Diffractive interactions in ep collisions

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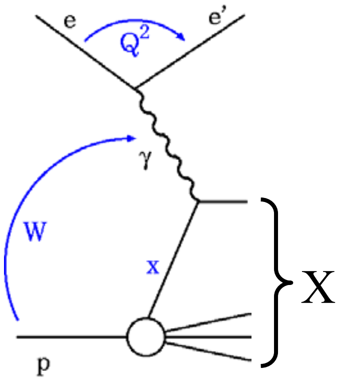
Outline

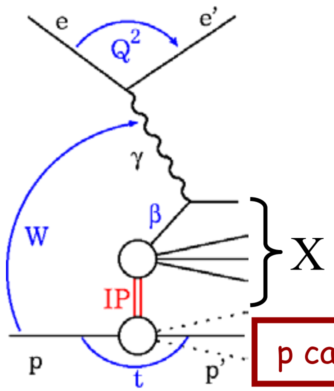
- Introduction
- Inclusive Diffraction, F_2^D
  - Measurements of diffraction with the M_x method, a leading proton or rapidity gap
  - Comparison to models
  - Extraction of diffractive parton distribution functions (PDFs)
- Diffractive Dijet and D* production
  - Measurements for deep inelastic scattering (DIS) and photoproduction ($Q^2 \approx 0$)
- Summary and Outlook

Diffrative DIS at HERA

Deep Inelastic Scattering at HERA:
diffraction contributes substantially to the cross section
(~ 10% of low-x events)



Inclusive DIS:
Probe partonic structure
of the proton → F_2



Diffractive DIS:
Probe structure
of the exchanged
color singlet → F_2^D

p can stay intact or dissociate

Q^2: 4-momentum exchange
W: γ p centre of mass energy
x: fraction of p momentum carried by struck quark

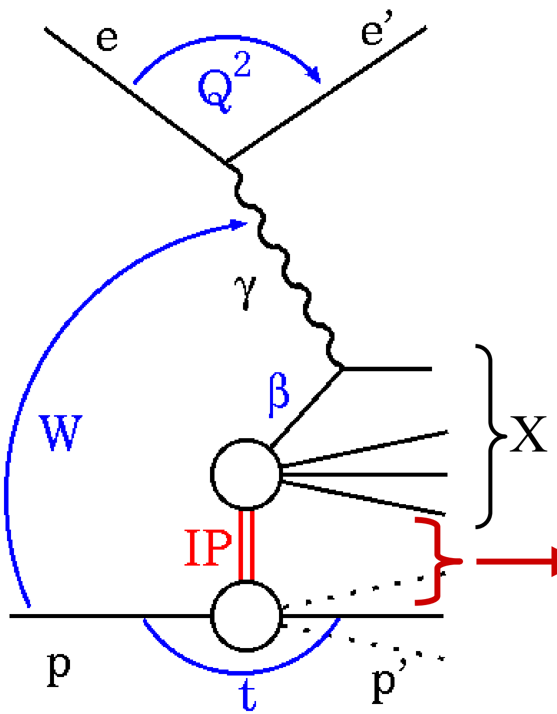
x_{IP}: fraction of p momentum carried by the Pomeron (IP)

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

β: fraction of IP momentum carried by struck quark

$$\beta = \frac{Q^2}{2q \cdot (p - p')} \approx \frac{Q^2}{Q^2 + M_X^2} = \frac{x}{x_{IP}}$$

Inclusive diffraction



Diffractive γ*p cross section:

$$\frac{d\sigma^D_{\gamma^* p}}{dM_X} = \frac{\pi Q^2 W}{\alpha(1+(1-y)^2)} \cdot \frac{d^3\sigma^D_{ep\to e'Xp'}}{dQ^2 dM_X dW}$$

Diffractive structure function:

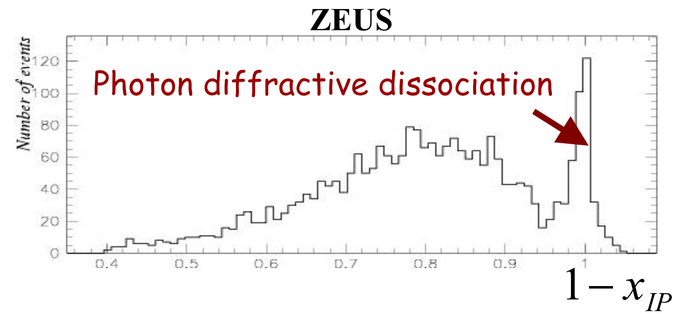
$$F_2^{D(3)}(\beta, Q^2, x_{IP}) = \frac{\beta Q^4}{4\pi\alpha^2(1-y+y^2/2)} \cdot \frac{d\sigma^D_{ep\to e'Xp'}}{d\beta dQ^2 dx_{IP}}$$

Rapidity gap due to exchange of colorless object with vacuum quantum numbers

Event selection: LPS, M_x and LRG method

LPS

- t-measurement
- access to high x_{IP} range
- free of p-dissociation background
- small acceptance → low statistics



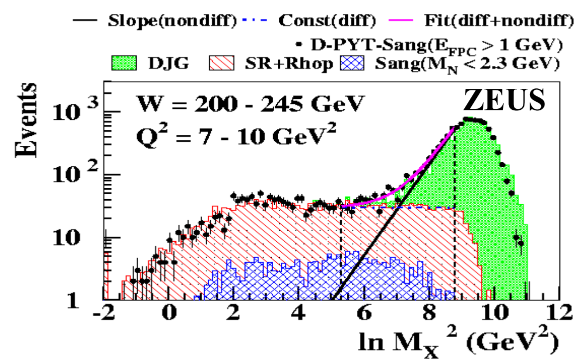
M_x

Diffr. Non-diffr.

$$\frac{dN}{dlnM_X^2} = D + c \cdot exp(b \cdot lnM_X^2)$$

(D, c, b from a fit to data)

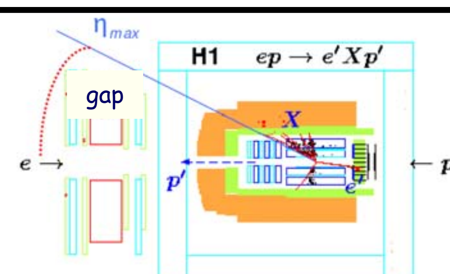
- **flat** vs ln M_x^2 for **diffractive** events
- **exponentially falling** for decreasing M_x for **non-diffractive** events



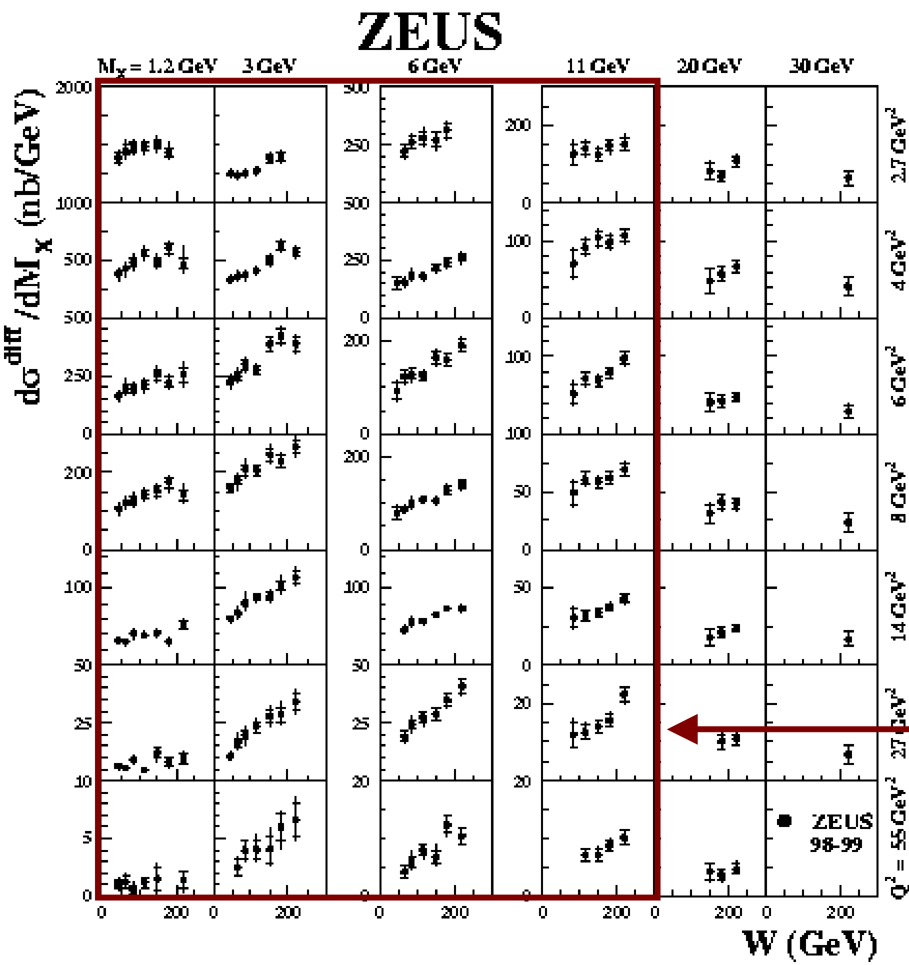
p-dissociation background subtracted for mass of diss. p M_N > 2.3 GeV

LRG

events with large rapidity gap (LRG):
p-dissociation background for
M_N < 1.6 GeV, |t|<1 GeV^2



Cross section: W dependence (M_x method)



ZEUS 98-99 FPC sample
(Lower M_x / higher β region)

Reminder:
p-dissociation events with
$M_N < 2.3$ GeV included (~ 30 %)

$M_X < 2$ GeV: weak rise with W
$M_X > 2$ GeV: strong rise with W

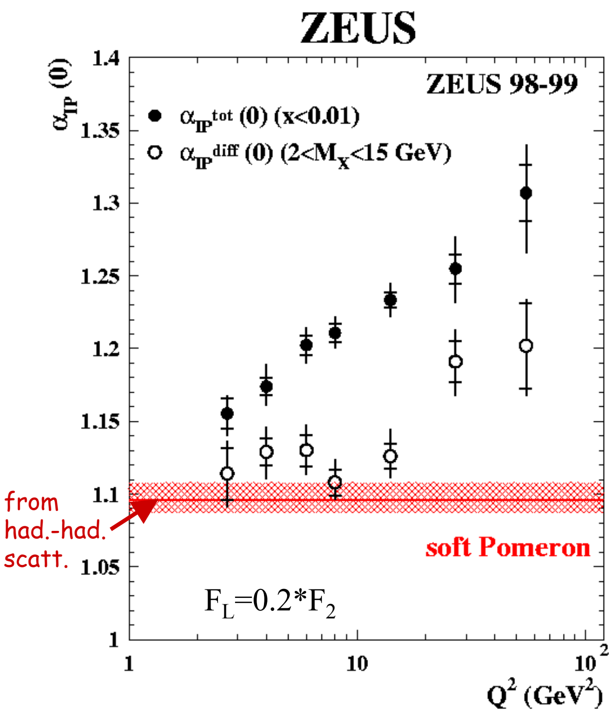
Fit these distributions with power-like fit:

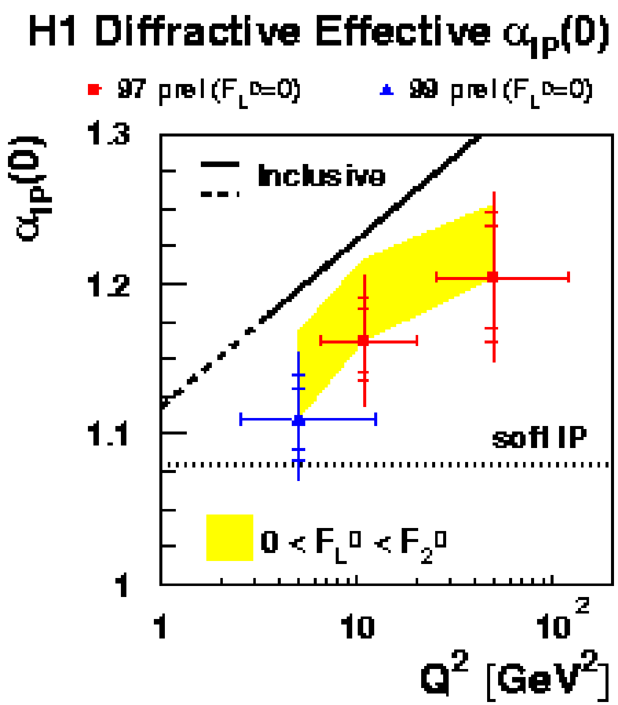
$$d\sigma^D_{\gamma^* p}/dM_X \propto (W^2)^{2\overline{\alpha_{IP}}-2}$$ (from Regge theory)

$$\alpha_{IP}^{diff}(0) = \overline{\alpha_{IP}} + \alpha'_{IP}/b$$

from LPS data

Effective $\alpha_{IP}(0)$ vs Q^2





Effective $\alpha_{IP}(0)$:
- diffr. lower than incl.
- for low Q^2 consistent with soft Pomeron
- data suggest rise with Q^2 → **Regge fact. breaking**

(H1 within errors consistent with no Q^2 dependance, ZEUS data show significant rise)

ZEUS:

$$\sigma_{tot}^{\gamma^* p} \propto (W^2)^{\alpha_{tot}(0)-1}$$ inclusive

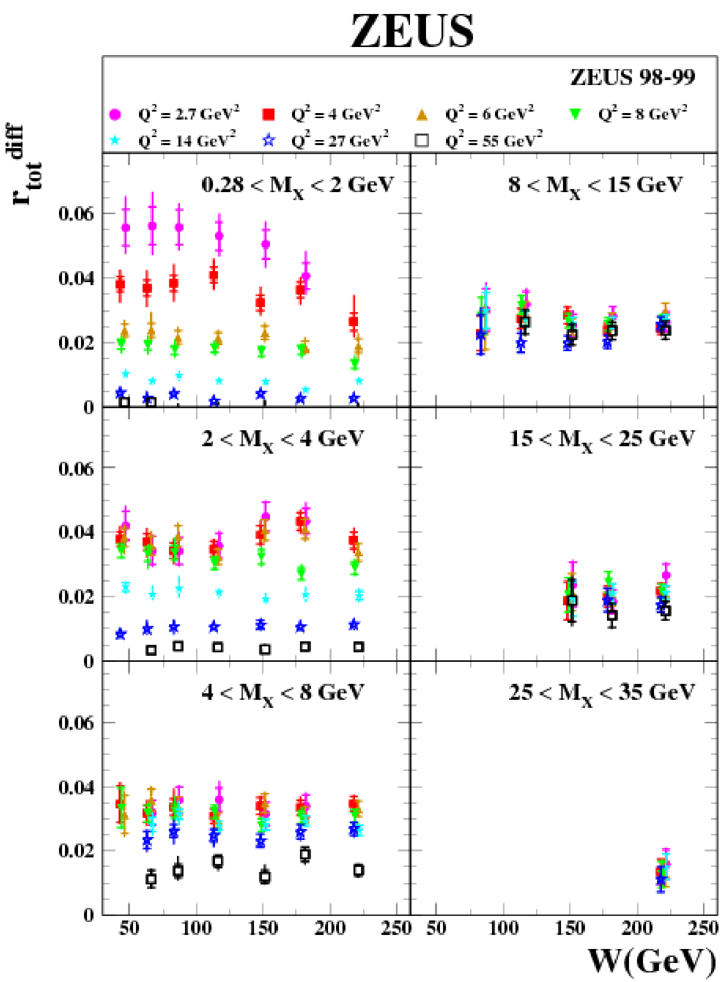
$$\frac{d\sigma^{diff}}{dM_X^2} \propto (W^2)^{2\bar{\alpha}_{IP}-2}$$ diffractive

H1:

$$F_2 \propto B \cdot x^{1-\alpha(Q^2)}$$ inclusive

$$x_{IP} F_2^D \propto A(\beta, Q^2) \cdot x_{IP}^{2-2\alpha_{IP}(t)}$$ diffractive

$\sigma_{diff}/\sigma_{tot}$: W dependence ($M_x$ method)



$$r_{tot}^{diff} = \frac{\sigma^{diff}}{\sigma^{tot}} = \frac{\int_{M_a}^{M_b} dM_X \, d\sigma^{diff}_{\gamma^* p \to XN, M_N < 2.3\,GeV} / dM_X}{\sigma^{tot}_{\gamma^* p}}$$

No W dependence

Low M_x: decreasing with rising Q^2
High M_x: weak Q^2 dependence

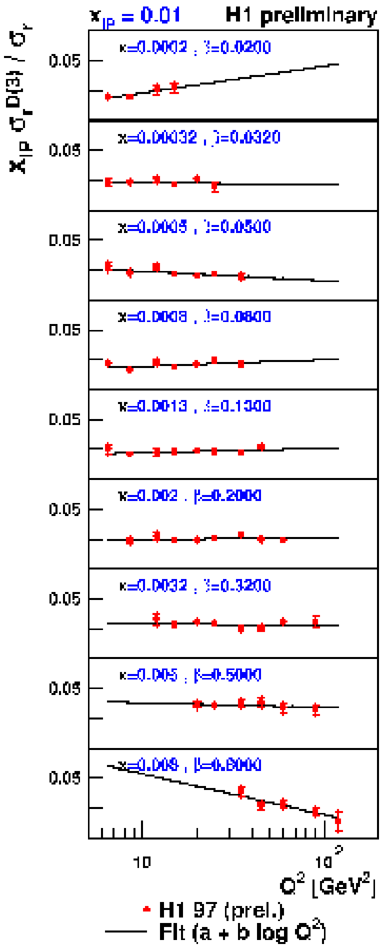
For the highest W bin:
($200 < W < 245$ GeV, $0.28 < M_x < 25$ GeV, $M_N < 2.3$GeV)

$r_{tot}^{diff} = 15.8^{+1.2}_{-1.0}$ % at Q^2 = 4 GeV^2

$r_{tot}^{diff} = 9.6^{+0.7}_{-0.7}$ % at Q^2 = 27 GeV^2

Diffraction contributes substantially to the total cross section!

Reduced cross section: Q^2 dependence (LRG)



Diffr. reduced CS:

$$\frac{d^4\sigma}{d\beta dQ^2 dx_{IP} dt} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1 - y + \frac{y^2}{2}\right)\sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

Relation to F_2^D and F_L^D:

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1 - y + y^2/2)} F_L^{D(4)}$$

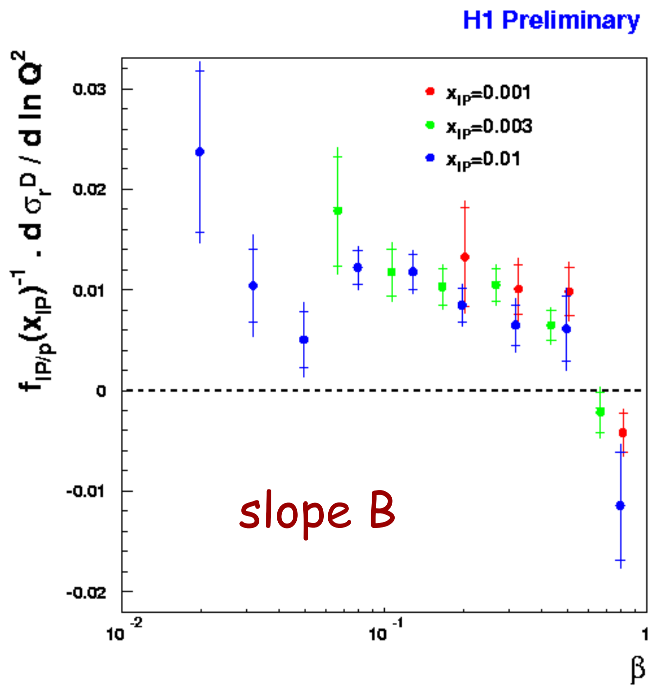
Quantify scaling violations at fixed x_{IP} and β:

$\sigma_r^D = A + B \ln Q^2$

$B = d\sigma_r^D / d \ln Q^2$

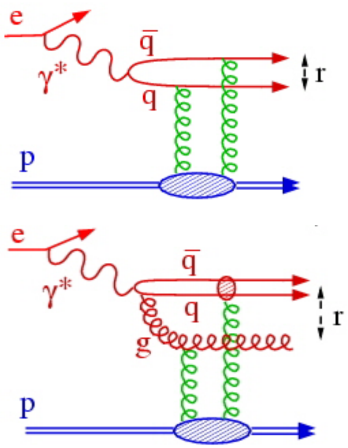
Large positive scaling violations up to $\beta \sim 0.6$

☛ large gluon contribution



Comparison with models

The color dipole model

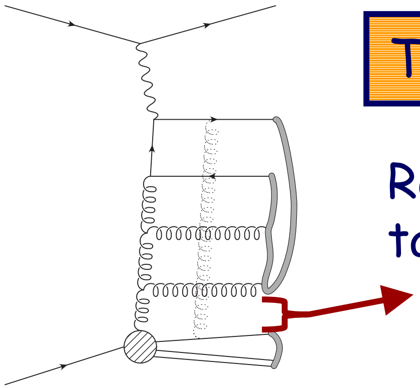


Virtual photon fluctuates to $q\bar{q}$ and $q\bar{q}g$ states long before interaction (color dipole):

- dipole has long lifetime → dipole interacts with p
- transverse size $1/\sqrt{(Q^2+M_{qq}^2)}$

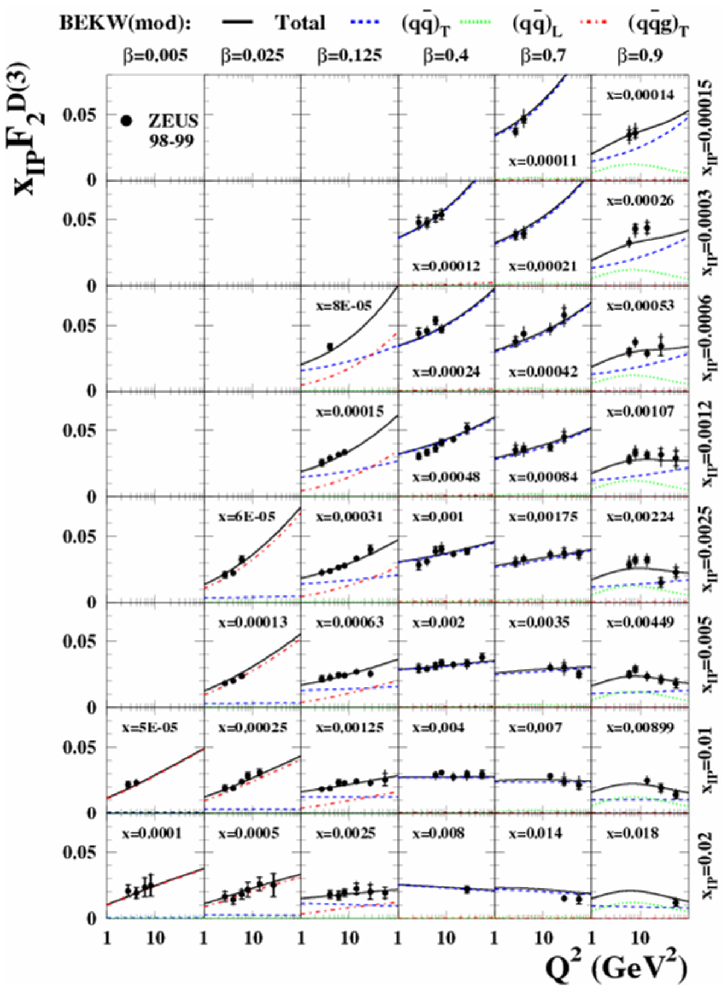
Transverse size of incoming hadron beam (from γ) can be reduced so small that strong interaction with proton becomes perturbative (color transparency)

The soft color interaction model



Re-scattering of soft longitudinal gluons on target spectators modifies color field topology
rapidity gap

Color dipole model: ZEUS data vs BEKW model



Bartels, Ellis, Kowalski and Wüsthoff:

$$x_{IP}F_2^{D(3)} = c_T F_{qq}^{\ T} + c_L F_{qq}^{\ L} + c_g F_{qqg}^{\ T}$$

Data mainly described by BEKW parametrisation (x_{IP} < 0.01)

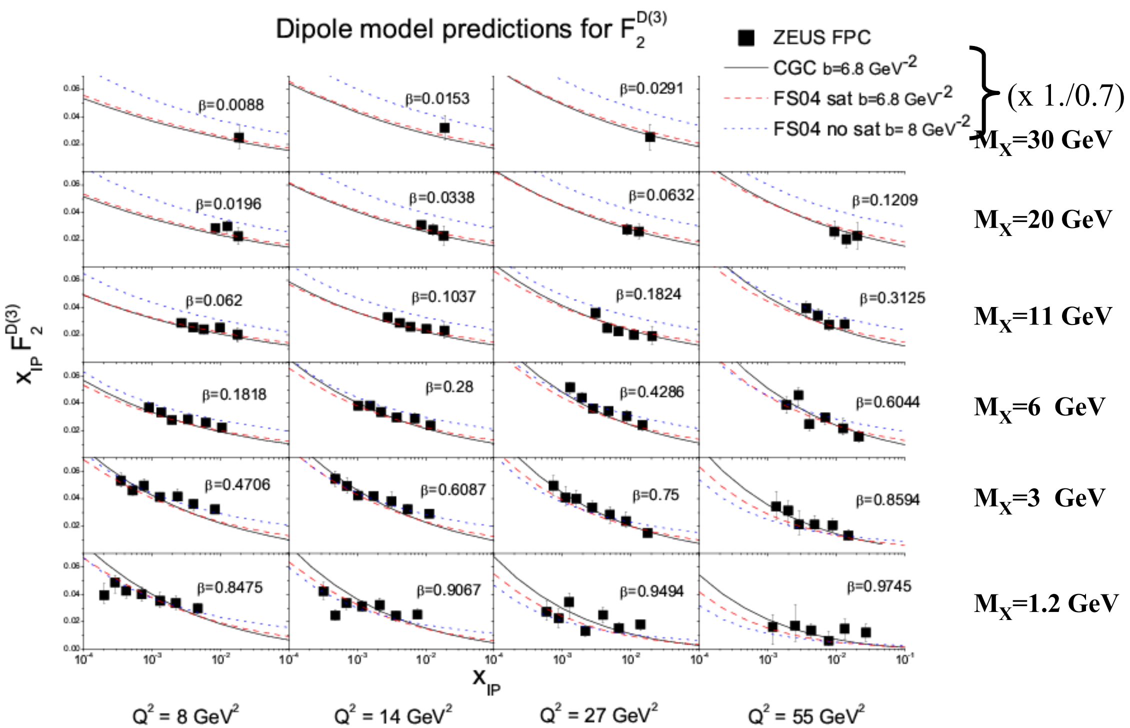
$F^T_{q\bar{q}g} \propto (1-\beta)^\gamma$ small β (high M_x)

$F^T_{q\bar{q}} \propto \beta(1-\beta)$ medium β

$F^L_{q\bar{q}} \propto \beta^3(1-2\beta)^2$ high β only (low M_x)

Color dipole model: ZEUS data vs FS and CGC model

High Q^2 from ZEUS M_X 98-99



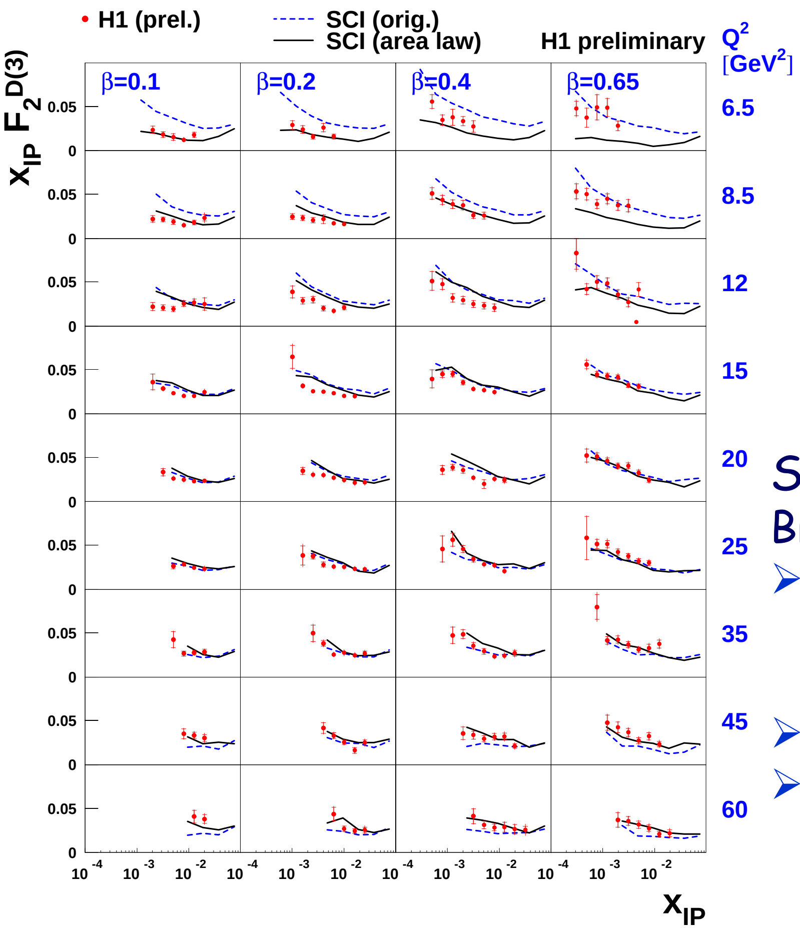
FS04(Forshaw & Shaw): hep-ph/0411337

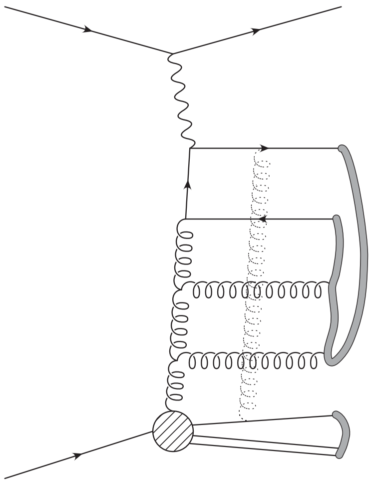
- fit F_2 data and predict $F_2^{D(3)}$
- need gluon saturation at low x to describe data

CGC(Color Glass Condensate):
Iancu, Itakura, Munier hep/0310338

- non-linear saturation effects at high gluon densities
- prediction consistent with data

Soft Color Interaction: SCI vs H1 data





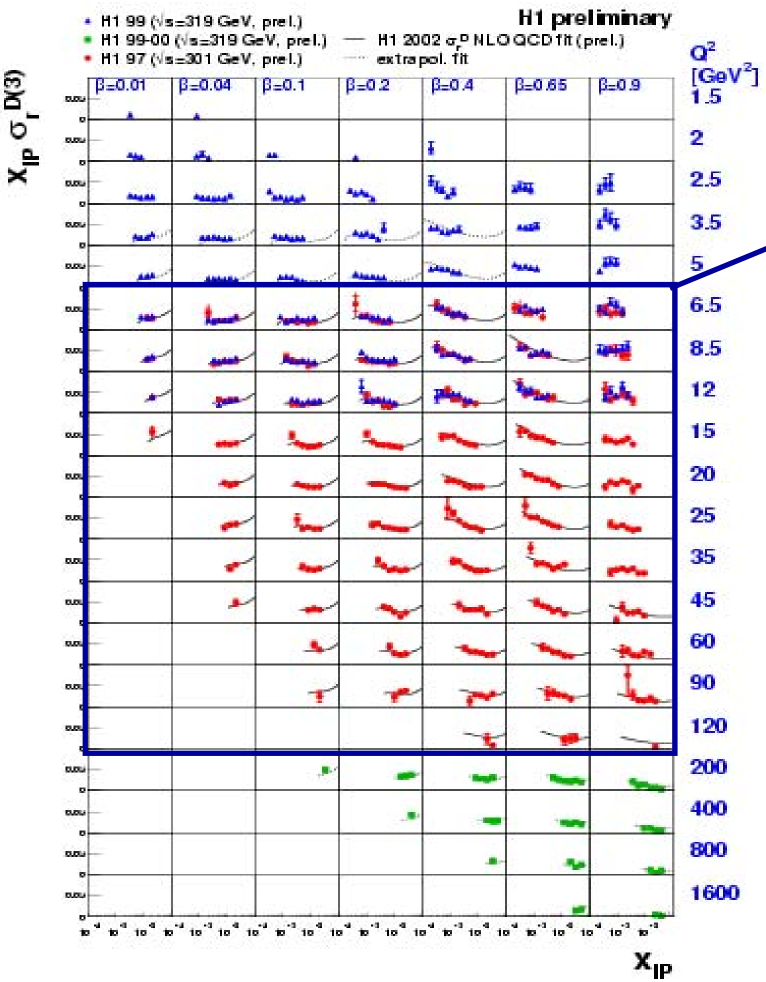
Soft color interaction and QCD rescattering:

Brodsky, Enberg, Hoyer, Ingelman

hep/0409119

- re-scattering of soft longitudinal gluons on target spectators modifies color field topology → rapidity gap
- β-dependence from splittings $g \to q\bar{q}$ and $g \to gg$
- same hard sub-process in diffractive and inclusive DIS, same Q^2 and W dependence

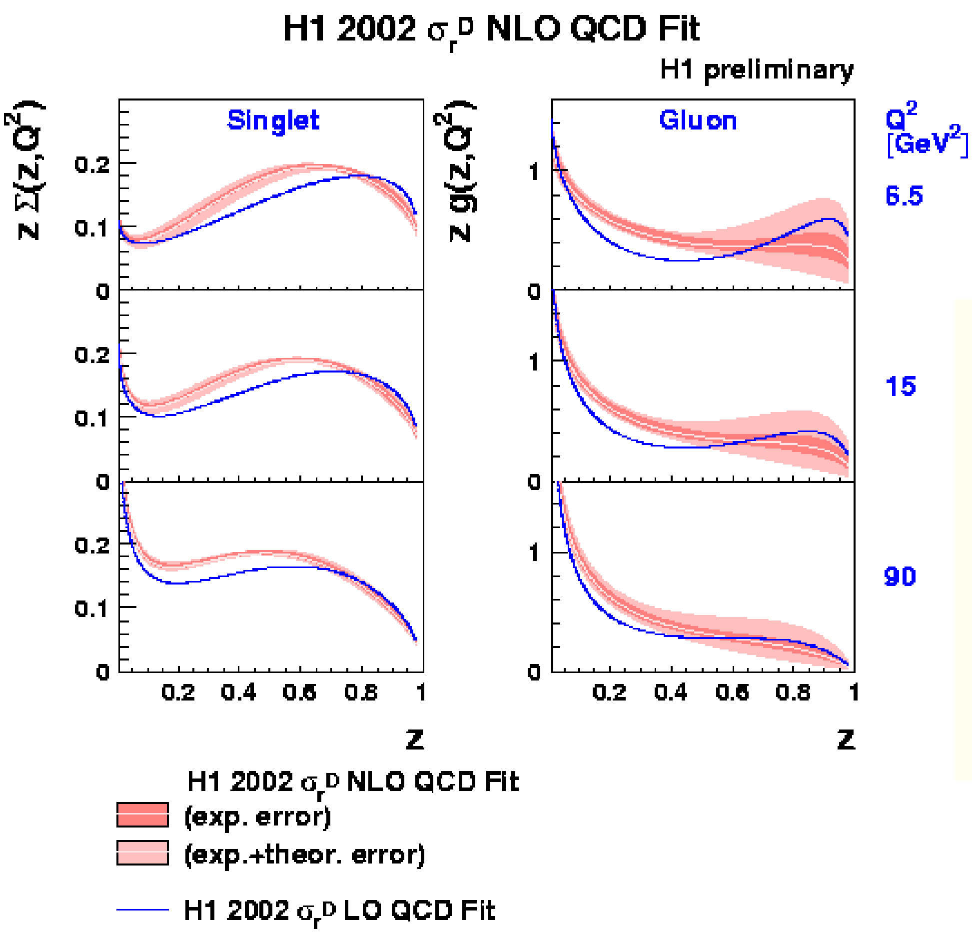
Reduced cross section: x_{IP} dependence (H1 NLO DGLAP fit)



QCD fit with NLO DGLAP to data from 6.5 to 120 GeV^2
$\Rightarrow$ **diffractive PDFs**

Extrapolation of the fit
to lower Q^2 and
to higher Q^2
shows reasonably good description of data!

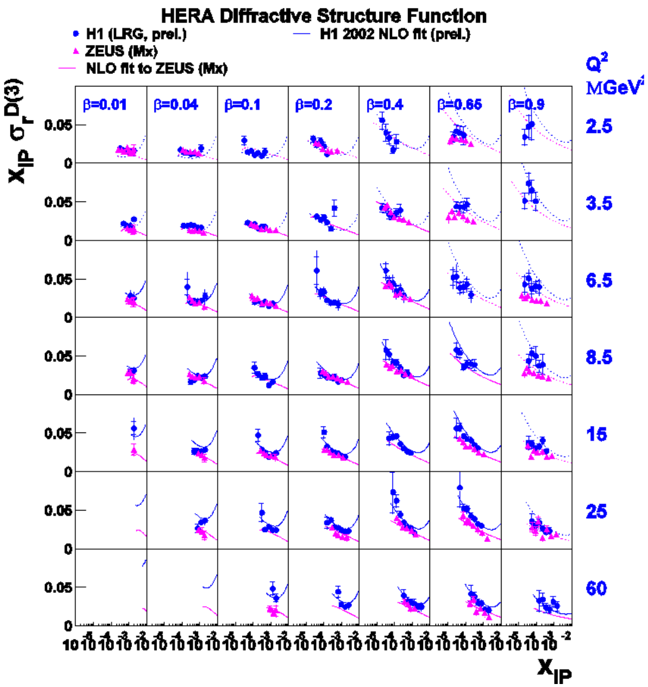
NLO DGLAP FIT
⇒ PDF (H1)



Diffractive PDFs:
- Regge factorisation assumption
- precise measurement of quark singlet distribution

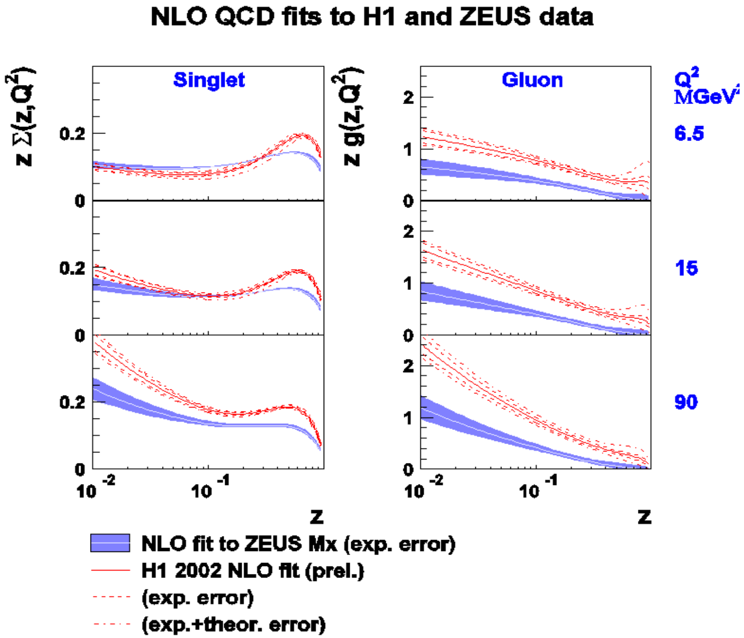
- Dominated by gluons:
  75 ± 15% gluon momentum fraction
- large gluon uncertainty at high z
  - need precision measurement at high β
- PDFs from fit useful to test QCD factorisation in **charm (D*) and dijet analyses**.

Comparison of reduced CS: H1 LRG vs ZEUS M_x



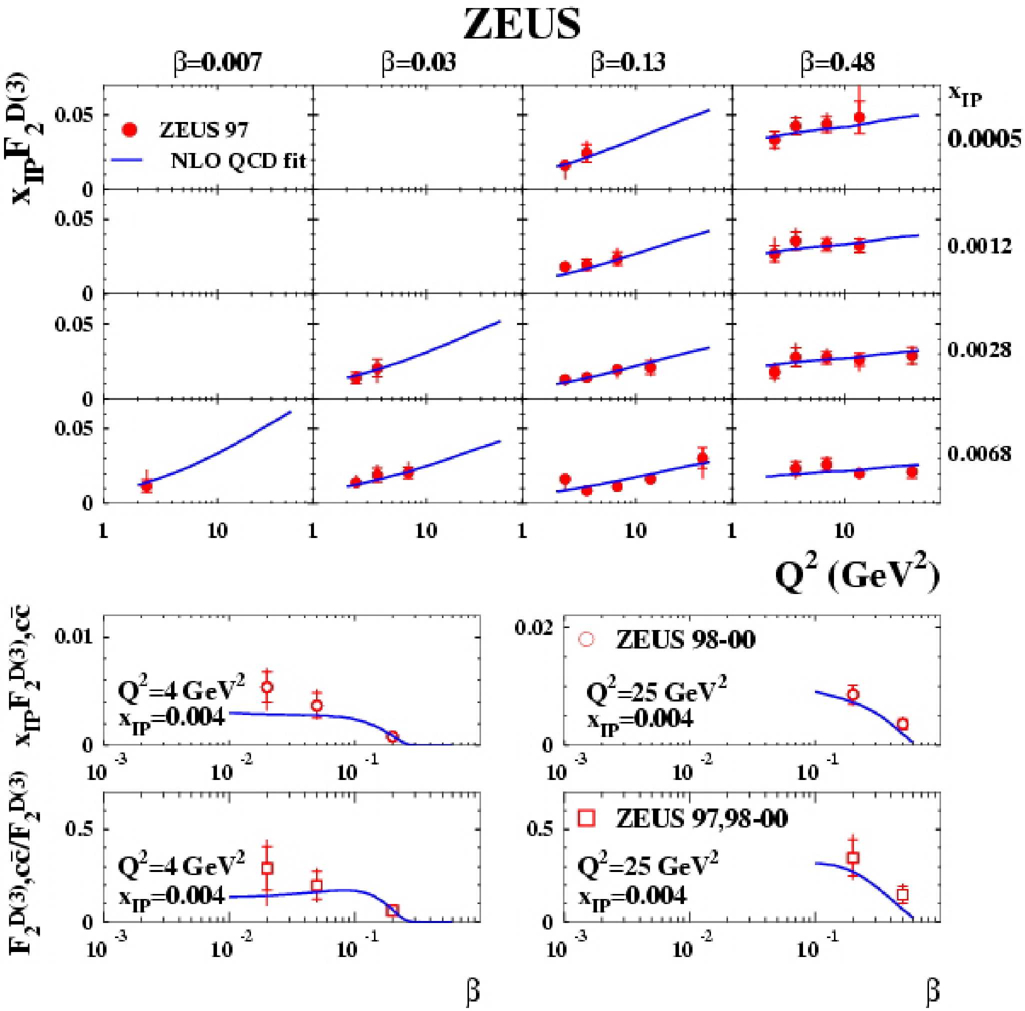
Newman, Schilling:

- QCD fit similar to H1 fit 2002
- ZEUS Mx data scaled to M_y < 1.6 GeV
- No IR component needed (doesn't improve fit)



- Reasonable agreement between H1 LRG and ZEUS M_x data
- Differences at higher β (low M_x)
- ZEUS M_x data: smaller positive scaling violations seen
- ☛ fraction of gluon momentum: 55%

NLO DGLAP FIT
⇒ PDF (ZEUS LPS)



Diffractive PDFs:

- Regge factorisation assumption
- diffractive charm data included in fit
- PDF parametrisation at initial scale Q_0^2=2GeV^2

Fraction of gluon momentum at initial scale:

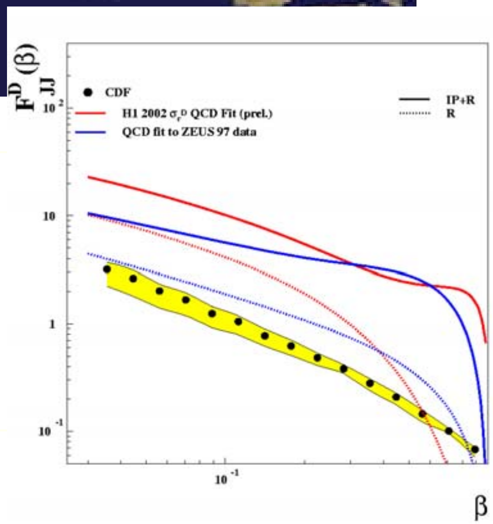
$82 \pm 8_{stat} \pm 9_{syst}$%

☛ consistent with H1 result

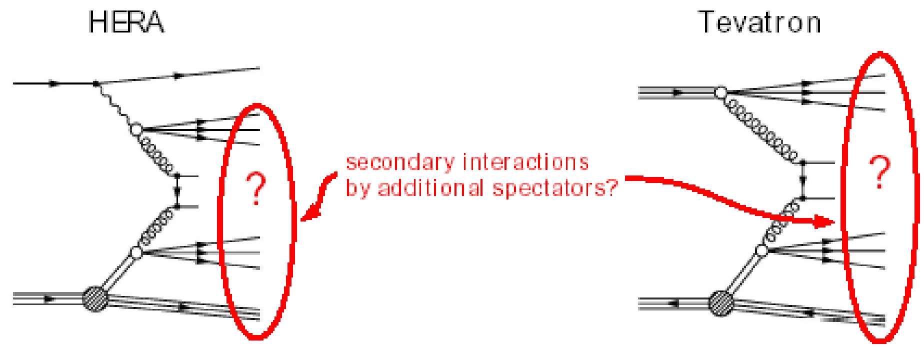
QCD fit describes data:

χ^2/ndf= 37.9/36

Comparison to Tevatron



Dijet cross section factor **3-10 lower** than expected using different HERA PDFs



Idea: suppression due to secondary interactions by add. spectators

Kaidalov et al.: resolved part needs to be rescaled by 0.34

Phys.Lett.B567 (2003),61

DIS (Q^2>5GeV^2) and direct photoproduction ($Q^2 \simeq 0$):

- photon directly involved in hard scattering

Resolved photoproduction:

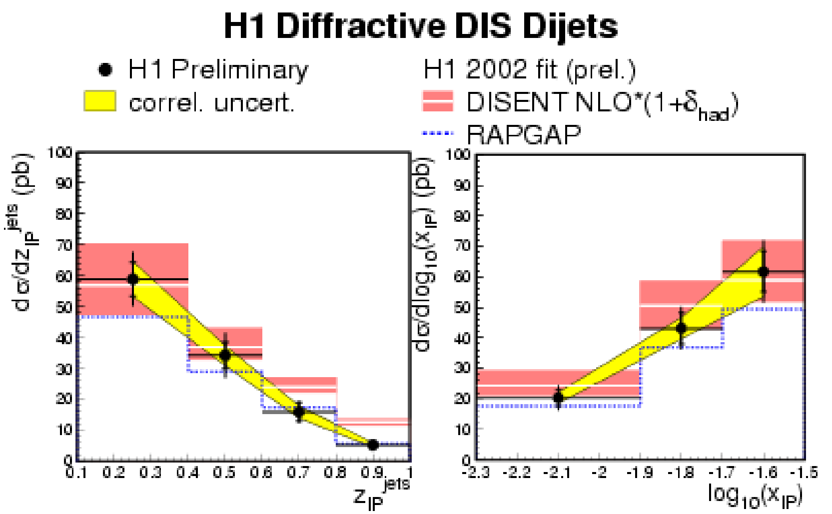
- photon fluctuates into hadronic system, which takes part in hadronic scattering

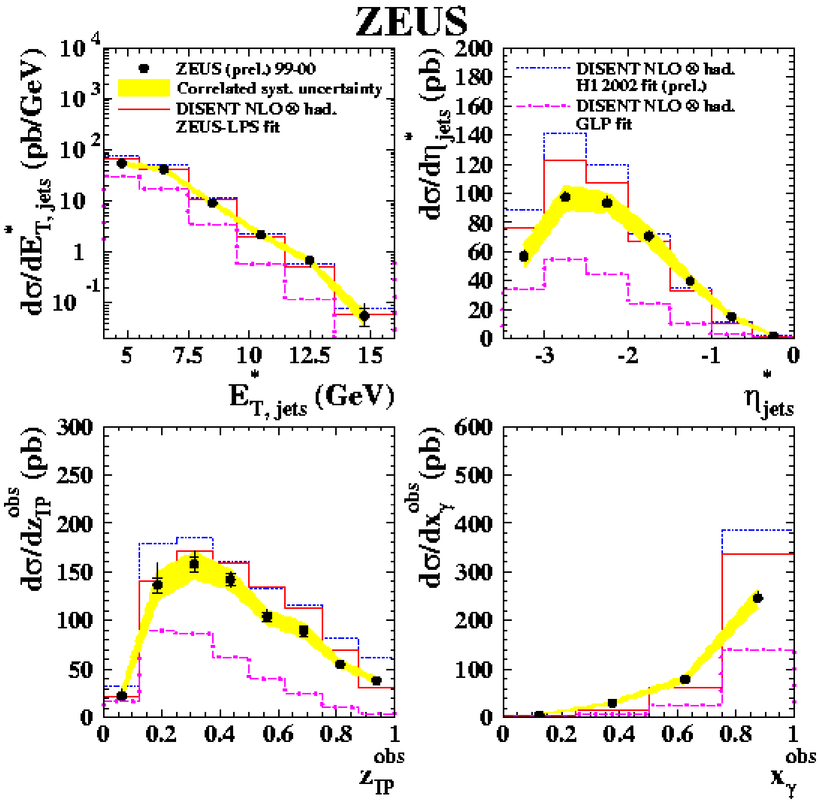
Test with dijet and charm at HERA:
Hard scale: E_T of jet or charm mass

- tests of universality of PDF's (=QCD factorisation)
- test of DGLAP evolution

Diffractive Dijets: DIS

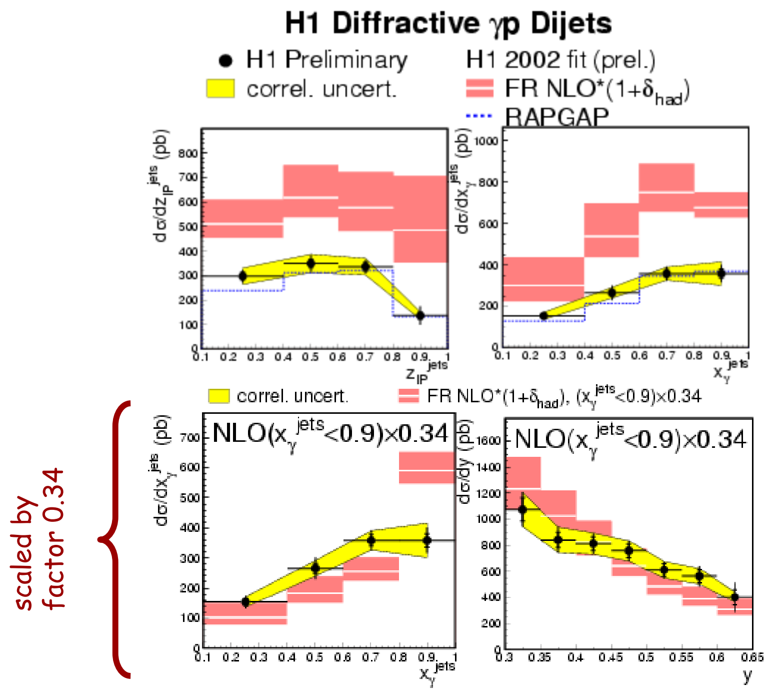
NLO calculations DISENT (diffr. extension)

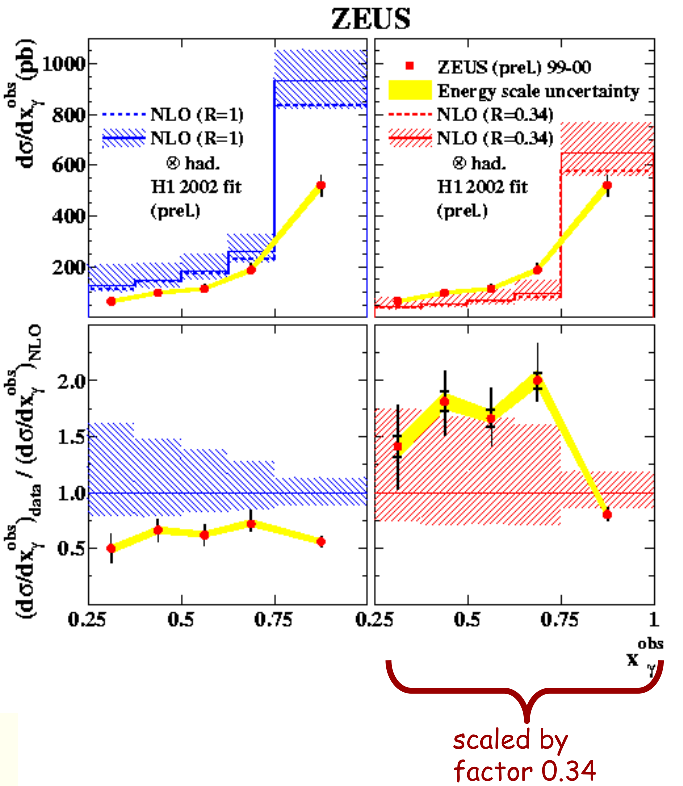




Agreement with NLO for H1
and ZEUS using H1 fit 2002 (prel.)
and LPS fit
NLO with GLP fit (ZEUS M_x data, see A. Levy DIS05)
underestimates data (ZEUS)
☛ **NLO calculations depend on PDFs**

Diffractive Dijets: γP

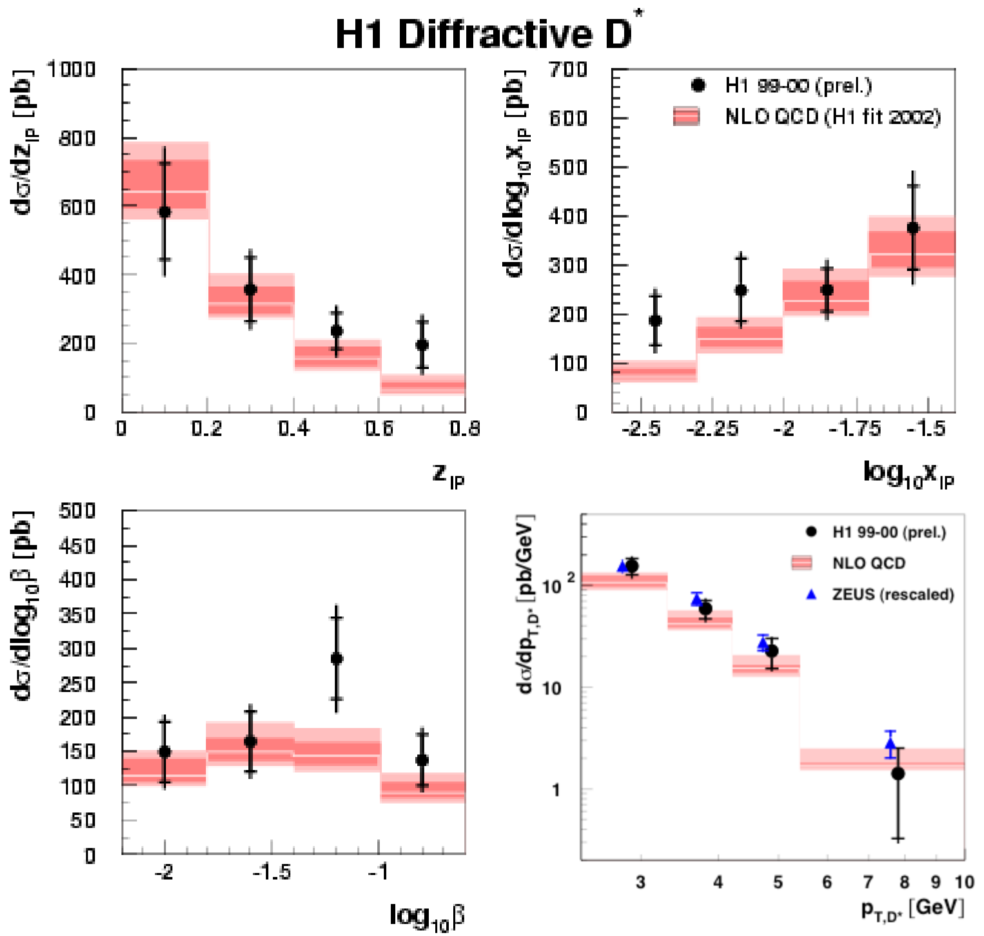




H1 and ZEUS:
NLO overestimates data by factor ~1.6.
Scaling only resolved part by 0.34
doesn't describe data.

PDF uncertainty?

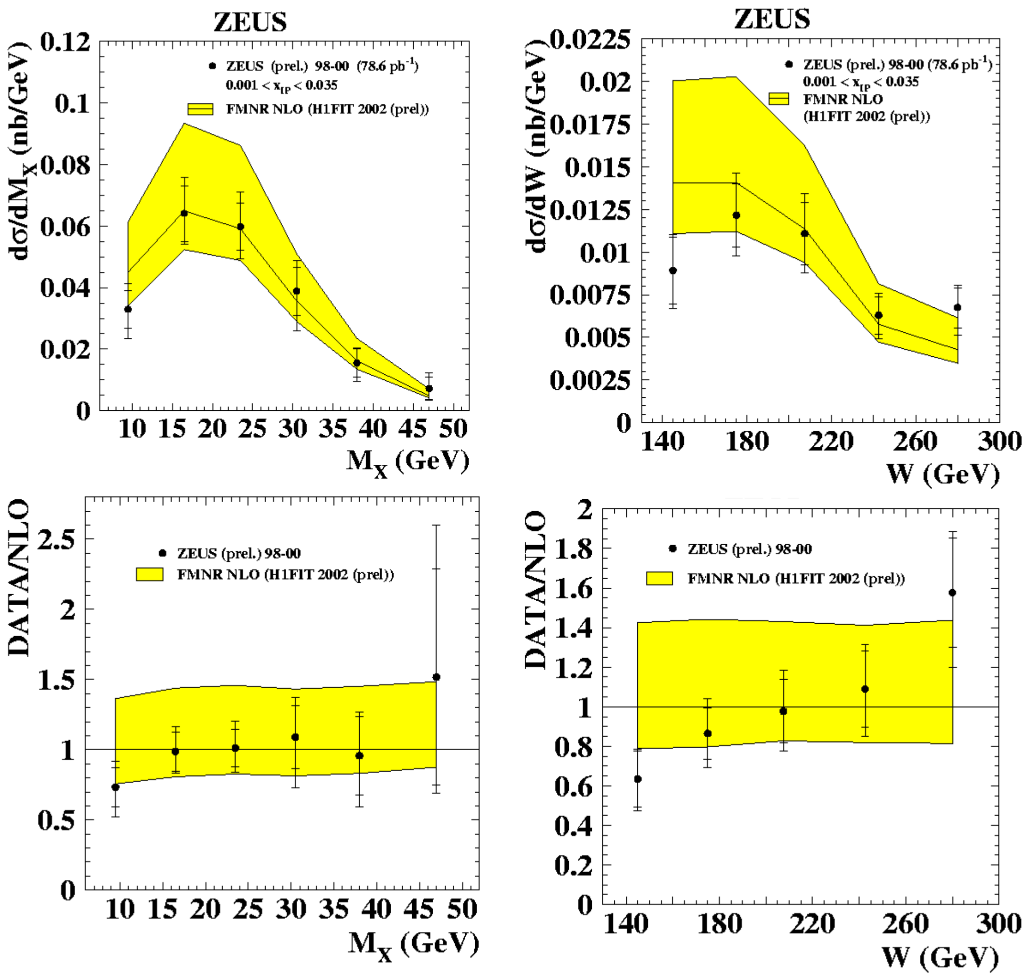
Diffractive D*: DIS



NLO calculations
HVQDIS with
H1 PDFs from
inclusive diffraction

Fairly good description
for DIS
☛ factorisation works

Diffractive D*: γP



Data not overestimated by NLO calculations!

Contradiction to dijet results?

Compare with incl. γP results:

- incl. dijets: data/NLO ~ 1
- diffr. dijets: data/NLO ~ 0.6
- incl. D*: data/NLO ~ 1.6
- diffr. D*: data/NLO ~ 1

☛ ratio incl./diffr. same for dijets and D*

Conclusions and Outlook

H1 and ZEUS: Large number of new diffractive measurements with increased statistics and extended kinematical range:

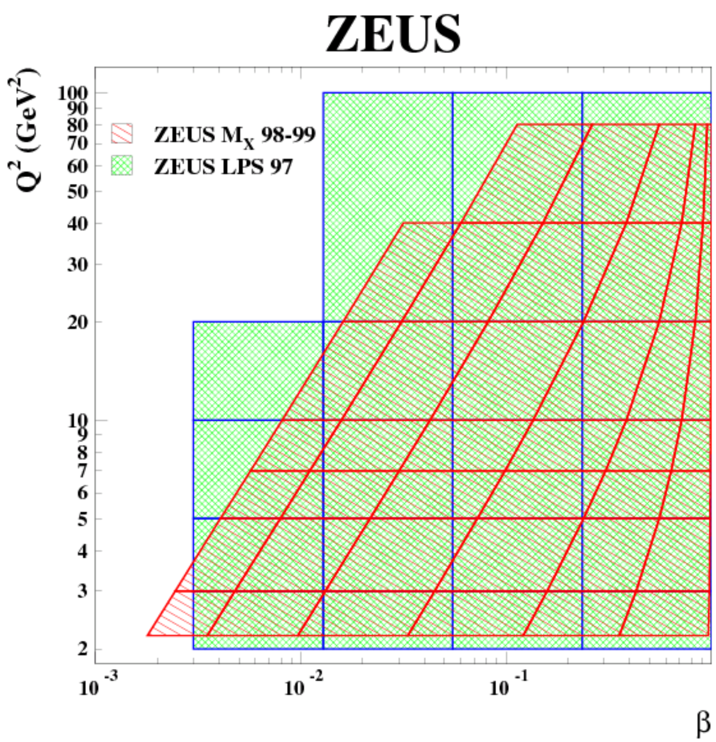
- indication of increase of intercept $\alpha_{IP}(0) \rightarrow$ **Regge factorisation breaking**
- Q^2 dependence of reduced CS: **large scaling violations** up to $\beta \sim 0.6$
- **Color dipole** and **QCD rescattering models describe data** reasonably well

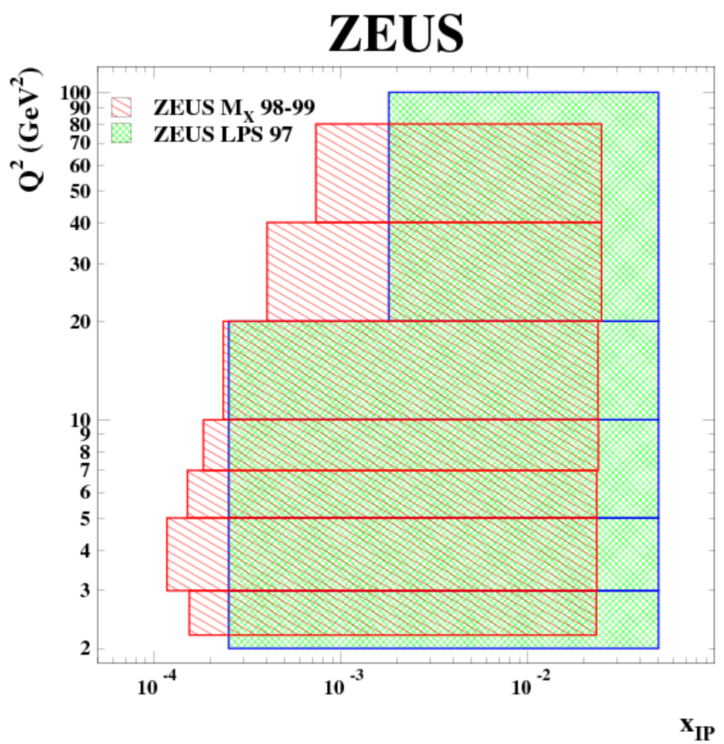
- diffractive PDFs extracted from DGLAP fits to H1 and ZEUS data:
  - **large gluon contribution** (difference between H1 and ZEUS due to different Q^2 evolution)

- test of diffractive PDFs with ep dijets and charm (D*) data:
  - **DIS:** NLO QCD calculations with **diffr. PDFs describe data**
  - **γP:** NLO QCD calculations **overestimate dijet data** by factor 1.6
    D* diffr. data described, but inclusive D* data underestimated

BACKUP

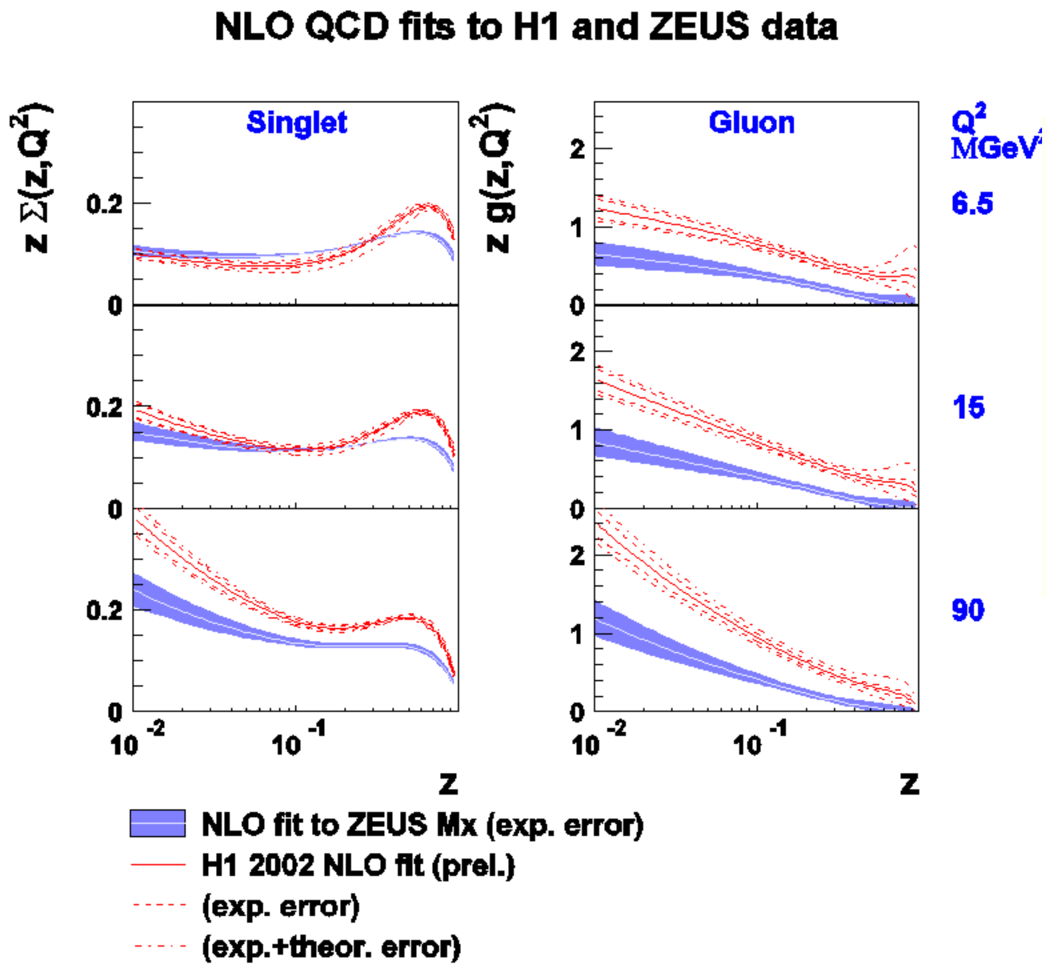
Kinematical ranges





- M_x method: Lower M_x region / higher β region and lower x_{IP} region
- LPS method: Higher x_{IP} region

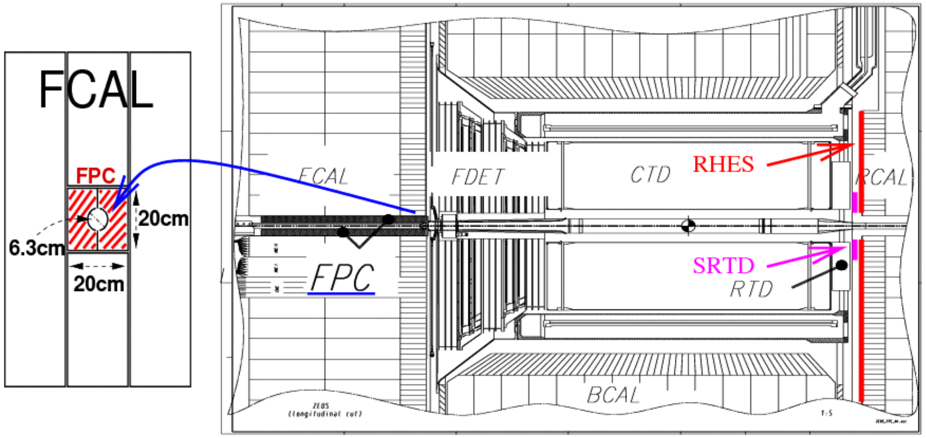
Comparison of NLO QCD fits: H1 LRG vs ZEUS M_x



Singlet similar at low Q^2, evolving differently at higher Q^2 due to coupling to gluon

Significant difference between diffractive gluon densities (almost factor 2) - main reason: different Q^2 evolution

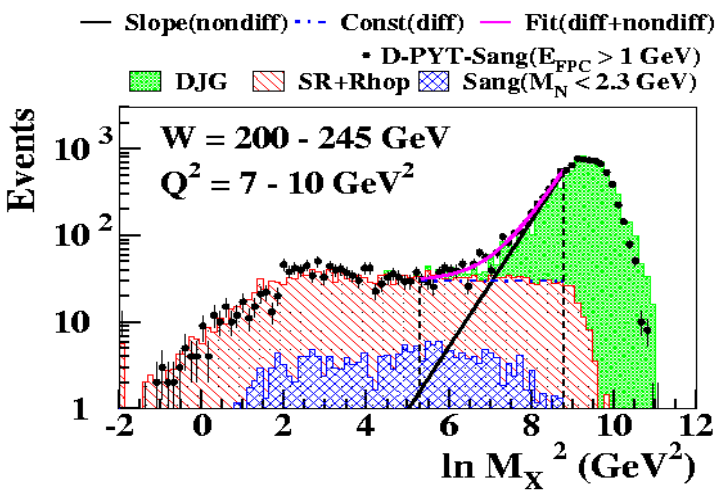
Event selection with M_x method (ZEUS)



Forward Plug Calorimeter (FPC):

CAL acceptance extended in pseudorapidity from $\eta=4$ to $\eta=5$

- higher M_x (a factor 1.7) and lower W
- p-dissociation events: for $M_N > 2.3$ GeV energy in FPC > 1GeV recognized and rejected



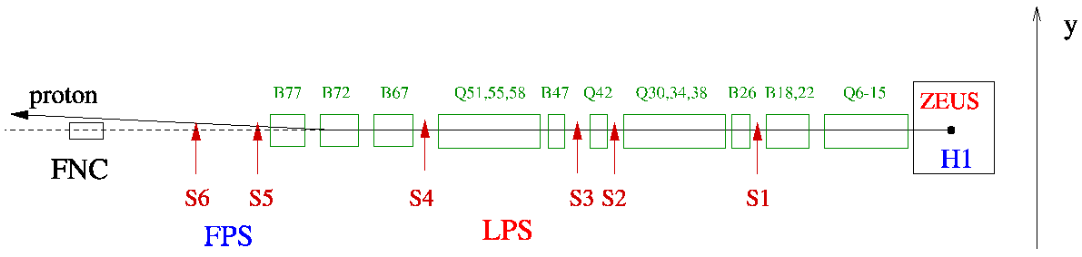
Diffr. Non-diffr.

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

(D, c, b from a fit to data)

- **flat** vs ln M_x^2 for **diffractive** events
- **exponentially falling** for decreasing M_x for **non-diffractive** events

Event selection with LPS (ZEUS and H1)

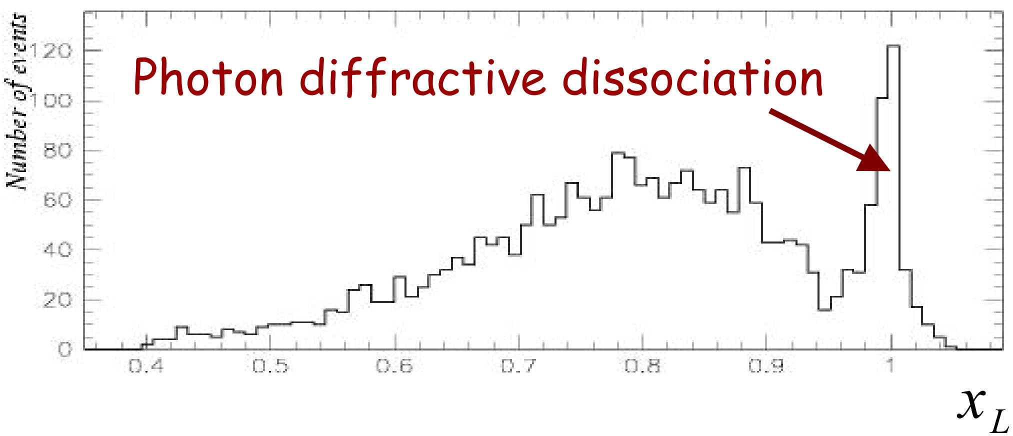


HERA I: ZEUS and H1
Leading proton spectrometers
HERA II: H1
Very forward proton spectrometer (~ 220 m)

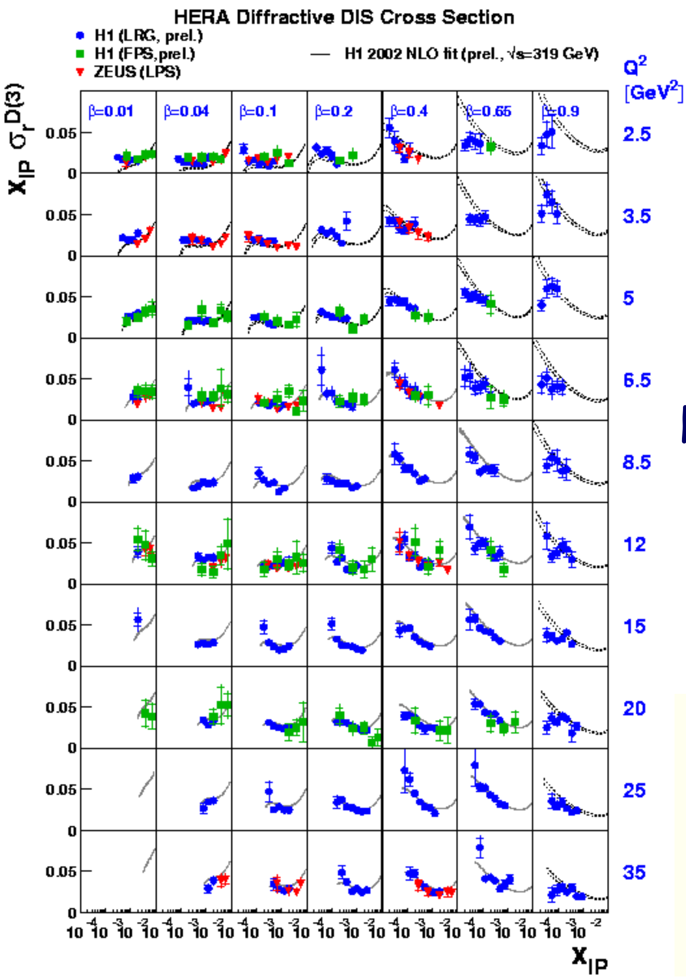
- t-measurement
- x_{IP} - measurement (access to high x_{IP} range)
- free of p-dissociation background
- small acceptance → low statistics

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

$$x_L = \frac{p'_z}{p_z} \approx 1 - x_{IP}$$



Reduced cross section: x_{IP} dependence (LRG/LPS Method)



Comparison of different methods:

- Large rapidity gap (LRG)
- Leading proton spectrometer (LPS)
- M_x

H1: LRG selection ⇔ LPS selection

M_Y<1.6 GeV	M_Y=m_p
|t|<1 GeV²	extrapol. to |t|<1 GeV²
	(IR contribution constrained at high x_{IP})

H1 LRG/LPS ratio: p dissociation contribution ~10%

Good agreement between both methods and both experiments.

ZEUS M_X/LPS ratio: p dissociation contribution ~30%