



New measurements of $F_2^{D(4)}$ at HERA



Low x workshop 2010, 23-27 June, Kavala, Greece

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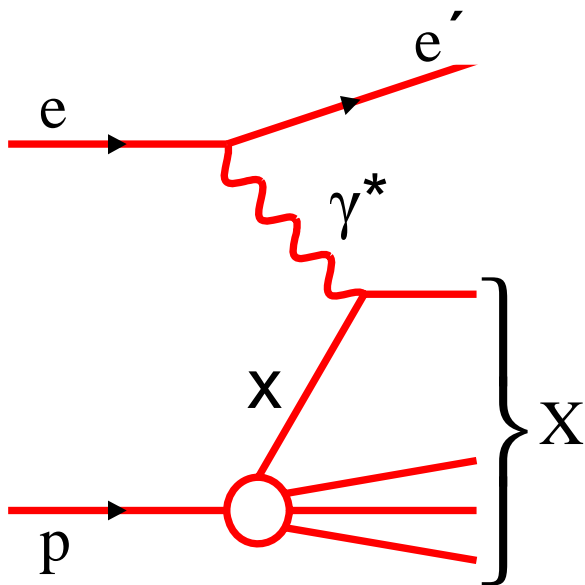
on behalf of the H1 and ZEUS Collaborations

- Selection of Diffraction at HERA
 - Forward Proton Spectrometers vs LRG method
- New H1 FPS HERA-2 results vs ZEUS leading proton data:
 - Diffractive reduced cross section $\sigma_r^{D(4)}$ and Regge fits
- Ratio of LRG to leading proton cross section
- 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

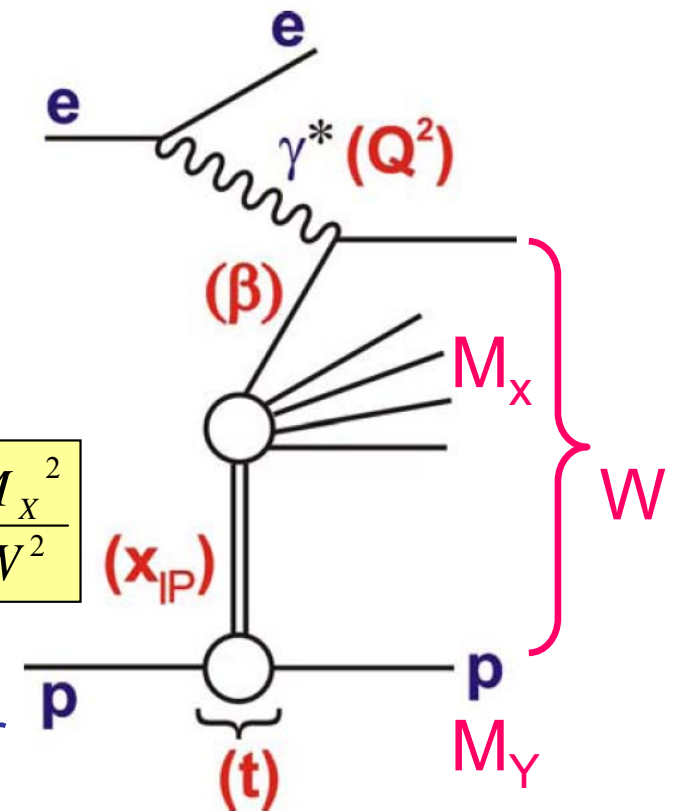
Diffractive DIS

Momentum fraction of color singlet carried by struck quark

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

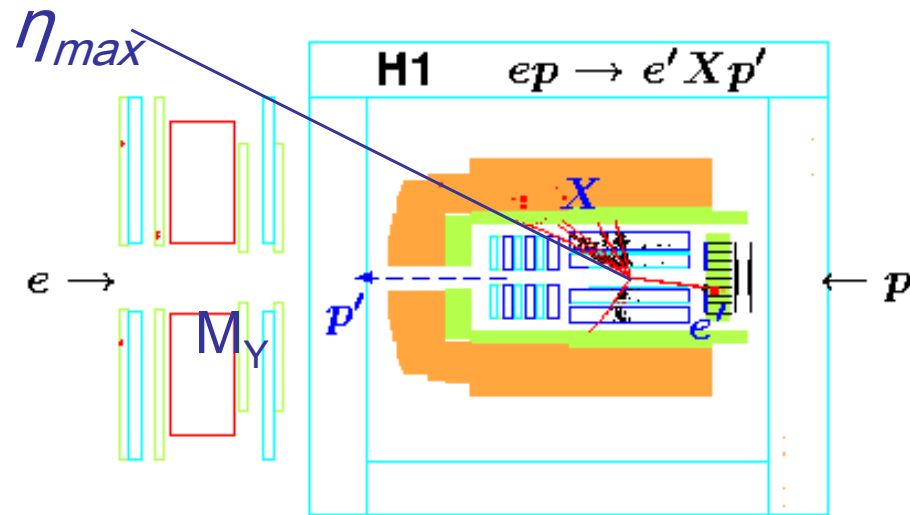
$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

Momentum fraction of proton carried by colour singlet exchange

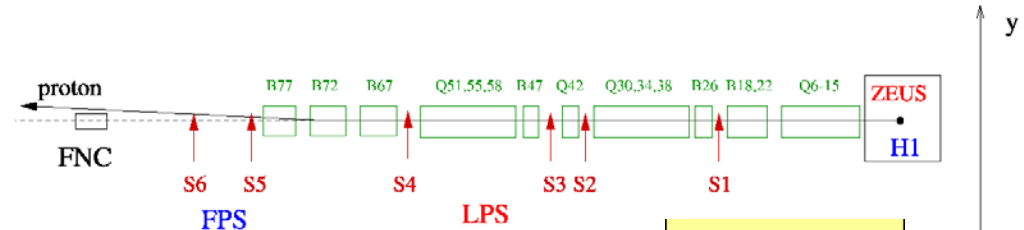


Selection of diffraction at HERA

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



Forward Proton Spectrometers



H1 FPS + ZEUS LPS
+ H1 VFPS

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

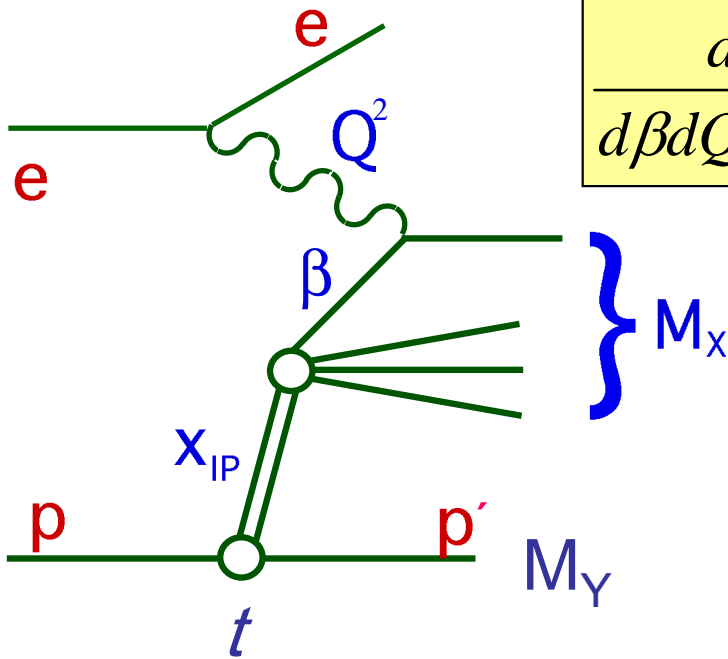
- ❑ high statistics, data integrated over $|t| < 1 \text{ GeV}^2$
- ❑ p-dissociation contribution
- ❑ limited by systematic uncertainties related to missing proton
- ➔ LRG and FPS methods have different systematic uncertainties

- ❑ free of p-dissociation background
- ❑ x_{IP} and t-measurements
- ❑ access to high x_{IP} range (IP+IR)
- ❑ low geometrical acceptance

HERA-2:

- H1 FPS detector upgrade
- ➔ 20 times higher statistics than collected at HERA-1
- H1 VFPS has high acceptance (see talk of Tomas Hreus)

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 LRG and diffractive PDF predictions

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

Ratio of diffractive to inclusive DIS σ_r

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

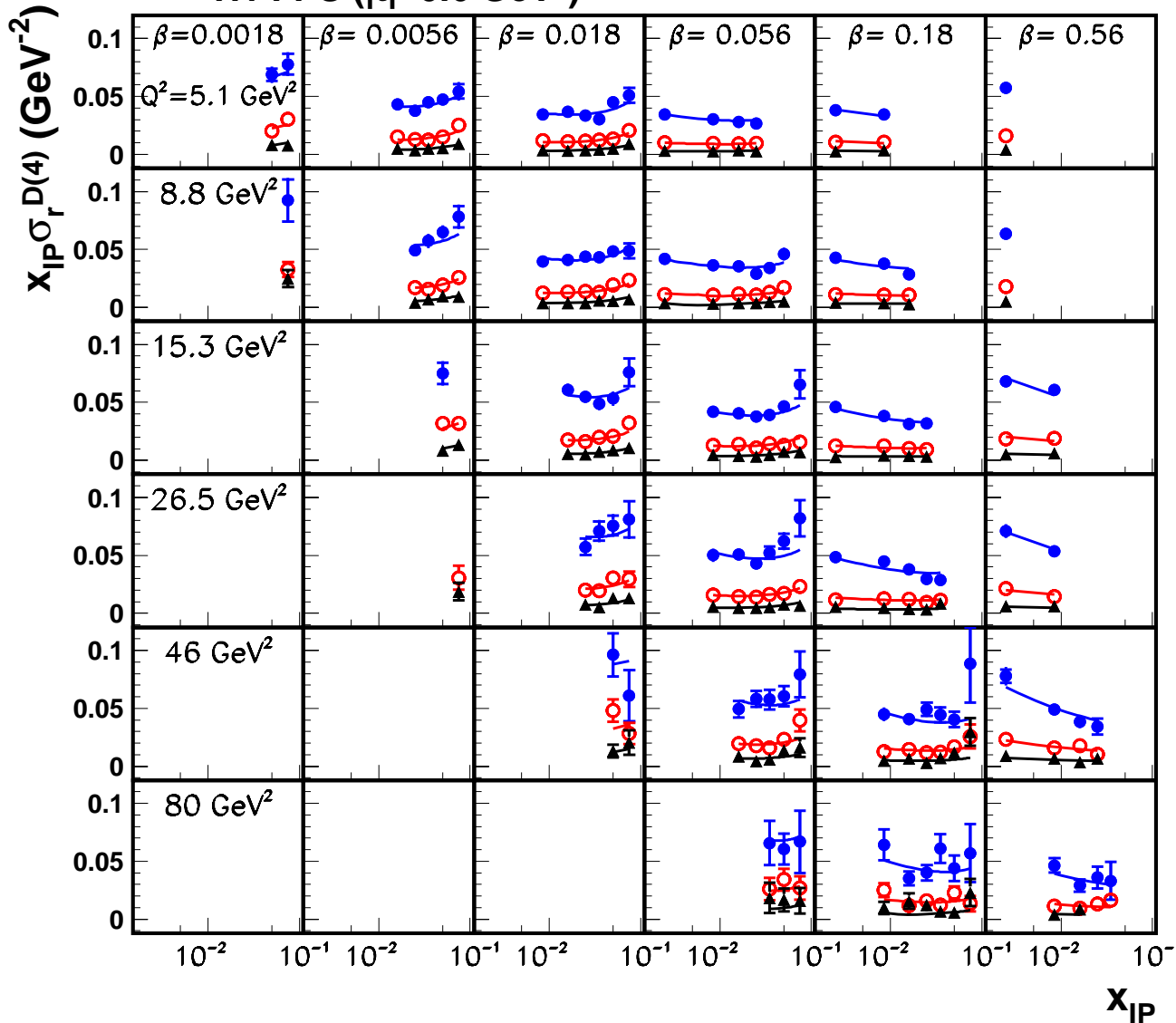


$$x_{IP} \sigma_r^{D(4)}(\beta, Q^2, x_{IP}, t)$$

H1 Preliminary

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

— Regge fit IP+IR



Q^2 New H1 FPS HERA-2

5 $\sigma_r^{D(4)}$ data:

- $5 < Q^2 < 80 \text{ GeV}^2$

9

- luminosity 156 pb^{-1}

15

- 20 times higher statistics than in HERA-1 data

26

- norm. uncertainty $\sim 4.3\%$
→ smaller than in HERA-1

46

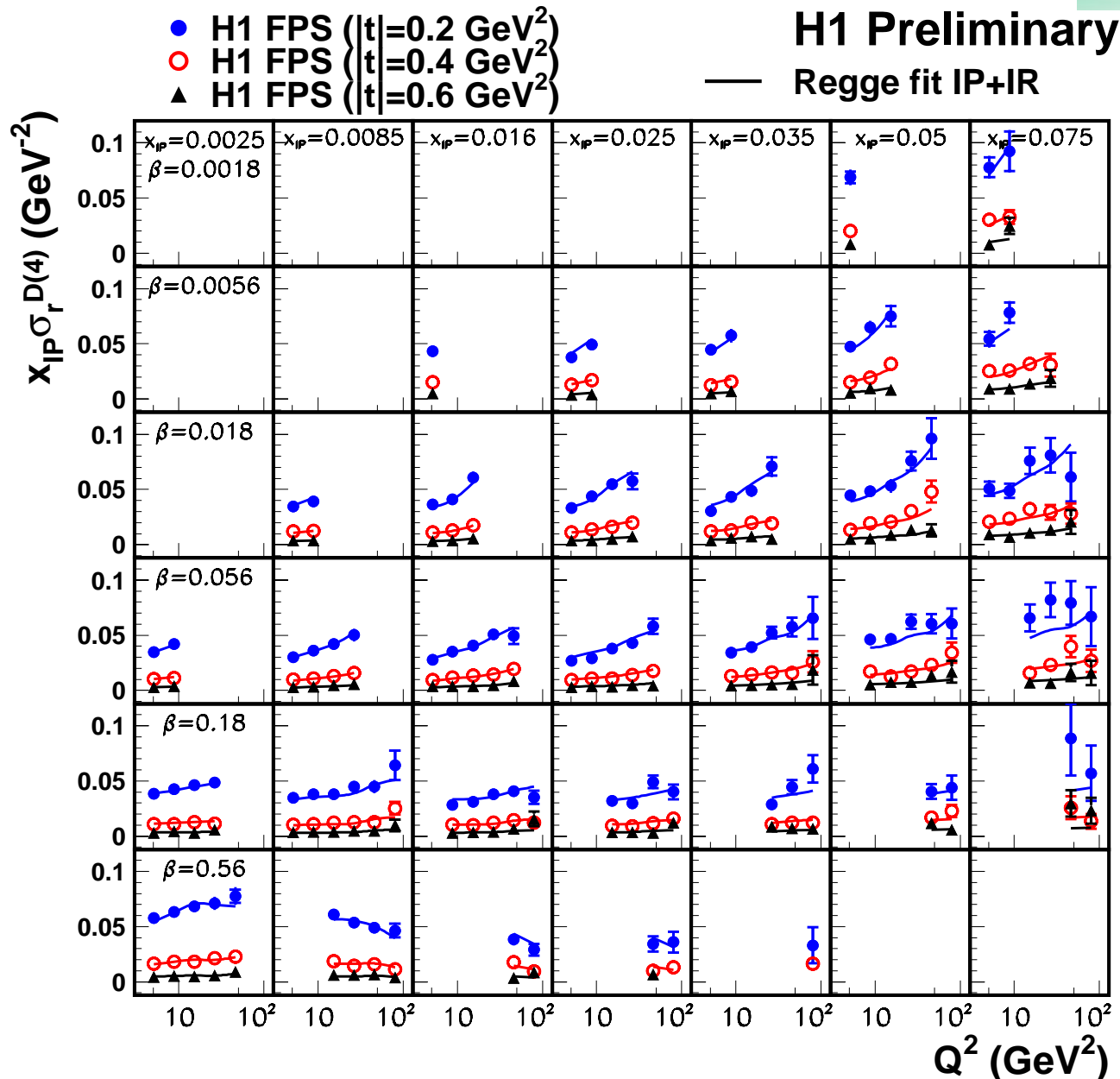
x_{IP} -dependence in (Q^2, β, t) bins

80

→ IP and IR contributions



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



β New H1 FPS HERA-2

0.0018 $\sigma_r^{D(4)}$ data

0.0056 Q^2 -dependence in (β, x_{IP}, t) bins

0.018 \rightarrow positive scaling violations except at high $\beta \rightarrow$ gluon contribution to diffractive exchange

0.056

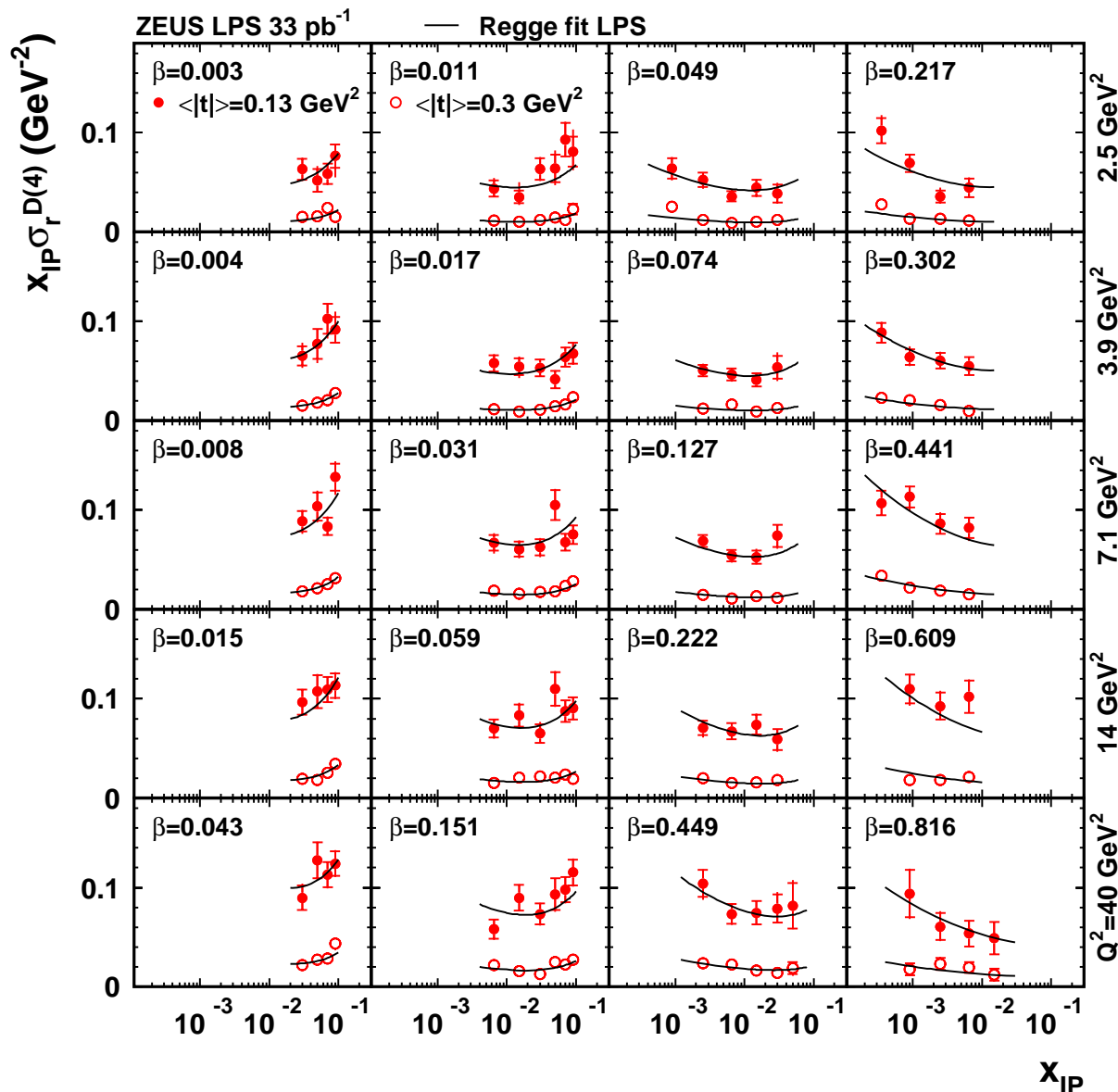
0.18

0.56

ZEUS LPS: $x_{IP}\sigma_r^{D(4)}$



ZEUS



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● ZEUS LPS $|t|=0.13 \text{ GeV}^2$

○ ZEUS LPS $|t|=0.3 \text{ GeV}^2$

— Regge fit IP+IR

• norm. uncertainty of ZEUS LPS $\sigma_r^{D(4)}$ data is 7%

x_{IP} -dependence in (β, Q^2, t) bins

➔ IP and IR contributions



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*:

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

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

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

- Fixed parameters for *IR* (as in H1 DPDF Fits): $\alpha_{IR}(0)=0.5$, $\alpha'_{IR}=0.3 \text{ GeV}^{-2}$, $B_{IR}=1.6 \text{ GeV}^{-2}$, $F_2^{IR}(\beta, Q^2)$ – 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



New H1 FPS
HERA-2 result:

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

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

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

$$\alpha'_{IP} = 0.04 \pm 0.02 \text{ (exp.)} \pm_{0.60}^{0.08} \text{ (model) GeV}^{-2}$$

$$B_{IP} = 5.73 \pm 0.25 \text{ (exp.)} \pm_{0.90}^{0.80} \text{ (model) GeV}^{-2}$$

$$\rightarrow \alpha_{IP}(0) \simeq \alpha_{IP}(\text{soft}) \sim 1.08$$

$$\rightarrow \alpha'_{IP} \simeq 0 \rightarrow \text{no "shrinkage"} \quad (\alpha'_{IP}(\text{soft}) \sim 0.25 \text{ GeV}^{-2})$$

$$\rightarrow B_{IP} \text{ consistent with hard process}$$

Compare with published HERA results:

H1 FPS HERA-1 parameterization:

ZEUS LPS Regge fit:

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

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

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

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

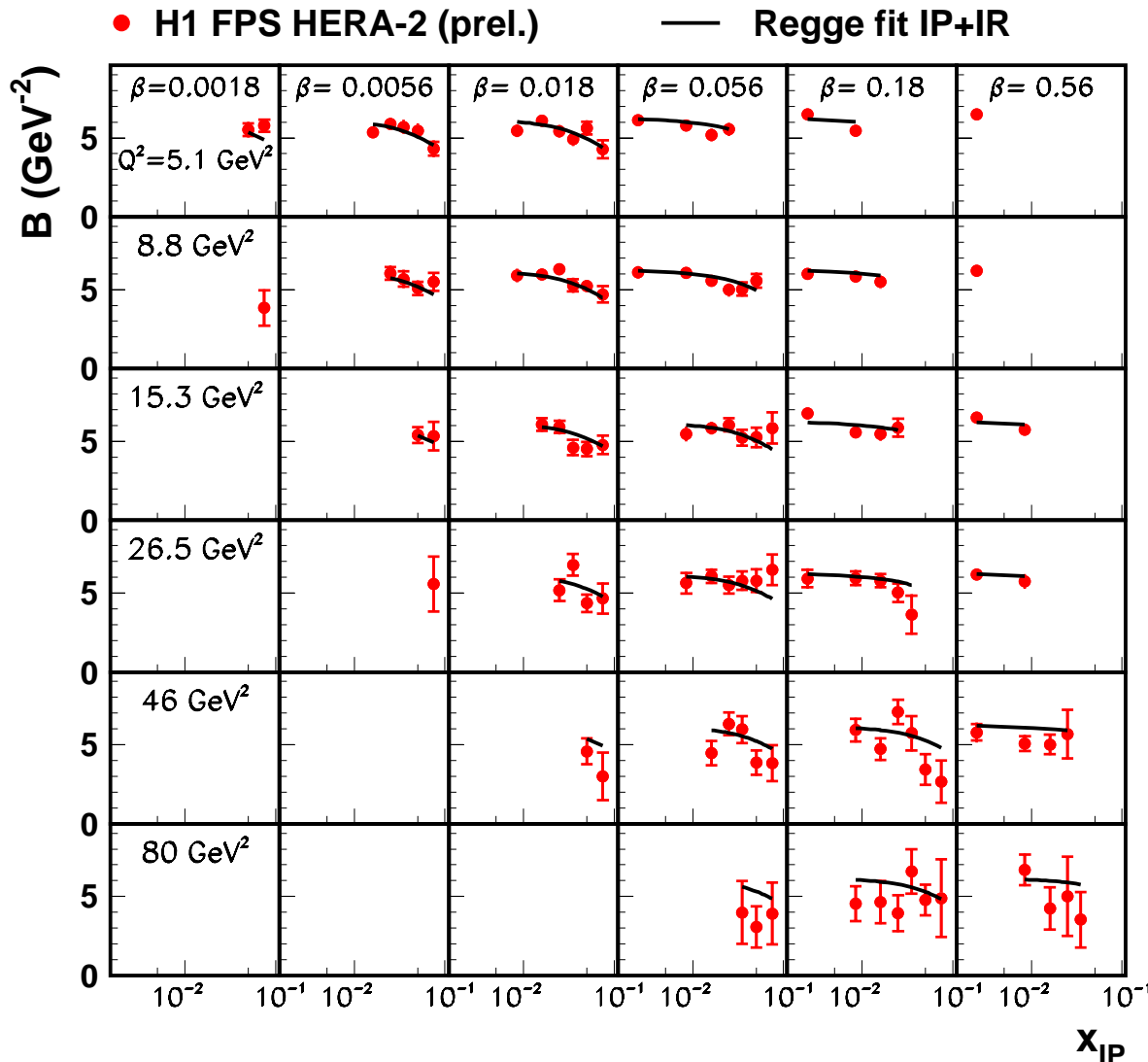
$$B_{IP} = 5.5_{+0.7}^{-2.0} \text{ GeV}^{-2}$$

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



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**

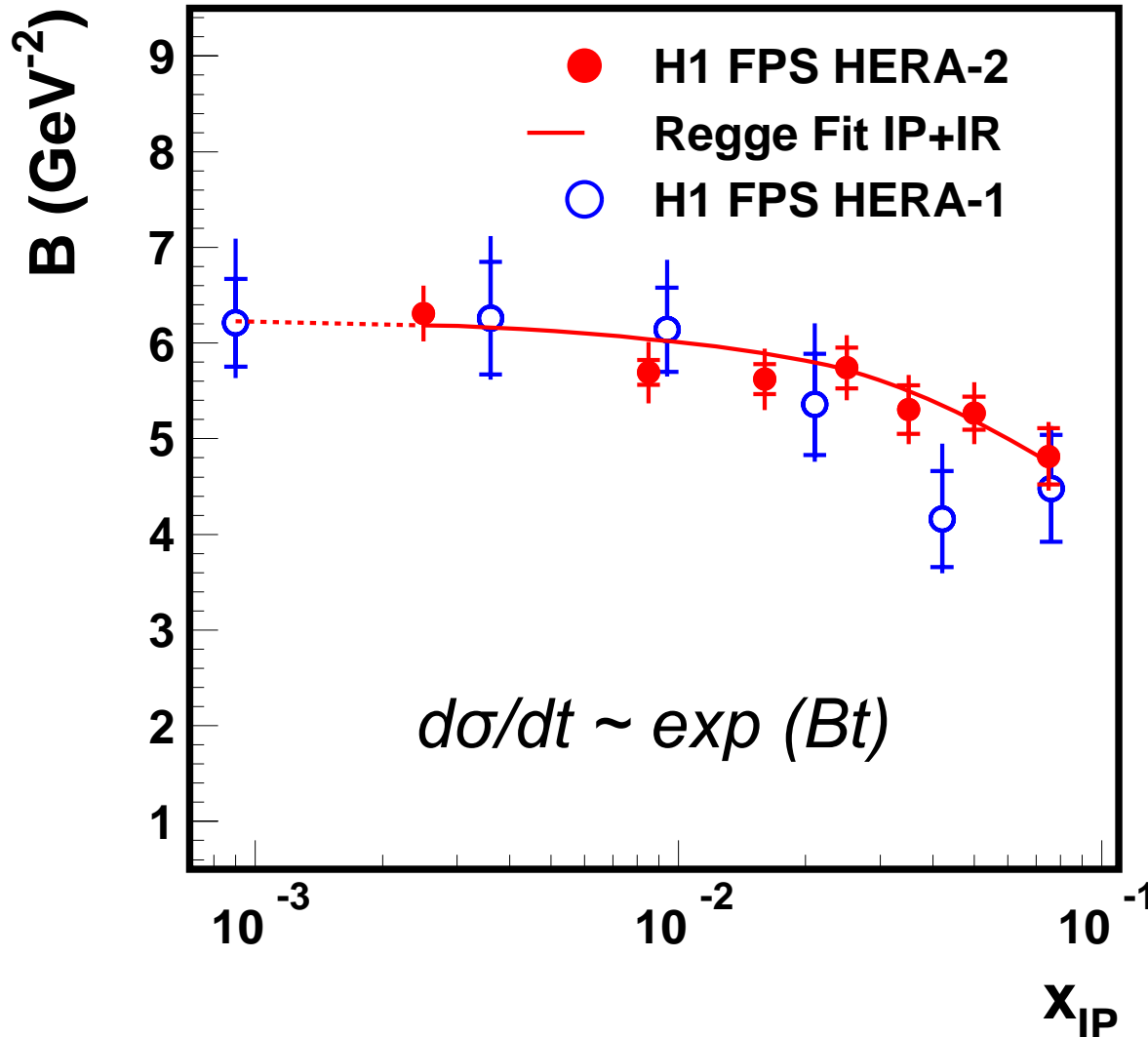


t-slope as a function of x_{IP}

Regge fit result:

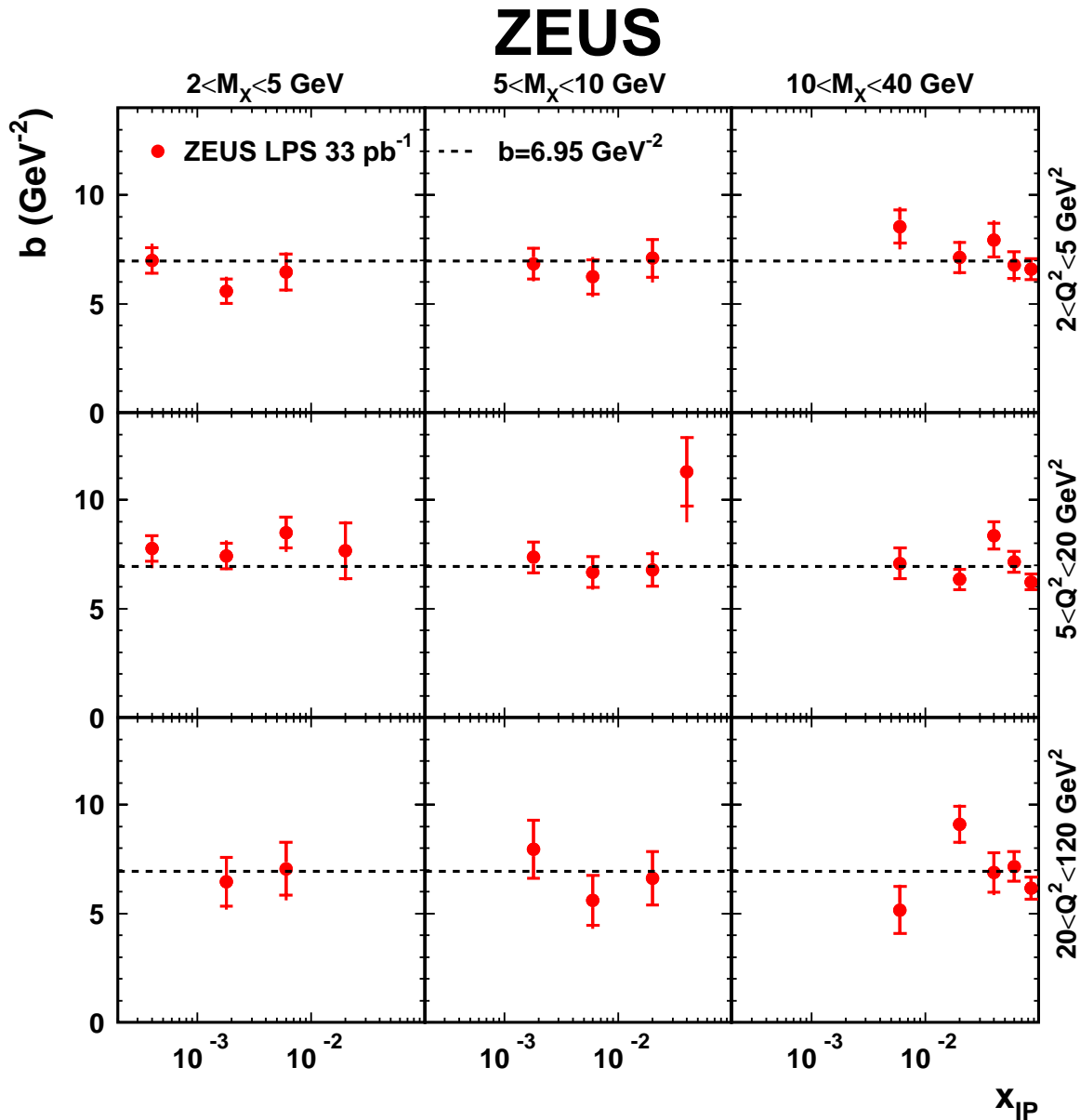
$$B(x_{IP}) = f_{IP}(x_{IP}) \cdot B_{IP}(x_{IP}) + f_{IR}(x_{IP}) \cdot B_{IR}(x_{IP})$$

H1 Preliminary



- x_{IP} -dependence of t-slope, data averaged over Q^2 and β
- New H1 FPS HERA-2 data have smaller uncertainties
- ➔ H1 FPS HERA-1 and HERA-2 data are consistent
- ➔ IR contribution at high x_{IP}

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



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

x_{IP} -dependence of t-slope
in (M_x, Q^2) bins

→ t-slope does not change
with M_x, Q^2 at fixed x_{IP}

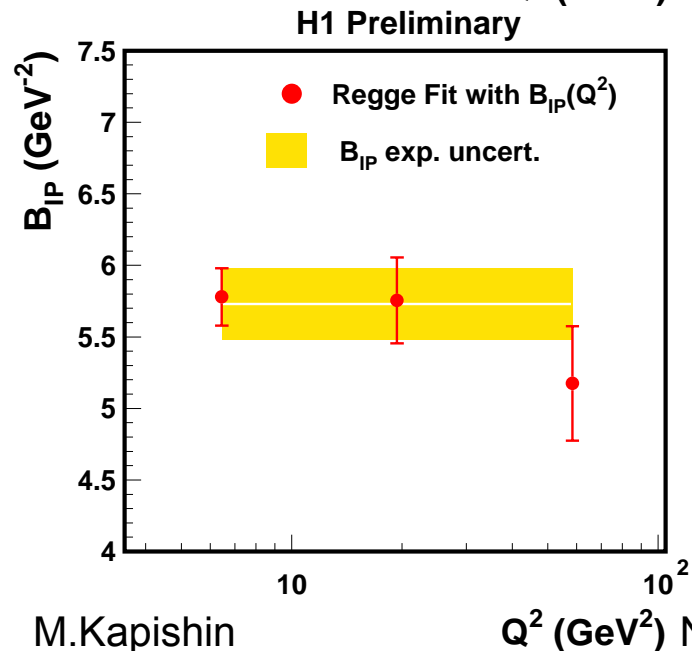
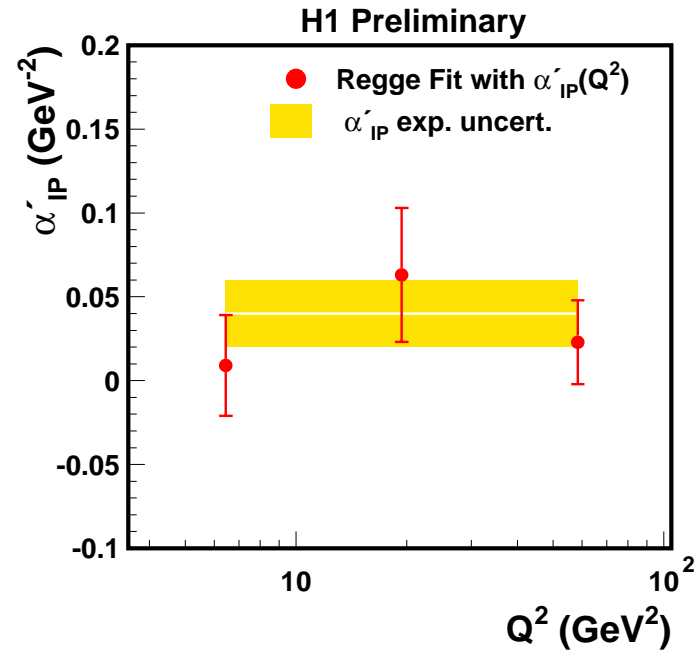
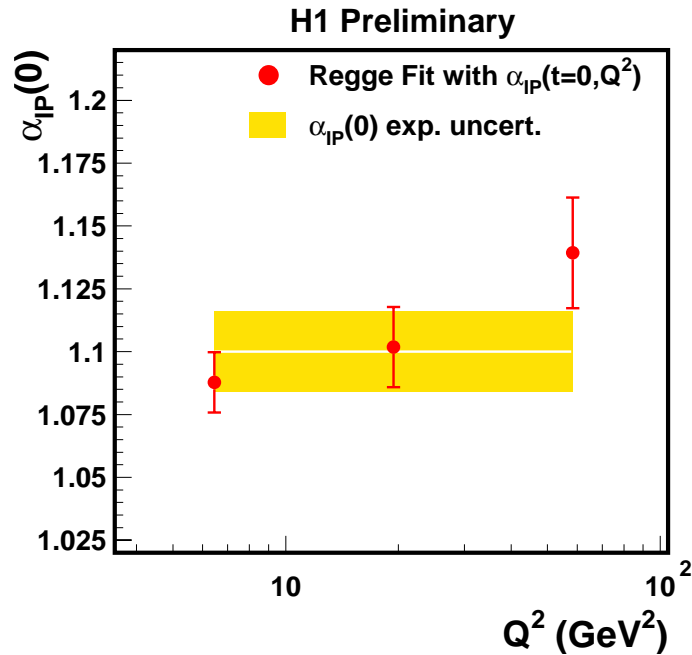
→ data consistent with

proton vertex factorization

→ no strong effect from IR
contribution



Modified Regge Fit in Q^2 bins



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

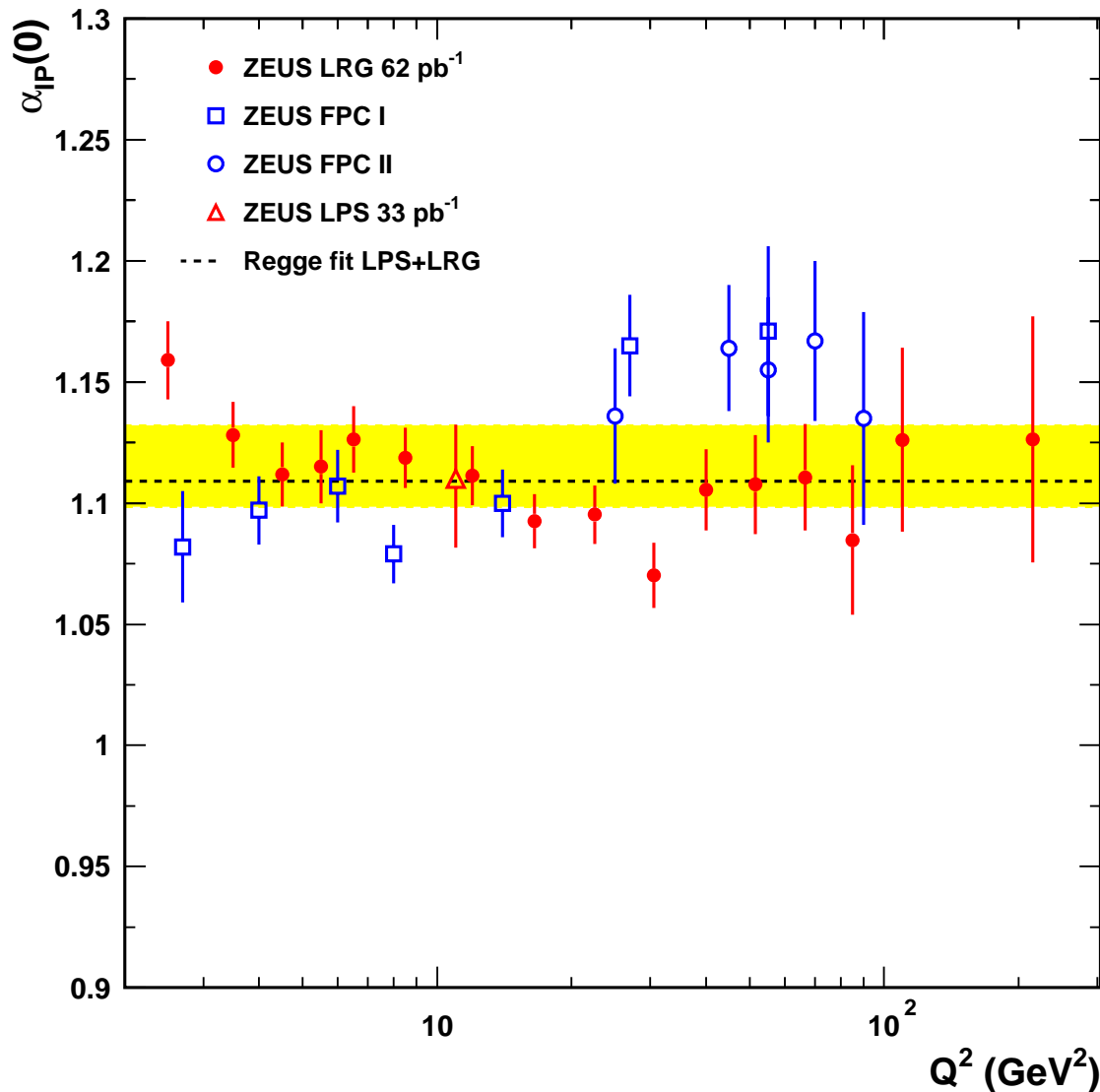
$$B(x_{IP}, Q^2) = B_{IP}(Q^2) + 2\alpha'_{IP}(Q^2)\ln(1/x_{IP})$$

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

Regge fit to LPS, LRG and Mx data



ZEUS



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--- Regge fit to LPS and LRG data

→ no strong dependence of $\alpha_{IP}(0)$ on Q^2

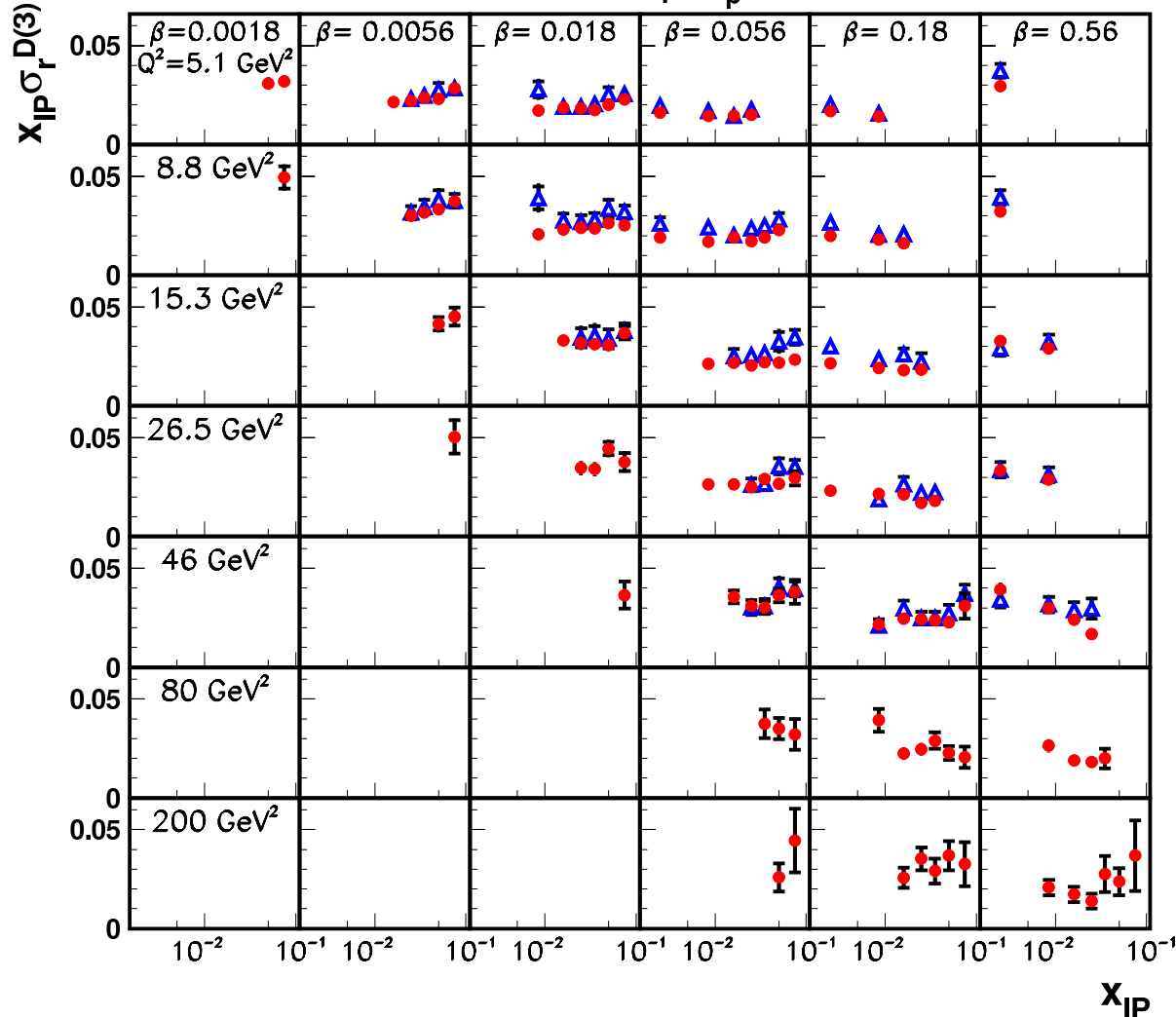
→ results consistent with proton vertex factorization within uncertainties



$\sigma_r^{D(3)}$: H1 FPS vs ZEUS LPS



- H1 FPS HERA-2 (prel.), $M_Y=M_p$
- ▲ ZEUS LPS (interpol.), $M_Y=M_p$



Forward Proton Spectrometer data integrated over $|t| < 1 \text{ GeV}^2$

x_{IP} -dependence in (β, Q^2) bins

- H1 FPS norm. uncertainty 6%, ZEUS LPS norm. uncertainty $\pm 11\%$ _{7%}

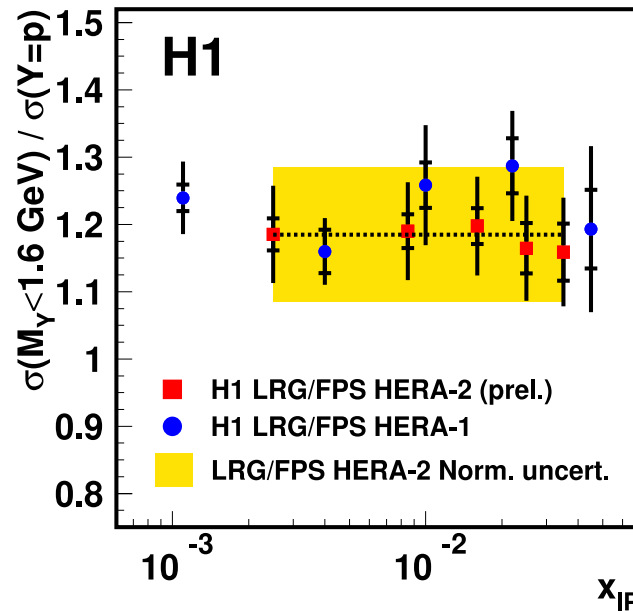
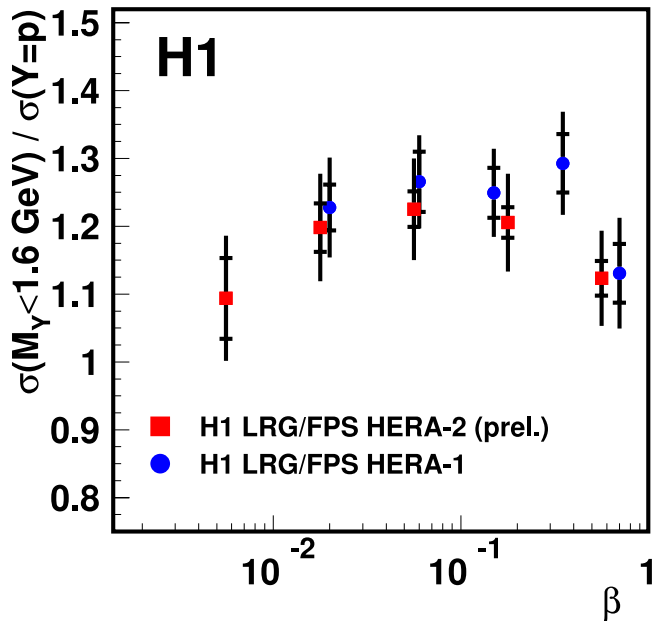
H1 / ZEUS: = $0.85 \pm 0.01(\text{stat.}) \pm 0.03(\text{syst.}) \pm 0.09_{0.12}(\text{norm.})$

➔ Reasonable agreement of new H1 FPS HERA-2 and ZEUS LPS data in shape of distribution

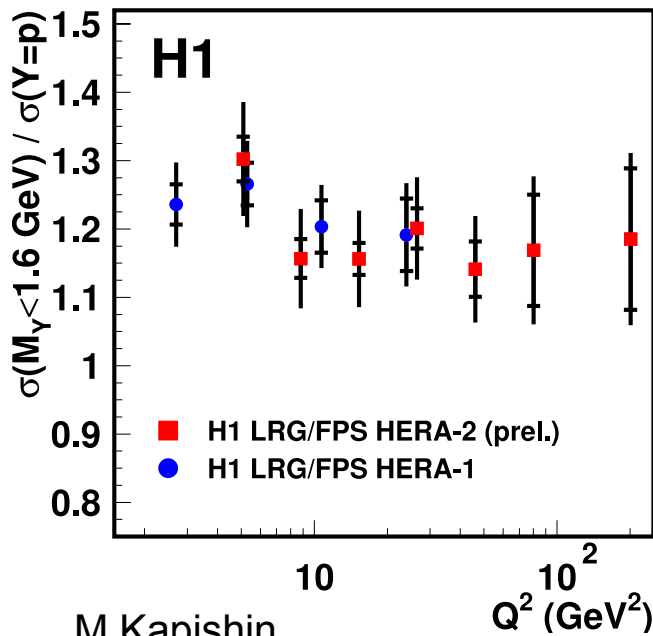
➔ H1 FPS HERA-2 data extend phase space to higher Q^2



LRG to FPS ratio



Ratio of LRG to FPS cross section for $|t| < 1 \text{ GeV}^2$



M_Y -dependence of cross section:

→ LRG / FPS ratio has no strong dependence on Q^2, β, x_{IP} within uncertainties

→ estimate p-dissociation contribution to H1 LRG data

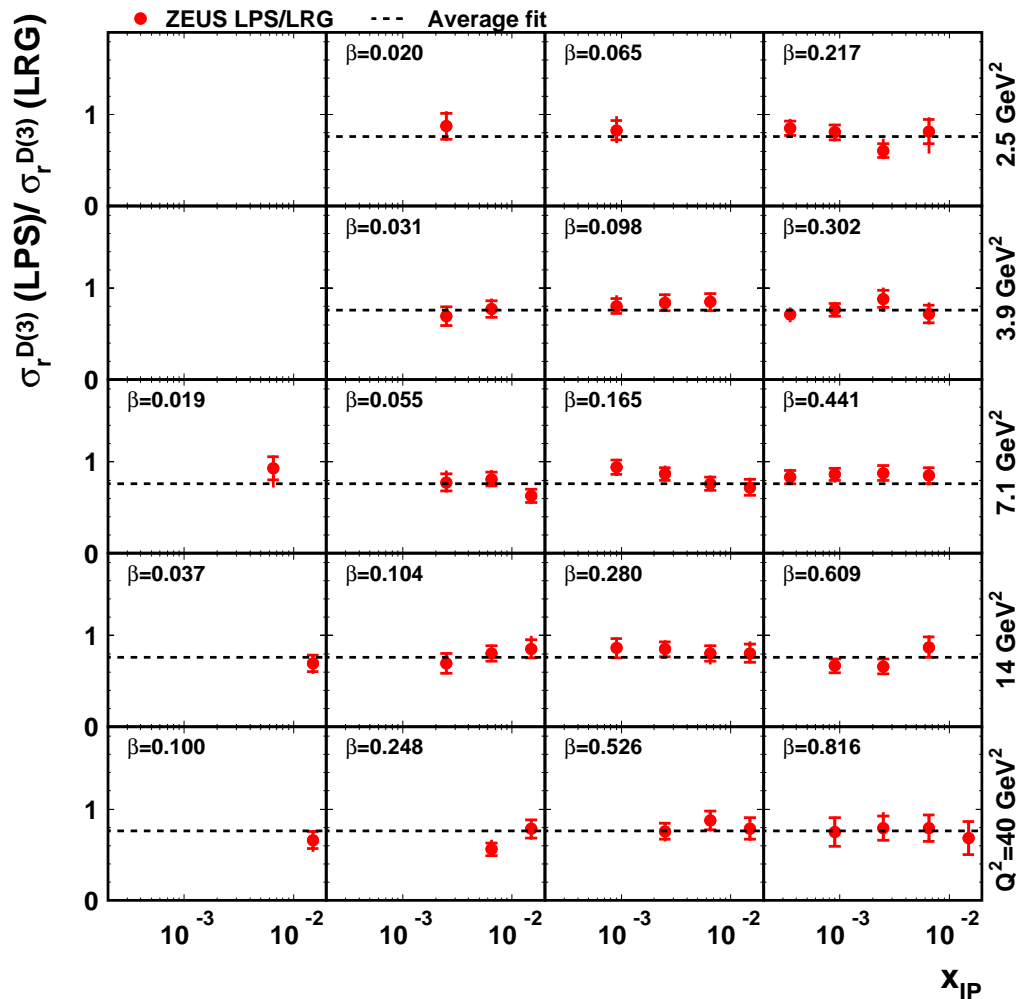
Combined H1 HERA-1 + HERA-2:

H1: $\sigma(M_Y < 1.6 \text{ GeV}) / \sigma(M_Y = M_p) = 1.20 \pm 0.11 \text{ (exp.)}$

ZEUS LPS / LRG ratio



ZEUS



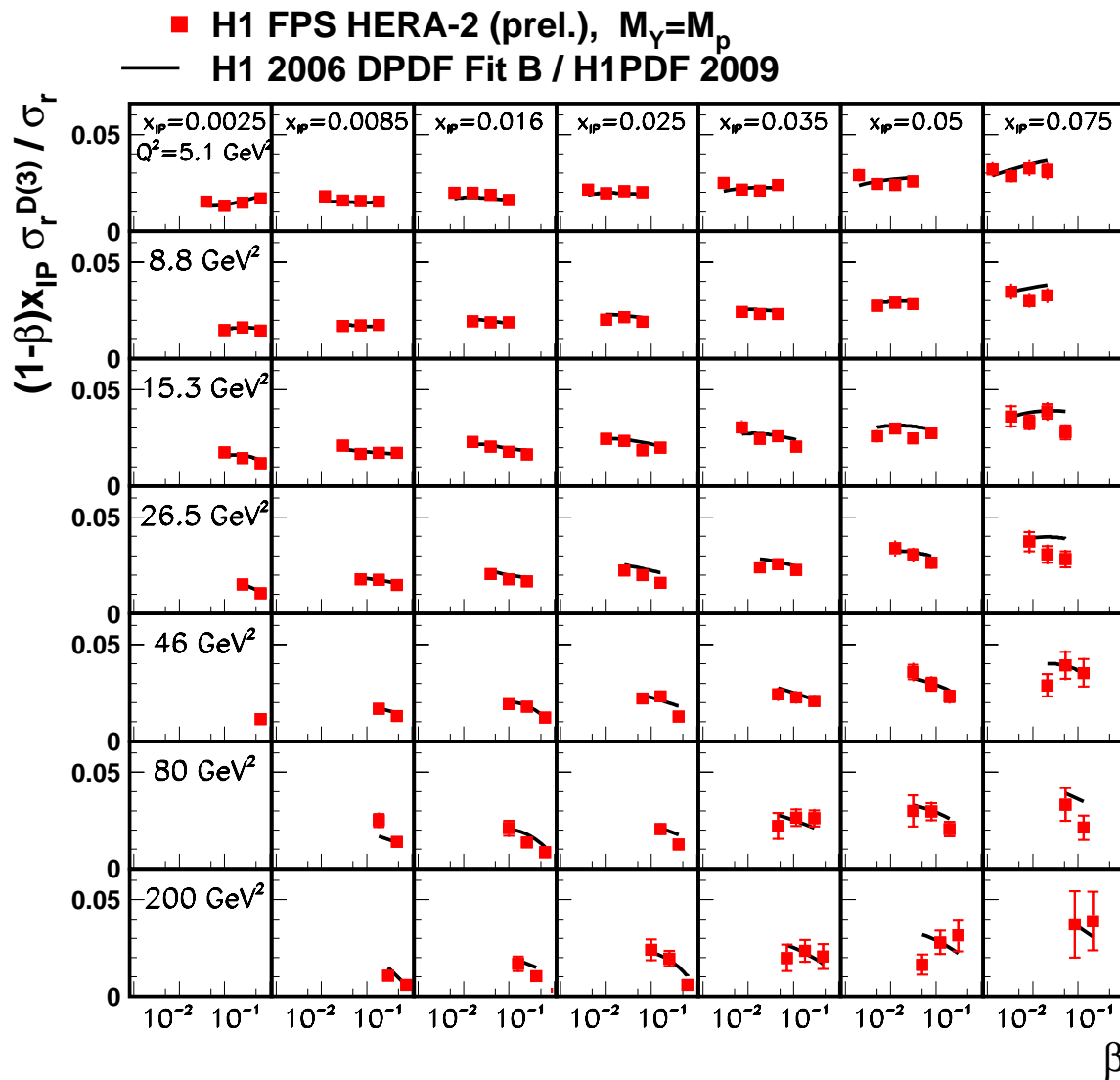
→ LPS / LRG ratio has no strong dependence on Q^2, β, x_{IP} within uncertainties
 → consistent with **proton vertex factorization**

- ZEUS data:
 $\sigma(\text{LPS}, M_Y = M_p) / \sigma(\text{LRG}) = 0.76 \pm 0.01(\text{stat}) \pm^{0.03}_{0.02}(\text{syst}) \pm^{0.08}_{0.05}(\text{norm})$
- Additional correction factor:
 $\sigma(M_Y < 1.6 \text{ GeV}) / \sigma(\text{LRG}) = 0.91 \pm 0.07(\text{syst})$

→ $\sigma(M_Y < 1.6 \text{ GeV}) / \sigma(M_Y = M_p)$ consistent with H1 result



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)

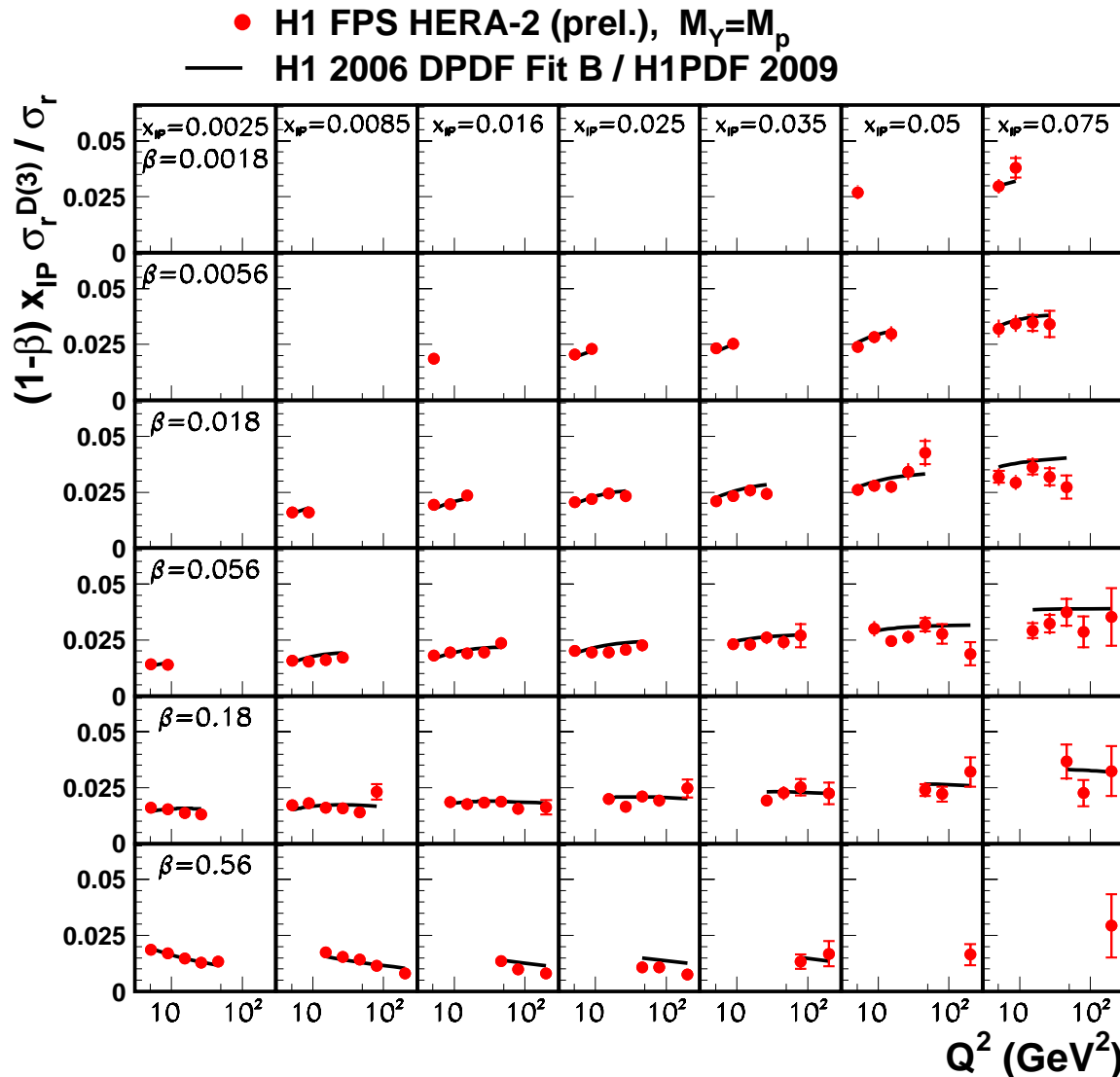
β -dependence in (x_{IP}, Q^2) bins
 $M_X > 2 \text{ GeV}$, $|t| < 1 \text{ GeV}^2$

→ Ratio is flat except at highest β → similar shape of diffractive and inclusive quark PDF in proton at low $x=x_{IP}\beta$

→ Ratio weakly rises with x_{IP} → IR contribution



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



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

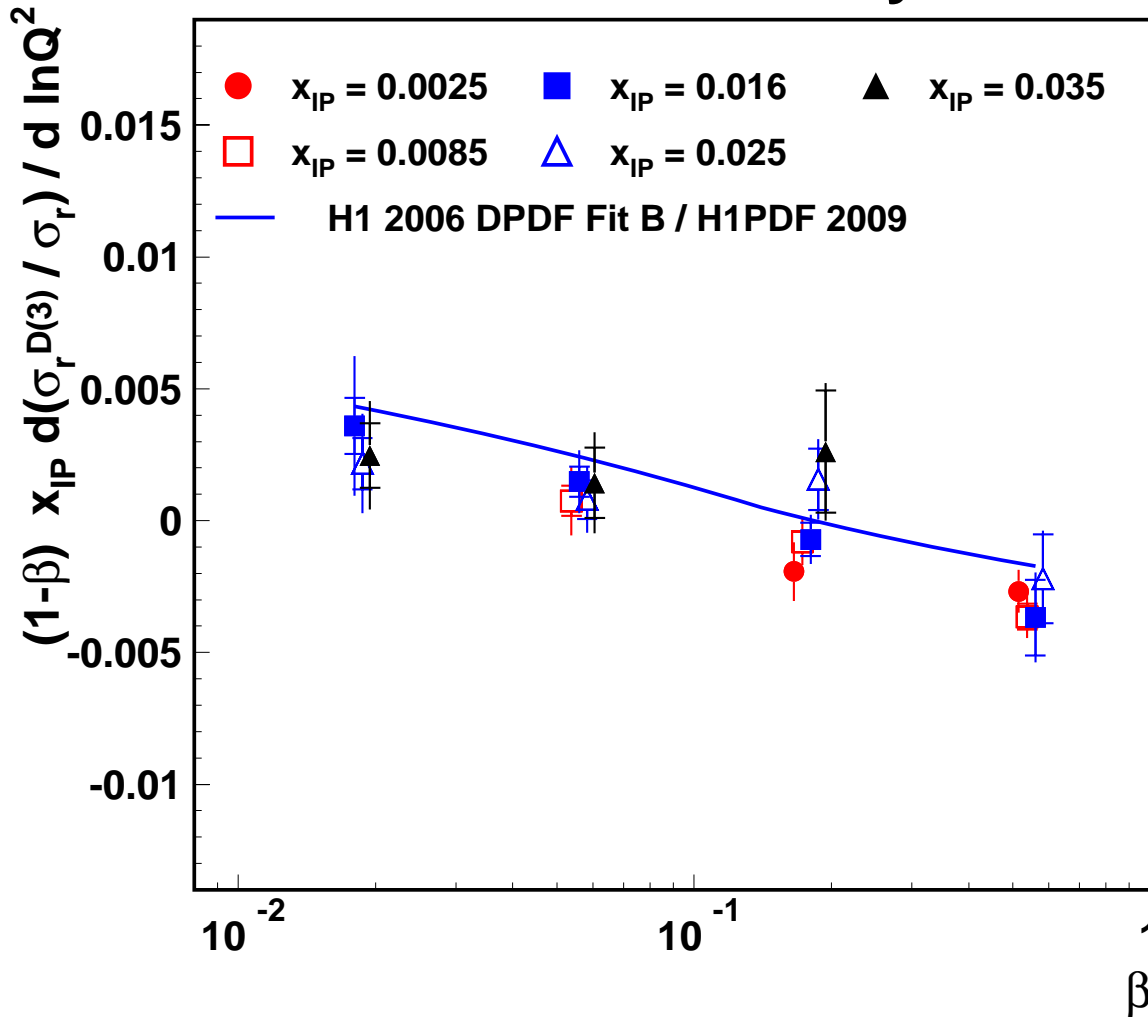
→ extract $\ln Q^2$ derivative sensitive to gluon PDF



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



- $\ln Q^2$ slope is consistent with zero within 1.5σ of exp. uncertainties

$\rightarrow (\text{gluon/quark})^{diff} \sim (\text{gluon/quark})^{incl}$
in proton at low $x=x_{IP}\beta$

- weak decrease of $\ln Q^2$ slope with β reproduced by DPDF / PDF predictions



Summary



- High statistics diffractive DIS data are measured with H1 Forward Proton Spectrometer at HERA-2 and ZEUS Leading Proton Spectrometer
- 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
- Results of Regge fit are consistent with **proton vertex factorization**
- no “shrinkage” of t-slope in diffractive DIS
- Ratio of diffractive to inclusive cross section only weakly depends on β and $Q^2 \rightarrow$ gluon PDF fraction in proton is similar in diffractive and inclusive DIS at low x