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

R.Roosen
Vrije Universiteit Brussel

Inclusive Diffraction at HERA

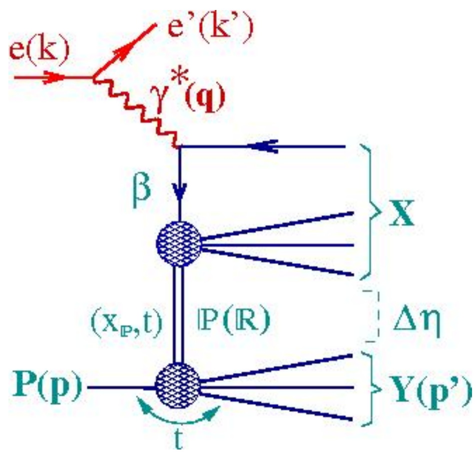
- Diffractive kinematics/signatures
- Experimental methods
- Comparison of different methods
- Results and factorisation

QCD fits and diffractive PDFs

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

Diffractive kinematics (e+p →e'+X+Y) and signatures

- Kinematical variables



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

- Diffractive signatures:

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

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

$$\Longrightarrow \left|\frac{\Delta p_z}{p_{z_i}}\right| = 1 - x_L \approx x_{I\!P} = \frac{M^2+Q^2}{W^2+Q^2}$$

$$x_L \Longrightarrow 1$$

$$\Delta\eta \approx \ln \frac{1}{x_{I\!P}} \frac{M_Y^2}{m_p^2}$$

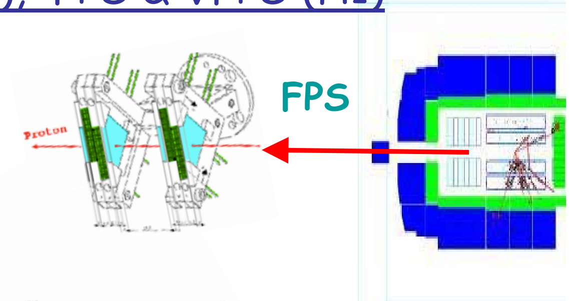
$x_{I\!P}$ small $\quad \Delta\eta$ large

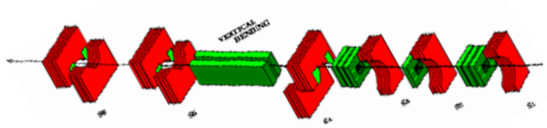
$x_{I\!P}$ large $\quad \Delta\eta$ small

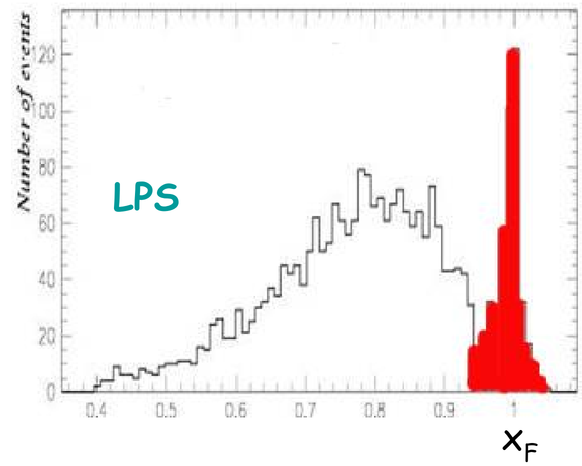
Diffractive processes: detection methods – (1)

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



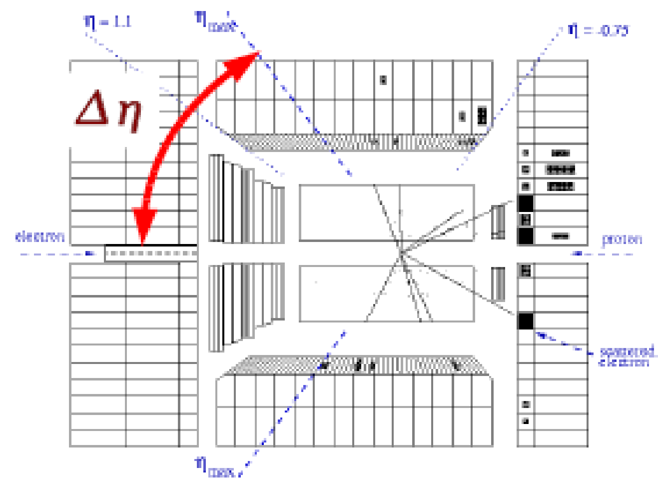




2. Large Rapidity Gap method: impose rapidity gap cut η_{max}

- ☺ Very good acceptance
- 😐 No t-measurement: integrate over t, -1 GeV^2, t_{min}
- ☹ Proton dissociation to be estimated

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



Diffractive processes: detection methods – (2)

3a. Mx subtraction method (Zeus)

Based on

$$\text{Dis} \quad P(\Delta\eta) \propto e^{-\lambda\Delta\eta} \rightarrow \frac{dN_{N-Diff}}{d\ln M_X^2} = c.e^{b.\ln M_X^2}$$

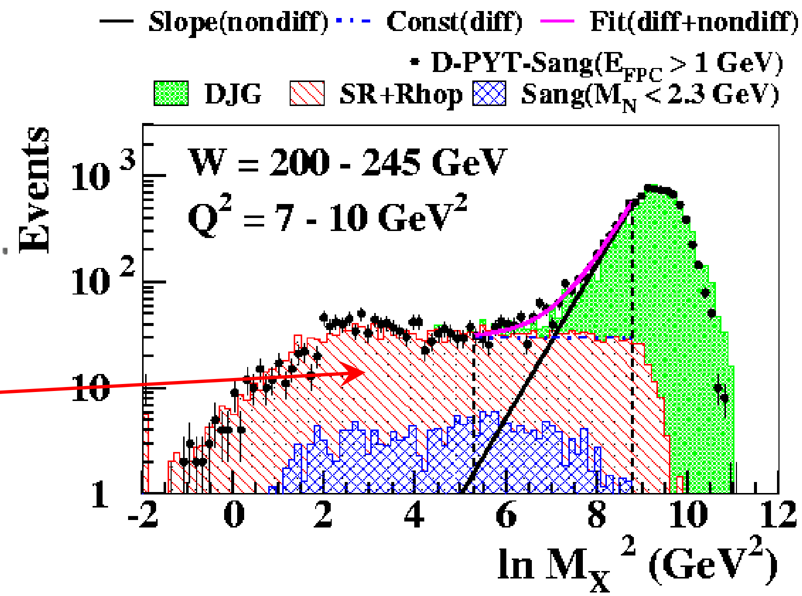
$$\text{DDis} \quad \text{Tripple Regge} \rightarrow \frac{dN_{Diff}}{d\ln M_X^2} \propto \ln M_X^2 \approx \text{const.}$$

Calculate M_X up to η_{max}(FPC) = 4-5

Fit to the inclusive DIS data

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

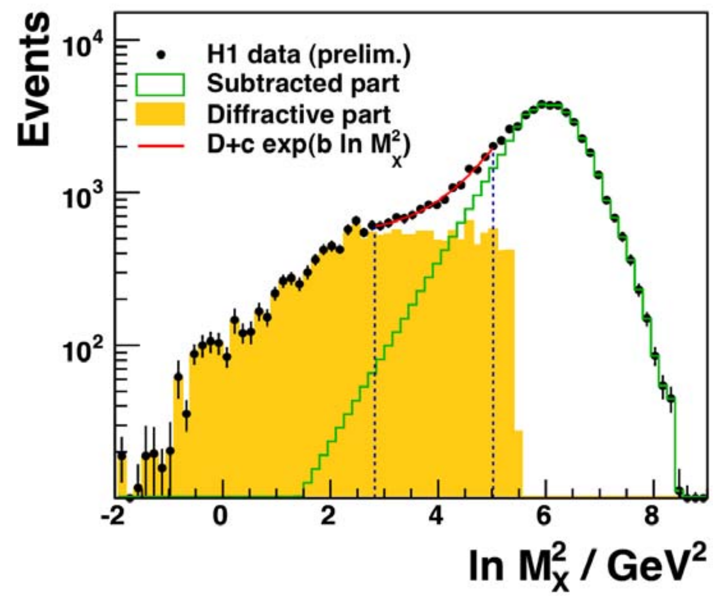
with D constant and subtract bin by bin
the non-diffractive component



- Reggeon contributions suppressed

- P-diss corrected to
  My < 2.3 GeV

LRG		Mx
H1	Zeus	Zeus
My < 1.6 GeV	My = mp	My < 2.3 GeV



3b. M_X subtraction method (H1)

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

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**

- $$\frac{d^4\sigma(ep \to e'Xp)}{dx\, dQ^2\, dx_{I\!P}\, dt} = \frac{4\pi\alpha^2}{xQ^4}\left(1 - y - \frac{y^2}{2}\right)\sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$$
- $$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2\,(1 - y - y^2/2)} F_L^{D(4)} \qquad \sigma_r^{D(4)} \approx F_2^{D(4)} \begin{cases} \to \text{at low y} \\ \to F_L^{D(4)} = 0 \end{cases}$$
- $$\sigma_r^{D(3)} = \int_{-1}^{t_{min}} dt\ \sigma_r^{D(4)}$$

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

Reduced cross section ratio LPS/LRG (**ZEUS**)

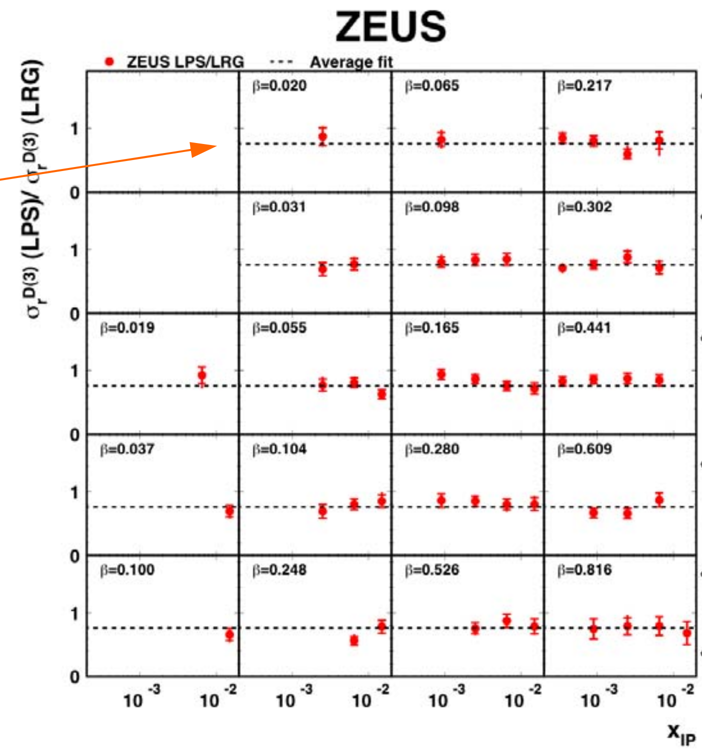
- $$Ratio = \frac{\sigma_r^{D(3)}(LPS)}{\sigma_r^{D(3)}(LRG)} \begin{pmatrix} Before\ Correction \\ M_Y = p \end{pmatrix}$$

$$= 0.76 \pm 0.01(stat.)^{+0.03}_{-0.02}(syst.)^{+0.08}_{-0.05}(norm.)$$

- Proton dissociation in LRG:

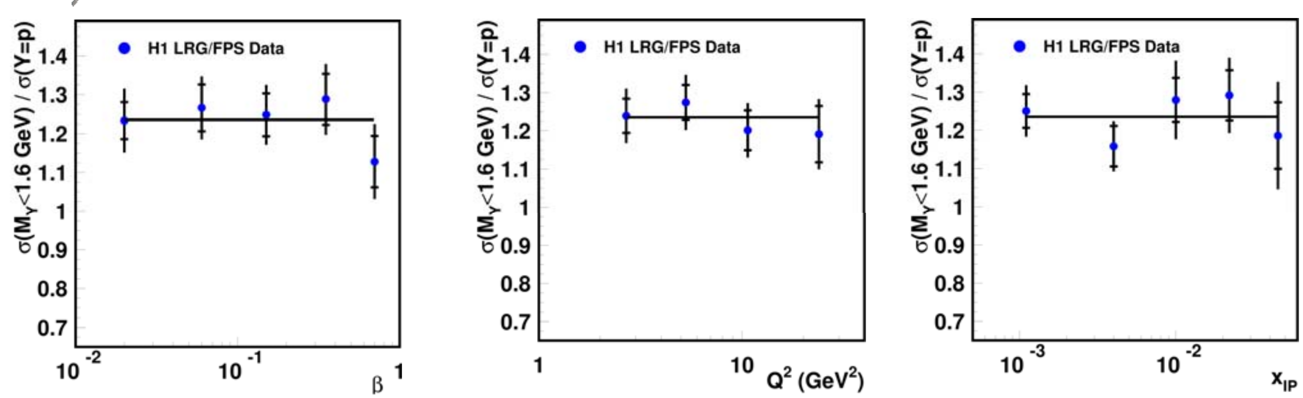
$$[\ 24 \pm 1(stat)^{+2}_{-3}(syst.)^{+5}_{-8}(norm.)\ ]\%$$

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



FPS/LRG (**H1**)

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



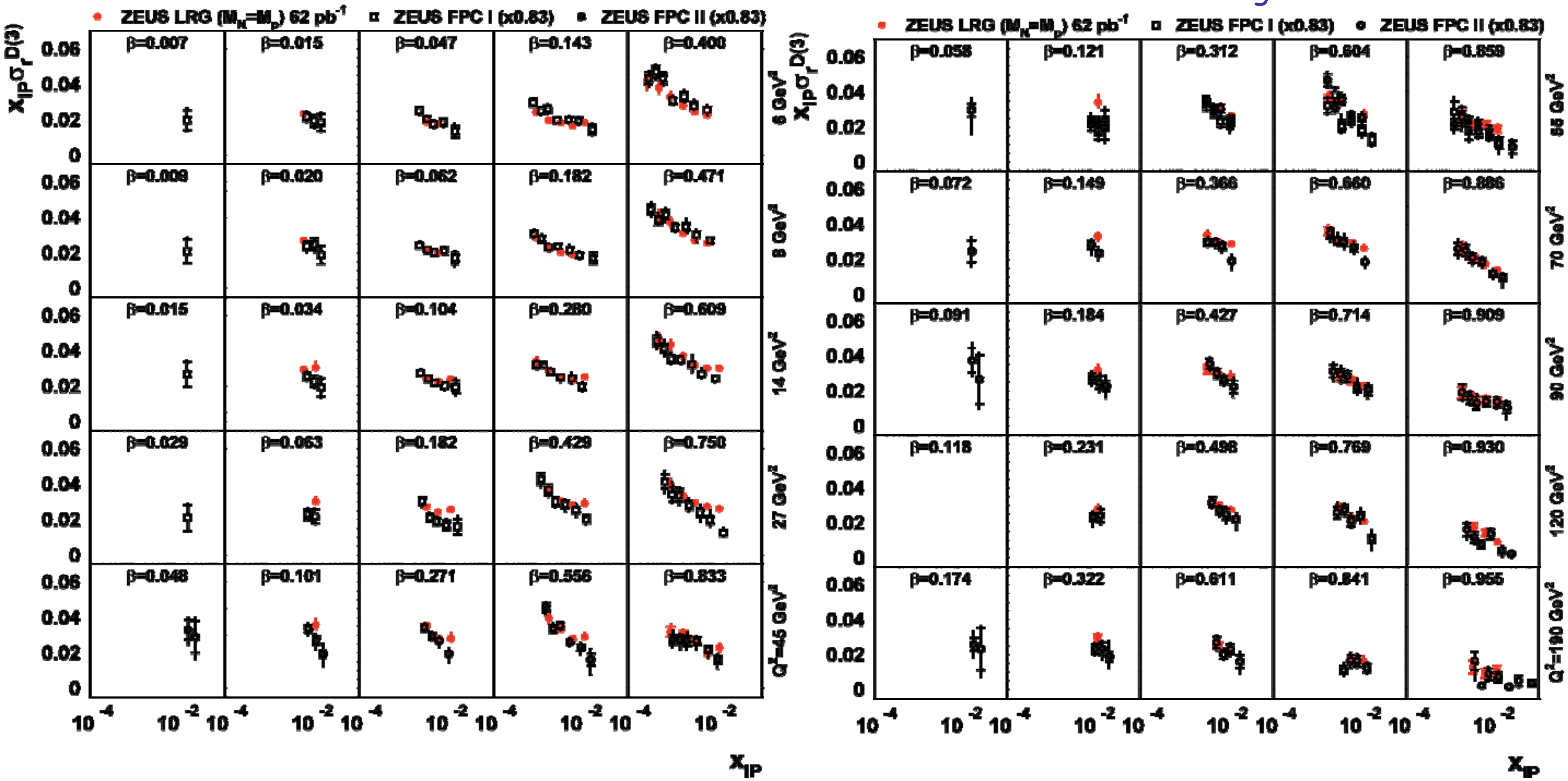
Comparison of data sets and methods: M_X- vs. LRG-method (ZEUS)

- LRG (M_p)-method
- Mx (M_Y<2.3 GeV) -method

Mx data normalized to LRG data from global fit

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

→ P-dissoc. background in Mx 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)

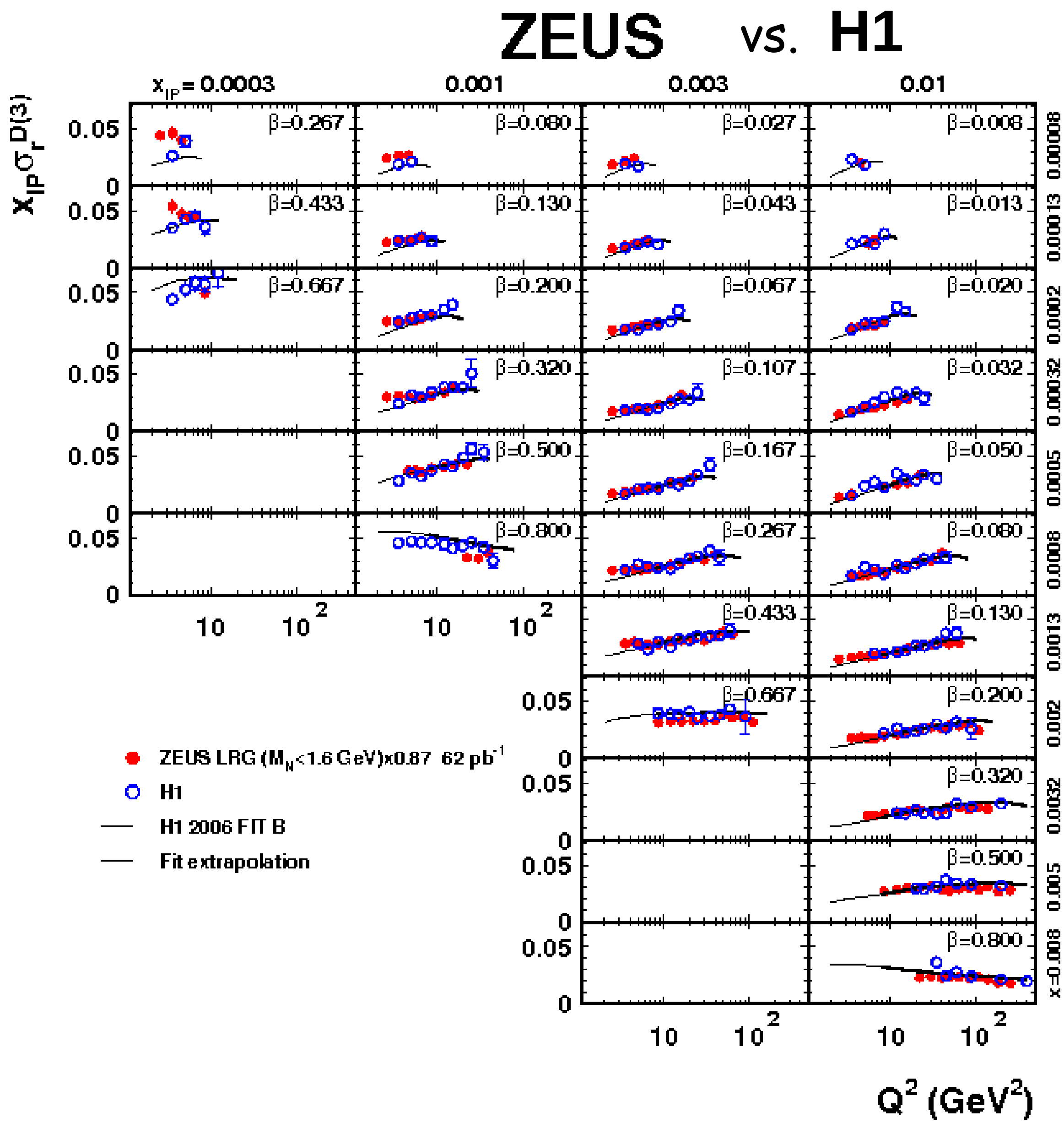
Zeus LRG data (62pb[-1])

normalised

(LRG(M_Y < 1.6 GeV) * Norm = 0.87)

to

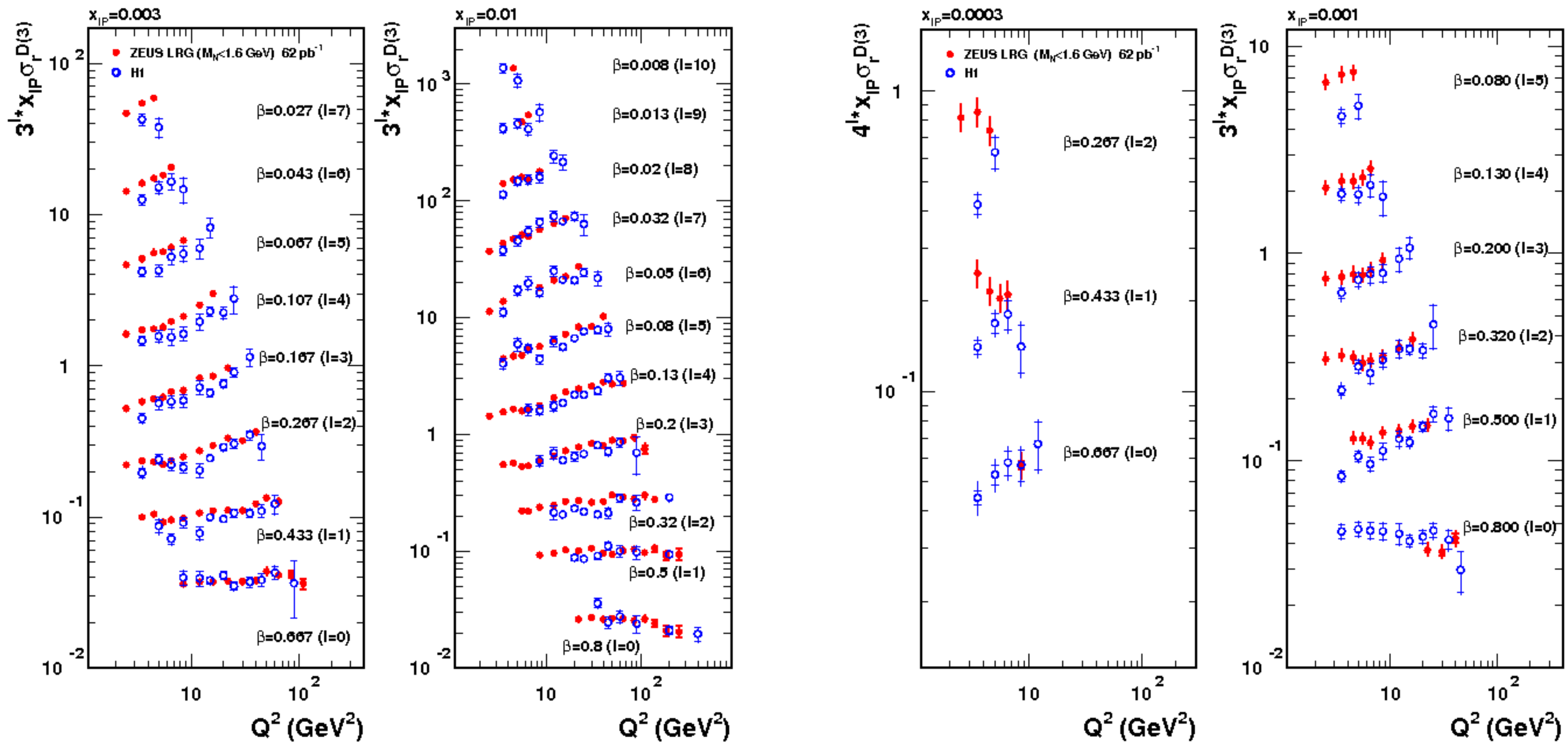
H1 LRG data



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

Zeus-LRG corrected to H1-LRG (M<1.6 GeV) (using Pythia)

ZEUS vs. H1 **ZEUS vs. H1**



Good agreement: differences covered by

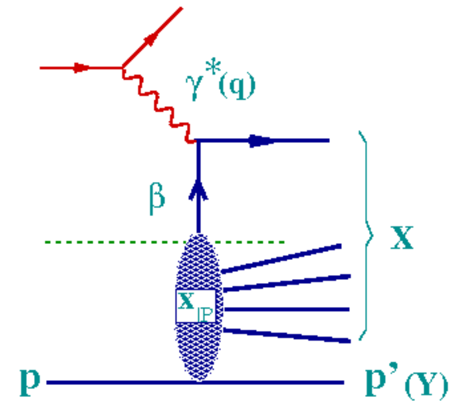
– Relative normalization uncertainty 7%

- Uncertainty in My<1.6 GeV correction 8%

Some differences still remain…

Defining diffractive parton densities

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

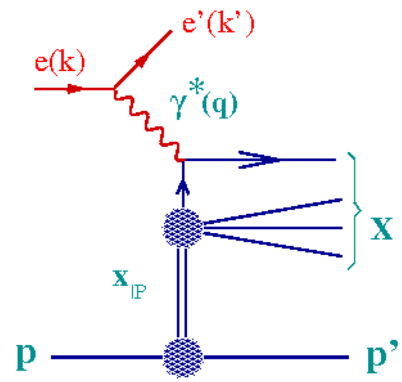


- QCD factorisation (collinear approx. as in DIS)

At fixed (t , x_P) the hard scattering factorizes

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

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

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

Partonic structure is $\quad f_i^{I\!P}(\beta, Q^2)$

Pomeron flux factor $\quad f_{I\!P/p}(x_{I\!P}, t) = A_{I\!P} \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$

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

H1

$\alpha_{I\!Pom}$	$-fit-$
$\alpha'_{I\!Pom}$	$0.06^{+0.19}_{-0.06}$ GeV^{-2}
$B_{I\!Pom}$	$5.5^{-2.0}_{+0.7}$ GeV^{-2}

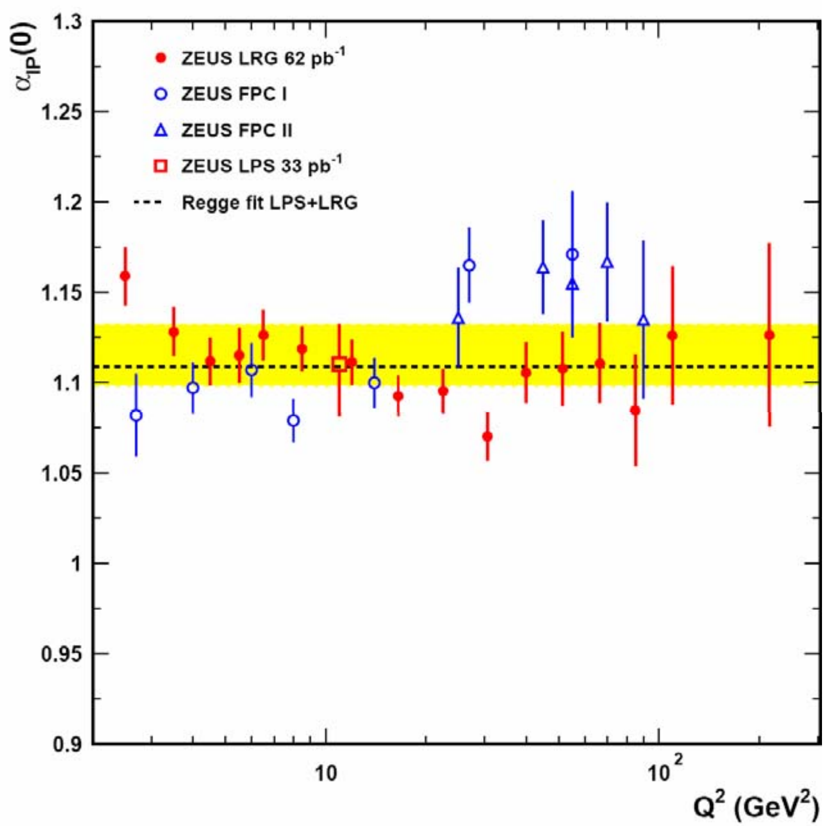
Factorisation supported by data ?

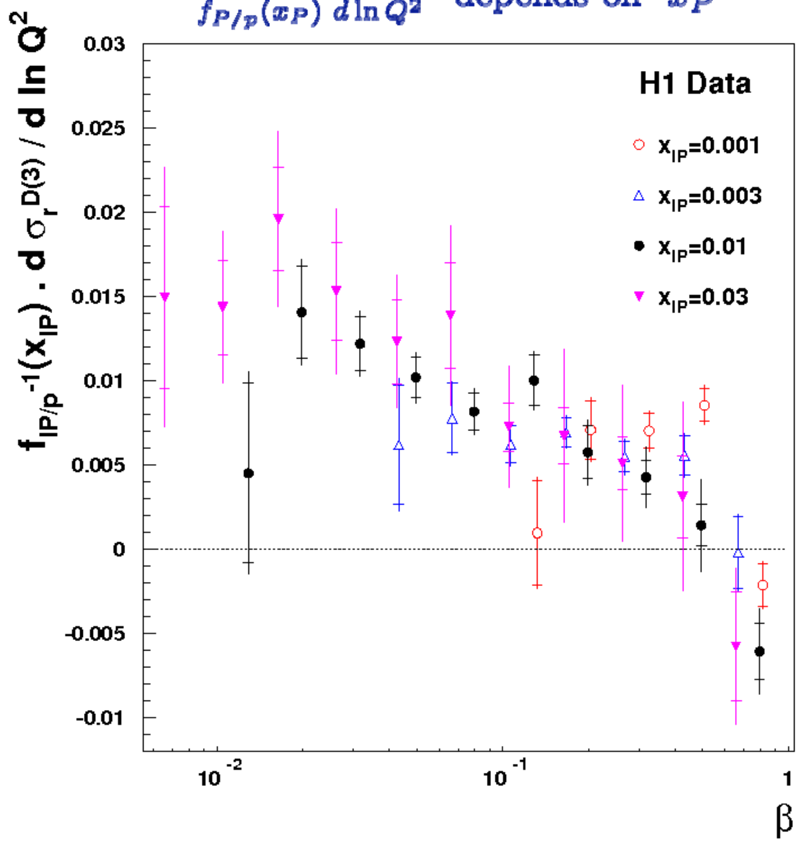
$$\sigma_r^{D(3)}(x_{I\!P}, Q^2, \beta) = a_D(x_{I\!P}, \beta) + b_D(x_{I\!P}, \beta) \ln Q^2$$

Regge factorisation breaking if
$\alpha_{I\!P}(0)$ depends on Q^2

Regge factorisation breaking if
at fixed β, x_P

$\frac{1}{f_{P/p}(x_P)} \frac{d\sigma_r^{D(3)}}{d\ln Q^2}$ depends on x_P

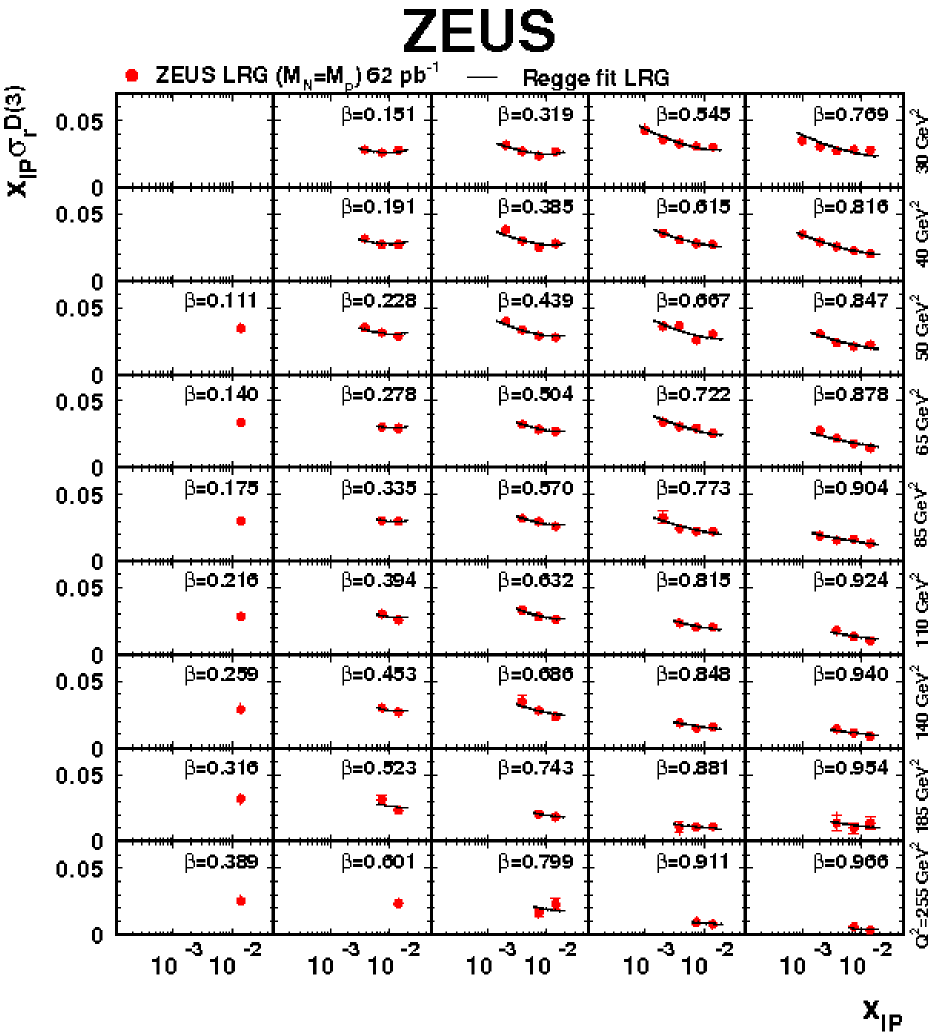


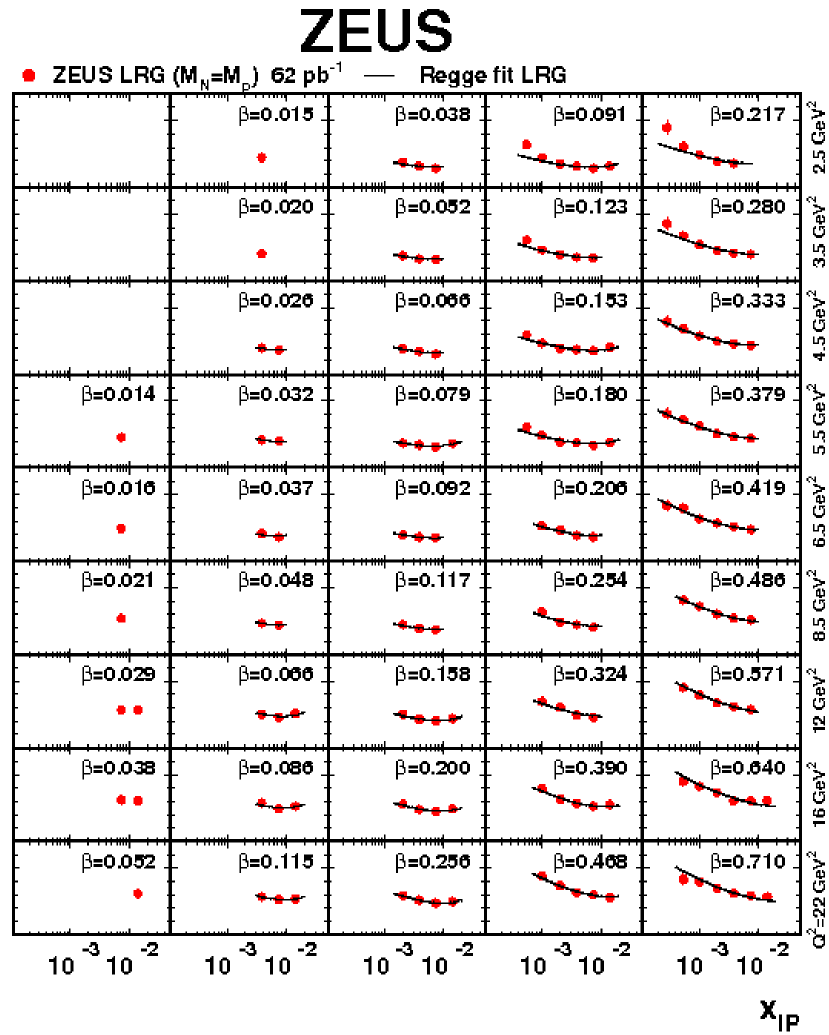


No significant scaling violations (within errors)

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

Covering large kinematical range with very good statistical precision





$$\alpha_{I\!P}(0) = 1.108 \pm 0.008\ (\text{stat.+syst.})\ {}^{+0.022}_{-0.007}\ (\text{model}) \quad (\text{Zeus})$$

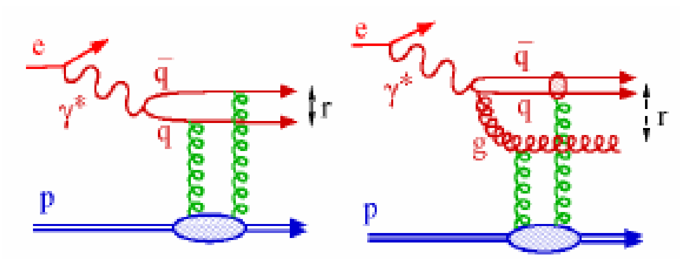
$$\alpha_{I\!P}(0) = 1.118 \pm 0.008\ (\text{exp.})\ {}^{+0.029}_{-0.010}\ (\text{model}) \quad (\text{H1})$$

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

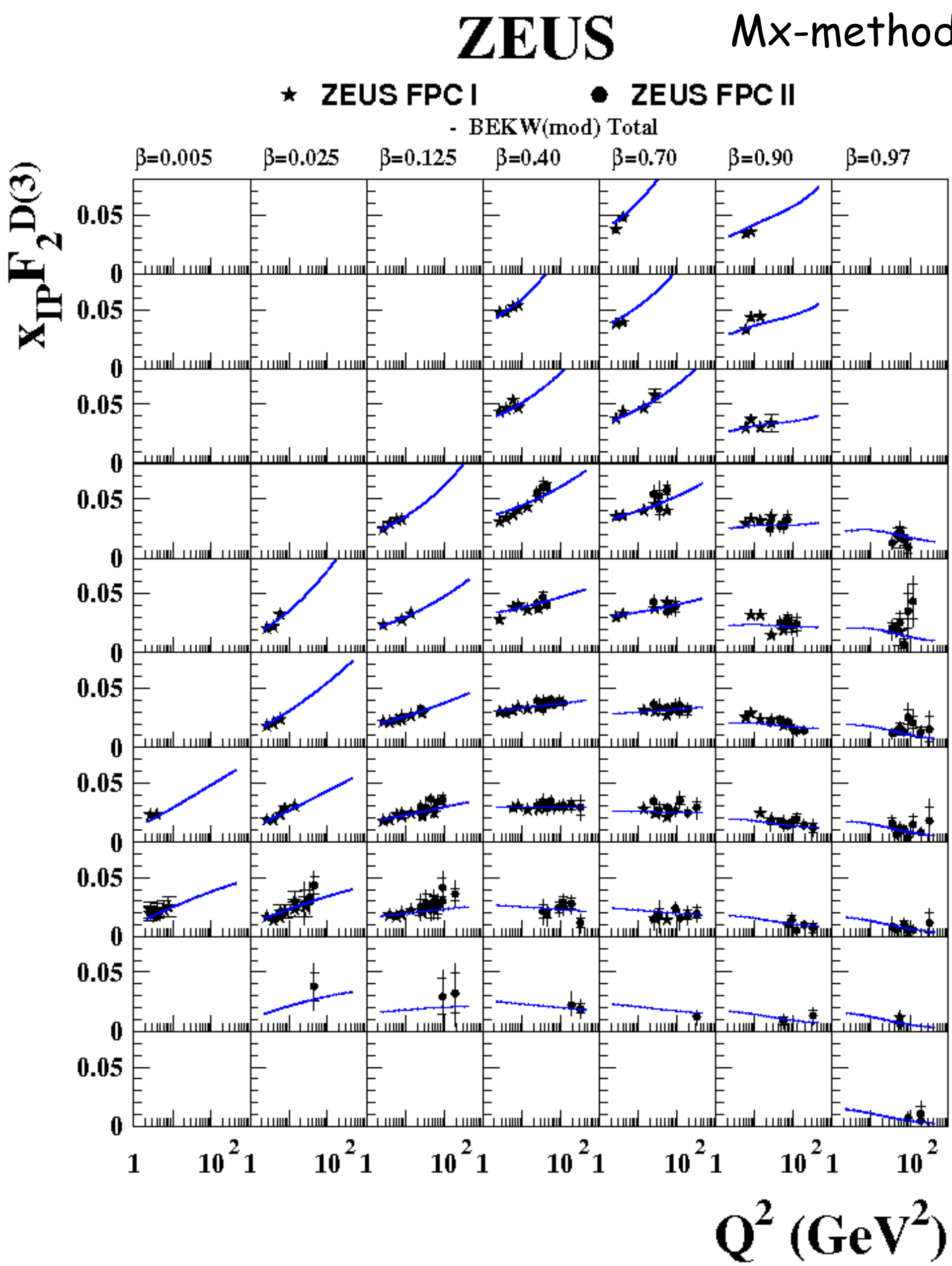
- Positive scaling violations up to large β
  → diffractive exchange is dominantly gluonic
  (confirming earlier observations)

- 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



β low	β central	β high
$(q\bar{q}g)_T$	$(q\bar{q})_T$	$(q\bar{q})_L$



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

Parameter range:

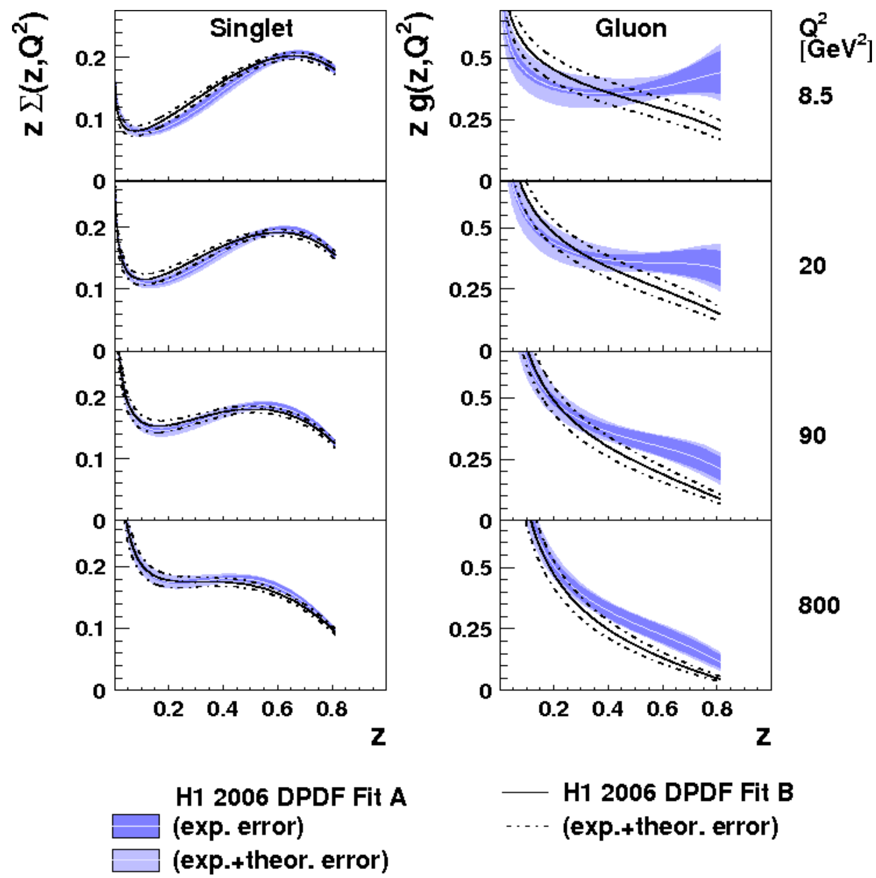
$$Q^2 \geq 8.5 \ \ GeV^2, \ M_X > 2 \ \ GeV \ , \ \beta \leq \ 0.8$$

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 $Q^2_0 = 1.45$ GeV^2

Evolve with NLO DGLAP



z fractional parton momentum in hard scattering

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

$$f_i^D(x,Q^2,x_{I\!P},t) = \underbrace{f_{I\!P/p}(x_{I\!P},t)}_{\alpha_{I\!P}(0)} \cdot \underbrace{f_i(\beta,Q^2)}_{A_i,B_i,C_i} + \underbrace{n_{I\!R}} \cdot f_{I\!R/p}(x_{I\!P},t) \cdot f_i^{I\!R}(\beta,Q^2)$$

→ DPDF - **Fit A**

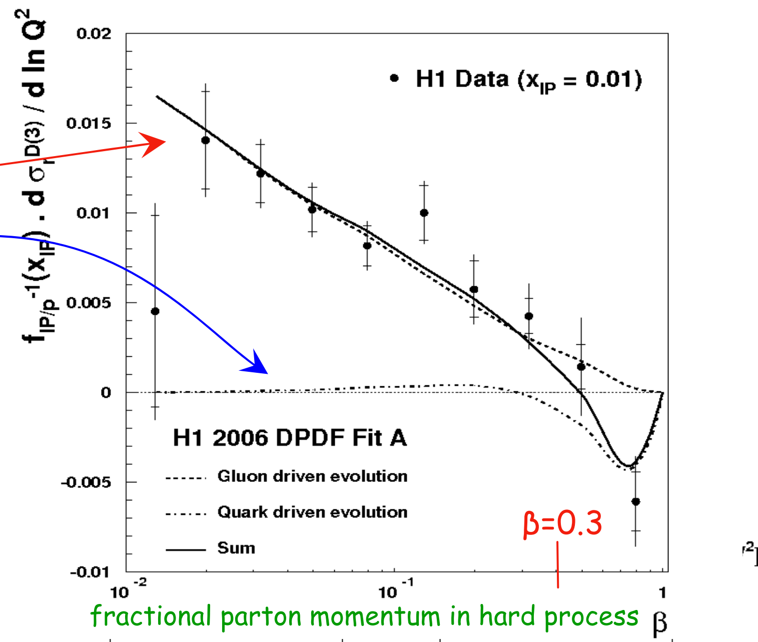
Singlet DPDF constrained (5%)
Gluon DPDF constrained (15%) at low z
error band increases at high z

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

Gluon contribution at high z not well constrained

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

$g \rightarrow q\bar{q}$ $\quad$ $q \rightarrow qg$



At high β (> 0.3)

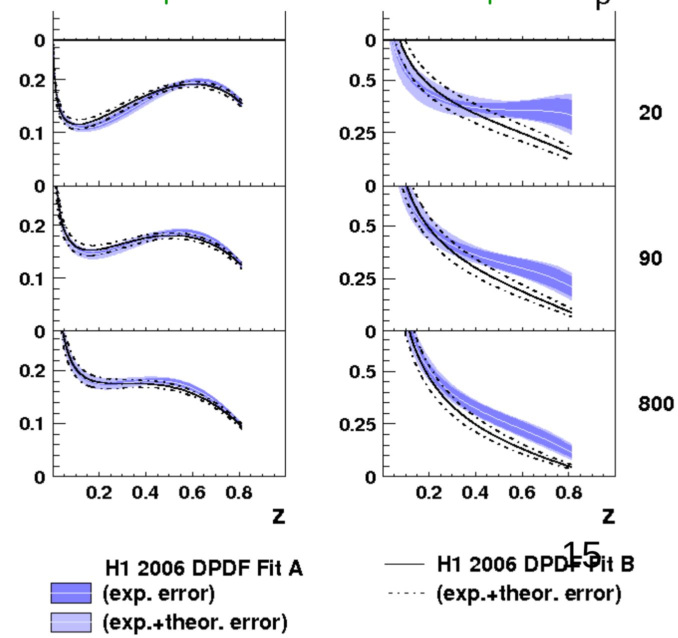
- gluon driven evolution has fractionally large errors
  → Sensitivity decreases
- evolution driven by quarks and insensitive to gluons

Modify gluon DPDF

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

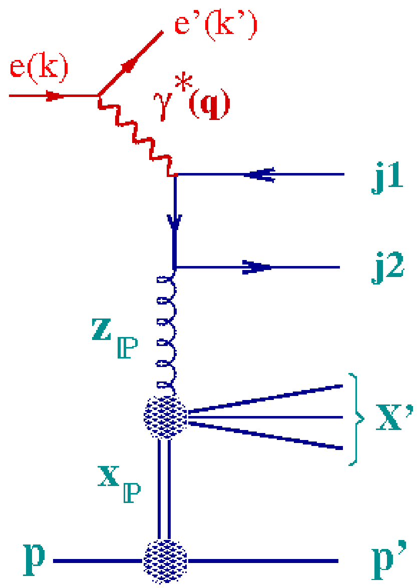
Re-fit data DPDF fit B (Q^2_0=2.5 GeV^2)

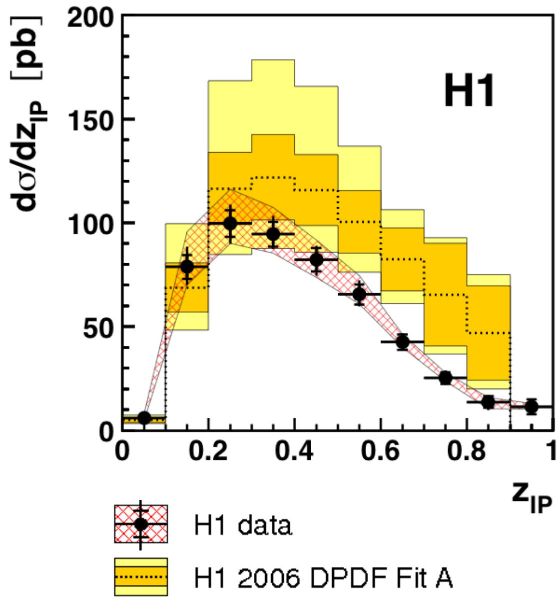
- At low z DPDFs similar to FIT A
- Gluon DPDF changes at high z

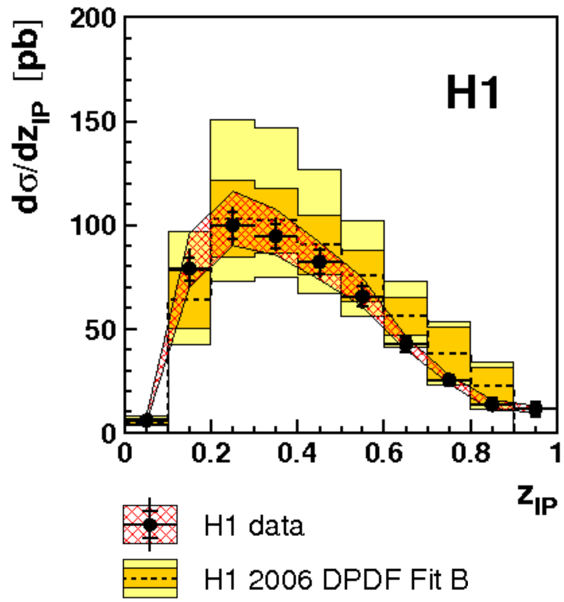


Both Fit A and Fit B describe inclusive diffractive data well

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 $z_{\mathbb{P}} = \frac{M^2_{j_1 j_2} + Q^2}{M^2_X + Q^2}$

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

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

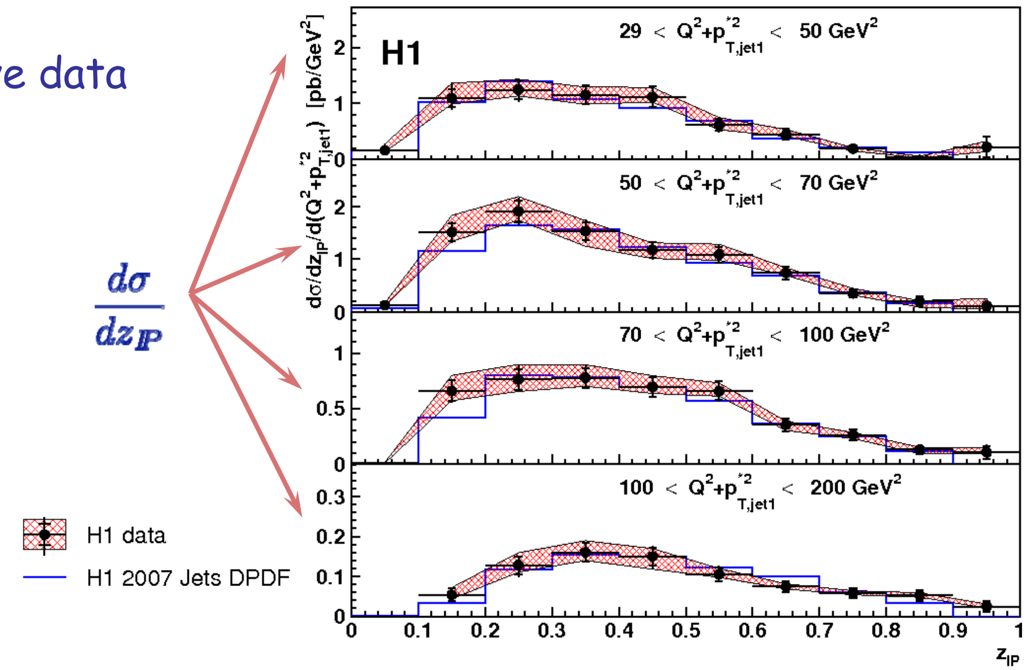
Gluon

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

$$\text{FitB} \quad zg(z,Q_0^2) = A_g$$

$$\text{Jets} \quad zg(z,Q_0^2) = A_g^{B_g}(1-z)^{C_g}$$

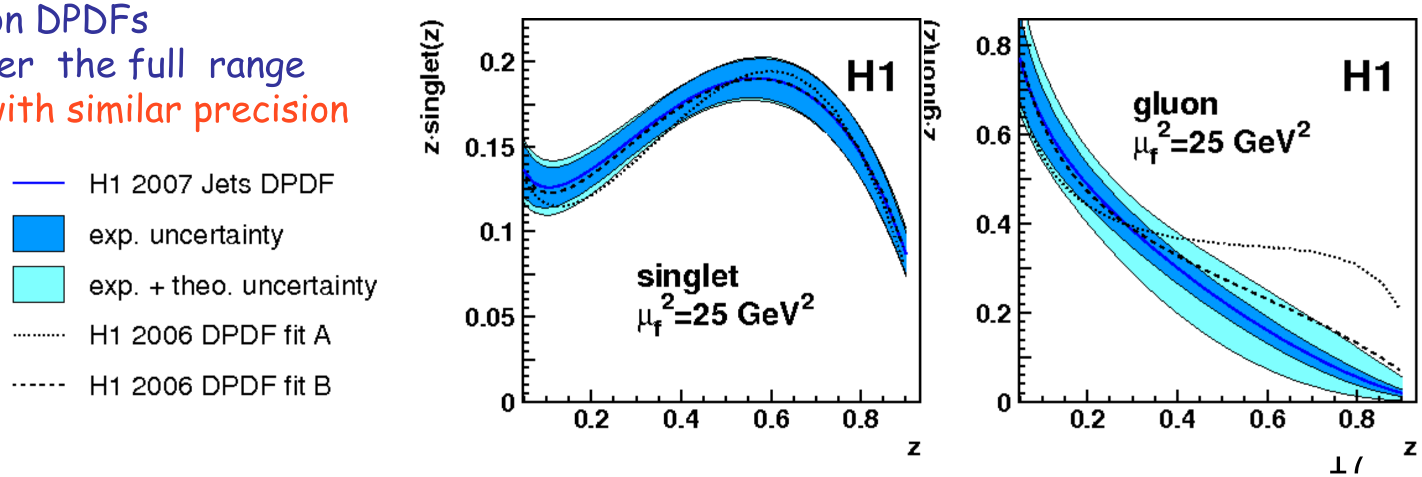
$$\frac{d\sigma}{dz_{I\!P}}$$



Results in:

- Improved χ^2

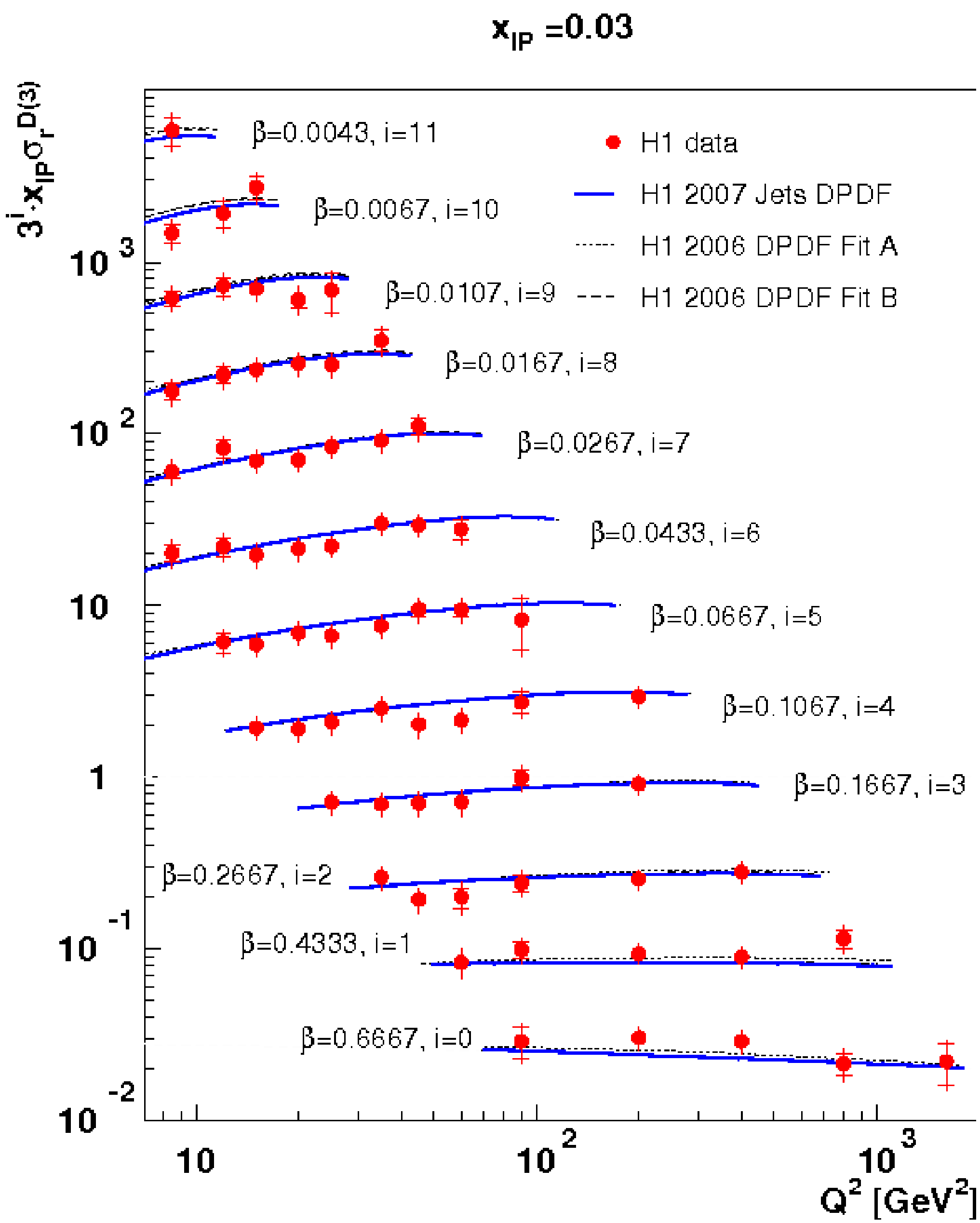
- singlet and gluon DPDFs constrained over the full range $z_P \in [0.05, 0.9]$ with similar precision



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