Diffractive DIS Cross Sections and PDFs from Rapidity Gap and Leading Proton Data

Frank-Peter Schilling (CERN and DESY)

On behalf of the H1 Collaboration

ICHEP 2006

Moscow, July 2006

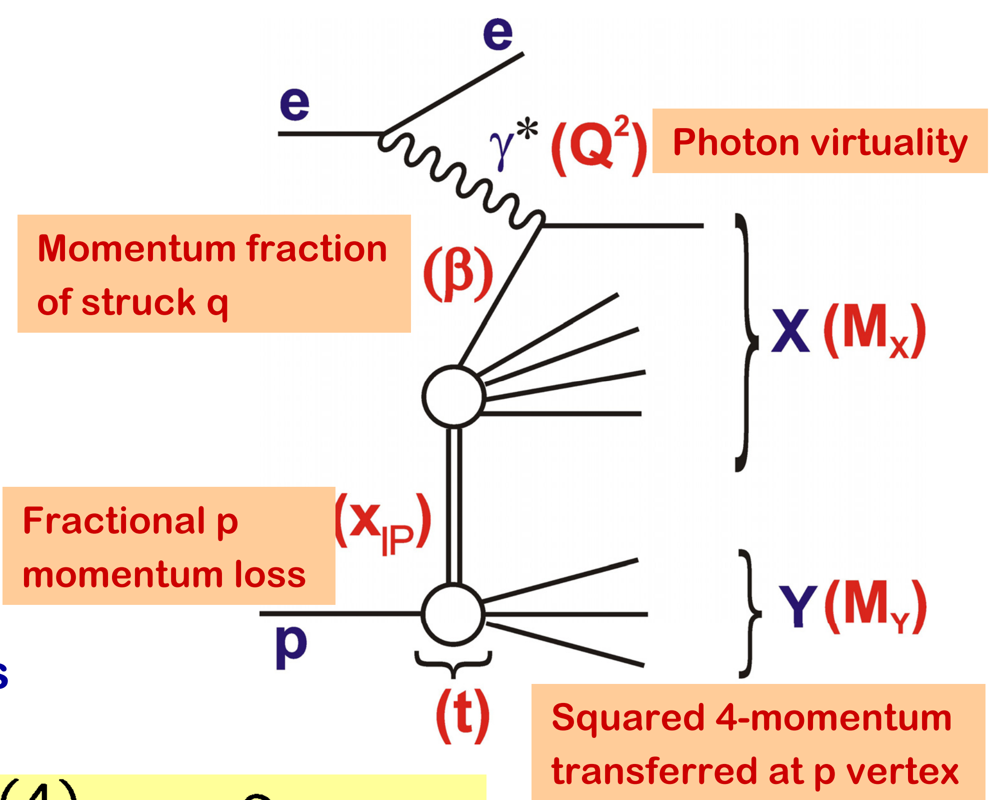
Results presented (mainly) from two recent papers:

- **DESY06-048, hep-ex/0606003 subm to EPJC**
- **DESY06-049, hep-ex/0606004 subm to EPJC**

Overview and Kinematics

Diffractive DIS at HERA: Deep Inelastic Scattering where the proton stays intact and loses just small momentum fraction …

- **Comparison between measurement methods:**
  - ❑ leading proton (Roman Pots)
  - ❑ Large rapidity gap
- **Dependences on t and x_{IP}**
- **Q^2 and β dependences and NLO DGLAP QCD fits**
- **Comparison between diffractive and inclusive DIS**
- **Main observable: Reduced cross section $\sigma_r^{D(3,4)}$**



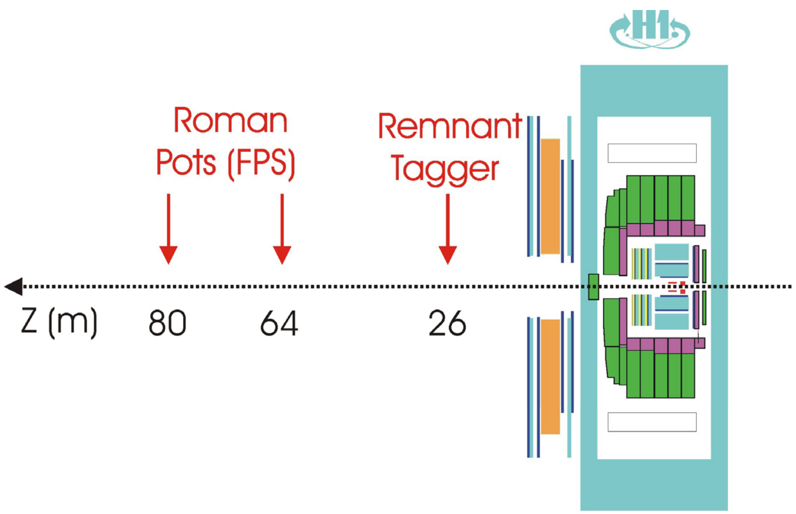
$$\frac{d^4\sigma^{ep\to eXp}}{dx\,dQ^2\,dx_{I\!P}\,dt} = \frac{4\pi\alpha^2}{xQ^4}\; Y_+\; \sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t)$$

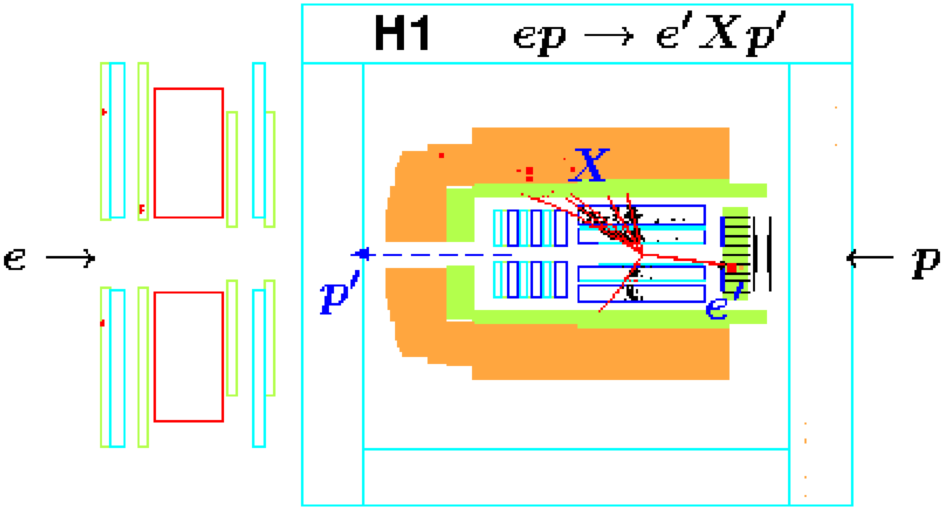
$$\sigma_r^{D(4)}(x, Q^2, x_{I\!P}, t) = F_2^{D(4)} - \frac{y^2}{Y_+} F_L^{D(4)} \approx F_2^{D(4)}$$

Event Selection Methods

1. Tag and measure final state proton in Forward Proton Spectrometer (FPS method)
   - No proton dissociation
   - Can measure t
   - Acceptance at high x_{IP}
   - … but low Pot acceptance

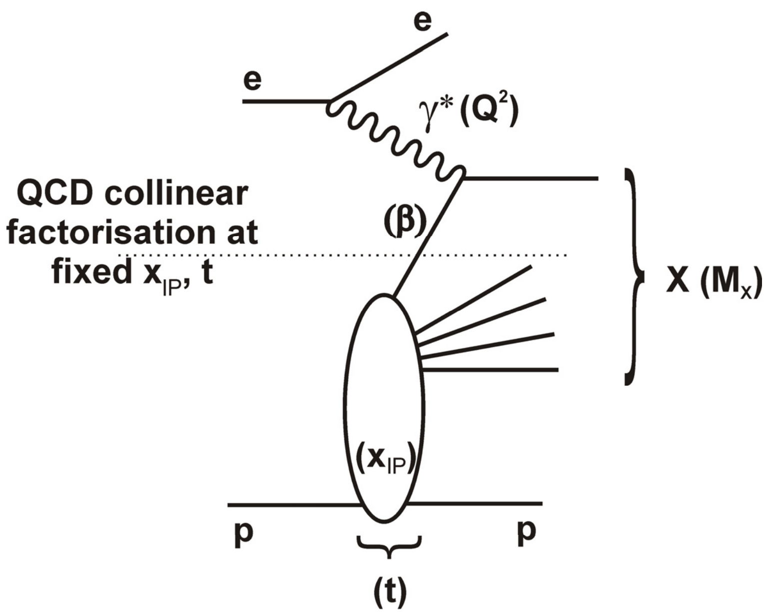
2. Require Large Rapidity Gap spanning at least $3.3<\eta<7.5$ and measure hadrons in central detector (LRG method)
   - Some proton dissociation
   - Correct to $M_Y<1.6$ GeV
   - Near-perfect acceptance at low x_{IP}





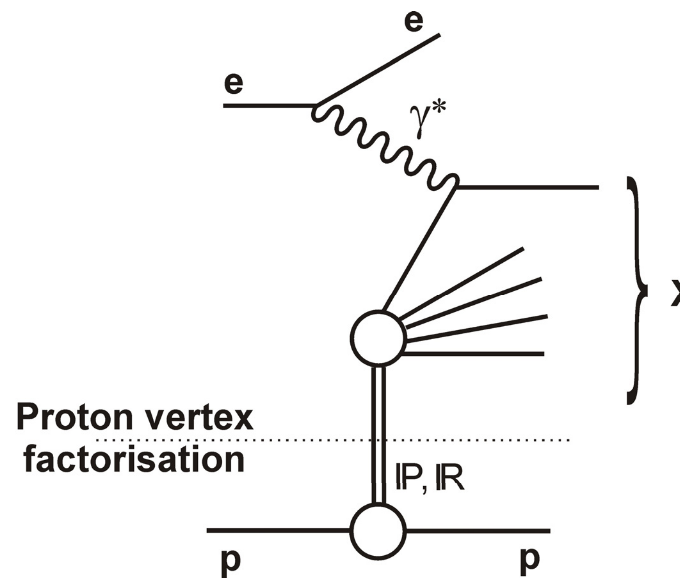
Two Levels of Factorization

- QCD hard scattering collinear factorization (Collins) at fixed x_{IP} and t
  - After integration over measured M_Y,t ranges



$$d\sigma_i(ep \to eXY) = f_i^D(x, Q^2, x_{I\!P}, t) \otimes d\hat{\sigma}^{ei}(x, Q^2)$$

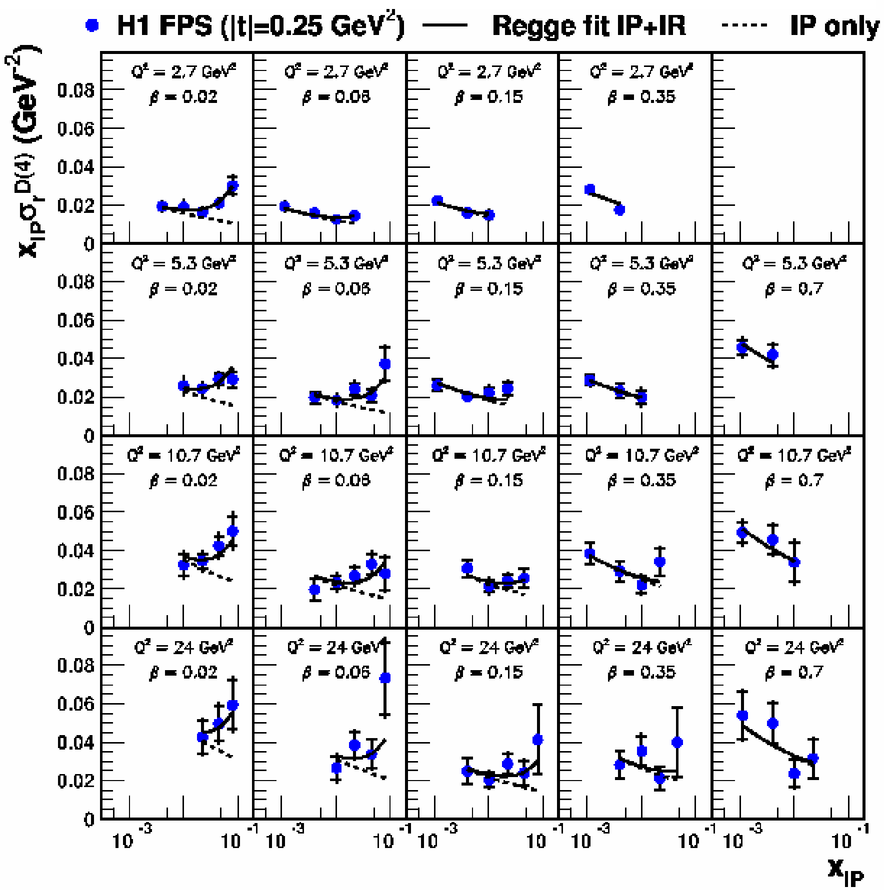
- "Proton vertex" factorization of x,Q^2 from x_{IP}, t (and M_Y) dependences
  - Separately for leading IP and sub-leading IR exchanges

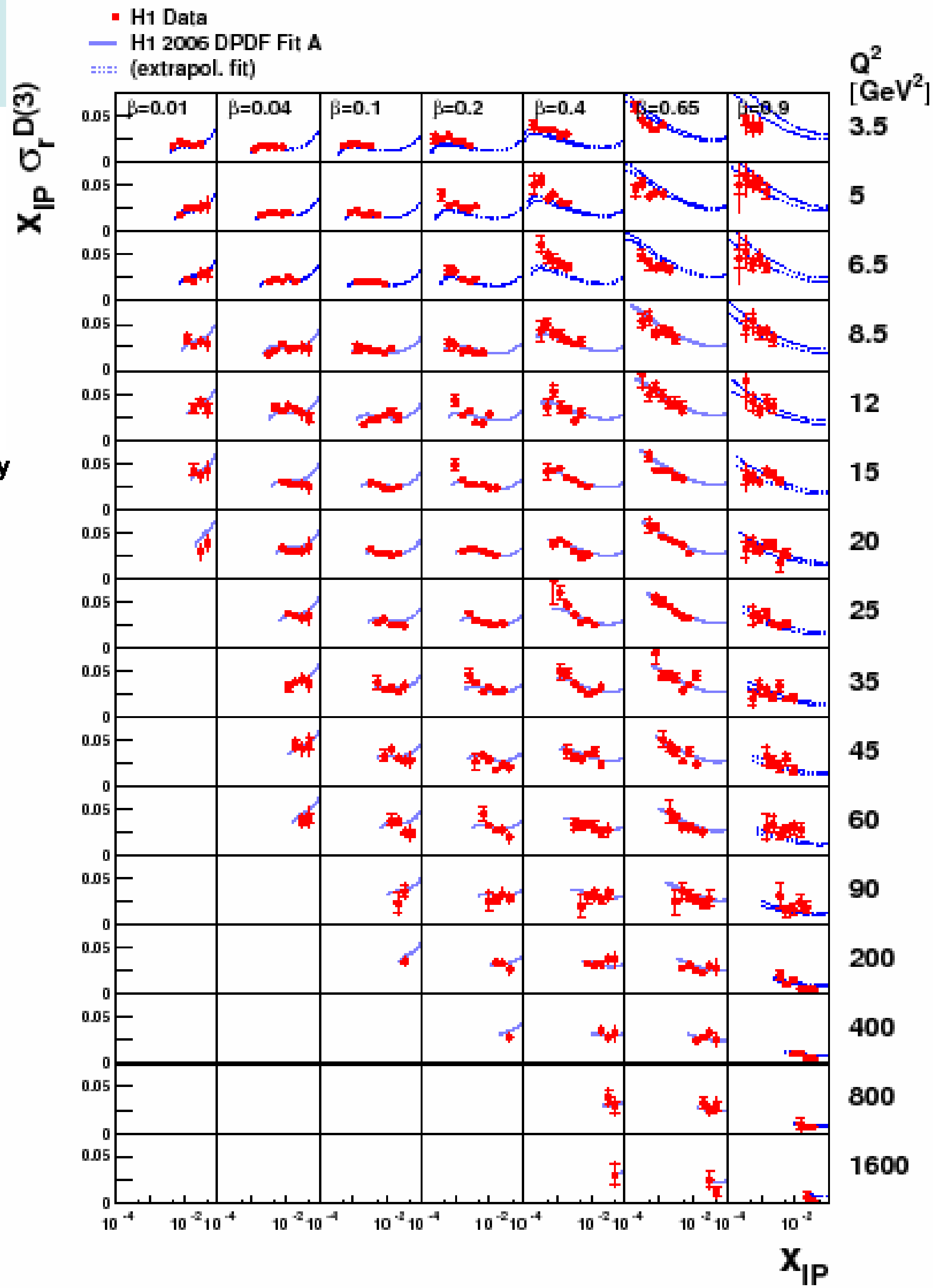


$$f_i^D(x, Q^2, x_{I\!P}, t) = f_{I\!P/p}(x_{I\!P}, t) \times f_i^{I\!P}(\beta = x/x_{I\!P}, Q^2)$$

Data Overview

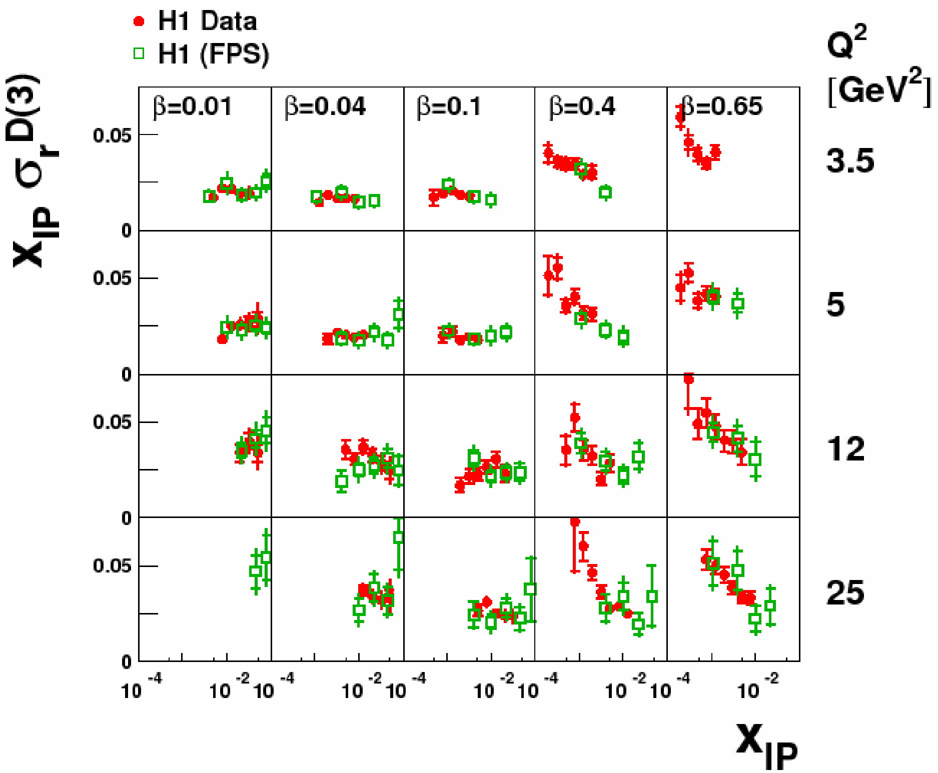
- **LRG: M_Y<1.6 GeV**
  - $3.5<Q^2<1600$ GeV^2
- **FPS: Y=p**
  - $2.7<Q^2<24$ GeV^2



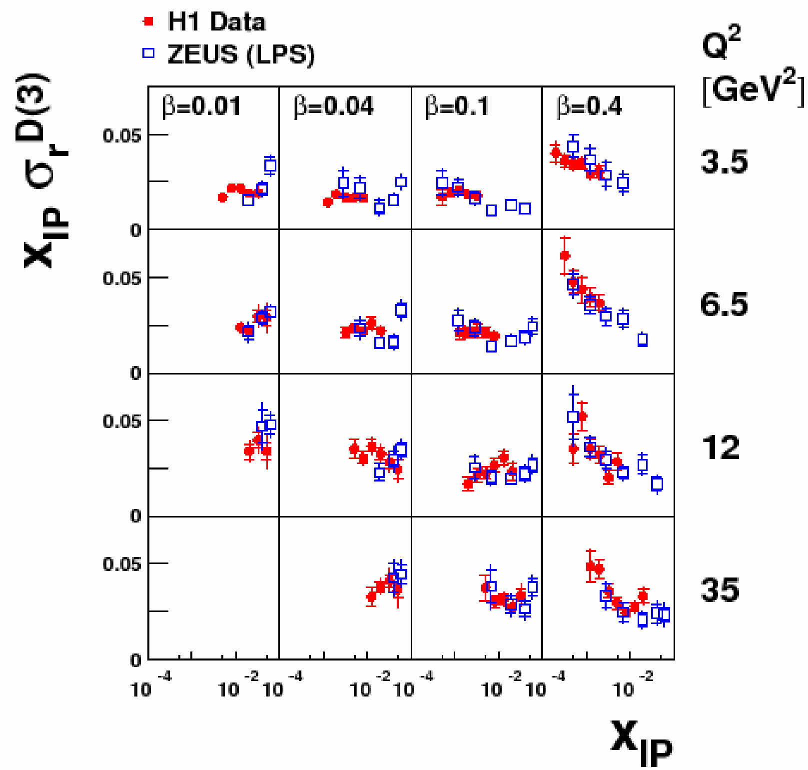


Comparison of Rapidity Gap with Leading Proton (H1,ZEUS) data

- **LRG vs FPS data:**



- **LRG vs ZEUS LPS data:**



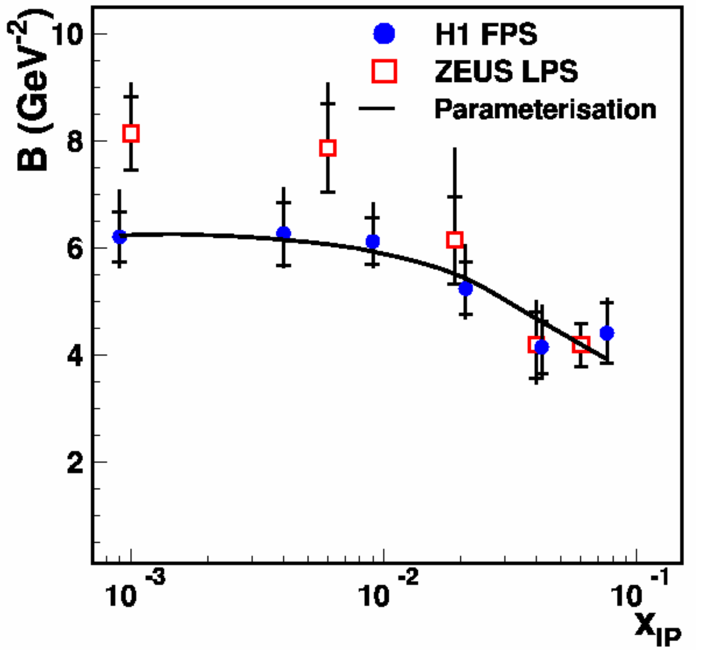
- **Agreement in detail between FPS and LRG methods: Ratio LRG/FPS independent of kinematics within errors:**

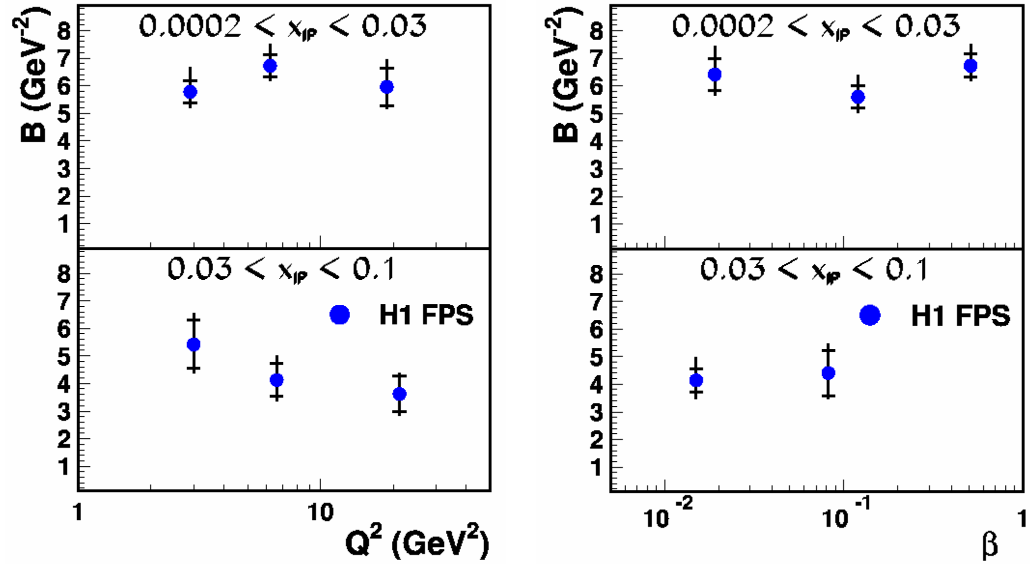
$$\frac{\sigma(M_Y<1.6\ \text{GeV})}{\sigma(Y=p)} = 1.23\pm0.03(\text{stat.})\pm0.16(\text{syst.})$$

- **ZEUS-LPS and H1-FPS normalizations agree to 8%**
- **Vergy good agreement between proton tagging and LRG methods if p dissociation is accounted for!**

t dependence from FPS measurements

- $B(x_{IP})$ from fit $d\sigma/dt \sim \exp(B|t|)$:
- Independent of β, Q^2 within errors



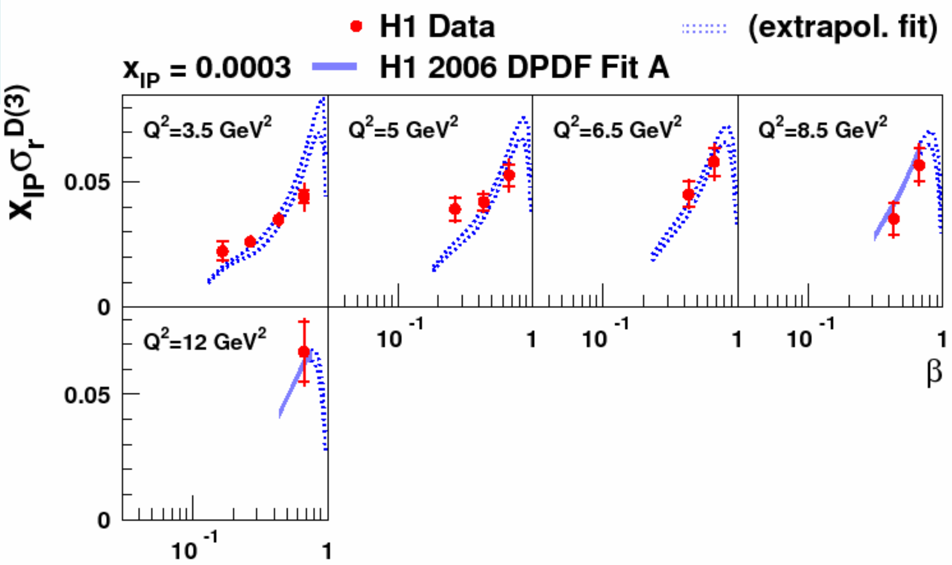


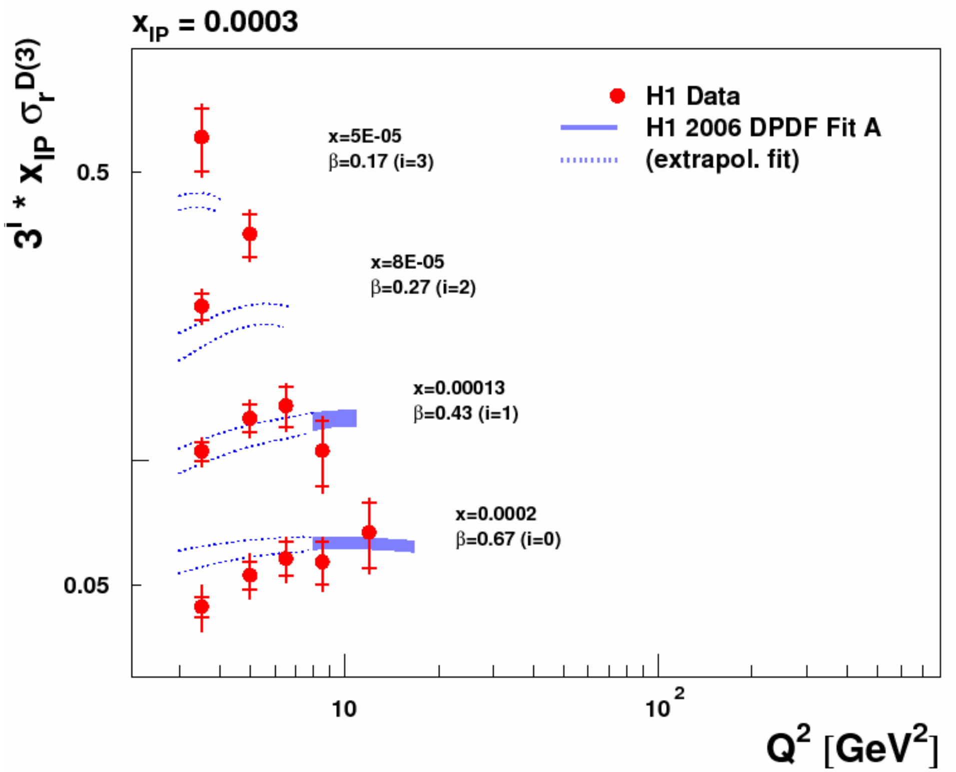
- $B(x_{IP})$ data constrain IP,IR flux factors in p vertex fact. Model
- Regge motivated form: $f_{I\!P/p}(x_{I\!P}, t) = \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$ $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} t$
- Fitting low x_{IP} data to $B = B_{I\!P} + 2\alpha'_{I\!P} \ln(1/x_{I\!P})$ yields

$$B_{I\!P} = 5.5^{-2.0}_{+0.7}\ \mathrm{GeV}^{-2} \quad \alpha'_{I\!P} = 0.06^{+0.19}_{-0.06}\ \mathrm{GeV}^{-2}$$

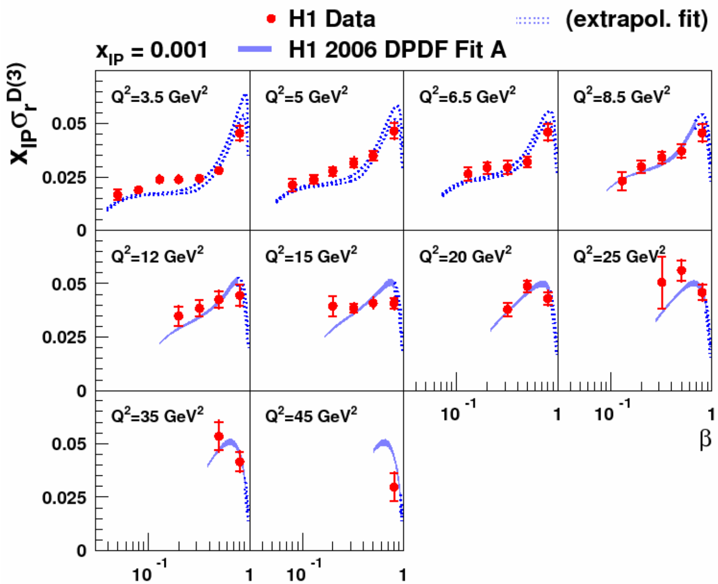
$\sigma_r^{D(3)}(\beta,Q^2,x_{IP})$ at x_{IP}=0.0003

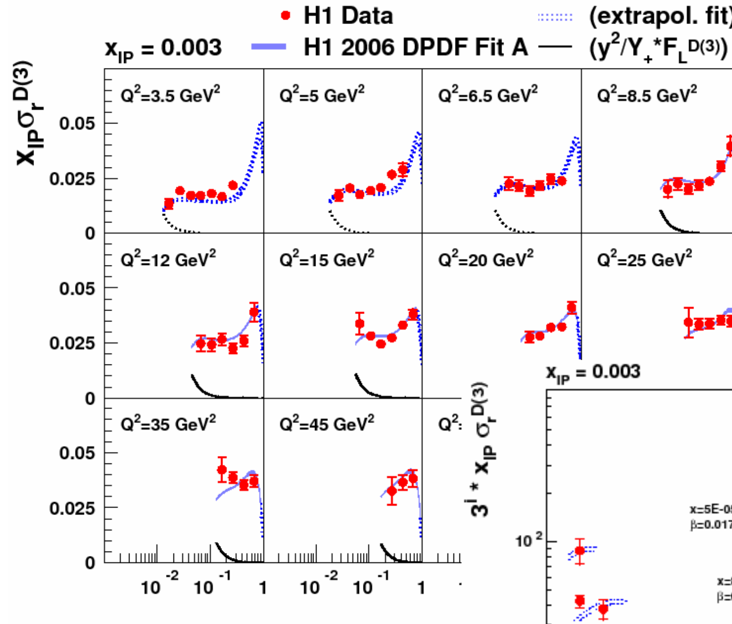
- **Principal binning scheme for LRG data**
- **Study Q^2 and x (=$\beta . x_{IP}$) dependences in detail at small number of fixed x_{IP} values**
- **Good precision – in best regions 5% (stat.), 5% (syst.), 6% (norm.)**
- **Data compared with "H1 2006 DPDF fit" and its error band (assumes p vtx factorization, see later)**

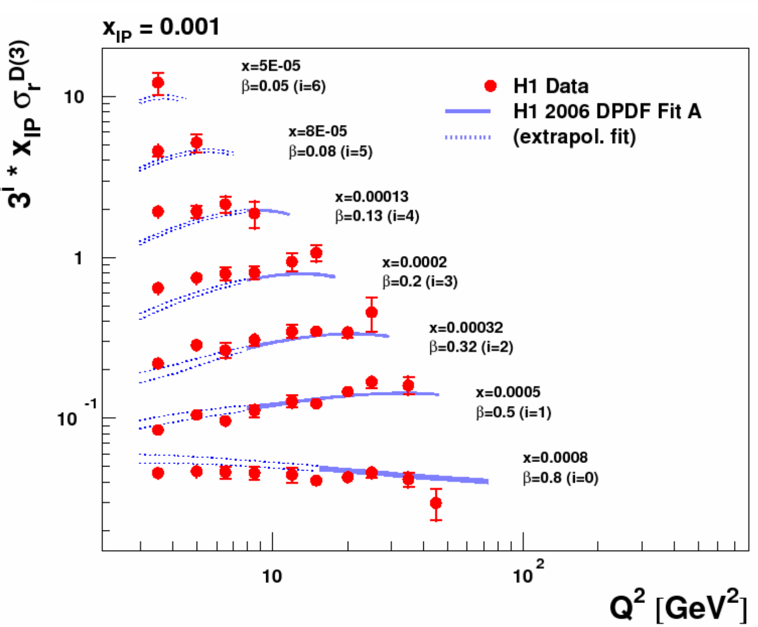


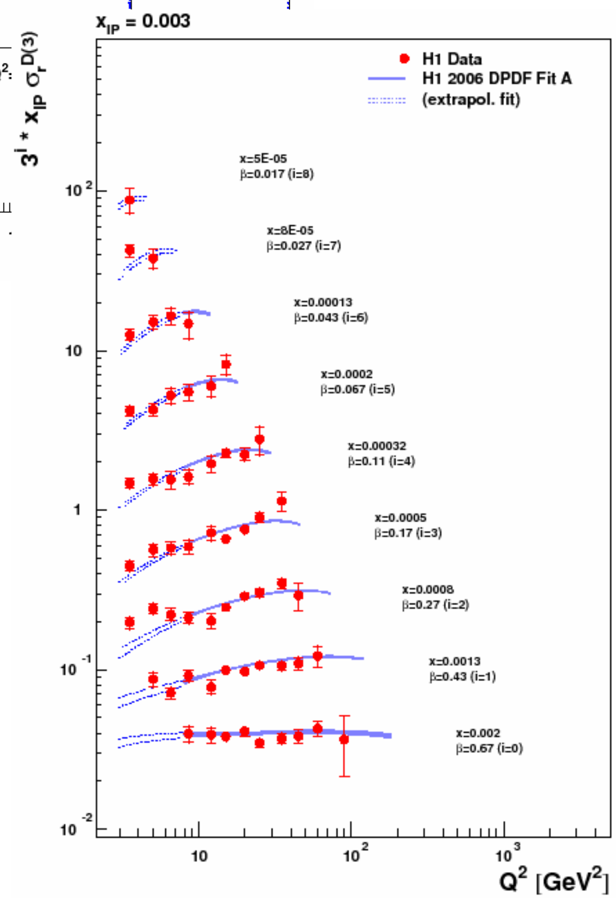


$\sigma_r^{D(3)}(\beta,Q^2,x_{IP})$ at x_{IP}=0.001 and 0.003

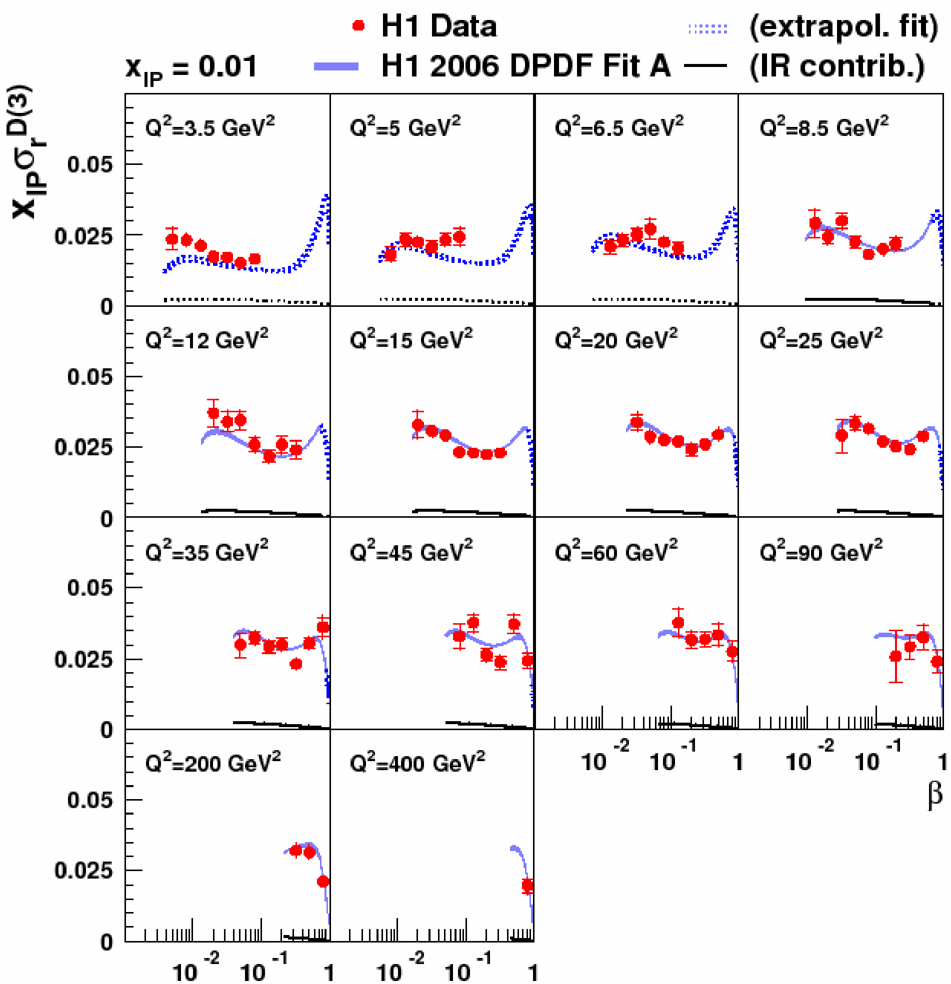


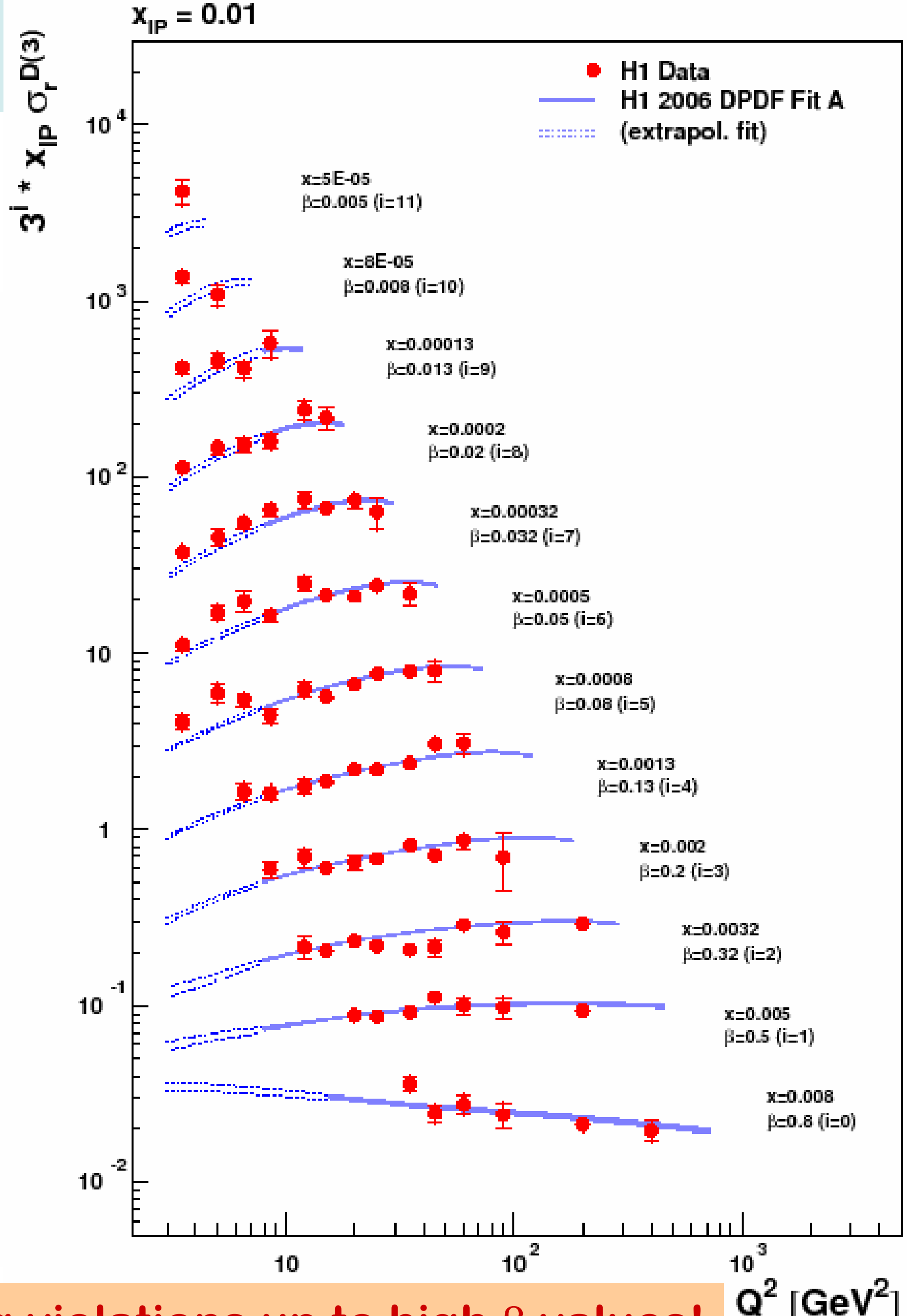






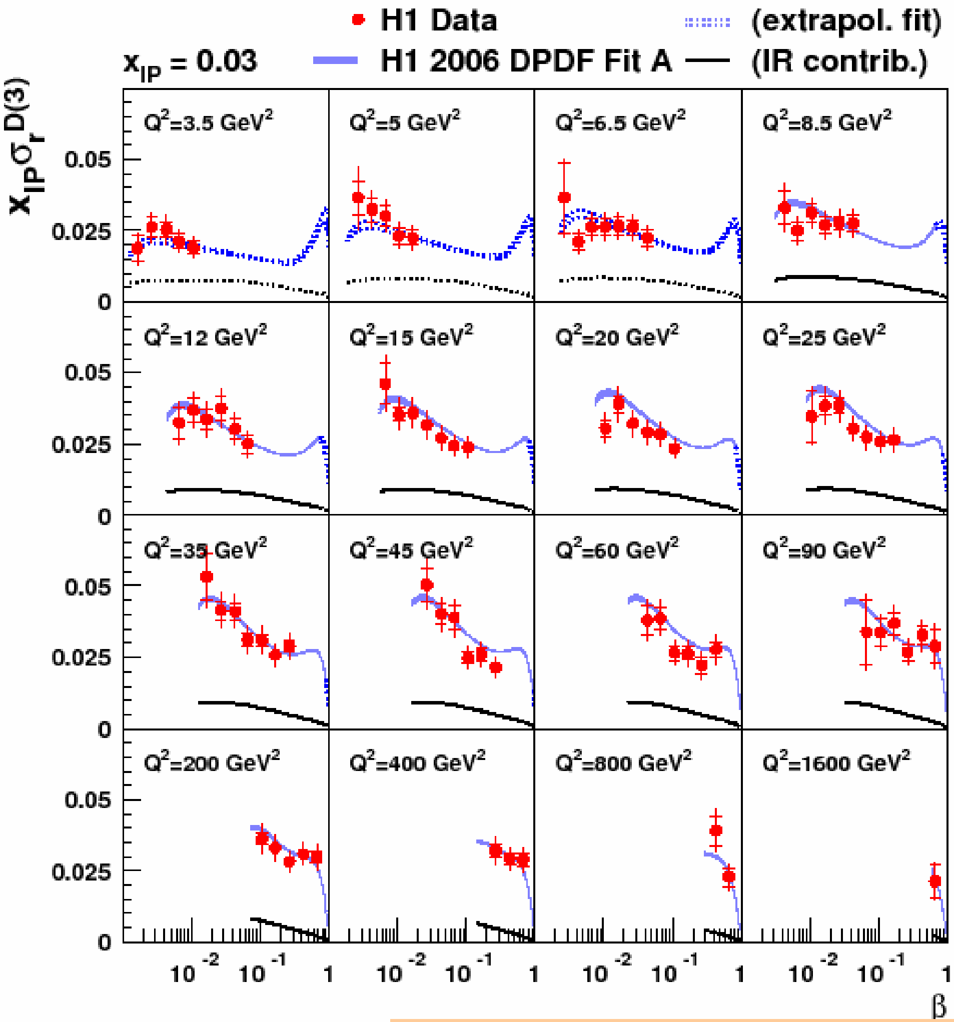
$\sigma_r^{D(3)}(\beta,Q^2,x_{IP})$ at x_{IP}=0.01

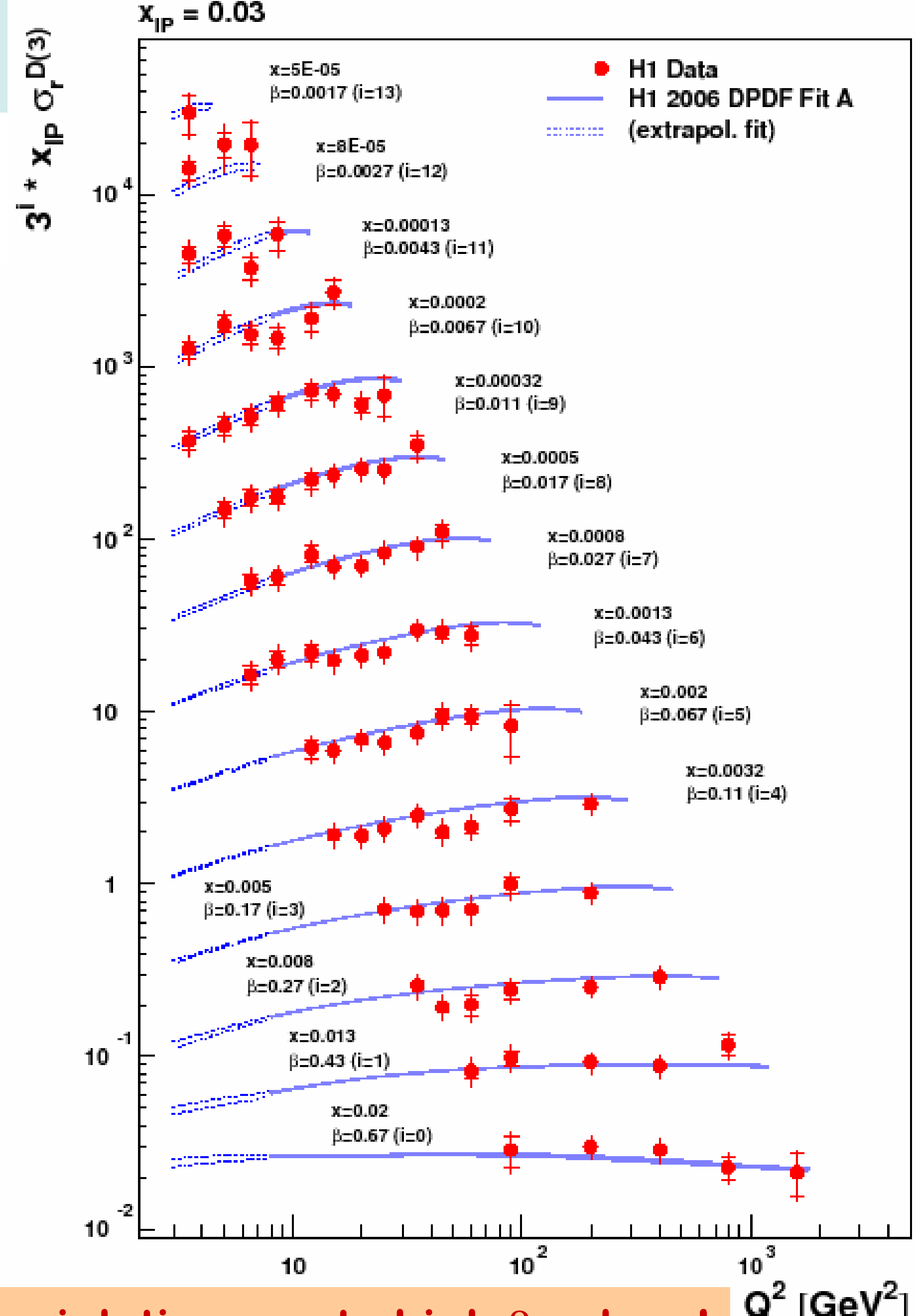




Large positive Q^2 scaling violations up to high β values!

$\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$ at $x_{IP}=0.03$

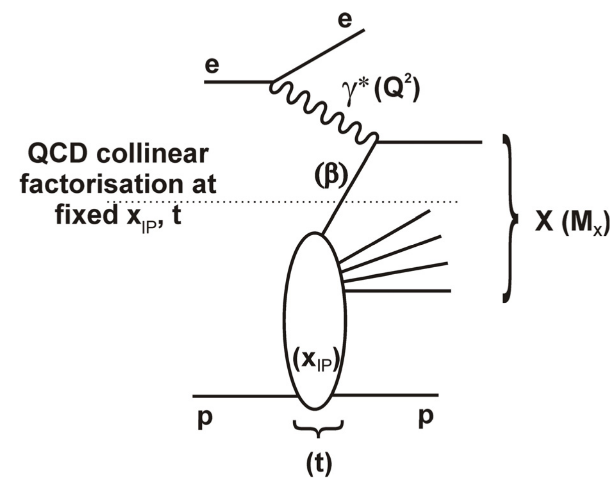




Large positive Q^2 scaling violations up to high β values!

H1 2006 DPDF fit: Overview

- Fit LRG data from fixed x_{IP} binning, using NLO DGLAP evolution of DPDFs (massive scheme) to describe x,Q^2 dependences
- Proton vtx factorisation framework (supported by data)
  - relate data from different x_{IP} values with complementary x,Q^2 coverage
- For IP exchange, free parameters are
  - $\alpha_{IP}(0)$ (describes x_{IP} dependence)
  - DPDF parameters at evolution starting scale Q_0^2



$$f_{IP/p}(x_{IP},t) = \frac{e^{B_{IP}t}}{x_{IP}^{2\alpha_{IP}(t)-1}}$$

- For sub-leading IR
  - all flux parameters taken from previous data
  - PDFs taken from Owens-π; single free param for normalization

Kinematic range and DPDF parameterization

- To ensure data fitted are compatible with chosen framework, test sensitivity of fit results to variations of kinematic boundaries
  - Results stable for most variations (β_{max}, β_{min}, $M_{X,min}$, $x_{IP,max}$)
  - Systematic variation of gluon density with minimum Q^2 of data included in fit for $Q^2 < 8.5$ GeV^2; stable for larger Q^2-min
- Fit all LRG data with $Q^2 \geq 8.5$ GeV^2, $M_x > 2$ GeV, $\beta \leq 0.8$
- Parameterize
  - quark singlet $z\Sigma(z,Q_0^2)$
  - gluon $zg(z,Q_0^2)$ density

$$z\Sigma(z,Q_0^2) = A_q z^{B_q}(1-z)^{C_q} \qquad zg(z,Q_0^2) = A_g(1-z)^{C_g}$$

  - Gluon insensitive to B_g
- Small number of parameters
  - need to optimize Q_0^2 wrt χ^2
- Using world average value for $\alpha_s(M_z)=0.118$
- Results reproducible with Chebychev polynomials

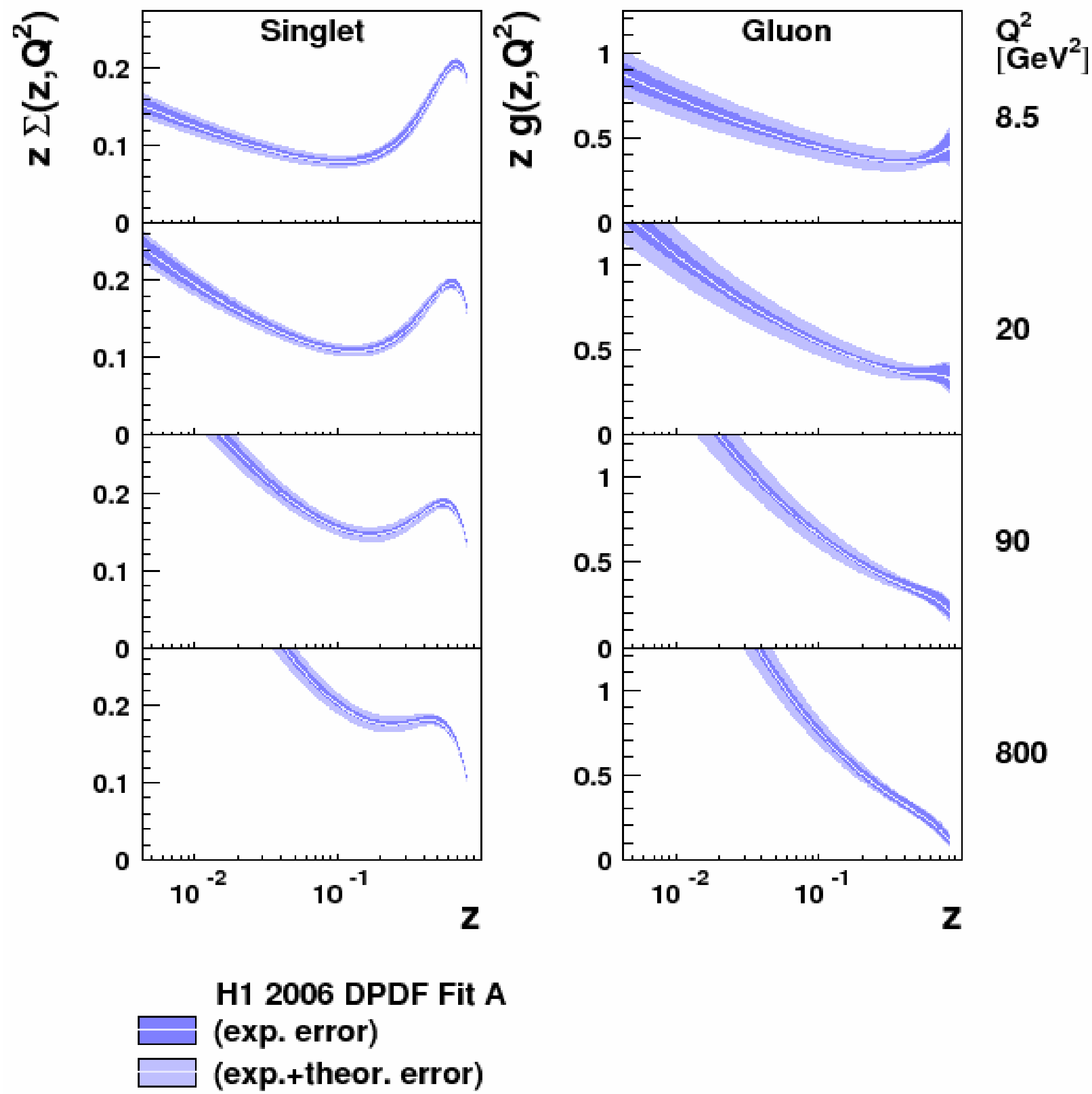
H1 2006 DPDF fit results (log z scale)

- Q_0^2=1.75 GeV^2
- χ^2~158 / 183 dof

- Experimental uncertainty obtained by propagating errors on data (c.f. incl. fits, $\Delta\chi^2$=1)

- Theoretical uncertainty from varying fixed parameters of fit (flux params, α_s, m_c, m_b etc.) and Q_0^2 ($\Delta\chi^2$=1)

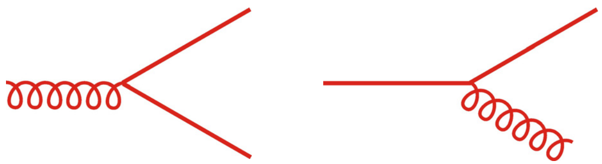
- Singlet constrained to ~5%, gluon to ~15% at low z; error blowing up at highest z



A closer look at high z region

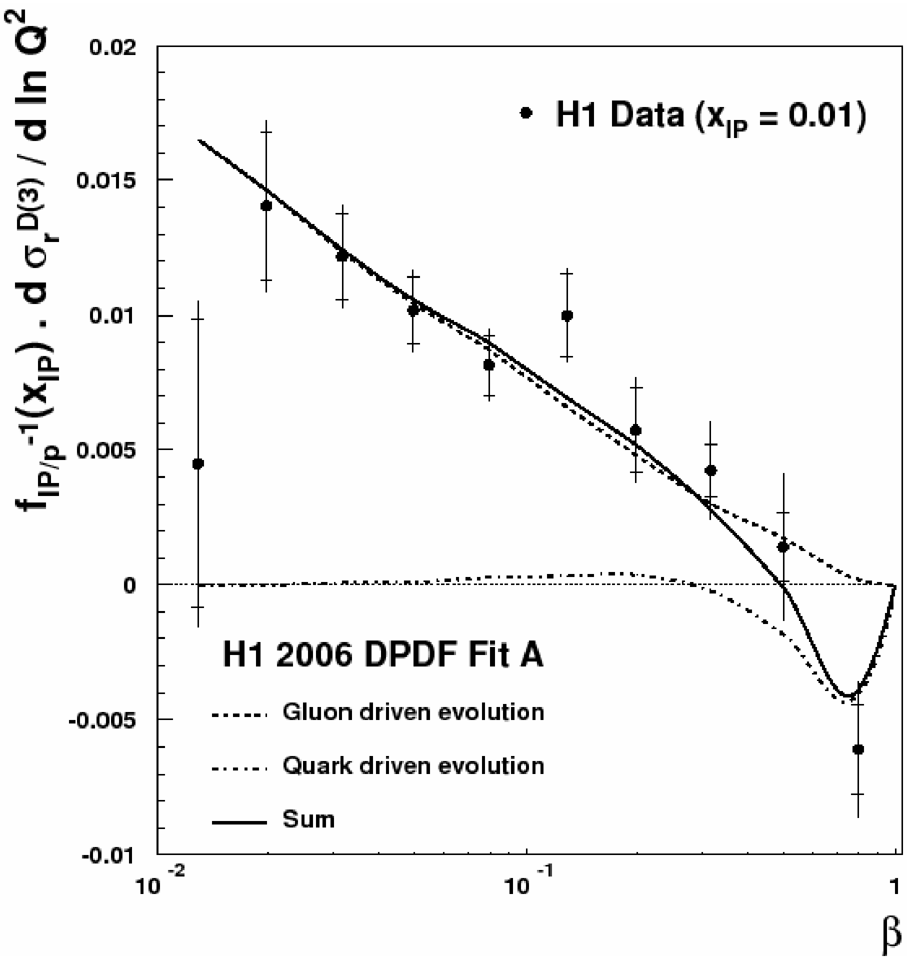
- As there are only singlet quarks, the evolution eq. for F_2^D is

$$\frac{dF_2^D}{d\ln Q^2} \sim \frac{\alpha_s}{2\pi}\left[P_{qg}\otimes g + P_{qq}\otimes\Sigma\right]$$



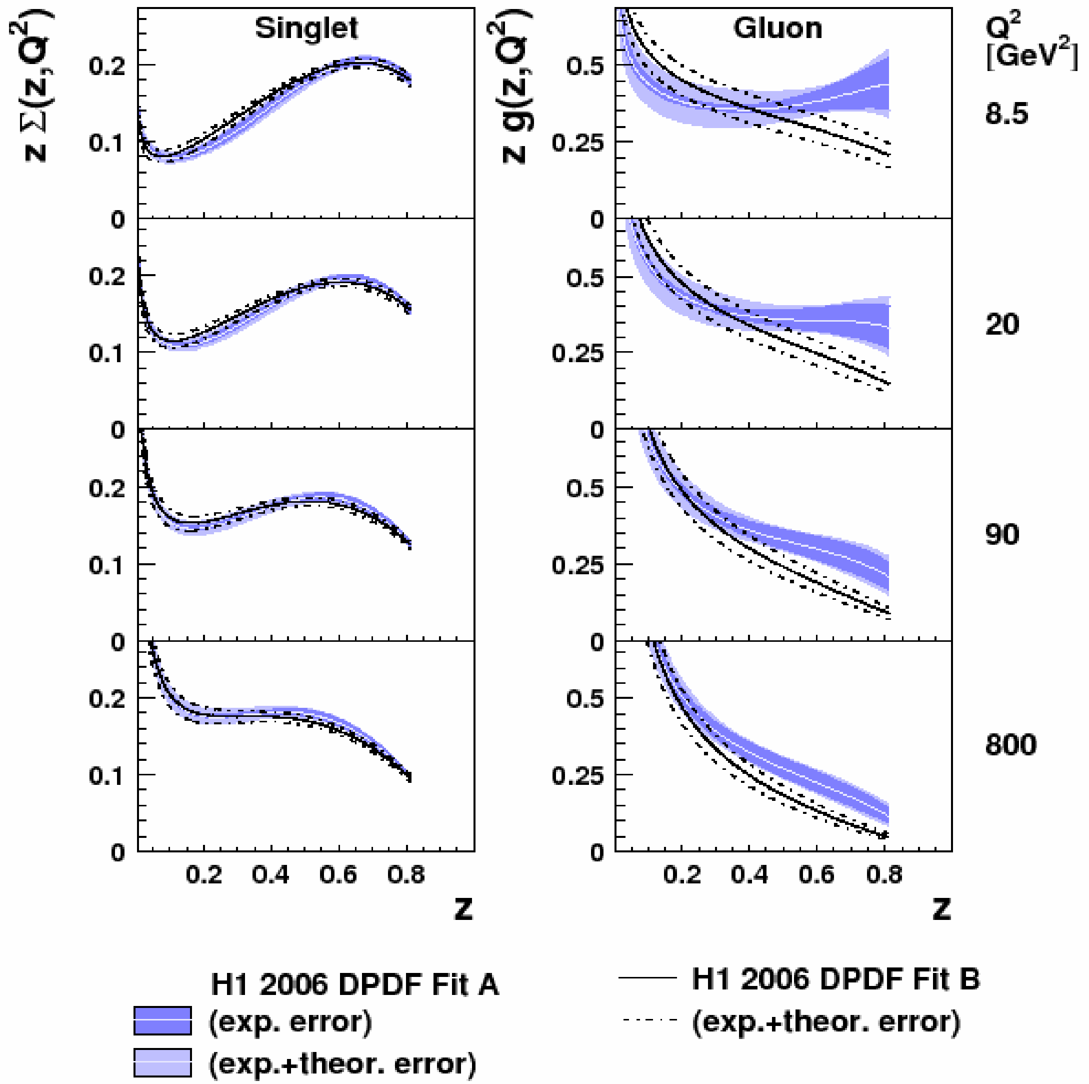
- At low β, evolution driven by $g\to qq$:
  - strong sensitivity to gluon
- At high β relative error on derivative grows, $q\to qg$ contribution becomes important:
  - sensitivity to gluon is lost

Log. Derivative wrt Q^2:



H1 2006 DPDF fit results (lin. z scale)

- **Lack of sensitivity to high z gluon confirmed by dropping C_g parameter, so gluon is simple constant at Q_0^2:**
- **Fit B, $\chi^2 \sim 164/184$ dof**
  - **Singlet very stable**
  - **Gluon similar at low z**
  - **Substantial change to gluon at high z**

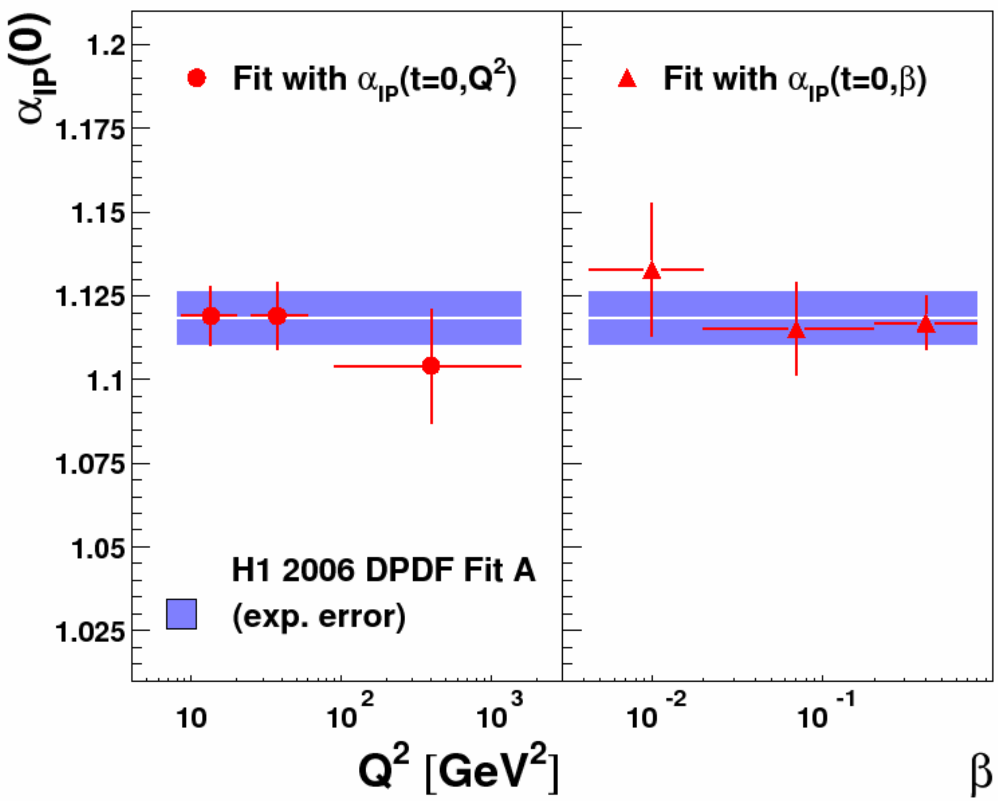


Effective Pomeron Intercept

- From QCD fit to LRG data

$$\alpha_{I\!P}(0) = 1.118 \pm 0.008(\text{exp.})^{+0.029}_{-0.010}(\text{th.})$$

- Dominant uncertainty from strong correlation with α'_{IP}: taking α'_{IP}= 0.25 instead of 0.06 GeV^{-2} yields $\alpha_{IP}(0)$~1.15

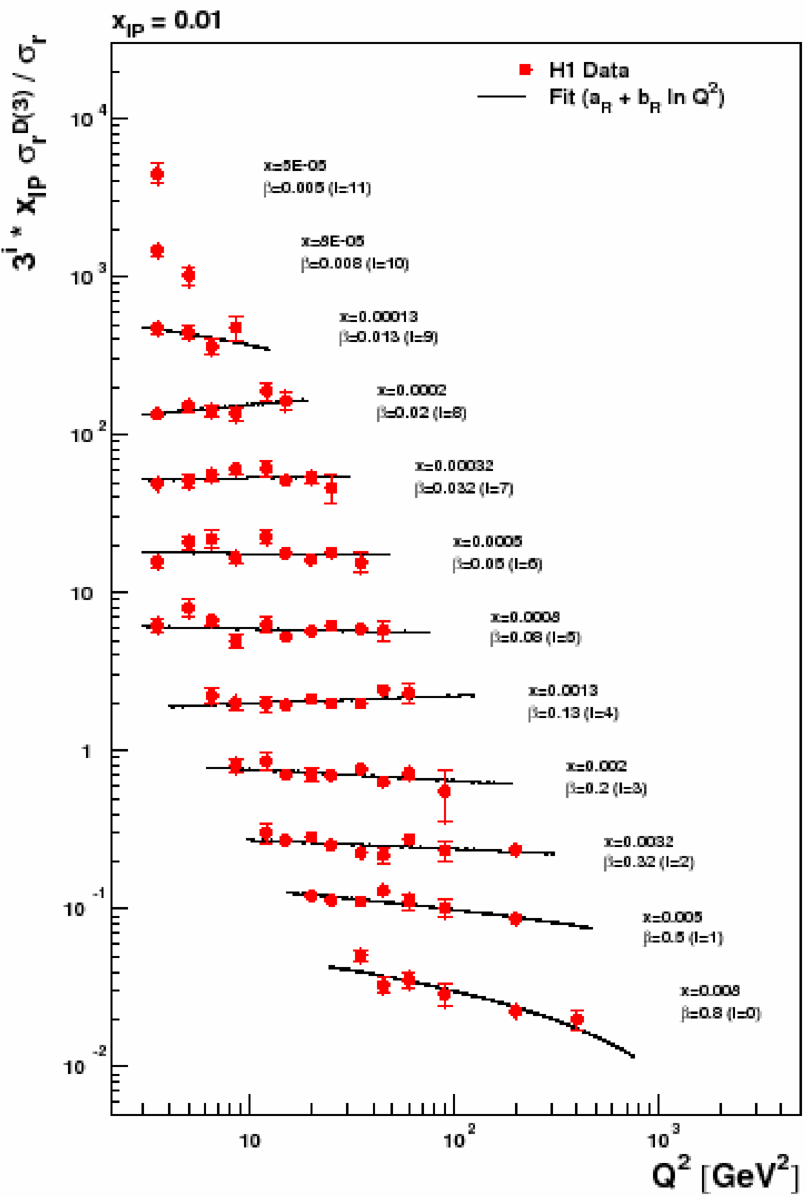


- No significant variation in Q^2 or β (consistent with p vtx factorization)
- Don't confirm $\alpha_{IP}(Q^2)$ seen by ZEUS

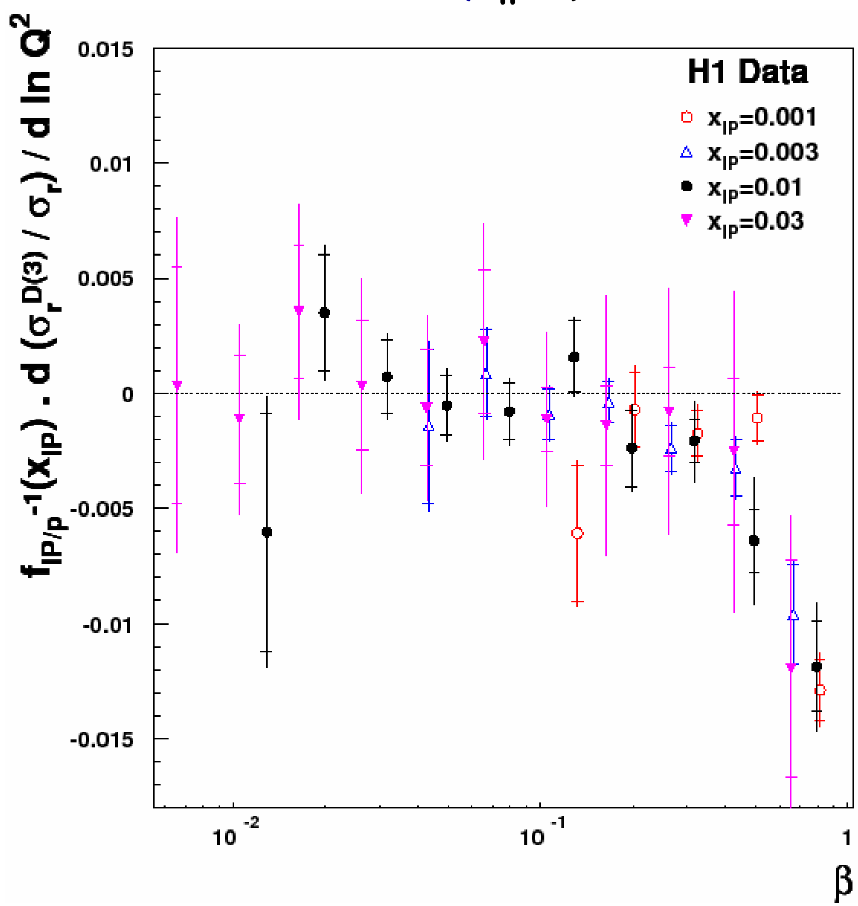
- Consistent result from fits to FPS data:

$$\alpha_{I\!P}(0) = 1.114 \pm 0.018(\text{stat.}) \pm 0.012(\text{syst.})^{+0.040}_{-0.020}(\text{th.})$$

Ratio diffractive / inclusive DIS



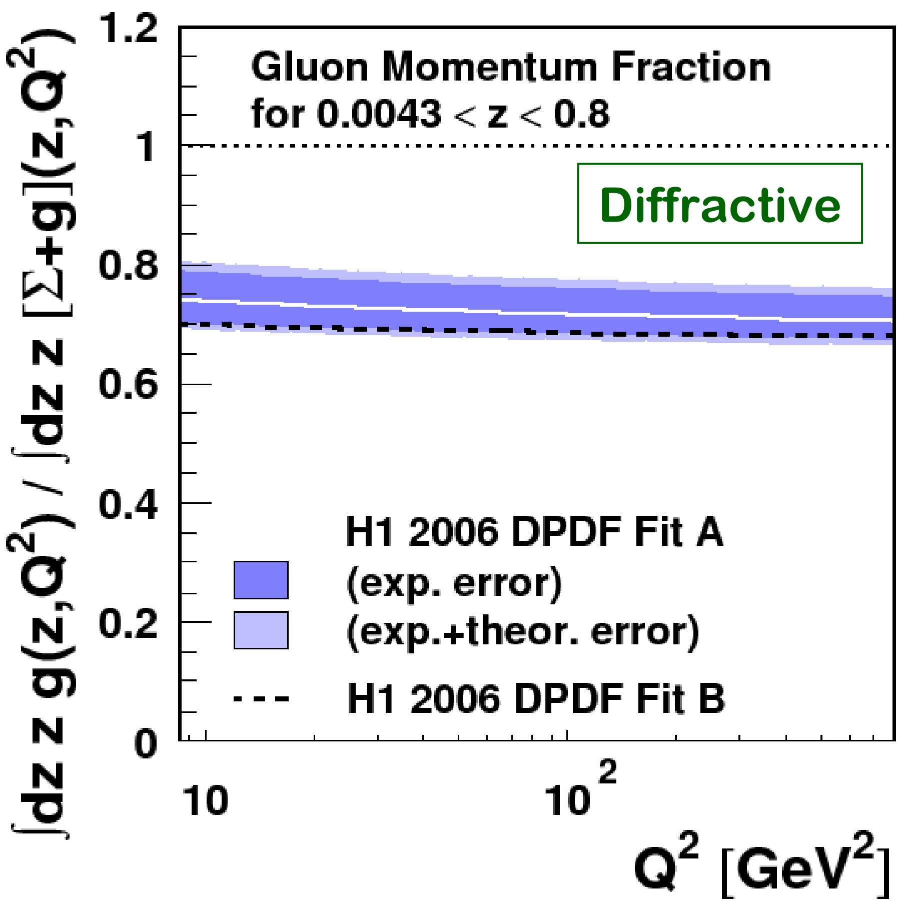
- Fit ratio at fixed (x_{IP},x) to A+B $\ln Q^2$

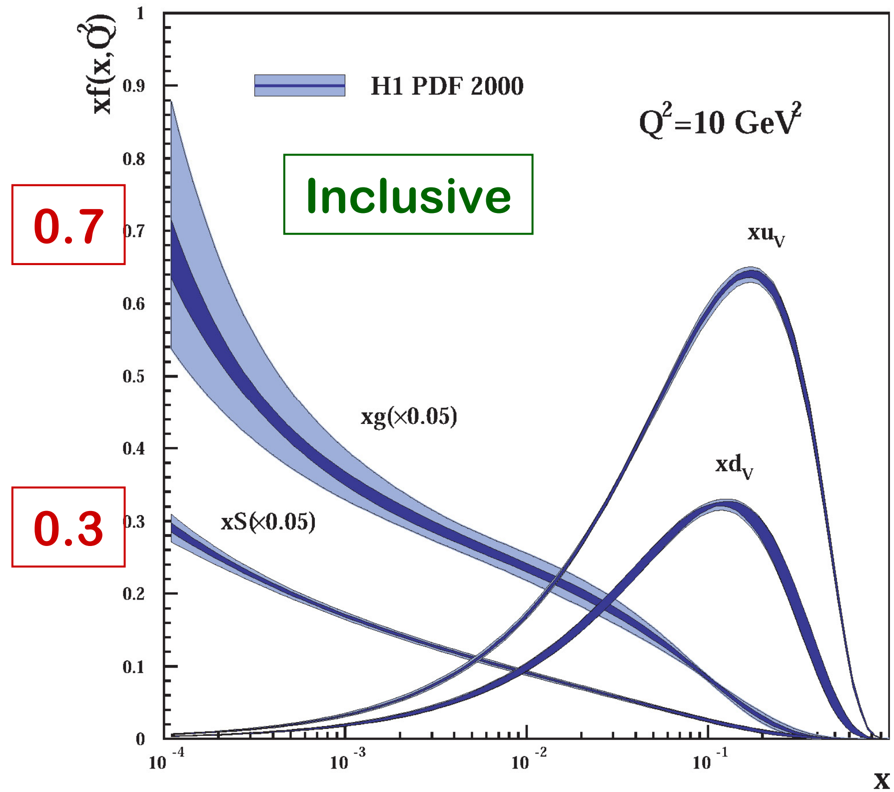


- Ratio remarkably flat (derivative~0) except at high β
- Ratio also measured vs x (not shown): approx. flat as well

Q^2 derivative and gluon/quark ratios

- **If** $\dfrac{\mathrm{d}(\sigma_r^D/\sigma_r)}{\mathrm{d}\ln Q^2} \sim 0$ **then** $\dfrac{1}{\sigma_r^D}\dfrac{\mathrm{d}\sigma_r^D}{\mathrm{d}\ln Q^2} \approx \dfrac{1}{\sigma_r}\dfrac{\mathrm{d}\sigma_r}{\mathrm{d}\ln Q^2} \quad \rightarrow \quad \dfrac{g^D}{q^D} \sim \dfrac{g}{q}$



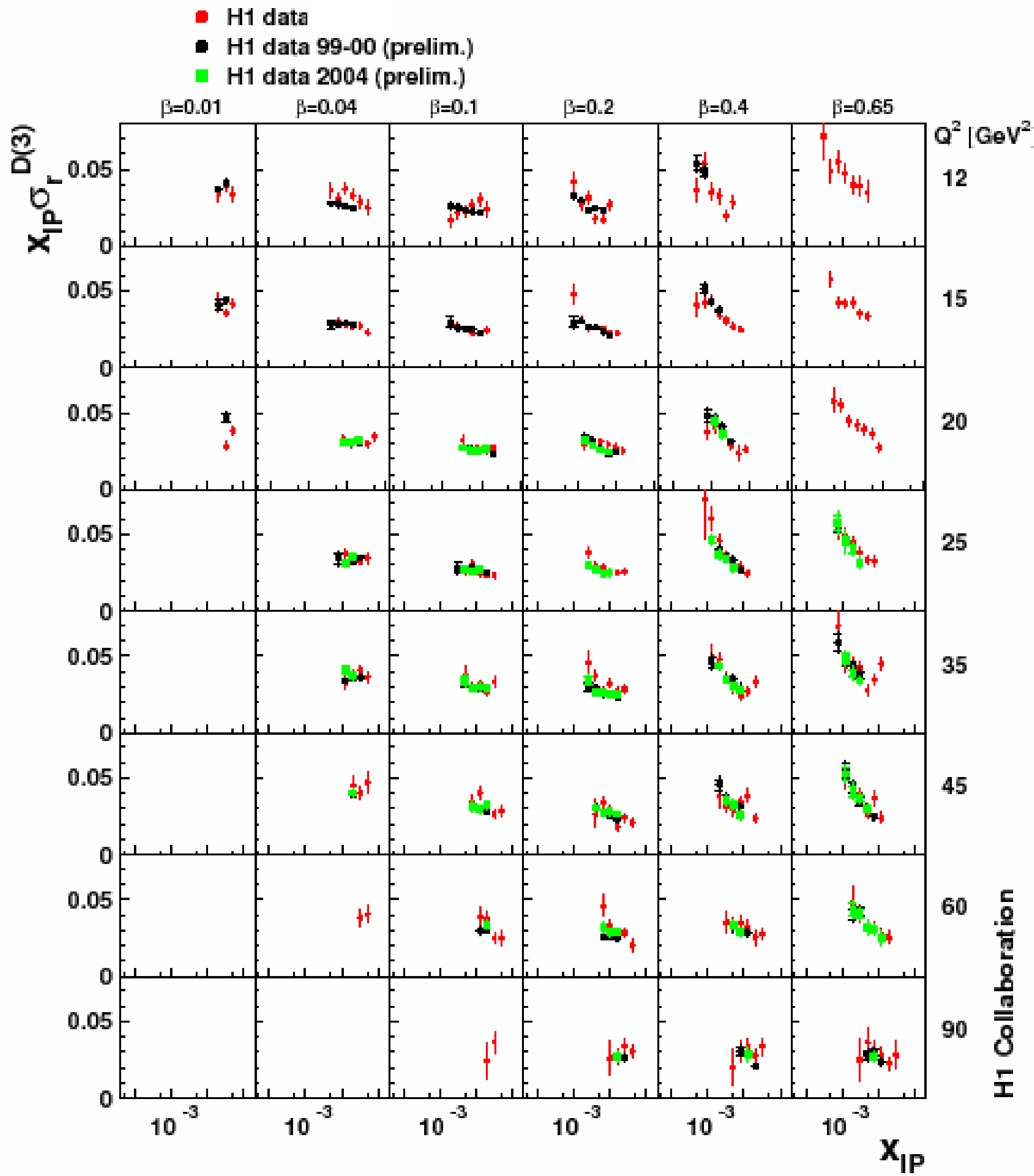


At low x, quark:gluon ratio ~ 70%/30%, common to diffractive and inclusive

New Data using Rapidity Gap Method

- **Published data**
- **Prel. 99-00 data, 34 pb^{-1}**
  - ❑ **10<Q²<105 GeV²**
- **Prel. 2004 data, 34 pb^{-1}**
  - ❑ **17.5<Q²<105 GeV²**

- **Large increase in statistics**
- **Consistent with published data**
- **For details, see contributed paper**



Summary

- H1 diffractive measurements using FPS and LRG methods published
  - hep-ex/0606003 and hep-ex/0606004 (both subm. to EPJC)
  - Data from two methods agree in detail! Also agreement with ZEUS-LPS
- New preliminary H1 data with large statistics

- Proton vertex factorization with reggeon exchanges at high x_{IP} provides good model for x_{IP} dependence: $\alpha_{IP}(t) \sim 0.118 + 0.06\,t$

- Ratio diffractive/inclusive DIS measured
  - ~flat with Q^2 (fixed x, x_{IP}), also with W (fixed Q^2, M_X)

- Diffractive PDFs extracted from NLO QCD fits to β, Q^2 dependences for $Q^2 \geq 8.5$ GeV^2 (H1 2006 DPDF Fits A+B)
  - Quark singlet very well constrained (~5%)
  - Gluon constrained to ~15%, but poorly known at high z
  - New DPDFs basis for prediction of diffractive cross sections at HERA, TEVATRON and LHC!
  - Use diffractive dijets to constrain gluon at high z (see talk by M.Kapishin)

Backup / Extra Figures

Data Sets and Observables

- **FPS data sample**
  - 1999-2000 data (28 pb^{-1})
  - Study of t dependence:

$$x_{I\!P}\frac{\mathrm{d}^2\sigma^{ep\to eXp}}{\mathrm{d}x_{I\!P}\mathrm{d}t}$$

- **LRG data sample**
  - 1997 data (2 pb^{-1}, $Q^2<13.5$ GeV^2)
  - 1997 data (11 pb^{-1}, $13.5<Q^2<105$ GeV^2)
  - 99-00 data (62 pb^{-1}, $Q^2>133$ GeV^2)

- The Diffractive reduced cross section:

$$\frac{\mathrm{d}^4\sigma^{ep\to eXp}}{\mathrm{d}x\mathrm{d}Q^2\mathrm{d}x_{I\!P}\mathrm{d}t}=\frac{4\pi\alpha^2}{xQ^4}\,Y_+\;\sigma_r^{D(4)}(x,Q^2,x_{I\!P},t)$$

- Relates to the structure functions F_2^D and F_L^D as:

$$\sigma_r^{D(4)}(x,Q^2,x_{I\!P},t)=F_2^{D(4)}-\frac{y^2}{Y_+}F_L^{D(4)}\approx F_2^{D(4)}$$

- Integrated over t:

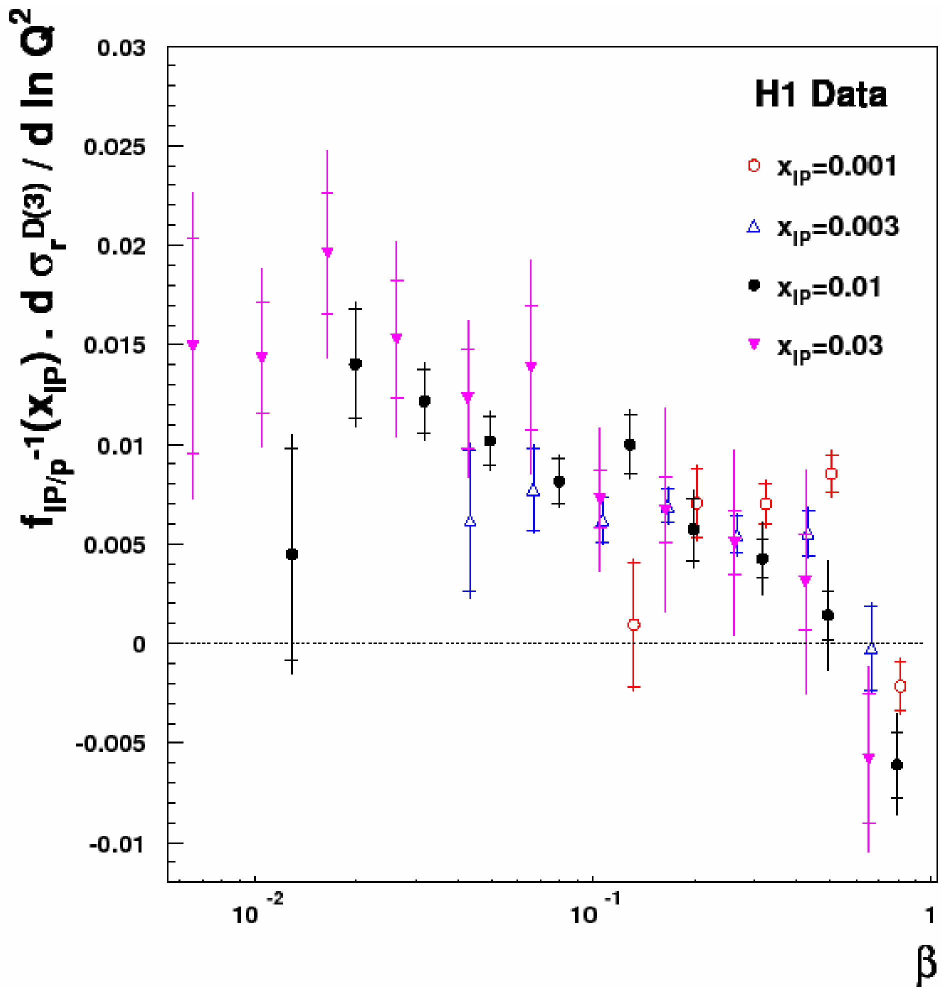
$$\sigma_r^{D(3)}(x,Q^2,x_{I\!P})=\int_{-1}^{t_{min}}\sigma_r^{D(4)}(x,Q^2,x_{I\!P},t)\mathrm{d}t$$

Logarithmic Q^2 derivative

- $\sigma_r^{D(3)}$ measures diffractive quark density
- Its dependence on Q^2 is sensitive to diffractive gluon density

- Fit data at fixed (x, x_{IP}) to $\sigma_r^D = A + B \ln Q^2$, so that $B = d\sigma_r^D / d \ln Q^2$

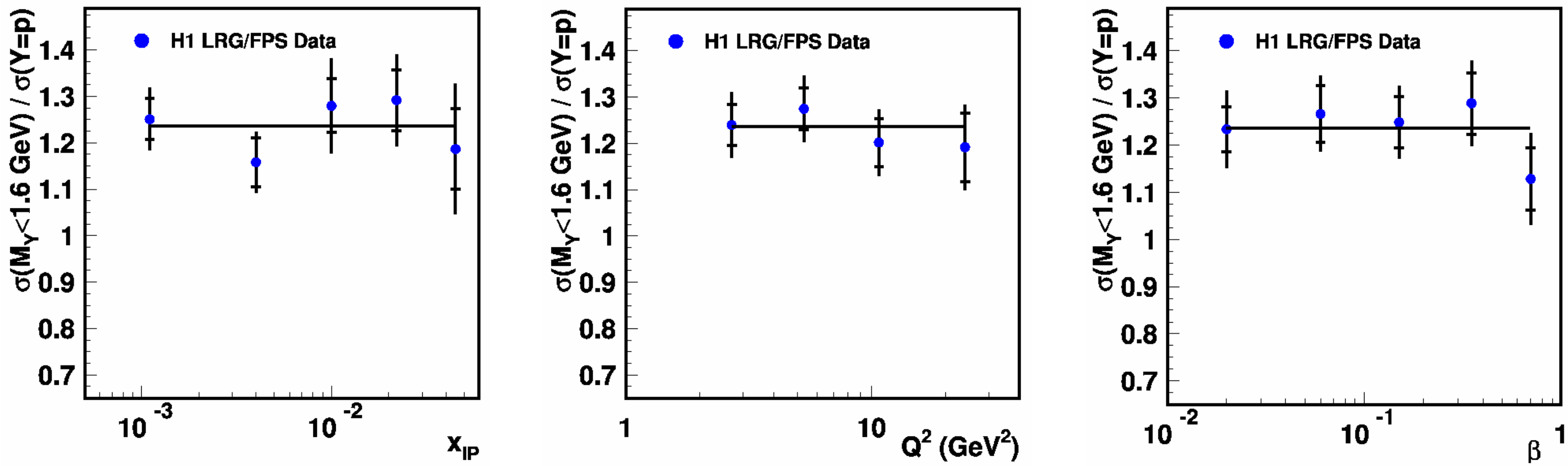
- Divide results by $f_{IP/p}(x_{IP})$ to compare different x_{IP} values



- Derivatives large and positive at low β
- Suggests large gluon density (independent of x_{IP} within errors)

Comparison LRG vs FPS Data

- **Form ratio LRG/FPS of measurements as function of x_{IP}, β or Q^2 after integration over others**



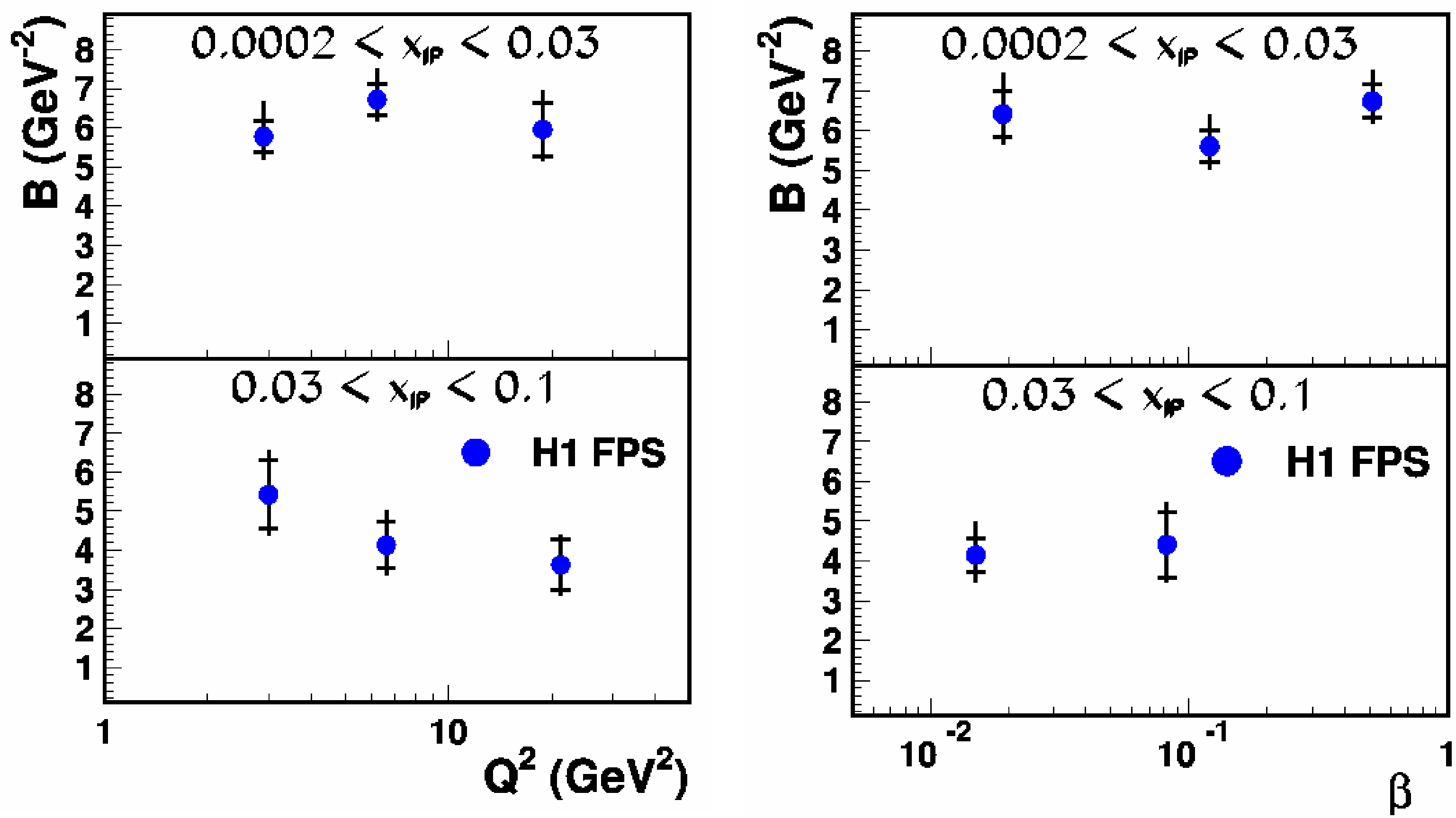
❑ **Independent of kinematics within errors**

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

- **Agreement in detail between methods**
- **M_Y dependence factorizes within (10% non-normalization) errors!**

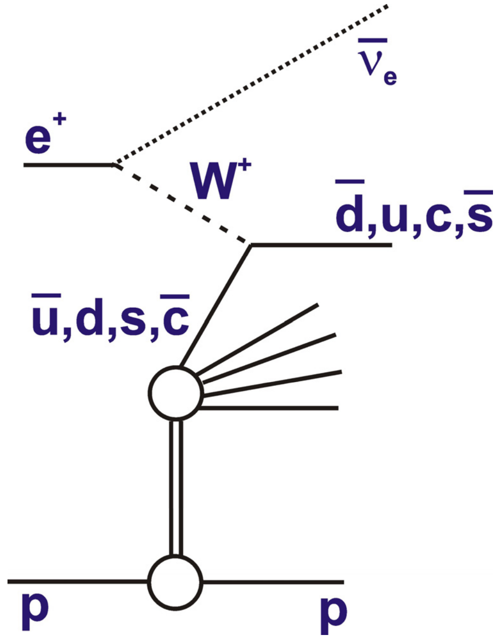
t-slope dependence on β or Q^2?

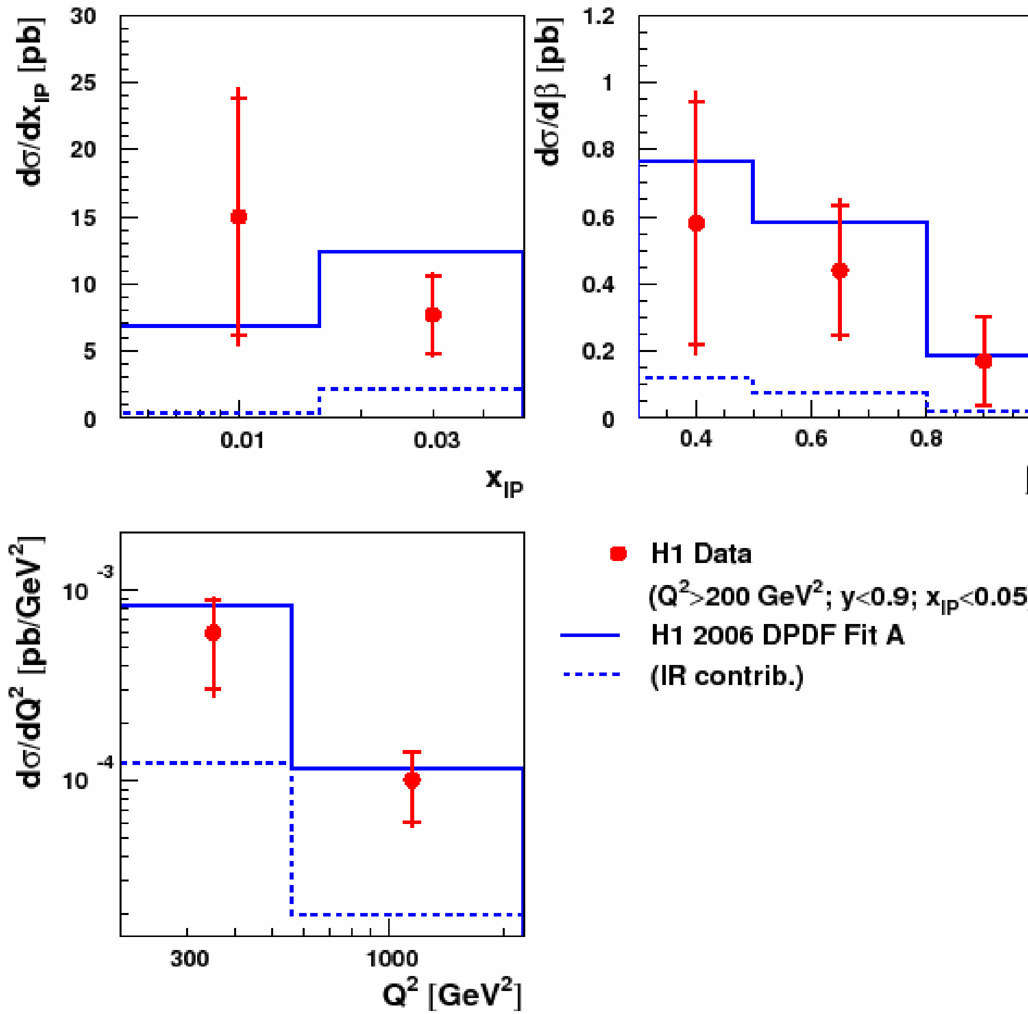
- **B measured double differentially in (β or Q^2) and x_{IP}**



- **No change of t dependence with β or Q^2 at fixed x_{IP}**
- **Proton vertex factorization for t dependence working within errors**

Diffractive Charged Current





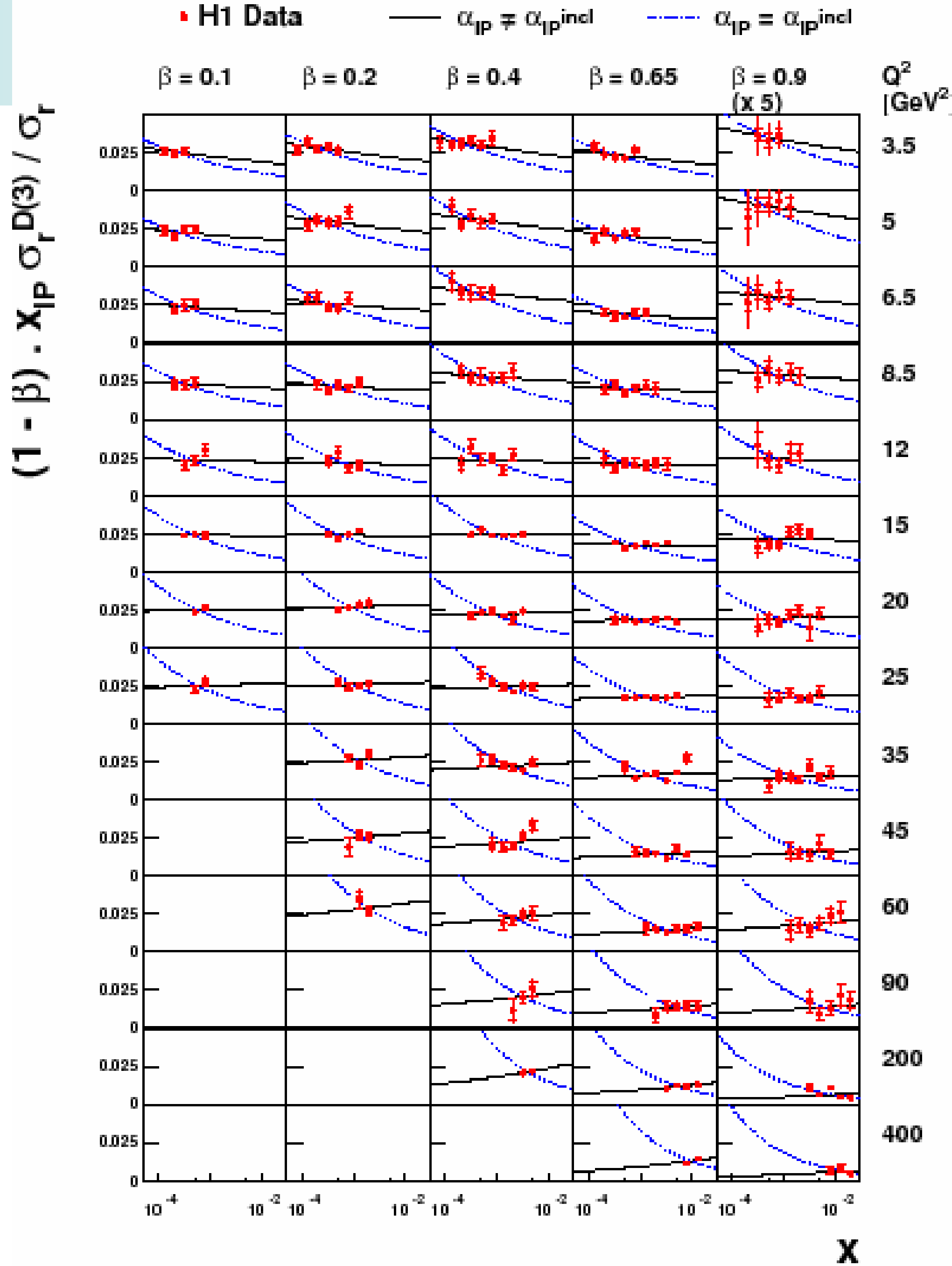
- Sensitive to flavour decomposition of singlet (completely unconstrained by NC data)
- Good agreement with 2006 DPDF fit (assumes u=d=s=ubar=dbar=sbar, c from BGF), though statistics very limited so far

Ratio diffractive/inclusive: x dependence

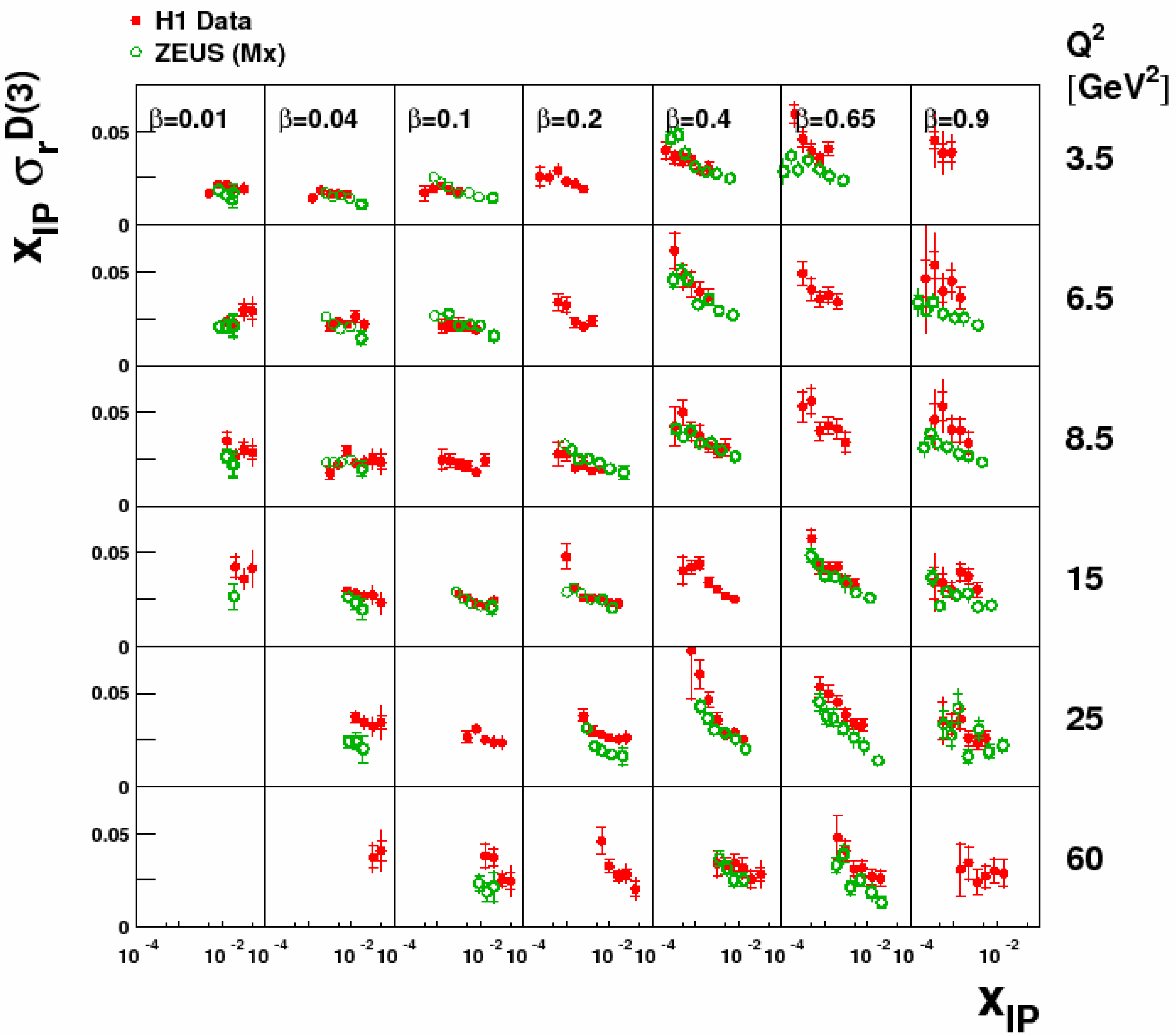
- **Plot σ_r^D/σ_r at fixed β,Q^2 (hence fixed M_X) vs x (~1/W^2)**
- **Corresponds to**

$$M_X^2 \cdot \frac{d\sigma_r^D}{dM_X^2} / \sigma_{tot}$$

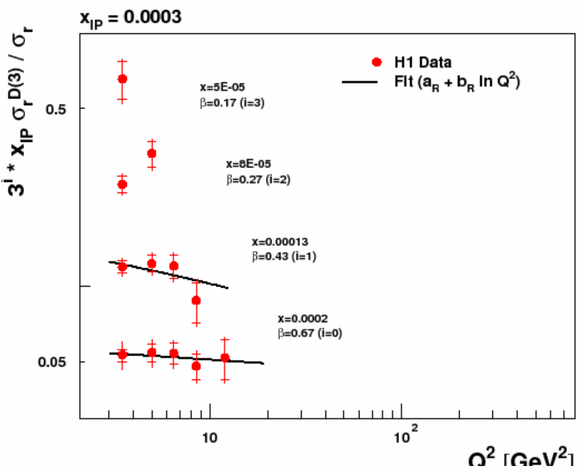
- **Remarkably flat vs x over most of kinematic range (bins with large F_L or IR contrib not shown)**
- **Diffractive and inclusive cross sections cannot be described with the same $\alpha_{IP}(0)$, even if it is Q^2 dependent**

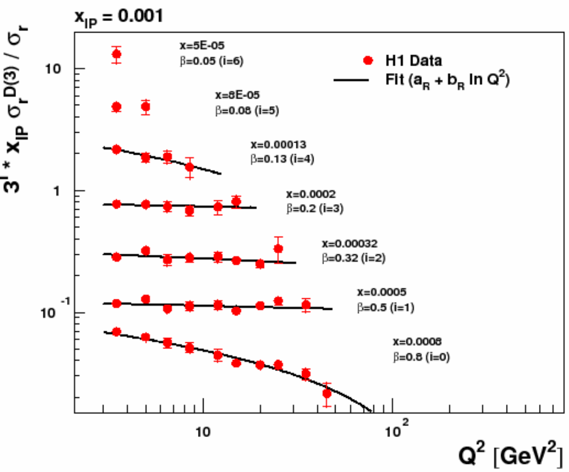


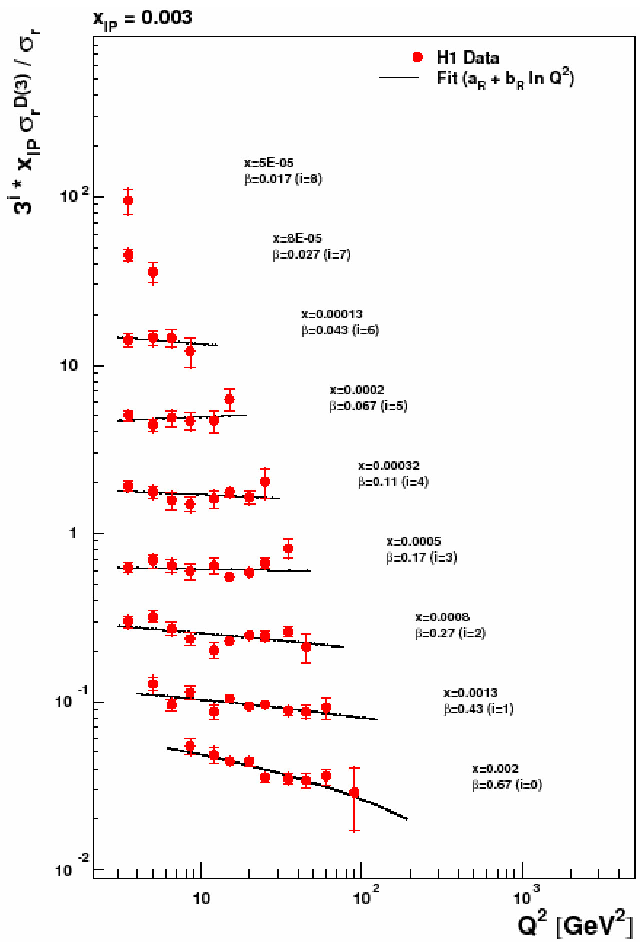
Comparison H1-LRG and ZEUS-Mx data

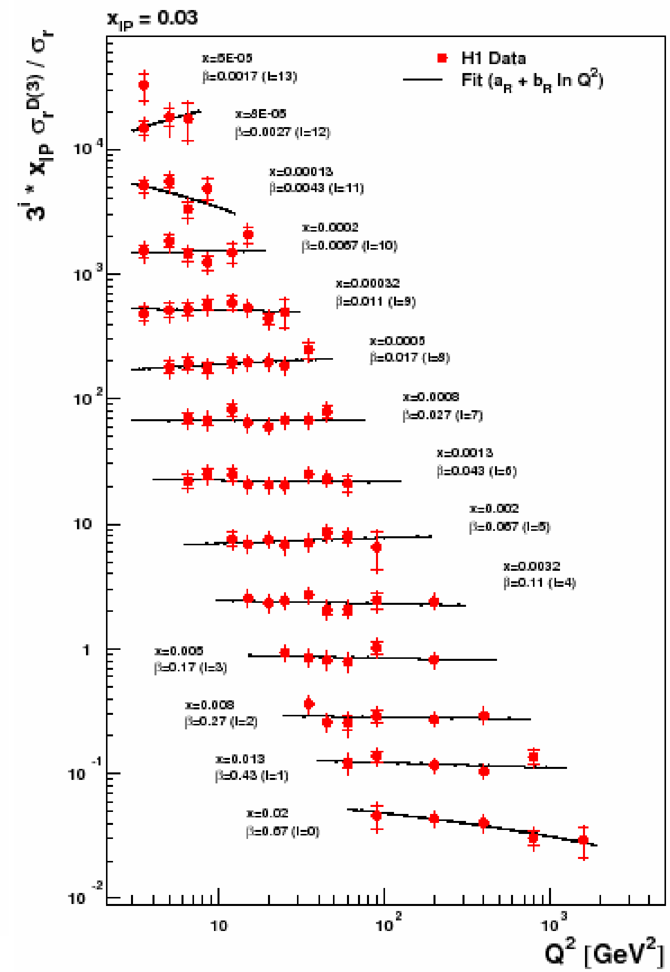


Ratio diffractive/inclusive vs Q^2 extra plots

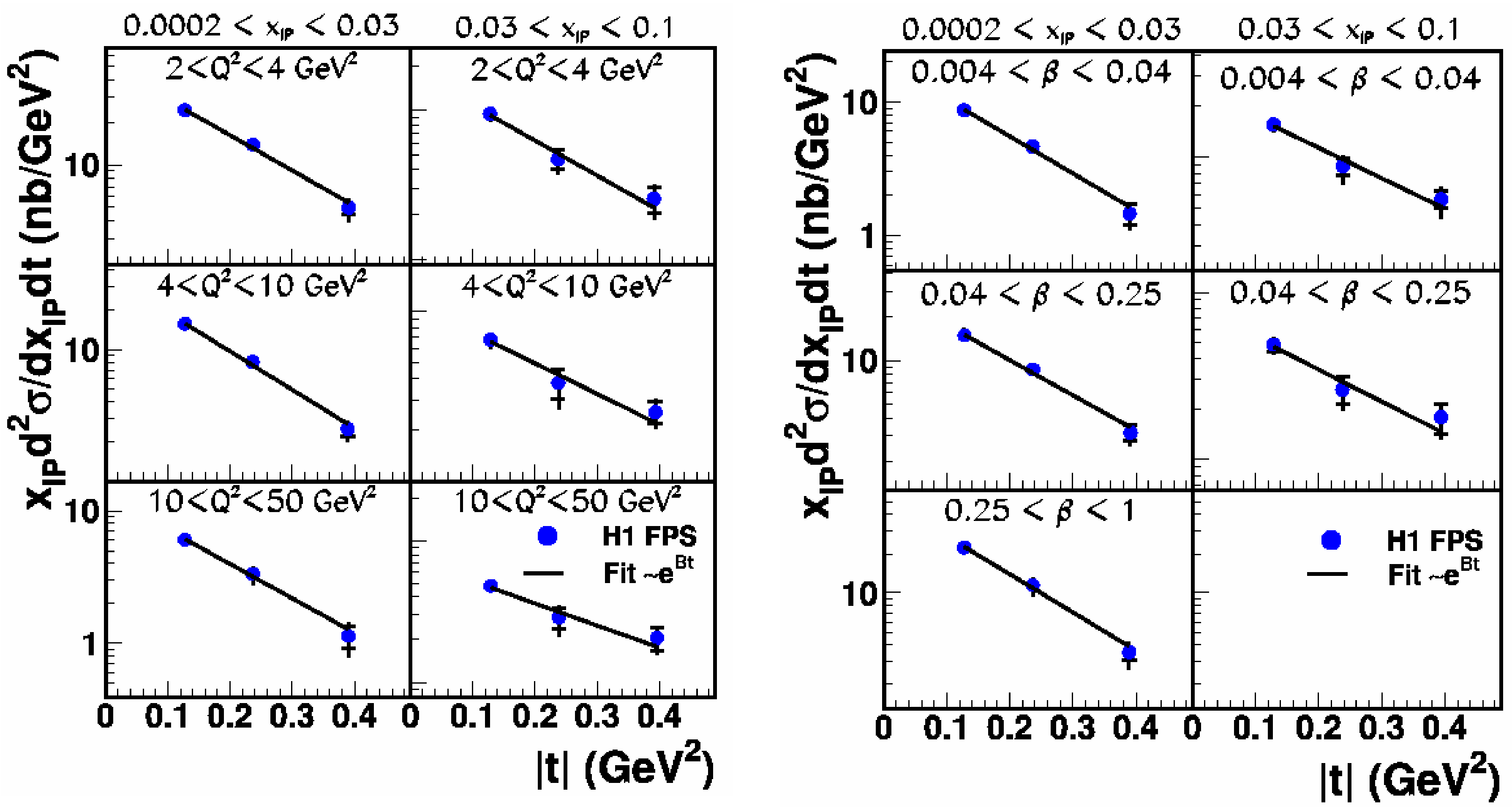




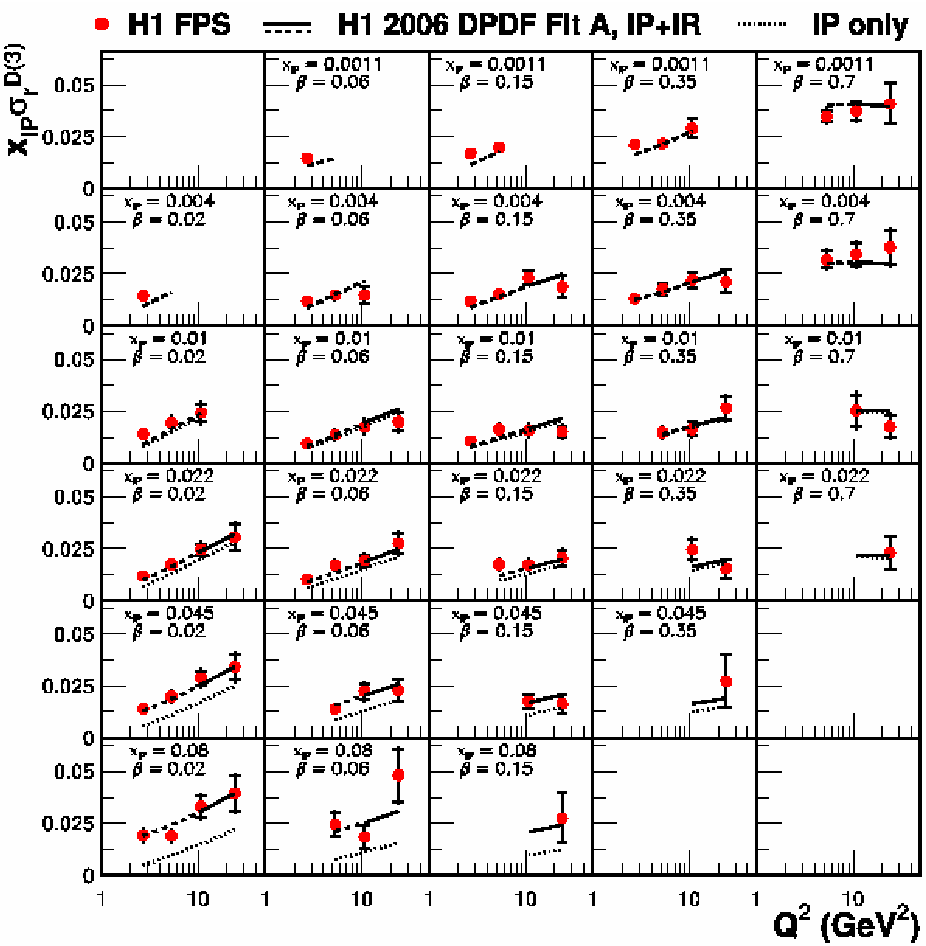


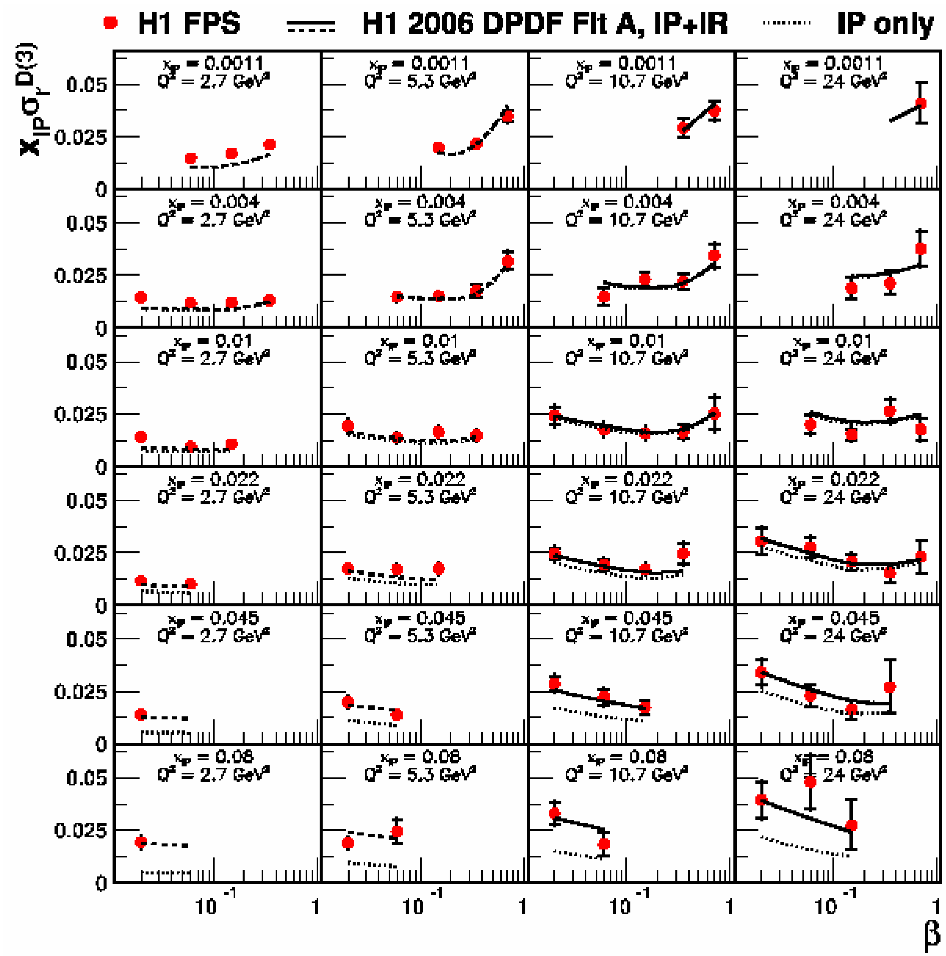


t dependence in bins of β or Q^2

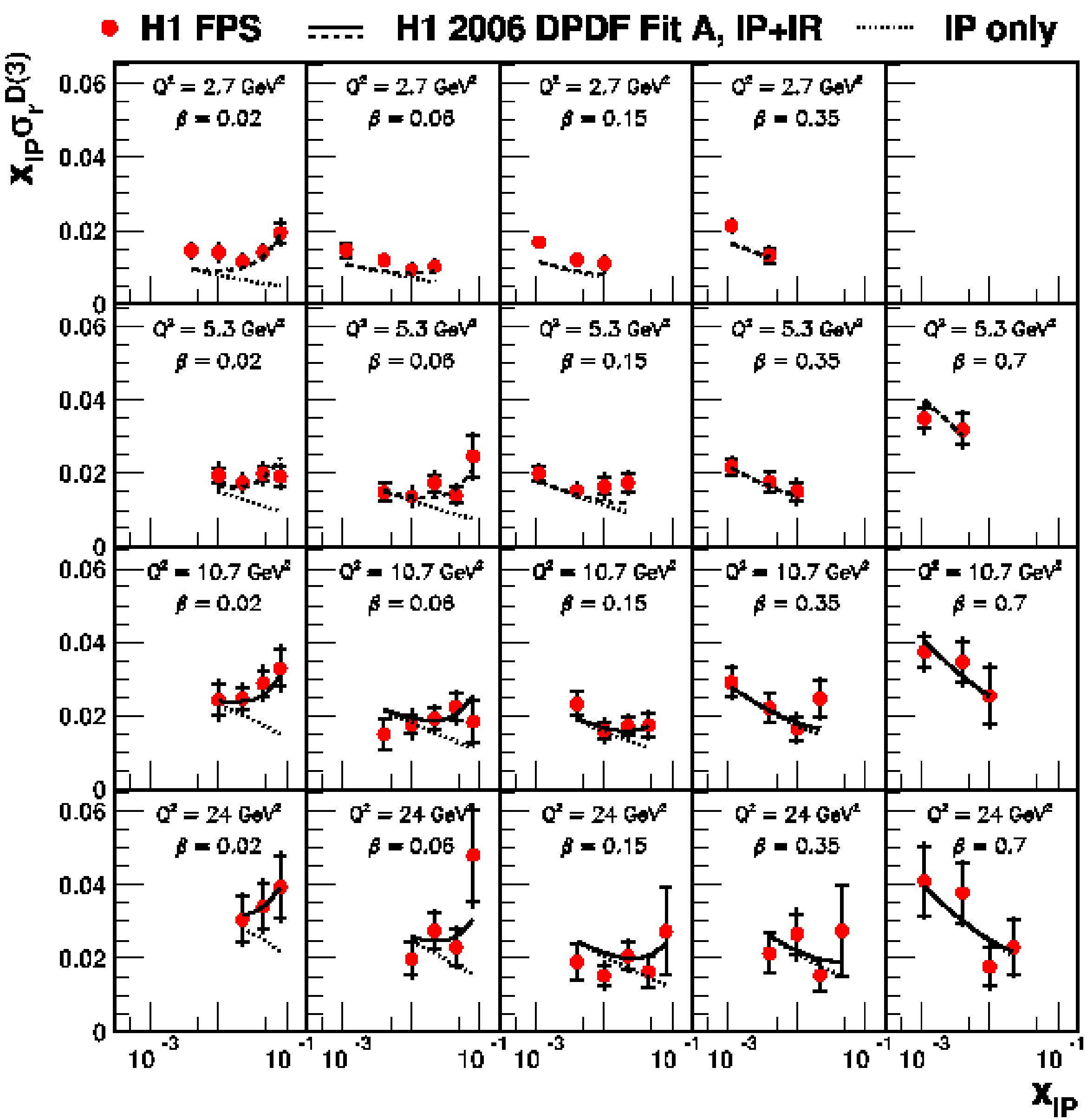


Q^2 and β dependences of FPS data





x_{IP} dependence of FPS data



Final Results from two Publications

DESY 06-049
May 2006
ISSN 0418-9833

arXiv:hep-ex/0606004 v1 1 Jun 2006

Measurement and QCD Analysis of the Diffractive Deep-Inelastic Scattering Cross Section at HERA

H1 Collaboration

DESY 06-049, hep-ex/0606004

Abstract

A detailed analysis is presented of the diffractive deep-inelastic scattering process $ep \to eXY$, where Y is a proton or a low mass proton excitation carrying a fraction $1-x_{I\!P} > 0.95$ of the incident proton longitudinal momentum and the squared four-momentum transfer at the proton vertex satisfies $|t| < 1\ \mathrm{GeV}^2$. Using data taken by the H1 experiment, the cross section is measured for photon virtualities in the range $3.5 \le Q^2 \le 1600\ \mathrm{GeV}^2$, triple differentially in $x_{I\!P}$, Q^2 and $\beta = x/x_{I\!P}$, where x is the Bjorken scaling variable. At low $x_{I\!P}$, the data are consistent with a factorisable $x_{I\!P}$ dependence, which can be described by the exchange of an effective pomeron trajectory with intercept $\alpha_{I\!P}(0) = 1.118 \pm 0.008\ (\mathrm{exp.})\ ^{+0.029}_{-0.010}\ (\mathrm{model})$. Diffractive parton distribution functions and their uncertainties are determined from a next-to-leading order DGLAP QCD analysis of the Q^2 and β dependences of the cross section. The resulting gluon distribution carries an integrated fraction of around 70% of the exchanged momentum in the Q^2 range studied. Total and differential cross sections are also measured for the diffractive charged current process $e^+p \to \bar{\nu}_e XY$ and are found to be well described by predictions based on the diffractive parton distributions. The ratio of the diffractive to the inclusive neutral current ep cross sections is studied. Over most of the kinematic range, this ratio shows no significant dependence on Q^2 at fixed $x_{I\!P}$ and x or on x at fixed Q^2 and β.

Submitted to *Eur. Phys. J.* C

DESY 06-048
May 2006
ISSN 0418-9833

arXiv:hep-ex/0606003 v1 1 Jun 2006

Diffractive Deep-Inelastic Scattering with a Leading Proton at HERA

H1 Collaboration

DESY 06-048, hep-ex/0606003

Abstract

The cross section for the diffractive deep-inelastic scattering process $ep \to eXp$ is measured, with the leading final state proton detected in the H1 Forward Proton Spectrometer. The data analysed cover the range $x_{I\!P} < 0.1$ in fractional proton longitudinal momentum loss, $0.08 < |t| < 0.5\ \mathrm{GeV}^{-2}$ in squared four-momentum transfer at the proton vertex, $2 < Q^2 < 50\ \mathrm{GeV}^2$ in photon virtuality and $0.004 < \beta = x/x_{I\!P} < 1$, where x is the Bjorken scaling variable. For $x_{I\!P} \lesssim 10^{-2}$, the differential cross section has a dependence of approximately $d\sigma/dt \propto e^{6t}$, independently of $x_{I\!P}$, β and Q^2 within uncertainties. The cross section is also measured triple differentially in $x_{I\!P}$, β and Q^2. The $x_{I\!P}$ dependence is interpreted in terms of an effective pomeron trajectory with intercept $\alpha_{I\!P}(0) = 1.114 \pm 0.018\ (\mathrm{stat.}) \pm 0.012\ (\mathrm{syst.})\ ^{+0.040}_{-0.020}\ (\mathrm{model})$ and a sub-leading exchange. The data are in good agreement with an H1 measurement for which the event selection is based on a large gap in the rapidity distribution of the final state hadrons, after accounting for proton dissociation contributions in the latter. Within uncertainties, the dependence of the cross section on x and Q^2 can thus be factorised from the dependences on all studied variables which characterise the proton vertex, for both the pomeron and the sub-leading exchange.

Submitted to *Eur. Phys. J.* C