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Coulomb-nuclear interference in high-energy pp and $\bar{p}p$ scattering

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Different approaches towards the Coulomb phase evaluation are tested altogether with the nuclear amplitude driven by the three-component Pomeron [1]. It is shown that the Coulombic amplitude and its interference with the nuclear amplitude are described well by three different approaches at all energies and the difference is negligible at **RHIC** and **LHC** energies. The model reproduces the existing data in the Coulomb interference domain quite accurately without any adjustment of the parameters. As a consequence, we predict the differential cross section in the region of the Coulomb nucleon interference for both **RHIC** and **LHC** energies.

1. INTRODUCTION

In Ref. [1] an eikonal model of a three-component Pomeron has been suggested and successfully used for describing the high energy pp and $\bar{p}p$ data in the wide region of momentum transfer $0.01 \leq |t| \leq 14.5$ GeV^2 . In this paper we apply the model to the region of small momentum transfer $0 \leq |t| \leq 0.01$ GeV^2.

The problem is a proper account of the Coulomb interaction which is most important at the smallest $|t|$. The standard way to do this is to represent the whole scattering amplitude $T(s,t)$, which is dominated by the Coulomb force at low momentum transfer and by the hadronic force at higher momentum transfer as

$$T(s,t) = T^N(s,t) + e^{i\alpha\Phi}T^C(s,t), \quad (1)$$

where if we normalize the scattering amplitude so that

$$\frac{d\sigma}{dt} = \frac{|T(s,t)|^2}{16\pi s^2}, \quad (2)$$

the Born Coulomb amplitude for pp and $\bar{p}p$ scattering is

$$T^C(s,t) = \mp\frac{8\pi\alpha s}{|t|}. \quad (3)$$

The upper (lower) sign corresponds to the scattering of particles with the same (opposite) charges. $T^N(s,t)$ stands for purely strong interaction amplitude, and the phase Φ depends generally on energy, the momentum transfer and on the properties of T^N. The study of the Coulomb nuclear interference is very important for extracting the real part of the strong interaction amplitude.

In what follows we will investigate four different cases of the Coulomb phase — the phase calculated with the nucleon amplitude of the model [1] (which does not acquire any additional parameter) with the prescription of West and Yennie [2], the phase calculated with prescription of Cahn [3], the prescription of Selyugin [4], and the phase equal to zero.

2. THE NUCLEAR AMPLITUDE

We believe that any nuclear amplitude that is capable of a high accuracy description of the combined set of high energy pp and $\bar{p}p$ data (total and differential cross sections, ρ parameter etc.) over the entire $|t|$ spectrum, if properly combined with the correct Coulomb amplitude, *must* account well for the data in the interference region. That this is so, we will prove using the particular nuclear amplitude which has been derived in [1] to describe total and differential cross sections at high energies ($\sqrt{s} \geq 10$ GeV) in the range of momentum transfer $0.01 < |t| < 14.5$ GeV^2 using the eikonal approach (another one could have been the amplitude of [6]). We just write the nuclear

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amplitude of [1]

$$T(s,\vec{b}) = \frac{e^{2i\delta(s,\vec{b})}-1}{2i}\,, \qquad (4)$$

where the eikonal has the following form

$$\delta^{\bar{p}p}_{pp}(s,b) = \delta^+_{\mathbb{P}_1}(s,b) + \delta^+_{\mathbb{P}_2}(s,b) + \delta^+_{\mathbb{P}_3}(s,b) \mp\delta^-_{\mathbb{O}}(s,b) + \delta^+_f(s,b) \mp \delta^-_\omega(s,b). \qquad (5)$$

We refer the reader to the original literature for details; let us simply remind that here $\delta^+_{\mathbb{P}_{1,2,3}}(s,b)$ are the Pomeron contributions.

Using this parametrization we obtain the following expressions for the Coulomb phase (see Ref. [5] for details)

$$\Phi_{W-Y} = \mp\frac{\sum_i \delta_i(s,t=0)\left[\ln\left(\frac{\rho_i(s)|t|}{4}\right)+\gamma\right]}{\sum_i \delta_i(s,t=0)}, \quad (6)$$

and

$$\Phi_{Cahn} = \mp\frac{\sum_i \delta_i(s,0)\left[\ln\left(\frac{\rho_i(s)|t|}{4}\left(1+\frac{16}{\rho_i(s)\Lambda^2}\right)\right)+\gamma\right]}{\sum_i \delta_i(s,t=0)} \mp(4|t|/\Lambda^2)\ln(4|t|/\Lambda^2) \mp 2|t|/\Lambda^2, \quad (7)$$

where $\rho_i^2 = 4\alpha_i'(0)\ln s/s_0 + r_i^2$, $i{=}P_1$, P_2, P_3, O, f, ω. The upper (lower) signs correspond to pp ($\bar{p}p$) scattering.

3. RESULTS

In [1], the adjustable parameters have been fitted over a set of 982 pp and $\bar{p}p$ data of both forward observables (total cross-sections σ_{tot}, and ρ – ratios of real to imaginary part of the amplitude) in the range $8 \le \sqrt{s} \le 1800$ GeV and angular distributions ($\frac{d\sigma}{dt}$) in the ranges $23 \le \sqrt{s} \le 1800$ GeV, $0.01 \le |t| \le 14$ GeV^2. A good $\chi^2/d.o.f. = 2.60$ was obtained. The description was improved to $\chi^2/d.o.f. = 1.4$ using the systematical errors of the different data sets and the procedure did not result in drastical changes of the parameter values. We conclude that the original model [1] is a good basis for numerical predictions.

We now consider (without any additional fitting) the complete set of data including the Coulomb region which consists of 2158 data points.

In order to compare different approaches to the Coulomb phase, we have calculated the χ^2 for the region of low $|t|:\ \ 0 \le |t| \le 0.01$ GeV^2 in four different cases:

1. The Coulomb phase is equal to zero.
2. The Coulomb phase is calculated with the prescription of West and Yennie (6).
3. The Coulomb phase is calculated with the prescription of Cahn (7).
4. The Coulomb phase is calculated with the prescription of Selyugin [4].

The results may be found in the table.

Phase	# points	χ^2
$\Phi = 0$	604	3.49
Φ_{W-Y} (6)	604	2.09
Φ_{Cahn}(7)	604	1.86
$\Phi_{Selyugin}$[4]	604	1.84

χ^2 per point for the region of low $|t|:\ \ 0 \le |t| \le 0.01$ (GeV^2).

As seen from the table, the experimental data marginally "prefer" the Coulomb phase calculated with the prescription of Cahn [3] and Selyugin [4] over that of West and Yennie, but taking the Coulomb phase equal to zero is excluded by the data and this is gratifying on physical grounds.

Angular distributions calculated with and without Coulomb phase are shown in Fig. 1. Even though the difference is minimal, the numerical conclusion is that the data, quite unambiguously, prefer the appropriate nonzero Coulomb phase.

We also report here, for completeness, the predictions at RHIC and LHC energies both in the interference region and over the entire $|t|$ range. Predictions of the model and comparison with the nuclear amplitude for **RHIC** and **LHC** are shown in Fig. 2.

CONCLUSION

All three choices for the Coulomb phase give good description of the existing data; in terms

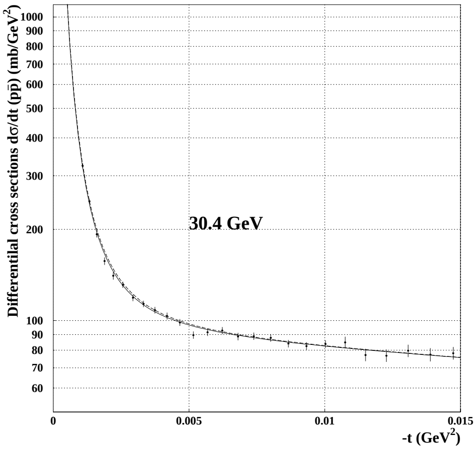

Figure 1. Differential cross section of $\bar{p}p$ scattering and curves corresponding to its description in the model.

of χ^2 per point the phases calculated with the prescriptions of Cahn [3] (7) and Selyugin [4] give us slightly better χ^2 (about 10% less than that of phase calculated with prescription of West and Yennie [2]).

As we have seen, the addition of the nuclear amplitude (with parameters fitted from total and differential cross sections) and of the Coulomb one (with its proper phase) is necessary to obtain a total amplitude which reproduces quite well the data in the interference region without any additional parameters and with no need to refit existing ones.

This allows us to predict the **RHIC** Coulomb interference which requires the measurements to start from $|t| \leq 0.005$ GeV^2 at the energy of $\sqrt{s} =$ 100 GeV and from $|t| \leq 0.004$ GeV^2 at the energy of $\sqrt{s}$ = 500 GeV. Likewise, **LHC** will be able to cover the Coulomb region if the measurement starts from $|t| \leq 0.001$ GeV^2.

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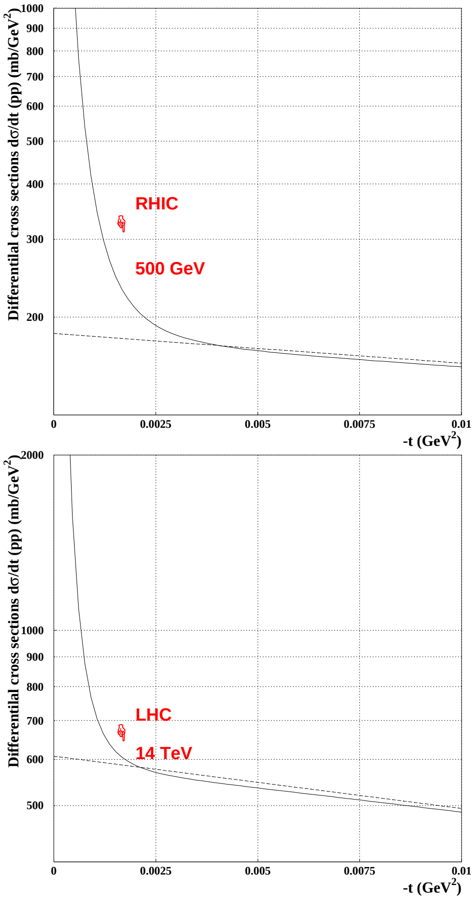

Figure 2. Prediction of the model for the pp scattering differential cross section at **RHIC** ($\sqrt{s}$ = 500 GeV) and **LHC** ($\sqrt{s}$ = 14 TeV). The solid line corresponds to full amplitude including the Coulombic one and the dashed line corresponds to the nuclear amplitude [1].

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