Modeling of non-exponential behaviour of pp elastic scattering at high energies

Norbert Bence
Uzhgorod National University

In collaboration with **A. Lengyel**

WE-Heraeus Physics School
24-30 September, 2017, *Bad Honnef*

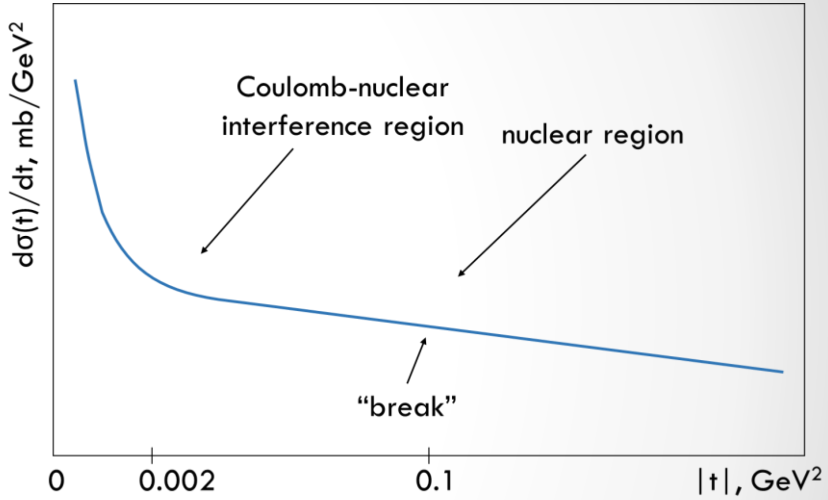
Outline

- The low-$|t|$ structure of proton-proton and proton-antiproton differential cross section:
  - ❑ Coulomb-nuclear interference region
  - ❑ „break"

- The description of the „break" using an effective pomeron contribution.

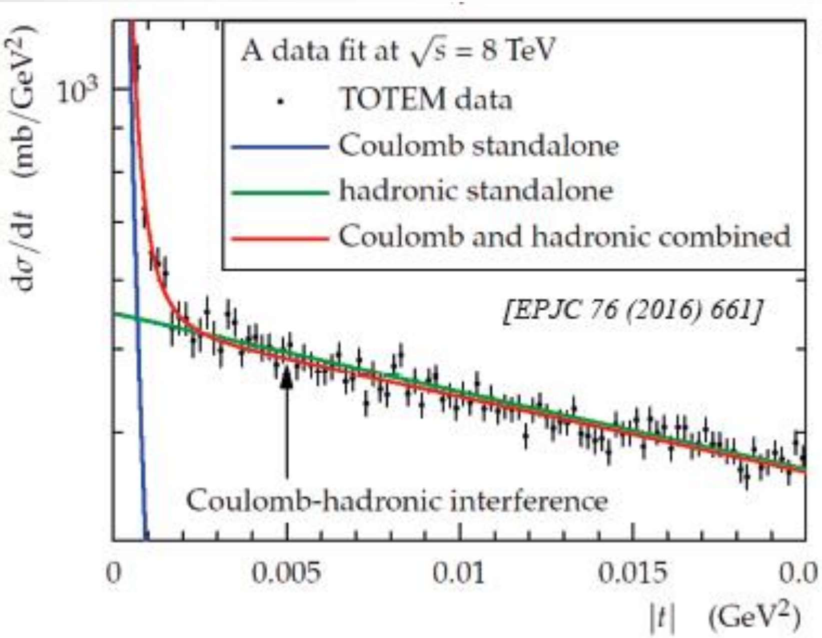
The CNI region and the „break”

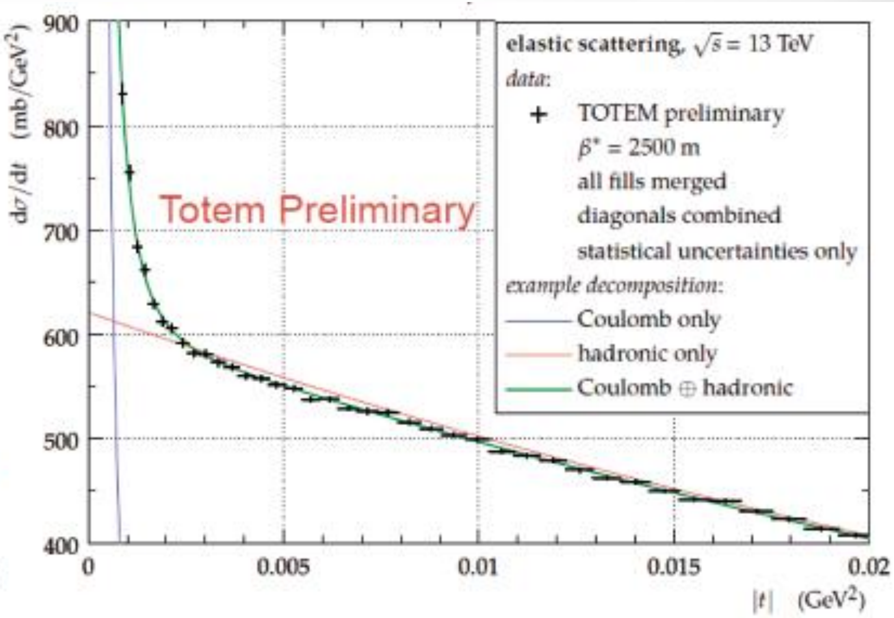
- Coulomb-nuclear interference (CNI) region as the effect of the electromagnetic interaction at very low|t|
- The “break” at low-|t| in the range of the the strong interaction: deviation of the differential cross section from the purely exponential form near |t|≈0.1 GeV^2



Shematic structure of the low-|t| *pp* and $p\bar{p}$ differential cross section

New CNI measurements





New LHC TOTEM CNI region measurements at *8* and *13* TeV

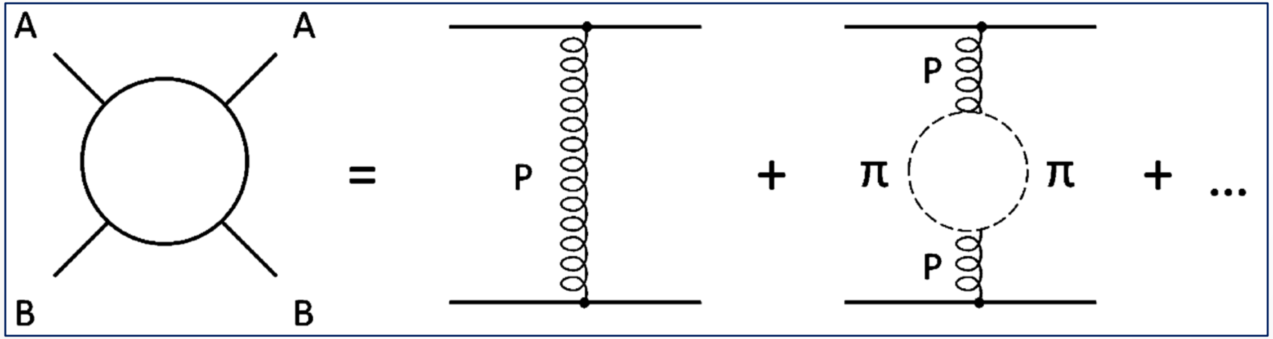
M. Deile: Elastic and Total Cross-Section Measurements by TOTEM. EDS Blois 2017, (2017, Prague).

„Break”

- Related to the two-pion exchange recquired by t-channel unitarity
- Description with the two-pion loop singularity in the pomeron trajectory:

$$\alpha(t) \sim \alpha_1 \sqrt{t_0 - t}$$

$$t_0 = 4m_\pi^2 \approx 0.08\ GeV^2$$



Feynman diagram for elastic scattering with a t-channel exchange containing a branch point at t = $4m_\pi^2$.

Effective Pomeron amplitude

- The scattering amplitude:

$$A(s,t) = g e^{bt} \tilde{s}^{\alpha(t)}, \quad \tilde{s} = -i\frac{s}{s_0}$$

- The pomeron trajectory contains the two-pion loop singularity and the purely exponential term is replaced in the amplitude with an exponential term which contains also the square root term in order to get a better description for the “break”:

$$\alpha(t) = 1 + \delta + \alpha' t - \gamma\left(\sqrt{4m_\pi^2 - t} - 2m_\pi\right)$$

where

$$e^{bt} \Rightarrow e^{\beta(t)}$$

$$\boldsymbol{\beta(t) = bt + \beta_0\left(\sqrt{4m_\pi^2 - t} - 2m_\pi\right)}$$

- The normalisation used for the differential cross section:

$$\frac{d\sigma}{dt} = \frac{\pi}{s^2}|A(s,t)|^2$$

Used data and fitting method

- To investigate the “break” five proton-proton differential cross section dataset and a proton-antiproton dataset have been choosen where the phenomenon was observed:

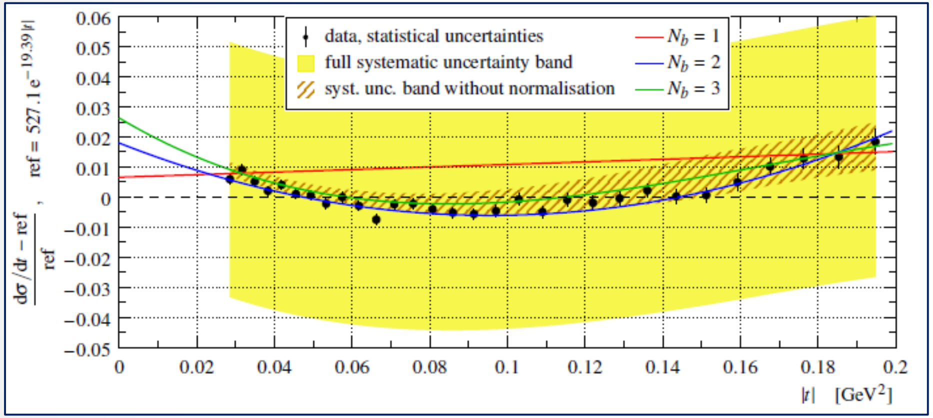
  - proton-proton data at **19.42**, **23.5**, **30.7**, **44.7** and **8000 GeV**.

  - proton-antiproton data at **546 GeV.**

- Fitting method: least square fit using the FORTRAN MIGRAD package.

Local slope and R(t) ratio

- Calculation of the local slopes and R ratios to make the small break visible.
- The R ratio shows the relative difference between the differential cross section and a reference exponential.



R(t) calculated for LHC TOTEM low-|t| 8 TeV data.

arXiv:1503.08111

- The local slope was used at the early years when the phenomenon was first obsereved at the ISR and it illustrates the “break” as a smooth curvature.

$$B(t) = \frac{d}{dt} ln \frac{d\sigma(t)}{dt}$$

$$R(t) = \frac{d\sigma(t)/dt - ref}{ref}$$

$$ref = Ae^{Bt}$$

Application of the effective pomeron ampliude to describe the differential cross section

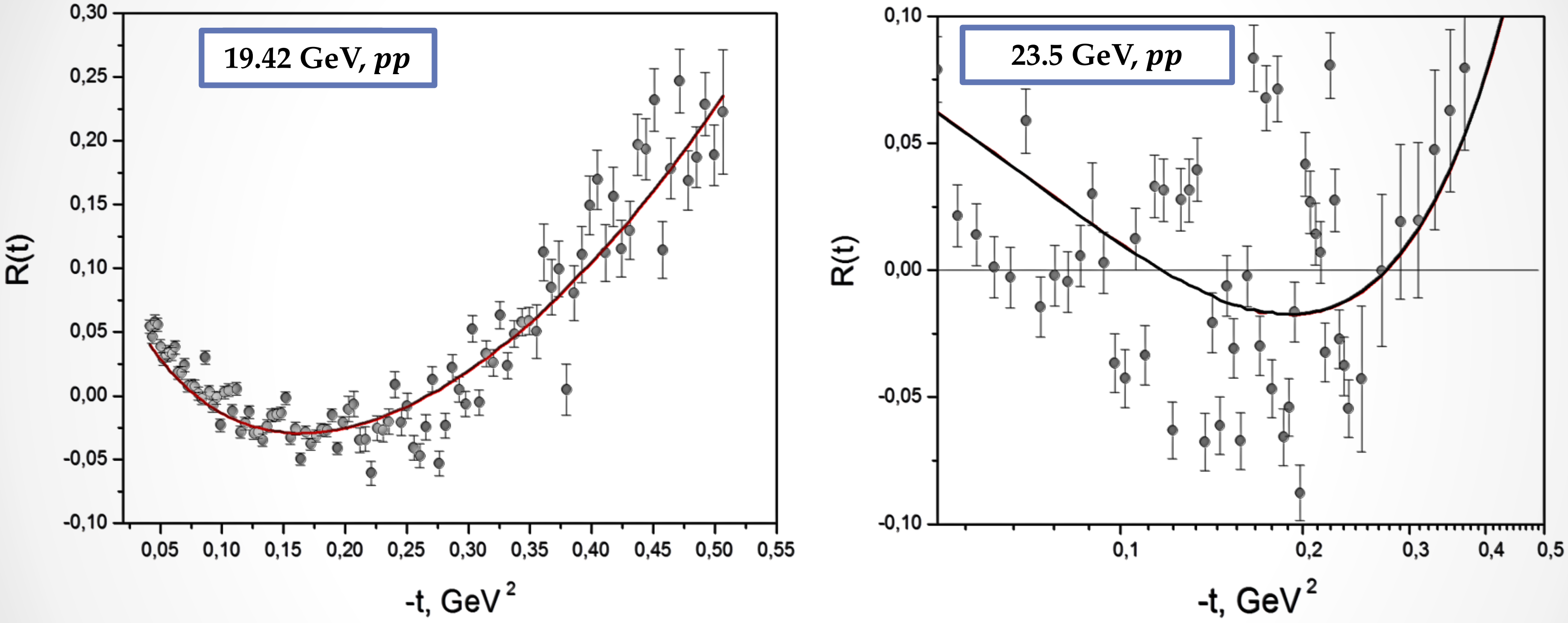


Fig. 1 : $\boldsymbol{R(t)}$ ratios calculated for $\mathbf{19.42}$ *and* $\mathbf{23.5}$ ***GeV***

Application of the effective pomeron ampliude to describe the differential cross section

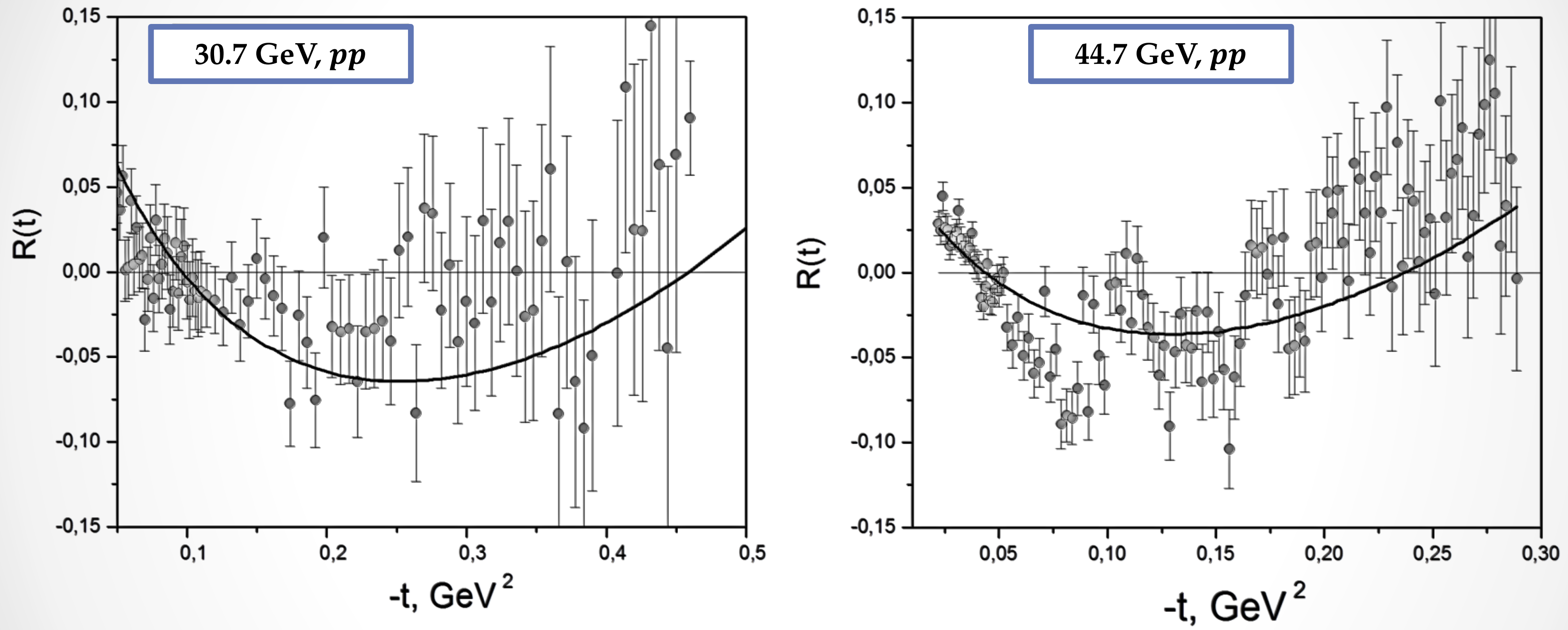
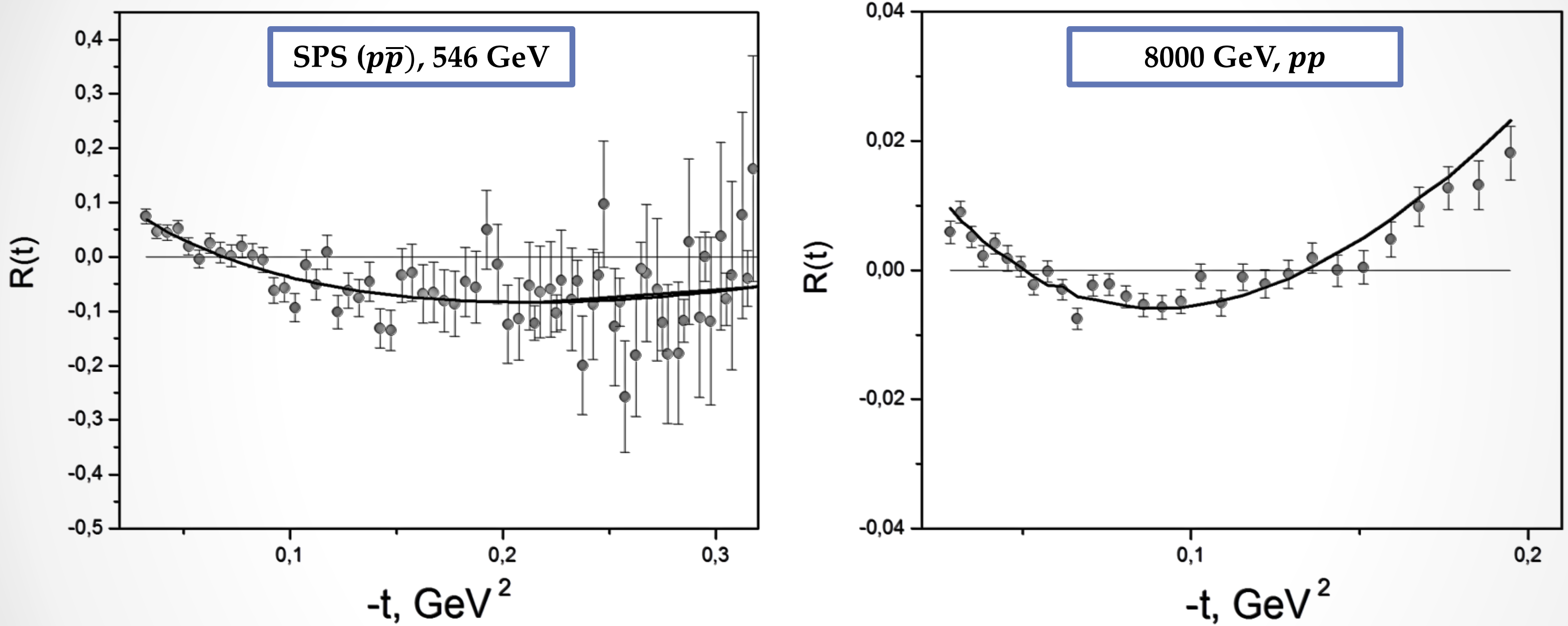


Fig. 2 : $\boldsymbol{R}(\boldsymbol{t})$ ratios calculated for **30.7** *and* **44.7 *GeV***

Application of the effective pomeron ampliude to describe the differential cross section



$Fig.\ 3: \boldsymbol{R(t)}$ ratios calculated for $\mathbf{546}$ and $\mathbf{8000}$ $\boldsymbol{GeV}$

Calculated local slopes

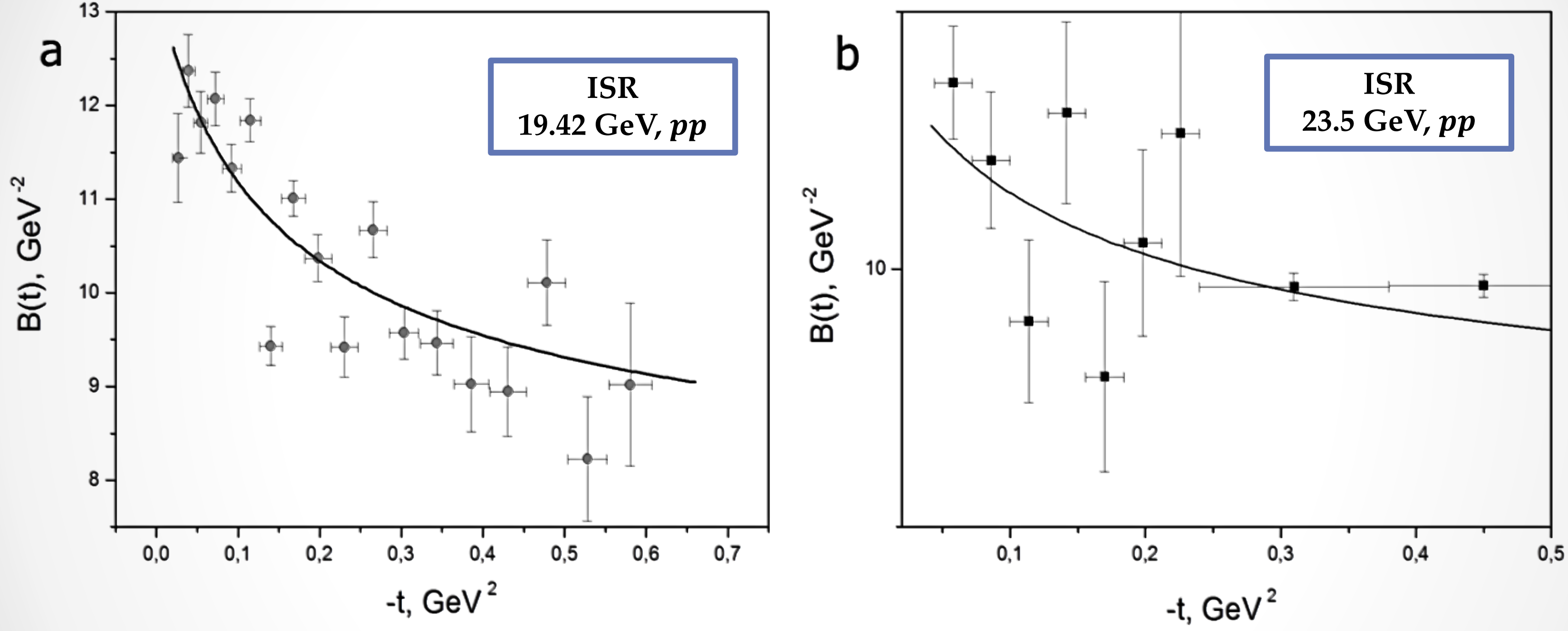
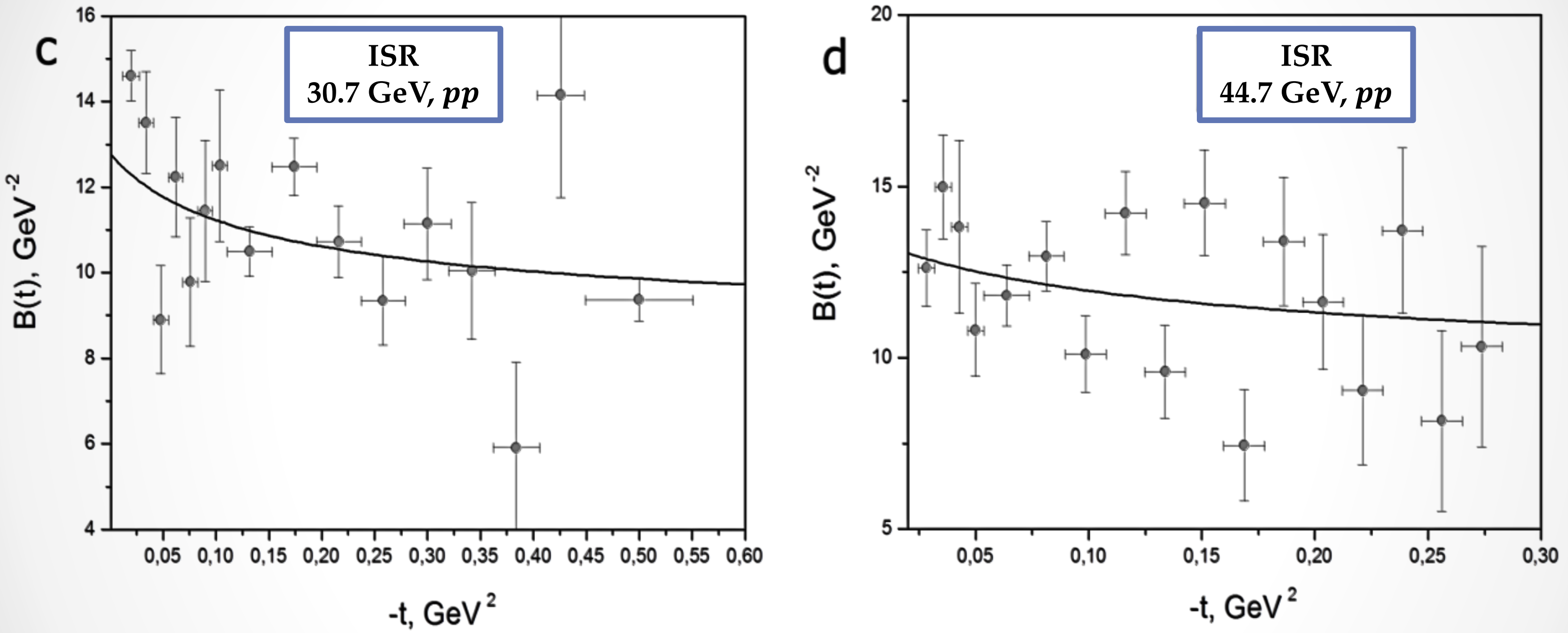


Fig. 4 : Calculated local slopes $\boldsymbol{B(t)}$ at $\mathbf{19.42}$ *and* $\mathbf{23.5}$ ***GeV***

Calculted local slopes



$Fig.\ 5:$ Calculated local slopes $\boldsymbol{B(t)}$ at $\mathbf{30.7}$ and $\mathbf{44.7}$ $\boldsymbol{GeV}$

Calculated local slopes

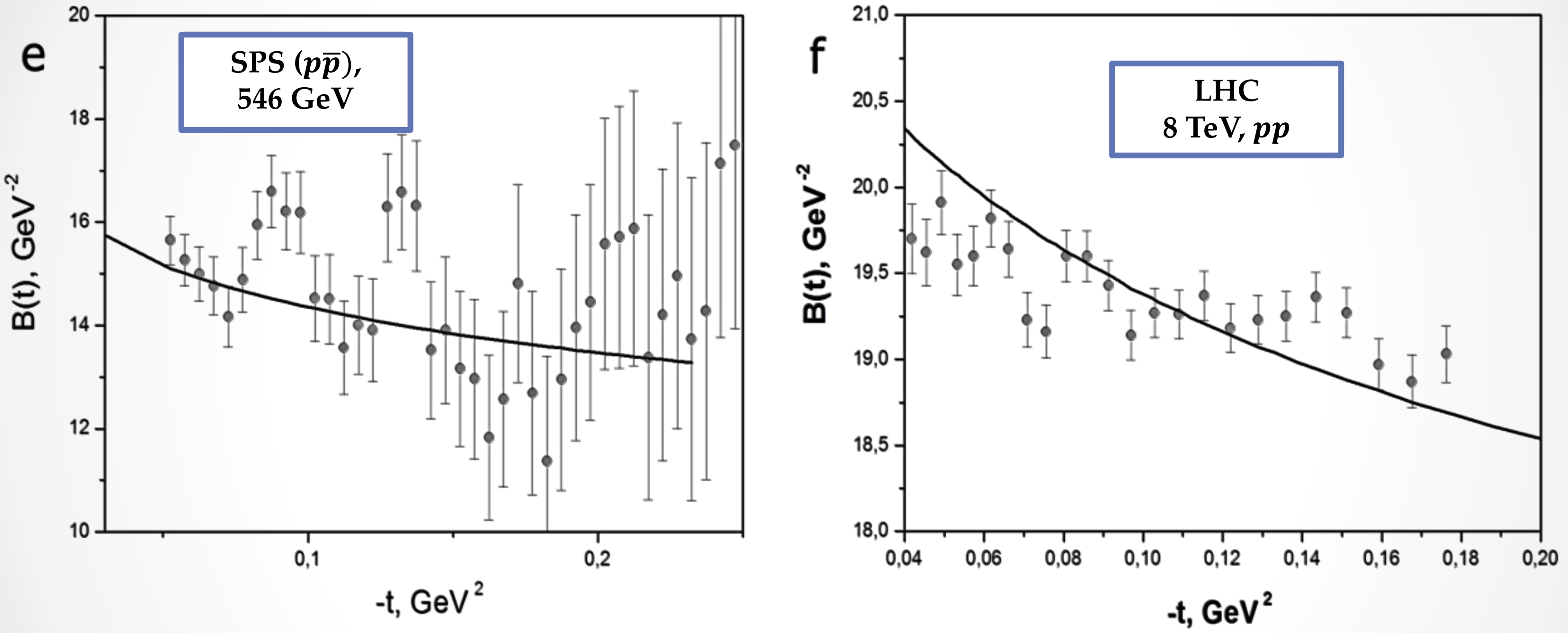


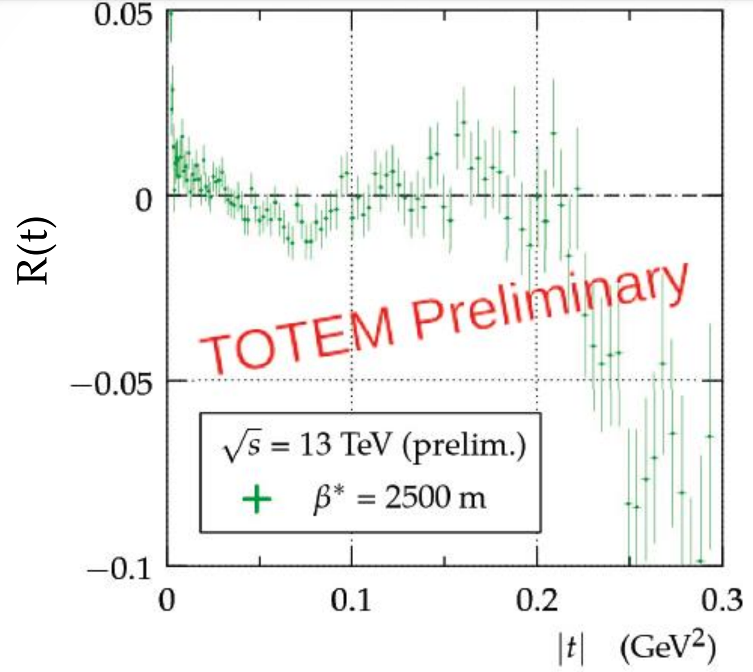
Fig. 6 : Calculated local slopes $\boldsymbol{B(t)}$ at **546** *and* **8000** ***GeV***

Table:

Values of fitted parameters

Parameter	Energy, GeV	Value	Error	Parameter	Value	Error
g_1	19.4	5.008	0.006	b	1.244	0.053
g_2	23	4.861	0.012	α'	0.4011	0.0059
g_3	32	4.851	0.005	γ	0.04852	0.0050
g_4	44.7	4.666	0.004	β_0	-1.881	0.049
g_5	52.8	4.686	0.005	δ	0.08	(fixed)
g_6	62	4.647	0.005	$\chi^2 / dof = 3.4$		
g_7	546	5.011	0.005			
g_8	8000	5.013	0.006			

New TOTEM low-|t| measurements at 13 TeV



R(t) calculated for low-|t| 13 *TeV* **TOTEM** preliminary data.

M. Deile: Elastic and Total Cross-Section Measurements by TOTEM. EDS Blois 2017, (2017, Prague).

Further plans

The scattering amplitude

$$A(s,t)_{pp}^{\bar{p}p} = A_P(s,t) + A_f(s,t) \pm A_\omega(s,t)$$

Pomeron amplitude

$$A_P(s,t) = -a_P e^{\varphi_P(t)} e^{-\frac{i\pi\alpha_P(t)}{2}} (s/s_{0P})^{\alpha_P(t)}$$

Pomeron trajectory

$$\alpha_P(t) = 1 + \delta_P + \alpha' t - \gamma_P\left(\sqrt{4m_\pi^2 - t} - 2m_\pi\right)$$

Residuum

$$\varphi_P(t) = b_P t + \varepsilon_P\left(\sqrt{4m_\pi^2 - t} - 2m_\pi\right)$$

Total cross section

$$\sigma_{tot} = \frac{4\pi}{s} ImA(s, t = 0)$$

ρ − paramether

$$\rho = \frac{ReA(s, t = 0)}{ImA(s, t = 0)}$$

Secondary reggeons

$$A_f(s,t) = a_f e^{b_f t} e^{-\frac{i\pi\alpha_f(t)}{2}} (s/s_{0f})^{\alpha_f(t)}$$

$$A_\omega(s,t) = i a_\omega e^{b_\omega t} e^{-\frac{i\pi\alpha_\omega(t)}{2}} (s/s_{0\omega})^{\alpha_\omega(t)}$$

Reggeons trajectory

$$\alpha_f(t) = 0.703 + 0.84t$$

$$\alpha_\omega(t) = 0.435 + 0.93t$$

In collaboration with L. Jenkovszky, A. Lengyel and I. Szanyi

Summary

- The low-|t| structure of the pp and $p\bar{p}$ differential cross section in the range of the srong interaction is the "break".

- The calculated R ratios and local slopes well illusrate the results of the fits and that the pp and $p\bar{p}$ differential cross sections deviates from the purely exponential form.

- The good description for the data using an effective pomeron contribution with non-linear regge trajectory and replacing the purely exponential term in the amplitude with an exponential term containing the two-pion loop singularity proves that the "break" can be interpreted with the two-pion exchange required by t-channel unitarity.

References:

- [1] И.М. Дремин. Упругое рассеяние адронов. *УФН*. 183. 3-32. (2013).
- [2] G. Antchev et al., (TOTEM Collaboration): Evidence for non-exponential elastic proton-proton differential cross-section at low $|t|$ and $sqrt(s) = 8\,TeV$ by TOTEM. *Nucl. Phys*., B 899, 527-546 (2015).
- [3] P.D.B. Collins: An Introduction to Regge Theory and High Energy Physics. *Cambridge Monographs on Mathematical Physics*, (1977).
- [4] Diána Himics, A.I. Lengyel, Z. Tarics, Jolán Turóci: Proton elastic scattering at the Large Hadron Collider. Scientific Herald of Uzhhorod University. *Series Physics. Issue* 32. – P. 51 – 55, (2012).
- [5] Р. Иден. Соударения элементарных частиц при высоких энергиях. Наука. М. (1970).
- [6] A. Schiz et al.: A High Statistics Study of π^+p, π^-p, and pp Elastic Scattering at $200 - GeV/c$. *Phys.Rev*., D 26, (1981).
- [7] B. Barbiellini et al.: Small-angle proton-proton elastic scattering at very high energies $(460\ GeV^2 < \sqrt{s} < 2900\ GeV^2)$. *Phys. Let*., B 39, 663-667, (1972).
- [8] F. Abe et al., (The CDF Collaboration): Measurement of Small Angle Antiproton-Proton Elastic Scattering at $(\sqrt{s})^{\frac{1}{2}} = 546$ and $1800\ GeV$. *Phys. Rev*., D50, 5518, (1994).
- [9] L. Jenkovkszy, A. Lengyel: Low−$|t|$ structures in elastic scattering at the LHC. *Acta Phys. Polonica*, B 46, 863, (2015).
- [10] G. Cohen-Tannoudji, V.V. Ilyin, L.L.Jenkovkszky: A model for the pomeron trajectory. *Lett.Nuovo Cim*., 5S2, 957-962, (1972).
- [11] F. James: MINUIT – Function Minimization and Error Analysis. *CERN Program Library entry*, D506, (1994).

Thank you for your attention!