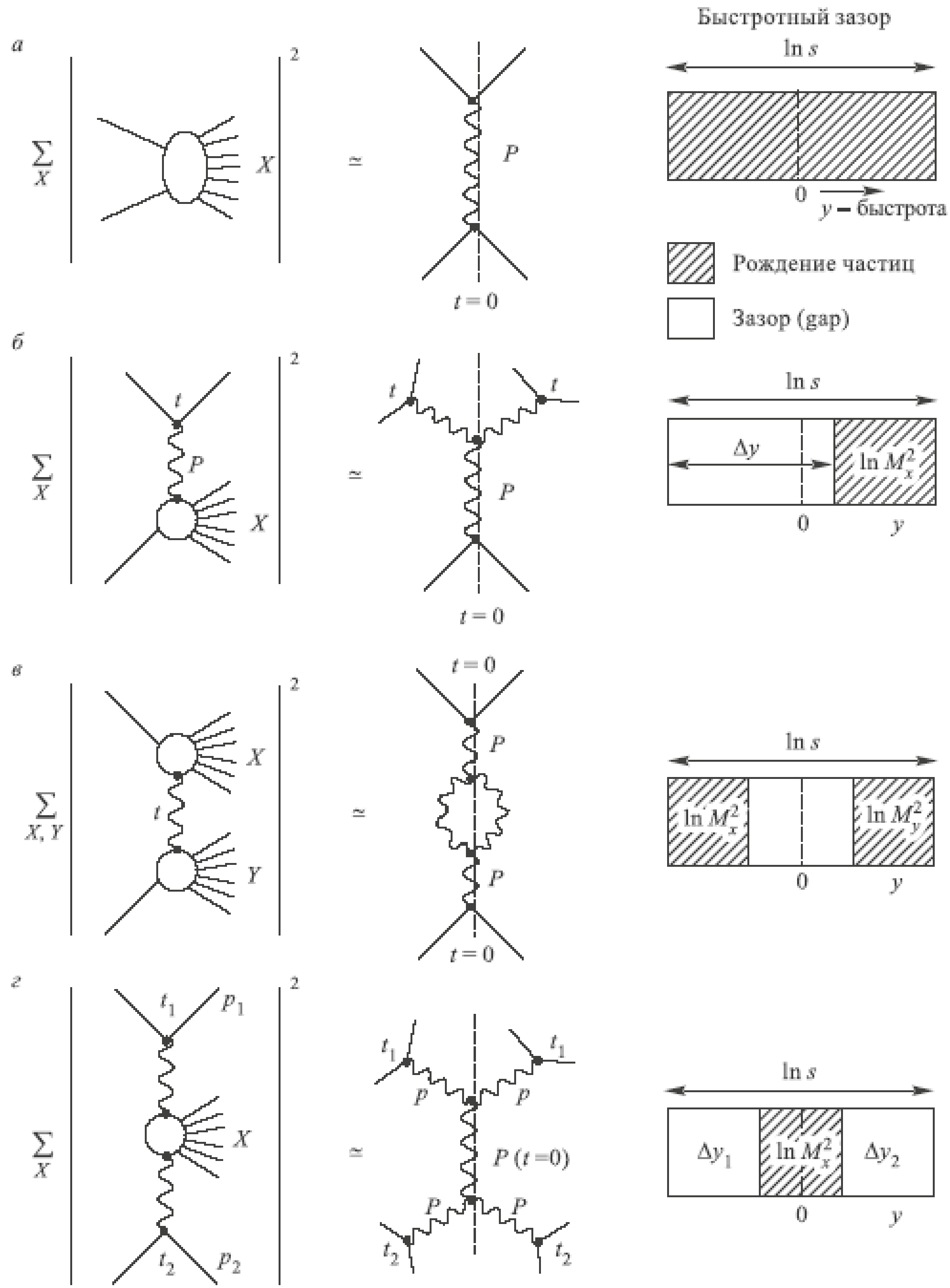
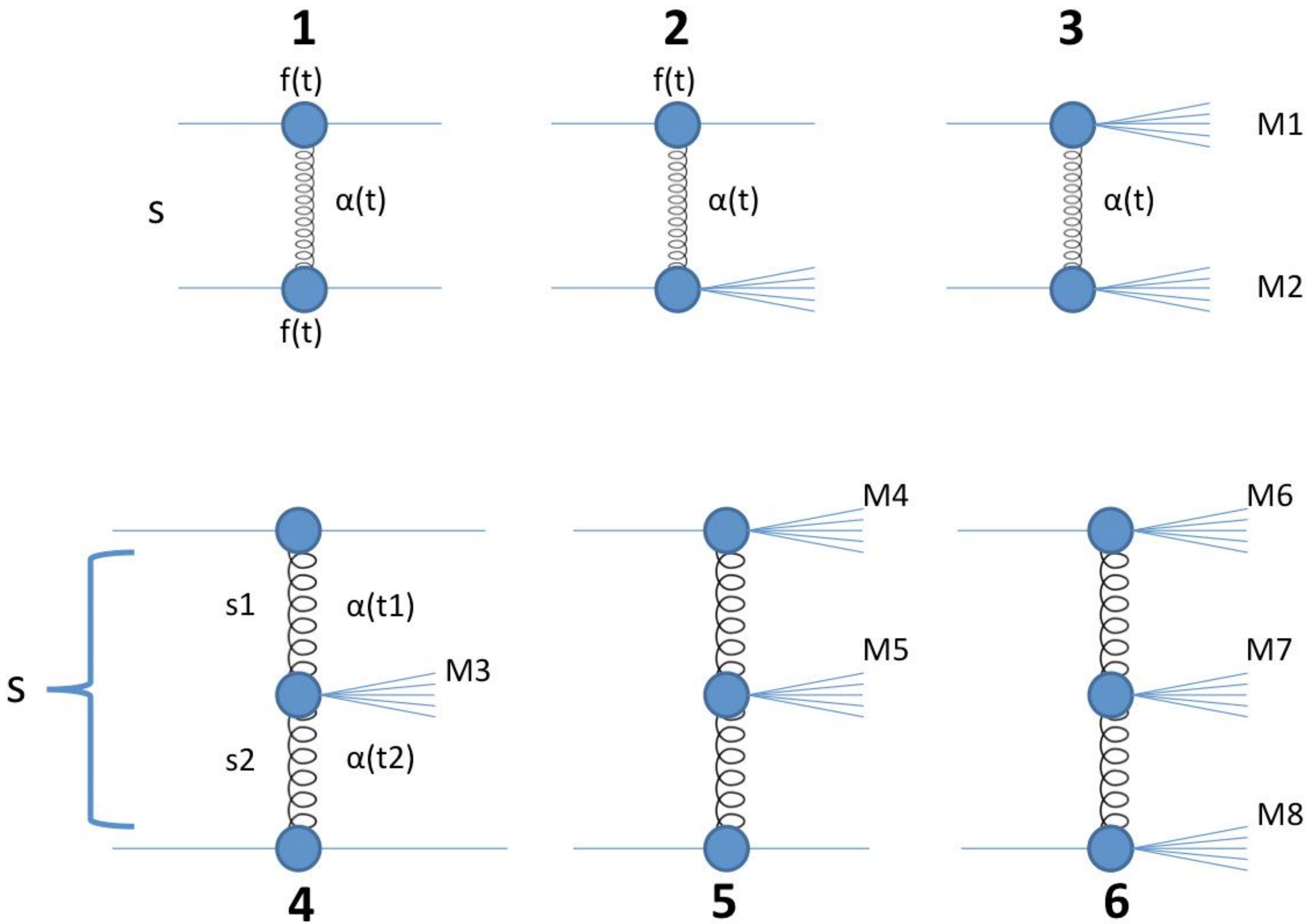
CERN, February, 2013

DIFFRACTION DISSOCIATION at the LHC

László Jenkovszky, Kiev



Быстротный зазор
ln s
0
y – быстрота
Рождение частиц
Зазор (gap)
a
б
в
г
t = 0
P
X
Y
Δy
ln M_x^2
ln M_y^2
Δy_1
Δy_2
P (t = 0)
t_1
t_2
p_1
p_2


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

Some open questions:

0) Definition of diffraction: rapidity gap vs. P exchange;
1) The ratio between SD, DD and CD?
2) Integrated cross section require the knowledge of the M-dependence for all M! Low- and high M:
3) Duality in M (FMSR);
4) Structures in t: a dip in t~1 GeV^2,…
5) The background (in s and in M);
6) Exclusive-inclusive relation;
7) From elastic to inelastic diffraction (dis)continuity.

Simple (but approximate) factorization relations

$$\frac{d^3\sigma_{DD}}{dt dM_1^2 dM_2^2} = \frac{d^2\sigma_{SD1}}{dt dM_1^2} \frac{d^2\sigma_{SD2}}{dt dM_2^2} \Big/ \frac{d\sigma_{el}}{dt}. \tag{1}$$

Assuming e^{bt} dependence for both SD and elastic scattering, integration over t yields

$$\frac{d^3\sigma_{DD}}{dM_1^2 dM_2^2} = k \frac{d^2\sigma_{SD1}}{dM_1^2} \frac{d^2\sigma_{SD2}}{dM_2^2} / \sigma_{el}. \tag{2}$$

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

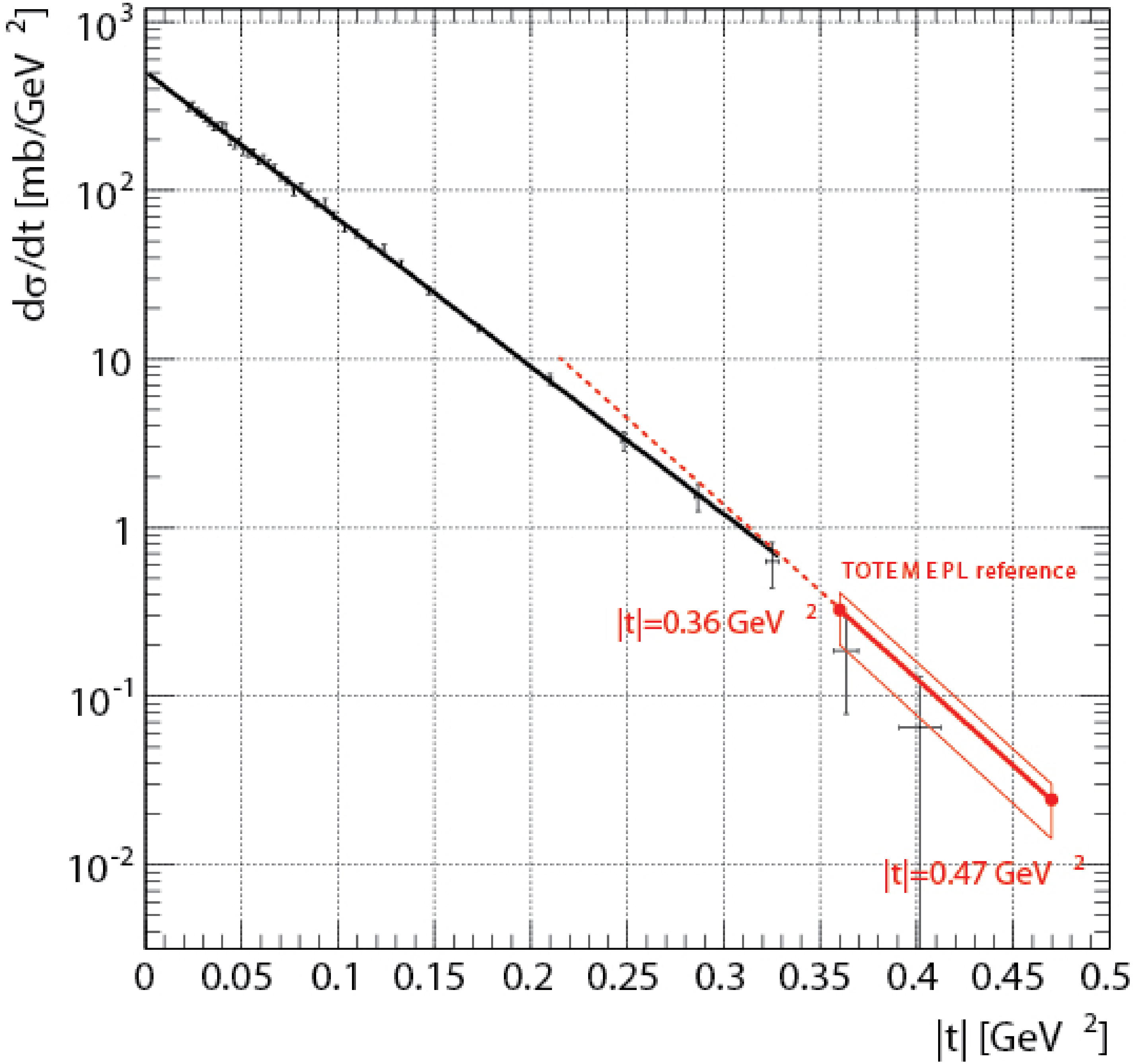
$$\sigma_t(s) = \frac{4\pi}{s} Im A(s, t=0); \quad \frac{d\sigma}{dt} = \frac{\pi}{s^2}|A(s,t)|^2; \quad \boldsymbol{n(s)};$$

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

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

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

α(0)\C	+	-
1	P	O
1/2	f	ω



dσ/dt [mb/GeV 2]
|t| [GeV 2]
TOTEM EPL reference
|t|=0.36 GeV 2
|t|=0.47 GeV 2

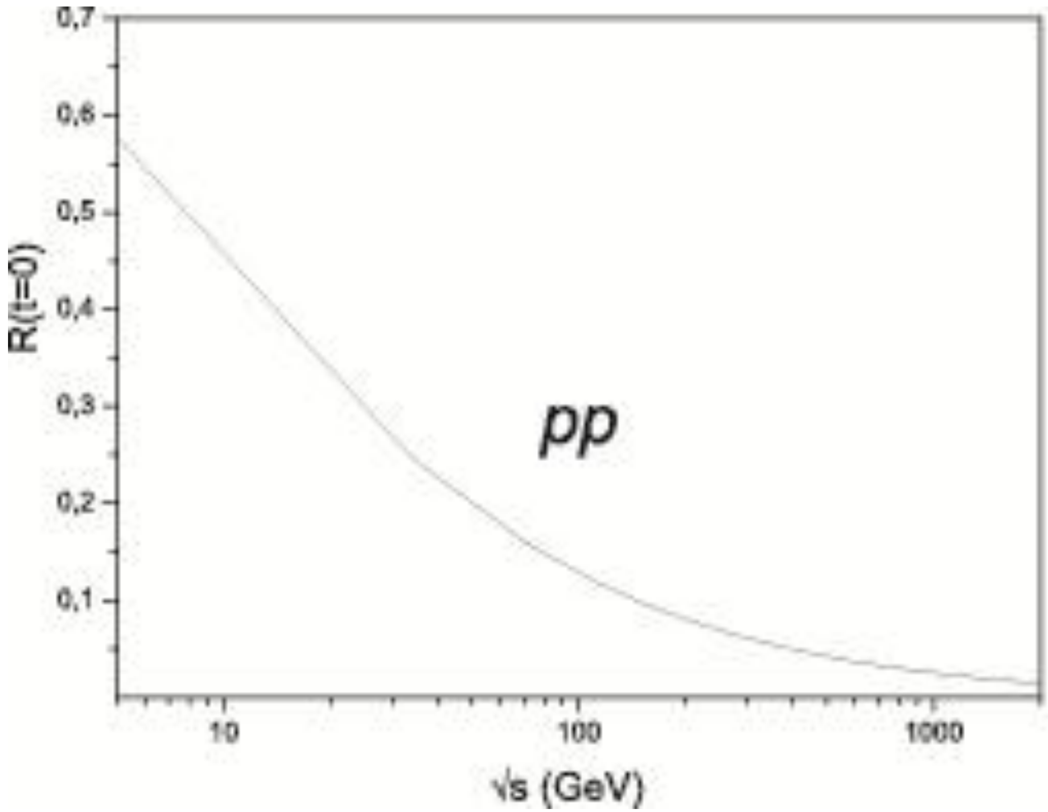
Energy variation of the relative importance of the Pomeron with respect to contributions from the secondary trajectories and the Odderon:

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

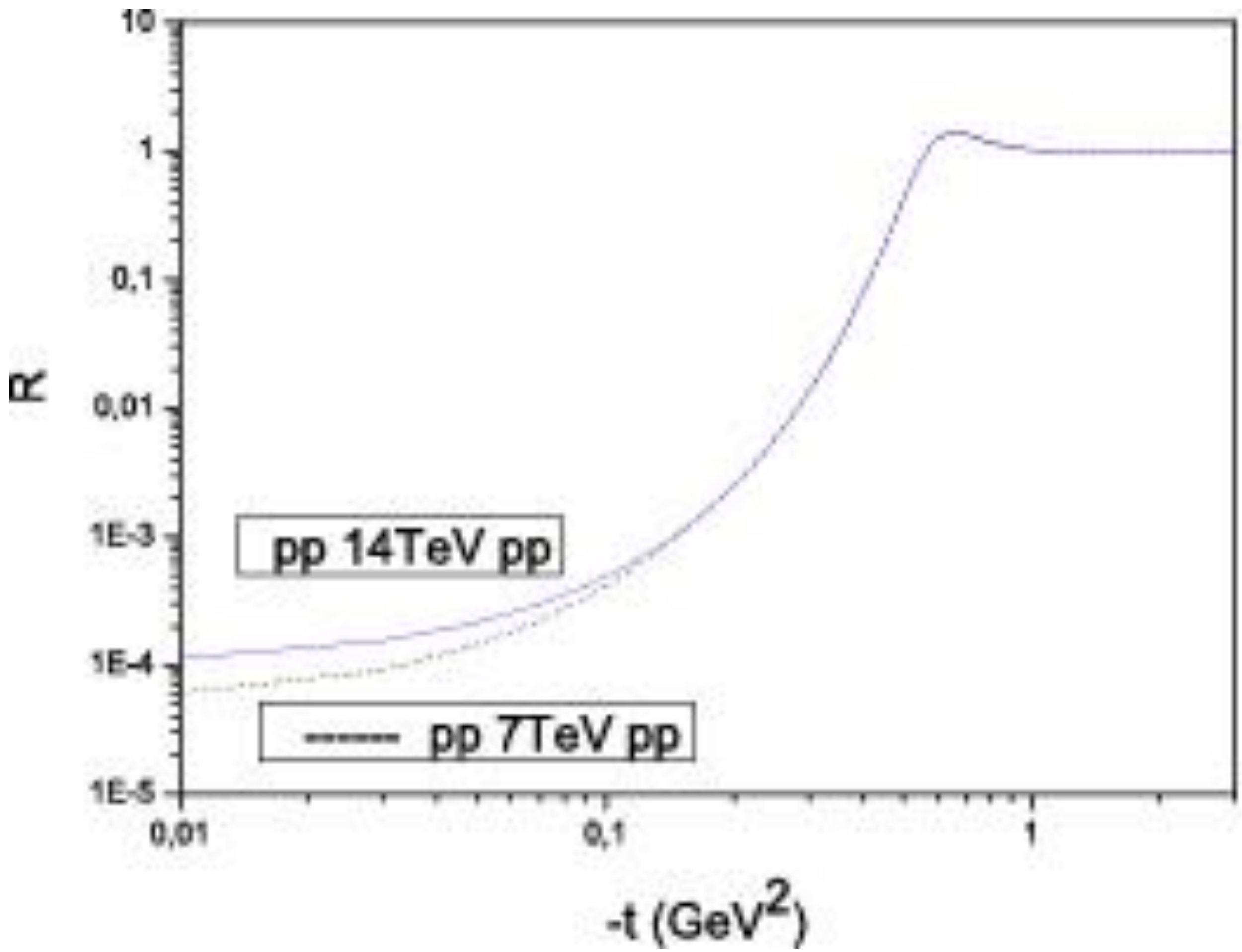
where the total scattering amplitude A includes the Pomeron contribution A_P plus the contribution from the secondary Reggeons and the Odderon.

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)



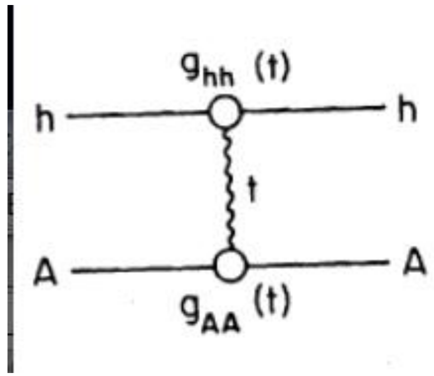
10
1
0,1
0,01
1E-3
1E-4
1E-5
R
pp 14TeV pp
pp 7TeV pp
0,01
0,1
1
-t (GeV2)

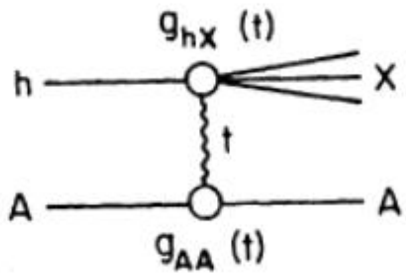
Low-mass diffraction dissociation at the LHC

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.

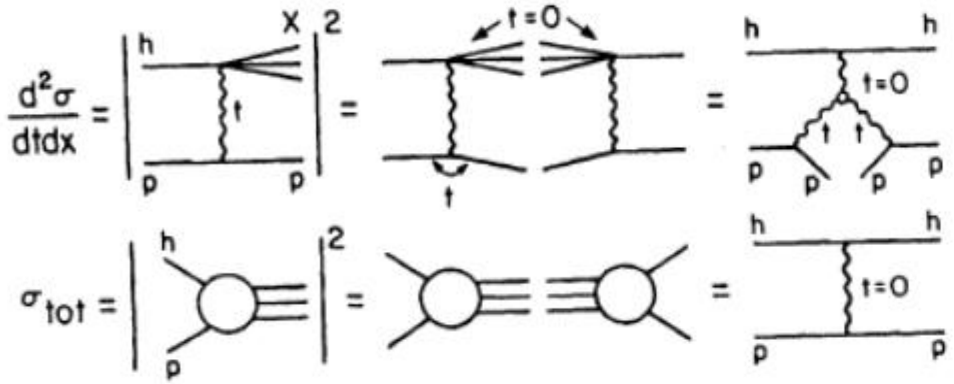
Experimentally, diffraction dissociation in proton-proton scattering was intensively studied in the '70-ies at the Fermilab and the CERN ISR. In particular, double differential cross section $\frac{d\sigma}{dtdM_X^2}$ was measured in the region $0.024 < -t < 0.234\ (\mathrm{GeV/c})^2,\quad 0 < M^2 < 0.12s$, and $(105 < s < 752)\ \mathrm{GeV}^2$, and a single peak in M_X^2 was identified.

Low-mass single diffraction dissociation (SDD) of protons, $pp \to pX$ as well as their double diffraction dissociation (DDD) are among the priorities at the LHC. For the CMS Collaboration, the SDD mass coverage is presently limited to some 10 GeV. With the Zero Degree Calorimeter (ZDS), this could be reduced to smaller masses, in case the SDD system produces very forward neutrals, i.e. like a N^* decaying into a fast leading neutron. Together with the T2 detectors of TOTEM, SDD masses down to 4 GeV could be covered.

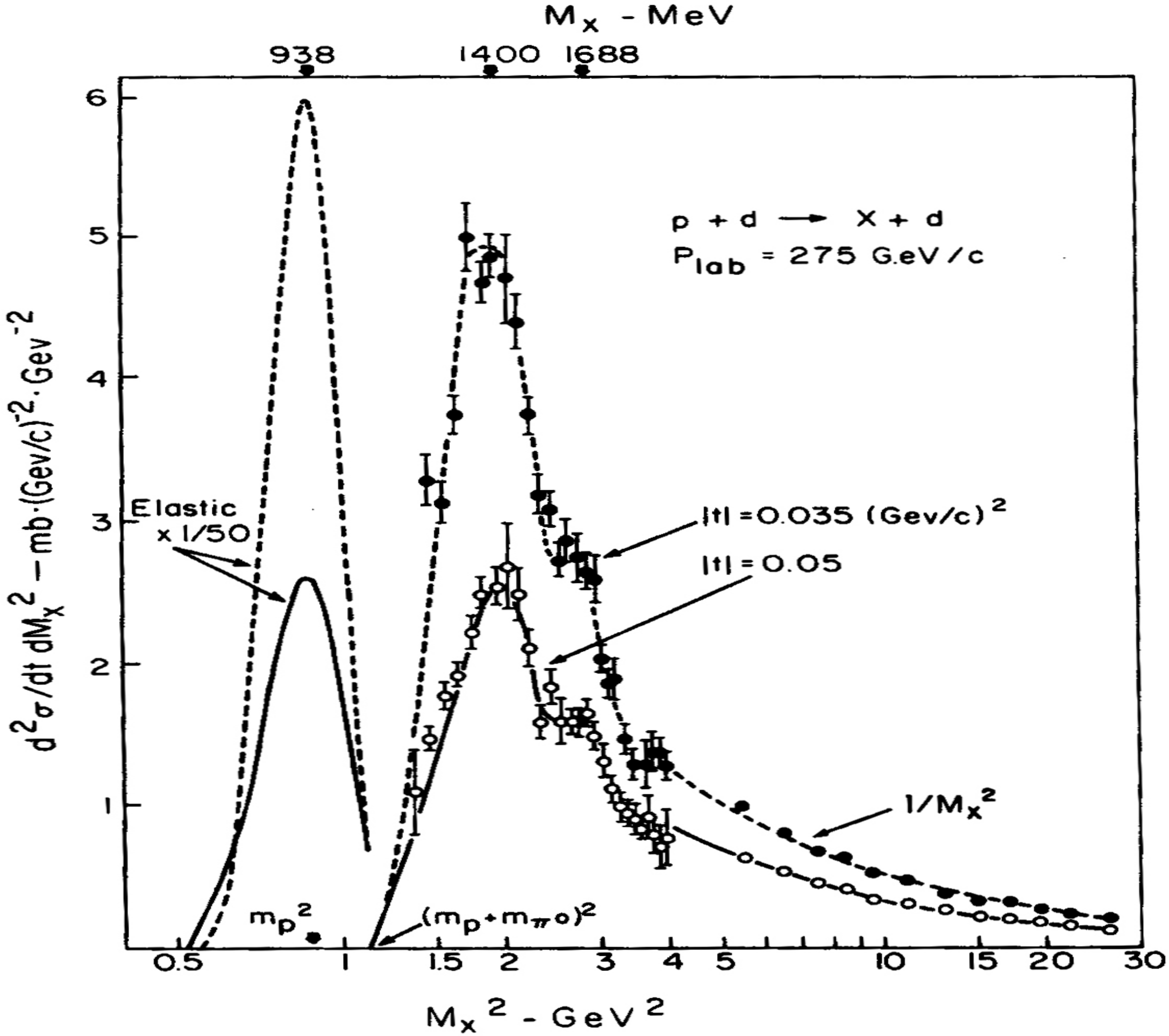




Triple Regge (Pomeron) limit::

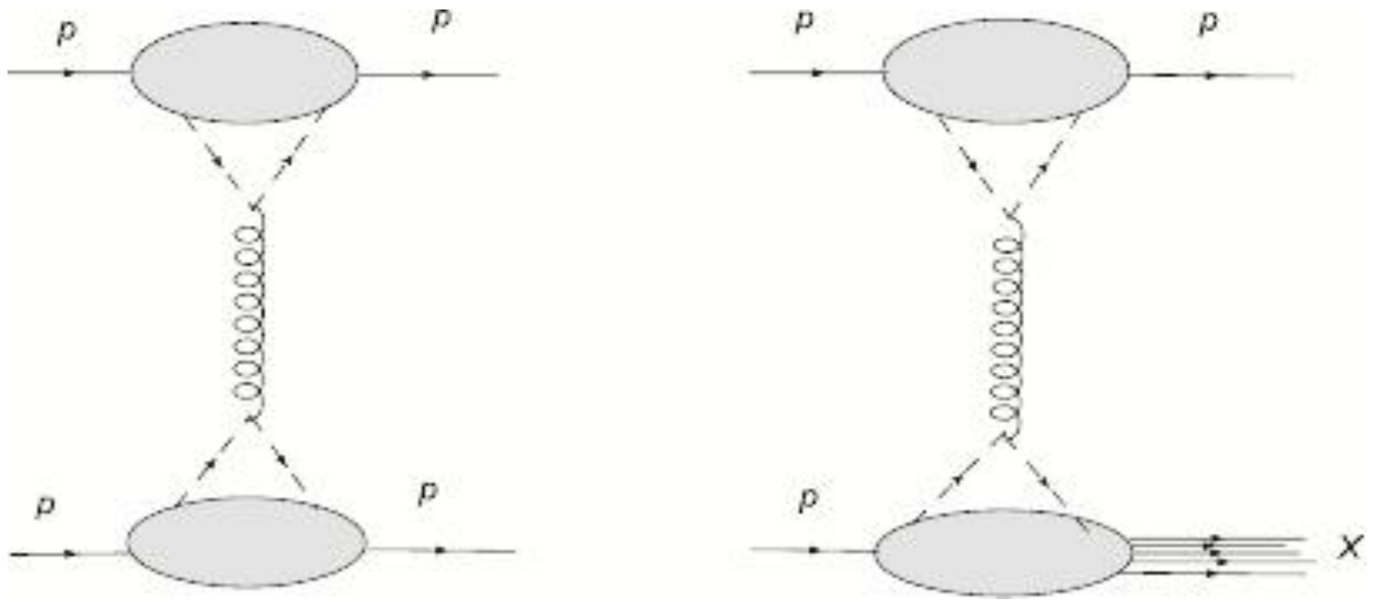


FNAL

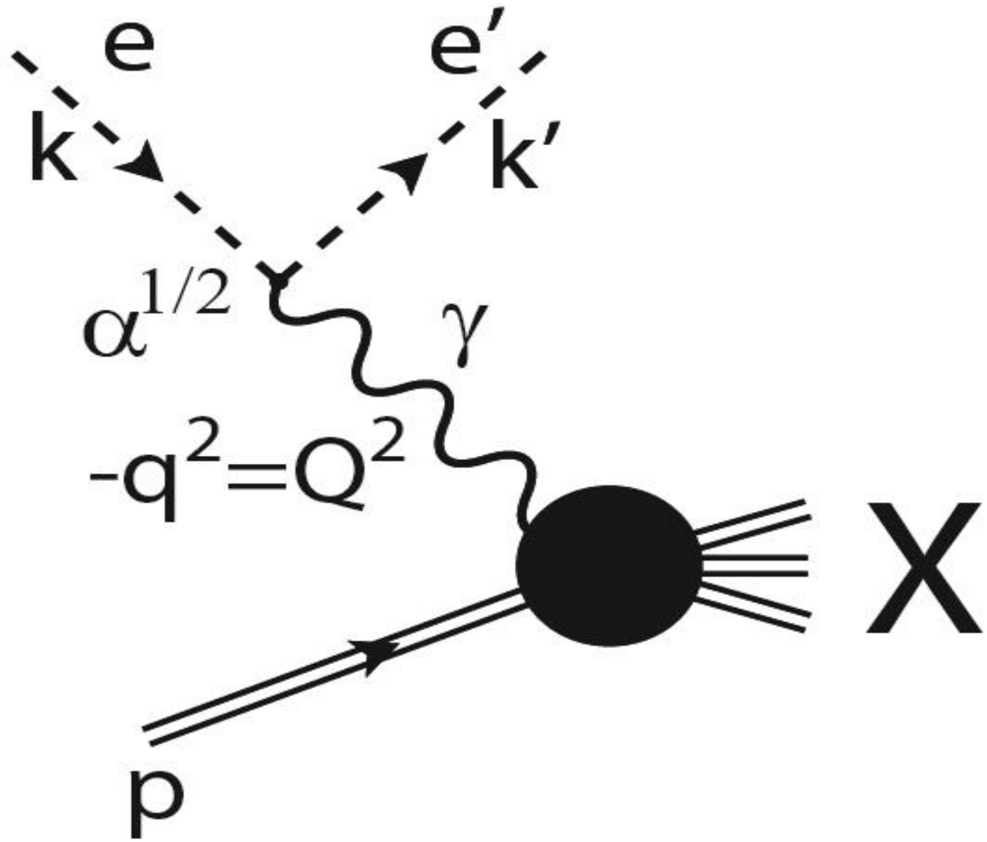


Mx - MeV
938
1400
1688
p + d → X + d
Plab = 275 GeV/c
Elastic
x 1/50
|t| =0.035 (Gev/c)2
|t| = 0.05
1/Mx2
mp2
(mp+mπo)2
d2σ/dt dMx2 — mb·(Gev/c)-2·Gev-2
Mx2 - GeV2

Alternative (to the triple Regge) approach: Diffraction dissociation and DIS :



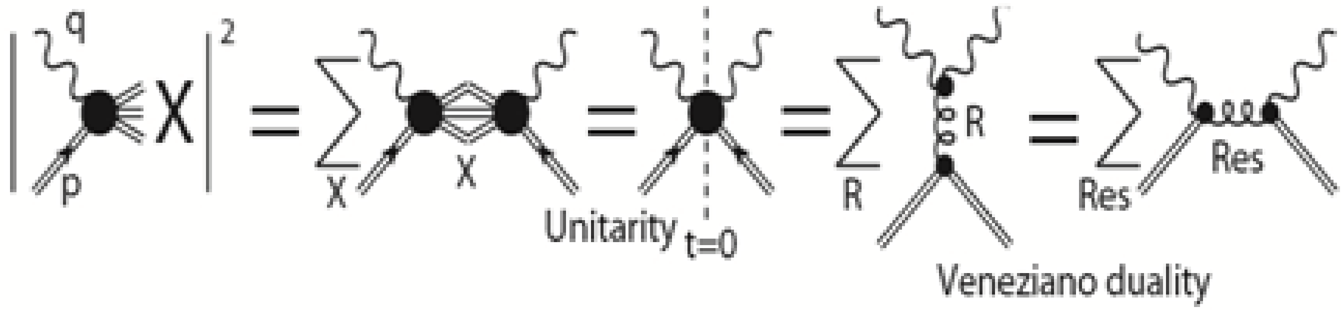
G.A. Jaroszkiewicz and P.V. Landshoff, Phys. Rev. 10 (1974) 170;
A. Donnachie, P.V. Landshoff, Nucl. Phys. B **244** (1984) 322.



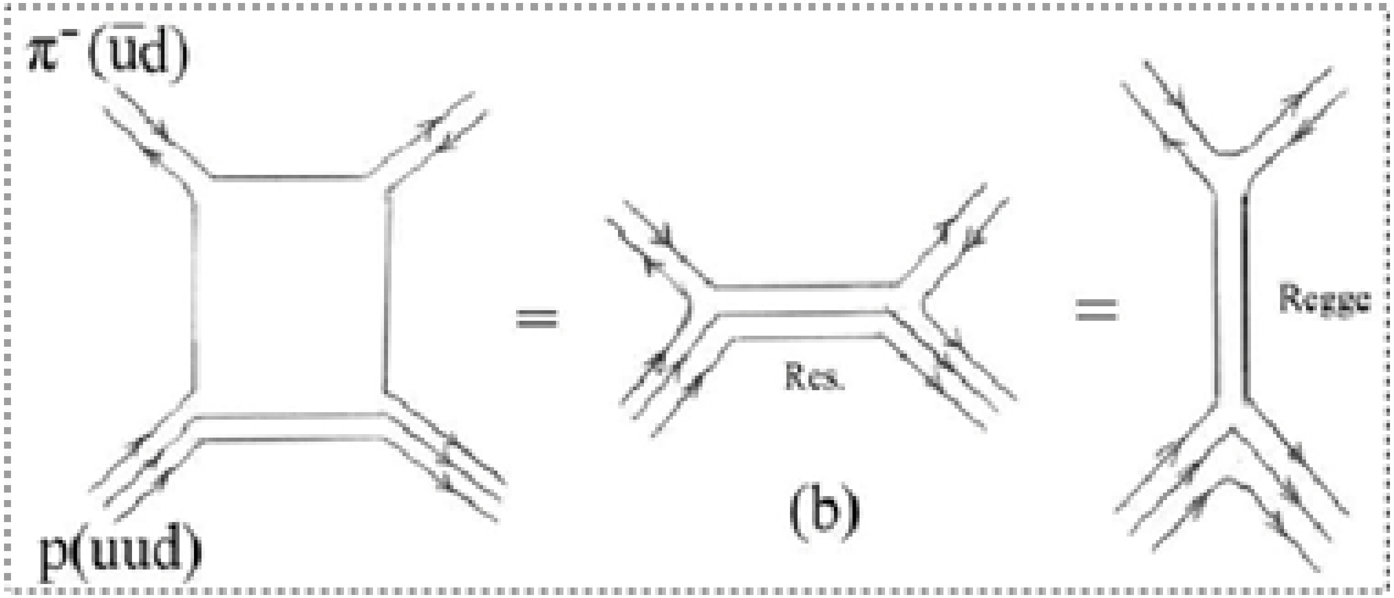
JLAB → LHC; γ→ P; q^2→ t

R. Fiore {\it et al.} EPJ A **15** (2002) 505,hep-ph/0206027;.
R. Fiore {\it et al.} Phys. Rev. D **68** (2004) 014004, hep-ph/0308178.

Dual properties of the inelastic SF (transition amplitude)



L. Jenkovszky, V.K. Magas, and E. Predazzi, EPJA 12 (2001) 36; hep-ph/0110374.


π⁻ (ūd)
p(uud)
=
Res.
(b)
=
Regge

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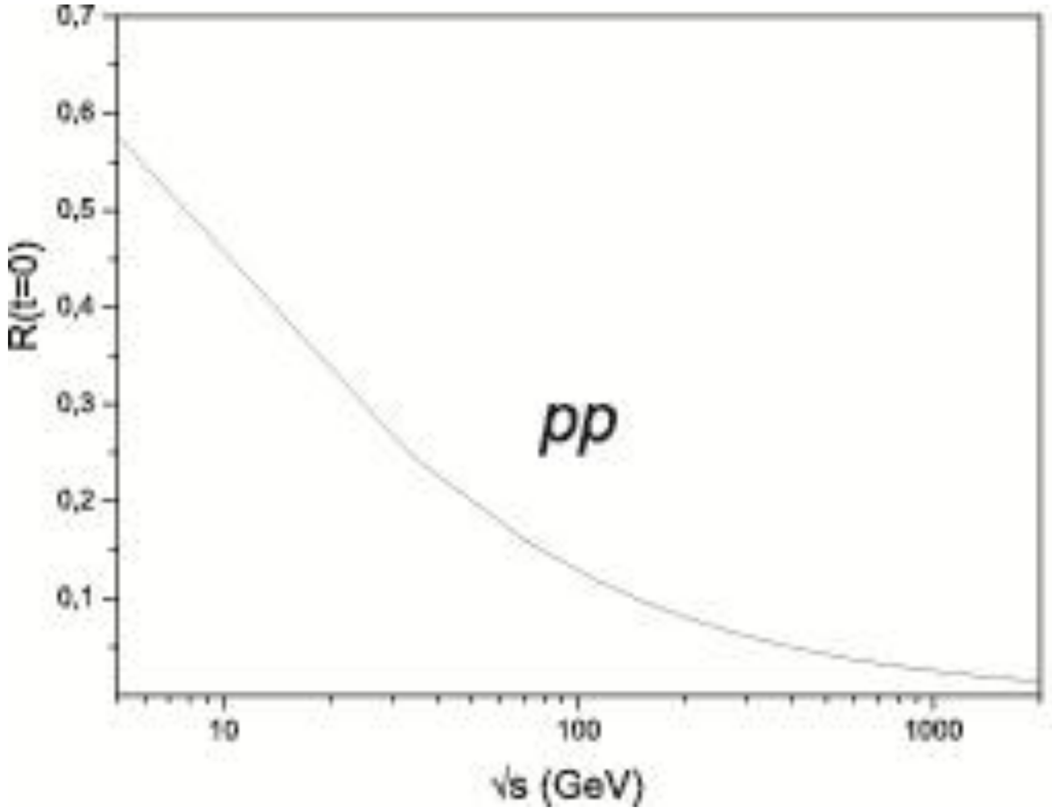
Low-mass single diffraction dissociation (SDD) of protons, $pp \to pX$ as well as their double diffraction dissociation (DDD) are among the priorities at the LHC. For the CMS Collaboration, the SDD mass coverage is presently limited to some 10 GeV. With the Zero Degree Calorimeter (ZDS), this could be reduced to smaller masses, in case the SDD system produces very forward neutrals, i.e. like a N^* decaying into a fast leading neutron. Together with the T2 detectors of TOTEM, SDD masses down to 4 GeV could be covered.

At the LHC, in the nearly forward direction, Pomeron exchange dominates; the rest, e.g. f-exchange, being negligible



The pp scattering amplitude

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

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

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

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, $i = 1, 2$ 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:

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

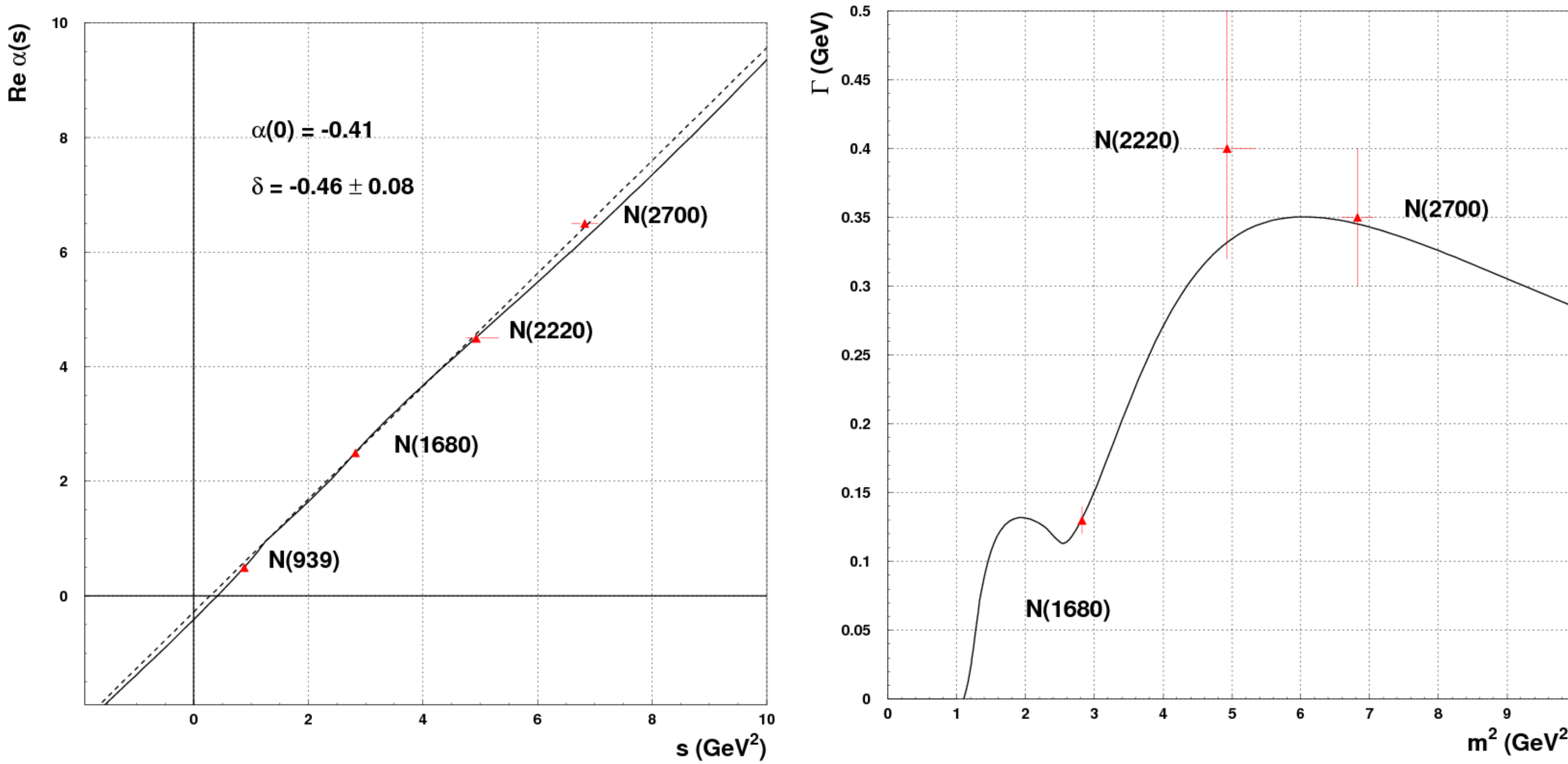
These expressions for SDD do not contain the elastic scattering limit because the inelastic form factor $W_2(M_X, t)$ has no elastic form factor limit $F(t)$ as $M_X \to m$. This problem is similar to the $x \to 1$ limit of the deep inelastic structure function $F_2(x, Q^2)$. The elastic contribution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

At the lower vertex, the inelastic FF (transition amplitude) is the structure function

$$W_2(M_X^2,t) = \frac{-t(1-x)}{4\pi\alpha_s(1+4m^2x^2/(-t))} Im\,A(M_X^2,t)\,,$$

(here the Briorken variable $x \sim -t/M_X^2$), where the imaginary part of the transition amplitude is

$$Im\,A(M_X^2,t) = a \sum_{n=0,1,...} \frac{[f(t)]^{2(n+1)} Im\,\alpha(M_x^2)}{(2n+0.5-Re\,\alpha(M_X^2))^2 + (Im\,\alpha(M_X^2))^2}.$$



The imaginary part of the trajectory can be written in the following way:

$$\mathcal{I}m\,\alpha(s) = s^{\delta} \sum_n c_n \left(\frac{s - s_n}{s}\right)^{\lambda_n} \cdot \theta(s - s_n)\,, \qquad (1)$$

where $\lambda_n = \mathcal{R}e\ \alpha(s_n)$.

The real part of the proton trajectory is given by

$$\mathcal{R}e\,\alpha(s) = \alpha(0) + \frac{s}{\pi}\sum_n c_n \mathcal{A}_n(s) \ , \tag{1}$$

where

$$\mathcal{A}_n(s) = \frac{\Gamma(1-\delta)\Gamma(\lambda_n+1)}{\Gamma(\lambda_n-\delta+2)s_n^{1-\delta}}\,{}_2F_1\left(1, 1-\delta; \lambda_n-\delta+2; \frac{s}{s_n}\right)\theta(s_n-s) +$$
$$\left\{\pi s^{\delta-1}\left(\frac{s-s_n}{s}\right)^{\lambda_n}\cot[\pi(1-\delta)] - \right.$$
$$\left.\frac{\Gamma(-\delta)\Gamma(\lambda_n+1)s_n^{\delta}}{s\Gamma(\lambda_n-\delta+1)}\,{}_2F_1\left(\delta-\lambda_n, 1; \delta+1; \frac{s_n}{s}\right)\right\}\theta(s-s_n) \ .$$

SD and DD cross sections

$$\frac{d^2\sigma_{SD}}{dtdM_x^2} = {F_p}^2(t)F(x_B,t)\frac{\sigma_T^{Pp}(M_x^2,t)}{2m_p}\left(\frac{s}{M_x^2}\right)^{2(\alpha(t)-1)}\ln\left(\frac{s}{M_x^2}\right)$$

$$\frac{d^3\sigma_{DD}}{dtdM_1^2dM_2^2} = C_nF^2(x_B,t)\frac{\sigma_T^{Pp}(M_1^2,t)}{2m_p}\frac{\sigma_T^{Pp}(M_2^2,t)}{2m_p}$$
$$\times\left(\frac{s}{(M_1+M_2)^2}\right)^{2(\alpha(t)-1)}\ln\left(\frac{s}{(M_1+M_2)^2}\right)$$

"Reggeized (dual) Breit-Wigner" formula:

$$\sigma_T^{Pp}(M_x^2,t) = Im\,A(M_x^2,t) = \frac{A_{N^*}}{\sum_n n-\alpha_{N^*}(M_x^2)} + Bg(t,M_x^2) =$$

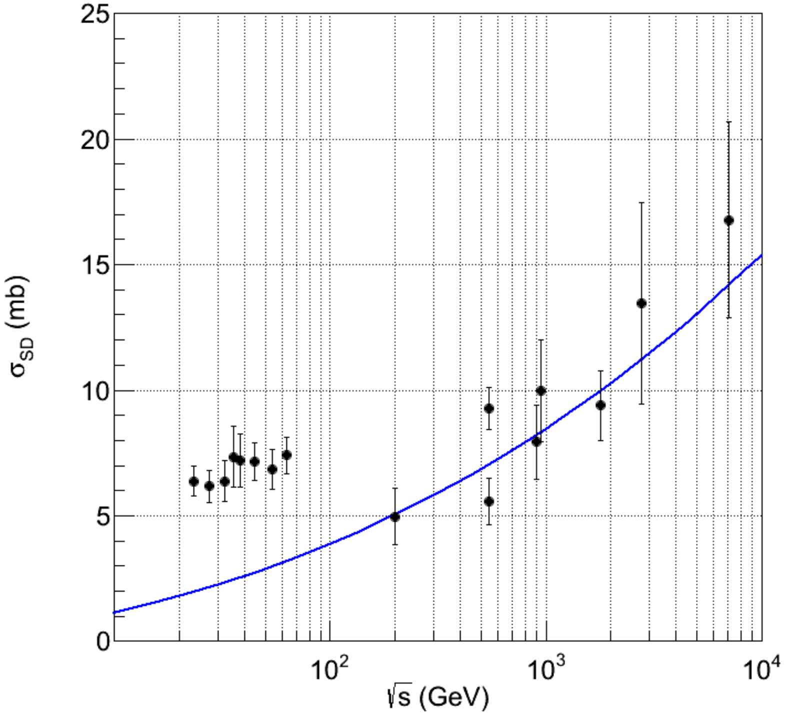
$$= A_n \sum_{n=0,1,\ldots} \frac{[f(t)]^{2(n+1)}\,Im\,\alpha(M_x^2)}{(2n+0.5-Re\,\alpha(M_x^2))^2+(Im\,\alpha(M_x^2))^2} + B_n e^{b_{in}^{bg}t}\left(M_x^2-M_{p+\pi}^2\right)^{\epsilon}$$

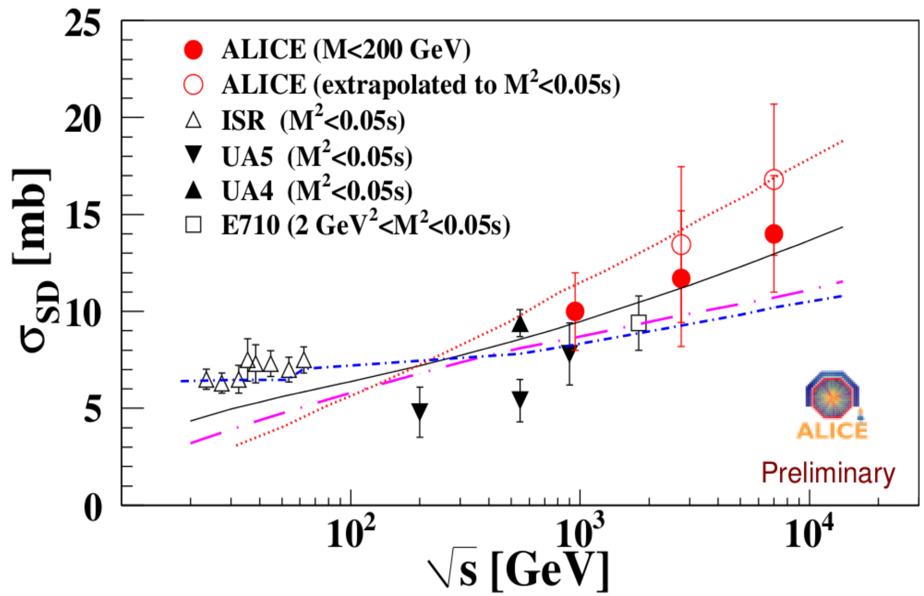
$$F(x_B,t) = \frac{x_B(1-x_B)}{\left(M_x^2-m_p^2\right)\left(1+4m_p^2x_B^2/(-t)\right)^{3/2}}, \quad x_B = \frac{-t}{M_x^2-m_p^2-t}$$

$$F_p(t) = \frac{1}{1-\frac{t}{0.71}}, \quad f(t) = e^{b_{in}t}$$

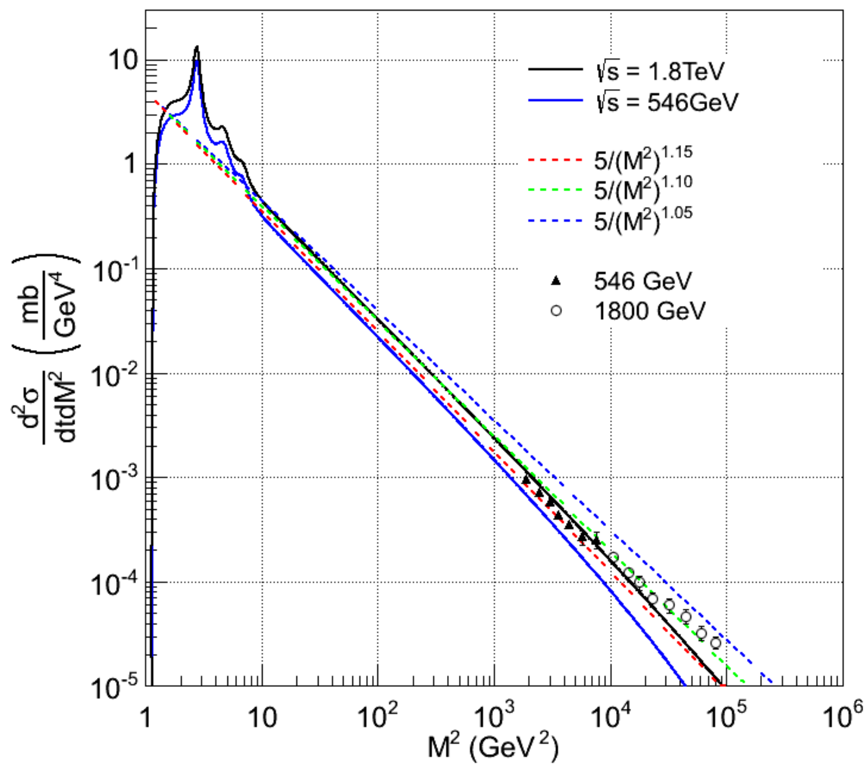
$$\alpha(t) = \alpha(0)+\alpha' t = 1.04+0.25t$$

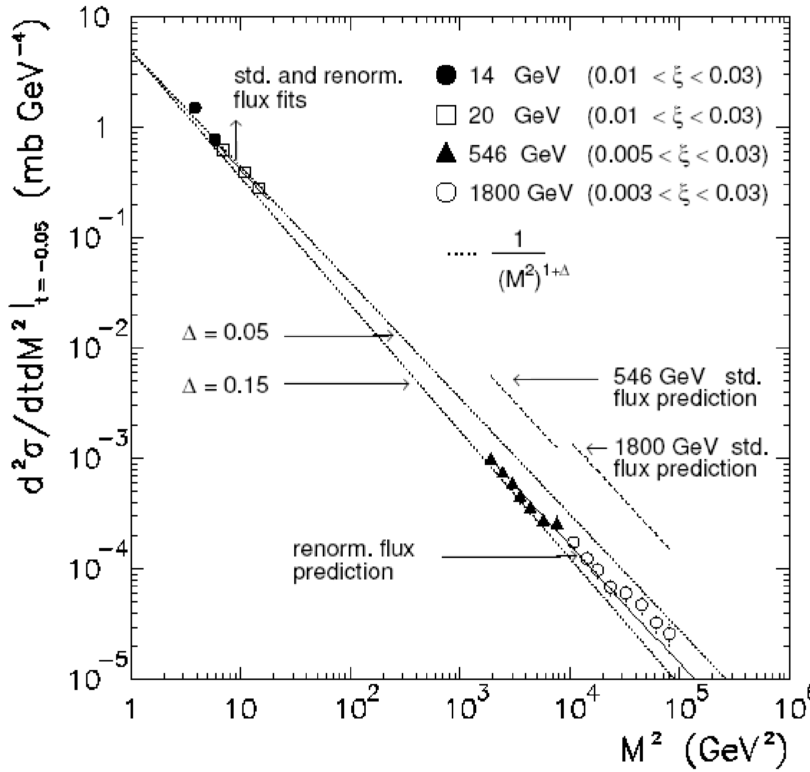
SDD cross sections vs. energy.



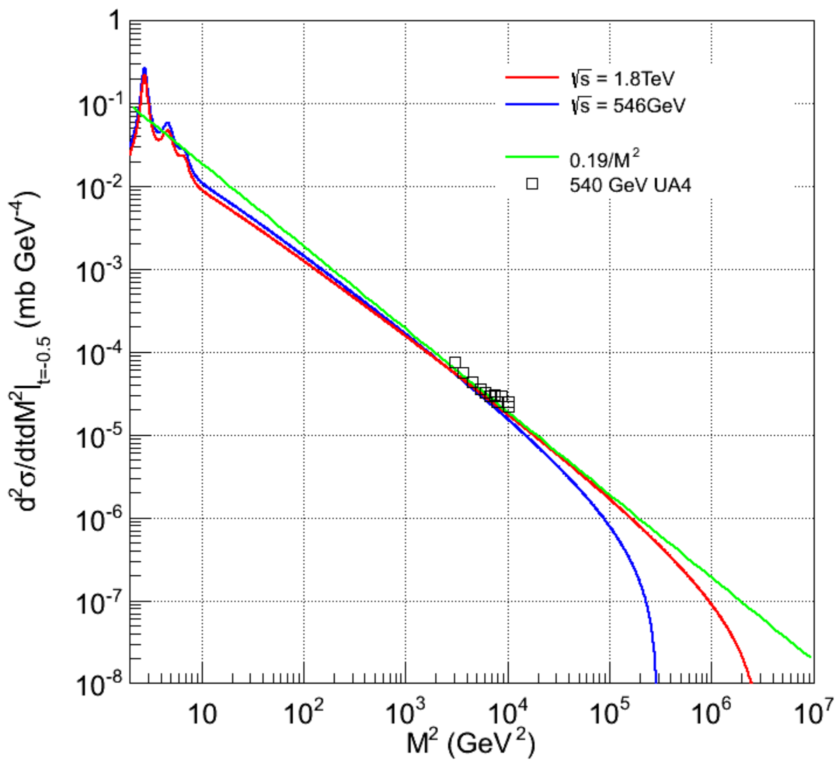


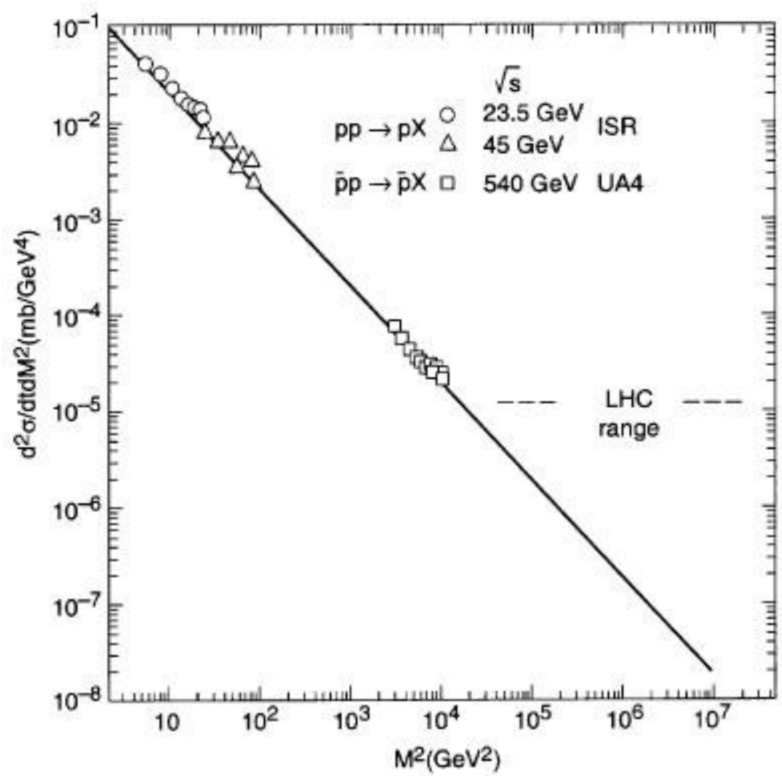
Approximation of background to reference points (t=-0.05)



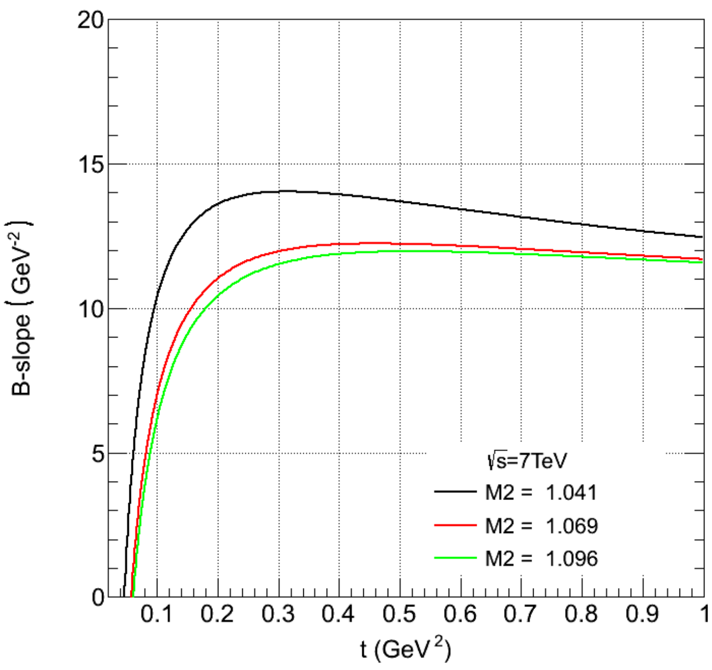


Approximation of background to reference points (t=-0.5)

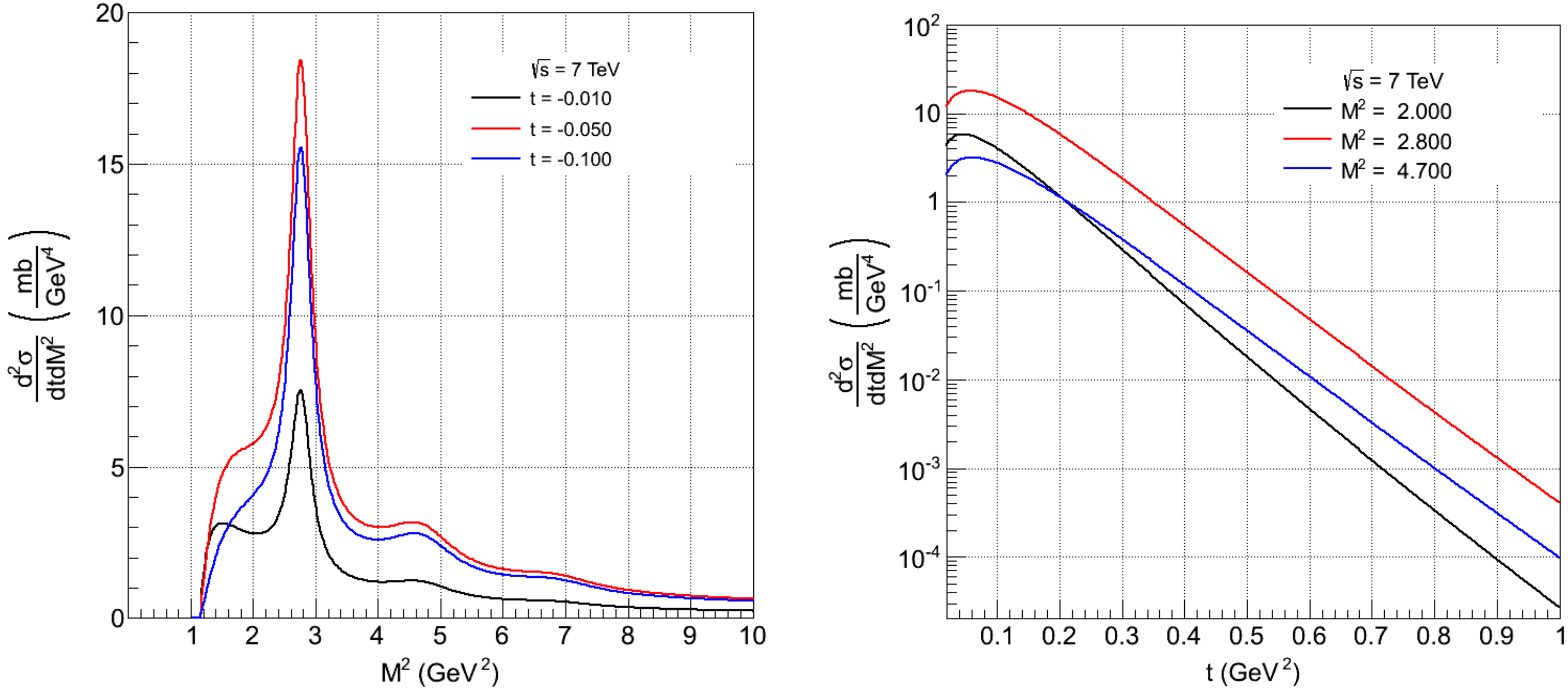




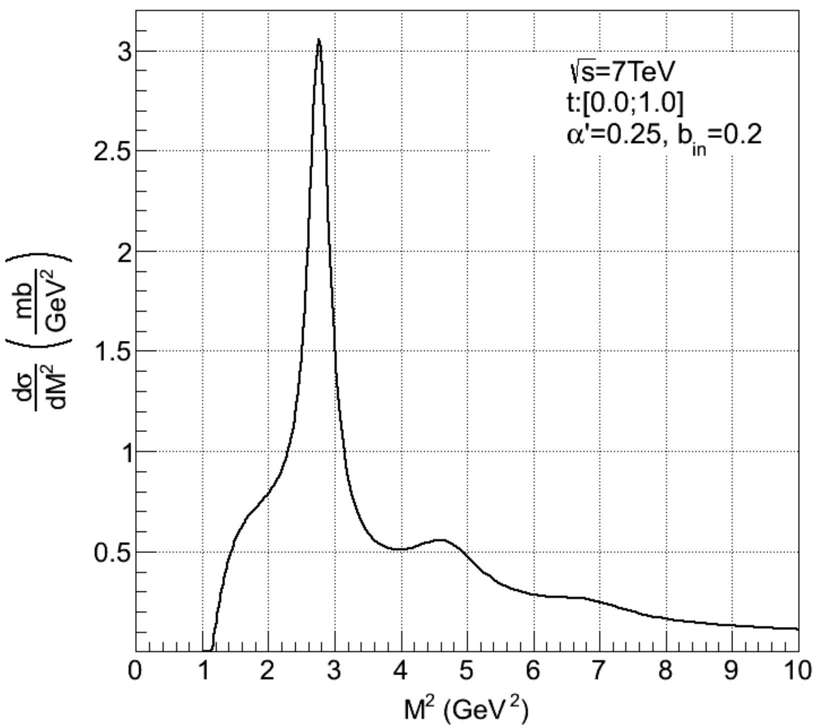
B-slopes for SD

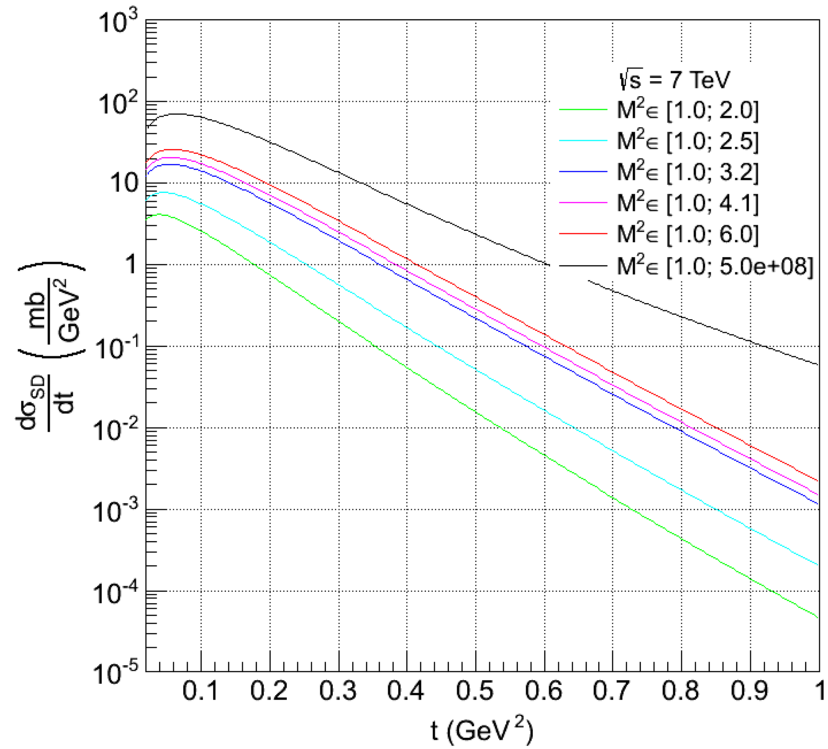


Double differential SD cross sections

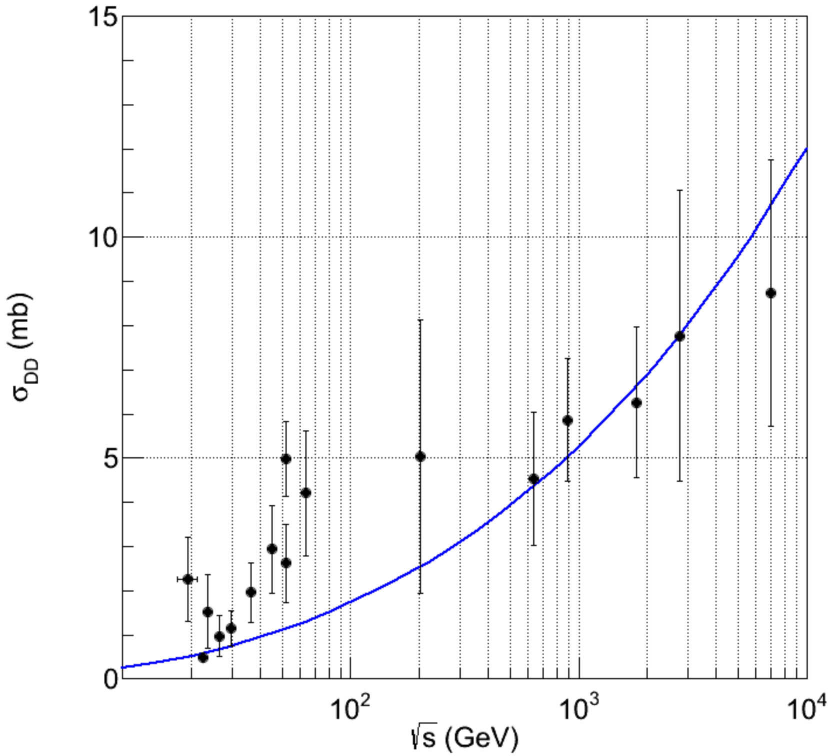


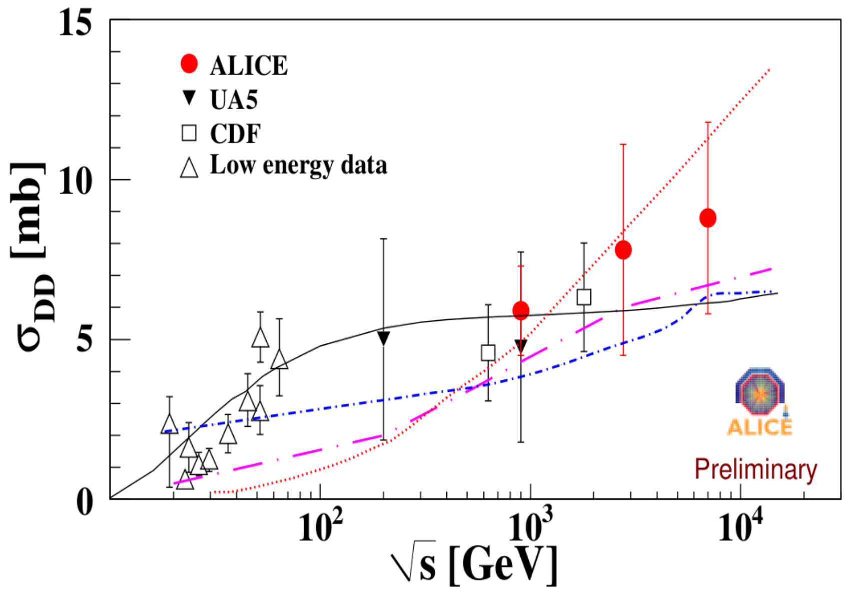
Single differential integrated SD cross sections



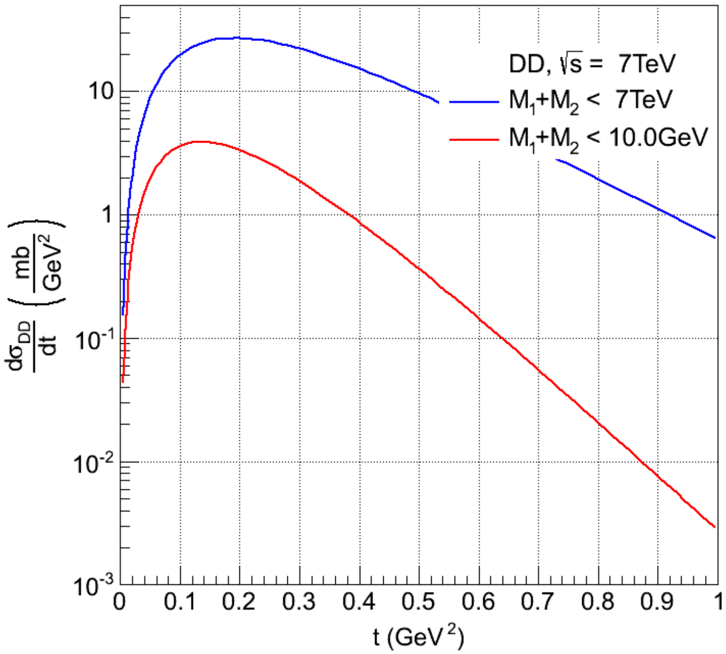


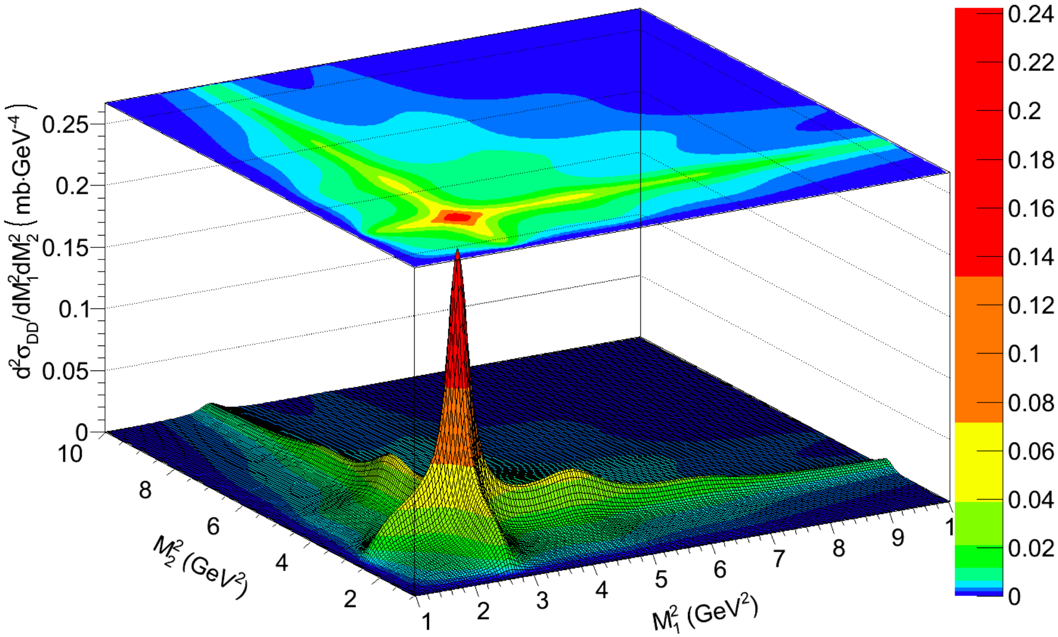
DDD cross sections vs. energy.



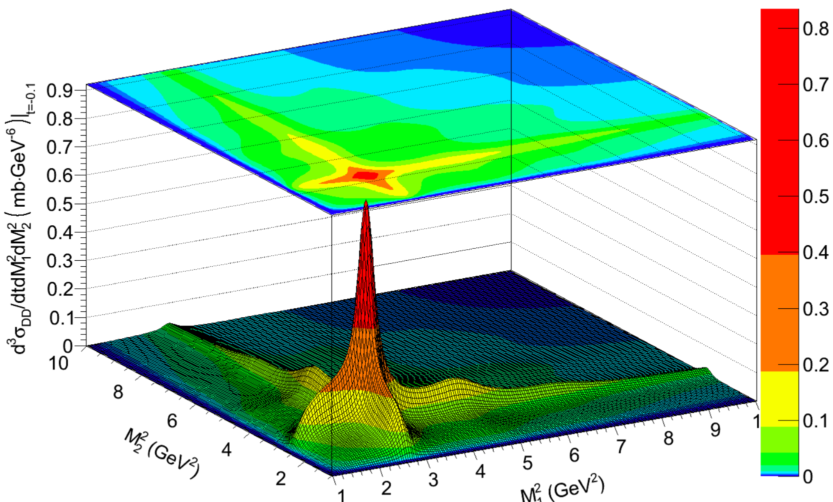


Integrated DD cross sections

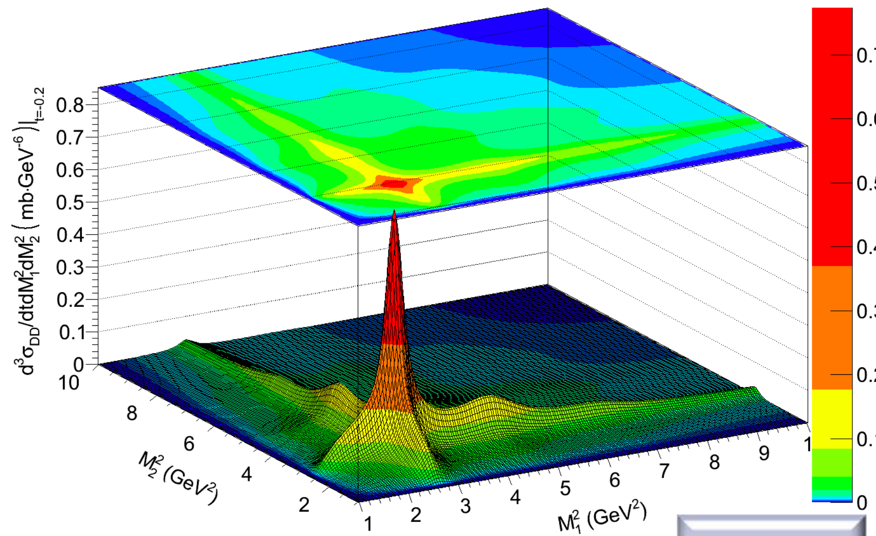




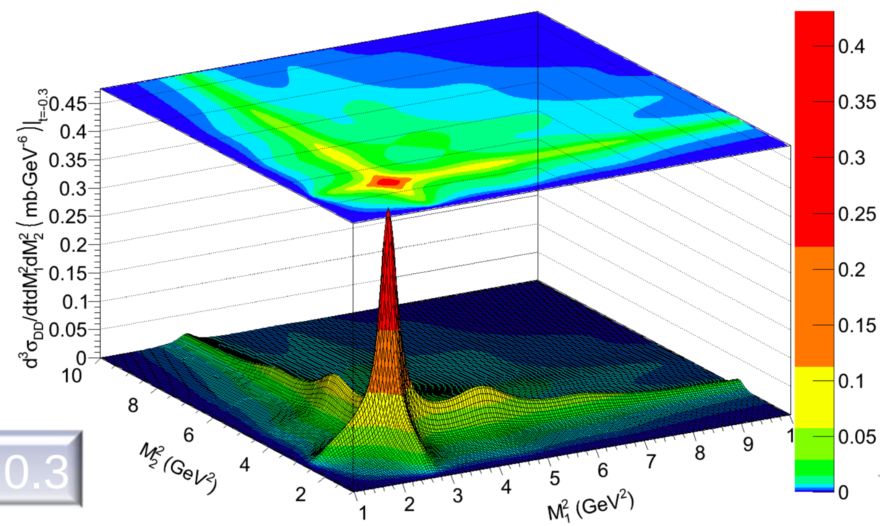
Triple differential DD cross sections



t = - 0.1



t = - 0.2



t = - 0.3

The parameters and results

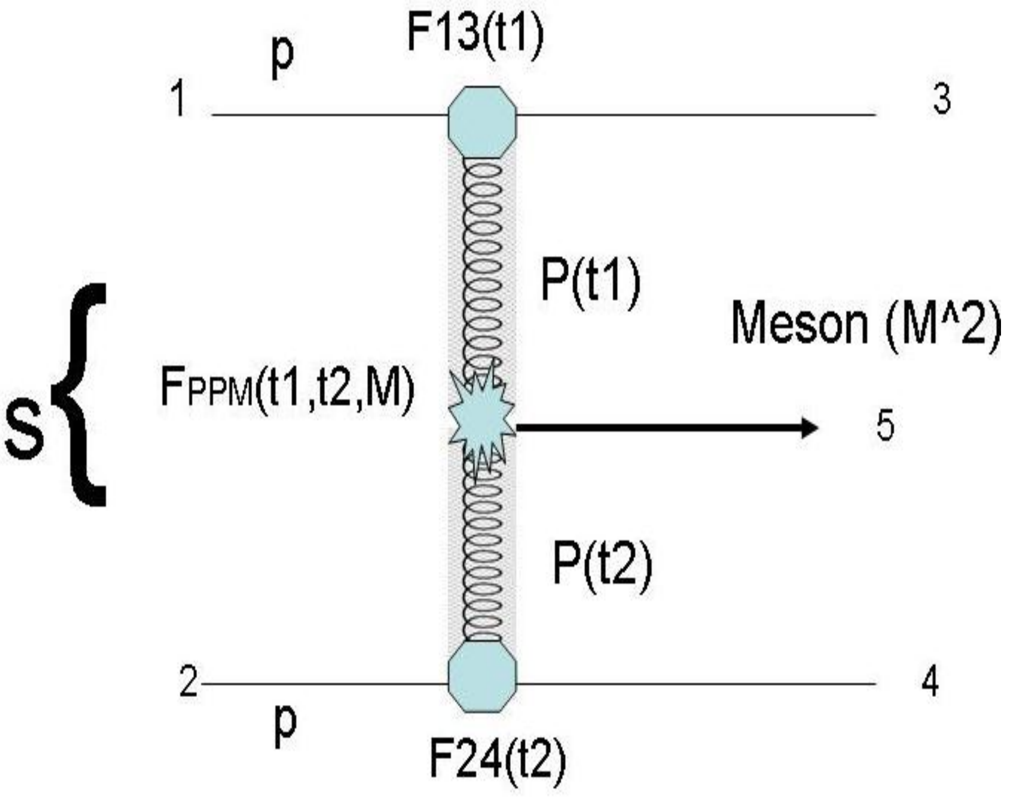
b_{in} (GeV^{-2})	0.2
b_{in}^{bg} (GeV^{-2})	3
α' (GeV^{-2})	0.25
$\alpha(0)$	1.04
ϵ	1.03
A_n	18.7
B_n	8.8
C_n	3.79e-2

σ_{SD} (mb)	14.13
$\sigma_{SD}(M < 3.5GeV)$ (mb)	4.68
$\sigma_{SD}(M > 3.5GeV)$ (mb)	9.45
σ_{Res}^{SD} (mb)	2.48
σ_{Bg}^{SD} (mb)	9.45
σ_{DD} (mb)	10.68
$\sigma_{DD}(M < 10GeV)$ (mb)	1.05
$\sigma_{DD}(M > 10GeV)$ (mb)	9.63

Open problems:

1. Interpolation in energy: from the Fermilab and ISR to the LHC;
   (Inclusion of non-leading contributions);
3. Deviation from a simple Pomeron pole model and breakdown of Regge-factorization;
4. Experimental studies of the exclusive channels (p+**π,…)** produced from the decay of resonances (N*, Roper?,,,) in the nearly forward direction.
5. Turn down of the cross section towards t=o?!

Prospects (future plans): central diffractive meson production (double Pomeron exchange)



Thanks for your attention!

Recent: L. Jenkovszky, R. Orava, A. Salii, Low-mass single- and double diffraction dissociation at the LHC, hep-ph, November.