

Elastic pp scattering at the LCH: the non-exponential low- $|t|$ diffraction cone and the energy dependence of the slope

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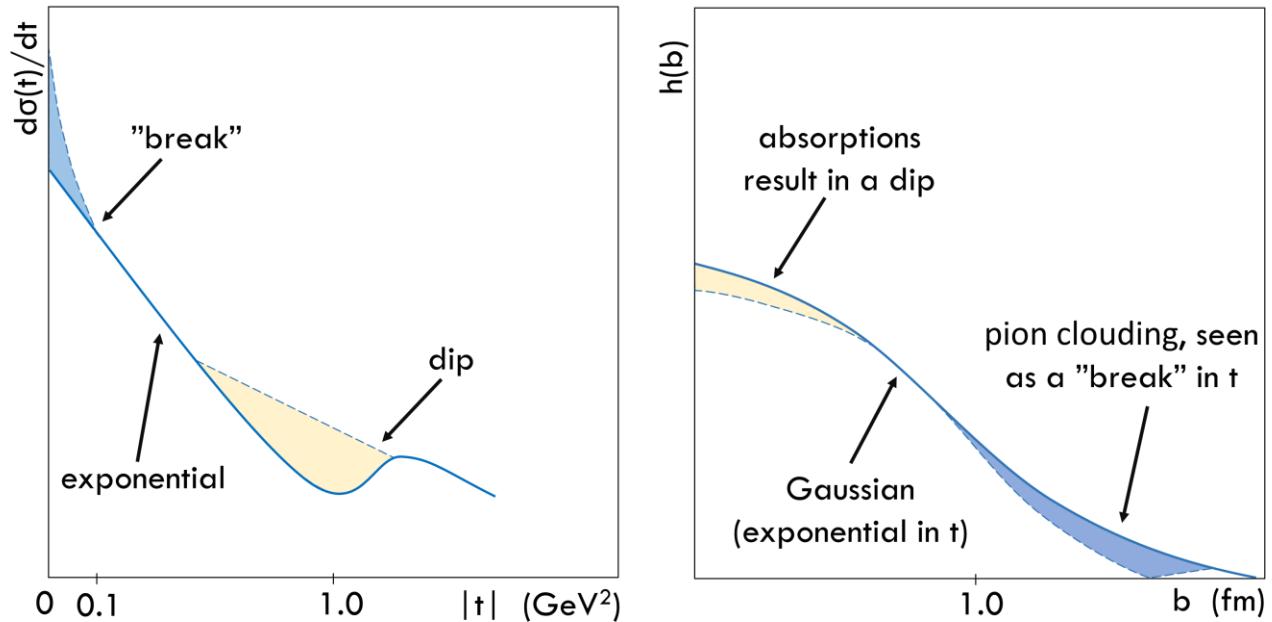


Outline

- The non-exponential low- $|t|$ diffraction cone.
- Analysis of the main forward pp and $p\bar{p}$ observables (elastic, inelastic and total cross sections, ρ -parameter and elastic slope) based on a dipole model.
- Unitarization of the dipole Pomeron, its application and predictions for the future forward data.

Structures of high-energy pp diffraction cone

- “break” – deviation from the purely exponential form of the diffraction cone near $|t| \approx 0.1 \text{ GeV}^2$ – i.e. it changes its slope;
- related to the two-pion exchange required by t-channel unitarity – corresponds to the nucleon “atmosphere”;
- “dip” – diffraction minimum moves slowly (logarithmically) with s towards smaller values of $|t|$;
- related to s-channel unitarity or absorption corrections to the scattering amplitude



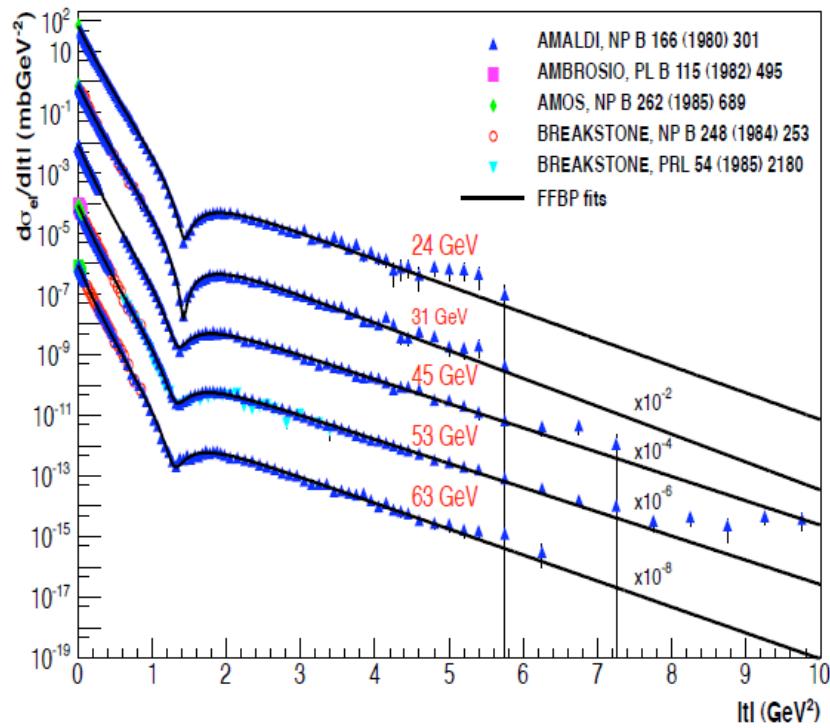
Schematic view of the pp elastic differential cross section in t and the impact parameter amplitude in b .

L. Jenkovszky: Phenomenology of Elastic Hadron Diffraction. Fortschritte der Physik, 84 (1986) 791.

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

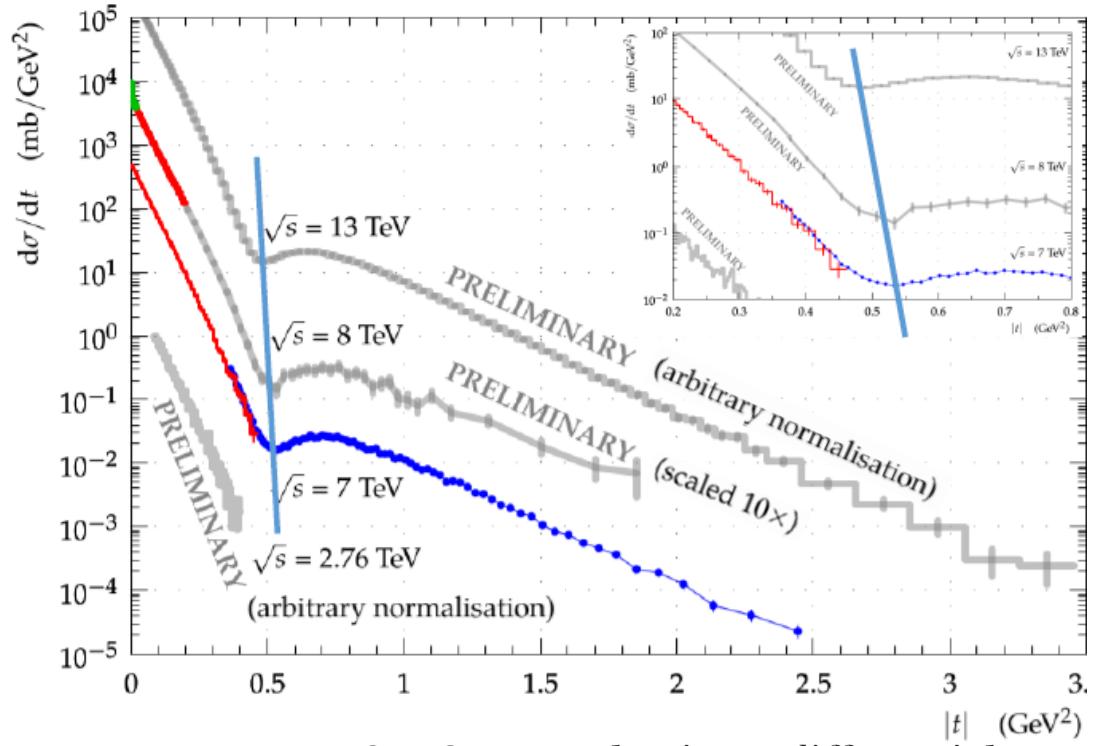
$$h(s,b) = \frac{1}{s} \int_0^\infty A(s,t) J_0(b, \sqrt{-t}) \sqrt{-t} d\sqrt{-t}$$

The movement of the “dip”



$$\text{ISR: } |t_{\text{dip}}| \approx 1.4 \text{ GeV}^2$$

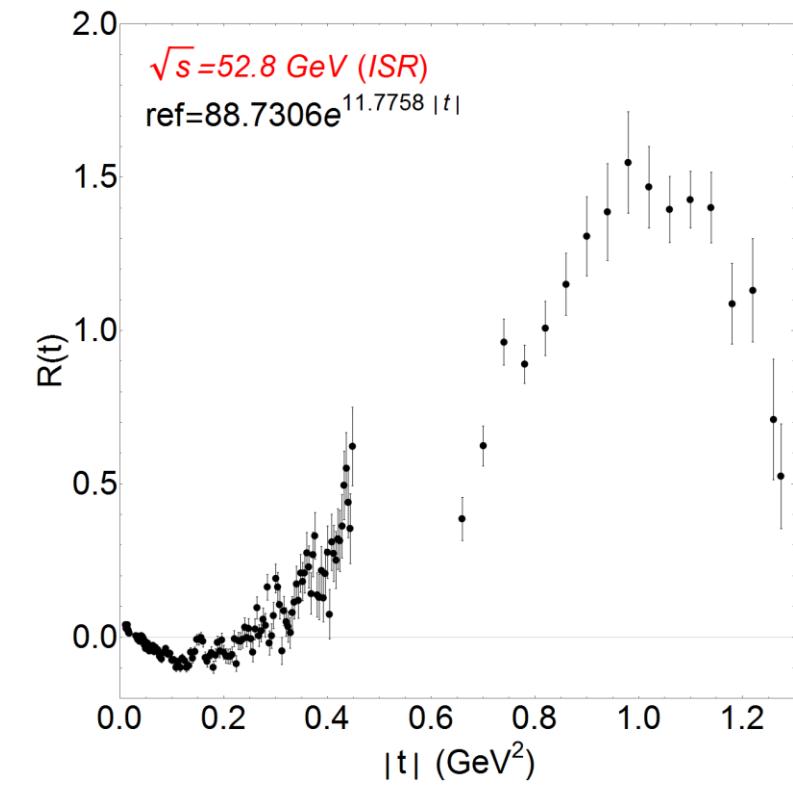
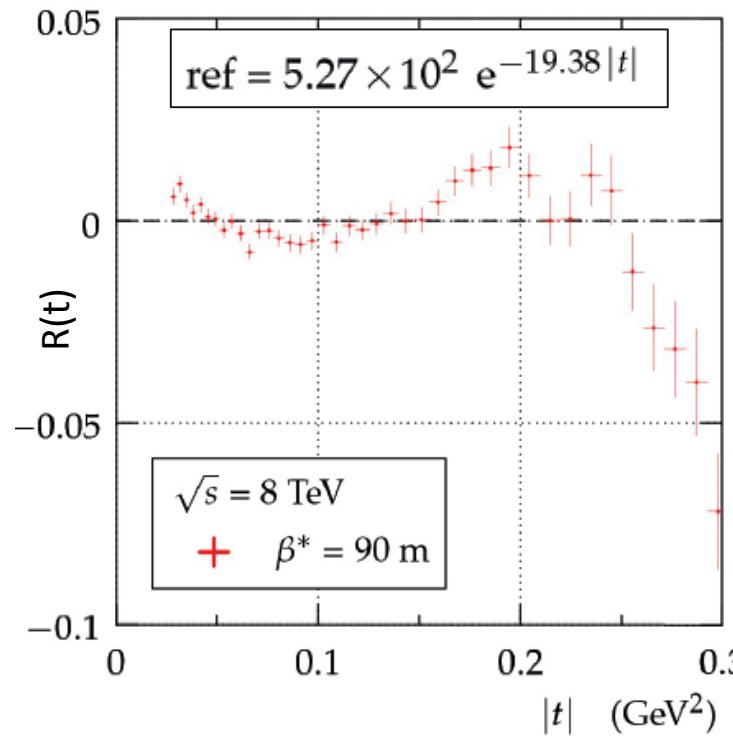
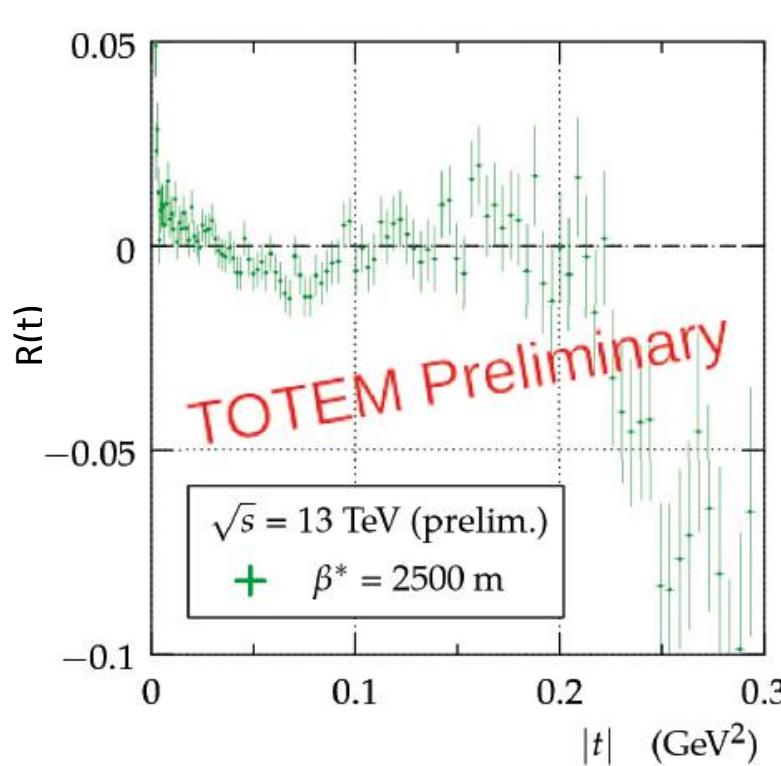
arXiv:1306.0452



$$\text{LHC: } |t_{\text{dip}}| \approx 0.5 \text{ GeV}^2$$

T. Sýkora: Total, elastic and inelastic p-p cross sections at the LHC. ICHEP 2016 (2016, Chicago)

Correlation between the “break” and “dip”



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

$$\text{ref} = Ae^{Bt}$$

$R(t)$ calculated for low- $|t|$ ISR 52,8 GeV, TOTEM 8 and 13 TeV data.

M. Deile: Elastic and Total Cross-Section Measurements by TOTEM. EDS Blois 2017, (2017, Prague).
L. Jenkovszky, I. Szanyi: **Structures in the diffraction cone: the “break” and “dip” in high-energy proton-proton scattering (International Journal of Modern Physics A, Vol. 32, No. 22 (2017) 1750116) - arXiv:1705.04880**

A dipole model

- Scattering amplitude:

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

Pomeron term:

$$A_P(s, t) = i \frac{a_P s}{b_P s_{0P}} [r_1^2(s) e^{r_1^2(s)[\alpha_P - 1]} - \varepsilon_P r_2^2(s) e^{r_2^2(s)[\alpha_P - 1]}]$$

where

$$r_1^2(s) = b_P + L - i\pi/2$$

$$L \equiv \ln(s/s_{0P})$$

$$r_2^2(s) = L - i\pi/2$$

Pomeron trajectory:

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P + \alpha_{1P}t - \alpha_{2P} \left(\sqrt{4m_\pi^2 - t} - 2m_\pi \right)$$

Reggeon terms:

$$A_f(s, t) = a_f e^{b_f t} e^{-\frac{i\pi\alpha_f(t)}{2}} (s/s_0)^{\alpha_f(t)}$$

$$A_\omega(s, t) = i a_\omega e^{b_\omega t} e^{-\frac{i\pi\alpha_\omega(t)}{2}} (s/s_0)^{\alpha_\omega(t)}$$

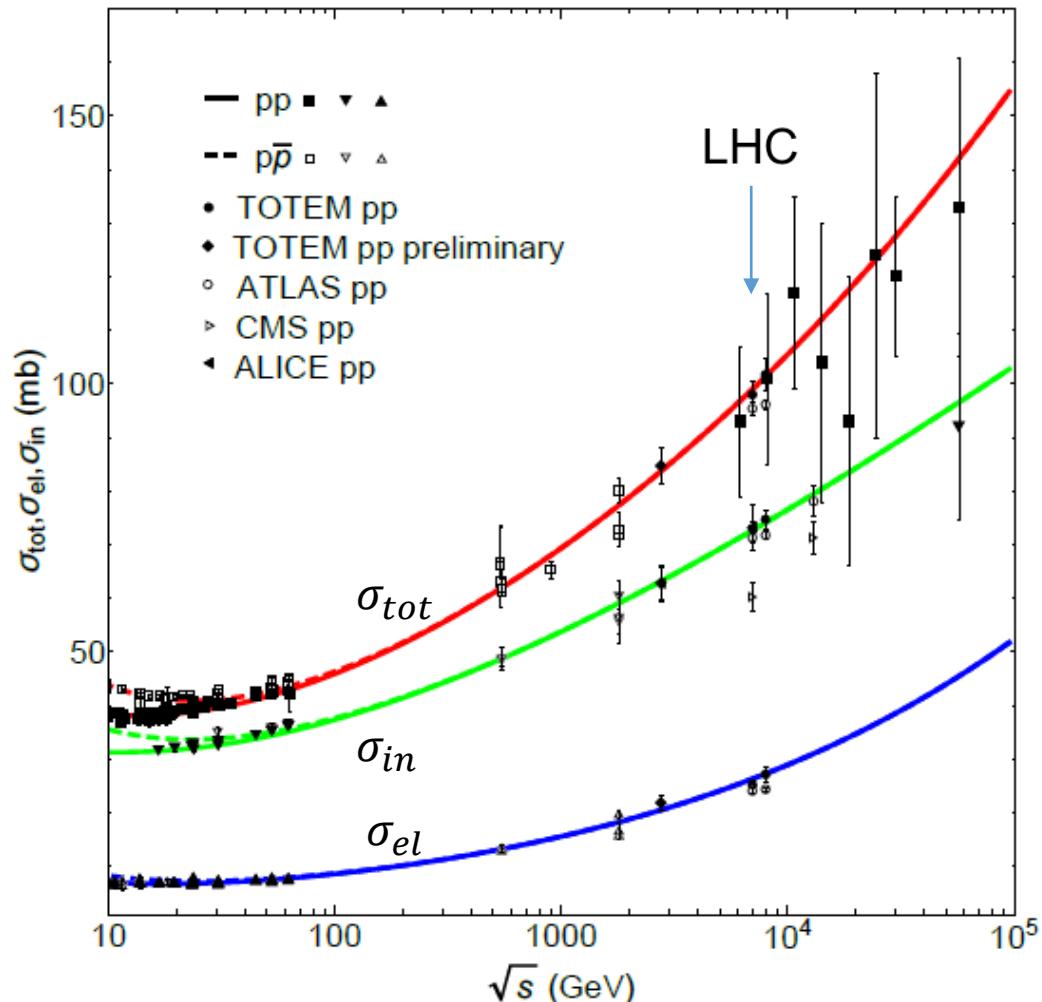
Reggeon trajectories:

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

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

arXiv:1206.5837

Elastic, inelastic and total cross sections



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

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

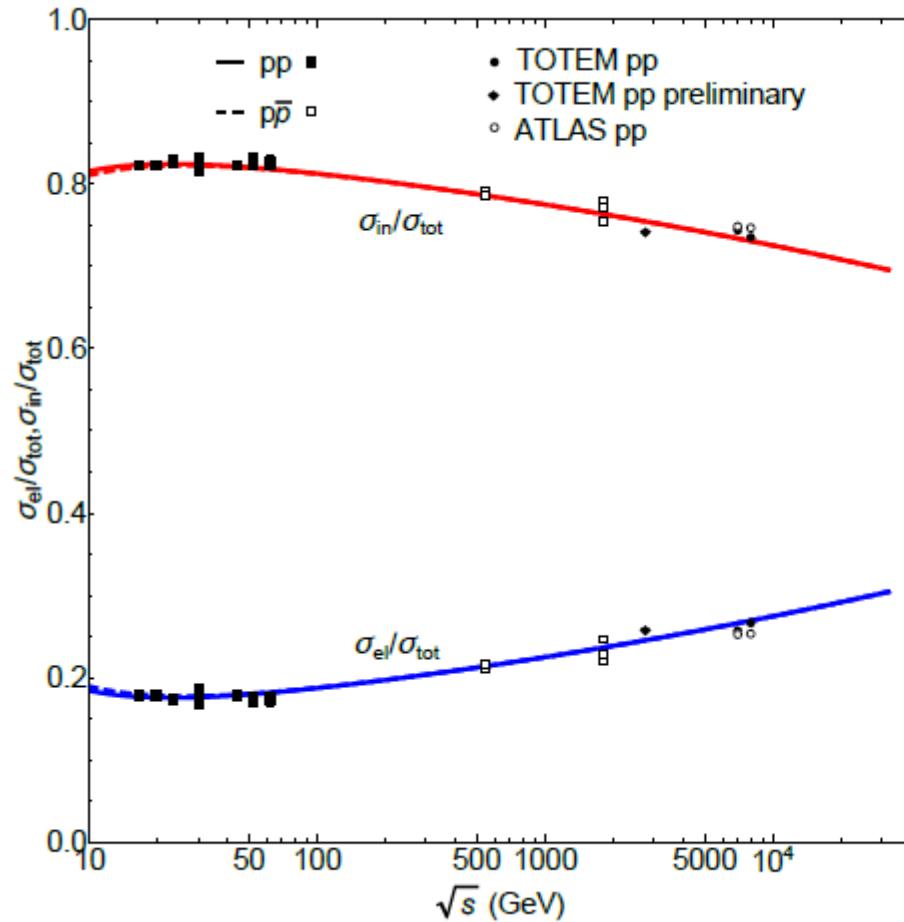
$$\sigma_{el}(s) = \int_{t_{min}}^{t_{max}} \frac{d\sigma(s, t)}{dt} dt$$

$$\sigma_{in}(s) = \sigma_{tot}(s) - \sigma_{el}(s)$$

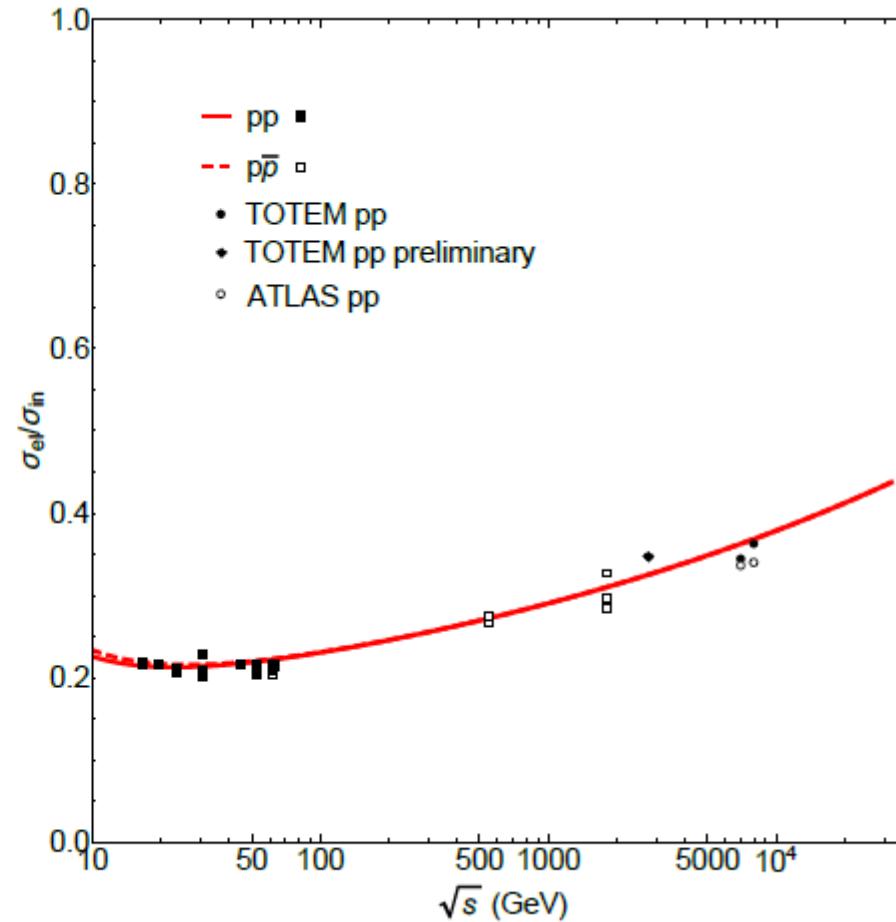
a_P	306 ± 0.48	a_f	-17 ± 0.055
b_P	9.04 ± 0.021	b_f	4.54 ± 0.061
δ_P	0.0451 ± 0.00011	a_ω	9.79 ± 0.094
α_{1P}	0.426 ± 0.0013	b_ω	8.23 ± 0.57
α_{2P}	0.0082 ± 0.001	s_0	$1 (fixed)$
ε_P	$0 (fixed)$	s_{0P}	$100 (fixed)$

Values of fitted parameters.

Ratios of σ_{el}/σ_{tot} , σ_{in}/σ_{tot} and σ_{el}/σ_{in}

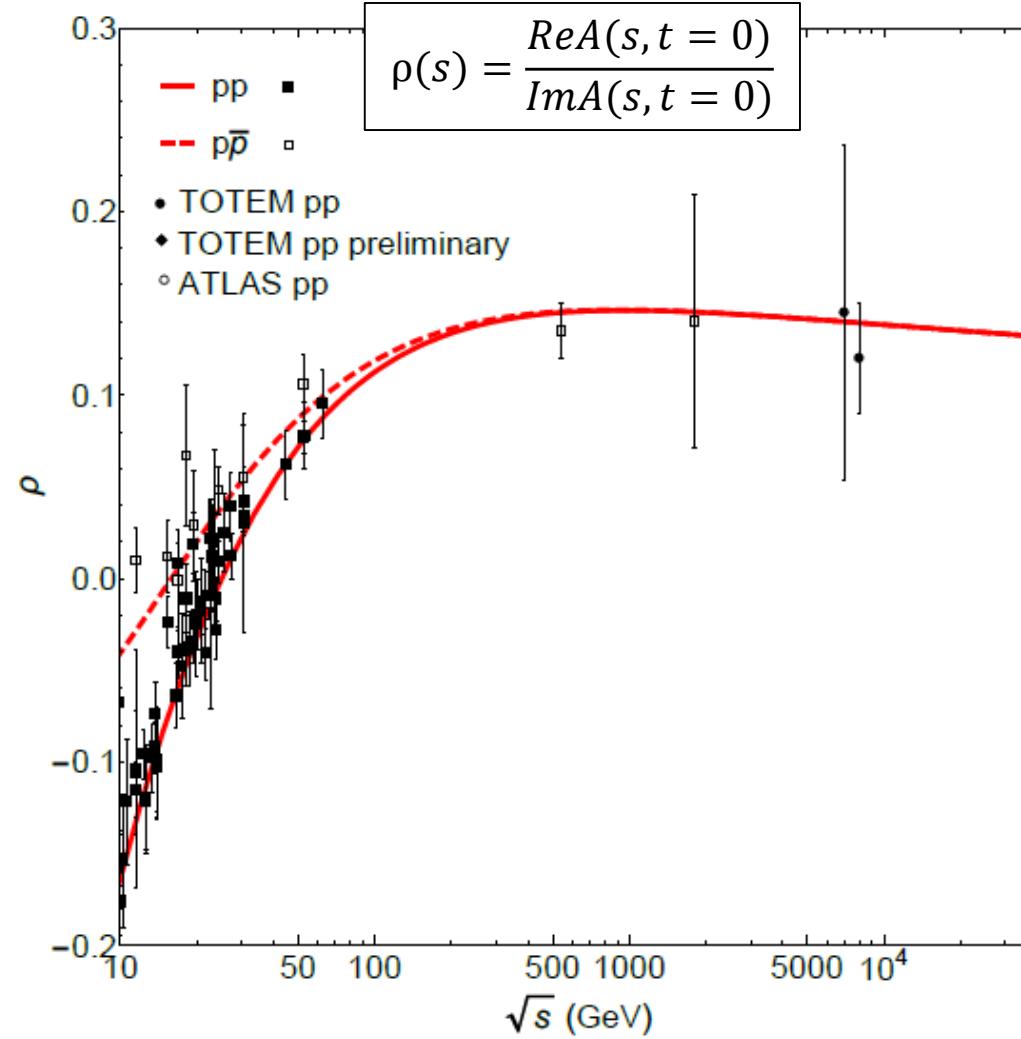


Calculated σ_{el}/σ_{tot} and σ_{in}/σ_{tot} ratios to pp and $p\bar{p}$ scattering.

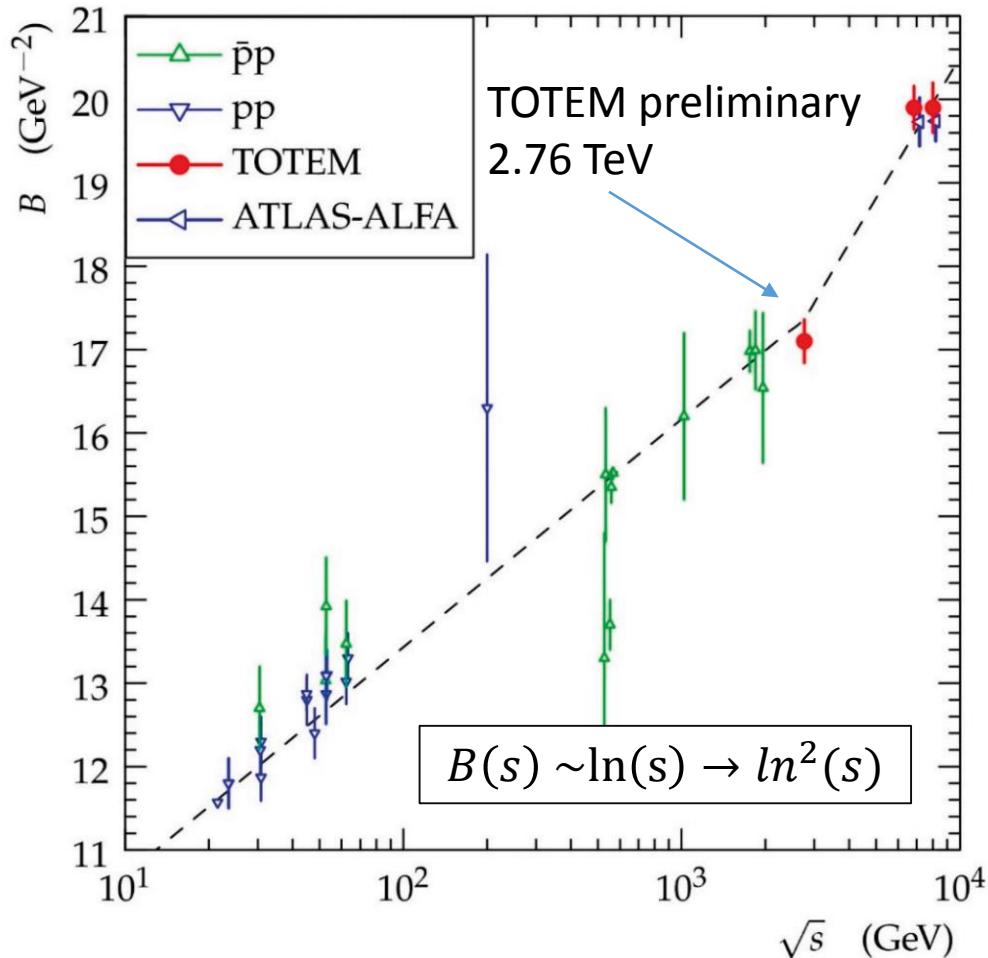


Calculated σ_{el}/σ_{in} ratio to pp and $p\bar{p}$ scattering.

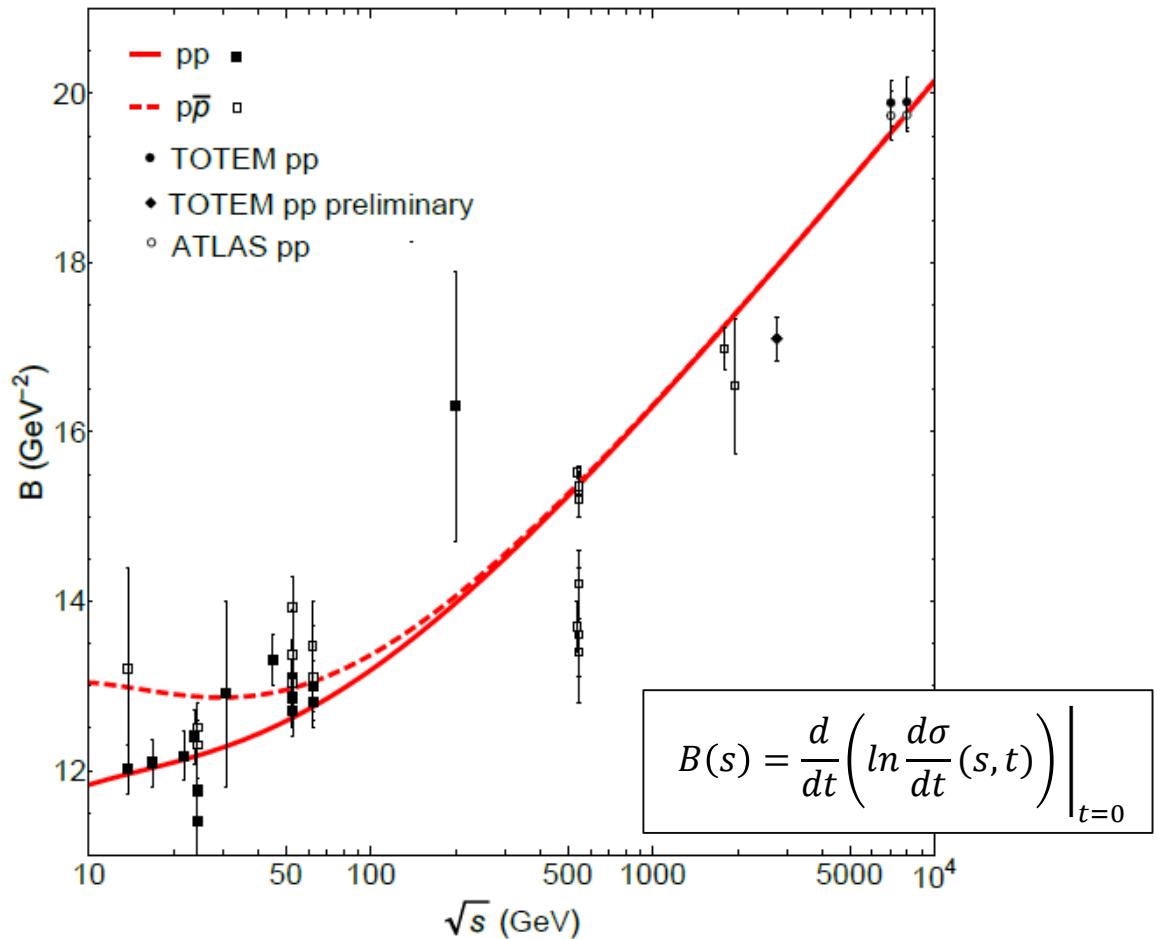
ρ -paramater



New elastic slope measurements



The elastic slope data with preliminary
TOTEM results.



Calculated pp and $p\bar{p}$ elastic slope.

Unitarization

- Unitarized scattering amplitude:

$$T(\rho, s) = \frac{u(\rho, s)}{1 - iu(\rho, s)}$$



$$T(s, t) = q^2 \int_0^\infty \frac{u(\rho, s)}{1 - iu(\rho, s)} J_0(\rho\sqrt{-t}) d\rho^2$$

(ρ - impact parameter; q - momentum in center-of-mass frame)

- Using $x = \frac{\rho^2}{4\alpha'L}$ the unitarized formulas for the forward measurables:

$$\sigma_{tot} = \frac{4\pi\alpha'}{\lambda} \ln(1 + g)(1 + \lambda L)$$

$$\sigma_{el} = \frac{4\pi\alpha'}{\lambda} \frac{g}{1 + g}(1 + \lambda L)$$

$$\sigma_{tot} = \frac{4\pi\alpha'}{\lambda} \left(\ln(1 + g) - \frac{g}{1 + g} \right) (1 + \lambda L)$$

$$\rho = \frac{ReT(s, 0)}{ImT(s, 0)} = \frac{\pi\lambda}{2(1 + \lambda L)}$$

$$\frac{\sigma_{el}}{\sigma_{tot}} = 1 - \frac{g}{(1 + g)\ln(1 + g)}$$

$$B = \frac{2\alpha'}{\lambda} \frac{\Sigma}{\ln(1 + g)} (1 + \lambda L)$$

$$\lambda = (1 - \epsilon_P)/b_P$$

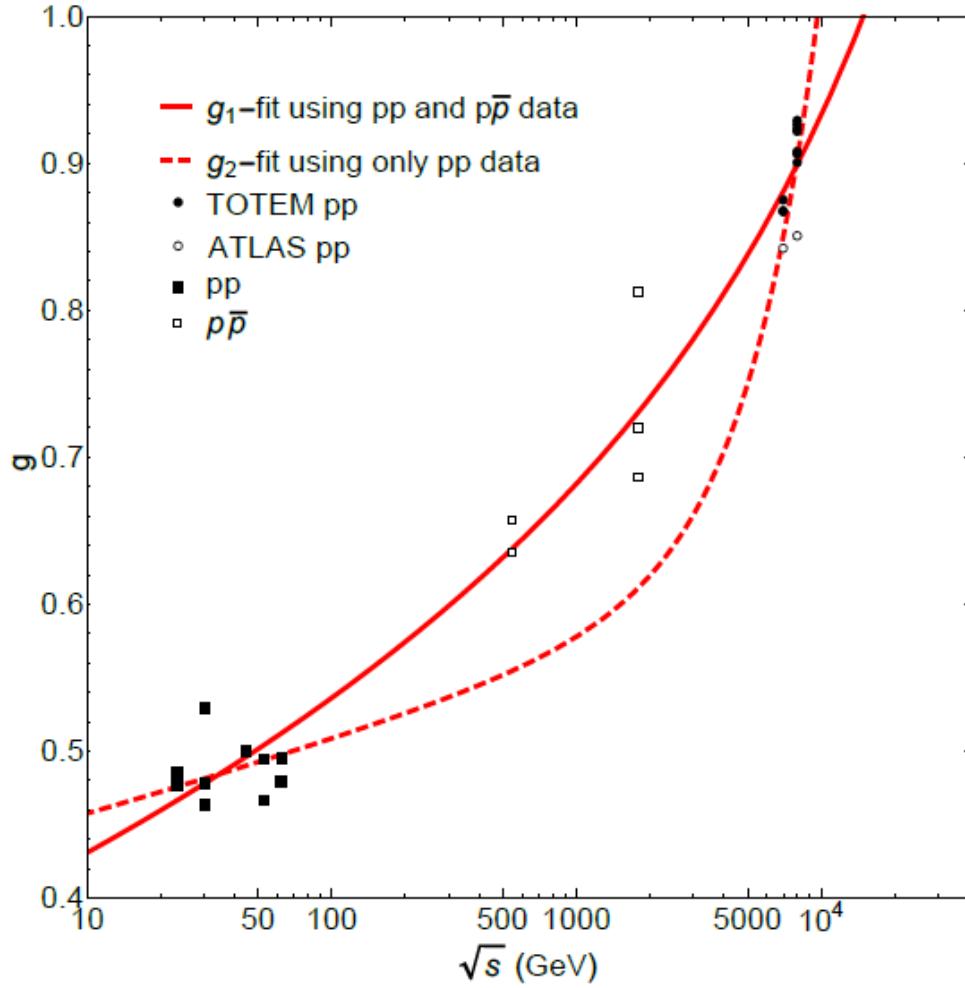
$$L = \ln(s/s_{0P})$$

$$g(s) = g_{01}(s/s_{01})^{\varepsilon_1} + g_{02}(s/s_{02})^{\varepsilon_2}$$

$$\Sigma = \int_0^\infty \frac{ge^{-x}x dx}{1 + ge^{-x}}$$

A.N. Wall, L.L. Jenkovszky, B.V. Struminsky, Sov. J. Particles and Nuclei, 19 (1988)

The energy dependence of the g parameter



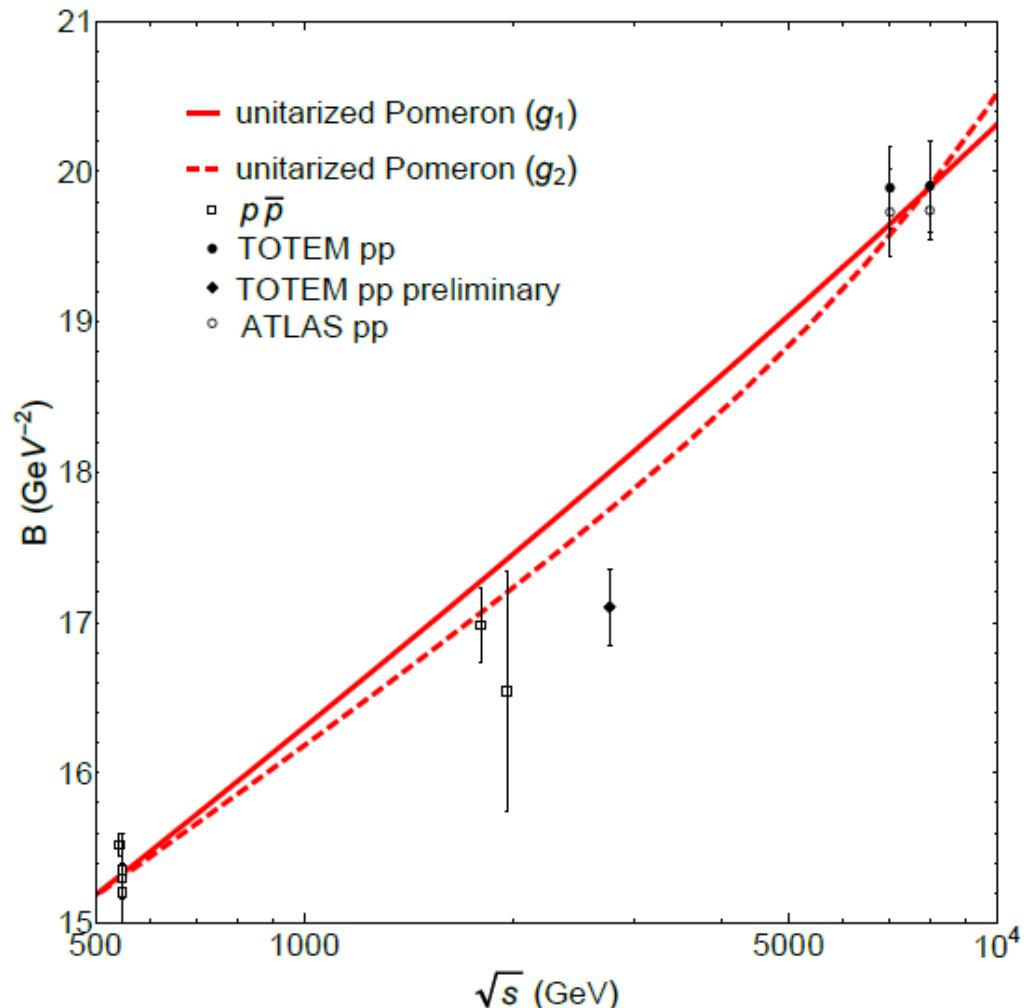
$g(s)$					
g_{01}	0.348	ϵ_1	0.0457	s_{01}	1
g_{02}	0.00135	ϵ_2	0.328	s_{02}	100

Fitted parameters of $g(s)$ using pp and $p\bar{p}$ data.

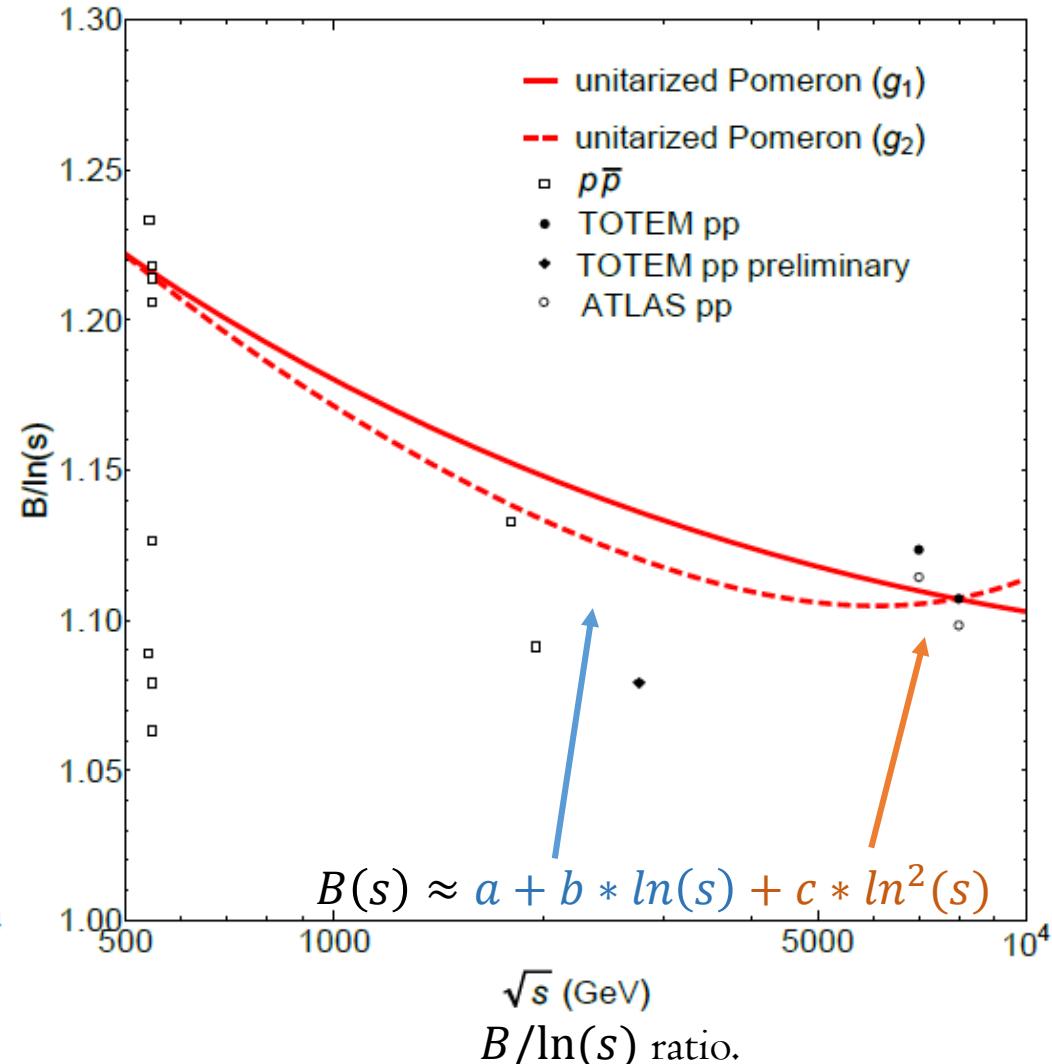
$g(s)$					
g_{01}	0.412	ϵ_1	0.0228	s_{01}	1
g_{02}	1.53×10^{-5}	ϵ_2	0.735	s_{02}	100

Fitted parameters of $g(s)$ using only the pp data.

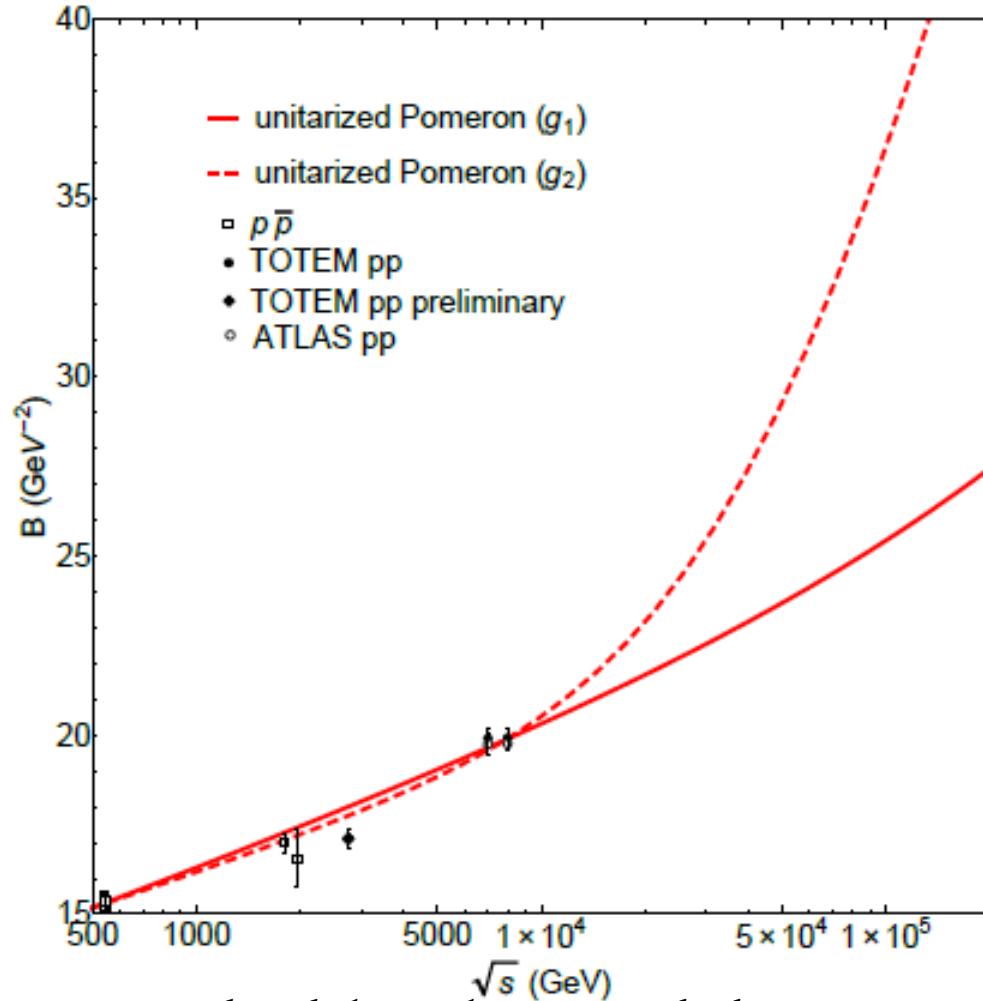
The unitarized slope



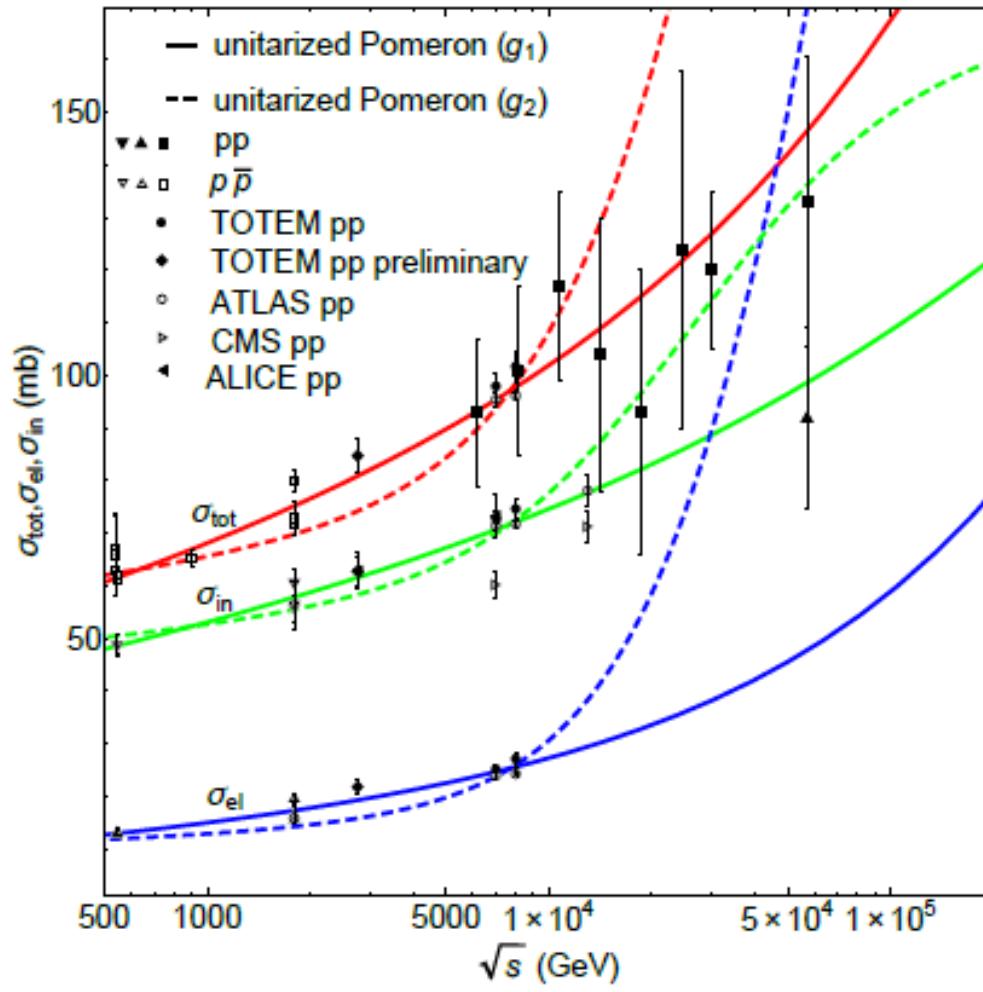
Description for the elastic slope data using
unitarization procedure.



Application of the unitarized amplitude



Predicted elastic slope at very high energies
using the unitarization procedure.



Predicted total, elastic and inelastic cross section at
very high energies using the unitarization procedure.

Predictions

\sqrt{s}, TeV	0.9	2.76	3	4	13	14	80	90	100
g	0.574	0.65	0.66	0.70	1.2	1.3	9	11	12
$\sigma_{tot}(mb)$	65.2	74.4	75.6	80.0	123	128	376	401	424
$\sigma_{el}(mb)$	12.7	15.9	16.3	18.0	38.2	41.0	229	252	272
$\sigma_{in}(mb)$	52.4	58.5	59.3	62.0	85.0	87.3	146	149	151
σ_{el}/σ_{tot}	0.196	0.213	0.215	0.224	0.310	0.319	0.610	0.627	0.643
$B(GeV^{-2})$	16.4	18.3	18.5	19.1	21.3	21.6	33.9	35.2	36.5

Predicted values of the forward measurables at different energies using the unitarization procedure in case of g_1 .

\sqrt{s}, TeV	0.9	2.76	3	4	13	14	80	90	100
g	0.674	0.772	0.781	0.812	0.977	0.990	1.464	1.513	1.560
$\sigma_{tot}(mb)$	66.9	80.9	82.0	86.2	107	108	158	163	167
$\sigma_{el}(mb)$	14.6	19.3	19.7	21.2	29.4	30.1	54.0	56.5	58.8
$\sigma_{in}(mb)$	52.3	61.6	62.3	65.0	77.6	78.5	104	106	108
σ_{el}/σ_{tot}	0.218	0.238	0.24	0.246	0.274	0.277	0.341	0.313	0.351
$B(GeV^{-2})$	16.0	17.9	18.1	18.6	20.8	20.94	24.8	25.1	25.4

Predicted values of the forward measurables at different energies using the unitarization procedure in case of g_2 .

Thank you for your attention!