Diffraction 2012, Las Canarias

Reggeometry of lepton- and hadron-induced reactions

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Goals and objectives

1 Reactions: DVCS: $\gamma^* p \to \gamma p$ (NB: elastic Compton, $\gamma p \to \gamma p$, is less known!), exclusive (diffractive) VMP $\gamma^* p \to Vp$ (at HERA) and elastic (diffractive) hadron scattering (*e.g.* $pp \to pp$ at ISR-LHC).

2. Measurables (observables): differential x-tion $d\sigma/dt$ and integrated in t : $\sigma_{el} = \int_{-t_{min}}^{-t_{max}} d\sigma/dt$, slope $B(s,t,Q^2)$, total x-tion σ_t (for elastic scattering only!).

3. Fitting strategy:

a) in DVCS and VMP: $d\sigma/dt$, vs. σ_{el} - which one is the "primitive" ? Coompatibility?!

b) weighting the data point? (the number of data points in pp is by an order of magnitude larger and better than in lepton-induced reactions!

c) simultaneous (multidimensional) vs. "sequent" (sequently in each variable and/or reaction)?

d) experientally measured bins and "symmetrization" (in DVCS and VMP).

e) the "soft" and "hard" components.

Regge-type DVCS amplitude

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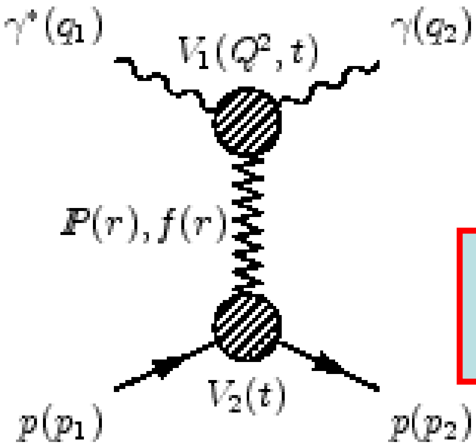


$$V_1 = e^{b\beta(z)}$$

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

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

Applications for the model can be:

- **Study of various regimes of the scattering amplitude vs *Q2, W, t* (perturbative –> unperturbative QCD)**
- **Study of GPD_s**

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

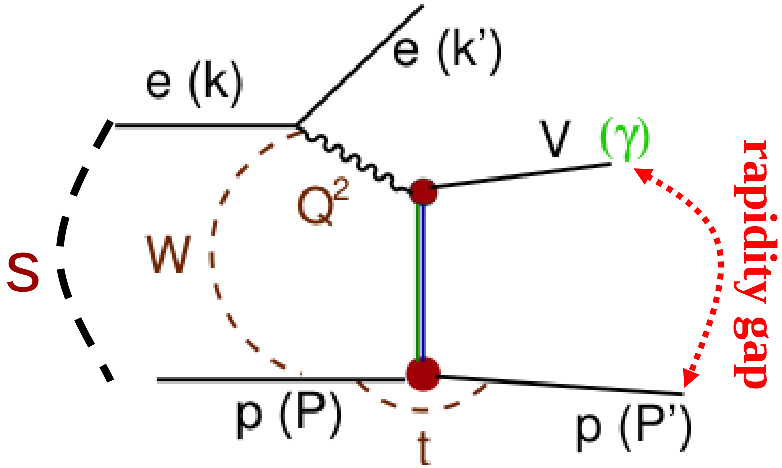
the *t* dependence at the vertex *pIPp* is introduced by: $$\alpha(t) = \alpha(0) - \alpha_1 \ln\left(1-\alpha_2 t\right)$$

the vertex *γ*IPγ* is introduced by the trajectory: $$\beta(z) = \beta(0) - \beta_1 \ln\left(1-\beta_2 z\right)$$

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

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

Exclusive diffraction



Main kinematic variables

electron-proton centre-of-mass energy:

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

photon virtuality:

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

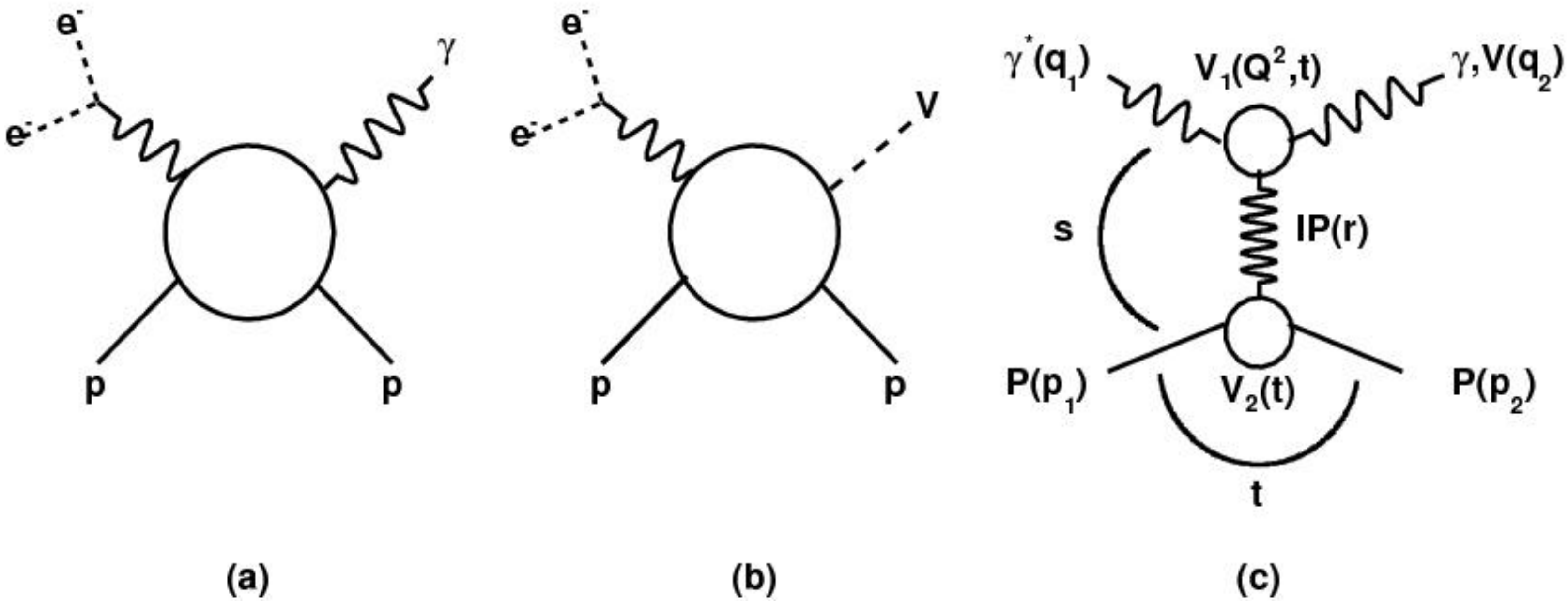
photon-proton centre-of-mass energy:

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

square 4-momentum at the *p* vertex:

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

- **Vector Mesons production in diffraction**
- **Deeply Virtual Compton Scattering**



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

Basic ideas:

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

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

1. The $s-$ and $t-$ dependences are related by the standard Regge-pole model:

$$A(s,t,Q^2)=\xi(t)\beta(t,M,Q^2)(s/s_0)^{\alpha(t)}$$

(see, however, item 3.);

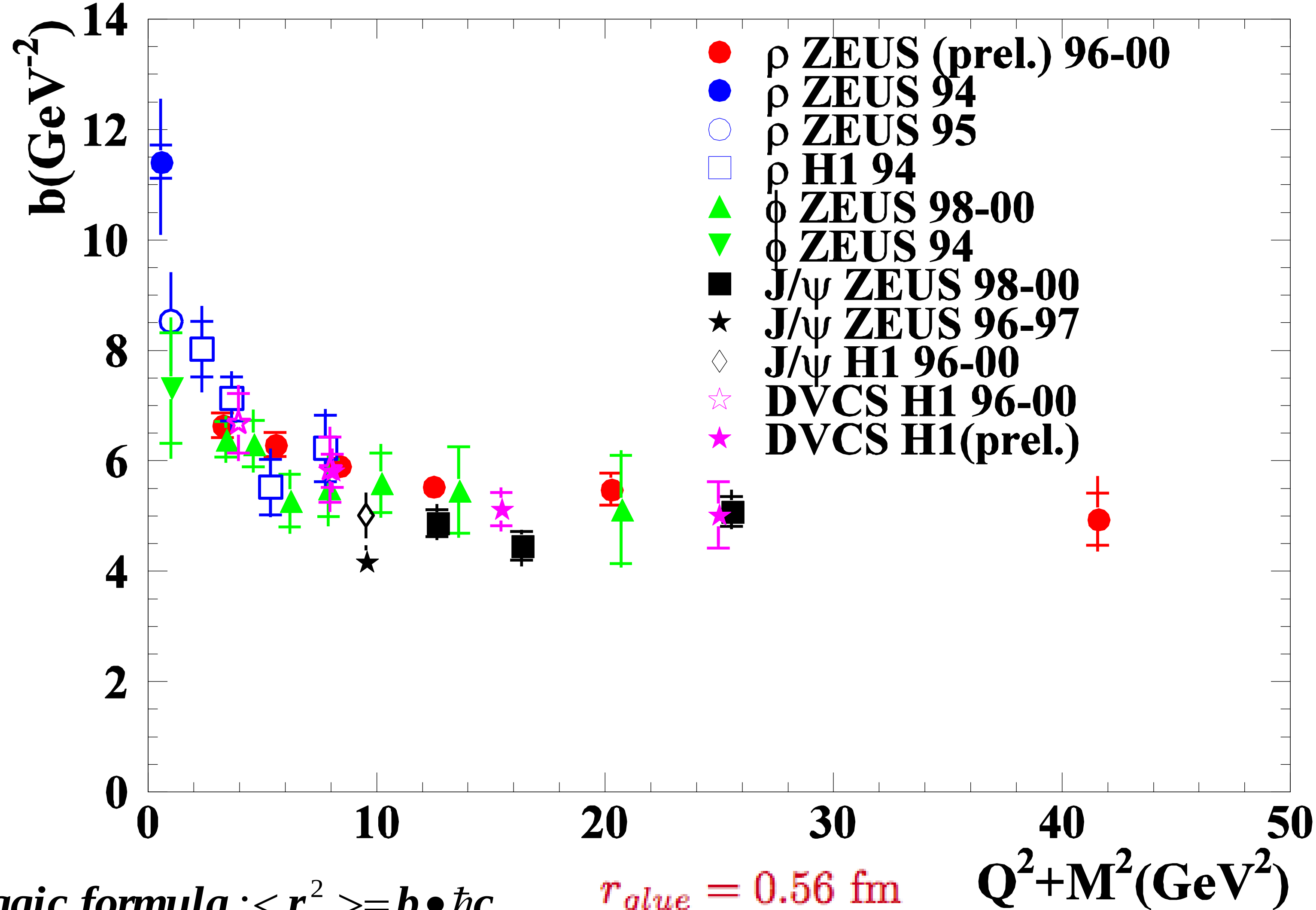
2. The $t-$ and $\tilde{Q}^2=Q^2+M_V^2-$ depedences are combined by geometrical considerations: the slope is related to the masses/virtualities of the external particles (see next figure);

A rough estimates, expected to be valid both for leptons and haddrons is (to be fine-tuned!)

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

3. There is only one, universal, Pomeron, but it has two components - soft and hard, their relative weights depending on $\tilde{Q}^2$.

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



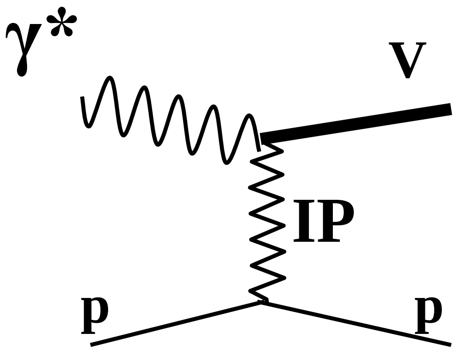
Magic formula : $< r^2 > = b \bullet \hbar c$

$r_{glue} = 0.56$ fm

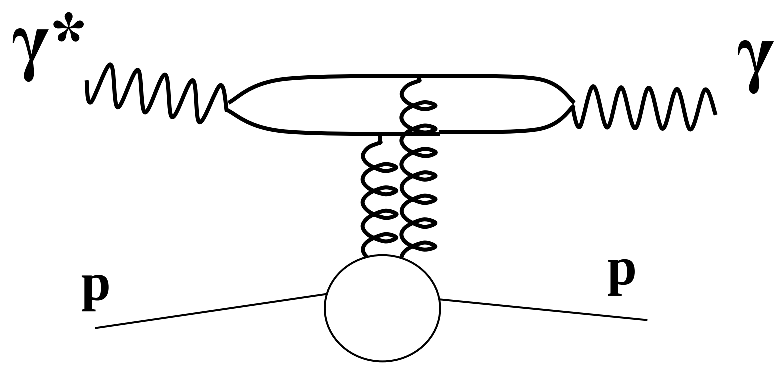
$r_{proton} = 0.8$ fm

Deeply Virtual Compton Scattering

VM (ρ, ω, φ, J/ψ, Y)



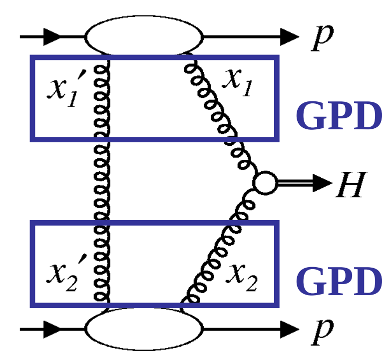
DVCS (γ)



Scale: $Q^2 + M^2$ Q^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**
- **GPD$_s$ are an ingredient for estimating diffractive cross sections at the LHC**



Pomeron Trajectory

Regge-type: $$\frac{d\sigma}{dt}(W) = \exp(b_0 t) \cdot W^{2\left[2\alpha_{IP}(t)+2\right]}$$

First measured in h-h scattering

Soft Pomeron values
$\alpha(0) \approx 1.09$
$\alpha' \approx 0.25$

Linear Pomeron trajectory

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

$\alpha(0)$ and α' are foundamental parameters to represent the basic features of strong interactions

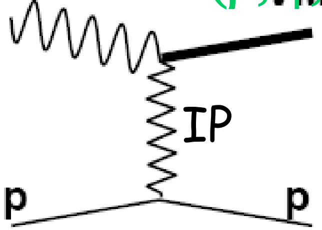
$\alpha(0)$: determines the energy dependence of the diff. Cross section

$$\frac{d\sigma}{dt} \propto \exp(b_0 t) \cdot W^{4\alpha(t)-4} = W^{4\underline{\alpha(0)}-4} \cdot \exp(bt); \qquad b = b_0 + 4\underline{\alpha'}\ln(W)$$

α': determines the energy dependence of the transverse extention system

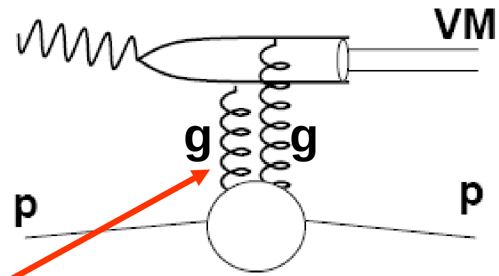
Diffraction: soft -> hard

Vector Meson production ($\rho, \phi, J/\psi, \Upsilon, \gamma$)



'soft'

$$Q^2 + M_V^2$$



2-gluon exchange (pQCD)

'hard'

Gluon density in the proton

Cross section proportional to probability of finding 2 gluons in the proton

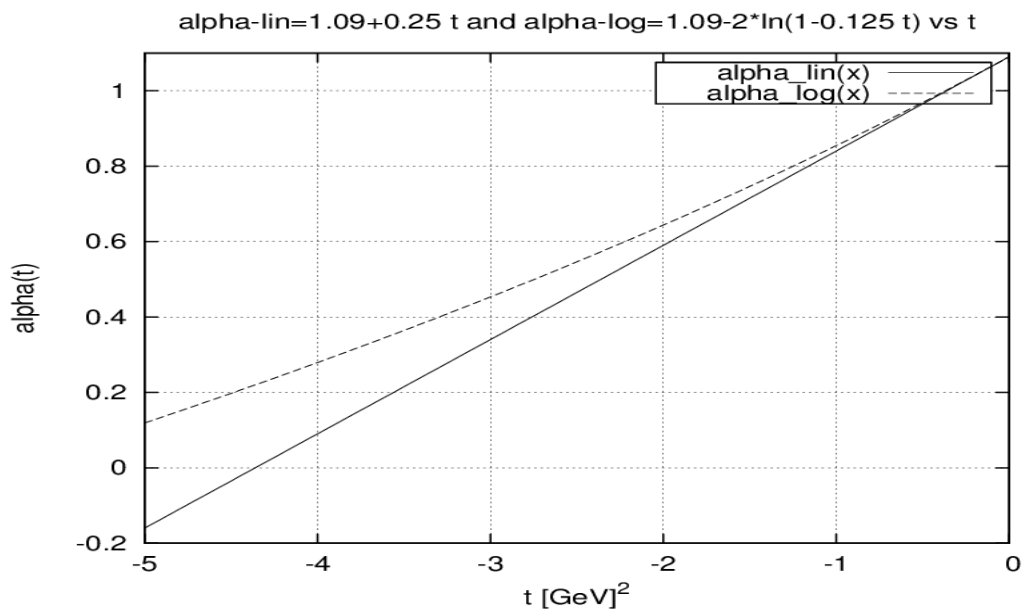
$$\begin{cases} \sigma \propto [x\, g(x, \mu^2)]^2 \\ \mu^2 \propto (Q^2 + M_V^2) \end{cases}$$

$$\sigma(W) \propto W^{\delta}$$

δ increases from soft (~0.2, "soft Pomeron") to hard (~0.8, "hard Pomeron")

$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$

b decreases from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})



alpha-lin=1.09+0.25 t and alpha-log=1.09-2*ln(1-0.125 t) vs t
alpha_lin(x)
alpha_log(x)
alpha(t)
1
0.8
0.6
0.4
0.2
0
-0.2
-5
-4
-3
-2
-1
0
t [GeV]^2

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

$$+\frac{\tilde{A}_h\left(\frac{\widetilde{Q^2}}{\widetilde{Q_h^2}}\right)}{\left(1+\frac{\widetilde{Q^2}}{\widetilde{Q_h^2}}\right)^{n_h+1}}e^{-i\frac{\pi}{2}\alpha_h(t)}\left(\frac{s}{s_{0h}}\right)^{\alpha_h(t)}e^{2\left(\frac{a_h}{\widetilde{Q^2}}+\frac{b_h}{2m_p^2}\right)t}$$

$$\frac{d\sigma_{el}}{d|t|} = H_s^2 e^{2L_s(\alpha_s(t)-1)+g_s t} + H_h^2 e^{2L_h(\alpha_h(t)-1)+g_h t}$$

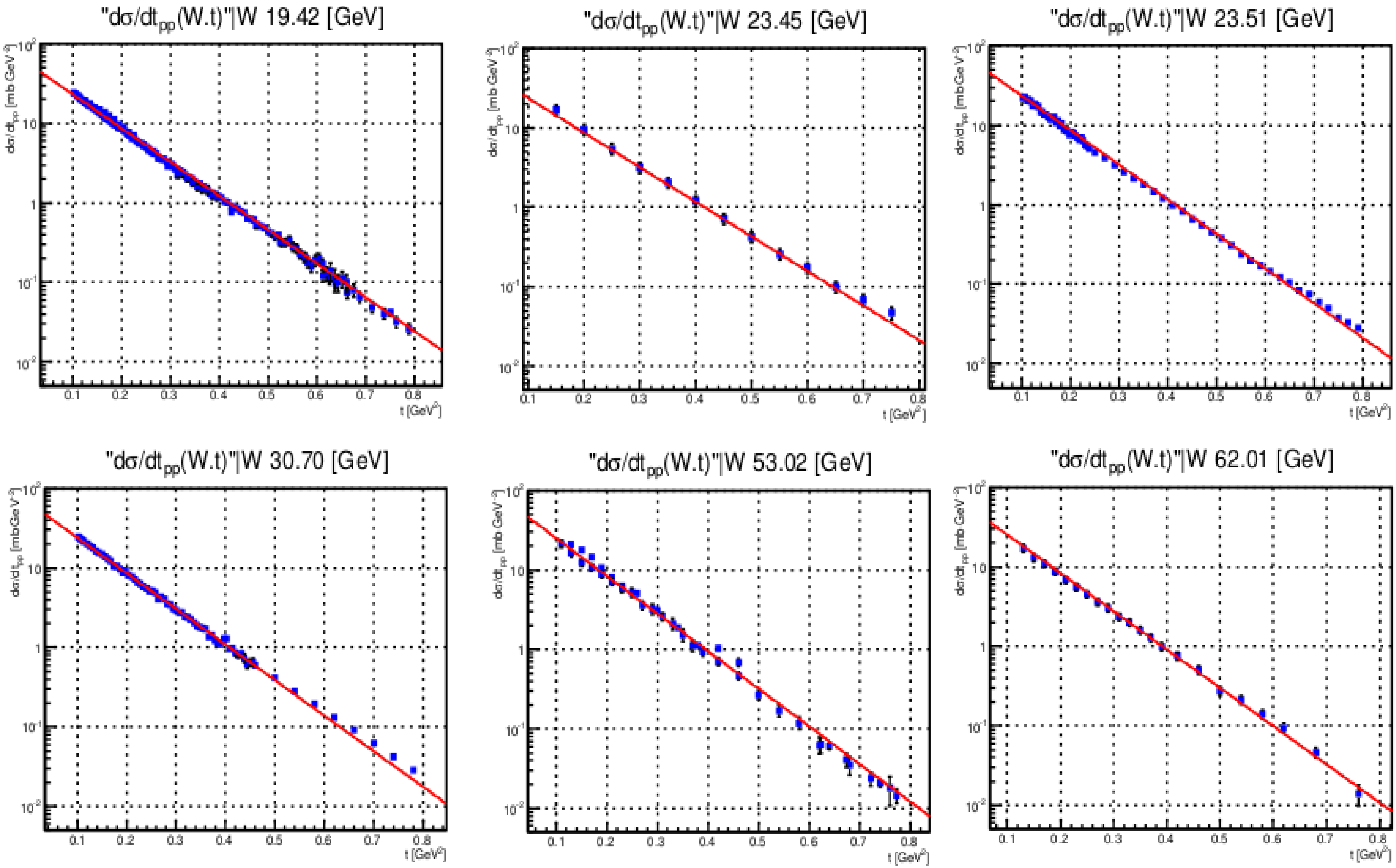
$$+2H_s H_h e^{L_s(\alpha_s(t)-1)+L_h(\alpha_h(t)-1)+(g_s+g_h)t} \cos\left(\frac{\pi}{2}(\alpha_s(t)-\alpha_h(t))\right)$$

$$H_s = \frac{A_s}{\left(1+\frac{\widetilde{Q^2}}{\widetilde{Q_s^2}}\right)^{n_s}} \quad H_h = \frac{A_h\left(\frac{\widetilde{Q^2}}{\tilde{Q}_h^2}\right)}{\left(1+\frac{\widetilde{Q^2}}{\widetilde{Q_h^2}}\right)^{n_h+1}}$$

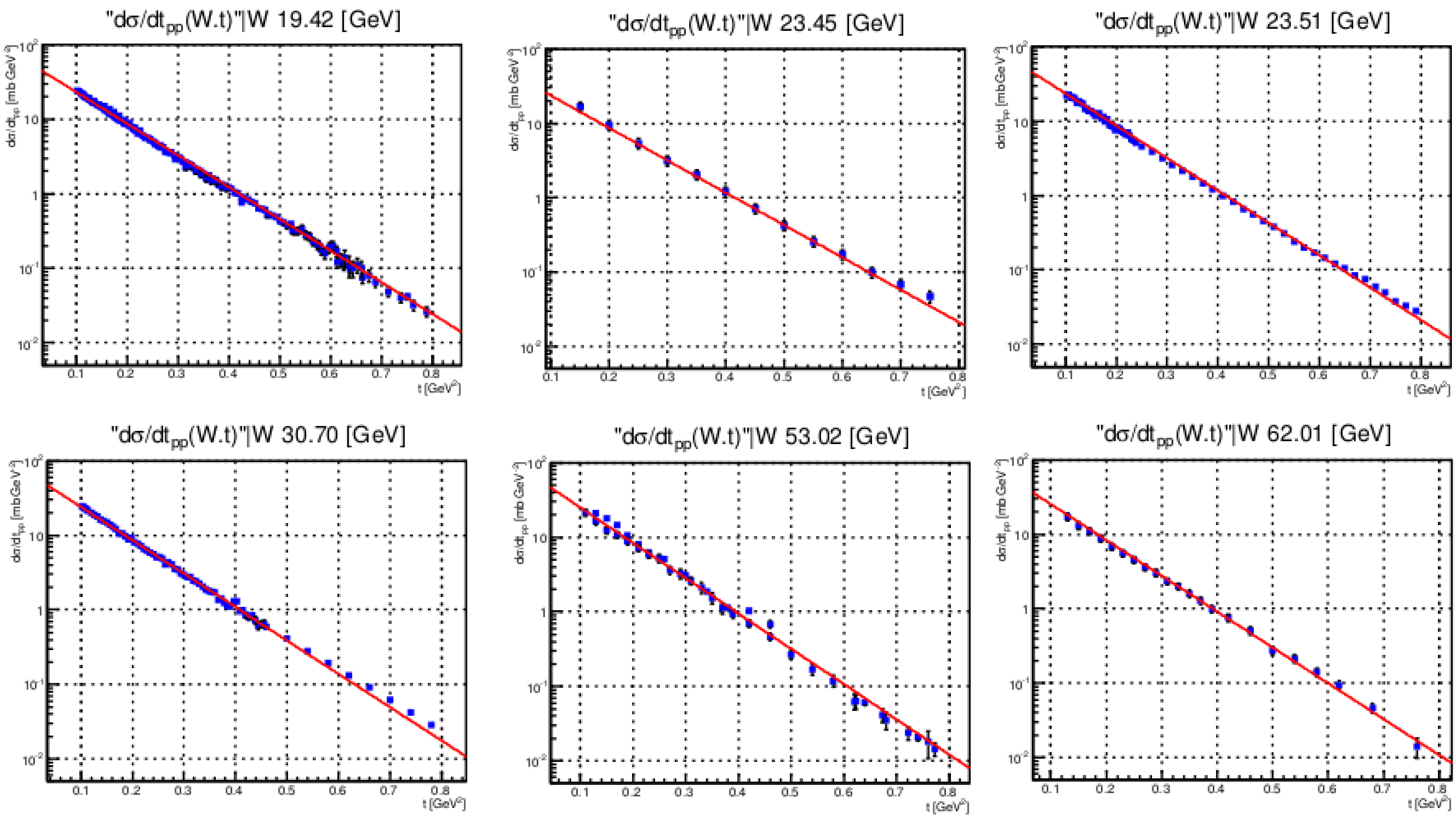
$$L_s = \ln\left(\frac{s}{s_{0s}}\right) \quad g_s = 2\left(\frac{a_s}{\widetilde{Q^2}} + \frac{b_s}{2m_p^2}\right) \quad \alpha_s(t) = \alpha_{0s} + \alpha'_s t$$

$$L_h = \ln\left(\frac{s}{s_{0h}}\right) \quad g_h = 2\left(\frac{a_h}{\widetilde{Q^2}} + \frac{b_h}{2m_p^2}\right) \quad \alpha_h(t) = \alpha_{0h} + \alpha'_h t$$

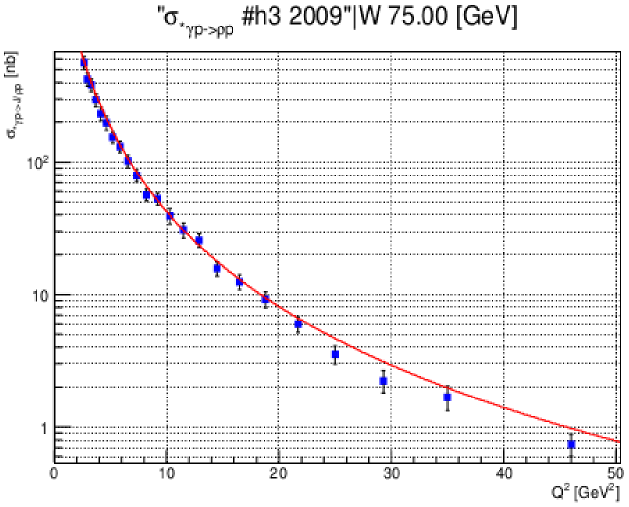
pp

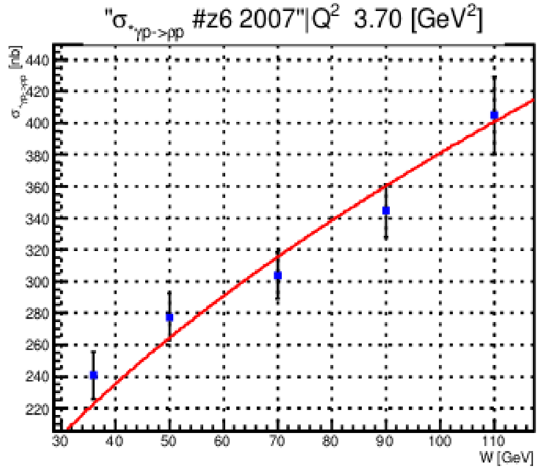

"dσ/dt$_{pp}$(W.t)"|W 19.42 [GeV]
"dσ/dt$_{pp}$(W.t)"|W 23.45 [GeV]
"dσ/dt$_{pp}$(W.t)"|W 23.51 [GeV]
"dσ/dt$_{pp}$(W.t)"|W 30.70 [GeV]
"dσ/dt$_{pp}$(W.t)"|W 53.02 [GeV]
"dσ/dt$_{pp}$(W.t)"|W 62.01 [GeV]
dσ/dt$_{pp}$ [mb GeV^{-2}]
t [GeV^2]

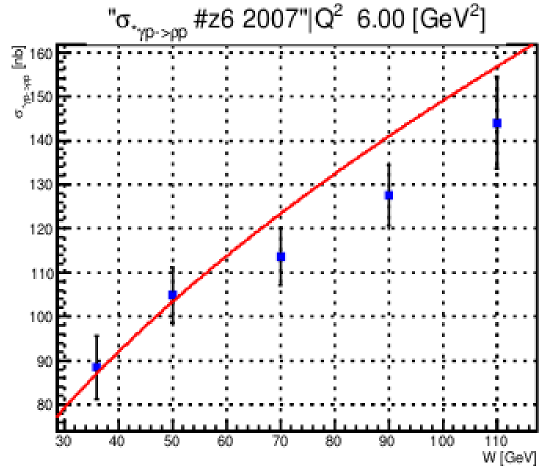
pp

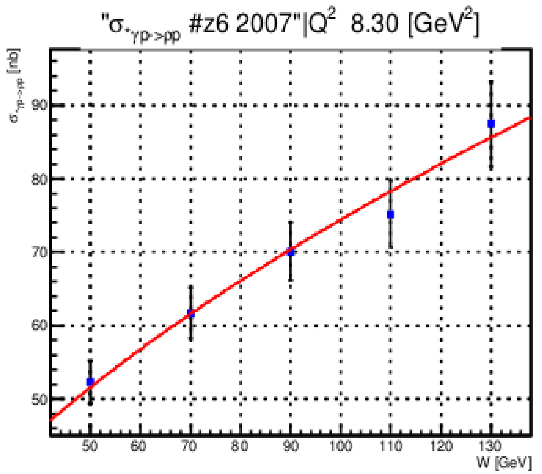

"dσ/dt_pp(W.t)"|W 19.42 [GeV]
"dσ/dt_pp(W.t)"|W 23.45 [GeV]
"dσ/dt_pp(W.t)"|W 23.51 [GeV]
"dσ/dt_pp(W.t)"|W 30.70 [GeV]
"dσ/dt_pp(W.t)"|W 53.02 [GeV]
"dσ/dt_pp(W.t)"|W 62.01 [GeV]
dσ/dt_pp [mb GeV^-2]
t [GeV^2]

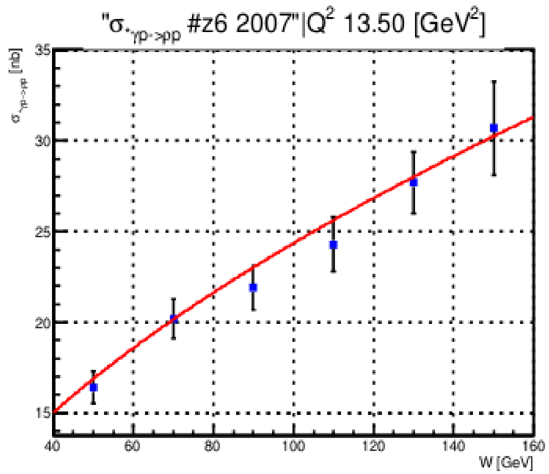
rho0(1)

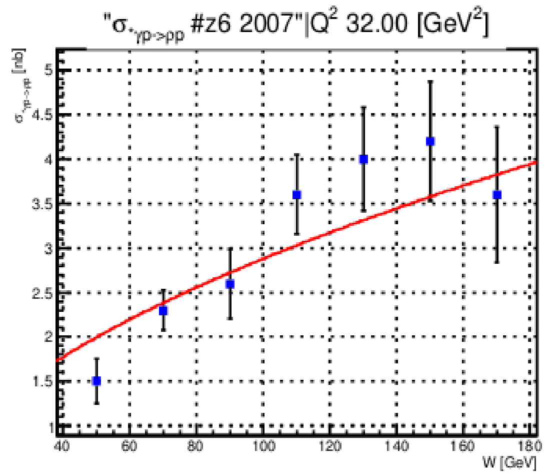

"σ*γp->ρp #h3 2009"|W 75.00 [GeV]
σ*γp->J/ψp [nb]
Q² [GeV²]


"σ*γp->ρp #z6 2007"|Q² 3.70 [GeV²]
σ*γp->ρp [nb]
W [GeV]

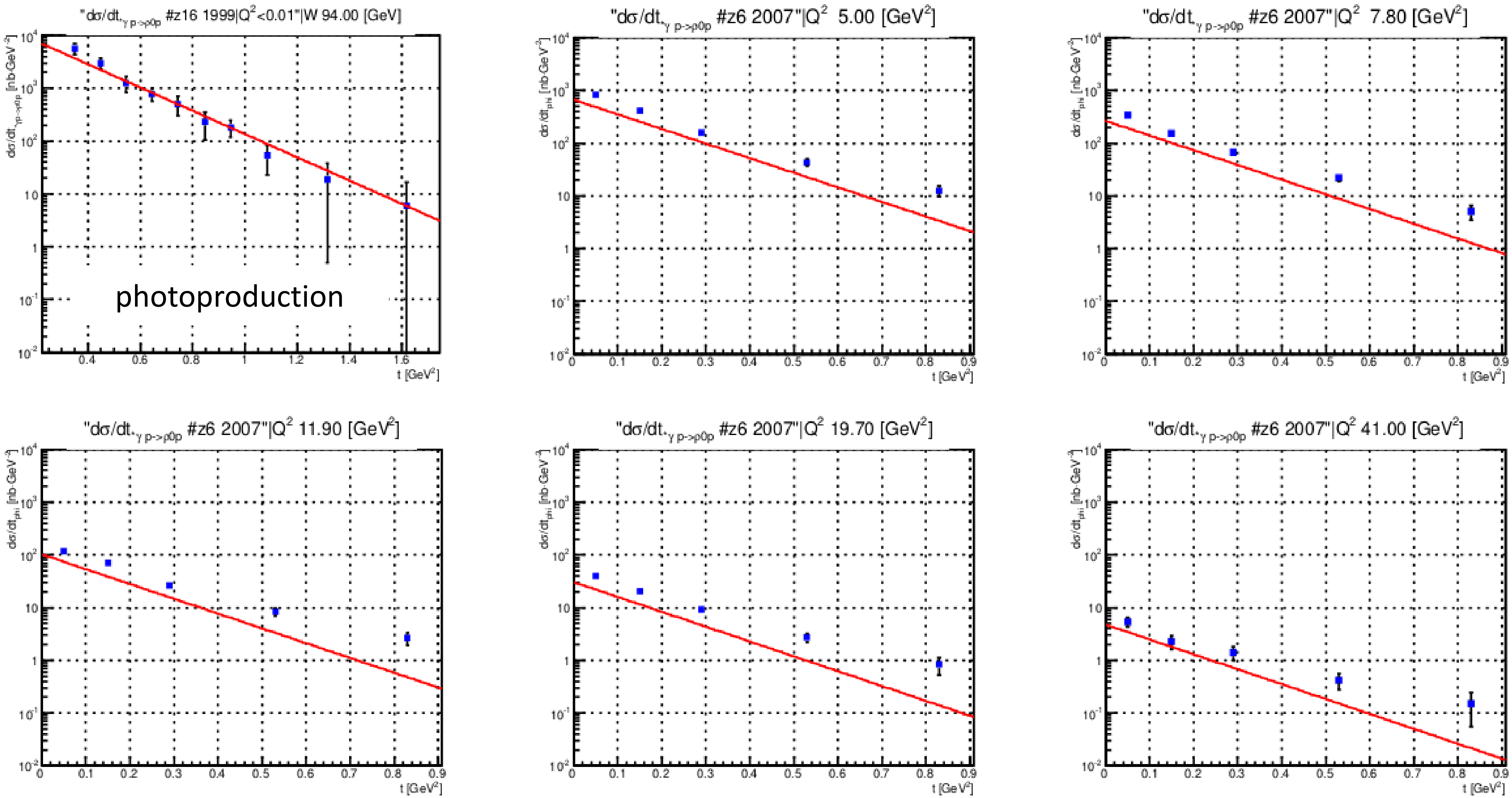

"σ*γp->ρp #z6 2007"|Q² 6.00 [GeV²]
σ*γp->ρp [nb]
W [GeV]


"σ*γp->ρp #z6 2007"|Q² 8.30 [GeV²]
σ*γp->ρp [nb]
W [GeV]


"σ*γp->ρp #z6 2007"|Q² 13.50 [GeV²]
σ*γp->ρp [nb]
W [GeV]

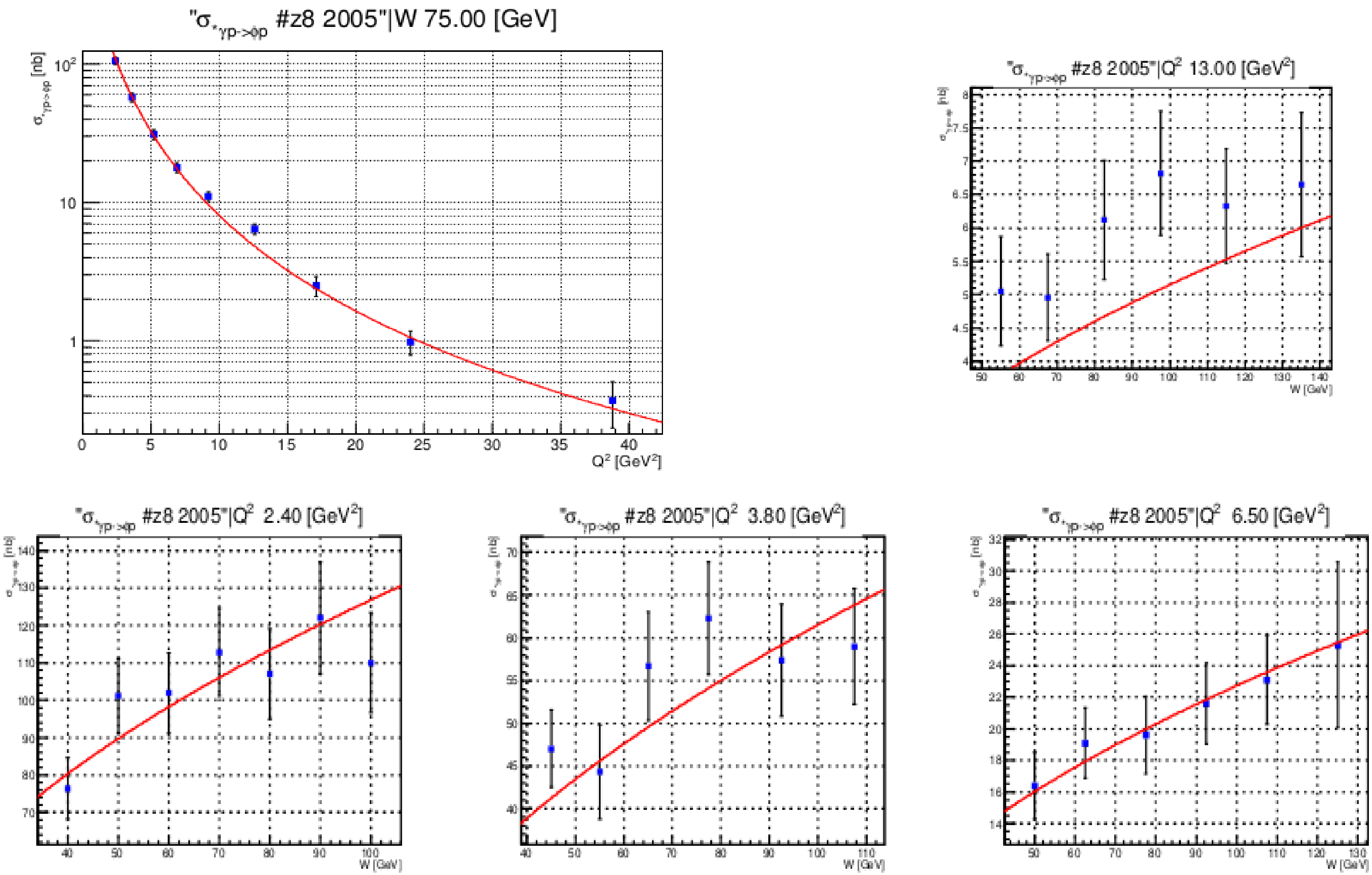

"σ*γp->ρp #z6 2007"|Q² 32.00 [GeV²]
σ*γp->ρp [nb]
W [GeV]

rho0 (2)

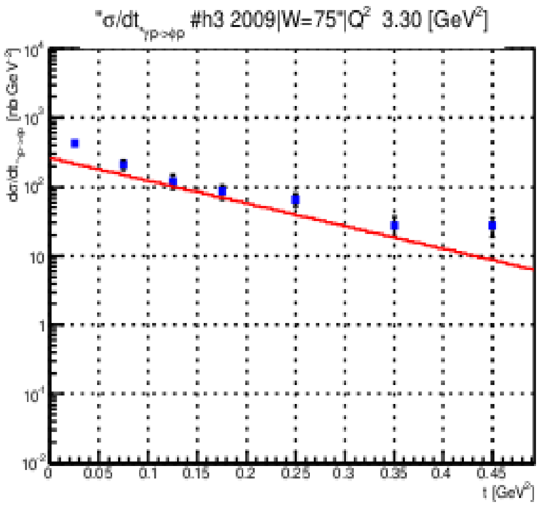


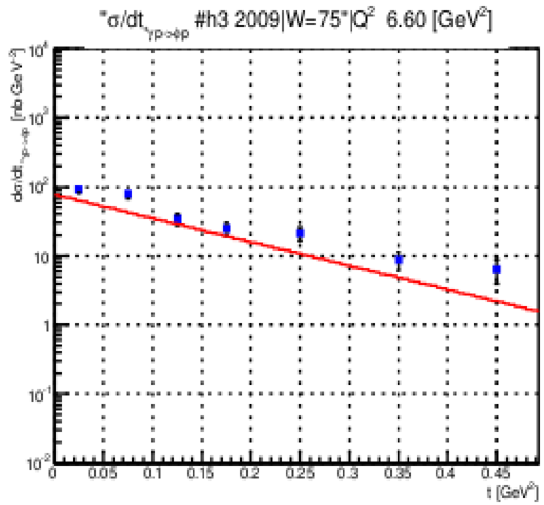
ZEUS 2007, $W = 90GeV^2$, electroproduction

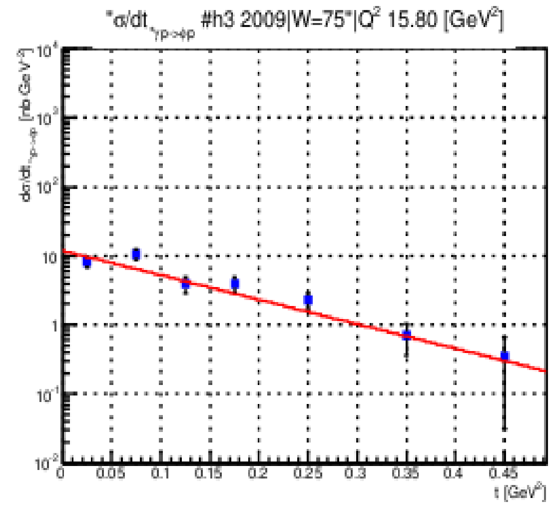
phi (1)


"σ*γp->φp #z8 2005"|W 75.00 [GeV]
Q² [GeV²]
"σ*γp->φp #z8 2005"|Q² 13.00 [GeV²]
W [GeV]
"σ*γp->φp #z8 2005"|Q² 2.40 [GeV²]
"σ*γp->φp #z8 2005"|Q² 3.80 [GeV²]
"σ*γp->φp #z8 2005"|Q² 6.50 [GeV²]

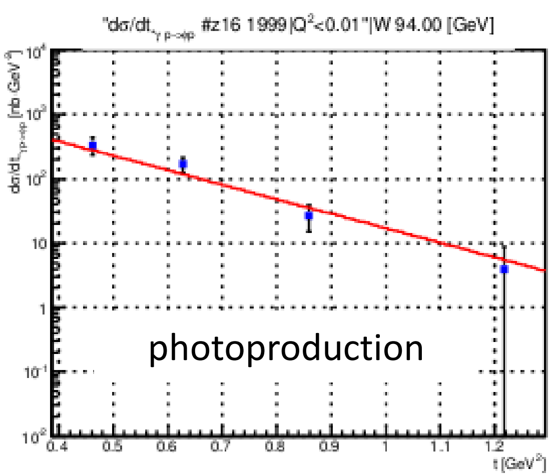
phi (2)





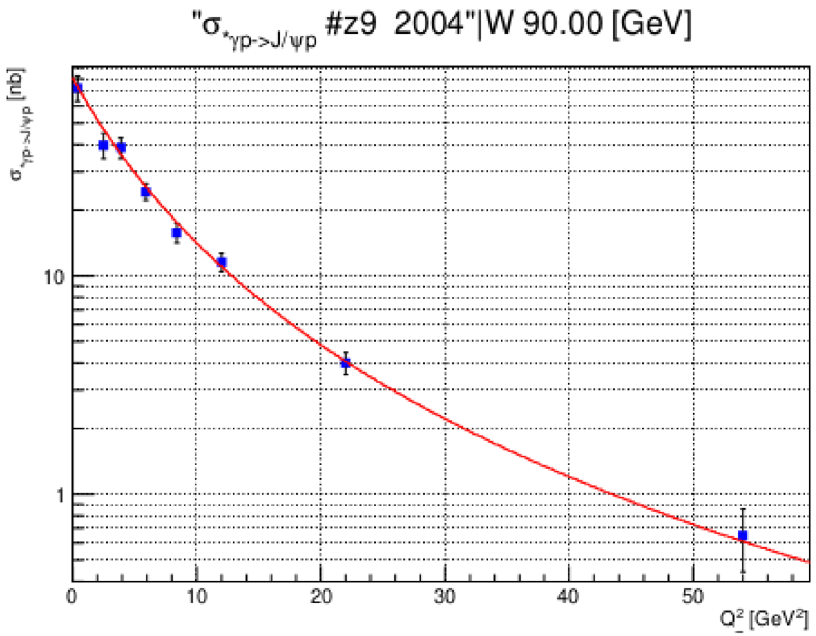


electropruction



photoproduction

J/psi (1)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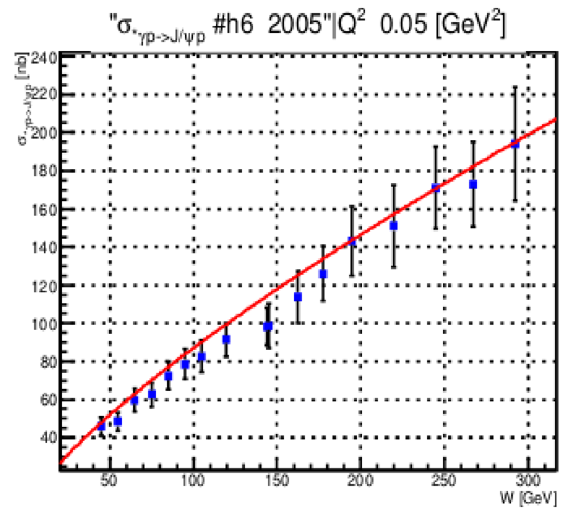
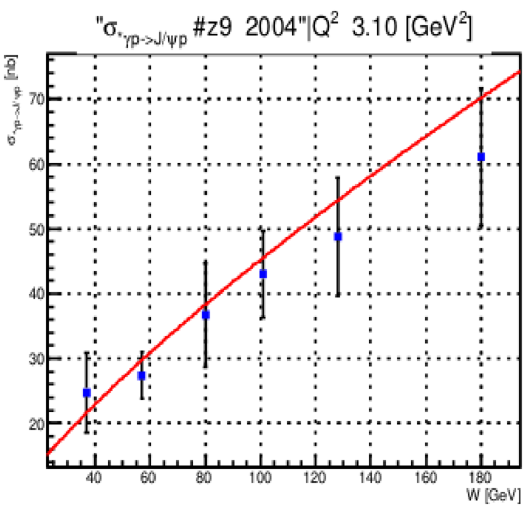
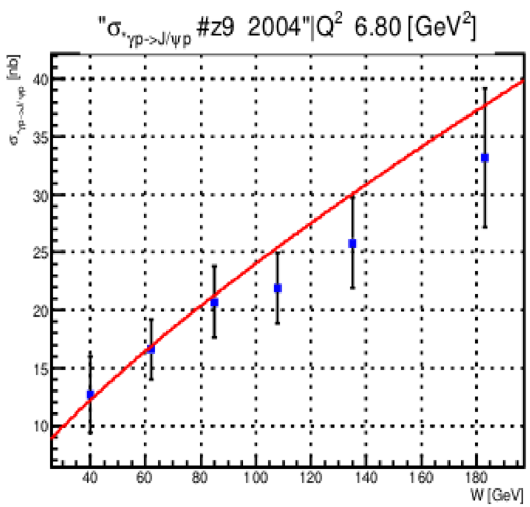
σ*γp->J/ψp [nb]
Q² [GeV²]


"σ*γp->J/ψp #h6 2005"|Q² 0.05 [GeV²]
σ*γp->J/ψp [nb]
W [GeV]


"σ*γp->J/ψp #z9 2004"|Q² 3.10 [GeV²]
σ*γp->J/ψp [nb]
W [GeV]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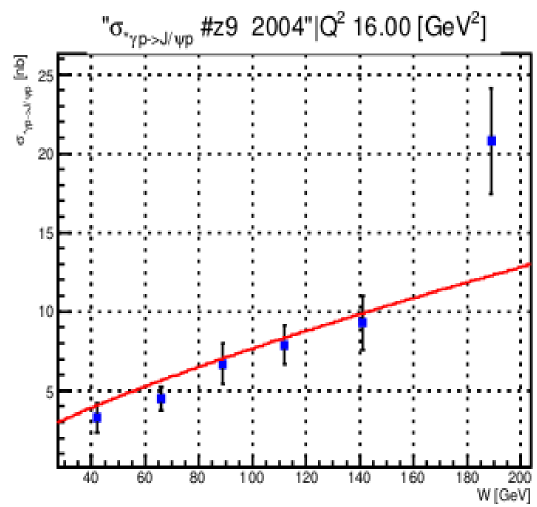
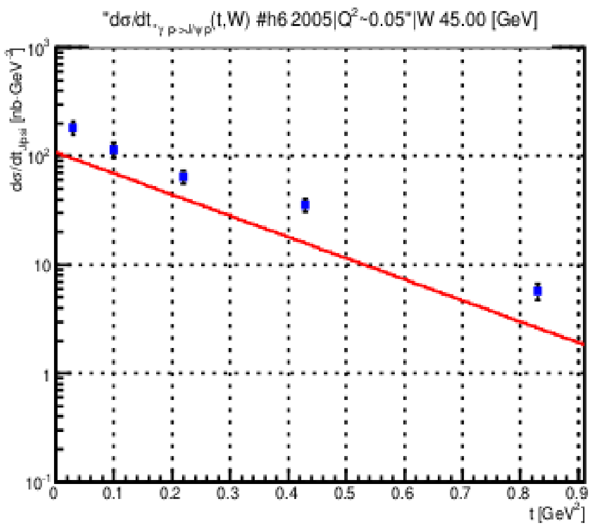
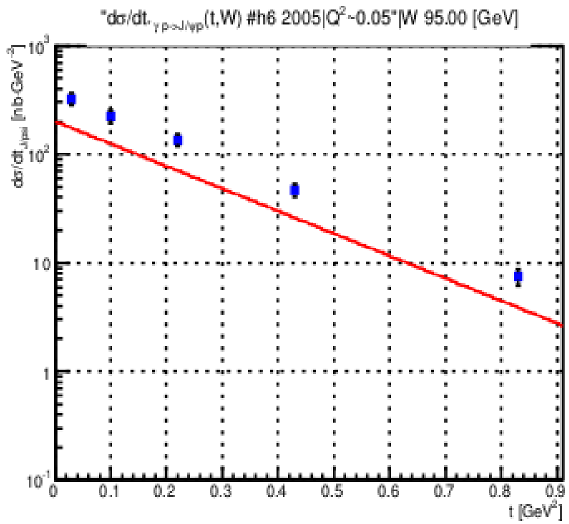
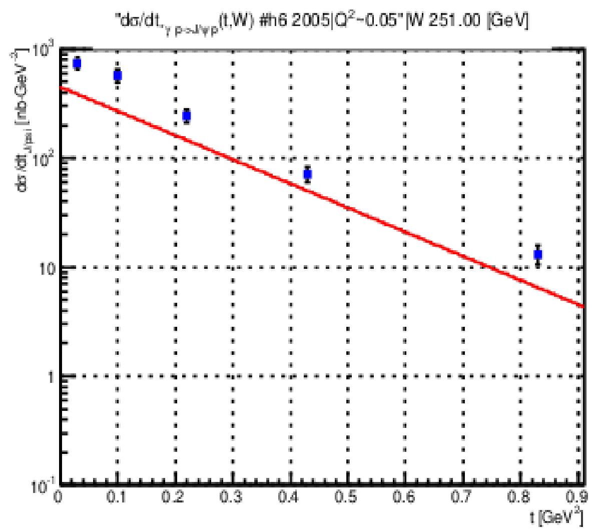
σ*γp->J/ψp [nb]
W [GeV]

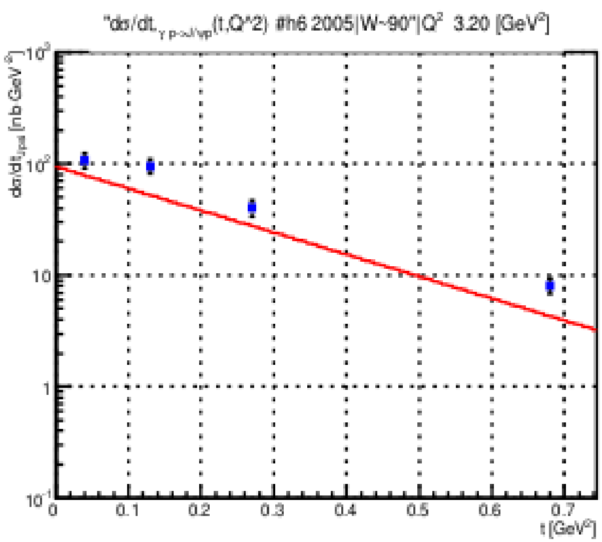

"σ*γp->J/ψp #z9 2004"|Q² 16.00 [GeV²]
σ*γp->J/ψp [nb]
W [GeV]

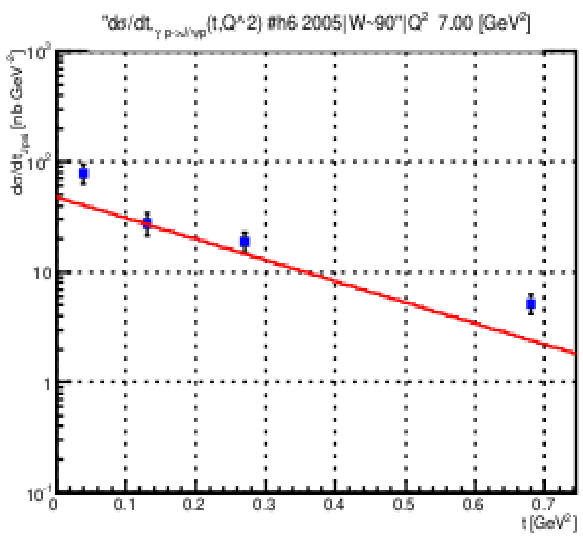
J/psi (2)

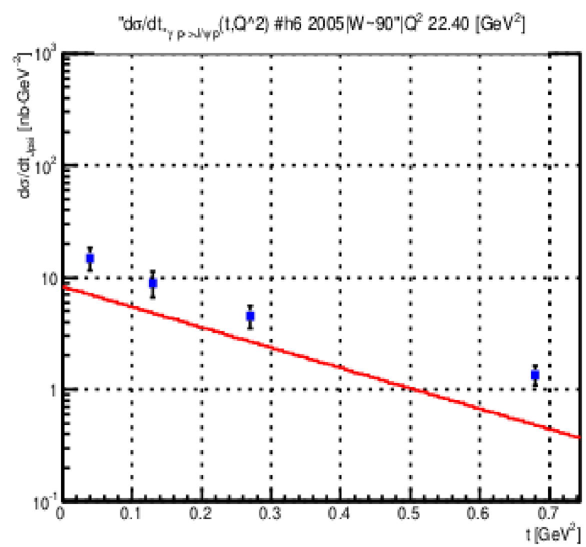

"dσ/dt_{γ p->J/ψp}(t,W) #h6 2005|Q^2~0.05"|W 45.00 [GeV]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]


"dσ/dt_{γ p->J/ψp}(t,W) #h6 2005|Q^2~0.05"|W 95.00 [GeV]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]

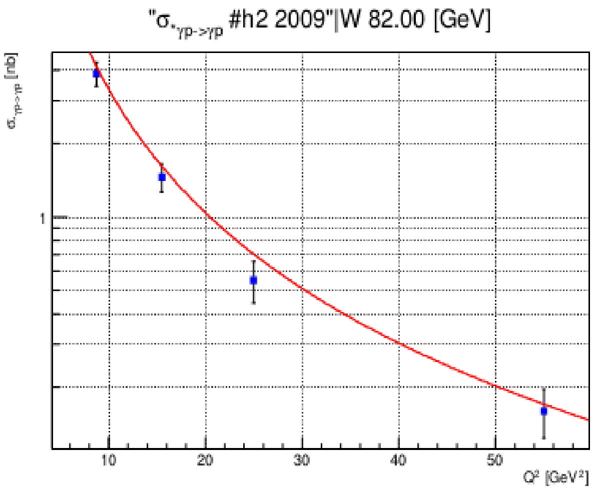

"dσ/dt_{γ p->J/ψp}(t,W) #h6 2005|Q^2~0.05"|W 251.00 [GeV]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]

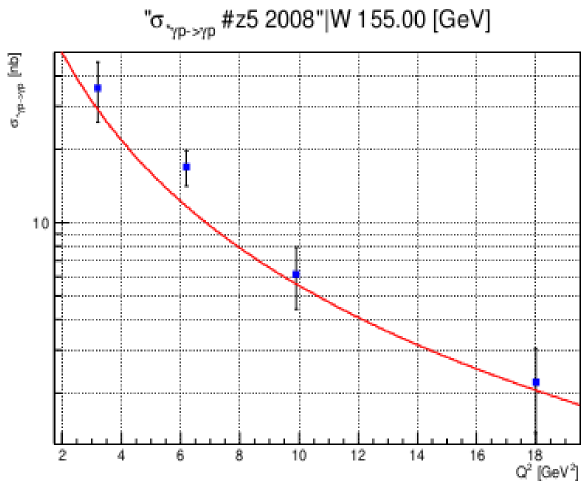

"dσ/dt_{γ p->J/ψp}(t,Q^2) #h6 2005|W~90"|Q^2 3.20 [GeV^2]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]


"dσ/dt_{γ p->J/ψp}(t,Q^2) #h6 2005|W~90"|Q^2 7.00 [GeV^2]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]


"dσ/dt_{γ p->J/ψp}(t,Q^2) #h6 2005|W~90"|Q^2 22.40 [GeV^2]
dσ/dt_{Jpsi} [nb·GeV^-2]
t [GeV^2]

DVCS (1)


"σ*γp->γp #h2 2009"|W 82.00 [GeV]
σ*γp->γp [nb]
Q² [GeV²]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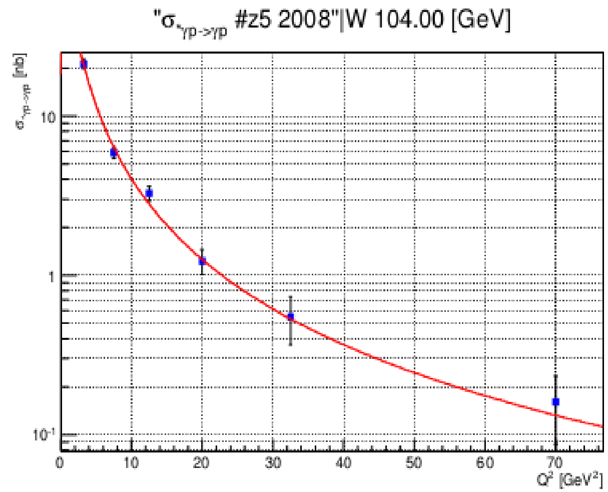
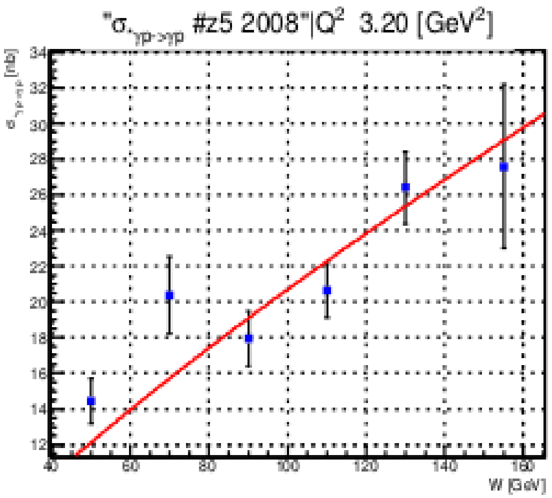
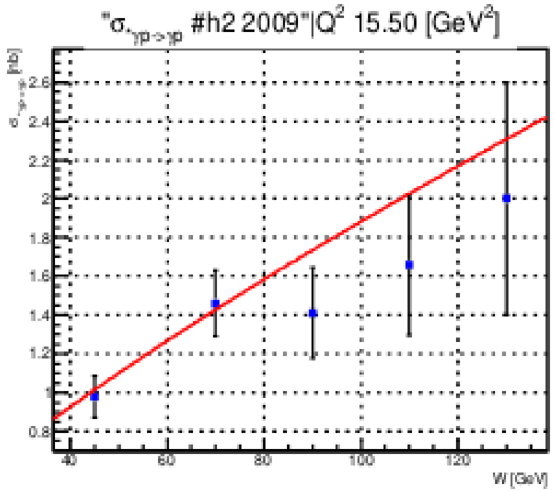
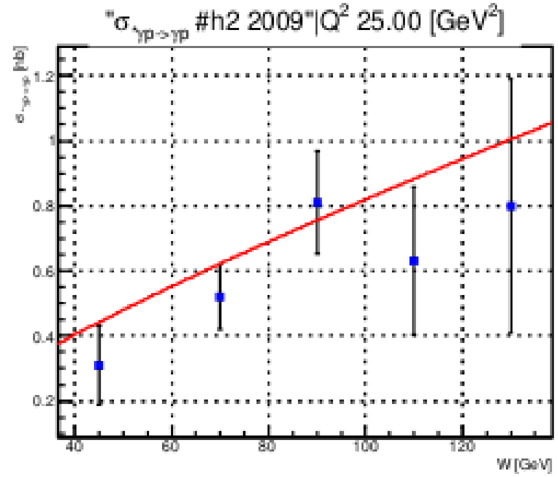
σ*γp->γp [nb]
Q² [GeV²]

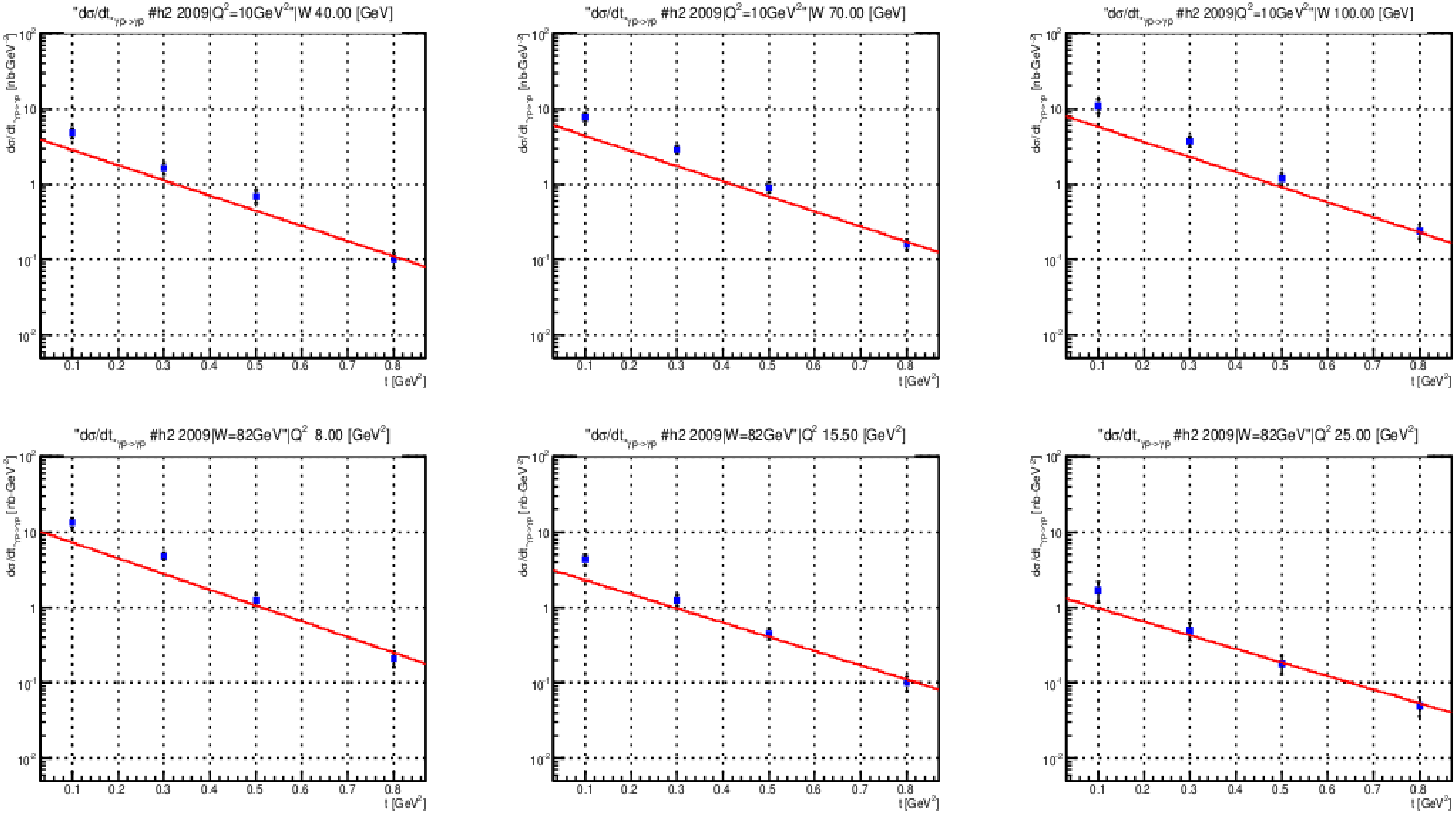

"σ*γp->γp #z5 2008"|W 104.00 [GeV]
σ*γp->γp [nb]
Q² [GeV²]


"σ*γp->γp #z5 2008"|Q² 3.20 [GeV²]
σ*γp->γp [nb]
W [GeV]


"σ*γp->γp #h2 2009"|Q² 15.50 [GeV²]
σ*γp->γp [nb]
W [GeV]


"σ*γp->γp #h2 2009"|Q² 25.00 [GeV²]
σ*γp->γp [nb]
W [GeV]

DVCS (2)

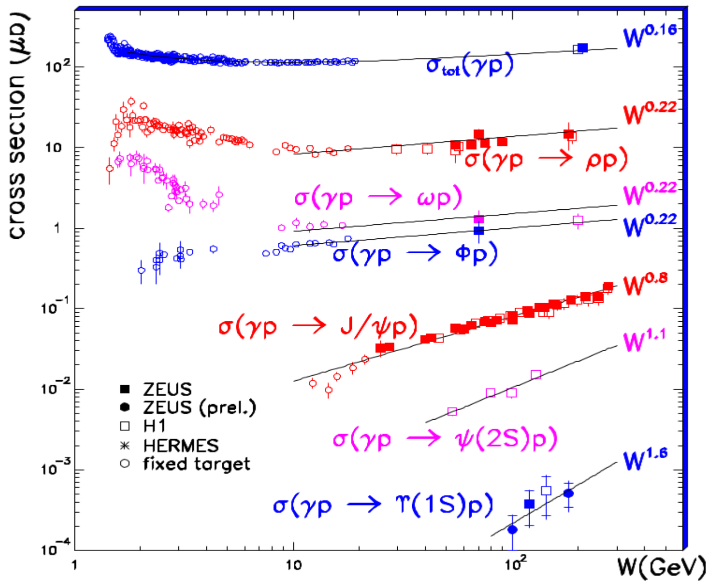

"dσ/dt,γp->γp #h2 2009|Q²=10GeV²"|W 40.00 [GeV]
"dσ/dt,γp->γp #h2 2009|Q²=10GeV²"|W 70.00 [GeV]
"dσ/dt,γp->γp #h2 2009|Q²=10GeV²"|W 100.00 [GeV]
"dσ/dt,γp->γp #h2 2009|W=82GeV"|Q² 8.00 [GeV²]
"dσ/dt,γp->γp #h2 2009|W=82GeV"|Q² 15.50 [GeV²]
"dσ/dt,γp->γp #h2 2009|W=82GeV"|Q² 25.00 [GeV²]
dσ/dtγp->γp [nb GeV⁻²]
t [GeV²]
10²
10
1
10⁻¹
10⁻²
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

	A_s	$\widetilde{Q_s^2}$	n_s	α_{0s}	α'_s	a_s	b_s	$\tilde{\chi}^2$
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. α(0), α'



(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.

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.

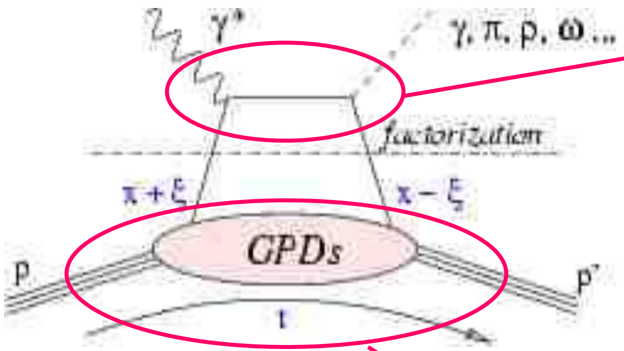
Conclusions and prospects:

1. There is one, unique Pomeron, but it may have many componts (e.d. “soft” and “hard”.

2. Regge trajectories are non-linear.

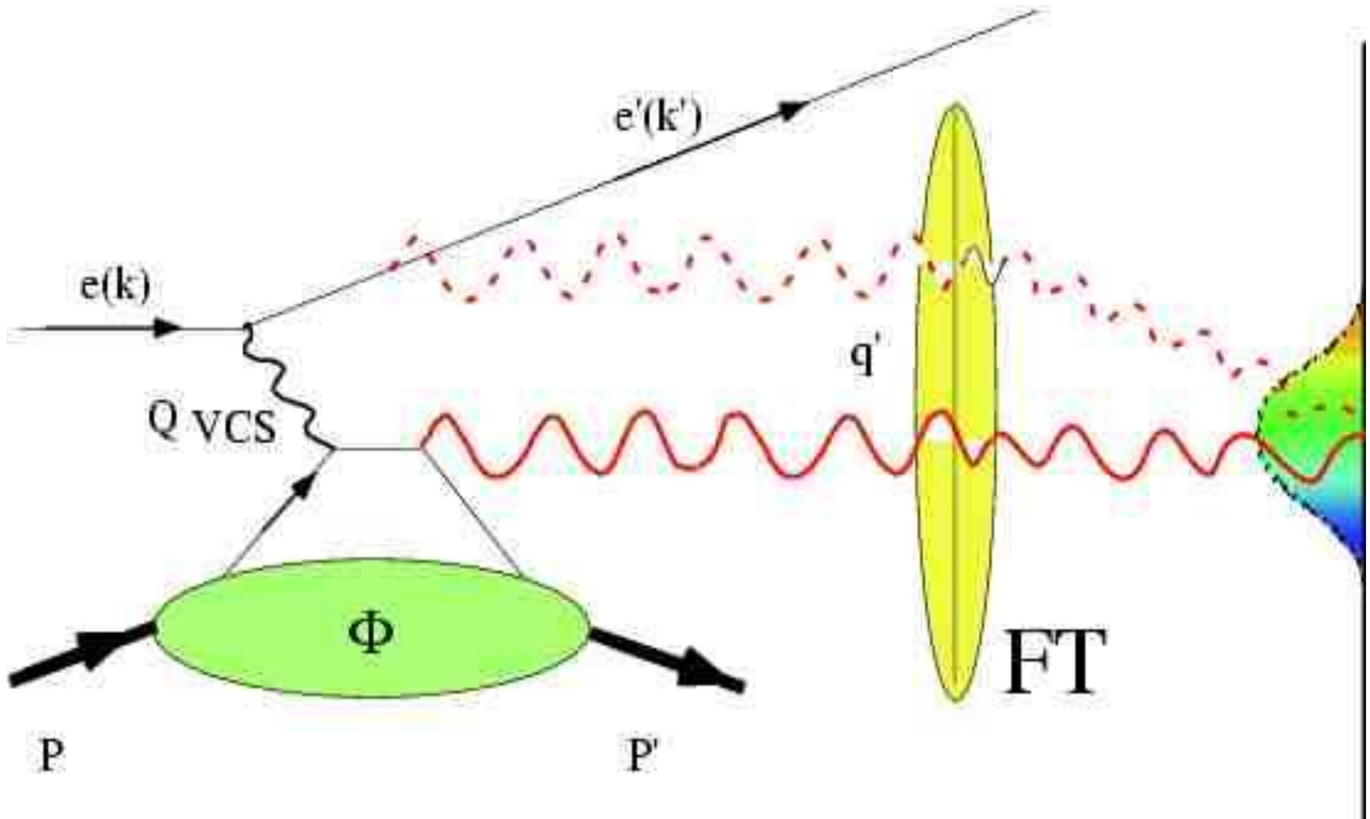
1. DVCS and VMP – a tool to access to GPD (below):

QCD-factorized form of a DVCS scatterigg amplitude



pQCD

non-perturbative region


e'(k')
e(k)
q'
Q VCS
Φ
FT
P
P'

GPDs cannot be measured directly,
instead they appear as convolution integrals,
difficult to be inverted !

$$A(\xi,\eta,t) \sim \int_{-1}^{1} dx \frac{GPD(x,\eta,t)}{x-\xi+i\varepsilon}$$

"Handbag"

$$\sigma_{tot} \sim \Im m A, \qquad \frac{d\sigma}{dt} \sim |A|^2$$

We need clues from phenomenological models - Regge behaviour, t-factorization etc.