Cross-sections of large-angle hadron production in proton– and pion–nucleus interactions VIII: aluminium nuclei and beam momenta from ±3 GeV/c to ±15 GeV/c

Abstract

We report on double-differential inclusive cross-sections of the production of secondary protons, charged pions, and deuterons, in the interactions with a 5% $\lambda_{\text{int}}$ thick stationary aluminium target, of proton and pion beams with momentum from ±3 GeV/c to ±15 GeV/c. Results are given for secondary particles with production angles $20^\circ < \theta < 125^\circ$. Cross-sections on aluminium nuclei are compared with cross-sections on beryllium, carbon, copper, tin, tantalum and lead nuclei.

The HARP–CDP group

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1 INTRODUCTION

The HARP experiment arose from the realization that the inclusive differential cross-sections of hadron production in the interactions of few GeV/c protons with nuclei were known only within a factor of two to three, while more precise cross-sections are in demand for several reasons.

These are the optimization of the design parameters of the proton driver of a neutrino factory (see Ref. [1] and further references cited therein), but also the understanding of the underlying physics and the modelling of Monte Carlo generators of hadron–nucleus collisions, flux predictions for conventional neutrino beams, and more precise calculations of the atmospheric neutrino flux.

The HARP experiment was designed to carry out a programme of systematic and precise (i.e., at the few per cent level) measurements of hadron production by protons and pions with momenta from 1.5 to 15 GeV/c, on a variety of target nuclei. It took data at the CERN Proton Synchrotron in 2001 and 2002.

The HARP detector combined a forward spectrometer with a large-angle spectrometer. The latter comprised a cylindrical Time Projection Chamber (TPC) around the target and an array of Resistive Plate Chambers (RPCs) that surrounded the TPC. The purpose of the TPC was track reconstruction and particle identification by $dE/dx$. The purpose of the RPCs was to complement the particle identification by time of flight.

This is the eighth of a series of cross-section papers with results from the HARP experiment. In the first paper [2] we described the detector characteristics and our analysis algorithms, on the example of $+8.9$ GeV/c and $-8.0$ GeV/c beams impinging on a 5% $\lambda_{\text{int}}$ Be target. The second paper [3] presented results for all beam momenta from this Be target. The third [4], fourth [5], fifth [6], sixth [7], and seventh [8] papers presented results from the interactions with 5% $\lambda_{\text{int}}$ tantalum, copper, lead, carbon, and tin targets. In this paper, we report on the large-angle production (polar angle $\theta$ in the range $20^\circ < \theta < 125^\circ$) of secondary protons and charged pions, and of deuterons, in the interactions with a 5% $\lambda_{\text{int}}$ aluminium target of protons and pions with beam momenta of $\pm3.0$, $\pm5.0$, $\pm8.0$, $+12.9$, $-12.0$, and $\pm15.0$ GeV/c.

Our work involves only the HARP large-angle spectrometer.

2 THE BEAMS AND THE HARP SPECTROMETER

The protons and pions were delivered by the T9 beam line in the East Hall of CERN’s Proton Synchrotron. This beam line supports beam momenta between 1.5 and 15 GeV/c, with a momentum bite $\Delta p/p \sim 1\%$.

The beam instrumentation, the definition of the beam particle trajectory, the cuts to select ‘good’ beam particles, and the muon and electron contaminations of the particle beams, are the same as described in Ref. [2].

The target was a disc made of high-purity (99.999%) aluminium, with a radius of 15.1 mm, a thickness of 19.80 mm (5% $\lambda_{\text{int}}$), and a measured density of 2.69 g/cm$^3$.

The finite thickness of the target leads to a small attenuation of the number of incident beam particles. The attenuation factor is $f_{\text{att}} = 0.975$.

Our calibration work on the HARP TPC and RPCs is described in detail in Refs. [9] and [10], and in references cited therein.

The momentum resolution $\sigma(1/p_T)$ of the TPC is typically 0.2 (GeV/c)$^{-1}$ and worsens towards small relative particle velocity $\beta$ and small polar angle $\theta$. The absolute momentum scale is determined to be correct to better than 2%, both for positively and negatively charged particles.
The polar angle $\theta$ is measured in the TPC with a resolution of $\sim 9$ mrad, for a representative angle of $\theta = 60^\circ$. In addition, a multiple scattering error must be considered that is for a proton with $p_T = 500$ MeV/c in the TPC gas $\sim 4.0$ mrad at $\theta = 20^\circ$, and $\sim 12.7$ mrad at $\theta = 90^\circ$. For a pion with the same characteristics, the multiple scattering errors are $\sim 3.3$ mrad and $\sim 6.4$ mrad, respectively. The polar-angle scale is correct to better than 2 mrad.

The TPC measures $dE/dx$ with a resolution of 16% for a track length of 300 mm.

The intrinsic efficiency of the RPCs that surround the TPC is better than 98%.

The intrinsic time resolution of the RPCs is 127 ps and the system time-of-flight resolution (that includes the jitter of the arrival time of the beam particle at the target) is 175 ps.

To separate measured particles into species, we assign on the basis of $dE/dx$ and $\beta$ to each particle a probability of being a proton, a pion (muon), or an electron, respectively. The probabilities add up to unity, so that the number of particles is conserved. These probabilities are used for weighting when entering tracks into plots or tables.

A general discussion of the systematic errors can be found in Ref. [2]. For the data from the $+15$ GeV/c beam, the systematic error of the momentum measurement was increased by a factor of 1.5 to account for minor problems with the correction for dynamic TPC distortions. For the data from the $-5$ GeV/c beam, the systematic error arising from the parametrization of the pion abundance in the respective Monte Carlo simulation was doubled, for a less satisfactory description of data distributions in the Monte Carlo simulation with the same number of weight parameters as used in comparable data sets. All systematic errors are propagated into the momentum spectra of secondaries and then added in quadrature. They add up to a systematic uncertainty of our inclusive cross-sections at the few-per-cent level, mainly from errors in the normalization, in the momentum measurement, in particle identification, and in the corrections applied to the data.

3 MONTE CARLO SIMULATION

We used the Geant4 tool kit [11] for the simulation of the HARP large-angle spectrometer.

Geant4’s QGSP.BIC physics list provided us with reasonably realistic spectra of secondaries from incoming beam protons with momentum below 12 GeV/c. For the secondaries from beam protons at 12.9 and 15 GeV/c momentum, and from beam pions at all momenta, we found the standard physics lists of Geant4 unsuitable [12].

To overcome this problem, we built our own HARP.CDP physics list. It starts from Geant4’s standard QBBC physics list, but the Quark–Gluon String Model is replaced by the FRITIOF string fragmentation model for kinetic energy $E > 6$ GeV; for $E < 6$ GeV, the Bertini Cascade is used for pions, and the Binary Cascade for protons; elastic and quasi-elastic scattering is disabled. Examples of the good performance of the HARP.CDP physics list are given in Ref. [12].

4 CROSS-SECTION RESULTS

In Tables A.1–A.45, collated in the Appendix of this paper, we give the double-differential inclusive cross-sections $d^2\sigma/dp_1d\Omega$ for various combinations of incoming beam particle and secondary particle, including statistical and systematic errors. In each bin, the average momentum at the vertex and the average polar angle are also given.

The data of Tables A.1–A.45 are available in ASCII format in Ref. [13].

Some bins in the tables are empty. Cross-sections are only given if the total error is not larger than the cross-section itself. Since our track reconstruction algorithm is optimized for tracks with $p_T$ above $\sim 70$ MeV/c in the TPC volume, we do not give cross-sections from tracks
with $p_T$ below this value. Because of the absorption of slow protons in the material between
the vertex and the TPC gas, and with a view to keeping the correction for absorption losses
below 30%, cross-sections from protons are limited to $p > 450$ MeV/$c$ at the interaction vertex.
Proton cross-sections are also not given if a 10% error on the proton energy loss in materials
between the interaction vertex and the TPC volume leads to a momentum change larger than
2%. Pion cross-sections are not given if pions are separated from protons by less than twice the
time-of-flight resolution.

The large errors and/or absence of results from the +15 GeV/$c$ pion beam are caused by
scarce statistics because the beam composition was dominated by protons.

We present in Figs. 1 to 7 what we consider salient features of our cross-sections. Figure 1
shows the inclusive cross-sections of the production of protons, $\pi^+$'s, and $\pi^-$'s, by
incoming protons between 3 GeV/$c$ and 15 GeV/$c$ momentum, as a function of their charge-
signed $p_T$. The data refer to the polar-angle range $20^\circ < \theta < 30^\circ$. Figures 2 and 3 show the
same for incoming $\pi^+$'s and $\pi^-$'s. Figure 4 shows inclusive Lorentz-invariant cross-sections of the production of protons, $\pi^+$'s
and $\pi^-$'s, by incoming protons between 3 GeV/$c$ and 15 GeV/$c$ momentum, in the rapidity range
$0.6 < y < 0.8$, as a function of the charge-signed reduced transverse particle mass, $m_T - m_0$,
where $m_0$ is the rest mass of the respective particle. Figures 5 and 6 show the same for incoming
$\pi^+$'s and $\pi^-$'s. We note the good representation of particle production by an exponential falloff
with increasing reduced transverse mass.

In Fig. 7, we present the inclusive cross-sections of the production of secondary $\pi^+$’s and
$\pi^-$’s, integrated over the momentum range 0.2 < $p$ < 1.0 GeV/$c$ and the polar-angle range
$30^\circ < \theta < 90^\circ$ in the forward hemisphere, as a function of the beam momentum.
Fig. 1: Inclusive cross-sections of the production of secondary protons, $\pi^+$'s, and $\pi^-$'s, by protons on aluminium nuclei, in the polar-angle range $20^\circ < \theta < 30^\circ$, for different proton beam momenta, as a function of the charge-signed $p_T$ of the secondaries; the shown errors are total errors.
Fig. 2: Inclusive cross-sections of the production of secondary protons, $\pi^+$'s, and $\pi^-$'s, by $\pi^+$'s on aluminium nuclei, in the polar-angle range $20^\circ < \theta < 30^\circ$, for different $\pi^+$ beam momenta, as a function of the charge-signed $p_T$ of the secondaries; the shown errors are total errors.
Fig. 3: Inclusive cross-sections of the production of secondary protons, π⁺’s, and π⁻’s, by π⁻’s on aluminium nuclei, in the polar-angle range $20^\circ < \theta < 30^\circ$, for different π⁻ beam momenta, as a function of the charge-signed $p_T$ of the secondaries; the shown errors are total errors.
Fig. 4: Inclusive Lorentz-invariant cross-sections of the production of protons, $\pi^+$’s and $\pi^-$’s, by incoming protons between 3 GeV/c and 15 GeV/c momentum, in the rapidity range $0.6 < y < 0.8$, as a function of the charge-signed reduced transverse particle mass, $m_T - m_0$, where $m_0$ is the rest mass of the respective particle; the shown errors are total errors.
Fig. 5: Inclusive Lorentz-invariant cross-sections of the production of protons, $\pi^+$'s and $\pi^-$'s, by incoming $\pi^+$'s between 3 GeV/$c$ and 15 GeV/$c$ momentum, in the rapidity range $0.6 < y < 0.8$, as a function of the charge-signed reduced transverse pion mass, $m_T - m_0$, where $m_0$ is the rest mass of the respective particle; the shown errors are total errors.
Fig. 6: Inclusive Lorentz-invariant cross-sections of the production of protons, $\pi^+$'s and $\pi^-$'s, by incoming $\pi^-$'s between 3 GeV/c and 15 GeV/c momentum, in the rapidity range $0.6 < y < 0.8$, as a function of the charge-signed reduced transverse pion mass, $m_T - m_0$, where $m_0$ is the rest mass of the respective particle; the shown errors are total errors.
Fig. 7: Inclusive cross-sections of the production of secondary $\pi^+$'s and $\pi^-$'s, integrated over the momentum range $0.2 < p < 1.0$ GeV/c and the polar-angle range $30^\circ < \theta < 90^\circ$, from the interactions on aluminium nuclei of protons (top row), $\pi^+$'s (middle row), and $\pi^-$'s (bottom row), as a function of the beam momentum; the shown errors are total errors and mostly smaller than the symbol size.
5 Comparison with results from the E802 Experiment

Experiment E802 [14] at Brookhaven National Laboratory measured secondary $\pi^\pm$'s and protons in the polar-angle range $5^\circ < \theta < 58^\circ$ from the interactions of $+14.6$ GeV/c protons with aluminium nuclei.

Figure 8 shows their published Lorentz-invariant cross-section of $\pi^\pm$ and $\pi^-$ production by $+14.6$ GeV/c protons, in the rapidity range $0.8 < y < 1.0$, as a function of $m_T - m_\pi$, where $m_T$ denotes the secondary particle’s transverse mass. Their data are compared with our respective cross-sections from the interactions of $+15.0$ GeV/c protons with aluminium nuclei.

Fig. 8: Comparison of our cross-sections (black symbols) of $\pi^\pm$ and proton production by $+15.0$ GeV/c protons off aluminium nuclei, with the respective cross-sections published by the E802 Collaboration for the proton beam momentum of $+14.6$ GeV/c (open symbols).

The E802 $\pi^\pm$ and proton cross-sections are in good agreement with our cross-sections measured nearly at the same proton beam momentum, taking into account the normalization uncertainty of (10–15)% quoted by E802.
6 Comparison with results from the HARP Collaboration

Figure 9 shows the comparison of our cross-sections of $\pi^\pm$ production by protons, $\pi^+$’s and $\pi^-$’s of 3.0 GeV/c and 8.0 GeV/c momentum, off aluminium nuclei, with the ones published by the HARP Collaboration [15][16], in the polar-angle range $20^\circ < \theta < 30^\circ$. The latter cross-sections are plotted as published, while we expressed our cross-sections in the unit used by the HARP Collaboration. The errors shown are the published total errors.

The discrepancy between our results and those published by the HARP Collaboration is evident. It shows the same pattern as observed in inclusive cross-sections off other target nuclei [2–8]. We hold that the discrepancy is caused by problems in the HARP Collaboration’s data analysis, discussed in detail in Refs [17–21], and summarized in the Appendix of Ref. [2].
Fig. 9: Comparison of HARP–CDP cross-sections (full circles) of $\pi^\pm$ production by protons, $\pi^+$’s and $\pi^-$’s of 3.0 GeV/c (left panels) and 8.0 GeV/c momentum (right panels), off aluminium nuclei, with the cross-sections published by the HARP Collaboration (open circles).
7 Comparison of Charged-pion Production on Beryllium, Carbon, Aluminium, Copper, Tin, Tantalum and Lead

Figure 10 presents a comparison between the inclusive cross-sections of $\pi^+$ and $\pi^-$ production, integrated over the secondaries’ momentum range $0.2 < p < 1.0$ GeV/$c$ and polar-angle range $30^\circ < \theta < 90^\circ$, in the interactions of protons, $\pi^+$ and $\pi^-$, with beryllium ($A = 9.01$), carbon ($A = 12.01$), aluminium ($A = 26.98$), copper ($A = 63.55$), tin ($A = 118.7$), tantalum ($A = 181.0$), and lead ($A = 207.2$) nuclei. The comparison employs the scaling variable $A^{2/3}$ where $A$ is the atomic mass number of the respective nucleus. We note the approximately linear dependence on this scaling variable. At low beam momentum, the slope exhibits a strong dependence on beam particle type, which tends to disappear with higher beam momentum.

Linearity with $A^{2/3}$ means that inclusive pion production scales with the geometrical cross-section of the nucleus. We note that at the lowest beam momenta the inclusive pion cross-section tends to fall below a linear dependence on $A^{2/3}$, while at the highest beam momenta the cross-sections tend to lie above a linear dependence. We conjecture that this behaviour arises from the production of tertiary pions from the interactions of secondaries in nuclear matter. At high beam momenta, the acceptance cut of $p > 0.2$ GeV/$c$ has a minor effect on the tertiary pions. The transition of the inclusive pion cross-section from an approximate $A^{2/3}$ dependence for light nuclei toward an approximate $A$ dependence for heavy nuclei (owing to the increasing contribution of pions from the re-interactions in nuclear matter) becomes apparent. At low beam momenta, the acceptance cut of $p > 0.2$ GeV/$c$ suppresses a large fraction of the primarily low-momentum secondaries, thus not only hiding this transition but even reversing its trend.

Figure 11 compares the ‘forward multiplicity’ of secondary $\pi^+$’s and $\pi^-$’s in the interaction of protons and pions with beryllium, carbon, aluminium, copper, tin, tantalum, and lead target nuclei. The forward multiplicities are averaged over the momentum range $0.2 < p < 1.0$ GeV/$c$ and the polar-angle range $30^\circ < \theta < 90^\circ$. They have been obtained by dividing the measured inclusive cross-section by the total cross-section inferred from the nuclear interaction lengths and pion interaction lengths, respectively, as published by the Particle Data Group [22] and reproduced in Table 1. The errors of the forward multiplicities are dominated by a 3% systematic uncertainty.

Table 1: Nuclear and pion interactions lengths used for the calculation of pion forward multiplicities.

| Nucleus   | $\lambda_{\text{nucl}}$ [g cm$^{-2}$] | $\lambda_{\text{int}}$ [g cm$^{-2}$] |
|-----------|--------------------------------------|---------------------------------------|
| Beryllium | 77.8                                 | 109.9                                 |
| Carbon    | 85.8                                 | 117.8                                 |
| Aluminium | 107.2                                | 136.7                                 |
| Copper    | 137.3                                | 165.9                                 |
| Tin       | 166.7                                | 194.3                                 |
| Tantalum  | 191.0                                | 217.7                                 |
| Lead      | 199.6                                | 226.2                                 |

The forward multiplicities display a ‘leading particle effect’ that mirrors the incoming beam particle. It is also interesting that the forward multiplicity decreases with the nuclear mass at

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1) The beryllium data with $+8.9$ GeV/$c$ beam momentum [2,3] have been scaled, by interpolation, to a beam momentum of $+8.0$ GeV/$c$; analogously, this paper’s aluminium data with $+12.9$ GeV beam momentum have been scaled to a beam momentum of $+12.0$ GeV/$c$
low beam momentum but increases at high beam momentum. Again, we interpret this as the effect of pion re-interactions in the nuclear matter in conjunction with the acceptance cut of $p > 0.2 \text{ GeV/c}$.

Figure 12 shows the increase of the inclusive cross-sections of $\pi^+$ and $\pi^-$ production by incoming protons of $+3.0 \text{ GeV/c}$ from the light beryllium nucleus to the heavy lead nucleus, for pions in the polar angle range $20^\circ < \theta < 30^\circ$. For comparison, Figure 13 shows the analogous cross sections for incoming protons of $+8.0 \text{ GeV/c}$ (in the case of beryllium target nuclei: +8.9 GeV/c).

We observe that the $\pi^+/\pi^-$ ratio depends on the proton beam momentum. We interpret the diminishing preponderance of $\pi^+$ over $\pi^-$ with increasing beam momentum as a consequence of the increase of phase space for particle production. We observe further that the general preponderance of $\pi^+$ over $\pi^-$ decreases with increasing atomic mass number $A$. For $+8.0 \text{ GeV/c}$ beam momentum, the trend even reverses from light to heavy nuclei. We interpret this feature as follows. The heavier the target nucleus, the larger the neutron-to-proton ratio. While low-energy secondary protons produce in their re-interactions in nuclear matter considerably more $\pi^+$ than $\pi^-$, the situation is the opposite for low-energy secondary neutrons as shown long ago in a pertinent experiment [23]. The heavier the target nucleus, the larger the neutron-to-proton ratio and therefore the contribution to $\pi^-$ production by secondary neutrons.
Fig. 10: Inclusive cross-sections of $\pi^+$ and $\pi^-$ production by protons (open squares), $\pi^+$'s (open circles), and $\pi^-$'s (black circles), as a function of $A^{2/3}$ for, from left to right, beryllium, carbon, aluminium, copper, tin, tantalum, and lead nuclei; the cross-sections are integrated over the momentum range $0.2 < p < 1.0 \text{ GeV/c}$ and the polar-angle range $30^\circ < \theta < 90^\circ$; the shown errors are total errors and often smaller than the symbol size.
Fig. 11: Forward multiplicity of $\pi^+$'s and $\pi^-$'s produced by protons (open squares), $\pi^+$'s (open circles), and $\pi^-$'s (black circles), as a function of $A^{2/3}$ for, from left to right, beryllium, carbon, aluminium, copper, tin, tantalum, and lead nuclei; the forward multiplicity refers to the momentum range $0.2 < p < 1.0$ GeV/c and the polar-angle range $30^\circ < \Theta < 90^\circ$ of secondary pions.
Fig. 12: Comparison of inclusive cross-sections of $\pi^\pm$ production by 3 GeV/c protons, in the forward region, between beryllium, carbon, copper, tin, tantalum, and lead target nuclei, as a function of the charge-signed pion $p_T$. 
Fig. 13: Comparison of inclusive cross-sections of $\pi^\pm$ production by 8 GeV/c protons, in the forward region, between beryllium, carbon, copper, tin, tantalum, and lead target nuclei, as a function of the charge-signed pion $p_T$. 

HARP-CDP $p + A \rightarrow (\pi^+,\pi^-) + X$

$+8.0$ (Be: +8.9) GeV/c

$20^\circ < \Theta < 30^\circ$
8 Deuteron Production

Besides pions and protons, also deuterons are produced on aluminium nuclei. Up to momenta of about 1 GeV/c, deuterons are easily separated from protons by $dE/dx$.

Table 2 gives the deuteron-to-proton production ratio as a function of the momentum at the vertex, for 8 GeV/c beam protons, $\pi^+$'s, and $\pi^-$'s. Cross-section ratios are not given if the data are scarce and the statistical error becomes comparable with the ratio itself—which is the case for deuterons at the high-momentum end of the spectrum.

The measured deuteron-to-proton production ratios are illustrated in Fig. 14 and compared with the predictions of Geant4’s FRITIOF model. FRITIOF’s predictions are shown for $\pi^+$ beam particles. While there is for small polar angles $\theta$ good agreement between the data and FRITIOF’s estimate, the latter tends to fall short of the data toward large polar angles.

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2) We observe no appreciable dependence of the deuteron-to-proton production ratio on beam momentum.

3) There is less than 10% difference between its predictions for incoming protons, $\pi^+$’s and $\pi^-$’s.
In Fig. 15 we show, for the polar-angle region $30^\circ < \theta < 45^\circ$, how the deuteron-to-proton ratio varies with the mass of the target nucleus. The ratios are for 8 GeV/c beam protons on beryllium, carbon, aluminium, copper, tin, tantalum and lead nuclei.

![Deuteron-proton ratio vs. momentum](image)

Fig. 15: Deuteron-to-proton production ratios for 8 GeV/c beam protons on beryllium, carbon, aluminium, copper, tin, tantalum and lead nuclei, as a function of the momentum at the vertex, for the polar-angle region $30^\circ < \theta < 45^\circ$.

In Fig. 16 we show how the deuteron-to-proton ratio depends on the atomic mass number $A$. Since in this ratio the geometrical scaling with $A^{2/3}$ should cancel out, any remaining dependence should reflect re-interactions in the nuclear matter for which $A^{1/3}$ seems the right scaling variable. The ratios are averaged over the $0.65 < p < 1.05$, where $p$ is the particle momentum at the vertex, and shown separately for the polar-angle bins $20^\circ < \theta < 30^\circ$ and $30^\circ < \theta < 45^\circ$. We note an approximately linear increase of the deuteron-to-proton ratio with $A^{1/3}$, and a tendency to increase with polar angle.
Fig. 16: Momentum-averaged deuteron-to-proton production ratios for 8 GeV/c beam protons on beryllium, carbon, aluminium, copper, tin, tantalum and lead nuclei, as a function of $A^{1/3}$, for the polar-angle regions $20^\circ < \theta < 30^\circ$ (black points) and $30^\circ < \theta < 45^\circ$ (open points).
Table 2: Ratio d/p of deuterons to protons produced by beam protons, \( \pi^+ \)'s and \( \pi^- \)'s of 8 GeV/c momentum, as a function of the particle momentum \( p \) [GeV/c] at the vertex, for bins of polar angle \( \theta \).

| \( p \) | Beam \( p \) d/p | Beam \( \pi^+ \) d/p | Beam \( \pi^- \) d/p |
|-------|---------------|----------------|----------------|
| \( \theta = 20^\circ - 30^\circ \) |
| 0.73  | 0.112 ± 0.018 | 0.143 ± 0.045 | 0.145 ± 0.026 |
| 0.79  | 0.138 ± 0.020 | 0.099 ± 0.021 | 0.120 ± 0.025 |
| 0.86  | 0.146 ± 0.018 | 0.114 ± 0.032 | 0.115 ± 0.021 |
| 0.93  | 0.122 ± 0.017 | 0.152 ± 0.044 | 0.138 ± 0.025 |
| 1.02  | 0.129 ± 0.019 | 0.082 ± 0.021 | 0.138 ± 0.031 |
| 1.10  | 0.135 ± 0.024 | 0.121 ± 0.039 | 0.117 ± 0.024 |
| 1.20  | 0.112 ± 0.023 | 0.213 ± 0.068 | 0.183 ± 0.064 |
| \( \theta = 30^\circ - 45^\circ \) |
| 0.71  | 0.153 ± 0.019 | 0.111 ± 0.017 | 0.191 ± 0.024 |
| 0.77  | 0.139 ± 0.013 | 0.129 ± 0.022 | 0.193 ± 0.024 |
| 0.85  | 0.135 ± 0.017 | 0.137 ± 0.021 | 0.184 ± 0.027 |
| 0.92  | 0.155 ± 0.024 | 0.140 ± 0.025 | 0.248 ± 0.044 |
| 1.01  | 0.144 ± 0.021 | 0.163 ± 0.053 | 0.157 ± 0.030 |
| 1.10  | 0.140 ± 0.023 | 0.137 ± 0.020 | 0.251 ± 0.109 |
| 1.19  | 0.127 ± 0.023 | 0.311 ± 0.087 | 0.351 ± 0.082 |
| \( \theta = 45^\circ - 65^\circ \) |
| 0.70  | 0.167 ± 0.015 | 0.188 ± 0.028 | 0.212 ± 0.022 |
| 0.77  | 0.173 ± 0.014 | 0.170 ± 0.028 | 0.235 ± 0.030 |
| 0.84  | 0.206 ± 0.037 | 0.230 ± 0.050 | 0.338 ± 0.055 |
| 0.92  | 0.187 ± 0.027 | 0.184 ± 0.037 | 0.436 ± 0.087 |
| 1.01  | 0.261 ± 0.045 | 0.248 ± 0.053 | 0.326 ± 0.074 |
| 1.10  | 0.336 ± 0.064 | 0.160 ± 0.050 | 0.212 ± 0.076 |
| 1.19  | 0.545 ± 0.130 | 0.133 ± 0.230 | 0.197 ± 0.230 |
| \( \theta = 65^\circ - 90^\circ \) |
| 0.70  | 0.255 ± 0.030 | 0.226 ± 0.035 | 0.323 ± 0.044 |
| 0.77  | 0.332 ± 0.040 | 0.353 ± 0.065 | 0.441 ± 0.072 |
| 0.84  | 0.412 ± 0.066 | 0.355 ± 0.071 | 0.367 ± 0.055 |
| 0.92  | 0.503 ± 0.098 | 0.220 ± 0.050 | 0.589 ± 0.101 |
| 1.01  | 0.581 ± 0.219 | 0.629 ± 0.177 | 0.620 ± 0.118 |
| 1.10  | 0.611 ± 0.140 | 0.354 ± 0.154 | 0.594 ± 0.101 |
| 1.19  | 0.879 ± 0.351 | 0.548 ± 0.142 | 0.579 ± 0.223 |
| \( \theta = 90^\circ - 125^\circ \) |
| 0.77  | 0.470 ± 0.069 | 0.441 ± 0.127 | 0.594 ± 0.101 |
| 0.84  | 0.562 ± 0.112 | 0.548 ± 0.142 | 0.620 ± 0.118 |
| 0.92  | 0.989 ± 0.393 | 0.579 ± 0.223 | 0.594 ± 0.101 |
| 1.01  | 1.053 ± 0.317 | 0.441 ± 0.127 | 0.594 ± 0.101 |
9 SUMMARY
From the analysis of data from the HARP large-angle spectrometer (polar angle $\theta$ in the range $20^\circ < \theta < 125^\circ$), double-differential cross-sections $d^2\sigma/dpd\Omega$ of the production of secondary protons, $\pi^+$'s, and $\pi^-$'s, and of deuterons, have been obtained. The incoming beam particles were protons and pions with momenta from $\pm 3$ to $\pm 15$ GeV/c, impinging on a 5% $\lambda_{int}$ thick stationary aluminium target.

We have compared the inclusive aluminium $\pi^+$ and $\pi^-$ production cross-sections with those on beryllium, carbon, copper, tin, tantalum, and lead and find an approximately linear dependence on the scaling variable $A^{2/3}$.

We also observe a significant production of deuterons off aluminium nuclei that we compared to the deuteron production on beryllium, carbon, copper, tin, tantalum, and lead.

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Table A.1: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $p + Al \to p + X$ interactions with $+3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|------|----------------|----------------|-------------------|----------------|----------------|----------------|
| 0.20–0.24 | 0.220 | 25.0 | 195.44 ± 8.79 ± 9.96 | 0.220 | 25.0 | 178.43 ± 6.52 ± 7.48 |
| 0.24–0.30 | 0.270 | 25.2 | 183.12 ± 6.94 ± 9.18 | 0.270 | 25.2 | 159.78 ± 6.31 ± 6.53 |
| 0.30–0.36 | 0.329 | 25.1 | 160.12 ± 6.71 ± 9.08 | 0.329 | 25.1 | 159.78 ± 6.31 ± 6.53 |
| 0.36–0.42 | 0.389 | 25.1 | 131.22 ± 6.08 ± 6.84 | 0.389 | 25.1 | 129.63 ± 5.94 ± 6.98 |
| 0.42–0.50 | 0.460 | 25.1 | 112.36 ± 4.75 ± 5.29 | 0.460 | 25.1 | 114.53 ± 4.96 ± 6.69 |
| 0.50–0.60 | 0.549 | 24.8 | 94.74 ± 3.84 ± 3.89 | 0.549 | 24.8 | 92.37 ± 3.99 ± 5.06 |
| 0.60–0.72 | 0.658 | 25.0 | 77.09 ± 3.20 ± 3.66 | 0.658 | 25.0 | 59.15 ± 2.88 ± 3.31 |
| 0.72–0.90 | 0.797 | 35.1 | 38.49 ± 1.92 ± 2.61 | 0.797 | 35.1 | 38.49 ± 1.92 ± 2.61 |
| 0.90–1.25 | 1.031 | 44.7 | 33.58 ± 1.85 ± 2.75 | 1.031 | 44.7 | 23.12 ± 1.64 ± 2.68 |
| 1.25–1.75 | 1.534 | 56.4 | 25.85 ± 1.26 ± 2.36 | 1.534 | 56.4 | 19.97 ± 1.17 ± 2.14 |
| 1.75–2.75 | 2.270 | 72.9 | 19.12 ± 0.99 ± 1.78 | 2.270 | 72.9 | 15.98 ± 0.85 ± 1.53 |
| 2.75–4.00 | 3.070 | 84.2 | 14.30 ± 0.75 ± 1.31 | 3.070 | 84.2 | 12.37 ± 0.62 ± 1.14 |
| 4.00–6.00 | 4.220 | 96.9 | 10.10 ± 0.56 ± 0.94 | 4.220 | 96.9 | 9.08 ± 0.48 ± 0.81 |
| 6.00–9.00 | 5.620 | 110.5 | 7.02 ± 0.39 ± 0.58 | 5.620 | 110.5 | 6.08 ± 0.32 ± 0.48 |
| 9.00–15.00 | 7.070 | 125.0 | 5.10 ± 0.27 ± 0.40 | 7.070 | 125.0 | 4.24 ± 0.22 ± 0.33 |

APPENDIX A: CROSS-SECTION TABLES
Table A.2: Double-differential inclusive cross-section \(d^2\sigma/dp d\Omega\) [mb/(GeV/c sr)] of the production of \(\pi^+\)’s in \(p + Al \to \pi^+ + X\) interactions with \(+3.0\) GeV/c beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) | \(\langle p_T \rangle\) | \(\langle \theta \rangle\) | \(d^2\sigma/dp d\Omega\) | \(\langle p_T \rangle\) | \(\langle \theta \rangle\) | \(d^2\sigma/dp d\Omega\) |
|--------|-----------------|-----------------|----------------|--------|-----------------|----------------|
| \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
Table A.3: Double-differential inclusive cross-section $d^2\sigma/dp\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $p + Al \rightarrow \pi^- + X$ interactions with $+3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|----------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\Omega$ |
| 0.10-0.13 | 0.116 | 24.6 | 47.65 ± 3.49 ± 3.81 | 0.114 | 35.2 | 49.54 ± 3.56 ± 3.95 | 0.103 | 35.9 | 20.13 ± 1.99 ± 2.21 |
| 0.13-0.16 | 0.146 | 25.1 | 54.47 ± 5.47 ± 3.55 | 0.146 | 35.3 | 54.70 ± 5.52 ± 3.96 | 0.135 | 36.4 | 22.37 ± 2.19 ± 2.52 |
| 0.16-0.20 | 0.178 | 24.8 | 52.28 ± 4.51 ± 2.87 | 0.181 | 34.9 | 47.42 ± 4.25 ± 2.76 | 0.170 | 36.0 | 24.03 ± 2.34 ± 2.67 |
| 0.20-0.24 | 0.217 | 24.7 | 39.41 ± 3.70 ± 1.93 | 0.219 | 34.9 | 41.96 ± 3.83 ± 2.15 | 0.207 | 35.8 | 25.58 ± 2.47 ± 2.70 |
| 0.24-0.30 | 0.268 | 25.5 | 30.17 ± 2.75 ± 1.31 | 0.270 | 35.1 | 35.12 ± 2.85 ± 1.52 | 0.256 | 36.6 | 27.10 ± 2.96 ± 3.19 |
| 0.30-0.36 | 0.329 | 24.9 | 20.93 ± 2.22 ± 0.99 | 0.329 | 34.8 | 23.66 ± 2.34 ± 1.06 | 0.298 | 38.6 | 29.60 ± 2.63 ± 2.86 |
| 0.36-0.42 | 0.386 | 26.1 | 8.48 ± 1.48 ± 0.50 | 0.387 | 34.9 | 15.28 ± 1.92 ± 0.78 | 0.356 | 41.2 | 32.50 ± 2.43 ± 2.66 |
| 0.42-0.50 | 0.453 | 25.7 | 7.05 ± 1.16 ± 0.49 | 0.456 | 35.4 | 7.93 ± 1.20 ± 0.46 | 0.424 | 44.0 | 39.90 ± 2.72 ± 2.94 |
| 0.50-0.60 | 0.542 | 25.2 | 1.87 ± 0.52 ± 0.17 | 0.540 | 35.1 | 4.91 ± 0.84 ± 0.37 | 0.510 | 51.2 | 47.30 ± 3.05 ± 3.33 |
| 0.60-0.72 | 0.628 | 24.8 | 0.36 ± 0.21 ± 0.04 | 0.645 | 34.0 | 1.18 ± 0.37 ± 0.12 | 0.600 | 60.0 | 55.00 ± 3.18 ± 3.45 |
| 0.72-0.90 | 0.742 | 32.7 | 0.16 ± 0.12 ± 0.02 | 0.724 | 31.8 | 0.91 ± 0.29 ± 0.09 | 0.700 | 67.0 | 62.00 ± 3.51 ± 3.73 |

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Table A.4: Double-differential inclusive cross-section $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^+ + \text{Al} \rightarrow p + X$ interactions with +3.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $\langle p_T\rangle$ | $\langle \theta \rangle$ | $d^2\sigma/d\Omega$ | $d^2\sigma/d\Omega$ |
|---------------|---------------------|---------------------|--------------------|--------------------|
| 20 $\leq \theta < 30$                | 30 $\leq \theta < 40$                |
| 0.20–0.24     | 0.221        | 25.0        | 165.87 ± 5.85 ± 8.55 | 0.271        | 34.9        | 168.78 ± 4.64 ± 7.14 |
| 0.24–0.30     | 0.269        | 25.1        | 156.82 ± 4.74 ± 8.16 | 0.329        | 35.0        | 144.78 ± 4.40 ± 6.01 |
| 0.30–0.36     | 0.329        | 25.2        | 121.35 ± 4.29 ± 7.36 | 0.329        | 35.0        | 118.77 ± 4.16 ± 6.47 |
| 0.36–0.42     | 0.389        | 25.1        | 108.39 ± 4.05 ± 6.07 | 0.389        | 35.0        | 92.62 ± 3.25 ± 5.47 |
| 0.42–0.50     | 0.458        | 25.0        | 91.27 ± 3.12 ± 4.78 | 0.459        | 35.1        | 78.74 ± 2.67 ± 4.44 |
| 0.50–0.60     | 0.546        | 25.3        | 73.59 ± 2.46 ± 3.39 | 0.546        | 35.0        | 54.15 ± 1.98 ± 3.20 |
| 0.60–0.72     | 0.655        | 25.3        | 49.11 ± 1.82 ± 2.46 | 0.654        | 35.0        | 30.75 ± 1.23 ± 2.20 |
| 0.72–0.90     |                |              |                    | 0.800        | 35.2        |                    |
| 40 $\leq \theta < 50$                | 50 $\leq \theta < 60$                |
| 0.30–0.36     | 0.329        | 45.0        | 169.77 ± 4.53 ± 5.52 | 0.329        | 45.0        | 156.83 ± 4.27 ± 4.74 |
| 0.36–0.42     | 0.388        | 45.1        | 129.06 ± 3.99 ± 4.30 | 0.388        | 55.1        | 119.55 ± 3.41 ± 4.08 |
| 0.42–0.50     | 0.457        | 45.2        | 102.88 ± 3.33 ± 4.67 | 0.457        | 55.1        | 92.62 ± 3.25 ± 5.47 |
| 0.50–0.60     | 0.544        | 45.1        | 80.03 ± 2.71 ± 4.85 | 0.543        | 55.0        | 72.08 ± 2.59 ± 4.99 |
| 0.60–0.72     | 0.650        | 45.0        | 56.32 ± 2.13 ± 3.83 | 0.651        | 54.9        | 43.11 ± 1.94 ± 3.91 |
| 0.72–0.90     | 0.795        | 44.9        | 28.05 ± 1.22 ± 2.45 | 0.791        | 54.9        | 20.03 ± 1.12 ± 2.52 |
| 0.90–1.25     | 1.023        | 44.8        | 7.13 ± 0.43 ± 0.96 | 0.800        | 35.0        | 30.75 ± 1.23 ± 2.20 |
| 50 $\leq \theta < 75$                | 75 $\leq \theta < 90$                |
| 0.42–0.50     | 0.458        | 67.6        | 121.03 ± 2.71 ± 3.51 | 0.457        | 82.0        | 98.83 ± 2.40 ± 3.52 |
| 0.50–0.60     | 0.545        | 67.2        | 71.38 ± 2.01 ± 3.74 | 0.546        | 82.1        | 59.49 ± 1.69 ± 2.87 |
| 0.60–0.72     | 0.652        | 67.1        | 36.12 ± 1.33 ± 2.36 | 0.652        | 82.2        | 35.70 ± 1.28 ± 1.84 |
| 0.72–0.90     | 0.795        | 66.9        | 20.03 ± 1.12 ± 2.52 | 0.791        | 82.3        | 20.03 ± 1.12 ± 2.52 |
| 0.90–1.25     | 1.023        | 66.8        | 7.13 ± 0.43 ± 0.96 | 0.800        | 35.0        | 30.75 ± 1.23 ± 2.20 |
| 75 $\leq \theta < 105$               | 105 $\leq \theta < 125$               |
| 0.42–0.50     | 0.456        | 96.9        | 71.71 ± 2.04 ± 3.69 | 0.456        | 113.5       | 35.70 ± 1.28 ± 1.84 |
| 0.50–0.60     | 0.545        | 96.8        | 36.12 ± 1.33 ± 2.36 | 0.542        | 112.4       | 12.73 ± 0.82 ± 1.66 |
Table A.5: Double-differential inclusive cross-section $d^2\sigma/dp^2d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $\pi^+ + A1 \rightarrow \pi^+ + X$ interactions with $+3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|-------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|       | $(p_T)$ | $d^2\sigma$ | $(p_T)$ | $d^2\sigma$ | $(p_T)$ | $d^2\sigma$ | $(p_T)$ | $d^2\sigma$ | $(p_T)$ | $d^2\sigma$ |
| 0.10-0.13 | 0.115 | 24.9 | 85.88 ± 5.65 | 6.95 | 0.115 | 34.9 | 91.52 ± 5.36 | 6.78 |
| 0.13-0.16 | 0.146 | 24.9 | 104.04 ± 5.56 | 6.37 | 0.145 | 34.7 | 74.24 ± 4.59 | 4.53 |
| 0.16-0.20 | 0.180 | 24.8 | 119.19 ± 5.05 | 6.00 | 0.180 | 34.9 | 95.73 ± 4.42 | 4.94 |
| 0.20-0.24 | 0.220 | 25.0 | 132.48 ± 5.35 | 6.01 | 0.220 | 34.9 | 114.26 ± 4.83 | 5.11 |
| 0.24-0.30 | 0.270 | 24.9 | 125.17 ± 4.10 | 4.59 | 0.270 | 34.9 | 109.25 ± 3.75 | 4.08 |
| 0.30-0.36 | 0.329 | 25.1 | 103.51 ± 3.71 | 3.47 | 0.329 | 34.9 | 92.67 ± 3.48 | 3.09 |
| 0.36-0.42 | 0.390 | 25.1 | 79.93 ± 3.23 | 2.72 | 0.389 | 34.5 | 68.93 ± 2.94 | 2.34 |
| 0.42-0.50 | 0.457 | 24.9 | 63.40 ± 2.44 | 2.49 | 0.458 | 34.9 | 59.36 ± 2.38 | 2.15 |
| 0.50-0.60 | 0.546 | 25.1 | 41.52 ± 1.70 | 2.19 | 0.547 | 34.9 | 40.56 ± 1.71 | 1.92 |
| 0.60-0.72 | 0.658 | 24.8 | 25.65 ± 1.20 | 2.00 | 0.655 | 34.8 | 22.47 ± 1.10 | 1.53 |
| 0.72-0.90 | 0.799 | 34.9 | 14.76 ± 0.74 | 1.66 |
| 0.90-1.25 | 1.017 | 54.5 | 1.62 ± 0.15 | 0.25 |
| 1.00-1.30 | 1.145 | 67.5 | 76.95 ± 4.12 | 4.73 | 0.146 | 81.9 | 68.94 ± 3.85 | 4.30 |
| 1.06-1.60 | 0.180 | 67.4 | 79.59 ± 3.32 | 3.81 | 0.180 | 82.4 | 69.41 ± 3.11 | 3.23 |
| 1.40-2.00 | 0.220 | 67.3 | 67.78 ± 2.97 | 2.81 | 0.219 | 82.3 | 55.30 ± 2.68 | 2.23 |
| 1.60-2.20 | 0.268 | 67.1 | 54.00 ± 2.20 | 1.96 | 0.268 | 82.1 | 40.12 ± 1.90 | 1.50 |
| 2.00-3.60 | 0.329 | 67.0 | 45.27 ± 2.00 | 1.55 | 0.329 | 82.0 | 27.62 ± 1.57 | 1.09 |
| 2.20-3.80 | 0.390 | 66.8 | 33.44 ± 1.73 | 1.25 | 0.388 | 81.9 | 21.97 ± 1.41 | 1.04 |
| 2.80-4.00 | 0.457 | 66.6 | 24.53 ± 1.55 | 1.07 | 0.459 | 81.7 | 15.90 ± 1.00 | 0.73 |
| 3.00-5.00 | 0.547 | 66.4 | 18.97 ± 1.00 | 1.10 | 0.543 | 81.8 | 9.14 ± 0.70 | 0.66 |
| 4.00-7.00 | 0.655 | 66.7 | 9.72 ± 0.65 | 0.76 | 0.652 | 80.9 | 5.41 ± 0.50 | 0.54 |
| 5.00-7.00 | 0.795 | 66.6 | 4.73 ± 0.36 | 0.52 | 0.782 | 81.2 | 1.61 ± 0.19 | 0.22 |
| 7.00-1.25 | 1.018 | 66.1 | 0.64 ± 0.07 | 0.12 | 1.023 | 82.2 | 0.11 ± 0.02 | 0.03 |
| 1.00-1.25 | 1.056 | 95.8 | 0.03 ± 0.01 | 0.02 |
Table A.6: Double-differential inclusive cross-section $d^2\sigma/d\theta d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^+ + \text{Al} \to \pi^- + X$ interactions with $+3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) | $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) |
|--------------|--------------------|---------------------------------------------|--------------|--------------------|---------------------------------------------|
| 0.10–0.13    | 0.115              | 25.1                                       | 0.115        | 34.9               | 64.52                                       |
|              | 0.13–0.16          | 0.146                                      | 0.20         | 25.1               | 76.99                                       |
|              | 0.16–0.20          | 0.179                                      | 0.24–0.24    | 0.219              | 25.3                                       |
|              | 0.24–0.30          | 0.269                                      | 0.30–0.36    | 0.328              | 25.1                                       |
|              | 0.36–0.42          | 0.390                                      | 0.42–0.50    | 0.457              | 25.3                                       |
|              | 0.50–0.60          | 0.546                                      | 0.60–0.72    | 0.648              | 25.4                                       |
|              | 0.72–0.90          | 1.034                                      |              |                    |                                             |

| $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) | $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) |
|--------------|--------------------|---------------------------------------------|--------------|--------------------|---------------------------------------------|
| 0.10–0.13    | 0.114              | 45.2                                       | 0.145        | 55.1               | 65.61                                       |
|              | 0.13–0.16          | 0.145                                      | 0.182        | 44.8               | 66.14                                       |
|              | 0.16–0.20          | 0.182                                      | 0.270        | 44.8               | 56.13                                       |
|              | 0.24–0.30          | 0.331                                      | 0.36–0.42    | 0.391              | 44.8                                       |
|              | 0.42–0.50          | 0.461                                      | 0.50–0.60    | 0.547              | 45.0                                       |
|              | 0.60–0.72          | 0.655                                      | 0.72–0.90    | 0.804              | 45.1                                       |
|              | 0.90–1.25          | 1.034                                      |              |                    |                                             |

| $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) | $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) |
|--------------|--------------------|---------------------------------------------|--------------|--------------------|---------------------------------------------|
| 0.13–0.16    | 0.144              | 67.1                                       | 0.145        | 82.6               | 47.34                                       |
|              | 0.16–0.20          | 0.180                                      | 0.179        | 82.2               | 44.56                                       |
|              | 0.24–0.24          | 0.220                                      | 0.268        | 96.8               | 59.63                                       |
|              | 0.30–0.36          | 0.330                                      | 0.389        | 67.1               | 20.99                                       |
|              | 0.36–0.42          | 0.459                                      | 0.42–0.50    | 0.547              | 67.1                                       |
|              | 0.50–0.60          | 0.651                                      | 0.72–0.90    | 0.783              | 67.1                                       |
|              | 0.90–1.25          | 1.016                                      |              |                    |                                             |

| $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) | $p_T$ (GeV/c) | $\theta$ (degree) | $d^2\sigma/d\theta d\Omega$ (mb/(GeV/c sr)) |
|--------------|--------------------|---------------------------------------------|--------------|--------------------|---------------------------------------------|
| 0.13–0.16    | 0.145              | 97.3                                       | 0.145        | 114.4              | 33.49                                       |
|              | 0.16–0.20          | 0.180                                      | 0.219        | 96.4               | 40.77                                       |
|              | 0.24–0.24          | 0.268                                      | 0.326        | 96.4               | 11.22                                       |
|              | 0.30–0.36          | 0.390                                      | 0.42–0.50    | 0.457              | 97.1                                       |
|              | 0.36–0.42          | 0.541                                      | 0.50–0.60    | 0.651              | 96.1                                       |
|              | 0.60–0.72          | 0.796                                      |              |                    |                                             |
Table A.7: Double-differential inclusive cross-section $d^2\sigma/dp_d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^- + Al \rightarrow p + X$ interactions with −3.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ ($GeV/c$) | 20 $< \theta < 30$ | 30 $< \theta < 40$ | 40 $< \theta < 50$ | 50 $< \theta < 60$ | 60 $< \theta < 75$ | 75 $< \theta < 90$ | 90 $< \theta < 105$ | 105 $< \theta < 125$ |
|-----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| \(10^{-4}\)     | \(\langle p_T \rangle\) \(\langle \theta \rangle\) | \(d^2\sigma/dp_d\Omega\) | \(\langle p_T \rangle\) \(\langle \theta \rangle\) | \(d^2\sigma/dp_d\Omega\) | \(\langle p_T \rangle\) \(\langle \theta \rangle\) | \(d^2\sigma/dp_d\Omega\) | \(\langle p_T \rangle\) \(\langle \theta \rangle\) | \(d^2\sigma/dp_d\Omega\) |
Table A.8: Double-differential inclusive cross-section $d^2\sigma/dp_T d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $\pi^- + A1 \rightarrow \pi^+ + X$ interactions with $-3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $\langle \theta \rangle$ | $d^2\sigma/dp_T d\Omega$ | $\langle \theta \rangle$ | $d^2\sigma/dp_T d\Omega$ |
|------|-----------------|-----------------|-----------------|-----------------|
|      | $20 < \theta < 30$ | $30 < \theta < 40$ | $50 < \theta < 60$ | $75 < \theta < 90$ |
|      | $40 < \theta < 50$ | $60 < \theta < 75$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
| 0.10-0.13 | 0.116 45.0 | 55.01 ± 2.94 ± 4.03 | 0.115 35.2 | 67.62 ± 3.19 ± 4.85 |
| 0.13-0.16 | 0.145 44.8 | 66.19 ± 2.87 ± 3.77 | 0.145 54.8 | 56.93 ± 2.70 ± 3.38 |
| 0.16-0.20 | 0.180 44.7 | 70.68 ± 2.94 ± 4.23 | 0.180 54.8 | 62.36 ± 2.32 ± 2.96 |
| 0.20-0.24 | 0.220 44.9 | 58.86 ± 1.82 ± 2.05 | 0.219 54.9 | 53.46 ± 2.11 ± 2.21 |
| 0.24-0.30 | 0.269 44.7 | 58.86 ± 1.82 ± 2.05 | 0.268 54.7 | 44.78 ± 1.55 ± 1.55 |
| 0.30-0.36 | 0.330 44.7 | 47.44 ± 1.60 ± 1.49 | 0.329 54.9 | 37.92 ± 1.44 ± 1.21 |
| 0.36-0.42 | 0.394 44.8 | 38.80 ± 1.44 ± 1.20 | 0.389 54.8 | 31.47 ± 1.31 ± 1.04 |
| 0.42-0.50 | 0.456 44.7 | 28.37 ± 1.09 ± 1.03 | 0.457 54.6 | 27.30 ± 1.11 ± 1.20 |
| 0.50-0.60 | 0.564 44.9 | 11.08 ± 0.54 ± 0.70 | 0.545 54.5 | 15.40 ± 0.69 ± 0.74 |
| 0.60-0.72 | 0.654 44.8 | 4.52 ± 0.26 ± 0.43 | 0.793 54.3 | 3.95 ± 0.25 ± 0.37 |
| 0.72-0.90 | 0.792 44.8 | 1.031 54.3 | 0.73 ± 0.06 ± 0.12 |
Table A.9: Double-differential inclusive cross-section $d^2\sigma/dp_d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$ in $\pi^- + \text{Al} \to \pi^- + \text{X}$ interactions with $-3.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|             | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ | $d^2\sigma/dp_d\Omega$ |
| 0.10–0.13   | 0.115 (44.9)    | 0.115 (44.9)    | 0.116 (44.9)    | 0.116 (44.9)    | 0.115 (44.9)    | 0.115 (44.9)    | 0.115 (44.9)    | 0.115 (44.9)    |
| 0.13–0.16   | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    | 0.145 (44.9)    |
| 0.16–0.20   | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    | 0.179 (45.0)    |
| 0.20–0.24   | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    | 0.219 (45.0)    |
| 0.24–0.30   | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    | 0.269 (45.0)    |
| 0.30–0.36   | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    | 0.329 (45.0)    |
| 0.36–0.42   | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    | 0.389 (45.0)    |
| 0.42–0.50   | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    | 0.457 (45.0)    |
| 0.50–0.60   | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    | 0.545 (45.0)    |
| 0.60–0.72   | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    | 0.655 (45.0)    |
| 0.72–0.90   | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    | 0.798 (45.0)    |

| $p_T$ (GeV/c) | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|-------------|-----------------|-----------------|-----------------|-----------------|
| 0.13–0.16   | 0.145 (71.4)    | 0.145 (71.4)    | 0.145 (71.4)    | 0.145 (71.4)    |
| 0.16–0.20   | 0.179 (71.4)    | 0.179 (71.4)    | 0.179 (71.4)    | 0.179 (71.4)    |
| 0.20–0.24   | 0.219 (71.4)    | 0.219 (71.4)    | 0.219 (71.4)    | 0.219 (71.4)    |
| 0.24–0.30   | 0.267 (71.4)    | 0.267 (71.4)    | 0.267 (71.4)    | 0.267 (71.4)    |
| 0.30–0.36   | 0.327 (71.4)    | 0.327 (71.4)    | 0.327 (71.4)    | 0.327 (71.4)    |
| 0.36–0.42   | 0.388 (71.4)    | 0.388 (71.4)    | 0.388 (71.4)    | 0.388 (71.4)    |
| 0.42–0.50   | 0.455 (71.4)    | 0.455 (71.4)    | 0.455 (71.4)    | 0.455 (71.4)    |
| 0.50–0.60   | 0.540 (71.4)    | 0.540 (71.4)    | 0.540 (71.4)    | 0.540 (71.4)    |
| 0.60–0.72   | 0.649 (71.4)    | 0.649 (71.4)    | 0.649 (71.4)    | 0.649 (71.4)    |
| 0.72–0.90   | 0.794 (71.4)    | 0.794 (71.4)    | 0.794 (71.4)    | 0.794 (71.4)    |
| 0.90–1.25   | 1.030 (71.4)    | 1.030 (71.4)    | 1.030 (71.4)    | 1.030 (71.4)    |
Table A.10: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in p + Al → p + X interactions with +5.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $\langle p_T \rangle$ (GeV/c) | $\langle \theta \rangle$ (deg) | $d^2\sigma/dp d\Omega$ (mb/(GeV/c sr)) | $\langle p_T \rangle$ (GeV/c) | $\langle \theta \rangle$ (deg) | $d^2\sigma/dp d\Omega$ (mb/(GeV/c sr)) |
|----------------|-----------------------------|-----------------------------|---------------------------------|-----------------------------|-----------------------------|---------------------------------|
| 0.20–0.24      | 0.220                       | 24.9                        | 202.12 ± 7.25 ± 10.04           | 0.226                       | 24.9                        | 202.12 ± 7.25 ± 10.04           |
| 0.24–0.30      | 0.269                       | 25.0                        | 176.21 ± 5.06 ± 8.00            | 0.262                       | 25.0                        | 176.21 ± 5.06 ± 8.00            |
| 0.30–0.36      | 0.330                       | 25.2                        | 160.61 ± 4.86 ± 7.00            | 0.329                       | 25.2                        | 160.61 ± 4.86 ± 7.00            |
| 0.36–0.42      | 0.389                       | 25.1                        | 142.79 ± 4.57 ± 5.50            | 0.389                       | 25.1                        | 142.79 ± 4.57 ± 5.50            |
| 0.42–0.50      | 0.460                       | 25.1                        | 116.71 ± 3.48 ± 4.13            | 0.458                       | 25.1                        | 116.71 ± 3.48 ± 4.13            |
| 0.50–0.60      | 0.548                       | 25.0                        | 106.96 ± 2.99 ± 3.62            | 0.547                       | 25.0                        | 106.96 ± 2.99 ± 3.62            |
| 0.60–0.72      | 0.658                       | 24.9                        | 90.34 ± 2.31 ± 3.16             | 0.657                       | 24.9                        | 90.34 ± 2.31 ± 3.16             |
| 0.72–0.90      |                             |                             | 65.84 ± 2.00 ± 2.71             |                             |                             | 65.84 ± 2.00 ± 2.71             |
| 40 < $\theta$ < 50 |                             |                             | 70.31 ± 4.76 ± 5.25             |                             |                             | 70.31 ± 4.76 ± 5.25             |
| 50 < $\theta$ < 60 |                             |                             | 146.66 ± 4.43 ± 4.24           |                             |                             | 146.66 ± 4.43 ± 4.24           |
| 60 < $\theta$ < 75 |                             |                             | 120.78 ± 3.58 ± 3.90           |                             |                             | 120.78 ± 3.58 ± 3.90           |
| 75 < $\theta$ < 90 |                             |                             | 89.03 ± 2.80 ± 3.68           |                             |                             | 89.03 ± 2.80 ± 3.68           |
| 90 < $\theta$ < 105 |                             |                             | 67.28 ± 2.28 ± 3.16           |                             |                             | 67.28 ± 2.28 ± 3.16           |
| 105 < $\theta$ < 125 |                             |                             | 40.01 ± 1.46 ± 2.39           |                             |                             | 40.01 ± 1.46 ± 2.39           |

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Table A.11: Double-differential inclusive cross-section $d^2\sigma/dpd\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$s in p + Al → $\pi^+$ + X interactions with +5.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$  | $(p_T)$ | $20 < \theta < 30$ | $d^2\sigma/dpd\Omega$ | $(p_T)$ | $30 < \theta < 40$ | $d^2\sigma/dpd\Omega$ |
|--------|--------|-------------------|----------------------|--------|-------------------|----------------------|
| 0.10-0.13 | 0.116  | 25.0              | 103.61 ± 6.31 ± 7.22 | 0.116  | 34.8              | 83.96 ± 5.53 ± 5.94  |
| 0.13-0.16 | 0.145  | 24.8              | 111.38 ± 6.09 ± 6.31 | 0.145  | 35.0              | 89.27 ± 5.30 ± 5.00  |
| 0.16-0.20 | 0.180  | 24.9              | 130.75 ± 5.48 ± 6.18 | 0.180  | 34.7              | 92.51 ± 4.52 ± 4.37  |
| 0.20-0.24 | 0.220  | 24.8              | 122.56 ± 5.18 ± 5.03 | 0.220  | 34.7              | 91.15 ± 4.42 ± 3.72  |
| 0.24-0.30 | 0.269  | 24.9              | 121.43 ± 4.19 ± 4.21 | 0.269  | 34.8              | 87.65 ± 3.52 ± 3.03  |
| 0.30-0.36 | 0.329  | 24.7              | 89.39 ± 3.50 ± 2.79  | 0.329  | 34.7              | 73.95 ± 3.19 ± 2.28  |
| 0.36-0.42 | 0.389  | 24.9              | 66.86 ± 3.02 ± 2.13  | 0.389  | 34.8              | 52.41 ± 2.70 ± 1.61  |
| 0.42-0.50 | 0.458  | 25.2              | 51.75 ± 2.30 ± 2.01  | 0.457  | 34.9              | 41.23 ± 2.07 ± 1.46  |
| 0.50-0.60 | 0.548  | 24.8              | 28.77 ± 1.43 ± 1.50  | 0.546  | 34.9              | 29.22 ± 1.50 ± 1.37  |
| 0.60-0.72 | 0.657  | 25.1              | 13.32 ± 0.78 ± 1.04  | 0.655  | 34.9              | 13.14 ± 0.84 ± 0.90  |
| 0.72-0.90 | 0.790  | 34.6              | 6.18 ± 0.41 ± 0.66   |

| $p_T$  | $(p_T)$ | $40 < \theta < 50$ | $d^2\sigma/dpd\Omega$ | $(p_T)$ | $50 < \theta < 60$ | $d^2\sigma/dpd\Omega$ |
|--------|--------|-------------------|----------------------|--------|-------------------|----------------------|
| 0.10-0.13 | 0.116  | 45.2              | 75.39 ± 5.40 ± 5.47  |
| 0.13-0.16 | 0.145  | 44.7              | 79.23 ± 5.05 ± 4.57  |
| 0.16-0.20 | 0.181  | 44.8              | 82.67 ± 4.25 ± 3.95  |
| 0.20-0.24 | 0.220  | 44.9              | 76.21 ± 4.01 ± 3.18  |
| 0.24-0.30 | 0.270  | 44.7              | 68.06 ± 3.14 ± 2.39  |
| 0.30-0.36 | 0.330  | 44.7              | 54.42 ± 2.76 ± 1.68  |
| 0.36-0.42 | 0.388  | 44.7              | 42.87 ± 2.45 ± 1.31  |
| 0.42-0.50 | 0.457  | 44.5              | 35.37 ± 1.93 ± 1.20  |
| 0.50-0.60 | 0.550  | 44.7              | 21.34 ± 1.29 ± 0.96  |
| 0.60-0.72 | 0.658  | 44.9              | 11.49 ± 0.85 ± 0.73  |
| 0.72-0.90 | 0.788  | 44.7              | 4.76 ± 0.40 ± 0.45   |
| 0.90-1.25 |        |                   | 1.005 34.7 $\pm 0.12 \pm 0.14$ |

| $p_T$  | $(p_T)$ | $60 < \theta < 75$ | $d^2\sigma/dpd\Omega$ | $(p_T)$ | $75 < \theta < 90$ | $d^2\sigma/dpd\Omega$ |
|--------|--------|-------------------|----------------------|--------|-------------------|----------------------|
| 0.13-0.16 | 0.146  | 66.8              | 63.84 ± 3.73 ± 3.79  |
| 0.16-0.20 | 0.181  | 67.4              | 58.61 ± 2.95 ± 2.76  |
| 0.20-0.24 | 0.221  | 67.2              | 52.01 ± 2.75 ± 2.11  |
| 0.24-0.30 | 0.270  | 67.2              | 38.89 ± 1.92 ± 1.32  |
| 0.30-0.36 | 0.329  | 66.9              | 30.70 ± 1.74 ± 0.99  |
| 0.36-0.42 | 0.391  | 66.9              | 24.55 ± 1.51 ± 0.86  |
| 0.42-0.50 | 0.460  | 67.0              | 16.17 ± 1.06 ± 0.69  |
| 0.50-0.60 | 0.548  | 67.1              | 9.91 ± 0.74 ± 0.57   |
| 0.60-0.72 | 0.650  | 66.3              | 6.48 ± 0.55 ± 0.51   |
| 0.72-0.90 | 0.793  | 65.8              | 1.79 ± 0.22 ± 0.20   |
| 0.90-1.25 | 1.016  | 65.0              | 0.37 ± 0.06 ± 0.07   |

| $p_T$  | $(p_T)$ | $90 < \theta < 105$ | $d^2\sigma/dpd\Omega$ | $(p_T)$ | $105 < \theta < 125$ | $d^2\sigma/dpd\Omega$ |
|--------|--------|-------------------|----------------------|--------|-------------------|----------------------|
| 0.13-0.16 | 0.145  | 97.6              | 52.33 ± 3.43 ± 3.05  |
| 0.16-0.20 | 0.180  | 97.3              | 45.94 ± 2.69 ± 1.95  |
| 0.20-0.24 | 0.219  | 97.2              | 32.08 ± 2.16 ± 1.16  |
| 0.24-0.30 | 0.267  | 96.7              | 21.85 ± 1.46 ± 0.78  |
| 0.30-0.36 | 0.327  | 97.0              | 13.24 ± 1.13 ± 0.59  |
| 0.36-0.42 | 0.390  | 96.8              | 8.53 ± 0.90 ± 0.49   |
| 0.42-0.50 | 0.459  | 96.1              | 5.64 ± 0.64 ± 0.42   |
| 0.50-0.60 | 0.546  | 96.6              | 3.47 ± 0.45 ± 0.34   |
| 0.60-0.72 | 0.655  | 95.9              | 1.11 ± 0.22 ± 0.15   |
| 0.72-0.90 | 0.799  | 96.6              | 0.19 ± 0.06 ± 0.04   |
Table A.12: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $p + Al \rightarrow \pi^- + X$ interactions with $+5.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $p_T$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|-------|-----------------|-----------------|-------|-----------------|-----------------|
| 0.10-0.13 | 0.116 | 45.1 | 0.10-0.13 | 0.116 | 45.1 |
| 0.13-0.16 | 0.145 | 25.0 | 0.13-0.16 | 0.145 | 25.0 |
| 0.16-0.20 | 0.180 | 24.9 | 0.16-0.20 | 0.180 | 24.9 |
| 0.20-0.24 | 0.218 | 24.8 | 0.20-0.24 | 0.218 | 24.8 |
| 0.24-0.30 | 0.269 | 24.9 | 0.24-0.30 | 0.269 | 24.9 |
| 0.30-0.36 | 0.328 | 25.0 | 0.30-0.36 | 0.328 | 25.0 |
| 0.36-0.42 | 0.386 | 24.9 | 0.36-0.42 | 0.386 | 24.9 |
| 0.42-0.50 | 0.454 | 25.1 | 0.42-0.50 | 0.454 | 25.1 |
| 0.50-0.60 | 0.545 | 24.9 | 0.50-0.60 | 0.545 | 24.9 |
| 0.60-0.72 | 0.650 | 25.3 | 0.60-0.72 | 0.650 | 25.3 |
| 0.72-0.90 | 0.776 | 35.4 | 0.72-0.90 | 0.776 | 35.4 |
| 0.90-1.25 | 1.042 | 54.2 | 0.90-1.25 | 1.042 | 54.2 |
| 1.25-1.75 | 1.448 | 78.0 | 1.25-1.75 | 1.448 | 78.0 |
| 1.75-2.25 | 2.046 | 96.0 | 1.75-2.25 | 2.046 | 96.0 |
| 2.25-2.75 | 2.570 | 114.0 | 2.25-2.75 | 2.570 | 114.0 |
| 2.75-3.25 | 2.964 | 132.0 | 2.75-3.25 | 2.964 | 132.0 |
| 3.25-3.75 | 3.278 | 150.0 | 3.25-3.75 | 3.278 | 150.0 |
| 3.75-4.25 | 3.475 | 168.0 | 3.75-4.25 | 3.475 | 168.0 |
| 4.25-4.75 | 3.627 | 186.0 | 4.25-4.75 | 3.627 | 186.0 |
| 4.75-5.25 | 3.709 | 204.0 | 4.75-5.25 | 3.709 | 204.0 |
| 5.25-5.75 | 3.719 | 222.0 | 5.25-5.75 | 3.719 | 222.0 |
| 5.75-6.25 | 3.654 | 240.0 | 5.75-6.25 | 3.654 | 240.0 |
| 6.25-6.75 | 3.498 | 258.0 | 6.25-6.75 | 3.498 | 258.0 |
| 6.75-7.25 | 3.290 | 276.0 | 6.75-7.25 | 3.290 | 276.0 |
| 7.25-7.75 | 2.981 | 294.0 | 7.25-7.75 | 2.981 | 294.0 |
| 7.75-8.25 | 2.616 | 312.0 | 7.75-8.25 | 2.616 | 312.0 |
| 8.25-8.75 | 2.169 | 330.0 | 8.25-8.75 | 2.169 | 330.0 |
| 8.75-9.25 | 1.655 | 348.0 | 8.75-9.25 | 1.655 | 348.0 |
| 9.25-9.75 | 1.184 | 366.0 | 9.25-9.75 | 1.184 | 366.0 |
| 9.75-10.25 | 0.769 | 384.0 | 9.75-10.25 | 0.769 | 384.0 |
| 10.25-10.75 | 0.459 | 402.0 | 10.25-10.75 | 0.459 | 402.0 |
| 10.75-11.25 | 0.272 | 420.0 | 10.75-11.25 | 0.272 | 420.0 |
| 11.25-11.75 | 0.162 | 438.0 | 11.25-11.75 | 0.162 | 438.0 |
| 11.75-12.25 | 0.094 | 456.0 | 11.75-12.25 | 0.094 | 456.0 |
| 12.25-12.75 | 0.055 | 474.0 | 12.25-12.75 | 0.055 | 474.0 |
Table A.13: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^+ + \text{Al} \rightarrow p + X$ interactions with +5.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$  | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|--------|------------------------|--------------------------|--------------------------|------------------------|--------------------------|--------------------------|
| 20 < $\theta$ < 30 | | | | | | |
| 0.20-0.24 | 0.220 | 25.0 | 160.55 ± 3.42 ± 8.01 | 0.270 | 35.0 | 159.32 ± 4.30 ± 6.56 |
| 0.24-0.30 | 0.270 | 25.2 | 154.49 ± 4.25 ± 7.06 | 0.329 | 35.1 | 130.20 ± 3.78 ± 4.78 |
| 0.30-0.36 | 0.329 | 25.0 | 118.90 ± 3.72 ± 5.29 | 0.388 | 34.9 | 112.22 ± 3.62 ± 4.30 |
| 0.36-0.42 | 0.388 | 25.2 | 110.40 ± 3.59 ± 4.40 | 0.389 | 34.9 | 112.22 ± 3.62 ± 4.30 |
| 0.42-0.50 | 0.458 | 25.1 | 87.13 ± 2.66 ± 3.25 | 0.458 | 35.0 | 92.95 ± 2.86 ± 3.70 |
| 0.50-0.60 | 0.547 | 25.1 | 78.88 ± 2.26 ± 2.81 | 0.548 | 35.0 | 73.31 ± 2.26 ± 2.88 |
| 0.60-0.72 | 0.655 | 25.1 | 50.79 ± 1.58 ± 2.08 | 0.656 | 34.9 | 52.37 ± 1.71 ± 2.33 |
| 0.72-0.90 | | | | 0.802 | 35.1 | 34.02 ± 1.12 ± 1.92 |
| | | | | | | |
| 40 < $\theta$ < 50 | | | | | | |
| 0.30-0.36 | 0.329 | 45.1 | 151.31 ± 4.02 ± 4.72 | 0.389 | 55.1 | 126.97 ± 3.62 ± 3.59 |
| 0.36-0.42 | 0.388 | 45.0 | 119.42 ± 3.59 ± 3.51 | 0.458 | 55.0 | 107.29 ± 2.96 ± 3.16 |
| 0.42-0.50 | 0.458 | 44.8 | 94.69 ± 2.84 ± 3.15 | 0.458 | 54.9 | 70.48 ± 2.27 ± 3.24 |
| 0.50-0.60 | 0.549 | 45.0 | 71.66 ± 2.25 ± 3.10 | 0.548 | 54.9 | 70.48 ± 2.27 ± 3.24 |
| 0.60-0.72 | 0.655 | 45.0 | 50.15 ± 1.76 ± 2.46 | 0.656 | 55.1 | 48.76 ± 1.80 ± 2.94 |
| 0.72-0.90 | 0.799 | 45.0 | 32.30 ± 1.16 ± 1.99 | 0.798 | 54.8 | 26.10 ± 1.08 ± 1.98 |
| 0.90-1.25 | 1.037 | 45.0 | 11.27 ± 0.48 ± 0.99 | 1.034 | 54.8 | 7.55 ± 0.41 ± 0.85 |
| | | | | | | |
| 60 < $\theta$ < 75 | | | | | | |
| 0.42-0.50 | 0.461 | 67.4 | 98.81 ± 2.27 ± 2.72 | 0.460 | 81.9 | 80.27 ± 2.03 ± 2.83 |
| 0.50-0.60 | 0.549 | 67.3 | 70.62 ± 1.80 ± 2.79 | 0.549 | 82.0 | 56.60 ± 1.56 ± 2.64 |
| 0.60-0.72 | 0.658 | 67.1 | 36.58 ± 1.29 ± 2.87 | 0.657 | 82.1 | 21.90 ± 1.03 ± 2.30 |
| 0.72-0.90 | 0.805 | 67.1 | 17.69 ± 0.77 ± 2.01 | 1.034 | 81.9 | 80.27 ± 2.03 ± 2.83 |
| | | | | | | |
| 75 < $\theta$ < 90 | | | | | | |
| 0.42-0.50 | 0.458 | 97.0 | 61.38 ± 1.78 ± 3.12 | 0.458 | 113.7 | 32.08 ± 1.13 ± 1.57 |
| 0.50-0.60 | 0.550 | 96.9 | 38.32 ± 1.29 ± 2.42 | 0.549 | 113.3 | 15.32 ± 0.75 ± 1.43 |
| 0.60-0.72 | 0.658 | 96.9 | 13.32 ± 0.85 ± 1.88 | 0.658 | 113.3 | 15.32 ± 0.75 ± 1.43 |
Table A.14: Double-differential inclusive cross-section $d^2\sigma/dp\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $\pi^+ + A \rightarrow \pi^+ + X$ interactions with +5.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|--------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
|              | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ |
| 0.10–0.13    | 0.116 ± 0.036       | 0.115 ± 0.034       | 0.115 ± 0.036       | 0.115 ± 0.034       | 0.116 ± 0.036       | 0.115 ± 0.034       | 0.115 ± 0.036       | 0.115 ± 0.034       |
| 0.13–0.16    | 0.145 ± 0.036       | 0.145 ± 0.034       | 0.145 ± 0.036       | 0.145 ± 0.034       | 0.145 ± 0.036       | 0.145 ± 0.034       | 0.145 ± 0.036       | 0.145 ± 0.034       |
| 0.16–0.20    | 0.181 ± 0.036       | 0.180 ± 0.034       | 0.180 ± 0.036       | 0.180 ± 0.034       | 0.181 ± 0.036       | 0.180 ± 0.034       | 0.180 ± 0.036       | 0.180 ± 0.034       |
| 0.20–0.24    | 0.221 ± 0.036       | 0.220 ± 0.034       | 0.220 ± 0.036       | 0.220 ± 0.034       | 0.221 ± 0.036       | 0.220 ± 0.034       | 0.220 ± 0.036       | 0.220 ± 0.034       |
| 0.24–0.30    | 0.270 ± 0.036       | 0.271 ± 0.034       | 0.271 ± 0.036       | 0.271 ± 0.034       | 0.270 ± 0.036       | 0.271 ± 0.034       | 0.271 ± 0.036       | 0.271 ± 0.034       |
| 0.30–0.36    | 0.329 ± 0.036       | 0.329 ± 0.034       | 0.329 ± 0.036       | 0.329 ± 0.034       | 0.329 ± 0.036       | 0.329 ± 0.034       | 0.329 ± 0.036       | 0.329 ± 0.034       |
| 0.36–0.42    | 0.389 ± 0.036       | 0.389 ± 0.034       | 0.389 ± 0.036       | 0.389 ± 0.034       | 0.389 ± 0.036       | 0.389 ± 0.034       | 0.389 ± 0.036       | 0.389 ± 0.034       |
| 0.42–0.50    | 0.458 ± 0.036       | 0.458 ± 0.034       | 0.458 ± 0.036       | 0.458 ± 0.034       | 0.458 ± 0.036       | 0.458 ± 0.034       | 0.458 ± 0.036       | 0.458 ± 0.034       |
| 0.50–0.60    | 0.547 ± 0.036       | 0.547 ± 0.034       | 0.547 ± 0.036       | 0.547 ± 0.034       | 0.547 ± 0.036       | 0.547 ± 0.034       | 0.547 ± 0.036       | 0.547 ± 0.034       |
| 0.60–0.72    | 0.657 ± 0.036       | 0.657 ± 0.034       | 0.657 ± 0.036       | 0.657 ± 0.034       | 0.657 ± 0.036       | 0.657 ± 0.034       | 0.657 ± 0.036       | 0.657 ± 0.034       |
| 0.72–0.90    | 0.798 ± 0.036       | 0.798 ± 0.034       | 0.798 ± 0.036       | 0.798 ± 0.034       | 0.798 ± 0.036       | 0.798 ± 0.034       | 0.798 ± 0.036       | 0.798 ± 0.034       |
| 0.90–1.25    | 0.928 ± 0.036       | 0.928 ± 0.034       | 0.928 ± 0.036       | 0.928 ± 0.034       | 0.928 ± 0.036       | 0.928 ± 0.034       | 0.928 ± 0.036       | 0.928 ± 0.034       |
| 1.0–1.3     | 1.028 ± 0.036       | 1.028 ± 0.034       | 1.028 ± 0.036       | 1.028 ± 0.034       | 1.028 ± 0.036       | 1.028 ± 0.034       | 1.028 ± 0.036       | 1.028 ± 0.034       |
Table A.15: Double-differential inclusive cross-section $d^2σ/dp dΩ$ [mb/(GeV/c sr)] of the production of $π^−$’s in $π^+ + Al → π^− + X$ interactions with $+5.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $θ$ in degrees.

| $p_T$ | $20 < θ < 30$ | $30 < θ < 40$ |
|-------|----------------|----------------|
|       | $<$ | $<$ |               |
|       | $<$ | $<$ |

| $p_T$ | $40 < θ < 50$ | $50 < θ < 60$ |
|-------|----------------|----------------|
|       | $<$ | $<$ |               |
|       | $<$ | $<$ |

| $p_T$ | $60 < θ < 75$ | $75 < θ < 90$ |
|-------|----------------|----------------|
|       | $<$ | $<$ |               |
|       | $<$ | $<$ |

| $p_T$ | $90 < θ < 105$ | $105 < θ < 125$ |
|-------|----------------|-----------------|
|       | $<$ | $<$ |               |
|       | $<$ | $<$ |
Table A.16: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^- + \text{Al} \rightarrow p + \text{X}$ interactions with $-5.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $\langle p_T \rangle$ (GeV/c) | $\langle \theta \rangle$ (degrees) | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ (GeV/c) | $\langle \theta \rangle$ (degrees) | $d^2\sigma/dp d\Omega$ |
|--------------|-----------------|-----------------|----------------|-----------------|-----------------|----------------|
| $20 < \theta < 30$ | | | | | | |
| 0.20–0.24 | 0.221 | 25.1 | 139.73 | ± 3.81 | ± 7.00 | 0.272 | 34.8 | 133.09 | ± 2.92 | ± 5.51 |
| 0.24–0.30 | 0.271 | 25.2 | 125.66 | ± 2.91 | ± 5.82 | 0.331 | 35.0 | 116.52 | ± 2.72 | ± 4.34 |
| 0.30–0.36 | 0.331 | 25.2 | 111.65 | ± 2.80 | ± 5.17 | 0.392 | 35.0 | 97.46 | ± 2.57 | ± 3.82 |
| 0.36–0.42 | 0.393 | 25.2 | 93.50 | ± 2.53 | ± 4.04 | 0.462 | 35.0 | 78.89 | ± 2.02 | ± 3.33 |
| 0.42–0.50 | 0.462 | 25.1 | 75.29 | ± 1.94 | ± 3.01 | 0.552 | 35.0 | 62.69 | ± 1.59 | ± 2.66 |
| 0.50–0.60 | 0.554 | 25.1 | 59.94 | ± 1.51 | ± 2.27 | 0.665 | 35.0 | 43.62 | ± 1.22 | ± 2.04 |
| 0.60–0.72 | 0.665 | 25.2 | 42.51 | ± 1.14 | ± 1.82 | 0.812 | 35.0 | 24.62 | ± 0.73 | ± 1.44 |
| 0.72–0.90 | | | | | | | |
| $30 < \theta < 40$ | | | | | | |
| 0.30–0.36 | 0.329 | 45.0 | 125.63 | ± 2.77 | ± 3.95 | 0.388 | 55.0 | 110.16 | ± 2.55 | ± 3.10 |
| 0.36–0.42 | 0.386 | 45.0 | 108.71 | ± 2.60 | ± 3.24 | 0.456 | 55.0 | 85.20 | ± 1.99 | ± 2.60 |
| 0.42–0.50 | 0.456 | 45.1 | 79.33 | ± 1.95 | ± 2.77 | 0.545 | 55.0 | 55.56 | ± 1.52 | ± 2.81 |
| 0.50–0.60 | 0.544 | 45.0 | 59.20 | ± 1.59 | ± 2.77 | 0.650 | 55.0 | 34.74 | ± 1.16 | ± 2.38 |
| 0.60–0.72 | 0.650 | 44.9 | 41.62 | ± 1.23 | ± 2.23 | 0.792 | 55.0 | 19.93 | ± 0.73 | ± 1.73 |
| 0.72–0.90 | 0.793 | 44.9 | 25.15 | ± 0.79 | ± 1.67 | 1.021 | 55.1 | 5.78 | ± 0.29 | ± 0.77 |
| $60 < \theta < 75$ | | | | | | |
| $50 < \theta < 60$ | | | | | | |
| 0.42–0.50 | 0.457 | 67.5 | 85.69 | ± 1.59 | ± 2.40 | 0.457 | 82.1 | 71.68 | ± 1.43 | ± 2.60 |
| 0.50–0.60 | 0.546 | 67.2 | 56.07 | ± 1.22 | ± 2.36 | 0.546 | 81.9 | 46.07 | ± 1.05 | ± 2.17 |
| 0.60–0.72 | 0.655 | 67.1 | 28.29 | ± 0.89 | ± 2.57 | 0.651 | 81.8 | 18.08 | ± 0.74 | ± 2.13 |
| 0.72–0.90 | 0.796 | 66.9 | 11.65 | ± 0.48 | ± 1.60 | | | | | |
| $75 < \theta < 90$ | | | | | | |
| $90 < \theta < 105$ | | | | | | |
| 0.42–0.50 | 0.457 | 97.0 | 51.45 | ± 1.22 | ± 2.63 | 0.457 | 113.7 | 27.82 | ± 0.79 | ± 1.38 |
| 0.50–0.60 | 0.547 | 97.0 | 30.41 | ± 0.86 | ± 1.93 | 0.543 | 113.5 | 12.17 | ± 0.51 | ± 1.19 |

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Table A.17: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$s in $\pi^- + A \to \pi^+ + X$ interactions with $-5.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $0 < \theta < 30$ | $30 < \theta < 60$ |
|-------|-------------------|-------------------|
|       | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ |
| 0.10-0.13 | 0.116 46.4 | 66.32 ± 3.44 ± 4.83 | 0.115 43.4 | 80.61 ± 3.63 ± 5.70 |
| 0.13-0.16 | 0.144 44.9 | 77.75 ± 3.33 ± 4.32 | 0.145 55.0 | 65.23 ± 3.08 ± 3.80 |
| 0.16-0.20 | 0.180 44.9 | 79.75 ± 2.75 ± 3.75 | 0.179 55.0 | 67.15 ± 2.55 ± 3.16 |
| 0.20-0.24 | 0.219 44.7 | 71.89 ± 2.58 ± 2.93 | 0.219 54.7 | 63.81 ± 2.43 ± 2.62 |
| 0.24-0.30 | 0.269 44.8 | 68.07 ± 2.06 ± 2.32 | 0.268 54.8 | 56.23 ± 1.86 ± 1.92 |
| 0.30-0.36 | 0.328 44.8 | 59.40 ± 1.90 ± 1.80 | 0.328 54.7 | 46.91 ± 1.74 ± 1.53 |
| 0.36-0.42 | 0.387 44.7 | 50.52 ± 1.79 ± 1.55 | 0.387 54.5 | 36.05 ± 1.49 ± 1.13 |
| 0.42-0.50 | 0.456 44.7 | 39.88 ± 1.38 ± 1.39 | 0.456 54.9 | 29.59 ± 1.18 ± 1.07 |
| 0.50-0.60 | 0.545 45.0 | 27.56 ± 1.01 ± 1.32 | 0.542 54.9 | 19.30 ± 0.84 ± 0.93 |
| 0.60-0.72 | 0.651 44.6 | 14.33 ± 0.63 ± 1.04 | 0.651 54.6 | 9.81 ± 0.54 ± 0.69 |
| 0.72-0.90 | 0.791 44.5 | 6.10 ± 0.32 ± 0.78 | 0.785 55.0 | 4.22 ± 0.27 ± 0.47 |
| 0.90-1.25 | 1.021 54.3 | 1.00 ± 0.08 ± 0.20 | 1.021 54.3 | 1.00 ± 0.08 ± 0.20 |

| $p_T$ | $0 < \theta < 75$ | $75 < \theta < 90$ |
|-------|-------------------|-------------------|
|       | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ |
| 0.13-0.16 | 0.145 67.2 | 59.93 ± 2.45 ± 3.52 | 0.145 82.3 | 46.83 ± 2.19 ± 2.79 |
| 0.16-0.20 | 0.180 67.4 | 57.51 ± 1.96 ± 2.67 | 0.179 82.2 | 49.66 ± 1.82 ± 2.24 |
| 0.20-0.24 | 0.219 67.2 | 47.39 ± 1.71 ± 1.88 | 0.220 82.1 | 39.86 ± 1.62 ± 1.50 |
| 0.24-0.30 | 0.269 67.1 | 42.55 ± 1.33 ± 1.40 | 0.269 82.3 | 29.40 ± 1.12 ± 0.95 |
| 0.30-0.36 | 0.330 67.0 | 33.56 ± 1.19 ± 1.03 | 0.329 81.7 | 20.15 ± 0.91 ± 0.68 |
| 0.36-0.42 | 0.389 66.9 | 27.89 ± 1.08 ± 0.94 | 0.390 81.7 | 16.28 ± 0.82 ± 0.66 |
| 0.42-0.50 | 0.458 66.6 | 19.15 ± 0.77 ± 0.79 | 0.459 81.5 | 11.36 ± 0.59 ± 0.58 |
| 0.50-0.60 | 0.544 66.6 | 13.93 ± 0.59 ± 0.78 | 0.546 81.7 | 7.41 ± 0.43 ± 0.51 |
| 0.60-0.72 | 0.654 66.5 | 6.29 ± 0.35 ± 0.50 | 0.653 82.0 | 3.59 ± 0.26 ± 0.34 |
| 0.72-0.90 | 0.790 66.4 | 2.71 ± 0.18 ± 0.32 | 0.795 81.8 | 1.12 ± 0.11 ± 0.16 |
| 0.90-1.25 | 1.008 65.6 | 0.41 ± 0.04 ± 0.09 | 0.105 81.0 | 0.09 ± 0.02 ± 0.03 |

| $p_T$ | $0 < \theta < 105$ | $105 < \theta < 125$ |
|-------|-------------------|-------------------|
|       | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ | $(\langle p_T \rangle)$ | $d^2\sigma/dp\,d\Omega$ |
| 0.13-0.16 | 0.145 97.6 | 41.71 ± 2.07 ± 2.43 | 0.144 114.4 | 41.13 ± 1.83 ± 2.10 |
| 0.16-0.20 | 0.179 97.1 | 41.83 ± 1.72 ± 1.78 | 0.179 114.0 | 29.79 ± 1.25 ± 1.14 |
| 0.20-0.24 | 0.219 97.3 | 34.38 ± 1.50 ± 1.25 | 0.218 114.0 | 20.32 ± 1.00 ± 0.76 |
| 0.24-0.30 | 0.268 97.2 | 22.80 ± 0.99 ± 0.78 | 0.267 113.7 | 11.82 ± 0.62 ± 0.50 |
| 0.30-0.36 | 0.329 96.9 | 14.07 ± 0.76 ± 0.59 | 0.327 114.3 | 7.51 ± 0.49 ± 0.42 |
| 0.36-0.42 | 0.388 97.0 | 10.14 ± 0.64 ± 0.56 | 0.388 113.6 | 5.45 ± 0.41 ± 0.41 |
| 0.42-0.50 | 0.458 96.8 | 7.03 ± 0.48 ± 0.50 | 0.454 112.8 | 2.88 ± 0.26 ± 0.28 |
| 0.50-0.60 | 0.546 96.1 | 3.98 ± 0.31 ± 0.38 | 0.537 112.3 | 1.36 ± 0.15 ± 0.19 |
| 0.60-0.72 | 0.652 96.3 | 1.52 ± 0.16 ± 0.21 | 0.647 109.7 | 0.32 ± 0.06 ± 0.07 |
| 0.72-0.90 | 0.800 95.8 | 0.28 ± 0.05 ± 0.06 | 0.798 112.4 | 0.04 ± 0.02 ± 0.02 |
Table A.18: Double-differential inclusive cross-section \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] of the production of \(\pi^+\)'s in \(\pi^- + \text{Al} \to \pi^- + \text{X}\) interactions with \(-5.0\ \text{GeV/c}\) beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) (GeV/c) | \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
|-----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
| \(p_T\) (GeV/c) | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] | \(d^2\sigma/dp\Omega\) [mb/(GeV/c sr)] |
Table A.19: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of protons in $p + Al \rightarrow p + X$ interactions with $+8.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $0.20-0.24$ | $0.24-0.30$ | $0.30-0.36$ | $0.36-0.42$ | $0.42-0.50$ | $0.50-0.60$ | $0.60-0.72$ | $0.72-0.90$ |
|--------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| $20 < \theta < 30$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ | $16.7$ | $21.8$ | $18.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |
| $30 < \theta < 40$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ | $16.7$ | $21.8$ | $18.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |

| $p_T$ (GeV/c) | $0.30-0.36$ | $0.36-0.42$ | $0.42-0.50$ | $0.50-0.60$ | $0.60-0.72$ | $0.72-0.90$ |
|--------------|-------------|-------------|-------------|-------------|-------------|-------------|
| $40 < \theta < 50$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ | $18.7$ | $16.7$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |
| $50 < \theta < 60$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ | $18.7$ | $16.7$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |

| $p_T$ (GeV/c) | $0.42-0.50$ | $0.50-0.60$ | $0.60-0.72$ | $0.72-0.90$ |
|--------------|-------------|-------------|-------------|-------------|
| $60 < \theta < 75$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |
| $75 < \theta < 90$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |

| $p_T$ (GeV/c) | $0.42-0.50$ | $0.50-0.60$ | $0.60-0.72$ | $0.72-0.90$ |
|--------------|-------------|-------------|-------------|-------------|
| $90 < \theta < 105$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |
| $105 < \theta < 125$ | $21.8$ | $18.7$ | $16.7$ | $21.8$ |
| $d^2\sigma/dp\,d\Omega$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ | $0.41 \pm 1.1$ |
| $p_T$ | (pT) | $d^2\sigma / dp d\Omega$ | (pT) | $d^2\sigma / dp d\Omega$ |
|-------|------|----------------|------|----------------|
| 0.10–0.13 | 0.116 | 24.8 | 0.808 | 24.8 |
| 0.13–0.16 | 0.146 | 24.8 | 0.046 | 24.8 |
| 0.16–0.20 | 0.181 | 24.7 | 0.046 | 24.7 |
| 0.20–0.24 | 0.221 | 24.8 | 0.146 | 24.8 |
| 0.24–0.30 | 0.271 | 24.7 | 0.146 | 24.7 |
| 0.30–0.36 | 0.331 | 24.6 | 0.146 | 24.6 |
| 0.36–0.42 | 0.392 | 24.7 | 0.146 | 24.7 |
| 0.42–0.50 | 0.462 | 24.7 | 0.146 | 24.7 |
| 0.50–0.60 | 0.552 | 24.8 | 0.146 | 24.8 |
| 0.60–0.72 | 0.662 | 24.8 | 0.146 | 24.8 |
| 0.72–0.90 | 0.808 | 24.8 | 0.146 | 24.8 |

| $p_T$ | (pT) | $d^2\sigma / dp d\Omega$ | (pT) | $d^2\sigma / dp d\Omega$ |
|-------|------|----------------|------|----------------|
| 0.10–0.13 | 0.117 | 44.9 | 1.065 | 44.9 |
| 0.13–0.16 | 0.146 | 44.9 | 1.065 | 44.9 |
| 0.16–0.20 | 0.182 | 44.9 | 1.065 | 44.9 |
| 0.20–0.24 | 0.222 | 44.8 | 1.065 | 44.8 |
| 0.24–0.30 | 0.272 | 44.7 | 1.065 | 44.7 |
| 0.30–0.36 | 0.333 | 44.7 | 1.065 | 44.7 |
| 0.36–0.42 | 0.394 | 44.6 | 1.065 | 44.6 |
| 0.42–0.50 | 0.467 | 44.6 | 1.065 | 44.6 |
| 0.50–0.60 | 0.558 | 44.6 | 1.065 | 44.6 |
| 0.60–0.72 | 0.673 | 44.5 | 1.065 | 44.5 |
| 0.72–0.90 | 0.820 | 44.7 | 1.065 | 44.7 |
| 0.90–1.25 | 1.049 | 65.9 | 1.065 | 65.9 |

| $p_T$ | (pT) | $d^2\sigma / dp d\Omega$ | (pT) | $d^2\sigma / dp d\Omega$ |
|-------|------|----------------|------|----------------|
| 0.13–0.16 | 0.146 | 67.2 | 1.046 | 67.2 |
| 0.16–0.20 | 0.181 | 69.6 | 1.046 | 69.6 |
| 0.20–0.24 | 0.220 | 69.1 | 1.046 | 69.1 |
| 0.24–0.30 | 0.271 | 70.7 | 1.046 | 70.7 |
| 0.30–0.36 | 0.331 | 70.7 | 1.046 | 70.7 |
| 0.36–0.42 | 0.394 | 70.6 | 1.046 | 70.6 |
| 0.42–0.50 | 0.467 | 70.5 | 1.046 | 70.5 |
| 0.50–0.60 | 0.554 | 70.2 | 1.046 | 70.2 |
| 0.60–0.72 | 0.660 | 66.4 | 1.046 | 66.4 |
| 0.72–0.90 | 0.805 | 65.9 | 1.046 | 65.9 |
| 0.90–1.25 | 1.049 | 69.5 | 1.046 | 69.5 |

Table A.20: Double-differential inclusive cross-section $d^2\sigma / dp d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $p + Al \rightarrow \pi^+ + X$ interactions with +8.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.
Table A.21: Double-differential inclusive cross-section \(d^2\sigma/dp d\Omega\) [mb/(GeV/c sr)] of the production of \(\pi^-\)'s in \(p + Al \rightarrow \pi^- + X\) interactions with +8.0 GeV/c beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) (GeV/c) | \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
|----------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| \(p_T\) (GeV/c) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) | \(d^2\sigma/dp d\Omega\) |
| 0.10–0.13 | 0.115 24.8 134.10 ± 4.16 ± 9.08 0.116 25.0 110.34 ± 3.71 ± 7.79 | 0.145 24.6 144.41 ± 4.00 ± 7.85 0.145 34.8 117.62 ± 3.55 ± 6.44 | 0.194 24.9 150.04 ± 3.37 ± 5.72 0.219 34.7 110.96 ± 2.86 ± 4.26 | 0.267 24.9 128.95 ± 2.52 ± 4.07 0.268 34.7 105.42 ± 2.26 ± 3.34 | 0.326 25.0 101.14 ± 2.24 ± 2.79 0.327 34.8 84.50 ± 2.05 ± 2.33 | 0.385 24.9 73.22 ± 1.89 ± 2.07 0.385 34.8 65.00 ± 1.77 ± 1.82 | 0.454 24.9 56.27 ± 1.45 ± 1.91 0.453 34.8 48.19 ± 1.31 ± 1.60 | 0.539 24.9 34.69 ± 1.02 ± 1.61 0.539 34.8 28.92 ± 0.90 ± 1.30 | 0.644 25.0 18.83 ± 0.67 ± 1.21 0.646 34.6 14.17 ± 0.56 ± 0.90 |
| 0.72–0.90 | 0.778 34.7 6.55 ± 0.30 ± 0.60 | | | | | | | |
| 0.80–0.90 | 0.806 34.7 5.16 ± 0.30 ± 0.56 | | | | | | | |
| 0.90–1.25 | 0.977 54.8 0.76 ± 0.07 ± 0.11 | | | | | | | |
| 1.25–1.50 | 1.251 90.9 0.37 ± 0.05 ± 0.08 | | | | | | | |

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Table A.22: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^+ + \text{Al} \rightarrow p + \text{X}$ interactions with +8.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|-------|------------------|-----------------|------------------|------------------|-----------------|------------------|
| 0.20–0.24 | 0.221 | 25.0 | 163.97 $\pm$ 5.12 $\pm$ 8.10 | 0.272 | 34.8 | 144.64 $\pm$ 3.85 $\pm$ 5.93 |
| 0.24–0.30 | 0.271 | 25.1 | 140.86 $\pm$ 3.83 $\pm$ 6.31 | 0.323 | 35.1 | 128.82 $\pm$ 3.56 $\pm$ 4.63 |
| 0.30–0.36 | 0.331 | 25.2 | 118.62 $\pm$ 3.52 $\pm$ 5.09 | 0.392 | 35.0 | 114.73 $\pm$ 3.44 $\pm$ 3.99 |
| 0.36–0.42 | 0.392 | 25.0 | 98.19 $\pm$ 3.19 $\pm$ 4.00 | 0.463 | 34.9 | 90.42 $\pm$ 2.66 $\pm$ 3.32 |
| 0.42–0.50 | 0.463 | 25.1 | 83.43 $\pm$ 2.47 $\pm$ 3.30 | 0.555 | 35.0 | 71.05 $\pm$ 2.11 $\pm$ 2.87 |
| 0.50–0.60 | 0.553 | 25.0 | 71.20 $\pm$ 2.02 $\pm$ 2.86 | 0.665 | 35.0 | 49.19 $\pm$ 1.60 $\pm$ 2.33 |
| 0.60–0.72 | 0.665 | 25.0 | 52.30 $\pm$ 1.54 $\pm$ 2.33 | 0.813 | 35.0 | 30.87 $\pm$ 1.00 $\pm$ 1.89 |
| 0.72–0.90 | 0.813 | 25.0 | 25.87 $\pm$ 0.81 $\pm$ 1.89 | 0.90–1.25 | 1.079 | 44.9 | 8.45 $\pm$ 0.38 $\pm$ 0.81 |

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|-------|------------------|-----------------|------------------|------------------|-----------------|------------------|
| 0.30–0.36 | 0.334 | 45.0 | 132.87 $\pm$ 3.56 $\pm$ 4.11 | 0.396 | 55.1 | 120.19 $\pm$ 3.31 $\pm$ 3.26 |
| 0.36–0.42 | 0.396 | 45.0 | 119.21 $\pm$ 3.38 $\pm$ 3.40 | 0.467 | 55.1 | 94.29 $\pm$ 2.61 $\pm$ 2.67 |
| 0.42–0.50 | 0.467 | 45.1 | 91.84 $\pm$ 2.63 $\pm$ 2.82 | 0.560 | 55.0 | 65.71 $\pm$ 2.05 $\pm$ 2.68 |
| 0.50–0.60 | 0.560 | 45.1 | 71.18 $\pm$ 2.14 $\pm$ 2.76 | 0.672 | 55.1 | 43.21 $\pm$ 1.57 $\pm$ 2.45 |
| 0.60–0.72 | 0.672 | 45.0 | 48.31 $\pm$ 1.63 $\pm$ 2.37 | 0.825 | 54.9 | 23.51 $\pm$ 0.98 $\pm$ 1.78 |
| 0.72–0.90 | 0.825 | 45.0 | 28.58 $\pm$ 1.02 $\pm$ 1.84 | 1.077 | 54.8 | 5.85 $\pm$ 0.34 $\pm$ 0.68 |
| 0.90–1.25 | 1.077 | 44.9 | 8.45 $\pm$ 0.38 $\pm$ 0.81 | 0.42–0.50 | 0.462 | 67.4 | 95.24 $\pm$ 2.09 $\pm$ 2.64 |
| 0.50–0.60 | 0.551 | 67.6 | 65.60 $\pm$ 1.62 $\pm$ 2.51 | 0.553 | 82.2 | 51.31 $\pm$ 1.39 $\pm$ 2.38 |
| 0.60–0.72 | 0.664 | 67.3 | 34.17 $\pm$ 1.17 $\pm$ 2.47 | 0.660 | 81.7 | 23.86 $\pm$ 0.99 $\pm$ 2.08 |
| 0.72–0.90 | 0.809 | 67.0 | 17.00 $\pm$ 0.69 $\pm$ 1.70 | 0.808 | 81.7 | 9.96 $\pm$ 0.54 $\pm$ 1.17 |
| 0.90–1.25 | 1.050 | 66.5 | 4.22 $\pm$ 0.26 $\pm$ 0.67 | 1.040 | 81.2 | 2.33 $\pm$ 0.20 $\pm$ 0.40 |
| 0.42–0.50 | 0.461 | 96.9 | 54.94 $\pm$ 1.58 $\pm$ 2.77 | 0.461 | 113.4 | 32.09 $\pm$ 1.06 $\pm$ 1.58 |
| 0.50–0.60 | 0.552 | 96.9 | 35.69 $\pm$ 1.17 $\pm$ 2.24 | 0.550 | 112.9 | 14.23 $\pm$ 0.67 $\pm$ 1.20 |
| 0.60–0.72 | 0.658 | 96.5 | 13.16 $\pm$ 0.76 $\pm$ 1.47 | 0.657 | 112.4 | 4.36 $\pm$ 0.39 $\pm$ 0.67 |
| 0.72–0.90 | 0.807 | 95.6 | 4.61 $\pm$ 0.39 $\pm$ 0.64 | 0.799 | 113.1 | 1.02 $\pm$ 0.16 $\pm$ 0.22 |
| $p_T$ | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|-------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|       | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ | $d^2\sigma/dp_Td\Omega$ |
| 0.10–0.13 | 0.116 | 24.8 | 133.16 $\pm$ 6.22 $\pm$ 9.40 | 0.016 | 34.7 | 103.03 $\pm$ 5.13 $\pm$ 7.09 | 0.116 | 45.0 | 81.24 $\pm$ 4.33 $\pm$ 5.75 | 0.016 | 44.7 | 98.71 $\pm$ 4.64 $\pm$ 5.34 | 0.146 | 54.8 | 85.41 $\pm$ 4.32 $\pm$ 4.85 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.13–0.16 | 0.146 | 44.7 | 98.71 $\pm$ 4.64 $\pm$ 5.34 | 0.146 | 54.8 | 85.41 $\pm$ 4.32 $\pm$ 4.85 | 0.180 | 82.3 | 5.89 $\pm$ 2.26 $\pm$ 2.47 | 0.180 | 82.1 | 48.65 $\pm$ 2.13 $\pm$ 1.79 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.16–0.20 | 0.181 | 44.8 | 108.61 $\pm$ 4.20 $\pm$ 4.95 | 0.181 | 54.6 | 82.21 $\pm$ 3.53 $\pm$ 3.72 | 0.270 | 82.1 | 35.41 $\pm$ 1.55 $\pm$ 1.20 | 0.270 | 82.1 | 35.41 $\pm$ 1.55 $\pm$ 1.20 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.20–0.24 | 0.222 | 44.7 | 107.66 $\pm$ 4.16 $\pm$ 4.29 | 0.222 | 54.8 | 76.84 $\pm$ 3.47 $\pm$ 3.01 | 0.334 | 54.9 | 60.42 $\pm$ 2.48 $\pm$ 1.80 | 0.334 | 54.9 | 60.42 $\pm$ 2.48 $\pm$ 1.80 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.24–0.30 | 0.272 | 44.6 | 105.65 $\pm$ 3.29 $\pm$ 3.56 | 0.272 | 54.9 | 71.86 $\pm$ 2.74 $\pm$ 2.47 | 0.466 | 54.8 | 56.20 $\pm$ 1.64 $\pm$ 1.30 | 0.466 | 54.8 | 56.20 $\pm$ 1.64 $\pm$ 1.30 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.30–0.36 | 0.333 | 44.7 | 85.68 $\pm$ 2.93 $\pm$ 2.53 | 0.334 | 54.9 | 60.42 $\pm$ 2.48 $\pm$ 1.80 | 0.497 | 54.9 | 56.20 $\pm$ 1.64 $\pm$ 1.30 | 0.497 | 54.9 | 56.20 $\pm$ 1.64 $\pm$ 1.30 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.36–0.42 | 0.395 | 44.6 | 73.44 $\pm$ 2.76 $\pm$ 2.14 | 0.395 | 54.8 | 54.27 $\pm$ 2.36 $\pm$ 1.66 | 0.637 | 54.6 | 50.70 $\pm$ 2.70 $\pm$ 2.97 | 0.637 | 54.6 | 50.70 $\pm$ 2.70 $\pm$ 2.97 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.42–0.50 | 0.466 | 44.8 | 55.09 $\pm$ 2.03 $\pm$ 1.80 | 0.466 | 54.6 | 56.20 $\pm$ 1.64 $\pm$ 1.30 | 0.803 | 54.6 | 50.70 $\pm$ 2.70 $\pm$ 2.97 | 0.803 | 54.6 | 50.70 $\pm$ 2.70 $\pm$ 2.97 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.50–0.60 | 0.557 | 44.6 | 36.03 $\pm$ 1.42 $\pm$ 1.53 | 0.558 | 54.8 | 23.77 $\pm$ 1.19 $\pm$ 1.09 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.60–0.72 | 0.622 | 44.6 | 22.88 $\pm$ 1.01 $\pm$ 1.33 | 0.671 | 54.6 | 16.01 $\pm$ 0.87 $\pm$ 1.01 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.72–0.90 | 0.825 | 44.6 | 13.37 $\pm$ 0.55 $\pm$ 1.05 | 0.823 | 54.5 | 6.48 $\pm$ 0.41 $\pm$ 0.60 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |
| 0.90–1.25 | 1.044 | 66.0 | 0.81 $\pm$ 0.08 $\pm$ 0.14 | 1.056 | 80.5 | 0.26 $\pm$ 0.04 $\pm$ 0.05 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 | 1.078 | 54.2 | 1.41 $\pm$ 0.12 $\pm$ 0.21 |

Table A.23: Double-differential inclusive cross-section $d^2\sigma/dp_Td\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+\alpha + p \rightarrow \pi^+\alpha + X$ interactions with $+8.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.
Table A.24: Double-differential inclusive cross-section $d^2\sigma/dp^d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^+ + A\rightarrow \pi^- + X$ interactions with $+8.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $20 < \theta < 30$ | $30 < \theta < 40$ | $d^2\sigma/dp^d\Omega$ | | $40 < \theta < 60$ | $50 < \theta < 60$ | $d^2\sigma/dp^d\Omega$ |
|-------|-----------------|-----------------|------------------------|-----------------|-----------------|-----------------|-----------------|
| $2.00-3.00$ | $0.116$ | $0.34$ | $98.96 \pm 5.03 \pm 7.01$ | | $0.783$ | $3.65 \pm 0.46 \pm 0.69$ | |
| $3.00-4.00$ | $0.34$ | $3.69 \pm 0.36 \pm 3.55$ | | | | | |
| $4.00-5.00$ | $0.78$ | $3.96 \pm 0.36 \pm 3.55$ | | | | | |
| $5.00-6.00$ | $3.69 \pm 0.36 \pm 3.55$ | | | | | | |
| $2.00-3.00$ | $0.116$ | $0.34$ | $98.96 \pm 5.03 \pm 7.01$ | | $0.783$ | $3.65 \pm 0.46 \pm 0.69$ | |
| $3.00-4.00$ | $0.34$ | $3.69 \pm 0.36 \pm 3.55$ | | | | | |
| $4.00-5.00$ | $0.78$ | $3.96 \pm 0.36 \pm 3.55$ | | | | | |
| $5.00-6.00$ | $3.69 \pm 0.36 \pm 3.55$ | | | | | | |
Table A.25: Double-differential inclusive cross-section \(d^2\sigma/d\theta d\Omega\) [mb/(GeV/c sr)] of the production of protons in \(\pi^- + \text{Al} \to p + X\) interactions with \(-8.0\) GeV/c beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) (GeV/c) | \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
|-----------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|                 | \(\langle p_T\rangle\) | \(\langle \theta\rangle\) | \(d^2\sigma/d\theta d\Omega\) | \(\langle p_T\rangle\) | \(\langle \theta\rangle\) | \(d^2\sigma/d\theta d\Omega\) | \(\langle p_T\rangle\) | \(\langle \theta\rangle\) | \(d^2\sigma/d\theta d\Omega\) |
| 0.20–0.24       | 0.221            | 25.0             | 131.35 ± 3.27 ± 6.50       | 0.271            | 34.9             | 127.10 ± 2.56 ± 5.22       | 0.801            | 35.0             | 22.63 ± 0.63 ± 1.39       |
| 0.24–0.30       | 0.270            | 25.2             | 120.09 ± 2.52 ± 5.37       | 0.329            | 35.0             | 110.94 ± 2.36 ± 4.00       | 0.654            | 35.0             | 21.9 ± 0.21 ± 0.35       |
| 0.30–0.36       | 0.329            | 25.2             | 94.11 ± 2.24 ± 4.16        | 0.390            | 35.0             | 90.62 ± 2.19 ± 3.25        | 0.548            | 35.0             | 17.3 ± 0.17 ± 0.34       |
| 0.36–0.42       | 0.389            | 25.2             | 81.02 ± 2.09 ± 3.47        | 0.459            | 35.0             | 73.95 ± 1.73 ± 2.84        | 0.458            | 35.0             | 13.6 ± 0.13 ± 0.24       |
| 0.42–0.50       | 0.459            | 25.1             | 72.20 ± 1.67 ± 2.85        | 0.548            | 35.0             | 57.00 ± 1.36 ± 2.34        | 0.654            | 34.9             | 10.4 ± 0.10 ± 0.19       |
| 0.50–0.60       | 0.548            | 25.1             | 55.79 ± 1.30 ± 2.30        | 0.458            | 35.0             | 46.67 ± 0.97 ± 1.81        | 0.801            | 35.0             | 6.33 ± 0.63 ± 0.19       |
| 0.60–0.72       | 0.655            | 25.2             | 39.55 ± 0.97 ± 1.81        | 0.801            | 35.0             | 22.63 ± 0.63 ± 1.39        | 0.458            | 35.0             | 4.28 ± 0.21 ± 0.53       |
| 0.72–0.90       | 1.035            | 44.8             | 6.10 ± 0.24 ± 0.59         | 0.801            | 35.0             | 22.63 ± 0.63 ± 1.39        | 0.458            | 35.0             | 4.28 ± 0.21 ± 0.53       |

Note: The values are given in units of mb/(GeV/c sr).
| $p_T$ | $(\frac{d^3\sigma}{dp_t d\Omega})$ | $20 < \theta < 30$ | | $(\frac{d^3\sigma}{dp_t d\Omega})$ | $30 < \theta < 40$ |
|------|----------------------------------|--|--|----------------------------------|--|
| 0.10–0.13 | 0.116 | 24.8 | 103.05 | $\pm$ | 3.66 | $\pm$ | 6.85 | 0.116 | 34.9 | 78.47 | $\pm$ | 3.18 | $\pm$ | 5.44 |
| 0.13–0.16 | 0.146 | 24.7 | 121.20 | $\pm$ | 3.68 | $\pm$ | 6.56 | 0.145 | 34.6 | 99.03 | $\pm$ | 3.27 | $\pm$ | 5.30 |
| 0.16–0.20 | 0.181 | 24.8 | 145.20 | $\pm$ | 3.35 | $\pm$ | 6.55 | 0.180 | 34.7 | 109.96 | $\pm$ | 2.92 | $\pm$ | 4.93 |
| 0.20–0.24 | 0.220 | 24.9 | 158.84 | $\pm$ | 3.48 | $\pm$ | 6.22 | 0.220 | 34.7 | 109.84 | $\pm$ | 2.84 | $\pm$ | 4.25 |
| 0.24–0.30 | 0.269 | 24.8 | 143.59 | $\pm$ | 2.67 | $\pm$ | 4.80 | 0.270 | 34.7 | 110.08 | $\pm$ | 2.36 | $\pm$ | 3.61 |
| 0.30–0.36 | 0.329 | 24.7 | 121.62 | $\pm$ | 2.44 | $\pm$ | 3.57 | 0.329 | 34.7 | 88.40 | $\pm$ | 2.07 | $\pm$ | 2.53 |
| 0.36–0.42 | 0.389 | 24.9 | 105.60 | $\pm$ | 2.26 | $\pm$ | 3.07 | 0.389 | 34.7 | 76.15 | $\pm$ | 1.92 | $\pm$ | 2.12 |
| 0.42–0.50 | 0.458 | 24.7 | 80.58 | $\pm$ | 1.67 | $\pm$ | 2.79 | 0.457 | 34.7 | 58.16 | $\pm$ | 1.46 | $\pm$ | 1.83 |
| 0.50–0.60 | 0.546 | 24.8 | 49.67 | $\pm$ | 1.13 | $\pm$ | 2.44 | 0.547 | 34.9 | 35.99 | $\pm$ | 0.98 | $\pm$ | 1.57 |
| 0.60–0.72 | 0.654 | 24.9 | 29.70 | $\pm$ | 0.76 | $\pm$ | 2.18 | 0.656 | 34.6 | 22.12 | $\pm$ | 0.67 | $\pm$ | 1.44 |
| 0.72–0.90 | 0.798 | 34.6 | 9.14 | $\pm$ | 0.30 | $\pm$ | 0.99 | 0.90–1.25 | 1.038 | 54.6 | 1.13 | $\pm$ | 0.07 | $\pm$ | 0.18 |

Table A.26: Double-differential inclusive cross-section $\frac{d^3\sigma}{dp_t d\Omega}$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $\pi^- +$ Al $\to \pi^+$ + X with $-8.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.
Table A.27: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^{-}$s in $\pi^{-} + Al \rightarrow \pi^{-} + X$ interactions with $-8.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $\theta$ | $d^2\sigma/dp\,d\Omega$ | $d^2\sigma/dp\,d\Omega$ |
|----------|-----------------|-----------------|
| $20 < \theta < 30$ | $(p_T)$ | $(\theta)$ |
| $30 < \theta < 40$ | $(p_T)$ | $(\theta)$ |
| $40 < \theta < 50$ | $(p_T)$ | $(\theta)$ |
| $50 < \theta < 60$ | $(p_T)$ | $(\theta)$ |
| $60 < \theta < 75$ | $(p_T)$ | $(\theta)$ |
| $75 < \theta < 90$ | $(p_T)$ | $(\theta)$ |
| $90 < \theta < 105$ | $(p_T)$ | $(\theta)$ |
| $105 < \theta < 125$ | $(p_T)$ | $(\theta)$ |

| $p_T$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.10-0.13 | 0.116 | 24.7 | 156.75 | 4.61 | 10.77 | 0.116 | 34.6 | 114.00 | 3.86 | 8.05 | 0.145 | 24.6 | 186.78 | 4.66 | 10.26 | 0.145 | 34.8 | 135.76 | 3.92 | 7.43 |
| 0.13-0.16 | 0.145 | 24.6 | 186.78 | 4.66 | 10.26 | 0.145 | 34.8 | 135.76 | 3.92 | 7.43 | 0.180 | 24.7 | 214.58 | 4.16 | 9.75 | 0.180 | 34.7 | 154.21 | 3.51 | 7.05 |
| 0.16-0.20 | 0.220 | 24.7 | 223.32 | 4.20 | 8.67 | 0.220 | 34.8 | 154.16 | 3.46 | 5.95 | 0.270 | 24.7 | 207.25 | 3.25 | 6.61 | 0.270 | 34.7 | 146.89 | 2.73 | 4.70 |
| 0.20-0.24 | 0.329 | 24.7 | 177.37 | 4.94 | 4.94 | 0.329 | 34.5 | 127.90 | 2.54 | 3.55 | 0.389 | 24.7 | 151.94 | 2.79 | 4.30 | 0.389 | 34.6 | 100.24 | 2.24 | 2.81 |
| 0.24-0.30 | 0.458 | 24.7 | 111.41 | 2.06 | 3.79 | 0.458 | 34.6 | 79.61 | 1.75 | 2.64 | 0.545 | 24.8 | 75.92 | 1.51 | 3.50 | 0.545 | 34.6 | 50.41 | 1.20 | 2.25 |
| 0.30-0.36 | 0.654 | 24.8 | 42.84 | 1.02 | 2.74 | 0.654 | 34.7 | 30.43 | 0.86 | 1.87 | 0.798 | 34.8 | 14.32 | 0.48 | 1.24 |

| $p_T$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ | $(p_T)$ | $(\theta)$ |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 0.10-0.13 | 0.116 | 44.9 | 96.67 | 3.68 | 7.03 | 0.116 | 54.7 | 82.54 | 3.01 | 4.77 | 0.146 | 44.9 | 109.35 | 3.51 | 6.09 | 0.146 | 54.7 | 82.54 | 3.01 | 4.77 |
| 0.13-0.16 | 0.145 | 44.9 | 109.35 | 3.51 | 6.09 | 0.146 | 54.7 | 82.54 | 3.01 | 4.77 | 0.180 | 44.8 | 118.13 | 3.06 | 5.44 | 0.180 | 54.9 | 85.24 | 2.57 | 3.92 |
| 0.16-0.20 | 0.180 | 44.8 | 118.13 | 3.06 | 5.44 | 0.180 | 54.9 | 85.24 | 2.57 | 3.92 | 0.220 | 44.7 | 116.78 | 3.04 | 4.56 | 0.220 | 54.9 | 86.30 | 2.56 | 3.30 |
| 0.20-0.24 | 0.269 | 44.7 | 101.52 | 2.25 | 3.62 | 0.269 | 54.7 | 74.95 | 1.93 | 2.37 | 0.329 | 44.7 | 87.73 | 2.10 | 2.46 | 0.329 | 54.9 | 59.07 | 1.71 | 1.67 |
| 0.24-0.30 | 0.389 | 44.7 | 71.01 | 1.89 | 2.05 | 0.388 | 54.7 | 50.67 | 1.60 | 1.52 | 0.457 | 44.7 | 50.60 | 1.36 | 1.76 | 0.459 | 54.8 | 36.61 | 1.16 | 1.34 |
| 0.30-0.36 | 0.457 | 44.7 | 32.82 | 0.98 | 1.55 | 0.547 | 54.7 | 25.37 | 0.85 | 1.25 | 0.654 | 44.9 | 22.04 | 0.73 | 1.44 | 0.654 | 54.6 | 14.52 | 0.59 | 0.98 |
| 0.36-0.42 | 0.793 | 44.7 | 10.05 | 0.40 | 0.92 | 0.797 | 54.7 | 7.24 | 0.34 | 0.68 | 1.029 | 54.4 | 4.59 | 0.10 | 0.24 |
| 0.42-0.50 | 0.816 | 54.5 | 44.7 | 32.82 | 0.98 | 1.55 | 0.547 | 54.7 | 25.37 | 0.85 | 1.25 | 0.654 | 44.9 | 22.04 | 0.73 | 1.44 | 0.654 | 54.6 | 14.52 | 0.59 | 0.98 |
| 0.50-0.60 | 0.816 | 54.5 | 44.7 | 32.82 | 0.98 | 1.55 | 0.547 | 54.7 | 25.37 | 0.85 | 1.25 | 0.654 | 44.9 | 22.04 | 0.73 | 1.44 | 0.654 | 54.6 | 14.52 | 0.59 | 0.98 |
| 0.60-0.72 | 0.90-1.25 | 1.066 | 66.3 | 65.65 | 0.05 | 0.110 | 1.070 | 81.2 | 0.26 | 0.04 | 0.035 |

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## Table A.28: Double-differential inclusive cross-section $\frac{d^2\sigma}{dpd\Omega}$ [mb/(GeV/c sr)] of the production of protons in $p + Al \rightarrow p + X$ interactions with $+12.9$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $<p_T>$ | $\langle\theta\rangle$ | $\frac{d^2\sigma}{dpd\Omega}$ | $<p_T>$ | $\langle\theta\rangle$ | $\frac{d^2\sigma}{dpd\Omega}$ |
|-------|---------|-----------------|-----------------|-------|---------|-----------------|
| $20 < \theta < 30$ | | | | | | |
| 0.20–0.24 | 0.220 | 25.1 | 197.63 $\pm$ 5.84 $\pm$ 9.62 | 0.220 | 25.1 | 197.63 $\pm$ 5.84 $\pm$ 9.62 |
| 0.24–0.30 | 0.270 | 25.1 | 180.23 $\pm$ 1.74 $\pm$ 7.92 | 0.271 | 34.9 | 184.83 $\pm$ 1.75 $\pm$ 7.44 |
| 0.30–0.36 | 0.329 | 25.1 | 156.23 $\pm$ 1.63 $\pm$ 6.49 | 0.329 | 35.0 | 168.84 $\pm$ 1.64 $\pm$ 5.90 |
| 0.36–0.42 | 0.389 | 25.0 | 133.49 $\pm$ 1.49 $\pm$ 5.36 | 0.389 | 35.0 | 141.55 $\pm$ 1.53 $\pm$ 4.78 |
| 0.42–0.50 | 0.459 | 25.0 | 116.86 $\pm$ 1.20 $\pm$ 4.57 | 0.458 | 35.0 | 119.66 $\pm$ 1.24 $\pm$ 4.20 |
| 0.50–0.60 | 0.548 | 25.0 | 96.07 $\pm$ 0.96 $\pm$ 3.76 | 0.548 | 35.0 | 92.26 $\pm$ 0.97 $\pm$ 3.51 |
| 0.60–0.72 | 0.656 | 25.0 | 71.39 $\pm$ 0.73 $\pm$ 3.13 | 0.656 | 35.0 | 66.43 $\pm$ 0.75 $\pm$ 3.13 |
| 0.72–0.90 | 0.800 | 34.9 | 39.75 $\pm$ 0.47 $\pm$ 2.42 | 0.800 | 34.9 | 39.75 $\pm$ 0.47 $\pm$ 2.42 |
| $40 < \theta < 50$ | | | | | | |
| 0.30–0.36 | 0.331 | 45.0 | 174.44 $\pm$ 1.65 $\pm$ 5.21 | 0.331 | 45.0 | 174.44 $\pm$ 1.65 $\pm$ 5.21 |
| 0.36–0.42 | 0.391 | 45.1 | 149.24 $\pm$ 1.53 $\pm$ 4.07 | 0.391 | 55.0 | 149.25 $\pm$ 1.50 $\pm$ 3.87 |
| 0.42–0.50 | 0.461 | 45.1 | 120.04 $\pm$ 1.21 $\pm$ 3.48 | 0.461 | 55.0 | 118.05 $\pm$ 1.17 $\pm$ 3.20 |
| 0.50–0.60 | 0.551 | 45.0 | 89.81 $\pm$ 0.96 $\pm$ 3.35 | 0.550 | 54.9 | 83.84 $\pm$ 0.93 $\pm$ 3.36 |
| 0.60–0.72 | 0.660 | 44.9 | 63.10 $\pm$ 0.75 $\pm$ 2.96 | 0.660 | 54.9 | 55.28 $\pm$ 0.72 $\pm$ 3.08 |
| 0.72–0.90 | 0.806 | 45.0 | 36.46 $\pm$ 0.47 $\pm$ 2.28 | 0.806 | 54.9 | 30.27 $\pm$ 0.44 $\pm$ 2.20 |
| 0.90–1.25 | 1.044 | 44.8 | 10.85 $\pm$ 0.18 $\pm$ 1.06 | 1.041 | 54.8 | 8.07 $\pm$ 0.16 $\pm$ 0.92 |
| $60 < \theta < 75$ | | | | | | |
| 0.42–0.50 | 0.453 | 67.4 | 114.08 $\pm$ 0.92 $\pm$ 3.24 | 0.454 | 82.1 | 92.82 $\pm$ 0.82 $\pm$ 3.30 |
| 0.50–0.60 | 0.540 | 67.3 | 78.68 $\pm$ 0.71 $\pm$ 2.94 | 0.540 | 82.0 | 62.19 $\pm$ 0.62 $\pm$ 2.85 |
| 0.60–0.72 | 0.646 | 67.1 | 44.51 $\pm$ 0.54 $\pm$ 2.33 | 0.645 | 81.9 | 28.23 $\pm$ 0.44 $\pm$ 2.47 |
| 0.72–0.90 | 0.785 | 66.9 | 21.96 $\pm$ 0.32 $\pm$ 2.14 | 0.781 | 81.7 | 12.04 $\pm$ 0.24 $\pm$ 1.38 |
| 0.90–1.25 | 1.006 | 66.6 | 5.62 $\pm$ 0.12 $\pm$ 0.86 | 1.003 | 81.5 | 2.92 $\pm$ 0.09 $\pm$ 0.49 |
| $75 < \theta < 90$ | | | | | | |
| 0.42–0.50 | 0.453 | 97.0 | 66.07 $\pm$ 0.70 $\pm$ 3.34 | 0.452 | 113.4 | 34.76 $\pm$ 0.44 $\pm$ 1.69 |
| 0.50–0.60 | 0.539 | 96.8 | 39.46 $\pm$ 0.49 $\pm$ 2.45 | 0.538 | 112.9 | 16.19 $\pm$ 0.29 $\pm$ 1.37 |
| 0.60–0.72 | 0.643 | 96.7 | 14.65 $\pm$ 0.32 $\pm$ 1.63 | 0.642 | 112.5 | 5.51 $\pm$ 0.18 $\pm$ 0.84 |
| 0.72–0.90 | 0.783 | 96.2 | 5.68 $\pm$ 0.17 $\pm$ 0.79 | 0.777 | 112.6 | 1.62 $\pm$ 0.08 $\pm$ 0.34 |
Table A.29: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega [\text{mb/(GeV/c sr)}]$ of the production of $\pi^+$'s in $p + \text{Al} \rightarrow \pi^+ + X$ interactions with +12.9 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ |
|------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|      | $(p_T) (0)$ | $d^2\sigma/dp d\Omega$ | $(p_T) (0)$ | $d^2\sigma/dp d\Omega$ | $(p_T) (0)$ | $d^2\sigma/dp d\Omega$ |
| 0.10–0.13 | 0.116 | 24.8 | 154.62 ± 2.64 ± 10.35 | 0.116 | 34.8 | 116.65 ± 2.50 ± 7.95 |
| 0.13–0.16 | 0.146 | 24.7 | 185.20 ± 2.67 ± 9.90 | 0.145 | 34.8 | 136.67 ± 2.25 ± 7.22 |
| 0.16–0.20 | 0.180 | 24.7 | 212.34 ± 2.37 ± 9.54 | 0.180 | 34.8 | 147.32 ± 1.98 ± 6.63 |
| 0.20–0.24 | 0.220 | 24.7 | 221.40 ± 2.36 ± 8.56 | 0.220 | 34.7 | 153.42 ± 1.97 ± 5.91 |
| 0.24–0.30 | 0.269 | 24.7 | 210.03 ± 1.87 ± 6.89 | 0.269 | 34.7 | 147.27 ± 1.58 ± 4.79 |
| 0.30–0.36 | 0.329 | 24.7 | 179.89 ± 1.72 ± 5.15 | 0.329 | 34.7 | 123.26 ± 1.42 ± 3.49 |
| 0.36–0.42 | 0.389 | 24.7 | 152.58 ± 1.57 ± 4.31 | 0.389 | 34.8 | 99.08 ± 1.27 ± 2.73 |
| 0.42–0.50 | 0.458 | 24.7 | 113.22 ± 1.15 ± 3.87 | 0.458 | 34.7 | 75.85 ± 0.94 ± 2.37 |
| 0.50–0.60 | 0.547 | 24.7 | 76.61 ± 0.82 ± 3.74 | 0.547 | 34.7 | 53.87 ± 0.71 ± 2.35 |
| 0.60–0.72 | 0.655 | 24.7 | 45.54 ± 0.55 ± 3.34 | 0.656 | 34.7 | 30.39 ± 0.45 ± 1.98 |
| 0.72–0.90 | 0.797 | 34.7 | 15.62 ± 0.24 ± 1.63 | 0.797 | 34.7 | 15.62 ± 0.24 ± 1.63 |

| $90 < \theta < 105$ | $105 < \theta < 125$ | $p_T$ | $d^2\sigma/dp d\Omega$ | $(p_T) (0)$ | $d^2\sigma/dp d\Omega$ |
|---------------------|---------------------|------|---------------------|---------------------|
| 0.13–0.16 | 0.145 | 97.4 | 48.98 ± 1.04 ± 2.99 | 0.144 | 114.5 | 40.56 ± 0.79 ± 2.51 |
| 0.16–0.20 | 0.179 | 97.2 | 45.20 ± 0.82 ± 2.14 | 0.179 | 114.2 | 44.52 ± 0.82 ± 2.14 |
| 0.20–0.24 | 0.218 | 97.2 | 35.72 ± 0.72 ± 1.36 | 0.218 | 113.8 | 24.42 ± 0.54 ± 0.81 |
| 0.24–0.30 | 0.267 | 97.0 | 25.01 ± 0.52 ± 0.78 | 0.265 | 113.5 | 13.57 ± 0.34 ± 0.52 |
| 0.30–0.36 | 0.326 | 96.8 | 16.29 ± 0.42 ± 0.63 | 0.325 | 113.5 | 8.11 ± 0.25 ± 0.44 |
| 0.36–0.42 | 0.385 | 96.9 | 10.77 ± 0.34 ± 0.56 | 0.385 | 113.6 | 4.74 ± 0.19 ± 0.34 |
| 0.42–0.50 | 0.452 | 96.9 | 6.75 ± 0.23 ± 0.47 | 0.449 | 112.4 | 2.98 ± 0.13 ± 0.28 |
| 0.50–0.60 | 0.539 | 96.5 | 3.86 ± 0.15 ± 0.36 | 0.536 | 113.0 | 1.23 ± 0.08 ± 0.15 |
| 0.60–0.72 | 0.642 | 96.0 | 1.62 ± 0.09 ± 0.20 | 0.634 | 112.5 | 0.39 ± 0.04 ± 0.06 |
| 0.72–0.90 | 0.783 | 95.5 | 0.56 ± 0.04 ± 0.09 | 0.784 | 111.6 | 0.10 ± 0.02 ± 0.02 |
| 0.90–1.25 | 1.001 | 95.9 | 0.10 ± 0.02 ± 0.03 | 1.001 | 95.9 | 0.10 ± 0.02 ± 0.03 |
Table A.30: Double-differential inclusive cross-section $d^2\sigma/d\eta d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $p + Al \rightarrow \pi^- + X$ interactions with $+12.9$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| $p_T$               | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ | $d^2\sigma/d\eta d\Omega$ |
| 0.10–0.13           | 0.116               | 24.8                | 166.11 ± 2.61 ± 10.95 | 0.115               | 34.8                | 122.89 ± 2.21 ± 8.62 |
| 0.13–0.16           | 0.145               | 24.8                | 195.17 ± 2.63 ± 10.36 | 0.145               | 34.7                | 140.99 ± 2.22 ± 7.64 |
| 0.16–0.20           | 0.180               | 24.7                | 206.82 ± 2.28 ± 9.24  | 0.180               | 34.8                | 142.91 ± 1.88 ± 6.45 |
| 0.20–0.24           | 0.220               | 24.8                | 201.48 ± 2.20 ± 7.60  | 0.220               | 34.7                | 147.31 ± 1.89 ± 5.58 |
| 0.24–0.30           | 0.269               | 24.9                | 184.10 ± 1.73 ± 5.73  | 0.269               | 34.7                | 131.00 ± 1.43 ± 4.09 |
| 0.30–0.36           | 0.329               | 24.7                | 147.56 ± 1.54 ± 3.98  | 0.329               | 34.8                | 111.14 ± 1.32 ± 2.99 |
| 0.36–0.42           | 0.389               | 24.8                | 115.76 ± 1.37 ± 3.17  | 0.388               | 34.8                | 84.31 ± 1.14 ± 2.29  |
| 0.42–0.50           | 0.458               | 24.7                | 85.73 ± 1.01 ± 2.86   | 0.458               | 34.7                | 63.67 ± 0.86 ± 2.06  |
| 0.50–0.60           | 0.547               | 24.8                | 58.74 ± 0.76 ± 2.68   | 0.546               | 34.7                | 39.54 ± 0.59 ± 1.74  |
| 0.60–0.72           | 0.655               | 24.8                | 31.87 ± 0.49 ± 2.02   | 0.654               | 34.7                | 23.09 ± 0.41 ± 1.43  |
| 0.72–0.90           | 0.798               | 34.7                | 11.05 ± 0.23 ± 0.97   |                    |                     |                     |                     |
| 0.90–1.25           | 1.008               | 54.6                | 0.96 ± 0.04 ± 0.15    |                    |                     |                     |                     |

p, $T$, $\theta$ 56
Table A.31: Double-differential inclusive cross-section $d^2\sigma/dp\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^+ + \text{Al} \rightarrow p + \text{X}$ interactions with +12.9 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $0 < \theta < 20$ | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|--------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|              | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ | $d^2\sigma/dp\Omega$ |
| 0.20–0.24    | 0.220            | 149.28 ± 5.08 ± 7.36 | 0.271            | 34.9            | 143.35 ± 3.80 ± 5.88 |
| 0.24–0.30    | 0.268            | 134.37 ± 3.65 ± 5.99 | 0.330            | 35.0            | 131.60 ± 3.54 ± 4.72 |
| 0.30–0.36    | 0.329            | 111.88 ± 3.37 ± 4.78 | 0.388            | 35.0            | 106.92 ± 3.26 ± 3.77 |
| 0.36–0.42    | 0.389            | 100.59 ± 3.16 ± 4.16 | 0.458            | 35.0            | 83.82 ± 2.54 ± 3.06 |
| 0.42–0.50    | 0.457            | 81.01 ± 2.43 ± 3.25 | 0.547            | 34.9            | 62.93 ± 1.94 ± 2.45 |
| 0.50–0.60    | 0.547            | 66.51 ± 1.93 ± 2.66 | 0.655            | 35.0            | 44.83 ± 1.50 ± 2.14 |
| 0.60–0.72    | 0.655            | 48.69 ± 1.46 ± 2.17 | 0.799            | 35.0            | 27.88 ± 0.95 ± 1.72 |
| 0.72–0.90    | 0.833            | 30.90 ± 1.30 ± 2.36 | 0.965            | 35.0            | 14.59 ± 0.75 ± 1.30 |
| 0.80–1.00    | 1.040            | 20.89 ± 1.20 ± 2.49 | 1.175            | 35.0            | 7.00 ± 0.50 ± 1.08 |
Table A.32: Double-differential inclusive cross-section $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $\pi^+ + \text{Al} \rightarrow \pi^+ + \text{X}$ interactions with $+12.9$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| \(p_T\) | \(p_T\) | \(\theta\) | \(d^2\sigma/d\Omega\) | \(\theta\) | \(d^2\sigma/d\Omega\) |
|-------|-------|-----|-----------------|-----|-----------------|
| \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
| 0.10–0.13 | 0.116 | 24.8 | 133.85 ± 6.05 ± 9.10 | 0.116 | 35.1 | 105.43 ± 5.11 ± 7.23 |
| 0.13–0.16 | 0.145 | 24.6 | 172.26 ± 6.29 ± 9.33 | 0.145 | 34.8 | 121.95 ± 5.19 ± 6.52 |
| 0.16–0.20 | 0.181 | 24.7 | 189.11 ± 5.45 ± 8.63 | 0.180 | 34.8 | 130.18 ± 4.55 ± 5.95 |
| 0.20–0.24 | 0.220 | 24.6 | 210.80 ± 5.64 ± 8.31 | 0.220 | 34.7 | 126.50 ± 4.37 ± 4.97 |
| 0.24–0.30 | 0.269 | 24.8 | 207.79 ± 4.55 ± 7.01 | 0.269 | 34.6 | 135.09 ± 3.70 ± 4.52 |
| 0.30–0.36 | 0.329 | 24.6 | 182.30 ± 4.22 ± 5.41 | 0.329 | 34.5 | 115.74 ± 3.35 ± 3.40 |
| 0.36–0.42 | 0.389 | 24.6 | 147.02 ± 3.75 ± 4.30 | 0.389 | 34.6 | 94.99 ± 3.03 ± 2.71 |
| 0.42–0.50 | 0.458 | 24.7 | 110.33 ± 2.80 ± 3.86 | 0.458 | 34.7 | 72.26 ± 2.26 ± 2.32 |
| 0.50–0.60 | 0.545 | 24.7 | 78.90 ± 2.06 ± 3.89 | 0.545 | 34.6 | 51.82 ± 1.70 ± 2.29 |
| 0.60–0.72 | 0.654 | 24.6 | 47.44 ± 1.40 ± 3.50 | 0.656 | 34.7 | 29.83 ± 1.11 ± 1.95 |
| 0.72–0.90 | 0.797 | 34.7 | 14.42 ± 0.59 ± 1.51 | 0.797 | 34.7 | 14.42 ± 0.59 ± 1.51 |
| 0.90–1.25 | 1.049 | 45.4 | 1.29 ± 0.11 ± 0.20 | 1.049 | 45.4 | 1.29 ± 0.11 ± 0.20 |
| 1.25–1.60 | 1.411 | 49.5 | 0.53 ± 0.05 ± 0.14 | 1.411 | 49.5 | 0.53 ± 0.05 ± 0.14 |
| 1.60–2.00 | 2.002 | 53.0 | 0.23 ± 0.03 ± 0.05 | 2.002 | 53.0 | 0.23 ± 0.03 ± 0.05 |
| 2.00–2.50 | 2.785 | 56.0 | 0.13 ± 0.02 ± 0.03 | 2.785 | 56.0 | 0.13 ± 0.02 ± 0.03 |
| 2.50–3.15 | 3.828 | 60.0 | 0.07 ± 0.01 ± 0.02 | 3.828 | 60.0 | 0.07 ± 0.01 ± 0.02 |
| 3.15–4.00 | 5.433 | 65.0 | 0.04 ± 0.004 ± 0.004 | 5.433 | 65.0 | 0.04 ± 0.004 ± 0.004 |
| 4.00–5.00 | 8.000 | 70.0 | 0.03 ± 0.003 ± 0.003 | 8.000 | 70.0 | 0.03 ± 0.003 ± 0.003 |
Table A.33: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^+ + A \rightarrow \pi^- + X$ interactions with $+12.9$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c; polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 75$ | $75 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|---------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.10-0.13     | 0.116            | 24.6             | 128.55 ± 5.54 ± 8.47 | 0.116            | 34.9             | 96.69 ± 4.30 ± 6.82 |
| 0.13-0.16     | 0.146            | 24.7             | 159.43 ± 5.81 ± 8.56 | 0.146            | 34.9             | 125.46 ± 5.15 ± 6.87 |
| 0.16-0.20     | 0.180            | 24.6             | 176.04 ± 5.11 ± 7.98 | 0.181            | 34.7             | 124.45 ± 4.28 ± 5.70 |
| 0.20-0.24     | 0.220            | 24.7             | 184.88 ± 5.16 ± 7.11 | 0.220            | 34.8             | 122.97 ± 4.24 ± 4.76 |
| 0.24-0.30     | 0.269            | 24.7             | 161.93 ± 3.95 ± 5.20 | 0.269            | 34.7             | 109.06 ± 3.20 ± 3.51 |
| 0.30-0.36     | 0.329            | 24.7             | 136.02 ± 3.61 ± 3.81 | 0.328            | 34.5             | 96.63 ± 3.01 ± 2.70 |
| 0.36-0.42     | 0.389            | 24.7             | 113.56 ± 3.30 ± 3.23 | 0.389            | 34.8             | 74.49 ± 2.62 ± 2.10 |
| 0.42-0.50     | 0.458            | 24.7             | 81.15 ± 2.41 ± 2.77  | 0.458            | 34.7             | 54.47 ± 1.95 ± 1.81 |
| 0.50-0.60     | 0.545            | 24.8             | 51.99 ± 1.74 ± 2.40  | 0.548            | 34.6             | 36.08 ± 1.39 ± 1.61 |
| 0.60-0.72     | 0.654            | 24.8             | 29.53 ± 1.16 ± 1.89  | 0.653            | 34.7             | 20.96 ± 0.96 ± 1.30 |
| 0.72-0.90     | 0.798            | 34.9             | 8.42 ± 0.49 ± 0.74   | 0.798            | 44.7             | 6.82 ± 0.30 ± 0.49 |
| 0.90-1.25     | 1.011            | 54.7             | 0.95 ± 0.10 ± 0.15   | 1.011            | 85.1             | 0.83 ± 0.10 ± 0.15 |

| $p_T$ (GeV/c) | $90 < \theta < 105$ | $105 < \theta < 125$ |
|---------------|------------------|------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.13-0.16     | 0.145            | 97.2             | 39.10 ± 2.21 ± 2.65  | 0.145            | 97.2             | 39.10 ± 2.21 ± 2.65  |
| 0.16-0.20     | 0.179            | 97.2             | 32.46 ± 2.18 ± 2.58  | 0.178            | 97.2             | 22.46 ± 1.21 ± 1.00  |
| 0.20-0.24     | 0.220            | 96.9             | 26.69 ± 1.55 ± 0.92  | 0.219            | 96.9             | 16.98 ± 0.86 ± 0.79  |
| 0.24-0.30     | 0.269            | 97.3             | 19.22 ± 1.09 ± 0.61  | 0.269            | 97.3             | 11.44 ± 0.73 ± 0.61  |
| 0.30-0.36     | 0.328            | 97.0             | 12.13 ± 0.85 ± 0.50  | 0.328            | 97.0             | 5.98 ± 0.52 ± 0.36   |
| 0.36-0.42     | 0.391            | 96.7             | 10.42 ± 0.80 ± 0.58  | 0.393            | 96.7             | 3.84 ± 0.41 ± 0.31   |
| 0.42-0.50     | 0.458            | 96.9             | 6.12 ± 0.52 ± 0.46   | 0.461            | 96.9             | 2.25 ± 0.28 ± 0.24   |
| 0.50-0.60     | 0.551            | 96.9             | 2.74 ± 0.31 ± 0.28   | 0.547            | 96.9             | 0.93 ± 0.16 ± 0.13   |
| 0.60-0.72     | 0.657            | 96.6             | 0.84 ± 0.16 ± 0.11   | 0.652            | 96.6             | 0.19 ± 0.07 ± 0.03   |
| 0.72-0.90     | 0.796            | 96.3             | 0.36 ± 0.09 ± 0.06   | 0.828            | 96.4             | 0.10 ± 0.04 ± 0.02   |
| 0.90-1.25     | 1.026            | 93.9             | 0.08 ± 0.03 ± 0.02   | 1.026            | 93.9             | 0.08 ± 0.03 ± 0.02   |
Table A.34: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^- + Al \rightarrow p + X$ interactions with $-12.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$   | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
|---------|-----------------------|---------------------------|-------------------------|-----------------------|---------------------------|-------------------------|
| 20 < $\theta$ < 30 | | | | 30 < $\theta$ < 60 | | |
| 0.20–0.24 | 0.220 | 25.1 | 111.64 ± 4.14 ± 6.61 | 0.271 | 34.9 | 124.18 ± 2.92 ± 5.17 |
| 0.24–0.30 | 0.270 | 25.1 | 118.61 ± 2.87 ± 5.42 | 0.329 | 35.0 | 110.23 ± 2.69 ± 4.05 |
| 0.30–0.36 | 0.329 | 25.0 | 98.76 ± 2.61 ± 4.30 | 0.390 | 35.1 | 91.82 ± 2.51 ± 3.30 |
| 0.36–0.42 | 0.389 | 25.0 | 85.76 ± 2.45 ± 3.66 | 0.459 | 35.1 | 73.43 ± 1.98 ± 2.81 |
| 0.42–0.50 | 0.459 | 24.9 | 66.70 ± 1.82 ± 2.79 | 0.547 | 35.0 | 59.25 ± 1.59 ± 2.50 |
| 0.50–0.60 | 0.548 | 25.0 | 54.86 ± 1.46 ± 2.25 | 0.656 | 35.0 | 37.65 ± 1.14 ± 1.88 |
| 0.60–0.72 | 0.656 | 25.0 | 40.06 ± 1.11 ± 1.83 | 0.798 | 35.0 | 22.91 ± 0.73 ± 1.47 |
| 0.72–0.90 | 0.798 | 25.0 | 24.91 ± 0.84 ± 1.47 | 0.948 | 35.0 | 10.91 ± 0.53 ± 0.89 |
| 40 < $\theta$ < 50 | | | | 50 < $\theta$ < 60 | | |
| 0.30–0.36 | 0.329 | 45.1 | 110.66 ± 2.65 ± 3.52 | 0.389 | 55.0 | 94.56 ± 2.40 ± 2.83 |
| 0.36–0.42 | 0.389 | 45.1 | 99.85 ± 2.54 ± 2.96 | 0.457 | 55.1 | 77.19 ± 2.12 ± 2.26 |
| 0.42–0.50 | 0.458 | 45.0 | 78.18 ± 1.99 ± 2.49 | 0.548 | 55.1 | 55.40 ± 1.55 ± 2.43 |
| 0.50–0.60 | 0.547 | 45.0 | 57.31 ± 1.59 ± 2.35 | 0.655 | 55.0 | 33.45 ± 1.13 ± 1.97 |
| 0.60–0.72 | 0.655 | 44.9 | 37.69 ± 1.17 ± 1.85 | 0.797 | 55.0 | 17.76 ± 0.70 ± 1.34 |
| 0.72–0.90 | 0.800 | 45.0 | 20.83 ± 0.73 ± 1.37 | 1.031 | 54.9 | 5.05 ± 0.27 ± 0.59 |
| 0.90–1.25 | 1.030 | 44.9 | 6.45 ± 0.28 ± 0.66 | 1.371 | 54.0 | 1.35 ± 0.21 ± 0.34 |
| 60 < $\theta$ < 75 | | | | 75 < $\theta$ < 90 | | |
| 0.42–0.50 | 0.454 | 67.6 | 77.10 ± 1.34 ± 2.30 | 0.541 | 81.9 | 41.21 ± 1.02 ± 1.94 |
| 0.50–0.60 | 0.541 | 67.3 | 52.30 ± 1.19 ± 2.05 | 0.644 | 81.9 | 17.74 ± 0.70 ± 1.62 |
| 0.60–0.72 | 0.645 | 67.1 | 25.48 ± 0.83 ± 2.01 | 0.780 | 81.9 | 6.29 ± 0.35 ± 0.76 |
| 0.72–0.90 | 0.786 | 66.6 | 12.31 ± 0.48 ± 1.25 | 0.992 | 81.7 | 1.55 ± 0.13 ± 0.27 |
| 0.90–1.25 | 1.011 | 66.2 | 3.25 ± 0.19 ± 0.52 | 1.371 | 81.0 | 0.49 ± 0.09 ± 0.21 |
| 90 < $\theta$ < 105 | | | | 105 < $\theta$ < 125 | | |
| 0.42–0.50 | 0.452 | 97.0 | 46.27 ± 1.18 ± 2.42 | 0.461 | 113.2 | 24.84 ± 0.76 ± 1.23 |
| 0.50–0.60 | 0.539 | 96.8 | 28.09 ± 0.85 ± 1.78 | 0.537 | 113.0 | 10.83 ± 0.49 ± 0.94 |
| 0.60–0.72 | 0.643 | 96.7 | 9.19 ± 0.54 ± 1.12 | 0.640 | 112.9 | 3.19 ± 0.28 ± 0.53 |
| 0.72–0.90 | 0.780 | 96.4 | 3.34 ± 0.27 ± 0.49 |
Table A.35: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$s in $\pi^- + A \rightarrow \pi^+ + X$ interactions with $\sim 12.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | 20 $< \theta <$ 30 | 30 $< \theta <$ 40 | 40 $< \theta <$ 50 | 50 $< \theta <$ 60 | 60 $< \theta <$ 75 | 76 $< \theta <$ 90 | 90 $< \theta <$ 105 | 106 $< \theta <$ 125 |
|-------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|       | $\langle p_T \rangle$ | $\sigma / d\Omega$ | $\langle p_T \rangle$ | $\sigma / d\Omega$ | $\langle p_T \rangle$ | $\sigma / d\Omega$ | $\langle p_T \rangle$ | $\sigma / d\Omega$ |
| 0.10-0.13 | 0.116 24.8 | 117.87 ± 4.56 ± 8.05 | 0.116 34.7 | 82.79 ± 3.65 ± 5.79 | 0.116 44.9 | 82.79 ± 3.65 ± 5.79 |
| 0.13-0.16 | 0.145 24.5 | 148.44 ± 4.73 ± 8.03 | 0.145 34.8 | 106.88 ± 3.93 ± 5.80 | 0.145 44.6 | 106.88 ± 3.93 ± 5.80 |
| 0.16-0.20 | 0.180 24.7 | 172.17 ± 4.19 ± 7.86 | 0.181 34.6 | 116.47 ± 3.45 ± 5.31 | 0.181 44.4 | 116.47 ± 3.45 ± 5.31 |
| 0.20-0.24 | 0.220 24.8 | 166.62 ± 4.07 ± 6.62 | 0.220 34.7 | 123.06 ± 3.51 ± 4.85 | 0.220 44.3 | 123.06 ± 3.51 ± 4.85 |
| 0.24-0.30 | 0.269 24.7 | 173.18 ± 3.40 ± 5.87 | 0.269 34.5 | 110.34 ± 2.69 ± 3.69 | 0.269 44.2 | 110.34 ± 2.69 ± 3.69 |
| 0.30-0.36 | 0.328 24.6 | 139.96 ± 3.01 ± 4.19 | 0.329 34.8 | 96.54 ± 2.52 ± 2.84 | 0.329 44.1 | 96.54 ± 2.52 ± 2.84 |
| 0.36-0.42 | 0.388 24.6 | 116.69 ± 2.75 ± 3.49 | 0.389 34.8 | 79.63 ± 2.23 ± 2.30 | 0.389 44.0 | 79.63 ± 2.23 ± 2.30 |
| 0.42-0.50 | 0.458 24.7 | 87.90 ± 2.02 ± 3.10 | 0.457 34.6 | 59.17 ± 1.64 ± 1.92 | 0.457 43.8 | 59.17 ± 1.64 ± 1.92 |
| 0.50-0.60 | 0.546 24.7 | 54.29 ± 1.35 ± 2.69 | 0.545 34.7 | 36.99 ± 1.13 ± 1.62 | 0.545 43.7 | 36.99 ± 1.13 ± 1.62 |
| 0.60-0.72 | 0.655 24.8 | 31.78 ± 0.89 ± 2.35 | 0.653 34.7 | 23.05 ± 0.77 ± 1.55 | 0.653 43.6 | 23.05 ± 0.77 ± 1.55 |
| 0.72-0.90 | 0.798 34.5 | 9.12 ± 0.36 ± 0.97 | 0.798 34.4 | 6.24 ± 0.29 ± 0.69 | 0.798 34.3 | 6.24 ± 0.29 ± 0.69 |
| 0.90-1.25 | 1.026 45.4 | 1.12 ± 0.08 ± 0.18 | 1.026 45.3 | 0.84 ± 0.05 ± 0.15 | 1.026 45.2 | 0.84 ± 0.05 ± 0.15 |
| 1.25-1.75 | 1.281 46.3 | 0.94 ± 0.04 ± 0.12 | 1.281 46.2 | 0.73 ± 0.03 ± 0.10 | 1.281 46.1 | 0.73 ± 0.03 ± 0.10 |
| 1.75-2.30 | 1.546 47.2 | 0.71 ± 0.03 ± 0.09 | 1.546 47.1 | 0.54 ± 0.02 ± 0.07 | 1.546 47.0 | 0.54 ± 0.02 ± 0.07 |
| 2.30-3.00 | 1.848 48.1 | 0.50 ± 0.02 ± 0.05 | 1.848 48.0 | 0.35 ± 0.02 ± 0.04 | 1.848 47.9 | 0.35 ± 0.02 ± 0.04 |
| 3.00-4.00 | 2.293 49.0 | 0.35 ± 0.01 ± 0.03 | 2.293 48.9 | 0.24 ± 0.01 ± 0.02 | 2.293 48.8 | 0.24 ± 0.01 ± 0.02 |
| 4.00-5.00 | 2.893 50.0 | 0.25 ± 0.01 ± 0.02 | 2.893 49.9 | 0.17 ± 0.01 ± 0.01 | 2.893 49.8 | 0.17 ± 0.01 ± 0.01 |
| 5.00-6.00 | 3.693 51.0 | 0.17 ± 0.01 ± 0.01 | 3.693 50.9 | 0.12 ± 0.01 ± 0.01 | 3.693 50.8 | 0.12 ± 0.01 ± 0.01 |
| 6.00-7.00 | 4.793 52.0 | 0.11 ± 0.01 ± 0.01 | 4.793 51.9 | 0.09 ± 0.01 ± 0.01 | 4.793 51.8 | 0.09 ± 0.01 ± 0.01 |
| 7.00-8.00 | 6.193 53.0 | 0.08 ± 0.01 ± 0.01 | 6.193 52.9 | 0.07 ± 0.01 ± 0.01 | 6.193 52.8 | 0.07 ± 0.01 ± 0.01 |
| 8.00-9.00 | 7.993 54.0 | 0.06 ± 0.01 ± 0.01 | 7.993 53.9 | 0.06 ± 0.01 ± 0.01 | 7.993 53.8 | 0.06 ± 0.01 ± 0.01 |
| 9.00-10.00 | 10.293 55.0 | 0.04 ± 0.01 ± 0.01 | 10.293 54.9 | 0.04 ± 0.01 ± 0.01 | 10.293 54.8 | 0.04 ± 0.01 ± 0.01 |
| 10.00-11.00 | 13.193 56.0 | 0.03 ± 0.01 ± 0.01 | 13.193 55.9 | 0.03 ± 0.01 ± 0.01 | 13.193 55.8 | 0.03 ± 0.01 ± 0.01 |
Table A.36: Double-differential inclusive cross-section $d^2\sigma/dp\omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^- + Al \rightarrow \pi^- + X$ interactions with $-12.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ |
|--------------|---------------------|---------------------|
|               | $(\theta)$         | $d^2\sigma/dp\omega$ | $(\theta)$         | $d^2\sigma/dp\omega$ |
| 0.10-0.13     | 0.116              | 24.6                | 0.115              | 34.8                |
| 0.20-0.24     | 0.186              | 24.6                | 0.181              | 34.6                |
| 0.30-0.36     | 0.389              | 24.6                | 0.389              | 34.7                |
| 0.40-0.50     | 0.548              | 24.6                | 0.548              | 34.7                |
| 0.60-0.70     | 0.844              | 24.6                | 0.844              | 34.7                |
| 0.70-0.90     | 1.23               | 24.6                | 1.23               | 34.7                |

| $p_T$ (GeV/c) | $40 < \theta < 50$ | $50 < \theta < 60$ |
|--------------|---------------------|---------------------|
|               | $(\theta)$         | $d^2\sigma/dp\omega$ | $(\theta)$         | $d^2\sigma/dp\omega$ |
| 0.10-0.13     | 0.113              | 45.0                | 0.113              | 66.0                |
| 0.20-0.24     | 0.219              | 44.8                | 0.220              | 43.0                |
| 0.30-0.36     | 0.388              | 44.8                | 0.389              | 43.0                |
| 0.40-0.50     | 0.548              | 44.7                | 0.548              | 43.0                |
| 0.60-0.70     | 0.844              | 44.6                | 0.844              | 43.0                |
| 0.70-0.90     | 1.23               | 44.6                | 1.23               | 43.0                |

| $p_T$ (GeV/c) | $60 < \theta < 75$ | $75 < \theta < 90$ |
|--------------|---------------------|---------------------|
|               | $(\theta)$         | $d^2\sigma/dp\omega$ | $(\theta)$         | $d^2\sigma/dp\omega$ |
| 0.10-0.13     | 0.146              | 67.2                | 0.146              | 82.2                |
| 0.20-0.24     | 0.221              | 66.8                | 0.220              | 82.0                |
| 0.30-0.36     | 0.392              | 66.7                | 0.392              | 81.8                |
| 0.40-0.50     | 0.552              | 66.6                | 0.551              | 81.7                |
| 0.60-0.70     | 0.862              | 66.7                | 0.862              | 81.7                |
| 0.70-0.90     | 1.23               | 66.6                | 1.23               | 81.7                |

| $p_T$ (GeV/c) | $90 < \theta < 105$ | $105 < \theta < 125$ |
|--------------|---------------------|---------------------|
|               | $(\theta)$         | $d^2\sigma/dp\omega$ | $(\theta)$         | $d^2\sigma/dp\omega$ |
| 0.10-0.13     | 0.145              | 97.5                | 0.145              | 114.5               |
| 0.20-0.24     | 0.221              | 97.3                | 0.220              | 113.9               |
| 0.30-0.36     | 0.393              | 97.1                | 0.392              | 112.9               |
| 0.40-0.50     | 0.548              | 97.1                | 0.547              | 112.7               |
| 0.60-0.70     | 0.805              | 94.7                | 0.805              | 111.5               |
| 0.70-0.90     | 1.23               | 96.7                | 1.23               | 110.0               |

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Table A.37: Double-differential inclusive cross-section $d^2\sigma/dp d\Omega$ [mb/(GeV/c sr)] of the production of protons in $p + Al \rightarrow p + X$ interactions with $+15.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ (GeV/c) | $20 < \theta < 30$ | $30 < \theta < 40$ |
|---------------|---------------------|---------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.20–0.24     | 0.290               | 25.2              | 195.69 $\pm$ 6.57 $\pm$ 13.19 | 0.279              | 34.8              | 179.29 $\pm$ 4.92 $\pm$ 9.57 |
| 0.24–0.30     | 0.269               | 25.1              | 185.22 $\pm$ 5.01 $\pm$ 10.88 | 0.330              | 34.9              | 162.74 $\pm$ 4.59 $\pm$ 7.15 |
| 0.30–0.36     | 0.262               | 25.2              | 156.81 $\pm$ 4.64 $\pm$ 8.08  | 0.389              | 35.0              | 142.01 $\pm$ 4.35 $\pm$ 5.44 |
| 0.36–0.42     | 0.390               | 25.1              | 139.06 $\pm$ 4.40 $\pm$ 6.40  | 0.457              | 35.1              | 119.21 $\pm$ 3.52 $\pm$ 4.35 |
| 0.42–0.50     | 0.459               | 25.0              | 113.64 $\pm$ 3.38 $\pm$ 4.79  | 0.547              | 35.1              | 87.80 $\pm$ 2.70 $\pm$ 3.48 |
| 0.50–0.60     | 0.547               | 25.0              | 89.03 $\pm$ 2.60 $\pm$ 3.58   | 0.655              | 35.0              | 64.37 $\pm$ 2.10 $\pm$ 3.39 |
| 0.60–0.72     | 0.654               | 25.1              | 69.02 $\pm$ 2.06 $\pm$ 3.30   | 0.800              | 35.0              | 35.42 $\pm$ 1.24 $\pm$ 2.68 |
| 0.72–0.90     |                    |                   |                                 |                    |                   |                                |

| $p_T$ (GeV/c) | $40 < \theta < 50$ | $50 < \theta < 60$ |
|---------------|---------------------|---------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.30–0.36     | 0.329               | 45.1              | 162.68 $\pm$ 4.62 $\pm$ 5.84 | 0.390              | 54.9              | 150.85 $\pm$ 4.25 $\pm$ 4.43 |
| 0.36–0.42     | 0.388               | 44.8              | 149.27 $\pm$ 4.37 $\pm$ 4.44 | 0.456              | 55.2              | 116.01 $\pm$ 3.30 $\pm$ 3.39 |
| 0.42–0.50     | 0.458               | 45.0              | 123.70 $\pm$ 3.49 $\pm$ 3.70 | 0.546              | 55.0              | 82.84 $\pm$ 2.63 $\pm$ 3.74 |
| 0.50–0.60     | 0.547               | 45.0              | 84.52 $\pm$ 2.68 $\pm$ 3.40  | 0.654              | 54.4              | 53.48 $\pm$ 2.02 $\pm$ 3.53 |
| 0.60–0.72     | 0.654               | 45.1              | 63.40 $\pm$ 2.14 $\pm$ 3.46  | 0.798              | 54.9              | 28.02 $\pm$ 1.20 $\pm$ 2.52 |
| 0.72–0.90     | 0.799               | 44.9              | 33.56 $\pm$ 1.27 $\pm$ 2.66  | 1.038              | 54.9              | 8.43 $\pm$ 0.48 $\pm$ 1.21  |
| 0.90–1.25     | 1.041               | 45.0              | 10.91 $\pm$ 0.51 $\pm$ 1.39  |                   |                   |                                |

| $p_T$ (GeV/c) | $60 < \theta < 75$ | $75 < \theta < 90$ |
|---------------|---------------------|---------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.42–0.50     | 0.458               | 67.4              | 117.20 $\pm$ 2.66 $\pm$ 3.47 | 0.458              | 82.2              | 86.88 $\pm$ 2.27 $\pm$ 3.86 |
| 0.50–0.60     | 0.547               | 67.1              | 76.34 $\pm$ 2.01 $\pm$ 3.44 | 0.547              | 82.1              | 61.41 $\pm$ 1.77 $\pm$ 3.86 |
| 0.60–0.72     | 0.652               | 67.2              | 42.71 $\pm$ 1.50 $\pm$ 3.63 | 0.653              | 81.6              | 25.08 $\pm$ 1.15 $\pm$ 2.68 |
| 0.72–0.90     | 0.797               | 66.9              | 20.81 $\pm$ 0.88 $\pm$ 2.54 | 0.796              | 81.7              | 11.66 $\pm$ 0.68 $\pm$ 1.75 |
| 0.90–1.25     | 1.032               | 66.8              | 5.55 $\pm$ 0.34 $\pm$ 1.11  | 1.023              | 81.2              | 2.69 $\pm$ 0.24 $\pm$ 0.60  |
|               |                     |                   |                                 |                     |                   |                                |

| $p_T$ (GeV/c) | $90 < \theta < 105$ | $105 < \theta < 125$ |
|---------------|---------------------|---------------------|
|               | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp d\Omega$ |
| 0.42–0.50     | 0.458               | 97.0              | 67.41 $\pm$ 2.01 $\pm$ 4.71 | 0.455              | 113.4             | 34.83 $\pm$ 1.26 $\pm$ 2.29 |
| 0.50–0.60     | 0.545               | 97.0              | 38.60 $\pm$ 1.40 $\pm$ 3.44 | 0.541              | 112.9             | 15.07 $\pm$ 0.80 $\pm$ 1.79 |
| 0.60–0.72     | 0.651               | 96.3              | 13.94 $\pm$ 0.91 $\pm$ 1.94 | 0.649              | 112.4             | 4.72 $\pm$ 0.48 $\pm$ 0.98  |
| 0.72–0.90     | 0.787               | 96.5              | 5.24 $\pm$ 0.47 $\pm$ 0.93  | 0.784              | 111.9             | 1.40 $\pm$ 0.21 $\pm$ 0.41  |
Table A.38: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^+$'s in $p + Al \to \pi^+ + X$ interactions with +15.0 GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $<\theta<30$ | $30<\theta<40$ | $<\theta<50$ | $50<\theta<60$ | $<\theta<75$ | $75<\theta<90$ |
|-------|---------------|---------------|---------------|---------------|---------------|---------------|
|       | ($p_T$) | ($\theta$) | $d^2\sigma/dp\,d\Omega$ | ($p_T$) | ($\theta$) | $d^2\sigma/dp\,d\Omega$ | ($p_T$) | ($\theta$) | $d^2\sigma/dp\,d\Omega$ | ($p_T$) | ($\theta$) | $d^2\sigma/dp\,d\Omega$ | ($p_T$) | ($\theta$) | $d^2\sigma/dp\,d\Omega$ |
| 0.10–0.13 | 0.115 | 24.8 | 153.74 ± 7.37 ± 12.42 | 0.116 | 34.8 | 124.70 ± 6.49 ± 10.31 | 0.115 | 90–125 | 6.49 ± 10.31 |
| 0.13–0.16 | 0.146 | 25.1 | 190.18 ± 7.68 ± 12.95 | 0.146 | 34.8 | 155.00 ± 6.89 ± 10.43 | 0.146 | 90–125 | 6.89 ± 10.43 |
| 0.16–0.20 | 0.180 | 24.7 | 227.01 ± 6.91 ± 13.07 | 0.180 | 34.7 | 157.07 ± 5.83 ± 8.94 | 0.180 | 90–125 | 5.83 ± 8.94 |
| 0.20–0.24 | 0.220 | 24.8 | 238.81 ± 7.03 ± 11.60 | 0.220 | 34.7 | 169.67 ± 5.96 ± 8.13 | 0.220 | 90–125 | 5.96 ± 8.13 |
| 0.24–0.30 | 0.271 | 24.8 | 219.09 ± 5.41 ± 8.51 | 0.269 | 34.7 | 153.46 ± 4.57 ± 5.86 | 0.269 | 90–125 | 4.57 ± 5.86 |
| 0.30–0.36 | 0.329 | 24.8 | 195.47 ± 5.11 ± 6.04 | 0.331 | 34.8 | 128.71 ± 4.18 ± 3.93 | 0.331 | 90–125 | 4.18 ± 3.93 |
| 0.36–0.42 | 0.389 | 24.8 | 157.44 ± 4.57 ± 4.60 | 0.389 | 34.7 | 103.01 ± 3.64 ± 2.97 | 0.389 | 90–125 | 3.64 ± 2.97 |
| 0.42–0.50 | 0.459 | 24.7 | 122.68 ± 3.39 ± 4.53 | 0.458 | 34.6 | 80.86 ± 2.80 ± 2.86 | 0.458 | 90–125 | 2.80 ± 2.86 |
| 0.50–0.60 | 0.547 | 24.7 | 82.50 ± 2.43 ± 4.66 | 0.547 | 34.5 | 50.66 ± 1.89 ± 2.71 | 0.547 | 90–125 | 1.89 ± 2.71 |
| 0.60–0.72 | 0.655 | 24.5 | 49.17 ± 1.61 ± 4.29 | 0.655 | 34.6 | 35.38 ± 1.42 ± 2.89 | 0.655 | 90–125 | 1.42 ± 2.89 |
| 0.72–0.90 | 0.795 | 34.6 | 35.38 ± 1.42 ± 2.89 | 0.795 | 34.6 | 35.38 ± 1.42 ± 2.89 | 0.795 | 90–125 | 1.42 ± 2.89 |

For the second systematic, $p_T$ in GeV/c, polar angle $\theta$ in degrees.
Table A.39: Double-differential inclusive cross-section \(d^2\sigma/dp d\Omega\) [mb/(GeV/c sr)] of the production of \(\pi^-\)'s in \(p + A \rightarrow \pi^- + X\) interactions with +15.0 GeV/c beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) (GeV/c) | \(<\theta<30\) | \(30<\theta<40\) | \(40<\theta<50\) | \(50<\theta<60\) | \(60<\theta<75\) | \(75<\theta<90\) | \(90<\theta<105\) | \(105<\theta<125\) |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                 | \(\langle p_T \rangle\) | \(\langle \theta \rangle\) | \(d^2\sigma/dp d\Omega\) | \(\langle p_T \rangle\) | \(\langle \theta \rangle\) | \(d^2\sigma/dp d\Omega\) | \(\langle p_T \rangle\) | \(\langle \theta \rangle\) | \(d^2\sigma/dp d\Omega\) |
| 0.10–0.13       | 0.115        | 24.7         | 157.25 ± 7.30 ± 13.03 | 0.116        | 34.8         | 125.55 ± 6.50 ± 10.83 | 0.112        | 34.8         | 125.55 ± 6.50 ± 10.83 |
| 0.13–0.16       | 0.145        | 24.9         | 191.84 ± 7.51 ± 13.19 | 0.145        | 34.6         | 133.02 ± 6.10 ± 9.25  | 0.142        | 34.6         | 133.02 ± 6.10 ± 9.25  |
| 0.16–0.20       | 0.180        | 24.6         | 218.41 ± 6.63 ± 12.54 | 0.180        | 34.5         | 135.91 ± 5.25 ± 7.86  | 0.177        | 34.5         | 135.91 ± 5.25 ± 7.86  |
| 0.20–0.24       | 0.220        | 24.7         | 224.74 ± 6.70 ± 10.53 | 0.220        | 35.0         | 155.94 ± 5.52 ± 7.39  | 0.216        | 35.0         | 155.94 ± 5.52 ± 7.39  |
| 0.24–0.30       | 0.269        | 24.7         | 195.78 ± 5.09 ± 6.99  | 0.269        | 34.7         | 127.39 ± 4.07 ± 4.62  | 0.263        | 34.7         | 127.39 ± 4.07 ± 4.62  |
| 0.30–0.36       | 0.329        | 24.6         | 169.55 ± 4.74 ± 4.74  | 0.329        | 34.7         | 115.81 ± 3.82 ± 3.24  | 0.324        | 34.7         | 115.81 ± 3.82 ± 3.24  |
| 0.36–0.42       | 0.388        | 24.6         | 132.60 ± 4.12 ± 3.91  | 0.389        | 34.8         | 84.07 ± 3.30 ± 2.48   | 0.384        | 34.8         | 84.07 ± 3.30 ± 2.48   |
| 0.42–0.50       | 0.457        | 24.8         | 92.66 ± 3.01 ± 3.80   | 0.457        | 34.6         | 71.68 ± 2.60 ± 2.86   | 0.452        | 34.6         | 71.68 ± 2.60 ± 2.86   |
| 0.50–0.60       | 0.548        | 24.7         | 65.70 ± 2.28 ± 4.09   | 0.546        | 34.6         | 48.98 ± 1.91 ± 2.93   | 0.541        | 34.6         | 48.98 ± 1.91 ± 2.93   |
| 0.60–0.72       | 0.653        | 24.8         | 38.33 ± 1.59 ± 3.49   | 0.654        | 34.9         | 28.28 ± 1.34 ± 2.48   | 0.649        | 34.9         | 28.28 ± 1.34 ± 2.48   |
| 0.72–0.90       | 0.799        | 34.8         | 11.94 ± 0.68 ± 1.53   | 0.797        | 34.8         | 11.94 ± 0.68 ± 1.53   | 0.793        | 34.8         | 11.94 ± 0.68 ± 1.53   |

Note: The table continues with similar entries for different intervals of \(p_T\) and \(\theta\).
Table A.40: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of protons in $\pi^+ + \text{Al} \rightarrow p + X$ interactions with $+15.0\text{ GeV/c}$ beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0.20–0.24 | 0.218 | 22.6 | 150.08 ± 47.10 ± 10.98 | 0.266 | 33.0 | 126.31 ± 35.11 ± 7.63 |
| 0.24–0.30 | 0.266 | 23.4 | 106.94 ± 32.13 ± 6.96 | 0.330 | 35.7 | 58.15 ± 24.36 ± 3.04 |
| 0.30–0.36 | 0.322 | 25.1 | 65.20 ± 25.90 ± 3.86 | 0.387 | 32.9 | 81.00 ± 27.58 ± 3.88 |
| 0.36–0.42 | 0.398 | 27.0 | 77.45 ± 29.47 ± 4.24 | 0.454 | 33.9 | 48.93 ± 19.47 ± 2.29 |
| 0.42–0.50 | 0.457 | 25.8 | 90.16 ± 25.92 ± 6.44 | 0.549 | 35.4 | 33.16 ± 14.33 ± 1.64 |
| 0.50–0.60 | 0.539 | 26.1 | 52.61 ± 18.29 ± 2.64 | 0.671 | 33.9 | 35.99 ± 13.80 ± 2.17 |
| 0.60–0.72 | 0.635 | 26.0 | 38.49 ± 13.24 ± 2.18 | 0.823 | 34.6 | 25.05 ± 8.94 ± 2.04 |

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0.30–0.36 | 0.332 | 44.8 | 141.67 ± 36.42 ± 6.53 | 0.383 | 54.6 | 83.72 ± 27.45 ± 3.46 |
| 0.36–0.42 | 0.389 | 45.9 | 105.45 ± 32.62 ± 4.33 | 0.461 | 55.0 | 42.08 ± 17.20 ± 1.72 |
| 0.42–0.50 | 0.457 | 44.6 | 130.27 ± 31.36 ± 5.42 | 0.545 | 54.3 | 39.57 ± 15.94 ± 2.15 |
| 0.50–0.60 | 0.549 | 45.2 | 41.90 ± 16.75 ± 2.09 | 0.645 | 55.3 | 12.31 ± 8.53 ± 0.89 |
| 0.60–0.72 | 0.655 | 45.1 | 22.84 ± 11.18 ± 1.41 | 0.816 | 54.1 | 7.92 ± 5.62 ± 0.75 |
| 0.72–0.90 | 0.789 | 44.2 | 18.93 ± 8.15 ± 1.60 | 1.946 | 53.2 | 4.29 ± 4.29 ± 1.33 |
| 0.90–1.25 | 1.044 | 45.9 | 10.16 ± 4.29 ± 1.33 | 2.610 | 52.4 | 2.09 ± 2.09 ± 0.71 |

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0.42–0.50 | 0.436 | 66.8 | 85.01 ± 19.85 ± 3.47 | 0.465 | 81.8 | 61.02 ± 16.59 ± 3.20 |
| 0.50–0.60 | 0.541 | 68.5 | 48.18 ± 14.09 ± 2.61 | 0.543 | 84.8 | 15.51 ± 7.82 ± 1.07 |
| 0.60–0.72 | 0.651 | 66.2 | 40.67 ± 12.83 ± 3.64 | 0.632 | 80.8 | 17.58 ± 8.40 ± 1.94 |
| 0.72–0.90 | 0.772 | 68.1 | 10.10 ± 5.43 ± 1.26 | 0.794 | 82.2 | 8.10 ± 4.96 ± 1.22 |
| 0.90–1.25 | 1.067 | 68.0 | 7.03 ± 3.38 ± 1.42 | 1.420 | 81.3 | 4.29 ± 4.29 ± 1.33 |

| $p_T$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ | $\langle p_T \rangle$ | $\langle \theta \rangle$ | $d^2\sigma/dp\,d\Omega$ |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0.42–0.50 | 0.474 | 99.2 | 41.31 ± 13.85 ± 3.11 | 0.455 | 113.9 | 13.12 ± 6.78 ± 0.94 |
| 0.50–0.60 | 0.537 | 99.8 | 26.32 ± 10.14 ± 2.46 | 0.534 | 112.4 | 19.87 ± 8.28 ± 2.47 |
| 0.60–0.72 | 0.681 | 96.7 | 14.37 ± 8.07 ± 2.00 | 0.722 | 95.8 | 4.59 ± 3.81 ± 0.80 |
Table A.41: Double-differential inclusive cross-section $d^2\sigma/dp\Omega$ [mb/(GeV/c sr)] of the production of \(\pi^+\)'s in \(\pi^+ + \text{Al} \rightarrow \pi^+ + \text{X}\) interactions with +15.0 GeV/c beam momentum; the first error is statistical, the second systematic; \(p_T\) in GeV/c, polar angle \(\theta\) in degrees.

| \(p_T\) (GeV/c) | \(20 < \theta < 30\) | \(30 < \theta < 40\) | \(40 < \theta < 50\) | \(50 < \theta < 60\) | \(60 < \theta < 75\) | \(75 < \theta < 90\) | \(90 < \theta < 105\) | \(105 < \theta < 125\) |
|----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | \((p_T)\)       | \(d^2\sigma/dp\Omega\) | \((p_T)\)       | \(d^2\sigma/dp\Omega\) | \((p_T)\)       | \(d^2\sigma/dp\Omega\) | \((p_T)\)       | \(d^2\sigma/dp\Omega\) |
| 0.10-0.13      | 0.114           | 24.5            | 0.108           | 4.7            | 0.38            | 0.26            | 0.134           | 0.18            |
| 0.13-0.16      | 0.144           | 25.1            | 0.146           | 3.6            | 0.35            | 0.26            | 0.172           | 0.24            |
| 0.16-0.20      | 0.185           | 23.8            | 0.176           | 4.0            | 0.30            | 0.25            | 0.206           | 0.29            |
| 0.20-0.24      | 0.223           | 24.9            | 0.218           | 3.5            | 0.29            | 0.25            | 0.269           | 0.30            |
| 0.24-0.30      | 0.267           | 25.2            | 0.270           | 3.7            | 0.34            | 0.25            | 0.318           | 0.33            |
| 0.30-0.36      | 0.323           | 24.2            | 0.343           | 5.7            | 0.47            | 0.25            | 0.375           | 0.37            |
| 0.36-0.42      | 0.387           | 23.9            | 0.367           | 6.1            | 0.54            | 0.25            | 0.414           | 0.42            |
| 0.42-0.50      | 0.456           | 24.6            | 0.470           | 6.1            | 0.59            | 0.25            | 0.458           | 0.45            |
| 0.50-0.60      | 0.536           | 23.0            | 0.542           | 6.3            | 0.64            | 0.25            | 0.500           | 0.51            |
| 0.60-0.72      | 0.658           | 23.8            | 0.633           | 6.8            | 0.71            | 0.25            | 0.552           | 0.56            |
| 0.72-0.90      | 0.773           | 43.7            | 0.800           | 1.5            | 0.87            | 0.25            | 0.661           | 0.67            |

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Table A.42: Double-differential inclusive cross-section $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^+ + \text{Al} \rightarrow \pi^- + X$ interactions with $+15.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $p_T$ ($\text{GeV}/c$) | $20 < \theta < 30$ | $30 < \theta < 40$ | $40 < \theta < 50$ | $50 < \theta < 60$ | $60 < \theta < 70$ | $70 < \theta < 90$ | $90 < \theta < 105$ | $105 < \theta < 125$ |
|------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] | $d^2\sigma/d\Omega$ [mb/(GeV/c sr)] |
Table A.43: Double-differential inclusive cross-section \( d^2\sigma/dp d\Omega \text{ [mb/(GeV/c sr)]} \) of the production of protons in \( \pi^- + Al \rightarrow p + X \) interactions with \(-15.0\ GeV/c\) beam momentum; the first error is statistical, the second systematic; \( p_T \) in GeV/c, polar angle \( \theta \) in degrees.

| \( p_T \) (GeV/c) | \( 20 < \theta < 30 \) | \( 30 < \theta < 40 \) | \( 40 < \theta < 50 \) | \( 50 < \theta < 60 \) | \( 60 < \theta < 75 \) | \( 75 < \theta < 90 \) | \( 90 < \theta < 105 \) | \( 105 < \theta < 125 \) |
|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                  | \( (p_T) \)     | \( \langle \theta \rangle \) | \( d^2\sigma/dp d\Omega \) | \( (p_T) \)     | \( \langle \theta \rangle \) | \( d^2\sigma/dp d\Omega \) | \( (p_T) \)     | \( \langle \theta \rangle \) | \( d^2\sigma/dp d\Omega \) |
| 0.20–0.24        | 0.222           | 24.9            | 129.77 ± 4.54 ± 7.39 | 0.274           | 34.7            | 118.48 ± 3.48 ± 5.88 | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54 |
| 0.24–0.30        | 0.272           | 25.1            | 122.02 ± 3.56 ± 6.42 | 0.333           | 34.7            | 103.98 ± 3.21 ± 4.73 | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54 |
| 0.30–0.36        | 0.334           | 25.0            | 97.64 ± 3.19 ± 5.00  | 0.396           | 35.0            | 88.68 ± 3.00 ± 4.01  | 0.825           | 34.9            | 21.31 ± 1.04 ± 2.16 |
| 0.36–0.42        | 0.394           | 25.1            | 78.73 ± 2.83 ± 3.94  | 0.468           | 34.9            | 69.54 ± 2.34 ± 3.25  | 0.825           | 34.9            | 21.31 ± 1.04 ± 2.16 |
| 0.42–0.50        | 0.468           | 25.2            | 71.87 ± 2.31 ± 3.50  | 0.538           | 35.0            | 57.95 ± 1.92 ± 2.78  | 0.825           | 34.9            | 21.31 ± 1.04 ± 2.16 |
| 0.50–0.60        | 0.592           | 25.2            | 52.89 ± 1.73 ± 2.58  | 0.674           | 34.9            | 39.23 ± 1.44 ± 2.21  | 0.825           | 34.9            | 21.31 ± 1.04 ± 2.16 |
| 0.60–0.72        | 0.675           | 25.1            | 37.71 ± 1.29 ± 2.01  | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54  | 0.825           | 34.9            | 21.31 ± 1.04 ± 2.16 |
| 0.72–0.90        | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54  | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54  | 0.825           | 34.9            | 22.21 ± 0.87 ± 1.54 |

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Table A.44: Double-differential inclusive cross-section \( d^2\sigma / d\Omega d\Omega \) [mb/(GeV/c sr)] of the production of \( \pi^+ \)'s in \( \pi^- + Al \rightarrow \pi^+ + X \) interactions with \(-15.0\) GeV/c beam momentum; the first error is statistical, the second systematic; \( p_T \) in GeV/c, polar angle \( \theta \) in degrees.

| \( p_T \) (GeV/c) | \( 0.50-0.60 \) | \( 0.42-0.50 \) | \( 0.36-0.42 \) | \( 0.30-0.36 \) | \( 0.24-0.30 \) | \( 0.20-0.24 \) | \( 0.16-0.20 \) | \( 0.13-0.16 \) | \( 0.10-0.13 \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( \theta \) (°) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) |
| 20 < \( \theta \) < 30 | | | | | | | | | |
| 0.10-0.13 | 0.116 | 0.146 | 0.221 | 0.333 | 0.395 | 0.467 | 0.557 | 0.672 | 0.819 |
| 0.13-0.16 | 0.147 | 0.182 | 0.223 | 0.335 | 0.467 | 0.588 | 0.672 | 0.826 | 1.080 |
| 0.16-0.20 | 0.182 | 0.233 | 0.273 | 0.364 | 0.467 | 0.588 | 0.672 | 0.826 | 1.080 |
| 0.20-0.24 | 0.221 | 0.273 | 0.335 | 0.467 | 0.578 | 0.672 | 0.826 | 1.070 | 1.490 |
| 0.24-0.30 | 0.271 | 0.333 | 0.428 | 0.557 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.30-0.36 | 0.371 | 0.467 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.36-0.42 | 0.467 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.42-0.50 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.50-0.60 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |

| \( p_T \) (GeV/c) | \( 0.50-0.60 \) | \( 0.42-0.50 \) | \( 0.36-0.42 \) | \( 0.30-0.36 \) | \( 0.24-0.30 \) | \( 0.20-0.24 \) | \( 0.16-0.20 \) | \( 0.13-0.16 \) | \( 0.10-0.13 \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| \( \theta \) (°) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) | \( d^2\sigma / d\Omega d\Omega \) |
| 30 < \( \theta \) < 40 | | | | | | | | | |
| 0.10-0.13 | 0.116 | 0.146 | 0.221 | 0.333 | 0.395 | 0.467 | 0.557 | 0.672 | 0.819 |
| 0.13-0.16 | 0.147 | 0.182 | 0.233 | 0.356 | 0.467 | 0.588 | 0.672 | 0.826 | 1.080 |
| 0.16-0.20 | 0.182 | 0.223 | 0.273 | 0.383 | 0.467 | 0.588 | 0.672 | 0.826 | 1.080 |
| 0.20-0.24 | 0.221 | 0.273 | 0.335 | 0.428 | 0.467 | 0.578 | 0.672 | 0.805 | 1.070 |
| 0.24-0.30 | 0.271 | 0.333 | 0.428 | 0.557 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.30-0.36 | 0.371 | 0.467 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.36-0.42 | 0.467 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.42-0.50 | 0.692 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
| 0.50-0.60 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 | 0.805 |
Table A.45: Double-differential inclusive cross-section $d^2\sigma/dp\,d\Omega$ [mb/(GeV/c sr)] of the production of $\pi^-$'s in $\pi^- + Al \to \pi^- + X$ interactions with $-15.0$ GeV/c beam momentum; the first error is statistical, the second systematic; $p_T$ in GeV/c, polar angle $\theta$ in degrees.

| $20 < \theta < 30$ | $30 < \theta < 40$ |
|-------------------|-------------------|
| $p_T$ (GeV/c)     | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) |
| $<0.10$–0.13      | $0.115 \pm 0.023$ | $0.116 \pm 0.035$ |
| $0.13$–0.16       | $0.179 \pm 0.036$ | $0.204 \pm 0.046$ |
| $0.16$–0.20       | $0.204 \pm 0.046$ | $0.235 \pm 0.056$ |
| $0.23$–0.30       | $0.264 \pm 0.079$ | $0.304 \pm 0.096$ |
| $0.30$–0.36       | $0.333 \pm 0.114$ | $0.364 \pm 0.134$ |
| $0.36$–0.42       | $0.402 \pm 0.160$ | $0.434 \pm 0.180$ |
| $0.42$–0.50       | $0.500 \pm 0.233$ | $0.530 \pm 0.253$ |
| $0.50$–0.60       | $0.629 \pm 0.320$ | $0.660 \pm 0.340$ |
| $0.60$–0.72       | $0.780 \pm 0.421$ | $0.820 \pm 0.441$ |
| $0.72$–0.90       | $0.950 \pm 0.541$ | $1.00 \pm 0.561$ |

| $40 < \theta < 50$ | $50 < \theta < 60$ |
|-------------------|-------------------|
| $p_T$ (GeV/c)     | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) |
| $<0.10$–0.13      | $0.115 \pm 0.023$ | $0.116 \pm 0.035$ |
| $0.13$–0.16       | $0.179 \pm 0.036$ | $0.204 \pm 0.046$ |
| $0.16$–0.20       | $0.204 \pm 0.046$ | $0.235 \pm 0.056$ |
| $0.23$–0.30       | $0.264 \pm 0.079$ | $0.304 \pm 0.096$ |
| $0.30$–0.36       | $0.333 \pm 0.114$ | $0.364 \pm 0.134$ |
| $0.36$–0.42       | $0.402 \pm 0.160$ | $0.434 \pm 0.180$ |
| $0.42$–0.50       | $0.500 \pm 0.233$ | $0.530 \pm 0.253$ |
| $0.50$–0.60       | $0.629 \pm 0.320$ | $0.660 \pm 0.340$ |
| $0.60$–0.72       | $0.780 \pm 0.421$ | $0.820 \pm 0.441$ |
| $0.72$–0.90       | $0.950 \pm 0.541$ | $1.00 \pm 0.561$ |

| $60 < \theta < 75$ | $75 < \theta < 90$ |
|-------------------|-------------------|
| $p_T$ (GeV/c)     | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) |
| $<0.10$–0.13      | $0.115 \pm 0.023$ | $0.116 \pm 0.035$ |
| $0.13$–0.16       | $0.179 \pm 0.036$ | $0.204 \pm 0.046$ |
| $0.16$–0.20       | $0.204 \pm 0.046$ | $0.235 \pm 0.056$ |
| $0.23$–0.30       | $0.264 \pm 0.079$ | $0.304 \pm 0.096$ |
| $0.30$–0.36       | $0.333 \pm 0.114$ | $0.364 \pm 0.134$ |
| $0.36$–0.42       | $0.402 \pm 0.160$ | $0.434 \pm 0.180$ |
| $0.42$–0.50       | $0.500 \pm 0.233$ | $0.530 \pm 0.253$ |
| $0.50$–0.60       | $0.629 \pm 0.320$ | $0.660 \pm 0.340$ |
| $0.60$–0.72       | $0.780 \pm 0.421$ | $0.820 \pm 0.441$ |
| $0.72$–0.90       | $0.950 \pm 0.541$ | $1.00 \pm 0.561$ |

| $90 < \theta < 105$ | $105 < \theta < 125$ |
|-------------------|-------------------|
| $p_T$ (GeV/c)     | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) | $d^2\sigma/dp\,d\Omega$ (mb/(GeV/c sr)) |
| $<0.10$–0.13      | $0.115 \pm 0.023$ | $0.116 \pm 0.035$ |
| $0.13$–0.16       | $0.179 \pm 0.036$ | $0.204 \pm 0.046$ |
| $0.16$–0.20       | $0.204 \pm 0.046$ | $0.235 \pm 0.056$ |
| $0.23$–0.30       | $0.264 \pm 0.079$ | $0.304 \pm 0.096$ |
| $0.30$–0.36       | $0.333 \pm 0.114$ | $0.364 \pm 0.134$ |
| $0.36$–0.42       | $0.402 \pm 0.160$ | $0.434 \pm 0.180$ |
| $0.42$–0.50       | $0.500 \pm 0.233$ | $0.530 \pm 0.253$ |
| $0.50$–0.60       | $0.629 \pm 0.320$ | $0.660 \pm 0.340$ |
| $0.60$–0.72       | $0.780 \pm 0.421$ | $0.820 \pm 0.441$ |
| $0.72$–0.90       | $0.950 \pm 0.541$ | $1.00 \pm 0.561$ |
| $0.90$–1.25       | $1.00 \pm 0.561$ | $1.00 \pm 0.561$ |