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ARE THERE SMALL-SCALE OSCILLATIONS IN HIGH-ENERGY PROTON-PROTON SCATTERING?

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ABSTRACT

We suggest the presence of "fine" oscillatory structure of the diffraction peak connected with reggeon instability.

Recent measurements[1] of the differential cross section for pp scattering in the CERN colliding beams have revealed a marked t-dependence of the diffraction cone slope on going from large $|t|$ (> 0.15 GeV^2) to small $|t|$ (< 0.15). This structure of the diffraction peak (we shall call it "averaged") has been widely discussed and it has been shown that it can be described by both the optical model (see for example Ref. 2) and the Regge model (Ref. 3 and many other papers).

In this note we discuss the possibility of the presence of extra "fine" structure of the diffraction peak. Deviations of the ISR experimental points from a smooth "average" t-dependence have already been mentioned by Amaldi.[4] We shall suggest here that these deviations are oscillations connected with complex Regge pole (CRP) contributions.

It is well known that CRP arise in many nonrelativistic and relativistid models for the scattering amplitude and probably are a general consequence of s- and t-channel unitarity in Regge theory (for a review of the current situation in the CRP model see Ref. 5). The fact that a Regge pole is complex means that the reggeon is unstable with respect to emission of the Pomeron ($\alpha \rightarrow \alpha + P$) or some other reggeons, so that the imaginary part of the trajectory is proportional to the corresponding triple Regge vertices.[6]

In s-channel multiperipheral dynamics oscillations which are connected with CRP correspond to the opening of new channels (new links in the multiperipheral chain) when the energy grows.[7]

We start from the simple model[8] which describes pp scattering by the ordinary (real) Pomeron P plus a complex conjugate pair of poles:

$$A(s,t) = \gamma e^{\lambda\alpha_P} + \beta e^{\alpha_+\lambda} + \beta^* e^{\alpha_-\lambda}, \tag{1}$$

where $\lambda \equiv \ln s - i\pi/2$, $\alpha_\pm = \alpha_R \pm i\alpha_I$ and $\alpha_R(0) \leq \alpha_p(0) = 1$.

If $\alpha_R(0) = 1$, then

$$\sigma_{tot}(s) = \gamma(0) + 2|\beta(0)|\mathrm{ch}\left(\frac{\pi\alpha_I(0)}{2}\right)\cos\left[\arg\beta(0) + \alpha_I(0)\ln s\right]. \tag{2}$$

It was shown in Ref. 8 that the second term in Eq. (2) can describe both the decrease of $\sigma_{tot}(s)$ in the Serpukhov region and the rise (~14%) in the ISR region if $\alpha_I(0) = 0.66$, $\beta(0)/\gamma(0) \simeq 0.02$ and $\arg\beta(0) \simeq 0$.

It is clear that this model is oversimplified because secondary trajectories and cut contributions are completely neglected. These contributions, in turn, also lead to a decrease of $\sigma_{tot}(s)$ at small s and to a rise at high s. However, it turns out[9] that the rise of σ_{tot} connected with the cut contribution is slower than the experimental rise. In what follows we shall assume that the rest of σ_{tot} arises from CRP, so that CRP contributes only 2 or 3 per cent of the whole increase (~14 per cent) of σ_{tot} in the ISR region.

Let us consider this model at $t \neq 0$. Denoting by $(d\sigma/dt)_{av}$ that part of the differential cross section which is not connected with CRP we can write:

$$\frac{d\sigma}{dt} \simeq \left(\frac{d\sigma}{dt}\right)_{av} \{1 + C \cos [\arg \beta(t) + \alpha_I(t) \ln s]\} , \qquad (3)$$

where $C \equiv 4 (\beta/\gamma) \mathrm{ch}(\pi\alpha_I/2)$.

If $\arg \beta$ or α_I depends on t then the differential cross section will oscillate with t. We shall assume for simplicity that $\arg \beta(t) = \arg \beta(0) \simeq 0$, $C(t) = C(0)$ and $\alpha_I(t)$ is linear in t

$$\alpha_I(t) = \alpha_I(0)\left(1 - \frac{t}{t_0}\right),$$

so that the differential cross section oscillates with a period

$$\Delta t = \frac{2\pi t_0}{\alpha_I(0) \ln s} .$$

If one assumes[10] that the characteristic value which defines the behavior of $\alpha_I(t)$ at small t is the position of the nearest t-channel threshold, i.e., $4\mu^2$ (μ = pion mass), then at large $\ln s >> 1$ CRP lead to fast oscillations and give "fine" structure of the diffraction peak on a background of smooth "averaged" t-dependence which is presumably contained in $(d\sigma/dt)_{av}$.

Figure 1 shows a comparison of $\{1 + C\cos(\alpha_I(t)\ln s)\}$ with the experimental cross section divided by the "averaged" value,[2] i.e., $(d\sigma/dt)_{exp}/(d\sigma/dt)_{av}$. The experimental situation is not very clear, so we do not make a fit but simply show a curve with C = 0.02 and $t_0/\alpha_I(0) = 3\mu^2$ which seems to be the most suitable values to describe the data at s = 2016 GeV^2, where oscillations are the most prominent. The data at s = 2809 GeV^2 are less definite and seem to indicate a little larger value of $t_0/\alpha_I(0) \sim 5\mu^2$.

At lower energies the period of the oscillations must be larger $\sim(\ln s)^{-1}$. Unfortunately we do not find clear evidence for oscillations from lower energy data. The ISR data at s = 462 GeV^2 and 949 GeV^2 have errors larger than the expected effect.

Recoil proton measurements at small $|t|$ ($\lesssim 0.1$ GeV^2) in the NAL and Serpukhov region[11] do not show up oscillations. At smaller energies ($\lesssim 30$ GeV) data obtained by the different groups usually have steps in t bigger than the expected value of the period Δt or the accuracy is not good enough. Some indication of oscillations can be found, however, at p = 19.33 GeV/c.[12]

To illustrate the expected effect we show in Fig. 1 two curves for $s = 50$ and $300\ \mathrm{GeV}^2$. We would like to stress that two assumptions were important in our considerations:

1. reggeon instability (i.e., existence of complex poles on the first sheet of the complex angular momentum plane), and

2. a large value and fast t-dependence of the imaginary part of the complex Regge pole trajectory (high instability of some reggeons).

There are some theoretical arguments in favor of the smallness of α_I for the Pomeron trajectory if $\alpha_P(0) = 1$ (Pomeron quasistability[6]) but there are no such constraints for trajectories with $\alpha_R(0) < 1$. The experimental data on inclusive spectra also indicate a small value for the triple Pomeron vertex (small α_I) but give large couplings for other triple Regge vertices. This means that probably the main contribution to the oscillatory component comes from secondary trajectories and consequently decreases with s as $s^{-(\alpha_P - \alpha_R)}$. If, however, the real part of the complex trajectory is close to α_P [or $\alpha_P(0) = 1 - \epsilon$, $\epsilon > 0$], this decrease may be very slow. The large value of α_I makes it quite possible to have $\alpha_R(t)$ close to $\alpha_P(t)$ even for ordinary secondary trajectories. Other possibilities are the existence of new complex poles with $\alpha_R \lesssim \alpha_P$, large α_I and very small residue, or complex branch points with $\mathrm{Re}\,\alpha_c(0) = 1$ [in the last case the oscillations decrease as $(\ln s)^{-1}$]. A large value of α_I for secondary trajectories can be found in some models, even at $t = 0$.[7]

If C and/or arg β depend on t and/or $\alpha_I(t)$ is not linear, there may be some changes of the oscillatory picture. Thus, if $\alpha_I(0) = 0$ or $C(0) = 0$, then $\sigma_{tot}(s)$ does not oscillate. If $\alpha_I(t)$ and arg $\beta(t)$ approach a constant, then oscillations in t disappear, but they still will be present in the s-dependence if $\alpha_I(t) \neq 0$ and $C(t) \neq 0$. In this respect it is very interesting to make precise measurements of the s-dependence of $d\sigma/dt$ at different t. If $\alpha_I(t)$ increases with $|t|$, oscillations in s will be faster at larger $|t|$.

We would like to emphasize in conclusion that the fact of the presence of "fine" oscillatory structure in the diffraction peak needs further experimental confirmation. It is possible that precise measurements (with accuracy 1% or better) of the differential cross sections for pp, πp, and Kp scattering may give us insight into a new physical phenomena.

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REFERENCES

[1]M. Holder et al., Phys. Letters 35B, 355 (1971); 36B, 400 (1971).

U. Amaldi et al., Phys. Letters 36B, 504 (1971); 43B, 231 (1973).

G. Barbiellini et al., Phys. Letters 39B, 663 (1972).

[2]J. N. White, Nucl. Phys. B51, 23 (1973).

[3]A. A. Anselm and V. N. Gribov, Phys. Letters 40B, 487 (1972).

G. Cohen-Tonnoudji, V. V. Ilyin, and L. L. Jenkovsky, Lett. Nuovo Cimento 5, 957 (1972).

V. A. Tsarev, ZhETF Pis. Red. 17, 171 (1973) [JETP Lett. 17, 121 (1973)].

[4]U. Amaldi, CERN Report 73-5 (1973).

[5]B. R. Desai and V. A. Tsarev, Fizika Elementarnykh Chastits i Atomnogo Yadra (Sov. J. Particles and Nuclei), to be published.

[6]V. N. Gribov and A. A. Migdal, Yad. Fiz. 8, 1002 (1968) [Sov. J. Nucl. Phys. 8, 583 (1969)]; V. N. Gribov, E. M. Levin, and A. A. Migdal, Yad. Fiz. 12, 173 (1970)[Sov. J. Nucl. Phys. 12, 93 (1971)].

[7]G. F. Chew and D. R. Snider, Phys. Letters 31B, 75 (1970).

[8]N. I. Starkov, V. A. Tsarev, N. P. Zotov, ZhETF Pis. Red. 18, 460 (1973).

[9]S. T. Sukhorukov and K. A. Ter-Martirosyan, Phys. Letters 41B, 618 (1972).

[10] V. A. Tsarev, Yad, Fiz. 18, 425 (1973); Lebedev Institute preprint 69 (1973), to be published in Nucl. Phys.

[11] V. Bartenev et al., Phys. Rev. Letters 31, 1088 (1973).

G. G. Beznogikh et al., Nucl. Phys. B54, 78 (1973).

[12] G. Bellettini et al., Phys. Letters 14, 164 (1965).

FIGURE CAPTION

Fig. 1. "Fine" structure of the differential cross section for pp scattering.

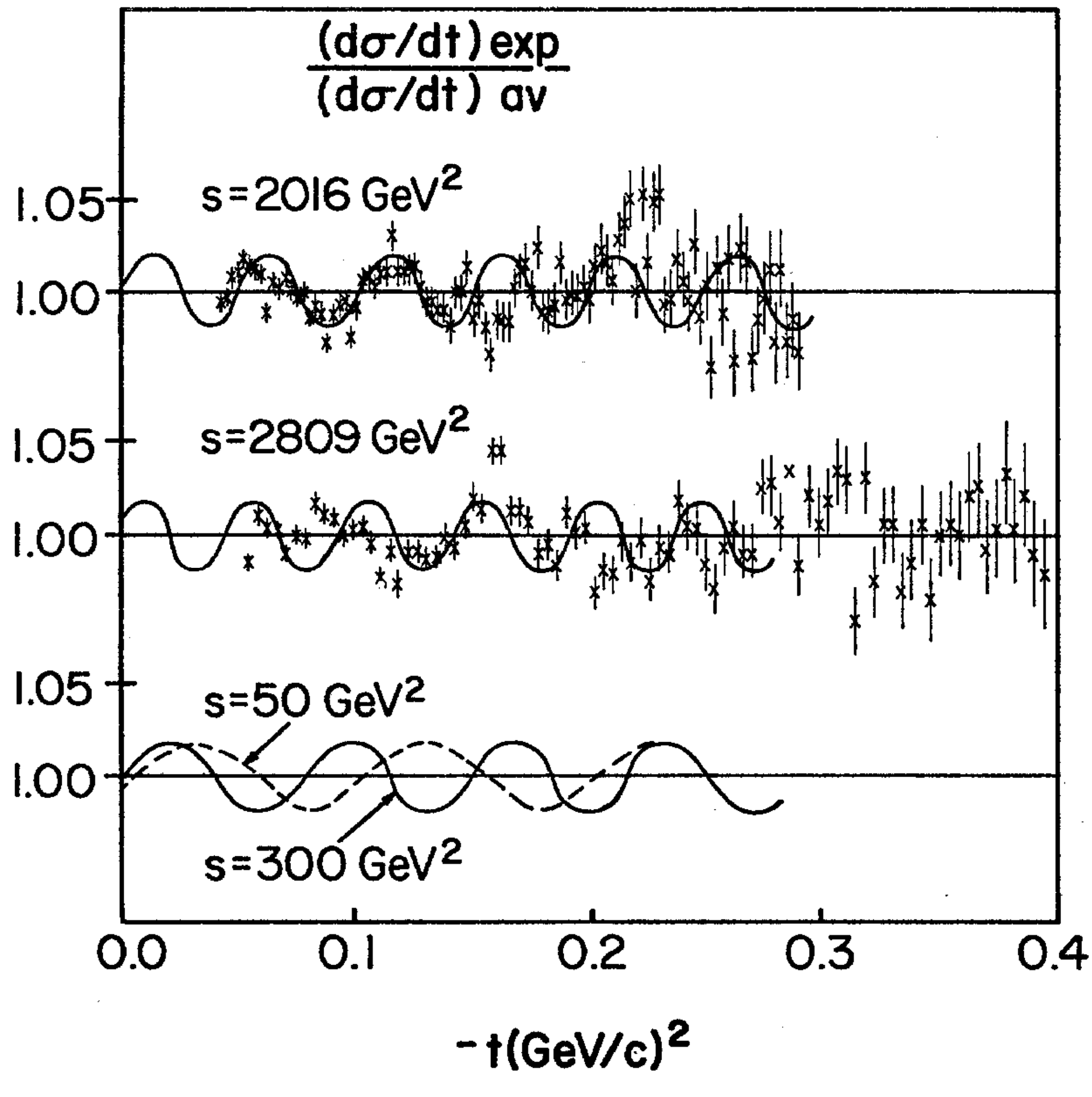
(dσ/dt) exp
(dσ/dt) av
1.05
s=2016 GeV2
1.00
1.05
s=2809 GeV2
1.00
1.05
s=50 GeV2
1.00
s=300 GeV2
0.0
0.1
0.2
0.3
0.4
-t(GeV/c)2

Fig. 1