Diffractive DIS with a Leading Proton at HERA-2

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on behalf of the H1 Collaboration

- Selection of Diffraction at HERA
- H1 Forward Proton Spectrometer
- H1 FPS HERA-2 results:

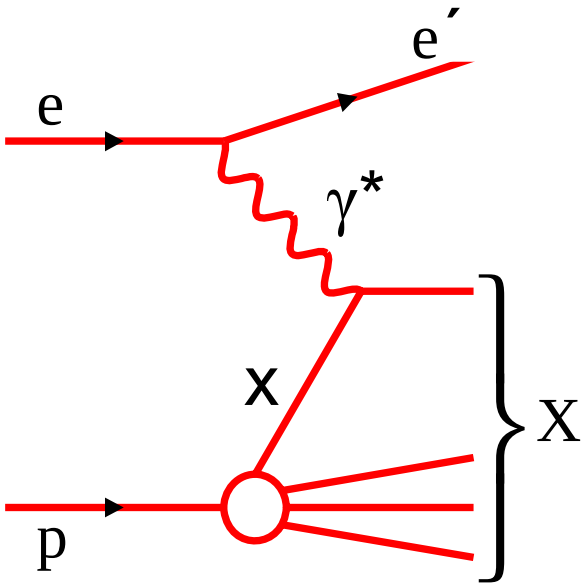
➔ Diffractive reduced cross section $\sigma_r^{D(4)}$ and Regge fit

➔ Ratio of Diffractive to Inclusive DIS cross section

Diffractive DIS at HERA

➔Probe structure of color singlet exchange with virtual photon at HERA → F_2^D

Standard DIS



F_2 → probe structure of proton

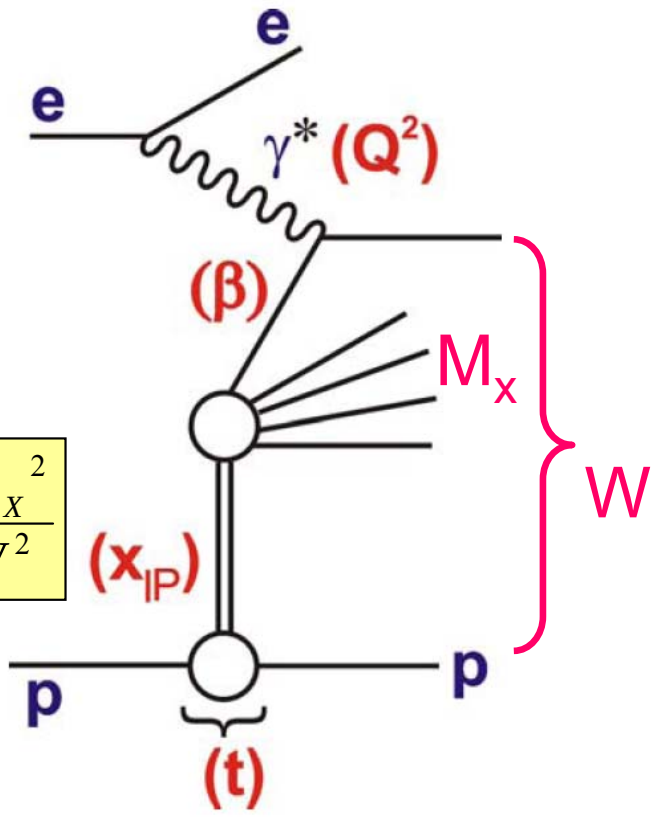
Diffractive DIS

Momentum fraction of color singlet carried by struck quark

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

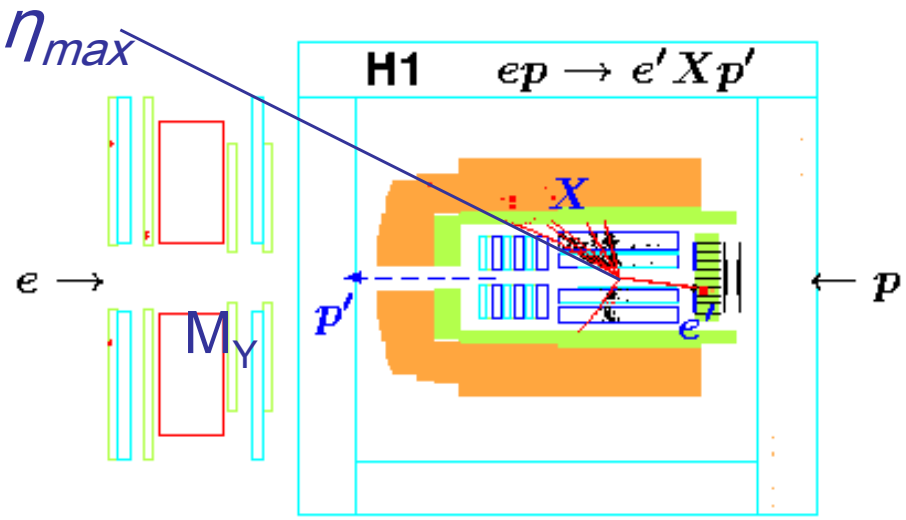
$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

Momentum fraction of proton carried by colour singlet exchange



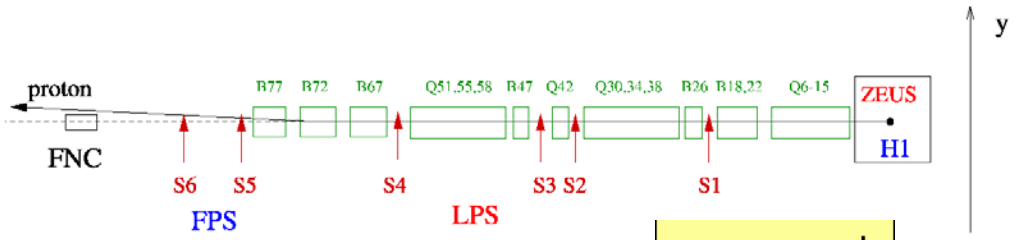
Selection of diffraction at HERA

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

Forward Proton Spectrometer H1 FPS



+ ZEUS LPS
+ H1 VFPS

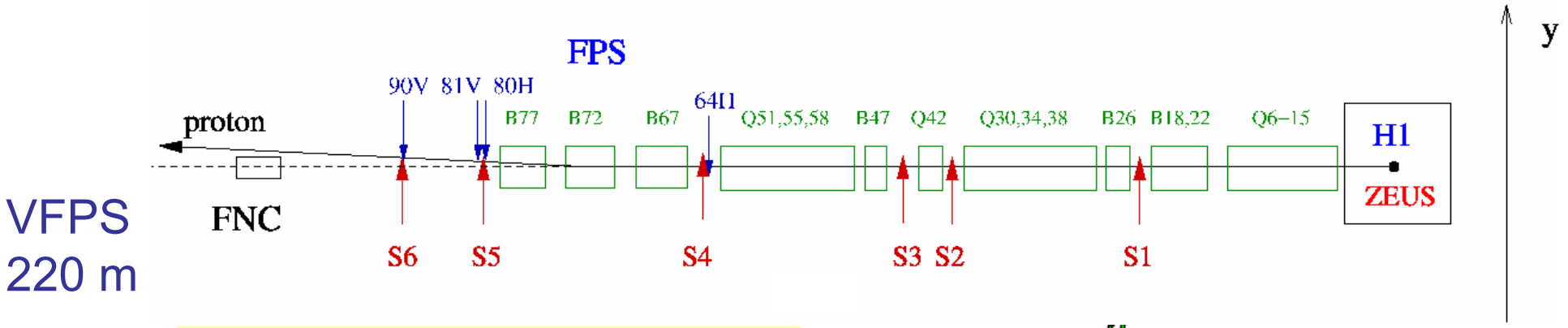
$$x_{IP} = 1 - \frac{E'_p}{E_p}$$

- free of p-dissociation background
- x_{IP} and t-measurements
- access to high x_{IP} range (IP+IR)
- low geometrical acceptance
  - H1 VFPS has high acceptance (see talk of Tomas Hreus)

➔ LRG and FPS methods have different systematic uncertainties

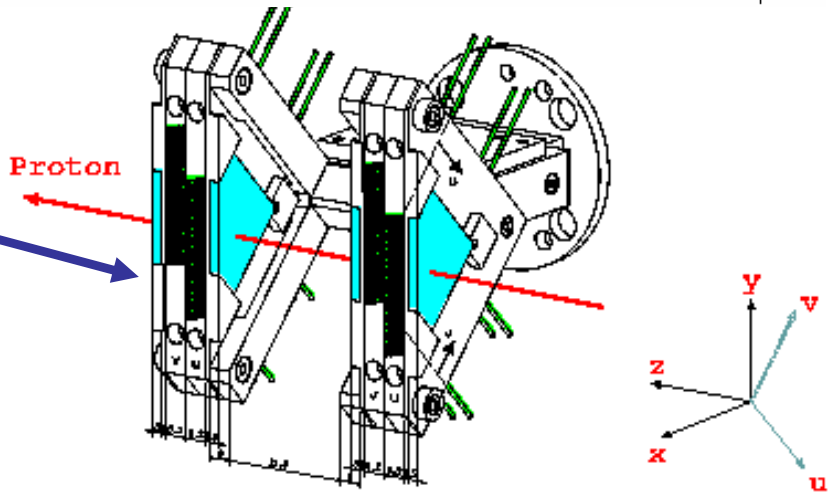
Forward Proton Spectrometer

- Purpose: measurement of leading proton momentum using coordinate detectors and system of HERA magnets
- Roman Pot technology, scintillating fibre detectors readout by position sensitive photo-multipliers



VFPS 220 m

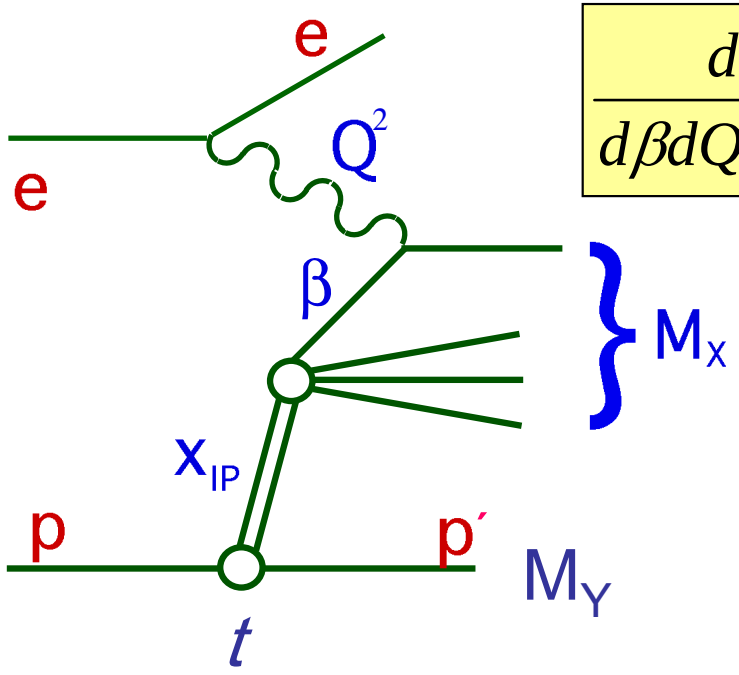
Horizontal detectors at 61m and 80m: $x_{IP}<0.1$



HERA-2: FPS detector upgrade

➔ 20 times higher statistics than collected at HERA-1

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:

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

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

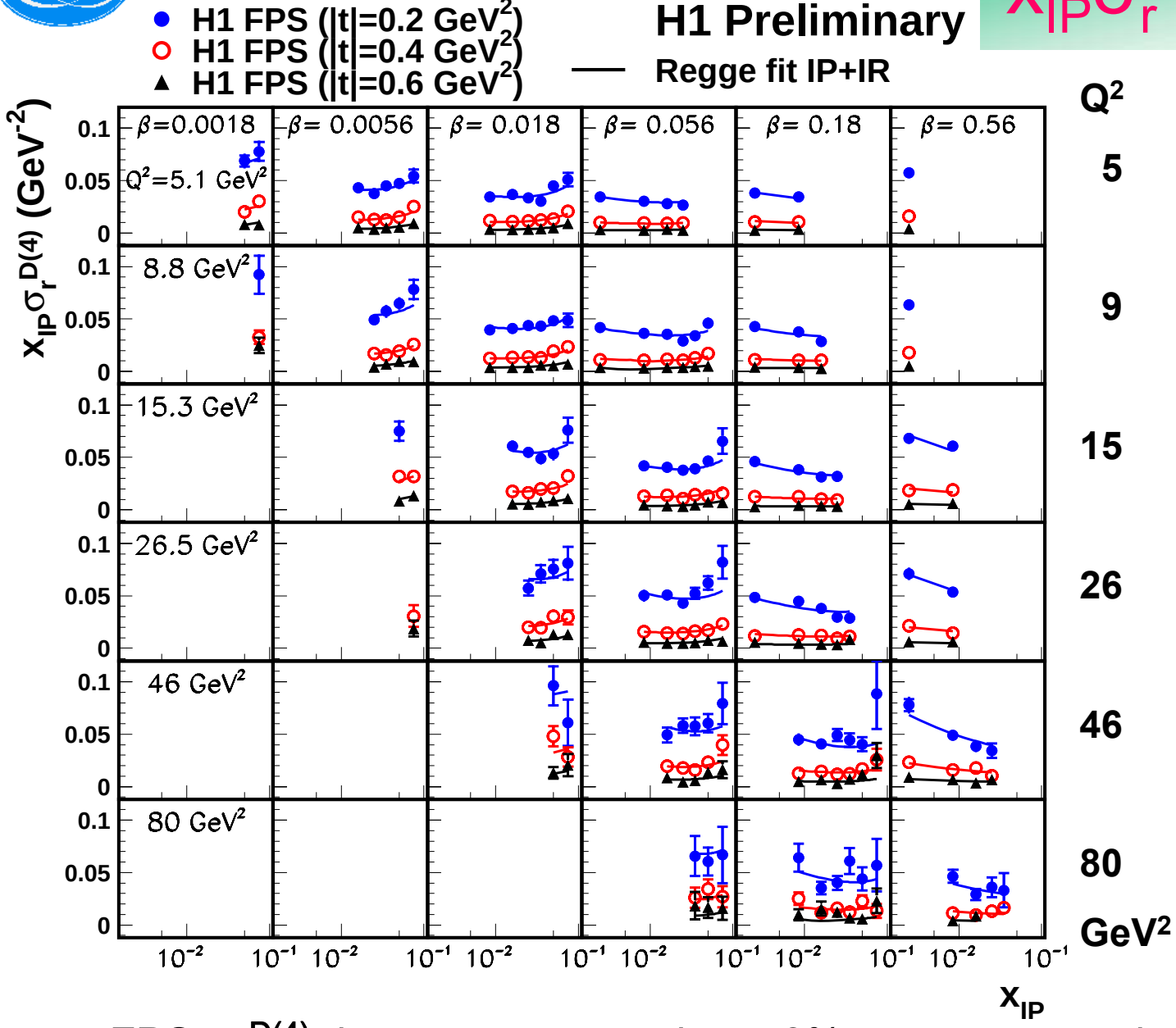
$$\sigma_r^{D(3)} = \int \sigma_r^{D(4)} dt$$

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

Ratio of diffractive to inclusive DIS σ_r

$$(1-\beta) x_{IP} \sigma_r^{D(3)} / \sigma_r^{incl} \approx M_X^2 \frac{d\sigma_{\gamma^* p \to Xp}(M_X, W, Q^2)}{dM_X^2} / \sigma_{\gamma^* p \to X}(W, Q^2)$$

$x_{IP}\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$



Q^2

5

9

15

26

46

80

GeV^2

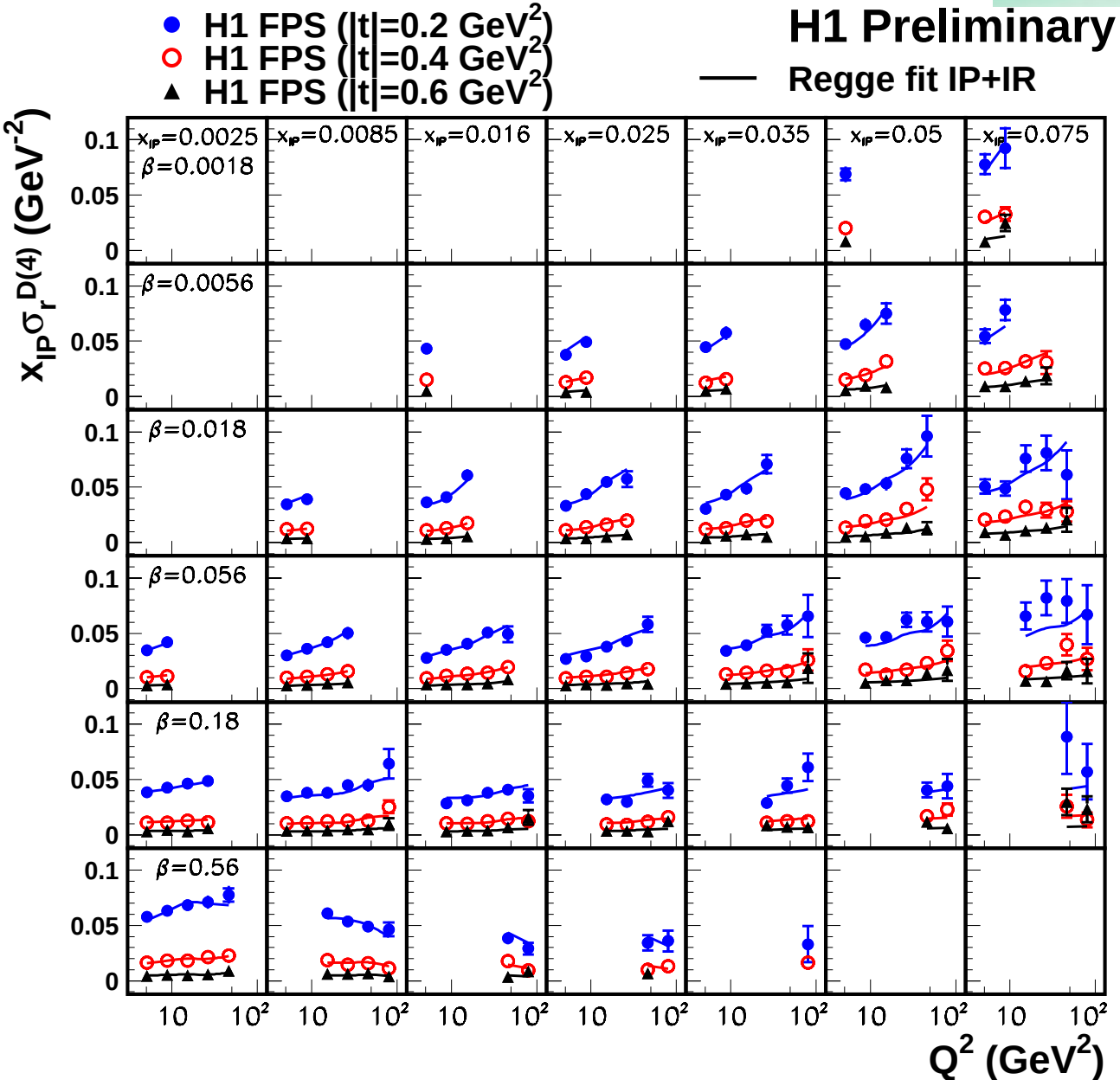
- FPS |t|=0.2 GeV^2
- FPS |t|=0.4 GeV^2
- FPS |t|=0.6 GeV^2
- Regge fit IP+IR

x_{IP}-dependence in (Q^2,β,t) bins

→ IP and IR contributions

- FPS $\sigma_r^{D(4)}$ data: syst. uncertainty ~8%, norm. uncertainty ~4.3%

$x_{IP}\sigma_r^{D(4)}(\beta,Q^2,x_{IP},t)$



β

0.0018

0.0056

0.018

0.056

0.18

0.56

- FPS |t|=0.2 GeV²
- FPS |t|=0.4 GeV²
- FPS |t|=0.6 GeV²
- Regge fit IP+IR

Q^2-dependence in (β, x_{IP}, t) bins

- Positive scaling violations except at high $\beta \rightarrow$ gluon contribution to diffractive exchange

Regge fit

- Assume proton vertex factorization for IP and IR

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

- Parameterization of x_{IP} and t dependences for *IP* and *IR*:

$$f_{IP}(x_{IP},t) = \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}} \qquad \frac{d\sigma}{dt} \sim \exp B|t|$$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha_{IP}'t \qquad B = B_{IP} + 2\alpha'_{IP}\ln(1/x_{IP})$$

- Fixed parameters for *IR* (as in H1 DPDF Fits): $\alpha_{IR}(0)$, α'_{IR}, B_{IR}, $F_2^{IR}(\beta,Q^2)$ – π structure function, F_L^D contribution corrected using H1 2006 DPDF fit B

- Free parameters: $\alpha_{IP}(0)$, α'_{IP}, B_{IP}, n_{IR} and *IP* normalization $F_2^{IP}(\beta,Q^2)$ in every (β,Q^2) bin

Result of Regge fit

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

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

$\alpha_{IP}(0) = 1.10 \pm 0.02\ (exp.) \pm {}^{0.03}_{0.02}\ (model)$

$\alpha'_{IP} = 0.04 \pm 0.02\ (exp.) \pm 0.03\ (model)\ GeV^{-2}$

$B_{IP} = 5.73 \pm 0.25\ (exp.) \pm 0.60\ (model)\ GeV^{-2}$

➔ $\alpha'_{IP} \simeq 0 \rightarrow$ no "shrinkage" (α'_{IP}(soft)~0.25 GeV^{-2})

➔ $B_{IP} \simeq B_{IP}$(hard process), $\alpha_{IP}(0) \simeq \alpha_{IP}$(soft)~1.08

Compare with published HERA results:

H1 FPS HERA-1 parameterization:

$$\alpha_{IP}(0) = 1.114 \pm 0.022(\text{exp.}) \pm^{0.040}_{0.020} (\text{model})$$

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06}\ \text{GeV}^{-2}$$

$$B_{IP} = 5.5^{-2,0}_{+0.7}\ \text{GeV}^{-2}$$

ZEUS LPS Regge fit:

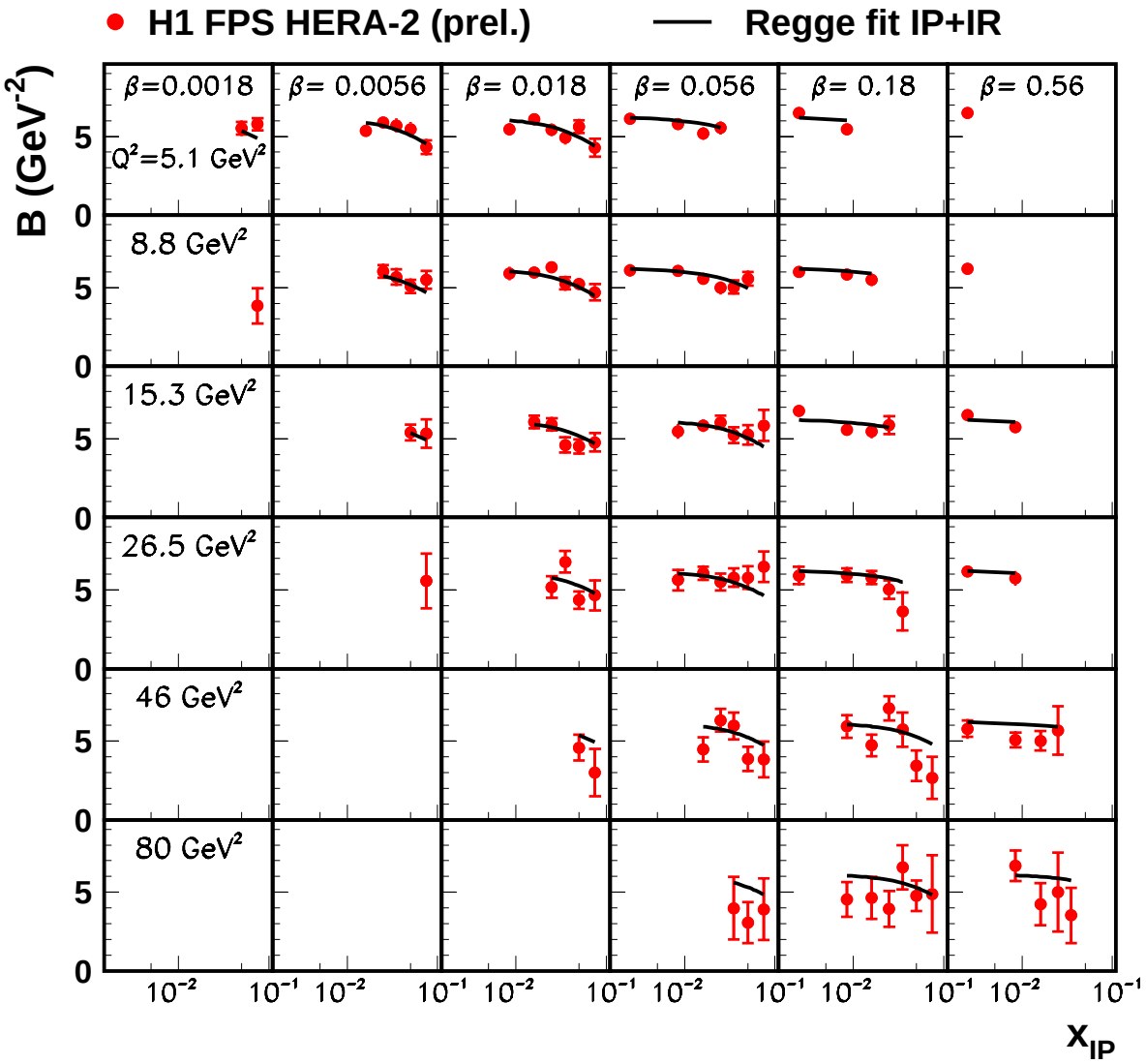
$$\alpha_{IP}(0) = 1.11 \pm 0.02(\text{stat.}) \pm^{0.01}_{0.02} (\text{syst.}) \pm 0.02(\text{model})$$

$$\alpha'_{IP} = -0.01 \pm 0.06(\text{stat.}) \pm^{0.04}_{0.08} (\text{syst.}) \pm 0.04(\text{model})\ \text{GeV}^{-2}$$

$$B_{IP} = 7.1 \pm 0.7(\text{stat.}) \pm^{1.4}_{0.7} (\text{syst.})\ \text{GeV}^{-2}$$

t-slope as a function of Q^2,β,x_{IP}

Regge fit result: $B(x_{IP},\beta,Q^2) = f_{IP}(x_{IP},\beta,Q^2)\cdot B_{IP}(x_{IP}) + f_{IR}(x_{IP},\beta,Q^2)\cdot B_{IR}(x_{IP})$

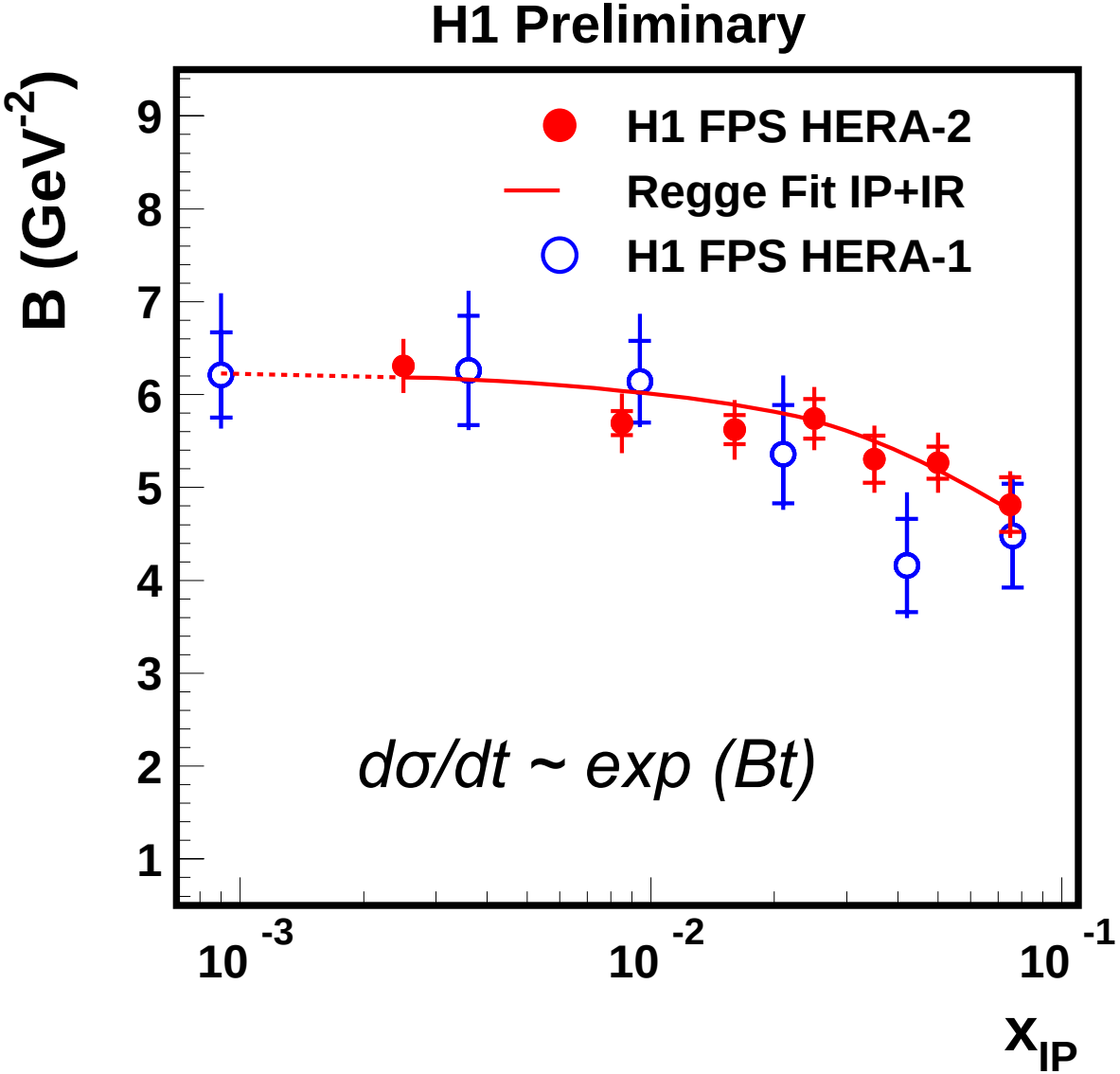


dσ/dt ~ exp (Bt)

- x_{IP}-dependence of t-slope in (Q^2,β) bins ➔ IR contribution at high x_{IP}
- *t*-slope does not change with β or Q^2 at fixed x_{IP} ➔ data consistent with proton vertex factorization

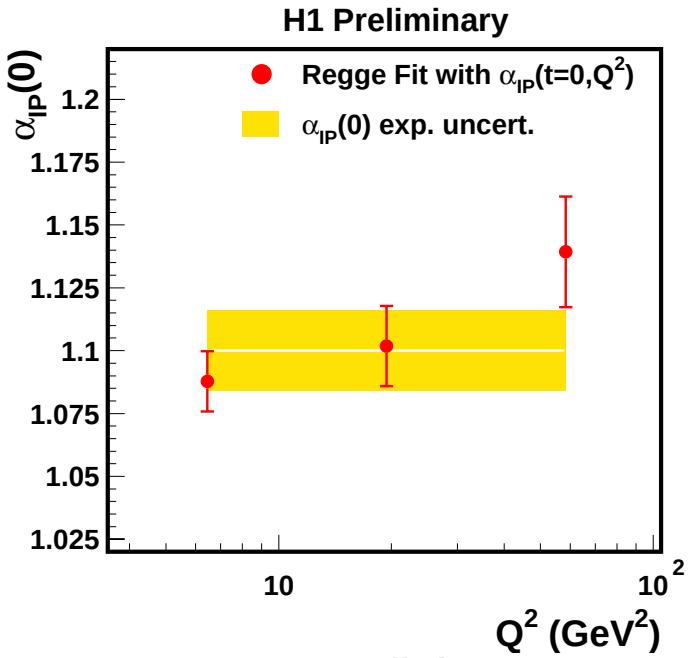
t-slope as a function of x_{IP}

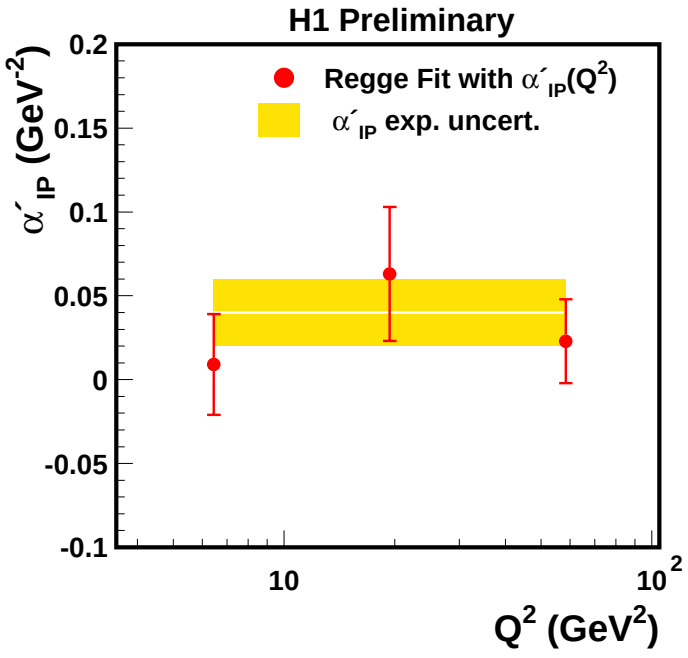
Regge fit result: $B(x_{IP}) = f_{IP}(x_{IP}) \cdot B_{IP}(x_{IP}) + f_{IR}(x_{IP}) \cdot B_{IR}(x_{IP})$

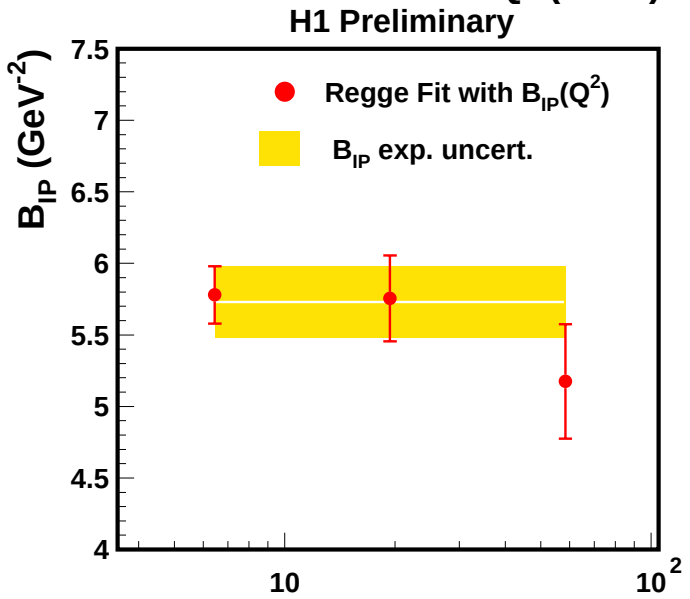


- x_{IP}-dependence of t-slope, data averaged over Q^2 and β
- ➔ IR contribution at high x_{IP}
- FPS HERA-1 and HERA-2 data are consistent

Modified Regge Fit in Q^2 bins





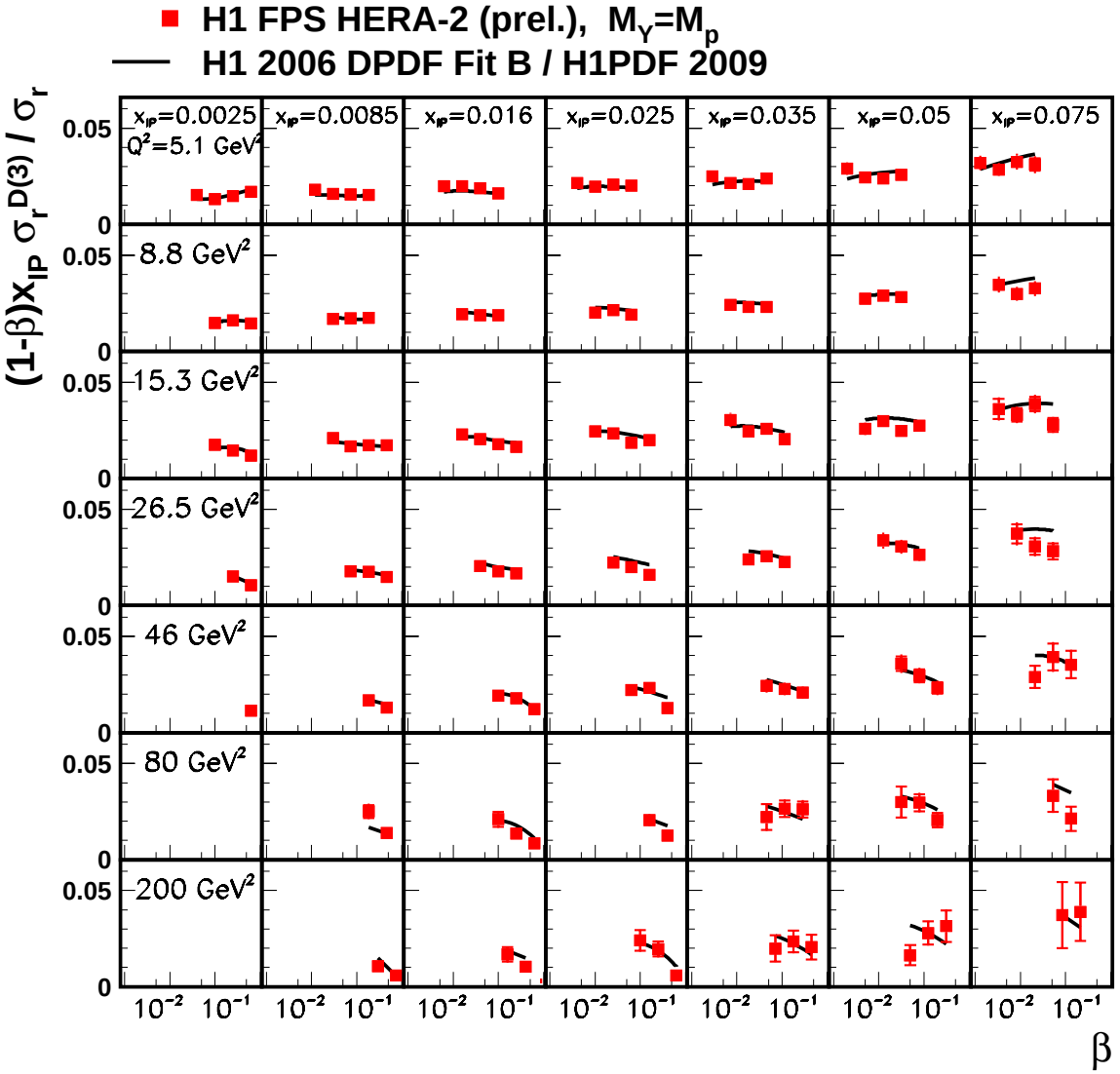


$$\alpha_{IP}(t,Q^2) = \alpha_{IP}(0,Q^2) + \alpha_{IP}'(Q^2)t$$

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

➔ results consistent with proton vertex factorization within uncertainties

Ratio $\sigma_r^{D(3)}/\sigma_r^{incl}$: β dependence



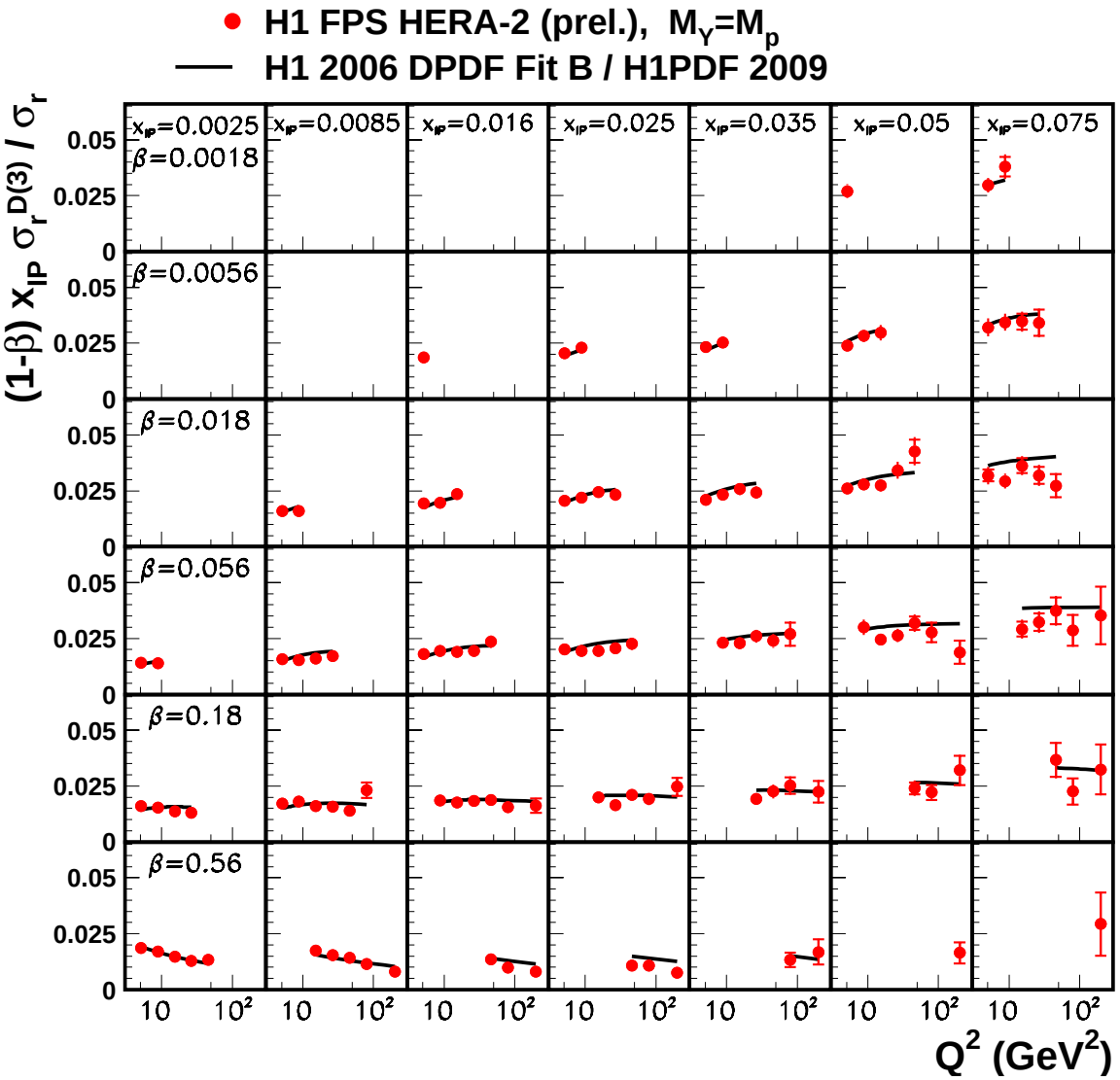
- $(1-\beta)x_{IP}\sigma_r^{D(3)}$ (FPS HERA-2) / σ_r^{incl} (H1PDF 2009)

– H1 2006 DPDF Fit B / H1PDF 2009

β-dependence in (x_{IP},Q^2) bins M_x>2 GeV, |t|<1GeV^2

- Ratio is flat except at highest β
- Ratio weakly rises with $x_{IP}\rightarrow$ IR contribution

Ratio $\sigma_r^{D(3)}/\sigma_r^{incl}$: Q^2 dependence



■ $(1-\beta)x_{IP}\sigma_r^{D(3)}$ (FPS HERA-2) / σ_r^{incl} (H1PDF 2009)

— H1 2006 DPDF Fit B / H1PDF 2009

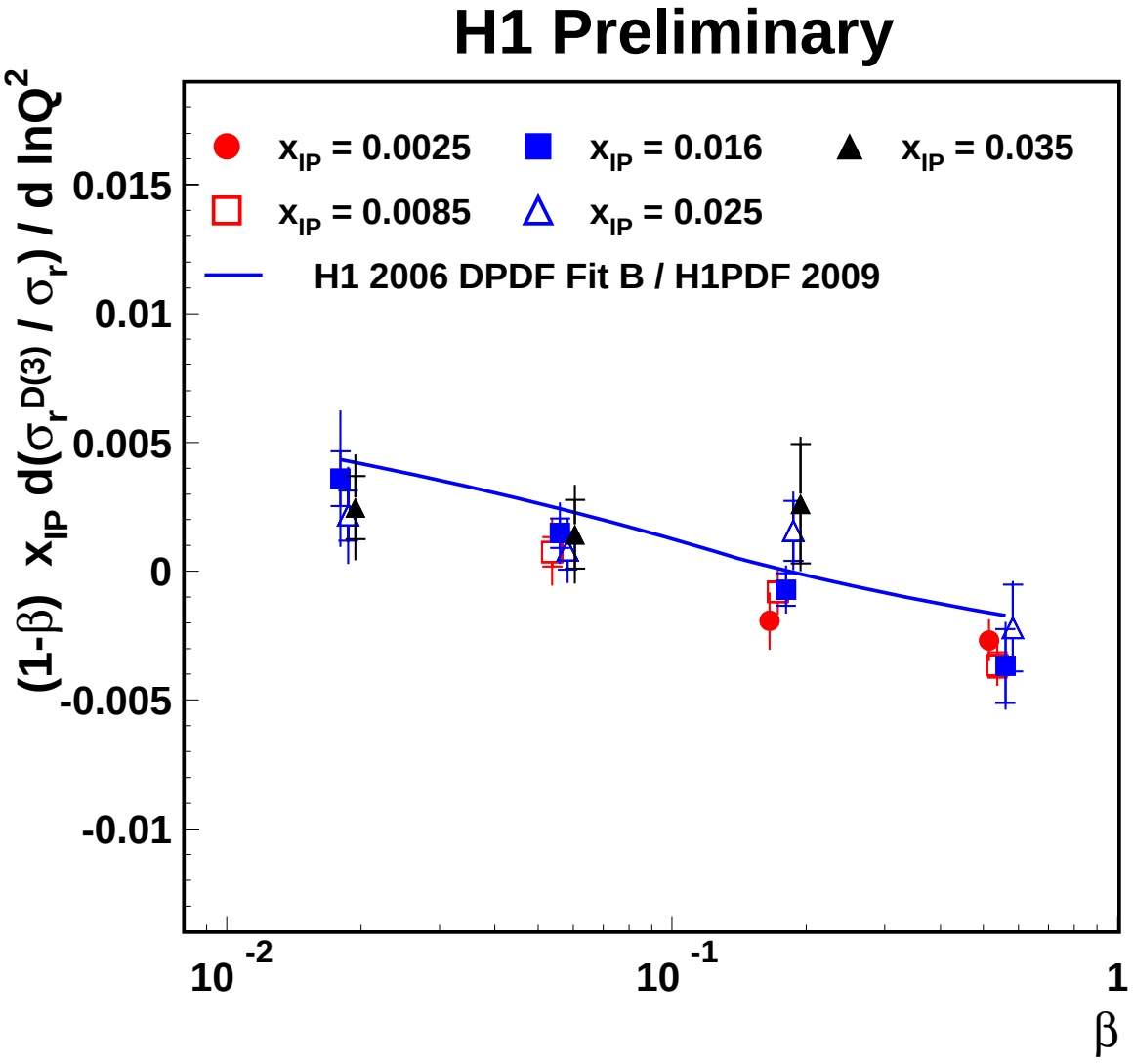
Q^2-dependence in (x_{IP},β) bins M_x>2 GeV, $|t|<1GeV^2$

- Ratio is flat or weakly rises with Q^2 except at highest β

→ extract $\ln Q^2$ derivative

Ratio $\sigma_r^{D(3)}/\sigma_r^{incl}$: $\ln Q^2$ derivative

- Slope D: $(1-\beta)x_{IP}\sigma_r^D / \sigma_r^{incl} = A + D \ln Q^2$ → $\ln Q^2$-dependence in selected (x_{IP},β) bins



— H1 2006 DPDF Fit B / H1PDF 2009

- Data are consistent with DPDF / PDF predictions
- $\ln Q^2$ slope is close to zero and only weakly depends on β

➔ $(\text{gluon/quark})^{diff} \sim (\text{gluon/quark})^{incl}$ if measured at same (low) $x=x_{IP}\beta$

Summary

- High statistics diffractive DIS data are measured with H1 Forward Proton Spectrometer at HERA-2

➢ diffractive reduced cross section $\sigma_r^{D(4)}(Q^2,\beta,x_{IP},t)$

➢ parameters of IP trajectory are evaluated from Regge fit to $F_2^{D(4)}(Q^2,\beta,x_{IP},t)$; Regge fit is also performed in Q^2 bins

➢ no "shrinkage" of t-slope in diffractive DIS,
t-slope as for hard process

➢ Results of Regge fit are consistent with proton vertex factorization

➢ Ratio of diffractive to inclusive cross section only weakly depends on β and $Q^2 \rightarrow$ gluon PDF fraction is similar in diffractive and inclusive DIS at low x