HERA and rapidity gaps

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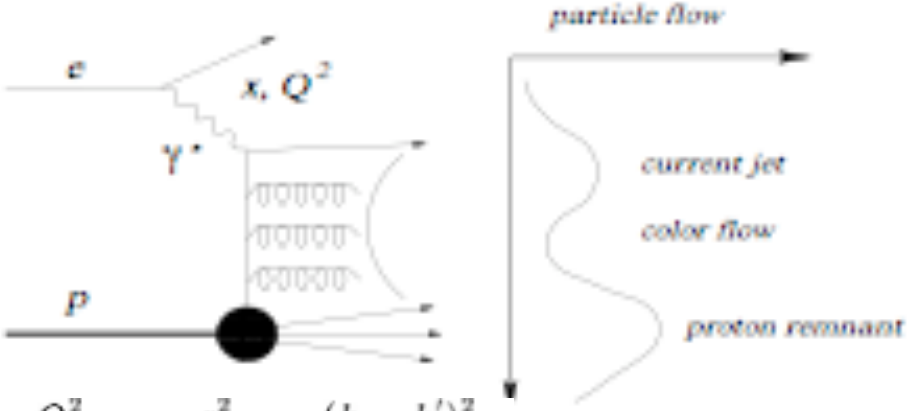
- Inclusive diffraction in DIS
- Factorization breaking
- Exclusive processes

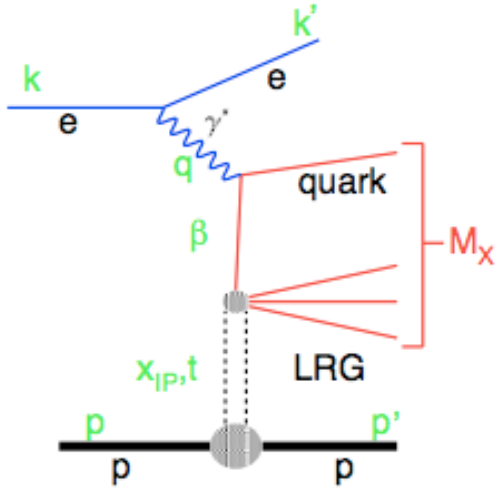
Diffraction in DIS

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

DGLAP



$$Q^2 = -q^2 = -(k-k')^2$$
$$x = \frac{Q^2}{2P\cdot q}$$
$$y = \frac{q\cdot P}{k\cdot P}$$
$$W^2 = (q+P)^2$$

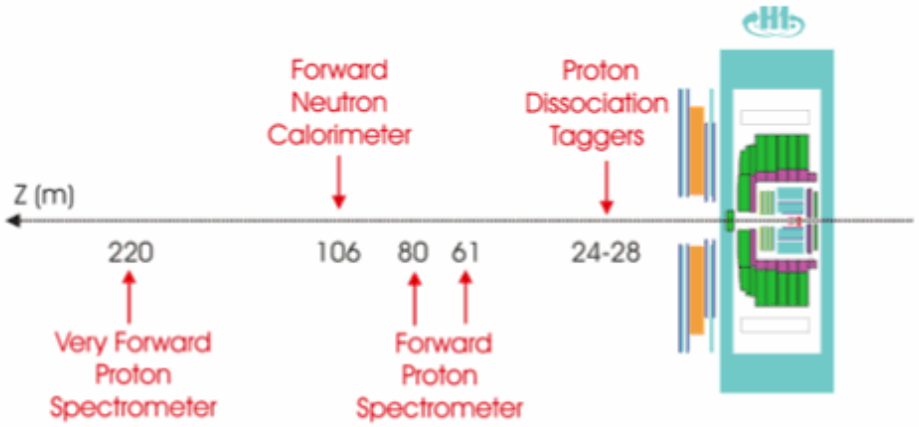


$$t = (p-p')^2$$
$$x_{I\!P} = \frac{q\cdot(p-p')}{q\cdot p} \simeq \frac{Q^2+M_X^2}{Q^2+W^2}$$
$$\beta = \frac{Q^2}{2q\cdot(p-p')} \simeq \frac{Q^2}{Q^2+M_X^2}$$

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

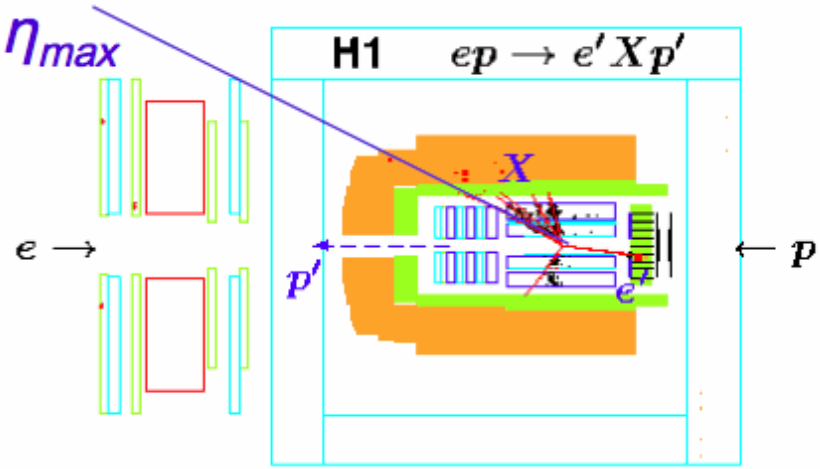
Diffraction in DIS - selection methods

Scattered proton in Leading Proton Spectrometers (LPS)



Limited by statistics and p-tagging systematics

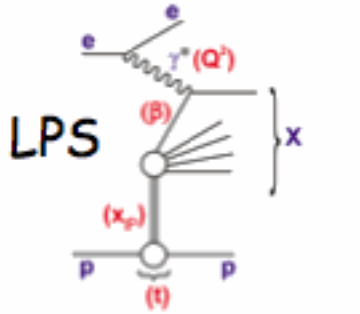
`Large Rapidity Gap' (LRG) adjacent to outgoing (untagged) proton

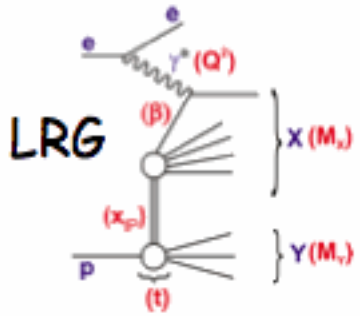


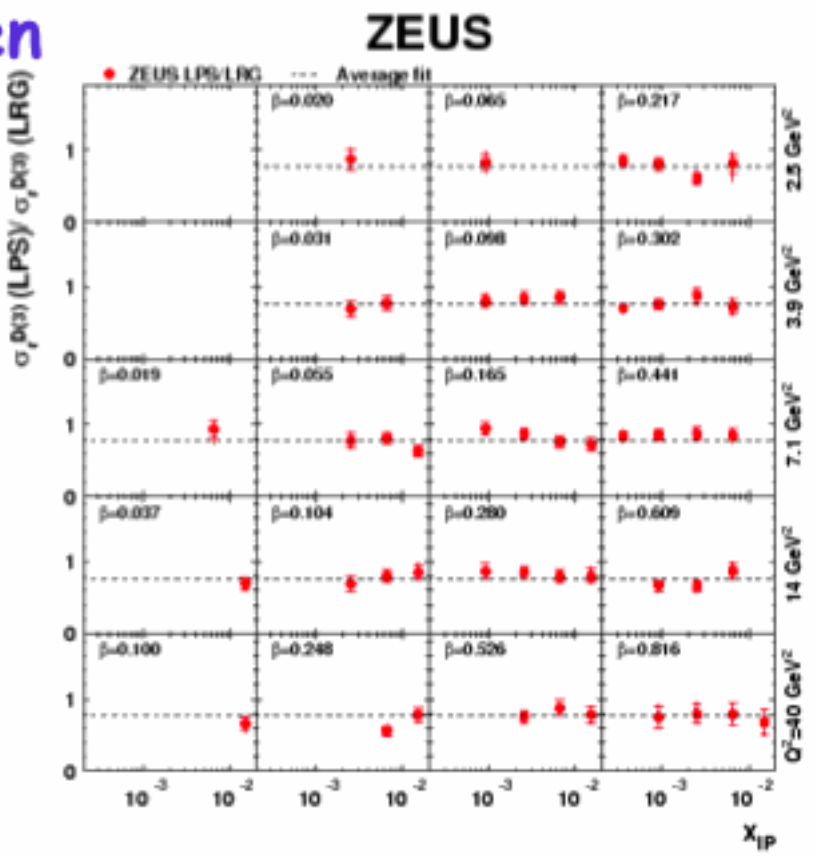
Limited by p-diss systematics

Diffraction in DIS – selection methods

Comparisons between Methods







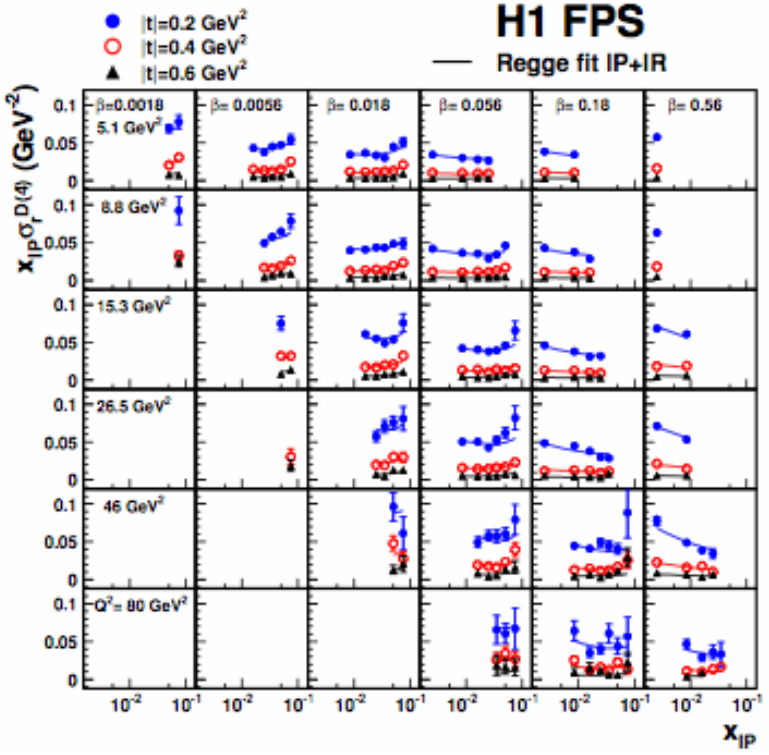
- LRG selections contain typically 20% p diss
- No significant dependence on any variable

Diffraction in DIS – vertex factorization

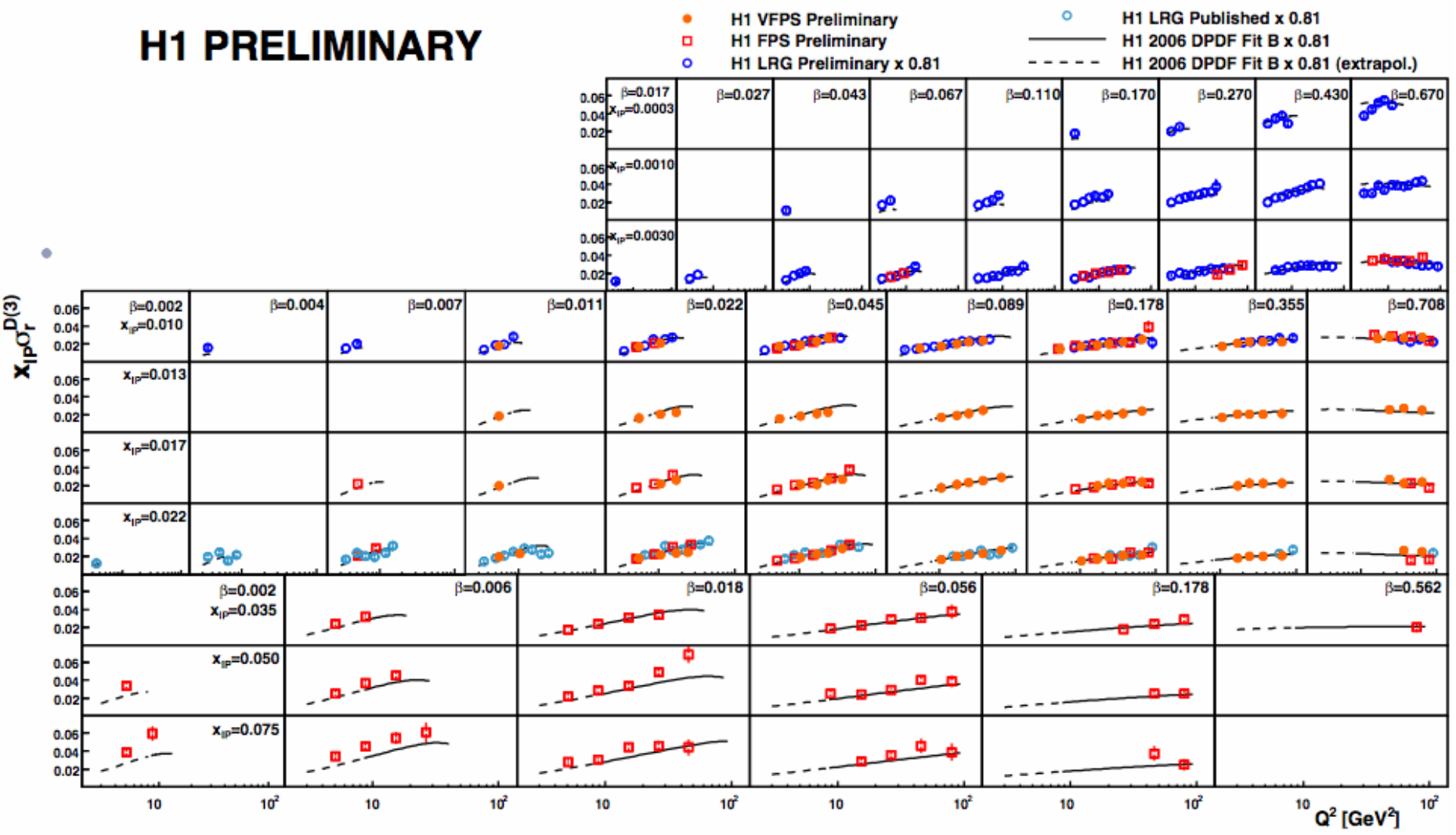
$$\frac{\mathrm{d}^4\sigma^D}{\mathrm{d}\beta\ \mathrm{d}Q^2\ \mathrm{d}x_{I\!P}\mathrm{d}t} = \frac{2\pi\alpha^2}{\beta Q^4}\ Y_+ F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) - \frac{y^2}{Y_+} F_L^{D(4)} \qquad Y_+ = 1+(1-y)^2$$

$$F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t)\ F_2^{I\!P}(\beta, Q^2) + n_{I\!R}\ f_{I\!R/p}(x_{I\!P}, t)\ F_2^{I\!R}(\beta, Q^2)$$

$$f_{I\!P,I\!R/p}(x_{I\!P}, t) = e^{bt}/x_{I\!P}^{2\alpha(t)-1} \qquad \alpha(t) = \alpha(0) + \alpha'\ t$$

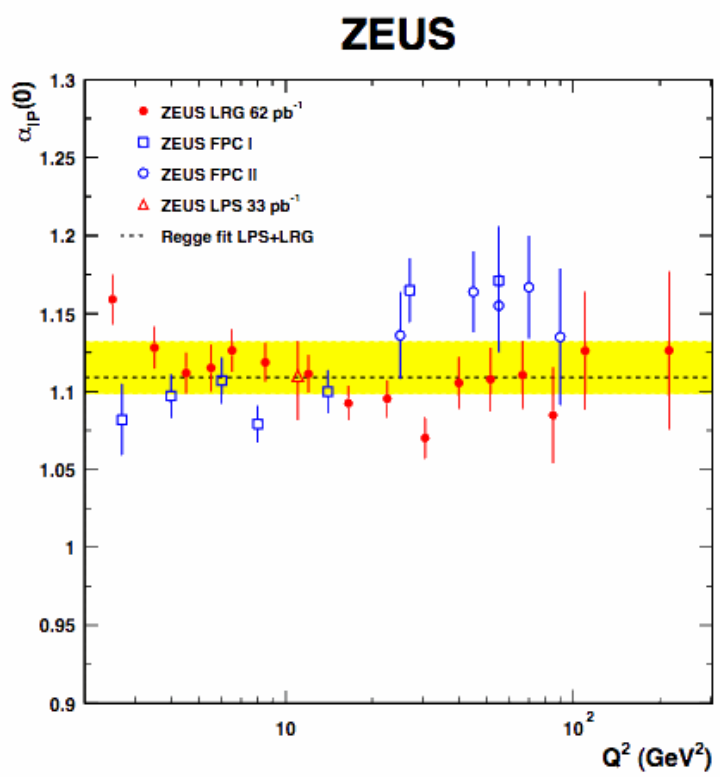


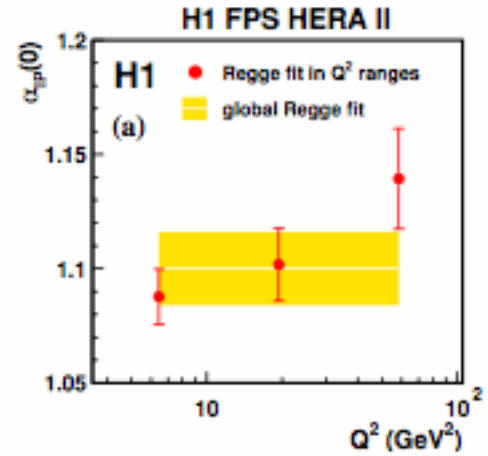
Diffraction in DIS – H1 summary plot

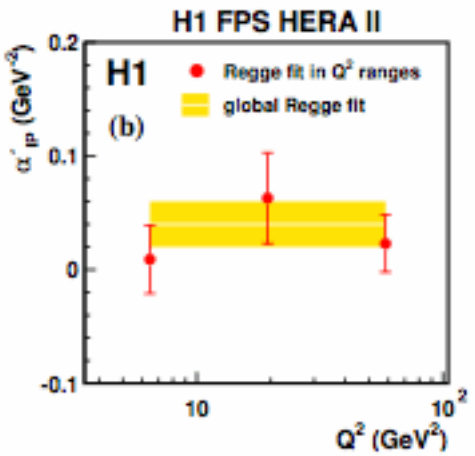


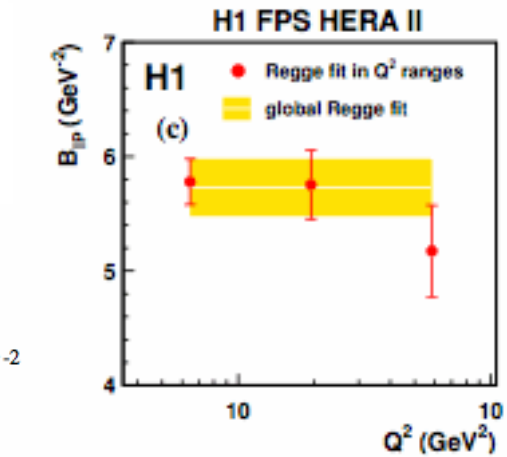
Diffraction in DIS – IP trajectory

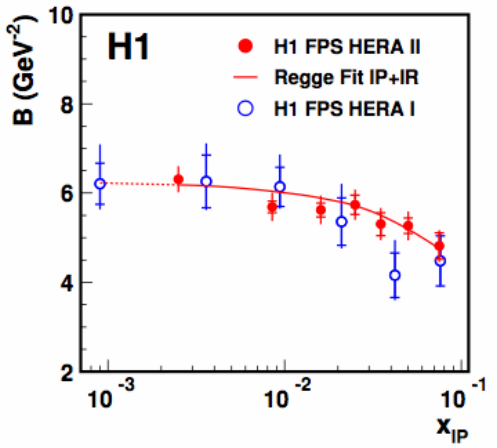
Is the origin of LRG soft or hard in nature?











e.g. From H1 FPS data:

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

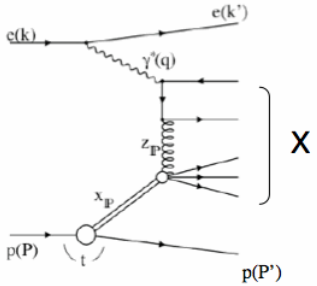
$$\alpha'_{IP} = 0.04 \pm 0.02\,(\text{exp.}) \pm 0.03\,(\text{model})\ \text{GeV}^{-2}$$

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

Diffractive parton distributions

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

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



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

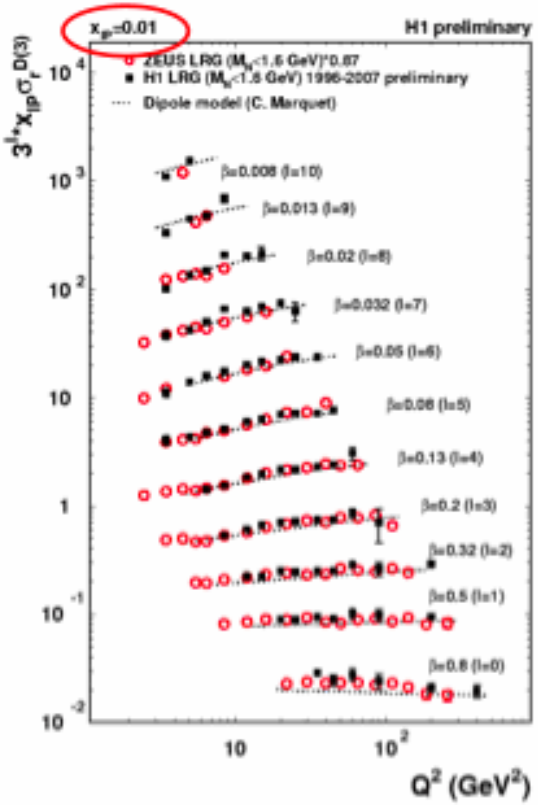
$$f(x_{IP}, t) = \frac{A e^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

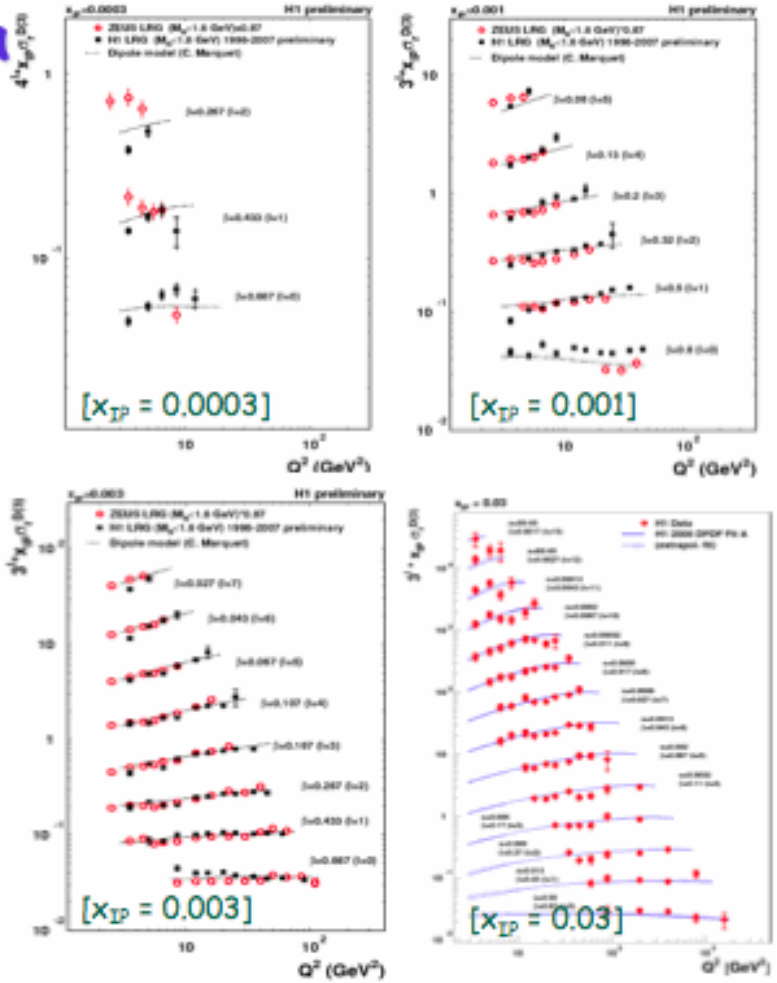
Pomeron PDFs

Reggeon PDFs taken from pion (GRV)

Diffraction in DIS – DGLAP evolution

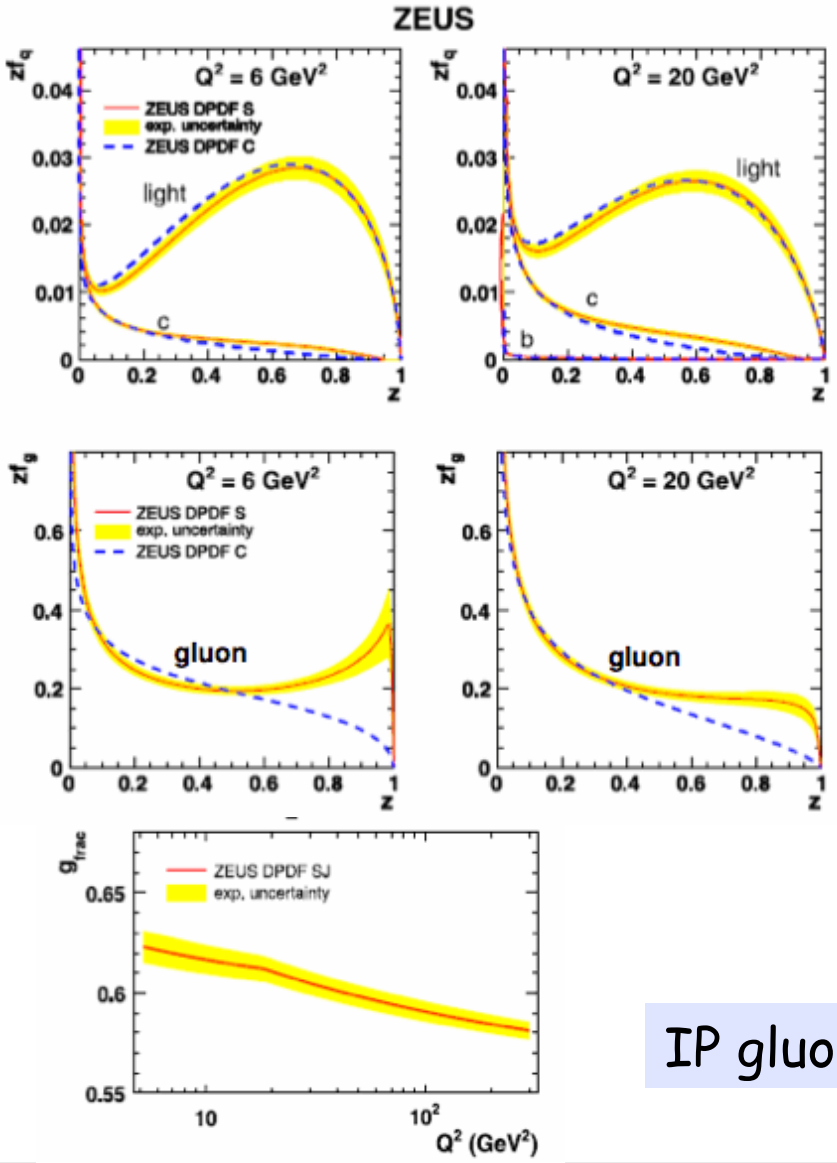
ZEUS v H1 LRG Data

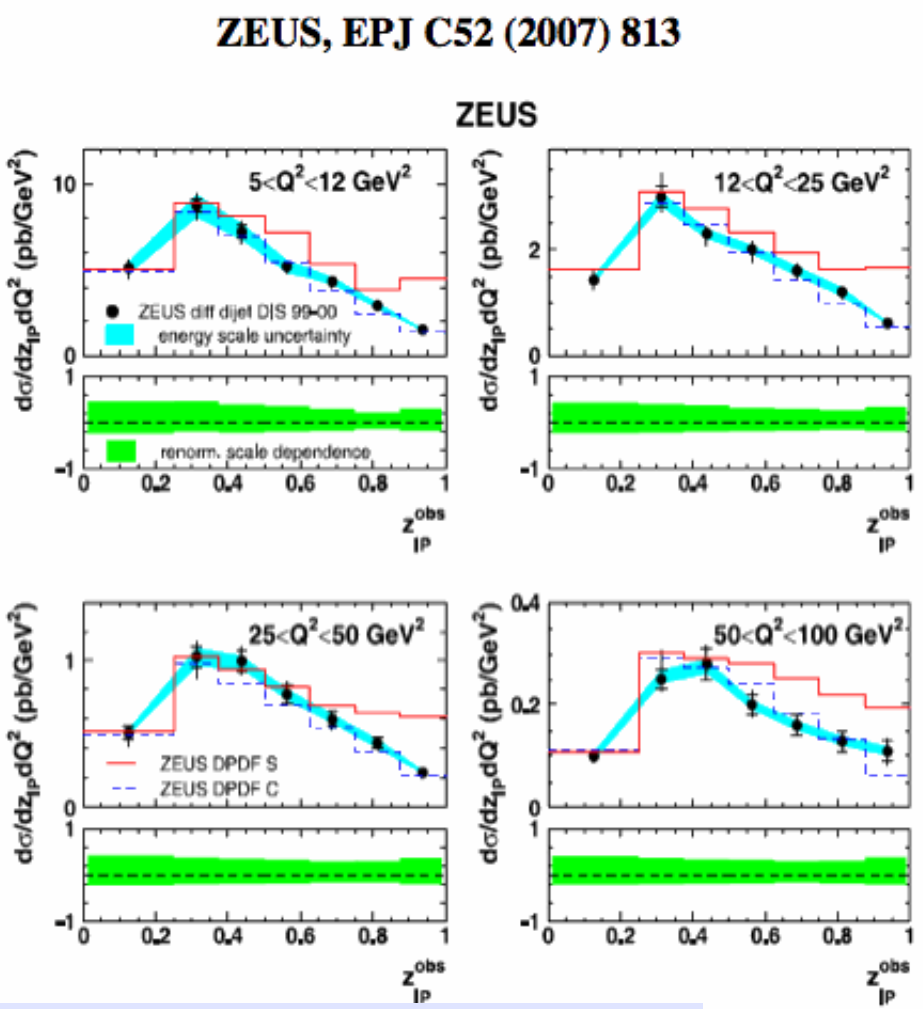




- New H1 data with 370 pb^{-1}
- Few % point-to-point precision over wide kinematic range
- ~13% difference between H1 and ZEUS within norm^n errors

Diffraction in DIS – constraining diffractive g

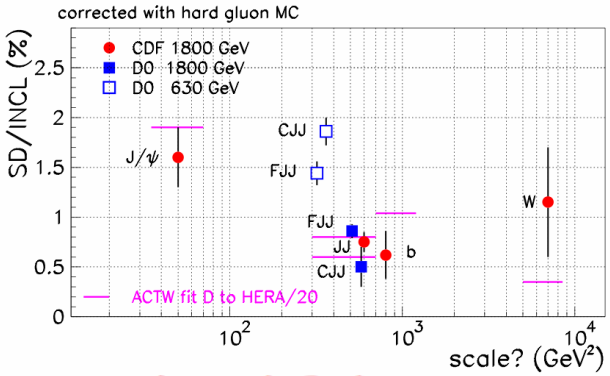


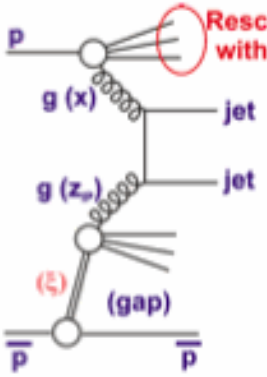


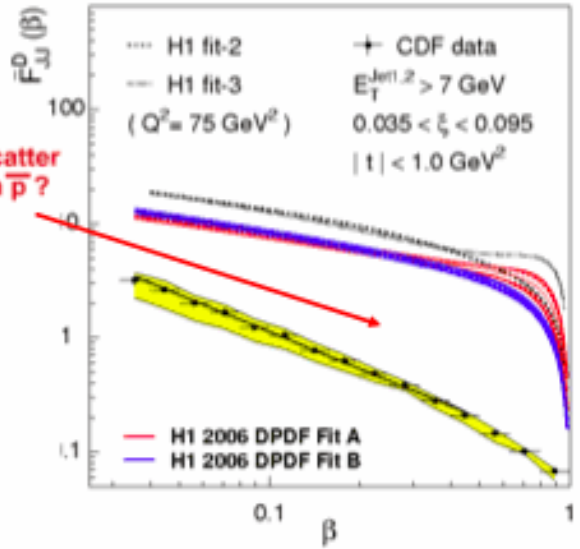
IP gluon dominated - ~60% of DPDF

Factorization breaking

.. meanwhile in pp(bar) ...





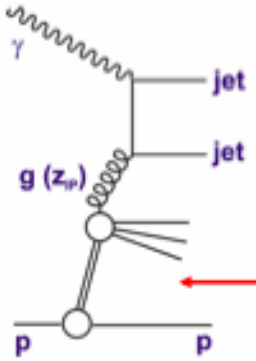


survival probability' $S^2 \sim 0.1$

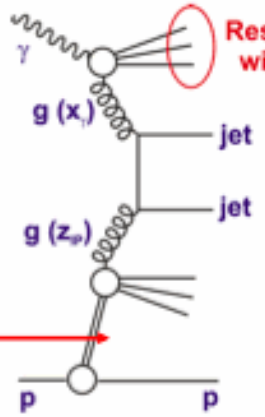
... photoproduction jets as the perfect control experiment?...

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

"$S^2 = 1$"



GAP



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

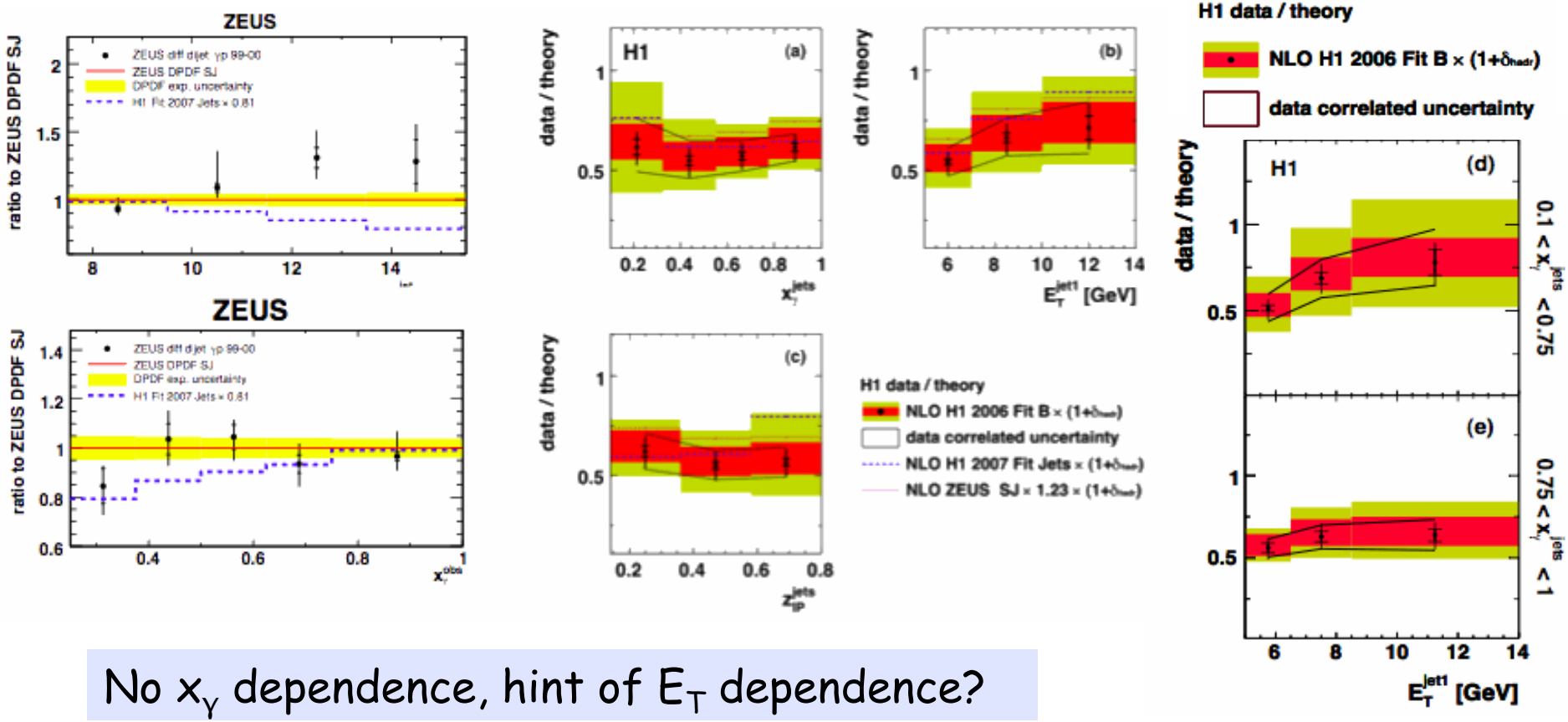
"$S^2 \sim 0.34$?"

Factorization breaking – dijets in γp

ZEUS [$E_T^1 > 7.5$ GeV]… No evidence for any gap destruction

H1 [$E_T^1 > 5$ GeV]… Survival probability < 1 at 2σ significance

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

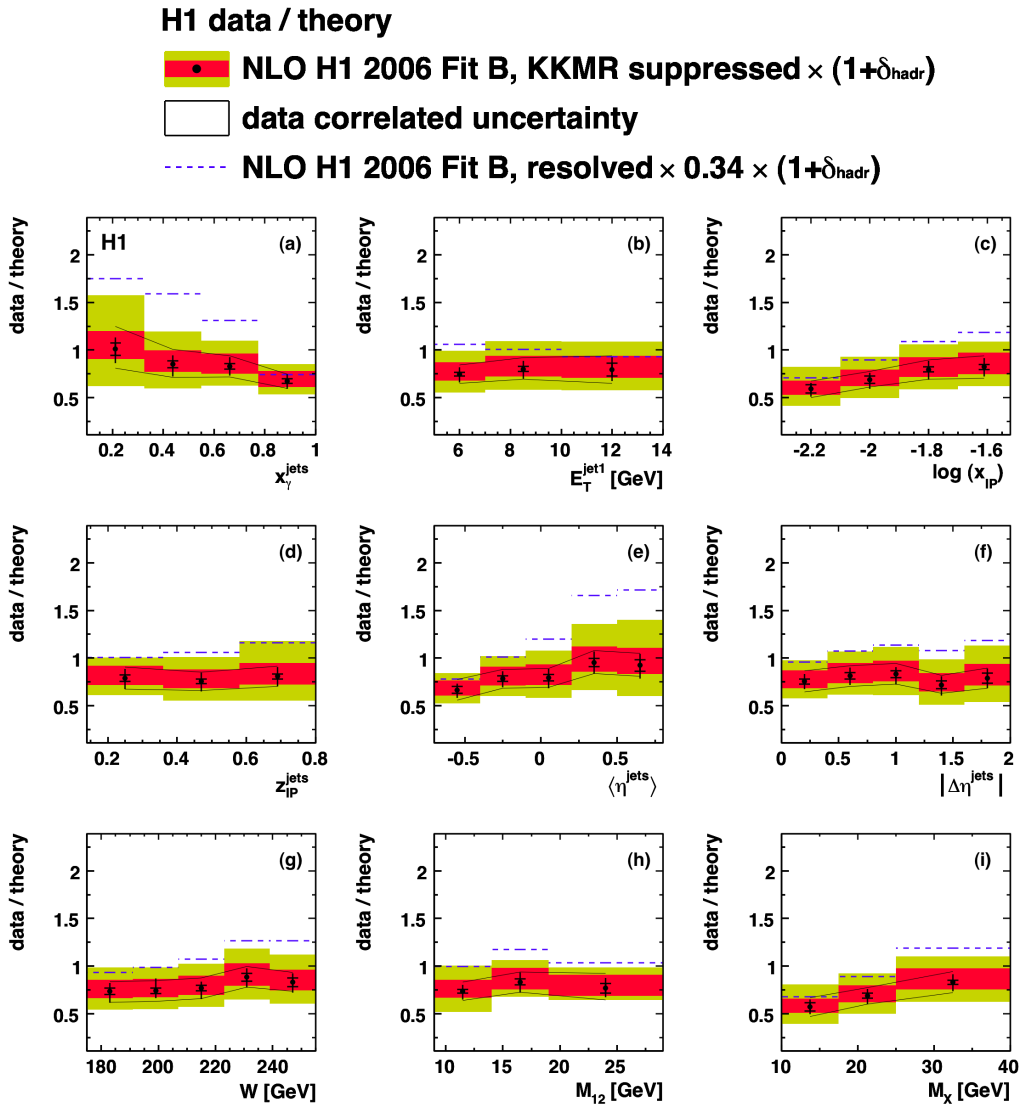


No x_γ dependence, hint of E_T dependence?

Factorization breaking – dijets in γp

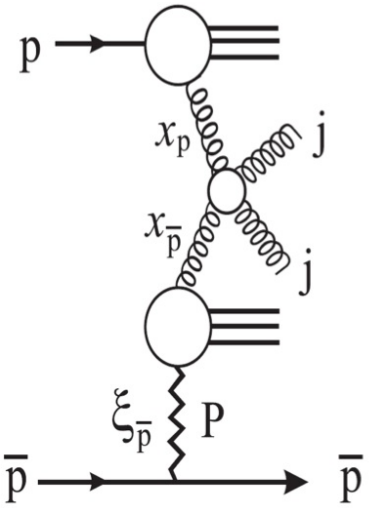
Refined gap survival model
(KKMR, **hep-ph/0911.3716**)
predicts a significantly **weaker suppression:**

- **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, ~0.7-0.8

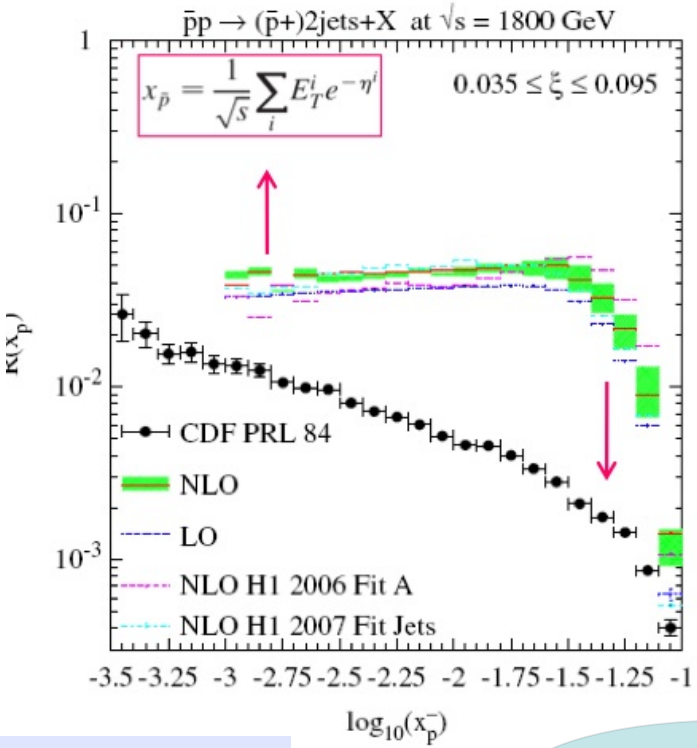


Factorization breaking – back to ppbar

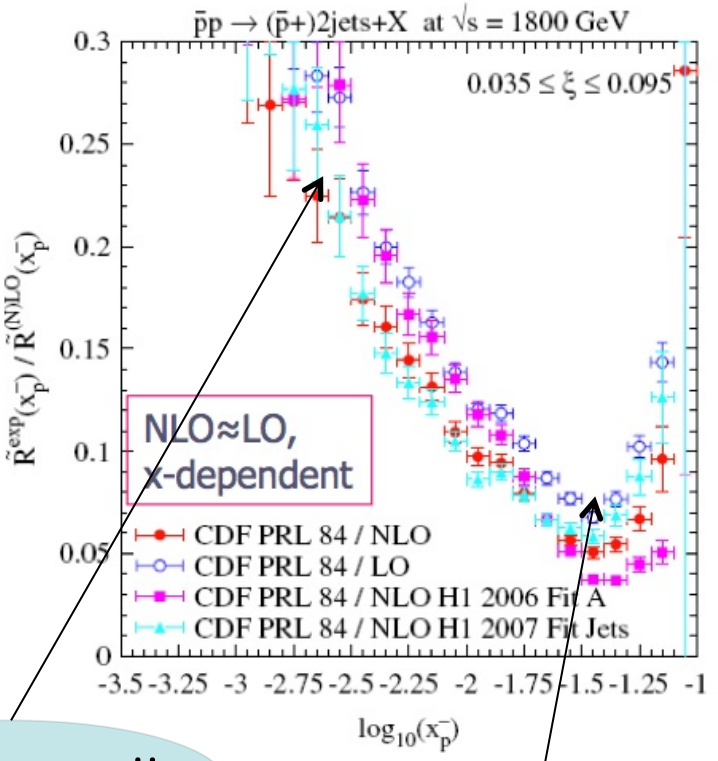
M. Klasen Due to rescattering



Ratio SD/ND:



Suppression factor:

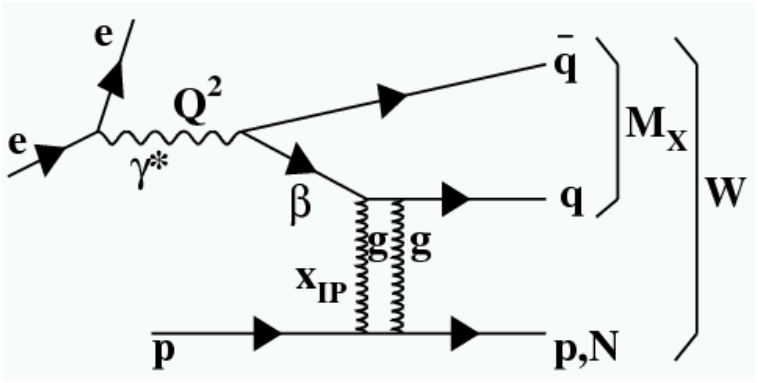


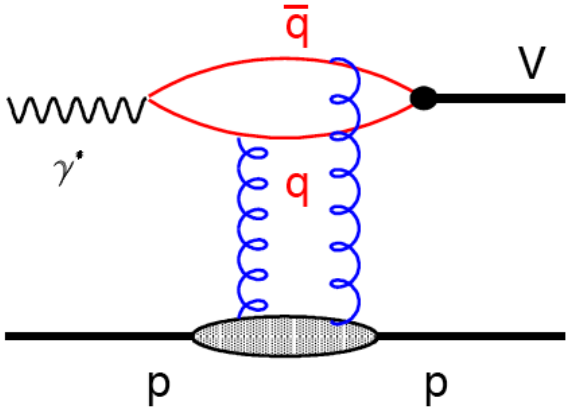
Rescattering depends on the size of the proton ?

Large-x, small p

small-x, large p

Diffraction in DIS – exclusive VM production





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

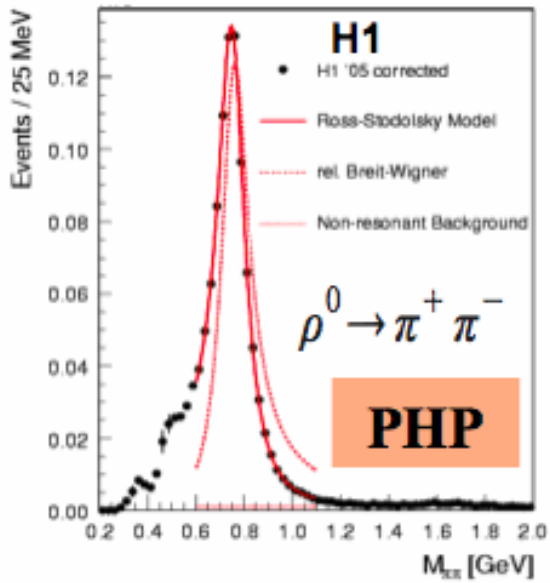
$$\sigma(Q^2) \Rightarrow n \quad (\propto (Q^2 + M^2)^{-n})$$

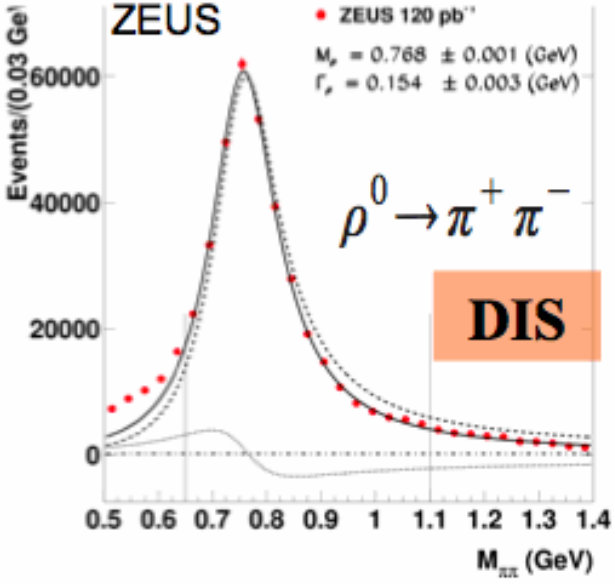
$$\frac{d\sigma}{dt} \Rightarrow b(Q^2)\ (\propto e^{-b|t|})\ ,\ \alpha_{IP}(t)\ (\propto W^{4(\alpha_{IP}-1)})\ ,\ n\ (\propto |t|^{-n} \text{ at large } |t|)$$

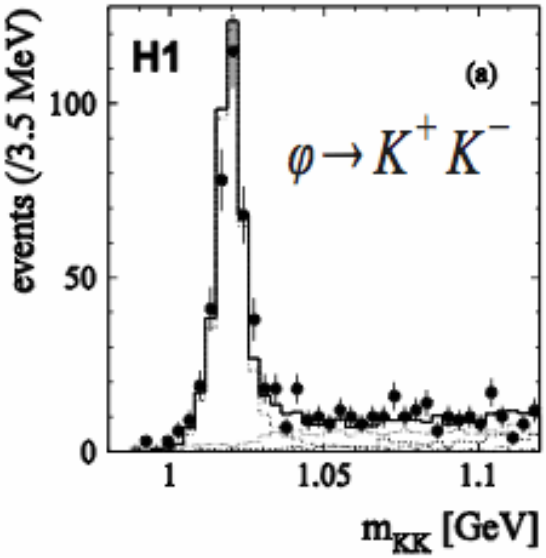
$$r_{ij}^{k} \Rightarrow R(W)\ ,\ R(Q^2)$$

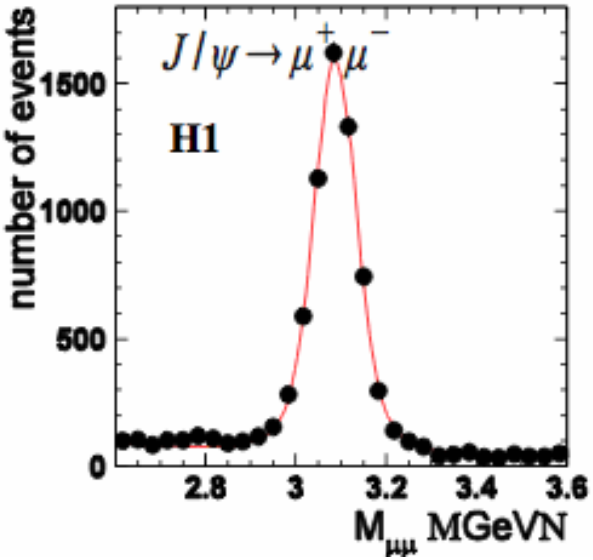
- Is the exclusive VM production a hard process?
- Can we learn something about the proton structure?

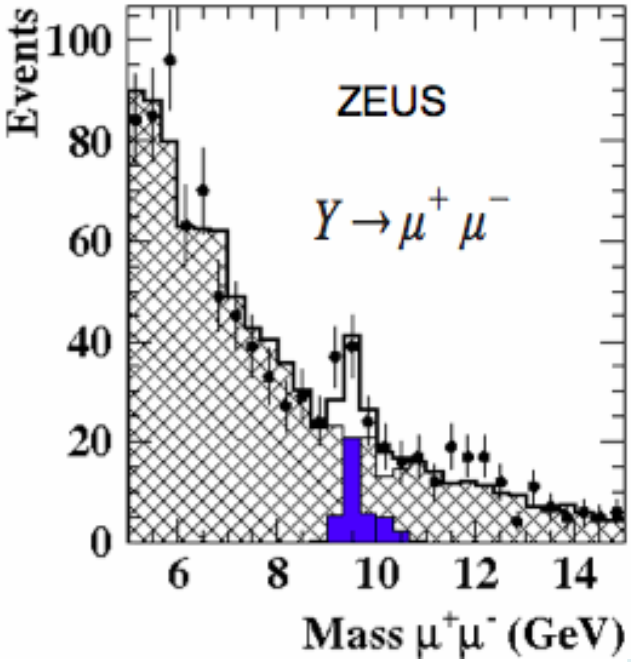
Exclusive VM production





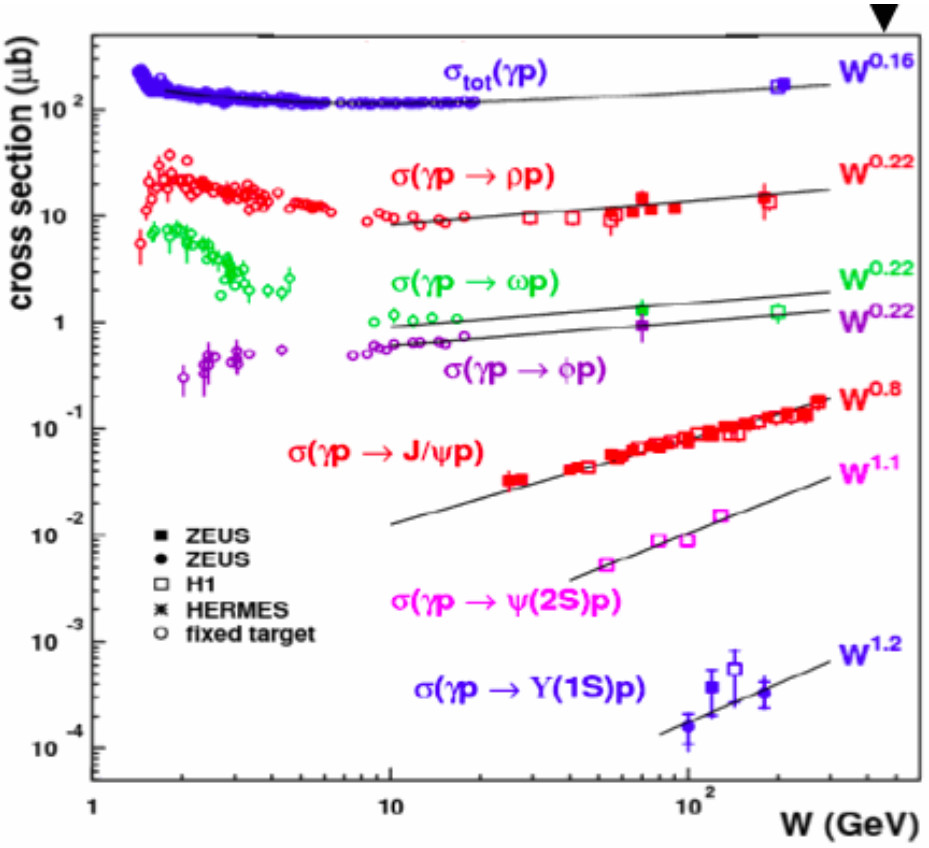






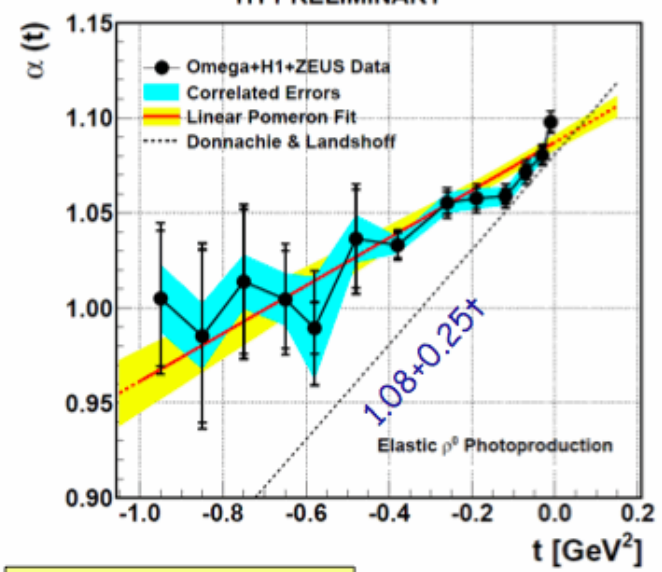
Exclusive VM production - photoproduction

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



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

Result of the fit

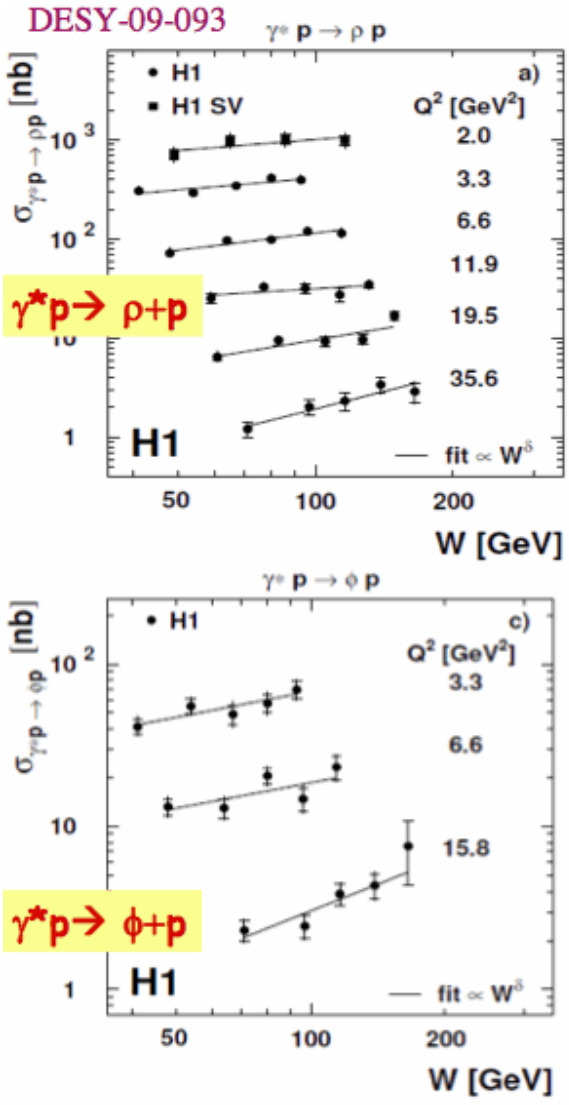


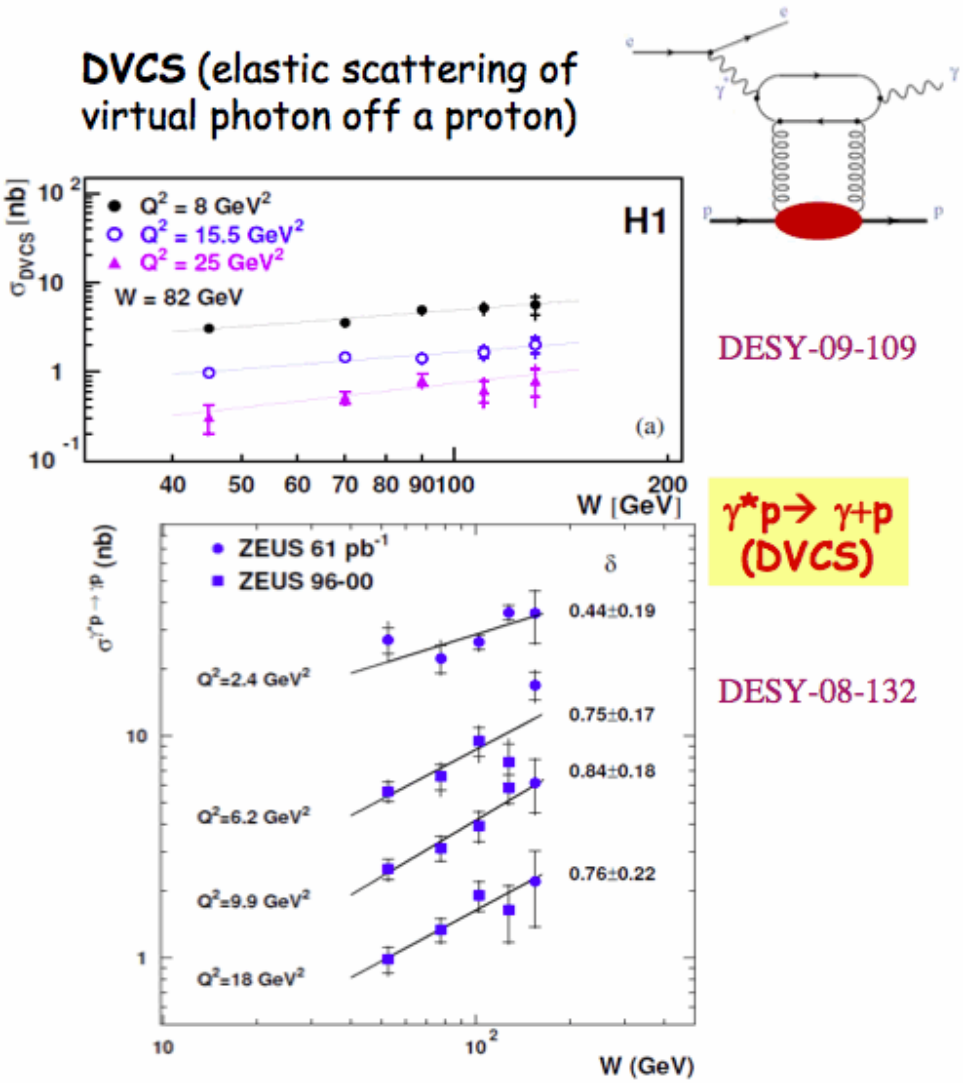
$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} \cdot t$$

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

α_{IP}' =0.126 ±0.013(stat)±0.012(sys) GeV^{-2}

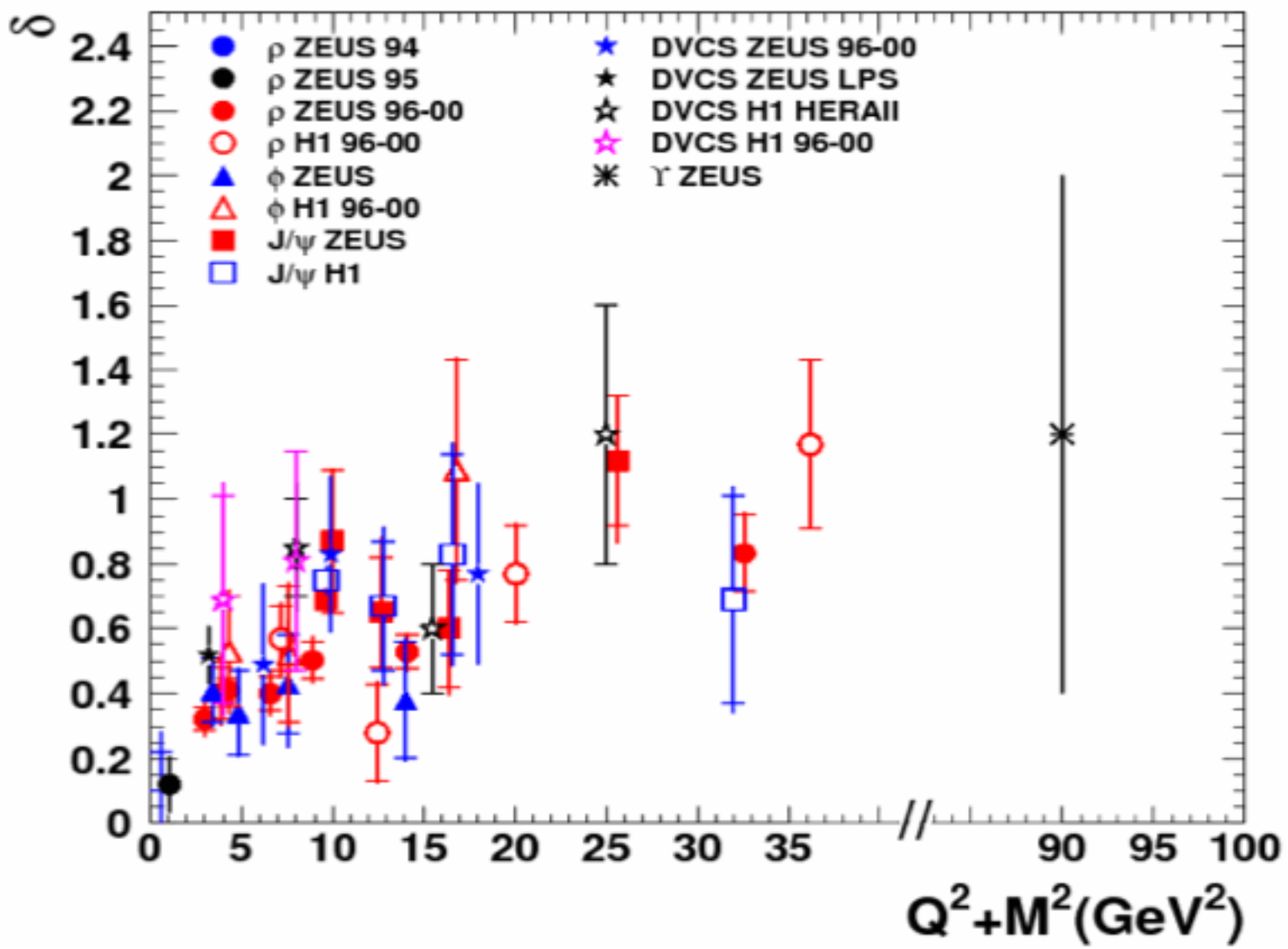
Exclusive VM production and DVCS in DIS





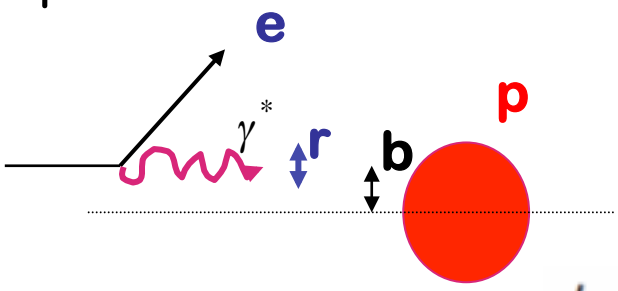
Exclusive VM production and DVCS in DIS

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



Exclusive VM and DVCS in DIS – t slope

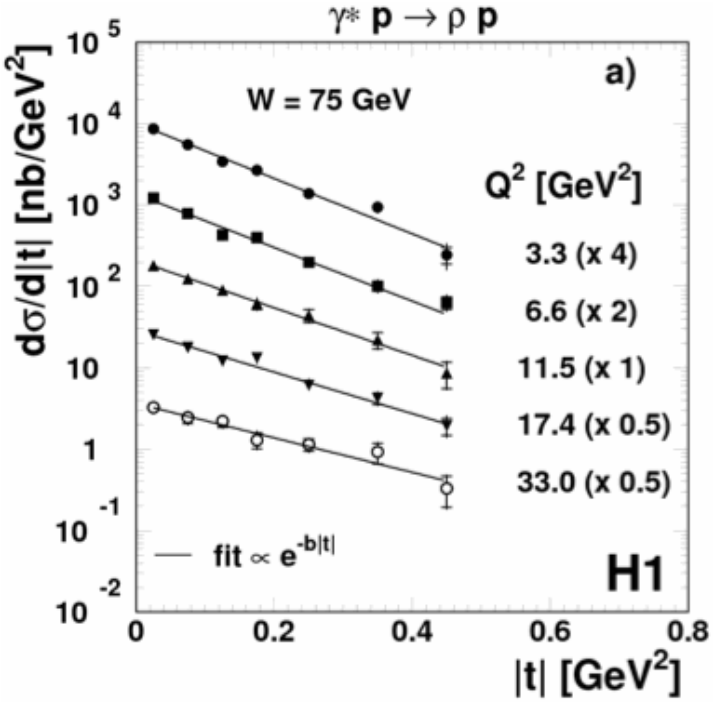
b – impact parameter

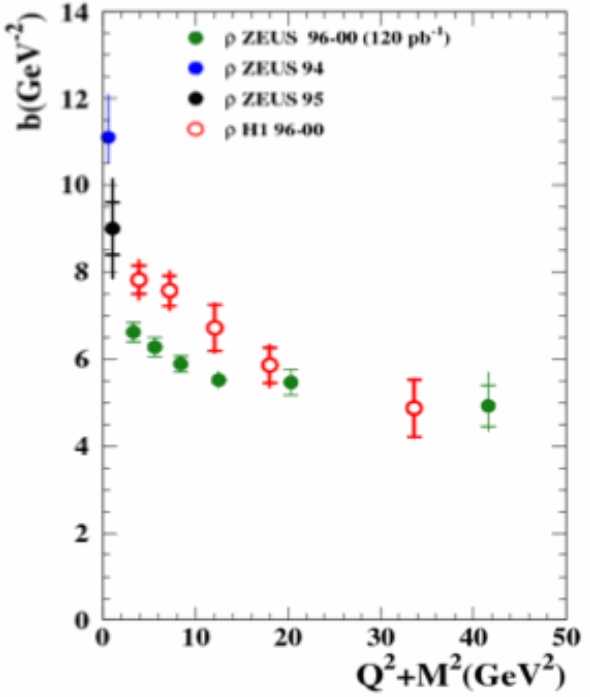


$$b = \frac{\hbar c}{\sqrt{t}}$$

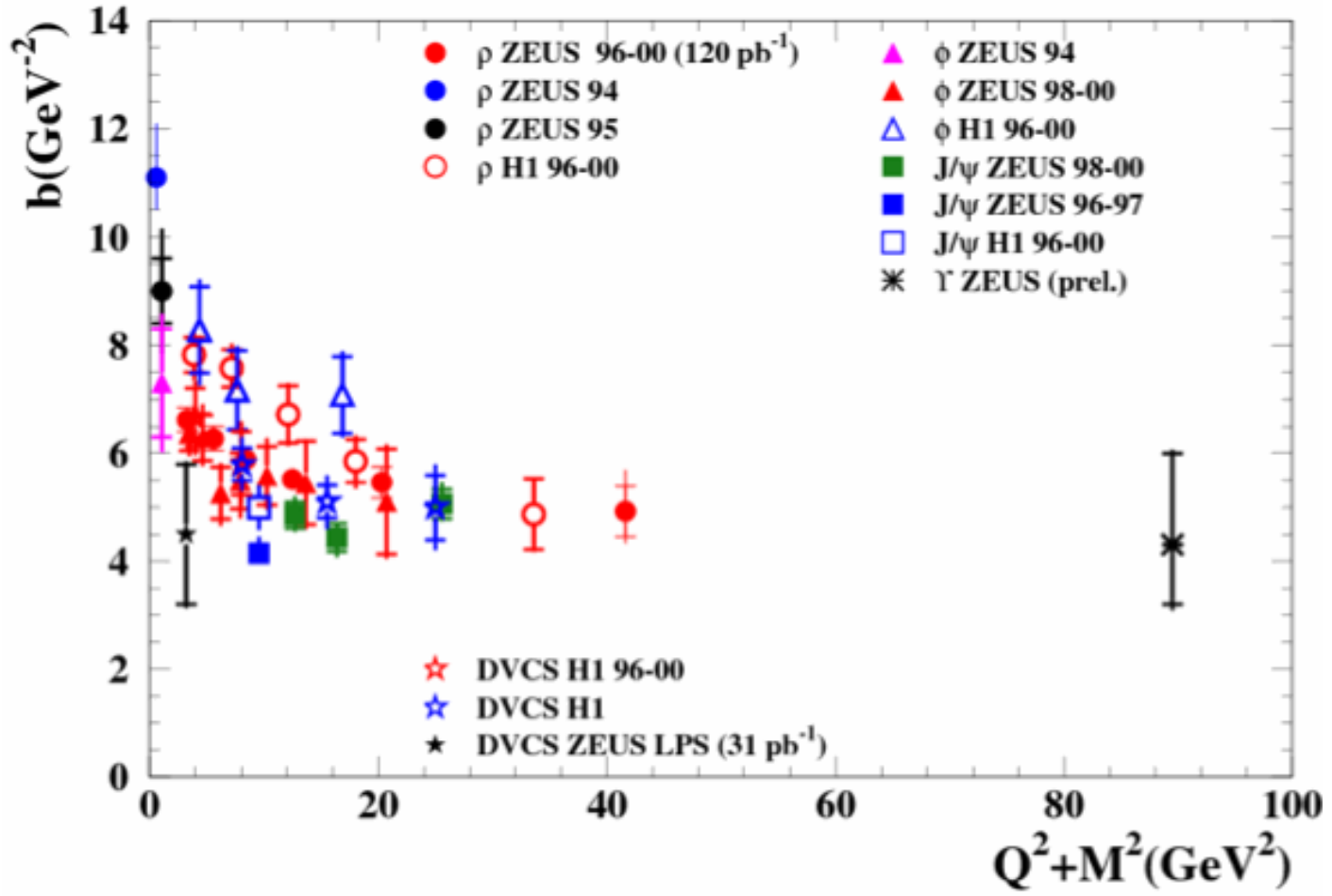
b – slope of t distribution

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



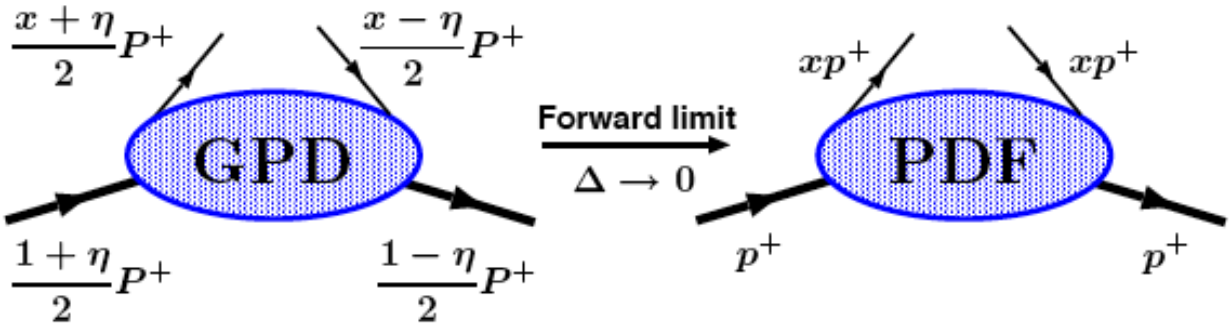


Exclusive VM and DVCS in DIS – t slope

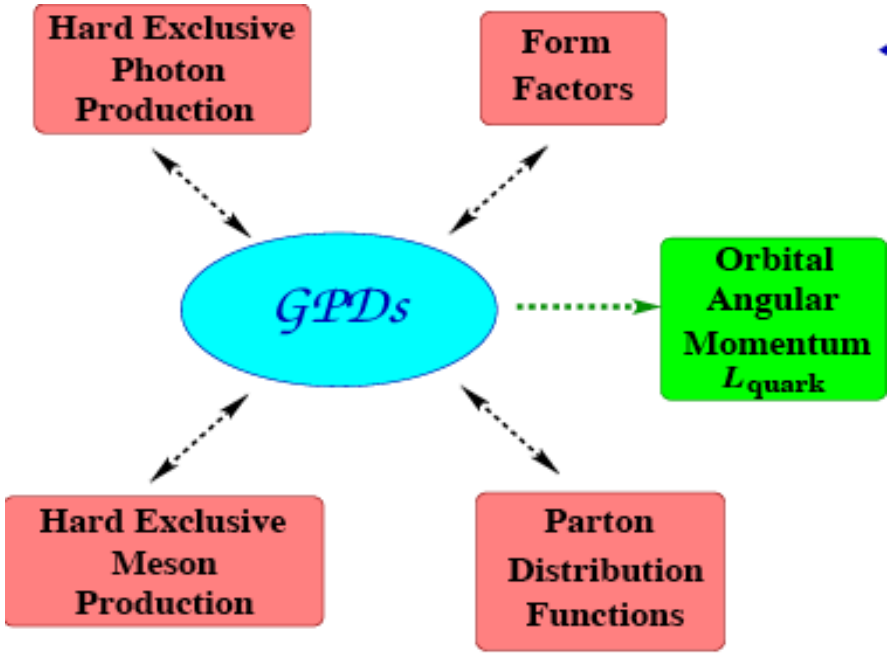


b_{hard} ~ 5 GeV^2 translates into r_g ~ 0.6fm, less than r_{em} of p

GPDs – 3-dimentional picture of the proton

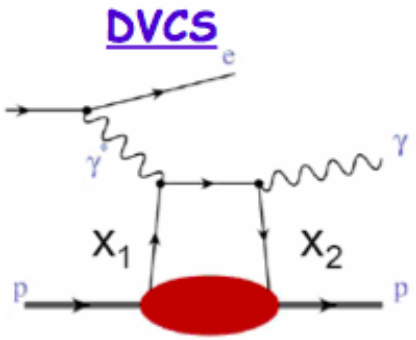


$$P = P_1 + P_2\,; \qquad \Delta = P_2 - P_1\,; \qquad \eta = -\frac{\Delta^+}{P^+} \text{ (skewedness)}$$



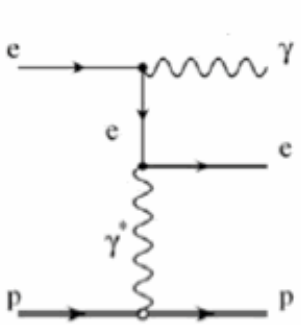
DVCS - charge asymmetry

DESY-09-109

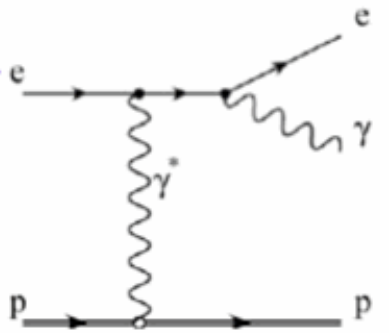


DVCS gives access to Generalized (skewed) Parton Distributions (GPD), which describe the correlations between two partons (x_1,x_2) which differ by longitudinal ($x_1 \neq x_2$) and transverse (t) momentum at given Q^2

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



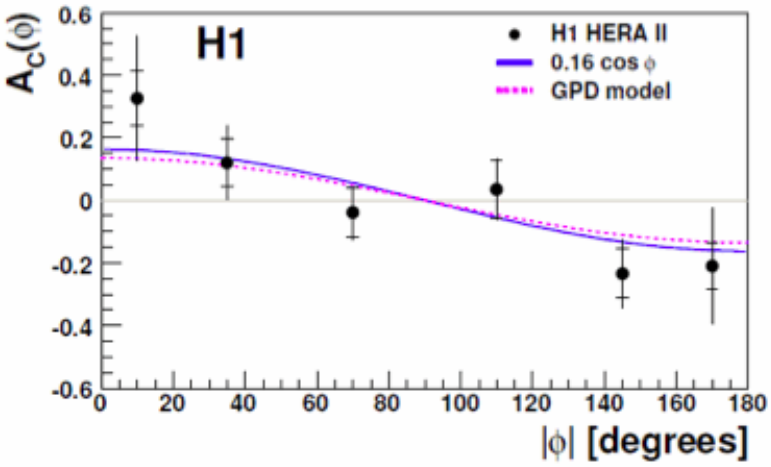
BH

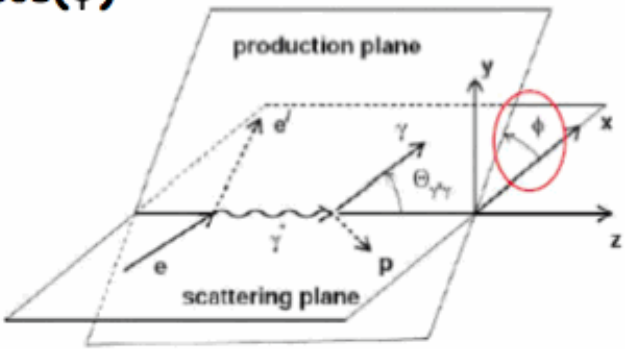


$|A|^2=|A_{DVCS}|^2+|A_{BH}|^2+|A_I|^2$ ← interference term

Beam Charge Asymmetry: $A_C(\varphi)=\dfrac{d\sigma^+-d\sigma^-}{d\sigma^++d\sigma^-}\propto \mathbf{Re}(A_{DVCS})\cdot\cos(\varphi)$

Related to GPD





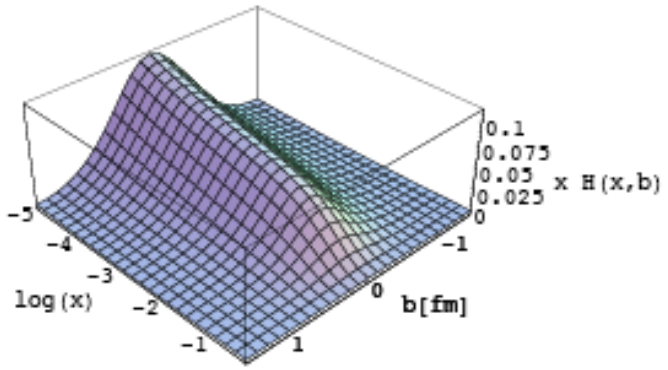
$\rho=\mathrm{Re}\,A_{DVCS}/\mathrm{Im}\,A_{DVCS}=0.20\pm0.05\pm0.08$

GPDs based model compatible with data

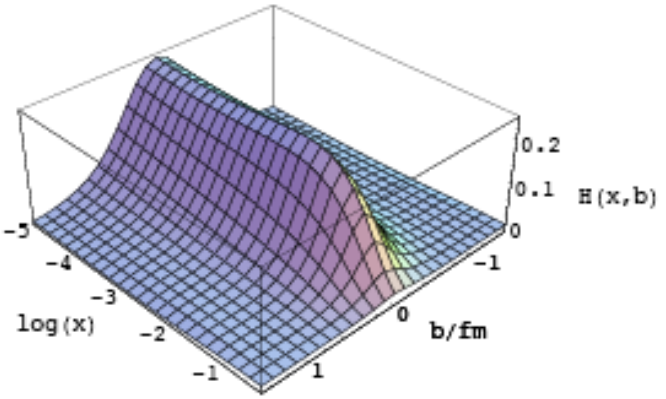
GPDs – 3-dimentional picture of the proton

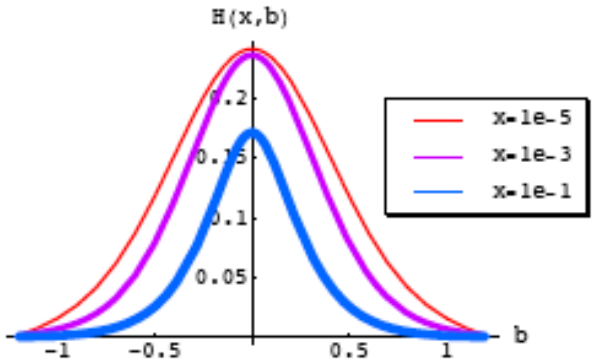
Three-dimensional image of a proton

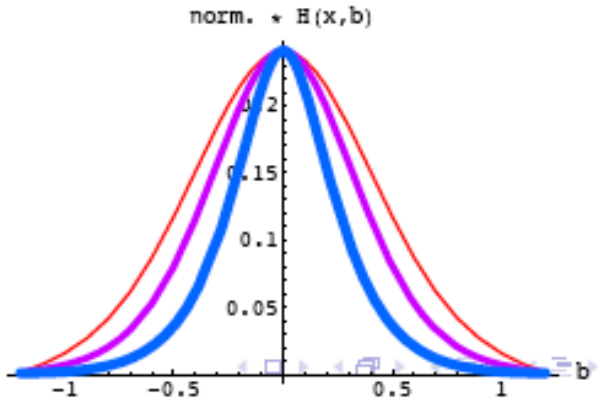
Quarks:



Gluons:



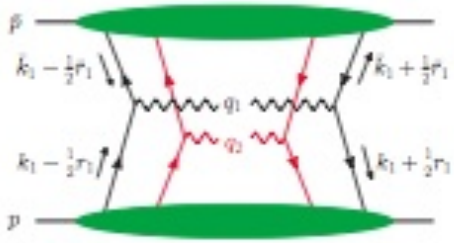




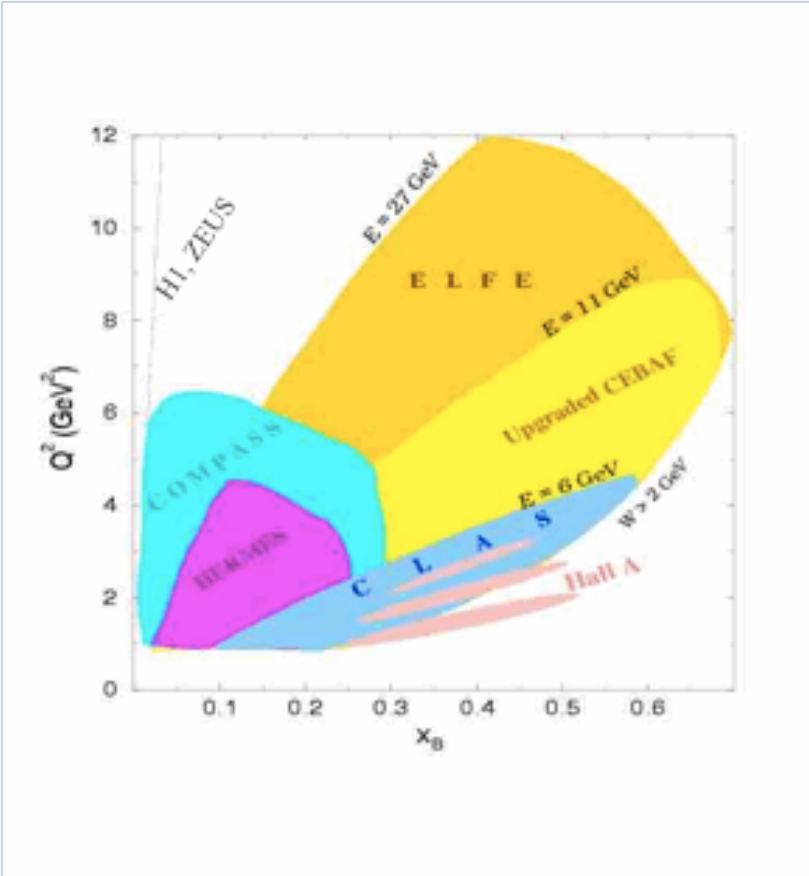
Kornelija Passek-Kumerički: Fitting DVCS at NLO and beyond ...

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