Measurement of the Diffractive Deep-Inelastic Scattering Cross Sections with a Leading Proton at HERA

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On behalf of the
H1 Collaboration

- Inclusive DIS Cross Sections
- Dijet Cross Sections

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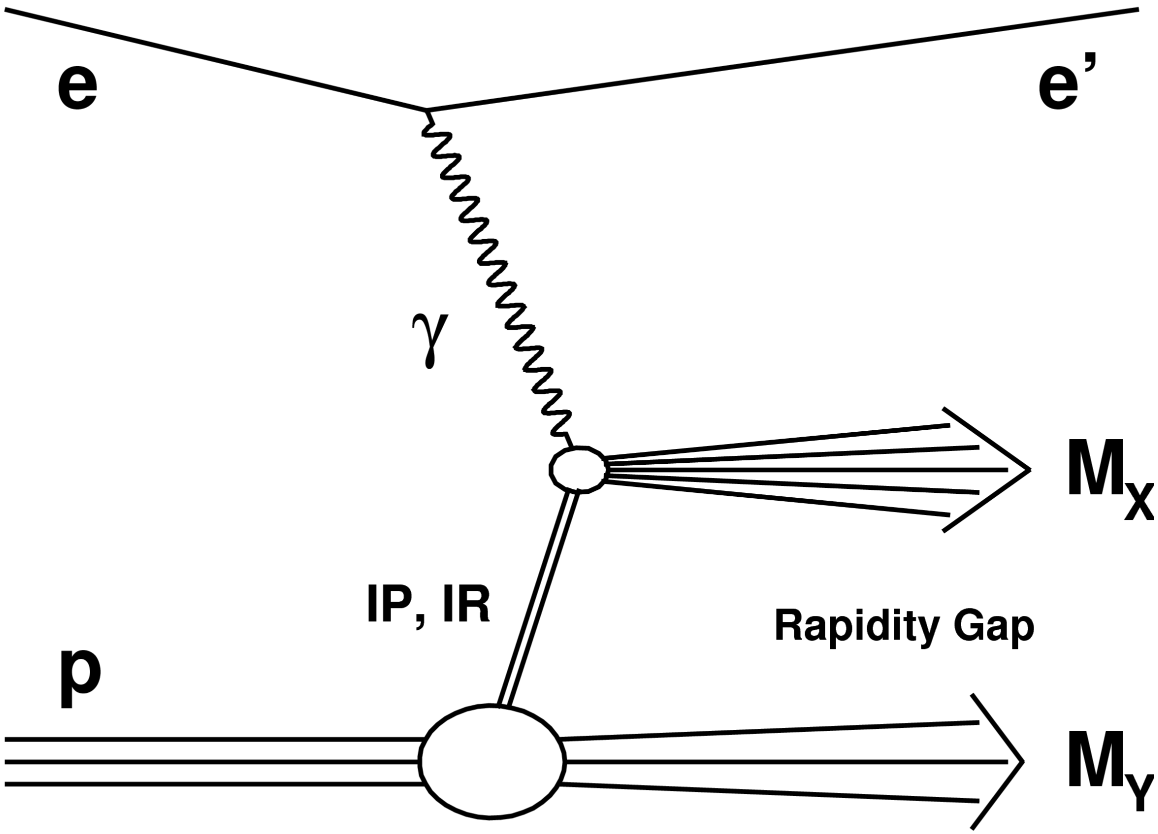
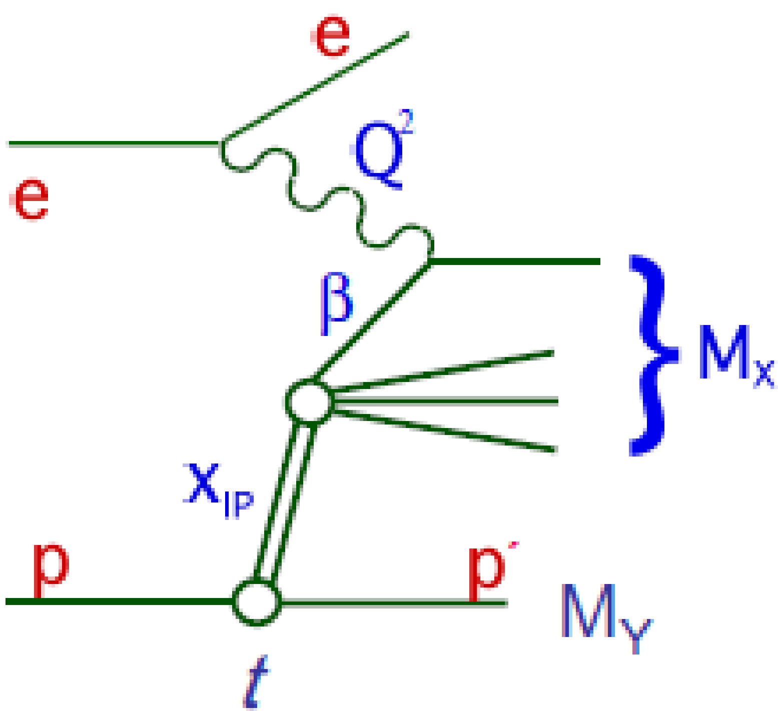
DIS 2011, Newport News

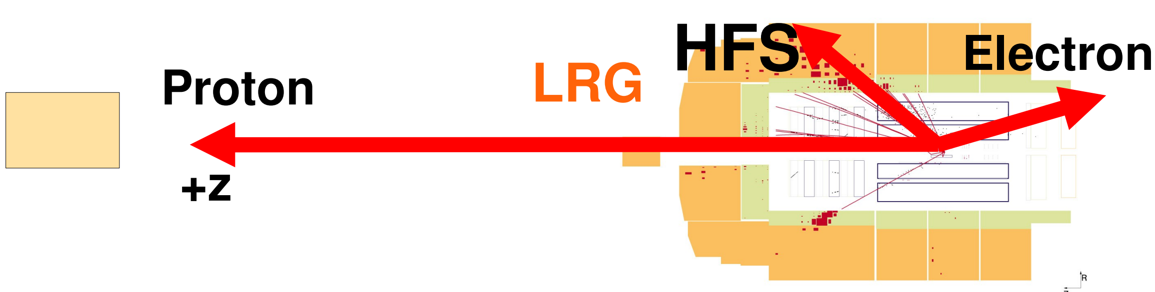
Diffractive Exchange



$M_Y = m_p$	intact proton
$m_p \leq M_Y \leq 1.6$ GeV	intact proton or proton dissociation

Diffractive measurements





Experimental techniques:

LRG method

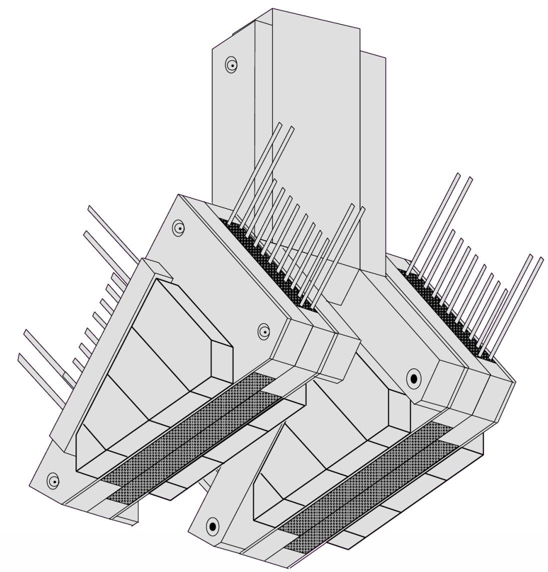
- \+ large acceptance → high statistics
- -- proton dissociative background
- -- restriction of the M_X system

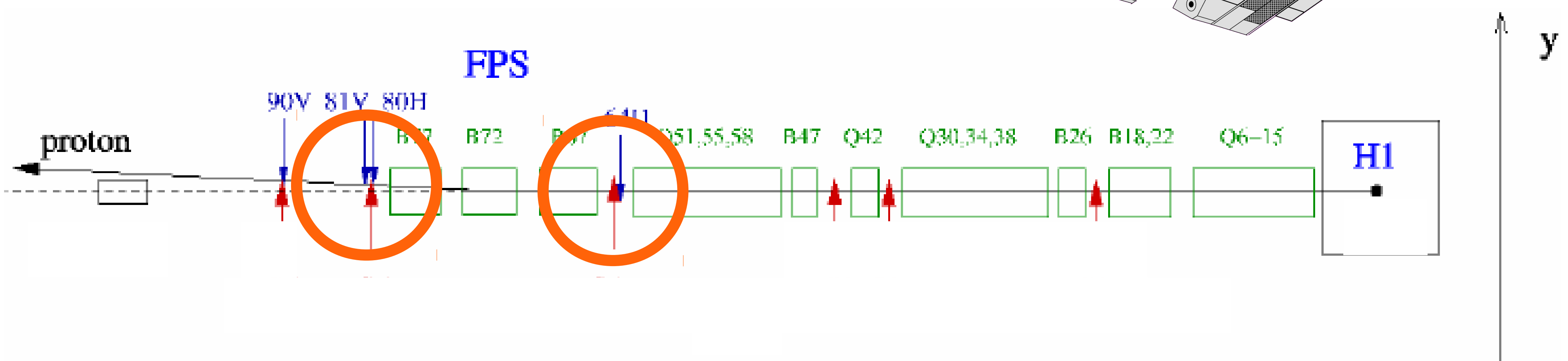
Proton Tagging

- \+ direct measurement of diffractive variables x_{IP} and t
- \+ free of proton dissociation background
- -- small acceptance → low statistics

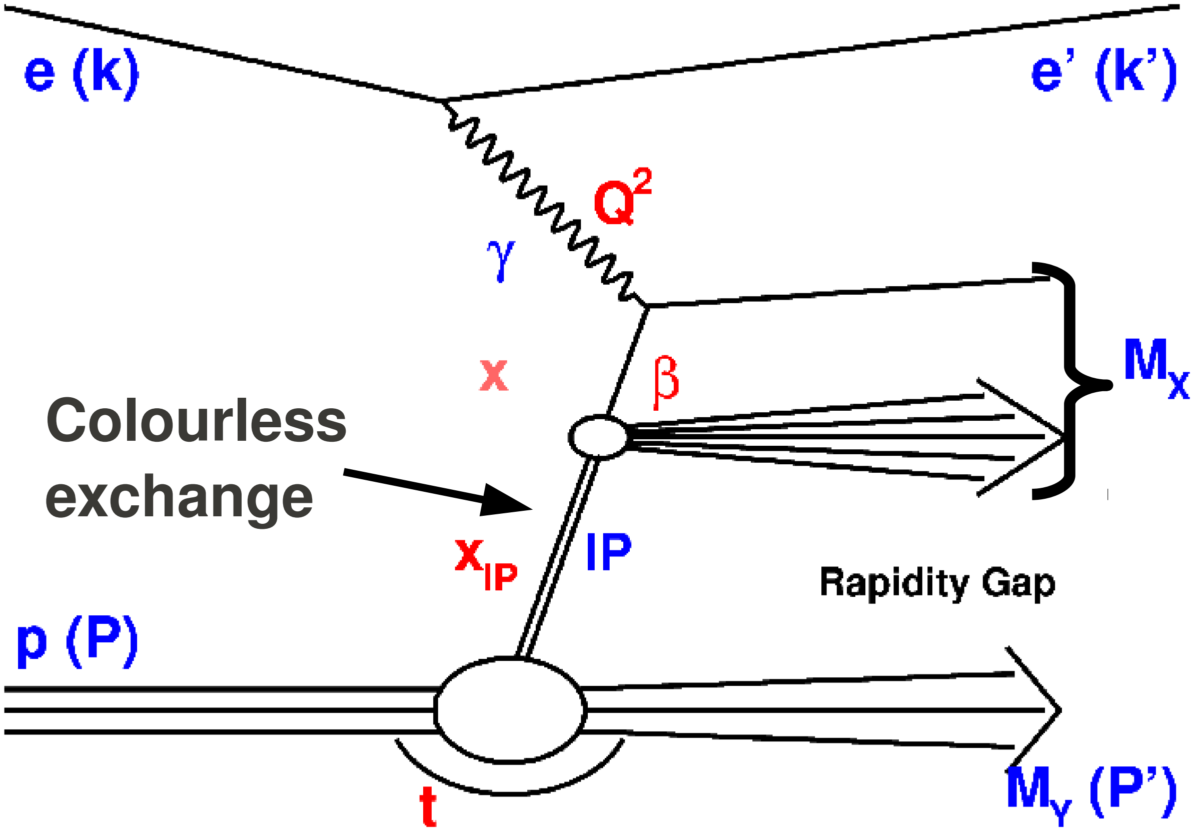
FPS at H1

- Forward Proton Spectrometer:
  - 61m and 80m stations, each station able to measure x and y position twice, 2 stations allow to measure the angle of the scattered proton
  - Scintilating fibres with PMT
  - Acceptance:
    - $x_{IP} = 1 – Ep'/Ep$ up to 0.1
    - $0.1\ GeV^2 < |t| < 0.7\ GeV^2$





Diffractive kinematics



$Q^2 = -q^2 = (k' - k)^2$

$x = Q^2/2Pq$

$x_{IP} = q(P' - P)/qP$

$= 1 - E_p/E'_p$

$\beta = x/x_{IP}$

$t = (P' - P)^2$

$M_Y = m_p$ intact proton

$m_p \leq M_Y \leq 1.6$ GeV intact proton or proton dissociation (incl. nucleon resonances)

Diffractive Cross Section

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

Where $\sigma_r^{D(4)}$ is diffractive reduced cross section:

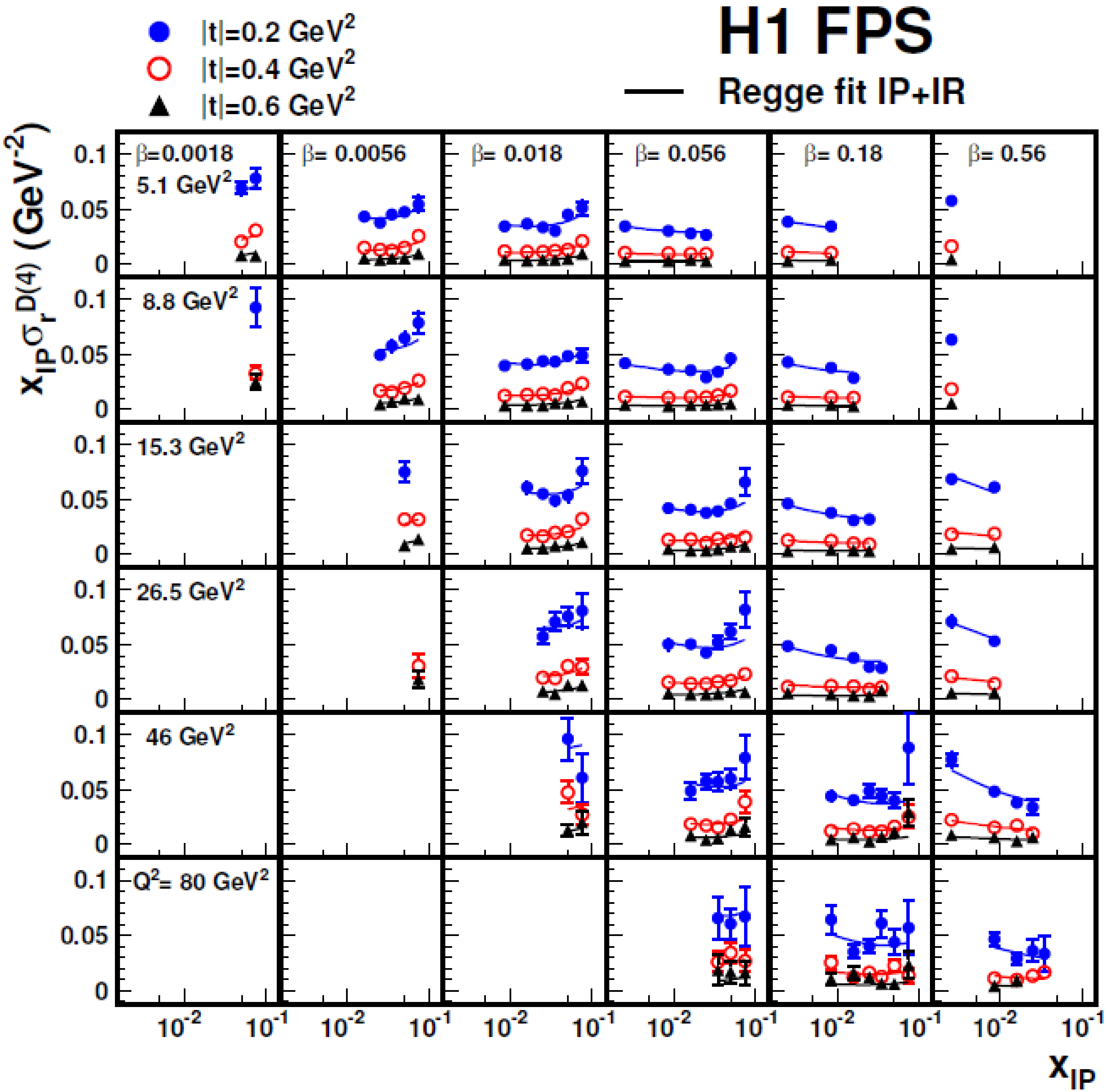
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1 - y + y^2/2)} F_L^{D(4)}$$

Longitudinal diffractive structure function, negligible for low *y*

$$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$$

LRG method unable to measure the *t* dependence → integration up to 1 GeV^2

Diffractive Reduced Cross Section



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L_{int} = 156.7 pb^{-1}

- FPS $|t|=0.2$ GeV^2
- FPS $|t|=0.4$ GeV^2
- FPS $|t|=0.6$ GeV^2
- Regge fit IP+IR

Normalisation uncertainty 4.3% not shown

Regge Factorisation

Assumption of **proton vertex factorisation**

$$F_2^{D(4)}(\beta,Q^2,x_{IP},t)=f_{IP}(x_{IP},t)\cdot F_2^{IP}(\beta,Q^2)+n_{IR}\cdot f_{IR}(x_{IP},t)\cdot F_2^{IR}(\beta,Q^2)$$

$$f_{IP}(x_{IP},t)=A_{IP}\frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

$$\frac{d\sigma}{dt}\sim e^{-B|t|}$$

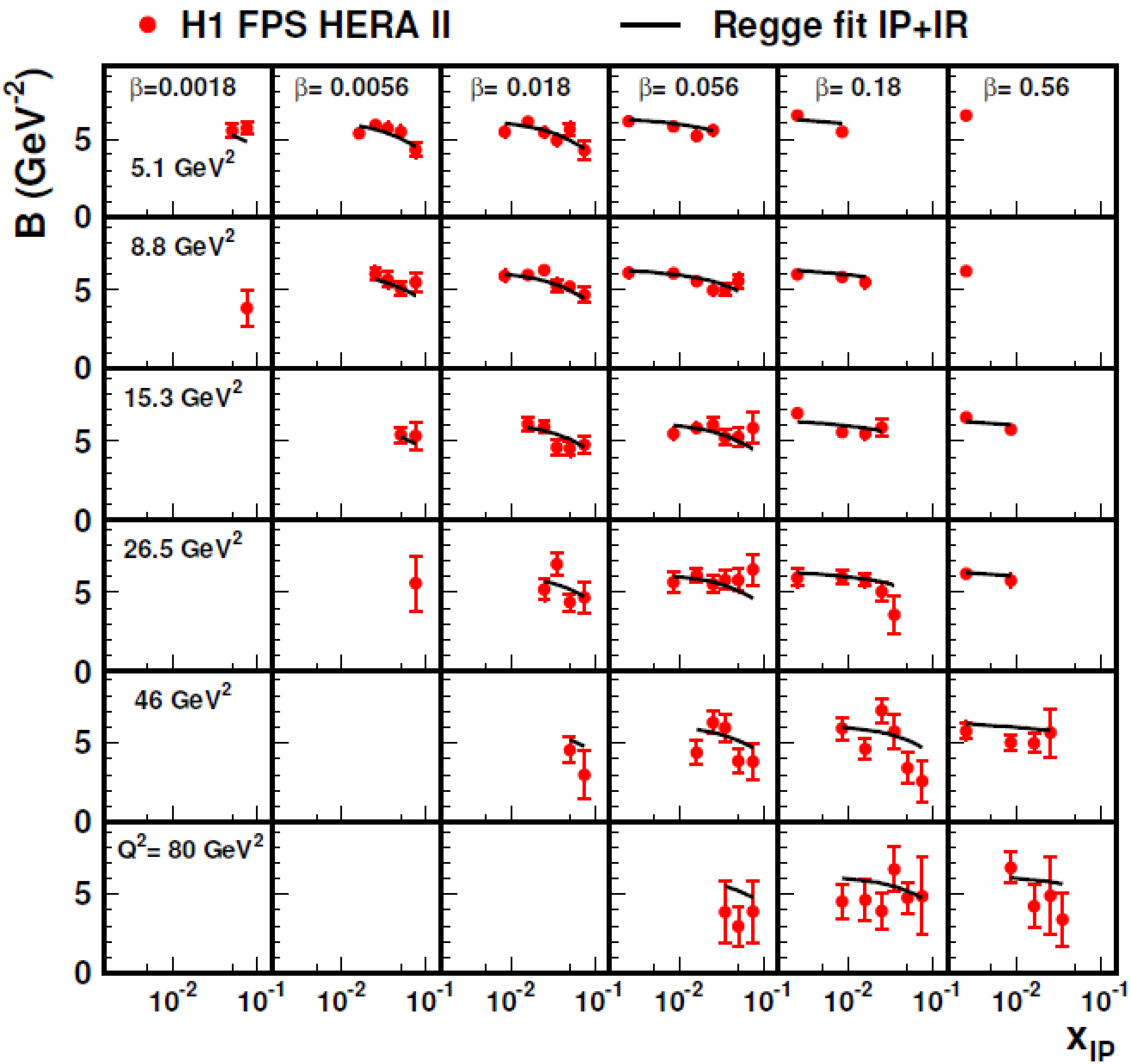
$$\alpha_{IP}(t)=\alpha_{IP}(0)+\alpha_{IP}'t$$

$$B=B_{IP}+2\alpha_{IP}'\ln(1/x_{IP})$$

Free: IP parameters + IR normalisation: $\alpha_{IP}(0)$, α'_{IP}, B_{IP}, n_{IR}

Fixed: IR flux and IR DPDF à la pion PDF from Owens

Proton Vertex Factorisation



$$\frac{d\sigma}{dt} \sim e^{-B|t|}$$

$$B = B_{IP} + 2\alpha_{IP}' \ln(1/x_{IP})$$

- Data are consistent with **proton vertex factorisation**
- Weak dependence at high x_{IP} due to IR exchange

Proton Vertex Factorisation

$$f_{IP}(x_{IP},t)=A_{IP}\frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

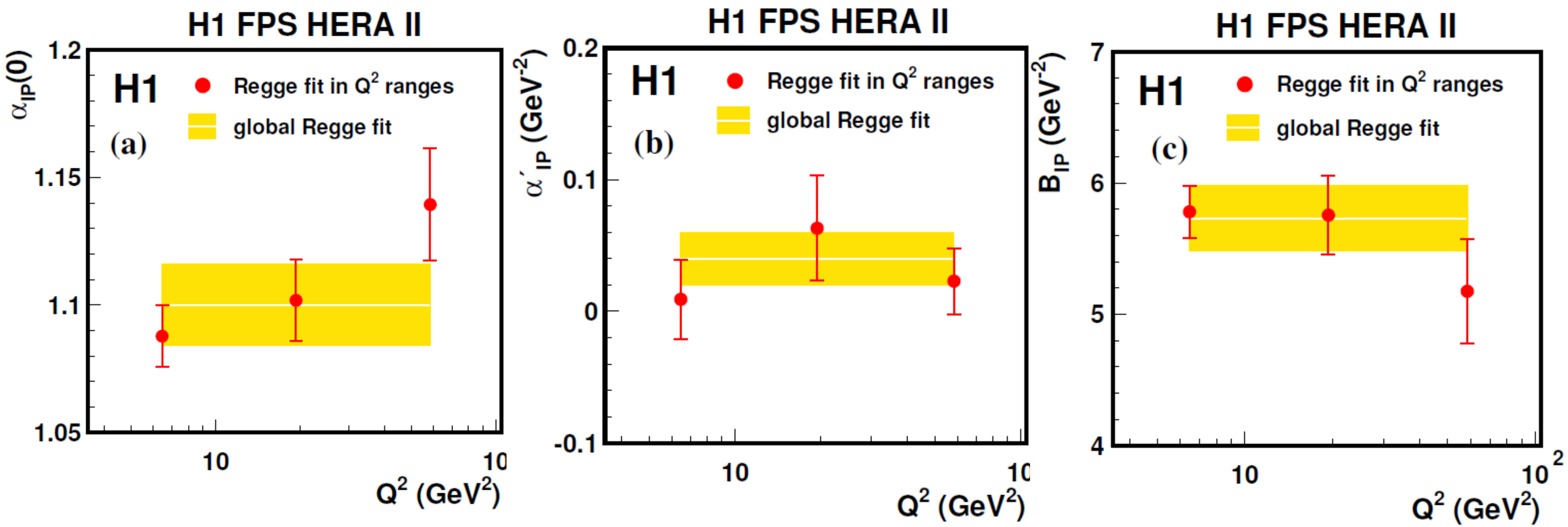
$$\alpha_{IP}(t)=\alpha_{IP}(0)+\alpha_{IP}'t$$

$\alpha_{IP}(0)$	$1.10\pm0.02(\exp)\pm0.03(model)$
α'_{IP} [GeV^{-2}]	$0.04\pm0.02(\exp)^{+0.08}_{-0.06}(model)GeV^{-2}$
B_{IP} [GeV^{-2}]	$5.73\pm0.25(\exp)^{+0.08}_{-0.09}(model)GeV^{-2}$

- $\alpha_{IP}(0)$ prefers soft pomeron intercept
- α'_{IP} smaller than in soft hadron-hadron scattering

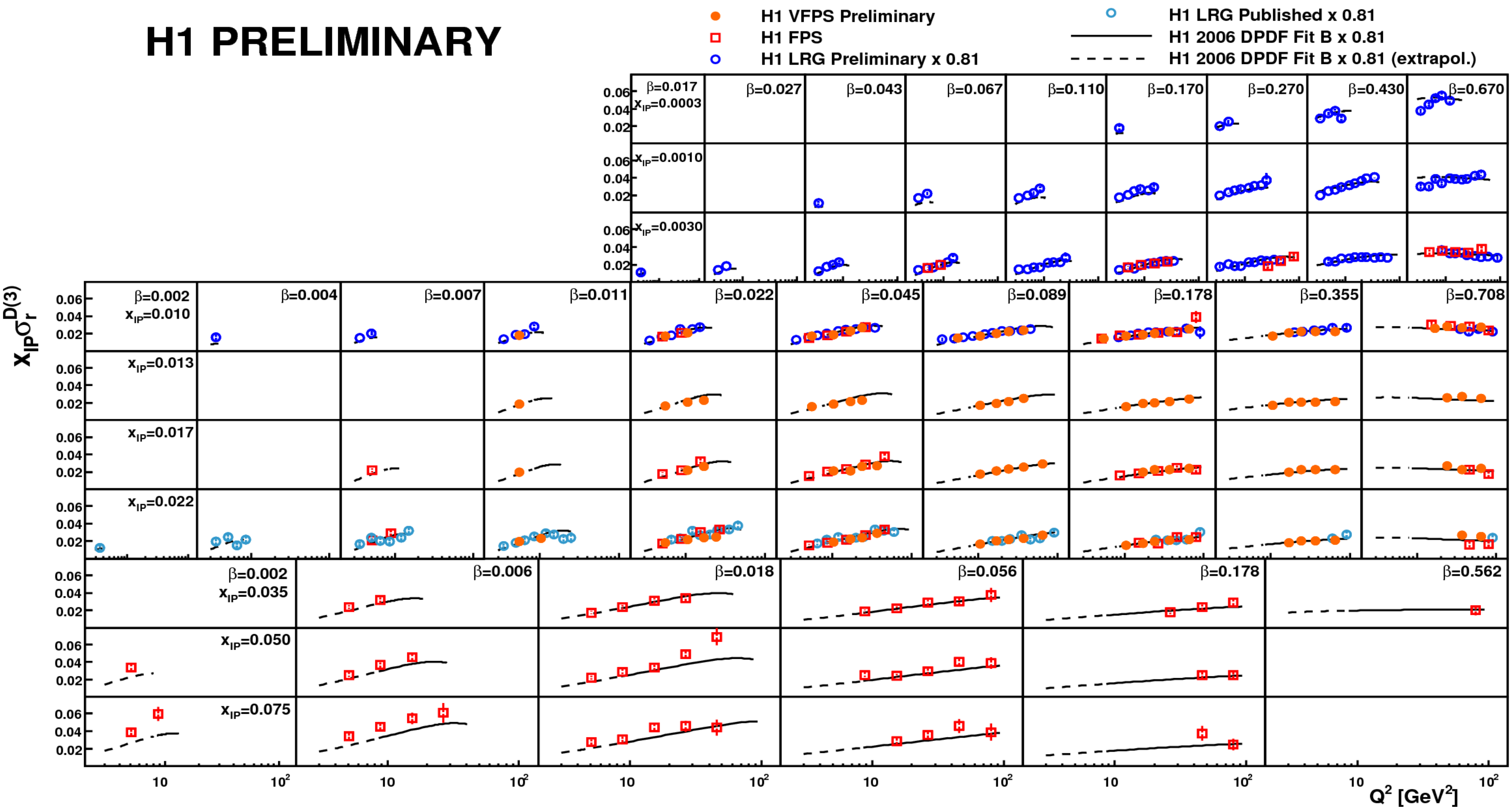
Proton Vertex Factorisation

$$f_{IP}(x_{IP},t) = A_{IP}\frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}} \qquad \alpha_{IP}(t)=\alpha_{IP}(0)+\alpha_{IP}'t$$



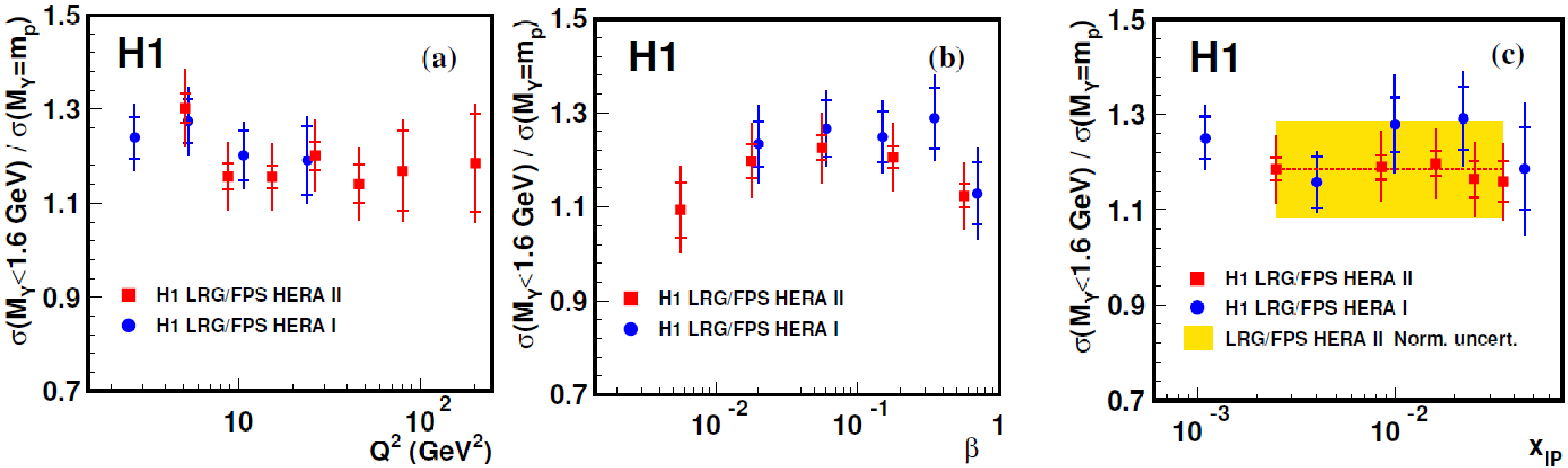
- **Independence on kinematical variables within errors favours proton vertex factorisation**

$\sigma_r^{D(3)}$



- Different measurements cover large region of phase space in x_{IP}, β and Q^2
- Excellent agreement between different reconstruction methods in regions of overlap

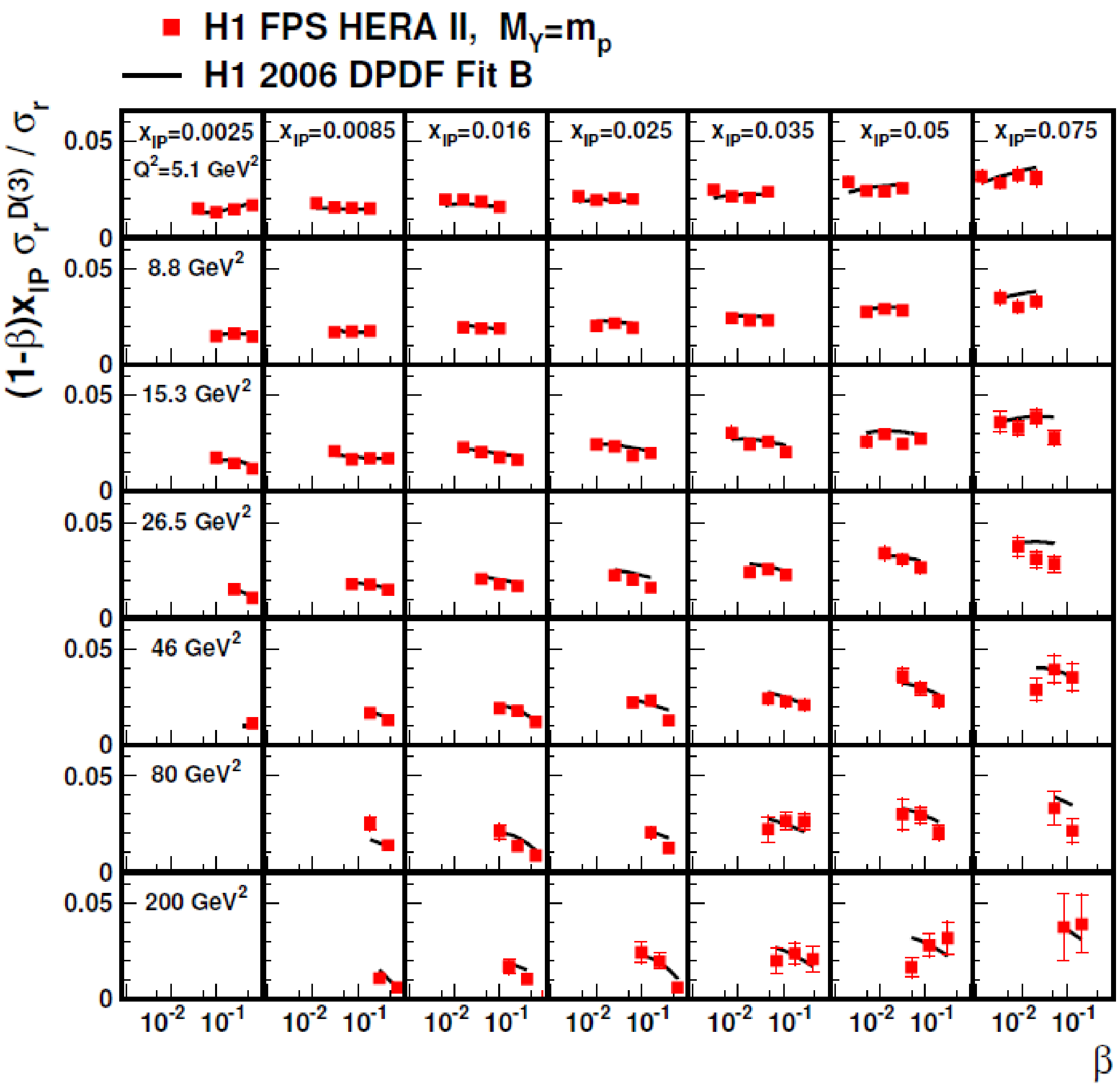
LRG / FPS

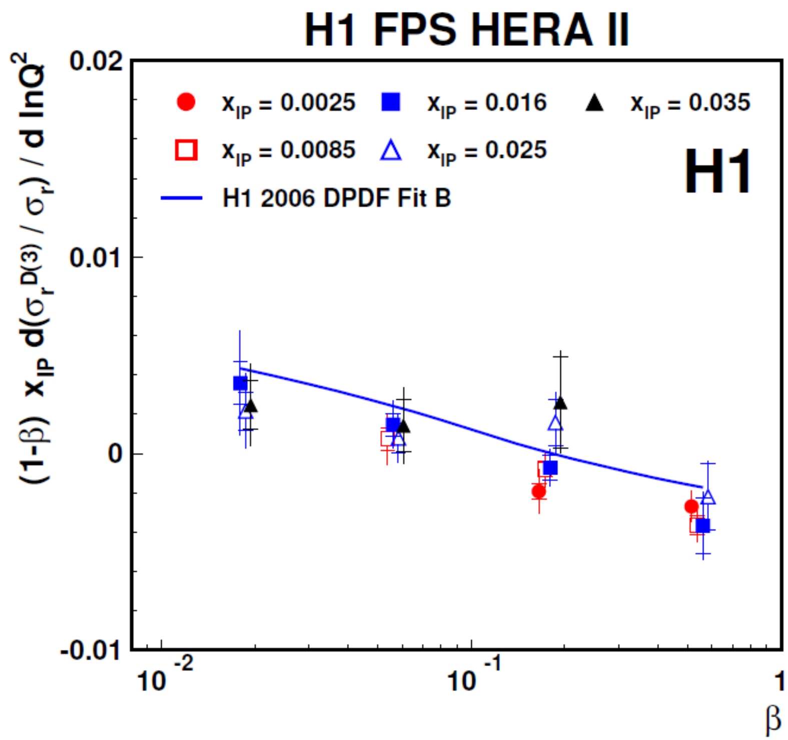


- **HERA I + II combined LRG/FPS ratio: 1.20 ± 0.11 (exp)**
  - 20% comes from the proton dissociation in the LRG selection

- **Constant in all kinematical variables**

$\sigma_{\mathrm{DiffrDIS}} / \sigma_{\mathrm{InclDIS}}$

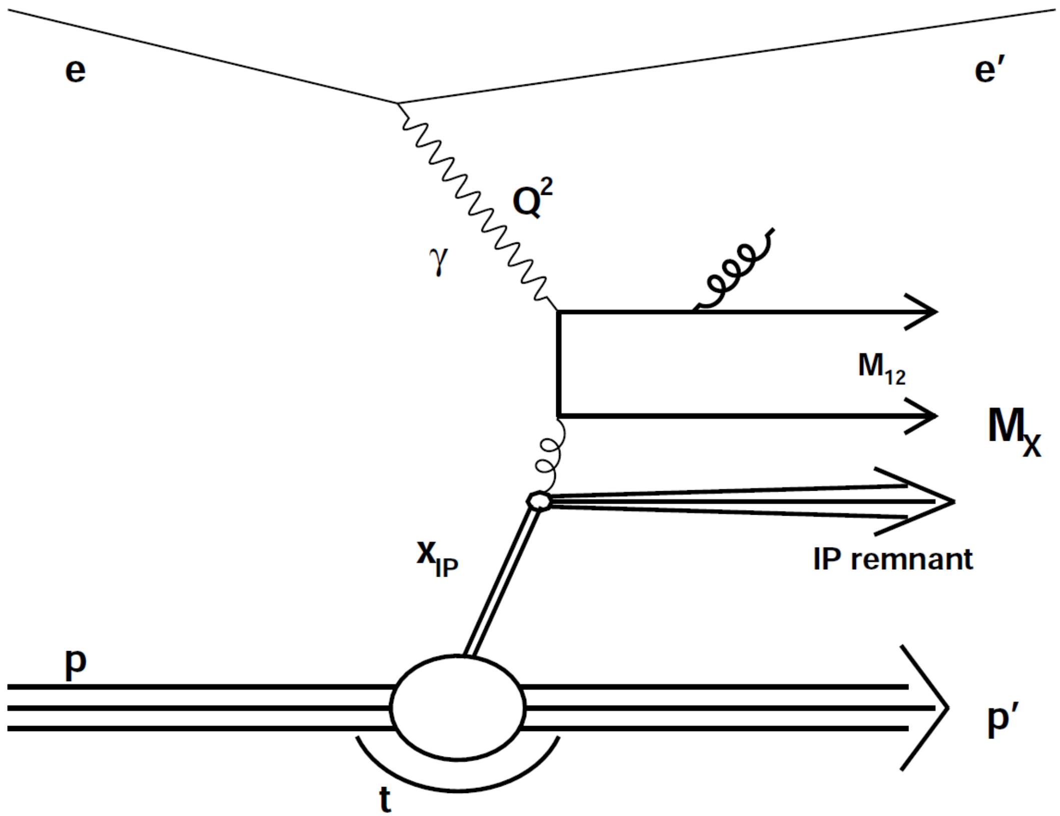




- $x_{Bj} = x_{IP}\beta$
- $\sigma_{\mathrm{DiffrDIS}} / \sigma_{\mathrm{InclDIS}}$ at same x_{Bj}
- H1PDF 2009

- Ratio of cross sections constant → Diffr. quarks behave like InclDIS quarks
- Log derivative ↔ scaling variations ↔ information about gluon
- Log derivative of ratio ~0 → Diffr. gluons behave similarly to InclDIS gluons

Jets in Diffraction



- Presence of an additional hard scale
- Direct sensitivity to gluon density in pomeron
- Study of parton evolution

- Measurement of Jets with FPS performed

$$z_{IP} = \frac{Q^2 + M_{12}^2}{x_{IP}\, y s}$$

Comparison to previous analysis

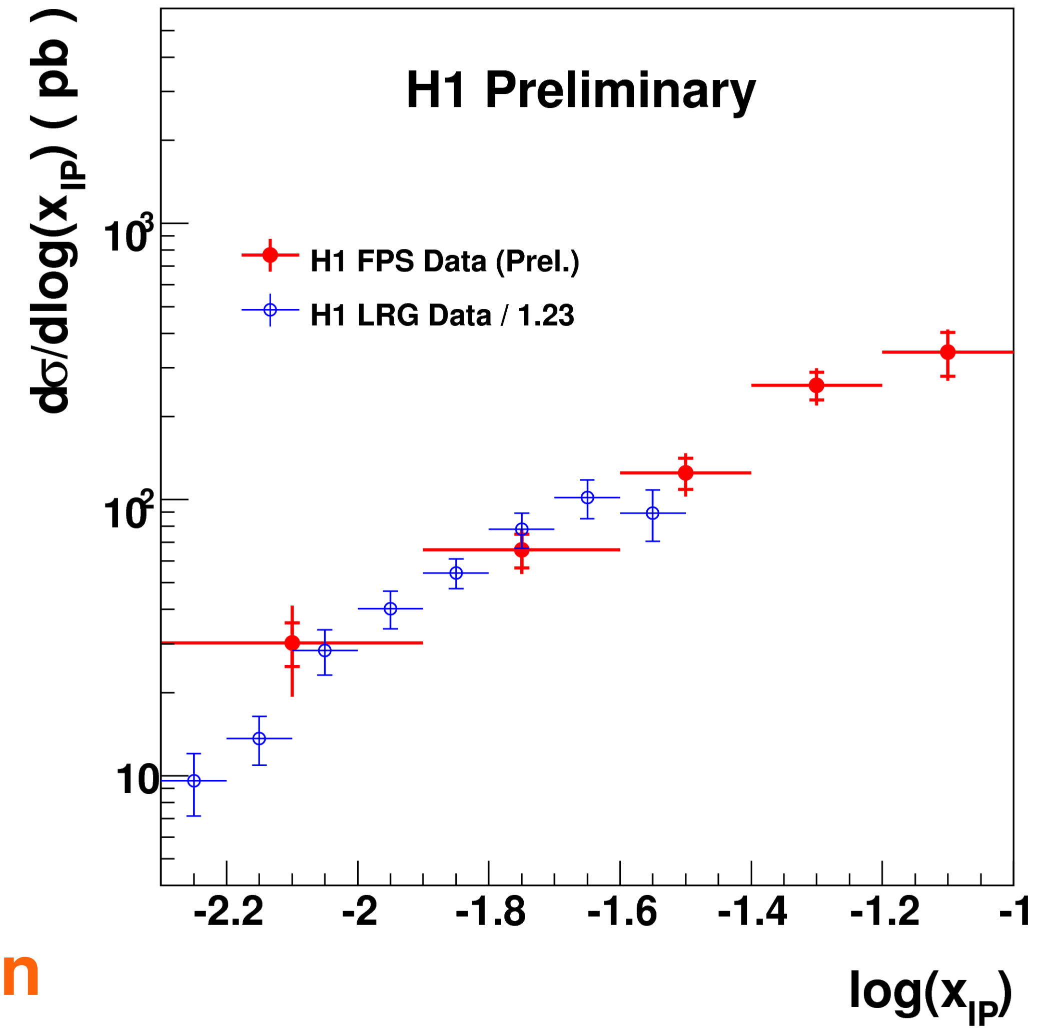
- Diffractive DIS dijet analysis with LRG (JHEP 0710:042)
- Published data corrected for proton dissociation

$4 < Q^2 < 80$ GeV^2

$0.1 < y < 0.7$

$p_{T1}^* > 5.5$ GeV

$p_{T2}^* > 4$ GeV



- **Very good consistency**
- **Phase space extension in x_{IP} by factor of 3**

2 central jets

$4 < Q^2 < 110$ GeV^2

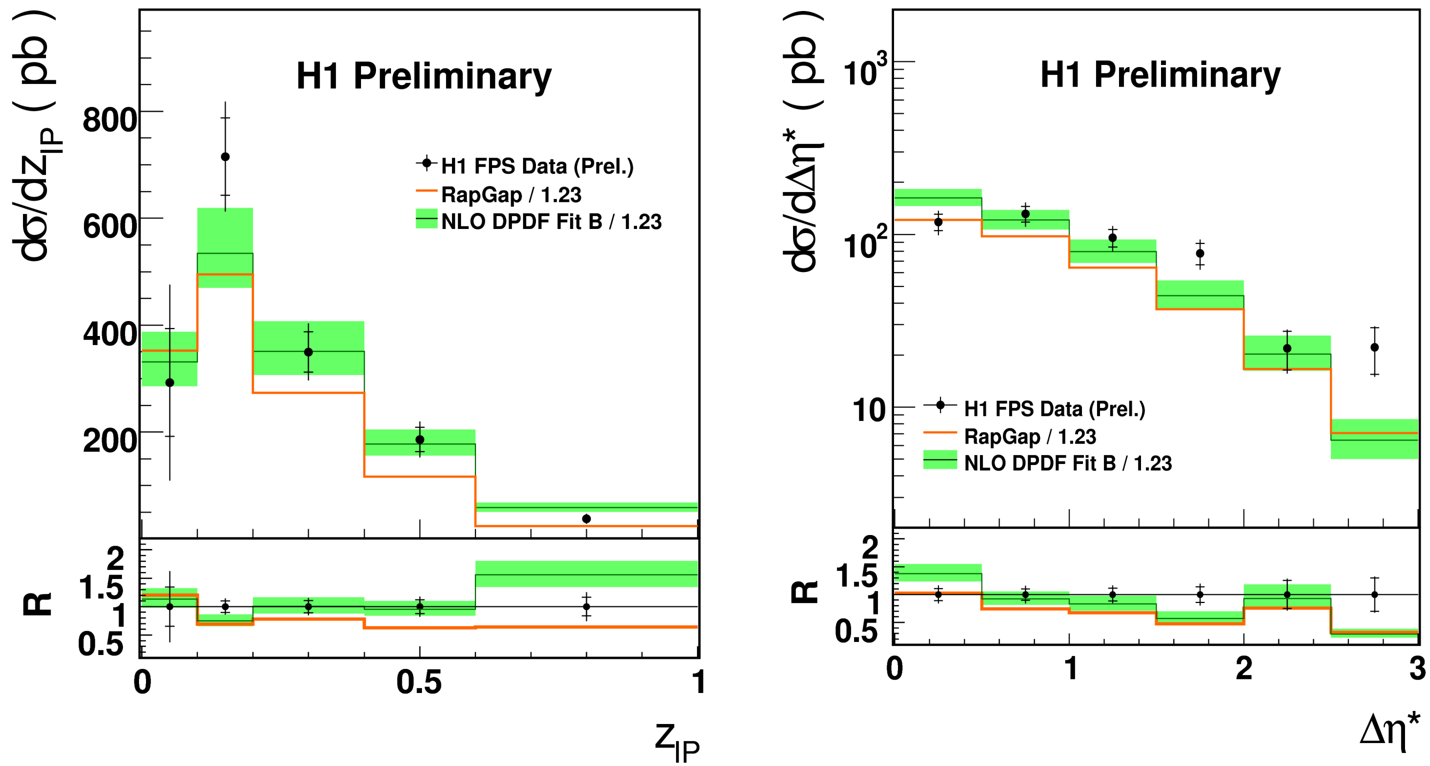
$0.05 < y < 0.7$

$x_{IP} < 0.1$

$p_{T1}^* > 5$ GeV

$p_{T2}^* > 4$ GeV

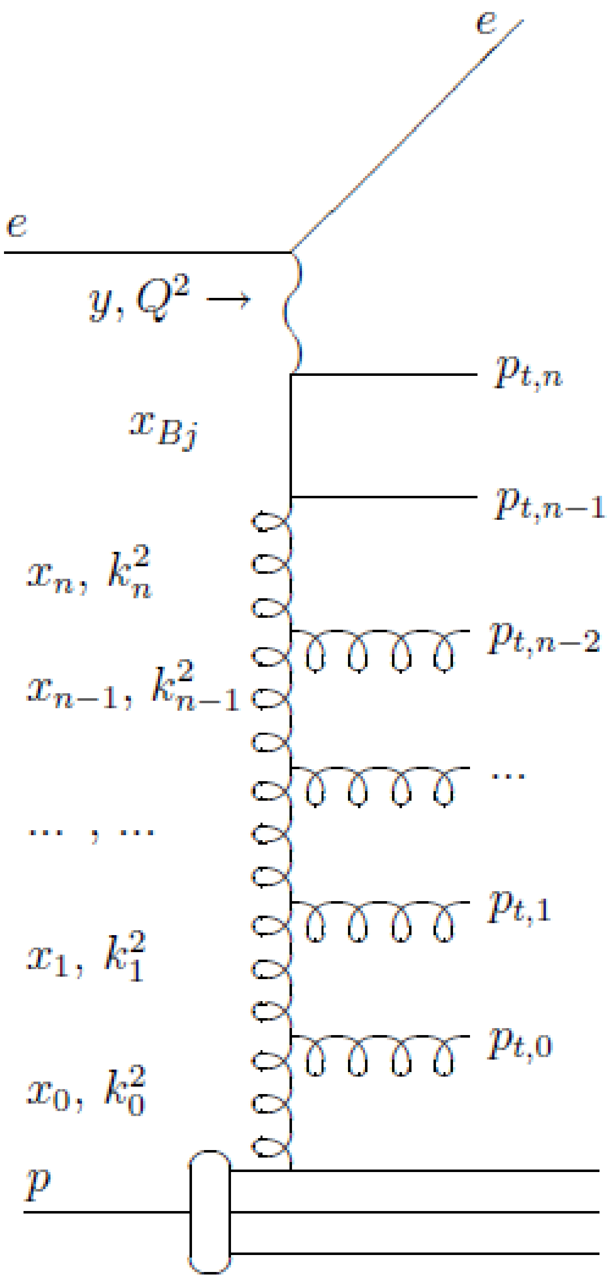
$-1 < \eta_{1,2} < 2.5$



- Good general description of the data by the NLO QCD calculations
- **RapGap describes the shape but it's off in normalisation**
- **Deviation of the theory for jets with largest η separation**

Diffractive Forward Jets

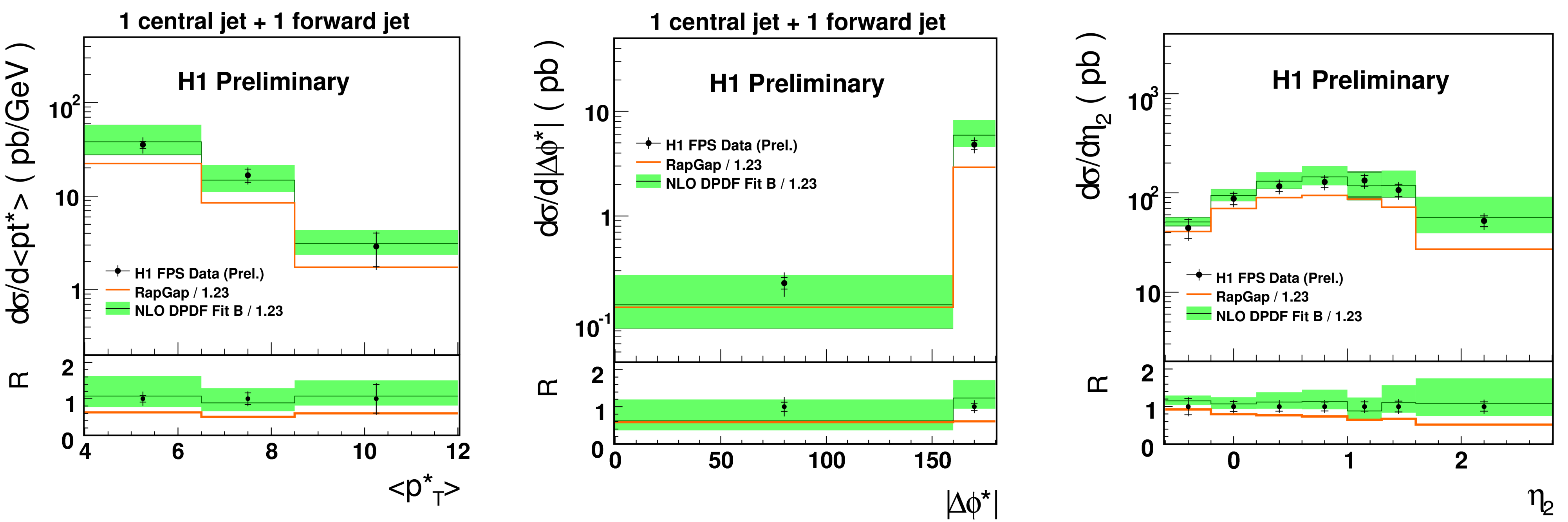
- DGLAP evolution equation assume strong k_T ordering and neglect terms ~1/x
- Forward jets with leading proton in DDIS – search for physics beyond DGLAP
  - Possible in leading proton measurement
  - Possibility to investigate jets close to the proton direction
  - Low x region
- Selection of **1 central + 1 forward jet** suppressing DGLAP phase space
- Calculable in NLO (NLOJET++ with DPDF H1 2006 Fit B)



Diffractive Forward Jets

$4 < Q^2 < 110\ \mathrm{GeV}^2$
$0.05 < y < 0.7$
$X_{IP} < 0.1$

$p^*_{T,forward} > 4.5$ GeV, $p^*_{T,central} > 3.5$ GeV
$1 < \eta_{forward} < 2.8$, $-1 < \eta_{central} < 2.5$
$\eta_{central} < \eta_{forward}$



Good description by NLO QCD DGLAP predicions

summary

- High statistics HERA-II Diffractive DIS data measured with the FPS
- Parameters of IP trajectory obtained from the Regge fit to the data
- Pomeron intercept ~soft diffraction, but slope of Regge trajectory favours hard process (no shrinkage)
- Measurement consistent with Proton Vertex Factorisation
- Parton distributions for diffractive and inclusive processes behave similarly

- Central jets with tagged leading proton measured in *ep* for the first time
- DPDFs tested in extended kinematical region up to $x_{IP} < 0.1$
- Within errors NLO describes the data, RapGap is off in normalisation
- No signs for physics beyond DGLAP in phase space accessible by H1+FPS

backup

Selection

- Data collected during whole HERA-II period with L_{int} = 156 pb^{-1}
  - Tagged proton selection requires a good understanding of background in FPS due to coincidence of beam halo protons and event in the central detector