Energy dependence of transverse mass spectra of Λ hyperons produced in p+p and p+p̅ interactions. A compilation.

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Abstract

The results on transverse mass spectra of Λ hyperons produced in all inelastic p+p and p+p̅ interactions in the energy range $\sqrt{s_{NN}} = 3.6 - 1800$ GeV are compiled and analyzed. The energy dependence of the mean transverse mass and the inverse slope parameter of the spectra is presented and discussed. These results should be used as a reference in the study of Λ hyperon production in nuclear collisions.

1 Introduction

Recently observed anomalies in the energy dependence of hadron production in central Pb+Pb collisions\cite{1} suggest that the onset of deconfinement may be located at the low CERN SPS energies $\sqrt{s_{NN}} \approx 7.5$ GeV\cite{2,3}. In the identification of the effects possibly related to the onset of deconfinement in heavy ion collisions a comparison with the corresponding results obtained in nucleon-nucleon interactions plays a special role. In case of the study of energy dependence of pion and kaon multiplicities this comparison was done based on the existing compilations of the data on all inelastic proton-proton (p+p), proton-neutron and proton-antiproton (p+p̅) interactions\cite{4}.
A recently found anomaly in the energy dependence of the shape of transverse mass ($m_T$) spectra of hadrons produced in central Pb+Pb collisions raised significant interest [5-8]. It motivates an effort to compile the corresponding results in p+p(\Pp) interactions. The first compilation of the transverse mass spectra of kaons was already published [9].

In this paper the compilation of the $m_T$ spectra of $\Lambda$ hyperons is presented and discussed. The paper is organized as follows. In section 2 the existing data are reviewed and analyzed. The energy dependence of the spectra is presented and discussed in section 3. The paper is closed by the summary, section 4.

2 A compilation of p+p(\Pp) data

We start from review of the data on $\Lambda$ hyperon transverse momentum ($p_T$) and transverse mass spectra in all inelastic p+p(\Pp) interactions.

In most cases the original experimental papers present $p_T$ spectra in the form $\frac{d^3n}{dp_T^2dy}$ or $Ed^4n$. From these results the transverse mass $m_T$ ($m_T = \sqrt{p_T^2 + m_0^2}$, where $m_0$ is the particle rest mass) spectra $\frac{d^2n}{m_Tdm_Tdy}$ can be easily obtained ($\frac{d^2n}{m_Tdm_Tdy} \sim \frac{d^3n}{dp_T^2dy} \sim Ed^4n$).

Our compilation and analysis is limited to the low $p_T$ region, $p_T \leq 1.4$ GeV/c. First, it is because in this region the $p_T$ spectra of $\Lambda$ hyperons were measured by many experiments and therefore a systematic study is possible. Second, this is the region where the shape of the spectra in A+A collisions is determined by the hydrodynamical expansion of the matter and thus it is sensitive to the change of the equation of state due to the onset of deconfinement. In this region an exponential parameterization of the p+p(\Pp) data:

$$\frac{dn}{m_Tdm_T} = C \cdot e^{-m_T/T}$$  \quad (1)

is approximately valid\textsuperscript{1}. In Eq. (1) the inverse slope parameter $T$ and the normalization parameter $C$ are free parameters and their values are extracted from the least square fits to the experimental spectra.

Most of the compiled $p_T$ spectra are measured either close to mid-rapidity ($y \approx 0$) or they are integrated over forward or backward hemispheres.

Transverse momentum spectra of $\Lambda$ hyperons produced in all inelastic p+p interactions are measured in fixed target [10-23] mostly bubble chamber

\textsuperscript{1}At high $m_T$ the spectra obey a power law behavior, $\frac{dn}{m_Tdm_T} \sim m_T^{-p}$, which is interpreted as due to hard (parton) scattering.
experiments, at energies below $\sqrt{s_{NN}} \approx 30$ GeV. At higher energies, $\sqrt{s_{NN}} = 44 - 200$ GeV, the data on the spectra are taken in collider experiments at ISR [24, 25] and RHIC [26]. The measurements for p+p interactions are performed at the SppS and Fermilab colliders [27, 28] at $\sqrt{s_{NN}} = 200 - 1800$ GeV. All results come from the analysis of charged decays of Λ hyperons, $\Lambda \rightarrow p + \pi^-$. The summary of the data on $m_T$ spectra of Λ hyperons is given in Tables 1 and 2, where $\sqrt{s_{NN}}$, the $p_T$ range selected for the analysis, the longitudinal acceptance in which the measurement was done and the reference to the original experimental papers are given. The $m_T$ spectra are plotted as a function of $(m_T - m_0)$ in Figs. 1-3. The normalization of the spectra is arbitrary. They are ordered from bottom to top according to increasing energy.

The spectra displayed in Figs. 1-3 are fitted by an exponential function, Eq. 1, in the whole $m_T$ range $(m_T - m_0) \leq 0.7$ GeV/$c^2)$. The inverse slope parameter $T$ and $\chi^2/NDF$ resulting from the fits are given in Tables 1 and 2. The corresponding functions are plotted in Figs. 1-3 by solid lines. It is seen that the used parametrization (Eq. 1), reasonably well describes Λ spectra in the studied $m_T$ range at all energies ($\sqrt{s_{NN}} = 3.6 - 1800$ GeV), both for p+p and p+p interactions. The mean $m_T$ in the range $0 < (m_T - m_0) < 0.7$ GeV/$c^2$ was calculated using measured data. If necessary, the results were corrected for the unmeasured tails of the distributions by use of the exponential function. The resulting values of $(< m_T > - m_0)$ are also given in Tables 1 and 2.

### 3 The energy dependence

The energy dependence of the $T$ and $(< m_T > - m_0)$ parameters calculated in the $m_T$ interval $(m_T - m_0) \leq 0.7$ GeV/$c^2$ to the $m_T$ spectra of Λ hyperons produced in all inelastic p+p(p) interactions are shown in Figs. 4 and 5. The results were parametrized by an expression:

$$y = a + b \cdot \ln \left( \sqrt{s_{NN}}/(1\text{GeV}) \right),$$

where $y = T$ or $(< m_T > - m_0)$, $a$ and $b$ are fit parameters and $\sqrt{s_{NN}}$ is given in units of GeV. The best fit to the inverse slope parameter data presented in Fig. 4 yields $a = (53.6 \pm 3.7)$ MeV, $b = (25.4 \pm 2.0)$ MeV and $\chi^2/NDF = 58/23$. The parameters fitted to the mean transverse mass data are $a = (60.7 \pm 4.3)$ MeV, $b = (26.7 \pm 2.2)$ MeV and $\chi^2/NDF = 31/23$.

In both cases the observed deviations of points from the parameterizations are mostly consistent with ones expected from the experimental errors.
The compiled results indicate that $T$ and $(< m_T > - m_0)$ increase monotonically with the collision energy from $T \approx 90$ MeV and $(< m_T > - m_0) \approx 100$ MeV at $\sqrt{s_{NN}} = 3.6$ GeV to $T \approx 280$ MeV and $(< m_T > - m_0) \approx 350$ MeV at $\sqrt{s_{NN}} = 1800$ GeV. No significant differences are seen between data for p+p and p+\bar{p} interactions and between mid-rapidity and integrated data. Note that in general one expects flatter spectra for mid-rapidity results, this trend is suggested by several low energy points.

Data of higher statistical precision are needed to draw firm conclusions on the details of energy dependence of the shape of $m_T$ spectra in p+p(\bar{p}) interactions. The measurements of the $m_T$ spectra in nucleus-nucleus collisions are still sparse, but the new results at SPS and RHIC energies are expected soon. The measured values of the $T$ parameter in central Pb+Pb (Au+Au) collisions are in the range $T = 200 − 350$ MeV at $\sqrt{s_{NN}} = 5 − 200$ GeV [29-34]. They are significantly larger than the corresponding p+p(\bar{p}) results.

4 Summary

We compiled and analyzed data on $m_T$ spectra of \Lambda hyperons produced in all inelastic p+p and p+\bar{p} interactions. The spectra can be reasonably well described by a simple exponential parametrization $\frac{dn}{dm_T} = C \cdot e^{-m_T/T}$ in the whole analyzed $m_T$ interval ($m_T - m_0 \leq 0.7 \text{ GeV/c}^2$). We do not observe any significant difference between data from p+p and p+\bar{p} interactions and results obtained in different rapidity or $x_F$ acceptances. The $T$ and $(< m_T > - m_0)$ parameters increase monotonically with $\sqrt{s_{NN}}$ from $T \approx 90$ MeV and $(< m_T > - m_0) \approx 100$ MeV at $\sqrt{s_{NN}} = 3.6$ GeV to $T \approx 280$ MeV and $(< m_T > - m_0) \approx 350$ MeV at $\sqrt{s_{NN}} \approx 1800$ GeV. This dependence can be parametrized as $T = (53.6 \pm 3.7) \text{ MeV} + (25.4 \pm 2.0) \text{ MeV} \cdot \ln(\sqrt{s_{NN}}/1 \text{ GeV})$ and $(< m_T > - m_0) = (60.7 \pm 4.3) \text{ MeV} + (26.7 \pm 2.2) \text{ MeV} \cdot \ln(\sqrt{s_{NN}}/1 \text{ GeV})$, where $\sqrt{s_{NN}}$ is given in units of GeV.

These results should serve as a reference in the study of \Lambda hyperon production in nuclear collisions.

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Table 1: Summary of the data on the $p_T$ spectra of Λ hyperons produced in p+p interactions. The collision energy $\sqrt{s_{NN}}$, the $p_T$-range used for this analysis, the rapidity (in center of mass system) or $x_F$ range in which the $p_T$ spectrum was measured and the references to the original papers are given. The fitted inverse slope parameter $T$, the corresponding $\chi^2/NDF$ and ($<m_T>-m_0$) are also presented.

| $\sqrt{s}$ (GeV) | $p_T$-range (GeV/c) | longitudinal acceptance | $T$(MeV) | $\chi^2/NDF$ | ($<m_T>-m_0$) (MeV) | ref. |
|-----------------|-----------------|-----------------|--------|------------|-----------------|-----|
| 3.63            | 0-0.94          | -0.25 $< x_F < 0.25$ | 91.8 ± 4.5 | 8.1/10     | 99.1 ± 5.9      | 10  |
| 3.78            | 0-0.97          | 0 $< y < 1.5$    | 81.1 ± 2.0  | 10.5/8     | 89.3 ± 3.1      | 11  |
| 4.93            | 0-1.00          | $x_F = 0$       | 123.6 ± 14.1 | 0.9/7     | 127.4 ± 14.9    | 12  |
| 4.93            | 0-1.02          | 0 $< y < 1.5$    | 99.5 ± 2.3  | 2.4/6      | 109.1 ± 3.6     | 11  |
| 5.01            | 0-1.15          | -1.6 $< y < 0$  | 102.8 ± 7.1 | 6.1/6      | 111.4 ± 10.0    | 14  |
| 6.84            | 0-1.03          | $x_F = 0$       | 146.4 ± 11.6 | 5.1/7     | 155.9 ± 13.4    | 12  |
| 6.84            | 0-1.02          | 0 $< y < 1.9$    | 103.0 ± 3.6 | 4.2/6      | 112.6 ± 4.7     | 11  |
| 11.56           | 0-0.81          | 0 $< y < 2.4$    | 106.2 ± 15.0 | 1.8/3     | 118.8 ± 21.7    | 13  |
| 11.56           | 0-0.92          | -2.5 $< y < 0$  | 114.0 ± 17.3 | 2.1/9     | 124.2 ± 16.4    | 16  |
| 13.90           | 0-0.94          | -2.2 $< y < 0$  | 186.5 ± 43.6 | 0.6/4     | 205.5 ± 34.7    | 17  |
| 16.66           | 0-1.12          | 0 $< y < 0.6$   | 134.1 ± 18.0 | 2.5/7     | 152.4 ± 30.4    | 18  |
| 19.66           | 0-1.02          | 0 $< y < 3.0$   | 118.9 ± 28.7 | 0.5/2     | 118.5 ± 32.8    | 11  |
| 19.66           | 0-1.11          | -3.0 $< y < 0$  | 137.4 ± 24.1 | 6.8/5     | 115.1 ± 22.8    | 15  |
| 23.76           | 0-1.13          | 0 $< y < 3.0$   | 119.6 ± 10.1 | 2.1/5     | 129.6 ± 14.2    | 19  |
| 23.76           | 0-1.00          | -3.1 $< y < 0$  | 171.1 ± 42.5 | 3.6/5     | 185.9 ± 31.8    | 20  |
| 26.03           | 0-1.32          | -3.2 $< y < 0$  | 123.5 ± 8.7  | 5.5/8     | 137.1 ± 11.1    | 21  |
| 27.60           | 0-1.28          | -3.4 $< y < 0$  | 125.8 ± 10.9 | 4.1/3     | 141.4 ± 20.3    | 22  |
| 27.60           | 0-1.34          | 0 $< y < 3.0$   | 127.0 ± 12.2 | 9.0/8     | 157.2 ± 16.5    | 23  |
| 44.00           | 0.71-1.41       | $y \approx 0$   | 130.5 ± 16.8 | 6.4/2     | 206.3 ± 35.5    | 24  |
| 63.00           | 0.71-1.21       | $y = 0$         | 132.2 ± 20.7 | 0.6/1     | 176.4 ± 22.6    | 25  |
| 200.00          | 0.44-1.40       | -0.5 $< y < 0.5$ | 235.9 ± 19.9 | 0.3/4     | 244.6 ± 17.7    | 26  |
Table 2: Summary of the data on the $p_T$ spectra of Λ hyperons produced in $p+p$ interactions. For details see the caption of Table 1.

| $\sqrt{s}$ (GeV) | $p_T$-range (GeV/c) | longitudinal acceptance | $T$ (MeV) | $\chi^2/NDF$ | $<m_T>-m_0$ (MeV) | ref. |
|------------------|---------------------|-------------------------|-----------|---------------|-------------------|------|
| 200              | 0.64-1.34           | $0<y<2$                 | 371.5 ± 157.8 | 1.2/2         | 404.2 ± 78.5     | 27   |
| 546              | 0.32-1.37           | $0<y<2$                 | 235.3 ± 52.5  | 1.6/3         | 229.7 ± 45.7     | 27   |
| 900              | 0.64-1.43           | $0<y<2$                 | 259.5 ± 53.9  | 2.2/2         | 271.9 ± 41.8     | 27   |
| 1800             | 0.47-1.24           | -0.36$<\eta<1.0$       | 277.0 ± 103.8 | 0.0/1         | 345.8 ± 108.0    | 28   |
Figure 1: (Color online) Transverse mass spectra of $\Lambda$ hyperons produced in p+p interactions at $\sqrt{s_{NN}} = 3.6 - 13.9$ GeV. The spectra are measured either at mid-rapidity (squares) or integrated over semi-hemisphere (circles). The normalization of the spectra is arbitrary and the numbers next to the spectra give the c. m. collision energy in GeV. They are ordered from bottom to top according to rising energy. The fits of the exponential function (Eq. 1) are indicated by the solid lines.
Figure 2: (Color online) Transverse mass spectra of Λ hyperons produced in p+p interactions at $\sqrt{s_{NN}} = 16.7 - 200$ GeV. For details see the caption of Fig. 1.
Figure 3: (Color online) Transverse mass spectra of Λ hyperons produced in p+π interactions at $\sqrt{s_{NN}} = 200 - 1800$ GeV. For details see the caption of Fig. 1.
Figure 4: (Color online) Energy dependence of the inverse slope parameter $T$ of transverse mass spectra of $\Lambda$ hyperons produced in p+p and p+p interactions. The $T$ parameter was determined by fitting the spectra (Eq. 1) in the whole analyzed $m_T$ interval, $(m_T - m_0) \leq 0.7 \text{ GeV}/c^2$. The logarithmic parameterization is indicated by the solid line.
Figure 5: (Color online) Energy dependence of the mean transverse mass of Λ hyperons produced in p+p and p+p̅ interactions. The \(<m_T> - m_0\) was calculated in the range \((m_T - m_0) \leq 0.7 \text{ GeV}/c^2\). The logarithmic parameterization is indicated by the solid line.