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

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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 cannot prove that you are right, but one experiment is enough to prove that you are wrong”
Odderon: 48 years old scientific puzzle

Received: 31 July 1973

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

Honorable mention: A. V. Efremov, R. Peschanski, JINR-E2-6350 (1972)
Odderon search at ISR: indication but no conclusive result

**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**


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

**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**

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


**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**

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: 2006.11461

**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

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

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 -

**S:** Model independent Odderon significance ≥ 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.

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

$x = -B t = -B_0(s) t$
Model dependent observation, 2020-

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 (EPJC, CERN)

https://doi.org/10.1140/epjc/s10052-021-09381-5

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

S: Model dependent Odderon significance ≥ 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 ≤ −t ≤ 1.2 GeV² and 0.546 ≤ sqrt(s) ≤ 7 → 8 TeV

Model dependent, Real Extended Bialas-Bzdak theory results,
Odderon significance ≥ 7.08 \sigma, from 1.96 and 2.76 TeV data only
**S:** Odderon significance $\geq 5.2\ \sigma$, \n**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 pbarp data and TOTEM pp extrapolation data are *assumed* to be equal at $t=0$

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

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

Lack of evidence for an odderon at small $t$

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

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

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]
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

CL = 100 %: too good
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 $d\sigma/dt$ 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 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)
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, 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

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.

Significance: 3.74 $\sigma$ / all D0 points
4..55 $\sigma$ / D0 signal region

8 TeV $\rightarrow$ 1.96 TeV ($\epsilon_{b,8\text{TeV}} = -1.37$):
$\chi^2$/NDF = 46.4 / 17, CL = 0.015%

1.96 TeV $\rightarrow$ 8 TeV ($\epsilon_{b,8\text{TeV}} = -0.56$):
$\chi^2$/NDF = 92.8 / 35, CL = 3.9e-05%
$H(x|\text{pbarp})/H(x|\text{pp})$: Odderon peak

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

Clear signal, even w/o statistics
7 TeV data shifted by $\varepsilon_{b,7\,\text{TeV}}$ to minimize $\chi^2$.
Type A errors are shown only.
Both swing and dip regions important!
Two sliding gates of size $n$ and size $m$: \((n,m)\): Leaving out the first $n$ and last $m$ D0 point

<table>
<thead>
<tr>
<th>$n$</th>
<th>$m$</th>
<th>Odderon signal</th>
<th>Background</th>
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<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>6.27 $\sigma$</td>
<td>1.68 $\sigma$</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
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<td>1.70 $\sigma$</td>
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<tr>
<td>4</td>
<td>2</td>
<td>6.21 $\sigma$</td>
<td>2.37 $\sigma$</td>
</tr>
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</table>

**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: $H(x|pp) = H(x,p\bar{p}p)$ pp and $p\bar{p}$ backgrounds agree within 1.7 $\sigma$
CROSS-CHECK: SIGNAL AT 8 TeV

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<th>1</th>
<th>2</th>
<th>3</th>
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<td>chi2=40.624</td>
<td>sigma=3.88</td>
<td>left=0.128</td>
</tr>
</tbody>
</table>

**Greatest σ in the row**

1

**Greatest σ in the column**

2

**Greatest σ in the table**

3

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 σ
- 5.0 ≥ signal ≥ 4.0 σ
- 4.0 ≥ signal ≥ 3.0 σ
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 Soufferr method, is: $7.02 \sigma$

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

$0^{th}$ 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 example, is there enough evidence for Odderon at $t = 0$?