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Gribov-Regge Pomeron and hadron structure phenomenology at high energy

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Abstract

Pomeron was introduced as a key object which provides the non-vanishing high energy asymptotic of the total cross sections of strong interactions. The universality of this object was observed first in the studies of the elastic cross sections t-slope shrinkage. Besides the one Pomeron exchange,the unitarity generates more complicated multi-Pomeron contributions which, in particular, describe the diffractive dip structure of the differential $2 \to 2$ cross sections at a larger t. Somewhat unexpected universal features of Bose-Einstein correlations reported in the studies of inelastic events at CERN hadron colliders (ISR, Sp$\bar{p}$S) are naturally explained within the Pomeron approach. Large Hadron Collider (LHC) opens the possibility to investigate such phenomena in more details and with a high precision.

Keywords: Elastic scattering, Bose-Einstein correlations, Multi-peripheral, Hadron colliders

1. Introduction

There are several ways to measure the "radius" of the strong interaction. Lepton-proton elastic scattering provides very valuable information on proton structure with precise knowledge of interaction mechanism. Interaction of hadrons (elastic and inelastic) is an instrument to investigate the nature of strong interaction and the information on the size of the radiation of secondaries is only the part of collected knowledge. Elastic scattering provides only one-dimensional information - differential cross-section. Parameters of this function are being used to chose the best theoretical model, and the slope of the forward cone is only one of them . Multiparticle production reactions have a lot of information, and Bose-Einstein correlations are being used to estimate the dimensions of radiation region.

2. Elastic scattering

Well known method to measure the radius of hadron-hadron (proton-proton, pion-proton, kaon-proton and so on) interactions is to study the t dependence of elastic cross section, $d\sigma/dt$. Since we are talking about the radius it is convenient to describe the elastic cross section in terms of the elastic amplitude, $A(\rho)$, written in impact parameter $\vec{\rho}$ representation. Two dimensional vector $\vec{\rho}$ is the difference between the centers of colliding (beam and target) hadrons in impact parameter (transverse to the beam axis) plane. At high energies $\sqrt{s}$ the value of ρ does not change during the interaction. This reflects the angular moment conservation; each ρ selects a corresponding partial wave $l = \rho\sqrt{s}/2$.
In ρ representation the elastic cross section reads

$$\frac{d\sigma}{dt} = \frac{1}{4\pi}\left|\int d^2\rho e^{i\vec{Q}_t\vec{\rho}}A(\rho)\right|^2, \quad (1)$$

where at high energies $t = -|Q_t^2|$.

Assuming, for simplicity, the Gausian distribution $A(\rho) = A_0\exp(-\rho^2/2B)$ we get from (1)

$$\frac{d\sigma}{dt} = \pi(A_0B)^2e^{Bt}.$$

The elastic slope $B = B_{el}$ measures the width $\sqrt{2B}$ of the distribution $A(\rho)$ in impact parameter plane.

With an accuracy $\sim O((ReA/ImA)^2)$ the amplitude $A(\rho)$ can be restored from the known elastic cross sec-

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$$ImA(\rho) = \int \sqrt{\frac{d\sigma}{dt}\frac{16\pi}{1+(Re/Im)^2}} e^{i\vec{Q}_t\vec{\rho}} \frac{d^2Q_t}{8\pi^2} \qquad (2)$$
$$\simeq \int \sqrt{\frac{d\sigma}{dt}} J_0(Q_t\rho)\frac{Q_t dQ_t}{\sqrt{\pi}}.$$

In this way we can study not only the width of the distribution but the precise shape of the amplitude.

Recall that in general the interaction radius depends on energy. In terms of a single/one boson exchange the largest radius is provided by the pion exchange. Due to a small mass m_π the corresponding Yukava potential has a long range tail $V \propto \exp(-rm_\pi)$. However the interaction caused by spin zero one pion exchange falls down with s as $\sigma \propto 1/s^2$.

Spin one gluon exchange gives the cross section which does not decrease with energy but its radius is limited by the confinement. To get the largest cross section we have to consider the chain (sequence) of interactions with relatively low partial sub-energies. On one hand in the resonance region the amplitude is close to its maximum value allowed by the unitarity, on another hand at each step the interaction radius changes (in one or another direction) by the value $\delta R \sim 1/m$ leading to the 'diffusion' in impact parameter plane. At each step the energy of incoming particle diminishes few times. After the number of steps $n \sim \ln s$ the final radius becomes $R^2 = R_0^2 + n\cdot(\delta R)^2$.

The picture described above is called the multi-peripheral model of high energy interaction. It was first considered in[1]. In terms of Feynman graphs (Fig 1) it looks as a sum of ladder-type diagrams.

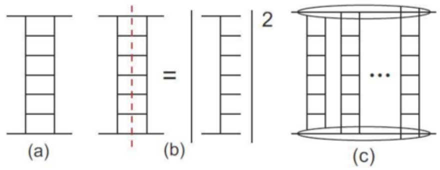

Figure 1: (a) The ladder diagram for one-Pomeron exchange; (b) cutting one-Pomeron exchange leads to the multi-peripheral chain of final state particles; (c) a multi-Pomeron exchange diagram.

After the summation we get the Regge amplitude for the Pomeron exchange

$$A(t) = A_0\left(\frac{s}{s_0}\right)^{\alpha_P(t)}$$

and the cross section

$$\sigma = \sigma_0(s/s_0)^{\alpha_P(0)-1}.$$

For a not too large momentum, $|t|$, transferred through the Pomeron the Pomeron trajectory $\alpha_P(t)$ can be parameterized as $\alpha_P(t) = 1 + \epsilon + \alpha'_P t$ where α'_P is called the slope of the trajectory.

Correspondingly the elastic ab-cross section takes the form

$$\frac{d\sigma_{ab}}{dt} = \frac{\sigma_0^2}{16\pi}F_a^2(t)F_b^2(t)\left(\frac{s}{s_0}\right)^{2\epsilon+2\alpha'_P t},$$

where the form factors F_a, F_b describe the matter distribution in the incoming hadrons ab, while the slope of Pomeron trajectory α'_P accounts for the growth of interaction radius caused by a long chain of intermediate (relatively low sub-energy) interactions which length increases with $\ln s$. In the case of Gaussian form factors $F_a^2F_b^2 = \exp(B_0 t)$ we get the elastic slope

$$B_{el} = B_0 + 2\alpha'_P \ln(s/s_0).$$

Pomeron was introduced initially as a key object which provides the non-vanishing high energy asymptotic of the total cross sections of strong interactions. The universality of this object was discovered in PNPI/CERN SPS experiments (WA9 and NA8 1976-1980 [2]).The pp-,$\pi^\pm p$- elastic scattering with small momentum transfer ($|t| < .04GeV^2$ was studied in wide energy range.

The conclusions were :

" The results of the slope parameters from this experiment together with the analysis of the available world data demonstrate that the existing experimental data are consistent with the hypothesis of a universal shrinkage of the hadronic diffraction cone at high energies. The value of the asymptotic shrinkage parameter α'_P was found to be independent of the kind of the incident hadron and of the momentum transfer in the $|t|$ range $|t| \leq 0.2GeV^2$; $\alpha'_P = 0.28 \pm 0.03GeV^{-2}$."

These days the slope has been measured till $\sqrt{s}$=1800 GeV (Fig 2). The measurement were done in the region of $|t| \sim .1GeV^2$.

One can see that collider data has quite large uncertainty. Pomeron exchange,the unitarity generates complicated multi-Pomeron contributions which, in particular,describes the diffractive dip structure of the differential $2 \to 2$ cross sections at a large t.Hopefully LHC experiments (ALFA [4] and TOTEM [5]) will measure elastic cross-section in wide energy- and momentum transfer range to come to precise conclusion on the Pomeron trajectory parameters.