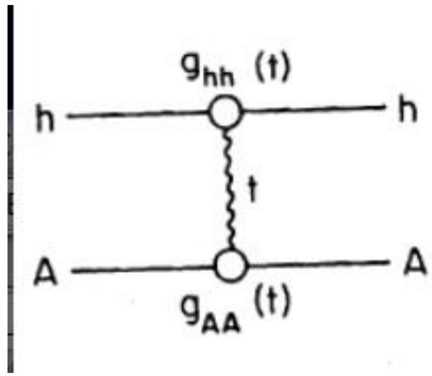
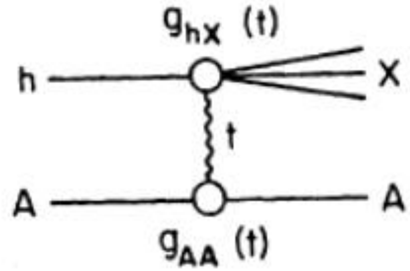
Diffraction *2012, Las Canarias*

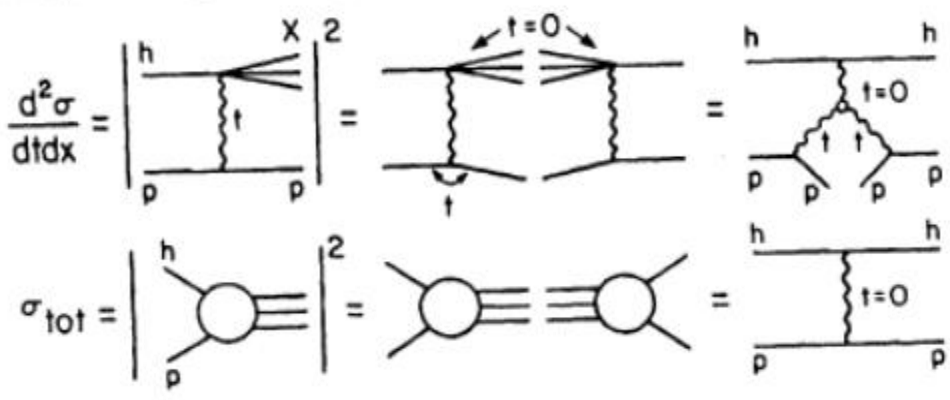
LOW-MASS, SINGLE- and DOUBLE-DIFFRACTION DISSOCIATION AT THE LHC

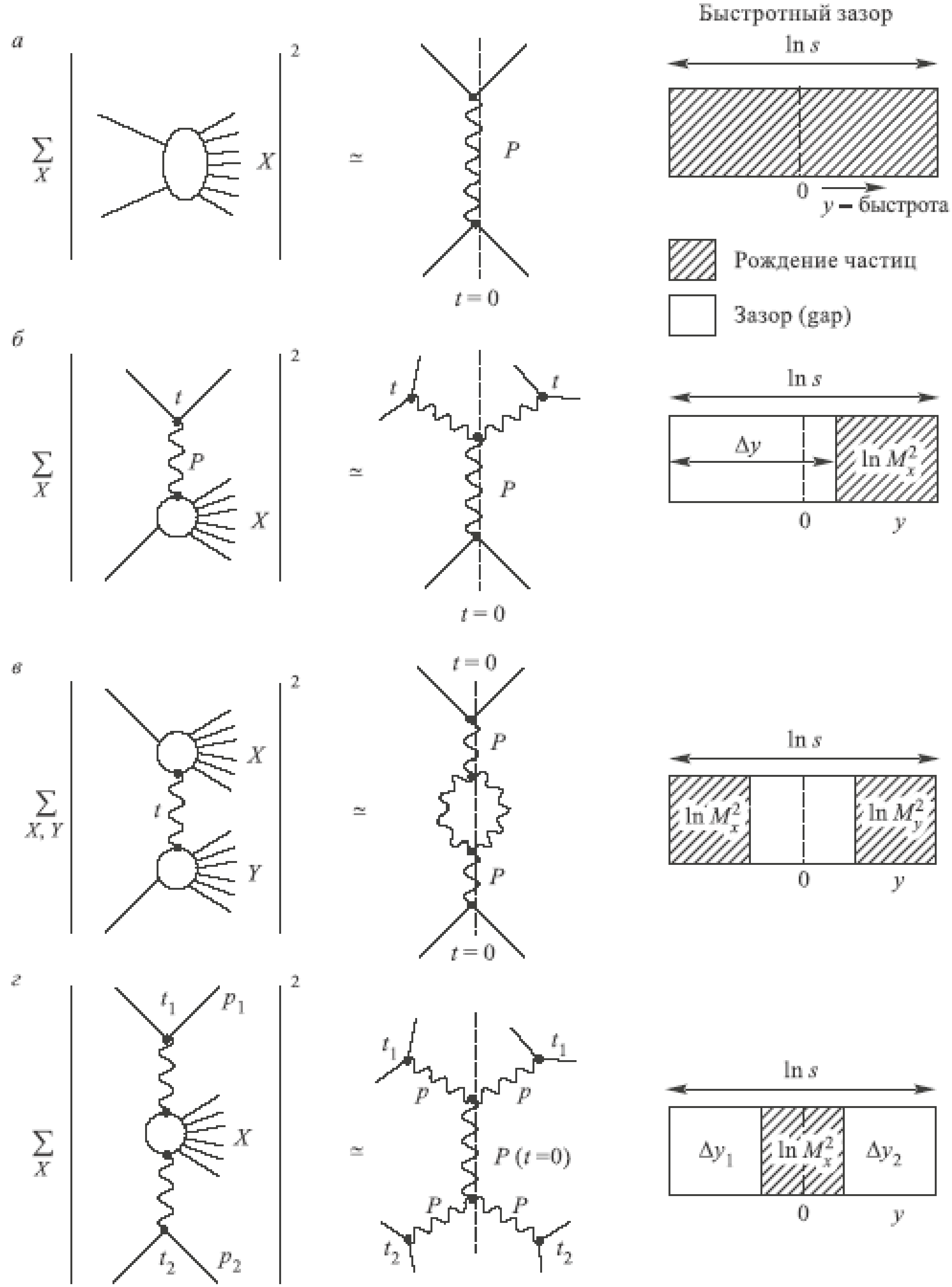
László Jenkovszky, Risto Orava, Andrii Salii





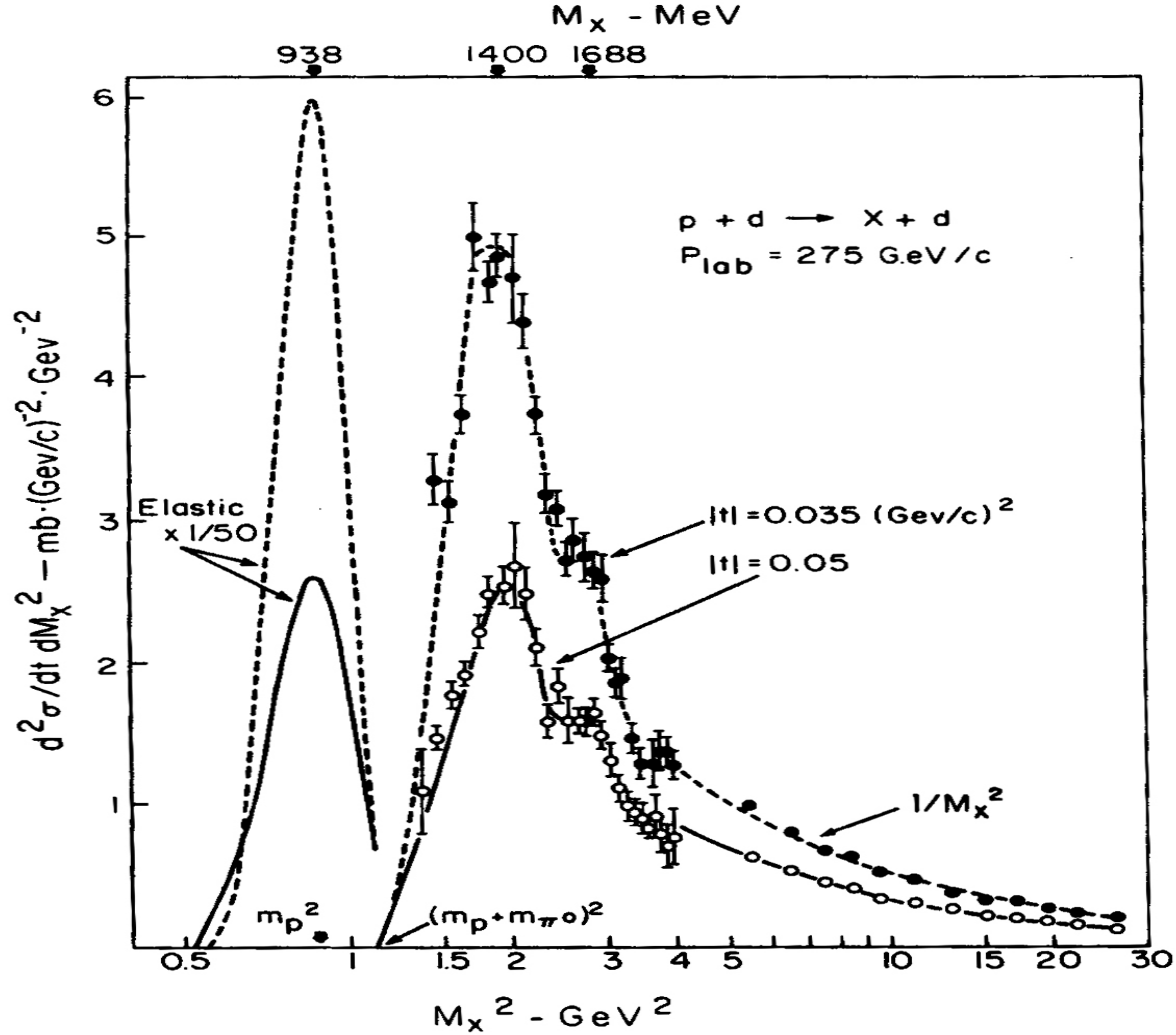
Triple Regge (Pomeron) limit::





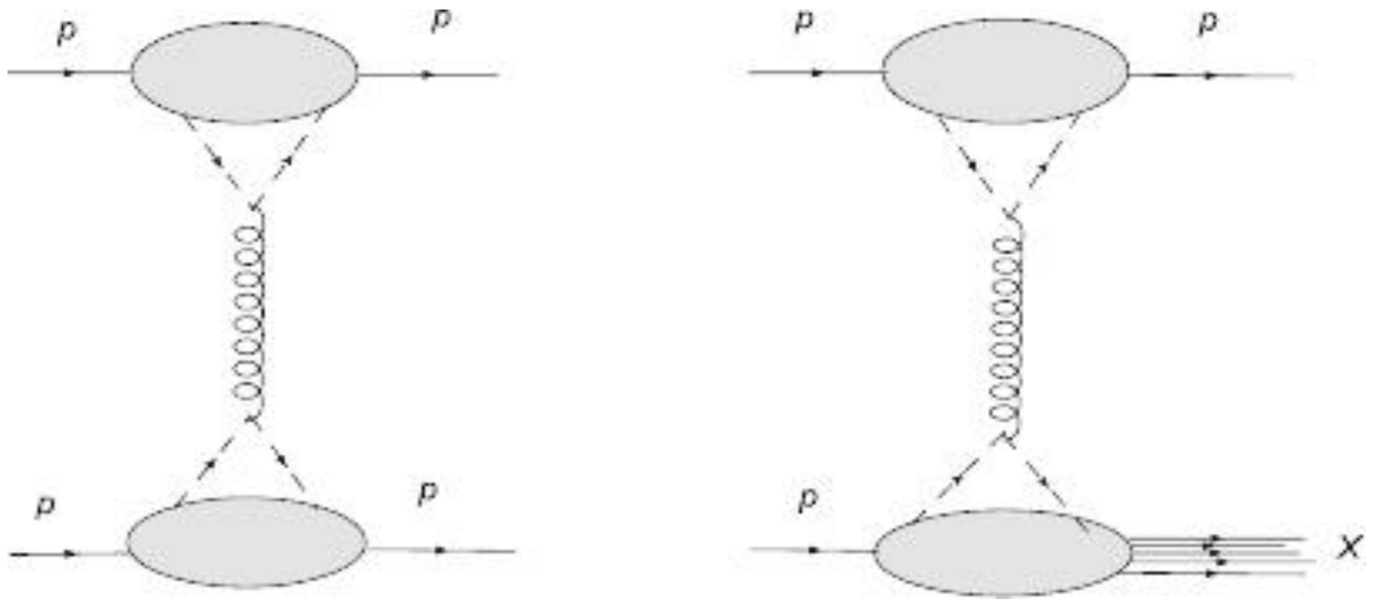
Быстротный зазор
ln s
y – быстрота
Рождение частиц
Зазор (gap)
a
б
в
г
P
X
t = 0
Δy
ln M_x^2
ln M_y^2
Y
t_1
t_2
p_1
p_2
P (t = 0)
Δy_1
Δy_2

FNAL

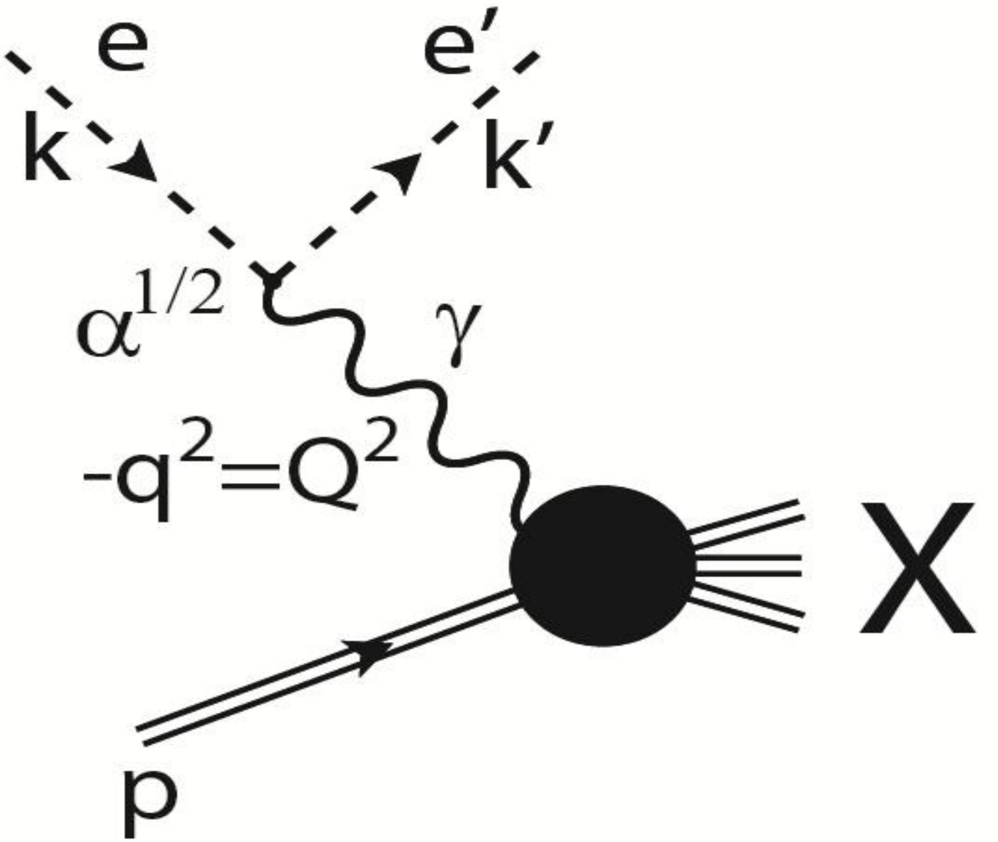


Mx - MeV
938
1400
1688
p + d → X + d
Plab = 275 GeV/c
Elastic
x 1/50
|t| =0.035 (Gev/c)²
|t| =0.05
1/Mx²
mp²
(mp+mπo)²
d²σ/dt dMx² — mb·(Gev/c)⁻²·Gev⁻²
Mx² - GeV²

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.

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 $0.024 < -t < 0.234$ (GeV/c)^2, $0 < M^2 < 0.12s$, and $(105 < s < 752)$ 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.

Pomeron dominance at the LHC

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

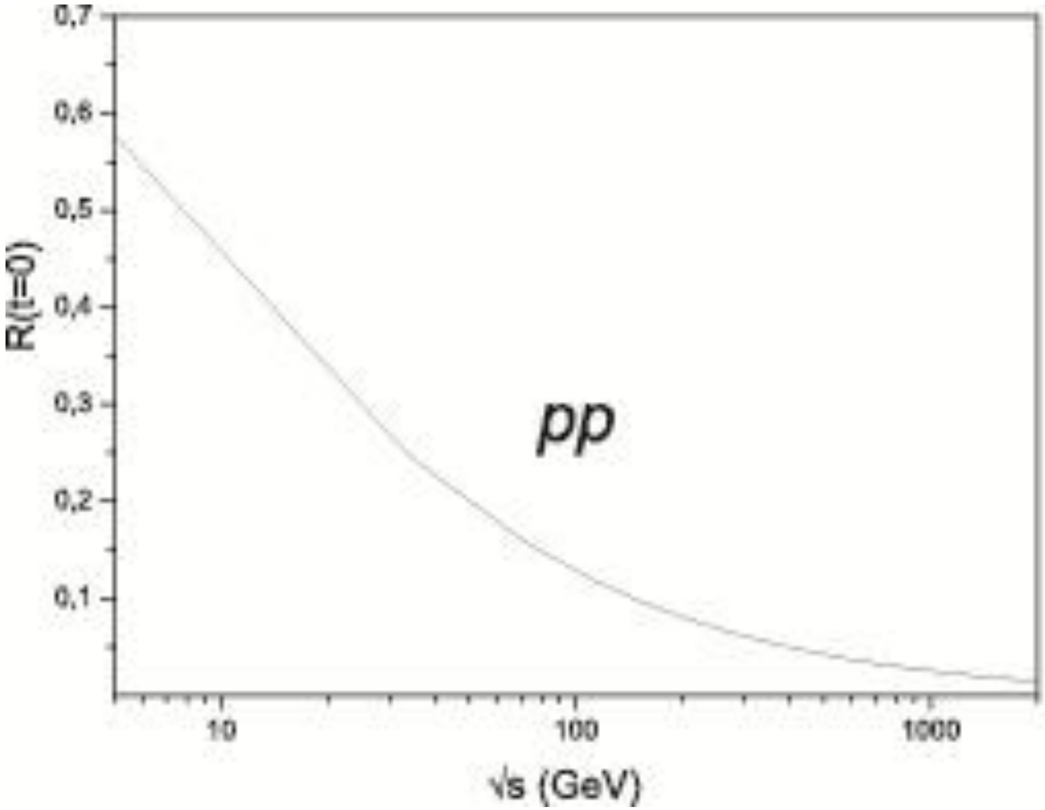
$$R(s,t=0) = \frac{\Im m(A(s,t) - A_P(s,t))}{\Im A(s,t)}, \tag{1}$$

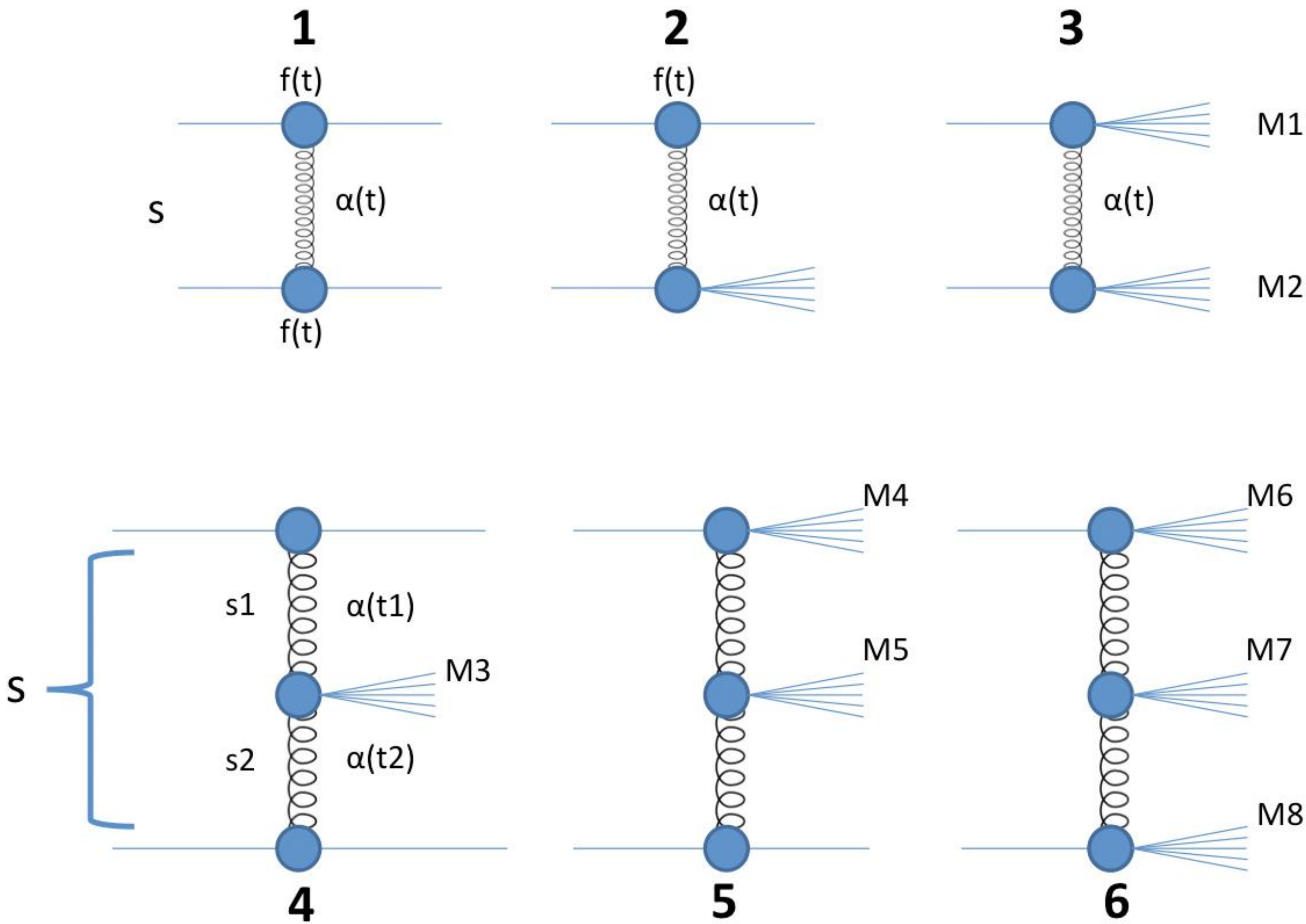
where the total scattering amplitude A includes the Pomeron contribution A_P plus the contribution from the secondary Reggeons and the Odderon.

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.

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

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





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

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

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

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

While high-mass diffraction dissociation receives much attention, mainly due to its relatively easy theoretical treatment within the triple Reggeon formalism and successful reproduction of the data, this is not the case for low-masses, which are beyond the range of perturbative quantum chromodynamics (QCD). The forthcoming measurements at the LHC urge a relevant theoretical understanding and treatment of low mass DD, which essentially has both spectroscopic and dynamic aspects. The low-mass, M_X spectrum is rich of nucleon resonances. Their discrimination is a difficult experimental task, and theoretical predictions of the appearance of the resonances depending on s, t and M is also very difficult since, as mentioned, perturbative QCD, or asymptotic Regge pole formula are of no use here. Below we concentrate on single diffraction dissociation; generalization to DDD is straightforward.

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

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

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.

In the LHC energy region it simplifies to:

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

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

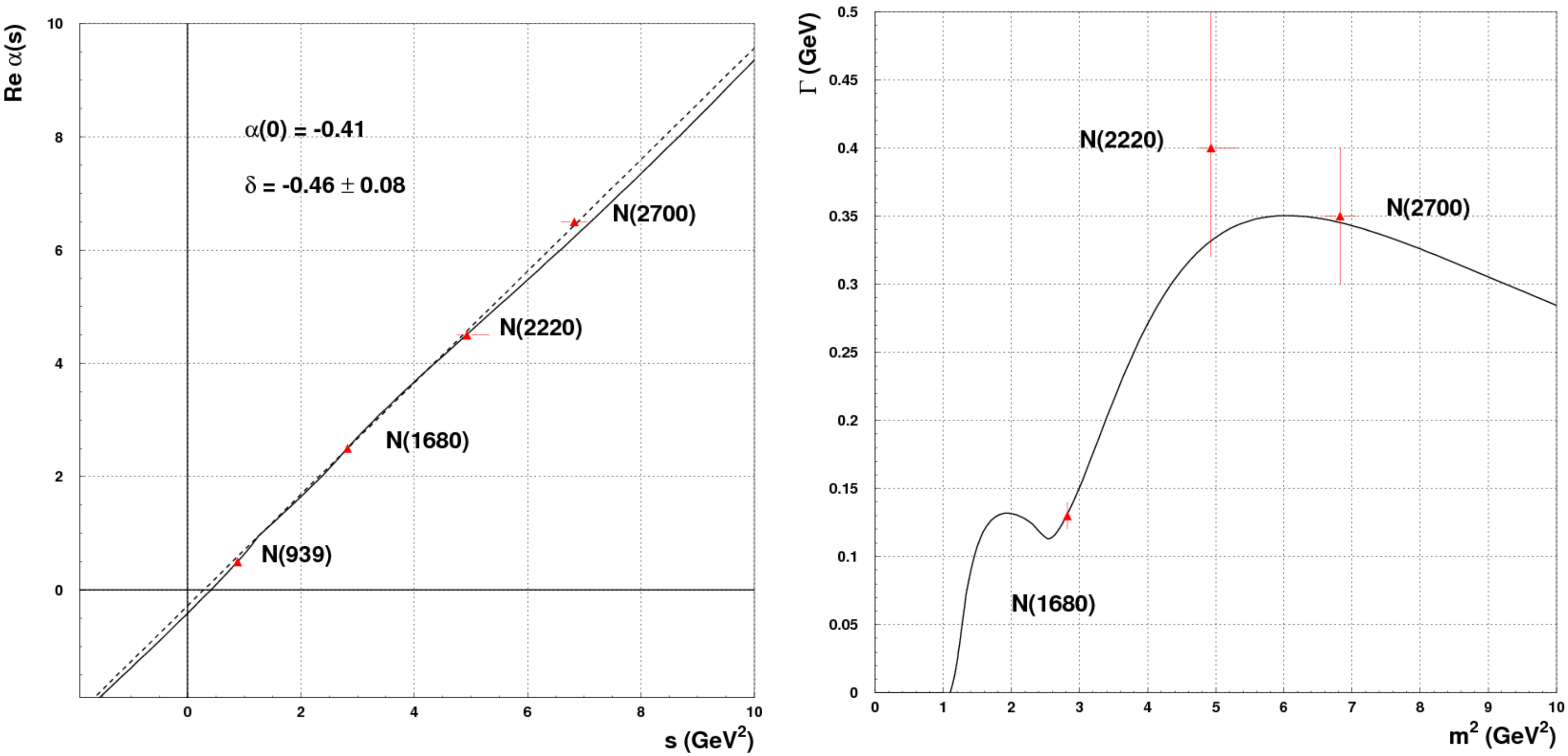
$$W_2(M_X^2, t) = \frac{-t(1-x)}{4\pi\alpha_s(1+4m^2x^2/(-t))} Im\, A(M_X^2, t)\,,$$

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

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

The Pomeron-proton channel, $Pp \to M_X^2$ (see the lower part of Fig. **??**, right pannel) couples to the proton trajectory, with the $I(J^P)$ resonances: $1/2(5/2^+)$, F_{15}, $m = 1680$ MeV, $\Gamma = 130$ MeV; $1/2(9/2^+)$, H_{19}, $m = 2200$ MeV, $\Gamma = 400$ MeV; and $1/2(13/2^+)$, $K_{1,13}$, $m = 2700$ MeV, $\Gamma = 350$ MeV. The status of the first two is firmly established [**?**], while the third one, $N^*(2700)$, is less certain, with its width varying between 350 ± 50 and 900 ± 150 MeV *(Data Particle Group Collaboration)*. Still, with the stable proton included, we have a fairly rich trajectory, $\alpha(M^2)$ (next figure).

Despite the seemingly linear form of the trajectory, it is not that: the trajectory must contain an imaginary part corresponding to the finite widths of the resonances on it. The non-trivial problem of combining the nearly linear and real function with its imaginary part was solved in: *R. Fiore, L. J., F. Paccanoni and A. Prokudin, PR D* **70** *(2004) 054003; hep-ph/0404021)* by means of dispersion relations.



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

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

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:

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

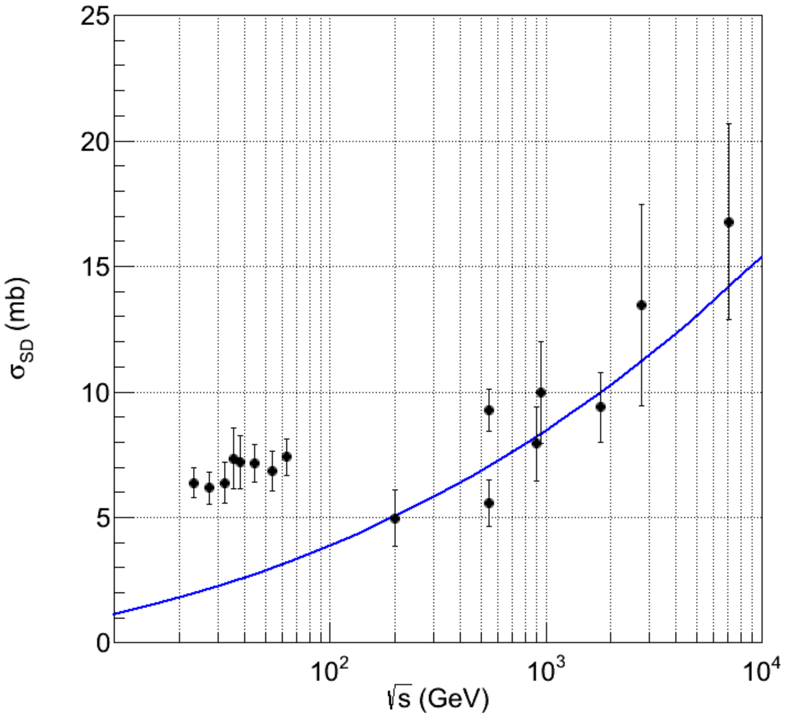
$$= A_n \sum_{n=0,1,\dots} \frac{[f(t)]^{2(n+1)} Im\, \alpha(M_x^2)}{(2n + 0.5 - Re\, \alpha(M_x^2))^2 + (Im\, \alpha(M_x^2))^2} + B_n e^{b_{in}^{bg} t} \left(M_x^2 - M_{p+\pi}^2\right)^{\epsilon}$$

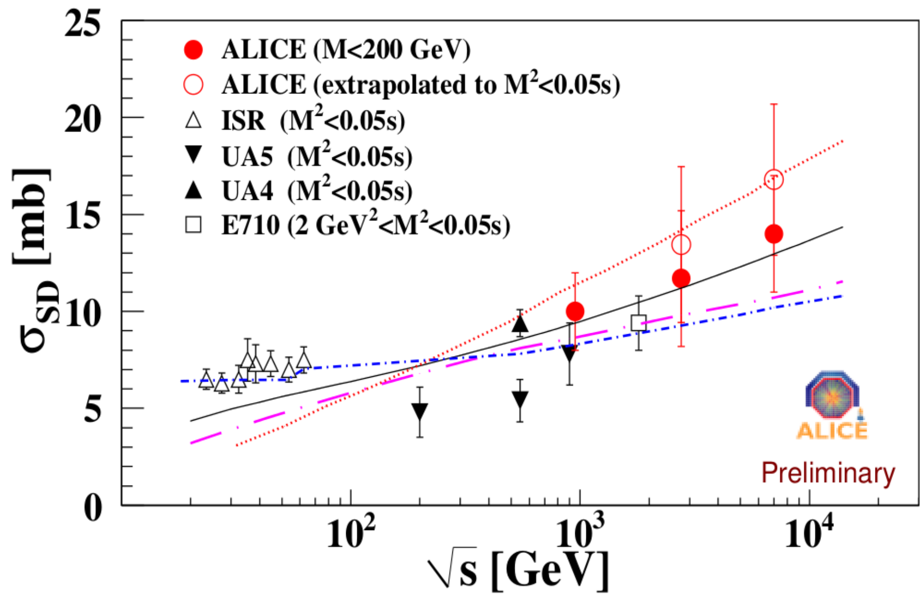
$$F(x_B, t) = \frac{x_B(1 - x_B)}{\left(M_x^2 - m_p^2\right)\left(1 + 4m_p^2 x_B^2/(-t)\right)^{3/2}}, \quad x_B = \frac{-t}{M_x^2 - m_p^2 - t}$$

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

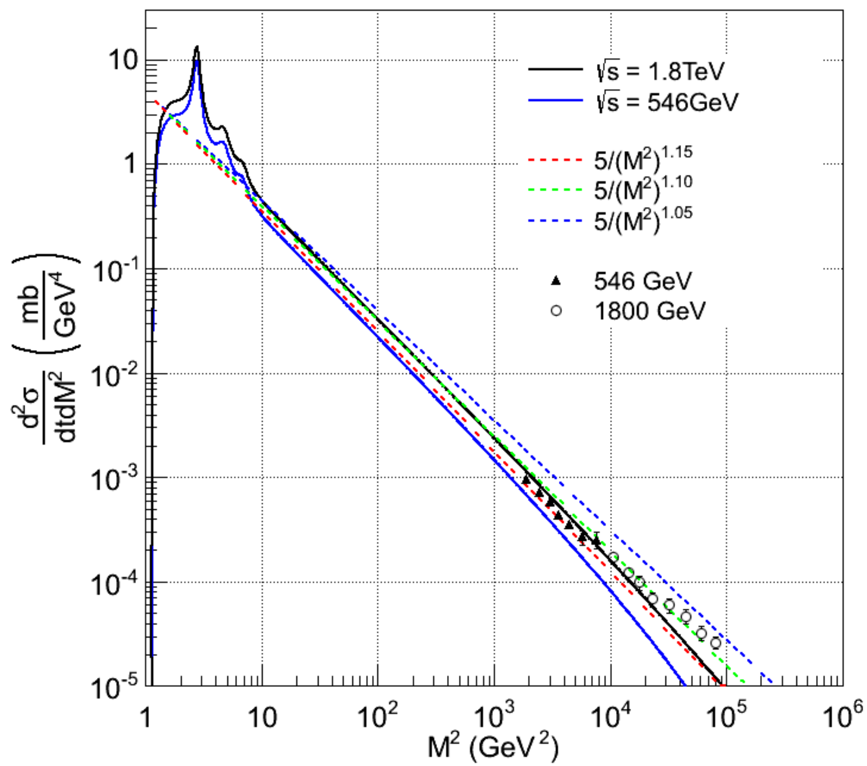
$$\alpha(t) = \alpha(0) + \alpha' t = 1.04 + 0.25t$$

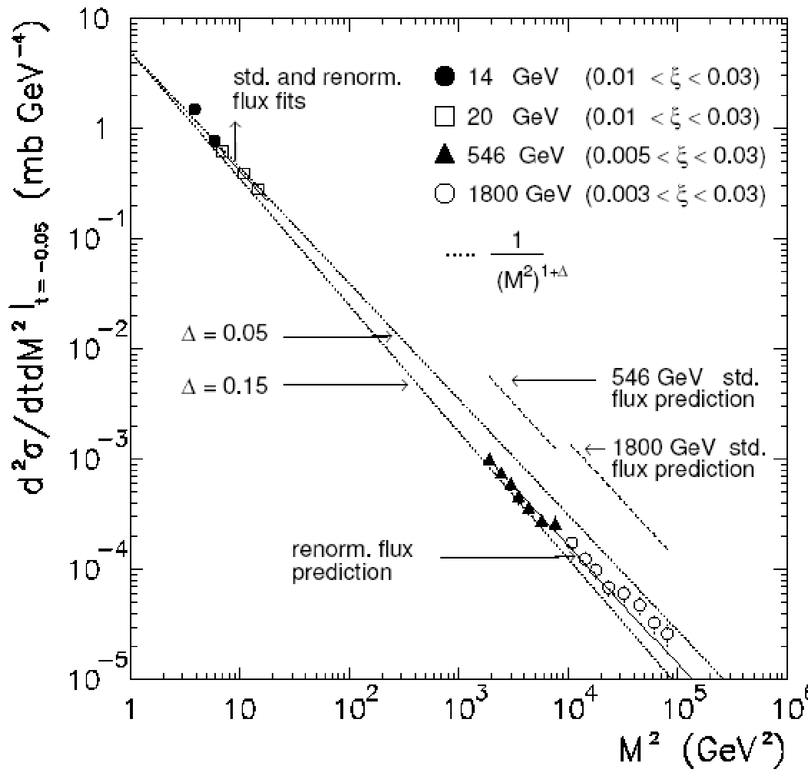
SDD cross sections vs. energy.



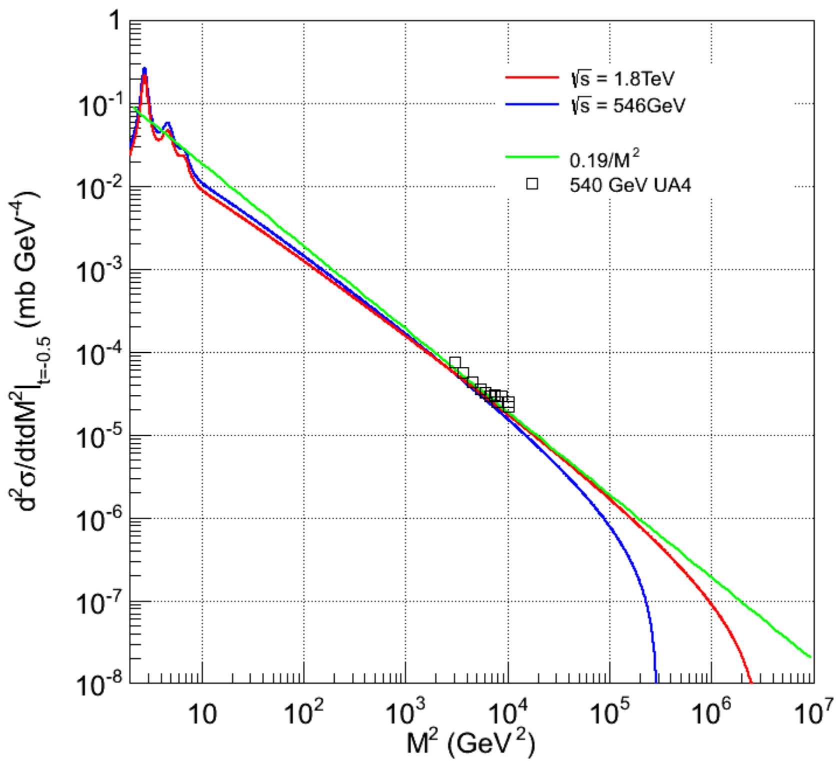


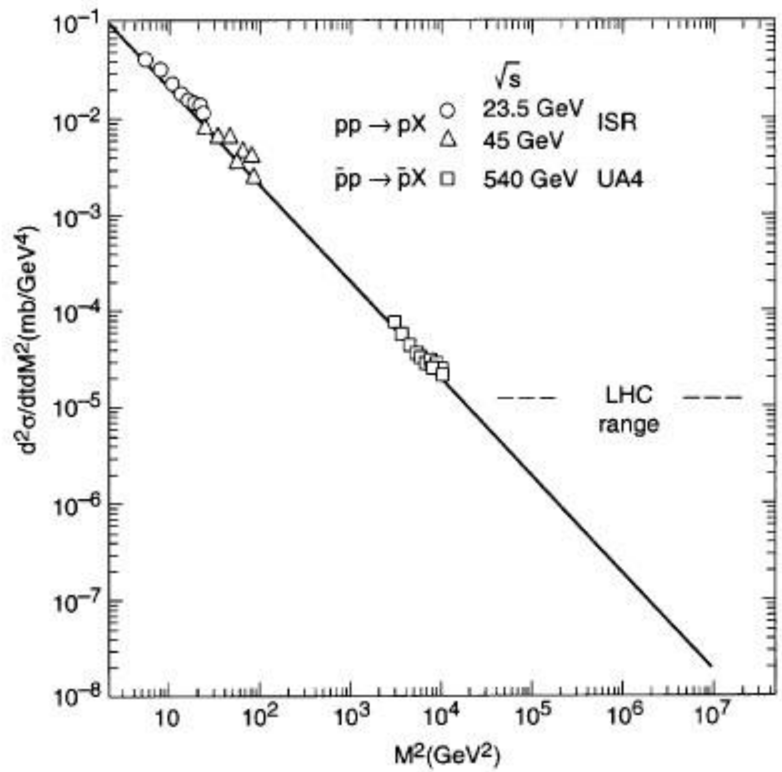
Approximation of background to reference points (t=-0.05)



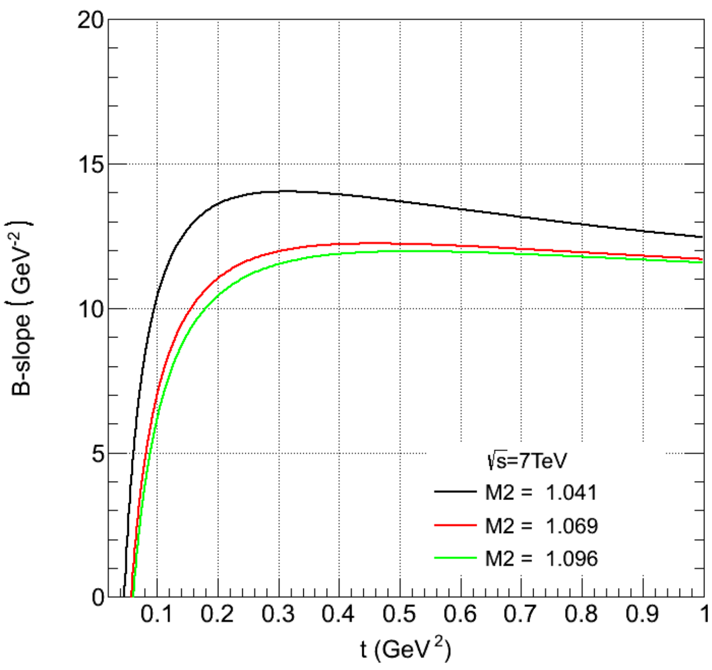


Approximation of background to reference points (t=-0.5)

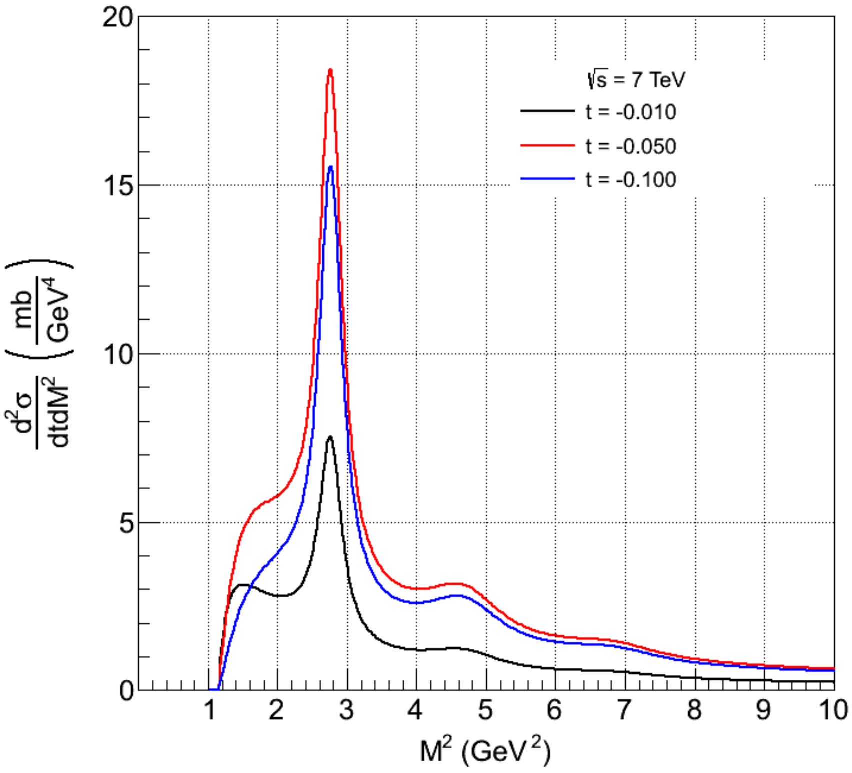


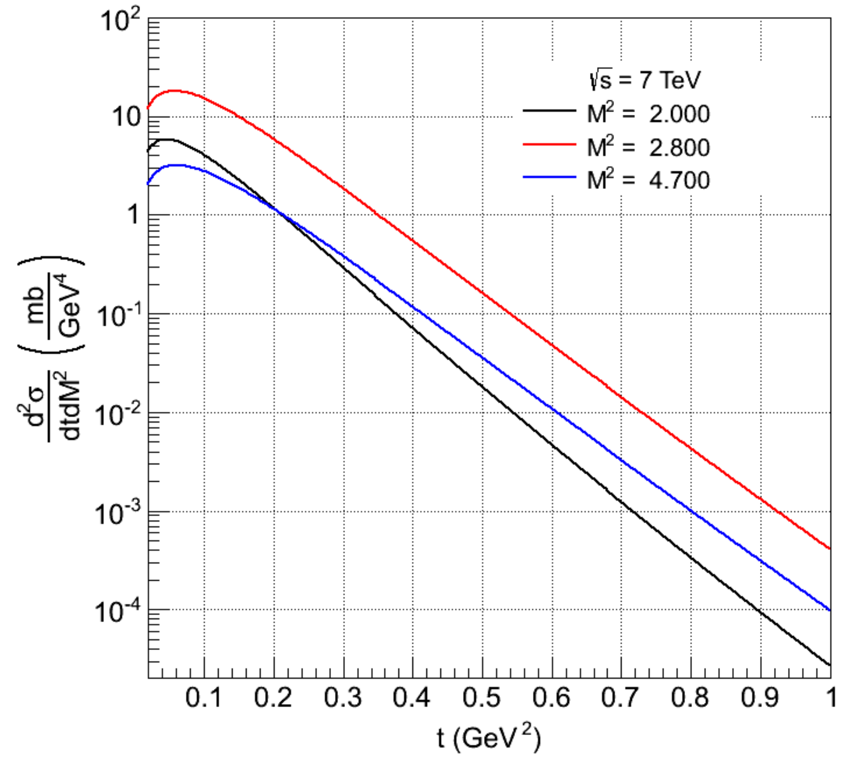


B-slopes for SD

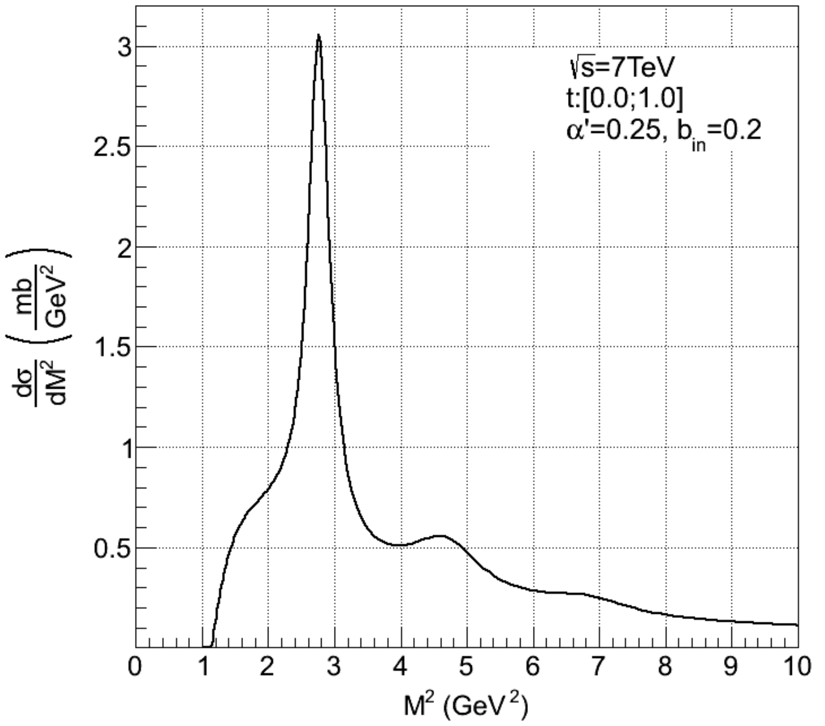


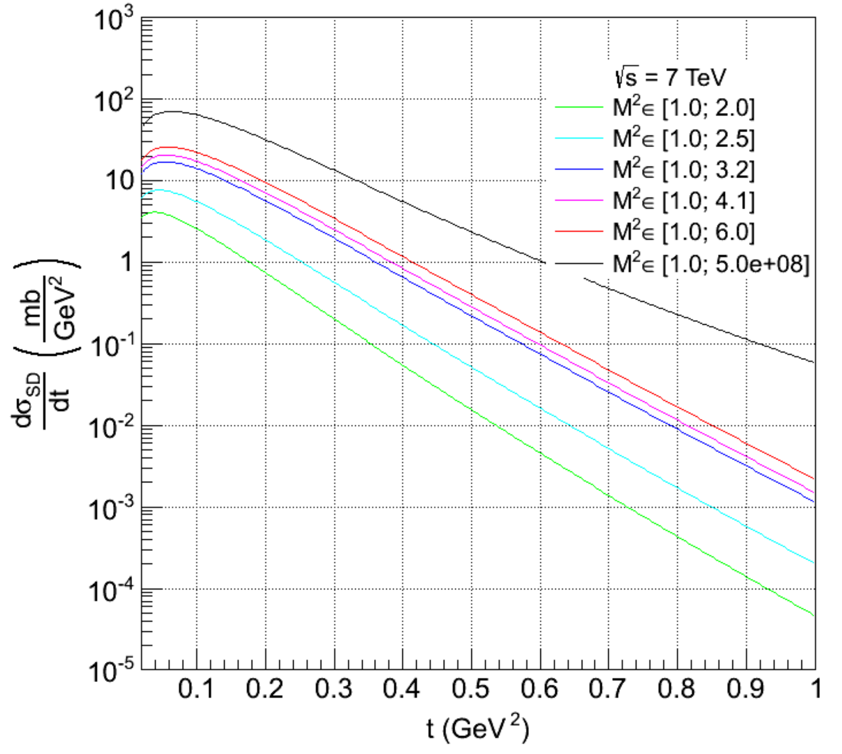
Double differential SD cross sections



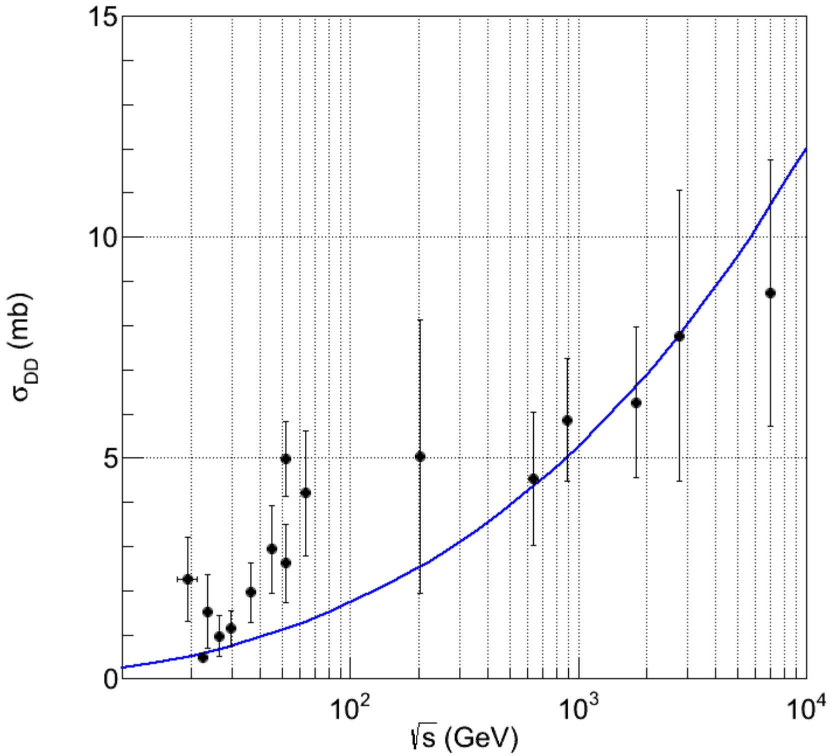


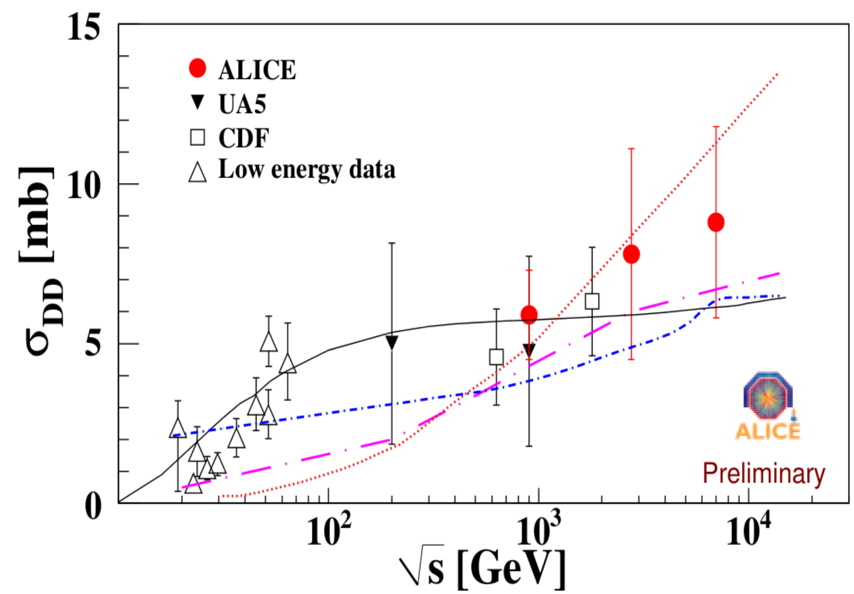
Single differential integrated SD cross sections



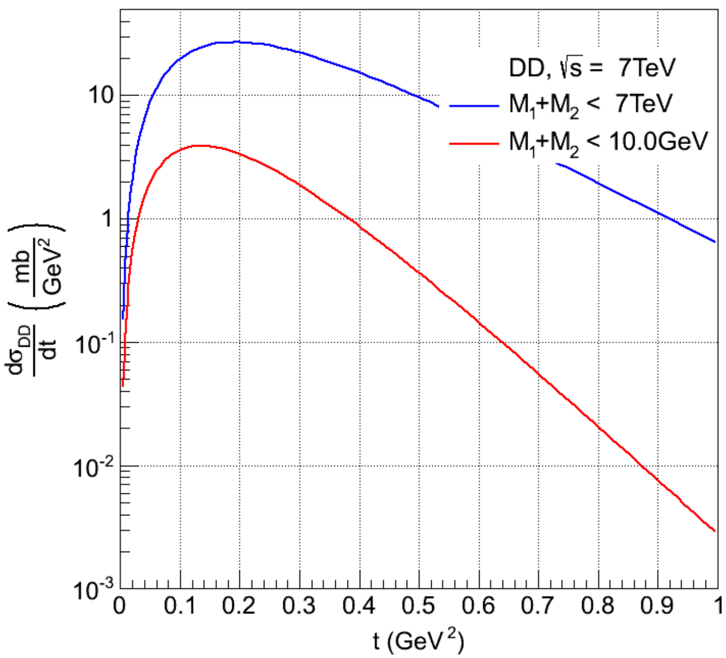


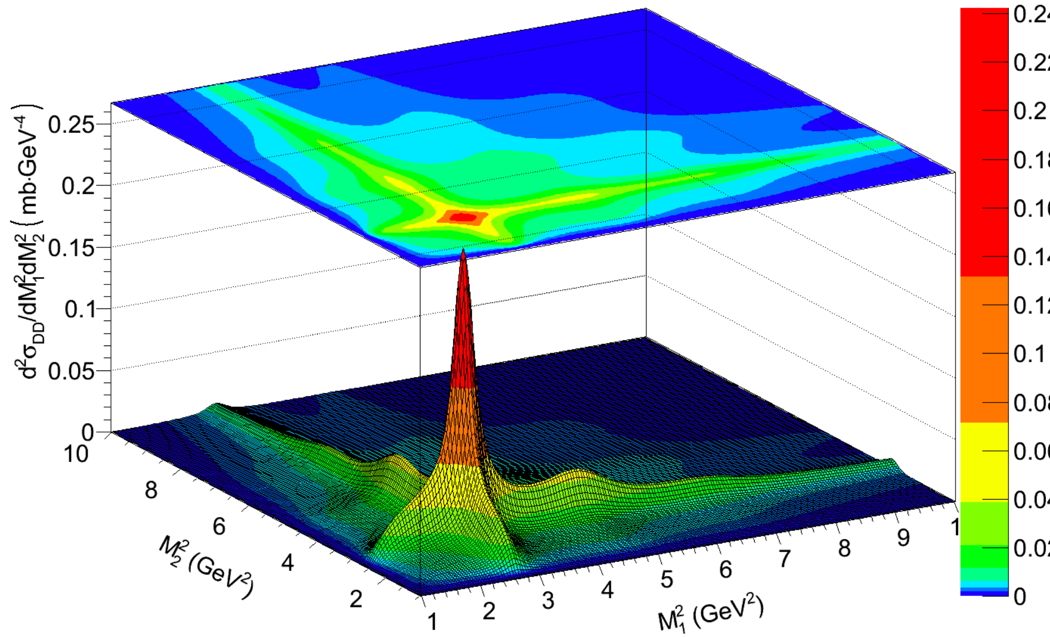
DDD cross sections vs. energy.



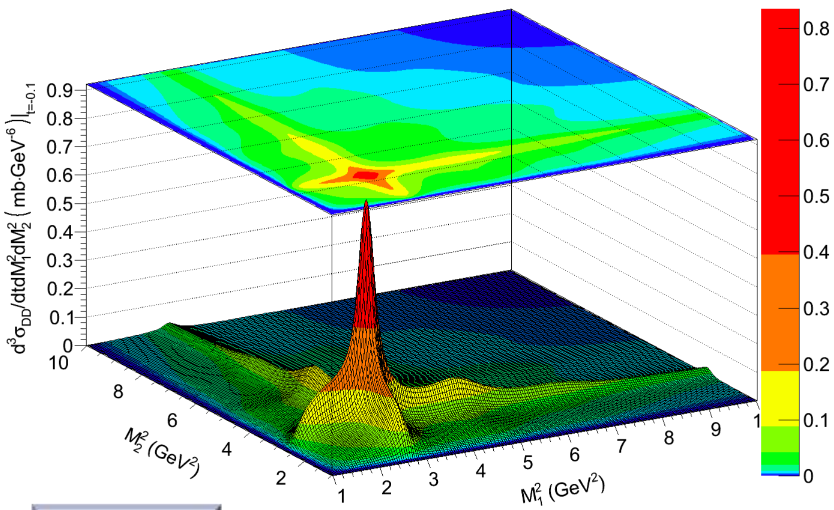


Integrated DD cross sections

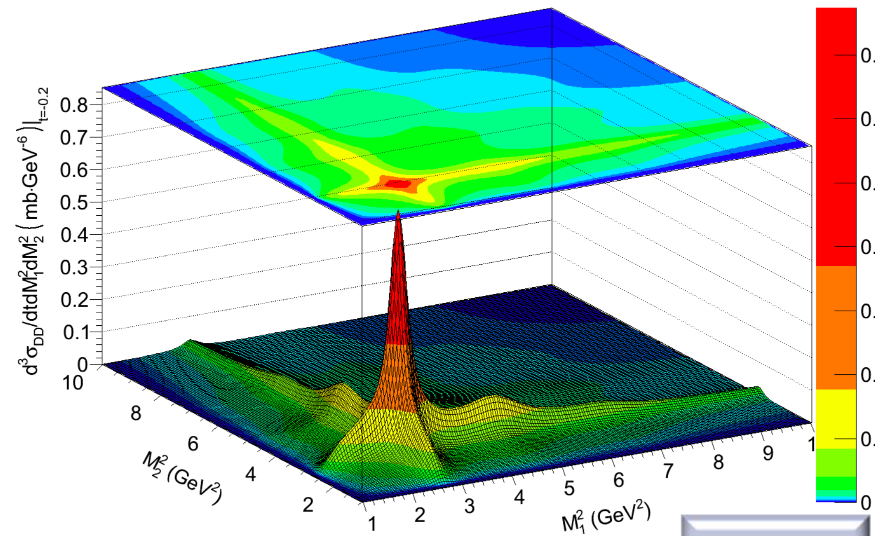




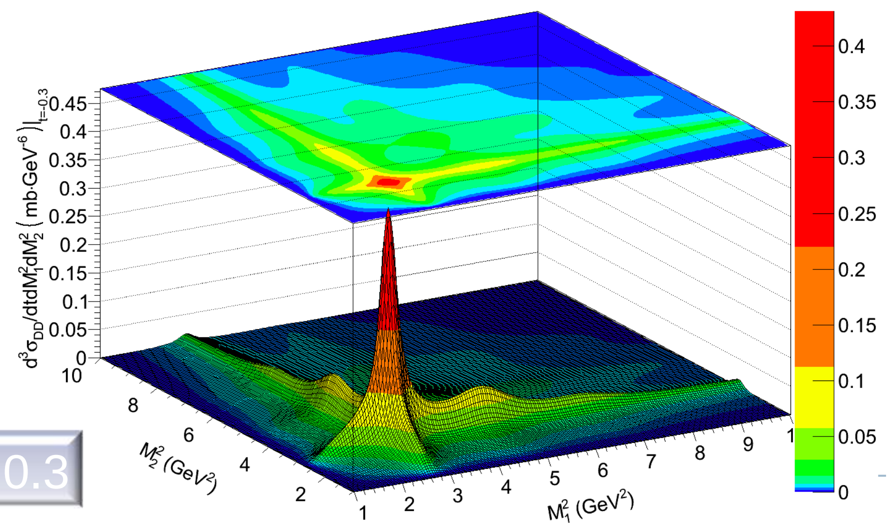
Triple differential DD cross sections



t = - 0.1



t = - 0.2



t = - 0.3

The parameters and results

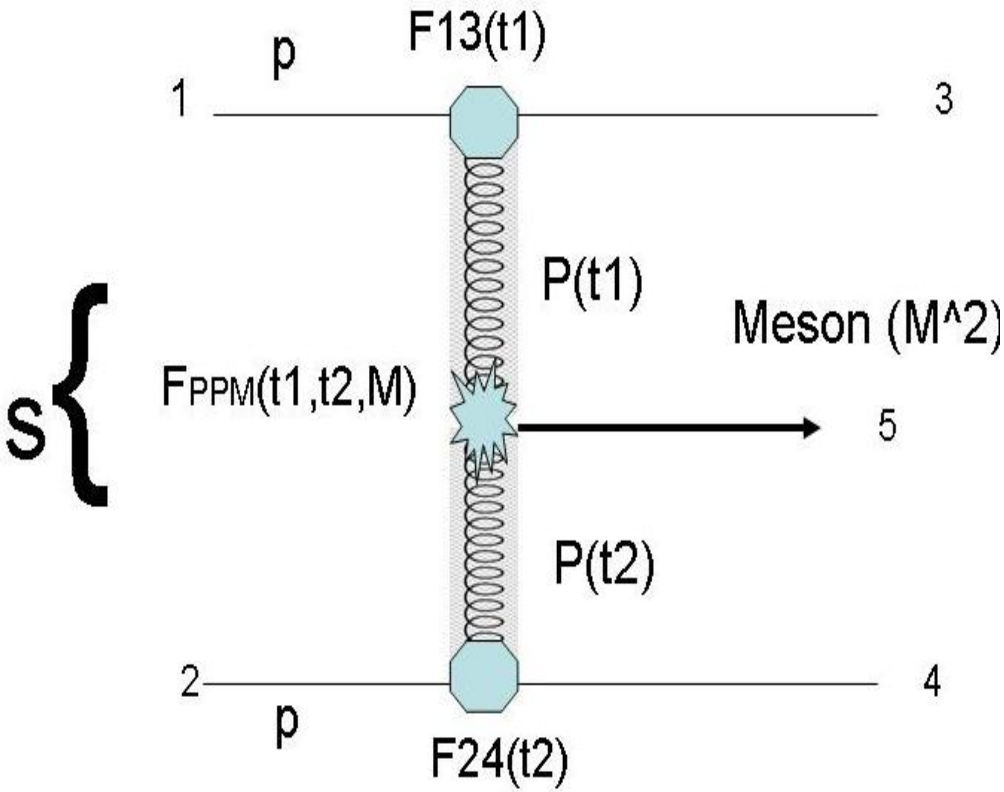
b_{in} (GeV^{-2})	0.2
b_{in}^{bg} (GeV^{-2})	3
α' (GeV^{-2})	0.25
$\alpha(0)$	1.04
ϵ	1.03
A_n	18.7
B_n	8.8
C_n	3.79e-2

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;
2. Inclusion of non-leading contributions;
3. Deviation from a simple Pomeron pole model and breakdown of Regge-factorization;
4. The background (in M^2);
5. Finite-mass sum rules (duality), inerpolation in M^2).

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



Thanks for your attention!

From Regge factorization (D.M. Chew, Nucl. Phys. **B82** (1974) 422; D.M. Chew and G.F. Chew, Phys. Letters, **B53** (1974) 191),

$$\frac{d\sigma}{dt_A dt_B dM_A dM_B} = \frac{1}{\sigma_t(AB)} \frac{d\sigma^A}{dt_A dM_A} \frac{d\sigma^B}{d_B dM_B},$$

where $t_{A,B}$ and $M_{A,B}$ and line numbers are as in the Figure;

$$t_A = (p_3 - p_1)^2\,, \quad t_B = (p_4 - p_2)^2\,,$$

$$M_A^2 = (p_5 + p_4)^2\,, \quad M_B^2 = (p_5 + p_3)^2\,.$$

Here $\sigma_T(AB)$ is the total AB cross section.

At high energies, central exclusive states are produced almost background-free, with constrained quantum numbers. The $t-$ channel exchanges over large rapidity gaps, can only be photons γ, pomerons or odderons ($C = 1$ counterparts of the pomeron).

The quantum numbers of the X state in a double Pomeron exchange (DPE) in the reaction $p + \bar{p} \rightarrow p + \bar{p} + X$ (at the Tevatron) or $p + p \rightarrow p + p + X$ (at the LHC) are constrained by the conservation laws of space and charge parity. The relative angular momentum of the pomerons is constrained to be even,

$$\hat{P}|0^{++}0^{++} = (+1)(+1)(-1)^{L=2k} = +1 = \hat{P}|X > .$$

The charge parity of of the state X can be deduced in the same way:

$$\hat{C}|0^{++}0^{++} >= (+1)(+1)(-1)^{L=2k} = +1 = \hat{C}|X > .$$

Furthermore, $Q = B = B = S = 0$.

At the CERN ISR, at $\sqrt{s}(pp) = 63$ GeV, the states $X = \pi^+\pi^-,\ K^+K^-, p\bar{p}$ and $\pi^+\pi^-\pi^+\pi^-$ were observed. The $\pi^+\pi^-$ spectrum had several structures: a broad $f_0(600)$, a narrow $f_0(980)$ and a structure possible related to a glueball $f_0(1710)$ but not yet completely identified.

Thank you !