Recent soft diffraction results from HERA

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on behalf of H1 and ZEUS Collaborations

HERA collider experiments

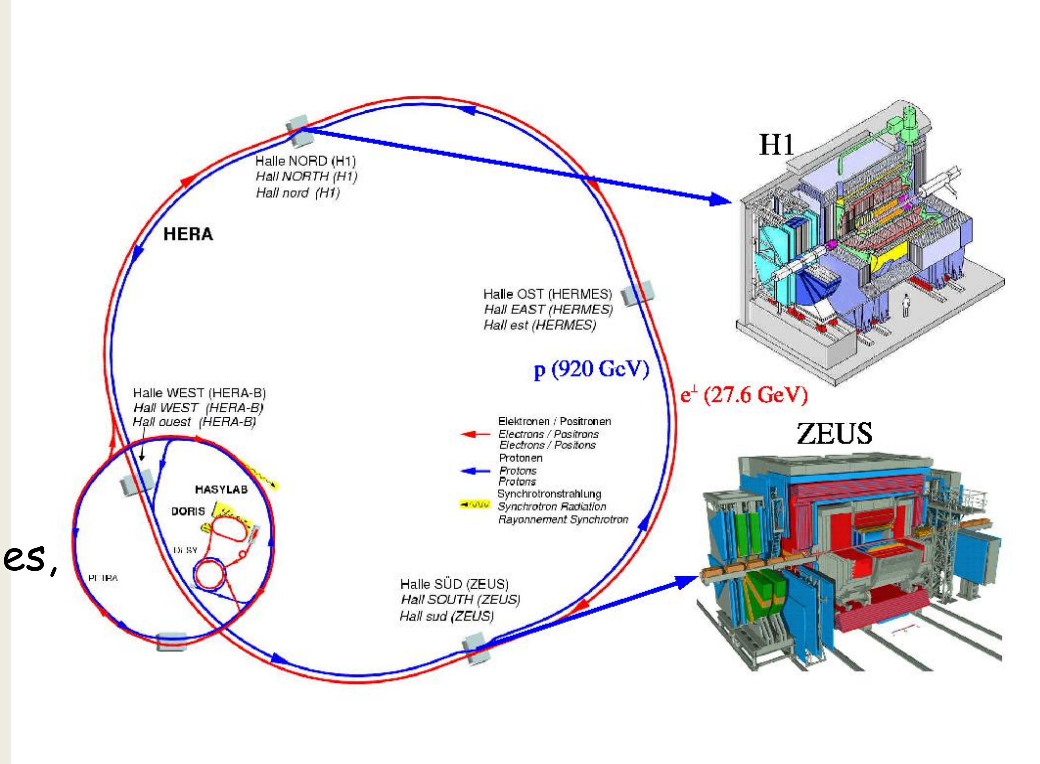
- 27.5 GeV electrons/positrons on 920 GeV protons →$\sqrt{s}$=318 GeV
- data taken in 1992-2007
- HERA I,II: ~ 500 pb^{-1} per experiment
- H 1 & ZEUS - 4π detectors

Why to study diffraction?

Fundamental aim:
understand high energy limit of QCD

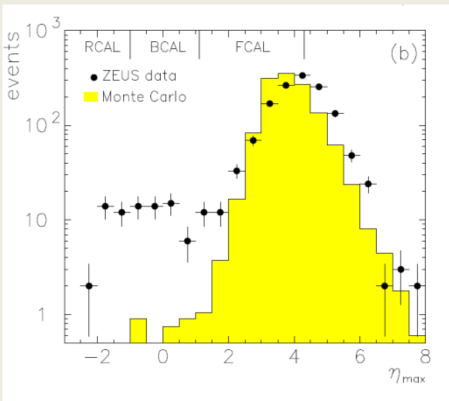
Novelty:
probe partonic structure of diffractive exchange for the first time

Applications: study facorisation properties, transport PDFs to hh scattering (Tevatron, LHC)??



Historical reminder

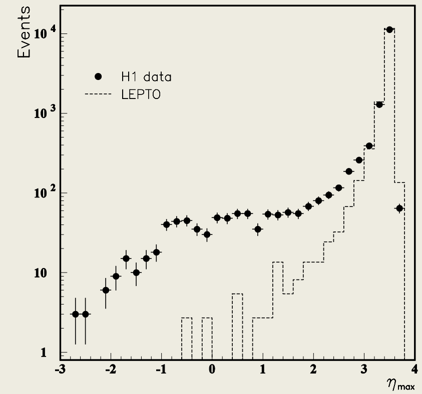
- **20 years** after the observation of diffractive DIS events at HERA!
- HERA opened **new era of diffraction studies**



ZEUS Collab.,Physics Letters B 315 (1993) 481-493

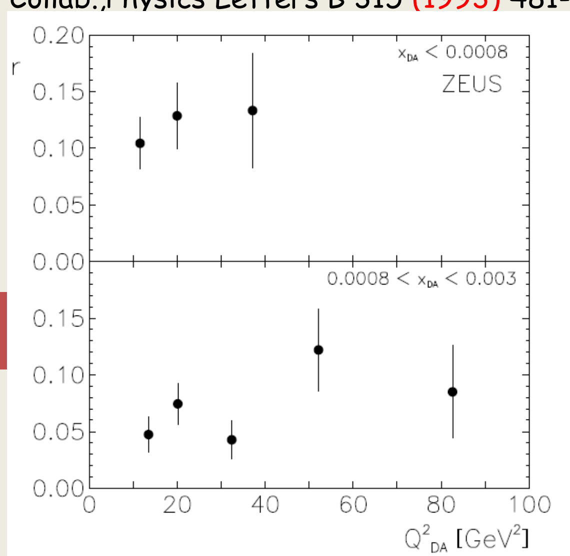
1993-1994

HISTORY

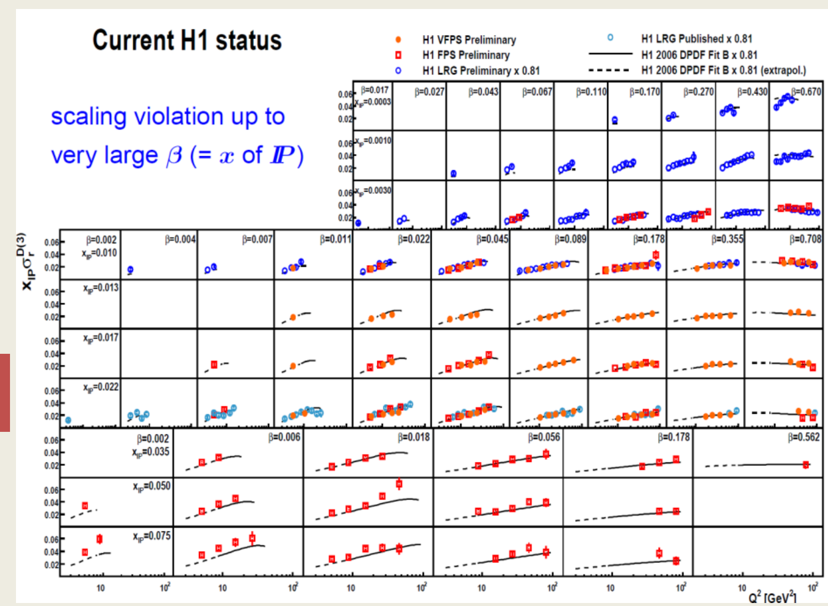


H1 Collab., Nucl. Phys. B429 (1994) 477

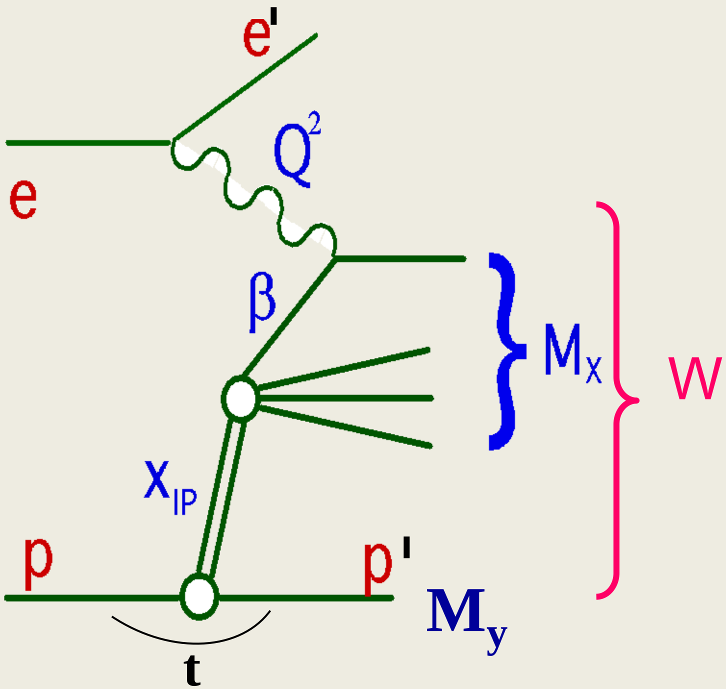
1993



2013



Diffractive kinematics



Q^2~0 GeV^2→ photoproduction
Q^2>>0 GeV^2→ deep inelastic scattering (DIS)

HERA: ~10% of events diffractive

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

momentum fraction of color singlet exchange

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

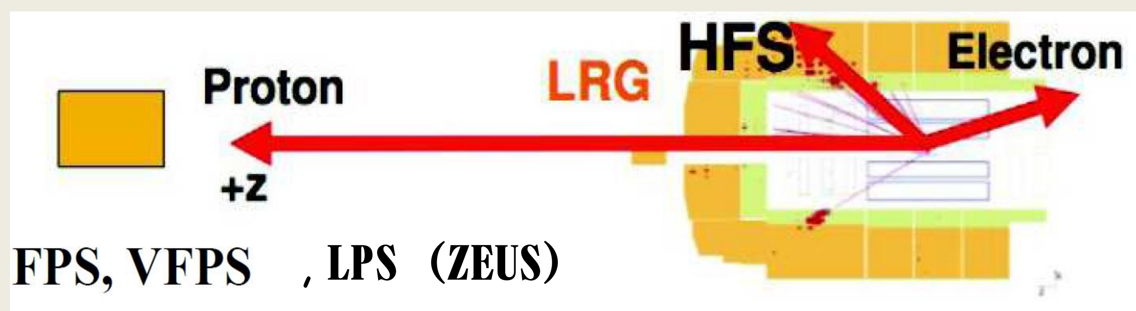
fraction of exchange momentum, coupling to γ

$$t = (p-p')^2 \longrightarrow$$ 4-momentum transfer squared

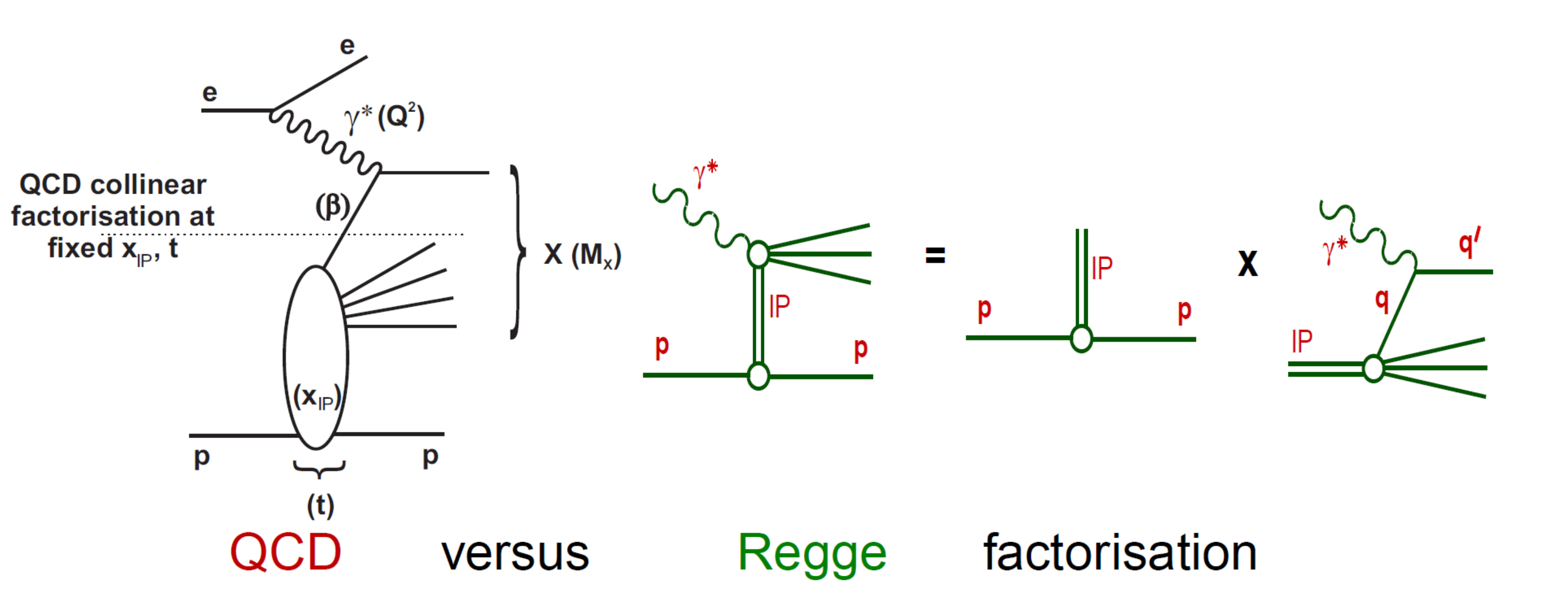
$M_y = m_p$ proton stays intact, needs detector setup to detect protons
$M_y > m_p$ proton dissociates, contribution should be understood

Experimental methods:

- selecting LRG events
- measuring p in Roman pots (60-220m from Int.Point)



Factorisation properties of diffraction



QCD factorisation
(rigorously proven for DDIS by Collins et al.)

$$\sigma^D(\gamma^* p \to Xp) = \sum_{parton\_i} f_i^{\,D}(x,Q^2,x_{IP},t)\cdot\sigma^{\gamma^* i}(x,Q^2)$$

$f_i^{\,D}$ - DPDFs – obey DGLAP, universal for diff. ep DIS (inclusive,dijet..)

$\sigma^{\gamma^* i}$ - hard scattering cross section (same as in non-diffractive DIS)

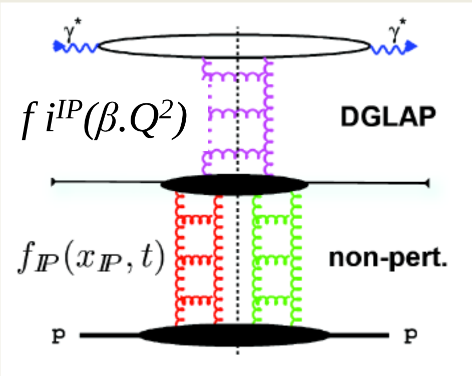
Regge factorisation
(conjecture, e.g. Resolved Pomeron Model by Ingelman&Schlein)

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

pomeron flux factor   pomeron PDF

Modelling of diffraction

QCD collinear factorisation theorem



Infinite momentum frame - partons

[H1 Coll. EPJC28 (2006) 715]

$$\sigma^D(\gamma^* p \to Xp) = \sum_{parton\_i} f_i^D(x, Q^2, x_{IP}, t) \cdot \sigma^{\gamma^* i}(x, Q^2)$$

Regge factorisation (conjecture, e.g. Resolved Pomeron Model by Ingelman&Schlein)

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

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

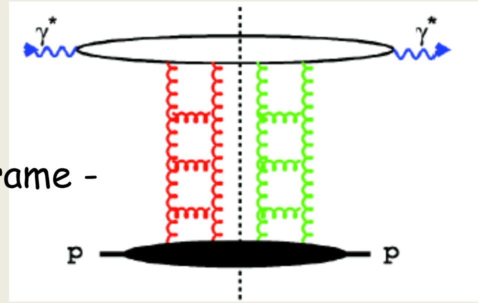
Pomeron flux factor

diffractive DPDF

DPDFs extracted from DIS data

Dipole model

Proton rest frame - dipoles



[C. Marquet PRD76 (2007) 094017]

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

Long living quark pairs interact with gluons of the proton

No extra parameters needed for DDIS

Diffractive reduced cross section

- select diffractive events
- correct for detector effects
- derive cross sections -> F_2^D

$$\frac{d^4\sigma(ep \to eXp)}{d\beta\, dQ^2 dx_P dt} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}(1-y+\frac{y^2}{2})\ \sigma_R^{D(4)}(\beta, Q^2, x_P, t)$$

y - inelasticity → 1-(E'$_e$/E$_e$)

$\sigma_R^{D(4)}$ → diffractive reduced cross section

$\sigma_R^{D(4)} \approx F_2^{D(4)}$ at low and medium *y*

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

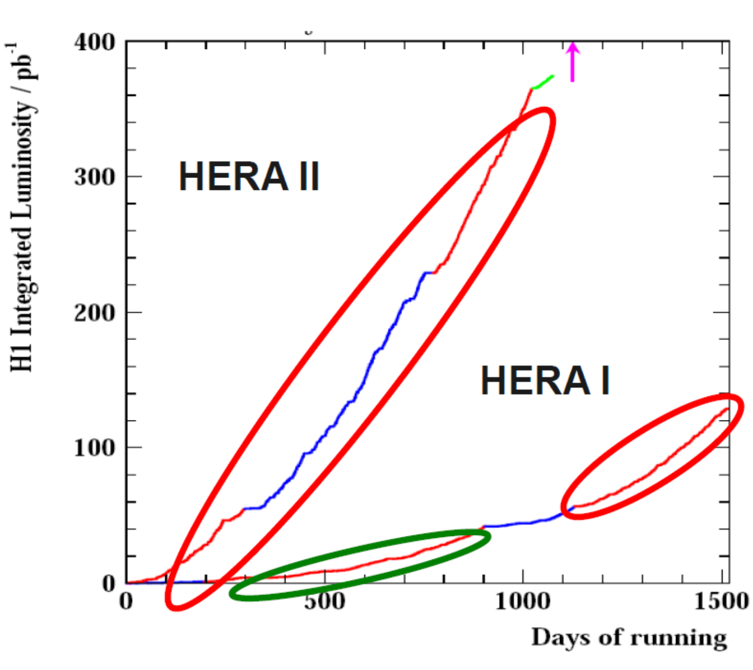
$\sigma_R^{D(4)} = F_2^{D(4)}$ if

$F_L^{D(4)} = 0$

Integrate over *t* when proton is not tagged

→ $\sigma_R^{D(3)}(\beta, Q^2, x_P)$

Full H1 LRG data sample



DESY - 12 - 041

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 results combined to one single LRG cross section set

Kinematic region →

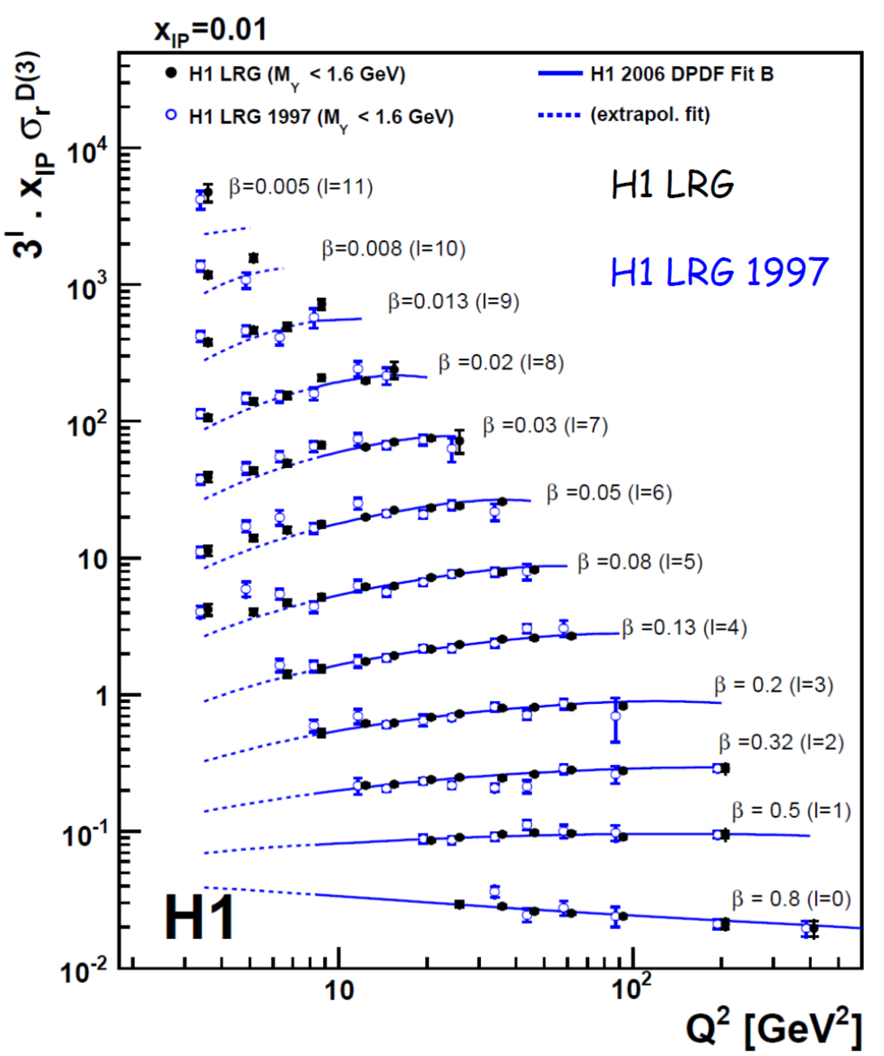
$3.5 < Q^2 < 1600\ GeV^2$

$0.0017 < \beta < 0.8$

$0.0003 < x_{IP} < 0.03$

Increase in statistics by factor 3 – 33

Combined H1 LRG cross section



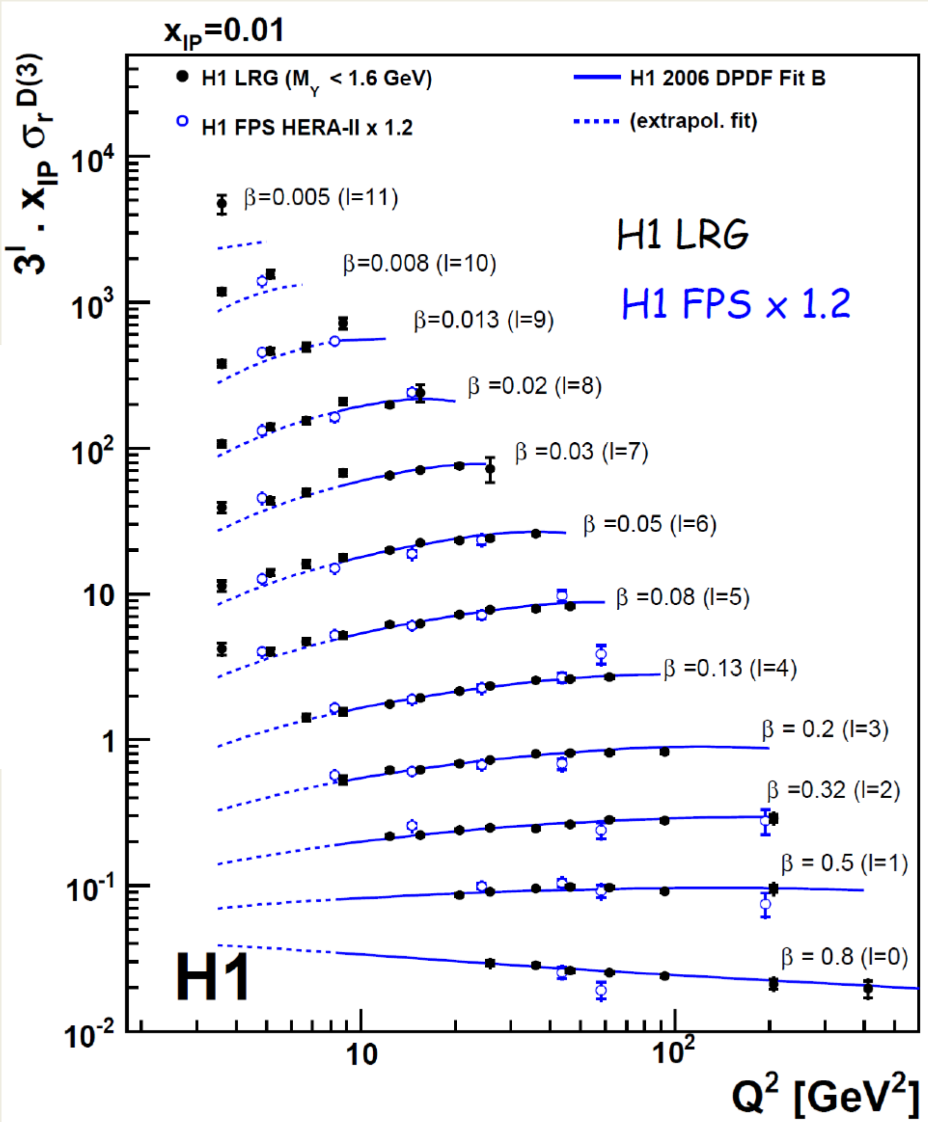
Published in 1997 and new cross sections agree well

Large reduction of statistical errors

Typical precisions for $Q^2 > 12$ GeV^2

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

Combined H1 LRG & FPS



Eur. Phys. J. C72 (2012) 2074

The ratio LRG/FPS :

$$\frac{\sigma\,(M_Y < 1.6\,\mathrm{GeV})}{\sigma\,(Y = p)} = 1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$$

(1.6%) (7.2%)

FPS cross sections are multiplied by factor 1.2 to take into account the dissociation admixture in LRG sample

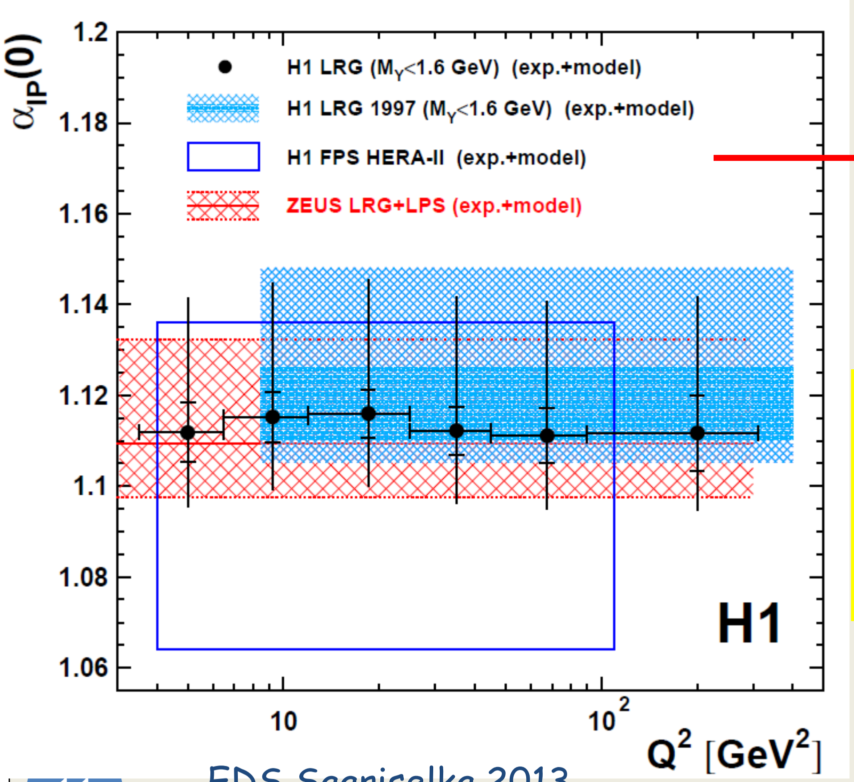
Agreement with previous results, no Q^2 or β dependence of differences observed !

Extraction of the pomeron trajectory

Regge fit to LRG cross sections:

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

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



The mean value of pomeron intercept

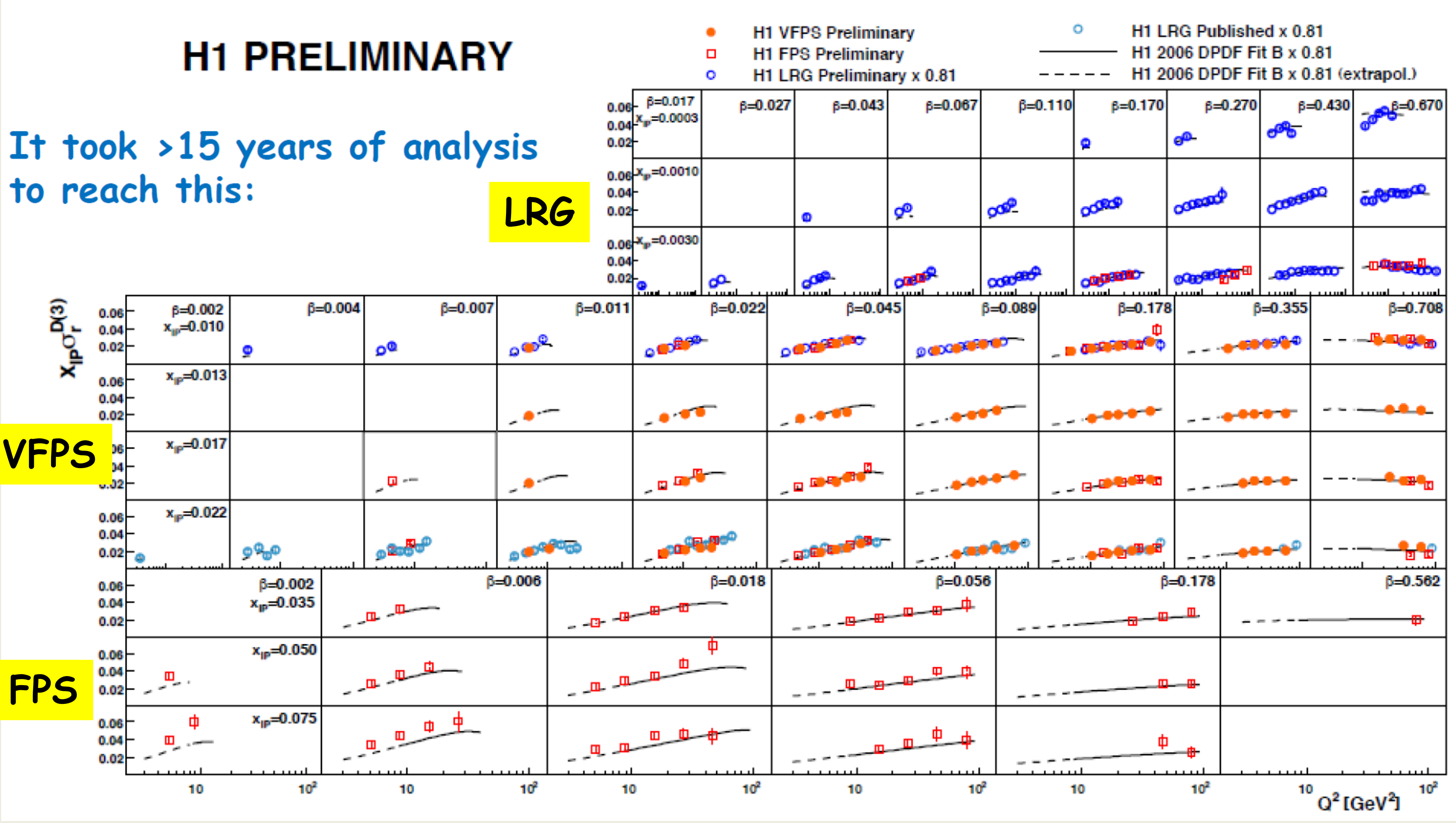
$$\alpha_{I\!P}(0) = 1.113\ \pm 0.002\ (\mathrm{exp.})\ {}^{+0.029}_{-0.015}\ (\mathrm{model})$$

- no Q^2 dependence observed
- consistent with other measurements
- supports the hypothesis of the proton vertex factorization

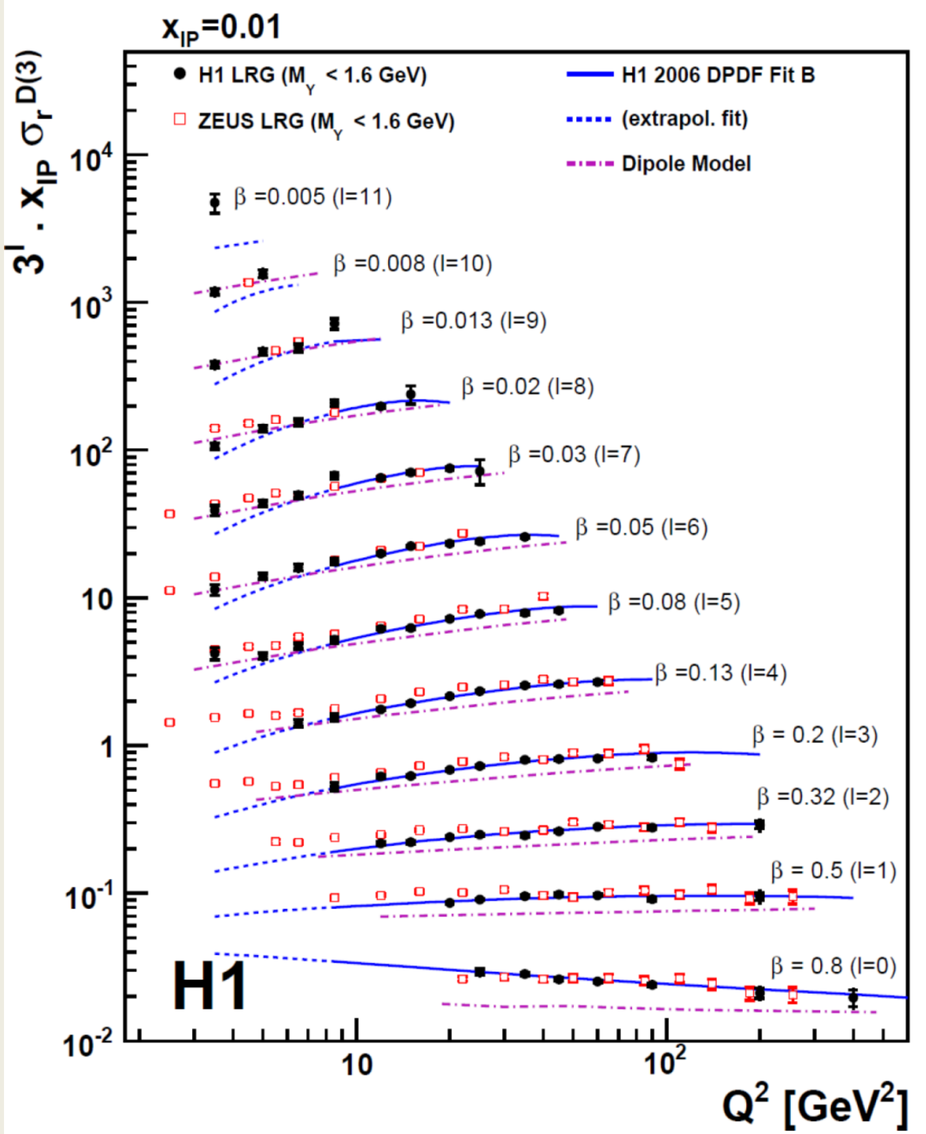
$\alpha_{I\!P}(0)$ – consistent with 'soft $I\!P$'

Experimental summary for H1 F_2^D

It took >15 years of analysis to reach this:



H1 & ZEUS LRG data



H1 LRG	H1 Collab., Eur. Phys. J. C48 (2006) 715 H1 Collab., Eur. Phys. J. C72 (2012) 2074
ZEUS LRG	ZEUS Collab., Nucl. Phys. B816 (2009) 1

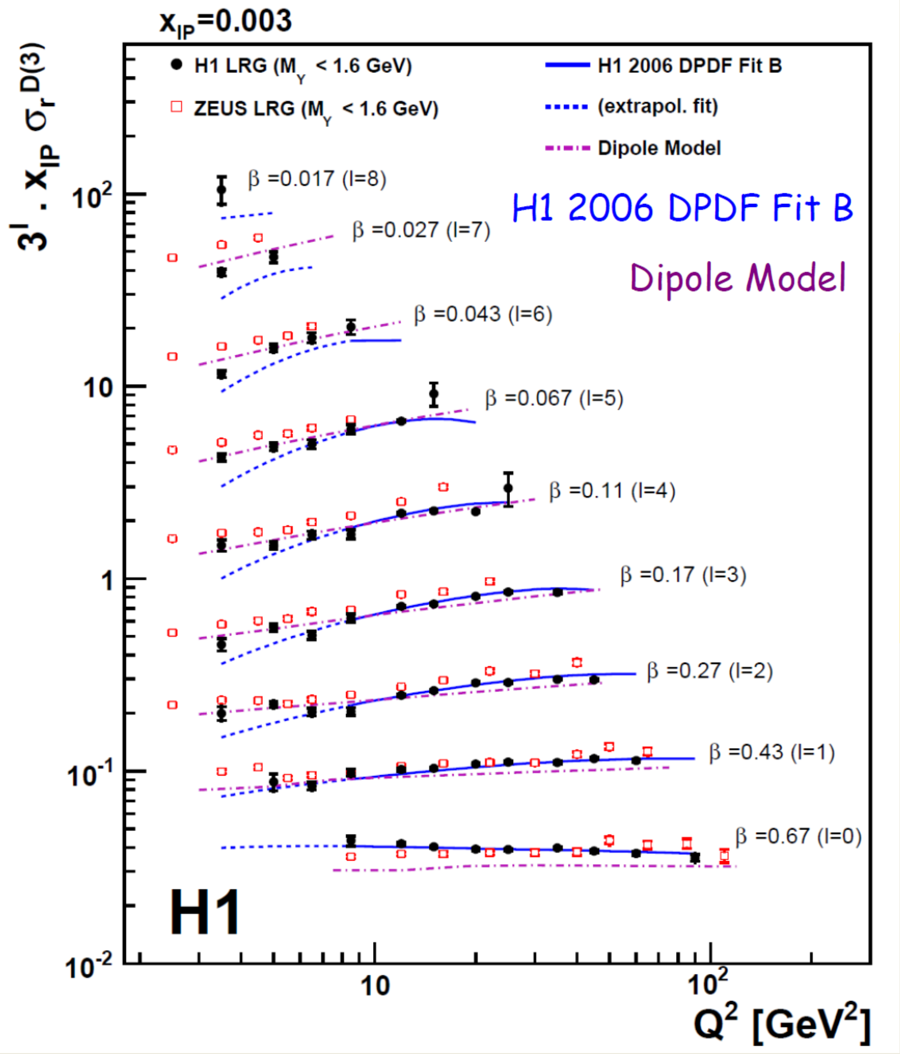
H1 data $M_Y < 1.6$ GeV²

ZEUS data rescaled to $M_Y < 1.6$ GeV² (by factor 0.91).

ZEUS data tend to be higher than H1, normalisation difference ~ 10%

Comparison is sensitive to systematic effects

H1 & ZEUS, comparison with models



Normalization difference of ~ 10% between H1 nad ZEUS is within normalization uncertainties of each experiment

- low Q^2 – better description by dipole model, higher twist contributions?
- high Q^2 – better description by H1 fit B DPDF

Data available for comparison with models

HERA LRG data combination……

HERA combined $\sigma_r^{D(3)}$ proton spectrometers

H1 FPS

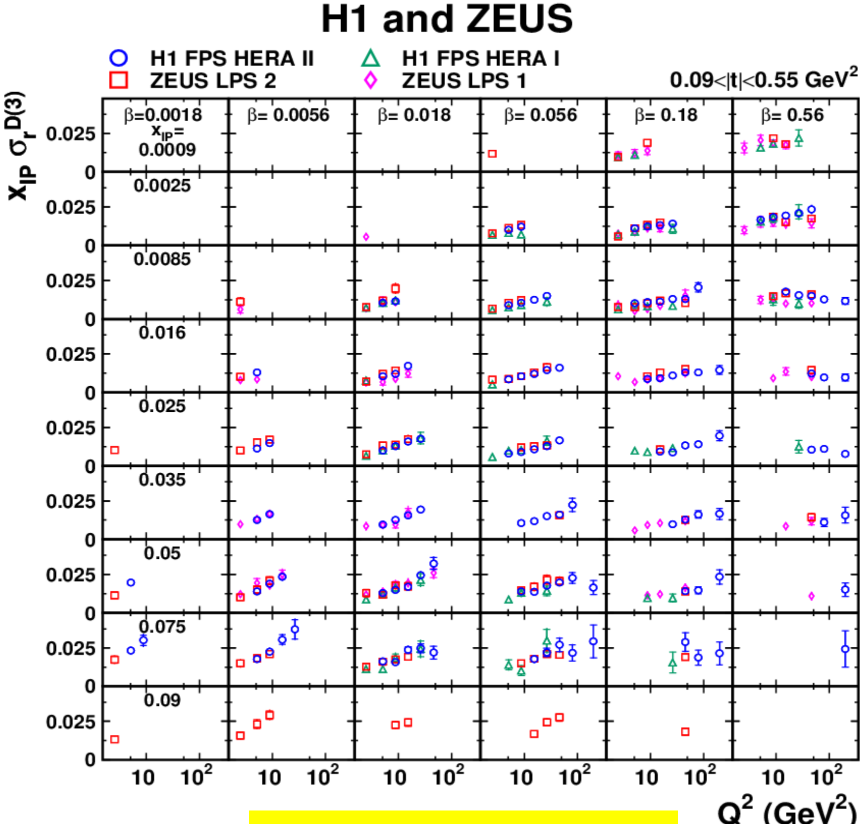
H1 Collab., Eur. Phys. J. C71 (2011) 1578
H1 Collab., Eur. Phys. J. C48 (2006) 749

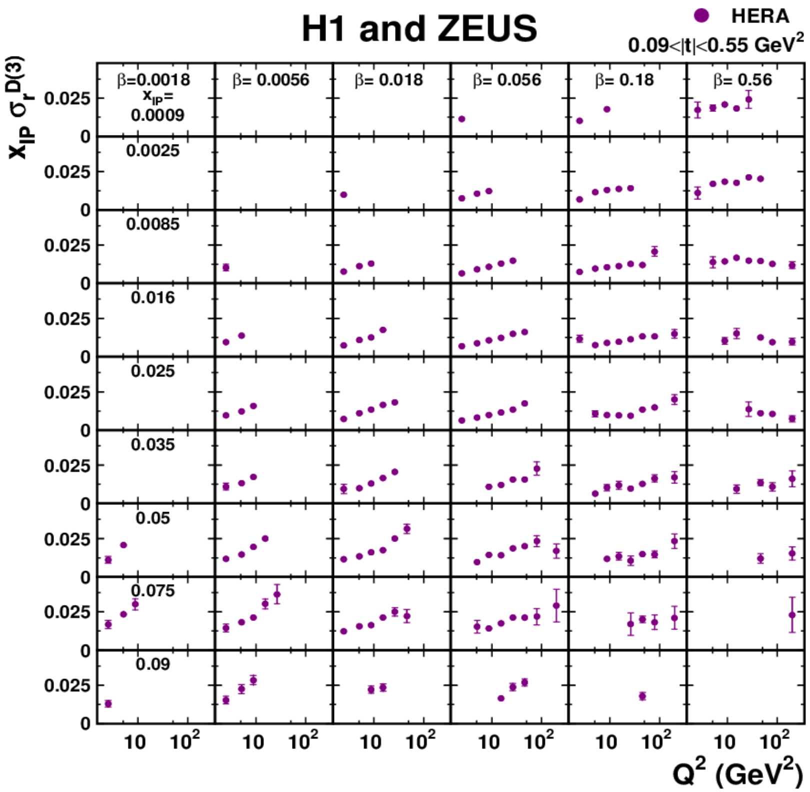
ZEUS LPS

ZEUS Collab., Nucl. Phys. B816 (2009) 1
ZEUS Collab., Eur. Phys. J. C38 (2004) 43

Kinematic range

Q^2 = 2.5 - 200 GeV^2
β = 0.0018 - 0.816
x_{IP} = 0.00035 - 0.09
$|t|$ = 0.09 - 0.55





$\sigma_r^{D(3)}$ for combination

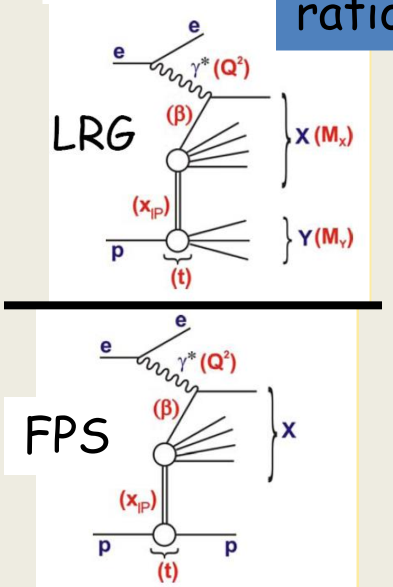
Conclusions

- Precision measurement representing a final H1 word on inclusive LRG cross sections in DIS is published based on full HERA I+II data ➔ EPJC C72 (2012), 3
- These data provide new constraints to QCD models and support proton vertex factorisation hypothesis
- ZEUS final results published in 2009 ➔ Nucl. Phys. B 816, (2009),1
- H1 and ZEUS combined inclusive cross section measured with forward proton spectrometers in DIS published ➔ EPJC C72 (2012),2175
- **HERA data available for comparison with models**

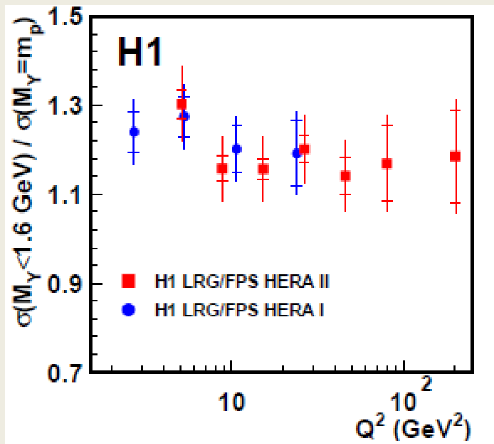
Comparison between methods – H1

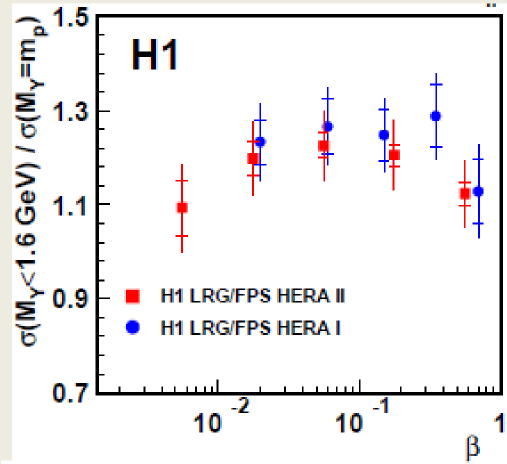
Are „rapidity gap“ and „forward proton“ methods compatible?

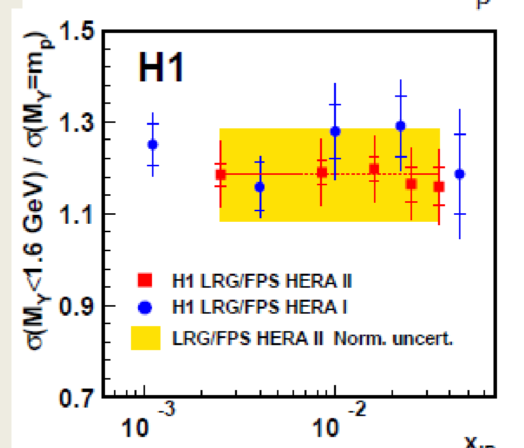
ratio



H1, LRG/FPS = 1.18 ± 0.03 (stat) ± 0.06(uncor.syst.) ± 0.10(norm)



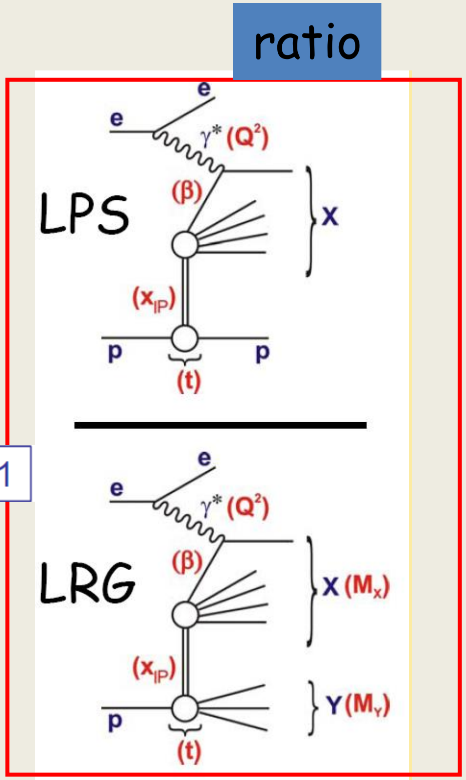




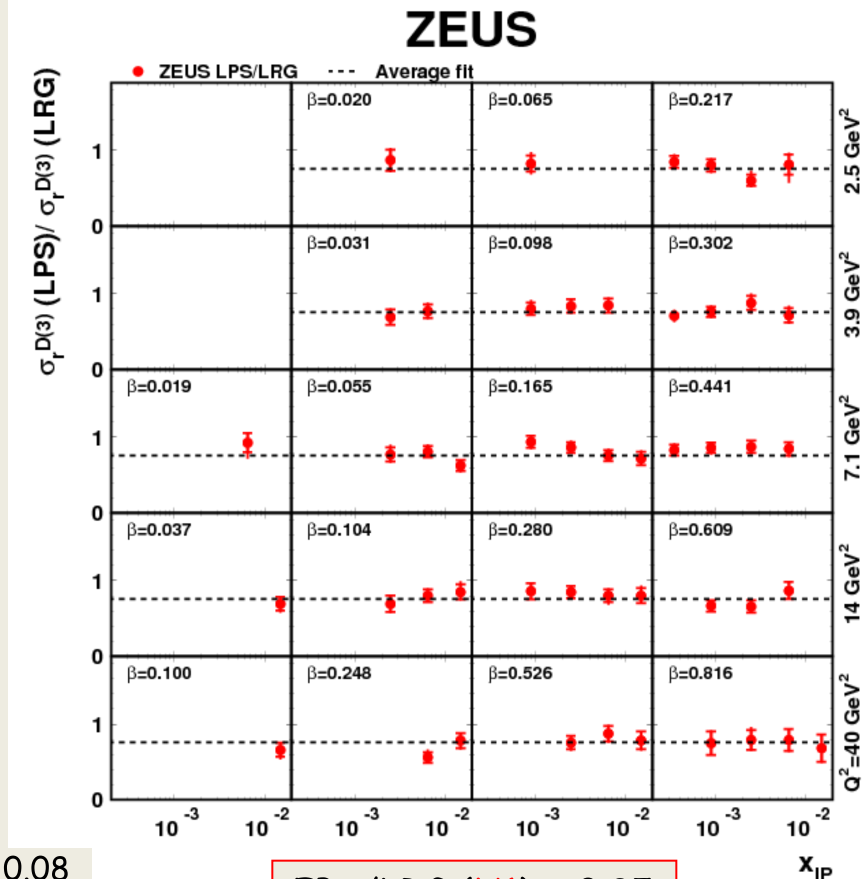
EPJ C71 (2011) 1578

Precise knowledge and corrections for proton dissociation background-
key point in H1- ZEUS data comparison

Comparison between methods - ZEUS



NP B816 (2009) 1



ZEUS, LPS/LRG = $0.76 \pm 0.01 \,^{+0.03}_{-0.02} \pm \,^{0.08}_{0.05}$

FPS/LRG (H1) ~ 0.85

- LRG selection contains about 20% events of proton diss.
- no significant dependence on any variable
- well controlled, precise measurements