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NEW PHYSICS FROM THE LHC (DEMYSTIFYING THE ODDERON)

László JENKOVSZKY (jenk@bitp.kiev.ua) (in Collab. with István Szanyi)

Based on papers:

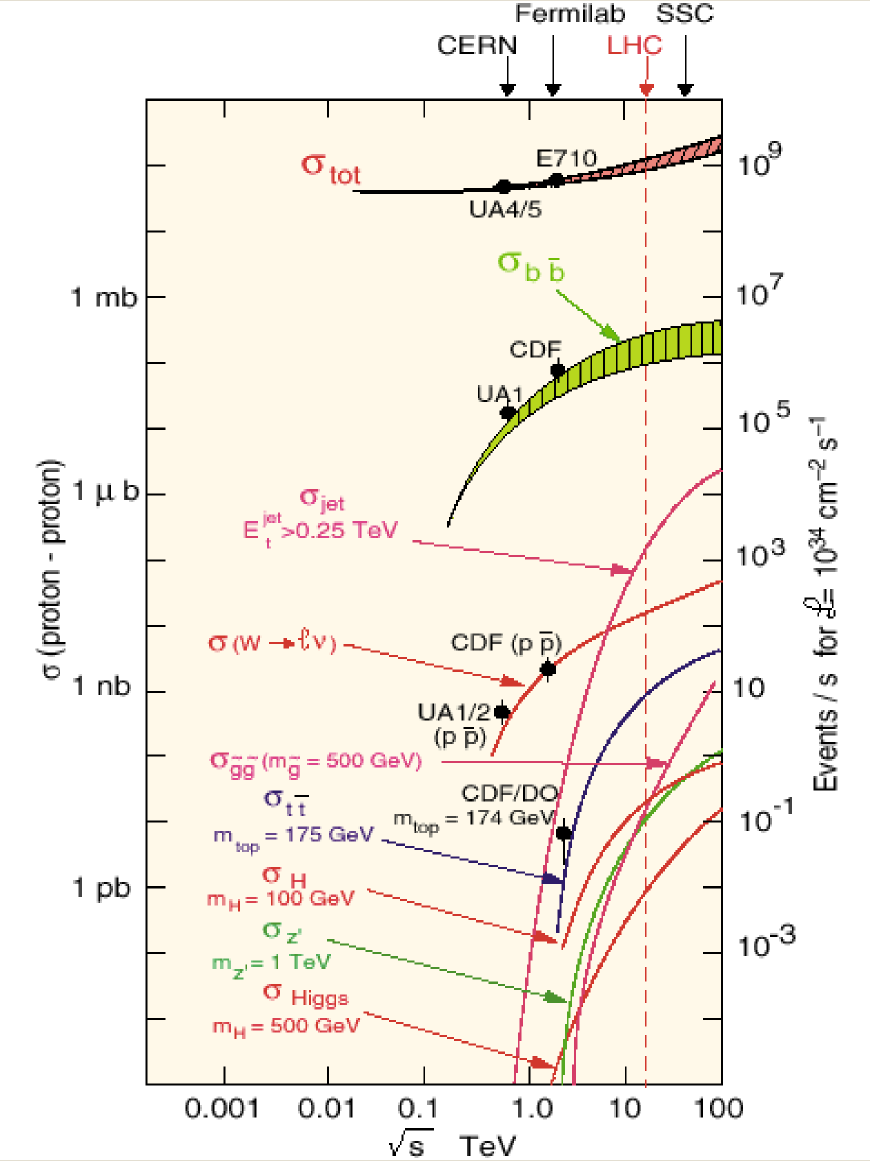
L. Jenkovszky, I. Szanyi, C.-I Tan, Eur. Phys. J. A (2018) **54**:116, arXiv:1710.10594.

L. Jenkovszky, I. Szanyi, Phys. Part. Nuclei Lett., **14**, 687 (2017), arXiv:1701.01269.

L. Jenkovszky, I. Szanyi, Mod. Phys. Lett. A, **32**, 1750116 (2017), arXiv:1705.04880.

László Jenkovszky, Rainer Schicker, István Szanyi: *Elastic and diffractive scattering in the LHC era,* International Journal of Modern Physics E Vol. 27, No. ~~7~~ (2018) 1830005 (59 pages)

- Total cross section at LHC
  $\sigma(pp \rightarrow \text{anything}) \sim 0.1$ barn
- So a 1 pb Higgs cross section corresponds to one being *produced* every 10^{11} interactions!
  (further reduced by BR × efficiency)
- Experiments have to be designed so that they can separate such a rare signal process from the background
- Rate = $L \cdot \sigma$
  where luminosity L (units $cm^{-2}s^{-1}$) is a measure of how intense the beams are
  LHC design luminosity = 10^{34} $cm^{-2}s^{-1}$



- ***ITEMS:***
- *Forward (diffractive, soft) physics at the LHC (TOTEM);*
- *Kinematics, measurables;*
- *The Regge-pole theory;*
- *Regge trajectories (the pomeron and odderon);*
- *TOTEM’s 2017 publication and speculations;*
- *Demystification of the odderon*

$$\sigma_t(s)=\frac{4\pi}{s}ImA(s,t=0);\quad \frac{d\sigma}{dt}=\frac{\pi}{s^2}|A(s,t)|^2;\quad n(s);$$

$$\sigma_{el}=\int_{t_{min\approx -s/2\approx\infty}}^{t_{thr.\approx 0}}\frac{d\sigma}{dt}dt;\ \sigma_{in}=\sigma_t-\sigma_{el};\quad B(s,t)=\frac{d}{dt}\ln\left(\frac{d\sigma}{dt}\right);$$

$$A_{pp}^{p\bar{p}}(s,t)=P(s,t)\pm O(s,t)+f(s,t)\pm\omega(s,t)\rightarrow_{LHC}\approx P(s,t)\pm O(s,t),$$

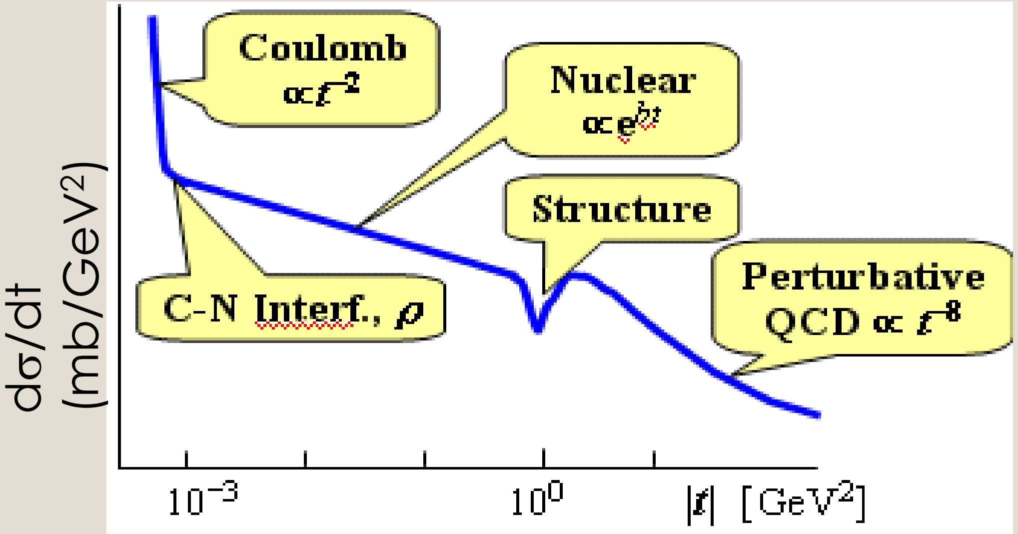
where P, O, f. ω are the Pomeron, odderon and non-leading Reggeon contributions.

α(0)\C	**+**	**-**
1	**P**	**O**
1/2	**f**	**ω**

NB: The S-matrix theory (including Regge pole) is applicable to asymptotically free states only (not to quarks and gluons)!

Elastic Scattering

$\sqrt{s}$ = 14 TeV prediction of BSW model



momentum transfer -t ~ $(p\theta)^2$

θ = beam scattering angle

p = beam momentum

$$\rho = \frac{\mathrm{Re}(f_{el}(t))}{\mathrm{Im}(f_{el}(t))}\bigg|_{t\to 0}$$

$$\frac{dN}{dt}\bigg|_{t=CNI} = L\pi |f_C + f_N|^2 \approx L\pi \left| -\frac{2\alpha_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-\frac{b|t|}{2}} \right|^2$$

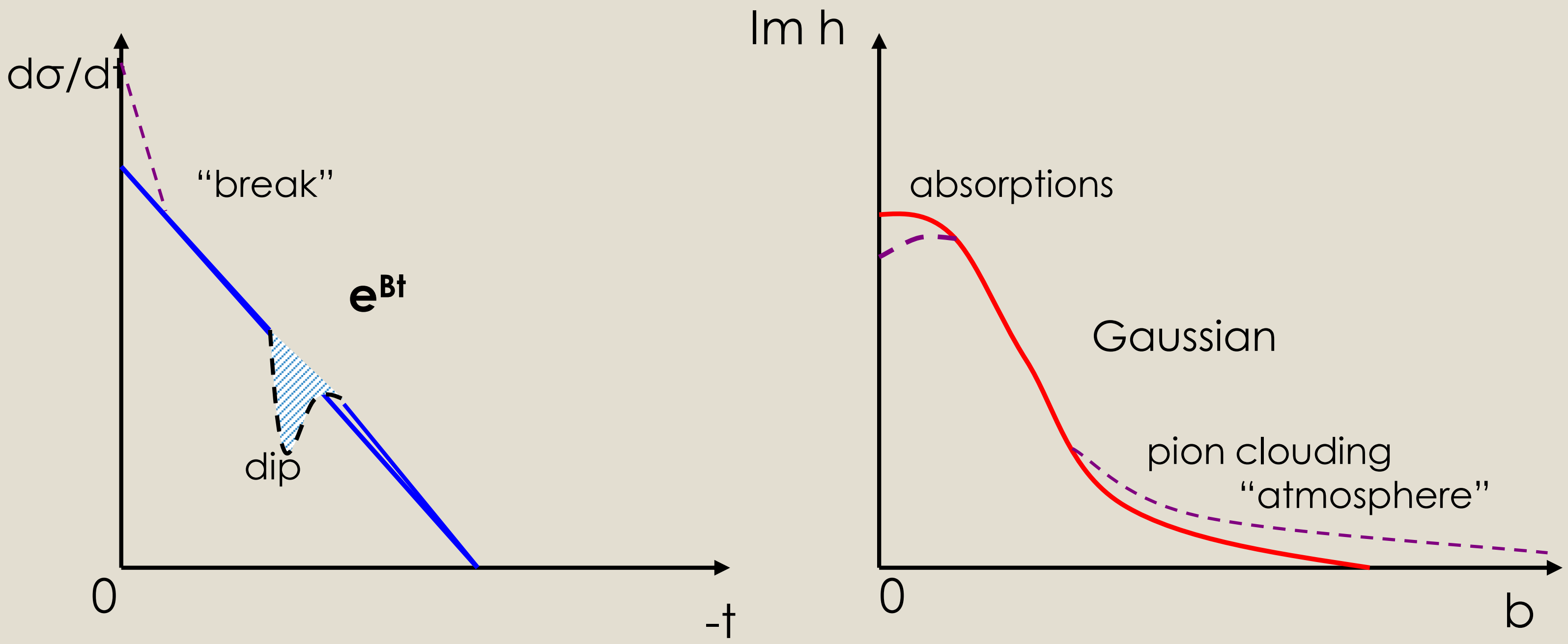
L, **σ_{tot}** , **b**, and **ρ** from FIT in CNI region (UA4)

CNI region: $|f_C|$ ~ $|f_N|$ → @ LHC: -t ~ 6.5 10^{-4} GeV^2; θ_{min}~3.4 μrad

(θ_{min}~120 μrad @ SPS)

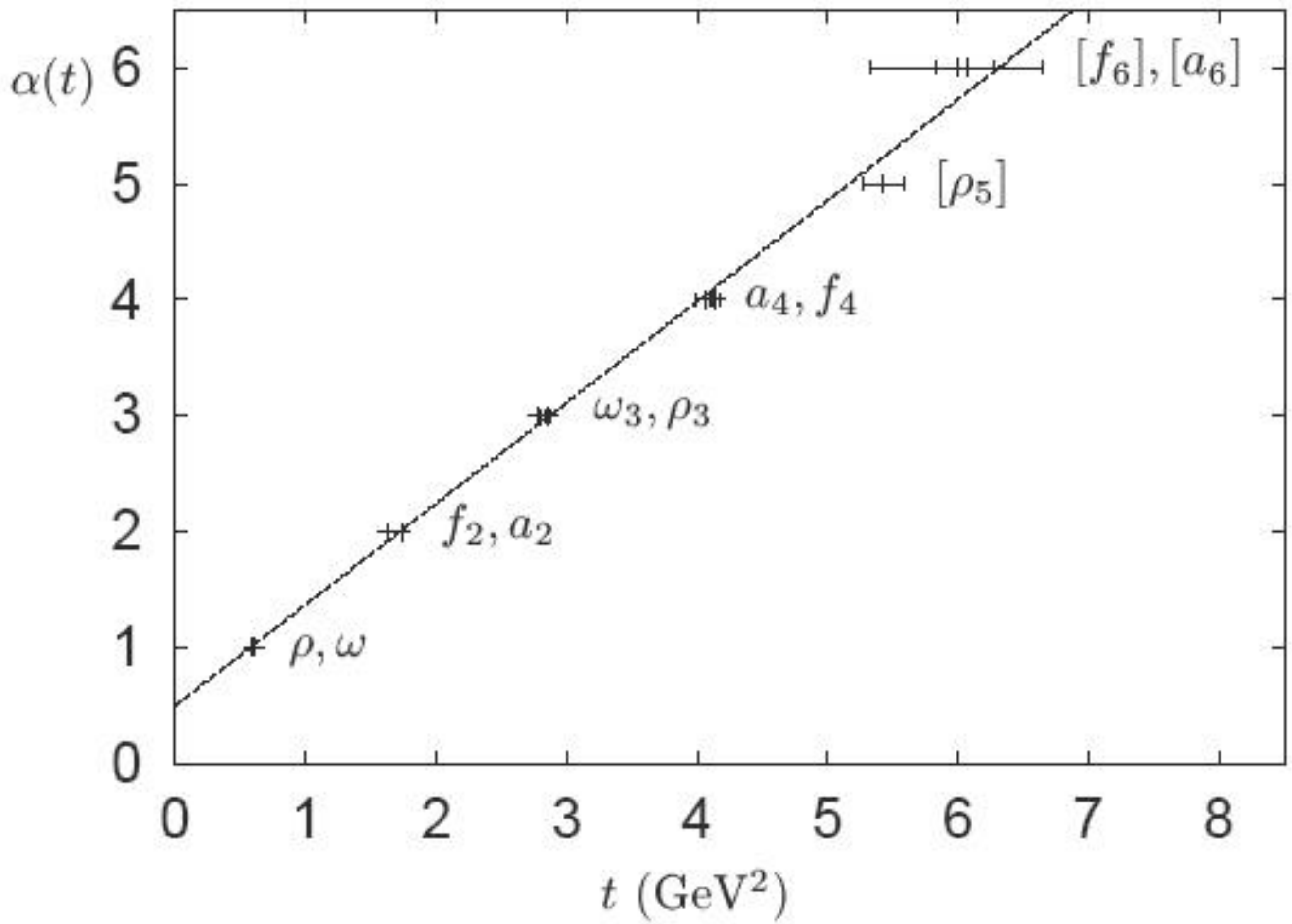
1. **On-shell (hadronic) reactions (s,t, Q^2=m^2);**
   t ←→ *b* **transformation dictionary:**

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



Linear particle trajectories

Plot of spins of families of particles against their squared masses:



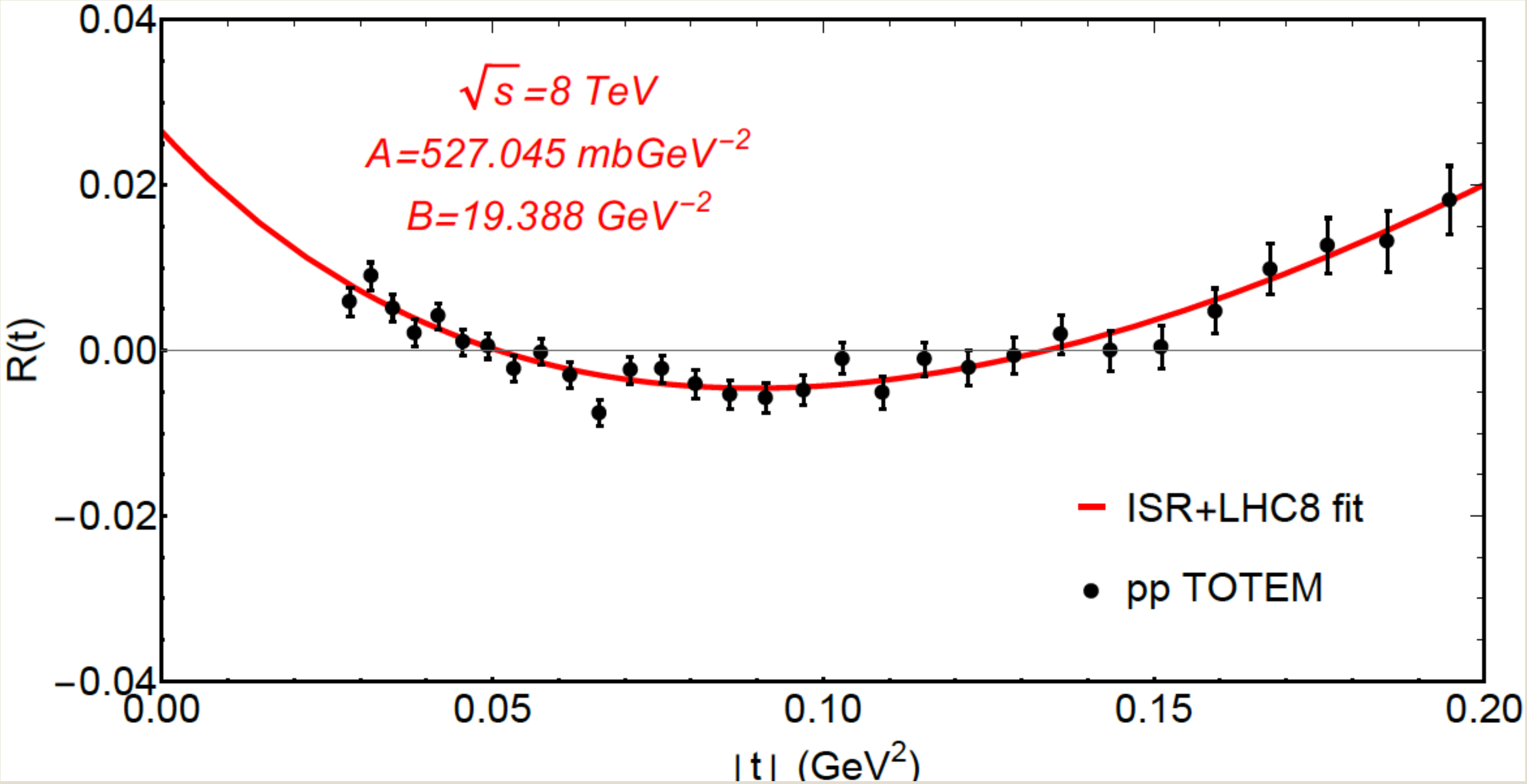
The Pomeron trajectory

The Pomeron trajectory has threshold singularities, the lowest one being due to the two-pion exchange, required by the $t-$channel unitarity. There is a constrain (Barut, Zwanziger; Gribov) from the $t-$ channel unitarity, by which

$$\Im\alpha(t) \sim (t-t_0)^{\Re\alpha(t_0)+1/2}, \quad t \to t_0,$$

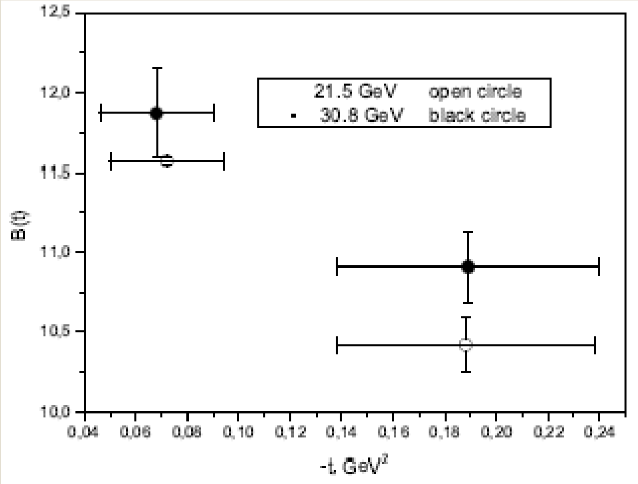
where t_0 is the lightest threshold. For the Pomeron trajectory it is $t_0 = 4m_\pi^2$, and near the threshold:

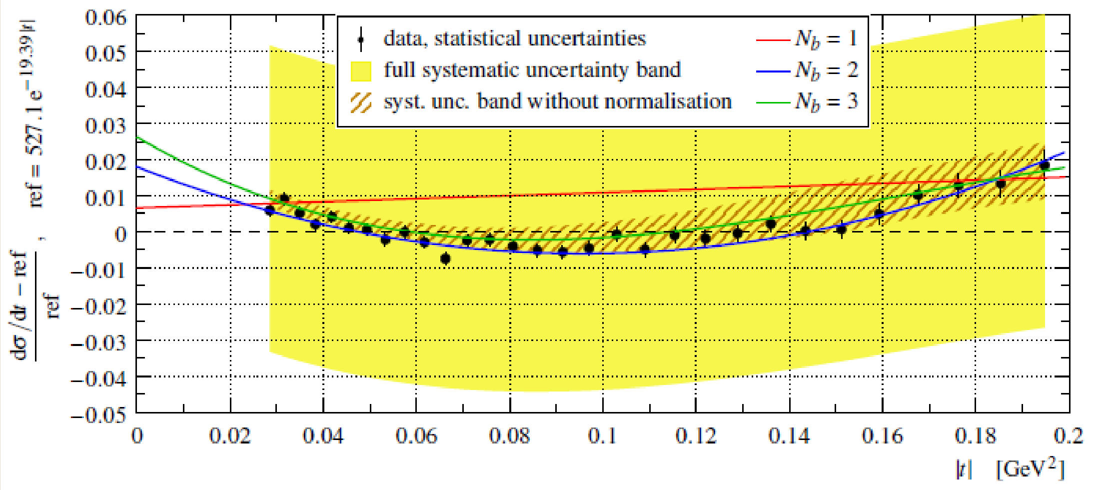
$$\alpha(t) \sim \sqrt{4m_\pi^2 - t}. \qquad (1)$$



√s =8 TeV
A=527.045 mbGeV⁻²
B=19.388 GeV⁻²
ISR+LHC8 fit
pp TOTEM
R(t)
|t| (GeV²)
0.04
0.02
0.00
−0.02
−0.04
0.00
0.05
0.10
0.15
0.20

“break”





Local slopes B(t) calculated for low-|t| ISR

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

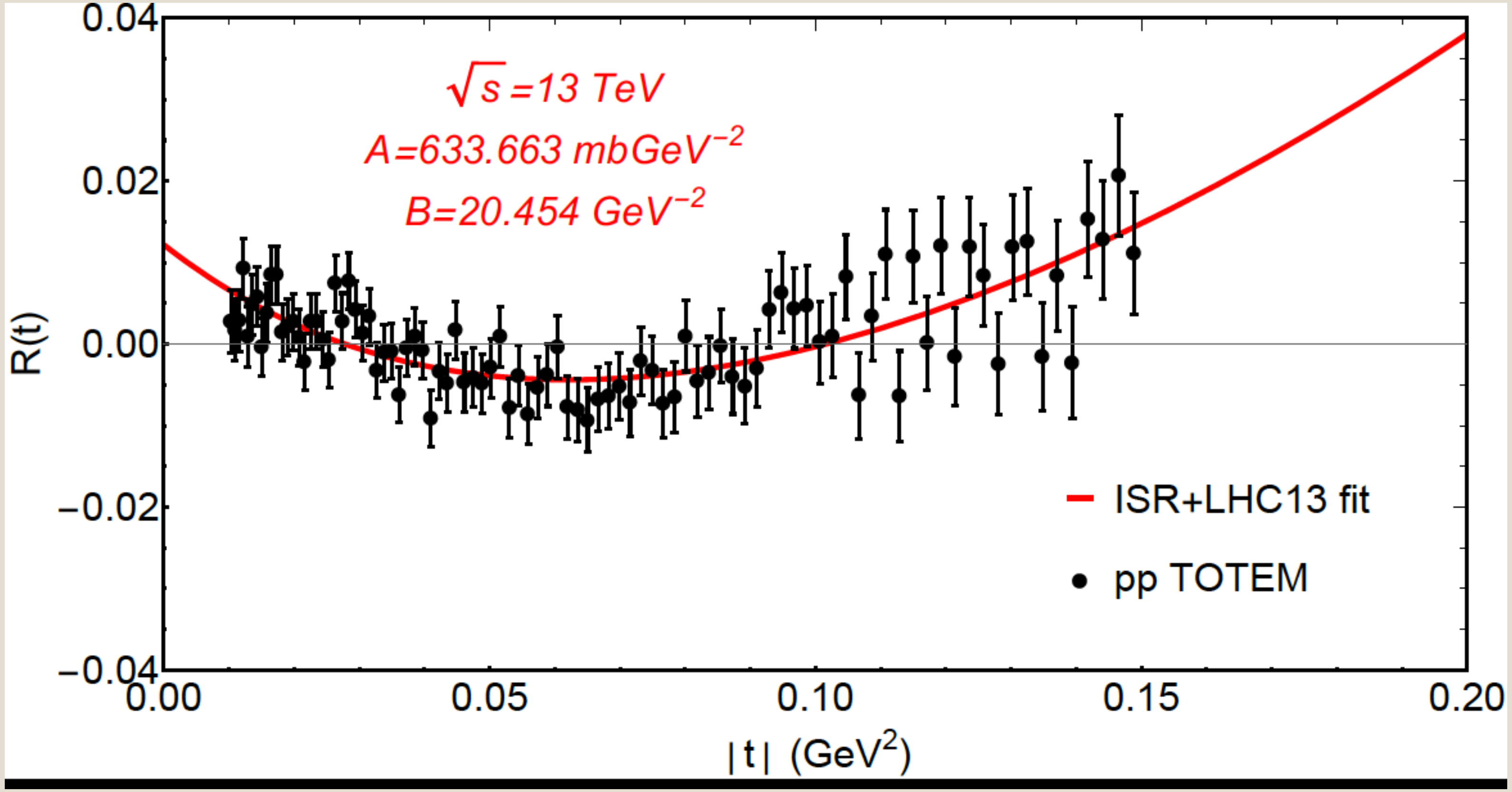
R(t) calculated for low-|t| 8 TeV data.

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

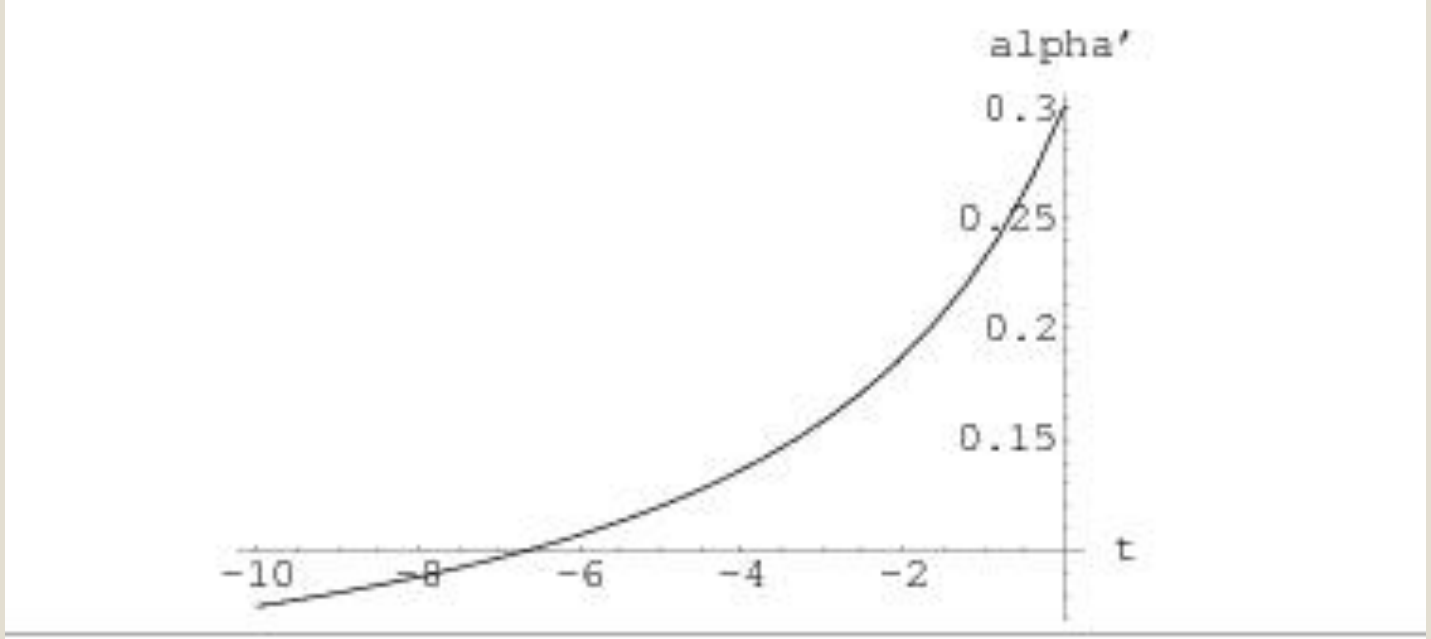
$$ref = Ae^{Bt}$$

arXiv:1410.4106
G. Barbiellini et al., Phys. Lett. B 39 (1972) 663

arXiv:1503.08111



√s =13 TeV
A=633.663 mbGeV^−2
B=20.454 GeV^−2
ISR+LHC13 fit
pp TOTEM
R(t)
|t| (GeV^2)
0.04
0.02
0.00
−0.02
−0.04
0.00
0.05
0.10
0.15
0.20



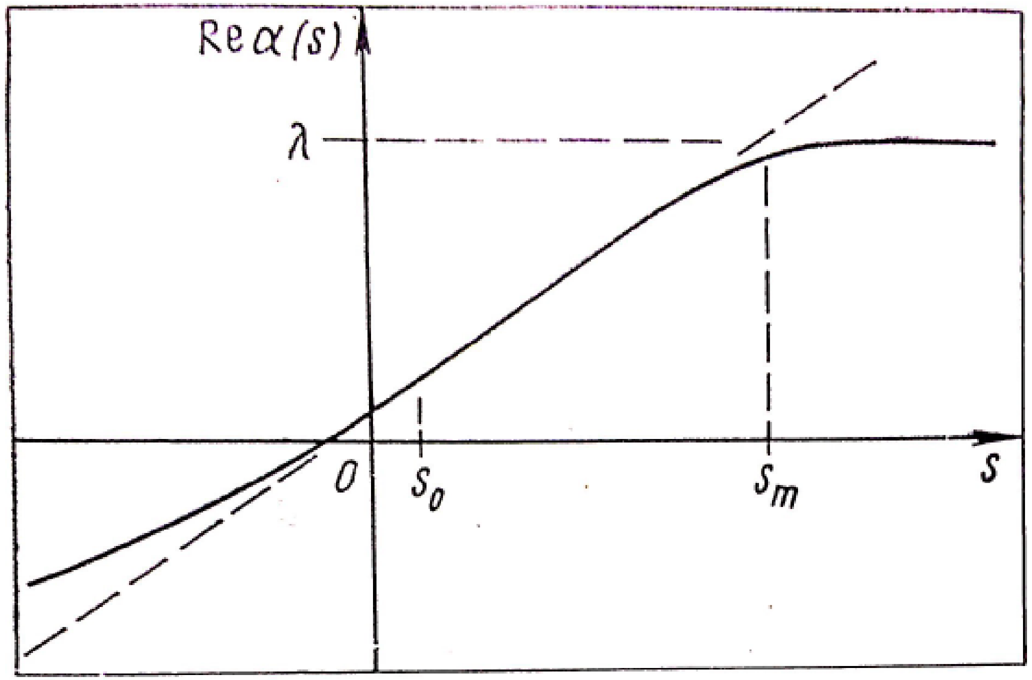
The slope of the cone for a single pole is: $B(s,t) \sim \alpha'(t)\ln s$. The Regge residue $e^{b\alpha(t)}$ with a logarithmic trajectory $\alpha(t) = \alpha(0) - \gamma\ln(1-\beta t)$, is identical to a form factor (geometrical model).

Representative examples of the Pomeron trajectories: 1) Linear; 2) With a square-root threshold, required by $t-$channel unitarity and accounting for the small-t “break” as well as the possible “Orear”, $e^{\sqrt{-t}}$ behavior in the second cone; and 3) A logarithmic one, anticipating possible “hard effects” at large $|t|$ $|t| < 8$ GeV^2.

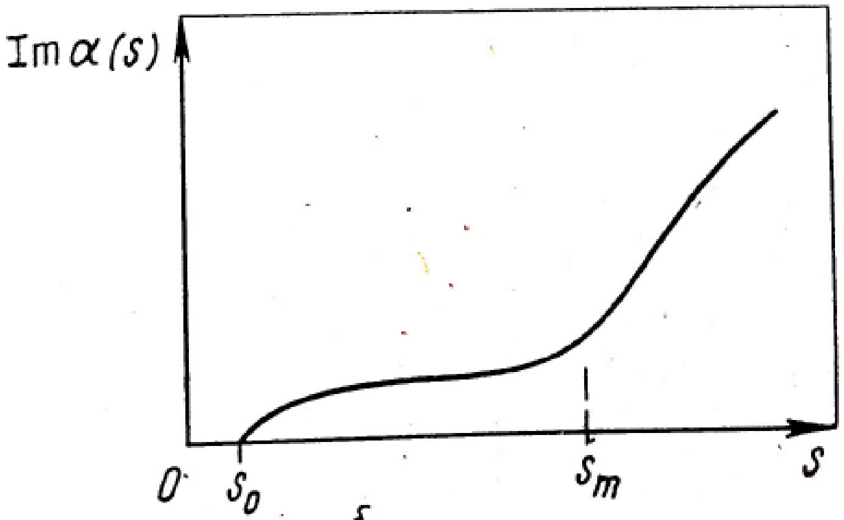
$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P + \alpha_{1P}t, \tag{TR.1}$$

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P + \alpha_{1P}t - \alpha_{2P}\left(\sqrt{4\alpha_{3P}^2 - t} - 2\alpha_{3P}\right), \tag{TR.2}$$

$$\alpha_P \equiv \alpha_P(t) = 1 + \delta_P - \alpha_{1P}\ln\left(1 - \alpha_{2P}t\right). \tag{TR.3}$$



а



б

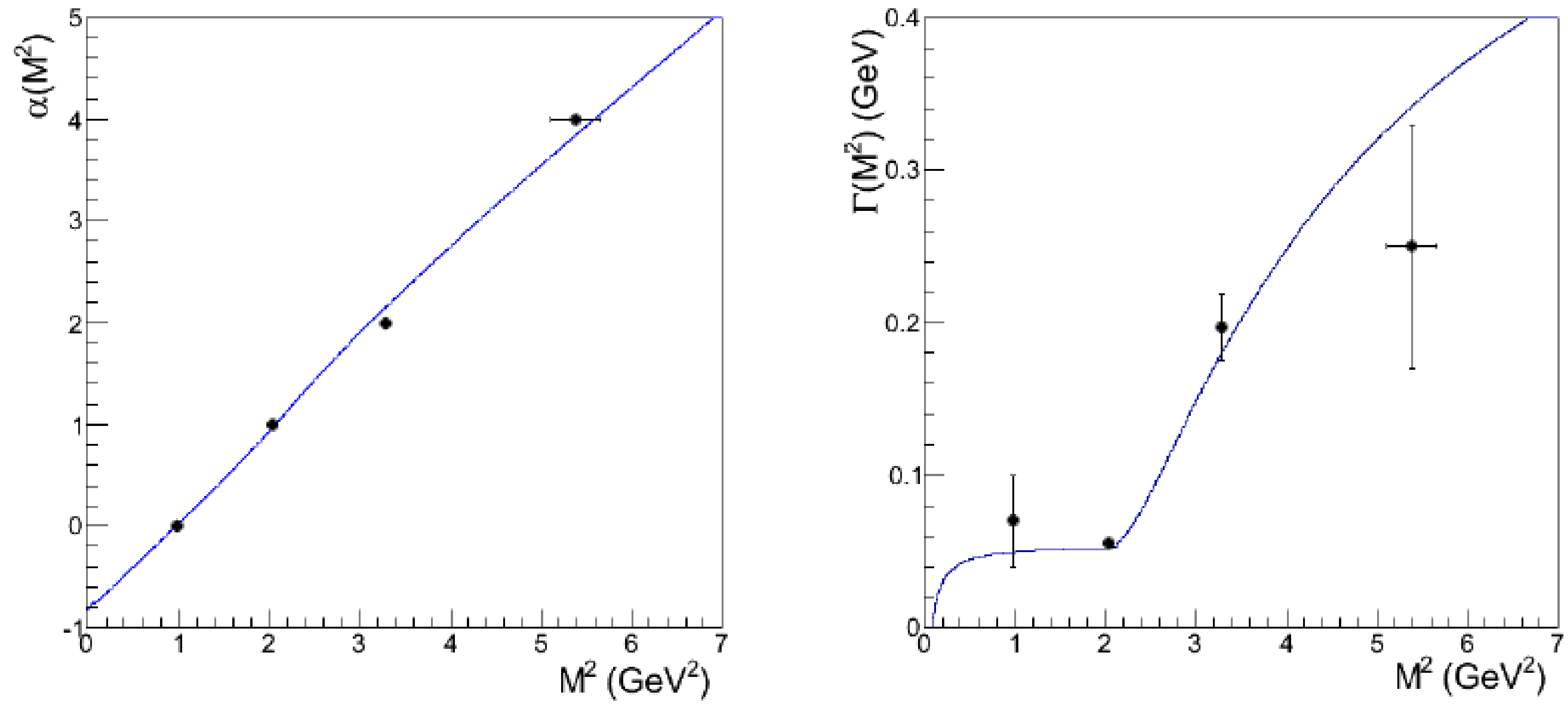


FIG. 6: Real part of f_1 trajectory on the left, width function $\Gamma(M^2)$ on the right.

$$A_{pp}^{p\bar{p}}(s,t) = P(s,t) \pm O(s,t) + f(s,t) \pm \omega(s,t) \rightarrow_{LHC} P(s,t) \pm O(s,t),$$

where P is the Pomeron contribution and O is that of the Odderon.

$$P(s,t) = i\frac{as}{bs_0}(r_1^2(s)e^{r_1^2(s)[\alpha_P(t)-1]} - \epsilon r_2^2(s)e^{r_2^2(s)[\alpha_P(t)-1]}),$$

where $r_1^2(s) = b + L - \frac{i\pi}{2}, \quad r_2^2(s) = L - \frac{i\pi}{2}$ with $L \equiv \ln\frac{s}{s_0}$; $\alpha_P(t)$ is the Pomeron trajectory and a, b, s_0 and ϵ are free parameters.

The Pomeron is a dipole in the $j-$plane

$$A_P(s,t) = \frac{d}{d\alpha_P}\Big[e^{-i\pi\alpha_P/2}G(\alpha_P)\Big(s/s_0\Big)^{\alpha_P}\Big] = \tag{1}$$

$$e^{-i\pi\alpha_P(t)/2}\Big(s/s_0\Big)^{\alpha_P(t)}\Big[G'(\alpha_P) + \Big(L - i\pi/2\Big)G(\alpha_P)\Big].$$

Since the first term in squared brackets determines the shape of the cone, one fixes

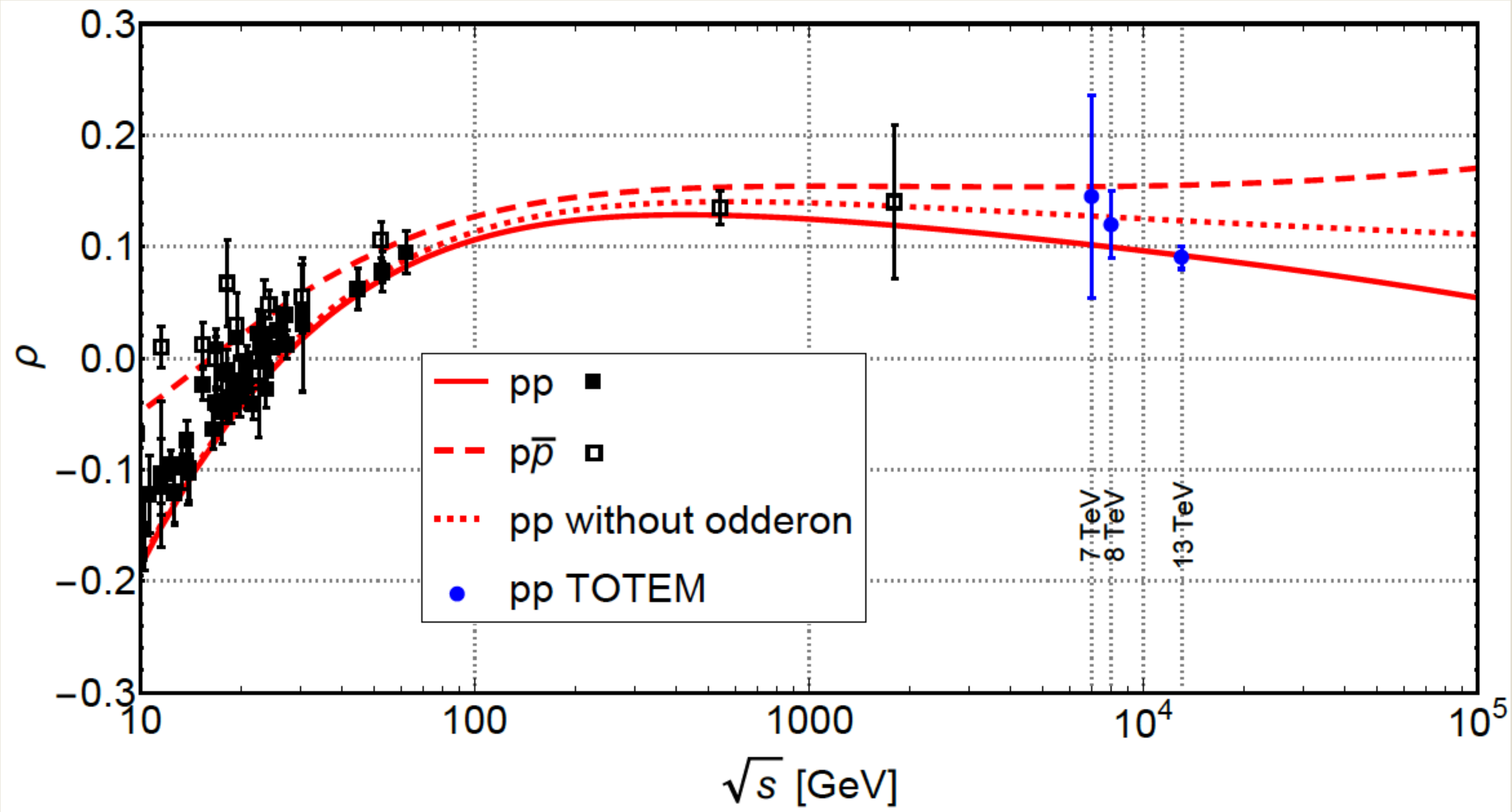
$$G'(\alpha_P) = -a_P e^{b_P[\alpha_P - 1]}, \tag{2}$$

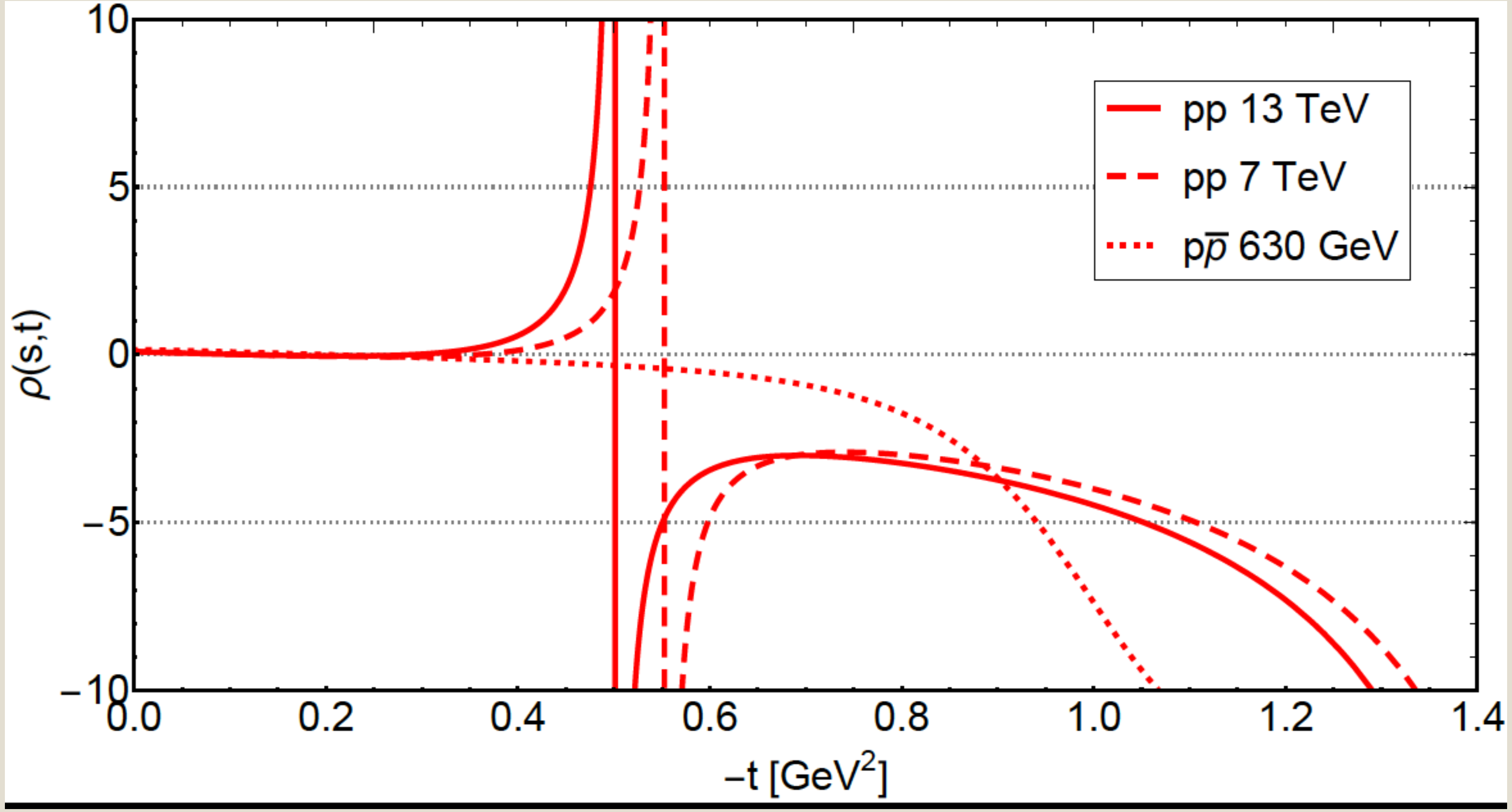
where $G(\alpha_P)$ is recovered by integration, and, as a consequence, the Pomeron amplitude can be rewritten in the following "geometrical" form

$$A_P(s,t) = i\frac{a_P\ s}{b_P\ s_0}[r_1^2(s)e^{r\ \ (s)[\alpha_P-1]} - \varepsilon_P r_2^2(s)e^{r\ \ (s)[\alpha_P-1]}], \tag{3}$$

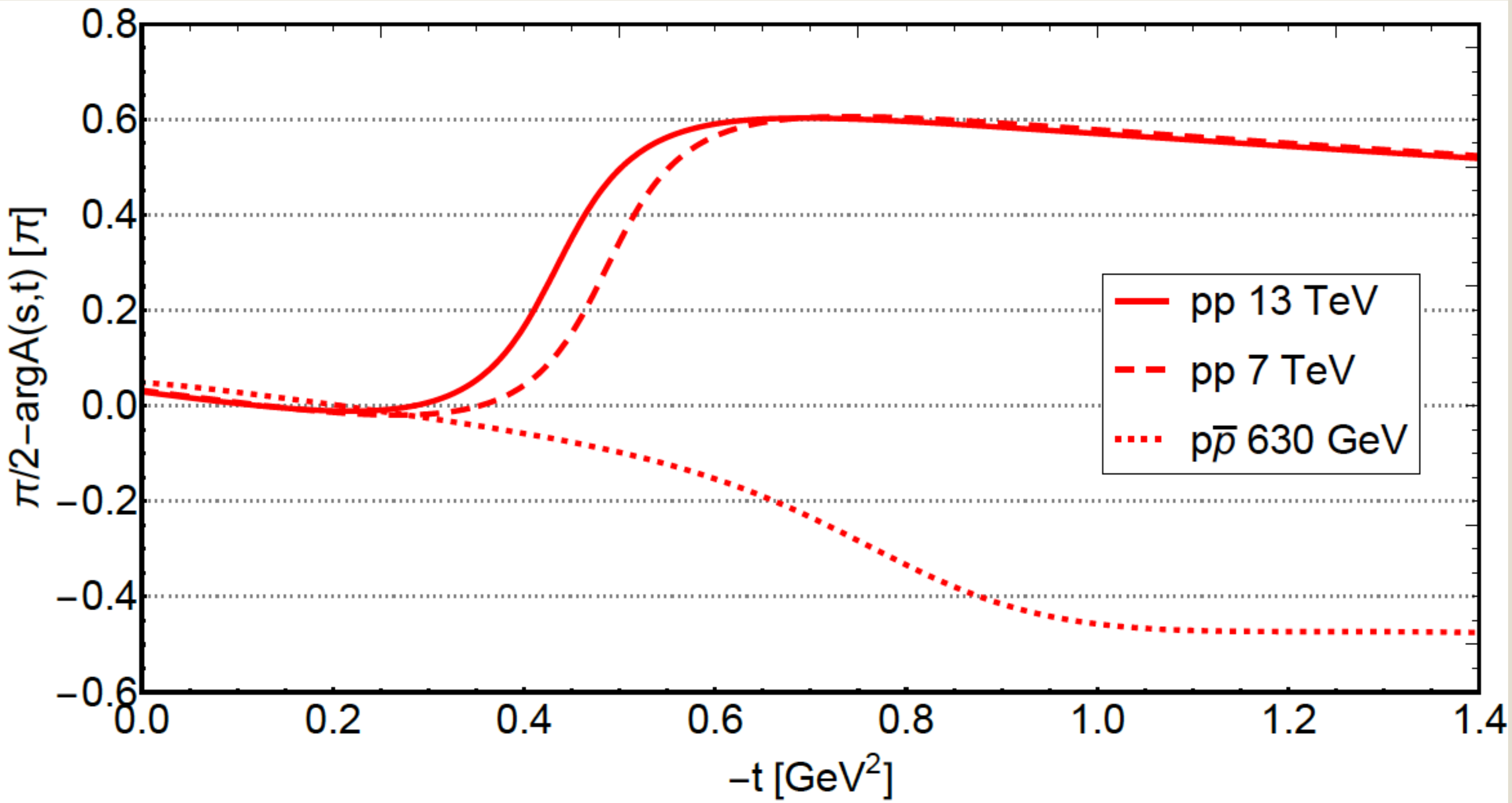
where $r_1^2(s) = b_P + L - i\pi/2$, $\ r_2^2(s) = L - i\pi/2$, $\ L \equiv \ln(s/s_0)$.

TOTEM (2017) and noise about the odderon

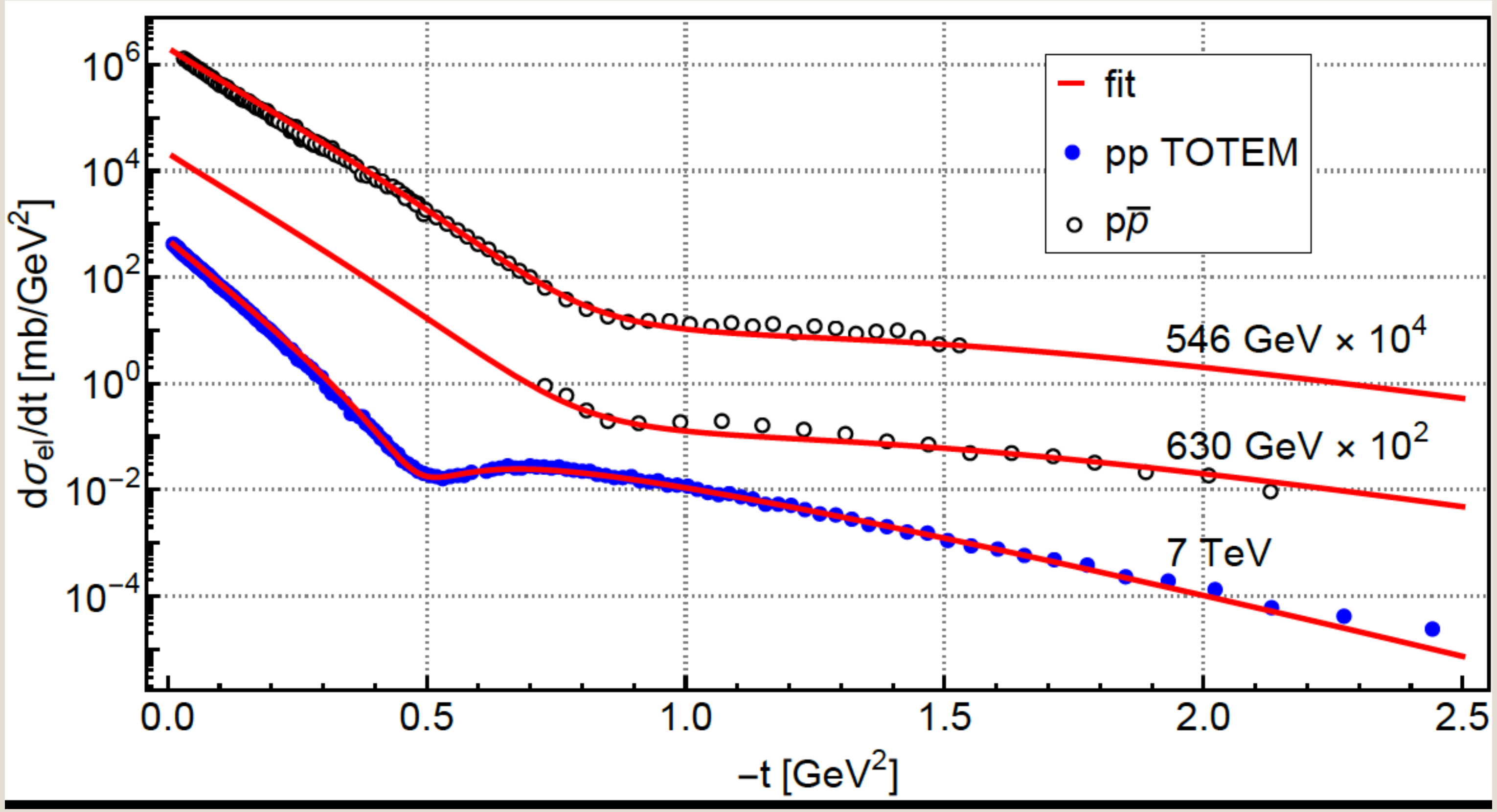




pp 13 TeV
pp 7 TeV
p$\bar{p}$ 630 GeV
ρ(s,t)
−t [GeV^2]
10
5
0
−5
−10
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

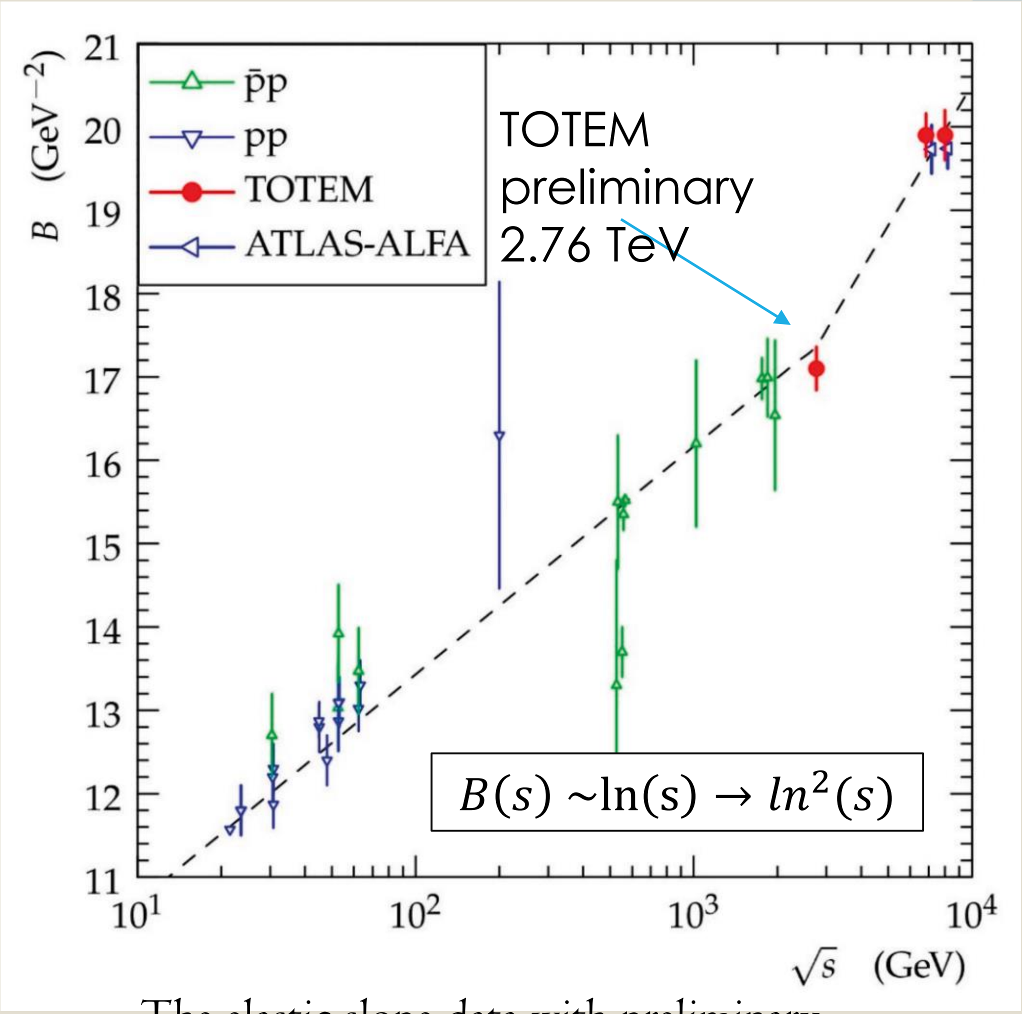


0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
π/2−argA(s,t) [π]
−t [GeV²]
pp 13 TeV
pp 7 TeV
pp̄ 630 GeV

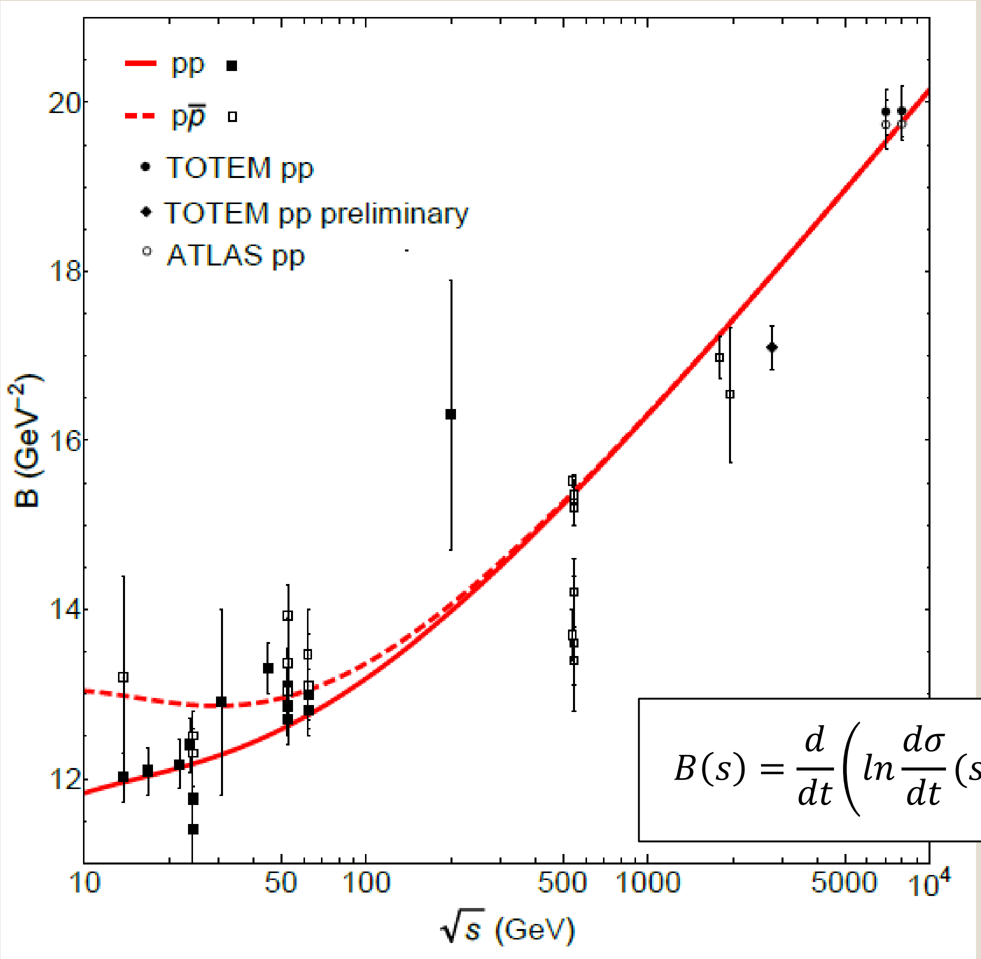


fit
pp TOTEM
p$\bar{p}$
546 GeV × 10^4
630 GeV × 10^2
7 TeV
$d\sigma_{el}/dt$ [mb/GeV^2]
$-t$ [GeV^2]

New elastic slope measurements



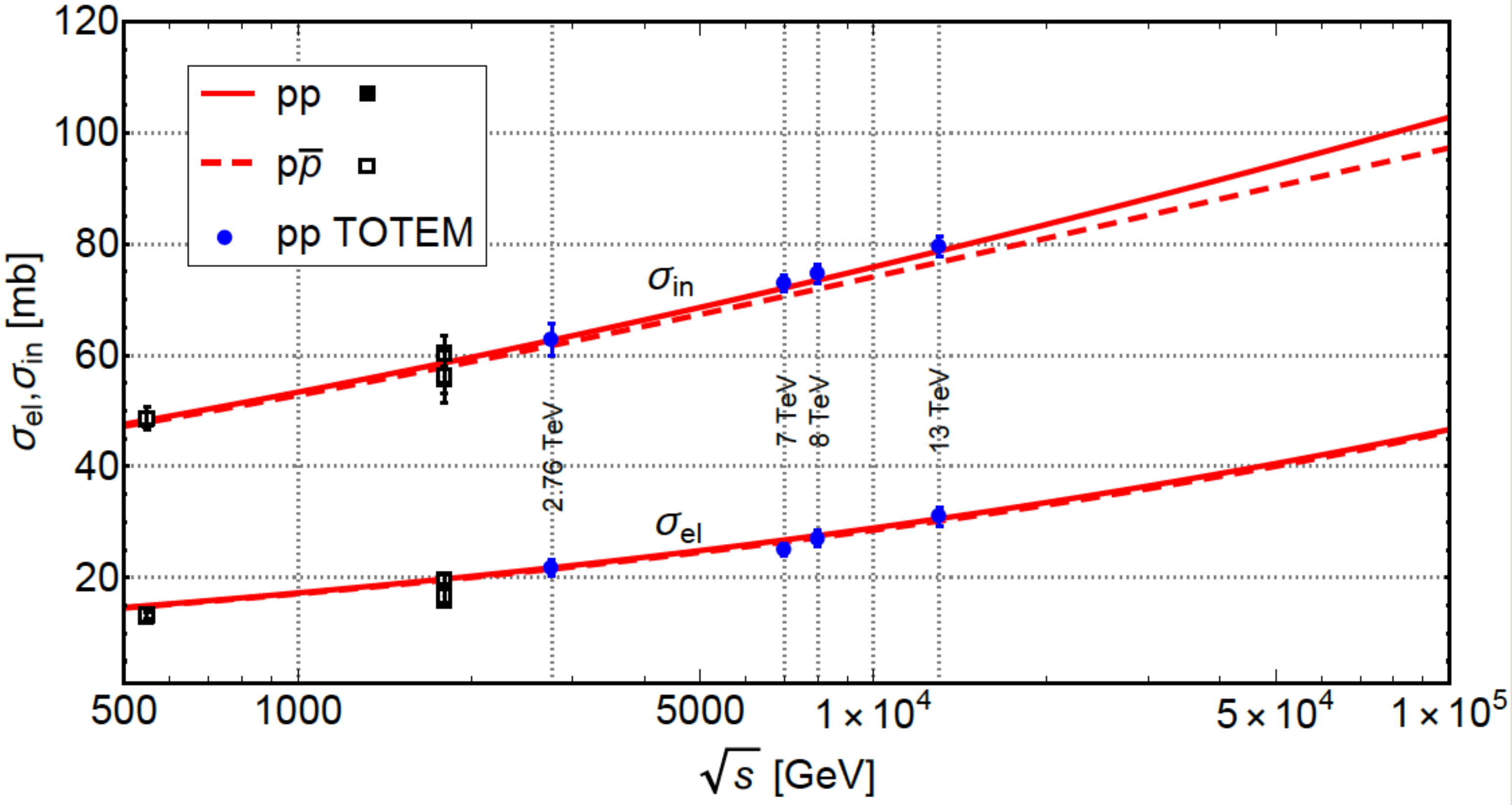
The elastic slope data with preliminary TOTEM results.



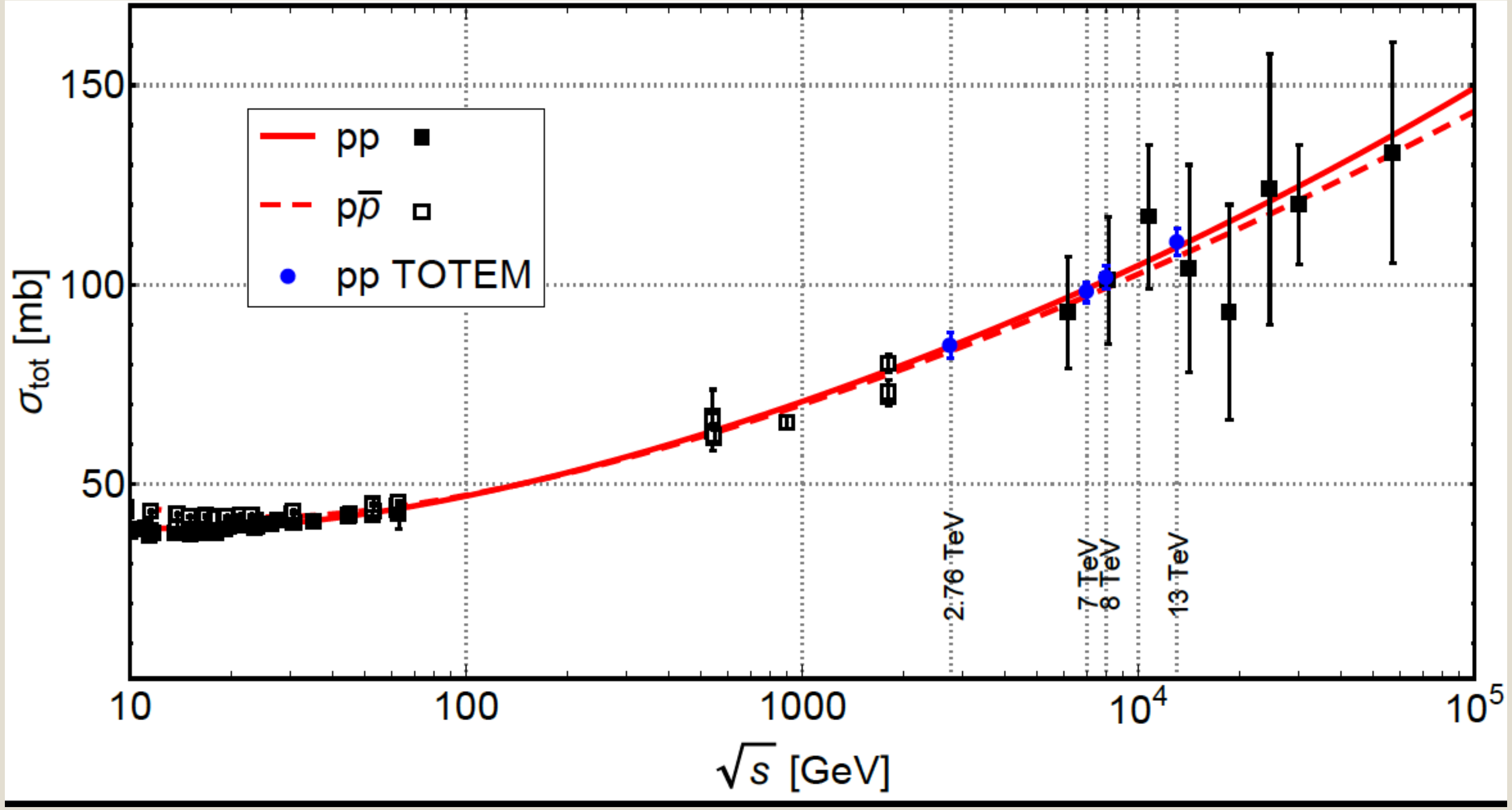
$$B(s) = \frac{d}{dt}\left(ln\frac{d\sigma}{dt}(s,t)\right)\Bigg|_{t=0}$$

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

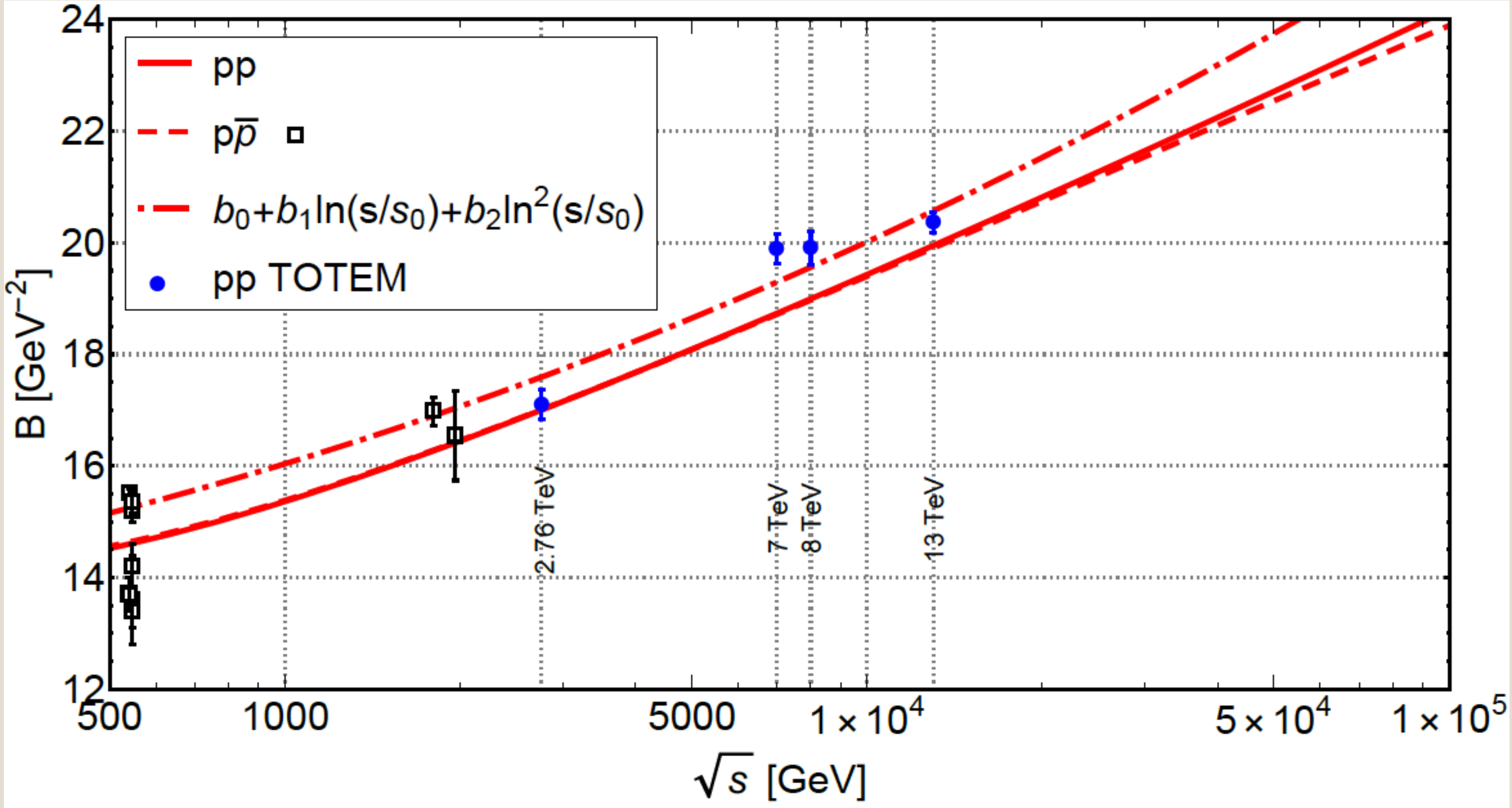
M. Deile: Elastic and Total Cross-Section Measurements by TOTEM. EDS Blois 2017 (Prague, 2017).



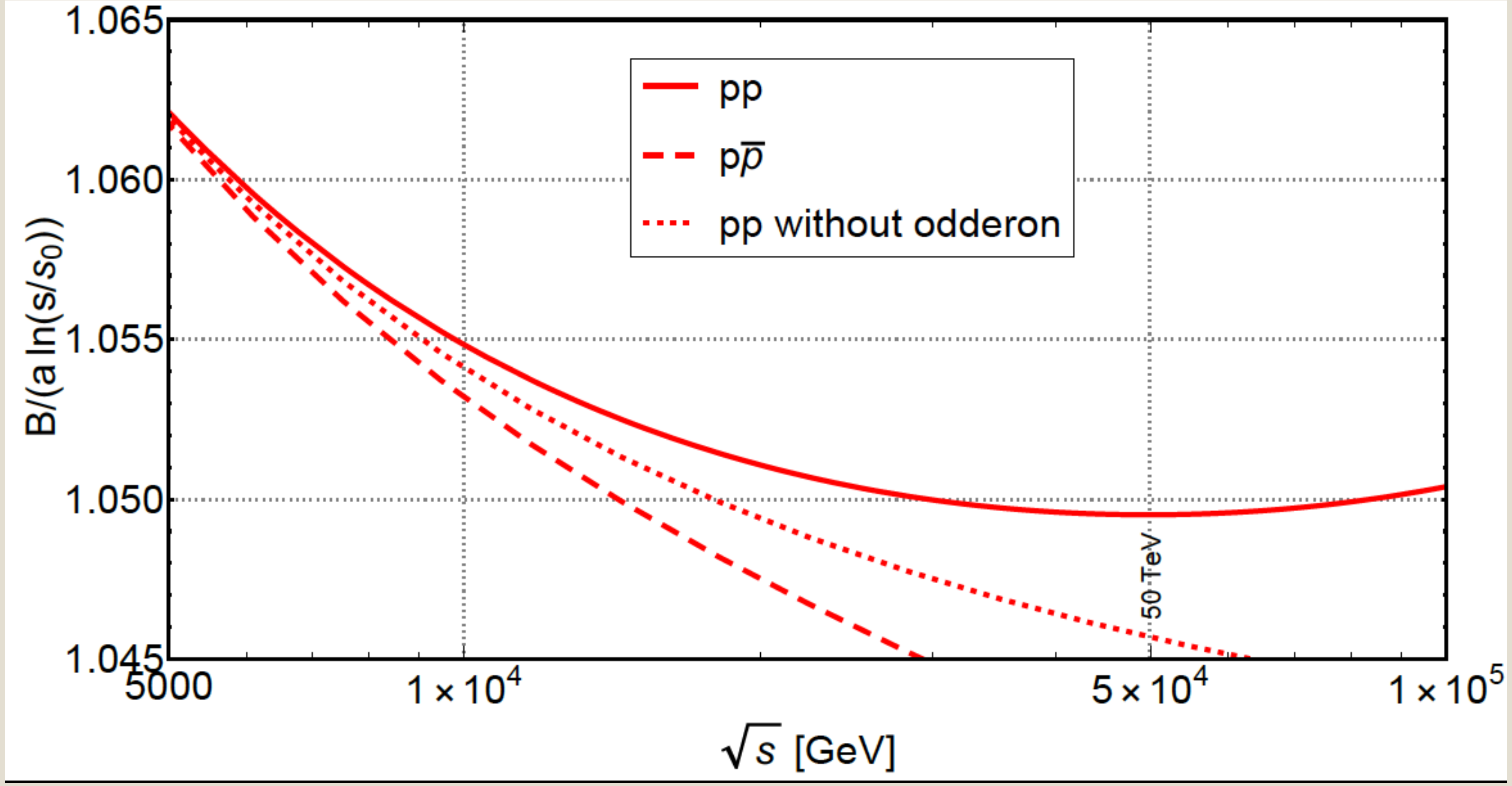
pp
p$\bar{p}$
pp TOTEM
σ_{in}
σ_{el}
2.76 TeV
7 TeV
8 TeV
13 TeV
σ_{el}, σ_{in} [mb]
$\sqrt{s}$ [GeV]
120
100
80
60
40
20
500
1000
5000
1×10^4
5×10^4
1×10^5



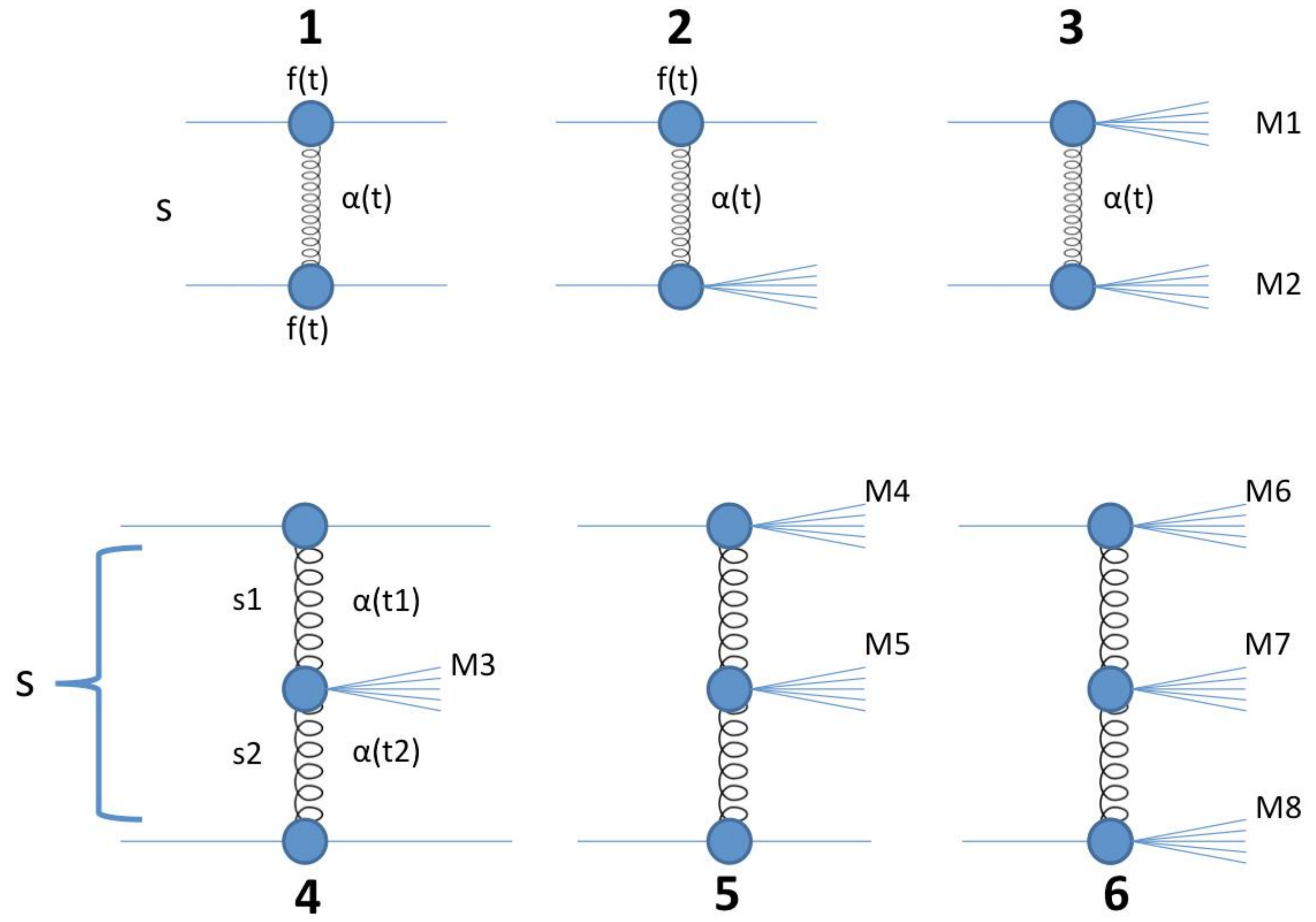
pp
p$\overline{p}$
pp TOTEM
150
100
50
σ_{tot} [mb]
2.76 TeV
7 TeV
8 TeV
13 TeV
10
100
1000
10^4
10^5
$\sqrt{s}$ [GeV]



pp
$p\bar{p}$
$b_0+b_1\ln(s/s_0)+b_2\ln^2(s/s_0)$
pp TOTEM
B [GeV^{-2}]
24
22
20
18
16
14
12
500
1000
5000
1×10^4
5×10^4
1×10^5
$\sqrt{s}$ [GeV]
2.76 TeV
7 TeV
8 TeV
13 TeV

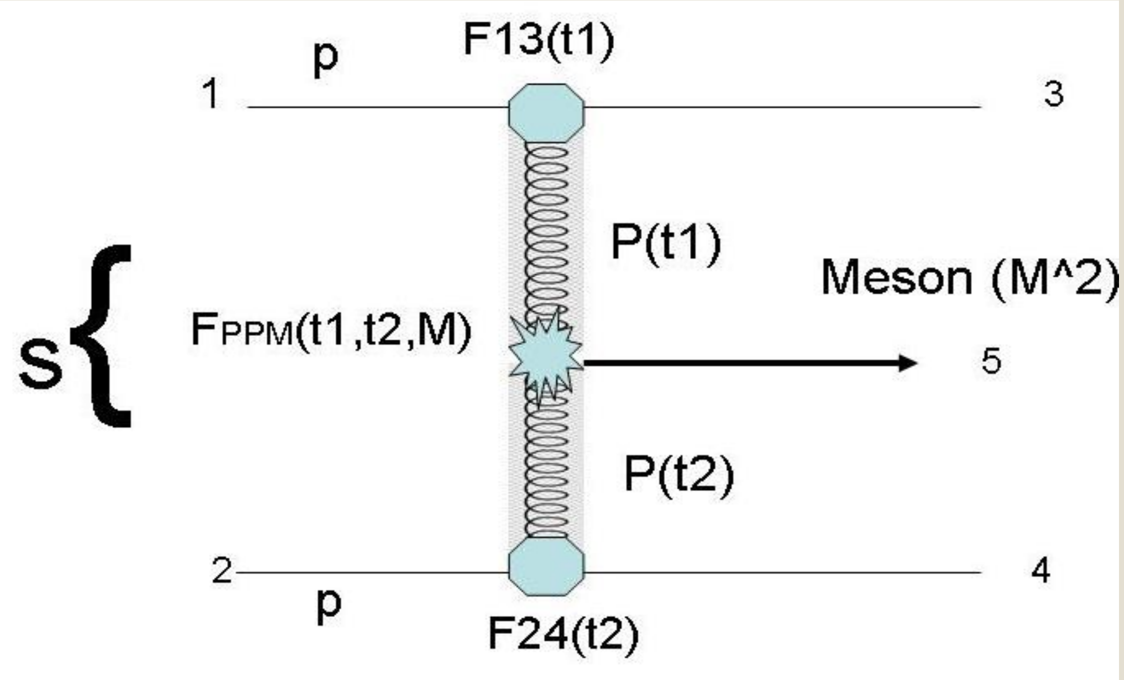


pp
p$\overline{p}$
pp without odderon
B/(a ln(s/s$_0$))
1.065
1.060
1.055
1.050
1.045
5000
1 × 10^4
5 × 10^4
1 × 10^5
50 TeV
$\sqrt{s}$ [GeV]


1
2
3
f(t)
f(t)
s
α(t)
α(t)
α(t)
M1
M2
f(t)
M4
M6
s1
α(t1)
M5
M7
s
M3
s2
α(t2)
M8
4
5
6

Prospects (future plans):

1. Central diffractive meson production (double Pomeron exchange);



2. Charge exchange reactions at the LHC (single Reggeon exchnge), e.g. pp→nΔ (in collaboration with Oleg Kuprash and Rainer Schicker)

Open problems:

1. Interpolation in energy: from the Fermilab and ISR to the LHC; (Inclusion of non-leading contributions);
3. Deviation from a simple Pomeron pole model and breakdown of Regge-factorization;
4. Experimental studies of the exclusive channels (p+**π,…)** produced from the decay of resonances (N*, Roper?,,,) in the nearly forward direction.
5. Turn down of the cross section towards t=0?!

Elastic and total scattering, diffraction in hadron- and lepton-induced reactions:

А.Н. Валл, Л.Л. Енковский, Б.В. Струминский: *Взаимодействие адронов при высоких энергиях*, Физика элементарных частиц и атомного ядра (ЭЧАЯ – Particles and Nuclei) **т.19** (1988) стр. 181-223.

Л.Л. Енковский: Дифракция *в адрон-адронных и лептон-адронных процессах при высоких энергиях*, (ЭЧАЯ – Particles and Nuclei) **т.34** (2003) стр. 1196-1255.

R. Fiore, L. Jenkovszky, R. Orava, E. Predazzi, A. Prokudin, O. Selyugin, *Forward Physics at the LHC; Elastic Scattering*, Int. J.Mod.Phys., **A24**: 2551-2559 (2009).

- **Thank you!**