Electroproduction of vector mesons

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on behalf the ZEUS collaboration

outline

Soft - hard

$$r_V \equiv \frac{\sigma(\gamma^* p \to Vp)}{\sigma_{tot}(\gamma^* p)}$$

Effective scale

soft - hard

Energy dependence of cross section ⇒ dynamics of process.

W dependence Regge type (DL) ⇒ process called soft.

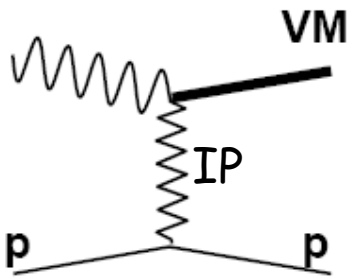
Example for soft: total hadron-p cross section.

W dependence described by pQCD ⇒ process called hard.

Example for hard: Exclusive J/ψ electroproduction.

At HERA see interplay of soft and hard.

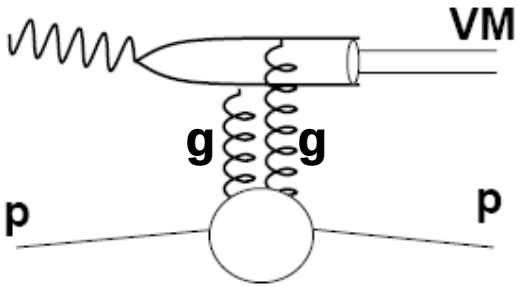
soft - hard transition



'soft'

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

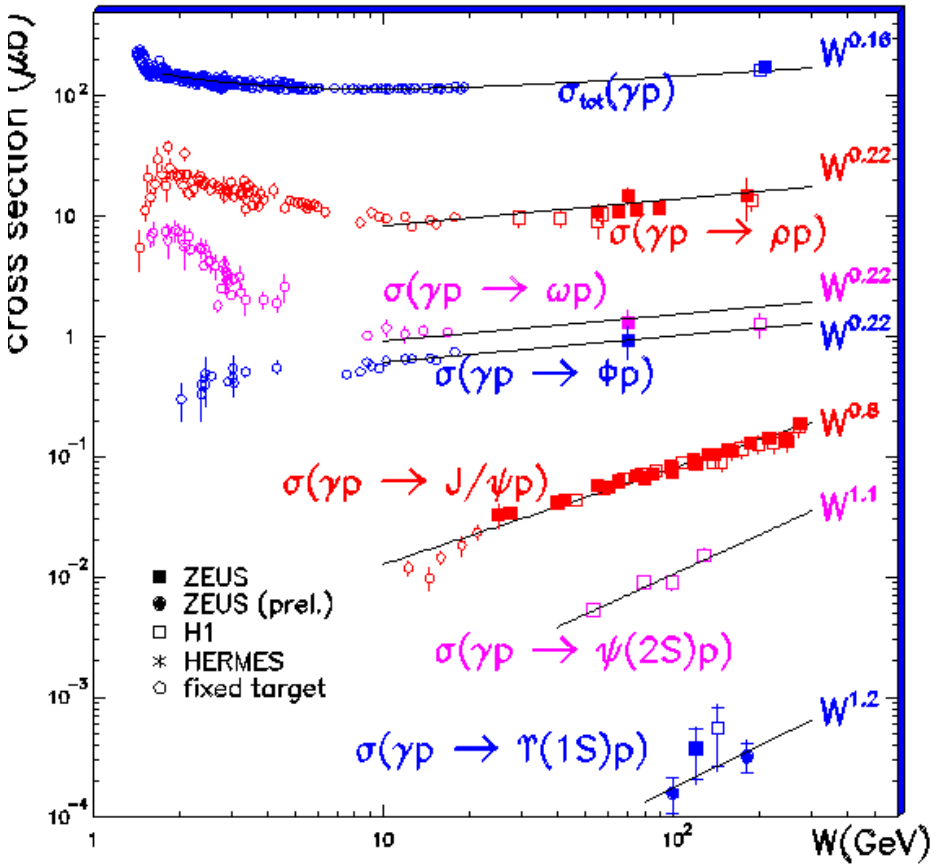
$$\frac{d\sigma}{dt} \propto e^{-b|t|}$$



'hard'

- Expect δ to increase from soft (~0.2, from 'soft Pomeron' value) to hard (~0.8, from $xg(x,Q^2)^2$)
- Expect b to decrease from soft (~10 GeV^{-2}) to hard (~4-5 GeV^{-2})

Photoproduction



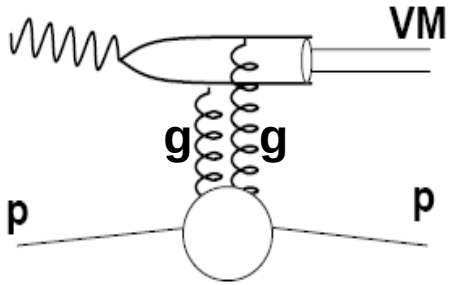
$$\sigma \propto W^{\delta}$$

process becomes hard as scale (mass) becomes larger.

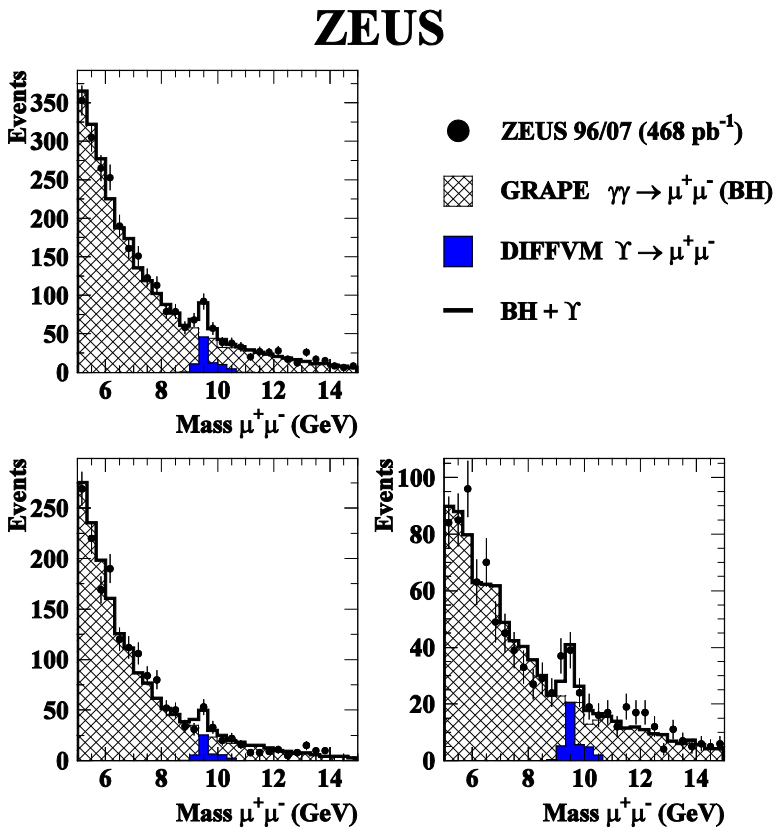
heavy quark mass ⇒ small configuration ⇒ color screening ⇒ σ small

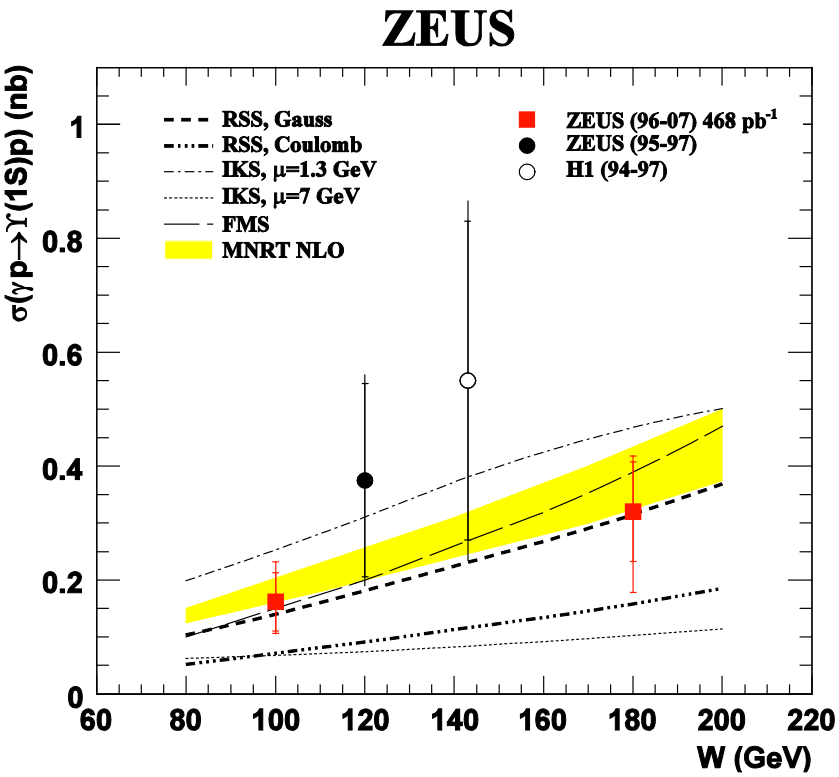
small size ⇒ resolve internal structure of proton

"elastic" scattering resolve 2-gluon in a colour-singlet configuration
$\sigma \sim xg(x,\mu^2)^2$ ⇒ steep rise with W

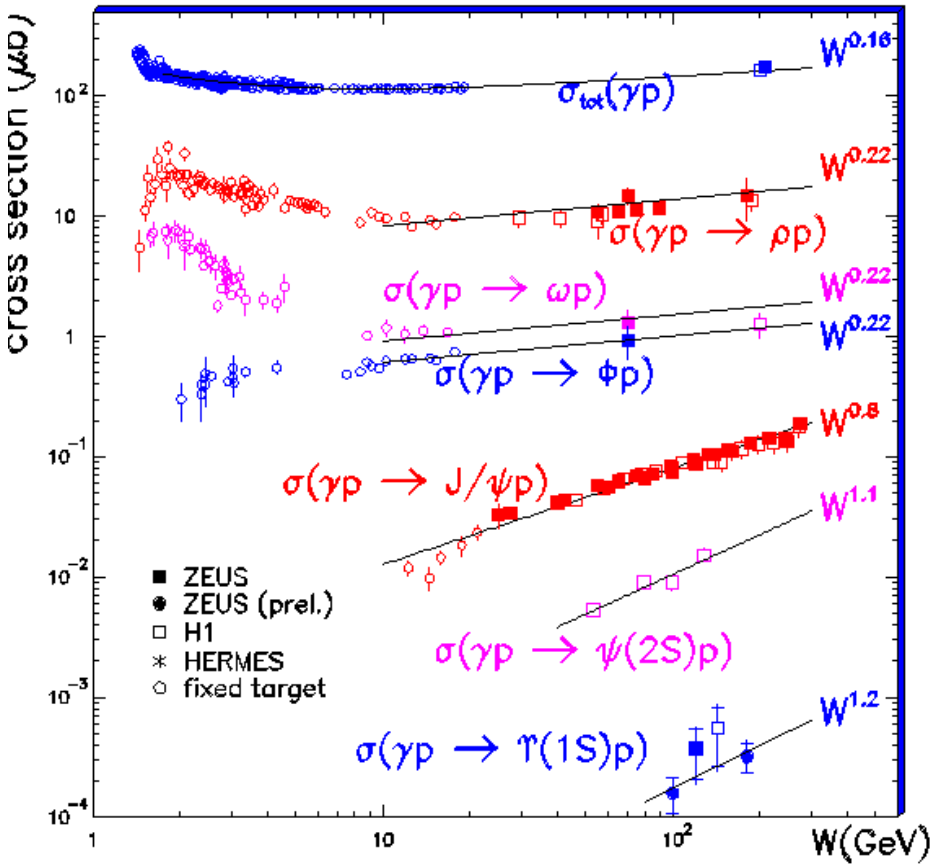


Upsilon photoproduction





Photoproduction



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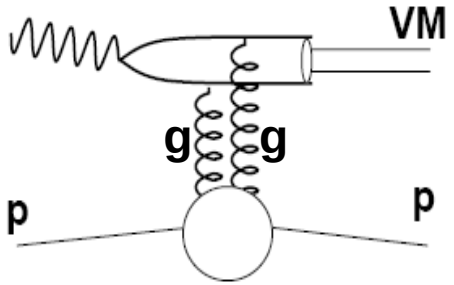
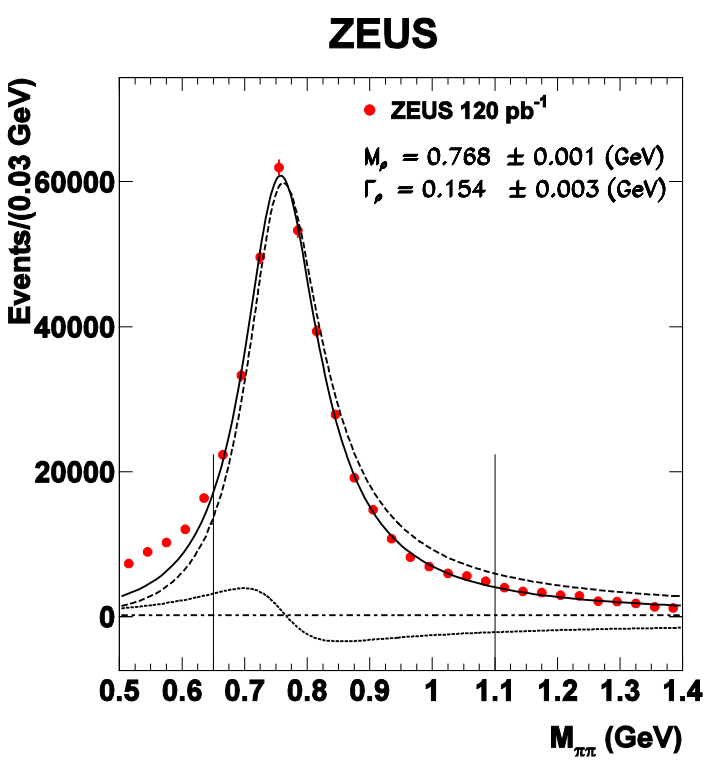
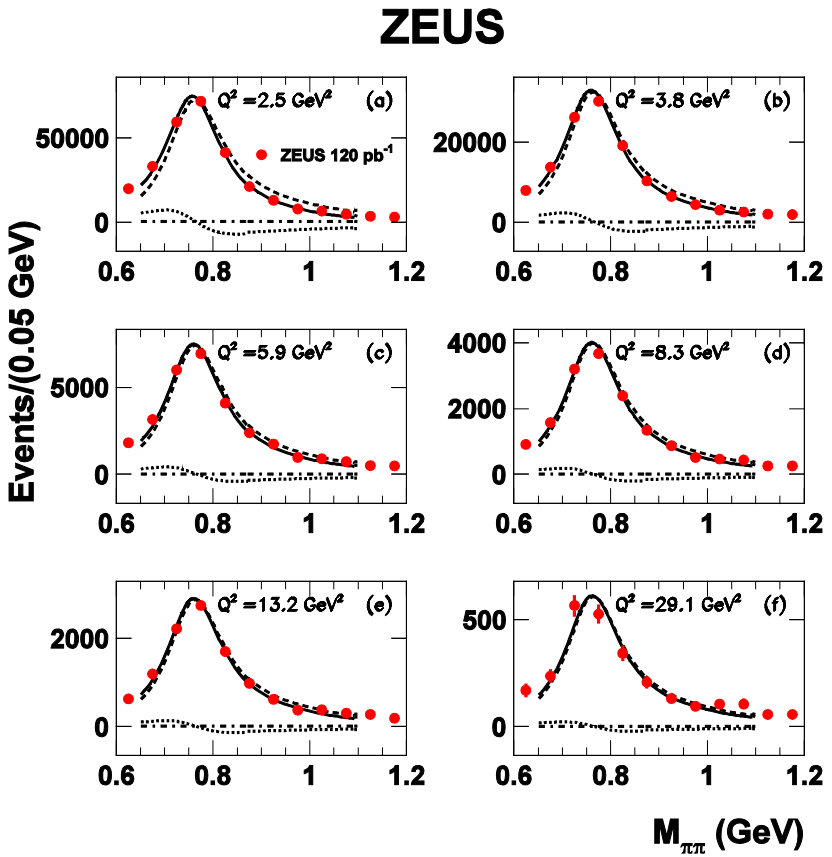


$\sigma(W) - \rho^0$

Fix mass – increase photon scale

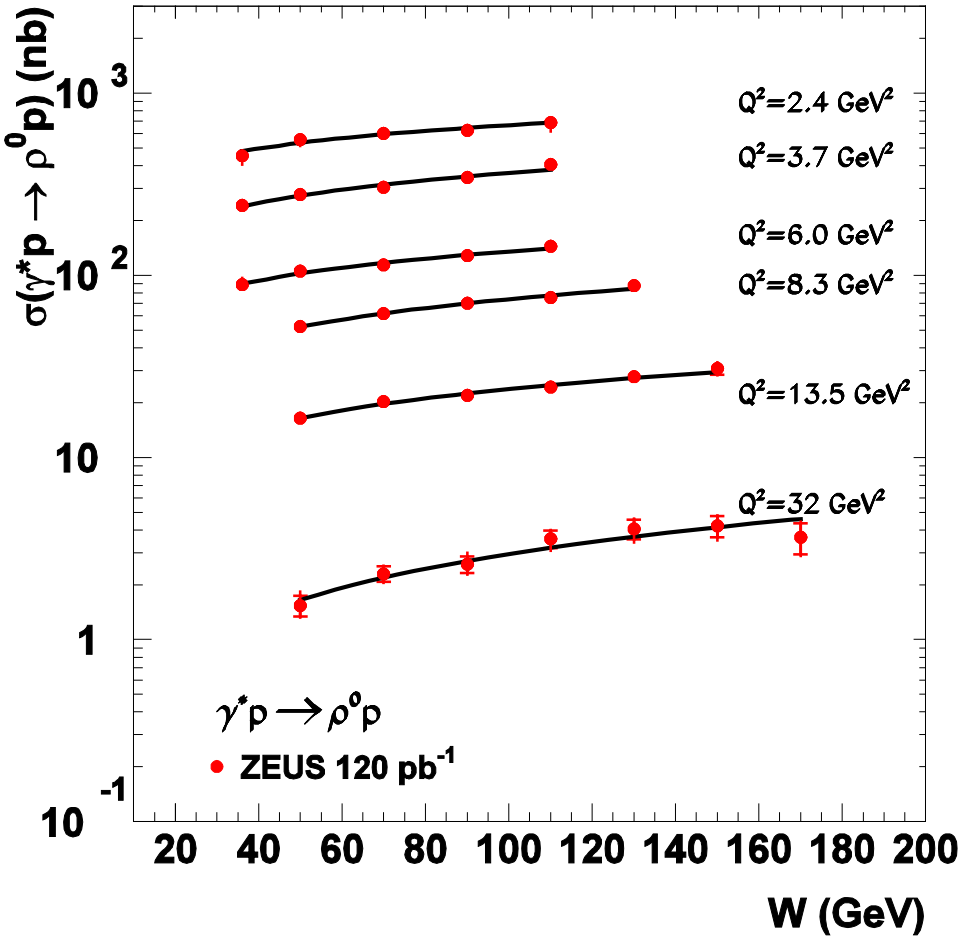


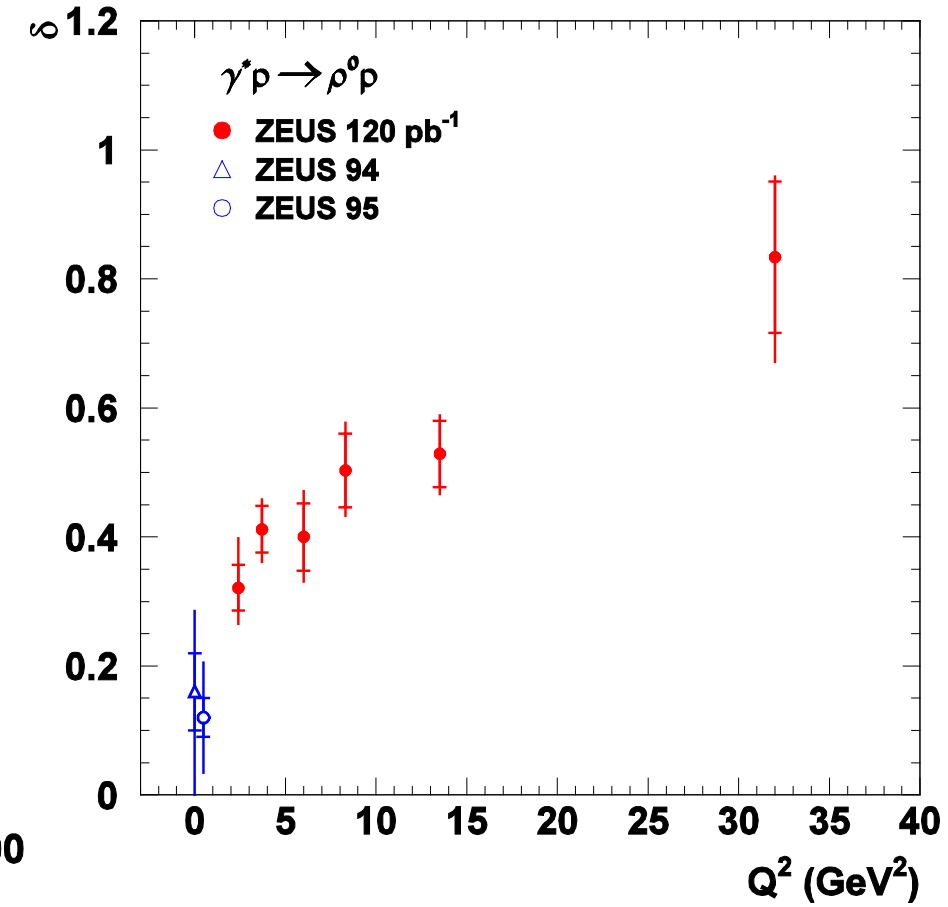


$\sigma(W)$ - ρ^0

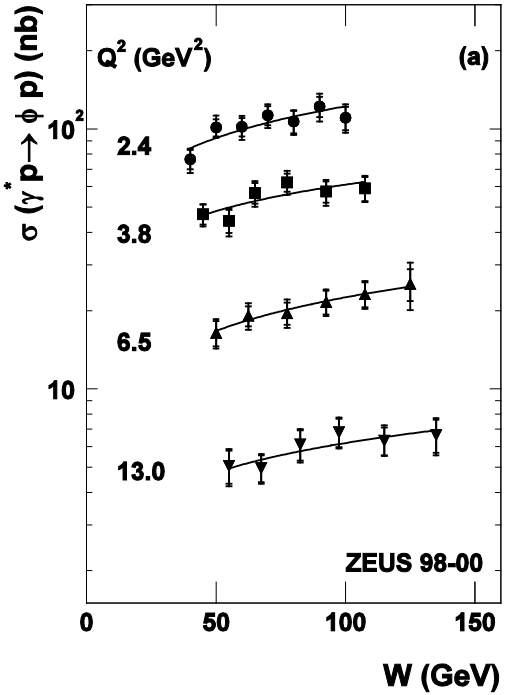
Fix mass – increase photon scale

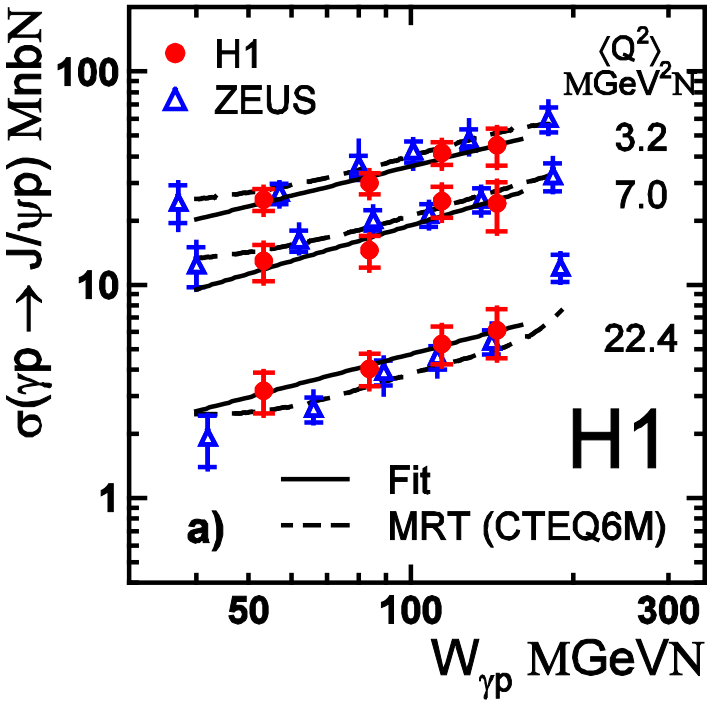
$$\sigma \propto W^{\delta}$$

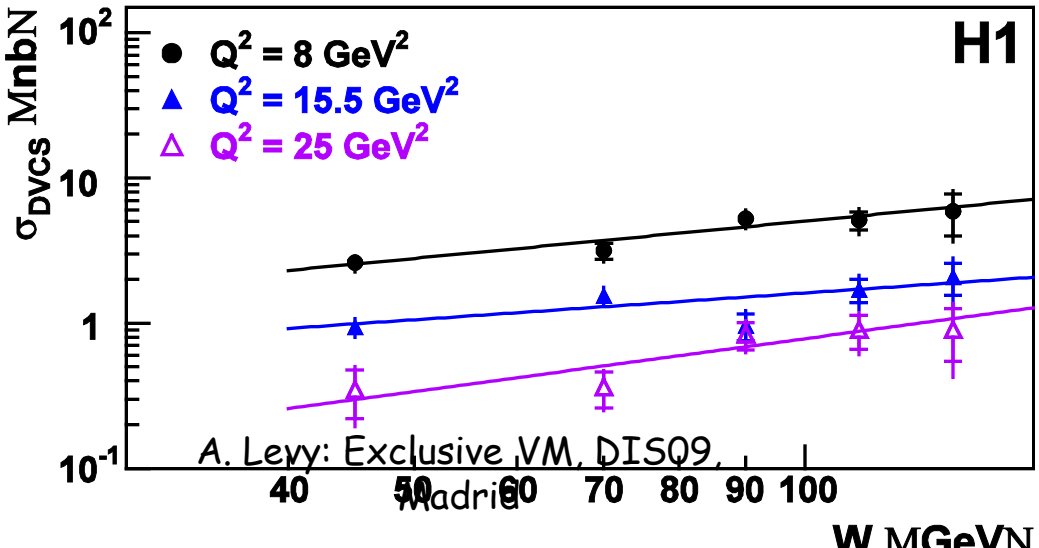




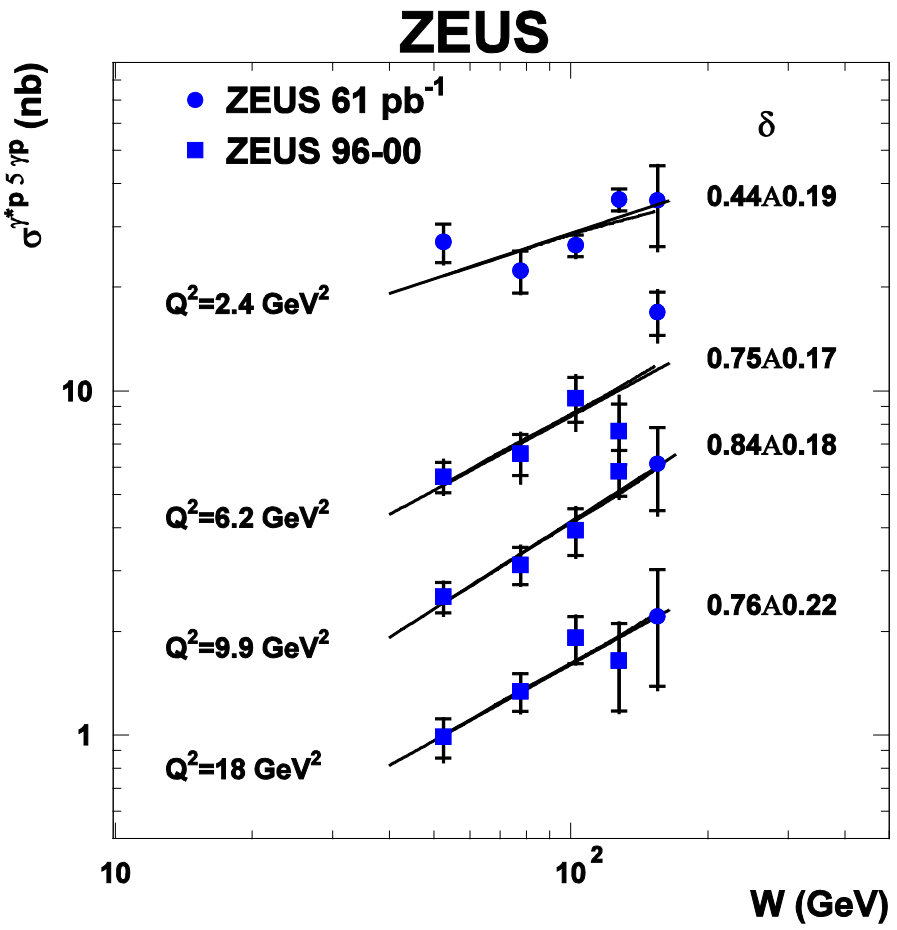
$\sigma(W)$ - ϕ, J/ψ, γ

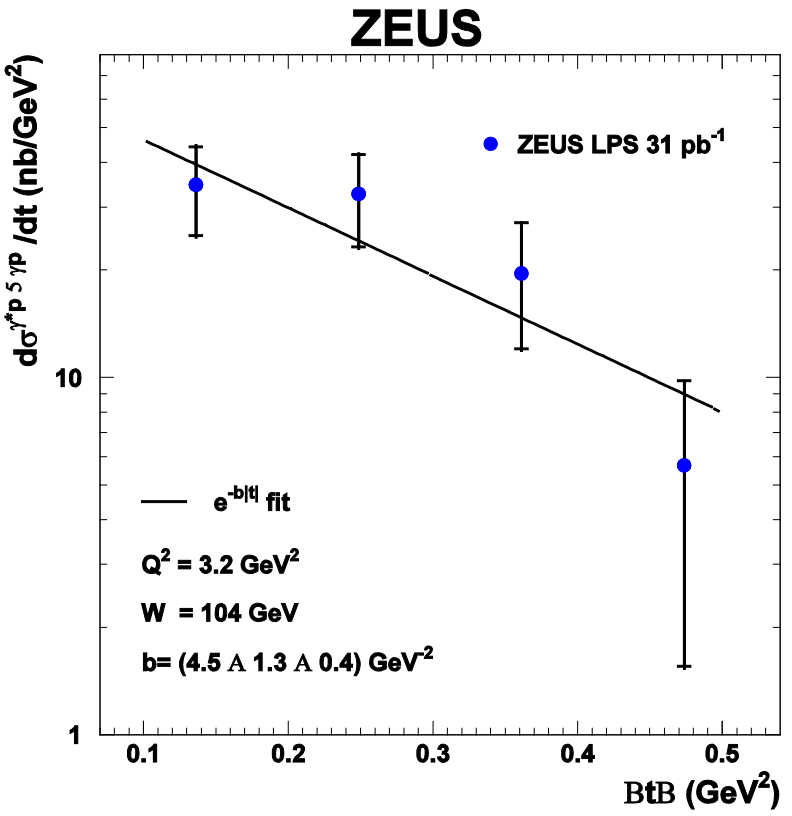




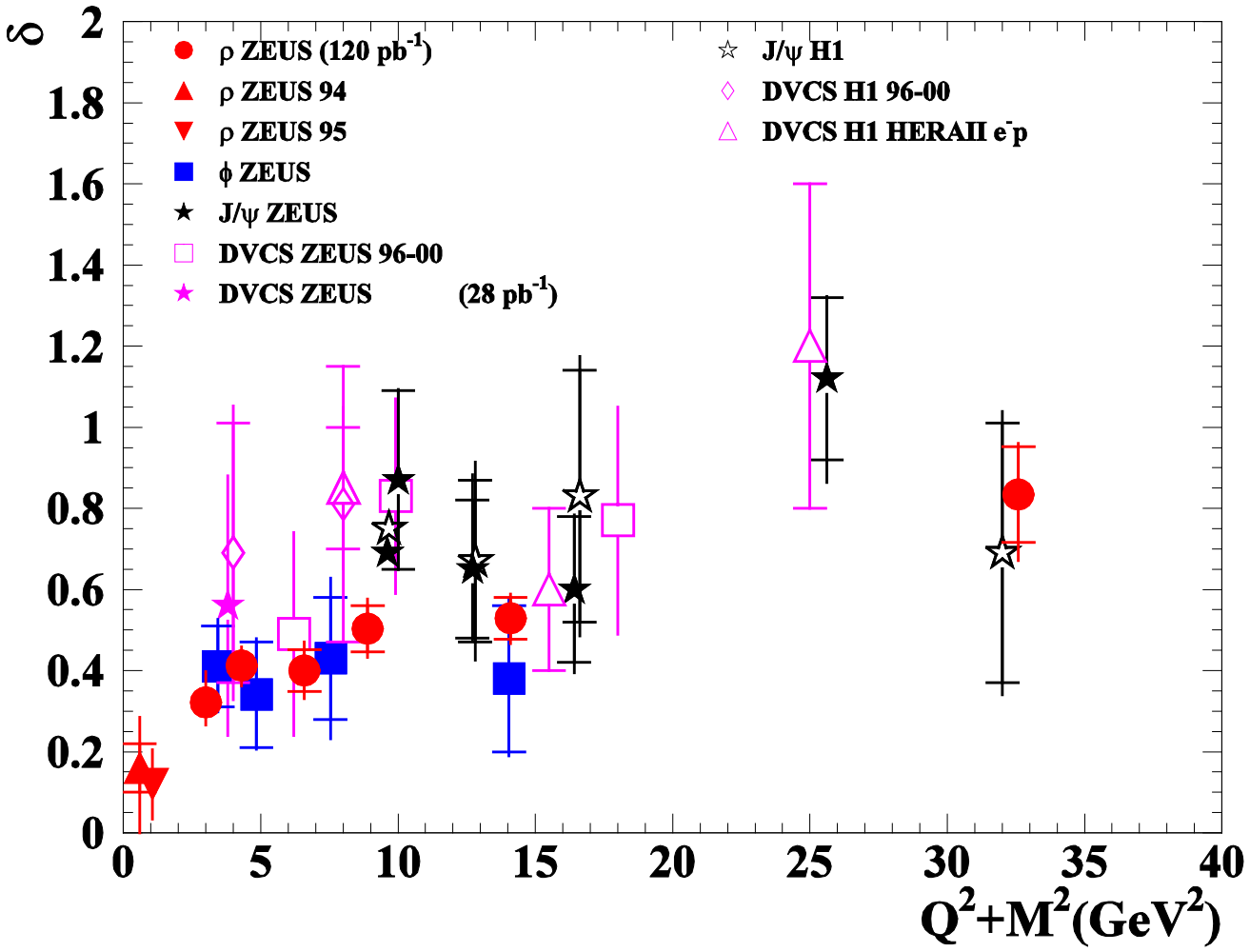


DVCS - ZEUS


ZEUS
ZEUS 61 pb-1
ZEUS 96-00
δ
0.44A0.19
0.75A0.17
0.84A0.18
0.76A0.22
Q2=2.4 GeV2
Q2=6.2 GeV2
Q2=9.9 GeV2
Q2=18 GeV2
σγ*p 5 γp (nb)
10
1
10
10 2
W (GeV)

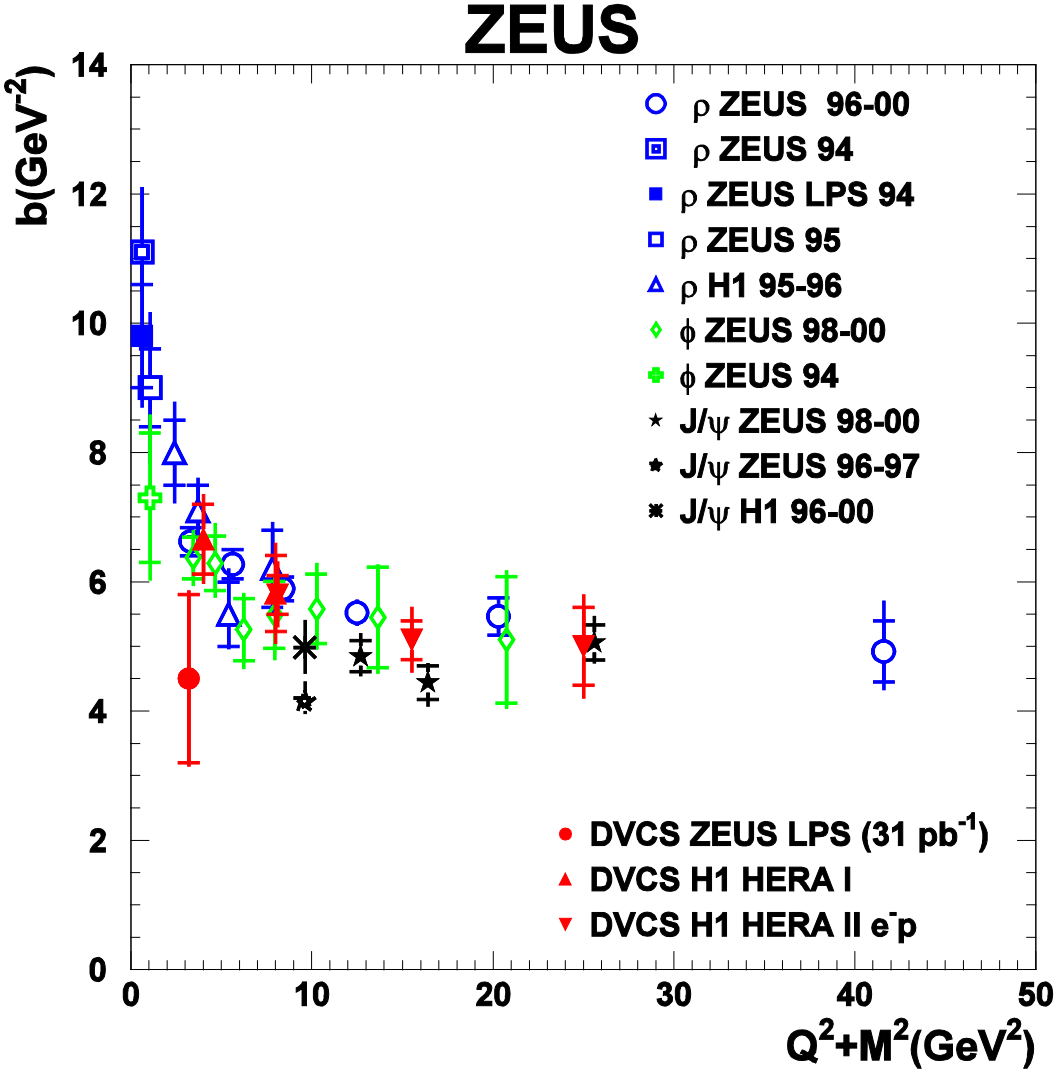

ZEUS
ZEUS LPS 31 pb-1
e-b|t| fit
Q2 = 3.2 GeV2
W = 104 GeV
b= (4.5 A 1.3 A 0.4) GeV-2
dσγ*p 5 γp /dt (nb/GeV2)
10
1
0.1
0.2
0.3
0.4
0.5
BtB (GeV2)

$\delta\,(Q^2+M^2)$ - VM

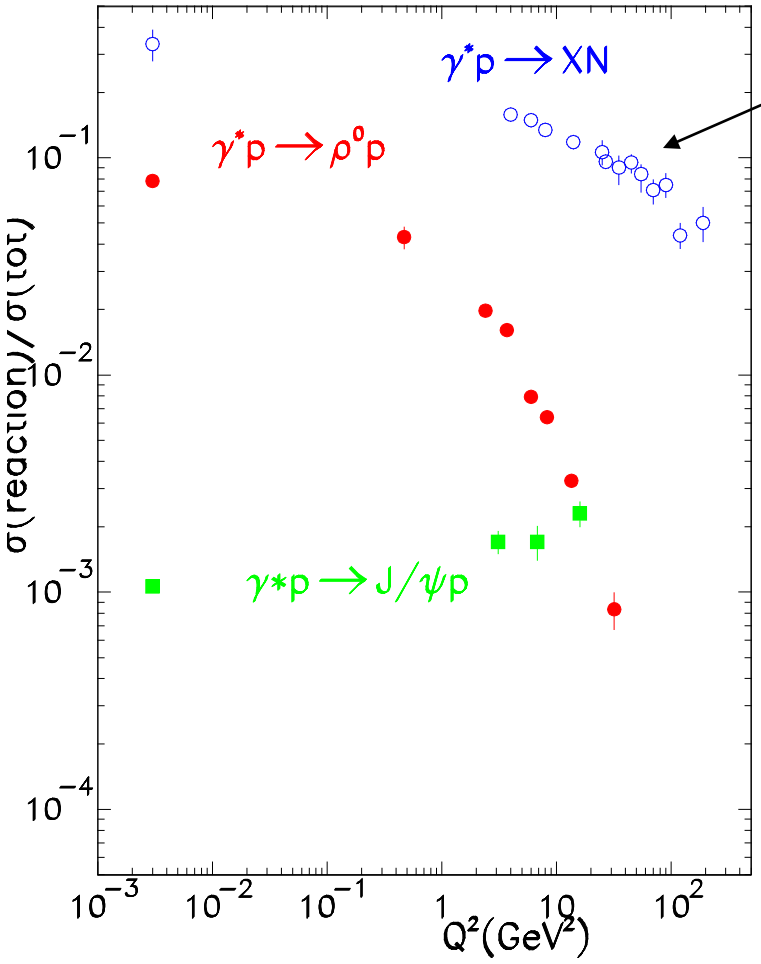


W dependence becomes steeper as scale increases

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

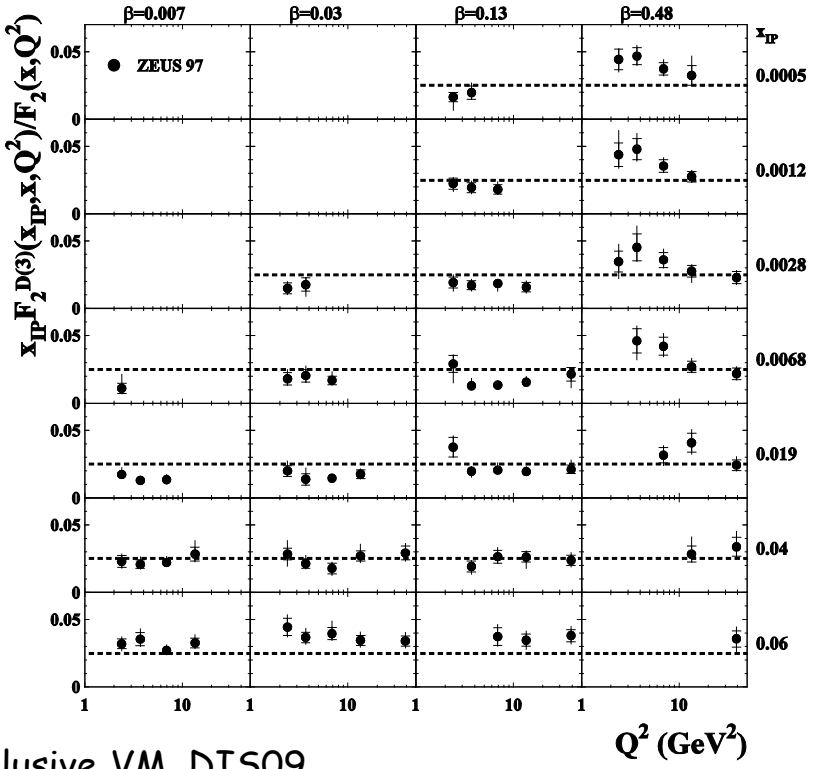

ZEUS
b(GeV^{-2})
Q^2+M^2(GeV^2)
ρ ZEUS 96-00
ρ ZEUS 94
ρ ZEUS LPS 94
ρ ZEUS 95
ρ H1 95-96
φ ZEUS 98-00
φ ZEUS 94
J/ψ ZEUS 98-00
J/ψ ZEUS 96-97
J/ψ H1 96-00
DVCS ZEUS LPS (31 pb^{-1})
DVCS H1 HERA I
DVCS H1 HERA II e$^-$p

Ratio of diff/tot (Q^2)



$W = 220\text{GeV}, 0.28 < M_X < 35\text{GeV}$

Decrease artificial; as Q^2 increases, x_{IP} range decreases. Better to look at F_2^D/F_2 as function of Q^2 at fixed x_{IP},β:



Ratio of VM/tot (W)

$$r_V \equiv \frac{\sigma(\gamma^* p \to Vp)}{\sigma_{tot}(\gamma^* p)}$$

$$F_2 \propto x^{-\lambda}$$

pQCD: $r_V \propto W^{2\lambda}$

Regge: $r_V \propto W^{2\lambda}$

$(\lambda \equiv \alpha_{IP}(0) - 1)$

$\sigma(\gamma^* V \to Vp)/\sigma_{tot}(\gamma^* p)$ - pQCD

$$\frac{d\sigma_L}{dt}\Big|_{t=0} \propto \frac{1}{Q^6}\alpha_S^2(Q^2)\Big[xg(x,Q^2)\Big]^2 \propto x^{-2\lambda} \text{ for fixed } Q^2$$

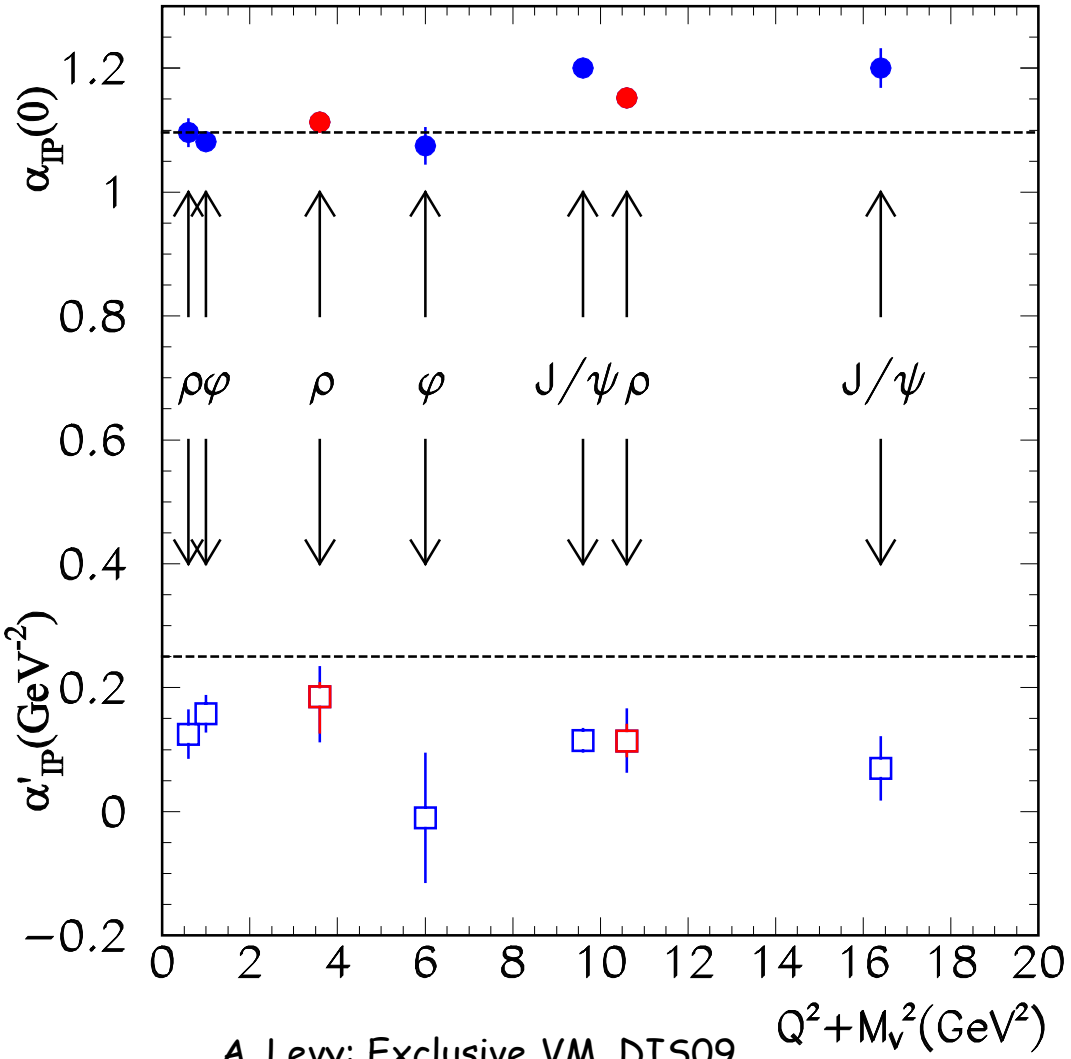
$$\frac{d\sigma_V}{dt} \propto e^{-b|t|}, \ \sigma_{tot}(\gamma^* p) \propto \frac{F_2}{Q^2} \propto x^{-\lambda} \text{ for fixed } Q^2, \text{ low x}$$

$$r_V \equiv \frac{\sigma(\gamma^* p \to Vp)}{\sigma_{tot}(\gamma^* p)} \propto \left(1+\frac{1}{R}\right)\frac{x^{-\lambda}}{b} \propto \frac{x^{-\lambda}}{b} = \frac{W^{2\lambda}}{b} \text{ for fixed } Q^2$$

R is W independent (for fixed Q^2);
α' small $\Rightarrow$ b slow W dependence

$$r_V \propto W^{2\lambda}$$

Effective Pomeron trajectory



$\sigma(\gamma^* V \to Vp)/\sigma_{tot}(\gamma^* p)$ - Regge

$$\sigma_{tot}(\gamma^* p) \propto W^{2(\alpha_P(0)-1)}$$

$$\sigma(\gamma^* p \to Vp) \propto \frac{W^{4(\alpha_P(0)-1)}}{b}$$

$$r_V \propto \frac{W^{2(\alpha_P(0)-1)}}{b}$$

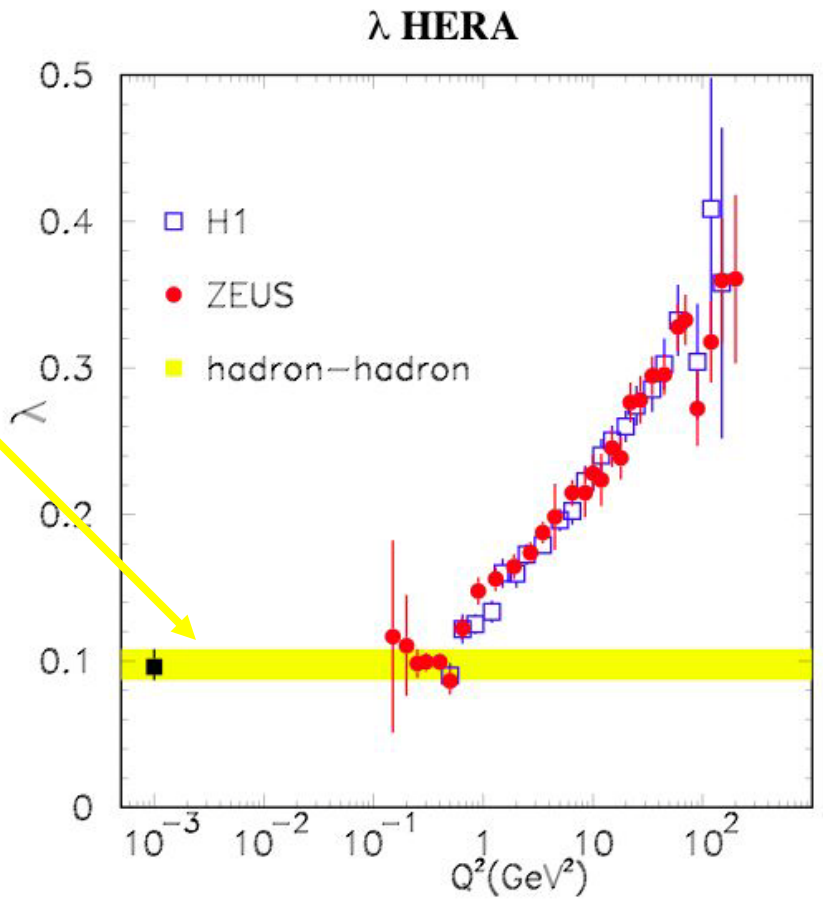
α' small $\Rightarrow$ b slow W dependence ;

$\lambda \equiv \alpha_P(0)-1$

$$r_V \propto W^{2\lambda}$$

$$F_2 \sim x^{-\lambda(Q^2)}$$

$\sigma \propto s^{0.096}$



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Regge: $r_V \propto W^{2\lambda}$

$(\lambda \equiv \alpha_{IP}(0) - 1)$

ratio - at what scale?

Try the following:

$$Q^2_{eff} = Q^2$$

$$Q^2_{eff} = \frac{Q^2 + M_V^2}{4}$$

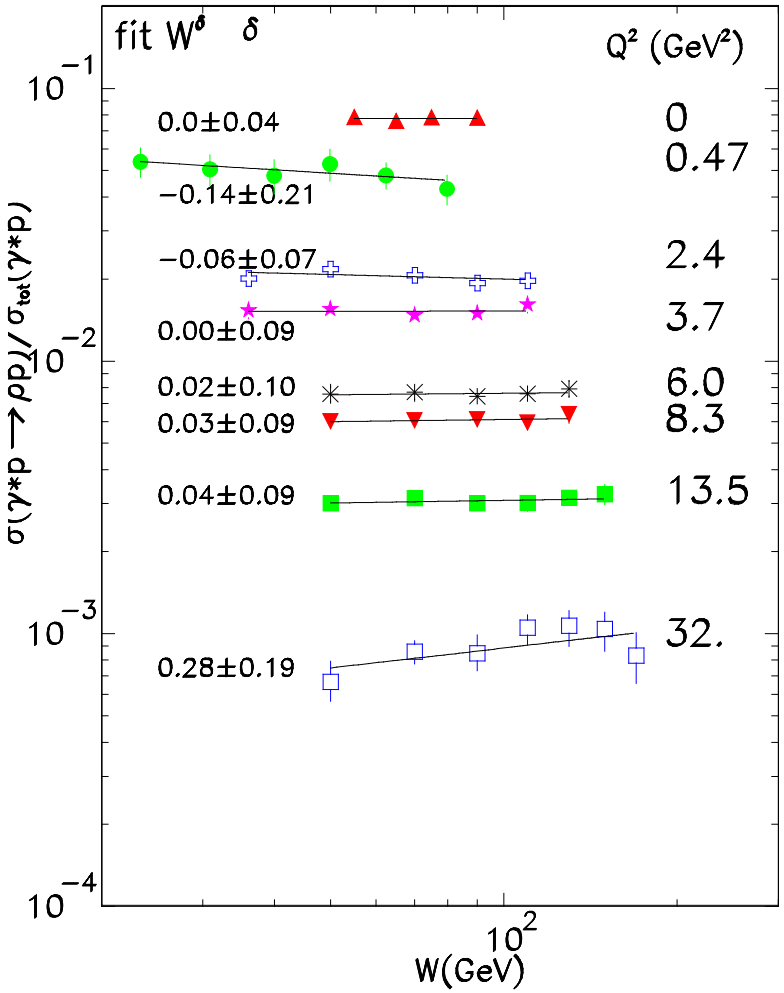
(for ρ - Mark Strikman)

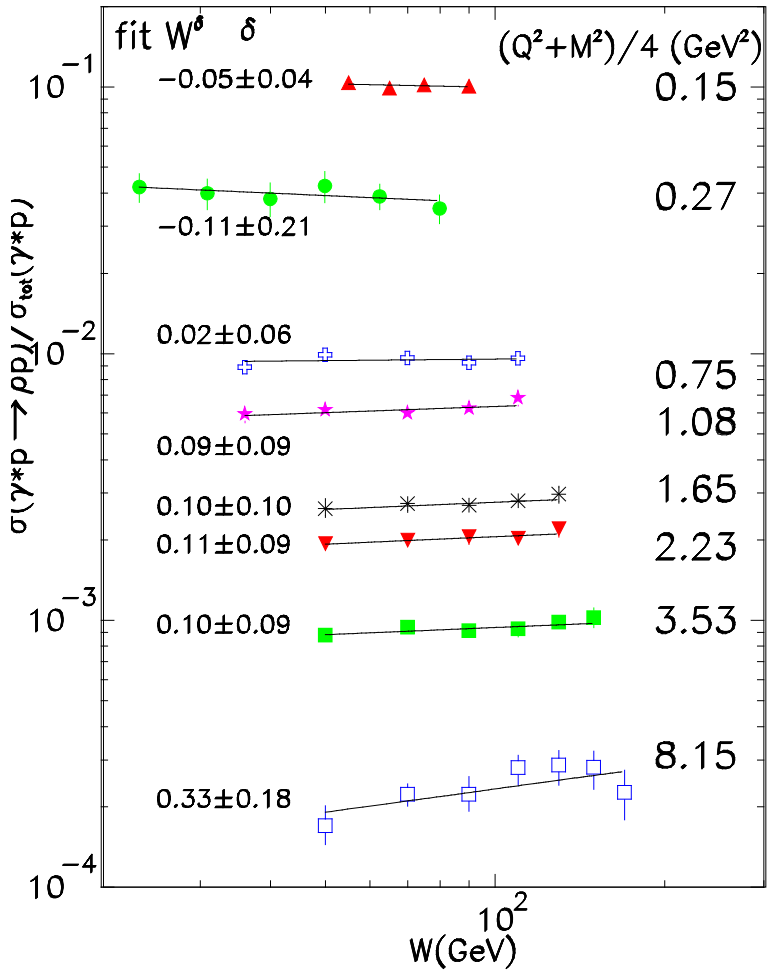
$$Q^2_{eff} = \left(\frac{Q^2}{2.65} \right)^{0.887}$$

(for ρ - see below)

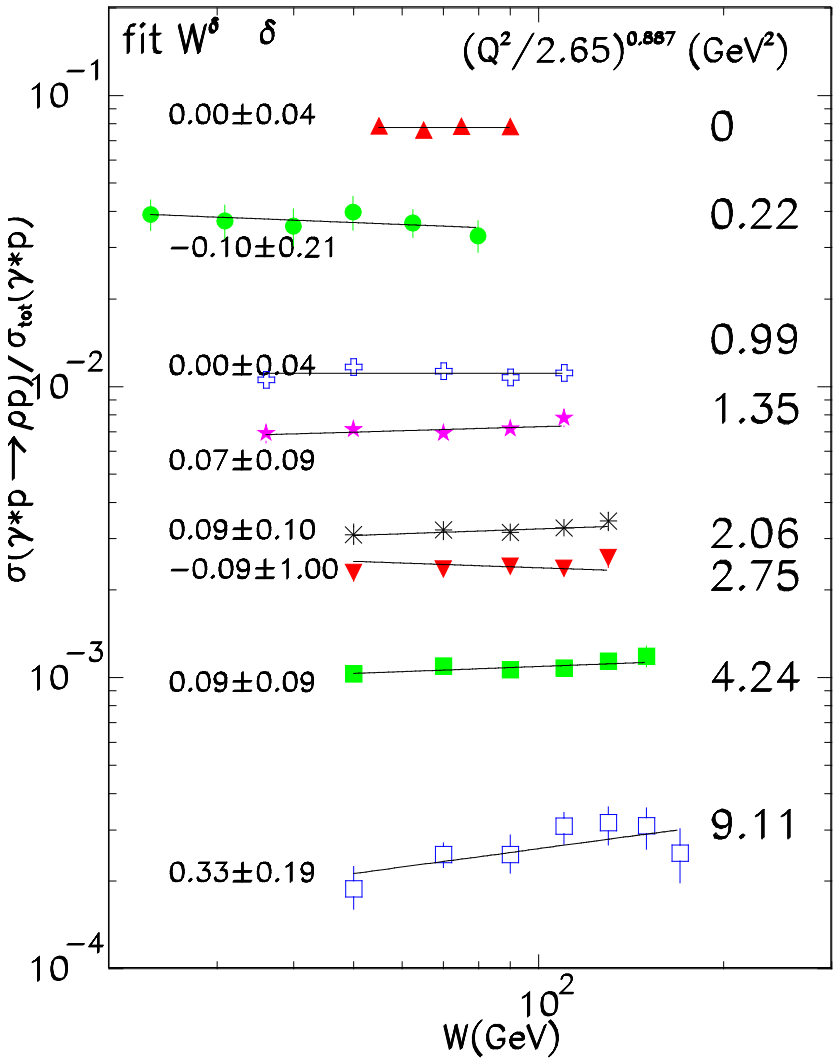
$$Q^2_{eff} = 0.23 e^{(0.1 Q^2)}$$

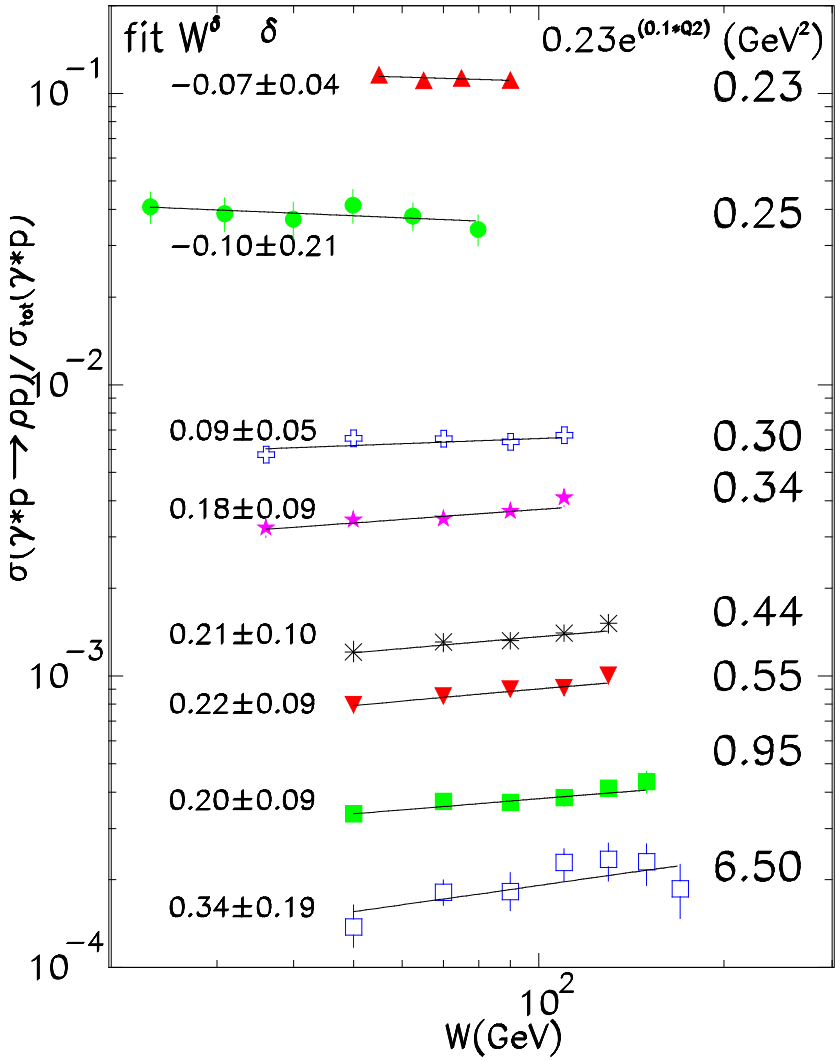
ρ


fit W^δ δ
Q² (GeV²)
0.0±0.04
0
−0.14±0.21
0.47
−0.06±0.07
2.4
0.00±0.09
3.7
0.02±0.10
6.0
0.03±0.09
8.3
0.04±0.09
13.5
0.28±0.19
32.
σ(γ*p → ρp)/σ_tot(γ*p)
W(GeV)

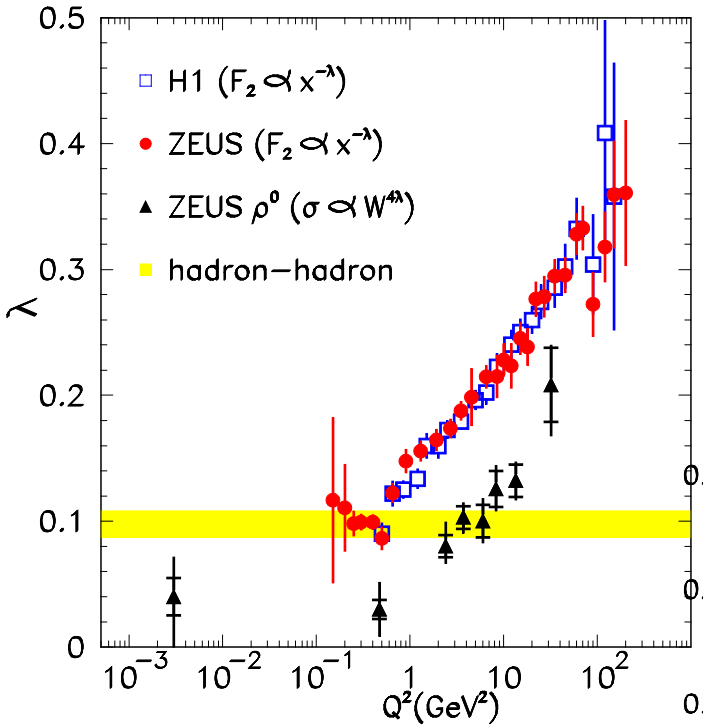

fit W^δ δ
(Q²+M²)/4 (GeV²)
−0.05±0.04
0.15
−0.11±0.21
0.27
0.02±0.06
0.75
0.09±0.09
1.08
0.10±0.10
1.65
0.11±0.09
2.23
0.10±0.09
3.53
0.33±0.18
8.15
σ(γ*p → ρp)/σ_tot(γ*p)
W(GeV)

ρ


fit W^{δ} δ
$(Q^2/2.65)^{0.887}$ (GeV²)
0.00±0.04
0
−0.10±0.21
0.22
0.00±0.04
0.99
0.07±0.09
1.35
0.09±0.10
2.06
−0.09±1.00
2.75
0.09±0.09
4.24
0.33±0.19
9.11
$\sigma(\gamma^* p \to \rho p)/\sigma_{tot}(\gamma^* p)$
W(GeV)

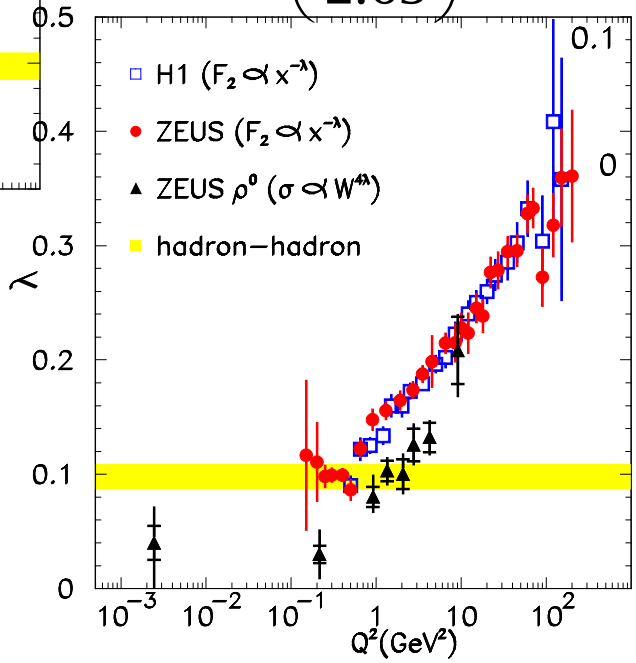

fit W^{δ} δ
$0.23e^{(0.1*Q2)}$ (GeV²)
−0.07±0.04
0.23
−0.10±0.21
0.25
0.09±0.05
0.30
0.18±0.09
0.34
0.21±0.10
0.44
0.22±0.09
0.55
0.20±0.09
0.95
0.34±0.19
6.50
$\sigma(\gamma^* p \to \rho p)/\sigma_{tot}(\gamma^* p)$
W(GeV)

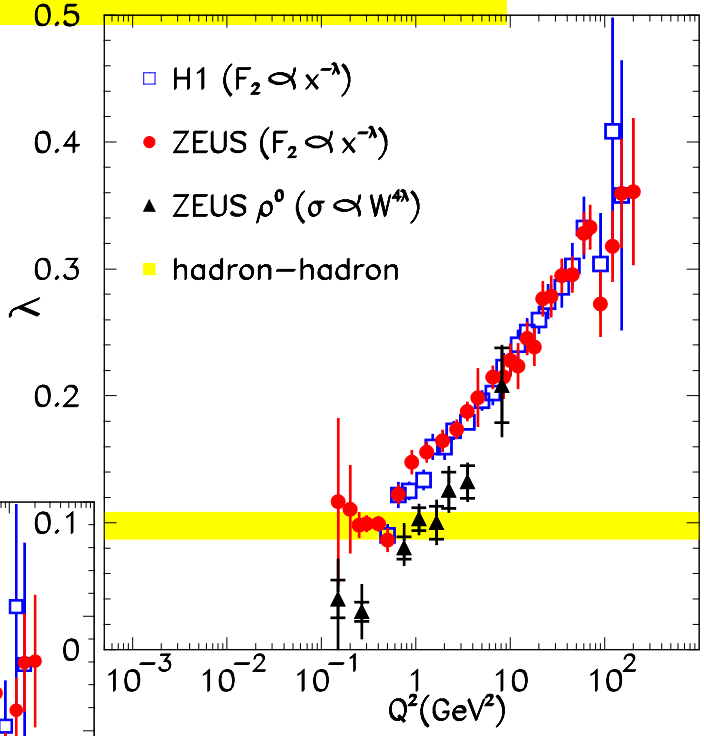
λ plots (ρ)



$$Q^2_{eff} = Q^2$$

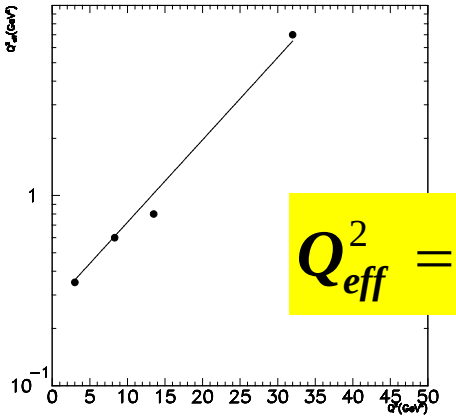
$$Q^2_{eff} = \left(\frac{Q^2}{2.65}\right)^{0.887}$$



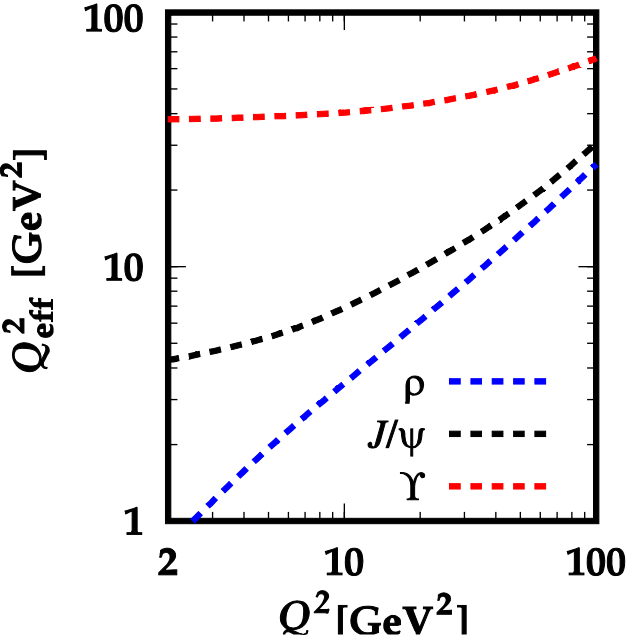


$$Q^2_{eff} = \frac{Q^2 + M^2}{4}$$

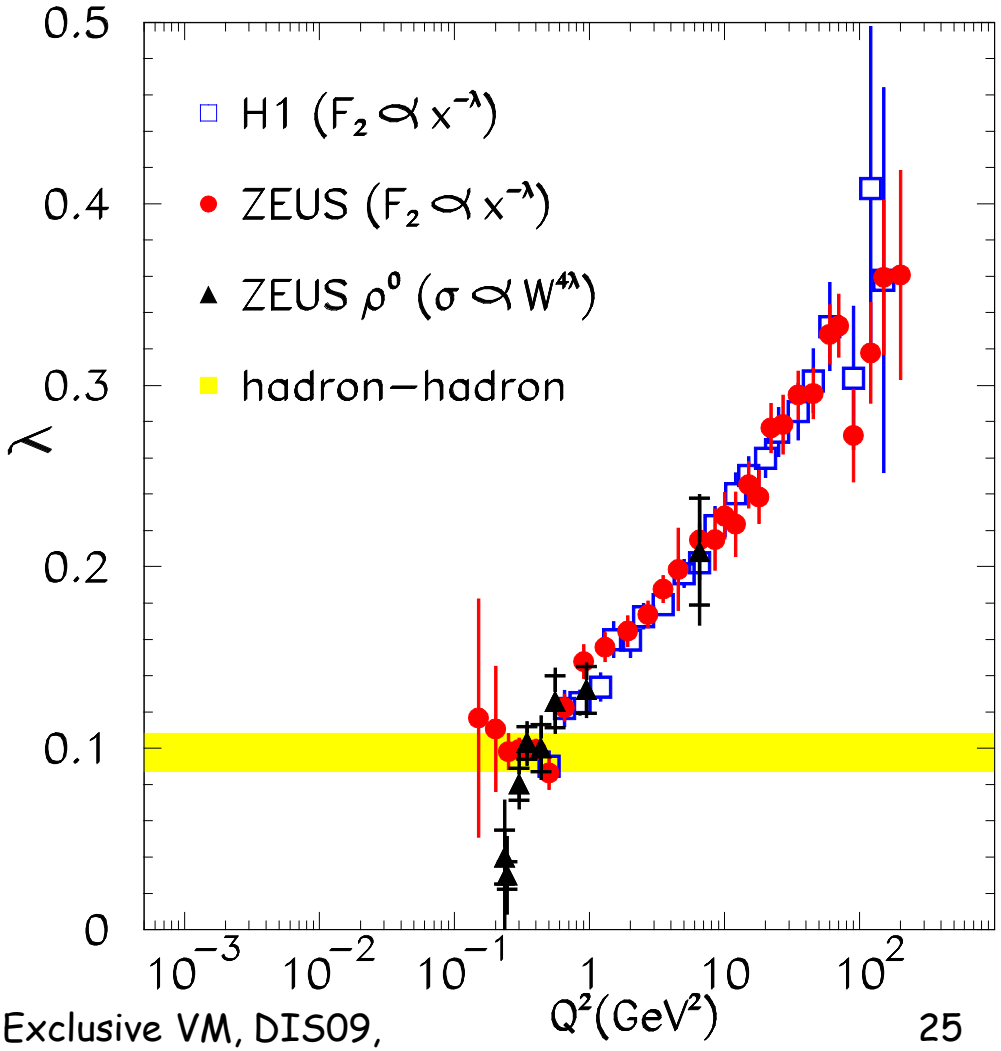
λ plots (ρ)



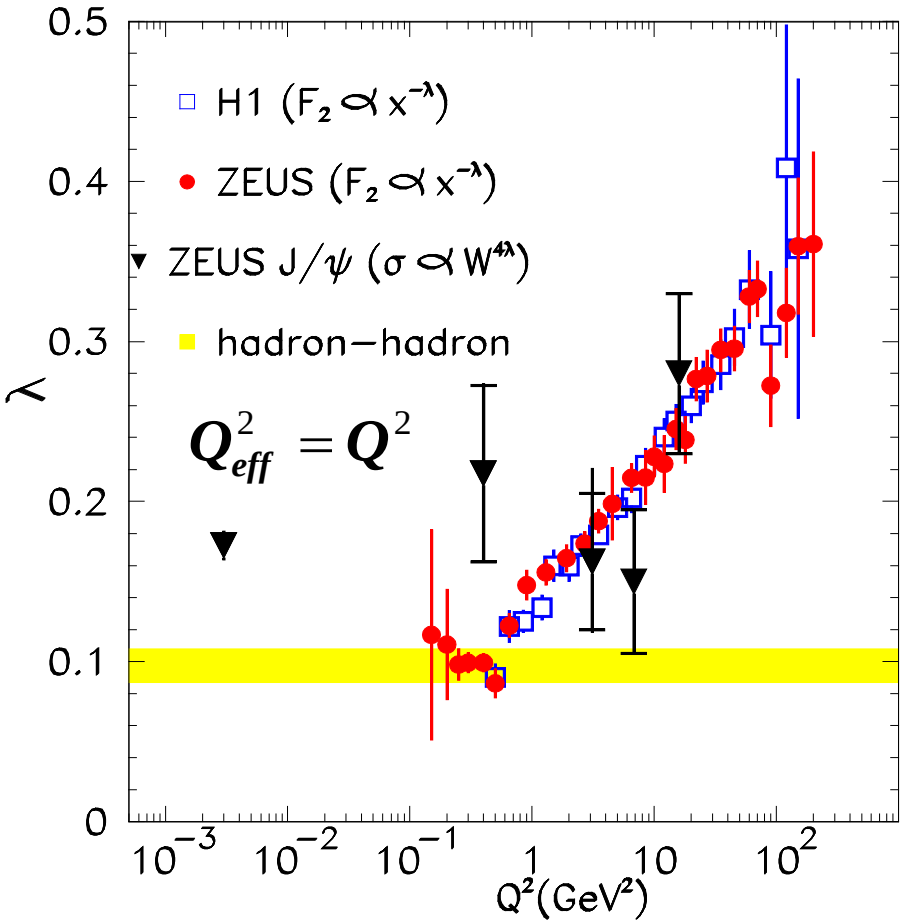
$$Q^2_{eff} = 0.23e^{0.1Q^2}$$

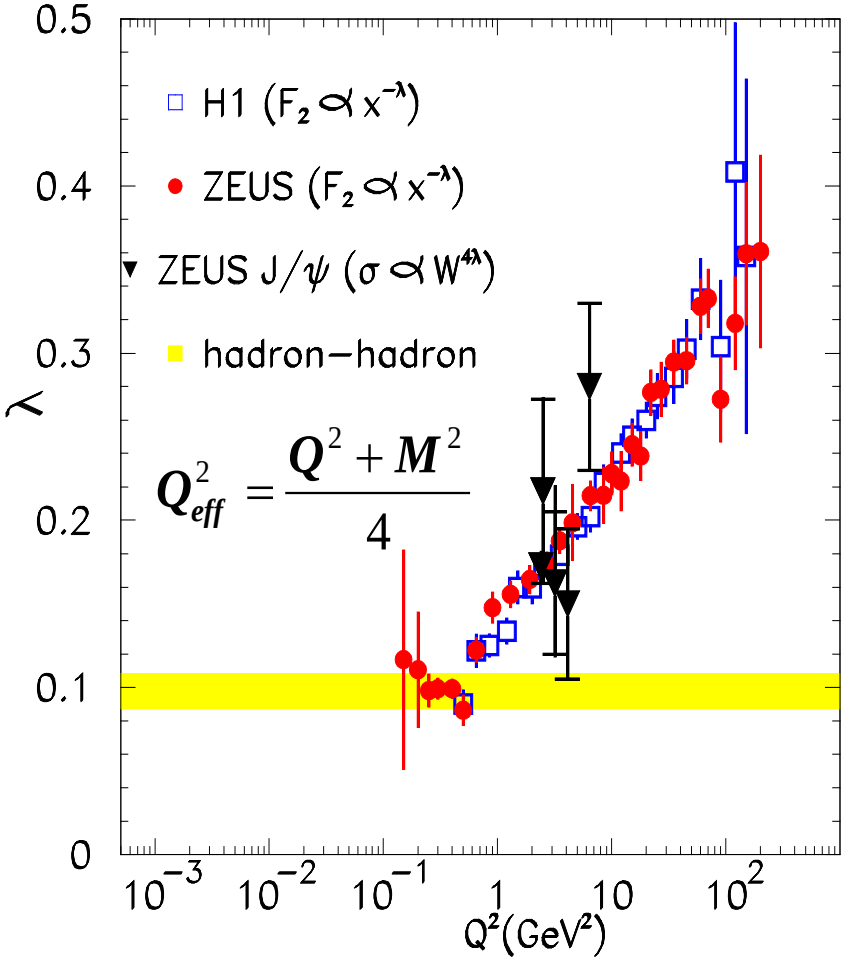


Frankfurt, Strikman, Weiss



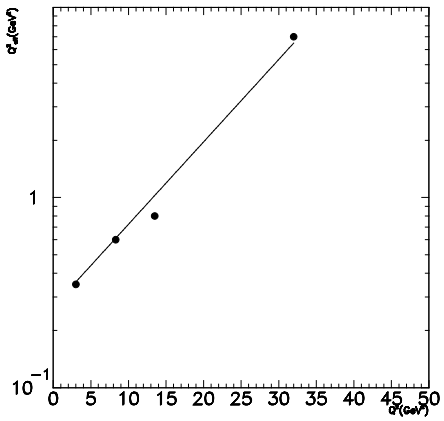
J/ψ

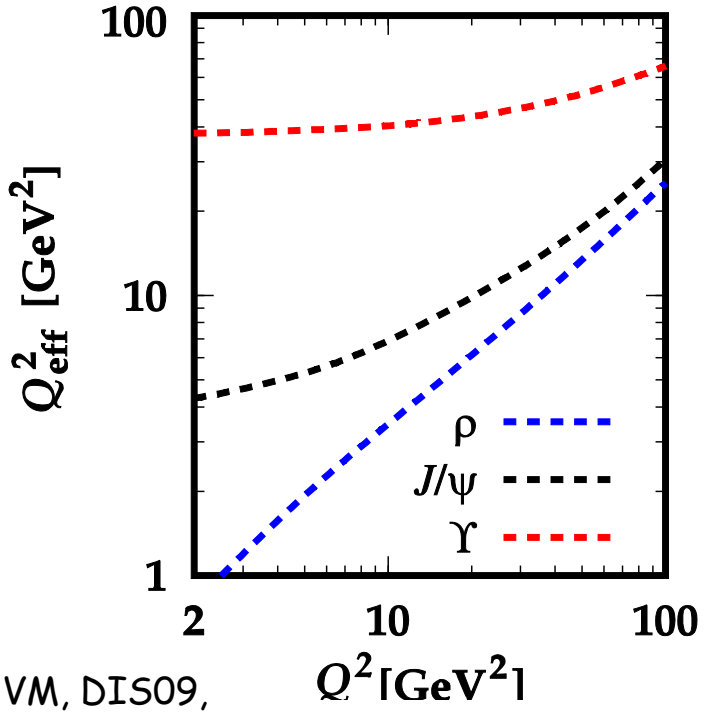

H1 ($F_2 \propto x^{-\lambda}$)
ZEUS ($F_2 \propto x^{-\lambda}$)
ZEUS J/ψ ($\sigma \propto W^{4\lambda}$)
hadron−hadron
$Q^2_{eff} = Q^2$
λ
Q^2(GeV^2)


H1 ($F_2 \propto x^{-\lambda}$)
ZEUS ($F_2 \propto x^{-\lambda}$)
ZEUS J/ψ ($\sigma \propto W^{4\lambda}$)
hadron−hadron
$Q^2_{eff} = \frac{Q^2 + M^2}{4}$
λ
Q^2(GeV^2)

Effective scale

M.S.: Q^2_{eff} in the ρ^0 production case is much smaller than Q^2 of the photon due to presence of the convolution of the soft ρ^0 wave function and small size longitudinal photon wave function





Summary

- HERA data – good source to observe interplay of soft and hard dynamics.
- Exclusive electroproduction of heavy meson – source to study pQCD.
- Need to understand issue of Q^2_{eff}.

Need high precision measurements of exclusive electroproduction of VM.