THEORETICAL PREDICTIONS FOR pp AND p\bar{p} ELASTIC SCATTERING
IN THE TeV ENERGY DOMAIN

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ABSTRACT

We present theoretical predictions on total cross-sections and elastic scattering in the TeV energy domain obtained from the present experimental situation at the ISR and SPPS.

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Theoretical Predictions for pp and p\overline{p} Elastic Scattering in the TeV Energy Domain

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Abstract:

We present theoretical predictions on total cross-sections and elastic scattering in the TeV energy domain obtained from the present experimental situation at the ISR and the p\overline{p} Collider.

There is now a decade that the rise of total cross-section with increasing energy was discovered at the ISR. These results raised the question of how close the experimental data were from an upper bound on the total cross-section, and also if we were already in an asymptotic regime. At that time theoretical analysis of the experimental data could not answer this question, so the advent of the p\overline{p} Collider brought a new hope to solve the problem. When the preliminary results of the UA1 and UA2 experiments\(^2\) were presented, a possible saturation of the Froissart bound\(^3\) was not excluded; however, the latest results from UA2 show that we are not in a situation where the asymptotic regime associated with the saturation of the Froissart bound is already reached. The construction of a hadron collider with an energy in the TeV range will probably give us a better indication of how far is asymptopia.

Now, let us discuss the extrapolation of different experimental observables in the TeV energy domain.

From the analyticity properties of the scattering amplitudes, we can write an explicit analytic and crossing symmetric form of the even signature amplitude\(^4\):

$$\hat{F}(s) = A + B \left( \log |s|/\delta^2 \right)^2$$

and make a fit to the ISR data on $$\sigma_{\text{tot}}$$ and $$\sigma$$, including also the Collider result:

$$(1 + s^2)\sigma_{\text{tot}} = 64 \text{ mb at } E = 546 \text{ GeV}.$$ 

With the above amplitude we saturate the Froissart bound if we suppose C = 0; otherwise, when C ≠ 0, the cross-section approaches a finite limit at infinite energy.

Fit I corresponds to C = 0; Fit II to C as large as possible, but compatible with "low-energy" data:

<table>
<thead>
<tr>
<th></th>
<th>I Froissart saturated</th>
<th>II $$\sigma_{\text{tot}} = \text{const.}$$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>41.065</td>
<td>41.824</td>
</tr>
<tr>
<td>b</td>
<td>0.43</td>
<td>0.415</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>0.006</td>
</tr>
<tr>
<td>s0</td>
<td>343.6</td>
<td>277.7</td>
</tr>
</tbody>
</table>

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The corresponding variations of $$\sigma_{\text{tot}}^+$$ and $$\sigma^+$$ with respect to $$E_{CM}$$ are shown below.

<table>
<thead>
<tr>
<th>E_{CM} (GeV)</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>41.4</td>
<td>41.2</td>
</tr>
<tr>
<td>52</td>
<td>43.1</td>
<td>43.5</td>
</tr>
<tr>
<td>62</td>
<td>43.9</td>
<td>44.5</td>
</tr>
<tr>
<td>550</td>
<td>62.4</td>
<td>63.1</td>
</tr>
<tr>
<td>7000</td>
<td>91.1</td>
<td>75.4</td>
</tr>
<tr>
<td>10000</td>
<td>112.5</td>
<td>88.6</td>
</tr>
<tr>
<td>20000</td>
<td>128.8</td>
<td>92.9</td>
</tr>
<tr>
<td>40000</td>
<td>146.6</td>
<td>97.8</td>
</tr>
</tbody>
</table>

We observe that in the present accessible energy domain both formulas give a good approximation to the data. The extrapolation to higher energies shows a marked difference in $$\sigma_{\text{tot}}^+$$ and $$\sigma^+$$.

In particular, as the p\overline{p} Collider energy the difference on $$\sigma^+$$ in the cases I and II may be seen experimentally if the measurement can be made with an accuracy of 0.01%\(^{10}\); in that case, an indication on the growth of $$\sigma_{\text{tot}}$$ will be obtained.

The ratio $$\sigma^+_{\text{tot}}/\sigma^+$$ is clearly increasing from 0.175 ± 0.005 at the ISR to 0.213 ± 0.006 at the Collider. Such a result provides an interesting criterion for judging different models; for instance, the "Critical Powervor" model\(^11\) predicts $$\sigma^+_{\text{tot}}/\sigma^+$$ decreasing with energy, while the "geometrical scaling" model\(^12\) gives $$\sigma^+_{\text{tot}}/\sigma^+$$ = const. In the case of eikonal models, Chen-Yang\(^11\) and Cheng-Wilson\(^11\) predict an increasing opacity of the nucleon in this energy range, the limiting value being $$\sigma^+_{\text{tot}}/\sigma^+$$ = 1. The most probable value in the TeV domain is around 0.28\(^13\). Let us notice that the string model of Kaidalov and Ter-Martirosian\(^11\) has similar features.

The recent measurement of the differential cross-section dp d^3p at $$s = 546 \text{ GeV}$$, has provided interesting information on the logarithmic slope and the dip structure. We observe an increase of the slope from 13 GeV^-2 at the ISR up to 15.7 GeV^-2 at the Collider. This trend is in agreement with rigorous results derived from analyticity properties\(^14\), namely the slope behaves in the forward direction like log s, while for fixed t ≠ 0, the slope has a non-uniform behaviour but is still bounded by log s.

The dip observed at the ISR transforms into a shoulder at p\overline{p} Collider energy because of the dominance of the real part of the amplitude over the imaginary part, a phenomenon which is well reproduced by different models. The difference between the models occurs in the momentum transfer region above the dip, where only eikonal models\(^15\) are in agreement with the data: the others\(^15\) are too low by one order of magnitude. We notice that a model of Bonnache-Landshoff\(^16\) exhibits an important difference between pp and p\overline{p} scattering in the dip region. In this model the large t behaviour is dominated by a triple gluon exchange which is real and odd under crossing: as a result the dip in p\overline{p} disappears at Collider energy and above, while it remains in pp. Such a high energy behaviour of the
differential cross-section seems difficult to understand because a theorem\textsuperscript{13} shows that both the pp and pp dipoles will survive or they will disappear as the energy goes to infinity.

In Fig. 1 an extrapolation of the differential cross-section in the energy range 10-40 TeV is made using the eikonal model of Ref. 9. We observe a continuous increase of the forward slope to a value around 20 GeV\textsuperscript{-2}; the dip reappears and becomes sharper with the energy increase, its position being around 0.5 GeV\textsuperscript{-2}; moreover a shoulder develops around 2 GeV\textsuperscript{-2}, indicating the presence of a second zero in the imaginary part of the amplitude. If this last point is confirmed by experiment, it will add a new piece of information about the compositeness of the proton, because the pp differential cross-section will exhibit a pattern similar to that of proton-nucleus scattering.

In conclusion, what can we learn on elastic scattering by exploring a domain of energy in the 10-40 TeV range? In a conservative situation where all the observable quantities extrapolate according to the present trend, we will obtain at least more accurate constraints on the behaviour of scattering amplitudes and at the same time on rigorous results obtained from unitarity and analyticity. Now in the non-conservative case anything can happen -- let us hope that Nature may sometimes be more imaginative than we are!

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Fig. 1}
\end{figure}

\textbf{REFERENCES}

4) UA4 Collaboration proposal, CERN/SPSC/84-7 (1984).