The Stationary Points and Structure High-Energy Scattering Amplitude

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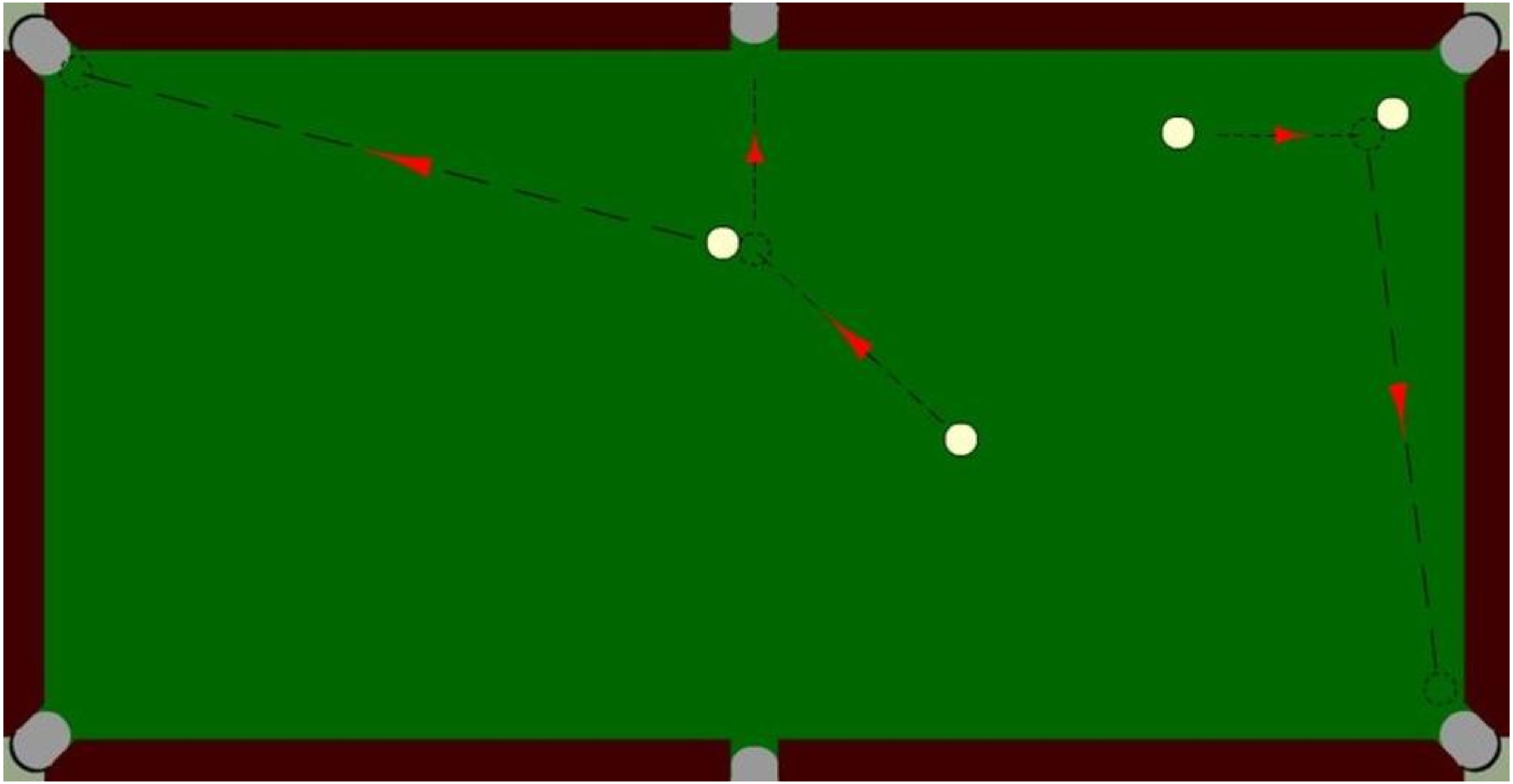
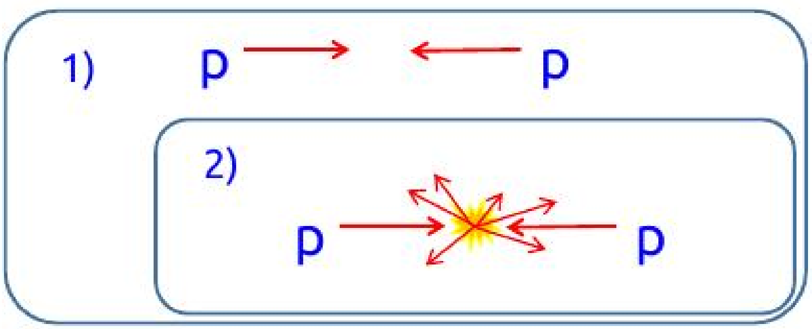
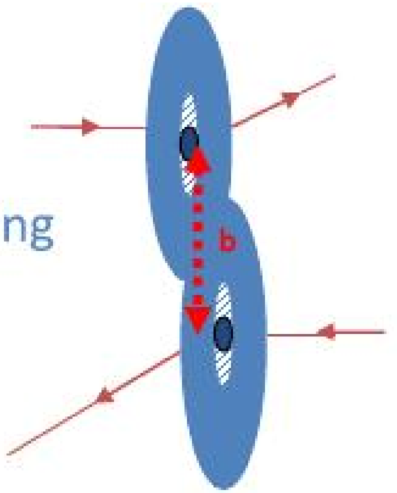
The classical elastic scattering



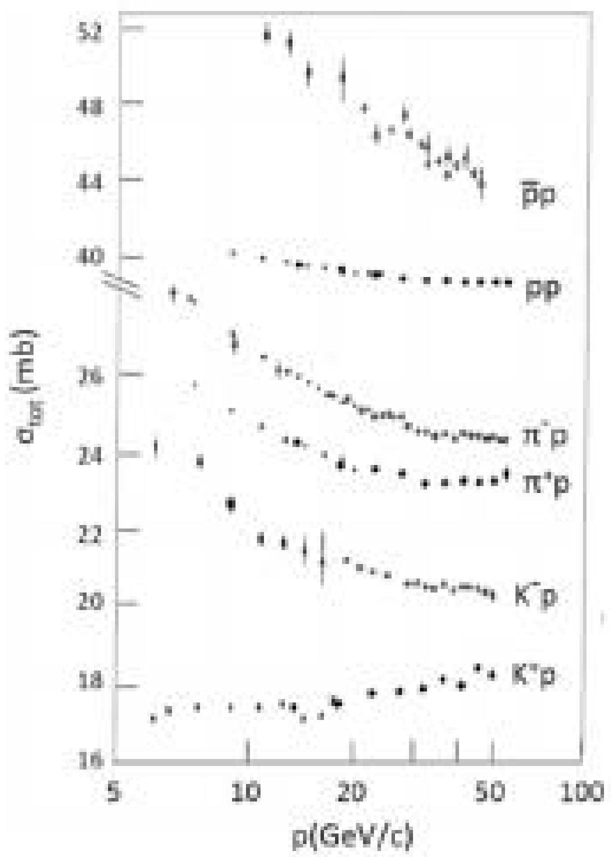
Hadron-hadron interaction

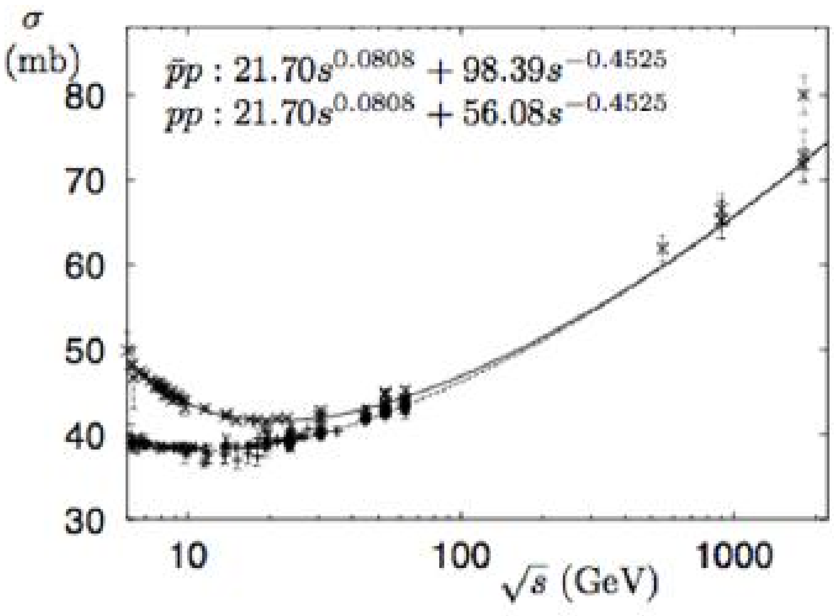


Elastic scattering

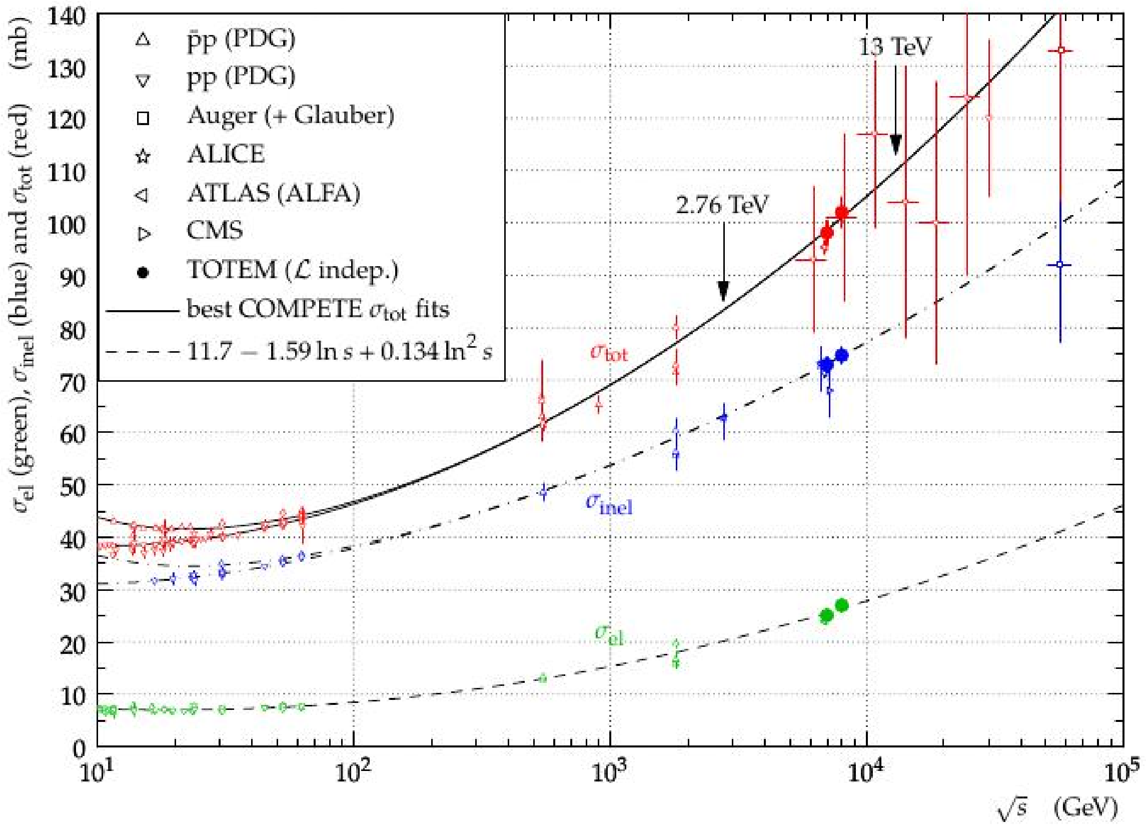


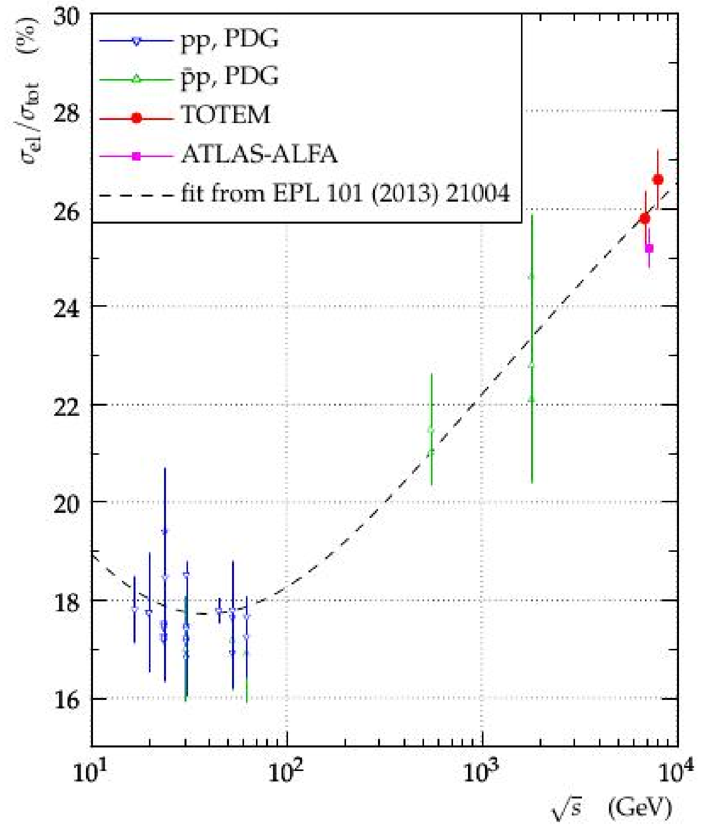
The total cross-section growth





Approximate Geometrical Scaling in the ISR energy region



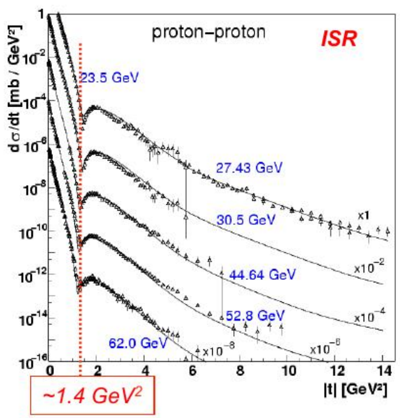


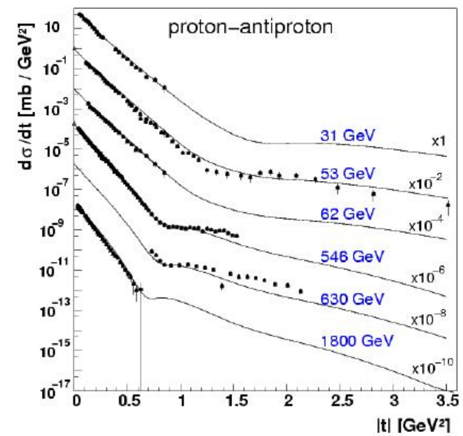
$T(s,b) = T(b/R(s))$

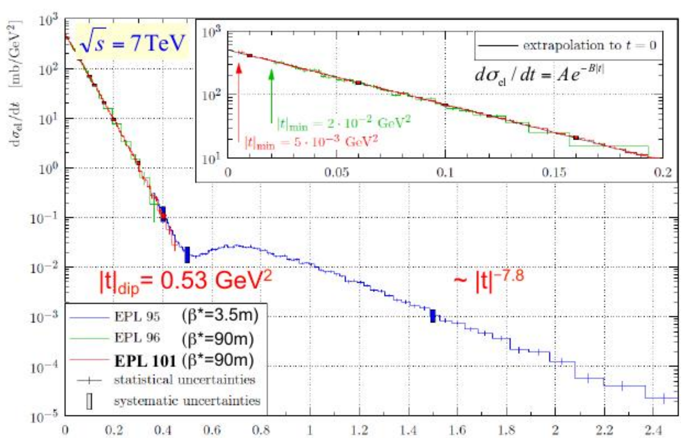
$d\sigma/dt = R^4 F(R^2 t)$

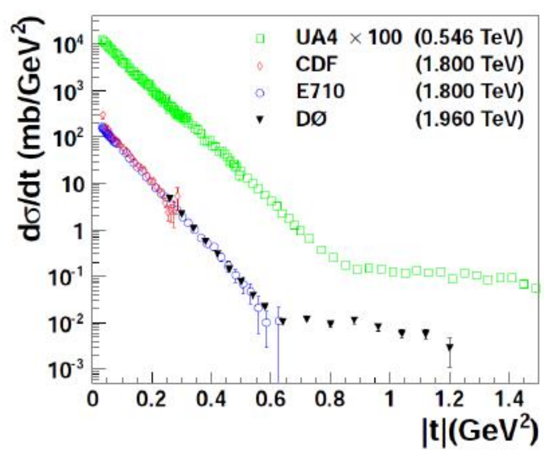
$\sigma_{el}(s) \sim \sigma_{tot}(s) \sim B(s) \sim R^2(s)$

The differential cross-sections

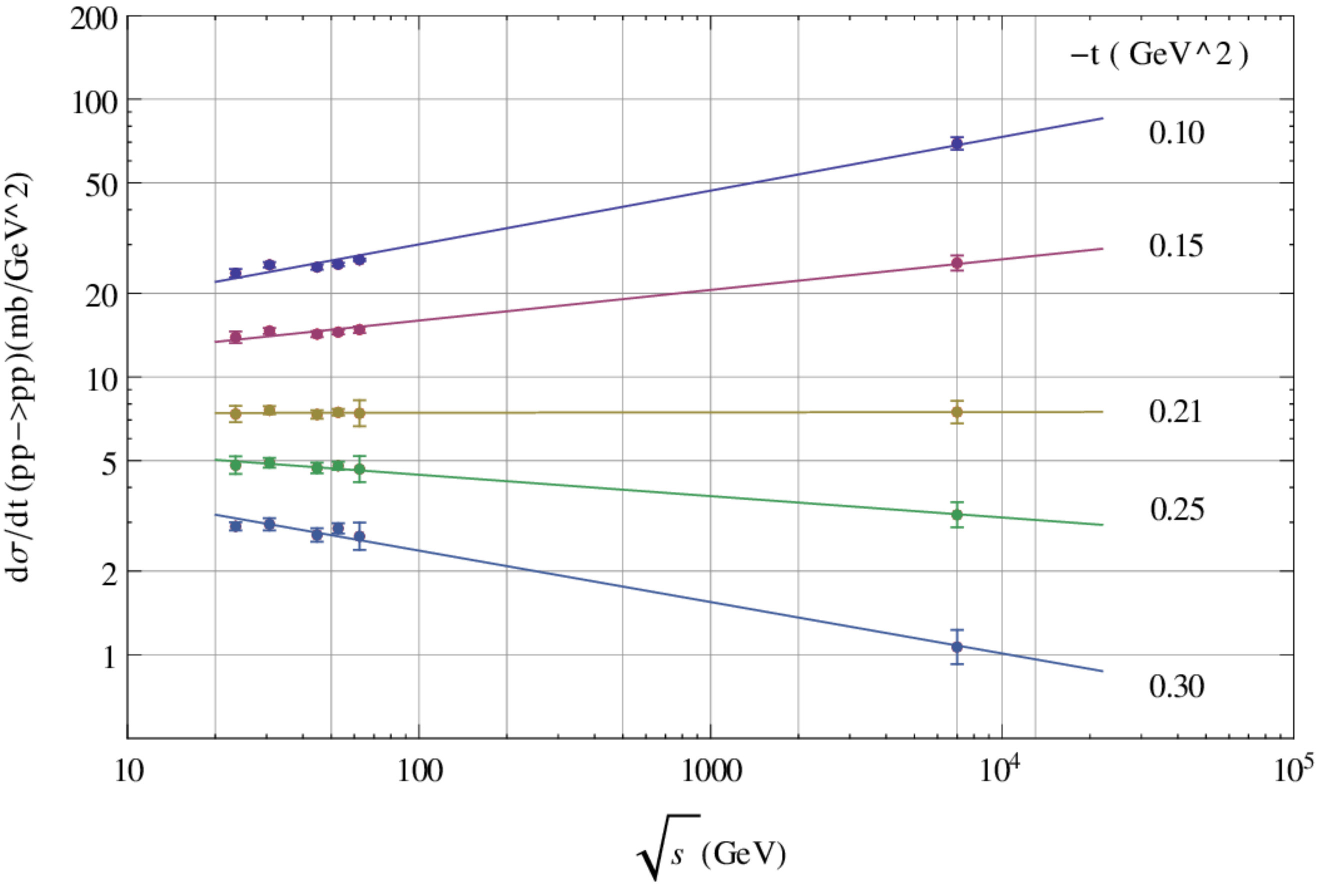








Energy evolution of dσ/dt at fixed values of transferred momenta



Stationary point ($t_\star$,$\sigma_\star$) of dσ/dt

$t_\star \approx -0.21$ GeV^2, $\sigma_\star(s) \equiv d\sigma(s,t_\star)/dt \approx 7.5$ mb / GeV^2

The behaviour of the differential cross-section

$$\frac{d\sigma(s,t)}{dt} = \sigma_0(s) exp[\int_0^t dt' B(s,t')]$$

at fixed t in the forward peak range is defined by the energy evolution of

$$\sigma_0(s) \equiv \frac{d\sigma(s,t)}{dt}|_{t=0} = \frac{\sigma_{tot}^2(s)(1+\rho^2(s))}{16\pi}, \quad \rho(s) = \frac{ReT(s,0)}{ImT(s,0)}$$

and of the local slope

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

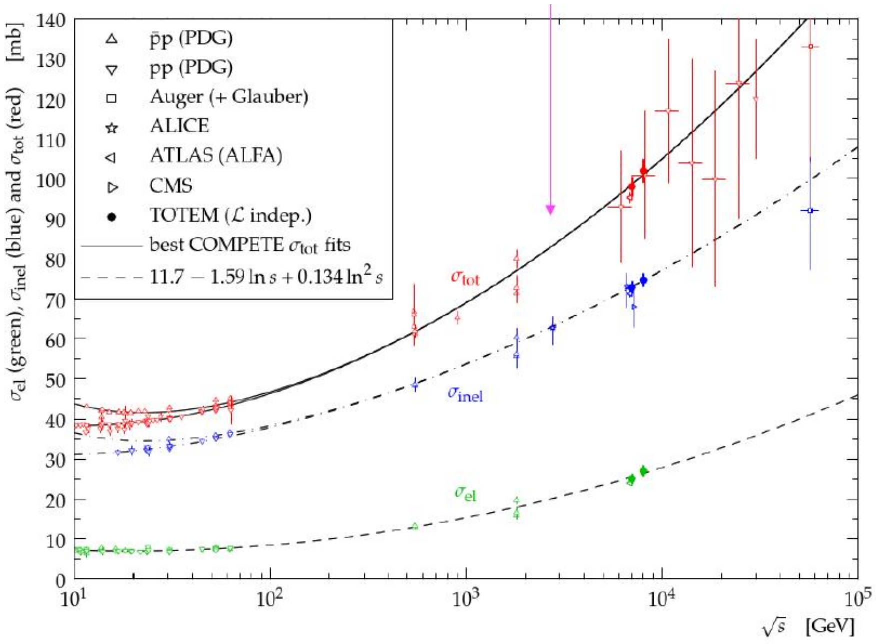
$$\frac{d\sigma(s,t)}{dt} = \sigma_0(s) exp(\tilde{B}t), \qquad \tilde{B} \equiv B(s,\tilde{t}), \;\; \tilde{t} \in [t,0], \;\; \tilde{t} = \tilde{t}(t,s).$$

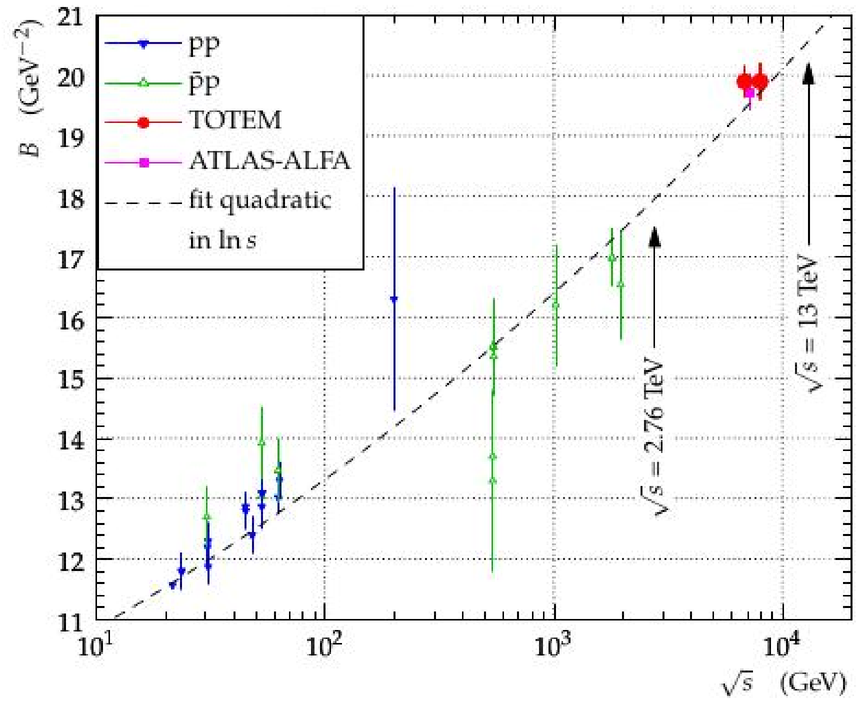
In particular, at $t = t_*$ we have

$$\sigma_*(s) = \sigma_0(s) exp(\tilde{B}_* t_*), \quad \tilde{B}_* \equiv B(s,\tilde{t}_*), \quad \tilde{t}_* \in [t_*, 0].$$

$$\tilde{B}_* \equiv \frac{1}{(-t_*)} \ln(\frac{\sigma_0(s)}{\sigma_*(s)}) \approx 9.52 \ln(\frac{\sigma_{tot}\sqrt{1+\rho^2}}{12.12(\mathrm{mb})}) \,\mathrm{GeV}^{-2}$$

At $t=t_*$ the growth of $\sigma_0(s)$ and growth of the local slope in $d\sigma/dt$ compensate each other, but due to the unitarity this stationarity has a transitory character and must be followed by decreasing of $d\sigma/dt$





Predictions for $d\sigma/dt$ at 13 TeV

Suggesting that the stationarity persists up to 13 TeV we can anticipate that

$$\sigma_*(s) \approx (7.5 \pm 0.5)\ \mathrm{mb/GeV}^2 \ \text{at} \ \sqrt{s} = 13\,\mathrm{TeV}. \qquad (*)$$

If we assume that at 13 TeV $\sigma_{tot}(s) \approx (109 \pm 2)$ mb then according to

$$\tilde{B}_* \equiv \frac{1}{(-t_*)} \ln(\frac{\sigma_0(s)}{\sigma_*(s)}) \approx 9.52 \ln(\frac{\sigma_{tot}\sqrt{1+\rho^2}}{12.12(\mathrm{mb})})\,\mathrm{GeV}^{-2}.$$

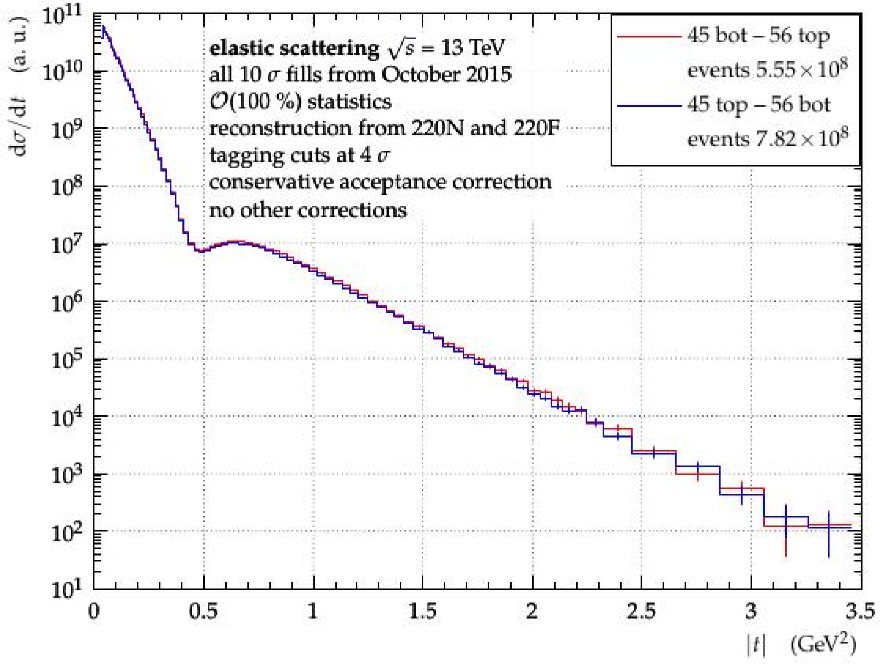
the mean value of the local slope at 13 TeV is $\tilde{B}_* \approx (21.0 \pm 0.5)\,\mathrm{GeV}^{-2}$.

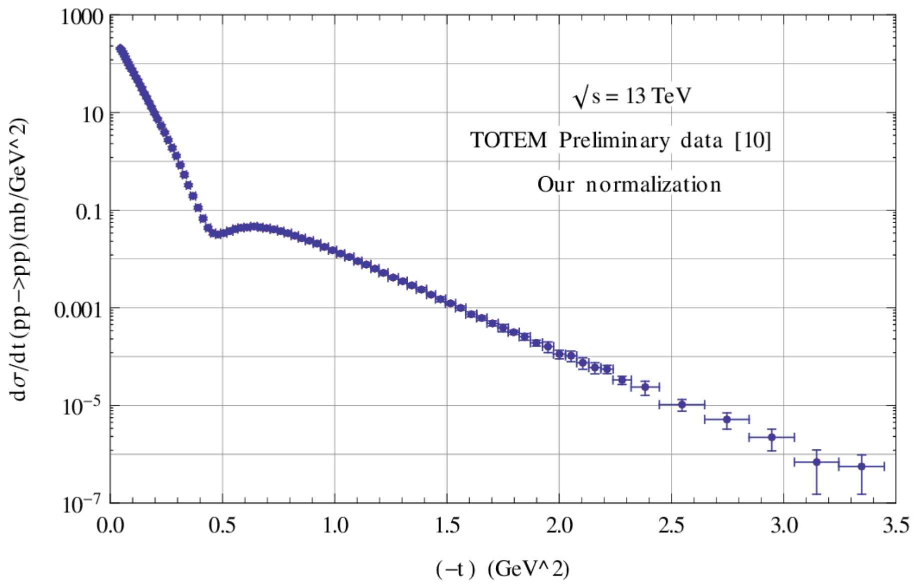
The TOTEM Collaboration exhibits the preliminary unnormalized 13 TeV

data for $d\sigma/dt$ in the $0.05 < |t| < 3.5\ \mathrm{GeV}^2$ region. The suggestion $(*)$

enables us to normalize these data and have got the values for $d\sigma/dt$:

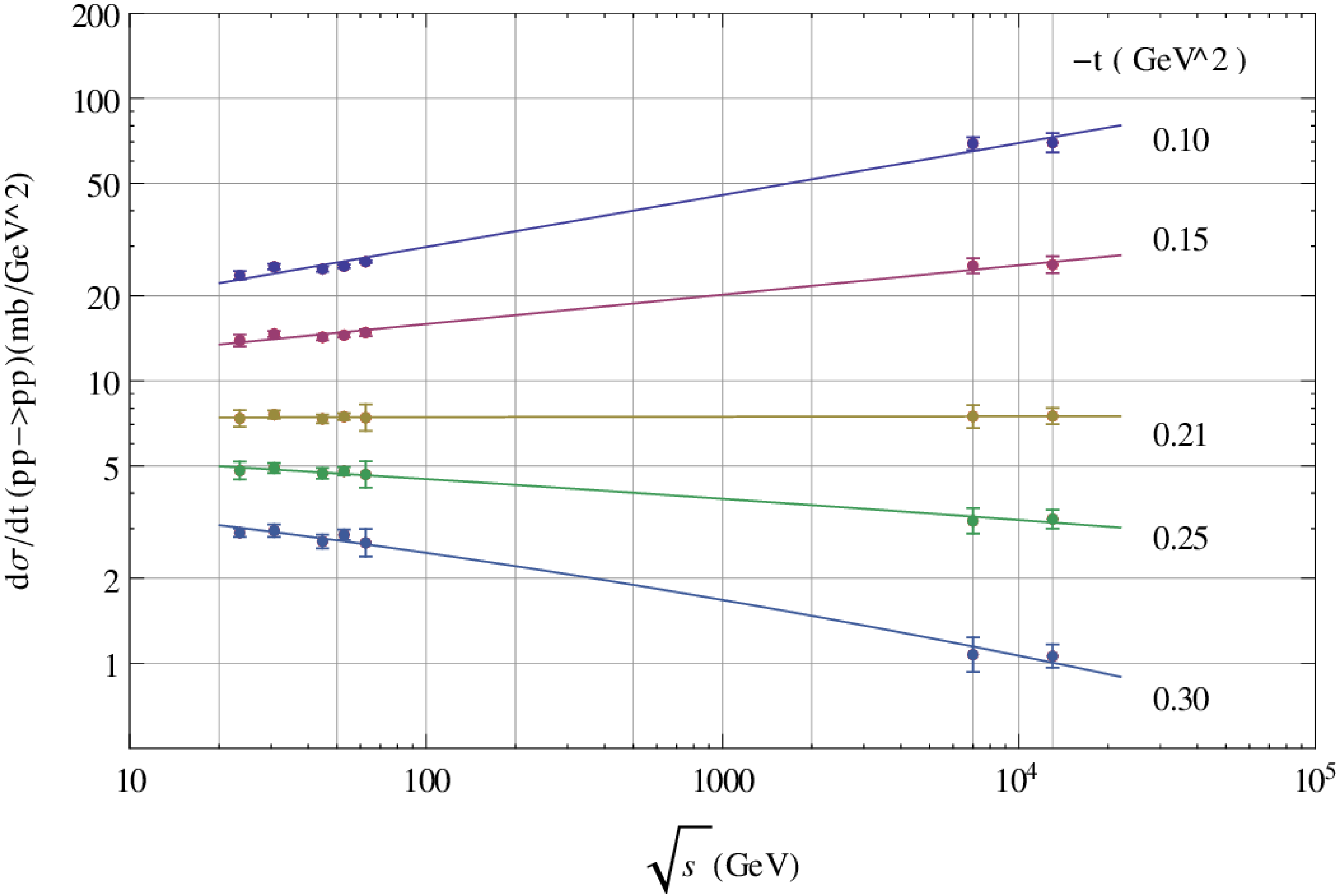
Predictions for dσ/dt at 13 TeV





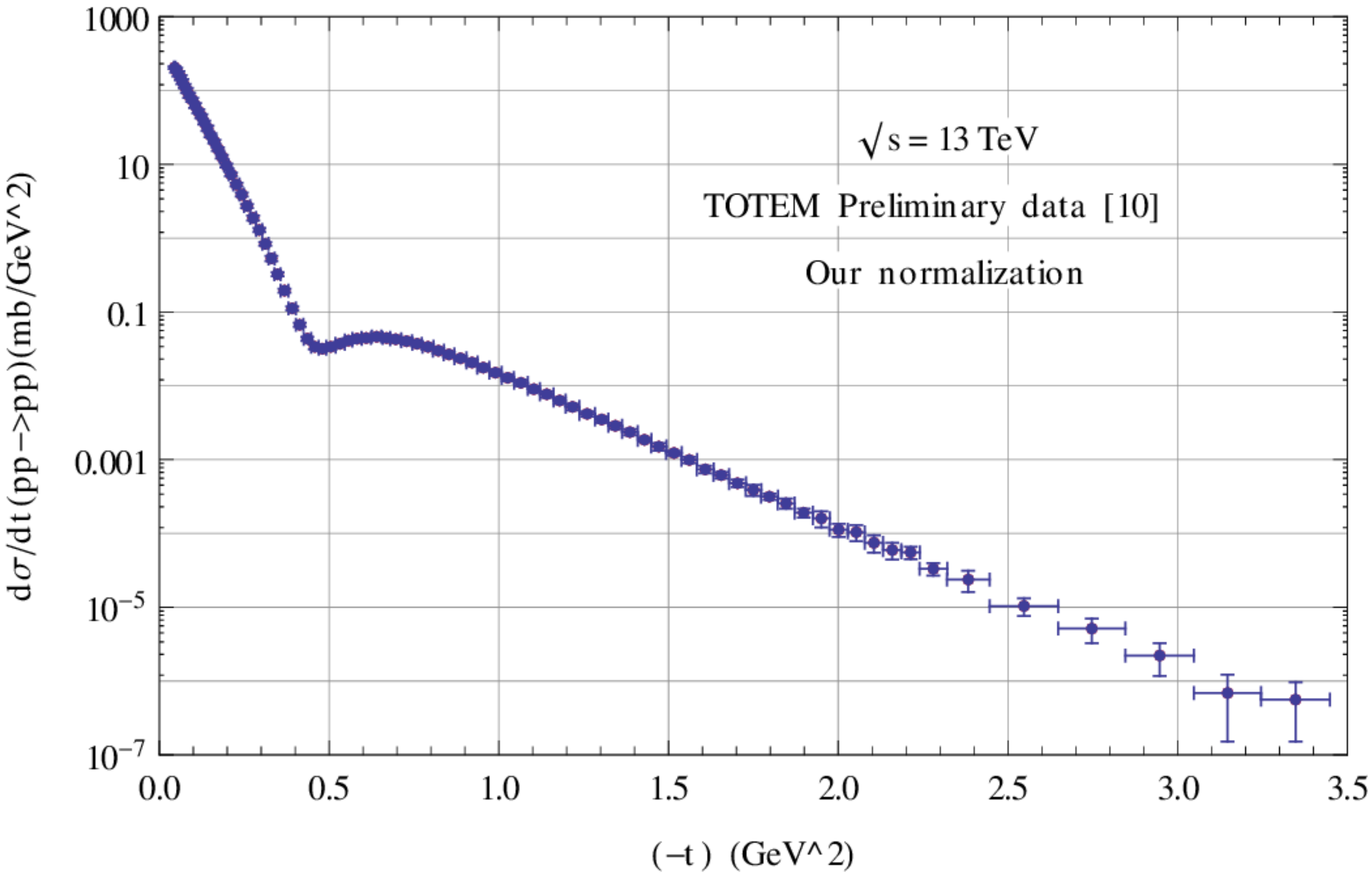
In particular, the value of $d\sigma/dt$ at the dip at 13 TeV

$$\frac{d\sigma}{dt}|_{dip} \approx 31.3 \pm 1.9 \ \mu\text{b}/\text{GeV}^2, \ \ -t_{dip} \approx 0.483 \pm 0.011 \ \text{GeV}^2$$

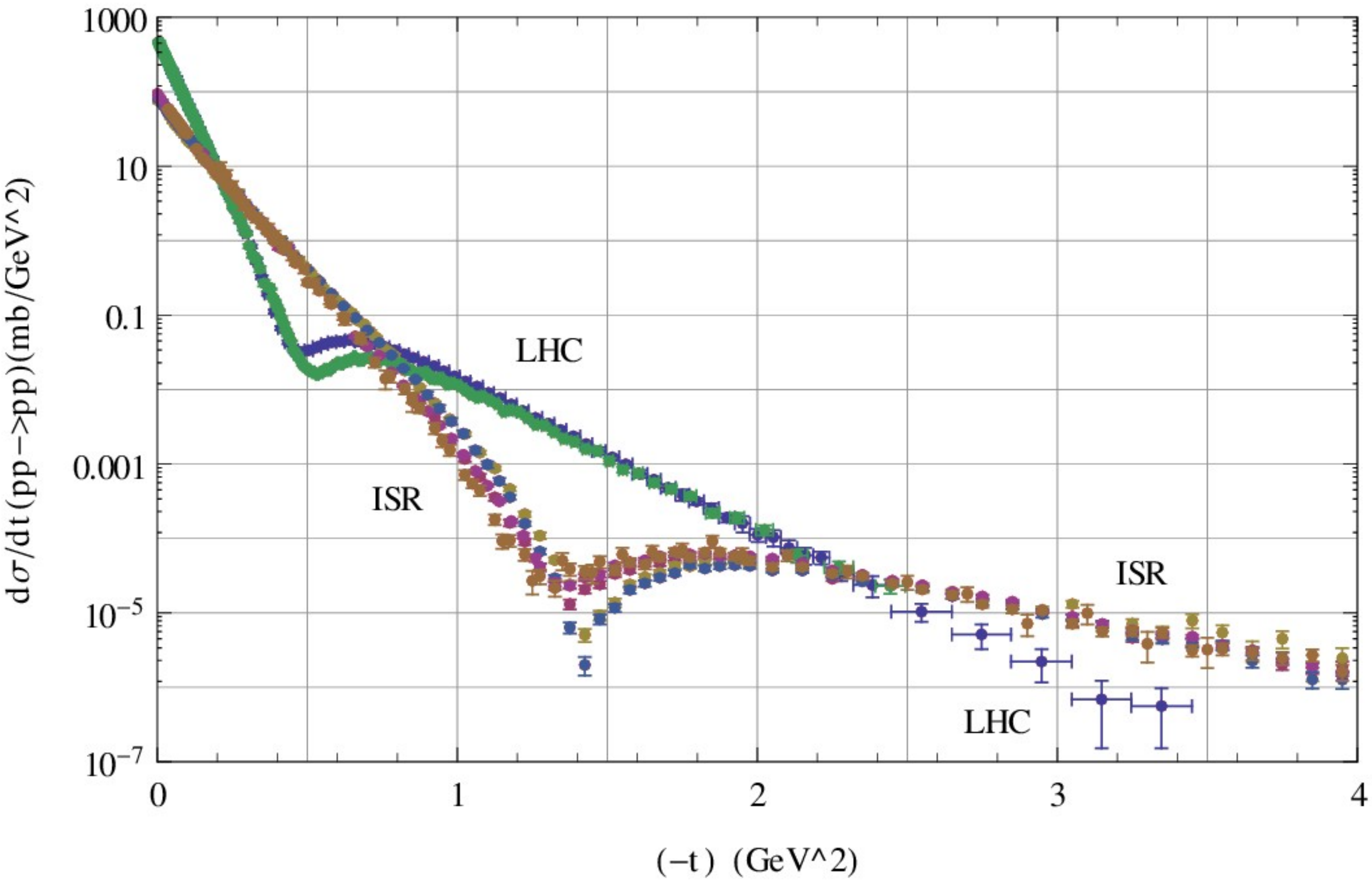


200
100
50
20
10
5
2
1
dσ/dt (pp->pp)(mb/GeV^2)
10
100
1000
10^4
10^5
√s (GeV)
−t (GeV^2)
0.10
0.15
0.21
0.25
0.30

The differential cross-section for pp-elastic scattering at 13 TeV in our normalization



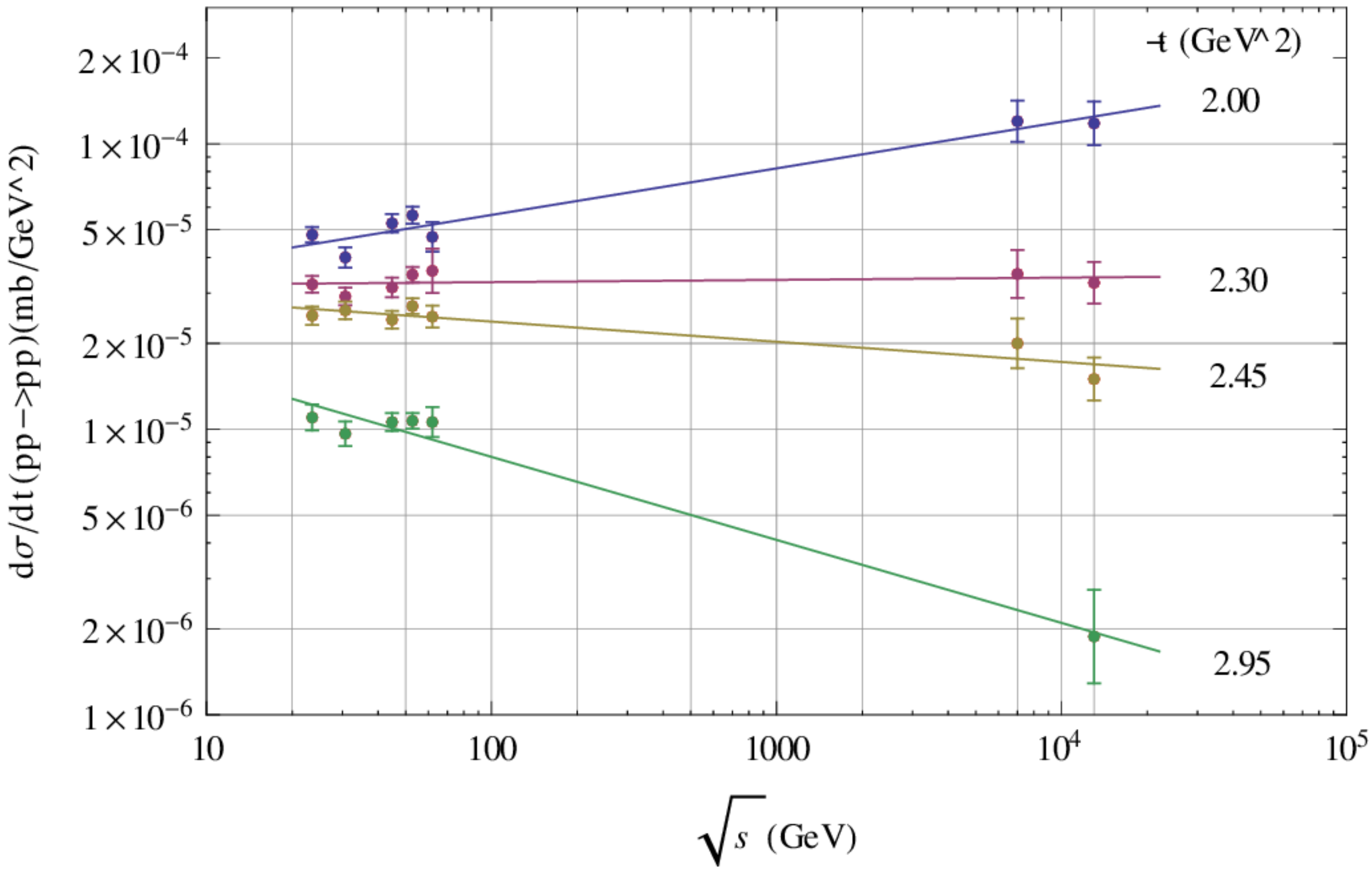
dσ/dt at the ISR and the LHC (7 and 13 TeV) energies



An evidence of the second stationary point at

$$t_{**} \approx -2.3\,\mathrm{GeV}^2, \quad \sigma_{**}(s) \equiv \frac{d\sigma(s, t_{**})}{dt} \approx 33\ \mathrm{nb/GeV}^2$$

dσ/dt in the vicinity of t = - 2.3 GeV^2



Instead of the expected simple energy-independent behaviour $d\sigma / dt \approx const\ |t|^{-8}$ (A. Donnachie, P.V. Landshoff 1979) the differential cross-section reveals in this *t*-region the second shrinking diffraction cone. The simplest way to understand this empirical fact is to assume that the high energy *pp* elastic scattering amplitude *T(s,t)* in the region $0 \le |t| \le 4$ GeV^2 is a sum of two *similar* terms

$$T(s,t) = 4\pi s(A_1(s,t) + A_2(s,t)).$$

The dip-bump structure in $d\sigma/dt$ is due to the interference of these terms

$$\frac{d\sigma(s,t)}{dt} = \pi[(|A_1| - |A_2|)^2 + 2|A_1||A_2|(1 + \cos(\varphi_1 - \varphi_2))],$$

where $\varphi_1(s,t)$ and $\varphi_2(s,t)$ are the phases of $A_1(s,t)$ and $A_2(s,t)$ respectively.

The growth of $\sigma_{tot}(s)$ and $B(s)$ are universal properties of the hadron-hadron scattering. Because the stationarity of $d\sigma/dt$ is a consequence of the correlated growth of $\sigma_{tot}(s)$ and $B(s)$ we can anticipate that the existence of the two stationary points and the two-component structure of the high energy elastic scattering amplitude are general properties for all elastic processes.

Summary

1. The ISR and the 7 TeV LHC data give an evidence of a stationary point of dσ/d*t*.

2. This scaling property is equivalent to the connection between the slope and $\sigma_{tot}(s)$.

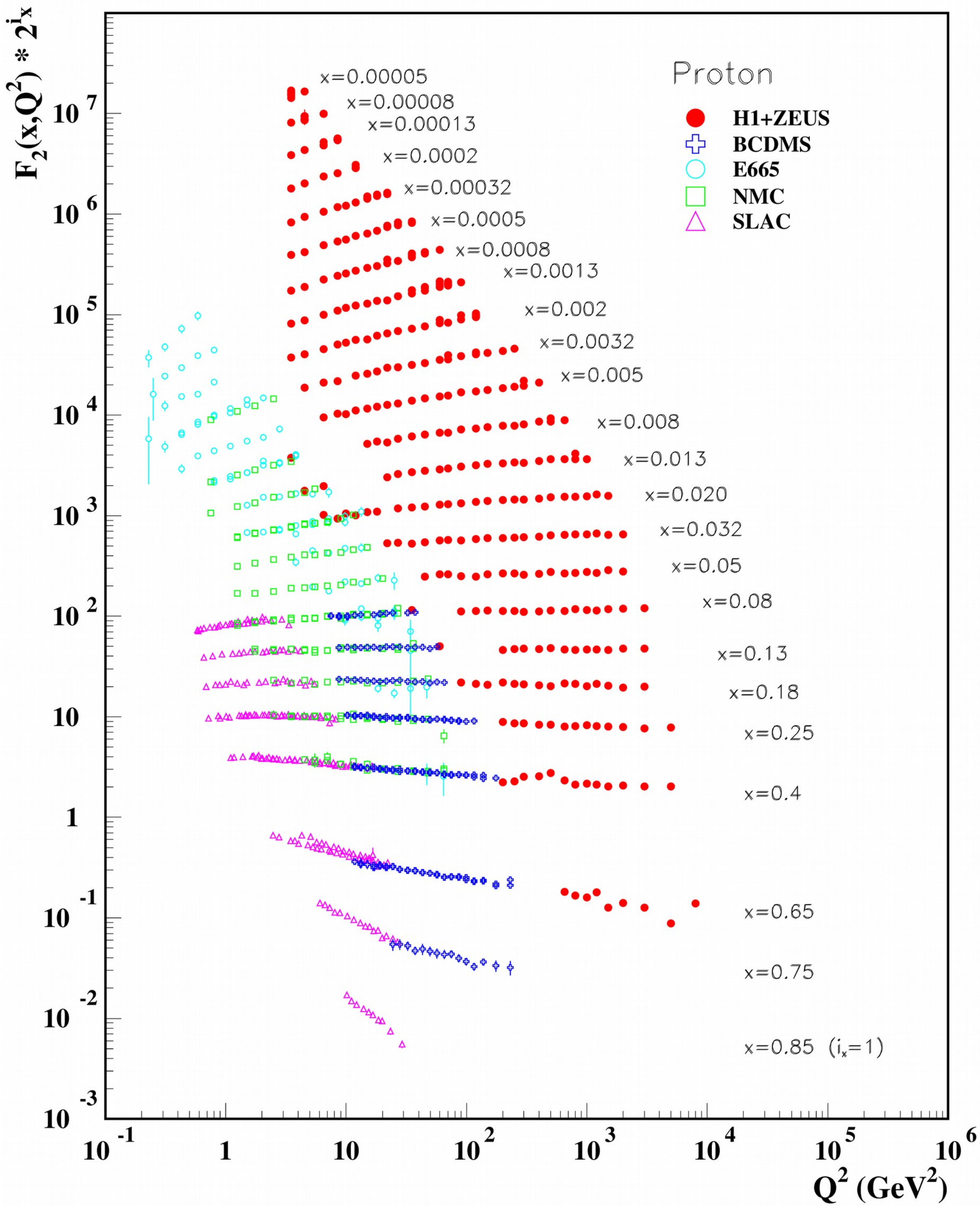
3. The stationarity has the compensatory nature and the transitory character.

4. Supposing the validity of the stationarity of dσ/d*t* up to 13 TeV we normalize the preliminary 13 TeV TOTEM data and have got the values for dσ/d*t* at 13 TeV.

5. These data give an evidence of a *second* stationary point in the region beyond the second maximum of dσ/d*t*. It means that the high energy elastic scattering amplitude is a sum of two *similar* terms.

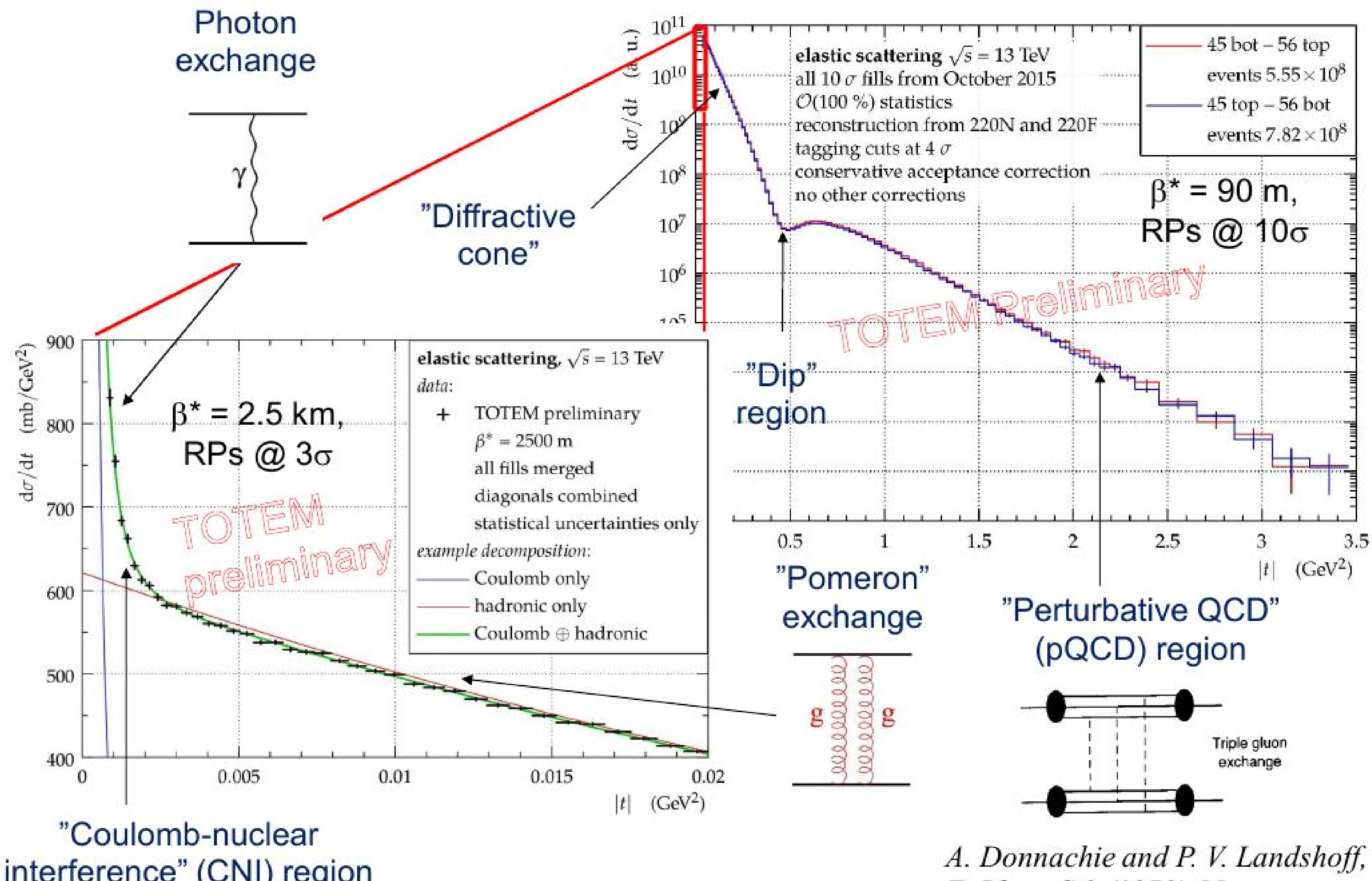
6. We argue that the above properties are general for all elastic processes.

Thank you !



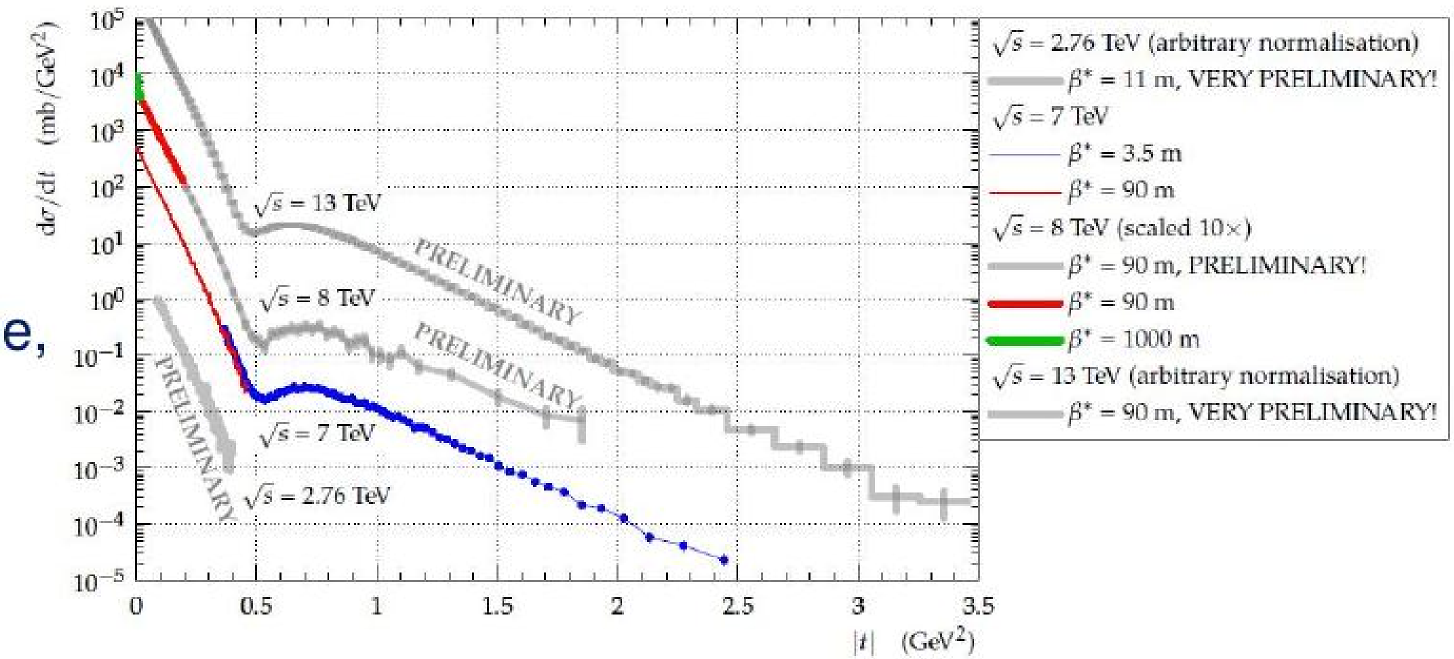
Proton
H1+ZEUS
BCDMS
E665
NMC
SLAC
x=0.00005
x=0.00008
x=0.00013
x=0.0002
x=0.00032
x=0.0005
x=0.0008
x=0.0013
x=0.002
x=0.0032
x=0.005
x=0.008
x=0.013
x=0.020
x=0.032
x=0.05
x=0.08
x=0.13
x=0.18
x=0.25
x=0.4
x=0.65
x=0.75
x=0.85 (i_x=1)
$F_2(x,Q^2) * 2^{i_x}$
Q^2 (GeV^2)

Elastic pp scattering @ √s =13 TeV



A. Donnachie and P. V. Landshoff, Z. Phys. C 2 (1979) 55.

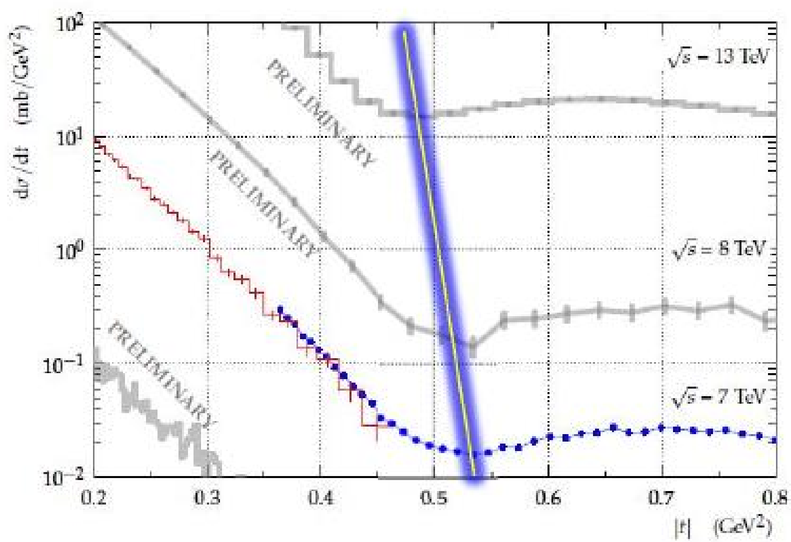
Elastic pp scattering: data summary & trends

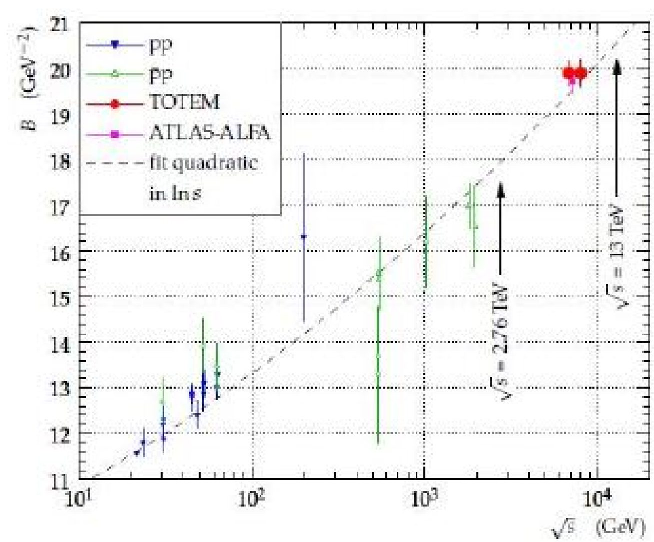


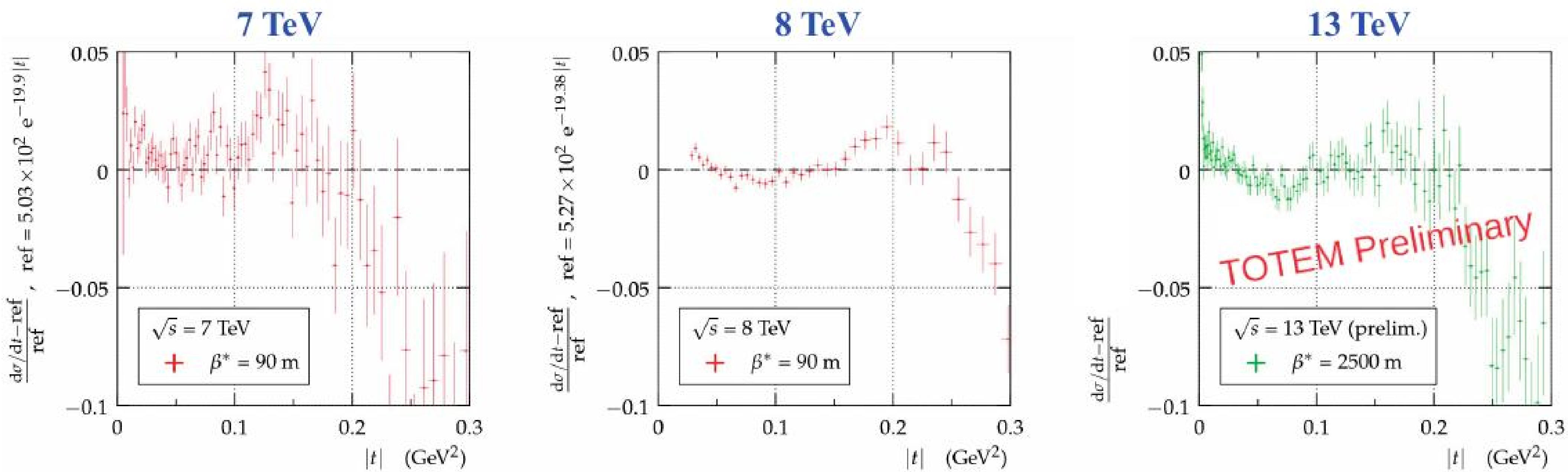
different |t|-ranges probes different physics regimes: Coulomb interference, diffractive cone, dip-bump, transition to pQCD etc…

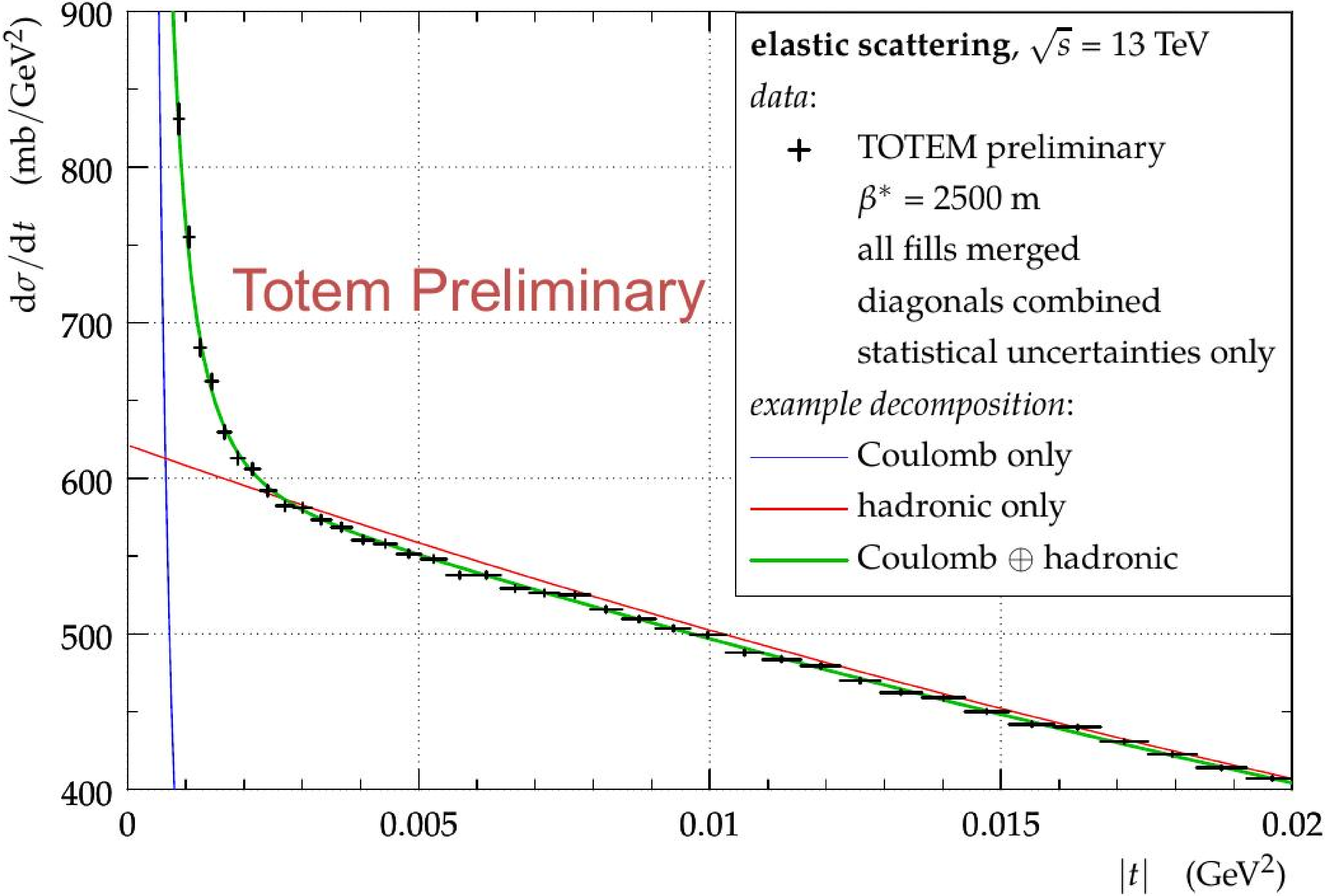
Trends:

- dip position in |t| decreases with increasing $\sqrt{s}$
- Forward slope $B = \frac{d}{dt}\ln\left(\left.\frac{d\sigma}{dt}\right|_{t=0}\right)$ increase with $\sqrt{s}$






7 TeV
8 TeV
13 TeV
dσ/dt−ref / ref , ref = 5.03 × 10^2 e^−19.9|t|
dσ/dt−ref / ref , ref = 5.27 × 10^2 e^−19.38|t|
dσ/dt−ref / ref
√s = 7 TeV
β* = 90 m
√s = 8 TeV
β* = 90 m
√s = 13 TeV (prelim.)
β* = 2500 m
TOTEM Preliminary
|t| (GeV^2)
0.05
0
−0.05
−0.1
0
0.1
0.2
0.3



dσ/dt (mb/GeV²)
900
800
700
600
500
400
0
0.005
0.01
0.015
0.02
|t| (GeV²)
Totem Preliminary
elastic scattering, √s = 13 TeV
data:
TOTEM preliminary
β* = 2500 m
all fills merged
diagonals combined
statistical uncertainties only
example decomposition:
Coulomb only
hadronic only
Coulomb ⊕ hadronic

- $\sqrt{s}$ = 8 TeV: first LHC determination from Coulomb-hadronic interference

$$\rho = 0.12 \pm 0.03$$