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THE NEW ISR AND COLLIDER $\bar{p}p$ AND pp DATA AND ASYMPTOTIC THEOREMS [::]

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<u>ABSTRACT</u>

We present a general discussion of the rigorous finite-energy effects of asymptotic theorems, with a special emphasis on the confrontation with the new ISR and collider $\bar{p}p$ and pp total cross-section data. We point out the possible existence of a minimum in the difference between the $\bar{p}p$ and pp total cross-sections.

Ten years ago, we pointed out, in collaboration with L. Lukaszuk, the fact that the asymptotic theorems allow rather surprising possibilities for the asymptotic behavior of scattering amplitudes. It has been shown[1] that these possibilities are associated with rigorous experimental effects at finite energy, without making use of the usual assumption of precocious asymptoticity. For example, we have shown that the $\bar{p}p$ - pp total cross-sections difference could go through a local zero or a local minimum at high energies, while tending to $\mp\infty$ at infinite energy. In a sequence of papers (see, e.g. Refs. 2 and 3) we made an extensive phenomenological study of the non-conventional behavior resulting from the presence of a $\ell = 1$ singularity in the odd-under-crossing amplitude. We baptised this singularity the "Odderon" [2], for obvious reasons.

Of course, this study rested on data available several years ago. The new ISR and collider data bring back the interest of checking the presence of such rather unexpected consequences of asymptotic theorems[4].

Let me first recall that the asymptotic theorems represent a wonderful and useful tool in particle physics[4,5]. They are rigorous results derived from general principles. Therefore any theory of strong interactions has to satisfy them. The most famous example of an asymptotic theorem is the Froissart bound[6]. It is true that sometimes additional assumptions are needed. It is also true that quite often the spectrum of different possibilities is quite large. In any case, the rigorous results are useful, as I will try to show, taking mainly the example of total cross sections. Other examples can be found in Ref. 4.

Our starting point in 1973 was the fact that the strong interactions can be such that one has simultaneously

$$\sigma_T \propto \ln^2 s \qquad (1)$$

and

$$\Delta\sigma \propto \ln s \qquad (2)$$

which represent the maximal behavior allowed by asymptotic theorems for the total cross section σ_T and for the antihadron-hadron and hadron-hadron total cross section difference $\Delta\sigma$. Eqs. (1)-(2) constitute a possible generalisation of the well-known principle of maximal strength of strong interactions[7], reformulated in the case of increasing total cross sections.

Letting $F_+(F_-)$ denote the amplitude which is even (odd) under crossing, we have

$$F_{AB} = F_+ + F_- \qquad (3)$$

and

$$F_{\bar{A}B} = F_+ - F_- \qquad (4)$$

The rigorous crossing-symmetrical asymptotic form of F_+ and F_- at $t = 0$ in the case of the maximal behavior is[1] :

$$\frac{F_+(s)}{is} \xrightarrow[s \to \infty]{} C_+ \left[\ln (s\, e^{-i\pi/2})\right]^2 \qquad (5)$$

and

$$\frac{F_-(s)}{is} \xrightarrow[s \to \infty]{} iC_- \left[\ln (s\, e^{-i\pi/2})\right]^2 \qquad (6)$$

where C_+ and C_- are real constants. Therefore

$$\sigma_T \xrightarrow[s \to \infty]{} C_+ \ln^2 s \qquad (7)$$

and

$$\Delta\sigma \xrightarrow[s \to \infty]{} - 2\pi\, C_- \ln s \qquad (8)$$

The constant C_+ is obviously positive and has to satisfy the rigorous upper bound[8]

$$C_+ < \frac{\pi}{m_\pi^2} = 60 \text{ mb} \qquad (9)$$

The phenomenological value of C_+ is $\simeq 0.5$ mb, much lower than the upper bound (9). This does not mean that we can not have the maximal behavior (1). As we underlined in Ref. 1, the asymptotic theorems allow for a saturation of the Froissart bound (1) without having at the same time a saturation of the Lukaszuk-Martin bound (9) for the constant C_+.

The constant C_- is in a completely different situation from that for C_+. There is no axiomatic constraint on C_-. In particular, C_- has not to satisfy a positivity condition. Its sign has to be fixed by fitting the data, in one way or another. In spite of this freedom, we can make clean experimental predictions[1].

From the above formula (8) for $\Delta\sigma$ and by considering the present experimental data, we deduce the following non-asymptotic (finite energy) result : $\Delta\sigma$ has either (at least) one minimum or (at least) one zero. This result is easily obtained, in the following way :

1) If $C_- > 0$, then $\Delta\sigma \to -\infty$ (from eq. (8)). But $\Delta\sigma$ is positive in the present experimental region. Therefore, one has at least one zero in $\Delta\sigma$, i.e. a crossing between $(\sigma_T)_{\bar{A}B}$ and $(\sigma_T)_{AB}$. For example, for some range of high energy, $(\sigma_T)_{pp}$ would become larger than $(\sigma_T)_{\bar{p}p}$. This unexpected result, which constitutes a deep challenge for the understanding of the mechanism of annihilation, is not forbidden by general principles.

2) If $C_- < 0$, then $\Delta\sigma \to +\infty$ (again from eq. (8)). But $\Delta\sigma$ is decreasing in the present experimental region. Therefore, one has at least one minimum in $\Delta\sigma$. For example, this means that $(\sigma_T)_{\bar{p}p}$ would continuously approach $(\sigma_T)_{pp}$ up to some value of the energy. Their difference at the minimum point can be, of course, arbitrarily small. After this value of the energy, $\Delta\sigma$ increases.

Note that the asymptotic Pomeranchuk theorem

$$\frac{(\sigma_T)_{AB}}{(\sigma_T)_{\bar{A}B}} \xrightarrow[s \to \infty]{} 1 \qquad (10)$$

is trivially satisfied by the amplitudes (3) - (6). The difference $\Delta\sigma$ can very well diverge and still the ratio (10) is going towards 1.

In a similar way one can obtain other non-asymptotic (finite energy) predictions[9], such as :

a) the possibility of zeros in the ratio ρ of the real over the imaginary part of a given scattering amplitude. For example, if $C_- < 0$, then $\rho_{pp} \xrightarrow[s \to \infty]{} -C_-/C_+ > 0$. But ρ_{pp} is negative in the low-energy region. Therefore ρ_{pp} has at least one zero in the high-energy region. Notice that the constant C_-/C_+ can be small, and therefote it would be difficult to distinguish our case from the conventional one $\rho \xrightarrow[s\to\infty]{} 0$ in a given energy range.

b) the possibility of local minima in the forward ($t = 0$) differential cross-section $d\sigma/dt$ (s).

c) the possibility of dramatic effects in the polarisation (a change of sign in the small-t region in going from low to high energies).

As in the case of the total cross-sections, <u>one has not to confuse</u> these non-asymptotic effects with the asymptotic ones : they can be very different. For example $\Delta\sigma$ is asymptotically divergent, but locally we can observe a zero or a minimum in $\Delta\sigma$. The new singularity in F_- associated with all these effects is a double pole at $\ell = 1$. The corresponding singularity in F_+ is a triple pole at $\ell = 1$.

The simple form of the amplitudes (5) - (6) can be generalized to[10] :

$$\frac{F_+(s)}{is} \xrightarrow[s\to\infty]{} C_+ \left[\ln\left(s\, e^{-i\pi/2}\right)\right]^{\beta_+} \tag{11}$$

and

$$\frac{F_-(s)}{is} \xrightarrow[s\to\infty]{} iC_- \left[\ln\left(s\, e^{-i\pi/2}\right)\right]^{\beta_-} \tag{12}$$

Analyticity, unitarity and positivity lead to the following constraints[10] on the constants β_+ and β_- :

$$\beta_+ \leq 2,\ \beta_- \leq \frac{1}{2}\beta_+ + 1,\ \beta_- \leq \beta_+ + 1 \tag{13}$$

These constraints can be visualised in the Cornille's plot shown in Fig. 1, where we also show the different behaviors of $\Delta\sigma$ and ρ in the different subregions allowed by general principles. It can be noted that the overall allowed region is strongly constrained, a fact which shows the power of general principles. It can also be noted that the "conventional" region (where $\Delta\sigma \to 0$ and $\rho \to 0$) is only a part (the hatched area of Fig. 1) of the allowed domain.

The "non-conventional" region was explored very little untill now from the phenomenological point of view. The previously discussed case is represented by the top point ($\beta_+ = 2$, $\beta_- = 2$) in the Cornille's plot.

We have also considered in the past another possible non-conventional behavior associated with the presence of a simple pole at $\ell = 1$ in F_- :

$$F_- \xrightarrow[s \to \infty]{} D_- s \qquad (14)$$

where D_- is a real constant[2]. This pole is the partner of the usual Pomeron pole in F_+. This case is a somewhat less dramatic one, in the sense that there are no effects in $\Delta\sigma$. However, important non-asymptotic effects can be obtained in the polarisation at high-energy. For example, we studied the case of pion-nucleon charge-exchange scattering[2], which is a good test for our ideas because it involves only the F_- amplitude. It is known experimentally that the low-energy ($p_L \simeq 5$ GeV/c) $\Pi^- p \to \Pi^0 n$ polarisation is positive in the small-t region. We have shown that the presence of an odderon of the type (14) will again induce a change of sign of the polarisation for $p_L \simeq 200$-300 GeV/c. The connection between a given asymptotic behavior for the scattering amplitude and a polarisation experiment is sufficiently interesting to justify such an experiment. Unfortunately, this experiment was never done in the appropriate energy-region.

Our overall conclusion in the period 1973-1976 was that the odderon effects, if present at all, were small in the region of energy accessible at that time. However, we underlined that there are possible interesting effects in the high-energy polarisation (which is sensitive, by definition, to the presence of small contributions to the scattering amplitude) or in the very-high (collider) energy $\Delta\sigma$. In any case, the non-conventional contributions, dominant at $s \to \infty$, had to manifest themselves first as corrections simply because the Regge-pole model describes very well the data in the low and intermediate energy domains.

What is the situation now ?

The new ISR and collider[11] $(\sigma_T)_{\bar{p}p}$ data show a spectacular increase of this total cross-section. These data, together with the new ISR data for $(\sigma_T)_{pp}$ presented at this Conference seem to clearly favor a $\ln^2 s$ increase of both $(\sigma_T)_{\bar{p}p}$ and $(\sigma_T)_{pp}$. The original phenomenological suggestion of the association between the increase of $(\sigma_T)_{pp}$ and the saturation of Froissart bound, made by Leader and Maor[12], seems to be justified both at experimental and theoretical level, namely on the more general grounds discussed in the present talk.

Notice that the $\ln^2 s$ new Pomeron-type contribution to the total cross sections appears first very small when compared with the usual constant Pomeron-pole contribution in F_+. It gradually increases, becoming comparable with the Pomeron-pole contribution at collider energies.

Concerning $\Delta\sigma$, we know that it is decreasing and positive up till the maximum available ISR energy $\sqrt{s} = 62.3$ GeV. In Fig. 2 we show the $\Delta\sigma$ data together with a typical one-Regge-pole fit[13]. It is seen that the dual Regge-pole model describes very well the gross features of the $\Delta\sigma$ data. The discrepancy at low-energy seen in Fig. 2, can be accounted for by the lower-lying (e.g. baryonium) Regge-pole contributions[13]. However, the departure of the $\Delta\sigma$ data from a straight-line behavior at the ISR energies can not be accounted for by a Regge-pole model. This effect, if it is really genuine, requires the presence of the Odderon[13]. Of course, as it is seen from Fig. 2, this effect is only marginally present, and depends heavily on the new R210 data presented at this Conference[14]. Also, detailed and careful phenomenological analysis of the data has to be done before any conclusion is drawn.

Block and Cahn tried recently[15] to test the presence of the different types of odderons proposed by us[1)-3)]. They concluded that the odderon contributions are small, in fact compatible with zero, when compared with the contributions to the even-under-crossing amplitude. However, the odderon has to be compared with the other contributions to the <u>odd</u>-under-crossing amplitude. When this is done, it is seen, from the parametrisation given in Ref. (15), that the odderon contribution becomes comparable to that of the corresponding Regge poles at ISR energies.

Moreover, one has to be careful in choosing the <u>non-asymptotic</u> form of the amplitudes. The non-asymptotic Regge form used in Ref. 15 is in conflict with duality. It is therefore not surprising that some discrepancies with the data are present in the fits of Ref. 15 both at low and high energies. One has also to note that the non-asymptotic forms influence, via the overall fit of the data, the conclusions which are drawn about the asymptotic contributions. For example, Block and Cahn concluded that if an odderon of type (6) is present in the data, it must have $C_- > 0$, leading to a crossing of $(\sigma_T)_{\bar{p}p}$ and $(\sigma_T)_{pp}$ at $\sqrt{s} \approx 75$ GeV. After this energy, the difference $\Delta\sigma$ has to change its sign. It is true though that this conclusion was drawn before the new R210 data[14] became available.

As we already mentioned, in a recent paper[13] we took into account the contributions of the low-lying (baryonium) trajectories and also duality was implemented. The resulting possible odderon of type (6) has $C_- < 0$, leading to a minimum in $\Delta\sigma$ at $\sqrt{s} \approx 70$ GeV. Details can be found in Ref. 13.

Let me conclude by saying that I do not share (yet) the pessimistic conclusion that nothing really new is seen at ISR or collider energies for the low-p_T data. Asymptotic theorems are a useful guide in looking for new finite-energy effects, without necessarily invoking precocious asymptoticity. Such an effect – $\Delta\sigma$ going towards a minimum located at $\sqrt{s} \approx 70$ GeV – is perhaps already present in the data, but is hidden by the experimental errors and by the scarcity of measured energy values. Even if the errors could not be improved, a bigger density of the experimental points for $\sqrt{s} > 50$ GeV would be helpful. Needless to say, the contradiction between the different pp data at $\sqrt{s} = 62.3$ GeV has also to be solved.

In fact, the presence of the Odderon is as important as its absence. The aim is not to check one model or another, one fit or another, but to establish in a firm way finite-energy effects associated with a given asymptotic behavior. The information on the asymptotic behavior of scattering amplitudes is, of course, needed for any theory of strong interactions, e.g. QCD. It is very plausible that the Fermilab and ISR energy domain represents the transition gate between the Regge-pole physics and the "ln s physics".

The ISR is, in this sense, a very useful experimental tool. The fact that we will not have data, for many years, on $\bar{p}p$ total cross-sections at ultra-high energies increases the urgency of extracting the maximum experimental information from ISR before their closing.

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FIGURE CAPTIONS

Fig. 1 The Cornille's plot (see text).

Fig. 2 The data for $\Delta\sigma = (\sigma_T)_{\bar{p}p} - (\sigma_T)_{pp}$ (△ Ref. 16, ● Ref. 17, ○ Ref. 18, ▽ Ref. 19, ■ Ref. 14 ; see also footnote (20)). A one-Regge-pole fit $\beta_R(s/s_o)^{\alpha_R - 1}$, with $s_o = 1\ GeV^2$, $\beta_R = 61.4$ mb and $\alpha_R = 0.465$ is also shown (see text for its significance).

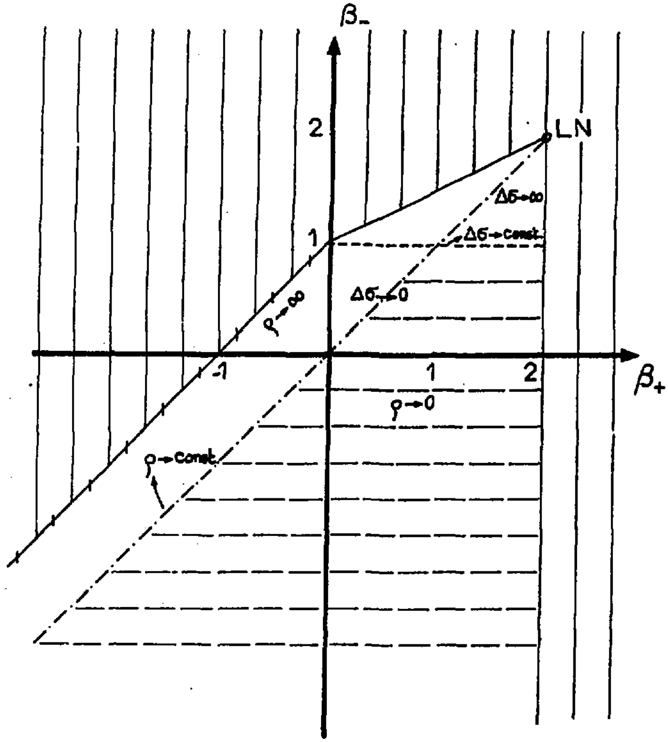

Fig. 1

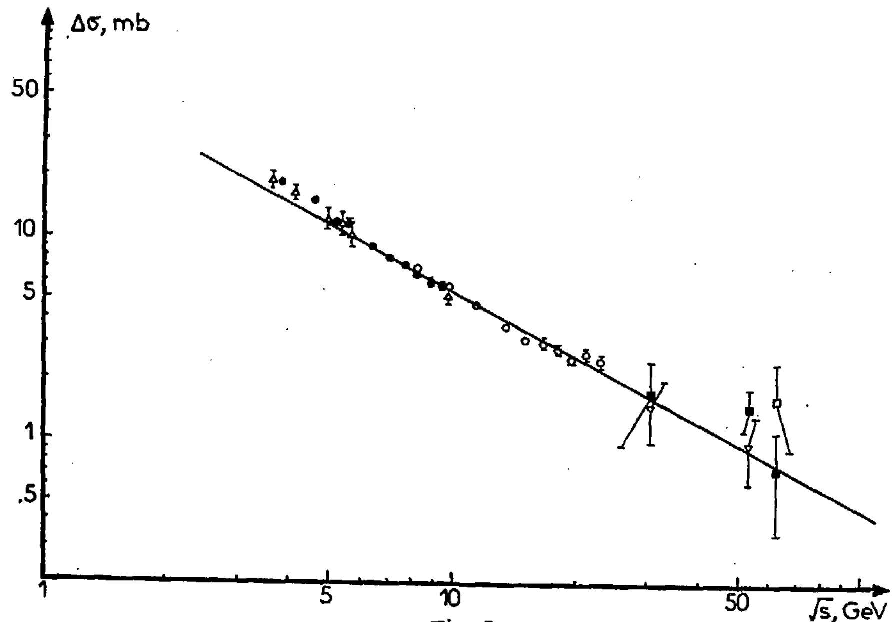

Fig. 2