Two remarks about UA5 published data on general characteristics of \( p\bar{p} \) collisions at \( \sqrt{s} = 900 \) GeV.

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Abstract

We study UA5 published data on \( p\bar{p} \) interaction cross-sections and on charged particles pseudorapidity distribution in single-diffractive, non-single diffractive and inelastic events and investigate their consistency/inconsistency.

1 Introduction

Proton-proton collisions at \( \sqrt{s} = 900 \) GeV have already appeared at the LHC and the results will be compared with \( pp\bar{s} \) data on proton-antiproton collisions at the same center of mass energy measured by UA5 collaboration. In this paper we point out some nuances concerning UA5 measurements and results and show that the uncertainties of measurements are underestimated concerning UA5 measurements and results and show that the uncertainties of measurements are underestimated by UA5. This can lead to discrepancies between \( pp \) and \( p\bar{p} \) at \( \sqrt{s} = 900 \) GeV and be wrongly interpreted in future theoretical analyses. First we investigate the result of measurements of cross-sections and then the result of measurements of charged particles pseudorapidity distribution.

2 The cross-sections

In this section we investigate the results of UA5 measurement on cross-sections of single-diffractive, non-single diffractive and inelastic \( p\bar{p} \) interactions.

The measurement of \( \sigma_{SD}/\sigma_{NSD} \) ratio at \( \sqrt{s} = 200 \) and 900 GeV.

The UA5 detector and event analysis procedures are described in [1]. Two large streamer chambers were placed above and below the \( pp\bar{s} \) beam pipe. The chambers were triggered by requiring one or more hits in scintillation counter hodoscopes at each end of the chambers covering \( 2 < |\eta| < 5.6 \). Two triggers were taken in parallel: a ”2-arm” trigger requiring hits at both ends to select mainly non single-diffractive events, and a ”1-arm” trigger demanding a hit in only one arm to select highly asymmetric events such as single diffractive events.

In case of single-diffraction dissociation UA5 triggered particles produced from anti-proton dissociation and the measured 1-arm triggering cross-section multiplied by factor 2 in order to correct for proton dissociation (assuming proton and anti-proton dissociations to be the same).

The triggering cross sections \( \sigma_1 \) and \( \sigma_2 \) for 1-arm and 2-arm triggers are related to the single-diffractive and non-single diffractive cross-sections by the trigger efficiencies \( \epsilon_{1,2}^{SD,NSD} \) as follows:

\[
\sigma_1 = \epsilon_1^{SD} \sigma_{SD} + \epsilon_1^{NSD} \sigma_{NSD},
\]

\[
\sigma_2 = \epsilon_2^{SD} \sigma_{SD} + \epsilon_2^{NSD} \sigma_{NSD}.
\]

Solving Eq. (1) for \( \sigma_{SD}/\sigma_{NSD} \) one finds:

\[
\frac{\sigma_{SD}}{\sigma_{NSD}} = \frac{r \cdot \epsilon_2^{NSD} - \epsilon_1^{NSD} \epsilon_2^{SD}}{\epsilon_1^{SD} - r \cdot \epsilon_2^{SD}}.
\]

Where \( r \equiv \sigma_1/\sigma_2 \) and the result of the measurement is [2]:

\[
r = 0.153 \pm 0.015 \text{ at } \sqrt{s} = 200 \text{ GeV},
\]

\[
r = 0.111 \pm 0.009 \text{ at } \sqrt{s} = 900 \text{ GeV}.
\]

Determining 1-arm and 2-arm triggering efficiencies for single-diffractive and non-single diffractive events based on MC simulations, UA5 reported the following value for \( R \equiv \sigma_{SD}/\sigma_{NSD} \) [2]:

\[
R = 0.132 \pm 0.016 \pm 0.024 \text{ at } \sqrt{s} = 200 \text{ GeV},
\]

\[
= 0.180 \pm 0.014 \pm 0.029 \text{ at } \sqrt{s} = 900 \text{ GeV}.
\]

The first error is statistical and the second systematic.

The evaluation of triggering efficiencies.

The triggering efficiencies \( \epsilon_{1,2}^{SD,NSD} \) in Eq. (1) were estimated by UA5 based on Monte Carlo simulations. UA5 detector did not have magnet and was not able to measure the transverse momentum of particles. The MC generator used for simulations was tuned to reproduce multiplicity and pseudo-rapidity distribution of particles, but simulations were done for different values of mean transverse momentum of particles in order to estimate the systematic uncertainties of measurements [2].

In UA5 MC generator [3] the cross-section of single-
diffraction dissociation as a function of diffracted system mass was parametrized as follows:

$$\frac{d\sigma_{SD}}{dM^2} = \frac{1}{M^2}. \quad (5)$$

and masses were generated in the interval from 1.08 GeV (=m_x + m_y) to \(\sqrt{s}0.05s\) (see [2] and [3] for more details).

At fragmentation of a diffracted system in single-diffractive interaction the distribution of particles is centered around \(y_0 \approx \ln(\sqrt{s}/M)\) and covers the rapidity region from \(0_{min} \approx \ln(\sqrt{s}m_p/M^2)\) to \(y_{max} \approx \ln(\sqrt{s}/m_p)\). When the mass of the diffracted system is small then the particles are mainly concentrated at the forward region. Increasing the mass of the diffracted system the distribution over (pseudo)rapidities moves to mid-rapidities and the spread of the distribution becomes wider. Thus acceptances of different triggers are sensitive to different mass regions of diffracted system (at given center of mass energy). In particular, if the triggers are not placed in very forward region then the particles produced from low-mass diffracted system will not hit the triggers.

In Ref. [2] UA5 claims that masses below 2.5 GeV/c\(^2\) were almost never seen by the detector. For this purpose they investigated trigger efficiencies enhancing this low-mass region by 50% and studying the consequences of this change in their results.

In Table 1 we present trigger efficiencies for single-diffractive events as reported by UA5 in Ref [2]. Those marked with an asterisk with the following relation:

$$\frac{\epsilon_{SD}^i}{\epsilon_{SD}^{1SD}} \quad (i = 1, 2) \quad (6)$$

Using the parameterization (5) one can easily evaluate the factor in the denominator:

$$\frac{\sigma_{SD}(1.08^2 < M^2 < 2.5^2)}{\sigma_{SD}(1.08^2 < M^2 < 0.05s)} = \frac{\ln(2.5^2/1.08^2)}{\ln(0.05s/1.08^2)}. \quad (7)$$

Thus the "re-normalized" efficiencies will be:

$$\epsilon_{1SD} = 0.54, \quad \epsilon_{2SD} = 0.043 \quad \text{at } \sqrt{s} = 200 \text{ GeV},$$

$$\epsilon_{1SD} = 0.46, \quad \epsilon_{2SD} = 0.0111 \quad \text{at } \sqrt{s} = 900 \text{ GeV}.$$

Comparing these numbers with the corresponding numbers in Table 1 we conclude that at \(\sqrt{s} = 200 \text{ GeV}\) the triggers saw some low-mass \((M < 2.5 \text{ GeV/c}^2)\) single-diffractive events but at \(\sqrt{s} = 900 \text{ GeV}\) they did not. This allows us to claim that at 900 GeV UA5 performed model-dependent extrapolation to the low-mass region and the seen cross-section of single-diffractive dissociation, \(\sigma_{SD}^{HM}\), has multiplied by factor 1.19 (= \(\ln(0.05s/1.08^2)/\ln(0.05s/2.5^2)\)) in order to obtain the "total" single-diffractive cross-section. Thus in Eq. (4) as cross-section of single-diffractive dissociation must be understood the following quantity:

$$\sigma_{SD} = 1.19 \cdot \sigma_{SD}^{HM}. \quad (8)$$

### Ratios of inelastic interaction cross-sections at 900 and 200 GeV.

In Ref. [4] UA5 reported the result of measurement of the ratio of the inelastic cross-sections at \(\sqrt{s} = 200\) and 900 GeV:

$$R_{inel} = \frac{\sigma_{900}^{inel}}{\sigma_{200}^{inel}} = 1.20 \pm 0.01 \pm 0.02. \quad (9)$$

The first error is statistical and the second error systematic which includes contributions of background corrections for 1-arm and 2-arm triggers, trigger efficiencies for single-diffractive and non-single diffractive processes and luminosity ratio.

### The absolute values of the cross-sections.

In order to obtain the value of inelastic cross-section at 200 GeV UA5 used the following identity:

$$\sigma_{inel}^{200} = \sigma_{tot}^{200} \left[ 1 - \frac{\sigma_{inel}^{200}}{\sigma_{tot}^{200}} \right] \quad (10)$$

The total cross-section at 200 GeV is calculated based on a fit to data on total cross-section from ISR and lower energies [5] which predicts \(\sigma_{tot} = 51.6 \pm 0.4 \text{ nb} \) at \(\sqrt{s} = 200 \text{ GeV}\). The value of \(\sigma_{inel}^{200}/\sigma_{tot}^{200}\) was estimated to be 0.19 ± 0.01. From the paper it is not clear how...
they estimated this value. They just say that they used UA4 measurement for \( \sigma_{el}/\sigma_{tot} = 0.215 \pm 0.005 \) at \( \sqrt{s} = 546 \text{ GeV} \) and did an interpolation. Using the values mentioned above UA5 estimated
\[
\sigma_{inel}^{200} = 41.8 \pm 0.6 \text{ mb},
\]
and then using Eq. (9) reported:
\[
\sigma_{inel}^{900} = 50.3 \pm 0.4 \pm 1.0 \text{ mb}.
\]

Where the first error is statistical and the second error is systematical including the error on the estimated values of \( \sigma_{el}/\sigma_{tot} \) and \( \sigma_{inel}^{200} \).

Taking into account (3) and (4) UA5 obtained the single-diffraction cross-section \( \sigma^{SD} \):
\[
\sigma_{SD}^{200} = 4.8 \pm 0.5 \pm 0.8 \text{ mb} \quad (13)
\]
\[
\sigma_{SD}^{900} = 7.8 \pm 0.5 \pm 1.1 \text{ mb} \quad (14)
\]

What are the consequences of the assumption \( \sigma_{SD} = 1.19 \cdot \sigma_{SD}^{HM,900} \) at \( 900 \text{ GeV} \)?

In Table 2 we compare UA5 data with predictions of two theoretical models \( [7,8] \). One can see that the result of UA5 on growth of inelastic cross-section is slightly smaller from predictions of both theoretical models where data from higher energy (\( \sqrt{s} = 1800 \text{ GeV} \)) are used in the fits. In order to understand this discrepancy, let us remember what is measured by UA5 as single-diffractive cross-section and make a detailed comparison with the theoretical models. Based on above discussions and taking into account Eq. (8) we write [11] as follows:
\[
1.19 \cdot \frac{\sigma_{SD}^{HM,900}}{\sigma_{NSD}^{900}} = 0.180 \pm 0.014 \pm 0.029, \quad (15)
\]
and Eq. (15) as follows:
\[
\frac{\sigma_{NSD}^{900} + 1.19 \cdot \sigma_{SD}^{HM,900}}{\sigma_{inel}^{200}} = 1.20 \pm 0.01 \pm 0.02. \quad (16)
\]

Analogously to Ref. [4], using [11] as an input absolute value for inelastic cross-section at 200 GeV we obtain:
\[
\sigma_{NSD}^{900} = 42.63 \pm 1.42 \text{ mb},
\]
\[
\sigma_{SD}^{HM,900} = 6.45 \pm 0.92 \text{ mb}.
\]

These errors include both statistical and systematical errors (added quadratically) of [11], [13] and [16].

In Table 3 we compare the predictions of both theoretical models with data from UA5. One can see the predictions of both theoretical models are in good agreement with the UA5 data which are "really" measured and deviations appear from the extrapolation of single-diffraction cross-section to low-mass region.

In Regge theory (see [11] for details) the \( \sim 1/M^2 \) dependence can be obtained assuming the intercept of the Pomeron to be unity in the cross-section corresponding to the triple-Pomeron diagram. Nevertheless, it is a known fact (and it was known at the times of UA5) that the intercept of the Pomeron is bigger than one and the cross-section falls much steeper than the former one. Thus the low-mass single-diffraction cross-section is bigger than the one expected from \( 1/M^2 \) dependence if one fixes the spectra at high-masses. This is the reason of discrepancy between the results of extrapolation of both theoretical models and UA5.

It must be stressed that the low-mass single-diffraction is experimentally studied in details up to ISR energies (a theoretical analysis of these data can be found in [9]). From Sppps and Tevatron experiments we do not know much about it. Nevertheless, UA4 [10] from Sppps reported that at \( \sqrt{s} = 546 \text{ GeV} \) the measured cross-section of single-diffraction in the region of masses \( M < 4 \text{ GeV}/c^2 \) is higher by about a factor two than the one expected from the extrapolation with \( 1/M^2 \) dependence from high-masses to low-masses. This experimental fact argues in favor of both theoretical models used in this analysis.

So, the value or the systematic error (of amount 1 mb, which should include the uncertainty of extrapolation to the single-diffraction dissociation cross-section to the low-mass region) assigned by UA5 to the inelastic and single-diffractive cross-sections at 900 GeV in [12] and [13] is underestimated at least \( 2 \pm 3 \text{ mb} \).
3 Pseudorapidity distribution

In this section we consider the results of UA5 measurement on charged particles pseudorapidity distribution in single-diffractive, non-single diffractive and inelastic \( p\bar{p} \) interactions and discuss their consistency/inconsistency.

Although the UA5 collaboration in [2] studied only diffraction dissociation of proton, the final results for inelastic events are expected to be corrected also for anti-proton dissociation. We compare the predictions of Quark-Gluon String Model (QGSM, see [11, 12]) for single and non-single diffractive events with the data and later for inelastic ones. In order to calculate the pseudorapidity distribution of charged particles for inelastic events we mixed single-diffractive and non-single diffractive events with the weights predicted by the theoretical model as well as with the weights deduced from experimental data.

Charged particles density \( dN_{ch}/d\eta \) as a function of \( \eta \) in single-diffractive and non-single diffractive events

QGSM predictions on charged particles pseudorapidity in single-diffractive and non-single diffractive events are in reasonable agreement with UA5 data (see Figs 1 and 2). UA5 data are taken from [2, 13, 14] and the details of theoretical calculations can be found in [12]. We stress that the description of these data is achieved in a parameter-free way.

Charged particles density \( dN_{ch}/d\eta \) as a function of \( \eta \) in inelastic events

By definition, in inelastic collisions of two hadrons the diffractive dissociations of each of the incoming hadrons may take place separately (single-diffractive dissociation), and in addition the non-single diffractive interactions may also take place. This is illustrated by (19) for proton-antiproton collision.

\[
p + \bar{p} \to pX_1 + X_2\bar{p} + NSD
\]

In Fig. 3 we compare the predictions of QGSM with the experimental data from UA5 ([13, 14]) for pseudorapidity distribution of charged particles in inelastic events. In order to calculate the \( dN_{ch}/d\eta \) for inelastic events we summed charged particles pseudorapidity distributions of single-diffractive and non-single diffractive events with the default theoretically calculated weights (solid lines) [7] as well as with the weights deduced from the experimental data (dotted lines) [2, 14]. We calculate \( dN/d\eta \) using the following expression:

\[
dN = \frac{\sigma_{NSD} dN_{NSD}}{d\eta} + \frac{\sigma_{SD} dN_{SD}(p+X)}{d\eta} + \frac{\sigma_{SD} dN_{SD}(X+\bar{p})}{d\eta}.
\]

As we see, the predictions of QGSM for inelastic events are significantly different from experimental data in \( \eta \) region from 1 to 3, whereas the predictions for single-diffractive and non-single diffractive events are described well enough.

4 Summary

At \( \sqrt{s} = 900 \text{ GeV} \) \( p\bar{p} \) single-diffractive interactions UA5 triggers were not able to register particles produced from diffracted systems with masses below 2.5 GeV/c\(^2\). For correcting inelastic and single-diffractive cross-sections for this low-mass diffraction region UA5 used \( d\sigma/dM^2 \sim 1/M^2 \) simple parameterization which
resulted to underestimation of inelastic and single-diffractive dissociation cross-sections by $2 \div 3$ mb. From an analysis of UA5 data for charged particles pseudorapidity distributions in single-diffractive, non-single diffractive and inelastic events we conclude that UA5 data are not self-consistent. These facts must be taken into account during the tuning of theoretical models (and MC generators) and at further comparison of LHC $pp$ data with UA5 $p\bar{p}$ data.

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