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

$$\sigma_{el}(s) = \int_0^\infty d|t| \frac{d\sigma(s)}{dt}$$

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

$$B(s) \equiv B_0(s) \; = \lim_{t\to 0} B(s,t),$$

$$\sigma_{\rm tot}(s) \equiv 2\,{\rm Im}\, T_{el}(\Delta = 0, s)$$

$$\rho(s,t) \equiv \frac{{\rm Re}\, T_{el}(s,\Delta)}{{\rm Im}\, T_{el}(s,\Delta)}$$

$$\rho(s) \equiv \rho_0(s) \; = \lim_{t\to 0} \rho(s,t)$$

$$\left.\frac{d\sigma(s)}{dt}\right|_{t\to 0} = \frac{1+\rho_0^2(s)}{16\pi}\, \sigma_{\rm tot}^2(s).$$

Looking for Odderon effects

$$
\begin{aligned}
T_{el}^{pp}(s,t) &= T_{el}^{+}(s,t) + T_{el}^{-}(s,t),\\
T_{el}^{p\bar{p}}(s,t) &= T_{el}^{+}(s,t) - T_{el}^{-}(s,t),\\
T_{el}^{+}(s,t) &= T_{el}^{P}(s,t) + T_{el}^{f}(s,t),\\
T_{el}^{-}(s,t) &= T_{el}^{O}(s,t) + T_{el}^{\omega}(s,t)\,.
\end{aligned}
$$

$$
\begin{aligned}
T_{el}^{P}(s,t) &= \frac{1}{2}\left(T_{el}^{pp}(s,t) + T_{el}^{p\bar{p}}(s,t)\right) \quad \text{for } \sqrt{s} \geq 1 \text{ TeV},\\
T_{el}^{O}(s,t) &= \frac{1}{2}\left(T_{el}^{pp}(s,t) - T_{el}^{p\bar{p}}(s,t)\right) \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}\,.
\end{aligned}
$$

Three simple consequences:

$$T_{el}^{O}(s,t) = 0 \implies \frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV}$$

$$\frac{d\sigma^{pp}}{dt} = \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \;\not\Longrightarrow\; T_{el}^{O}(s,t) = 0.$$

$$\frac{d\sigma^{pp}}{dt} \neq \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^{O}(s,t) \neq 0$$

Odderon search: a possible strategy

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 $\sigma_{tot}(s)$, $\sigma_{el}(s)$, $B(s)$ 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
$\sigma_{tot}(s)$, $\sigma_{el}(s)$, B(s), $\rho(s)$

Try to scale this out
Data collapsing (scaling)

Look for scaling violations

Scaling in the diffractive cone region

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

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

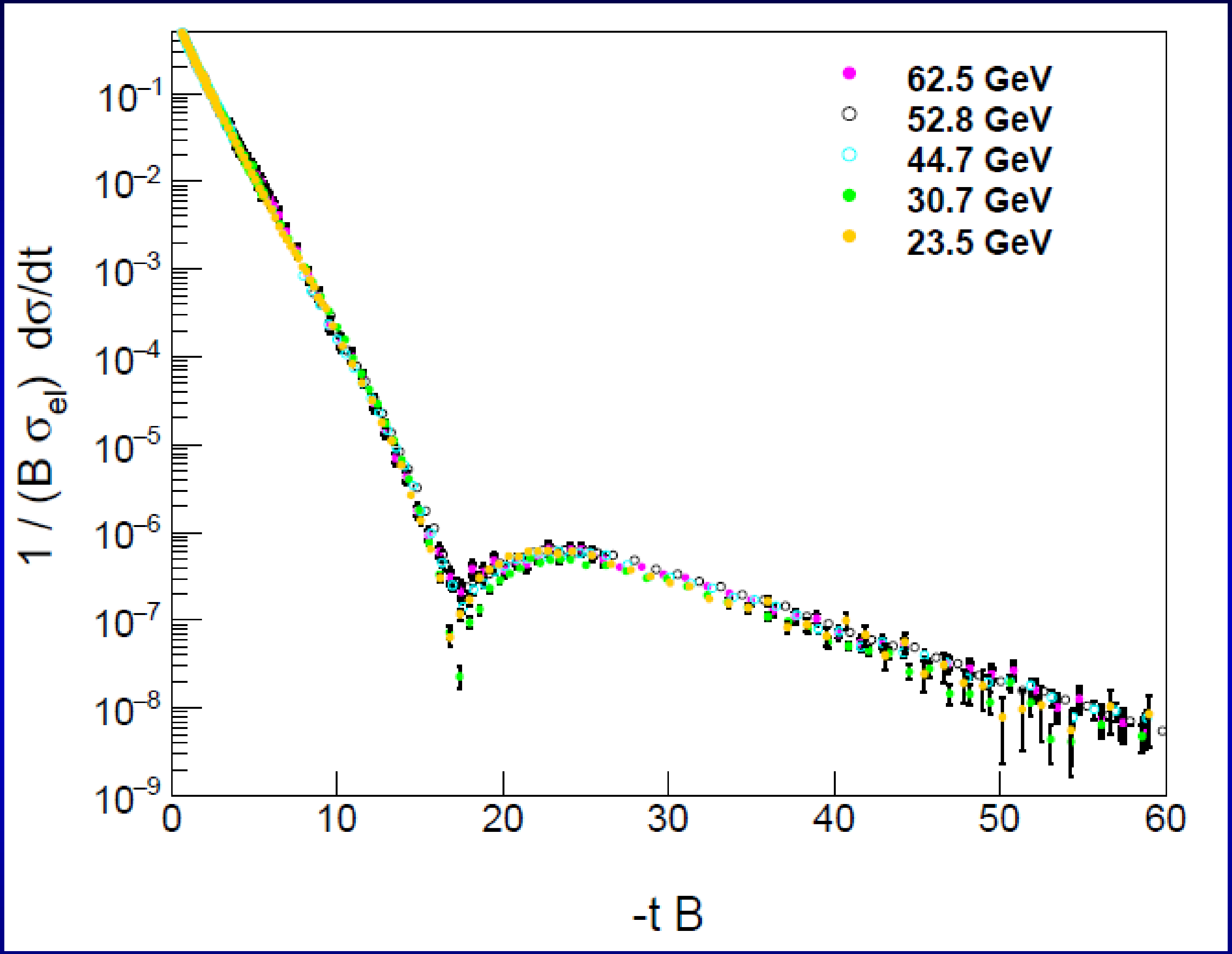
$$B(s) \;=\; \frac{1+\rho_0^2(s)}{16\,\pi}\,\frac{\sigma_{\rm tot}^2(s)}{\sigma_{\rm el}(s)}.$$

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

$$H(x) \;=\; \frac{1}{B(s)\sigma_{el}(s)}\frac{d\sigma}{dt},$$
$$x \;=\; -tB(s).$$

Advantages:
H(x) = exp(-x) 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 ~ exp(-x)
H(x) scaling works also in the dip and bump region

H(x) scaling in greater x region

$$t_{el}(s, \mathrm{b}) = (i + \rho_0)\, r(s) E(\tilde{\mathrm{x}}).$$

$$\begin{aligned} \mathrm{Re}\, \exp\left[-\Omega(s,b)\right] &= 1 - r(s) E(\tilde{\mathrm{x}}), \\ \mathrm{Im}\, \exp\left[-\Omega(s,b)\right] &= \rho_0\, r(s) E(\tilde{\mathrm{x}}), \\ \tilde{\mathrm{x}} &= \mathrm{b}/R(s), \\ R(s) &= \sqrt{B(s)}, \end{aligned}$$

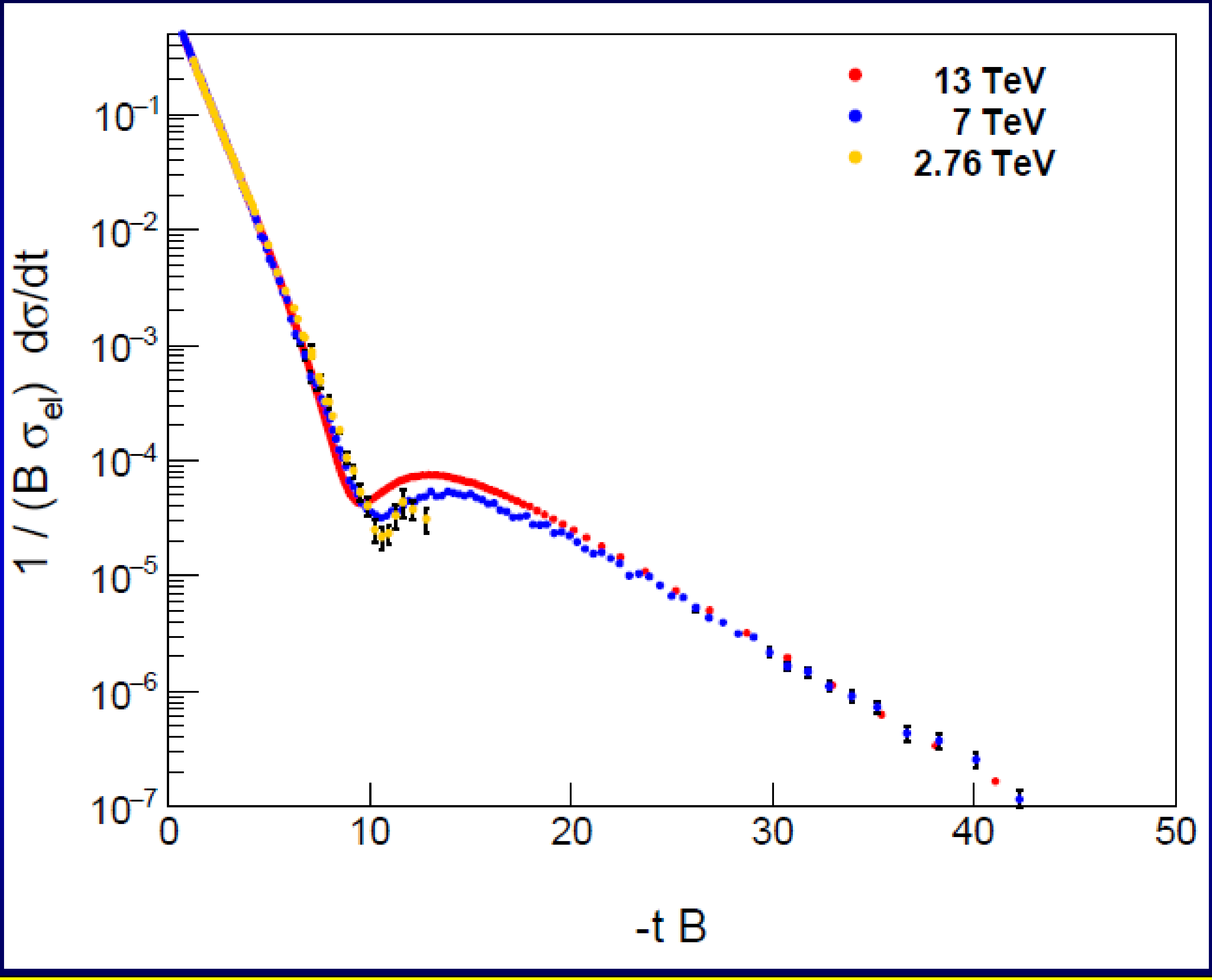
$$\frac{d\sigma}{dt} = \frac{1}{4\pi} |T_{el}(\Delta)|^2 = \frac{1+\rho_0^2}{4\pi} r^2(s) R^2(s) |\tilde{E}(R(s)\Delta)|^2$$

$$A = \left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{1+\rho_0^2}{4\pi} r^2(s) R^2(s) |\tilde{E}(0)|^2,$$

$$\frac{1}{A}\frac{d\sigma}{dt} = \frac{|\tilde{E}(\sqrt{x})|^2}{|\tilde{E}(x=0)|^2} = H(x),$$

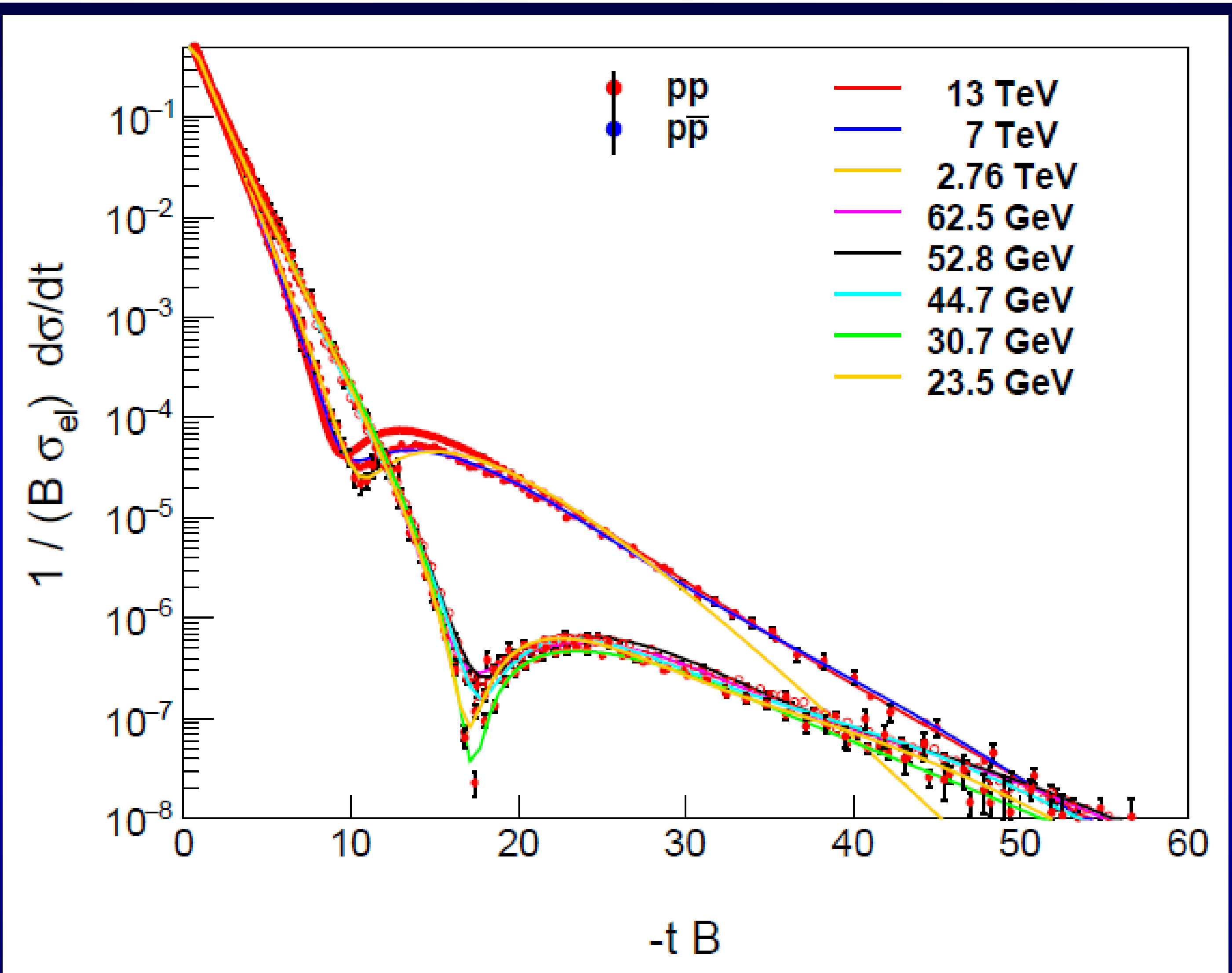
Advantages:
H(x) ≠ exp(-x) arbitrary positive def. in the dip-bump region
Measurable both for pp and p-antip

Test of H(x) scaling on LHC pp data



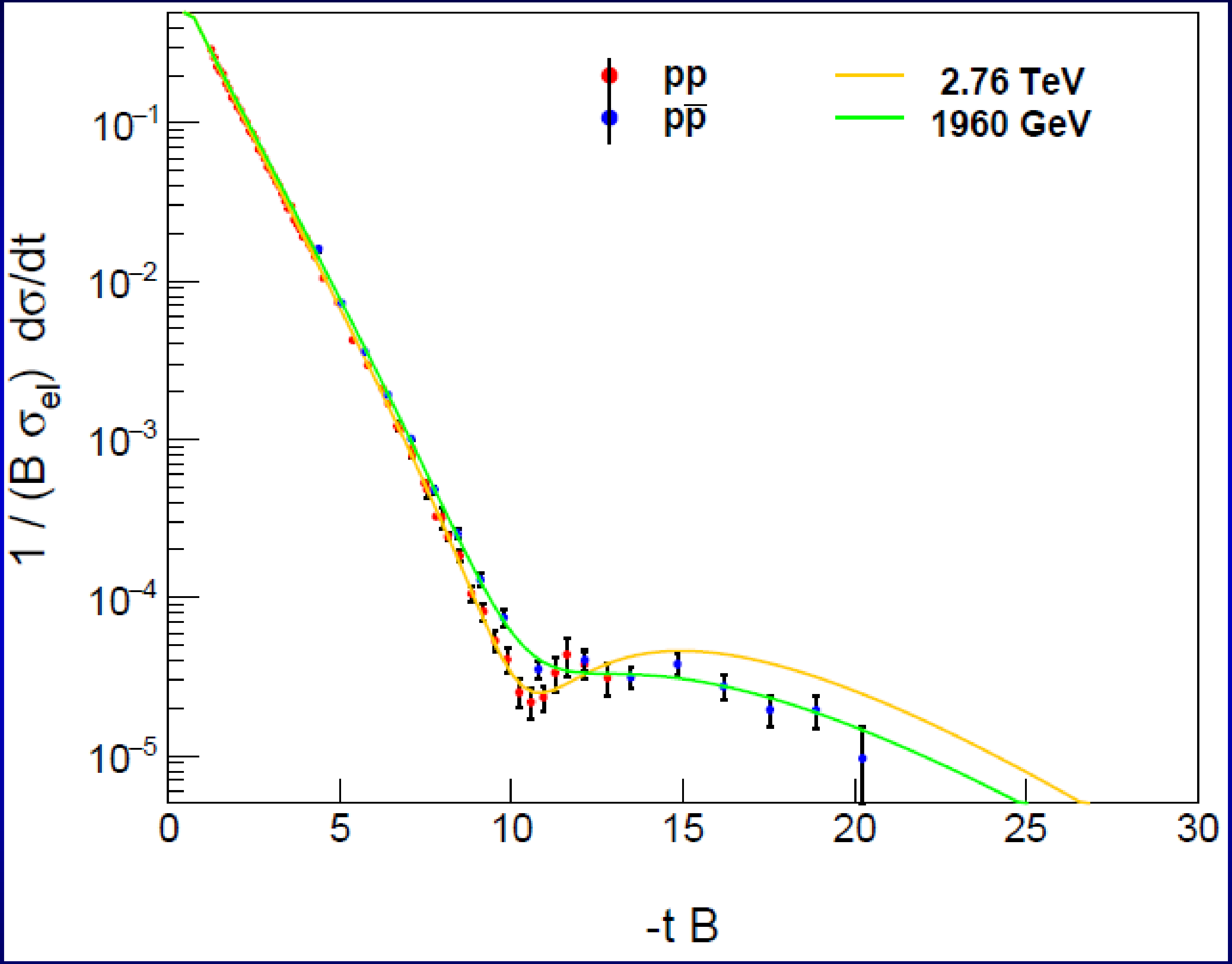
Energy range: 2.76 – 13 TeV (nearly factor of 4)
H(x) nearly works with ~small scaling violating terms

H(x) scaling vs LHC + ISR pp data



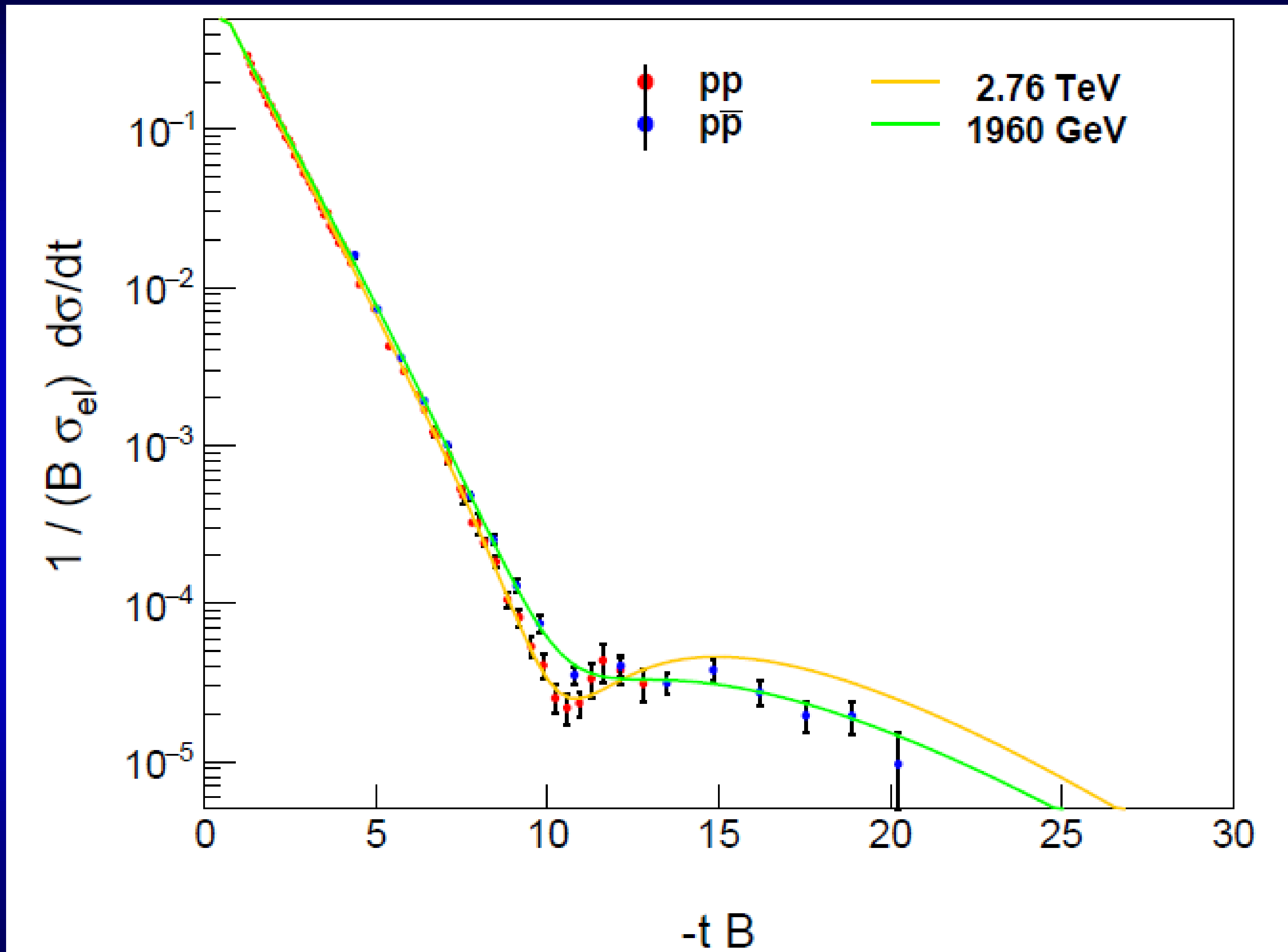
Energy range: 23.5 GeV – 13 TeV (nearly factor of 100)
scaling violating terms are large, Levy fits guide the eye

H(x) scaling for TOTEM + D0 data



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