

# Model independent Odderon results based on new TOTEM data at 8 TeV

T. Csörgő<sup>1,2</sup> T. Novák<sup>2</sup>, R. Pasechnik<sup>3</sup>, A. Ster<sup>1</sup>, I. Szanyi<sup>1,2,4</sup>

<sup>1</sup> Wigner RCP, Budapest, Hungary

<sup>2</sup> MATE KRC, Gyöngyös, Hungary

<sup>3</sup> University of Lund, Lund, Sweden

<sup>4</sup> Eötvös University, Budapest, Hungary



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K 74458, Hungary

# Outline

## Statistically Significant Observations of Odderon in 2021

### Model independent (Hungarian-Swedish Collaboration):

Significance  $\geq 6.26 \sigma$  : *EPJC (2021) 81:180*

### Model dependent (Hungarian-Polish Collaboration):

Significance  $\geq 7.08 \sigma$  :

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

### Partially model independent (D0-TOTEM Collaboration):

Significance  $\geq 5.2 \sigma$  : *PRL (2021) 127, 062003*

## New in 2022:

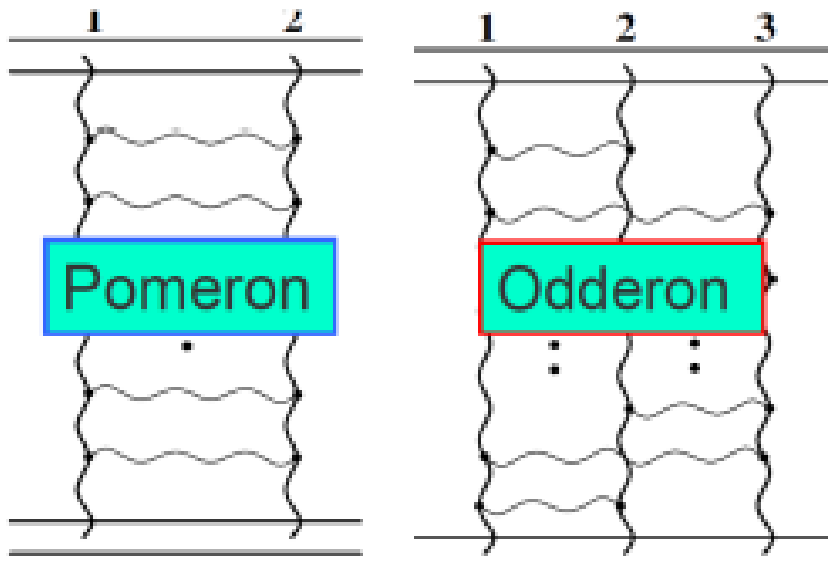
## TOTEM data at 8 TeV published

**Motivation: Einstein said something like: „Even infinite number of experiments can not prove that you are right, but one experiment is enough to prove that you are wrong”**

# 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



СООБЩЕНИЯ  
ОБЪЕДИНЕННОГО  
ИНСТИТУТА  
ЯДЕРНЫХ  
ИССЛЕДОВАНИЙ  
Дубна



E2-6350

A.V.Efremov, R.Peschanski

EVIDENCE FOR NEW SINGULARITIES  
IN REGGE PHENOMENOLOGY

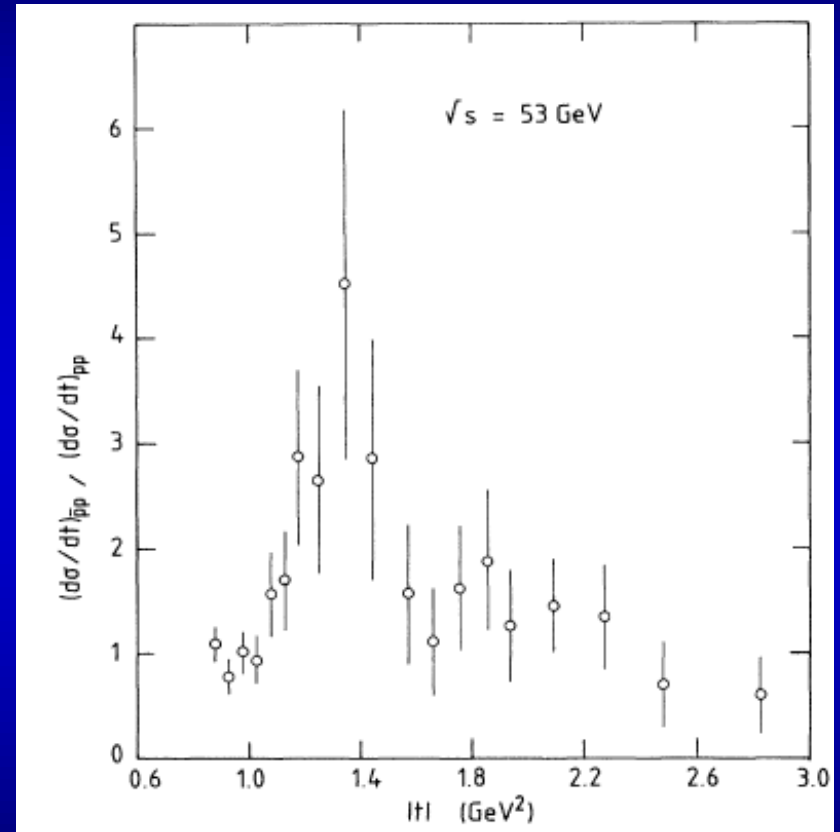
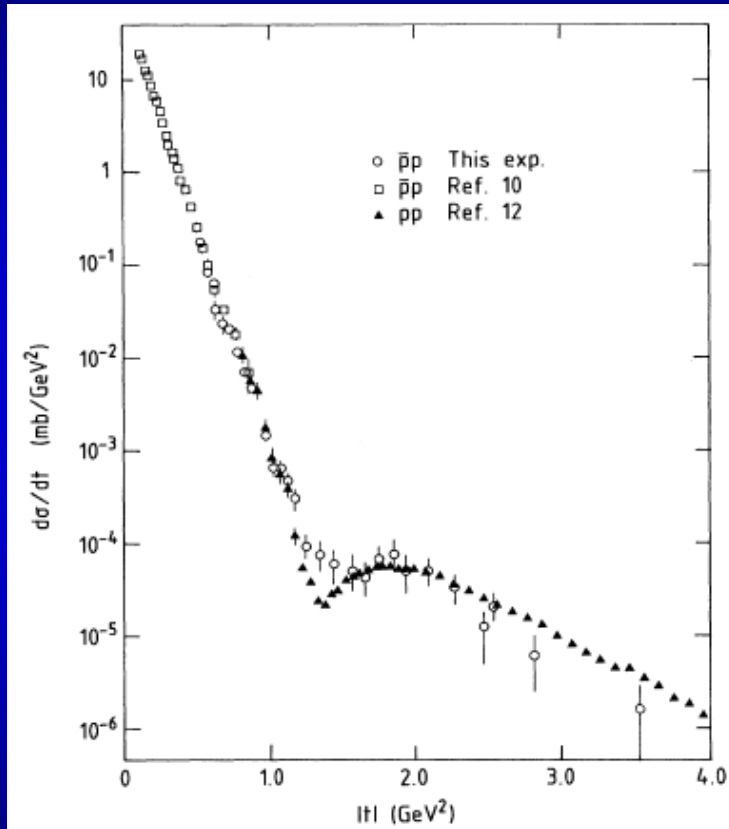
1972

ЛАБОРАТОРИЯ ТЕОРЕТИЧЕСКОЙ ФИЗИКИ

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:  $3.35 \sigma$

# 2021 observations of Odderon with $> 5 \sigma$

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

T. Csörgő (Wigner RCP, Budapest and CERN), [T. Novák](#) (Unlisted, HU), R. Pasechnik (Lund U., Dept. Theor. Phys.), [A. Sten](#) (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 EKV 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: 2012.03431

 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 $> 5 \sigma$

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

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

Published in: *Eur.Phys.J.C* 82 (2022) 3, 263 • e-Print: 2111.1195




 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

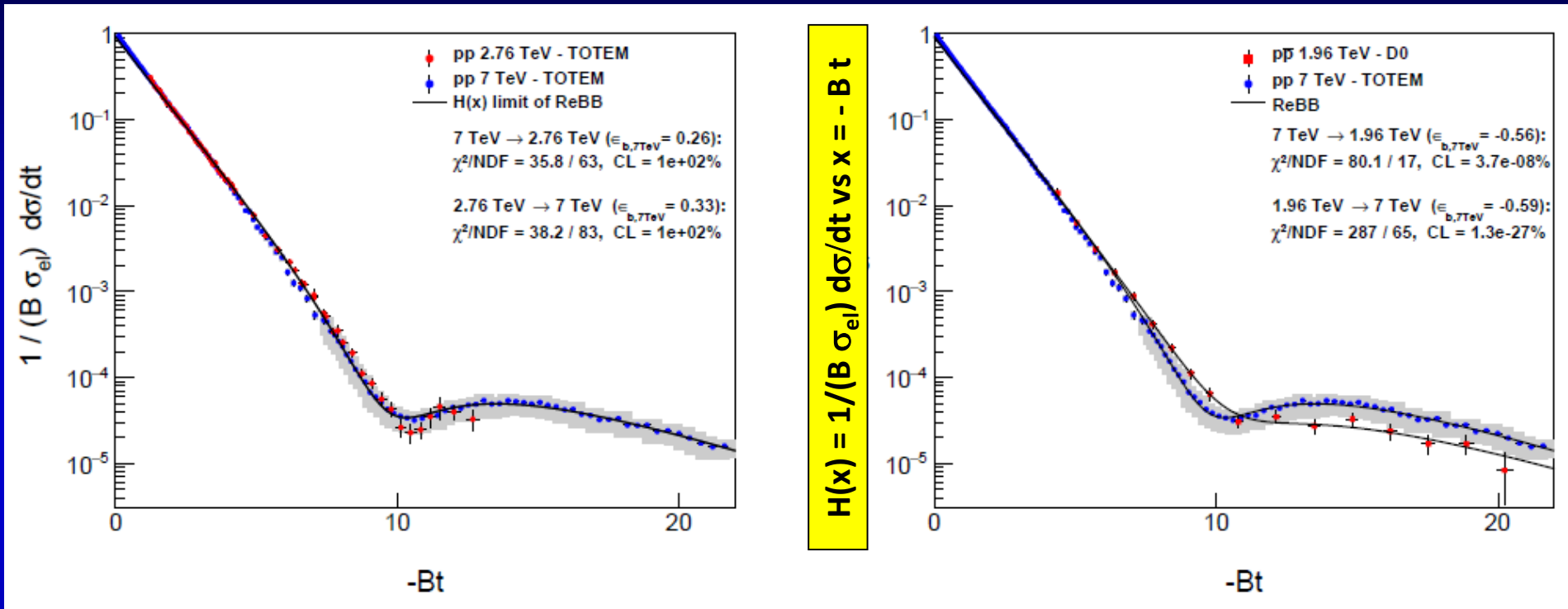
I. Szanyi (Eotvos U. and Wigner RCP, Budapest and Karoly Robert U. Coll.), T. Csörgő (Wigner RCP, Budapest and Karoly Robert U. Coll.) (Apr 21, 2022)

Published in: *Eur.Phys.J.C* 82 (2022) 9, 827, *Eur.Phys.J.C* 82 (2022) 9, 827

 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

# Model independent observation, 2019 -



$H(x) = 1/(B \sigma_{el}) \frac{d\sigma}{dt} \text{ vs } x = -Bt$

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

$x = -Bt = -B_0(s)t$

**S: Model independent Odderon significance  $\geq 6.26 \sigma$**   
**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 independent observation, 2019 -

Definition of the model independent  $H(x)$  scaling function constructed from published data:

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

$$x = B t$$

where:

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

**$\sigma_{el}$ :** total elastic  $\sigma$  (data, published with  $d\sigma/dt$ )

Definition of  $\chi^2$  according to definition in ref. of PHENIX Collaboration:

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

$$\chi_{2 \rightarrow 1}^2 = \sum_{j=1}^{n_{21}} \frac{(d_1^j + \epsilon_{b,1} e_{B,1}^j - d_{21}^j - \epsilon_{b,21} e_{B,21}^j)^2}{(\tilde{e}_{A,1}^j)^2 + (\tilde{e}_{A,21}^j)^2} + \epsilon_{b,1}^2 + \epsilon_{b,21}^2,$$

$$\tilde{e}_{A,k}^j = e_{A,k}^j \frac{d_k^j + \epsilon_{b,k} e_{B,k}^j}{d_k^j},$$

$$e_{M,k}^j = \sqrt{(\sigma_{M,k}^j)^2 + (d_k^{j,j})^2 (\delta_{M,k}^j x)^2},$$

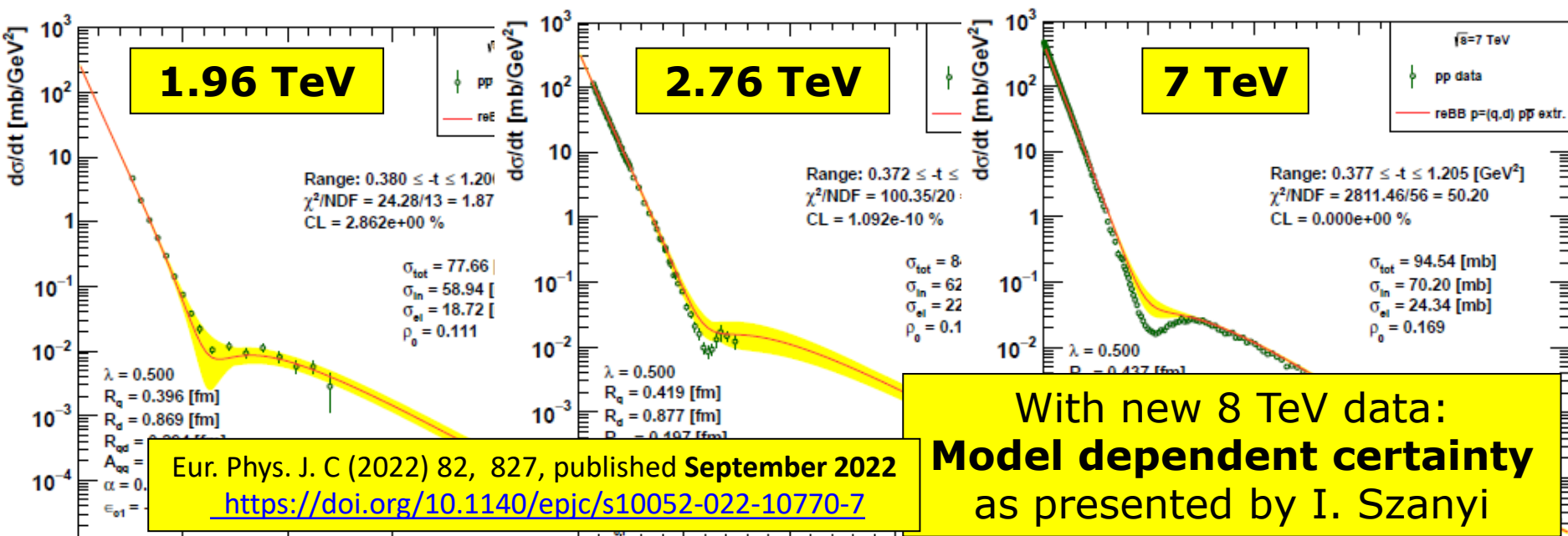


# Model dependent observation, 2020-

Observation of Odderon Effects at LHC energies -- A Real Extended Bialas-Bzdak Model Study #2

T. Csorgo (Wigner RCP, Budapest and Eötvös KRC, Gyongyos), I. Szanyi (Eötvös KRC, Budapest)  
 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>



**S: Model dependent Odderon significance  $\geq 7.08 \sigma$**

**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  $0.37 \leq -t \leq 1.2 \text{ GeV}^2$  and  $0.546 \leq \sqrt{s} \leq 7 \rightarrow 8 \text{ TeV}$

**Model dependent, Real Extended Bialas-Bzdak theory results,**  
**Odderon significance  $\geq 7.08 \sigma$ , from 1.96 and 2.76 TeV data only**

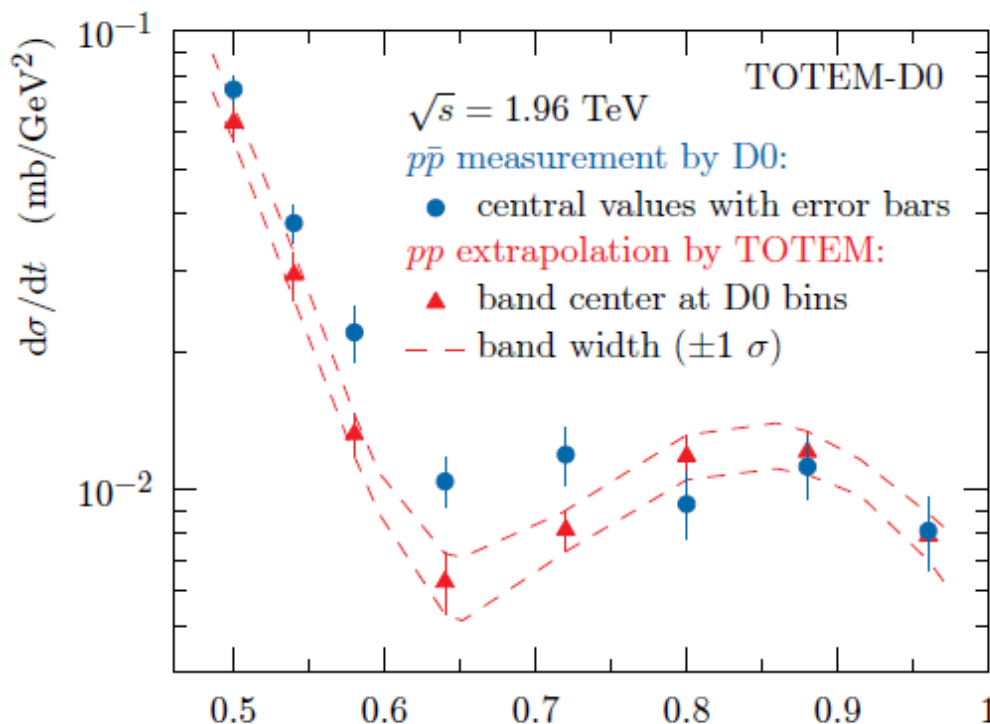
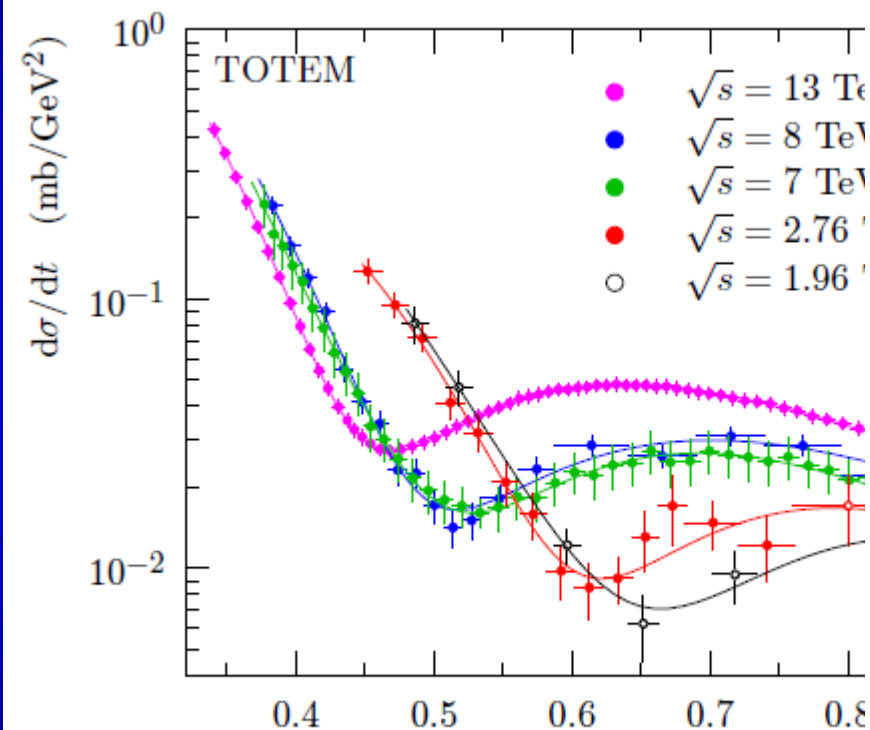
# Partially model independent, 2020-

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) et al.  
Published in: *Phys.Rev.Lett.* 127 (2021) 6, 062003 • e-Print: 2008.08111

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



**S:** Odderon significance  $\geq 5.2 \sigma$ , C1: *almost* model independently combined with  $\sqrt{s} = 13$  TeV data at  $t = 0$ :  $\sigma_{\text{tot}}$  and  $\rho_0$

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  $p\bar{p}$  data and TOTEM  $pp$  extrap.data are **assumed** to be **equal** at  $t=0$

**C5:**  $\rho_0$  (1.96 TeV) = 0.145

# 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

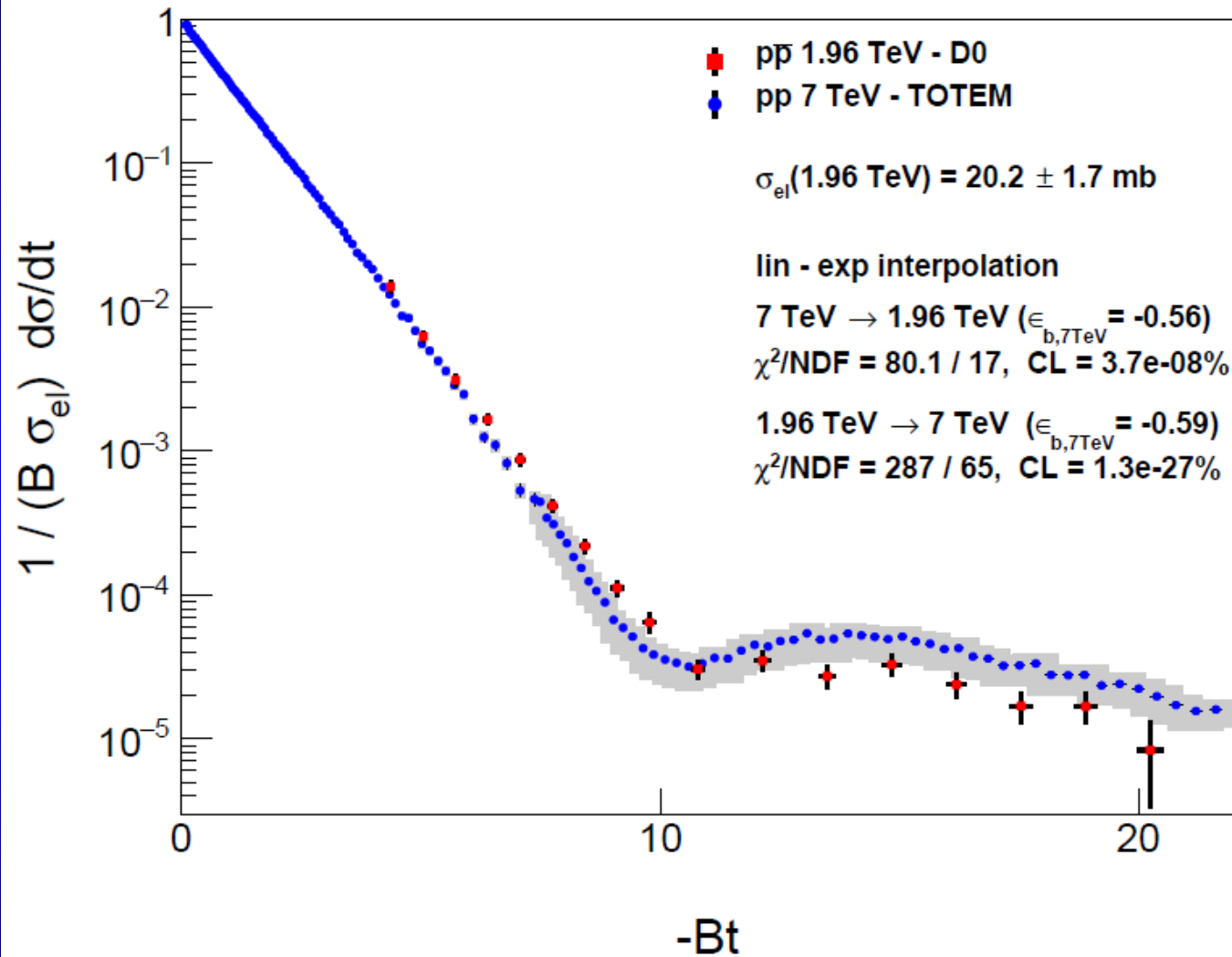
Vladimir A. Petrov (Serpuukhov, IHEP), Nikolai P. Tkachenko (Serpuukhov, IHEP) (Apr 19, 2022)

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

 pdf  DOI  cite

 0 citations

# Back to Scaling: Model independently



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

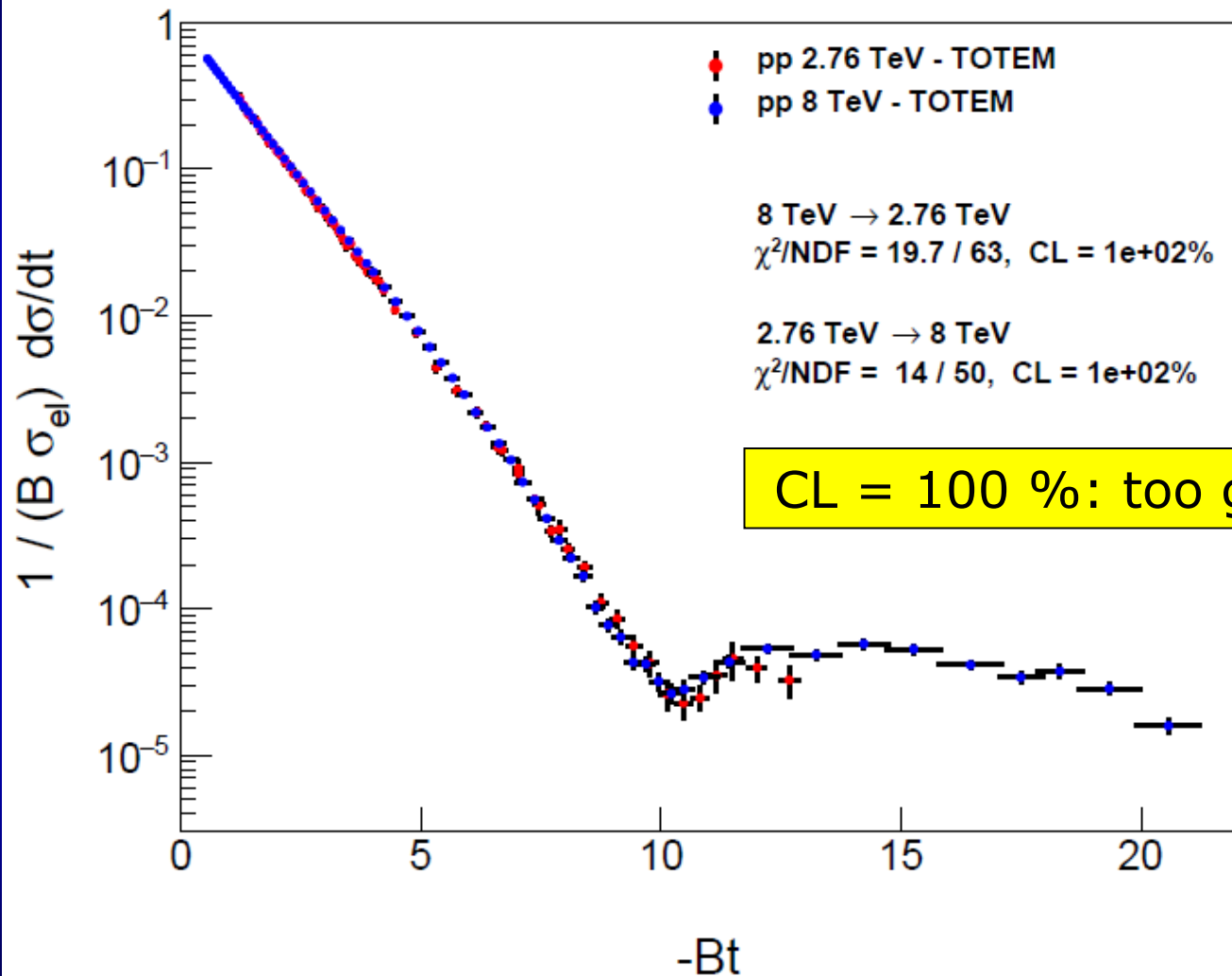
$H(x|pp, 7 \text{ TeV})$   
 $\neq$   
 $H(x|p\bar{p}, 1.96)$

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

**6.26  $\sigma$**   
**Odderon effect**

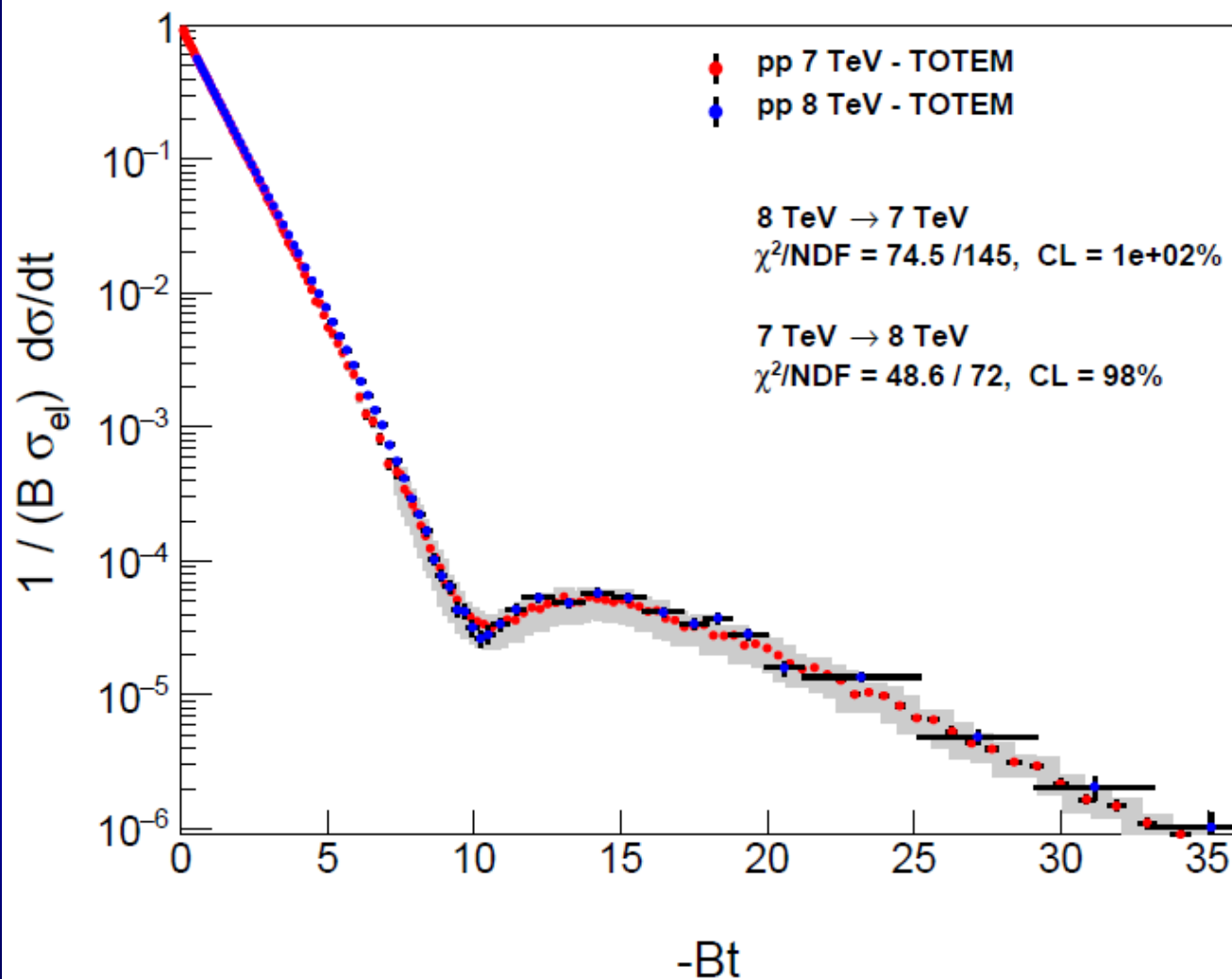
Energy range: tested **both** model independently and with modelling.  
 Modelling is useful, but model independent tests more important!

# H(x) scaling of 2.76 and 8 TeV data



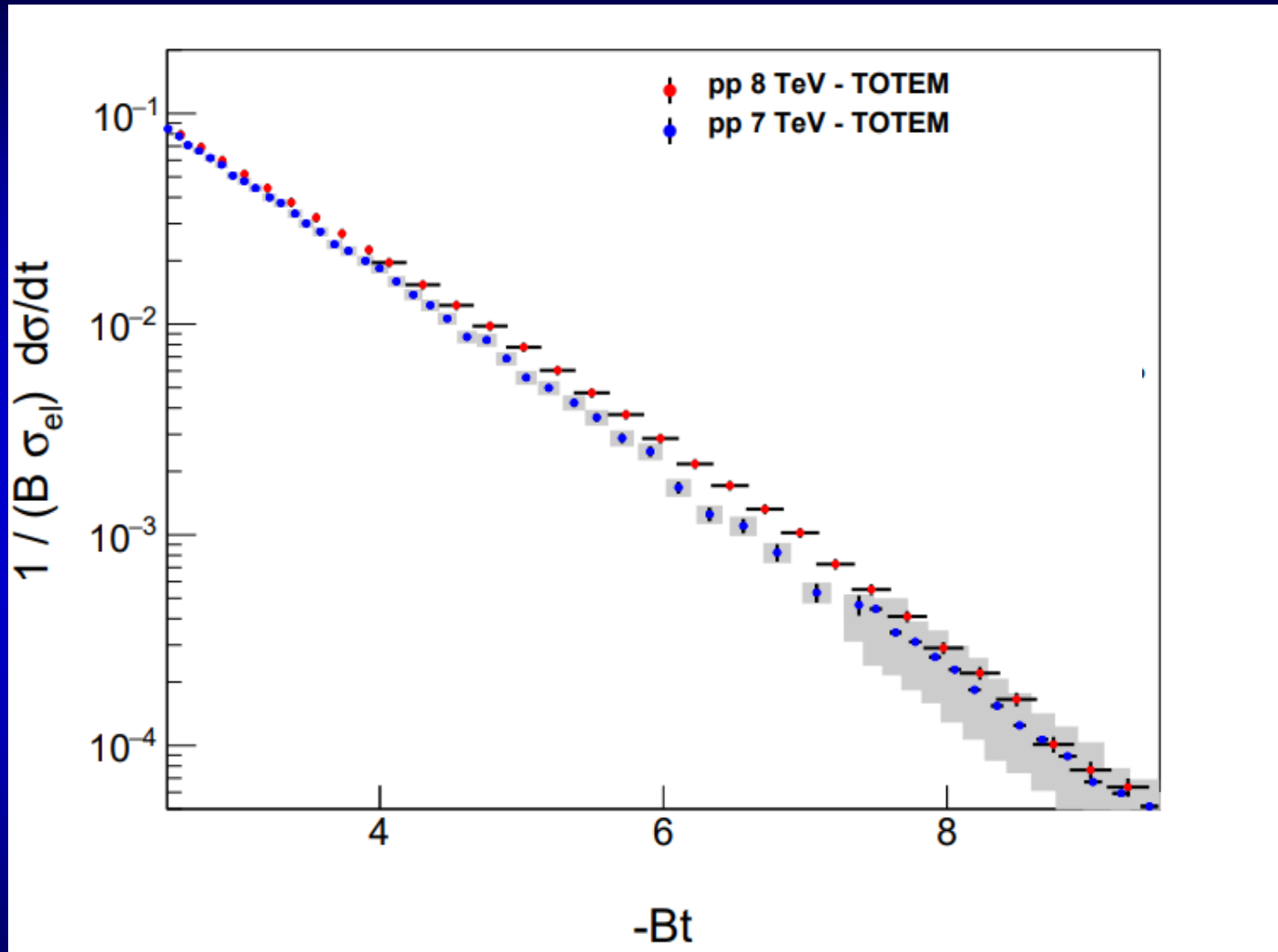
Energy range: H(x) scaling valid between  $\sqrt{s} = 8$  and 2.76 TeV.  
Uses final, published TOTEM  $d\sigma/dt$  data at 8 TeV

# H(x) scaling of 7 and 8 TeV data



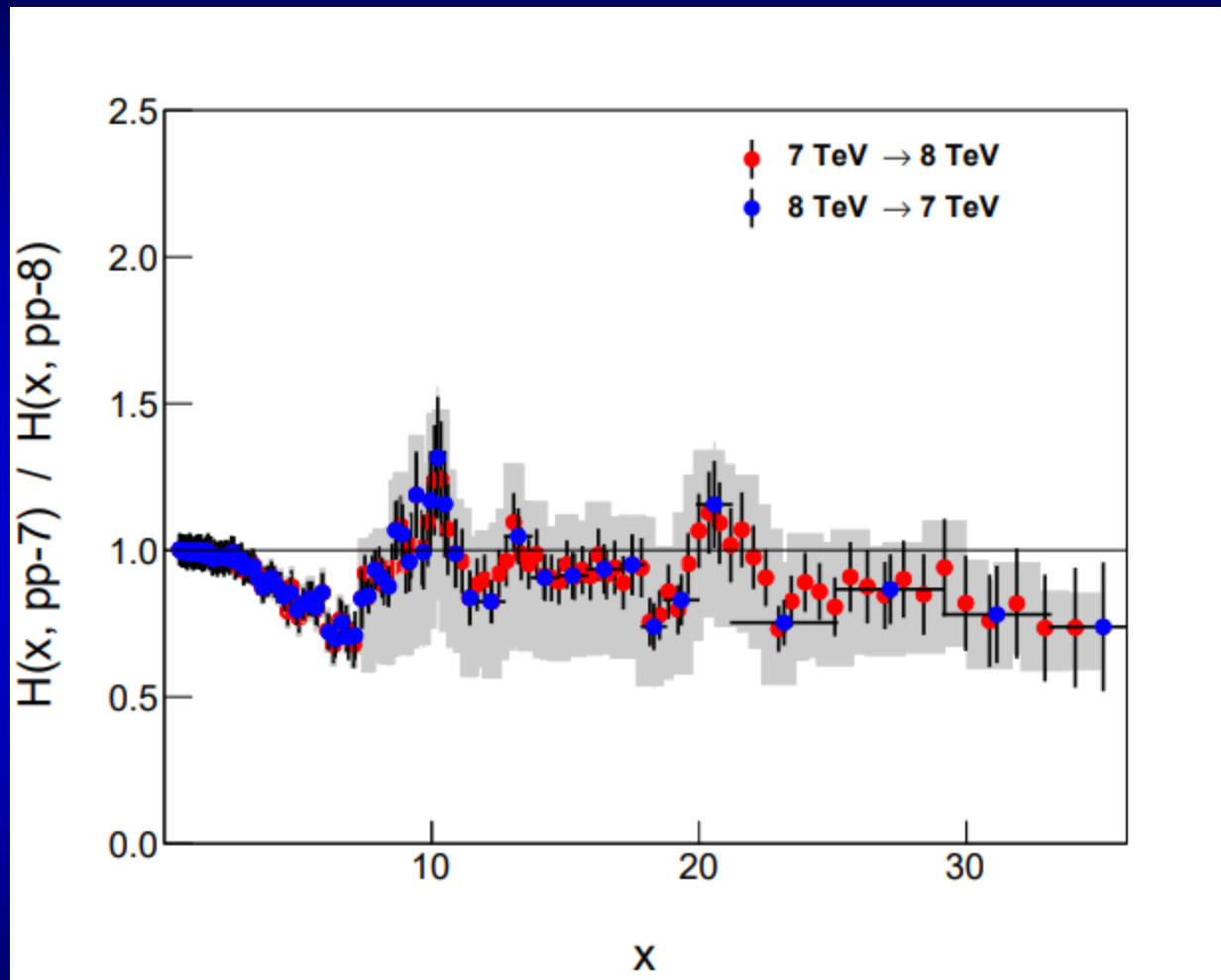
Energy range: H(x) scaling model independently up to  $\sqrt{s} = 8$  TeV.  
Uses final, published TOTEM  $\text{d}\sigma/\text{d}t$  data at 8 TeV

# H(x) scaling of 7 and 8 TeV data



Closer look: systematic effects beyond the reported errors at dataset1 of 7 TeV (regarding type A and B ones, Type\_C cancels)

# 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)



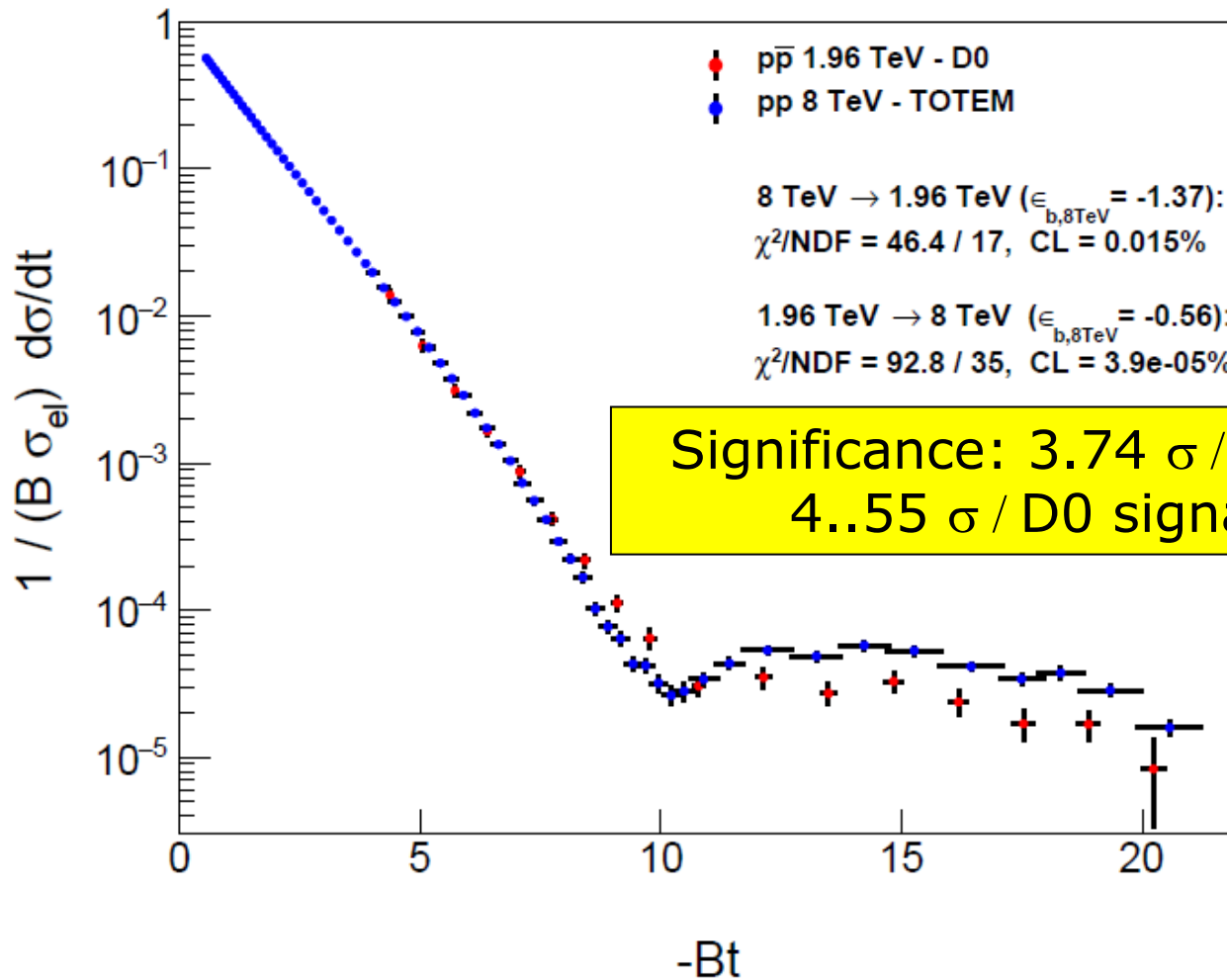
# H(x) scaling of 7 and 8 TeV data

This is a 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:

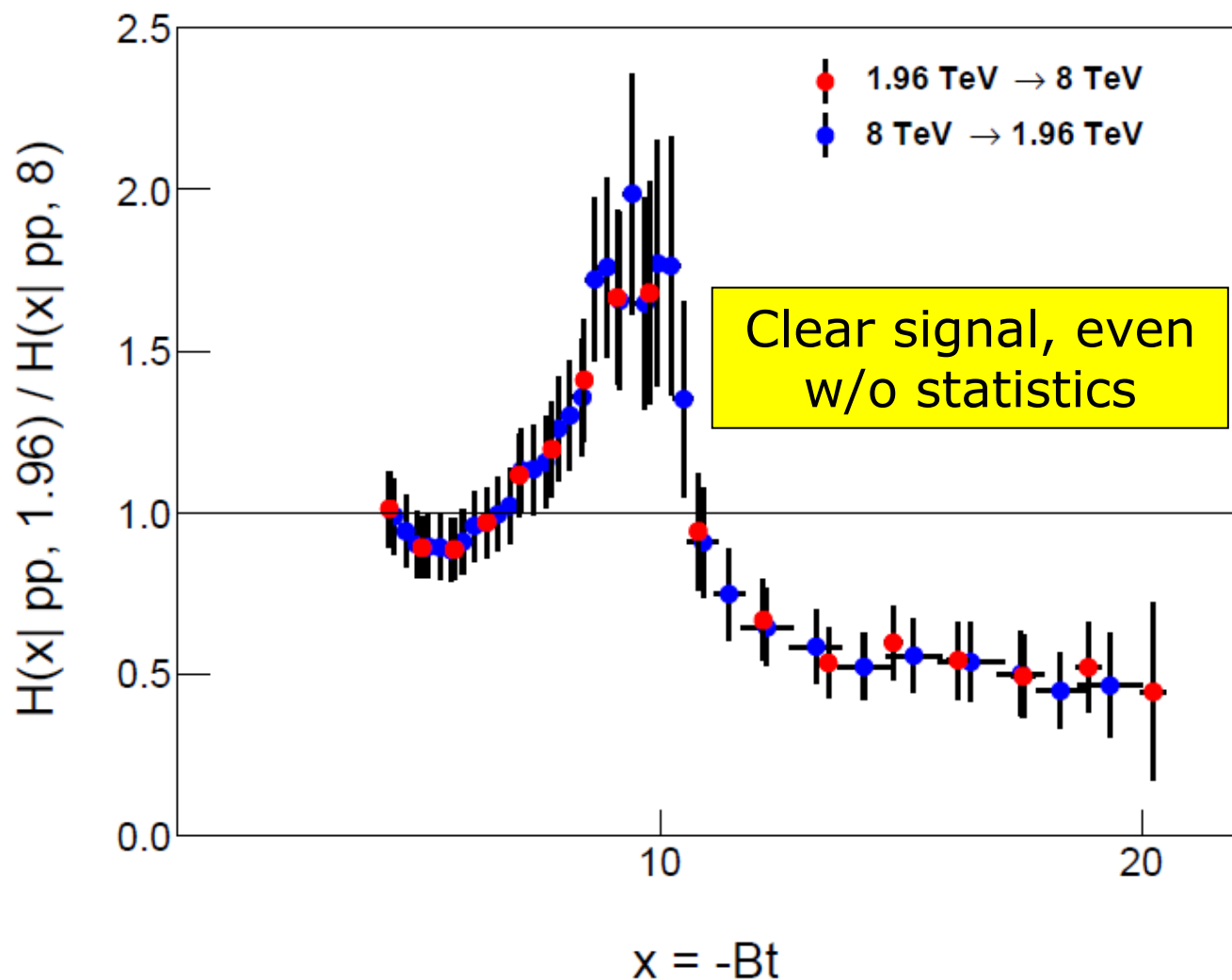
- In this presentation: Model independent analysis
- Fagundes et al.,: Phys. Rev. D88, 094019
- Ster, Jenkovszky and Csörgő. Phys. Rev. D91, 074018; also presented in Bad Honnef at WE Heraeus Physics Scholl, 2015:  
„Extracting the Odderon from pp and pp<sup>-</sup> scattering data”

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



H(x) scaling is violated between  $\sqrt{s} = 8$  TeV pp and 1.96 TeV pbarp.  
Hungarian-Swedish Odderon signal confirmed with final, published  
TOTEM  $d\sigma/dt$  data at 8 TeV. Model independently.

# $H(x|p\bar{p})/H(x|pp)$ : Odderon peak



$H(x)$  scaling is violated between  $\sqrt{s} = 8 \text{ TeV}$  pp and  $1.96 \text{ TeV}$  p $\bar{p}$ . TOTEM  $d\sigma/dt$  data at 8 TeV. Odderon exchange, as a peak.

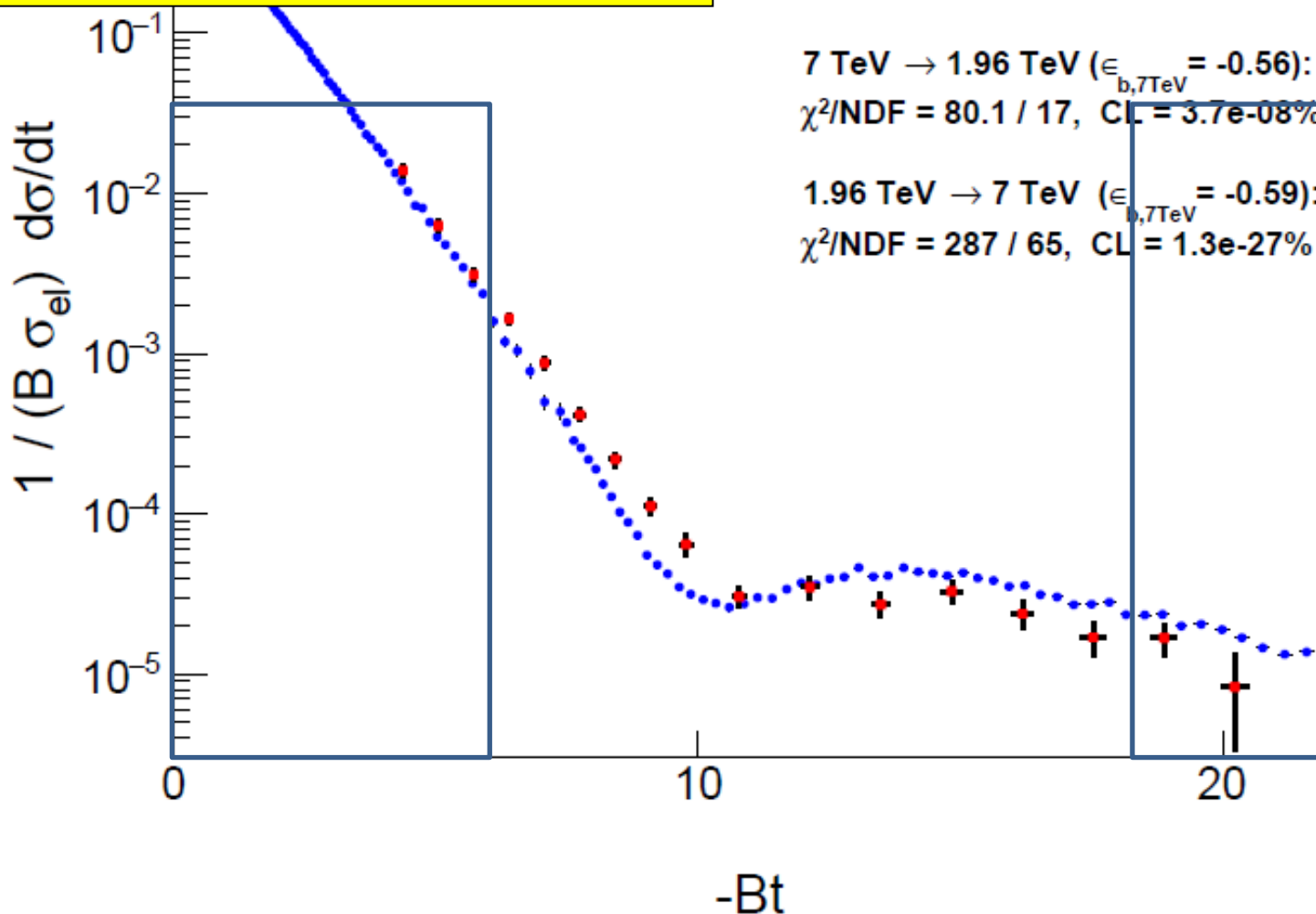
# 7 TeV: CLOSING DOORS/GATES

7 TeV data shifted

by  $\epsilon_{B7,TeV}$  to minimize  $\chi^2$

Type A errors are shown only

Both swing and dip regions important!



# 7 TeV RESULTS, CLOSING GATES

**Two sliding gates 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 $\sigma$	1.68 $\sigma$		
	3	2	6.33 $\sigma$	1.70 $\sigma$		
	4	2	6.21 $\sigma$	2.37 $\sigma$		

## MODEL INDEPENDENT RESULT 1:

In best window, optimized Odderon signal is 6.33  $\sigma$

## MODEL INDEPENDENT RESULT 2:

Best window: leaving out first 3 and last 2 D0 point

## MODEL INDEPENDENT RESULT 3:

Outside the best window:  $H(x|pp) = H(x,p_{\text{barp}})$   
pp and pbarp backgrounds agree within 1.7  $\sigma$

# CROSS-CHECK: SIGNAL AT 8 TeV

	n=left m=right				
	n\m	0	1	2	3
<u>Colours</u>	0	eps=-1.26 chi2=45.854 sigma=3.74 left=0.1384 right=1.31	eps=-1.20 chi2=44.541 sigma=3.77 left=0.1275 right=3.5	eps=-1.05 chi2=41.006 sigma=3.60 left=0.1023 right=6.44	
Greatest $\sigma$ in the row	1	eps=-1.33 chi2=45.709 sigma=3.87 left=0.073 right=2.29	eps=-1.26 chi2=44.408 sigma=3.90 left=0.082 right=3.47	eps=-1.11 chi2=40.898 sigma=3.74 left=0.103 right=6.38	
Greatest $\sigma$ in the column	2	eps=-1.29 chi2=45.633 sigma=4.01 left=0.115 right=3.30	eps=-1.21 chi2=44.323 sigma=4.04 left=0.128 right=3.50	eps=-1.07 chi2=40.792 sigma=3.88 left=0.153 right=6.42	
Greatest $\sigma$ in the table	3	eps=-1.22 chi2=45.512 sigma=4.15 left=0.018 right=3.32	eps=-1.15 chi2=44.191 sigma=4.19 left=0.014 right=3.53	eps=-0.99 chi2=40.631 sigma=4.03 left=0.006 right=6.50	
	4	eps=-1.26 chi2=45.492 sigma=4.30 left=0.436 right=3.31	eps=-1.18 chi2=44.175 sigma=4.34 left=0.415 right=3.51	eps=-1.02 chi2=40.624 sigma=4.19 left=0.374 right=6.47	
	5	eps=-1.36 chi2=45.044 sigma=4.42 left=0.899 right=3.29	eps=-1.28 chi2=43.748 sigma=4.46 left=0.866 right=3.46	eps=-1.10 chi2=40.241 sigma=4.32 left=0.794 right=6.39	
	6	eps=-1.52 chi2=44.113 sigma=4.50 left=2.29 right=1.26	eps=-1.40 chi2=42.850 sigma=4.55 left=2.24 right=3.39	eps=-1.26 chi2=39.416 sigma=4.42 left=2.13 right=6.23	
	7	eps=-1.78 chi2=41.738 sigma=4.46 left=6.08 right=1.20	eps=-1.68 chi2=40.527 sigma=4.52 left=5.97 right=3.28	eps=-1.51 chi2=37.211 sigma=4.41 left=5.80 right=5.98	

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

(n+1,m): pull  
 vs (n,m+1) pull  
 Go direction of  
 greater signal

Color code:

- Best signal  $4.55 \sigma$
- $5.0 \geq \text{signal} \geq 4.0 \sigma$
- $4.0 \geq \text{signal} \geq 3.0 \sigma$

# **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: **7.02  $\sigma$**

**Odderon first discovered in three published papers:**  
three different analysis, each with a statistical significance  $> 5 \sigma$

**0<sup>th</sup> property: Odderon exists!**

**Odderon properties: from Bialas-Bzdak model, so far valid in a limited s and  $-t > 0.37 \text{ GeV}^2$  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  $t= 0$ ?**