# Detailing the Odderon effect with numerical examples at 8 TeV

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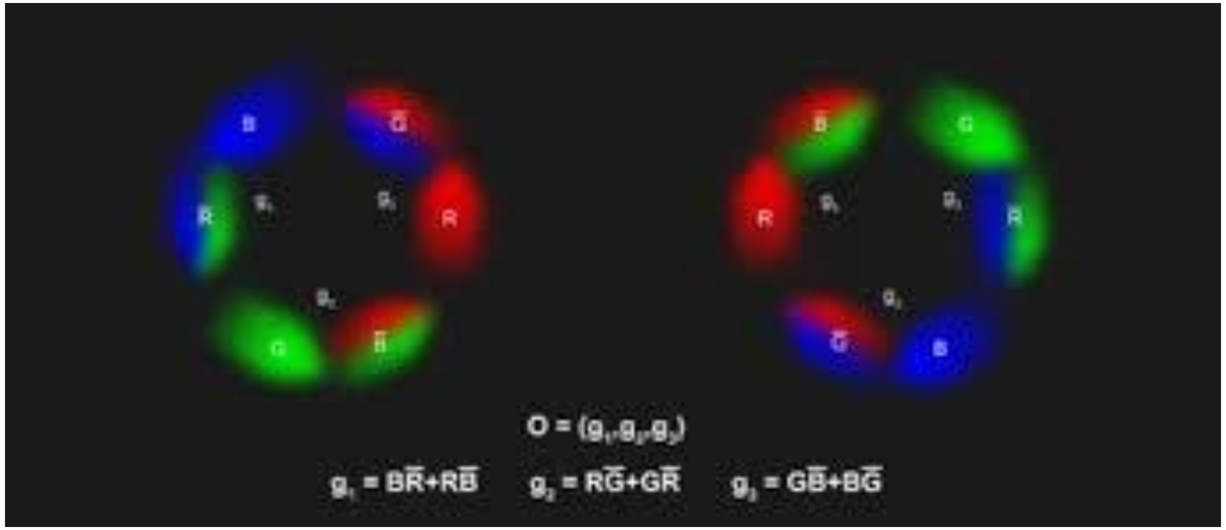


# Outline

- Strategy of Odderon search
- Difficulties of Odderon discovery
- Odderon-signal at 8 TeV
- Comparing (and combining) 7 és 8 TeV data
- Optimalaizing the Odderon-signal
- Summary

# Odderon: A 48-year-old problem solved

L. Lukaszuk, B. Nicolescu,
Lett. Nuovo Cim. 8, 405 (1973)

Received: **31 July 1973**

Abstract
It is shown that the assumption that the rise of pp total cross sections at ISR energies can be understood by the existence of a contribution proportional to In/sup 2/s is nut necessarily within the existing knowledge of experimental data. Also by assuming that asymptotically Re F ~- s ln/sup 2/s together with sigma T~ ln/sup 2/s it is possible to propose a parametrization which seems interesting both from the experimental and theoretical points of view. (JFP)

Basarab Nicolescu

# Strategy of Odderon Search

- The contribution of Odderon in proton-proton and proton-antiproton collisions

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

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

- Consequencies

Differential cross-sections → measureable

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

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

# Quantification / Extrapolation

- How to compare two different measured ***H*(*x*)** scaling functions
- Determine if two different measurement correspond to significantly different ***H*(*x*)** scaling functions, or not.
- Compare the data-sets $\boldsymbol{D_1}$ and $\boldsymbol{D_2}$ by creating a common domain $\boldsymbol{X_{12}}$ and linear extrapolation between neighbouring data points.
- Using

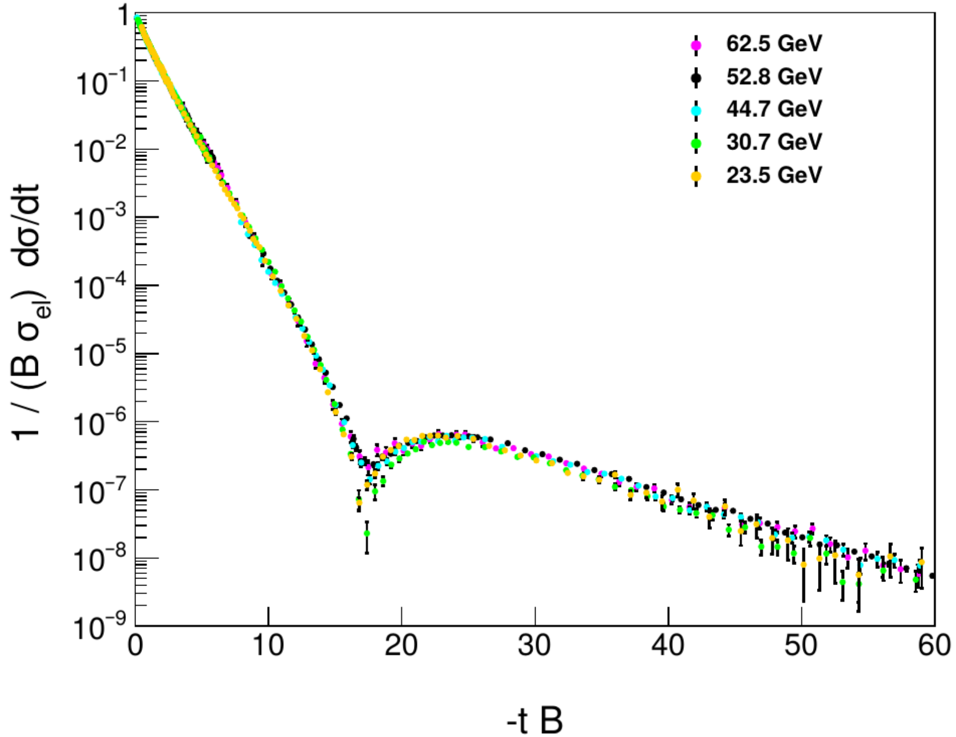
$$\chi^2 = \sum \frac{(d_{12}(j) - d_{21}(j))^2}{e_{12}^2(j) + e_{21}^2(j)}.$$

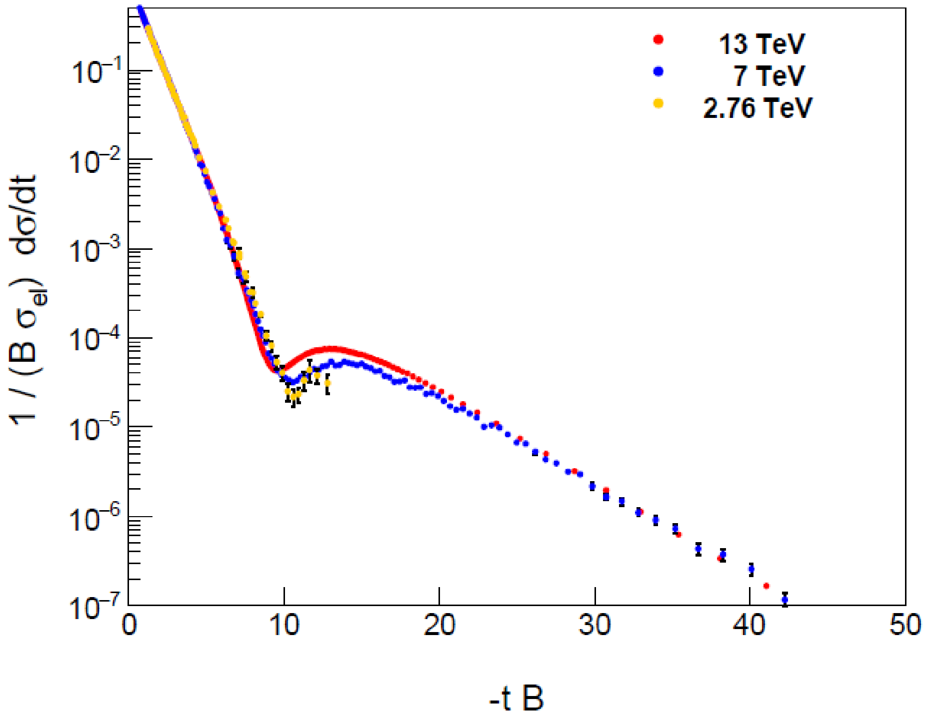
- Evaluate the CL of the hypothesis that the two data sets represent the same $H(x)$ scaling function.

# Difficulties I.: *H*(*x*,*s*) scaling function

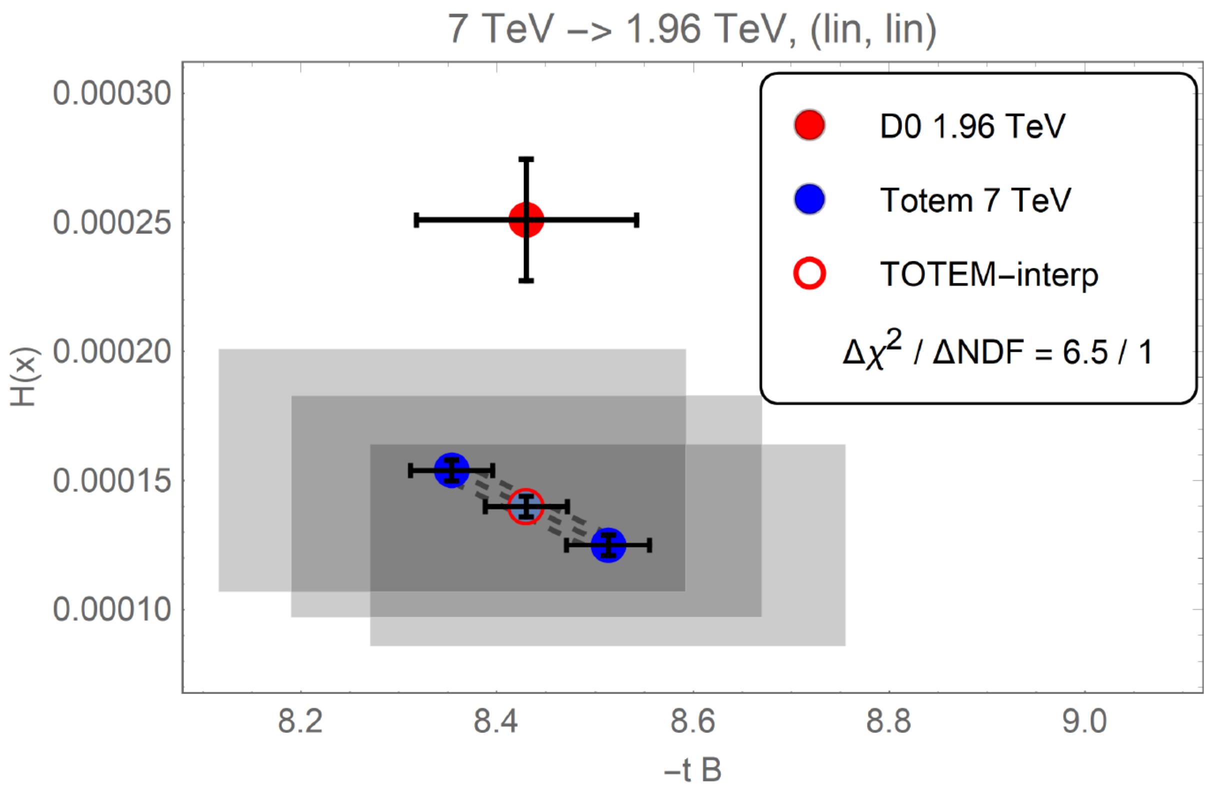
- The Mandelstam variables defined as $s = (p_1 + p_2)^2$ és $t = (p_1 - p_3)^2$ with incoming four momenta $(p_1, p_2)$and outgoing four-momenta $(p_3, p_4)$.

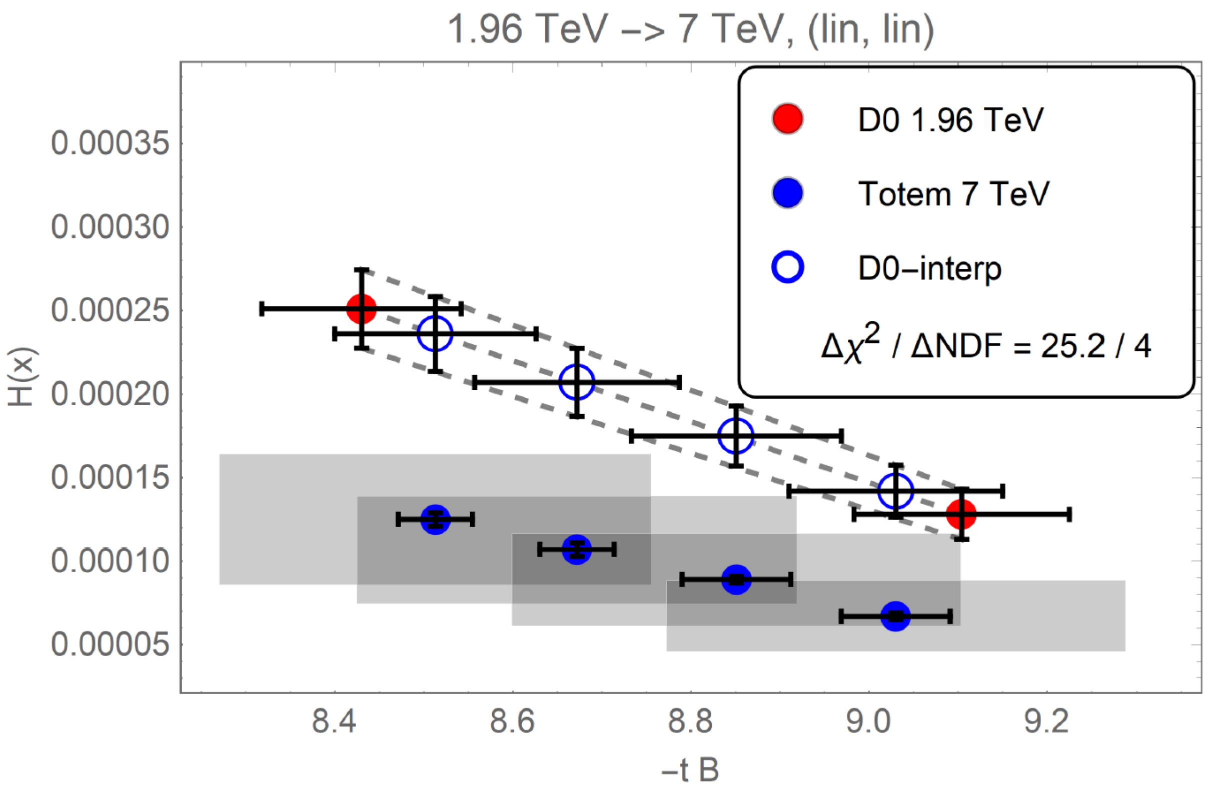
$$H(x,s) = \frac{1}{B(s)\sigma_{el}(s)} \frac{d\sigma}{dt}, \text{ where } x = -tB(s).$$



# Difficulties II. -> need a projection




Illustrate the model independent nature of the interpolations

# Difficulties III. -> different types of errors

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

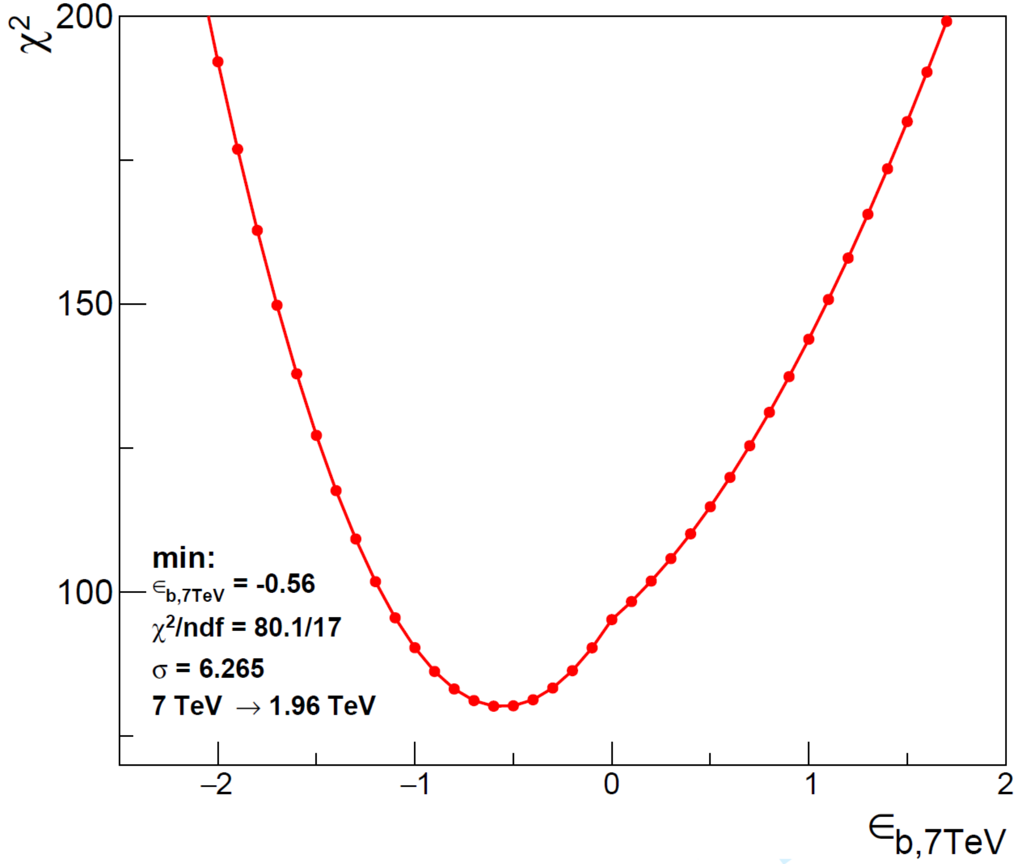
$$\tilde{e}^j_{A,k} = e^j_{A,k} \frac{d^j_k + \epsilon_{b,k} e^j_{B,k}}{d^j_k},$$

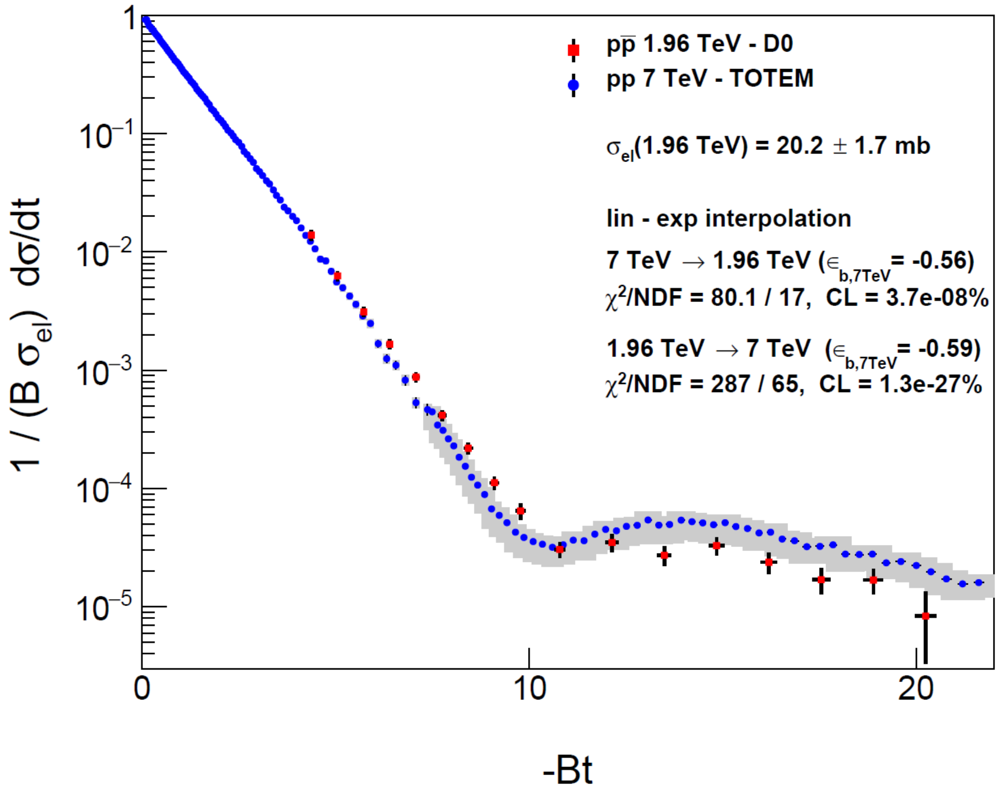
$$e^j_{M,k} = \sqrt{(\sigma^j_{M,k})^2 + (d'^{,j}_k)^2 (\delta^j_{M,k} x)^2},$$

where $k \in \{1, 21\}$ and $M \in \{A, B\}$ type error

- Type A: point-to-point fluctuating (uncorrelated) systematic and statistical errors
- Type B: point-to-point dependent, but 100% correlated systematic errors

# Significant Odderon-signal (7 TeV)

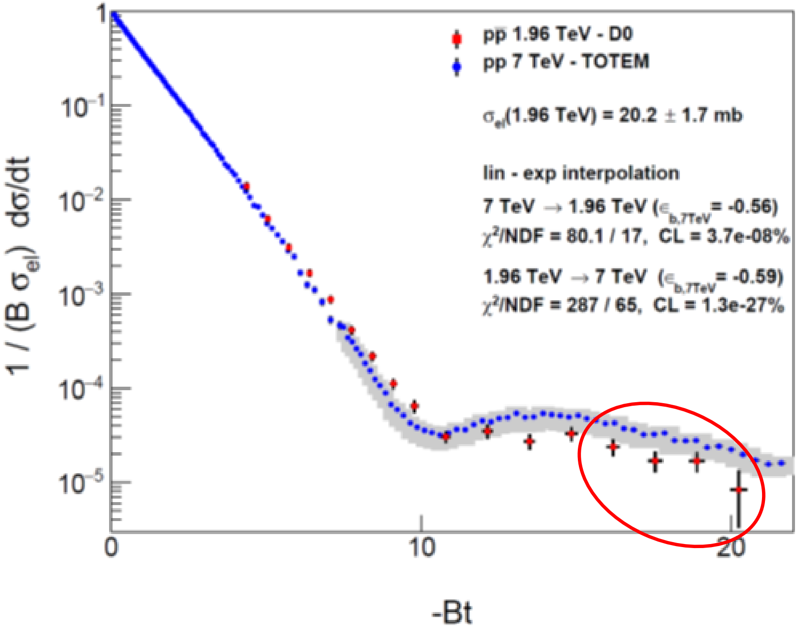



| $\sigma_{el}$ (mb) | interpolation | direction of projection | $\chi^2$ | NDF | CL (% ) | Significance [σ] |
|---|---|---|---|---|---|---|
| 20.2 ± 1.7 | lin-exp | 7 → 1.96 TeV | 80.1 | 17 | $3.7 \times 10^{-8}$ | 6.26 |

# Stability of Odderon-signal

| Stability of the results for the cutoff at large x, for $\varepsilon_{B21}$(7 TeV) optimized for $x \leq x_{max}$ | | | | | | | |
|---|---|---|---|---|---|---|---|
| $x_{max}$ | $\varepsilon_{B21}$ of $\min[\chi^2(x \leq x_{max})]$ | $\min[\chi^2(x \leq x_{max})]$ | NDF($x \leq x_{max}$) | $\sigma$ ($x \leq x_{max}$) | $\chi^2$(all x) | NDF(all x) | $\sigma$ (all x) |
| 18.9 | -0.51 | 77.28 | 16 | 6.22 | 80.18 | 17 | 6.27 |
| 17.5 | -0.46 | 75.84 | 15 | 6.25 | 80.53 | 17 | 6.29 |
| 16.2 | -0.32 | 67.83 | 14 | 5.86 | 82.84 | 17 | 6.44 |
| 14.8 | -0.13 | 58.51 | 13 | 5.33 | 89.01 | 17 | 6.82 |
| 13.5 | 0.37 | 50.05 | 12 | 4.83 | 108.78 | 17 | 7.94 |
| 12.1 | 1.05 | 24.11 | 11 | 2.50 | 147.29 | 17 | > 8.3 |

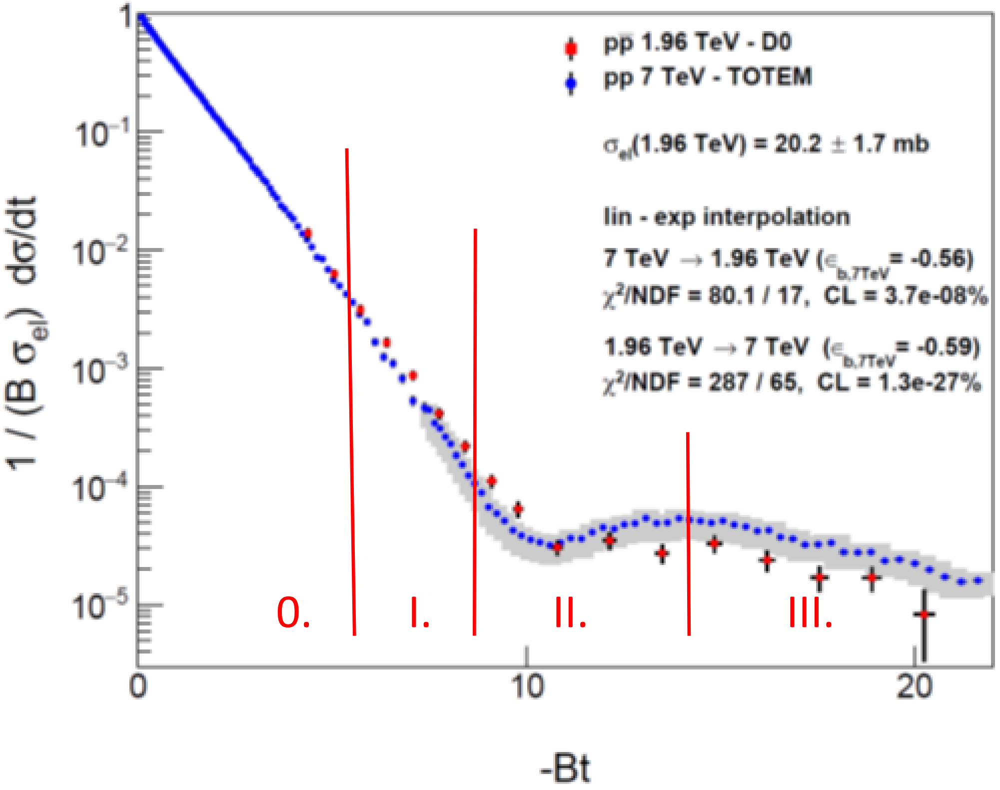



Optimized for the range of investigation

Greater than 5 σ

For all the datapoints

# Stability of Odderon-signal



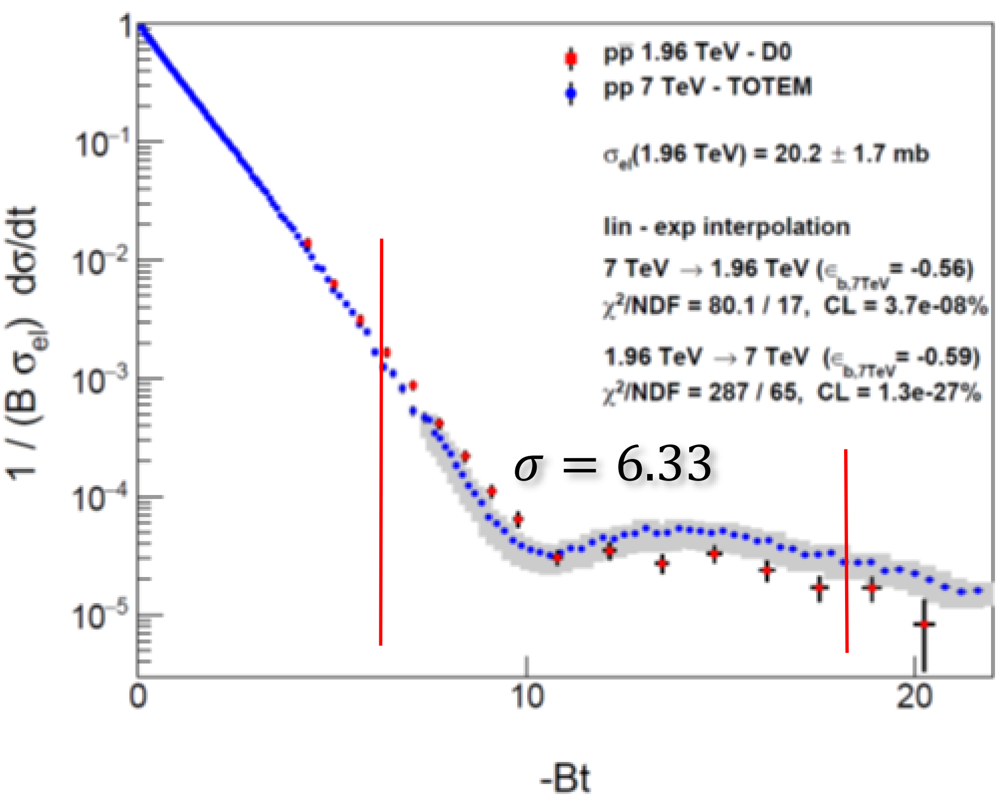

| Partial significances from the swing, interference, tail and all regions, characterized by $x_{min} < x \leq x_{max}$ | | | | | |
|---|---|---|---|---|---|
| $x_{min}$ | $x_{max}$ | $\epsilon_{B21}$ of min $\Delta\chi^2$ in $x_{min} < x \leq x_{max}$ | $\Delta\chi^2$ in $x_{min} < x \leq x_{max}$ | NDF in $x_{min} < x \leq x_{max}$ | $\sigma$ 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 |

The 10 D0 points in the swing and diffractive interference region provide a significant Odderon effect

# Optimizing Odderon signal at 7 TeV

Left door excludes the first n, right door excludes the last m D0 points

| n\m | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 0 | eps=-0.56 chi2=80.074 sigma=6.26 left=2.26 right=2.69 | eps=-0.51 chi2=77.278 sigma=6.21 left=2.17 right=1.34 | eps=-0.46 chi2=75.842 sigma=6.25 left=2.08 right=7.23 | eps=-0.32 chi2=67.834 sigma=5.85 left=1.83 right=8.09 | eps=-0.13 chi2=58.513 sigma=5.33 left=1.52 right=5.94 | eps=0.35 chi2=50.046 sigma=4.83 left=0.87 right=21.2 | | |
| 1 | eps=-0.57 chi2=77.8 sigma=6.25 left=2.01 right=2.65 | eps=-0.53 chi2=75.082 sigma=6.20 left=1.95 right=1.25 | eps=-0.48 chi2=73.740 sigma=6.25 left=1.86 right=7.00 | eps=-0.34 chi2=65.983 sigma=5.86 left=1.63 right=7.83 | eps=-0.15 chi2=56.974 sigma=5.36 left=1.35 right=5.71 | eps=0.3 chi2=49.150 sigma=4.91 left=0.79 right=20.6 | | |
| | | | s=-0.50 chi2=71.858 sigma=6.26 left=1.2 right=6.78 | eps=-0.36 chi2=64.330 sigma=5.9 left=0.98 right=7.57 | eps=-0.17 chi2=55.605 sigma=5.42 left=0.73 right=5.49 | eps=0.25 chi2=48.339 sigma=5.01 left=0.30 right=19.9 | eps=0.98 chi2=23.631 sigma=2.81 left=0.001 right=7.36 | |
| | | | s=-0.52 chi2=70.644 sigma=6.33 left=5.57 right=6.56 | eps=-0.38 chi2=63.331 sigma=5.98 left=5.18 right=7.32 | eps=-0.19 chi2=54.859 sigma=5.52 left=4.68 right=5.27 | eps=0.22 chi2=48.024 sigma=5.15 left=3.69 right=19.5 | eps=0.97 chi2=23.630 sigma=3.00 left=2.20 right=7.30 | |
| | | | s=-0.55 chi2=65.028 sigma=6.09 left=7.89 right=6.24 | eps=-0.42 chi2=58.101 sigma=5.76 left=7.53 right=6.83 | eps=-0.23 chi2=50.123 sigma=5.15 left=7.03 right=4.84 | eps=0.11 chi2=44.210 sigma=5.02 left=3.69 right=19.5 | eps=0.87 chi2=21.344 sigma=2.94 left=4.48 right=6.66 | |
| | | | s=-0.58 chi2=57.084 sigma=5.68 left=7.52 right=5.82 | eps=-0.45 chi2=50.529 sigma=5.35 left=6.18 right=6.47 | eps=-0.27 chi2=53.034 sigma=4.74 left=4.66 right=4.43 | eps=-0.09 chi2=37.706 sigma=4.64 left=3.36 right=14.8 | | |
| | | | ps=-0.71 chi2=48.99 sigma=5.23 left=12.7 right=4.64 | eps=-0.58 chi2=43.744 sigma=4.98 left=11.1 right=5.03 | | | | |
| | | | s=-0.88 chi2=35.114 sigma=4.21 left=14.1 right=3.2 | effect | | | | |



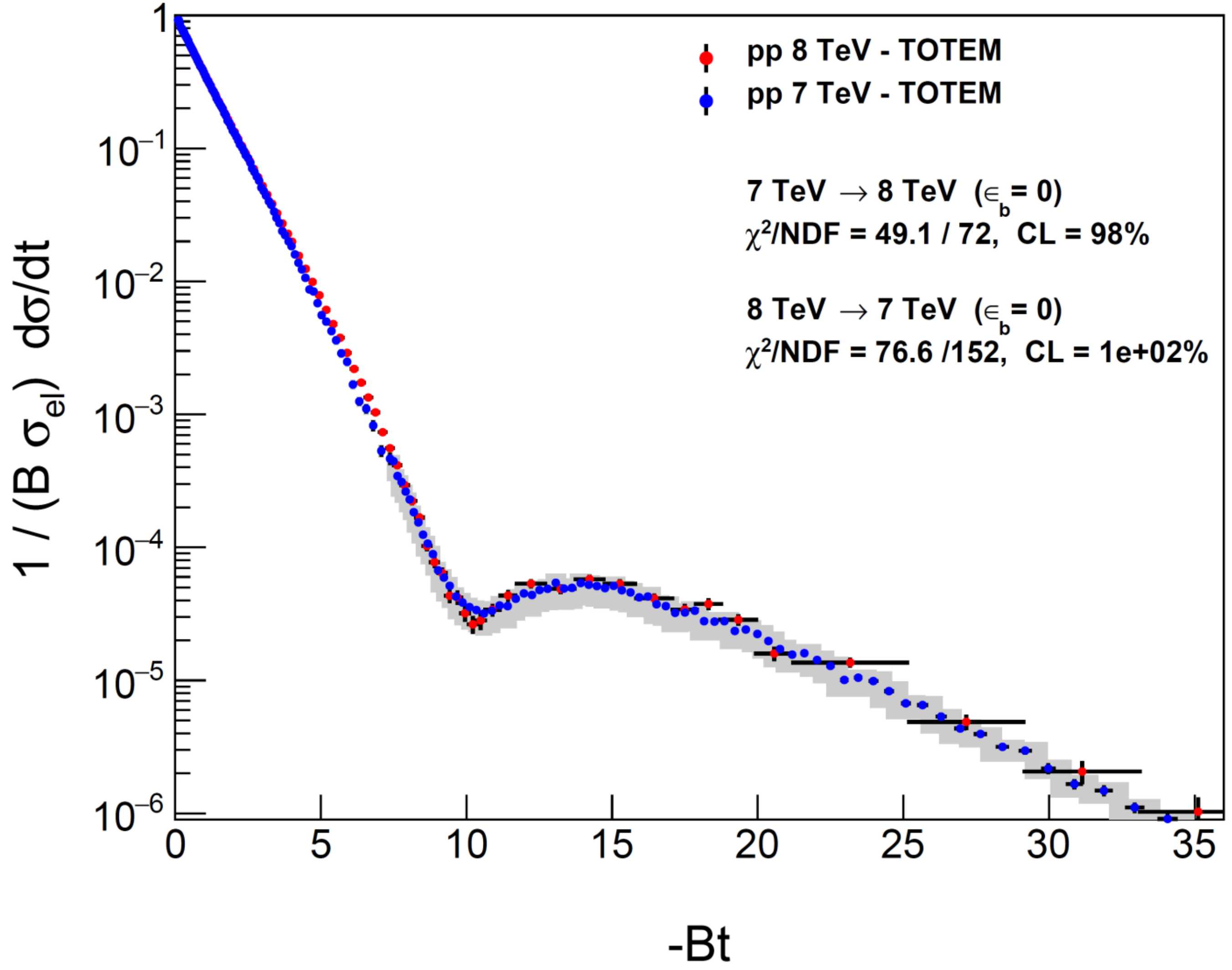
# 7 TeV results, closing gates

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

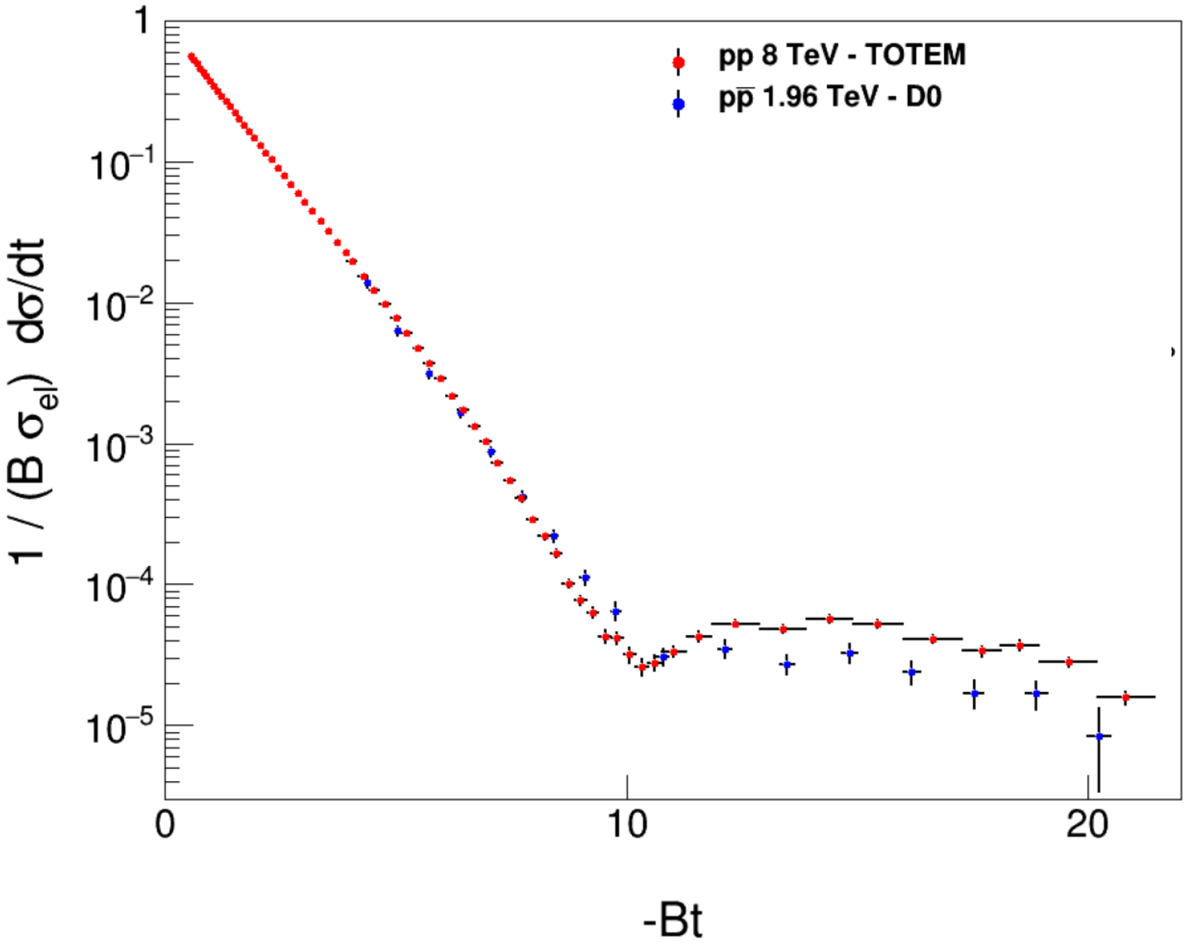
| Sliding door technique with two wings (n,m)<br>Left door excludes the first n, right door excludes the last m D0 points | | | |
|---|---|---|---|
| n | m | Odderon signal | Background |
| 2 | 2 | 6.27 σ | 1.68 σ |
| 3 | 2 | 6.33 σ | 1.70 σ |
| 4 | 2 | 6.21 σ | 2.37 σ |

**MODEL INDEPENT RESULT:**
**Outside the best window: *H*(*x*|pp) = *H*(*x*,pbarp)**
**pp and pbarp backgrounds agree within 1.7 sigma**

# No difference between 7 and 8 TeV data



# 8 TeV data also confirm the Odderon signal




**Projection 1.96--->8**

| | | | |
|---|---|---|---|
| eps_b1_7tev | -1.17 | | |
| eps_b12_1.96tev | 0 | | |
| **chi2 1--->2** | **88.382** | **CL (%)** | **1.7E-04** |
| **ndf 1--->2** | **35** | **Significance** | **4.7919** |

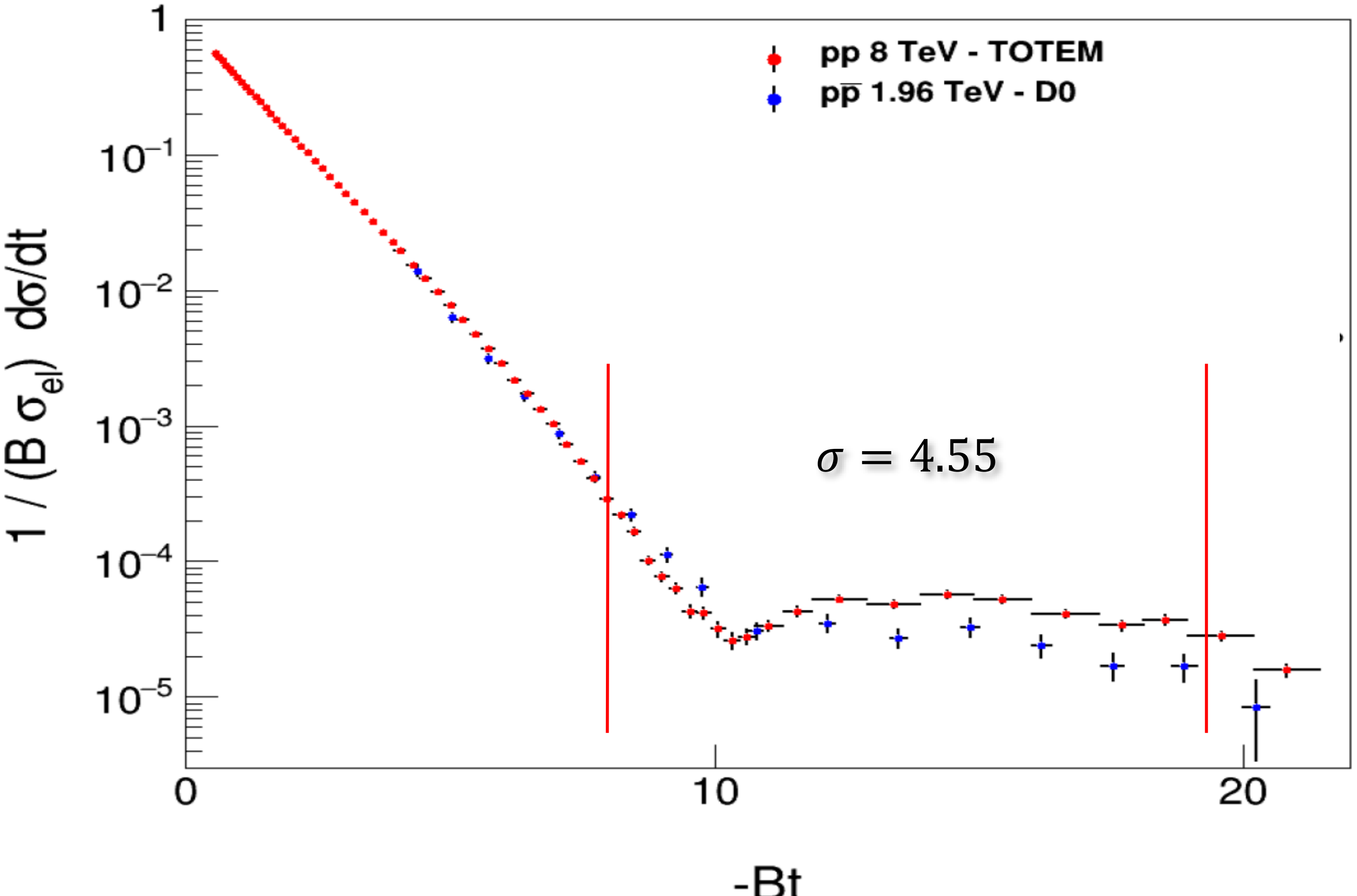
**Projection 8--->1.96**

| | | | |
|---|---|---|---|
| eps_b2_1.96tev | -1.45 | | |
| eps_b21_7tev | 0 | | |
| **chi2 2--->1** | **46.817** | **CL (%)** | **1.3E-02** |
| **ndf 2--->1** | **17** | **Significance** | **3.8266** |

# Optimizing Odderon signal at 8 TeV

Left door excludes the first n, right door excludes the last m D0 points

**Previous TOTEM slope value: 20.14+-0.15**




**Optimized TOTEM slope value: 19.9+-0.3**

n=left m=right

| \m | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 0 | eps=-1.26 chi2=45.854<br>sigma=3.74 …<br>left=0.1384 …ht=1.31 | eps=-1.20 chi2=44.541<br>sigma=3.77<br>left=0.1275 right=3.5 | eps=-1.05 chi2=41.006<br>sigma=3.60 left=0.1023<br>right=6.44 | |
| 1 | eps=-1.33 c… 45.709<br>sigma=3.87 … =0.073<br>right=1.29 | eps=-1.26 chi2=44.408<br>sigma=3.90 left=0.082<br>right=3.47 | eps=-1.11 chi2=40.898<br>sigma=3.74 left=0.103<br>right=6.38 | |
| 2 | eps=-1.29 c… 45.633<br>sigma=4.01 … =0.115<br>right=1.30 | eps=-1.21 chi2=44.323<br>sigma=4.04 left=0.128<br>right=3.50 | eps=-1.07 chi2=40.792<br>sigma=3.88 left=0.153<br>right=6.42 | |
| 3 | eps=-1.22 c… 45.512<br>sigma=4.15 … =0.018<br>right=1.32 | eps=-1.15 chi2=44.191<br>sigma=4.19 left=0.014<br>right=3.53 | eps=-0.99 chi2=40.631<br>sigma=4.03 left=0.006<br>right=6.50 | |
| 4 | eps=-1.26 c… 45.492<br>sigma=4.30 … =0.436<br>right=1.31 | eps=-1.18 chi2=44.175<br>sigma=4.34 left=0.415<br>right=3.51 | eps=-1.02 chi2=40.624<br>sigma=4.19 left=0.374<br>right=6.47 | |
| 5 | eps=-1.36 c… 45.044<br>sigma=4.42 … =0.899<br>right=1.29 | eps=-1.28 chi2=43.748<br>sigma=4.46 left=0.866<br>right=3.46 | eps=-1.10 chi2=40.241<br>sigma=4.32 left=0.794<br>right=6.39 | |
| 6 | eps=-1.52 c… 44.113<br>sigma=4.50 le…<br>right=1.26 | eps=-1.40 chi2=42.850<br>…a=4.55 left=2.24<br>right=3.39 | eps=-1.26 chi2=39.416<br>sigma=4.42 left=2.13<br>right=6.23 | |
| 7 | eps=-1.78 chi2=41.738<br>sigma=4.46 left=6.08<br>right=1.20 | eps=-1.68 chi2=40.527<br>sigma=4.52 left=5.97<br>right=3.28 | eps=-1.51 chi2=37.211<br>sigma=4.41 left=5.80<br>right=5.98 | |

# Combining the 7 and 8 TeV data

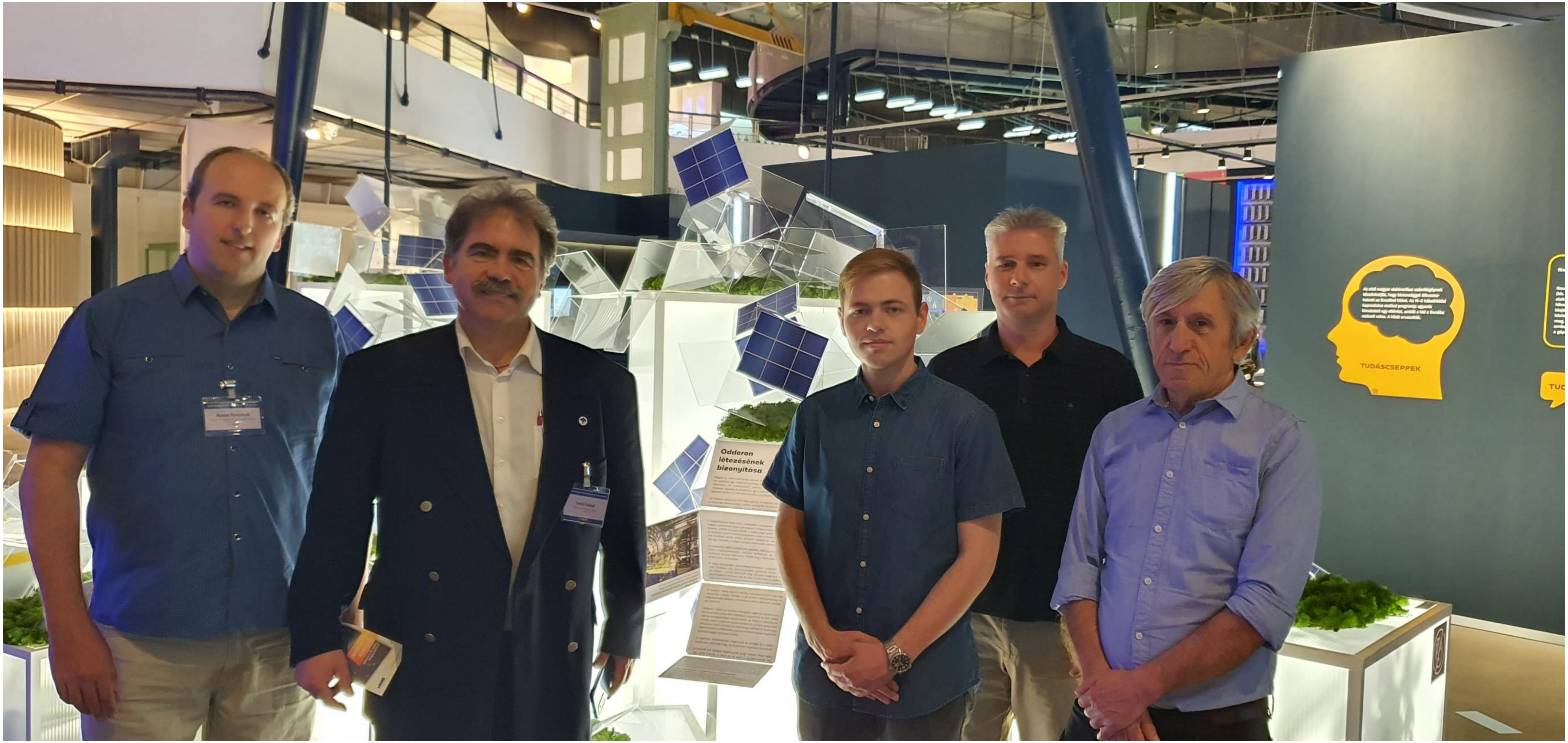
| n=left m=right | CL (%) | | | |
|---|---|---|---|---|
| n\m | 0 | 1 | 2 | 3 |
| 0 | 1,76E-10 | 2,09E-10 | 3,43E-10 | 2,19E-08 |
| 1 | 1,10E-10 | 1,24E-10 | 1,90E-10 | 1,13E-08 |
| 2 | 5,95E-11 | 6,38E-11 | 9,29E-11 | 5,38E-09 |
| 3 | 2,41E-11 | 2,44E-11 | 3,37E-11 | 1,92E-09 |
| 4 | 5,38E-11 | 5,10E-11 | 6,54E-11 | 3,24E-09 |
| 5 | 3,55E-10 | 3,18E-10 | 3,78E-10 | 1,57E-08 |
| 6 | 3,81E-09 | 2,86E-09 | 2,79E-09 | 6,44E-08 |
| 7 | 7,25E-07 | 4,64E-07 | 3,89E-07 | 4,22E-06 |

| n=left m=right | sigma | | | |
|---|---|---|---|---|
| n\m | 0 | 1 | 2 | 3 |
| 0 | 7,05 | 7,03 | 6,96 | 6,35 |
| 1 | 7,12 | 7,10 | 7,04 | 6,45 |
| 2 | 7,20 | 7,19 | 7,14 | 6,56 |
| 3 | **7,32** | **7,32** | 7,28 | 6,71 |
| 4 | 7,22 | 7,22 | 7,19 | 6,64 |
| 5 | 6,95 | 6,97 | 6,95 | 6,40 |
| 6 | 6,61 | 6,65 | 6,66 | 6,18 |
| 7 | 5,79 | 5,86 | 5,89 | 5,48 |

**Itt a chi2-ek és az NDF-ek össze lettek adva, majd kiszámoltam a konfidenciákat, abból pedig a szignifikanciákat.**

| n=left m=right | sigma | | | |
|---|---|---|---|---|
| n\m | 0 | 1 | 2 | 3 |
| 0 | 7,07 | 7,06 | 6,97 | 6,34 |
| 1 | 7,16 | 7,14 | 7,06 | 6,46 |
| 2 | 7,25 | 7,25 | 7,17 | 6,59 |
| 3 | 7,38 | **7,39** | 7,33 | 6,75 |
| 4 | 7,31 | 7,33 | 7,27 | 6,71 |
| 5 | 7,09 | 7,11 | 7,07 | 6,53 |
| 6 | 6,78 | 6,82 | 6,82 | 6,35 |
| 7 | 5,98 | 6,05 | 6,10 | 5,69 |

**Itt a szignifikanciák összegét osztottam \sqrt{2}-vel.**


Odderon
létezésének
bizonyítása
TUDÁSCSEPPEK

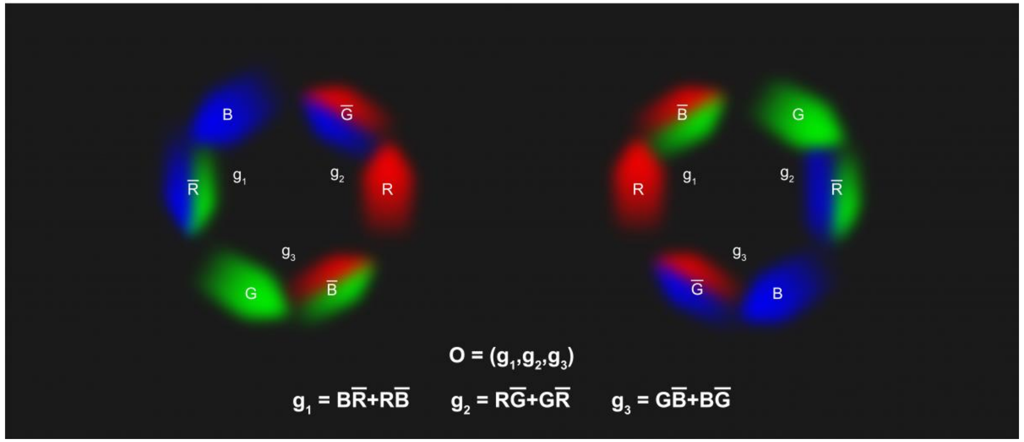
# Summary

ODDERON and the colorful GLUONS

Observation of the Odderon and its Illustration 4.0

Csörgő Tamás, Novák Tamás, Roman Pasechnik, Ster András, Szanyi István: Eur. Phys. J. C 81, 180 (2021).

https://doi.org/10.1140/epjc/s10052-021-08867-6
https://en.wikipedia.org/wiki/Gluon




- Strategy of Odderon search
- Difficulties of Odderon discovery
- Odderon-signal at 8 TeV
- No significant difference between 7 és 8 TeV data
- Optimalaizing the Odderon-signal

**Thank you for your attention!**