



Diffraction: from HERA to the LHC



M.Kapishin for the H1 and ZEUS Collaborations

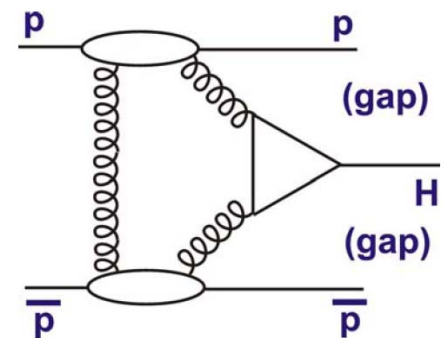
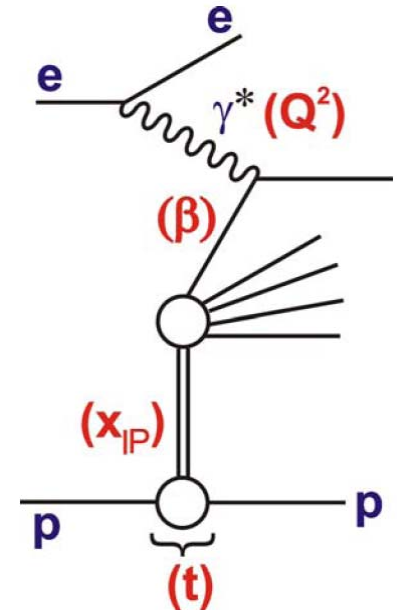
Diffraction 2008

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



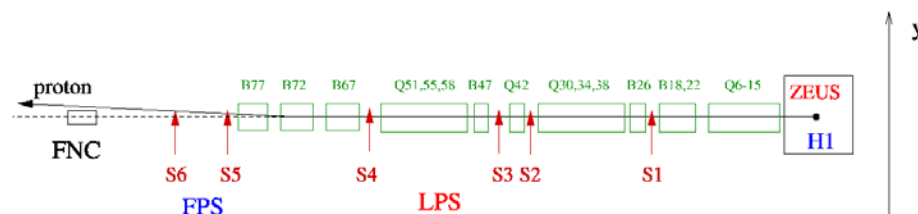
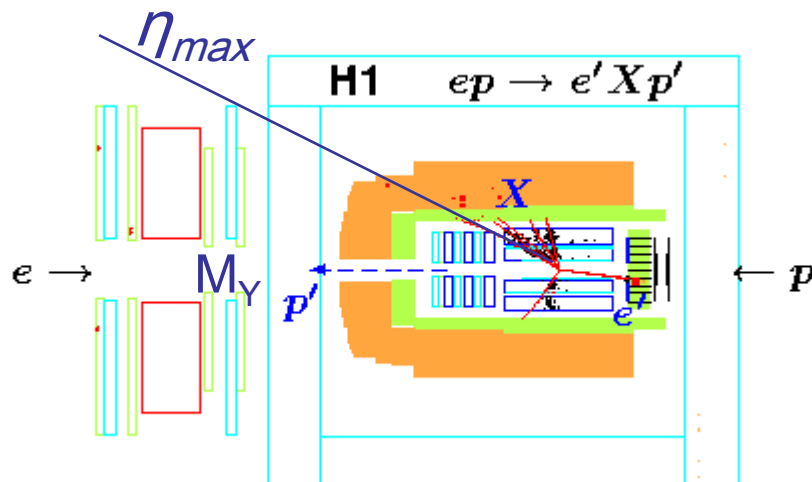


Selection of diffraction at HERA



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

Leading Proton Spectrometers
ZEUS and **H1**



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



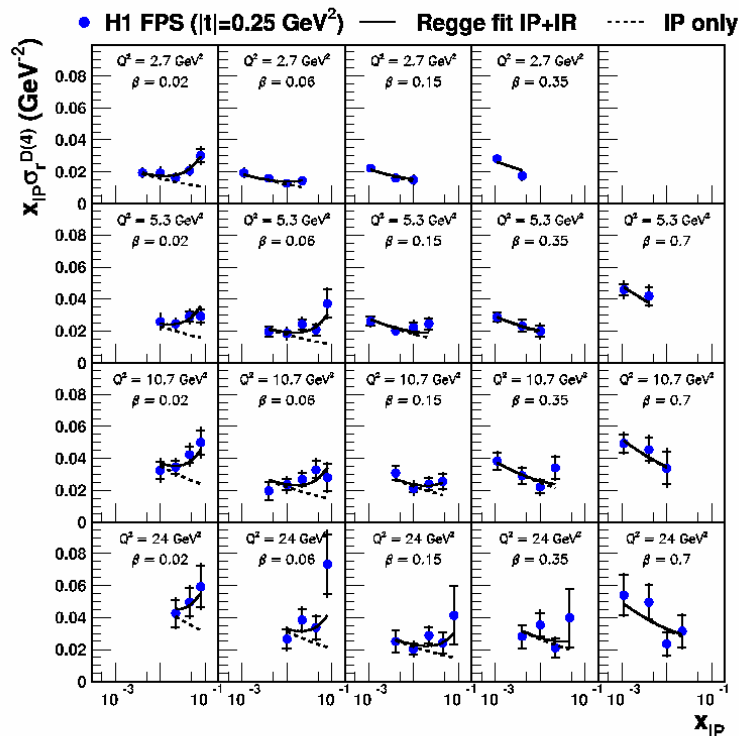
$\sigma_r^{D(4)}(t, x_{IP}, \beta, Q^2)$ LPS measurement



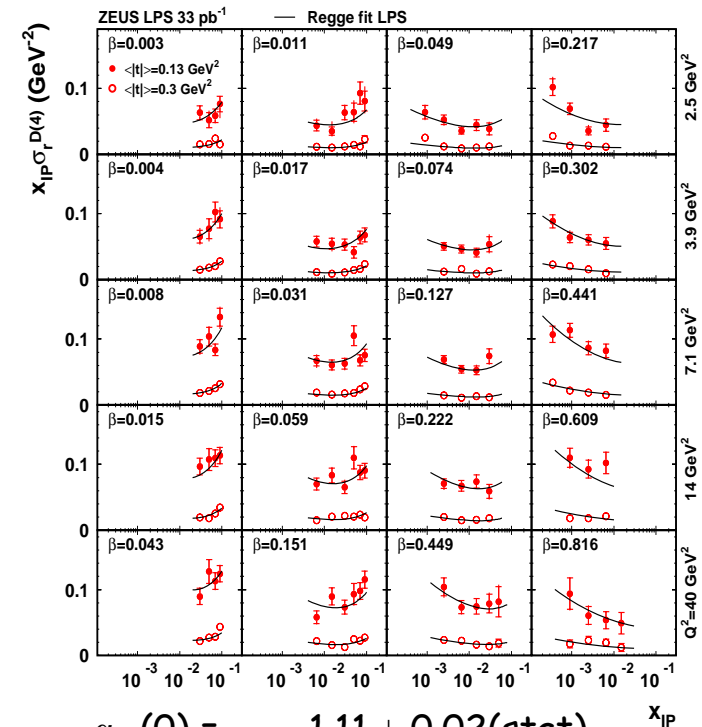
$$F_2^{D(4)}(\beta, Q^2, x_{IP}, t) = f_{IP}(x_{IP}, t) \cdot F_2^{IP}(\beta, Q^2) + n_{IR} \cdot f_{IR}(x_{IP}, t) \cdot F_2^{IR}(\beta, Q^2)$$

Parameterization of x_{IP} dependence \rightarrow
IP intercept

First measurement in
the two t bins



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



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

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

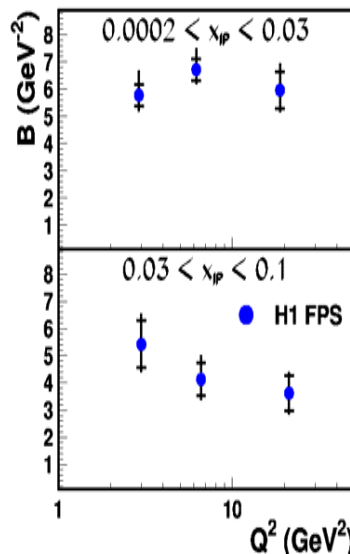
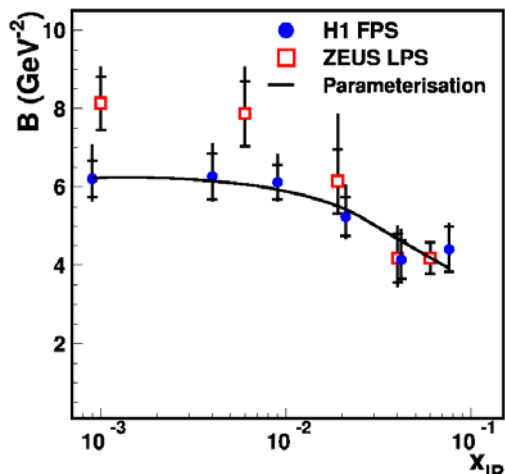
Plans: results based on full statistics of HERA-I,II



Test of Proton Vertex Factorization



LPS measurements of t -slopes in diffractive DIS

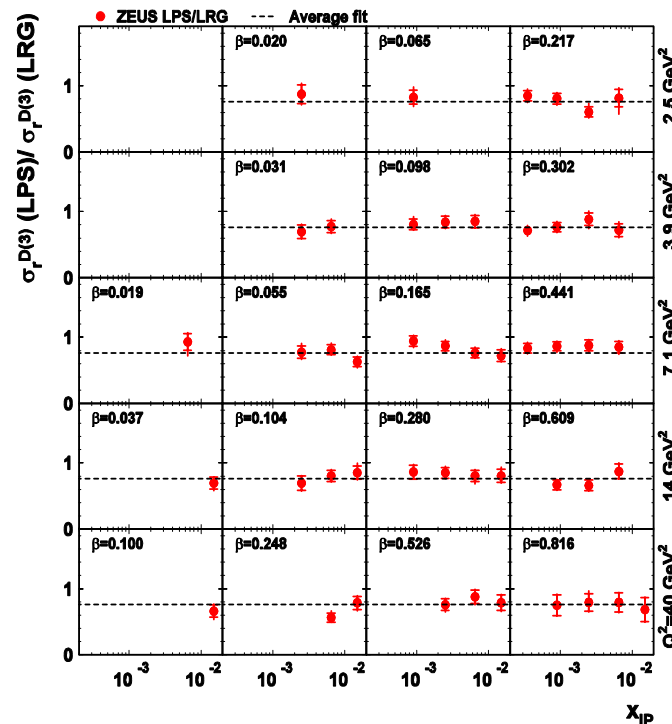


$$B = B_{IP} + 2\alpha'_{IP} \ln(1/x_{IP})$$

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

$$B_{IP} = 5.5^{+2.0}_{-0.7} \text{ GeV}^{-2}$$

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” ($\alpha'_{IP}(\text{soft}) \sim 0.25 \text{ GeV}^{-2}$)

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



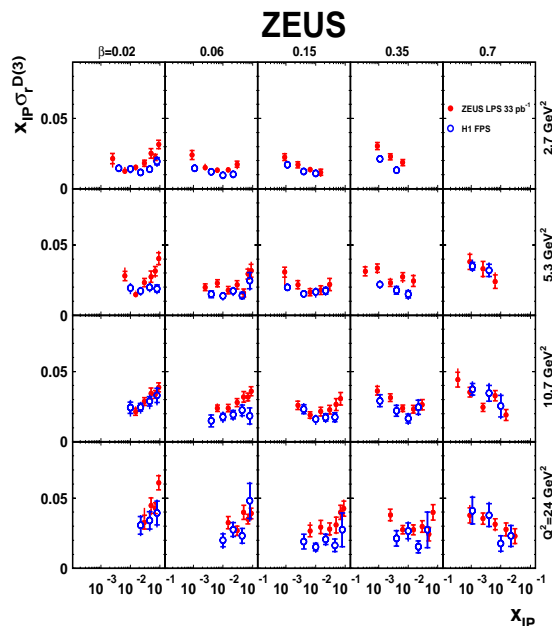
Inclusive Diffraction in DIS



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

Leading Proton Spectrometer data

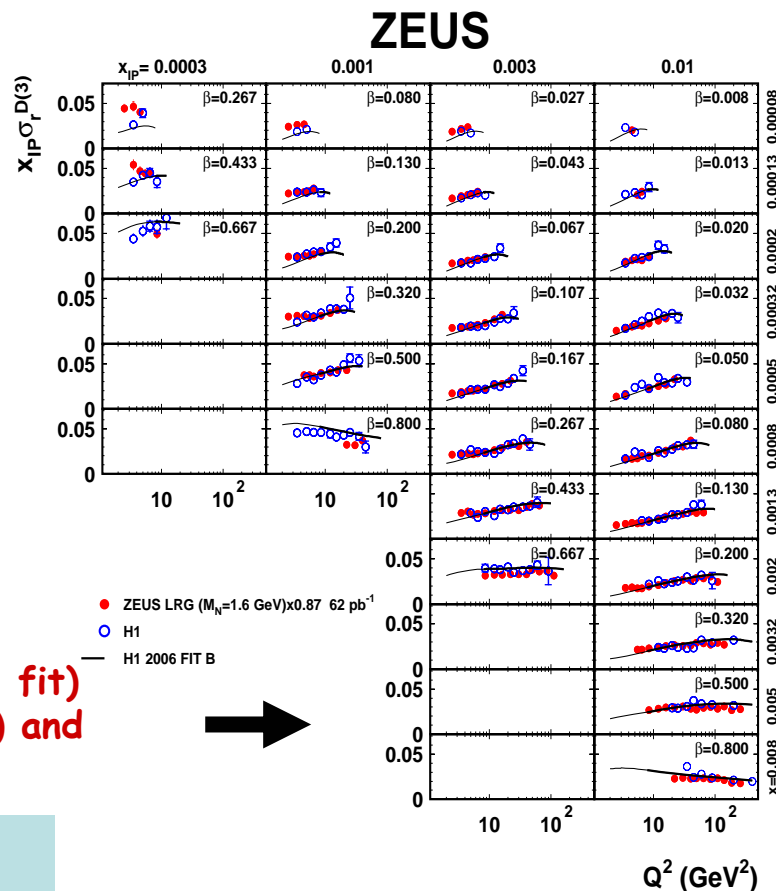
Large Rapidity Gap data



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:

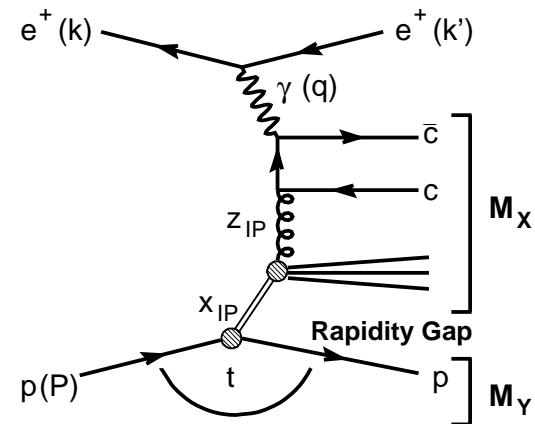
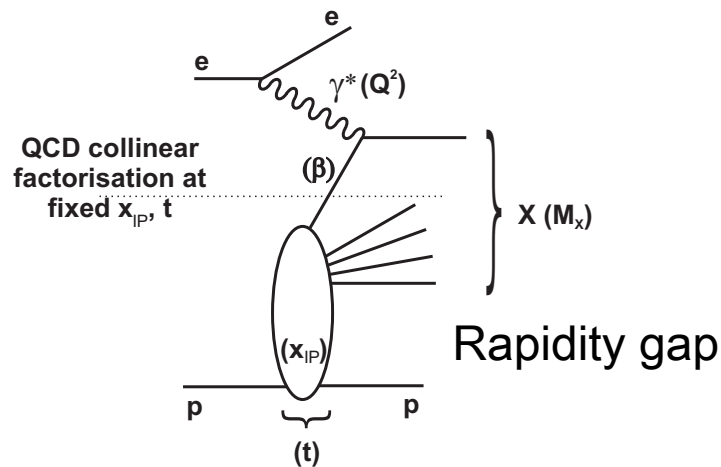
$$\sigma^D(\gamma^* p \rightarrow Xp) = \sum_{parton_i} f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

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

f_i^D - Diffractive Parton Distribution Function \rightarrow 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)

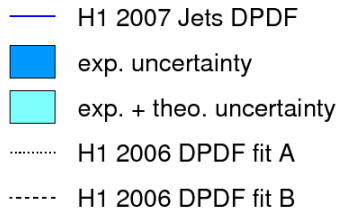


❑ Assumption: Proton vertex factorization $\rightarrow Q^2$ and β dependences of diffractive PDFs factorize from x_{IP}, t, M_Y dependences



Diffractive PDFs

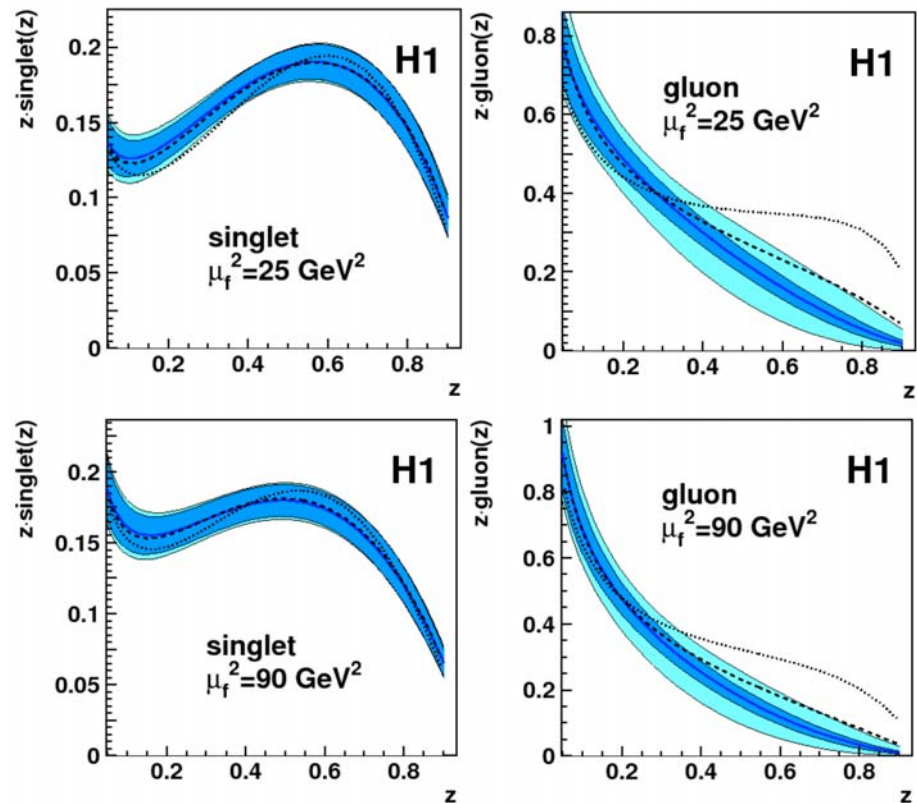
- Diffractive Dijet DIS data used as an additional constrain in a NLO QCD fit



- Combined fit to inclusive DIS and Dijet DIS data constrain quark singlet to $\sim 5\%$ and gluon PDFs to $\sim 15\%$ 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:

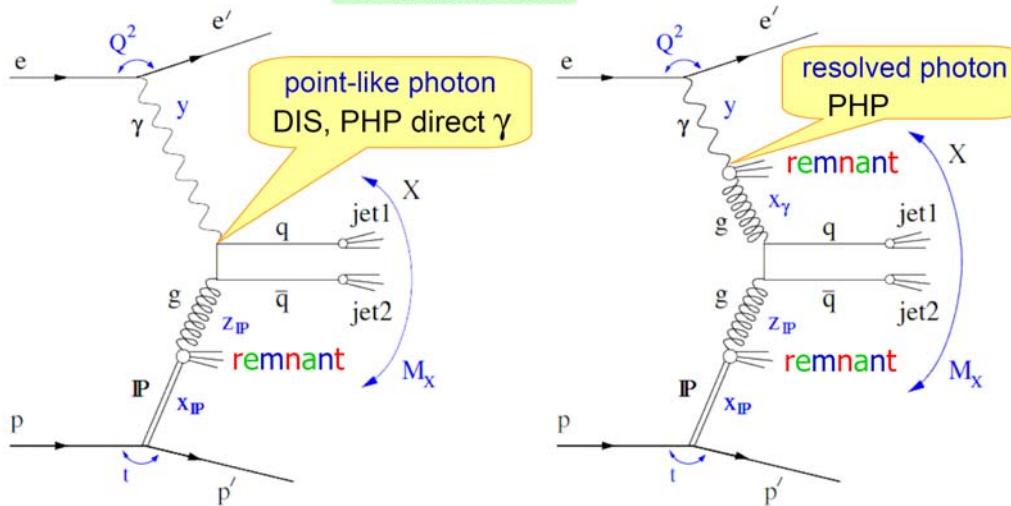
- include high Q^2 inclusive and Dijet DIS data to reduce scale uncertainty
- combine H1+ZEUS data in a joint NLO QCD fit
- constrain F_L^D from H1+ZEUS data



Diffractive Dijet Photo-production

Test of hard scattering collinear factorization

LO intuitive view



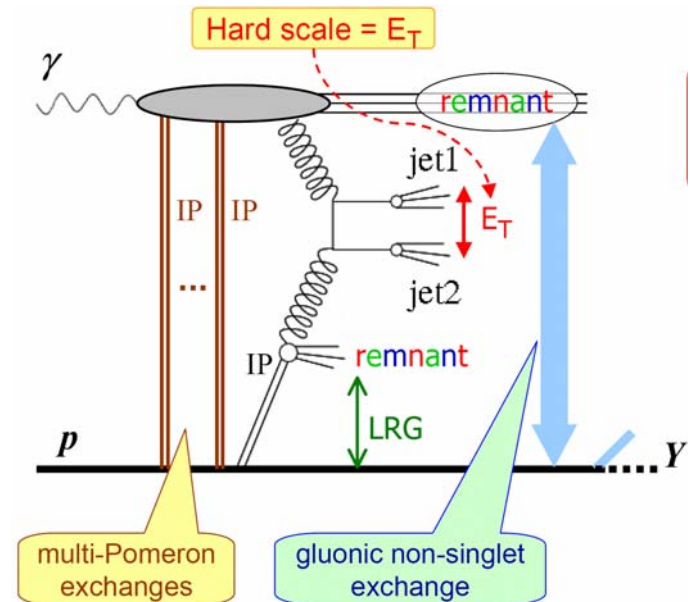
Rescattering leads to:

- Factorisation breaking
- Screening
- Rapidity gap fill-up

- Does factorisation hold for the diffractive dijet photoproduction where ...?

– known to be strongly broken in pp diffraction

- Factorisation should hold for direct photon – $x_\gamma = 1$
- Suppression – if any – expected for resolved photon – $x_\gamma < 1$





Diffractive Dijet Photoproduction



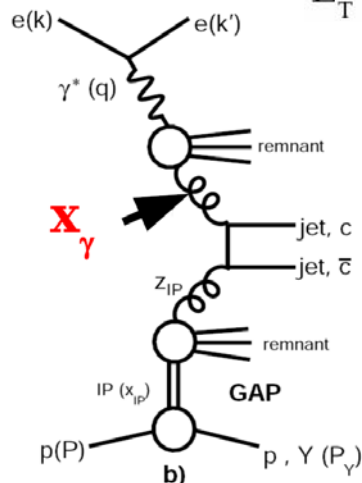
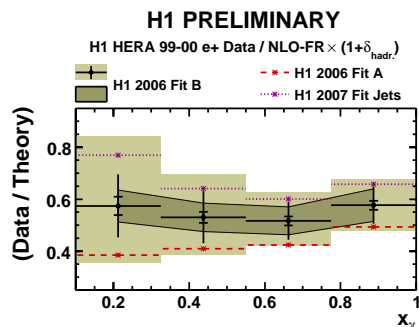
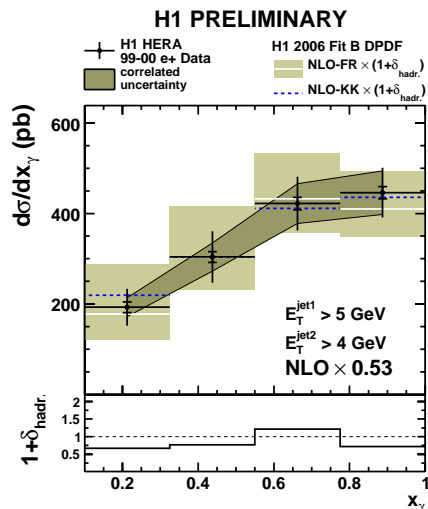
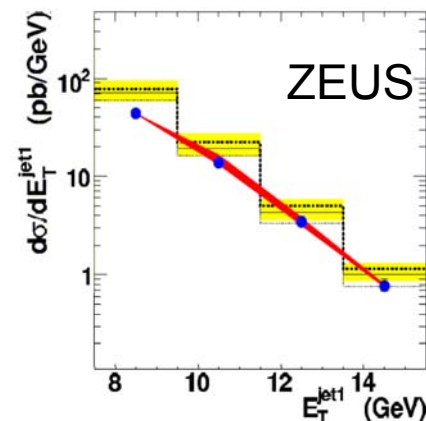
H1 Dijet analysis with higher statistics data vs NLO QCD calculations:

H1 and ZEUS:

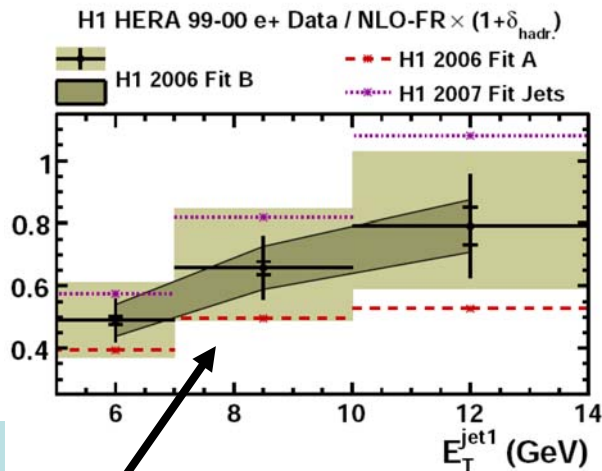
There is no evidence for any difference in survival probabilities for resolved and direct photons.

$$E_{T}^{jet1} > 5 \text{ GeV}$$

$$E_{T}^{jet2} > 4 \text{ GeV}$$



H1 PRELIMINARY



H1 and ZEUS:

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

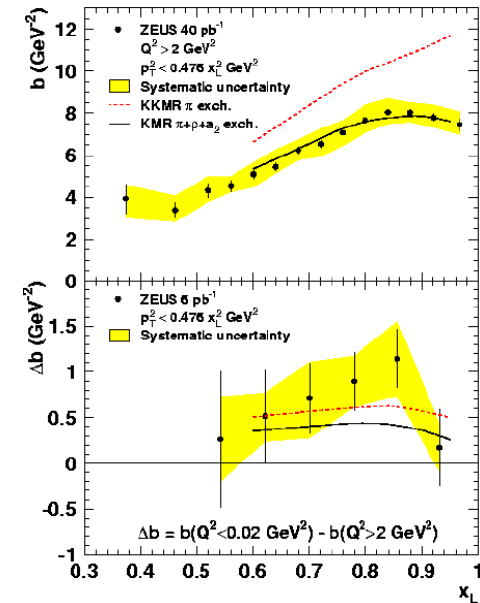
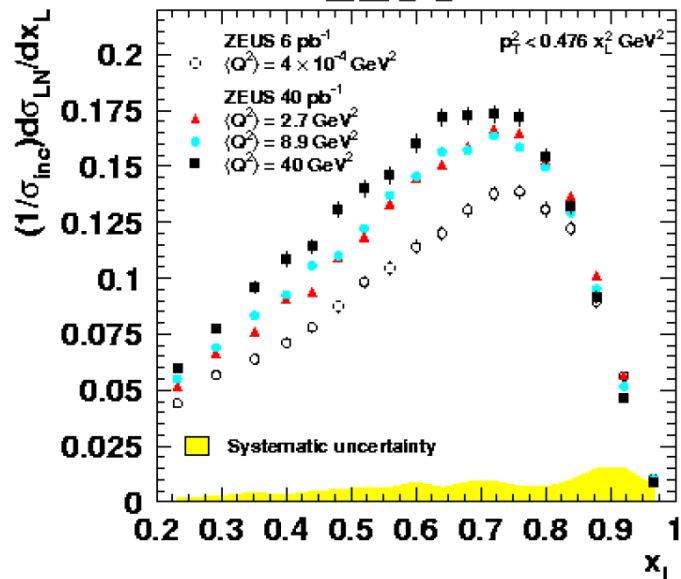
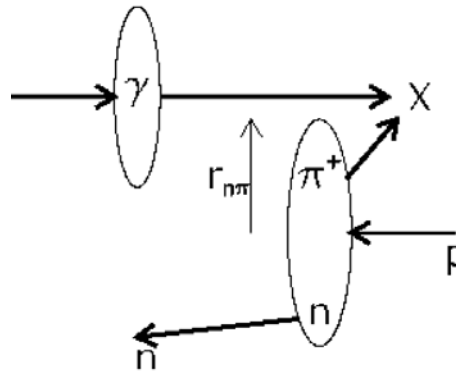
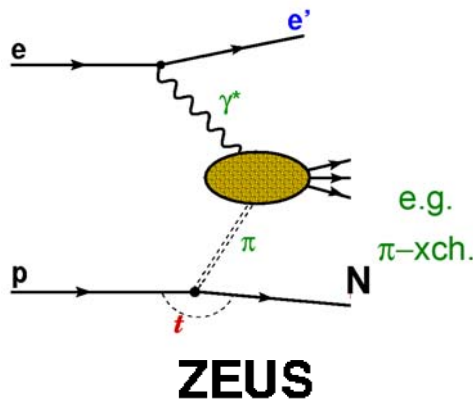
H1:

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

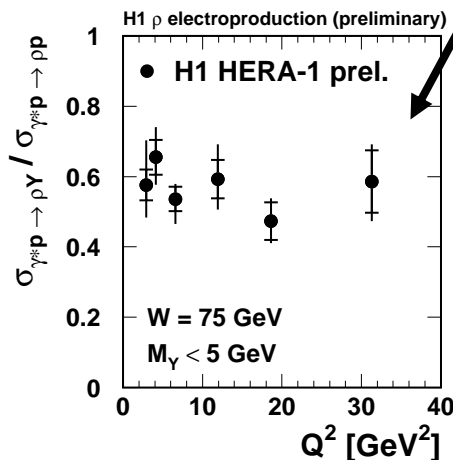
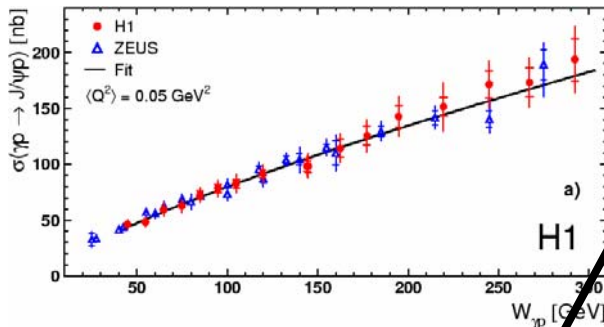
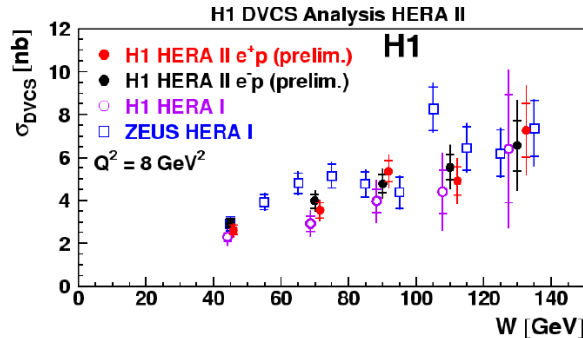


LN yield increases with Q^2 → consistent with absorption model: larger Q^2 → smaller γ^*

Plans:

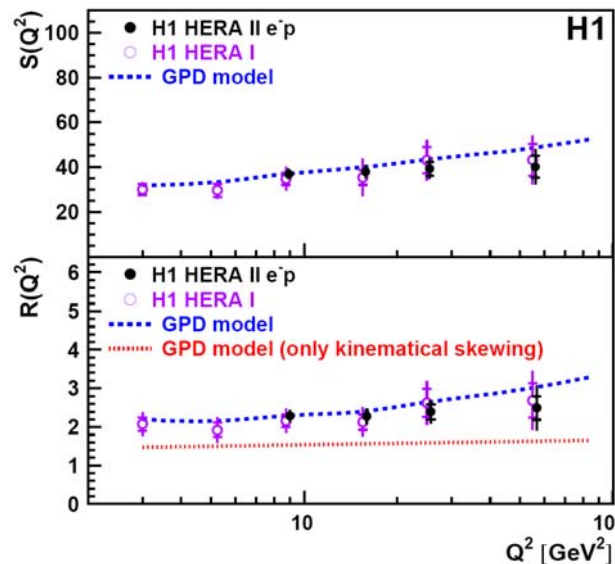
- Detailed studies of x_L and p_T^2 spectra
- Test of proton vertex factorization using leading neutron data at low, medium and high proton beam energies

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 \rightarrow hard' transition
- t measurements \rightarrow transverse picture of proton
- Proton vertex factorization tests \rightarrow PD / EL ratio
- Constrain Generalized Gluon Density (best with heavy VM and DVCS)

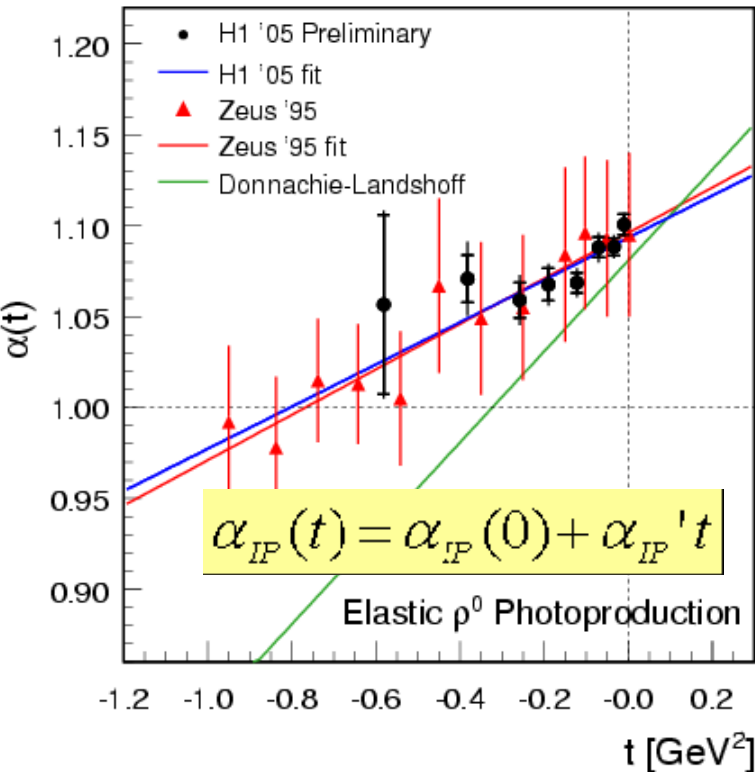


$$S = \sqrt{\frac{\sigma_{DVCS} Q^4 b(Q^2)}{(1 + \rho^2)}}$$

skewing factor: around 2

$$R = \frac{\text{Im } A(\gamma^* p \rightarrow \gamma p)}{\text{Im } A(\gamma^* p \rightarrow \gamma^* p)}$$

H1 PRELIMINARY



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:

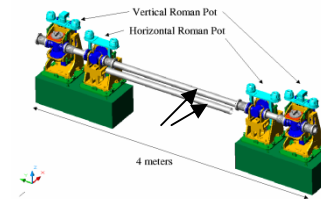
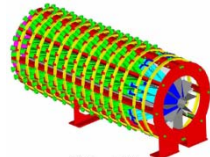
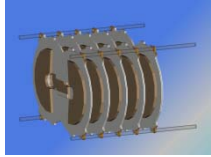
$$\alpha_{IP}(t) = [1.085] + [0.25] t$$

- 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

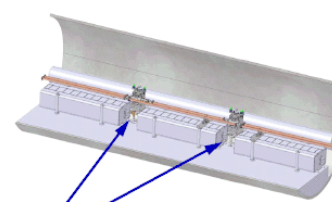
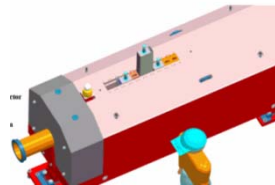
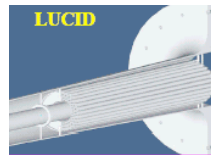
420m

LUCID

ZDC

ALFA/FP220

FP420

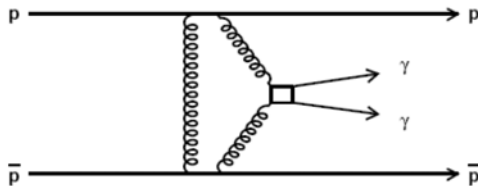
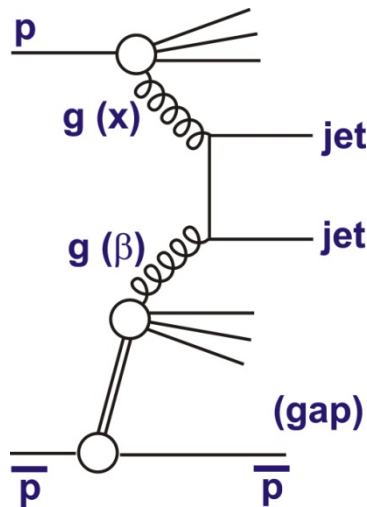
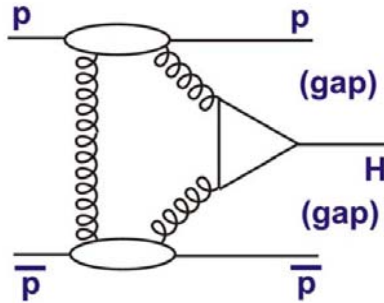


IP1

Experimental techniques:

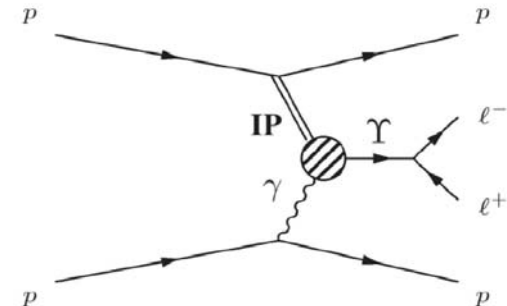
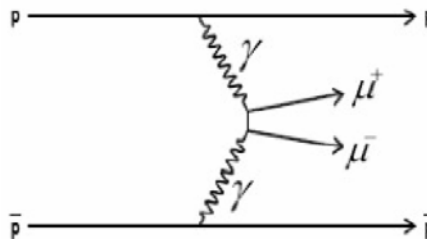
- Large rapidity gaps (low luminosity phase)
- Leading protons tagged in Roman Pots

Hard Diffraction at the LHC

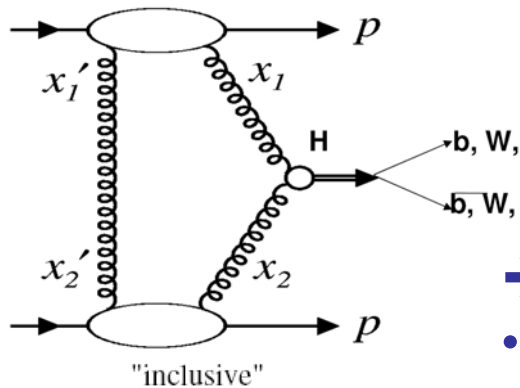


Wide scope of measurements:

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



LHC: Central Exclusive Production



Physics motivation: Higgs and processes beyond SM

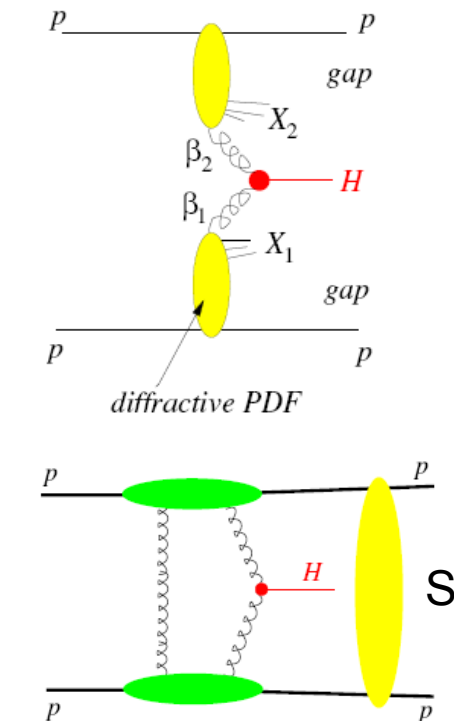
HERA input:

→ 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

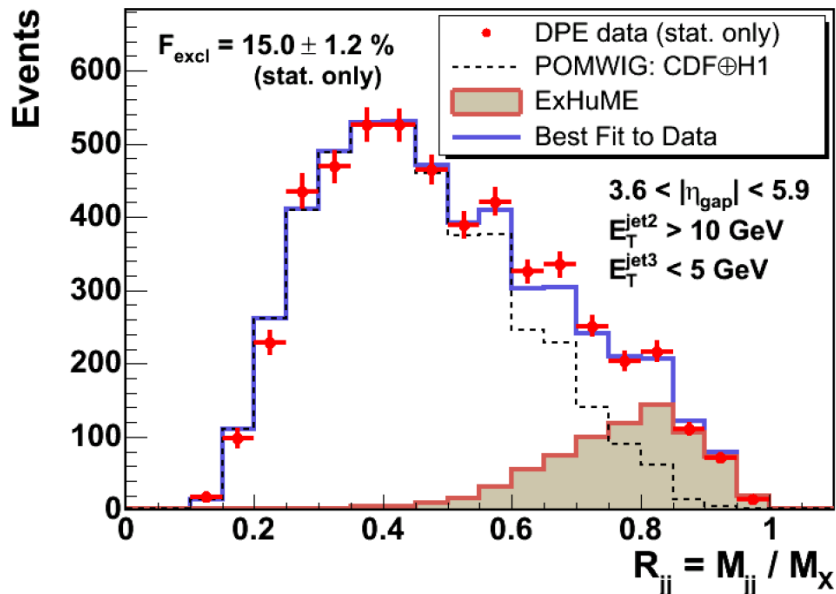


$$\sigma = \sigma_{\text{hard}} \otimes |S|^2$$

Tevatron: Central Exclusive Jet Production

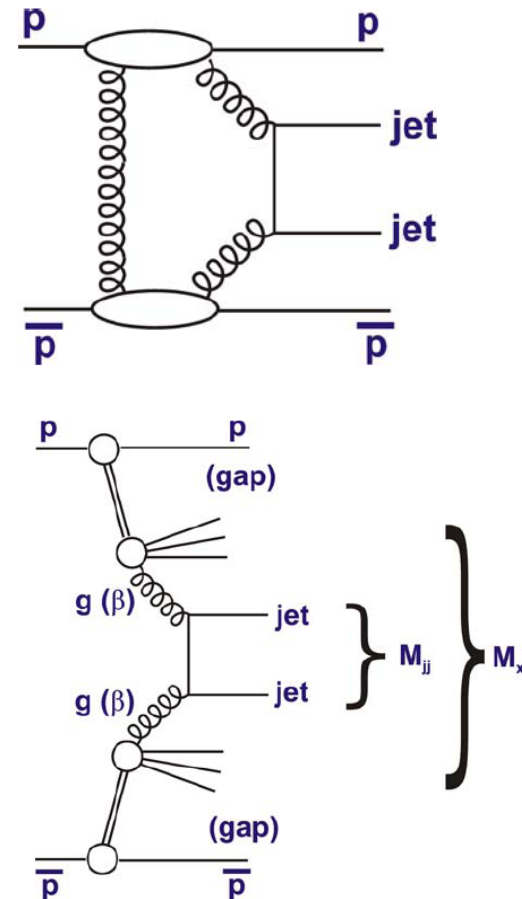
Look for excess over inclusive Dijet prediction at large dijet mass fraction R_{jj}

CDF Run II Preliminary



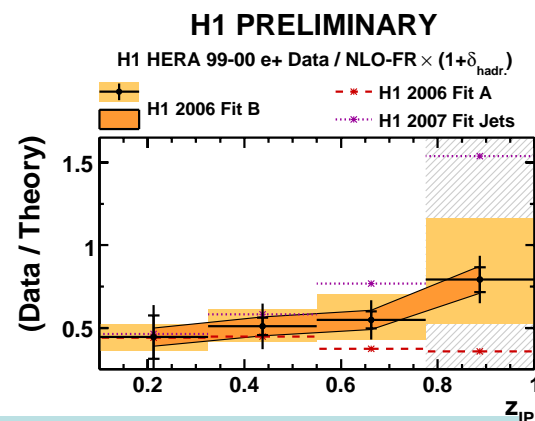
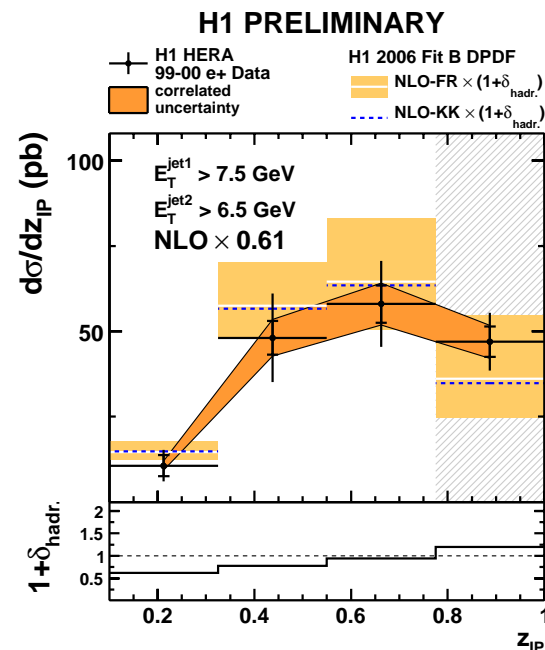
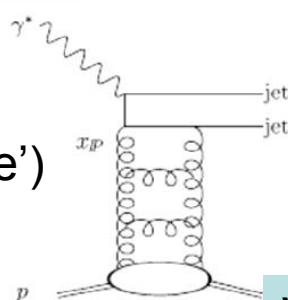
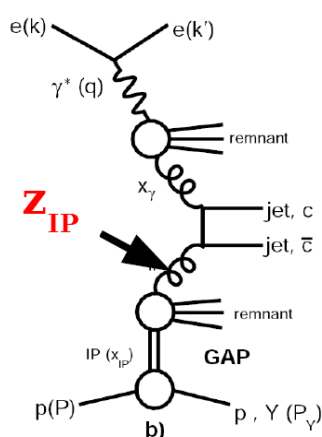
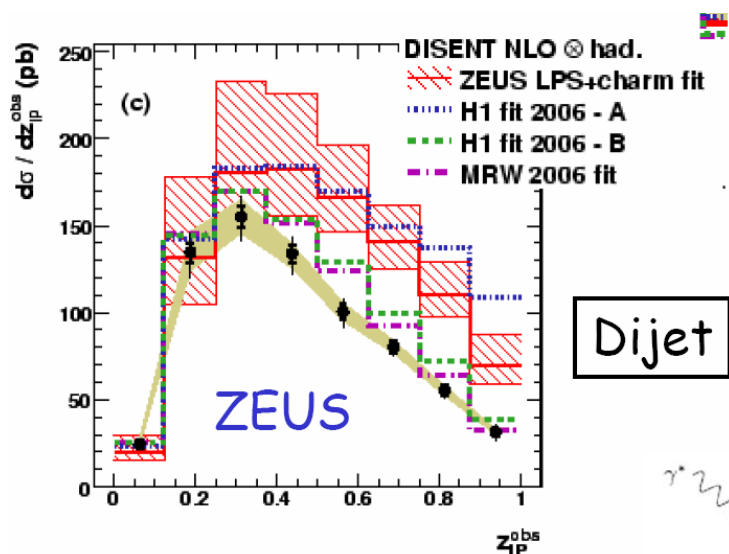
Excess at large R_{jj} described by $gg \rightarrow gg$ LO pQCD KMR calculation and by DPE MC based on Regge model, Gap Survival probability $\sim 5\%$, 'uncertainty factor' ~ 2.5

What about HERA results?



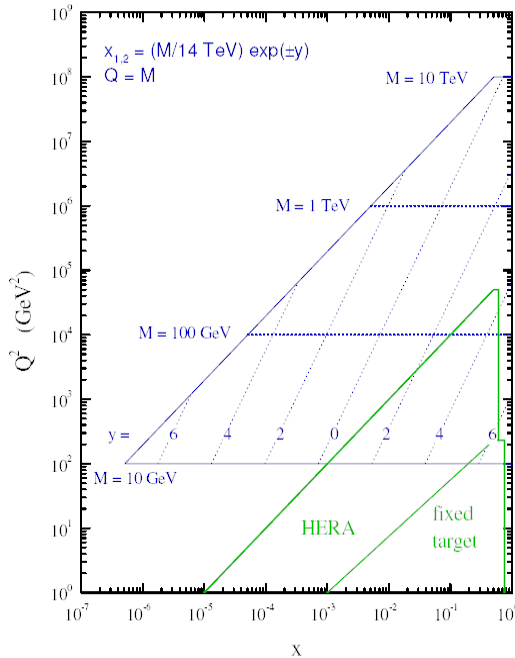
DPE Dijets: $R_{jj} = M_{jj} / M_x$
 $R_{jj} \rightarrow 1$ exclusive jets
 $R_{jj} < 1$ inclusive jets

- 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

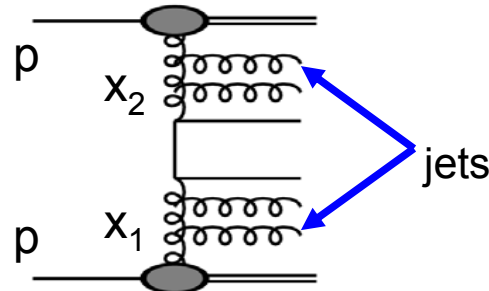


Very large theory uncertainty at high fractional momentum z_{IP}

Forward Jets with leading proton



LHC: Probe PDFs in different kinematical domains

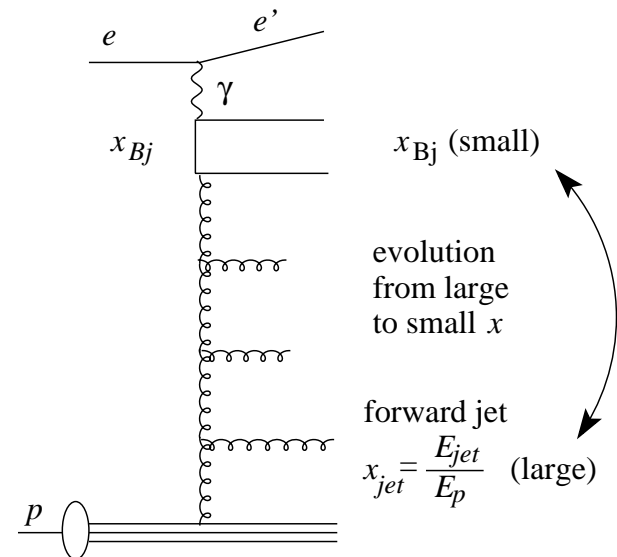


$$x_{Bj} = \frac{Q}{\sqrt{s}} e^{-\eta}, \quad Q = p_T, M, \dots$$

- $x_2 \simeq x_1 \rightarrow$ 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 \rightarrow 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_γ distribution \rightarrow 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