pp AND p[MATH] DIFFRACTIVE SCATTERING
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1. Introduction. - The CERN colliders offer a unique opportunity to test general consequences of analyticity and unitarity of scattering amplitudes. The ISR, allowing a comparison of pp and $p\bar{p}$ amplitudes and total cross-sections at energies from $15 + 15$ to $31 + 31$ GeV makes it possible to test the Pomeranchuck theorem and its generalizations. The SPS collider makes it possible to explore a new range of energies (equivalent to 150 000 GeV lab energy) and test asymptotic bounds and high energy models.

2. Pomeranchuck theorems and ISR experiments. - Notations:

$E_{\text{lab}}$ = lab energy = $s/2M$ (in GeV)

$F^+ = F_{pp} + F_{p\bar{p}}$  $F^- = F_{\bar{p}p} - F_{p\bar{p}}$.

The Pomeranchuck theorem says: $\sigma_{pp}^\text{Tot} - \sigma_{pp}^\text{Tot} = 0$, if $F^-/E \log E \to 0$ for $E \to \infty$ 1).

or $\text{Re} F^-/ \text{Im} F^- \to 0$ for $E > E_c$ 3).

$F^-$, up to recently, was not directly accessible to experiment and one could prefer to the weaker statement 2):

$\sigma_{pp}^\text{Tot} \sigma_{pp}^\text{Tot} + 1$ if either $\sigma_{pp}^\text{Tot} \to \infty$  or $\sigma_{pp}^\text{Tot} \to \infty$.

Analysis of previous experiments 5), with the best fit

$\sigma_{pp}/\sigma_{pp} = 42 E^{-0.37} \pm 24 E^{-0.55} + 27 + 0.17 (\log 2E)^2.1 \text{ mb}$,

suggest that indeed $\sigma_{pp} \to \infty$.

Finally, there is a version of the Pomeranchuck theorem for elastic scattering 6):

$(d\sigma_{pp}/dt)/(d\sigma_{p\bar{p}}/dt) = 1$ inside the diffraction peak. In particular $b_{pp}/b_{p\bar{p}} = 1$, if $b(s,t) = d/dt[\log(d\sigma/dw)(s,t)]$.

Two experiments at the ISR test these properties, R 210 and R 211. R 210 measures $\sigma_{pp}$ and $b(s,t)$ for $0.02 < |t| < 0.7 (GeV)^2$. They find that $\sigma_{pp} > \sigma_{p\bar{p}}$. Their best fit is

$\sigma_{pp} = 38.3 \pm 0.5 \log^2(E/62) \text{ mb}$

$\Delta \sigma = \sigma_{p\bar{p}} - \sigma_{pp} = 79 (2E)^{0.58} \text{ mb}$

In particular

$\Delta \sigma = 1.85 \pm 0.8 \text{ at } p_{\text{lab}} = 500 \text{ GeV}$

$1.5 \pm 0.55 \text{ at } p_{\text{lab}} = 1500 \text{ GeV}$

$0.85 \pm 0.45 \text{ at } p_{\text{lab}} = 2000 \text{ GeV}$
So not only $\sigma_{PP}/\sigma_{PP} + 1$ but $\sigma_{PP} - \sigma_{PP} + 0$. Concerning slopes they get, at $E_{CM} = 53$ GeV, $b_{pp} = 12.6 \pm 1.4 \text{GeV}^{-2}$, $b_{pp} = 10.4 \pm 0.6$ for $t < 0.1$ (GeV)$^2$ consistent with $b_{pp}/b_{pp} = 1$, $b_{pp} = 10.4 \pm 0.6$, $b_{pp} = 10.4 \pm 0.4$ for $t > 0.1 \text{GeV}^2$. The theorem on the slopes is therefore satisfied. In fact, for $|t| < 0.2$ GeV$^2$, we have,

$$b_{pp}/b_{pp} = 1.12 \quad \text{at} \quad E_{lab} = 30 \text{ GeV}$$

$$1.05 \quad \text{at} \quad E_{lab} = 100 \text{ GeV}$$

$$1.00 \pm 0.06 \quad \text{at} \quad E_{lab} = 1500 \text{ GeV}$$

which shows the right trend.

$R_{2117}$ measures differential cross-sections at very small $t$, $10^{-5} < |t| < 6 \times 10^{-3}$ GeV$^2$, and sees the Coulomb peak and the Coulomb nuclear interference. Hence they measure $\rho = \text{ReF}/\text{ImF}$, $\sigma_T$ and $b(s,t \geq 0)$, both for pp and pp scattering. Their results are at $E_{CM} = 30.4 \text{ GeV}$ and $E_{CM} = 52.3 \text{ GeV}$:

$$\sigma_T = 41.7 \pm 0.5 \text{ mb} \quad \sigma_T^{pp} = 43.68 \pm 0.2 \text{ mb}$$

$$\Delta \sigma = 1.5 \pm 0.5 \text{ mb} \quad \Delta \sigma^{pp} = 0.98 \pm 0.36 \text{ mb}$$

$$\rho_{pp} = 0.040 \pm 0.005 \quad \rho_{pp} = 0.060 \pm 0.006$$

$$\rho_{pp} = 0.031 \pm 0.021 \quad \rho_{pp} = 0.101 \pm 0.018$$

(Here $b$ is postulated to be $12.2 \text{ GeV}^{-2}$ for pp and $12.6 \text{ GeV}^{-2}$ for pp).

It is remarkable that here, for the first time, both the real and imaginary parts of $F_{PP}$ and $F_{PP}$, and therefore of $F^+$ and $F^-$ are obtained. These measurements:

1) favour, like $R_{210}$, $\Delta \sigma \to 0$;
2) show that $|\text{ReF}/\text{ImF}|$ is not large and also that $\text{ReF}^+ \times \text{ImF}^- > 0$ and hint that two sufficient conditions for the validity of the Pomeronchuck theorem might be satisfied;
3) make very unlikely unorthodox possibilities such as the presence of "oddons".

On the other hand, the ratio of the slopes, at $E_{CM} = 53$ GeV, is compatible with unity in agreement with our theorem.

The data at $E_{CM} = 62$ GeV are not yet analyzed.

From the existing data a fit of $\sigma_T$ has been proposed, compatible with a $(\log t)^2$ increase, which predicts $\sigma_T = 71 \text{ mb}$ at $E_{CM} = 540 \text{ GeV}$ or 66mb if $\sigma_T^{PP} = 130 \text{ mb}$ while $R_{210}$ predicts $\sigma_T = 69 \text{ mb}$ at $E_{CM} = 540 \text{ GeV}$ and Ref. 5) predicts $\sigma_T = 63 \text{ mb}$ at $E_{CM} = 540 \text{ GeV}$.

A fit of the slope $^9$ based on $R_{211}$ indicates that a linear fit in log $E$ is unacceptable and that a quadratic fit $b = A + B \log E + (\log E)^2$ is needed.
3. Asymptotic bounds and behaviour, and SPS collider experiments.- The fastest growth of the total cross-section allowed by field theory\textsuperscript{10}) is given by the "Froissart bound" first derived from Mandelstam representation\textsuperscript{11})

\[ \alpha_{\text{Tot}} < \text{Const} \ (\log E)^2 \]

If \[ \frac{\alpha_{\text{Tot}}}{(\log E)^2} \neq \text{Const} \neq 0 \]
a situation which, to the best of our knowledge, is compatible with analyticity and unitarity in all channels\textsuperscript{12}) we have\textsuperscript{13})

\[ \frac{\alpha_{\text{elastic}}}{\alpha_{\text{Tot}}} \neq \text{Const} \neq 0 \]
\[ b(s, t = 0) \sim (\log E)^2 \]
\[ \frac{d\sigma}{dt} = \frac{d\sigma}{dt} (t = 0) \times F\left[t(\log E)^2\right] \]

F(z) = entire function of order 1/2 = analytic function of z, bounded by \( e^{\sqrt{|z|}} \) in the whole complex plane.

Another possible asymptotic behaviour is that of the critical Pomeron\textsuperscript{14}), for which

\[ \alpha_T \sim (\log E)^{0.26} \]
\[ \frac{\alpha_{\text{el}}}{\alpha_T} \sim (\log E)^{-0.86} \]
\[ b \sim (\log E)^{1.13} \]

and

\[ \frac{d\sigma}{dt} = \frac{d\sigma}{dt} (t = 0) \times G[t(\log E)^{1.13}] \]

Data at energy \( \leq \) ISR energies are compatible with a qualitative saturation of the Froissart bound \( \text{[the best fit of Ref. 5] gives} \ \alpha_T \sim (\log E)^{2.150.1} \), but this is based on a 10% increase of \( \alpha_T \). The great interest of the SPS collider is that it allows to observe a much more impressive effect. The UA4 collaboration has measured at 540 GeV cm the slope of the diffraction peak for \( 0.05 < |t| < 0.18 \text{ GeV}^2 \); it is

\[ b = 17.2 \pm 1.0 \text{ GeV}^{-2} \]

By extrapolating to \( t = 0 \), they get \( L \times \frac{d\sigma}{dt} (0) = \text{const} \times L \times (\sigma_T)^2 (1 + \rho^2) \). L luminosity can be eliminated by measuring the total rate of events, \( L \sigma_T \), and one gets (with \( \rho = 0 \); remember that \( \rho \leq 0.15 \))

\[ \sigma_T = 66 \pm 7 \pm 3 \text{ mb} \]
This measurement is compatible with the various extrapolations from ISR and slightly favours a model saturating the Froissart bound.

The slope, thought first to be anomalously large, is in fact compatible with a model saturating the Froissart bound but also with the critical Pomeron.

The UA1 group, on the other hand, has made measurements of $b$ at larger $t$ with $0.15 < |t| < 0.26$ GeV$^2$ and found a much smaller value:

$$b = 13.3 \pm 1.5 \text{ GeV}^{-2}$$

The tendency of the slope to decrease with $|t|$ is seen at lower energies but seems to be more marked here. This is not incompatible with theory because, if $\alpha_T \propto (\log E)^2$ we expect a non uniform behaviour of $b(E,t)$ as a function of $t$: $b(s,t=0) \propto (\log s)^2$ while $b(s,t)_{t, fixed} < 0 \propto \log s$.

In this short review we have tried to show the great potential of the SPS collider elastic scattering experiments. It is only in one or two years time that, with increased accuracy, we shall be able to draw firmer conclusions. If real part measurements were also made at these energies they would allow to guess what happens to $\alpha_{total}$ at much higher energies (as was done at the ISR) and this would be a most valuable information.

REFERENCES

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