

Low x workshop, Lisbon, Portugal, June 28 - July 1, 2006

H1 measurements on $F_2^{D(3)}$ and $F_2^{D(4)}$ and diffractive PDF

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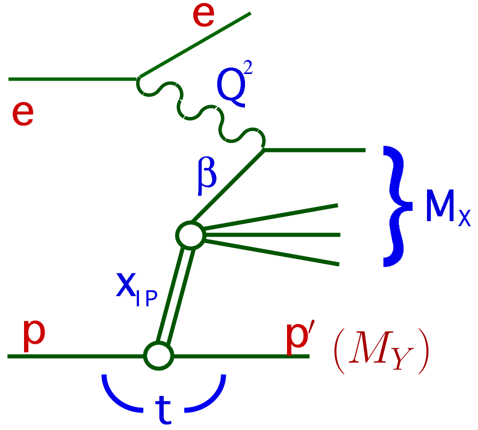
- Data samples and Phenomenological framework
- $(x_{I\!P}, t)$ - dependencies and Pomeron trajectory
- (Q^2, β) - dependencies and diffractive PDFs
- Summary and Outlook

Diffraction at HERA

- Fundamental aim: understand high energy limit of QCD (gluodynamics; CGC ?)
- Novelty: for the first time probe partonic structure of diffractive exchange
- Practical motivations: study factorisation properties of diffraction; try to transport to hh scattering (e.g. predict diffractive Higgs production at LHC)



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

(momentum fraction of colour singlet exchange)

$$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$$

(fraction of exchange momentum, coupling to γ^*)

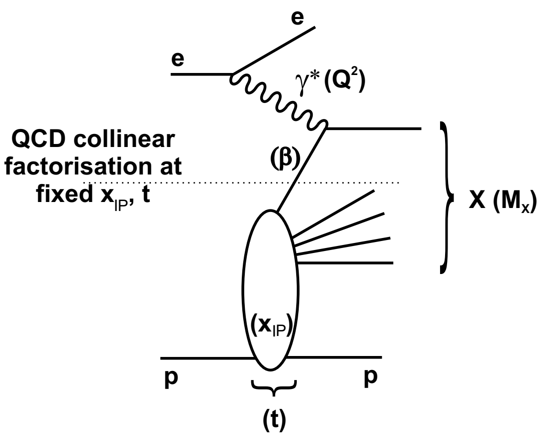
$$t = (p-p')^2$$

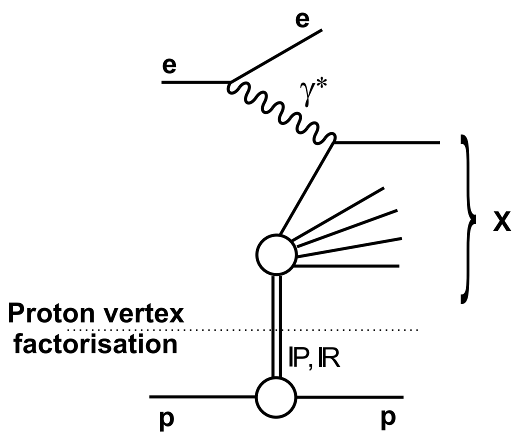
(4-momentum transfer squared)

$$\frac{d^4\sigma}{dx_{I\!P}\, dt\, d\beta\, dQ^2} = \frac{4\pi\alpha^2}{\beta Q^4}\left(1-y+\frac{y^2}{2}\right)\sigma_r^{D(4)}(x_{I\!P}, t, \beta, Q^2)$$

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)}F_L^{D(4)} \quad \Rightarrow \quad F_2^{D(3)} = \int dt F_2^{D(4)}$$

Factorisation properties in diffractive DIS





QCD versus Regge factorisation

QCD factorisation

(leading twist, coll.approx. for DDIS: Collins et al.)

$$\sigma_r^{D(4)} \propto \sum_i \hat{\sigma}^{\gamma^* i}(x, Q^2) \otimes f_i^D(x, Q^2; x_{I\!P}, t) + \mathcal{O}(1/Q)$$

- $\hat{\sigma}^{\gamma^* i}$ – hard scattering part, same as in inclusive DIS
- f_i^D – diffractive PDF's, valid at fixed $x_{I\!P}, t$ which obey (NLO) DGLAP

$\Rightarrow$ Inhomogeneous term ('direct Pomeron') not considered

Regge factorisation

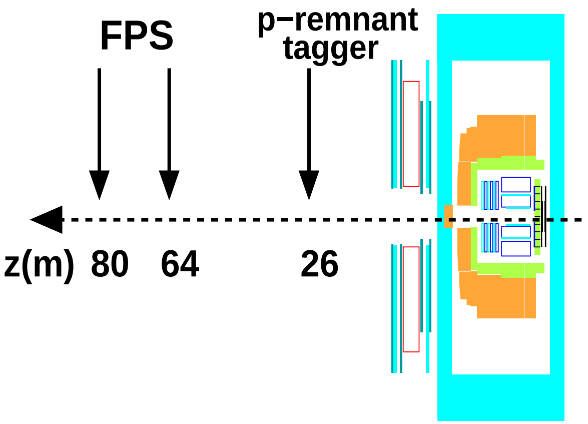
(conjecture, e.g. RPM by Ingelman,Schlein)

$$F_2^{D(4)}(x_{I\!P}, t, \beta, Q^2) = \Phi(x_{I\!P}, t) \cdot F_2^{I\!P}(\beta, Q^2)$$

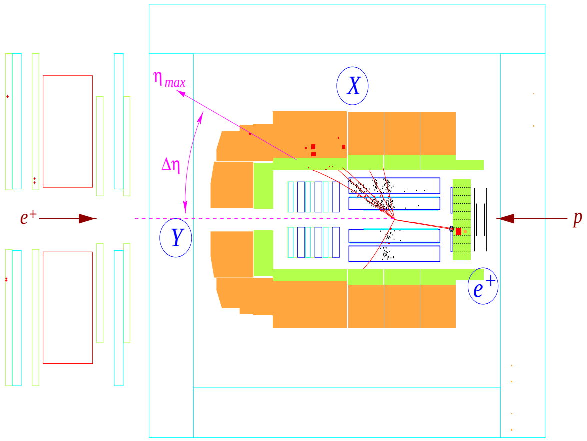
- In this case shape of diffractive PDF's is independent of $x_{I\!P}, t$ while normalization is controlled by Regge flux $\Phi(x_{I\!P}, t) = A_{I\!P} \frac{e^{B_{I\!P} t}}{x_{I\!P}^{2\alpha_{I\!P}(t)-1}}$
- Sub-leading $I\!R$ contributions are included in the same manner

Selecting Diffractive Events at HERA

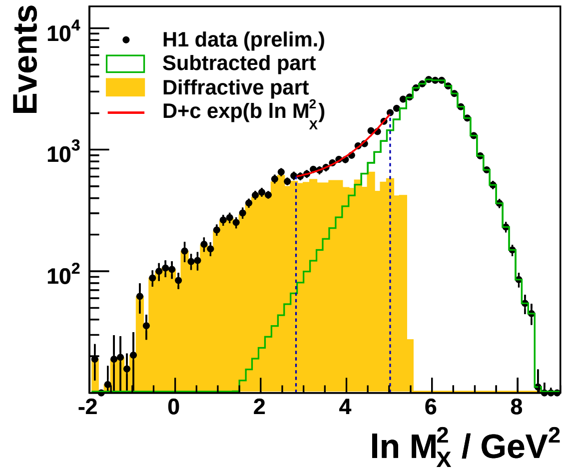
FPS



LRG



M_X



- clean sample, free of p-dissociative bgr
- large statistics, bigger phase space coverage: $3.3 < \eta_{\rm gap} < 7.5$ (tag) $\eta_{\rm max} < 3.3$ (meas)
- provides t measurement
- integrate over $t > -1$ GeV^2
- access to high $x_{I\!P}$ $\Rightarrow$ better constrain sub-leading terms
- some dissociative admixture remains in the sample: $M_Y < 1.6$ GeV
- limited statistics (beam cond., geom. acceptance)
- M_X method is not well adapted to H1 detector and hence is used only to study systematics and in limited η range

Data Samples

- **FPS sample** (hep-ex/0606003)

  1999-2000 data (28 pb^{-1}, $2 < Q^2 < 50$ GeV^2)

  $0.08 < |t| < 0.5$ GeV^2, $x_{I\!P} < 0.10$
  Precision = (8-30)$\%_{\text{stat}} \oplus 12\%_{\text{syst}} \oplus 10\%_{\text{norm}}$

- **LRG samples** (hep-ex/0606004)

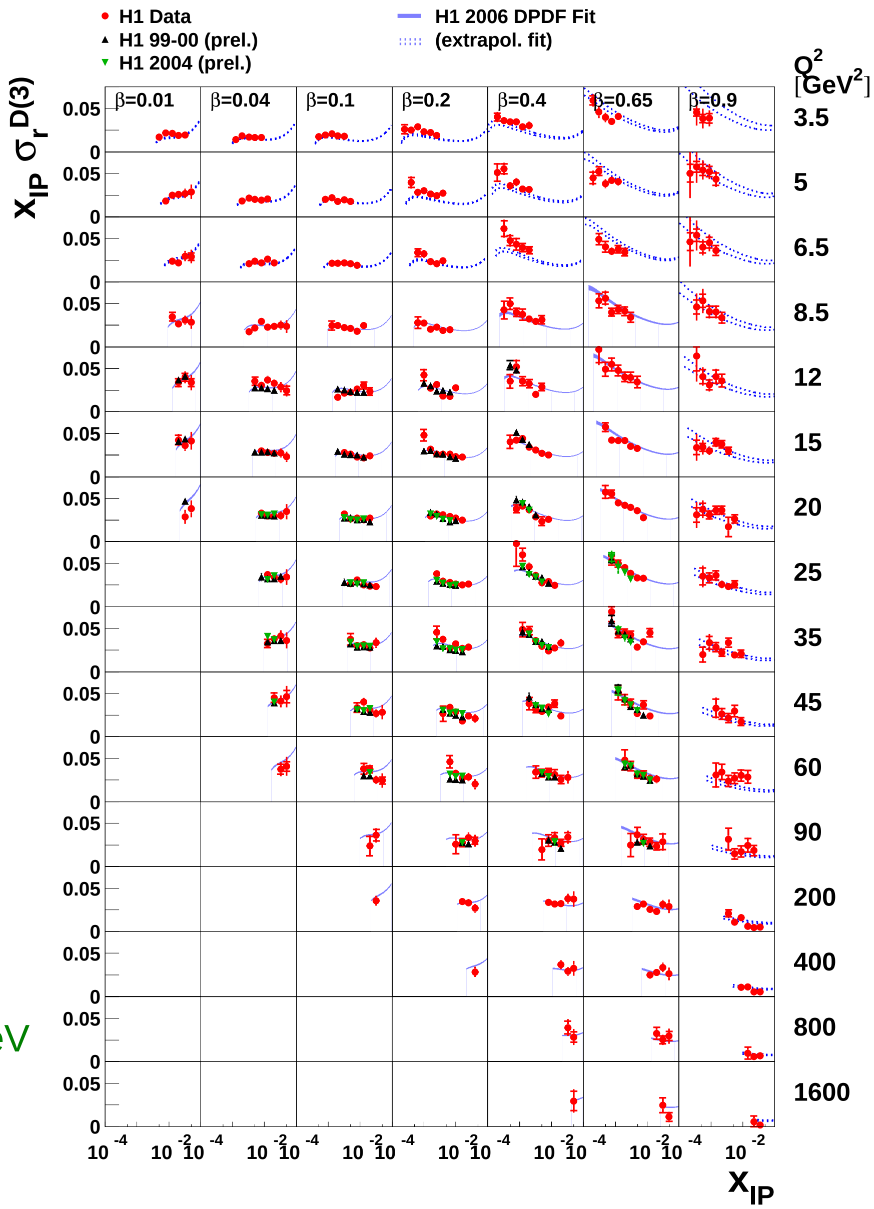
  1997 data (2 pb^{-1}, $3 < Q^2 < 13.5$ GeV^2)
  1997 data (11 pb^{-1}, $13.5 < Q^2 < 105$ GeV^2)
  1999-2000 data (62 pb^{-1}, $Q^2 > 133$ GeV^2)

  $M_Y < 1.6$ GeV, $|t| < 1$ GeV^2, $x_{I\!P} < 0.05$
  Precision = (5-20)$\%_{\text{stat}}\oplus$(5-15)$\%_{\text{syst}}\oplus$(6-8)$\%_{\text{norm}}$

- **LRG samples** (preliminary at DIS 2006)

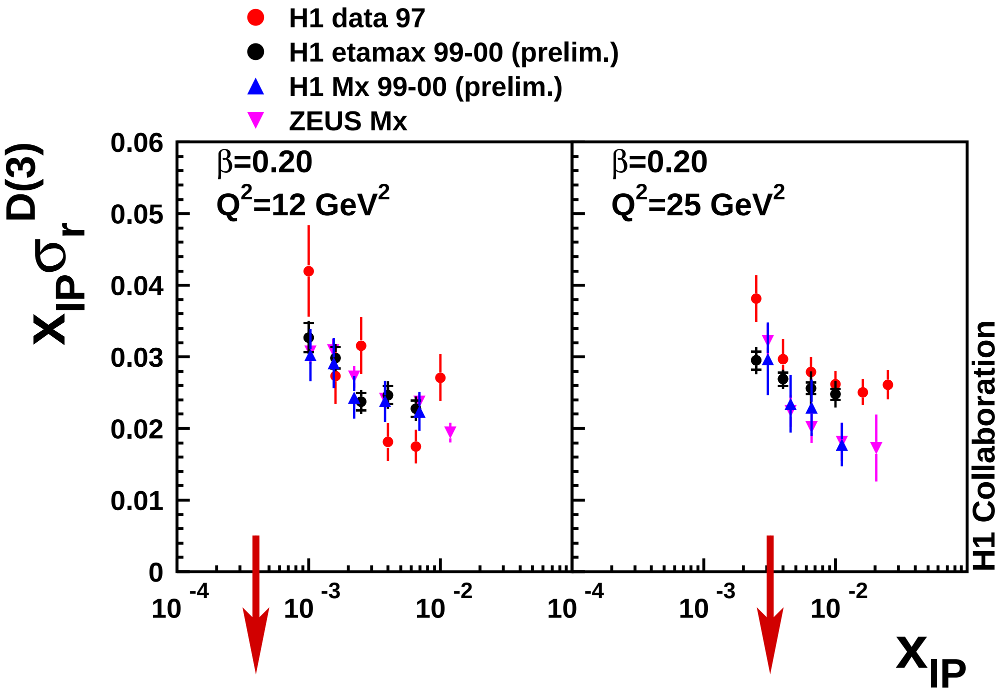
  1999-2000 data (34 pb^{-1}, $10 < Q^2 < 105$ GeV^2)
  2004 data (34 pb^{-1}, $17.5 < Q^2 < 105$ GeV^2)

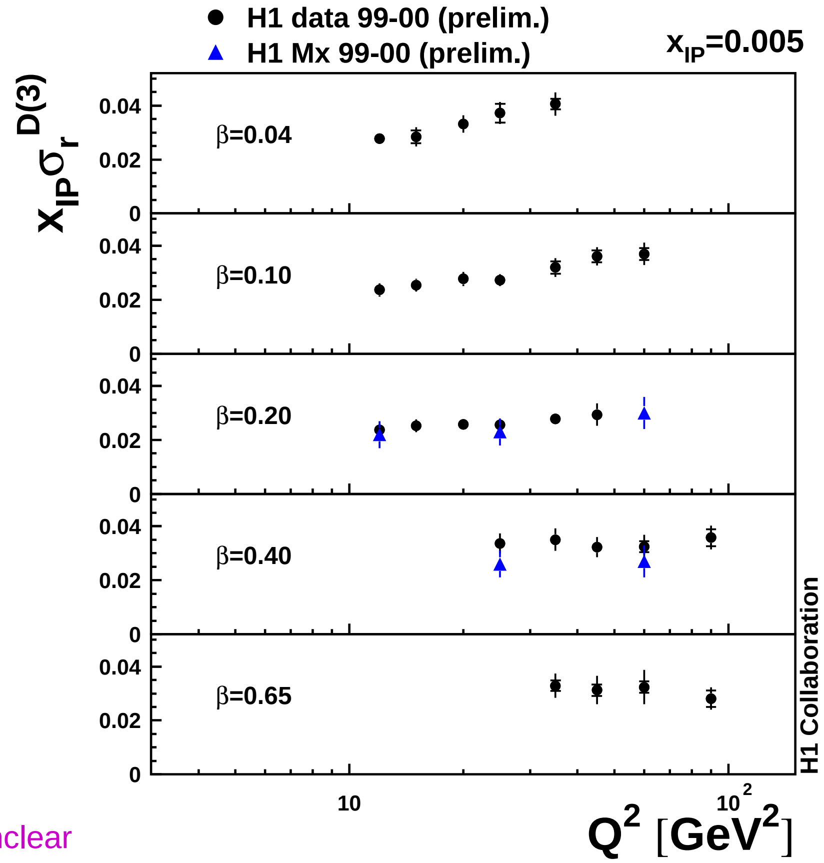
  $M_Y < 1.6$ GeV, $|t| < 1$ GeV^2, $x_{I\!P} < 0.1$, $M_X > 4$ GeV
  Precision = (3-10)$\%_{\text{stat}}\oplus$(5-15)$\%_{\text{syst}}\oplus$(6-8)$\%_{\text{norm}}$



LRG data: $\eta_{\max}$ vs M_X results

- Compare all data sets in two specific bins



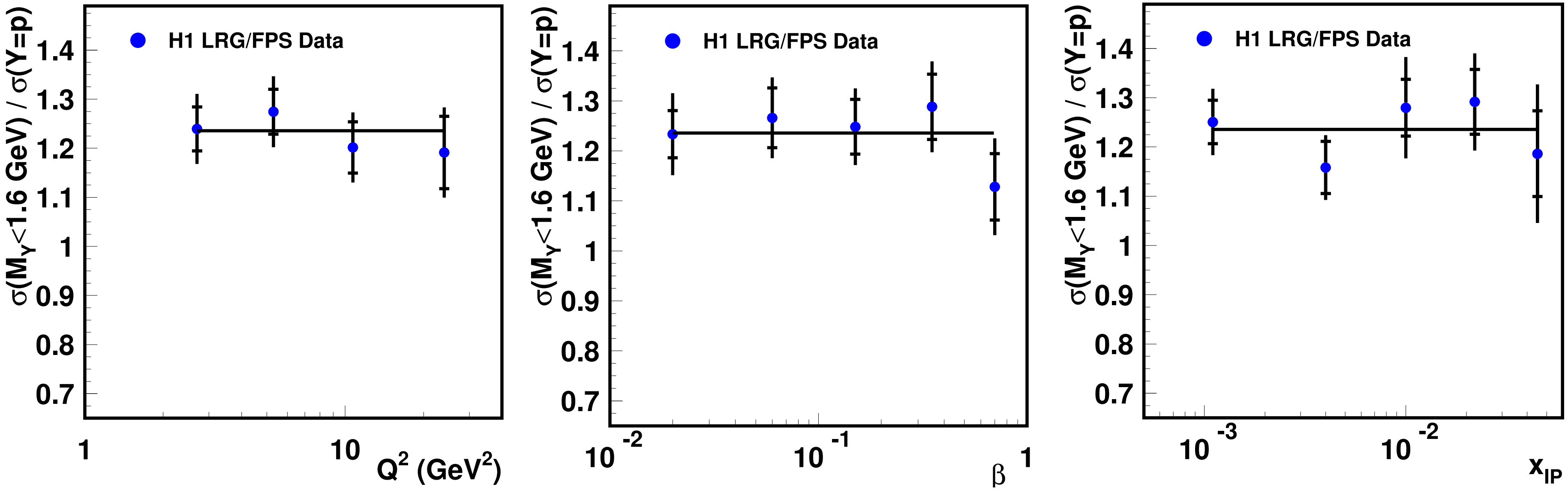


- Bin of typical agreement between data sets and methods
- Bin of worst agreement
  - $\Rightarrow$ large systematics for M_X
  - $\Rightarrow$ syst. difference $M_X/\eta_{\max}$ unclear

- Good overall agreement between all data samples with only few exceptions
- Too few M_X points $\longrightarrow$ method is not well adapted to H1 apparatus

Comparison of LRG vs FPS results

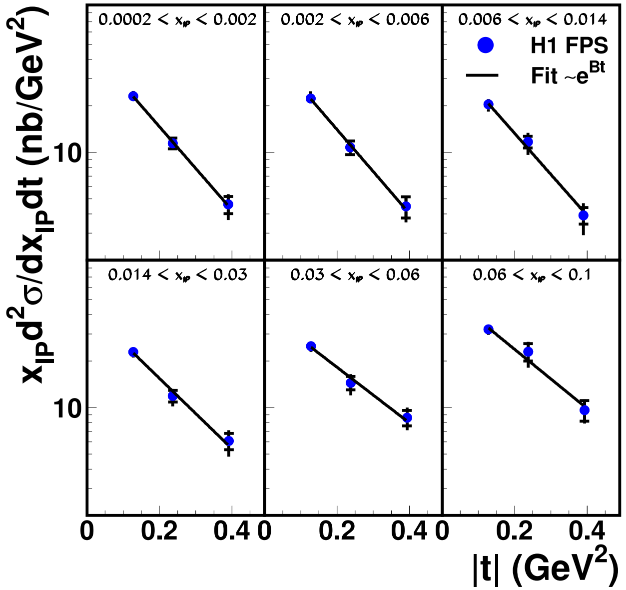
Plot LRG/FPS ratio as a function of Q^2, β and $x_{I\!P}$ after intergation over the other two:

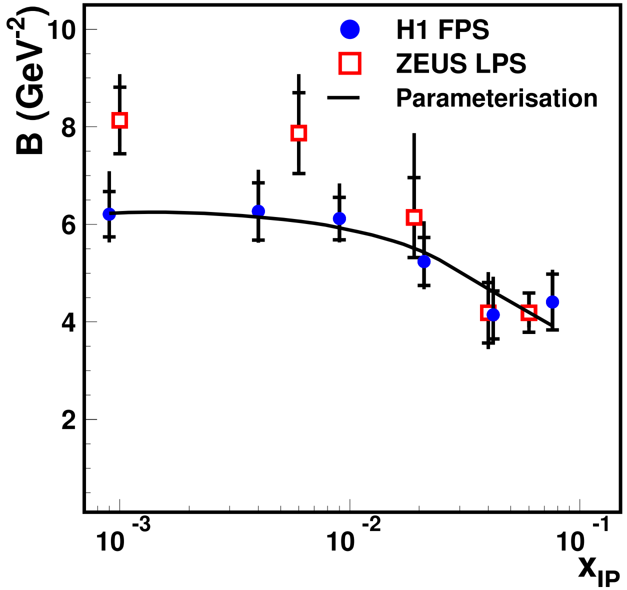


$$\frac{\sigma(M_Y < 1.6\mathrm{GeV})}{\sigma(Y = p)} = 1.23 \pm 0.03(\mathrm{stat}) \pm 0.16(\mathrm{syst})$$

- M_Y dependence factorises within errors (consistent with DIFFVM prediction: $1.15^{+0.15}_{-0.08}$)
- Dominant uncertainty arises from the normalisation of FPS and LRG data

t Dependence and $\alpha'_{I\!P}$



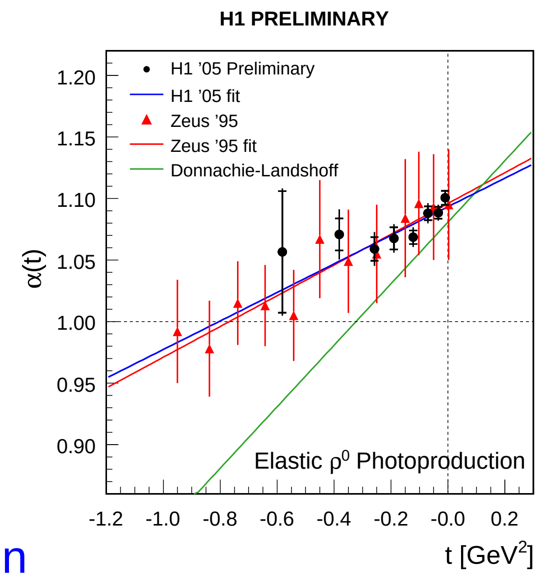


$B = B_{I\!P} + 2\alpha'_{I\!P} \ln(1/x_{I\!P})$ at small $x_{I\!P}$:

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

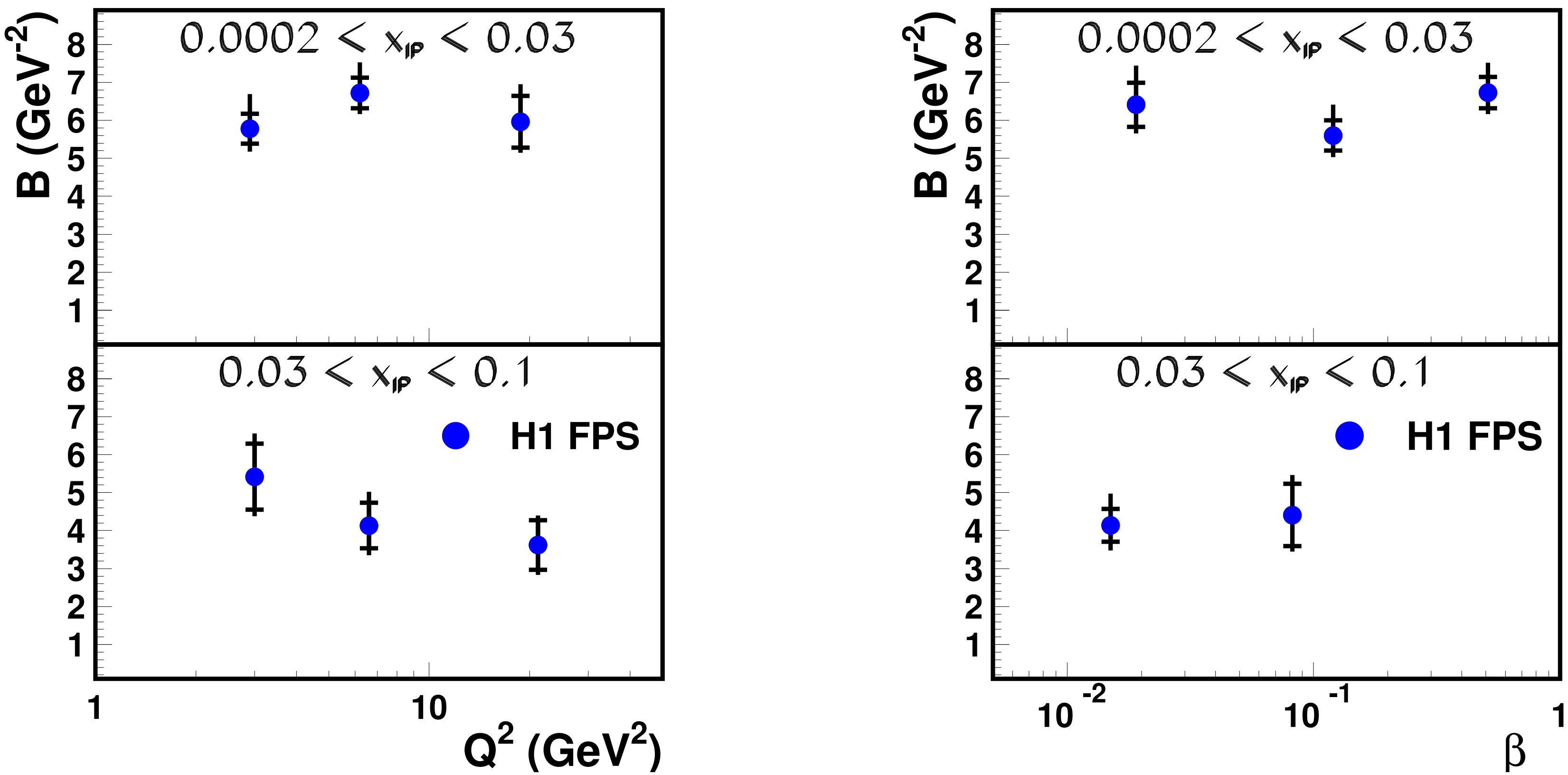
from fit of $F_2^{D(4)}$ at large $x_{I\!P}$:

$\alpha'_{I\!R} = 0.3^{+0.6}_{-0.3}$ GeV^{-2} $\qquad$ $B_{I\!R} = 1.6^{-1.6}_{+0.4}$ GeV^{-2}



★ Measured $\alpha'_{I\!P}$ is smaller than that in hh reactions
and consistent with $I\!P$ trajectory measured in VM production

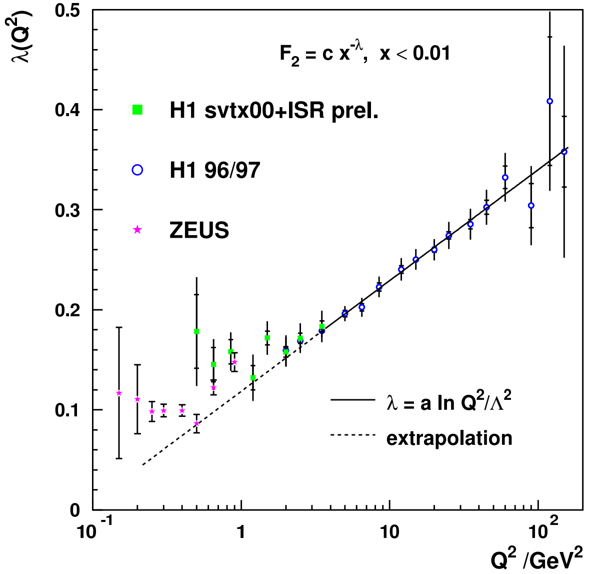
t slope dependence on Q^2 and β

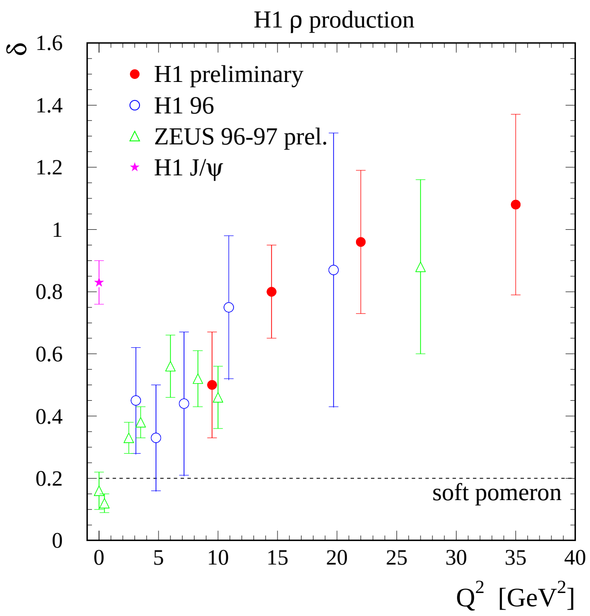


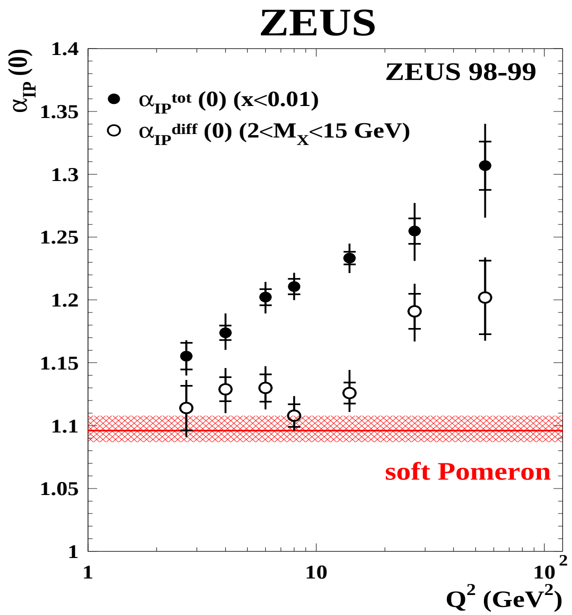
- t dependence does not change with Q^2 or β at fixed $x_{\mathbb{P}}$
- Supports proton vertex factorisation for t dependence within errors

Question: what about $x_{\mathbb{P}}$ dependence and $\alpha_{\mathbb{P}}(0)$?

Pomeron intercept in inclusive, elastic and diffractive DIS







$\alpha_{\mathbb{P}}(0) = 1 + \lambda$

$\alpha_{\mathbb{P}}(0) \simeq 1 + \frac{\delta}{4}$

- Similar behaviour of $\alpha_{\mathbb{P}}(0)$ vs Q^2 in inclusive DIS and elastic VM production (expected from Optical Theorem)

- In diffractive DIS more complicated behavior is observed, inconclusive so far (significant extra systematics from F_L^D and $\alpha'_{\mathbb{P}}$ uncertainties)

$x_{\mathbb{P}}$ dependence and Effective Pomeron Intercept

- From FPS data: $\alpha_{\mathbb{P}}(0) = 1.114 \pm 0.018(\mathrm{stat}) \pm 0.012(\mathrm{syst})^{+0.040}_{-0.020}(\mathrm{model})$

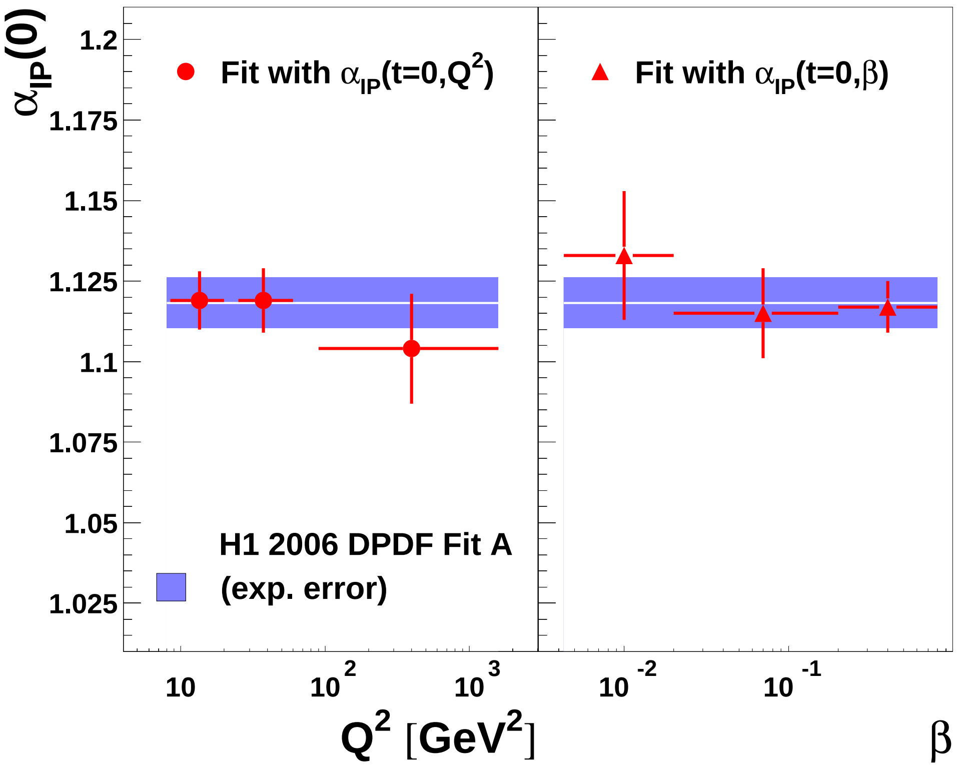
- From QCD fit to LRG data:

$\alpha_{\mathbb{P}}(0) = 1.118 \pm 0.008(\mathrm{exp})^{+0.029}_{-0.010}(\mathrm{mod})$

- Dominant uncertainty arises from strong correlation with $\alpha'_{\mathbb{P}}$

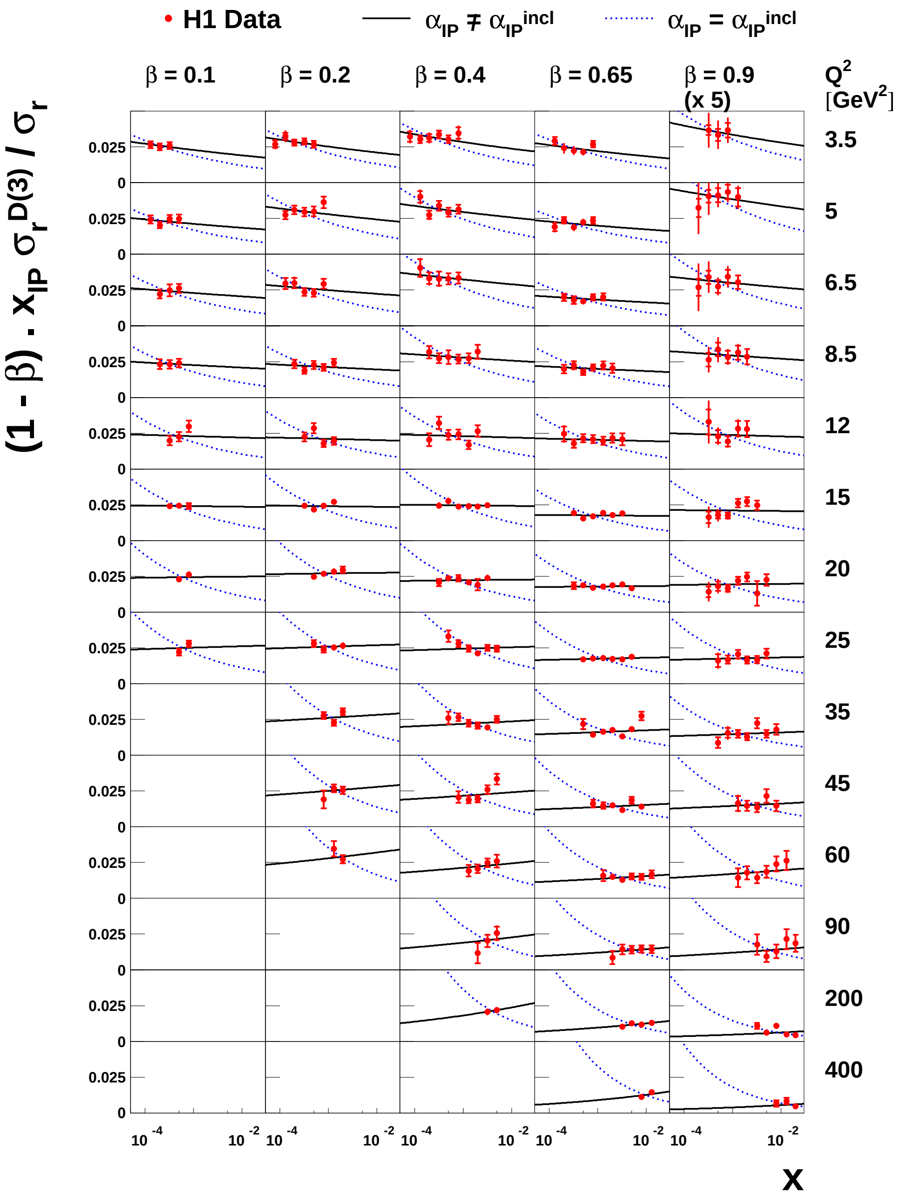
- No significant variation with Q^2 or β observed

- $\alpha_{\mathbb{P}}(0)$ is only slightly above 'soft Pomeron' value of 1.08

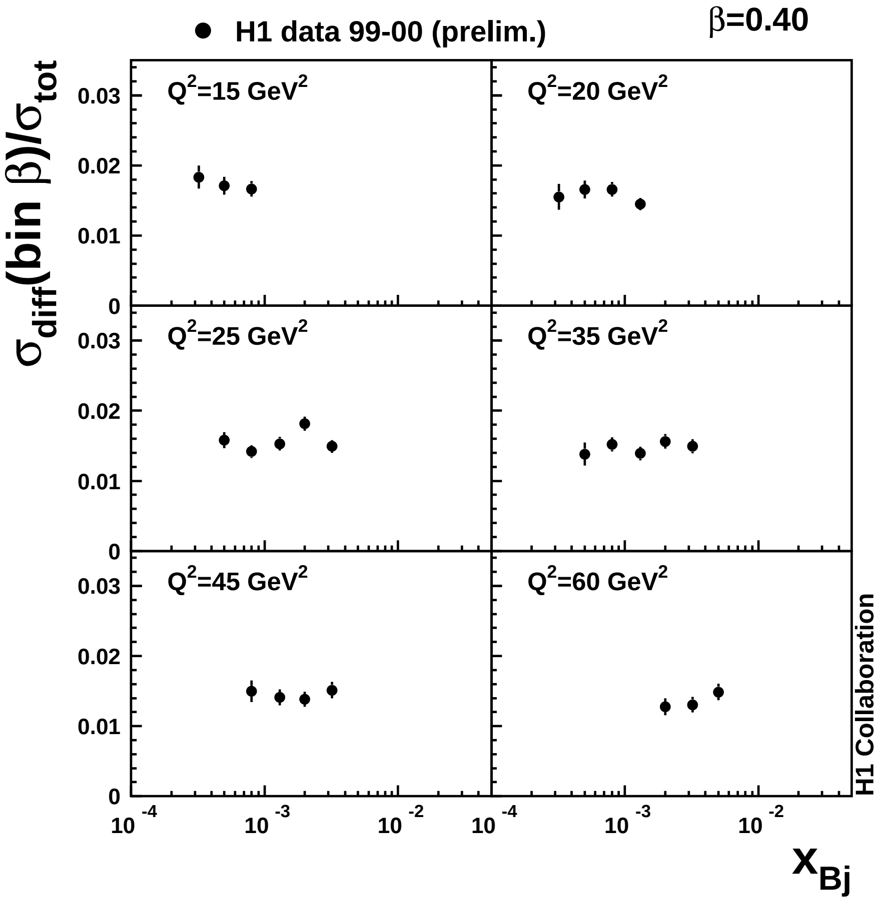


★ Consistent with Regge factorisation hypothesis in studied region

Diffractive to incusive ratio $\sigma_r^{D(3)}/\sigma_r$



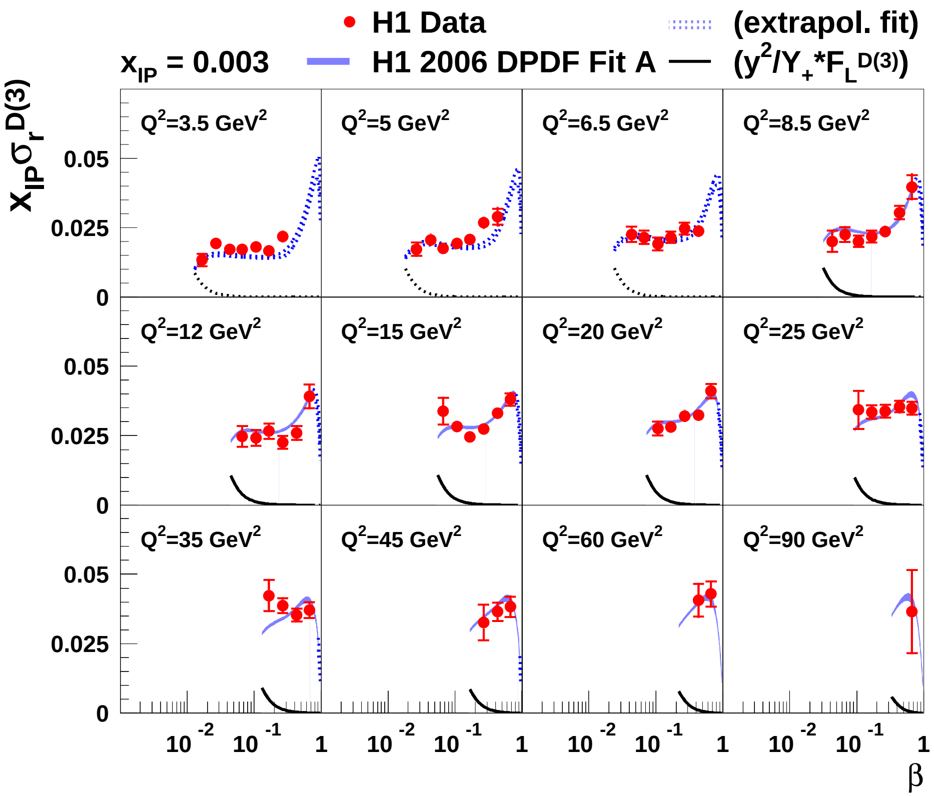
- Remarkably flat in contrast to Regge prediction
- Cannot be descibed with the same $\alpha_{I\!P}(0)$ even if it is Q^2 dependent

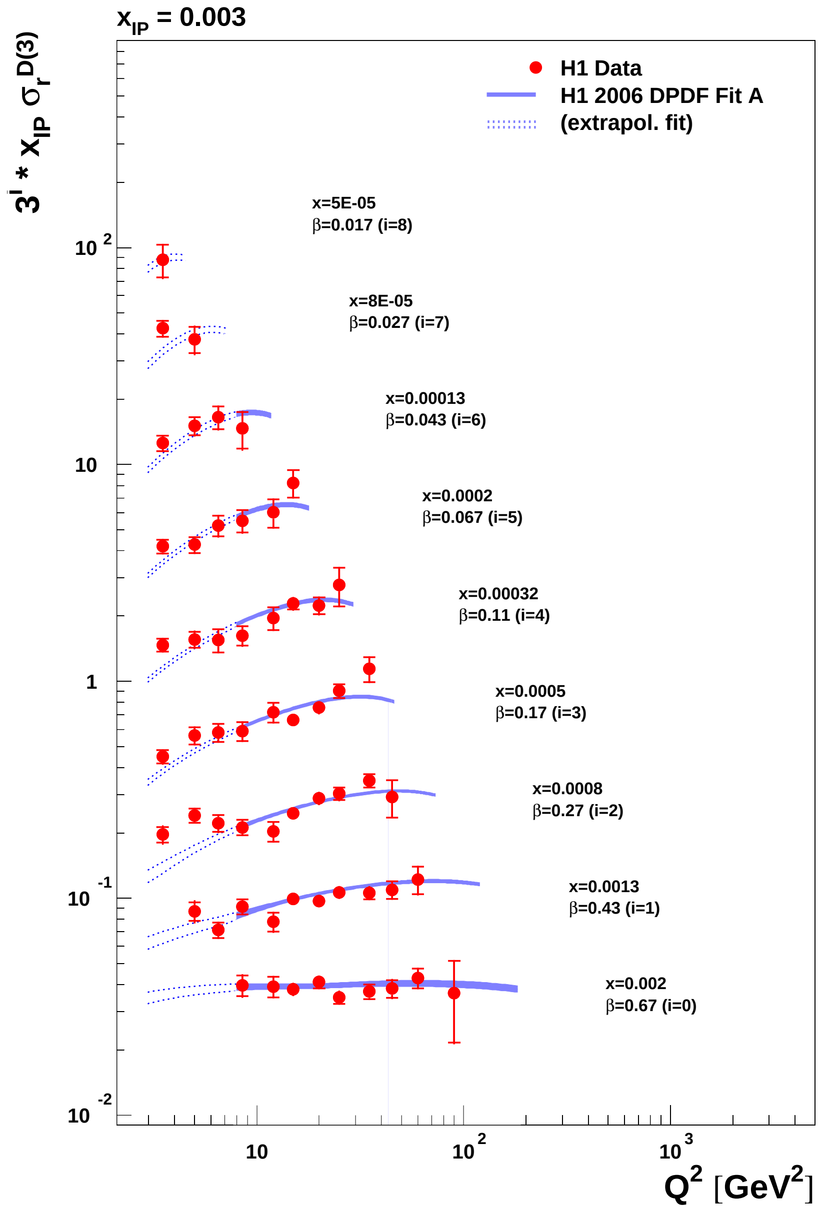


β and Q^2 Dependence at fixed $x_{I\!P} = 0.003$

LRG data: Q^2, β dependencies at 5 fixed values of $x_{I\!P}$ $(0.0003, 0.001, 0.003, 0.01, 0.03)$

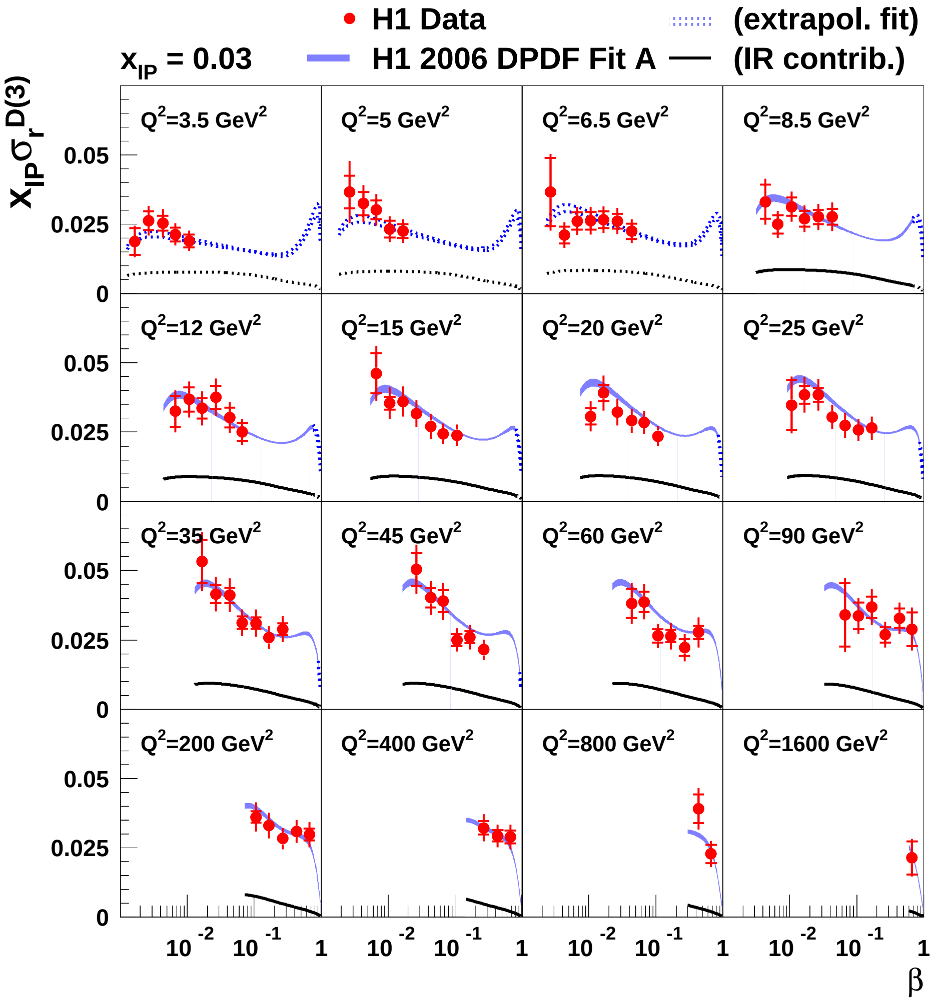
- Data are comared to H1 2006 DPDF Fit and its error band (assuming p-vertex fact'n)

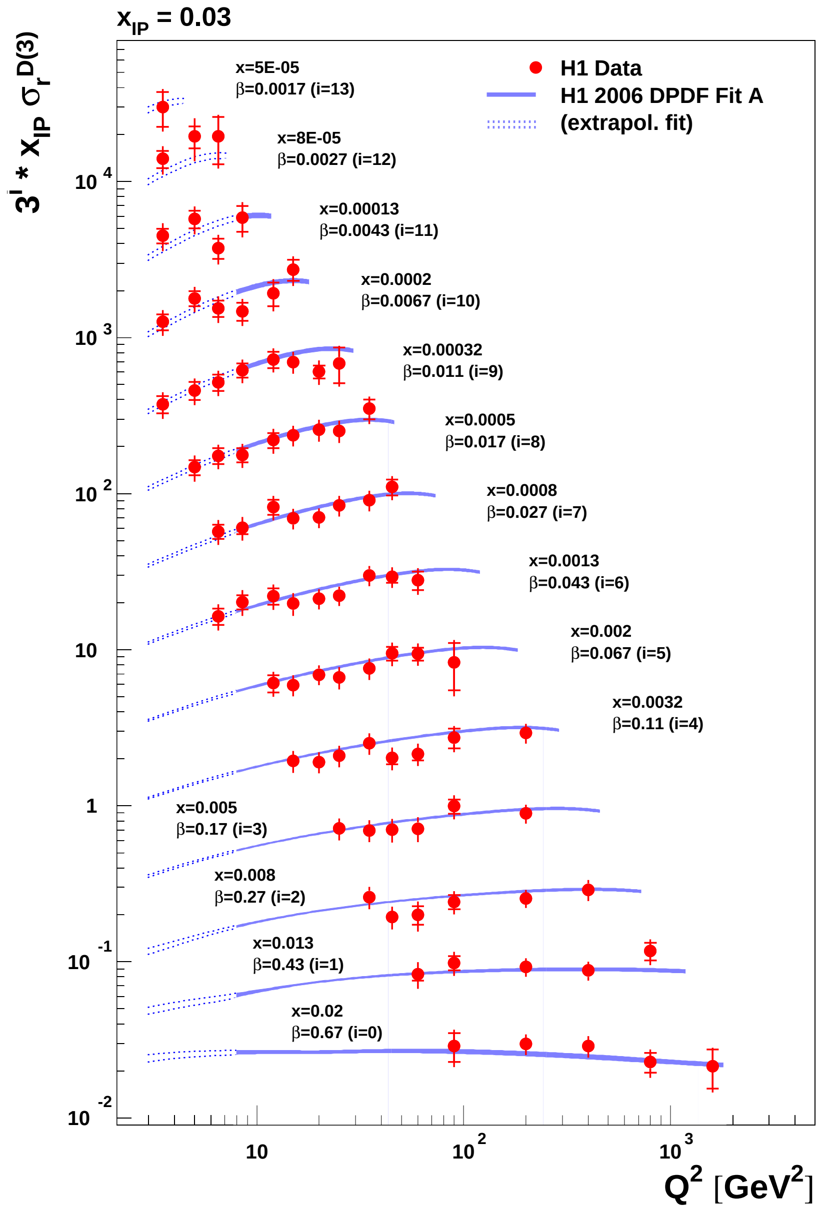




β and Q^2 Dependence at fixed $x_{I\!P} = 0.03$

Sub-leading ($I\!R$) contribution becomes important in largest $x_{I\!P}$ bin





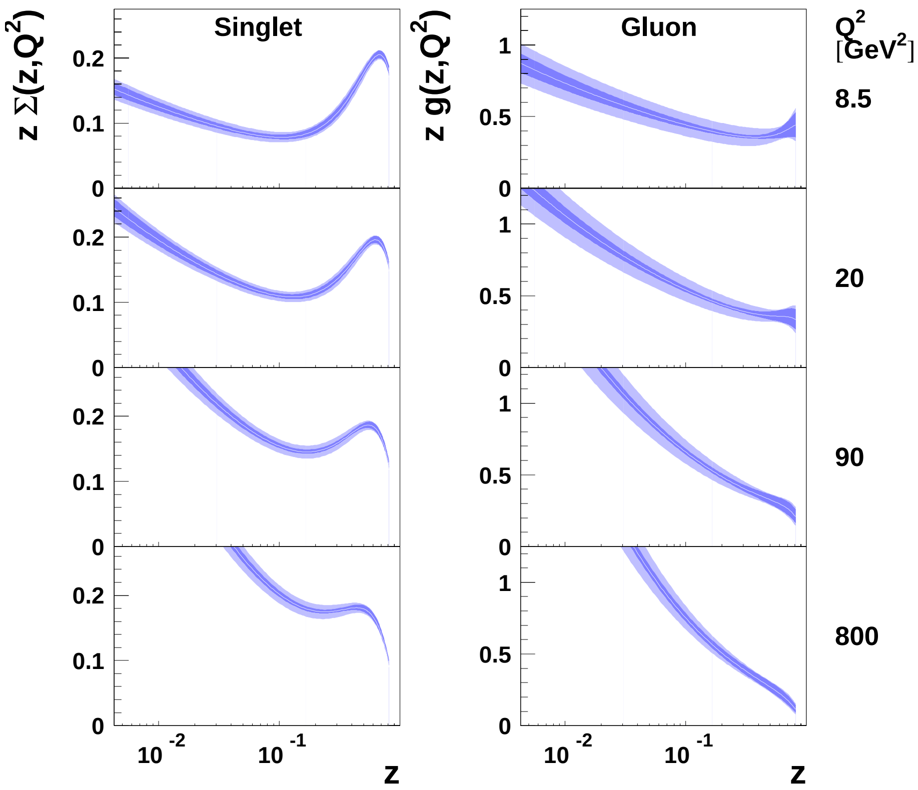
NLO QCD Fit

- Use NLO DGLAP evolution of DPDFs (massive charm, $\Lambda_{QCD}^{(n_f=3)} = 399$ MeV)
- Assume Regge factorisation for p-vertex with flux factors $f_{I\!P,I\!R} = A_{I\!P,I\!R} \frac{e^{B_{I\!P,I\!R} t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}}$
- Parametrisation at starting scale: $z f_i(z, Q_0^2) = A_i z^{B_i} (1-z)^{C_i}$ with Q_0^2 optimized wrt χ^2 (Chebyshev polynomials are used as cross-check and provide similar results)
- $I\!R$ PDFs are taken from Owens-π with normalisation as the only free parameter
- Fit 190 data points at 5 fixed $x_{I\!P}$ values with $Q^2 > Q^2_{\text{min}}$ and $M_X > 2$ GeV, $\beta \leq 0.8$ $Q^2_{\text{min}} = 8.5$ GeV^2 is chosen from the fit stability requirement
- Free parameters: **Fit A** – $\alpha_{I\!P}(0), n_{I\!R}, A_q, B_q, C_q, A_g, C_g$ **Fit B** – $C_g = 0$ (B_g is dropped from both fits as the data was found to be insensitive to it)

H1 2006 DPDF Fit Results

Fit A (log z scale)

$Q_0^2 = 1.75$ GeV^2 $\chi^2 \simeq 158/183$ d.o.f.



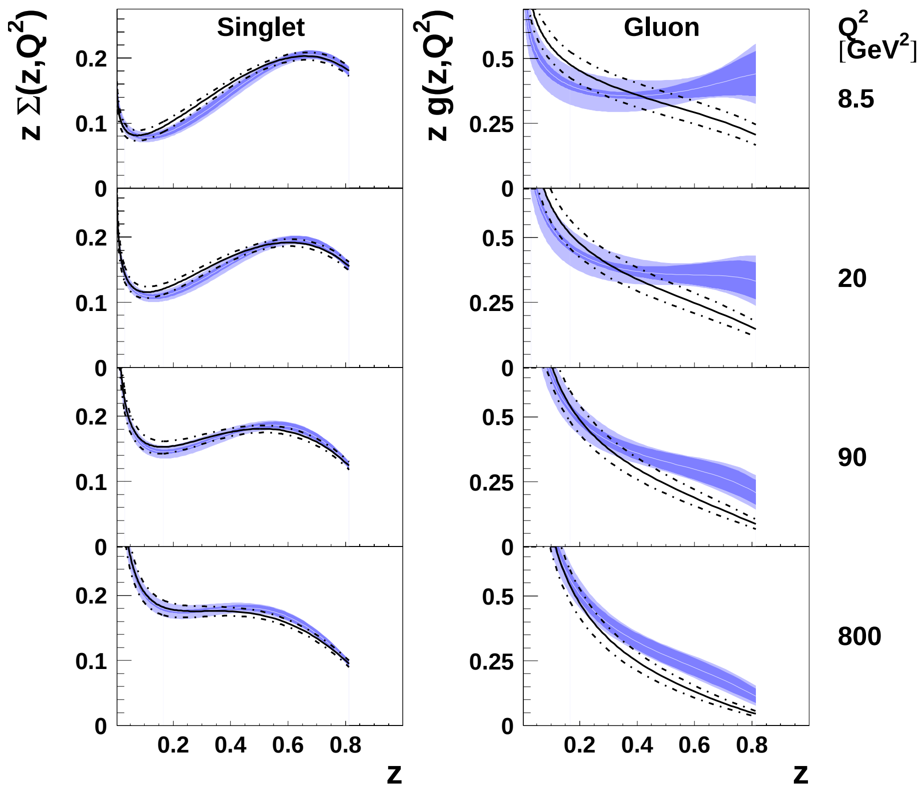
H1 2006 DPDF Fit A
(exp. error)
(exp.+theor. error)

$\sim 70\%$ gluons integrated over z

Singlet constrained to $\sim 5\%$

Fit A vs Fit B (linear z scale)

$Q_0^2 = 2.5$ GeV^2 $\chi^2 \simeq 164/184$ d.o.f.



H1 2006 DPDF Fit A
(exp. error)
(exp.+theor. error)

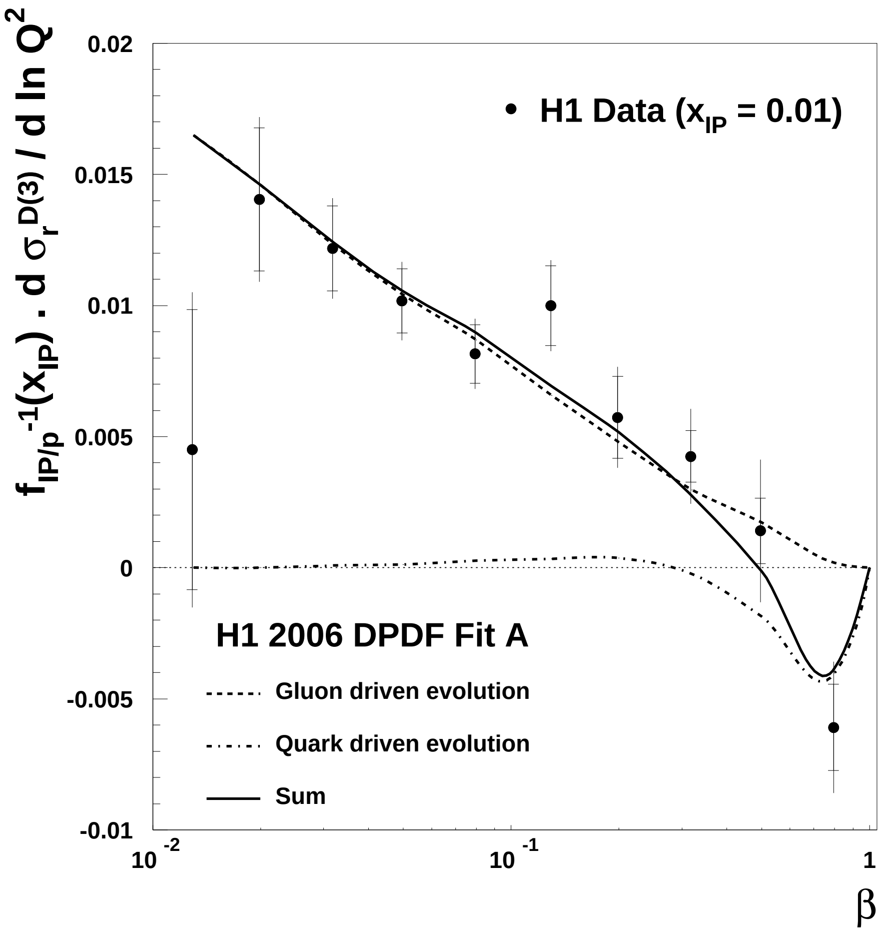
H1 2006 DPDF Fit B
(exp.+theor. error)

Large gluon variations at high z

Sensitivity to Gluon at different z

$$\frac{\mathrm{d}F_2^{D(3)}}{\mathrm{d}\ln Q^2} \sim \frac{\alpha_s}{2\pi}[P_{qg} \otimes g + P_{qq} \otimes \Sigma]$$

- Measure normalised $\ln Q^2$ derivative of $\sigma_r^{D(3)}$ at fixed $x_{I\!P}$ and β
- Compare to NLO QCD Fit decomposed into different contributions
- At low β, evolution is driven by $g \rightarrow qq$, hence strong sensitivity to gluon
- At high β, $q \rightarrow qg$ contribution becomes important; additionally relative error on derivative grows – hence sensitivity to gluon is lost



★ Need other observables directly sensitive to gluon (jets, charm, ...)

Summary

- FPS and LRG measurements based on HERA-1 data are published. New preliminary results are available also from first HERA-2 data. Large kinematic range is covered with good precision. Agreement between data samples and methods

- Within present uncertainties Regge factorisation is compatible with data.
  $x_{I\!P}$ dependence is described by $\alpha_{I\!P}(t) \simeq 1.118 + 0.06t$

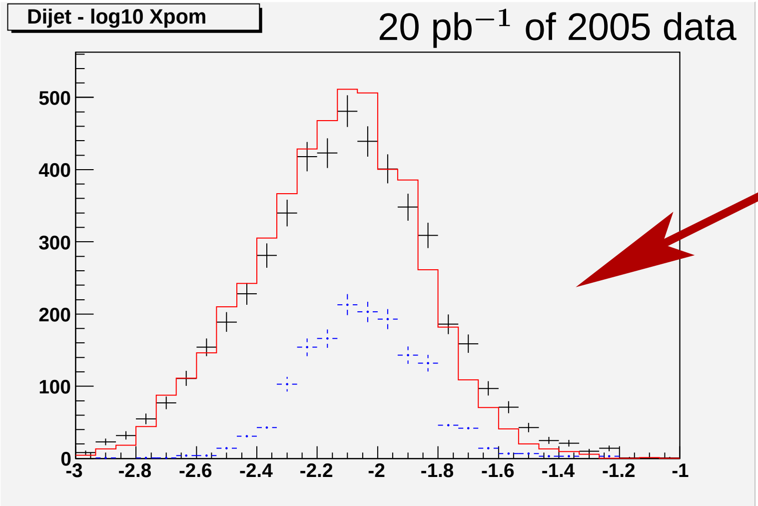
- New set of DPDFs is obtained from NLO QCD fit of $F_2^{D(3)}$ at $Q^2 > 8.5$ GeV^2:
  – singlet quarks well constrained ($\sim 5\%$)
  – gluon is known to $\sim 15\%$ in low z region and poorly constrained at high z

- Over the bulk of the measured range the ratio of diffractive to inclusive cross sections is remarkably flat as a function of energy at fixed Q^2 and M_X, in contrast to naïve Regge expectation

- In future need to improve experimental precision and consolidate theoretical framework (soft vs hard Pomeron, rôle of inhomogeneous term, evidence for 'direct $I\!P$' in data?)

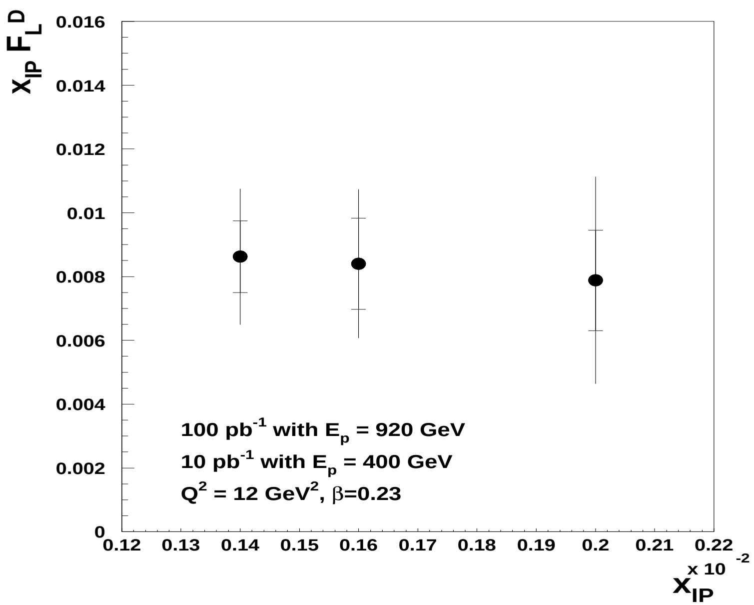
Outlook

Experimetal part: Full use of HERA-2 data (Q: nothing is forgotten? Only one year remains)



- 20 times more FPS data ($\mathcal{L}$, running eff., detector eff.)
- New VFPS pots with high acceptance (40% at $x_{I\!P} \sim 0.01$)

$\Rightarrow$ test factorisation in more detail: $\alpha_{I\!P}(Q^2, \beta)$

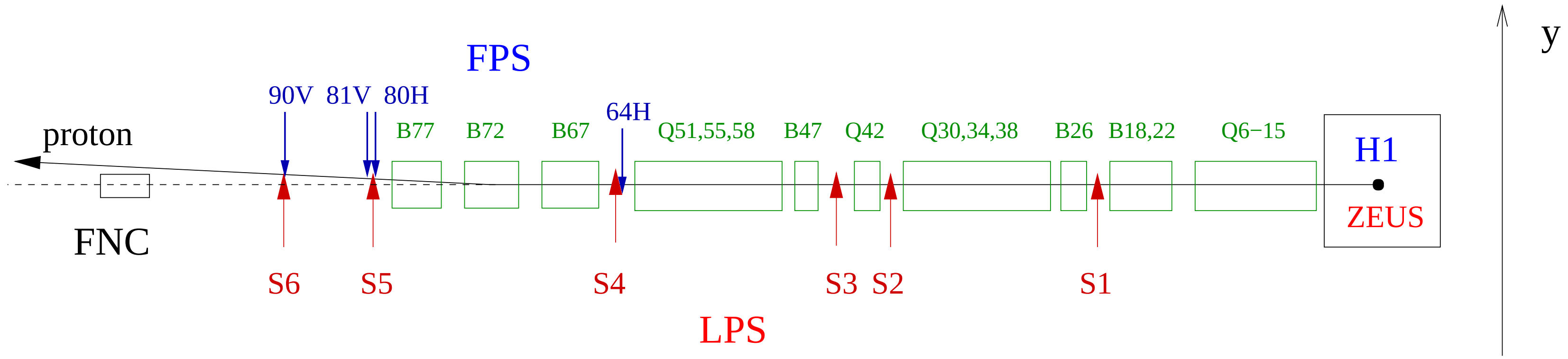


- 10-15 pb^{-1} with reduced E_p running $\Rightarrow$ Measure F_L^D
  - reduce F_L^D uncertainty contribution to syst.errors
  - direct sensitivity to gluon, better constrain DPDFs

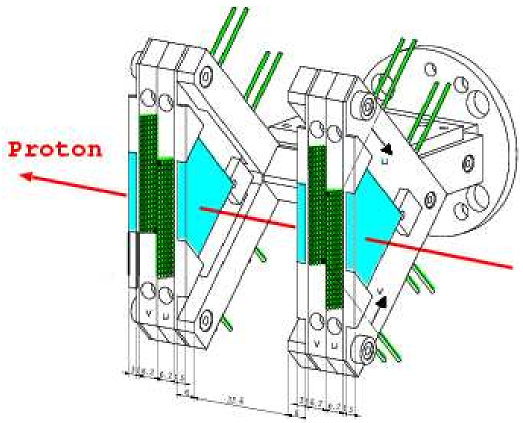
Theory part: Consolidate the framework (HERA-LHC Workshop)

BACKUP SLIDES...

HERA I Proton Spectrometer

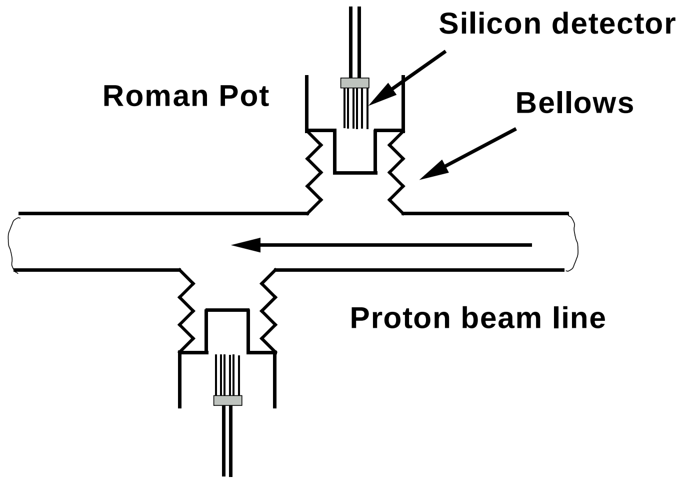


Forward Proton Spectrometer



Scintillating fi bre detector

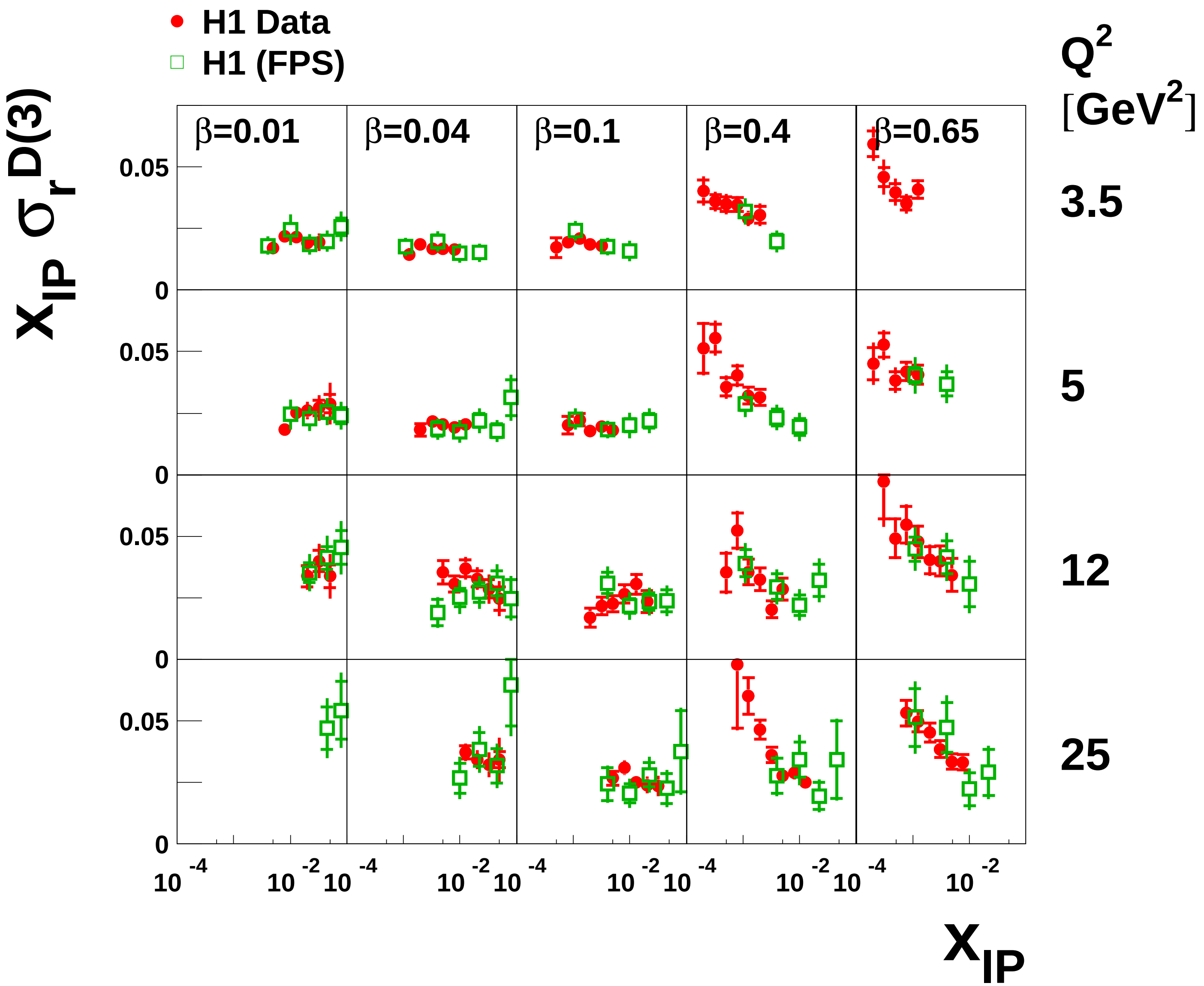
Leading Proton Spectrometer



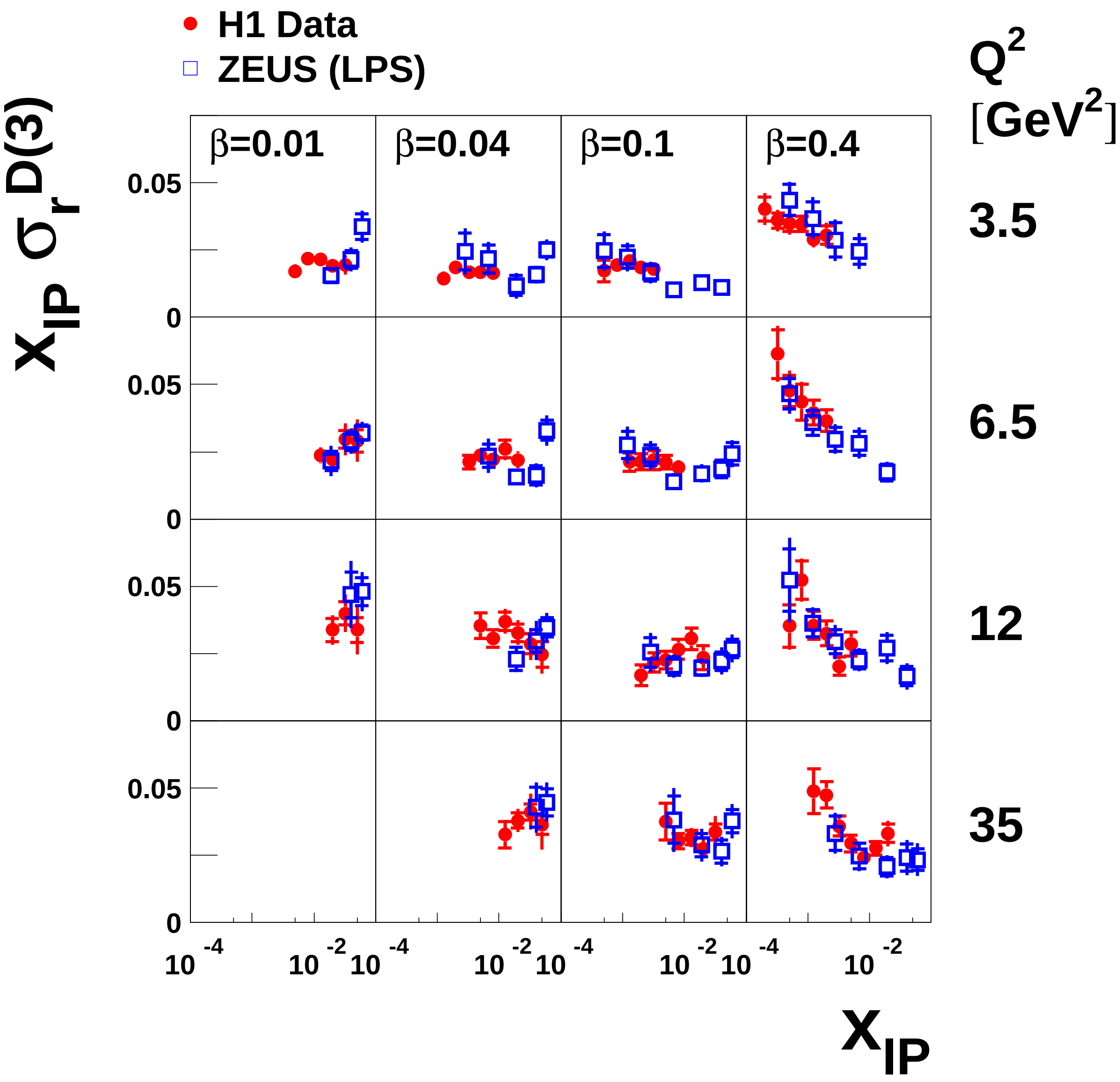
Silicon Micro-Strip Detector

- Free of dissociation bkgd
- p 4-momemtum measurment $\rightarrow\ t$
- Low statistic (acceptance)

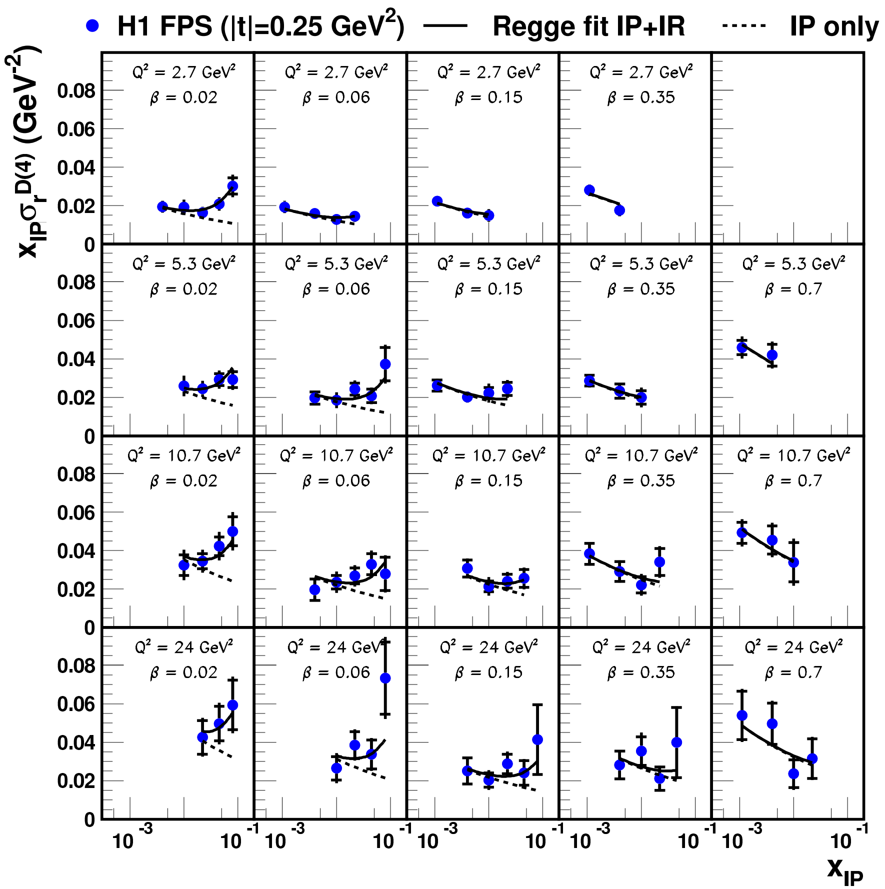
LRG vs FPS data in fixed Q^2, β binning scheme

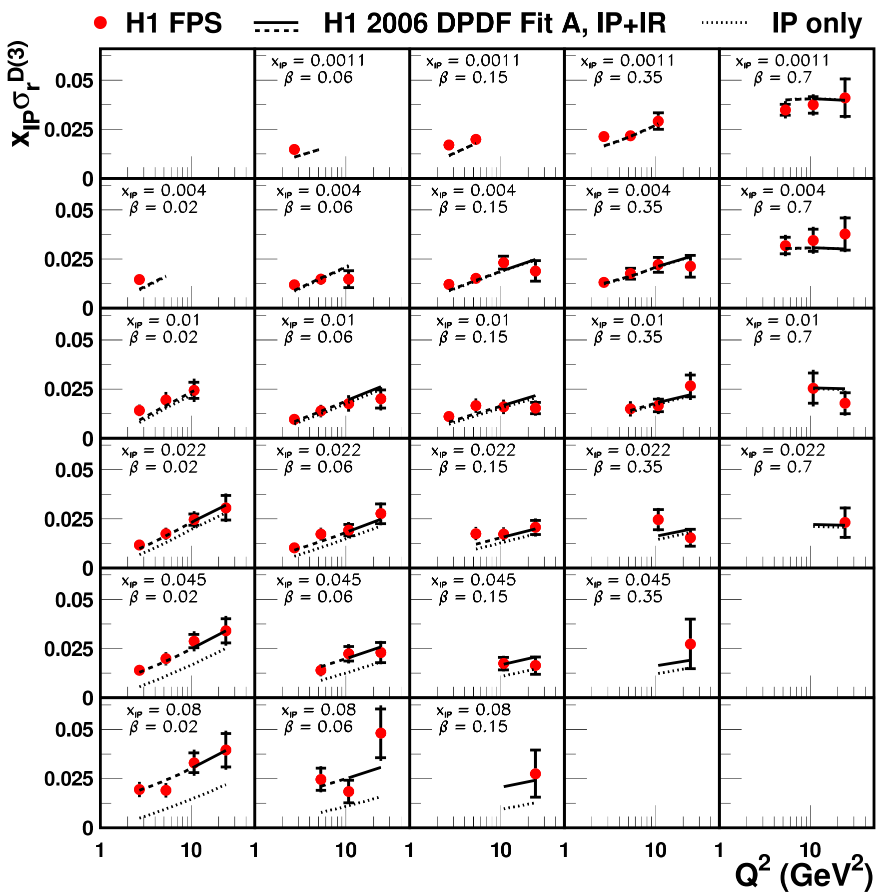


LRG(H1) vs LPS(ZEUS) data

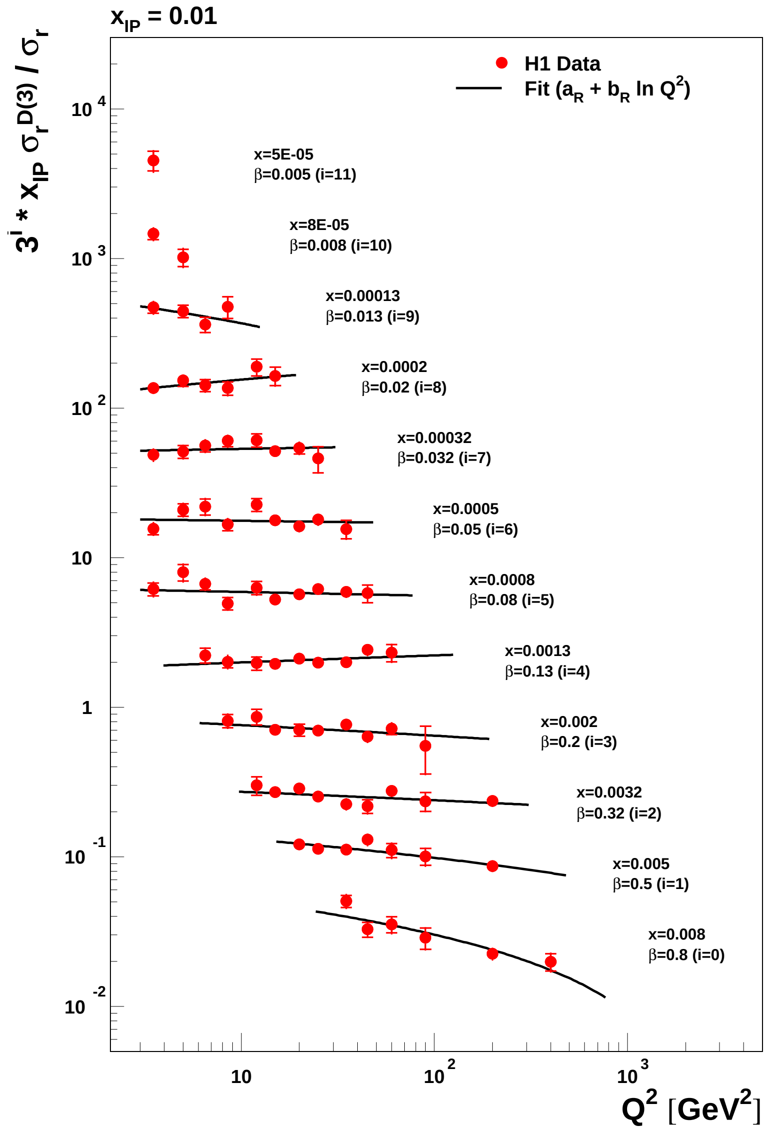


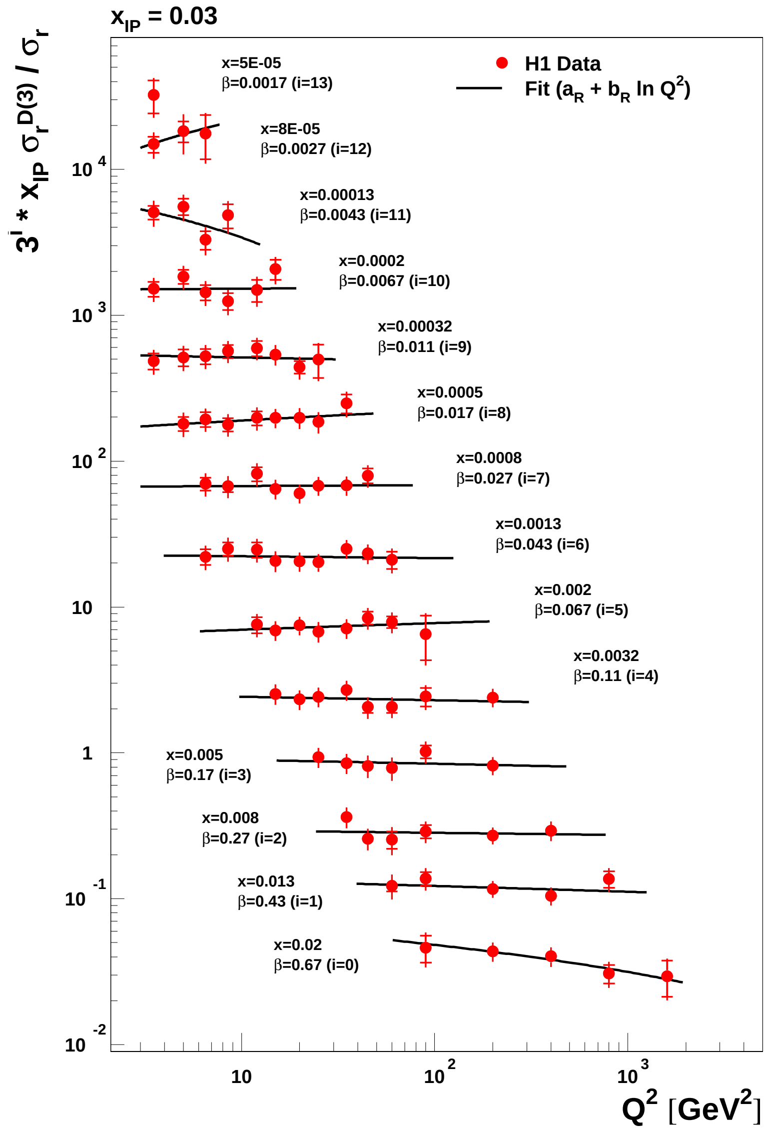
FPS $F_2^{D(4)}$ and $F_2^{D(3)}$ compared to H1 2006 DPDF Fit results





Diffractive to incusive ratio $\sigma_r^{D(3)}/\sigma_r$ vs Q^2





Diffractive CC cross sections