Diffraction and precise QCD measurements at HERA

Rencontres de Moriond QCD 2012

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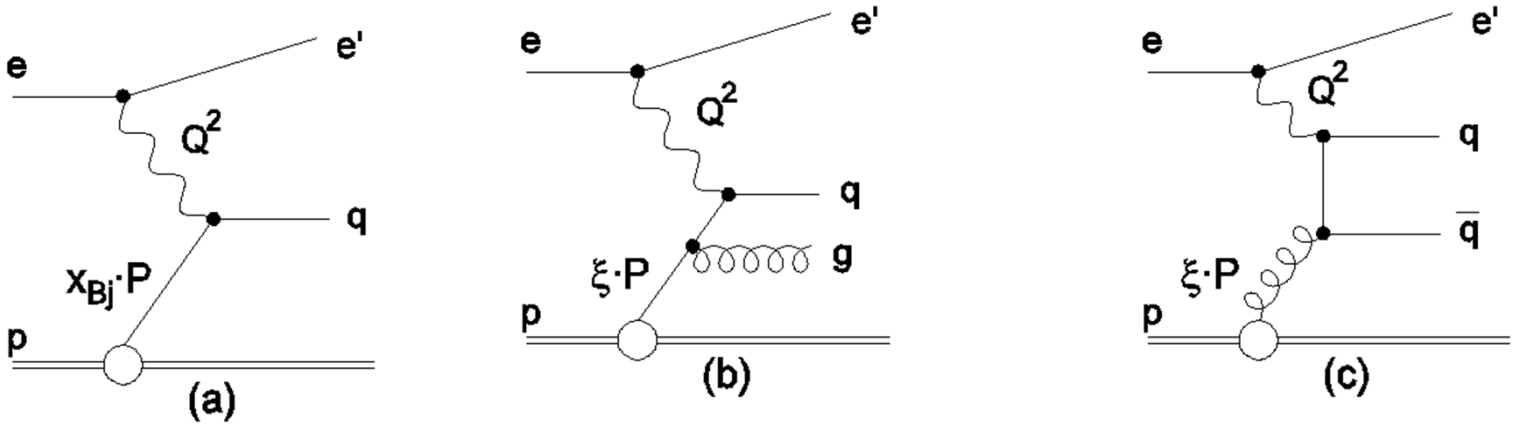
on behalf of the H1 and ZEUS Collaborations

- Jet cross sections in DIS and γp and $\alpha_s(M_Z)$
- Jets in HERAPDF fits
- New charm data in DIS
- Combined diffractive cross sections
- Tests of diffractive PDFs with dijets in DIS
- Diffractive heavy vector meson production

Inclusive and Jet production in DIS

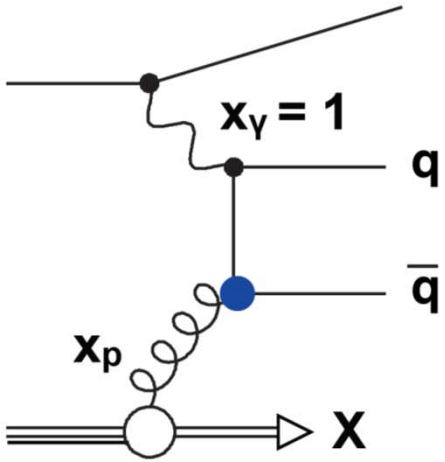


- Inclusive LO DIS: $\sigma \sim q(x,\mu_f)$
- High P_T Jets in the Breit frame in LO DIS: $\sigma_{jet} \sim \alpha_s(\mu_r)\cdot(c_g g(x,\mu_f)+c_q q(x,\mu_f))$
- QCD fits to inclusive NC and CC DIS data: α_s and gluon PDF are strongly correlated, sensitivity to gluon in NLO via scaling violations
- Jet data are sensitive to α_s and gluon PDF already in LO

➔ Combined inclusive DIS and Jet data reduce correlation between α_s and gluon PDF

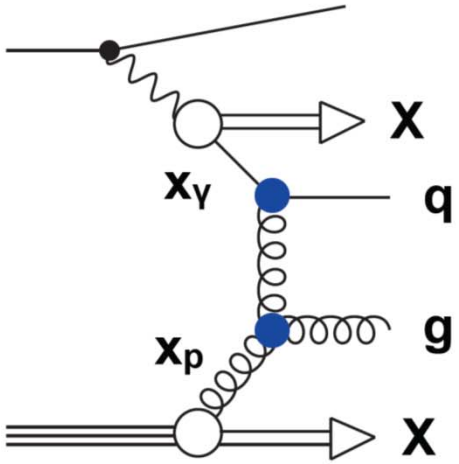
Jets in γp

Direct photo-production

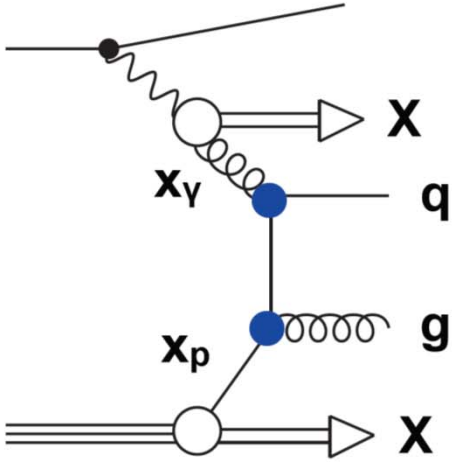


$\sim\alpha_s$

Resolved photo-production



$\sim\alpha_s^2$

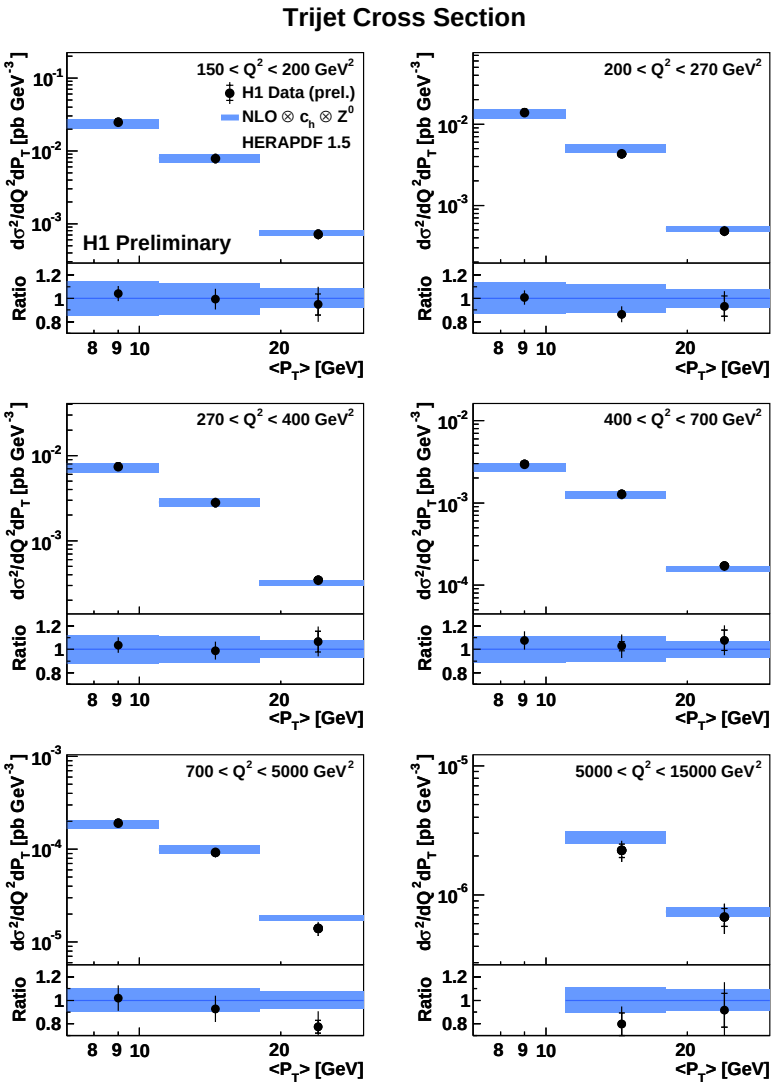


$\sim\alpha_s^2$

- $Q^2 \sim 0$ GeV^2, hard scale $\rightarrow$ P_T jet in lab frame
- Direct sensitivity to α_s, gluon and photon PDFs
- n-jet production in LO $\sim\alpha_s^{n-1}$ (direct) and α_s^n (resolved)
- x_γ distinguish between resolved photon ($x_\gamma<1$) and direct ($x_\gamma\sim1$) photon processes

Jets in DIS at high Q^2

H1 prel-11-032



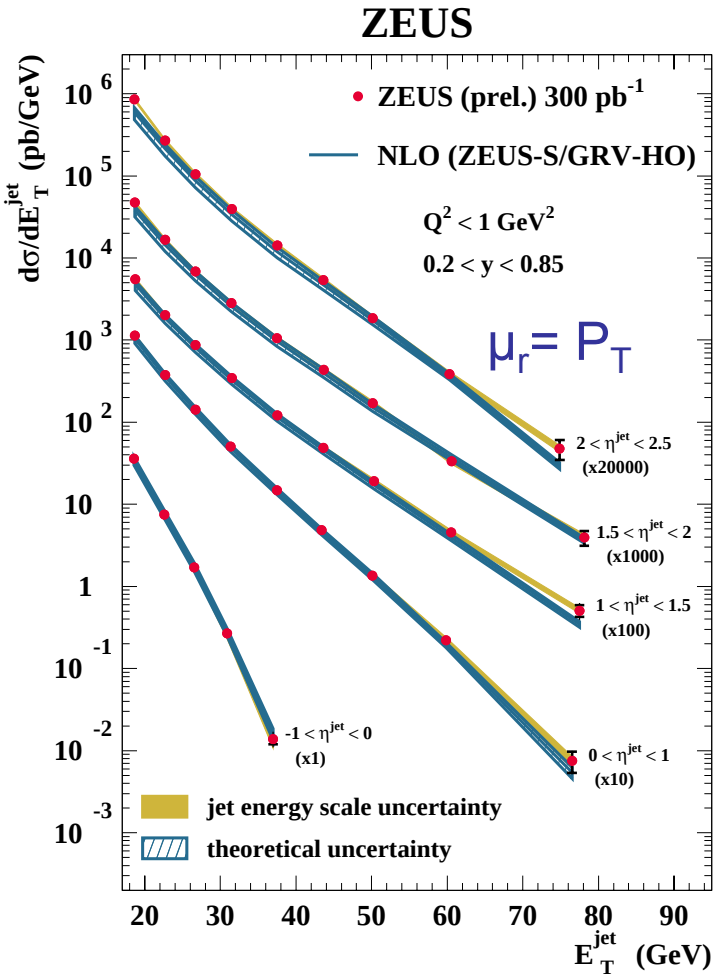
$L=351pb^{-1}$

- Inclusive jet, 2-jet, 3-jet production
- 1% jet energy scale uncertainty
- first double-differential 3-jet measurement at high Q^2
- data are well described by NLO calculation with $\mu_r^2 = (Q^2+P_T^2)/2$

3-jet: $\alpha_s(M_Z) = 0.1196 \pm 0.0016(exp) \pm 0.0010(pdf) \,{}^{+0.0055}_{-0.0039}$ (theory)

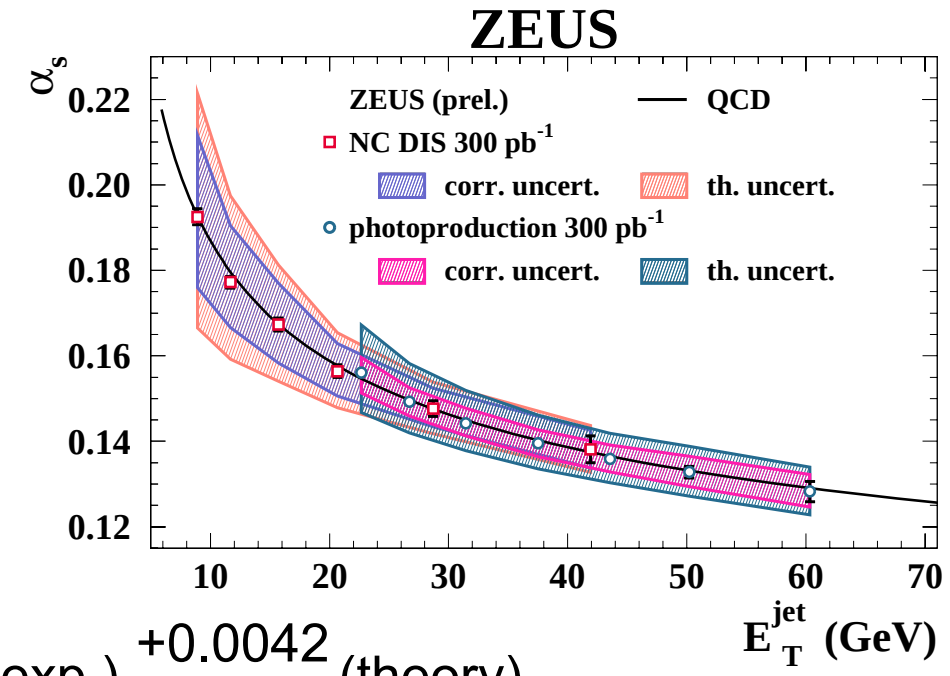
→ theory uncertainty dominates

α_s from Inclusive Jets in γp



ZEUS-prel-11-005

- 1% jet energy scale uncertainty
- large P_T accessible
- running of α_s measured in a single experiment at high Q^2 and in γp



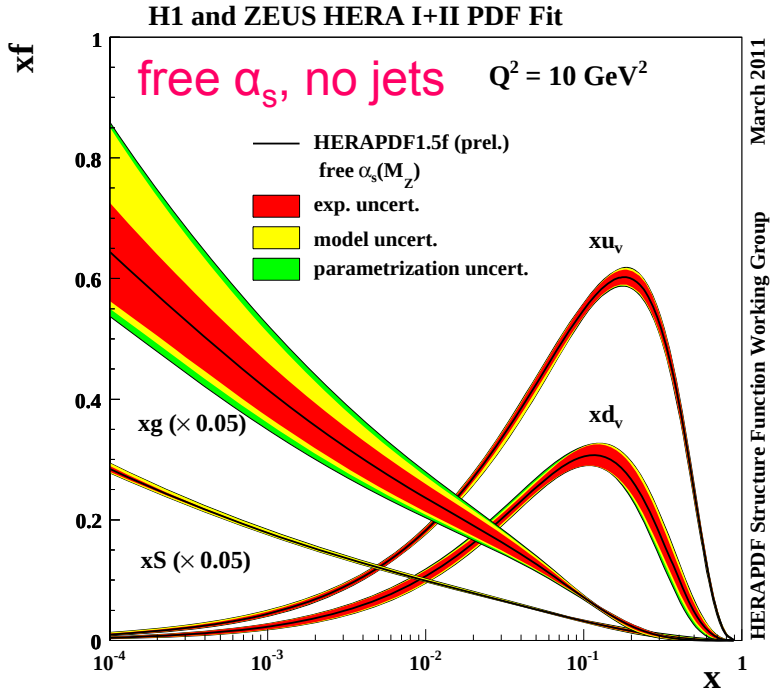
$$\alpha_s(M_Z) = 0.1206\ ^{+0.0023}_{-0.0022}\ (\text{exp.})\ ^{+0.0042}_{-0.0033}\ (\text{theory})$$

Combined PDF and α_s fit

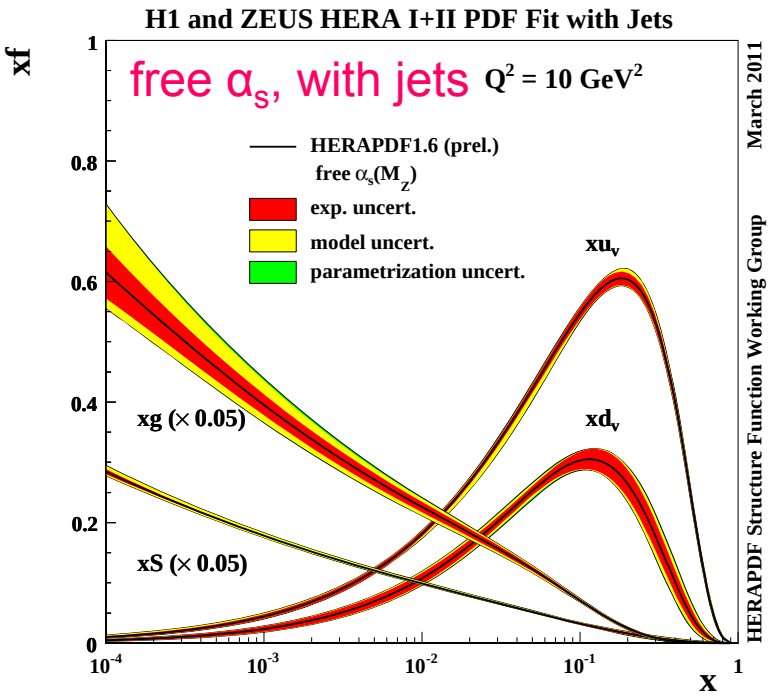
- PDF fit of inclusive DIS data: free α_s leads to very large uncertainty on gluon density

H1 prel-11-034
ZEUS-prel-11-001

- including jet DIS data dramatically decreases low-x gluon uncertainty

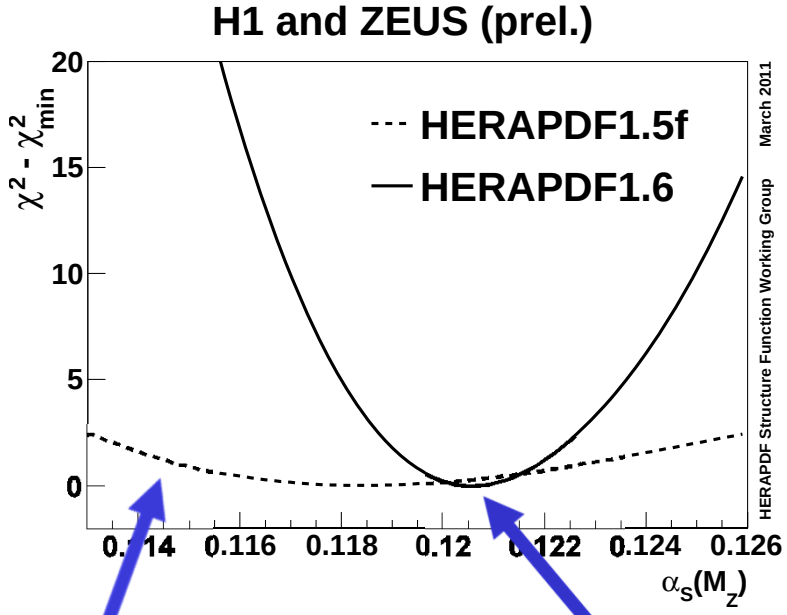


HERAPDF 1.5f



HERAPDF 1.6

HERAPDF: $\alpha_s(M_Z)$

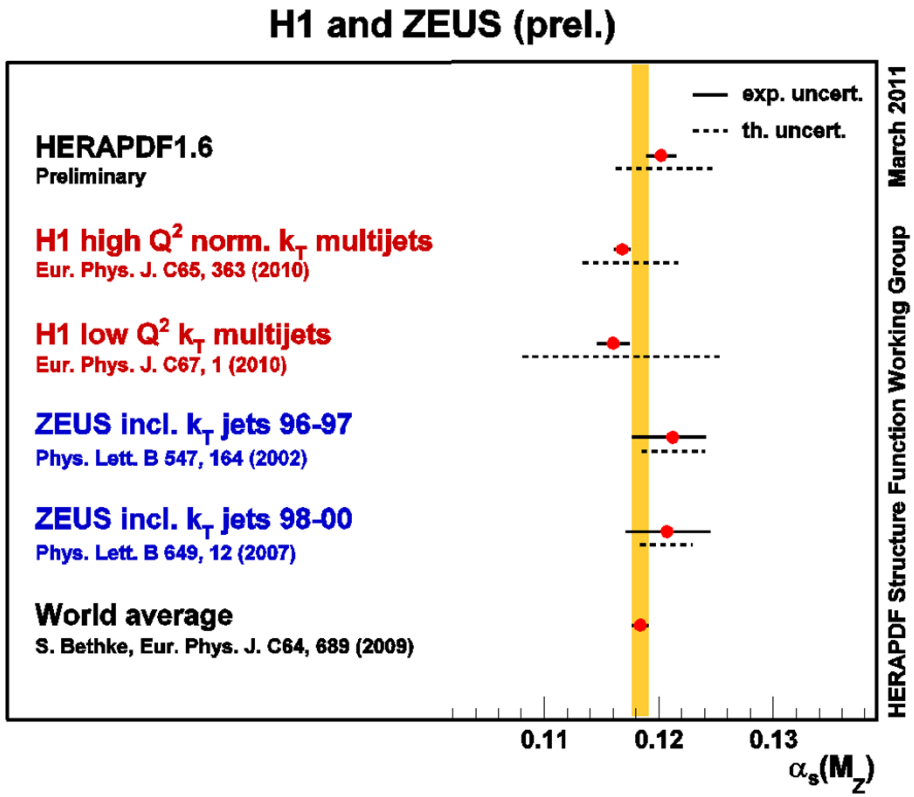


inclusive DIS data only

inclusive DIS + jet data

➔ adding jet DIS data reduces correlation of α_s and gluon PDF

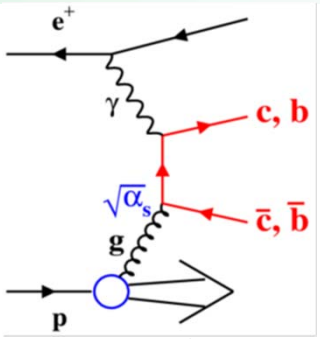
H1 prel-11-034 ZEUS-prel-11-001



$$\alpha_s(M_Z) = 0.1202 \pm 0.0019\ (\text{exp+mod+hadr})\ {}^{+0.0045}_{-0.0036}\ (\text{scale})$$

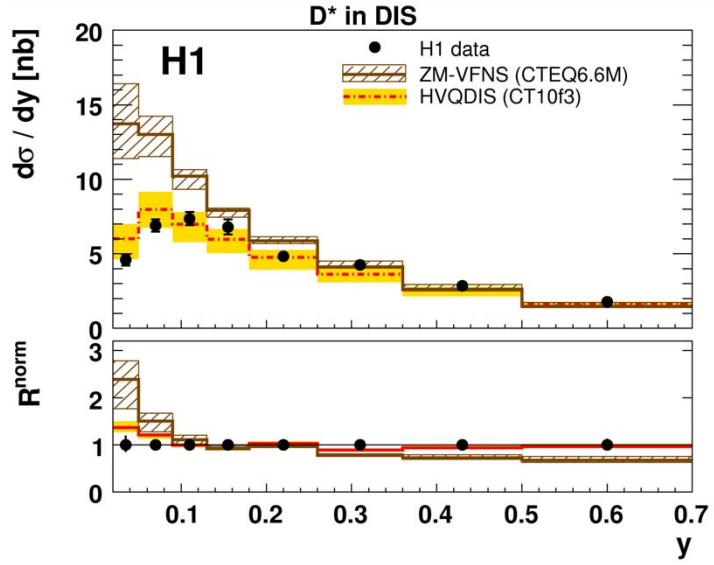
Charm in DIS with D*

- New precise HERA D* data are sensitive to different schemes of HF treatment
- Massive charm FFNS NLO better describes D* than massless ZM-VFNS

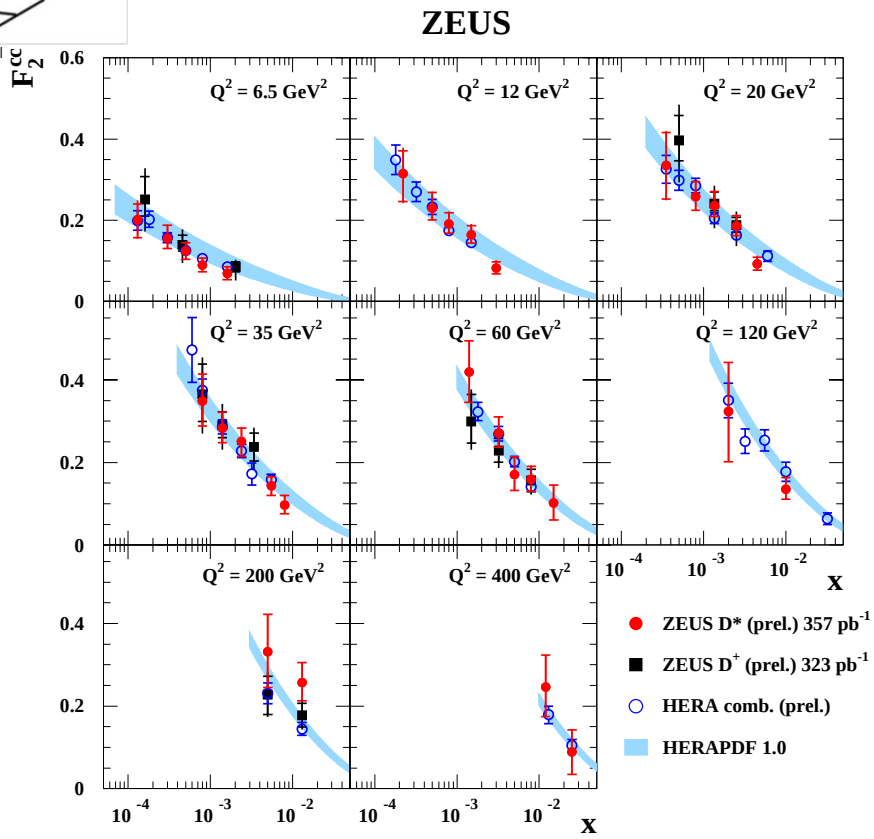


H1: EPJ C71 (2011) 1769

ZEUS-prel-11-012



F_2^{cc} from D* in DIS



Diffractive DIS at HERA

HERA: ~10% of low-x DIS events are diffractive with no color flow between hadron systems Y(p) and X

➔Probe structure of color singlet exchange with virtual photon

Selection of diffraction

- Large rapidity gap between leading proton and system X (limited by p-diss systematics)
- Proton spectrometers (limited by low acceptance and p-tagging systematics)

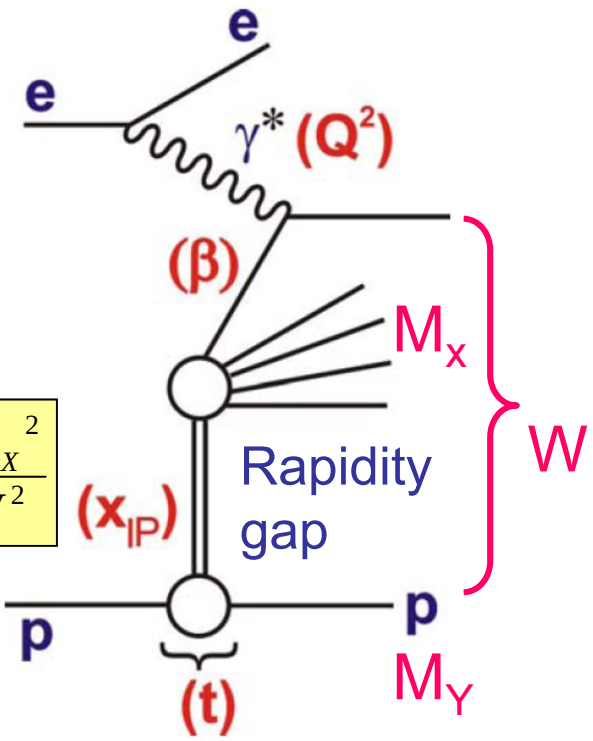
Diffractive DIS

Momentum fraction of color singlet carried by struck quark

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

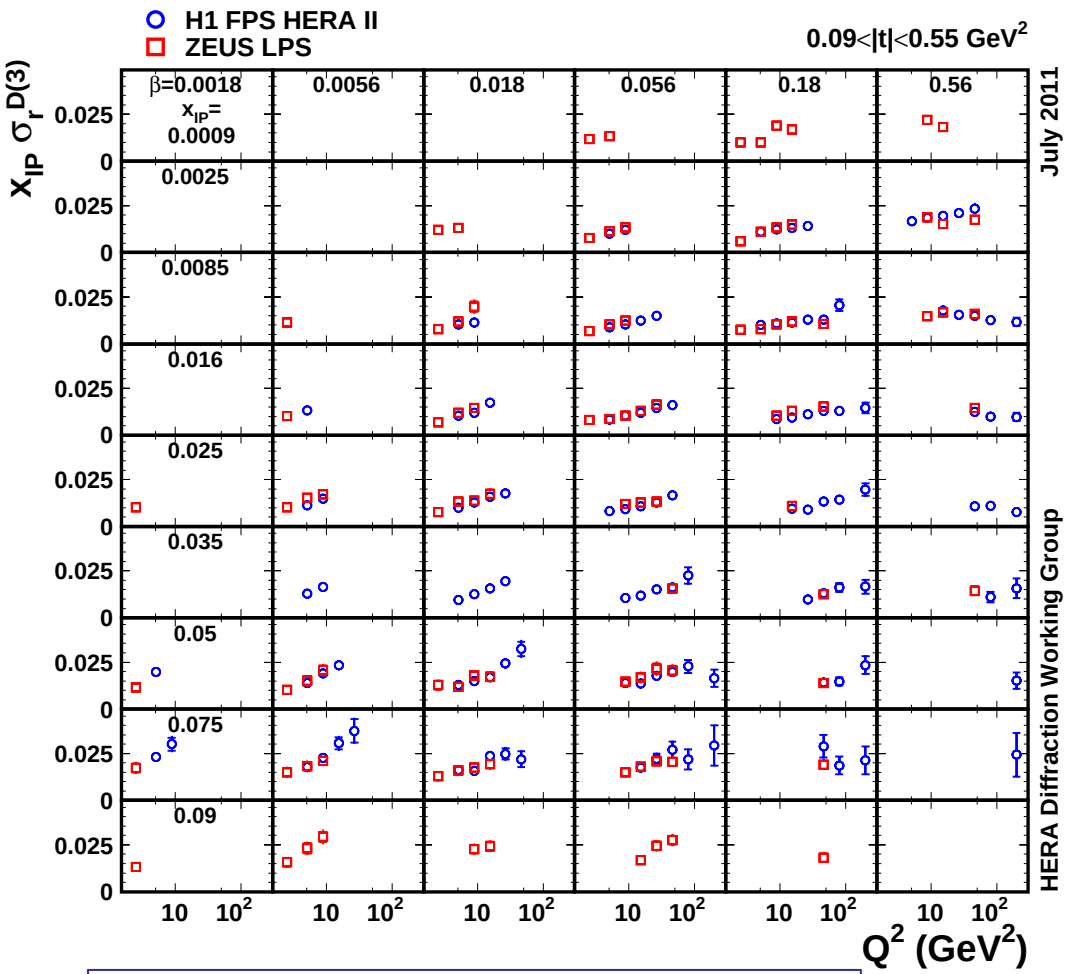
$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

Momentum fraction of proton carried by color singlet exchange



Squared 4-momentum transfer

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



H1 prel-11-111, ZEUS prel-11-011

Proton Spectrometer data in $0.09<|t|<0.55\text{GeV}^2$

Q^2-dependence in (β, x_{IP}) bins

- H1 FPS norm. uncertainty 4.5%, ZEUS LPS norm. uncertainty 7%

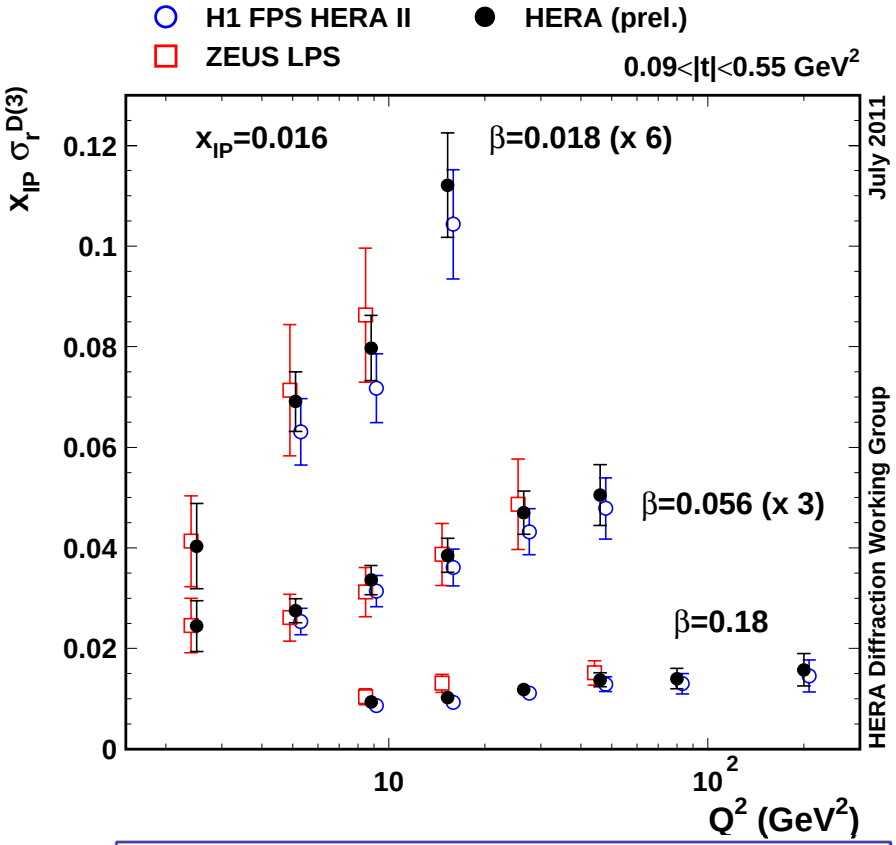
H1 / ZEUS: = 0.91 +/- 0.01(stat.) +/- 0.03(syst.) +/- 0.08(norm.)

➔ Reasonable agreement of H1 FPS HERA-2 and ZEUS LPS data in shape & normalisation

➔ Combine H1 and ZEUS cross sections to extend phase space and reduce uncertainties

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

A detailed look to the combined data



H1 prel-11-111, ZEUS prel-11-011

First combination of H1 and ZEUS diffractive data

➔Combined results from proton spectrometers

➔Consistency between data sets

➔Combination method uses iterative χ^2 minimization and include full error correlations

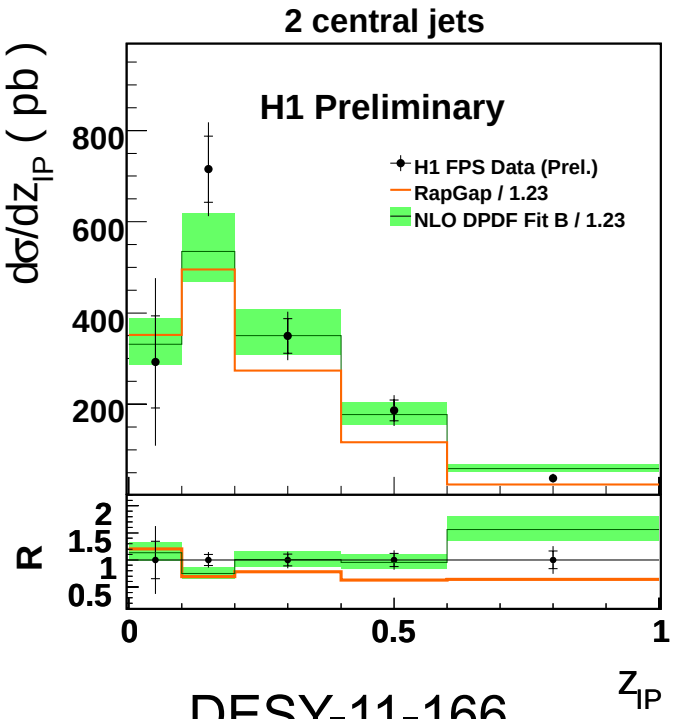
➔ Two experiments calibrate each other resulting in reduction of systematic uncertainties

➔ combined data have ~20% smaller uncertainties with respect to H1 data

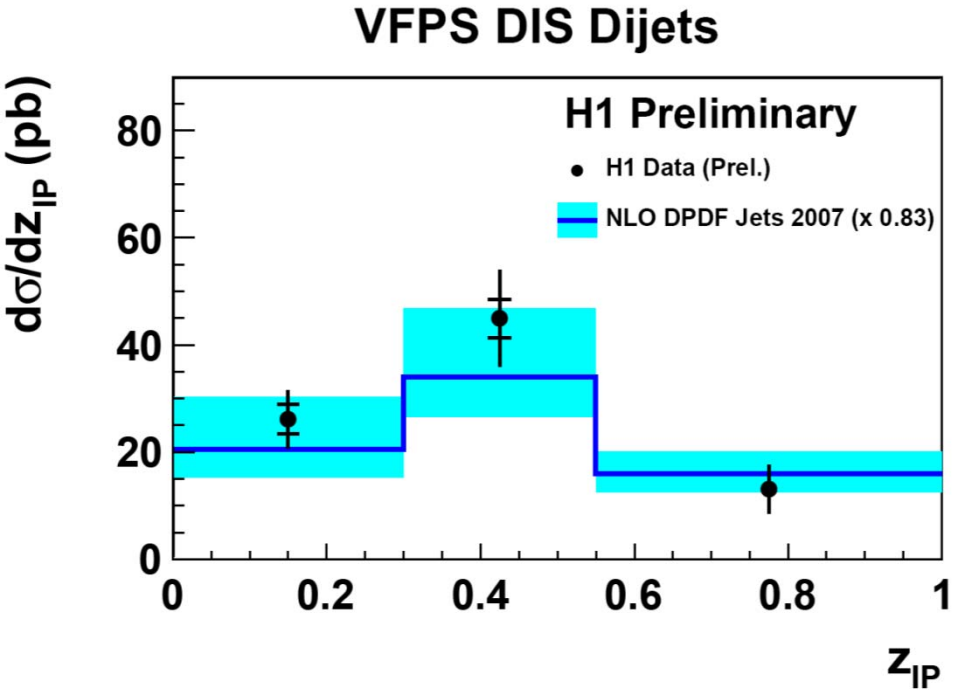
Central Jets in DDIS with tagged proton

FPS: $x_{IP}<0.1$, $p^*_{T1}>5$GeV, $p^*_{T1}>4$GeV

VFPS: $0.009<x_{IP}<0.024$, $p^*_{T1}>5.5$GeV, $p^*_{T1}>4$GeV



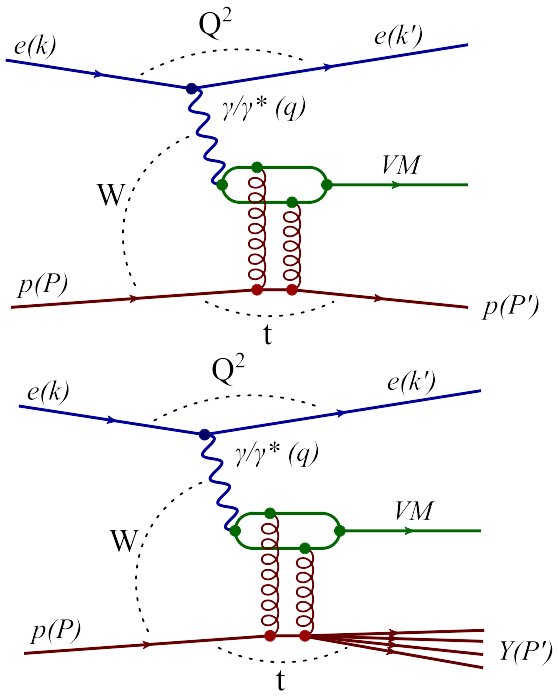
DESY-11-166



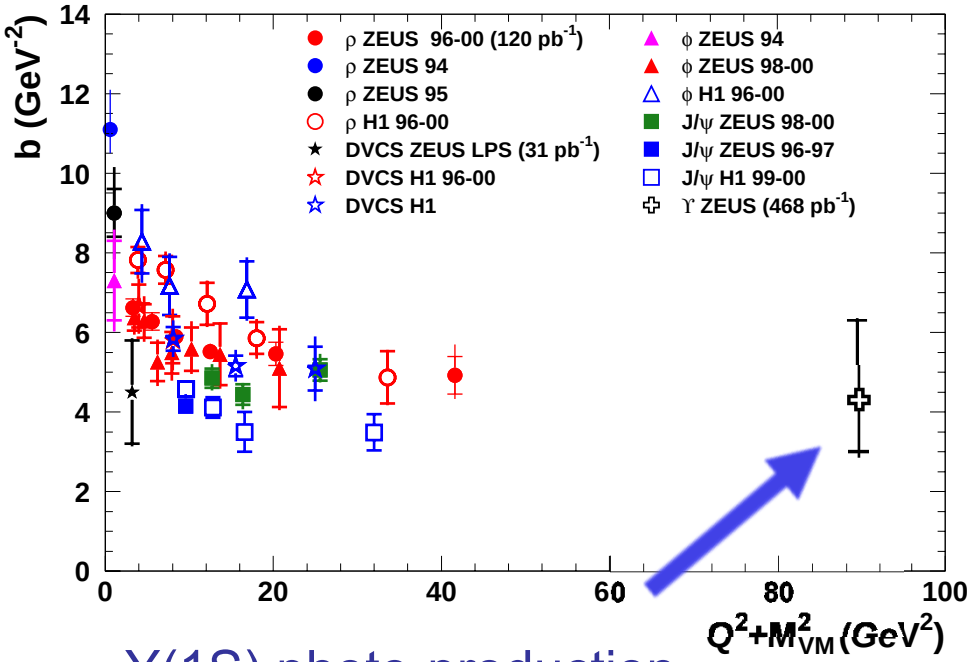
H1 prel-11-013

➔NLO predictions based on DPDFs H1 Jets an H1 Fit B describe central dijet production in DIS with tagged leading proton

Diffractive Vector Meson production



pQCD: simplest approach → 2 gluon colorless exchange



b is a measure of transverse size of interaction region

$\frac{d\sigma}{dt} \sim \exp(-B|t|)$ b = $b_V + b_p$

$b_V = 1/(Q^2+M_V^2)$ $b_p \sim 5$ GeV^{-2}

Y(1S) photo-production

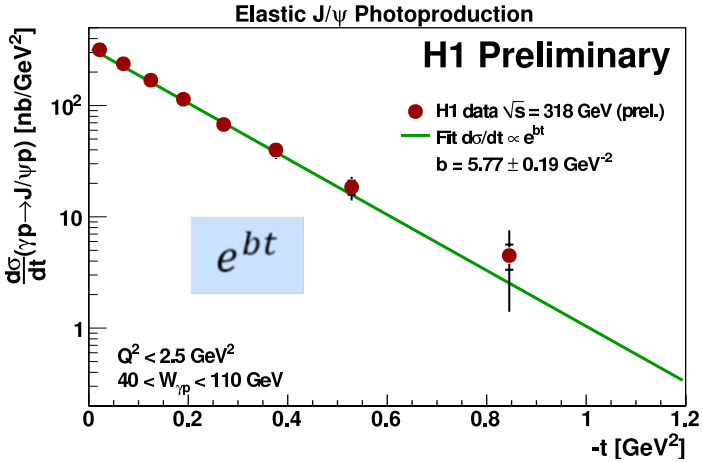
$$b = 4.3^{+1.7}_{-1.1}\ ^{+0.5}_{-0.5}\ [GeV^{-2}]$$

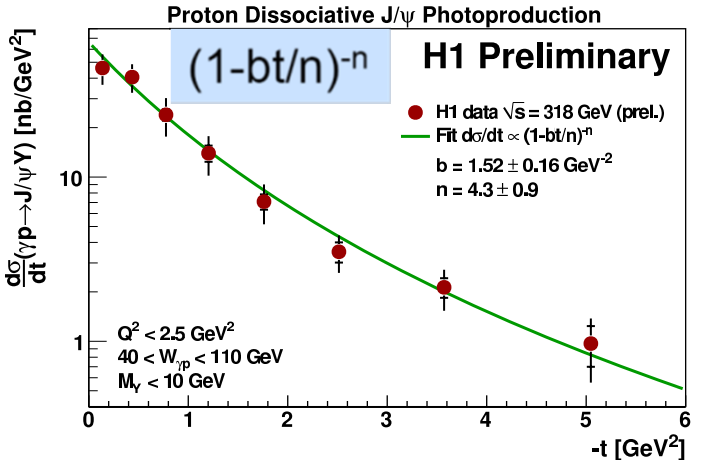
ZEUS: DESY-11-186

Diffractive J/ψ photo-production

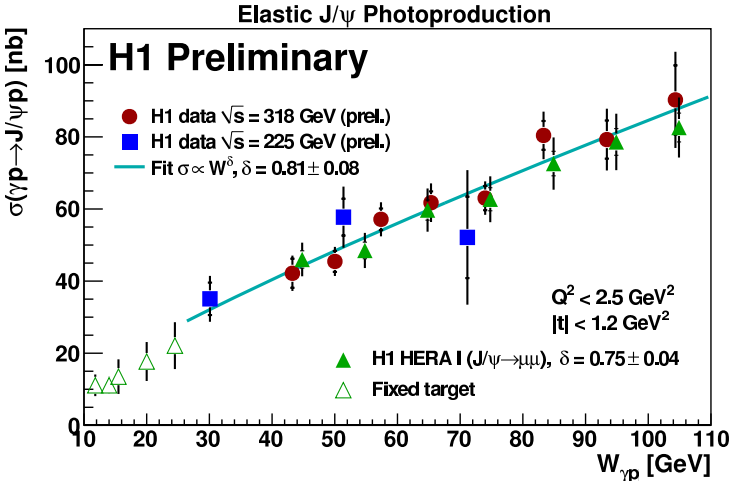
- Simultaneous measurement of elastic and proton dissociation J/ψ photo-production as a function of t and $W_{\gamma p}$

H1 prel-11-011





- Reduced proton energy run → extend data to lower $W_{\gamma p}$



pQCD:

$$\sigma_L \propto \alpha_s^2(Q^2_{eff}) \cdot |x \cdot g(x, Q^2_{eff})|^2 \quad Q^2_{eff} = \frac{1}{4}\left(Q^2 + M_V^2 + |t|\right)$$

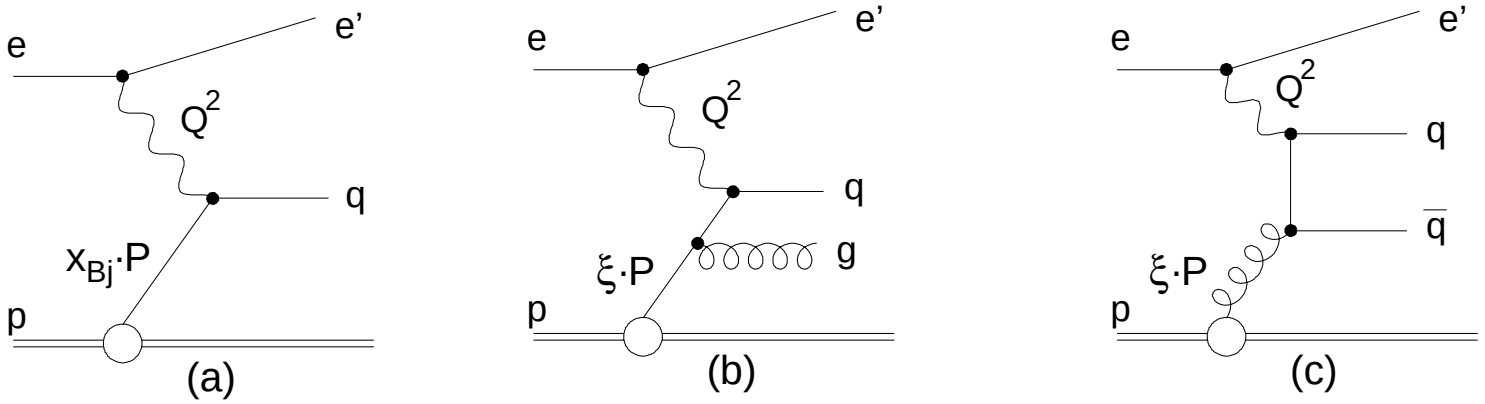
$$\sigma(W) \propto W^{\delta} \; ; \; \delta \approx 0.8 \text{ fast rise with W}$$

Summary

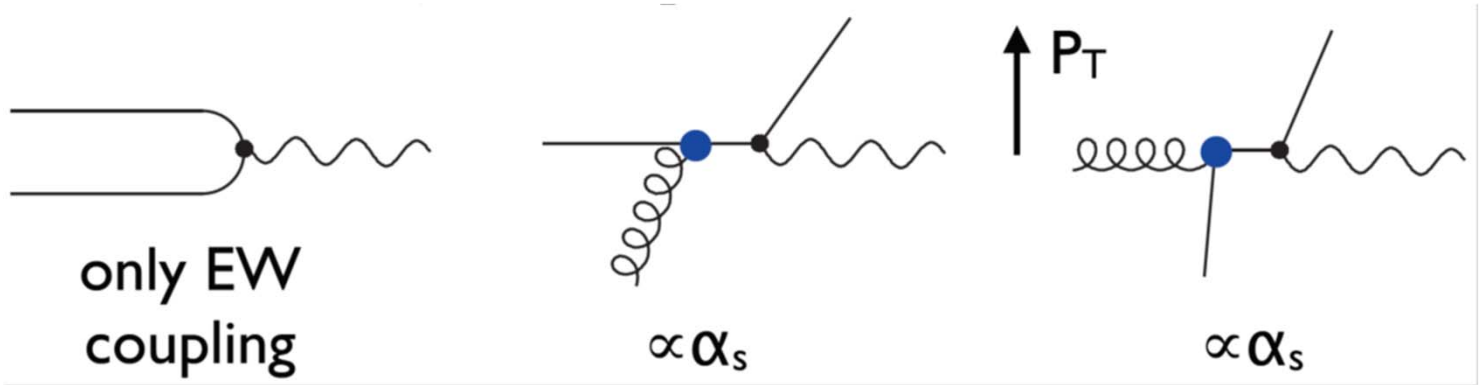
- Inclusive multi-jet data in DIS and photo-production provide stringent tests of proton PDFs
- NLO QCD fit of inclusive DIS and jet cross sections from H1 and ZEUS provide simultaneous determination of PDF and $\alpha_s(M_Z)$
  - ➢ Jets dramatically reduce correlation between gluon PDF and $\alpha_s(M_Z)$
- New precise charm data are sensitive to schemes of HF treatment
- HERA provide diffractive DIS data sensitive to structure of color singlet exchange.
  - ➢ First combination of H1 and ZEUS diffractive data with tagged proton give consistent results
  - ➢ Diffractive PDFs are tested in dijet production in DIS with tagged proton
  - ➢ New results are obtained on t and energy dependence of heavy vector meson photo-production

Backup slides

Inclusive and Jet production in DIS



DIS processes in the Breit frame: $2xP + q = 0$



QPM processes generate no P_T

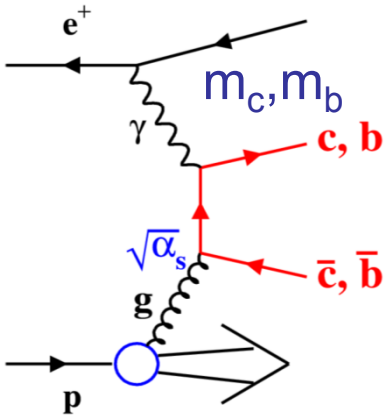
Only hard QCD processes generate large P_T in the Breit frame

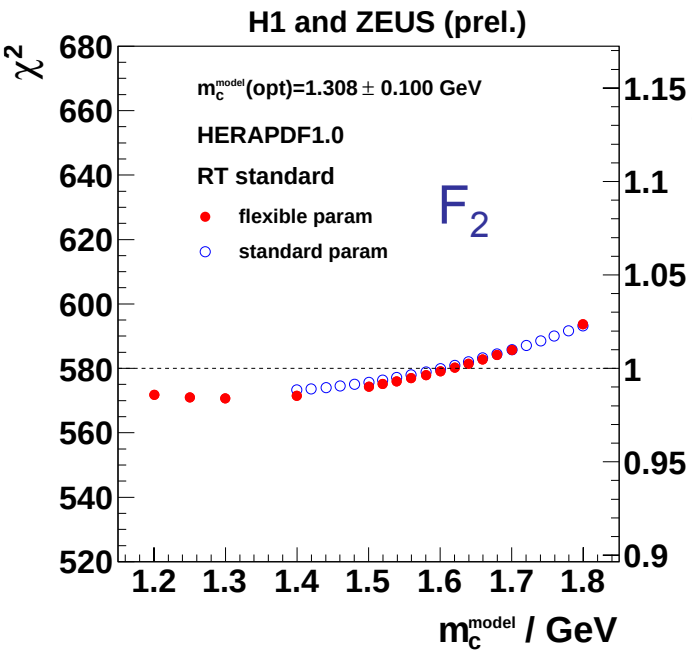
Charm mass as PDF fit parameter

➔ Study sensitivity of PDF fit to m_c value

H1 prel-10-143
ZEUS-prel-10-019

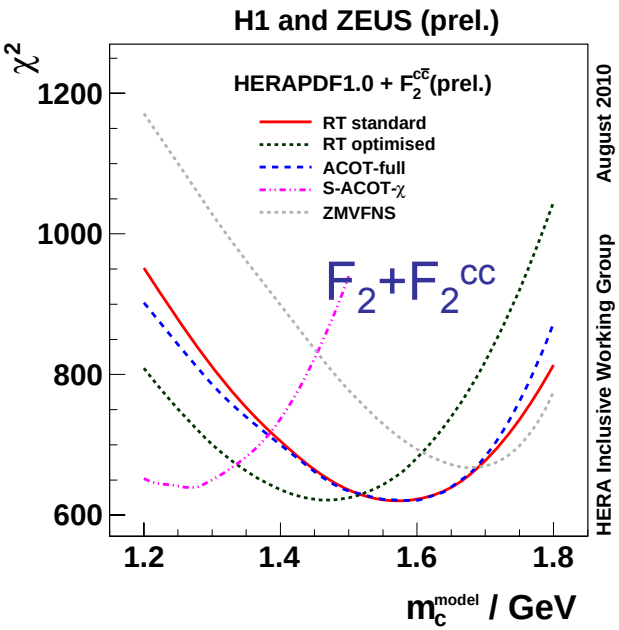
PDF fit to inclusive DIS





Little sensitivity to m_c

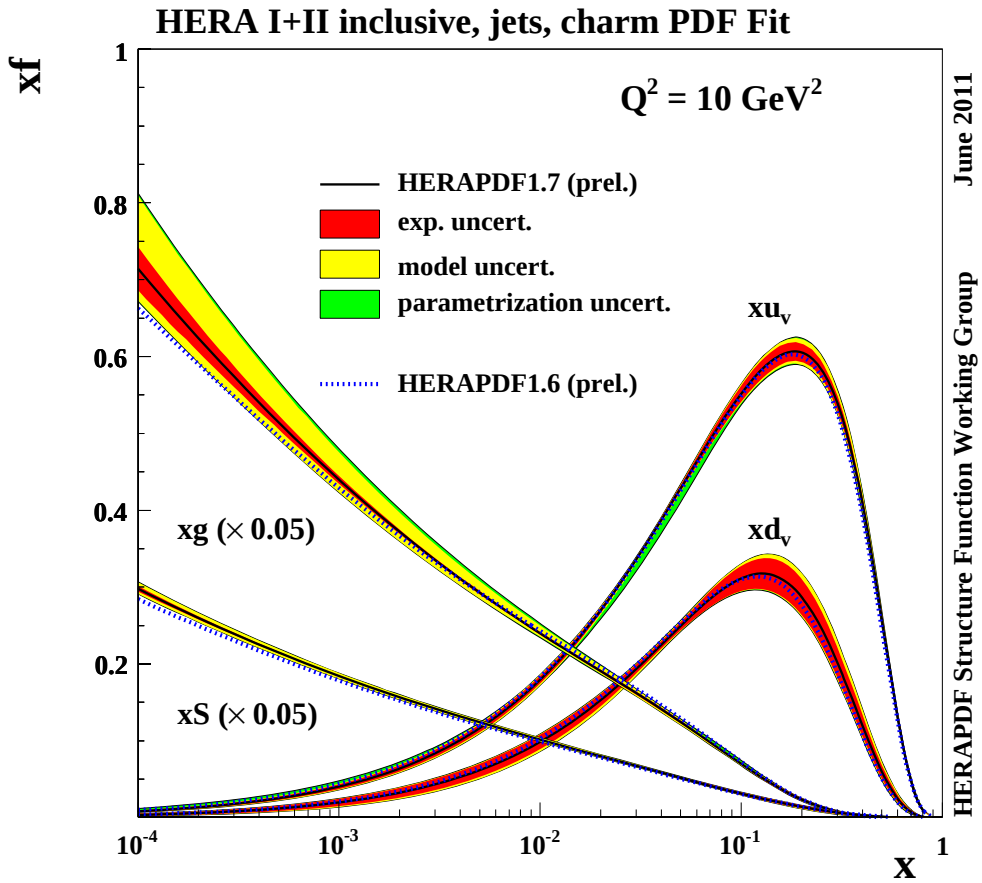
PDF fits to inclusive DIS + charm



strong dependence on m_c

- Optimal m_c depends on HF scheme in PDF fits: m_c =1.26-1.68 GeV for ZM-VFNS and GM-VFNS (RT:MSTW, ACOT:CTEQ)

NLO PDF fit to NC,CC,F_2^c,F_L,jets



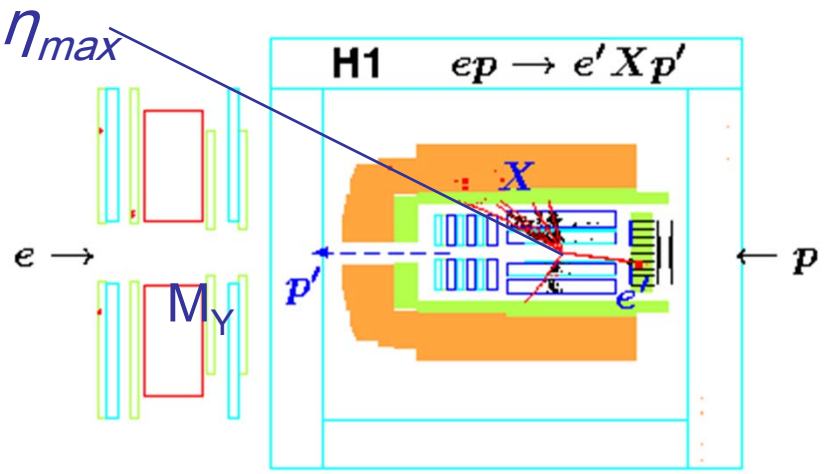
H1 prel-11-143
ZEUS-prel-11-010

- 14 parameter fit of gluon PDF → more flexible at low x
- α_s= 0.119, m_c= 1.5+/-0.15 GeV
- Gluon PDF decoupled from α_s and m_c

- NLO QCD fit to NC and CC cross sections, F_L, jet and charm data gives consistent picture of the proton

Selection of diffraction at HERA

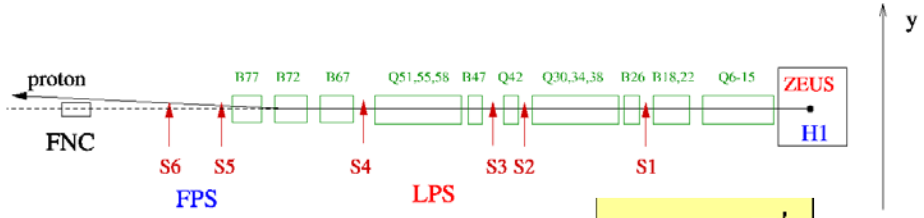
Large rapidity gap (LRG) between leading proton p and X



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

➔ LRG and FPS methods have different systematic uncertainties

Proton Spectrometers (PS)



H1 FPS + ZEUS LPS + H1 VFPS

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

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

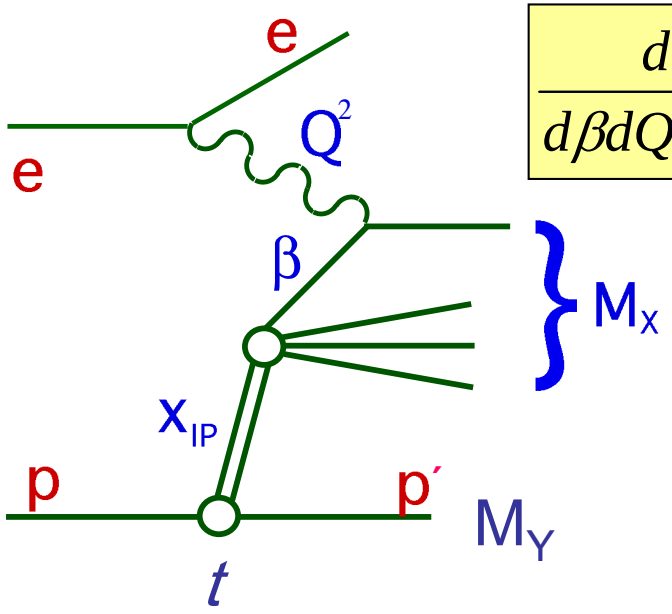
HERA-2:

➢ H1 FPS detector upgrade

➔ 20 times higher statistics than collected at HERA-1

➢ H1 VFPS has high acceptance

Diffractive Reduced Cross Section



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

Relation to F_2^D and F_L^D:

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

$$\sigma_r^D \approx F_2^D \text{ at low and medium y}$$

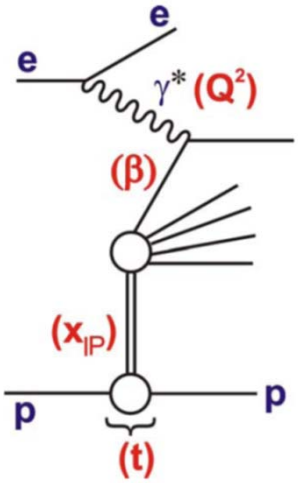
$$\sigma_r^{D(3)} = \int \sigma_r^{D(4)} dt$$

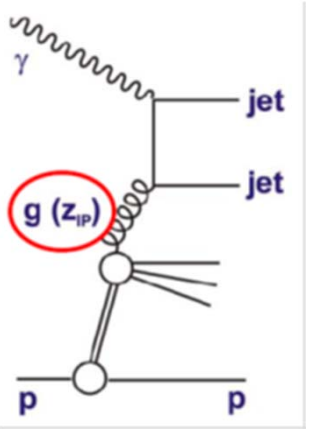
→ integrate over $|t|<1$ GeV^2 to compare PS results with LRG and diffractive PDF predictions

- F_2 directly related to quark density in proton
- $dF_2/d\ln Q^2$ (scaling violations) sensitive to gluon density
- F_L only non-zero in higher order QCD – independent access to gluon density

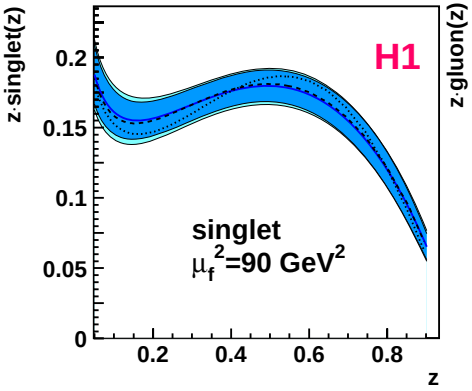
Diffractive PDFs: H1 vs ZEUS

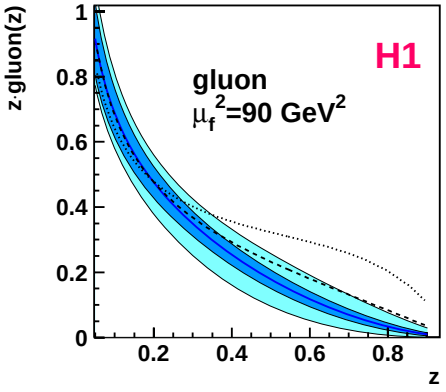
- Fit β and Q^2 dependences at fixed x_{IP}
- Parameterize quark singlet and gluon PDFs at starting scale Q_0 and evolve with Q^2 using NLO DGLAP
- Proton vertex factorisation assumption to fit data from different x_{IP} with complementary β,Q^2 coverage

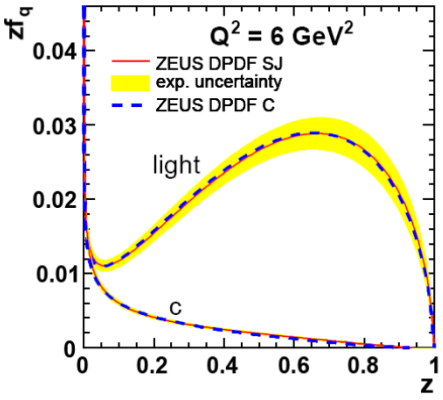


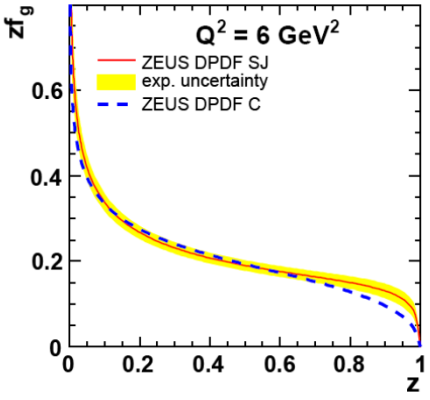


- Inclusive diffractive DIS cross sections constrain quark singlet and gluon (via scaling violations); Dijet DIS cross sections constrain high z gluon







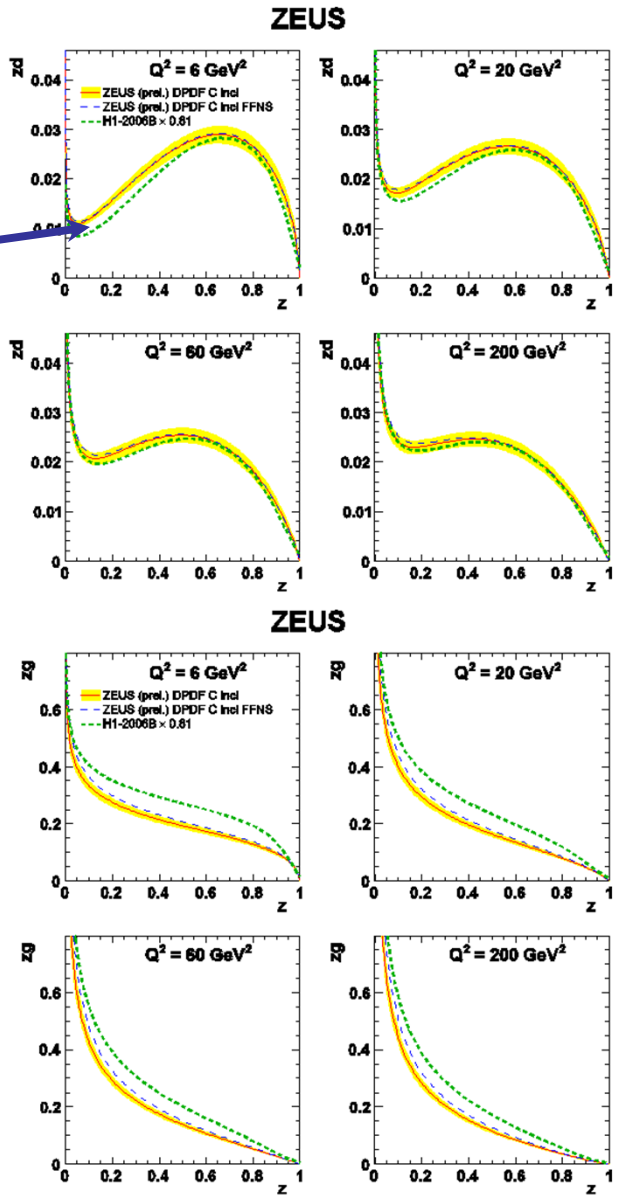


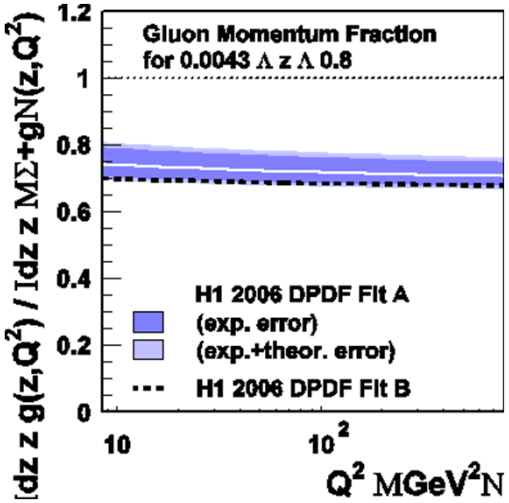
JHEP: 0710:042 (2007)

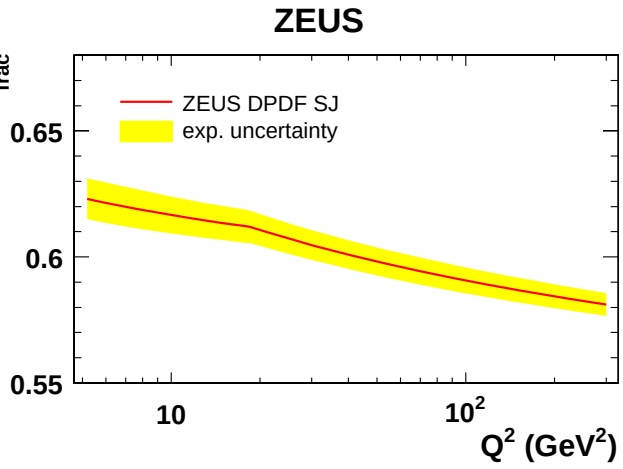
NP B831 (2010) 1

Diffractive PDFs: H1 vs ZEUS

- Recent ZEUS DPDF fits to inclusive LRG & LPS & diffractive Dijet DIS consistent with previous H1 DPDF fits up to normalization factor in data







- Overall ratio of gluon to quark density is 70:30 (H1) or 60:40 (ZEUS) ➔ similar to inclusive PDFs at low x

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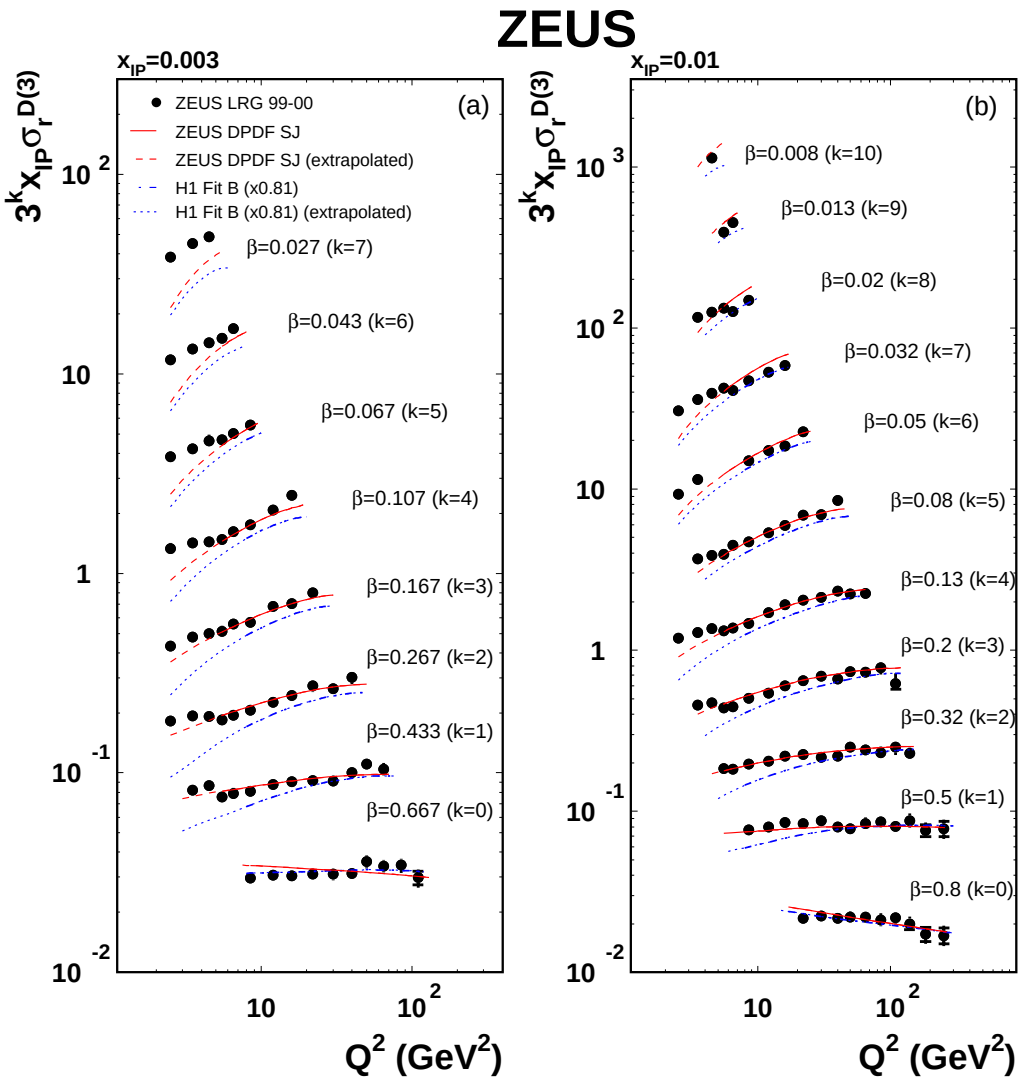
Diffractive PDFs: H1 vs ZEUS



➔H1 DPDF Fit B and ZEUS DPDF Fit SJ predict somewhat different behavior at low Q^2

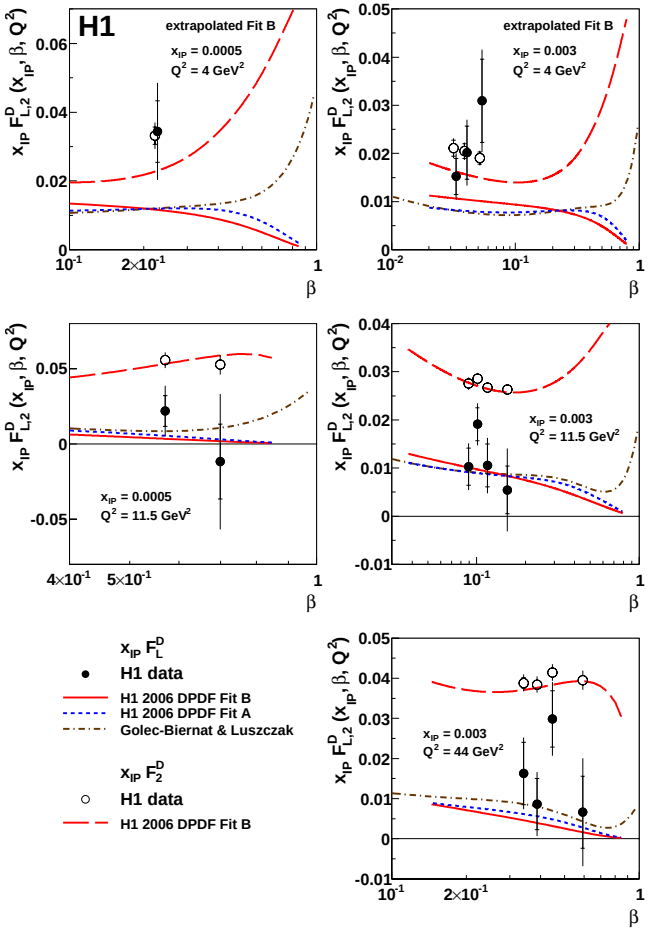
➔ fits reflect difference in normalization of H1 and ZEUS LRG data

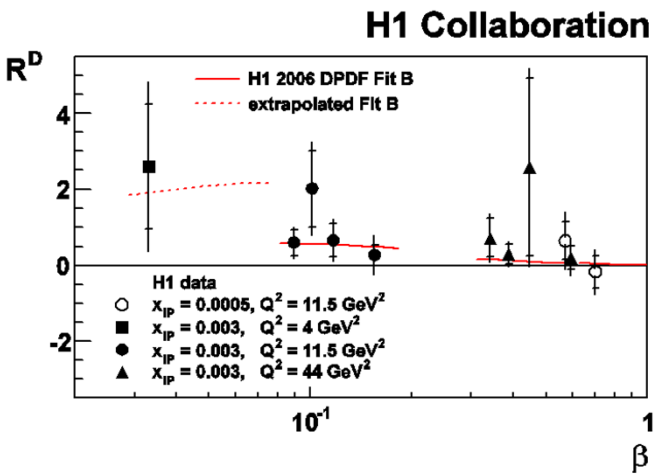
➔ need to understand differences in H1 and ZEUS LRG data sets to combine them and perform a QCD fit

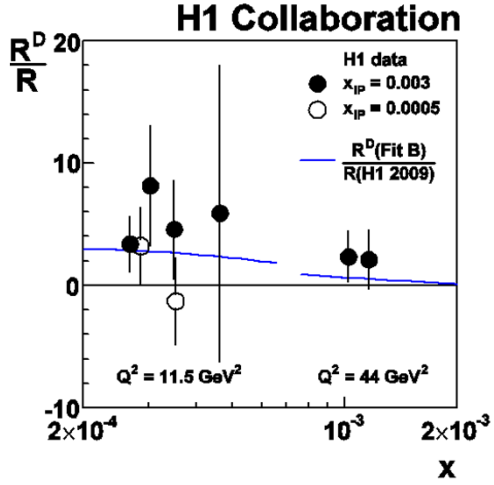
➔ most of H1 LRG data (1999-2000 HERA-1 and HERA-2) are still preliminary

F_2^D and F_L^D structure functions

$$R = \sigma_L / \sigma_T \rightarrow F_L^D / (F_2^D - F_L^D)$$







- F_2^D and F_L^D extracted in bins of Q^2, x_{IP} and β
- ➔ F_2^D and F_L^D data agree with H1 DPDF Fits
- Ratio of R^D to R(incl DIS) ➔ longitudinal component is larger in diffraction