The structure of diffraction and the diffractive hadronic final state in *ep* collisions at HERA

- Diffractive DIS at HERA
- Factorization & Parton Densities
- Dijets & D^* production
- Summary

on behalf of the H1 & ZEUS collaborations

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12th International QCD Conference

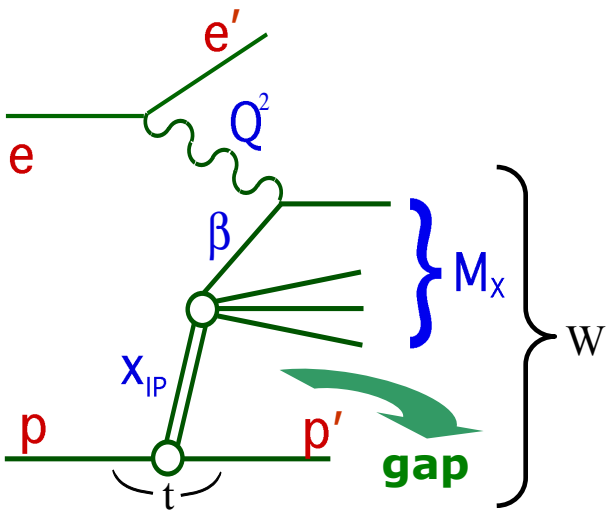
4-9 July 2005 , Montpellier , France

Diffractive DIS at HERA

HERA: p(920 Gev), e(27.6 GeV)

Structure of high energy diffraction with virtual photon

Exchange: color singlet with vacuum quantum numbers



Colorless exchange:

- **large region in pseudorapidity is left empty of particles**
- **proton survives the collision intact**

Pomeron (IP):

- **Regge model**
- **2-gluons exchange**

$$x_{IP} = 1 - \frac{q \cdot p'}{q \cdot p} \approx \frac{Q^2 + M_X{}^2}{Q^2 + W^2}$$

Fraction of proton momentum carried by IP

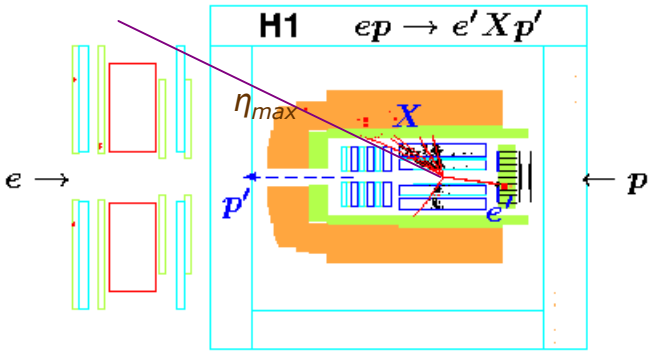
$$\beta = \frac{x_{Bj}}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X{}^2}$$

Fraction of IP momentum carried by struck quark

✓ ~10% of DIS events at HERA are diffractive

Diffractive Event Selection

❑ Large rapidity gap



$$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$$

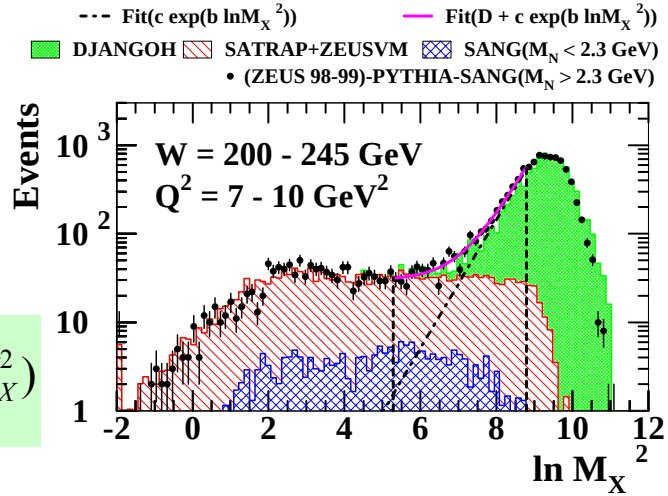
✓ **Scattered proton keep most part of its initial energy**

❑ ZEUS M_X method: $\gamma^* p \to X + p'$, $M_X^2 = \left(\sum P_h\right)^2$

1) NON-Diff. events: exponential rise **$\ln M_x^2$**

2) Diff. Events: flat in **$\ln M_x^2$**

$$\frac{dN}{d\ln M_X^2} = D + c\cdot\exp(b\cdot\ln M_X^2)$$



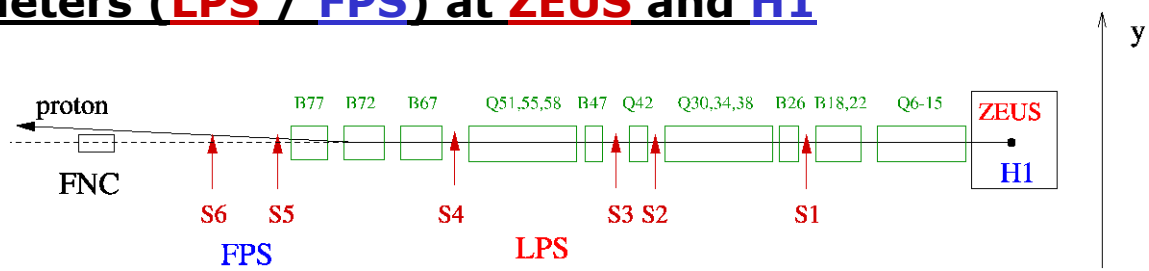
✓ **fit subtracts non-diff. events**

❑ Leading Proton Spectrometers (LPS / FPS) at ZEUS and H1

- Direct $t=(P-P')$ measurement
- x_{IP} measurement:

$$x_{IP} = 1 - E'_p / E_p$$

✓ Reject proton dissociation background



HERA-II: **H1 Very Forward Proton Spectrometer (VFPS) at ~220m**

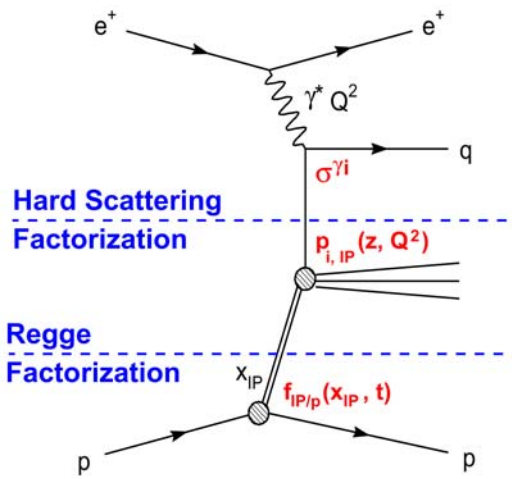
Diffractive PDFs & Factorization

Proven QCD factorization in DIS:

$$\sigma^D = \sum_i f^D_{i,IP} \otimes \sigma^{\gamma,i}$$

$f^D_{i,IP}$ diffractive Parton Distribution Function (dPDF)

$\sigma^{\gamma,i}$ universal hard scattering cross section



Regge factorization is assumed:

PDF = IP-flux × IP Parton Density
(IS or resolved pomeron model)

$$f^{D(4)}_{i,IP}(x_{Bj}, Q^2, x_{IP}, t) = f_{IP/p}(x_{IP}, t) \cdot p_{i,IP}(\beta, Q^2)$$

IP-flux is defined in Regge model

✓ **If factorization holds =>**
universal pomeron parton densities to be used for:

- jets & charm in diffractive processes
- $p\bar{p}$ diffraction

DDIS measurement with LPS/FPS & LRG

σ_r^D ZEUS-LPS and H1-FPS data

compared with H1 LRG measurement

$$\sigma_r^{D(3)} = F_2^{D(3)} - \left(\frac{y^2}{1+(1-y)^2}\right)\cdot F_L^{D(3)}$$

✓ **Reasonable agreement between the H1 and ZEUS datasets**

Proton dissociation contribution:

H1 LRG / LPS ratio: ~10%

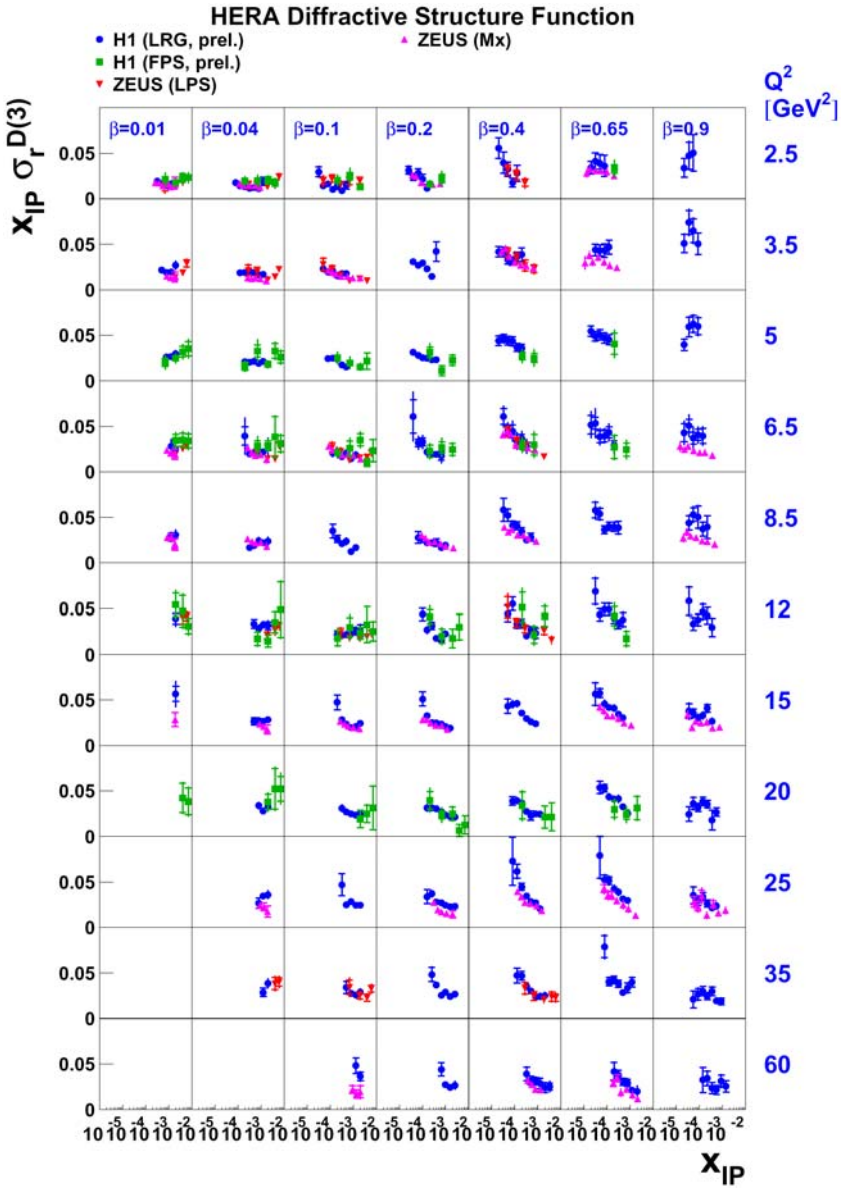
ZEUS M_X / LPS ratio: ~30%

Interpretation of σ^D in terms of pomeron PDFs

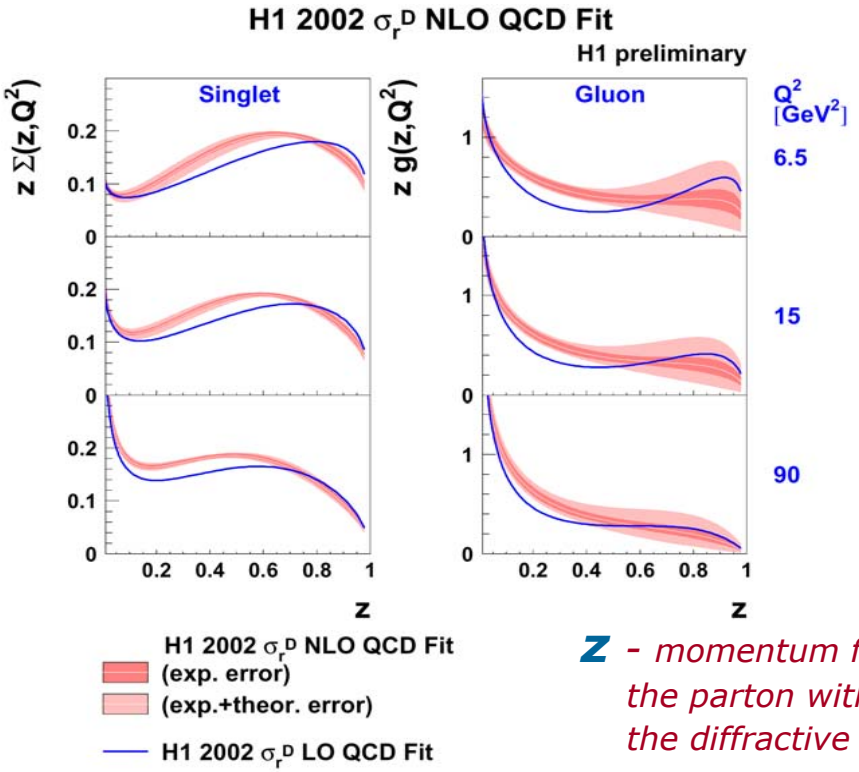
$$F_2^{D(3)}(Q^2, x_{IP}, \beta) = f_{IP/p}(x_{IP}) \times F_2^{IP}(Q^2, \beta)$$

IP-flux defined in Regge model:

$$f_{IP/p}(x_{IP}, t) = e^{B\cdot t}\cdot x_{IP}^{1-2\alpha(t)} \quad , \quad \alpha(t) = \alpha_{IP} + \alpha' \cdot t$$



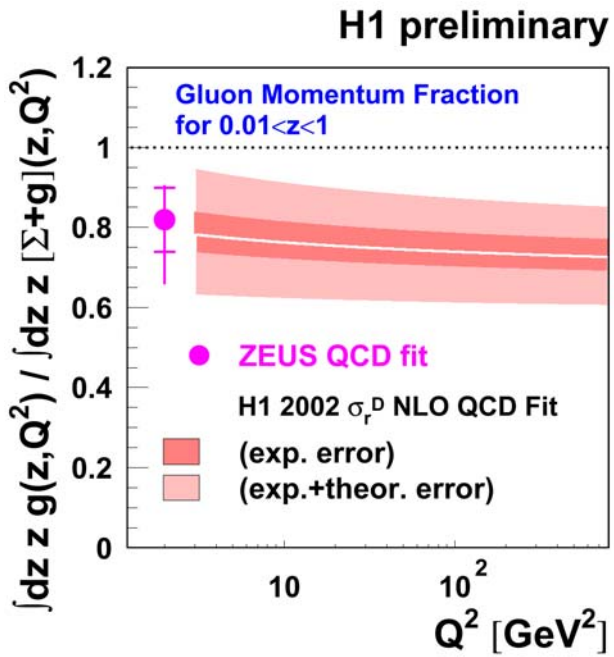
Pomeron Parton Densities



$p_{i,IP}(z,Q^2)$ determined from NLO-QCD

- large uncertainty at high z
- gluon carries 75% of pomeron momentum

Fraction of the overall diffractive exchange momentum carried by gluons in NLO fit:



z *- momentum fraction of the parton with respect to the diffractive exchange*

For lowest-order parton model: *z=β*

For higher order processes: *0<β<z*

$$\beta = \frac{x_{Bj}}{x_{IP}}$$

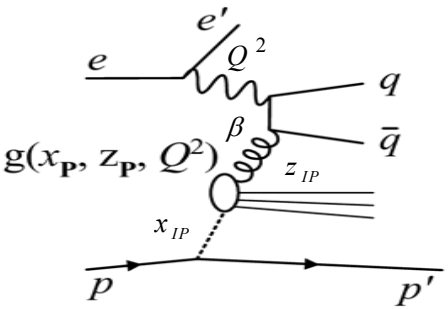
Test of the hard scattering factorization:
Dijets & D* production

Diffractive D* in DIS

Direct interaction with gluon:

photon-gluon fusion

$\gamma g \to c\bar{c}$



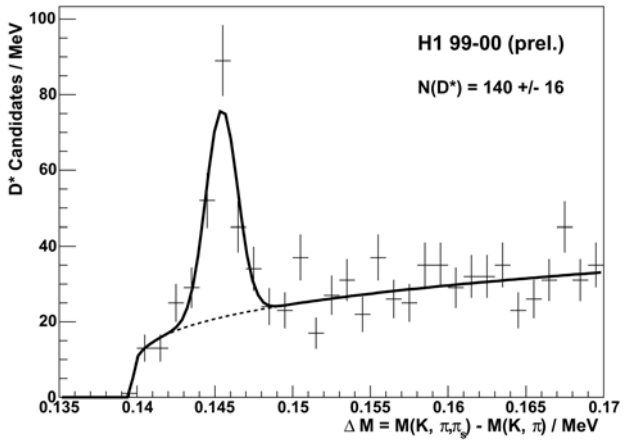
$ep \to e(D^{*\pm}X')Y$

$D^* \to D^0\pi_s \to K\pi\pi_s$

Extract D^* from fit to ΔM:

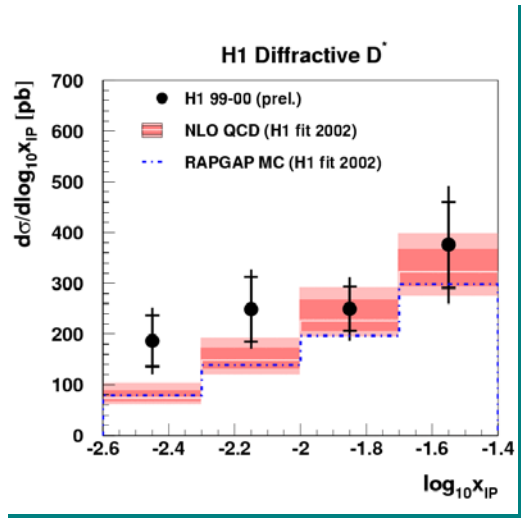
$\Delta M = M_{K\pi\pi_s} - M_{K\pi}$

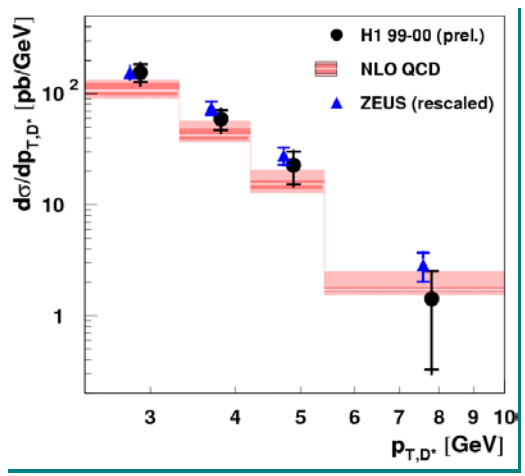
Gaussian fit for the signal



✓ **NLO calculation is in agreement with data**

✓ **Good agreement between H1 and ZEUS data**

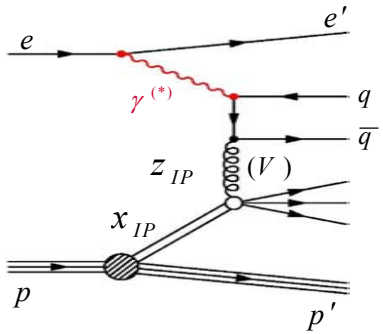




✓ D* data and NLO agreement supports hard scattering factorization

Dijets in DIS

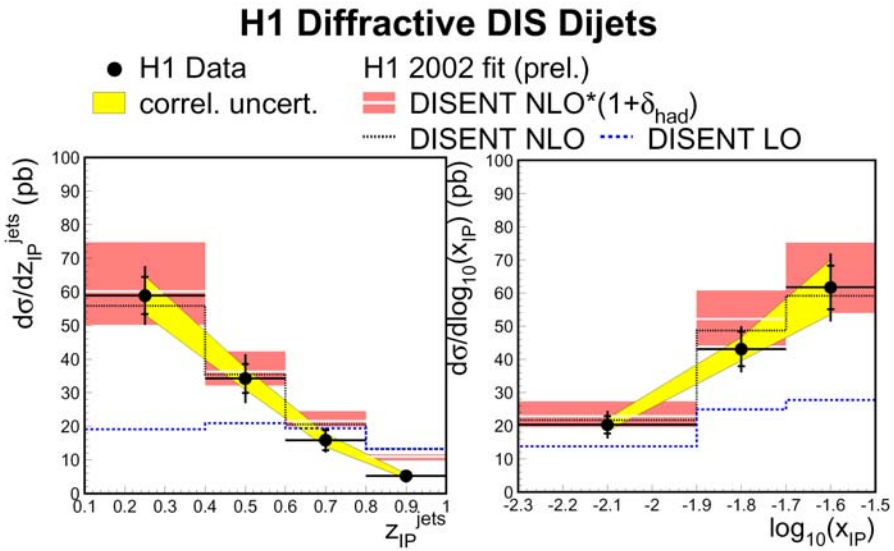
- DIS γ interaction:



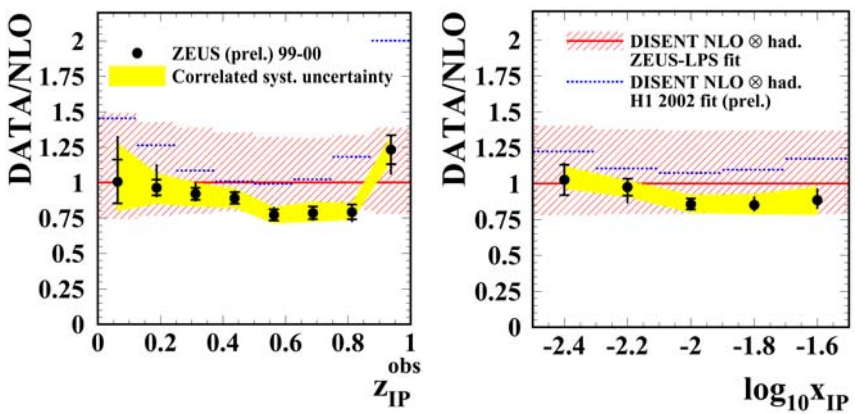
$$x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

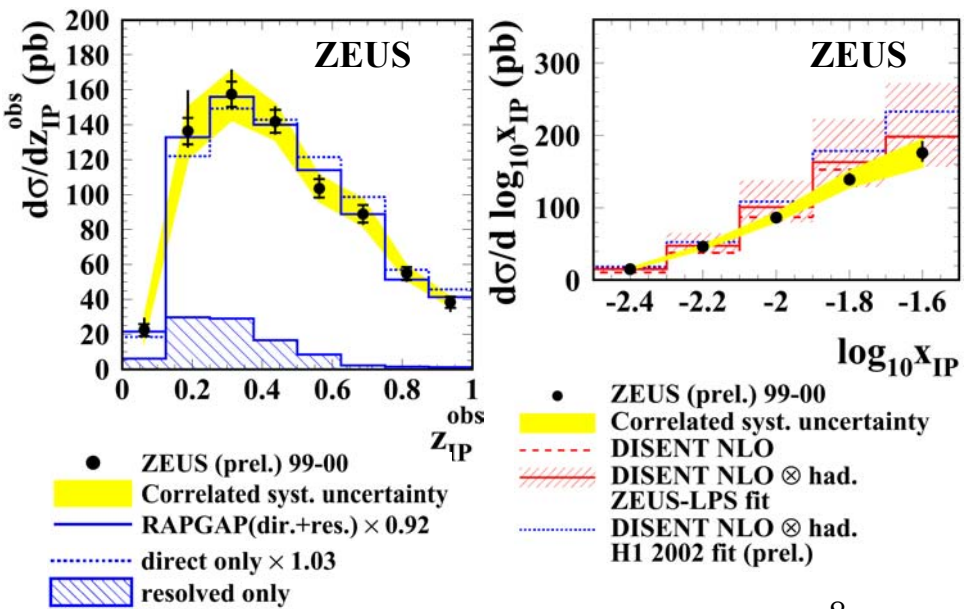
$$z_{IP} = \frac{Q^2 + M_{J1\,J2}^2}{Q^2 + M_X^2}$$

✓ **Factorization holds**



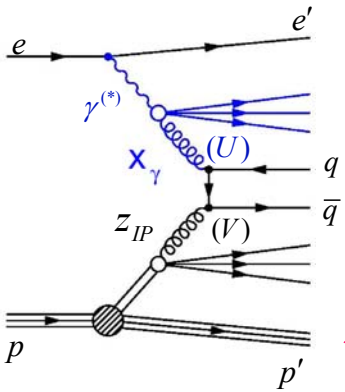
Ratio DATA/NLO for dijets in DIS





Dijets in γp PhP

- Direct and Resolved γ interaction:
  - γ involved point-like into γp $x_\gamma \sim 1$
  - γ fluctuate into hadronic system $x_\gamma < 1$

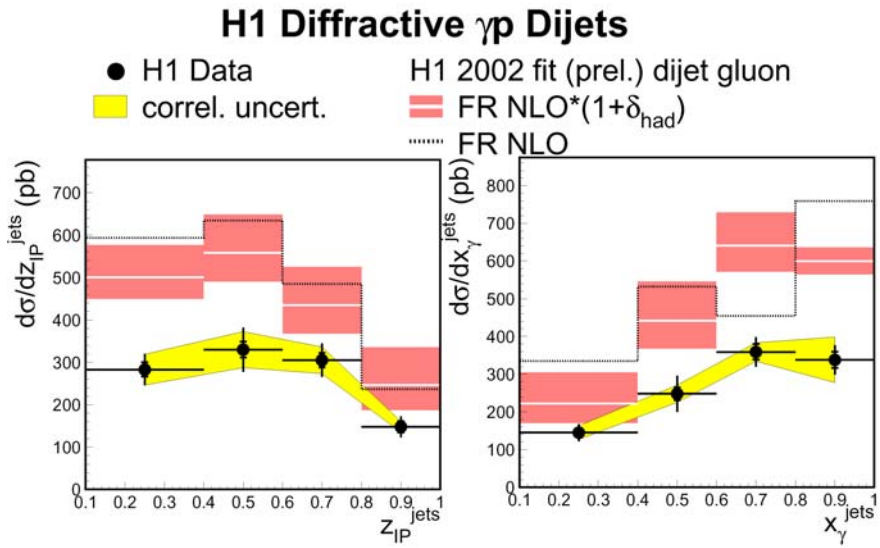


photon remnant

$$x_\gamma = \frac{\sum_{jets}(E - p_z)}{2yE_e}$$

Momentum fraction of γ carried by γ-parton

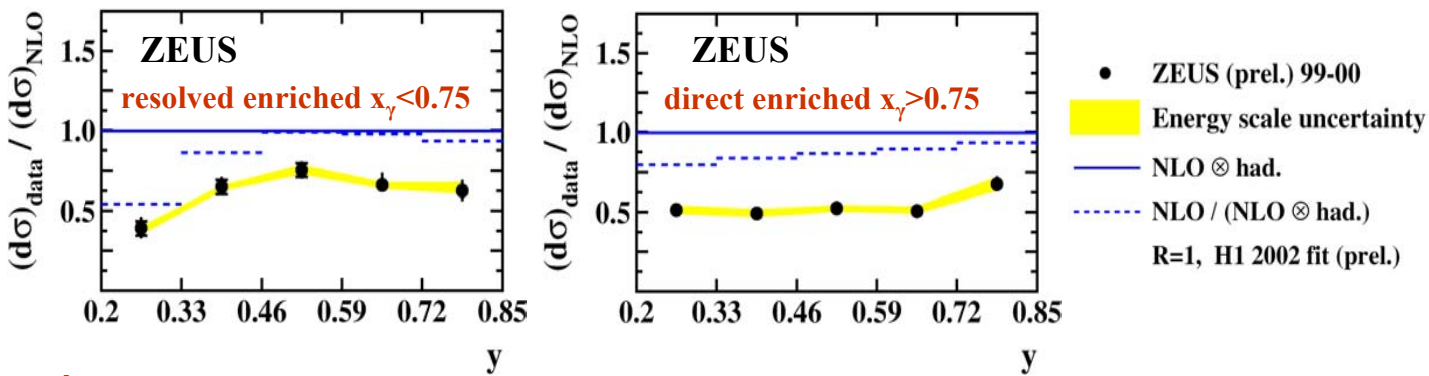
✓ **Factorization fails**



Ratio DATA/NLO for dijets in γp PhP

$y = Q^2 / sx$

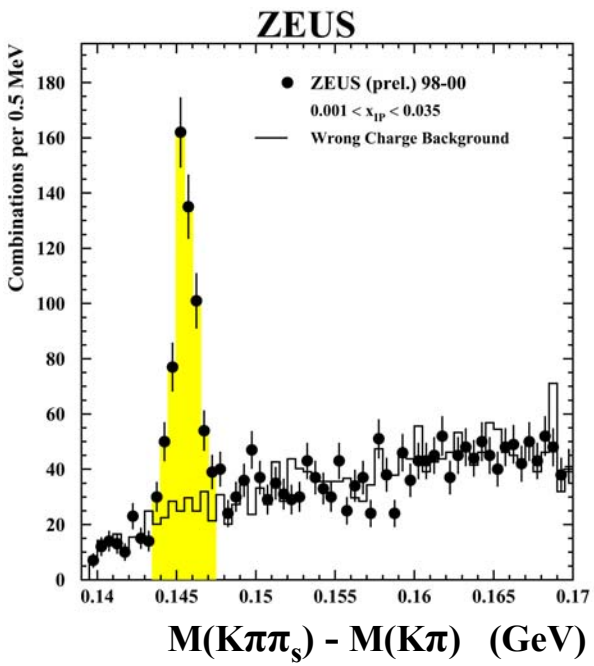
inelastisity

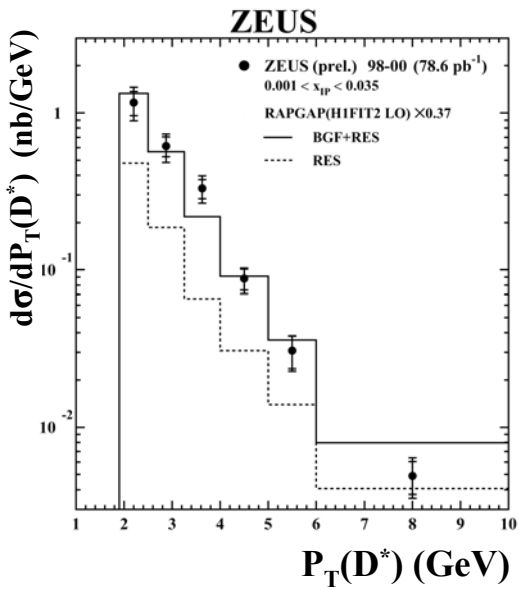


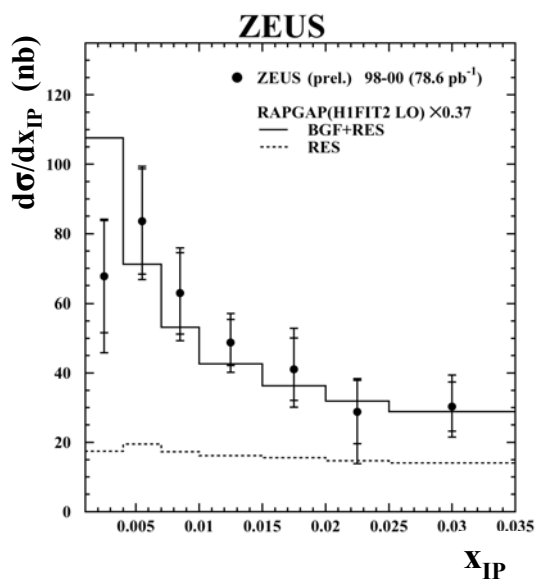
✓ **NLO overestimates PhP data by ~ 2 for both direct and resolved enriched**

D* in γp PhP

✓ First D* measurement in diffractive PhP at HERA







✓ **shape of data is well described by LO MC**

NLO calculation is in progress:

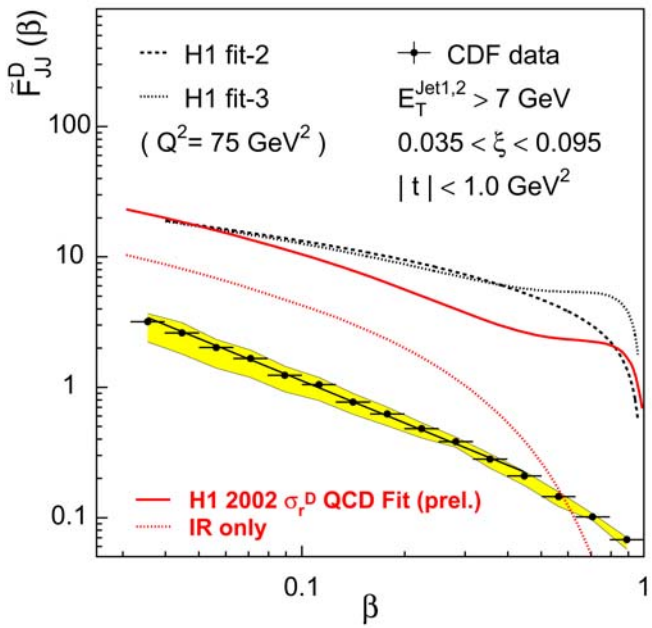
- results coming soon…
- test whether the factorization is hold or broken in diffractive γp ***D****

✓ *Statistics: 450 candidates*

Approaches to factorization breaking

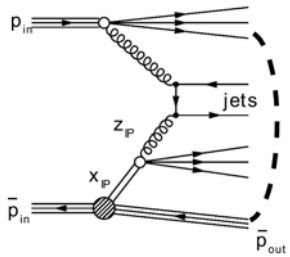
Effective diffractive structure function

$$\tilde{F}_{jj}^{D}(\beta,\mu^2) = \beta \cdot \left[g(\beta,\mu^2) + \frac{4}{9} q(\beta,\mu^2) \right]$$



✓ **QCD factorization fails in $p\bar{p}$ dijet production at TEVATRON**

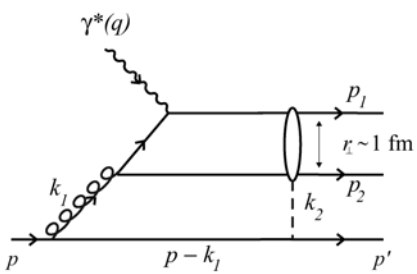
Dijet cross section at TEVATRON: ~10 times lower than the QCD calculation at HERA

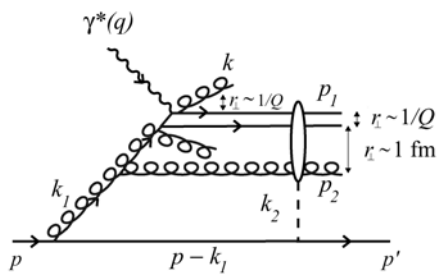


Multi-parton scattering (rescattering)?

Alternative approach

- no Regge model for 'initial' IP:
  - Single model describes all final states
- Soft Color Interaction (SCI):
  - Color dipole
  - soft gluon exchange (k_2) turns color octet (p_1,p_2) into a color singlet

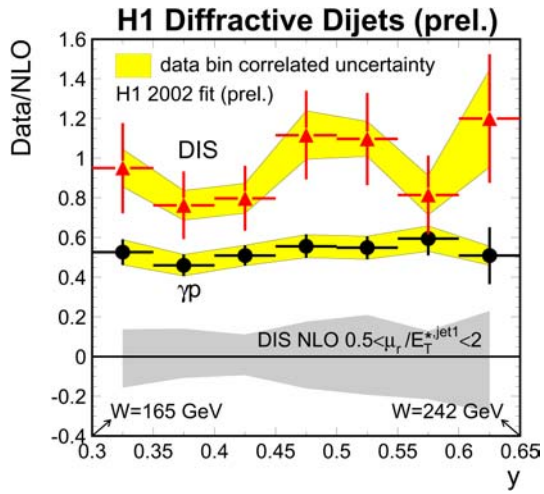




Summary

- ZEUS and H1: recent measurements of diffractive data
  - ZEUS: first measurement of diffractive D^* in photoproduction

- QCD factorization in dijets and $c\bar{c}$:
  - holds in DIS scattering
  - fails 1) in $\gamma^* p$ photoproduction for dijets in both direct and resolved regions
    2) in $p\bar{p}$ collisions



- Alternative approach: QCD parton rescattering models

- 20+X years understanding color singlet exchange … X=? :-)