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Structures in single- and double diffractive dissociation at the LHC

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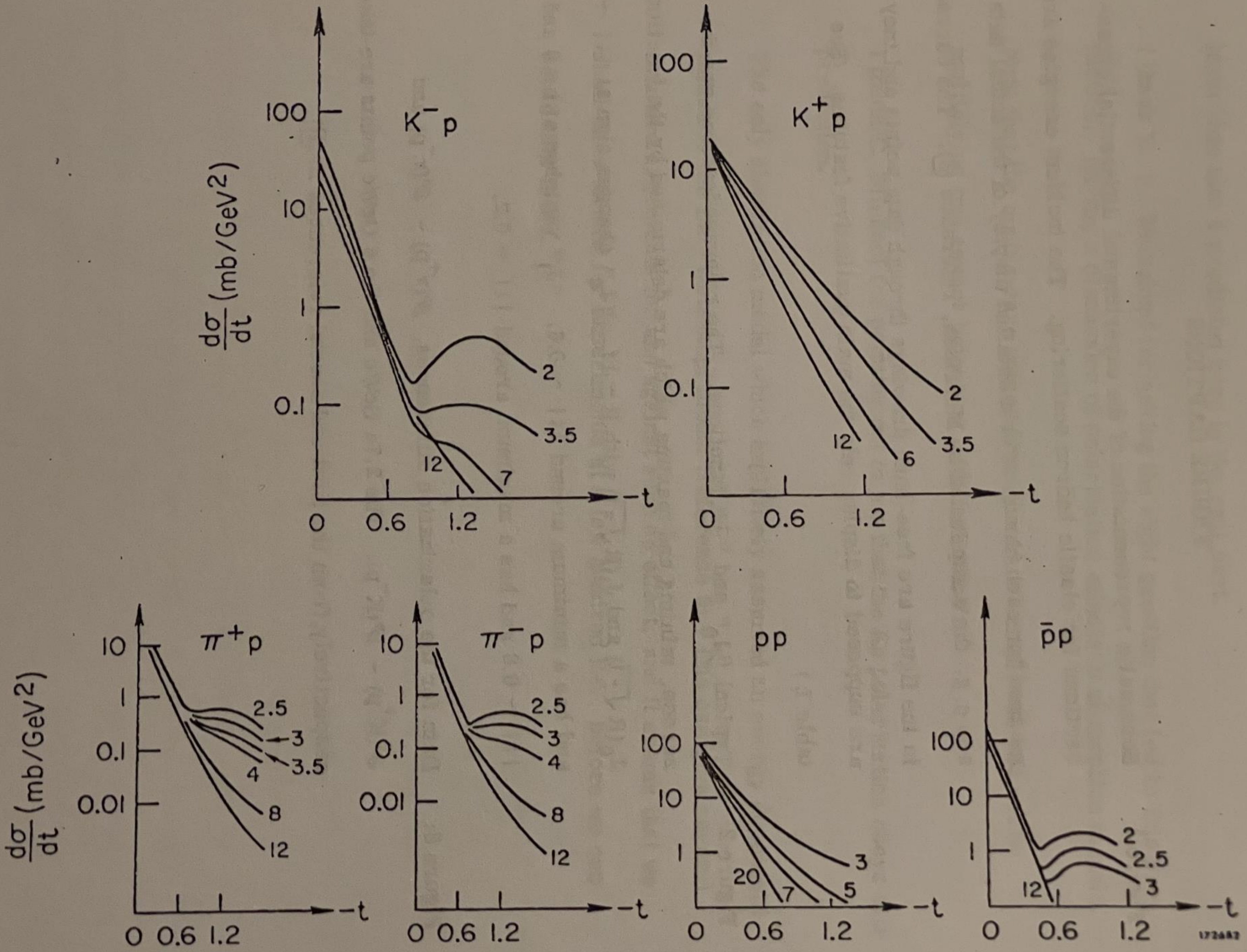
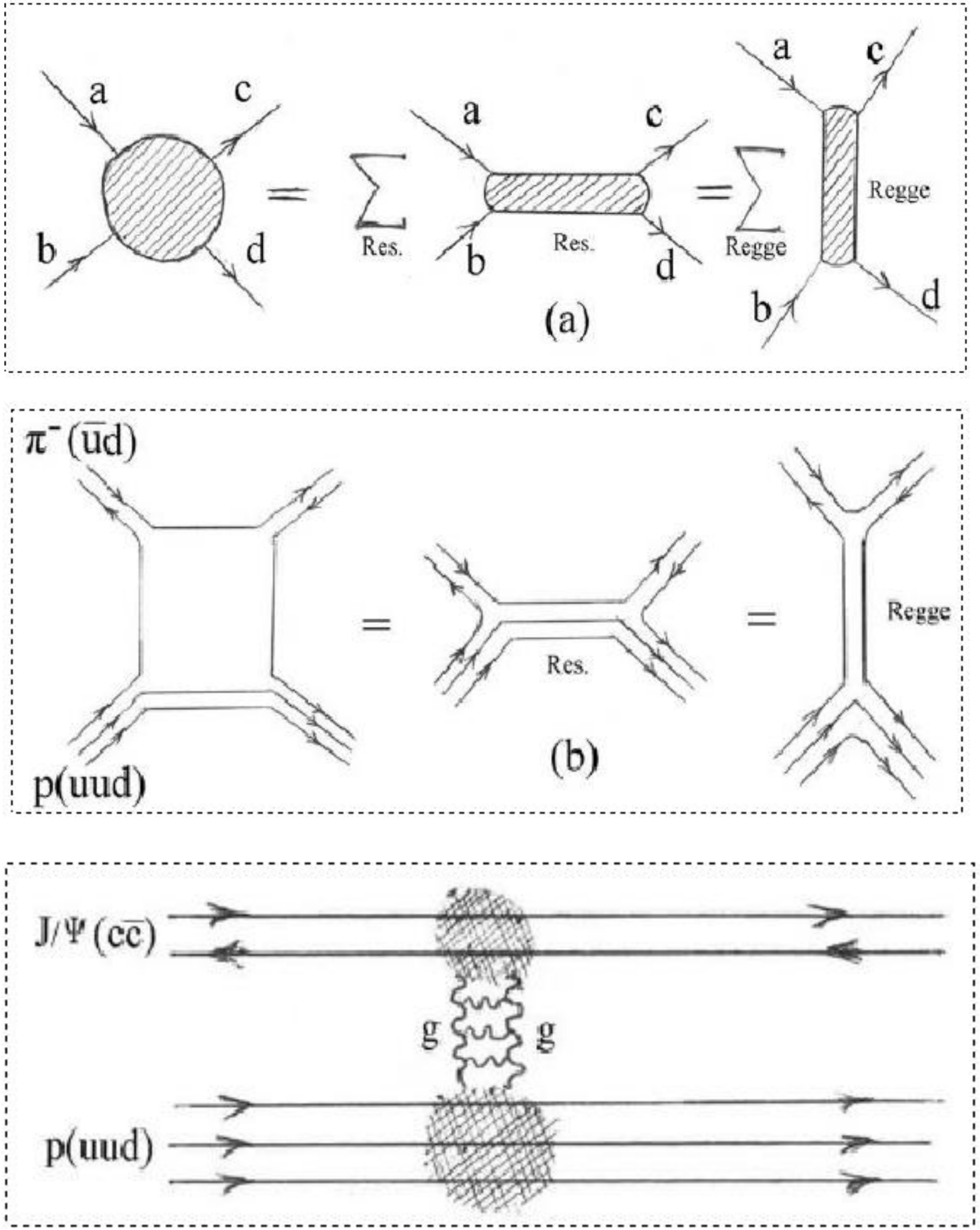


K⁻p
K⁺p
π⁺p
π⁻p
pp
p̄p
dσ/dt (mb/GeV²)
-t
0 0.6 1.2
100
10
1
0.1
0.01
2
3.5
7
12
6
2.5
3
4
8
5
20
172682



a
b
c
d
Res.
Regge
(a)
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	$s^{\alpha-1},\ \alpha<1$	$s^{\alpha-1},\ \alpha\geq 1$

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

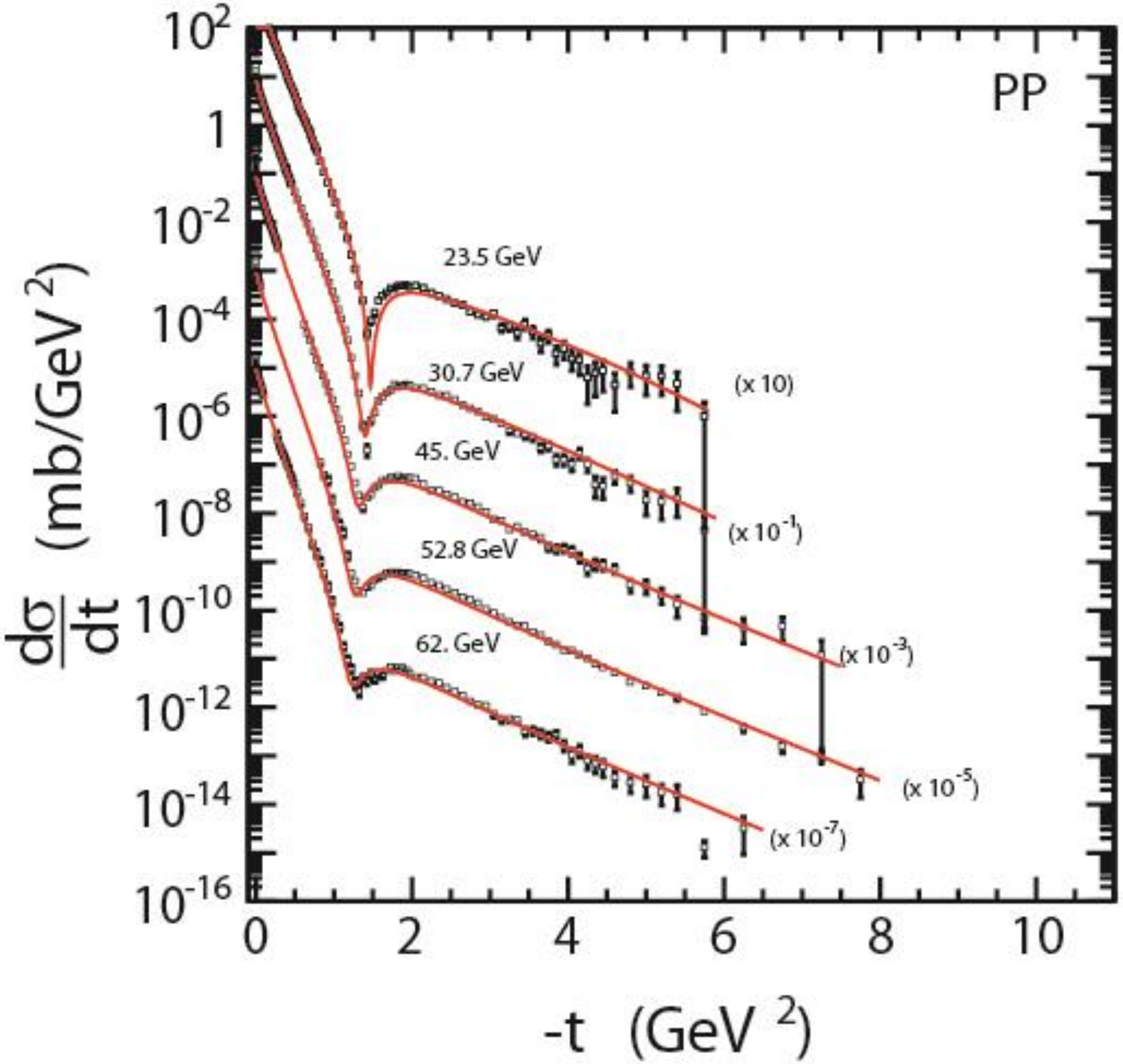
$$\sigma_{el} = \int_{t_{min\approx -s/2\approx\infty}}^{t_{thr.\approx 0}} \frac{d\sigma}{dt} dt; \quad \sigma_{in} = \sigma_t - \sigma_{el}; \quad B(s,t) = \frac{d}{dt} \ln\left(\frac{d\sigma}{dt}\right);$$

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

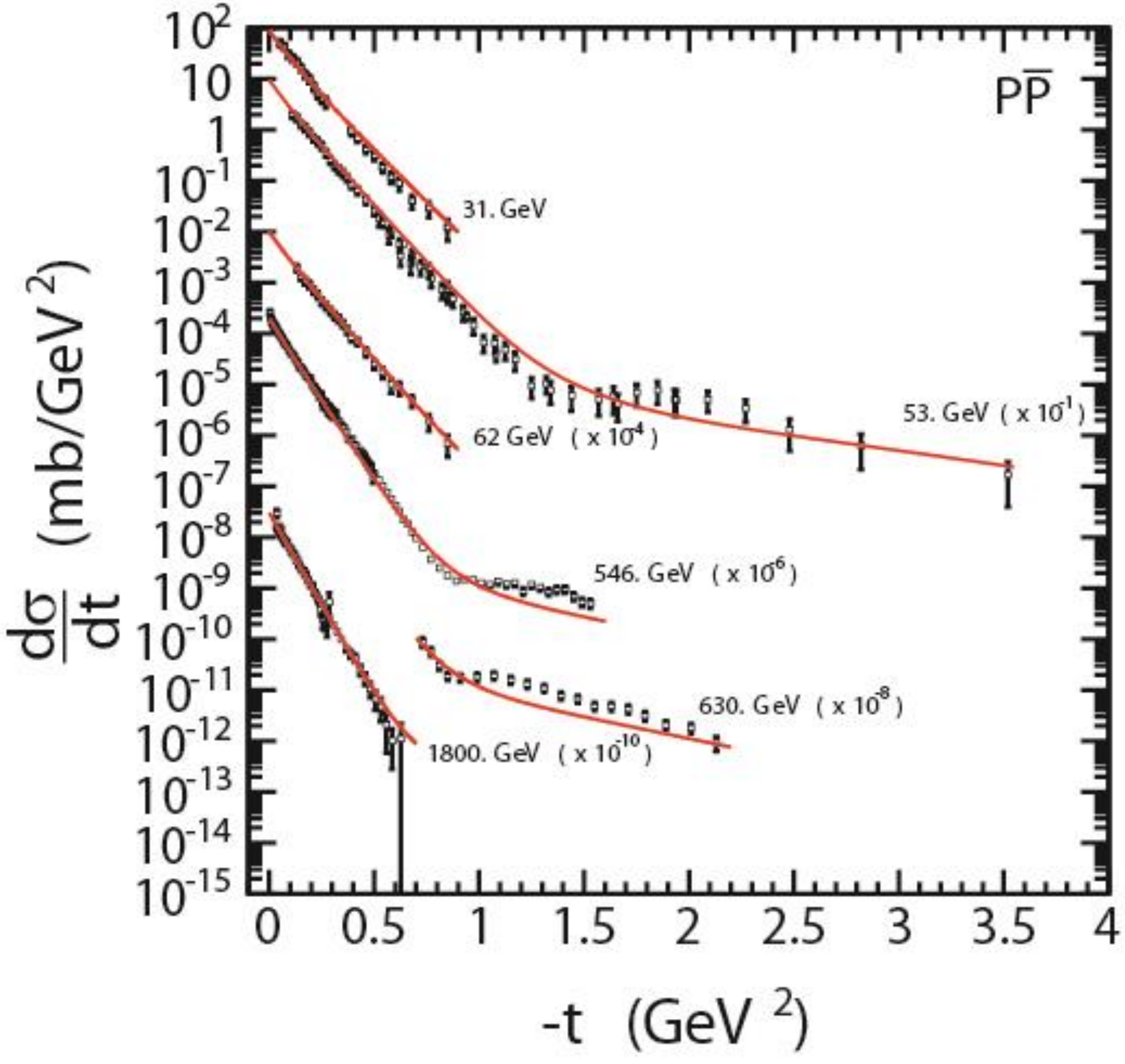
where P, O, f. ω are the Pomeron, odderon and non-leading Reggeon contributions.

α(0)\C	+	-
1	P	O
1/2	f	ω

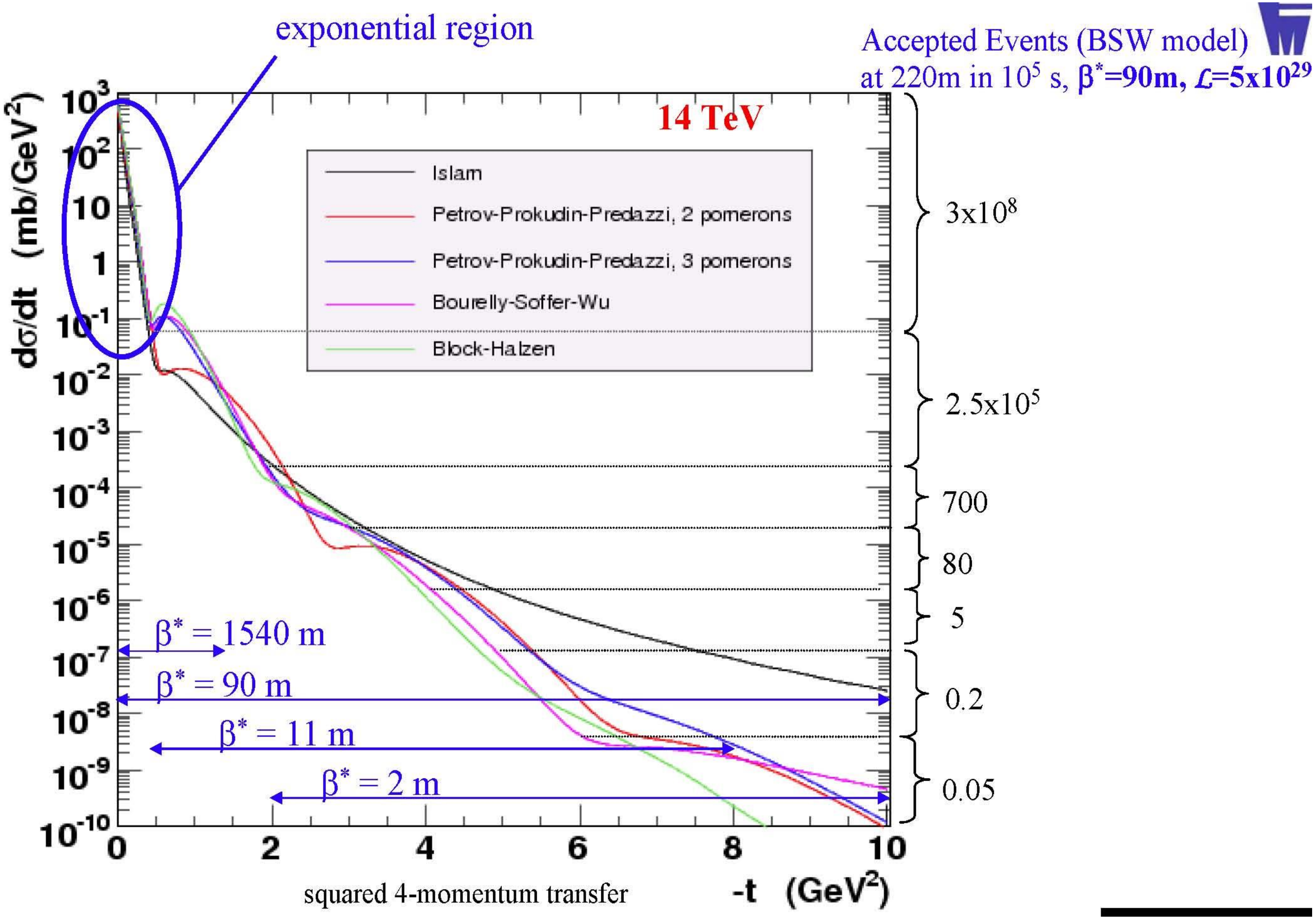
NB: The S-matrix theory (including Regge pole) is applicable to asymptotically free states only (not to quarks and gluons)!



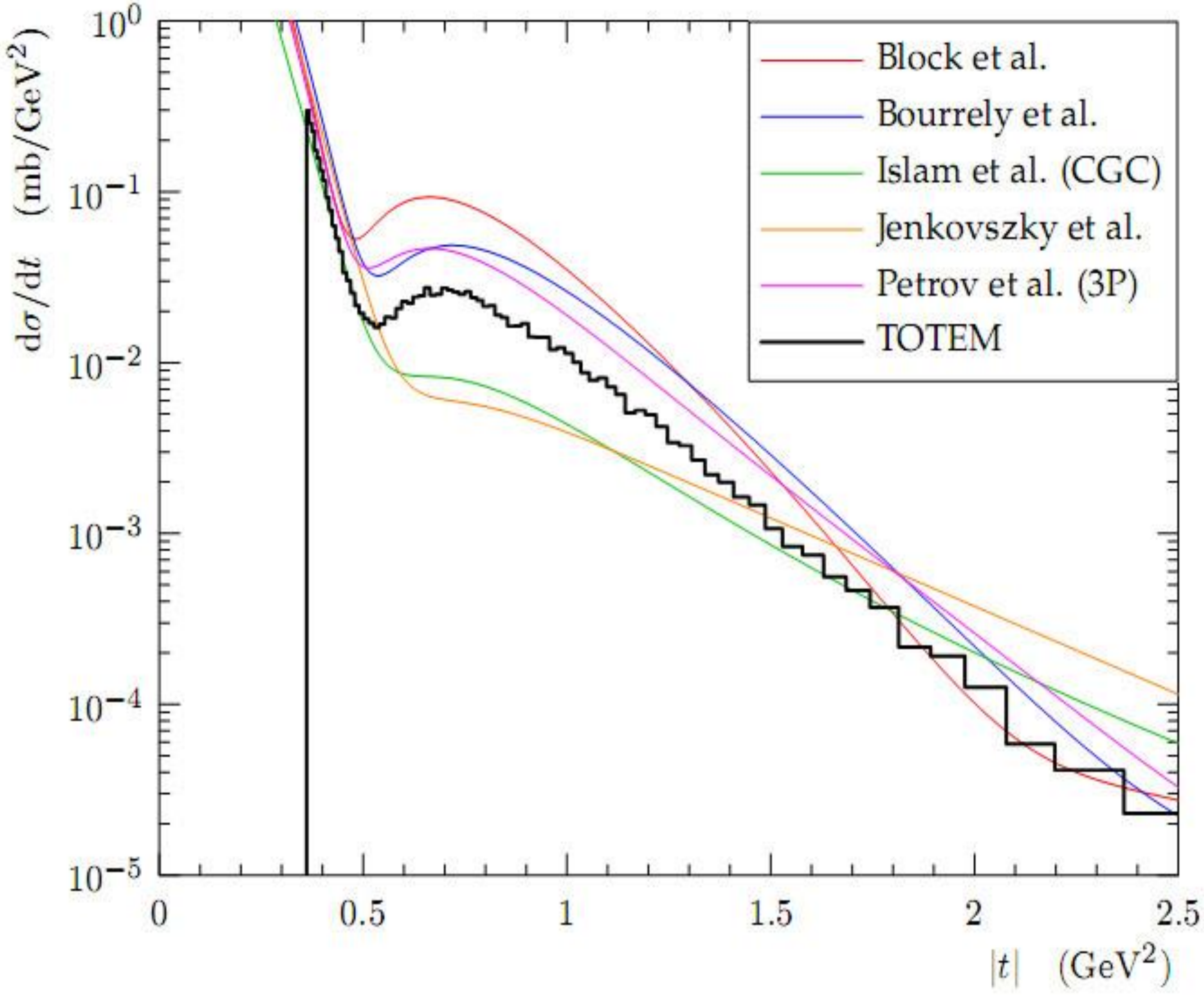
PP
23.5 GeV
30.7 GeV
45. GeV
52.8 GeV
62. GeV
(x 10)
(x 10^-1)
(x 10^-3)
(x 10^-5)
(x 10^-7)
dσ/dt (mb/GeV ^2)
-t (GeV ^2)



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)


exponential region
Accepted Events (BSW model)
at 220m in 10^5 s, β^*=90m, $\mathcal{L}$=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 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.

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

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

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

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.

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

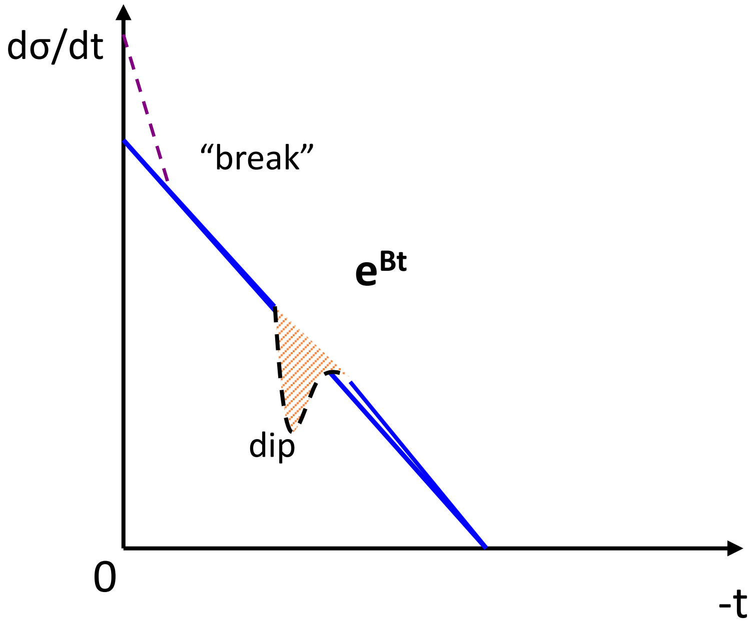
$$e^{-i\pi\alpha_P(t)/2}\Big(s/s_0\Big)^{\alpha_P(t)}\Big[G'(\alpha_P) + \Big(L - i\pi/2\Big)G(\alpha_P)\Big].$$

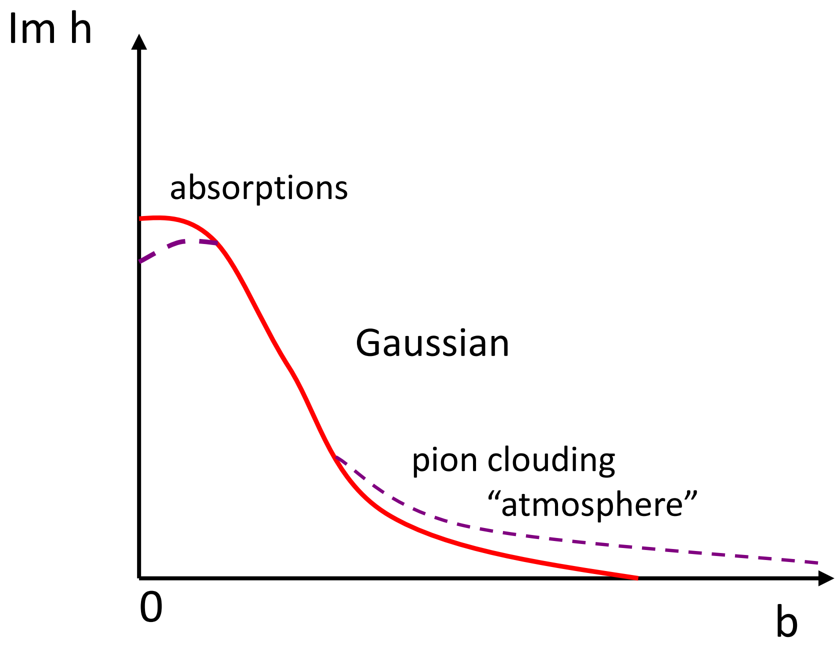
Geometrical scaling (GS), saturation and unitarity

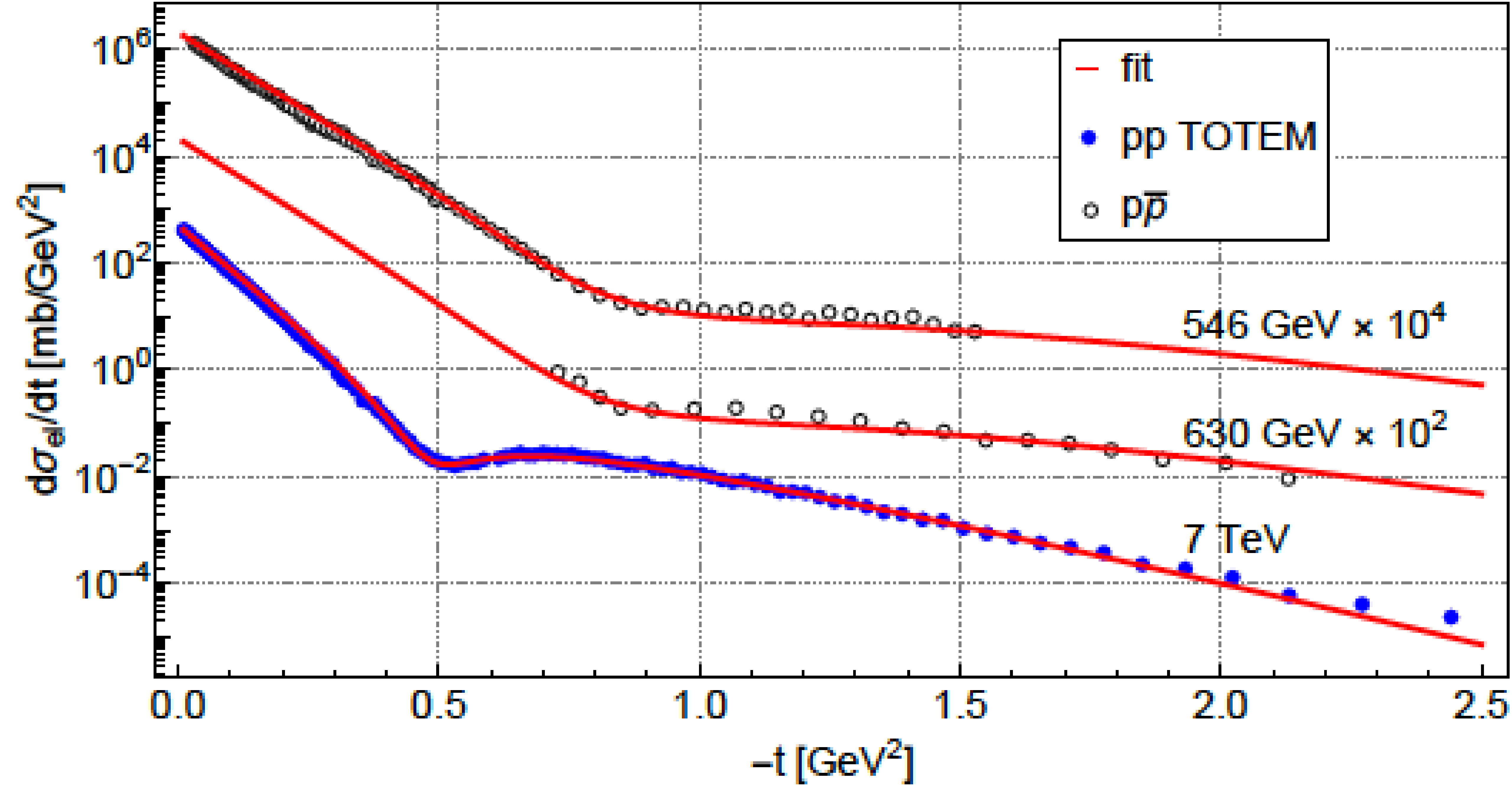
1. On-shell (hadronic) reactions (s,t, Q^2=m^2);

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

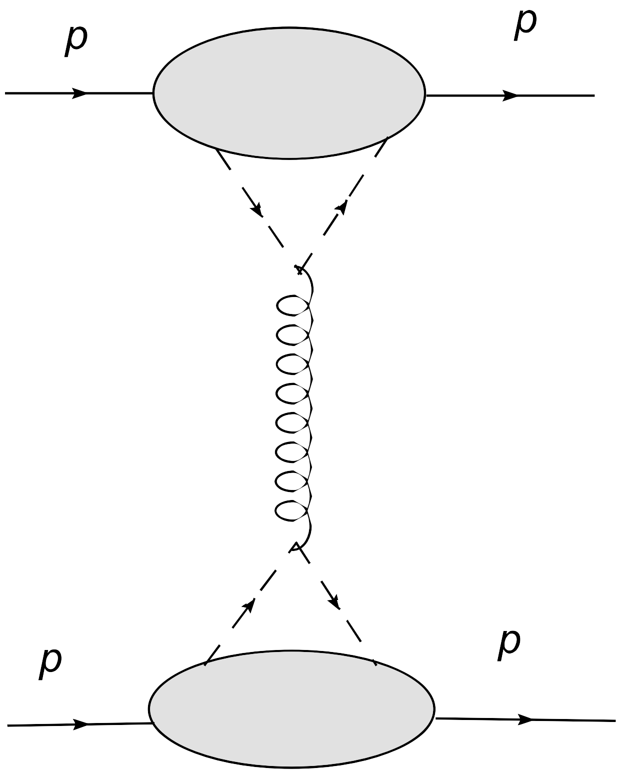
and dictionary:

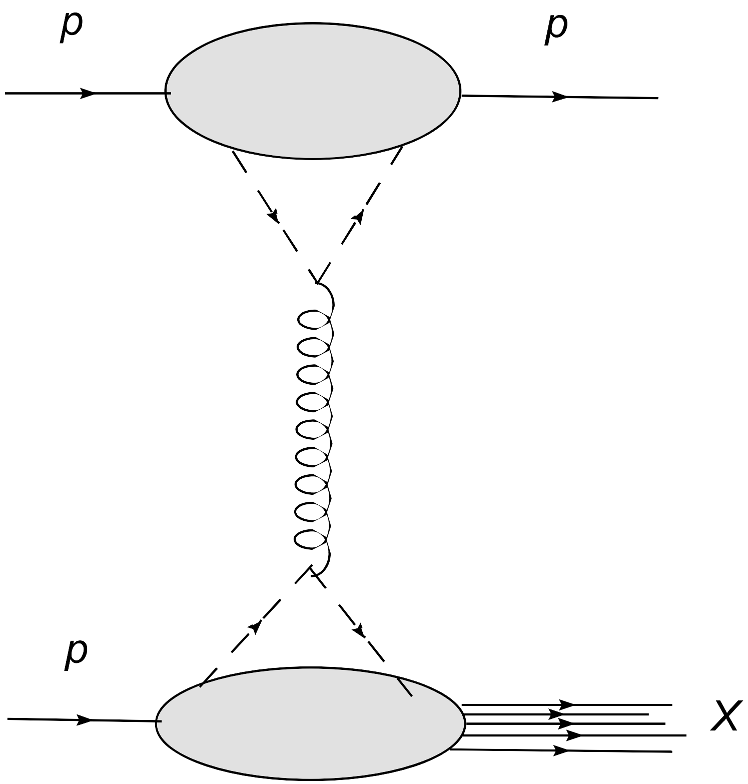


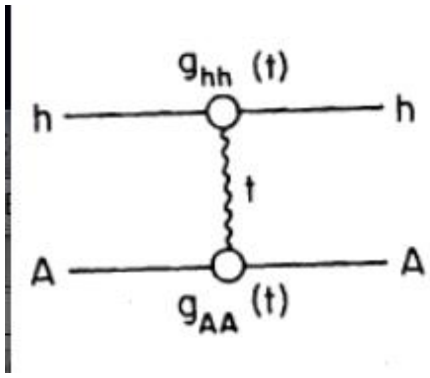


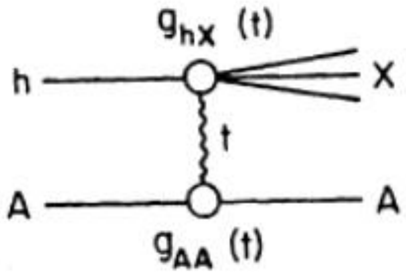


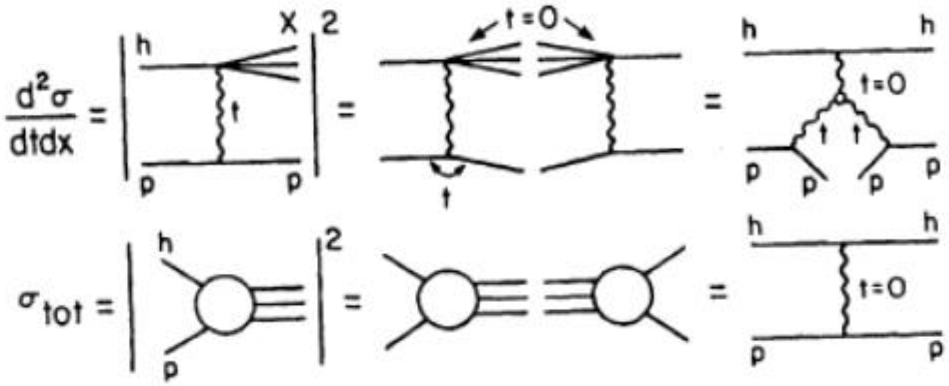
fit
pp TOTEM
$p\bar{p}$
546 GeV × 10^4
630 GeV × 10^2
7 TeV
$d\sigma_{el}/dt$ [mb/GeV^2]
$-t$ [GeV^2]
10^6
10^4
10^2
10^0
10^{-2}
10^{-4}
0.0
0.5
1.0
1.5
2.0
2.5


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)

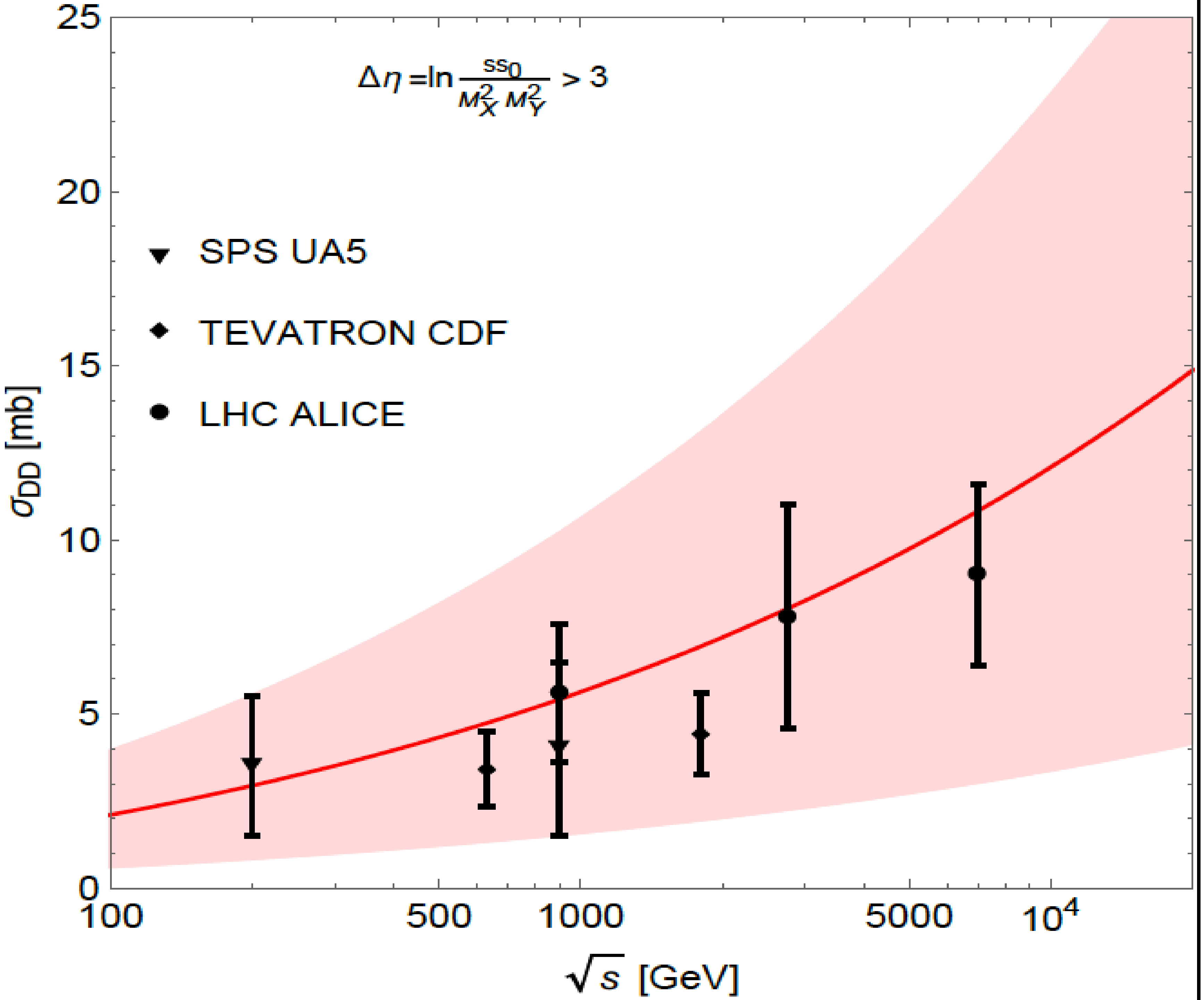

d²σ/dtdx =
h
X
t
p
p
2
=
t=0
t
=
h
h
t=0
t
t
p
p
p
p
σ_tot =
h
p
2
=
=
h
h
t=0
p
p

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:

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



$\Delta\eta = \ln \frac{s s_0}{M_X^2 M_Y^2} > 3$
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

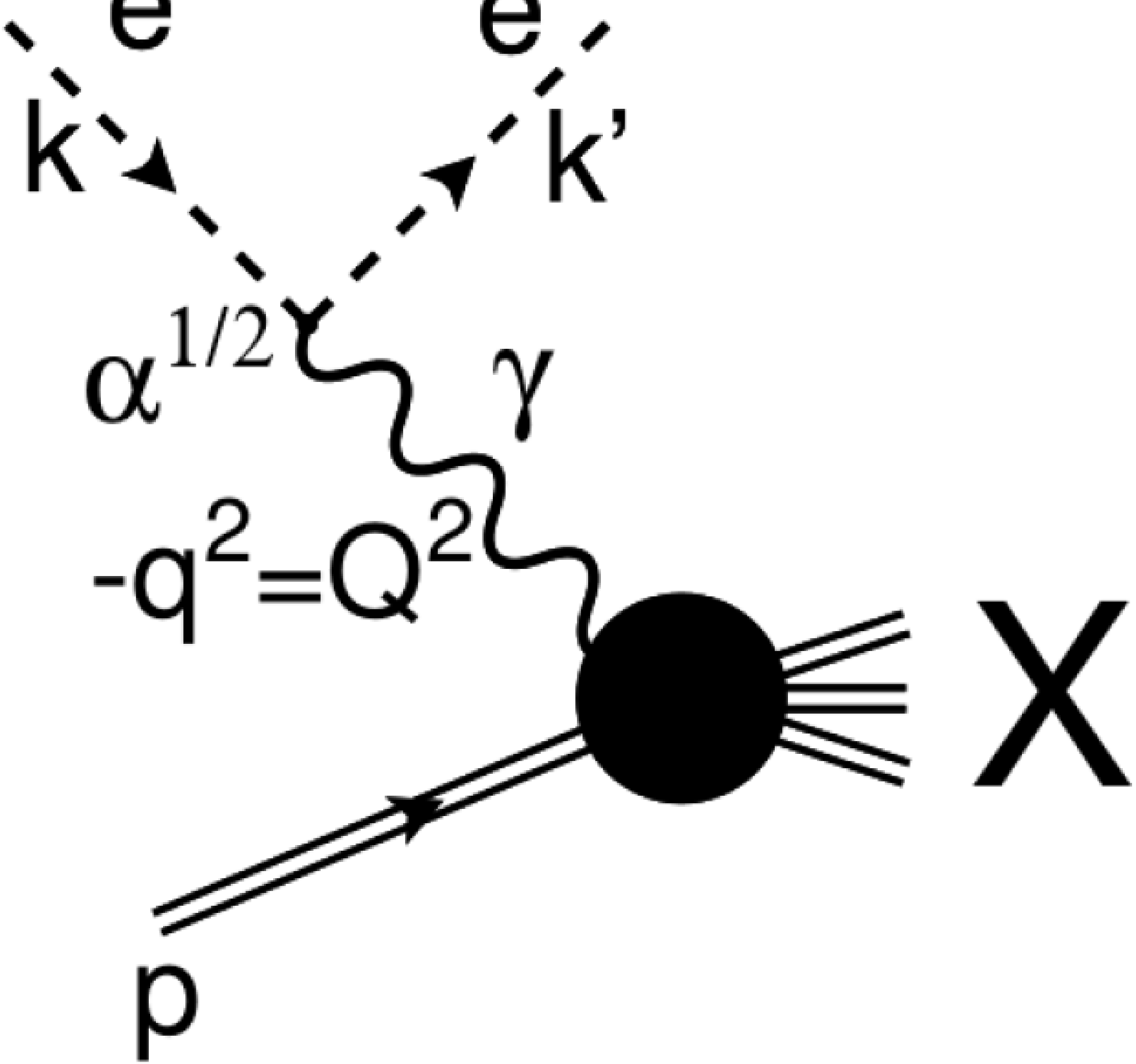
$$\frac{d^2\sigma}{dt dM_X^2} = \frac{9\beta^4[F^p(t)]^2}{4\pi \sin^2[\pi\alpha_P(t)/2]}(s/M_X^2)^{2\alpha_P(t)-2}\times \left[\frac{W_2}{2m}\left(1 - M_X^2/s\right) - mW_1(t+2m^2)/s^2\right], \tag{1}$$

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.

From elastic pp to single diffractive dissociation
(in the high mass (triple Regge) limit):

$G'_{El}(\alpha)=\exp(b*\alpha) \rightarrow F'_{Inel}\exp(\alpha * (b+\mathrm{Log}\, M^2))$

Low-M resonances, finite mass sum rules



e
e’
k
k’
α^{1/2}
γ
-q²=Q²
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)):

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

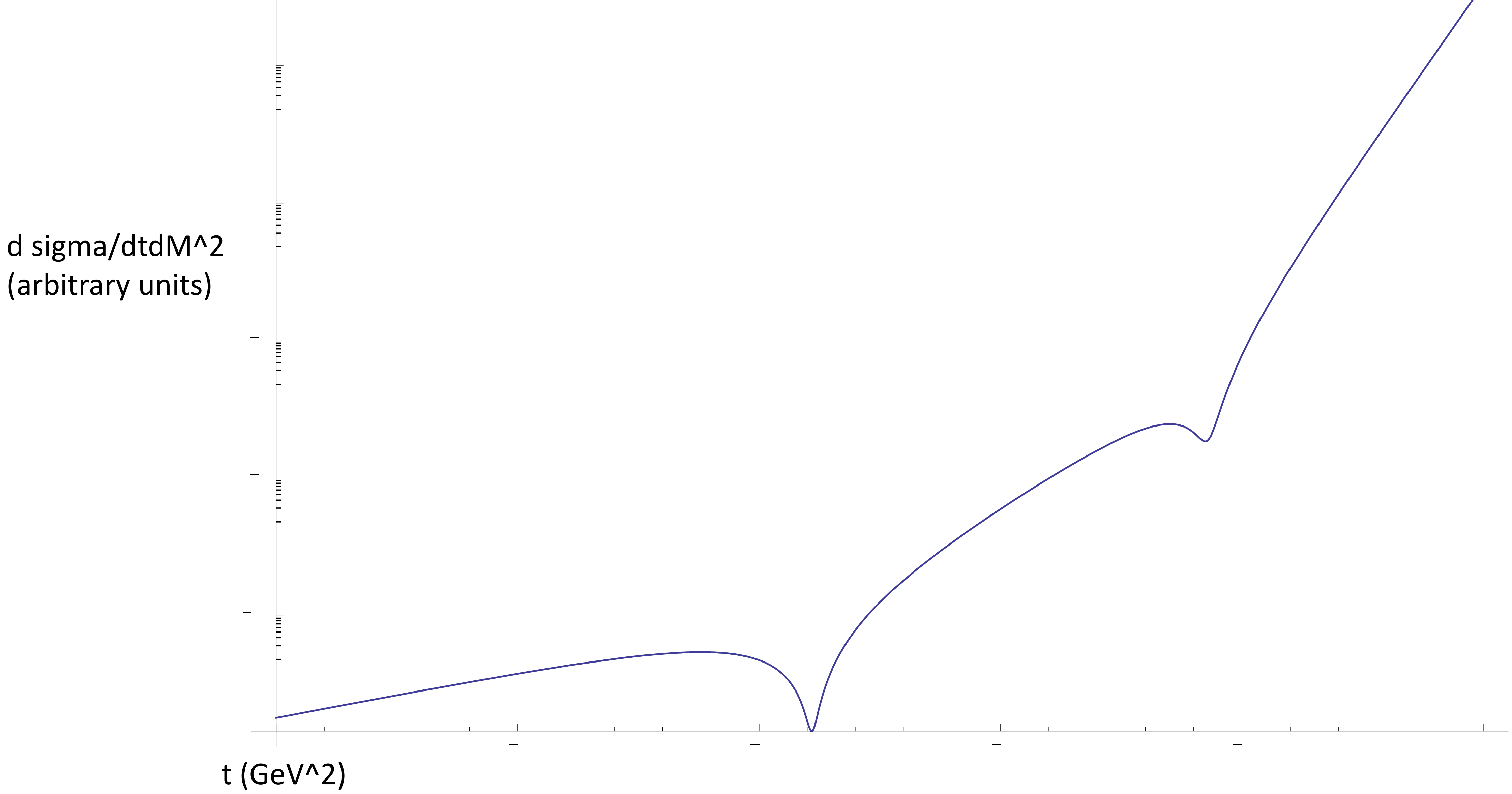
where $L = \ln(s/(1 GeV^2))$ and the primes imply differentiation in $\alpha(t)$.

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:

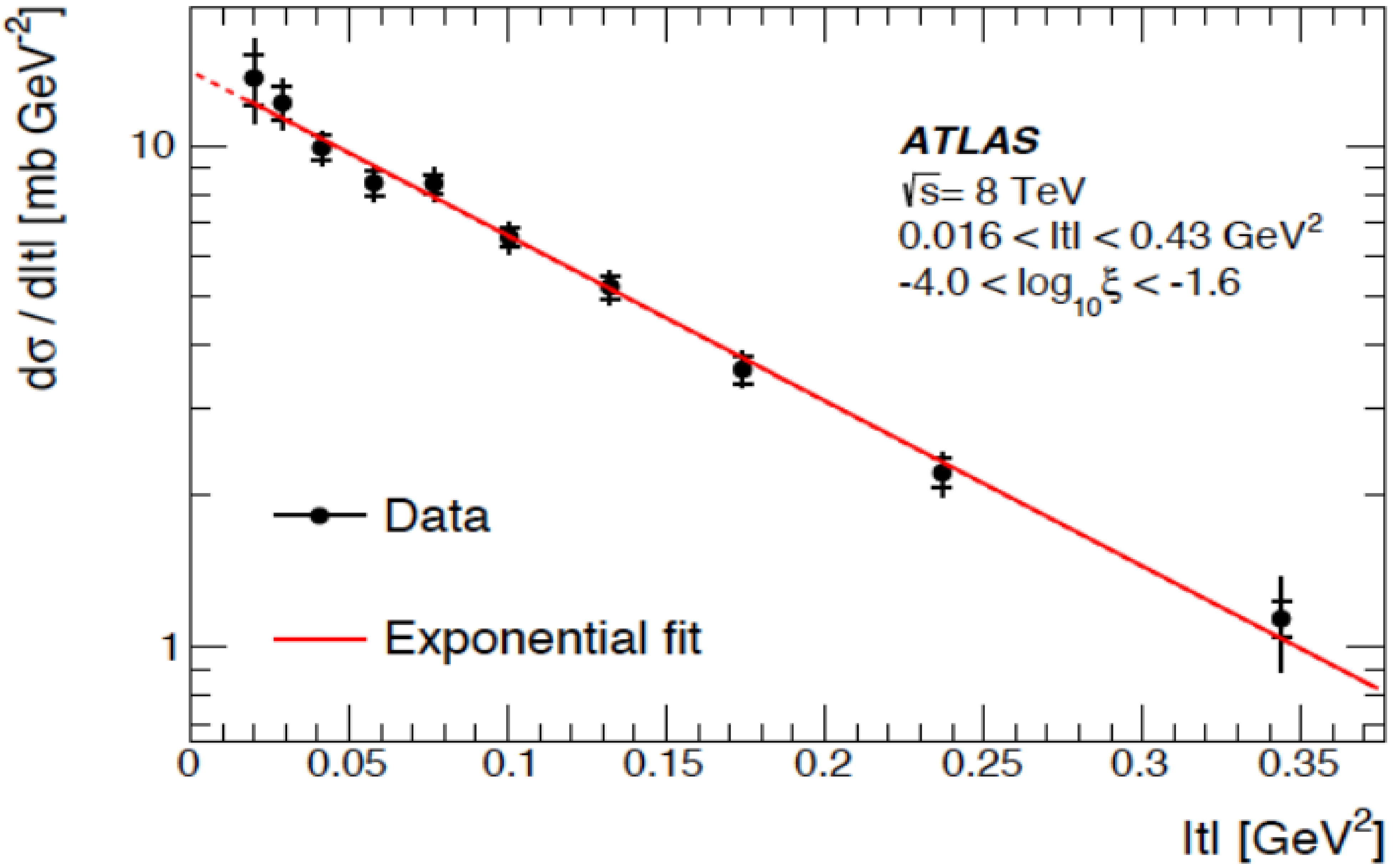
$$\frac{d|T_{SD}|^2}{d\alpha} = \frac{1}{2}\Big(\frac{s^2}{s_0^2}\Big)^{\alpha}\Big[GF' + F(LG + G')\Big]\Big[8F'G' + 4G\Big(2LF' + F''\Big)$$

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

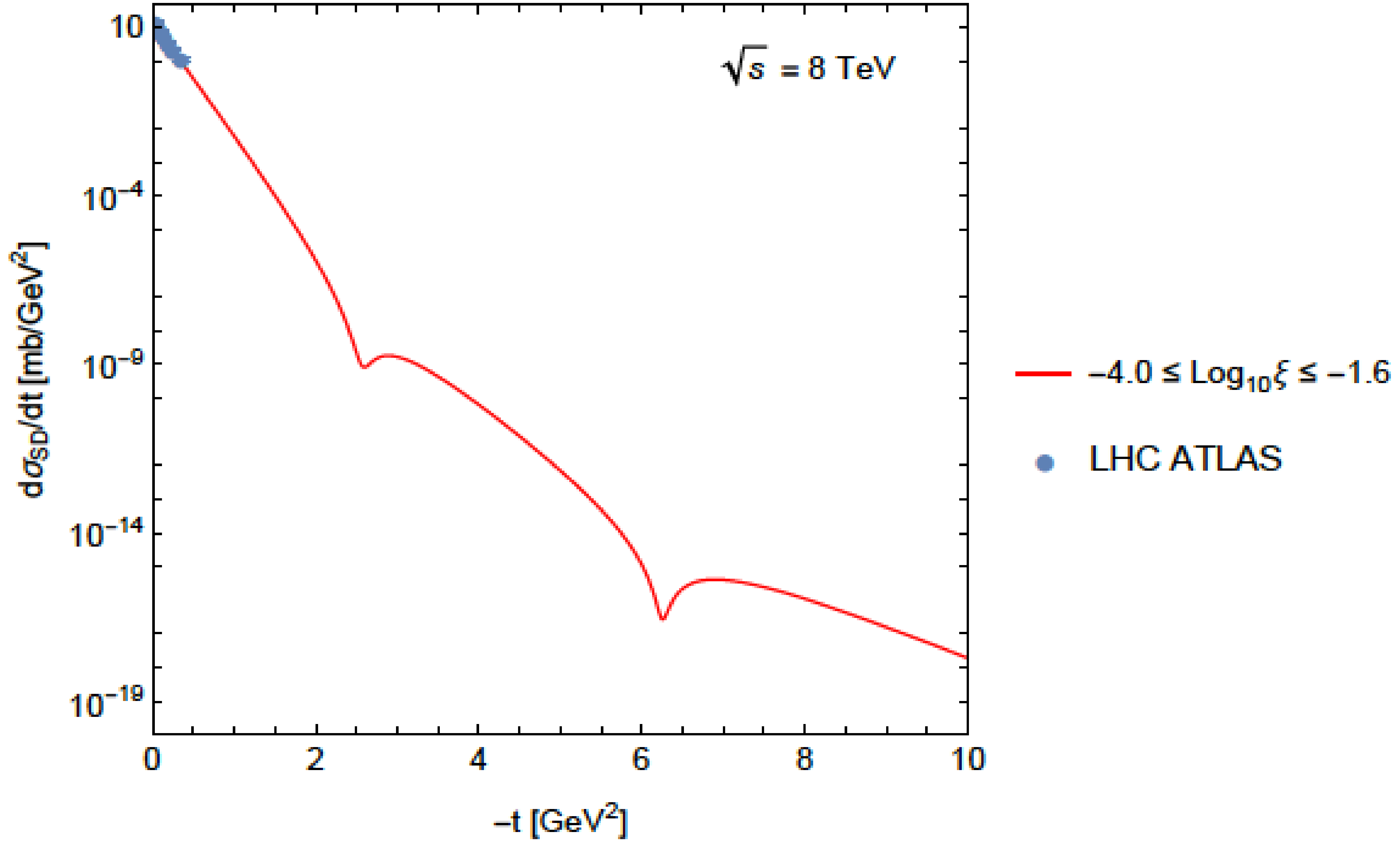
where $L = \ln(s/s_0))$ and the primes imply differentiation in $\alpha(t)$.



Single diffraction dissociation in the LHC kinematical region (prediction)



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



$\sqrt{s}$ = 8 TeV
10
10^{-4}
10^{-9}
10^{-14}
10^{-19}
$d\sigma_{SD}/dt$ [mb/GeV^2]
0
2
4
6
8
10
$-t$ [GeV^2]
$-4.0 \le Log_{10}\xi \le -1.6$
LHC ATLAS

Conclusions

Theoretical and experimental searches for structures in proton diffractive dissociation at the LHC kinematical region (and elsewhere) provide a new discovery window in high-energy physics -- virgin, immaculate (unlike the case of the odderon), not yet crowded or jammed.

Make your pioneer prediction, propose measurements!

Thank you for your attention!