Observation of Odderon Exchange at TeV Energies

based on Real extensions of the Bialas – Bzdak (ReBB) model

T. Csörgő [1,2]

[1] Wigner RCP, Budapest, Hungary
[2] MATE KRC, Gyöngyös, Hungary

Timeline
Formalism of elastic scattering
Discoveries of Odderon exchange
Model-independent
ReBB model dependent

H(x): Generalized Geometric Scaling
Derivations of H(x) scaling
Model independently
In the ReBB model and
why it works at LHC energies

Summary

TIMELINE

1986-1988: INTERMITTENCY

Moments of Rapidity Distributions as a Measure of Short Range Fluctuations in High-Energy Collisions

#2

A. Bialas (Orsay, LPT and Jagiellonian U.), Robert B. Peschanski (Saclay) (Sep, 1985)

Published in: *Nucl.Phys.B* 273 (1986) 703-718

ELSEVIER

Nuclear Physics B

Volume 273, Issues 3–4, 1 September 1986, Pages 703-718

Moments of rapidity distributions as a measure of short-range fluctuations in high-energy collisions

Intermittency in Multiparticle Production at High-Energy

#1

A. Bialas (Jagiellonian U.), Robert B. Peschanski (Saclay) (Mar, 1988)

Published in: *Nucl.Phys.B* 308 (1988) 857-867

Abstract

It is proposed to study the dependence of factorial moments of the rapidity distribution on the size δy of the resolution. It is shown that if the fluctuations are purely statistical no variation of moments δy is expected, and thus observation of such a variation indicates the presence of genuine fluctuations of physical origin. The region in which the change occurs corresponds to the size (in rapidity) of the observed fluctuations. Intermittency, i.e. fluctuations of many different sizes, would show up as a power-law behaviour of moments on δy. A good experimental resolution can be obtained from the rapidity distribution of high multiplicity events.

Nuclear Physics B

ume 308, Issue 4, 24 October 1988, Pages 857-867

The physics of hadrons

Intermittency in multiparticle production at high energy ☆

A. Bialas, R. Peschanski

Abstract

We present predictions of random cascading models for multiparticle production at high energy. Standard and correlated factorial moments in rapidity are shown to provide stringent tests of the intermittency patterns characteristic of random cascades. Using the central limit theorem we show how to test directly for the existence of a cascading process. Finally, we discuss how to take into account statistical corrections.

1992 - 2004: INTERMITTENCY & HBT EFFECT

Vol. 23(1992) ACTA PHYSICA POLONICA B

INTERMITTENCY AND THE HANBURY-BROWN–TWISS EFFECT

A. Bialas

Institute of Physics, Jagellonian University
Reymonta 4, 30-059 Cracow, Poland

(Received April 15, 1992)

Dedicated to Wiesław Czyż in honour of his 65th birthd

Relation of the intermittency phenomenon observed in spec ticles produced in high-energy collisions to the intensity corre tween identical particles is discussed. It is argued that the co of the two effects requires scale-invariant (power law) fluctuat size of the interaction region.

Intermittency and the Hanbury-Brown-Twiss effect

A. Bialas (Jagiellonian U.) (Apr, 1992)

Published in: *Acta Phys.Polon.B* 23 (1992) 561-567

Bose-Einstein correlations for Levy stable source distributions #4

T. Csorgo (Budapest, RMKI), S. Hegyi (Budapest, RMKI), W.A. Zajc (Columbia U.) (Oct, 2003)

Published in: *Eur.Phys.J.C* 36 (2004) 67-78 • e-Print: nucl-th/0310042 [nucl-th]

Eur. Phys. J. C 36, 67–78 (2004)
Digital Object Identifier (DOI) 10.1140/epjc/s2004-01870-9

THE EUROPEAN PHYSICAL JOURNAL C

Bose–Einstein correlations for Lévy stable source distributions

T. Csörgő[1,a], S. Hegyi[1,b], W.A. Zajc[2,c]

[1] KFKI RMKI, 1525 Budapest 114, POB 49, Hungary
[2] Dept. Physics, Columbia University, 538 W 120th St, NY 10027 New York, USA

Received: 19 November 2003 / Revised version: 27 April 2004 /
Published online: 23 June 2004 –

Abstract. The peak of the two-particle Bose–Einstein correlation functions has a very interesting structure. It is often believed to have a multivariate Gaussian form. We show here that for the class of stable distributions, characterized by the index of stability $0 < \alpha \leq 2$, the peak has a stretched exponential shape. The Gaussian form corresponds then to the special case of $\alpha = 2$. We give examples for the Bose–Einstein correlation functions for univariate as well as multivariate stable distributions, and we check the model against two-particle correlation data.

2006: BIALAS-BZDAK MODEL FOR ELASTIC PP

Constituent quark and diquark properties from small angle proton-proton elastic scattering at high energies

A. Bialas (Jagiellonian U.), A. Bzdak (Jagiellonian U.) (Dec, 2006)

Published in: *Acta Phys.Polon.B* 38 (2007) 159-168 • e-Print: hep-ph/0612038 [hep-ph]

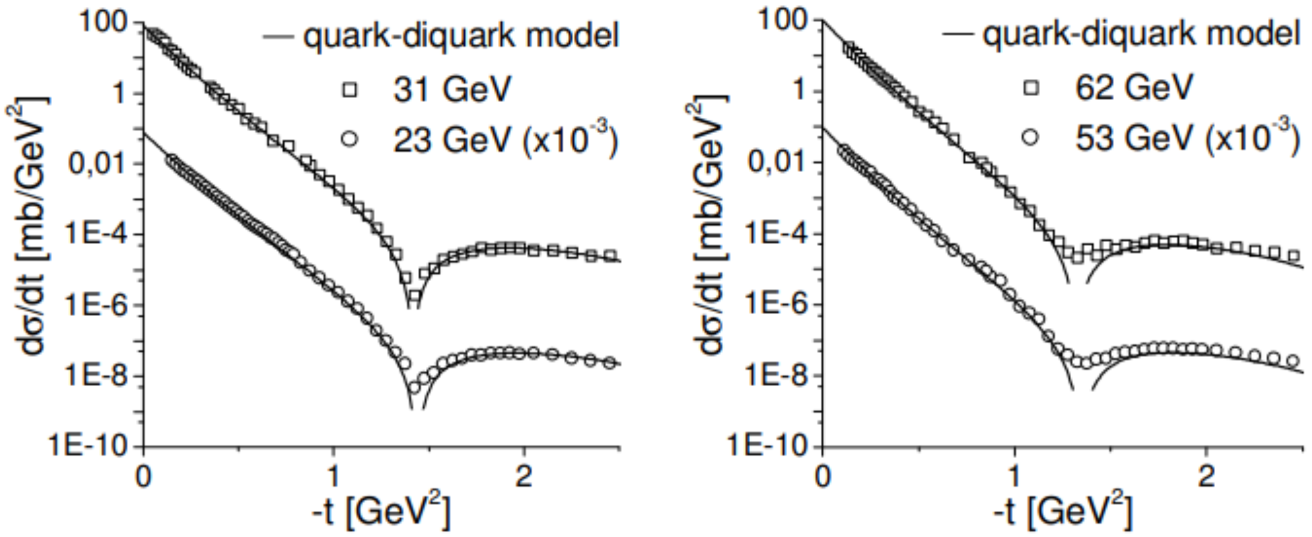


Fig. 3. The quark–diquark model compared to data on differential cross section at four energies. Diquark as a qq system.

Singularity of BB at the dip
→ Add real part to fix it.

2. Low momentum transfer elastic scattering in the quark–diquark model

We follow the standard point of view that the imaginary part of the elastic scattering amplitude, dominating at high energy, is generated by the absorption of the incident particle wave, represented by the inelastic (non-diffractive) collisions. The inelastic proton–proton cross-section at a fixed impact parameter b, $\sigma(b)$, is calculated using the rules of the probability calculus. One writes

$$\sigma(b) = \int d^2s_q d^2s'_q d^2s_d d^2s'_d D(s_q,s_d)D(s'_q,s'_d)\sigma(s_q,s_d;s'_q,s'_d;b)\,, \qquad (1)$$

where $D(s_q,s_d)$ denotes the distribution of quark and diquark inside the nucleon, $s_q(s'_q)$, $s_d(s'_d)$ are transverse positions of the quarks and diquarks in the two colliding nucleons, and $\sigma(s_q,s_d;s'_q,s'_d;b)$ is the probability of interaction at fixed impact parameter and the transverse positions of all constituents taking part in the process. This configuration is illustrated in Fig. 1. Since the constituents act independently we have [11, 12]:

$$\begin{aligned} 1-\sigma(s_q,s_d;s'_q,s'_d;b) &= [1-\sigma_{qq}(b+s'_q-s_q)][1-\sigma_{qd}(b+s'_d-s_q)] \\ &\times[1-\sigma_{dq}(b+s'_q-s_d)][1-\sigma_{dd}(b+s'_d-s_d)]\,, \qquad (2)\end{aligned}$$

where $\sigma_{ab}(s) \equiv d^2\sigma_{ab}(s)/d^2s$ are inelastic differential cross-sections of the constituents (ab denotes qq, qd or dd).

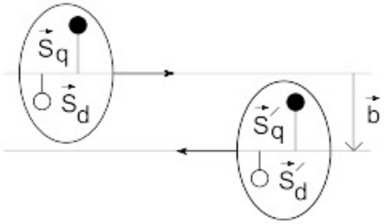


Fig. 1. Proton–proton scattering in the quark–diquark model.

For the distribution of the constituents inside the nucleon we take a Gaussian with radius R:

2015: BIALAS-BZDAK MODEL REAL EXTENSION

Excitation function of elastic pp scattering f

F. Nemes (CERN and Wigner RCP, Budapest), T. Csörgő (
2015)

Published in: *Int.J.Mod.Phys.A* 30 (2015) 14, 1550076 • e-

pdf DOI cite claim

The unitarity of the scattering matrix S is exp

$$SS^{\dagger} = I\,,$$

where I is the identity matrix. The decompositio
transition matrix, leads the unitarity relation Eq.

$$T - T^{\dagger} = iTT^{\dagger}\,,$$

which can be rewritten in the impact parameter b

$$2\,\mathrm{Im}\,t_{el}(s,b) = |t_{el}(s,b)|^2 + \tilde{\sigma}_i$$

We have studied several possible choices. (
the imaginary part of the opacity function so
probability of inelastic scatterings, which is kno
of the impact parameter b. A possible interpreta
that the inelastic collisions arising from non-colli
and diquarks follow the same spatial distributio
the same constituents

$$\mathrm{Im}\,\Omega(s,b) = -\alpha \cdot \tilde{\sigma}_{inel}($$

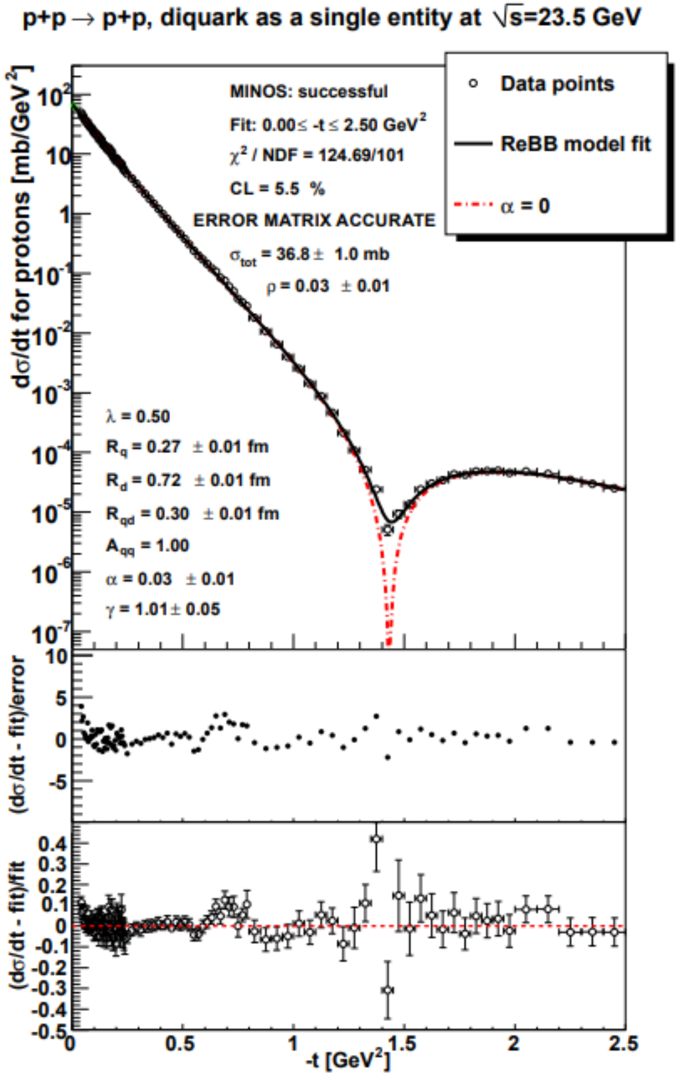


Figure 4: The fit of the ReBB model at $\sqrt{s} = 23.5$ GeV in the $0 < |t| < 2.5$ GeV^2 squared four-momentum transfer $|t|$ range. The fit uses the statistical errors of the data points and the luminosity error of the systematic uncertainty according to Eq. (32). Parameter values are rounded up to two valuable decimal digits.

Singularity of BB at the dip
Add real part to fix it.
ReBB solves three problems:
Describes dip-bump structure
Provides $\rho_0 \neq 0$
Provides Odderon

a second order polynomial equation in terms of
$_{el}(s,b)$. If one introduces the opacity or eikonal

$$) = i\left[1 - e^{-\Omega(s,b)}\right]\,, \qquad (4)$$

$$b) = 1 - e^{-2\,\mathrm{Re}\,\Omega(s,b)}\,. \qquad (5)$$

ed eikonal form. From Eqs. (5) the real part of
be expressed as

$$= -\frac{1}{2}\ln\left[1 - \tilde{\sigma}_{inel}(s,b)\right]\,. \qquad (6)$$

sumed that the real part of t_{el} vanishes. In this

$$i\left[1 - \sqrt{1 - \tilde{\sigma}_{inel}(s,b)}\right]\,. \qquad (7)$$

ken into account in Eq. (4) the result is

$$e^{-i\,\mathrm{Im}\,\Omega(s,b)}\sqrt{1 - \tilde{\sigma}_{inel}(s,b)}\right]\,, \qquad (8)$$

ion of $\mathrm{Im}\,\Omega(s,b)$ is discussed later.

ELASTIC SCATTERING

Formalism: elastic scattering

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

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

$$A(s) = \lim_{t\to 0} \frac{d\sigma}{dt}(s,t)$$

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

$$B(s,t) = \frac{d}{dt}\ln\frac{d\sigma(s)}{dt}$$

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

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

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

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

Basic problem: dσ/dt measures an amplitude, *modulus squared*.
If Odderon exists: signals in elastic scattering at t = 0 and at –t > 0.

Formalism in b space

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

$$t_{\rm el}(s,b) = \int \frac{d^2\Delta}{(2\pi)^2} e^{-i\boldsymbol{\Delta b}} T_{\rm el}(s,\Delta) =$$
$$= \frac{1}{2\pi}\int J_0(\Delta\, b)\, T_{\rm el}(s,\Delta)\,\Delta\, d\Delta\,,$$
$$\Delta \equiv |\boldsymbol{\Delta}|, \quad b \equiv |\boldsymbol{b}|.$$

$$t_{\rm el}(s,b) = i\left[1 - e^{-\Omega(s,b)}\right]$$

$$P(s,b) = 1 - \left|e^{-\Omega(s,b)}\right|^2$$

Impact parameter or b space:
elastic scattering interferes with propagation w/o collisions: Genuine quantum physics.
In general, a complex opacity function Ω(s,b) (eikonal, from unitarity)
$0 \leq P(s,b) \leq 1$: *inelastic* scattering has a probabilistic interpretation

Looking for Crossing-Odd(eron) effects

$$T_{\rm el}^{pp}(s,t) = T_{\rm el}^{+}(s,t) - T_{\rm el}^{-}(s,t),$$
$$T_{\rm el}^{p\overline{p}}(s,t) = T_{\rm el}^{+}(s,t) + T_{\rm el}^{-}(s,t),$$
$$T_{\rm el}^{+}(s,t) = T_{\rm el}^{P}(s,t) + T_{\rm el}^{f}(s,t),$$
$$T_{\rm el}^{-}(s,t) = T_{\rm el}^{O}(s,t) + T_{\rm el}^{\omega}(s,t).$$

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

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

Three simple consequences:

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

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

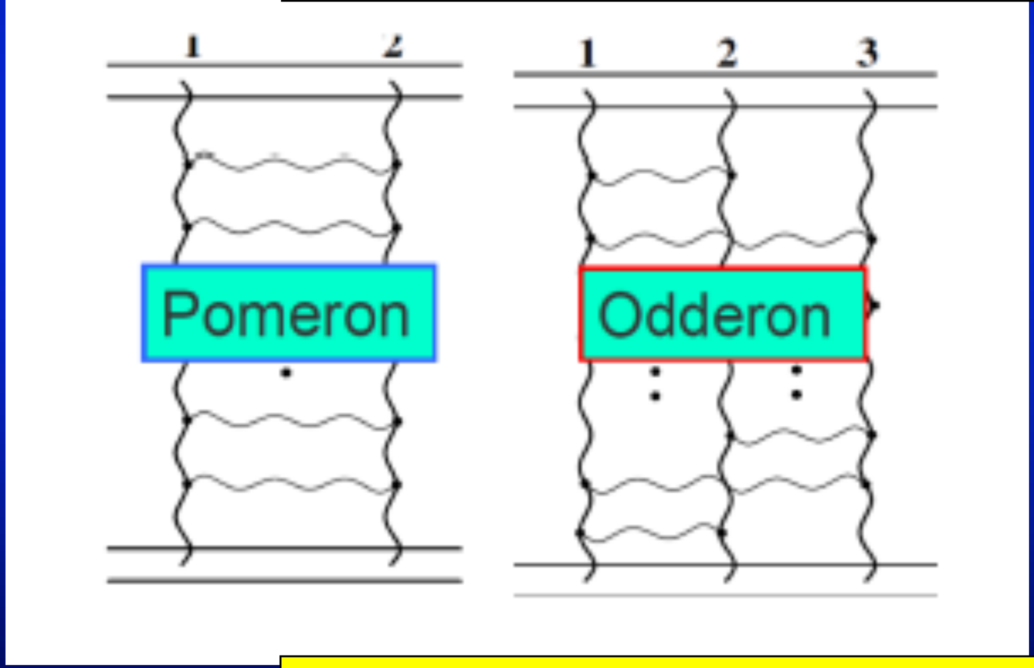
$$\frac{d\sigma^{pp}}{dt} \neq \frac{d\sigma^{p\bar{p}}}{dt} \quad \text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^{O}(s,t) \neq 0$$

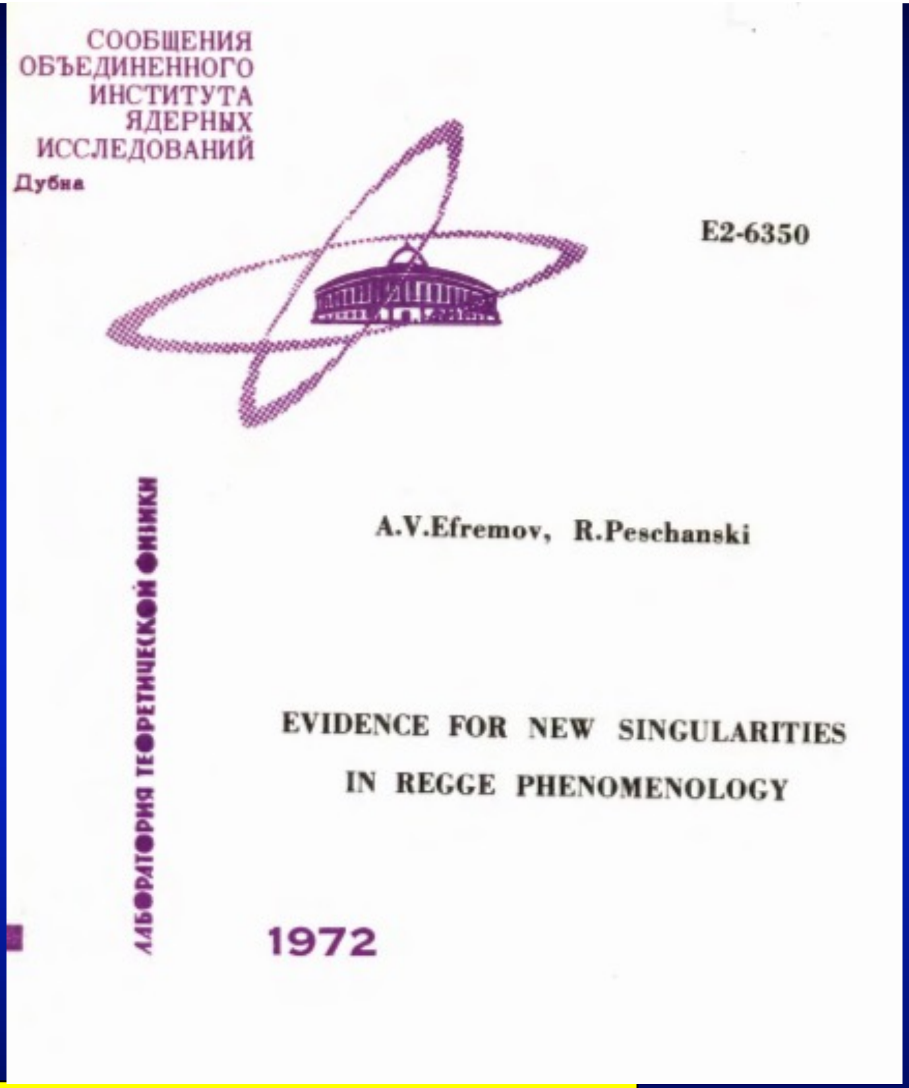
Odderon differential cross-section from pp and ppbar collisions, Reggeized Philips-Barger:
A. Ster, L. Jenkovszky, T. Cs., **arxiv:1501.03860,** *Phys.Rev.D* **91** (2015) 7, 074018

Odderon: extremely elusive, for 48 years

Odderon: L. Lukaszuk, B. Nicolescu, Lett. Nuovo Cim. 8, 405 (1973)
Received: **31 July 1973**

Odderon is an odd component of elastic scattering:
Changes sign for crossing





Odderon name coined: D. Joynson, E. Leader, B. Nicolescu, C. Lopez, Nuovo Cim. 30A, 345 (1975) - Well established in QCD by now !
Honorable mention: A. V. Efremov, R. Peschanski, JINR-E2-6350 (1972)

Odderon: well established in QCD

Odderon proposed in Regge phenomenology:
L. Lukaszuk, B. Nicolescu, Lett. Nuovo Cim. 8, 405 (1973)

Three Gluon Integral Equation and Odd c Singlet Regge Singularities in QCD
BKP evolution equation
J. Bartels, Nucl. Phys. B 175 (1980) 365-401
J. Kwiecinski, M. Praszalowicz, Phys.Lett.B 94 (1980) 413-416

A new Odderon intercept from QCD:
R. A. Janik, J. Wosiek, Phys. Rev. Lett. 82 (1999) 1092

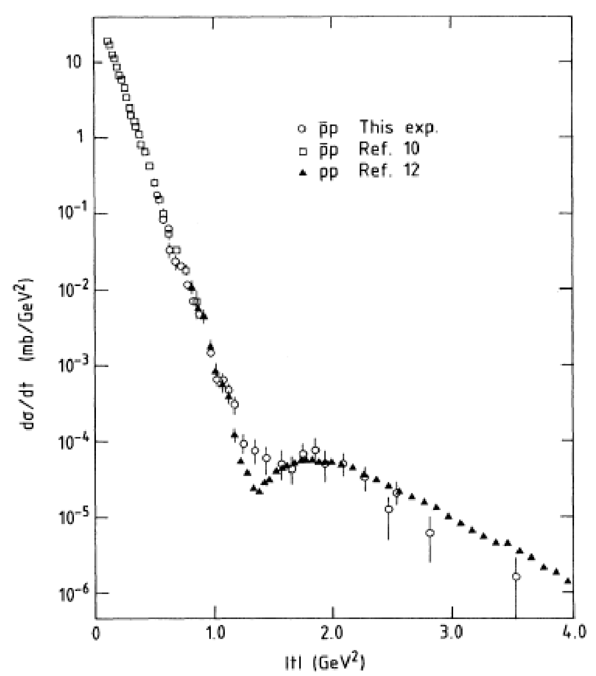
Odderon in QCD:
J. Bartels, L.N. Lipatov, G. P. Vacca: Phys. Lett. B (2000) 178

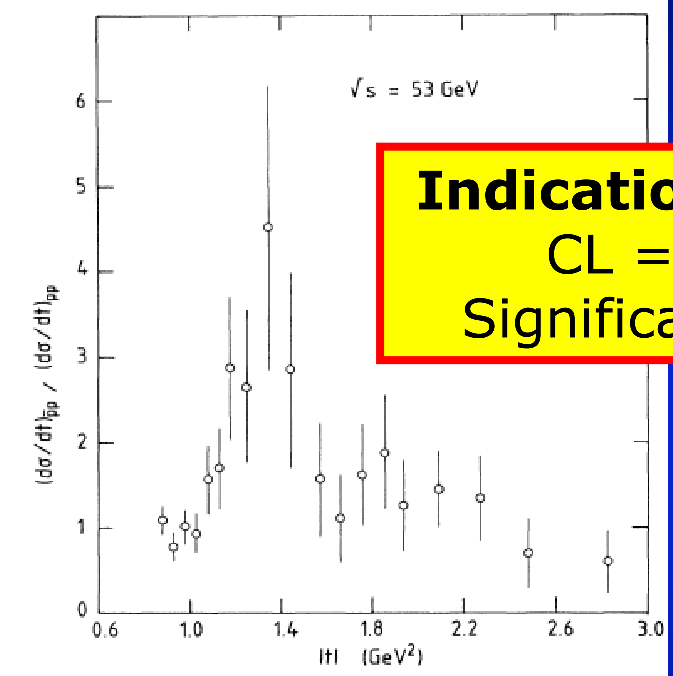
Odderon in QCD with running coupling:
J. Bartels, C. Contreras, G. P. Vacca, *JHEP* 04 (2020) 183

For an excellent theory intro/review, see Yu. Kovchegov's
CTEQ Webinar, April 28, 2021
http://youtu.be/yHBO3zcB3V4

Odderon: elusive experimentally

Odderon search at ISR: indication but no conclusive result
Breakstone et al, Phys. Rev. Lett. 54, 2180 (**1985**): CL = 99.9 %





Indication of Odderon
CL = 99.9 %,
Significance: 3.35 σ

Terminology for **this** talk:
Agreement if statistical significance is < **3** σ
Indication of signal if **3** $\sigma \leq$ significance < **5** σ
Evidence or observation of signal if **5** $\sigma \leq$ significance
Discovery of signal if **5** $\sigma \leq$ significance, **for the first time**.
Accepted: Discovery if Clay Mathematical Institute (CMI) criteria satisfied.
Miscovery if CMI criteria for Millenium Prize Problems are **not** satisfied.

A. STER, L. JENKOVSZKY, T. Cs. (PRD 2015): PREDICTION OF ODDERON DISCOVERY AT LHC

PHYSICAL REVIEW D **91,** 074018 (2015)

Extracting the Odderon from *pp* a

András Ster*
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László Jenkovszk
BITP, National Academy of Sciences of Ukr
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Tamás Csörgő‡
Wigner Research Centre for Physics, Hunga
H-1525 Budapest 114, P.O. Bo
and KRF, H-3200 Gyöngyös, Mátr

(Received 15 January 2015; publish

Starting from a simple empirical parametrization of the scatt
dip-bump structure of elastic *pp* scattering in *t* at fixed values
between missing energy intervals to extract the Odderon contri
pp elastic and total cross sections. The model is fitted to data
extract the Odderon and its ratio to the Pomeron. From o
as predicted by J. Bartels, L. N. Lipatov, and G. P. Vacc
chromodynamics.

DOI: 10.1103/PhysRevD.91.074018

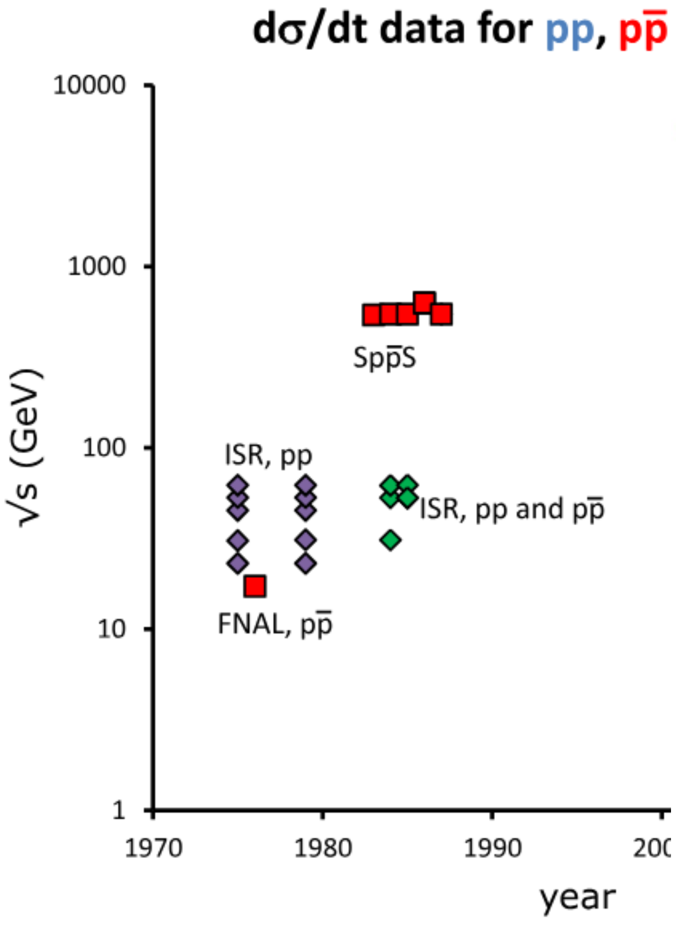


FIG. 1 (color online). Timeline of protoi
scattering measurements. New accelerat
maximum available energies; however, at
accelerator, the pp and the $p\bar{p}$ elastic scattering data were
measured at the same $\sqrt{s} = 31$, 53, and 62 GeV.

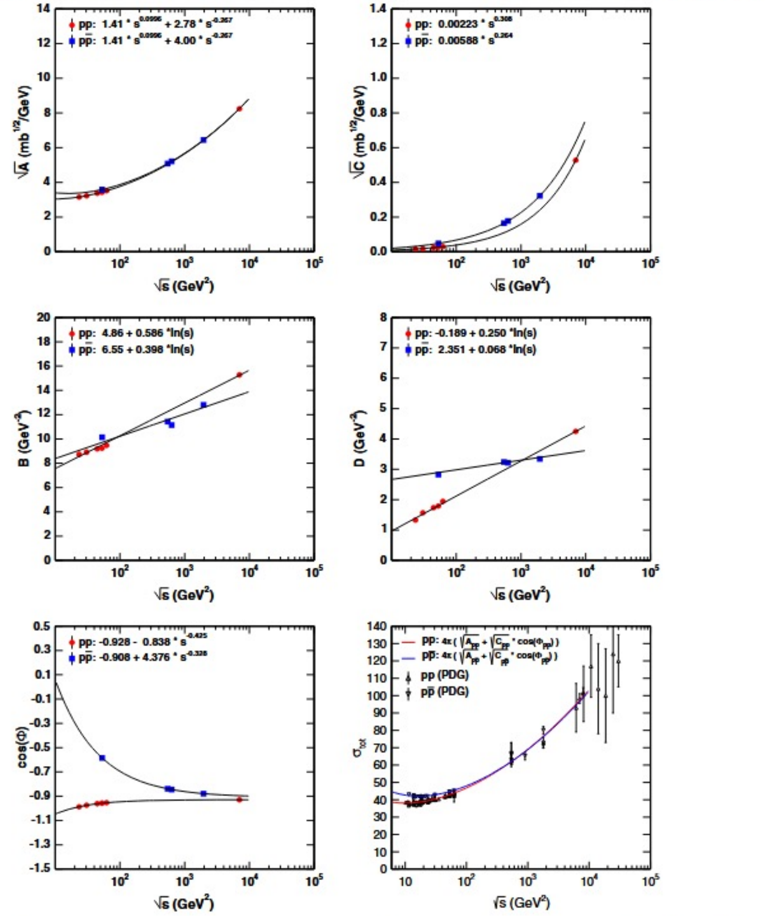


FIG. 4 (color online). Energy-dependent values of the parameters from a fit to pp and $p\bar{p}$ data, constrained by $\sigma_t^{p\bar{p}} = \sigma_t^{pp}$ as $\sqrt{s} \to \infty$. The lowest right icon shows a cross-check for the (asymptotically converting) total cross sections.

Odderon search with scaling: a possible strategy

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

In the TeV energy range:
Odderon is equivalent with
a crossing-odd component
Look for violations of C-symmetry

DISCOVERY: ODDERON EXCHANGE

Odderon: first observation with > 5 σ

EPJ Web of Conf. (2020) **235**: 06005
https://doi.org/10.1051/epjconf/202023506002

Proton Holography -- Discovering Odderon from Scaling Properties of Elastic Scattering #4

T. Csorgo (Wigner RCP, Budapest and Eszterhazy Karoly U., Eger), T. Novak (EKU KRC, Gyongyos), R. Pasechnik (Lund U. and Rez, Nucl. Phys. Inst.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest and Eotvos U.) (Apr 15, 2020)

Published in: *EPJ Web Conf.* 235 (2020) 06002 • Contribution to: ISMD 2019 • e-Print: 2004.07095 [hep-ph]

First publication of an at least 5.0 σ (6.26 σ) Odderon exchange effect:
published on **May 11, 2020**,
EPJ Web of Conf. 235 (2020) 06002
in an **anonymously** **refereed / peer reviewed** conference proceedigs.
(Proc. ISMD 2019, Santa Fe, USA)

BUT: „*Never be the first! It is too early!*"
P. Carruthers ~ 1990

First journal publications, Odderon > 5 σ

Evidence of Odderon-exchange from scaling properties of elastic scattering at TeV energies #5

T. Csörgő (Wigner RCP, Budapest and CERN), T. Novak (Unlisted, HU), R. Pasechnik (Lund U., Dept. Theor. Phys.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest) (Dec 26, 2019)

Published in: *Eur.Phys.J.C* 81 (2021) 2, 180 • e-Print: 1912.11968 [hep-ph]

Online attention

- 26 tweeters
- 15 news outlets
- 3 Mendeley
- 4 blogs
- 4 Wikipedia page
- 2 Facebook pages

This article is in the 98th percentile (ranked 6,037th) of the 428,075 tracked articles of a similar age in all journals and the 99th percentile (ranked 1st) of the 231 tracked articles of a similar age in *The European Physical Journal C*

Hungarian-Swedish team:
Eur. Phys. J. C (2021) **81**: 180, Published: 23 February 2021
https://doi.org/10.1140/epjc/s10052-021-08867-6

Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study #2

T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]

Hungarian team, Real Extended Bialas-Bzdak model:
Eur. Phys. J. C (2021) **81**:611 , Published: 13 July 2021
https://doi.org/10.1140/epjc/s10052-021-09381-5

Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements

TOTEM and D0 Collaborations • V.M. Abazov (Dubna, JINR) et al. (Dec 7, 2020)

Published in: *Phys.Rev.Lett.* 127 (2021) 6, 062003 • e-Print: 2012.03981 [hep-ex]

SUMMARY | News | Blogs | Twitter | Wikipedia | Dimensions citations

Title	Odderon Exchange from Elastic Scattering Differences between pp and pp̄ Data at 1.96 TeV and from pp Forward Sc Measurements
Published in	Physical Review Letters, August 2021
DOI	10.1103/physrevlett.127.062003
Pubmed ID	34420329
Authors	V. M. Abazov, B. Abbott, B. S. Acharya, M. Adams, T. Adams, J. P. Agnew, G. D. Alexeev, G. Alkhazov... [show]

TWITTER DEMOGRAPHICS MENDELEY READERS

Defense of this D0-TOTEM paper is in progress

D0 and TOTEM Collaborations:
Phys. Rev. Lett. **127** (2021) 6, 062003, Published: 4 August 2021
https://doi.org/10.1103/PhysRevLett.127.062003

2022 observations of Odderon with > 5 σ

Characterisation of the dip-bump structure observed in proton–proton elastic scattering at $\sqrt{s}$ = 8 TeV #1

TOTEM Collaboration • G. Antchev (Pilsen U.) et al. (Nov 23, 2021)

Published in: *Eur.Phys.J.C* 82 (2022) 3, 263 • e-Print: 2111.11991 [hep-ex]

Online attention

1

1 tweeters

This article is in the 1st percentile (ranked 279,419th) of the 343,918 tracked articles of a similar age in all journals and the 1st percentile (ranked 73rd) of the 114 tracked articles of a similar age in *The European Physical Journal C*

TOTEM Collaboration:
8 TeV: EPJ C (2022) 82, 263 (2022). Published: March 26, 2022
https://doi.org/10.1140/epjc/s10052-022-10065-x
Publishes final data for D0-TOTEM PRL published in 2021

The ReBB model and its H(x) scaling version at 8 TeV: Odderon exchange is a certainty #1

I. Szanyi (Eotvos U. and Wigner RCP, Budapest and Karoly Robert U. Coll.), T. Csörgő (Wigner RCP, Budapest and Karoly Robert U. Coll.) (Apr 21, 2022)

Published in: *Eur.Phys.J.C* 82 (2022) 9, 827, *Eur.Phys.J.C* 82 (2022) 827 • e-Print: 2204.10094 [hep-ph]

Online attention

3

1 Wikipedia page

This article is in the 64th percentile (ranked 57,525th) of the 166,532 tracked articles of a similar age in all journals and the 99th percentile (ranked 1st) of the 1 tracked articles of a similar age in *The European Physical Journal C*

Hungarian team, using the Real extended Bialas-Bzdak (ReBB) model:
New TOTEM 8 TeV data vs ReBB model predictions:
EPJ C 82 (2022) 9, 827. Published: Sept 19, 2022
In the ReBB model, Odderon exchange is a certainty-

What about model independent results?
→ See some of the backup slides

Three Oldest Hungarian Universities

UP Story - 650 years

Home » University » UP Story 650 years

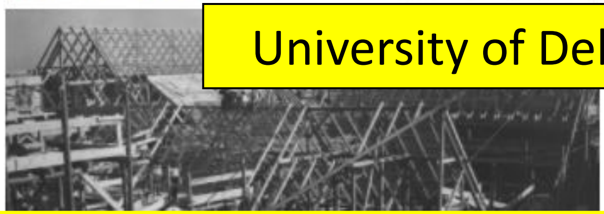
University of Pécs: 1367

The history of higher education in Pécs dates back to 1367, when Louis th…
…e episcopal city of Pécs. As a result of an integration proc…
…d, which has become one of the most famous, prestigiou…
…on. It has ten faculties which cover the full spectrum of h…

1367

University of Pécs:
S: Oldest, C: in Hungary

The University o… …nstitution of higher education in the country operated continuously in the same city, is one of the research universities of na… …gary offering the widest spectrum of educational programs in 14 faculties and 24 doctoral schools.



…tion
…rian
education and cu… …vell,
the *gerundium*, … …ires,
showing respect…

University of Debrecen: 153…

University of Debrecen:
S: Oldest, C: in Hungary,
operating continuously and in the *same city*

(S,C) structure evident,
S: statement, valid if
C: condition is satisfied
See talk of R. Dardashti at ISMD21
Condition changes → Statement changes (!!)

Eötvös Loránd University: 1635

Eötvös University:
S: Oldest, C: in Hungary,
teaching continuously

…in Nagyszombat in 1635 (sixteen thirty-five) by Archbishop of Esztergom, Péter Pázmány, and it is the oldest Hungarian university where the teaching has continued uninterrupted since its inception. More than sixty years

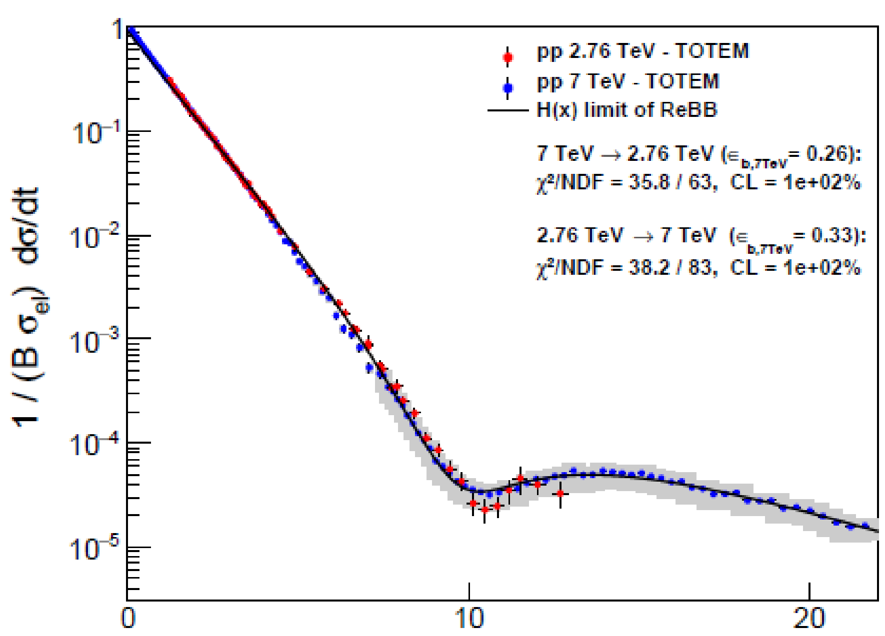
Model independent H(x|pp) scaling yields Odderon > 6.26 σ

Evidence of Odderon-exchange from scaling properties of elastic scattering at TeV energies #5

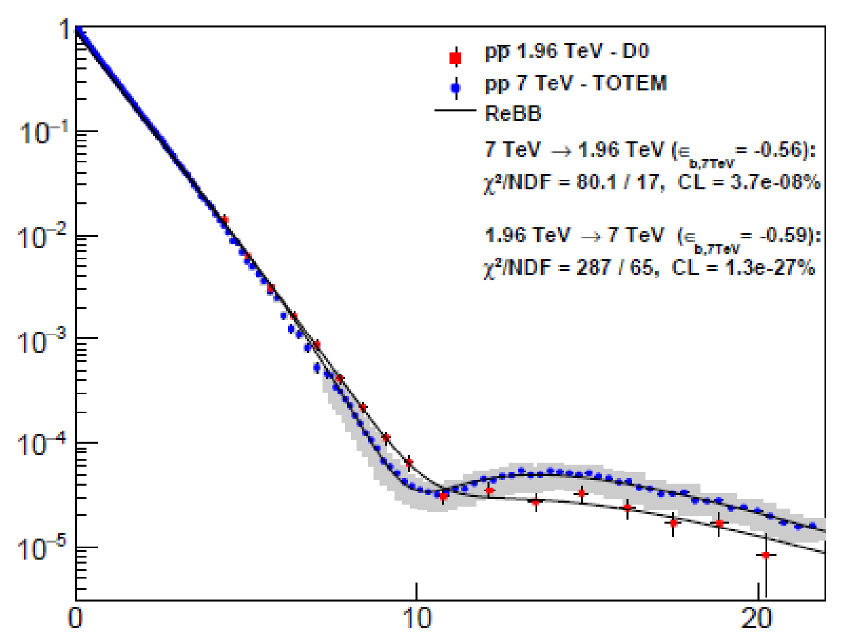
T. Csörgő (Wigner RCP, Budapest and CERN), T. Novak (Unlisted, HU), R. Pasechnik (Lund U., Dept. Theor. Phys.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest) (Dec 26, 2019)

Published in: *Eur.Phys.J.C* 81 (2021) 2, 180 • e-Print: 1912.11968 [hep-

Eur. Phys. J. C (2021) **81**: 180, published February 2021
https://doi.org/10.1140/epjc/s10052-021-08867-6



H(x) = 1/(B σ_el) dσ/dt vs x = - B t



$B \equiv B_0(s)$ from now on

$x = - B\, t = - B_0(s)\, t$

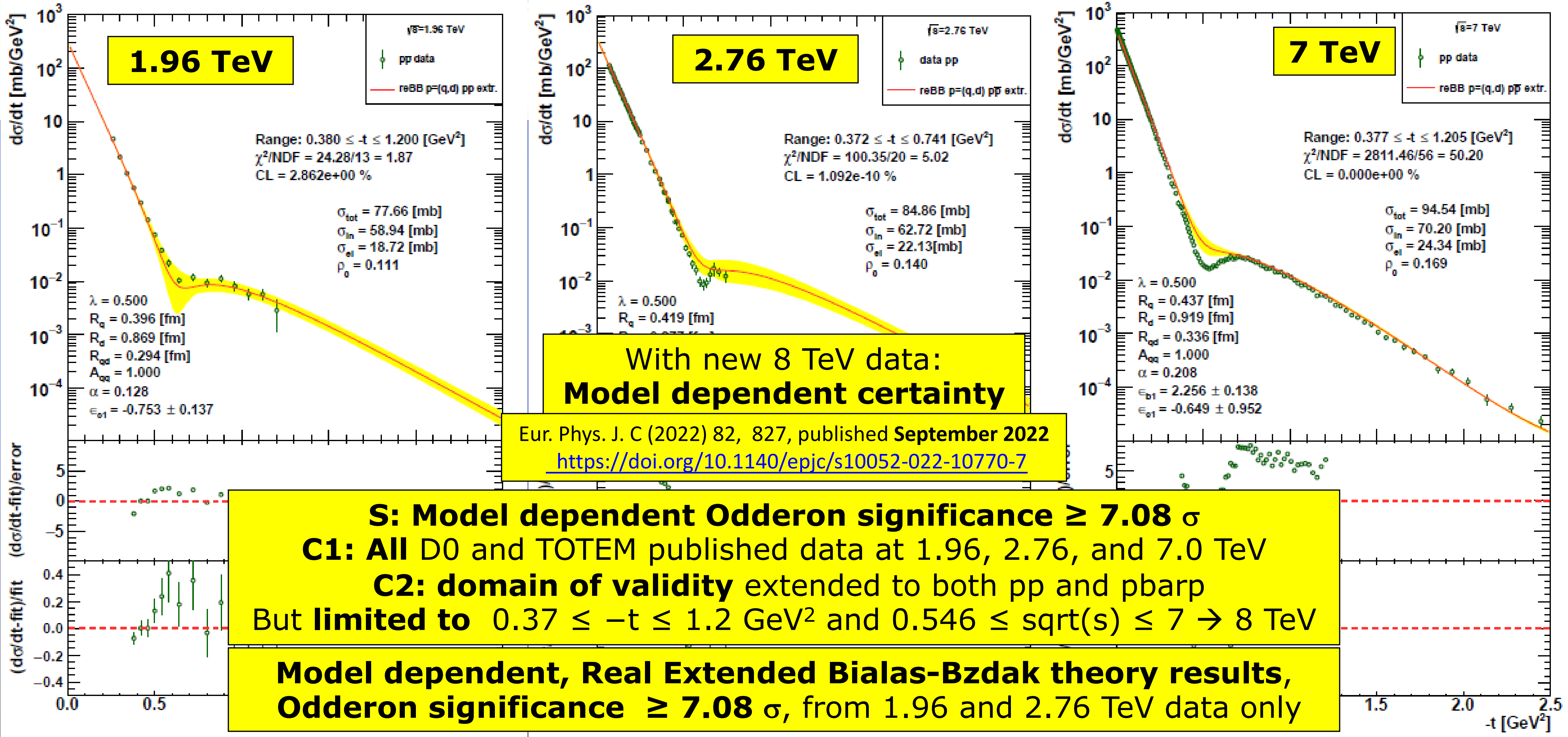
S: Model independent Odderon significance ≥ 6.26 σ
C1: All D0 and TOTEM published data at 1.96, 2.76 and 7.0 TeV
C2: domain of validity is still determined **model dependently**.

REAL EXTENDED BIALAS-BZDAK AND MINIMAL ODDERON MODELS

Real Extended Bialas-Bzdak: dip fits, Odderon > 7.08 σ

Observation of Odderon Effects at LHC energies -- A Real Extended Bialas-Bzdak Model Study

Eur. Phys. J. C (2021) **81**:611, published July 2021
https://doi.org/10.1140/epjc/s10052-021-09381-5



With new 8 TeV data:
Model dependent certainty

Eur. Phys. J. C (2022) 82, 827, published **September 2022**
https://doi.org/10.1140/epjc/s10052-022-10770-7

S: Model dependent Odderon significance ≥ 7.08 σ
C1: All D0 and TOTEM published data at 1.96, 2.76, and 7.0 TeV
C2: domain of validity extended to both pp and pbarp
But **limited to** $0.37 \le -t \le 1.2$ GeV² and $0.546 \le \sqrt{s} \le 7 \to 8$ TeV

Model dependent, Real Extended Bialas-Bzdak theory results,
Odderon significance ≥ 7.08 σ, from 1.96 and 2.76 TeV data only

Real Extended Bialas-Bzdak Model for Odderon

Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study #4

T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]

Structure:

Introduction,

Fits with CL > 0.1 % to published pp and pbarp data function

In the dip/bump region (large –t fits)

Linear excitation functi

Sanity tests: V

Extrapolations bo

Odderon significance fr

From combined 1.9

Odderon seen at 7.08 σ

Cross-checks (quadratic trend, ISR data)

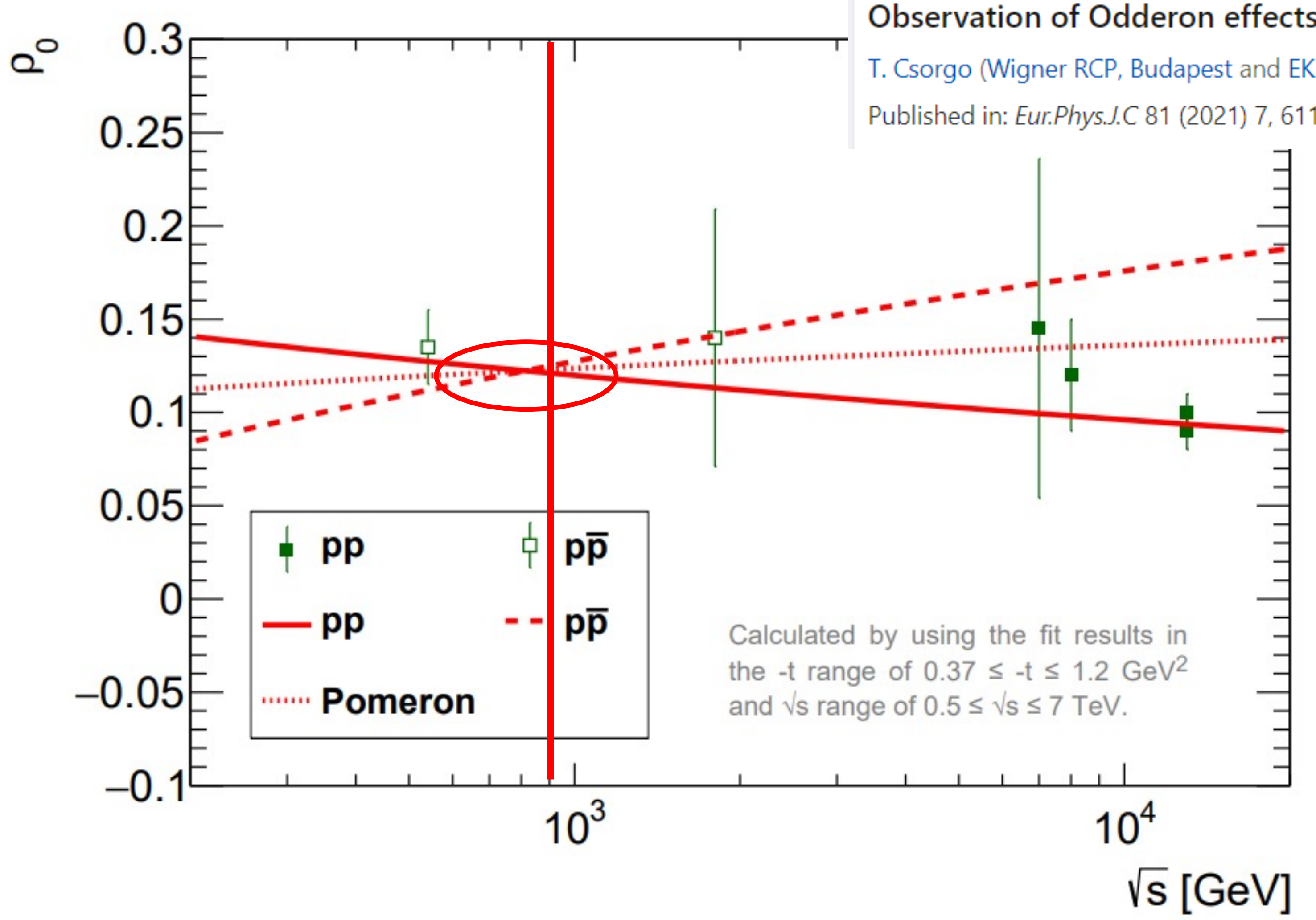
The ReBB model and its H(x) scaling version at 8 TeV: Odderon exchange is a certainty #4

I. Szanyi (Eotvos U. and Wigner RCP, Budapest and Karoly Robert U. Coll.), T. Csörgő (Wigner RCP, Budapest and Karoly Robert U. Coll.) (Apr 21, 2022)

Published in: *Eur.Phys.J.C* 82 (2022) 9, 827, *Eur.Phys.J.C* 82 (2022) 827 • e-Print: 2204.10094 [hep-ph]

82 pages, 31 figures, model dependent Odderon significance ≥ 7.08 σ,
If 8 TeV TOTEM data are added: significance more than 30 σ

ρ_0 from ReBB fits to data – Bonus 2



Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study

T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]

$$\rho_0^{pp}(s) \neq \rho_0^{p\bar{p}}(s),$$

except at √s ~ 0.9 TeV

ReBB fits: R_q, R_d, R_{qd} is the same in pp and pbarp, but $\rho(s)$ is not !
ReBB predicts: at √s ~ 0.9 TeV, $\rho(s)$ is the same in pp and pbarb !

Minimal Odderon Model (MOM) and H(x) scaling in ReBB

$$t_{el}(s,b) = i\left[1 - e^{-\Omega(s,b)}\right],$$

$$P(s,b) = 1 - |\exp(-\Omega)|^2 = \tilde{\sigma}_{in}(s,b),$$

$$\mathrm{Re}\,\Omega(s,b) = -\frac{1}{2}\ln\left[1 - \tilde{\sigma}_{in}(s,b)\right].$$

$$\mathrm{Im}\,\Omega(s,b) = -\alpha \cdot \tilde{\sigma}_{in}(s,b),$$

$$t_{el}(s,b) = i\left(1 - e^{i\,\alpha\,\tilde{\sigma}_{in}(s,b)}\sqrt{1 - \tilde{\sigma}_{in}(s,b)}\right).$$

Excitation function of elastic pp scattering from a unitarily extended Bialas–Bzdak model

F. Nemes (CERN and Wigner RCP, Budapest), T. Csörgő (Wigner RCP, Budapest and Unlisted, HU), M. Csanád (Eotvos U.) (Apr 16, 2015)

Published in: *Int.J.Mod.Phys.A* 30 (2015) 14, 1550076 • e-Print: 1505.01415 [hep-ph]

Scaling assumtion: $\sigma_{in}(s,b) = \sigma_{in}(b/R(s))$

Result: **H(x) scaling follows,**
but $\sigma_{el}(s)/\sigma_{tot}(s)$ is not a constant of s and $\rho_0(s) \neq 0$.

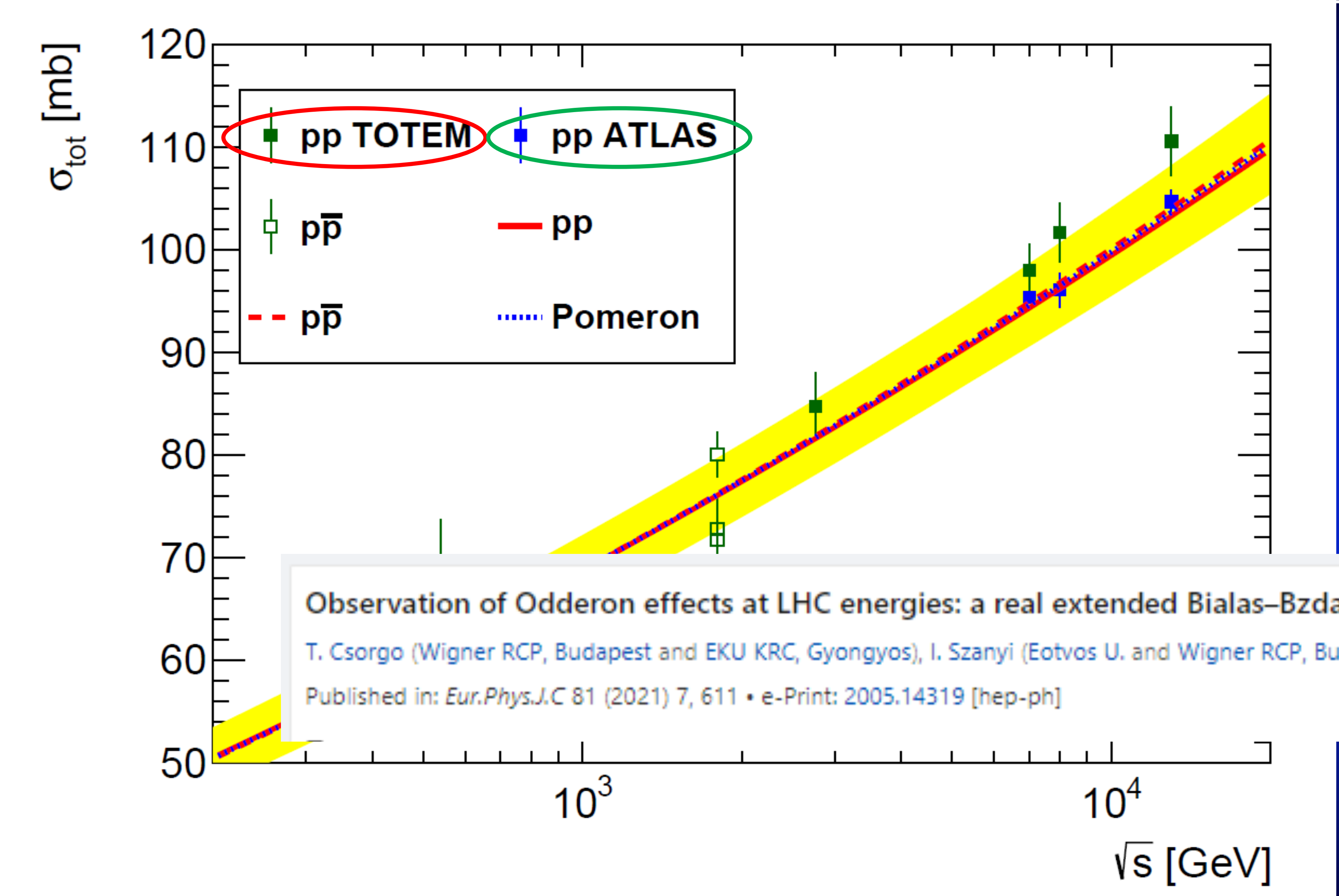
Minimal Odderon Model (MOM):

Odderon exchange signal if $\alpha(s|pp) \neq \alpha(s|pbarp)$

Odderon exchange: by only **one s-dependent parameter**.

ReBB is a MOM if $R_q(s) : R_d(s) : R_{qd}(s) = R_q(s_0) : R_d(s_0) : R_{qd}(s_0)$

Bonus Extra: ReBB model for σ_{tot} vs TOTEM and ATLAS



Observation of Odderon effects at LHC energies: a real extended Bialas–Bzdak model study

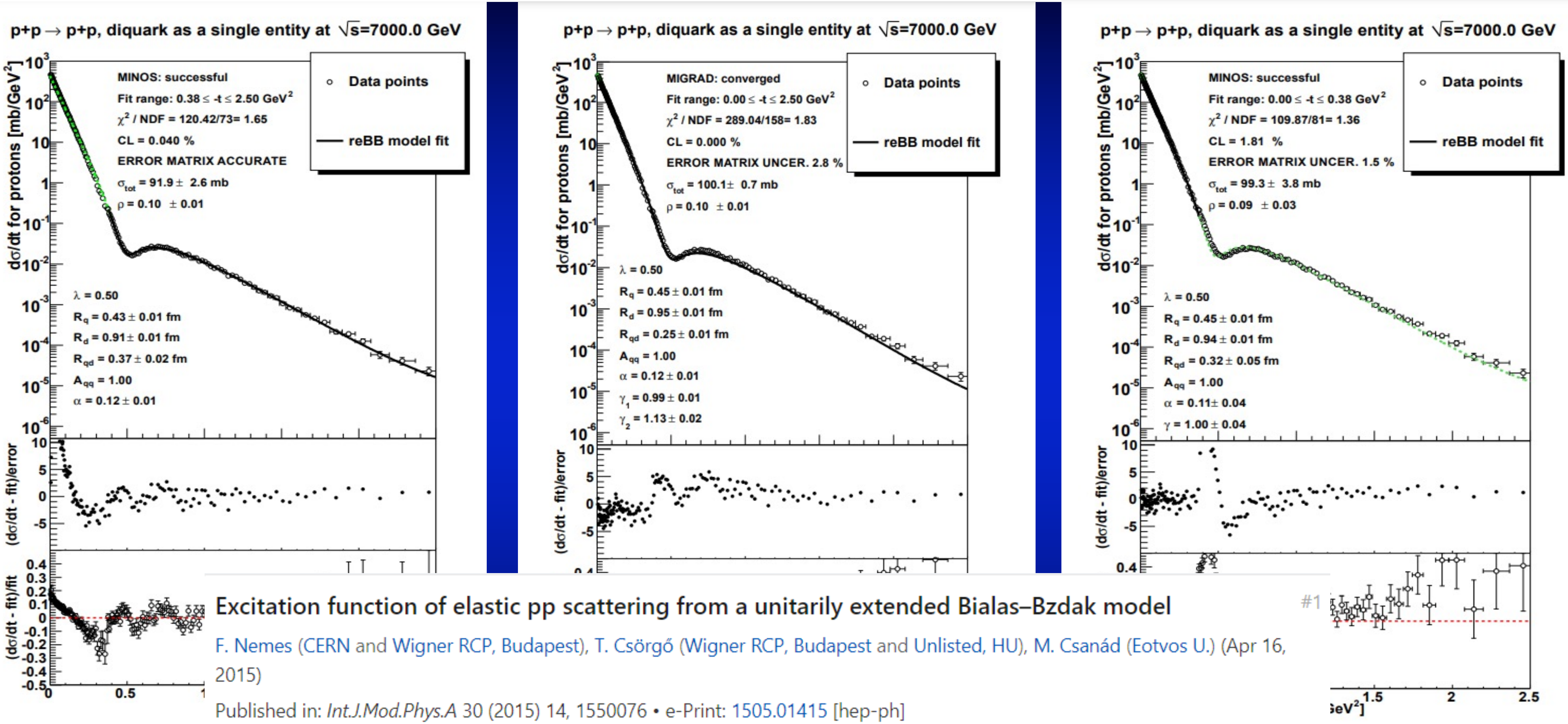
T. Csorgo (Wigner RCP, Budapest and EKU KRC, Gyongyos), I. Szanyi (Eotvos U. and Wigner RCP, Budapest) (May 28, 2020)

Published in: *Eur.Phys.J.C* 81 (2021) 7, 611 • e-Print: 2005.14319 [hep-ph]

TOTEM data on σ_{tot} are systematically above ReBB result, but ...

ATLAS σ_{tot} data agree with ReBB result, published in EPJ C81 (2021) 7, 611

Statement of the problem, with old χ^2



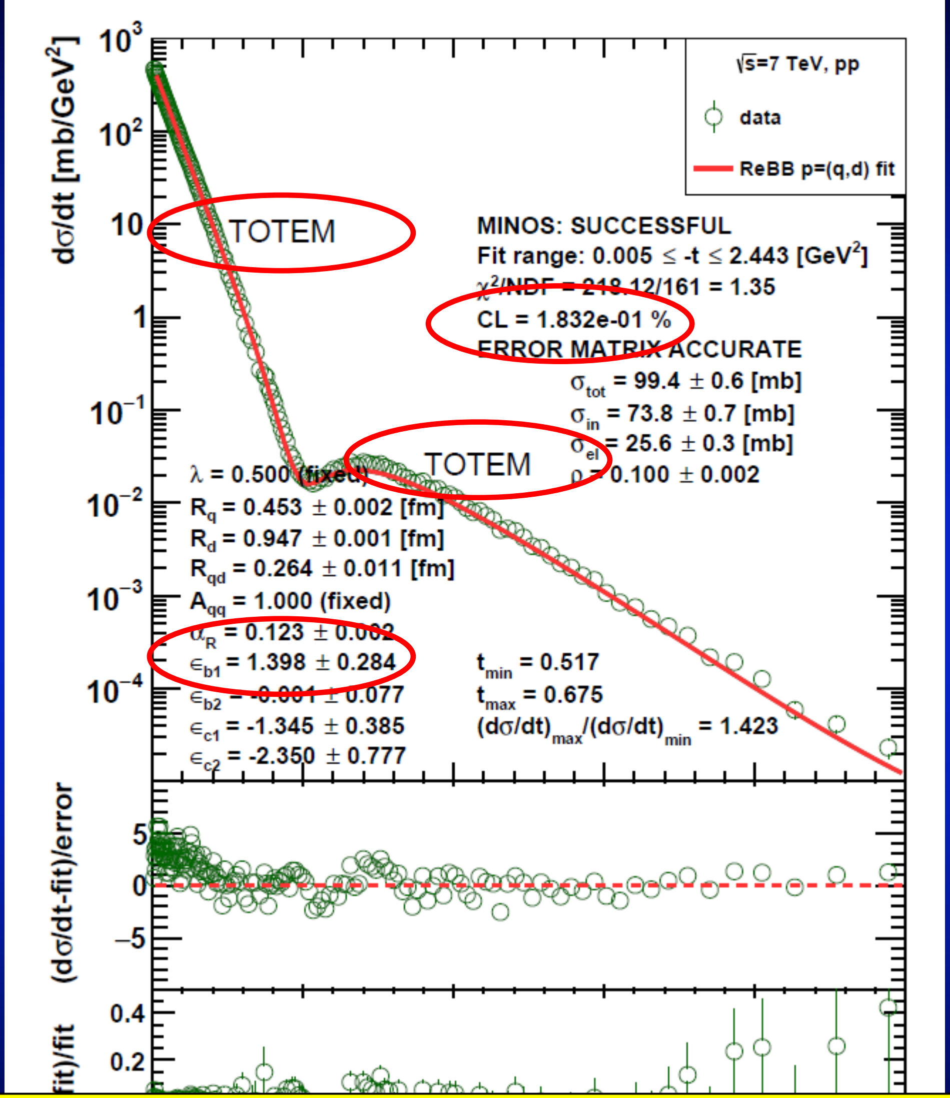
Excitation function of elastic pp scattering from a unitarily extended Bialas–Bzdak model #1

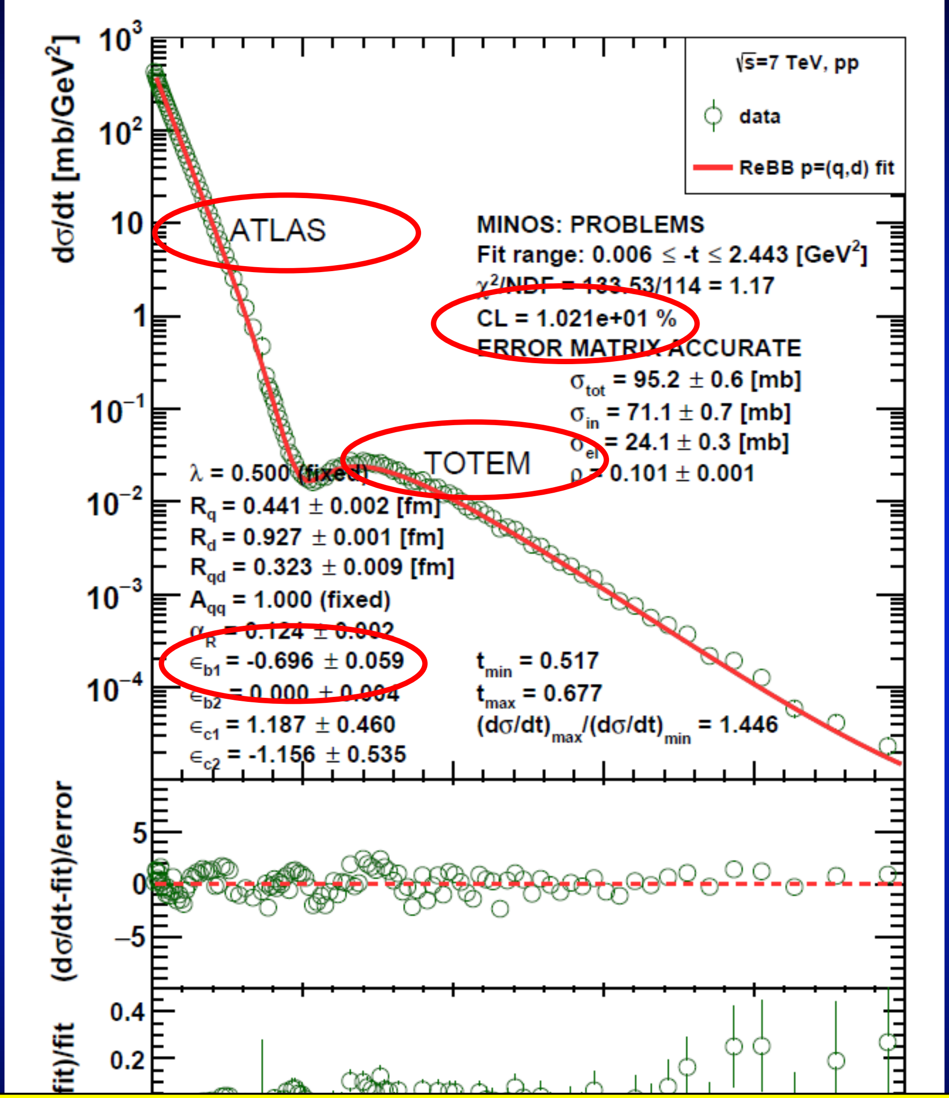
F. Nemes (CERN and Wigner RCP, Budapest), T. Csörgő (Wigner RCP, Budapest and Unlisted, HU), M. Csanád (Eotvos U.) (Apr 16, 2015)

Published in: *Int.J.Mod.Phys.A* 30 (2015) 14, 1550076 • e-Print: 1505.01415 [hep-ph]

ReBB fits to both TOTEM low-t and TOTEM-large-t fit acceptable at 7 TeV, but
The two datasets could not be ReBB fitted simultaneously, without an advanced χ^2 definition !

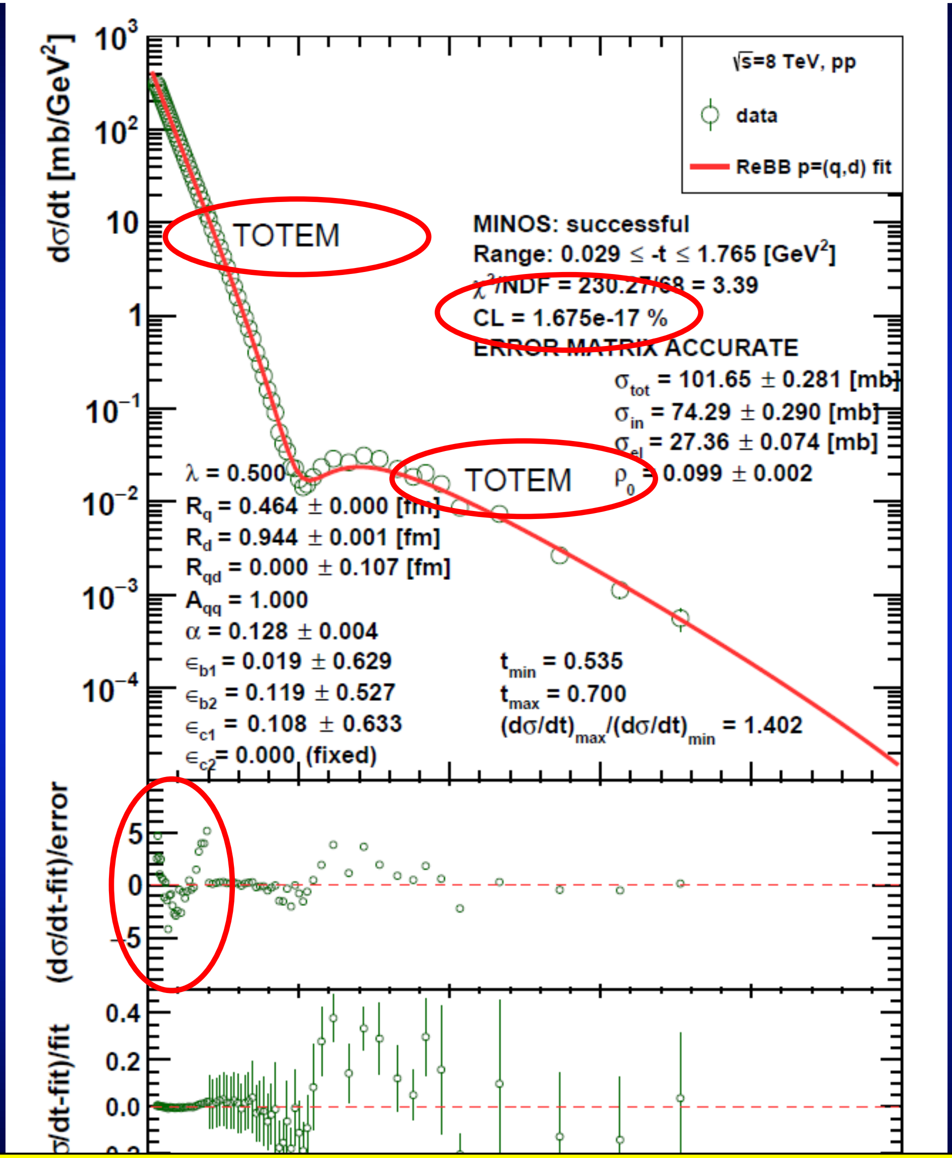
ATLAS and TOTEM: ReBB model to low –t, 7 TeV

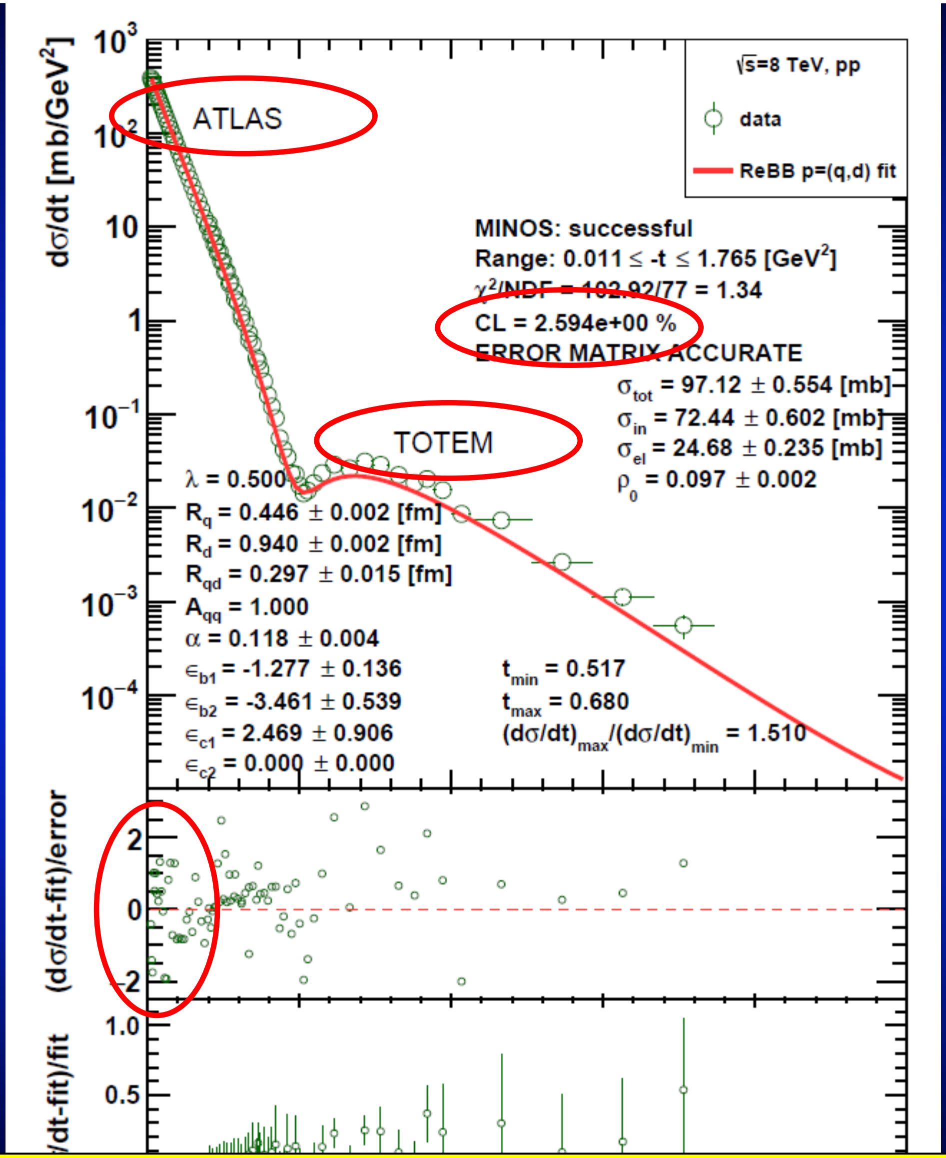




TOTEM low-t vs TOTEM-large-t fit acceptable at 7 TeV, obtained with advanced PHENIX χ^2 definition, but with $\varepsilon_B > 1$, outside expected range (-1,1) …
ATLAS low-t vs TOTEM-large-t fit successful (CL = 10.2 %) at 7 TeV !

ReBB model extension to low –t, 8 TeV

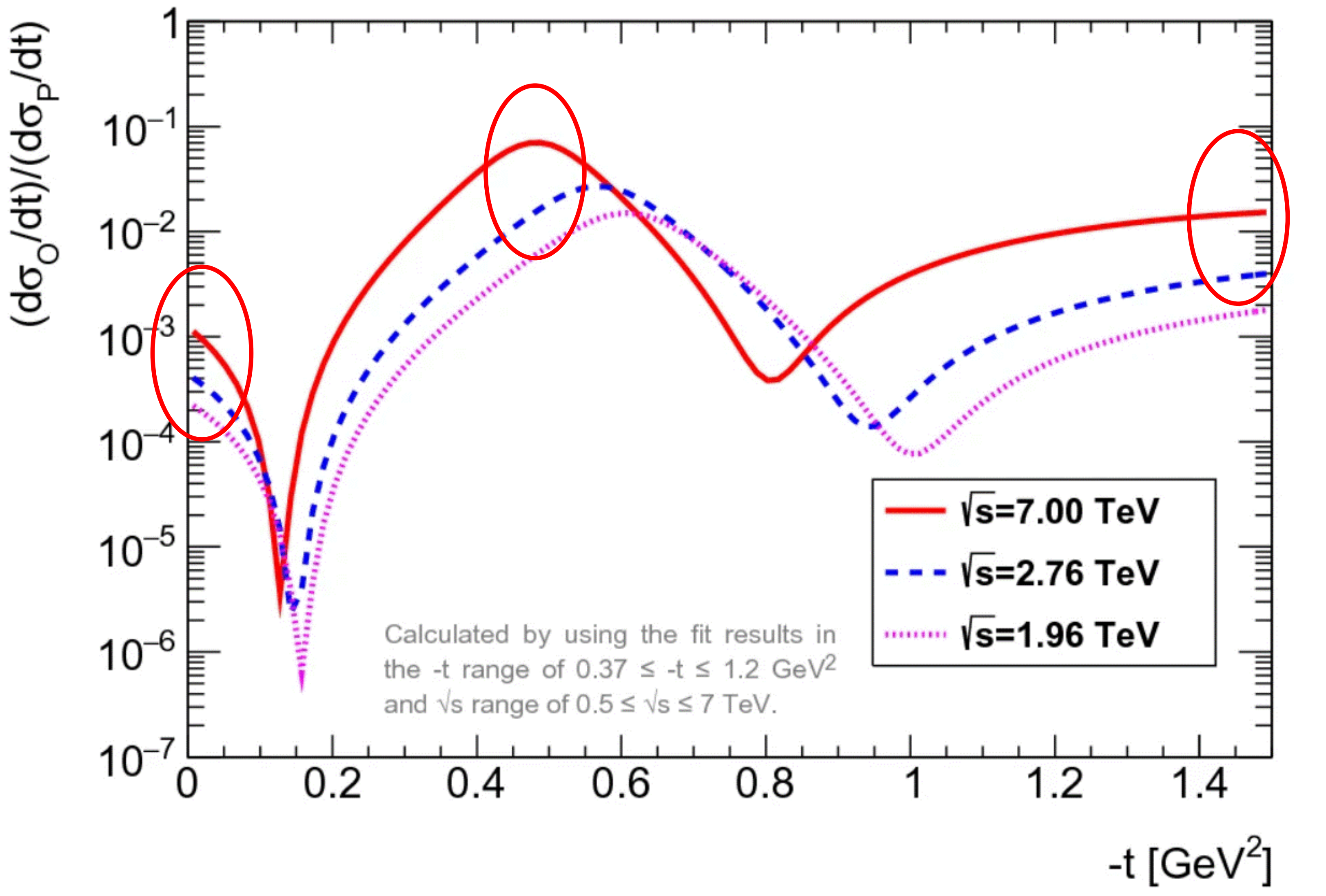


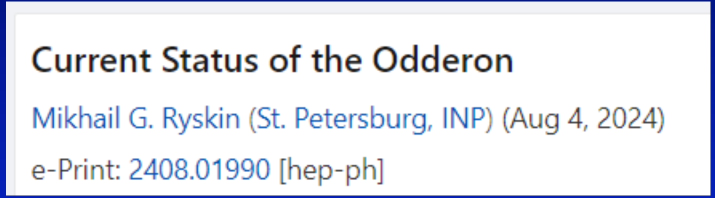


TOTEM low-t vs TOTEM-large-t fit FAILS at 8 TeV, but ...
ATLAS low-t vs TOTEM-large-t fit SUCCESSFUL with CL = 2.59 % at 8 TeV !

ReBB model: where to look for Odderon?

Recent review of Ryskin: asks for Odderon amplitude, intercept etc.
But this has been done (for ReBB) already in 2021!

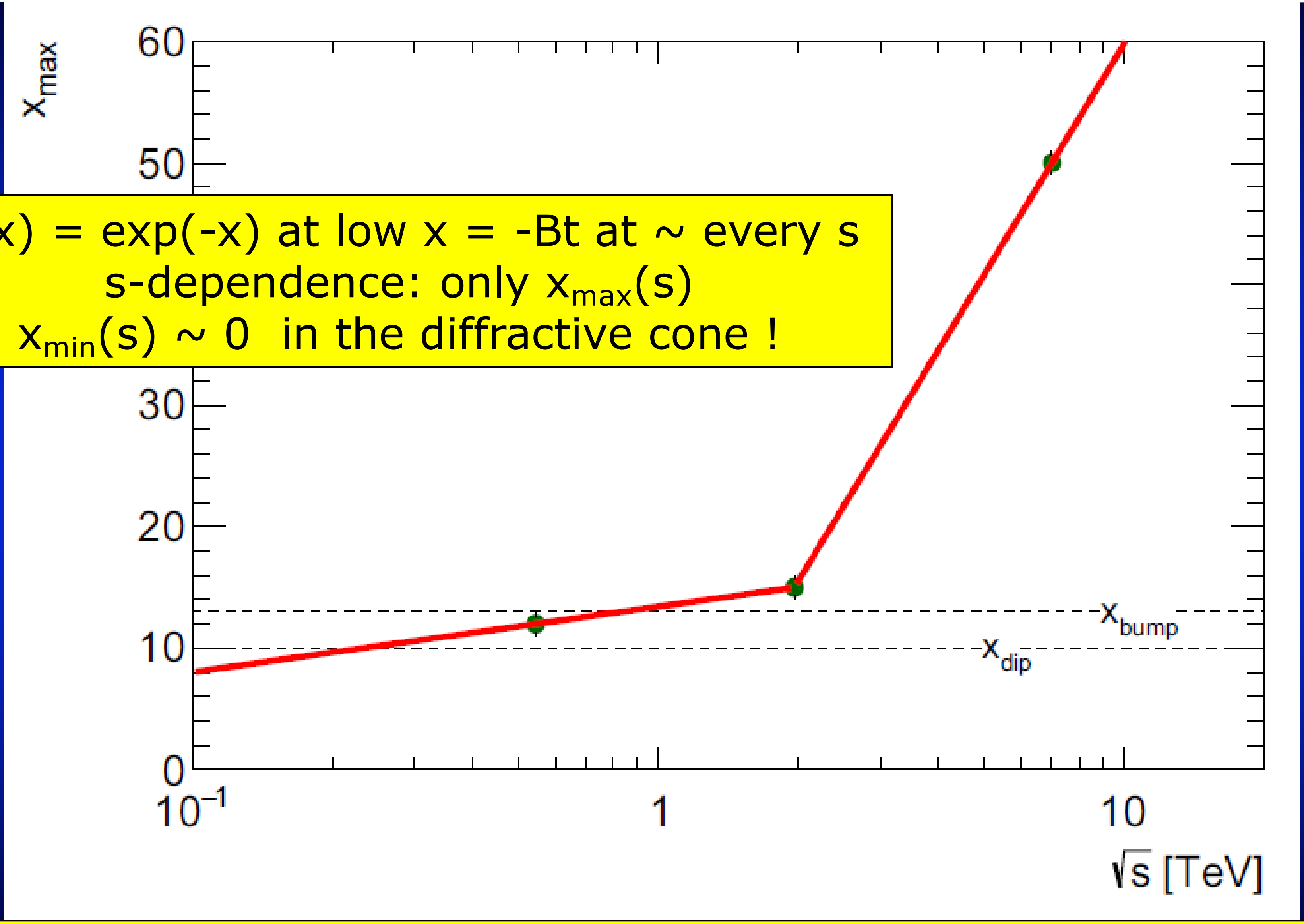




Modulus and phase for both Odderon and Pomeron
Extracted from UA4, D0 and TOTEM data using ReBB fit

Best @ dip/bump: ~ 10%
Second best @ large –t: 1 %
Most difficult @ t=0: 0.1%

pp: ReBB model limit on H(x,s) = H(x) scaling



H(x) = exp(-x) at low x = -Bt at ~ every s
s-dependence: only x_{max}(s)
x_{min}(s) ~ 0 in the diffractive cone !

Energy range: 200 GeV – 8 TeV (nearly factor of 40)
With decreasing s, the x = -Bt range for H(x) scaling decreases

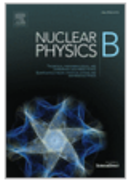
AN OLD STORY REVIVED

GEOMETRIC SCALING

GEOMETRIC SCALING (GS)

ELSEVIER

Nuclear Physics B
Volume 59, Issue 1, 13 August 1973, Pages 231-236



Geometric scaling, multiplicity distributions and cross sections

J. Dias De Deus

ELSEVIER

Nuclear Physics B
Volume 71, Issue 3, 25 March 1974, Pages 481-492

Scaling law for the elastic differential section in pp scattering from geometr scaling ☆

A.J. Buras, J. Dias de Deus

Vol. B6 (1975) *ACTA PHYSICA POLONICA* No 4

GEOMETRICAL SCALING, QUARKS AND THE POMERON

By J. Dias de Deus

The Niels Bohr Institute, University of Copenhagen

and

Theory Division, Rutherford Laboratory, Chilton*

(Received December 10, 1974)

From quark model additivity applied in the impact parameter plane to the inelastic overlap function we obtain a kind of scale invariant factorizable Pomeron. Quarks themselves are seen as behaving asymptotically like extended objects (quark pancakes), cross-sections and multiplicities being related to their overlap in a high energy collision. Predictions, which can be tested soon at NAL, are given for overlap functions, cross-sections, the ratio σ^{el}/σ^{tot} in the case of various reactions. Universality features of multiplicity distributions are explained in a natural way and an attempt is made to compute the modifications coming from the leading particle effect.

AN OLD STORY REVIVED

Phys. Lett. B 856 (2024) 138960

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Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

PHYSICS LETTERS B

Letter

Scaling laws of elastic proton-proton scattering

Cristian Baldenegro [a], Michał Praszałowicz [b,*], Christophe

[a] Dipartimento di Fisica, Sapienza Universitá di Roma, Piazzale Aldo Moro, 2, 00185 Rome, Italy

[b] Institute of Theoretical Physics, Faculty of Physics, Astronomy and Applied Computer Science, Jagiello

[c] Department of Physics and Astronomy, The University of Kansas, Lawrence, KS 66045, USA

[d] Department of Physics, Penn State University, University Park, PA 16802, USA

A R T I C L E I N F O

Editor: G.F. Giudice

Keywords:
Elastic *pp* scattering
Geometrical scaling

A B S T R A C T

We show that elastic scattering *pp*
square |*t*| have a universal property
the ISR to the LHC, from tens of GeV
scaling observed at the ISR with the
present experimental uncertainties,
scaling laws impose on the paramet

Phys. Lett. B 869 (2025) 139848

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Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

PHYSICS LETTERS B

Letter

Geometric scaling of elastic *pp* cross section at the LHC

Check for updates

Michał Praszałowicz

Institute of Theoretical Physics, Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University, S. Łojasiewicza 11 30-348 Kraków, Poland

A R T I C L E I N F O

Editor: Dr Francois Gelis

Keywords:
Elastic *pp* scattering
geometrical scaling

A B S T R A C T

We show that geometric scaling conjectured and observed at the ISR more than 50 years ago, still holds at the LHC. We discuss regularities of the dip - bump structures of the differential elastic cross sections, emphasizing the fact that the ratio of bump to dip positions is constant from the ISR to the LHC. Applying crossing and analyticity we identify imaginary and real parts of the scattering amplitude and compute the ρ parameter and the ratio of bump to dip values of the differential *pp* cross sections. We also discuss the energy dependence of the total elastic cross section and the violation of geometrical scaling outside the dip - bump region at the LHC.

GS: DEFINITIONS

Geometric scaling

$$\Omega(s,b) = \Omega\left(b/R(s)\right)$$

Opacity is a function of one varible, and $R(s)$ grows with energy. Changing variable

$$\boldsymbol{b} \to \boldsymbol{B} = \boldsymbol{b}/R(s)$$

$$\sigma_{\rm inel} = R^2(s) \underbrace{\int d^2\boldsymbol{B} \left[1 - \left|e^{-\Omega(B)}\right|^2\right]}_{\text{constant}}$$

Geometric Scaling (GS) assumes $\rho_0(s) \sim 0$

Immediate consequences

$$\sigma_{\rm el} = R^2(s) \int d^2\boldsymbol{B} \left|1 - e^{-\Omega(B)}\right|^2$$

$$\sigma_{\rm tot} = 2R^2(s) \int d^2\boldsymbol{B}\ {\rm Re}\left[1 - e^{-\Omega(B)}\right]$$

$$\sigma_{\rm inel} = R^2(s) \int d^2\boldsymbol{B} \left[1 - \left|e^{-\Omega(B)}\right|^2\right]$$

If we neglect χ (indeed ρ parameter is small), then all cross-sections have the same energy dependence.

Does not work at the LHC!

Immediate consequences

$$\sigma_{\rm el} = \int d^2\boldsymbol{b} \left|1 - e^{-\Omega(s,b) + i\chi(s,b)}\right|^2,$$

$$\sigma_{\rm tot} = 2\int d^2\boldsymbol{b}\ {\rm Re}\left[1 - e^{-\Omega(s,b) + i\chi(s,b)}\right],$$

$$\sigma_{\rm inel} = \int d^2\boldsymbol{b} \left[1 - \left|e^{-\Omega(s,b)}\right|^2\right].$$

M. Praszalowitz:
PLB **869** (2025) 1398-48,

M. Praszalowitz:
Talk at Moriond QCD 2025,

Motivating issue (Cs.T.):
Opacity is, in general complex.

Why not scaling for the imaginary part of the optical opacity (here denoted by χ) too?

GS: WHY DOES NOT WORK AT LHC?

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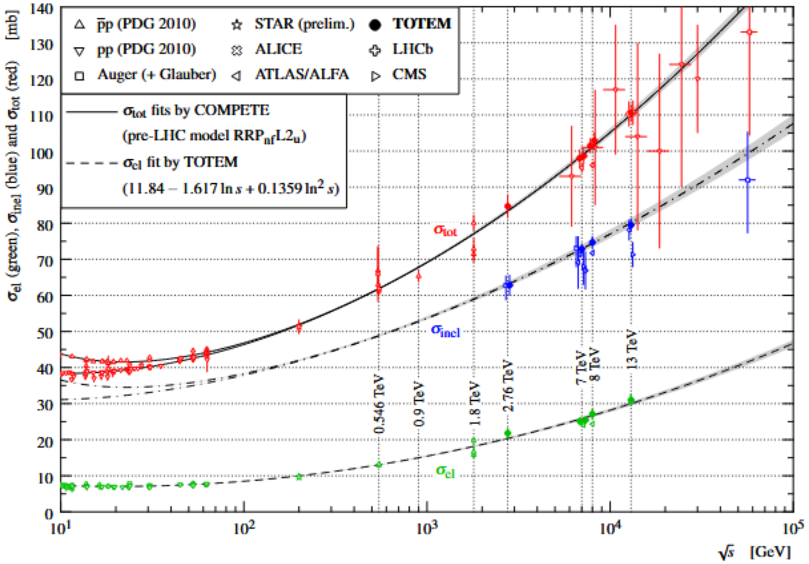
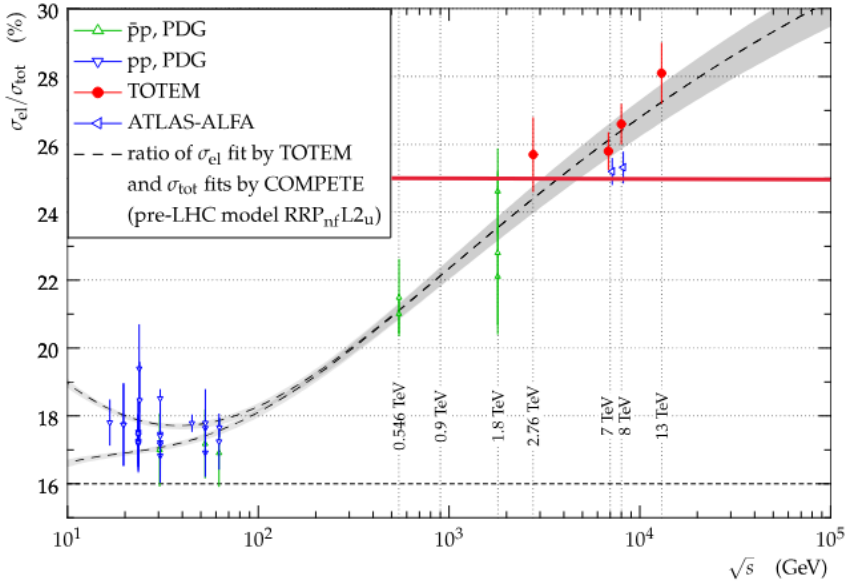
Table 1. Summary of cross-section results of TOTEM at $\sqrt{s}$ = 2.76 and 13 TeV in pp collisions [1, 3, 4, 51].

$\sqrt{s}$ (TeV)	σ_{tot} (mb)	σ_{el} (mb)	σ_{in} (mb)	σ_{el}/σ_{tot} (%)
2.76	84.7 ± 3.3	21.8 ± 1.4	62.8 ± 2.9	25.7 ± 1.1
13.0	110.6 ± 3.4	31.0 ± 1.7	79.5 ± 1.8	28.1 ± 0.9





onsequences

$$\left|1 - e^{-\Omega(B)}\right|^2$$

$$3\ \mathrm{Re}\left[1 - e^{-\Omega(B)}\right]$$

$$\left[1 - \left|e^{-\Omega(B)}\right|^2\right]$$

ρ parameter is small),
have the same energy

$\sigma_{el}(s)/\sigma_{tot}(s)$ is not a constant of s at LHC energies:
Table 1 and Fig, 1 from T. Csörgő for TOTEM, Proc. ISMD 2018

Does not work at the LHC!

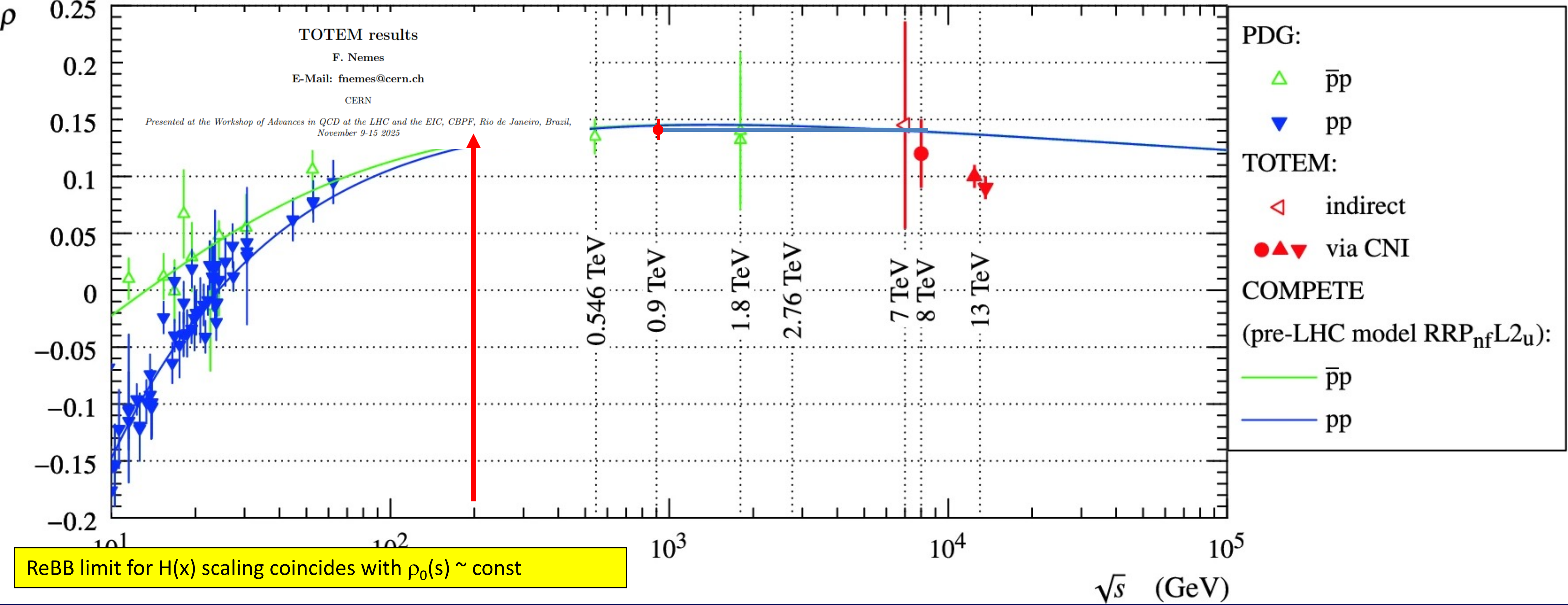
Recent Results from the CERN LHC Experiment TOTEM -- Implications for Odderon Exchange

TOTEM Collaboration • T. Csörgő (Wigner RCP, Budapest and Eszterhazy Karoly U., Eger and CERN) for the collaboration. (Mar 16, 2019)

Published in: *EPJ Web Conf.* 206 (2019) 06004 • Contribution to: ISMD 2018, ISMD 2018 • e-Print: 1903.06992 [hep-ex]

M. Praszalowitz:
PLB **869** (2025) 1398-48,

GS: Does NOT work at LHC, because neither $\rho(s)$ is 0, nor $\sigma_{el}(s)/\sigma_{tot}(s)$ is constant



ReBB limit for H(x) scaling coincides with $\rho_0(s)$ ~ const

Recent Results from the CERN LHC Experiment TOTEM -- Implications for Odderon Exchange

TOTEM Collaboration • T. Csörgő (Wigner RCP, Budapest and Eszterhazy Karoly U., Eger and CERN) for the collaboration. (Mar 16, 2019)

Published in: *EPJ Web Conf.* 206 (2019) 06004 • Contribution to: ISMD 2018, ISMD 2018 • e-Print: 1903.06992 [hep-ex]

DERIVATION 1

H(x) SCALING FOR SMALL x « 1

H(x) scaling for small-x, in the cone region (x « 1)

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

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

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

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

Advantages:

1) H(x) ≈ exp(-x) in the diffractive cone, for x « 1
2) H(0) = 1 → Start from a place that you know
3) Measurable both for pp and pbarp

BONUS EXTRA: An Odderon signal

H(x|pp) scales with energy, but for pbarp, no scaling

DERIVATION 2

H(x) SCALING FOR ALL x

Derivation of H(x) scaling for all x

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

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

Similarly to GS, only one s-dependent scale R(s)

Dissimilarly to GS,
$\rho_0(s) = \rho_0(s_0) = \rho_0$
But it is not vanishing!

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

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

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

Dissimilarly to GS, no singularity at minimum!

Advantages:
H(x) ≠ exp(-x) arbitrary positive def. in the dip-bump region
Measurable both for pp and p-antip. Normalized as H(0) = 1.

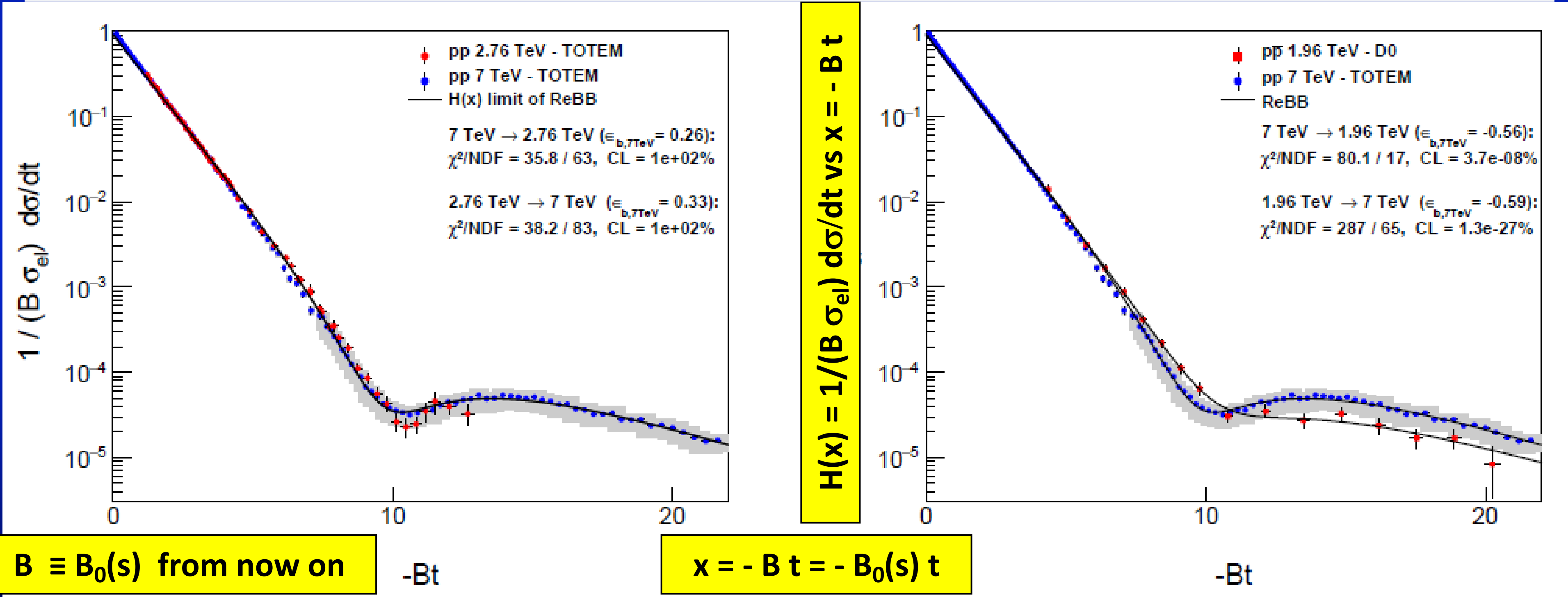
Model independent H(x|pp) scaling yields Odderon > 6.26 σ

Evidence of Odderon-exchange from scaling properties of elastic scattering at TeV energies #5

T. Csörgő (Wigner RCP, Budapest and CERN), T. Novak (Unlisted, HU), R. Pasechnik (Lund U., Dept. Theor. Phys.), A. Ster (Wigner RCP, Budapest), I. Szanyi (Wigner RCP, Budapest) (Dec 26, 2019)

Published in: *Eur.Phys.J.C* 81 (2021) 2, 180 • e-Print: 1912.11968 [hep-

Eur. Phys. J. C (2021) **81**: 180, published February 2021
https://doi.org/10.1140/epjc/s10052-021-08867-6



$H(x) = 1/(B\,\sigma_{el})\, d\sigma/dt$ vs $x = -B\,t$

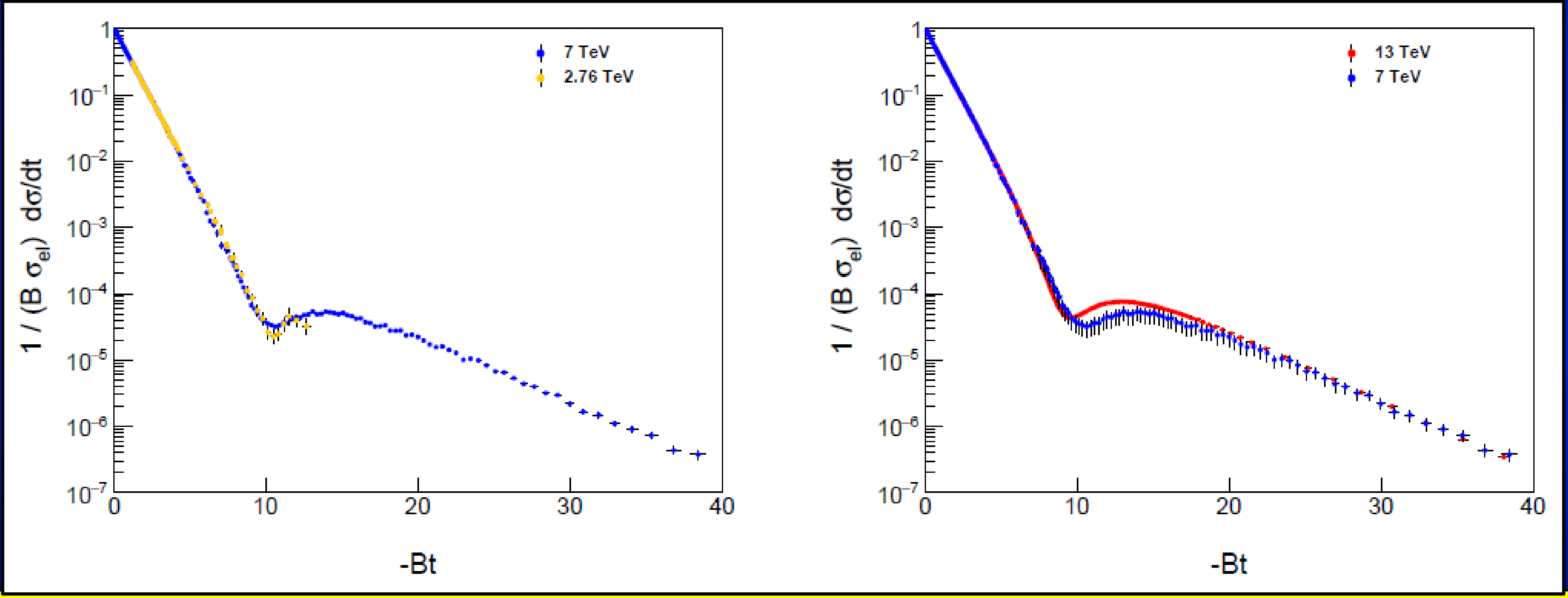
$B \equiv B_0(s)$ from now on

$x = -B\,t = -B_0(s)\,t$

S: Model independent Odderon significance ≥ 6.26 σ
C1: All D0 and TOTEM published data at 1.96, 2.76 and 7.0 TeV
C2: domain of validity is still determined **model dependently**.

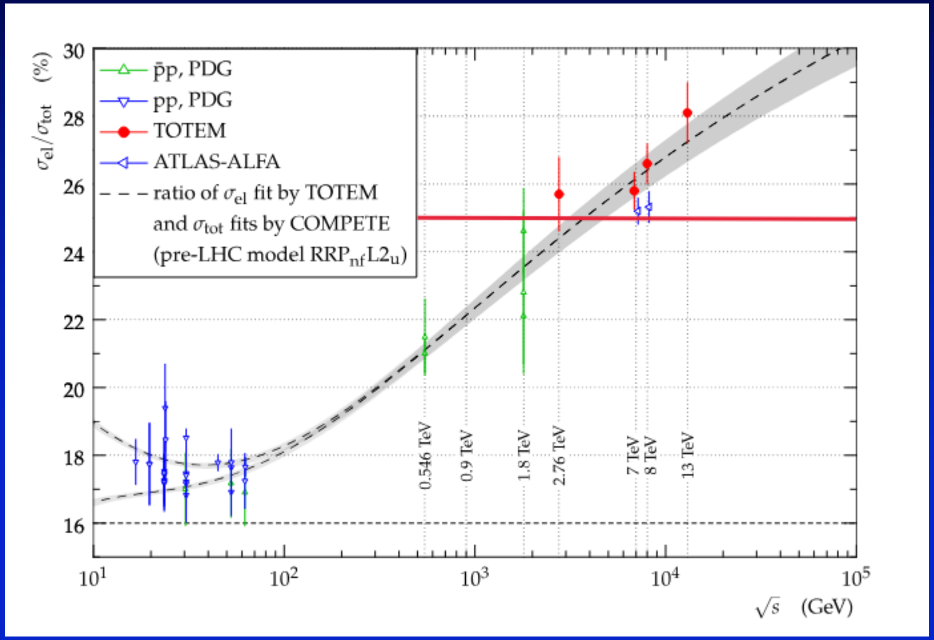
Test of the H(x) scaling at 7 vs 2.76 TeV

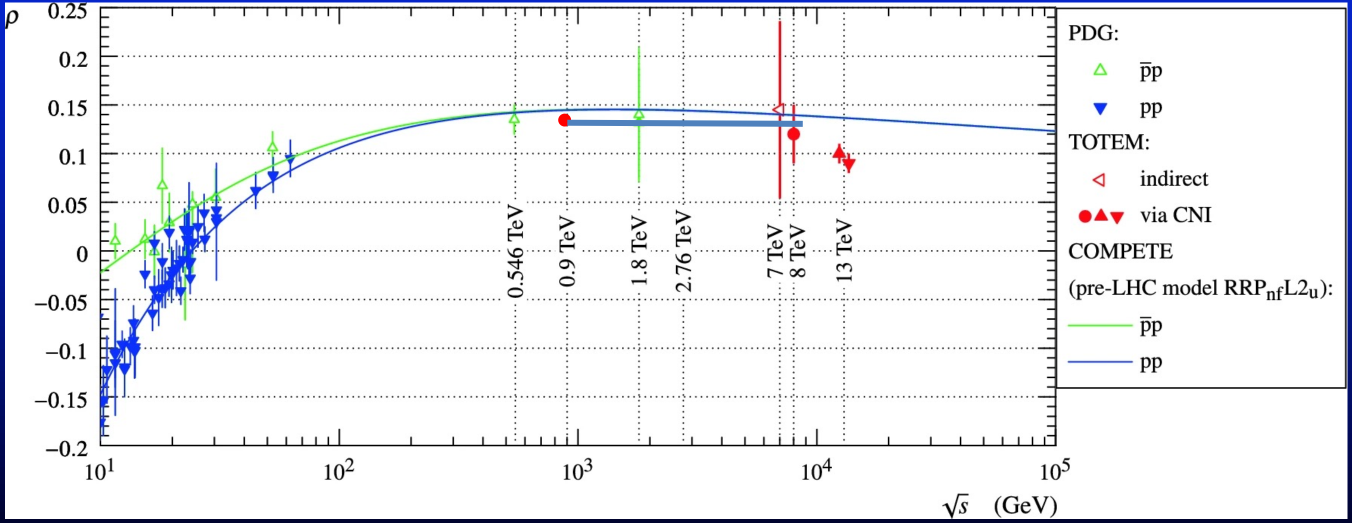
$$H(x) \equiv \frac{1}{B(s)\sigma_{\rm el}(s)}\frac{d\sigma}{dt},$$
$$x = -tB(s).$$



Valid between 2.76 and 7 TeV, even with stat errors only,
H(x) scaling valid even in the bump/tail region!
Between 8 and 13 TeV, scaling limited to the cone,
as ρ(s) starts to decrease, so H(x|pp) scaling **violated** beyond stat+syst errors in dip/bump!

H(x) vs GS: Summary and conclusions





Geometric scaling is revived but does NOT work at LHC,

because at LHC, $\sigma_{el}(s)/\sigma_{tot}(s)$ is not a constant of s and $\rho_0(s) \neq 0$

But H(x) is valid if $\rho_0(s)$ = const

→ reason for H(x) violations at 13 TeV

If $\rho_0(s) = 0$, geometric scaling is recovered and $\sigma_{el}(s)/\sigma_{tot}(s)$ becomes const(s)

Thus H(x) scaling is a generalized geometric scaling ! Foundation of Odderon discovery extended to $0.2 \leq \sqrt{s} \leq 8$ TeV for H(x) scaling of the ReBB model. TOTEM/ATLAS data support this.

Summary and conclusions

Real Extended Bialas Model is beautiful

because it is a Minimal Odderon Model
it has a H(x) scaling limit
describes elastic pp and pbarp data
from 23 GeV to 8 TeV

It predicted successfully ATLAS $\sigma_{tot}(s)$
and combined ATLAS low-t
+ TOTEL large-t $d\sigma/dt$ data

Foundation of Odderon discovery
extended to $0.2 \leq \sqrt{s} \leq 8$ TeV.

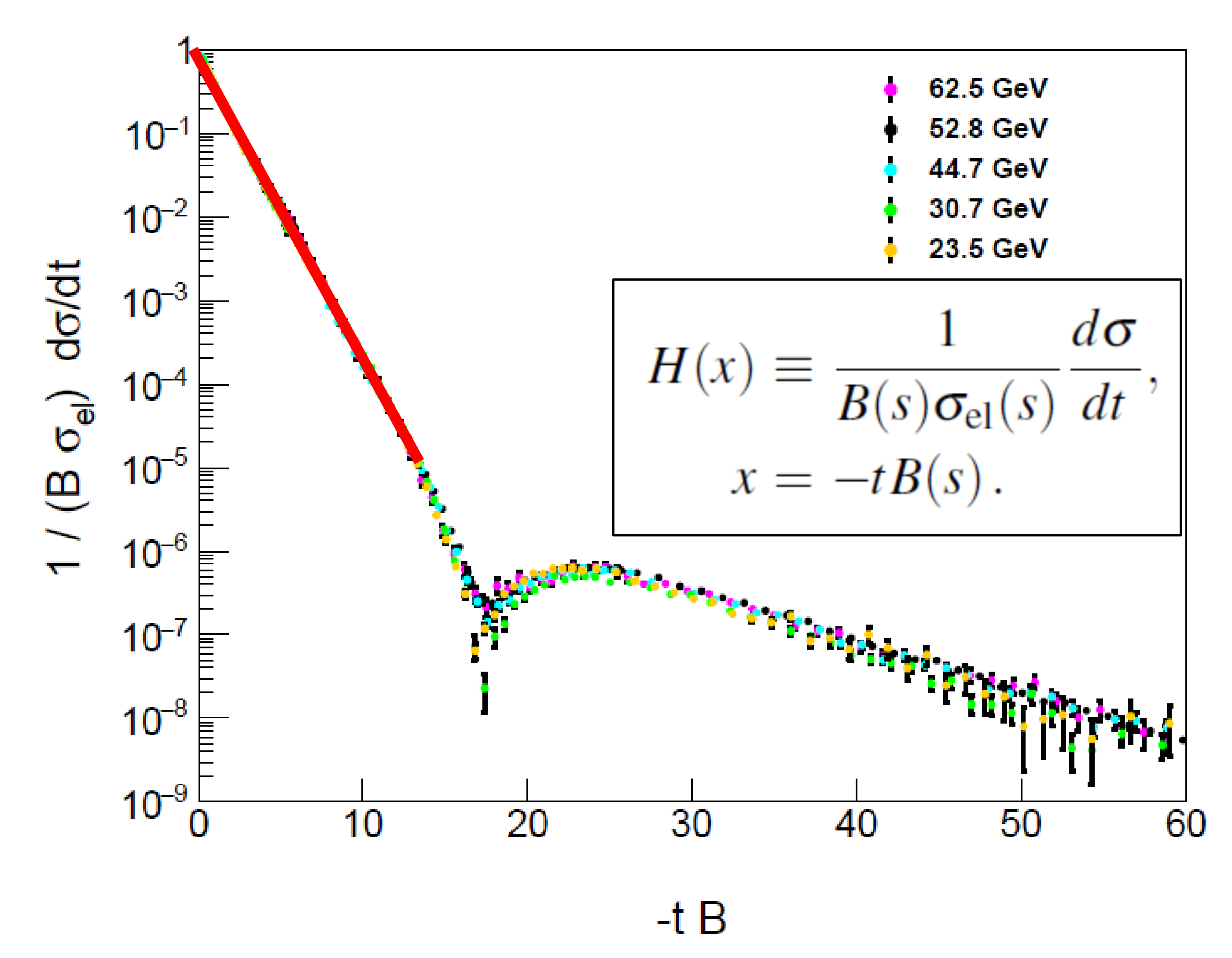
Within the ReBB model, Odderon
exchange is a certainty!

Dear Andrzej,
Happy 90!

THANK YOU FOR YOUR ATTENTION !

BACKUP SLIDE

Test of the H(x) scaling at ISR

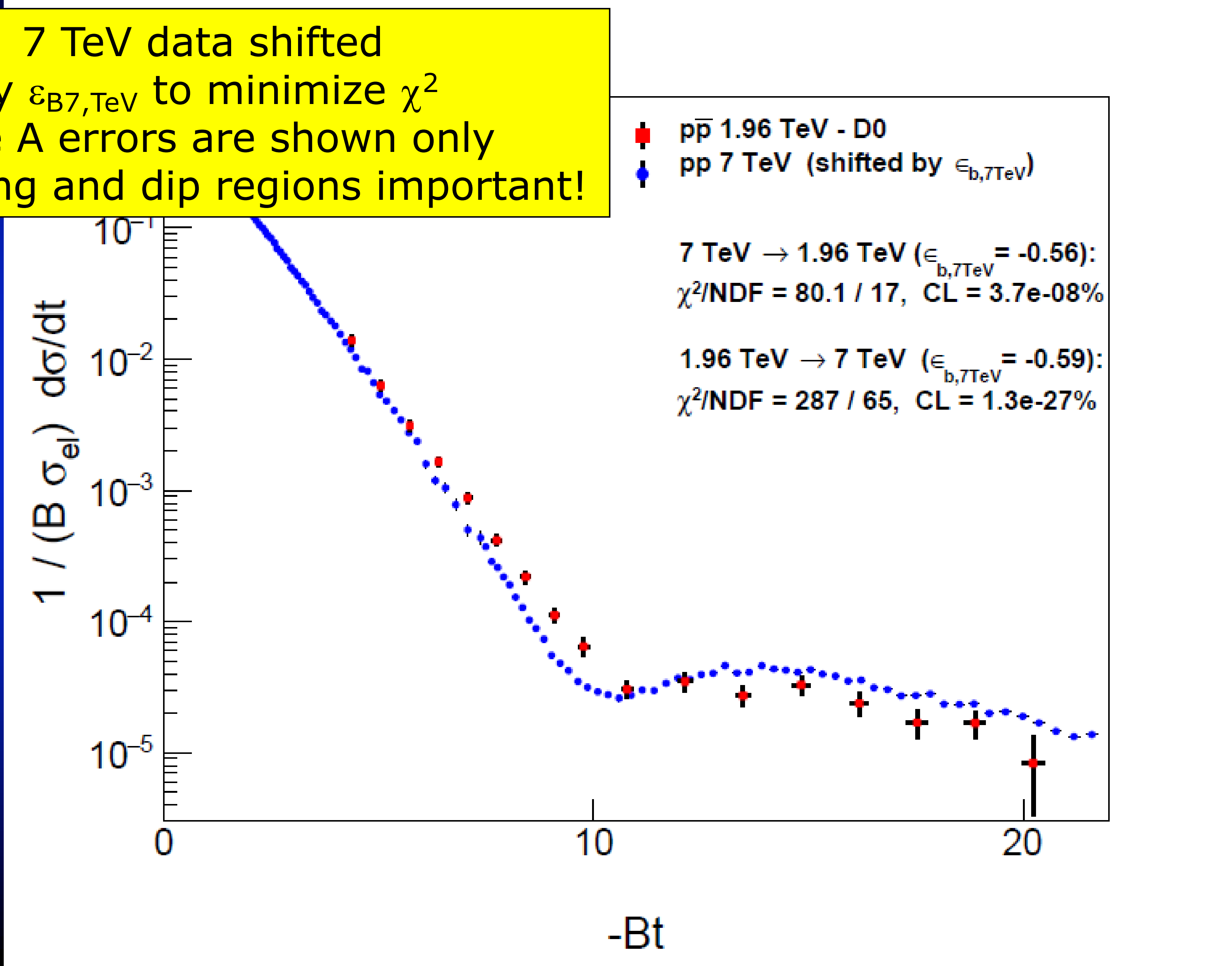


Hungarian-Swedish team:
Eur. Phys. J. C (2021) **81**: 180,

H(x) = exp(-x) in the cone
Works better than expected, up to x ~ 10, even in the bump/tail, x > 25 region!

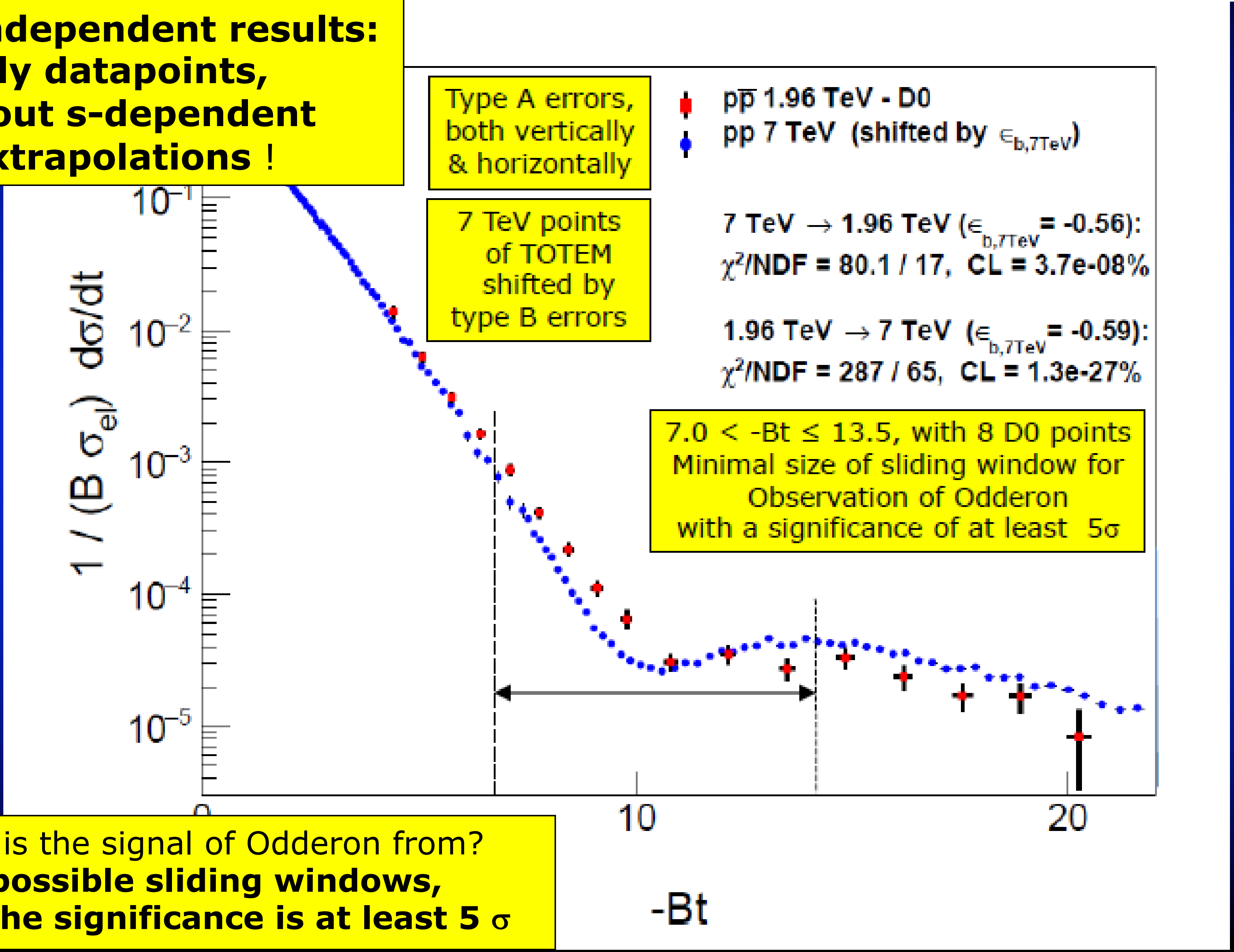
OBSERVATION OF ODDERON

7 TeV data shifted
by $\varepsilon_{B7,TeV}$ to minimize χ^2
Type A errors are shown only
Both swing and dip regions important!



SLIDING WINDOW for 5 σ

Model independent results: only datapoints, without s-dependent extrapolations !



Where is the signal of Odderon from?
All possible sliding windows, where the significance is at least 5 σ

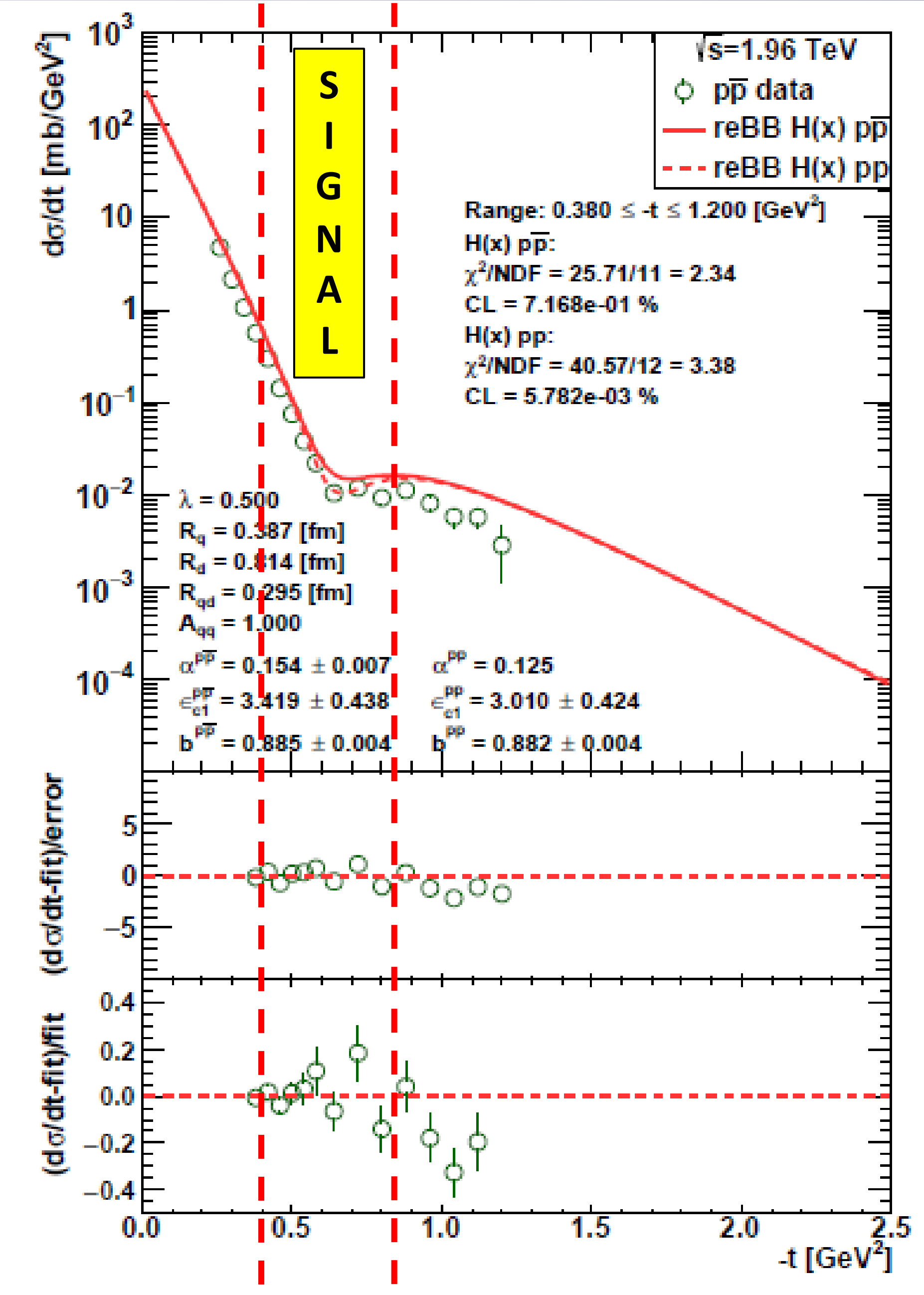
Is $H(x,s) = H(x)$ at 1.96 TeV?

MODEL INDEPENDENTLY: YES!
In the background of the Odderon signal,
defined as $x \leq 7.0$ in union with $x > 13.5$
H(x|pp,7 TeV) ~ H(x|pbarp, 1.96 TeV)
Agreement: a significance of 2.39 σ

Results for the background: $x \leq 7.0$ in union with $x > 13.5$ for ε_{B21}(7 TeV) = -1.1 that minimizes signal in the background				
x_{max}	ε_{B21} of min[χ^2(background)]	$\Delta\chi^2$(background)	NDF(background)	σ (background)
20.2	-1.10	20.20	9	2.39

New MODEL INDEPENDENT result

Is H(x,s) = H(x) at 1.96 TeV?



MODEL DEPENDENTLY: Yes
1.96 TeV
Highest energy where p+antip data are available

H(x) scaling limit:
in the Bialas-Bzdak model

Fits pbarp data up to largest -t
(red line, dashed line: pp)

Pull plots:
(data-fit)/error
(data-fit)/fit

t_{max}(1.96 TeV, pp) > 1.2 GeV^2

→ x_{max}(1.96 TeV, pp) > 20

Safely above the 5 σ threshold

Role of the H(x) scaling violations
Do they decrease the signal or not?

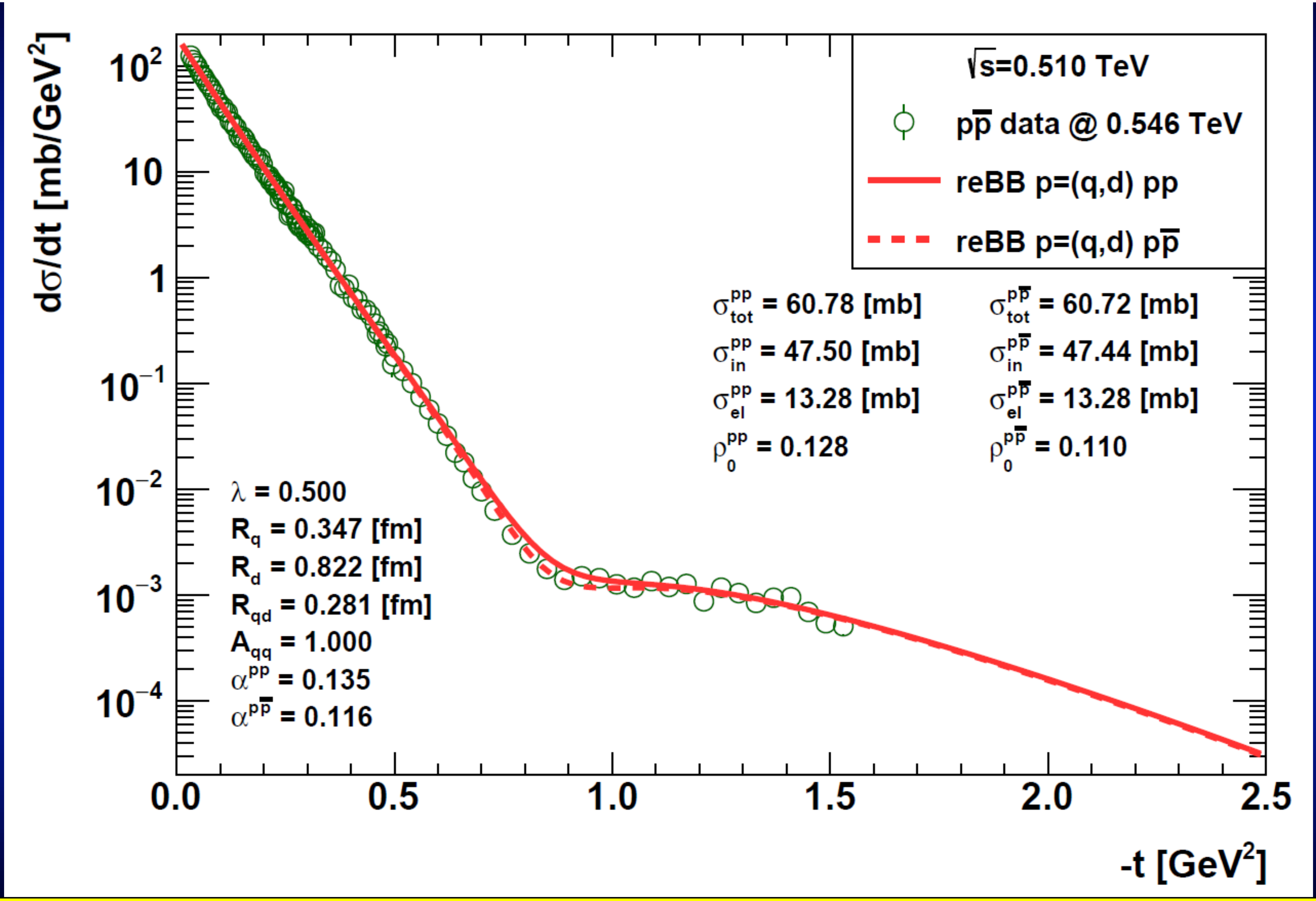
√s (TeV)	χ^2	NDF (ReBB)	σ (ReBB)
1.96	24.28	13	2.19
2.76	100.35	20	7.12
1.96 and 2.76	124.63	33	7.08

H(x) scaling: allows to project pp data ONLY
Scaling violations decrease significance at 1.96 TeV
BUT
Also allow to evaluate pbarp data at 2.76 TeV

Trade-off effect!

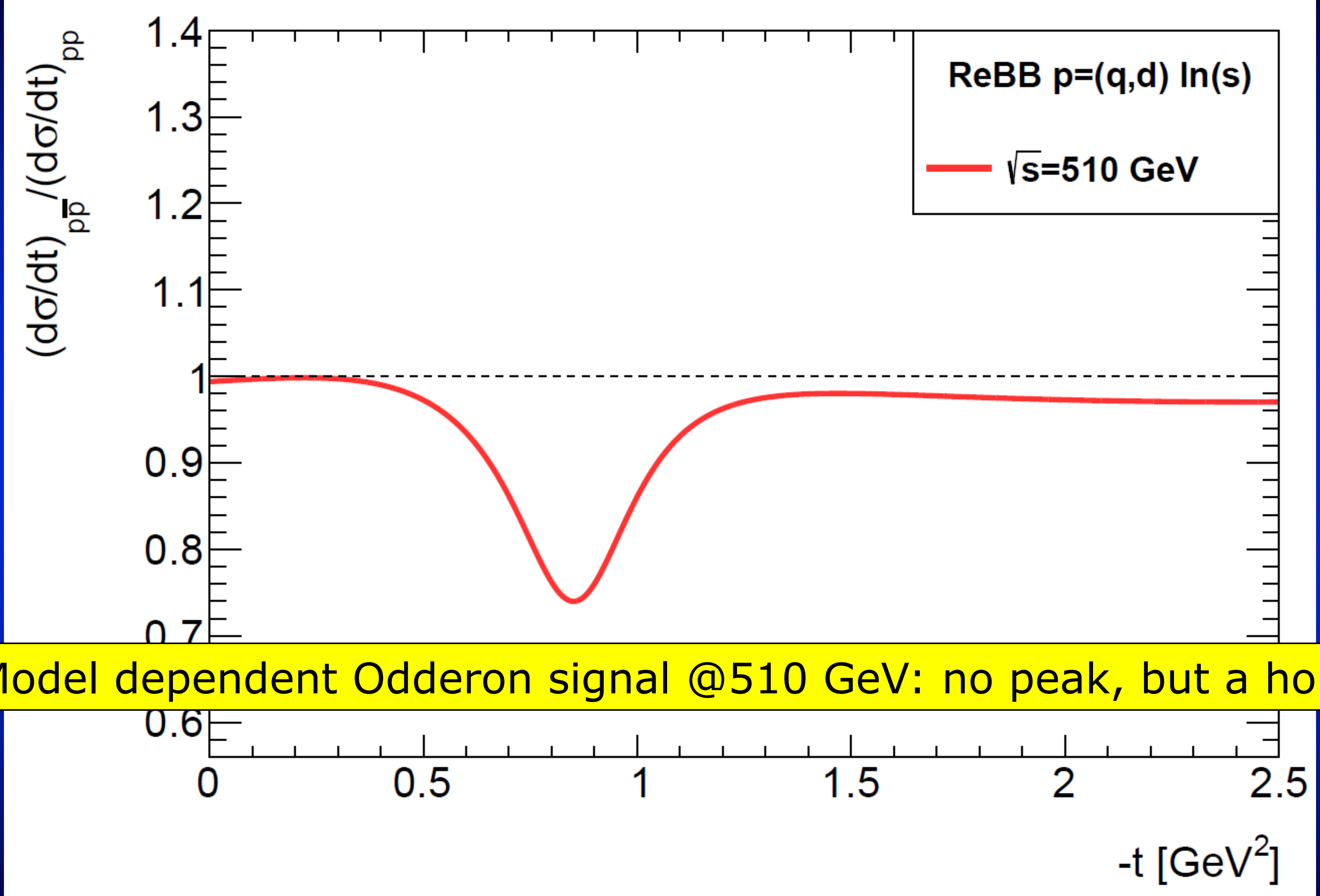
Odderon significance increases
from 6.26 to 7.08 σ.

Predictions for pp and pbarp dσ/dt @ 510 GeV



Model dependent Odderon signal @510 GeV: pp above pbarp !

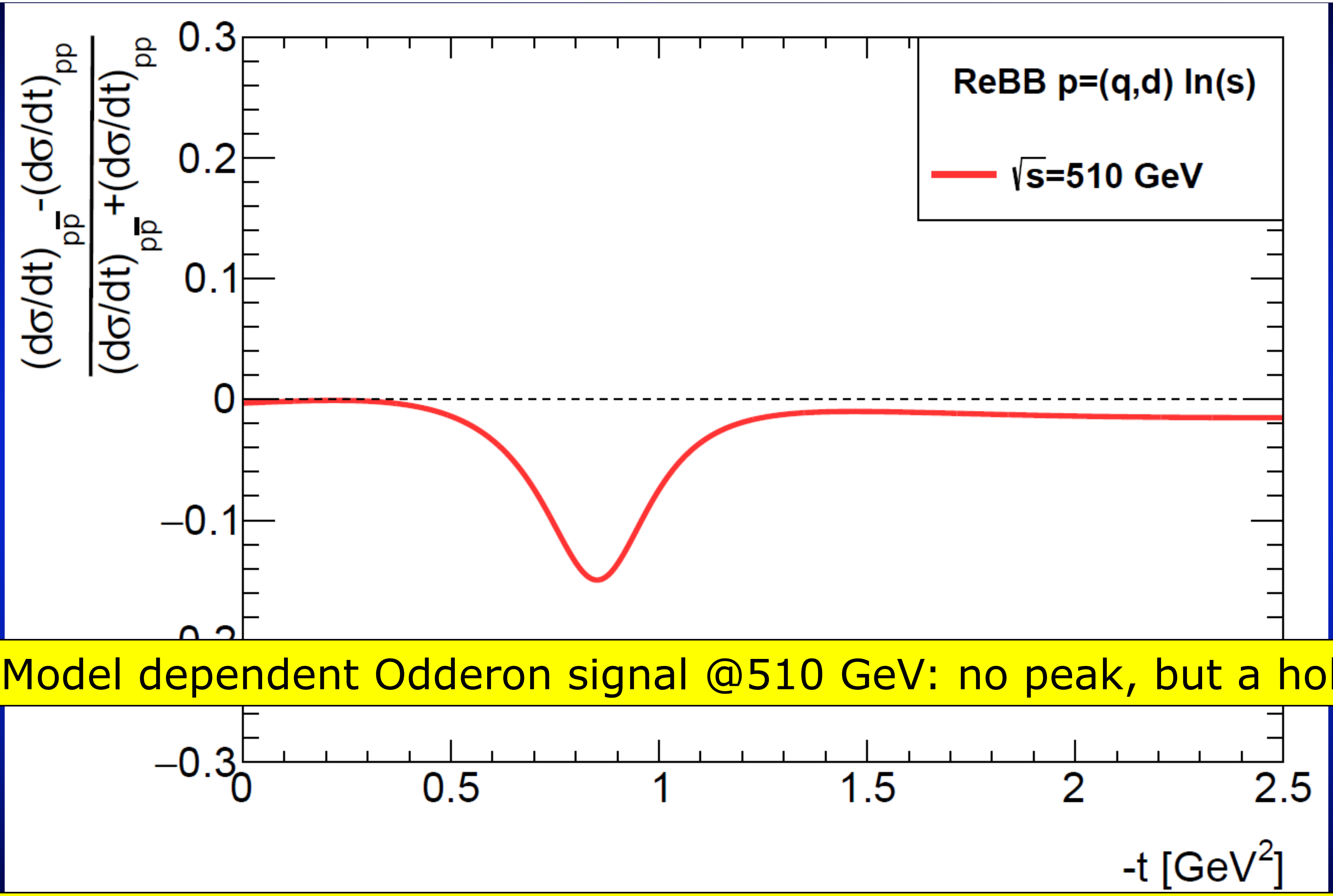
Ratio of pbarp to pp cross-sections @ 510 GeV



Model dependent Odderon signal @510 GeV: no peak, but a hole

Scaling violations: dominant @510 GeV
Model dependent Odderon signal: pbarp dσ/dt ~ 25 % below pp !!

Asymmetry parameter @ 510 GeV



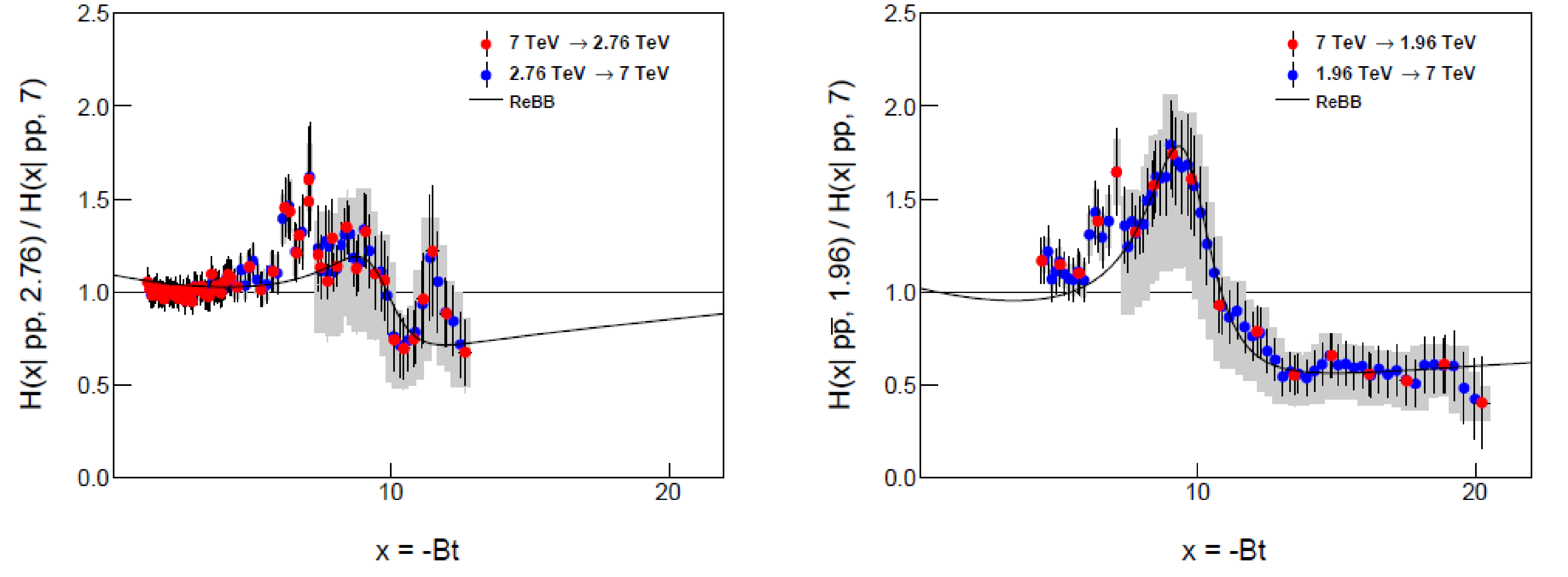
Model dependent Odderon signal @510 GeV: no peak, but a hole

Scaling violations: dominant @510 GeV

Model dependent Odderon signal: A ~ - 15 % @ -t ~ 0.85 GeV^2

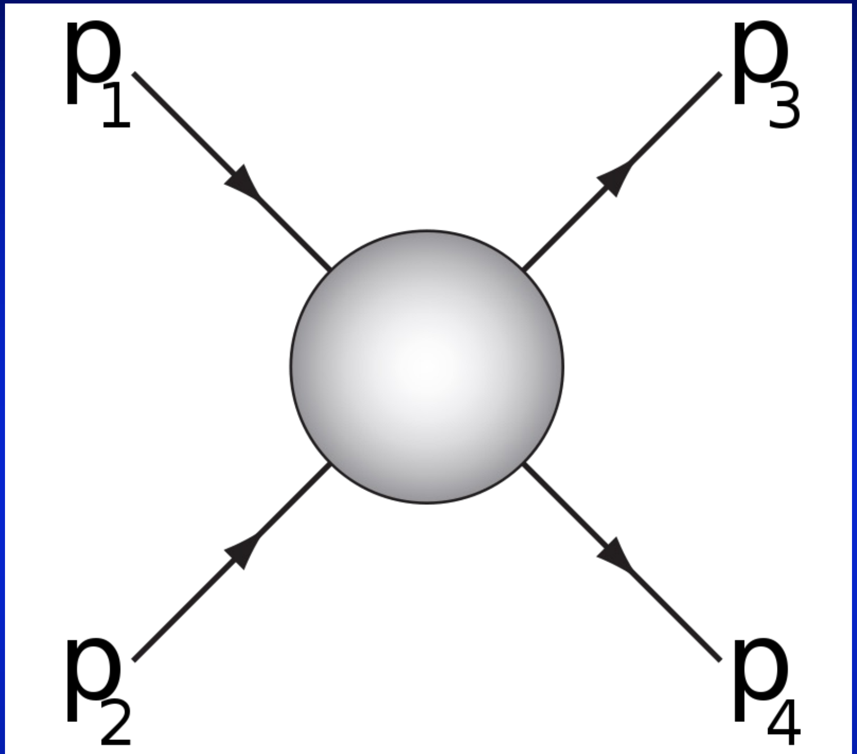
SUMMARY: AT LEAST 6.26 σ ODDERON

An at least 6.26 σ Odderon effect



A discovery level, **model independent** Odderon effect at TeV scale.
Published: Eur. Phys. J. C **81**, 180 (2021).
https://doi.org/10.1140/epjc/s10052-021-08867-6
Domain of validity of H(x) scaling: full x =-tB range of D0 at 1.96 TeV.
Published result confirmed with NEW, model INDEPENDENT result !
Model dependent results, using the ReBB model
Significance ≥ 7.08 σ , see e-Print: 2005.14319 [hep-ph]

Mandelstam variables



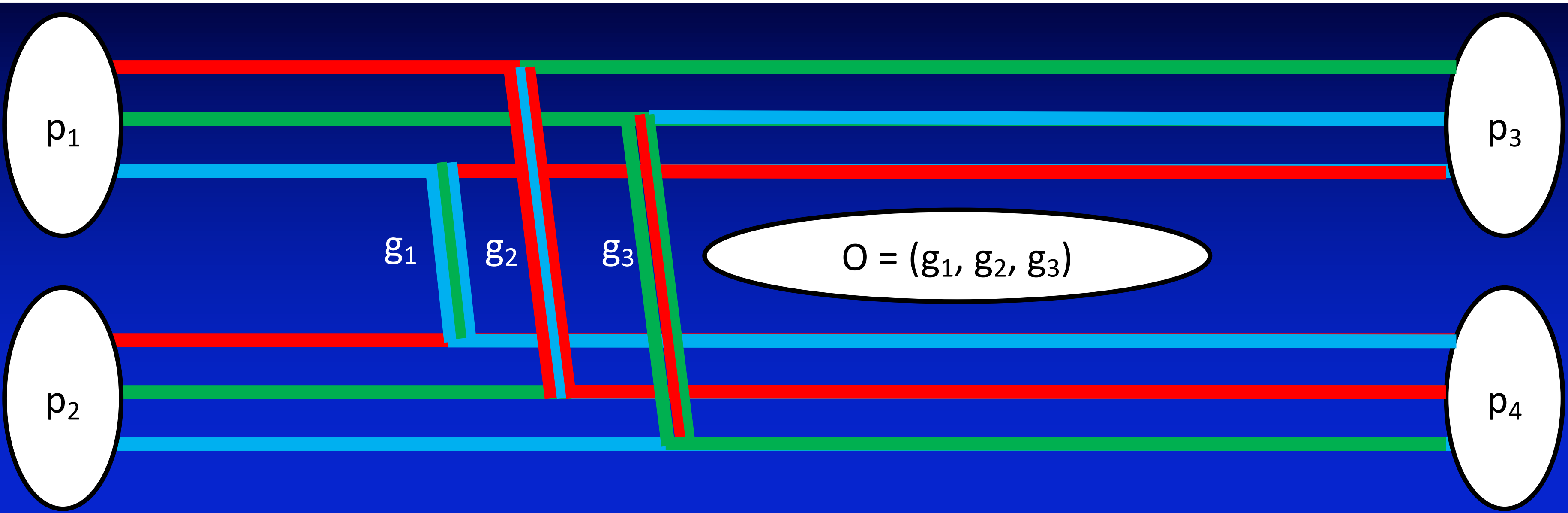
$$s = (p_1 + p_2)^2 = (p_3 + p_4)^2$$
$$t = (p_1 - p_3)^2 = (p_4 - p_2)^2$$
$$u = (p_1 - p_4)^2 = (p_3 - p_2)^2$$

p_1,p_2: four-momenta
before elastic scattering

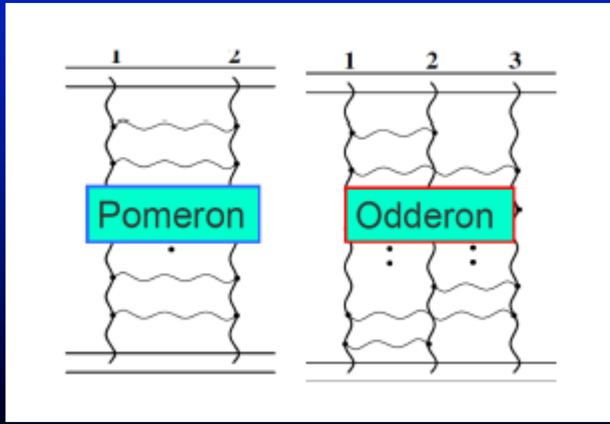
p_3,p_4: four-momenta
after elastic scattering

s: square of the cms energy
t: square of four-momentum transfer

Odderon and QCD in Laymen's Terms



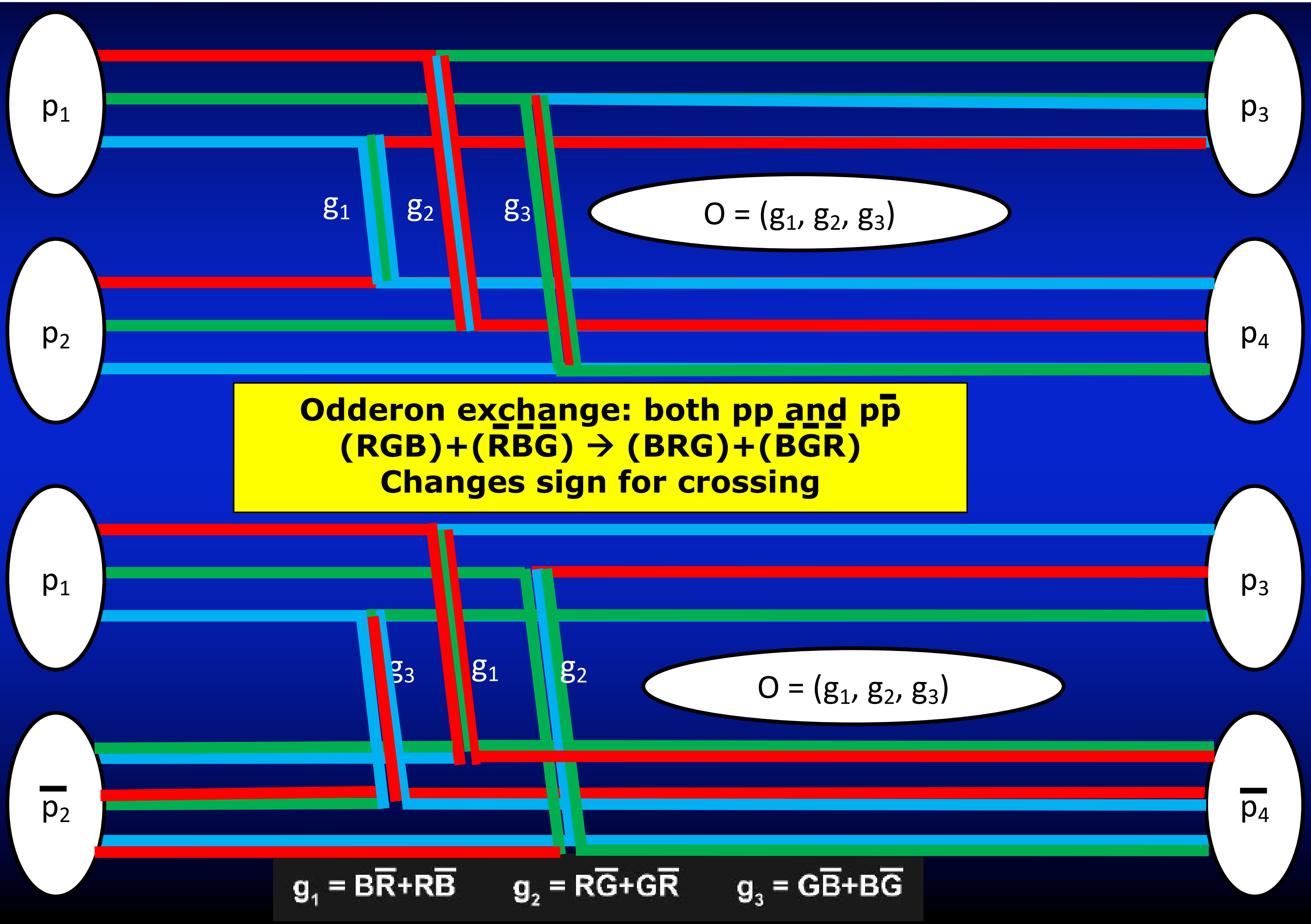
$g_1 = B\bar{R} + R\bar{B}$ $g_2 = R\bar{G} + G\bar{R}$ $g_3 = G\bar{B} + B\bar{G}$



Pomeron (2+4+…) gluon in pp:
(RGB)+(RGB) → (GRB)+(GRB)

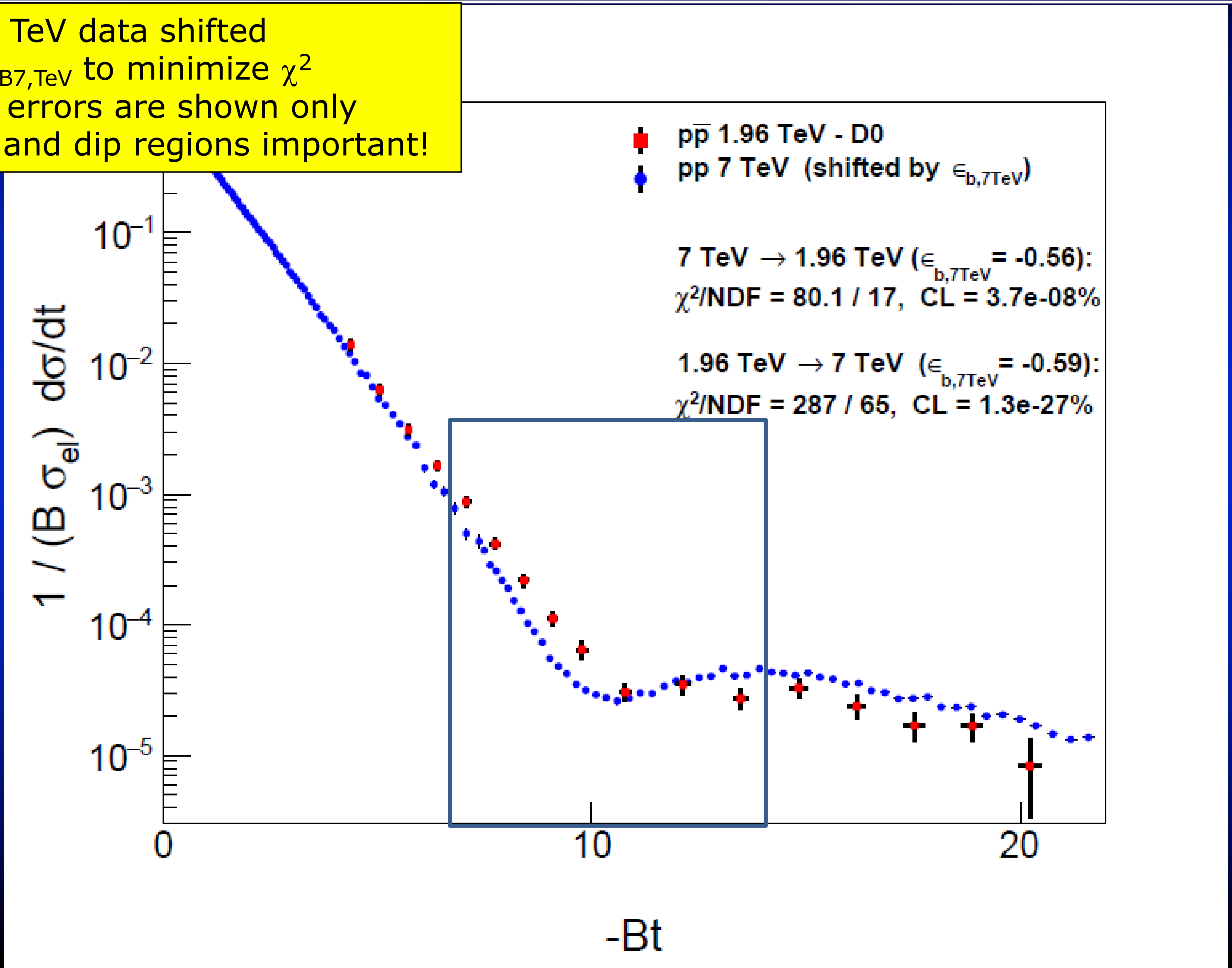
Odderon (3+5+… gluon) in pp:
(RGB)+(RGB) → (GBR)+(BRG)
Well established in QCD

Odderon and elastic collisions



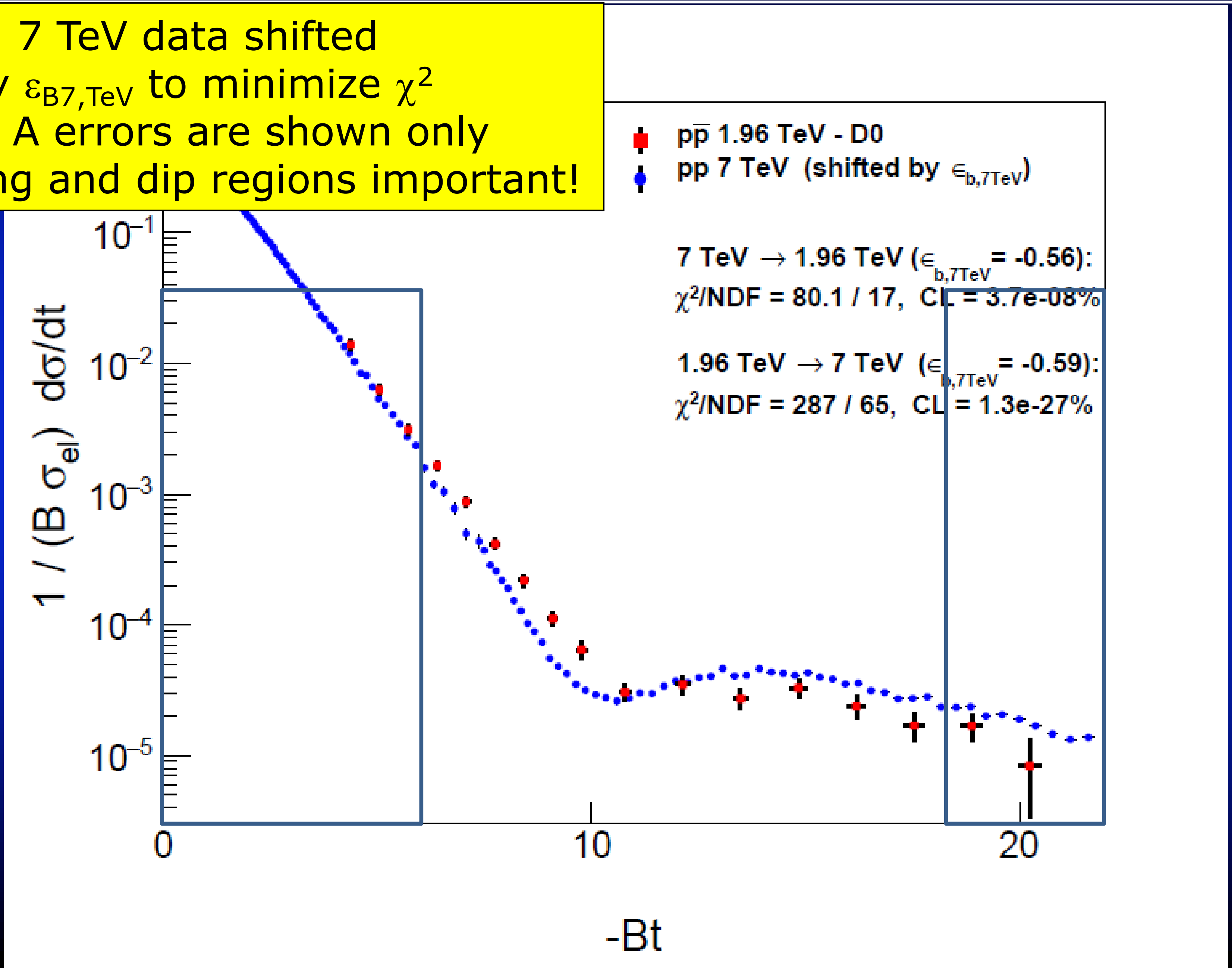
SLIDING WINDOWS

7 TeV data shifted
by $\varepsilon_{B7,TeV}$ to minimize χ^2
Type A errors are shown only
Both swing and dip regions important!



CLOSING DOORS

7 TeV data shifted
by $\varepsilon_{B7,TeV}$ to minimize χ^2
Type A errors are shown only
Both swing and dip regions important!



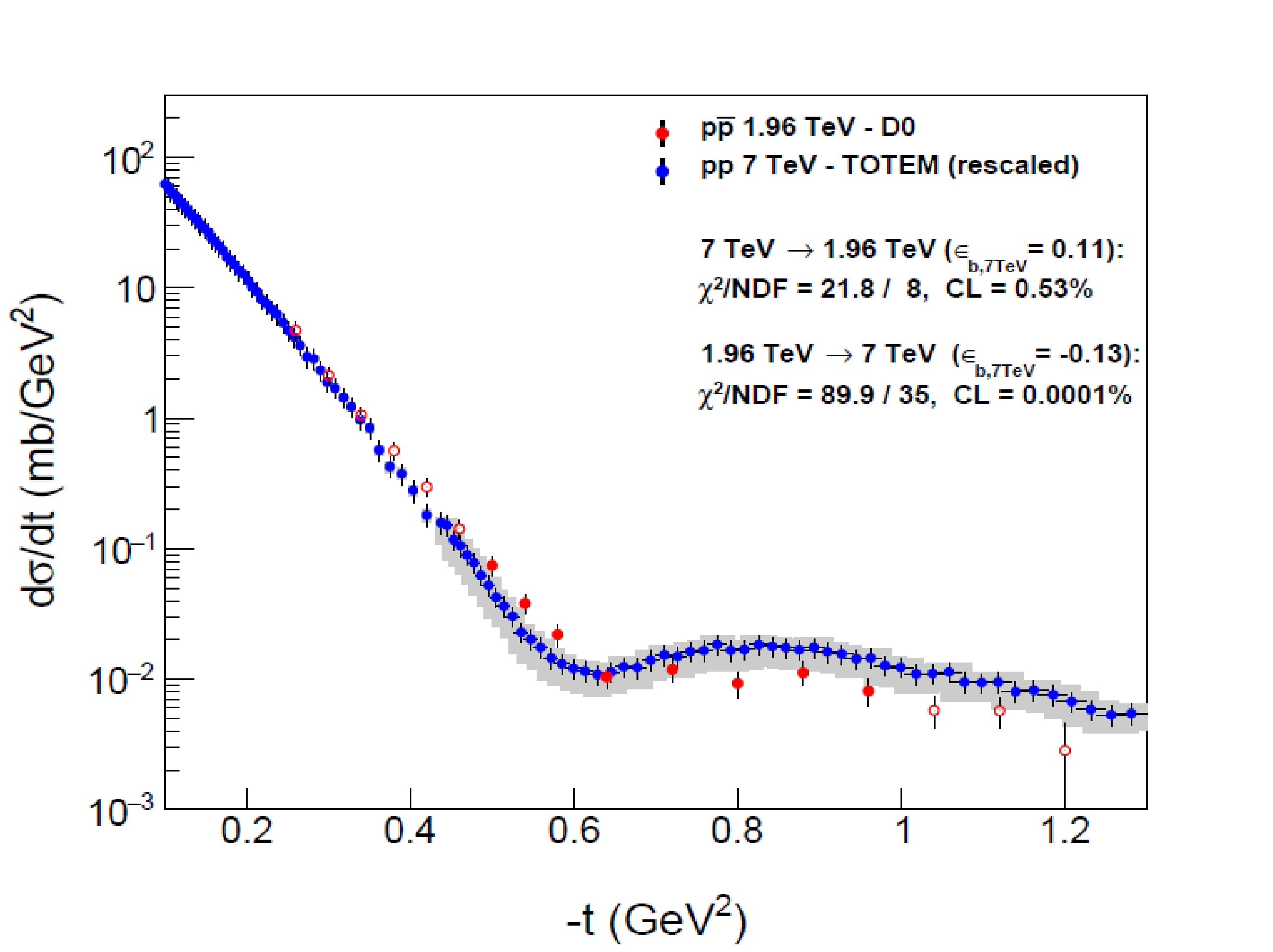
RESULTS FOR CLOSING DOORS

Two sliding doors of size n and size m:
(n,m): Leaving out the first n and last m D0 point

Sliding door technique with two wings (n,m) Left door excludes the first n, right door excludes the last m D0 points			
n	m	Odderon signal	Background
2	2	6.27 σ	1.68 σ
3	2	6.33 σ	1.70 σ
4	2	6.21 σ	2.37 σ
2	1	6.11 σ	TBD
2	2	6.27 σ	TBD
2	3	5.90 σ	TBD

New MODEL INDEPENT RESULT
Odderon signal at least 6.33 σ

D0/TOTEM FIRMS UP OUR RESULTS



If we study dσ/dt and limit **our analysis to the same range as D0/TOTEM:** Significance reduces to **5.01 σ effect,** due to leaving out 9 D0 points

If we conservatively optimize coefficient $\varepsilon_{B,7TeV}$ of point-to-point correlated errors: **2.79 σ**
Significance of D0/TOTEM for dσ/dt: **3.4 σ**

If we add D0's 14.4 % overall correlated error to fluctuating errors, for all D0 data: Our *published* value is **3.27 σ**

Recent results from D0/TOTEM

including our contributions

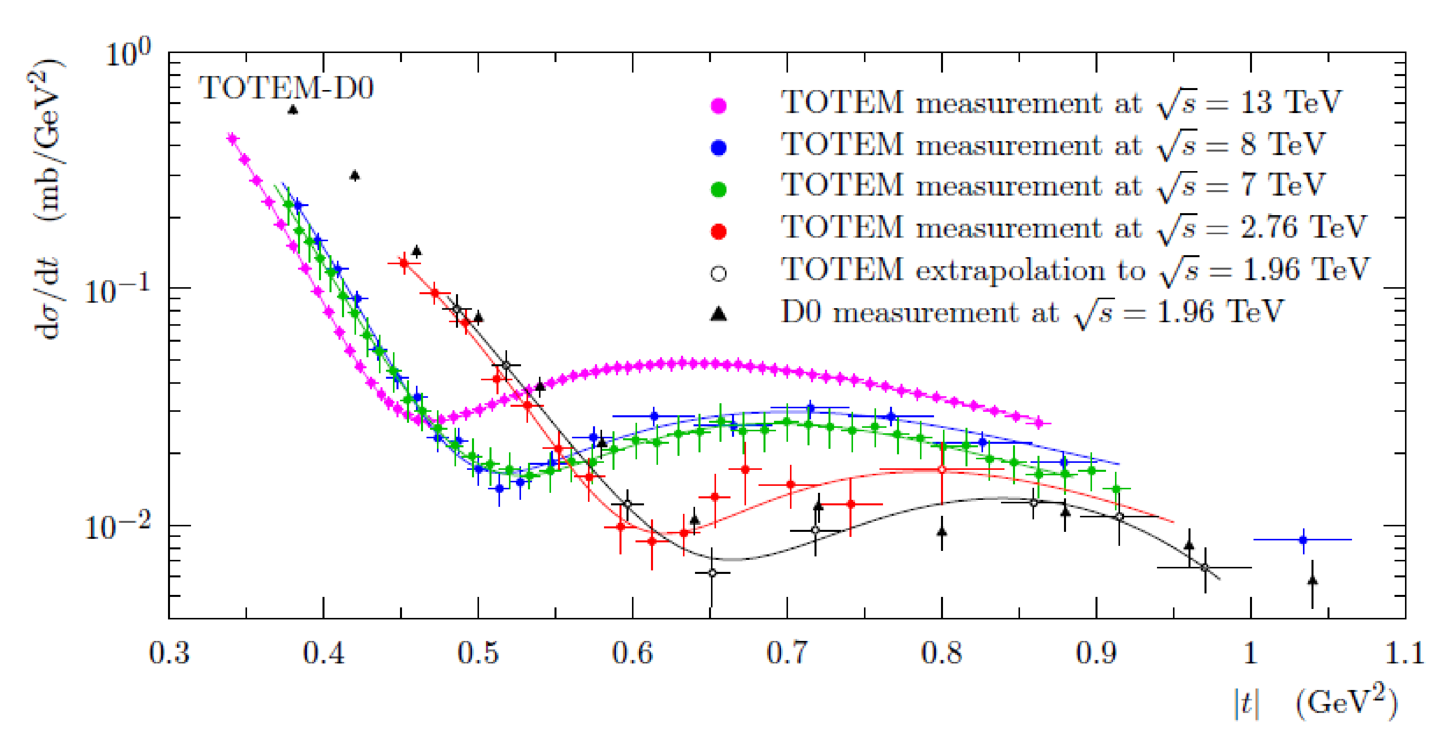
Comparison of pp and $p\bar{p}$ differential elastic cross sections and observation of the exchange of a colorless C-odd gluonic compound #1

D0 and TOTEM Collaborations • V.M. Abazov (Dubna, JINR) et al. (Dec 7, 2020)

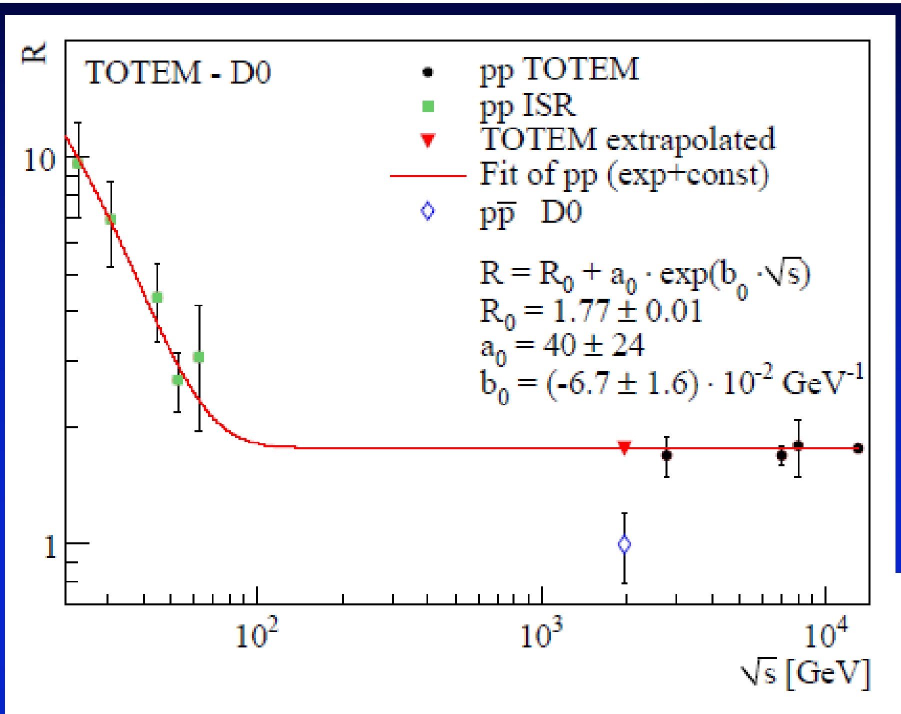
e-Print: 2012.03981 [hep-ex]

pdf links cite 1 citation

Submitted to PRL in December 2020. Uses *13, 8*, 7 and 2.76 TeV TOTEM data, *limited in -t* to the dip-bump structure.



APPENDIX: D0/TOTEM Fig. 2 OK



Our cross-test of Fig. 2 of arxiv:2012.03981:
Fits ISR and LHC data with *separate* lines

$p_1^{LHC} = 0.034 \pm 0.050$

Consistent with 0 → fix it to 0!

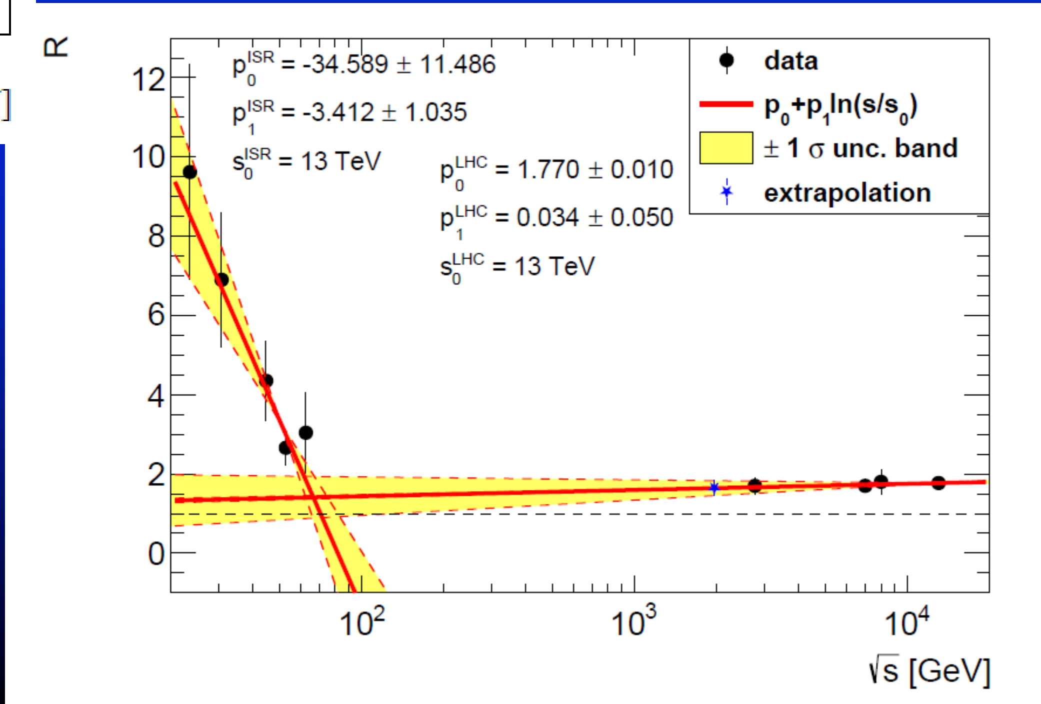
R(pp) = 1.77 ± 0.01 @ 1.96 TeV

→ Reggeon effects negiligble @ 1.96 TeV, OK.

Fig. 2 of arxiv:2012.03981:
Fits ISR and LHC data with *same* curve

R(pp) = 1.77 ± 0.01 @ 1.96 TeV

Reggeon effects from ISR? Test this!



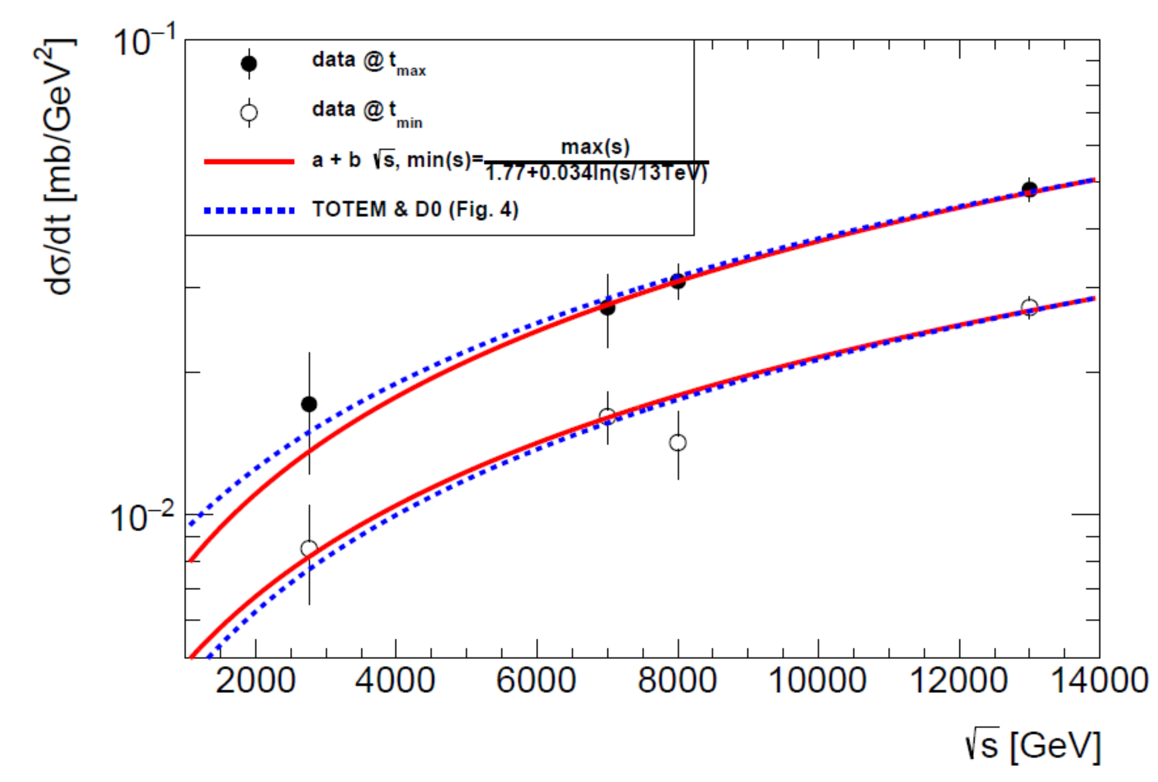
APPENDIX: D0/TOTEM FIG. 3 OK

Our cross-test of
Fig. 3 of [arxiv:2012.03981]:
Fits to max(s) and min(s) neglect the constraint of Fig. 2:

R(s|pp) = max(s|pp)/min(s|pp)

measured to be 1.77 ±0.01 !

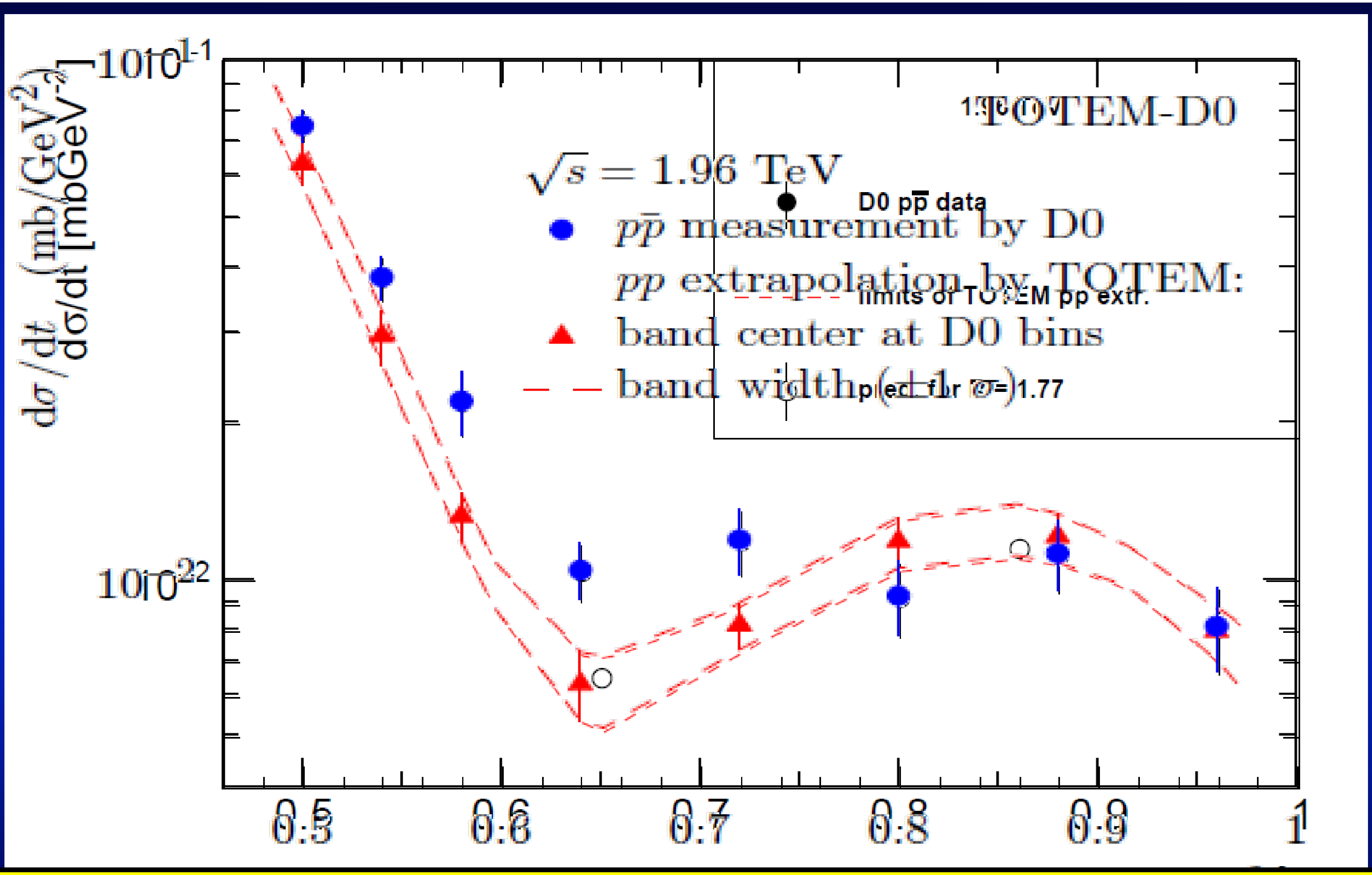
What about constrained fits?



Only two out of three quantities can be fitted independently :
max(s), min(s) and R(s) = max(s) / min(s)
Red lines: min(s|pp) = max(s|pp)/R(s|pp) constrained fits

→ Fig. 3. of D0/TOTEM OK within 1 σ

CROSS-CHECK OF D0/TOTEM FIG. 5



Empty circles from min(s|pp) = max(s|pp)/R(s|pp) <u>constrained fits</u>

→ Fig. 5. of D0/TOTEM OK within 1 σ

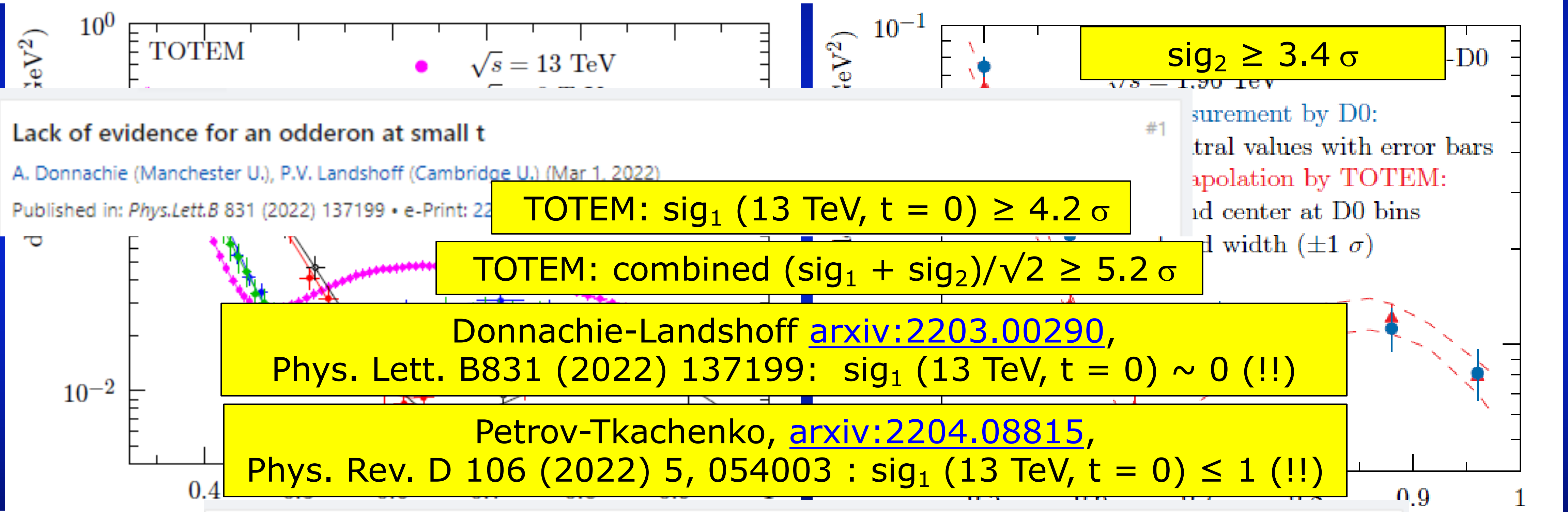
Status of D0-TOTEM Odderon search

Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements #1

TOTEM and D0 Collaborations • V.M. Abazov (Dubna, JINR) et al. (Dec 7, 2020)

Published in: *Phys.Rev.Lett.* 127 (2021) 6, 062003 • e-Print: 2012.03981 [hep-ex]

Phys. Rev. Lett. **127** (2021) 6, 062003, Published: 4 August 2021
https://doi.org/10.1103/PhysRevLett.127.062003



sig$_2$ ≥ 3.4 σ

Lack of evidence for an odderon at small t #1

A. Donnachie (Manchester U.), P.V. Landshoff (Cambridge U.) (Mar 1, 2022)

Published in: *Phys.Lett.B* 831 (2022) 137199 • e-Print: 22

TOTEM: sig$_1$ (13 TeV, t = 0) ≥ 4.2 σ

TOTEM: combined (sig$_1$ + sig$_2$)/√2 ≥ 5.2 σ

Donnachie-Landshoff arxiv:2203.00290,
Phys. Lett. B831 (2022) 137199: sig$_1$ (13 TeV, t = 0) ~ 0 (!!)

Petrov-Tkachenko, arxiv:2204.08815,
Phys. Rev. D 106 (2022) 5, 054003 : sig$_1$ (13 TeV, t = 0) ≤ 1 (!!)

It is shown tha

Coulomb-nuclear interference: Theory and practice for pp-scattering at 13 TeV #3

TOTEM – D0 detailed response :
in preparation, see also
K. Österberg's talk at LHC Forward Physics meeting, Oct 2022

$\rho = 0.10 \pm 0.04,$
$0.01 \lesssim |t| \lesssim 0.05$ GeV^2.

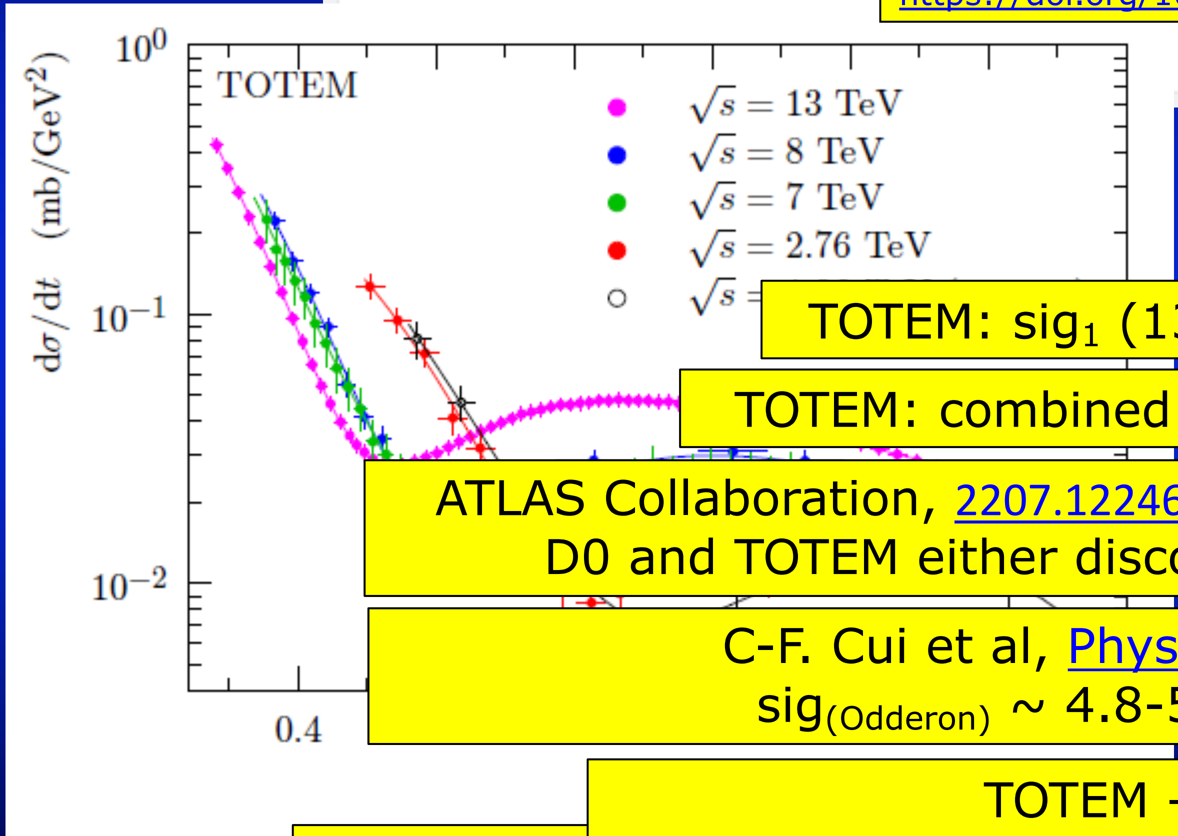
Status of D0-TOTEM Odderon 2.0

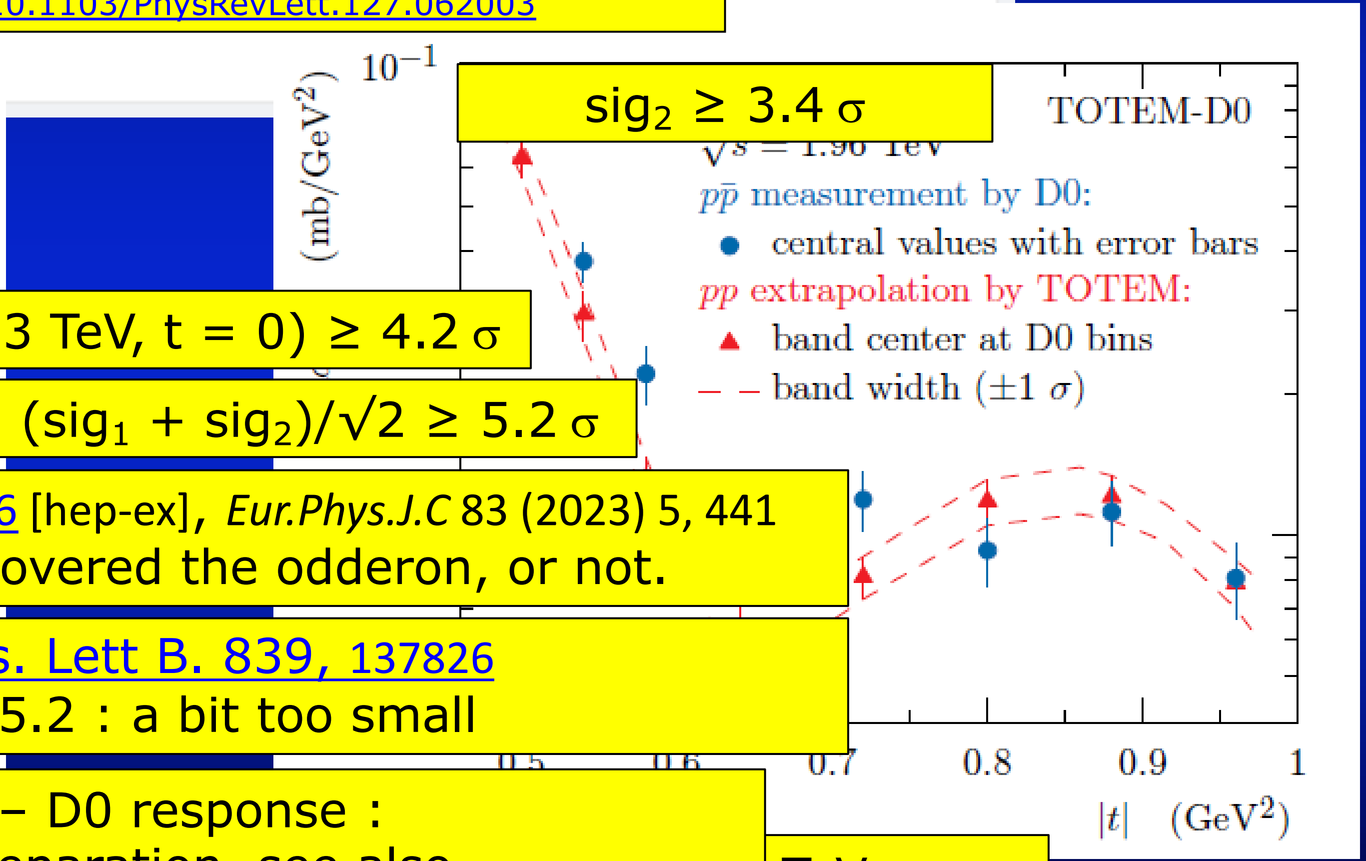
Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements #1

TOTEM and D0 Collaborations • V.M. A

Published in: *Phys.Rev.Lett.* 127 (2021) 6

Phys. Rev. Lett. **127** (2021) 6, 062003, Published: 4 August 2021
https://doi.org/10.1103/PhysRevLett.127.062003





$sig_2 \geq 3.4\ \sigma$

TOTEM: sig_1 (13 TeV, t = 0) $\geq 4.2\ \sigma$

TOTEM: combined $(sig_1 + sig_2)/\sqrt{2} \geq 5.2\ \sigma$

ATLAS Collaboration, 2207.12246 [hep-ex], *Eur.Phys.J.C* 83 (2023) 5, 441
D0 and TOTEM either discovered the odderon, or not.

C-F. Cui et al, Phys. Lett B. 839, 137826
$sig_{(Odderon)} \sim$ 4.8-5.2 : a bit too small

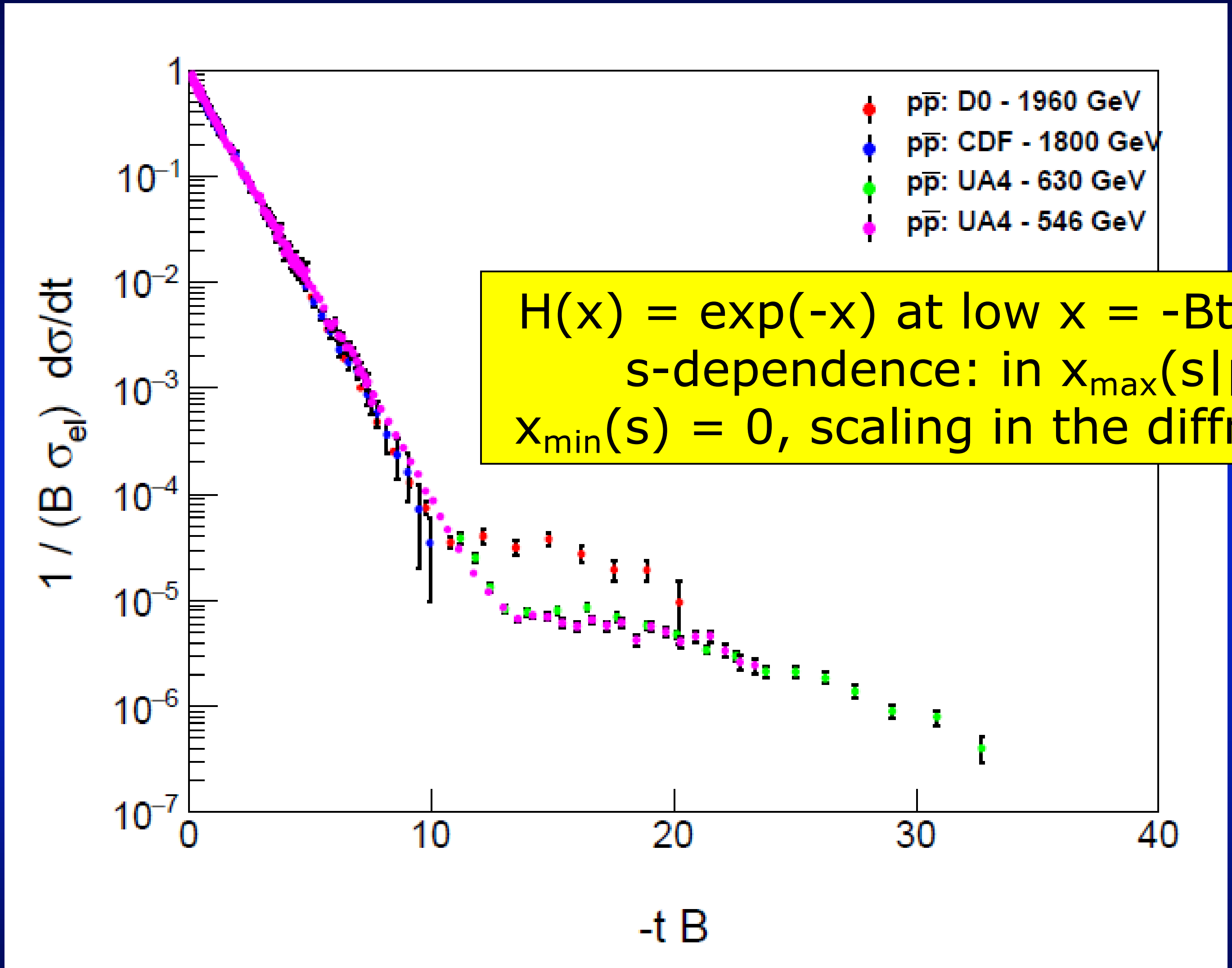
C0: i ... TeV

TOTEM – D0 response :
Paper in preparation, see also
K. Österberg's talk at ISMD 2023
in August 2023 and at Diffraction and Low-x 2024

NEW RESULTS 1

H(x) SCALING, USING 8 TeV

H(x) scaling for p antip scattering



$H(x) = \exp(-x)$ at low $x = -Bt$ at ~ every s
s-dependence: in $x_{max}(s|p+antip)$
$x_{min}(s) = 0$, scaling in the diffractive cone !

Energy range: 546 GeV – 1.96 TeV
Qualitatively different from pp: scaling in the cone only for p+antip

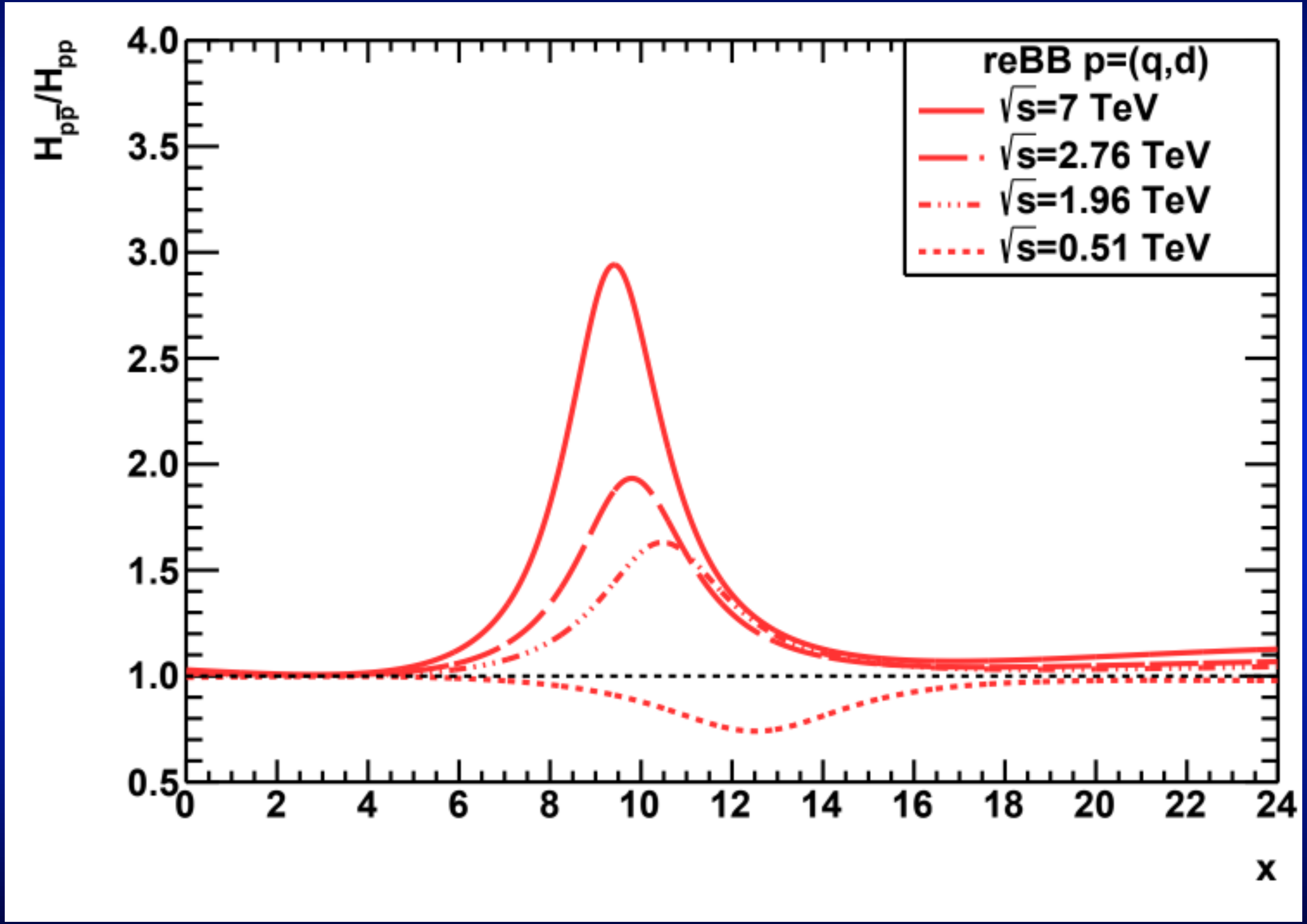
Where is the Odderon signal from?

Swing, interference, tail regions
Interference region is dominant

Partial significances from the swing, interference, tail and all regions, characterized by $x_{min} < x \leq x_{max}$					
x_{min}	x_{max}	ε_{B21} of min $\Delta\chi^2$ in $x_{min} < x \leq x_{max}$	$\Delta\chi^2$ in $x_{min} < x \leq x_{max}$	NDF in $x_{min} < x \leq x_{max}$	σ in $x_{min} < x \leq x_{max}$
5.1	8.4	1.90	4.19	5	0.64
8.4	13.5	-0.49	25.31	5	3.84
13.5	20.2	-1.39	1.79	5	0.15
5.1	13.5	0.28	48.27	10	5.01
8.4	20.2	-0.96	35.79	10	3.91
5.1	20.2	-0.60	75.41	15	6.23

OBSERVATION OF ODDERON

2020 → 2O2O

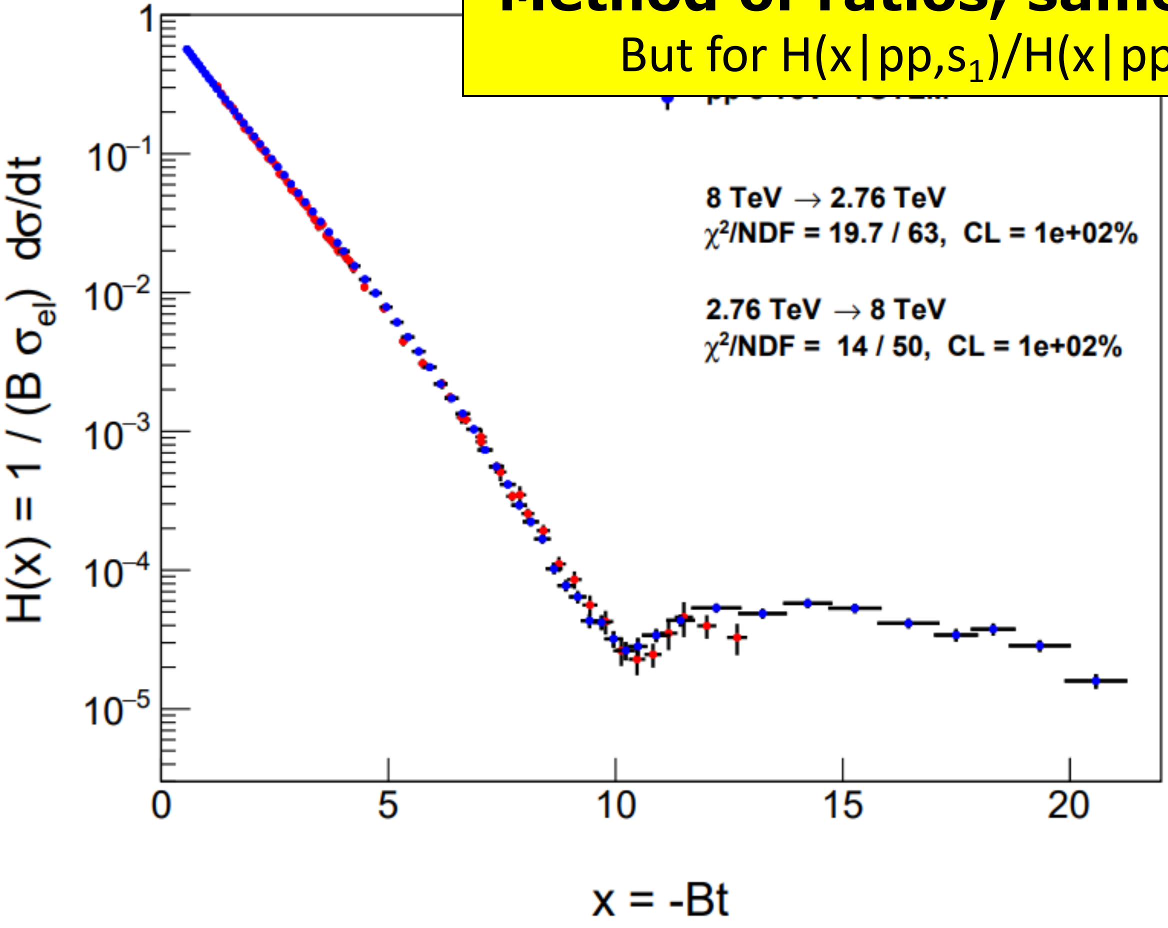


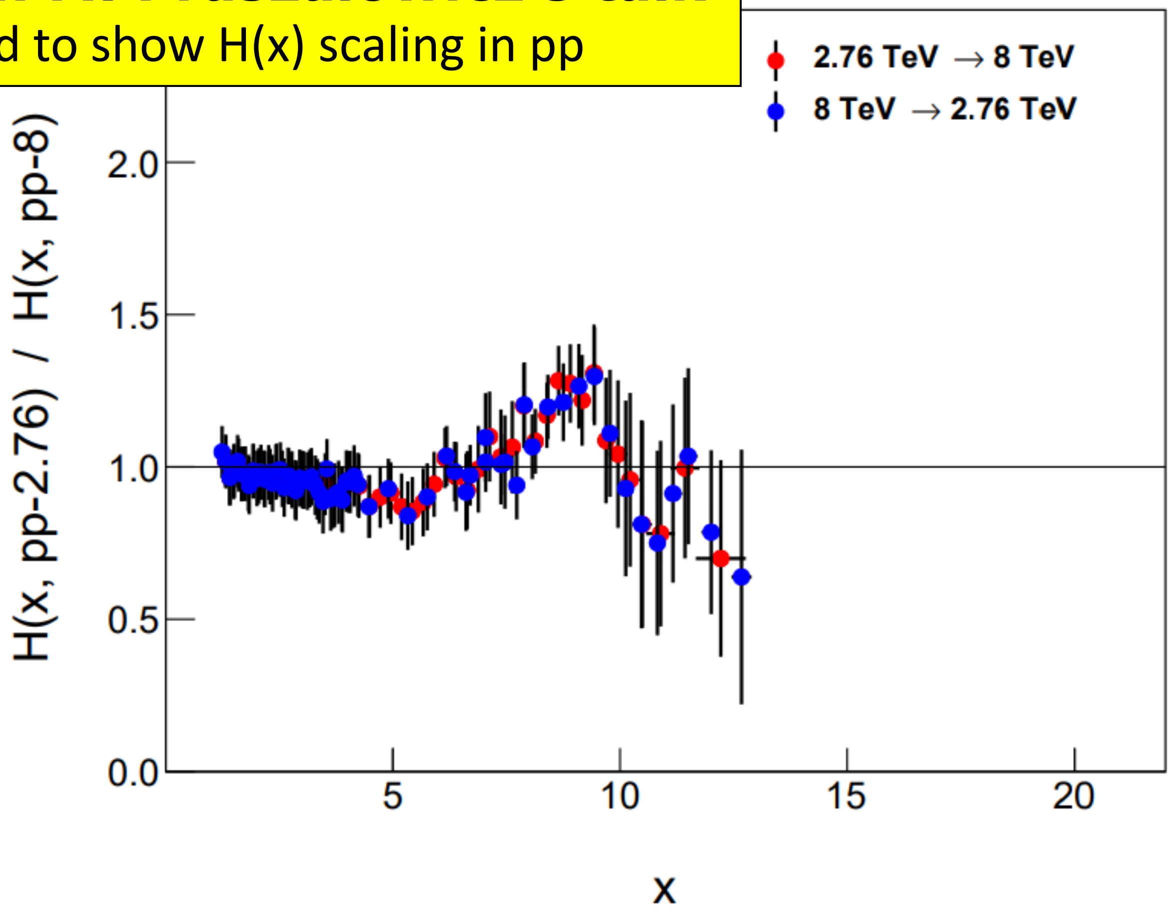
Prediction for 510 GeV pp @ RHIC: scaling violations

Test of H(x) scaling: 8 vs 2.76 TeV

Method of ratios, same as in M. Praszalowicz's talk

But for $H(x|pp,s_1)/H(x|pp,s_2)$ and to show H(x) scaling in pp





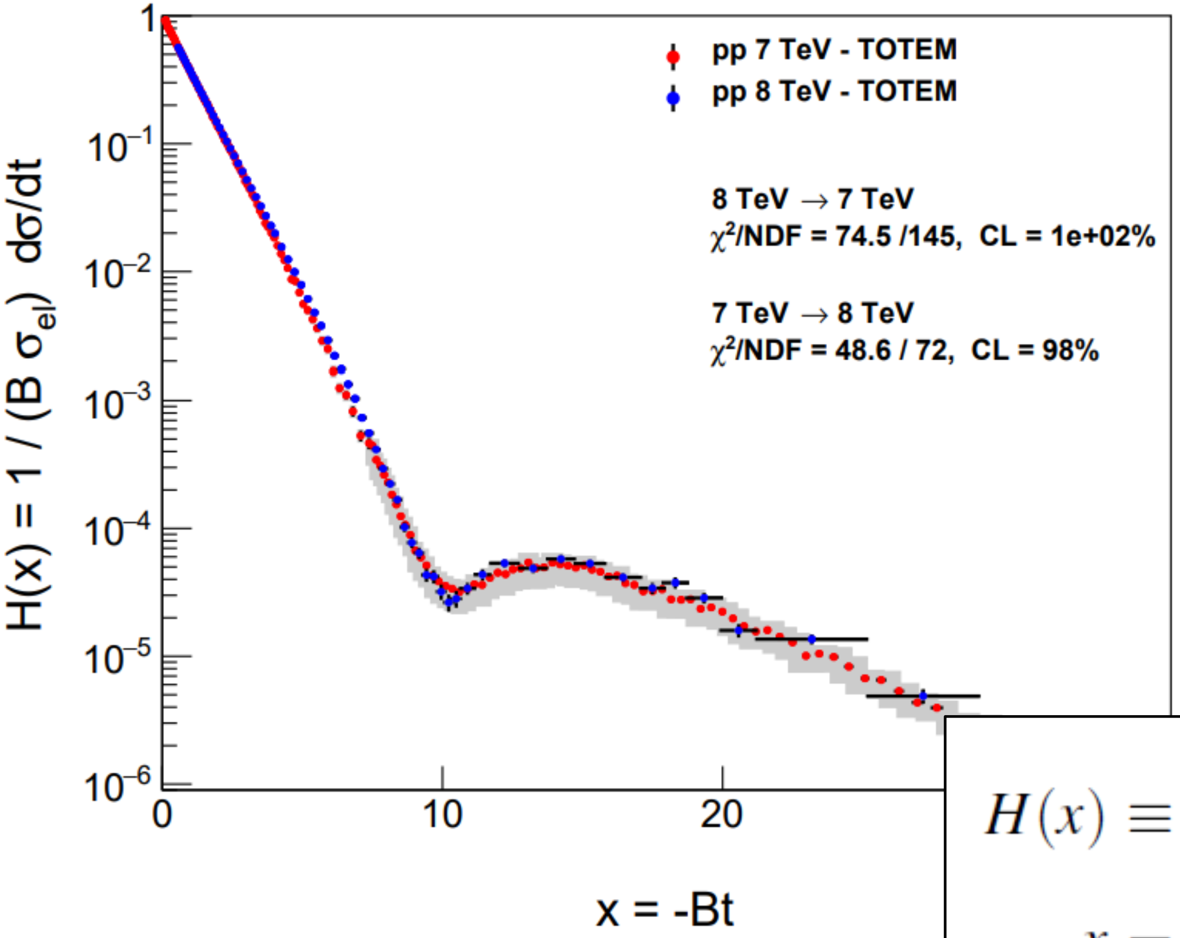
Between 2.76 and 8 TeV, H(x) scaling observed!

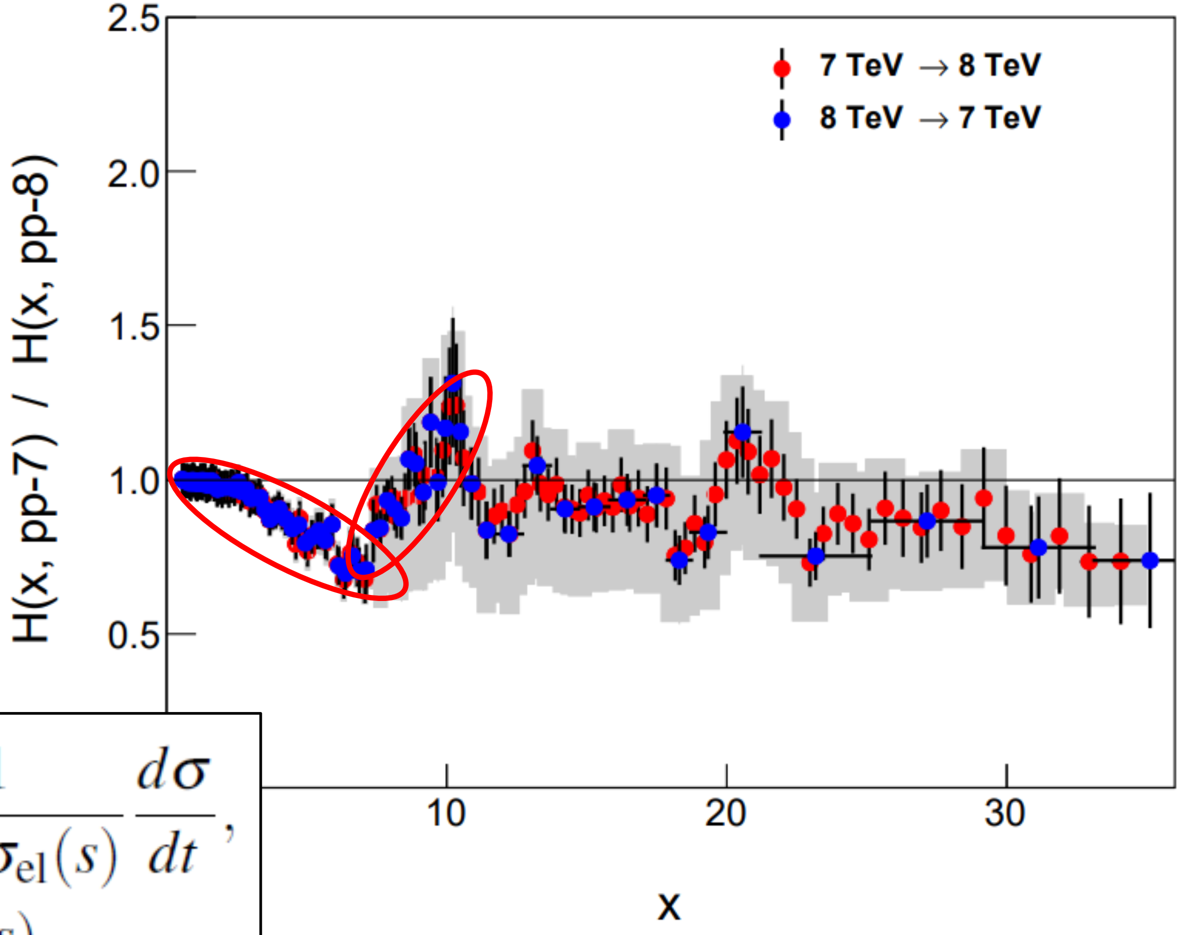
Hungarian-Swedish team, e-Print: 2405.06733 [hep-ph],

MDPI Universe **2024**, *10*(6), 264

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

Test of H(x) scaling: 8 vs 7 TeV TOTEM





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

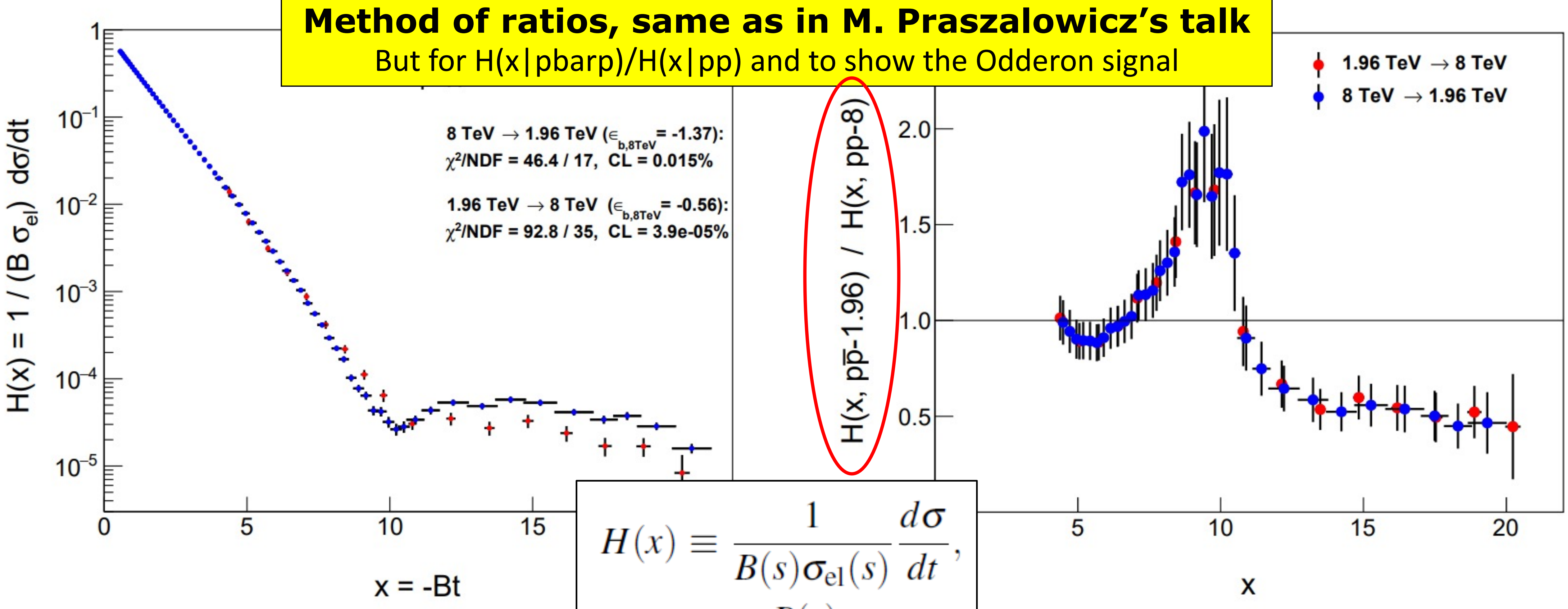
Between 7 and 8 TeV, H(x) scaling observed, but ...

Hungarian-Swedish team, e-Print: 2405.06733 [hep-ph],

MDPI Universe **2024**, *10*(6), 264

Odderon of H(x) scaling: 8 vs 1.96 TeV

Method of ratios, same as in M. Praszalowicz's talk
But for H(x|pbarp)/H(x|pp) and to show the Odderon signal



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

Between 1.96 and 8 TeV, H(x|s,pp) and H(x|s,pbarp) are clearly different, with 3 < 3.79 < 5 σ
Hungarian-Swedish team, e-Print: 2405.06733 [hep-ph], MDPI Universe **2024**, *10*(6), 264

Odderon significances from H(x) scaling

$\sqrt{s}$ (TeV)	χ^2	NDF	CL	significance (σ)
1.96 vs. 2.76	3.85	11	9.74×10^{-1}	0.03
1.96 vs. 7	80.1	17	3.681×10^{-10}	6.26
1.96 vs. 8	46.4	17	1.502×10^{-4}	3.79

$\sqrt{s}$ (TeV)	χ^2	NDF	CL	χ^2/NDF method	combined σ Stouffer's method
1.96 vs 2.76 & 8	50.25	28	6.064×10^{-3}	2.74	2.70
1.96 vs 2.76 & 7	83.95	28	1.698×10^{-7}	5.22	4.44
1.96 vs 2.76 & 7 & 8	130.35	45	2.935×10^{-10}	6.30	5.81
1.96 vs 7 & 8	126.5	34	1.415×10^{-12}	7.08	7.10

If 1.96, 2.76, 7 and 8 TeV data are combined, H(x) significances on all data results in 5 < 5.8 σ
If 1.96, 7 and 8 TeV data are combined, at least 7.08 σ.

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