Palermo, September 2024

Structures in diffractive dissociation at the LHC

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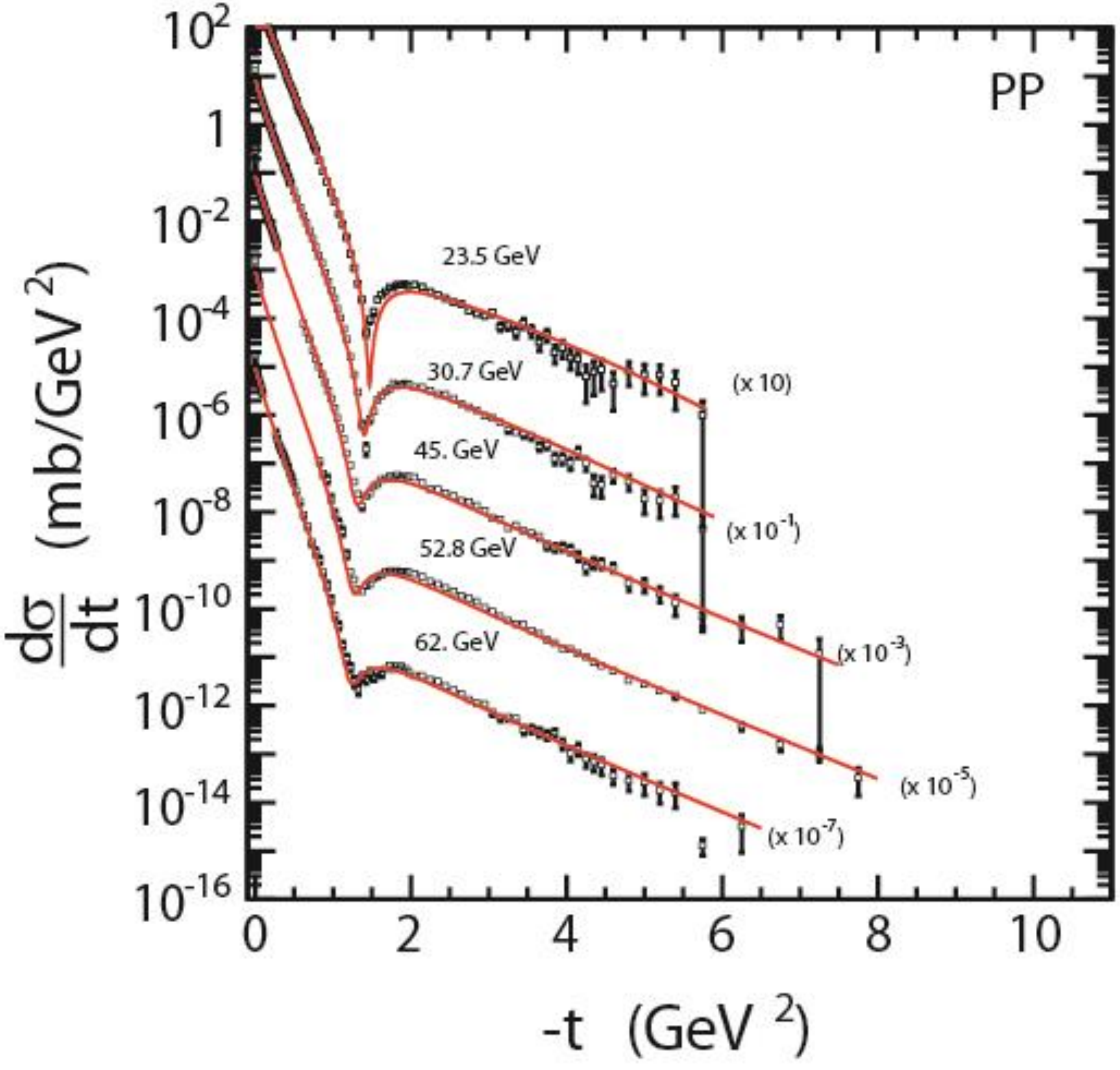
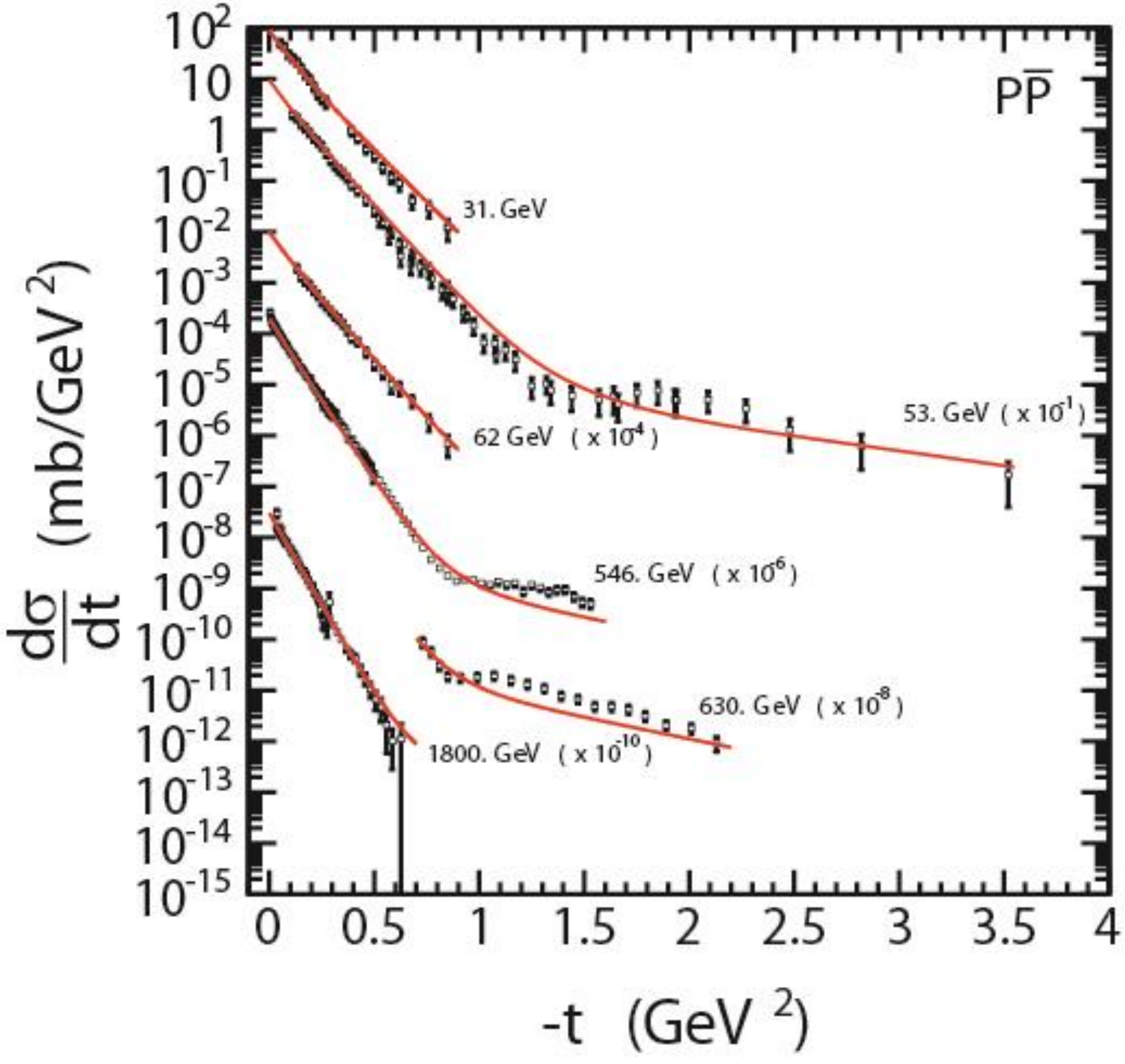
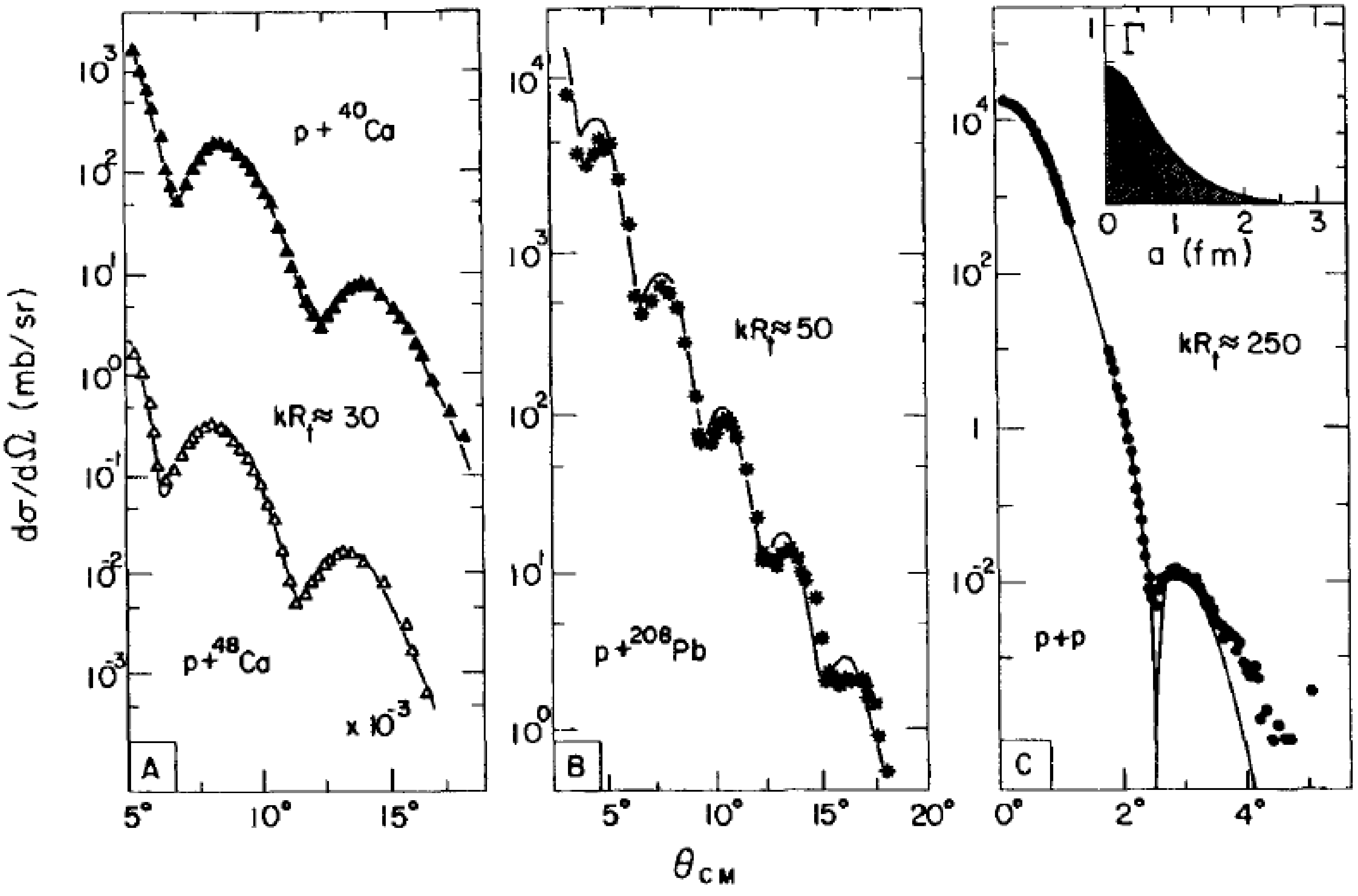


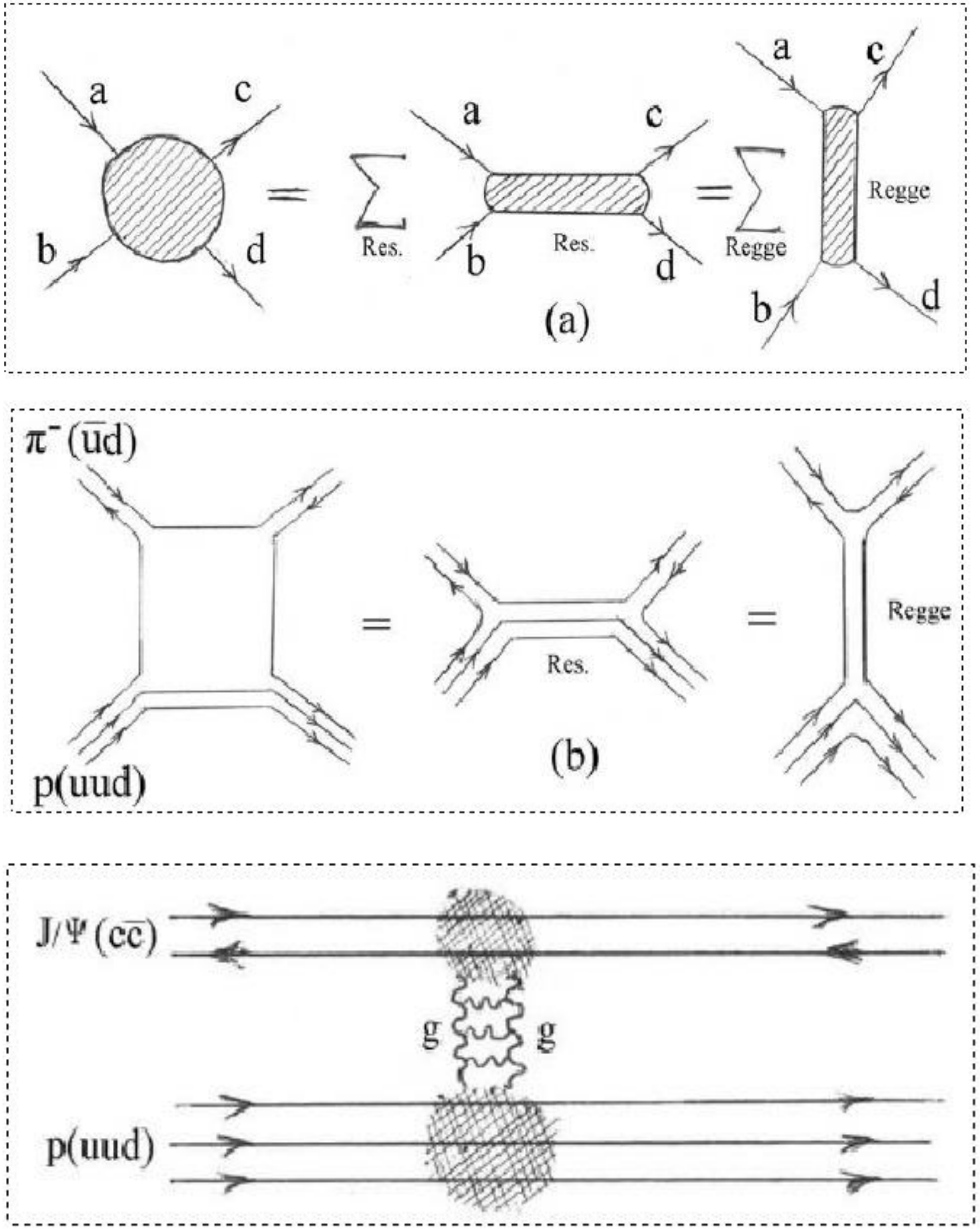
PP
23.5 GeV
30.7 GeV
45. GeV
52.8 GeV
62. GeV
(x 10)
(x 10^-1)
(x 10^-3)
(x 10^-5)
(x 10^-7)
dσ/dt (mb/GeV 2)
-t (GeV 2)



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)



dσ/dΩ (mb/sr)
p + 40Ca
kRf ≈ 30
p+48Ca
x 10-3
A
p+208Pb
kRf ≈ 50
B
p+p
kRf ≈ 250
Γ
a (fm)
C
θCM



a
c
b
d
Res.
a
c
b
Res.
d
(a)
Regge
a
c
Regge
b
d
π⁻ (ūd)
p(uud)
Res.
Regge
(b)
J/Ψ (cc̄)
g
g
p(uud)

TABLE I: Two-component duality

$\mathcal{I}mA(a+b\to c+d)=$	R	Pomeron
$s-$channel	$\sum A_{Res}$	Non-resonant background
$t-$channel	$\sum A_{Regge}$	Pomeron ($I=S=B=0;\ C=+1$)
Duality quark diagram	Fig. 1b	Fig. 2
High energy dependence	$s^{\alpha-1},\ \alpha<1$	$s^{\alpha-1},\ \alpha\geq 1$

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

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

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

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

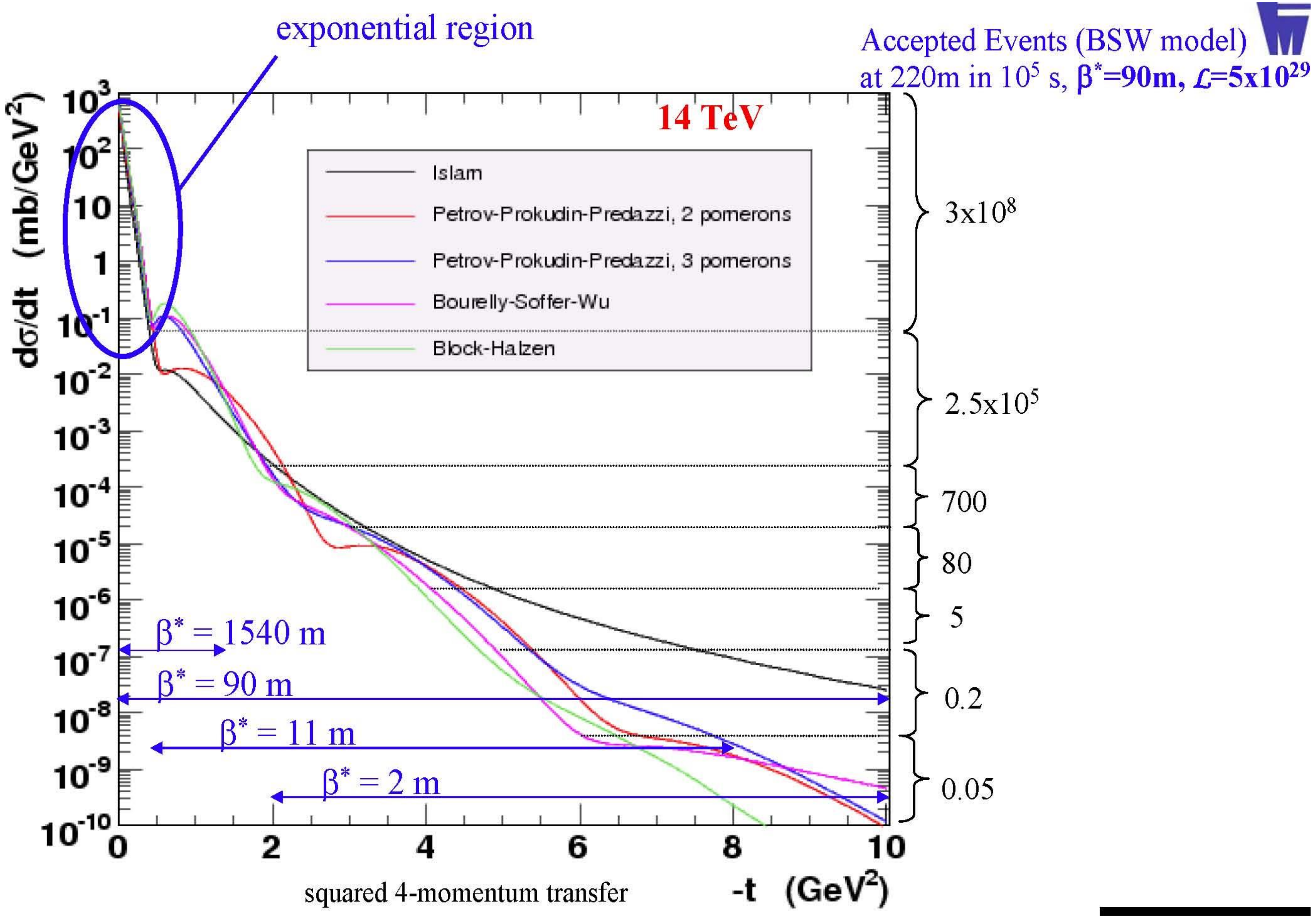
α(0)\C	**+**	**-**
1	**P**	**O**
1/2	**f**	**ω**

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

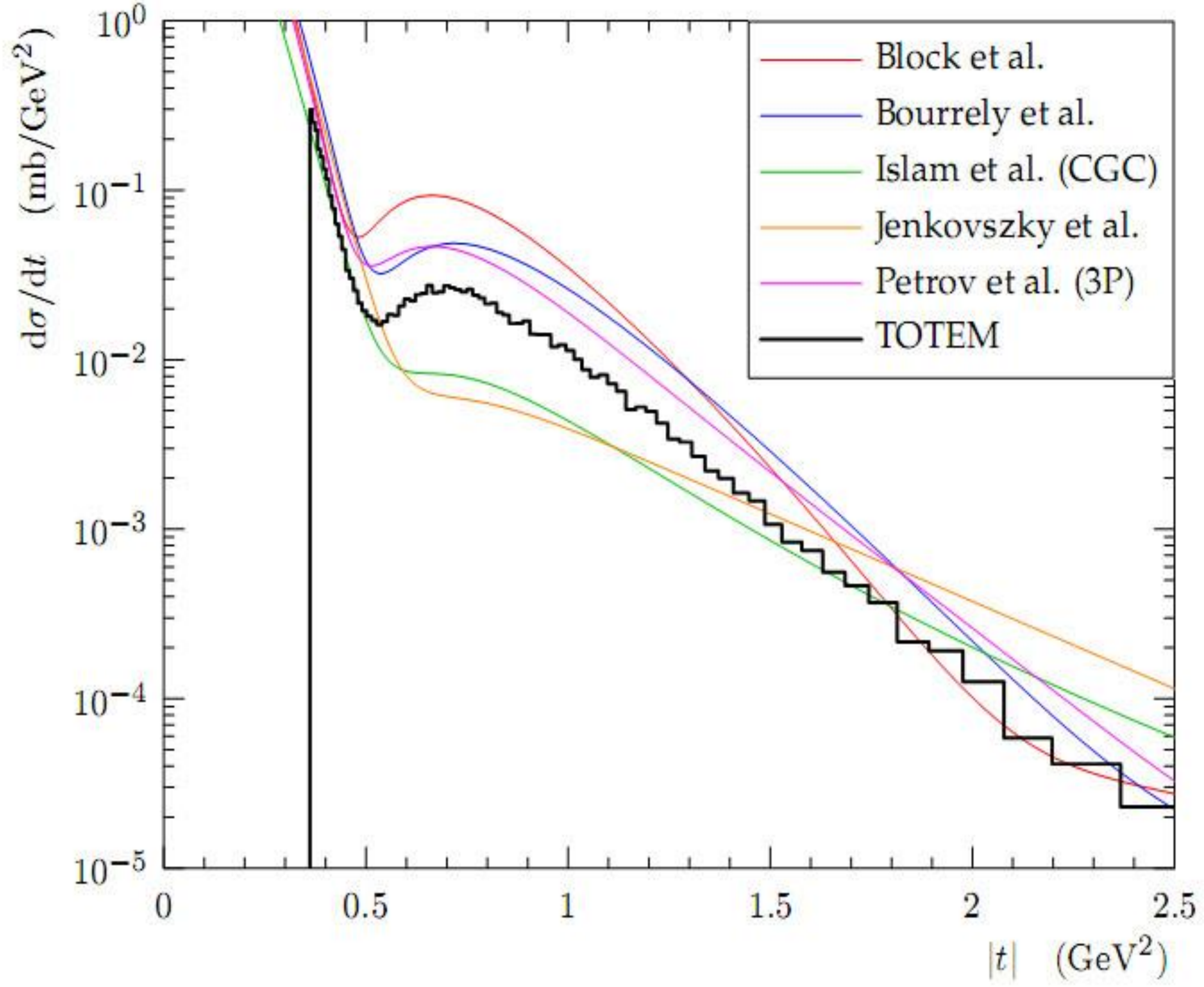
The differential cross section of elastic (EL) proton-proton scattering is:

$$\frac{d\sigma_{EL}}{dt} = A_{EL}\beta^2(t)|\eta(t)|^2\left(\frac{s}{s_0}\right)^{2\alpha_P(t)-2},$$

where A_{EL} is a free parameter including normalization. The proton-pomeron coupling is: $\beta^2(t) = e^{bt}$, where b is a free parameter, $b \approx 1.97$ GeV^{-2}. The pomeron trajectory is $\alpha_P(t) = 1 + \epsilon + \alpha' t$, where $\epsilon \approx 0.08$ and $\alpha' \approx 0.3$ GeV^{-2}. The signature factor is $\eta(t) = e^{-i\frac{\pi}{2}\alpha(t)}$; its contribution to the differential cross section is $|\eta(t)|^2 = 1$, therefore we ignore it in what follows.


exponential region
Accepted Events (BSW model)
at 220m in 10^5 s, β*=90m, L=5x10^29
14 TeV
Islam
Petrov-Prokudin-Predazzi, 2 pomerons
Petrov-Prokudin-Predazzi, 3 pomerons
Bourelly-Soffer-Wu
Block-Halzen
dσ/dt (mb/GeV^2)
3x10^8
2.5x10^5
700
80
5
0.2
0.05
β* = 1540 m
β* = 90 m
β* = 11 m
β* = 2 m
squared 4-momentum transfer
-t (GeV^2)

CERN LHC, TOTEM Collab., June 26, 2011:



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

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

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 $r_1^2(s) = b + L - \frac{i\pi}{2}$, $r_2^2(s) = L - \frac{i\pi}{2}$ 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.

P and f (second column) have positive C-parity, thus entering in the scattering amplitude with the same sign in pp and $\bar{p}p$ scattering, while the Odderon and ω (third column) have negative C-parity, thus entering pp and $\bar{p}p$ scattering with opposite signs, as shown below:

$$A\left(s,t\right)_{pp}^{\bar{p}p} = A_P\left(s,t\right) + A_f\left(s,t\right) \pm \left[A_\omega\left(s,t\right) + A_O\left(s,t\right)\right], \tag{1}$$

where the symbols P, f, O, ω stand for the relevant Regge-pole amplitudes and the super(sub)script, evidently, indicate $\bar{p}p(pp)$ scattering with the relevant choice of the signs in the sum.

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

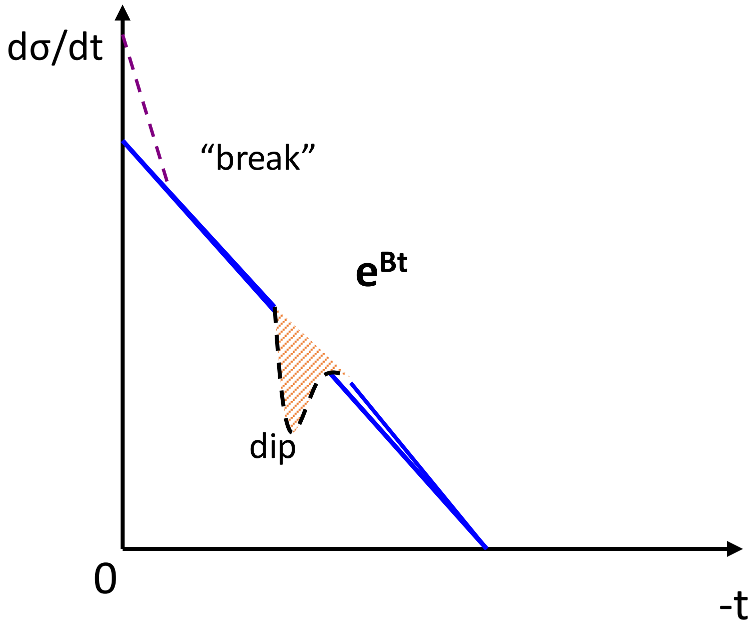
$$e^{-i\pi\alpha_P(t)/2}\Big(s/s_0\Big)^{\alpha_P(t)}\Big[G'(\alpha_P) + \Big(L - i\pi/2\Big)G(\alpha_P)\Big].$$

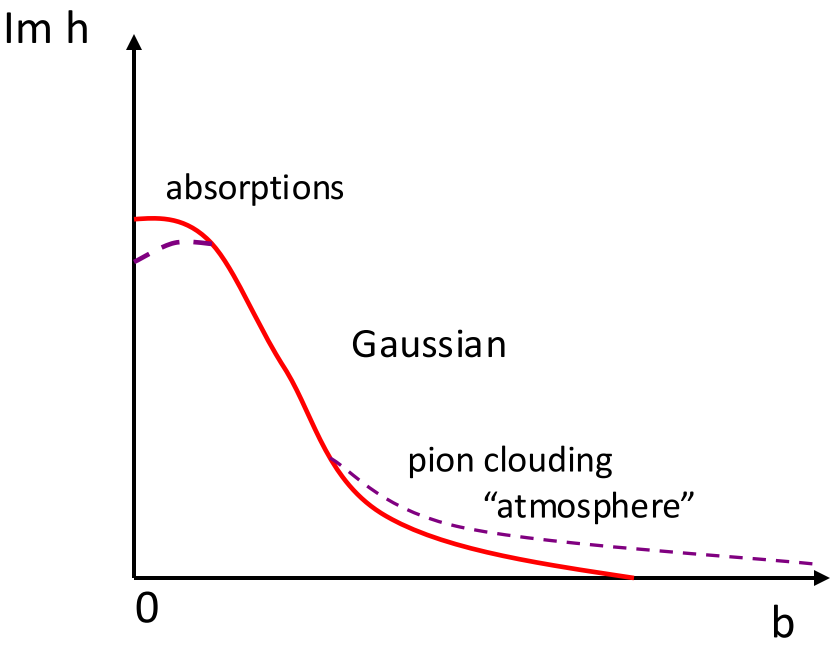
Geometrical scaling (GS), saturation and unitarity

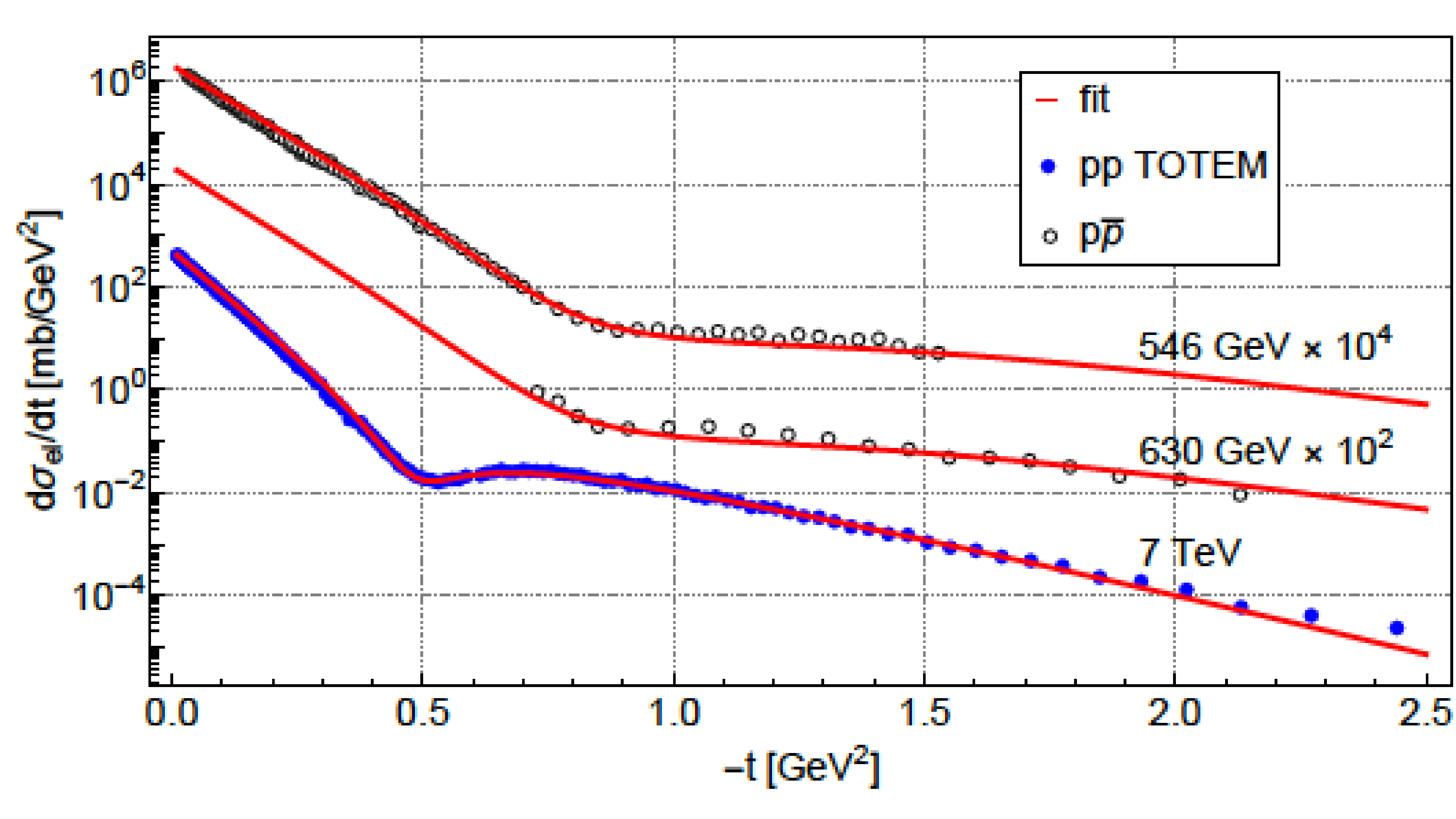
1. On-shell (hadronic) reactions (s,t, Q^2=m^2);

t **←→** b **transformation:** $h(s,b) = \int_0^\infty d\sqrt{-t}\sqrt{-t}A(s,t)$

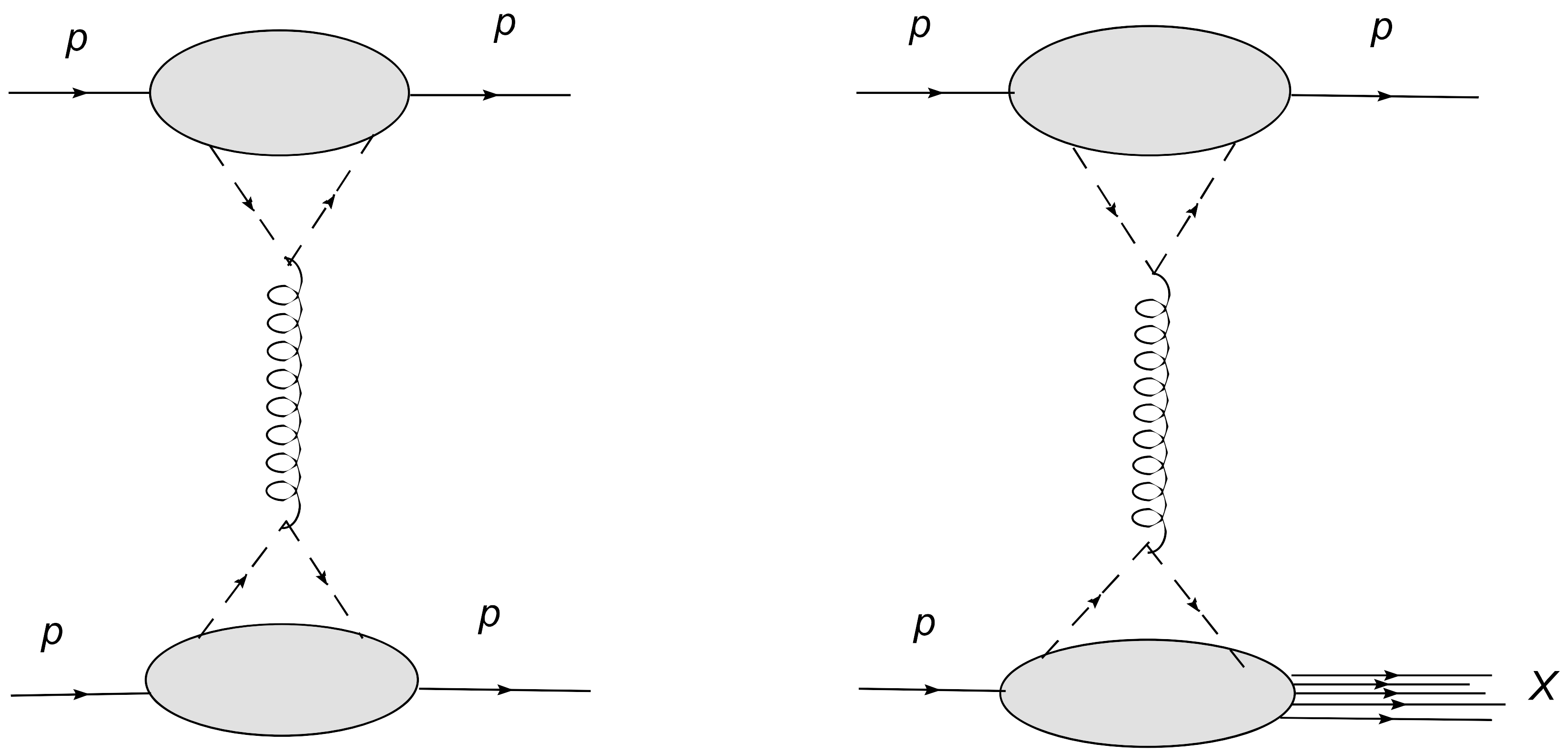
and dictionary:



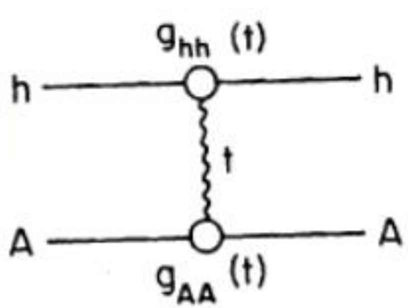


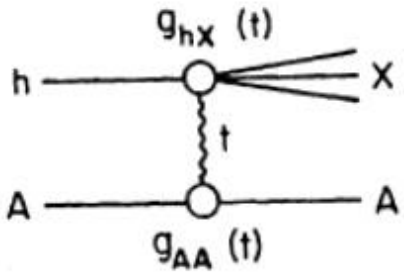


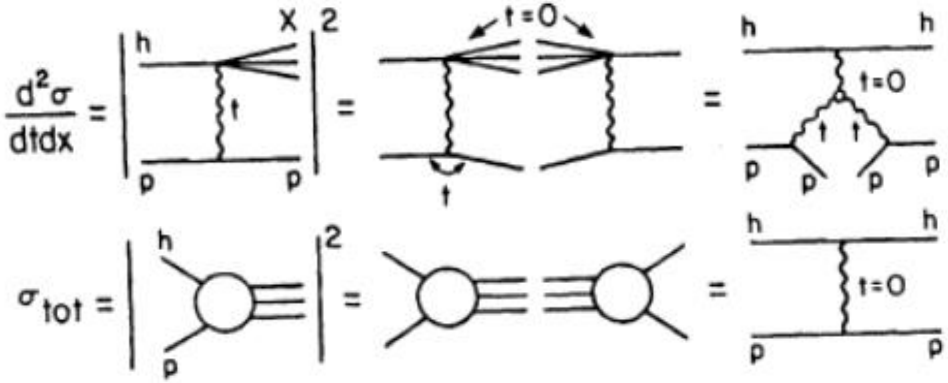
fit
pp TOTEM
$p\bar{p}$
546 GeV × 10^4
630 GeV × 10^2
7 TeV
$d\sigma_{el}/dt$ [mb/GeV^2]
$-t$ [GeV^2]



p
p
p
p
p
p
p
X


g_hh (t)
h
h
t
A
A
g_AA (t)


g_hX (t)
h
X
t
A
A
g_AA (t)

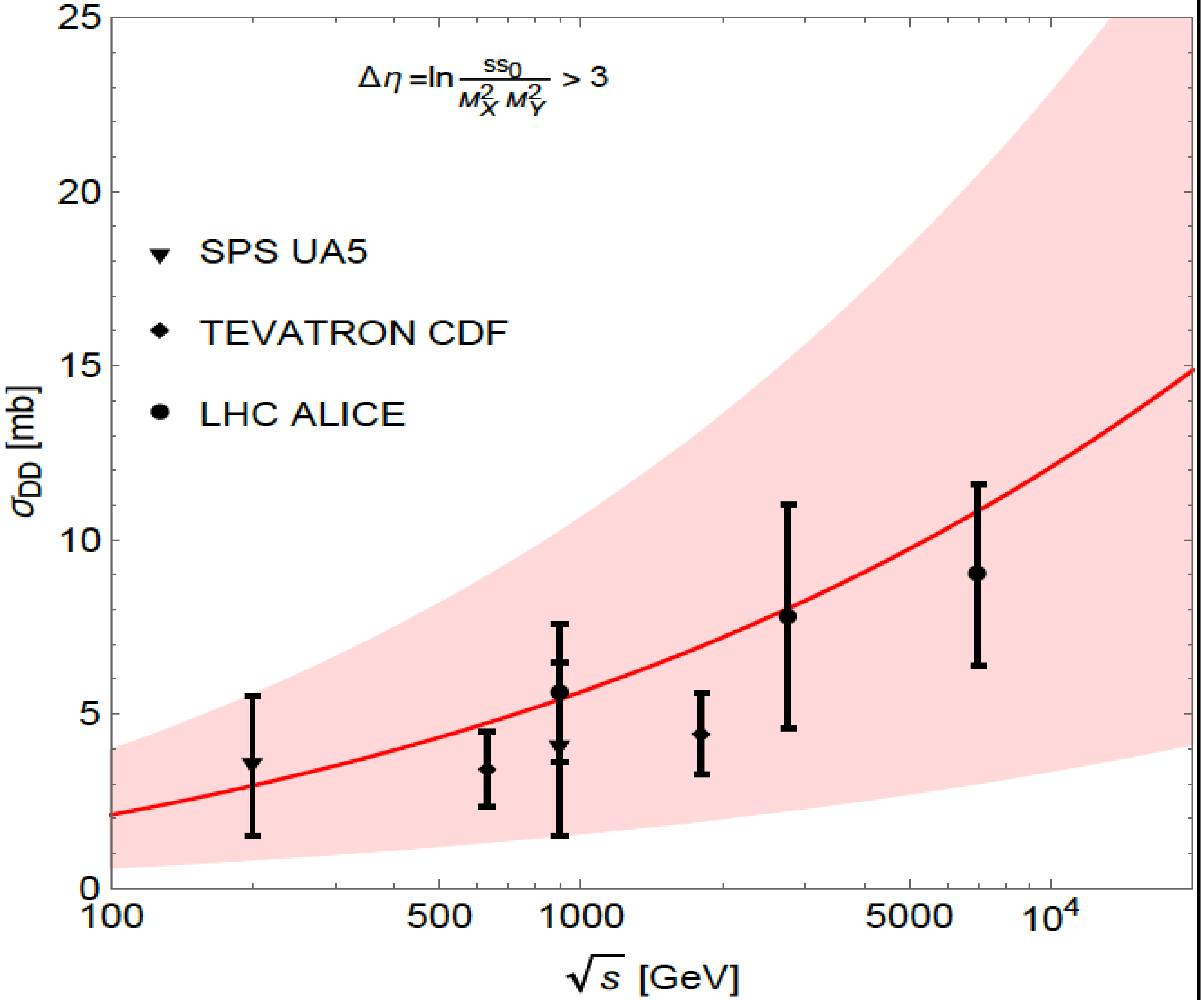

d²σ/dtdx =
h
X
2
t
p
p
=
t=0
t
=
h
h
t=0
t
t
p
p
p
p
σ_tot =
h
p
2
=
=
h
h
t=0
p
p

The differential cross section of proton-proton single diffraction (SD) is:

$$2 \cdot \frac{d^2\sigma_{SD}}{dtdM_X^2} = A_{SD}\beta^2(t)\tilde{W}_2^{Pp}(M_X^2, t)\left(\frac{s}{M_X^2}\right)^{2\alpha_P(t)-2} ,$$

where $\tilde{W}_2^{Pp}(M_X^2, t) \sim F_2^p(M_X^2, t)$.
Similarly, the differential cross section of proton-proton double diffraction (DD) process is:

$$\frac{d^3\sigma_{DD}}{dtdM_X^2 dM_Y^2} = A_{DD}\tilde{W}_2^{Pp}(M_X^2, t)\tilde{W}_2^{Pp}(M_Y^2, t)\left(\frac{ss_0}{M_X^2 M_Y^2}\right)^{2\alpha_P(t)-2} .$$

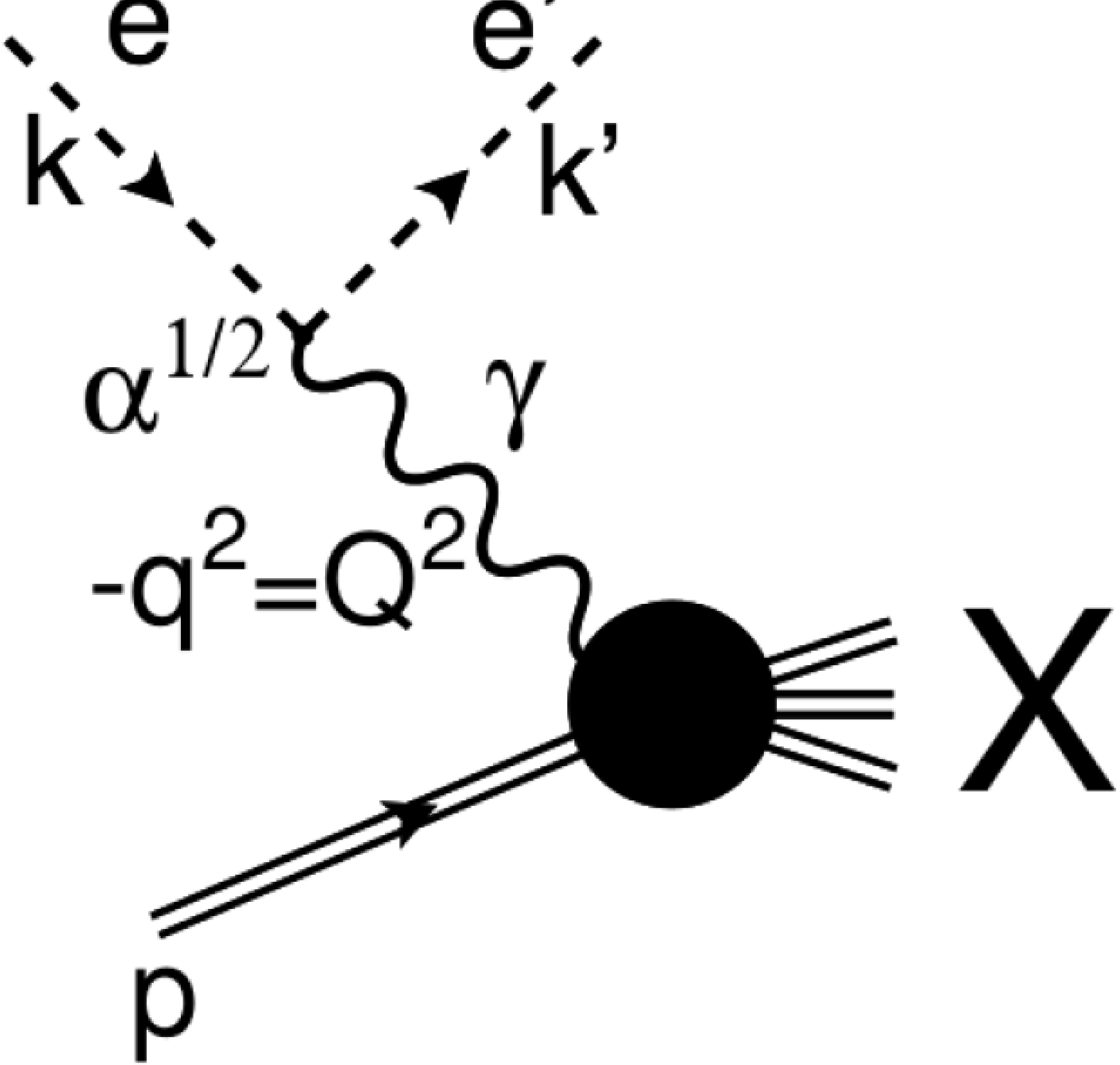


$\Delta\eta = \ln \frac{ss_0}{M_X^2 M_Y^2} > 3$
SPS UA5
TEVATRON CDF
LHC ALICE
σ_{DD} [mb]
$\sqrt{s}$ [GeV]
0
5
10
15
20
25
100
500
1000
5000
10^4

Similar to the case of elastic scattering, the double differential cross section for the SDD reaction, by Regge factorization, can be written as

$$\frac{d^2\sigma}{dtdM_X^2} = \frac{9\beta^4[F^p(t)]^2}{4\pi\sin^2[\pi\alpha_P(t)/2]}(s/M_X^2)^{2\alpha_P(t)-2}\times \left[\frac{W_2}{2m}\left(1 - M_X^2/s\right) - mW_1(t+2m^2)/s^2\right], \tag{1}$$

where $W_i, \quad i = 1,2$ are related to the structure functions of the nucleon and $W_2 \gg W_1$. For high M_X^2, the $W_{1,2}$ are Regge-behaved, while for small M_X^2 their behavior is dominated by nucleon resonances. The knowledge of the inelastic form factors (or transition amplitudes) is crucial for the calculation of low-mass diffraction dissociation.


e
e’
k
k’
$\alpha^{1/2}$
γ
$-q^2=Q^2$
X
p

Similar to the case of elastic scattering, the Dipole SD amplitude is recovered by differentiation (for simplicity (we set $s_0 = 1$ GeV^2)):

$$T_{DP} = \frac{d}{d\alpha} T(s, t, M^2) = e^{-i\pi\alpha/2} s^{\alpha} [G' F_2 + F_2' G + (L - i\pi/2) G F_2],$$

where $L = \ln(s/(1GeV^2))$ and the primes imply differentiation in $\alpha(t)$.

The extrema (dip(s) and bump(s)) are calculated by a standard procedure, i.e. by equating to zero the derivative of the cross section:

$$\frac{d|T_{SD}|^2}{d\alpha} = \frac{1}{2}\Big(\frac{s^2}{s_0^2}\Big)^{\alpha}\Big[GF' + F(LG + G')\Big]\Big[8F'G' + 4G\Big(2LF' + F''\Big)$$

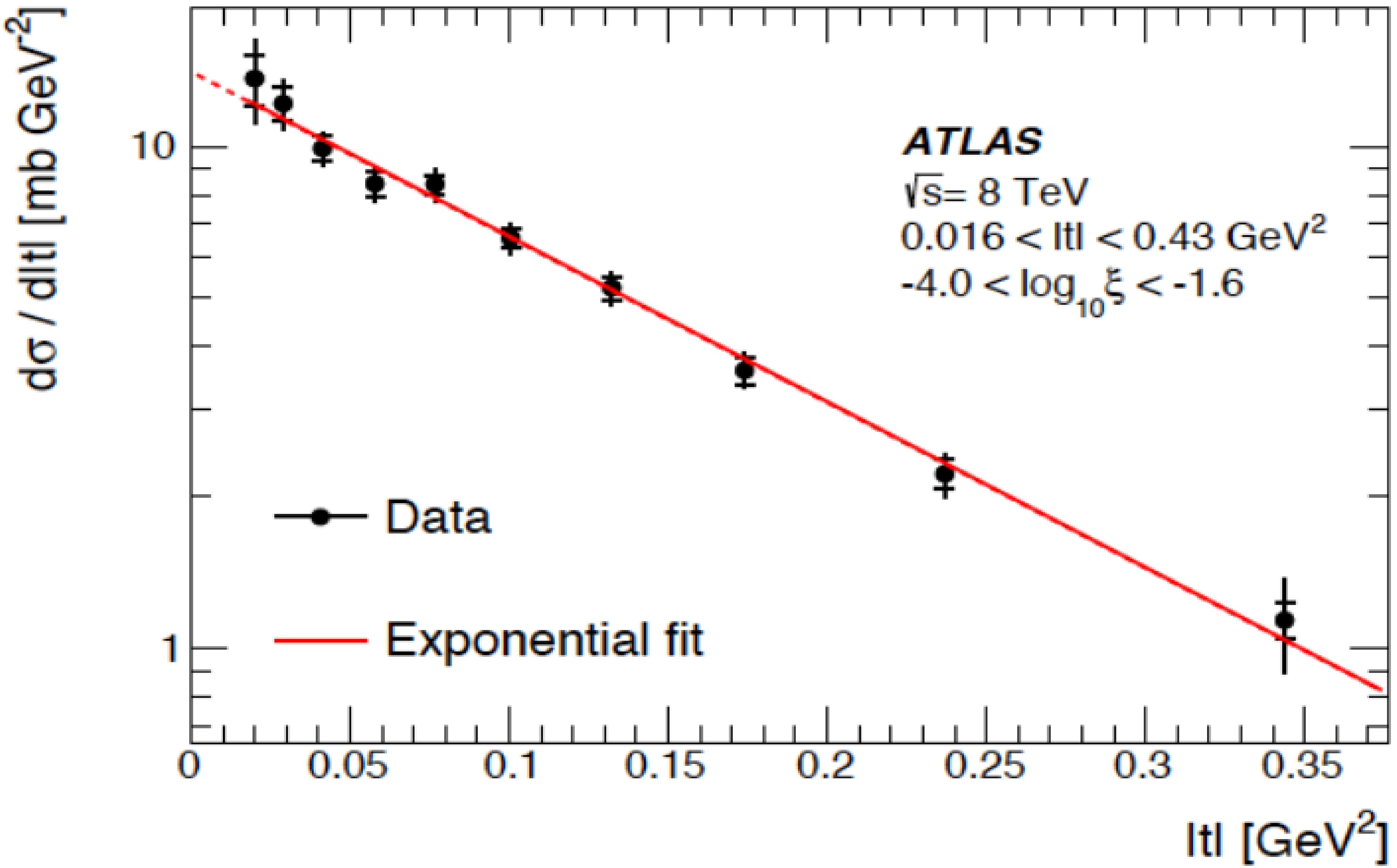
$$+F(4L^2 + \pi^2)G + 4\Big(2LG' + G''\Big)\Big],$$

where $L = \ln(s/s_0))$ and the primes imply differentiation in $\alpha(t)$.

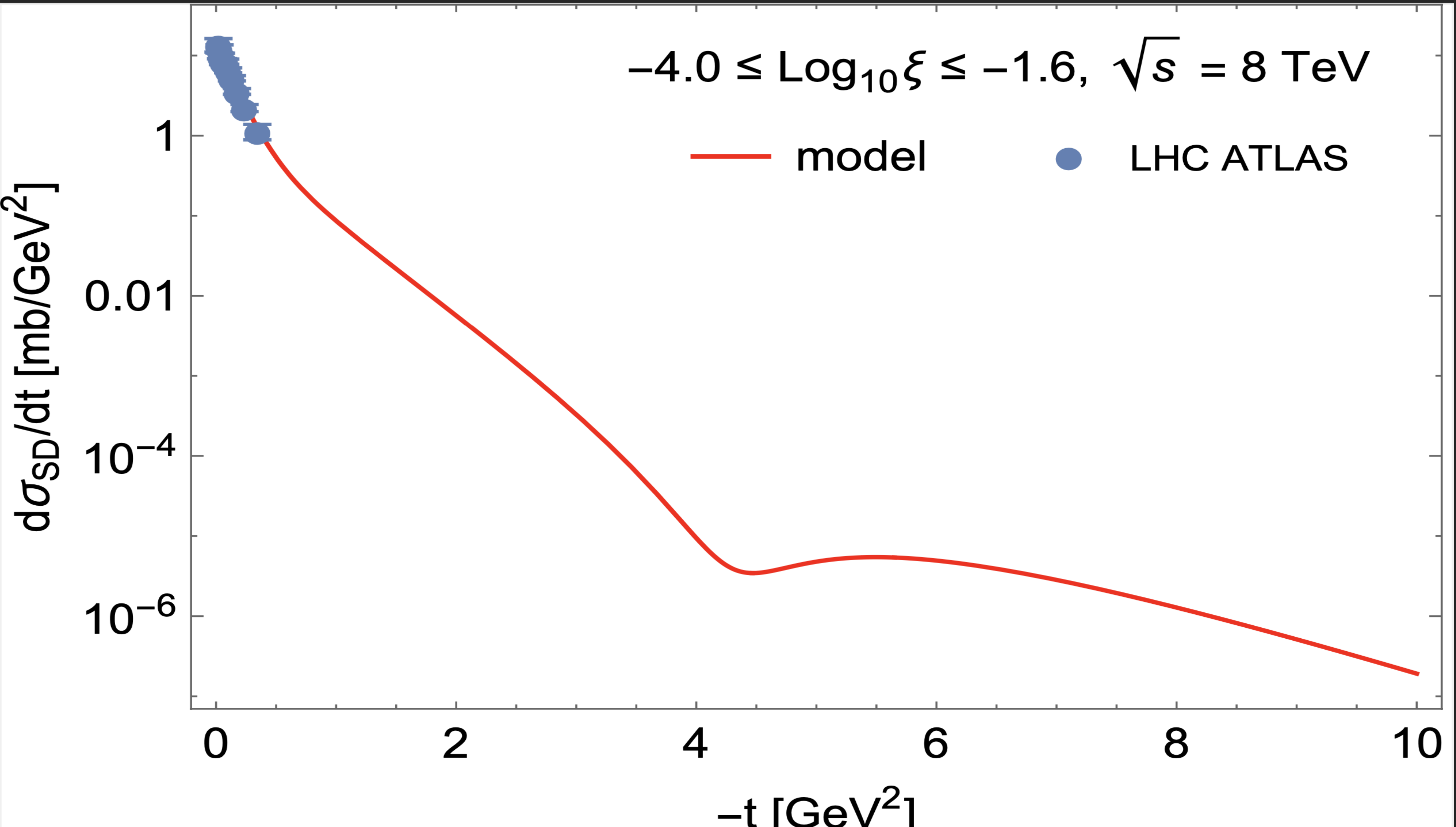
Similar to the case of elastic scattering, the Dipole SD amplitude is recovered by differentiation (for simplicity (we set $s_0 = 1$ GeV^2)):

$$T_{DP} = \frac{d}{d\alpha} T(s, t, M^2) = e^{-i\pi\alpha/2} s^{\alpha} [G' F_2 + F_2' G + (L - i\pi/2) G F_2], \tag{19}$$

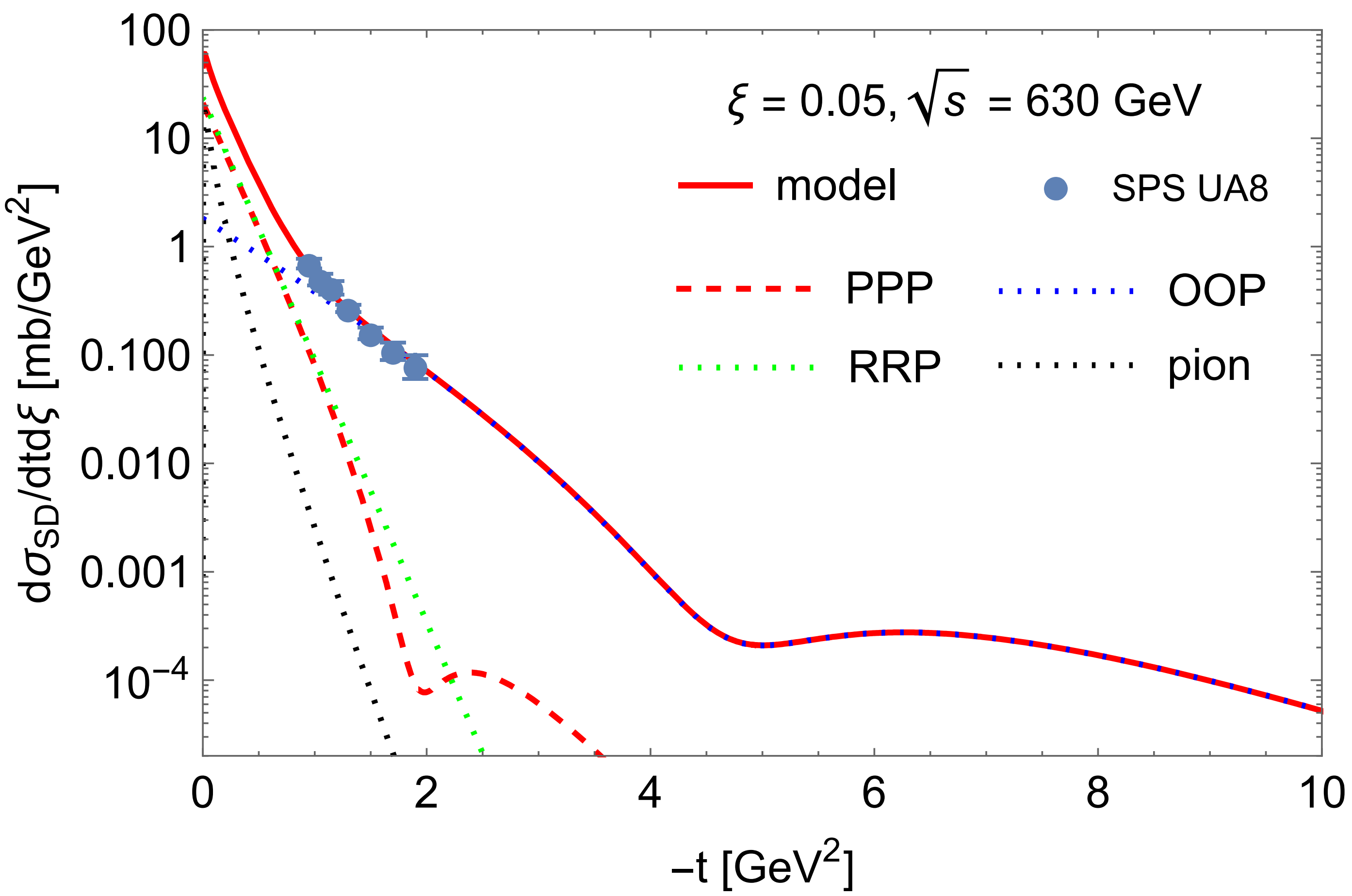
where $L = \ln(s/(1GeV^2))$ and the primes imply differentiation in $\alpha(t)$.



dσ / d|t| [mb GeV^{-2}]
10
1
ATLAS
√s= 8 TeV
0.016 < |t| < 0.43 GeV^2
-4.0 < $\log_{10}\xi$ < -1.6
Data
Exponential fit
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
|t| [GeV^2]

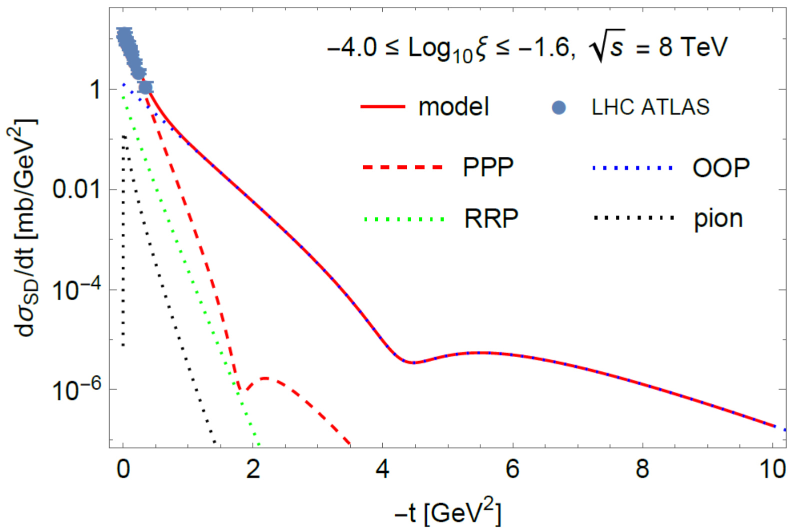


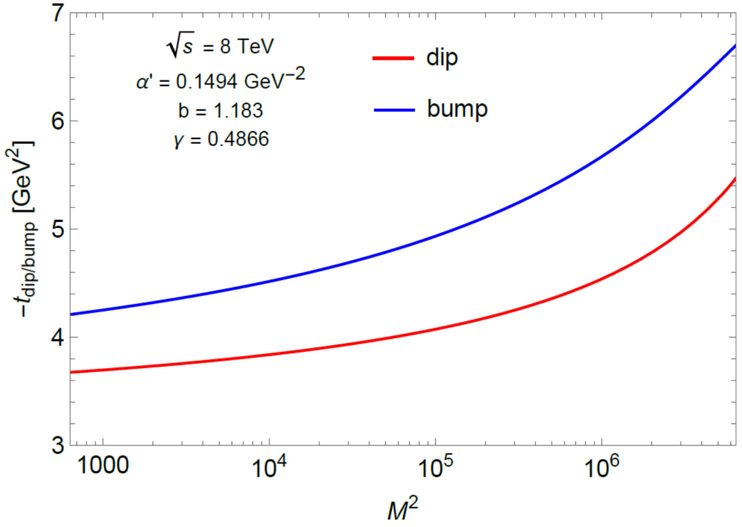
$-4.0 \leq \mathrm{Log}_{10}\xi \leq -1.6,\ \sqrt{s} = 8$ TeV
model
LHC ATLAS
$d\sigma_{SD}/dt$ [mb/GeV^2]
$-t$ [GeV^2]
1
0.01
10^{-4}
10^{-6}
0
2
4
6
8
10



ξ = 0.05, √s = 630 GeV
model
SPS UA8
PPP
OOP
RRP
pion
dσSD/dtdξ [mb/GeV2]
−t [GeV2]
100
10
1
0.100
0.010
0.001
10−4
0
2
4
6
8
10

dip-bump in –t at LHC





$$-t_{dip} = \frac{1}{\alpha' b}\ln\frac{b+L_s}{\gamma b L_s}$$

$$-t_{bump} = \frac{1}{\alpha' b}\ln\frac{4(b+L_s)^2+\pi^2}{\gamma b(4L_s^2+\pi^2)}$$

$$L_s = \ln(s/M^2)$$

Conclusions

Theoretical and experimental search for structures in proton diffractive dissociation at the LHC kinematical region (and elsewhere) provide new perspectives in high-energy physics.

Make your prediction, do your measurements!

Thank you for your attention!