Diffraction at Medium Energies

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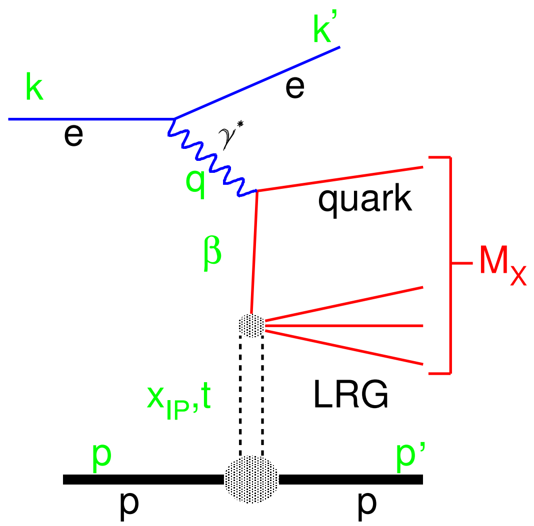
Ferrara, April 2002

- What have we learned?
  - Inclusive processes
  - Exclusive vector mesons production
  - DVCS

- Why are we doing it?

Kinematics in ep scattering



$$Q^2 = -q^2 = -(k-k')^2$$

$$x = \frac{Q^2}{2p \cdot q}$$

$$y = \frac{q \cdot p}{k \cdot p}$$

$$s = (k+p)^2$$

$$W^2 = (q+p)^2$$

Diffraction at high energy $\Rightarrow$ Large Rapidity Gap

Additional diffractive variables

$$x_{I\!P} = \frac{q \cdot (p-p')}{q \cdot p} \simeq \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

$$\beta = \frac{Q^2}{2q \cdot (p-p')} \simeq \frac{Q^2}{Q^2 + M_X^2}$$

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

Picture of soft Diffraction

LRG due to exchange of Pomeron trajectory

$$\begin{aligned}
\alpha_{I\!P}(t) &= \alpha_{I\!P}(0) + \alpha'_{I\!P} \cdot t \\
\sigma_{\rm tot} &\sim s^{\alpha_{I\!P}(0)-1} \\
\frac{d\sigma_{\rm el}}{dt} &\sim \frac{\sigma_{\rm tot}^2}{16\pi} e^{2(b_0^{\rm el} + \alpha'_{I\!P} \ln s)t} \\
\frac{d^2\sigma_{\rm D}}{dt dx_{I\!P}} &\sim \left(\frac{1}{x_{I\!P}}\right)^{2\alpha_{I\!P}(t)-1} e^{2(b_0^{\rm D} - \alpha'_{I\!P} \ln x_{I\!P})t}
\end{aligned}$$

where $\rm D$ stands for diffraction and $x_{I\!P} = \frac{M_X^2}{s}$.

- Experimentally $\alpha_{I\!P}(0) = 1 + \epsilon$ with $\epsilon = 0.08 - 0.10$ and $\alpha'_{I\!P} = 0.25({\rm GeV}^{-2})$

- $\frac{\sigma_{\rm el,D}}{\sigma_{\rm tot}} \sim s^{\epsilon}$

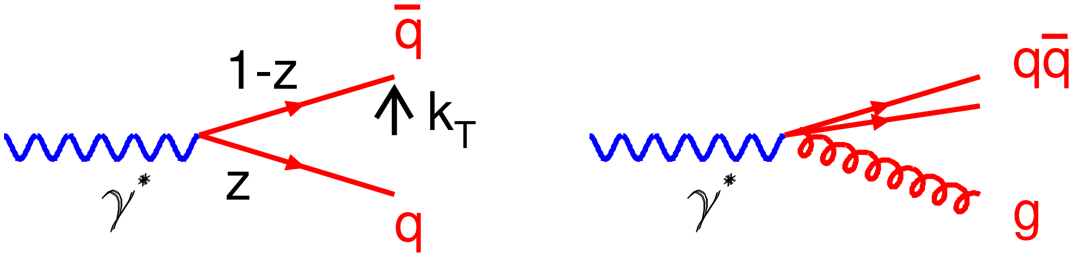
- shrinkage of the t slope $x_{I\!P}$

- enhancement of low diffractive masses $\frac{d\sigma_{\rm D}}{x_{I\!P}} \sim \left(\frac{1}{x_{I\!P}}\right)^{1+2\epsilon}$

Picture of Diffraction in DIS

In the target rest frame:

(1) $\gamma^* \to q\bar{q}$ or $q\bar{q}g$ forming color dipoles



$$\tau_{\text{fluctuation}} \simeq \frac{1}{2mx} \gg 1\,\text{fm}$$

(2) The dipole interacts with the target T

- if k_T large, small transverse size $r \to$ pQCD

$$\sigma_{q\bar{q}T} = \frac{\pi^2}{3} r^2 \alpha_S(Q^2) x G_T(x, Q^2 \simeq \frac{\lambda}{r^2})$$
$$\sigma_{q\bar{q}gT} = \sigma_{ggT} = \frac{9}{4}\sigma_{q\bar{q}T}$$

Color transparency

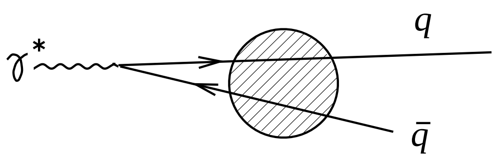
- if k_T small, large transverse size $r \to$ non-perturbative physics dominates

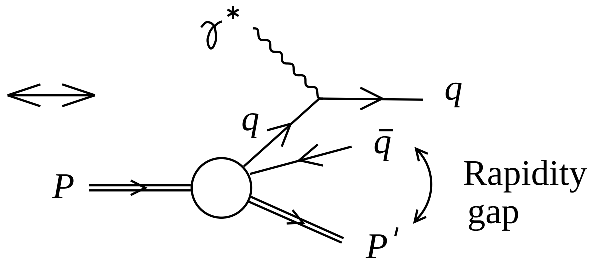
Essence of diffractive dynamics

- Diffraction $=$ quasi-elastic scattering of dipoles

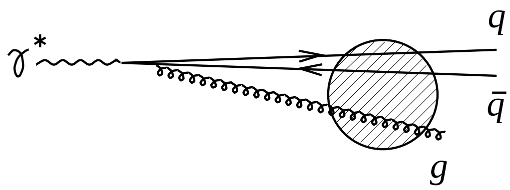
$$\frac{d\sigma_D}{dt} = \frac{\sigma^2_{\mathrm{dipole}T}}{16\pi}$$

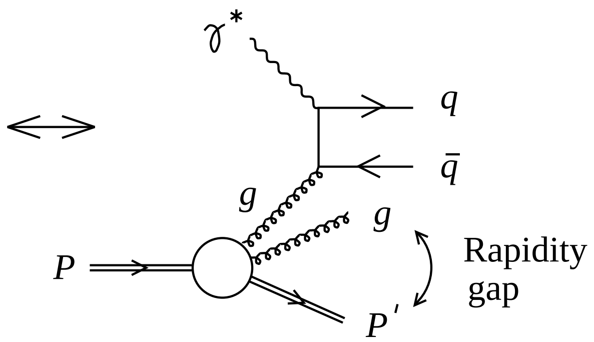
Target rest frame | Breit frame





a) quark distribution



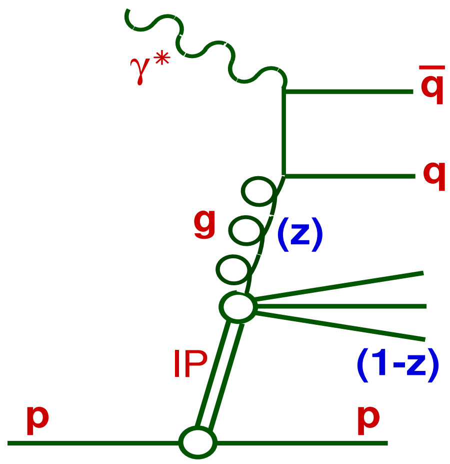


b) gluon distribution

Models differ in the treatement of the 'blobs'

- β distribution $\leftarrow$ wave function of the photon
- $x_{I\!P}$ dependence $\leftarrow$ "blob" (soft vs hard?)
- gluons dominate $\leftarrow$ $\sigma_{q\bar{q}g} > 2\sigma_{q\bar{q}}$

The making of the blob



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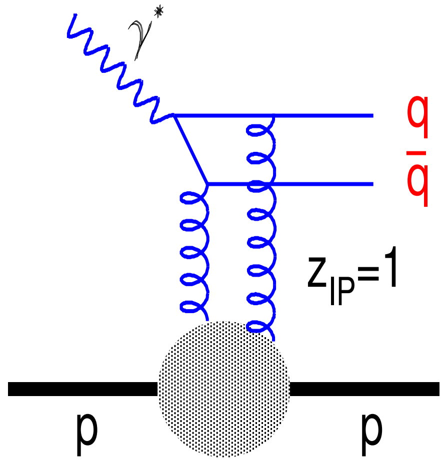


Soft

Factorizable $I\!P$

à la Ingelman-Schlein

Diffractive gluons

For jets $z < 1$

Universal $x_{I\!P}$ dep.

Shrinkage in t slope

Hard

Prototype of QCD $I\!P$

à la Low & Nussinov

Gluons in p

For jets $z = 1$

Non-universal $x_{I\!P}$ dep.

Universal t dep.,

with $b \simeq 4\,\mathrm{GeV}^{-2}$

- Diffractive structure function F_2^D

$$\frac{d^4\sigma^D(ep\to epX)}{dx_{I\!P}dtdxdQ^2} = \frac{2\pi\alpha^2}{xQ^4}(1+(1-y)^2)\frac{d^2F_2^D(x_{I\!P},t,x,Q^2)}{dx_{I\!P}dt}$$

- QCD factorization for diffractive DIS holds

(Collins, Berera &Soper, Trentadue & Veneziano)

$$\frac{d^2F_2^D(x_{I\!P},t,x,Q^2)}{dx_{I\!P}dt} = \sum_i \int dz \frac{d^2f_{i/p}^D(x_{I\!P},t,z,\mu^2)}{dx_{I\!P}dt} \quad \hat{F}_i(\frac{x}{z},\frac{Q^2}{\mu^2})$$

diffractive parton distribution functions

pQCD as in incl. DIS

Diffractive parton distributions evolve in μ^2 following DGLAP equations

- If in addition postulate Regge factorization

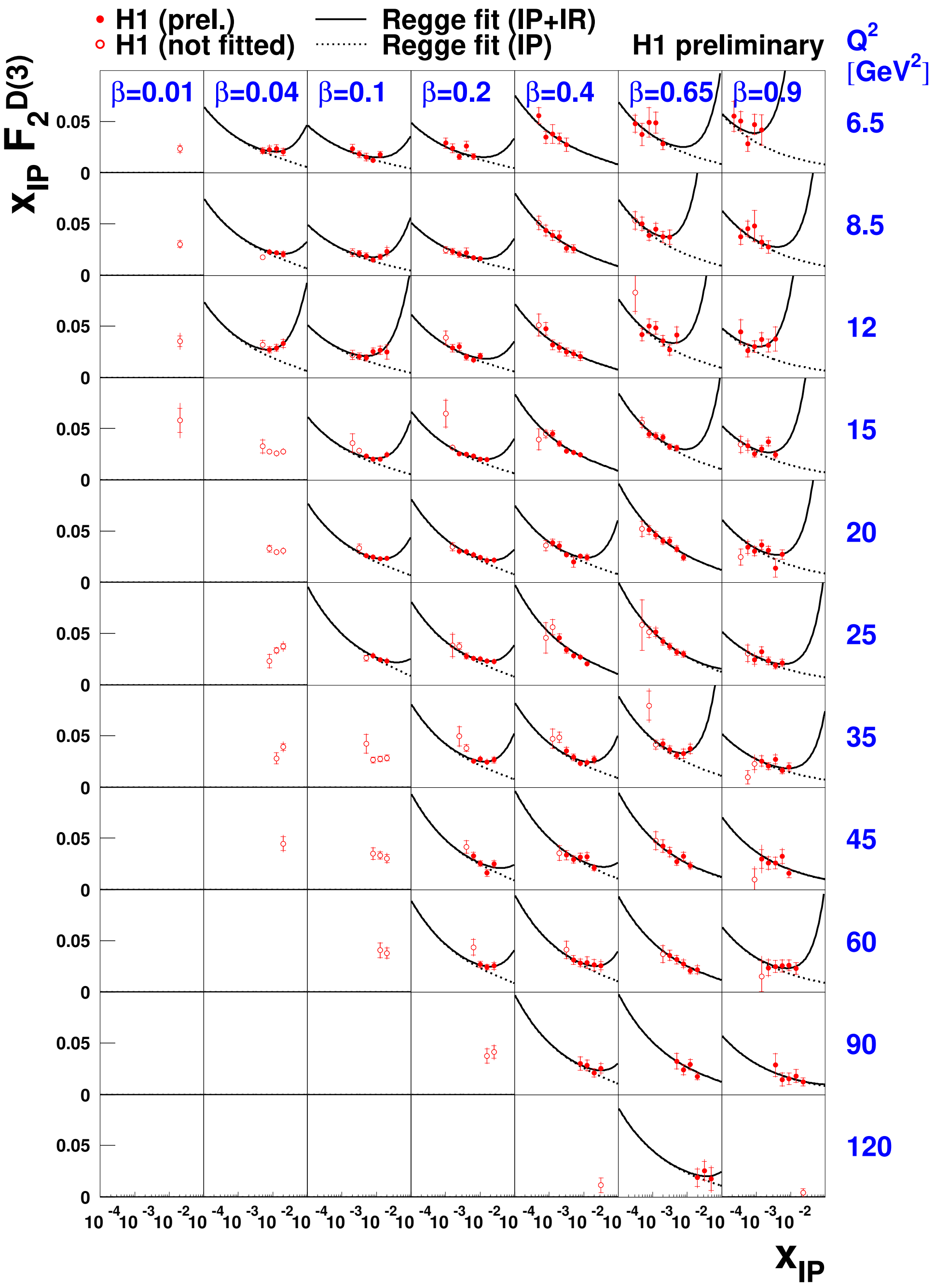
(Ingelman & Schlein)

$$\frac{d^2F_2^D(x_{I\!P},t,x,Q^2)}{dx_{I\!P}dt} = f_{I\!P/p}(x_{I\!P},t)F_2^{I\!P}(\beta,Q^2)$$

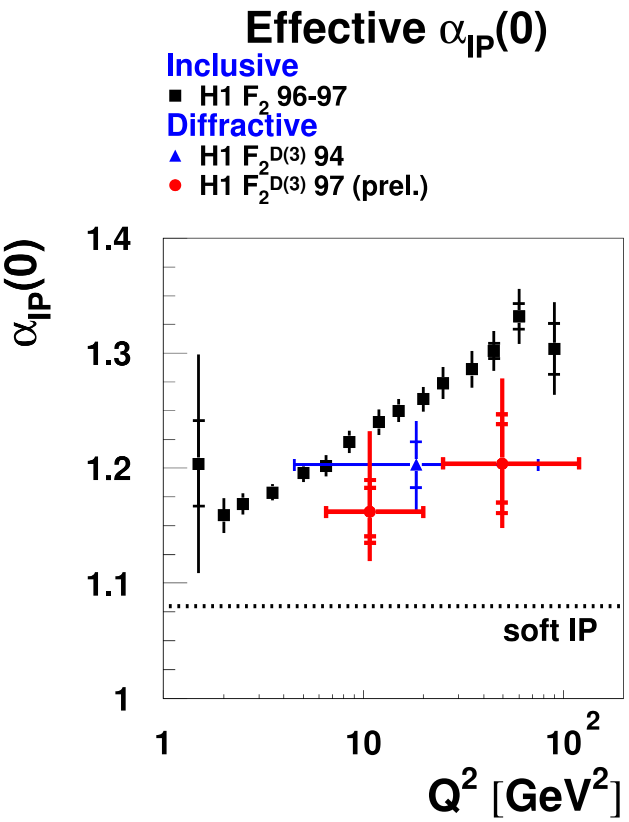
$F_2^{I\!P}(\beta,Q^2)$ evolves following DGLAP equations

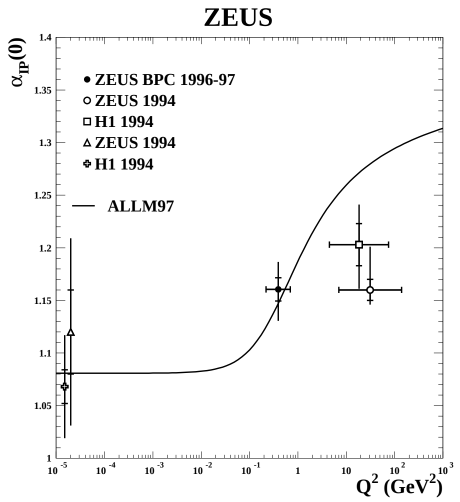
Diffractive Structure Function $F_2^{D(3)}$

$$x_{I\!P}F_2^{D(3)}(x_{I\!P},\beta,Q^2) \sim \frac{1}{x_{I\!P}^{2\bar{\alpha}_{I\!P}-2}}F_2^{I\!P}(\beta,Q^2)$$



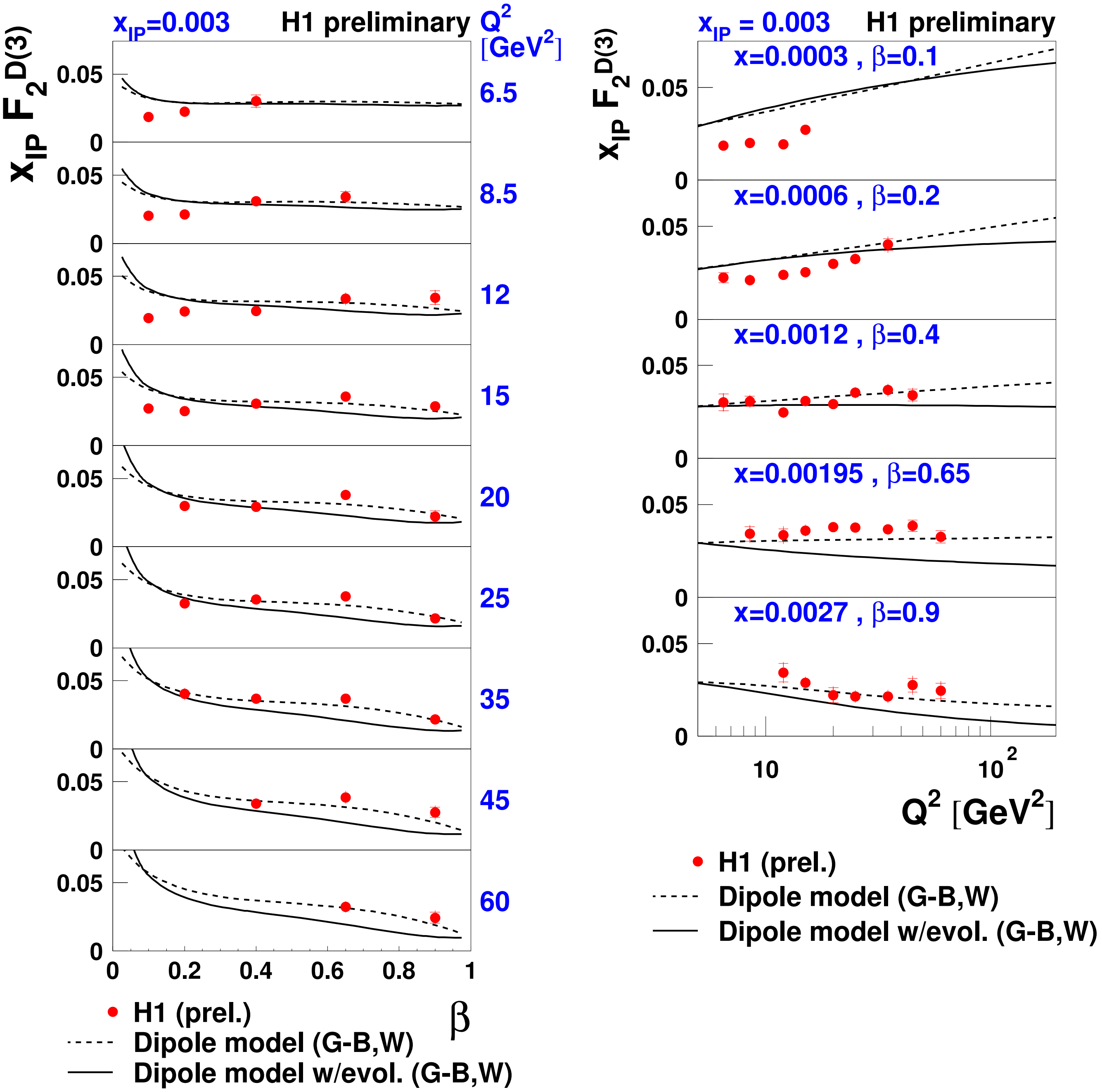
- $x_{I\!P}$ dependence



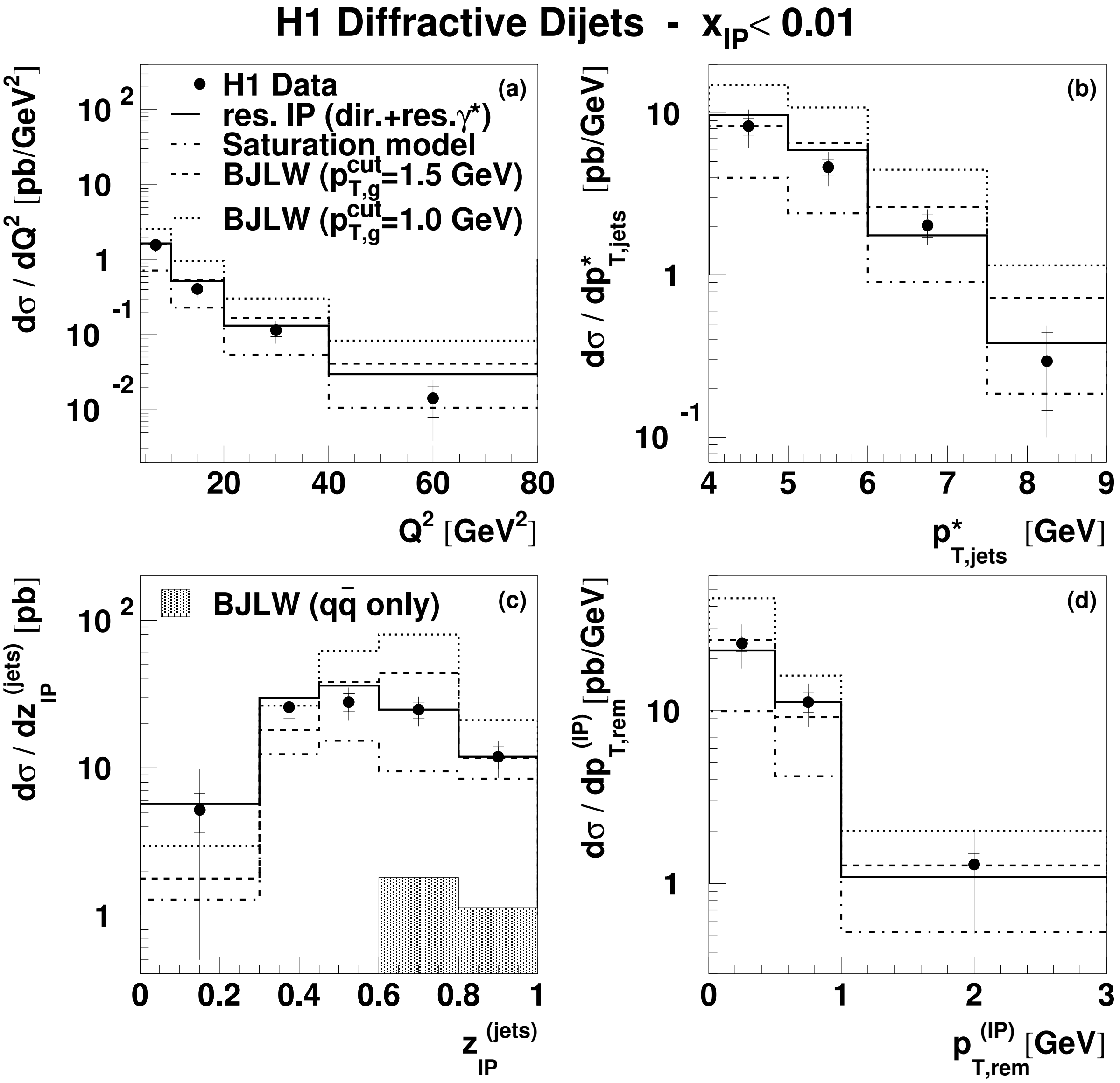


- $\alpha_{I\!P}$ dependence on Q^2 not excluded
- $\alpha_{I\!P}$ from LRG not the same as for incl. DIS

- Dipole based model with saturation of Golec-Biernat–Wuesthoff

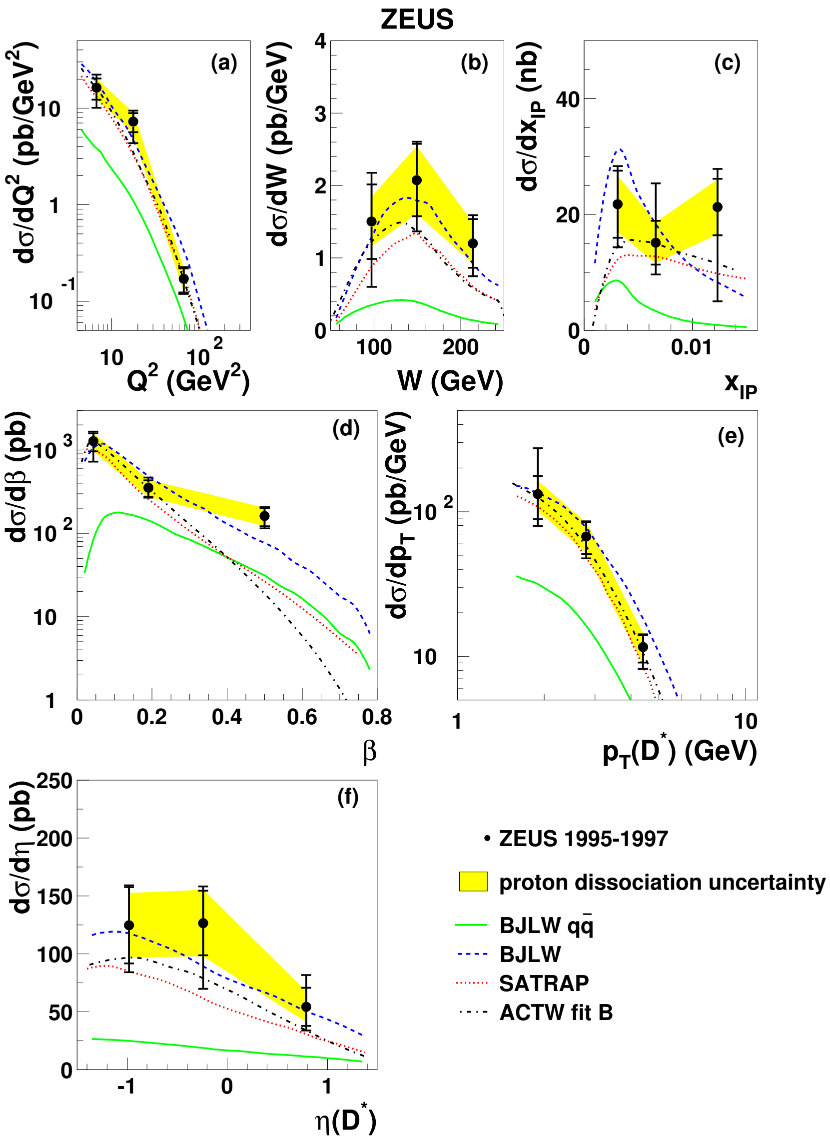


- Jet production
- $ep \to ep$ jet jet



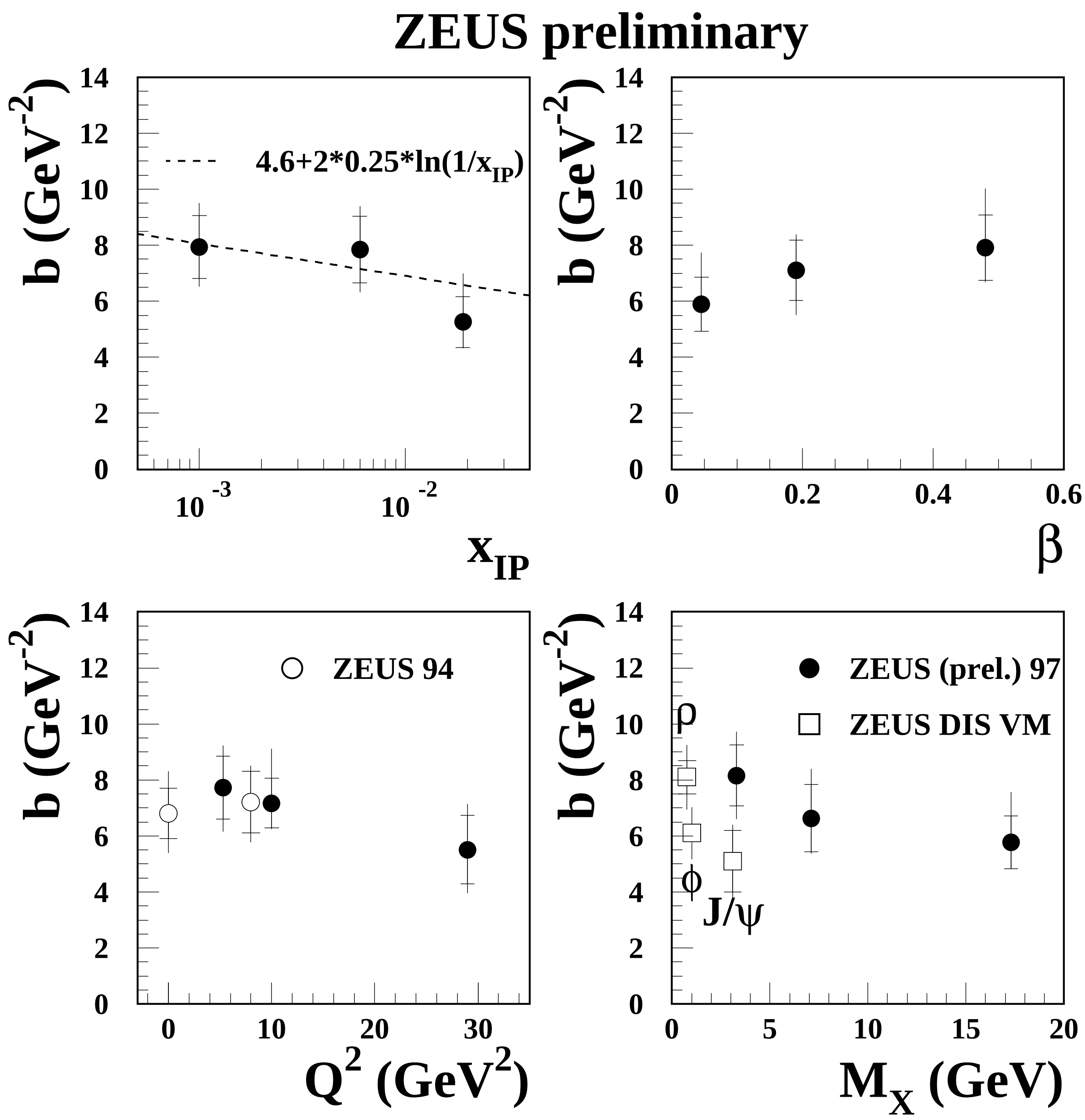
- The resolved $I\!P$ model does well
- pQCD based model of Bartels et al. also does well

- Charm production
- $ep \to epD^{\star\pm}X$



- The resolved $I\!\!P$ model does well
- pQCD based model of Bartels et al. maybe does better (high β)

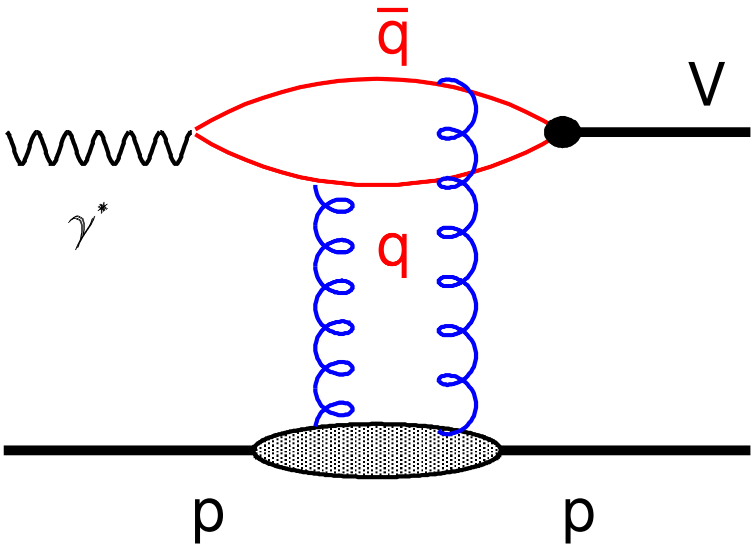
- Ultimate measure of hardness, t distribution
- Needs LPS to access scattered proton



- b value far from the 'hard' limit

Exclusive vector meson in ep

Candidate for a hard process $\Rightarrow$ pQCD



If $q\bar{q}$ form small configuration $\Rightarrow$ resolves gluons

either γ^*_L or $V = c\bar{c}, \quad b\bar{b}$

- $\sigma_L \sim \frac{\alpha_S^2}{Q^6} \mid xG(x, Q^2) \mid^2$

  $\Rightarrow$ fast increase of $\sigma(\gamma^* p \to Vp)$ with W^2

  $\Rightarrow$ universality of t dependence $\sim e^{b_{2g}t}$

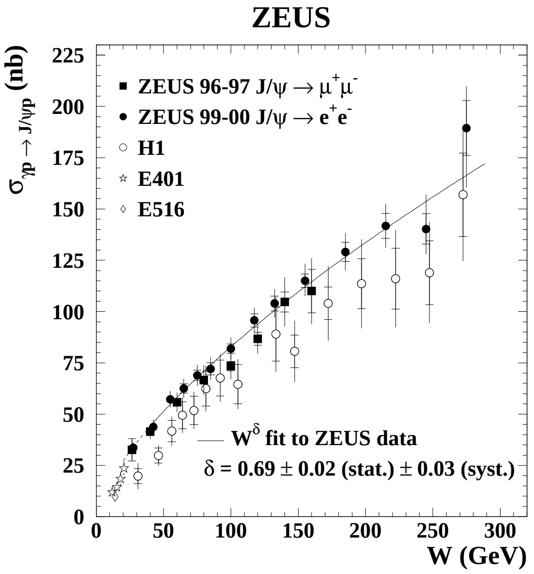
  $b_{2g} \simeq 4 \text{ GeV}^{-2}$ and $\alpha'_{I\!P} \simeq 0$

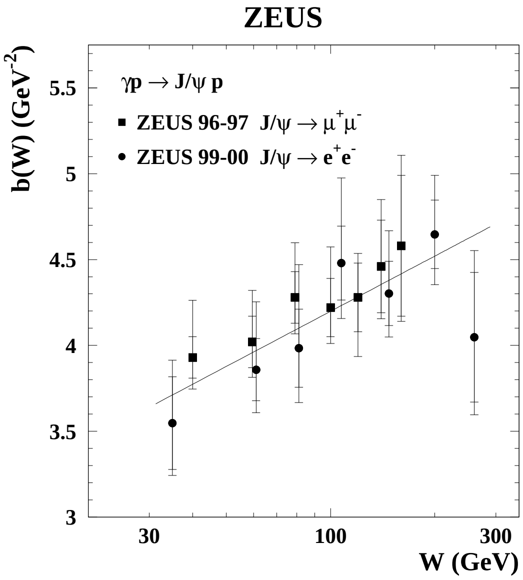
  $\Rightarrow$ Q^2 dependence slower than $1/Q^6$

  $\Rightarrow$ SU(4) restoration

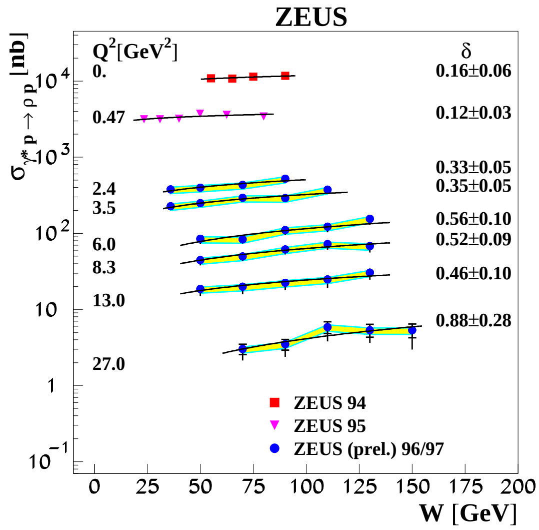
  $\rho : \omega : \Phi : J/\psi = 9 : 1 : 2 : 8$

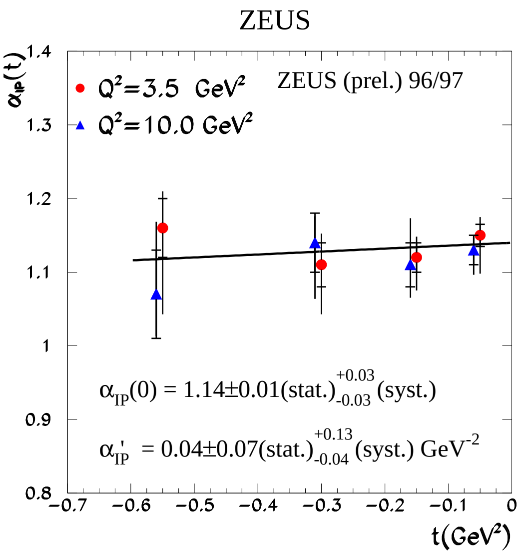
Exclusive J/ψ in γp and ρ in $\gamma^* p$



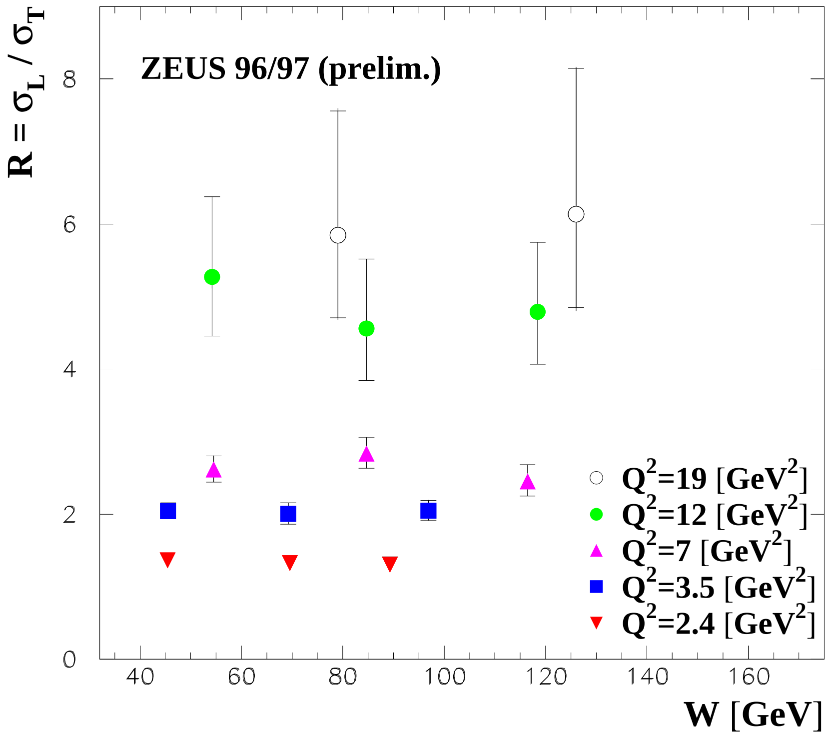


$$\alpha'_{J/\psi} = 0.115 \pm 0.018(\text{stat})^{+0.008}_{-0.016}(\text{syst.})\ \text{GeV}^{-2}$$





• The contribution of (softer) $\gamma_T^\star$ seems suppressed



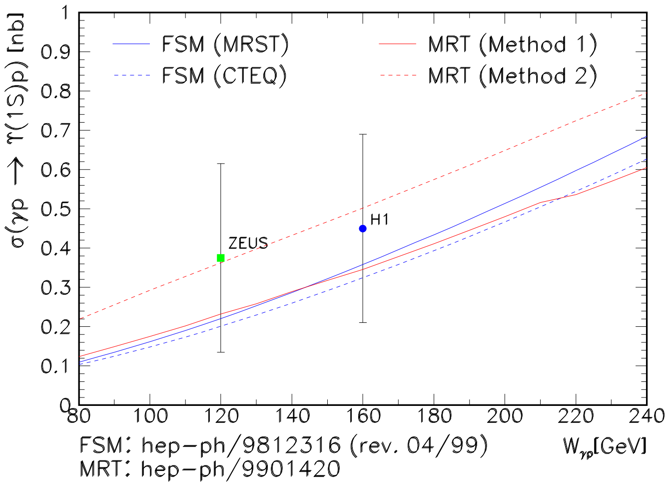
• the increase of the slope of the W dependence with increasing hardness of the scale, and

• the flattening of the exchanged trajectory,

may indicate the dominance of pQCD regime for scales $\sim 10\,\mathrm{GeV}^2$

Factorization for hard exclusive processes + dominance of pQCD $\Rightarrow$ access to parton densities of the proton.

Exclusive Υ in γp



FSM - Frankfurt, Strikman and McDermott

MRT - Martin, Ryskin and Teubner

To get agreement with data:

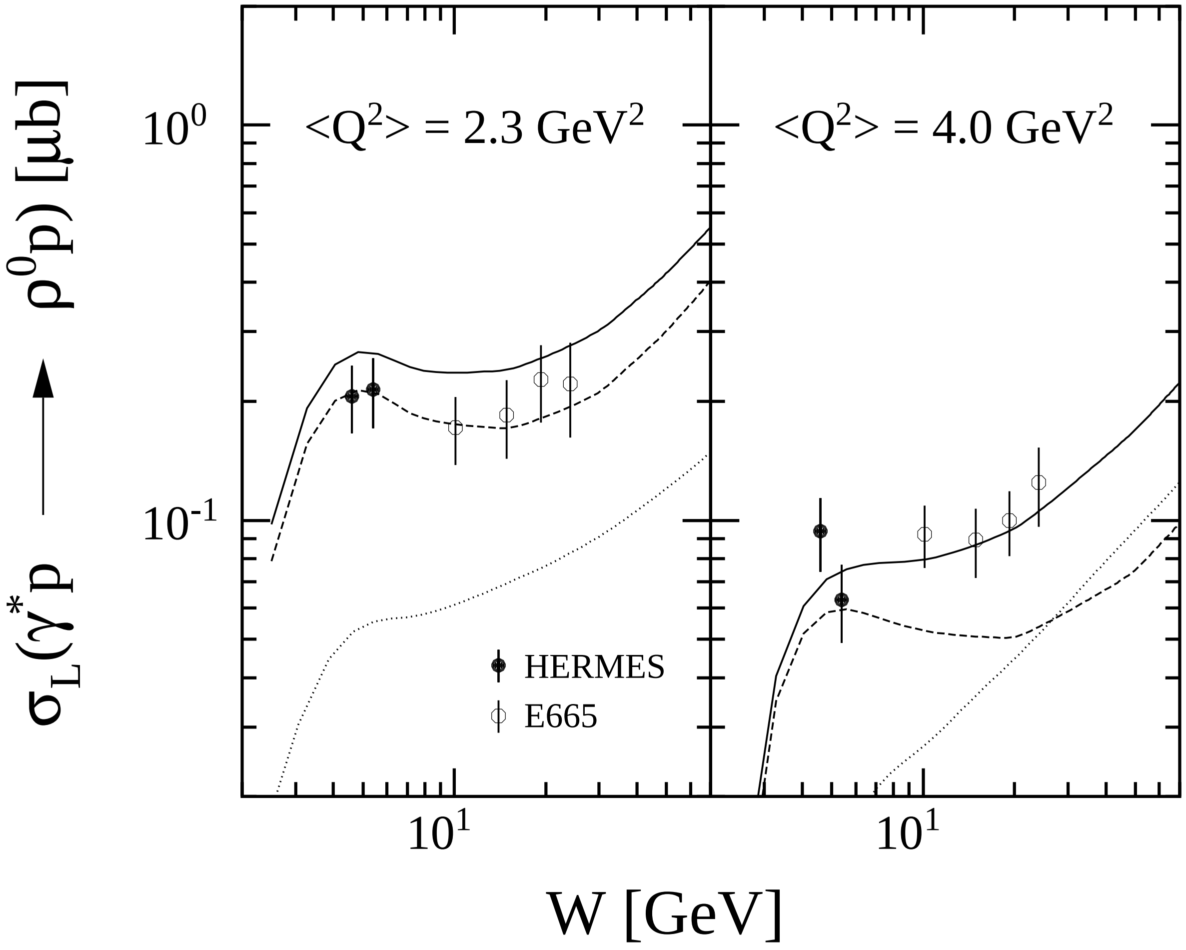
- Skewed parton distributions
  The two exchanged g have different x:
  $\delta x = \frac{M_V^2+Q^2}{W^2+Q^2} \Rightarrow$ factor 2 enhancement

- Real part of the scattering amplitide $\neq 0$
  $\frac{d\sigma_{\rm el}}{dt}\,|_{t=0}= (1+\eta^2)\frac{\sigma^2_{\rm tot}}{16\pi}$
  $\eta = \frac{ReA}{ImA}$
  Gribov-Migdal relation $\eta \simeq \frac{\pi}{2}\frac{d\ln \sigma_{\rm tot}}{d\ln W^2}$
  Since $\sigma_{\rm tot} \sim W^{1.8} \Rightarrow$ another factor 1.5 - 1.7 enhancement

Exclusive ρ in $\gamma^* p$ at low W

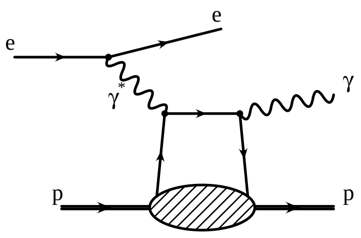
Low W and low Q^2 ($b = 6.82 \pm 0.15\,\mathrm{GeV}^{-2}$):

- $0.1 < x < 0.16 \Rightarrow$ need quark contribution
- $0.12 < \delta x < 0.16 \Rightarrow$ need Generalized Parton Distribution

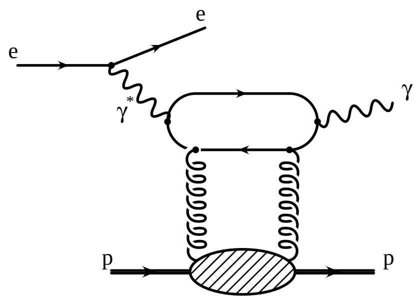


Amazing agreement with pQCD + HT (calculations by Vanderhaeghen, Guichon and Guidal)

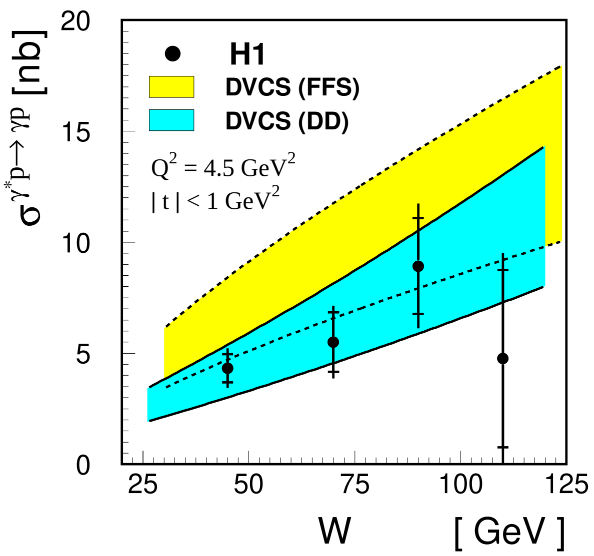
DVCS

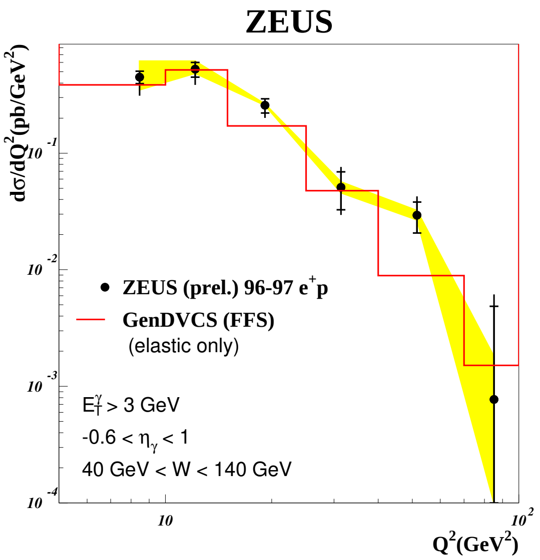


a)



b)





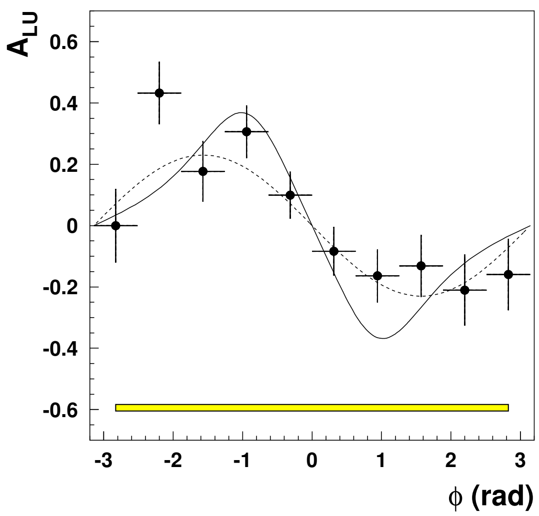
HERMES

Beam-spin asymmetry in the azimuthal angle

$A_{LU} = \frac{1}{\langle |P| \rangle} \frac{N^+ - N^-}{N^+ + N^-}(\phi)$

$\langle x \rangle = 0.11$

$\langle Q^2 \rangle = 2.6\,\mathrm{GeV}^2$



Why are we doing it ?

to ourselves !!!

Motivation:

- Study the structure of strong interactions (hadronic degrees of freedom)
- Explore the asymptotic behavior of high energy interactions (approach to unitarity limit)
- Measure Generalized Parton Distributions (structure of hadrons)

Philosophy:

- Identify processes where pQCD dominates
- Confront theory with experiment
- Iterate and expand

Shortcomings:

- We do not have tools to establish dominance of pQCD
- Too often the problems have many components and the agreement with data may be coincidental
- Too many possibly conflicting messages
- Since the subject is relatively new, the detectors are not best equipped to do measurements

It is of paramount importance to:

- define the goals
- define apap (as precisely as possible) the theoretical tools
- define kinematical areas of interest
- design dedicated experiments