SCALING PROPERTIES OF ELASTIC PP AND PBARP AT LHC ENERGIES

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Searching for Odderon Formalism
$F(y), G(z), H(x)$
Scaling at ISR
Scaling at LHC
Conclusion
Formalism: elastic scattering

\[ \sigma_{el}(s) = \int_0^\infty dt \left| \frac{d\sigma(s)}{dt} \right| \]

\[ \frac{d\sigma(s)}{dt} = \frac{1}{4\pi} |T_{el}(s, \Delta)|^2, \quad \Delta = \sqrt{|t|}. \]

\[ B(s) \equiv B_0(s) = \lim_{t \to 0} B(s, t), \]

\[ \sigma_{tot}(s) \equiv 2 \text{Im} T_{el}(\Delta = 0, s) \]

\[ \rho(s, t) = \frac{\text{Re} T_{el}(s, \Delta)}{\text{Im} T_{el}(s, \Delta)} \]

\[ \rho(s) \equiv \rho_0(s) = \lim_{t \to 0} \rho(s, t) \]

\[ \left. \frac{d\sigma(s)}{dt} \right|_{t \to 0} = \frac{1 + \rho_0^2(s)}{16\pi} \sigma_{tot}^2(s). \]
Looking for Odderon effects

\[ T_{el}^{pp}(s, t) = T_{el}^{+}(s, t) + T_{el}^{-}(s, t), \]
\[ T_{el}^{pp}(s, t) = T_{el}^{+}(s, t) - T_{el}^{-}(s, t), \]
\[ T_{el}^{+}(s, t) = T_{el}^{P}(s, t) + T_{el}^{f}(s, t), \]
\[ T_{el}^{-}(s, t) = T_{el}^{O}(s, t) + T_{el}^{\omega}(s, t). \]

Three simple consequences:

\[ T_{el}^{P}(s, t) = \frac{1}{2} \left( T_{el}^{pp}(s, t) - T_{el}^{pp}(s, t) \right) \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}, \]
\[ T_{el}^{O}(s, t) = \frac{1}{2} \left( T_{el}^{pp}(s, t) - T_{el}^{pp}(s, t) \right) \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}. \]

\[ T_{el}^{O}(s, t) = 0 \implies \frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{pp}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}. \]
\[ \frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{pp}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^{O}(s, t) = 0. \]
\[ \frac{d\sigma^{pp}}{dt} \neq \frac{d\sigma^{pp}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^{O}(s, t) \neq 0. \]
Our research strategy in this paper is to try to scale out the $s$-dependence of the differential cross-section by scaling out its dependencies on $\sigma_{\text{tot}}(s)$, $\sigma_{\text{el}}(s)$, $B(s)$, and $\rho(s)$. The residual scaling functions will be compared for proton-proton and proton-antiproton elastic scattering to see if any difference remains. Such residual difference is a clear as a signal for Odderon-exchange, if the differential cross-sections were measured at exactly the same energies. However, currently such data are lacking. So we may expect that after scaling out the trivial $s$-dependences, only small scaling violating terms remain that depends on $s$, which can be estimated by the scaling violations of differential cross-sections measured at various nearby energies. If we see larger differences between the scaling functions of proton-proton and proton-antiproton collisions as compared to the $s$-dependent scaling violating term, that will be an indication for the Odderon effect.

Known trivial $s$-dependences in
$\sigma_{\text{tot}}(s)$, $\sigma_{\text{el}}(s)$, $B(s)$, $\rho(s)$

Try to scale this out
Data collapsing (scaling)

Look for scaling violations
Scaling in the diffractive cone region

\[
\frac{d\sigma}{dt} = A(s) \exp[B(s)t],
\]

\[
A(s) = B(s) \sigma_{el}(s) = \frac{1 + \rho_0^2(s)}{16\pi} \sigma_{tot}^2(s),
\]

\[
B(s) = \frac{1 + \rho_0^2(s)}{16\pi} \frac{\sigma_{tot}^2(s)}{\sigma_{el}(s)}.
\]

\[
\frac{1}{B(s)\sigma_{el}(s)} \frac{d\sigma}{dt} = \exp[-tB(s)] \quad \text{versus} \quad x = -tB(s).
\]

\[
H(x) = \frac{1}{B(s)\sigma_{el}(s)} \frac{d\sigma}{dt},
\]

\[x = -tB(s).
\]

Advantages:

\[
H(x) = \exp(-x) \text{ in the cone}
\]

Measurable both for pp and p-antip
Test of the $H(x)$ scaling on ISR data

Energy range: 23.5 – 62.5 GeV (nearly factor of 3)
$H(x)$ works in the cone, shape $\sim \exp(-x)$
$H(x)$ scaling works also in the dip and bump region
Advantages:

$H(x) \neq \exp(-x)$ arbitrary positive def. in the dip-bump region
Measurable both for pp and p-antip
Energy range: 2.76 – 13 TeV (nearly factor of 4)

H(x) nearly works with ~small scaling violating terms
H(x) scaling vs LHC + ISR pp data

Energy range: 23.5 GeV – 13 TeV (nearly factor of 100) scaling violating terms are large, Levy fits guide the eye
Energy range: 1.96 TeV – 2.76 TeV (factor of 1.5) scaling violating terms are large: indicates Odderon effect
Summary and conclusion

Strong and model independent indication of Odderon effect