

HERA and rapidity gaps

Halina Abramowicz for

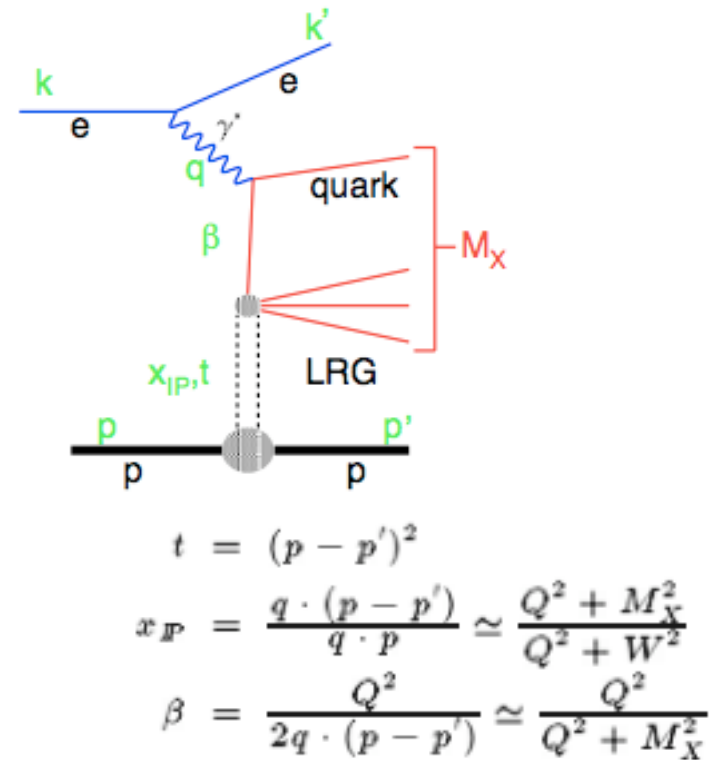
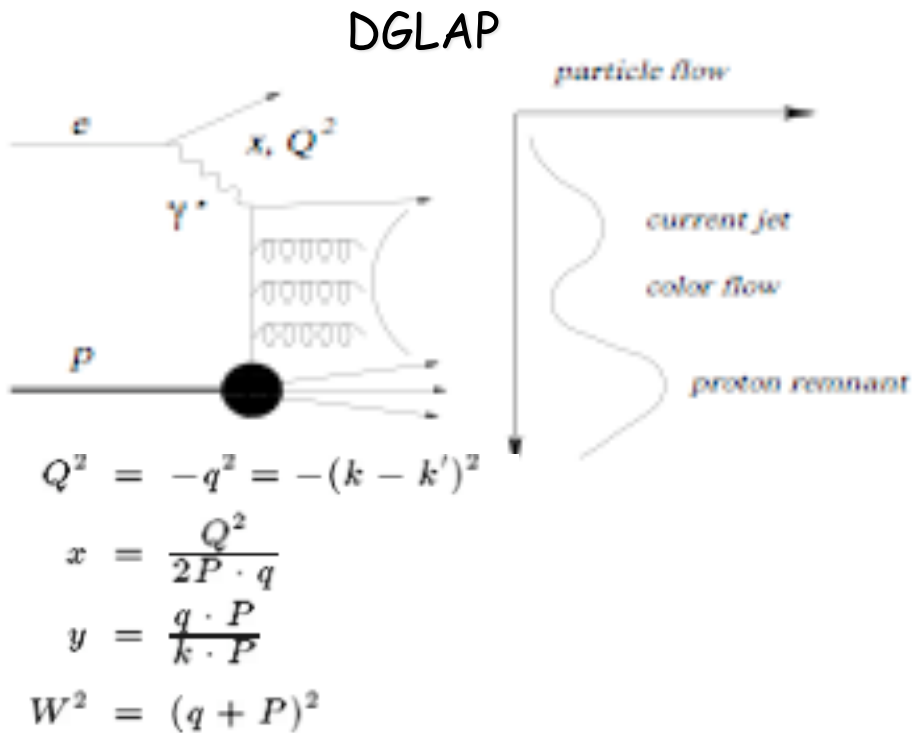


Tel Aviv University

- Inclusive diffraction in DIS
- Factorization breaking
- Exclusive processes

Diffractive DIS

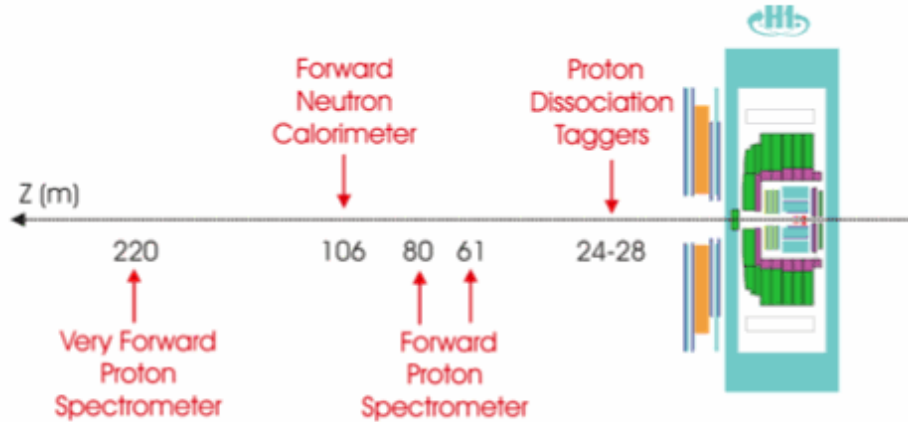
Large fraction of DIS events have LRG (visible 10%)



LRG cannot be generated by DGLAP.
Maybe it is there in the initial condition?

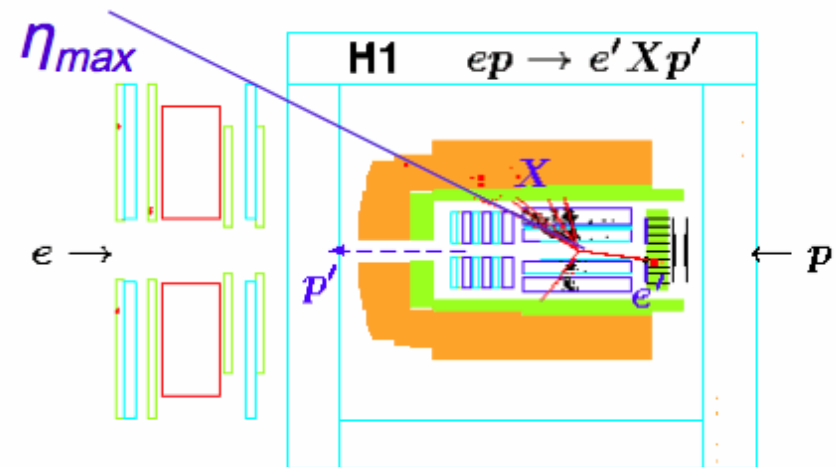
Diffraction in DIS - selection methods

Scattered proton in Leading Proton Spectrometers (LPS)



Limited by statistics and p-tagging systematics

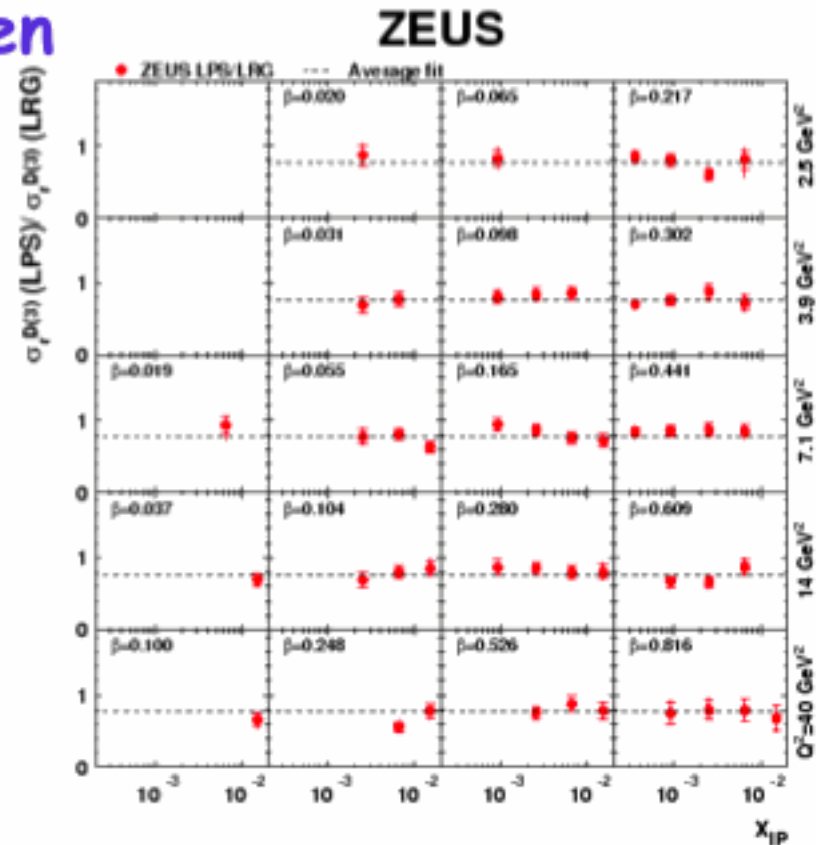
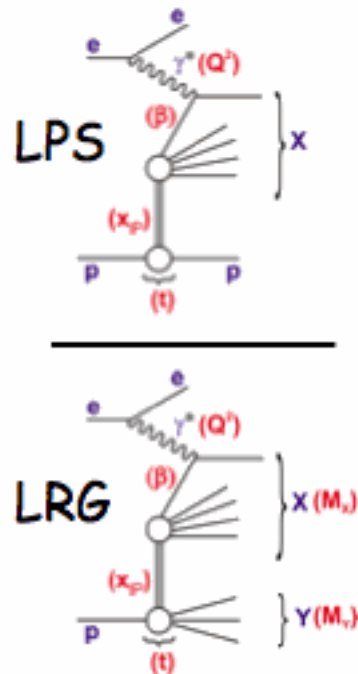
'Large Rapidity Gap' (LRG) adjacent to outgoing (untagged) proton



Limited by p-diss systematics

Diffraction in DIS - selection methods

Comparisons between Methods



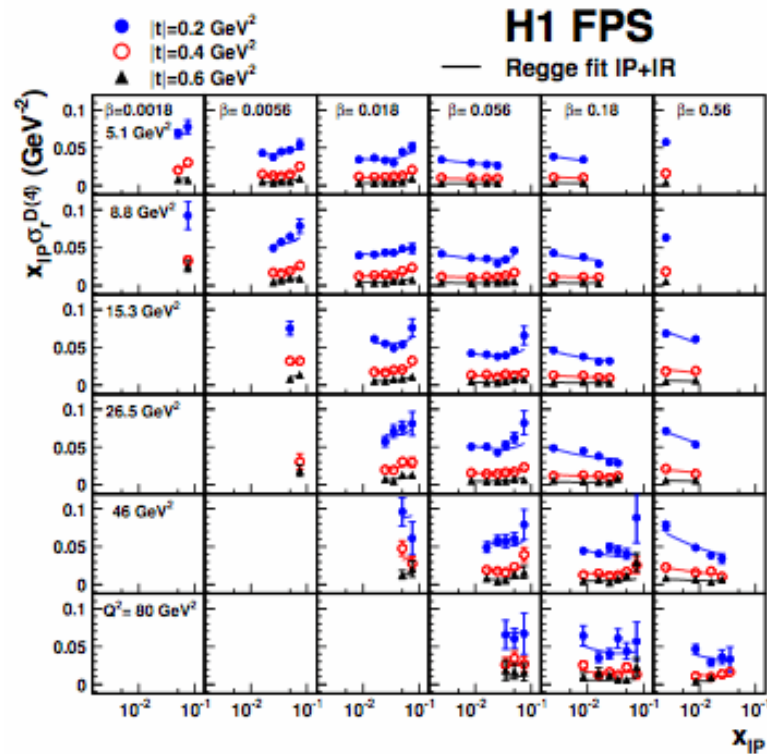
- LRG selections contain typically 20% p diss
- No significant dependence on any variable

Diffraction in DIS - vertex factorization

$$\frac{d^4 \sigma^D}{d\beta dQ^2 dx_P dt} = \frac{2\pi\alpha^2}{\beta Q^4} Y_+ F_2^{D(4)}(\beta, Q^2, x_P, t) - \frac{y^2}{Y_+} F_L^{D(4)} \quad Y_+ = 1 + (1-y)^2$$

$$F_2^{D(4)}(\beta, Q^2, x_P, t) = f_{IP/p}(x_P, t) F_2^{IP}(\beta, Q^2) + n_R f_{R/p}(x_P, t) F_2^{R}(\beta, Q^2)$$

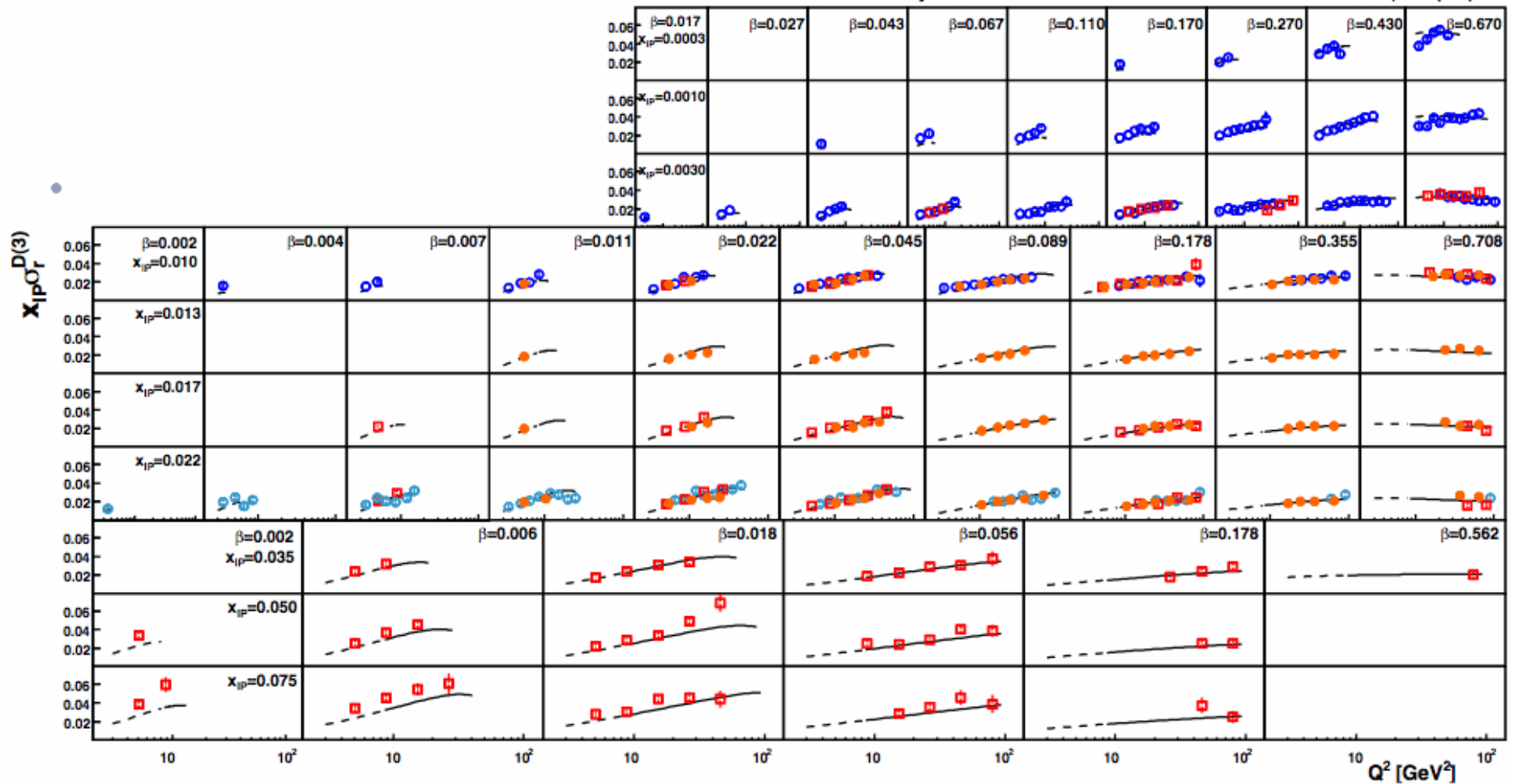
$$f_{IP,R/p}(x_P, t) = e^{bt} / x_P^{2\alpha(t)-1} \quad \alpha(t) = \alpha(0) + \alpha' t$$



Diffraction in DIS - H1 summary plot

H1 PRELIMINARY

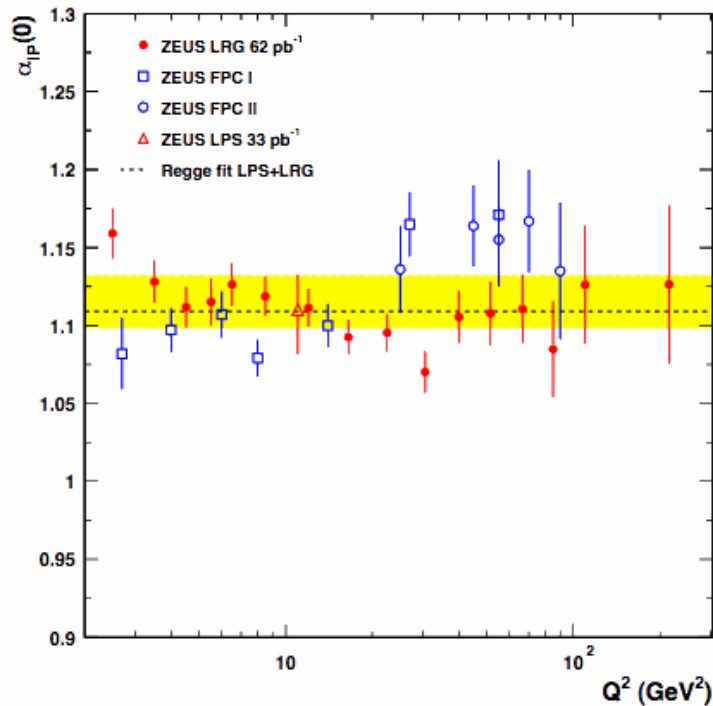
- H1 VFPS Preliminary
- H1 FPS Preliminary
- H1 LRG Preliminary x 0.81
- H1 LRG Published x 0.81
- H1 2006 DPDF Fit B x 0.81
- - - H1 2006 DPDF Fit B x 0.81 (extrapol.)



Diffraction in DIS - IP trajectory

Is the origin of LRG soft or hard in nature?

ZEUS

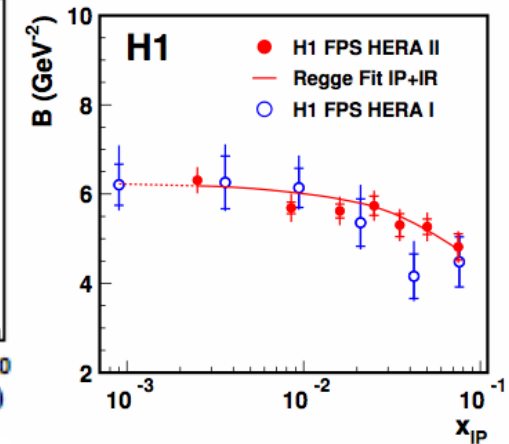
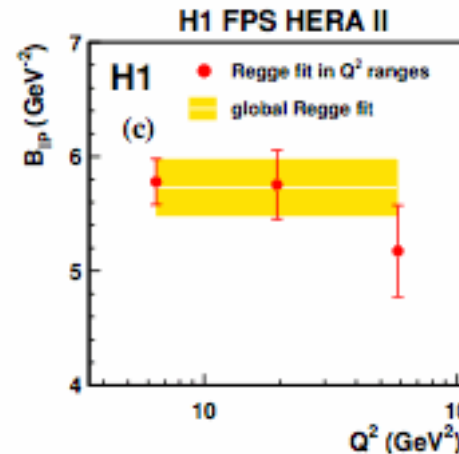
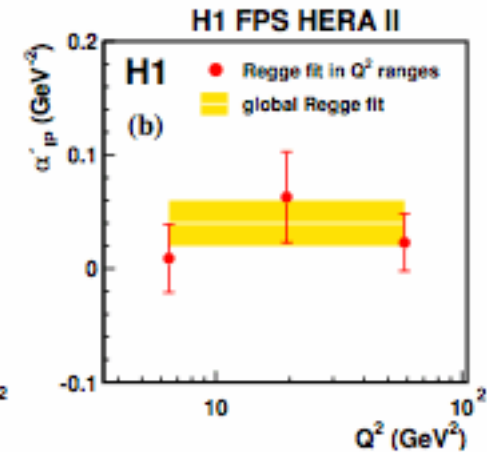
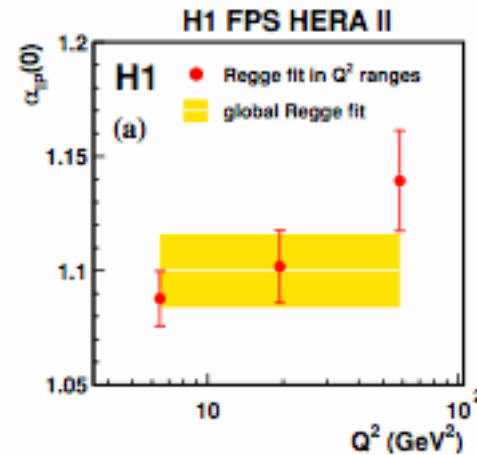


e.g. From H1 FPS data:

$$\alpha_{IP}(0) = 1.10 \pm 0.02 \text{ (exp.)} \pm 0.03 \text{ (model)}$$

$$\alpha'_{IP} = 0.04 \pm 0.02 \text{ (exp.)} \pm 0.03 \text{ (model)} \text{ GeV}^{-2}$$

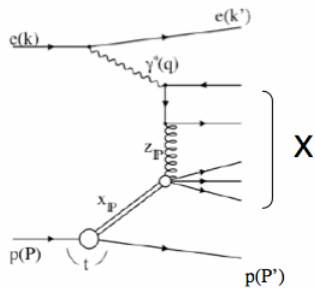
$$B_{IP} = 5.7 \pm 0.3 \text{ (exp.)} \pm 0.6 \text{ (model)} \text{ GeV}^{-2}$$



Diffractive parton distributions

QCD factorisation theorem, proven for DDIS by **J.Collins** [PR D57 (1998) 3051]

$$\sigma^D(\gamma^* p \rightarrow Xp) = \sum_i \hat{\sigma} \otimes f_i^D(x_{IP}, t, z, Q^2)$$



Hard subprocess ME
pQCD calculable

DPDFs, universal for diffractive DIS processes

Proton-vertex factorisation assumption, supported by H1 and ZEUS data

$$f_i^D(x_{IP}, t, z, Q^2) = f_{IP}(x_{IP}, t) f_i^{IP}(z, Q^2) + f_{IR}(x_{IP}, t) f_i^{IR}(z, Q^2)$$

Flux parametrisation

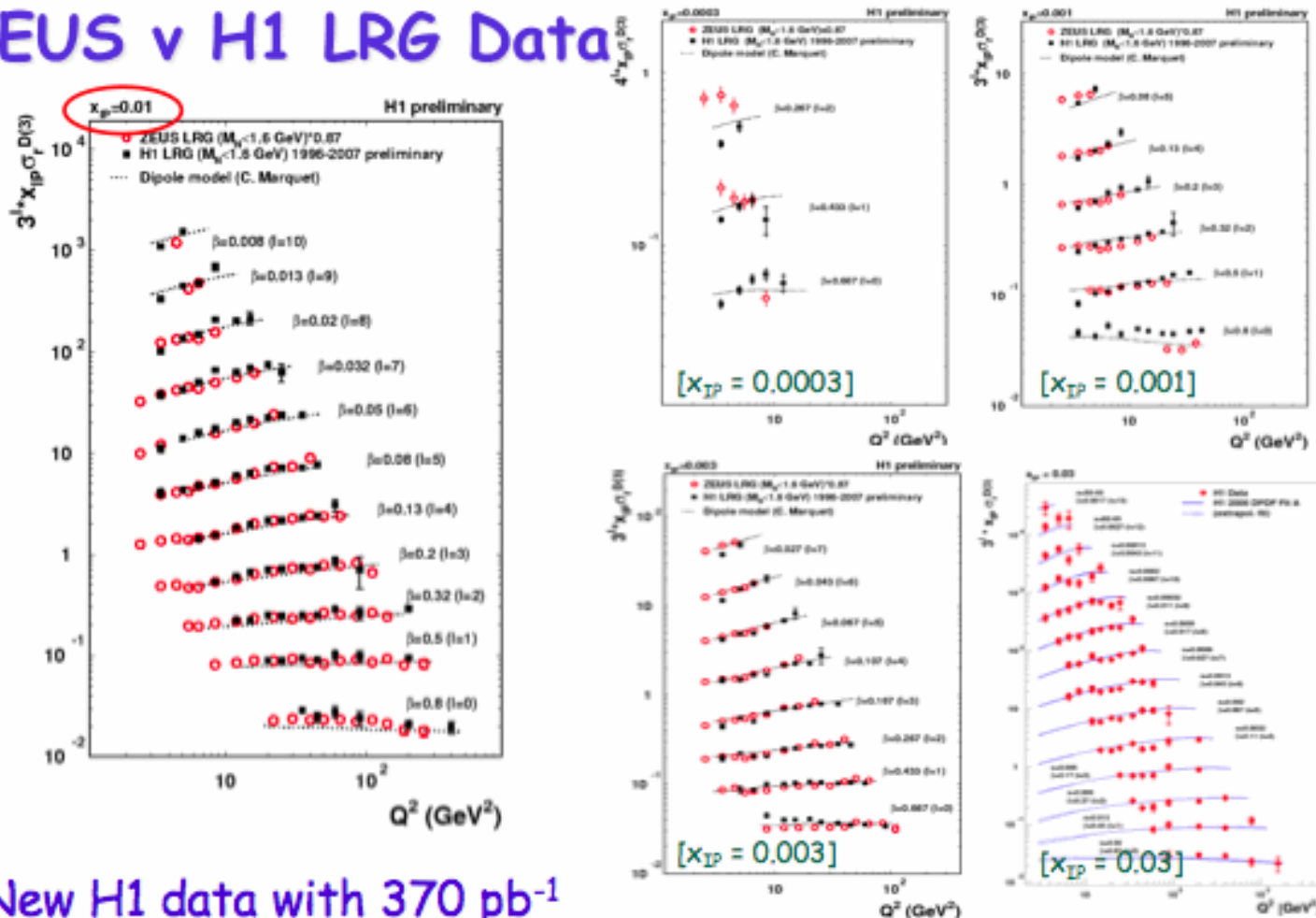
$$f(x_{IP}, t) = \frac{Ae^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

Pomeron PDFs

Reggeon PDFs taken from pion (GRV)

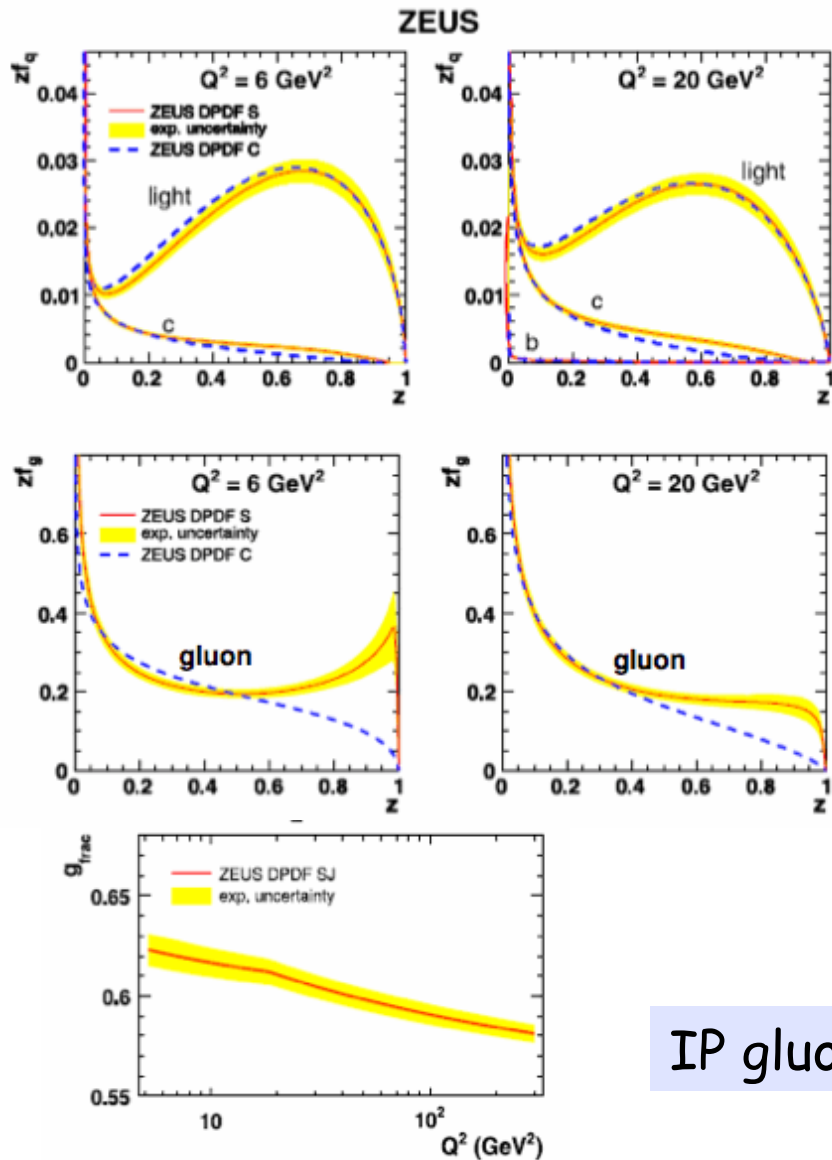
Diffraction in DIS - DGLAP evolution

ZEUS v H1 LRG Data

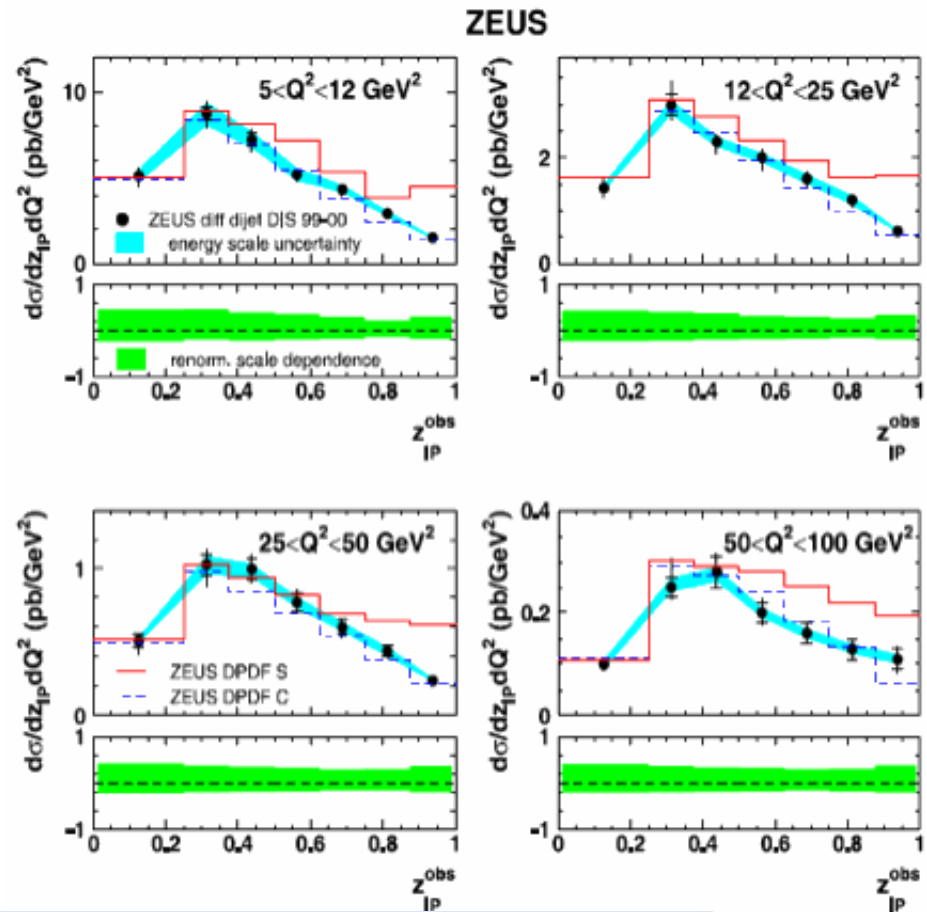


- New H1 data with 370 pb⁻¹
- Few % point-to-point precision over wide kinematic range
- ~13% difference between H1 and ZEUS within normⁿ errors

Diffraction in DIS - constraining diffractive g



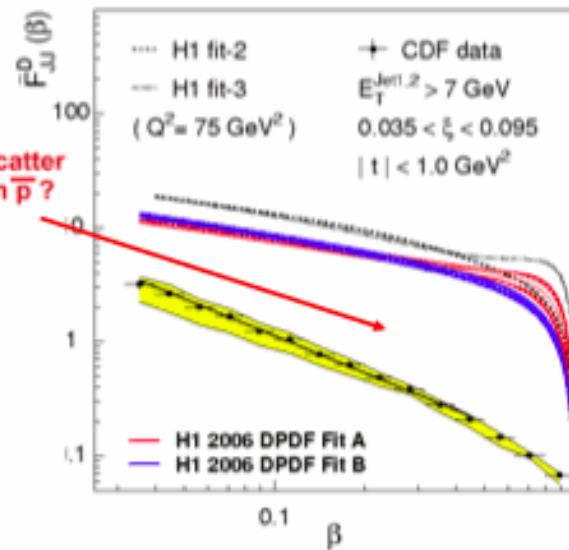
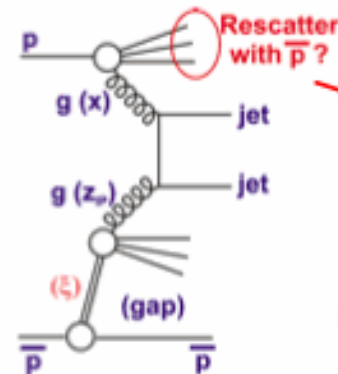
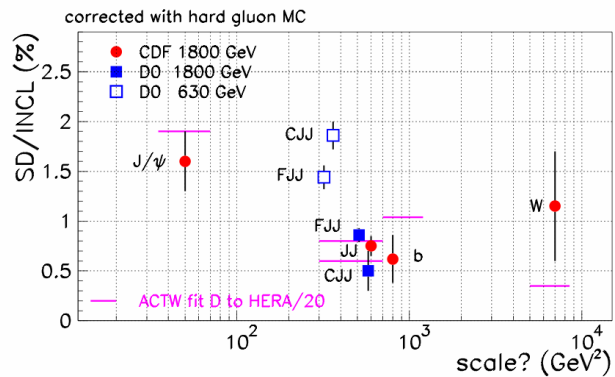
ZEUS, EPJ C52 (2007) 813



IP gluon dominated - ~60% of DPDF

Factorization breaking

.. meanwhile in pp(bar) ...

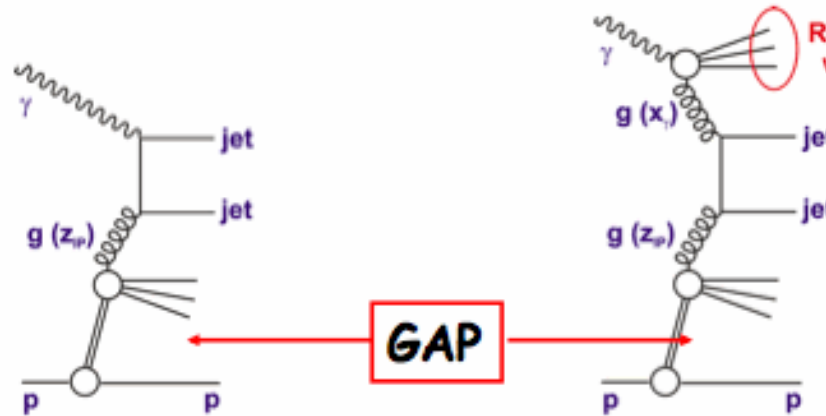


survival probability' $S^2 \sim 0.1$

... photoproduction jets as the perfect control experiment...

"Direct" photon
($x_\gamma \rightarrow 1$)

" $S^2 = 1$ "



"Resolved" photon
($x_\gamma < 1$)

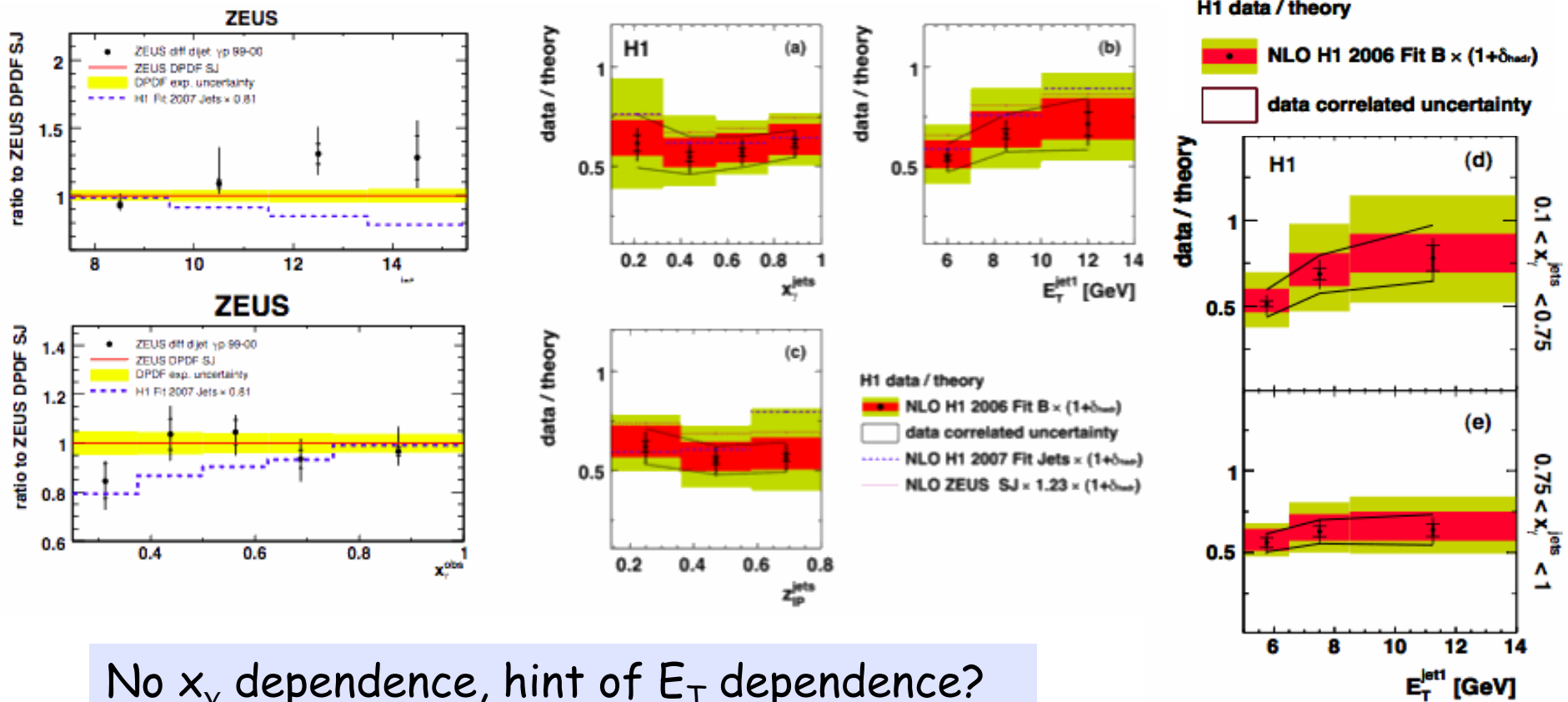
" $S^2 \sim 0.34$?"

Factorization breaking - dijets in γp

ZEUS [$E_T^{-1} > 7.5 \text{ GeV}$]... No evidence for any gap destruction

H1 [$E_T^{-1} > 5 \text{ GeV}$]... Survival probability < 1 at 2σ significance

$$\sigma(\text{H1 data}) / \sigma(\text{NLO}) = 0.58 \pm 0.12 (\text{exp.}) \pm 0.14 (\text{scale}) \pm 0.09 (\text{DPDF})$$



No x_T dependence, hint of E_T dependence?

Factorization breaking - dijets in γp

Refined gap survival model
(KKMR, hep-ph/0911.3716)
predicts a significantly **weaker**
suppression:

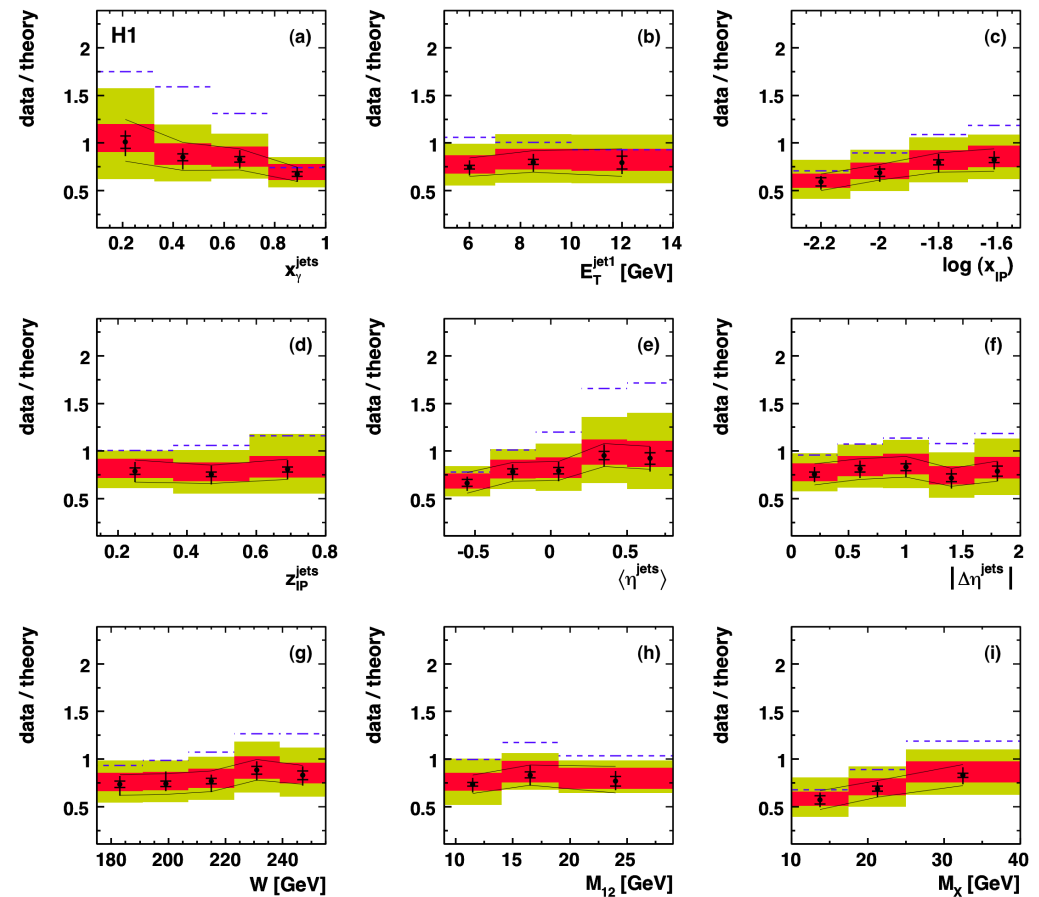
- **direct γ unsuppressed**
- **hadron-like part of resolved γ suppressed by ~ 0.34 (only $x_\gamma < 0.1$)**
- **point-like part of resolved γ less suppressed, $\sim 0.7-0.8$**

H1 data / theory

• NLO H1 2006 Fit B, KKMR suppressed $\times (1 + \delta_{\text{hadr}})$

□ data correlated uncertainty

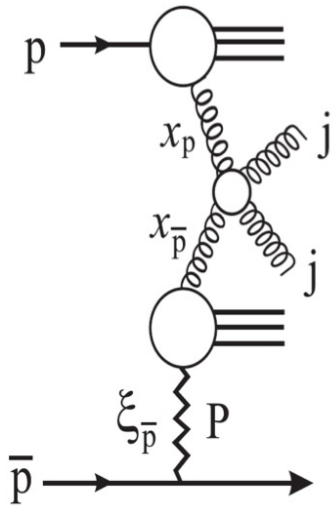
--- NLO H1 2006 Fit B, resolved $\times 0.34 \times (1 + \delta_{\text{hadr}})$



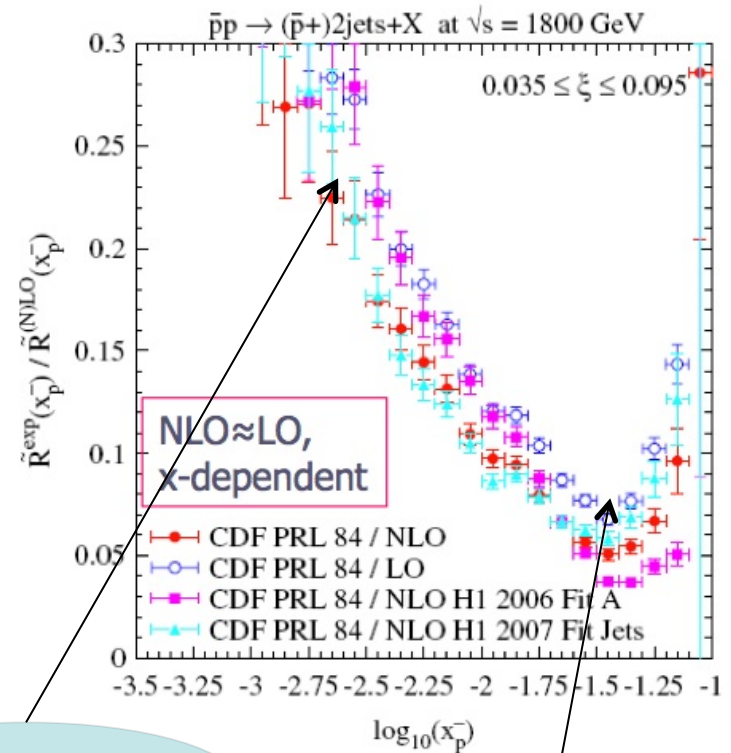
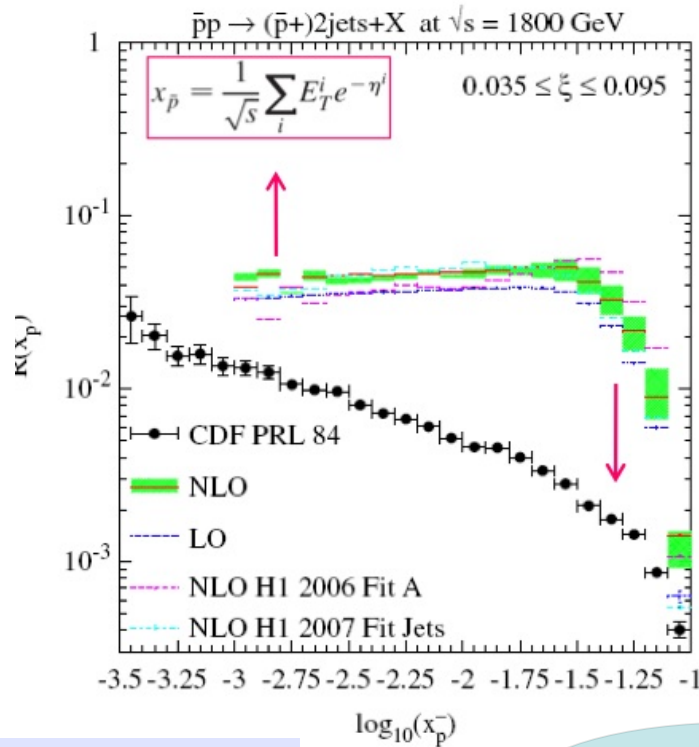
Factorization breaking - back to ppbar

M. Klasen

Due to rescattering
Suppression factor:



Ratio SD/ND:

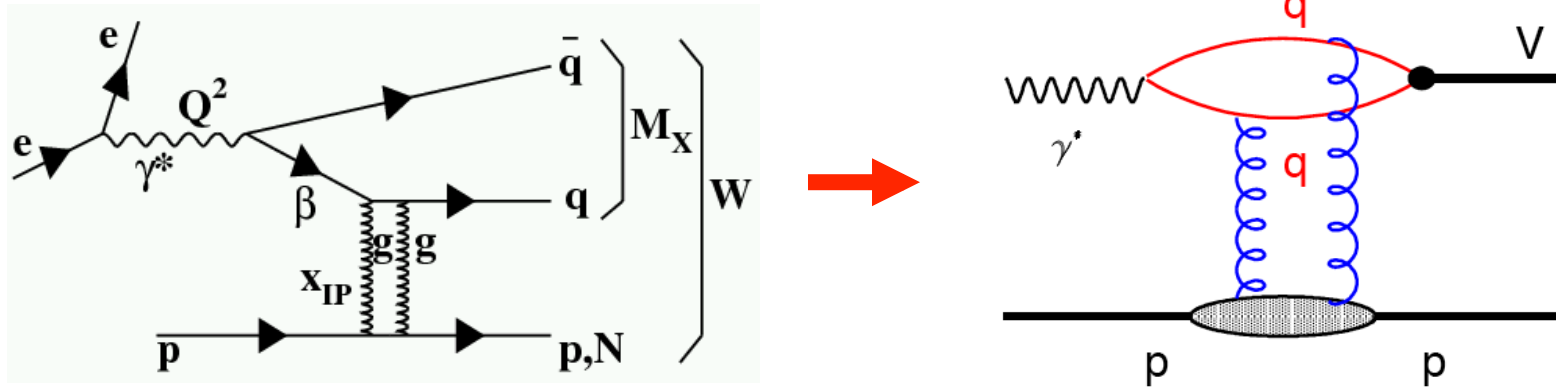


Rescattering depends on the size of the proton ?

Large-x, small p

small-x, large p

Diffractive DIS - exclusive VM production



$$\sigma(W) \Rightarrow \delta \quad (\propto W^\delta)$$

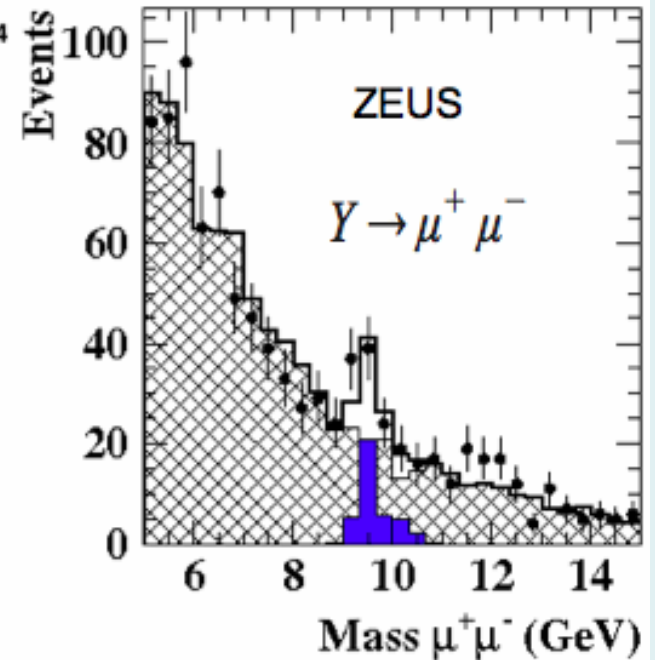
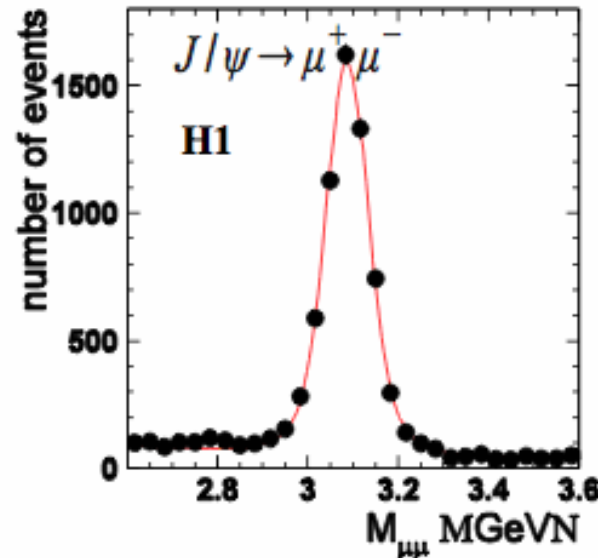
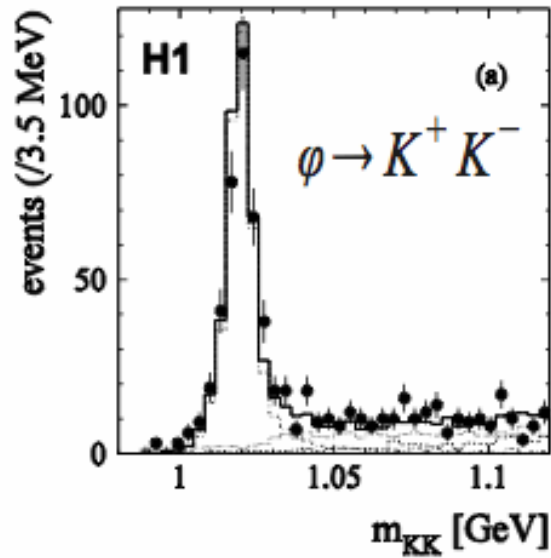
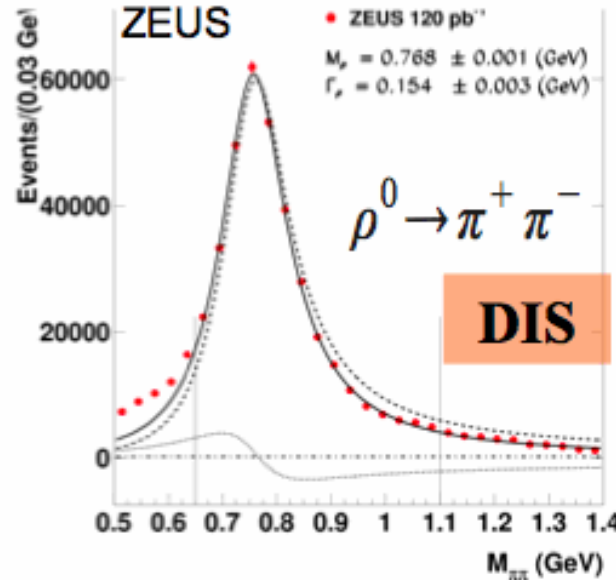
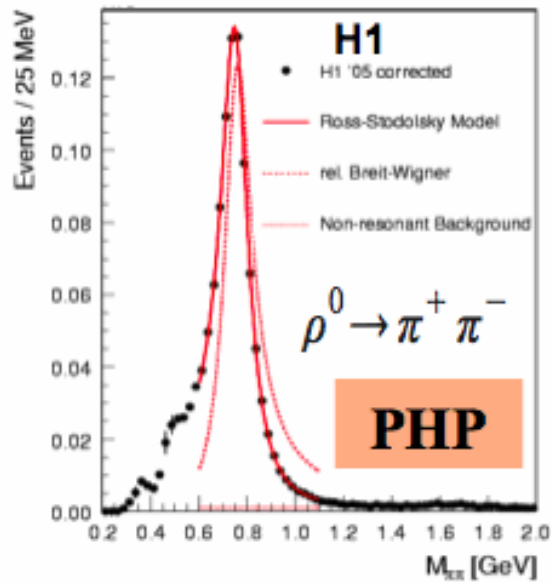
$$\sigma(Q^2) \Rightarrow n \quad (\propto (Q^2 + M^2)^{-n})$$

$$\frac{d\sigma}{dt} \Rightarrow b(Q^2) \quad (\propto e^{-b|t|}), \quad \alpha_{IP}(t) \quad (\propto W^{4(\alpha_{IP}-1)}), \quad n \quad (\propto |t|^{-n} \text{ at large } |t|)$$

$$r_{ij}^k \Rightarrow R(W), \quad R(Q^2)$$

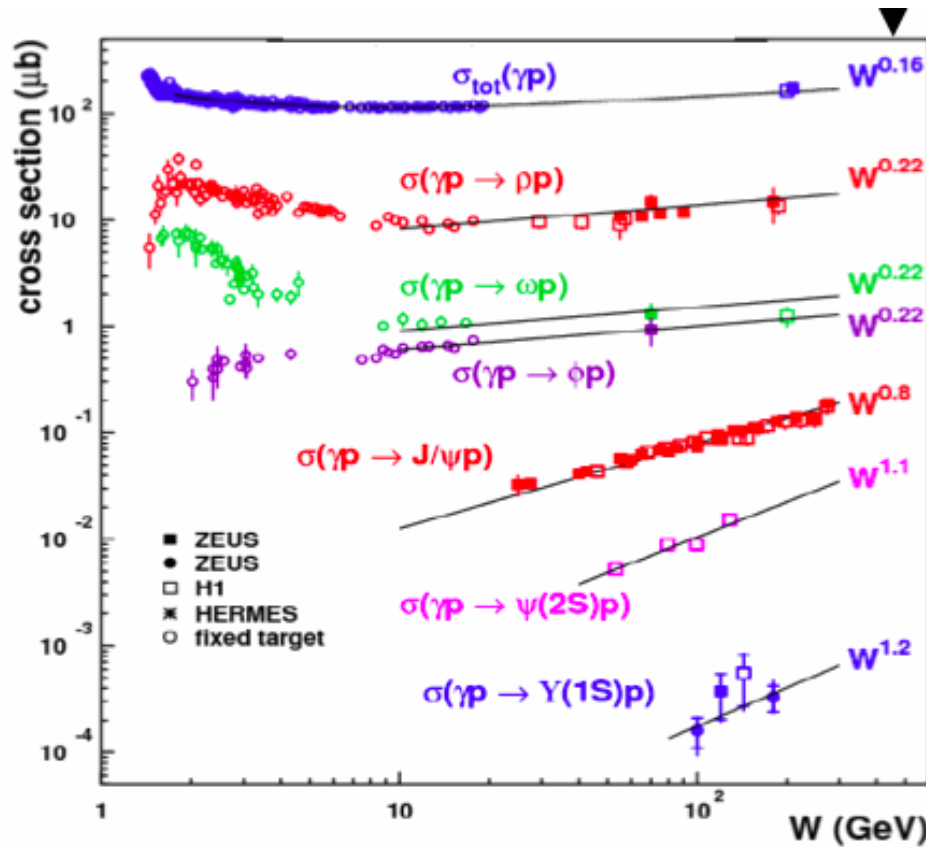
- Is the exclusive VM production a hard process?
- Can we learn something about the proton structure?

Exclusive VM production



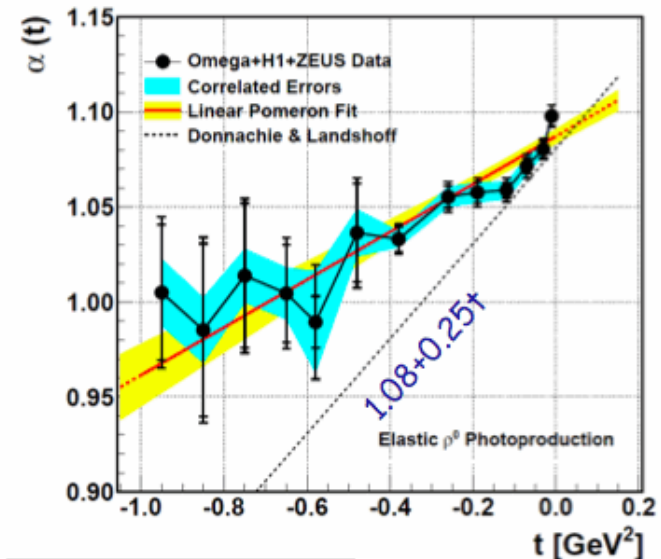
Exclusive VM production - photoproduction

$$\frac{d\sigma_{\gamma P}(W)}{dt} \propto \left(\frac{W}{W_0}\right)^{4(\alpha_{IP}(t)-1)}$$



Pomeron trajectory $\alpha_{IP}(t)$ from the global fit to H1, ZEUS and Omega data

Result of the fit
H1 PRELIMINARY



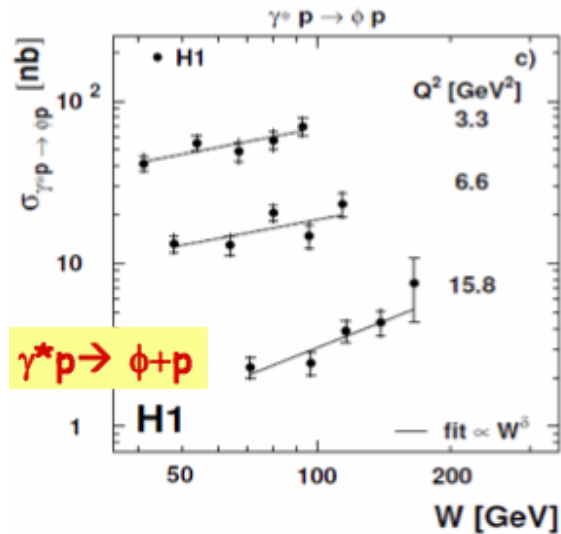
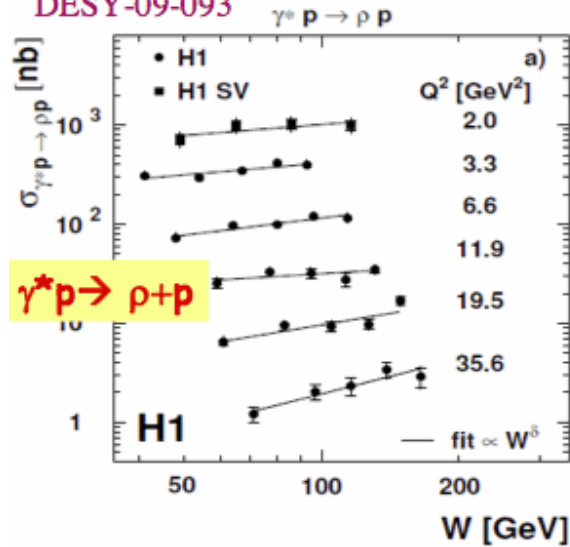
$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} \cdot t$$

$$\alpha_{IP}(0) = 1.0871 \pm 0.0026(\text{stat}) \pm 0.0030(\text{sys})$$

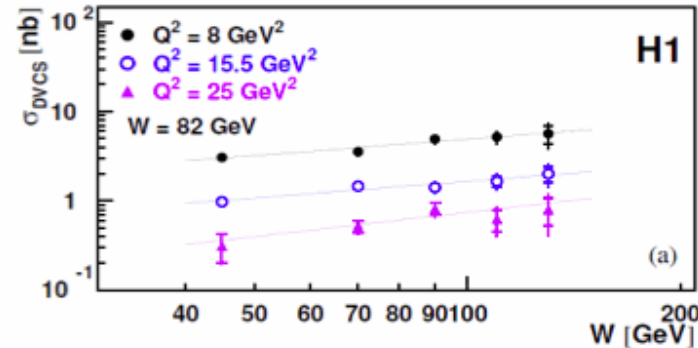
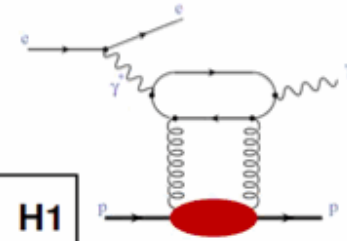
$$\alpha'_{IP} = 0.126 \pm 0.013(\text{stat}) \pm 0.012(\text{sys}) \text{ GeV}^{-2}$$

Exclusive VM production and DVCS in DIS

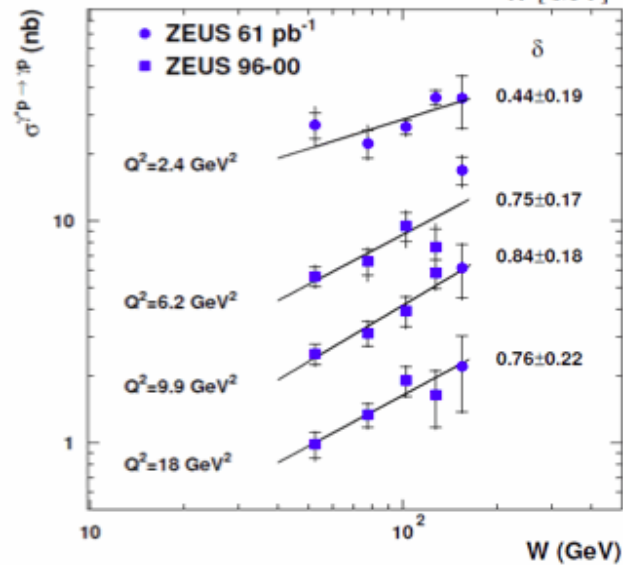
DESY-09-093



DVCS (elastic scattering of virtual photon off a proton)



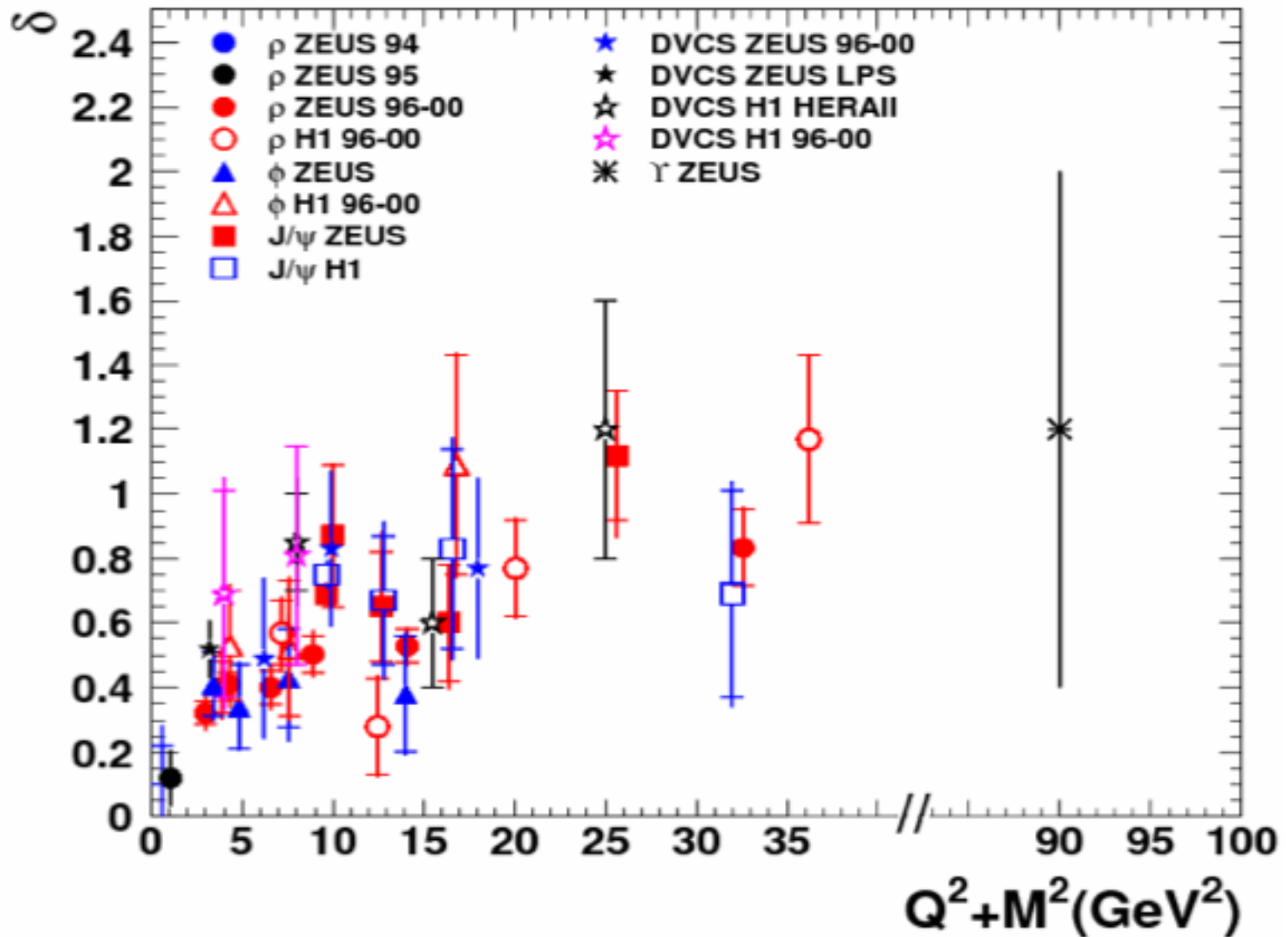
DESY-09-109



DESY-08-132

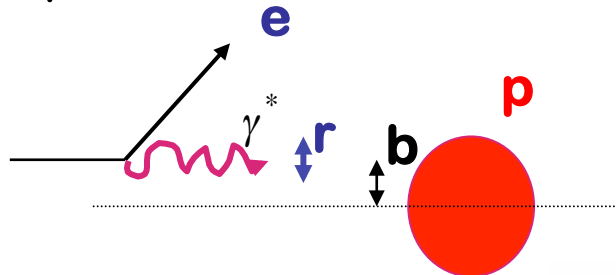
Exclusive VM production and DVCS in DIS

$$\sigma \sim W^\delta$$



Exclusive VM and DVCS in DIS - t slope

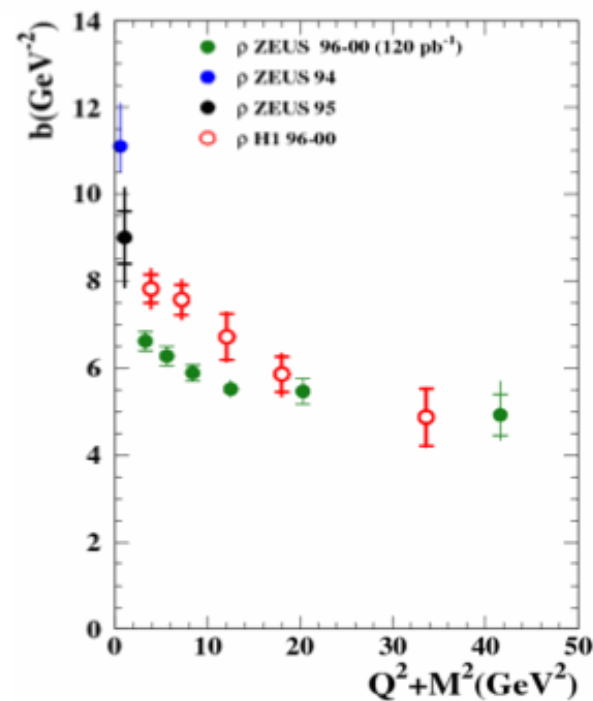
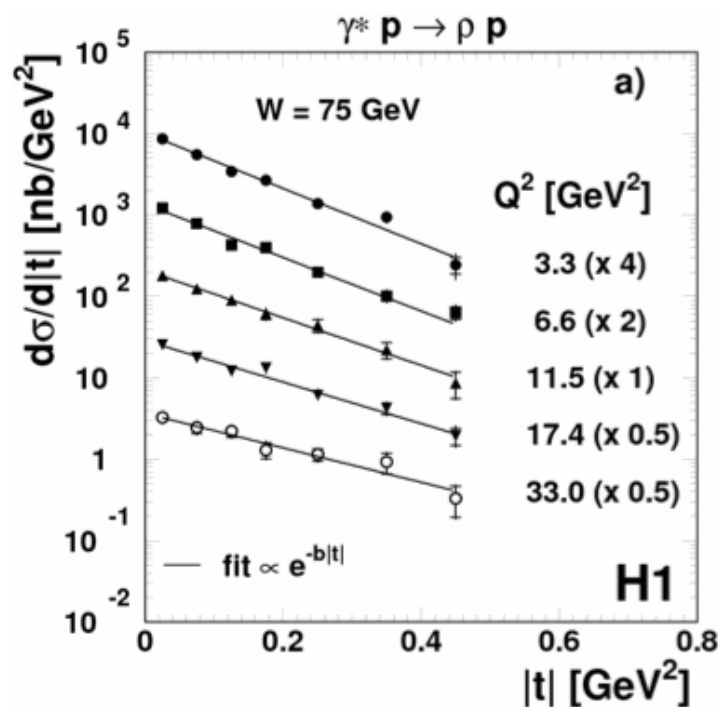
b - impact parameter



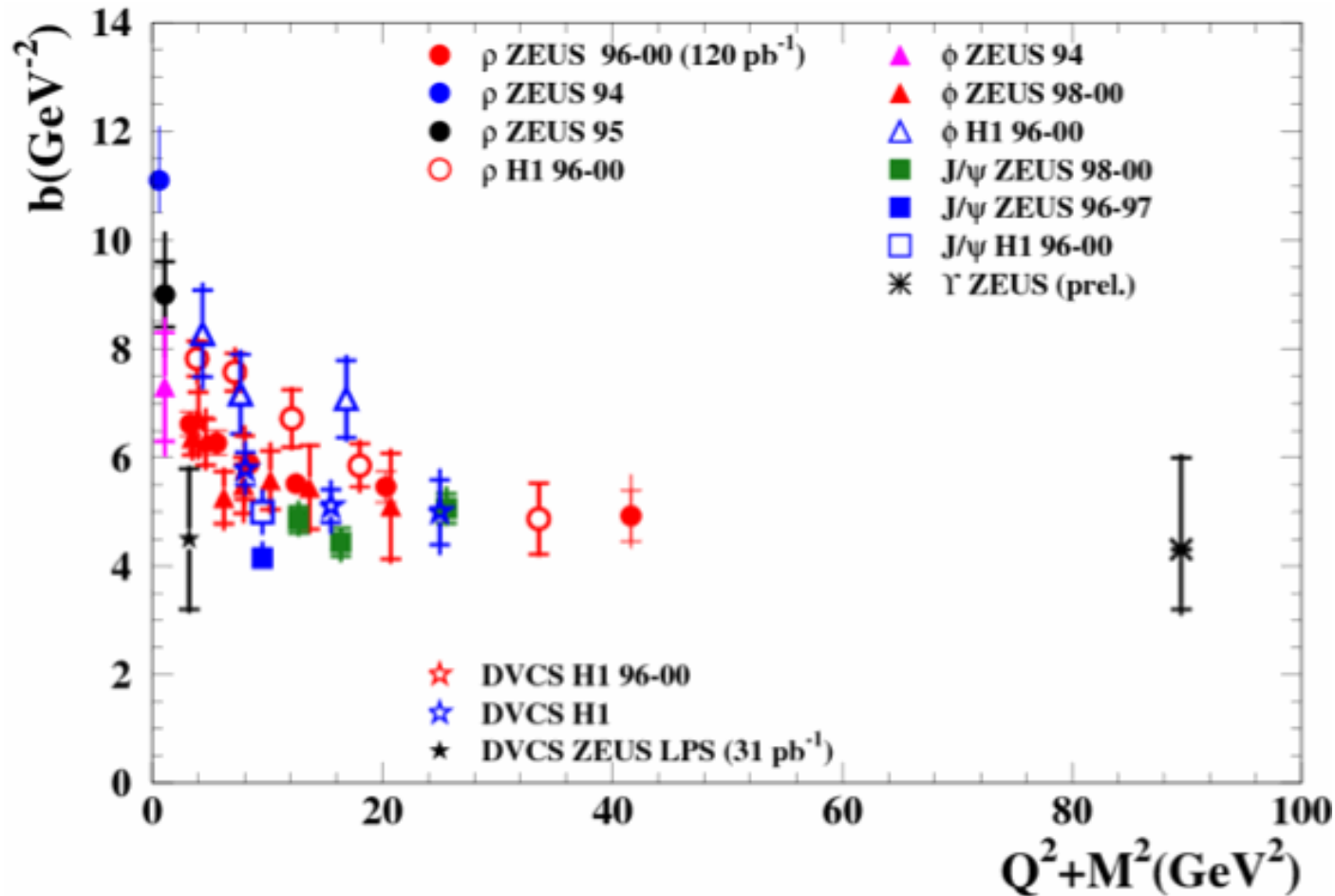
$$b = \frac{\hbar c}{\sqrt{t}}$$

b - slope of t distribution

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

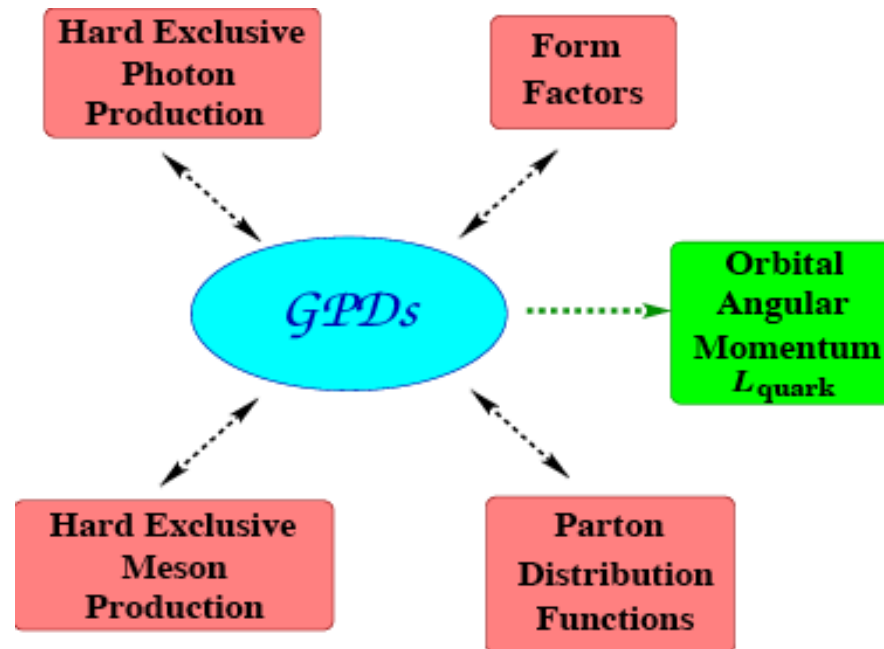
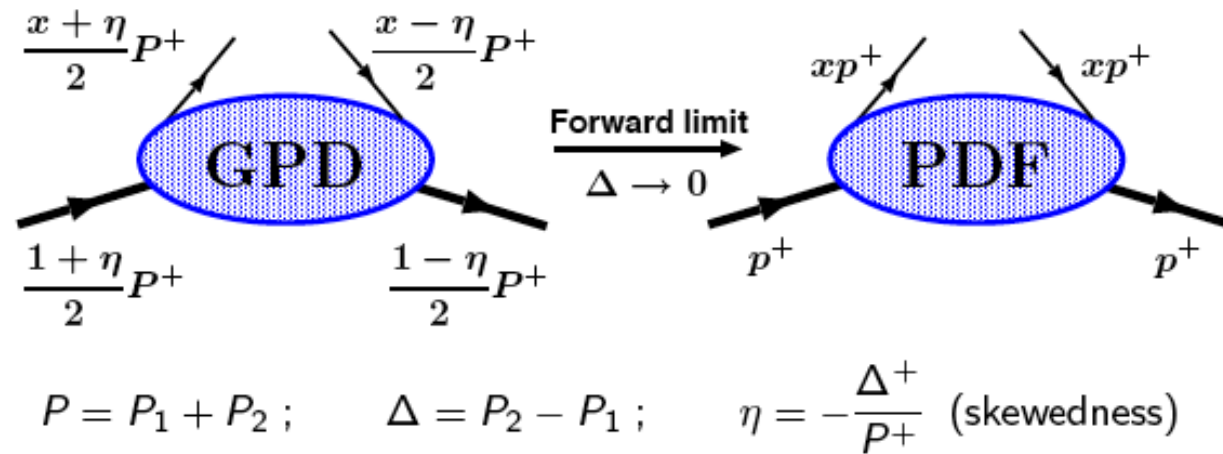


Exclusive VM and DVCS in DIS - t slope



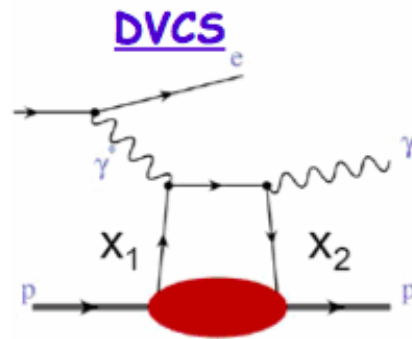
$b_{\text{hard}} \sim 5 \text{ GeV}^2$ translates into $r_g \sim 0.6 \text{ fm}$, less than r_{em} of p

GPDs - 3-dimensional picture of the proton



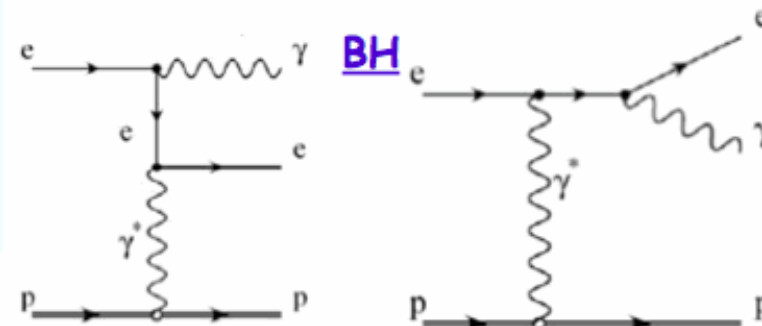
DVCS - charge asymmetry

DESY-09-109



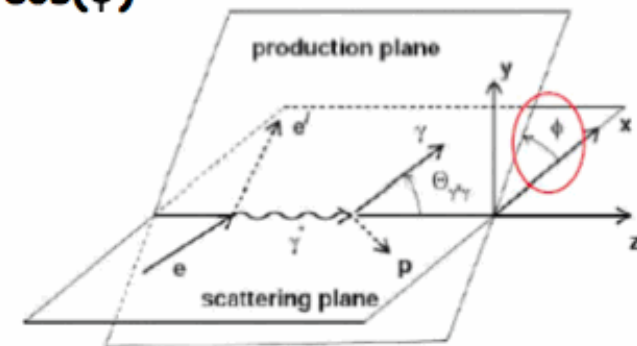
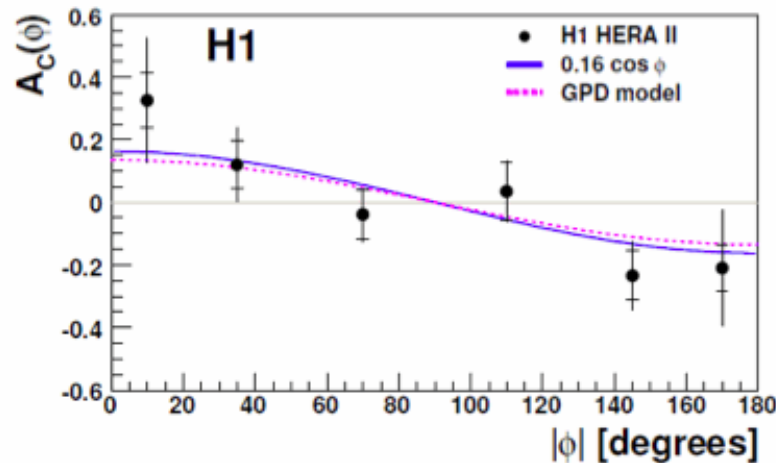
DVCS gives access to Generalized (skewed) Parton Distributions (GPD), which describe the correlations between two partons (x_1, x_2) which differ by longitudinal ($x_1 \neq x_2$) and transverse (t) momentum at given Q^2

Interference between DVCS (QCD) and Bethe-Heitler (QED) processes



$$|A|^2 = |A_{DVCS}|^2 + |A_{BH}|^2 + |A_I|^2 \quad \leftarrow \text{interference term}$$

Beam Charge Asymmetry: $A_C(\varphi) = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} \propto \text{Re}(A_{DVCS}) \cdot \cos(\varphi)$
 Related to GPD



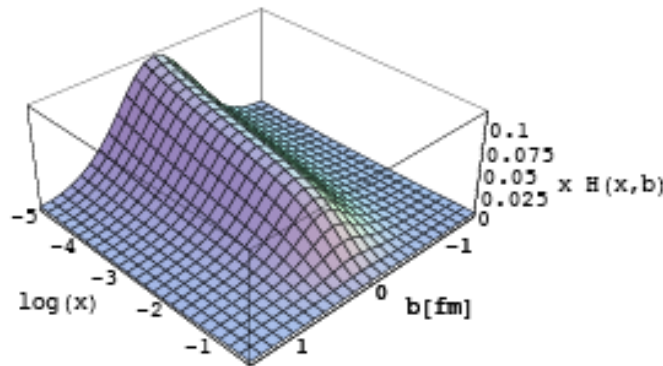
$$\rho = \text{Re } A_{DVCS} / \text{Im } A_{DVCS} = 0.20 \pm 0.05 \pm 0.08$$

GPDs based model compatible with data

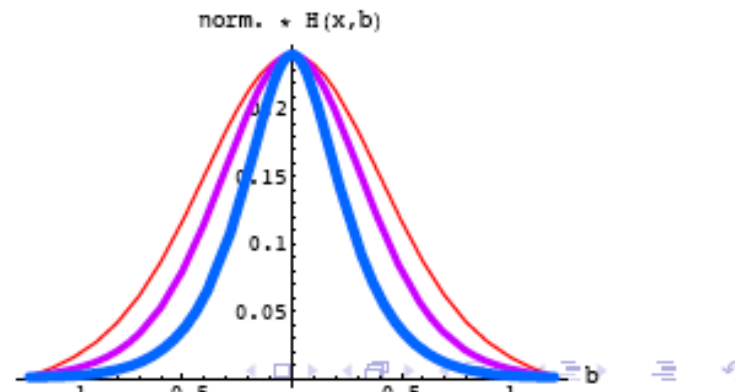
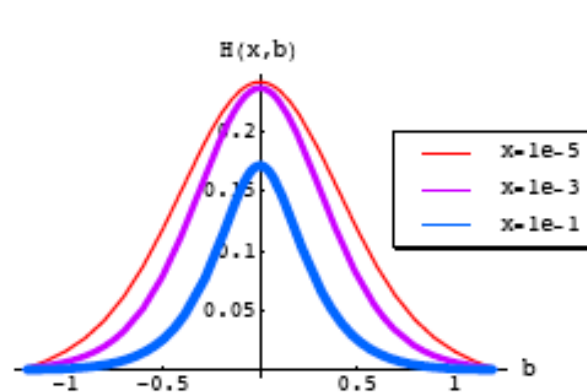
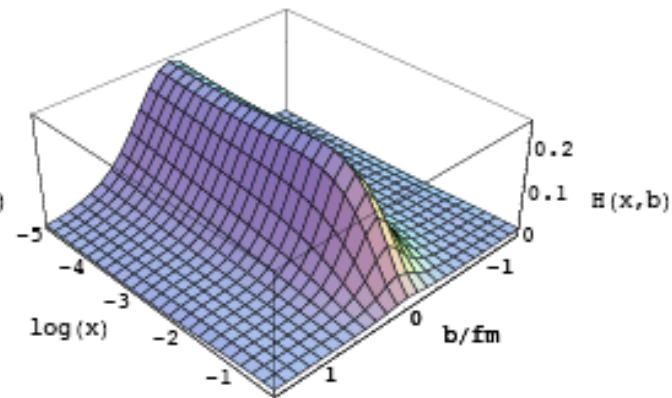
GPDs - 3-dimensional picture of the proton

Three-dimensional image of a proton

Quarks:



Gluons:

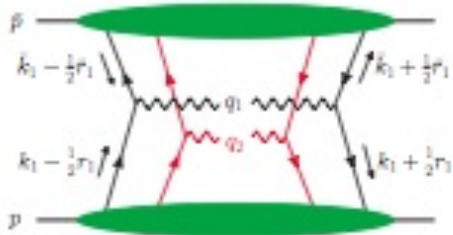
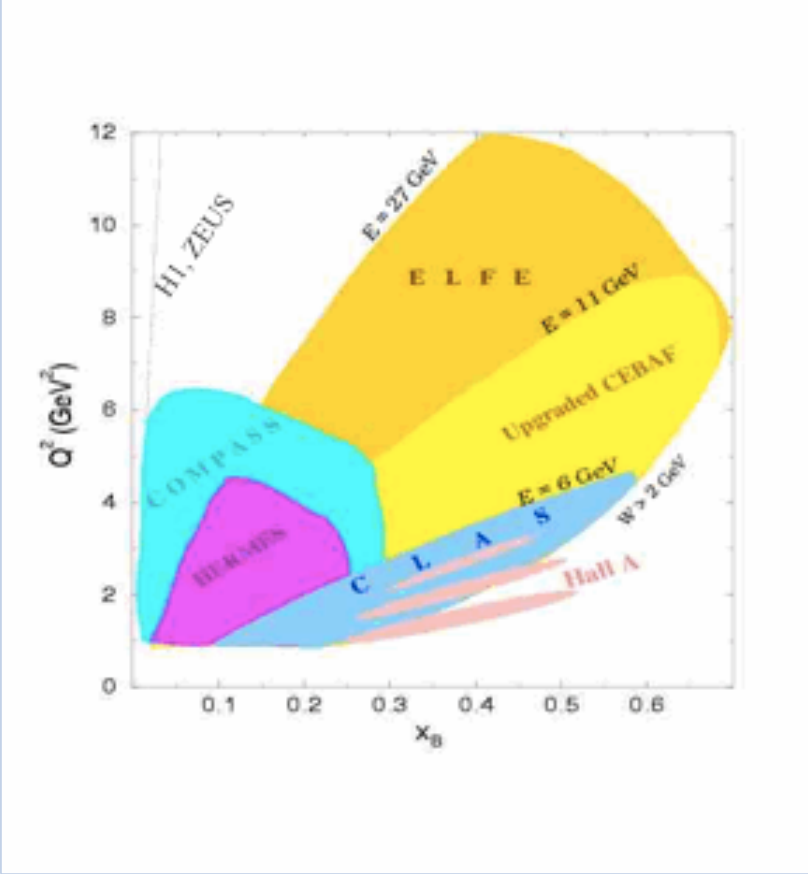


Kornelija Passek-Kumerički: Fitting DVCS at NLO and beyond ...

Multiple interactions and Generalized Parton Distributions

M. Diehl

Basic structure: cross section



Great potential for 3D proton

Summary

- HERA provides reliable diffractive parton distributions
- Factorization breaking may shed light on rescattering mechanism - scale dependence
- Hard exclusive processes provide a 3D structure of the proton

These results should be kept in mind when modeling MPIs