NEW RESULTS ON OPTICAL POINT at 1.96 TeV elastic pp scattering

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Statistically Significant Observations of Odderon

Model independent results:
Significance ≥ 6.26 σ
Model dependent results:
Significance ≥ 7.08 σ
D0-TOTEM results:
Significance ≥ 5.2 σ
Important (S,C) structure
New: Checks on conditions
Optical point effects
Both model-independently
and model dependently

Strategy of Odderon Search

and symmetry violation in elastic collisions

$$T_{\rm el}^{O}(s,t) = \frac{1}{2}\left(T_{\rm el}^{p\bar{p}}(s,t) - T_{\rm el}^{pp}(s,t)\right)$$

$$\sqrt{s} \geq 1\ \mathrm{TeV},$$

Four simple consequences:

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

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

$$\rho_0^{pp}(s) \neq \rho_0^{p\bar{p}}(s) \quad \text{for } \sqrt{s} \geq 1\ \mathrm{TeV} \implies T_{el}^{O}(s,t) \neq 0$$

$$\sigma_{tot}^{pp}(s) \neq \sigma_{tot}^{p\bar{p}}(s) \quad \text{for } \sqrt{s} \geq 1\ \mathrm{TeV} \implies T_{el}^{O}(s,t) \neq 0$$

Honorable mentions: Odderon, qualitatively

Proposal for LHC to hunt down the Odderon:

Extracting the Odderon from pp and $\bar{p}p$ scattering data #1

Andras Ster (Budapest, RMKI), Laszlo Jen

Budapest, RMKI) (Jan 15, 2015)

Published in: *Phys.Rev.D* 91 (2015) 7, 074

Searching for the odderon in $pp \to ppK^+K^-$ and $pp \to pp\mu^+\mu^-$ reactions in the $\phi(1020)$ resonance region at the LHC #2

Piotr Lebiedowicz (Cracow, INP), Otto Nachtmann (U. Heidelberg, ITP and Rzeszow U.), Antoni Szczurek (Cracow, INP) (Nov 5, 2019)

Published in: *Phys.Rev.D* 101 (2020) 9, 094012 • e-Print: 1911.01909 [hep-ph]

Qualitative Odderon signals: in t-dependence of B(s,t) and ρ(s,t)

Odderon and proton substructure from a model-independent Lévy imaging of elastic pp and $p\bar{p}$ collisions #6

T. Csörgő (Wigner RCP, Budape

Ster (Wigner RCP, Budapest) (Ju

Published in: *Eur.Phys.J.C* 79 (2

Analytical representation for amplitudes and differential cross section of pp elastic scattering at 13 TeV #1

E. Ferreira (Rio de Janeiro Federal U.), A.K. Kohara (SENAI/CETIQT, Rio de Janeiro), T. Kodama (Rio de Janeiro Federal U. and Niteroi, Fluminense U.) (Nov 26, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 4, 290 • e-Print: 2011.13335 [hep-ph]

Odderon effects in the

Evgenij Martynov (Kiev, INR), Basarab Nicolescu (Babes-Bolyai U.) (Au

Published in: *Eur.Phys.J.C* 79 (2019) 6, 461 • e-Print: 1808.08580 [hep-

Ratio $\rho^{pp}_{\bar{p}p}(s)$ in Froissaron and maximal odderon approach

E. Martynov (BITP, Kiev), G. Tersimonov (BITP, Kiev) (Nov 15, 2019)

Published in: *Phys.Rev.D* 100 (2019) 11, 114039 • e-Print: 1911.06873 [hep-ph]

New physics from TOTEM's recent measurements of e

István Szanyi (Uzhgorod Nat.

Published in: *J.Phys.G* 46 (201

Froissaron and Maximal Odderon with spin-flip in pp and $\bar{p}p$ high energy elastic scattering #1

N. Bence (Uzhgorod Nat. U.), A. Lengyel (Unlisted, UA), Z. Tarics (Unlisted, UA), E. Martynov (BITP, Kiev), G. Tersimonov (BITP, Kiev) (Sep 4, 2021)

Published in: *Eur.Phys.J.A* 57 (2021) 9, 265

Scaling in the diffractive cone region

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

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

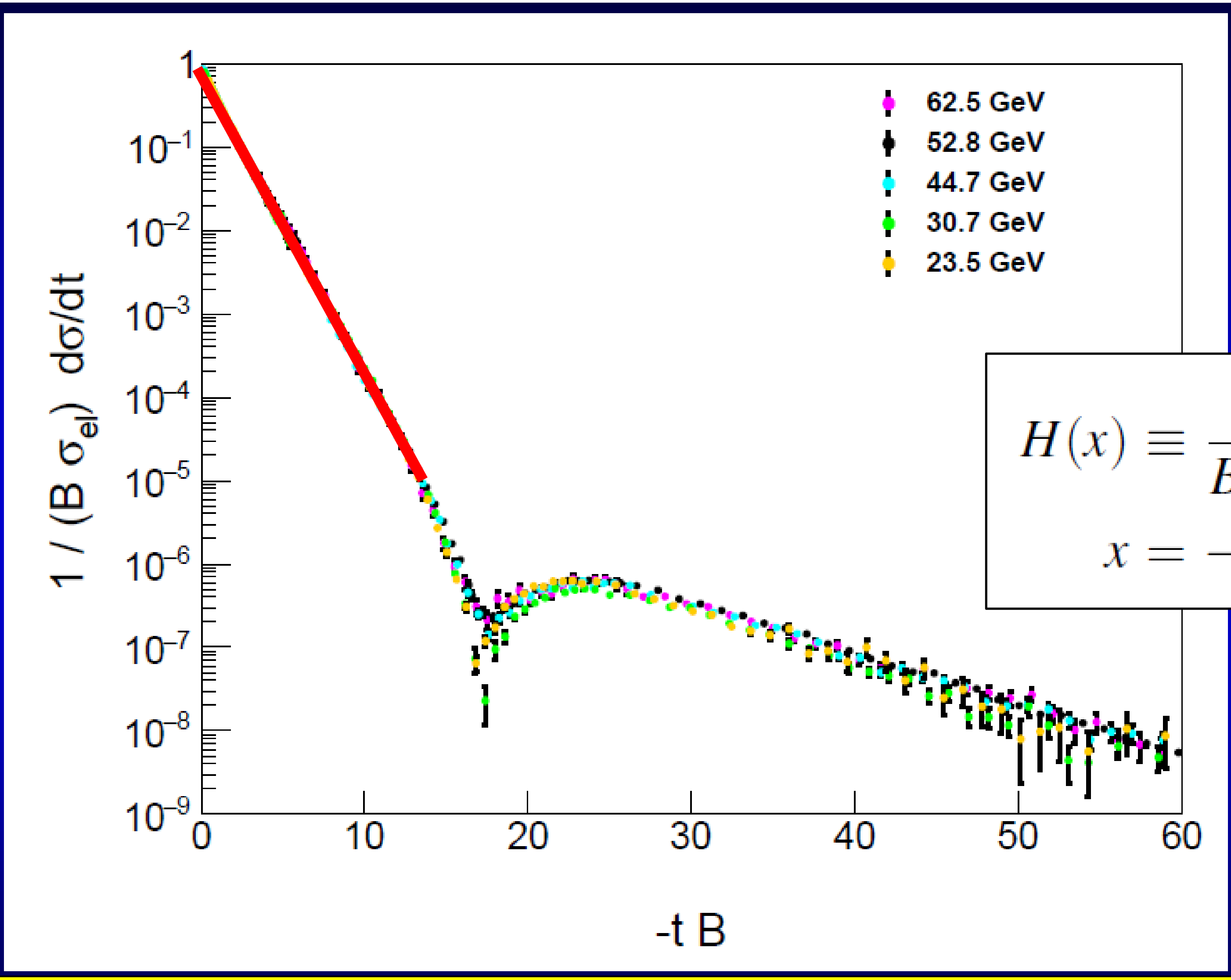
$$\frac{1}{B(s)\sigma_{\rm el}(s)}\,\frac{d\sigma}{dt} = \exp\left[tB(s)\right]$$

$$H(x) \equiv \frac{1}{B(s)\sigma_{\rm el}(s)}\,\frac{d\sigma}{dt},$$

$$x = -tB(s).$$

Advantages:
1) H(x) = exp(-x) in the x = -Bt << 1 region (cone)
2) Start from a place that you know
3) Measurable both for pp and pbarp

Test of the H(x) scaling at ISR



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

H(x) = exp(-x) not only in x << 1 but also up to x ~ 10 in pp.
Works much better than expected, even in the 25 < x < 40 region!

Optical point from the diffractive cone

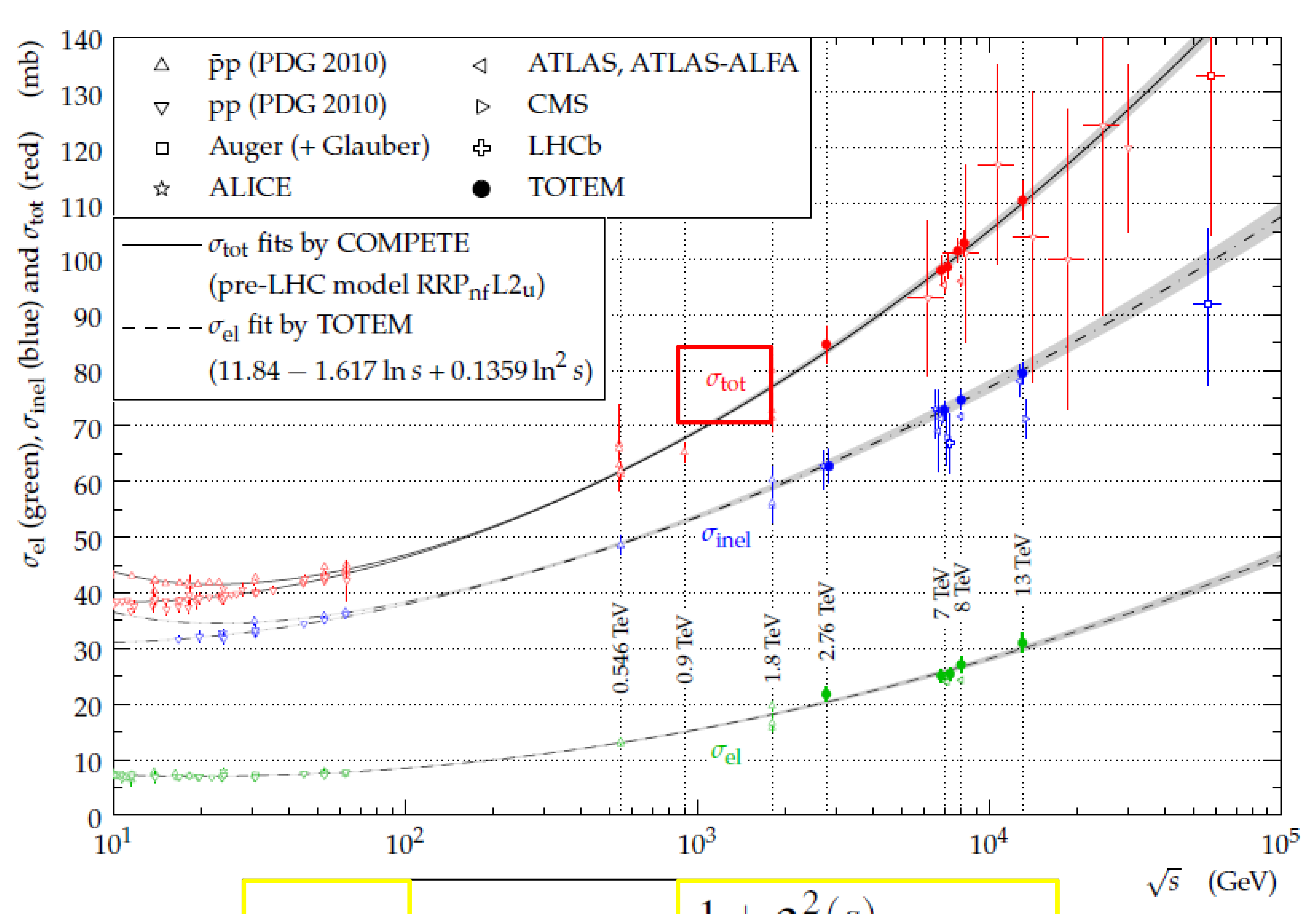
$$\frac{d\sigma}{dt} = A(s) \exp\left[B(s)t\right].$$

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

A(s): Optical point (OP) = differential cross-section at t=0
1) ρ_0(s) and σ_{tot}(s) are well measured → OP1 = A(s)
2) B(s) and and σ_{el}(s) are well measured too → OP2 = A(s)
3) H(x) scaling is valid at small x → OP3 = A(s) from H(x):
3a, 3b, 3c: H(0) measured at 2.76 TeV, 7 TeV and 8 TeV
See the details of 1-3) in A. Ster's talk
4) H(x|pp) = H(x|pbarp) in the first few points,
Maximal overlap obtained by MINUIT

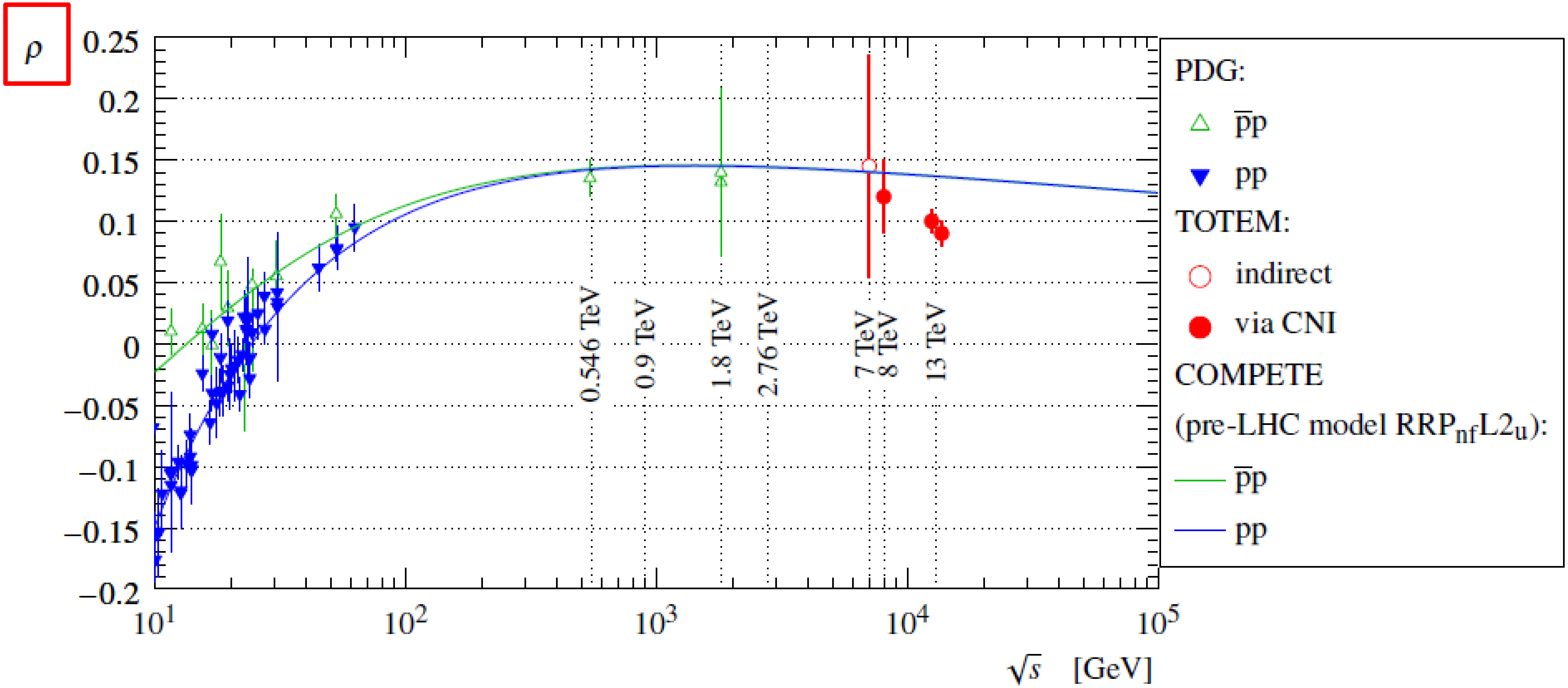
5) ReBB model calculation → OP4 = A(s)
6) H(x) scaling limit of ReBB model calculation → OP5 = A(s)
7) Pomeron-Odderon Regge model → OP6 = A(s)
5-7: See the details in I. Szanyi's talk

Method 1: OP1 from $\rho_0(s)$ and $\sigma_{tot}(s)$



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

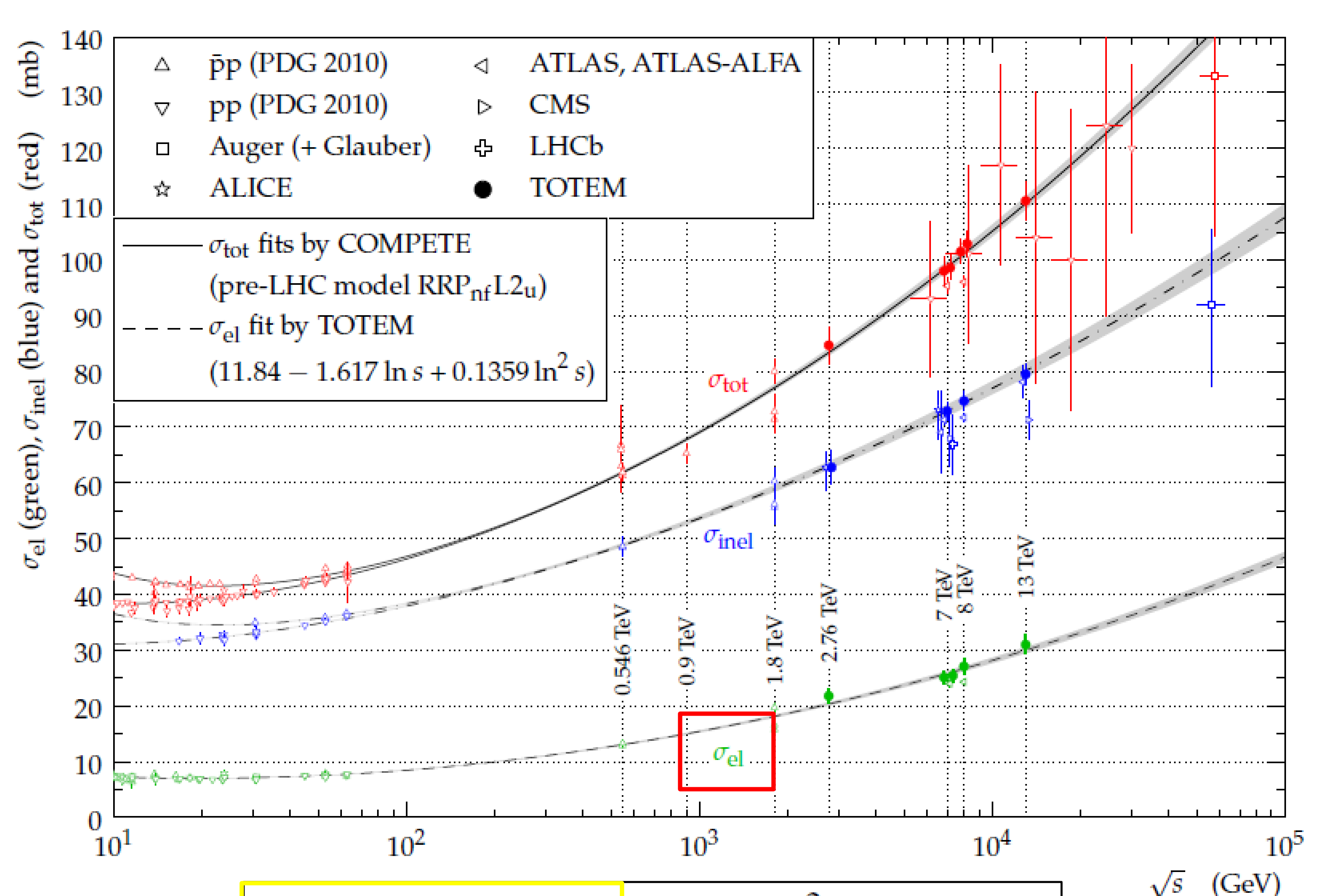
Method 1: OP1 from $\rho_0(s)$ and $\sigma_{tot}(s)$



TOTEM published the trend of $\rho_0(s)$ in *Eur.Phys.J.C* 79 (2019) 9, 785 and the trend of $\sigma_{tot}(s)$ in *Eur.Phys.J.C* 79 (2019) 2, 103, yielding OP1

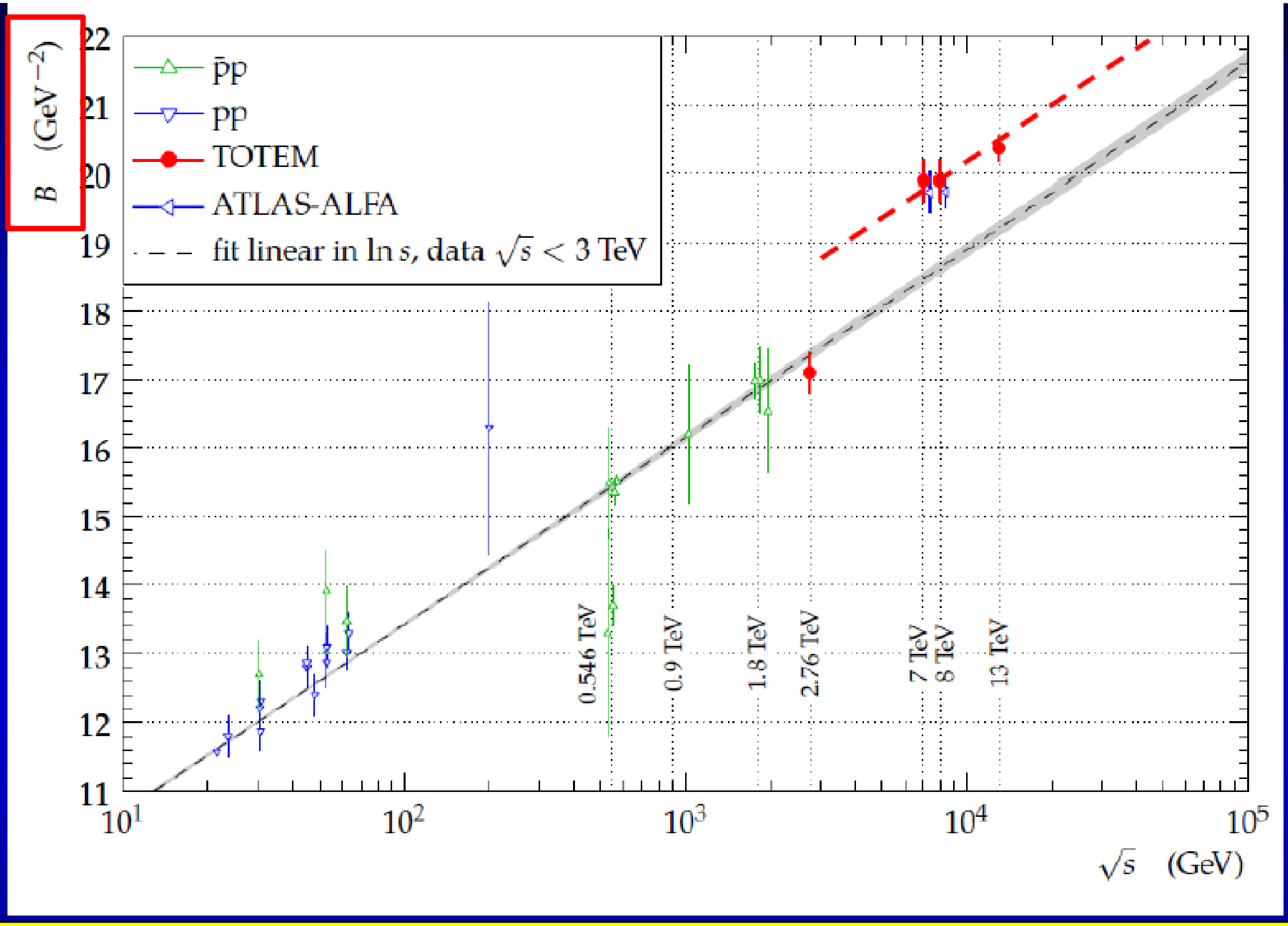
$$A(s) = B(s)\,\sigma_{el}(s) = \frac{1+\rho_0^2(s)}{16\pi}\,\sigma_{tot}^2(s),$$

Method 2: OP2 from $B_0(s)$ and $\sigma_{el}(s)$



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

Method 2: OP2 from $B_0(s)$ and $\sigma_{el}(s)$



TOTEM trend of $B_0(s) = B(s)$ from EPJ Web Conf. 206 (2019) 06004 and the trend of $\sigma_{el}(s)$ from *Eur.Phys.J.C* 79 (2019) 2, 103, yielding OP2

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

Method 3: OP3 from pp H(x) scaling

Method 3:
H(x) ~ exp(-x) ~ 1-x at small x, energy independently,
both in pp and in pbarp

→ OP3(s_1) from H(x) scaling and OP(s_2) measurements:
3a, 3b, 3c: OP(s_2) measured at 2.76 TeV, 7 TeV and 8 TeV

See also eq. (67) of
Eur.Phys.J.C 81 (2021) 2, 180, arXiv: 1912.11968 [hep-ph]

Note: at the OPs, $t_2 = t_1 = 0$, OP scales to OP

$$\left.\frac{d\sigma}{dt}\right|_{t_1} = \frac{B_1\sigma_1}{B_2\sigma_2}\left.\frac{d\sigma}{dt}\right|_{t_2=t_1 B_1/B_2}$$

See further details in A. Ster’s talk

EFFECT OF SAME OPTICAL POINT

OP3,d: H(x|pp) = H(x|pbar) valid at small x

Pomeranchuk's Theorem:
Based on asymptotic equality
f(x) ~ g(x) **IF** $\lim_{x \to \infty} f(x)/g(x) = 1$
Does NOT imply that $\lim_{x \to \infty} f(x) - g(x) = 0$
Ratio is equal to 1 but the difference is not zero…

Consequently
OP(s|pp) ~ OP(s|pbarp)
Does NOT imply that
$\lim_{s \to \infty}$ OP(s|pp) = OP(s|pbarp)
but the difference does not tend to 0

Significance in on all 17 D0 points:
$\varepsilon_C = 0.83$ fixed chi2/ndf = 153/17 CL = 5.0e-18%
significance of Odderon exchange
on all the 17 D0 points = 9.16 σ

Significance on selected 8 D0 points:
$\varepsilon_C = 0.83$ fixed chi2/ndf = 60.3/8 CL = 4.1e-8%
significance of Odderon exchange
on the selected 8 D0 points = 6.25 σ

Model-independently: By minimizing H(x,s) differences
for pp and pbarp at the first 3 D0 points
increases singificance from 6.26 σ to 9.15 σ artificially, then
selecting 8 D0 points reduces
statistical significance to 6.25 σ : almost fully compensating errors

Methods 5, 6 and 7: OP-s from models

5) ReBB model calculation → OP4

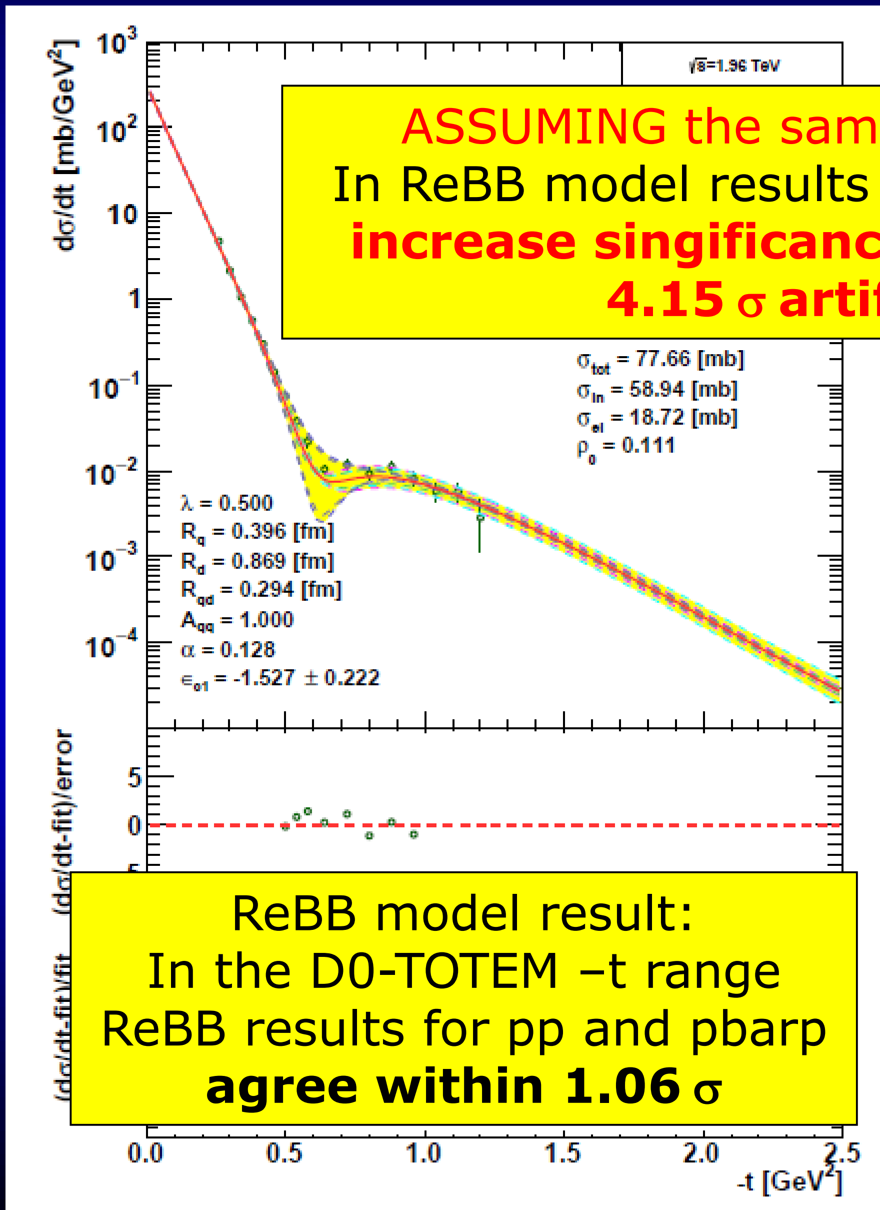
6) H(x) scaling limit of ReBB model calculation → OP5

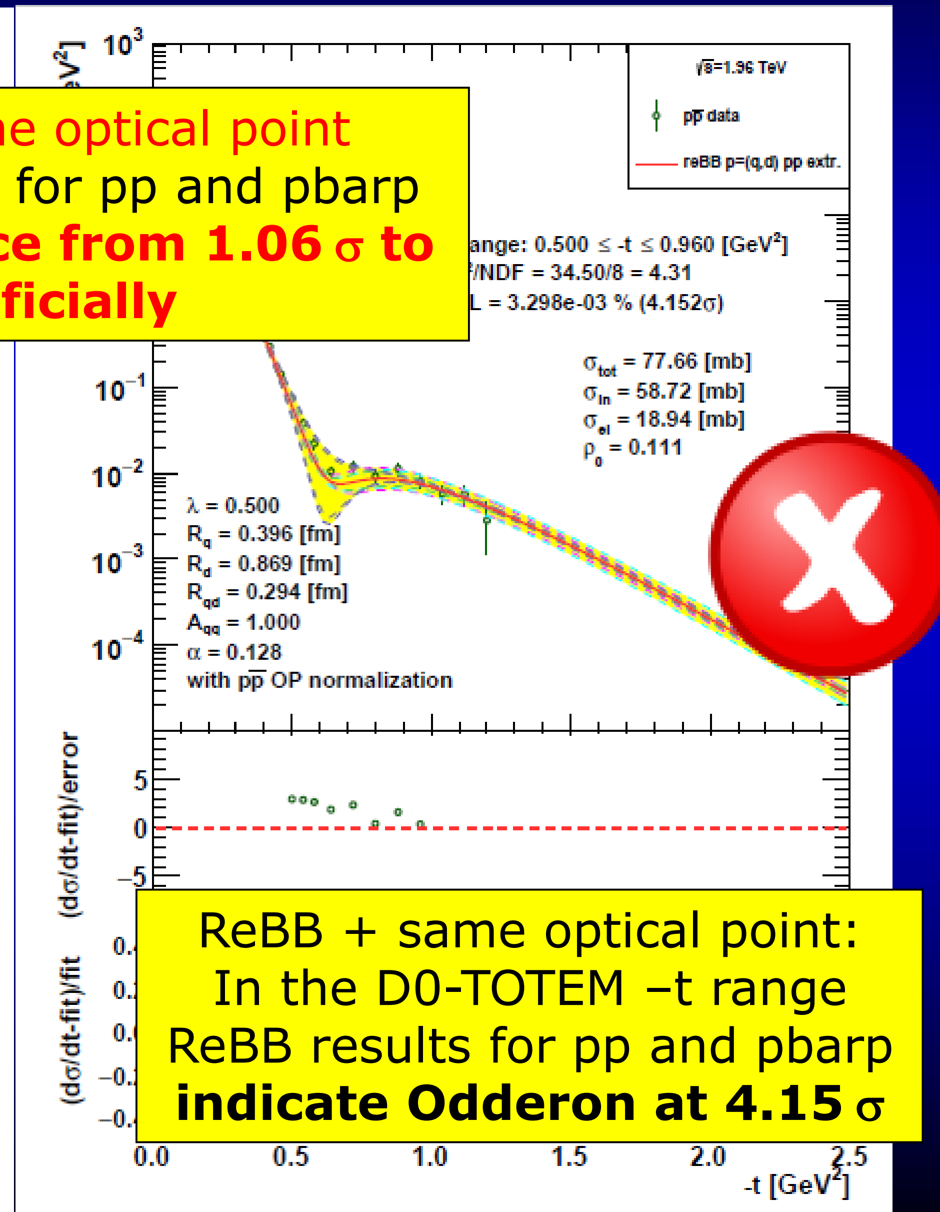
7) Pomeron-Odderon Regge model → OP6 = A(s)

See the details in I. Szanyi's talk

TESTING SAME OPTICAL POINT

Method 5: MODEL DEPENDENT RESULTS





ASSUMING the same optical point
In ReBB model results for pp and pbarp
increase singificance from 1.06 σ to 4.15 σ artificially

ReBB model result:
In the D0-TOTEM –t range
ReBB results for pp and pbarp
agree within 1.06 σ

ReBB + same optical point:
In the D0-TOTEM –t range
ReBB results for pp and pbarp
indicate Odderon at 4.15 σ

SUMMARY

Odderon first discovered in three papers.
All the three published by now, but
under three different conditions,
that are now being tested.

(S,C) structure evident,
S: statement, valid if
C: condition is satisfied
Importantly: Odderon is **seen in three different analysis with statistical significance > 5 σ**

C: conditions and assumptions are now being tested
New results for the assumption on the same optical point in pp and pbarp
Two of D0-TOTEM assumptions are tested, both in the model independent and in the model dependent analysis.
This assumption is may or may not be safe, has to be tested: 7 new methods
OP equality was assumed neither in the H(x) scaling analysis nor in the ReBB model analysis for Odderon discovery.

Thank you for your attention!