The odderon and the spin dependence of proton-proton scattering

T.L. Trueman
Brookhaven National Lab

Talk given at RBRC workshop on Odderon Searches at RHIC
September 27, 2005
leader &trueman

\begin{align*}
\frac{A_{NN}}{} & \quad \text{equal mixture} \\
& \quad \text{pure pomeron} \\
& \quad \text{pure odderon} \\
\end{align*}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure}
\caption{Graph showing the relationship between $A_{NN}$ and $t$ GeV$^2$.}
\end{figure}

Leader & Trueman PRD 61 077504
The proton-proton helicity amplitudes

\[ \phi_1(s, t) = \langle + + | M | + + \rangle \]
\[ \phi_2(s, t) = \langle + + | M | - - \rangle \]
\[ \phi_3(s, t) = \langle + - | M | + - \rangle \]
\[ \phi_4(s, t) = \langle + - | M | - + \rangle \]
\[ \phi_5(s, t) = \langle + + | M | + - \rangle \]

Two important initial state polarization asymmetries

\[ A_N \frac{d\sigma}{dt} = - \frac{4\pi}{s^2} Im \{ \phi_5 \ast (\phi_1 + \phi_2 + \phi_3 + \phi_4) \} \]
\[ A_{NN} \frac{d\sigma}{dt} = - \frac{4\pi}{s^2} \{ 2|\phi_5|^2 + Re(\phi_1 \ast \phi_2 - \phi_3 \ast \phi_4) \} \]

Buttimore, *ibid.*
Amplitudes are normalized so that

\[ \phi^\text{had}_1 = \frac{s}{8\pi} \sigma_{\text{tot}}(i + \rho) \exp(bt/2) \]

The singular electromagnetic amplitudes are

\[ \phi^\text{em}_1 = \frac{\alpha s}{t} \frac{1}{(1 - t/0.71)^2} \]

\[ \phi^\text{em}_5 = -\frac{\alpha s \kappa}{2m \sqrt{-t}} \frac{1}{(1 - t/0.71)^2} \]

\[ \kappa = 1.79 \]

The parameters in the hadronic amplitudes have \( s \) dependence determined from unpolarized scattering
Regge pole couplings: cf. Berger et al PRD 17, 2971

\[
\phi_1^{\text{had}} = -\frac{1}{8\pi} \sum_R \beta^R_{nf} \beta^R_{nf} (s/s_0)^{\alpha_R} (\exp(-i\pi\alpha_R) + S_R)/\sin \pi\alpha_R
\]

for single flip amplitude, replace

\[
\beta^R_{nf} \beta^R_{nf} \rightarrow \beta^R_f \beta^R_{nf}
\]

for double flip amplitude, replace

\[
\beta^R_{nf} \beta^R_{nf} \rightarrow \beta^R_f \beta^R_f
\]

I use \( \beta^R_f = \tau_R \sqrt{-t/m^2} \beta^R_{nf} \) with \( \tau_R \) constant
Regge Classification

<table>
<thead>
<tr>
<th></th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau = P = C$</td>
<td>$\tau = -P = -C$</td>
<td>$\tau = -P = C$</td>
<td></td>
</tr>
<tr>
<td>$\phi_+, \phi_5, \phi_2-\phi_4$</td>
<td>$\phi_-$</td>
<td>$\phi_2 + \phi_4$</td>
<td></td>
</tr>
<tr>
<td>$I^P, O, \rho, \omega, f, a_2$</td>
<td>$a_1$</td>
<td>$\pi, \eta, b$</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Classification of pp amplitudes by exchange symmetries and the associated Regge poles.

cf. Buttimore et al PRD 59, 114010
The Model

• is based on Regge fit to $pp$ scattering over wide energy range (cf. Cudell et al) which fixes non-flip parameters for the Pomeron (simple or multiple pole), a $C = -1$ vector meson (mainly $\omega$) and a $C' = +1$ tensor meson (mainly $f_2$).

• The non-flip amplitude is

$$g_0(s, 0) = g_P(s) + g_f(s) + g_\omega(s),$$

where the functions $g_R(s)$ have energy dependence and phase determined by standard Regge theory.

• The corresponding flip amplitude is determined by three real, energy independent constants

$$g_5(s, t) = \tau(s) \frac{\sqrt{-t}}{m} g_0(s, t)$$

$$= \frac{\sqrt{-t}}{m} \{ \tau_P g_P(s) + \tau_f g_f(s) + \tau_\omega g_\omega(s) \}. $$
so

\[
\tau(s) = \left\{ \tau_P g_P(s) + \tau_f g_f(s) + \tau_\omega g_\omega(s) \right\}/g_0(s, 0)
\]

- The two constants in \( \tau(21.7) = -0.213 - 0.054i \) determines two relations between the three constants \( \tau_P, \tau_f, \tau_\omega \)

- We need one more measurement to fix their values. If one measures the “shape” of the raw asymmetry over the CNI region without knowing the value of \( P \) at that energy one can obtain the needed information:

\[
S(p_L) = \frac{P \text{Im}[\tau(p_L)]}{P(\kappa/2 - \text{Re}[\tau(p_L)])} = \frac{\text{Im}[\tau(p_L)]}{\kappa/2 - \text{Re}[\tau(p_L)]}
\]
21.7 GeV data and E950 fit with known P(upper) and Regge prediction based on fit to 100 GeV data and 21.7 GeV shape (lower)

new 100 GeV data, best fit with known P(lower) and Regge prediction based on E950 fit and 100 GeV shape (upper)
$I = 1$ couplings and proton-proton elastic scattering

- Because pp scattering involves the exchange of of $I = 1$ Regge poles, the $\rho$ and the $a_2$ in particular, we cannot simply use the results above to make predictions for this case. But we can use the beautiful new p-jet data and a couple of reasonable assumptions to achieve this. We assume (1) at these energies the proton-proton and neutron-proton unpolarized scattering amplitudes are approximately equal and (2) the two $I = 1$ Regge poles are degenerate with the corresponding $I = 0$ Regge pole of the same Charge Conjugation parity, $C = -1$ for $\omega, \rho$ and $C = +1$ for $f, a_2$. Then we can describe pp scattering in terms of 3-parameters: $\tau_+, \tau_-$ and the pomeron coupling $\tau_P$. Since we already know $\tau_P$, in some sense, from the $pC$ analysis and we can determine two parameters from the real and imaginary parts of $\tau$ obtained by fitting the p-jet data, we are in business.
\( \tau \) from p-jet fit = -0.0625 -0.011 i

\( \tau \) from E704 fit = 0.185 + 0.024 i
Regge residues in $1/\text{GeV}$

non-flip from Cudell et al. PR D61:034019
flip from Trueman, Spin2004

<table>
<thead>
<tr>
<th></th>
<th>non-flip</th>
<th>flip</th>
</tr>
</thead>
<tbody>
<tr>
<td>pomeron</td>
<td>$6.95 \pm 0.10$</td>
<td>$0.626 \pm 0.10$</td>
</tr>
<tr>
<td>$C=+$</td>
<td>$12.73 \pm 0.23$</td>
<td>$-4.12 \pm 0.25$</td>
</tr>
<tr>
<td>$C=-$</td>
<td>$9.65 \pm 0.43$</td>
<td>$10.22 \pm 0.77$</td>
</tr>
</tbody>
</table>
pp2pp data for $A_N$ compared with prediction of my Regge analysis (lower) and no hadronic spin flip (upper).
Odderon pole form assumed for intercept of 1

\[ \phi_2^O = \frac{t}{m^2} \frac{1}{8\pi} \beta_f^O \beta_f^O \left( \frac{s}{s_0} \right) \]

Threshold $t$ factors explicitly shown here. These destroy the CNI enhancement.
Regge pole model prediction for $A_{\text{NN}}$

$s=200$

$A_{\text{NN}}$

odderon flip = $\rho$ flip

odderon flip = 0 or = pomeron flip
To estimate Regge cut associated with odderon use absorption model of Henyey et al, PR 182, 1579

\[ \phi_{2\text{ cut}}^O = -\frac{s\sigma_{\text{tot}}}{4\pi b} (1 - i\rho) \left(\frac{\beta_f^O}{bm^2}\right)^2 \]

The most important feature of this formula is that the suppression factor of \(-t\) has been replaced by the inverse of the slope \(b\).
Cut properties

for pomeron-pole cut

1. Power behavior very close to pole case, up to logs.
   Phase the same as pole.
2. $C$ and signature the same as pole
3. Both parities present
4. No factorization of residues-$<++|M|->$
   so is not forced to vanish at $t=0$
$A_{NN}$ for odderon cut with Regge pole background, odderon flip = $\rho$ flip assumed
$A_{NN}$ at 200x200 for odderon flip = rho flip (upper) and for odderon flip = pomeron flip (lower)
Ann at $s = 500 \times 500$
Odderon flip residue equal to $\rho$ flip residue
$A_{NN}$ from $\rho$ absorptive cut, no odderon at all

\begin{figure}
\centering
\includegraphics[width=\textwidth]{plot.png}
\end{figure}
Height of Ann peak at $t=-0.001$ as a function of the Odderon spin flip coupling at three different energies.

$s=200$

$s=200 \times 200$

$s=500 \times 500$

Odderon flip coupling

Unsuppressed rho cut included here and in following
<table>
<thead>
<tr>
<th>$s$ GeV$^2$</th>
<th>Pomeran flip</th>
<th>Rho flip</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.0256</td>
<td>6.849</td>
</tr>
<tr>
<td>200×200</td>
<td>0.148</td>
<td>39.70</td>
</tr>
<tr>
<td>500×500</td>
<td>0.251</td>
<td>67.08</td>
</tr>
</tbody>
</table>
Conclusions

1. If the odderon exists and has a “reasonable” spin-flip coupling there is a good chance of observing it in $A_{NN}$.

2. The odderon-pomeron cut is essential to producing an observable signal in the small-$t$ region.

3. There is a significant background mainly arising from the $\rho$-pomeron cut. If the odderon spin-flip is small, but larger than the pomeron spin-flip, measurements of $A_{NN}$ over a wide energy range will be needed to separate out the signal.