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

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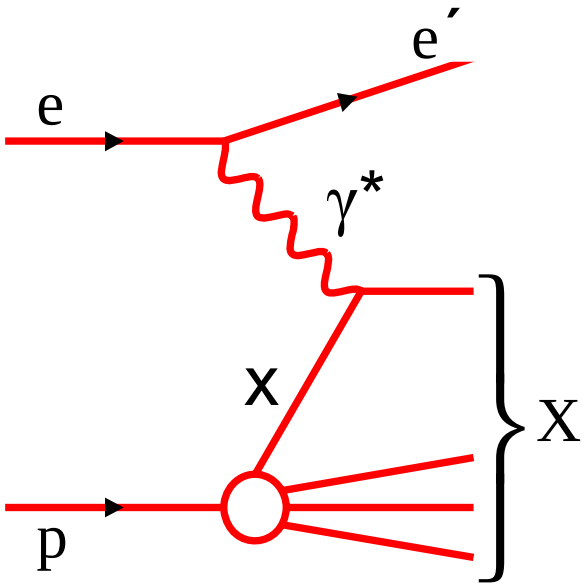
on behalf of the H1 and ZEUS Collaborations

- 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 → probe structure of proton

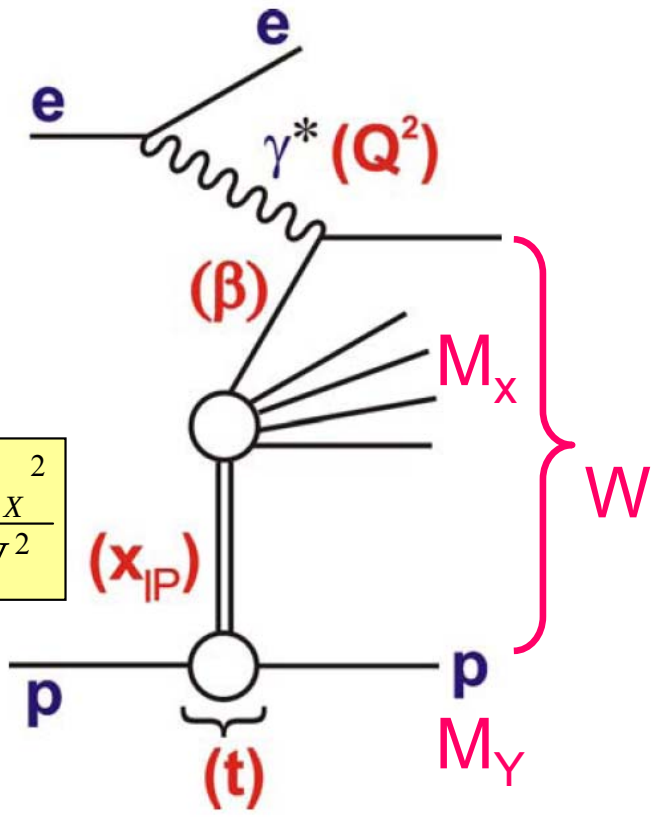
Diffractive DIS

Momentum fraction of color singlet carried by struck quark

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

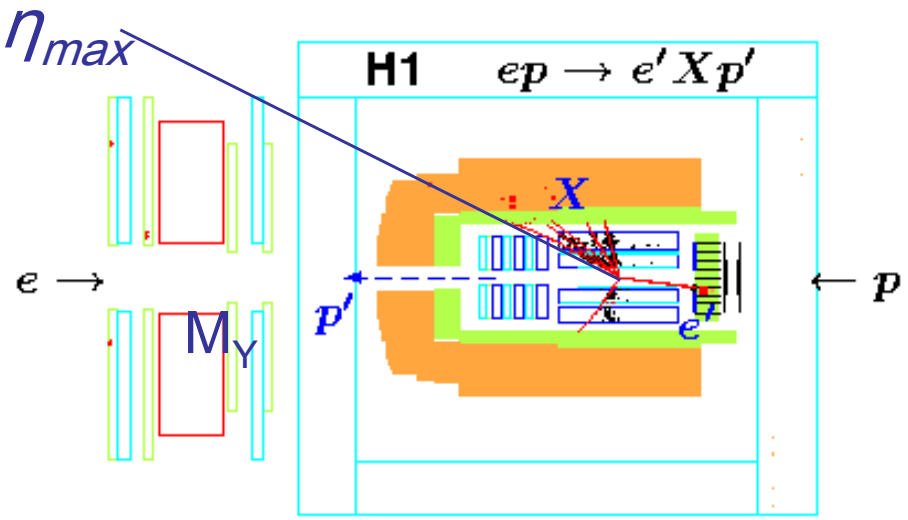
$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

Momentum fraction of proton carried by colour singlet exchange



Selection of diffraction at HERA

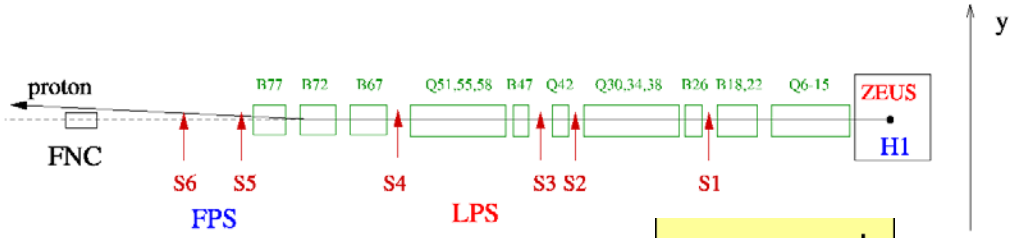
Large rapidity gap (LRG) between leading proton p' and X



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

➔ LRG and FPS methods have different systematic uncertainties

Forward Proton Spectrometers



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

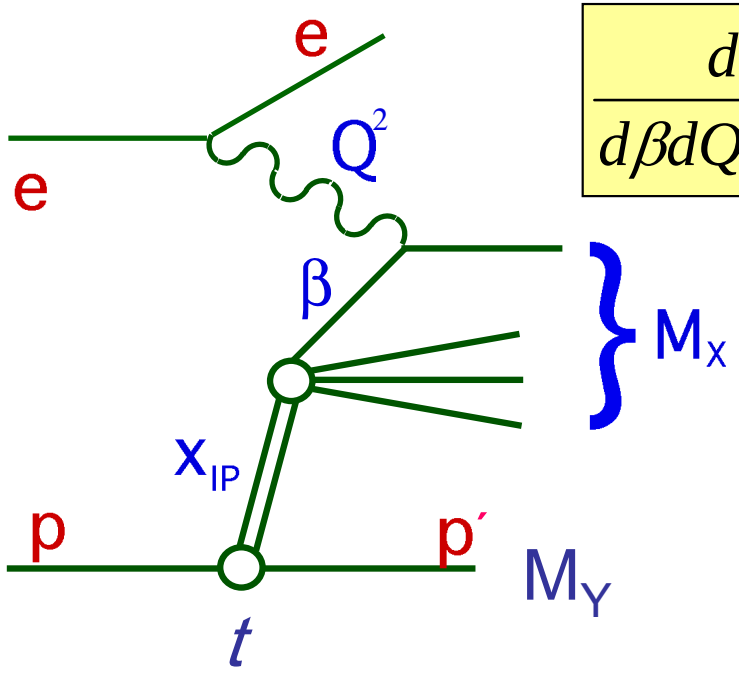
HERA-2:

➢ 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:

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

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

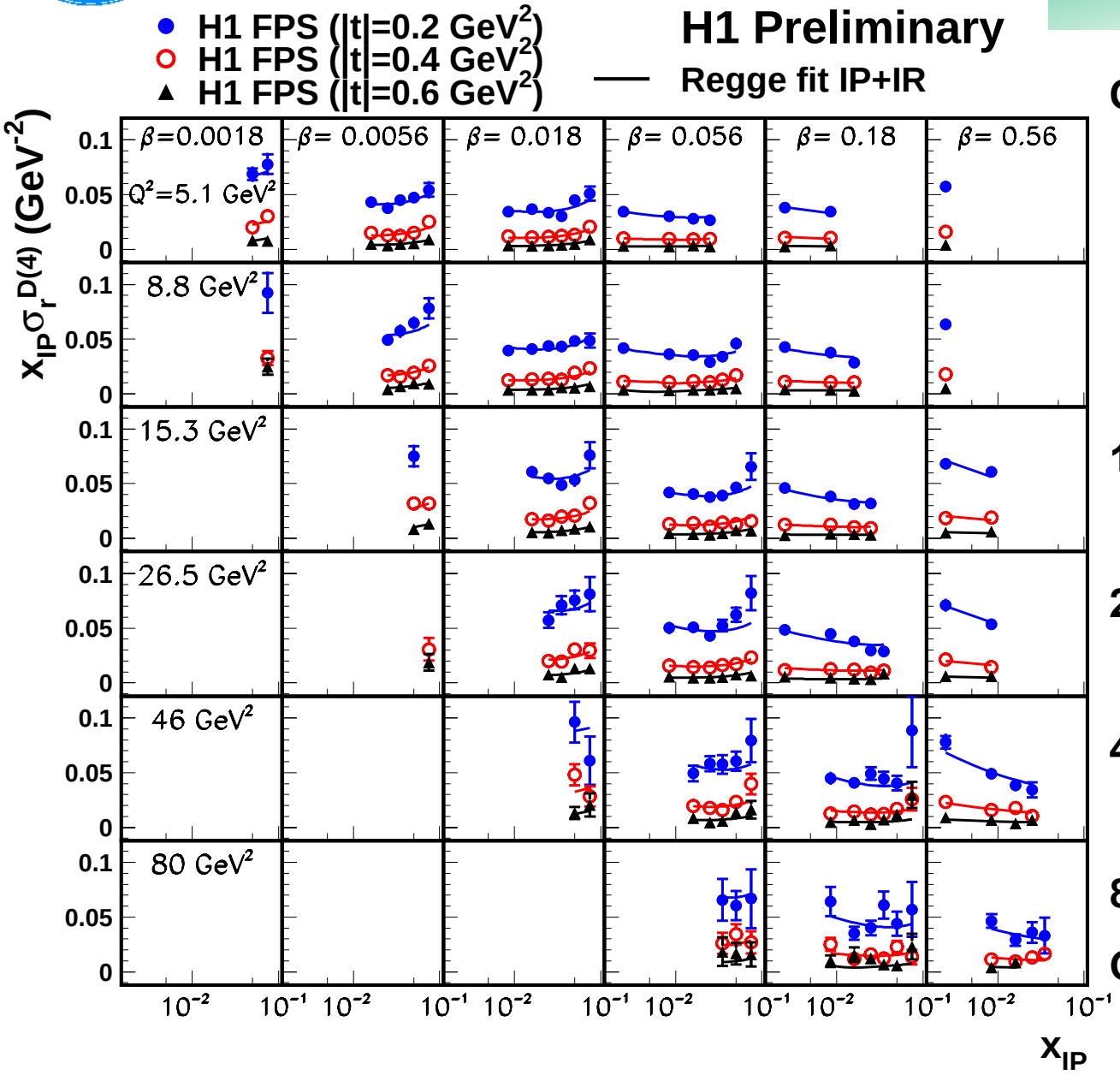
$$\sigma_r^{D(3)} = \int \sigma_r^{D(4)} dt$$

→ integrate over $|t|<1$ GeV² to compare with LRG and 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

GeV²

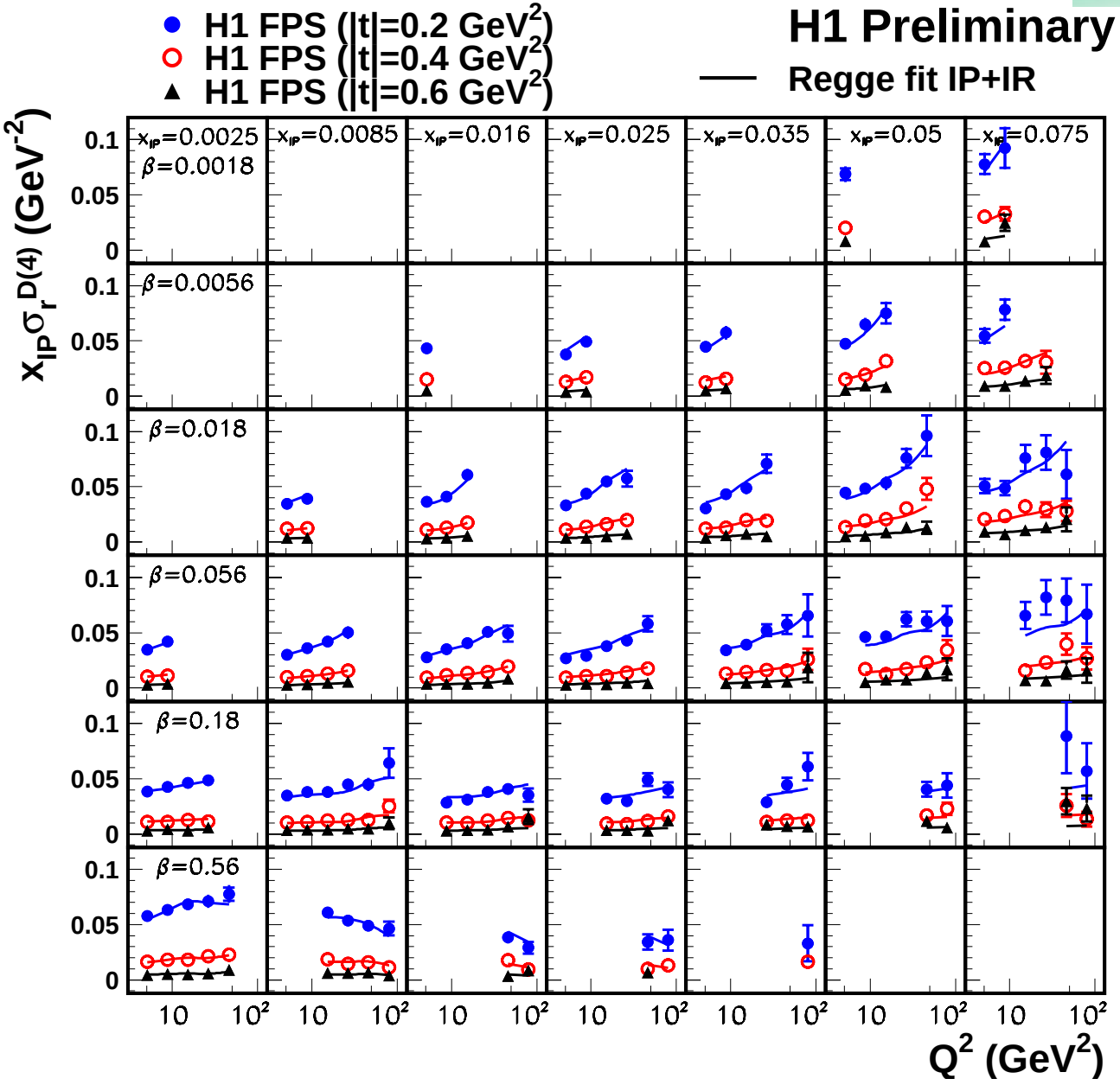
New H1 FPS HERA-2 $\sigma_r^{D(4)}$ data:

- $5 < Q^2 < 80$ GeV²
- luminosity 156 pb^{-1}
- 20 times higher statistics than in HERA-1 data
- norm. uncertainty ~4.3% → smaller than in HERA-1

x_{IP}-dependence in (Q^2,β,t) bins

➔ IP and IR contributions

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



β

0.0018

0.0056

0.018

0.056

0.18

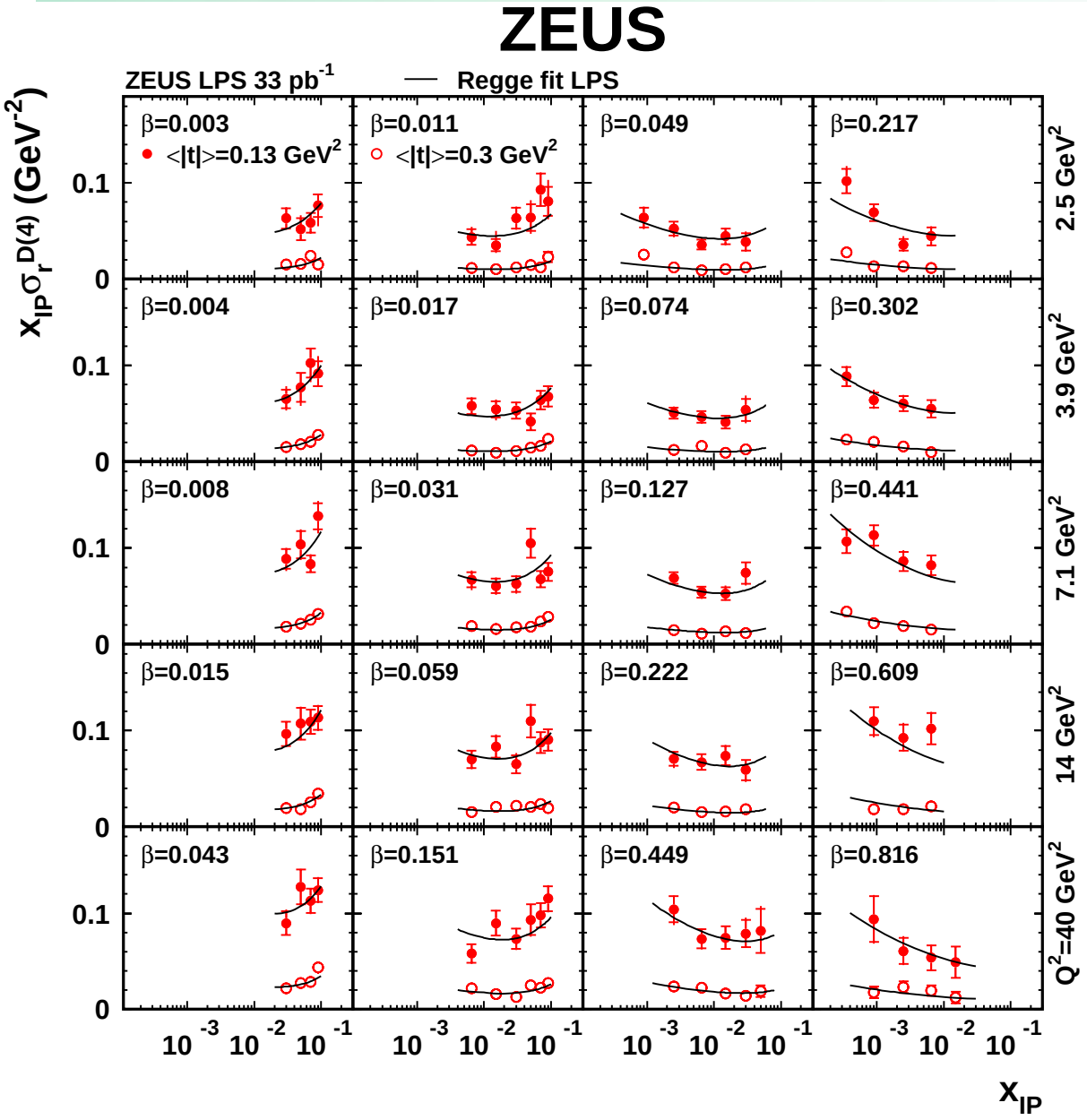
0.56

New H1 FPS HERA-2 $\sigma_r^{D(4)}$ data

Q^2-dependence in (β, x_{IP}, t) bins

➔ positive scaling violations except at high β ➔ gluon contribution to diffractive exchange

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



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- ● ZEUS LPS |t|=0.13 GeV^2
- ○ ZEUS LPS |t|=0.3 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*:

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

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

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

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

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

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

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

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

- $\alpha_{IP}(0) \simeq \alpha_{IP}$(soft)~1.08
- $\alpha'_{IP} \simeq 0 \rightarrow$ no "shrinkage" (α'_{IP}(soft)~0.25 GeV^{-2})
- B_{IP} consistent with hard process

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:

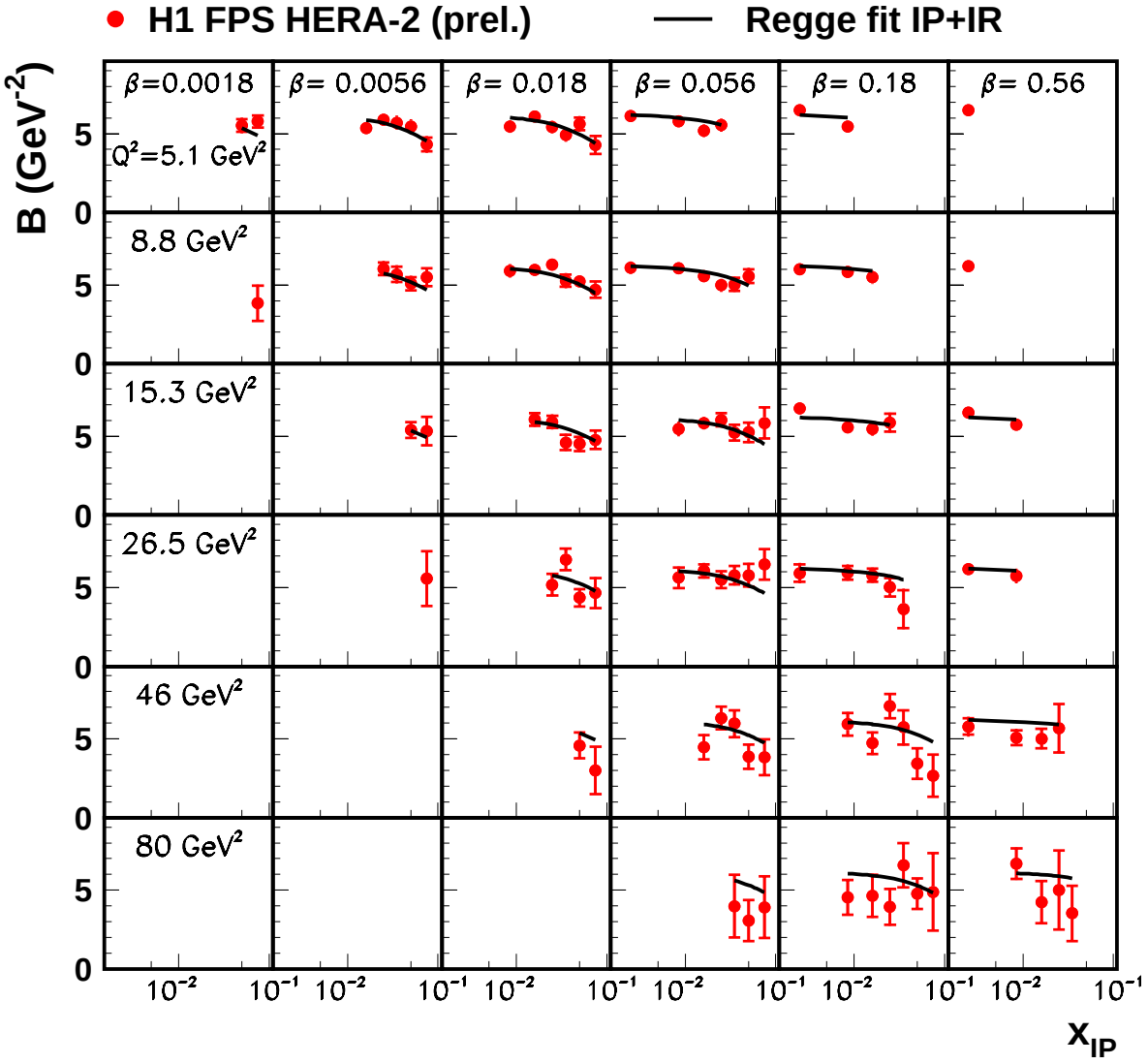
$$\alpha_{IP}(0) = 1.11 \pm 0.02(\text{stat.}) \pm^{0.01}_{0.02}(\text{syst.}) \pm 0.02(\text{model})$$

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

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

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

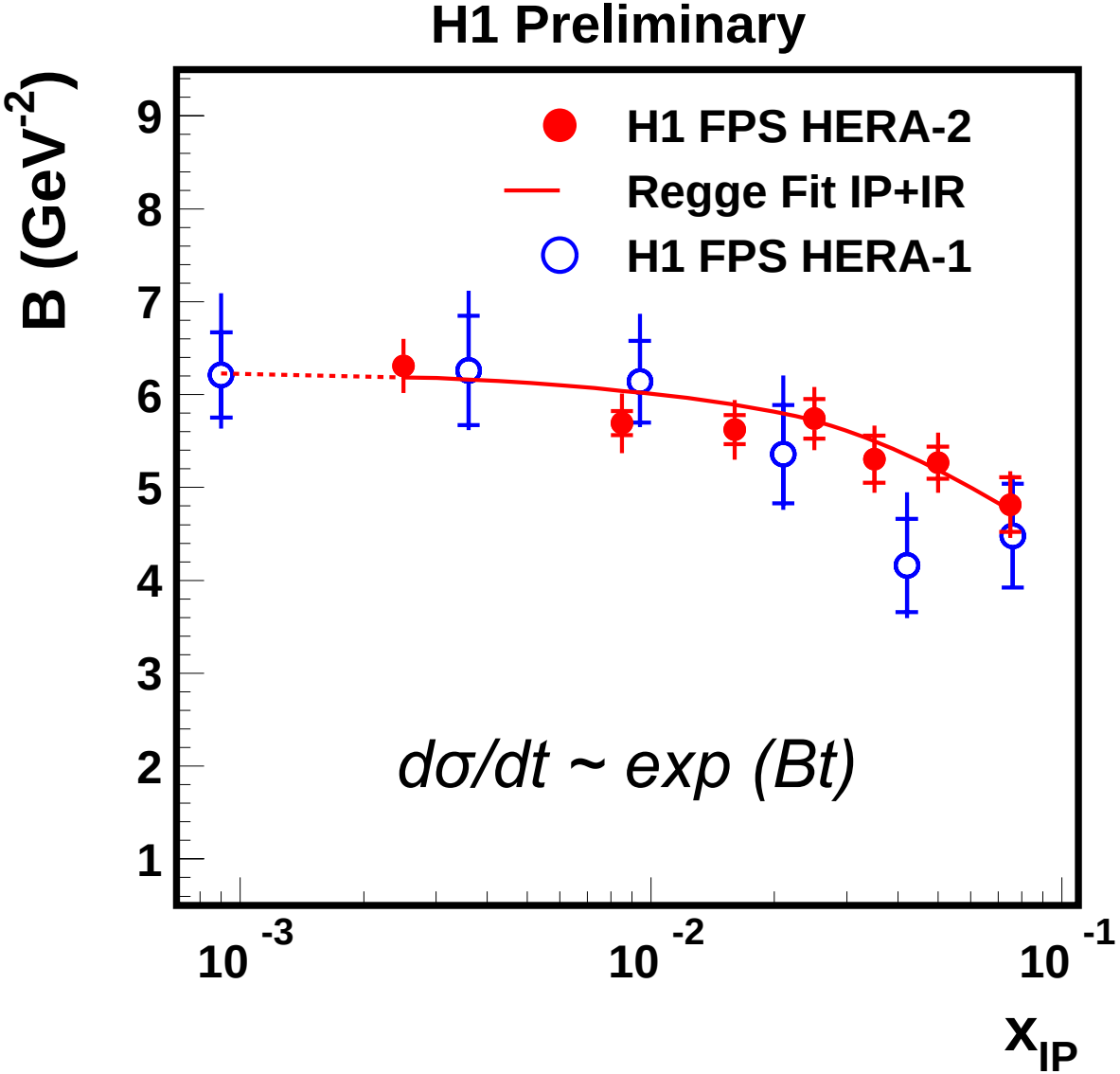
➔ IR contribution at high x_{IP}

➔ *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:

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

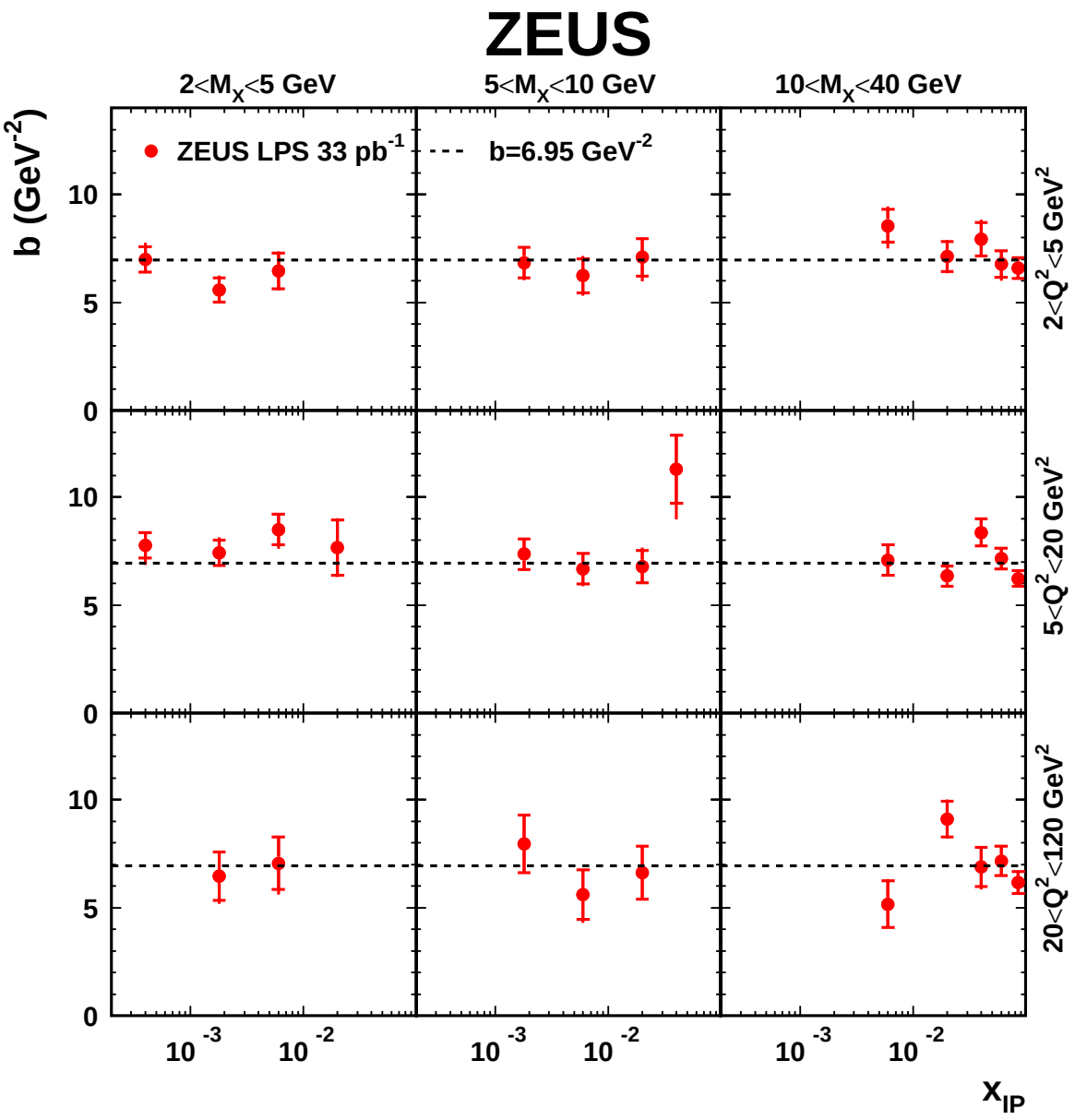


- x_{IP}-dependence of t-slope, data averaged over Q^2 and β
- New H1 FPS HERA-2 data have smaller uncertainties

➔ 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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$d\sigma/dt \sim exp\ (bt)$

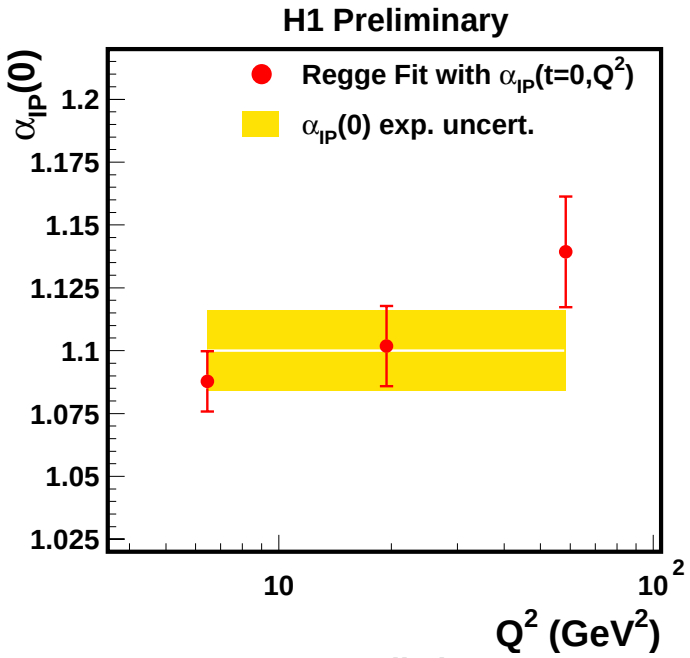
x_{IP}-dependence of t-slope in (M_x,Q^2) bins

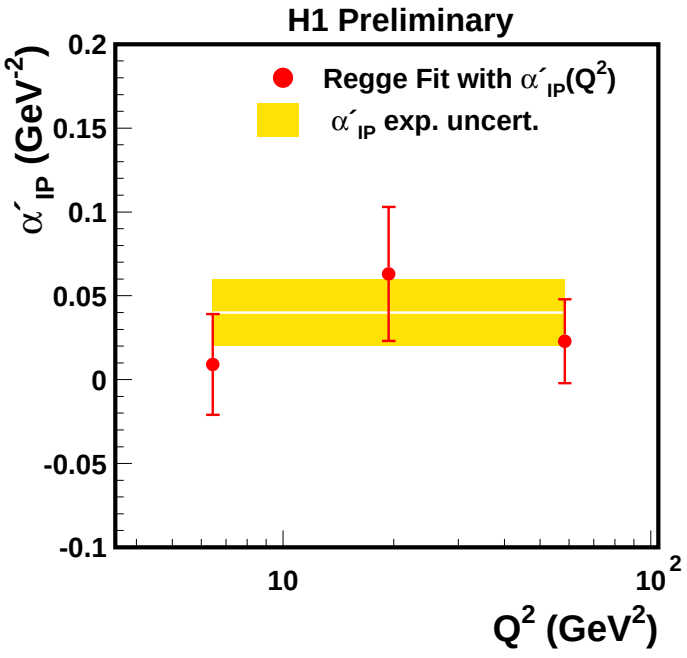
➔ *t*-slope does not change with M_x, Q^2 at fixed x_{IP}

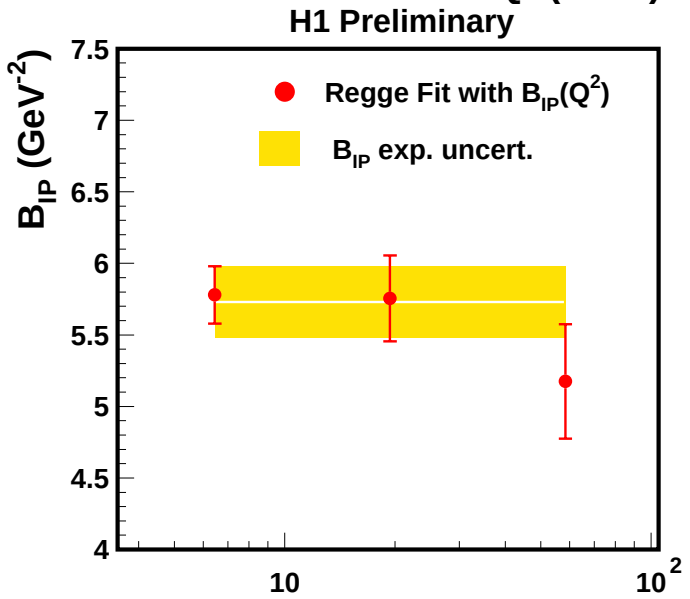
➔ data consistent with proton vertex factorization

➔ no strong effect from IR contribution

Modified Regge Fit in Q^2 bins





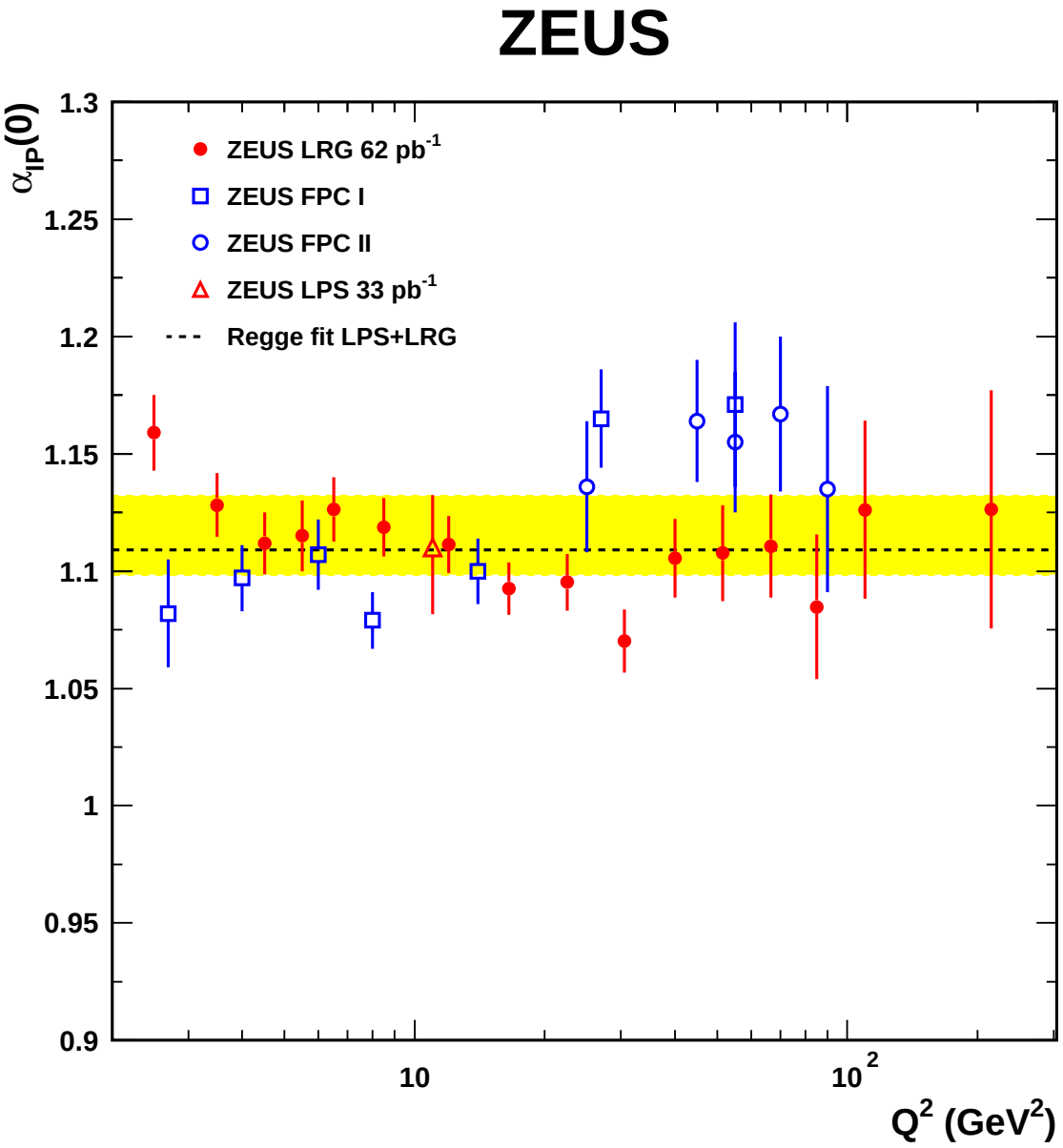


$$\alpha_{IP}(t,Q^2) = \alpha_{IP}(0,Q^2) + \alpha_{IP}'(Q^2)t$$

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

➔ results consistent with proton vertex factorization within uncertainties

Regge fit to LPS, LRG and Mx data



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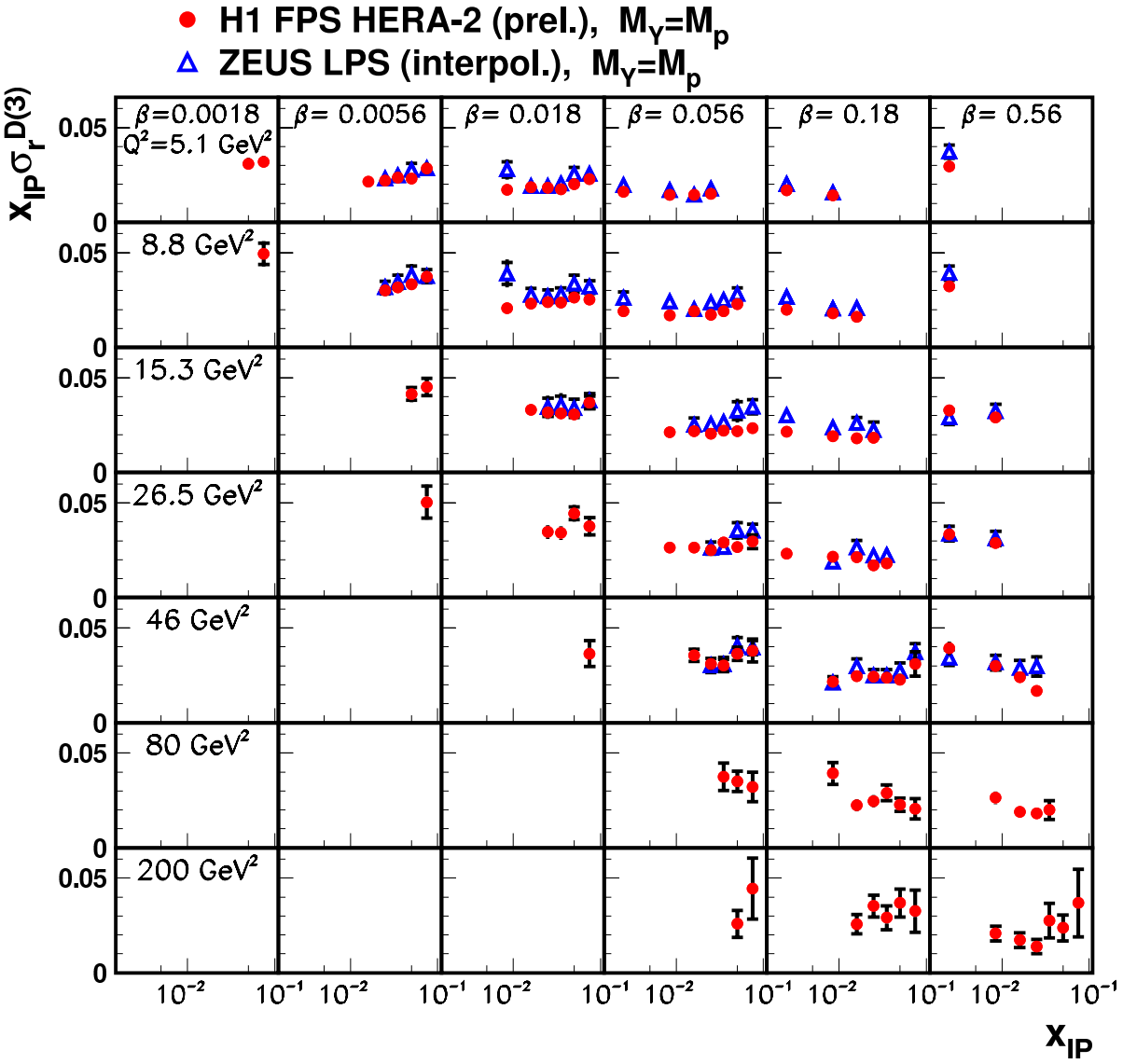
--- Regge fit to LPS and LRG data

➔ 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



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

x_{IP}-dependence in (β,Q^2) bins

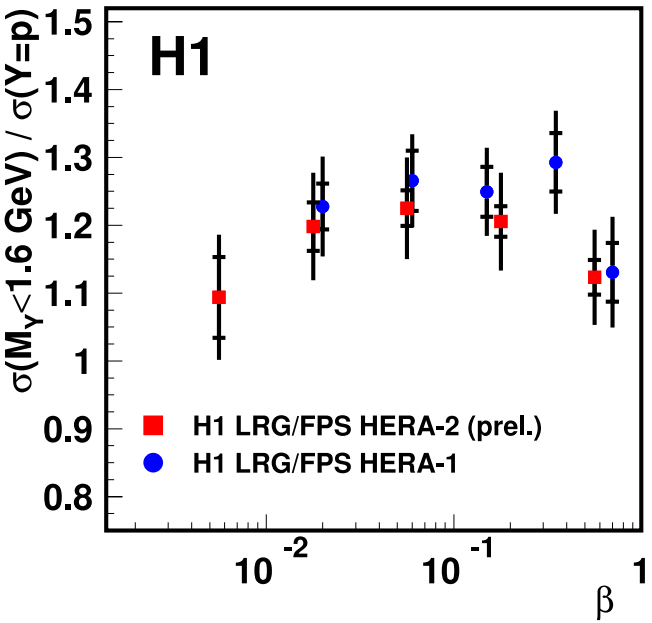
- H1 FPS norm. uncertainty 6%, ZEUS LPS norm. uncertainty $\pm^{11\%}_{7\%}$

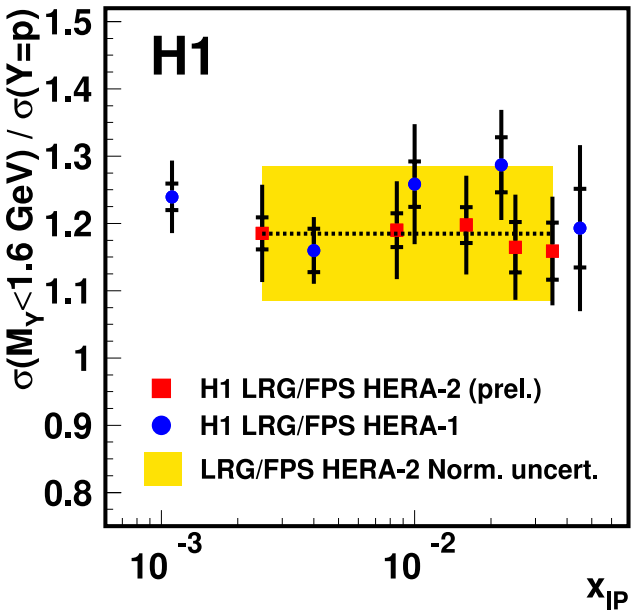
H1 / ZEUS: = 0.85 ± 0.01(stat.) ± 0.03(syst.) $\pm^{0.09}_{0.12}$(norm.)

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

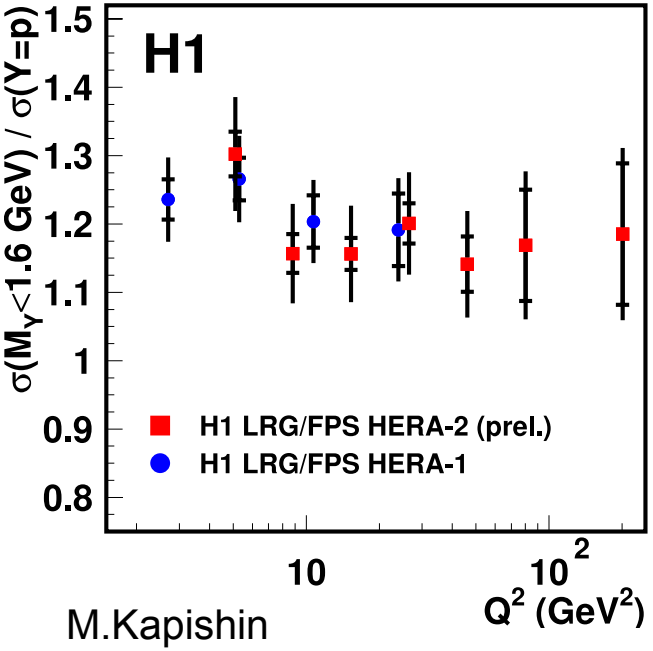
➔ H1 FPS HERA-2 data extend phase space to higher Q^2

LRG to FPS ratio





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



M_Y-dependence of cross section:

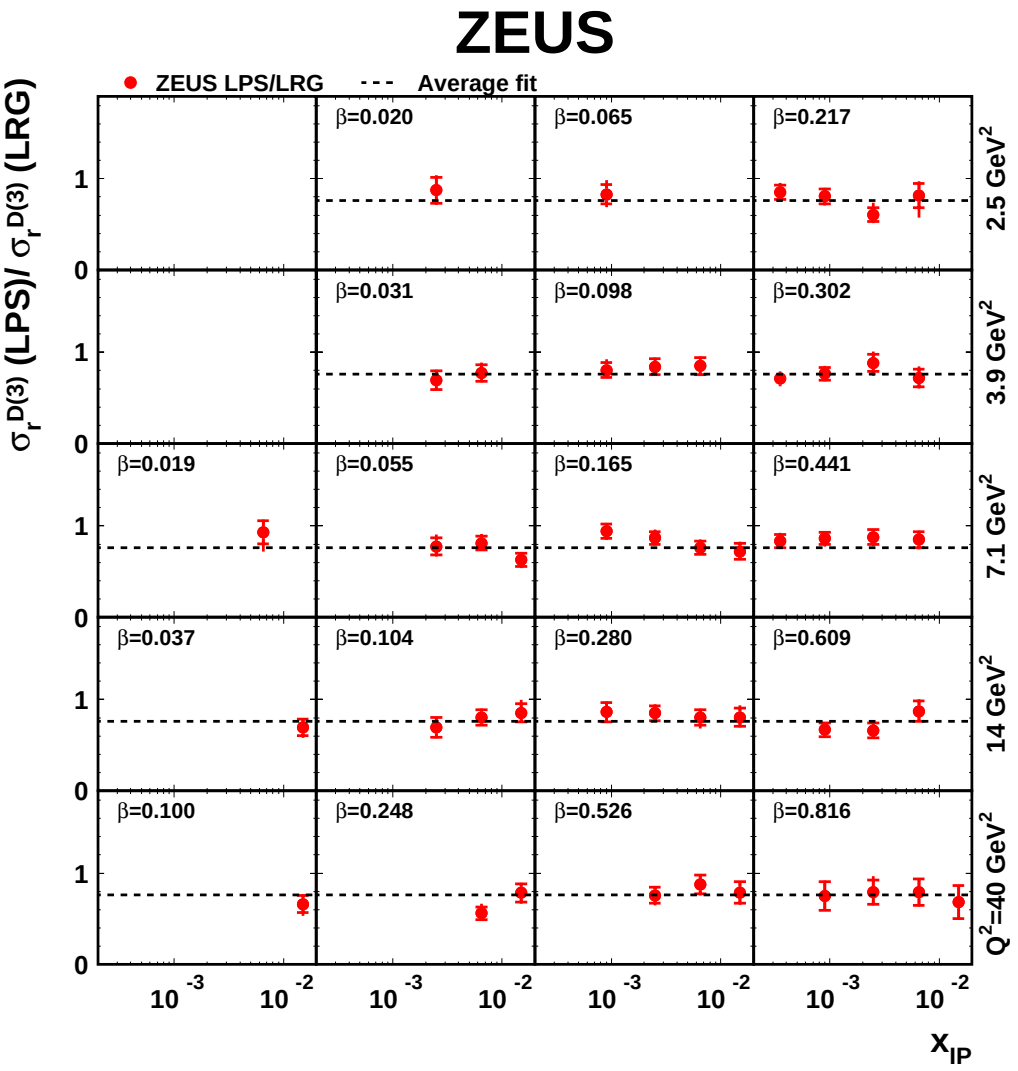
➔ LRG / FPS ratio has no strong dependence on Q^2,β, x_{IP} within uncertainties

➔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



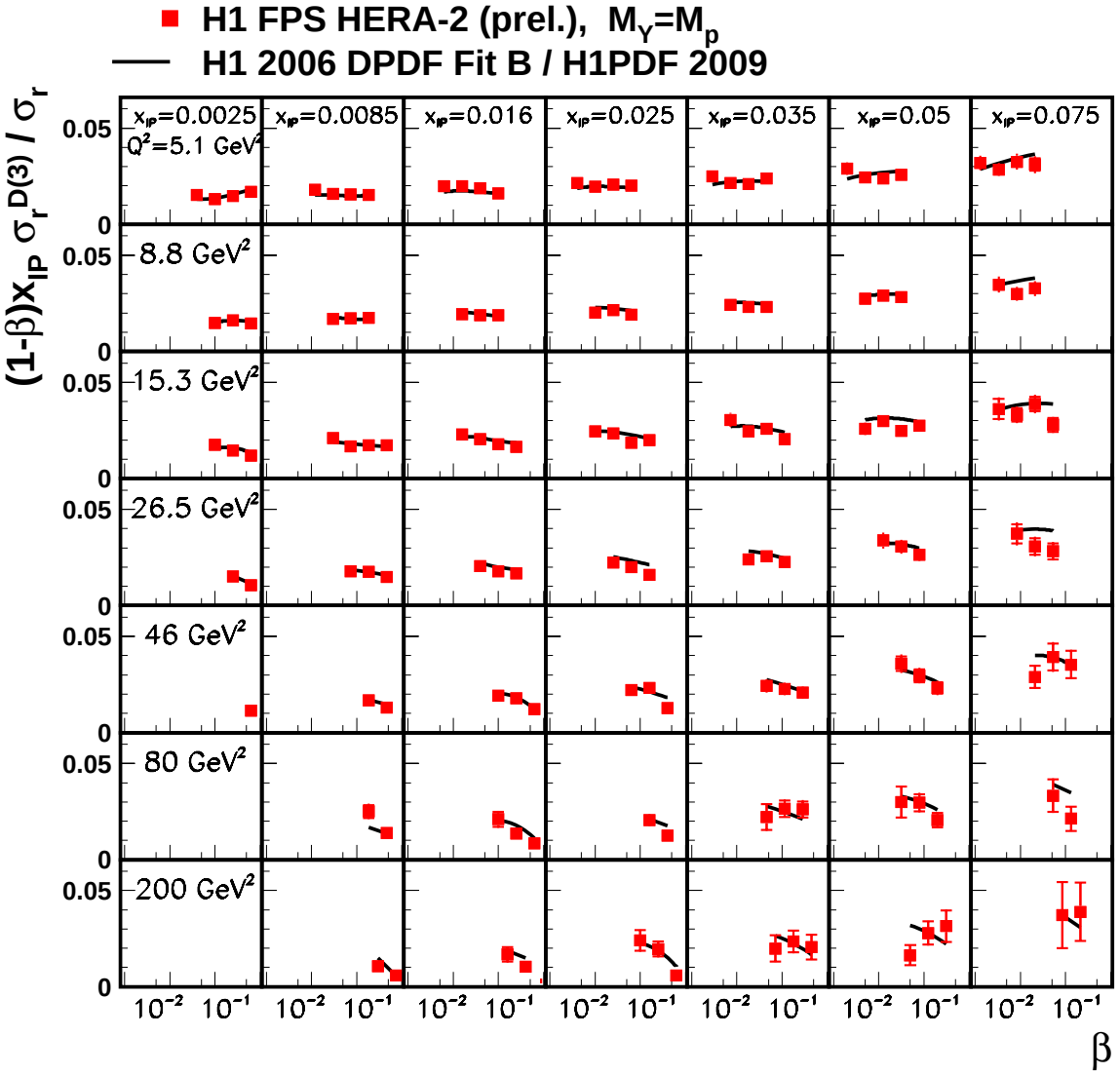
➔ LPS / LRG ratio has no strong dependence on Q^2,β, x_{IP} within uncertainties

➔ consistent with proton vertex factorization

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

➔ $\sigma(M_Y<1.6\ GeV) / \sigma(M_Y=M_p)$ consistent with H1 result

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



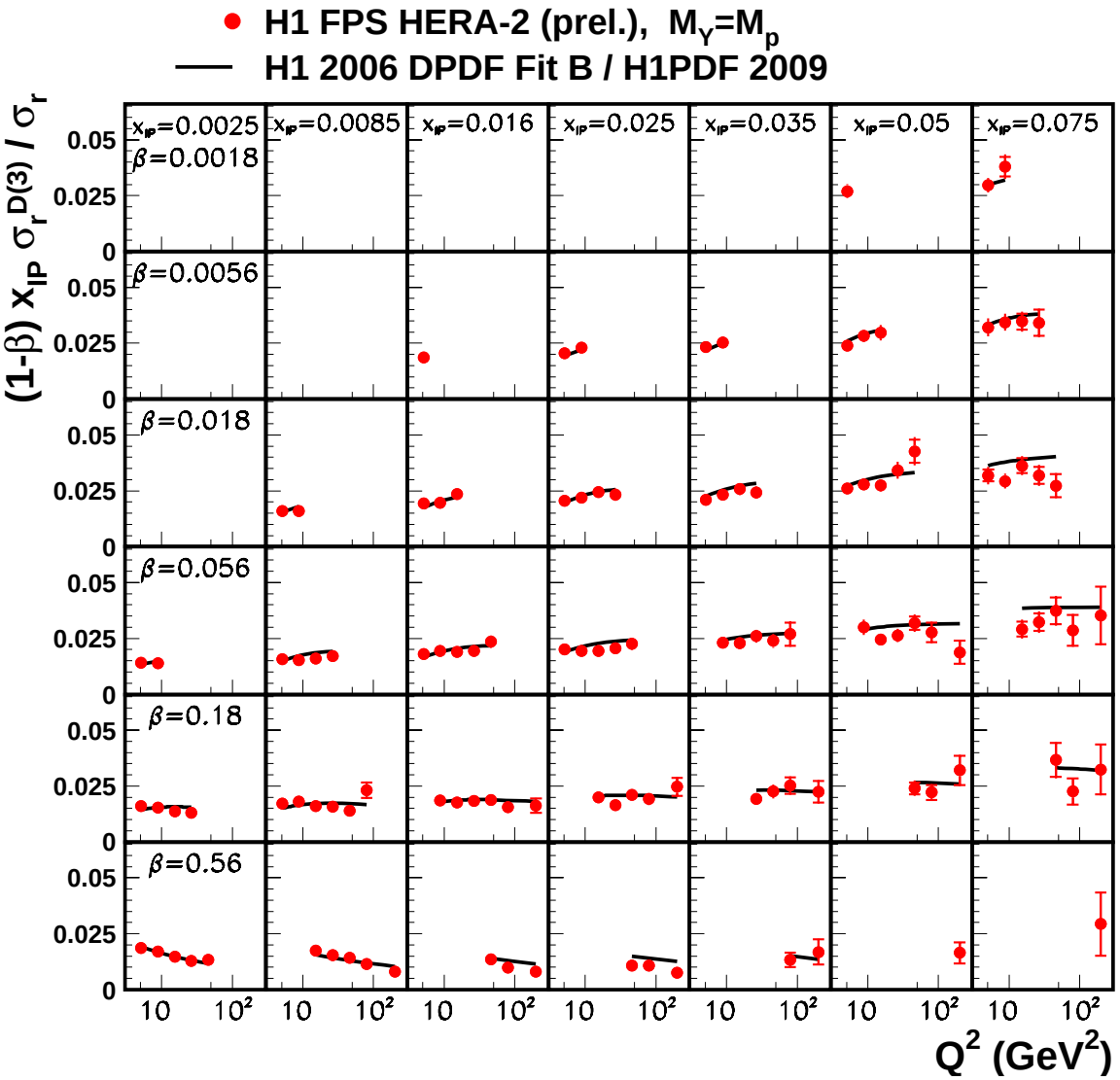
- $(1-\beta)x_{IP}\sigma_r^{D(3)}$ (FPS HERA-2) / σ_r^{incl} (H1PDF 2009)

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



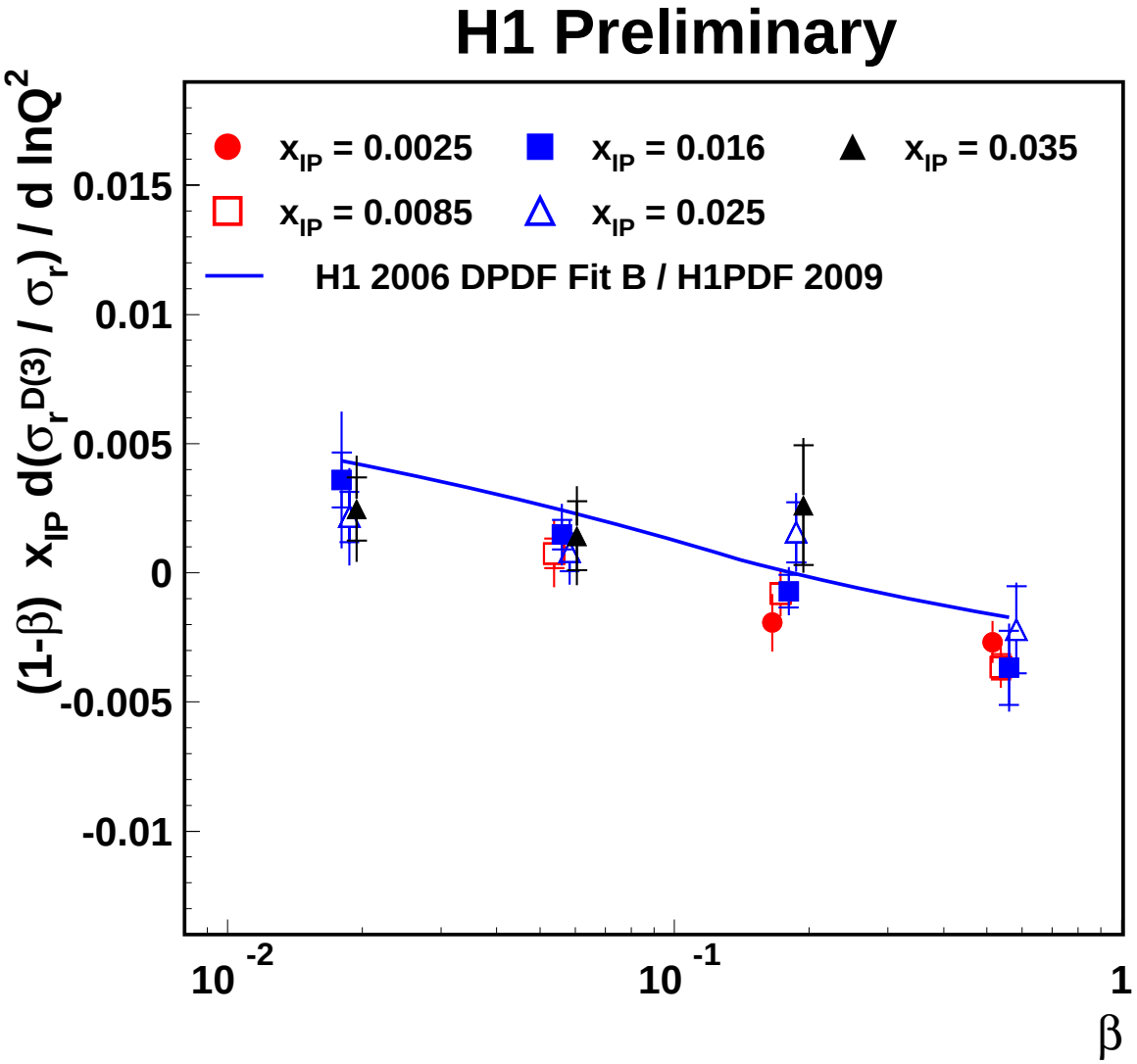
Q^2-dependence in (x_{IP},β) bins
M_x>2 GeV, |t|<1GeV^2

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

➔ extract lnQ^2 derivative sensitive to gluon PDF

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

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



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

➔ $(\text{gluon/quark})^{diff} \sim (\text{gluon/quark})^{incl}$ 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 → gluon PDF fraction in proton is similar in diffractive and inclusive DIS at low x