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Total Cross Sections at current/Future Colliders, conventional models and QCD

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Abstract

Rise in total cross sections for elastic scattering generated immense interest both for experimental measurements and theoretical investigations. How will total cross section behave at LHC and Cosmic Ray energies is therefore in the limelight of our future measurements. Theoretical studies become even more interesting when we take into consideration the ratio of real and imaginary parts of the scattering amplitudes. We will briefly undertake the current results and future prospects in the light of conventional as well as QCD-based phenomenology.

1. Introduction

In hadron scattering one of the most fundamental parameters is the total cross section. It is believed that at high energies the strong interaction mechanism that controls hadron scattering would become simpler. This should help us to understand easily the underlying dynamics. Total cross sections at high energies have therefore been a primary focus of both experimental measurements as well as theoretical models. In this paper we will take up the total cross section and ρ measurements at current and future colliders for proton-proton(antiproton) scattering.

2. Experimental Data

Total cross section for pp and $p\bar{p}$ scattering has been measured at FNAL (Carrol et al), ISR (Amos et al and Ambrosio et al), UA4 (Bozzo et al), UA4/2 (Augier et al) UA5 (Alner et al), CDF (Abe et al) and E710 (Amos et al) over the last twenty years [1]. These measurements are shown in Fig. 1. Experimental results from UA4 Collaboration (Bozzo et al) in 1986 created a lot of interest as the value of the total cross section $\sigma_T = 78.3 \pm 5.9$ mb was higher than that predicted by various models. More interesting was the value of $\rho = .24 \pm .04$ measured by UA4 (Bozzo et al) group which was significantly higher than predicted by the conventional models. This gave rise to many models which predicted a new threshold in the TeV region. Precise measurements were later on made by UA4/2 group at 540 GeV and E710 and CDF collaboration at 1.8 TeV. Their measurements give $\sigma_T = 72.2 \pm 2.7$ mb and $\rho = .134 \pm .069$ at 1.8 TeV and $\sigma_T = 61.6 \pm 5.7$ mb and $\rho = .134 \pm .069$ at 546 GeV. These values are not in agreements with the earlier measurements. It was pointed out by Augier et al in their measurements that the previous result obtained with poor beam optics, a factor eleven statistics and much less control of systematic effects should be considered as superseded. Results of Augier er al are in agreement with the predictions of conventional models. Recently, using a detector of solid bundle of scintillating fibers, **E-811** collaboration which is a successor to E710 Collaboration has measured the $\bar{p}p$ elastic scattering in the small momentum region. The scattering angle is small enough to observe coulomb interference and to use the optical theorem to get total cross section. The data is being analyzed currently and results at 1.8 TeV are expectedly shortly. These results will be of quite significance in the light of discrepancy of CDF and E710 data.

Another important addition to our knowledge of experimental data are the measurements of *the ratio* ρ of the real and imaginary parts of the scattering amplitude in the forward direction. The counting rate for this quantity is measured in a rather broad interval of t values running from 10^{-3} to a few $(GeV/c)^2$. Therefore the region of t's where the momentum transfer distribution can be determined covers not only the region where the pure hadronic (nuclear) scattering in realized but also the region which exhibits a significant contribution of coulomb scattering (in the case of charged particles). At high energy and low -t the amplitude of the elastic hadron-hadron scattering consists of two parts, real and imaginary. The imaginary part of the scattering amplitude is obtained from the total cross section using the optical theorem while the real part (phase) is determined experimentally by measuring the interference with the known coulomb amplitude. Once the real part of the hadronic amplitude is known, the dispersion relations provide a constraint on the behaviour of the total cross section at energies much higher than those accessible to present accelerators. As the ratio of the real and imaginary parts and the total cross section are related through dispersion relations, the energy behaviour of these quantities is mutually constrained by these (dispersion) relations.

As pointed out earlier, measurements of ρ at UA4 experiment indicated that new surprise in the asymptotic behaviour of hadron scattering might arrive from the measurements of Tevatron near 1 TeV energy domain. However, measurements at UA4/2 and E710/CDF have shown that the ideas of new threshold may not be true as these results can be explained even by the conventional models. The results of these measurements along with earlier results are given in Fig.2 Measurements in the future are planned at PP2PP experiment at RHIC and CSM, FELIX, TOTEM experiments at LHC. We will include predictions of the theory at these energies.

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3. Conventional Models

Theoretical description of the data has been multidimensional. Considerable effort is devoted to the analysis of forward elastic scattering measurements in a model independent manner assuming only *dispersion relations.* Such models [2] are essentially based on the respect for Froissort-Martin bound and other asymptotic theorems.

Most of the work, using dispersion relations, fits the forward scattering amplitude parameters, σ_T and ρζ A typical dispersion relation result as done by Aleem &Shaukat and Augier et al [3] gives us total

cross section which is shown in Fig. 3. Here data over a wide range of $5\leq \sqrt{s} \leq 546$ GeV has been used to fit the parameters. The resulting asymptotic dependence found for the total cross section is $\sigma_T \approx [\log (s / s_0)]^{2.2 \pm 0.3}$. This analysis favours $\ln^2 s$ dependence of σ_T as compared to lns. This kind of behaviour thus corresponds to the maximum rate of rise of energy which is allowed by the analyticity and unitarity and is close to the Froissart bound. The extrapolated values for 10 TeV and 14 TeV are 103 ± 7 mb and 112 ± 10 mb respectively.

A lot of work [4-9] has been carried out within the framework of Regge pole theory involving the dominance of Pomeron, commonly known as soft Pomeron, at high energies. If Regge pole exchange is the dominant mechanism at high energy, then, the amplitude at large s is dominated by the trajectory α (t) with the largest intercept at t = 0. In a Regge pole model, the increase in total cross section is approximated by the incercept of the Pomeron tractory $\alpha(0) = 1.08$ [9]. High energy data is well fitted by this approximation although at ISR contribution from masonic trajectories is needed. The predicted cross section at 1.8 and 14 TeV is 75 and 95 mb respectively [9] and is consistent with lns behaviour. The σ_T value is predicted to be significantly higher when Odderon is taken in to account [8] in the Regge framework Predictions differ in the RIHC and LHC region. However, the simple Regge pole picture does not satisfy unitarity. Due to this violation, predictions of this model can only be taken as an upper bound to the predicted cross sections of the future accelerators.

An elegant account of this parameter is given by Hufner and Povh [10] in the geometrical picture. Here, total cross section is described by the shape of the colliding hadrons which varies with energy. The

geometrical picture thus gives a good fit to the experimental data for $\sqrt{s} \geq 20$ GeV. Real part of the radius (which has been taken as energy dependent) increases linearly with lns, which makes predictions to higher energy straightforward. The model predict σ_T = 73 and 95 mb respectively for 1.8 and 14 TeV respectively. Similar predictions are made by other models that are based on geometrical picture. Measurements of E811 collaboration will therefore give us a good indication of the trend for the total cross section. However, measurements in the near forward direction would be of significant importance at LHC as it would unambiguously establish or definitely contradict $(\log s)^2$ behaviour which emerges as a consequence of Odderon.

The ratio ρ is also of major interest because of its close relationship with the energy-integrated inelasticity of the collision via the dispersion relation. This quantity will in principle be accessible to measurements at RHIC and LHC energies. The kinematical range to be covered corresponds to the Coulomb-nuclear interference region. The expected $|t_0|$ value at the RHIC and LHC are estimated to about 0.0005 and 0.0007 $(GeV/c)^2$ respectively. Measurement at smallest possible -t value will therefore minimize the extrapolation error. Only the models incorporating Odderon predict high ρ value (≈0.2) at FERMILAB, RHIC and LHC [9]. Recent results of 0.135 ± 0.02 at UA4/2 do not favour the presence of Odderon at current and future energies. In the simple Regge picture of Landshoff and Donnachie [9], a constant value of ρ = 0.12 is predicted which is in agreement with the UA4/2 data. In the geometrical model [18] this value is predicted to be ≈ 0.14 at SPS, FERMILAB and LHC colliders. It is interesting to note that at the time of publication of result of geometrical models UA4 measurements of ρ =0 .24 ± .04 suggested a new threshold and differed from the predicted value of geometrical model. The new results of UA4/2 are consistent with geometrical models. In the Eikonal models, the dip of the differential cross section is very sensitive to the ρ value. This clearly suggests that in case of higher measured value of this parameter the structure in dσ/dt would disappear and turn into shoulder. It can be seen that current data for differential cross section does not support a higher value of ρ at RHIC and LHC within the framework of geometrical picture.

4. Quantum Chromodynamics

As pointed out earlier, in Regge theory the increase in total cross section is approximated by the intercept of the Pomeron trajectory. It would therefore be natural to try to find an origin of Pomeron in QCD. A simple picture is through the exchange of two gluon exchange. This picture however does not give rise the total cross section. In order to account for increase in total cross section, the exchanged gluons must interact with each other [11]. There has been some recent attempts to account for these parameters through different aspects of QCD. The recent observation [12] of rapid rise of parton density at small x has generated much theoretical interest as this rise is equivalent to an increase of the total photon-proton cross section. Lam [12] in a different approach, by looking at QCD phase shift have attempted to account for the rise of the total cross section which certainly guarantee the Froissart bound. They have used this idea to compute the quark-quark scattering phase shift in two loop order, in the leading log approximation. Within a limited energy scale Λ(Q) the theory compares well with the energy variations of hadronic data. These results are shown in Fig.3.

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Figures: 1-4 Total cross section and rho measurements plotted against the predictions of varous models.