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TESTING FOR NEW PHENOMENA IN HIGH ENERGY ELASTIC SCATTERING

SW9621

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ABSTRACT — We discuss and enlarge upon a very neat and succinct relation proposed recently by Giffon, Predazzi and Samokhin, linked to the behaviour of elastic scattering at asymptotically high energies. We demonstrate that their result, which was established within a limited class of possible asymptotic behaviours, is actually extremely general and can be proved in an essentially axiomatic framework. We discuss how this relation can be used as a basis for detecting new phenomena at RHIC and LHC energies.

IPNO/TH 96-16

APRIL 1996

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It is generally believed that hadronic total cross-sections grow with energy at very high energies. Still under debate is the question of the difference $\Delta\sigma$ between particle and antiparticle cross-sections. Does $\Delta\sigma \rightarrow 0$ according to classical Regge notions or does it grow as suggested by perturbative QCD, where the odd signature Odderon is on the same footing as the even signature Pomeron [1]. In practical terms we are thinking particularly about the pp and $\bar{p}p$ cross-sections.

The question, mathematically, may be phrased as follows. Let

$$F_{\pm} = \frac{1}{2}(F \mp \bar{F}) \quad (1)$$

be the symmetric and antisymmetric under crossing combinations, respectively, of forward scattering amplitudes: F for $AB \rightarrow AB$ and $\bar{F}$ for $\bar{A}B \rightarrow \bar{A}B$, normalised so that the total cross-sections are given by $\sigma = (1/s) \text{Im}F$, $\bar{\sigma} = (1/s) \text{Im}\bar{F}$. Here, as usual, s is the square of the center-of-mass energy.

The growth of the total cross-sections implies that

$$|F_+(s)| > \text{const. } s, \text{ as } s \rightarrow \infty, \quad (2)$$

while the maximum permitted asymptotic growth is given by the Froissart bound

$$|F_+(s)| \leq \text{const. } s \ln^2 s, \text{ as } s \rightarrow \infty. \quad (3)$$

For $F_-(s)$, Regge theory would suggest [2]

$$|F_-(s)| \sim s^{\frac{1}{2}} \quad (4)$$

corresponding to

$$\Delta\sigma(s) \sim s^{-\frac{1}{2}}, \text{ as } s \rightarrow \infty. \quad (5)$$

On the other hand, axiomatically, the maximum permitted asymptotic growth is

$$|F_-(s)| \leq \text{const. } s \ln^2 s, \text{ as } s \rightarrow \infty, \quad (6)$$

corresponding to

$$|\Delta\sigma(s)| \leq \text{const. } \ln s. \quad (7)$$

We regard as interesting new physics any behaviour such that for $s \rightarrow \infty$,

$$|F_-(s)| > \text{const. } s \quad (8)$$

and we ask how such behaviour can be identified experimentally. The problem is that (8) does not imply that $|\Delta\sigma|$ necessarily increases with energy, whereas $|\Delta\sigma|$ increasing with energy does imply (7).

Recently, Giffon, Predazzi and Samokhin [3] have suggested a succinct method to identify (8) from experiment. Their derivation however is limited to a particular class of functions and the principle aim of this note is to draw attention to the fact that their result is actually very general and can essentially be deduced from axiomatic results. The only additional assumption is that the amplitudes do not oscillate indefinitely, i.e. that beyond some value $s = s_0$ they approach their limiting behaviour monotonically.

Let us write

$$F_+(s) = R_+(s) + iI_+(s) \quad \text{and} \quad \rho_+(s) = R_+(s)/I_+(s) \quad . \quad (9)$$

Then, given that $\sigma_{\bar{p}p} + \sigma_{pp}$ increases with energy, it follows that $I_+(s) > C_1 \cdot s$ (C_1 a positive constant), from which, via axiomatic arguments [4], one deduces

$$\frac{C_2}{(\ln s)(\ln \ln s) \dots} \leq \rho_+(s) \leq \frac{\pi}{\ln s} \quad , \quad (C_2 > 0) \quad , \quad (10)$$

i.e. $\rho_+(s) \rightarrow 0$ at least as fast as $\text{const.}/\ln s$, as $s \rightarrow \infty$.

Consider now $F_-(s) = R_-(s) + iI_-(s)$ with $R_-(s)$ approaching its limiting behaviour monotonically. Take the case $R_-(s)$ positive with

$$R_-(s) > C_3 \cdot s \quad , \quad \text{as } s \rightarrow \infty \quad (C_3 > 0) \quad (11)$$

By putting $R_-(s) = -if_+(s)$ it is easy to see that $f_+(s)$ respects all the conditions satisfied by $F_+(s)$ needed to derive (10). Then since $R_-(s) = \text{Im}f_+(s)$ and $I_-(s) = -\text{Re}f_+(s)$, eq. (10) implies

$$\frac{C_4}{(\ln s)(\ln \ln s) \dots} \leq \left[-\frac{I_-(s)}{R_-(s)} \right] \leq \frac{\pi}{\ln s} \quad (C_4 > 0) \quad , \quad (12)$$

showing that $I_-(s)/R_-(s)$ is negative asymptotically.

For the case $R_-(s)$ negative one puts $F_-(s) = if_+(s)$ and again finds $I_-(s)/R_-(s)$ negative asymptotically. Hence we have the important following results.

If $|R_-(s)| > \text{const. } s$, as $s \rightarrow \infty$, then :

$$\text{i) } I_-(s)/R_-(s) \text{ is negative ;} \quad (13)$$

$$\text{ii) } \frac{C_4}{(\ln s)(\ln \ln s) \dots} \leq \left| \frac{I_-(s)}{R_-(s)} \right| \leq \frac{\pi}{\ln s} . \quad (14)$$

Consider now the experimental quantity introduced in ref. [3]. Let

$$\delta(s) \equiv [\bar{\sigma}(s) - \sigma(s)][\bar{\rho}(s) - \rho(s)] , \quad (15)$$

where $\rho(s)$ and $\bar{\rho}(s)$ are the ratios of the real to imaginary parts of the forward, spin-averaged amplitudes for $AB \rightarrow AB$ and $\bar{A}B \rightarrow \bar{A}B$, respectively.

After a little algebra one finds

$$\delta(s) = \frac{2}{s} \frac{\sigma + \bar{\sigma}}{\sigma \bar{\sigma}} \left(1 - \frac{\rho_+}{\rho_-} \right) I_- R_- . \quad (16)$$

From eqs. (10) and (14),

$$|\rho_+(s)/\rho_-(s)| \ll 1 \quad (17)$$

in the case that $|R_-(s)| > \text{const. } s$, as $s \rightarrow \infty$.

All other factors multiplying $(I_- R_-)$ in (16) are manifestly positive. Hence we have

$$\text{sign } (\delta) = \text{sign } (I_- R_-), \quad (18)$$

and from eq. (13) therefore

$$\delta(s) < 0 \quad (19)$$

when $|R_-(s)| > \text{const. } s$, asymptotically.

On the other hand, if $F_-(s)$ has the usual Regge behaviour, it will be given by

$$F_-(s) = C_R \left(i + \tan \frac{\pi\alpha}{2} \right) s^\alpha , \quad (20)$$

where C_R is an unknown constant and α is the Regge intercept of the highest lying odd J -parity mesonic trajectory. This is associated with the $\rho - \omega$ trajectory with $\alpha \approx 1/2$.

Irrespective of the precise value of the intercept α , we have

$$\frac{R_-(s)}{I_-(s)} = \tan \frac{\pi\alpha}{2} > 0 , \quad \text{for } 0 < \alpha < 1 . \quad (21)$$

Thus

$$\delta(s) > 0 \quad (22)$$

when $F_-(s)$ has the usual Regge behaviour.

To summarize, an experimental strategy to identify new phenomena in nucleon-nucleon scattering, given that $\Delta\sigma = \sigma_{\bar{p}p} - \sigma_{pp}$ is *positive* and *decreasing* and that $\rho_{\bar{p}p} - \rho_{pp}$ is positive up to and at ISR energies, might be the following :

- a) Measure $\Delta\sigma$ at RHIC energies.
- b) If it is negative then (5) has failed and the nucleon-nucleon system is displaying non-Regge dynamics.
- c) If $\Delta\sigma$ is positive, measure δ . If δ is negative, eq. (8) must hold and there are new phenomena controlling the behaviour of F_- .
- d) If $\Delta\sigma$ is positive *and* δ is positive there is no evidence for new phenomena. A detailed study of the energy dependence is then needed to confirm or reject the usual Regge behaviour.

There is one case which the above tests fail to identify. It is possible to have a new phenomena scenario where

$$|F_-(s)| \rightarrow \text{const. } s, \text{ as } s \rightarrow \infty . \quad (23)$$

coupled with

$$\Delta\sigma(s) \rightarrow 0, \text{ as } s \rightarrow \infty. \quad (24)$$

The sign of $I_- R_-$ is undetermined in this case. However, it can be identified or eliminated by studying the energy dependence of $\bar{\rho} - \rho$. Provided one is at an energy where $|\Delta\sigma| \ll (\bar{\sigma} + \sigma)$ one will have asymptotically

$$(\bar{\rho} - \rho)(\bar{\sigma} + \sigma) \approx \text{const.} \quad (25)$$

if eq. (23) holds.

Although we have focussed mainly on nucleon-nucleon scattering in this note, it should be stressed that the entire argument applies equally well to any pair of particle and antiparticle reactions. The possibility of utilizing such tests should become feasible when RHIC and later LHC are functioning.

REFERENCES

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