QCD CHALLENGES

inTrento on February 27 – March 3

QCD CHALLENGES

in *pp*, *pA* and *AA* collisions

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Heidelberg, February 2017

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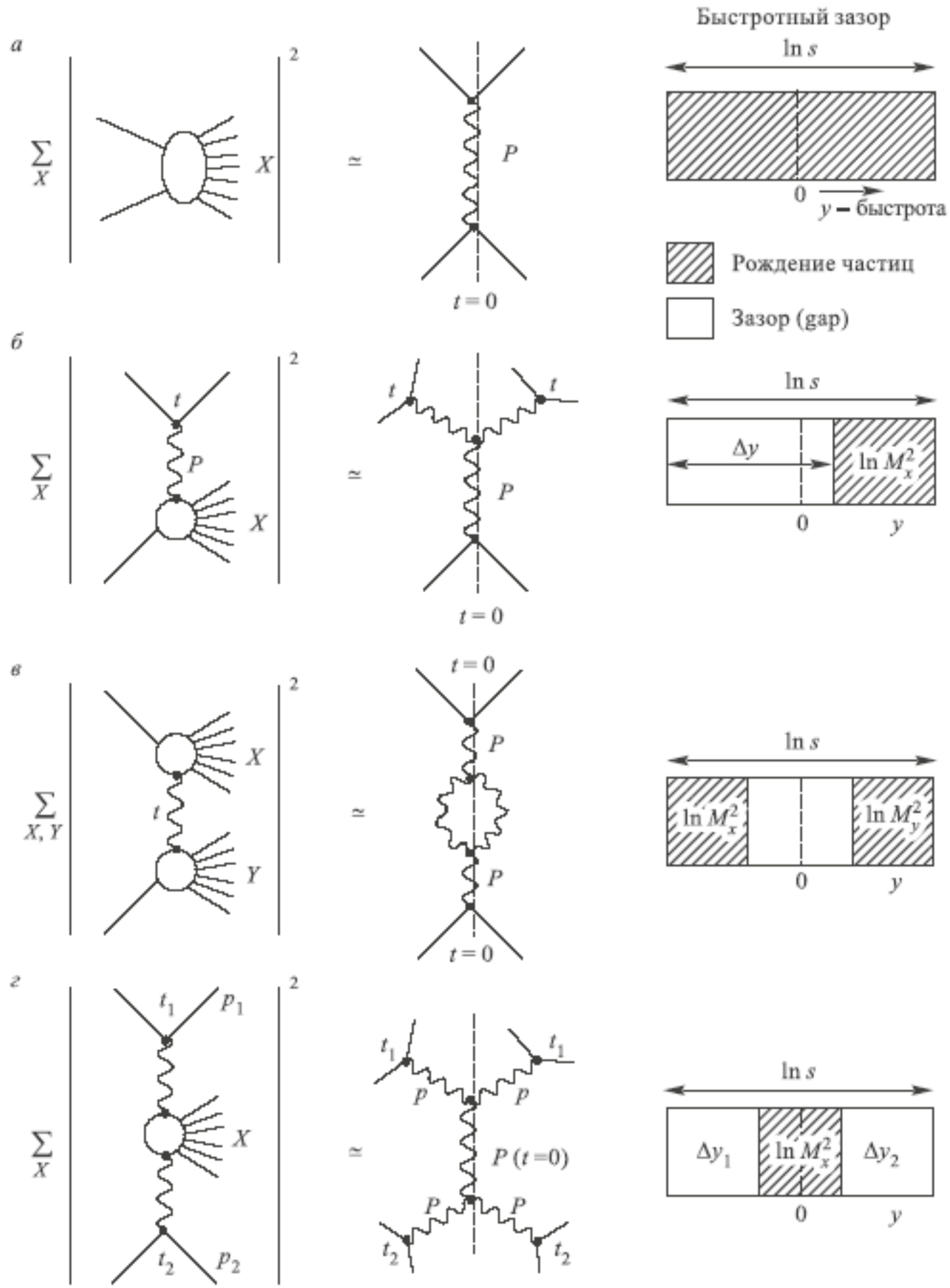
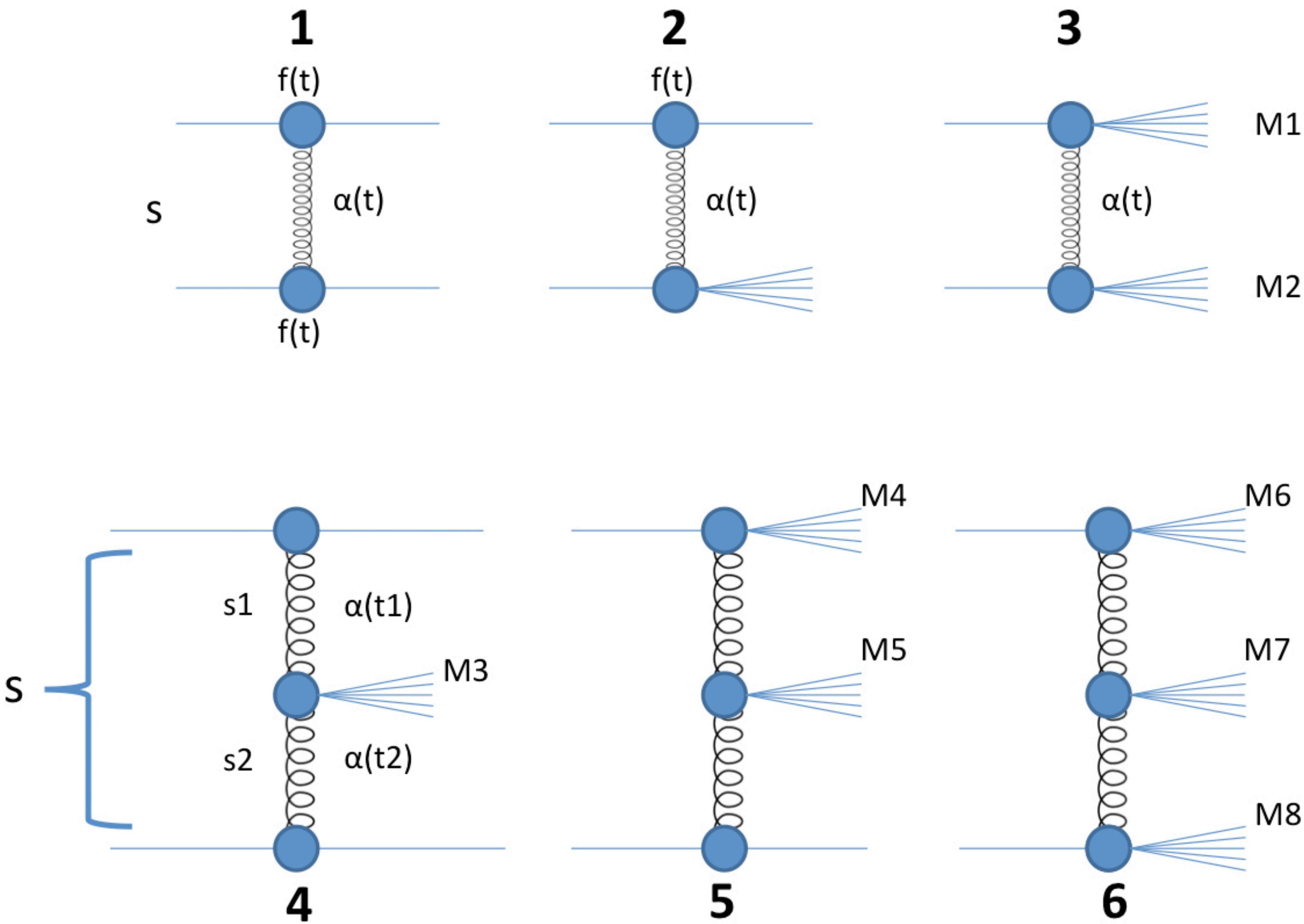
Content of the talk: *evergreen, still confusing issues*

- What is the Pomeron and what are the glueballs?
- How many Pomerons (“soft”, “hard”/”QCD”-, *etc.* Pomerons,…);
- “BFKL (Lipatov) Pomeron”: $s^{\alpha(t)} \rightarrow$ pQCD $\rightarrow$ $s^{\alpha(t)}$;
- Does (should) the Odderon exist and how to detect it?
- See: **Carlo Ewerz,** The Odderon: Theoretical Status and Experimental Tests, arXiv:hep-ph/0511196;
- *A proposal (let us put it forward!):* rescale LHC down to ~1.8 TeV ?!
- Momenum (t) vs. coordinate (b) picture (F-B transform);
- Beyond “*standard QCD*”?
- How many resonances, do they terminate on the ρ(m) plot?


Быстротный зазор
ln s
y – быстрота
Рождение частиц
Зазор (gap)
а
б
в
г
t = 0
P
X
Y
Δy
ln M_x^2
ln M_y^2
P (t = 0)
Δy_1
Δy_2



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

Factorization (nearly perfect at the LHC!)

$$(g_1g_2)^2 = \frac{(g_1f_1)^2(f_1g_2)^2}{(f_1f_2)^2}.$$

Hence

$$\frac{d^3\sigma}{dtdM_1^2dM_2^2} = \frac{d^2\sigma_1}{dtdM_1^2}\frac{d^2\sigma_2}{dtdM_2^2}\frac{d\sigma_{el}}{dt}.$$

Assuming exponential cone, t^{bt} and integrating in t, one gets

$$\frac{d^2\sigma_{DD}}{dM_1^2dM_2^2} = k\frac{1}{\sigma_{el}}\frac{d\sigma_1}{dM_1^2}\frac{d\sigma_2}{dM_2^2},$$

where $k = r^2/(2r-1)$, $r = b_{SD}/b_{el}$.

Further integration in M^2 yelds $\sigma_{DD} = k\frac{\sigma_{SD}^2}{\sigma_{el}}$.

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

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

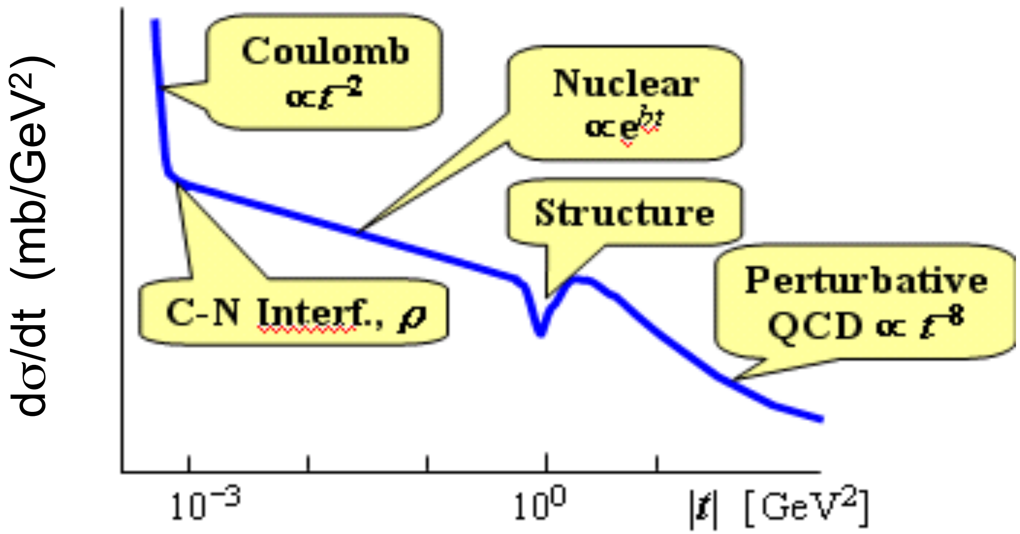
$$A_{pp}^{p\bar{p}}(s,t) = P(s,t) \pm O(s,t) + f(s,t) \pm \omega(s,t) \rightarrow_{LHC} \approx P(s,t) \pm O(s,t),$$

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

α(0)\C	+	-
1	P	O
1/2	f	ω

Elastic Scattering

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



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

θ = beam scattering angle

p = beam momentum

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

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

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

CNI region: $|f_C| \sim |f_N|$ → @ LHC: $-t \sim 6.5\ 10^{-4}$ GeV²; $\theta_{min} \sim 3.4$ μrad

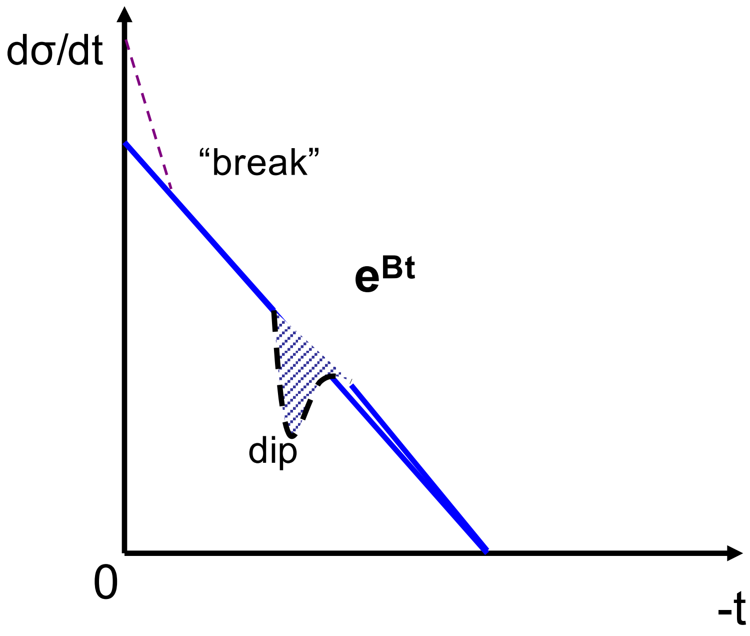
($\theta_{min} \sim 120$ μrad @ SPS)

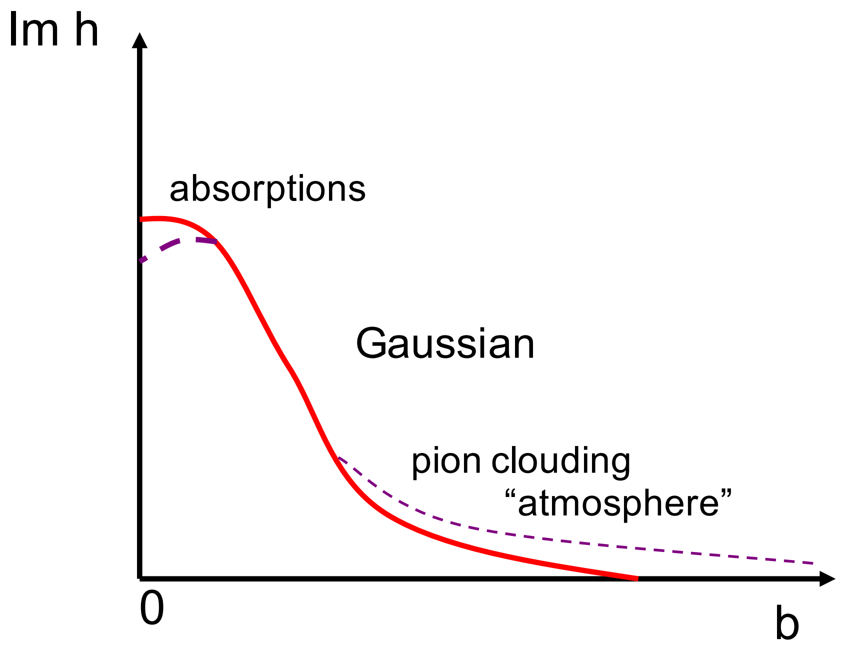
Geometrical scaling (GS), saturation and unitarity

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

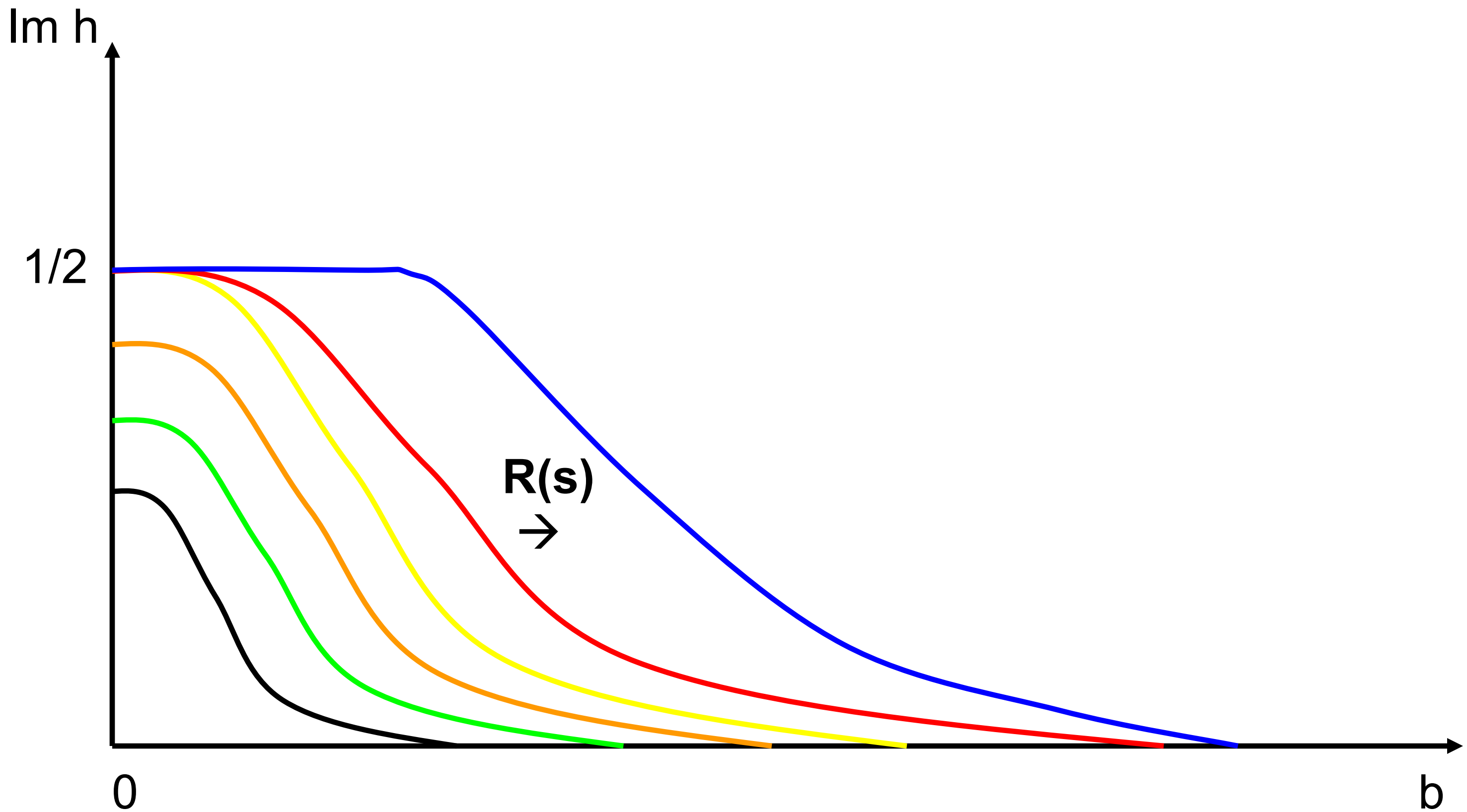
$t \leftrightarrow b$ **transformation:** $h(s,b) = \int_0^\infty d\sqrt{-t}\sqrt{-t}A(s,t)$

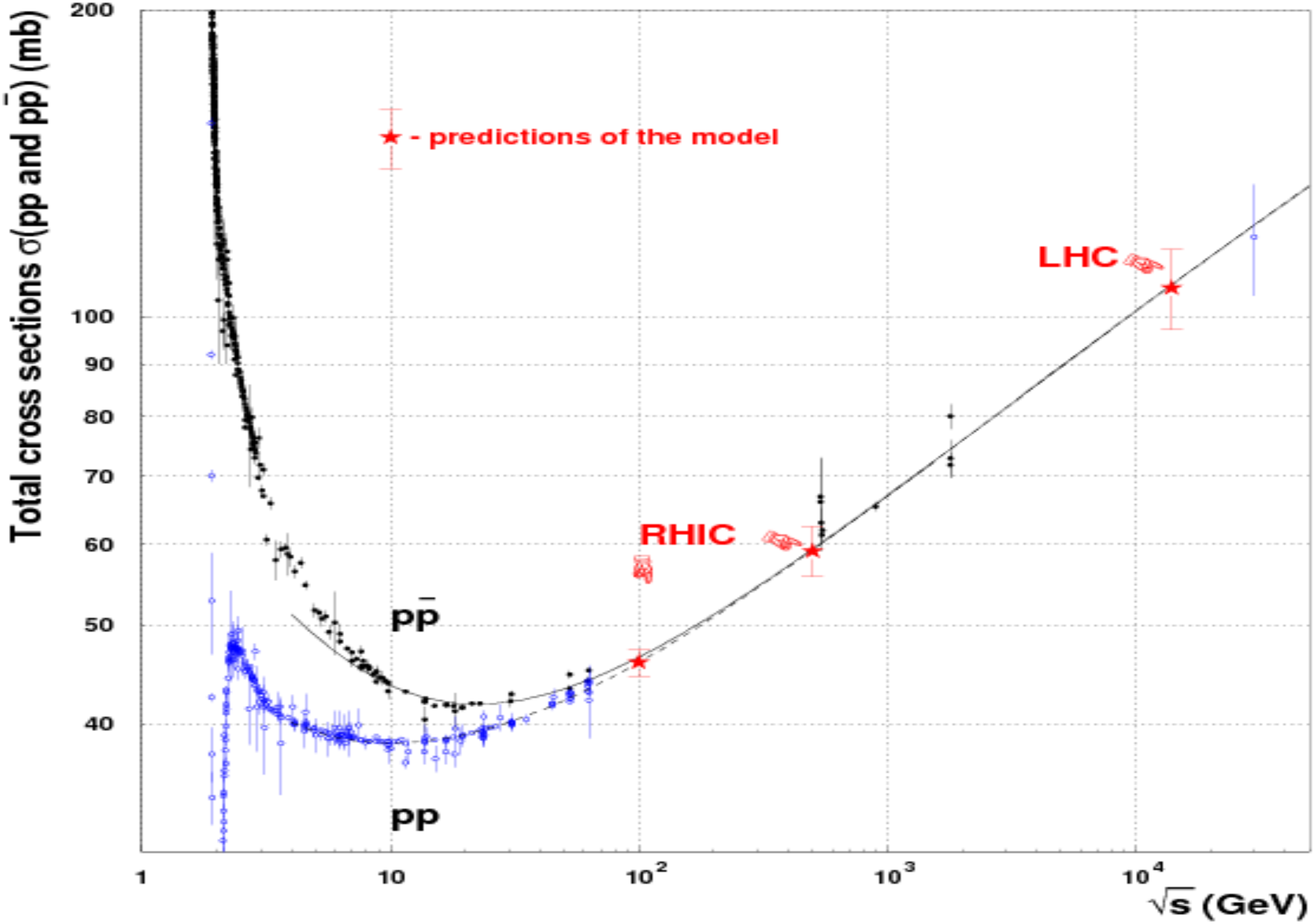
and dictionary:



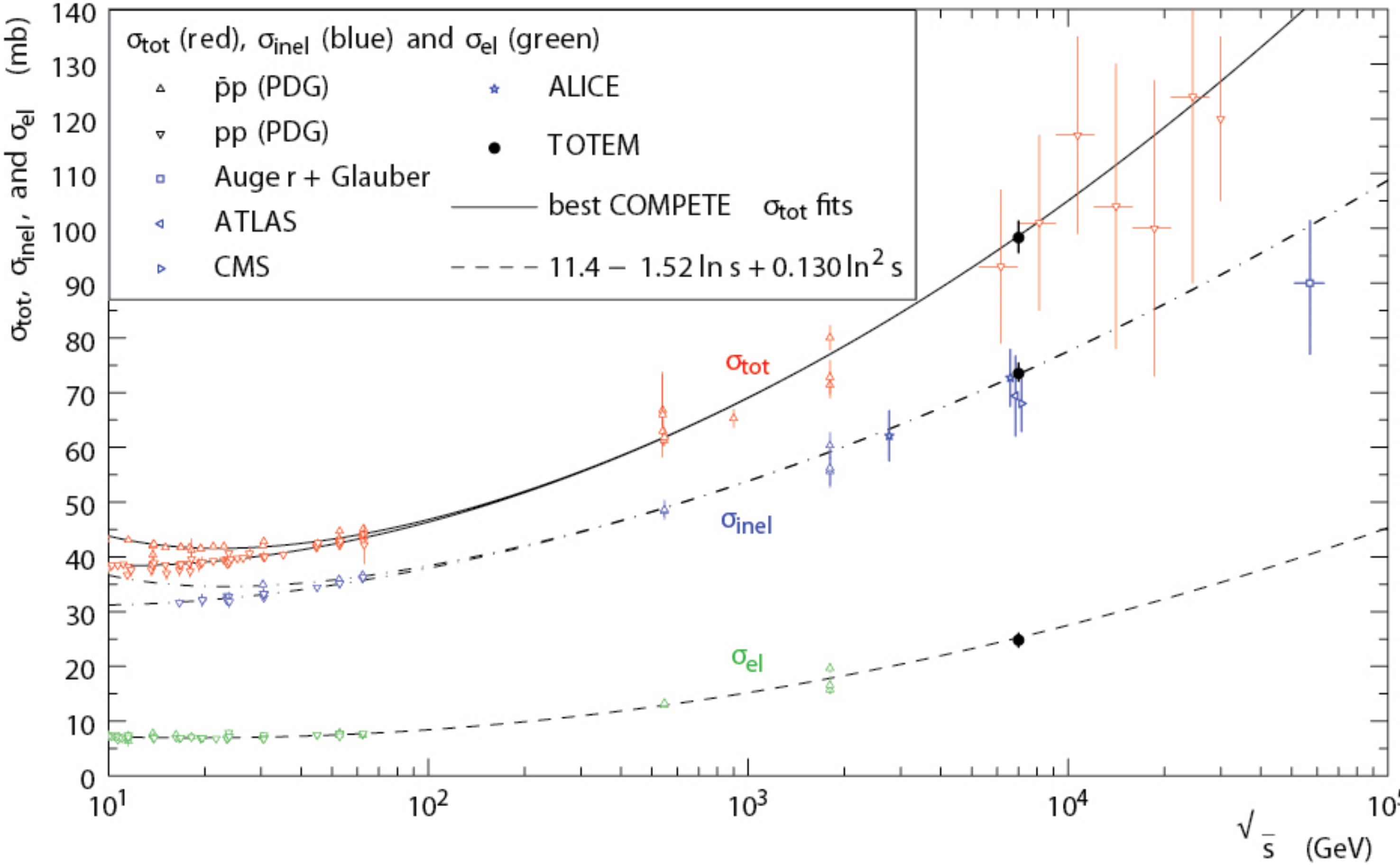


П.Дегрола, Л.Л. енковский, Б.В. Струминский, ЯФ

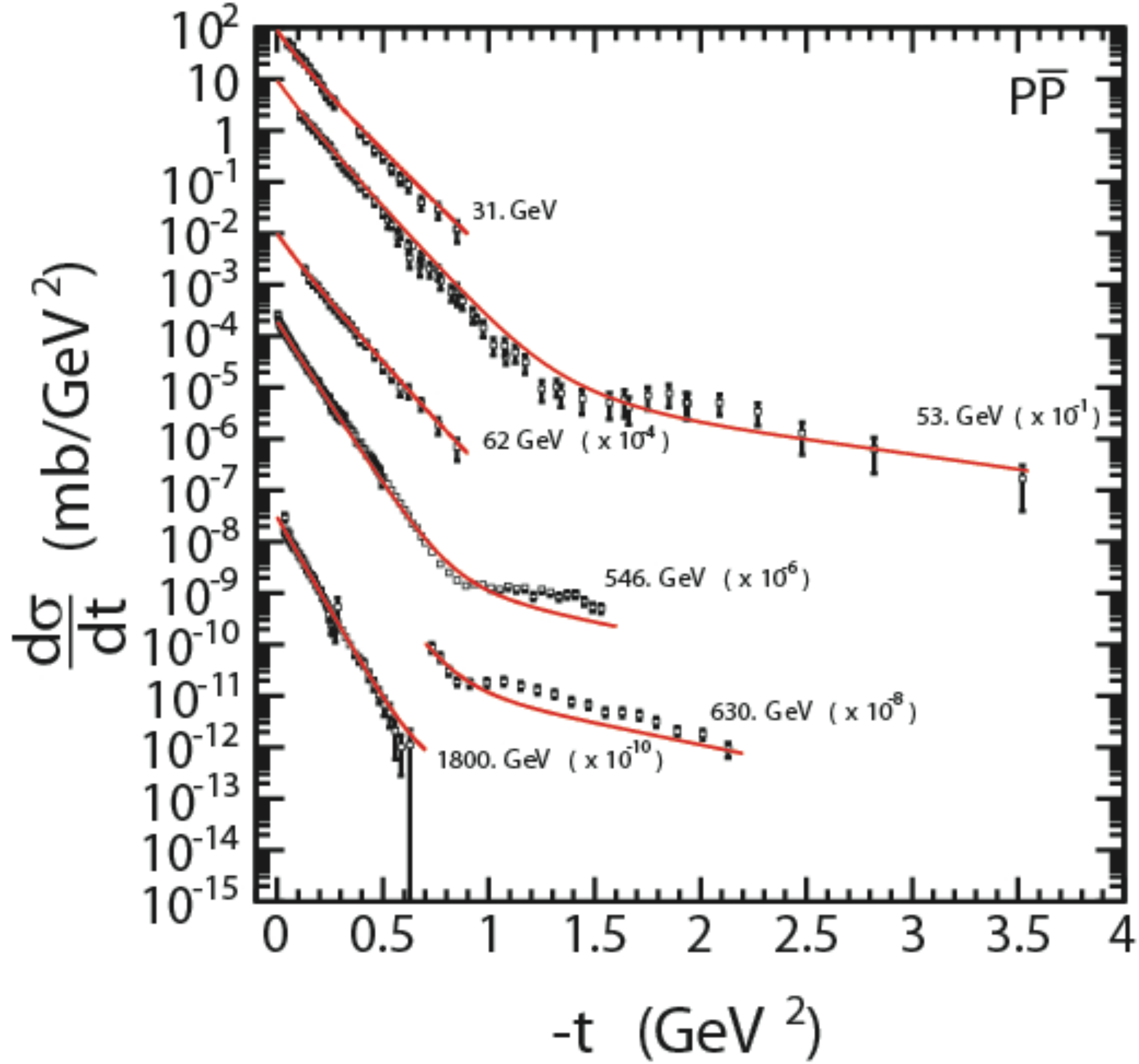




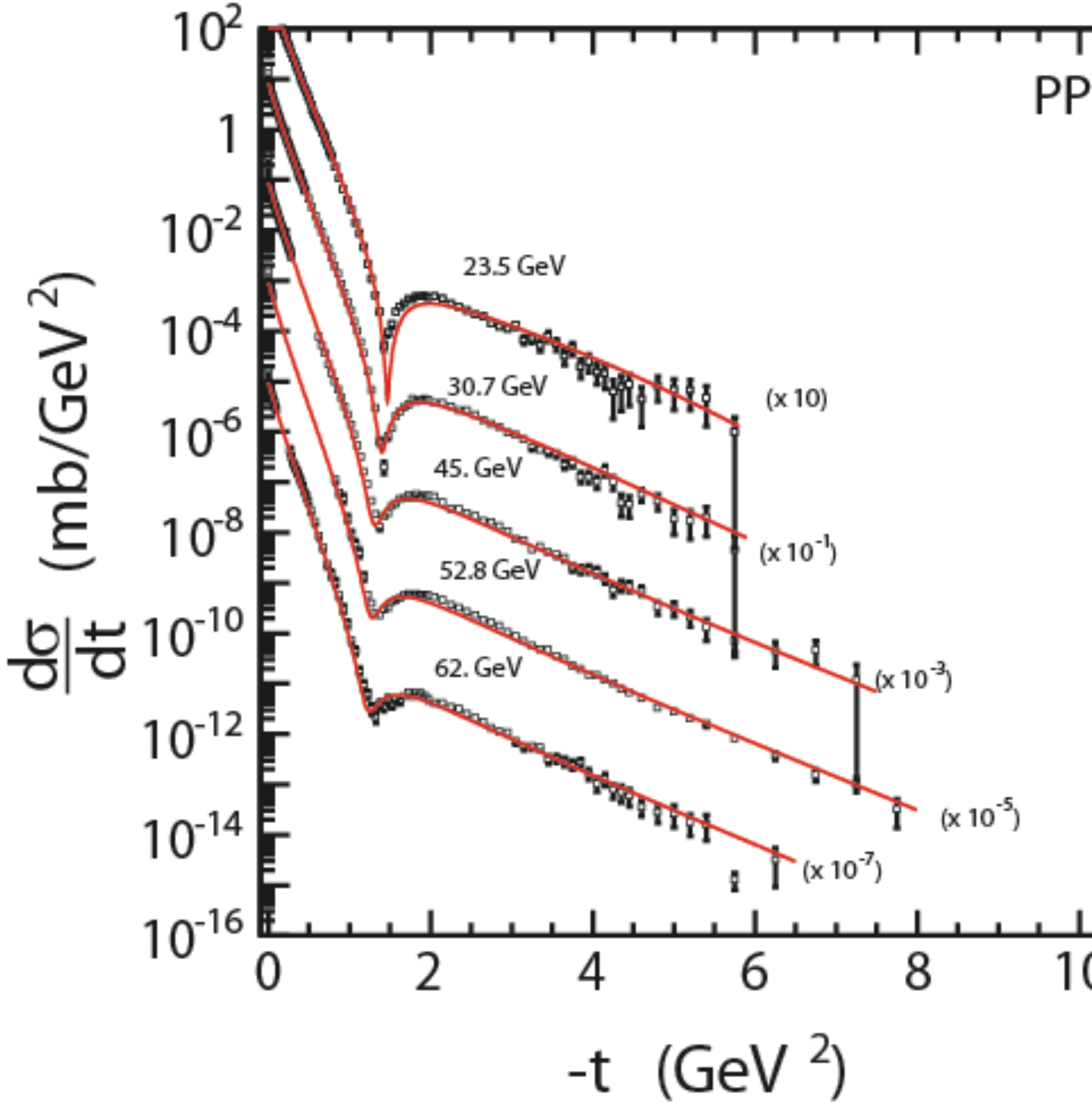
Total cross sections σ(pp and pp̄) (mb)
200
100
90
80
70
60
50
40
★ - predictions of the model
LHC
RHIC
pp̄
pp
1
10
10^2
10^3
10^4
√s (GeV)



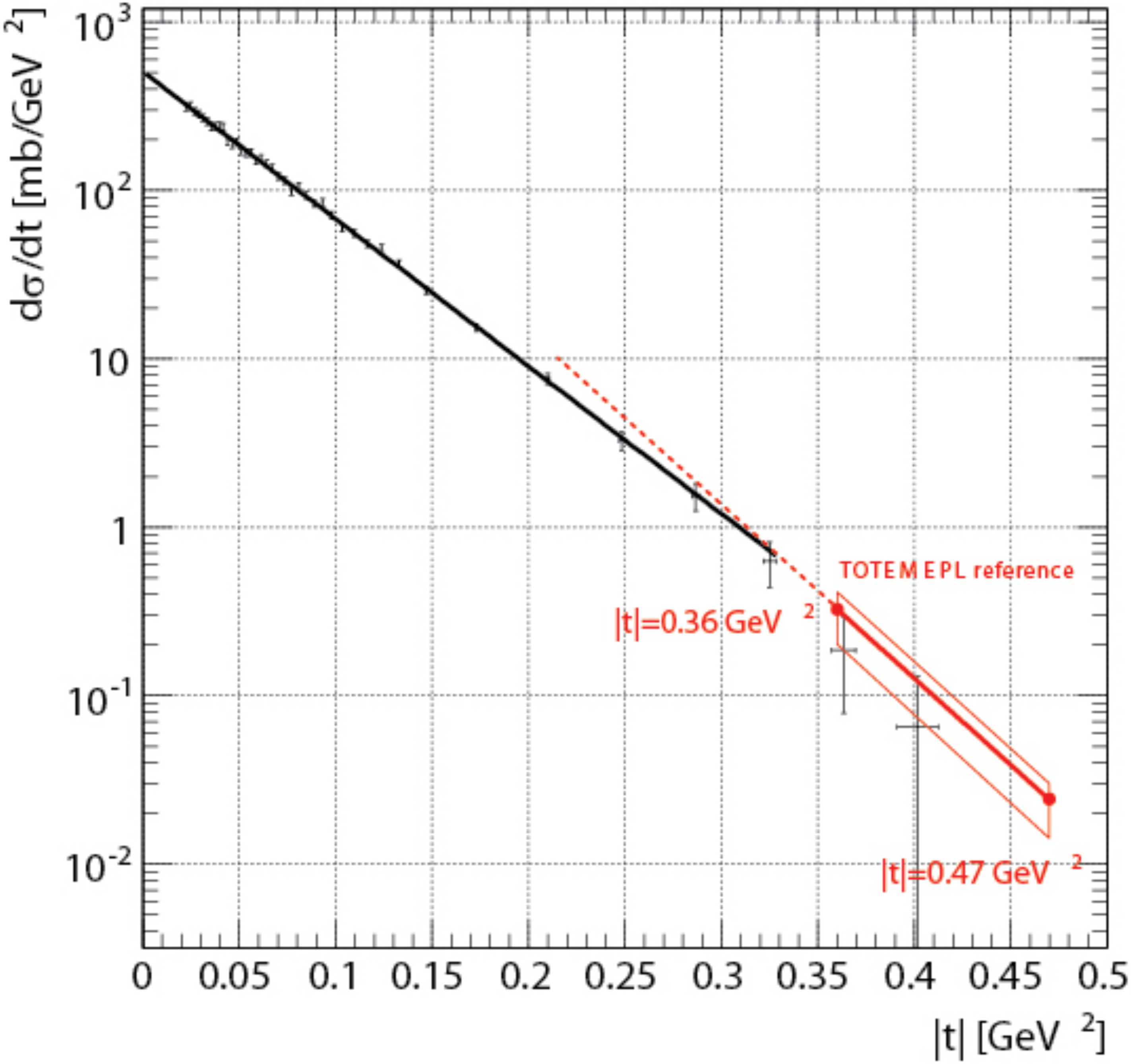
σ_{tot} (red), σ_{inel} (blue) and σ_{el} (green)
$\bar{p}p$ (PDG)
pp (PDG)
Auger + Glauber
ATLAS
CMS
ALICE
TOTEM
best COMPETE σ_{tot} fits
$11.4 - 1.52 \ln s + 0.130 \ln^2 s$
σ_{tot}
σ_{inel}
σ_{el}
σ_{tot}, σ_{inel}, and σ_{el} (mb)
$\sqrt{s}$ (GeV)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
10^1
10^2
10^3
10^4
10^5



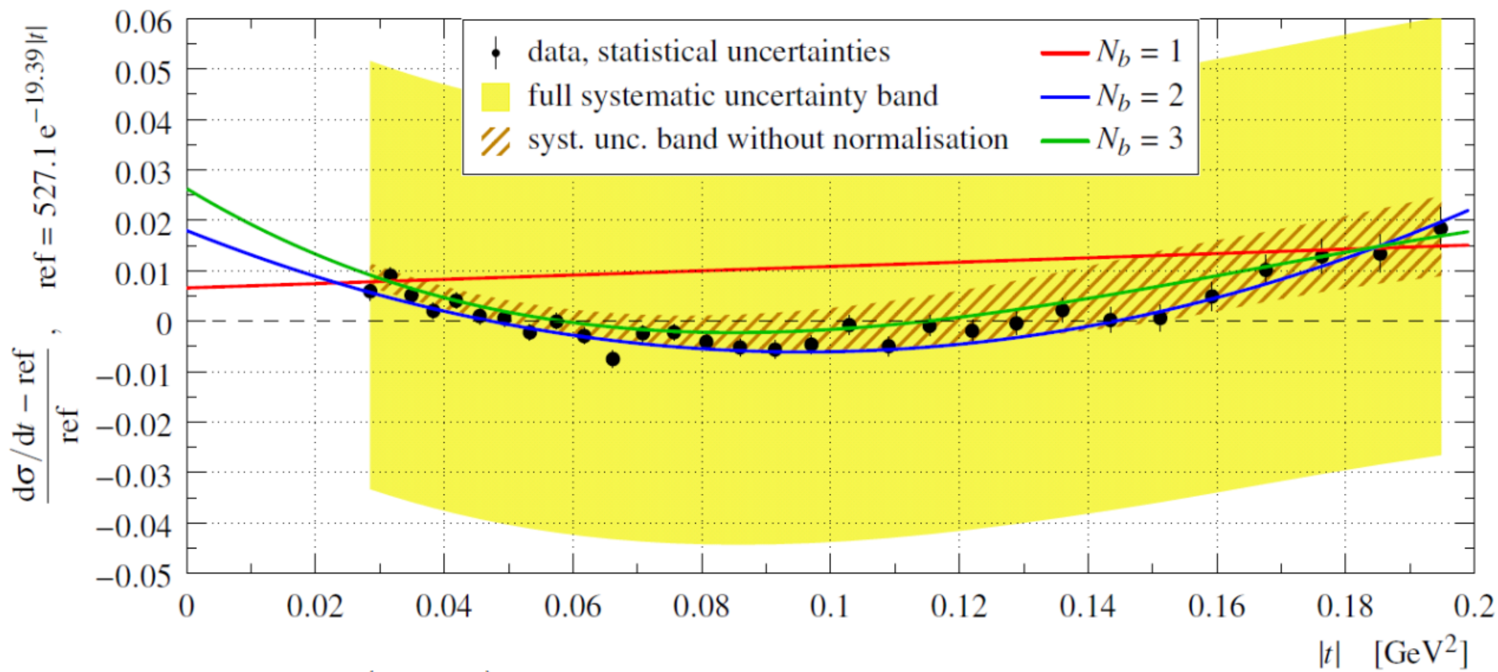
$P\bar{P}$
31. GeV
53. GeV (x 10^-1)
62 GeV (x 10^-4)
546. GeV (x 10^-6)
630. GeV (x 10^-8)
1800. GeV (x 10^-10)
dσ/dt (mb/GeV^2)
-t (GeV^2)



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)


dσ/dt [mb/GeV 2]
10^3
10^2
10
1
10^-1
10^-2
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
|t| [GeV 2]
TOTEM EPL reference
|t|=0.36 GeV 2
|t|=0.47 GeV 2

NEW: Elastic scattering: non-exponentiality at low |t|



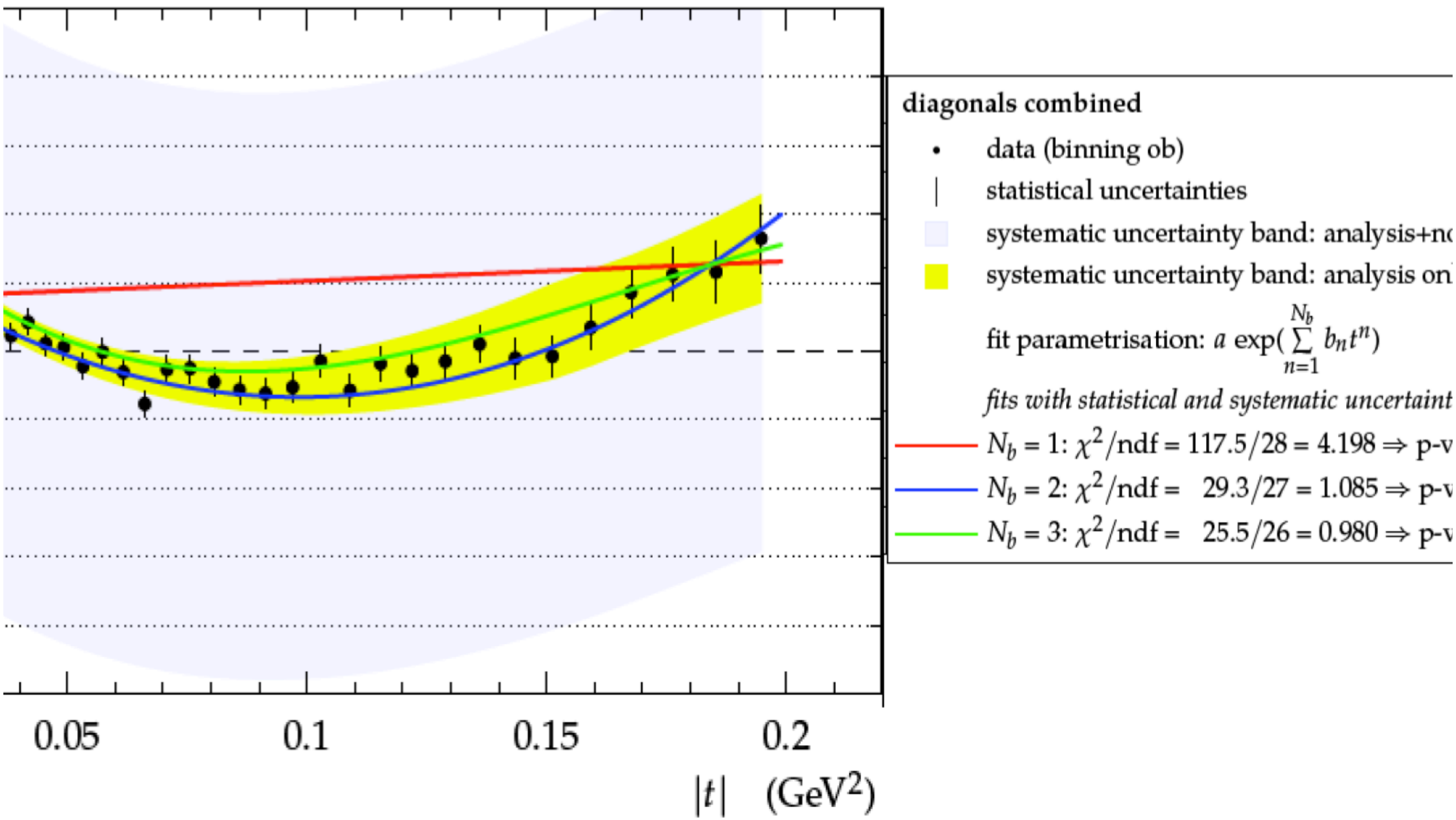
$$\frac{d\sigma}{dt}(t) = \left.\frac{d\sigma}{dt}\right|_{t=0} \exp\left(\sum_{i=1}^{N_b} b_i t^i\right)$$

$N_b = 1$ excluded with 7σ significance!

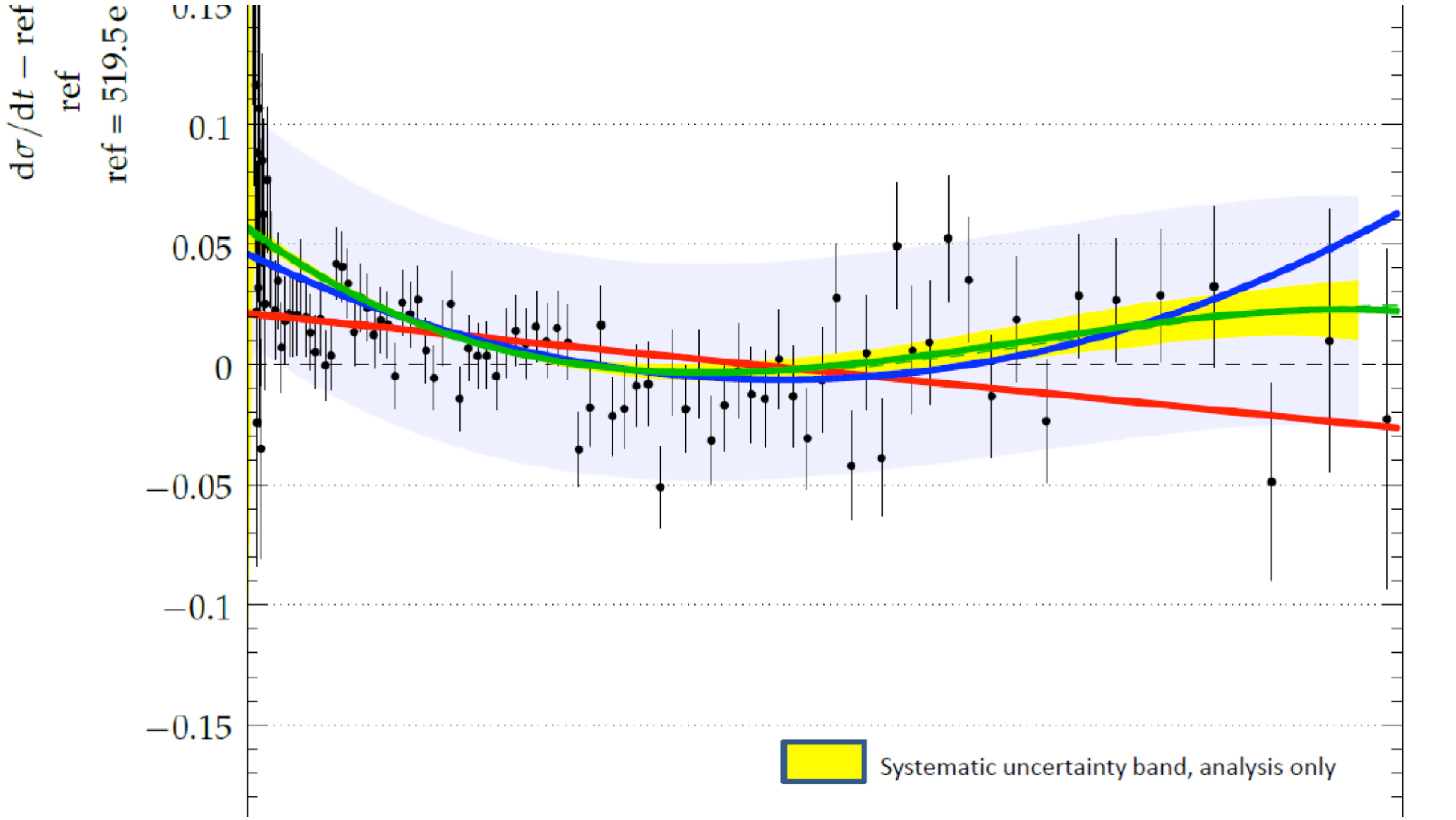
$N_b = 2 : \sigma_{tot} = (101.5 \pm 2.1)$ mb
$N_b = 3 : \sigma_{tot} = (101.9 \pm 2.1)$ mb

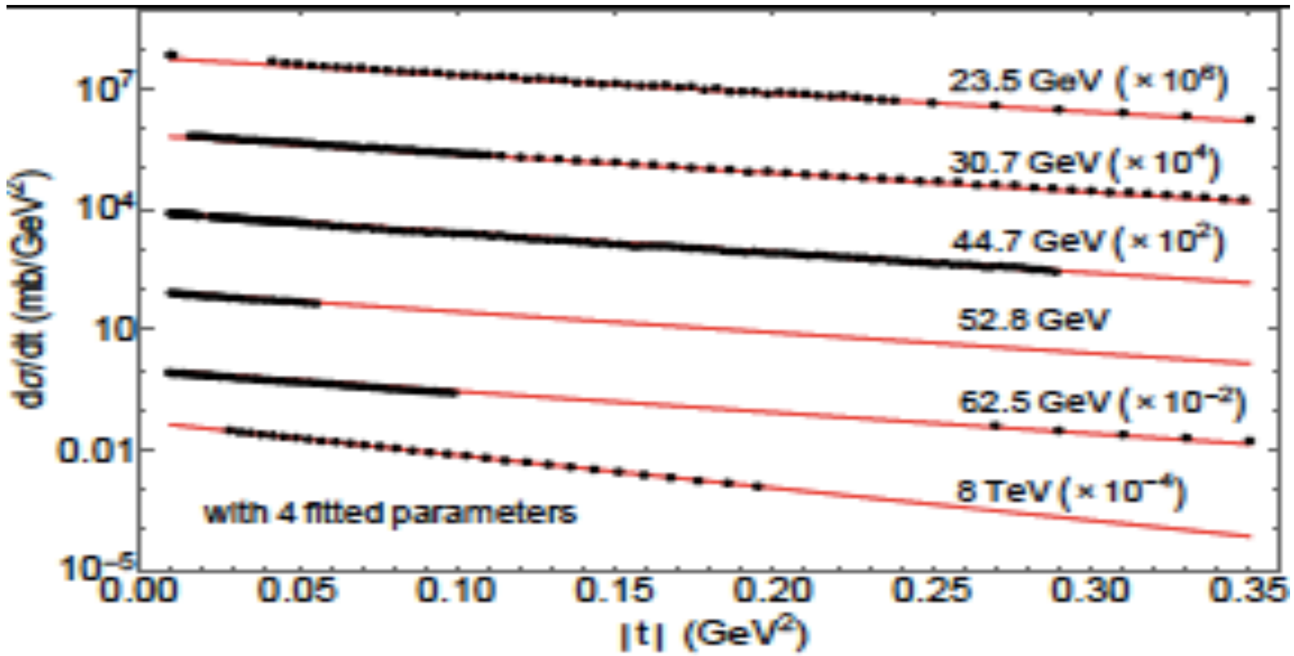
Nuclear Physics B 899 (2015) 527–546

Fine structure of the Pomeron (at the LHC)

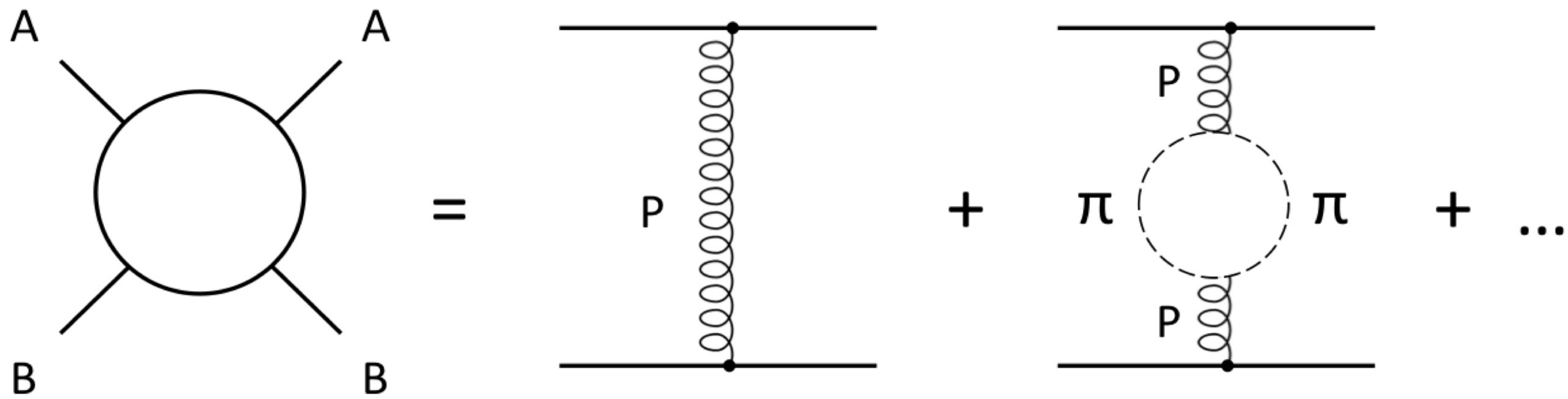


Fine structure of the Pomeron (TOTEM)





G. Antchev et al. (TOTEM Collaboration), Nucl. Phys. **B 899** (2015) 527-546, arXiv:1503.08111; T. Csörgő (for the TOTEM Collaboration), Evidence for Non-Exponential Differential Cross-Section of *pp* Elastic Scattering at Low $|t|$ and $\sqrt{s} = 8$ TeV by TOTEM, arXiv:1602.00219.
Frigyes Nemes (for the TOTEM Collaboration), LHC optics and elastic scattering measured by the TOTEM experiment, arXiv:1602.06207; Frigyes Nemes (for the TOTEM collaboration), The results of the TOTEM experiment, to be publ. in the Proceedings of the Diffraction 2016 conference, held in Acireale, Sicily, Sept. 2-8, 2016; Nicola Minafra, Latest results of the TOTEM experiment at LHC, Low-x Workshop, Gyöngyös, June 6-11, 2016; G. Antchev *et al.* (TOTEM Collaboration), *Measurement of Elastic pp Scattering at $\sqrt{s} = 8$ TeV in the Coulomb-Nuclear Interference Region Determination of the ρ-Parameter and the Total Cross-Section*, Eur. Phys. J. C **76** (2016) 661; arXiv:1610.00603.
B. Barbiellini *et. al.* Phys. Letters **B39** (1972) 663.



Experimentalists usually quantify the departure from the linear exponential by replacing

$$|A^N| = a\exp(Bt) \to a\exp(b_1 t + b_2 t^2 + b_3 t^3 + ...) \qquad (1)$$

with coefficients b_i fitted to the data.

Two-pion loop contributes in the t channel through Regge trajectories, that are non-linear complex functions,

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

where t_0 is the lightest threshold, $4m_\pi^2$ in the case of the vacuum quantum numbers (Pomeron or f meson). Since $Re\alpha(4m_\pi^2)$ is small, a square-root threshold is a reasonable approximation to the above constrain.

$$A(s,t) = A_P(s,t) + A_f(s,t),$$

where

$$A_P(s,t) = -a_P e^{b_P \alpha_P(t)} e^{-i\pi\alpha_P(t)/2} (s/s_0)^{\alpha_P(t)}, \quad A_f(s,t) = -a_f e^{b_f \alpha_f(t)} e^{-i\pi\alpha_f(t)/2} (s/s_0)^{\alpha_f(t)}$$

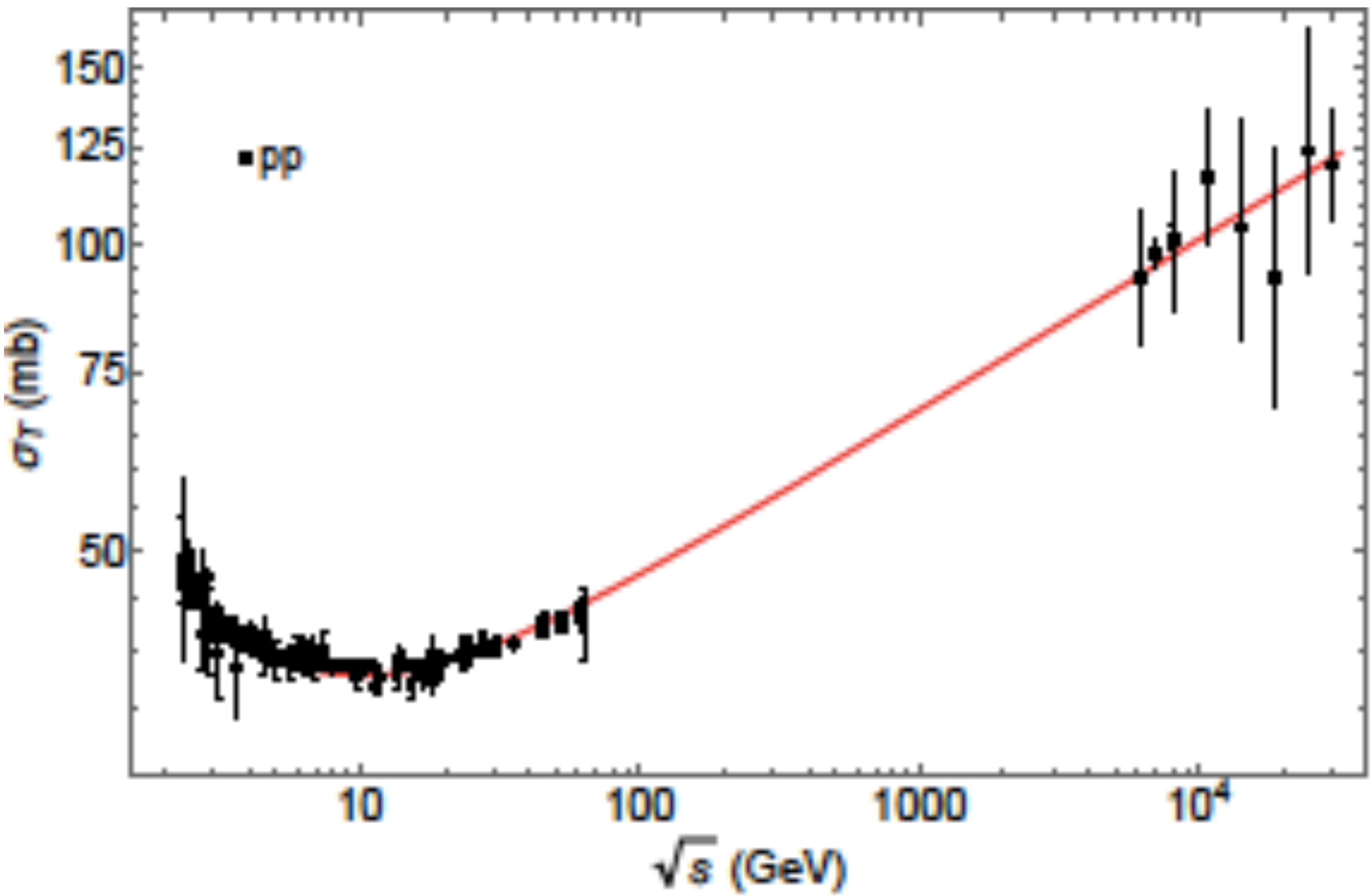
with the trajectories

$$\alpha_P(t) = \alpha_{0P} + \alpha'_P t - \alpha_{1P}(\sqrt{4m_\pi^2 - t} - 2m_\pi), \quad \alpha_f(t) = \alpha_{0f} + \alpha'_f t - \alpha_{1f}(\sqrt{4m_\pi^2 - t} - 2m_\pi).$$

Norm:

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

D.A. Fagundes *et. al.* Phys. Rev. **D88** (2013) 094019.
Giulia Pancheri, Yogendra N. Srivastava, *Introduction to the physics of the total cross-section at LHC: A Review of Data and Models*, arXiv:1610.10038; to be published in the European Journal of Physics C.
D.A. Fagundes, L. Jenkovszky, E.Q. Miranda, G. Pancheri, P.V.R.G. Silva, *Fine structure of the diffraction cone: from the ISR to the LHC*, International Journal of Modern Physics A **31**, Nos. 28 & 29 (2016) 1645022, World Scientific Publishing Company DOI: 10.1142/S0217751X16450226 D, arXiv:1509.02197.
R. Fiore, L. Jenkovszky and R. Schicker, EPJ C **76** (2016) 1; hep-ph/1512.04977.
Laszlo Jenkovszky and Alexander Lengyel, Acta Phys. Pol. B **46**(2015) 863; arXiv:1410.4106.
Laszlo Jenkovszky and Istvan Szanyi, arXiv:hep-ph/1701.01269; to be publ. in PEPAN Letters.

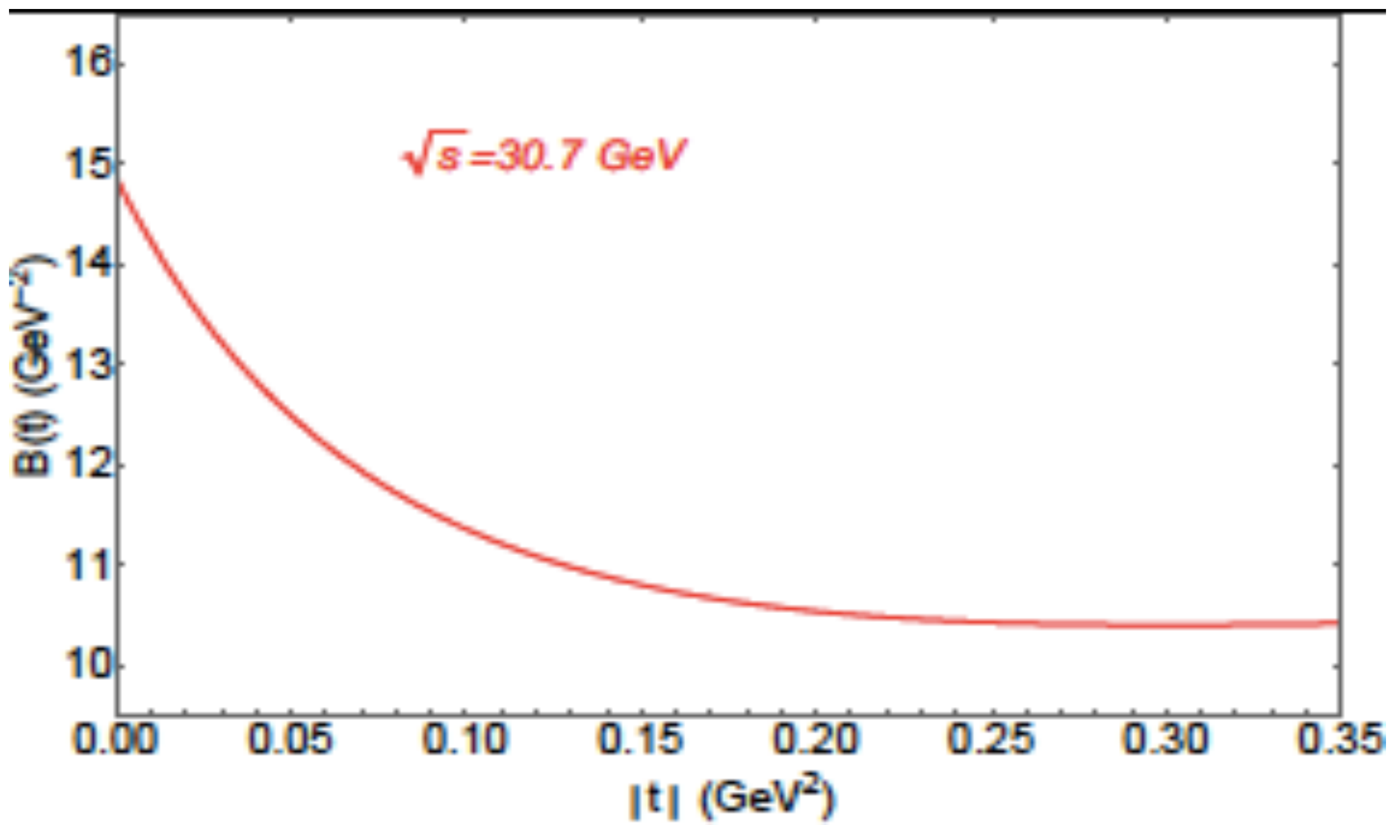


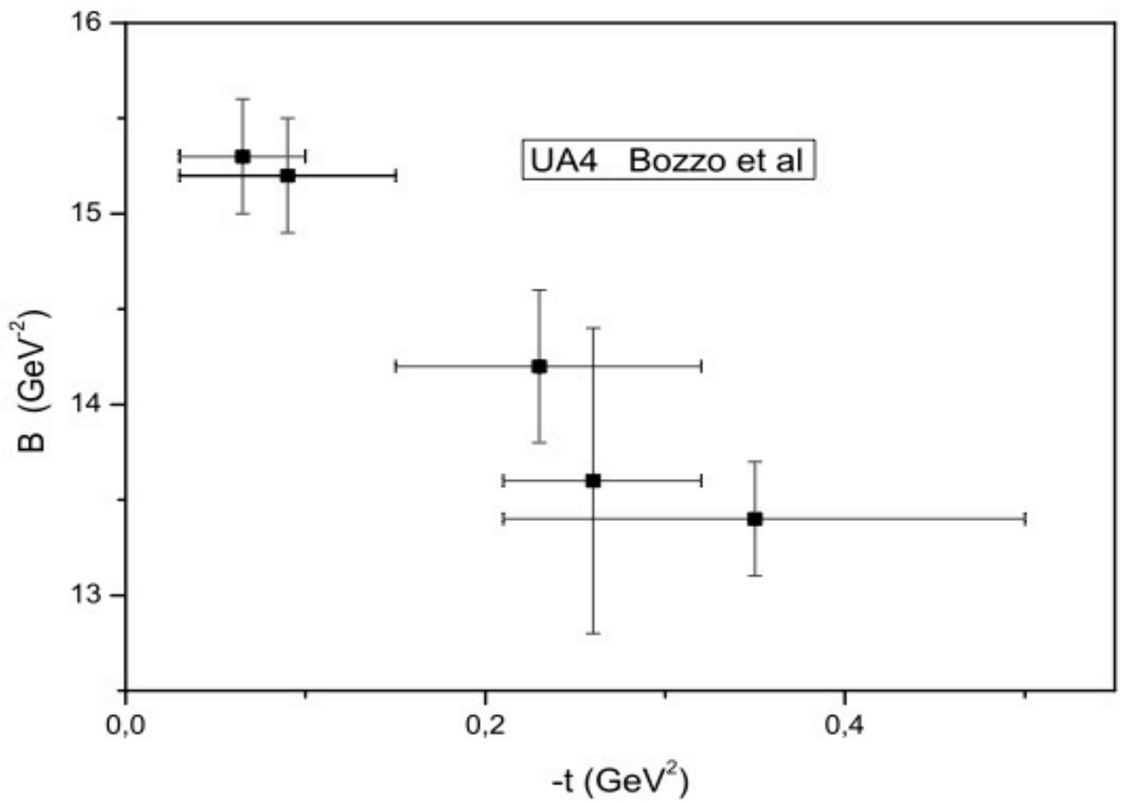
pp
150
125
100
75
50
σ_T (mb)
10
100
1000
10^4
$\sqrt{s}$ (GeV)

To see the fines structure, on calculates the local slope ias $B(s,t) = \frac{d}{dt} ln \frac{d\sigma}{dt}$ (in t bins!). TOTEM instead uses "normalized" cross sections:

$$R = \frac{\frac{d\sigma}{dt} - ref}{ref}, \tag{7}$$

where $ref = Ae^{B|t|}$.





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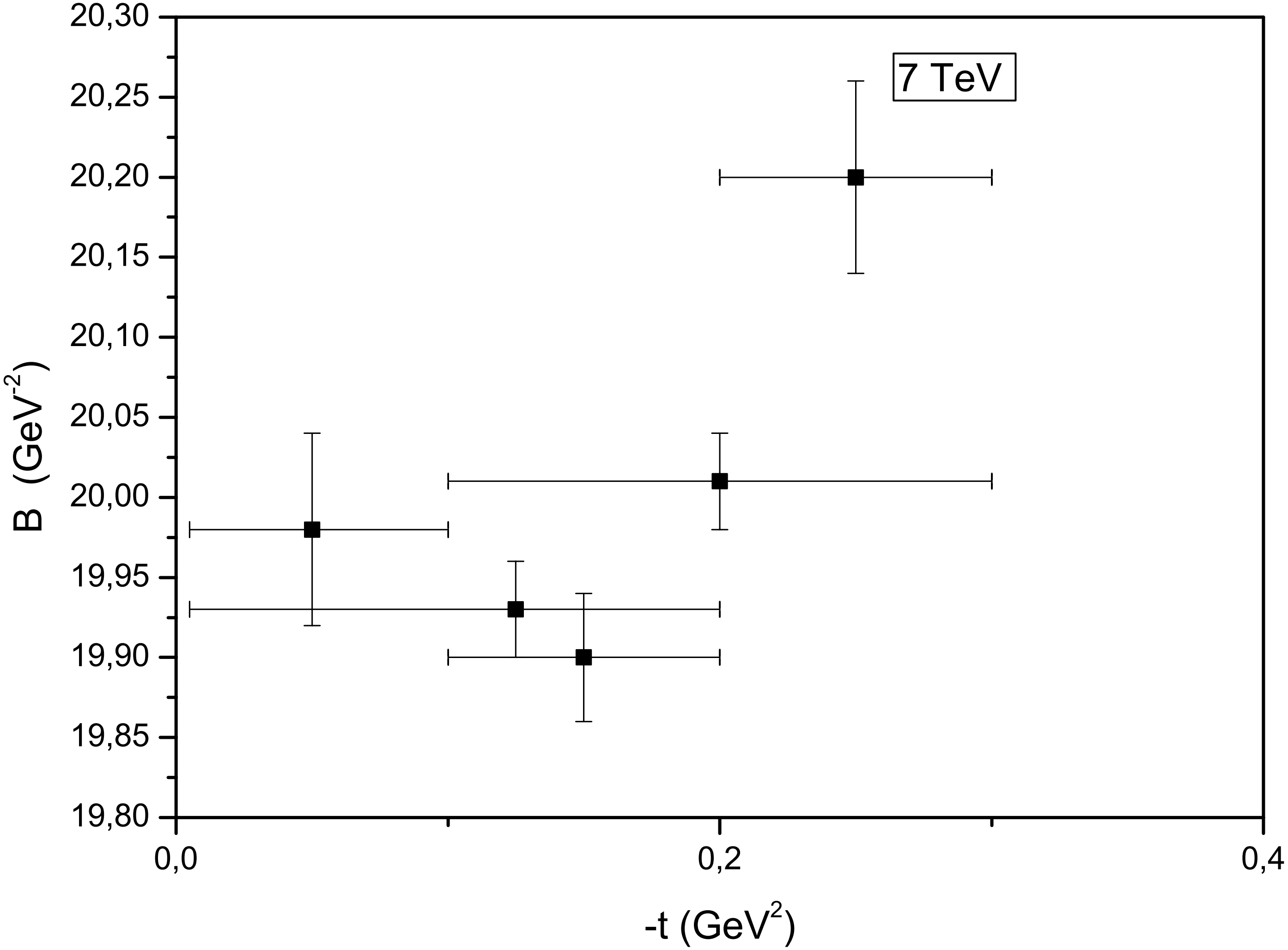
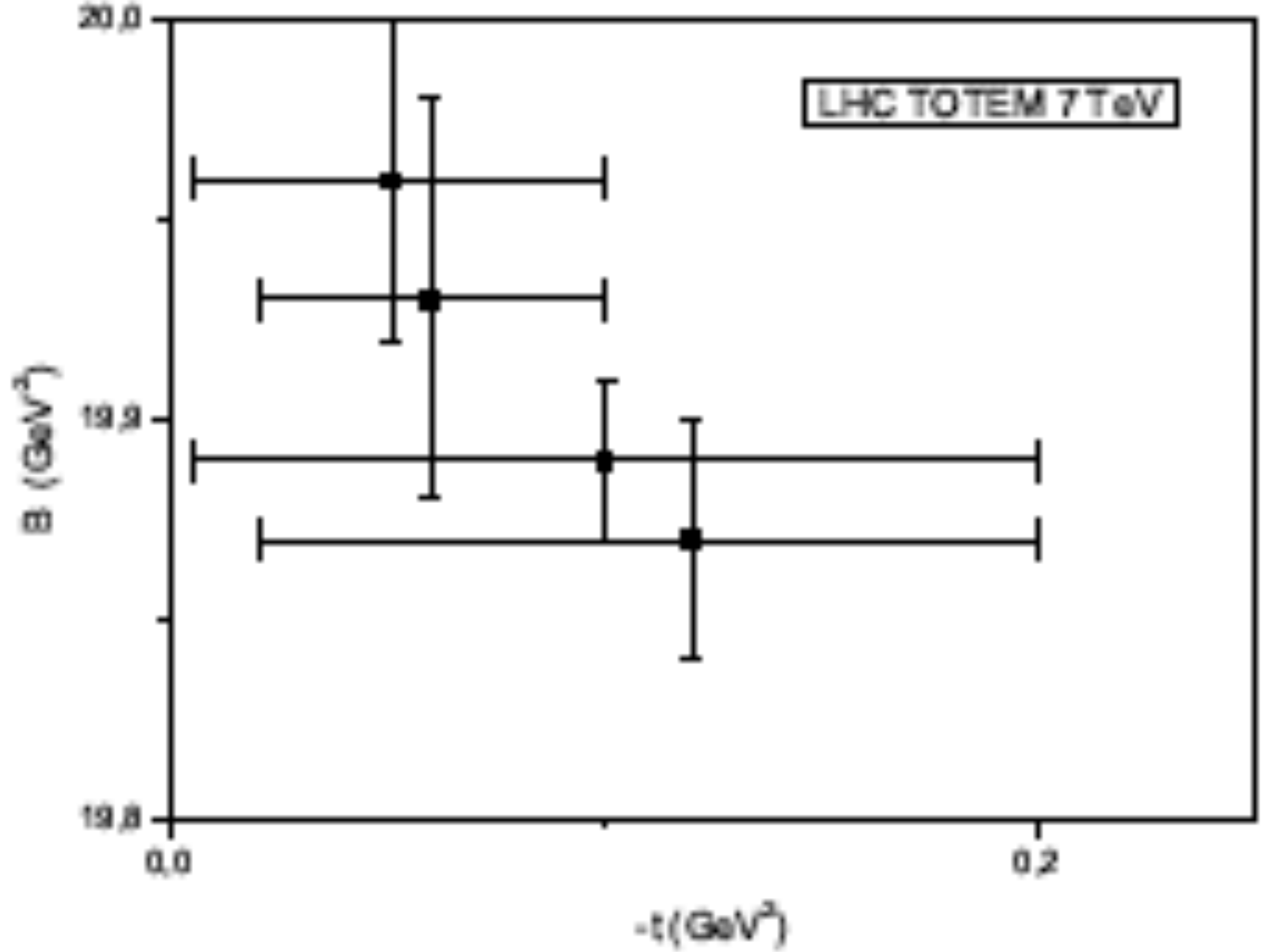


7 TeV
B (GeV^{-2})
20,30
20,25
20,20
20,15
20,10
20,05
20,00
19,95
19,90
19,85
19,80
0,0
0,2
0,4
-t (GeV^{2})



LHC TOTEM 7 TeV
20,0
19,9
19,8
0,0
0,2
B (GeV^2)
-t (GeV^2)

Hagedorn spectrum:

$$\rho(m) \sim f(m)\exp(m/T), \quad T \approx 160 \text{ MeV}. \tag{8}$$

From stastistical bootrstrap (duality): $f(m) \sim \alpha'(m)$.

A trajectory obeying the known constraints (unitarity, analyticity, polynomial boundedness) generally can be written as (the signs are fixed uniquely be imposing positivity of the imaginary part (unitarity)).

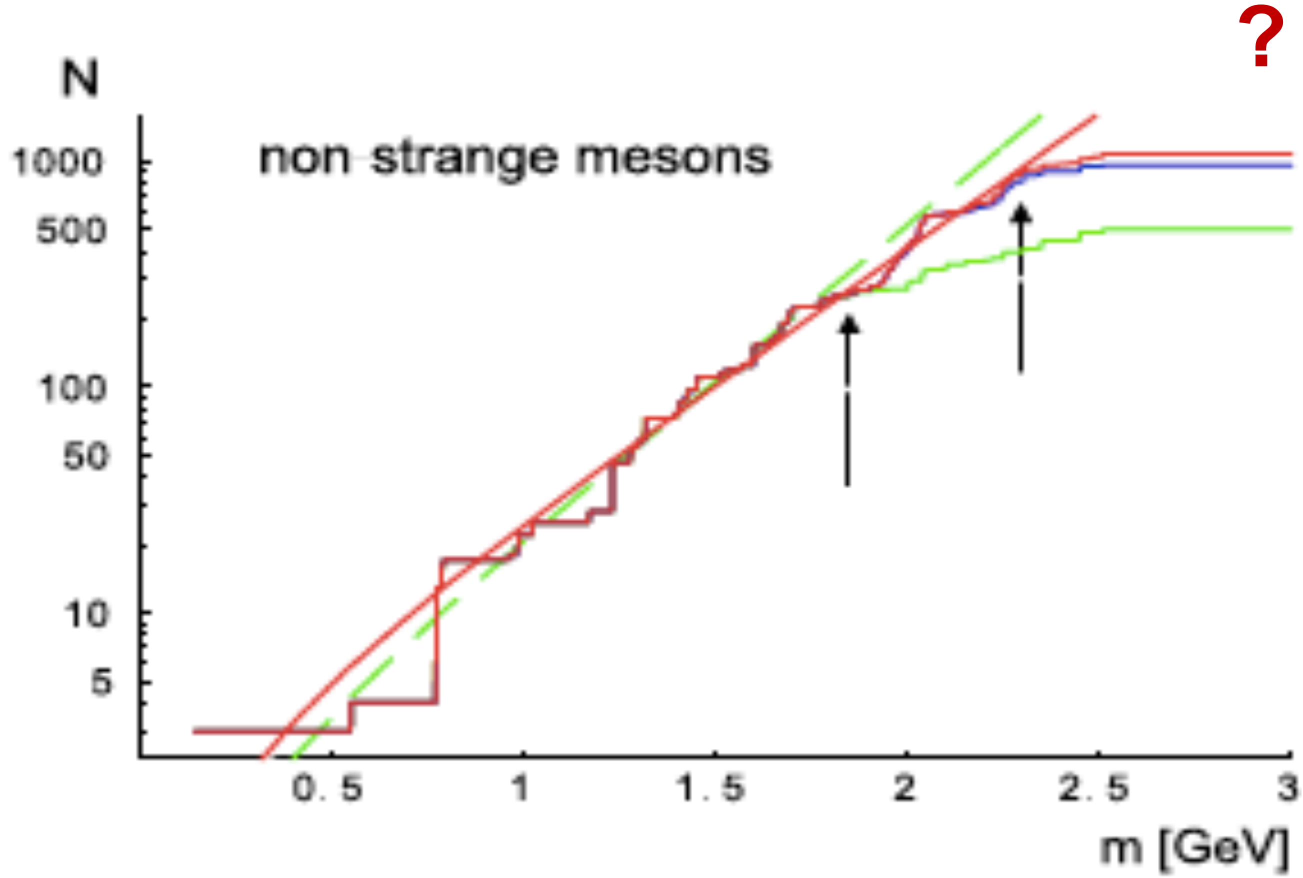
$$\alpha(s) = \alpha_0 - \sum_i \gamma_i \ln(1 + \beta_i\sqrt{s_i - s}). \tag{9}$$

A simple model satisfying the above conditions, yet fitting the observed spectrum of resonances can be written as a sum, *e.g.*

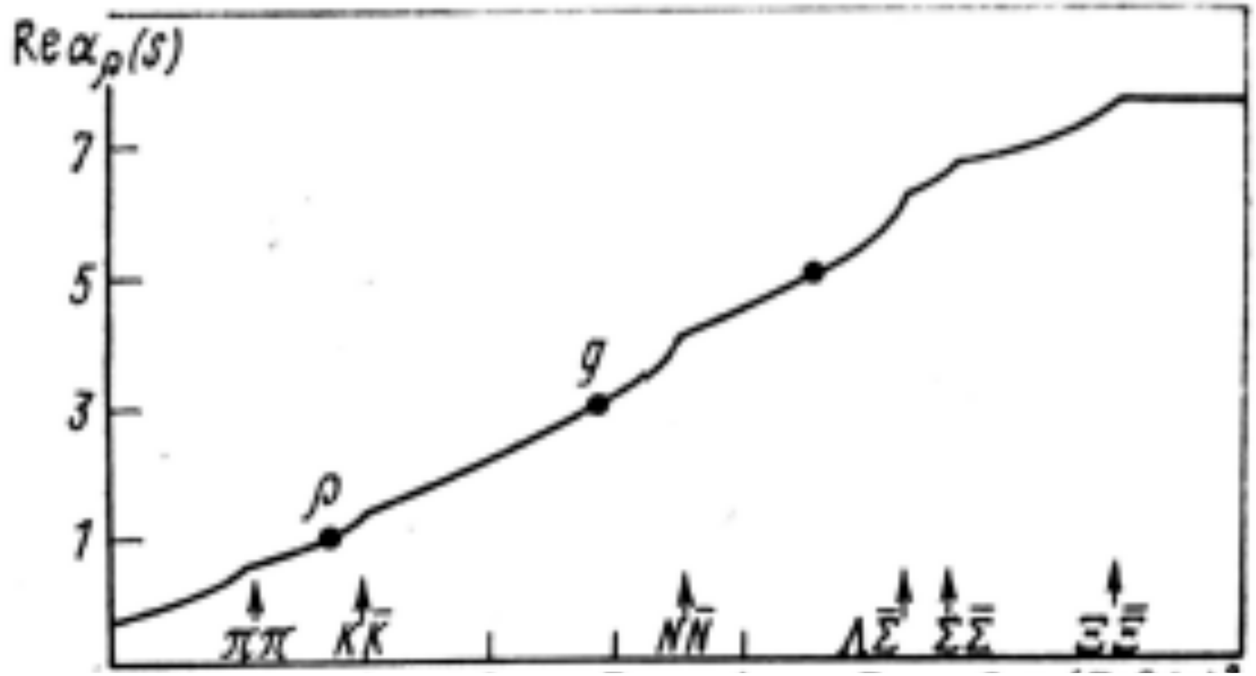
$$\alpha_\rho(m) = 7.64 - 0.127\sqrt{m-0.28} - 0.093\sqrt{m-0.988} - 0.761\sqrt{m-1.88} - (\Lambda\bar{\Sigma},\ \Sigma\bar{\Sigma},\ \Xi\bar{\Xi}?), \tag{10}$$

with parameters fitted to the masses and widths of known resonances.

A.O. Barut and D.E. Zwanziger, Phys. Rev. **127** (1962) 974.
G. Cohen-Tannoudji, V. Ilyin, Jenkovszky *et al.*, Lett. Nuov. Cim. **5** (1972) 957.
A.I. Bugrij and N.A. Kobylinsky, Annalen der Physik, **32** (1975) 297.



W.Broniowski, L.J., and R. Schicker, work in progress



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with parameters fitted to the masses and widths of known resonances.

Pomerons (diffraction's) fraction

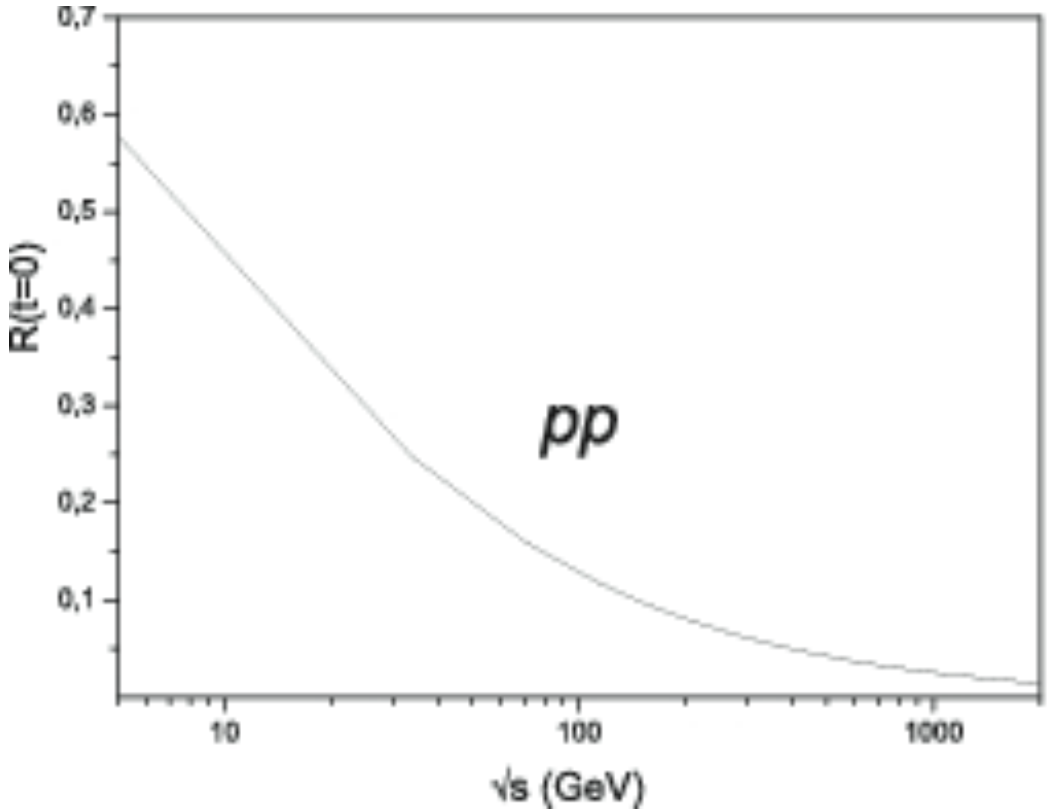
Energy variation of the relative importance of the Pomeron with respect to contributions from the secondary trajectories and the Odderon:

$$R(s,t=0) = \frac{\Im m(A(s,t) - A_P(s,t))}{\Im A(s,t)}, \tag{1}$$

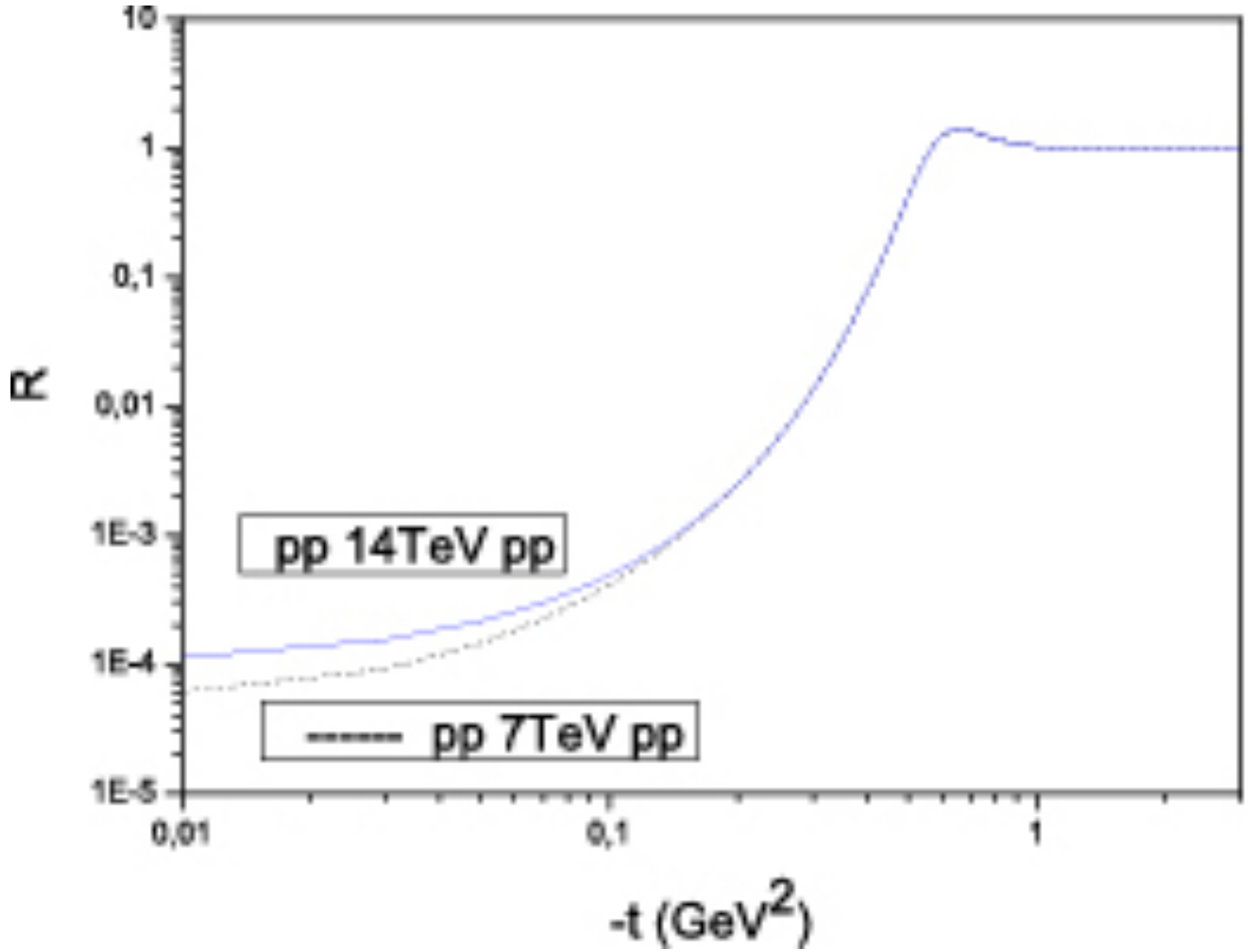
where the total scattering amplitude A includes the Pomeron contribution A_P plus the contribution from the secondary Reggeons and the Odderon.

Starting from the Tevatron energy region, the relative contribution of the non-Pomeron terms to the total cross-section becomes smaller than the experimental uncertainty and hence at higher energies they may be completely neglected, irrespective of the model used.

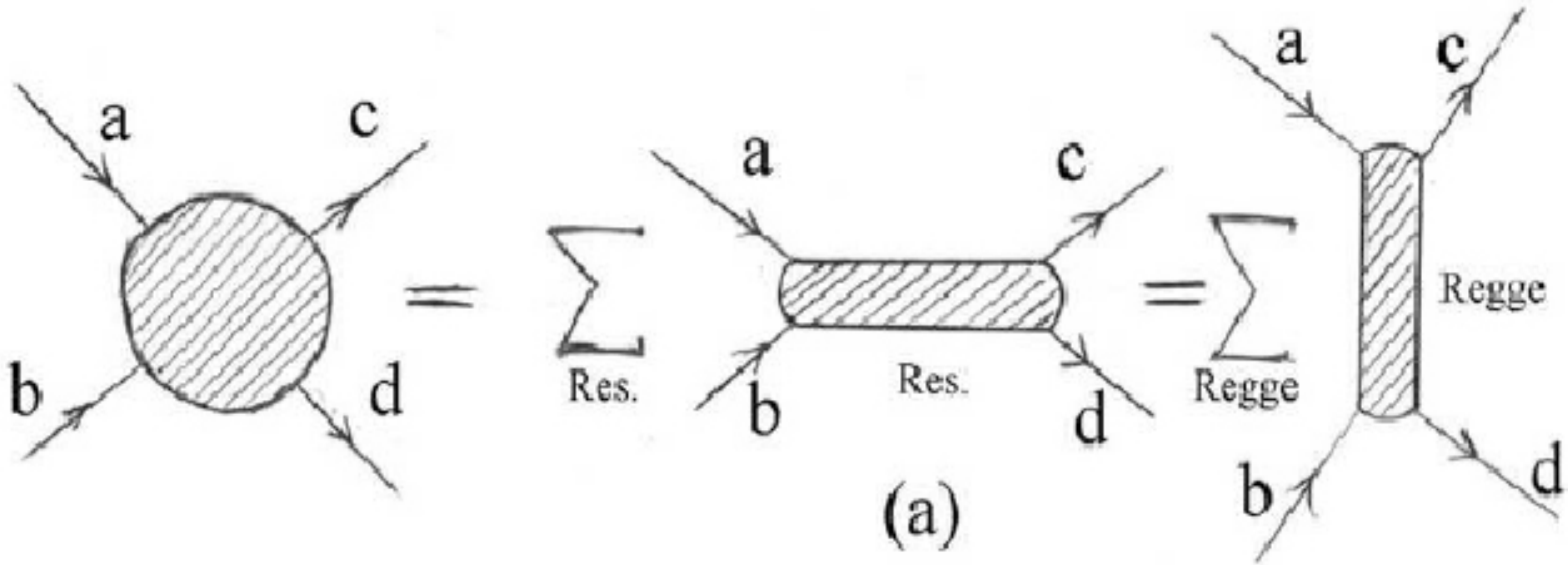
$$R(s,t) = \frac{|(A(s,t) - A_P(s,t)|^2}{|A(s,t)|^2}. \tag{2}$$



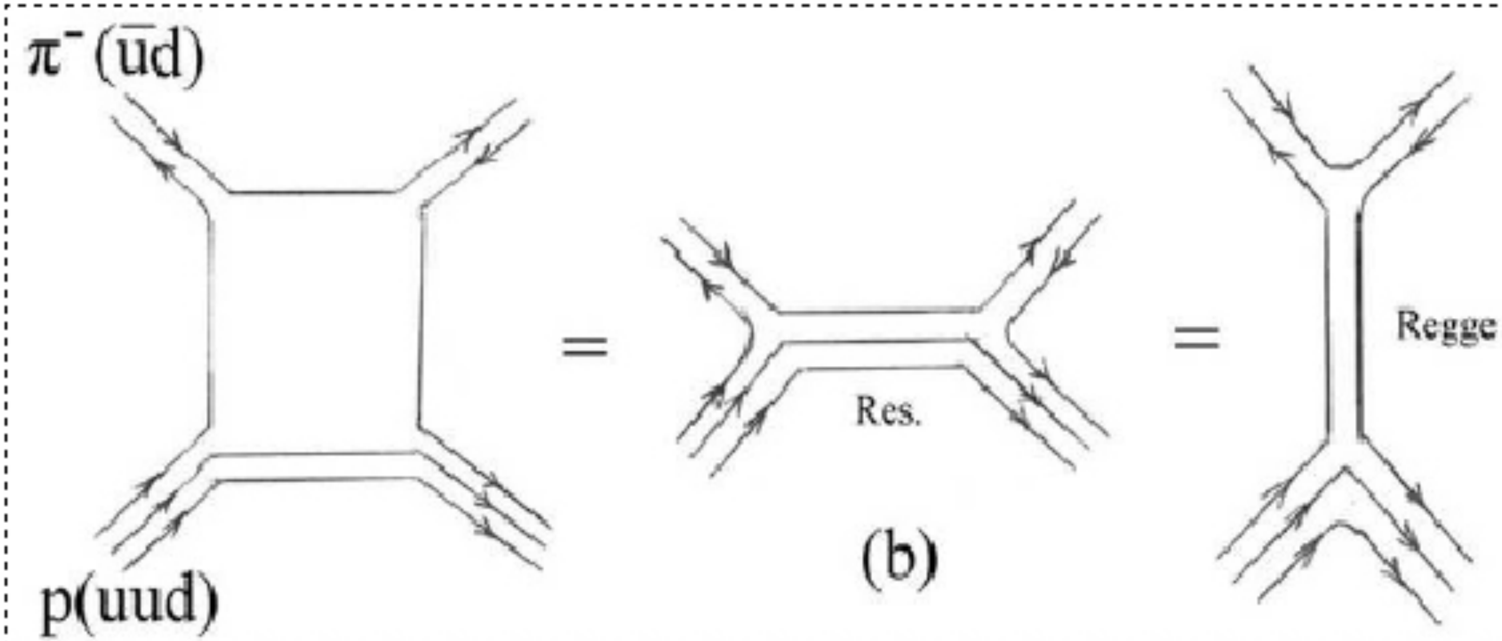
0,7
0,6
0,5
0,4
0,3
0,2
0,1
R(t=0)
pp
10
100
1000
√s (GeV)



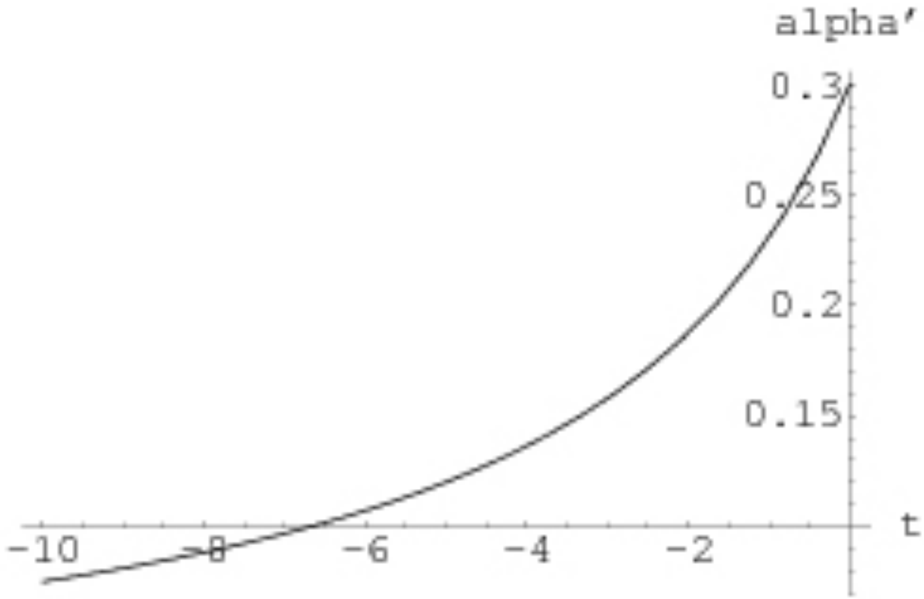
10
1
0,1
0,01
1E-3
1E-4
1E-5
R
0,01
0,1
1
-t (GeV2)
pp 14TeV pp
pp 7TeV pp



(a)



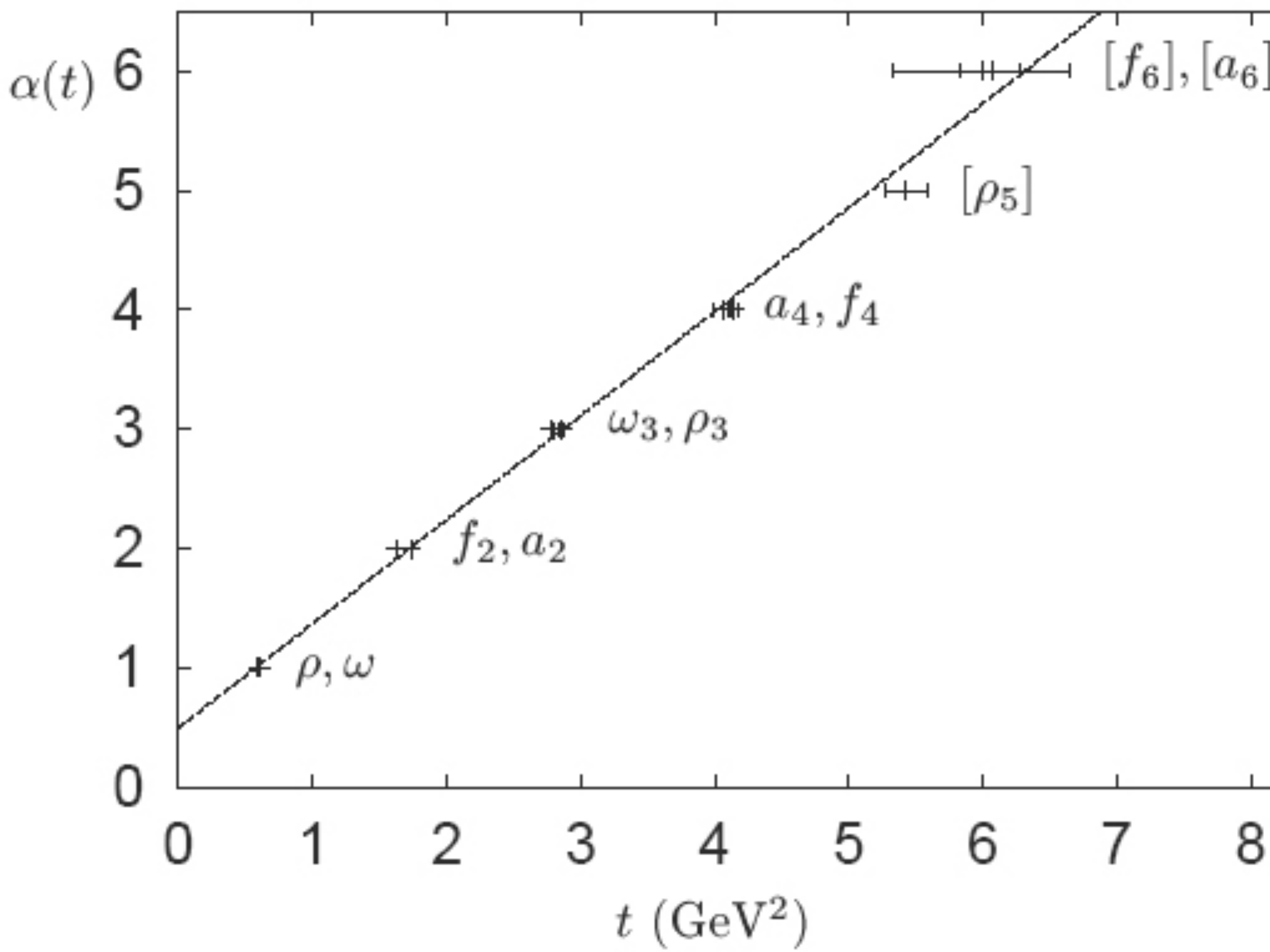
(b)

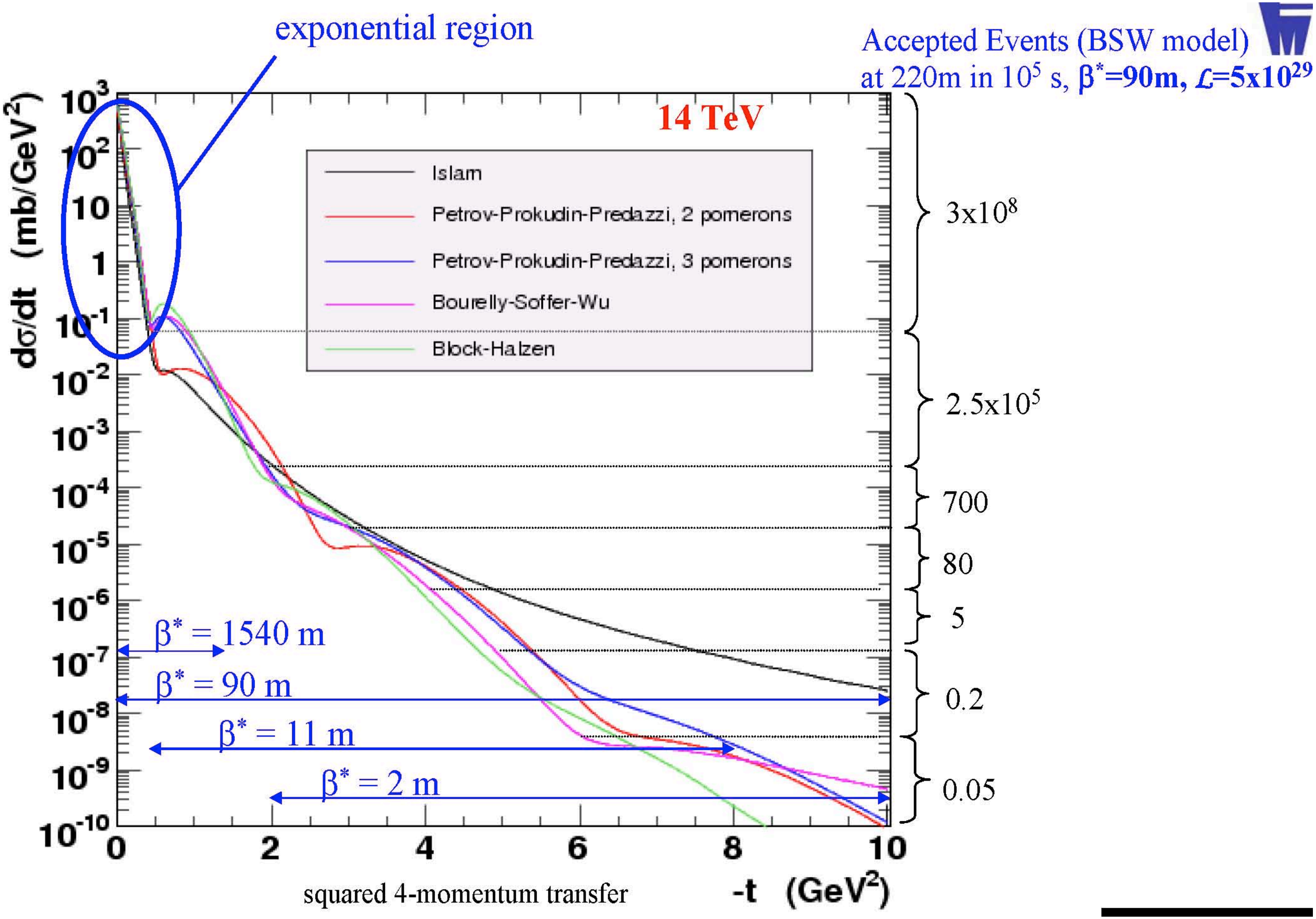


The slope of the cone for a single pole is: $B(s,t) \sim \alpha'(t) \ln s$. The Regge residue $e^{b\alpha(t)}$ with a logarithmic trajectory $\alpha(t) = \alpha(0) - \gamma \ln(1 - \beta t)$, is identical to a form factor (geometrical model).

Linear particle trajectories

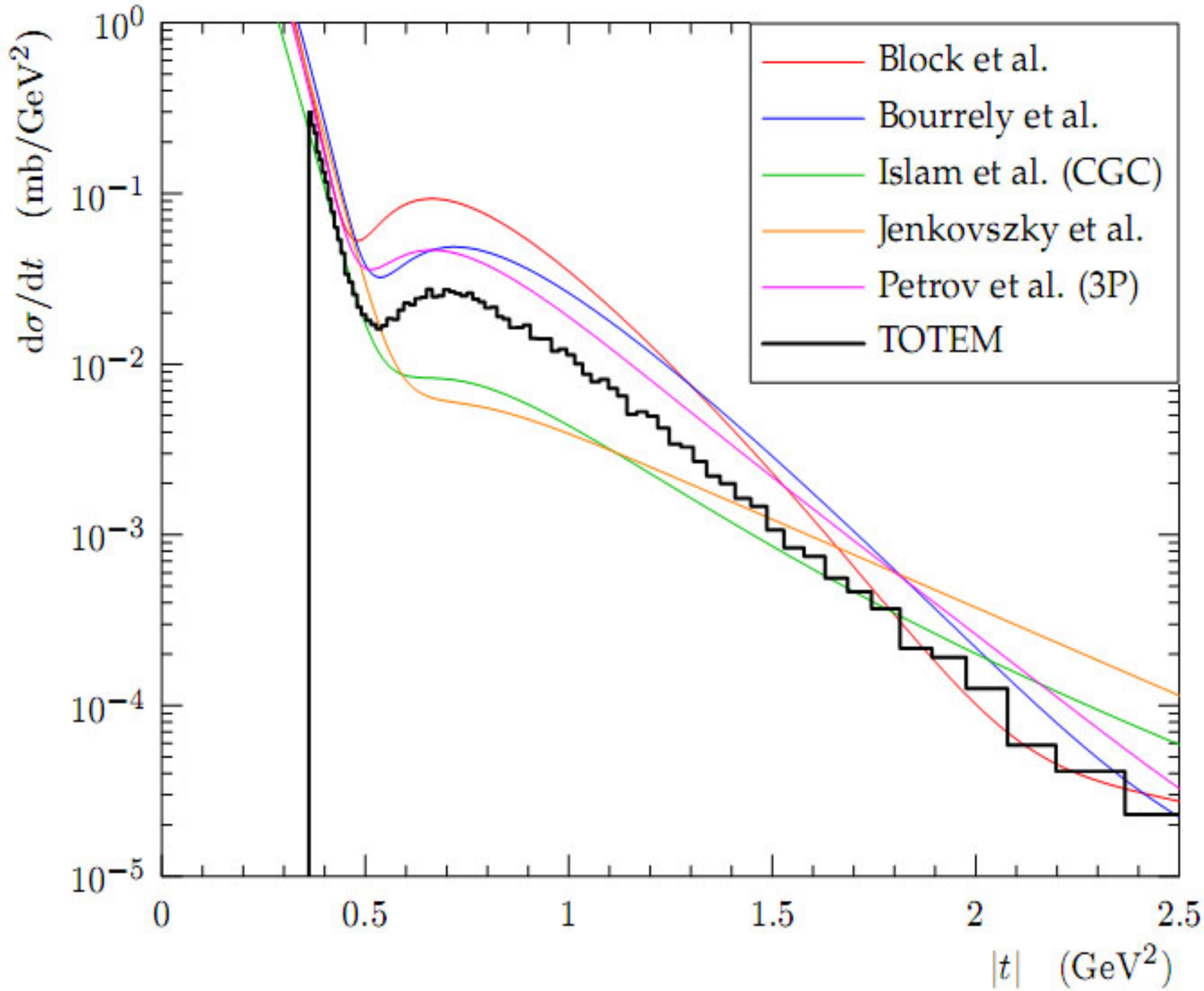
Plot of spins of families of particles against their squared masses:

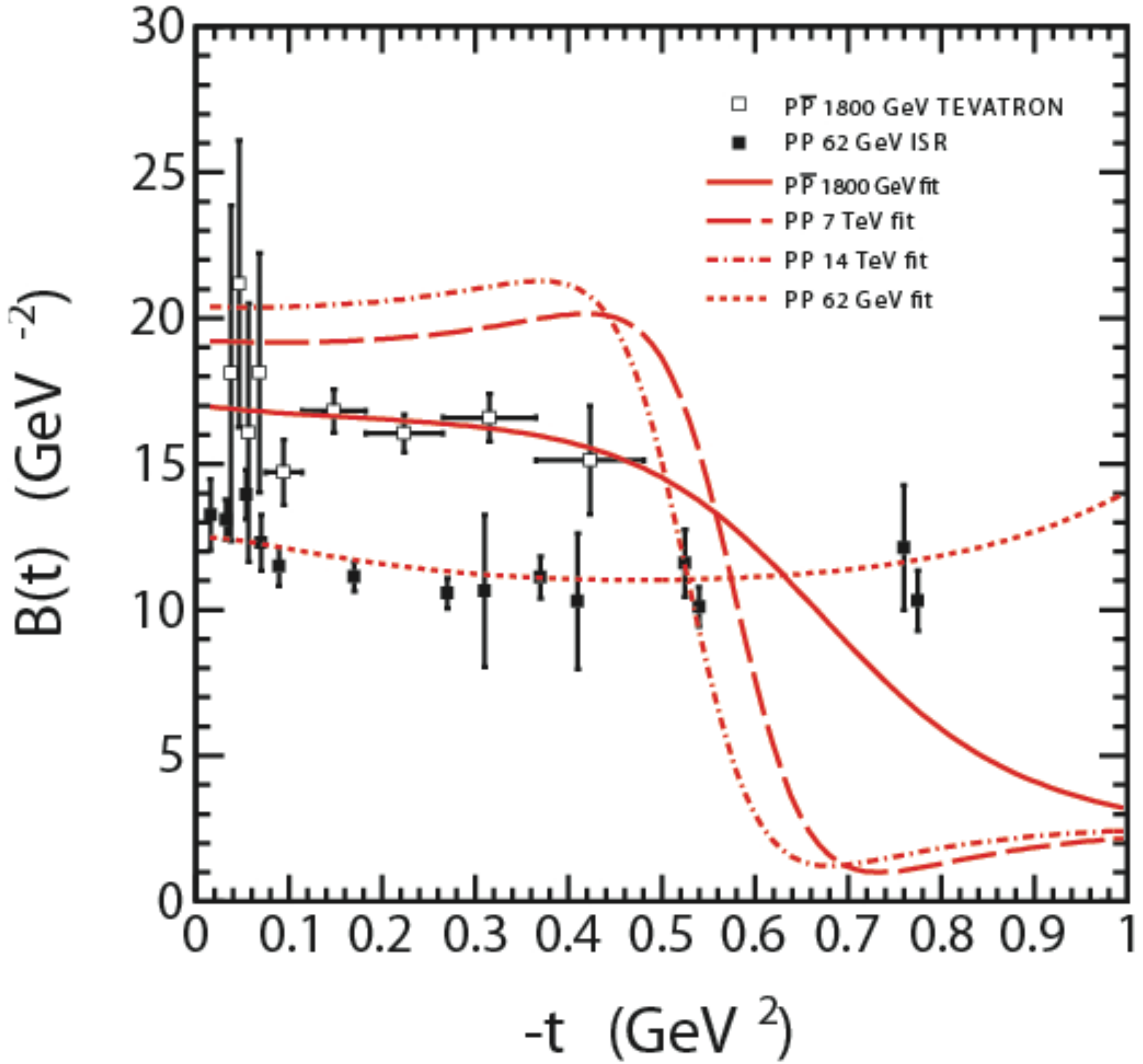


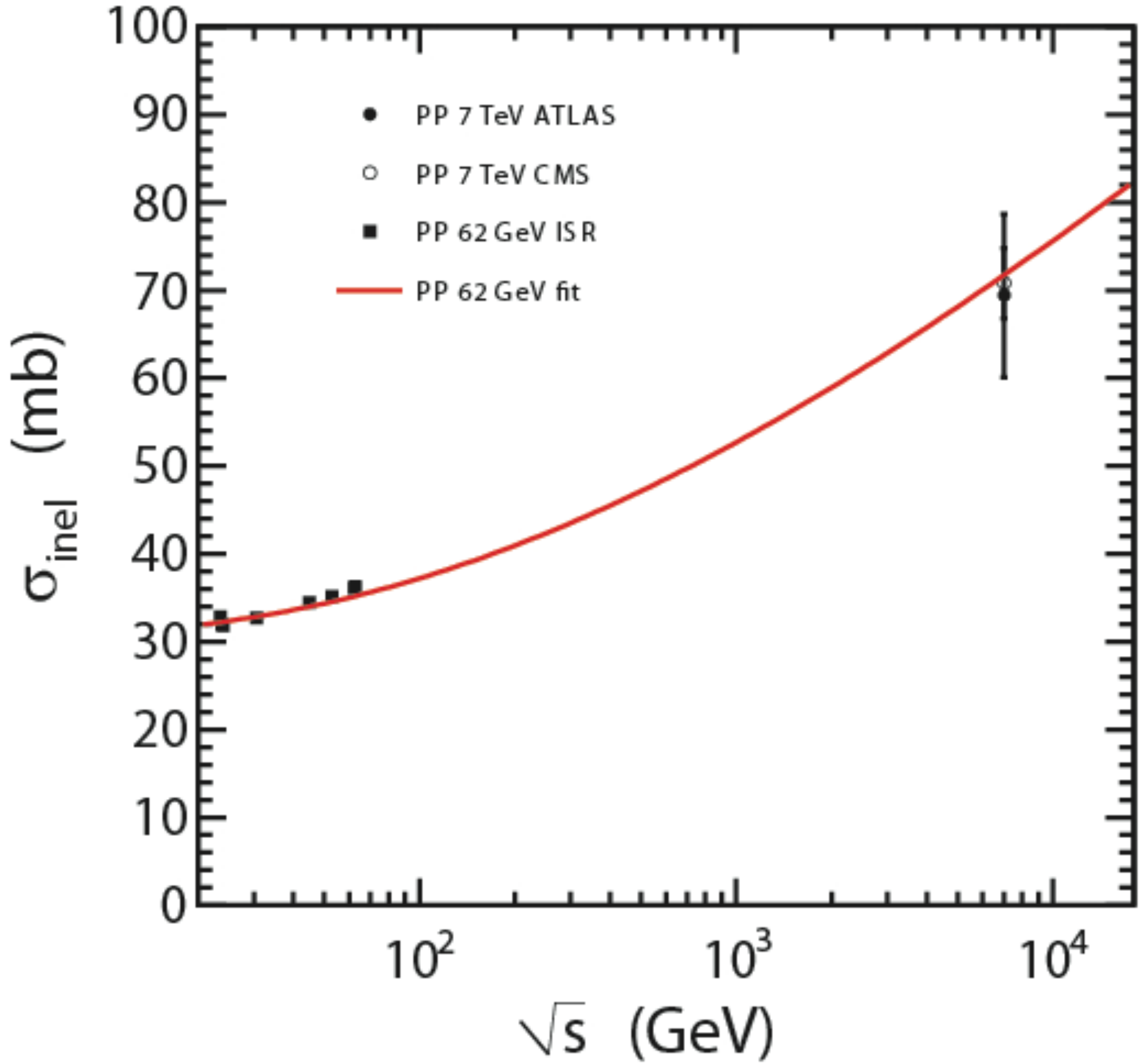


exponential region
Accepted Events (BSW model)
at 220m in 10^5 s, β*=90m, L=5x10^29
14 TeV
Islam
Petrov-Prokudin-Predazzi, 2 pomerons
Petrov-Prokudin-Predazzi, 3 pomerons
Bourelly-Soffer-Wu
Block-Halzen
dσ/dt (mb/GeV^2)
3x10^8
2.5x10^5
700
80
5
0.2
0.05
β* = 1540 m
β* = 90 m
β* = 11 m
β* = 2 m
squared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

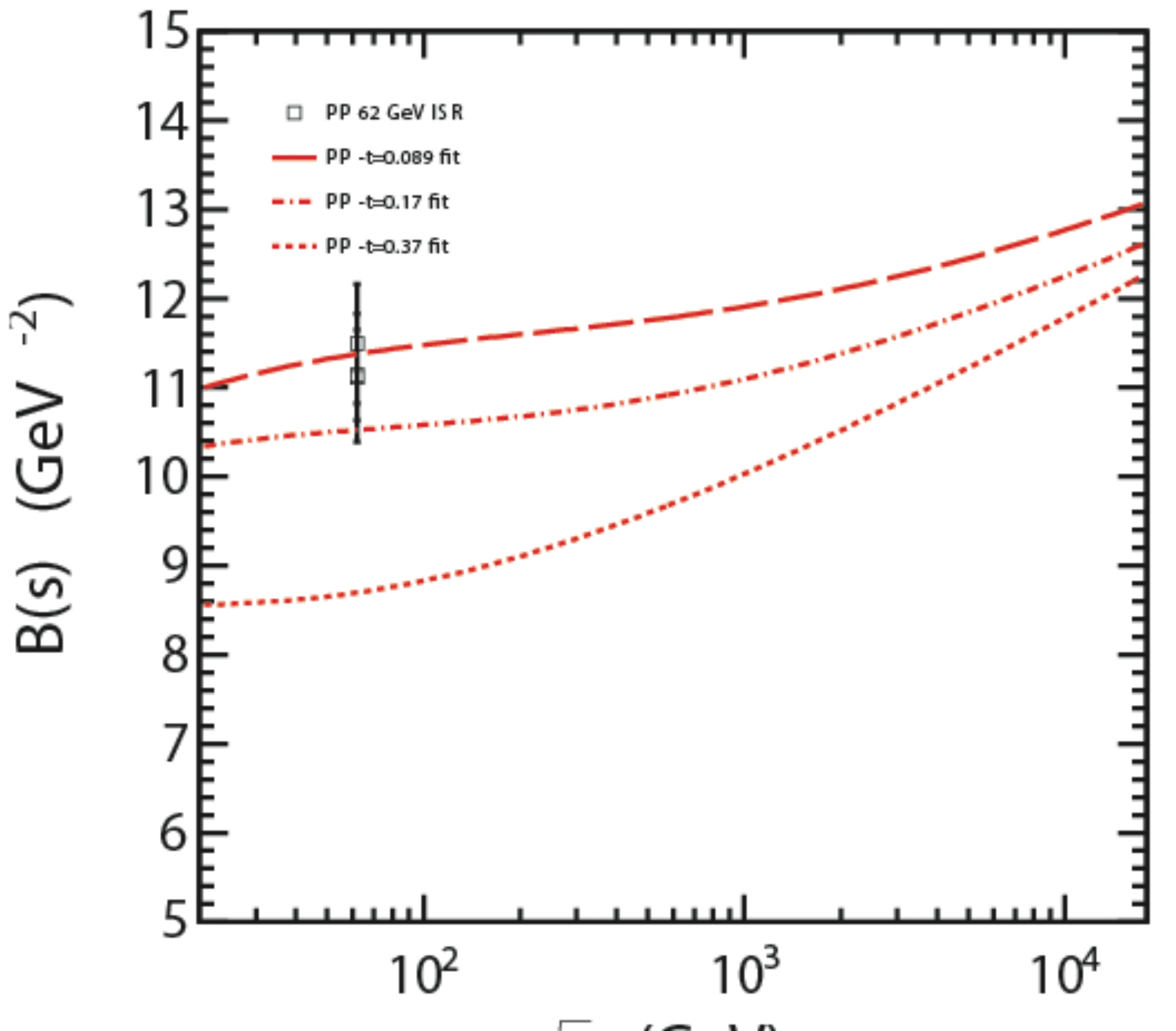
CERN LHC, TOTEM Collab., June 26, 2011:



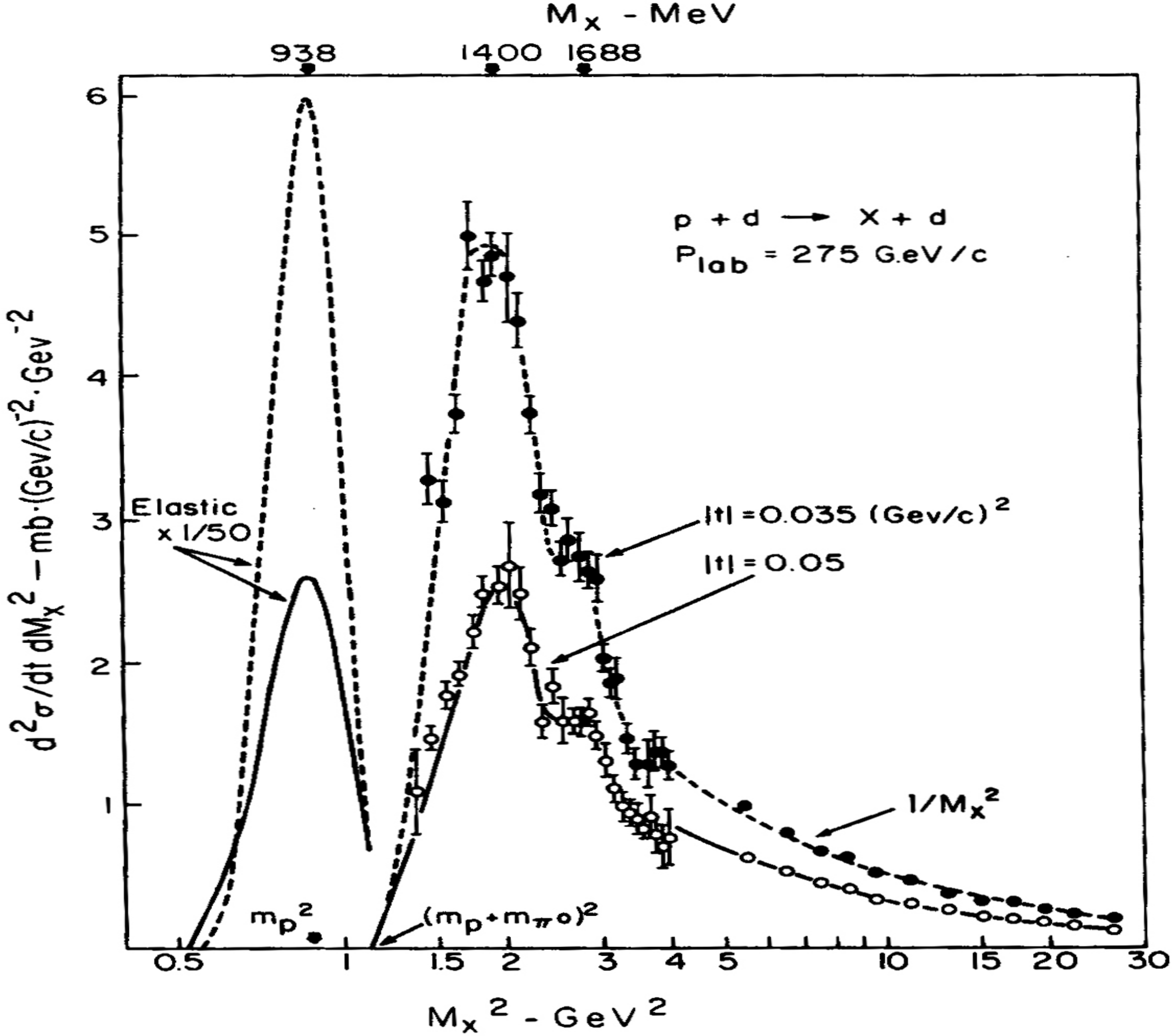

PP̄ 1800 GeV TEVATRON
PP 62 GeV ISR
PP̄ 1800 GeV fit
PP 7 TeV fit
PP 14 TeV fit
PP 62 GeV fit
B(t) (GeV^{-2})
-t (GeV^{2})
0
5
10
15
20
25
30
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



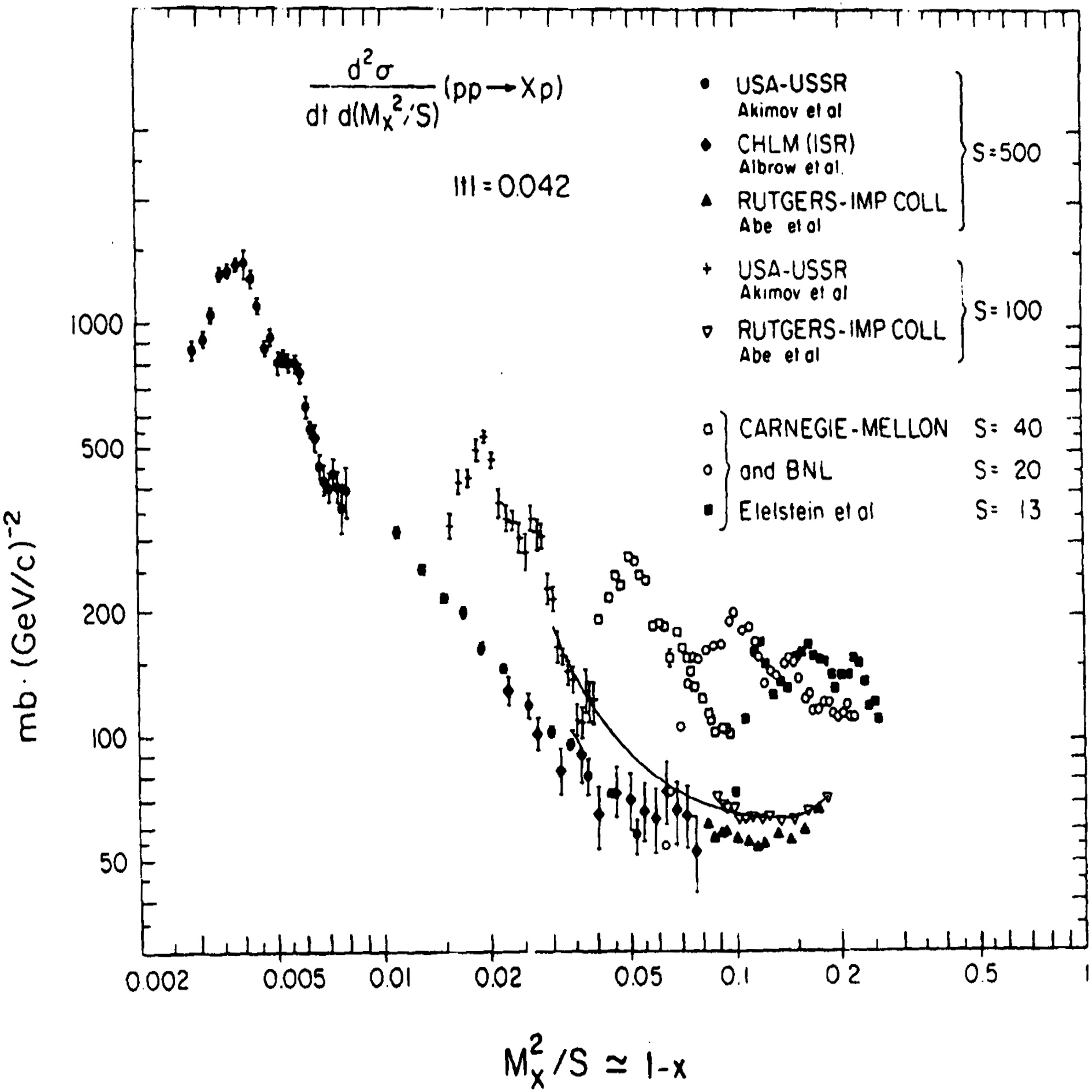
100
90
80
70
60
50
40
30
20
10
0
σ_{inel} (mb)
PP 7 TeV ATLAS
PP 7 TeV CMS
PP 62 GeV ISR
PP 62 GeV fit
10^2
10^3
10^4
$\sqrt{s}$ (GeV)


PP 62 GeV ISR
PP -t=0.089 fit
PP -t=0.17 fit
PP -t=0.37 fit
B(s) (GeV -2)
15
14
13
12
11
10
9
8
7
6
5
10^2
10^3
10^4

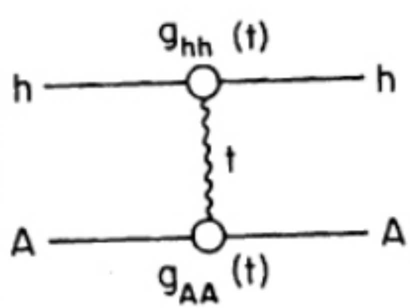
FNAL



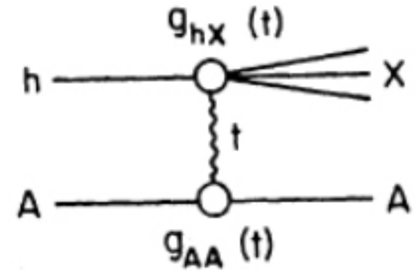
M_x - MeV
938
1400
1688
6
5
4
3
2
1
p + d → X + d
P_{lab} = 275 GeV/c
Elastic
x 1/50
|t| = 0.035 (Gev/c)²
|t| = 0.05
1/M_x^2
m_p^2
$(m_p + m_{\pi^0})^2$
$d^2\sigma/dt\,dM_x^2$ — mb·(Gev/c)$^{-2}$·Gev^{-2}
0.5
1
1.5
2
3
4
5
10
15
20
30
M_x^2 - GeV²



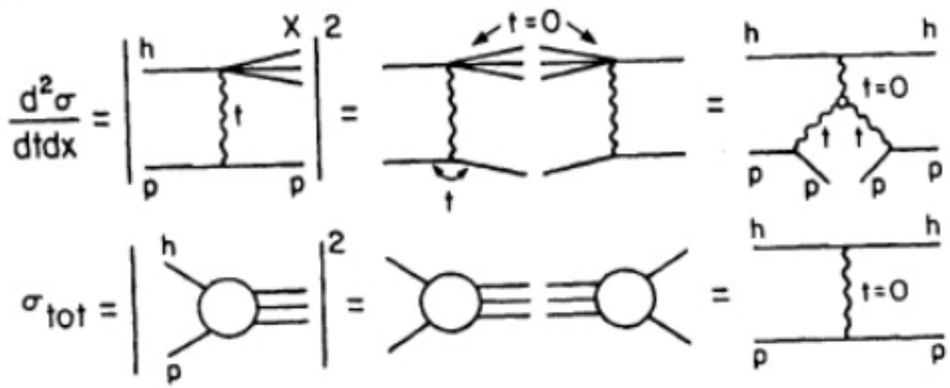
$\frac{d^2\sigma}{dt\, d(M_X^2/S)}$ (pp → Xp)
|t| = 0.042
USA-USSR
Akimov et al
CHLM (ISR)
Albrow et al.
RUTGERS-IMP COLL
Abe et al
S = 500
USA-USSR
Akimov et al
RUTGERS-IMP COLL
Abe et al
S = 100
CARNEGIE-MELLON
and BNL
Elelstein et al
S = 40
S = 20
S = 13
mb · (GeV/c)$^{-2}$
1000
500
200
100
50
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
$M_X^2/S \simeq 1-x$



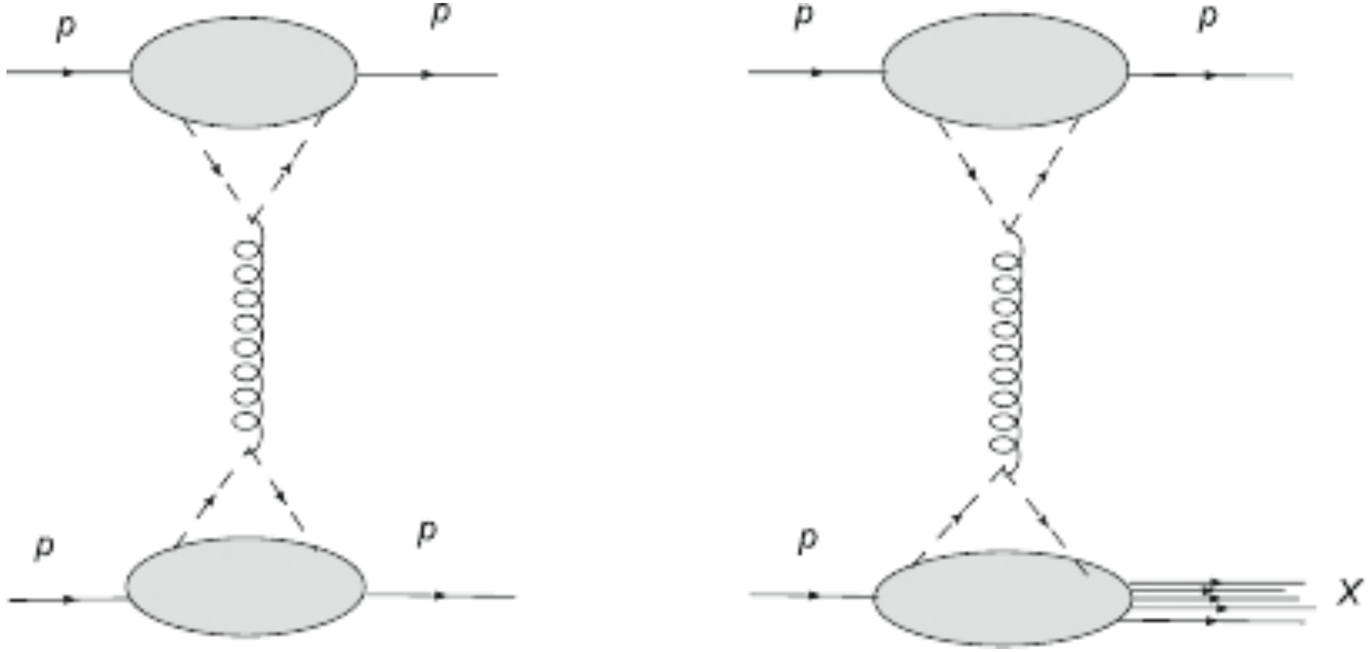
g_hh (t)
h
h
t
A
A
g_AA (t)



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



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


p
p
p
p
p
p
p
X

The pp scattering amplitude

$$A(s,t)_P = \\ - \beta^2[f^u(t)+f^d(t)]^2 \left(\frac{s}{s_0}\right)^{\alpha_P(t)-1} \frac{1+e^{-i\pi\alpha_P(t)}}{\sin\pi\alpha_P(t)}, \tag{1}$$

where $f^u(t)$ and $f^d(t)$ are the amplitudes for the emission of u and d valence quarks by the nucleon, β is the quark-Pomeron coupling, to be determined below; $\alpha_P(t)$ is a vacuum Regge trajectory. It is assumed that the Pomeron couples to the proton via quarks like a scalar photon.

A single-Pomeron exchange is valid at the LHC energies, however at lower energies (e.g. those of the ISR or the SPS) the contribution of non-leading Regge exchanges should be accounted for as well.

Thus, the unpolarized elastic pp differential cross section is

$$\frac{d\sigma}{dt} = \frac{[3\beta F^p(t)]^4}{4\pi\sin^2[\pi\alpha_P(t)/2]}(s/s_0)^{2\alpha_P(t)-2}. \tag{2}$$

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

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

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.

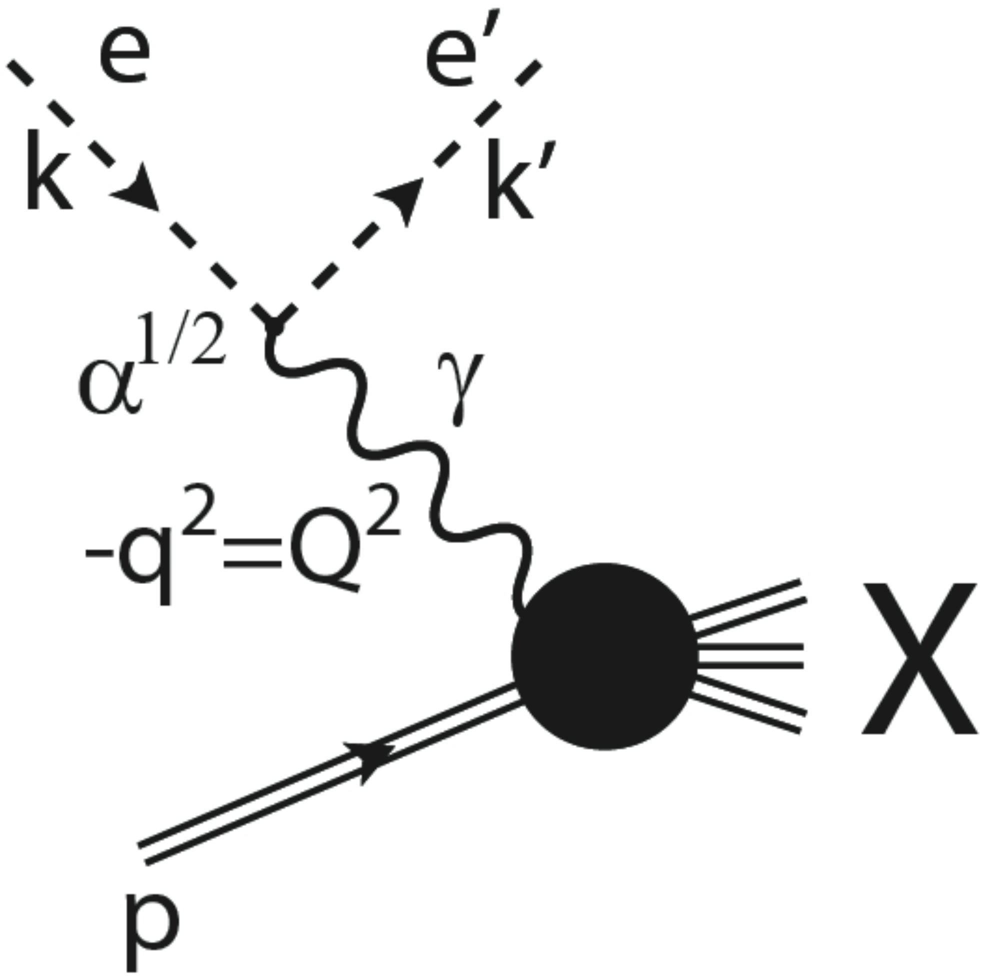
In the LHC energy region it simplifies to:

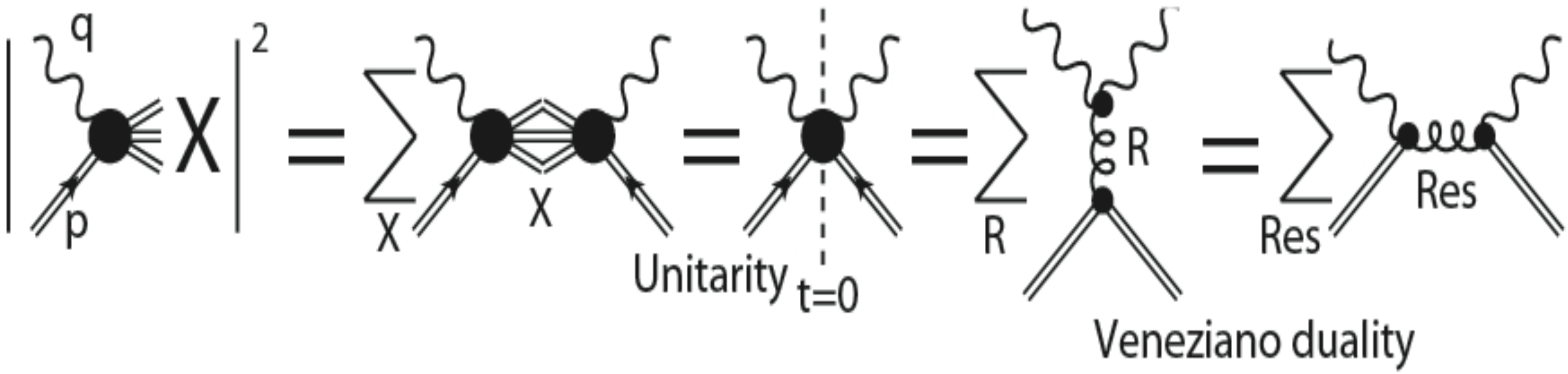
$$\frac{d^2\sigma}{dtdM_X^2} \approx \frac{9\beta^4[F^p(t)]^2}{4\pi}(s/M_X^2)^{2\alpha_P(t)-2}\frac{W_2}{2m}\,. \qquad (1)$$

These expressions for SDD do not contain the elastic scattering limit because the inelastic form factor $W_2(M_X, t)$ has no elastic form factor limit $F(t)$ as $M_X \to m$. This problem is similar to the $x \to 1$ limit of the deep inelastic structure function $F_2(x, Q^2)$. The elastic contribution to SDD should be added separately.

Low-mass diffraction dissociation at the LHC

L. Jenkovszky, O. Kuprash, J. Lamsa, V. Magas, and R,. Orava:
Dual-Regge approach to high-energy, low-mass DD at the LHC,
Phys. Rev. D83(2011)0566014; hep-ph/1-11.0664.
L. Jenkovszky, O. Kuprash, J. Lamsa and R. Orava: hep-ph/11063299,
Mod. Phys. Letters A. **26**(2011) 1-9, August 2011.

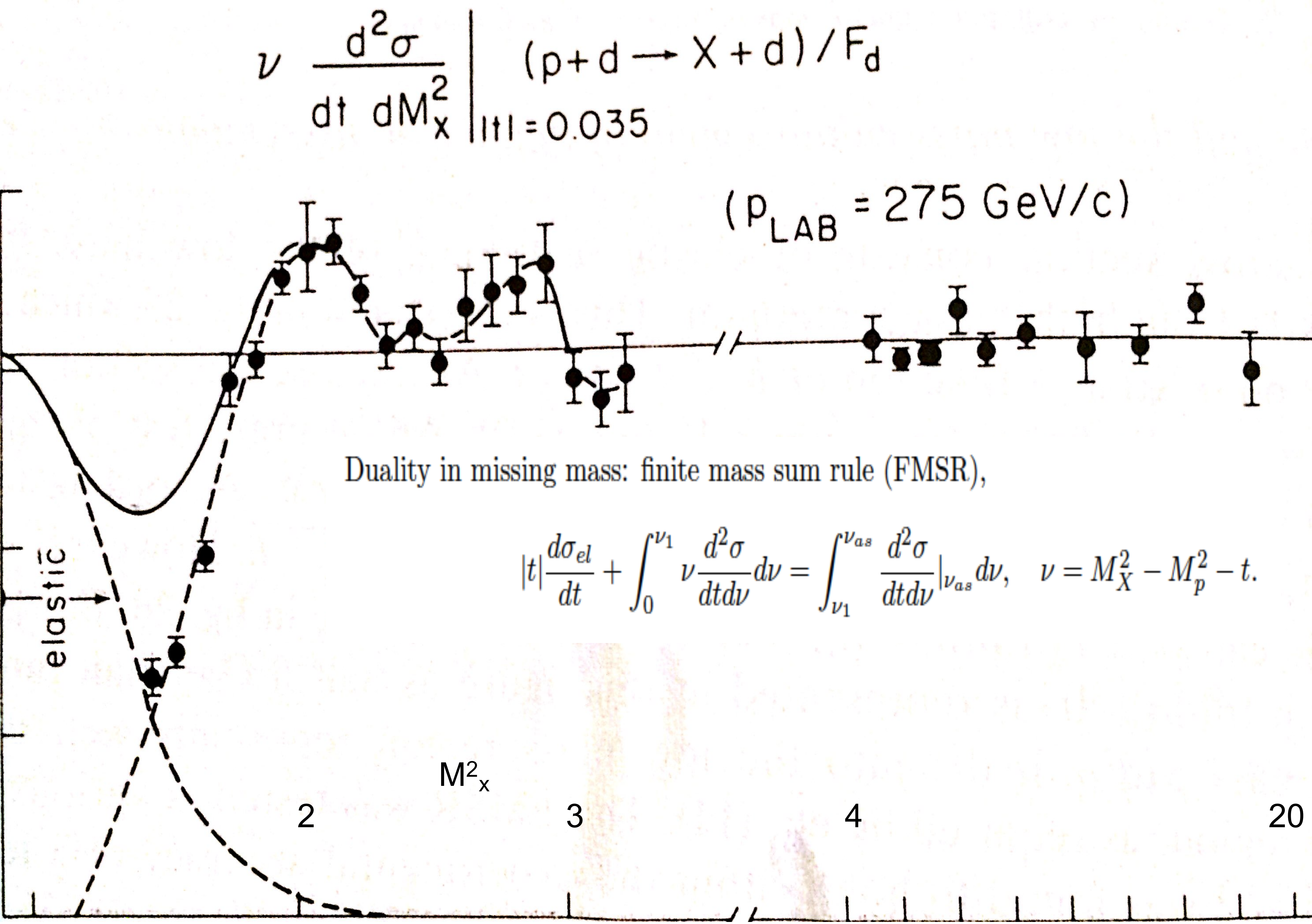

e
e′
k
k′
$\alpha^{1/2}$
γ
$-q^2=Q^2$
X
p



q
p
X
2
X
X
Unitarity
t=0
R
R
Res
Res
Veneziano duality

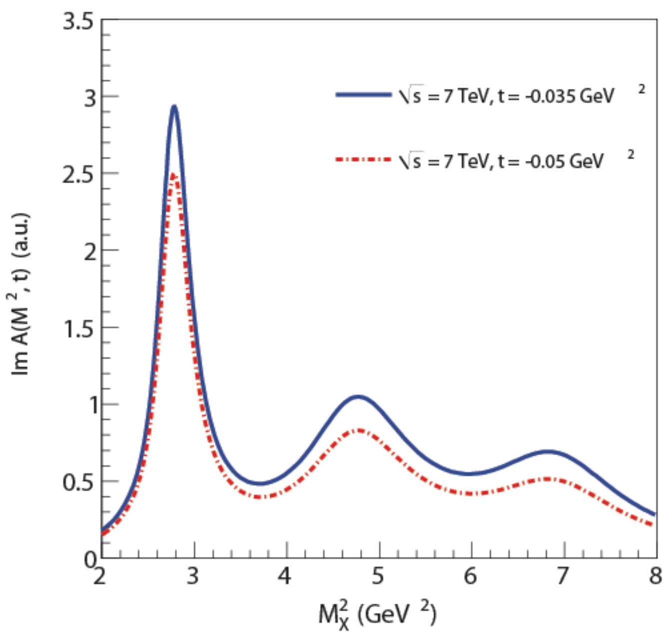
The final expression for the double differential cross section reads:

$$\frac{d^2\sigma}{dt dM_X^2} = A_0 \left(\frac{s}{M_X^2}\right)^{2\alpha_P(t)-2} \frac{x(1-x)^2\ [F^p(t)]^2}{(M_x^2-m^2)\left(1+\frac{4m^2x^2}{-t}\right)^{3/2}} \times \sum_{n=1,3} \frac{[f(t)]^{2(n+1)}\, Im\, \alpha(M_X^2)}{(2n+0.5-Re\,\alpha(M_X^2))^2+(Im\,\alpha(M_X^2))^2}\,. \tag{1}$$

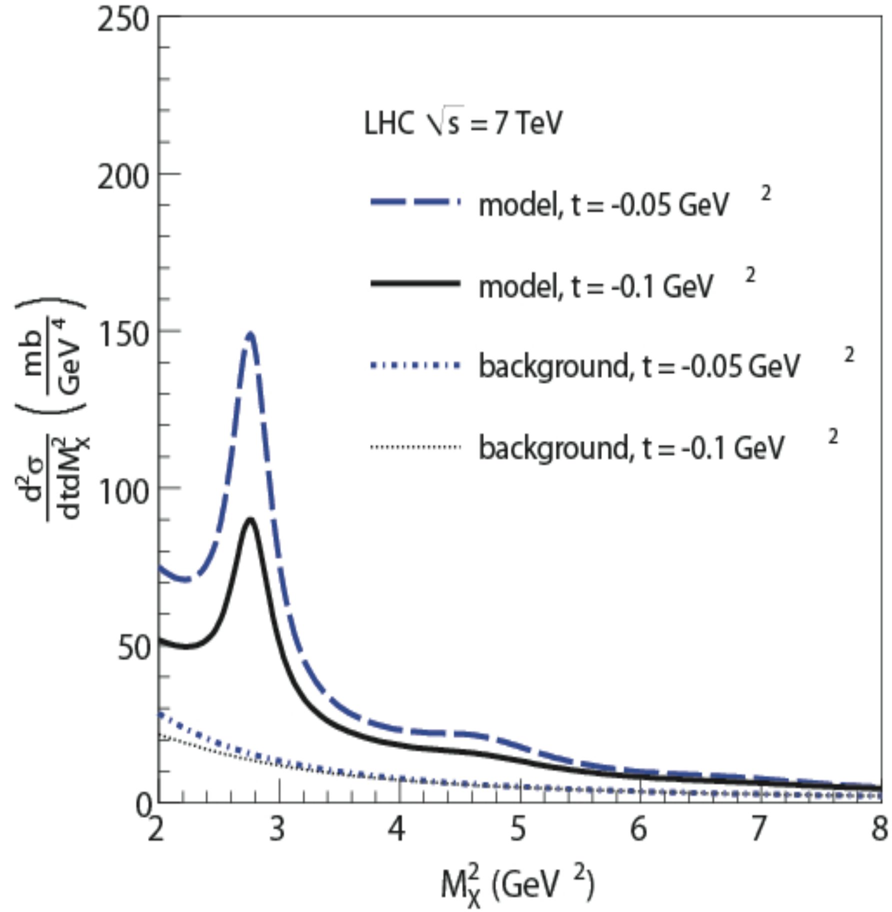


Duality in missing mass: finite mass sum rule (FMSR),

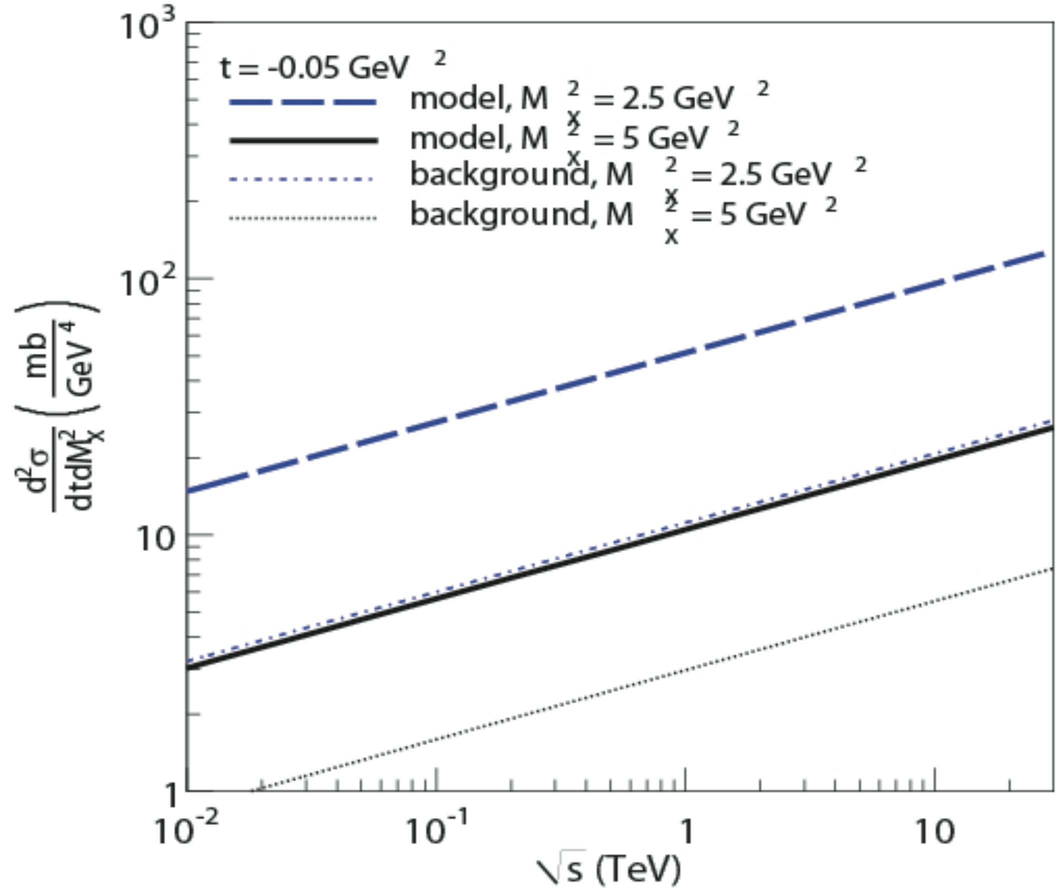
$$|t|\frac{d\sigma_{el}}{dt}+\int_0^{\nu_1}\nu\frac{d^2\sigma}{dtd\nu}d\nu=\int_{\nu_1}^{\nu_{as}}\frac{d^2\sigma}{dtd\nu}|_{\nu_{as}}d\nu,\quad \nu=M_X^2-M_p^2-t.$$



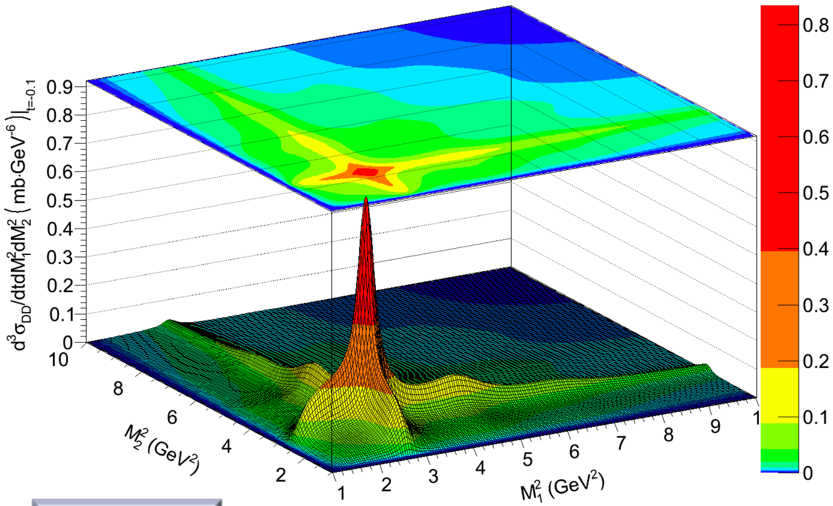
√s = 7 TeV, t = -0.035 GeV 2
√s = 7 TeV, t = -0.05 GeV 2
Im A(M 2, t) (a.u.)
M2X (GeV 2)
3.5
3
2.5
2
1.5
1
0.5
0
2
3
4
5
6
7
8



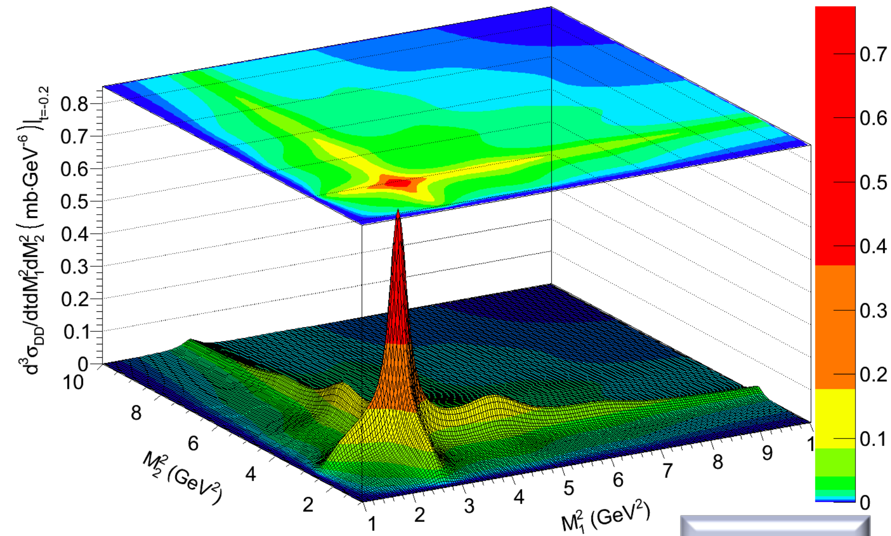
LHC √s = 7 TeV
model, t = -0.05 GeV 2
model, t = -0.1 GeV 2
background, t = -0.05 GeV 2
background, t = -0.1 GeV 2
d2σ/dtdM2X (mb/GeV4)
M2X (GeV 2)
0
50
100
150
200
250
2
3
4
5
6
7
8


t = -0.05 GeV 2
model, M x 2 = 2.5 GeV 2
model, M x 2 = 5 GeV 2
background, M x 2 = 2.5 GeV 2
background, M x 2 = 5 GeV 2
d2σ/dtdM2X (mb/GeV4)
√s (TeV)
10-2
10-1
1
10
102
103

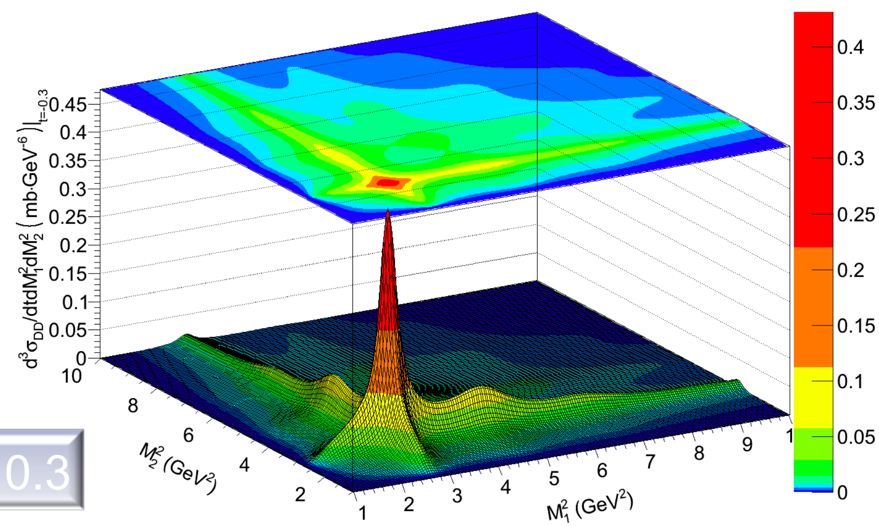
Triple differential DD cross sections



t = - 0.1



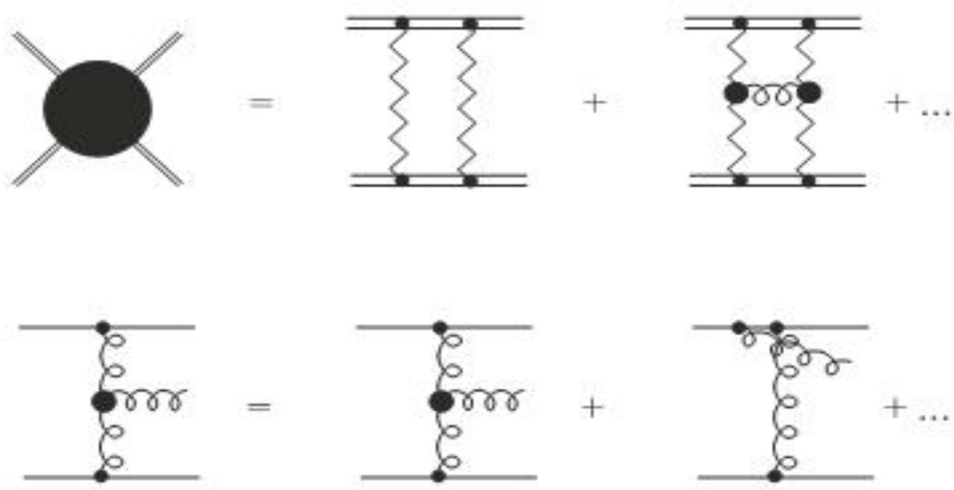
t = - 0.2



t = - 0.3

Thank you !

R. Fiore, L.L. Jenkovszky, E.A. Kuraev, A.I. Lengyel, and Z.Z. Tarics, *Predictions for high-energy pp and \bar pp scattering from a finite sum of gluon ladders,* Phys. Rev. D81, #5 (2010) 056005; arXiv0911.2094/hep-ph



$$\sigma_t^{(P)}(s) = \sum_{i=0}^{N} f_i \, \theta(s - s_0^i) \, \theta(s_0^{i+1} - s) \, , \qquad (1)$$

where

$$f_i = \sum_{j=0}^{i} a_{ij} L^j \, , \qquad (2)$$