Inclusive Diffraction in DIS – H1 Results

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Diffraction 2006, Milos

Overview

- Diffractive DIS at H1
  - Kinematics and Observables
- Comparison of Experimental Techniques
  - Rapidity Gap and Leading Proton Techniques Agree
- Factorisation, NLO QCD Fits and Diffractive PDFs
  - M_Y, t and x_{IP} Dependences Factorise from Q^2 and β Dependences
  - QCD and the High z Gluon
- Ratio of Diffractive : Inclusive Cross Sections
  - Gluon : Quark Ratio is the Same
- Diffractive Charged Currents
  - Predicted from Fit to NC Data
- New Preliminary Data
  - H1 and the M_X Method

Diffractive DIS Kinematics

Fractional momentum of Parton wrt Pomeron

$$\beta = \frac{Q^2}{Q^2+M_X^2}$$

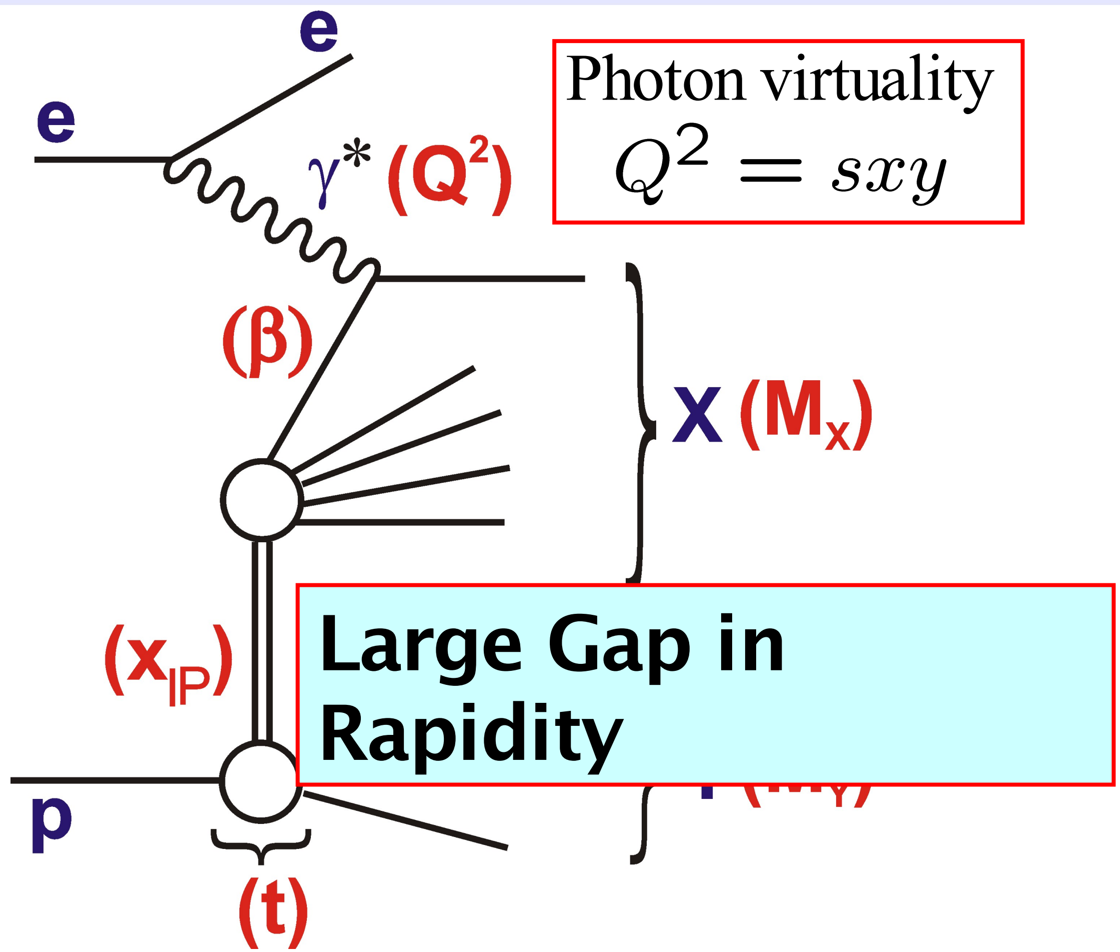
$$x = x_{I\!P}\beta$$

Fractional Momentum of Pomeron wrt Proton

$$x_{I\!P} = \frac{Q^2+M_X^2}{Q^2+W^2}$$

Photon virtuality

$$Q^2 = sxy$$

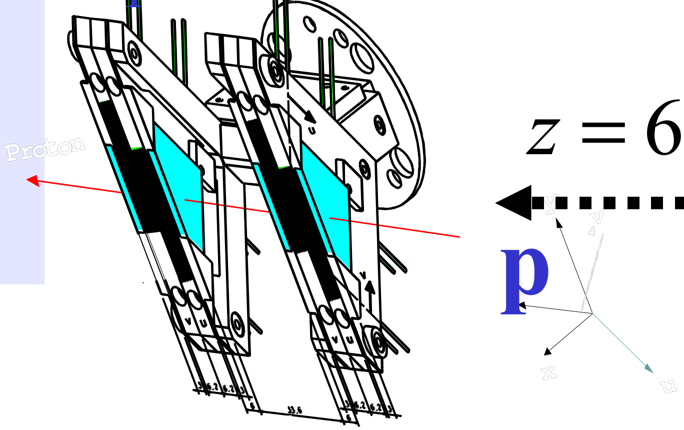


Momentum Transfer at Proton Vertex

$$t = (p-Y)^2$$

Experimentally selecting $ep \rightarrow eXp$

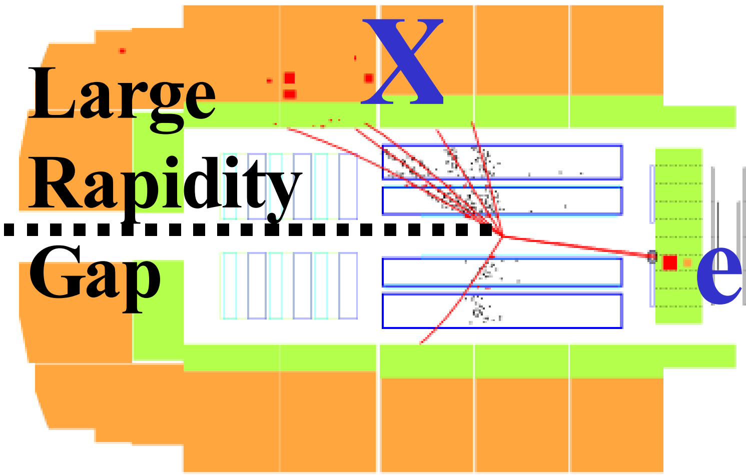
Forward Proton Spectrometer



$z = 64, z = 80m$

p

Large Rapidity Gap in H1



Measure Leading Proton (FPS)

No proton dissociation

Measure the t dependence

Low detector acceptance

Require Large Rapidity Gap (LRG) spanning at least $3.3 < \eta < \sim 7.5$

Kinematics measured from X system, integrate $|t| < 1.0$ GeV^2, $M_Y < 1.6$ GeV

High detector acceptance $\rightarrow$ precision

Data Sets and Observables

- FPS data sample – 1999–2000 data, 28 pb^{-1} hep-ex/0606003
- Measure *t* Dependence $\frac{d\sigma}{dt} \sim \exp B|t|$
- And Differential Cross Section

$$\frac{d^4\sigma^{ep\rightarrow eXp}}{dx dQ^2 dx_{I\!P} dt} = \frac{4\pi\alpha^2}{xQ^4} Y_+ \sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$$

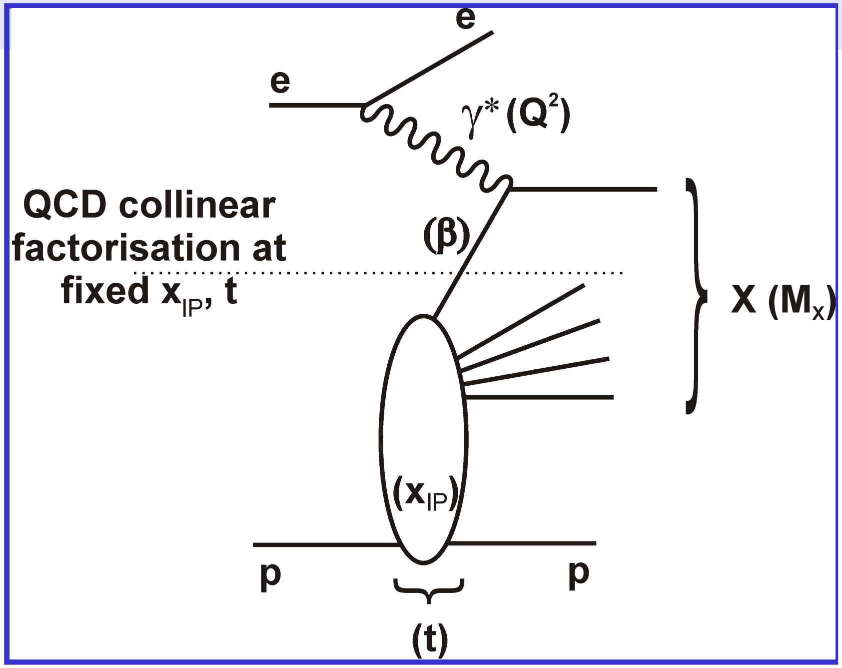
Where

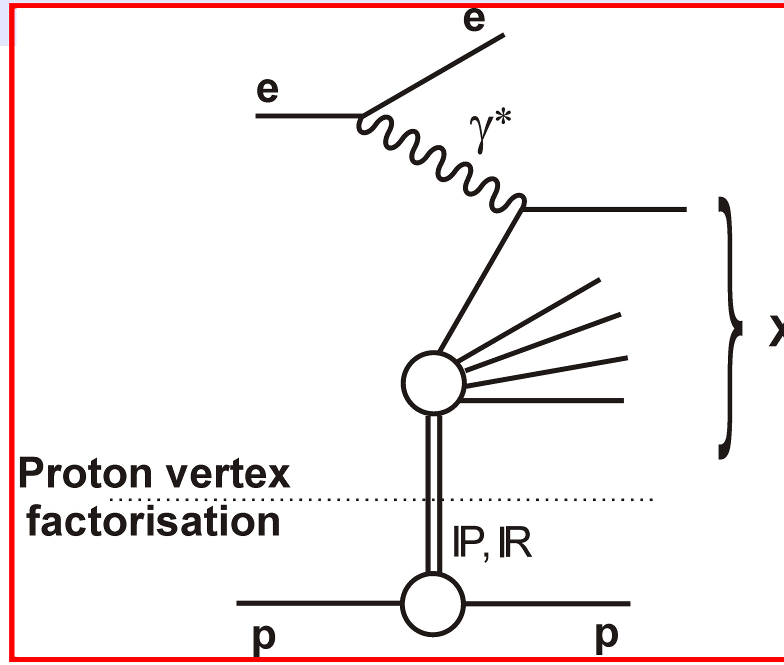
$$Y_+ = 1 + (1-y)^2 \quad \text{and} \quad \sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{Y+} F_L^{D(4)}$$

- LRG Data – 1997 – 2000 e+ data hep-ex/0606004
  - $3 < Q^2 < 13.5$ GeV^2 2.0 pb^{-1}
  - $13.5 < Q^2 < 105$ GeV^2 10.6 pb^{-1}
  - $Q^2 > 133$ GeV^2 61.6 pb^{-1}
- Measure Reduced Cross Section Integrated over *t*

$$\sigma_r^{D(3)} = \int_{-1}^{t_{min}} \sigma_r^{D(4)} dt$$

Two Levels of Factorisation





QCD hard scattering collinear factorisation (Collins) at fixed x_{IP} and t

$$d\sigma_{parton\,i}(ep \rightarrow eXY) = f_i^D(x, Q^2, x_{I\!P}, t)) \otimes d\sigma^{ei}(x, Q^2)$$

Applied after integration over M_Y and t ranges

\`Proton vertex' factorisation of β and Q^2 from x_{IP}, t, and M_Y dependences

$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i^{I\!P}(\beta = \frac{x}{x_{I\!P}}, Q^2)$$

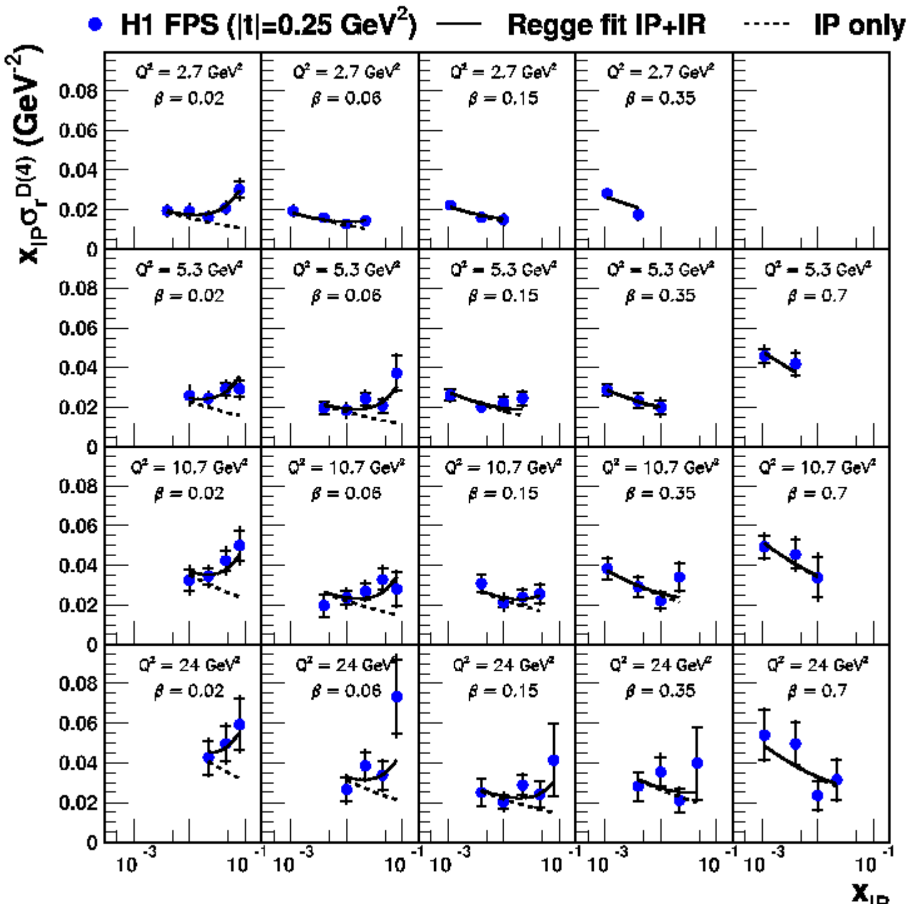
Data Overview

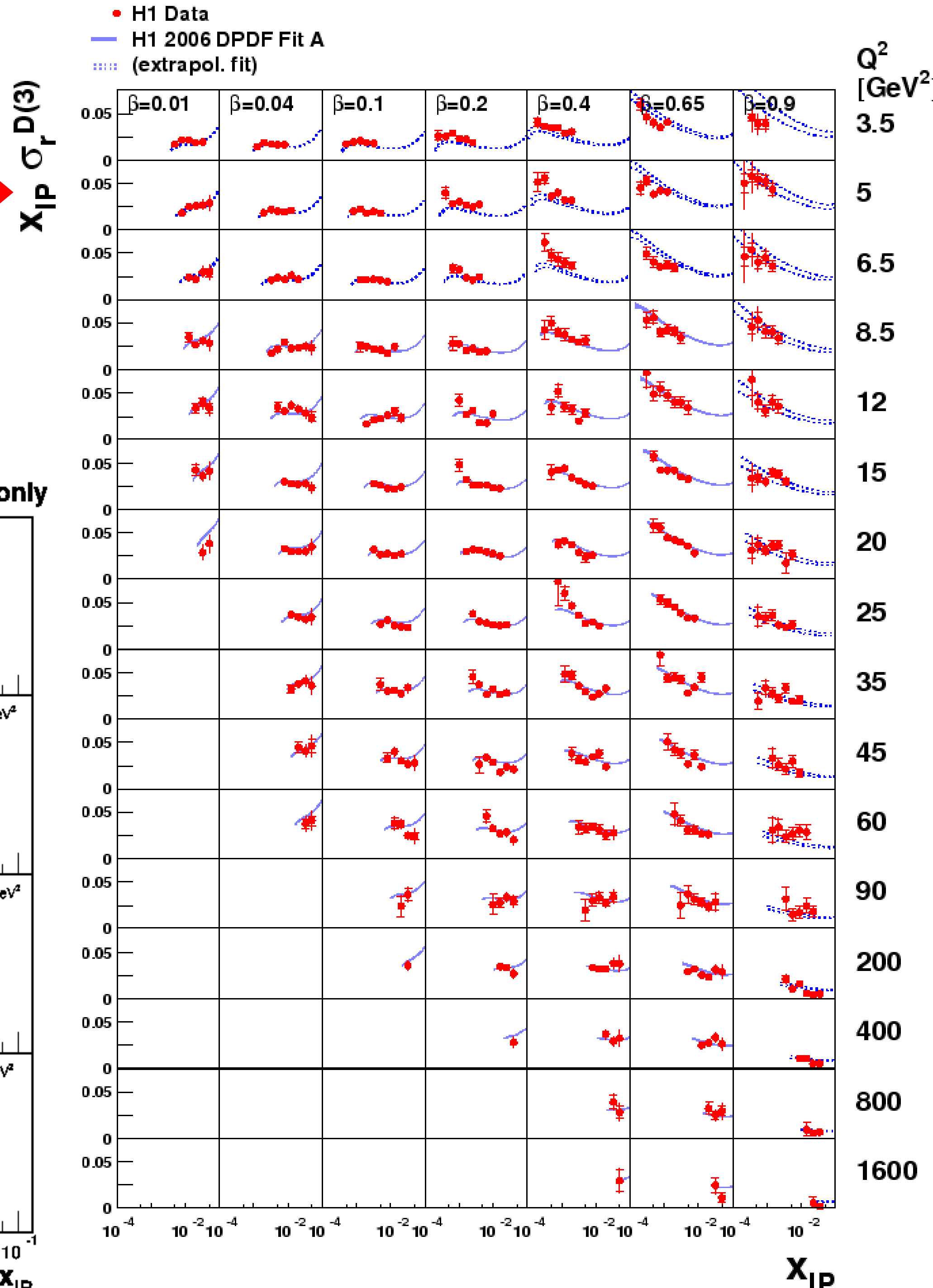
LRG: $M_Y < 1.6$ GeV

$3.5 \quad Q^2 \quad 1600$ GeV^2

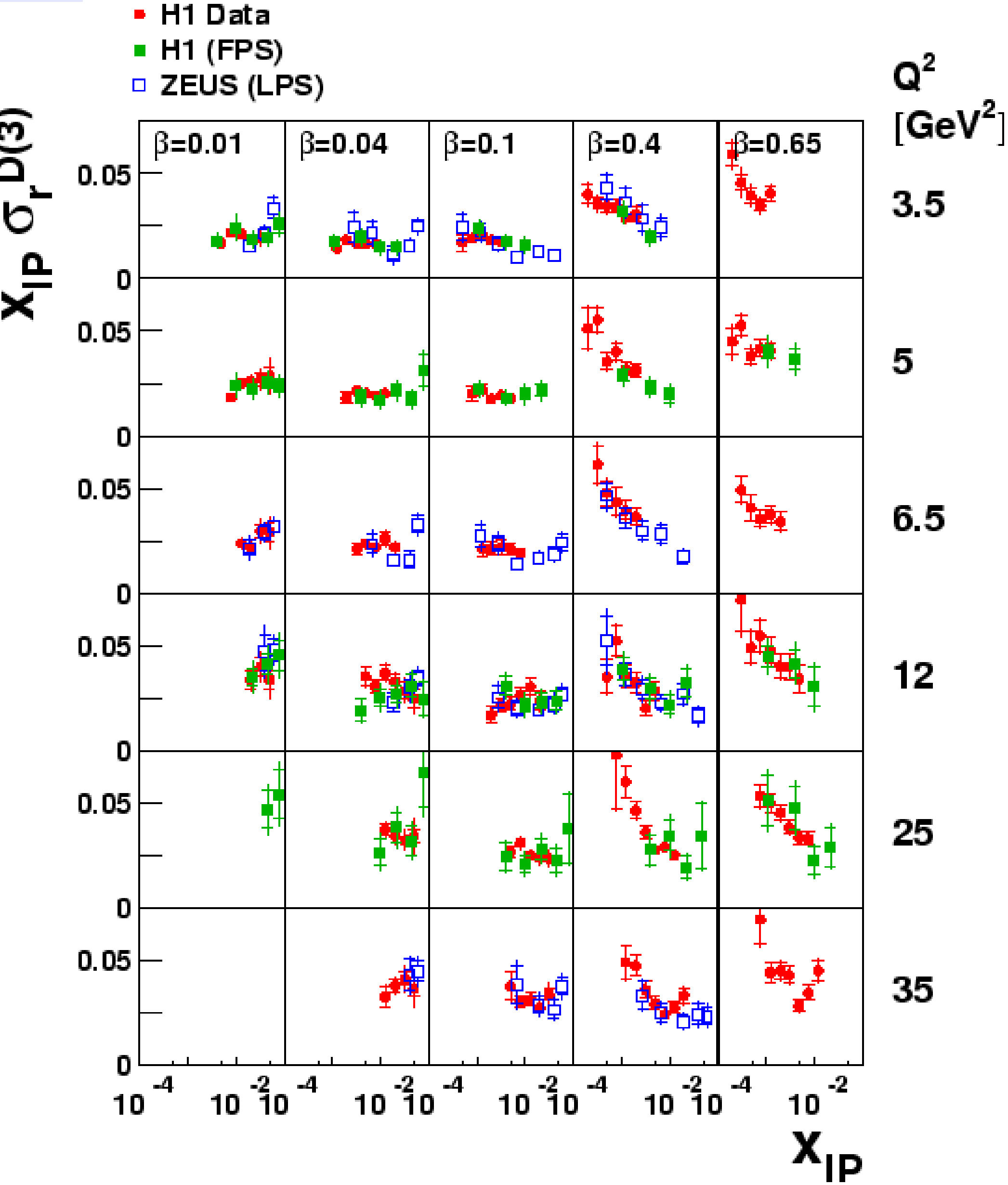
FPS: $Y=p$

$2.7 \quad Q^2 \quad 24$ GeV^2





Comparison of H1 LRG, H1 FPS, ZEUS LPS Data



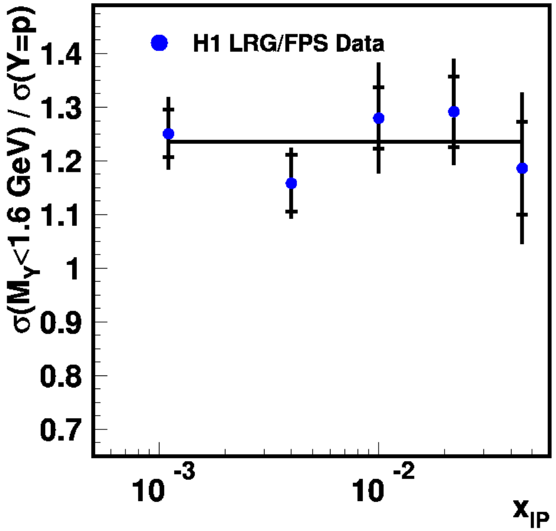
- **ZEUS (LPS)** and **H1 (FPS)** Leading Proton Data agree very well (they agree to 8% cf. 10% normalisation uncertainities)

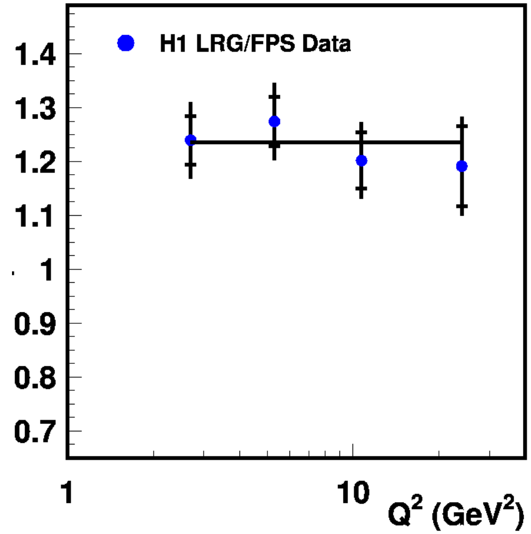
- **ZEUS LPS** and **H1 FPS** scaled by global factor of 1.23 to compare with LRG $M_Y < 1.6$ GeV

- Very good agreement between Leading Proton and LRG methods after accounting for proton diss'n

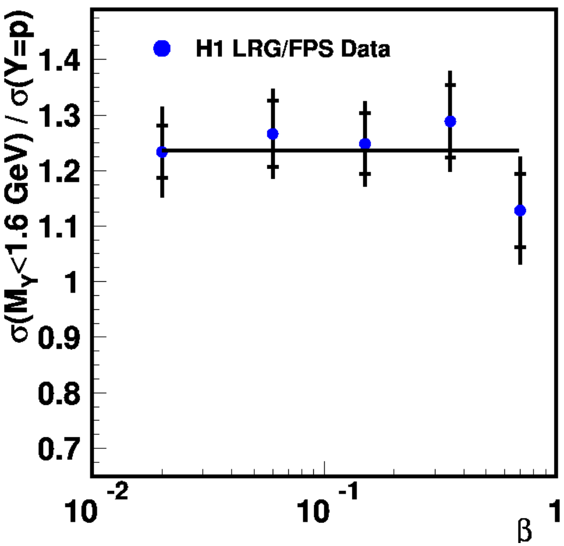
- Both experimental techniques measure the same cross section

Detailed Comparison LRG v FPS





- LRG measurement also done with FPS bins
- Form ratio of measurements as a function of x_{IP}, β and Q^2

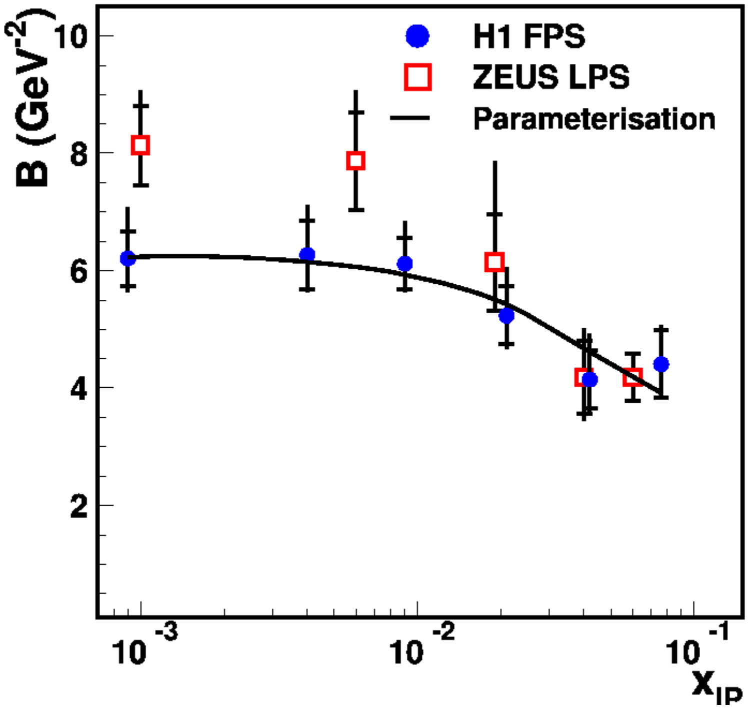


$$\frac{\sigma(M_Y < 1.6\ \text{GeV})}{\sigma(Y = p)} = 1.23 \quad 0.03\ (\text{stat.}) \quad 0.16\ (\text{syst.})$$

M_Y dependence factorises from x_{IP}, β and Q^2 within 10% (non-normalisation) errors

t dependence from FPS measurements

B(x_{IP}) from fit to $\frac{d\sigma}{dt} \sim \exp B|t|$



- Fitting low x_{IP} data to

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

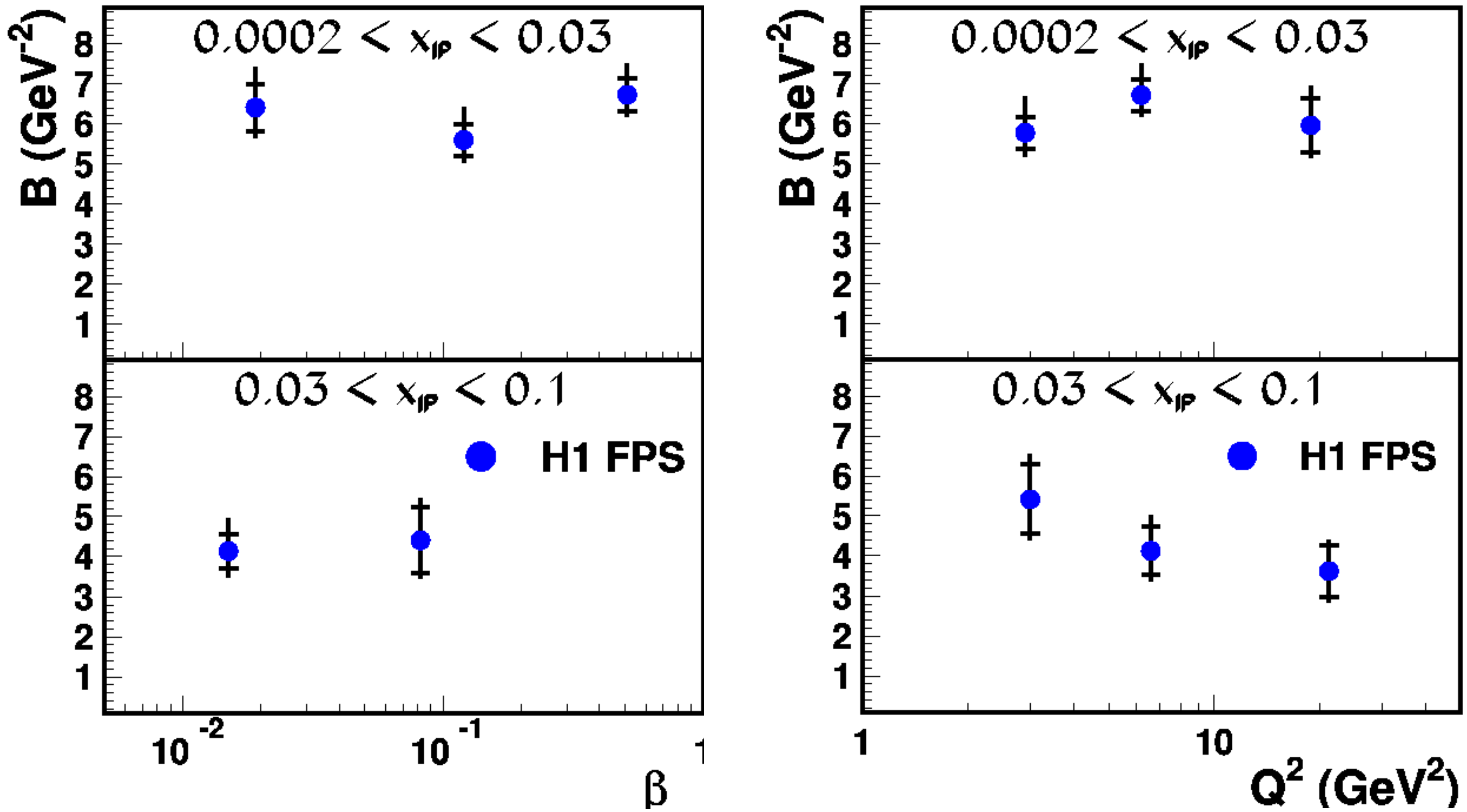
yields:

$$\alpha'_{IP} = 0.06^{+0.19}_{-0.06}\ \mathrm{GeV}^{-2} \quad B_{IP} = 5.5^{-2,0}_{+0.7}\ \mathrm{GeV}^{-2}$$

- *B(x_{IP})* data constrain *IP, IR* flux factors in proton vertex factorisation model

t Slope Dependence on β or Q^2?

B measured double differentially in (β or Q^2) at fixed x_{IP}

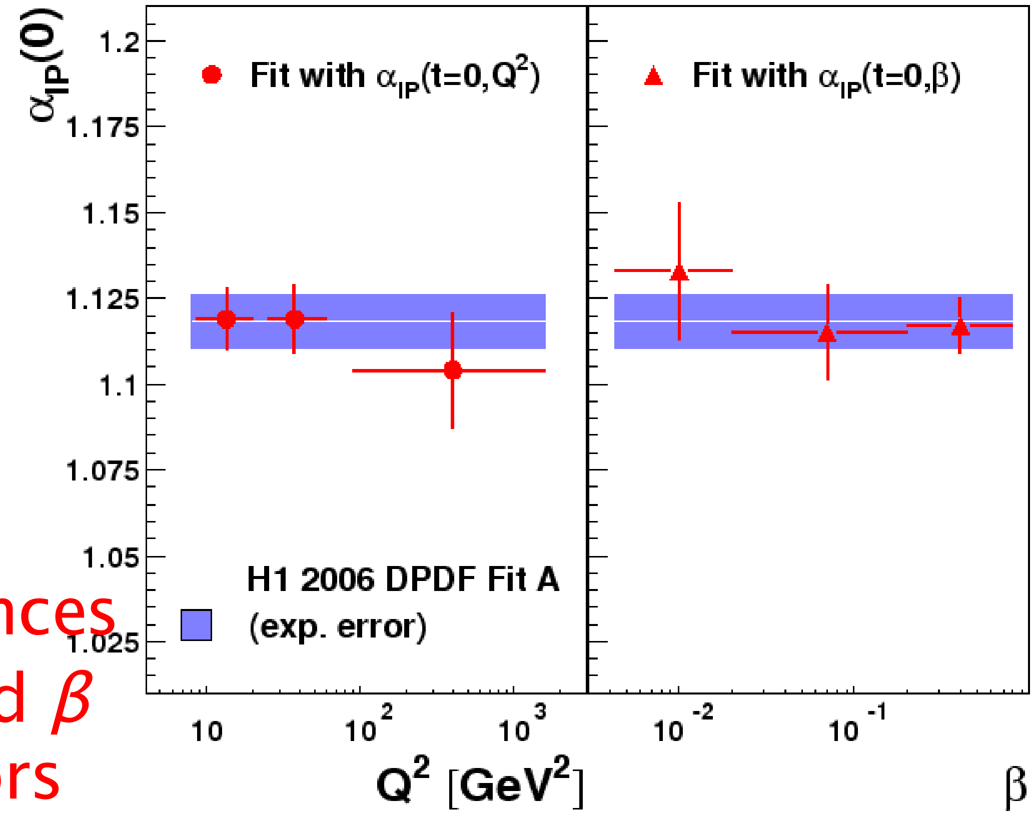


- t dependence does not change with β or Q^2 at fixed x_{IP}

Effective Pomeron Intercept Independent of β and Q^2

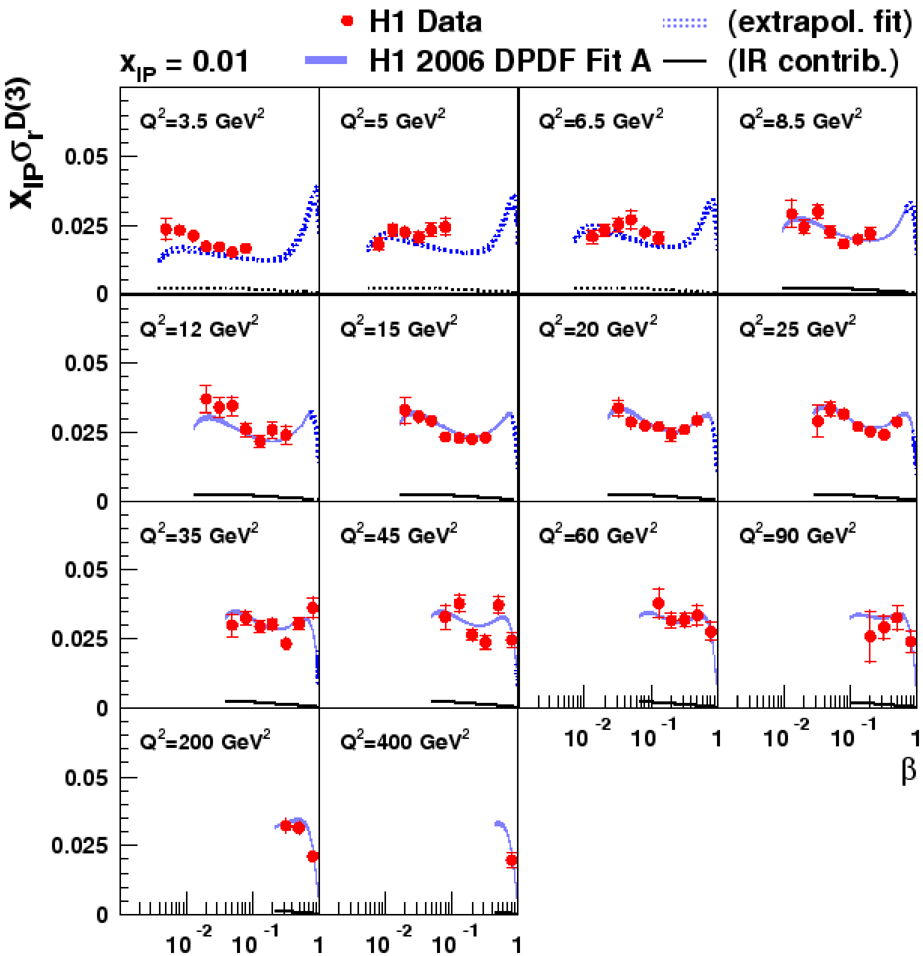
From fit to LRG data: $\alpha_{IP}(0) = 1.118 \quad 0.008\,(\text{exp.})\,^{+0.029}_{-0.010}\,(\text{theory})$

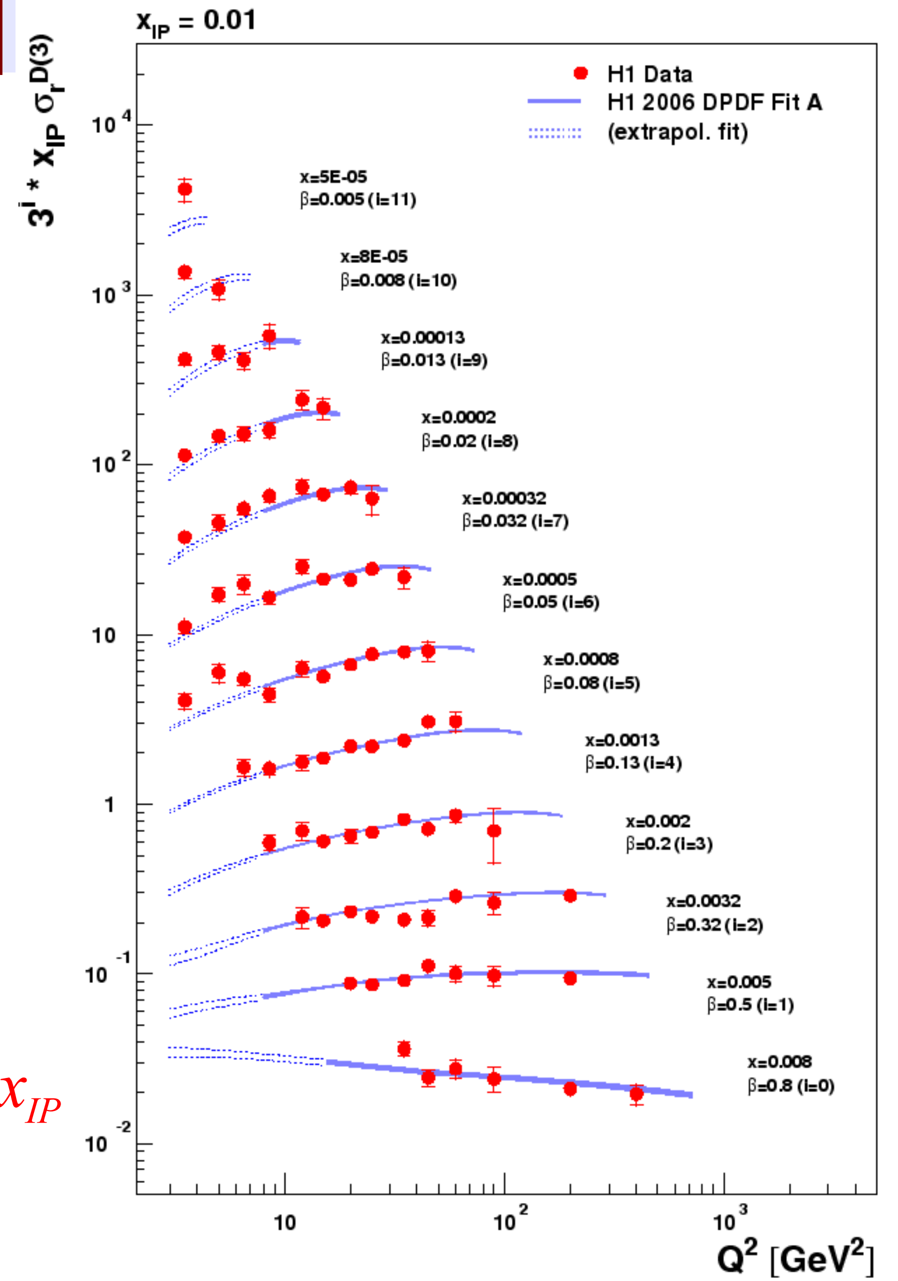
- No dependence of $\alpha_{IP}(0)$ on Q^2 or β
- The x_{IP} dependence also factorises from Q^2 and β
- x_{IP}, t and M_Y dependences factorise from the Q^2 and β dependences within errors



→ Data support Proton Vertex Factorisation

$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.01$

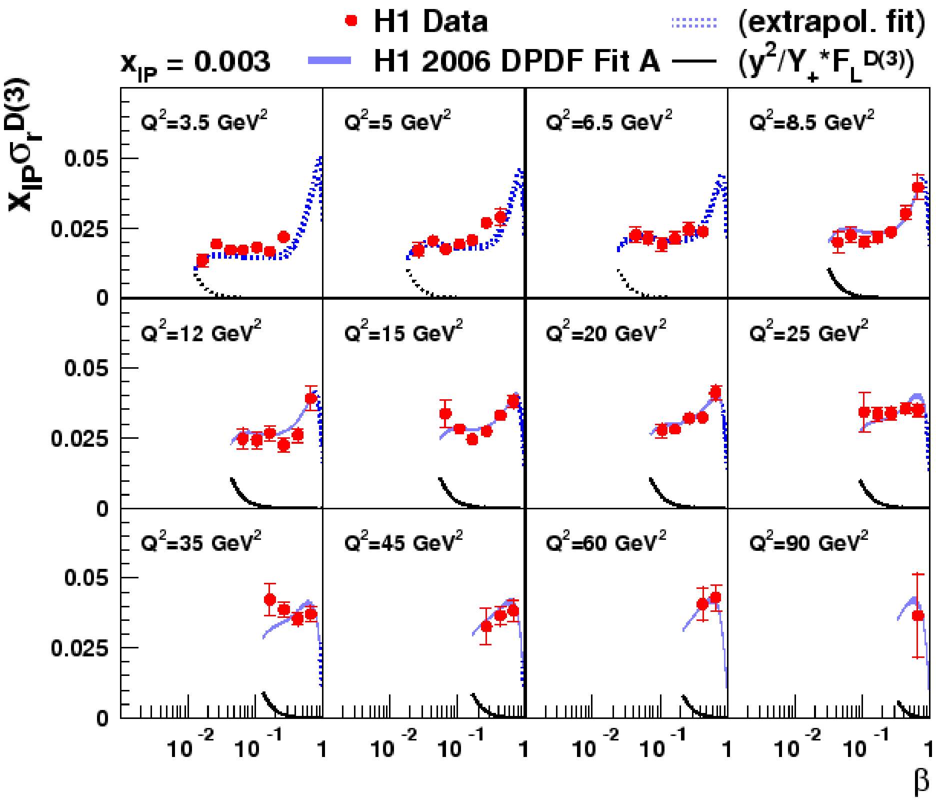


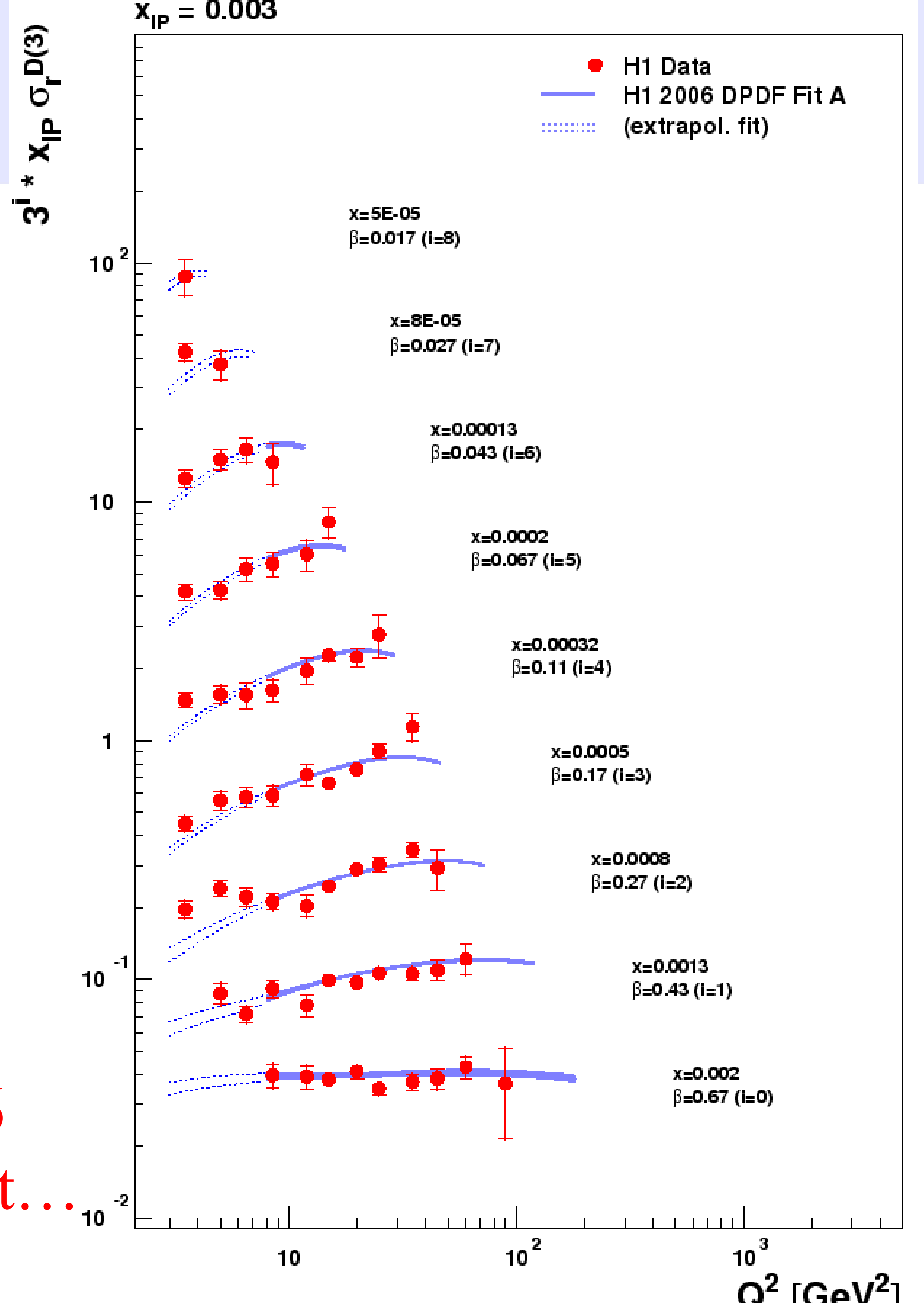


Study β and Q^2 dependences at fixed x_{IP}

Analogous to making an inclusive F_2 measurement at each value of x_{IP}

$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP} = 0.003$





Directly measure the quark content

Large scaling violations out to $\beta \sim 0.6$ are suggestive of a large gluon content…

Q^2 Dependence in More Detail

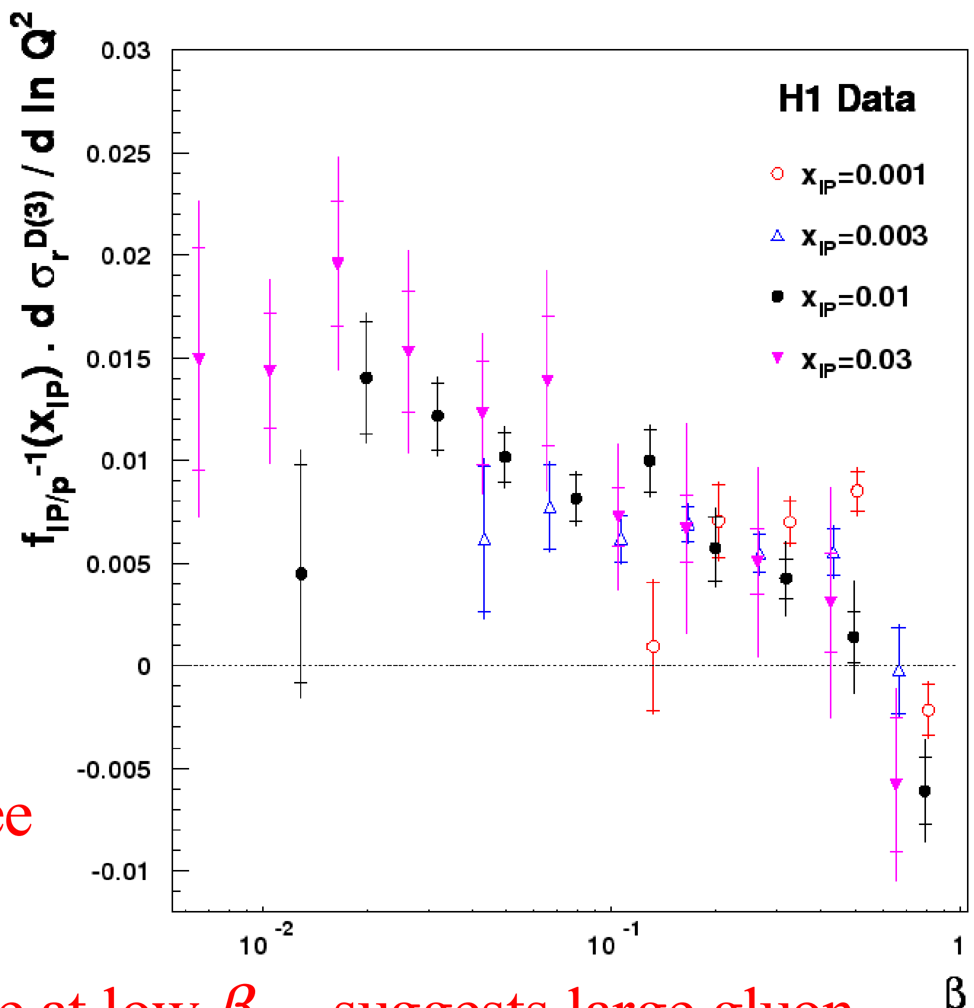
Fit data at fixed x, x_{IP} to

$$\sigma_r^D = A + B \ln Q^2$$

such that $$B = \frac{d\sigma_r^D}{d \ln Q^2}$$

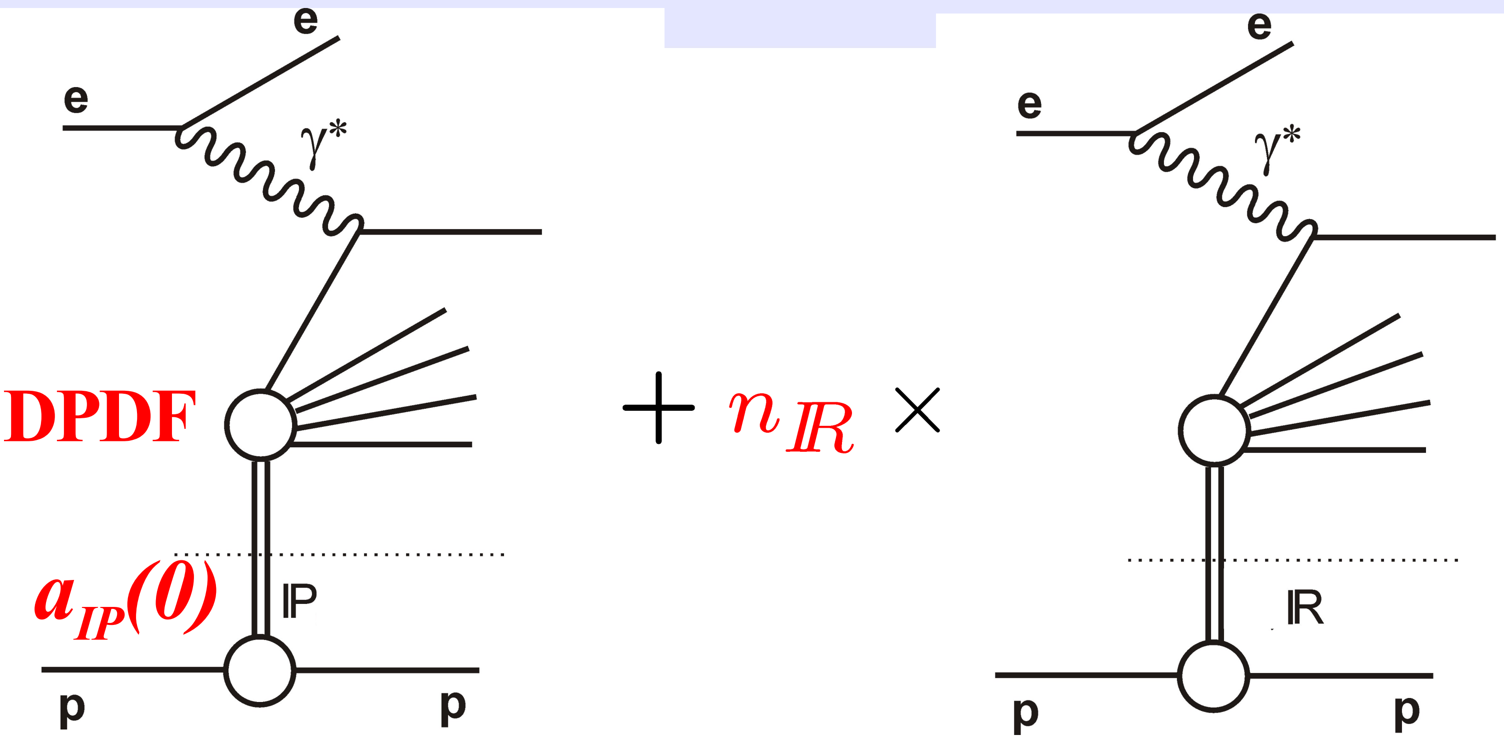
Divide results by $f_{IP/p}(x_{IP})$ to compare different x_{IP} values

Different x_{IP} measurements agree



Derivatives large and positive at low β ... suggests large gluon

H1 2006 DPDF Fit, Overview



- *IP* component: Fit $\alpha_{IP}(0)$ (x_{IP} dependence). Simultaneously, fit 5 parameters of DPDFs (β and Q^2 dependences) using NLO QCD.

- *IR* component: fit one free parameter for normalisation, n_{IR}

All flux params taken from previous H1 data. PDFs taken from Owens-π.

Kinematic Range and DPDF Parameterisation

• Fit is stable with variations of, e.g. β_{max} – the maximum value of β allowed in the fit

• Systematic variation of gluon density with minimum Q^2 of data included in fit for Q^2_{min} < 8.5 GeV^2. Stable for larger Q^2_{min}

• Fit all data with Q^2 8.5 GeV^2 (and $M_X > 2$ GeV, β 0.8)

• Parameterise quark singlet $z\Sigma(z,Q_0^2)$ and gluon $zg(z,Q_0^2)$ densities, where z is parton momentum fraction (= β for QPM).

Parameterisation used is $z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q}$ and $zg(z,Q_0^2) = A_g(1-z)^{C_g}$
(gluon insensitive to B_g)

• Results reproducible with Chebyshev polynomials.

H1 2006 DPDF Fit Results (log z scale)

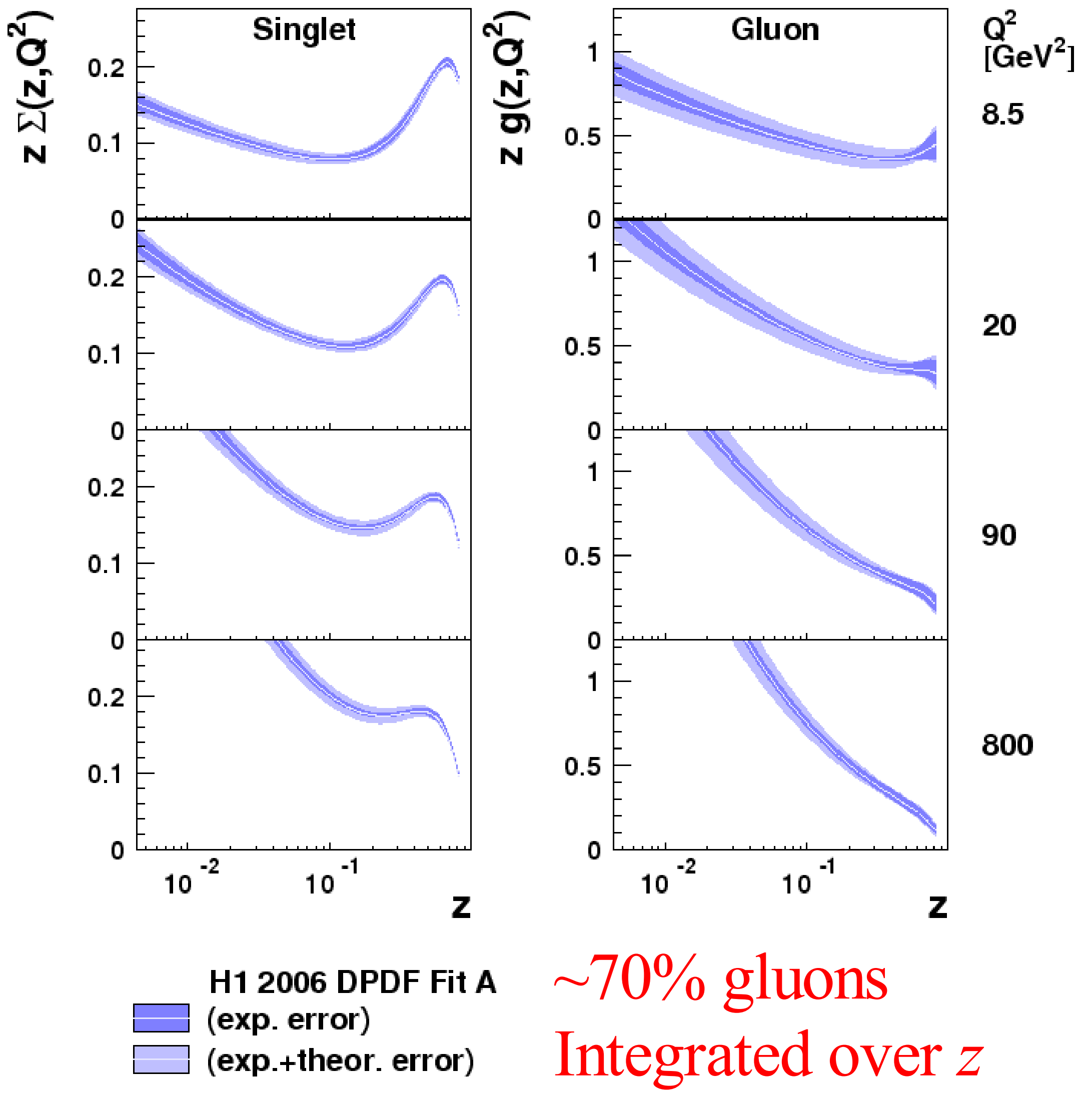
$Q_0^2 = 1.75\ \text{GeV}^2$

$\chi^2 \sim 158\ /\ 183$ d.o.f.

- Experimental uncertainty obtained by propagating errors on data through χ^2 minimisation procedure

- Theoretical uncertainty estimated by varying fixed parameters of fit and Q_0^2

- Singlet constrained to ~5%, gluon to ~15% at low z, growing considerably at high z

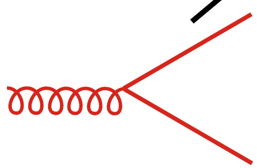


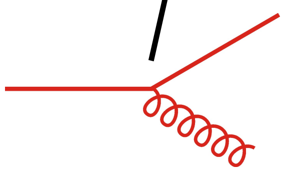
~70% gluons
Integrated over z

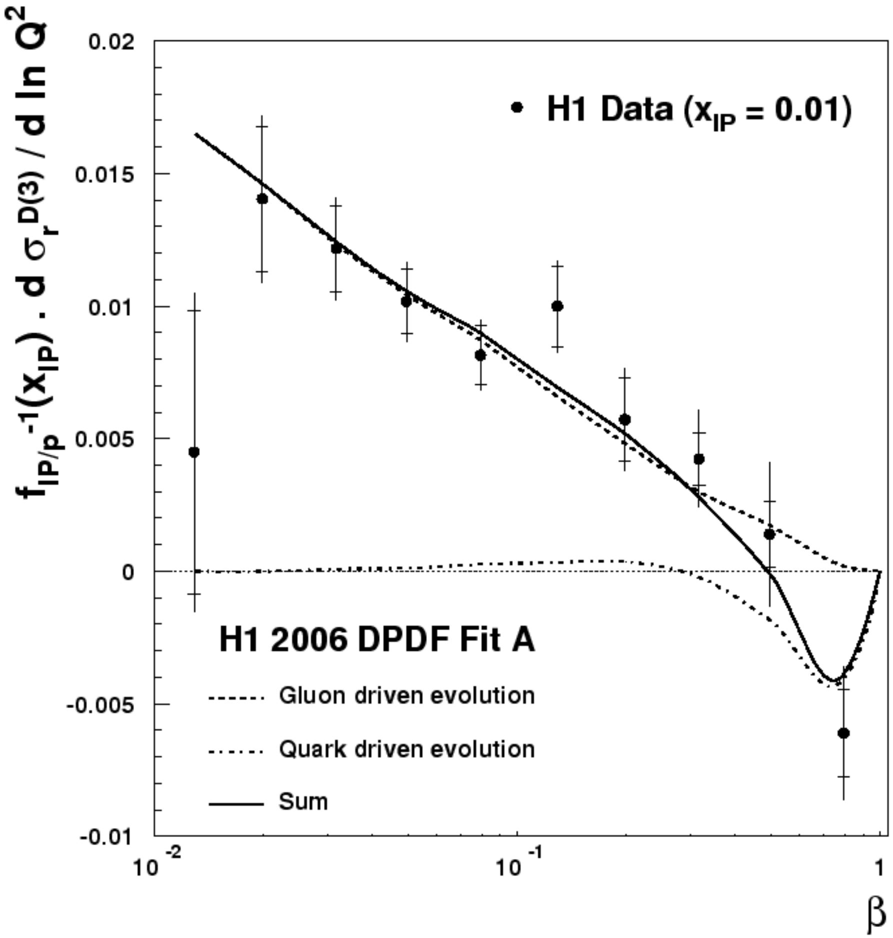
A Closer Look at the High z Region

We have only singlet quarks, so DGLAP evolution equation for F_2^D ….

$$\frac{dF_2^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi} \; P_{qg} \quad g \; + \; P_{qq} \quad \Sigma$$







At high β, relative error on derivative grows, $q \quad qg$ contribution to evolution becomes important … sensitivity to gluon is lost

DPDFs (linear *z* scale)

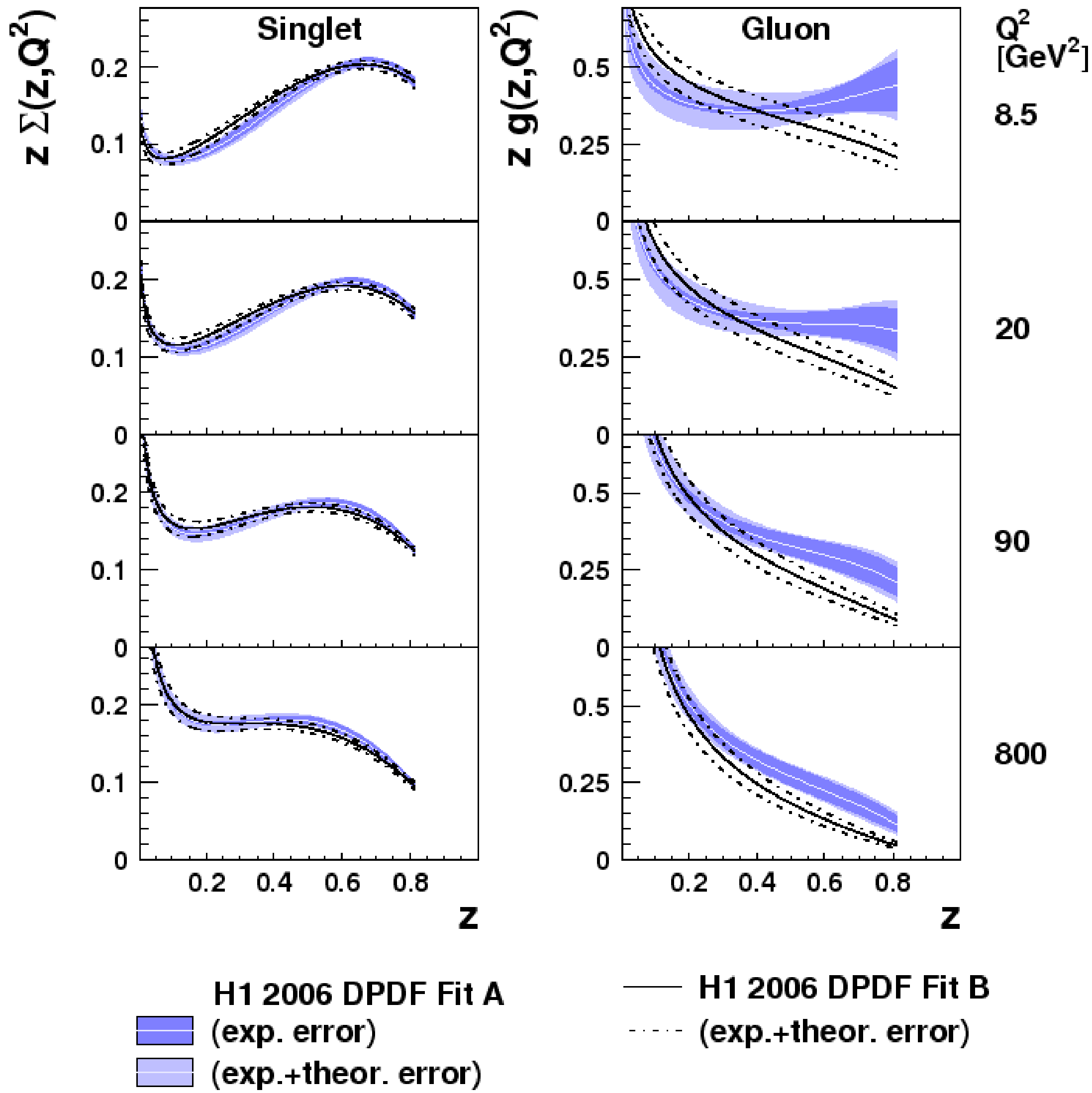
- Lack of sensitivity to high *z* gluon confirmed by dropping (high *z*) C_g parameter, so gluon is a simple constant at the star scale!

•Fit B

$\chi^2 \sim 164 / 184$ d.o.f.

$Q_0^2 = 2.5$ GeV^2

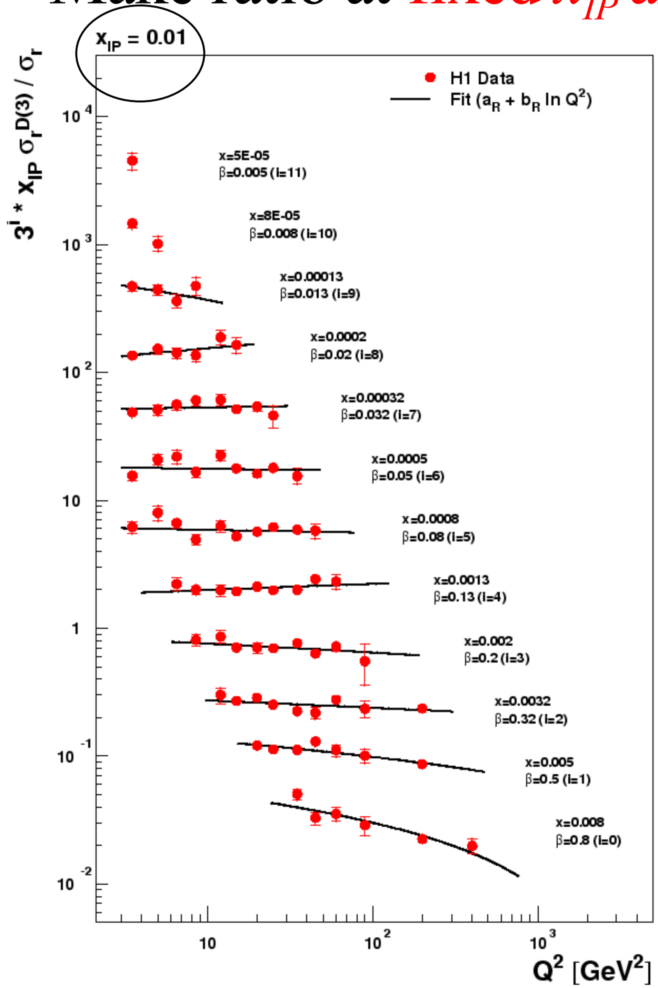
- Quarks very stable
- Gluon similar at low *z*
- Substantial change to gl at high *z*

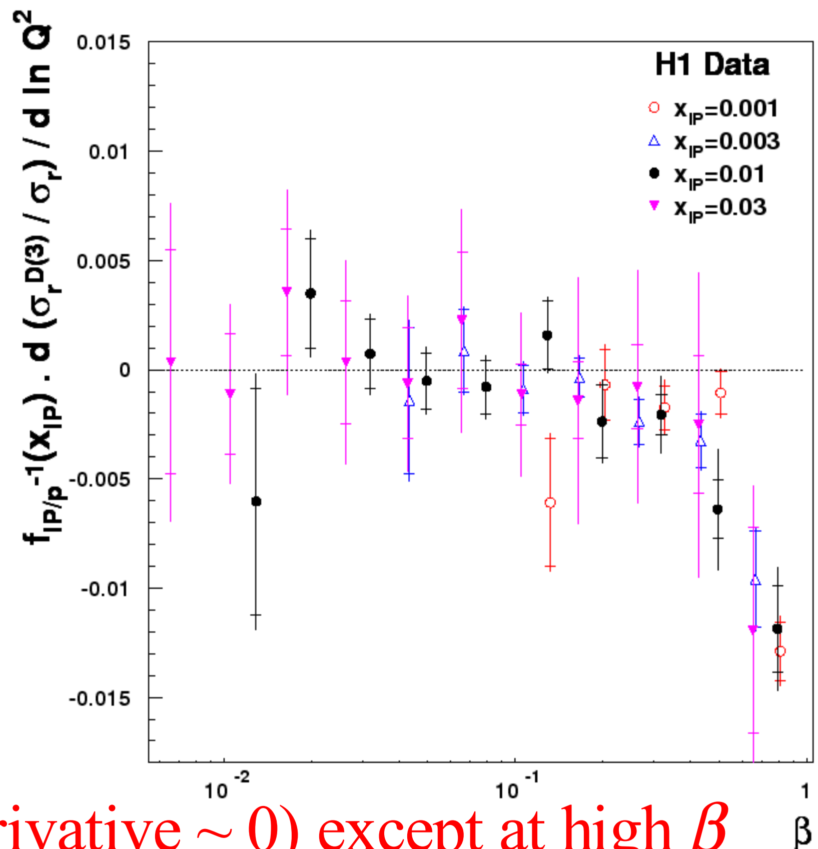


Q^2 dependence of diffractive/inclusive ratio

Make ratio at fixed x_{IP} and x and fit to $\sigma_r^D/\sigma_r = A + B\ln Q^2$

such that $B = \dfrac{d\left(\sigma_r^D/\sigma_r\right)}{d\ln Q^2}$

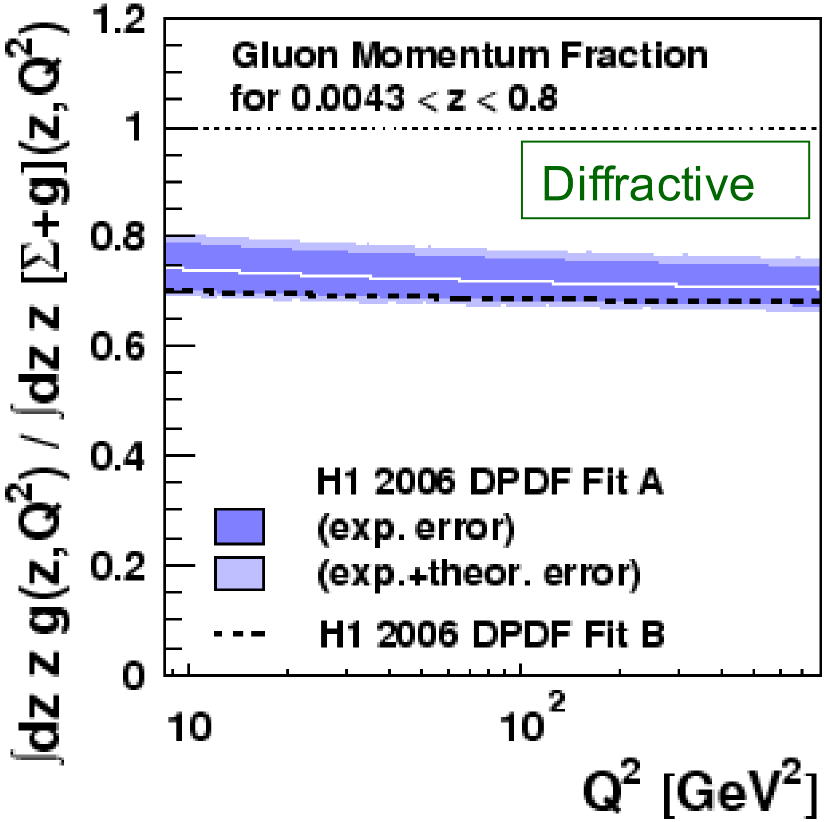


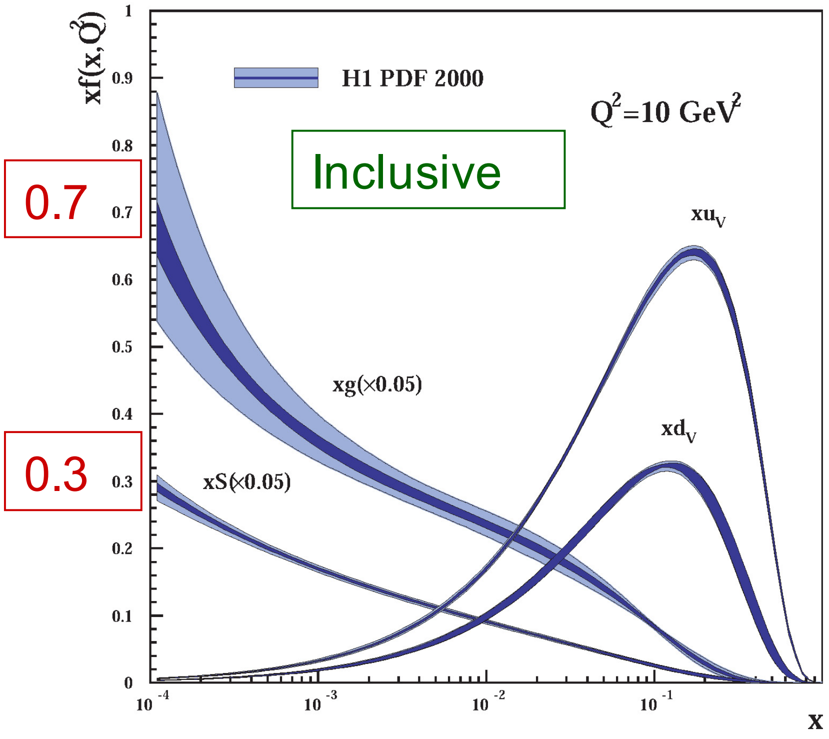


Ratio remarkably flat (derivative ~ 0) except at high β

Q^2 derivative and gluon/quark ratios

If $\frac{d(\sigma_r^D/\sigma_r)}{d\ln Q^2} \sim 0$ then $\frac{1}{\sigma_r^D}\frac{d\sigma_r^D}{d\ln Q^2} \approx \frac{1}{\sigma_r}\frac{d\sigma_r}{d\ln Q^2} \rightarrow \frac{g^D}{q^D} \sim \frac{g}{q}$





low x, gluon:quark ratio ~ 70%/30%, common to diffractive and inclusi

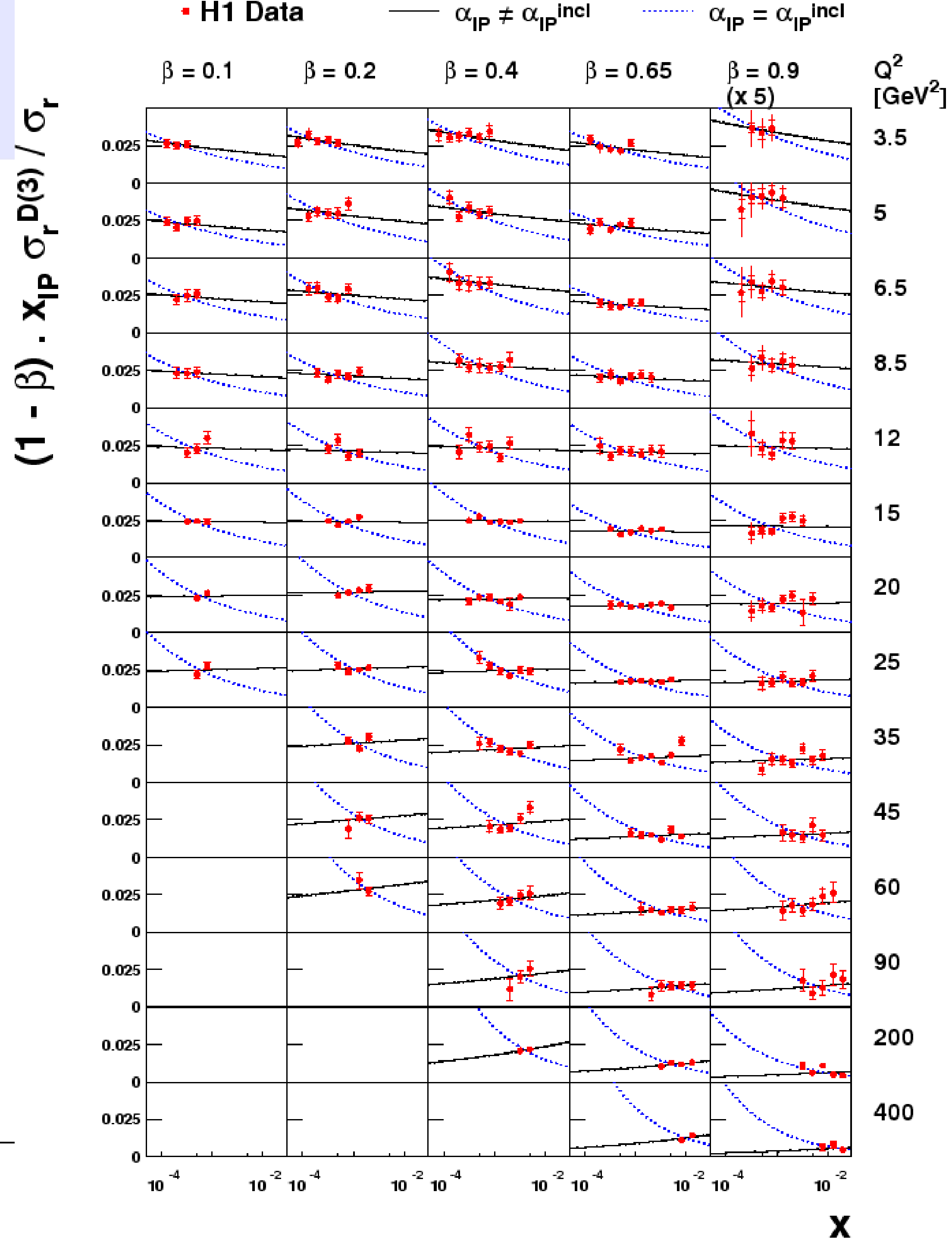
Ratio diffractive/inclusive: x dependence

- Plot σ_r^D/σ_r vs x ($\sim 1/W^2$)

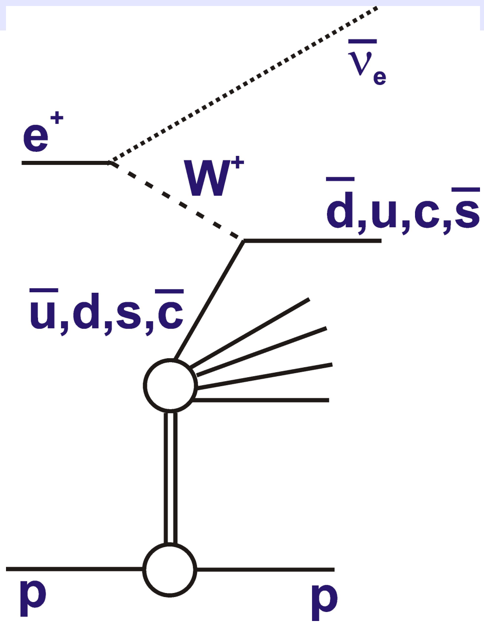
at fixed β, Q^2 (hence fixed M_X)

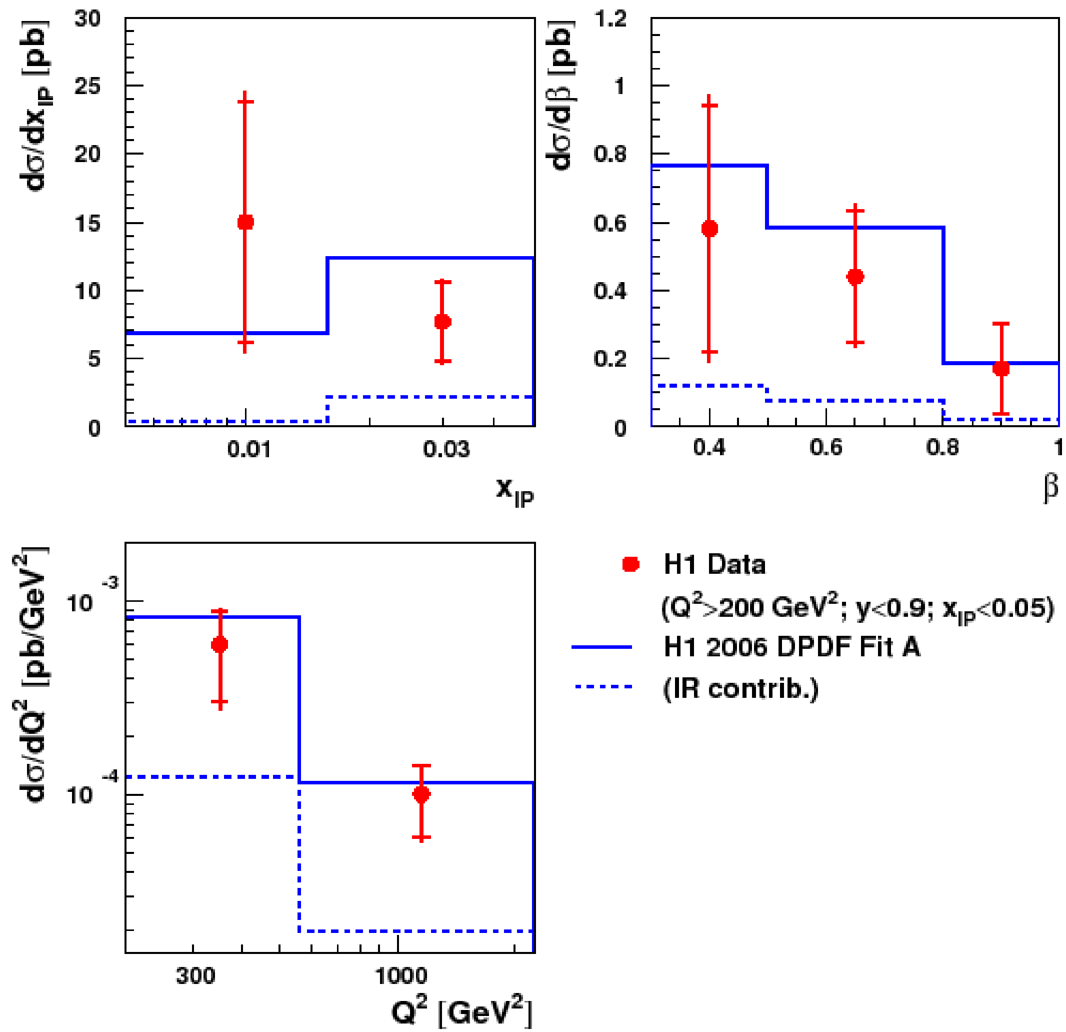
- Remarkably flat vs x over most of kinematic range (bins with large F_L or IR contribution not shown)

- Diffractive and inclusive cross sections cannot be described with the same $\alpha_{IP}(0)$, even if it is Q^2 dependent



Diffractive Charged Current





- Sensitive to flavour decomposition of singlet (which is completely unconstrained by NC data)

- Good agreement with H1 2006 DPDF fit (which assumes

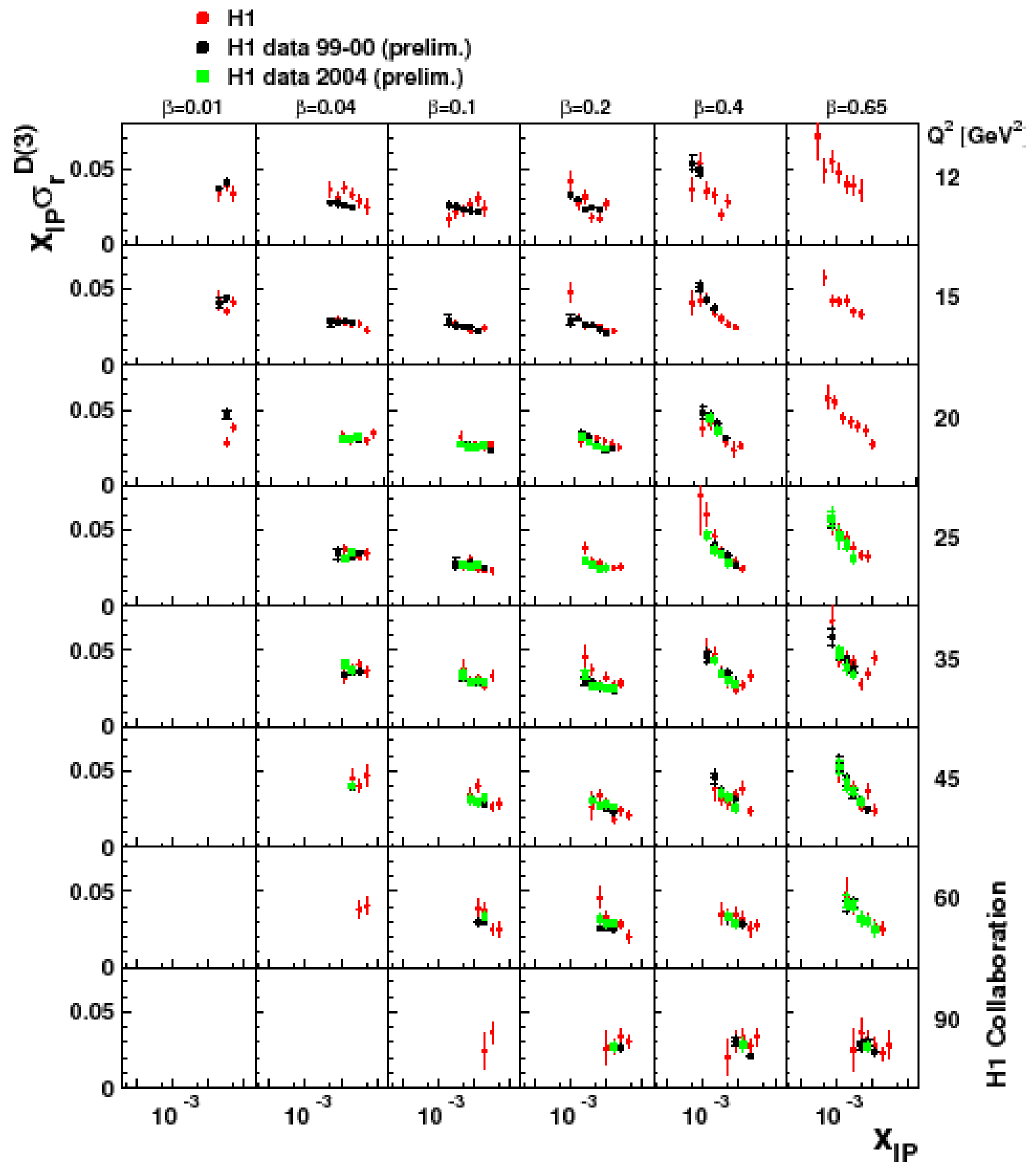
$$u = d = s = \bar{u} = \bar{d} = \bar{s}$$

though statistics very limited so far

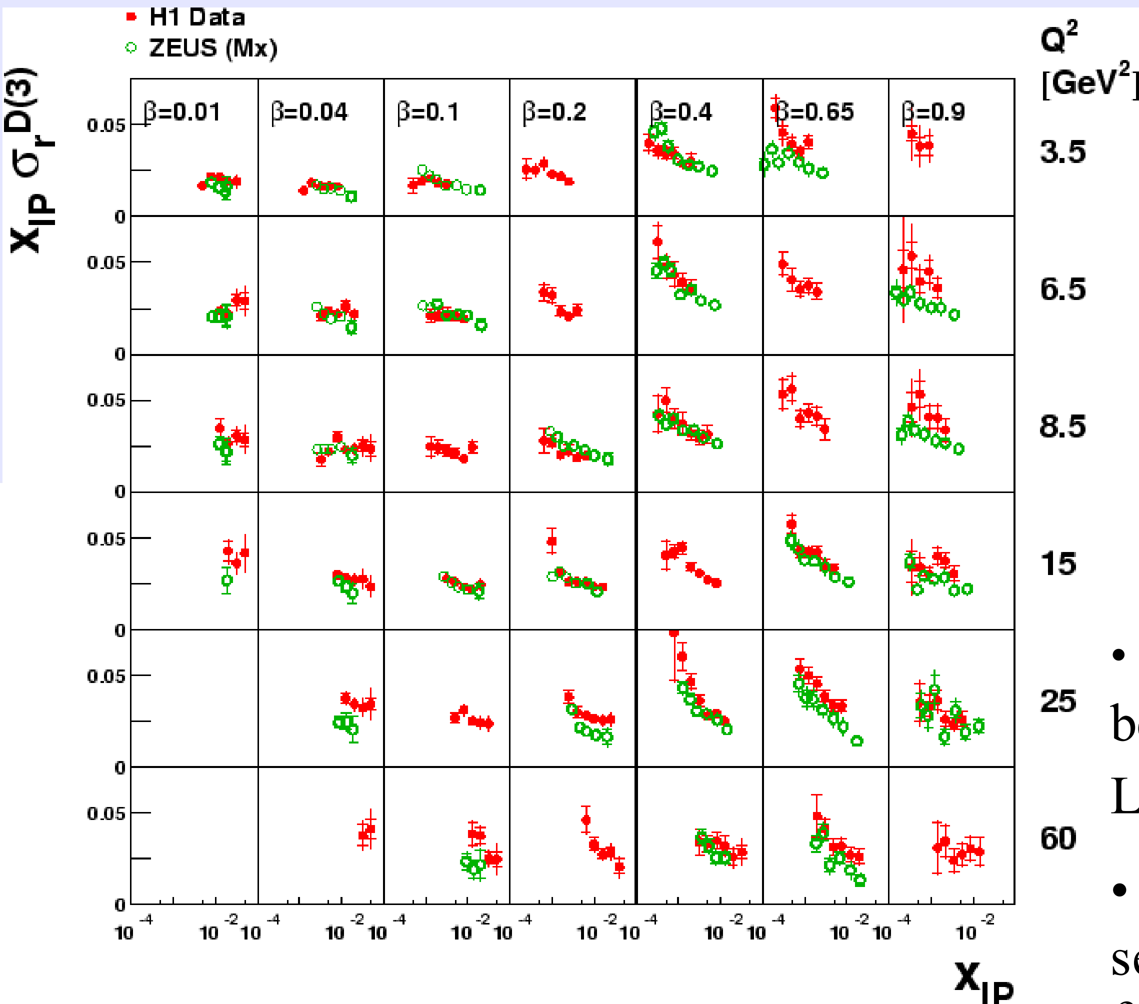
New Data using Rapidity Gap Method

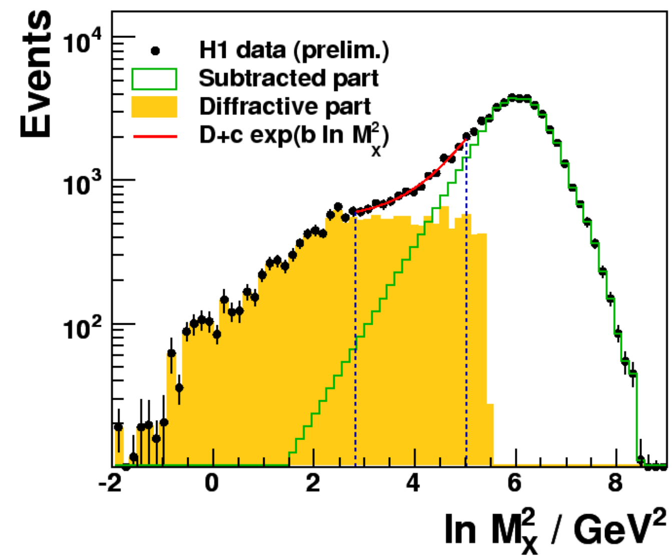
- Published data
- Prel. 99-00 data, 34 pb^{-1}
  $10 < Q^2 < 105$ GeV^2
- Prel. 2004 data, 34 pb^{-1}
  $17.5 < Q^2 < 105$ GeV^2

- Large increase in statistics at medium Q^2
- Consistent with published data



H1 LRG and ZEUS Mx

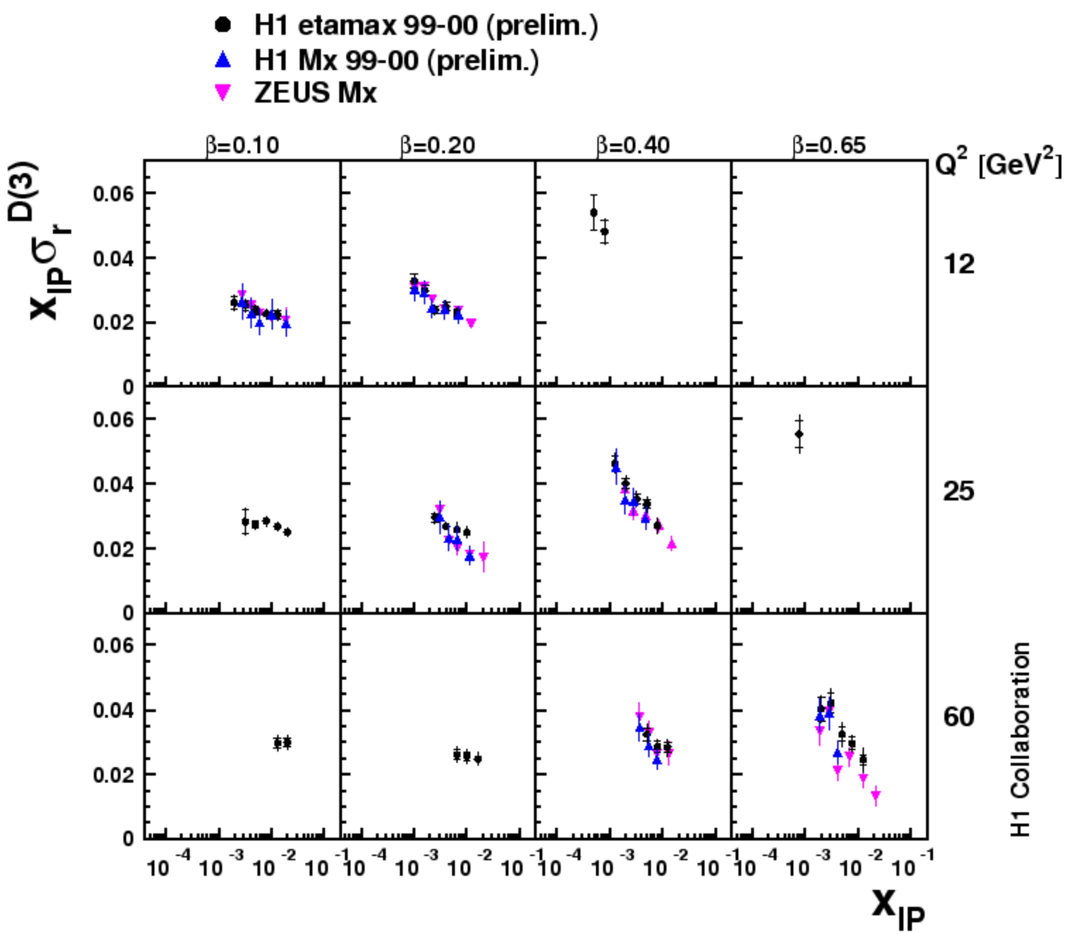




- Long-standing discrepancy between M_X and both LRG and Leading Proton methods
- Differences apparent at the cross-section level (see also comparisons for Hera-LHC workshop by Newman and Schilling)

The M_X method does not agree with the other two experimental methods

Comparisons of H1 LRG, H1 M_X and ZEUS M_X



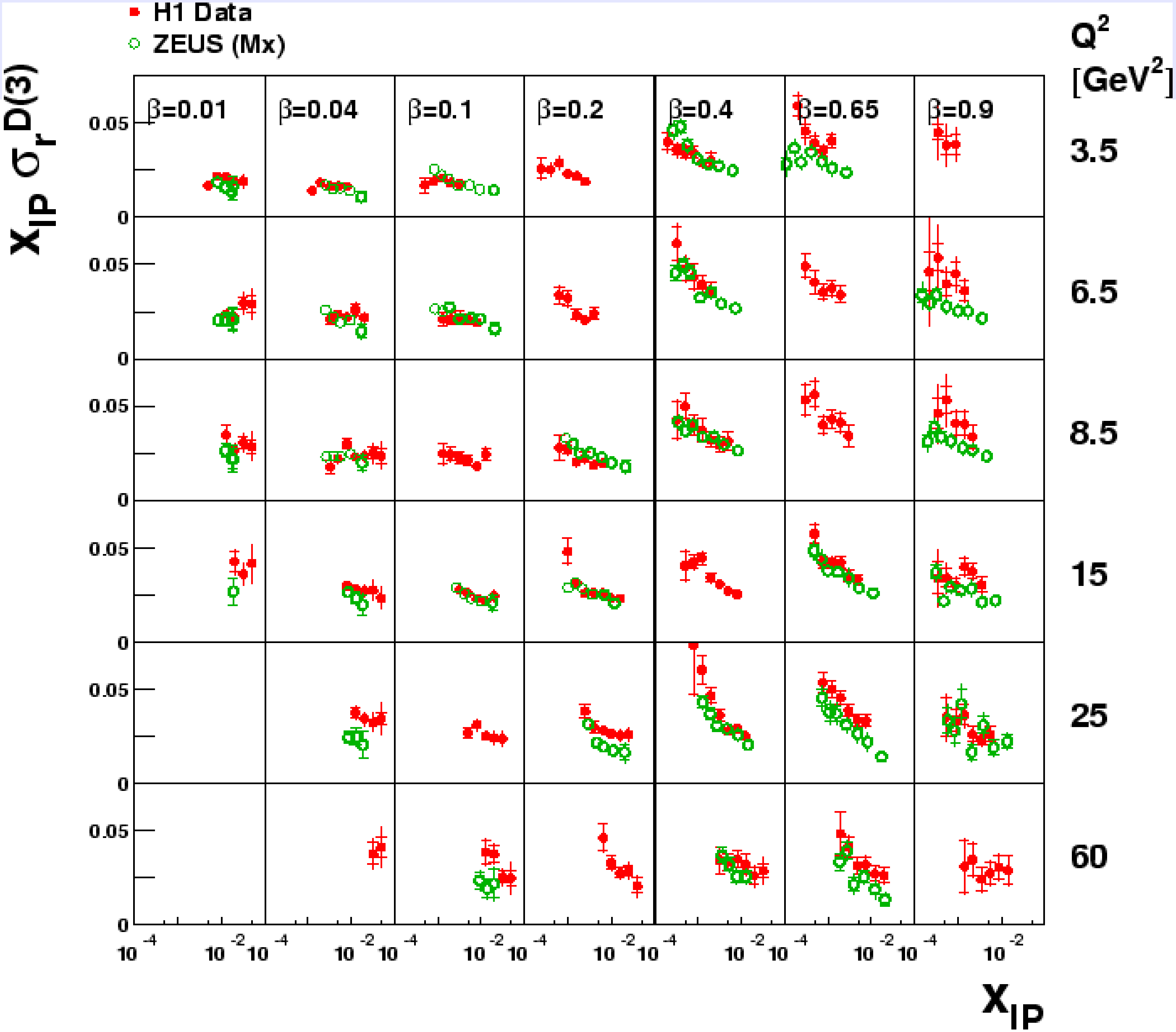
- H1 M_X measurement limited in acceptance to low M_X (no forward plug calorimeter)
- In this region of small subtraction the two experimental methods agree rather well

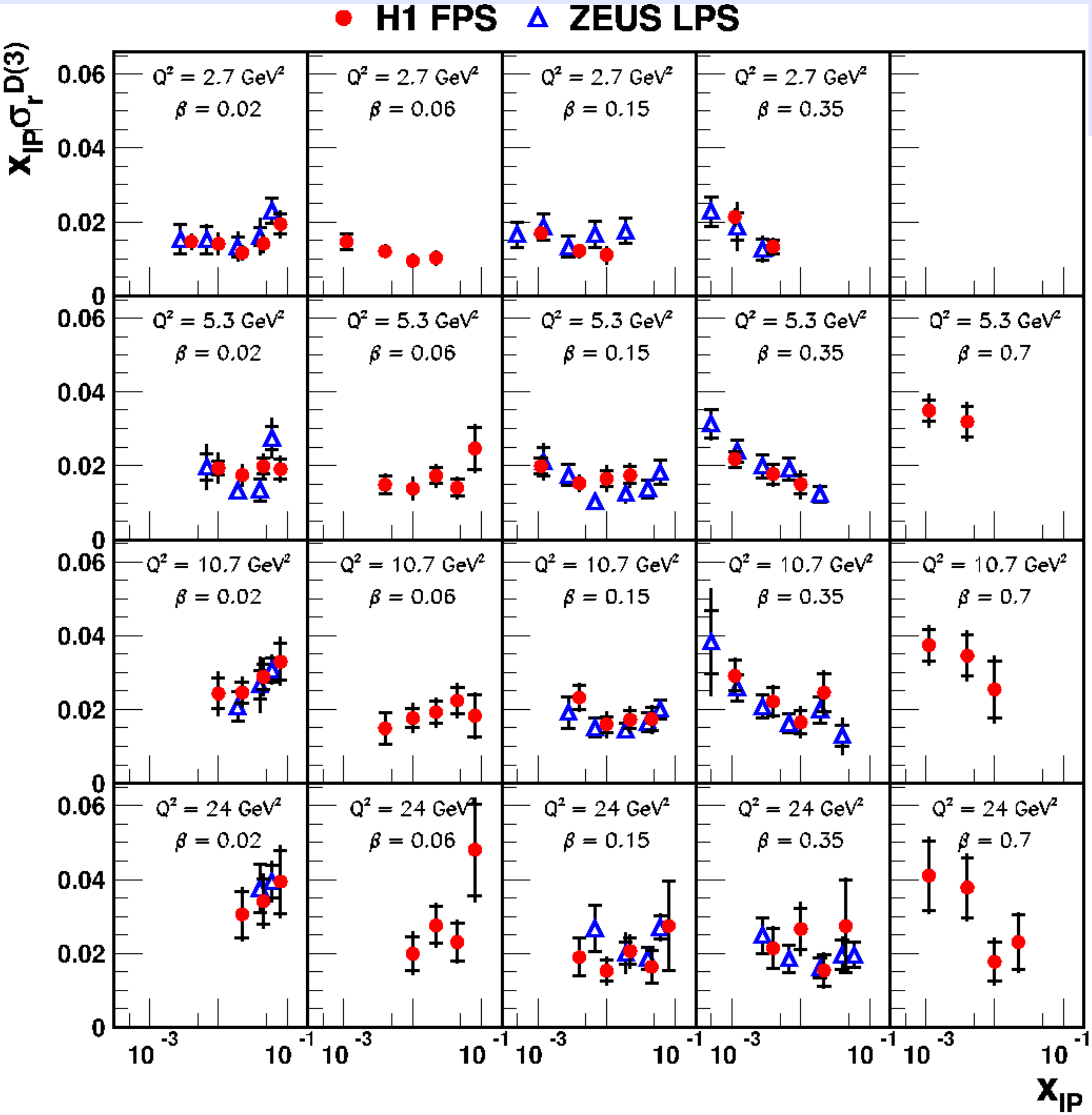
Suggests the difference comes from making the subtraction

Summary

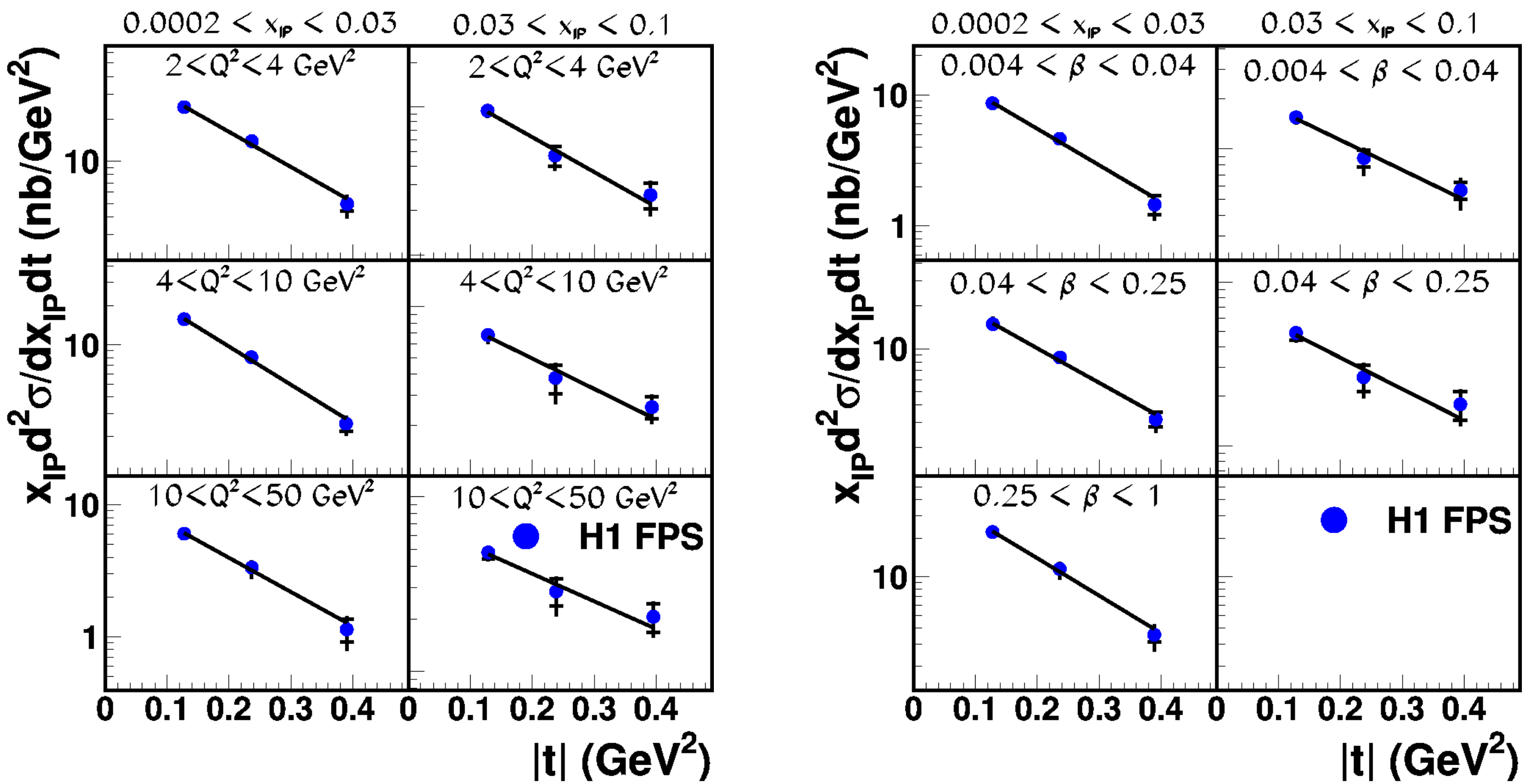
- H1 diffractive measurements using FPS and LRG methods published
  - hep-ex/0606003 and hep-ex/0606004 (both accepted by EPJC)
  - Data from two methods agree in detail! Also agreement with ZEUS-LPS
- Proton vertex factorization holds: M_Y, t and x_{IP} dependences factorise from β and Q^2
- DPDFs from NLO QCD fits to β, Q^2 dependences (H1 2006 DPDF Fits A+B)
  - Quark singlet very well constrained (~5%)
  - Gluon constrained to ~15%, but poorly known at high z (see talk by M. Mozer)
- Ratio of diffractive/inclusive DIS measured
  - ~flat with Q^2 (fixed x, x_{IP}), also with x (fixed Q^2, M_X)
- Diffractive Charged Currents predicted by fit to NC data, thought statistics are low
- New preliminary H1 data with large improvement in statistics at medium Q^2
  - M_X method agrees with other experimental techniques when subtraction is small

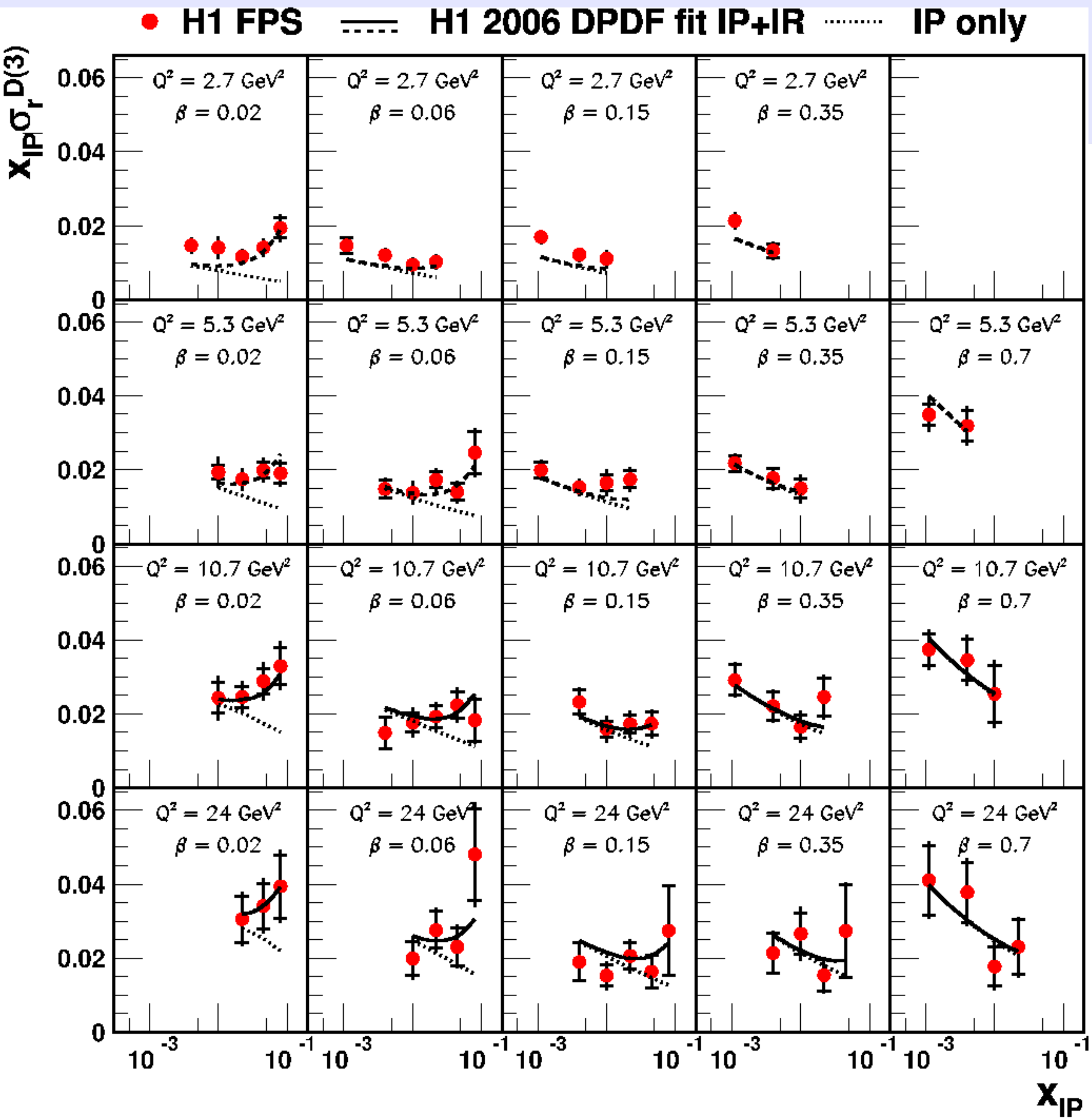
BACK-UP SLIDES FOLLOW

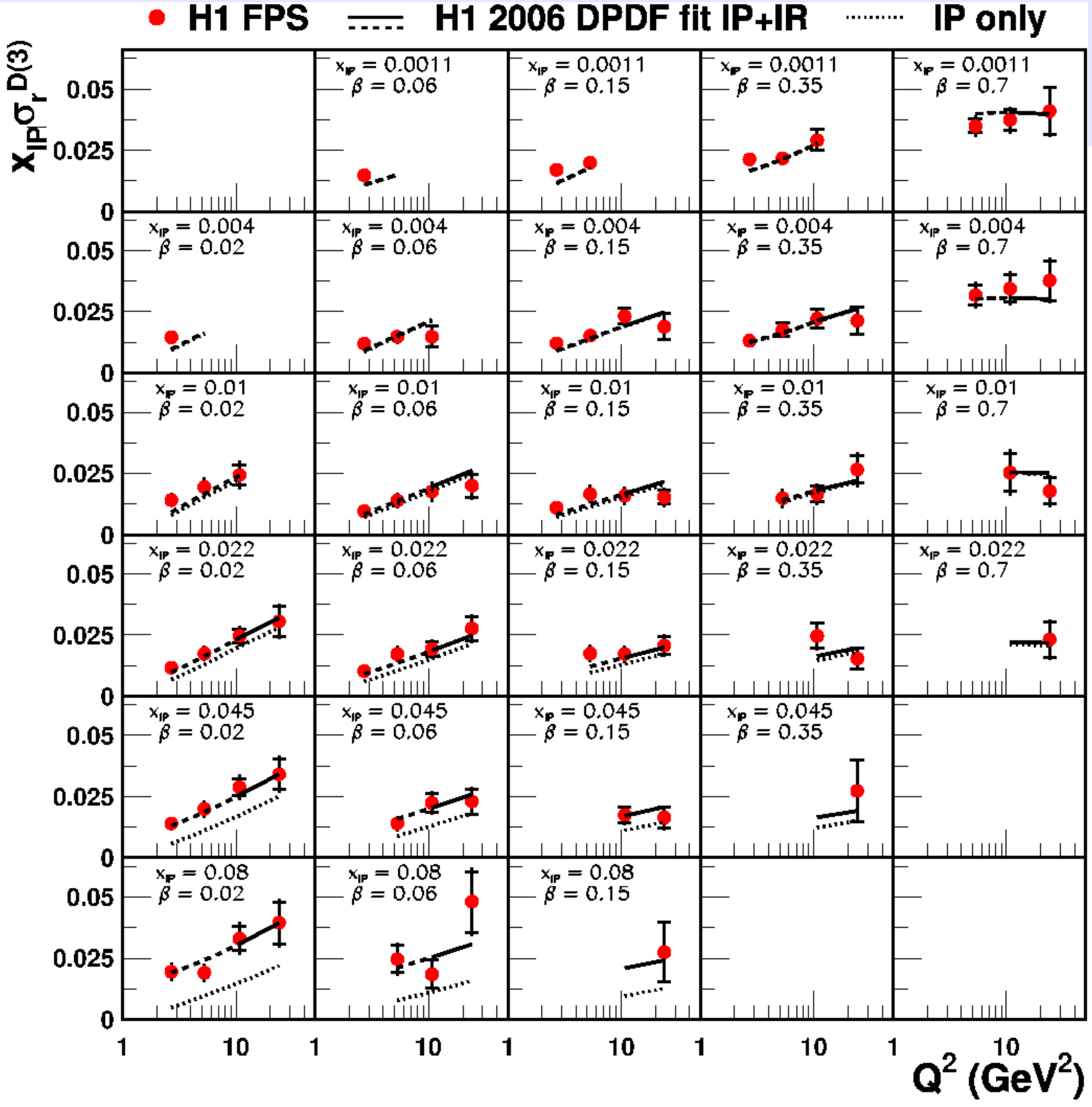

H1 Data
ZEUS (Mx)
$x_{IP}\,\sigma_r^{D(3)}$
Q^2 [GeV^2]
β=0.01
β=0.04
β=0.1
β=0.2
β=0.4
β=0.65
β=0.9
3.5
6.5
8.5
15
25
60
0.05
0
10^{-4}
10^{-2}
x_{IP}



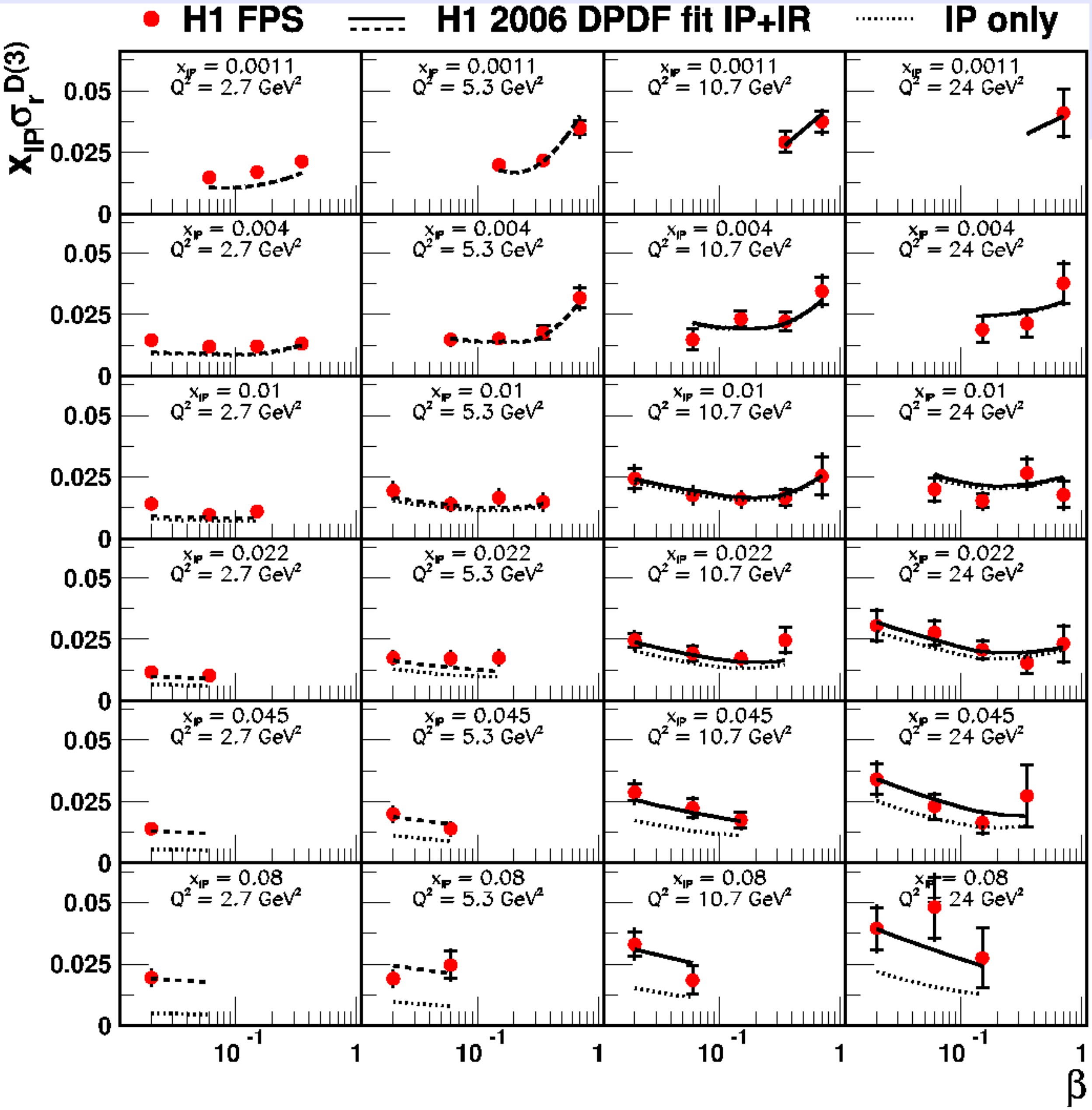
H1 FPS
ZEUS LPS
$x_{IP}\sigma_r^{D(3)}$
Q^2 = 2.7 GeV^2
β = 0.02
β = 0.06
β = 0.15
β = 0.35
Q^2 = 5.3 GeV^2
β = 0.7
Q^2 = 10.7 GeV^2
Q^2 = 24 GeV^2
0.06
0.04
0.02
0
10^{-3}
10^{-1}
x_{IP}


0.0002 < x_IP < 0.03
0.03 < x_IP < 0.1
2<Q²<4 GeV²
4<Q²<10 GeV²
10<Q²<50 GeV²
0.004 < β < 0.04
0.04 < β < 0.25
0.25 < β < 1
H1 FPS
x_IP d²σ/dx_IP dt (nb/GeV²)
|t| (GeV²)

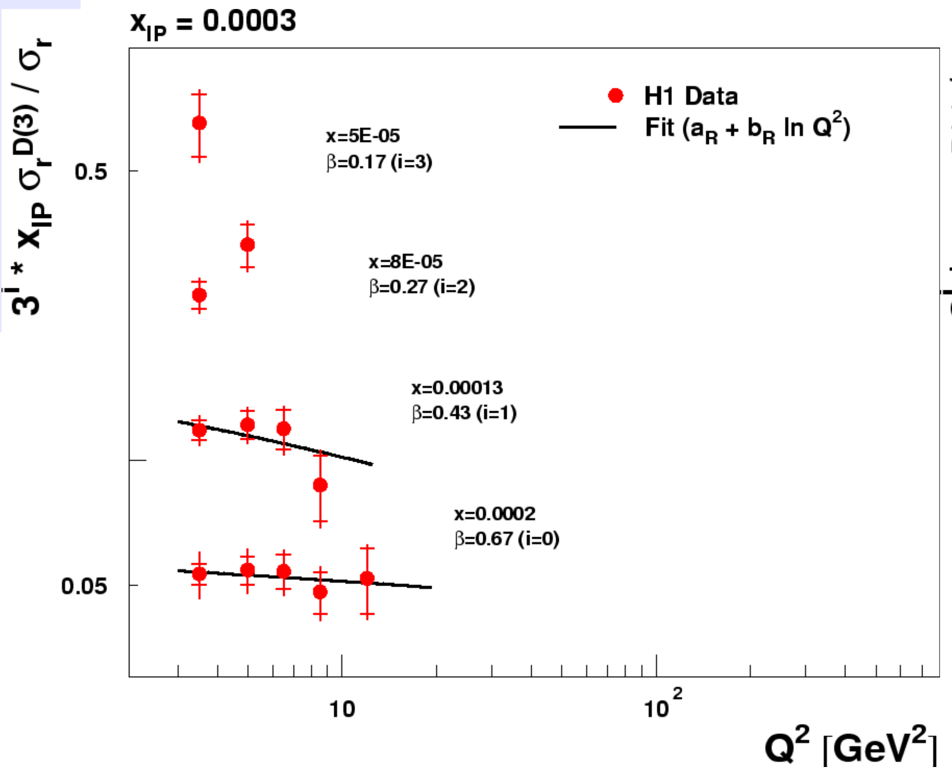

H1 FPS
H1 2006 DPDF fit IP+IR
IP only
$x_{IP}\sigma_r^{D(3)}$
Q^2 = 2.7 GeV^2 β = 0.02
Q^2 = 2.7 GeV^2 β = 0.06
Q^2 = 2.7 GeV^2 β = 0.15
Q^2 = 2.7 GeV^2 β = 0.35
Q^2 = 5.3 GeV^2 β = 0.02
Q^2 = 5.3 GeV^2 β = 0.06
Q^2 = 5.3 GeV^2 β = 0.15
Q^2 = 5.3 GeV^2 β = 0.35
Q^2 = 5.3 GeV^2 β = 0.7
Q^2 = 10.7 GeV^2 β = 0.02
Q^2 = 10.7 GeV^2 β = 0.06
Q^2 = 10.7 GeV^2 β = 0.15
Q^2 = 10.7 GeV^2 β = 0.35
Q^2 = 10.7 GeV^2 β = 0.7
Q^2 = 24 GeV^2 β = 0.02
Q^2 = 24 GeV^2 β = 0.06
Q^2 = 24 GeV^2 β = 0.15
Q^2 = 24 GeV^2 β = 0.35
Q^2 = 24 GeV^2 β = 0.7
0.06
0.04
0.02
0
10^{-3}
10^{-1}
x_{IP}



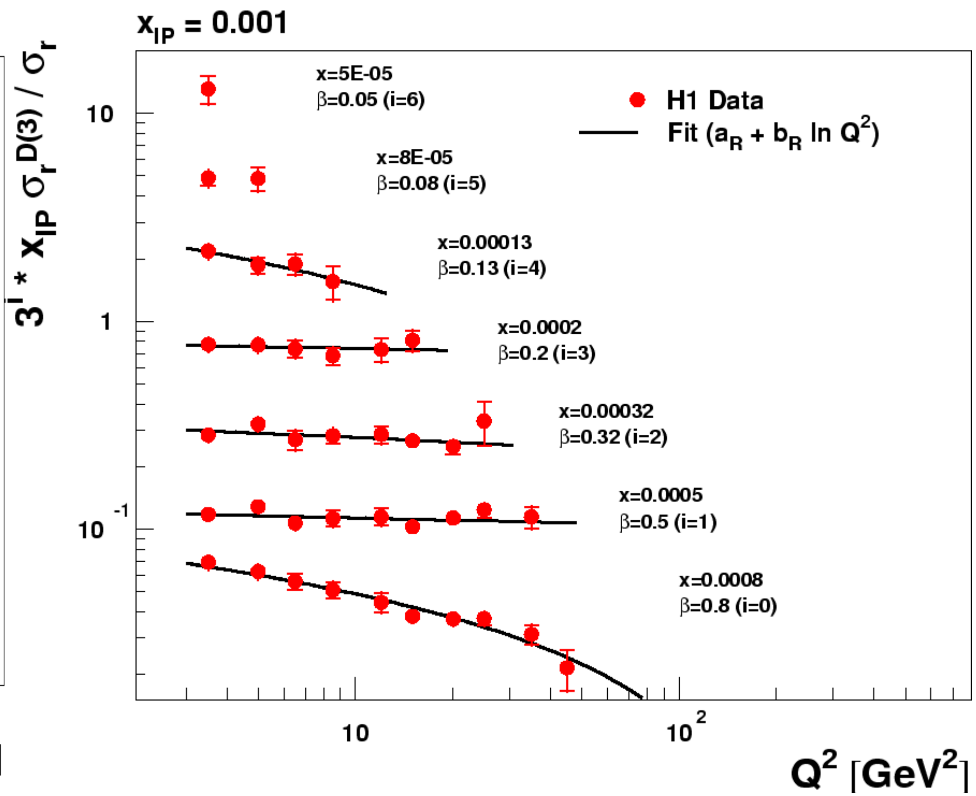
H1 FPS
H1 2006 DPDF fit IP+IR
IP only
$x_{IP}\sigma_r^{D(3)}$
Q^2 (GeV^2)



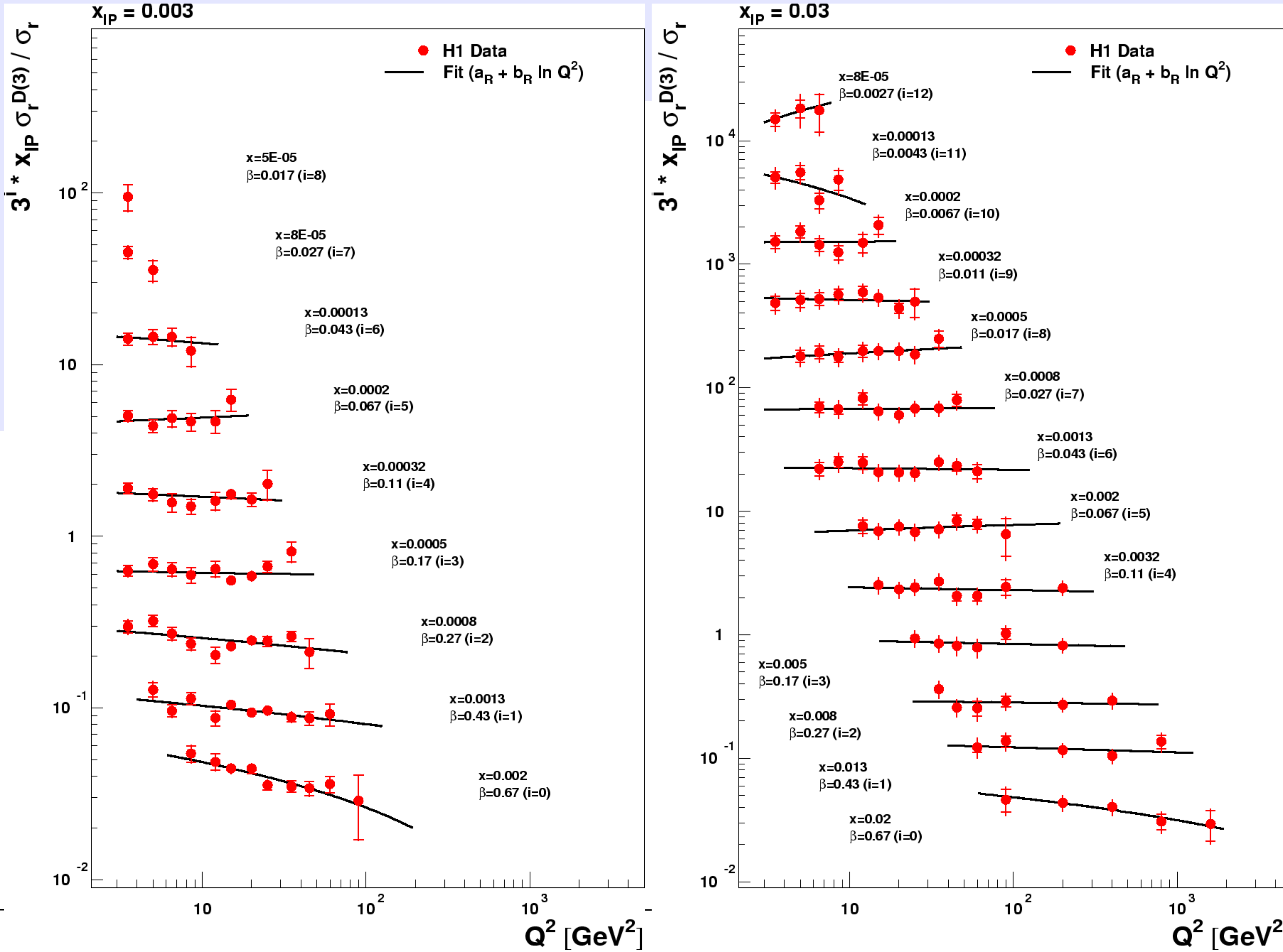
H1 FPS
H1 2006 DPDF fit IP+IR
IP only
$x_{IP}\sigma_r^{D(3)}$
β



x_{IP} = 0.0003
H1 Data
Fit ($a_R + b_R \ln Q^2$)
x=5E-05
β=0.17 (i=3)
x=8E-05
β=0.27 (i=2)
x=0.00013
β=0.43 (i=1)
x=0.0002
β=0.67 (i=0)
0.5
0.05
10
10^2
Q^2 [GeV^2]
$3^i * x_{IP} \sigma_r^{D(3)} / \sigma_r$



x_{IP} = 0.001
H1 Data
Fit ($a_R + b_R \ln Q^2$)
x=5E-05
β=0.05 (i=6)
x=8E-05
β=0.08 (i=5)
x=0.00013
β=0.13 (i=4)
x=0.0002
β=0.2 (i=3)
x=0.00032
β=0.32 (i=2)
x=0.0005
β=0.5 (i=1)
x=0.0008
β=0.8 (i=0)
10
1
10^{-1}
10
10^2
Q^2 [GeV^2]
$3^i * x_{IP} \sigma_r^{D(3)} / \sigma_r$



x_IP = 0.003
x_IP = 0.03
H1 Data
Fit (a_R + b_R ln Q^2)
3^i * x_IP σ_r^D(3) / σ_r
Q^2 [GeV^2]
x=5E-05 β=0.017 (i=8)
x=8E-05 β=0.027 (i=7)
x=0.00013 β=0.043 (i=6)
x=0.0002 β=0.067 (i=5)
x=0.00032 β=0.11 (i=4)
x=0.0005 β=0.17 (i=3)
x=0.0008 β=0.27 (i=2)
x=0.0013 β=0.43 (i=1)
x=0.002 β=0.67 (i=0)
x=8E-05 β=0.0027 (i=12)
x=0.00013 β=0.0043 (i=11)
x=0.0002 β=0.0067 (i=10)
x=0.00032 β=0.011 (i=9)
x=0.0005 β=0.017 (i=8)
x=0.0008 β=0.027 (i=7)
x=0.0013 β=0.043 (i=6)
x=0.002 β=0.067 (i=5)
x=0.0032 β=0.11 (i=4)
x=0.005 β=0.17 (i=3)
x=0.008 β=0.27 (i=2)
x=0.013 β=0.43 (i=1)
x=0.02 β=0.67 (i=0)