Model independent Odderon results

based on new TOTEM pp elastic data at 8 TeV

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Outline

Statistically Significant Observations of Odderon in 2021

Model independent (Hungarian-Swedish Collaboration):

Significance ≥ 6.26 σ : *EPJC (2021) 81:180*

Model dependent (Hungarian-Polish Collaboration):

Significance ≥ 7.08 σ :

EPJC (2021) 81:611 and EPJC (2022) 82:827

Partially model independent (D0-TOTEM Collaboration):

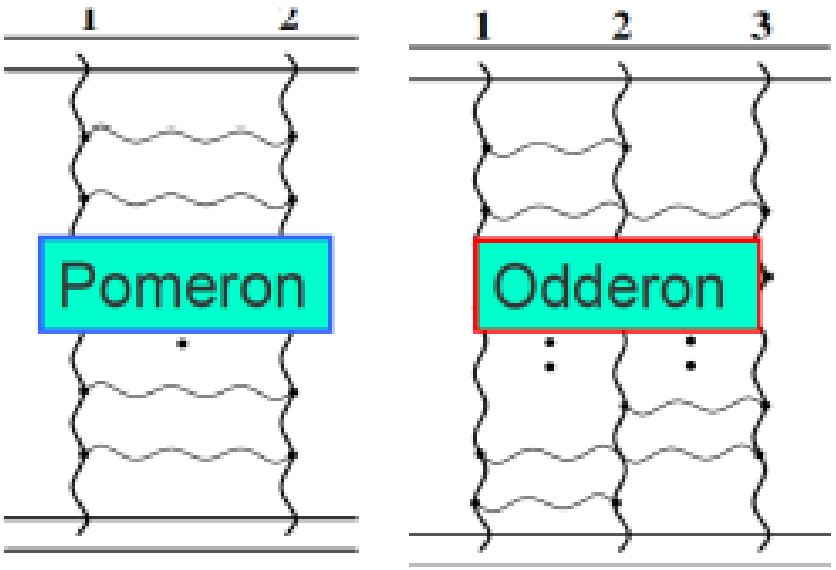
Significance ≥ 5.2 σ : *PRL (2021) 127, 062003*

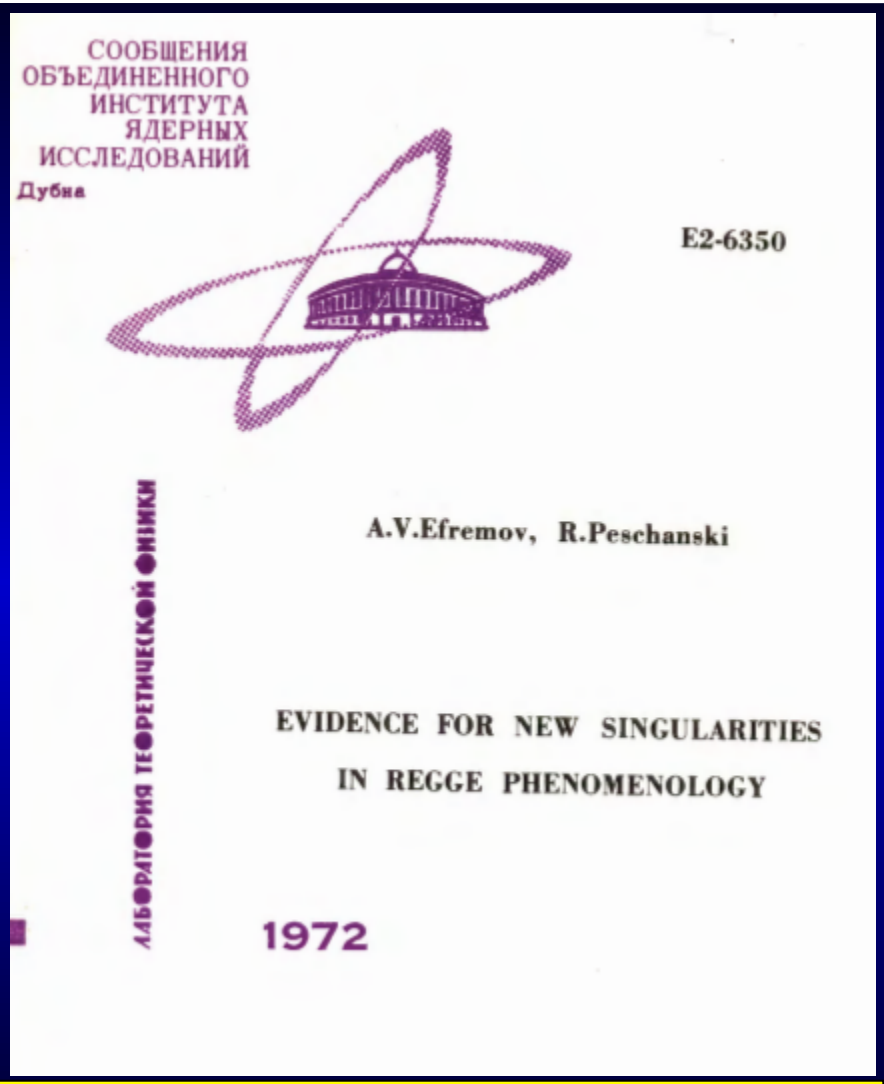
Motivation: In 2022 new TOTEM data at 8 TeV were published

Odderon: 48 years old scientific puzzle

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

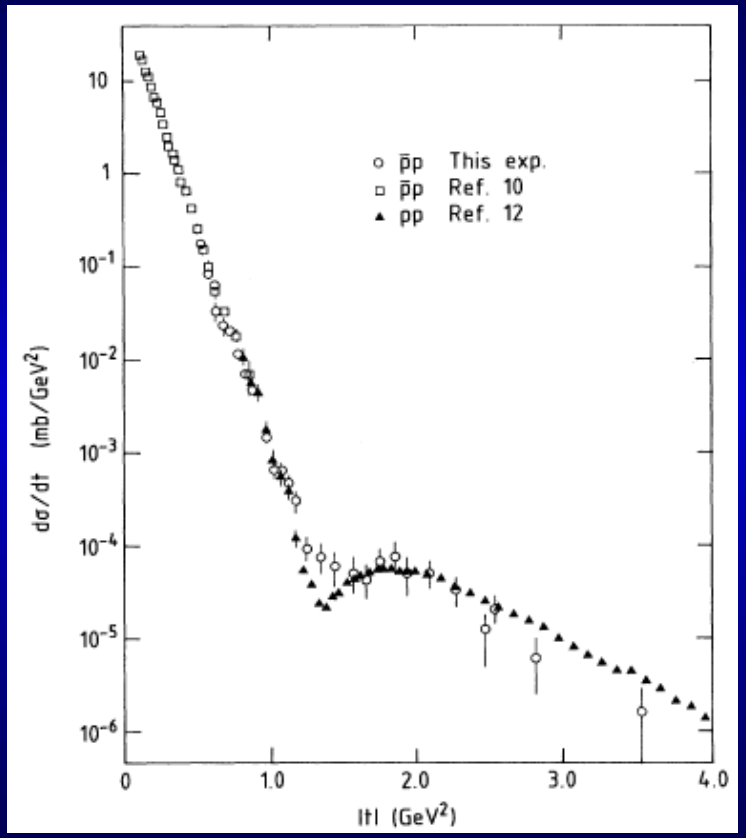


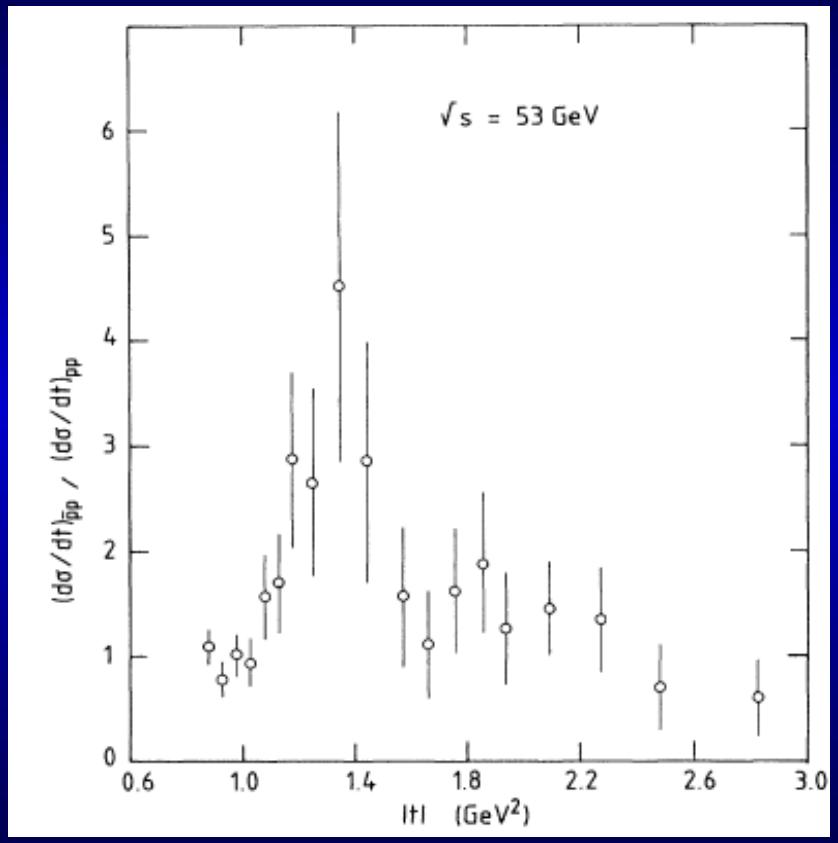


Odderon name coined: D. Joynson, E. Leader, B. Nicolescu, C. Lopez, Nuovo Cim. 30A, 345 (1975) - Well established in QCD by now !
Honorable mention: A. V. Efremov, R. Peschanski, JINR-E2-6350 (1972)

Odderon: 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 $\boldsymbol{\sigma}$

Three 2021 Odderon observations with > 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

pdf DOI cite

Hungarian-Swedish Odderon:
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

pdf DOI cite

Hungarian-Polish Odderon:
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 #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: 20

pdf links DOI cite

D0-TOTEM Odderon:
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: 2111.119

pdf DOI cite

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 (20

pdf DOI cite

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
Presented at Zimányi'22 by I. Szanyi

The model indepedent observation, 2019 -

Definition of the model independent H(x) scaling function made from published pp elastic differential cross-section data:

$H(x) = 1/(B\,\sigma_{el})\ d\sigma/dt$ (~ exp(Bt) at low -t)

B slope at t = 0 (published with $d\sigma/dt$)

σ_{el} total elastic σ (published with $d\sigma/dt$)

$x = -B\,t$

For further details see, for example, in EPJC (2021) 81:180

The model indepedent observation, 2019 -

We defined a general data-data χ^2 derivated from the diagonalized function-data χ^2 defined in the below ref. of PHENIX Collaboration: (backward compatible)

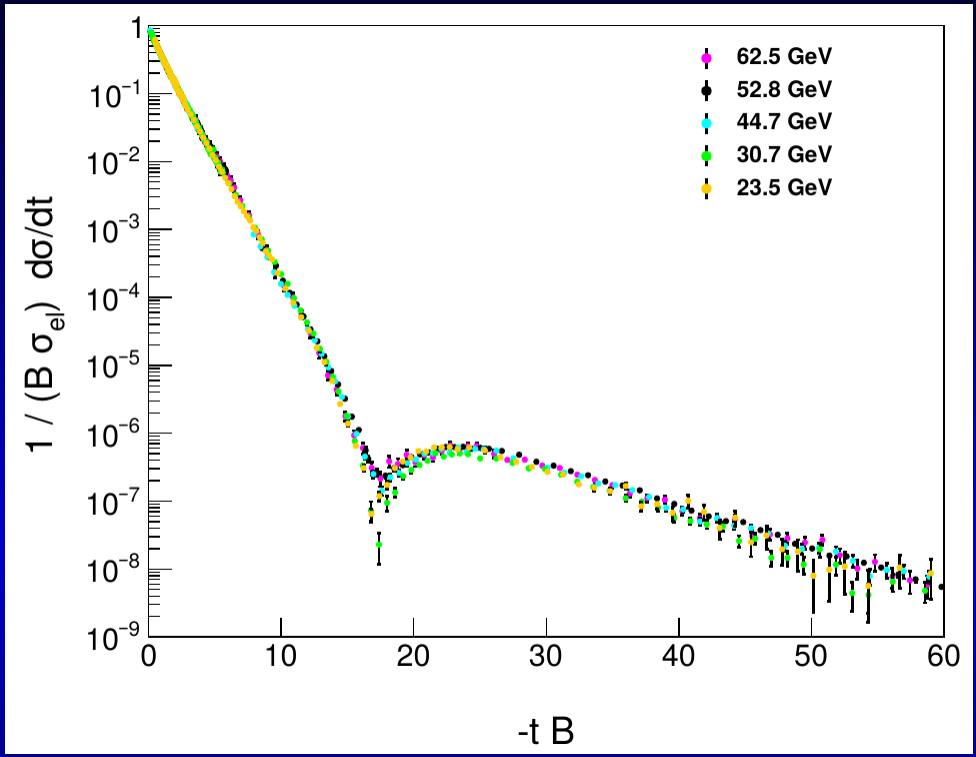
$$\chi^2_{2\to1} = \sum_{j=1}^{n_{21}} \frac{(d_1^j+\epsilon_{b,1}e^j_{B,1}-d^j_{21}-\epsilon_{b,21}e^j_{B,21})^2}{(\tilde{e}^j_{A,1})^2+(\tilde{e}^j_{A,21})^2}+\epsilon^2_{b,1}+\epsilon^2_{b,21},$$

$$\tilde{e}^j_{A,k} = e^j_{A,k}\frac{d^j_k+\epsilon_{b,k}e^j_{B,k}}{d^j_k},$$

$$e^j_{M,k} = \sqrt{(\sigma^j_{M,k})^2+(d'^{,j}_k)^2(\delta^j_{M,k}x)^2},$$

A. Adare et al. (PHENIX), Phys. Rev. **C77**, 064907 (2008), 0801.1665.

The model indepedent observation, 2019 -



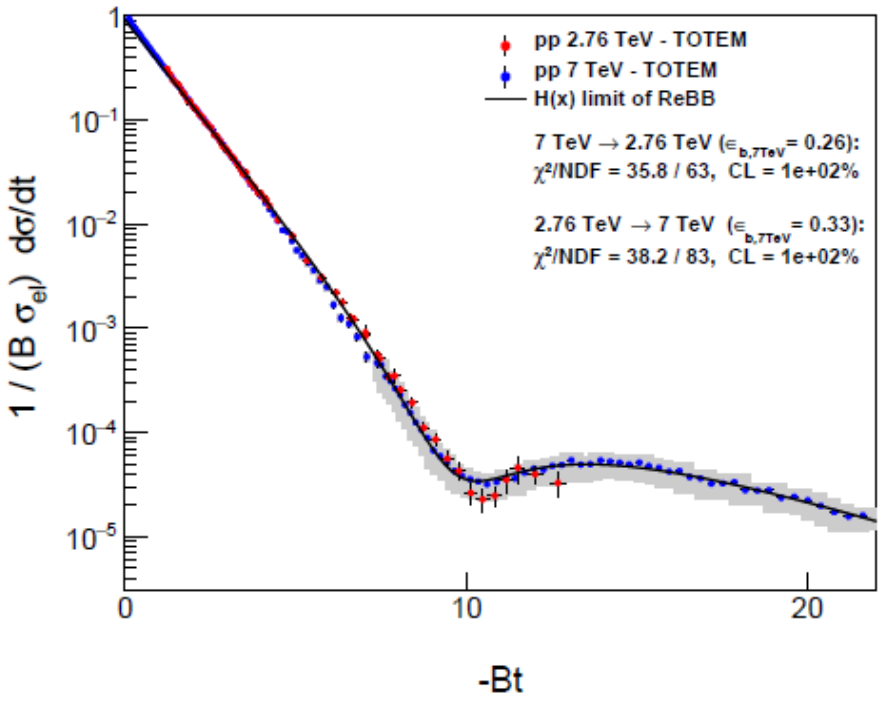
$B \equiv B_0(s)$

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

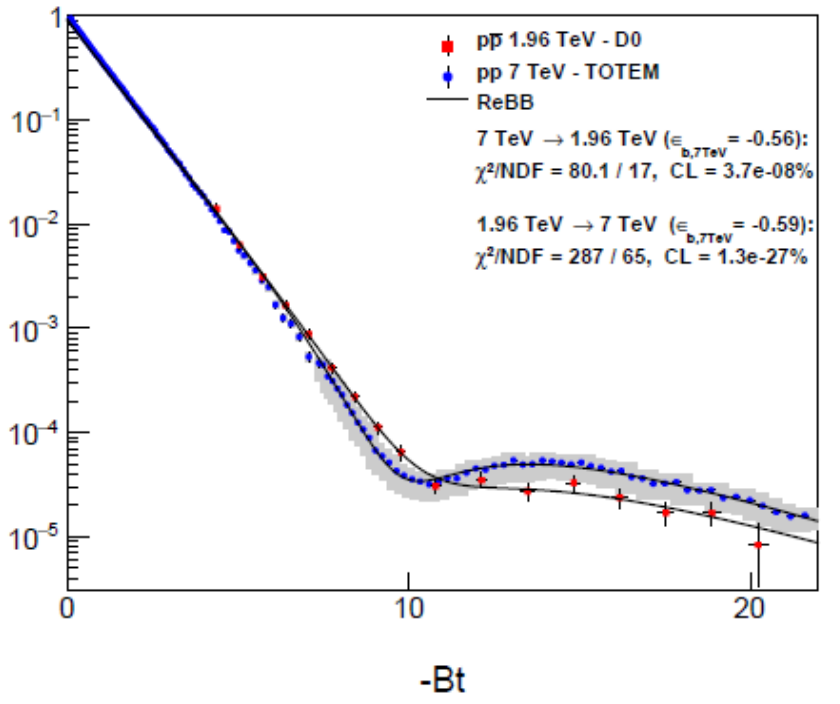
Data agree within 1 σ of standard deviation.

H(x) scaling of elastic p+p scattering data at ISR energies of 23 - 63GeV. (See details in the publication)

The model indepedent observation, 2019 -



H(x) = 1/(B s_{el}) ds/dt vs x = - B t



B ≡ $B_0(s)$ 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**.

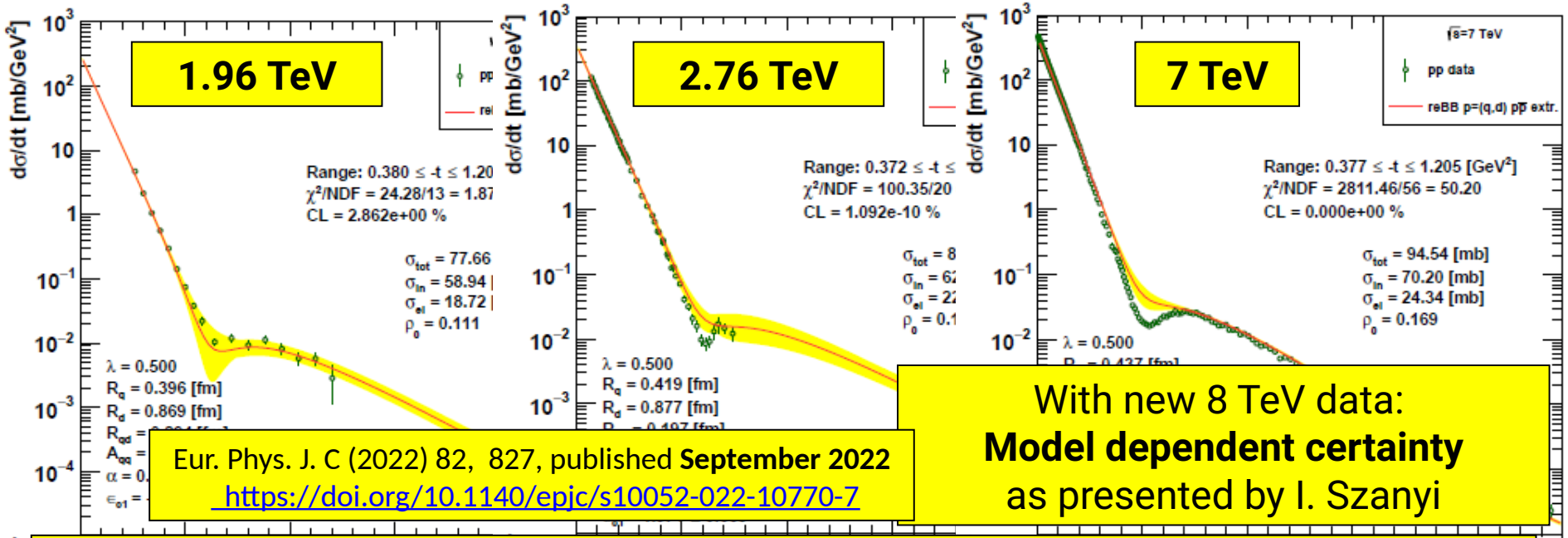
Model dependent observation, 2020-

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 (Ec

e-Print: 2005.14319 [hep-ph]

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



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

With new 8 TeV data:
Model dependent certainty
as presented by I. Szanyi

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 $0.37 \le -t \le 1.2$ GeV^2 and $0.546 \le \sqrt{s} \le 7$ ⍰ 8 TeV

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

Partially model independent, 2020-

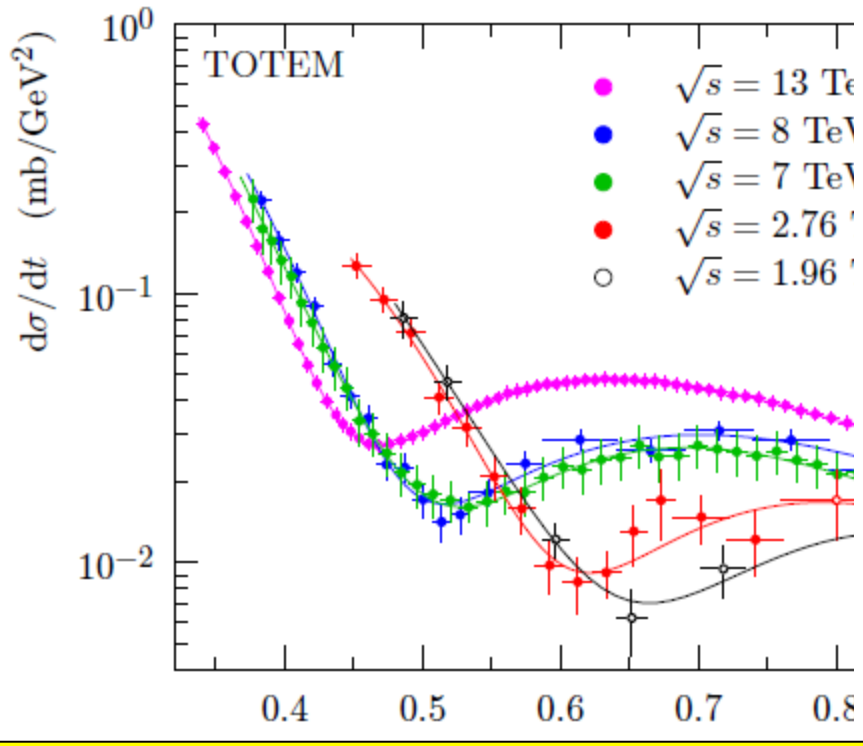
Odderon Exchange from Elastic Scattering Differences between pp and $p\bar{p}$ Data at 1.96 TeV and from pp Forward Scattering Measurements

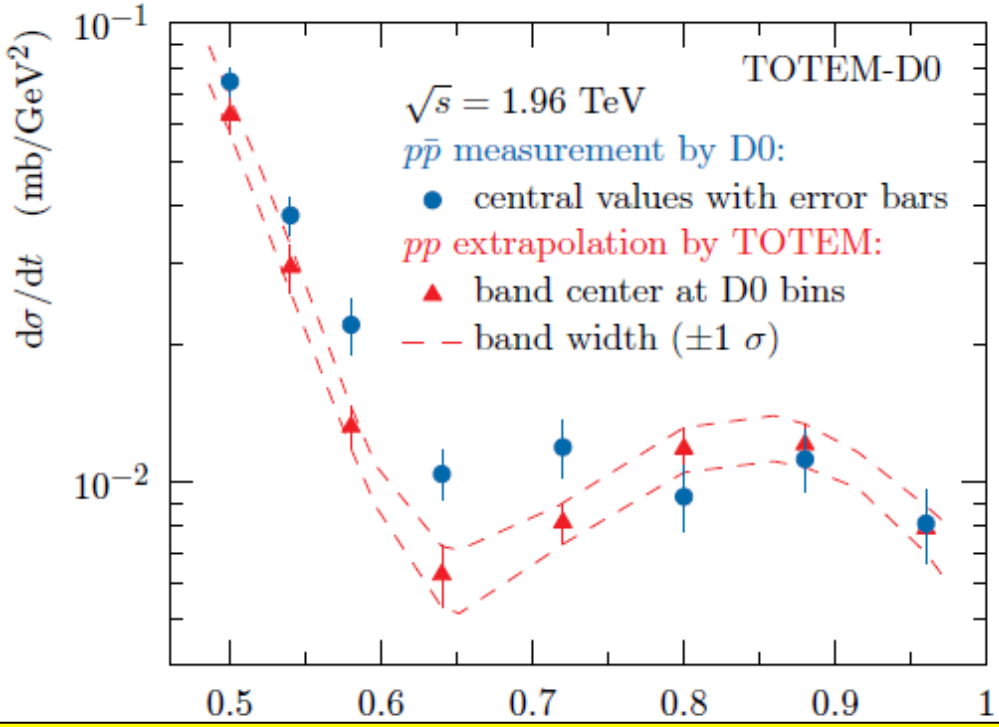
#1

TOTEM and D0 Collaborations • V.M. Abazov (Dubna, JINR) e

Published in: *Phys.Rev.Lett.* 127 (2021) 6, 062003 • e-Print: 20

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





S: Odderon significance ≥ 5.2 σ, C1: ***almost* model independently combined** with √s = 13 TeV data

at t = 0: σ_{tot} and r_0

C2: one additional **pp dataset** at 8 TeV and **one additional data point** at 2.76 TeV,

C3: **8 out of the 17 D0 points are used**

C4: D0 pbarp data and TOTEM pp extrap.data are **assumed** to be **equal at t=0**

Some reflections on D0-TOTEM results

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]

pdf links DOI cite

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

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: 2203.00290 [hep-ph]

pdf DOI cite 3 citations

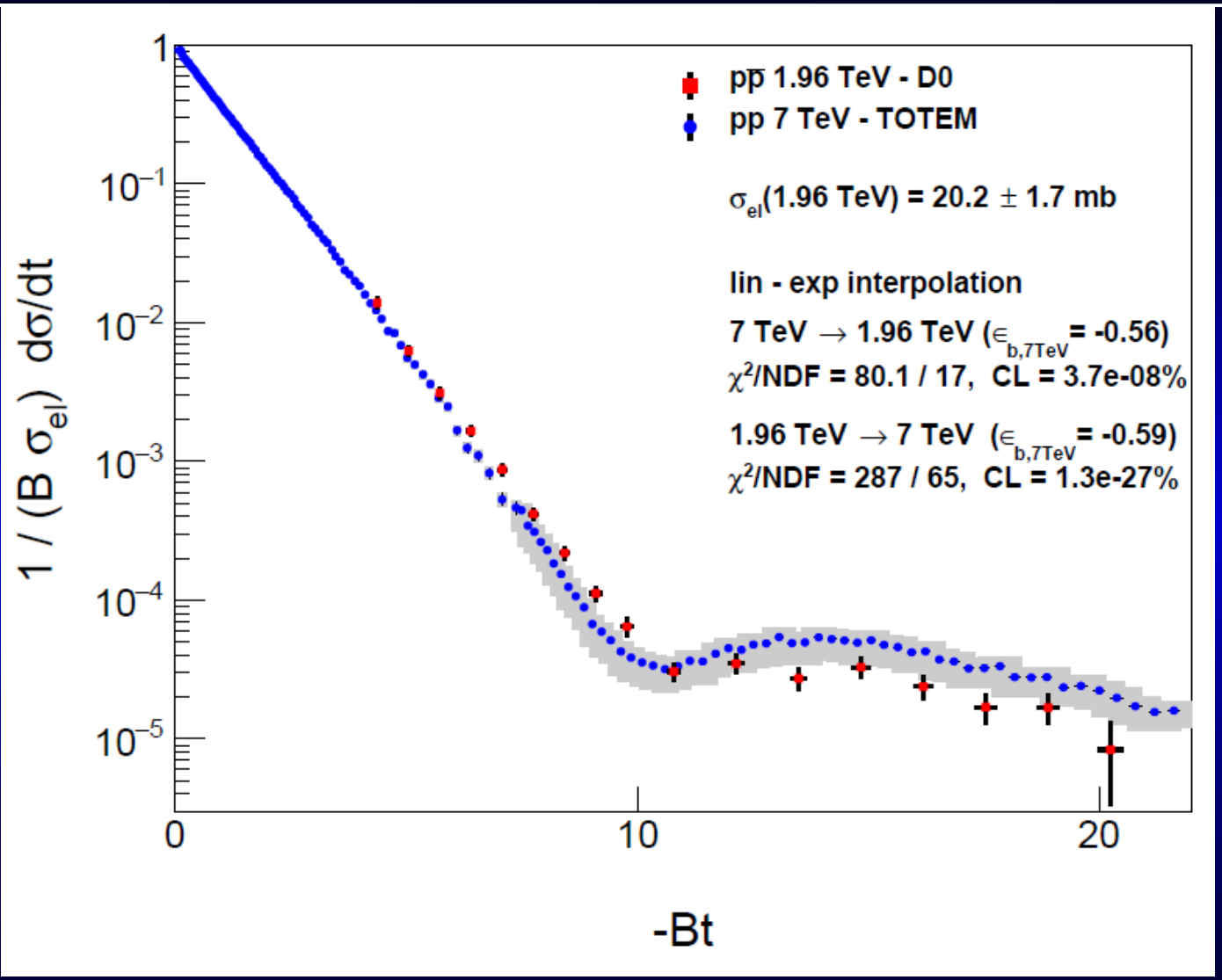
Coulomb-nuclear interference: Theory and practice for pp-scattering at 13 TeV #3

Vladimir A. Petrov (Serpukhov, IHEP), Nikolai P. Tkachenko (Serpukhov, IHEP) (Apr 19, 2022)

Published in: *Phys.Rev.D* 106 (2022) 5, 054003 • e-Print: 2204.08815 [hep-ph]

pdf DOI cite 0 citations

Back to Scaling: Model independent



H(x|pp)
s-independent:
2.76 – 7(8) TeV

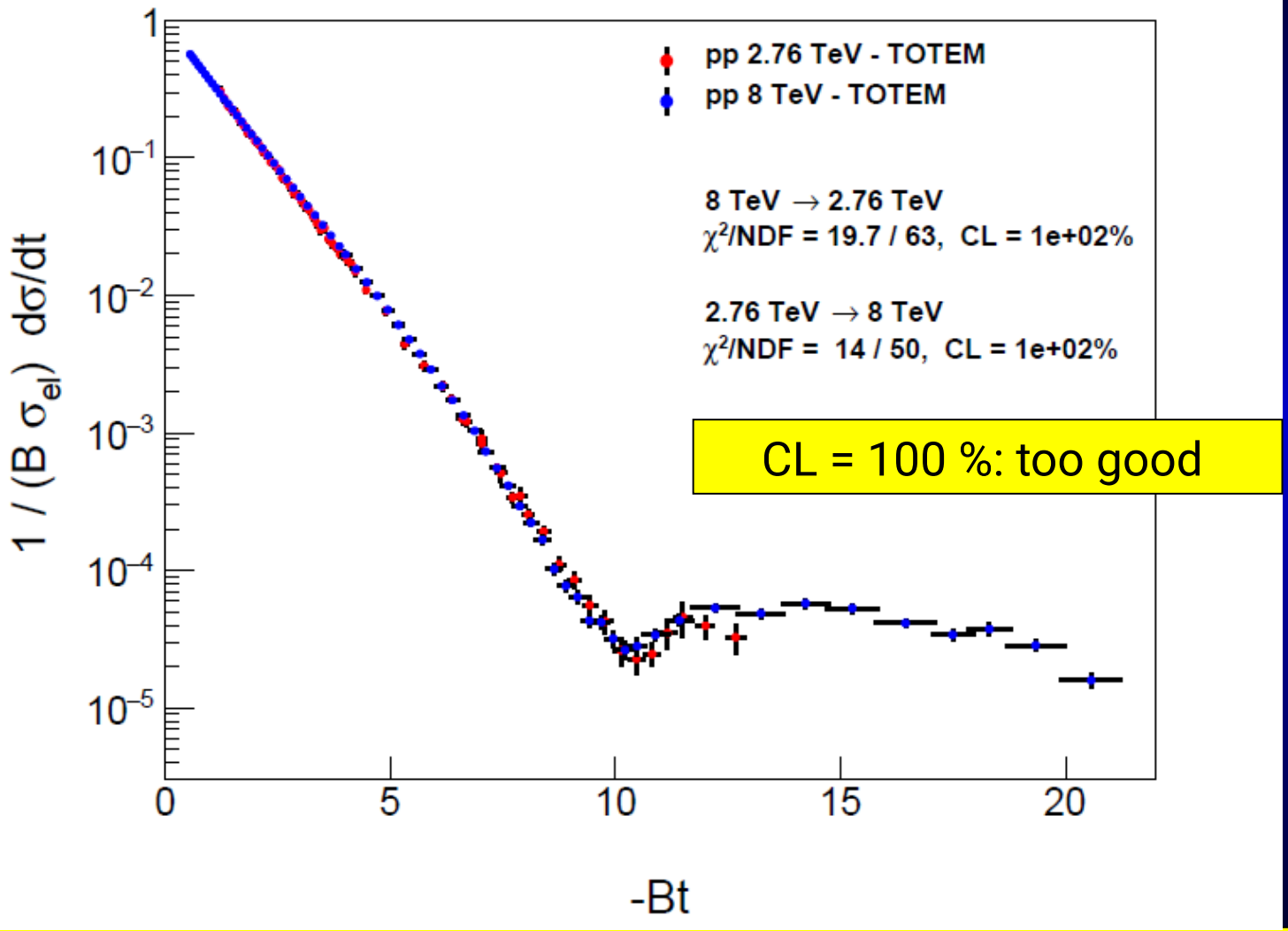
H(x|pp, 7 TeV)
≠
H(x|pbarp, 1.96)

Odderon,
IF scaling holds
in pp down to
1.96 TeV
Domain of validity:
ReBB model
dependent

6.26 σ
Odderon effect

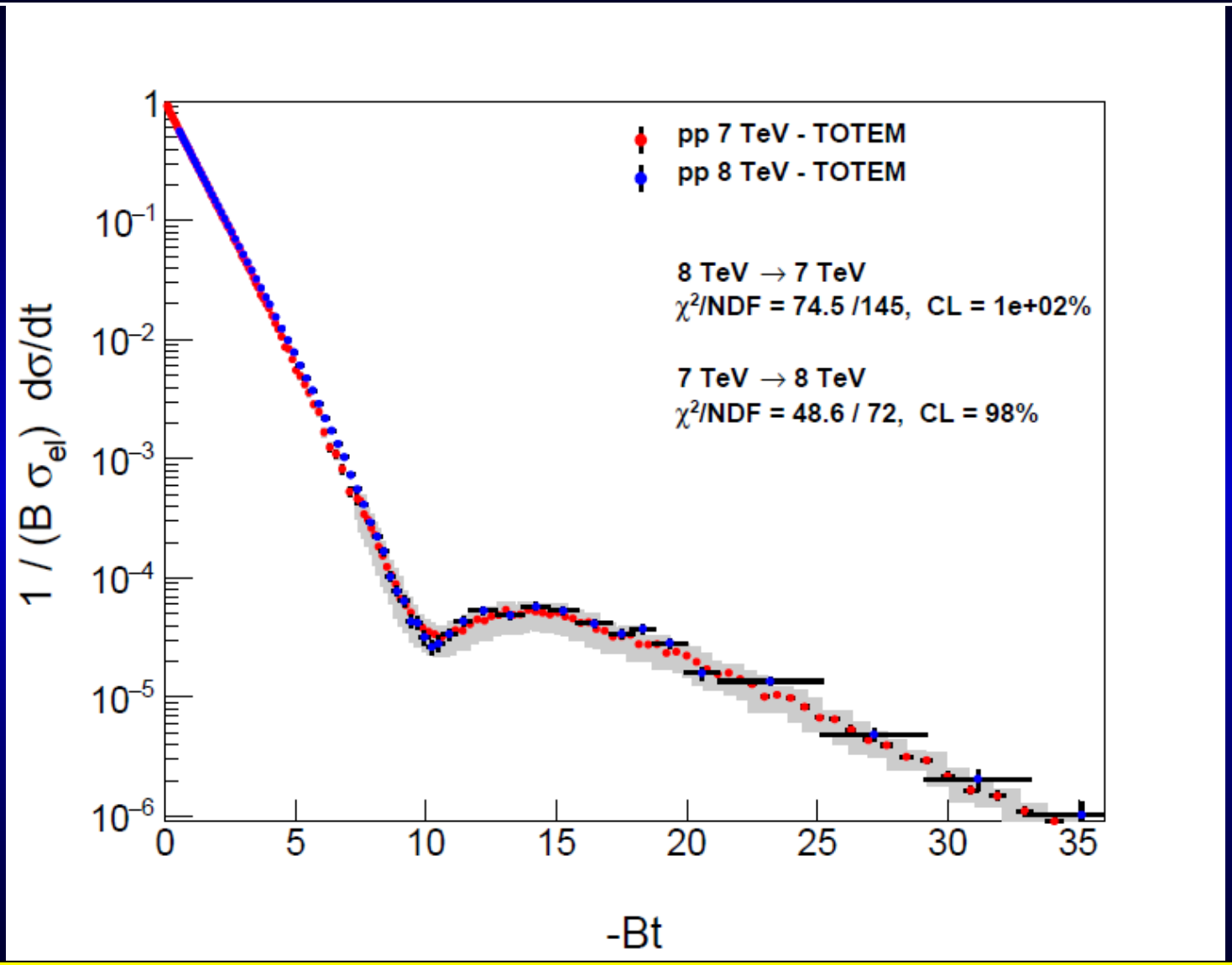
Energy range: tested **both** model independently and with modelling.
Modelling is useful, but model independent tests more important!

H(x) scaling of 2.76 and 8 TeV data



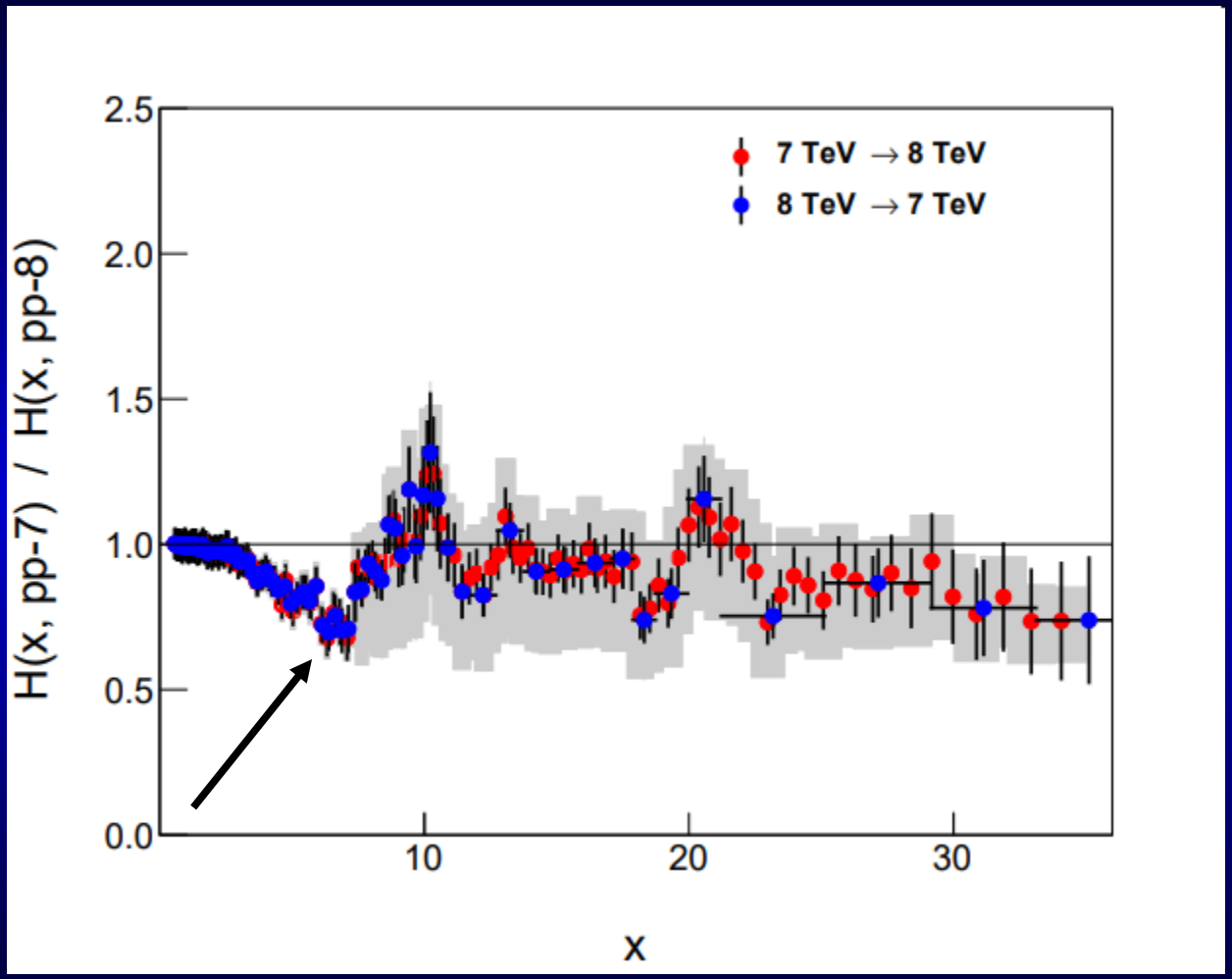
Energy range: H(x) scaling valid between √s= 8 and 2.76 TeV.
Uses final, published TOTEM ds/dt data at 8 TeV

H(x) scaling of 7 and 8 TeV data



Energy range: H(x) scaling model independently up to √s= 8 TeV.
Uses final, published TOTEM ds/dt data at 8 TeV

H(x) scaling of 7 and 8 TeV data



Closer look: systematic effects beyond the reported errors at dataset1 of 7 TeV (regarding all types of errors, type_C cancels)

H(x) scaling of 7 and 8 TeV data

This is the first direct observation of systematics in the 7 TeV low –t dataset beyond the reported errors.

Such problems were also seen in many earlier data analyses, but the problems were always attributed to the insufficiency of the methods applied in the analyses. A few examples:

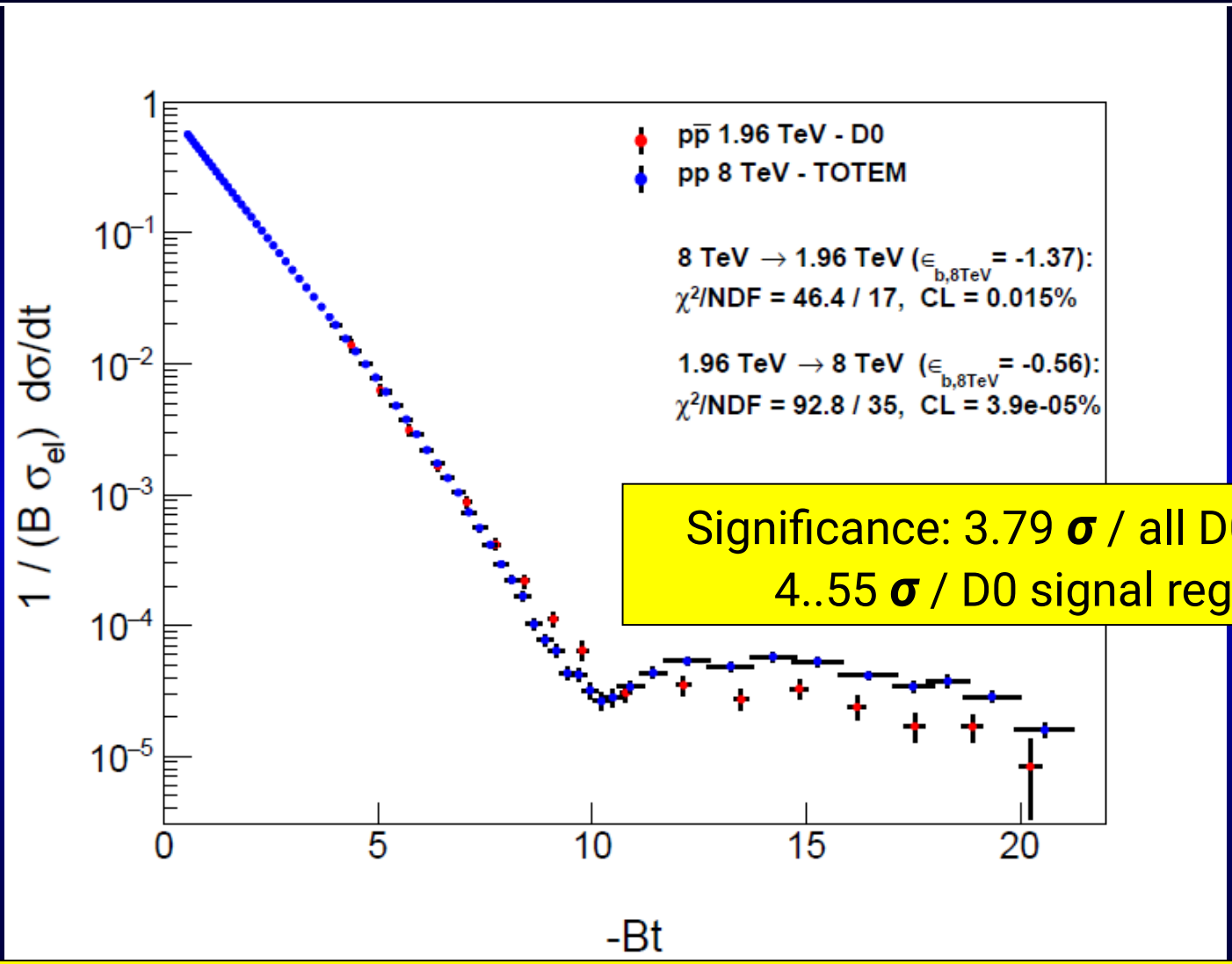
- In tthis presentation: Model independent analysy

- Fagundes et al.,: Phys. Rev. D88, 094019

- Ster, Jenkovszzky and Csörgő. Phys. Rev. D91, 074018; also presented in Bad Honnef at WE Heraeus Physics Scholl, 2015:

„Extracting the Odderon from pp and pp^{-} scattering data”

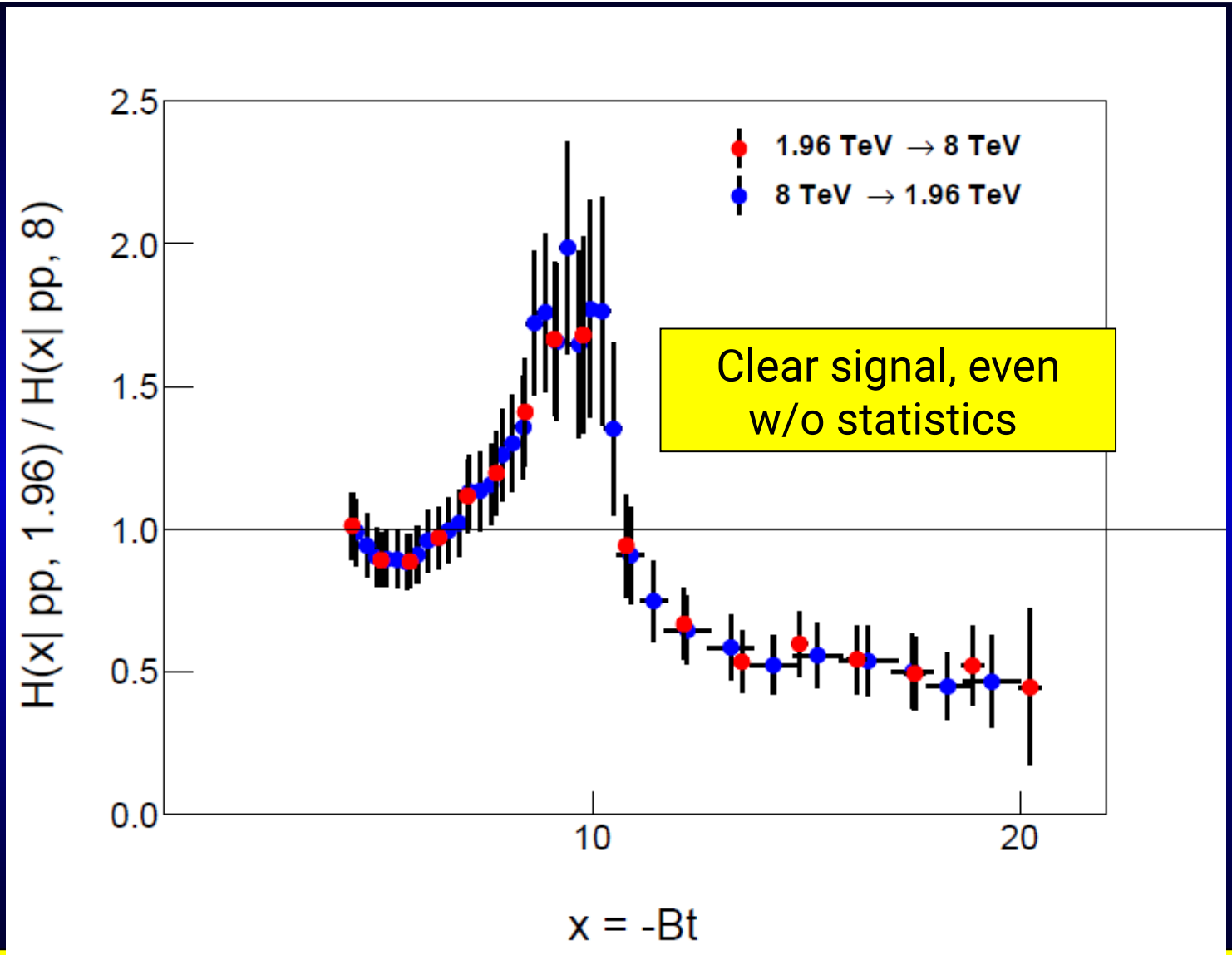
H(x): Odderon signal, new 8 TeV data



Significance: 3.79 ***σ*** / all D0 points
4..55 ***σ*** / D0 signal region

H(x) scaling is violated between √s= 8 TeV pp and 1.96 TeV pbarp. Hungarian-Swedish Odderon signal confirmed with final, published TOTEM ds/dt data at 8 TeV. Model independently.

H(x|pbarp)/H(x|pp): Odderon peak



H(x) scaling is violated between √s= 8 TeV pp and 1.96 TeV pbarp. TOTEM ds/dt data at 8 TeV. Odderon exchange, as a peak.

Summary of Odderon significancies

Summary of the Odderon signals by the H(x) scaling study

$\sqrt{s}$ (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

Combined Odderon significances:

$\sqrt{s}$ (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

SUMMARY: ODDERON DISCOVERED IN 3 PAPERS, NEW: FOCUS ON ITS PROPERTIES

The H(x) analysis of the 8 TeV data CONFIRMED the existence Odderon. The united significance with the 7 and 8 TeV data, using the Stouffer's method is: $7.08\ \sigma$

Odderon first discovered in three published papers: three different analysis, each with a statistical significance > 5 σ

0^{th} property: Odderon exists!

Odderon properties: from Bialas-Bzdak model, so far valid in a limited s and $-t > 0.37\ GeV^2$ range only.
1.96 TeV – 8 TeV: Threshold effect, just appearing.

There is an ongoing debate in reflective papers about the magnitude of the significance in the D0-TOTEM PRL
For exemple, is there enough evidence for Odderon at t= 0?