



Diffraction DIS with a Leading Proton at HERA-2

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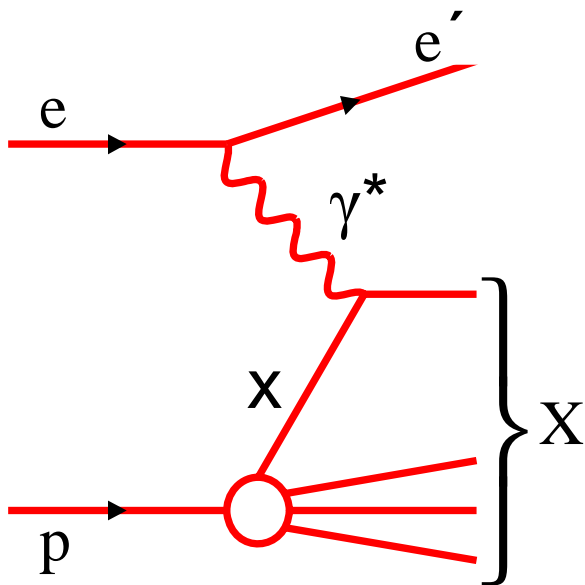
on behalf of the H1 Collaboration

- 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



$F_2 \rightarrow$ probe structure of proton

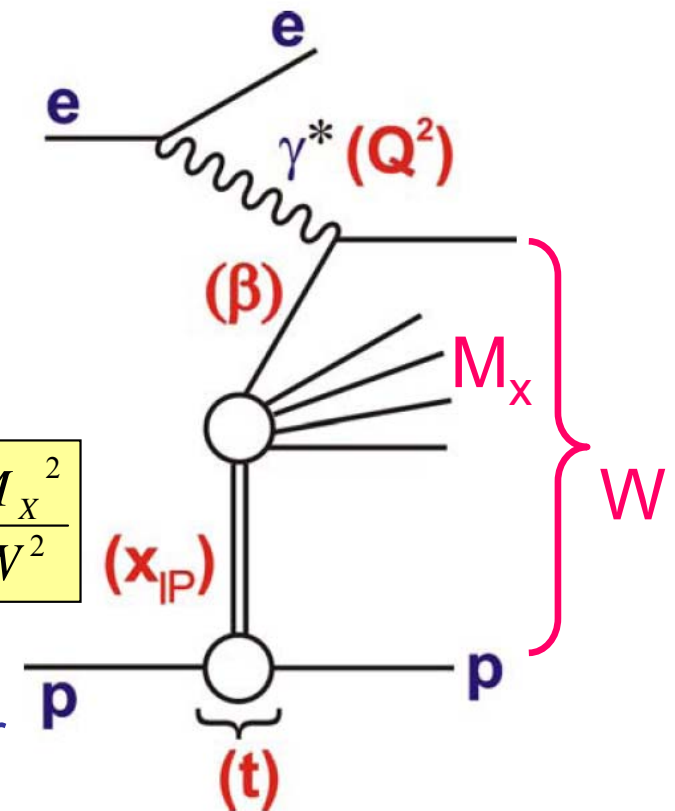
Diffractive DIS

Momentum fraction of color singlet carried by struck quark

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

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

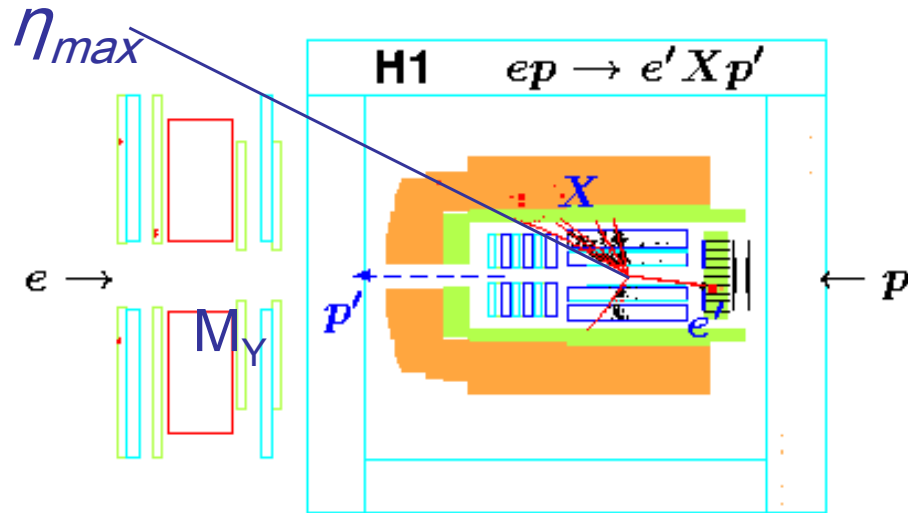
Momentum fraction of proton carried by colour singlet exchange



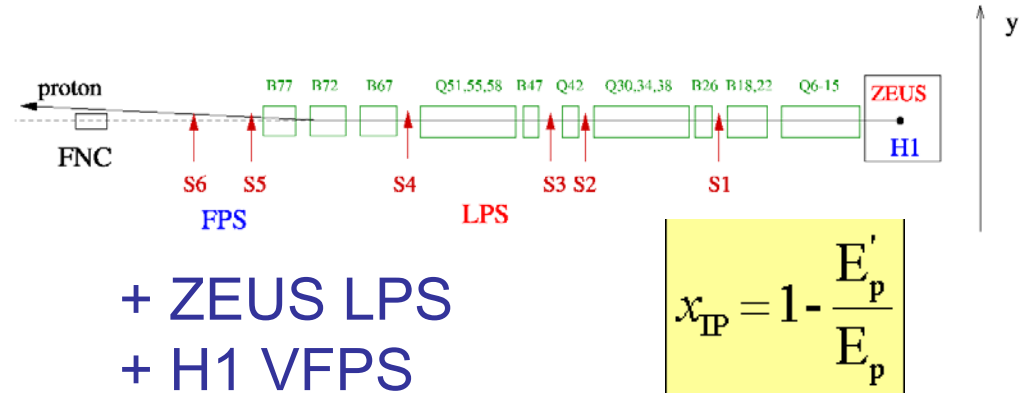


Selection of diffraction at HERA

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



Forward Proton Spectrometer H1 FPS



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

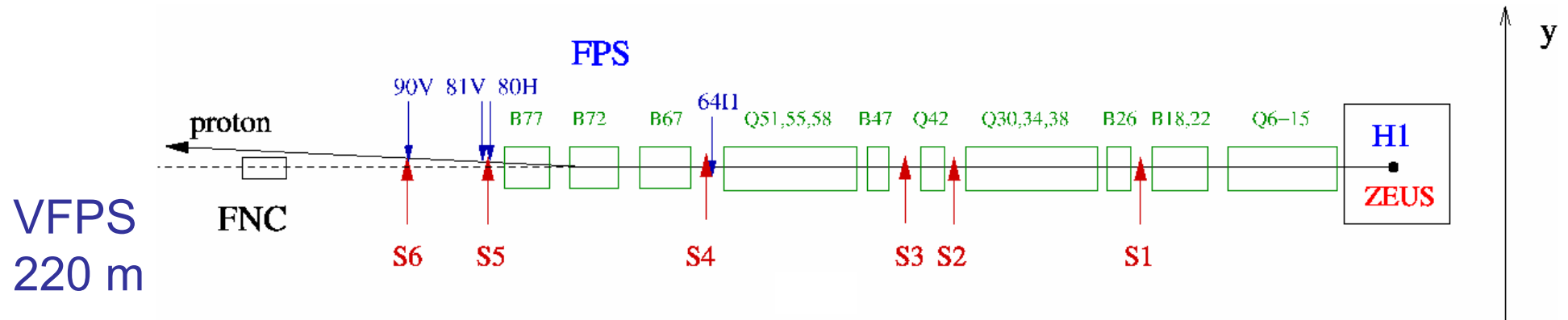
- free of p-dissociation background
- x_{IP} and t-measurements
- access to high x_{IP} range (IP+IR)
- low geometrical acceptance
 - H1 VFPS has high acceptance (see talk of Tomas Hreus)

➔ LRG and FPS methods have different systematic uncertainties

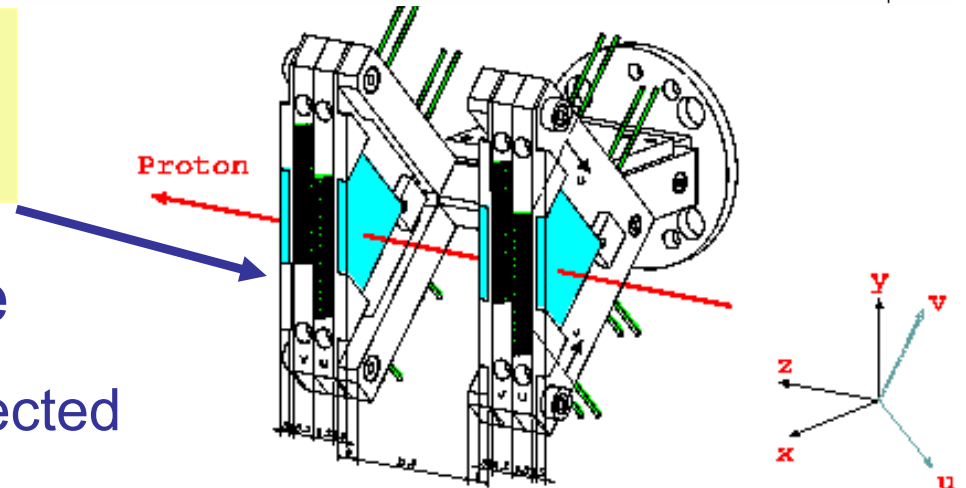


Forward Proton Spectrometer

- ❑ **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



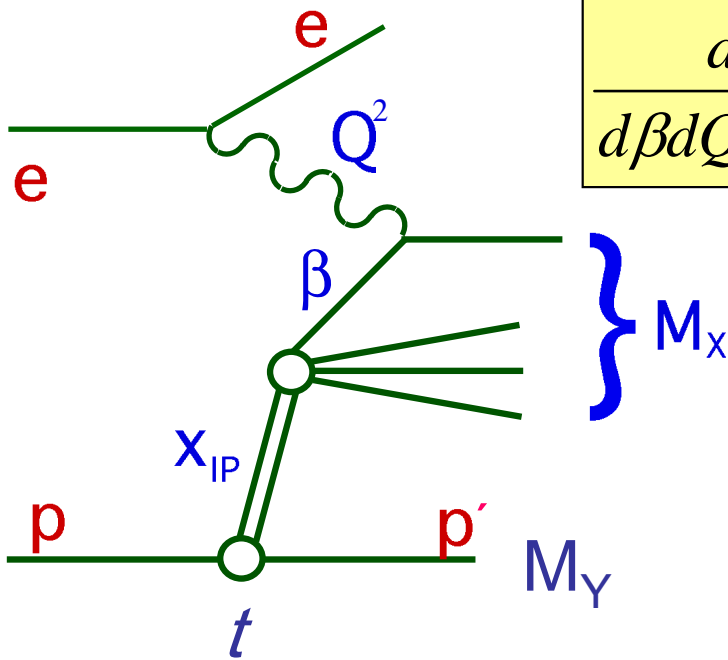
Horizontal detectors at
61m and 80m: $x_{IP} < 0.1$



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 :

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

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

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

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

Ratio of diffractive to inclusive DIS σ_r

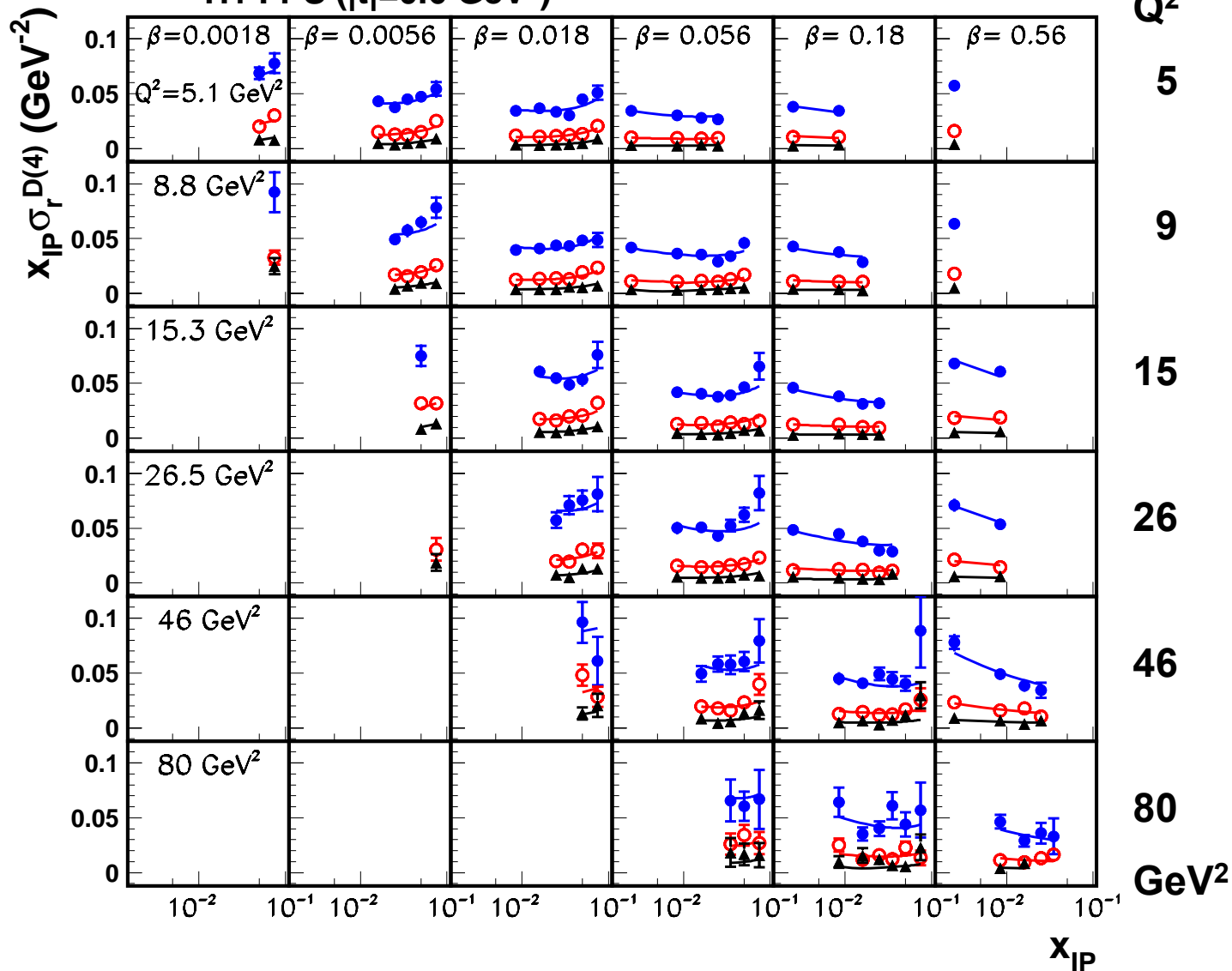
$$(1 - \beta) x_{IP} \sigma_r^{D(3)} / \sigma_r^{incl} \approx M_X^2 \frac{d\sigma_{\gamma^* p \rightarrow Xp}(M_X, W, Q^2)}{dM_X^2} / \sigma_{\gamma^* p \rightarrow X}(W, Q^2)$$



- H1 FPS ($|t|=0.2 \text{ GeV}^2$)
- H1 FPS ($|t|=0.4 \text{ GeV}^2$)
- ▲ H1 FPS ($|t|=0.6 \text{ GeV}^2$)

H1 Preliminary
— Regge fit IP+IR

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



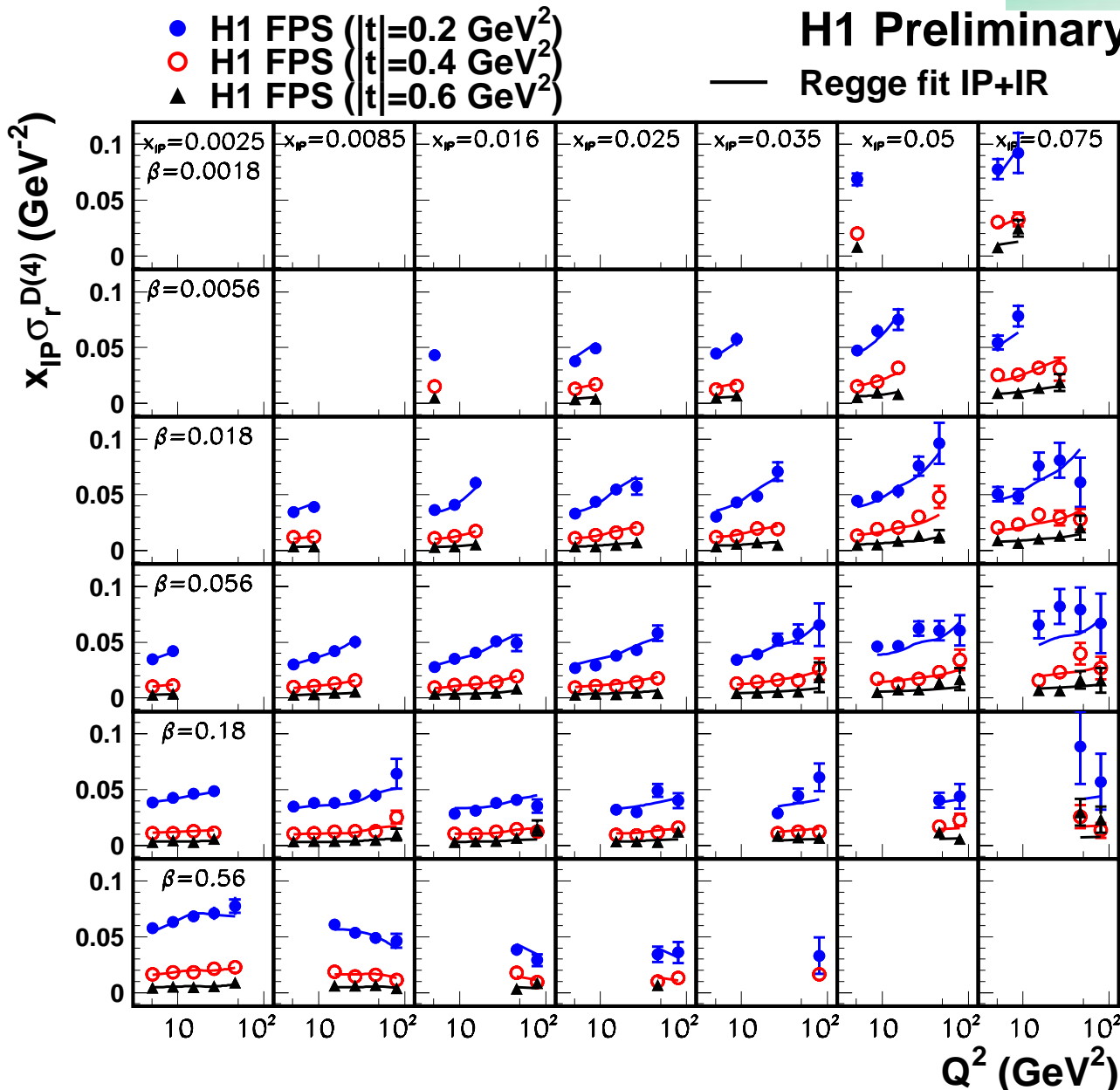
Q^2

- 5 ● FPS $|t|=0.2 \text{ GeV}^2$
- 9 ○ FPS $|t|=0.4 \text{ GeV}^2$
- 15 ▲ FPS $|t|=0.6 \text{ GeV}^2$
- 26 — Regge fit IP+IR
- 46 X_{IP} -dependence in (Q^2, β, t) bins
- 80 → IP and IR contributions

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



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



- FPS $|t|=0.2 \text{ GeV}^2$
- FPS $|t|=0.4 \text{ GeV}^2$
- ▲ FPS $|t|=0.6 \text{ GeV}^2$
- 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*:

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

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

- 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

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

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

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

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

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

→ $\alpha'_{IP} \approx 0 \rightarrow$ no “shrinkage” ($\alpha'_{IP}(\text{soft}) \sim 0.25 \text{ GeV}^{-2}$)

→ $B_{IP} \approx B_{IP}(\text{hard process}), \alpha_{IP}(0) \approx \alpha_{IP}(\text{soft}) \sim 1.08$

Compare with published HERA results:

H1 FPS HERA-1 parameterization:

ZEUS LPS Regge fit:

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

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

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

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

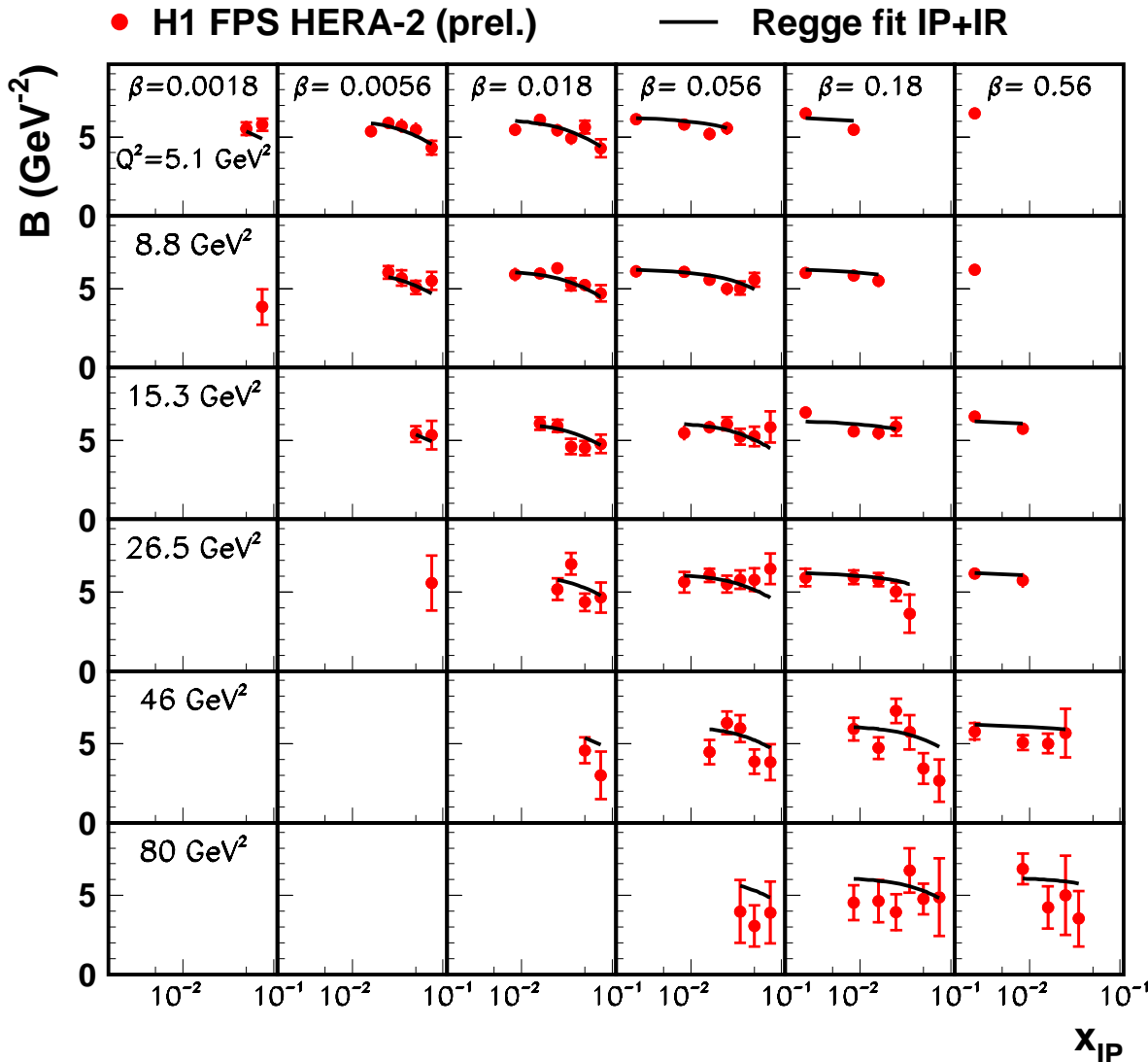
$$B_{IP} = 5.5^{+2.0}_{+0.7} \text{ GeV}^{-2}$$

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



t-slope as a function of Q^2, β, x_{IP}

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



$$d\sigma/dt \sim \exp(Bt)$$

- 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

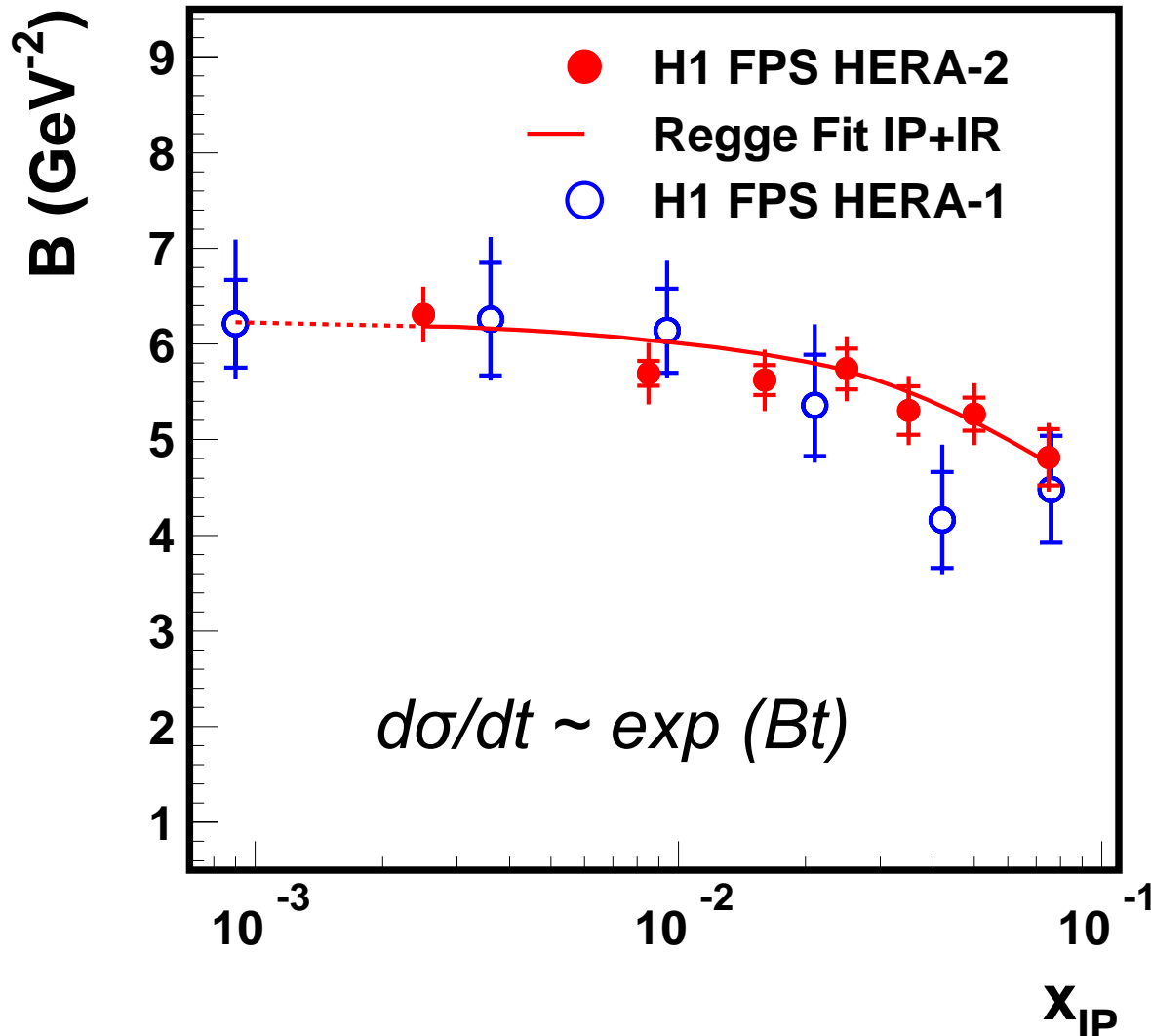


t-slope as a function of x_{IP}

Regge fit result:

$$B(x_{IP}) = f_{IP}(x_{IP}) \cdot B_{IP}(x_{IP}) + f_{IR}(x_{IP}) \cdot B_{IR}(x_{IP})$$

H1 Preliminary



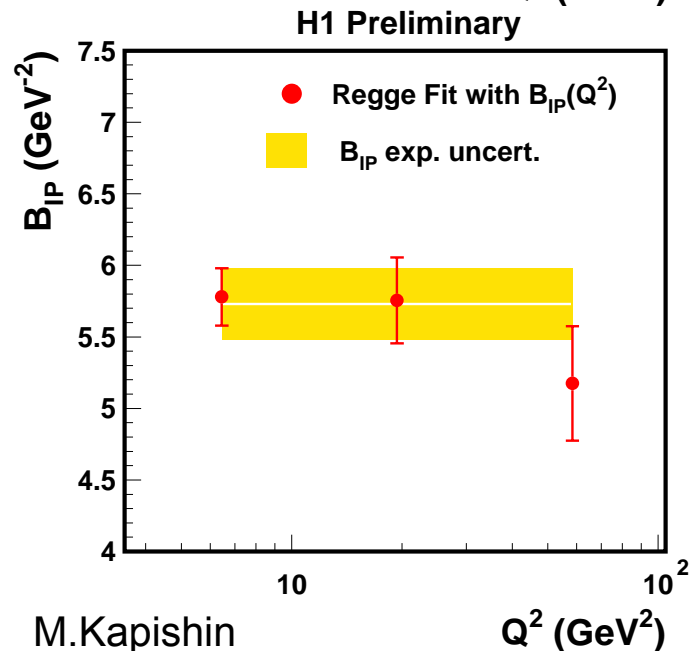
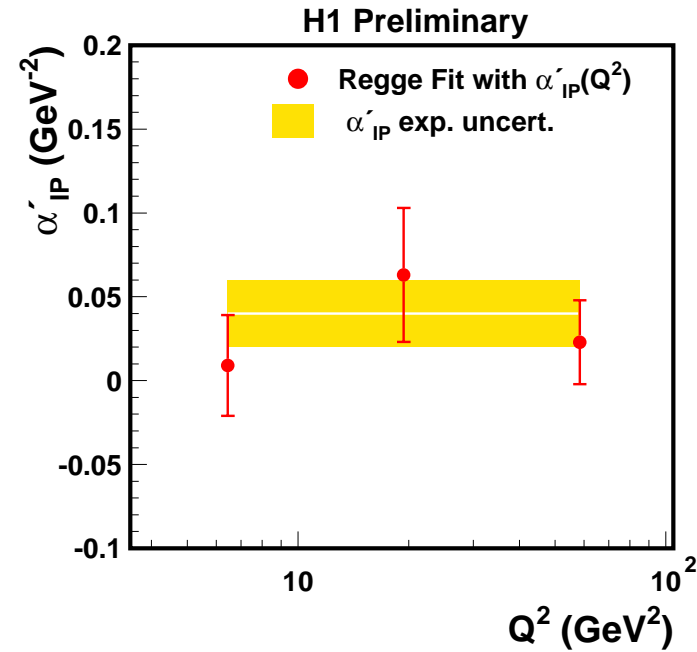
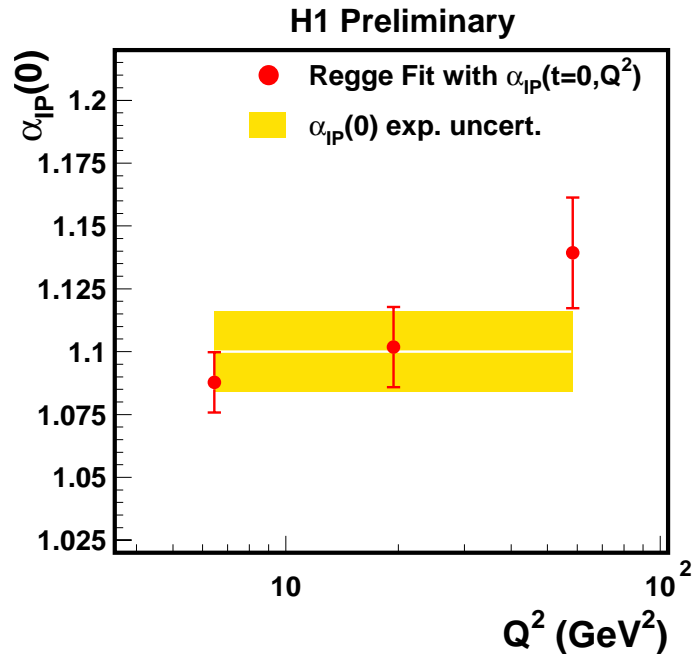
- x_{IP} -dependence of t-slope, data averaged over Q^2 and β

→ IR contribution at high x_{IP}

- FPS HERA-1 and HERA-2 data are consistent



Modified Regge Fit in Q^2 bins



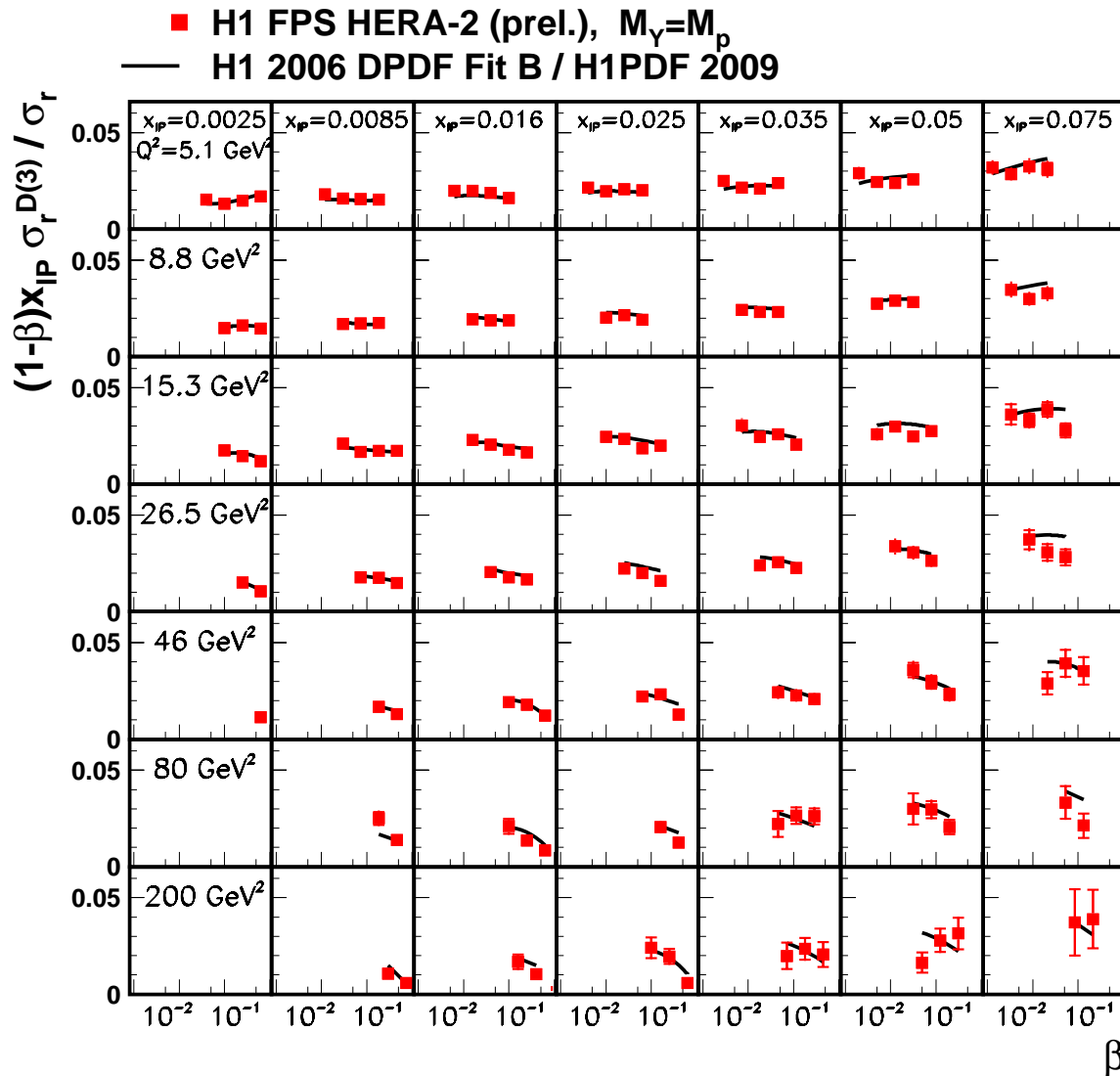
$$\alpha_{IP}(t, Q^2) = \alpha_{IP}(0, Q^2) + \alpha'_{IP}(Q^2)t$$

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

→ results consistent with **proton vertex factorization** within uncertainties



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



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

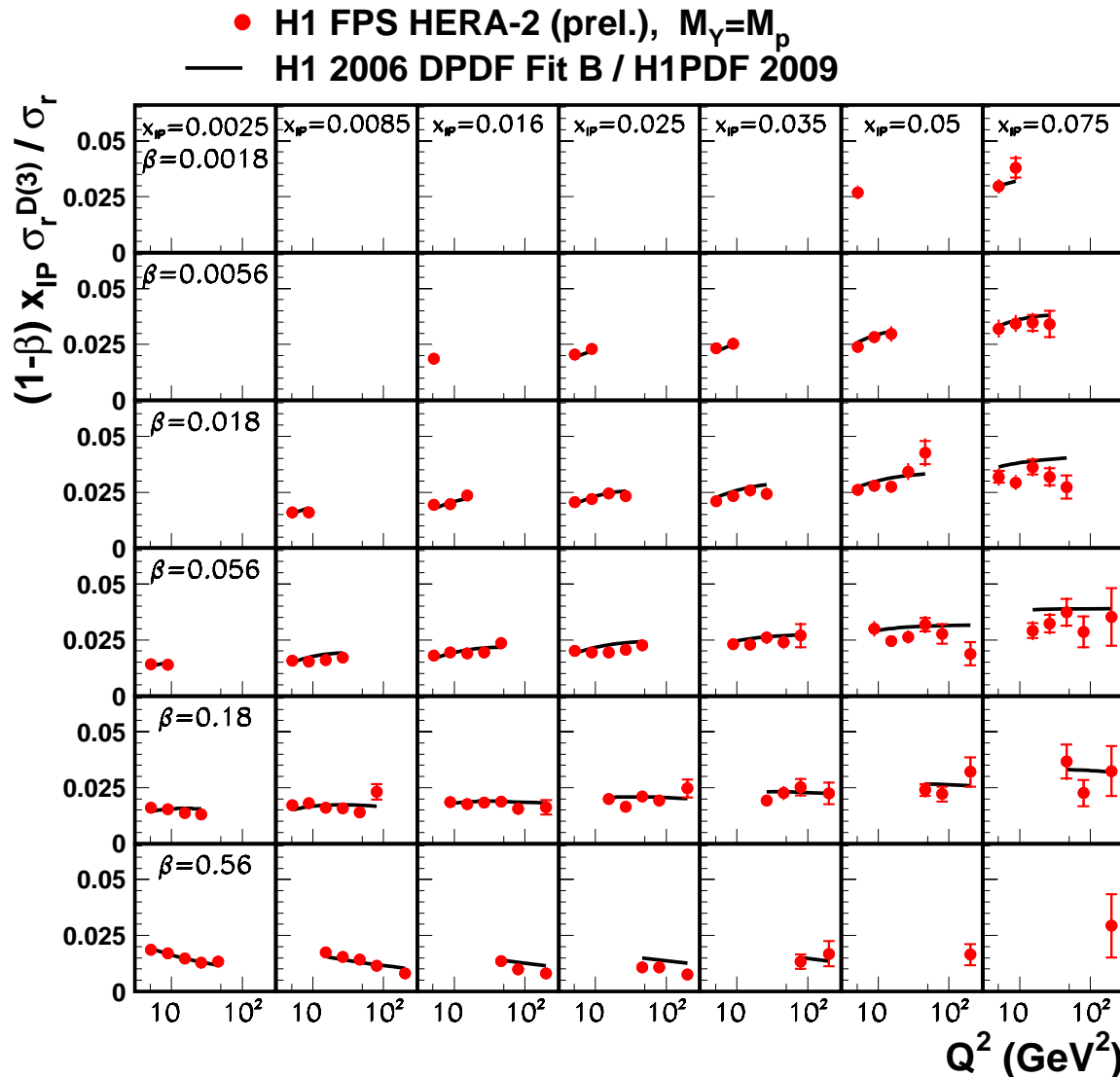
— H1 2006 DPDF Fit B /
H1PDF 2009

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

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



Ratio $\sigma_r^{D(3)}/\sigma_r^{\text{incl}}$: 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, $|t| < 1$ GeV²

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

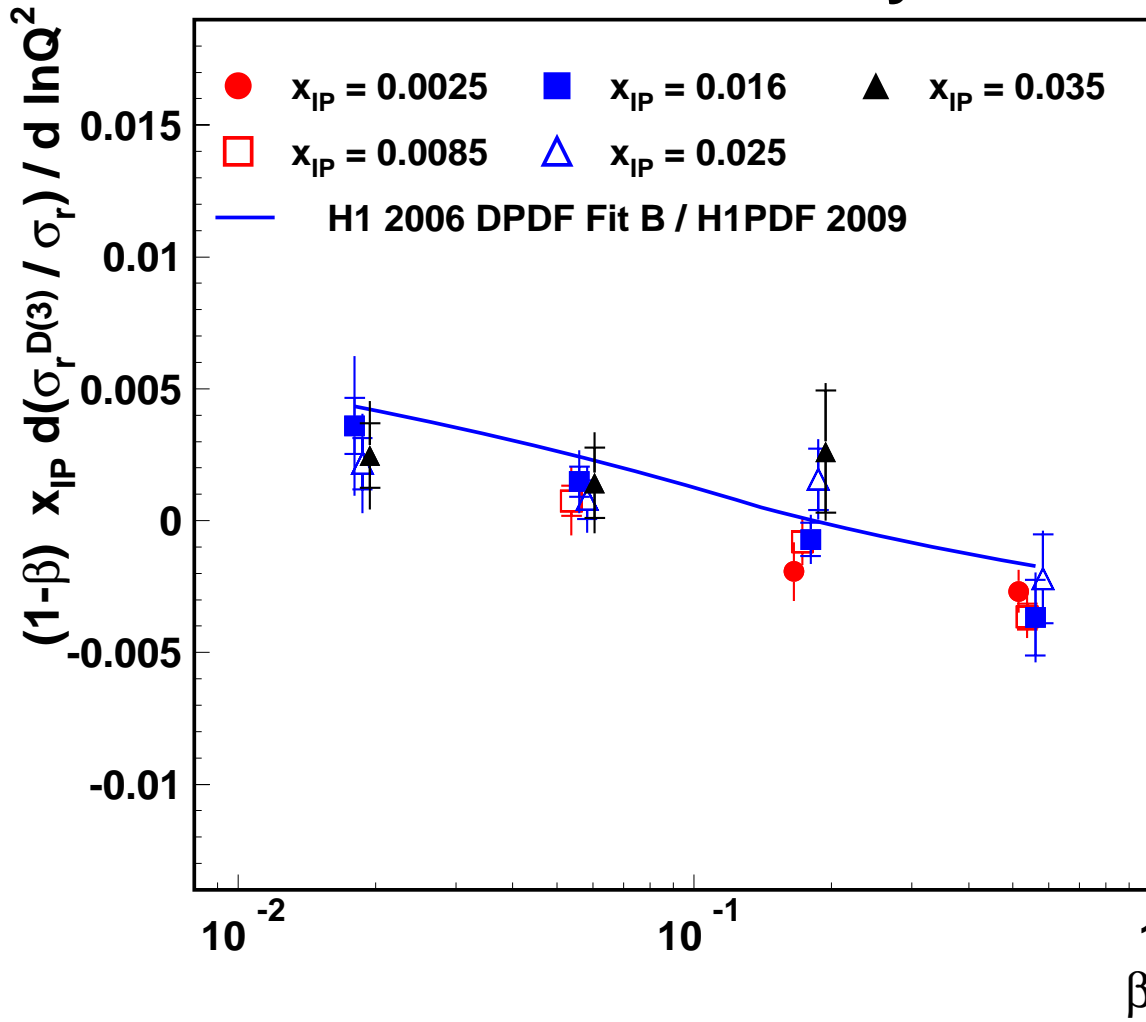
→ extract $\ln Q^2$ derivative



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

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

H1 Preliminary



— 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

$\rightarrow (\text{gluon/quark})^{diff} \sim (\text{gluon/quark})^{incl}$

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