

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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Diffractive DIS at HERA

HERA: $p(920 \text{ GeV})$, $e(27.6 \text{ GeV})$

Structure of high energy diffraction with virtual photon

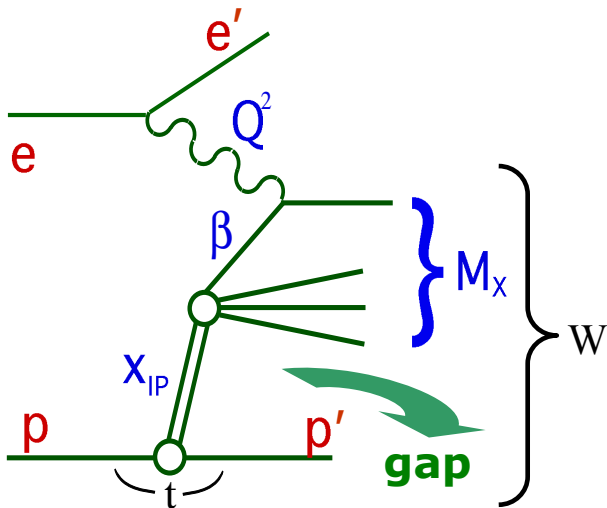
Exchange: color singlet with vacuum quantum numbers

Colorless exchange:

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

Pomeron (IP):

- Regge model
- 2-gluons exchange



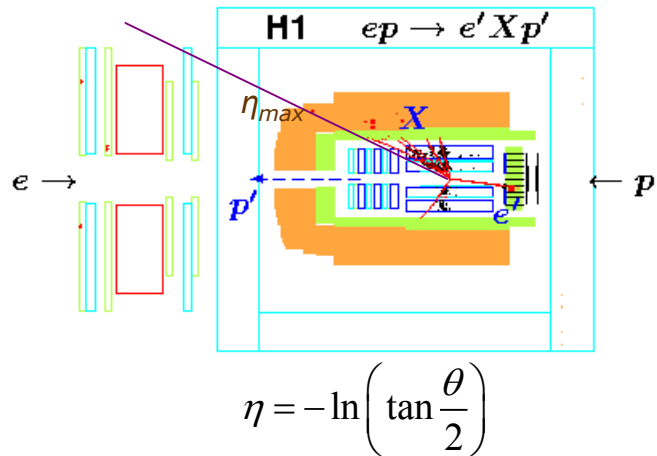
$$x_{IP} = 1 - \frac{q \cdot p'}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2} \quad \text{Fraction of proton momentum carried by IP}$$

$$\beta = \frac{x_{Bj}}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2} \quad \text{Fraction of IP momentum carried by struck quark}$$

✓ ~10% of DIS events at HERA are diffractive

Diffractive Event Selection

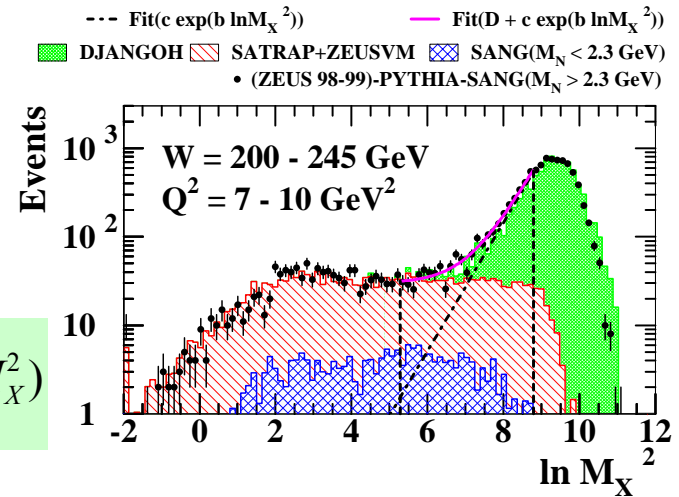
Large rapidity gap



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

- 1) NON-Diff. events:
exponential rise $\ln M_X^2$
- 2) Diff. Events:
flat in $\ln M_X^2$

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



✓ Scattered proton keep most part of its initial energy

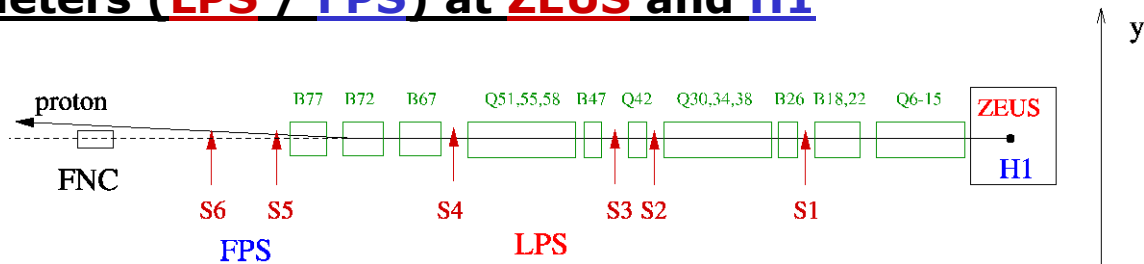
✓ fit subtracts non-diff. events

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



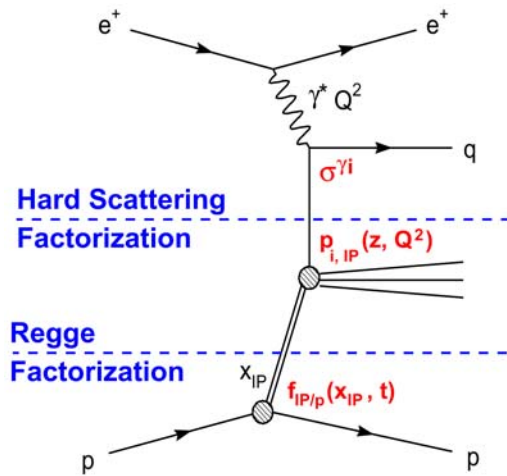
HERA-II: H1 Very Forward Proton Spectrometer (VFPS) at $\sim 220\text{m}$

Diffractive PDFs & Factorization

Proven QCD factorization in DIS:

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

$f_{i,IP}^D$ diffractive Parton Distribution Function (dPDF)
 $\sigma^{\gamma,i}$ universal hard scattering cross section



Regge factorization is assumed:

**PDF = IP-flux \times IP Parton Density
 (IS or resolved pomeron model)**

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

IP-flux is defined in Regge model

- ✓ **If factorization holds \Rightarrow**
 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%

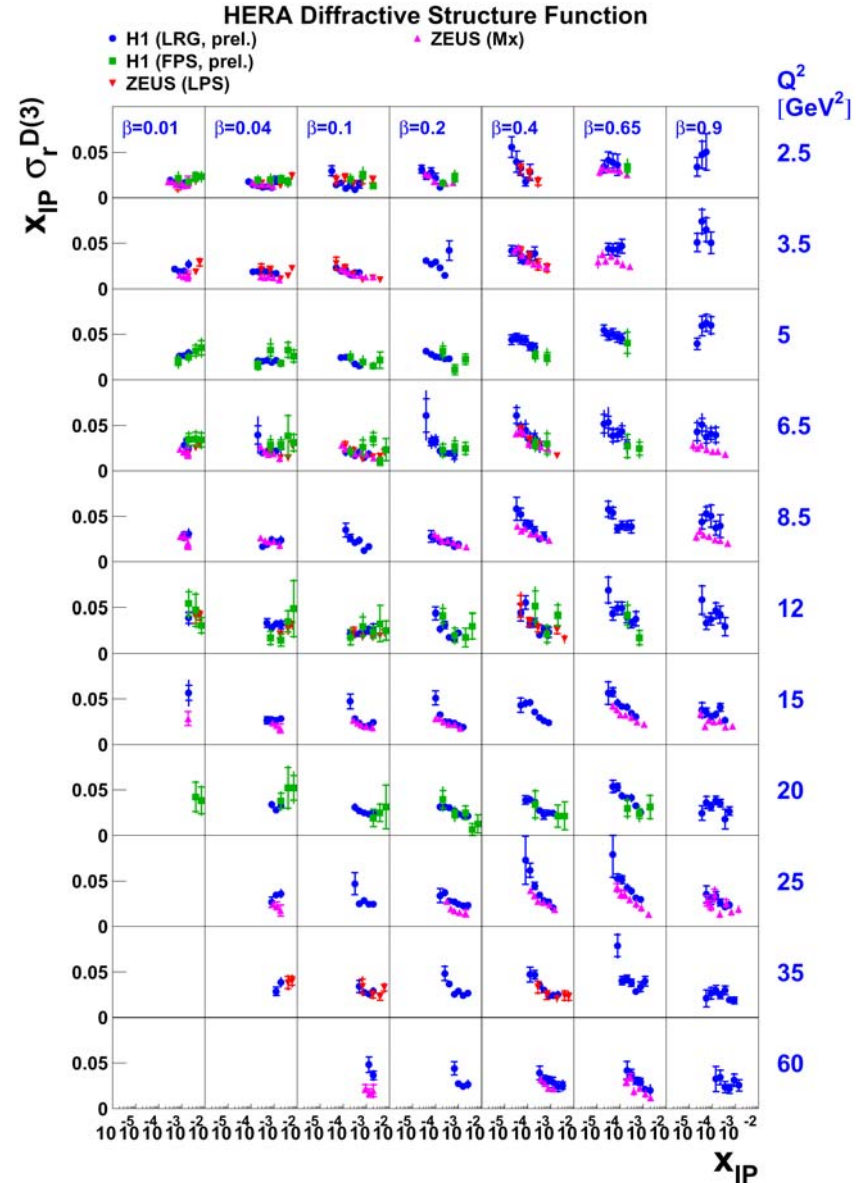
ZEUS M_x / LPS ratio: ~30%

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:

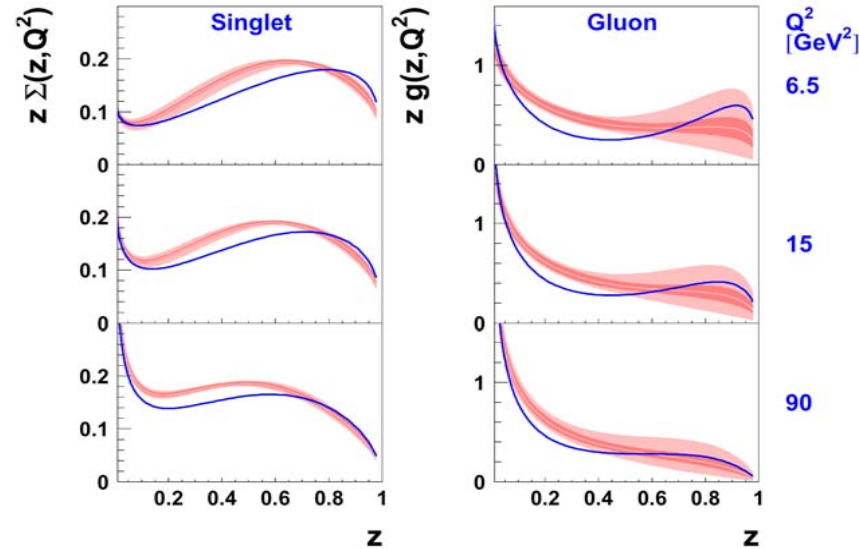
$$f_{IP/p}(x_{IP}, t) = e^{B \cdot t} \cdot x_{IP}^{1-2\alpha(t)}, \quad \alpha(t) = \alpha_{IP} + \alpha' \cdot t$$



Pomeron Parton Densities

H1 2002 σ_r^D NLO QCD Fit

H1 preliminary



H1 2002 σ_r^D NLO QCD Fit
 (exp. error)
 (exp.+theor. error)
 H1 2002 σ_r^D LO QCD Fit

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

For lowest-order parton model: $z=\beta$
 For higher order processes: $0 < \beta < z$

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

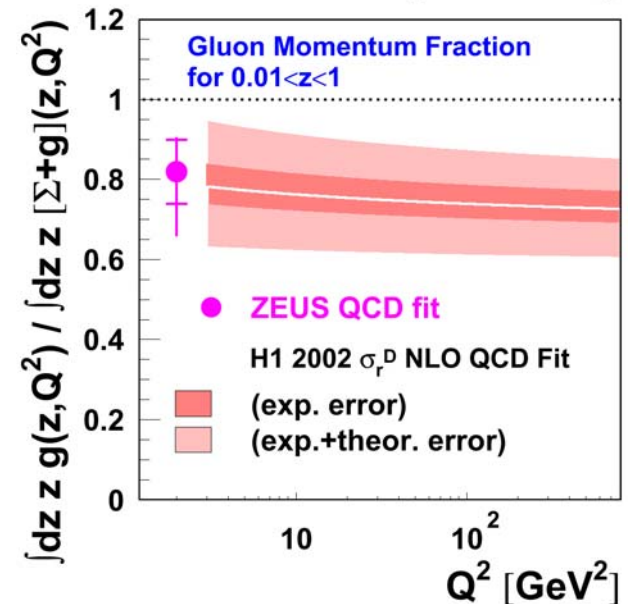
Test of the hard scattering factorization:
 Dijets & D^* production

$P_{i,IP}(z, Q^2)$ 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:

H1 preliminary

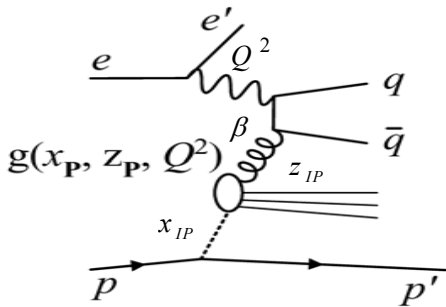


Diffractive D* in DIS

Direct interaction
with gluon:

photon-gluon fusion

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



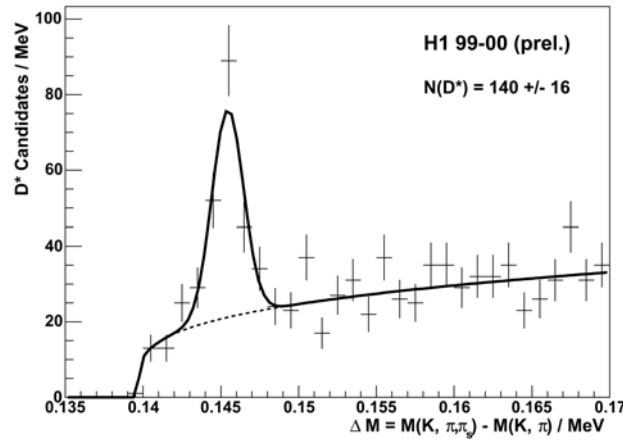
$$ep \rightarrow e(D^{*\pm} X')Y$$

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

Extract D^* from fit to ΔM :

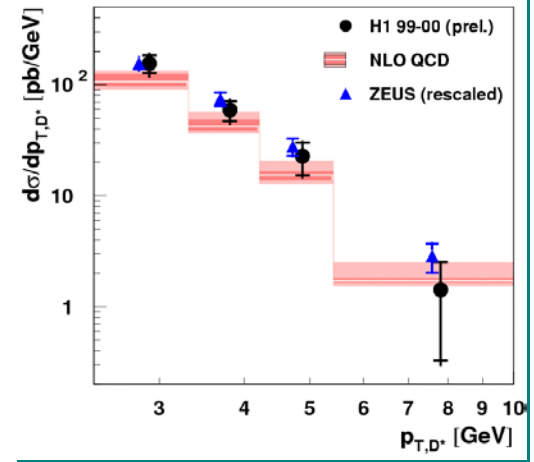
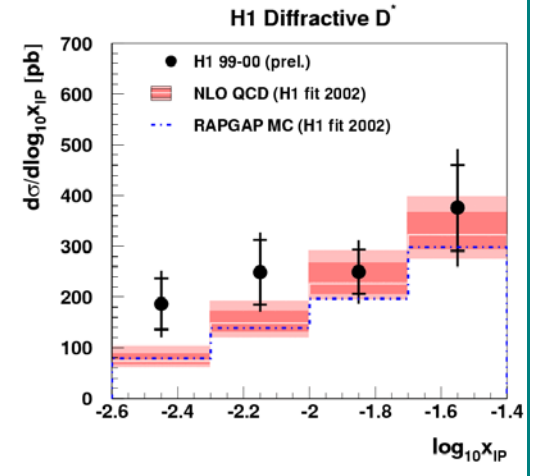
$$\Delta M = M_{K\pi\pi_s} - M_{K\pi}$$

Gaussian fit for the signal



✓ NLO calculation is in agreement with data

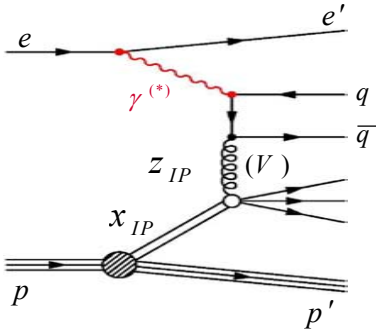
✓ Good agreement between H1 and ZEUS data



✓ D^* data and NLO agreement supports hard scattering factorization

Dijets in DIS

DIS γ interaction:

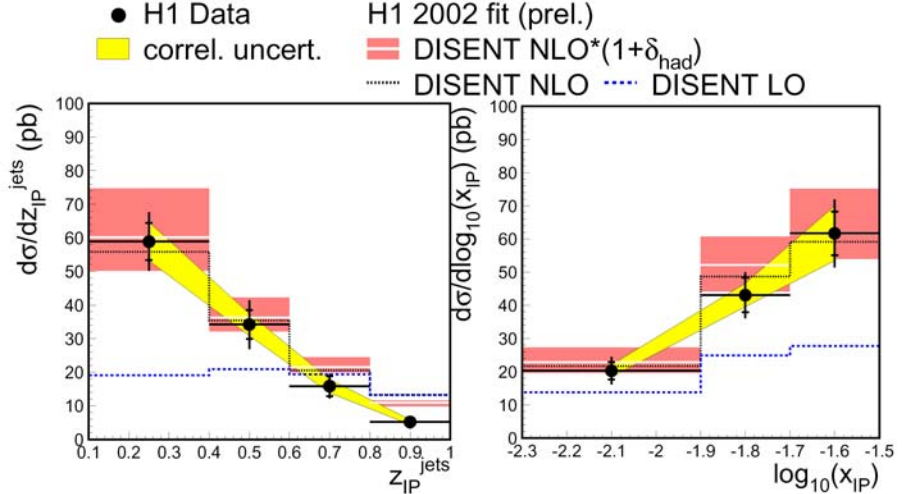


$$x_{IP} = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

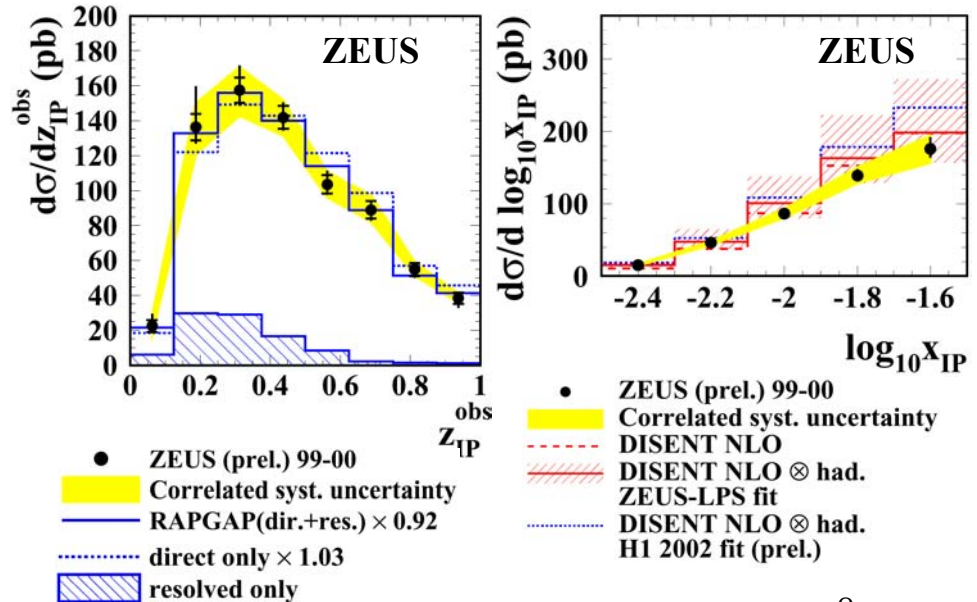
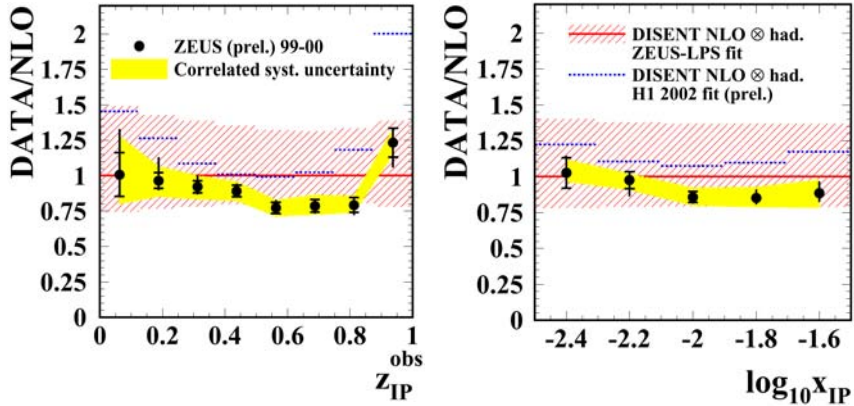
$$z_{IP} = \frac{Q^2 + M_{J1 J2}^2}{Q^2 + M_X^2}$$

✓ Factorization holds

H1 Diffractive DIS Dijets



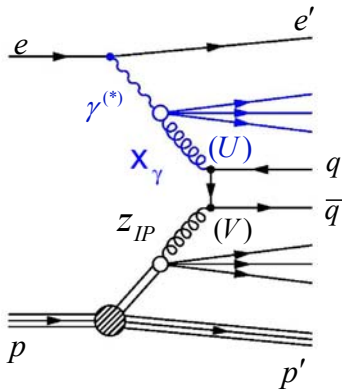
Ratio DATA/NLO for dijets in DIS



Dijets in γp PhP

□ Direct and Resolved γ interaction:

- γ involved point-like into γp $x_\gamma \sim 1$
- γ fluctuate into hadronic system $x_\gamma < 1$



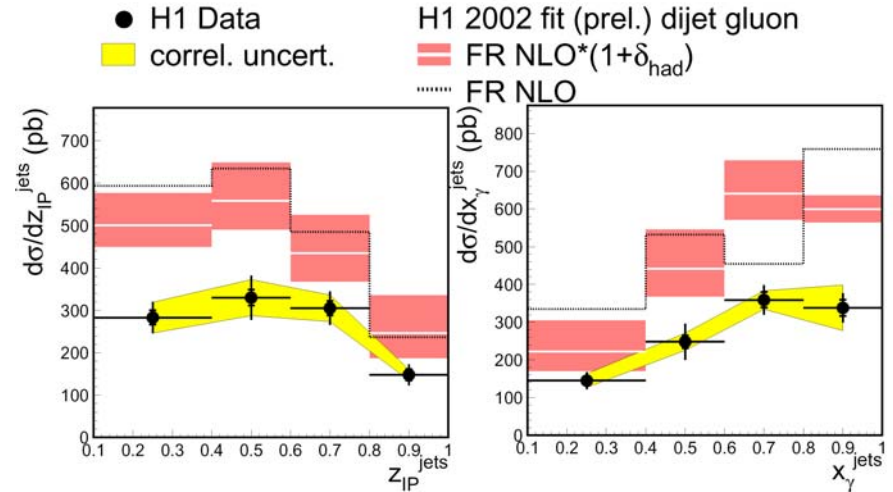
photon remnant

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

Momentum fraction of γ carried by γ -parton

✓ **Factorization fails**

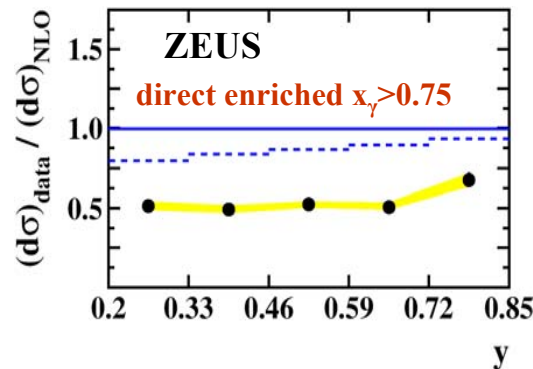
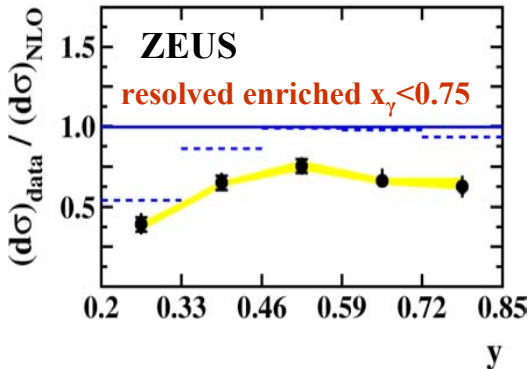
H1 Diffractive γp Dijets



Ratio DATA/NLO for dijets in γp PhP

$$y = Q^2 / sx$$

inelasticity

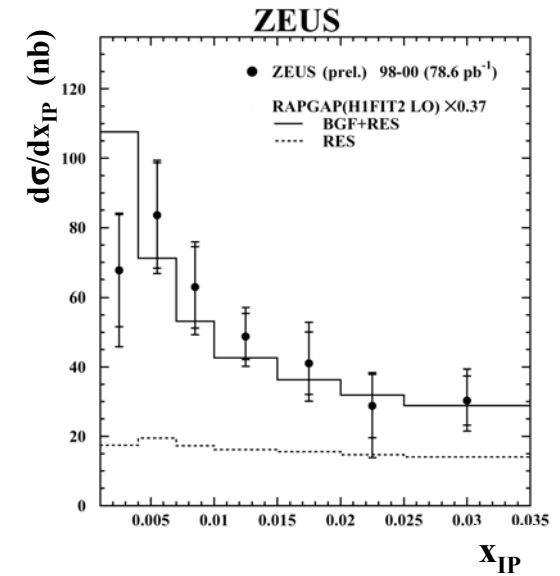
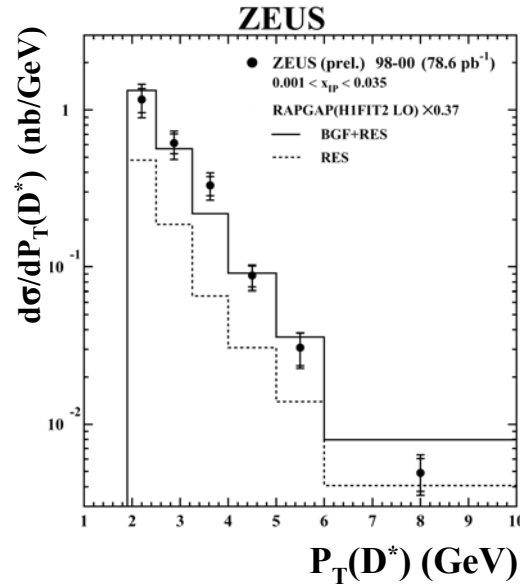
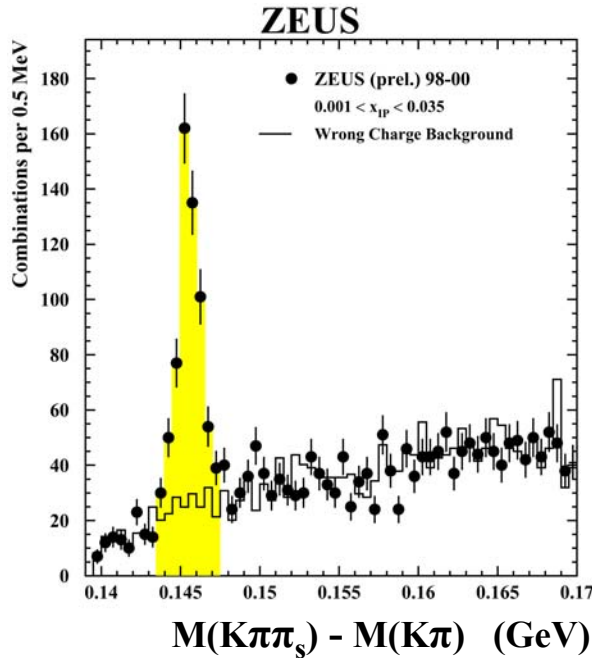


- ZEUS (prel.) 99-00
- Energy scale uncertainty
- NLO \otimes had.
- - - NLO / (NLO \otimes had.)
- R=1, H1 2002 fit (prel.)

✓ **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:

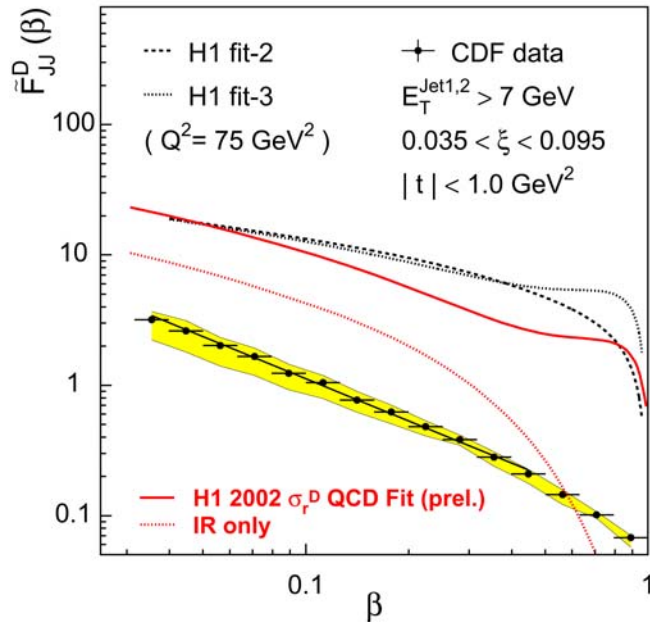
- ✓ *Statistics: 450 candidates*

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

Approaches to factorization breaking

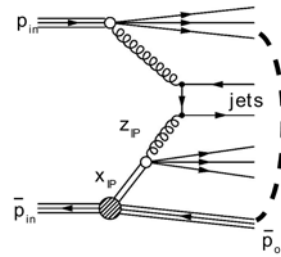
Effective diffractive structure function

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



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

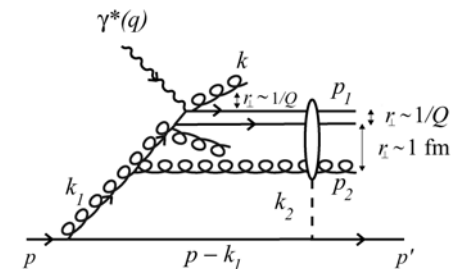
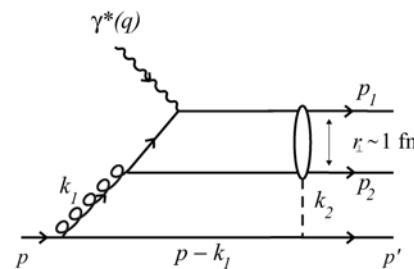
Dijet cross section at TEVATRON:
 ~ 10 times lower than the QCD calculation at HERA



Multi-parton scattering (rescattering)?

Alternative approach

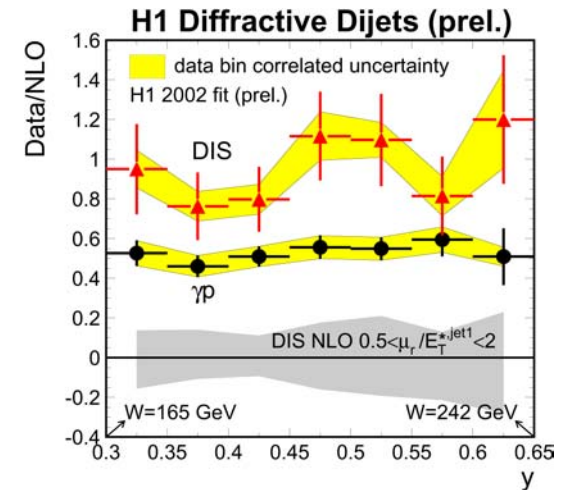
- no Regge model for 'initial' IP:
 - Single model describes all final states
- Soft Color Interaction (SCI):
 - Color dipole
 - soft gluon exchange (k_2) turns color octet (p_1, p_2) into a color singlet



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 γ^*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=? :-)