Inclusive Measurement of Diffractive Deep Inelastic Scattering at HERA

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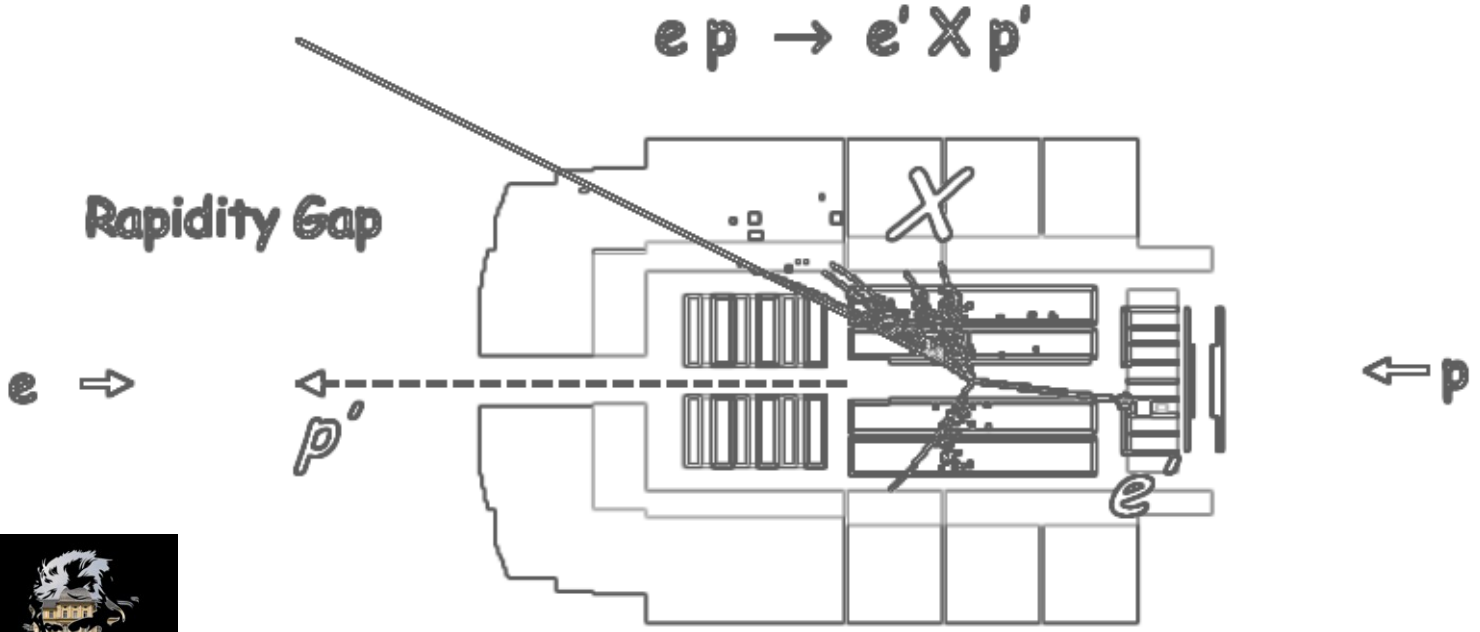
On behalf of the H1 Collaboration

LAPP Annecy / Université de Savoie



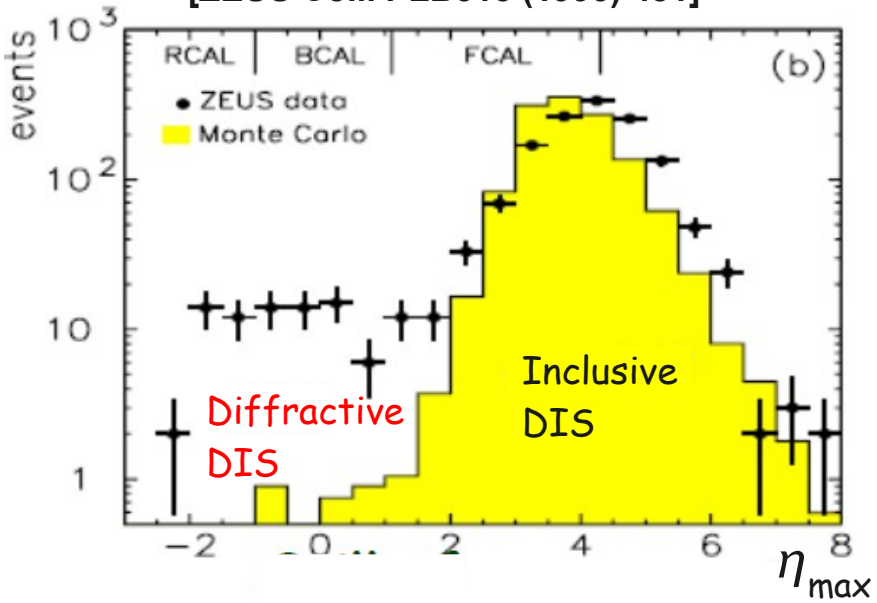
XX International Workshop on Deep-Inelastic Scattering and Related Subjects

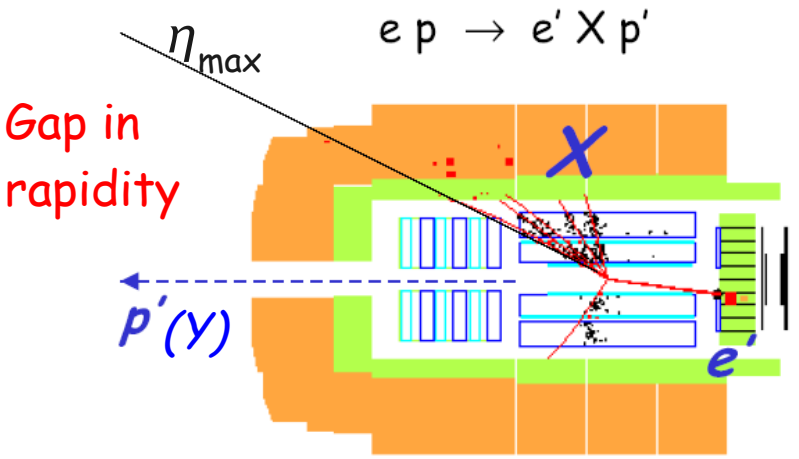
26-30 March 2012, University of Bonn

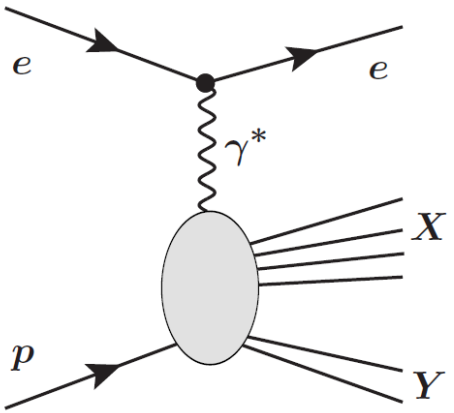
Inclusive Diffraction at HERA

- A surprise of HERA → ~ 10% of low-x DIS events are diffractive

[ZEUS Coll. PLB315 (1993) 481]



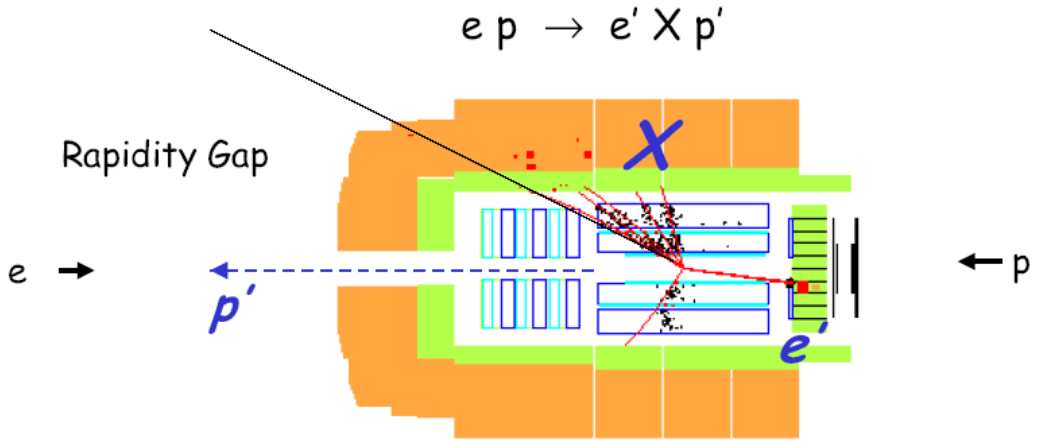


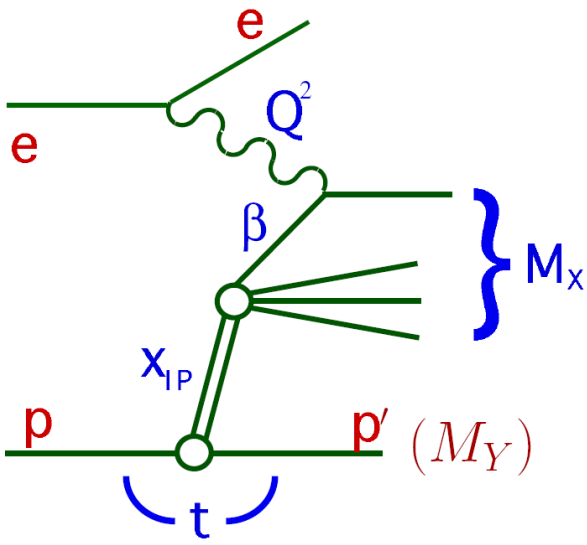


→ No color flow between hadron systems Y(p) and X

↘ Probes the structure of color singlet exchange with virtual γ

Diffractive kinematics





Invariant mass of the diffractive final state

- Momentum fraction of colour singlet exchange:

$$x_{\mathbb{P}} = \xi = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

- Fraction of exchange momentum of q coupling to γ^*:

$$\beta = \frac{Q^2}{Q^2 + M_X^2} = \frac{x}{x_{\mathbb{P}}}$$

- 4-momentum transfer squared:

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

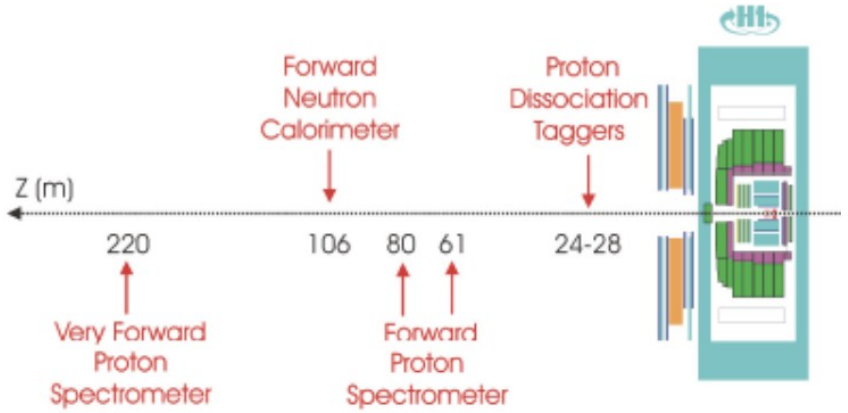
- Reduced diffractive cross-section (integrated over t):

$$\sigma_r^{D(3)}(Q^2, \beta, x_{I\!P}) = \frac{\beta Q^4}{4\pi\alpha_{em}^2} \frac{1}{(1 - y + \frac{y^2}{2})} \frac{\mathrm{d}^3\sigma^{ep\to eXY}}{\mathrm{d}Q^2\,\mathrm{d}\beta\,\mathrm{d}x_{I\!P}}$$

Selection of Diffractive Events

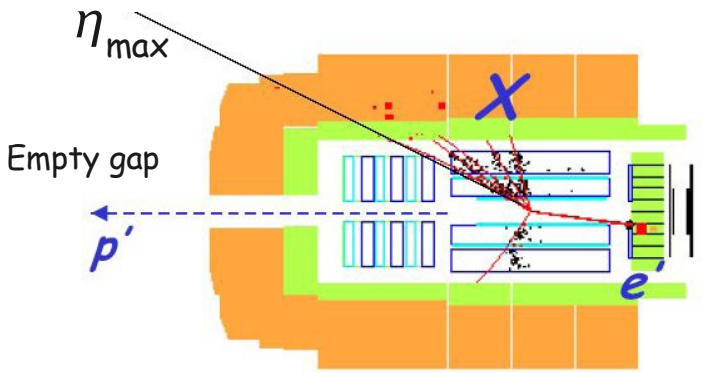
Measure the leading proton

➔ Forward spectrometers (H1 FPS/VFPS)



- x_{IP} and t measurements
- Less statistics
- p-tagging systematics

Measure a Large Rapidity Gap



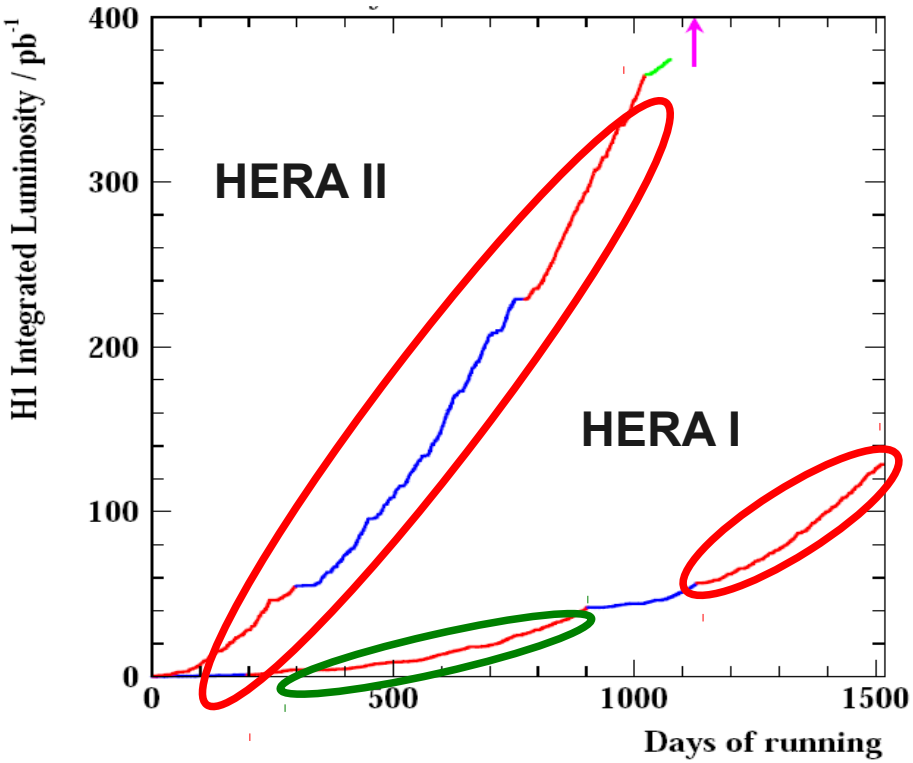
- Data integrated over $|t| < 1\ GeV^2$
- High statistics
- Contamination from proton dissociation events

➔ Needs to be controlled

↘ Different systematics

↘ Different kinematic coverage

H1 LRG Data Samples



Data Set	Q^2 range (GeV^2)	Proton Energy E_p (GeV)	Luminosity (pb^{-1})
New data samples			
1999 MB	$3 < Q^2 < 25$	920	3.5
1999-2000	$10 < Q^2 < 105$	920	34.3
2004-2007	$10 < Q^2 < 105$	920	336.6
Previously published data samples			
1997 MB	$3 < Q^2 < 13.5$	820	2.0
1997	$13.5 < Q^2 < 105$	820	10.6
1999-2000	$133 < Q^2 < 1600$	920	61.6

[H1 Coll. EPJC28 (2006) 715]

- All H1 data samples now analysed

➔ Increase in statistics of 3 to 30

↘ All combined into one single H1 LRG cross section set

↘ Total kinematic range:

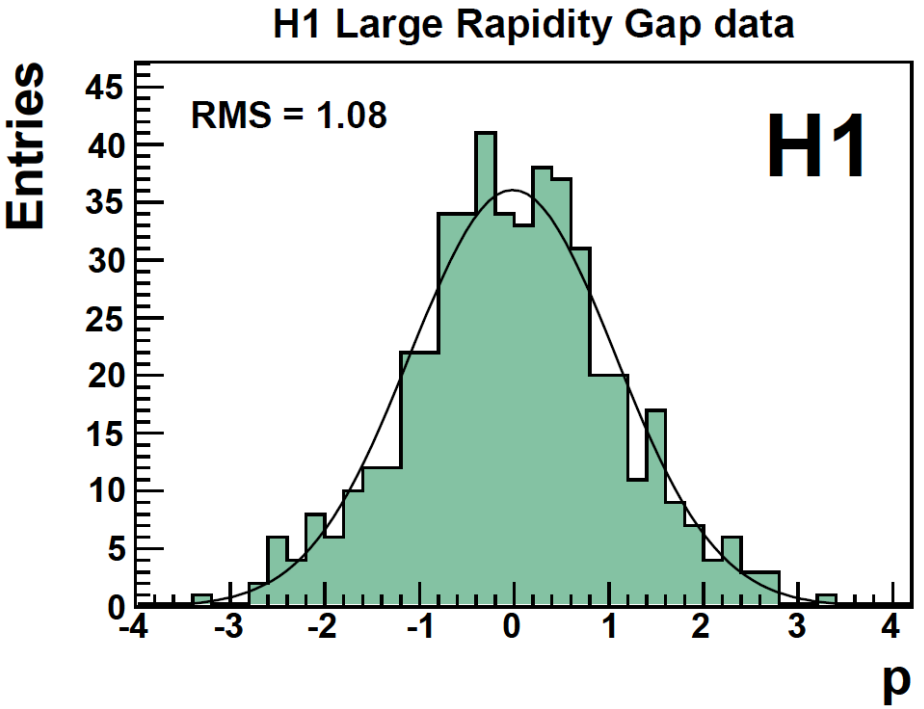
$3.5 < Q^2 < 1600$ GeV^2

$0.0017 < \beta < 0.8$

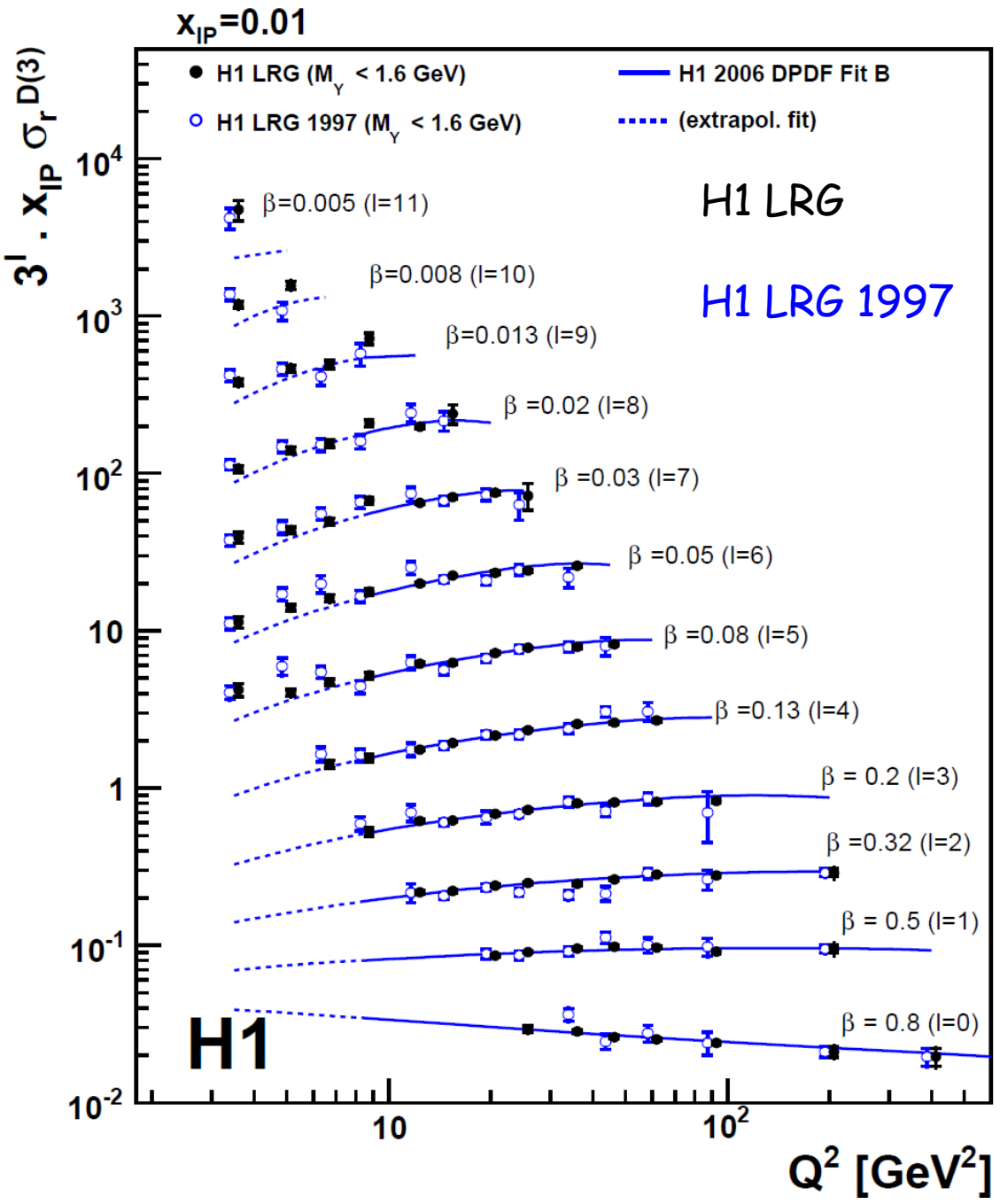
$0.0003 < x_{IP} < 0.03$

Combination of H1 LRG Data

- Combine reduced cross sections from each data period
- Iterative χ^2 minimisation used
- Full error correlations considered
  - ➔ 597 data points averaged to 277 measurements
  - ➔ χ^2 / ndof = 371 / 320
- Pulls of individual points to combined points
  - ➔ No large tension between data sets observed



Combined LRG cross section



- Example of Q^2 dependence for x_{IP}=0.01

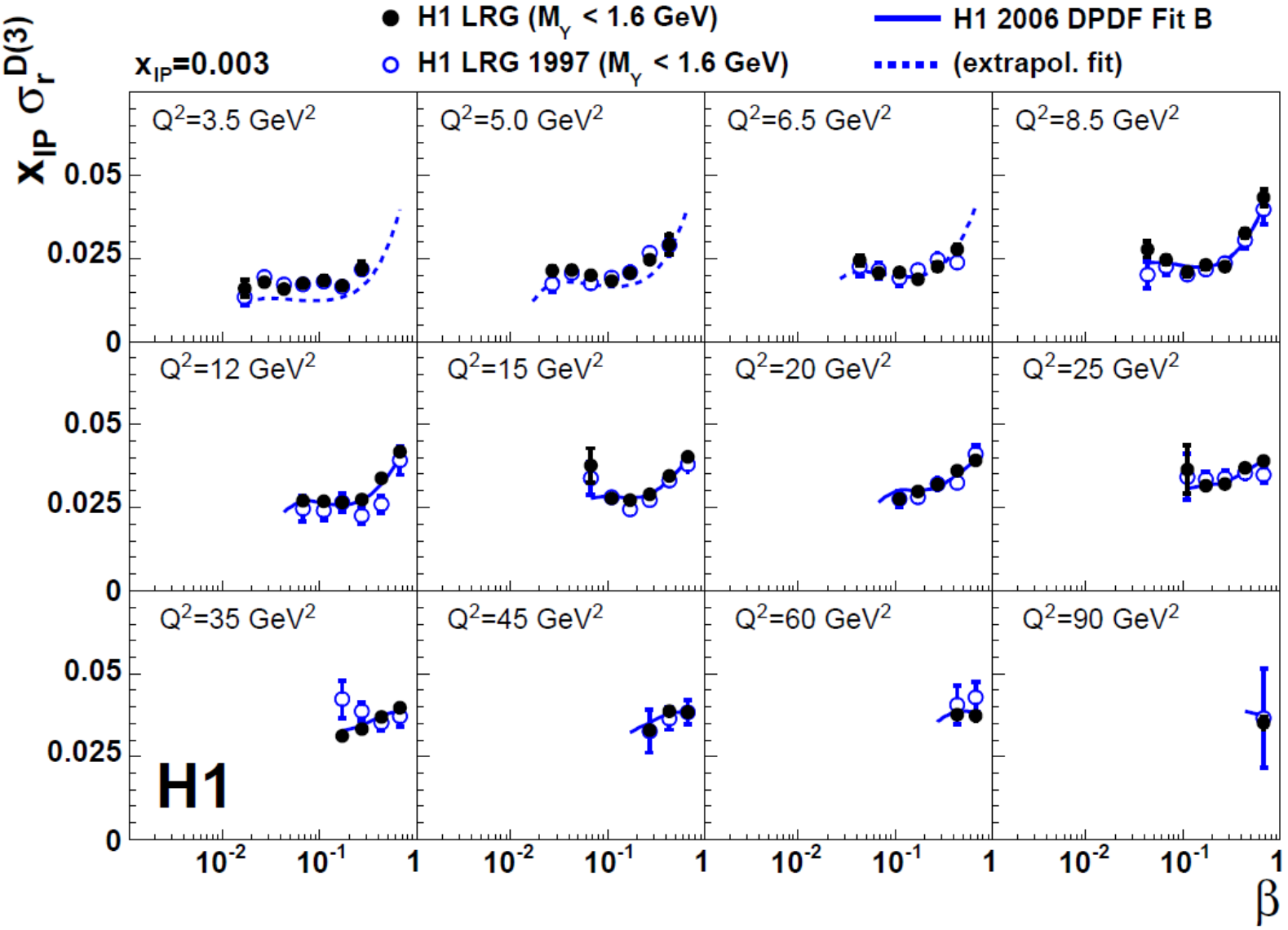
  ➔ Large reduction of statistical errors

  ➔ Typical precision for $Q^2 > 12$ GeV^2:

  1% (stat.)
  5% (sys.)
  4% (norm.)

Combined LRG cross section -II-

- Example of β dependence for x_{IP}=0.003



H1 LRG

H1 LRG 1997

LRG vs p-tagged methods

- Compare H1 LRG and FPS cross sections

➔ Ratio LRG / FPS :

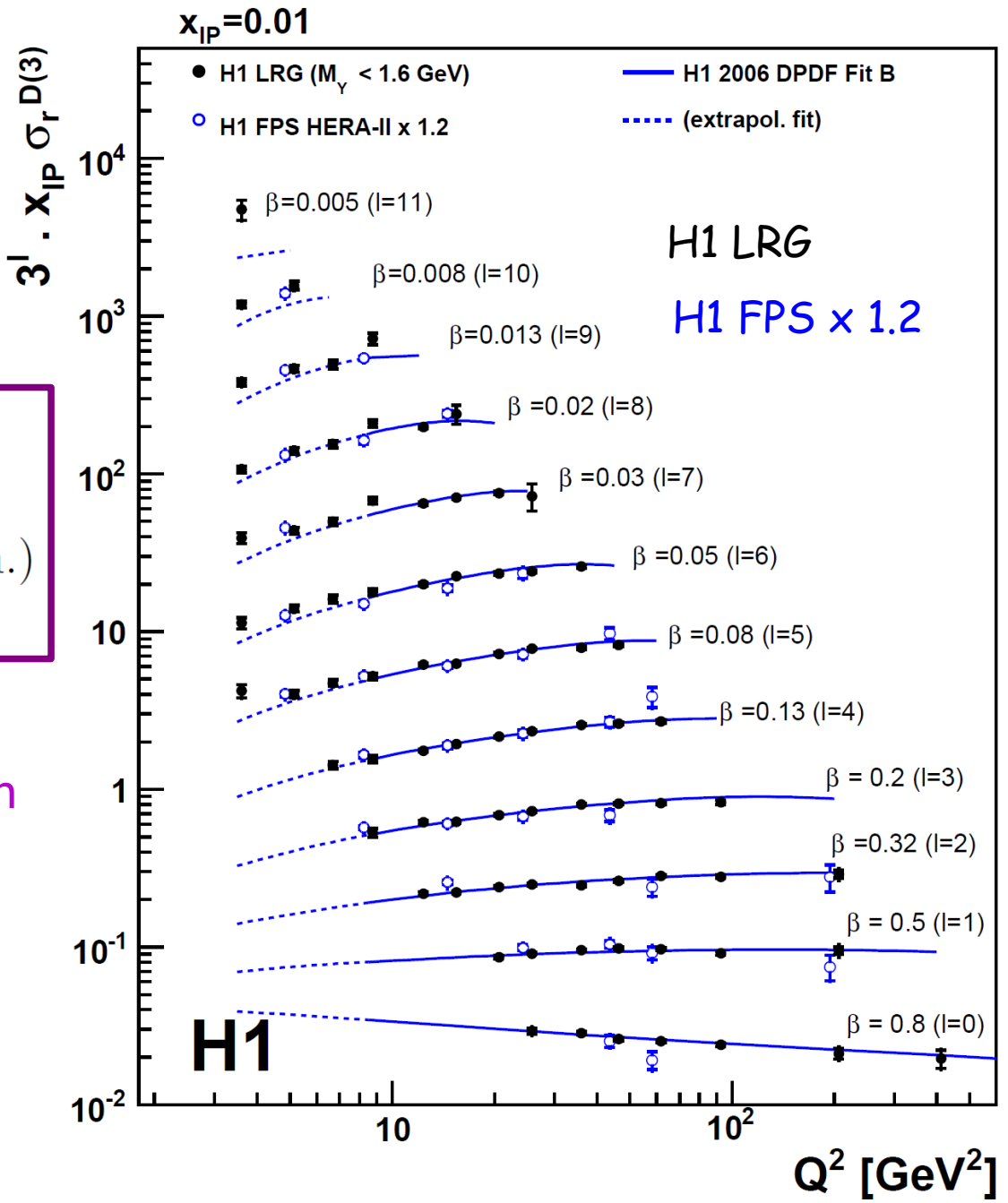
$$\frac{\sigma\left(M_Y < 1.6\,\mathrm{GeV}\right)}{\sigma\left(Y = p\right)} =$$

$$1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$$

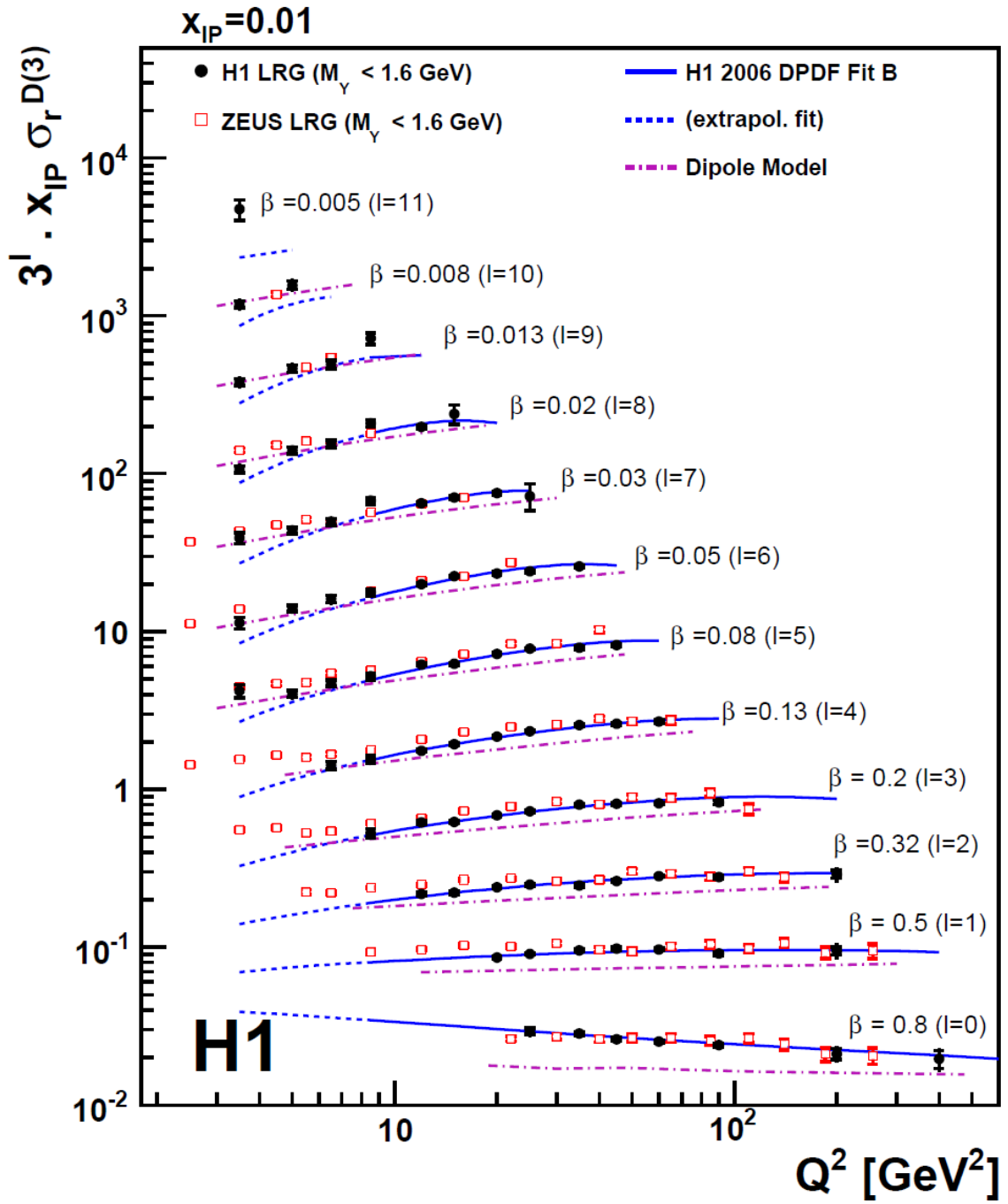
(1.6%) (7.2%)

➔ Experimental control of the amount of proton dissociation in LRG data

➔ No β or Q^2 dependent differences observed



H1 and ZEUS LRG data



H1 LRG (M_Y < 1.6 GeV^2)

ZEUS LRG (M_Y < 1.6 GeV^2)

- ZEUS data rescaled to M_Y < 1.6 GeV^2

  [ZEUS Coll. NPB816 (2009) 1]

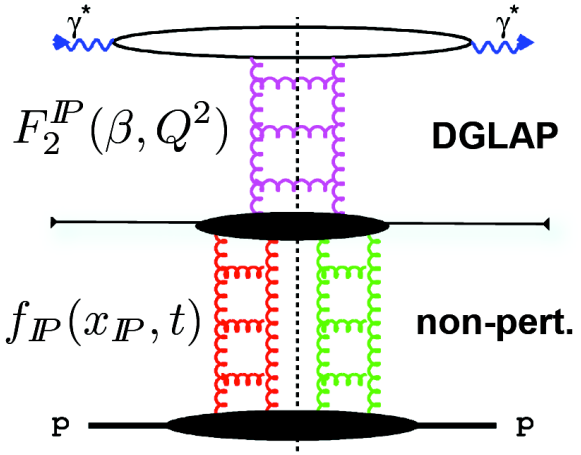
- General overall agreement
- Overall ~10% normalisation difference

  ➔ Within normalisation uncertainties of each measurement

- Comparison sensitive to systematics effect

Theoretical views of Diffraction: Partons and Dipoles

- Infinite momentum frame: partons



- An assumption: factorise (β,Q^2) and ($x_{I\!P}$,t)

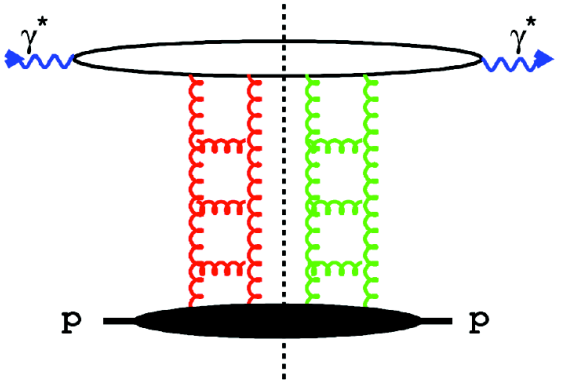
$$F_2^D = f_{I\!P}(x_{I\!P}, t)\, F_2^{I\!P}(\beta, Q^2)$$

$$f_{I\!P} = \frac{e^{bt}}{x_{I\!P}^{2\alpha_{I\!P}-1}}$$

➔ Derive diffractive PDFs $F_2^{I\!P}$

[H1 Coll. EPJC28 (2006) 715]

- Proton rest frame: dipoles



- Long-living quark pair interacts with gluons of the proton

$$d\sigma_{diff}^{\gamma^* p}/dt \propto \int dz dr^2 \Psi^* \sigma_{qq}^2(x, r^2, t)\Psi$$

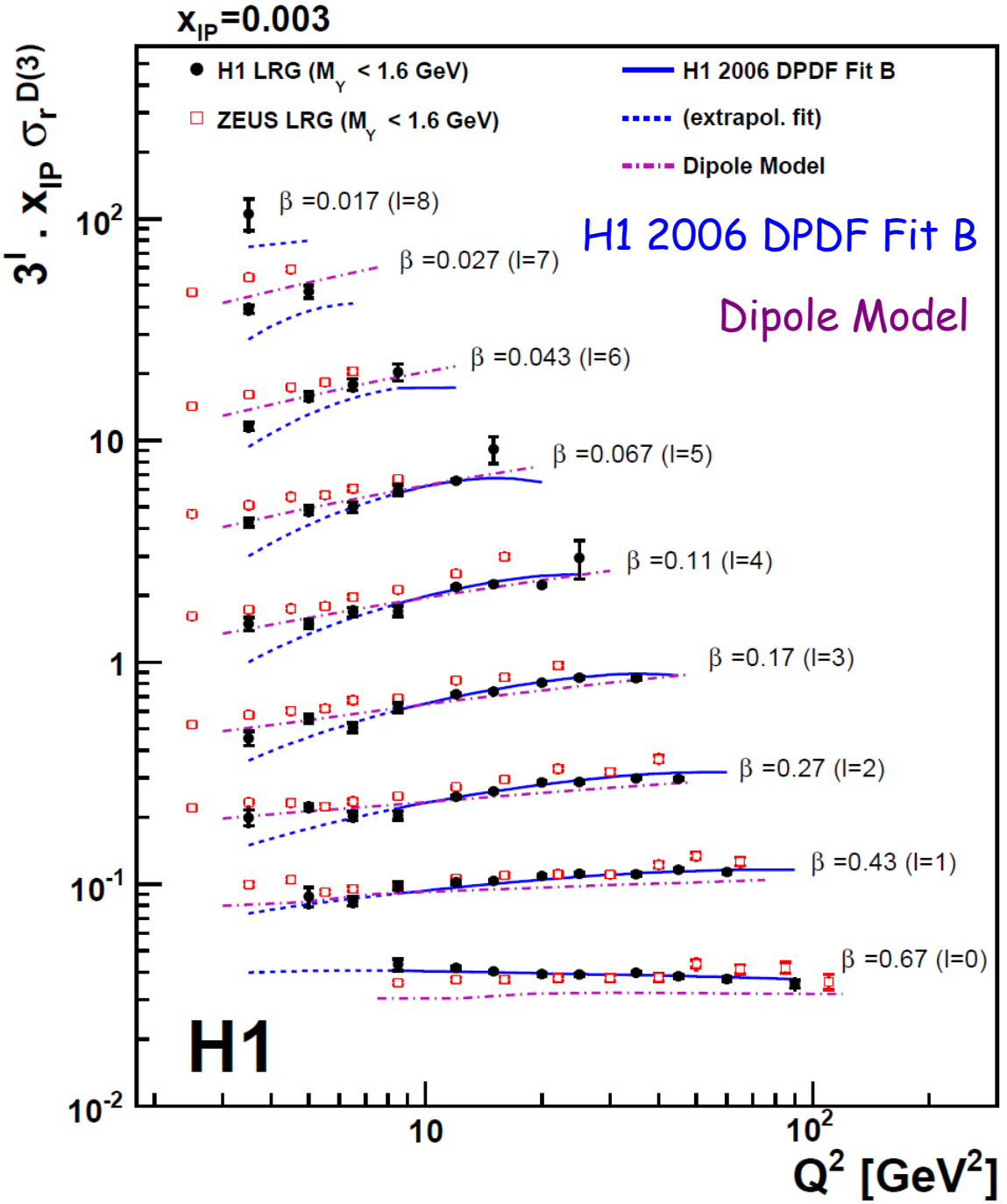
➔ Direct relation to inclusive DIS

➔ Incorporates saturation dynamics

➔ No extra parameters used for DDIS

[C. Marquet PRD76 (2007) 094017]

Models and Data comparison



- Compare LRG data to H1 DPDF Fit B and dipole model

➔ Low Q^2 trend better described by the Dipole model

➔ DPDF in better agreement in higher Q^2 region

➘ Challenging precise H1 and ZEUS data now available to test models

Diffractive and Inclusive DIS

- Relations between Inclusive and Diffractive DIS ?

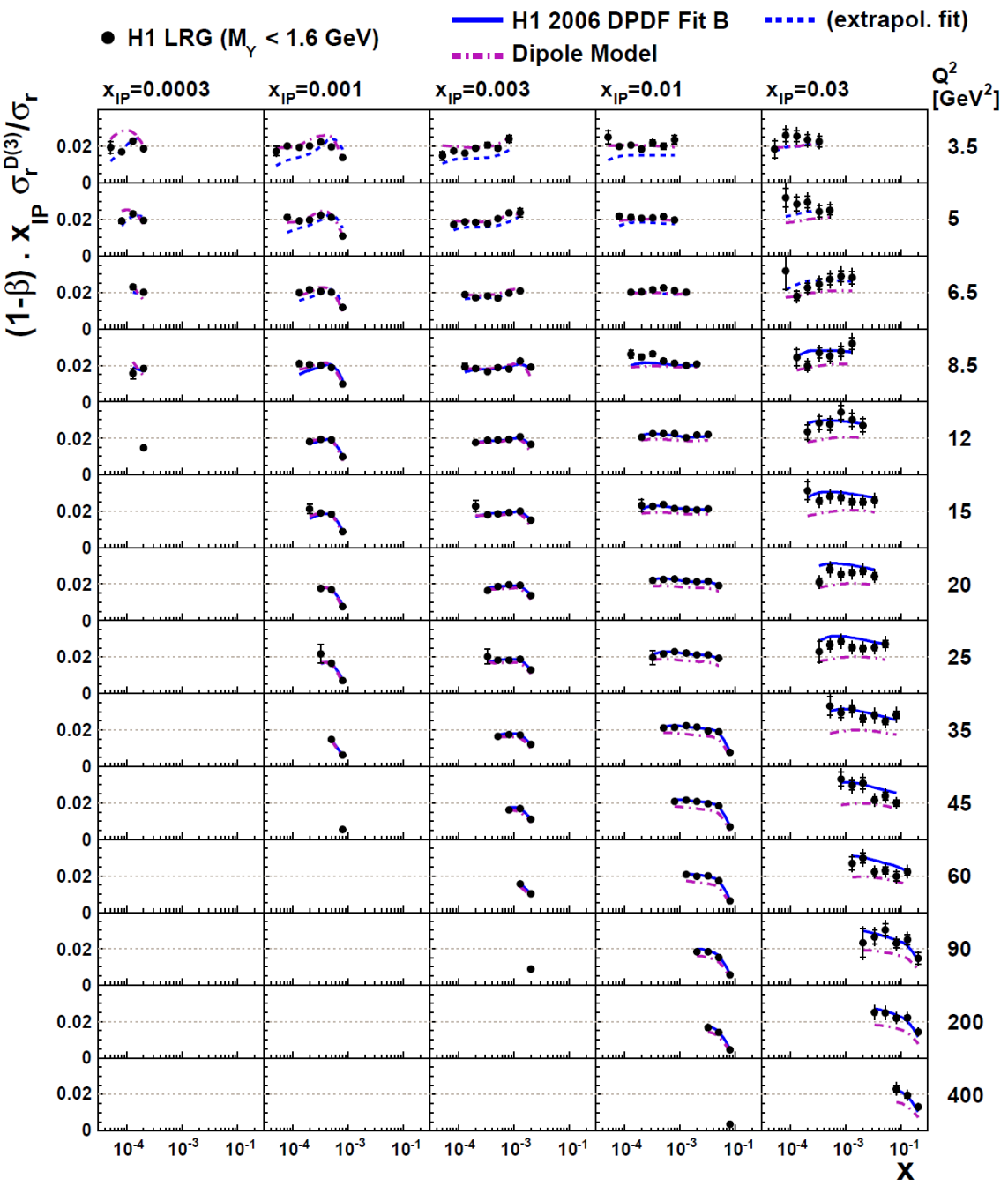
  - Ratio of diffractive to inclusive cross section

$$\frac{\sigma_r^{D(3)}(x_{I\!P}, x, Q^2)}{\sigma_r(x, Q^2)} \cdot (1-\beta)\, x_{I\!P}$$

$$\frac{M_X^2 \, \dfrac{\mathrm{d}\sigma_r^{D(3)}(M_X, W, Q^2)}{\mathrm{d}M_X}}{\sigma_{incl.}^{\gamma^* p}(W, Q^2)}$$

- Flat in x, apart at highest β

- Ratio of quarks to gluons is similar in diffractive and inclusive DIS



The Pomeron trajectory

- Regge fit to LRG cross section:

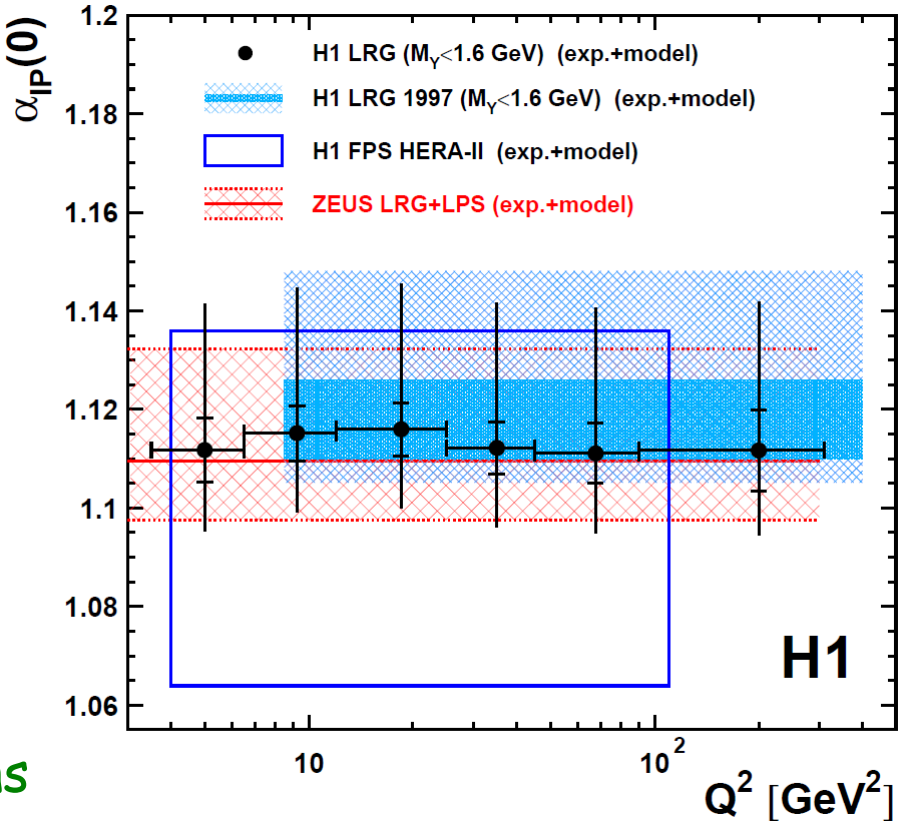
$$F_2^{D(3)}(Q^2,\beta,x_{I\!P}) = f_{I\!P/p}(x_{I\!P})\ F_2^{I\!P}(Q^2,\beta) + n_{I\!R}\ f_{I\!R/p}(x_{I\!P})\ F_2^{I\!R}(Q^2,\beta)$$

$$f_{I\!P/p,I\!R/p}(x_{I\!P}) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{I\!P,I\!R}t}}{x_{I\!P}^{2\alpha_{I\!P,I\!R}(t)-1}}\mathrm{d}t \qquad \alpha_{I\!P,I\!R}(t) = \alpha_{I\!P,I\!R}(0) + \alpha'_{I\!P,I\!R}t$$

- Mean value of the pomeron intercept:

$$\alpha_{I\!P}(0) = 1.113\ \pm 0.002\ (\mathrm{exp.})\ ^{+0.029}_{-0.015}\ (\mathrm{model})$$

➔ Check Q^2 dependence, by repeating the fit per Q^2 bins



↘ Statistically precise determination

↘ Compatible with no dependence

↘ Good agreement of all determinations

➔ Supports the proton-vertex factorisation hypothesis

Summary

- 19 years after first HERA diffractive events …
- H1 released its final LRG cross section measurement

[H1 Coll. arXiv:1203.4495]

➔ A precision measurement

➔ Reduced statistical and systematic errors

- Amount of proton dissociation: 20%
- New constraints for QCD models
- Data support the proton-vertex factorisation hypothesis

$$\alpha_{I\!P}(0) = 1.113 \pm 0.002\,(\text{exp.})\,{}^{+0.029}_{-0.015}\,(\text{model})$$

- Overall general agreement with ZEUS LRG data

↘ Outlook: an HERA LRG data combination ?

Summary

- 19 years after first HERA diffractive events …
- H1 released its final LRG cross section measurement

[H1 Coll. arXiv:1203.4495]

Thanks to all H1 members

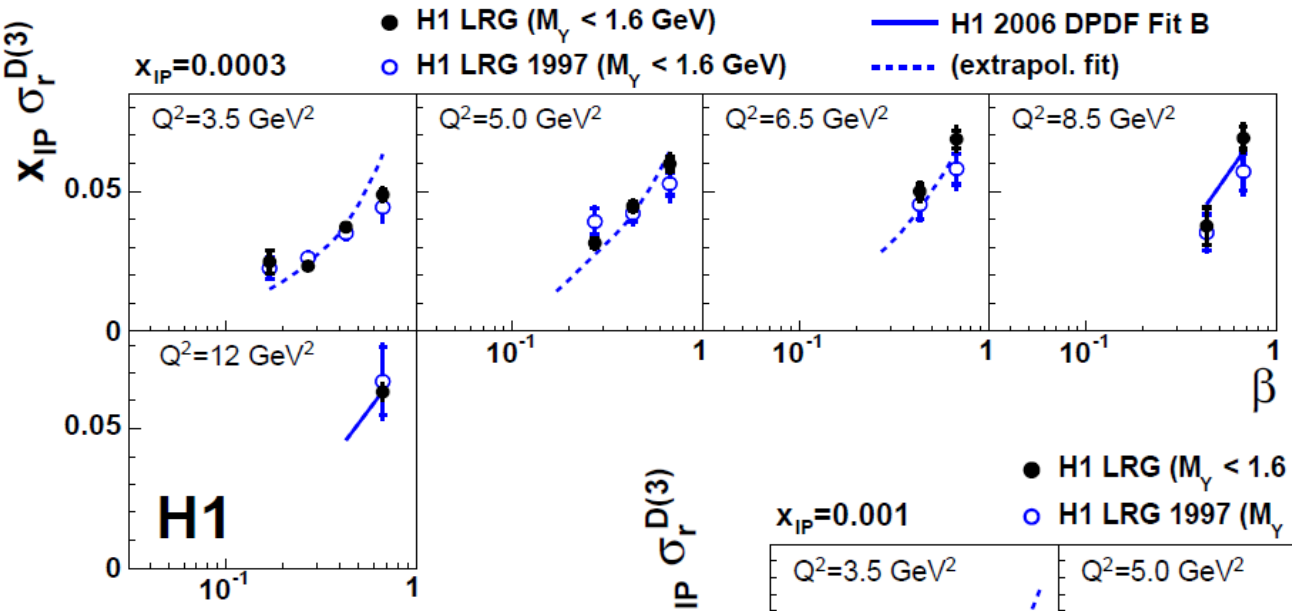
who worked during years

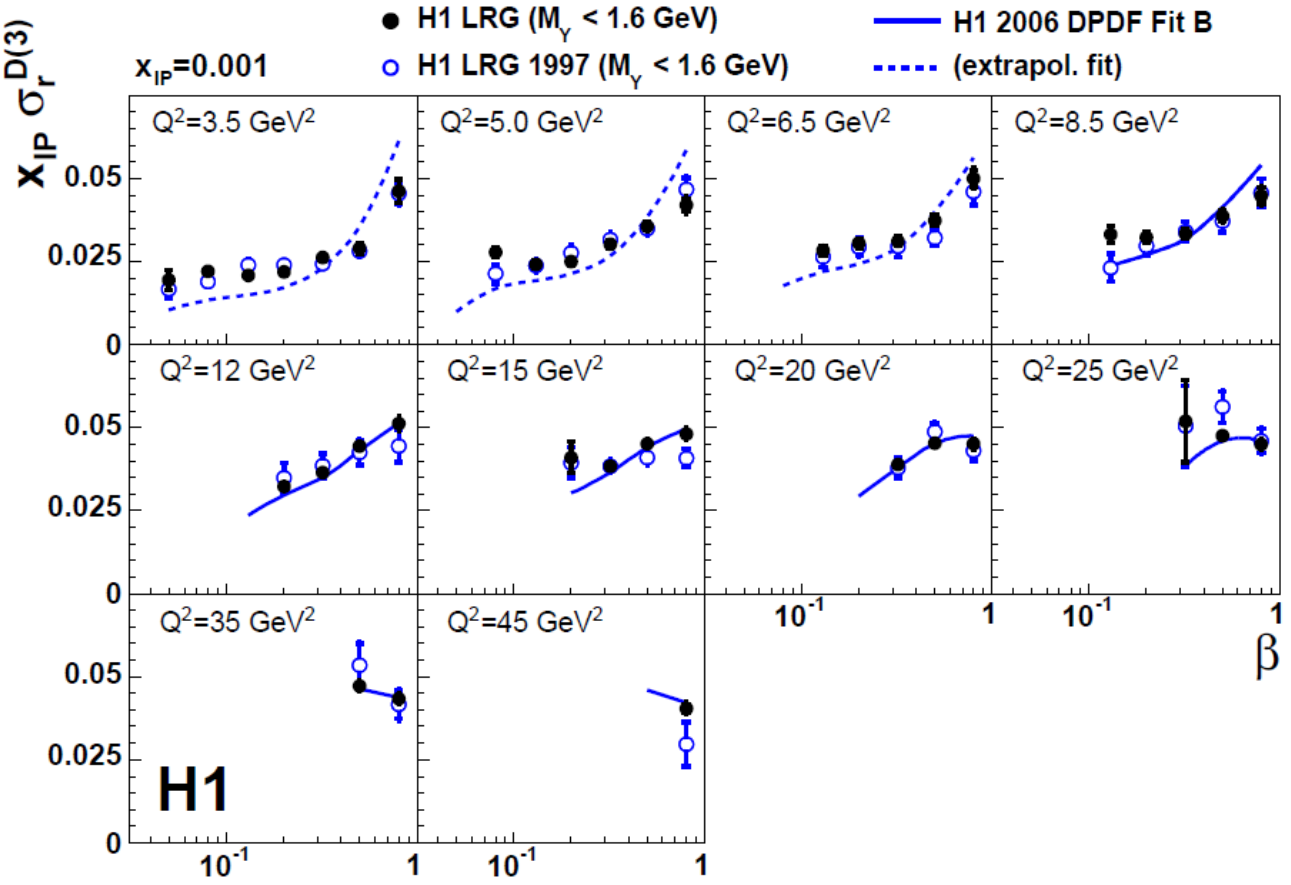
to make this measurement possible

↘ Outlook: an HERA LRG data combination ?

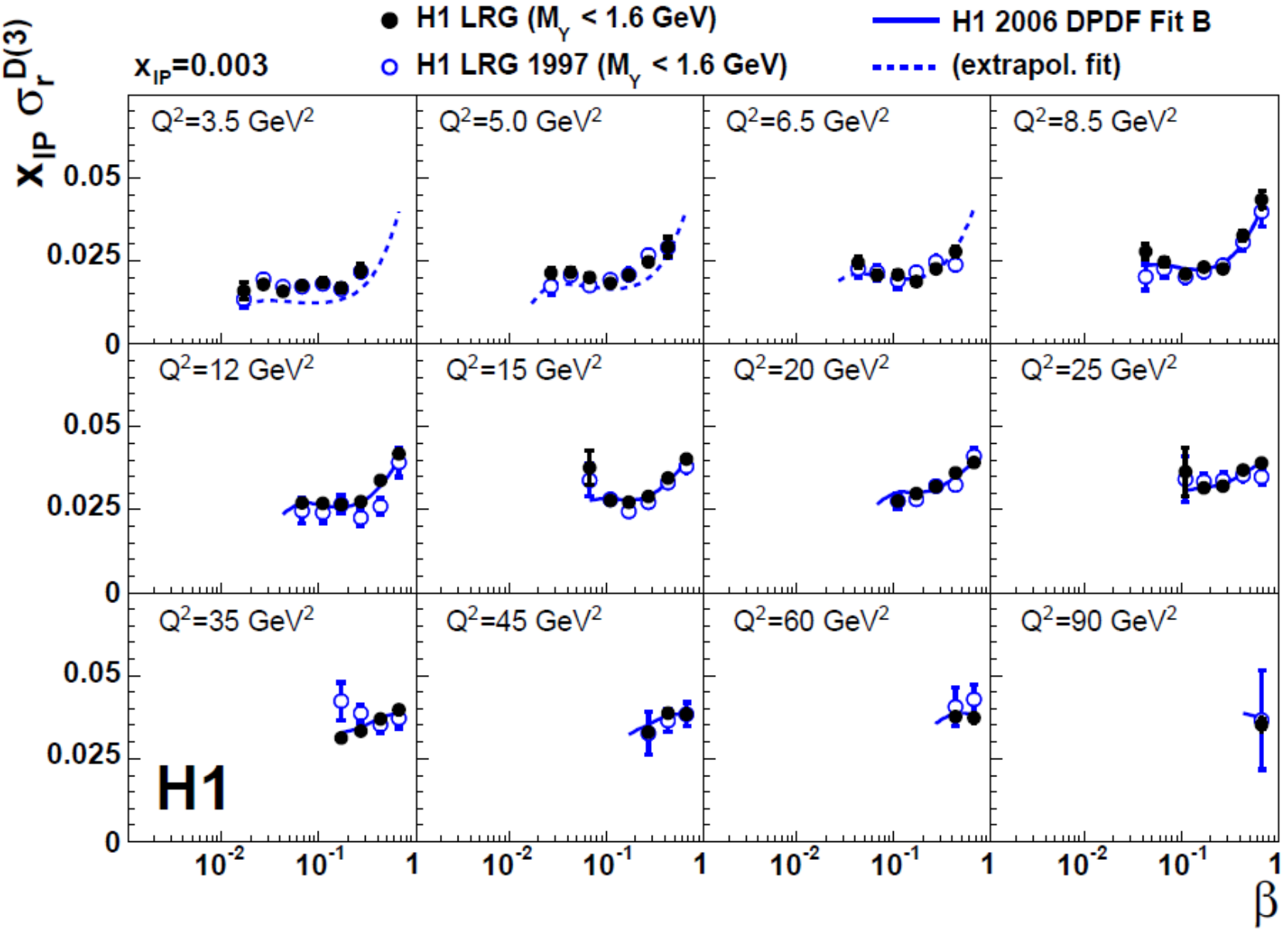
More ...

Combined LRG cross section -1-





Combined LRG cross section -2-



Combined LRG cross section -3-