Cross sections at HERA

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Talk dedicated to the memory of Jan Kwiecinski

soft - hard

Energy dependence of cross section $\Rightarrow$ dynamics of process.

W dependence Regge type (DL) $\Rightarrow$ process called soft.

Example for soft: total hadron-p cross section.

W dependence described by pQCD $\Rightarrow$ process called hard.

Example for hard: Exclusive J/ψ electroproduction.

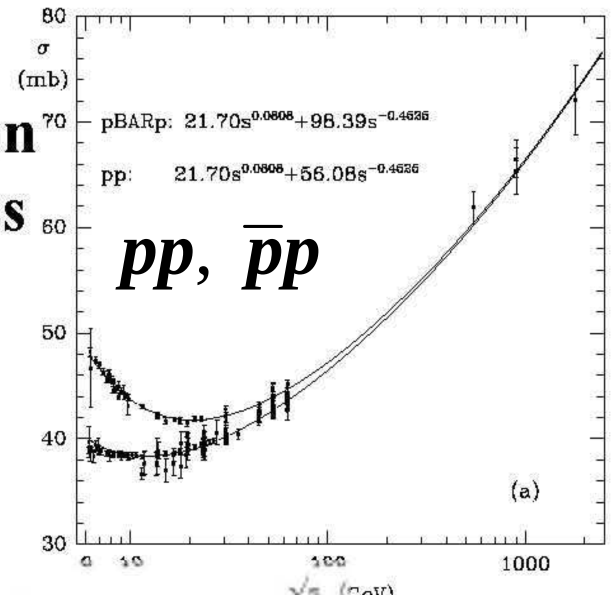
At HERA see interplay of soft and hard.

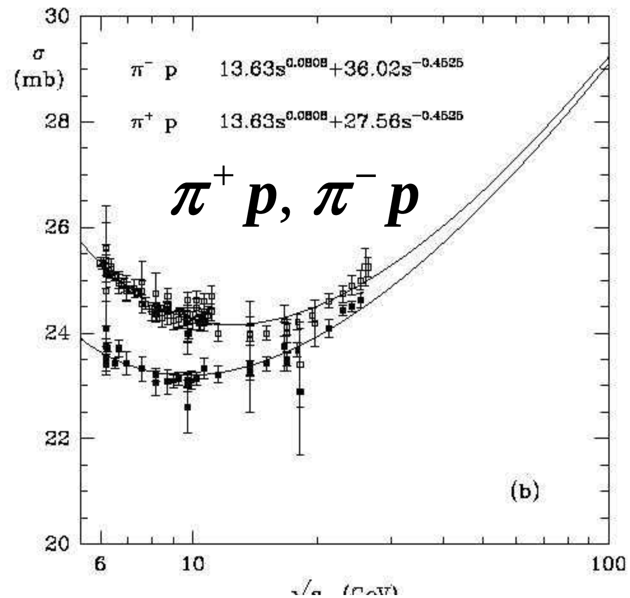
Jan Kwiecinski contributed much to this subject by his studies of h-h, γ-γ, γ-p and e-p. He inspired many of the HERA studies by his findings. Very appropriate to dedicate this conference to his memory.

Soft from hadron-hadron

Setting the baseline of soft processes

Hadron-hadron scattering cross section versus CM energy

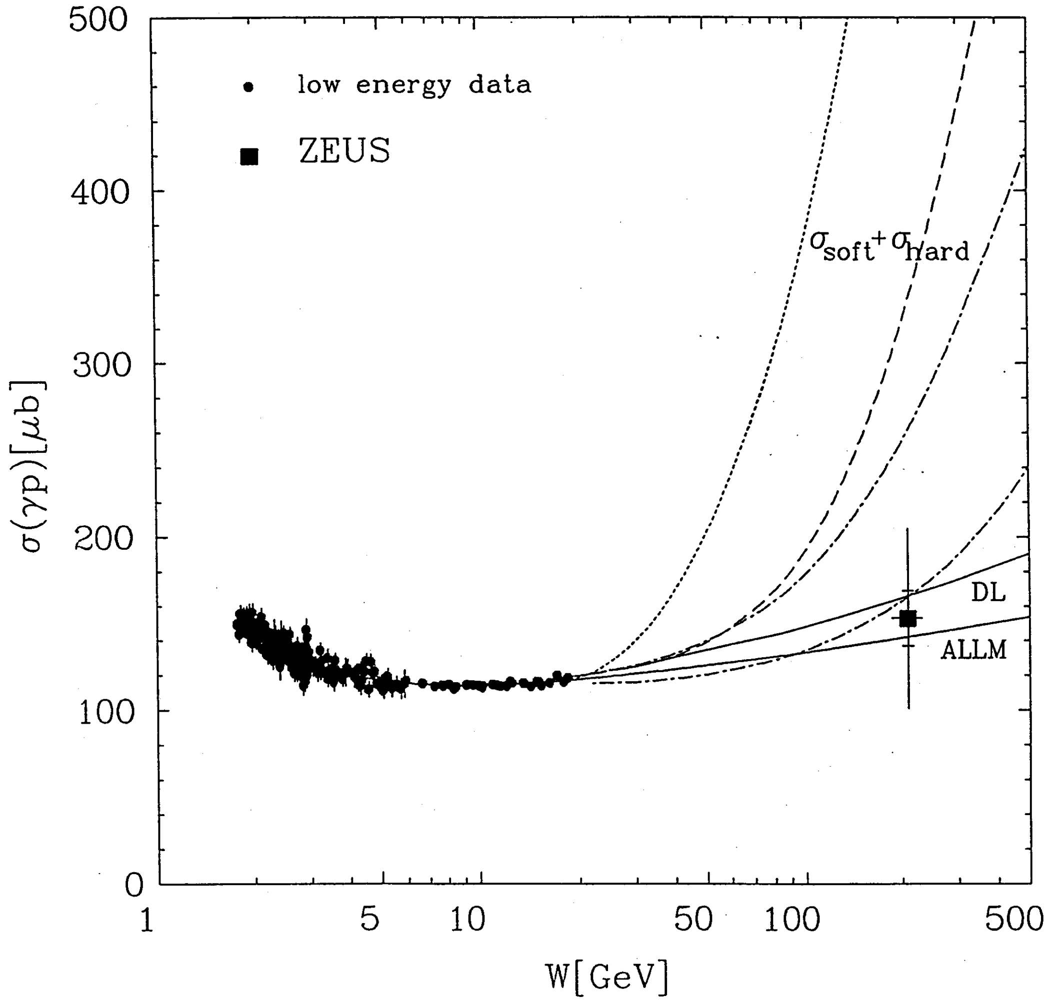




Donnachie and Lanshoff (DL) – universal behavior of total hadron-hadron cross section :

$$\sigma_{tot}(h-h) = As^{\alpha_{IP}(0)-1} + Bs^{\alpha_{IR}(0)-1}$$
$$= As^{0.0808} + Bs^{-0.4525}$$

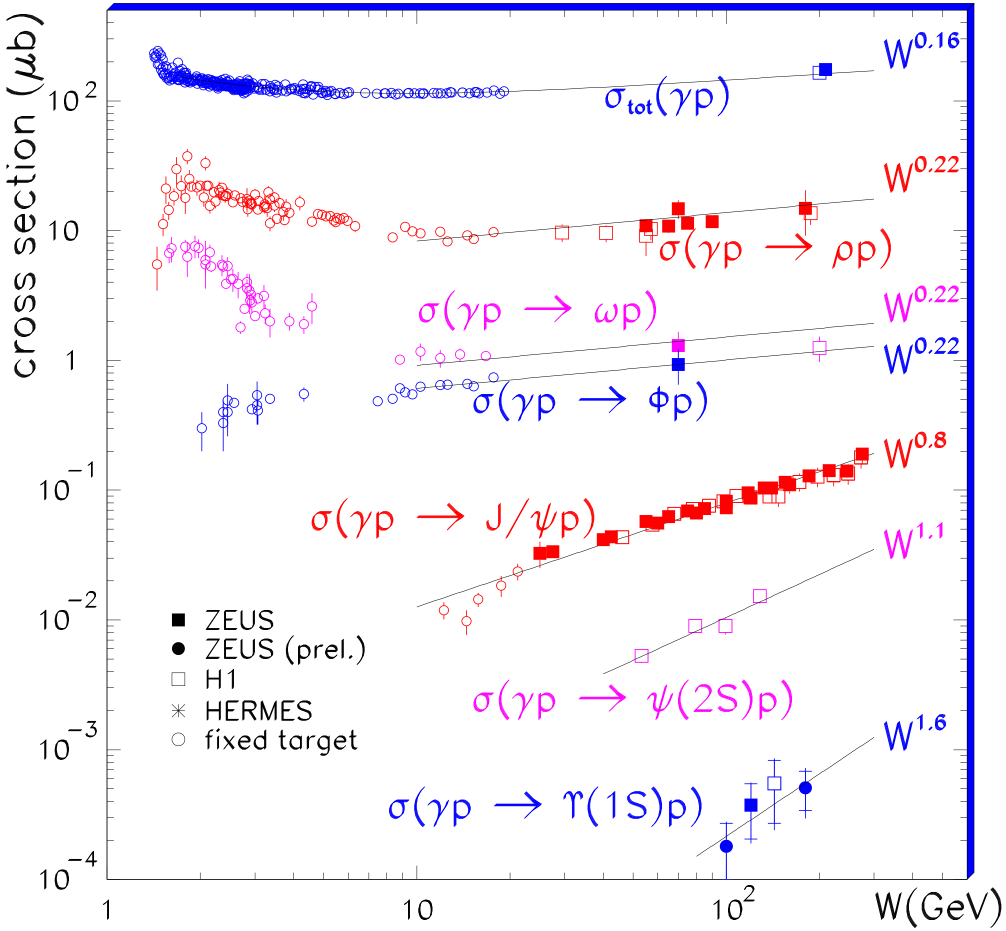
$\sigma_{tot}(\gamma p)$



Before HERA started: predictions included dominant hard part.

HERA: total photoproduction cross section ~ hadron-p total cross section ⇒ soft

Photoproduction



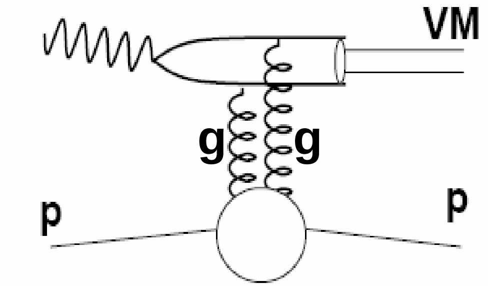
$$\sigma \propto W^{\delta}$$

process becomes hard as scale (mass) becomes larger.

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

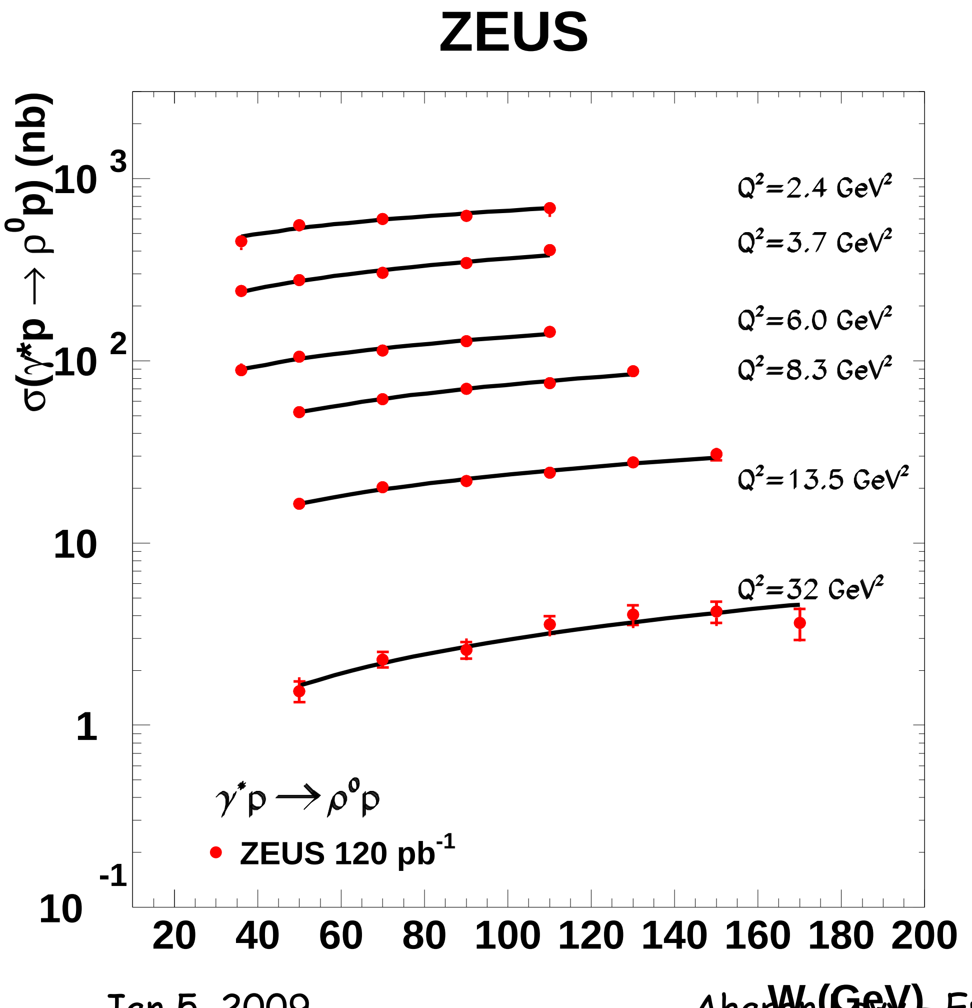
small size ⇒ resolve internal structure of proton

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

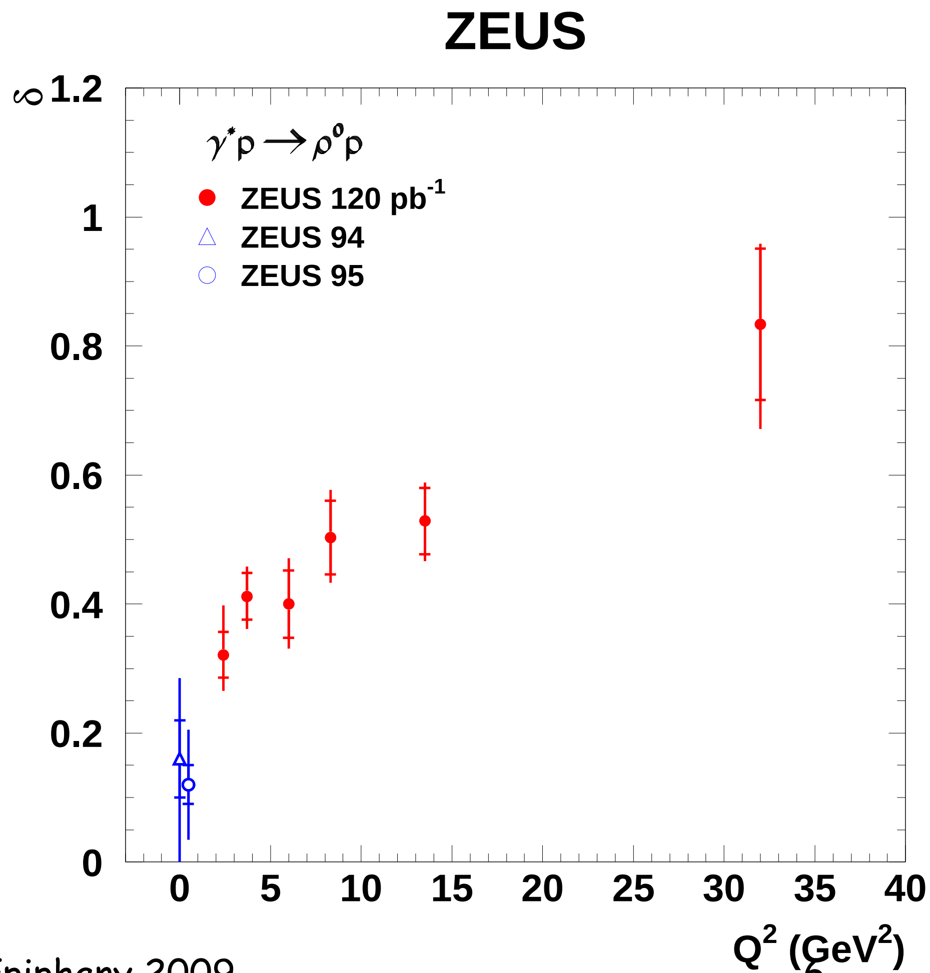


$\sigma(W) - \rho^0$

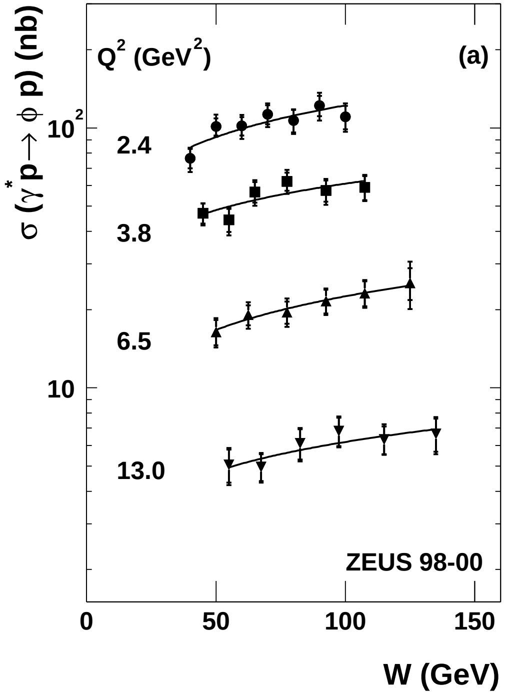
Fix mass – increase photon scale



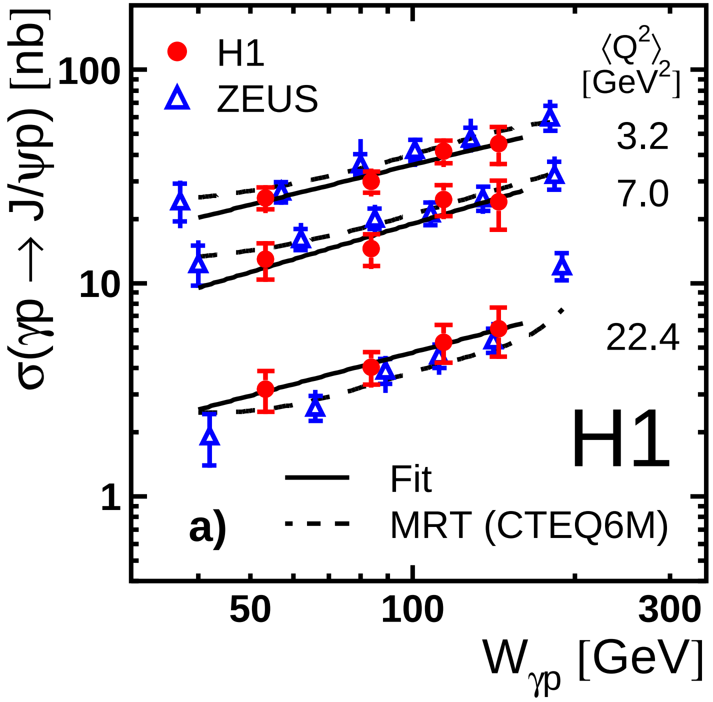
$$\sigma \propto W^{\delta}$$



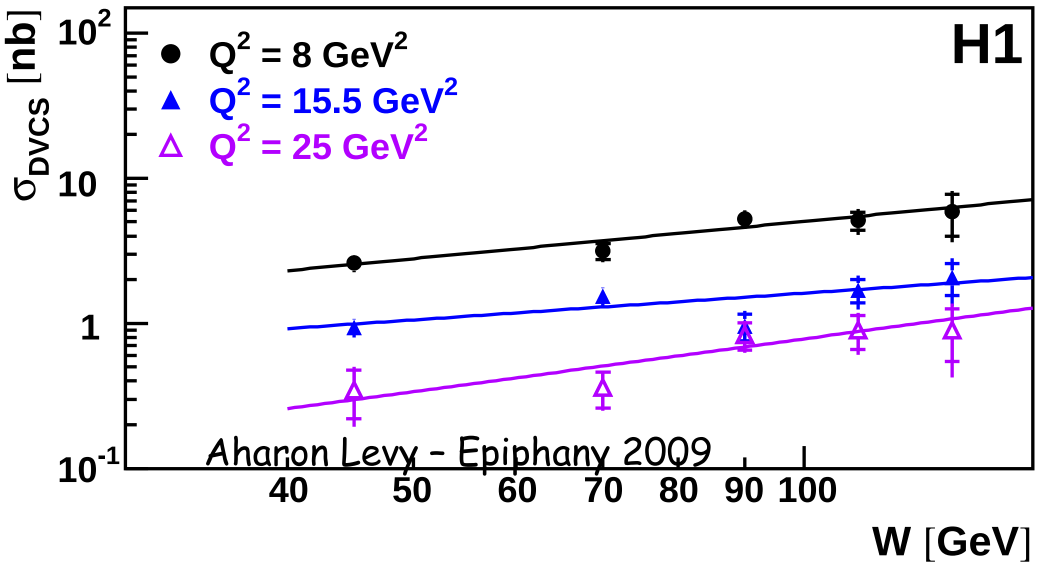
σ(W) - φ, J/ψ, γ



σ (γ* p → φ p) (nb)
Q² (GeV²)
(a)
2.4
3.8
6.5
13.0
ZEUS 98-00
W (GeV)

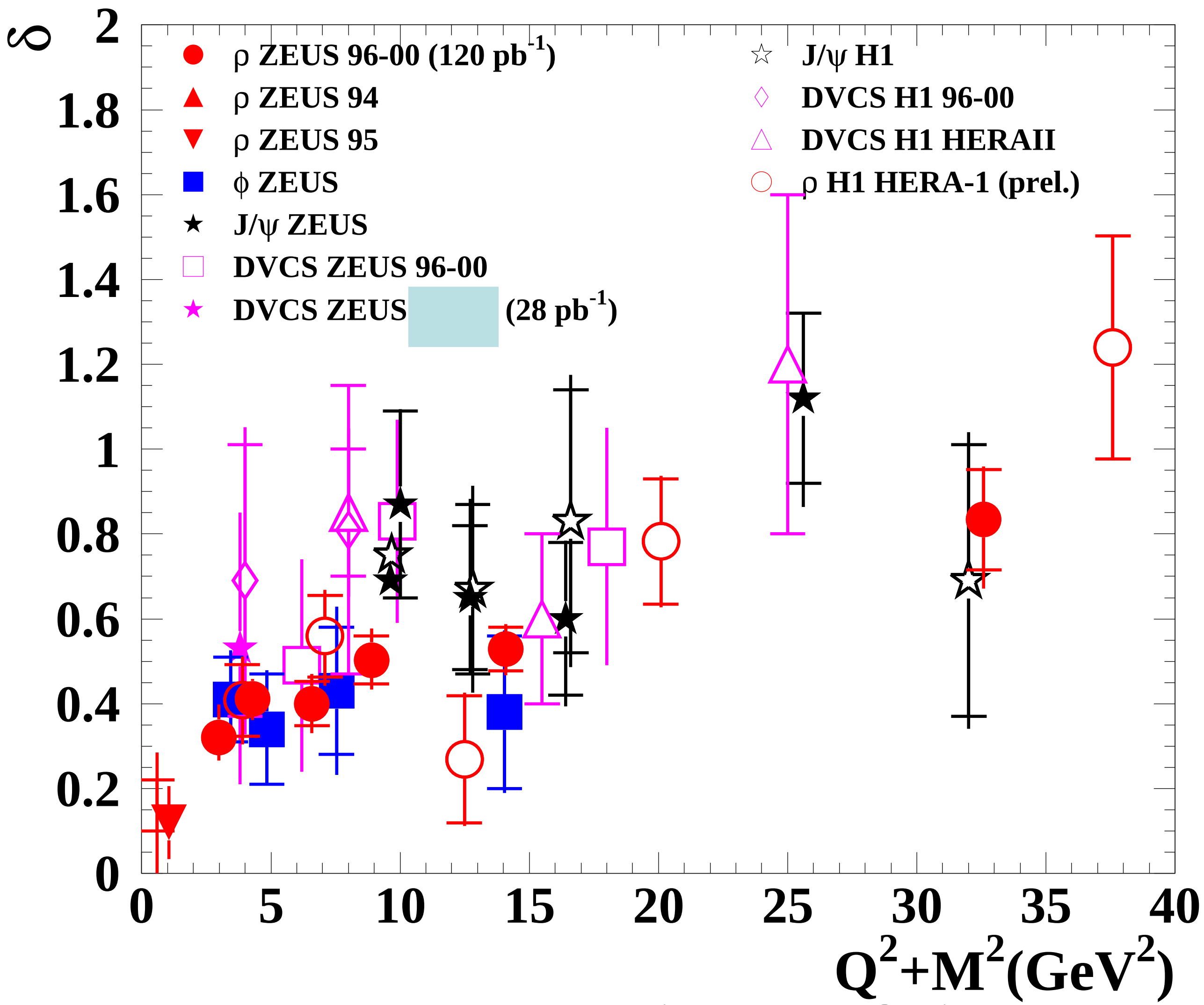


σ(γp → J/ψp) [nb]
H1
ZEUS
⟨Q²⟩ [GeV²]
3.2
7.0
22.4
H1
Fit
MRT (CTEQ6M)
a)
W_γp [GeV]



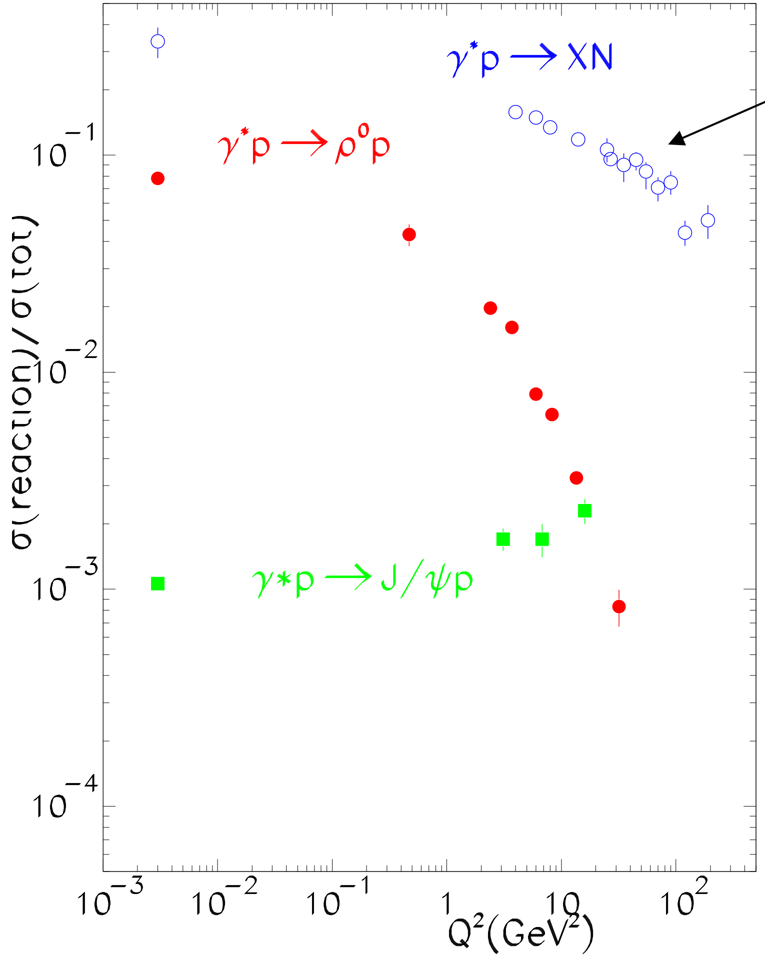
σ_DVCS [nb]
Q² = 8 GeV²
Q² = 15.5 GeV²
Q² = 25 GeV²
H1
W [GeV]

δ (Q²+M²) - VM



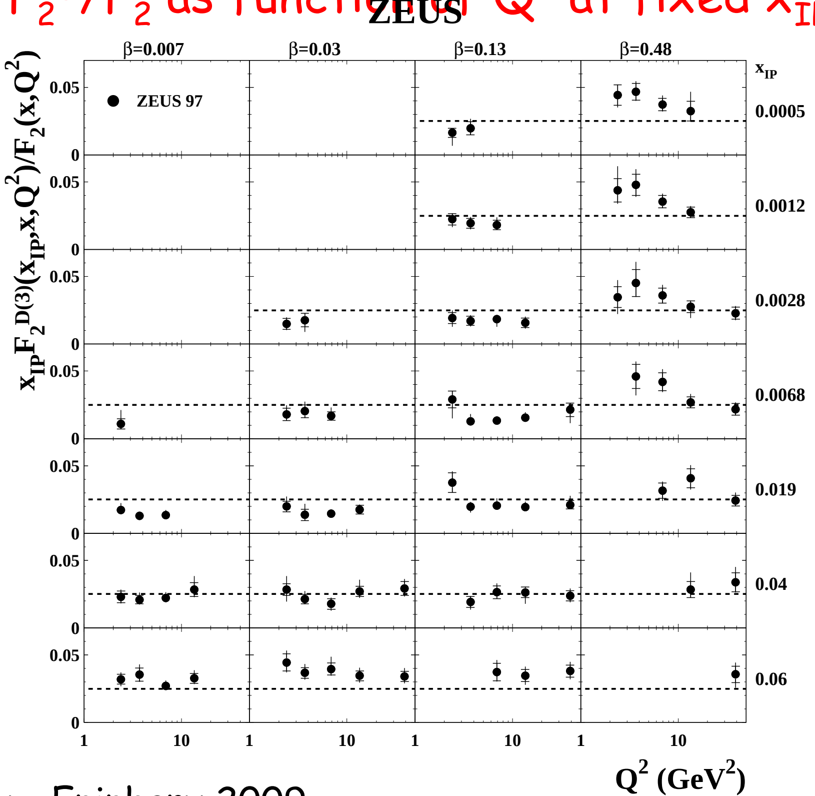
W dependence becomes steeper as scale increases

Ratio of diff/tot (Q^2)



$W = 220 GeV, 0.28 < M_X < 35 GeV$

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)

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

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

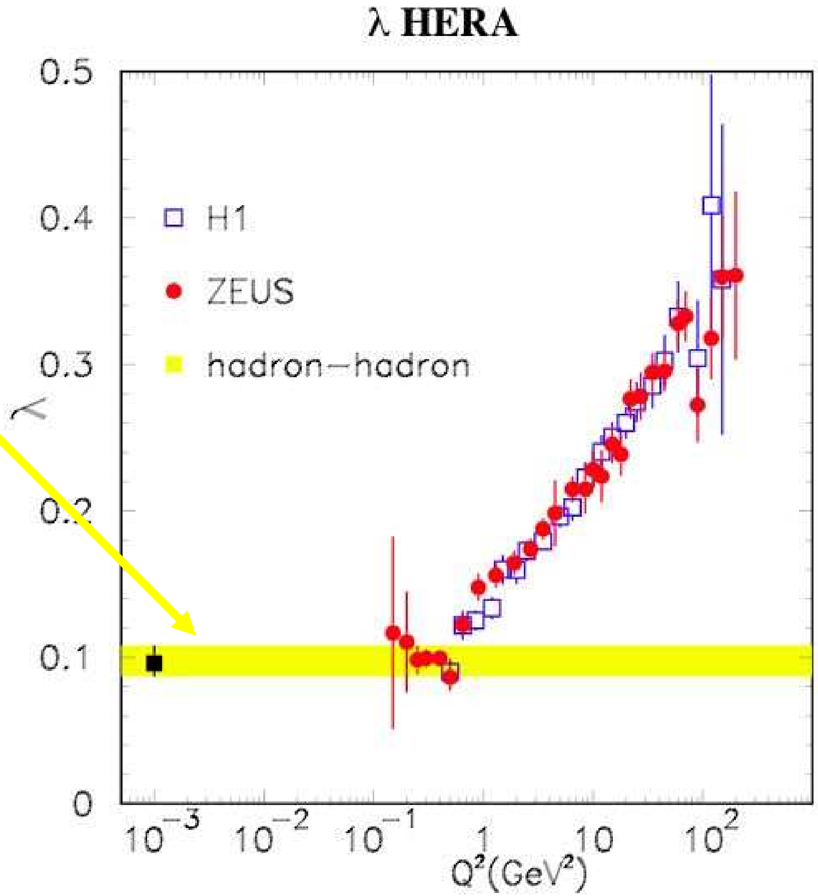
$$\text{pQCD}: r_V \propto W^{2\lambda}$$

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

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

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

$\sigma \propto s^{0.096}$



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

ratio - at what scale?

Try the following:

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

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

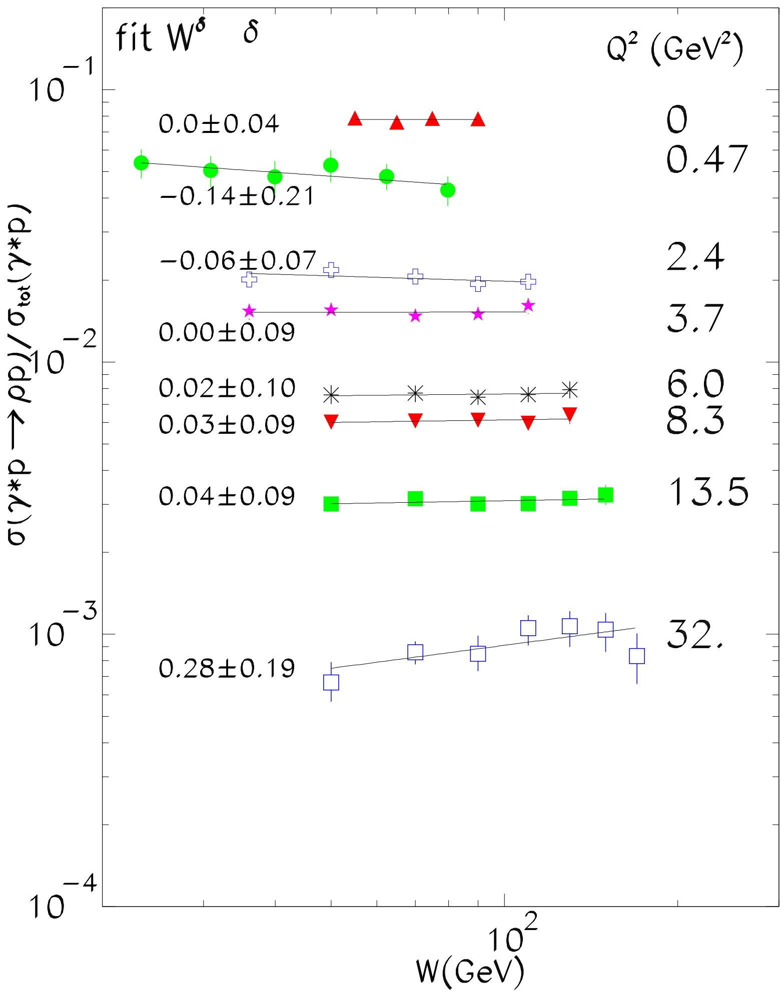
(for ρ - Mark Strikman)

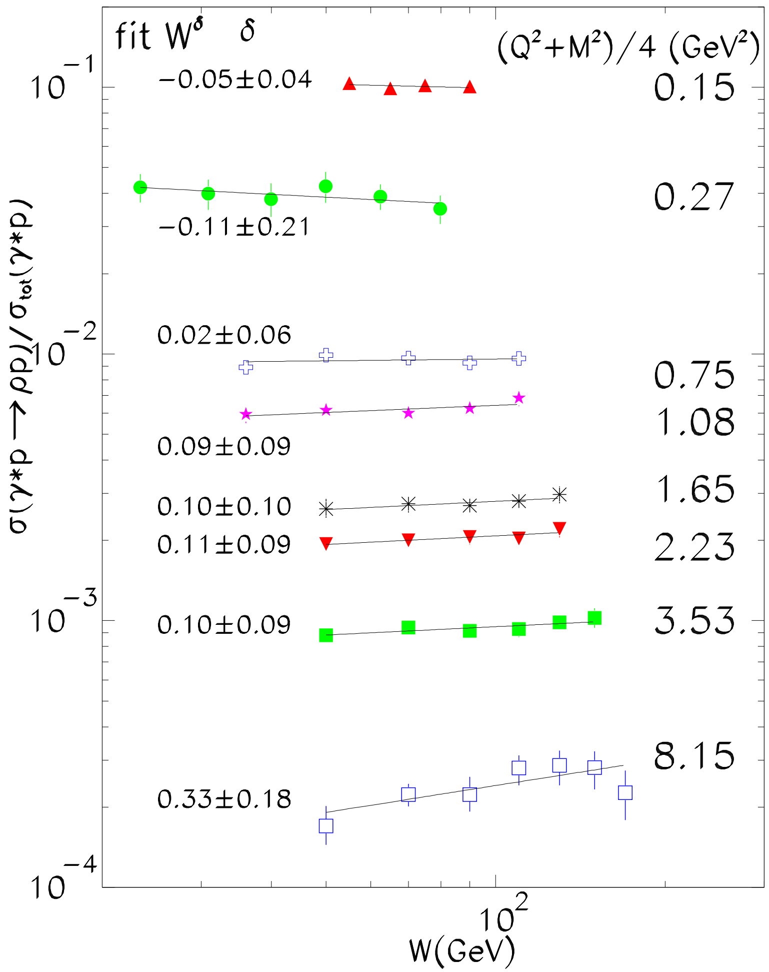
$$Q^2_{eff} = \left(\frac{Q^2}{2.65}\right)^{0.887}$$

(for ρ - see below)

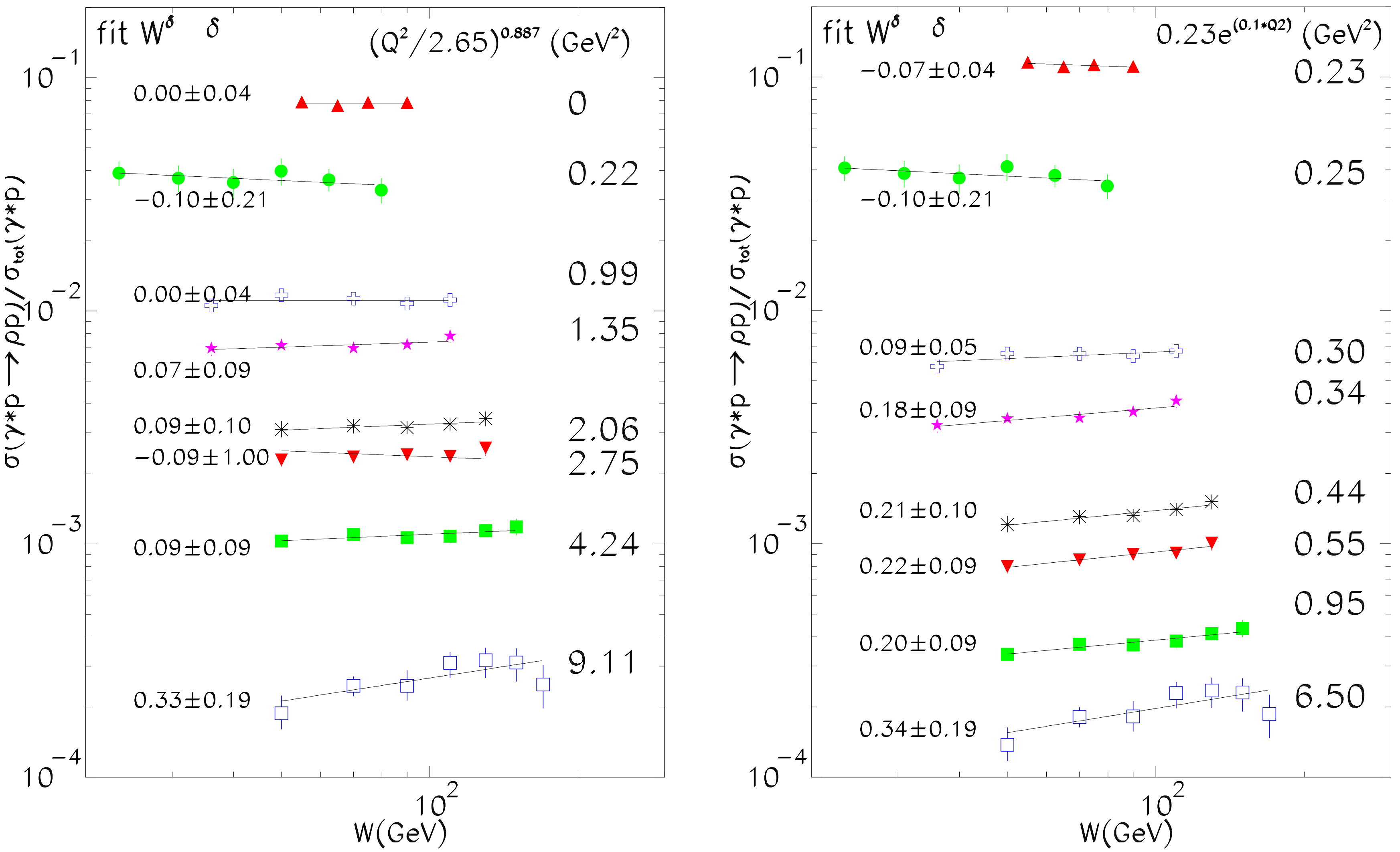
$$Q^2_{eff} = 0.23315 e^{(0.10398 Q^2)}$$

ρ


fit W^δ δ
Q^2 (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.
$\sigma(\gamma^* p \to \rho p)/\sigma_{tot}(\gamma^* p)$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^2
W(GeV)

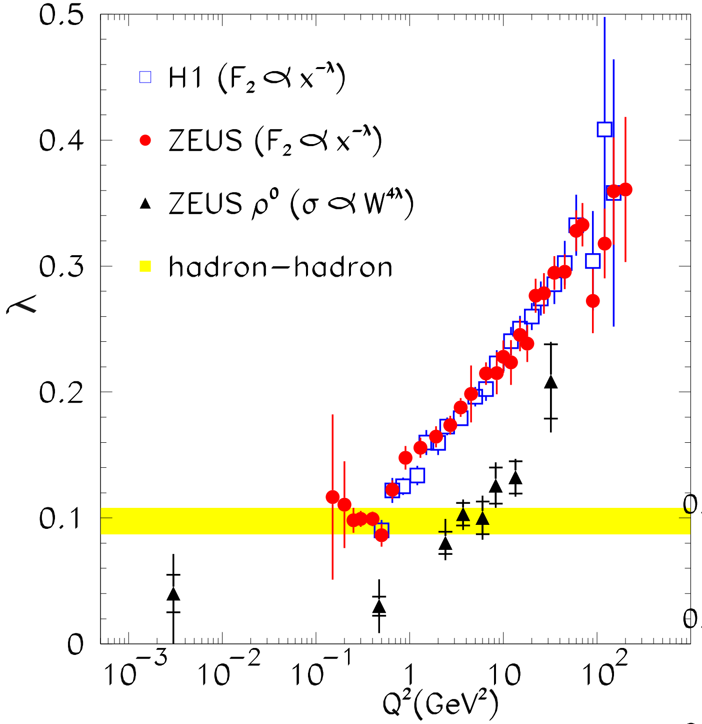

fit W^δ δ
$(Q^2+M^2)/4$ (GeV²)
−0.05±0.04
0.15
−0.11±0.21
0.27
0.02±0.06
0.75
0.09±0.09
1.08
0.10±0.10
1.65
0.11±0.09
2.23
0.10±0.09
3.53
0.33±0.18
8.15
$\sigma(\gamma^* p \to \rho p)/\sigma_{tot}(\gamma^* p)$
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^2
W(GeV)

ρ



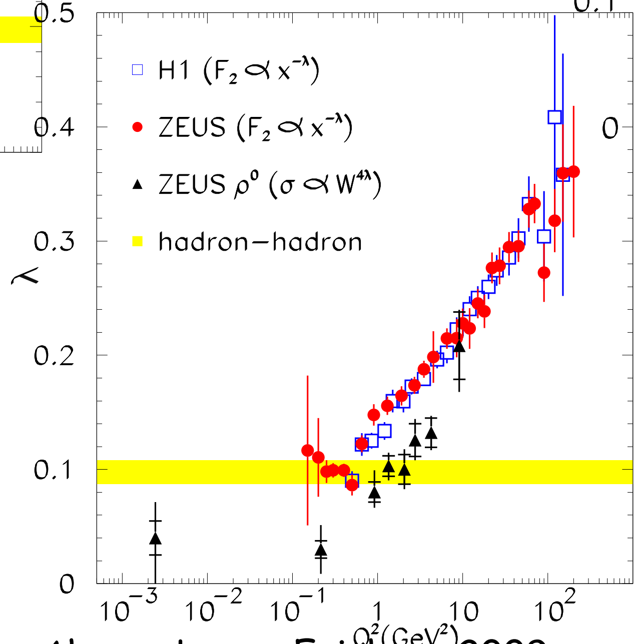
fit W^δ δ
$(Q^2/2.65)^{0.887}$ (GeV²)
0.00±0.04
0
−0.10±0.21
0.22
0.00±0.04
0.99
1.35
0.07±0.09
0.09±0.10
2.06
−0.09±1.00
2.75
0.09±0.09
4.24
0.33±0.19
9.11
$\sigma(\gamma^* p \to \rho p) / \sigma_{tot}(\gamma^* p)$
W(GeV)
fit W^δ δ
$0.23e^{(0.1*Q2)}$ (GeV²)
−0.07±0.04
0.23
−0.10±0.21
0.25
0.09±0.05
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)

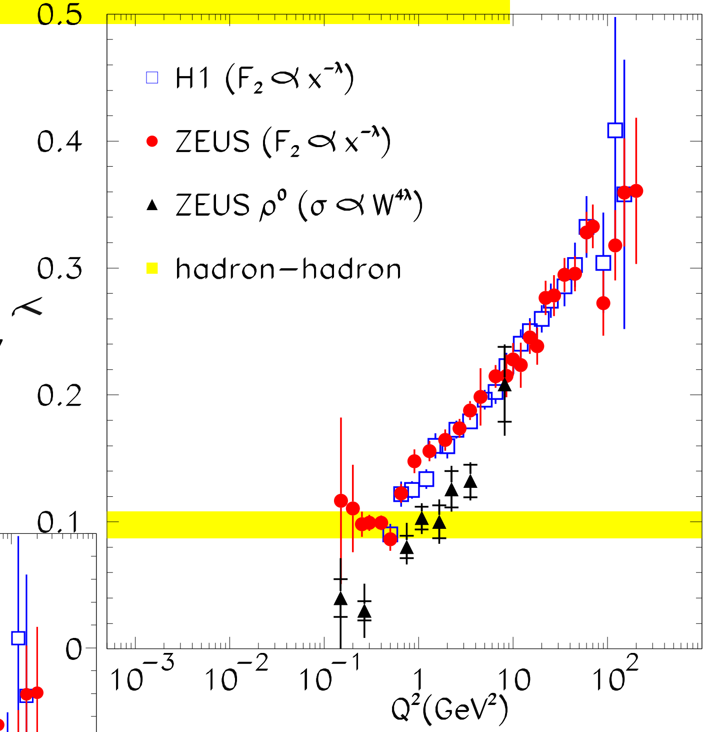
λ plots (ρ)



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

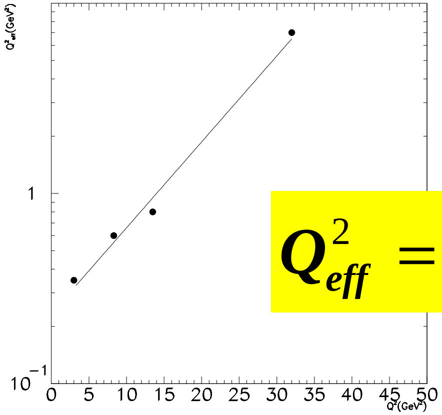
$$Q^2_{eff} = \left(\frac{Q^2}{2.65}\right)^{0.887}$$



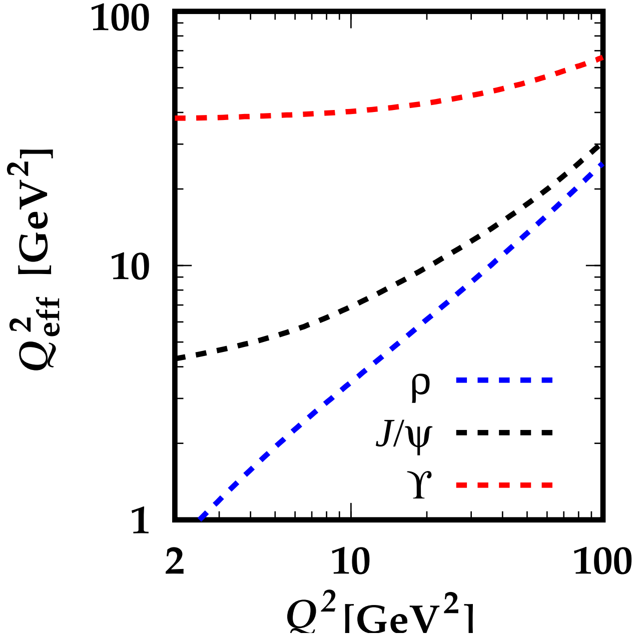


$$Q^2_{eff} = \frac{Q^2 + M^2}{4}$$

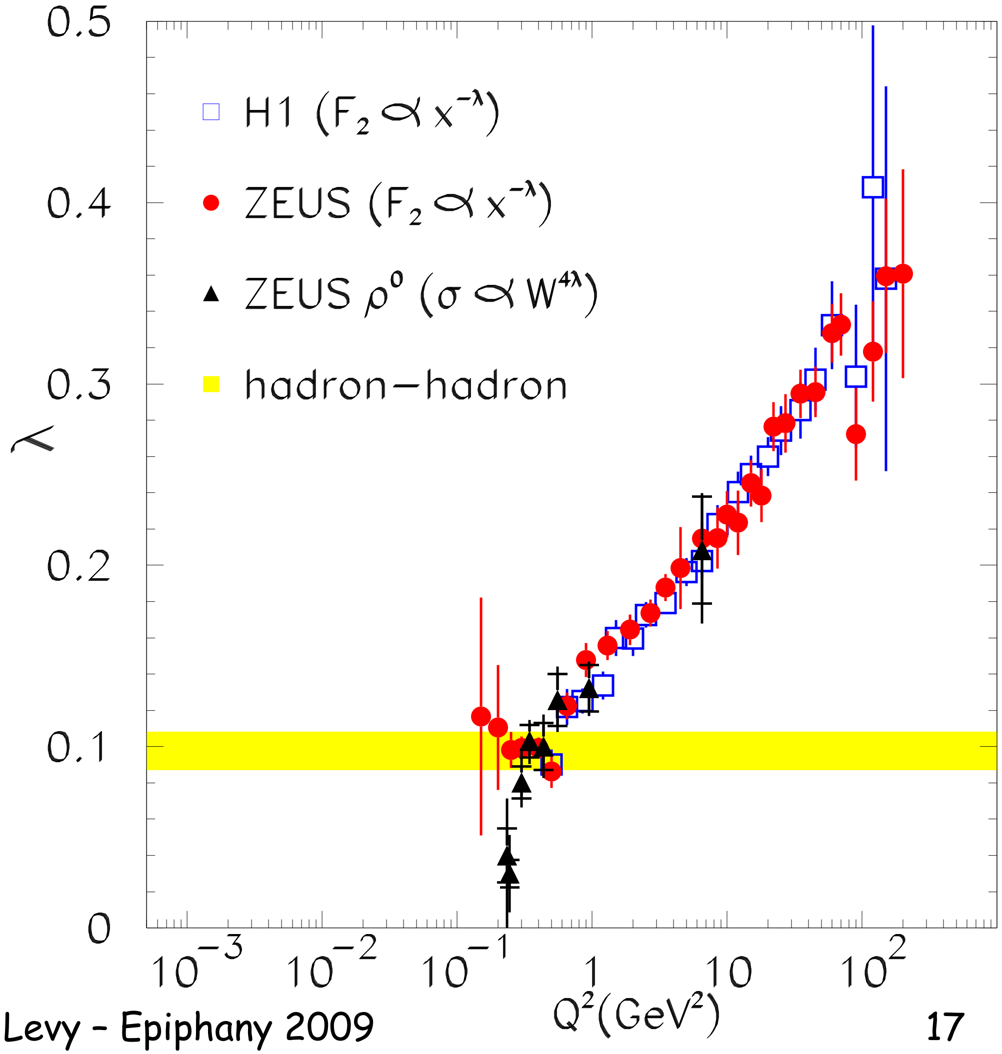
λ plots (ρ)



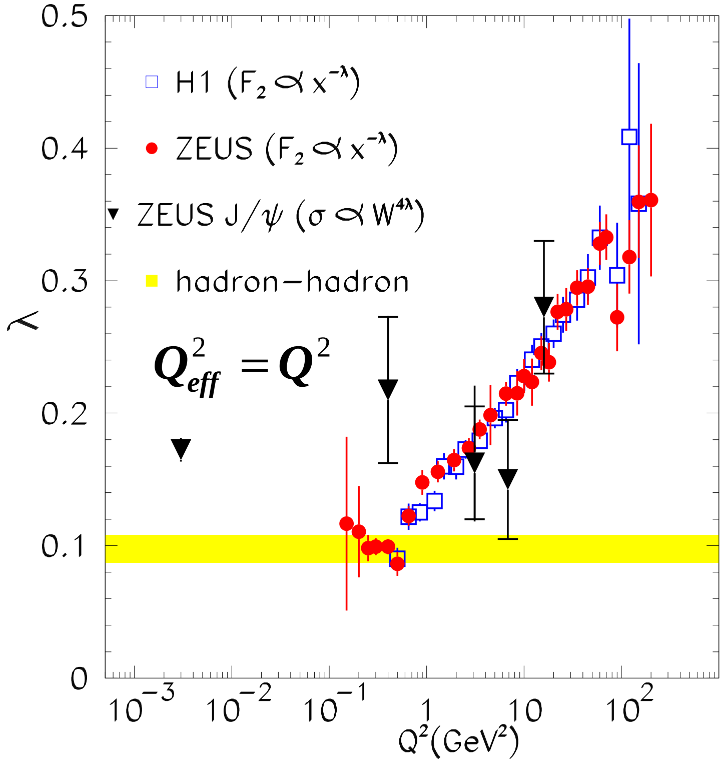
$$Q^2_{eff} = 0.233 e^{0.1Q^2}$$



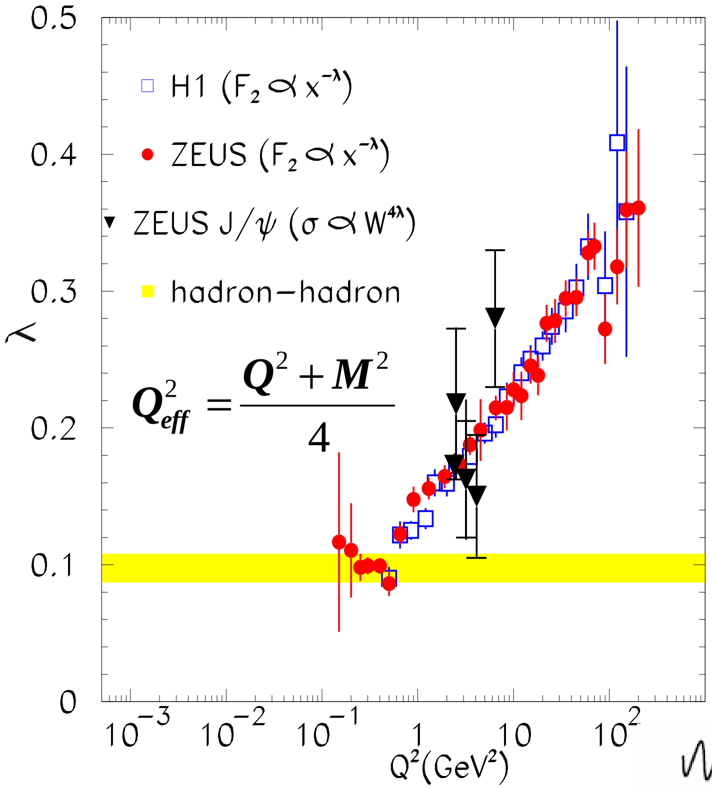
Frankfurt, Strikman, Weiss



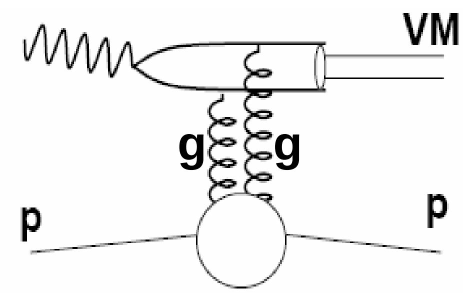
J/ψ



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
$Q^2(GeV^2)$

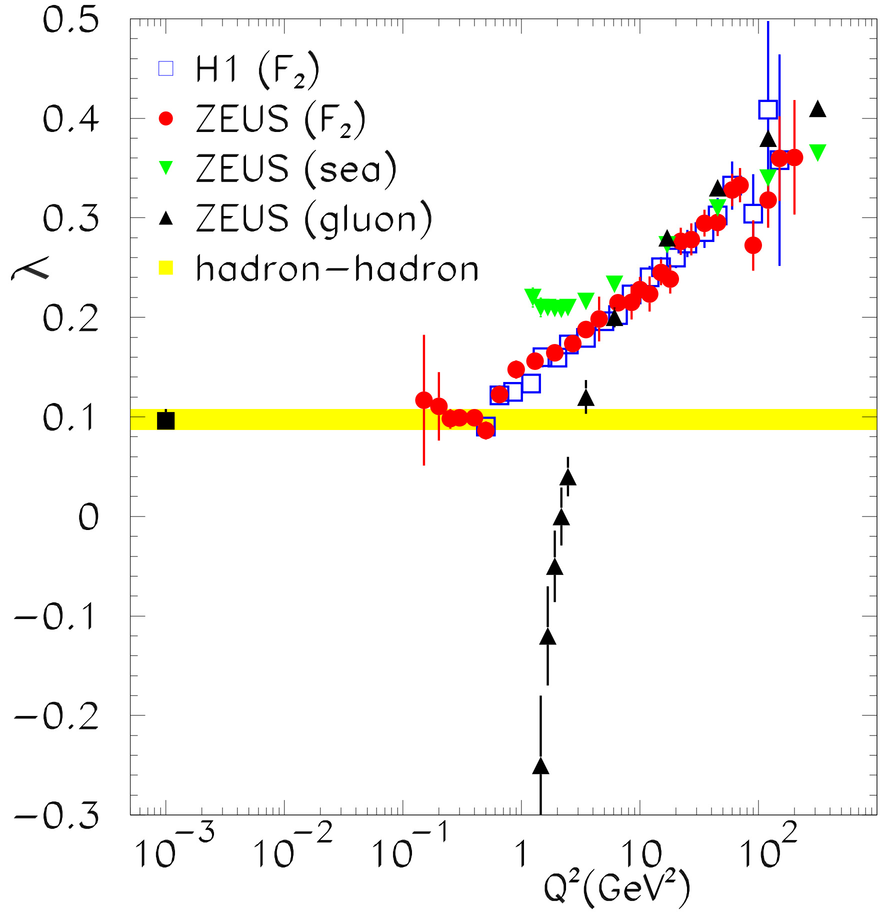


H1 ($F_2 \propto x^{-\lambda}$)
ZEUS ($F_2 \propto x^{-\lambda}$)
ZEUS J/ψ ($\sigma \propto W^{4\lambda}$)
hadron−hadron
$Q^2_{eff} = \frac{Q^2 + M^2}{4}$
λ
$Q^2(GeV^2)$



VM
g
g
p
p

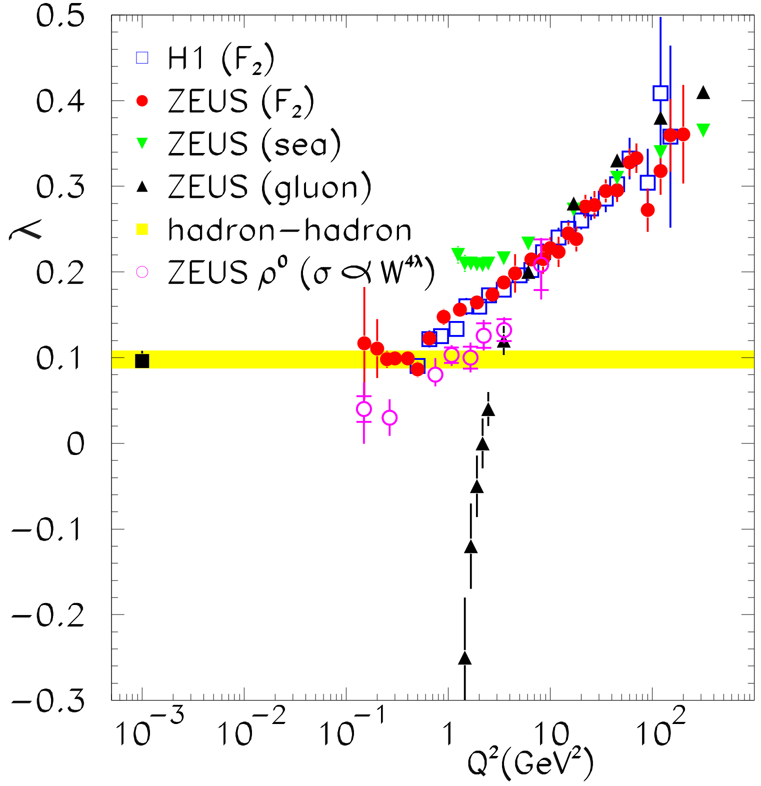
λ - gluons

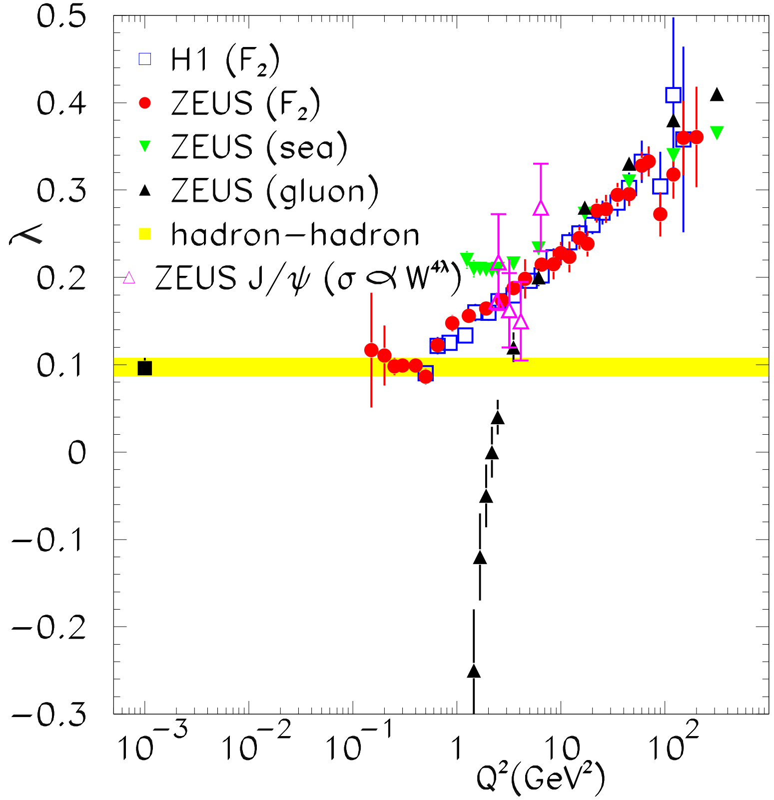


Mandy Cooper-Sarkar : from ZEUS pdfs – get λ_g and λ_{sea}

Frankfurt, Strikman, Weiss: NLO DGLAP describe x-dependence of structure function even at low Q^2, at the price of a lack of a smooth matching of the x-dependence of the gluon distribution to the soft regime (Ann.Rev.Nucl.Part.Sci.55:403,2005)

λ_g, λ_ρ, $\lambda_{J/\psi}$

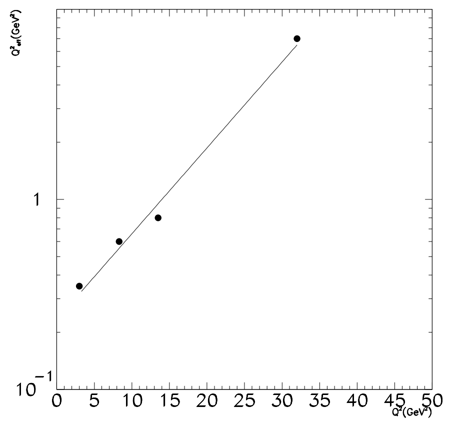


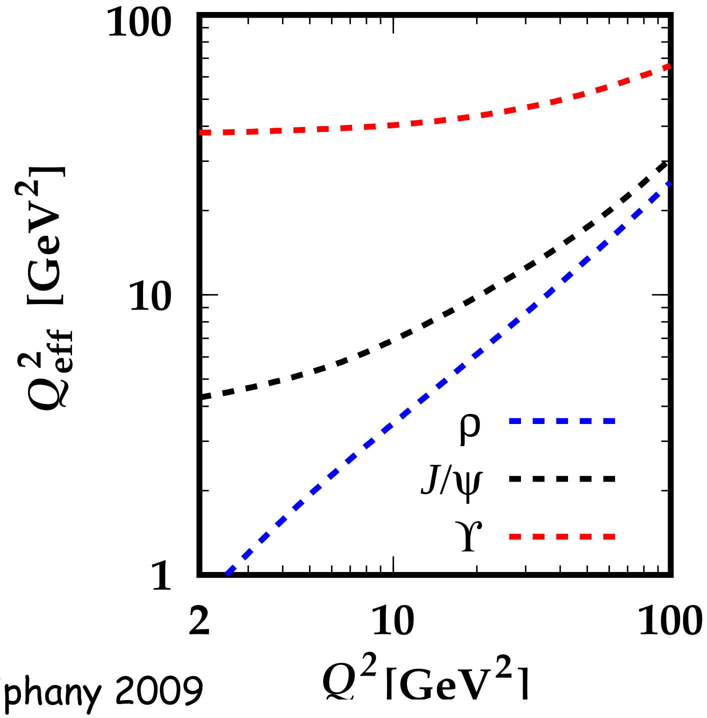


Scale for comparison $(Q^2 + M_V^2)/4$.

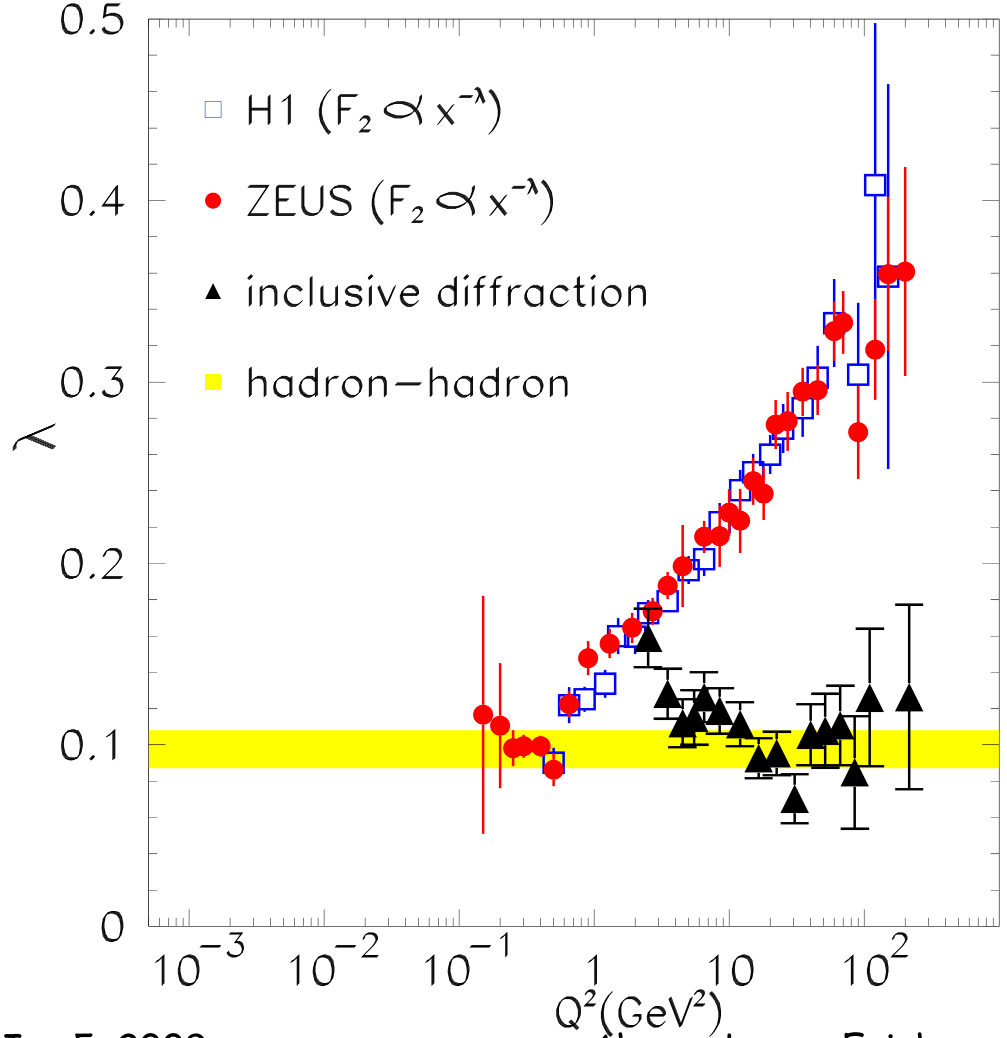
Effective scale

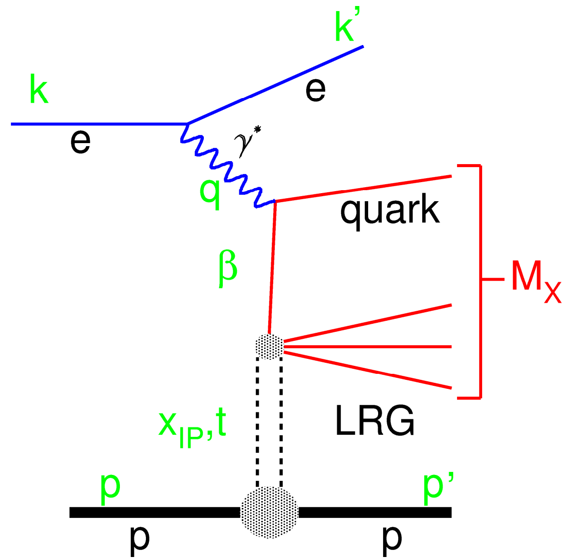
Q^2_{eff} in the ρ^0 production case is much smaller than Q^2 of the photon due to presence of the convolution of the soft ρ^0 wave function and small size longitudinal photon wave function





λ-$\alpha_{IP}(0)$ from inclusive diffraction





Source of LRG – soft process.

Ingelman: diffractive hard-process

(J/ψ - hard-diffractive process)

λ-$\alpha_{IP}(0)$ from inclusive diffraction

$\alpha_{IP}(0)$ from x_{IP} dependence

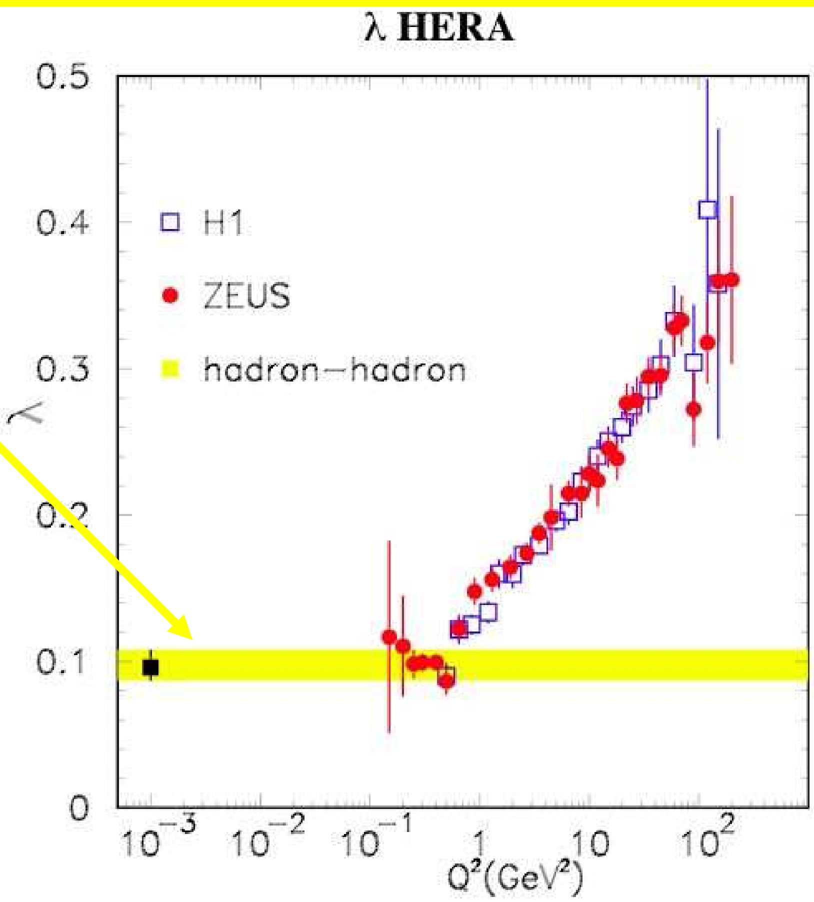
The large rapidity gap produced through a soft mechanism

Gribov – Feynman: the wee partons

Large W, have enough time for cloud of parton to develop from 'perturbative' partons to 'non-pertubative' partons, dressed large-size configurations – wee partons. Large size leads to a soft process

soft → hard

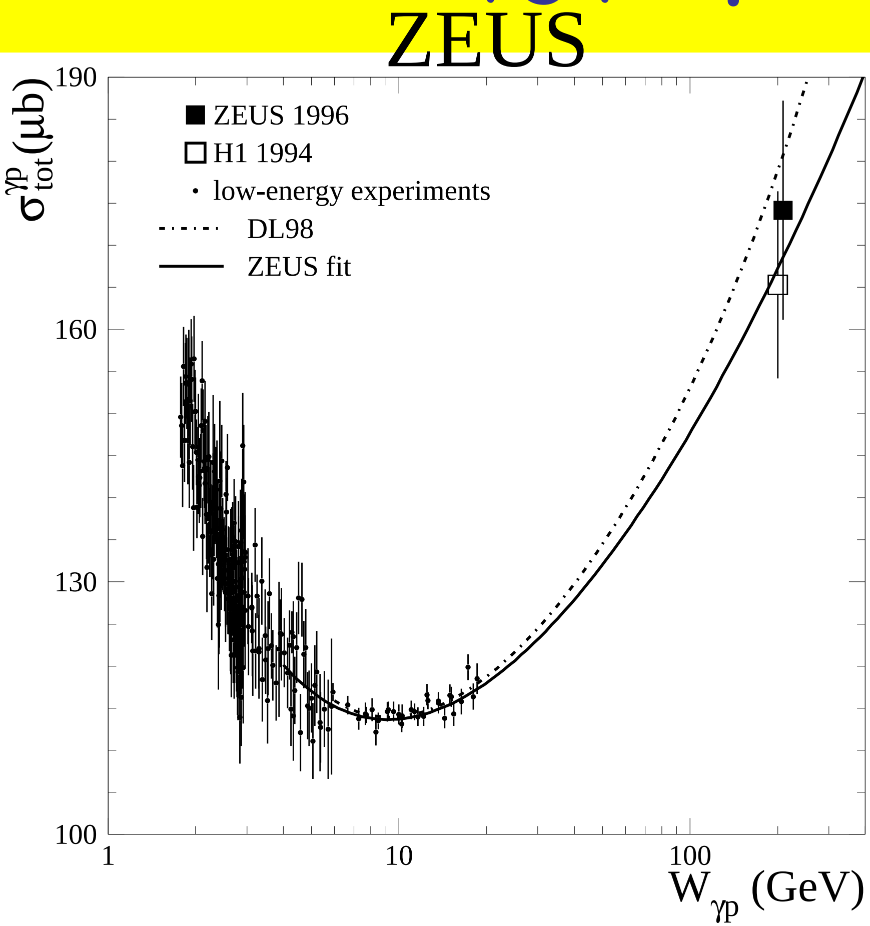
$\sigma \propto s^{0.096}$



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

Where exactly is the band? How narrow can one make it? Need to have a precise determination of W dependence of σ_{TOT}.

$\sigma_{TOT}(\gamma p)$ at HERA



At HERA:

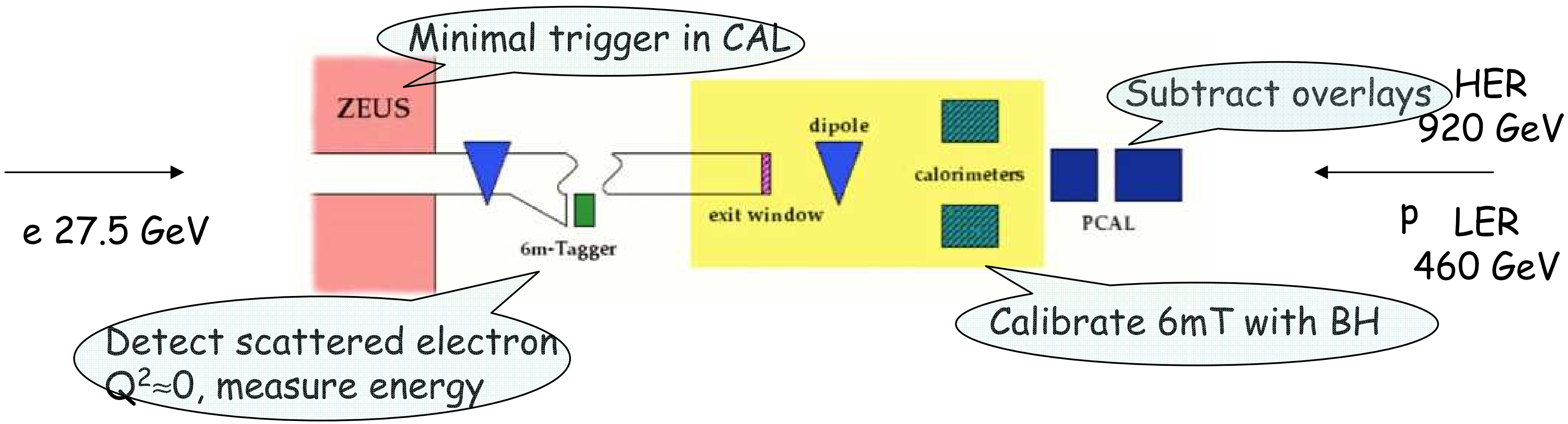
H1 (W=200 GeV), 165 ± 2 ± 11 μb

ZEUS (W=209 GeV), 174 ± 1 ± 13 μb

Large systematic uncertainties from 35m tagger acceptance and Calorimeter acceptance.

Want to reduce the large systematic error on total cross section by measuring ratios at different W.

W dependence of $\sigma_{tot}(\gamma p)$



Expect CAL acceptances at different W to be same – (checked with PYTHIA). Tagger acceptance under control – practically 100%.

W dependence of $\sigma_{tot}(\gamma p)$

ZEUS preliminary

$$R = \frac{\sigma^{\gamma p}_{HER}}{\sigma^{\gamma p}_{LER}} = \frac{N^{HER}_{evt}}{N^{LER}_{evt}} \cdot \frac{L_{LER}}{L_{HER}} \cdot \frac{f_{LER}}{f_{HER}}$$

Uncertainties:

$$\pm 0.52\%(\text{stat.}) \pm 1.05(\text{sys.}) \pm 1\% \pm 3.5\%$$

from: signal measurement LUMI tag6

(to be improved)

$$\varepsilon = 0.070 \pm 0.007(\text{stat.}) \pm 0.021(\text{syst.}) \pm 0.050(6\text{mT})$$

Comments

- Result preliminary –

  shows that the principle works

- Can improve –

  reduce systematic uncertainty

- Will use also data

  from intermediate run (E_p = 575 GeV)

Summary

- HERA data – good source to observe interplay of soft and hard dynamics in an event.
- Exclusive electroproduction of heavy meson – source to study pQCD.
- Need to understand issue of Q^2_{eff}.
- Plans to measure precisely the soft baseline from γp.

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

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

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

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

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

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

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

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

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

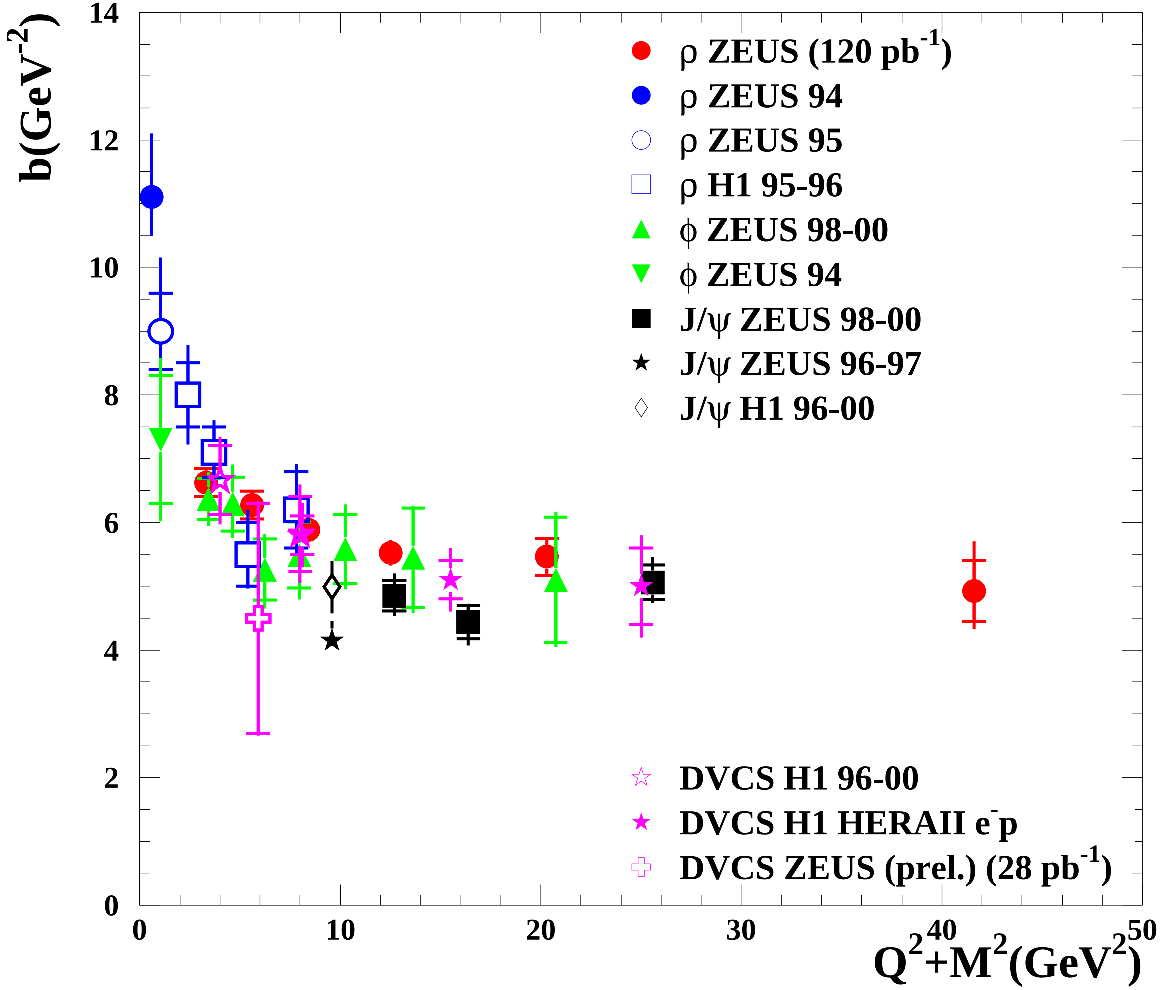
$$r_V \propto \frac{W^{2(\alpha_P(0)-1)}}{b}$$

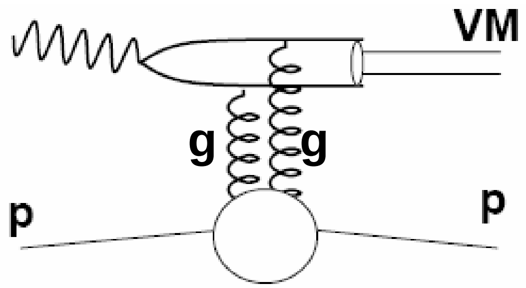
α' small $\Rightarrow$ b slow W dependence ;

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

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

b(Q²+M²) - VM





'hard'

$$< r^2 >= b \bullet (\hbar c)^2$$

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

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