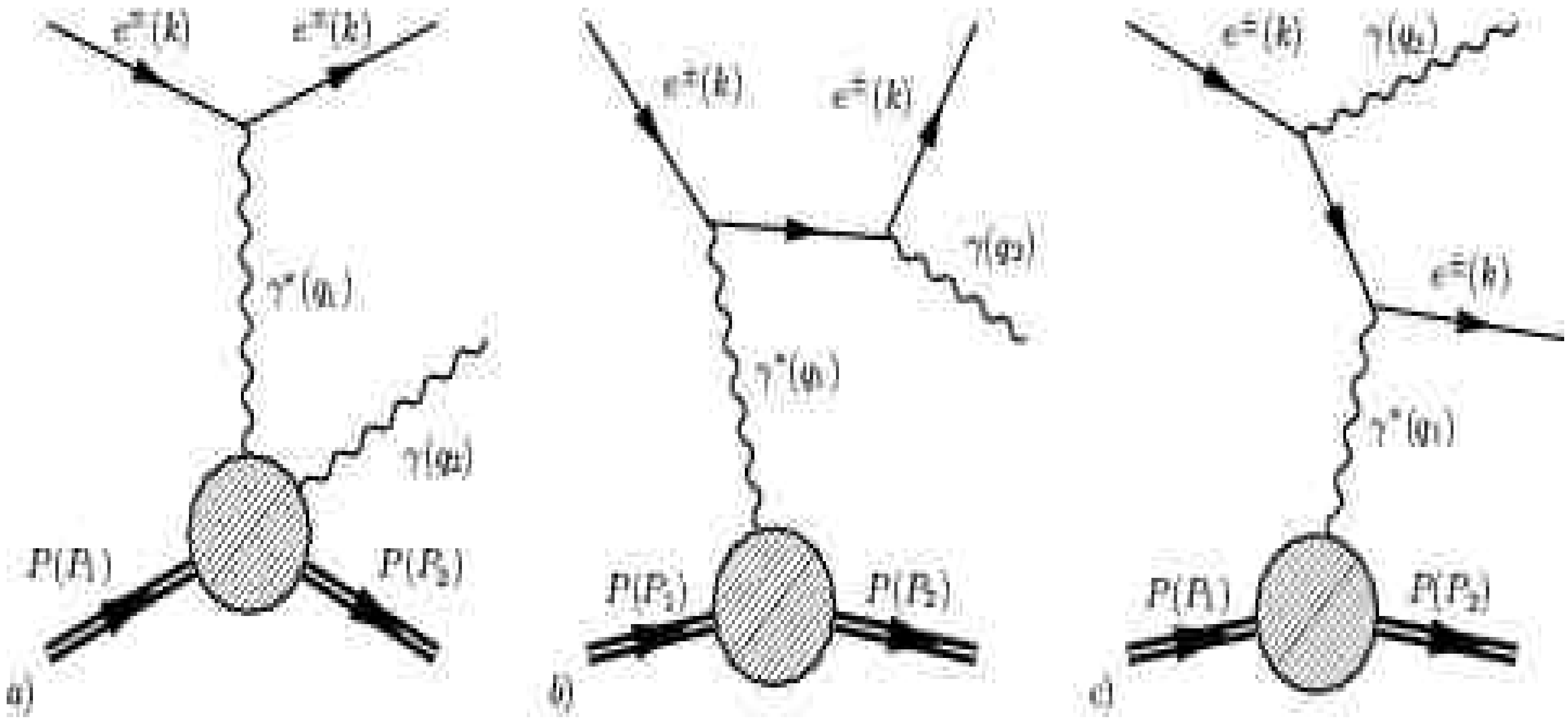
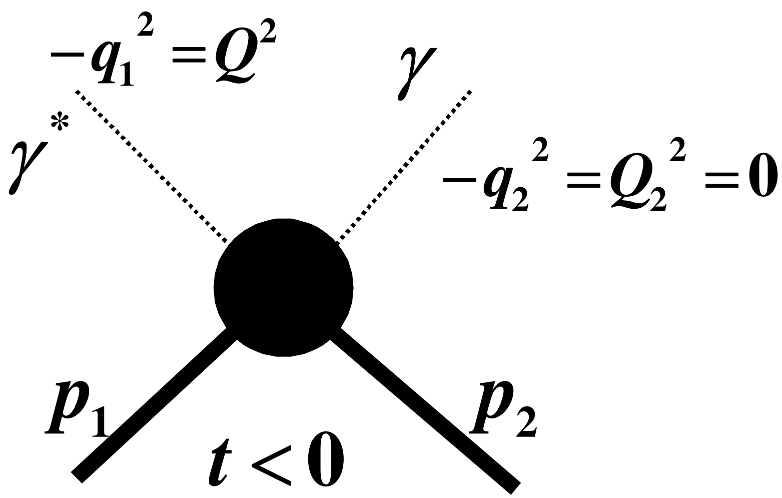
Exclusive (diffractive) J/Ψ photo- and electroproduction in a dual model (from the threshold to asymptotics)

L. Jenkovszky
(BITP, Kiev)

DVCS & Bethe-Heitler



DVCS kinematics



$$P = p_1 + p_2, \, q = (q_1 + q_2)/2$$

$$\Delta = p_2 - p_1, \ \ t = \Delta^2$$

$$x_B = \frac{-q_1^{\ 2}}{2p_1 q_1} = \frac{Q^2}{2p_1 q_1}$$

$$\xi = \frac{-q^2}{2Pq} = x_B \frac{1 + \dfrac{\Delta^2}{2Q^2}}{2 - x_B + x_B \dfrac{\Delta^2}{Q^2}}$$

$$\eta = \frac{\Delta q}{Pq} = -\xi \left(1 + \frac{\Delta^2}{2Q^2} \right)^{-1}$$

The basic object of the theory

$$A(s,t,Q^2) \to A(s,t,Q^2=m^2) \text{ (on mass shell)}$$

$$A(s,t,Q^2) \to \Im m A(s,t=0,Q^2) \sim F_2 \quad \text{DIS}$$

Reconstruction of the DVCS amplitude from DIS

$$F_2 \sim \Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \to \Im m A(\gamma^* p \to \gamma p)\Big|_{t=0}$$

$$\to A(\gamma^* p \to \gamma p)\Big|_{t=0} \to A(\gamma^* p \to \gamma p)$$

or

$$\Im m A(\gamma^* p \to \gamma^* p)\Big|_{t=0} \sim F_2(x_B,Q^2) = x_B q(x_B,Q^2)$$

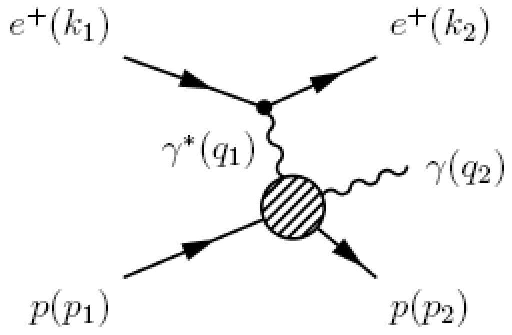
$$q(x_B,Q^2) \to q(\xi,\eta,t,x_B,Q^2) \to$$

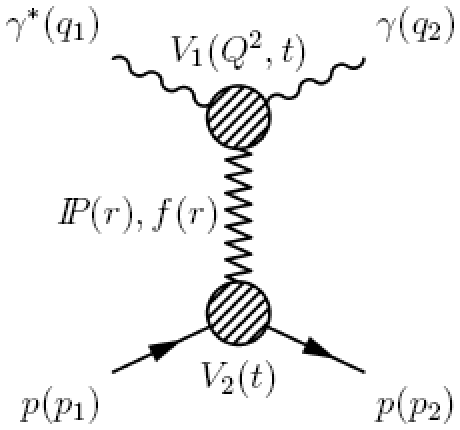
$$\to \xi q(\xi,\eta,t,x_B,Q^2) \overset{?}{=} GPD(\xi,\eta,t,x_B,Q^2)$$

The sub-process $\gamma^* p \rightarrow \gamma p$ in a Regge-factorized form:

$$A(s,t,Q^2) \sim V_1(Q^2,t)V_2(t)s^{\alpha(t)}$$

$r^2 = t = (q_1 - q_2)^2$ r is the four-momentum of the Reggeon exchanged in the t channel,and $s = W^2 = (q_1 + p_1)^2$ is the squared centre-of-mass energy of the incoming system.





Two alternative/coomplementary appoaches to hard exclusive $(s, t, Q^2, M^2))$ processes exist:
1) Start from partonic (gluonic) desnities, e.g. (e.g. S.J. Brodsky *et al.*, Phys. Rev. D **50** (1994) 3134) $\frac{d\sigma_L}{dt}|_{t=0} \sim \alpha_S(Q^2)[xg(x, Q^2)]^2$, to be extended (multiplied by) some t dependence.

2) Start from an elastic on-shall scattering amplitude e.g. (A. Donnachie, P.V. Landshoff, hep-ph/0803.0686):

$$T(s,t) = i \sum_i X_i F(t)_A F(t)_B (t) e^{-i\pi\alpha_i(t)/2} (\nu_i)^{\alpha_i - 1},$$

$\nu = (s-u)/2$, $\alpha_1(t) = 1.08+0.25t$, $\alpha_2(t) = 0.45+0.93t$, $F(t) = (1-t/0.5)$; $X_0 = 0.069$, $X_1 = 5.33$, $X_2 = 21.1$, extended by a Q^2-dependent multiplier, also mimmicing DGLAP evolution

Low-energy diffraction= the background; an s-channel point of view

R. Fiore, L.L., V. Magas, F. Paccanoni, and A. Prokudin: J/Ψ photoproduction in a dual model, Phys, Rev, **D75** (2007) 116005.

Regge trajectories, including that of the Pomeron, are nonlinear complex functions, with a limited real part, which impliies that the resonances terminate. The Pomeron trajectory terminates before it would arrive to the first resonance (with sping 2), i.e. by construction, Re ♋(t) < 2.

The Pomeron trajectory

The Pomeron trajectory has threshold singularities, the lowest one being due to the two-pion exchange, required by the $t-$channel unitarity. There is a constrain (Barut, Zwanziger; Gribov) from the $t-$ channel unitarity, by which

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

where t_0 is the lightest threshold. For the Pomeron trajectory it is $t_0 = 4m_\pi^2$, and near the threshold:

$$\alpha(t) \sim \sqrt{4m_\pi^2 - t}. \qquad (1)$$

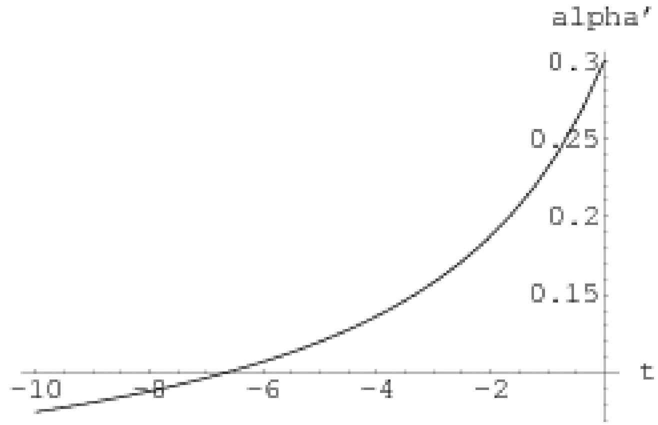
The observed nearly linear behaviour of the trajectory is promoted by higher, additive thresholds.

Asymptotically, the trajectories are logarithmic. This follows from the compatibility of the Regge behavior with the quark counting rules (Brodsky, Farrar; MMT), as well as from the solution of the BFKL equation. A simple parametrization combining the linear behaviour at small $|t|$ with its logarithmic asymptotic is:

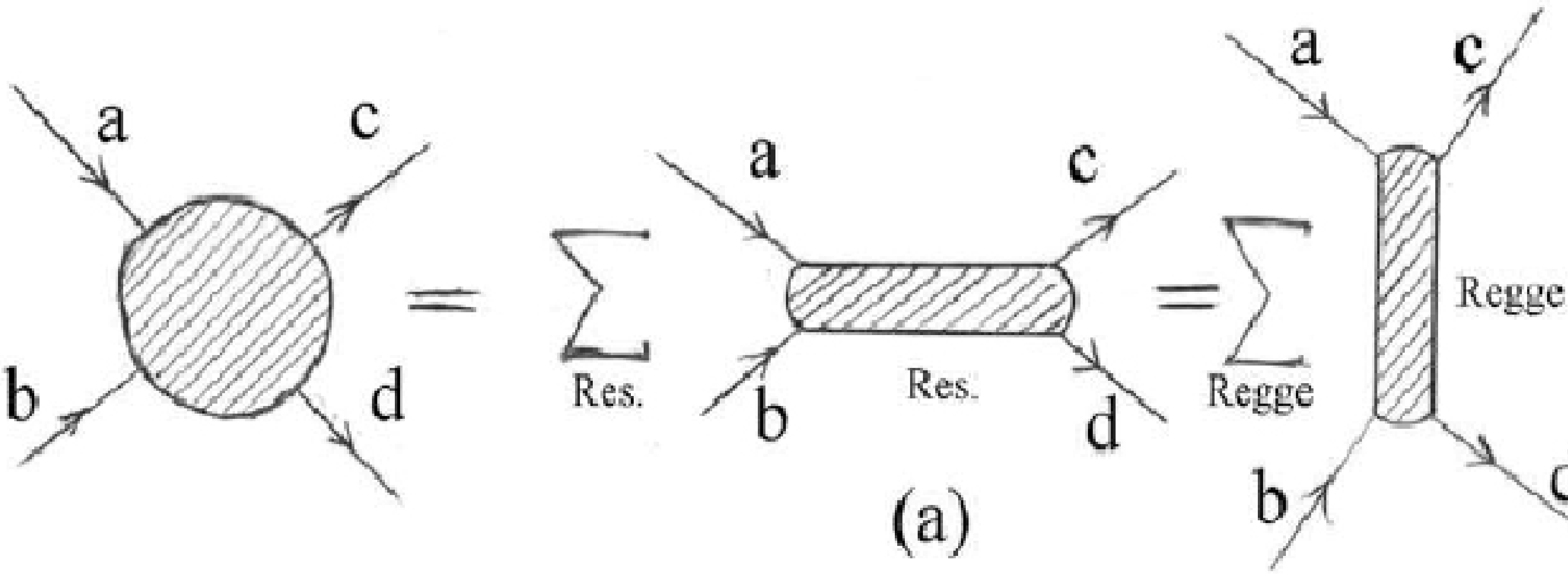
$$\alpha(t) = \alpha_0 - \gamma \ln(1 - \beta_1 t).$$

Nearly linear at small $|t|$, it reproduces the forward cone of the differential cross section, while its logarithmic asymptotic provides for the wide-angle scaling behavior. A combined form is:

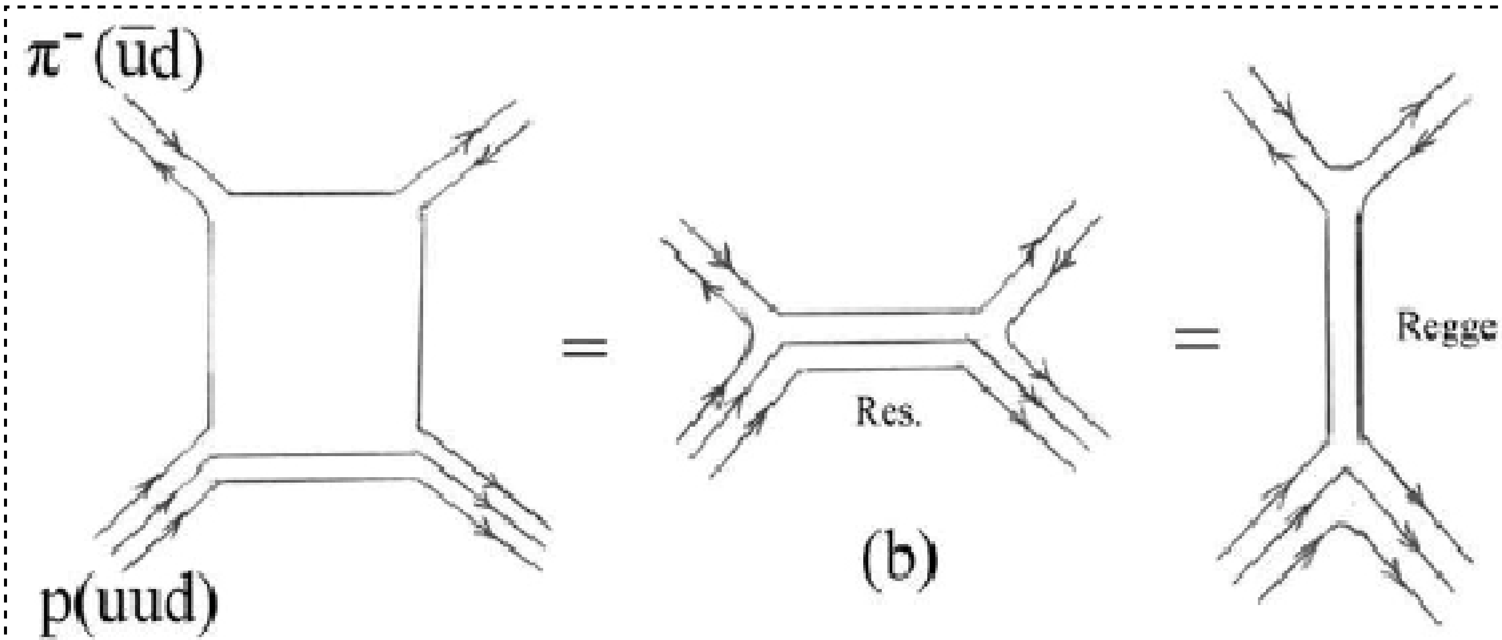
$$\alpha(t) = \alpha_0 - \gamma \ln(1 + \beta_2 \sqrt{t_0 - t}).$$



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



(a)



$\pi^-(\bar{u}d)$
p(uud)
Res.
Regge
(b)

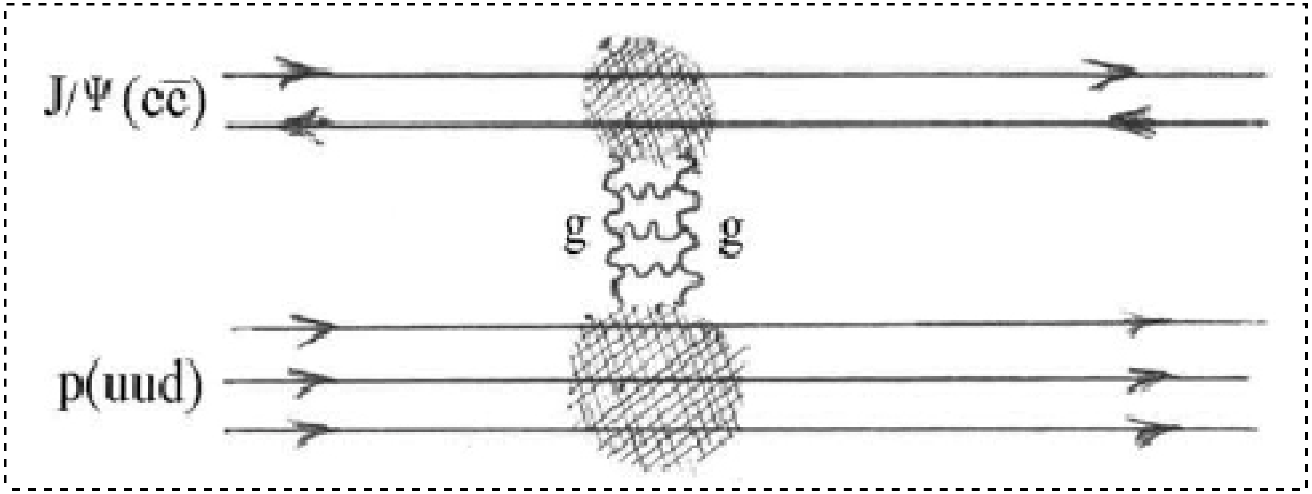

J/Ψ (cc̄)
g
g
p(uud)

TABLE I: Two-component duality

$\mathcal{I}mA(a+b\rightarrow c+d)=$	R	Pomeron
$s-$channel	$\sum A_{Res}$	Non-resonant background
$t-$channel	$\sum A_{Regge}$	Pomeron $(I=S=B=0;\ C=+1)$
Duality quark diagram	Fig. 1b	Fig. 2
High energy dependence	$s^{\alpha-1},\ \alpha<1$	$s^{\alpha-1},\ \alpha\geq 1$

The (s,t) term of a dual amplitude is

$$D(s,t) = c\int_0^1 dx\Big(\frac{x}{g_1}\Big)^{-\alpha(s')-1}\Big(\frac{1-x}{g_2}\Big)^{-\alpha(t')-1},$$

where s and t are the Mandelstam variables, and g_1, g_2 are parameters, $g_1, g_2 > 1$. For simplicity, we set $g_1 = g_2 = g_0$.

1. Regge behavior, $s \to \infty$, $t = const$: $D(s,t) \sim s^{\alpha(t)-1}$;

2. Thereshold behavior, $s \to s_0$: $D(s,t) \sim \sqrt{s_0 - s}[const + \ln(1 - s_0/s)]$;

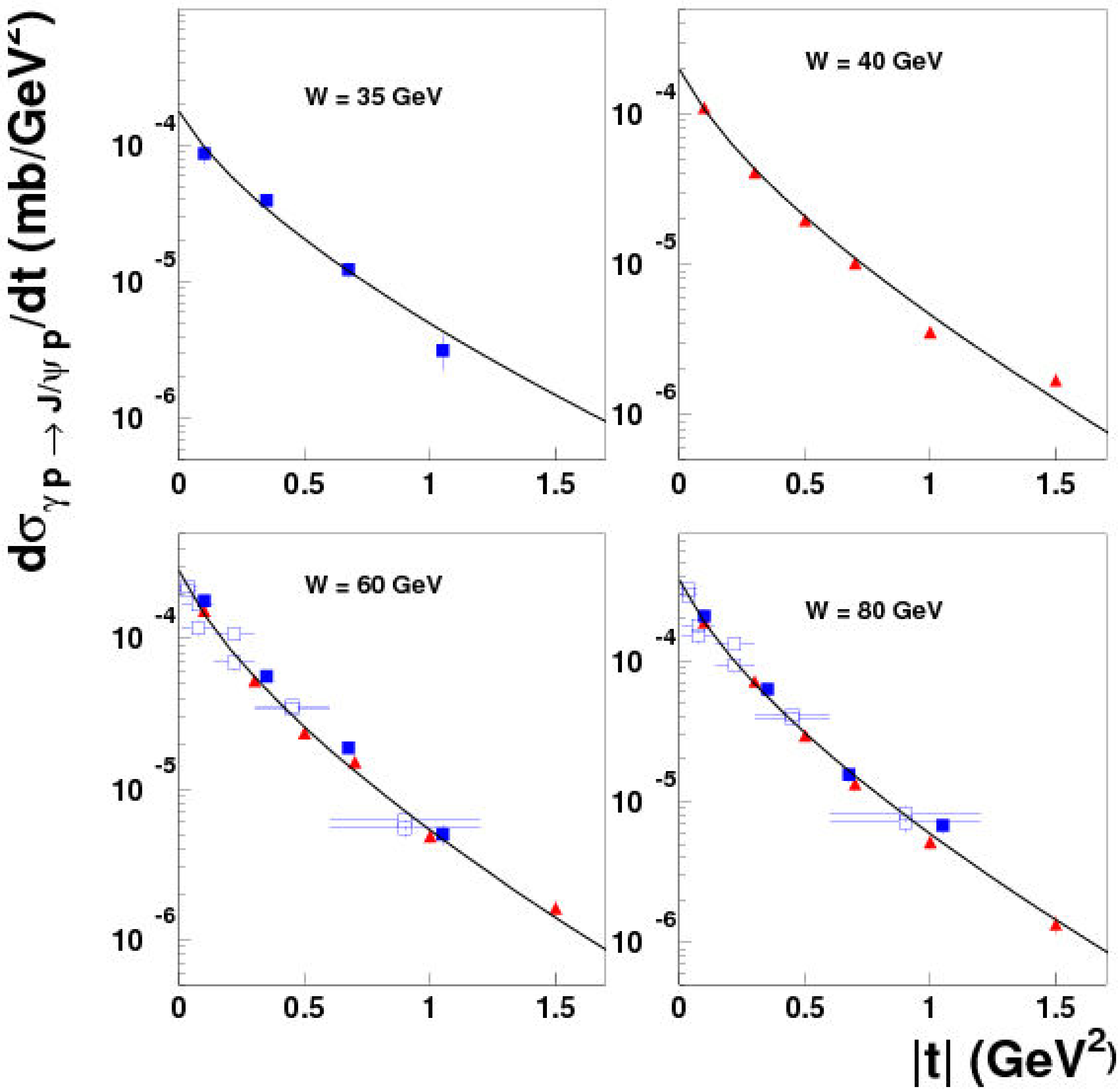
3. Direct-channel poles:

$$D(s,t)=\sum_{n=0}^{\infty}g^{n+1}\sum_{l=o}^{n}\frac{[-s\alpha'(s)]^{l}C_{n-l}(t)}{[n-\alpha(s)]^{l+1}}.$$

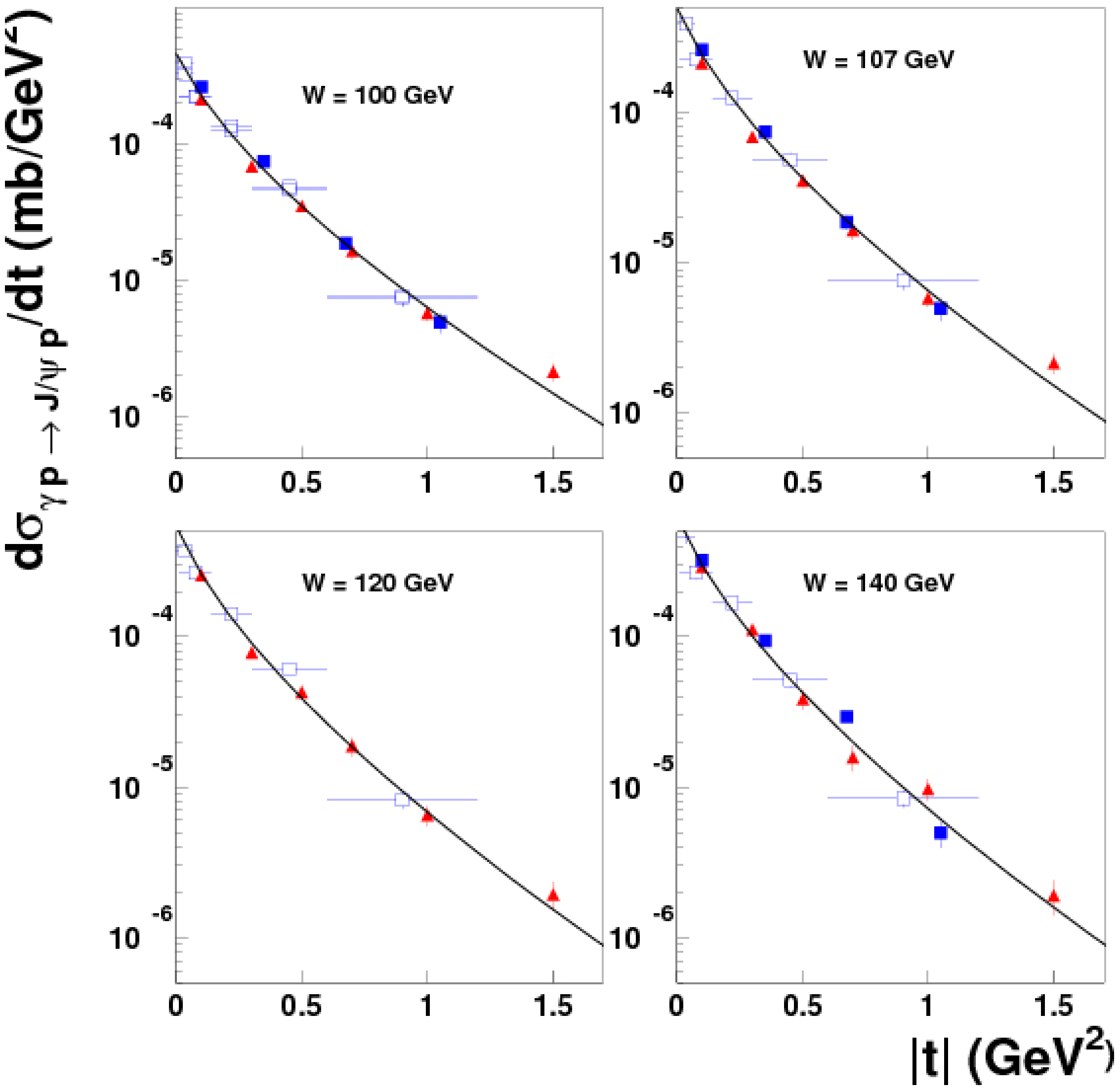
Exotic direct-channel trajectory: $\alpha(s)=\alpha(0)+\alpha_1(\sqrt{s_0}-\sqrt{s_0-s})$.

"GOLDEN" diffraction reaction: $J/\Psi p-$ scattering: By VMD, photoproduction is reduced to elastic hadron scattering:

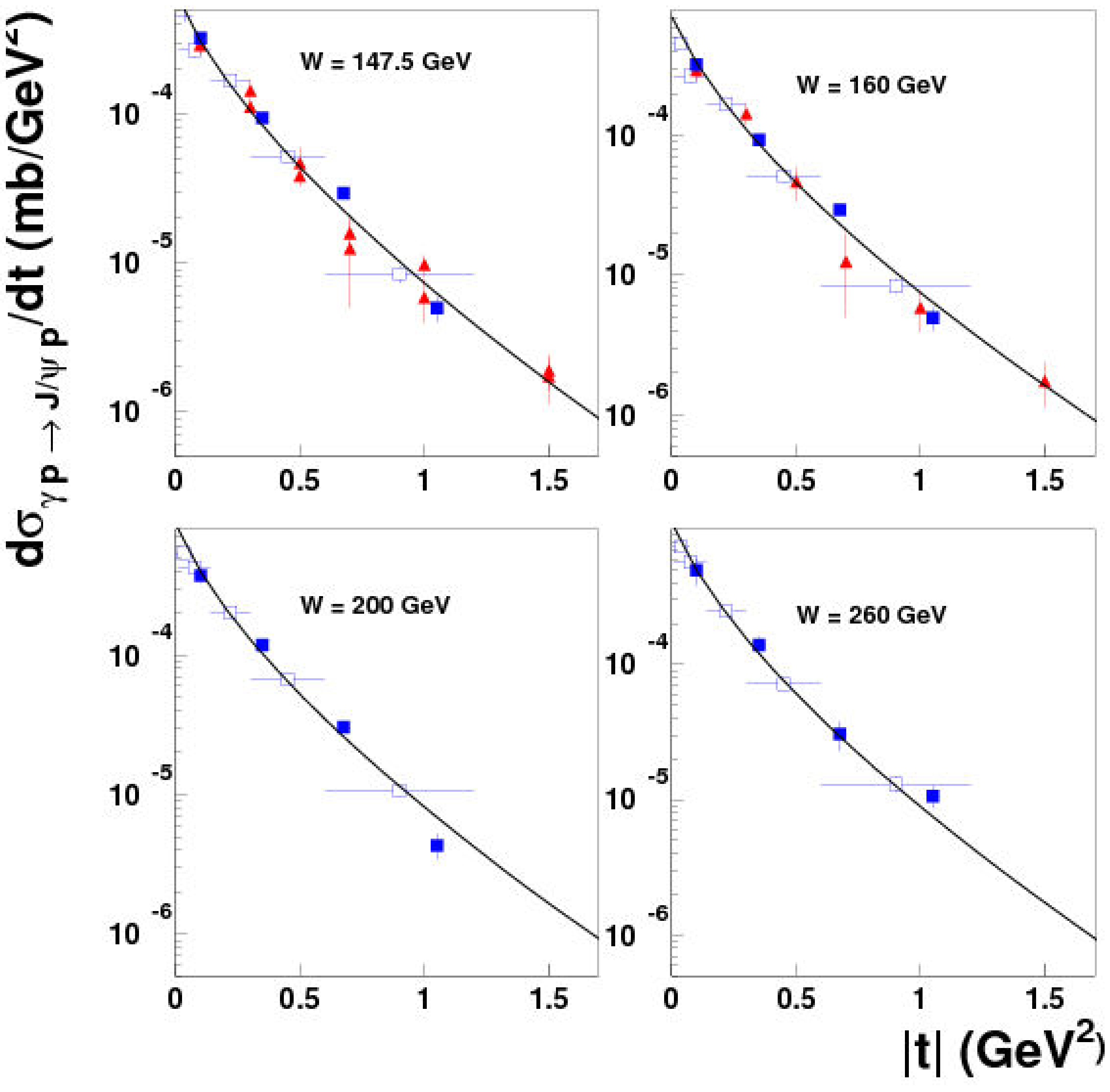
$$D(\gamma p-Vp)=\sum\frac{e}{f_V}D(Vp-Vp).$$



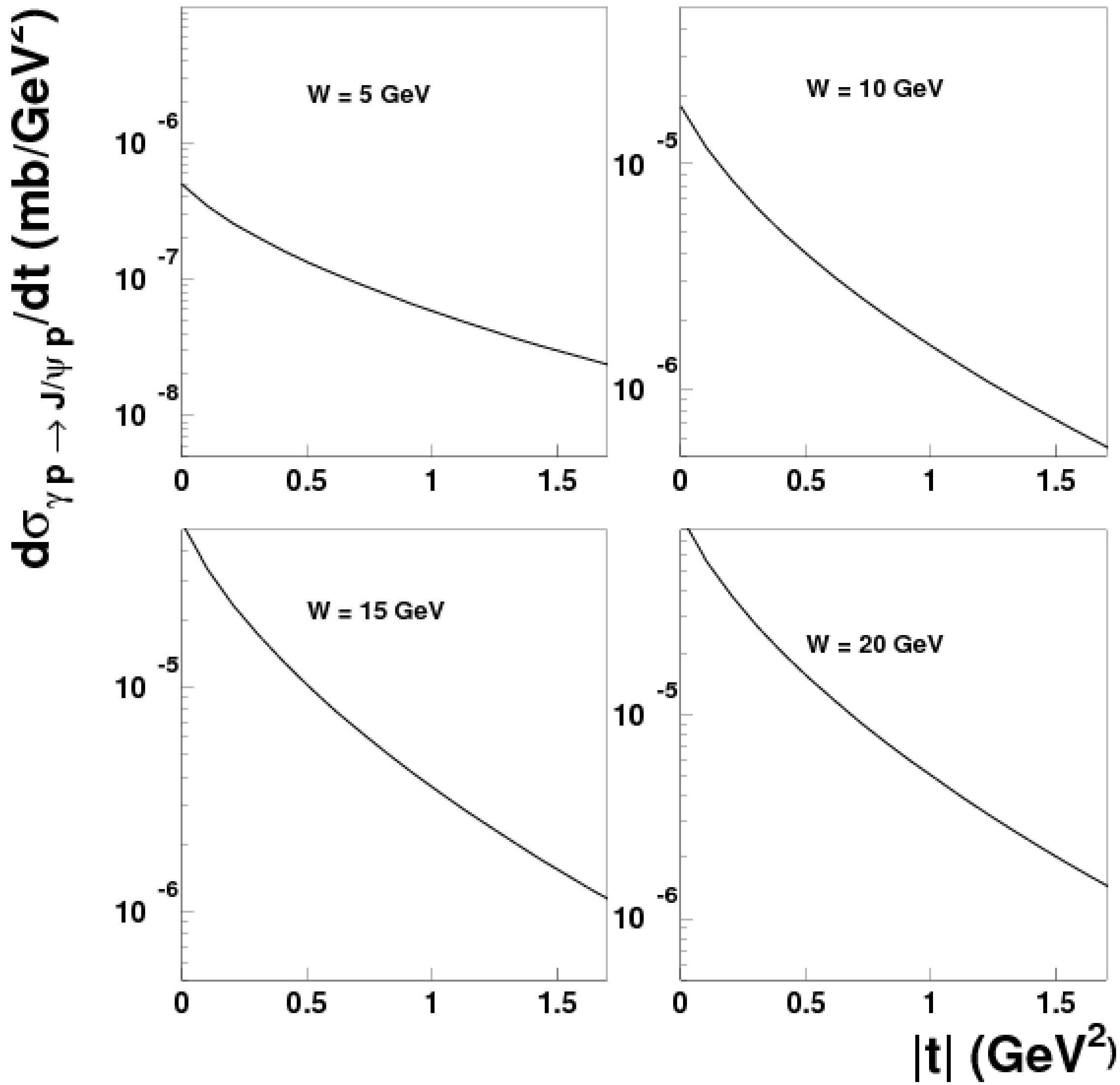
$d\sigma_{\gamma p \to J/\psi p}/dt$ (mb/GeV^2)
W = 35 GeV
W = 40 GeV
W = 60 GeV
W = 80 GeV
10^{-4}
10^{-5}
10^{-6}
0
0.5
1
1.5
|t| (GeV^2)



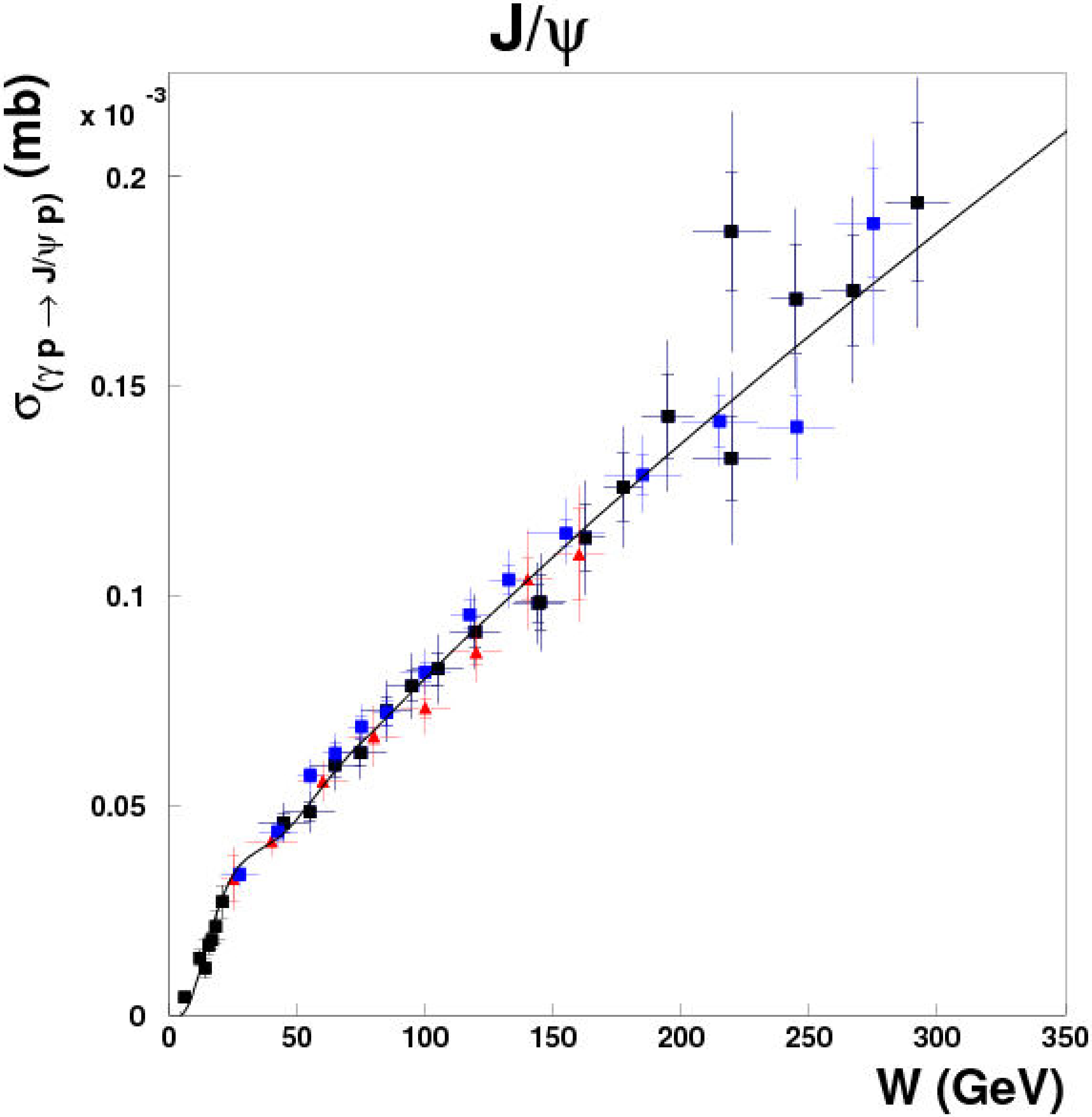
W = 100 GeV
W = 107 GeV
W = 120 GeV
W = 140 GeV
$d\sigma_{\gamma p \to J/\psi\, p}/dt$ (mb/GeV^2)
|t| (GeV^2)



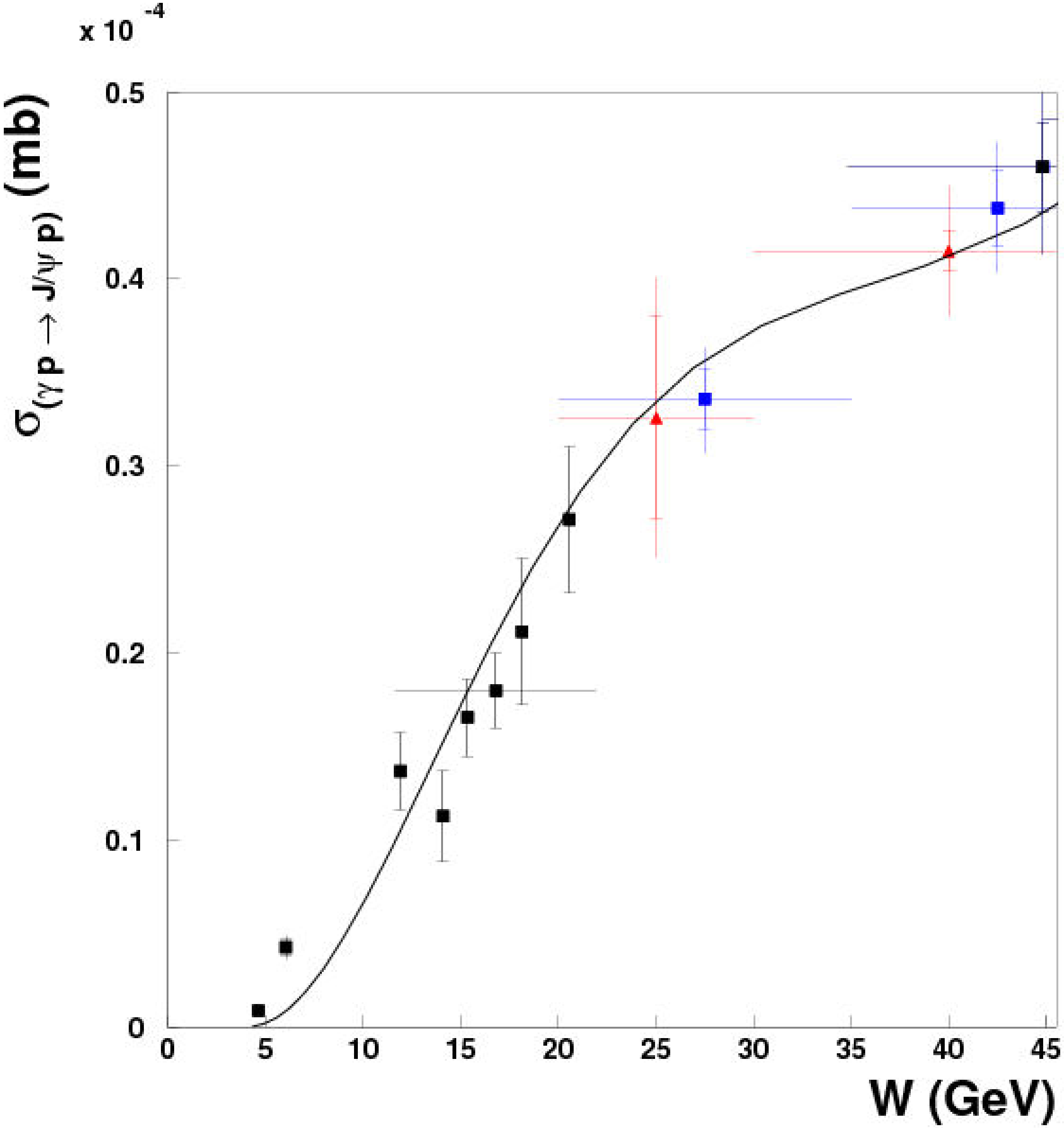
W = 147.5 GeV
W = 160 GeV
W = 200 GeV
W = 260 GeV
$d\sigma_{\gamma p \to J/\psi p}/dt$ (mb/GeV^2)
|t| (GeV^2)

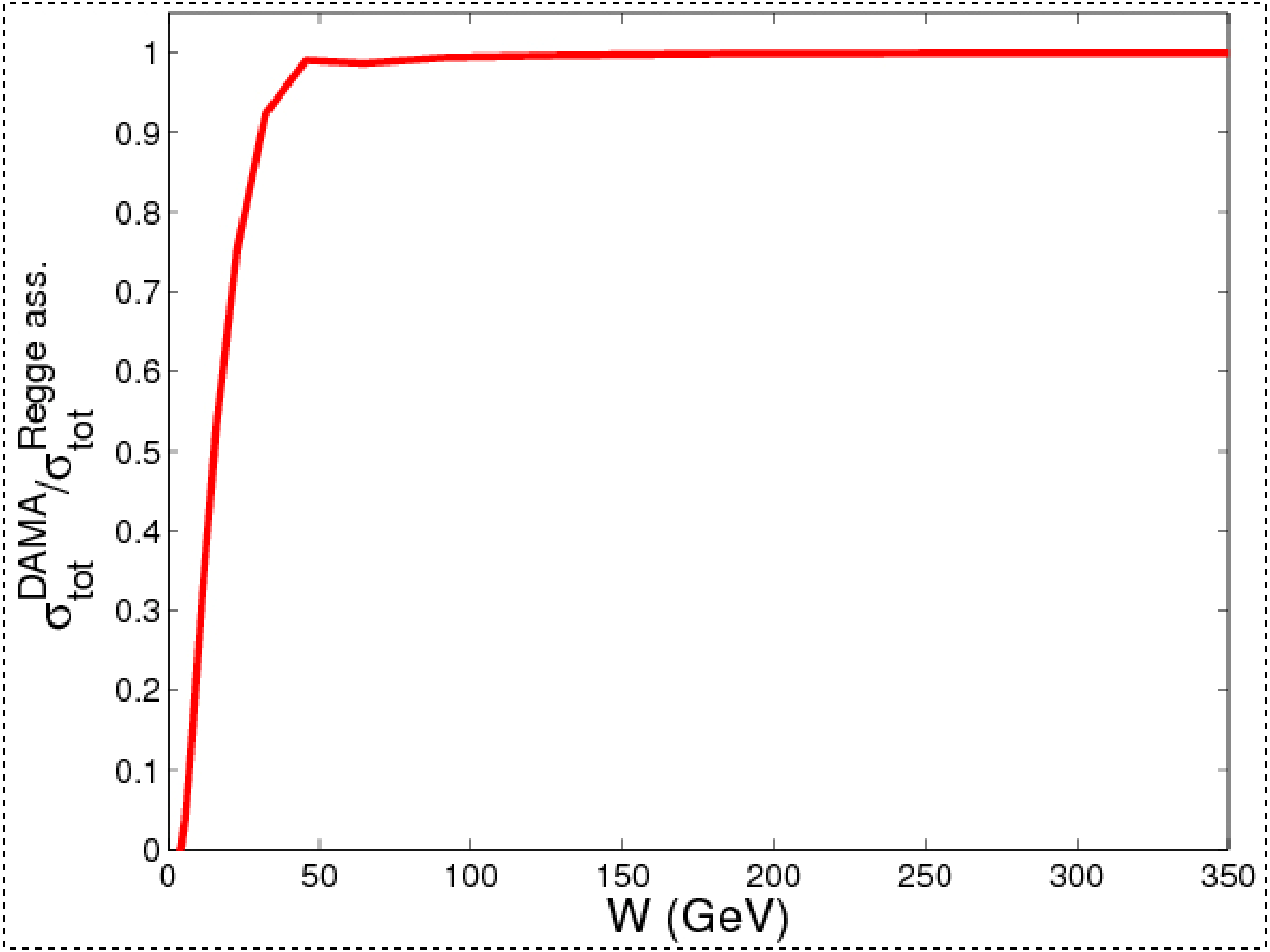


dσ γ p → J/ψ p /dt (mb/GeV²)
W = 5 GeV
W = 10 GeV
W = 15 GeV
W = 20 GeV
10^-5
10^-6
10^-7
10^-8
0
0.5
1
1.5
|t| (GeV²)

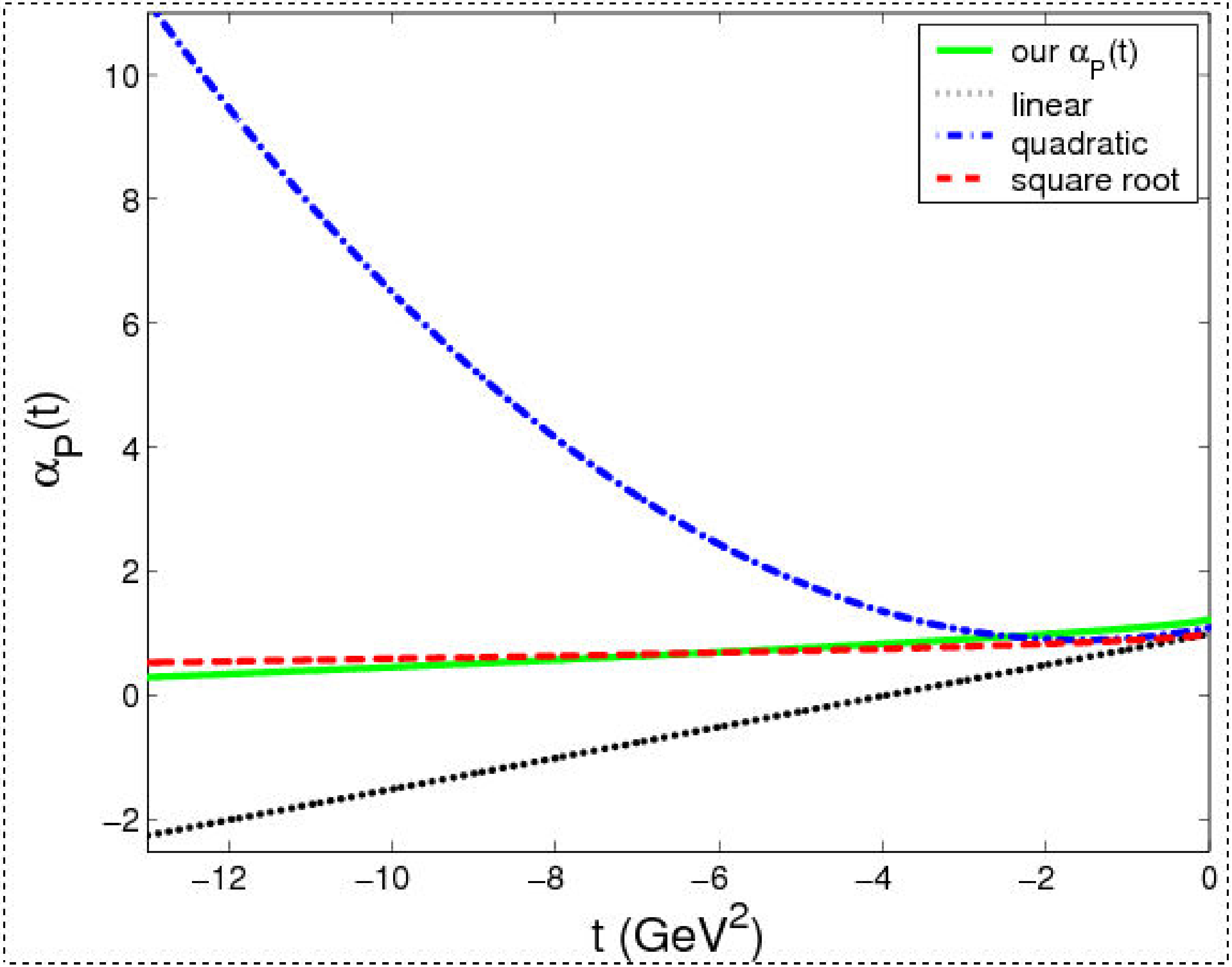


J/ψ
σ(γ p → J/ψ p) (mb)
x 10 -3
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
W (GeV)

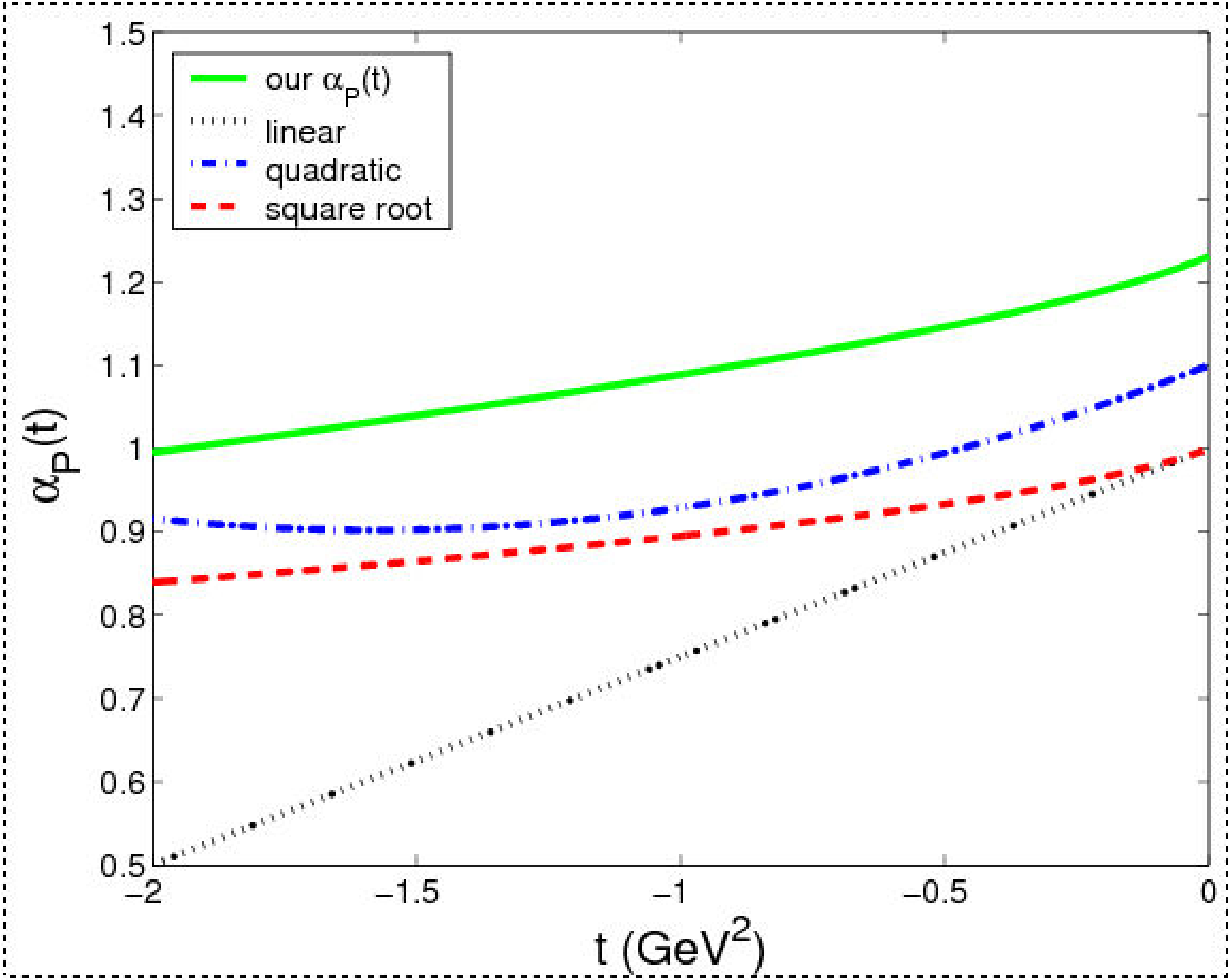

x 10^-4
σ(γ p → J/ψ p) (mb)
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
45
W (GeV)



$\sigma_{tot}^{DAMA}/\sigma_{tot}^{Regge\ ass.}$
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
W (GeV)

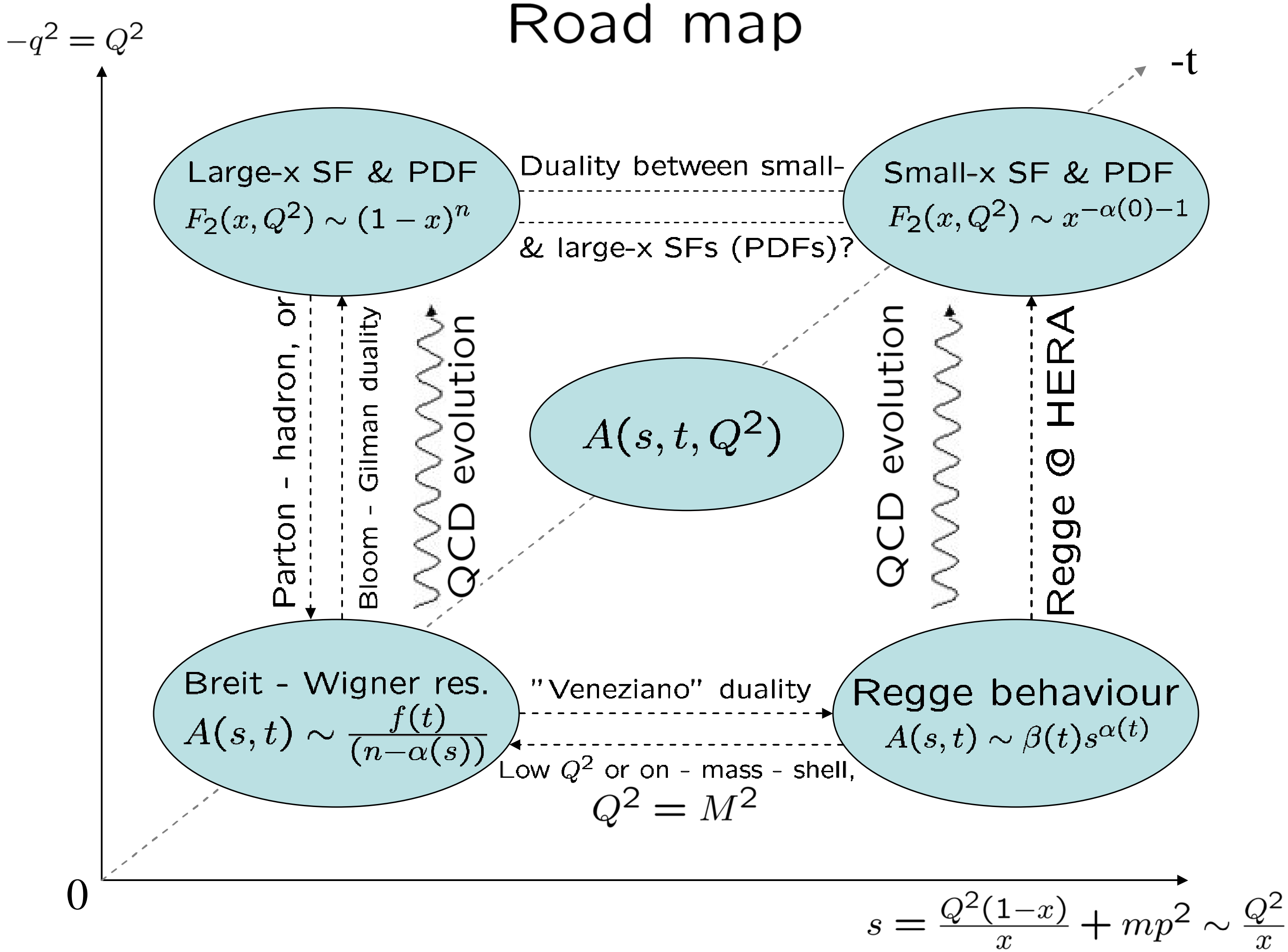


our $\alpha_P(t)$
linear
quadratic
square root
$\alpha_P(t)$
t (GeV^2)
10
8
6
4
2
0
−2
−12
−10
−8
−6
−4
−2
0



our $\alpha_P(t)$
linear
quadratic
square root
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
−2
−1.5
−1
−0.5
0
$\alpha_P(t)$
t (GeV^2)

Road map



$-q^2 = Q^2$
-t
Large-x SF & PDF
$F_2(x, Q^2) \sim (1-x)^n$
Duality between small-
& large-x SFs (PDFs)?
Small-x SF & PDF
$F_2(x, Q^2) \sim x^{-\alpha(0)-1}$
Parton - hadron, or
Bloom - Gilman duality
QCD evolution
$A(s, t, Q^2)$
QCD evolution
Regge @ HERA
Breit - Wigner res.
$A(s,t) \sim \frac{f(t)}{(n-\alpha(s))}$
"Veneziano" duality
Regge behaviour
$A(s,t) \sim \beta(t) s^{\alpha(t)}$
Low Q^2 or on - mass - shell,
$Q^2 = M^2$
0
$s = \frac{Q^2(1-x)}{x} + mp^2 \sim \frac{Q^2}{x}$

From photo- to electroproduction (off mass-shall, Q^2>0):

R. Fiore, L.L. Jenkovszky, V.K. Magas, S. Melis, and A. Prokudin, Exclusive J/Ψ ***electroproduction*** in a dual model, arXiv:0911.2094, Phys. Rev. D, in press.

The (s,t) term of a dual amplitude is

$$D(s,t) = c\int_0^1 dx \Big(\frac{x}{g_1}\Big)^{-\alpha(s')-1}\Big(\frac{1-x}{g_2}\Big)^{-\alpha(t')-1},$$

where s and t are the Mandelstam variables, and g_1, g_2 are parameters, $g_1, g_2 > 1$. For simplicity, we set $g_1 = g_2 = g_0$.

1. Regge behavior, $s \to \infty$, $t = const$: $D(s,t) \sim s^{\alpha(t)-1}$;

2. Thereshold behavior, $s \to s_0$: $D(s,t) \sim \sqrt{s_0 - s}[const + \ln(1 - s_0/s)]$;

The off-shall scattering amplitude is given by

$$D(s,t,Q^2) = c\int_0^1 dz(\frac{z}{g})^{-\alpha(s')-\beta(Q^{2''})-1}(\frac{1-z}{g})^{-\alpha_t(t'')-\beta(Q^{2'})},$$

where $\beta(Q^2)$ is a monotonically decreasing dimensionless function of Q^2; $x' = x(1-z)$, $x'' = xz$, where $x \equiv s, Q^2, t$.

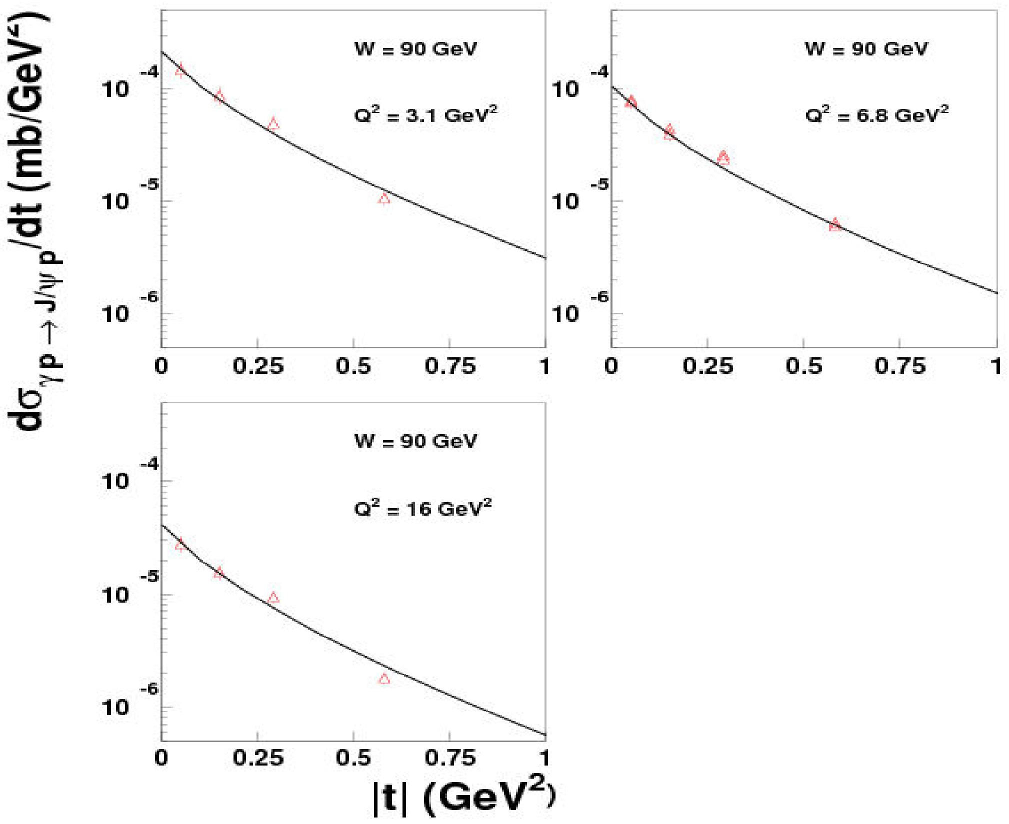
The total transverse cross section reads

$$\sigma_T(s,Q^2) = \int_{-t_{max}=s/2}^{t_{thr.}\approx 0} dt\, \frac{d\sigma_T}{dt}(s,t,Q^2)\,.$$

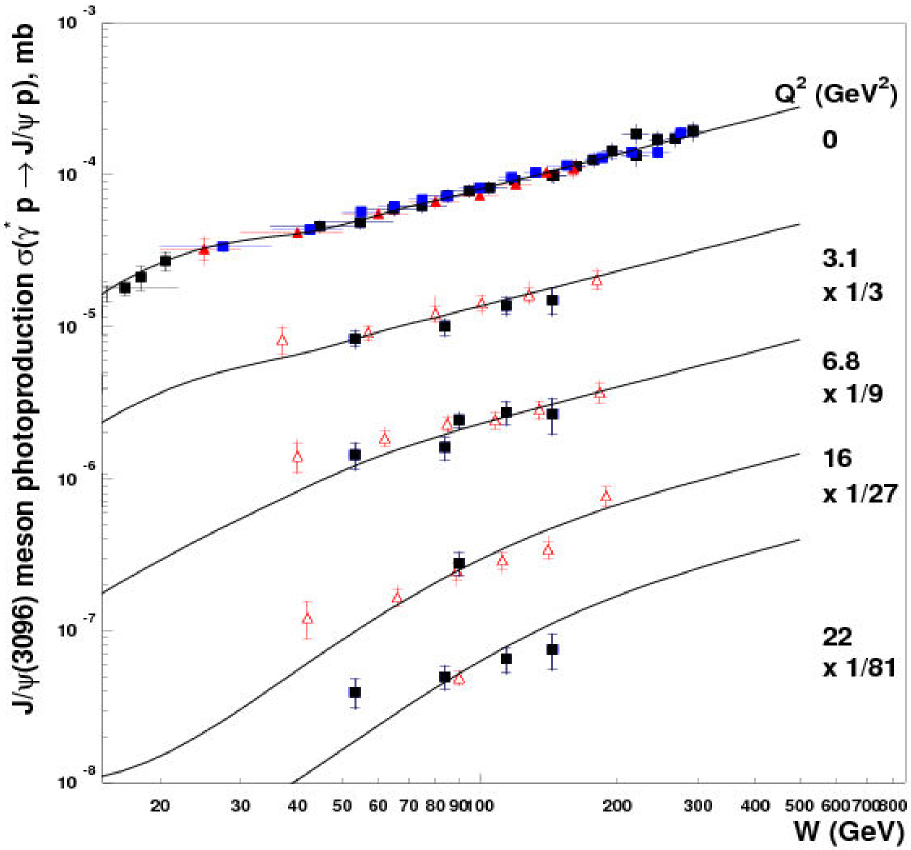
The total elastic cross section is the sum of longitudinal and transverse cross sections:

$$\sigma_{el}(s,Q^2) = (1+R(Q^2))\sigma_T(s,Q^2)\,,$$

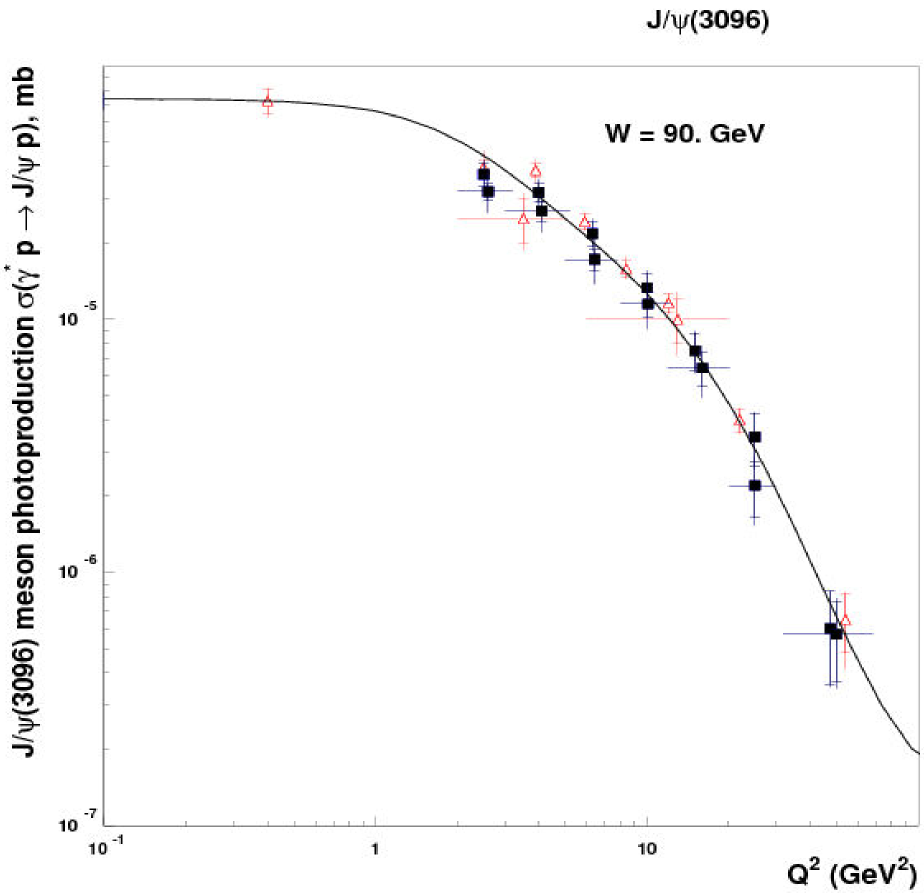
where $R = \sigma_L/\sigma_T$.



W = 90 GeV
Q^2 = 3.1 GeV^2
W = 90 GeV
Q^2 = 6.8 GeV^2
W = 90 GeV
Q^2 = 16 GeV^2
dσ_{γp → J/ψ p}/dt (mb/GeV^2)
|t| (GeV^2)
10^-4
10^-5
10^-6
0
0.25
0.5
0.75
1



J/ψ(3096) meson photoproduction σ(γ* p → J/ψ p), mb
Q² (GeV²)
0
3.1
x 1/3
6.8
x 1/9
16
x 1/27
22
x 1/81
W (GeV)


J/ψ(3096)
W = 90. GeV
J/ψ(3096) meson photoproduction σ(γ* p → J/ψ p), mb
10^-5
10^-6
10^-7
10^-1
1
10
Q^2 (GeV^2)

Prospects:

1. Universal background;
2. Photo- and electroproduction near the threshold (JLab);
3. Different targets (nuclei effects);
4. Alternative vector mesons, e.g. Φ (Tedeschi at the JLab).

I Thanks the Organizeres

THE END