

Study of the Odderon signal at 7 and 8 TeV

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10th Day of Femtoscopy,
29-30 Oct. 2024

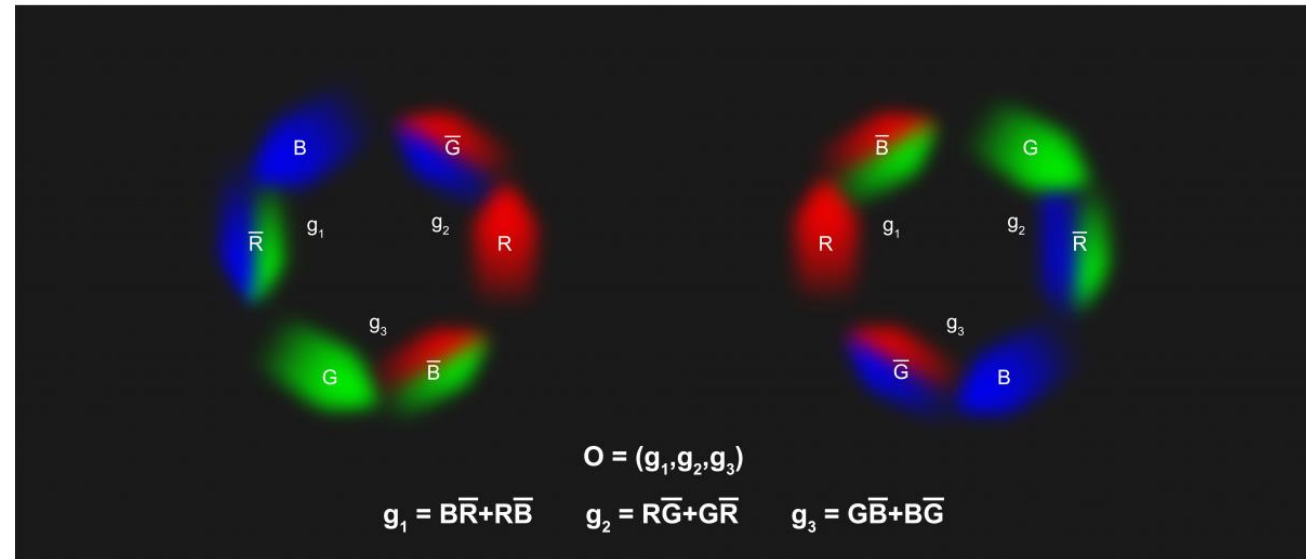
ODDERON and the colorful GLUONS

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>



Outline

- Strategy of Odderon search
- Difficulties of Odderon discovery
- Odderon-signal at 8 TeV
- Comparing (and combining) 7 and 8 TeV data
- Optimizing 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

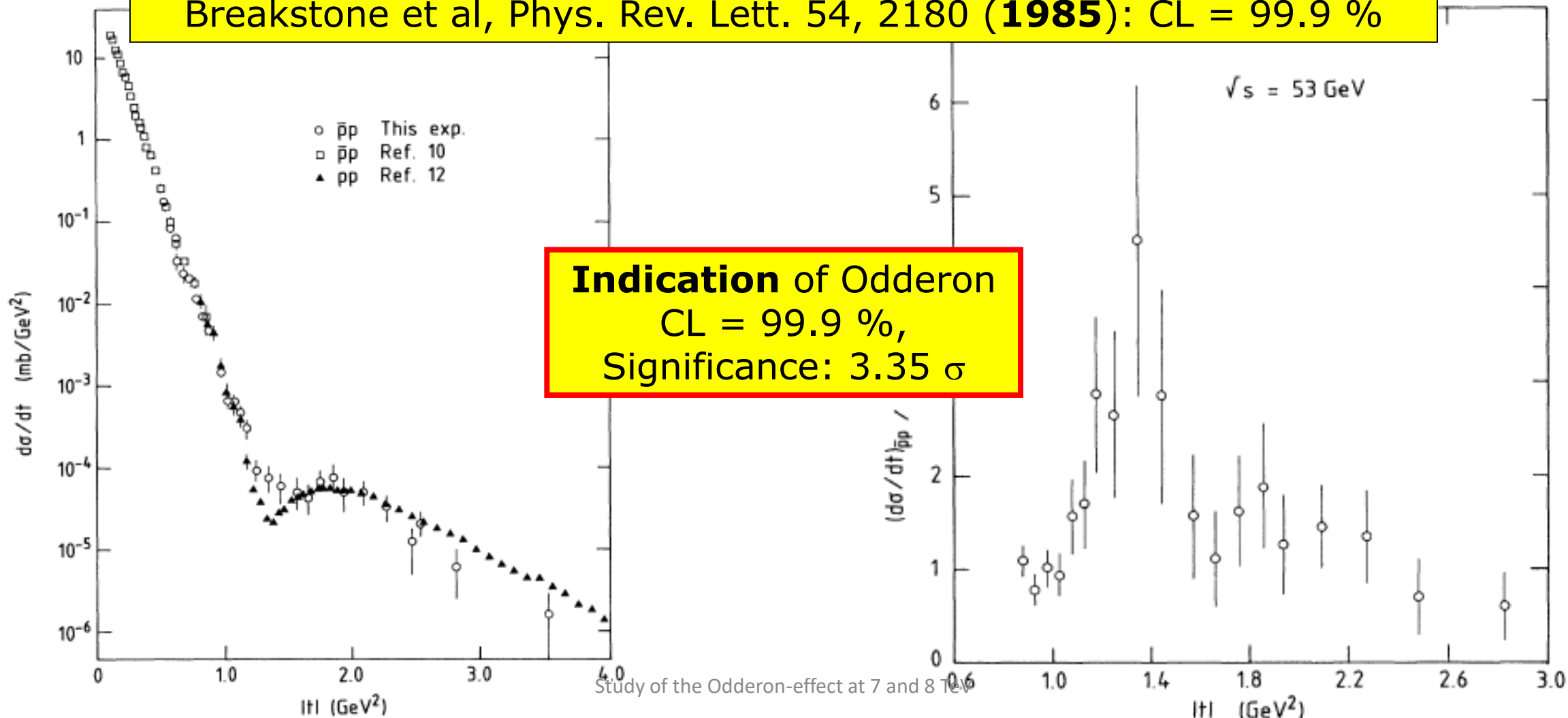
It is shown that the assumption that the rise of pp total cross sections at ISR energies can be understood by the existence of a contribution proportional to \ln^2/s is not necessarily within the existing knowledge of experimental data. Also by assuming that asymptotically $\text{Re } F \sim s \ln^2/s$ together with $\sigma_T \sim \ln^2/s$ it is possible to propose a parametrization which seems interesting both from the experimental and theoretical points of view. (JFP)



Basarab Nicolescu

Odderon: kísérletileg nehezen megfogható

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



Strategy of Odderon Search

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

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

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

- Consequencies

Differential cross-sections → measurable

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

$$\frac{d\sigma^{pp}}{dt} \neq \frac{d\sigma^{p\bar{p}}}{dt}$$

$$\text{for } \sqrt{s} \geq 1 \text{ TeV} \implies T_{el}^O(s, t) \neq 0$$

Quantification / Extrapolation

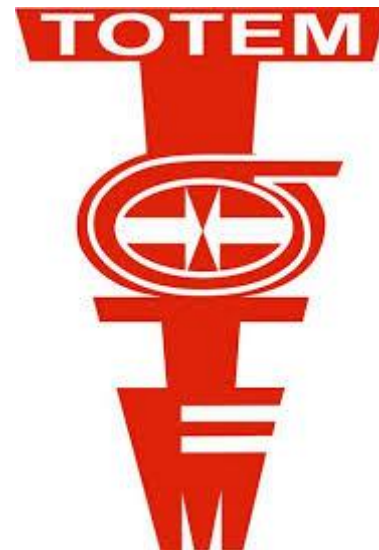
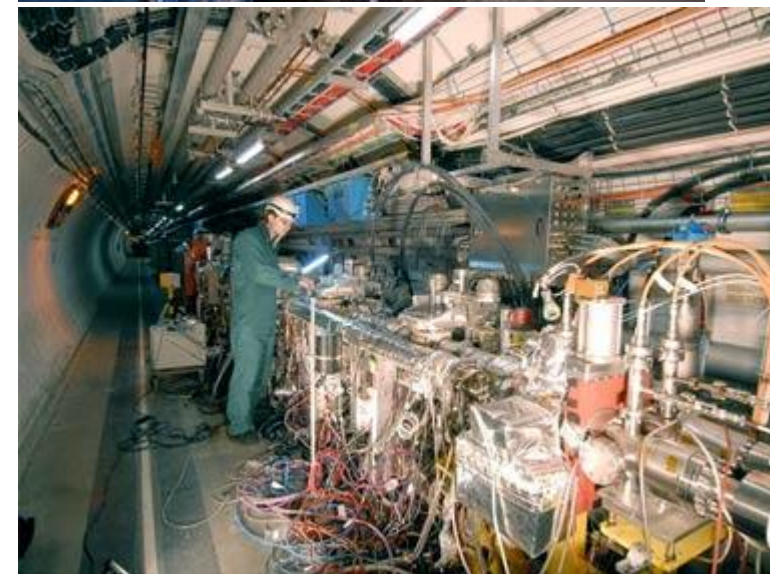
- How to compare two different measured $H(x)$ scaling functions
- Determine if two different measurement correspond to significantly different $H(x)$ scaling functions, or not.
- Compare the data-sets D_1 and D_2 by creating a common domain X_{12} and linear extrapolation between neighbouring data points.

- Using

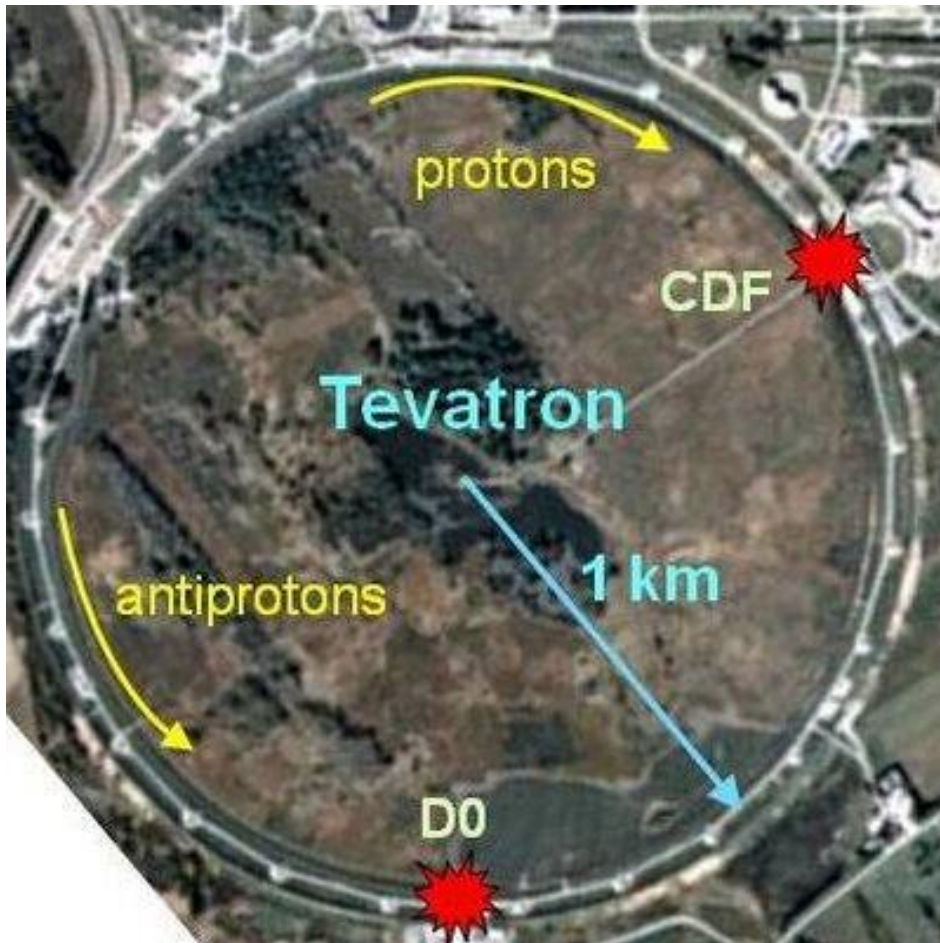
$$\chi^2 = \sum \frac{(d_{12}(j) - d_{21}(j))^2}{e_{12}^2(j) + e_{21}^2(j)}.$$

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

Large Haron Collider (LHC) and the TOTEM



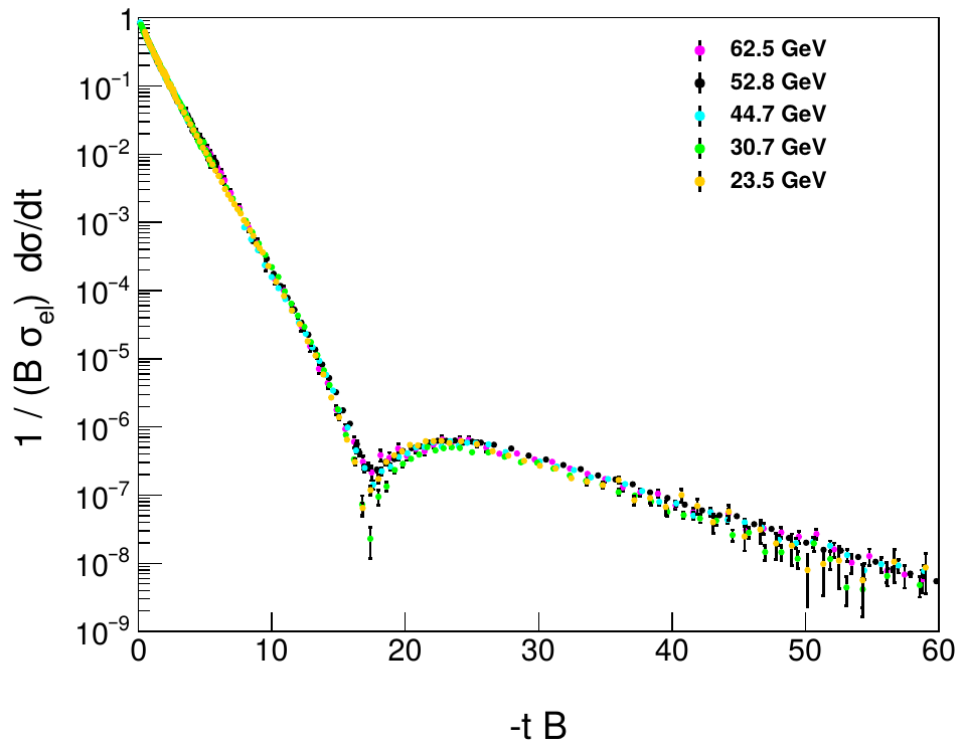
Tevatron and D0



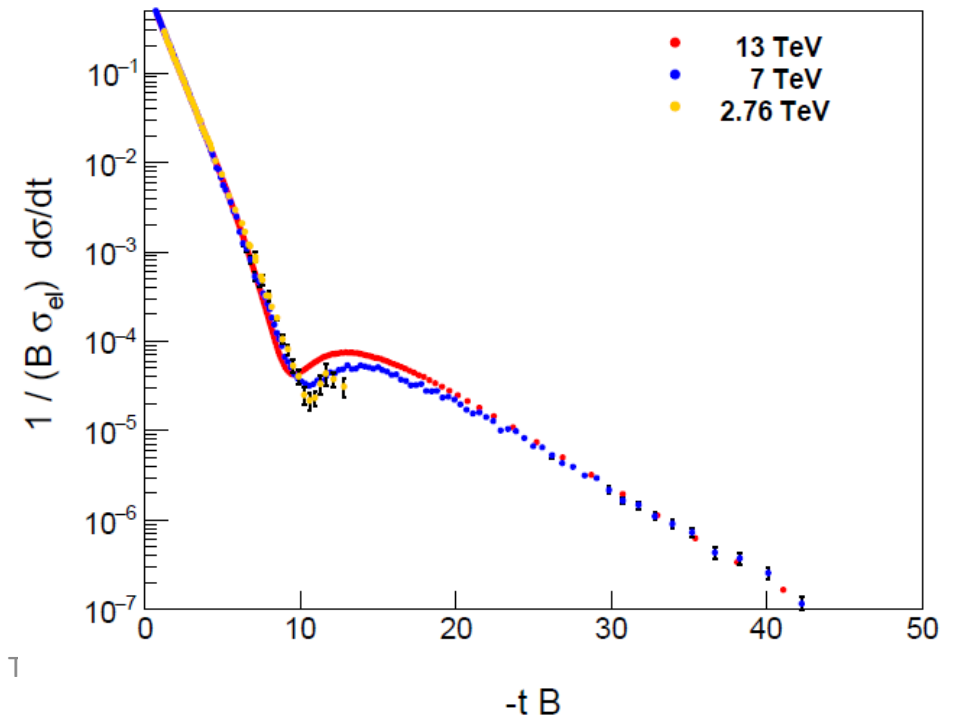
Difficulties I.: $H(x,s)$ scaling function

- 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) .

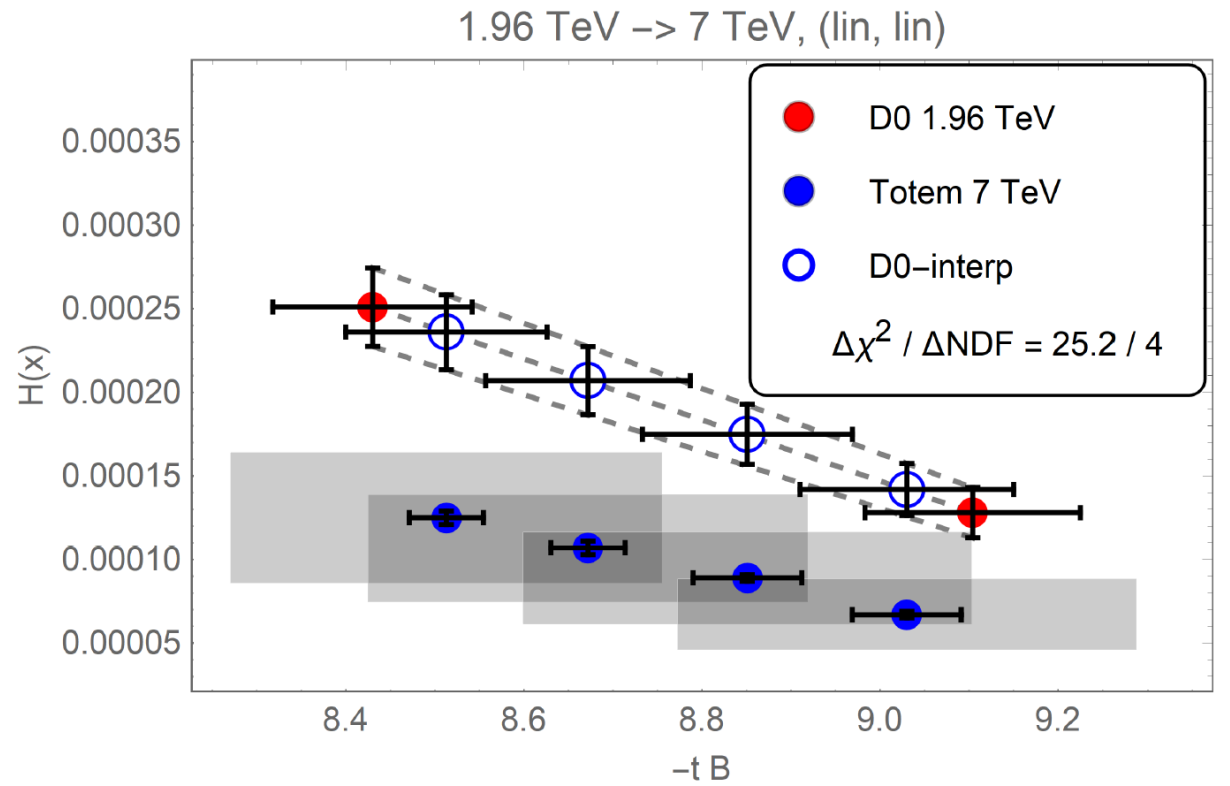
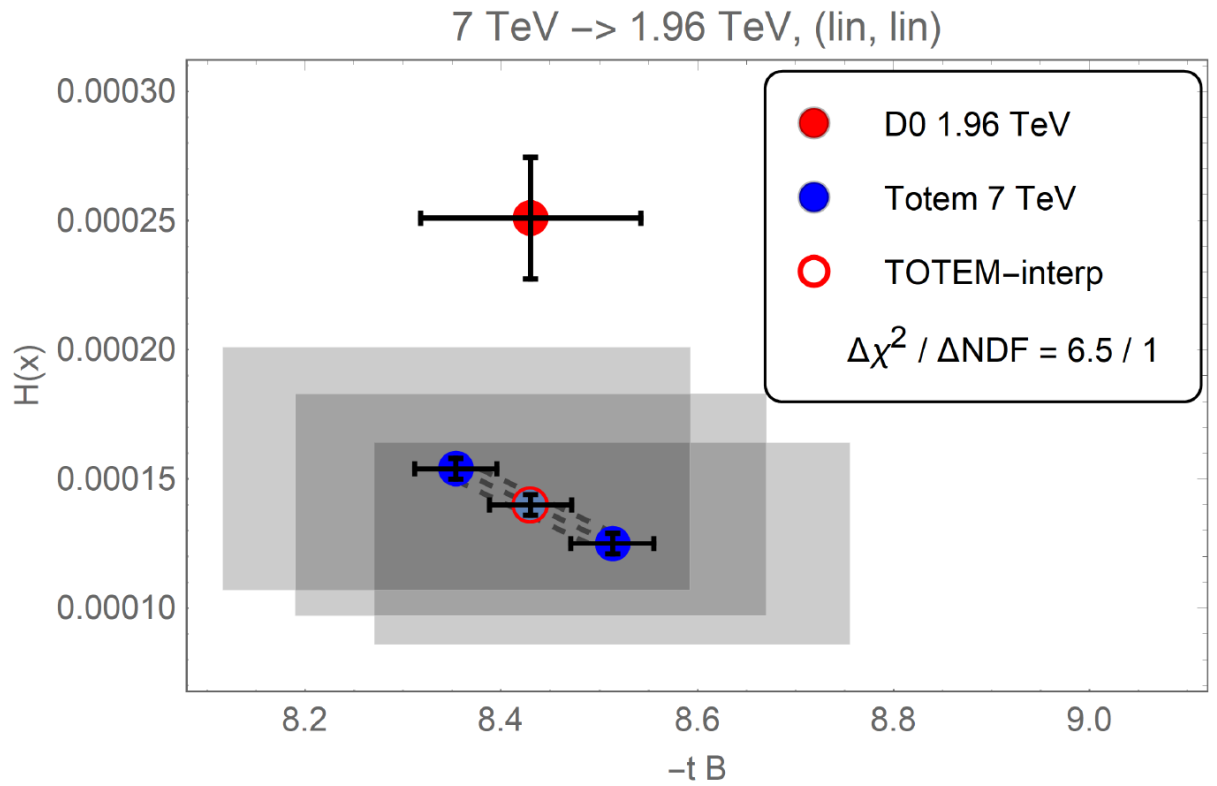
$$H(x, s) = \frac{1}{B(s)\sigma_{el}(s)} \frac{d\sigma}{dt}, \text{ where } x = -tB(s).$$



study of the Odderon-effect at 7 and 8 TeV



Difficulties II. -> need a projection



Illustrate the model independent nature of the interpolations

Difficulties III. -> different types of errors

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

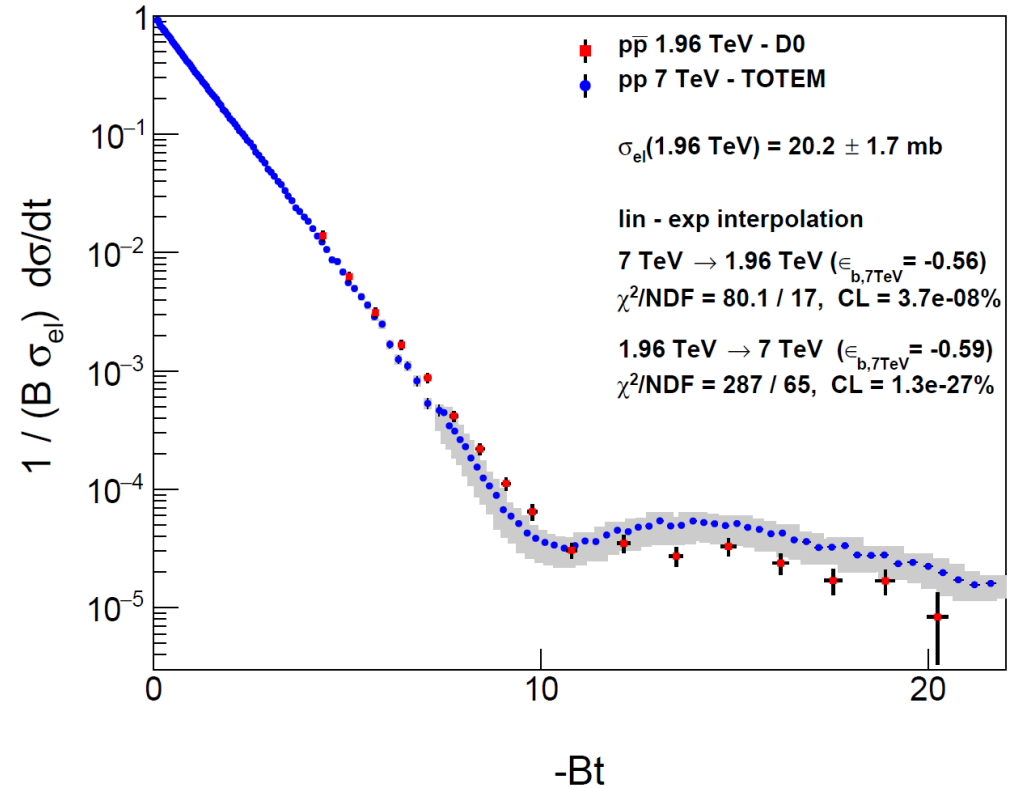
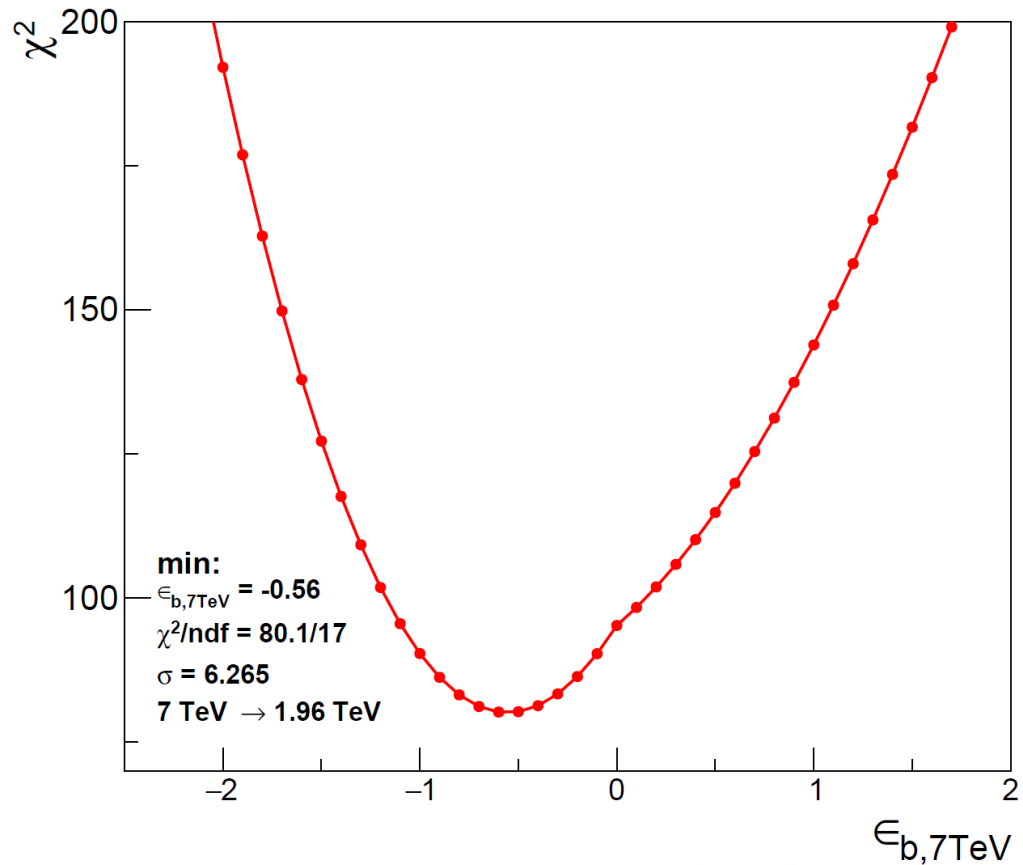
$$\tilde{e}_{A,k}^j = e_{A,k}^j \frac{d_k^j + \epsilon_{b,k} e_{B,k}^j}{d_k^j},$$

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

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

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

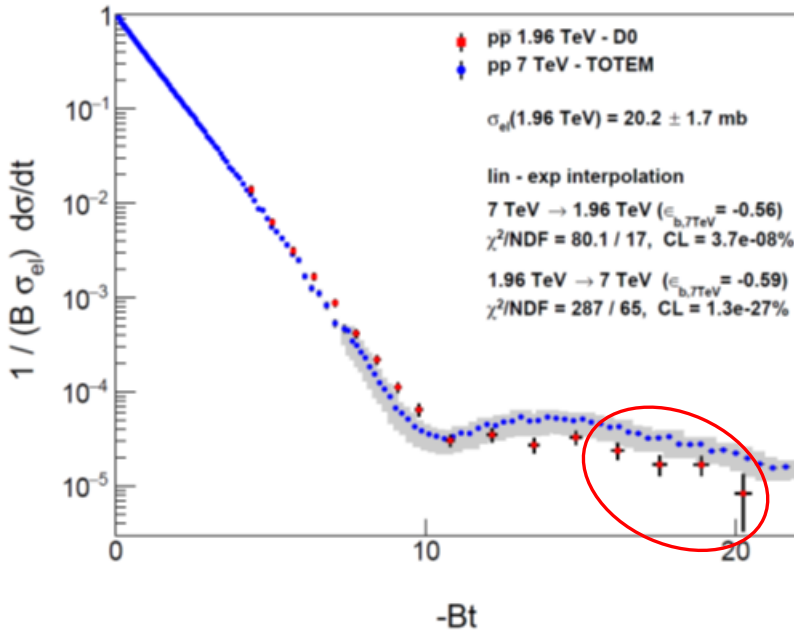
Significant Odderon-signal (7 TeV)




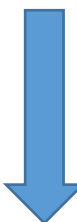
σ_{el} (mb)	interpolation	direction of projection	χ^2	NDF	CL (%)	Significance [σ]
20.2 ± 1.7	lin-exp	7 \rightarrow 1.96 TeV	80.1	17	3.7×10^{-8}	6.26


Stability of Odderon-signal

Stability of the results for the cutoff at large x, for $\epsilon_{B21}(7 \text{ TeV})$ optimized for $x \leq x_{\max}$							
x_{\max}	ϵ_{B21} of $\min[\chi^2(x \leq x_{\max})]$	$\min[\chi^2(x \leq x_{\max})]$	NDF($x \leq x_{\max}$)	$\sigma(x \leq x_{\max})$	$\chi^2(\text{all } x)$	NDF(all x)	$\sigma(\text{all } x)$
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

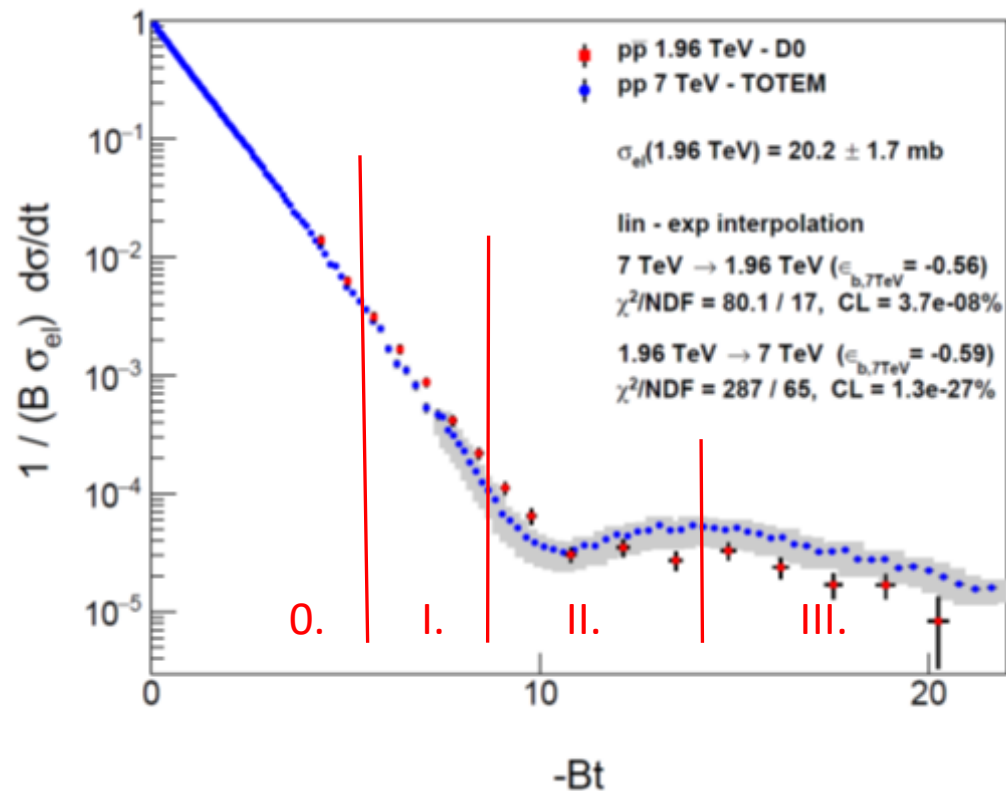



 Optimized for the
 range of investigation


 Greater than 5 σ


 For all the datapoints

Stability of Odderon-signal



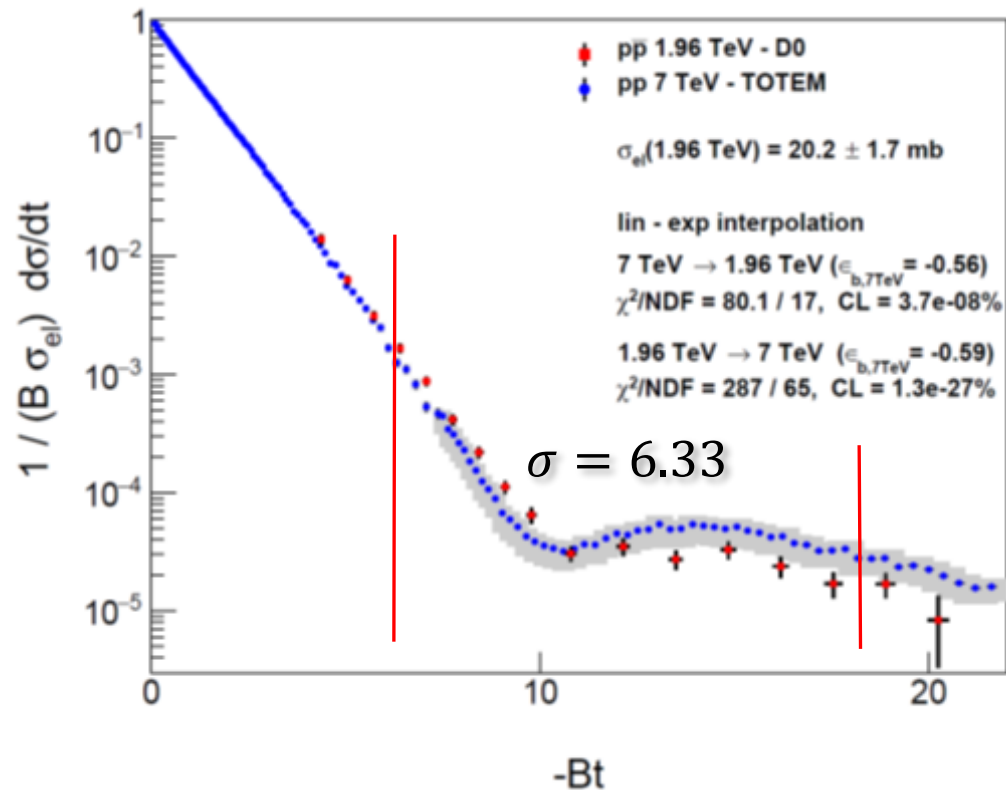
Partial significances from the swing, interference, tail and all regions, characterized by $x_{\min} < x \leq x_{\max}$					
x_{\min}	x_{\max}	ϵ_{B21} of $\min \Delta \chi^2$ in $x_{\min} < x \leq x_{\max}$	$\Delta \chi^2$ in $x_{\min} < x \leq x_{\max}$	NDF in $x_{\min} < x \leq x_{\max}$	σ in $x_{\min}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

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		



eps=-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
eps=-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
eps=-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
eps=-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	
eps=-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			
eps=-0.88 chi2=35.114 sigma=4.21 left=14.1 right=3.2				

and 8 TeV

7 TeV results, closing gates

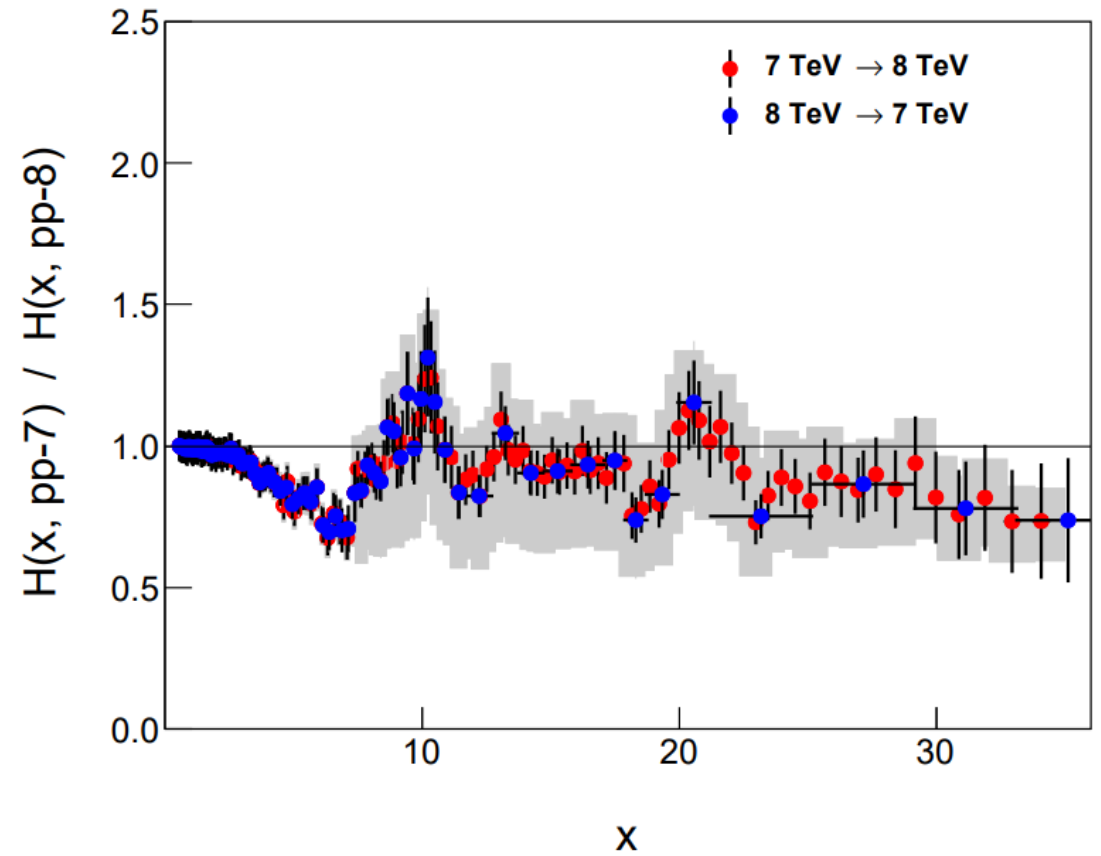
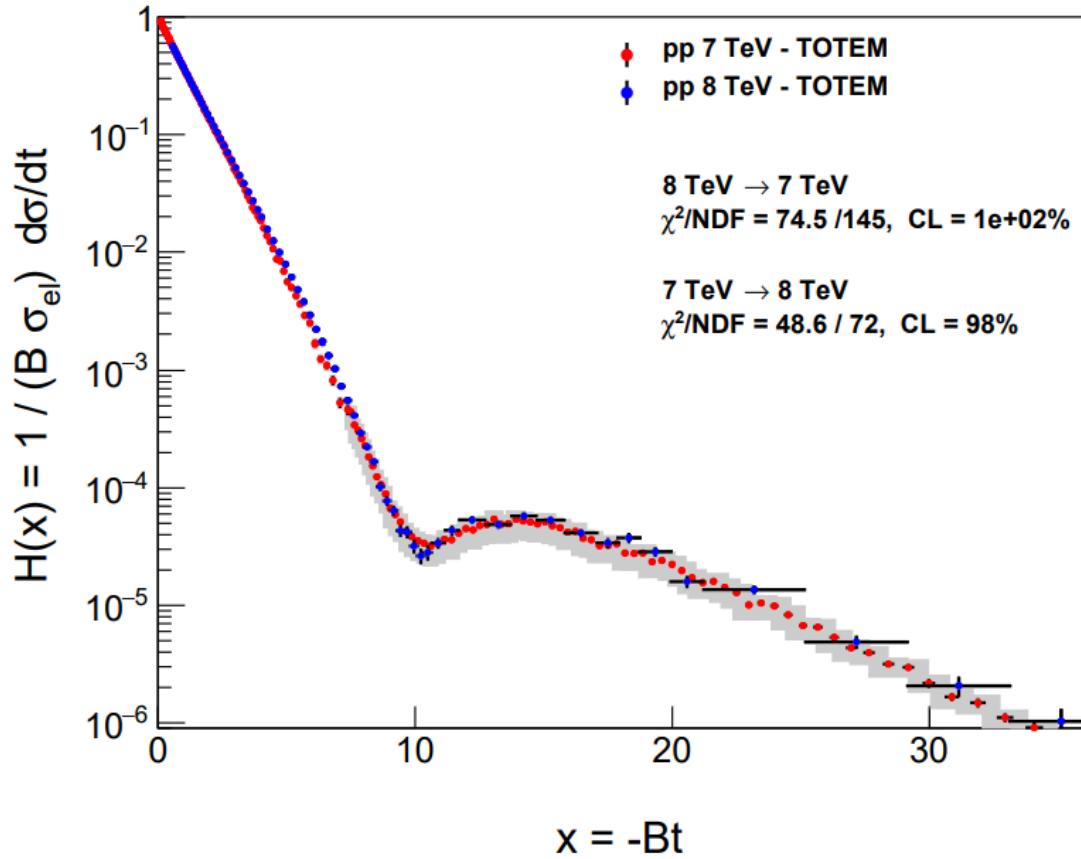
**Two sliding gates of size n and size m :
(n,m): Leaving out the first n and last m D0 point**

Sliding door technique with two wings (n,m)
Left door excludes the first n , right door excludes the last m D0 points

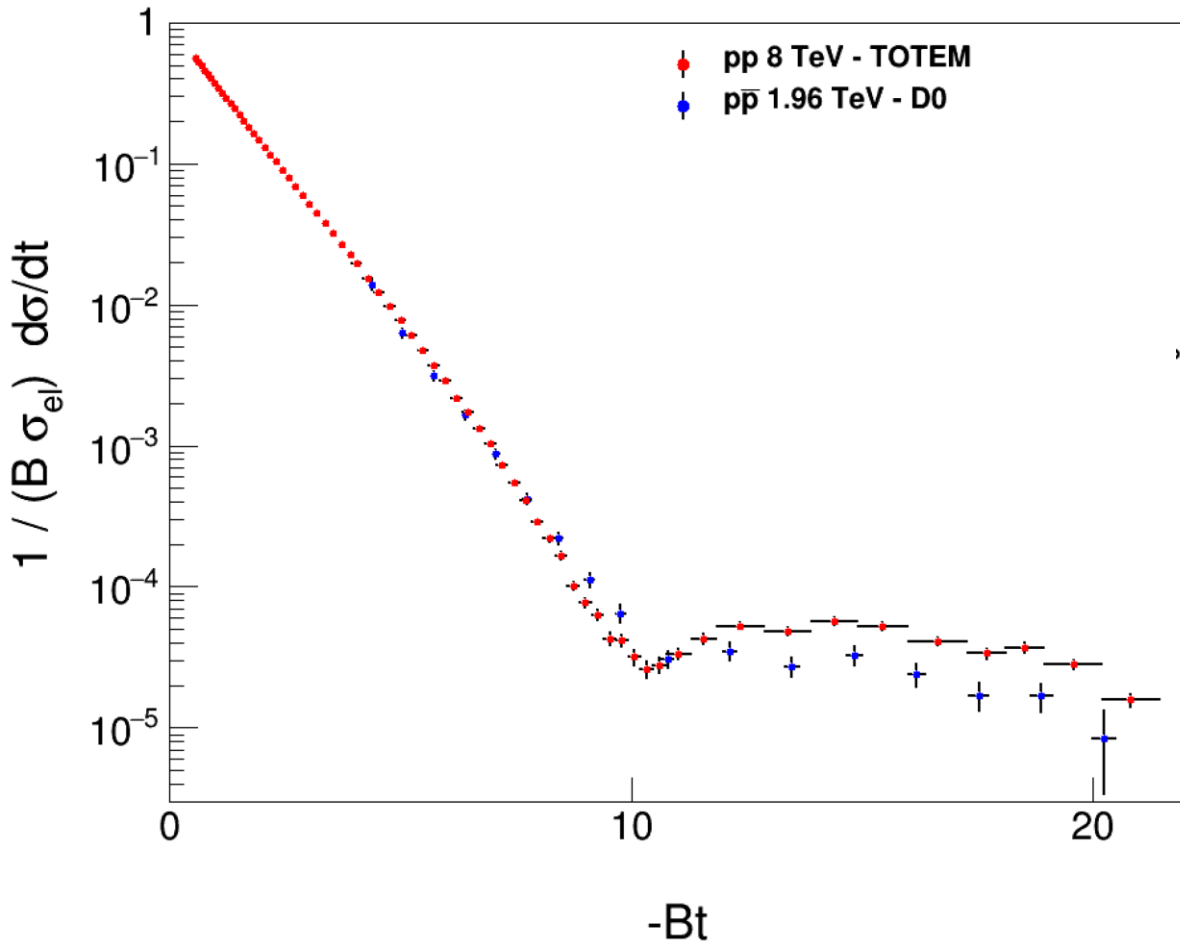
	n	m	Odderon signal	Background		
	2	2	6.27 σ	1.68 σ		
	3	2	6.33 σ	1.70 σ		
	4	2	6.21 σ	2.37 σ		

MODEL INDEPENDENT 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 confirms the Odderon signal



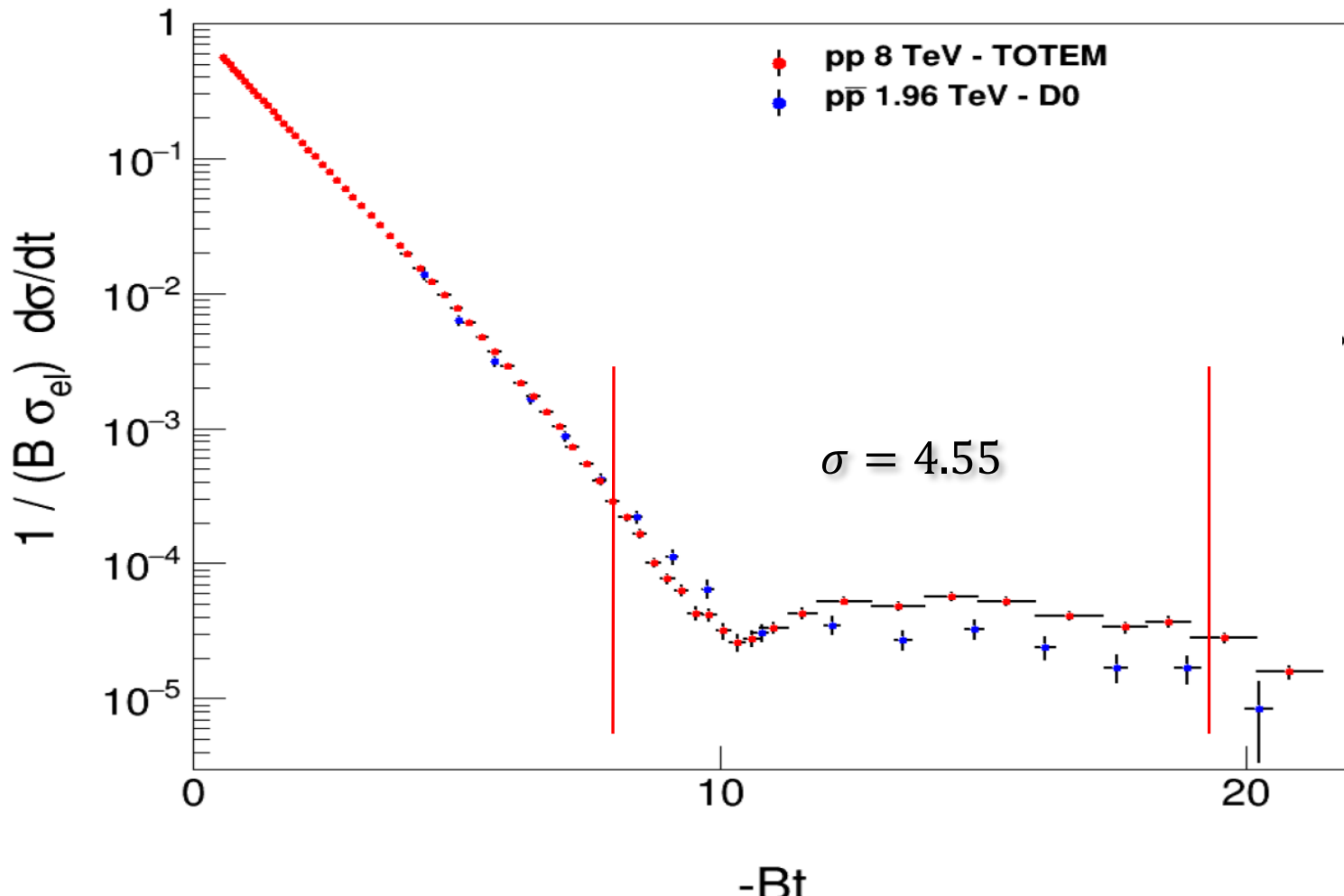
Projection 1.96--->8		
eps_b1_7tev	-1.17	
eps_b12_1.96tev	0	
chi2 1--->2	88.382 CL (%)	1.7E-04
ndf 1--->2	35 Significance	4.7919
Projection 8--->1.96		
eps_b2_1.96tev	-1.45	
eps_b21_7tev	0	
chi2 2--->1	46.817 CL (%)	1.3E-02
ndf 2--->1	17 Significance	3.8266

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**

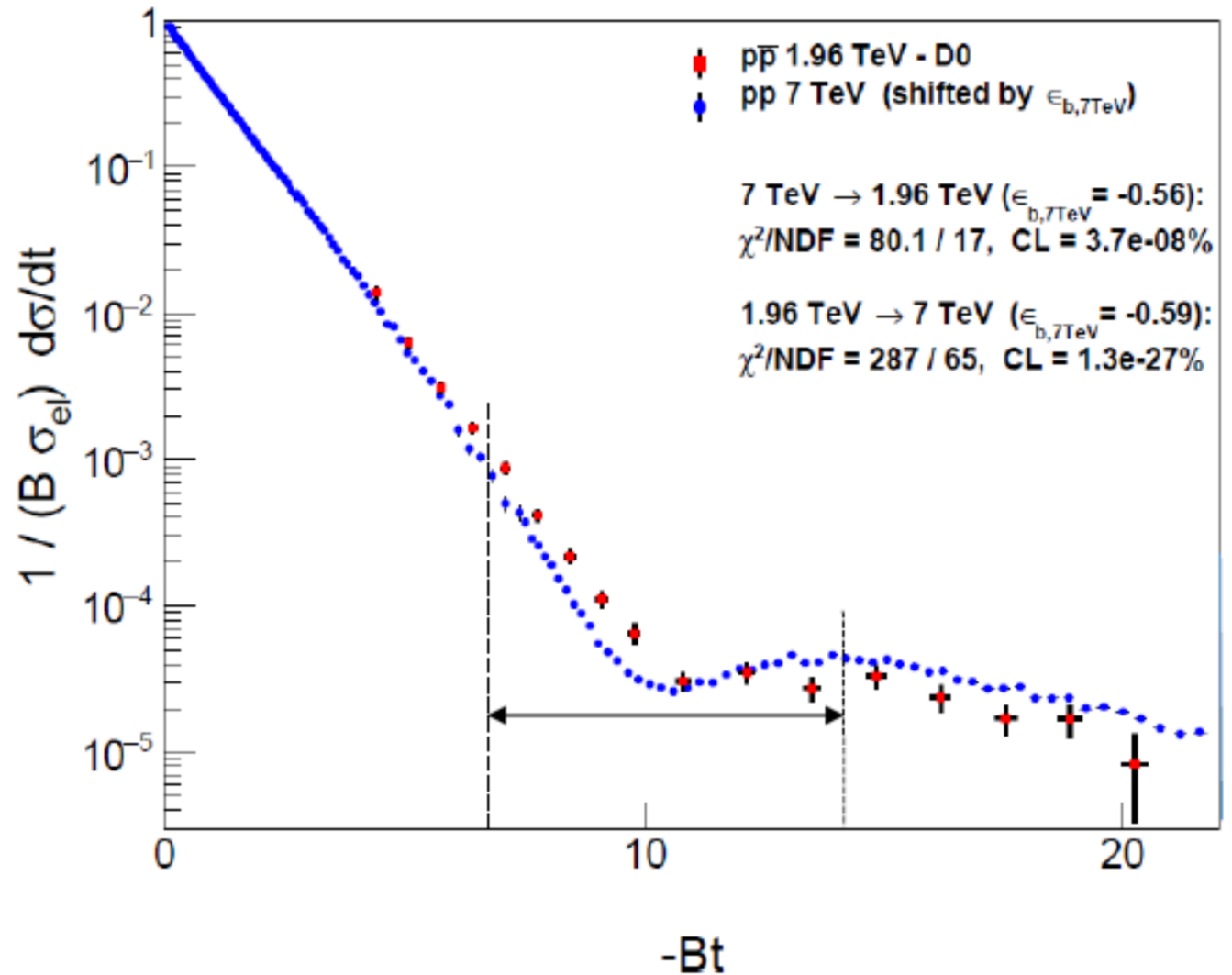


n=left m=right					
n	m	0	1	2	3
0	0	eps=-1.26 chi2=45.854 sigma=3.74 left=0.1384 right=1.31	eps=-1.20 chi2=44.541 sigma=3.77 left=0.1275 right=3.5	eps=-1.05 chi2=41.006 sigma=3.60 left=0.1023 right=6.44	
1	1	eps=-1.33 chi2=45.709 sigma=3.87 right=1.29	eps=-1.26 chi2=44.408 sigma=3.90 left=0.082 right=3.47	eps=-1.11 chi2=40.898 sigma=3.74 left=0.103 right=6.38	
2	2	eps=-1.29 chi2=45.633 sigma=4.01 right=1.30	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	
3	3	eps=-1.22 chi2=45.512 sigma=4.15 right=1.32	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	4	eps=-1.26 chi2=45.492 sigma=4.30 right=1.31	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	5	eps=-1.36 chi2=45.044 sigma=4.42 right=1.29	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	6	eps=-1.52 chi2=44.113 sigma=4.50 left=1.26 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	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	

Sliding windows

Smallest window where the signal is at least 5 sigma:

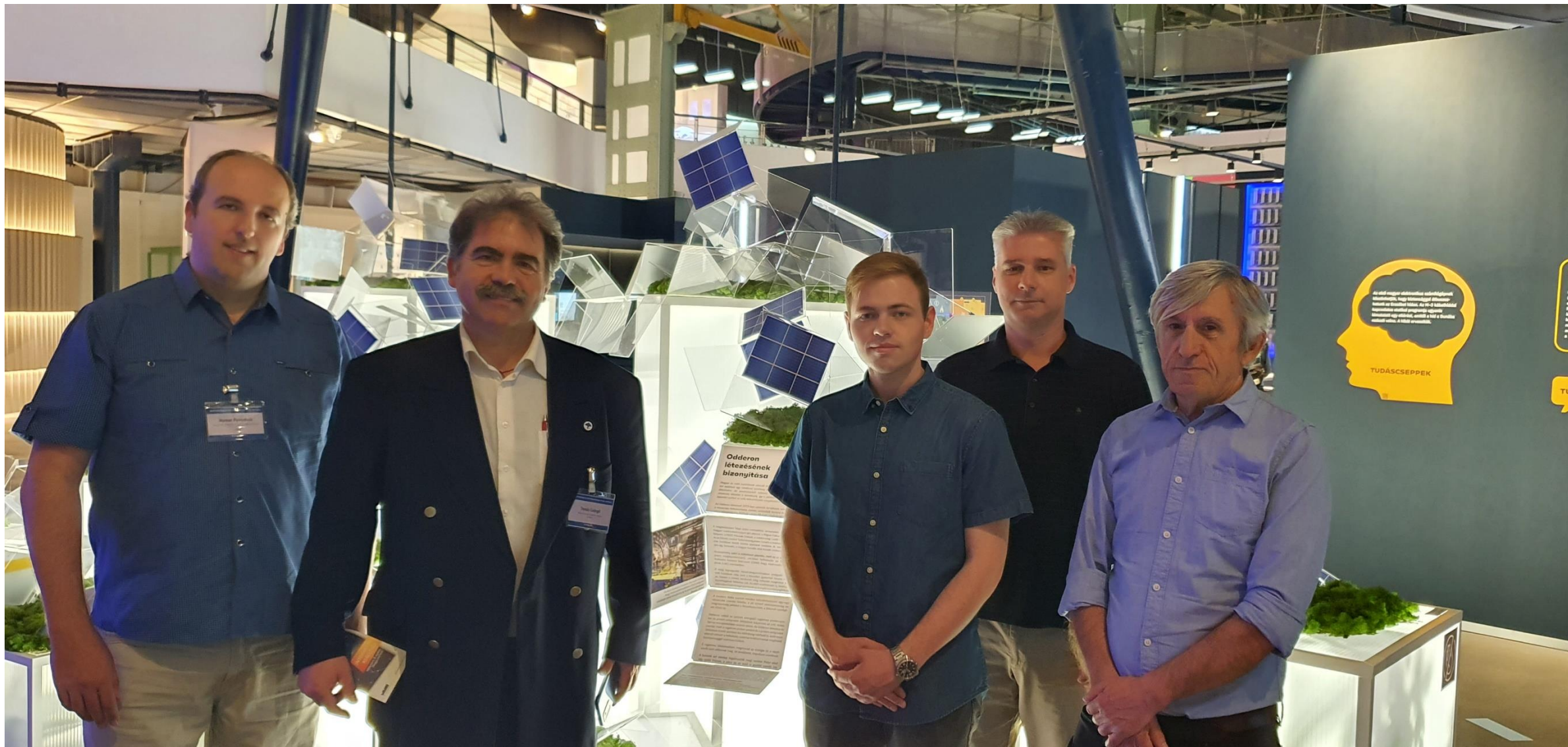
Leaving out the first four and last five D0 data points.



Combined Odderon significances

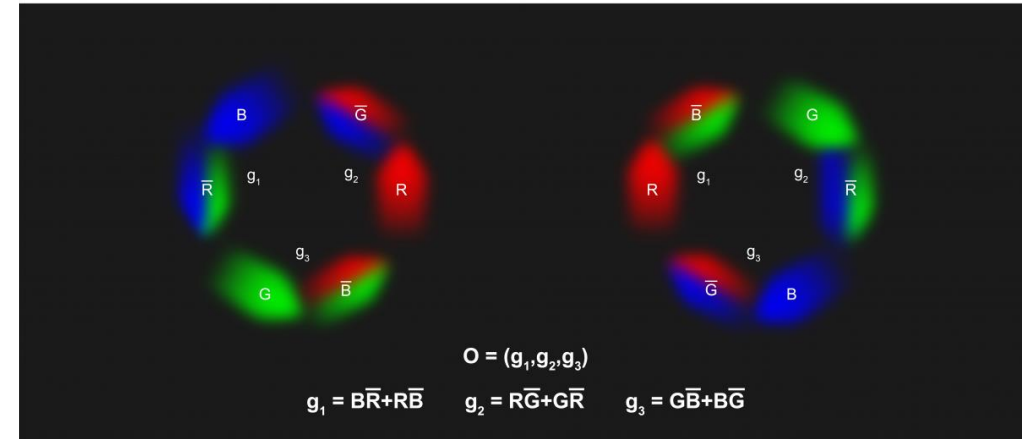
\sqrt{s} (TeV)	χ^2	NDF	CL	significance (σ)
1.96 vs. 2.76	3.85	11	9.74×10^{-1}	0.03
1.96 vs. 7	80.1	17	3.681×10^{-10}	6.26
1.96 vs. 8	46.4	17	1.502×10^{-4}	3.79

\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



Summary

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



Thank you for your attention!