REGGIO CALABRIA, AUGUST 27, 2018

NEW PHYSICS FROM TOTEM (THE ODDERON: MYTHS AN REALITY)

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E. Martynov, B. Nicolescu, **Evidence for maximality of strong interactions from LHC forward data,** **arXiv:1804.10139;**

Evgenij Martynov, Basarab Nicolescu,
Did TOTEM experiment discover the Odderon?
Phys. Lett. B 778, 414, 2018, **arXiv:1711.03288;**

M. Broilo, E.G.S. Luna, M.J. Menon, **Forward Elastic Scattering and Pomeron Models,** **arXiv:1807.10337.**

M. Broilo, E.G.S. Luna, M.J. Menon, **Soft Pomerons and the Forward LHC,** **arXiv:1803.07167,**
To be publ. in Phys. Lett. B;

M. Broilo, E.G.S. Luna, M.J. Menon
Leading Pomeron Contributions and the TOTEM Data at 13 TeV, **arXiv:1803.06560.**

- *Related papers:*
- O. Selugin: **The energy dependence of the diffraction minimum in the elastic scattering and new LHC data**, Nucl. Phys. A959 (2017) 116; arXiv:1609.08847.
- V.A. Khoze, A.D. Martin, M.G. Ryskin, **Elastic proton-proton scattering at 13 TeV**, Phys. Rev. D 97, 034019 (2018), **arXiv:1712.00325**;
- T. Csorgo, R. Pasechnik, A. Ster, **Odderon and substructures of protons from a model-independent Levy imaging of elastic proton-proton and proton-antiproton collisions, arXiv:1807.02897.**

Based on papers:

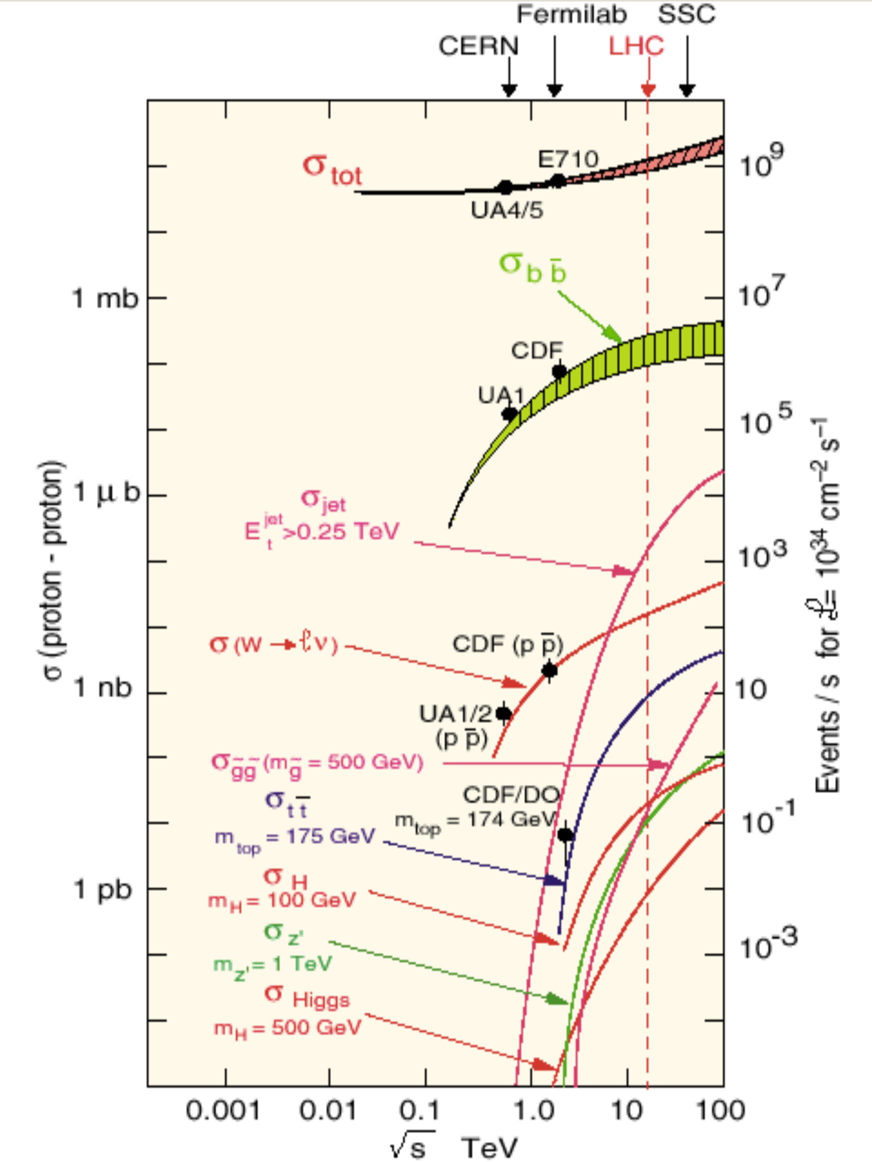
L. Jenkovszky, I. Szanyi, C.-I Tan, Eur. Phys. J. A (2018) **54**:116, arXiv:1710.10594.

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} $cm^{-2}s^{-1}$

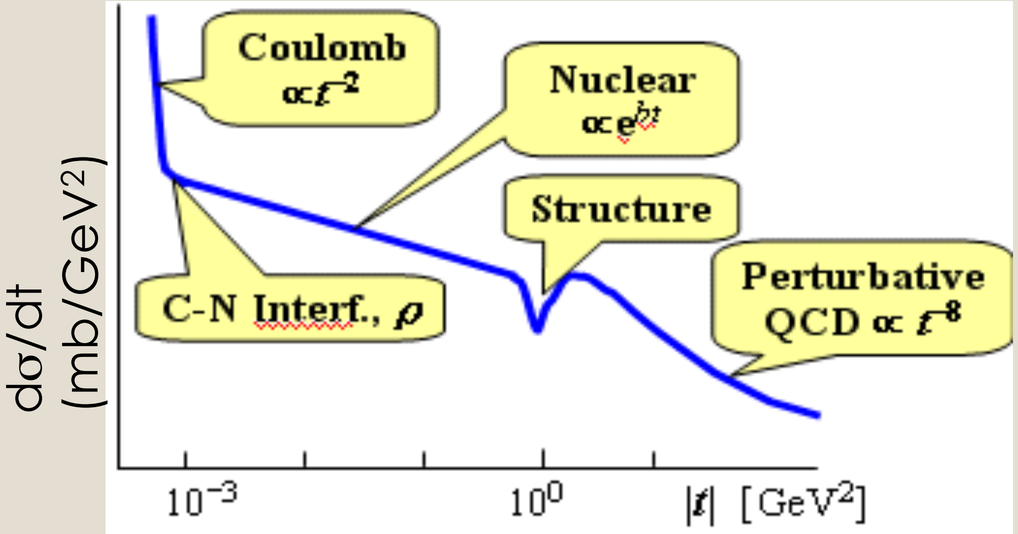


- ***PLAN:***

- The “break” B(t) and proton’s atmosphere;
- The forward slope B(s);
- The real part (or phase) at all t;
- Dip-bump (crucial!);
- Conclusions, problems.

Elastic Scattering

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



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

θ = beam scattering angle

p = beam momentum

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

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

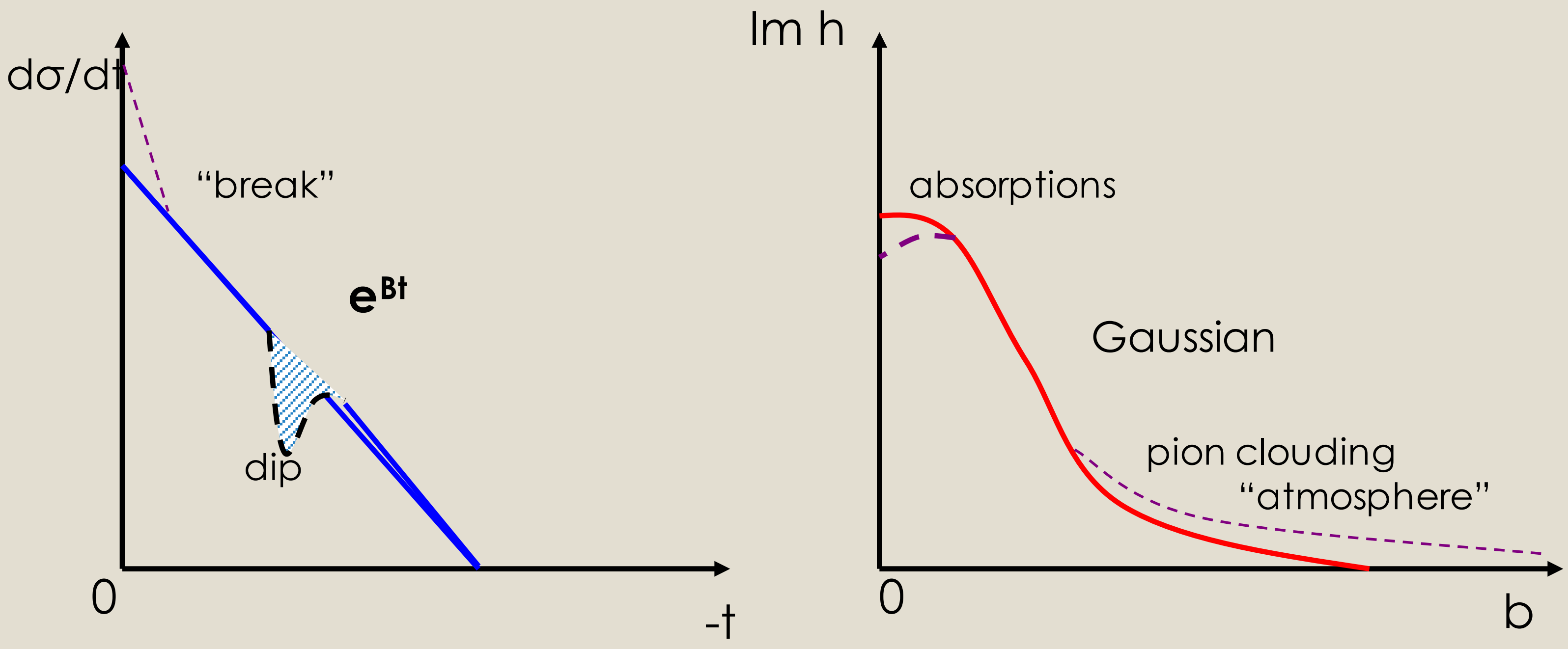
L, **σ_{tot}**, **b**, and **ρ** from FIT in CNI region (UA4)

CNI region: $|f_C| \sim |f_N|$ → @ LHC: $-t \sim 6.5\ 10^{-4}$ 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:**

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



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

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

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

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

α(0)\C	+	-
1	P	O
1/2	f	ω

Ahogy most a modellünket használjuk, a kapcsolat O=-i*P (nem O=i*P, mivel a pomeronban van egy "i" szorzó, addig az odderonban nincs; tehát ahhoz, hogy eltüntessük azt az "i" szorzót az odderon esetén a pomeront "-i"-vel kell megszorozni) és omega=i*f. Tehát ezek az i szorzók elméletileg egyfajta normalizációnak vehetőek?

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

A simple 'handle" (tool): DP (reproduces itself against unitarity corrections)

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

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

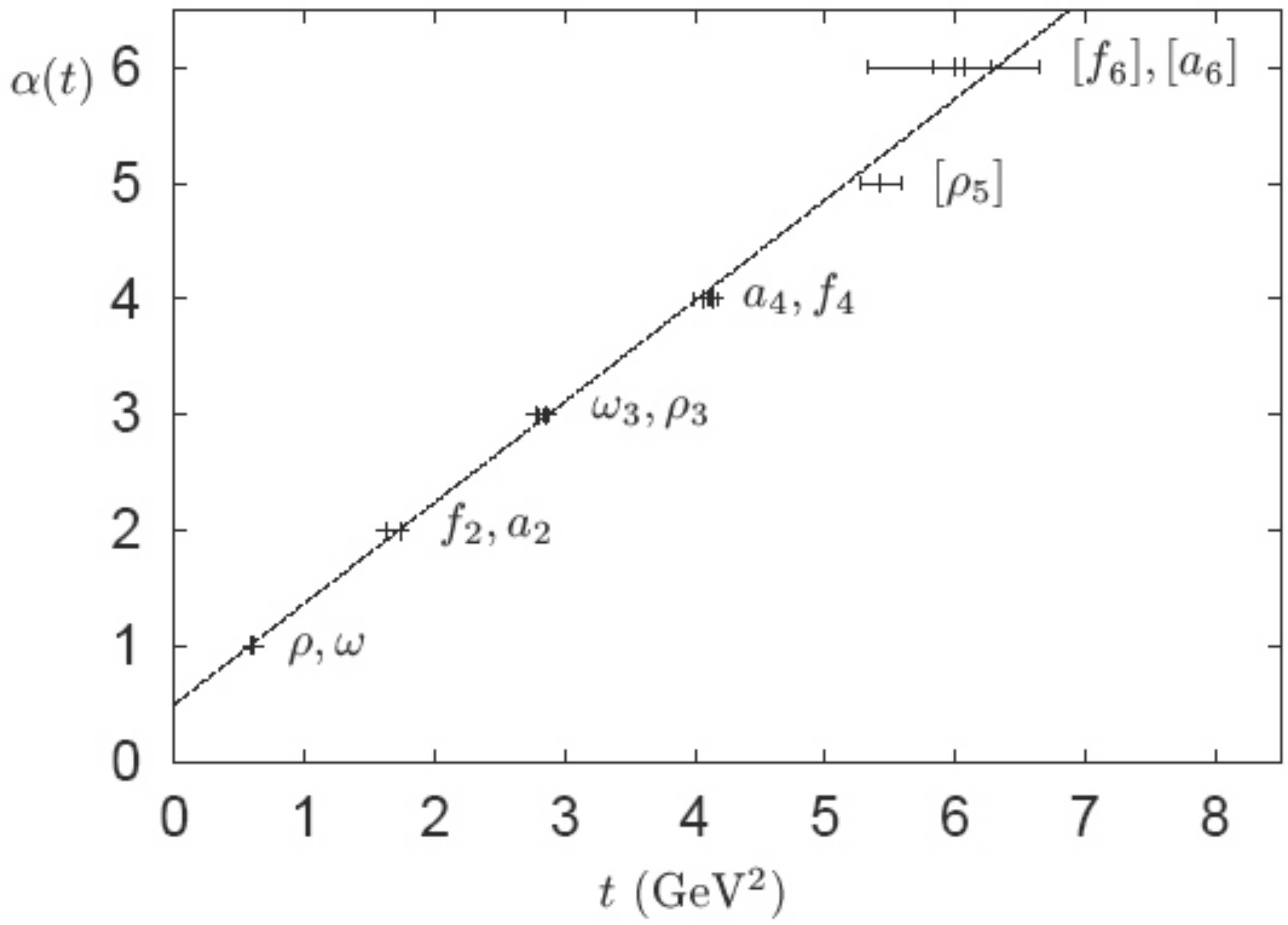
where $G(\alpha_P)$ is recovered by integration, and, as a consequence, the Pomeron amplitude can be rewritten in the following "geometrical" form

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

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

Linear particle trajectories

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



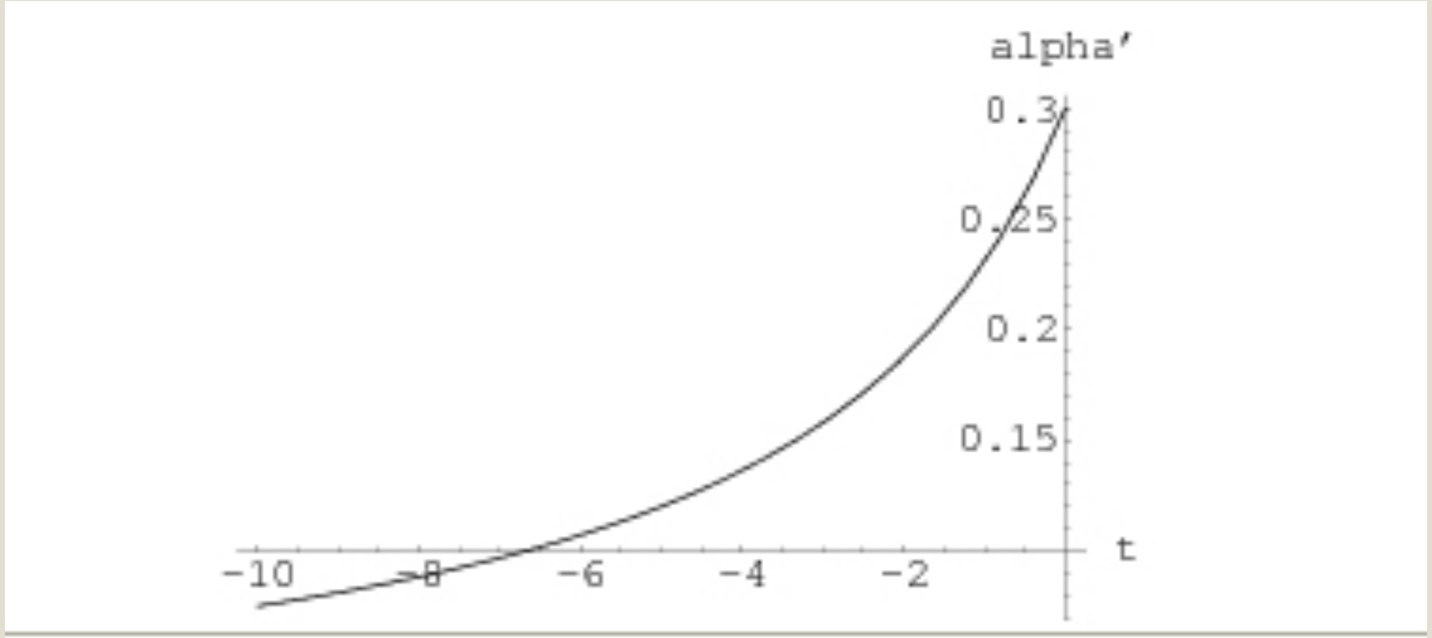
The Pomeron trajectory

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

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

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

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



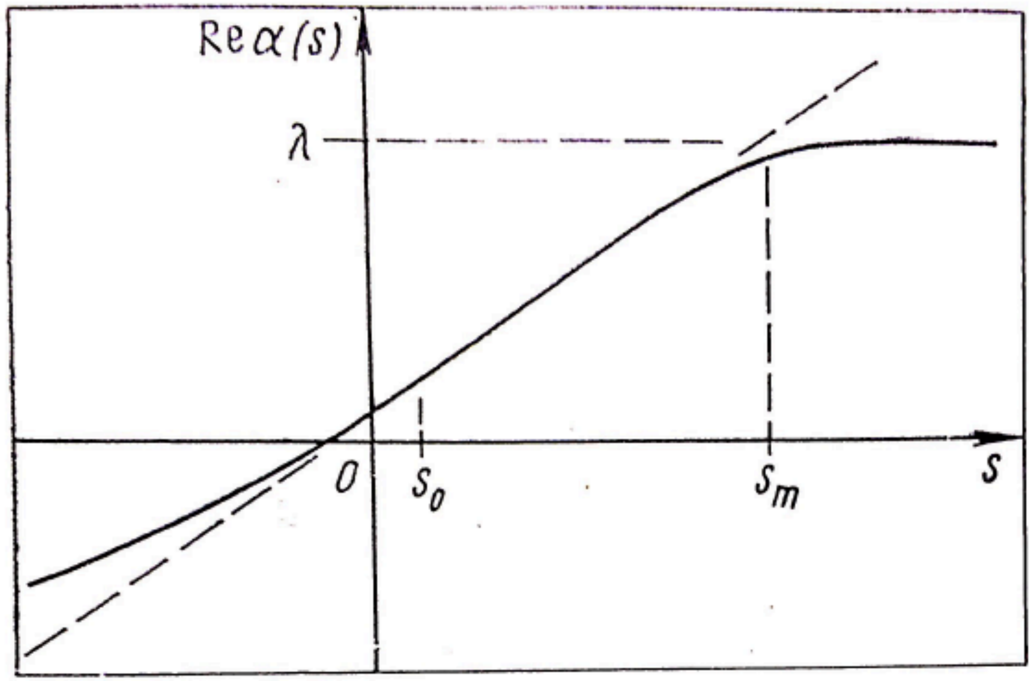
The slope of the cone for a single pole is: $B(s,t) \sim \alpha'(t) \ln s$. The Regge residue $e^{b\alpha(t)}$ with a logarithmic trajectory $\alpha(t) = \alpha(0) - \gamma \ln(1 - \beta t)$, is identical to a form factor (geometrical model).

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.

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

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

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



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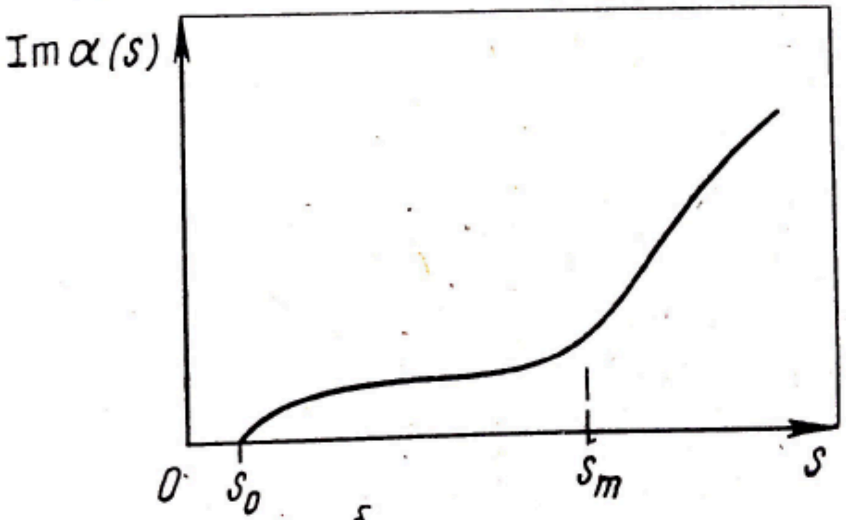

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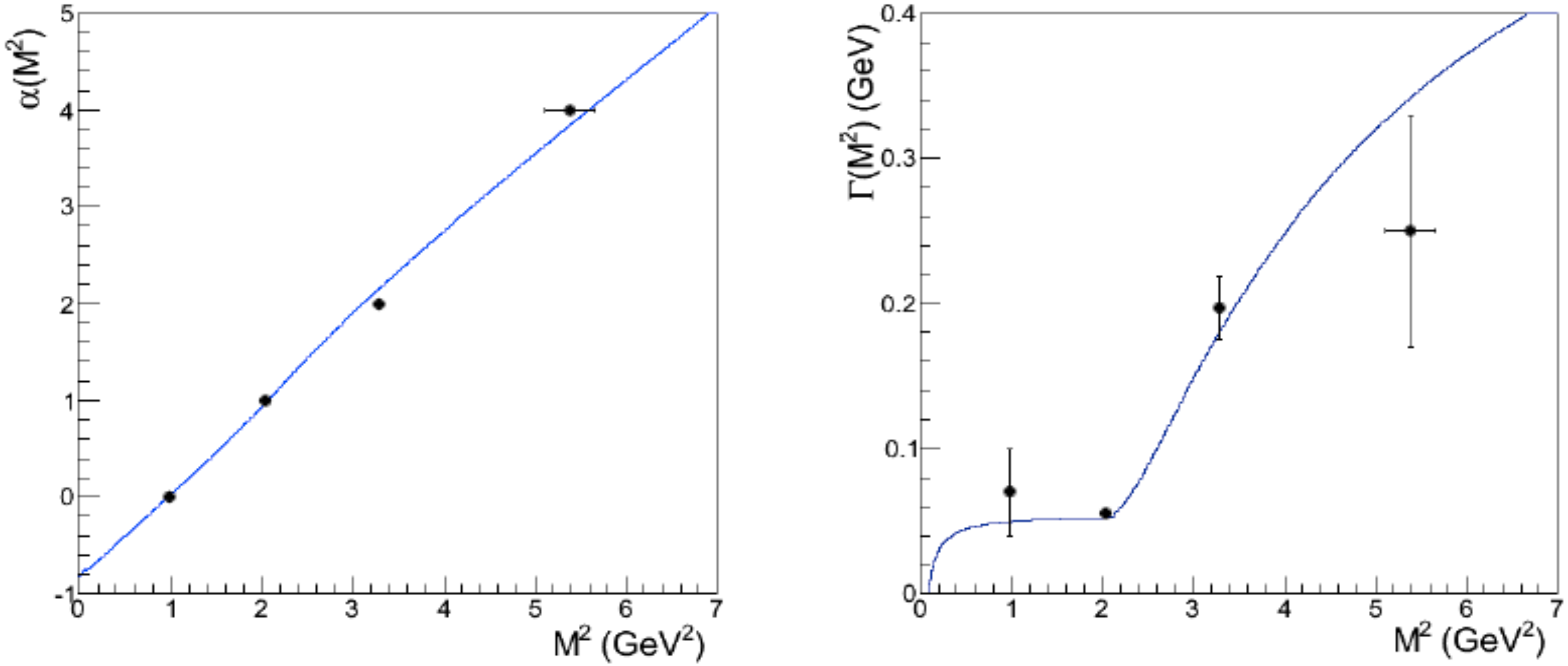


FIG. 6: Real part of f_1 trajectory on the left, width function $\Gamma(M^2)$ on the right.

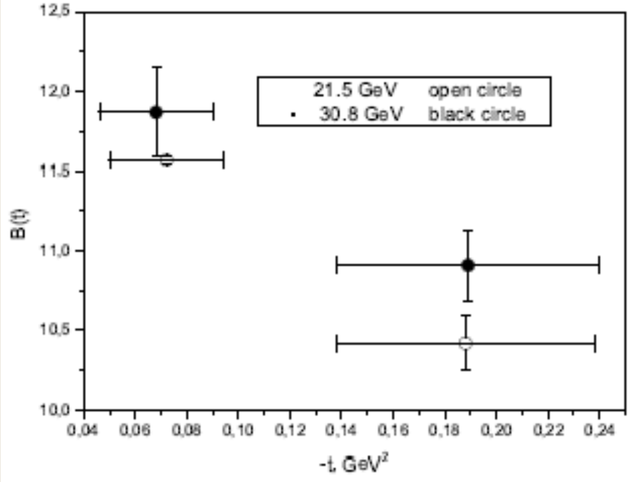
R. Fiore, L. Jenkovszky, V. Magas, F. Paccanoni, A. Papa, *Eur.Phys.J. A* **10** (2001) 217-221, hep-ph/0011035.

R. Fiore, L. Jenkovszky, R. Schicker, *Eur.Phys.J. C* **76** (2016) no.1, 38, arXiv:1512.04977.

G. Cohen-Tannoudji, V.V. Ilyin, Laszlo L. Jenkovszky, Nuov. Cim. **5**, 957 (1972).

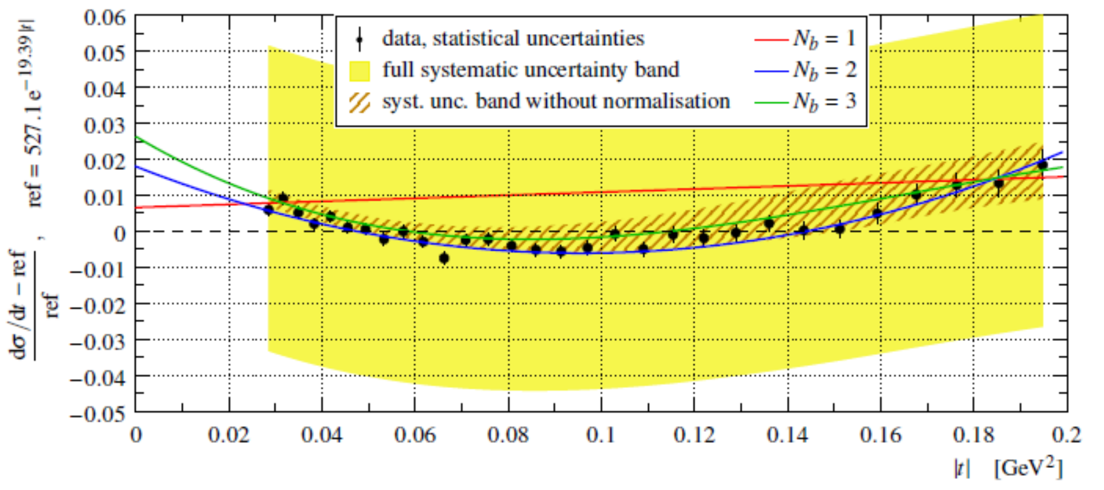
A.A. Anselm, V.N. Gribov, Phys. Letters **40B**, 487 (1972).

"Break"



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

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



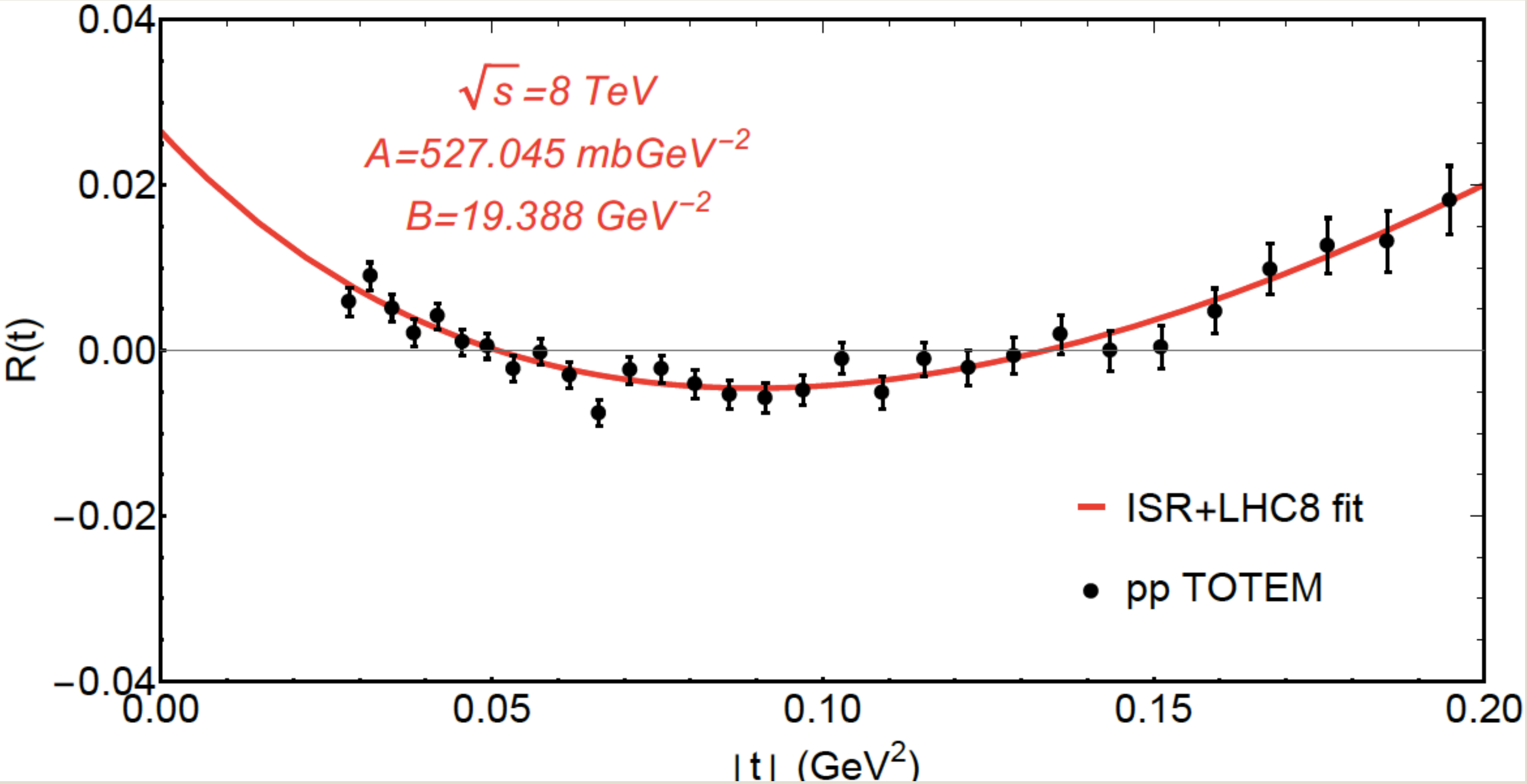
R(t) calculated for low-|t| 8 TeV data.

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

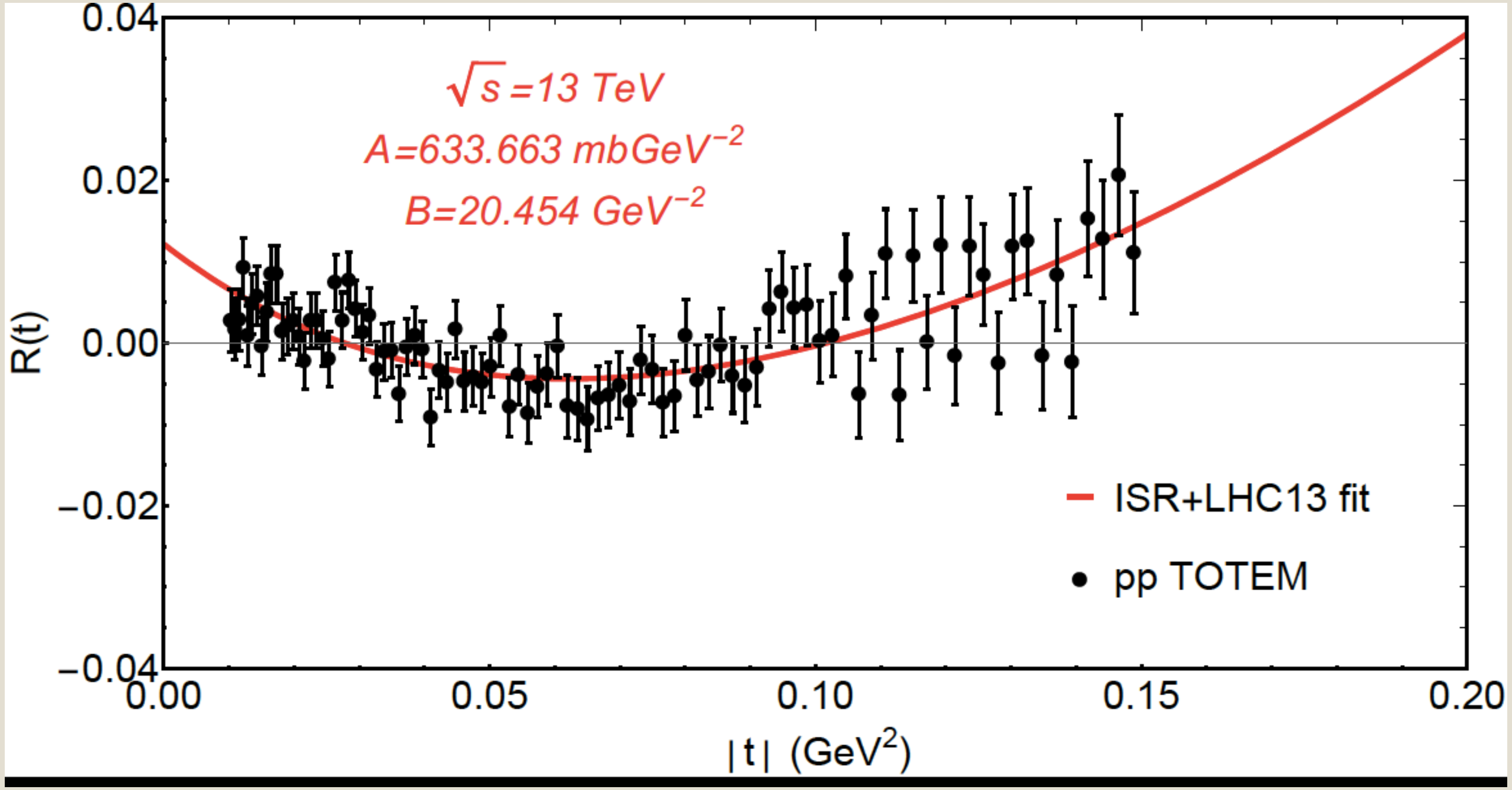
$$ref = Ae^{Bt}$$

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

arXiv:1503.08111

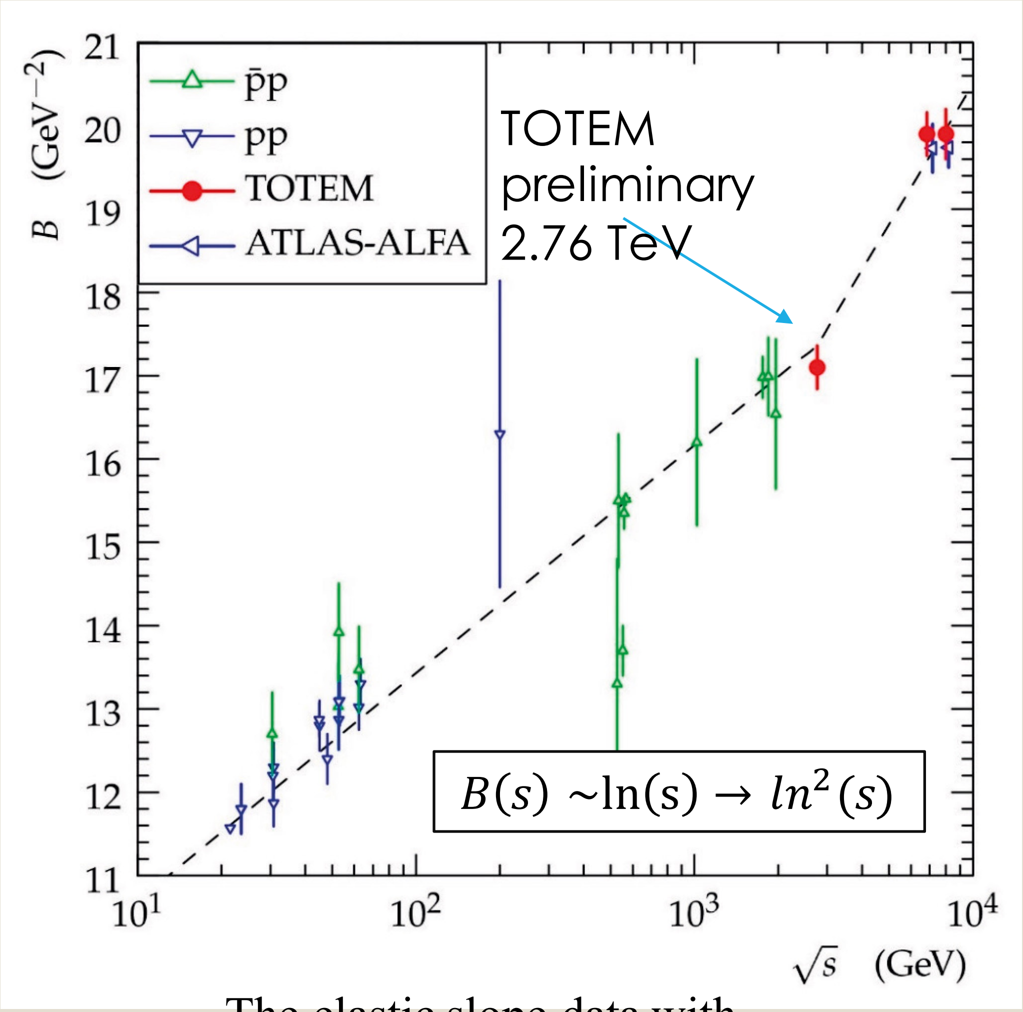


$\sqrt{s}$ =8 TeV
A=527.045 mbGeV^{-2}
B=19.388 GeV^{-2}
ISR+LHC8 fit
pp TOTEM
R(t)
|t| (GeV^2)
0.04
0.02
0.00
−0.02
−0.04
0.00
0.05
0.10
0.15
0.20

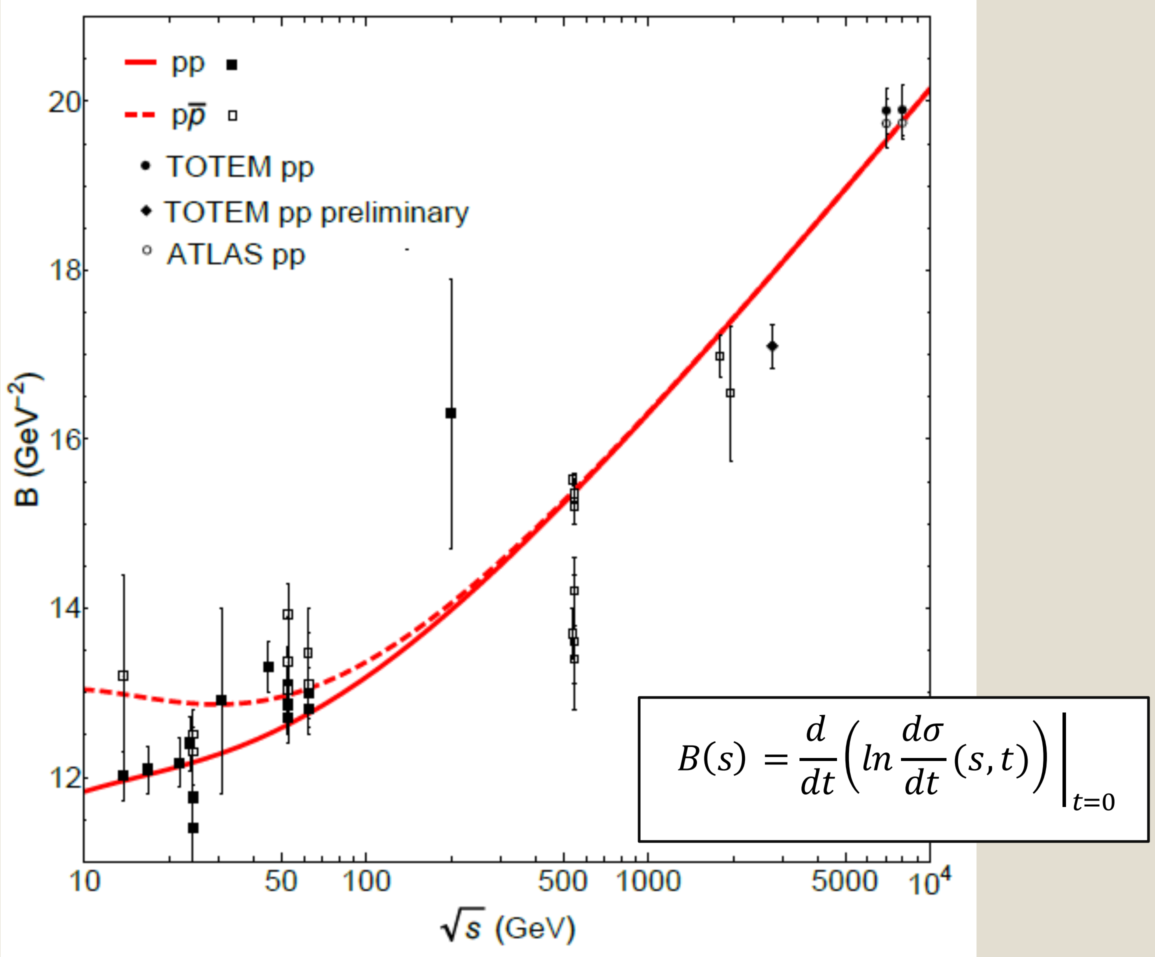


√s =13 TeV
A=633.663 mbGeV^−2
B=20.454 GeV^−2
ISR+LHC13 fit
pp TOTEM
R(t)
|t| (GeV^2)
0.04
0.02
0.00
−0.02
−0.04
0.00
0.05
0.10
0.15
0.20

New elastic slope measurements

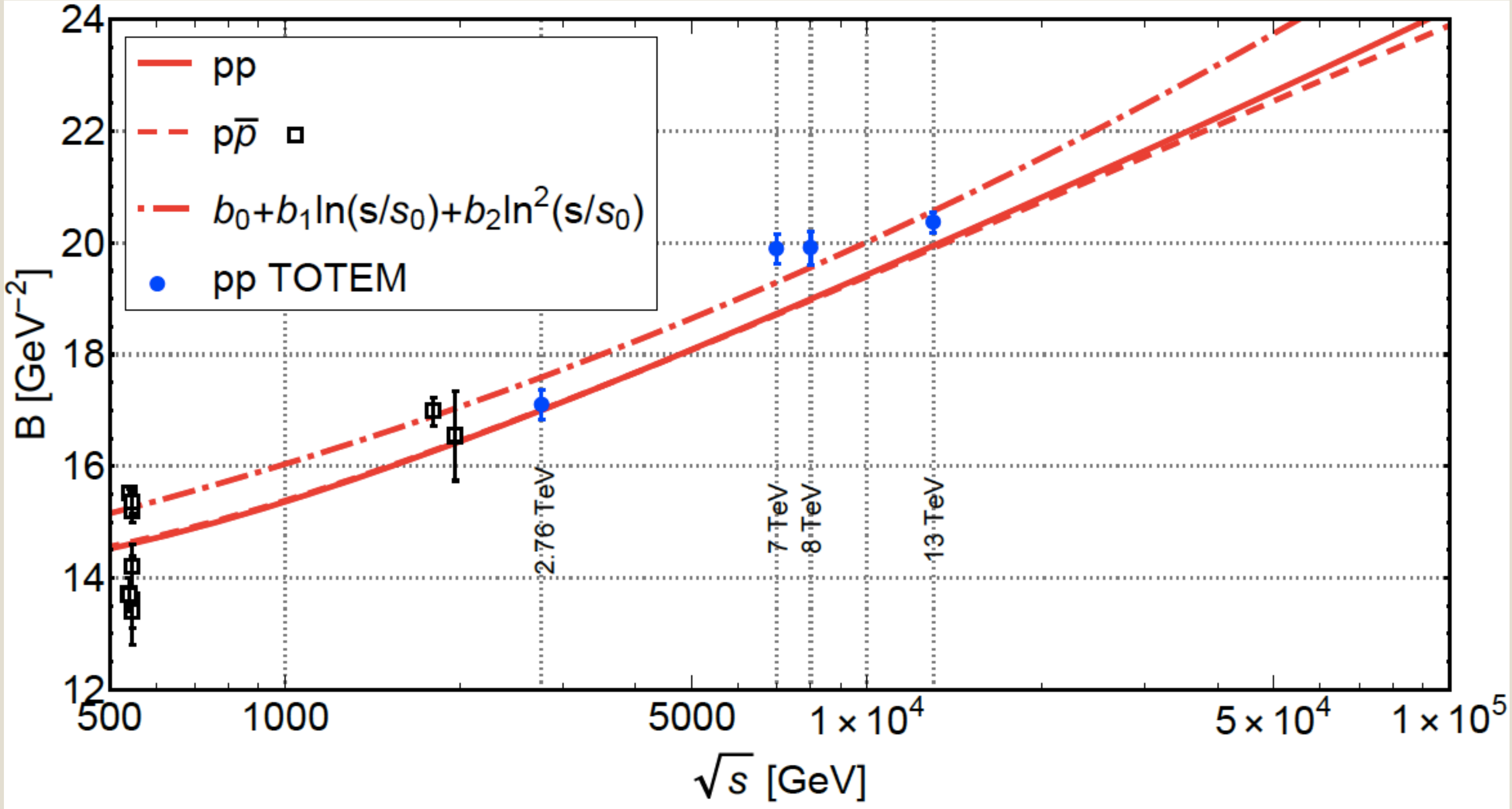


The elastic slope data with preliminary TOTEM results.

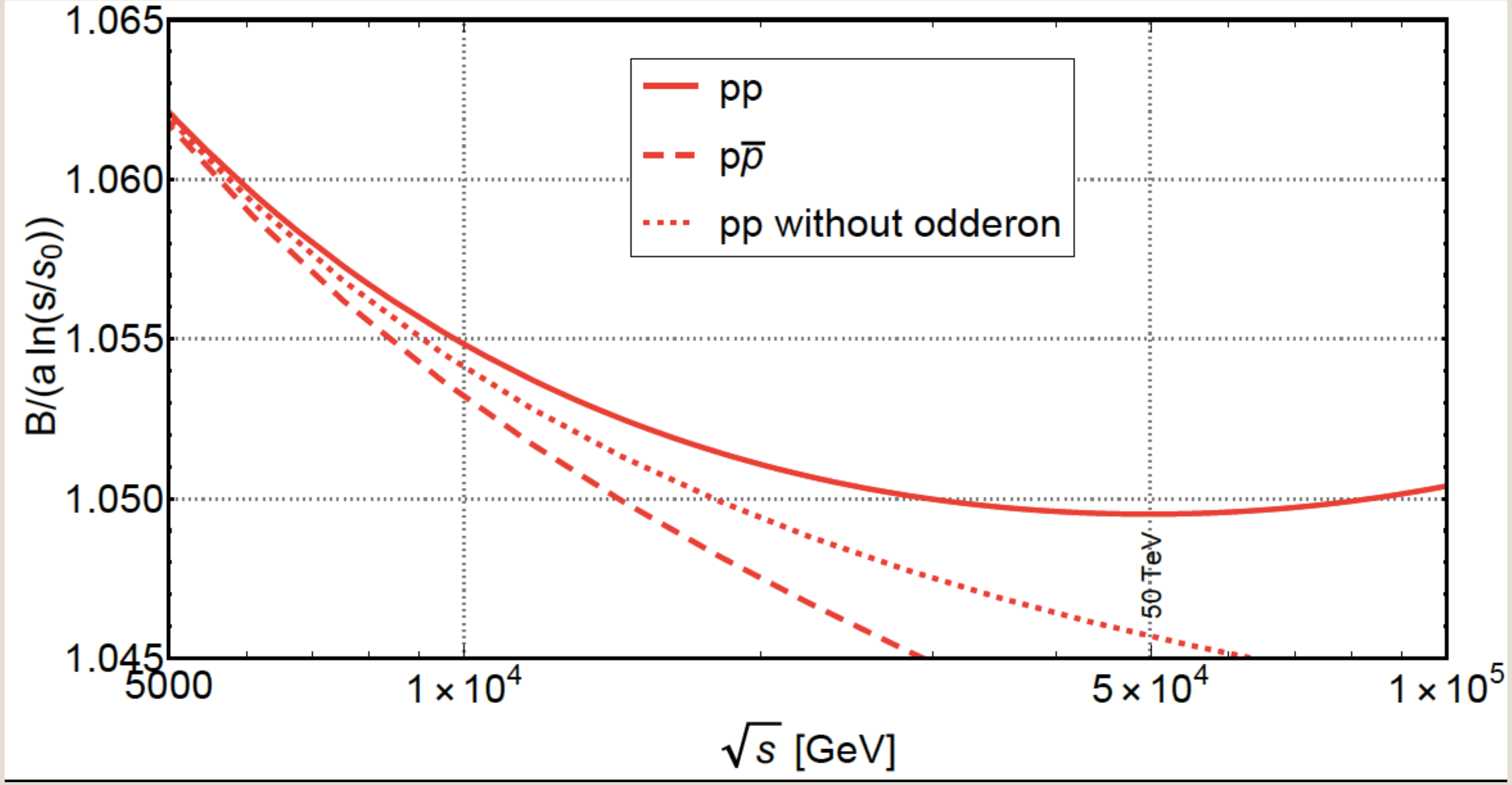


Fitted pp and $p\bar{p}$ elastic slope.

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

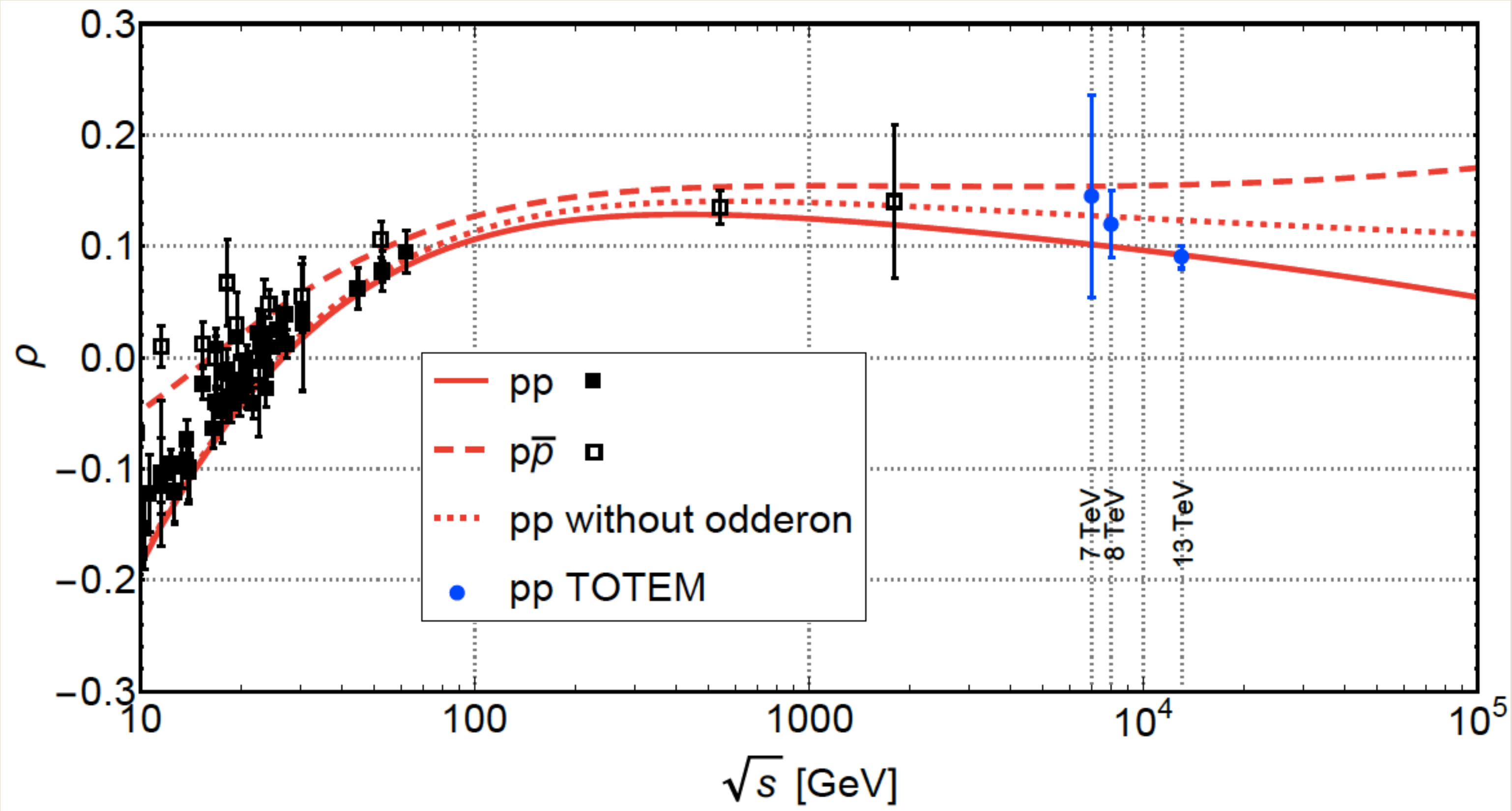


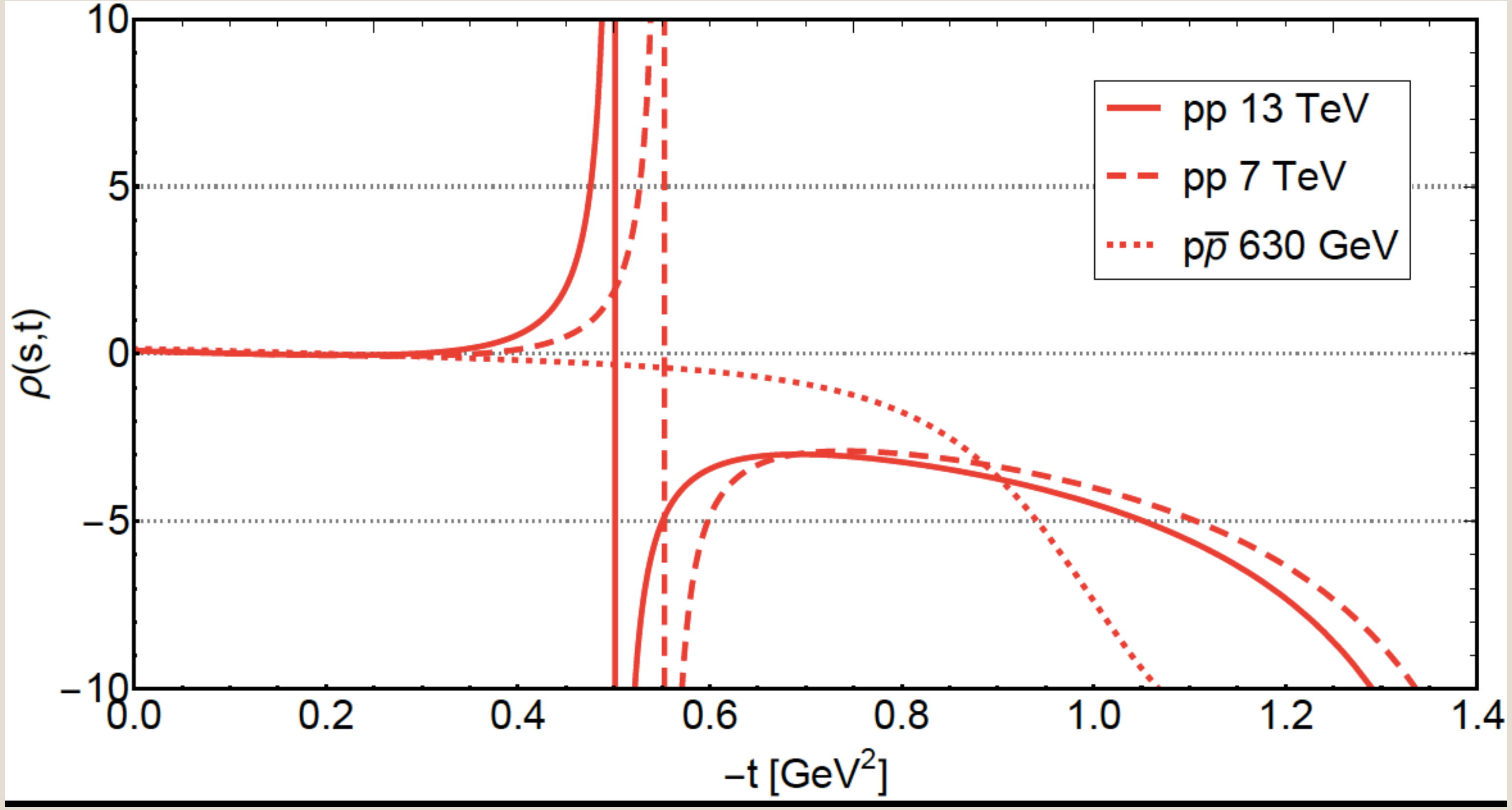
pp
p$\bar{p}$
$b_0+b_1\ln(s/s_0)+b_2\ln^2(s/s_0)$
pp TOTEM
2.76 TeV
7 TeV
8 TeV
13 TeV
B [GeV^{-2}]
$\sqrt{s}$ [GeV]
12
14
16
18
20
22
24
500
1000
5000
1×10^4
5×10^4
1×10^5



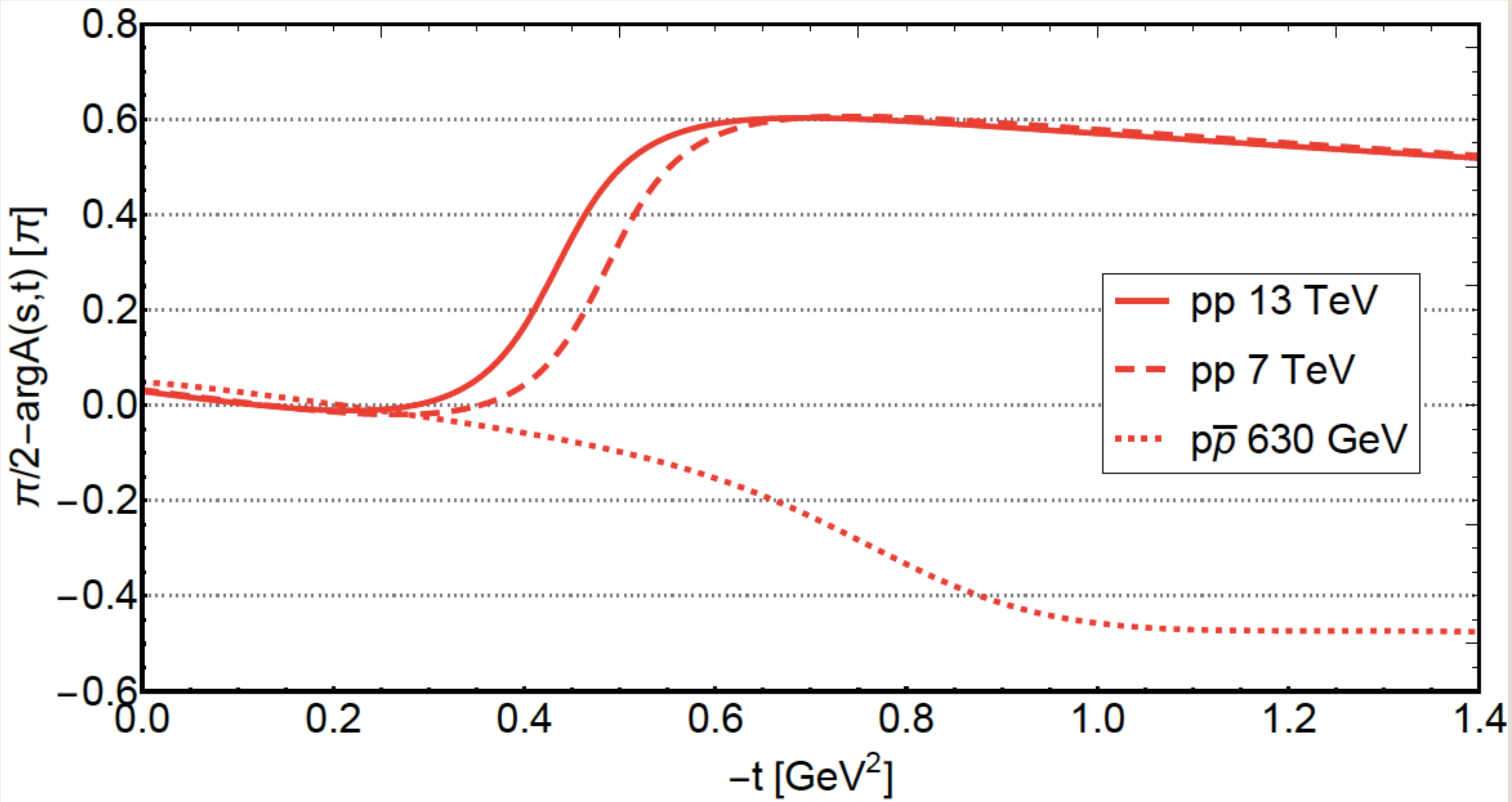
1.065
1.060
1.055
1.050
1.045
B/(a ln(s/s0))
5000
1 × 10^4
5 × 10^4
1 × 10^5
√s [GeV]
pp
pp̄
pp without odderon
50 TeV

TOTEM (2017) and “discovery” the odderon

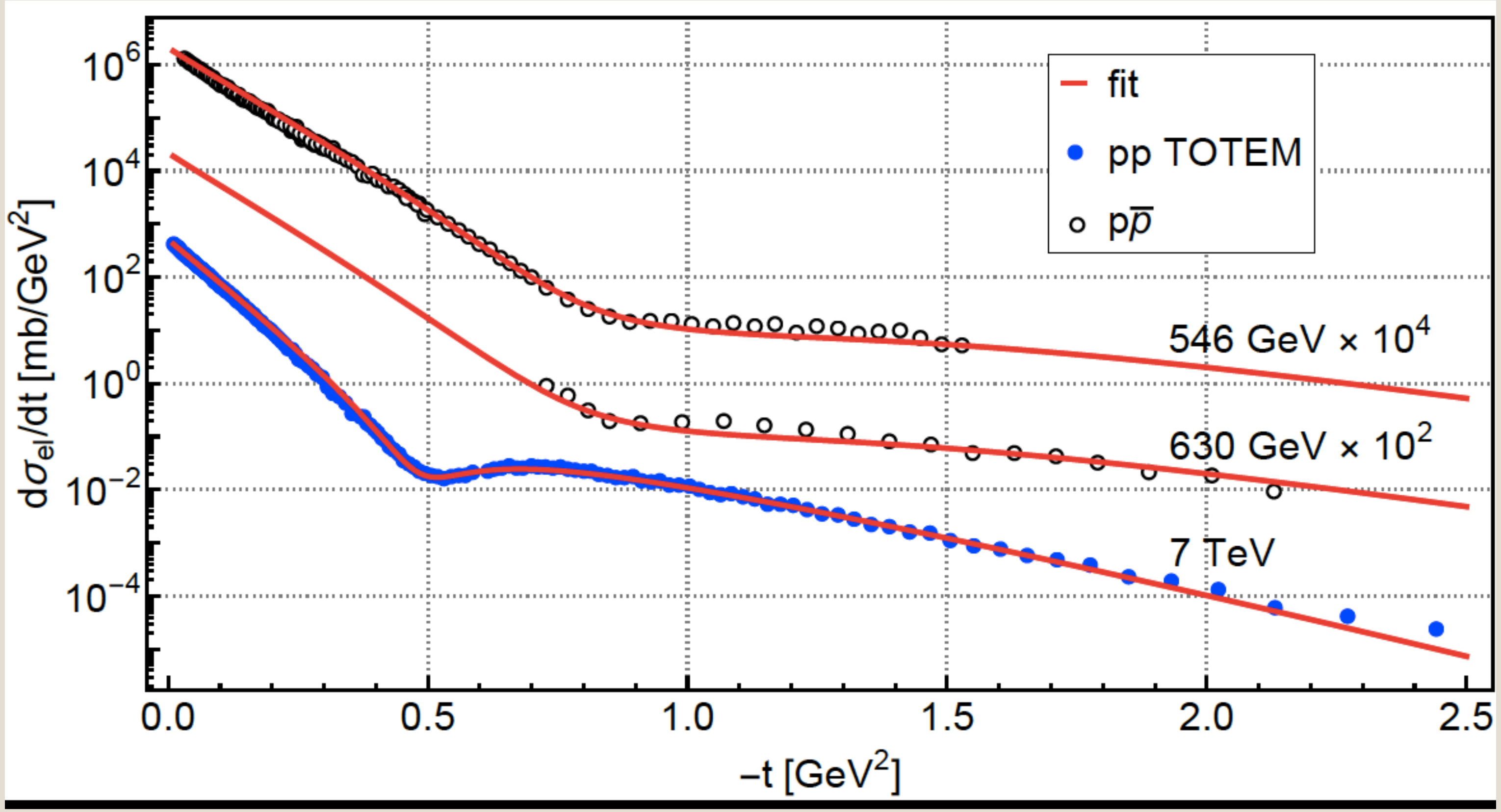




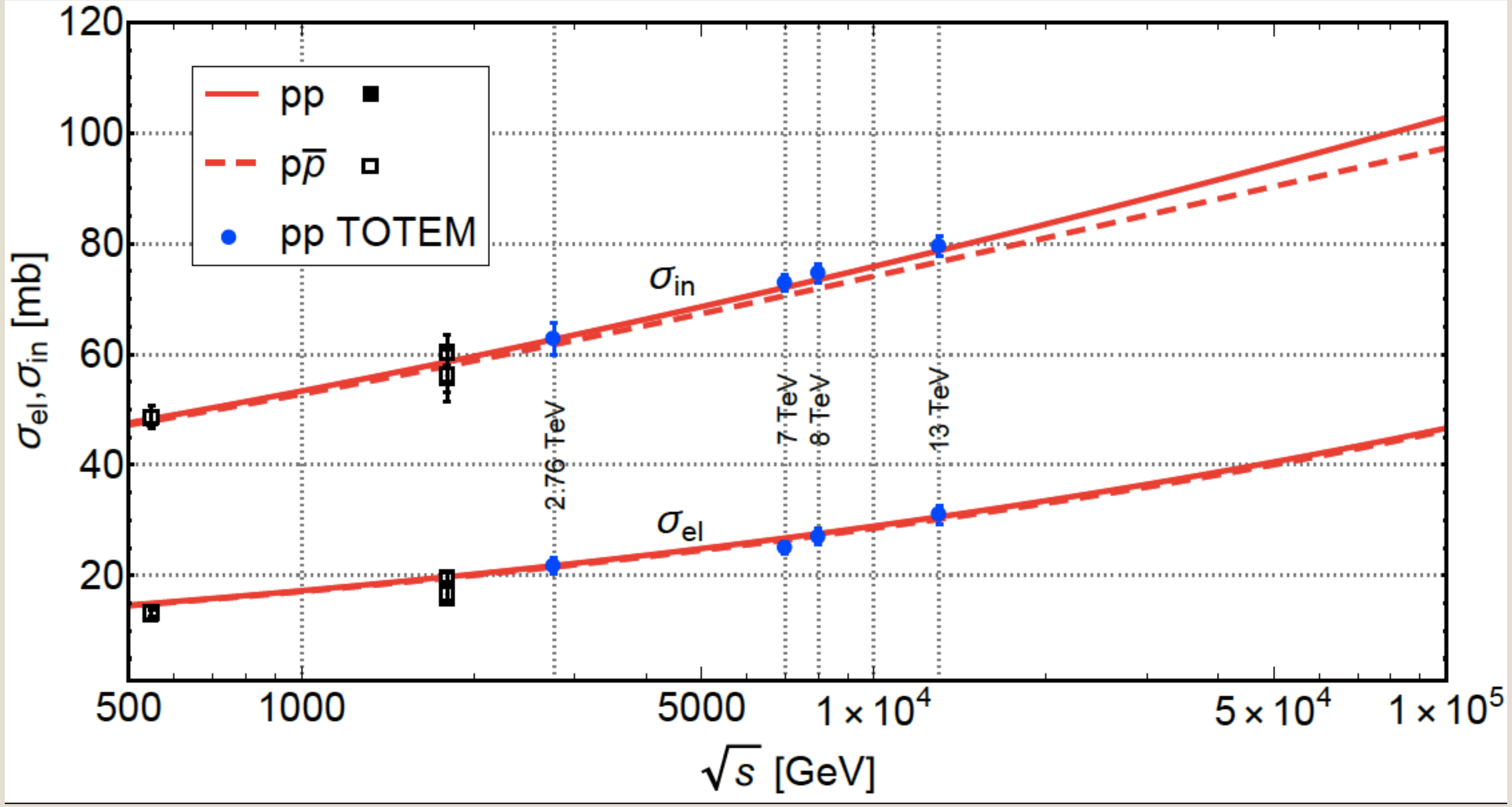
10
5
0
−5
−10
ρ(s,t)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
−t [GeV²]
pp 13 TeV
pp 7 TeV
pp̄ 630 GeV



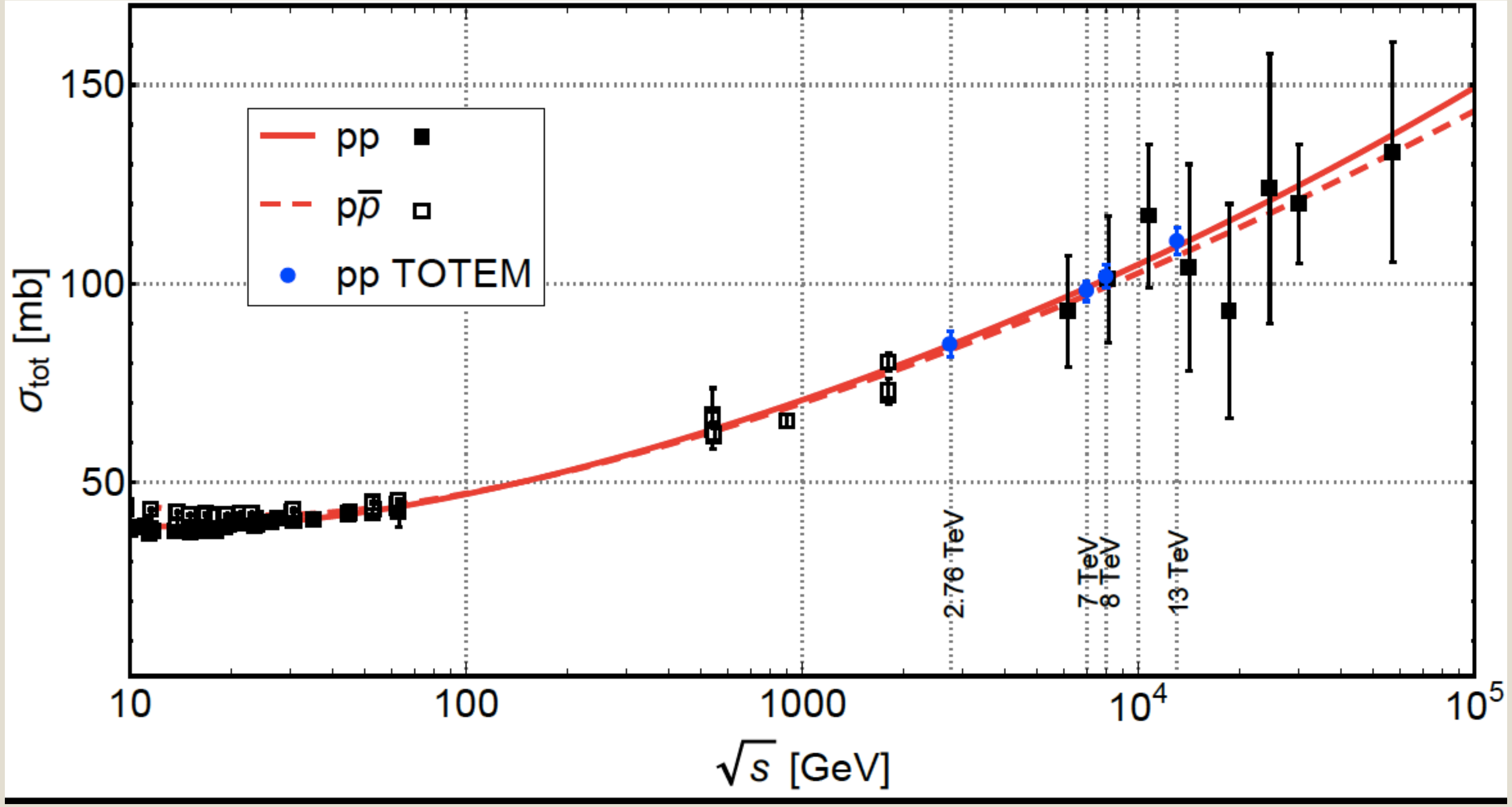
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
π/2−argA(s,t) [π]
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
−t [GeV^2]
pp 13 TeV
pp 7 TeV
p$\bar{p}$ 630 GeV



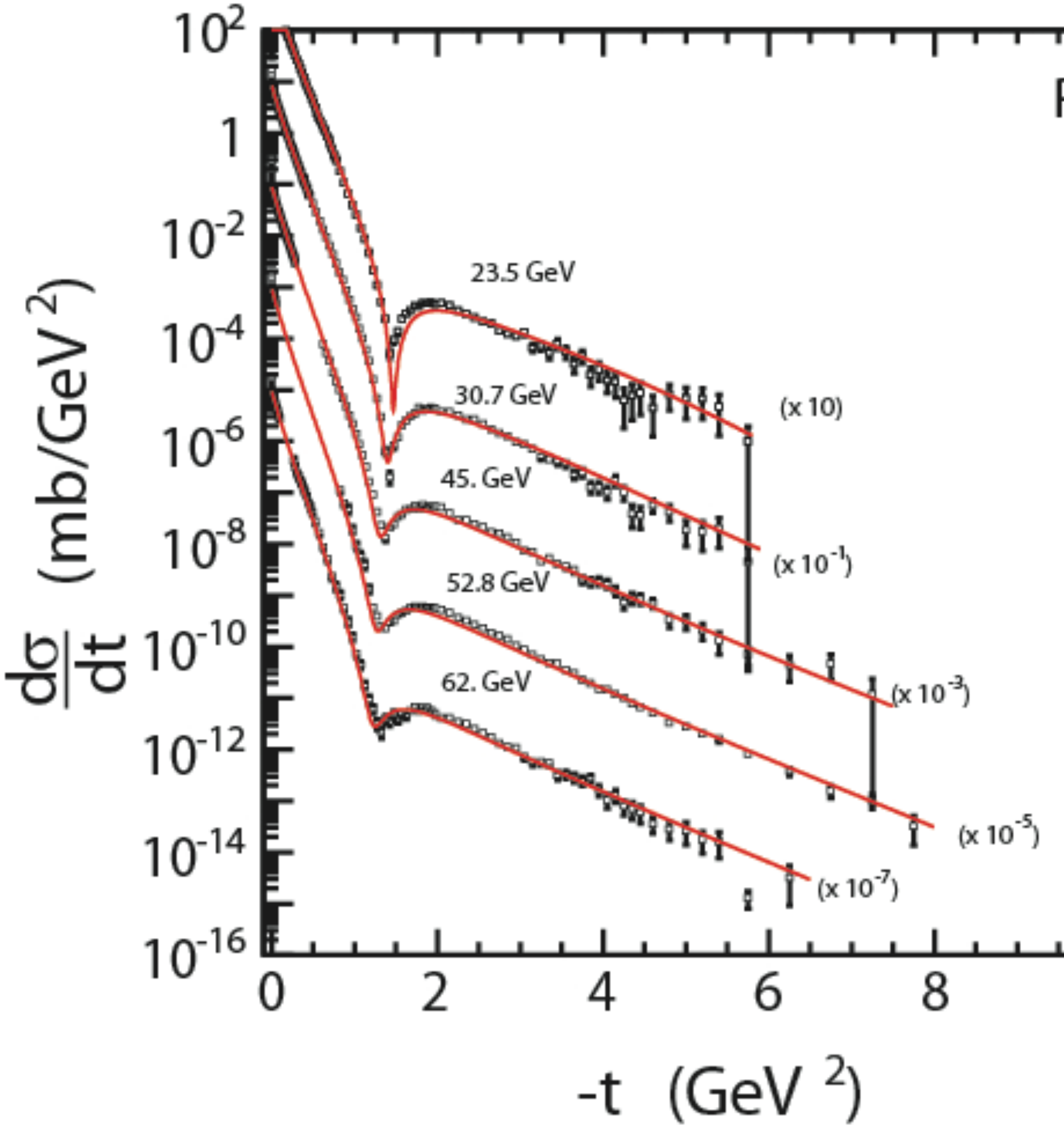
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
$d\sigma_{el}/dt$ [mb/GeV^2]
0.0
0.5
1.0
1.5
2.0
2.5
$-t$ [GeV^2]
fit
pp TOTEM
$p\bar{p}$
546 GeV × 10^4
630 GeV × 10^2
7 TeV



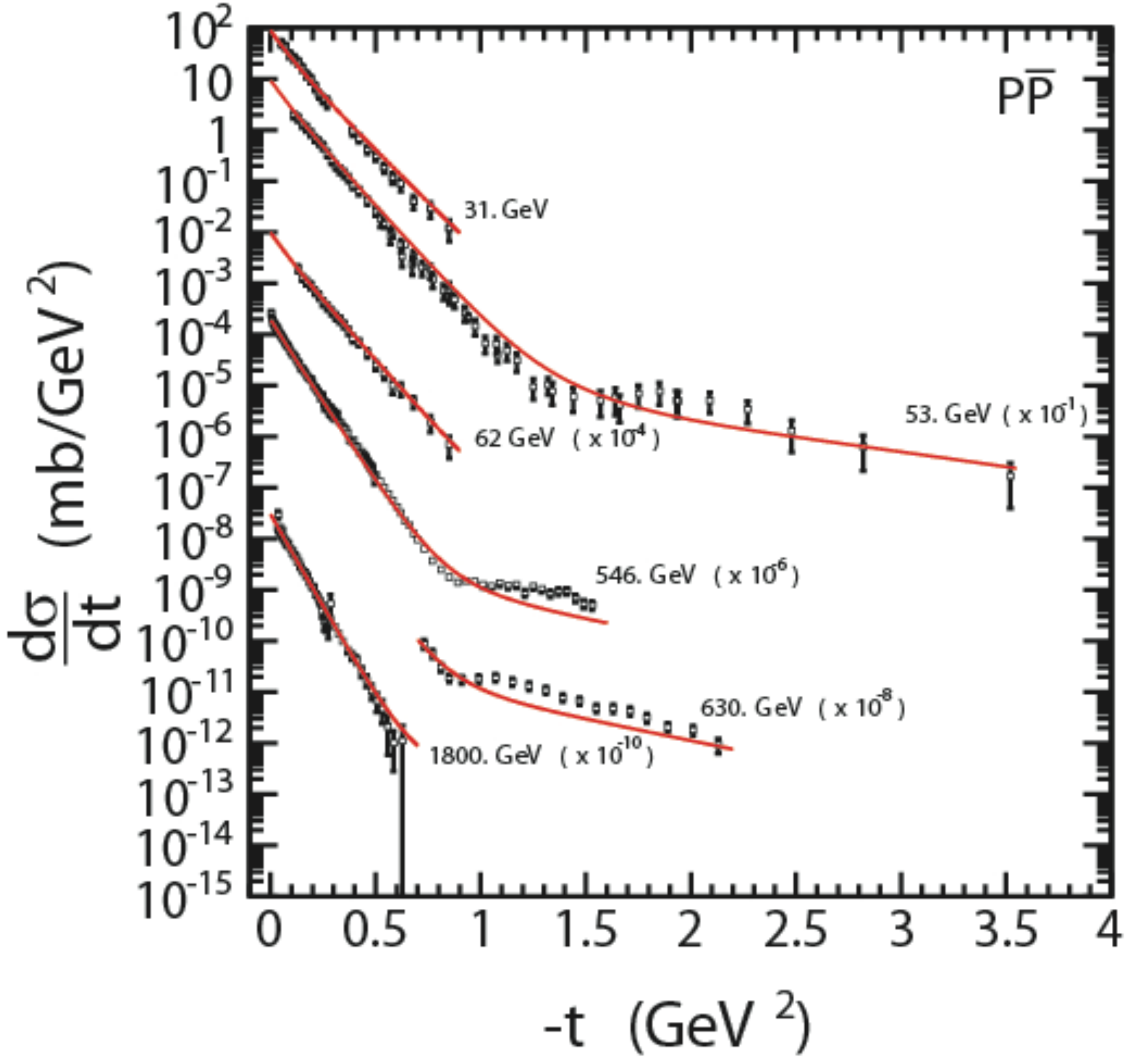
pp
p$\bar{p}$
pp TOTEM
σ_{in}
σ_{el}
2.76 TeV
7 TeV
8 TeV
13 TeV
σ_{el}, σ_{in} [mb]
$\sqrt{s}$ [GeV]
120
100
80
60
40
20
500
1000
5000
1×10^4
5×10^4
1×10^5



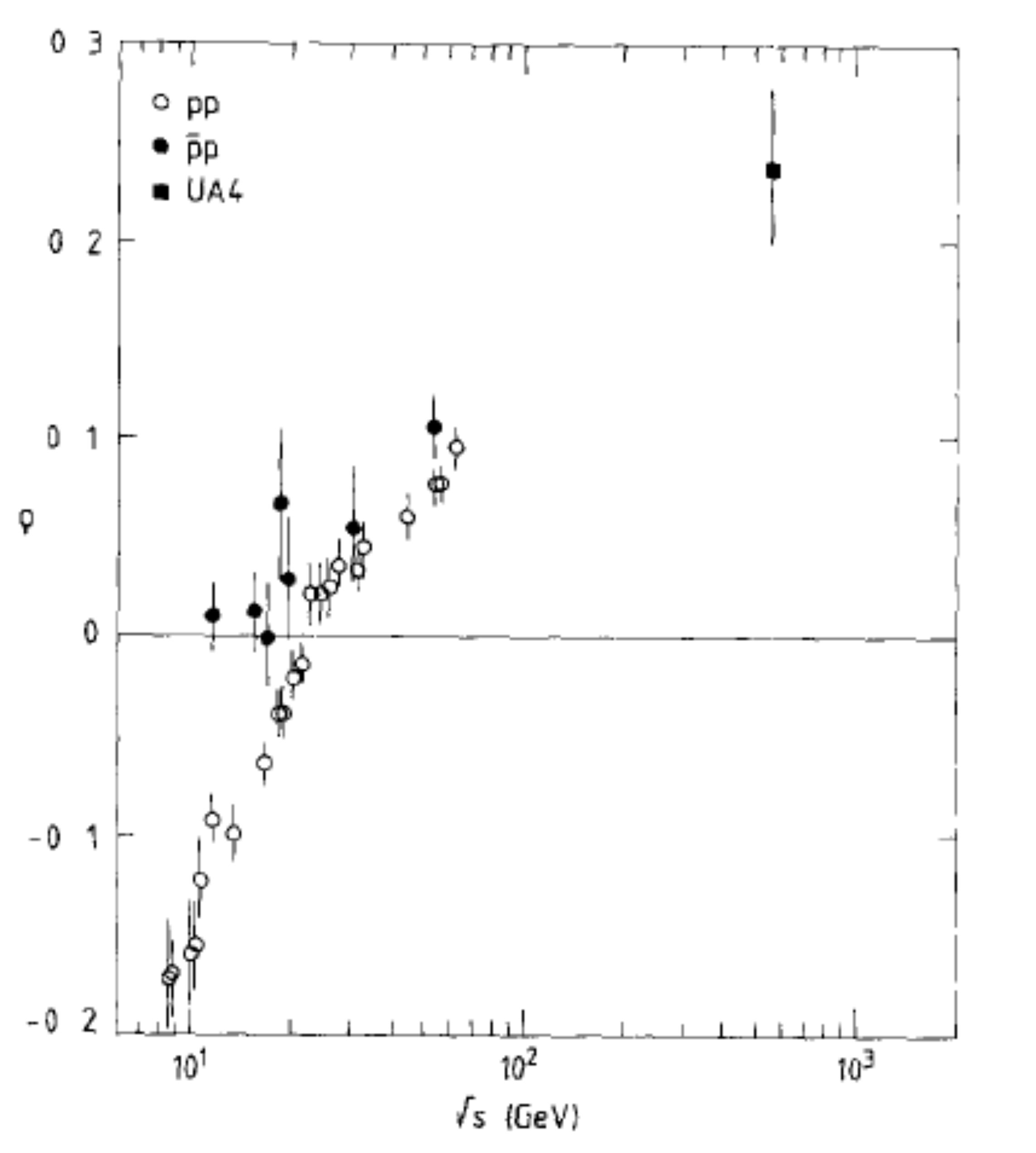
150
100
50
10
100
1000
10^4
10^5
σ_{tot} [mb]
$\sqrt{s}$ [GeV]
pp
$p\bar{p}$
pp TOTEM
2.76 TeV
7 TeV
8 TeV
13 TeV



PP
23.5 GeV
30.7 GeV
45. GeV
52.8 GeV
62. GeV
(x 10)
(x 10^-1)
(x 10^-3)
(x 10^-5)
(x 10^-7)
dσ/dt (mb/GeV^2)
-t (GeV^2)



PP̄
31. GeV
53. GeV (x 10⁻¹)
62 GeV (x 10⁻⁴)
546. GeV (x 10⁻⁶)
630. GeV (x 10⁻⁸)
1800. GeV (x 10⁻¹⁰)
dσ/dt (mb/GeV²)
-t (GeV²)


0 3
0 2
0 1
0
-0 1
-0 2
ρ
pp
p̄p
UA4
10^1
10^2
10^3
√s (GeV)

Phys. Lett B, 1987

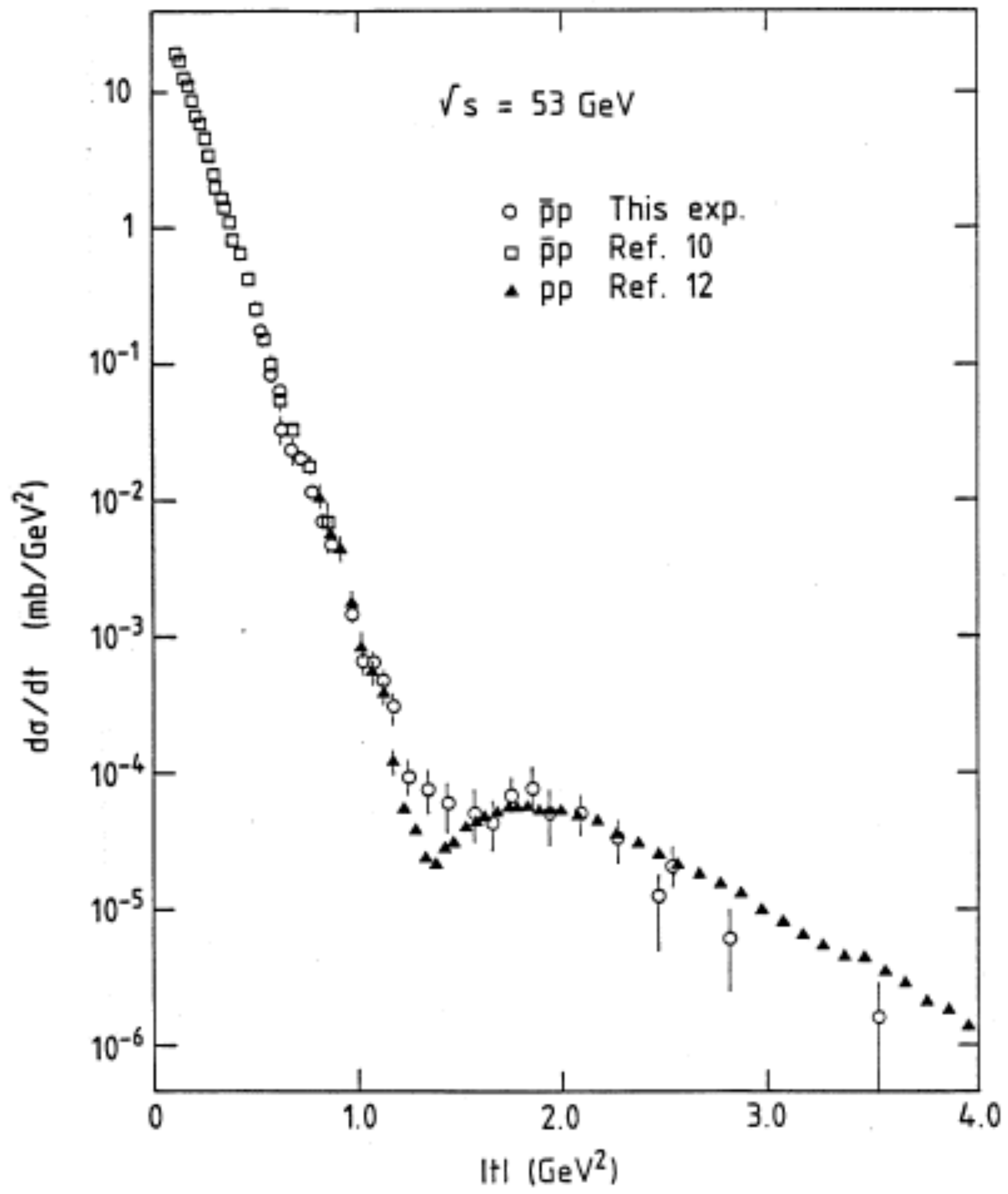
REAL PART OF THE PROTON–ANTIPROTON ELASTIC SCATTERING AMPLITUDE
HE CENTRE OF MASS ENERGY OF 546 GeV

Collaboration

rdam–CERN–Genova–Napoli–Palaiseau–Pisa

RNARD [a 1], M BOZZO [b], P L BRACCINI [c], F CARBONARA [d], R. CASTALDI [c],
RVELLI [c], G CHIEFARI [d], E DRAGO [d], M HAGUENAUER [e], V INNOCENTE [e 2],
UIT [f], S LANZANO [d], G MATTHIAE [d 3], L MEROLA [d], M. NAPOLITANO [d],
LLADINO [d], G. SANGUINETTI [c], P. SCAMPOLI [c], S SCAPELLATO [c 4], G SCIACCA [d],
TTE [b], J. TIMMERMANS [f], C VANNINI [c], J VELASCO [a 5], P G VERDINI [c] and F VISCO [d]

(2009).



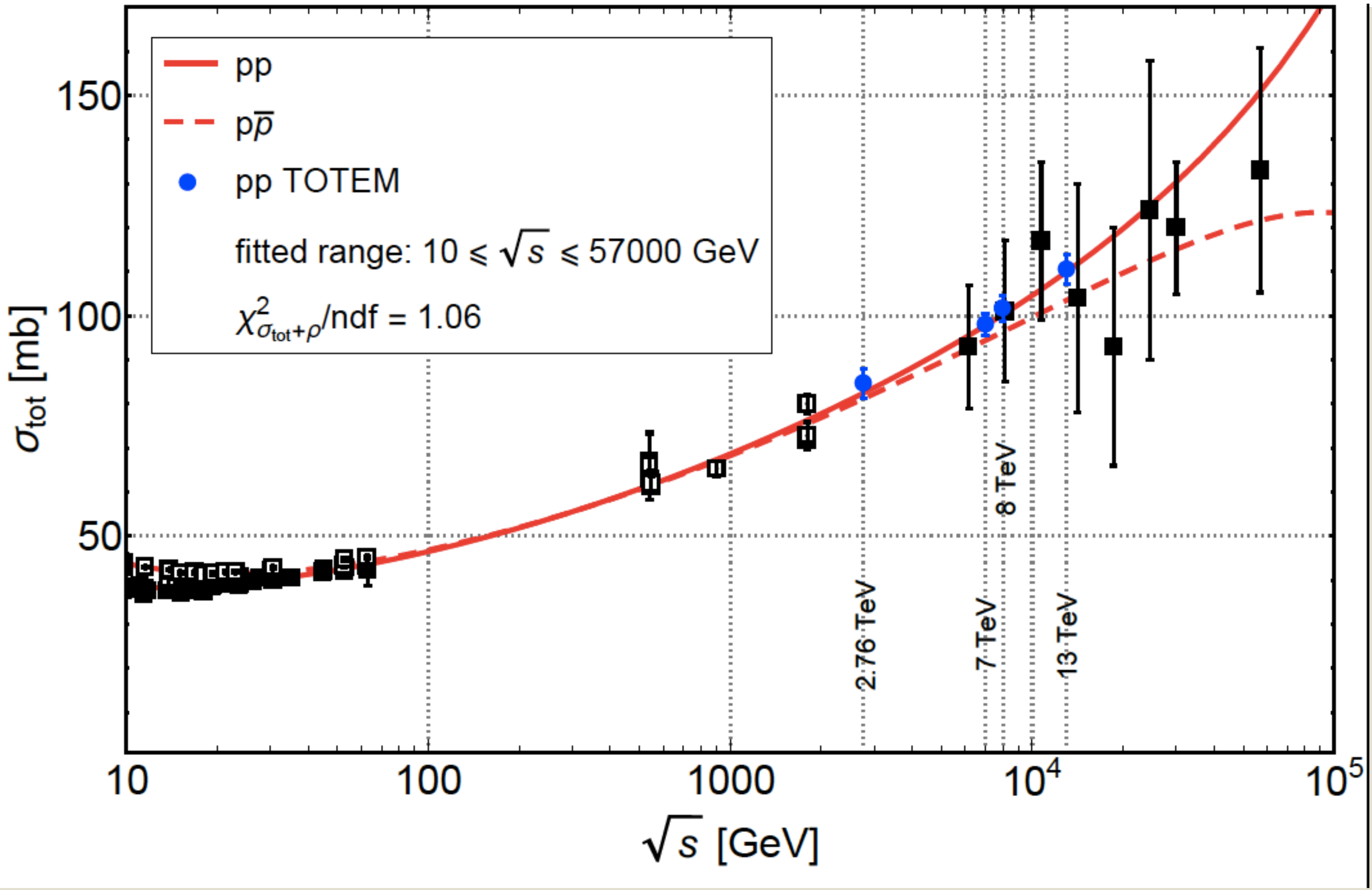
√s = 53 GeV
○ p̄p This exp.
□ p̄p Ref. 10
▲ pp Ref. 12
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
dσ/dt (mb/GeV²)
0
1.0
2.0
3.0
4.0
|t| (GeV²)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

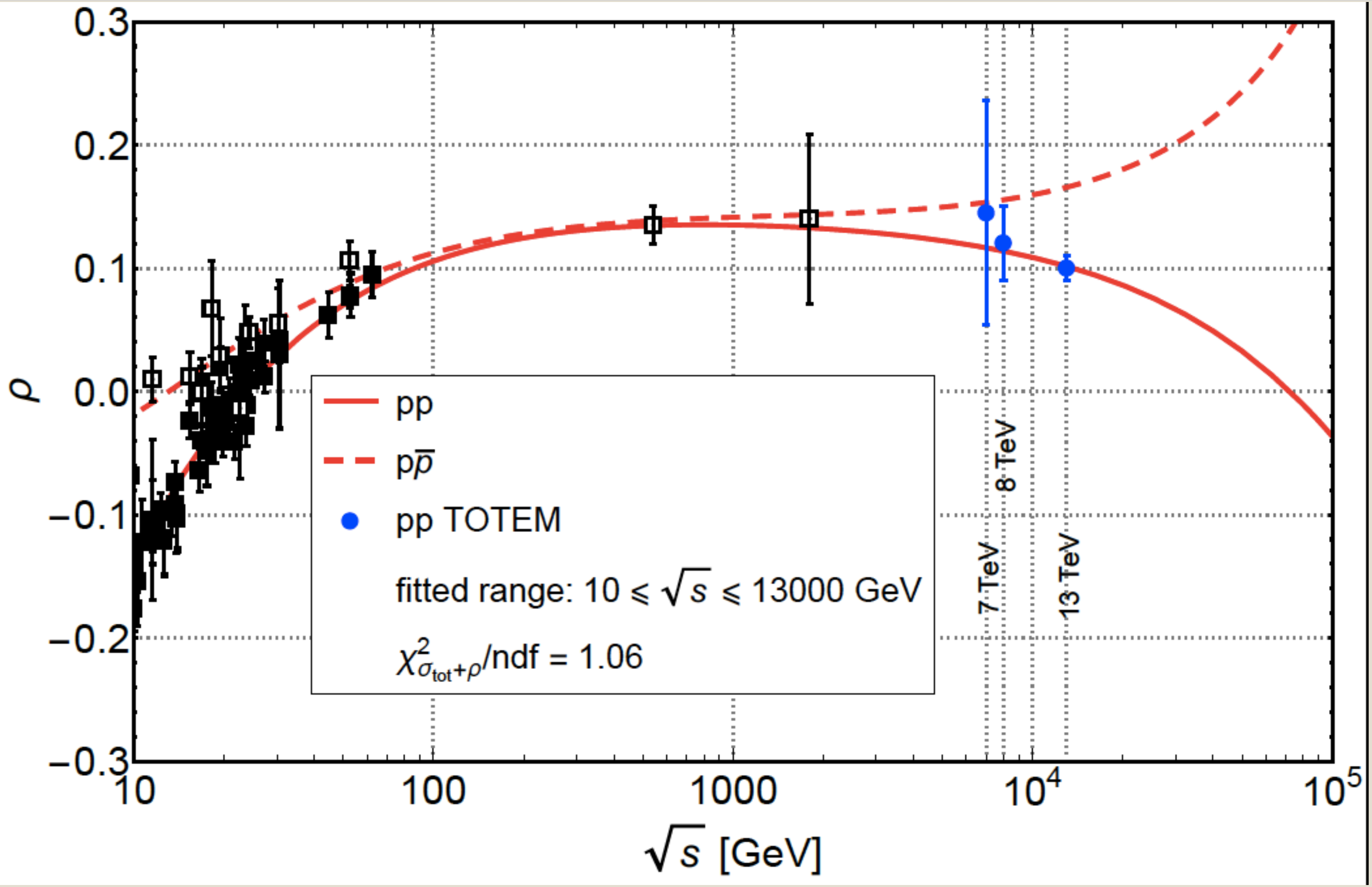
CERN/EP 85-9
24 January 1985

A MEASUREMENT OF $\bar{p}p$ AND pp ELASTIC SCATTERING IN THE DIP REGION AT $\sqrt{s}$ = 53 GeV

A. Breakstone[1(*)], H.B. Crawley[1], G.M. Dallavalle[5], K. Doroba[6], D. Drijard[3], F. Fabbri[3], A. Firestone[1], H.G. Fischer[3], H. Frehse[3(**)], W. Geist[3(***)], G. Giacomelli[2], R. Gokieli[6], M. Gorbics[1], P. Hanke[5], M. Heiden[3(***)], W. Herr[5], E.E. Kluge[5], J.W. Lamsa[1], T. Lohse[4], W.T. Meyer[1], G. Mornacchi[3], T. Nakada[5(+)], M. Panter[3], A. Putzer[5], K. Rauschnabel[4], F. Rimondi[2], G.P. Siroli[2], R. Sosnowski[6], M. Szczekowski[3], O. Ullaland[3] and D. Wegener[4]



pp
p$\bar{p}$
pp TOTEM
fitted range: $10 \leqslant \sqrt{s} \leqslant 57000$ GeV
$\chi^2_{\sigma_{tot}+\rho}$/ndf = 1.06
2.76 TeV
7 TeV
8 TeV
13 TeV
150
100
50
σ_{tot} [mb]
10
100
1000
10^4
10^5
$\sqrt{s}$ [GeV]



0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
ρ
10
100
1000
10^4
10^5
$\sqrt{s}$ [GeV]
pp
$p\bar{p}$
pp TOTEM
fitted range: $10 \leqslant \sqrt{s} \leqslant 13000$ GeV
$\chi^2_{\sigma_{tot}+\rho}$/ndf = 1.06
7 TeV
8 TeV
13 TeV

Conclusions & open problems:

A single data point, rho(13)=0.1 does not prove the "discovery" of the odderon;
Fits to rho+sig_t are not critical (informative); data on diff. cross sections should be added;
The odderon (or 3-g exchange) **does** exist since nothing prevents its existence;

Measuring of pp and \bar pp at the same energy;
The odderon & dynamics of the dip-bump;
Universality of the "break"; the break in \bar pp?
Rise (log s?) of the slope B(s);
Correlation between rho, sig_t and the dip;
BNL measurements are eagerly awaited!
Slow-down of total cross sections (saturation)?
"Oddballs"?