

Protvino-2014

**Diffractive vector meson
production in
ultra-peripheral collisions
at the LHC etc.**

László Jenkovszky (BIP, Kiev)

Diffraction in:

- Elastic hadron scattering,
- Inelastic hadron scattering (SD, DD, CED),
- Exclusive ep collisions (HERA),
- Ultra-peripheral pp, Ap and AA collisions (LHC)

*L.J. with R. Fiore, S. Fazio, A. Lengyel, R. Orava,
F. Paccanoni, A. Papa, E. Predazzi, A. Papa et al.*

Elastic and total cross sections:

Anton Godizov: Current stage... , arXiv: 1404.7678;

S. Troshin and N. Tyurin: PR D 88(2013)077502;

Igor Dremin: Pomeranchuk centennial seminar, arXiv: 1311.4159 .

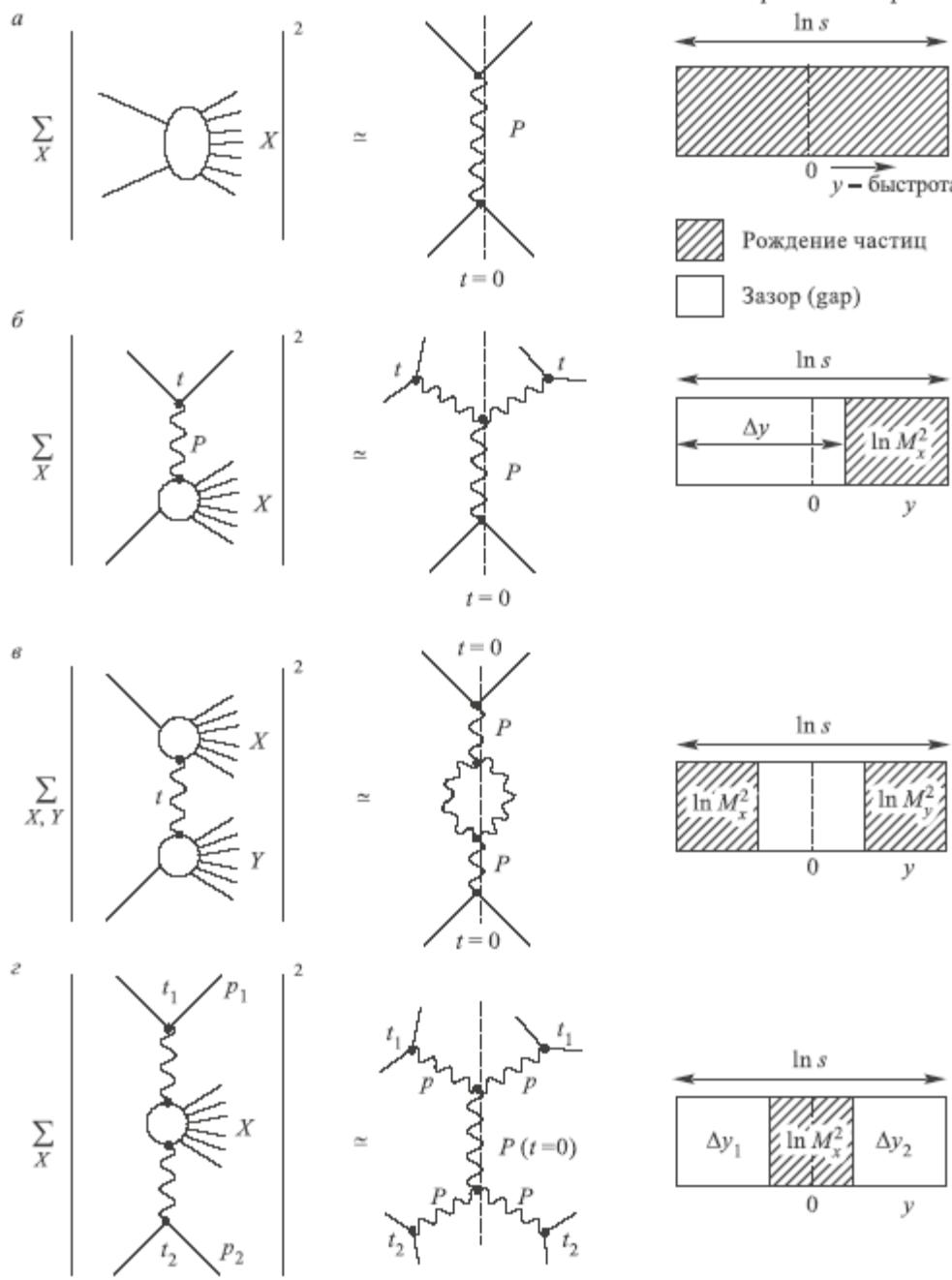
Elastic and DD

Roman Ryutin: arXiv: 1404.7678;

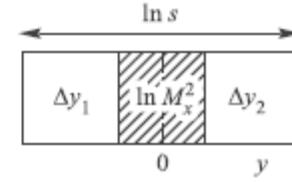
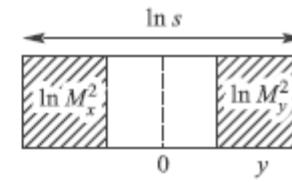
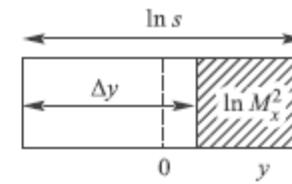
V.A. Petrov's School in Protvino;

L. J. + R.Fiore, S. Fazio, O, Kuprash, V. Magas, Risto Orava, A. Salii

(*PR D & Yad. Fizika, 2012-2014*)

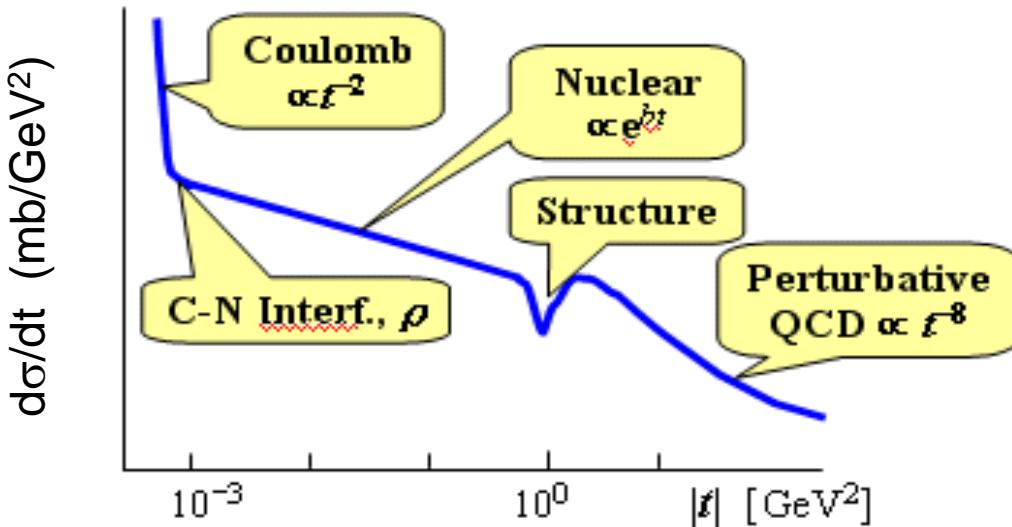


■ Рождение частиц
□ Зазор (gap)



Elastic Scattering

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



momentum transfer $-t \sim (p\theta)^2$
 θ = beam scattering angle
 p = beam momentum

$$\rho = \frac{\operatorname{Re}(f_{el}(t))}{\operatorname{Im}(f_{el}(t))} \Big|_{t \rightarrow 0}$$

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

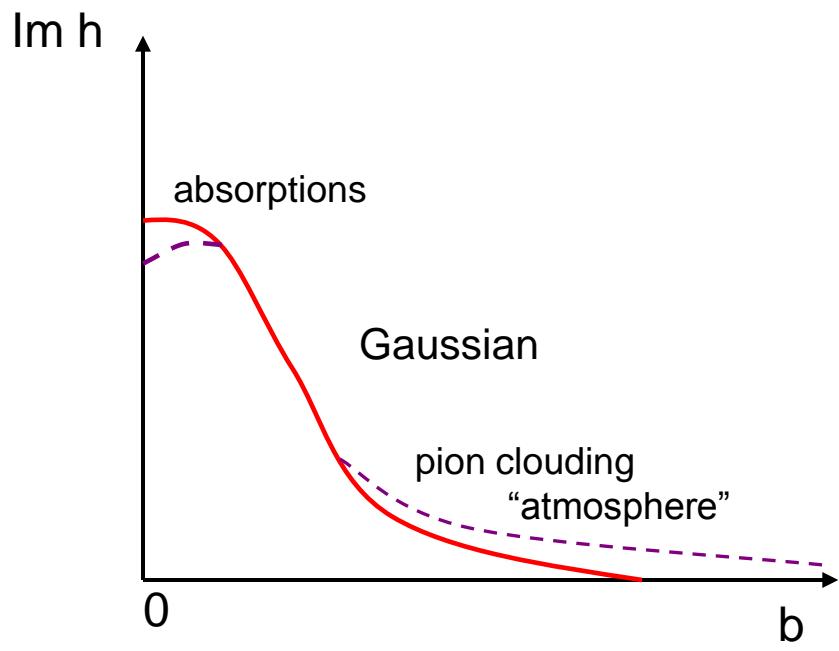
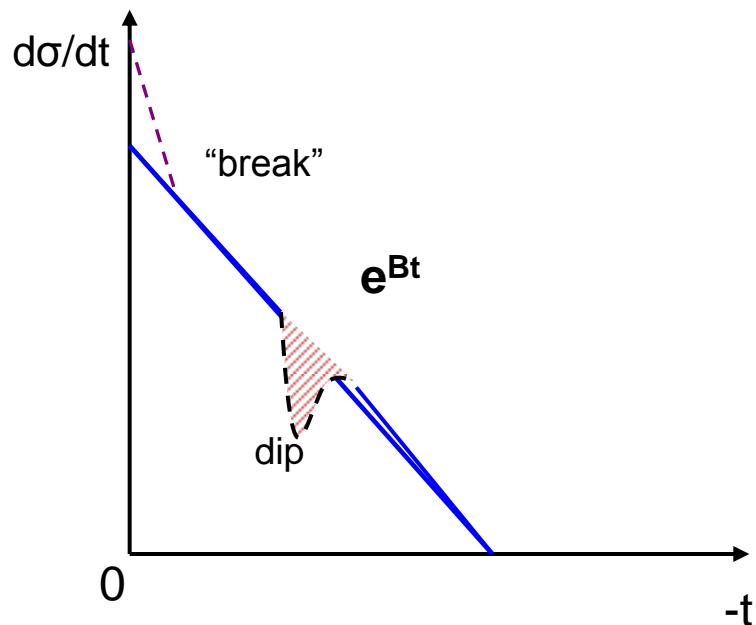
L , σ_{tot} , b , and ρ
from FIT in CNI
region (UA4)

CNI region: $|f_C| \sim |f_N| \rightarrow$ @ LHC: $-t \sim 6.5 \cdot 10^{-4} \text{ GeV}^2$; $\theta_{min} \sim 3.4 \mu\text{rad}$
 $(\theta_{min} \sim 120 \mu\text{rad} @ SPS)$

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:



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

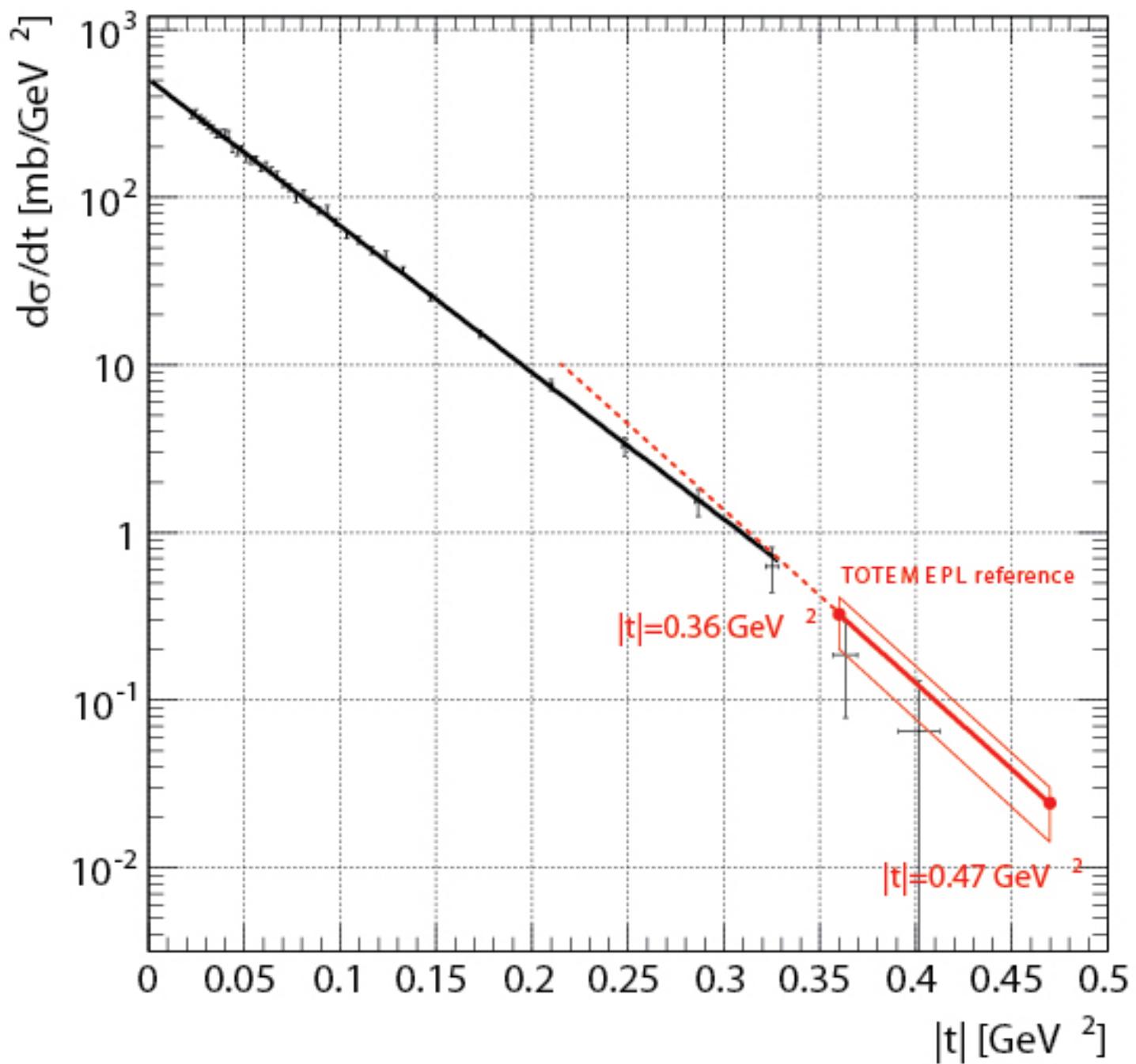
$$\sigma_{el} = \int_{t_{min} \approx -s/2 \approx \infty}^{t_{thr.} \approx 0} \frac{d\sigma}{dt}; \quad \sigma_{in} = \sigma_t - \sigma_{el}; \quad B(s, t) = \frac{d}{dt} \ln\left(\frac{d\sigma}{dt}\right);$$

(and ratios: $\sigma/B, \dots$).

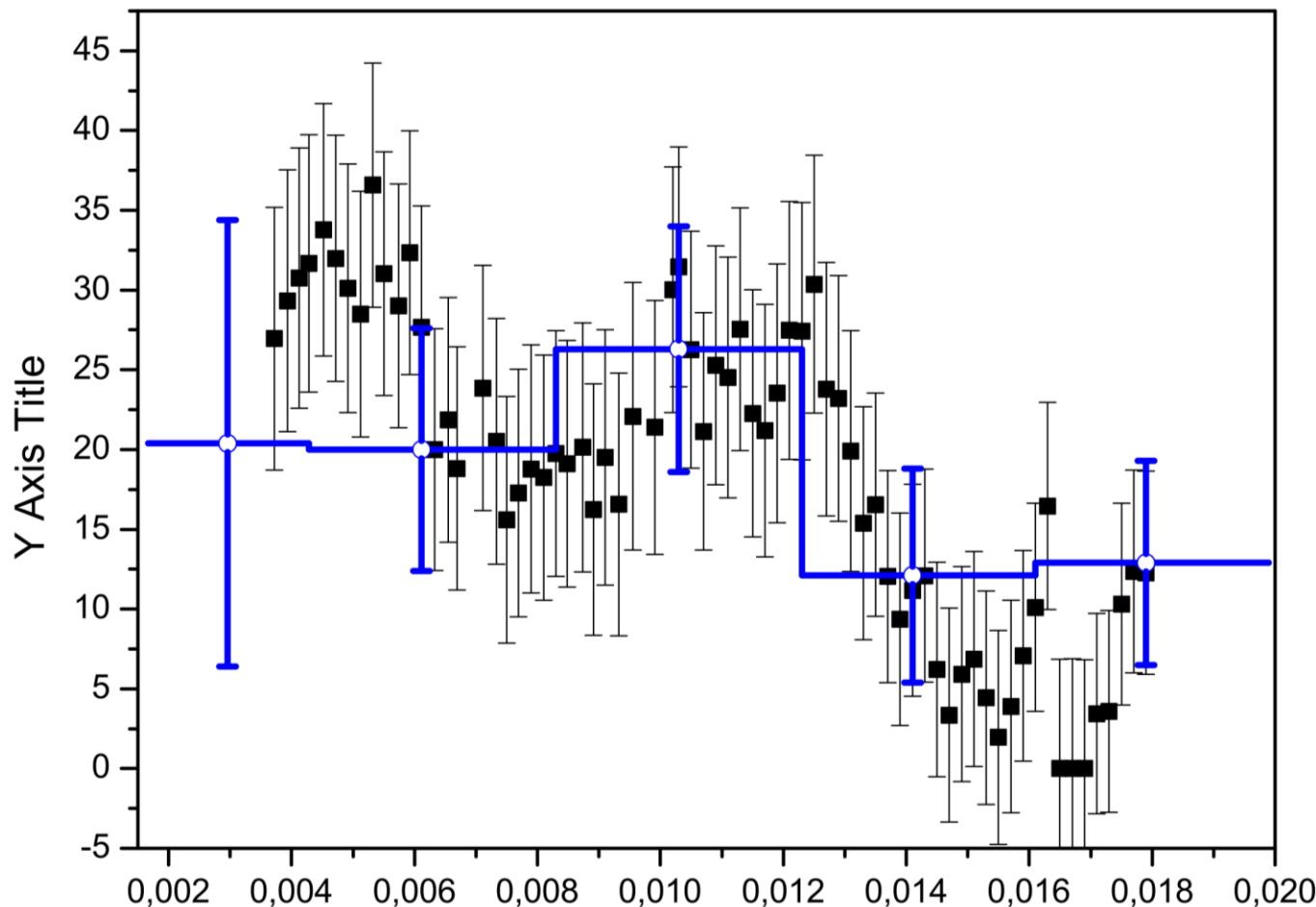
$$A_{pp}^{p\bar{p}}(s, t) = P(s, t) \pm O(s, t) + f(s, t) \pm \omega(s, t) \rightarrow_{LHC} \approx P(s, t) \pm O(s, t),$$

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

a(0)\C	+	-
1	P	O
1/2	f	ω



Local slope, $Y=B(t)$ from the new TOTEM data (Jan Kašpar's talk):
A. Lengyel et al. (Uzhgorod, 1994), V. Ezhela (ISMD, Alushta, 2004),
S. Denisov Protivno)



Pomeron dominance at the LHC

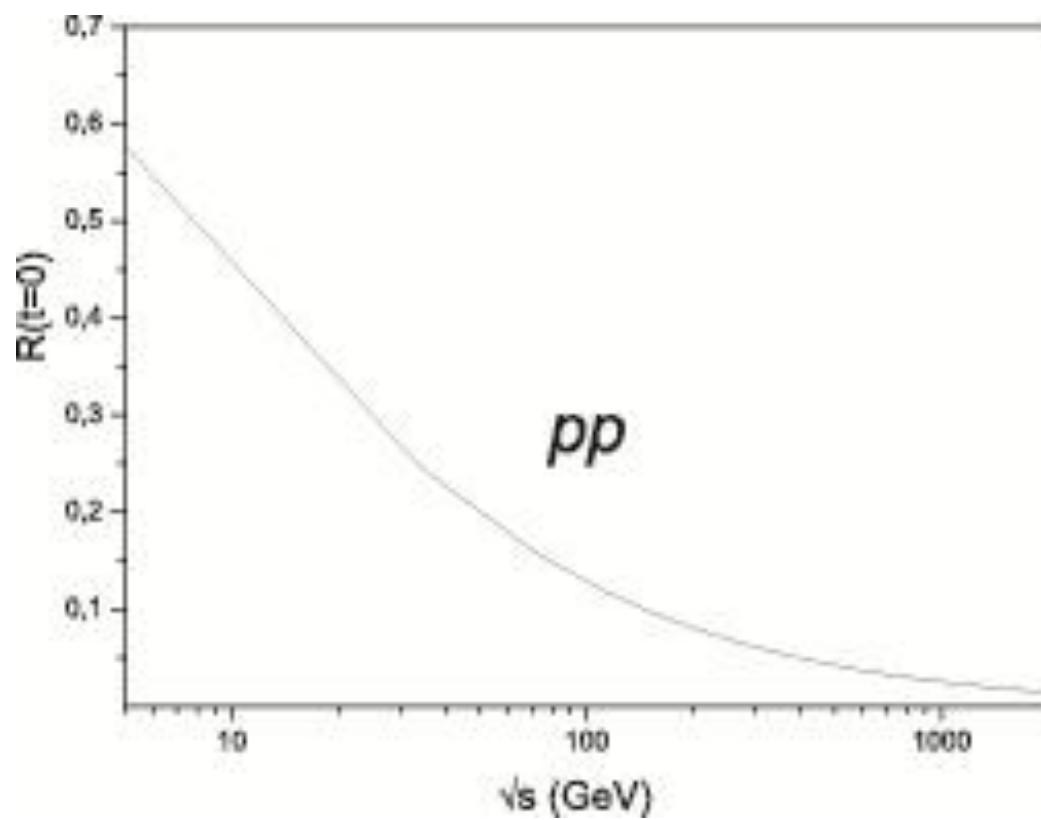
Energy variation of the relative importance of the Pomeron with respect to contributions from the secondary trajectories and the Odderon:

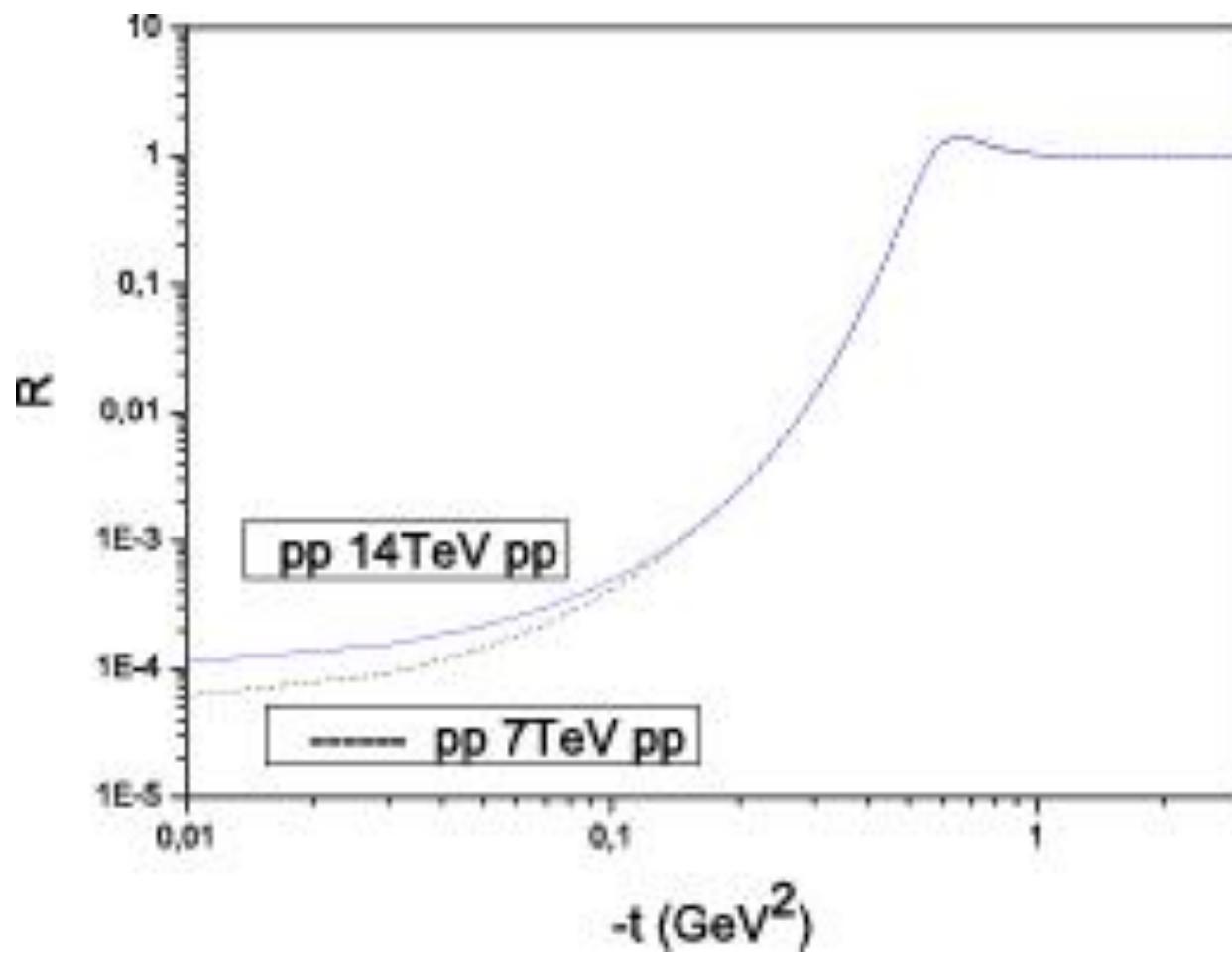
$$R(s, t = 0) = \frac{\Im m(A(s, t) - A_P(s, t))}{\Im A(s, t)}, \quad (1)$$

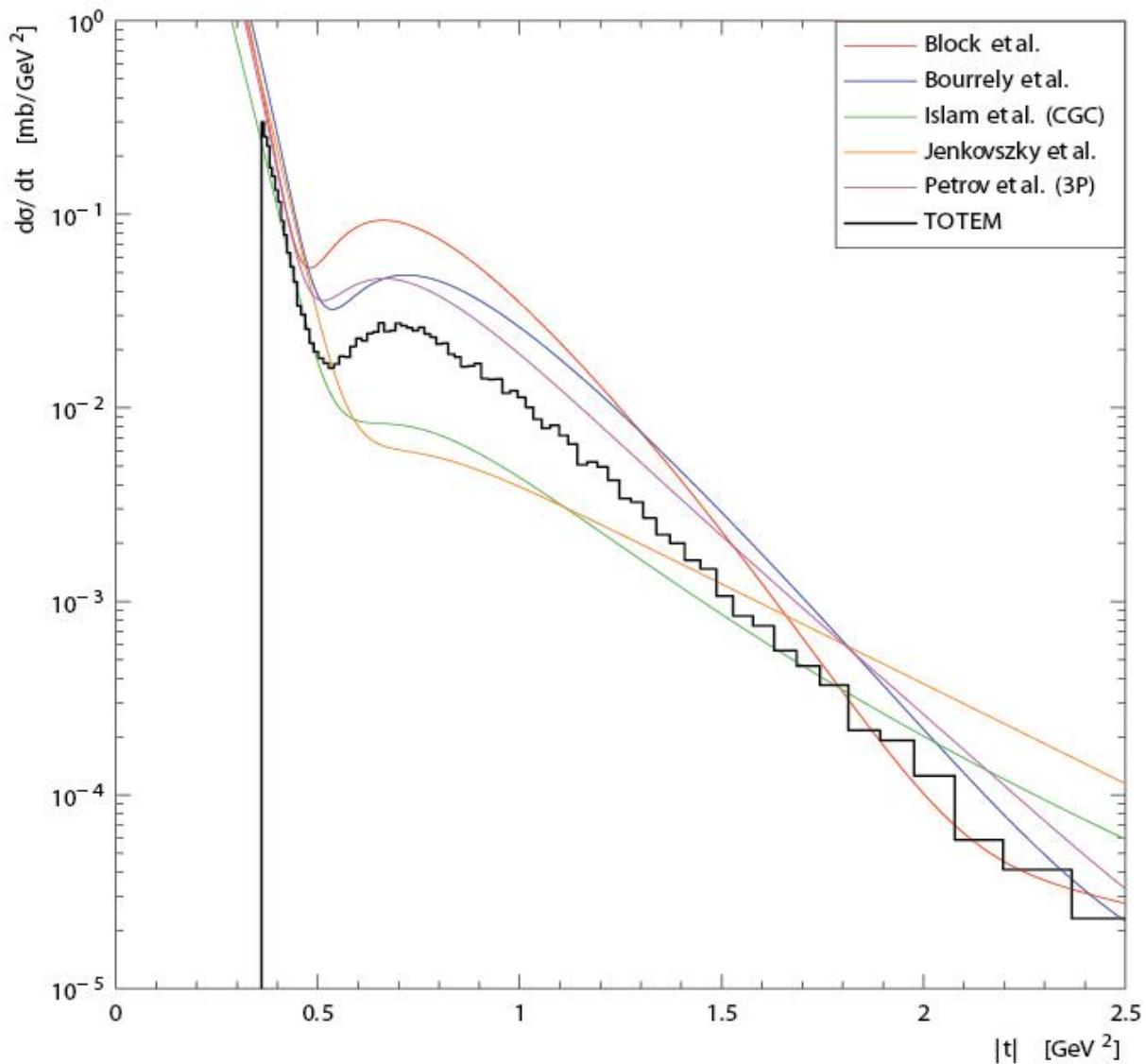
where the total scattering amplitude A includes the Pomeron contribution A_P plus the contribution from the secondary Reggeons and the Odderon.

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.

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







L. Jenkovszky, A. Lengyel, D. Lontkovskyi, The Pomeron and Odderon in elastic, inelastic and total cross sections at the LHC, Int. J. Mod. Phys. A 26, # 26 & 27 (2011) 4755-4771, arXiv:1105.1202

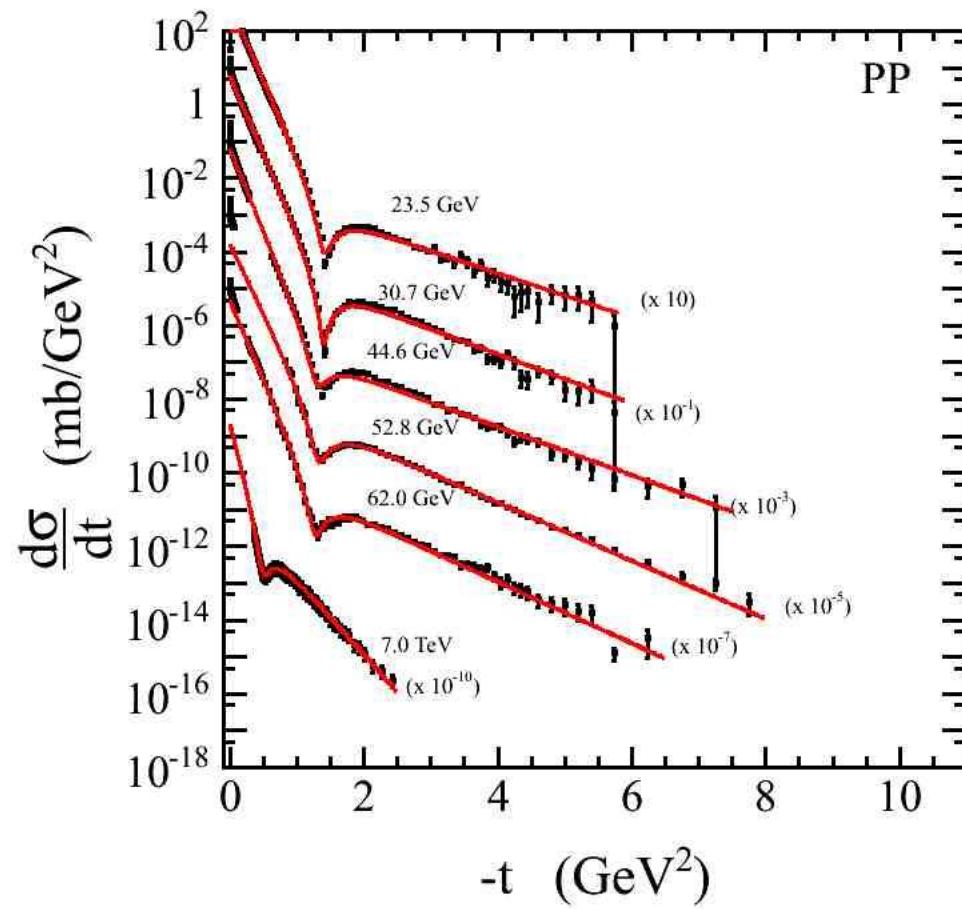
Phenomenology

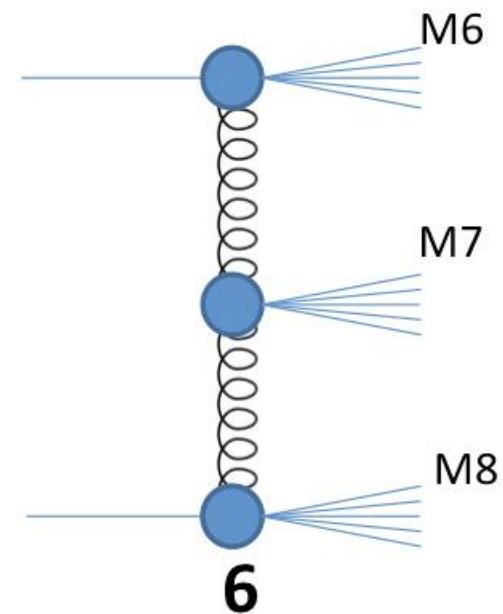
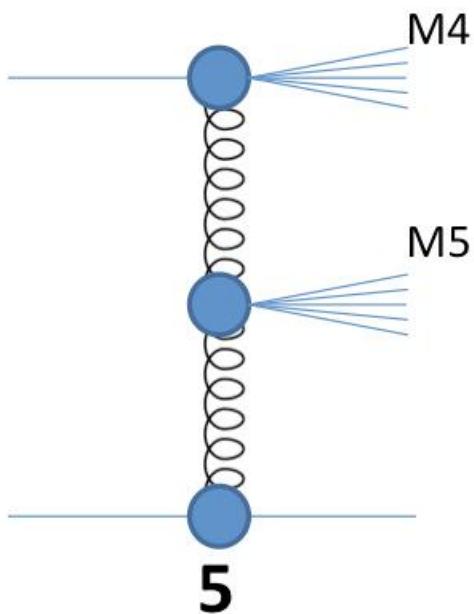
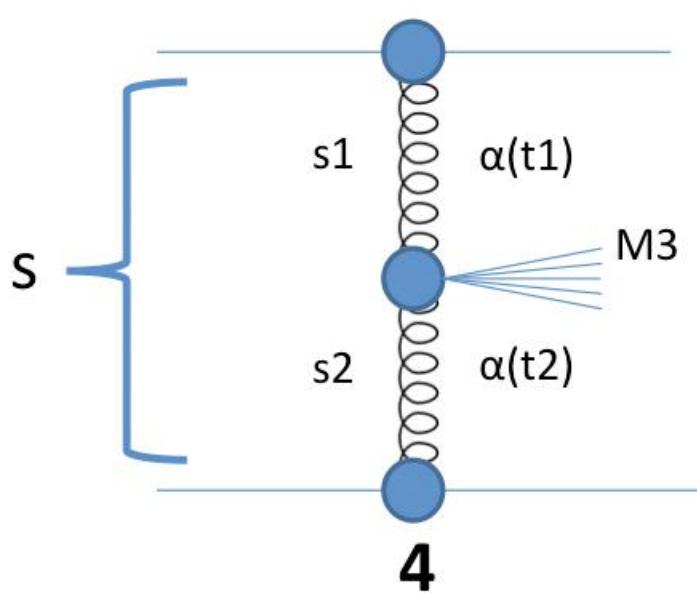
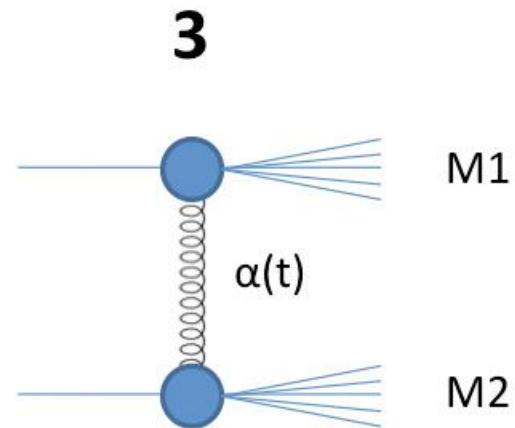
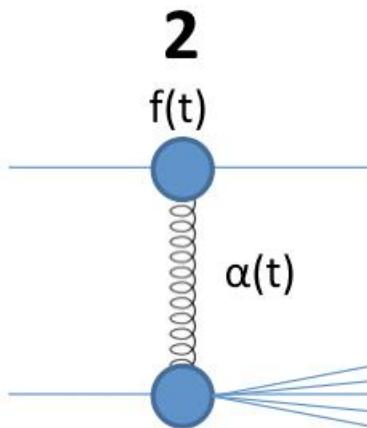
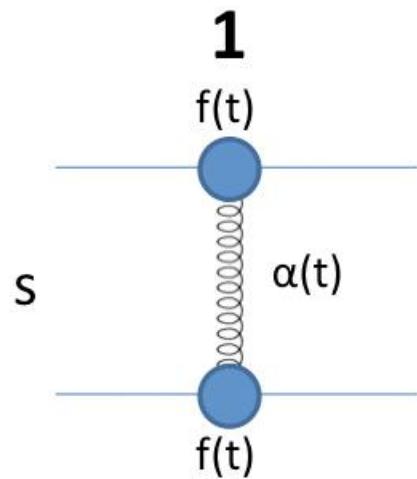
R.J.J. Phillips and V. Barger, *Model independent analysis of the structure in pp scattering*, Phys. Lett. B 46 (1973) 412.

Phillips and Barger in 1973 [], right after its first observation at the ISR.
Their formula reads

$$\frac{d\sigma}{dt} = |\sqrt{A} \exp(Bt/2) + \sqrt{C} \exp(Dt/2 + i\phi)|^2, \quad (1)$$

where A , B , C , D and ϕ are determined independently at each energy.





- 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 $t \sim 1 \text{ GeV}^2, \dots$
 - 5) The background (in s and in M);
 - 6) Exclusive-inclusive relation;
 - 7) From elastic to inelastic diffraction (dis)continuity.

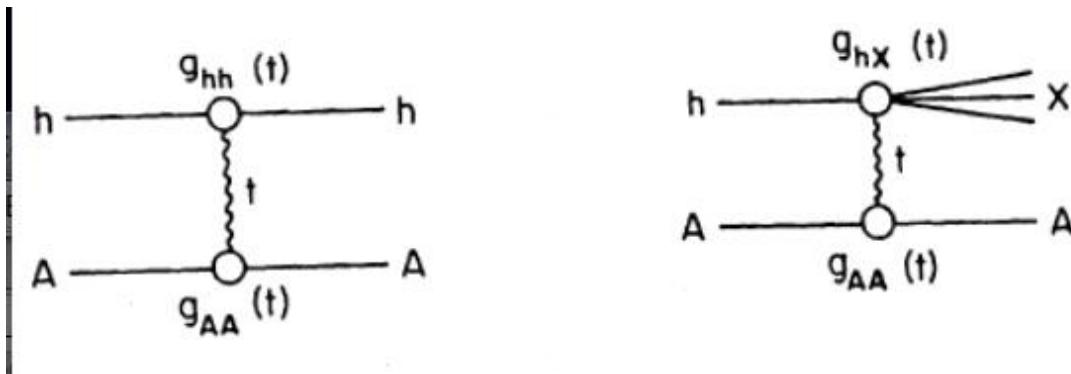
Simple (but approximate) factorization relations

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

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

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

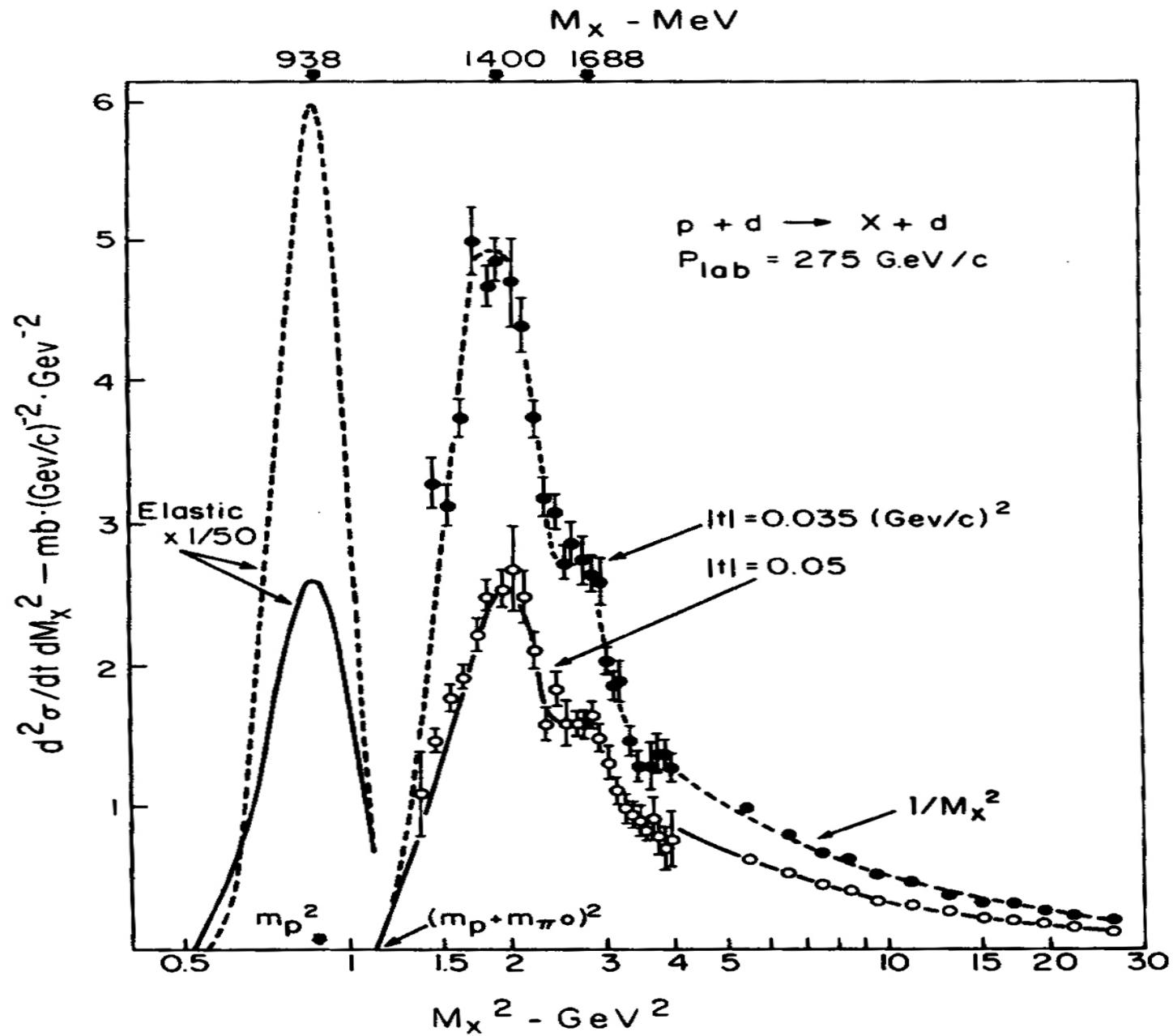
where $k = r^2/(2r - 1)$, $r = b_{SD}/b_{el}$.



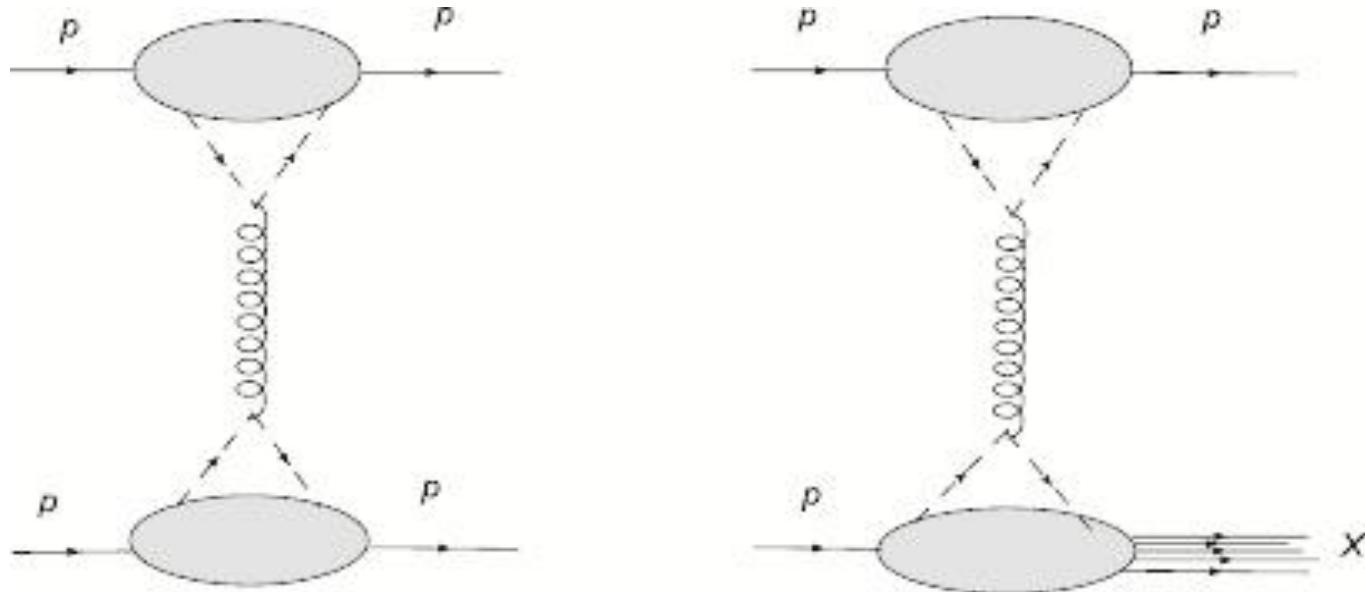
TriTriple Regge (Pomeron) limit::

$$\begin{aligned}
 \frac{d^2\sigma}{dt dx} &= \left| \begin{array}{c} h \\ | \quad \backslash \\ p \quad p \end{array} \right|^2 = \begin{array}{c} h \quad X \\ | \quad \backslash \\ t=0 \end{array} = \begin{array}{c} h \quad h \\ | \quad | \\ p \quad p \end{array} \\
 \sigma_{\text{tot}} &= \left| \begin{array}{c} h \\ | \quad \backslash \\ p \end{array} \right|^2 = \begin{array}{c} h \\ | \quad \backslash \\ p \end{array} = \begin{array}{c} h \\ | \quad \backslash \\ t=0 \\ | \quad | \\ p \quad p \end{array}
 \end{aligned}$$

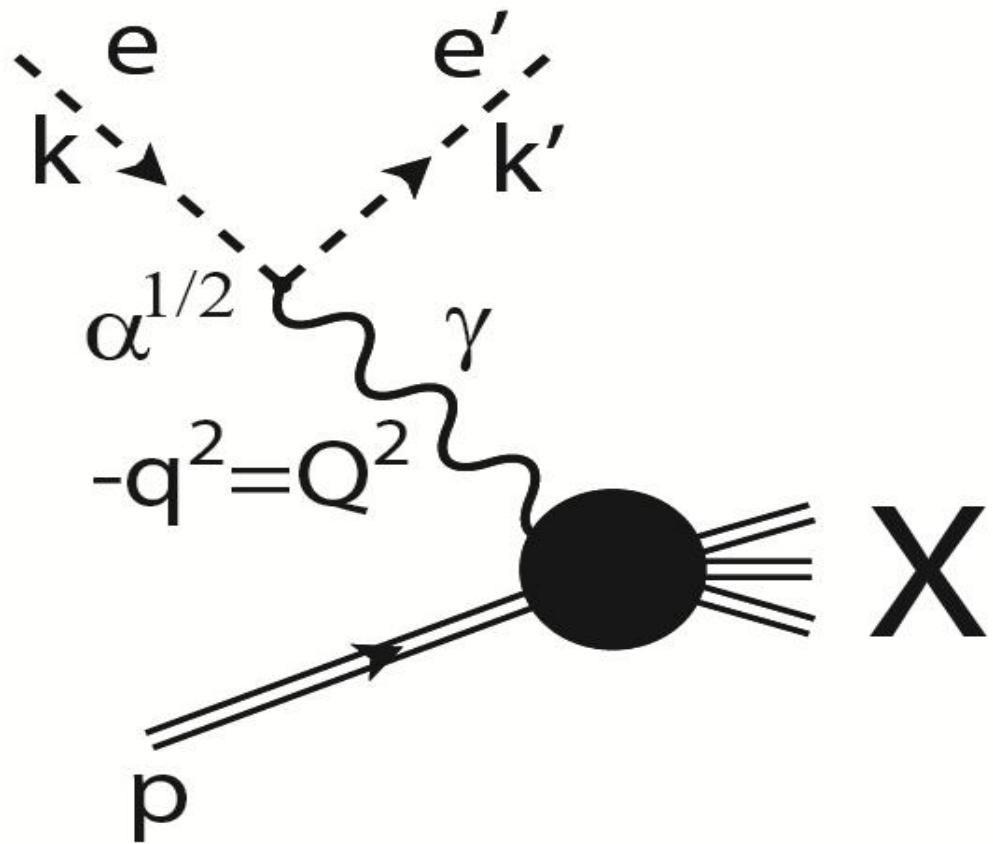
FNAL



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 \rightarrow LHC; $\gamma \rightarrow P$; $q^2 \rightarrow t$

R. Fiore {lit et al.} EPJ A **15** (2002) 505, hep-ph/0206027;

R. Fiore {lit et al.} Phys. Rev. D **68** (2004) 014004, hep-ph/0308178.

Dual properties of the inelastic SF (transition amplitude)

$$\left| \frac{q}{p} X \right|^2 = \sum_X \text{Diagram with } X \text{ vertex} = \text{Diagram with } X \text{ vertex} \text{ (Unitarity)} = \sum_R \text{Diagram with } R \text{ vertex} = \sum_{\text{Res}} \text{Diagram with Resonance vertex}$$

Veneziano duality

L. Jenkovszky, V.K. Magas, and E. Predazzi, EPJA 12 (2001) 36;
[hep-ph/0110374](https://arxiv.org/abs/hep-ph/0110374).

$\pi^-(\bar{u}d)$ $p(uud)$

=

(b)

Res.

Regge

 $\pi^-(\bar{u}d)$ $p(uud)$

=

(b)

Res.

Regge

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

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

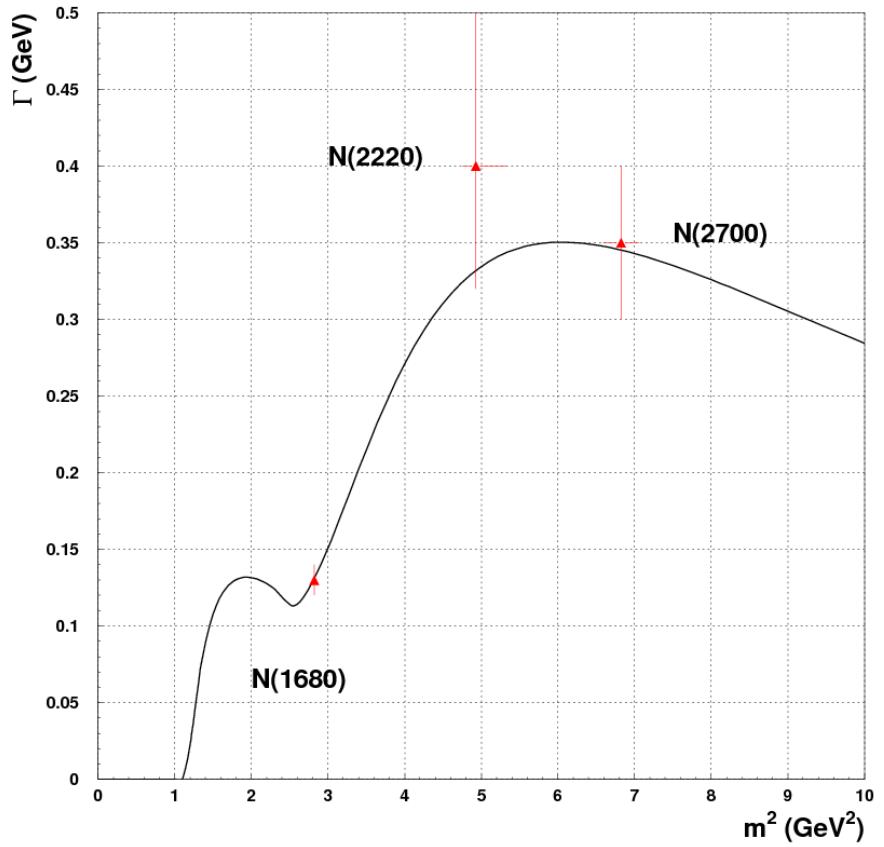
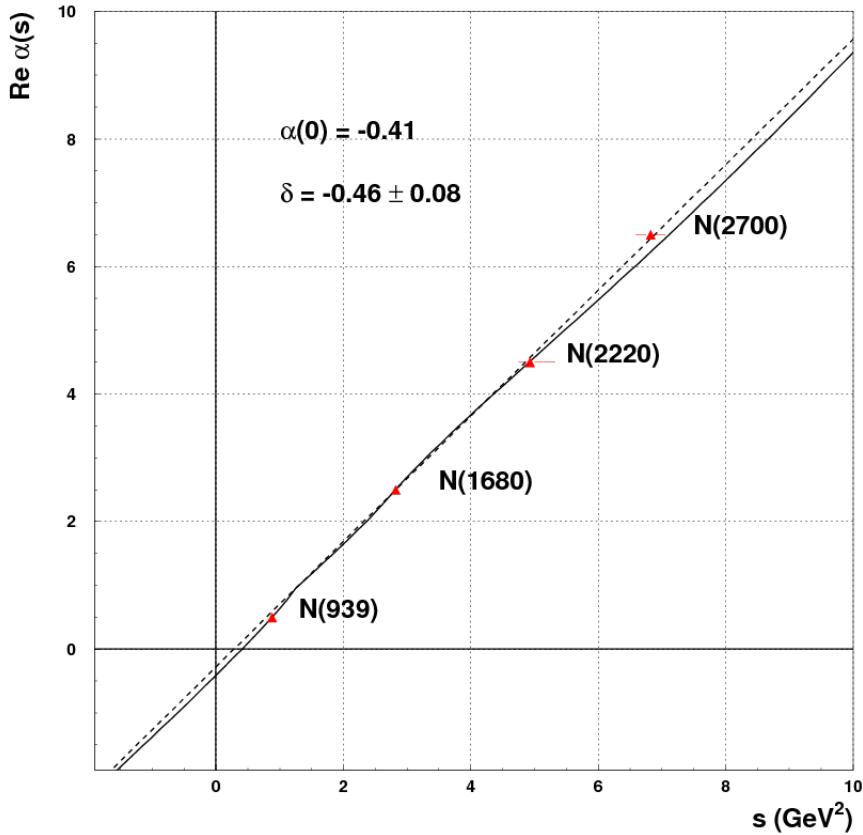
where W_i , $i = 1, 2$ are related to the structure functions of the nucleon and $W_2 \gg W_1$. For high M_X^2 , the $W_{1,2}$ are Regge-behaved, while for small M_X^2 their behavior is dominated by nucleon resonances. The knowledge of the inelastic form factors (or transition amplitudes) is crucial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

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

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

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

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



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

$$\text{Im } \alpha(s) = s^\delta \sum_n c_n \left(\frac{s - s_n}{s} \right)^{\lambda_n} \cdot \theta(s - s_n), \quad (1)$$

where $\lambda_n = \text{Re } \alpha(s_n)$.

The real part of the proton trajectory is given by

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

where

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

SD and DD cross sections

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

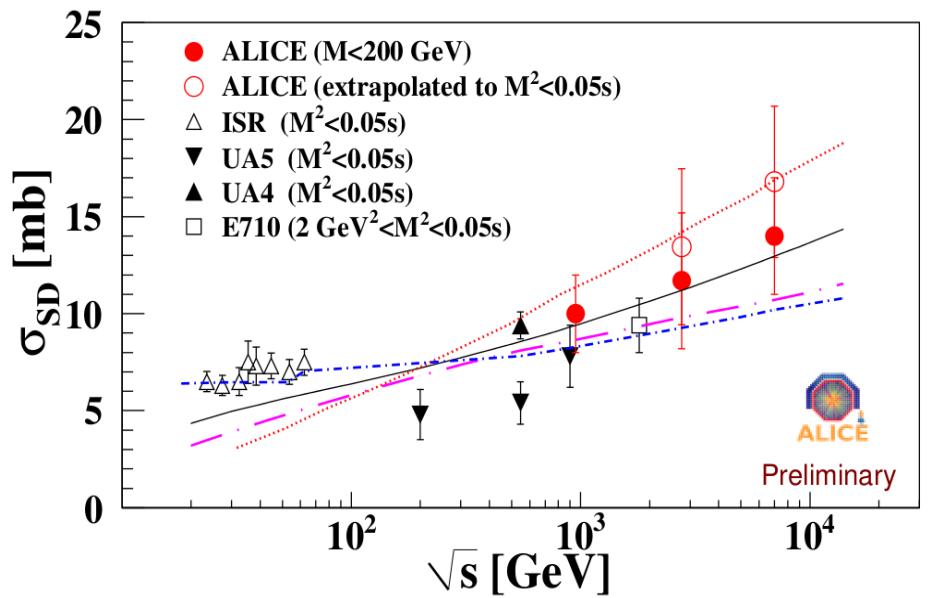
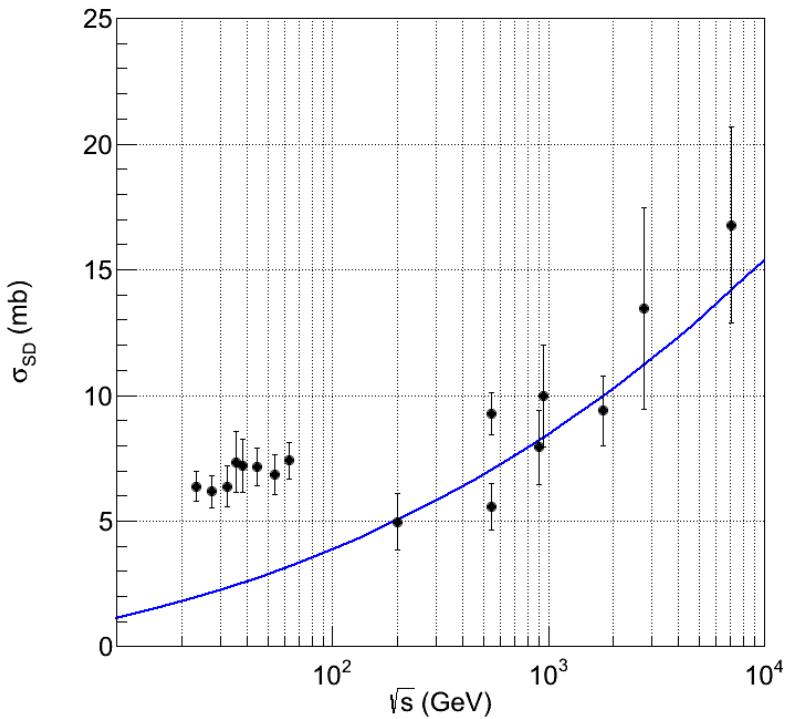
$$\frac{d^3\sigma_{DD}}{dt dM_1^2 dM_2^2} = C_n F^2(x_B, t) \frac{\sigma_T^{Pp}(M_1^2, t)}{2m_p} \frac{\sigma_T^{Pp}(M_2^2, t)}{2m_p}$$

$$\times \left(\frac{s}{(M_1 + M_2)^2} \right)^{2(\alpha(t)-1)} \ln \left(\frac{s}{(M_1 + M_2)^2} \right)$$

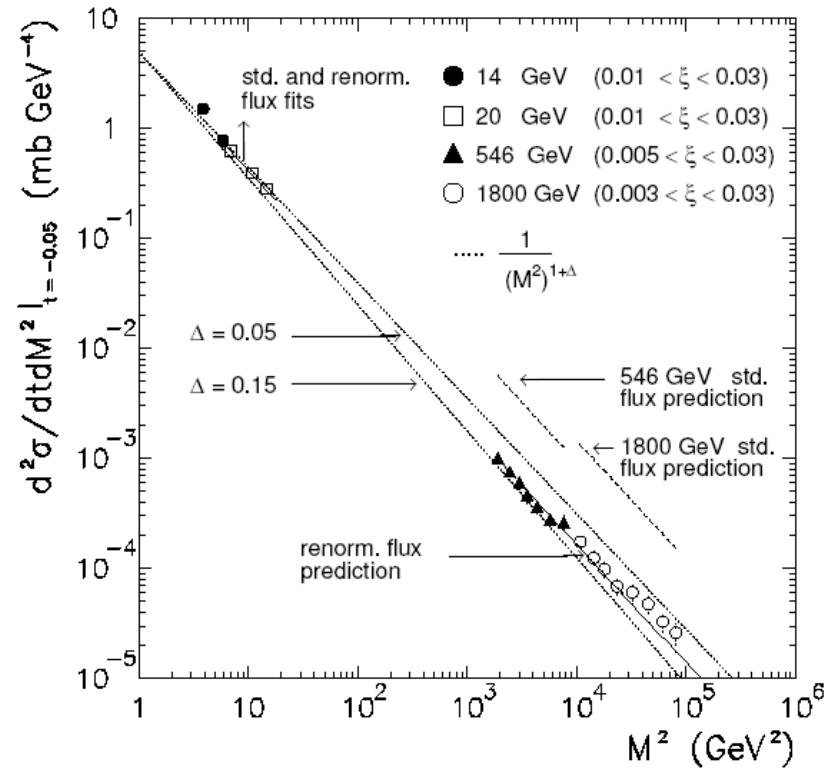
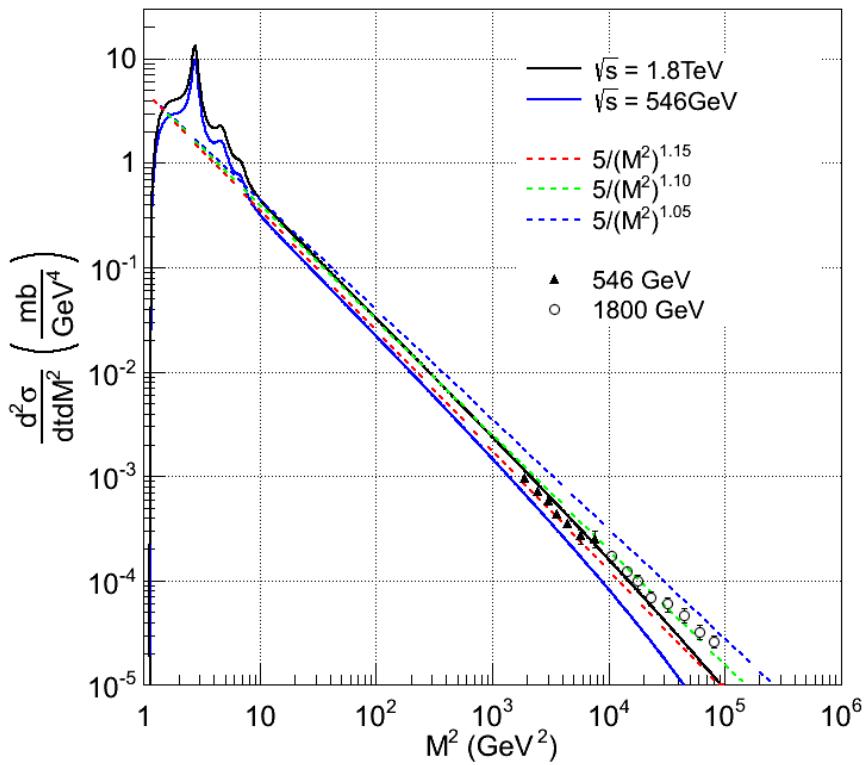
“Reggeized (dual) Breit-Wigner” formula:

$$\begin{aligned}
& \sigma_T^{Pp}(M_x^2, t) = \text{Im } A(M_x^2, t) = \frac{A_{N^*}}{\sum_n n - \alpha_{N^*}(M_x^2)} + Bg(t, M_x^2) = \\
& = A_n \sum_{n=0,1,\dots} \frac{[f(t)]^{2(n+1)} \text{Im } \alpha(M_x^2)}{(2n + 0.5 - \text{Re } \alpha(M_x^2))^2 + (\text{Im } \alpha(M_x^2))^2} + B_n e^{b_{in}^{bg} t} (M_x^2 - M_{p+\pi}^2)^\epsilon \\
& F(x_B, t) = \frac{x_B(1-x_B)}{(M_x^2 - m_p^2) \left(1 + 4m_p^2 x_B^2 / (-t)\right)^{3/2}}, \quad x_B = \frac{-t}{M_x^2 - m_p^2 - t} \\
& F_p(t) = \frac{1}{1 - \frac{t}{0.71}}, \quad f(t) = e^{b_{in} t} \\
& \alpha(t) = \alpha(0) + \alpha' t = 1.04 + 0.25t
\end{aligned}$$

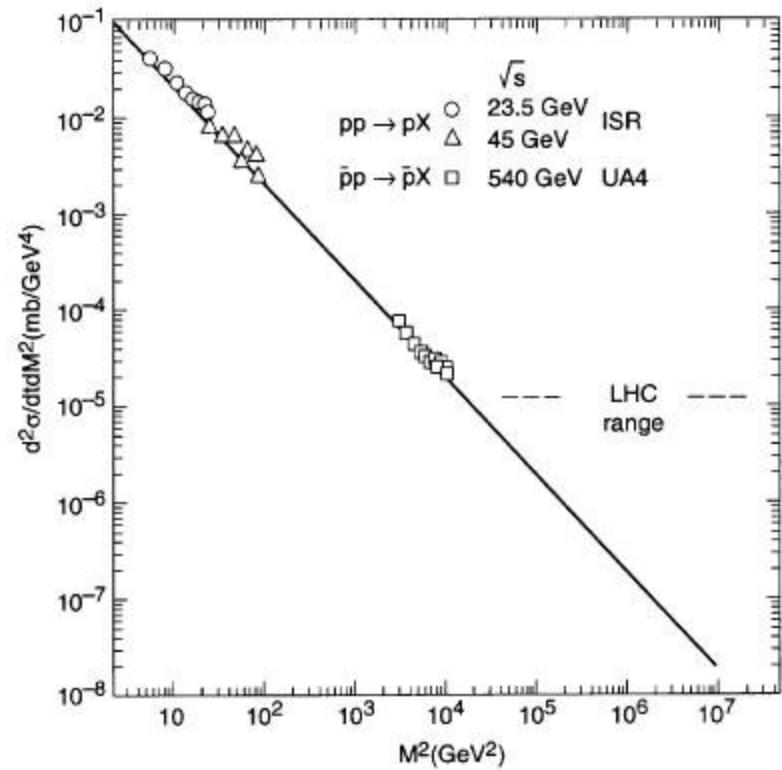
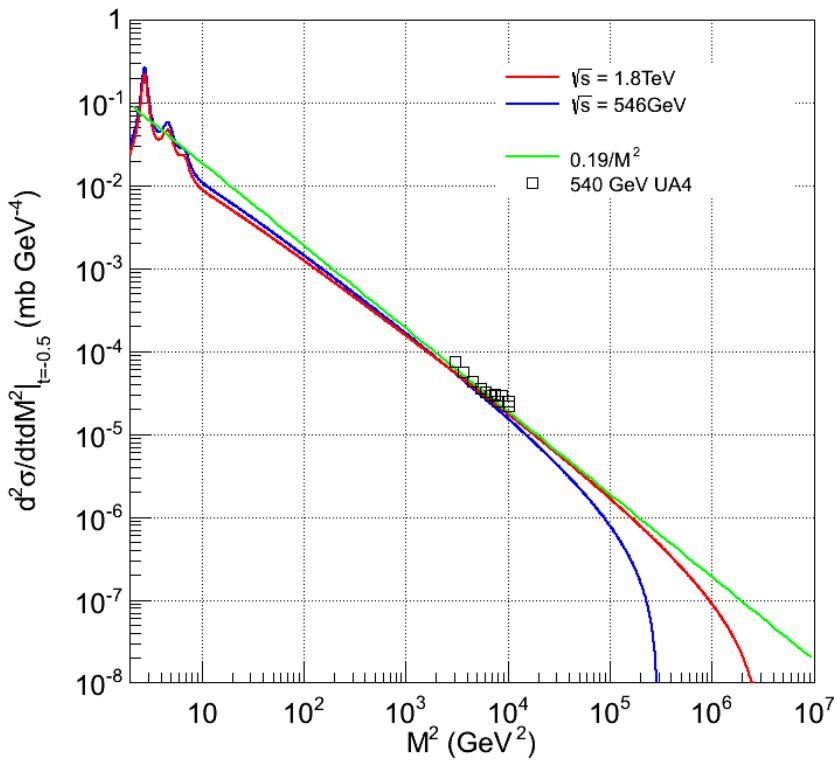
SDD cross sections vs. energy.



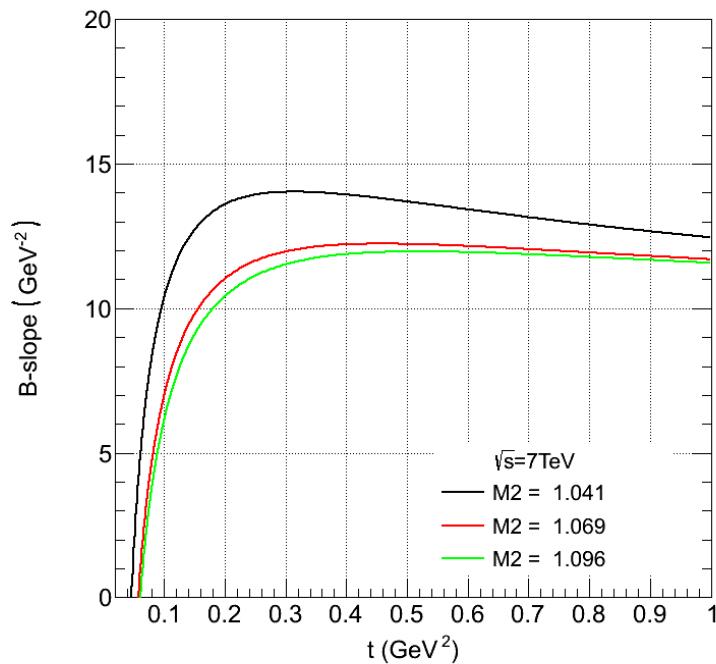
Approximation of background to reference points (t=-0.05)



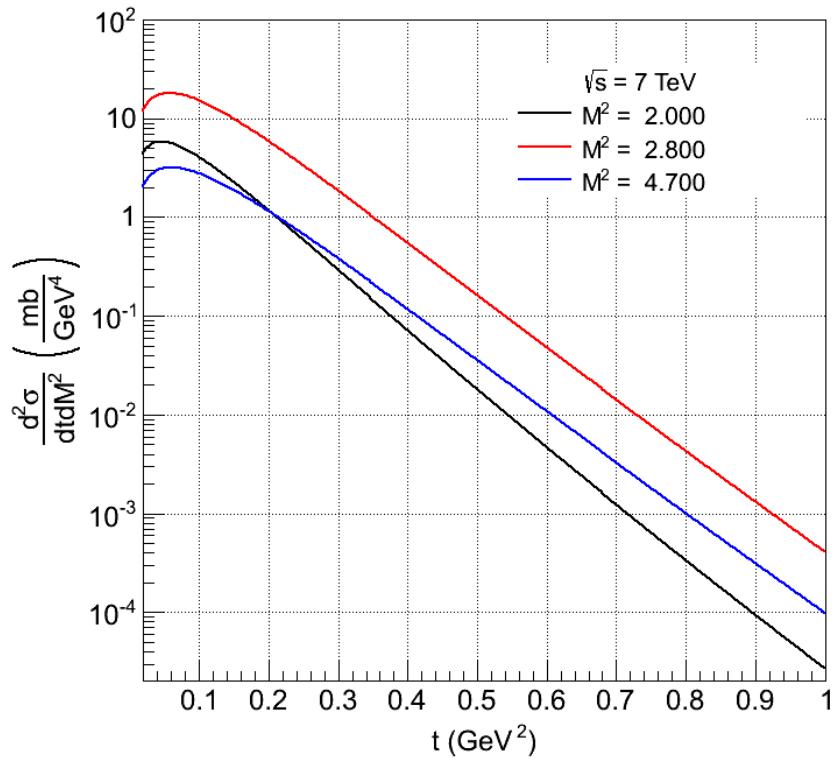
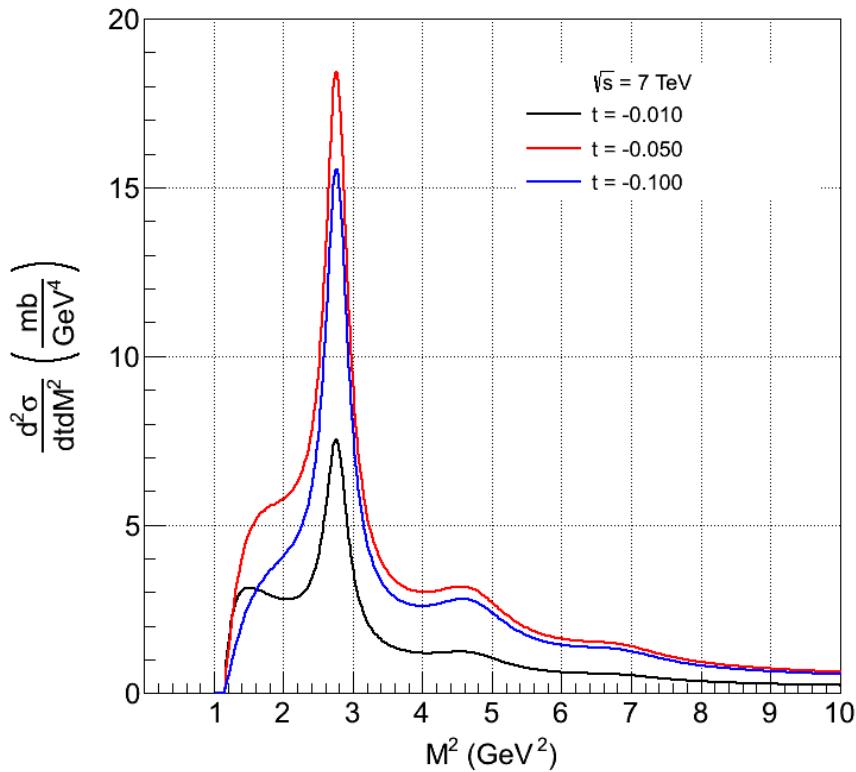
Approximation of background to reference points ($t=-0.5$)



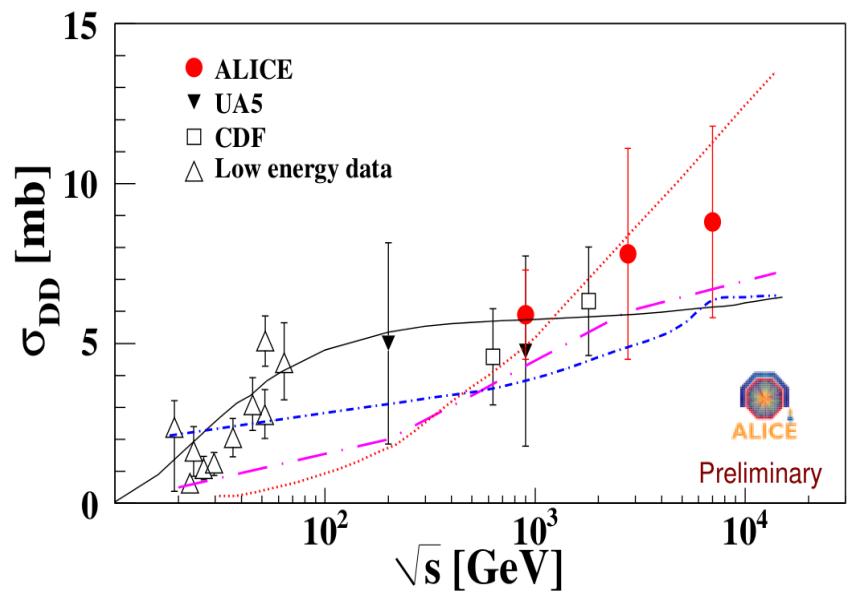
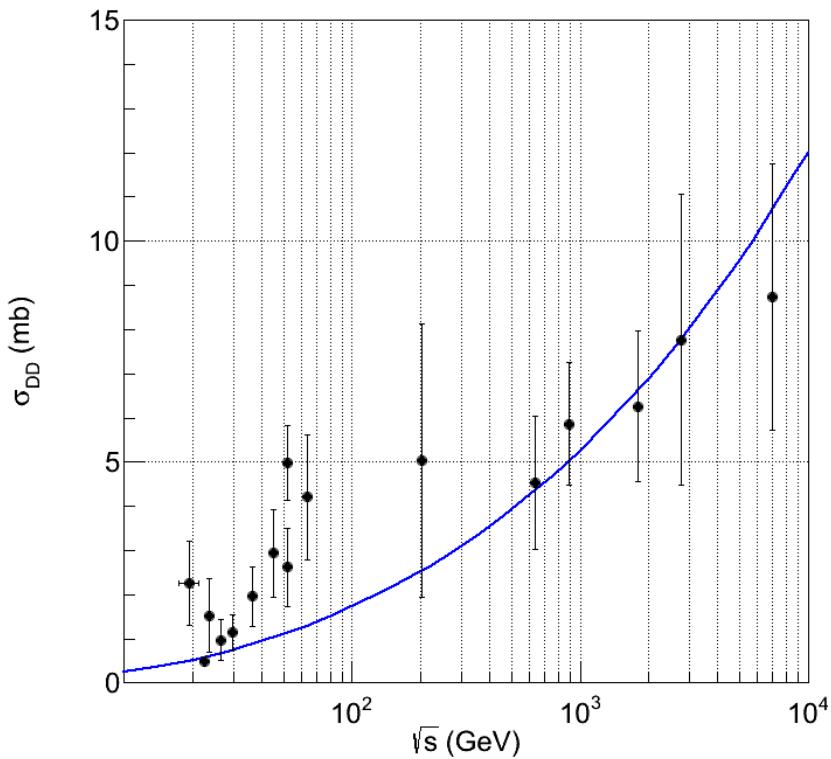
B-slopes for SD



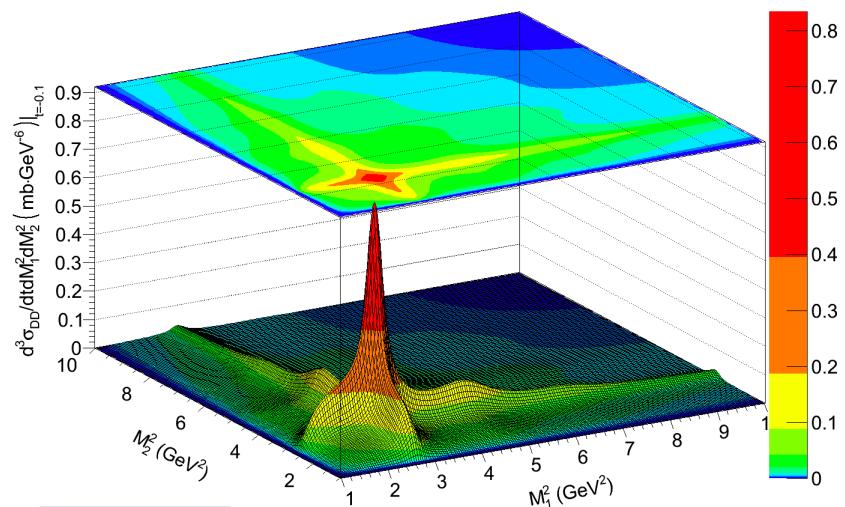
Double differential SD cross sections



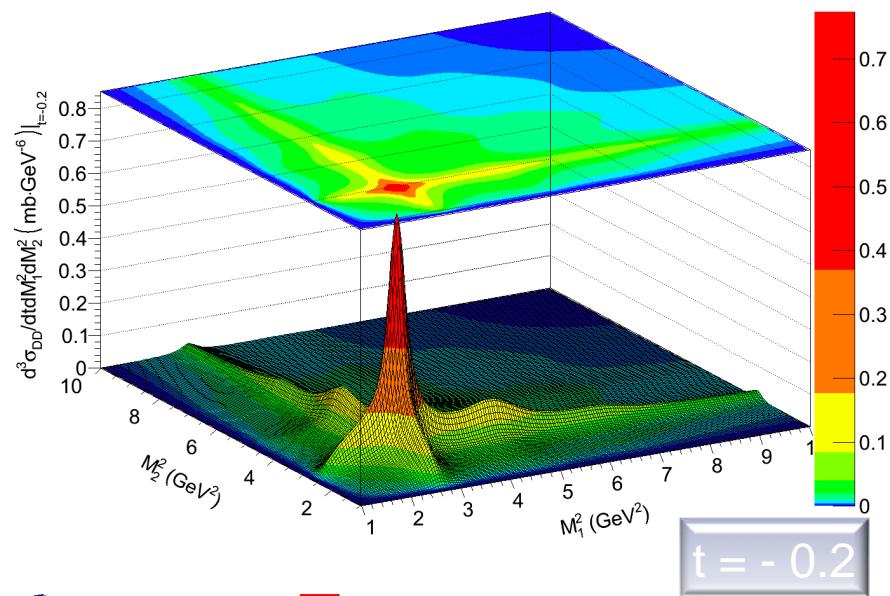
DDD cross sections vs. energy.



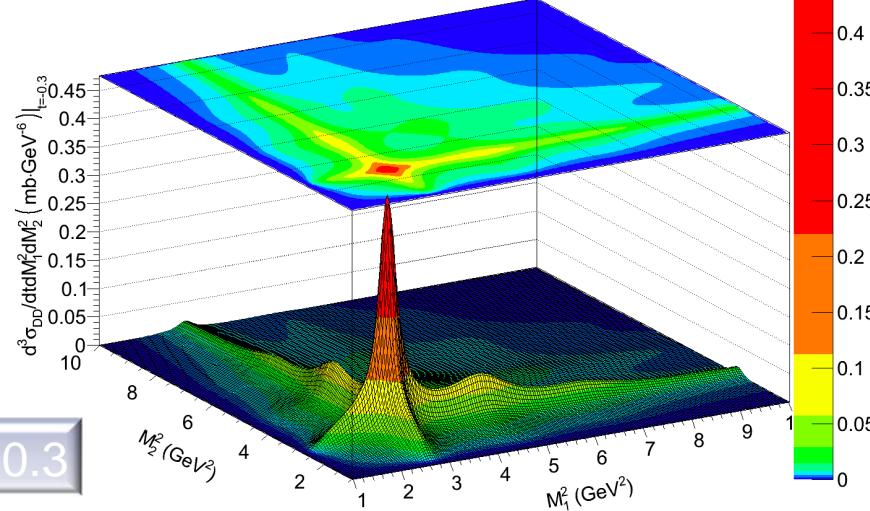
Triple differential DD cross sections



$t = -0.1$

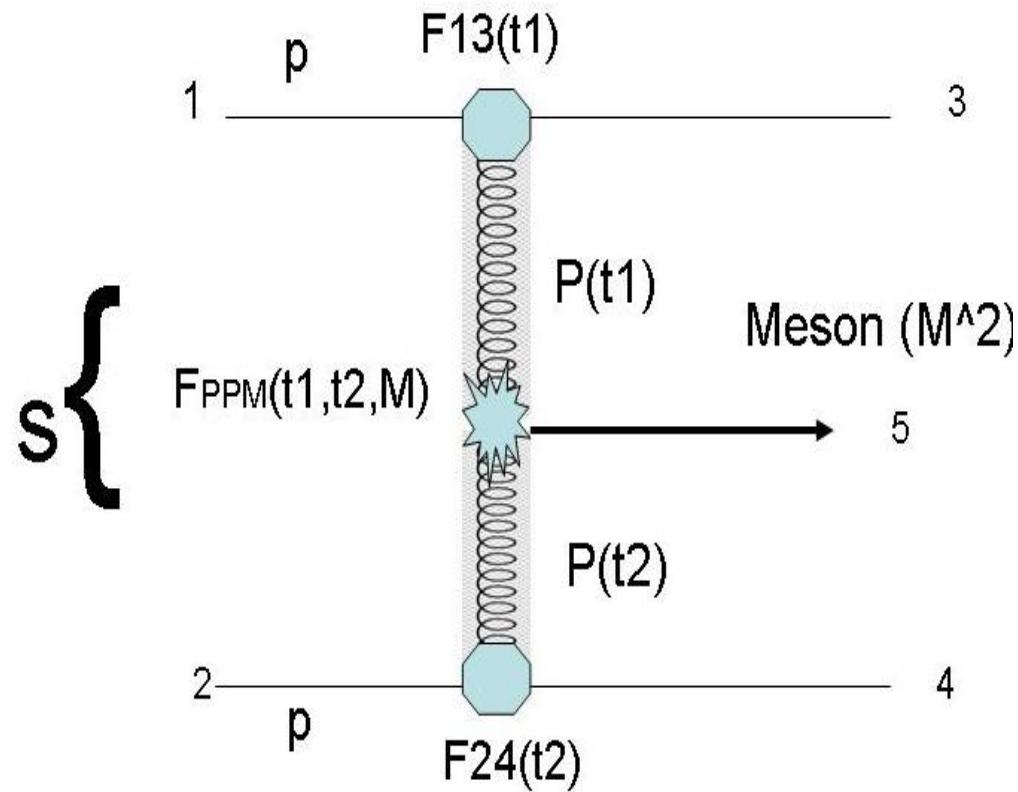


$t = -0.2$



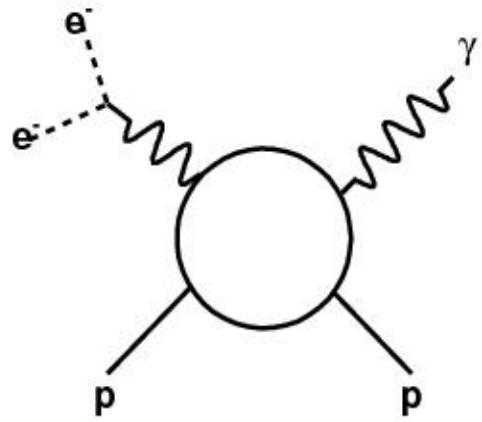
$t = -0.3$

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

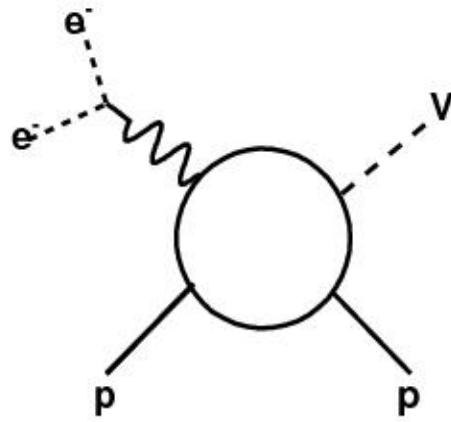


Open problems:

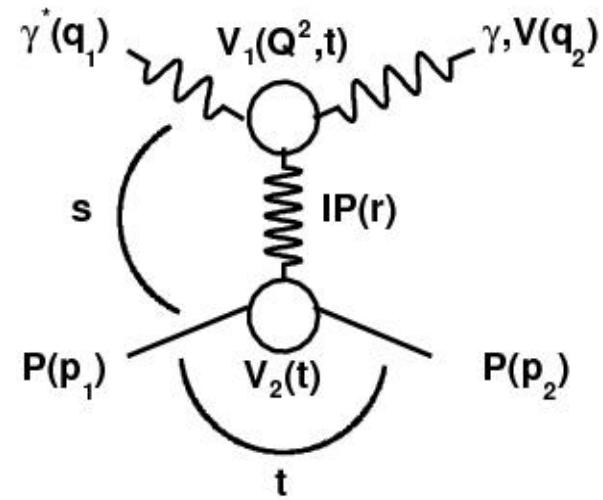
1. Interpolation in energy: from the Fermilab and ISR to the LHC;
(Inclusion of non-leading contributions);
3. Deviation from a simple Pomeron pole model and breakdown of Regge-factorization;
4. Experimental studies of the exclusive channels ($p+\pi, \dots$)
produced from the decay of resonances (N^* , Roper? \dots) in the nearly forward direction.
5. Turn down of the cross section towards $t=0$!?



(a)



(b)



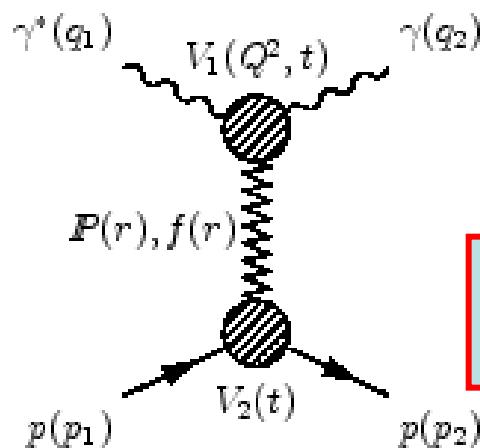
(c)

Diagrams of DVCS (a) and VMP (b) amplitudes and their Regge-factorized form (c)

Regge-type DVCS amplitude

M. Capua, S. F., R. Fiore, L. L. Jenkovszky, and F Paccanoni

Published in: Physics Letters B645 (Feb. 2007) 161-166



$$V_1 = e^{b\beta(z)}$$

$$V_2 = e^{b\alpha(t)}$$

A new variable is introduced: $z = t - Q^2$

Applications for the model can be:

- Study of various regimes of the scattering amplitude vs Q^2 , W , t (perturbative \rightarrow unperturbative QCD)
- Study of GPDs

DVCS amplitude: $A(s, t, Q^2)_{\gamma^* p \rightarrow \gamma p} = -A_0 V_1(t, Q^2) V_2(t) (-is/s_0)^{\alpha(t)}$

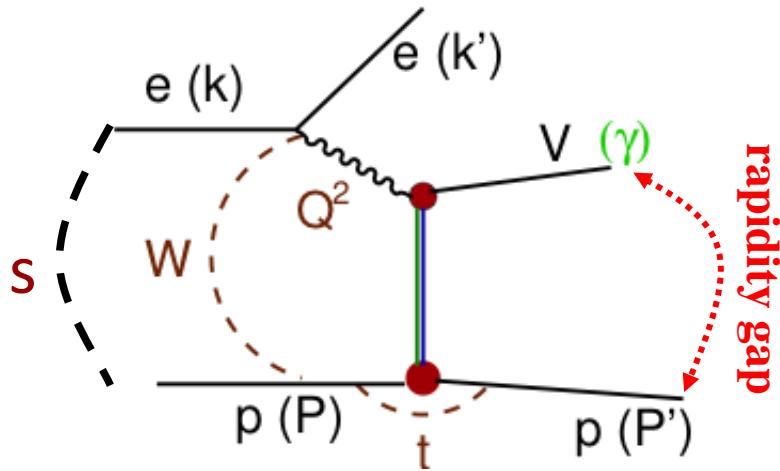
the t dependence at the vertex $pIPp$ is introduced by: $\alpha(t) = \alpha(0) - \alpha_1 \ln(1 - \alpha_2 t)$

the vertex $\gamma^*IP\gamma$ is introduced by the trajectory: $\beta(z) = \beta(0) - \beta_1 \ln(1 - \beta_2 z)$

indicating with: $L = \ln(-is/s_0)$ the DVCS amplitude can be written as:

$$A(s, t, Q^2)_{\gamma^* p \rightarrow \gamma p} = -A_0 e^{b\alpha(t)} e^{b\beta(z)} (-is/s_0)^{\alpha(t)} = -A_0 e^{(b+L)\alpha(t) + b\beta(z)}$$

Exclusive diffraction



Main kinematic variables

electron-proton centre-of-mass energy:

$$s = (k + p)^2 \approx 4E_e E_p$$

photon virtuality:

$$Q^2 = -q^2 = -(k - k')^2 \approx 4E_e E'_e \sin^2 \frac{\theta}{2}$$

photon-proton centre-of-mass energy:

$$W^2 = (q + p)^2, \text{ where } m_p < W < \sqrt{s}$$

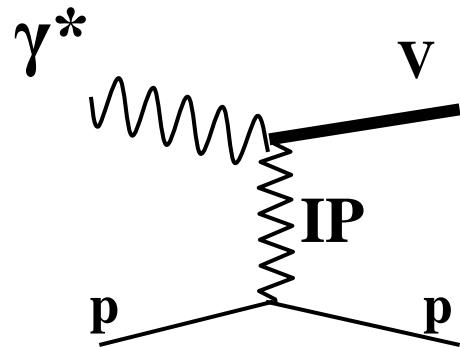
square 4-momentum at the p vertex:

$$t = (p' - p)^2$$

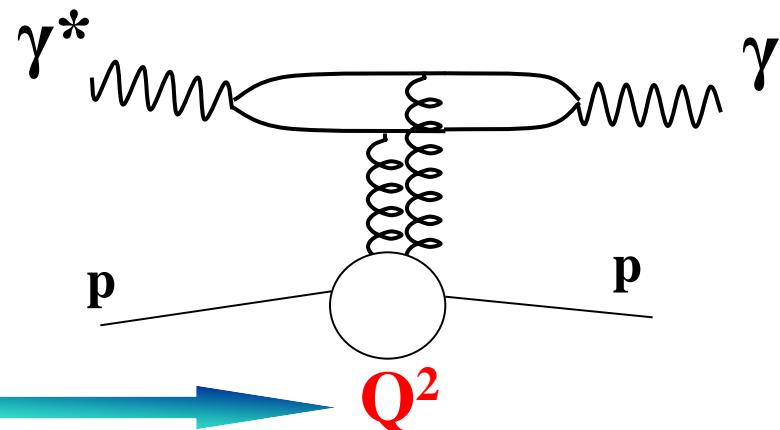
- Vector Mesons production in diffraction
- Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering

VM ($\rho, \omega, \phi, J/\psi, Y$)



DVCS (γ)

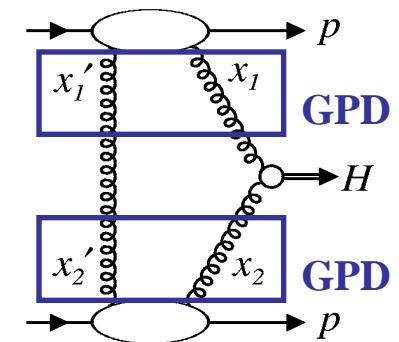


Scale: $Q^2 + M^2$

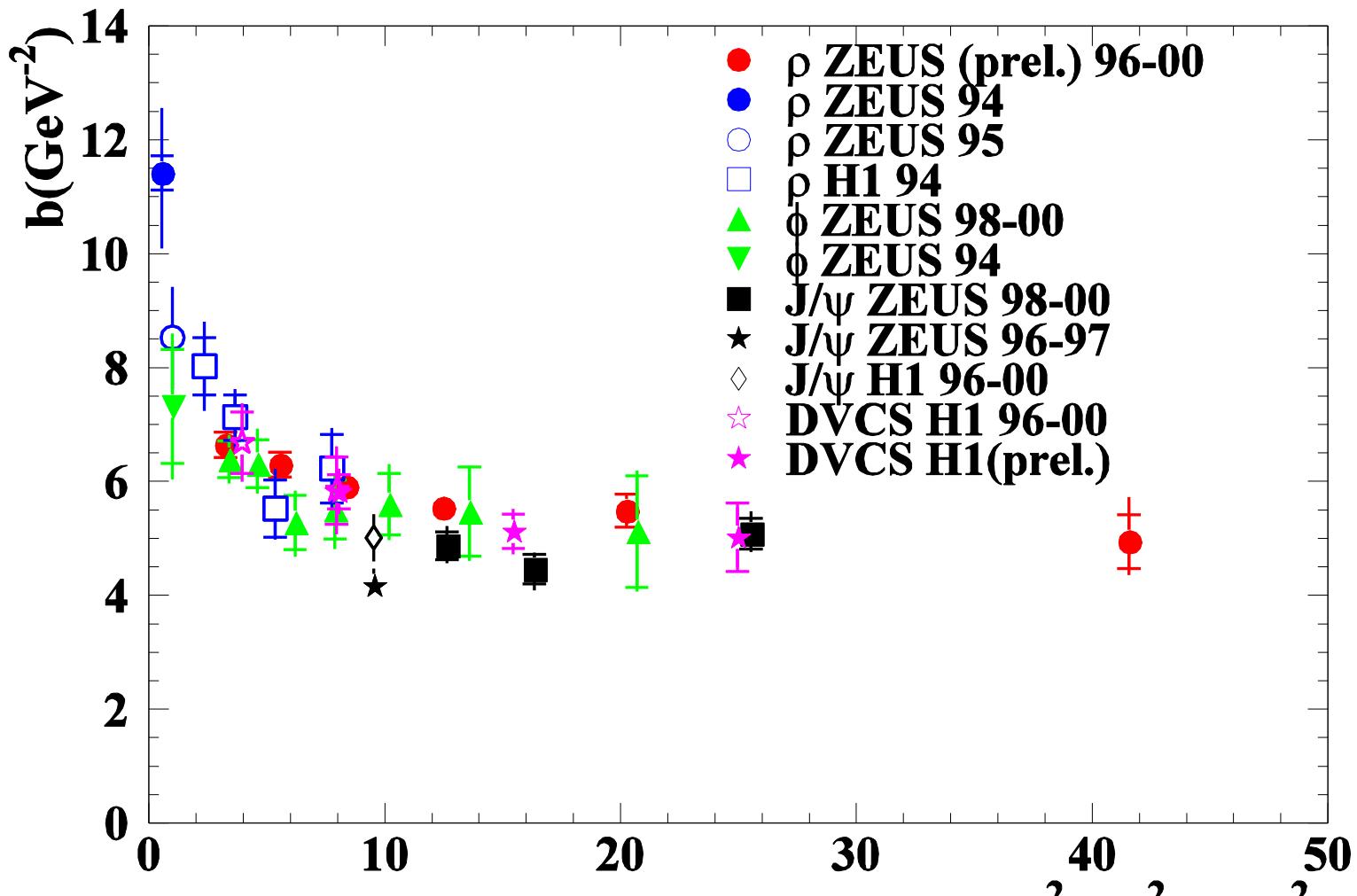


DVCS properties:

- Similar to VM production, but γ instead of VM in the final state
- No VM wave-function involved
- Important to determine Generalized Parton Distributions
sensible to the correlations in the proton
- GPDs are an ingredient for estimating diffractive cross sections
at the LHC



$b(Q^2+M^2) - VM$



Magic formula : $\langle r^2 \rangle = b \bullet \hbar c$

$$r_{glue} = 0.56 \text{ fm}$$

$$r_{proton} = 0.8 \text{ fm}$$

Basic ideas

Reggeometry=Regge+geometry (play on words, or pun)

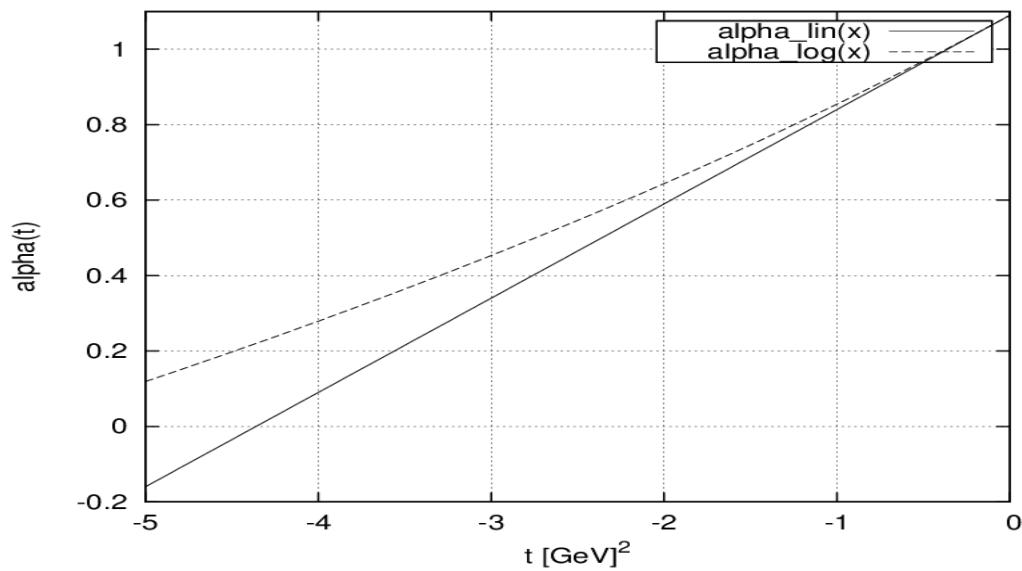
How to combine s, t and Q^2 dependencies in a binary reaction?

1. The t and \tilde{Q}^2 dependences are combined by "geometry":
A rough estimates (to be fine-tuned!) yields

$$\beta(t, M, Q^2) = \exp\left[4\left(\frac{1}{M_V^2 + Q^2} + \frac{1}{2m_N^2}\right)t\right].$$

2. The s and t behavior are related by the Regge-pole model;
3. There is only one, universal, Pomeron, but it has two components - soft and hard, their relative weights depending on \tilde{Q}^2 .

alpha-lin=1.09+0.25 t and alpha-log=1.09-2*ln(1-0.125 t) vs t



$$A(s,t,Q^2,{M_v}^2)=\frac{\tilde{A}_s}{\left(1+\frac{\widetilde{Q}^2}{\widetilde{Q}_s^2}\right)^{n_s}}e^{-i\frac{\pi}{2}\alpha_s(t)}\left(\frac{s}{s_{0s}}\right)^{\alpha_s(t)}e^{2\left(\frac{a_s}{\widetilde{Q}^2}+\frac{b_s}{2m_p^2}\right)t}\\+\frac{\tilde{A}_h\left(\frac{\widetilde{Q}^2}{\widetilde{Q}_h^2}\right)}{\left(1+\frac{\widetilde{Q}^2}{\widetilde{Q}_h^2}\right)^{n_h+1}}e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_{0h}}\right)^{\alpha_h(t)}e^{2\left(\frac{a_h}{\widetilde{Q}^2}+\frac{b_h}{2m_p^2}\right)t}$$

	A_s	\tilde{Q}_s^2	n_s	α_{0s}	α'_s	a_s	b_s	χ^2
pp	5.9 ± 5.7	***	0.00	1.05 ± 0.14	0.276 ± 0.474	2.877 ± 2.837	0.00	1.52
ρ^0	59.5 ± 29.3	1.33	1.35 ± 0.05	1.15 ± 0.06	0.15	-0.22	1.69	6.56
ϕ	31.8 ± 35.3	1.30	1.32 ± 0.10	1.14 ± 0.12	0.15	-0.85 ± 1.60	2.51 ± 2.67	3.81
J/ψ	34.2 ± 19.0	1.4 ± 0.7	1.39 ± 0.13	1.21 ± 0.05	0.09	1.90	1.03	4.50
$\Upsilon(1S)$	37 ± 101	0.9 ± 1.7	1.53 ± 0.55	1.29 ± 0.26	0.01 ± 0.6	1.90	1.03	1.28
$DVCS$	9.7 ± 9.0	0.45 ± 0.5	0.94 ± 0.24	1.19 ± 0.09	-0.007 ± 0.3	1.94 ± 4.65	1.74 ± 2.28	1.75

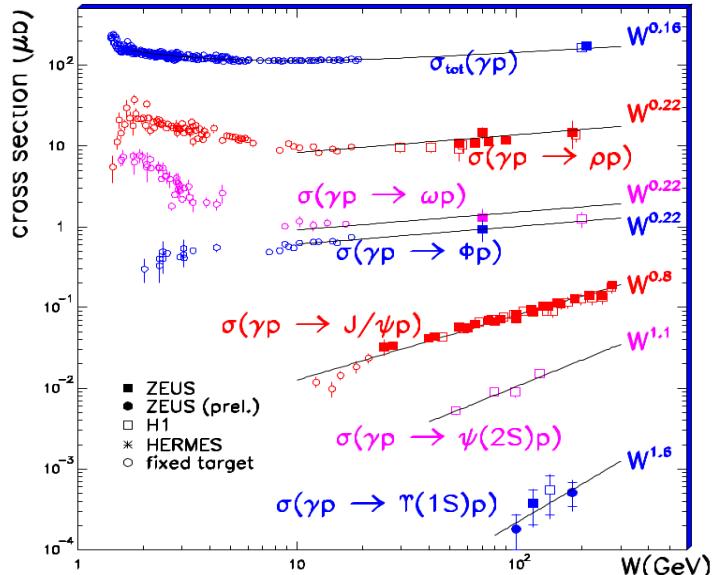
Table 1. Fitting results

	δ	α_{0s}	$\alpha_{0s}(fit)$	α'_s
pp		1.08(DL)	1.05 ± 0.14	0.276 ± 0.474
ρ^0	0.22	1.055	1.15 ± 0.06	0.15
ϕ	0.22	1.055	1.14 ± 0.12	0.15
J/ψ	0.8	1.2	1.21 ± 0.05	0.09
$\Upsilon(1S)$	1.6	1.4	1.29 ± 0.26	0.01 ± 0.6
$DVCS$	0.54	1.135	1.19 ± 0.09	-0.007 ± 0.3

Table 2. $\alpha(0)$, α'

Parameter s_{0s} for simplicity is also fixed $s_{0s} = 1$.

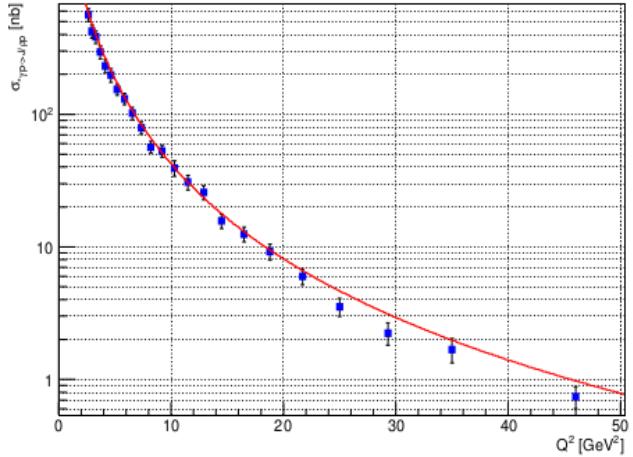
* Parameters that doesn't have errors in table[1] were fixed at fitting stage.



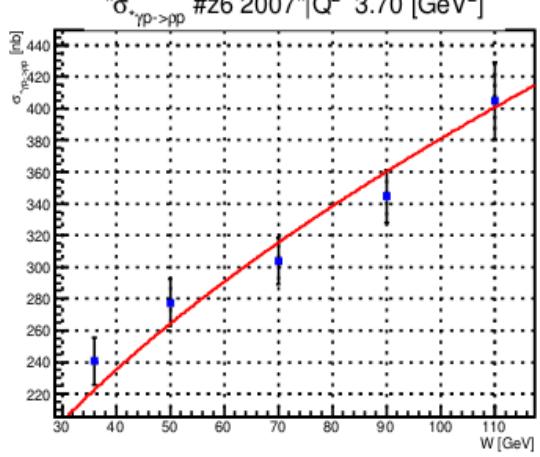
(a) The W dependence of the cross section for exclusive VM photoproduction together with the total photoproduction cross section. Lines are the result of a W^δ fit to the data at high W -energy values.

rho0(1)

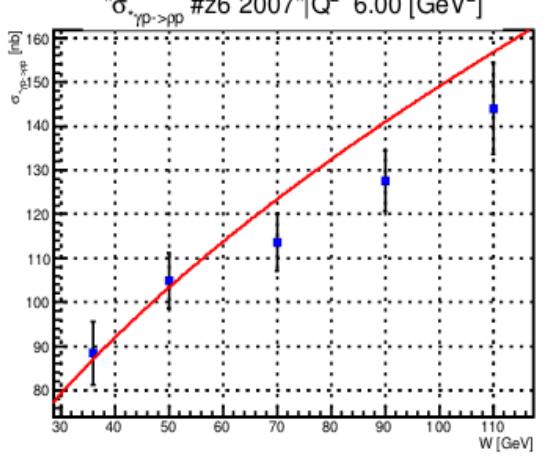
" $\sigma_{\gamma p \rightarrow pp}$ #h3 2009" | $W = 75.00$ [GeV]



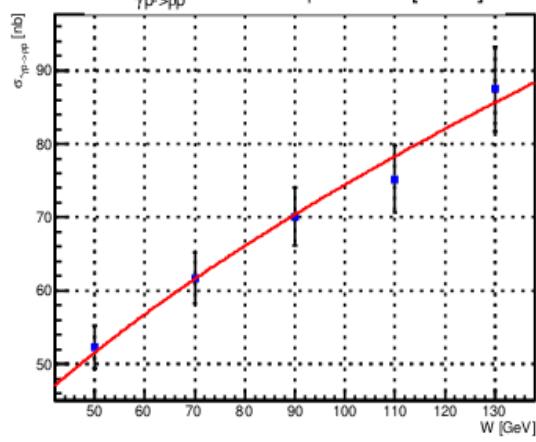
" $\sigma_{\gamma p \rightarrow pp}$ #z6 2007" | $Q^2 = 3.70$ [GeV^2]



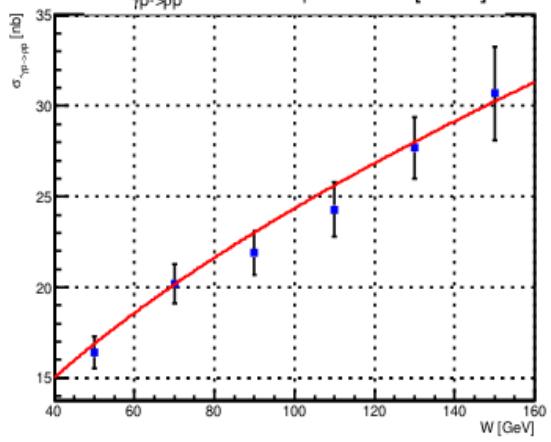
" $\sigma_{\gamma p \rightarrow pp}$ #z6 2007" | $Q^2 = 6.00$ [GeV^2]



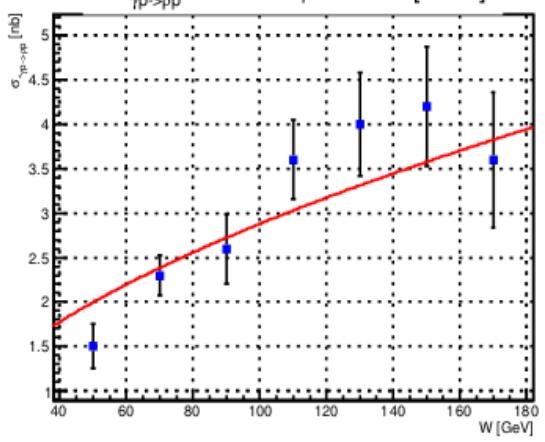
" $\sigma_{\gamma p \rightarrow pp}$ #z6 2007" | $Q^2 = 8.30$ [GeV^2]



" $\sigma_{\gamma p \rightarrow pp}$ #z6 2007" | $Q^2 = 13.50$ [GeV^2]

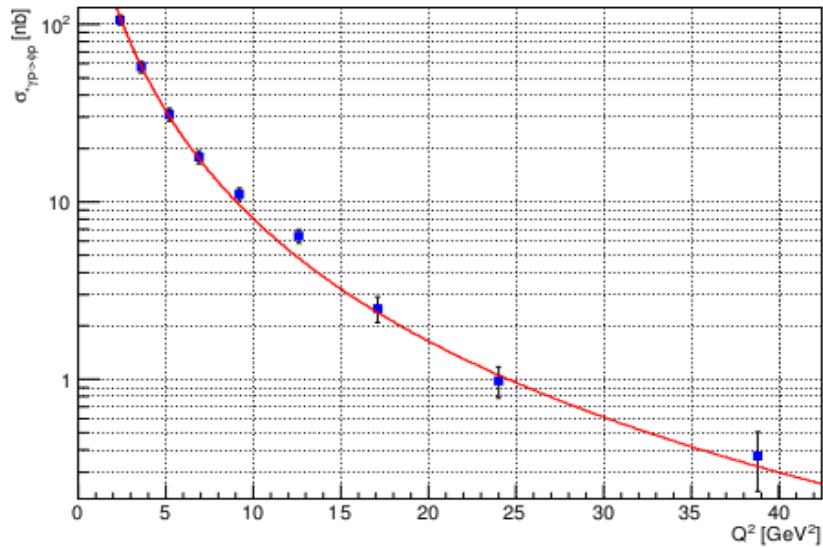


" $\sigma_{\gamma p \rightarrow pp}$ #z6 2007" | $Q^2 = 32.00$ [GeV^2]

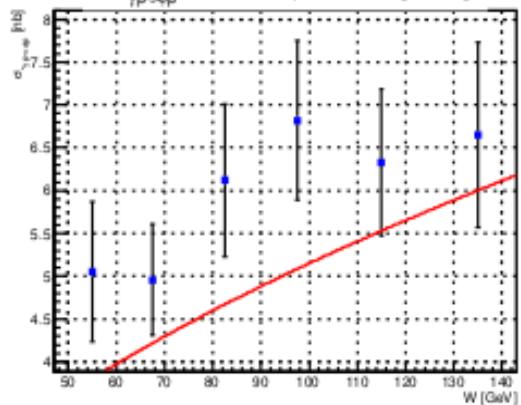


phi (1)

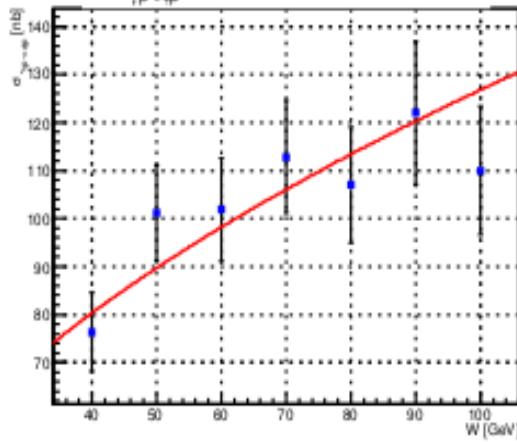
" $\sigma_{\gamma p \rightarrow \phi p}$ #z8 2005" | W 75.00 [GeV]



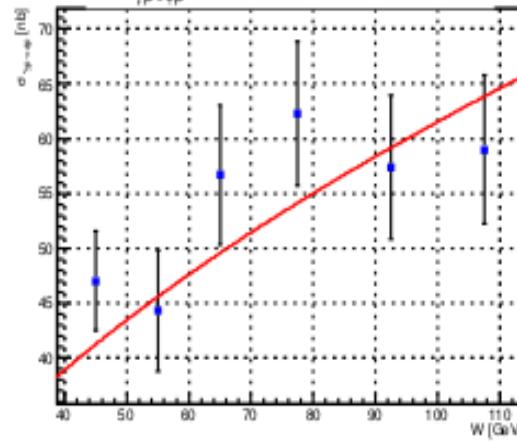
" $\sigma_{\gamma p \rightarrow \phi p}$ #z8 2005" | Q^2 13.00 [GeV 2]



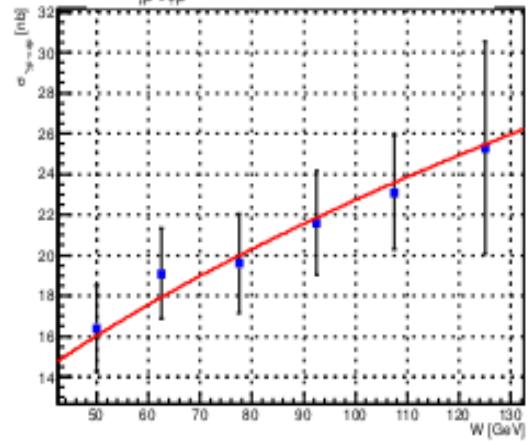
" $\sigma_{\gamma p \rightarrow \phi p}$ #z8 2005" | Q^2 2.40 [GeV 2]



" $\sigma_{\gamma p \rightarrow \phi p}$ #z8 2005" | Q^2 3.80 [GeV 2]

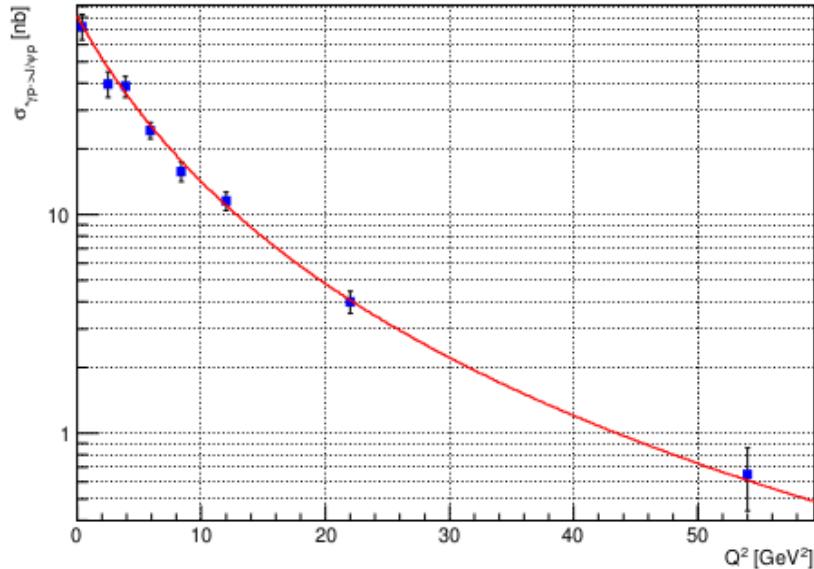


" $\sigma_{\gamma p \rightarrow \phi p}$ #z8 2005" | Q^2 6.50 [GeV 2]

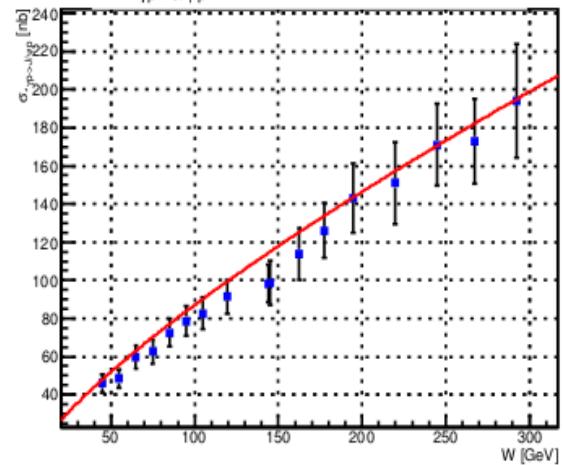


J/psi (1)

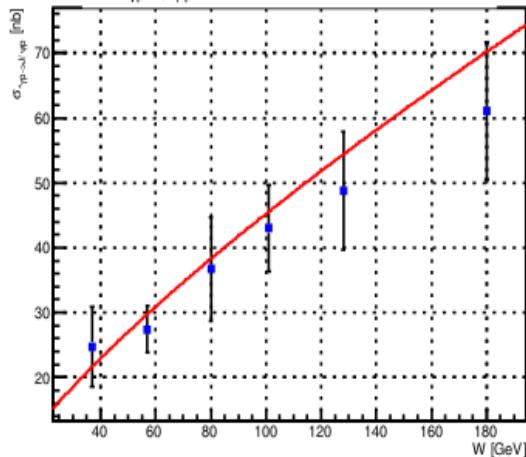
" $\sigma_{\gamma p \rightarrow J/\psi p}$ #z9 2004" | $W = 90.00$ [GeV]



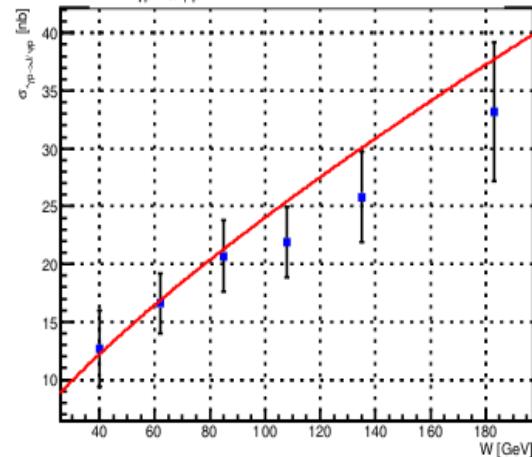
" $\sigma_{\gamma p \rightarrow J/\psi p}$ #h6 2005" | $Q^2 = 0.05$ [GeV 2]



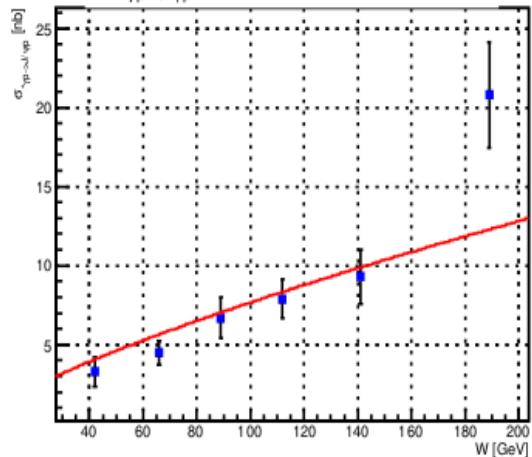
" $\sigma_{\gamma p \rightarrow J/\psi p}$ #z9 2004" | $Q^2 = 3.10$ [GeV 2]



" $\sigma_{\gamma p \rightarrow J/\psi p}$ #z9 2004" | $Q^2 = 6.80$ [GeV 2]

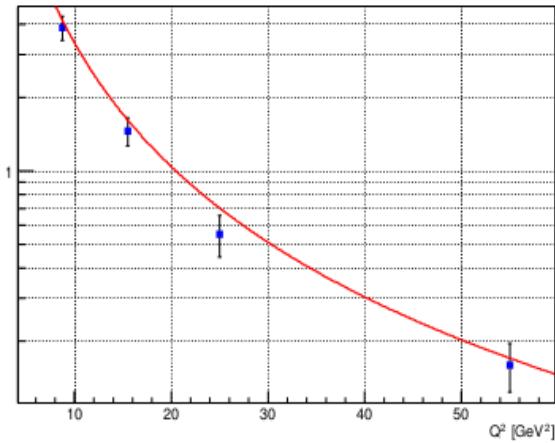


" $\sigma_{\gamma p \rightarrow J/\psi p}$ #z9 2004" | $Q^2 = 16.00$ [GeV 2]

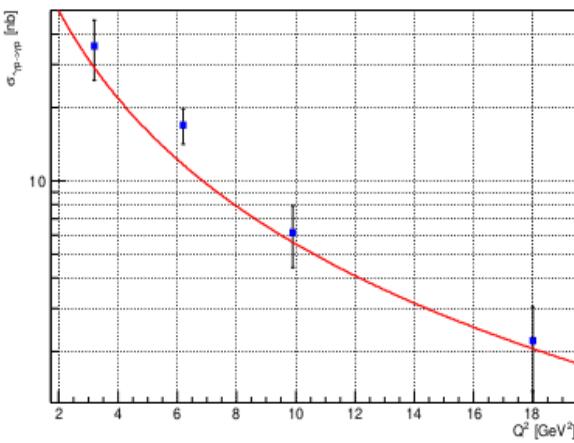


DVCS (1)

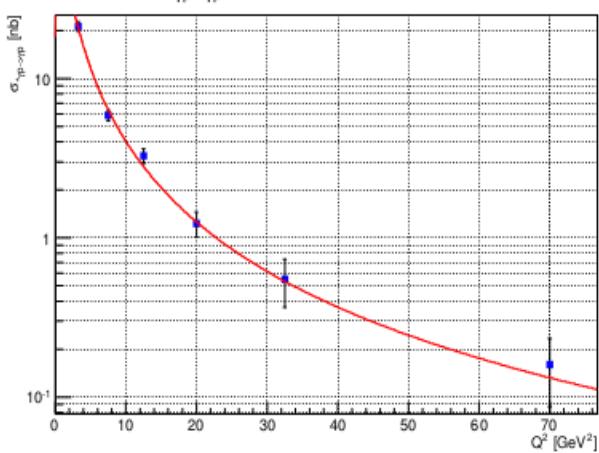
" $\sigma_{\gamma p \rightarrow \gamma p}$ #h2 2009" | $W = 82.00$ [GeV]



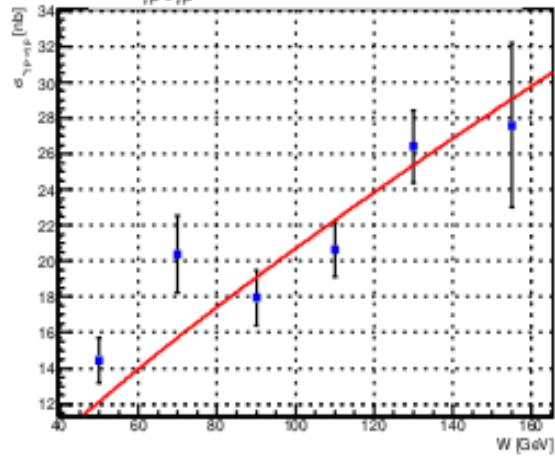
" $\sigma_{\gamma p \rightarrow \gamma p}$ #z5 2008" | $W = 155.00$ [GeV]



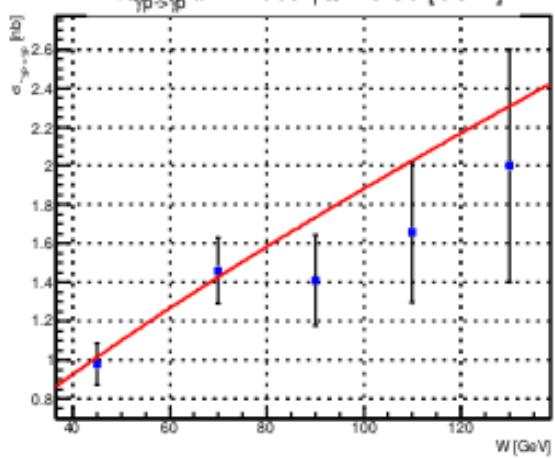
" $\sigma_{\gamma p \rightarrow \gamma p}$ #z5 2008" | $W = 104.00$ [GeV]



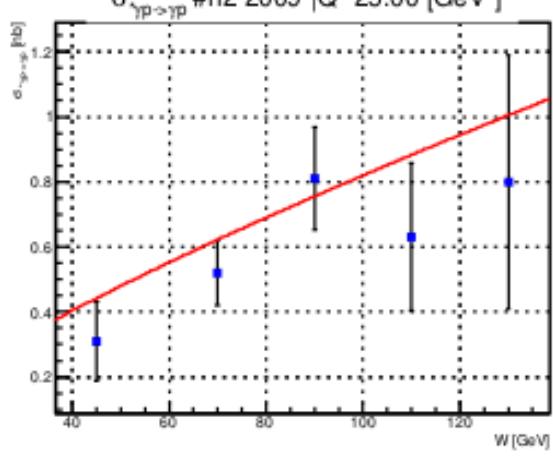
" $\sigma_{\gamma p \rightarrow \gamma p}$ #z5 2008" | $Q^2 = 3.20$ [GeV^2]

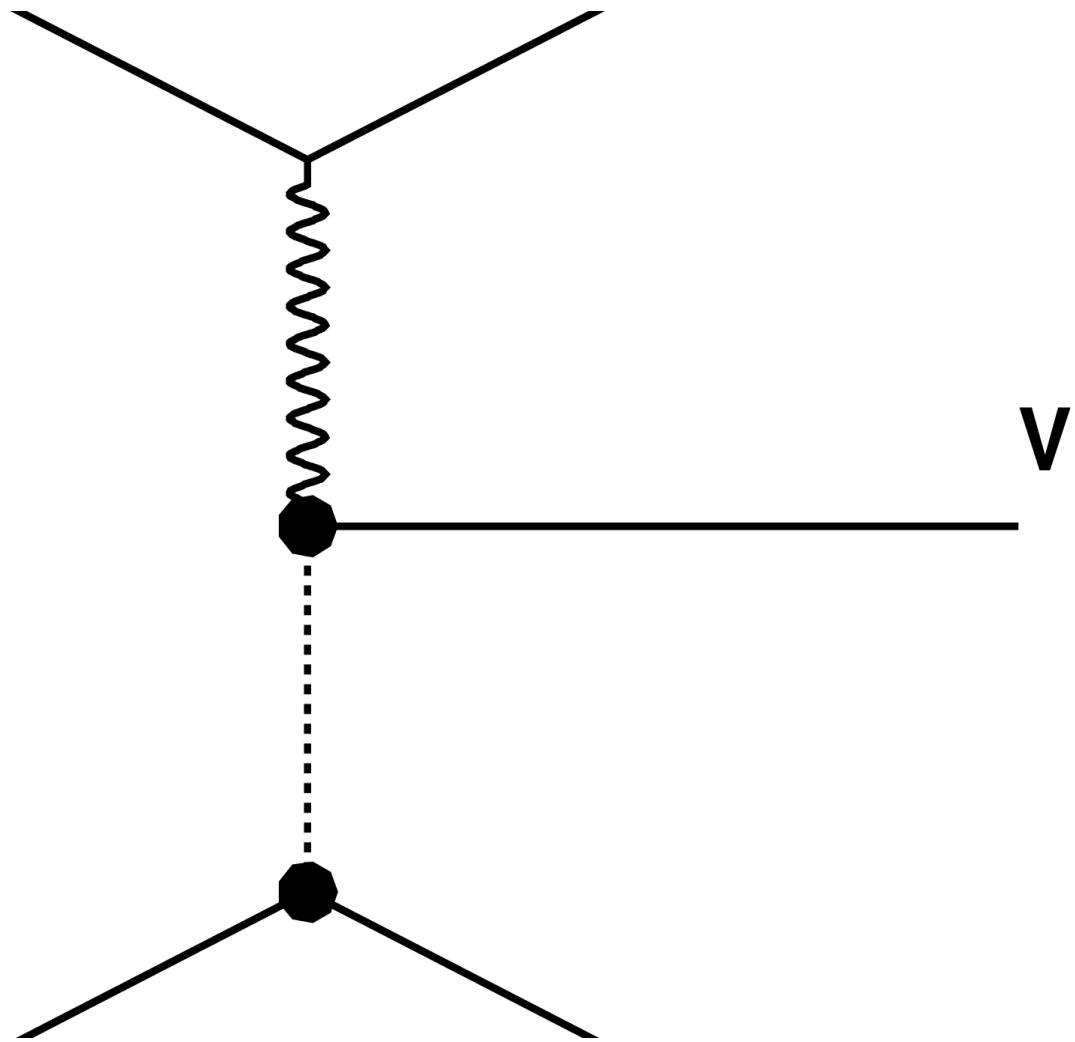


" $\sigma_{\gamma p \rightarrow \gamma p}$ #h2 2009" | $Q^2 = 15.50$ [GeV^2]



" $\sigma_{\gamma p \rightarrow \gamma p}$ #h2 2009" | $Q^2 = 25.00$ [GeV^2]





V

The differential cross section reads:

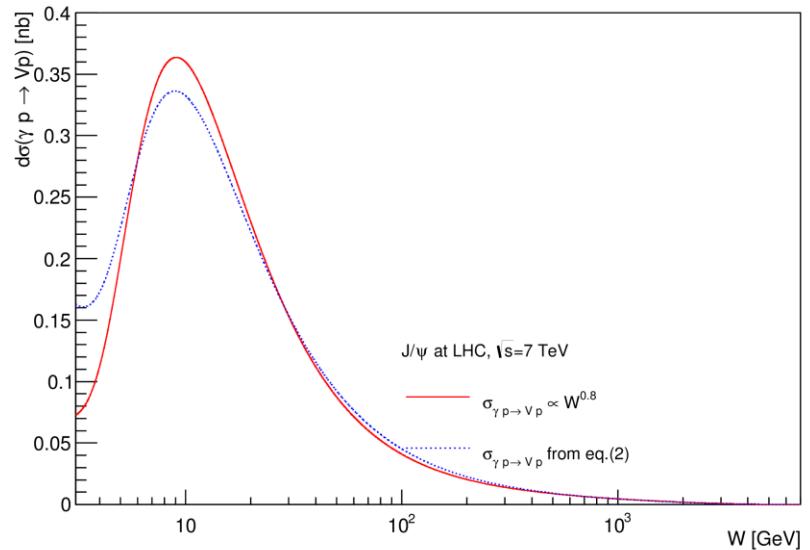
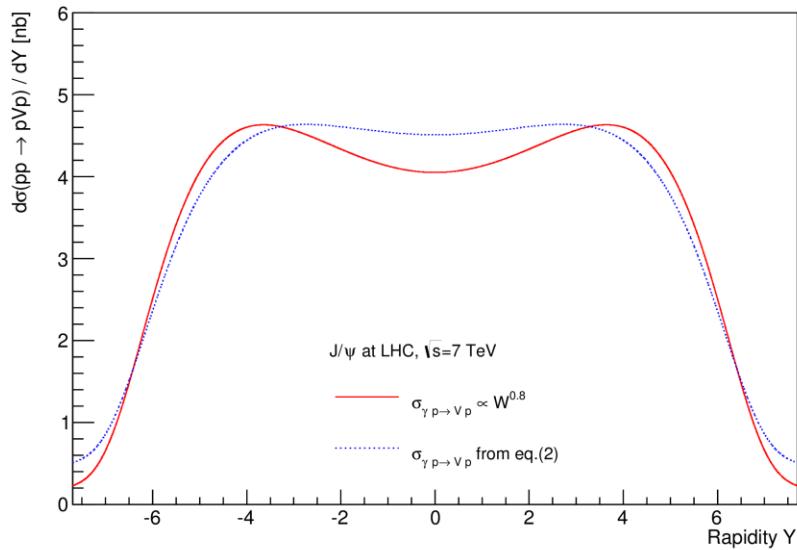
$$\frac{d\sigma(h_1 + h_2 \rightarrow h_1 + V + h_2)}{dY}$$

=

$$\omega_+ \frac{dN_{\gamma/h_1}(\omega_+)}{d\omega} \sigma_{\gamma h_2 \rightarrow V h_2}(\omega_+) + \omega_- \frac{dN_{\gamma/h_2}(\omega_-)}{d\omega} \sigma_{\gamma h_1 \rightarrow V h_1}(\omega_-),$$

where $\frac{dN_{\gamma/h}(\omega)}{d\omega}$ is the "equivalent" photon flux $\frac{dN_{\gamma/h}(\omega)}{d\omega} = \frac{\alpha_{em}}{2\pi\omega} [1 + (1 - \frac{2\omega}{\sqrt{s}})^2] (\ln \Omega - \frac{11}{6} + \frac{3}{\Omega} - \frac{3}{2\Omega^2} + \frac{1}{3\Omega^3})$ and $\sigma_{\gamma p \rightarrow V p}(\omega)$ is the total cross section of the vector meson photoproduction subprocess. ω is the photon energy, $\omega = W_{\gamma p}^2 / 2\sqrt{s}_{pp}$ with $\omega_{min} = M_V^2 / (4\gamma_L m_p)$, where $\gamma_L = \sqrt{s}/(2m_p)$ is the Lorentz factor, e.g., for pp at the LHC for $\sqrt{s} = 7$ TeV, $\gamma_L = 3731$.

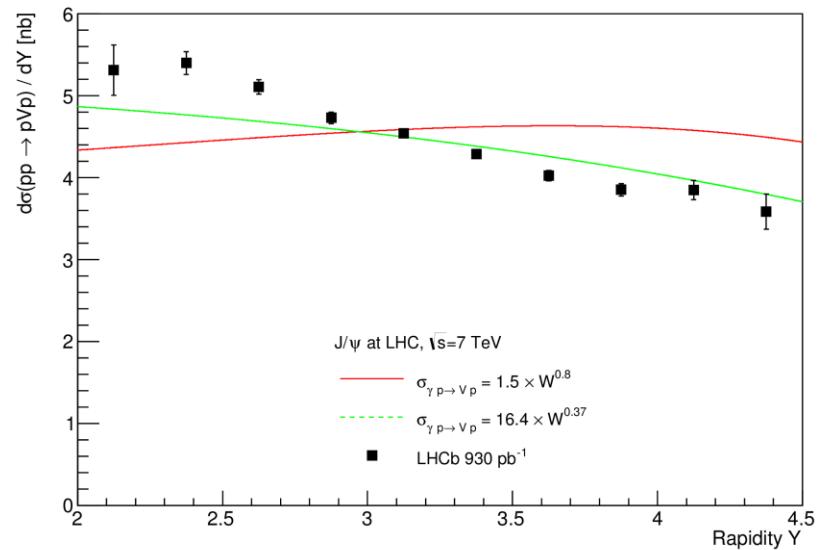
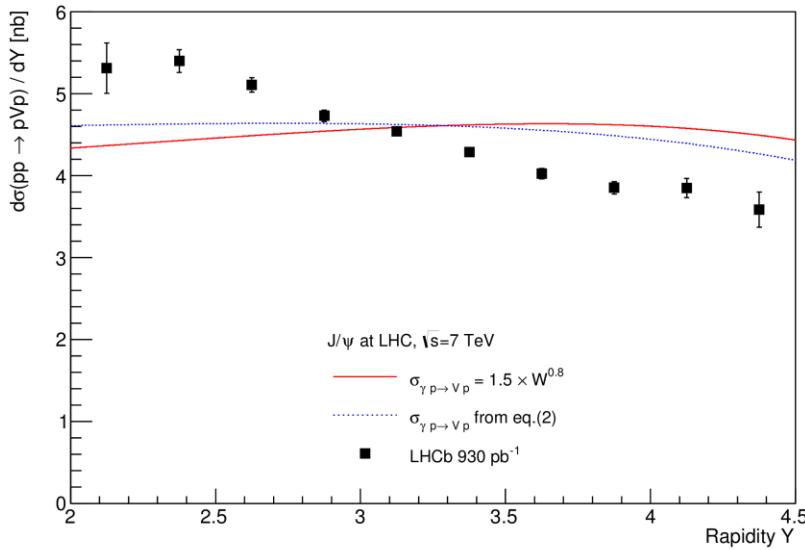
Power law vs geometric model at LHC



Generally similar behaviour

Power law is somewhat steeper in $W \rightarrow$ a more distinct bell-like structure in y

Adding LHCb rapidity cross section

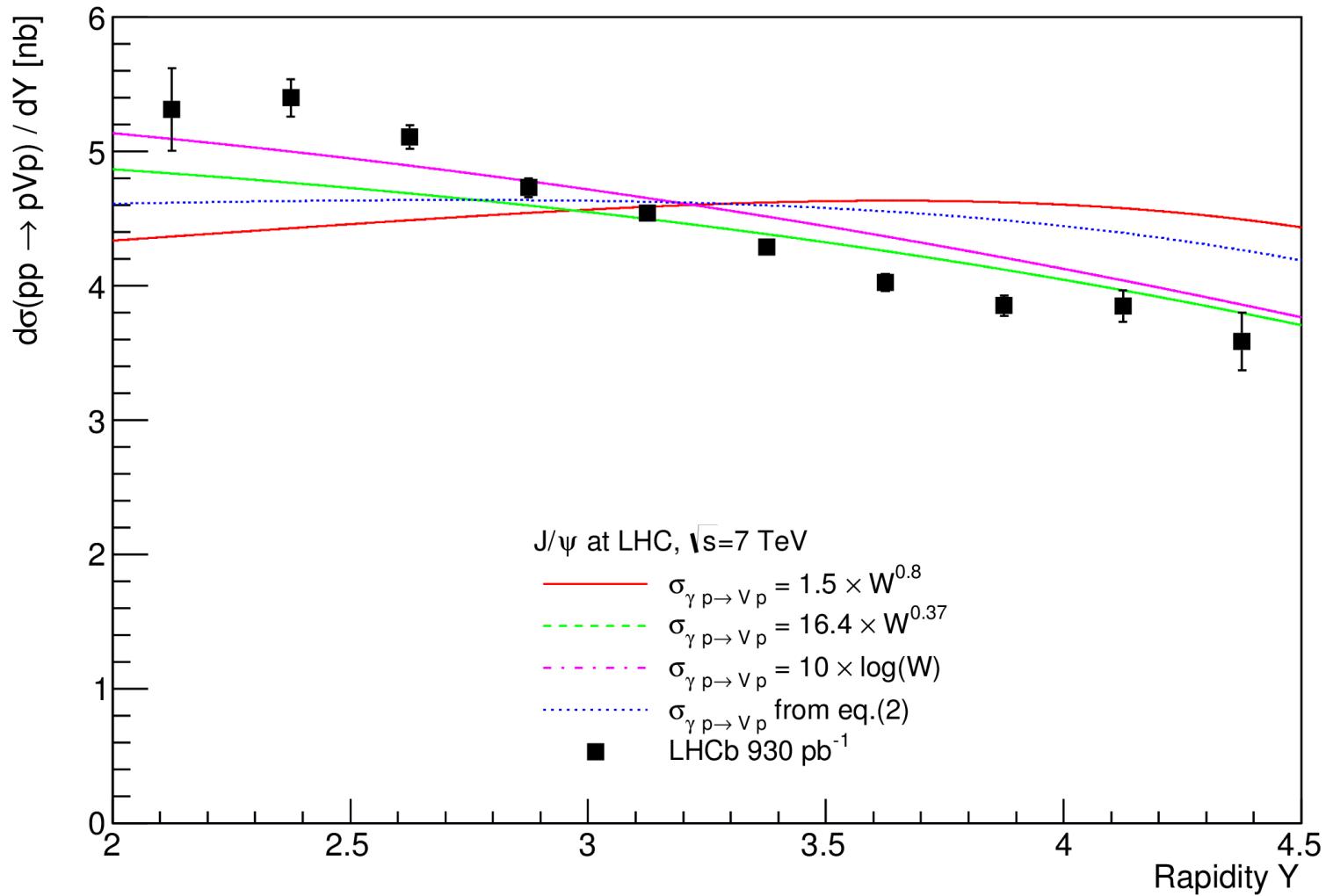


Both power law and geometric model are much flatter than the data

By fitting the power (and normalization) a much better description of data can be obtained (green curve)
However, power tends to be very small ($\delta=0.37$) which contradicts HERA (page 4)

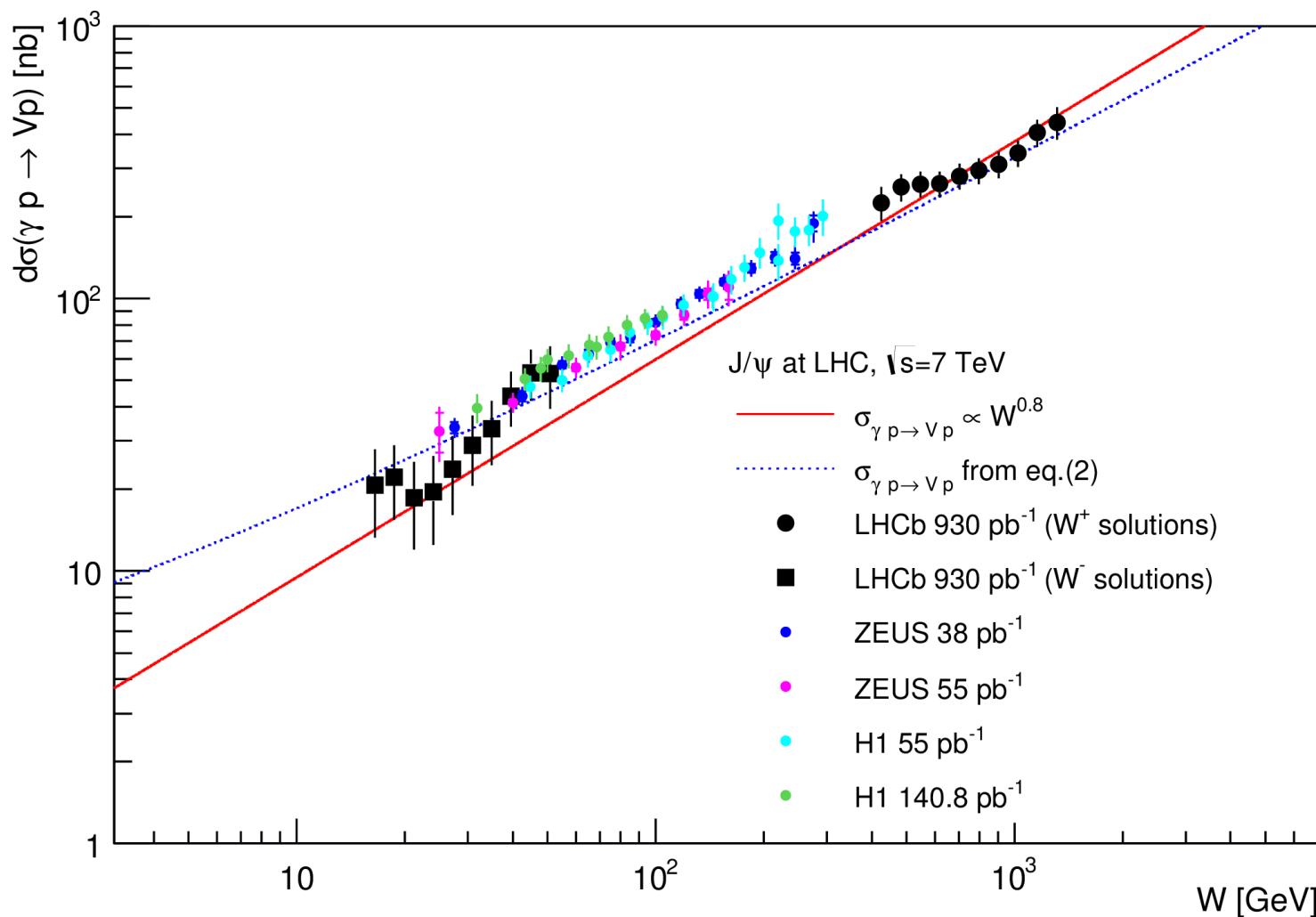
Grand comparison

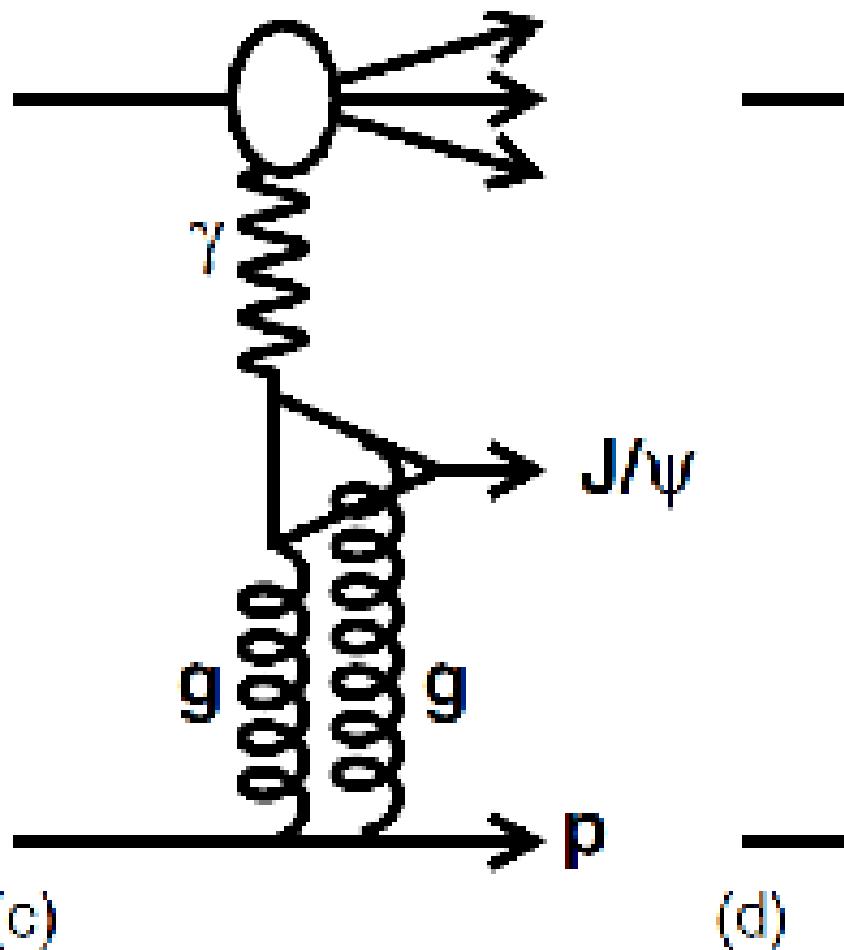
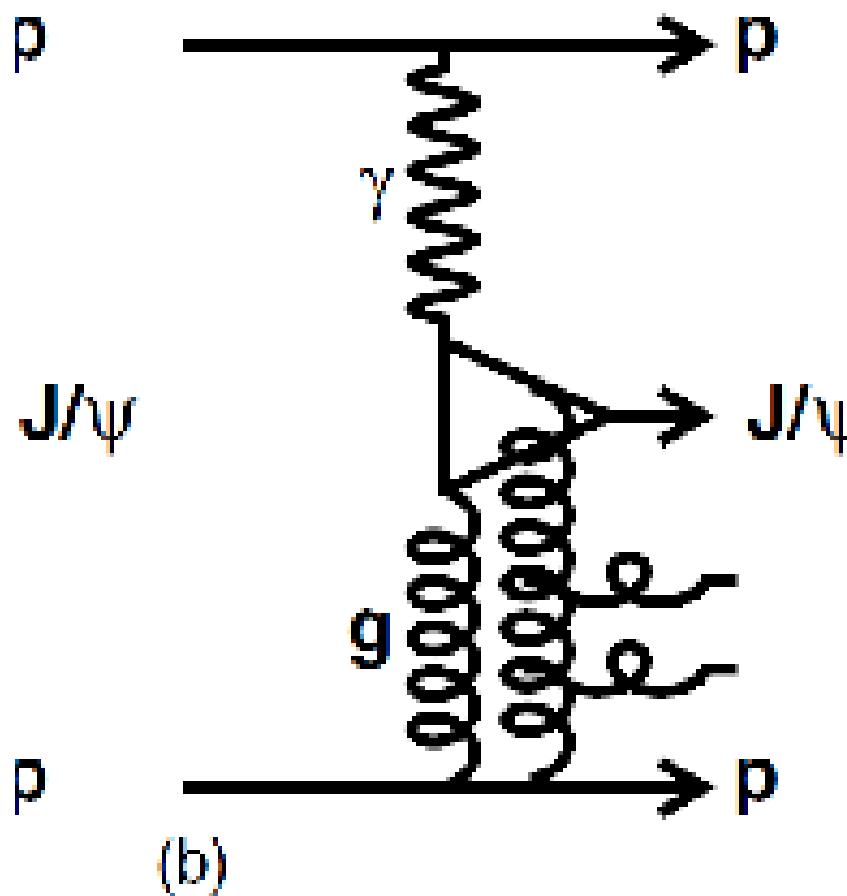
Here all available curves are summarized, also the result using the logarithmic growth of the photo-



Logarithm describes data best

γp cross section





Спасибо !