

International Workshop on Diffraction in High Energy Physics
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Inclusive Diffraction and DPDF's



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Inclusive Diffraction at HERA

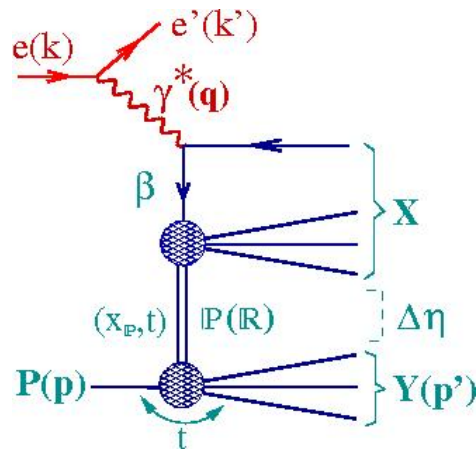
- Diffractive kinematics/signatures
- Experimental methods
- Comparison of different methods
- Results and factorisation

QCD fits and diffractive PDFs

- Diffractive PDF's from inclusive data
- Diffractive PDF's from inclusive and dijets

Diffractive kinematics ($e+p \rightarrow e'+X+Y$) and signatures

➤ Kinematical variables



$$\begin{aligned}
 x &= \frac{Q^2}{2p \cdot q} \approx \frac{Q^2}{W^2 + Q^2} \\
 Q^2 &= -q^2 = (k - k')^2 \\
 W_{\gamma p}^2 &= (p + k)^2 \\
 t &= (p - p')^2 \\
 x_P &= \frac{(p - p') \cdot q}{p \cdot q} \approx \frac{M_X^2 + Q^2}{W^2 + Q^2} \\
 \beta &= \frac{Q^2}{2(p - p') \cdot q} = \frac{x}{x_P} \approx \frac{Q^2}{M_X^2 + Q^2}
 \end{aligned}$$

➤ Diffractive signatures:

Longitudinal momentum transfer to proton is small
(coherence condition - Good and Walker)

$$|\Delta p_z| \lesssim \frac{1}{R_{Target}}$$

$$\Rightarrow \left| \frac{\Delta p_z}{p_{z_i}} \right| = 1 - x_L \approx x_P = \frac{M^2 + Q^2}{W^2 + Q^2}$$

$$x_L \Rightarrow 1$$

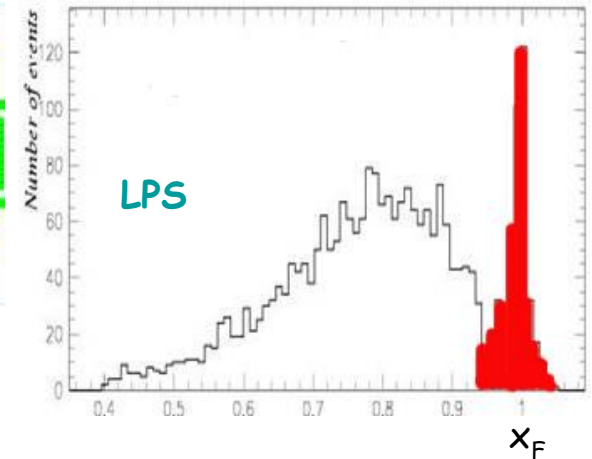
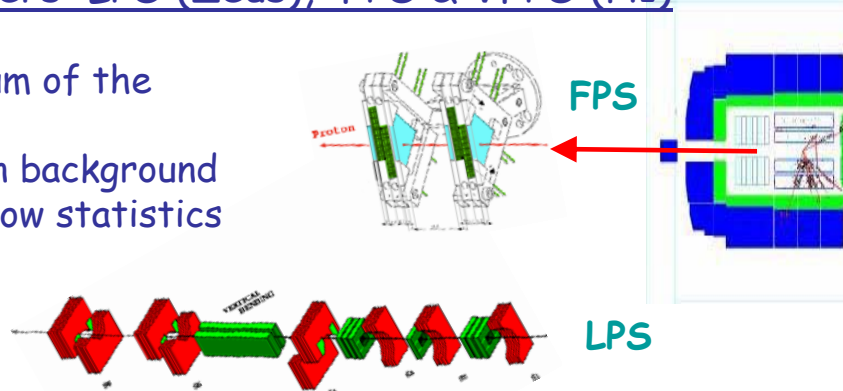
$$\Delta\eta \approx \ln \frac{1}{x_P} \frac{M_Y^2}{m_p^2}$$

$$\begin{array}{ll}
 x_P \text{ small} & \Delta\eta \text{ large} \\
 x_P \text{ large} & \Delta\eta \text{ small}
 \end{array}$$

Diffractive processes: detection methods - (1)

1. Proton Spectrometers: LPS (Zeus), FPS & VFPS (H1)

- ☺ Measure the momentum of the diffracted proton
- ☺ No proton dissociation background
- ☹ Small acceptance i.e. low statistics

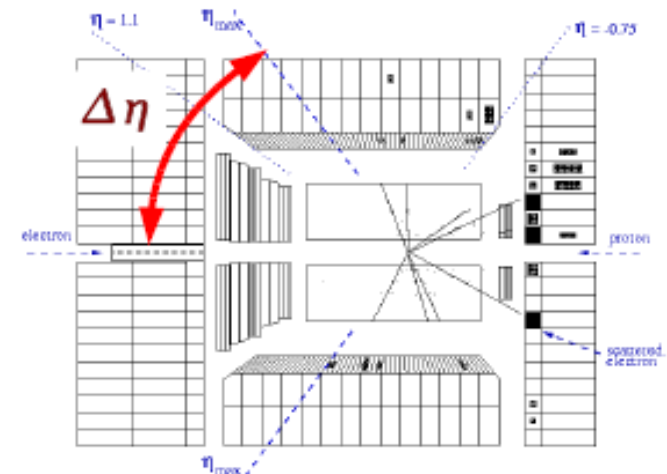


2. Large Rapidity Gap method: impose rapidity gap cut η_{\max}

- ☺ Very good acceptance
- ☹ No t -measurement:
- ☹ Proton dissociation

integrate over t , -1 GeV^2 , t_{\min} to be estimated

	H1	Zeus
Max. rapidity	$\eta_{\max} < 3.3$	$\eta_{\max} < 3.$
Proton dissociation corrected to	$M_y < 1.6 \text{ GeV}$	$M_y = M_p$ (param. p-dissoc. background)



Diffractive processes: detection methods - (2)

3a. M_X subtraction method (Zeus)

Based on

$$\begin{aligned} \text{Dis} \quad P(\Delta\eta) &\propto e^{-\lambda\Delta\eta} \rightarrow \frac{dN_{N-Diff}}{d\ln M_X^2} = c \cdot e^{b \cdot \ln M_X^2} \\ \text{DDis} \quad \text{Tripple Regge} &\rightarrow \frac{dN_{Diff}}{d\ln M_X^2} \propto \ln M_X^2 \approx \text{const.} \end{aligned}$$

Calculate M_X up to $n_{\max}(\text{FPC}) = 4-5$

Fit to the inclusive DIS data

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

with D constant and subtract bin by bin the non-diffractive component

- Reggeon contributions suppressed

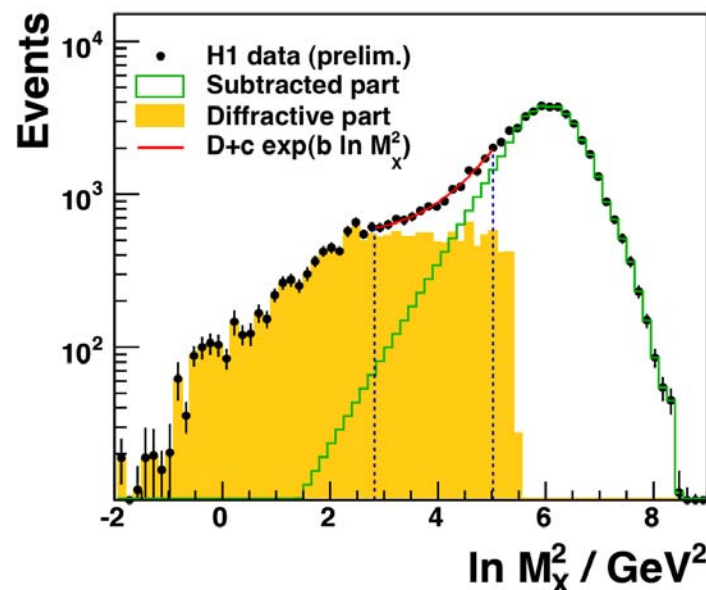
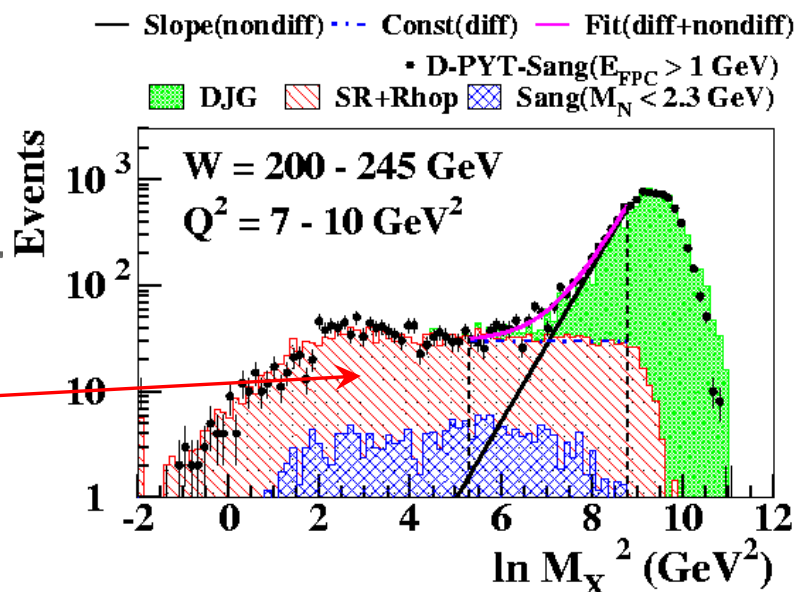
- P-diss corrected to $M_Y < 2.3 \text{ GeV}$

LRG		M_X
H1	Zeus	Zeus
$M_Y < 1.6 \text{ GeV}$	$M_Y = m_p$	$M_Y < 2.3 \text{ GeV}$

3b. M_X subtraction method (H1)

- Smaller η reach (3.3 vs. 5) \rightarrow restricted W range
- M_X - subtraction method less appropriate for H1

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Comparison of data sets and methods

Compare data sets and methods

- different systematic
- different kinematical regions

- LRG (Zeus) vs. M_X (Zeus)
- LPS (Zeus)/LRG (Zeus) , FPS(H1)/LRG(H1)
- LRG (Zeus) vs. LRG (H1)

Reduced cross section - diffractive structure function

- $\frac{d^4\sigma(ep \rightarrow e' X p)}{dx dQ^2 dx_P dt} = \frac{4\pi\alpha^2}{xQ^4} \left(1 - y - \frac{y^2}{2}\right) \sigma_r^{D(4)}(x, Q^2, x_P, t)$
- $\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1 - y - y^2/2)} F_L^{D(4)} \quad \sigma_r^{D(4)} \approx F_2^{D(4)} \left\{ \begin{array}{l} \rightarrow \text{at low } y \\ \rightarrow F_L^{D(4)} = 0 \end{array} \right.$
- $\sigma_r^{D(3)} = \int_{-1}^{t_{min}} dt \sigma_r^{D(4)}$

Comparison of data sets and methods: LPS/LRG - LRG/FPS

Reduced cross section ratio LPS/LRG (ZEUS)

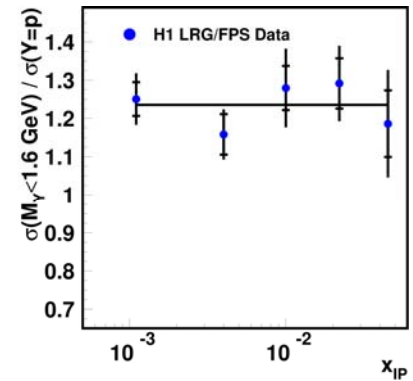
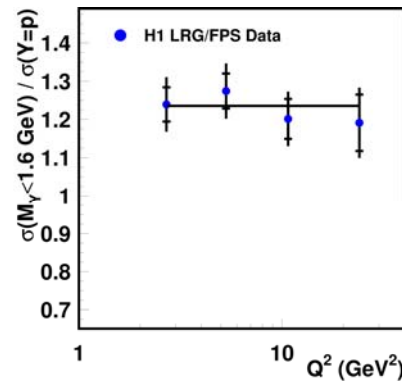
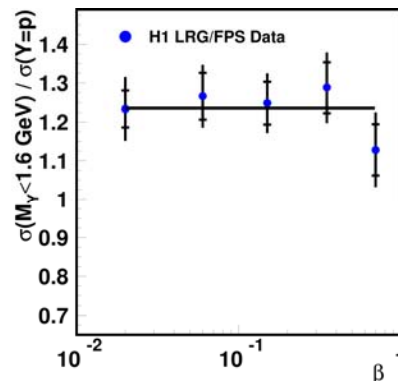
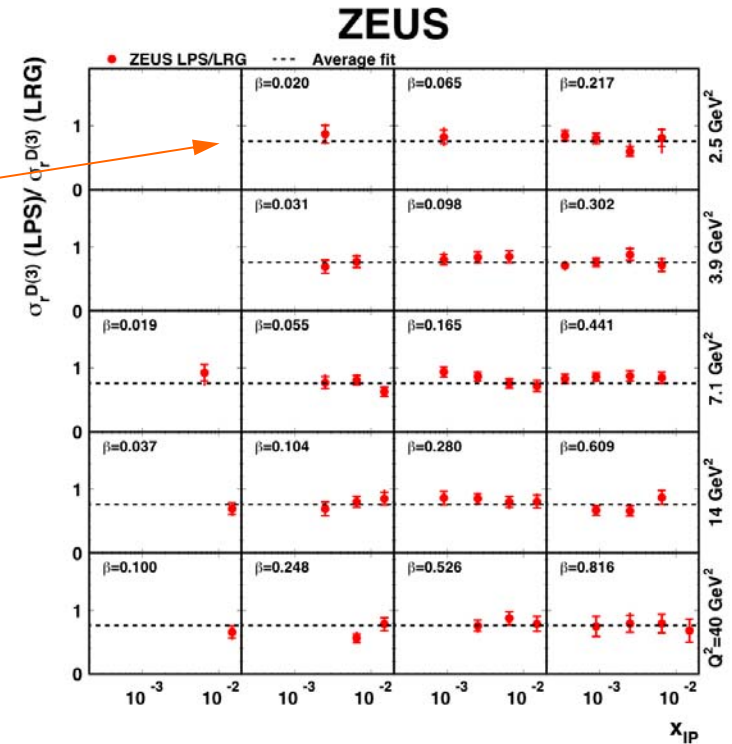
$$\begin{aligned} \text{Ratio} &= \frac{\sigma_{\tau}^{D(3)}(LPS)}{\sigma_{\tau}^{D(3)}(LRG)} \left(\begin{array}{c} \text{Before Correction} \\ M_Y = p \end{array} \right) \\ &= 0.76 \pm 0.01(\text{stat.})_{-0.02}^{+0.03}(\text{syst.})_{-0.05}^{+0.08}(\text{norm.}) \\ \bullet \text{ Proton dissociation in LRG:} \end{aligned}$$

$$[24 \pm 1(\text{stat.})_{-3}^{+2}(\text{syst.})_{-8}^{+5}(\text{norm.})]\%$$

Ratio independent of Q^2 , x_{IP} and β

FPS/LRG (H1)

$$\text{Ratio} = \frac{\sigma_{\tau}^{D(3)}(LRG)|_{M_Y < 1.6 \text{ GeV}}}{\sigma_{\tau}^{D(3)}(FPS)} = 1.23 \pm 0.03(\text{stat.}) \pm 0.16(\text{syst.})$$



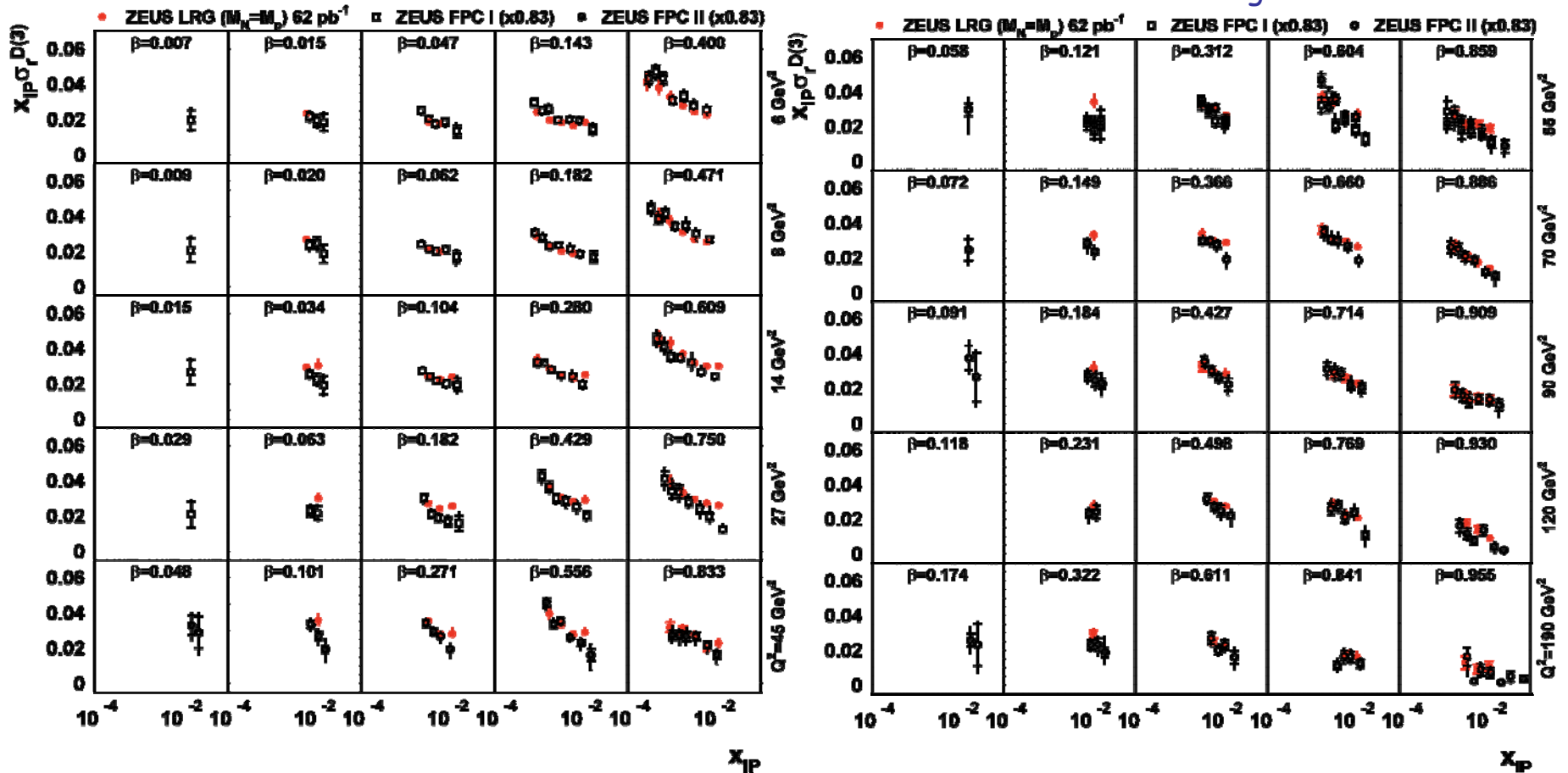
Comparison of data sets and methods: M_x - vs. LRG-method (ZEUS)

- LRG (M_p)-method
- M_x ($M_y < 2.3$ GeV) -method

M_x data normalized to
LRG data from global fit

$$\text{Norm. Fac.}(M_x/\text{LRG}) = 0.83 \pm 0.04$$

→ P-dissoc. background in M_x method



Good overall agreement: differences for $x_{IP} > 0.01$ and low Q^2
attributable to Reggeon suppression in M_x data

Comparisons of data sets and methods: LRG(H1)-LRG(Zeus) - (1)

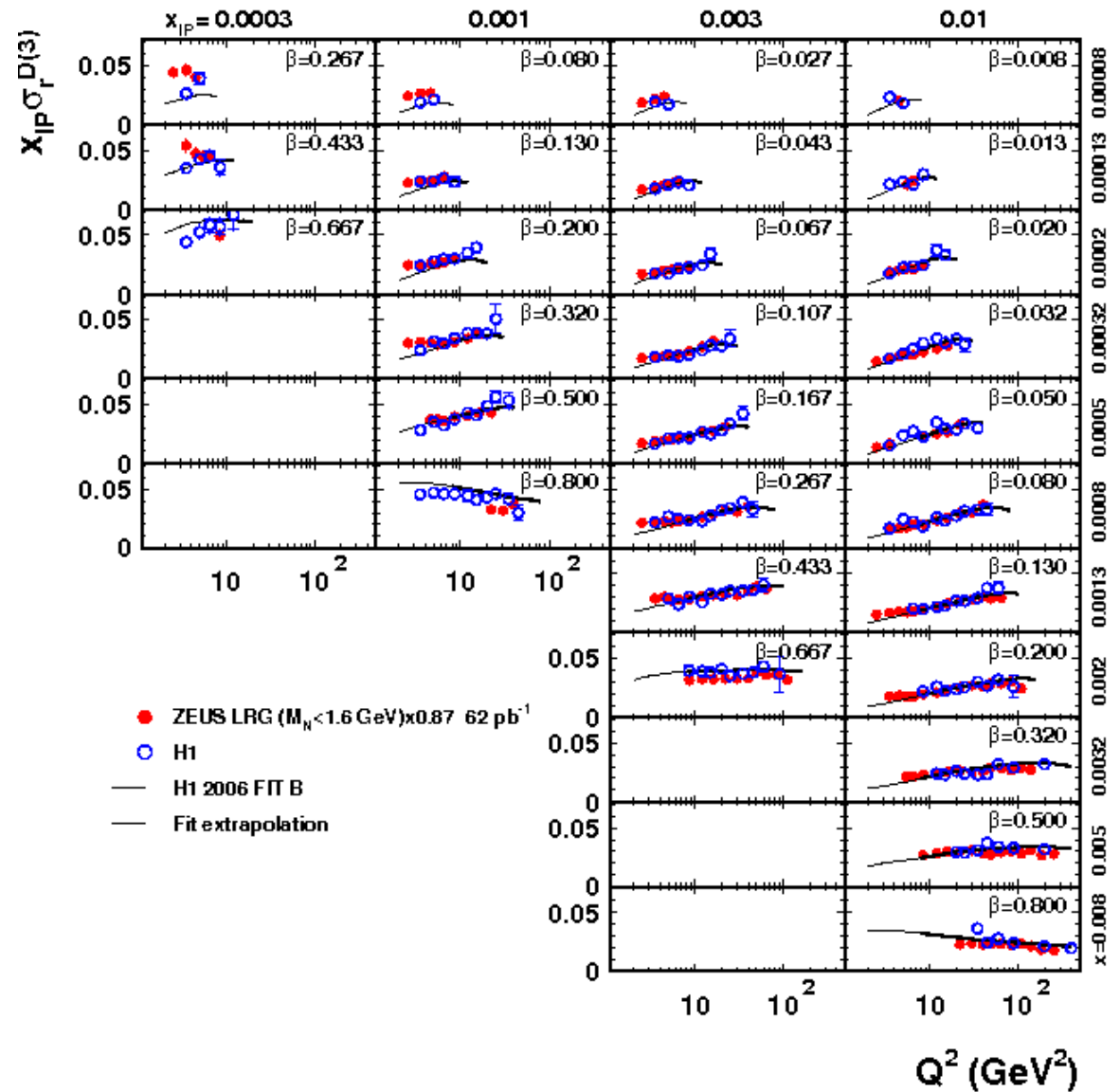
ZEUS vs. H1

Zeus LRG data (62pb⁻¹)

normalised
(LRG($M_y < 1.6$ GeV) * Norm = 0.87)

to

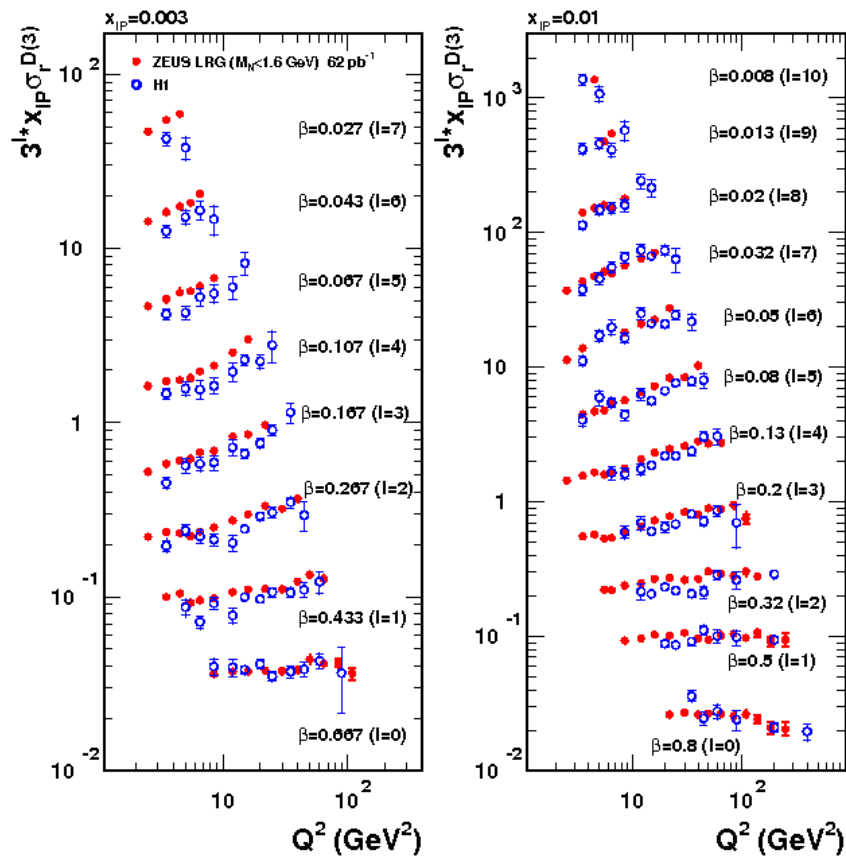
H1 LRG data



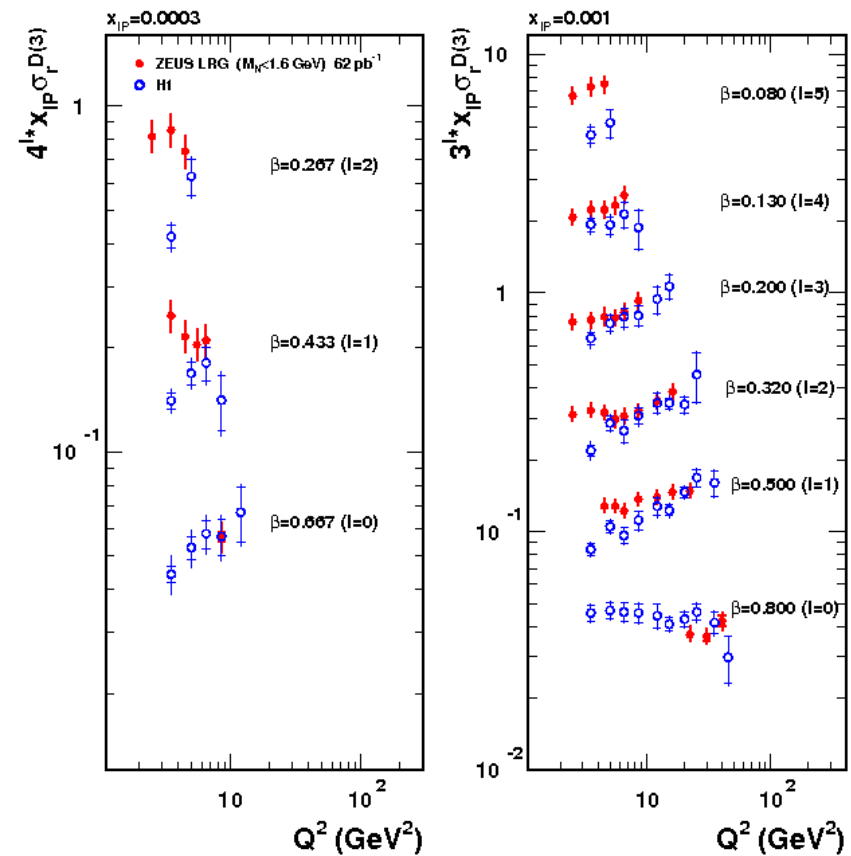
Comparisons of data sets and methods: LRG(H1)-LRG(Zeus) - (2)

Zeus-LRG corrected to H1-LRG ($M_T < 1.6 \text{ GeV}$) (using Pythia)

ZEUS vs. H1



ZEUS vs. H1



Good agreement: differences covered by

- Relative normalization uncertainty 7%
- Uncertainty in $M_T < 1.6 \text{ GeV}$ correction 8%

Some differences still remain...

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Defining diffractive parton densities

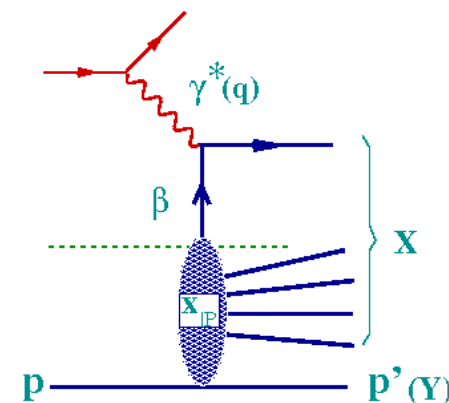
Factorisation: ... beyond the structure function $F_2^{D(4)}$

- QCD factorisation (collinear approx. as in DIS)

At fixed (t, x_p) the hard scattering factorizes

$$\frac{d\sigma^D(\gamma^* p)}{dx_P dt} = \sum_{i=(q,g)} \int_x^{x_P} d\xi \underbrace{\frac{df_i^D(\mu^2, x/\xi, Q^2, x_P, t)}{dx_P dt}}_{DPDF} \underbrace{\sigma^{\gamma^* i}(\mu^2, x/\xi, Q^2)}_{cfr. DIS}$$

Diffractive PDFs are non-perturbative - universal - follow DGLAP
 $\sigma^{\gamma^* i}$ are hard scattering coefficients as in DIS



- Regge factorisation: conjecture in Regge phenomenology

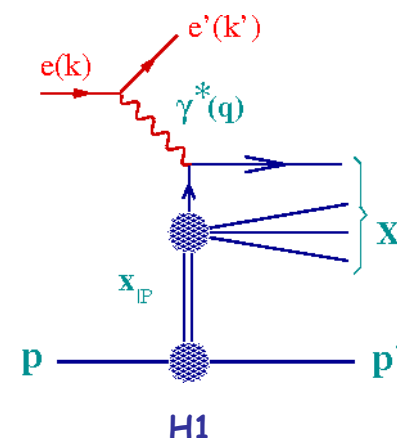
In resolved pomeron model (exchange IP, IR) - soft processes

$$f_i^D(x, Q^2, x_P, t) = f_{P/p}(x_P, t) \times f_i^P(\beta = \frac{x}{x_P}, Q^2)$$

Partonic structure is $f_i^P(\beta, Q^2)$

Pomeron flux factor $f_{P/p}(x_P, t) = A_P \frac{e^{B_P t}}{x_P^{2\alpha_P(t)-1}}$

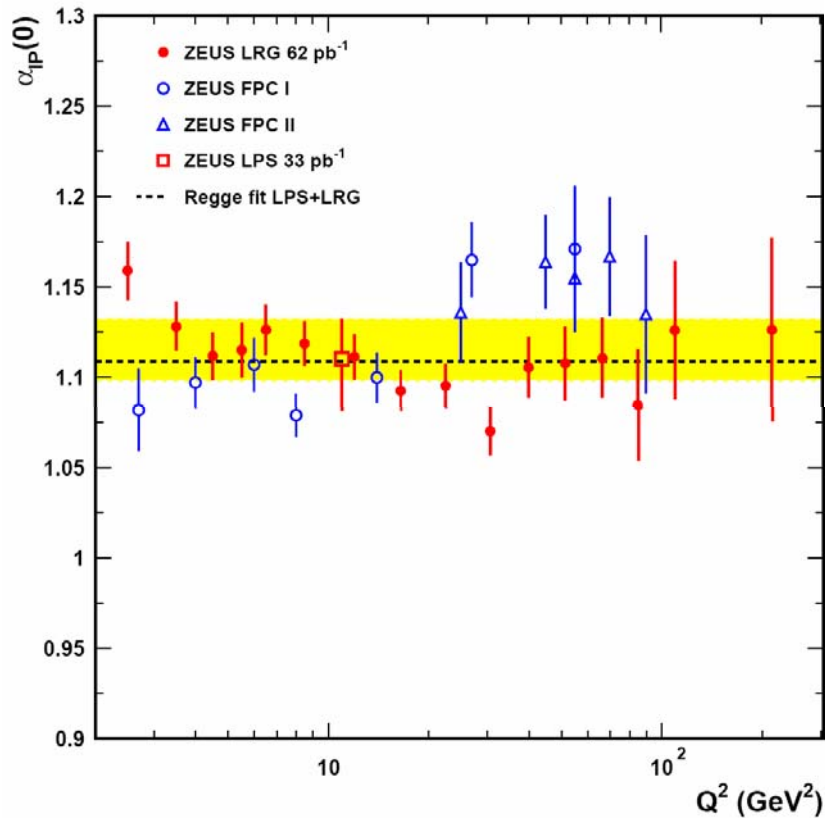
$$\bar{f}_{P/p}(x_P) = \int_{t_{cut}=-1}^{t_{min}} f_{P/p}(x_P, t) dt$$



α_{Pom}	- fit -
α'_{Pom}	$0.06^{+0.19}_{-0.06} \text{ GeV}^{-2}$
B_{Pom}	$5.5^{+2.0}_{-0.7} \text{ GeV}^{-2}$

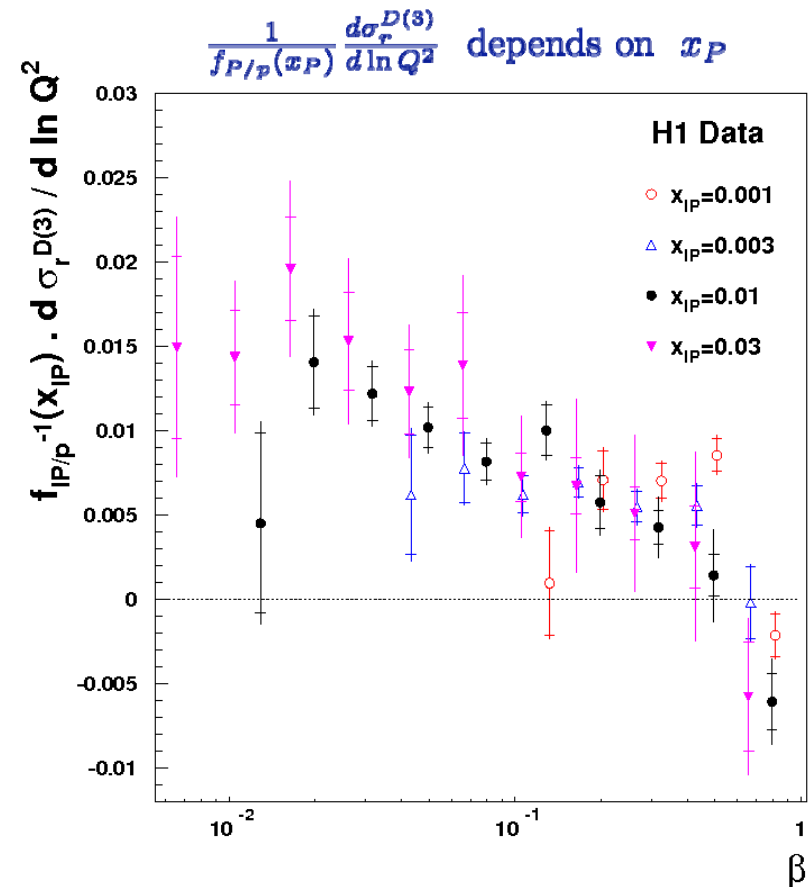
Factorisation supported by data ?

Regge factorisation breaking if
 $\alpha_P(0)$ depends on Q^2



$$\sigma_r^{D(3)}(x_P, Q^2, \beta) = a_D(x_P, \beta) + b_D(x_P, \beta) \ln Q^2$$

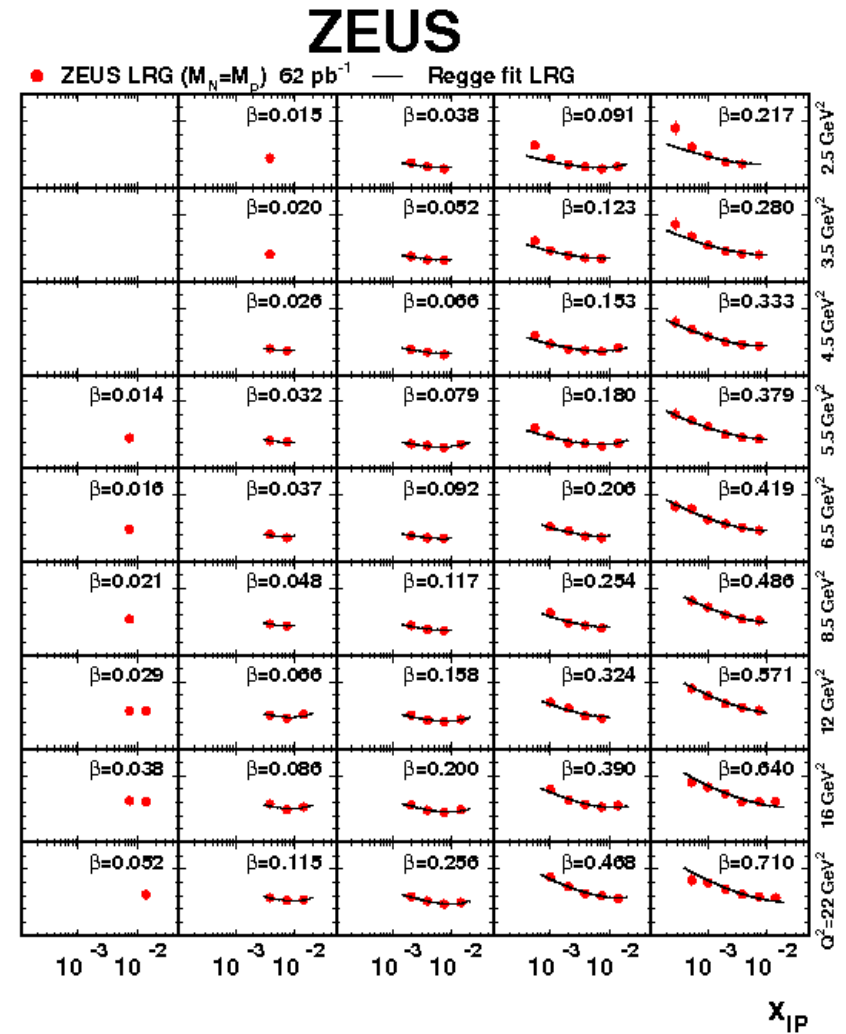
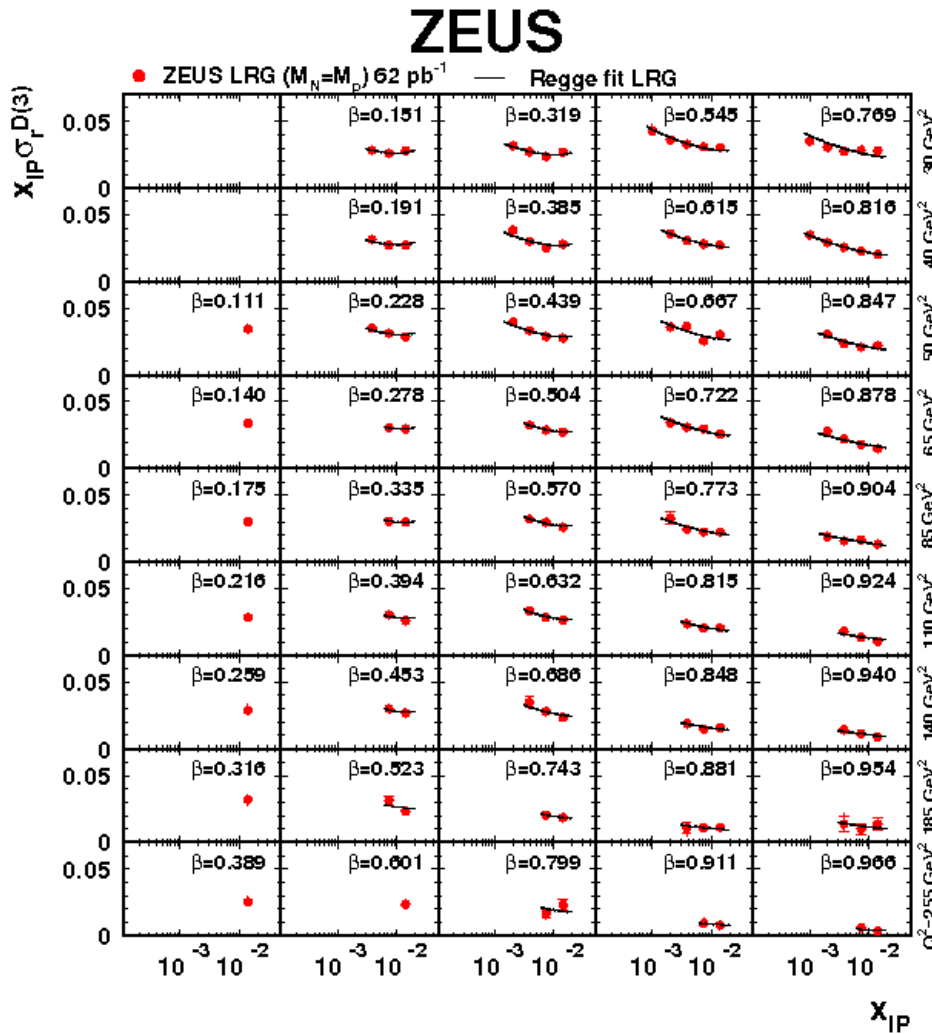
Regge factorisation breaking if
 at fixed β, x_P



No significant scaling violations (within errors)

$\sigma_r^{D(3)} - x_{IP}$ dependence: Regge fit to latest Zeus LRG sample

Covering large kinematical range with very good statistical precision



$$\alpha_P(0) = 1.108 \pm 0.008 \text{ (stat.+syst.) } \begin{matrix} +0.022 \\ -0.007 \end{matrix} \text{ (model) (Zeus)}$$

$$\alpha_P(0) = 1.118 \pm 0.008 \text{ (exp.) } \begin{matrix} +0.029 \\ -0.010 \end{matrix} \text{ (model) (H1)}$$

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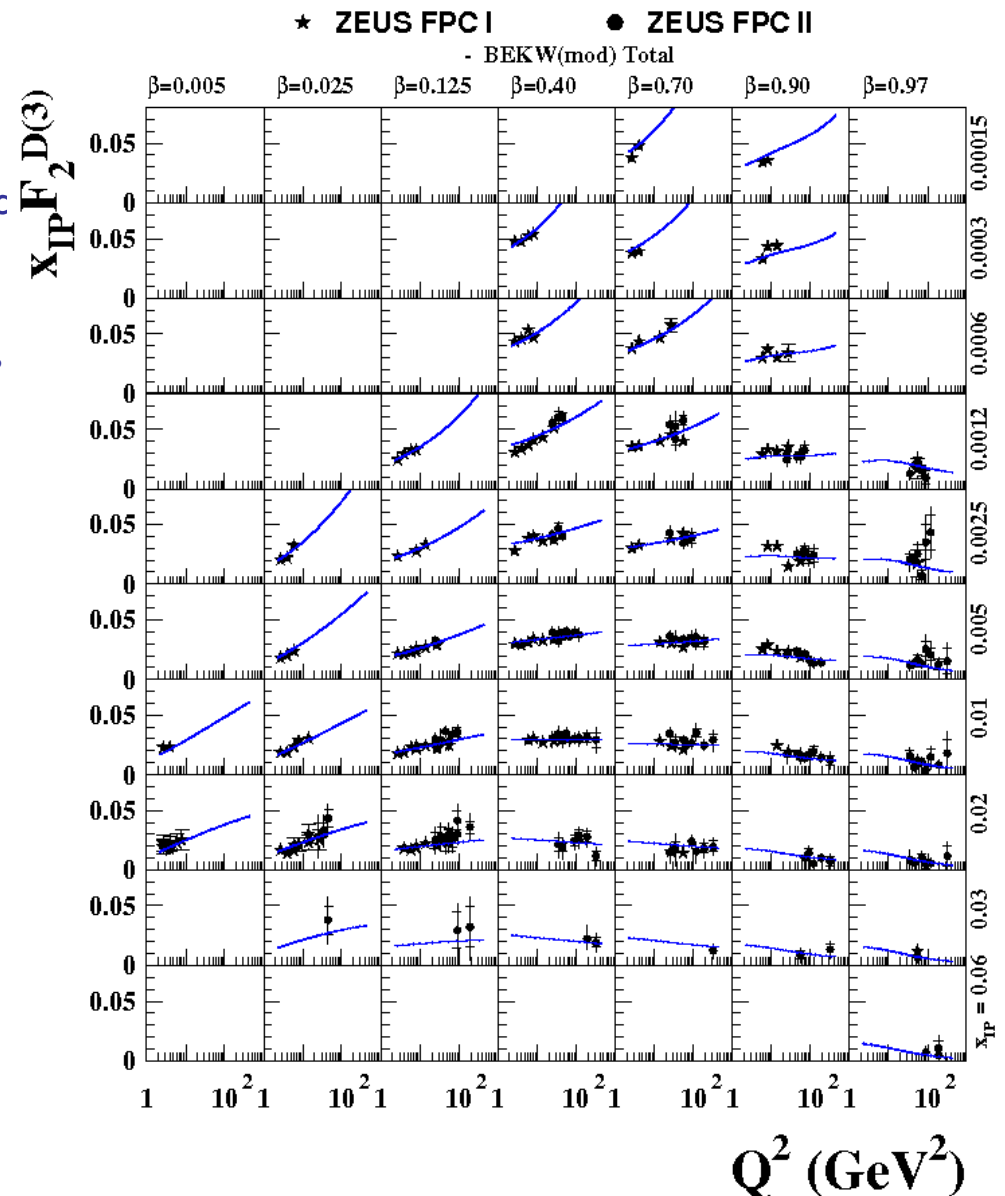
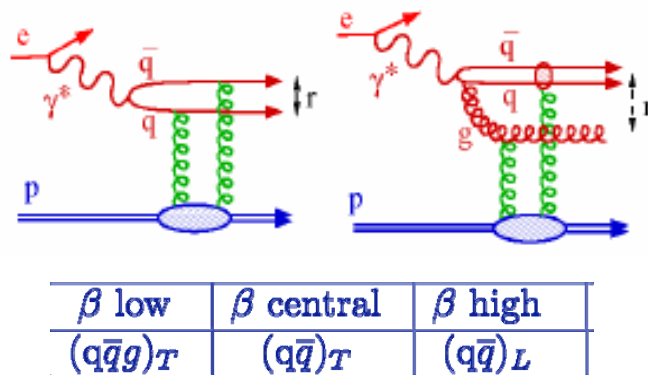
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$\sigma_r^{D(3)}$ - dependence on Q^2

ZEUS

Mx-method

- Positive scaling violations up to large β
→ diffractive exchange is dominantly gluonic (confirming earlier observations)
- At fixed β the shape of $\sigma_r^{D(3)}$ depends on x_{IP}
→ contrary to Regge prediction
- Fit shown is result of BEKW model



Diffractive PDF's - H1 2006 - inclusive data (1)

Parameter range:

$$Q^2 \geq 8.5 \text{ GeV}^2, M_X > 2 \text{ GeV}, \beta \leq 0.8$$

Model quark singlet and gluon DPDF

$$z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q}$$

$$zg(z, Q_0^2) = A_g (1-z)^{C_g}$$

Starting scale $Q_0^2 = 1.45 \text{ GeV}^2$

Evolve with NLO DGLAP

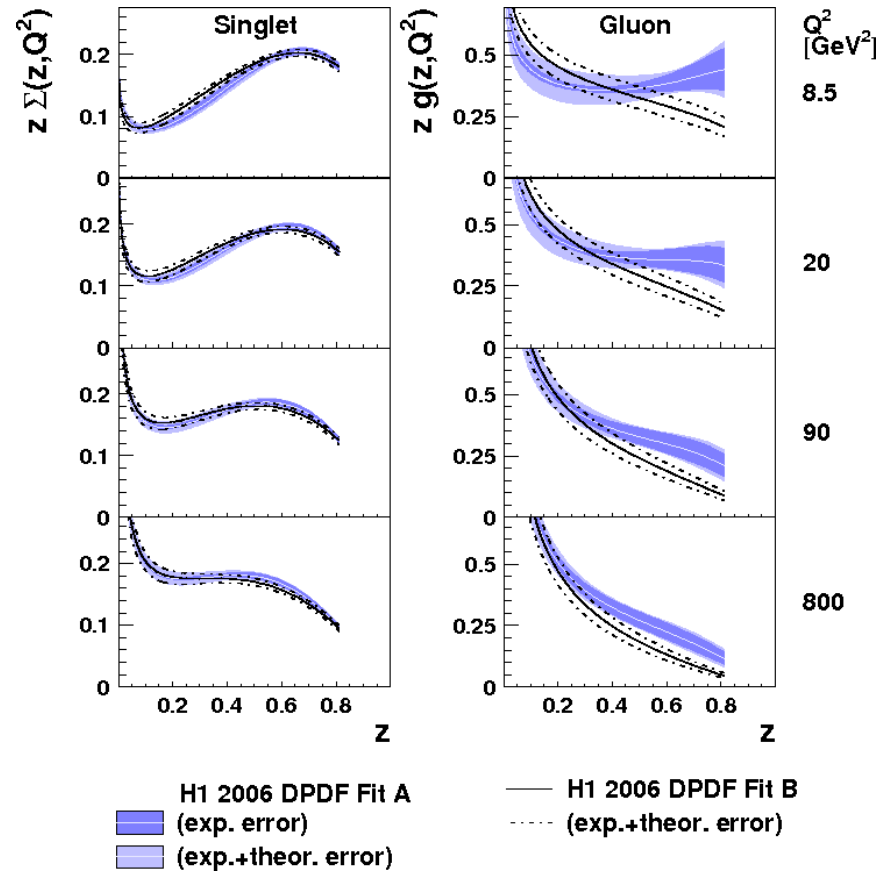
Fit to $\sigma_r^{D(3)}$ data

$$f_i^D(x, Q^2, x_P, t) = \underbrace{f_{P/p}(x_P, t)}_{\alpha_P(0)} \cdot \underbrace{f_i(\beta, Q^2)}_{A_i, B_i, C_i} + \underbrace{n_R}_{\text{}} \cdot f_{R/p}(x_P, t) \cdot f_i^R(\beta, Q^2)$$

→ DPDF - Fit A

Singlet DPDF constrained (5%)

Gluon DPDF constrained (15%) at low z
error band increases at high z



z fractional parton momentum in hard scattering

Diffractive PDF's - H1 2006 - inclusive data (2)

Gluon contribution at high z not well constrained

$$\frac{dF_2^{D(3)}}{d \ln Q^2} \propto \alpha_s (P_{gq} \otimes g + P_{qq} \otimes \Sigma)$$

$g \rightarrow q\bar{q}$

$q \rightarrow qg$

At high β (> 0.3)

- gluon driven evolution has fractionally large errors
→ Sensitivity decreases
- evolution driven by quarks and insensitive to gluons

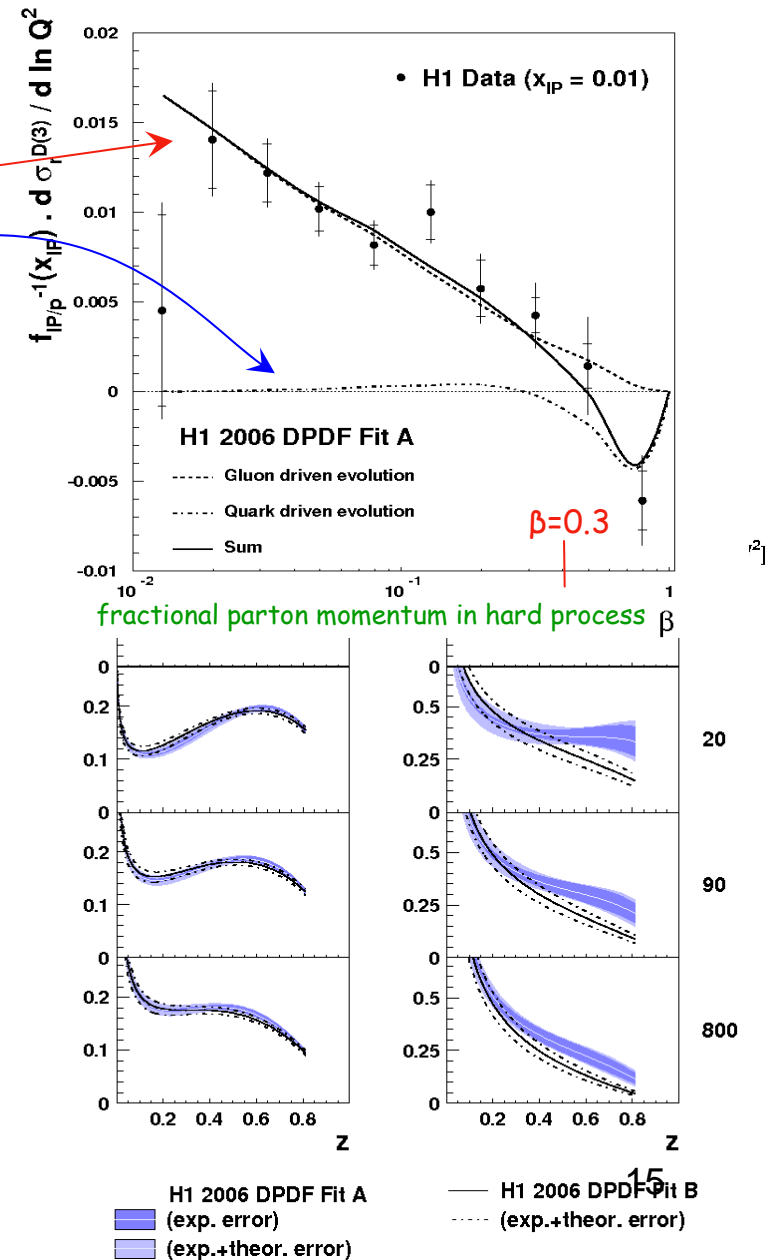
Modify gluon DPDF

$$zg(z, Q_0^2) = A_g(1-z)^{C_g} \xrightarrow{C_g=0} zg(z, Q_0^2) = A_g$$

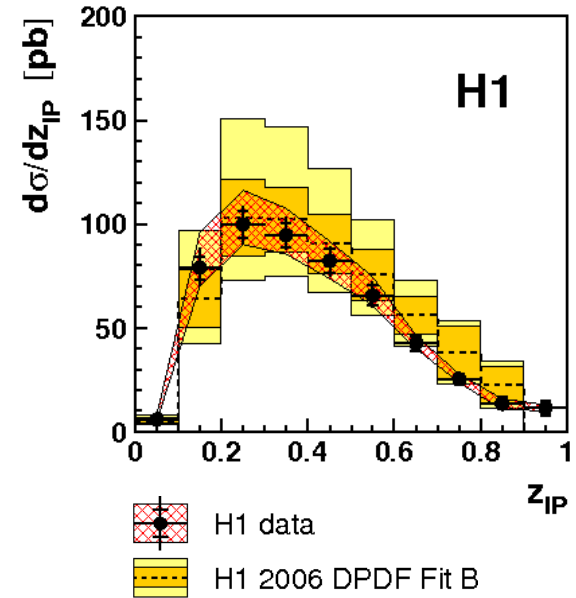
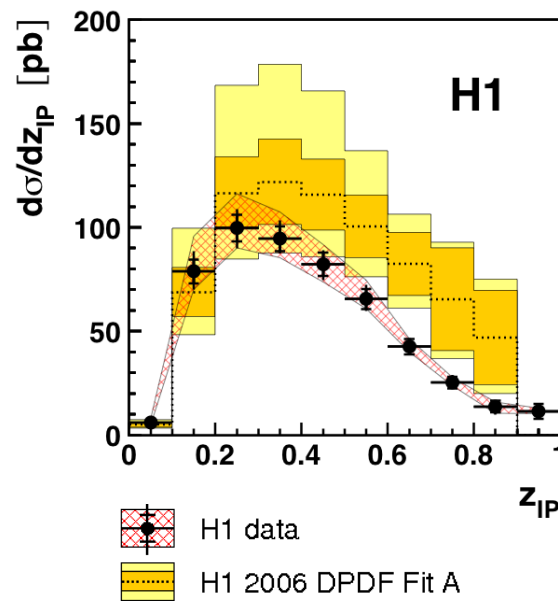
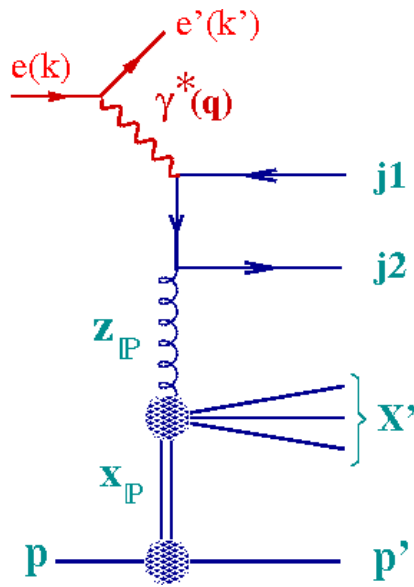
Re-fit data **DPDF fit B** ($Q_0^2 = 2.5 \text{ GeV}^2$)

- At low z DPDFs similar to FIT A
- Gluon DPDF changes at high z

Both Fit A and Fit B describe inclusive diffractive data well



Diffractive PDFs: from inclusive data to Dijets



- At low z ($z < 0.4$) reasonable description of the data
- At high z ($z > 0.4$) **FIT B** favored
- Direct sensitivity to the diffractive gluon via
$$z_P = \frac{M_{j_1 j_2}^2 + Q^2}{M_X^2 + Q^2}$$

Combine inclusive diffractive and diffractive jet data to constrain the DPDF's

Inclusive diffractive data (LRG) + Jets: Combined fit-(1)

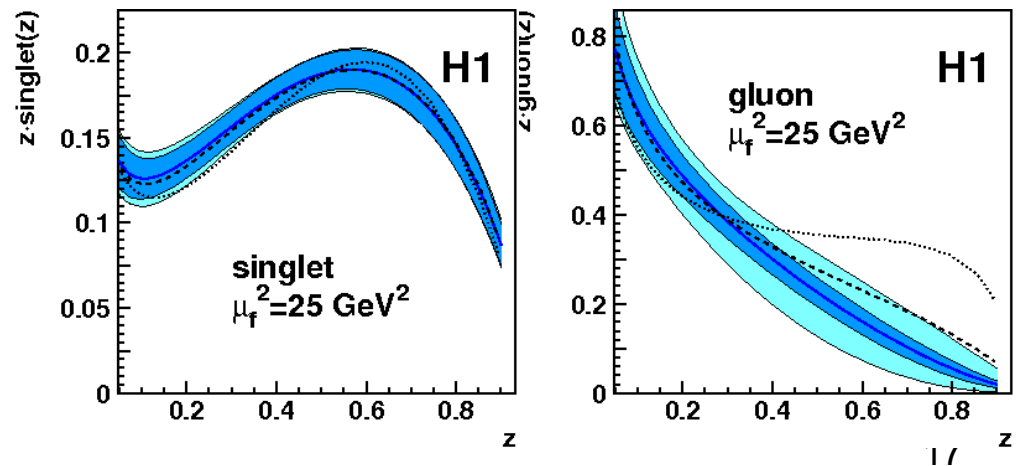
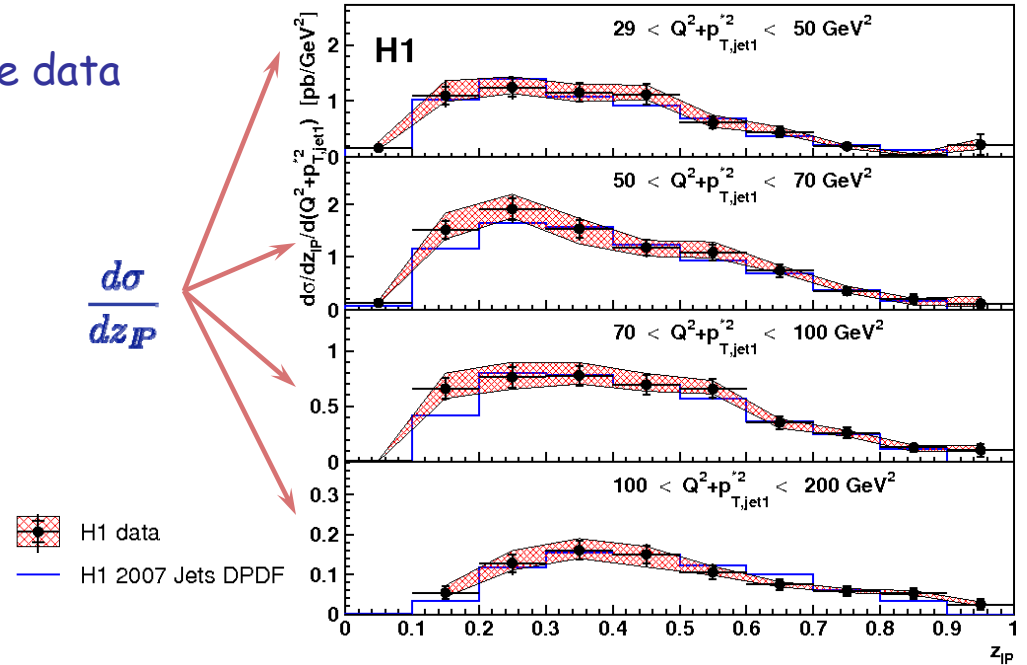
Same NLO -fit procedure as for inclusive data

$$\begin{array}{ll}
 \text{Singlet} & z\Sigma(z, Q_0^2) = A_q z^{B_q} (1-z)^{C_q} \\
 \text{Gluon} & \\
 \text{FitA} & zg(z, Q_0^2) = A_g (1-z)^{C_g} \\
 \text{FitB} & zg(z, Q_0^2) = A_g \\
 \text{Jets} & zg(z, Q_0^2) = A_g^{B_g} (1-z)^{C_g}
 \end{array}$$

Results in:

- Improved χ^2
- singlet and gluon DPDFs constrained over the full range $z \in [0.05, 0.9]$ with similar precision

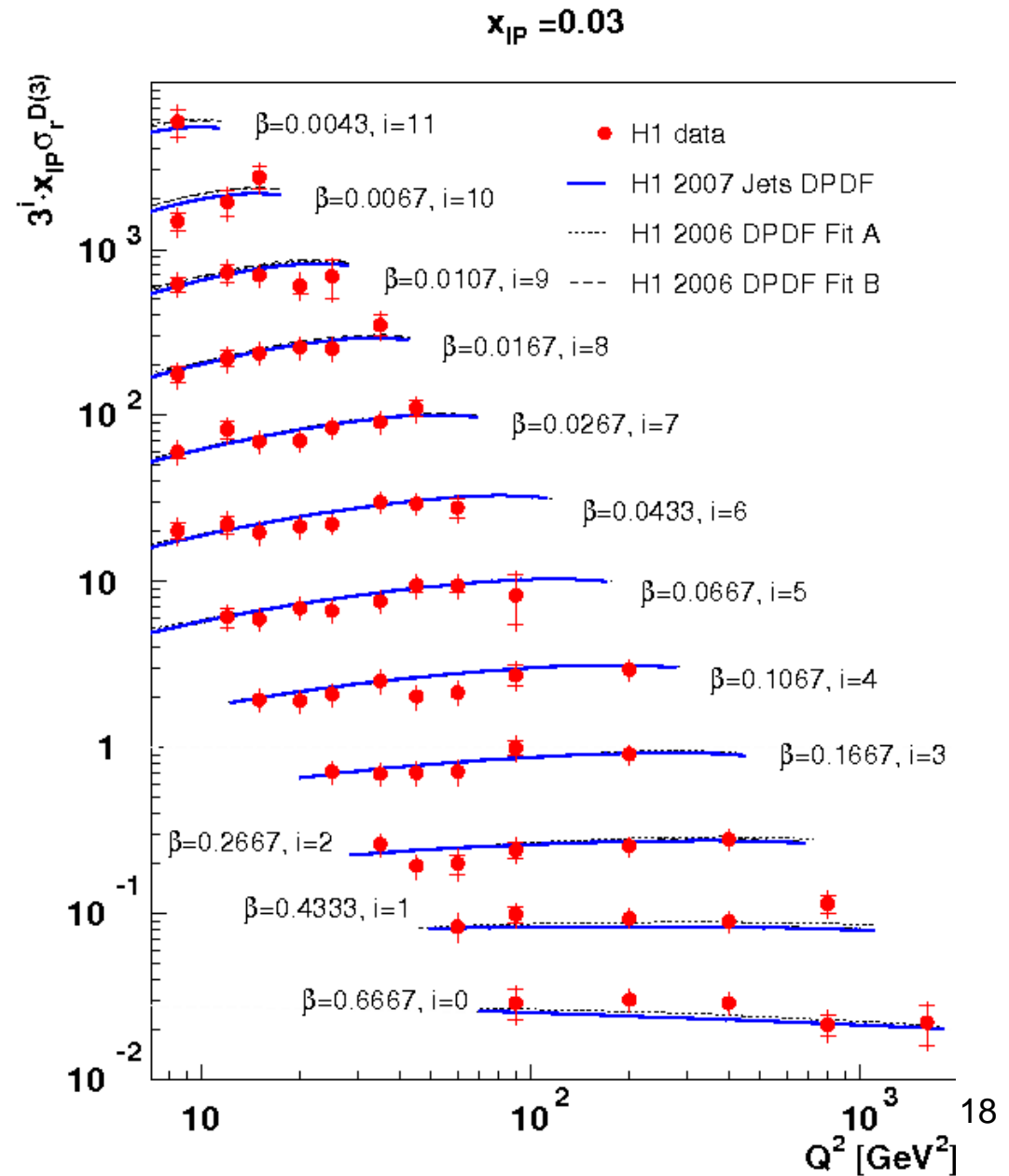
- H1 2007 Jets DPDF
- exp. uncertainty
- exp. + theo. uncertainty
- H1 2006 DPDF fit A
- H1 2006 DPDF fit B



Inclusive diffractive data (LRG) + Jets: Combined fit - (2)

Inclusive data also well described by all fits

- 2006 DPDF Fit A
- 2006 DPDF Fit B
- 2007 Jet DPDF fit



Summary

- Inclusive diffraction has been investigated by various methods LRG, Mx and Proton Spectrometers covering the full kinematical plane with very good precision indicating good agreement between data sets and methods
- Data are compatible with Regge factorisation allowing to extract DPDFs as functions of β and Q^2
- DPDF's obtained from NLO QCD fits to inclusive diffractive data fit well the diffractive di-jet data.
- A QCD fit to the combined inclusive diffractive and jet data constrain the quark and gluon PDFs over the full z -interval with equal good precision