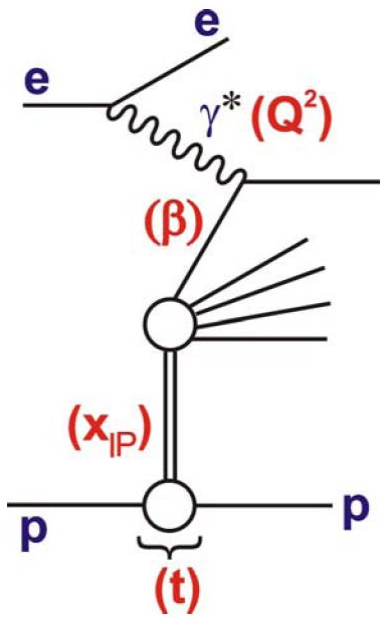
Diffraction: from HERA to the LHC

M.Kapishin for the H1 and ZEUS Collaborations

Diffraction 2008

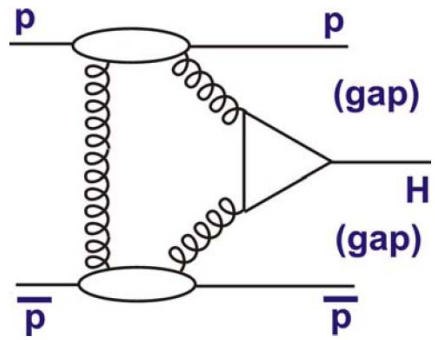
International Workshop on Diffraction in High-Energy Physics

La Londe-les-Maures, France, September 9–14, 2008



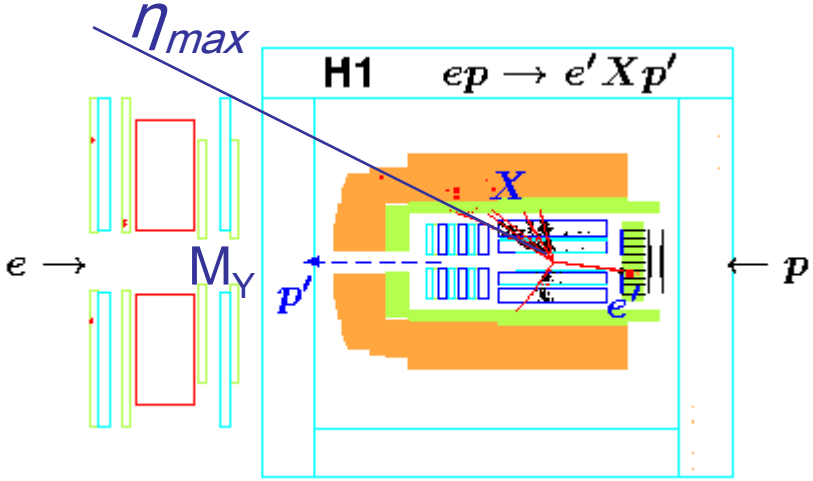
What HERA can provide for future LHC measurements:

- Diffractive Parton Densities at HERA
- Factorization tests at HERA
  - ➢ Hard scattering collinear factorization
  - ➢ Gap survival probability: from *γp* to *pp*
  - ➢ Proton vertex factorization
- Exclusive processes at HERA
  - ➢ Exclusive Dijet production
  - ➢ towards Generalized Parton Densities: heavy VM and DVCS



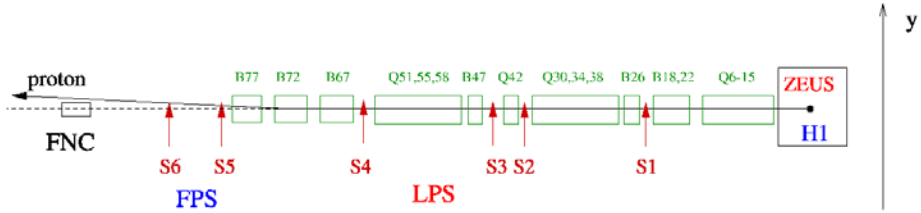
Selection of diffraction at HERA

Large rapidity gap between leading proton p' (Y) and X



- high statistics, data integrated over $|t|<1\text{GeV}^2$
- low M_Y p-dissociation contribution
- limited by systematic uncertainties related to missing proton

Leading Proton Spectrometers ZEUS and H1



- free of p-dissociation background
- x_{IP} and t-measurements
- access to high x_{IP} range (IP+IR)

- limited by low acceptance and systematic uncertainties of proton measurement

LRG and LPS methods have different systematic uncertainties

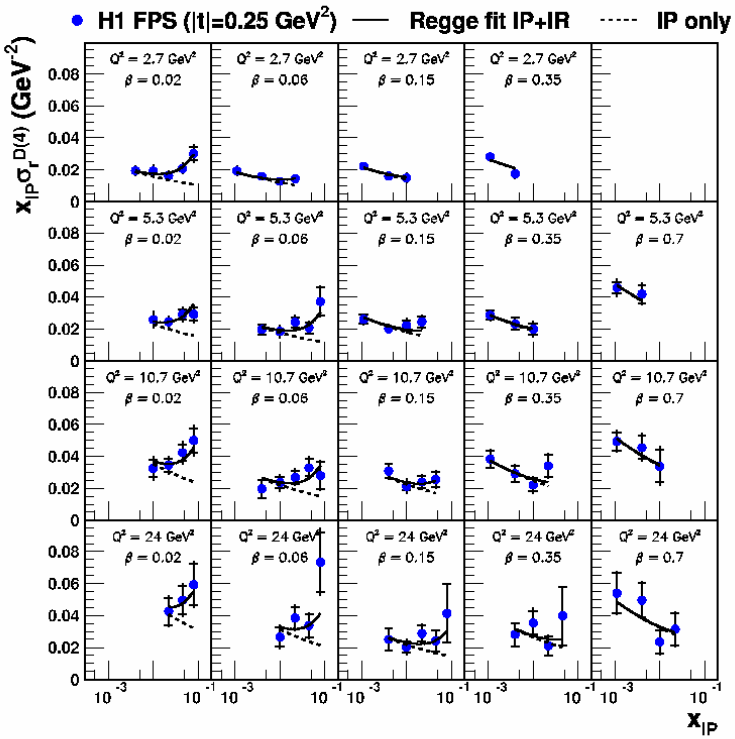
ZEUS: M_x method via decomposition of diffractive mass distribution

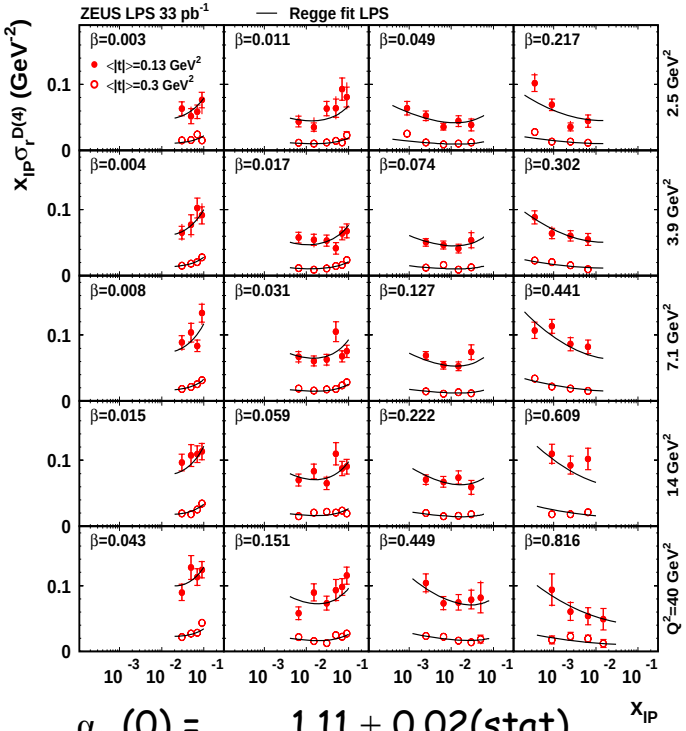
$\sigma_r^{D(4)}(t, x_{IP}, \beta, Q^2)$ LPS measurement

$$F_2^{D(4)}(\beta, Q^2, x_{IP}, t) = f_{IP}(x_{IP}, t) \cdot F_2^{IP}(\beta, Q^2) + n_{IR} \cdot f_{IR}(x_{IP}, t) \cdot F_2^{IR}(\beta, Q^2)$$

Parameterization of x_{IP} dependence → IP intercept

First measurement in the two t bins





$$\alpha_{IP}(0) = 1.118 \pm 0.008\,(\text{exp.})\ ^{+0.029}_{-0.010}\,(\text{theory})$$

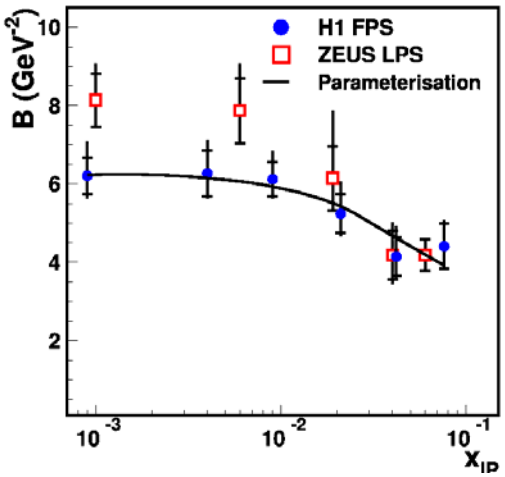
$$\alpha_{IP}(0) = 1.11 \pm 0.02(\text{stat})\ ^{+0.01}_{-0.02}(\text{syst})\ +0.02(\text{model})$$

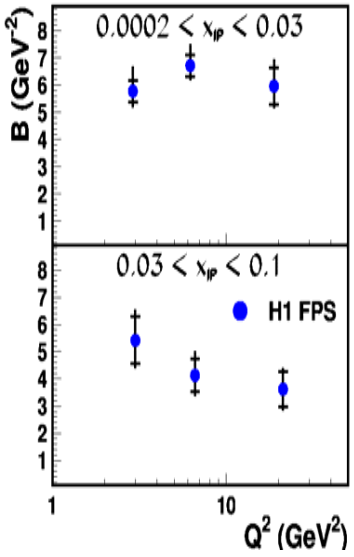
$$\alpha'_{IP} = -0.01 \pm 0.06(\text{stat})\ ^{+0.04}_{-0.08}(\text{syst})\ \text{GeV}^{-2}$$

Plans: results based on full statistics of HERA-I,II

Test of Proton Vertex Factorization

LPS measurements of t-slopes in diffractive DIS



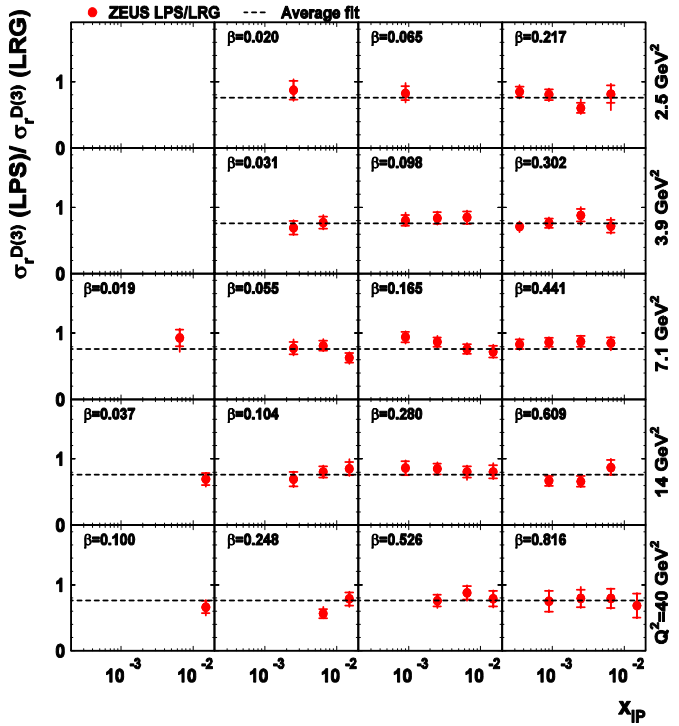


$$B = B_{IP} + 2\alpha'_{IP} \ln(1/x_{IP})$$

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06}\ \text{GeV}^{-2}$$

$$B_{IP} = 5.5^{-2,0}_{+0.7}\ \text{GeV}^{-2}$$

LRG / LPS ratio



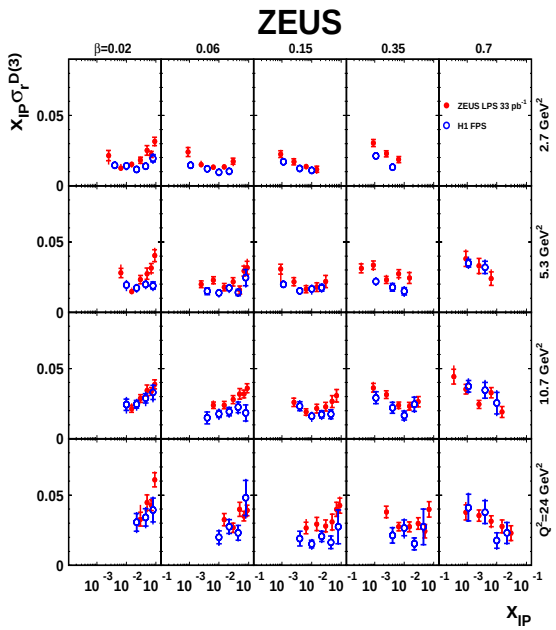
- *t* dependence does not change with β or Q^2 at fixed x_{IP} → consistent with proton vertex factorization
- α'_{IP} is not "soft" (α'_{IP}(soft)~0.25 GeV^{-2})

- M_Y-dependence (H1+ZEUS): LRG / LPS ratio does not depend on Q^2, β, x_{IP} within uncertainties → consistent with proton vertex factorization

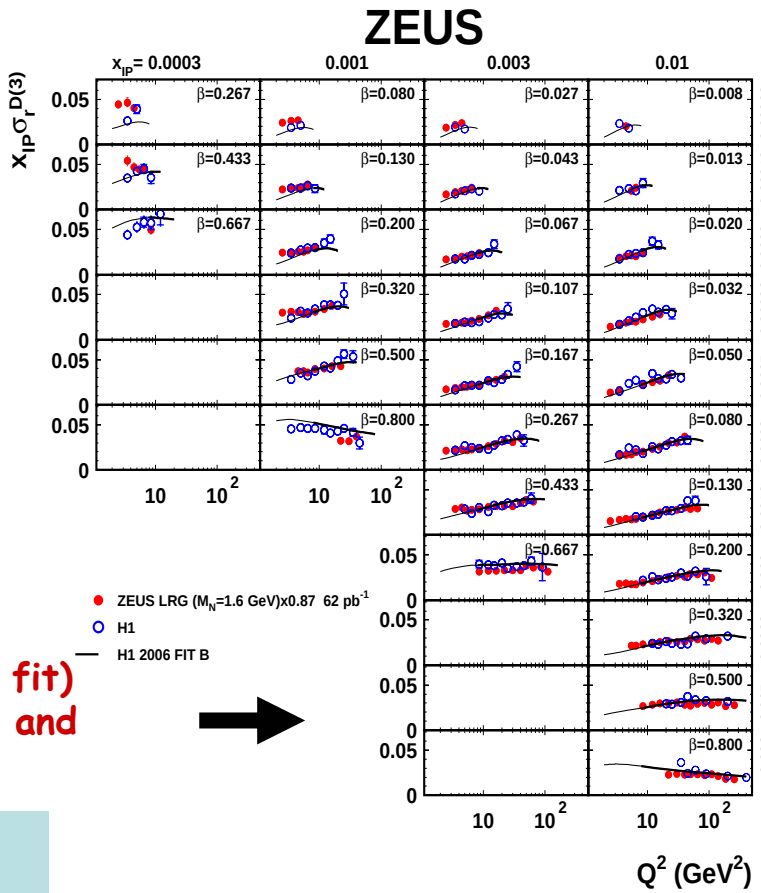
Inclusive Diffraction in DIS

$\sigma_r^{D(3)}$ ZEUS vs H1

Leading Proton Spectrometer data



Large Rapidity Gap data



Remaining normalisation difference of 13% (global fit) covered by uncertainty on p-diss. correction (8%) and relative normalisation uncertainty (7%)

Plans:

- combine H1+ZEUS $\sigma_r^{D(3)}$ data
- measure F_L^D using H1+ZEUS data at low, medium and high proton energies

ZEUS results consistent with H1 results within uncertainties

Factorization in Diffractive DIS

QCD hard scattering collinear factorization:

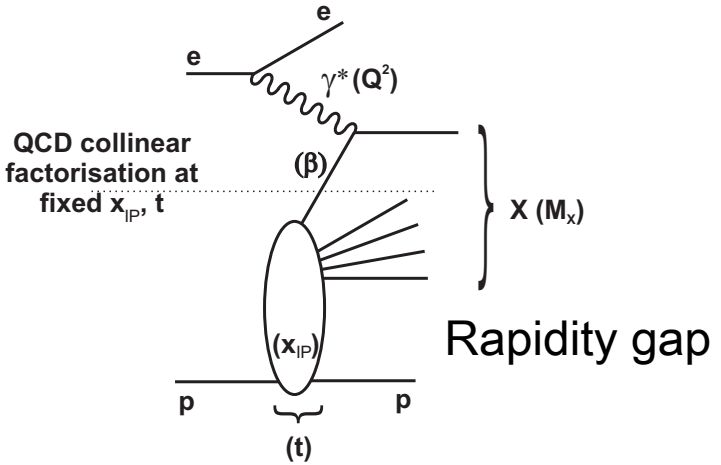
$$\sigma^D(\gamma^* p \to Xp) = \sum_{parton\_i} f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

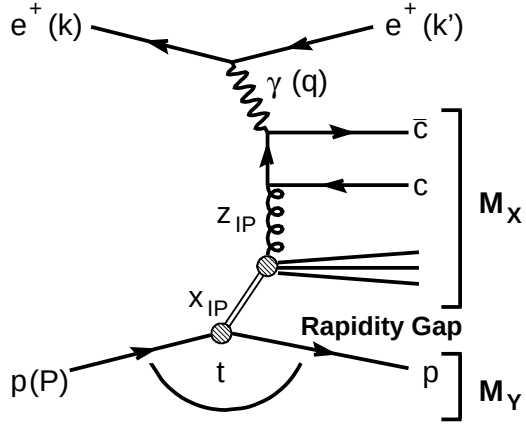
$\sigma^{\gamma^* i}$ - universal hard scattering cross section (same as in inclusive DIS)

f_i^D - Diffractive Parton Distribution Function ➔ obey DGLAP, universal for diffractive *ep* DIS (inclusive, Dijets, Charm)

❑ Extract DPDFs from QCD fit to inclusive diffractive DIS

❑ Test DPDFs in diffractive Final States (Boson Gluon Fusion)

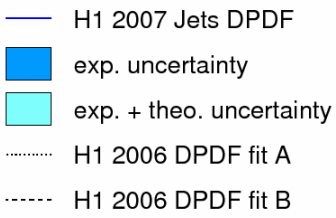


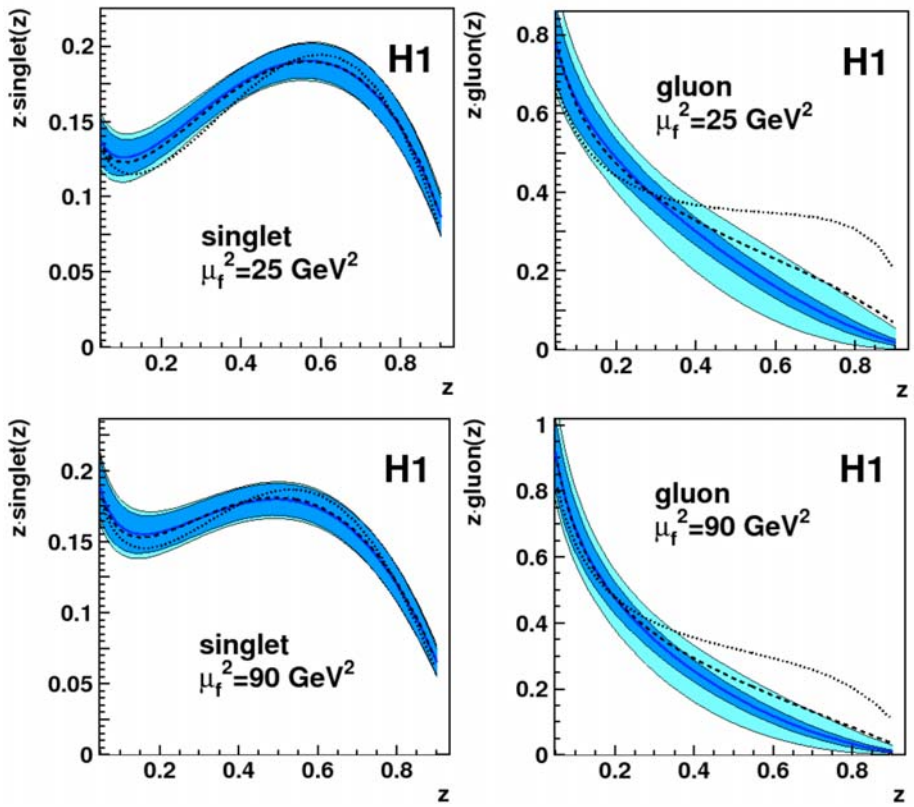


❑ Assumption: Proton vertex factorization ➔ Q^2 and β dependences of diffractive PDFs factorize from x_{IP}, t, M_Y dependences

Diffractive PDFs

- Diffractive Dijet DIS data used as an additional constrain in a NLO QCD fit





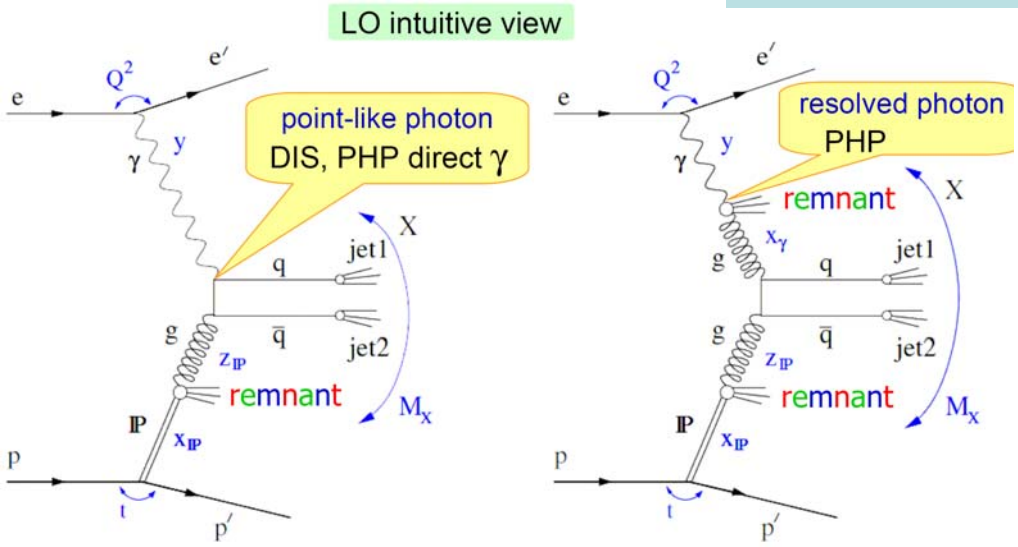
- Combined fit to inclusive DIS and Dijet DIS data constrain quark singlet to ~5% and gluon PDFs to ~15% at low z
- H1 Jets 2007 DPDF are the most precise diffractive partons
- Gluon PDF at high z important to estimate background for Central Exclusive Production

Plans:

- include high Q^2 inclusive and Dijet DIS data to reduce scale uncertainty
- combine H1+ZEUS data in a joint NLO QCD fit
- constrain F_L^D from H1+ZEUS data

Diffractive Dijet Photo-production

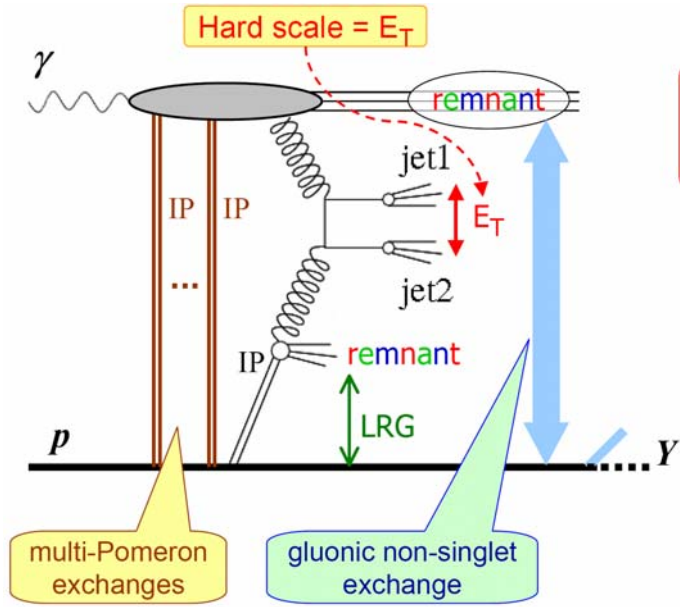
Test of hard scattering collinear factorization



- Does factorisation hold for the diffractive dijet photoproduction where ...?
  - known to be strongly broken in *pp* diffraction
    - Factorisation should hold for <u>direct</u> photon – $x_\gamma=1$
    - Suppression – if any – expected for <u>resolved</u> photon – $x_\gamma<1$

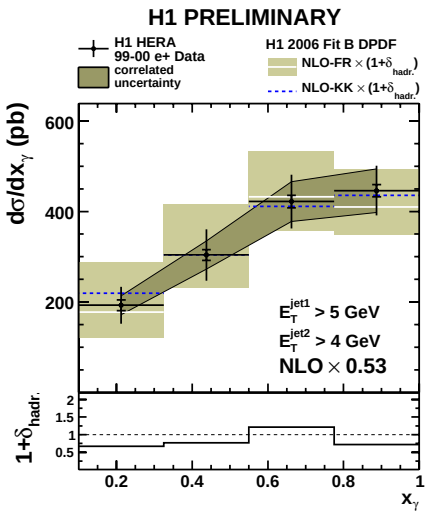
Rescattering leads to:

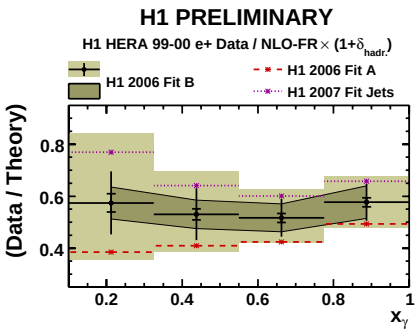
- Factorisation breaking
- Screening
- Rapidity gap fill-up



Diffractive Dijet Photoproduction

H1 Dijet analysis with higher statistics data vs NLO QCD calculations:



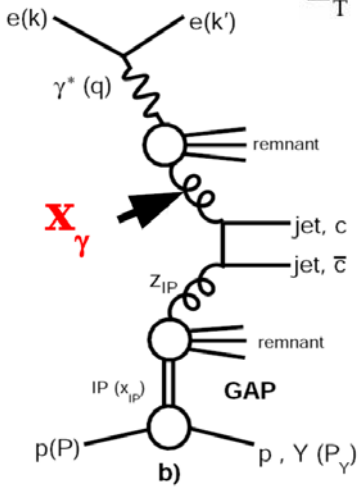


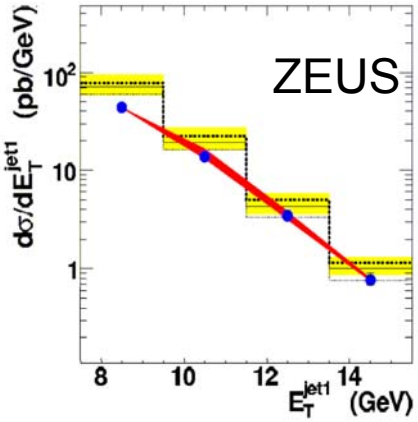
H1 and ZEUS:

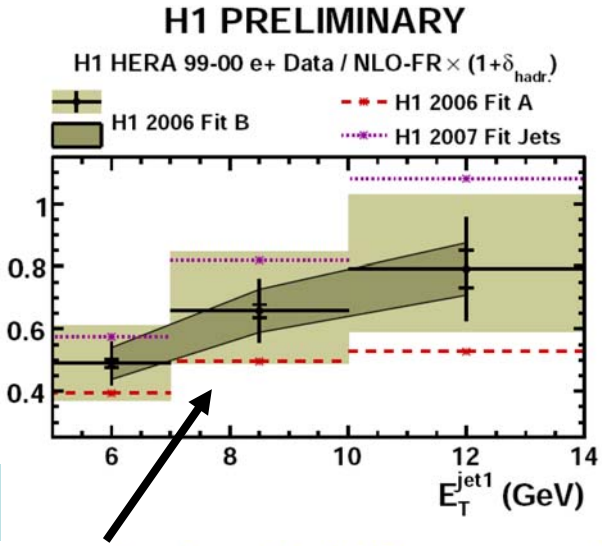
There is no evidence for any difference in survival probabilities for resolved and direct photons.

$E_T^{jet1} > 5$ GeV

$E_T^{jet2} > 4$ GeV







H1 and ZEUS:

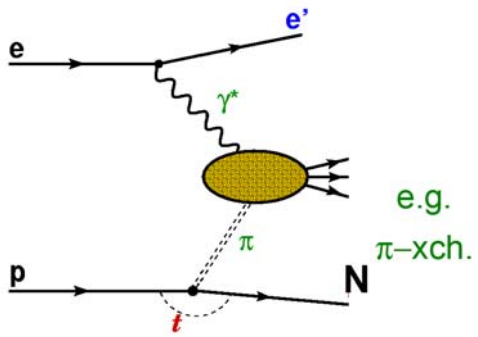
Another suggestion for harder E_T^{jet1} slope in data than NLO theory.

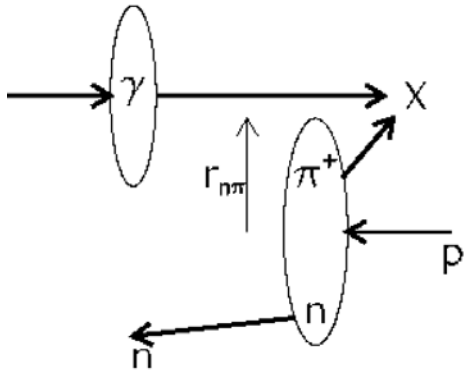
H1:

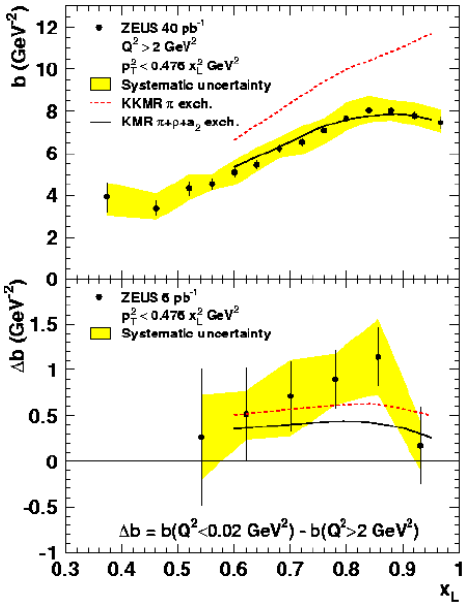
Similar survival probability range to ZEUS in similar E_T range if data and DPDF uncertainties taken into account.

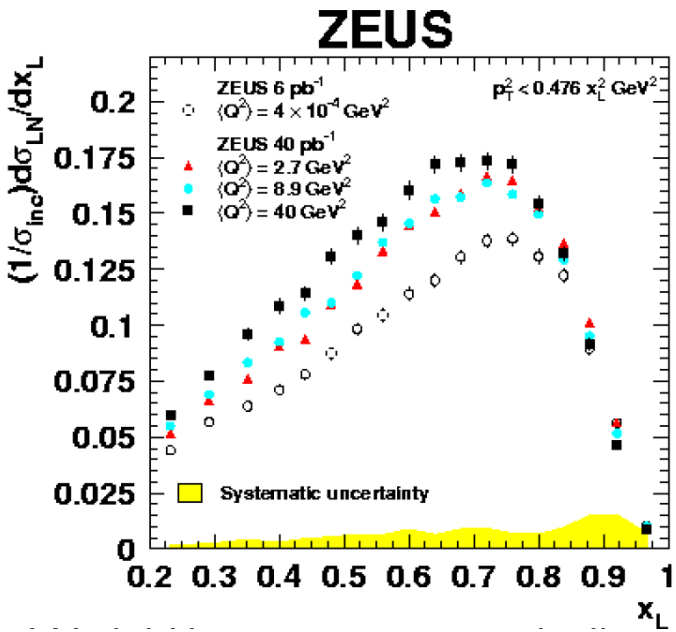
Leading neutrons: absorptive corrections

• Effect of absorption (re-scattering) in Leading Neutron production (PhP & DIS) → compare Data with KKMR calculations based on absorption corrections









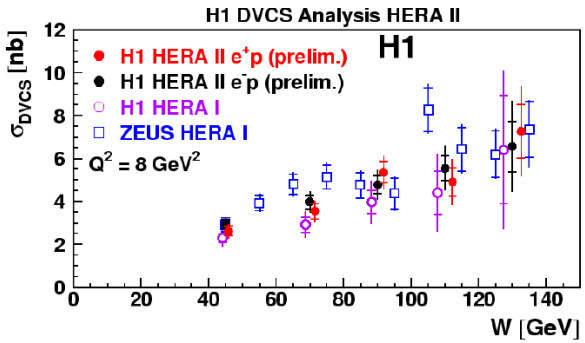
LN yield increases with Q^2 → consistent with absorption model: larger Q^2 → smaller γ*

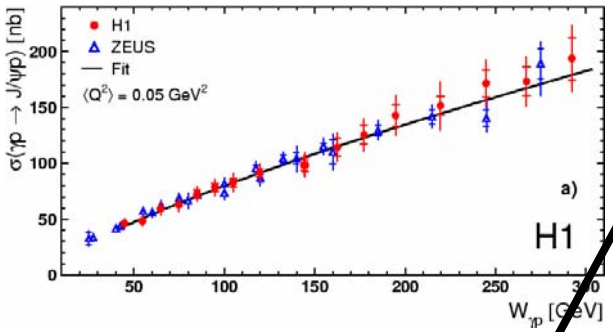
Plans:

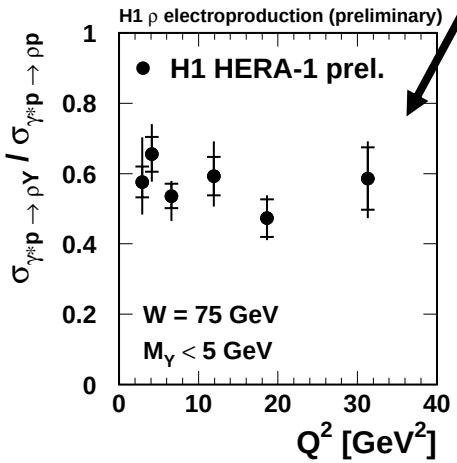
• Detailed studies of x_L and p_T^2 spectra

• Test of proton vertex factorization using leading neutron data at low, medium and high proton beam energies

Vector mesons and DVCS at HERA

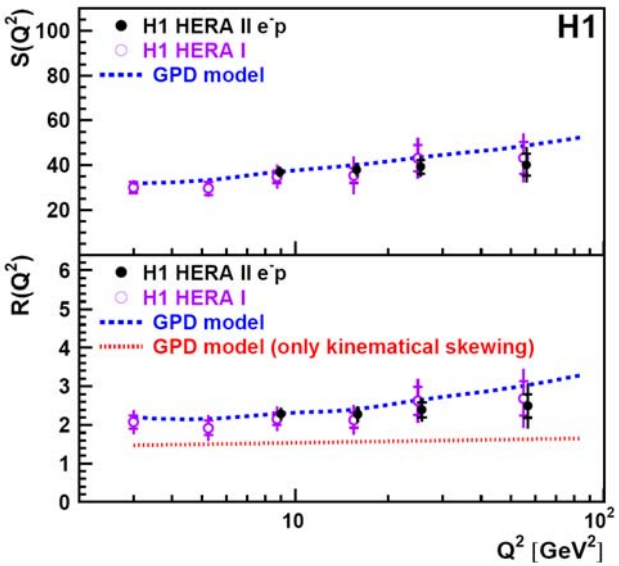






Tests of γ(*) p scattering in diffractive VM photo-production and DIS:

- Unique transverse / longitudinal γ* separation
- Unique sensitivity to `soft → hard' transition
- t measurements → transverse picture of proton
- Proton vertex factorization tests → PD / EL ratio
- Constrain Generalized Gluon Density (best with heavy VM and DVCS)

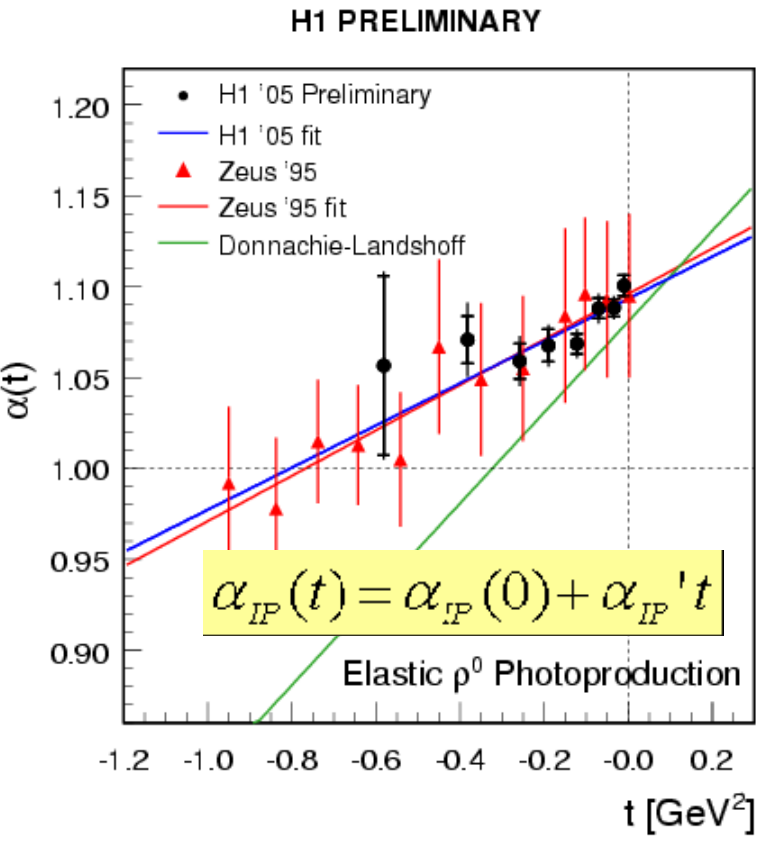


$$S = \sqrt{\frac{\sigma_{DVCS}\ Q^4\ b(Q^2)}{(1+\rho^2)}}$$

skewing factor: around 2

$$R = \frac{\mathcal{I}m\ A(\gamma^* p \to \gamma p)}{\mathcal{I}m\ A(\gamma^* p \to \gamma^* p)}$$

Soft IP trajectory



Elastic ρ-meson photo-production

H1: $\alpha_{IP}(t) = [1.093 \pm 0.008] + [0.116 \pm 0.049]t$

ZEUS: $\alpha_{IP}(t) = [1.096 \pm 0.021] + [0.125 \pm 0.038]t$

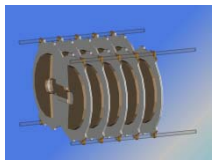
Soft h-h scattering: $\alpha_{IP}(t) = [1.085] + [0.25]t$

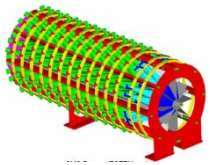
- slope α_{IP}' is smaller than value 0.25 GeV^{-2} extracted from soft hadron-hadron scattering
- slope α_{IP}' from inclusive diffractive DIS is even smaller
- No universal soft IP in photo-production and hadron-hadron scattering

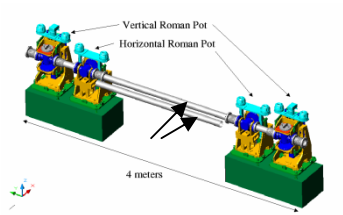
- Need confirmation with Leading Proton Spectrometer data

LHC Forward Instrumentation

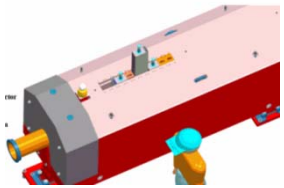
IP5

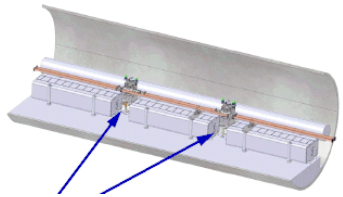






TOTEM-T2	CASTOR	ZDC	TOTEM-RP	FP420
14m	16m	140m	147-(180)-220m	420m
	LUCID	ZDC	ALFA/FP220	FP420



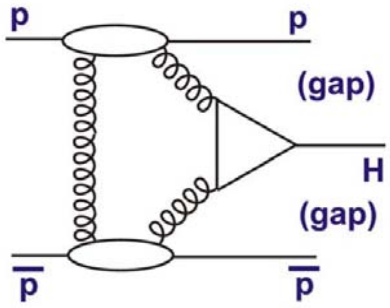


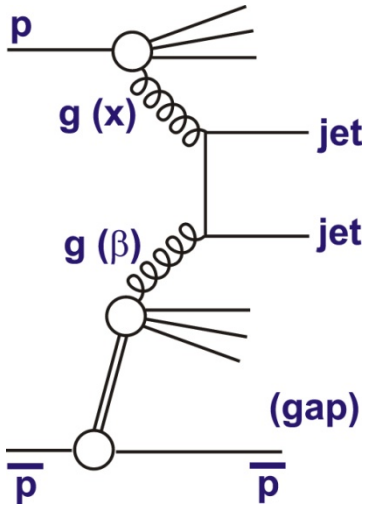
IP1

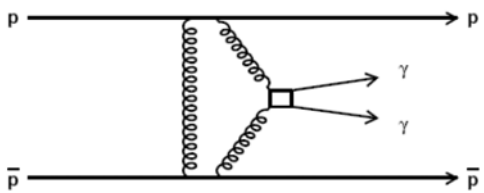
Experimental techniques:

- Large rapidity gaps (low luminosity phase)
- Leading protons tagged in Roman Pots

Hard Diffraction at the LHC

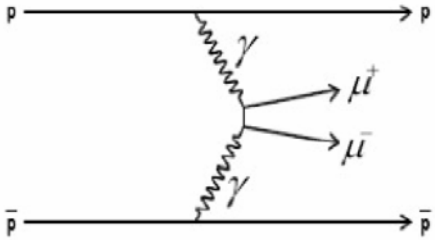


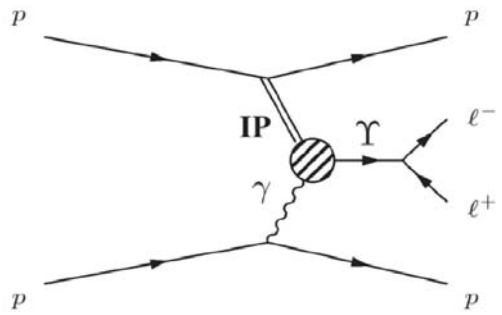




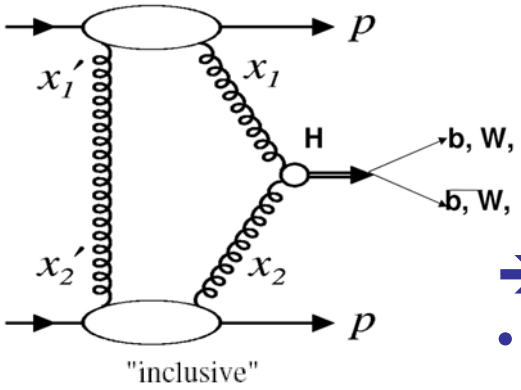
Wide scope of measurements:

- Single and double diffraction: x_{IP}, t, M_x spectra, gap survival probabilities
- Hard Pomeron–Pomeron scattering → high p_T jets, heavy flavors, W, Z production
- Central exclusive production → Di-jets, γγ production, Higgs and processes beyond SM
- Forward jets and forward Drell-Yan pair production
- γγ and γp physics and luminosity measurements

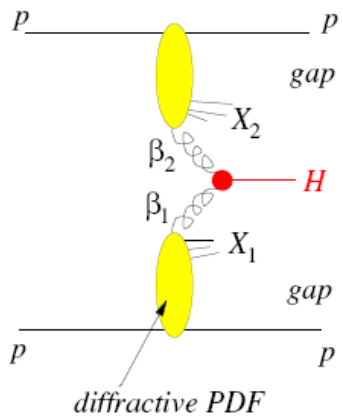




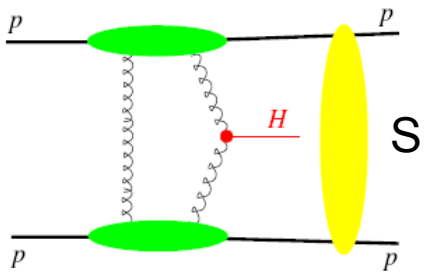
LHC: Central Exclusive Production



"inclusive"



diffractive PDF



S

$$\sigma = \sigma_{\text{hard}} \otimes |S|^2$$

Physics motivation: Higgs and processes beyond SM

HERA input:

➔ rate and background estimate

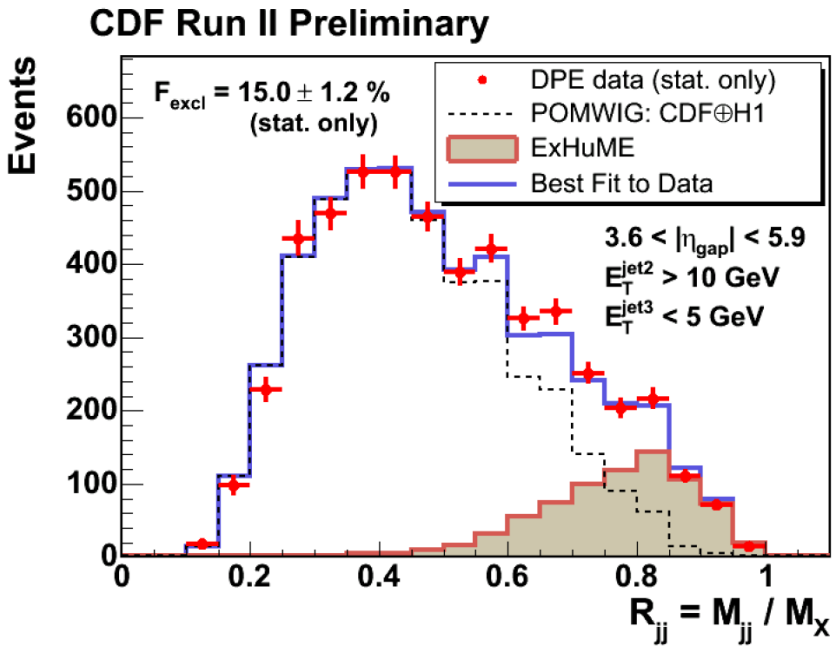
- diffractive PDFs: control non-exclusive background
- gap survival probability (γp & DIS Dijets, leading neutrons), compare HERA DPDF predictions with Tevatron data
- exclusive Dijet cross section

➔ generalized (skewed) gluon distribution

- exclusive J/ψ production → high rate; double differential distributions
- exclusive Y production → large mass scale, but very low rate; t, energy dependences
- DVCS → clean process for theory, but low rate

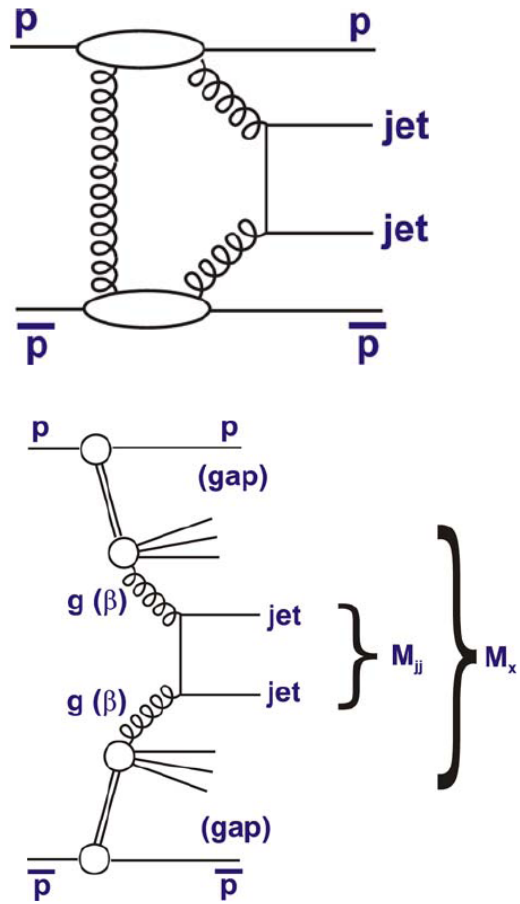
Tevatron: Central Exclusive Jet Production

Look for excess over inclusive Dijet prediction at large dijet mass fraction R_{jj}



Excess at large R_{jj} described by gg→gg LO pQCD KMR calculation and by DPE MC based on Regge model, Gap Survival probability ~5%, 'uncertainty factor' ~2.5

What about HERA results?



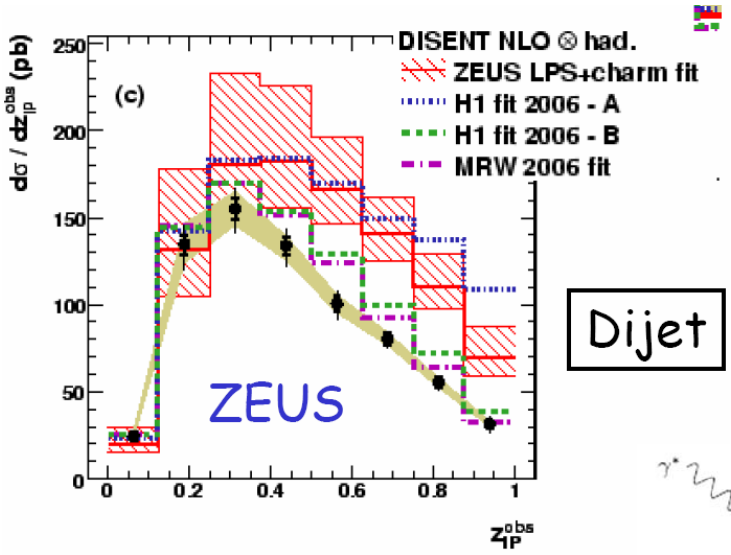
DPE Dijets: $R_{jj} = M_{jj} / M_x$

$R_{jj} \rightarrow 1$ exclusive jets

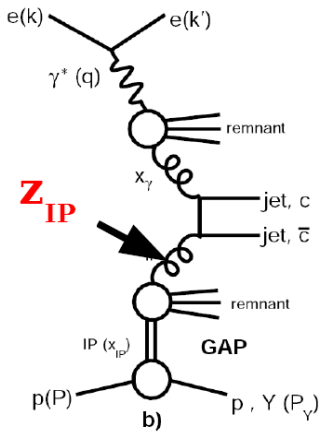
$R_{jj} < 1$ inclusive jets

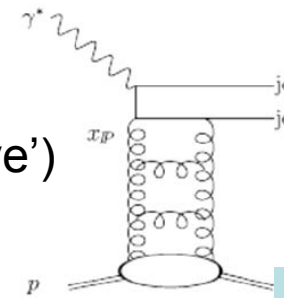
HERA: Dijets in DIS and PhP

- No excess over gluon DPDF prediction at large fractional momentum z_{IP} within model uncertainties
- Need systematic search for exclusive jets in PhP and DIS

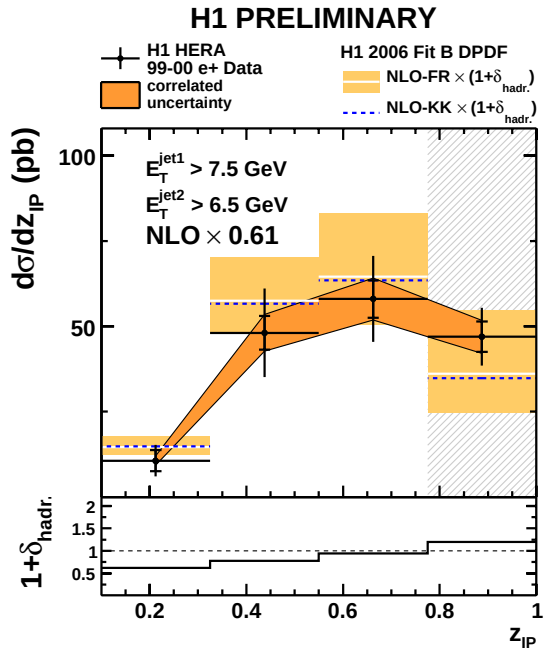


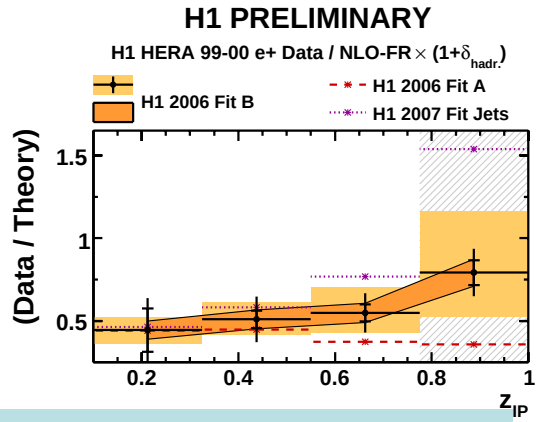
Dijet





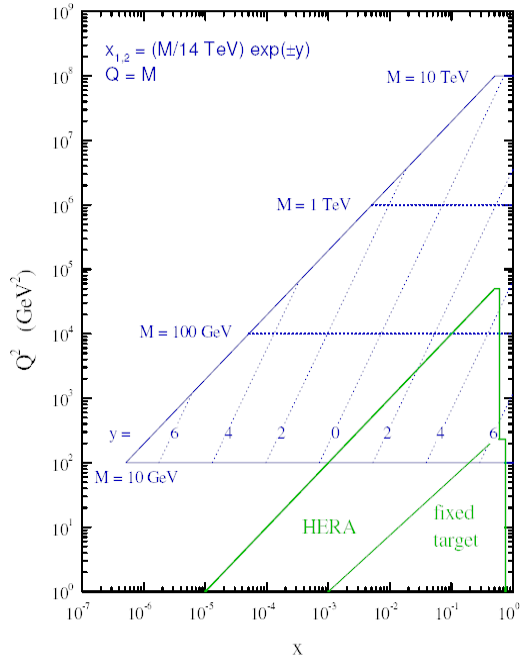
constrain direct ('hard, perturbative') Pomeron (MRW approach) →



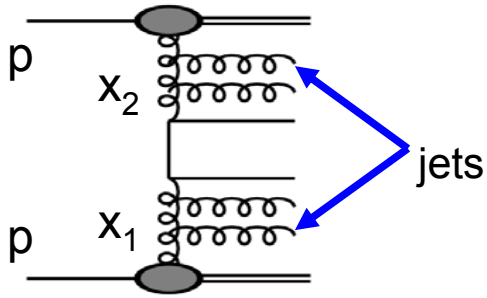


Very large theory uncertainty at high fractional momentum z_{IP}

Forward Jets with leading proton



LHC: Probe PDFs in different kinematical domains

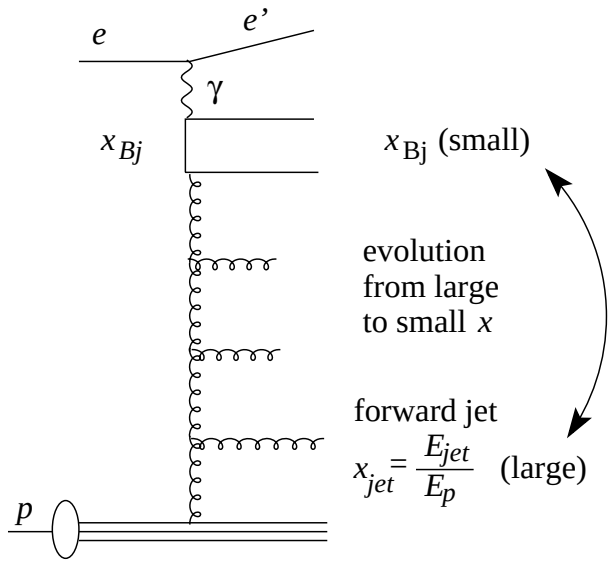


$$x_{Bj} = \frac{Q}{\sqrt{s}} e^{-\eta}, \qquad Q = p_T, M, \ldots$$

- $x_2 \simeq x_1 \rightarrow$ study jets in central detector
- $x_2 \ll x_1 \rightarrow$ forward jets, forward Drell-Yan pairs, access to very low-$x_{Bj} \approx 10^{-6}$

HERA input:

- Study forward jets with LPS leading proton → distinguish between soft and perturbative Pomeron
- Forward energy flow and forward hadron multiplicity in DIS events with LPS leading proton



A wish list of HERA measurements

Inclusive DIS:

- $F_2^D(t,x_{IP},\beta,Q^2)$ measurement using full HERA-I,II LPS data
- F_L^D measurement using data at low / medium / high proton energies
- High Q^2 HERA-II data (F_2^D+DIS Dijets) to reduce DPDF uncertainty
- combine DPDFs from H1 and ZEUS data

Dijets in γp and DIS:

- Ratio of Diffractive to Inclusive Dijet cross sections (Q^2 dependence)
- Systematic search for Exclusive Dijets
- Forward Jets, forward energy flow in hard diffraction with LPS proton

Elastic VM and DVCS:

- Measure t-slopes using LPS data
- Double differential distributions to constrain GPDs using full HERA-I,II data
- Diffractive J/ψ photo-production: measure M_Y distribution → bare 3IP vertex

Summary of HERA results

• HERA experiments give consistent results for diffractive DIS with different methods and provide tools for future diffractive measurements at the LHC

• Diffractive Parton Densities extracted at HERA are used to predict cross sections of diffractive processes at the LHC

• Factorization tests at HERA

➢ confirm hard scattering collinear factorization in diffractive DIS

➢ give estimation of gap survival probability in *γp* scattering

➢ data consistent with proton vertex factorization within uncertainties

• Measurements of exclusive processes at HERA

➢ constrain t, Q^2 and energy dependence of heavy VM and DVCS

➢ constrain Generalized Parton Densities for predictions of Central Exclusive Processes at the LHC