Diffraction at HERA

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On behalf of the

H1 & ZEUS Collaborations

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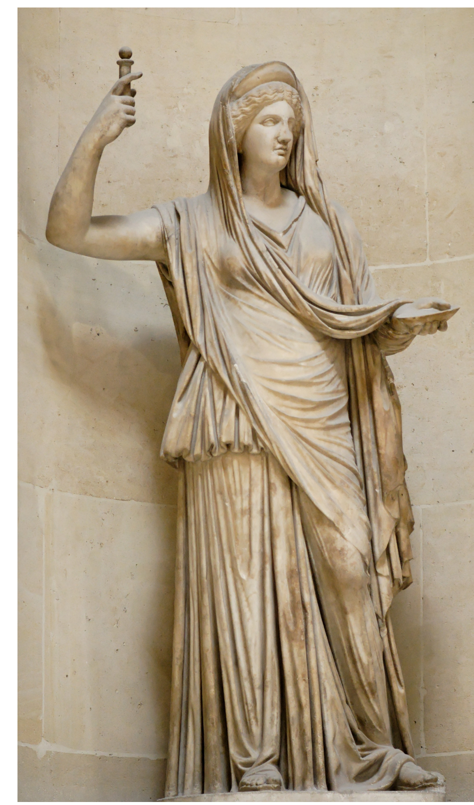
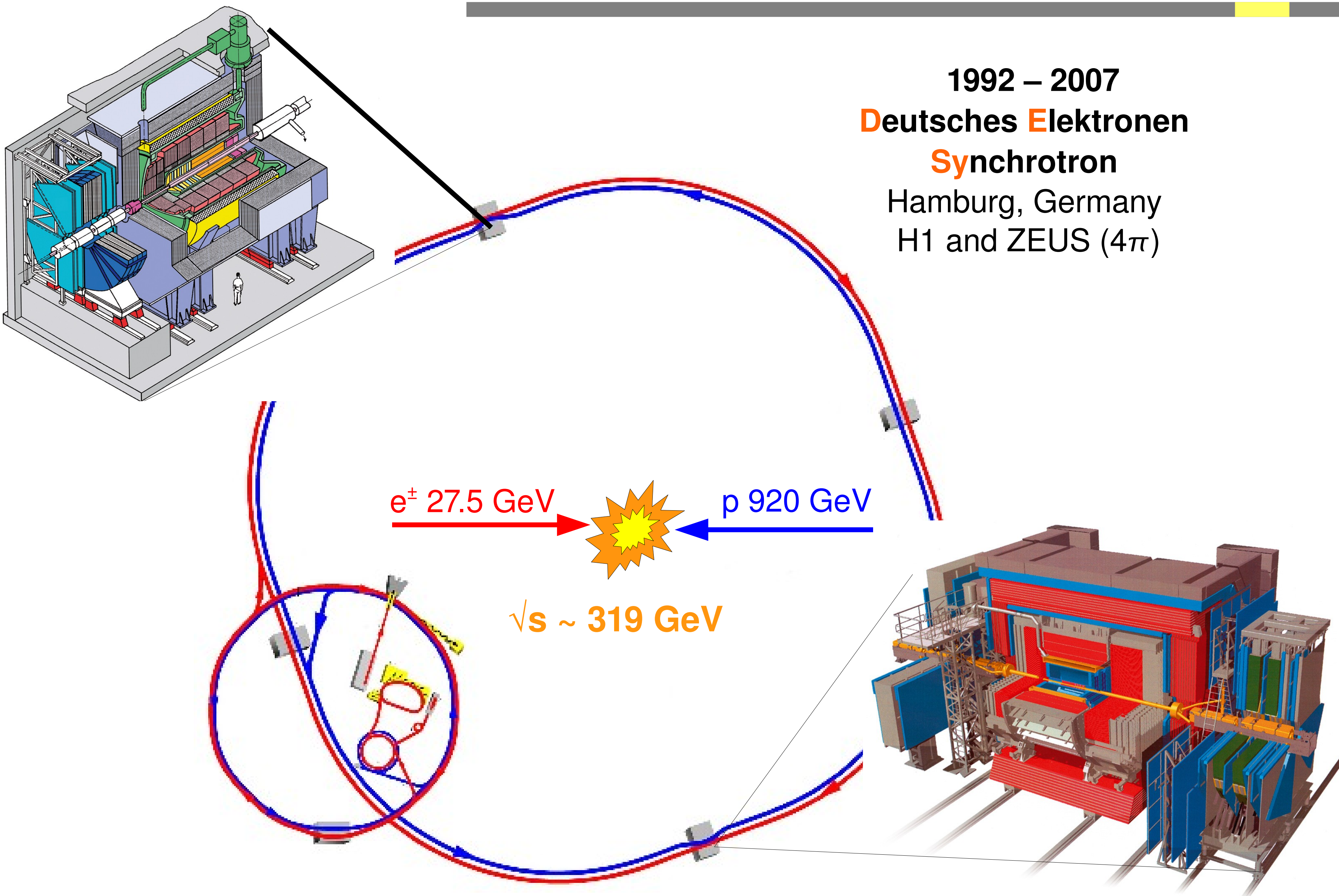
XL ISMD, 2010, Antwerp



HERA

1992 – 2007
Deutsches Elektronen Synchrotron
Hamburg, Germany
H1 and ZEUS (4π)



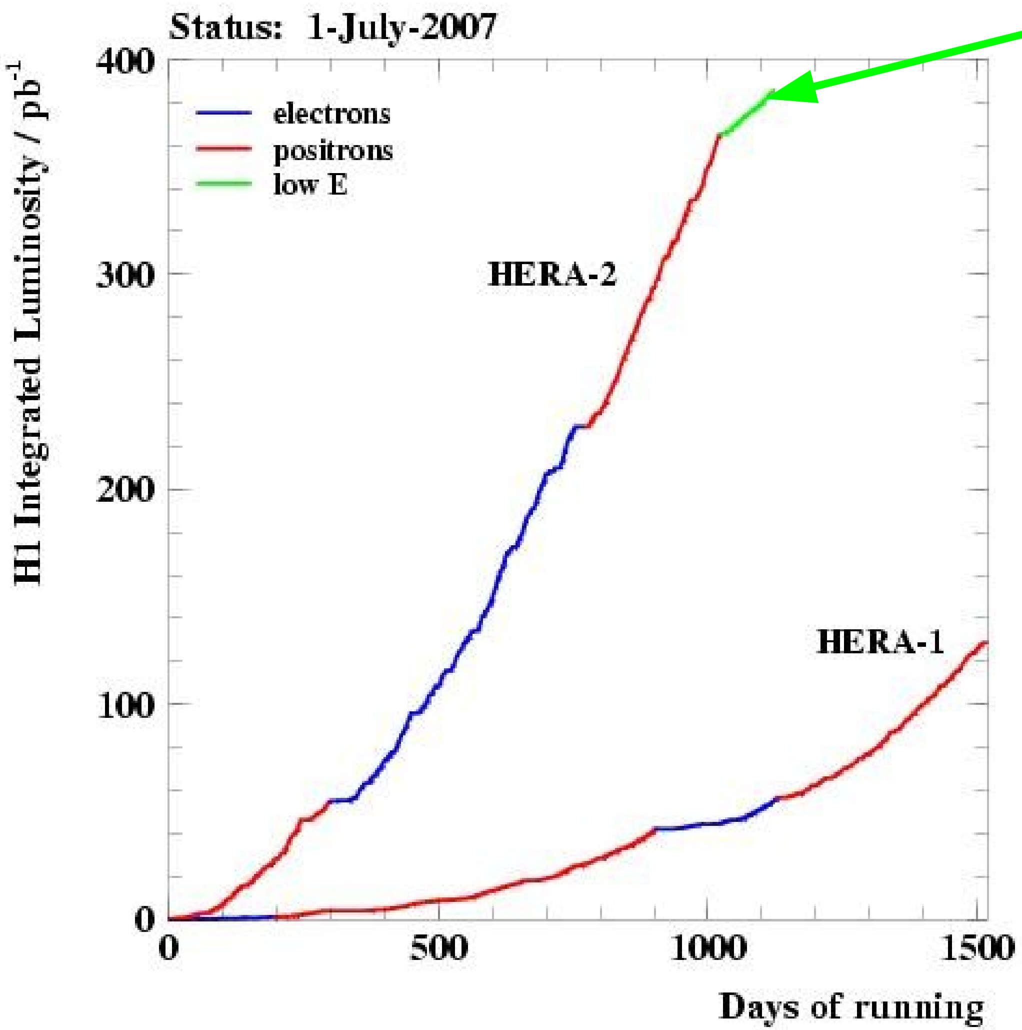
Data

L = 0.5 fb^{-1}

HERA 1:
1992 – 2000

HERA 2:
2003 – 2007

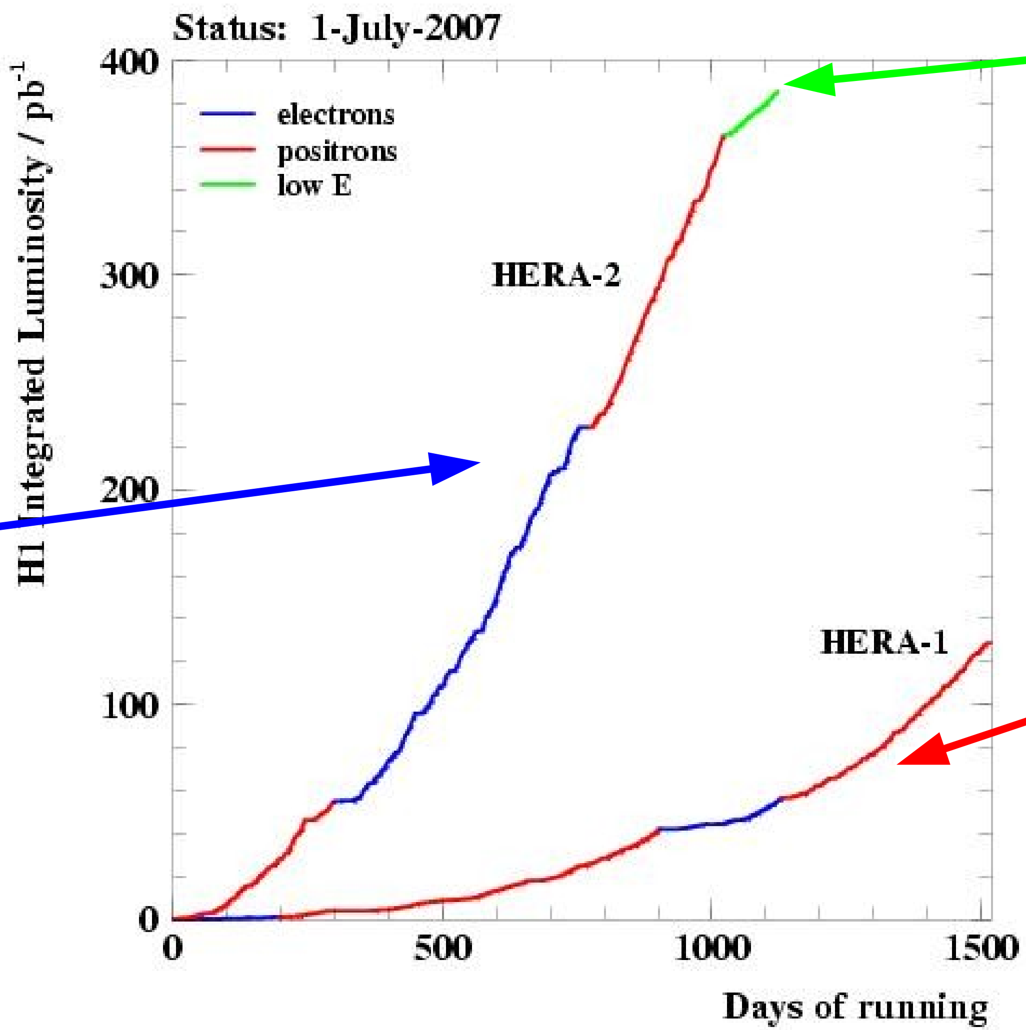
E_p = 460 GeV
L = 12.4 pb^{-1}
E_p = 575 GeV
L = 6.2 pb^{-1}



460 and 575 GeV Special dedicated runs for measuring F_L

Data

HERA 1:
1992 – 2000
HERA 2:
2003 – 2007

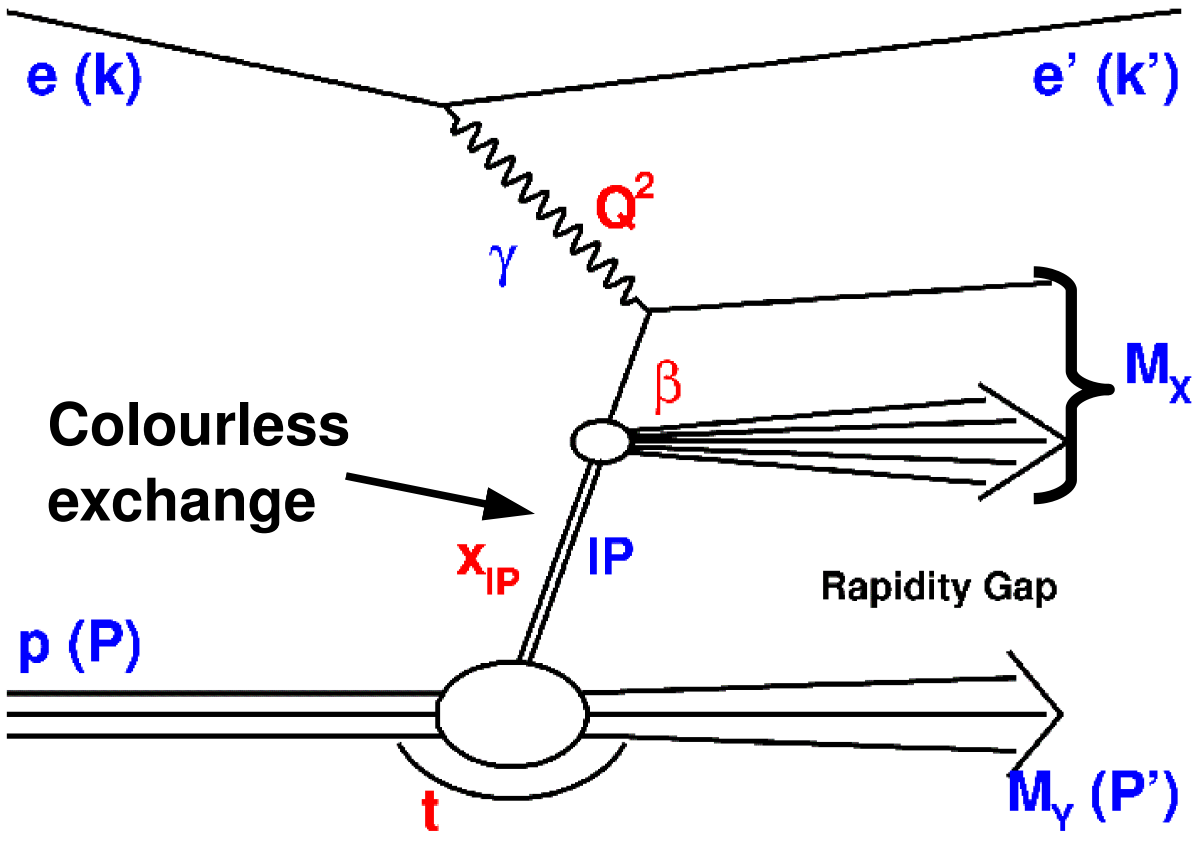


460 and 575 GeV - F_L^D measurement

- Inclusive diffractive cross sections with leading proton and LRG
- Jet final states with leading proton

- Inclusive diffractive cross sections with leading proton and LRG
- Jet final states with LRG

Diffractive kinematics



$Q^2 = -q^2 = (k' - k)^2$

$x = Q^2/2Pq$

$x_{IP} = q(P' - P)/qP$

$= 1 - E_p/E'_p$

$\beta = x/x_{IP}$

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

$M_Y = m_p$

proton stays intact

$m_p < M_Y < 1.6$ GeV

proton dissociation

incl. nucleon resonances

$Q^2 >> 0$ GeV^2.... deep inelastic scattering

$Q^2 \sim 0$ GeV^2...... photoproduction (γp)

Experimental methods

LRG method:

Requirement of no activity in the forward part

\+ high statistics

-- proton dissociative background

Neutron tagging:

Detection at z = +106m in FNC (**H1**, **ZEUS**)

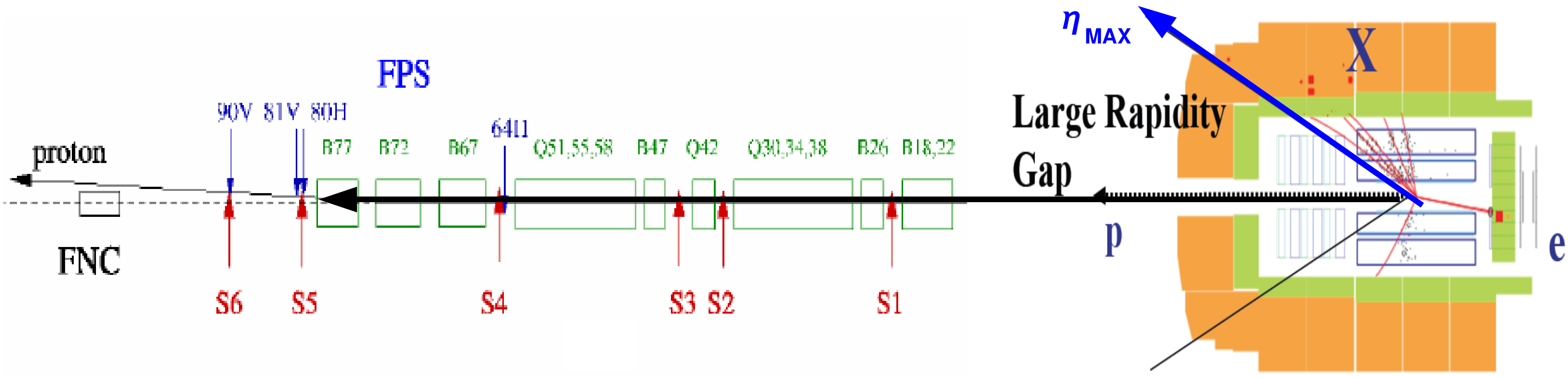
Proton Tagging:

Detection of the leading proton in forward detectors - FPS (**H1**), VFPS(**H1**), LPS (**ZEUS**)

\+ direct extraction of diffractive variables, *t* dependence measured

\+ free of proton dissociation background

-- small acceptance → low statistics



Diffractive Cross Section

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

Where $\sigma_r^{D(4)}$ is diffractive reduced cross section:

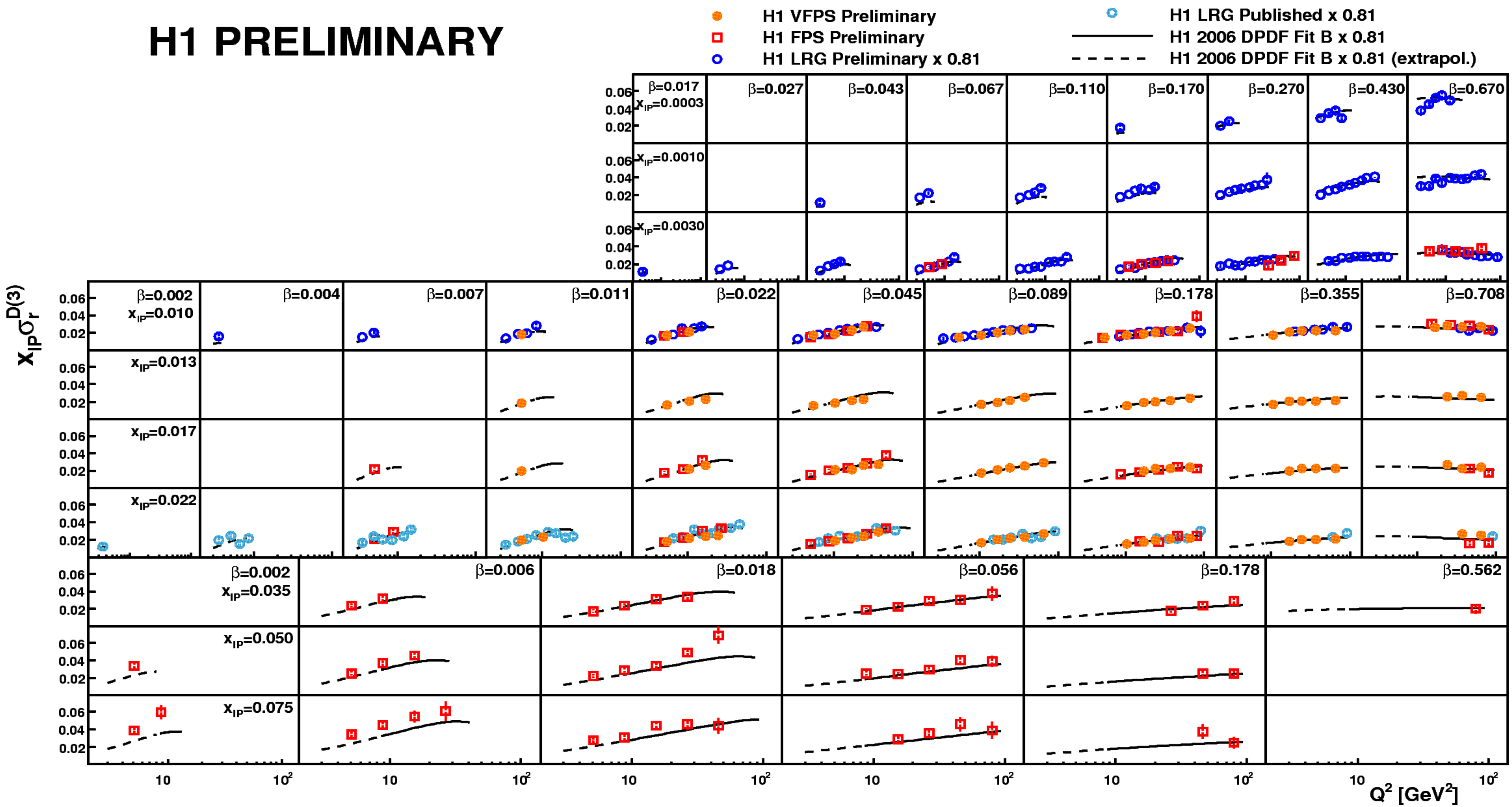
$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)} F_L^{D(4)}$$

Longitudinal diffractive structure function

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

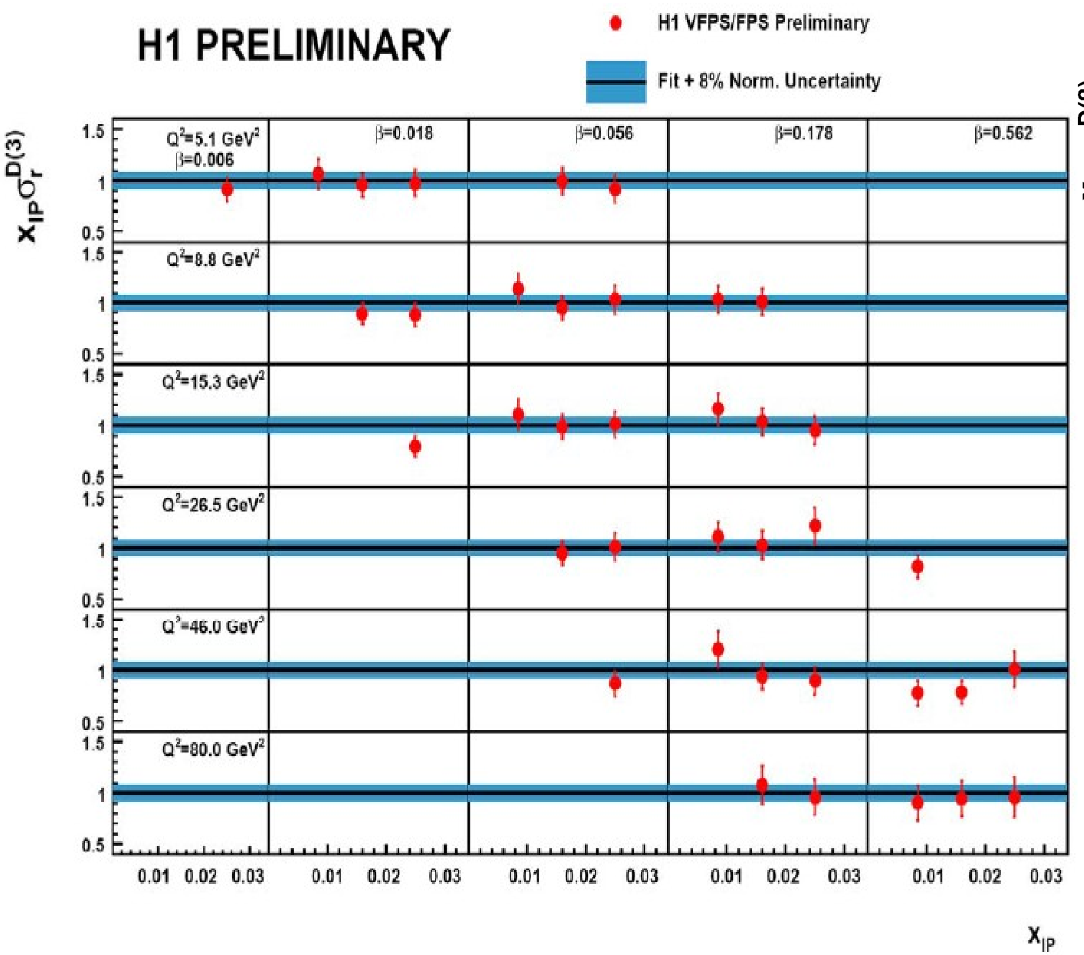
LRG method unable to measure the *t* dependence → integration

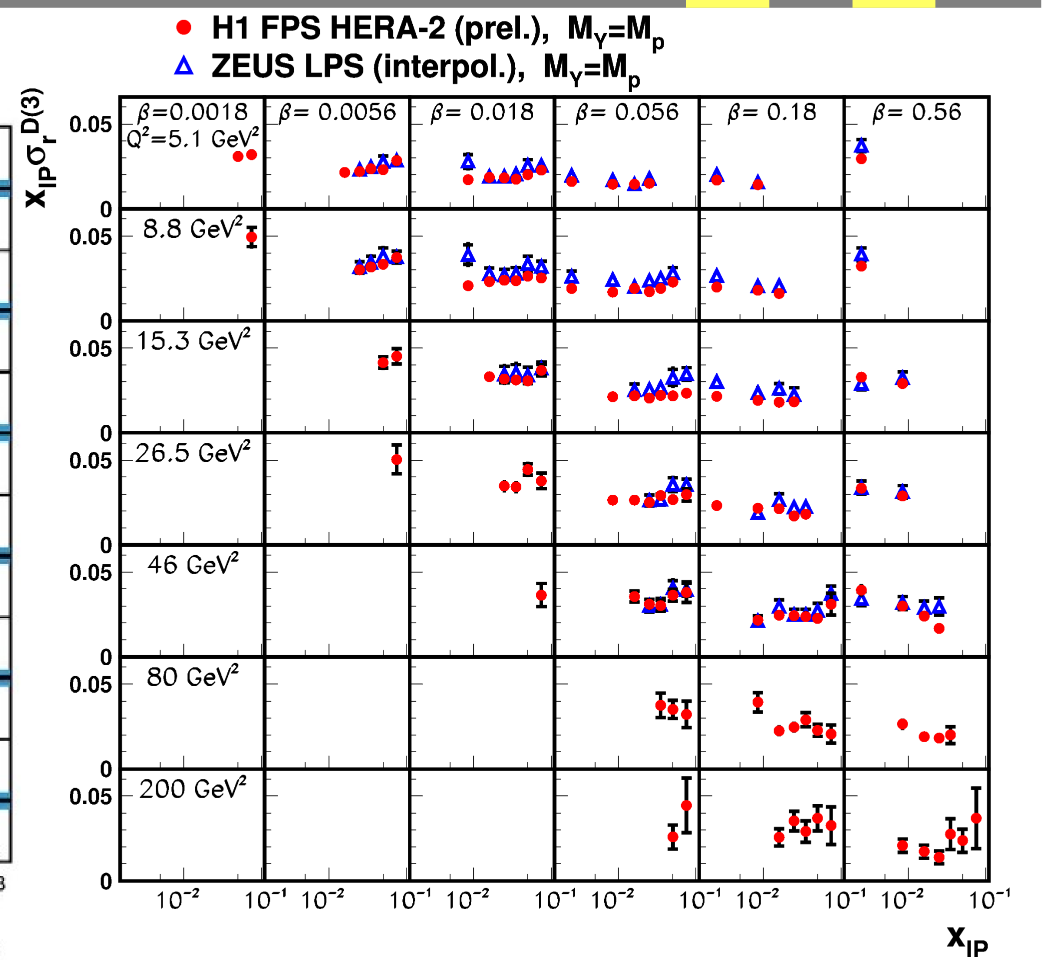
Reduced Cross Section



- Different measurements cover large region of phase space in x_{IP}, β and Q^2
- Excellent agreement between different reconstruction methods in regions of overlap

Leading Protons @ H1 and ZEUS



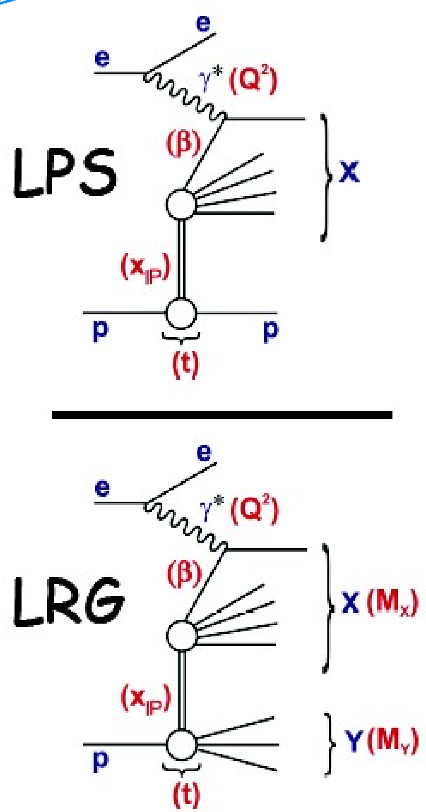


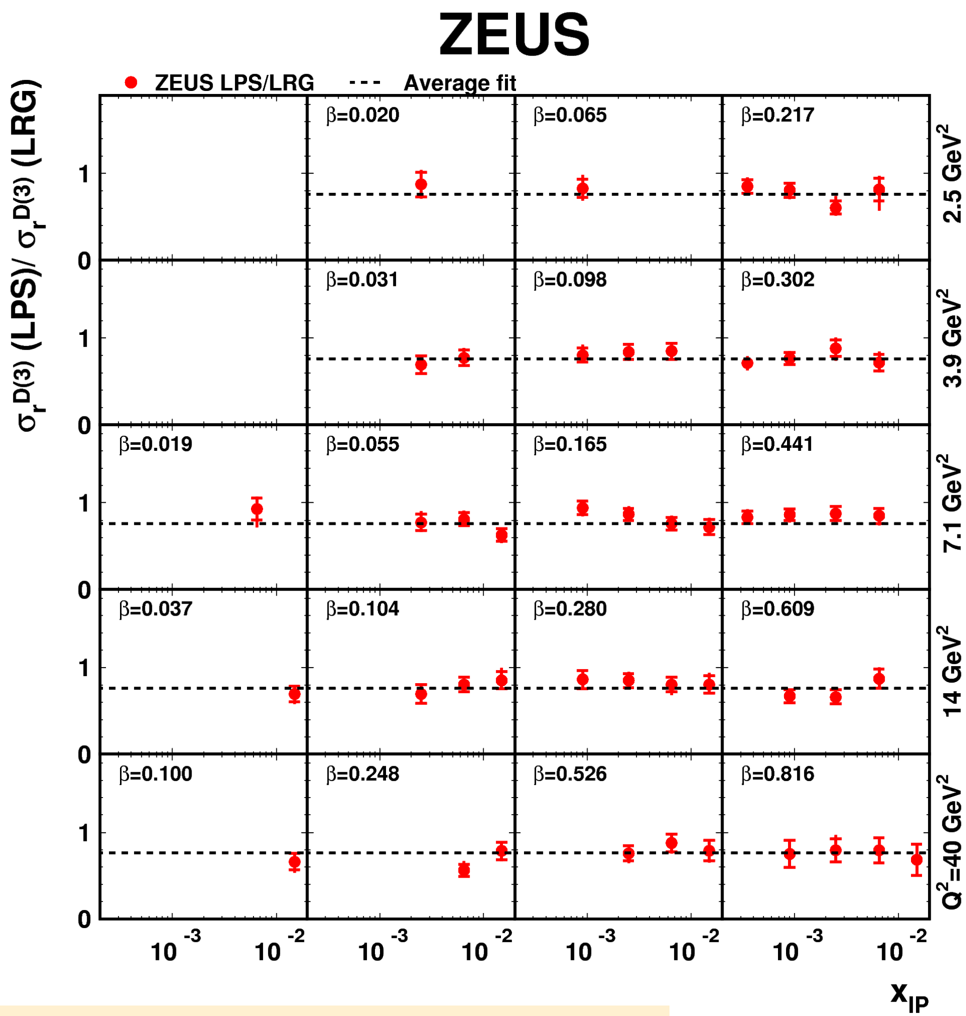
- **VFPS** / **FPS**, HERA 2 (157 pb^{-1})
- In the whole kinematical range in agreement within the errors

Successful consistency check in the region of overlap

- **FPS** x **LPS**
- H1 – ZEUS agreement within errors
- 15% difference in overall normalisation compatible with normalisation uncertainties (6% FPS, 10% ZEUS)

Leading Protons vs LRG



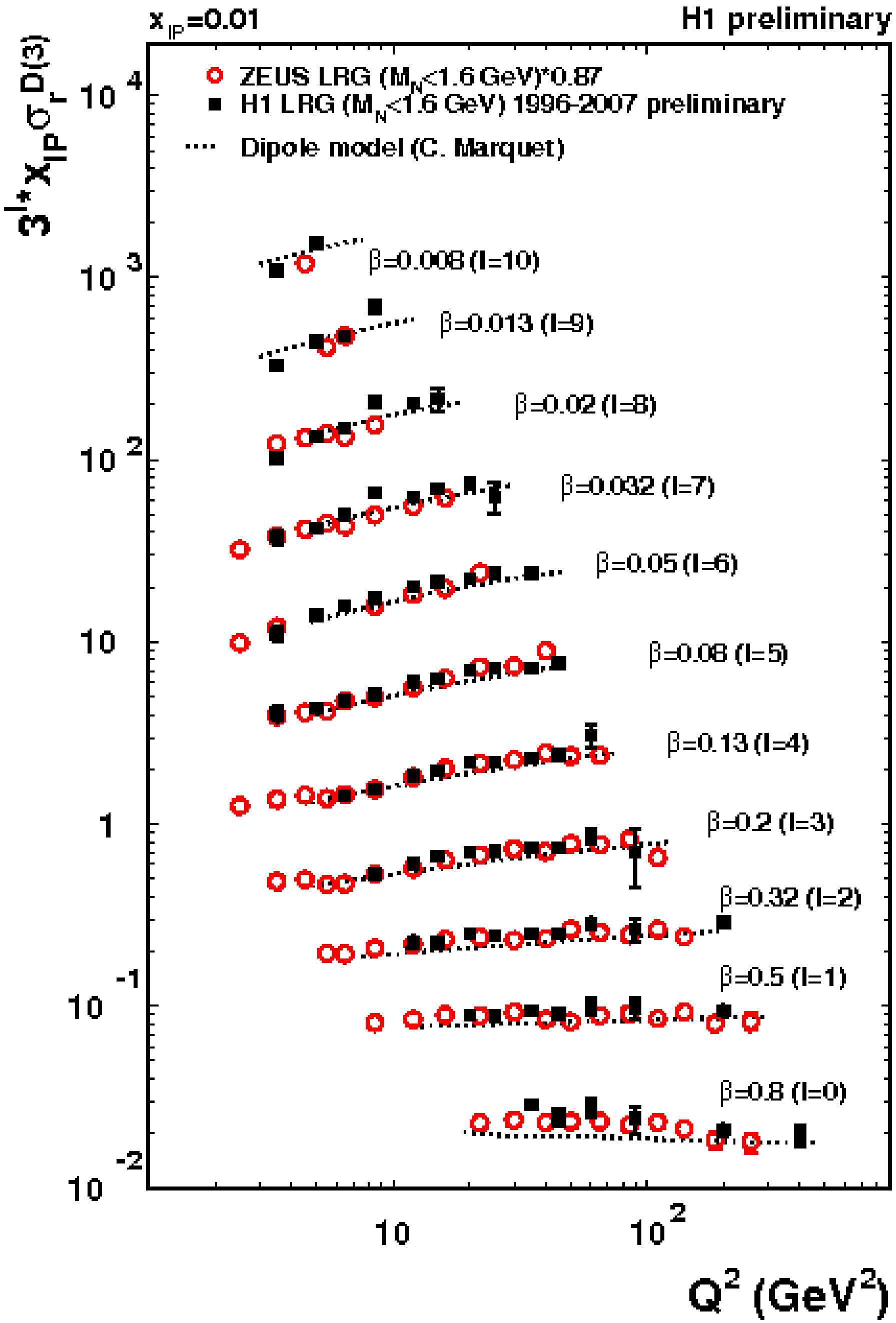


ZEUS LPS/LRG: **0.76** ±0.01 ±0.03 ±0.08

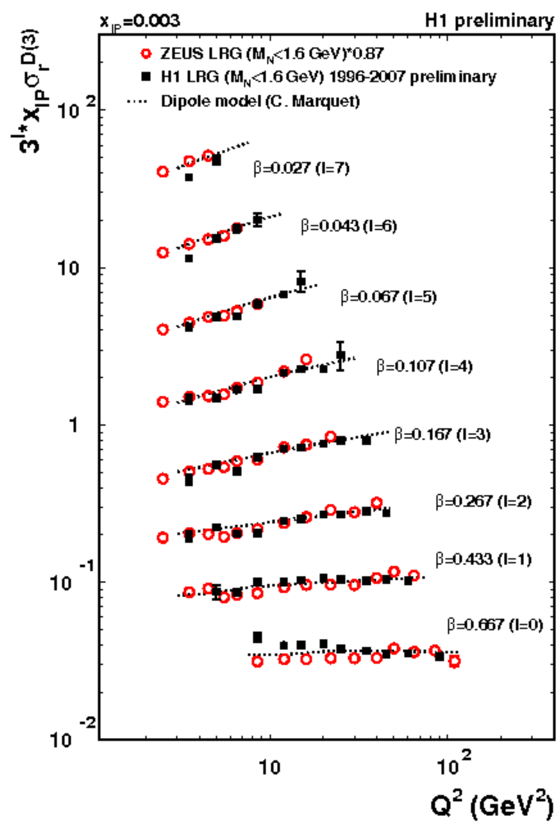
H1 LRG/FPS: **1.18** ±0.01 ±0.06 ±0.1

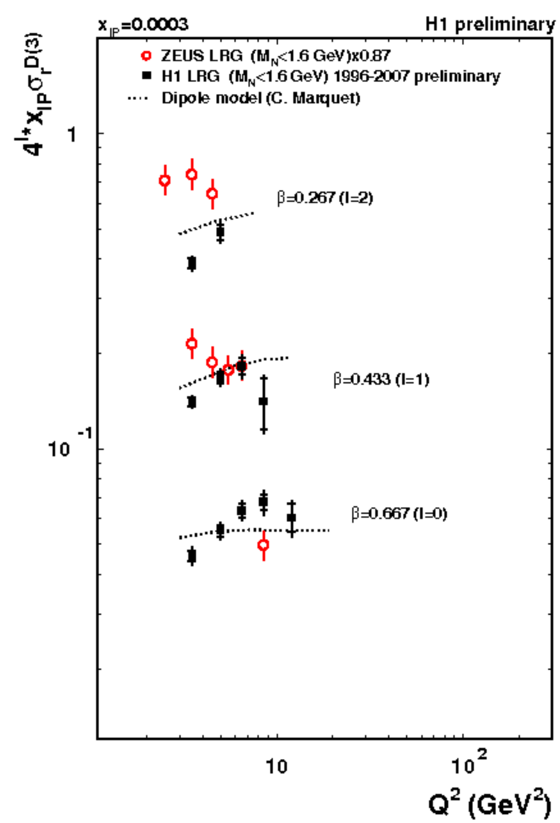
No dependence on any kinematic variable
Both measurements on 99/00 HERA 1 - Data
Consistency between H1 and ZEUS within errors

LRG @ H1 and ZEUS

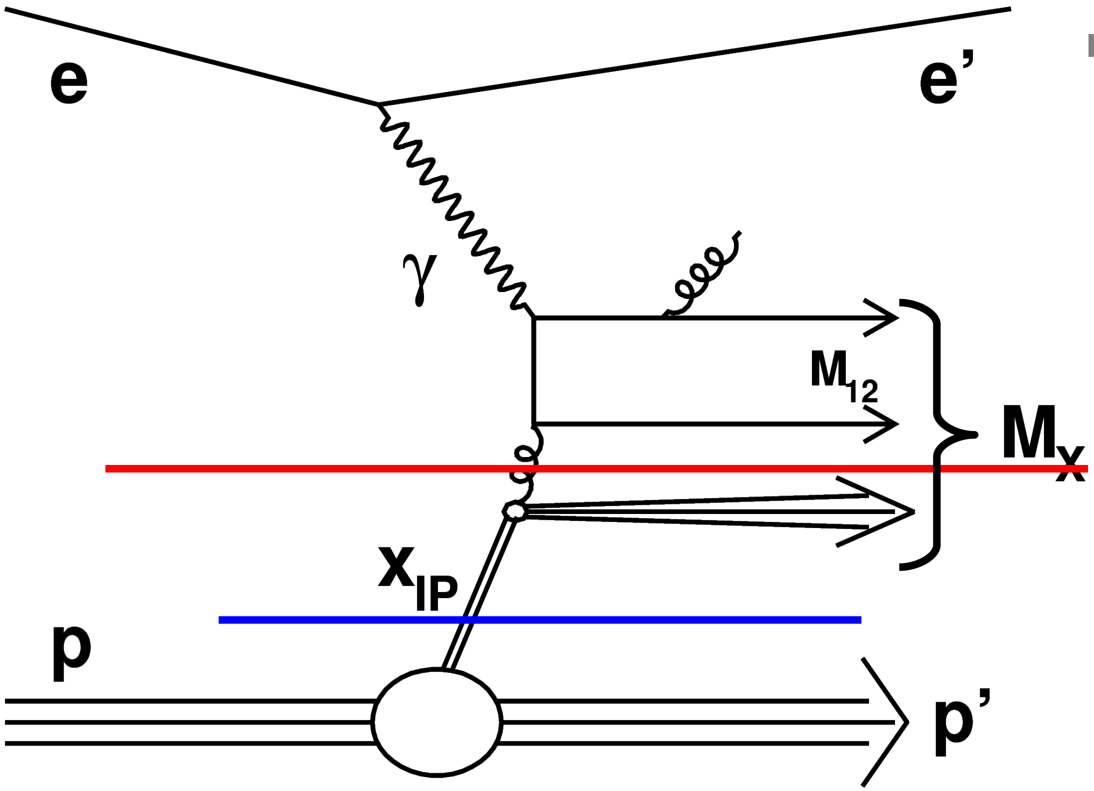


- New H1 HERA 2 data with 370 pb^{-1}
- ZEUS data rescaled by 0.87 (normalisation difference)
- Agreement over wide kinematic range within normalisation errors





Factorisation



QCD collinear factorisation (Collins)

Proton vertex factorisation

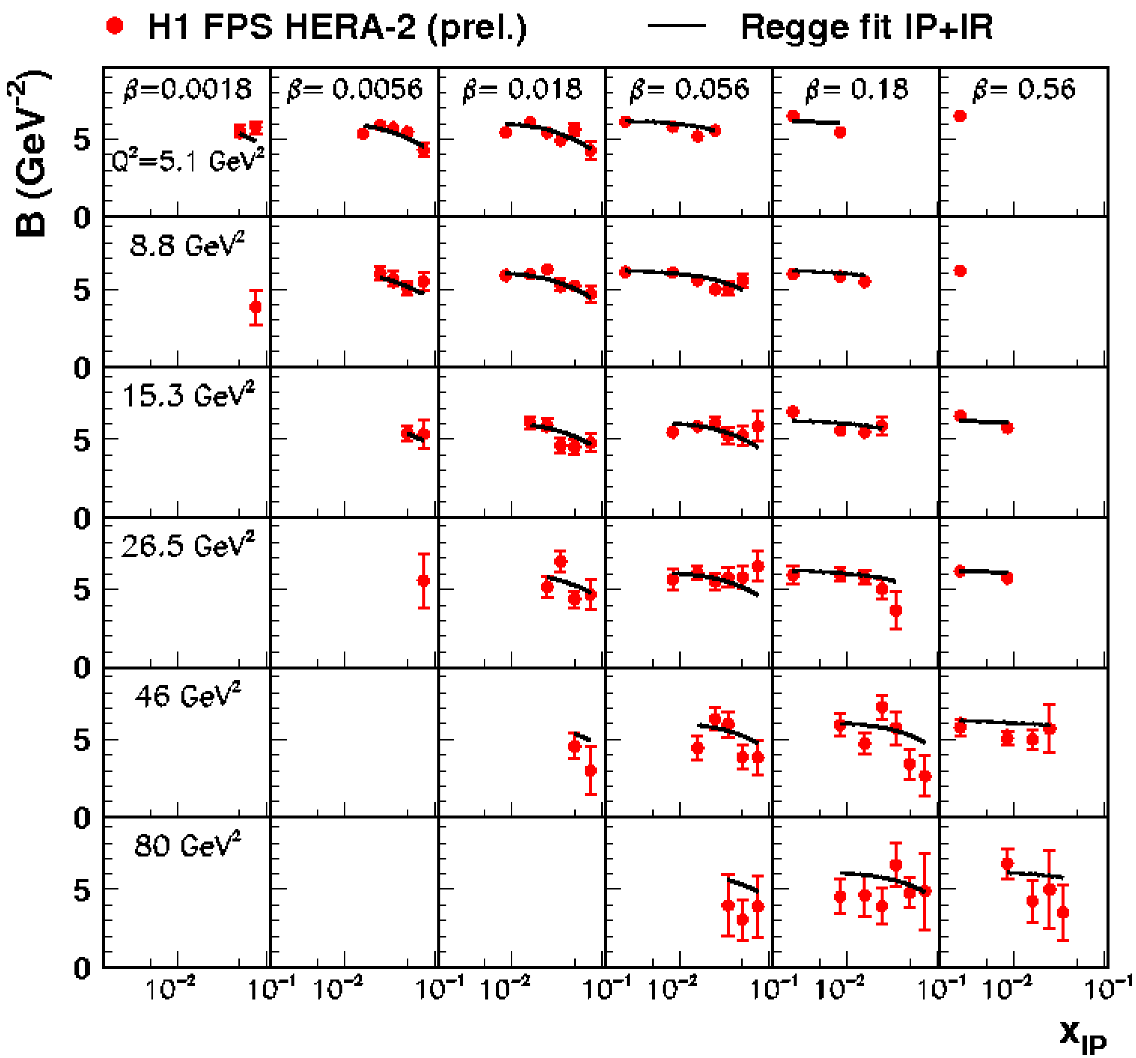
$$d\sigma^{ep\rightarrow eXp}(\beta,Q^2,x_{IP},t)=\sum_i f_i^D(\beta,Q^2,x_{IP},t)\cdot d\hat{\sigma}^{ei}(\beta,Q^2)$$

$$f_i^D(\beta,Q^2,x_{IP},t)=f_{IP/p}(x_{IP},t)\cdot f_i(\beta,Q^2) \qquad f_{IP/p}(x_{IP},t)=A_{IP}\frac{e^{B_{IP}t}}{x_{IP}^{2\alpha(t)-1}}$$

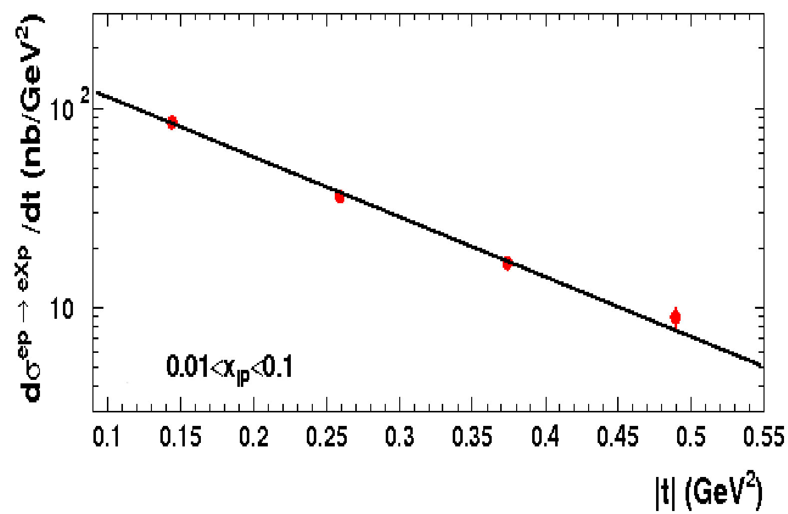
Proton Vertex Factorisation

Expectation of PVF: independence of ***B***-slope on kinematical variables

FPS HERA 2 data, L = 157 pb^{-1}, LPS HERA 1 data L = 33 pb^{-1}



$$\frac{d\sigma}{dt} \sim e^{-B|t|}$$

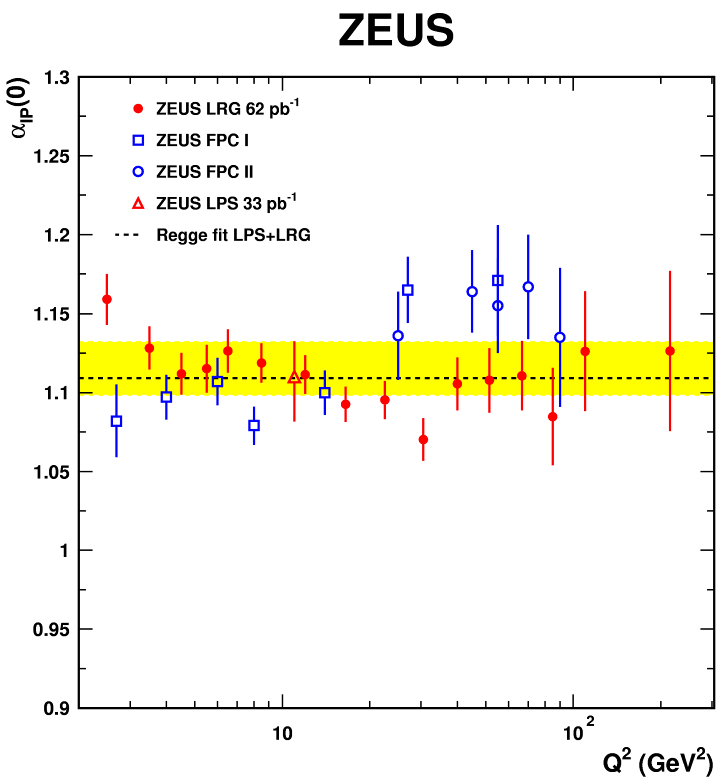


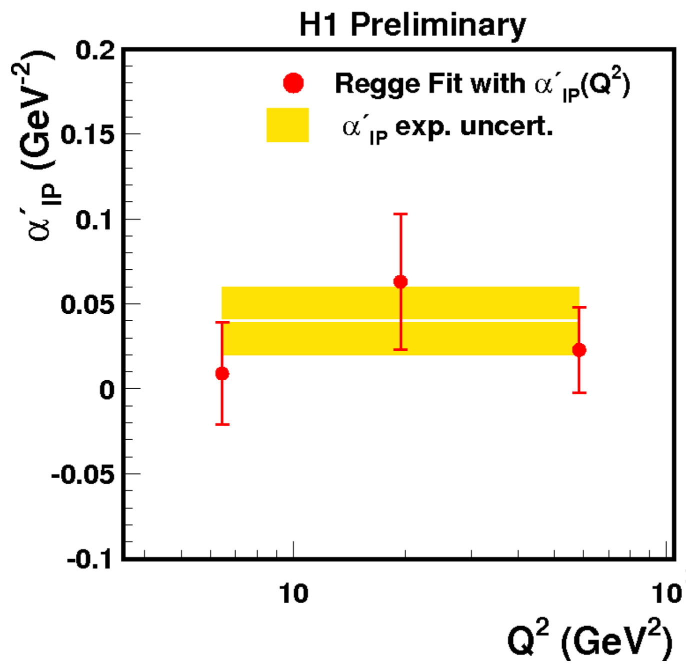
- Data are consistent with **proton vertex factorisation**
- Weak dependence at high x_{IP} due to IR exchange

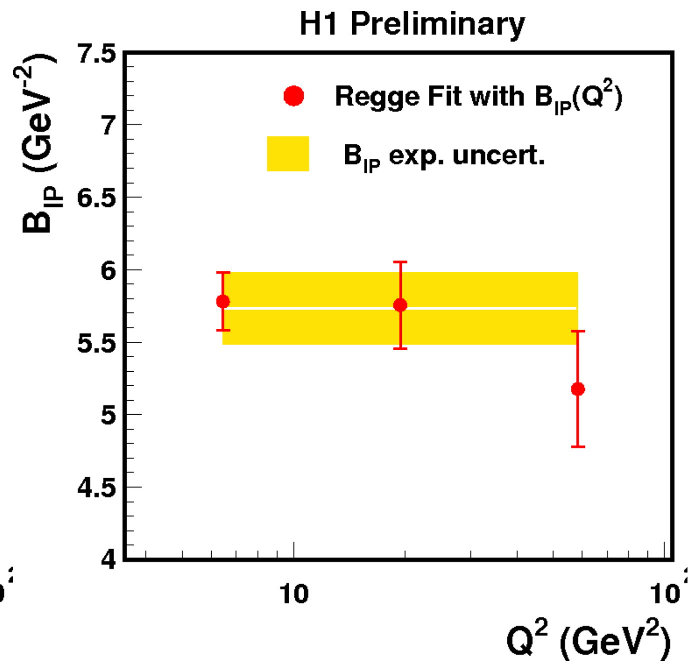
Proton Vertex Factorisation

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

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP}\, t$$



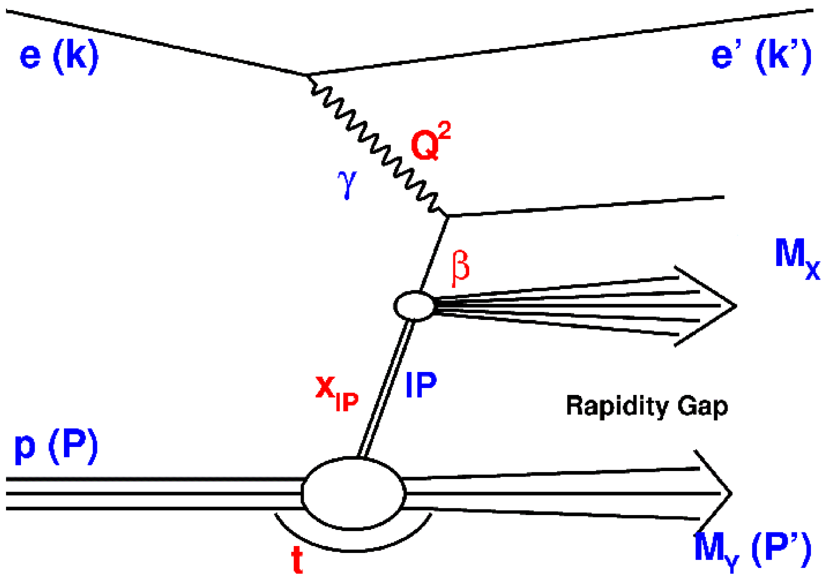




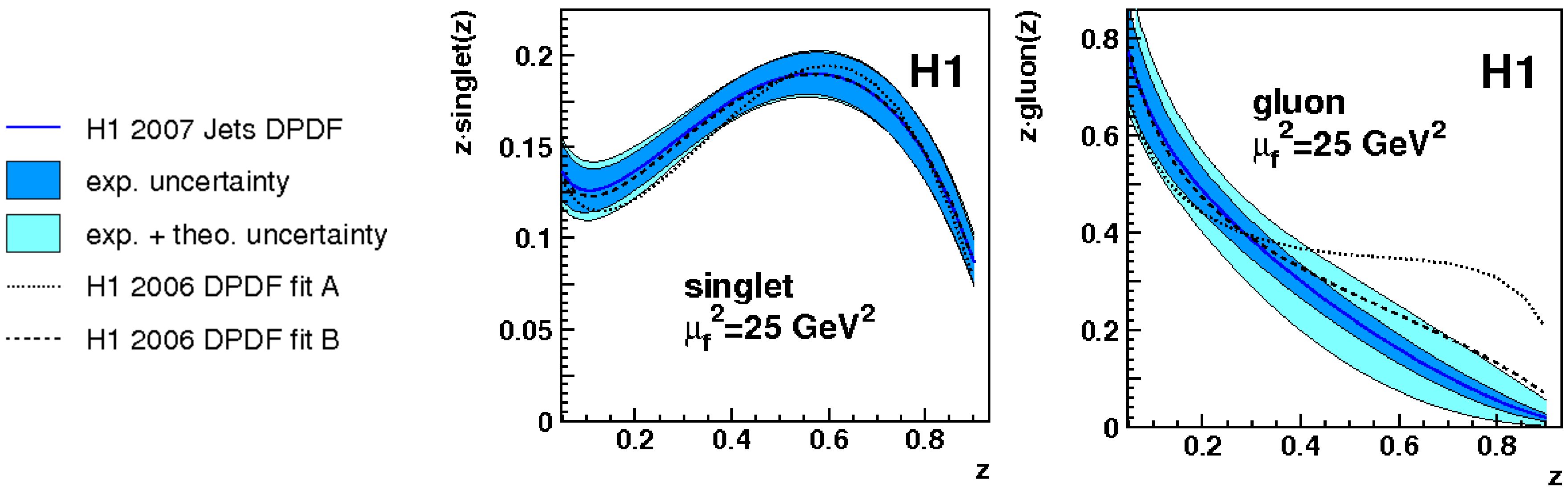
	H1	ZEUS
$\alpha_{IP}(0)$	1.10 ± 0.04	1.11 ± 0.04
α'_{IP} [GeV^{-2}]	0.04 ± 0.04	-0.01 ± 0.11
B_{IP} [GeV^{-2}]	5.73 ± 0.26	7.1 ± 1.57

Independence on kinematical variables within errors favours proton vertex factorisation
Good consistency between experiments
$\alpha_{IP}(0)$ prefers soft exchange

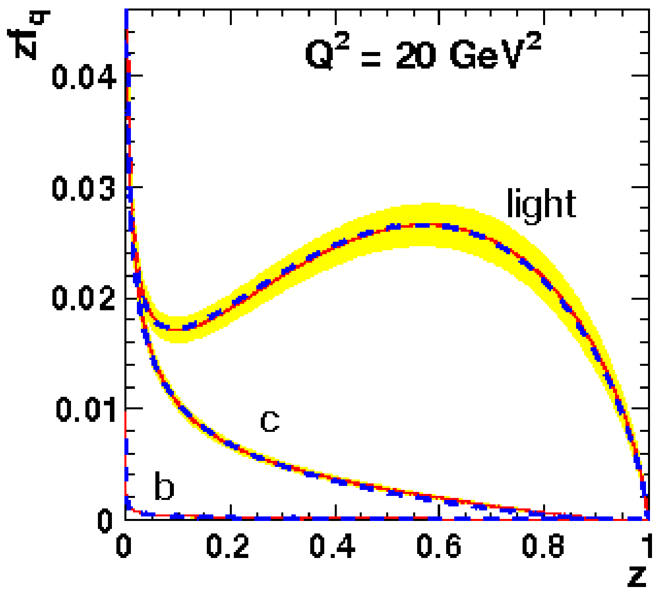
Extracting DPDFs

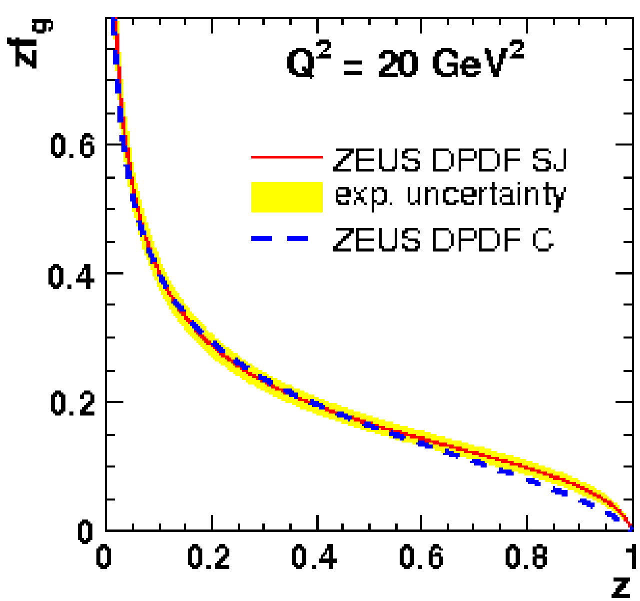


- Fit β and Q^2 dependence at fixed x_{IP}
- Parametrise at starting scale Q_0^2 and evolve using NLO DGLAP
- PVF allows to combine DPDFs with pomeron flux Ansatz
- Diffractive Jets constrain gluon part of DPDFs

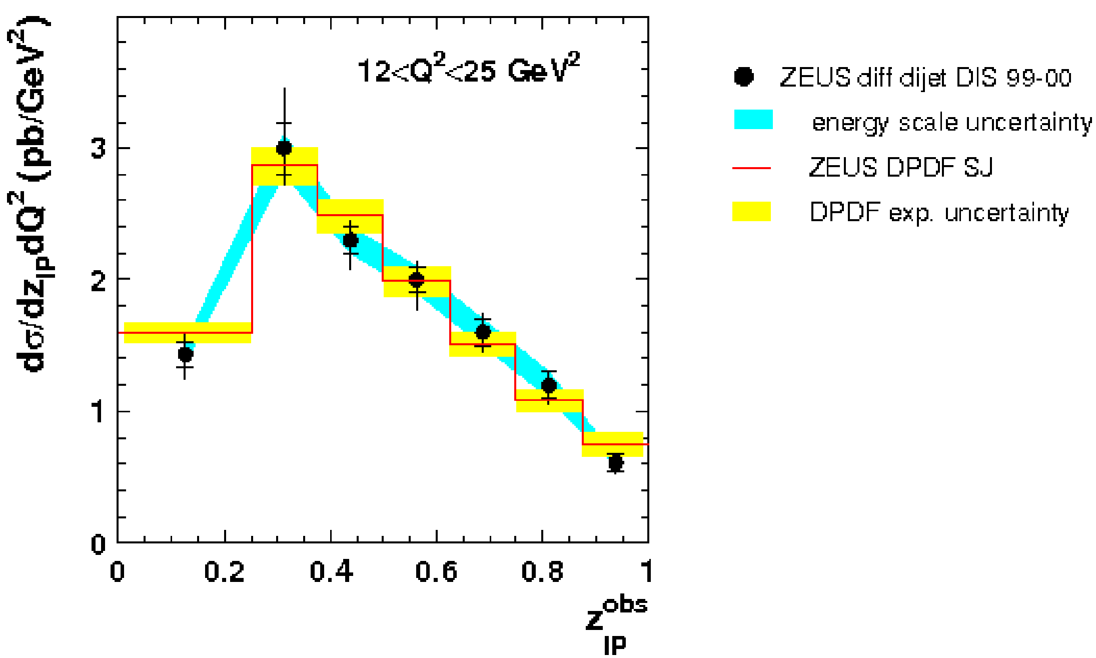


DPDFs

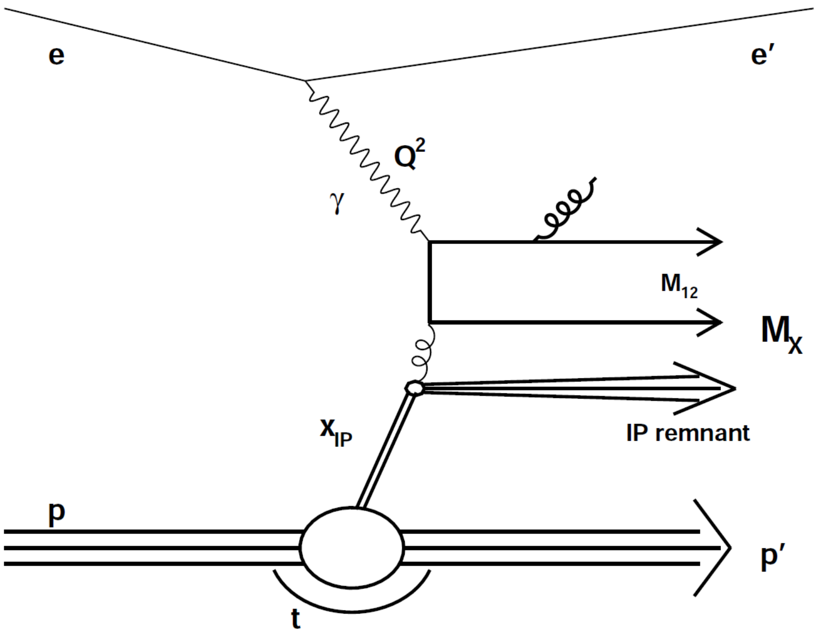




- Recent ZEUS fits to LRG and LPS inclusive and dijet data
- Improved heavy flavour treatment
- Good agreement with H1 up to normalisation uncertainty
- **Excellent** description of dijet data



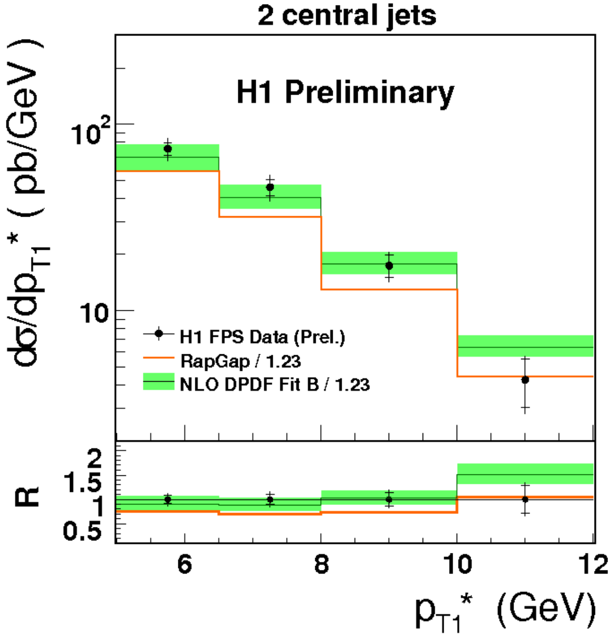
Jets in Diffraction



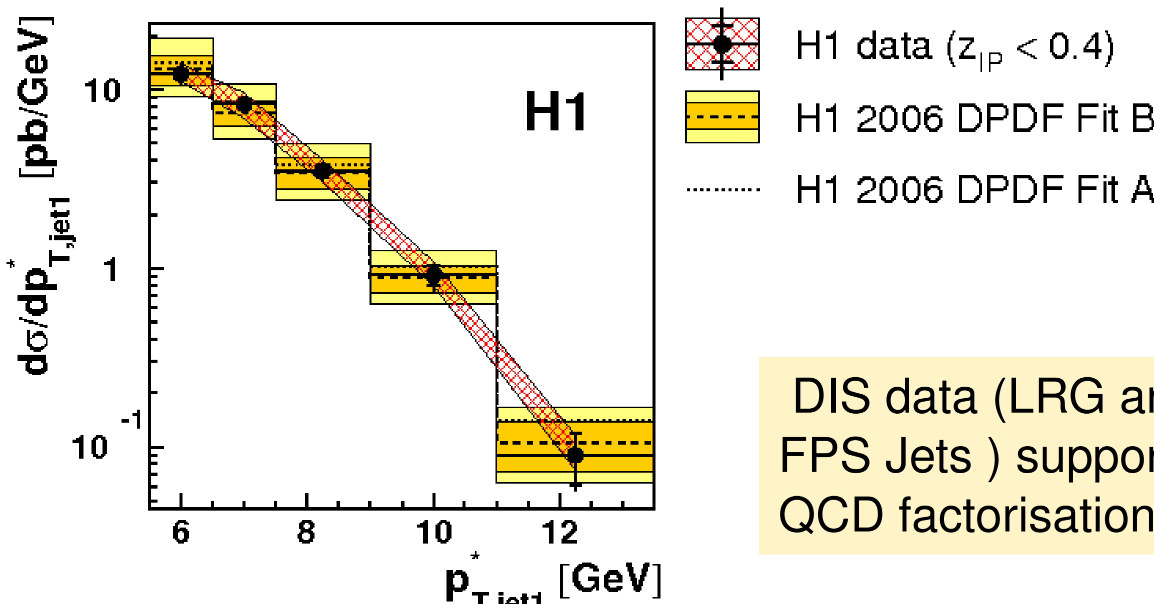
- Presence of a hard scale
- Tool for proving QCD collinear factorisation – possible to test pQCD predictions convoluted with DPDFs
- Direct extraction of gluon density in pomeron
- Study of parton evolution

FPS

2 central jets

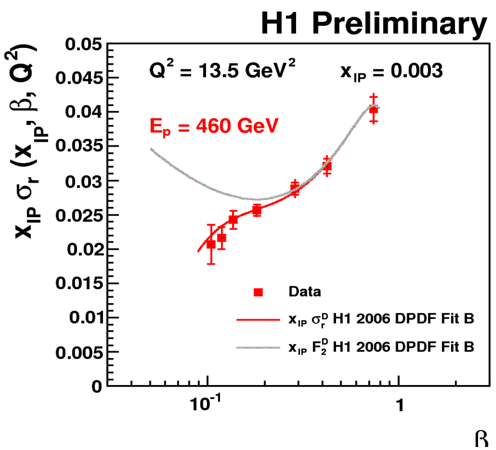


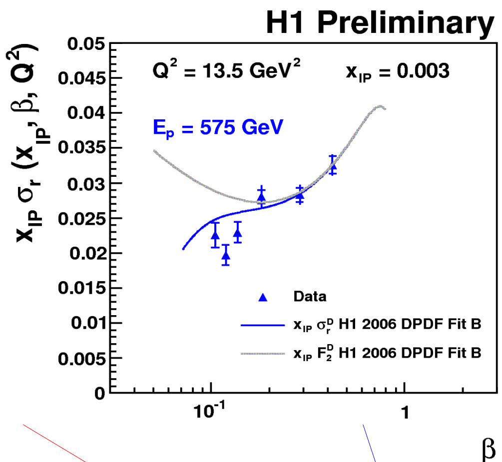
LRG



DIS data (LRG and FPS Jets) support QCD factorisation

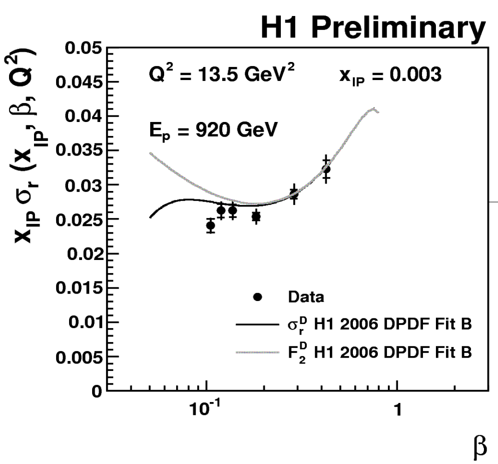
Longitudinal Structure Function

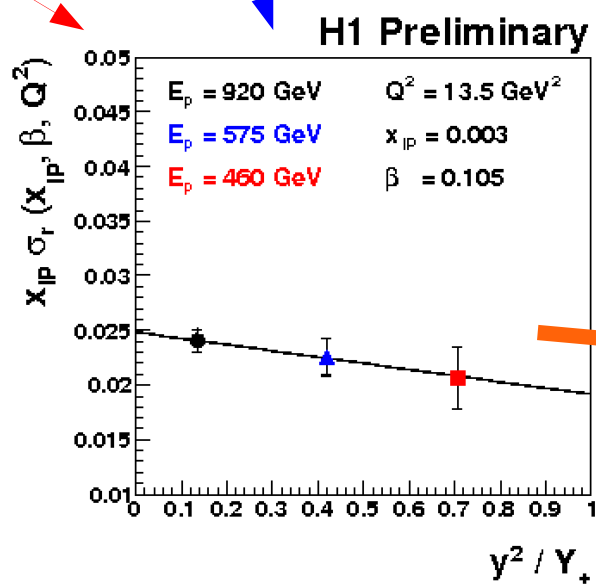


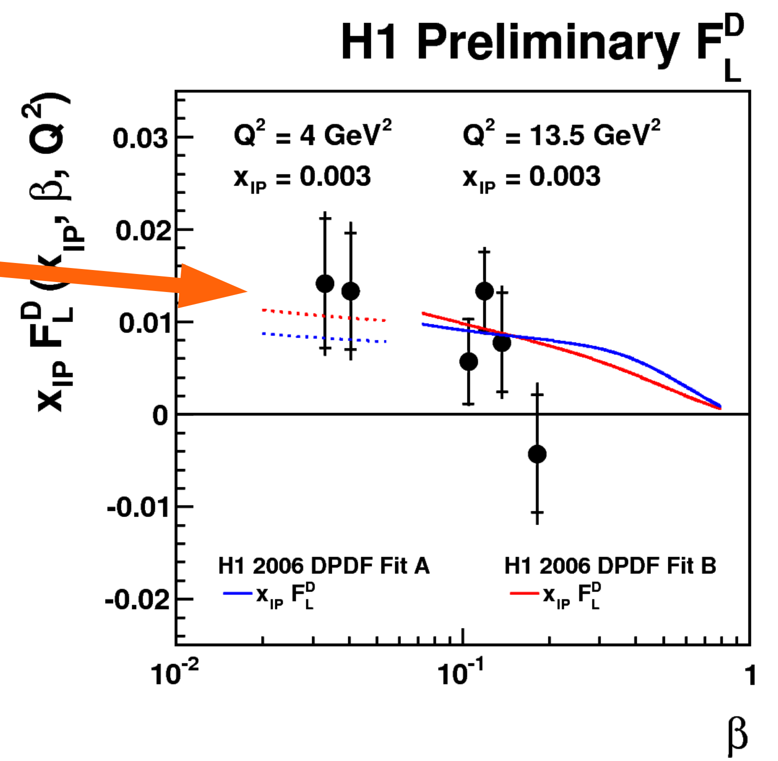


$$\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)}$$

- Sensitive to gluons
- Independent test of QCD factorisation
- For fixed β,Q^2 and x_{IP} different beam energies necessary



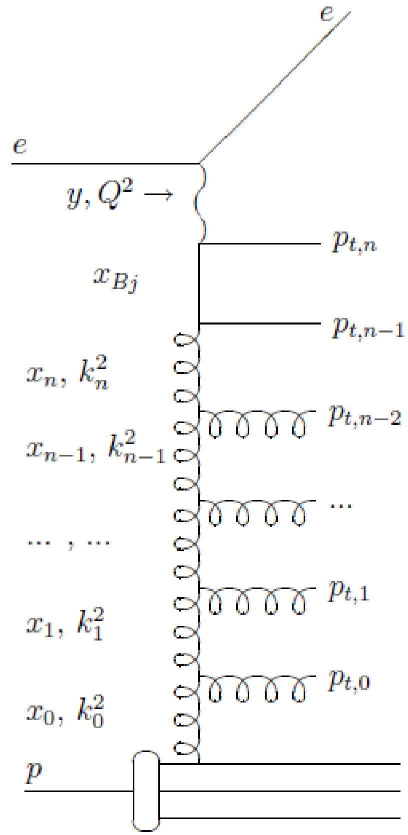




F_L^D significantly nonzero

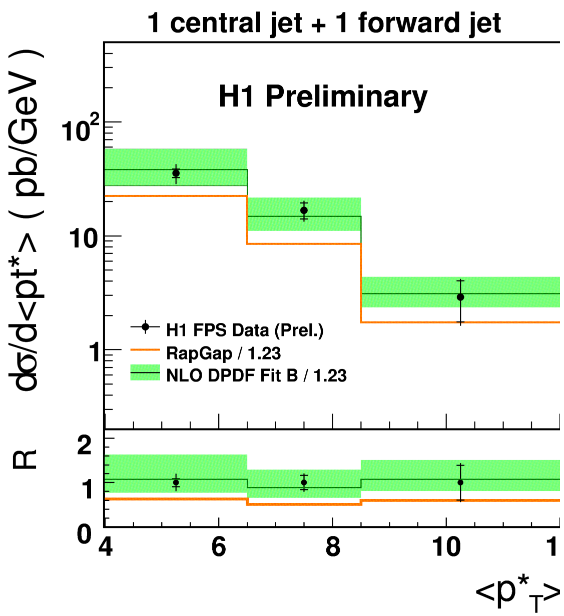
Consistent with NLO DGLAP

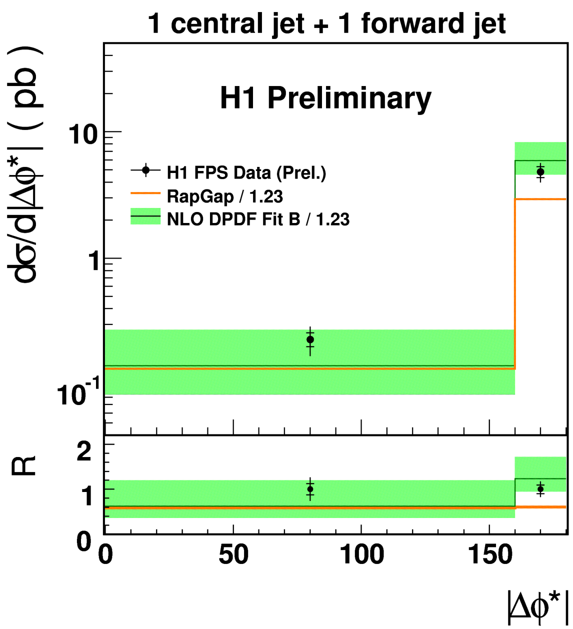
Diffractive Forward Jets



- DGLAP assumes strong k_T ordering and neglects terms ~1/x
- Forward jets with leading proton in DDIS – search for physics beyond DGLAP
  - Possibly **only** in leading proton measurement
  - Possibility to investigate jets close to the proton direction
  - Low x region

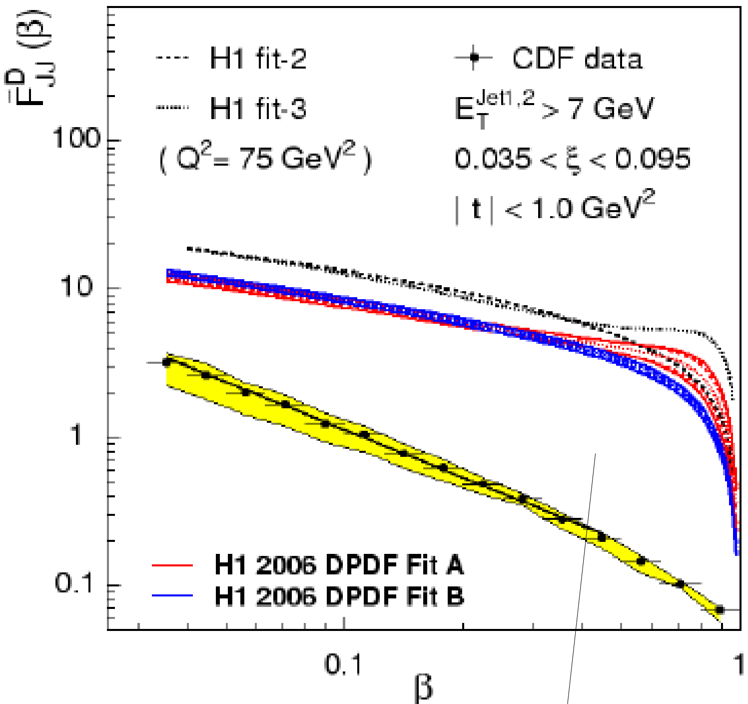
$p^*_{T,forward} > 4.5$ GeV
$1 < \eta_{forward} < 2.8$
$p^*_{T,central} > 3.5$ GeV
$-1 < \eta_{central} < 2.5$





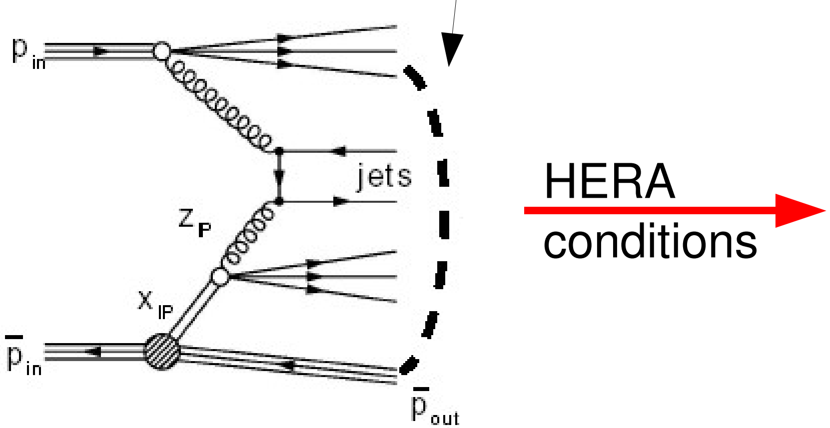
Good description by DGLAP

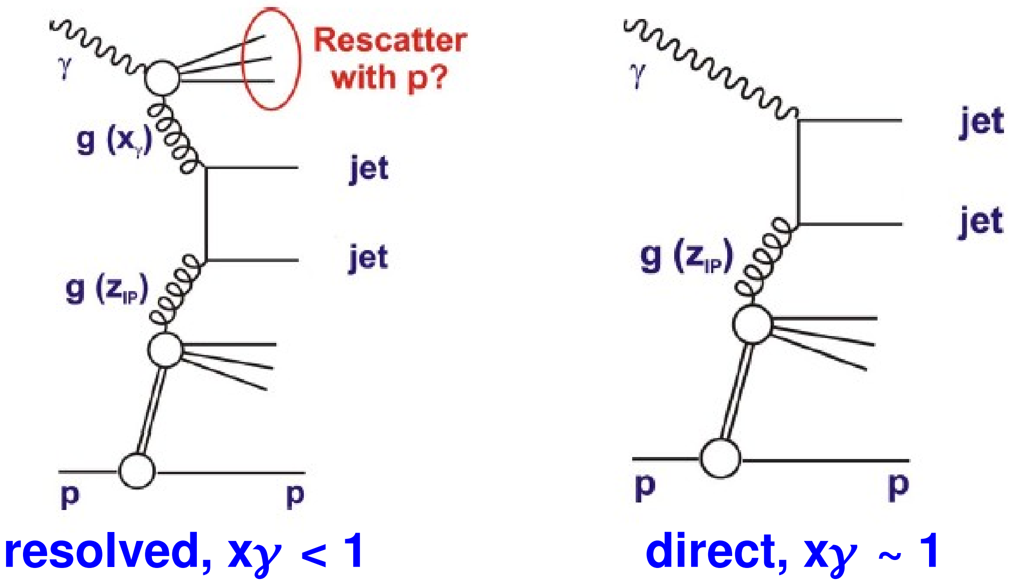
Factorisation in photoproduction



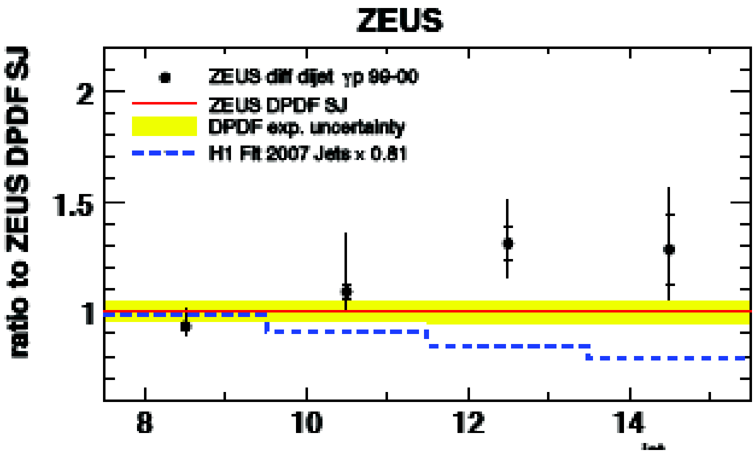
- CDF dijet cross section differs by factor 5-10 in comparison to predictions based on HERA DPDFs
- Soft interactions between proton remnants destroys the rapidity gap → **Survival Probability** (S^2 ~ 0.1 for CDF)
- Factorisation test at HERA → measurement of PHP dijets
- For HERA kinematics prediction S^2 (KKMR)~ 0.34 for resolved component
- Studied also at LHC

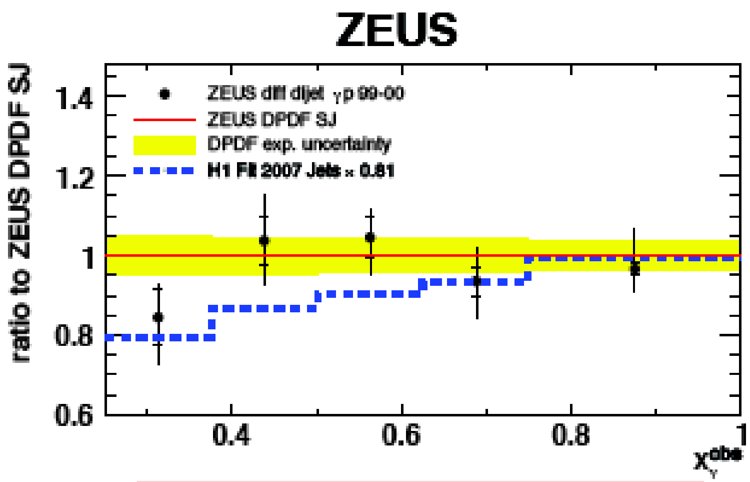
$$x_\gamma \approx x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$





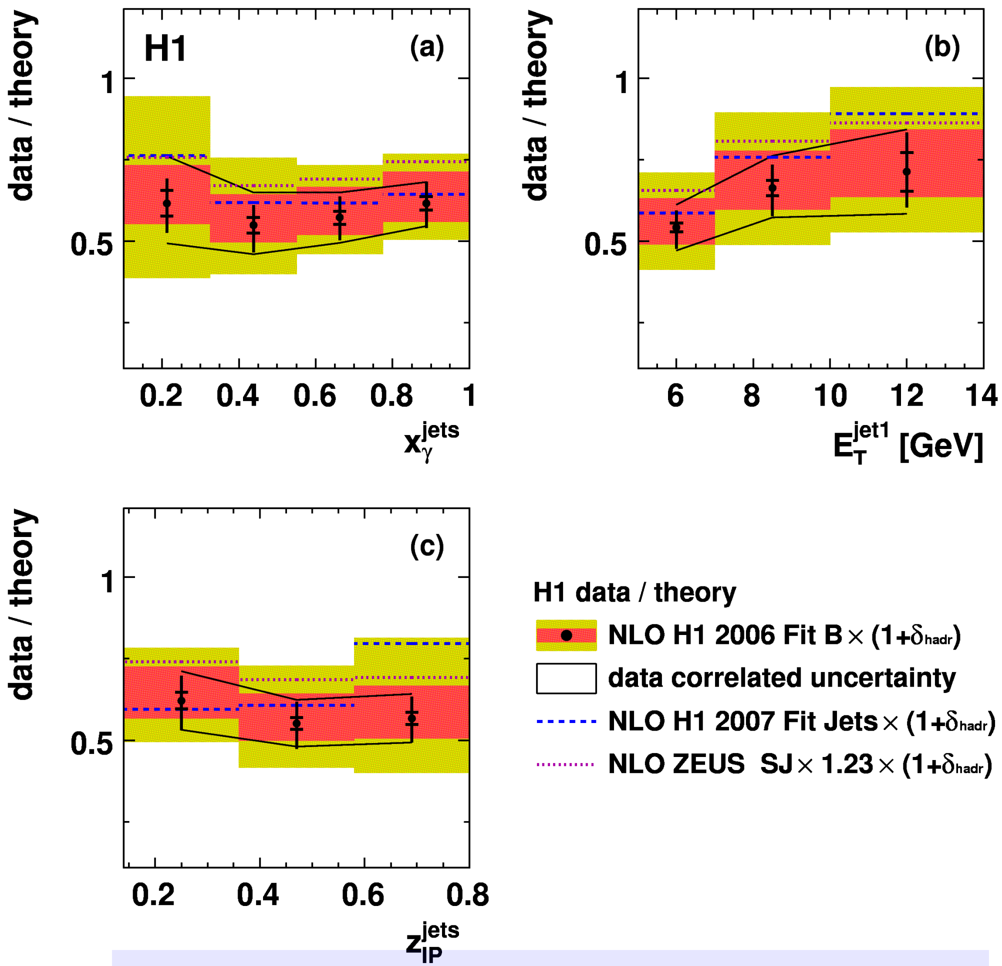
Survival Probability in photoproduction





E_T > 7.5 GeV

No factorisation breaking



E_T > 5 GeV

E_T dependence?

σ(data)/σ(NLO) = 0.58 ± 0.21 (tot)

Survival Probability in photoproduction revised

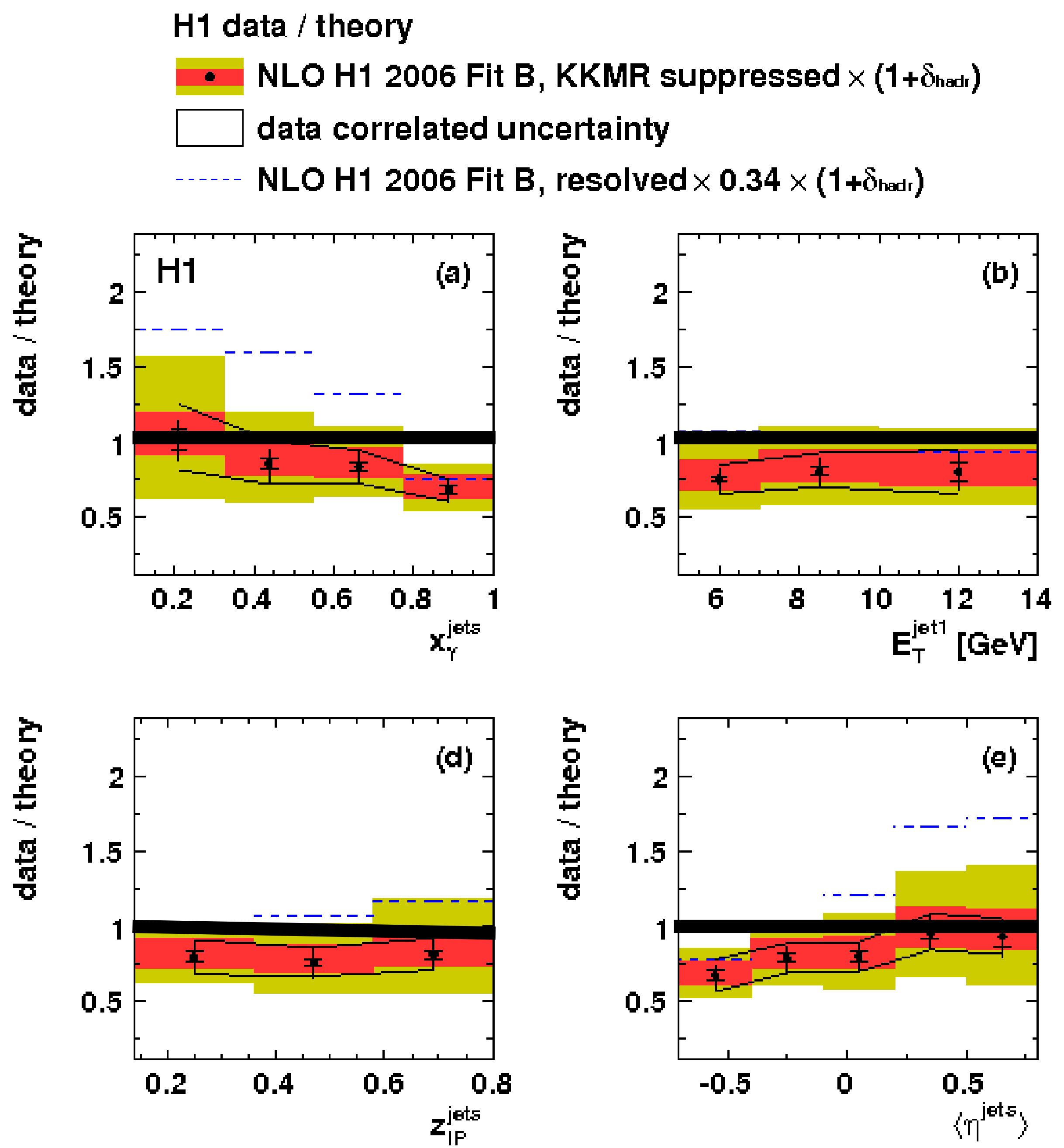
Revision (KKMR):

Direct process remains unsuppressed

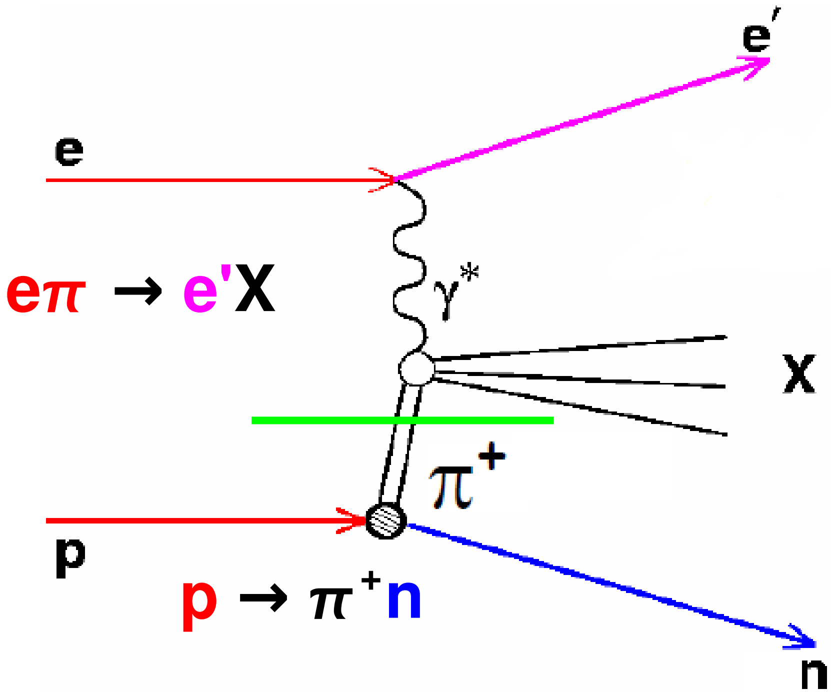
Previously predicted $S^2 \sim 0.34$ applies only to **Hadron-like** photon structure function (**$x_\gamma < 0.1$**, inaccessible in current analysis)

$0.1 < x_\gamma < 1$. „anomalous" part of photon structure function, less suppression (~ 0.7 – 0.8)

KKMR: Better E_T dependence, x_γ still unsatisfactory described, additional suppression for x_γ necessary in all cases – **factorisation breaking?**



Leading Baryons



Pion structure function measurement

Tests of fragmentation models

$$x_L = E_n / E_p$$

In presence of a hard scale tests factorisation:

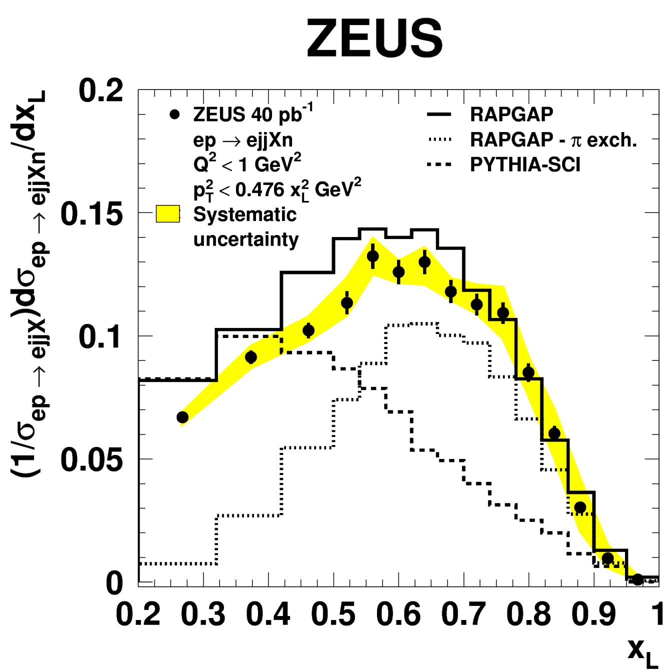
$$\sigma(ep \rightarrow e'nX) = f_{\pi/p}(x_L, t) \cdot \sigma(e\pi \rightarrow e'X)$$

Pion flux factor – probability to find π in proton

Calculable cross section for $e\pi$ scattering

Model dependent, pion exchange as implemented in RapGap assumed

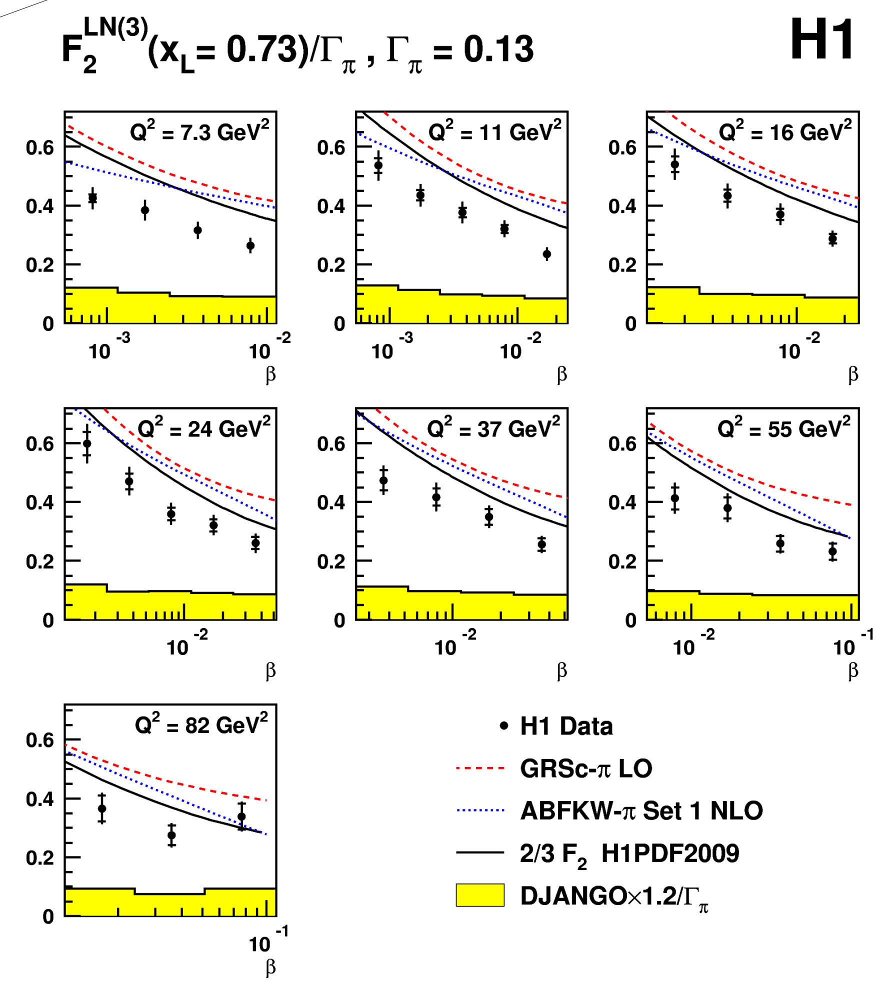
Leading Baryons



$$\frac{d^3\sigma(ep \to enX)}{dQ^2\, d\beta\, dx_L} = \frac{4\pi\alpha^2}{xQ^4}\left[1 - y + \frac{y^2}{2}\right] F_2^{LN(3)}(Q^2, \beta, x_L)$$

$$F_2^{LN(3)}(\beta, Q^2, x_L) = \Gamma_\pi(x_L) \cdot F_2^\pi(\beta, Q^2)$$

- Pion flux parametrization by Holtman et. al
- Integrated over *t*

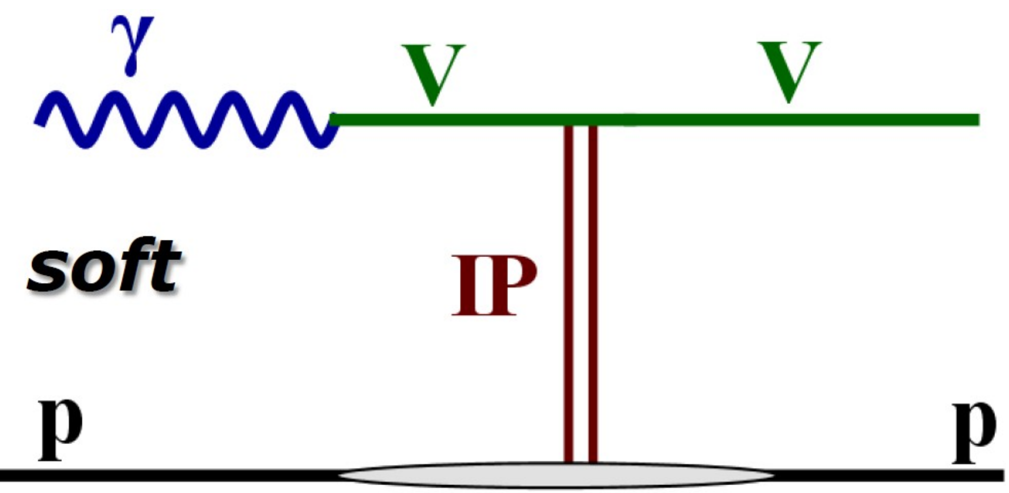


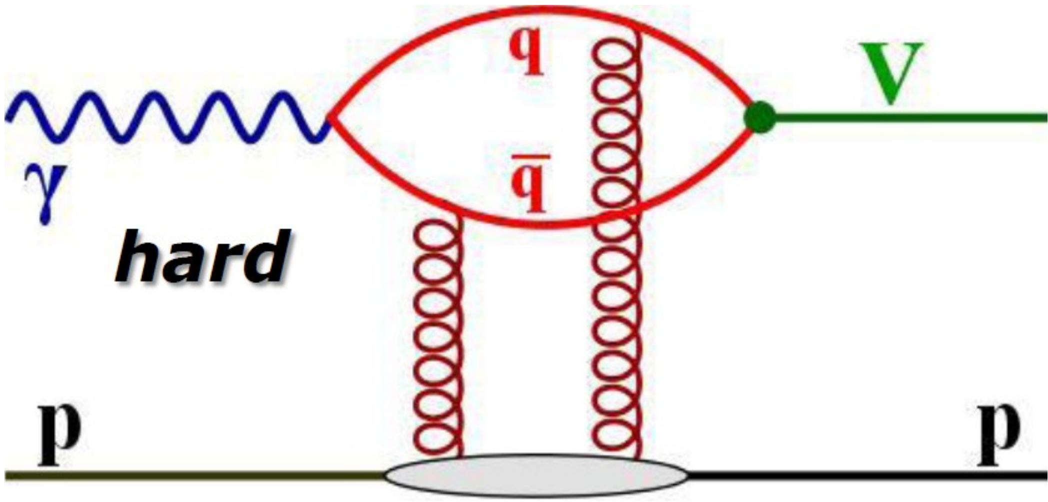
RapGap gives best description

Shape reasonably well described even by naive prediciton $F_\pi = 2/3\, F_2$

Consistent with proton vertex factorisation

Exlusive VM Production





- Regge theory and Vector Dominance Model
- $\sigma \sim W^{\delta}$, $\delta_{soft} \sim 0.2$

$$\frac{d\sigma}{d|t|} \sim e^{-b|t|}$$

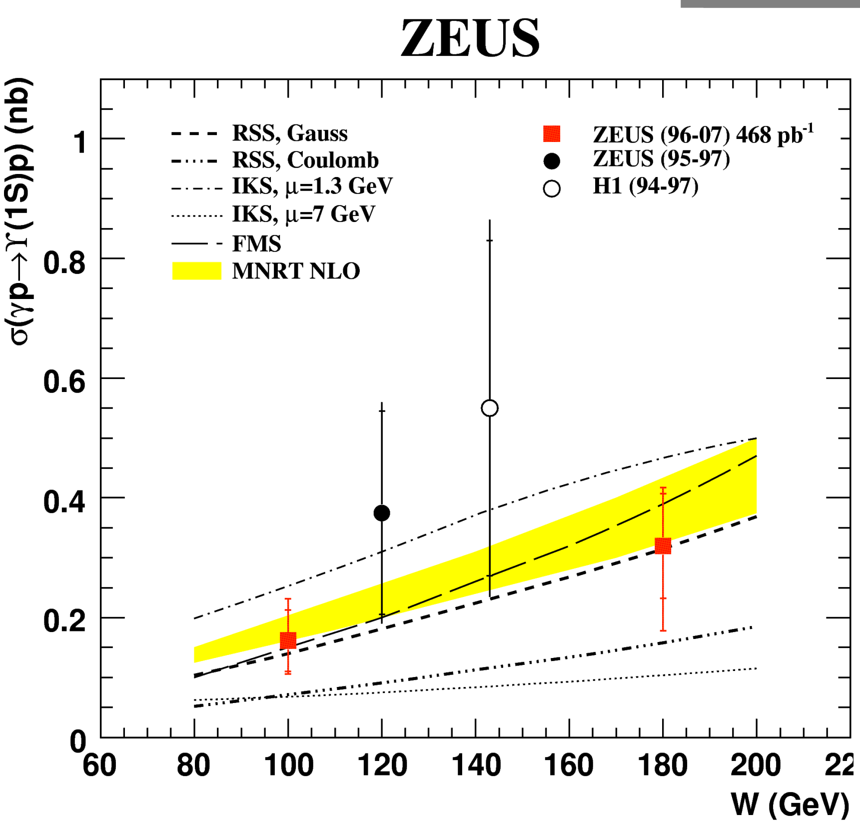
- b ~ 10 GeV^{-2}

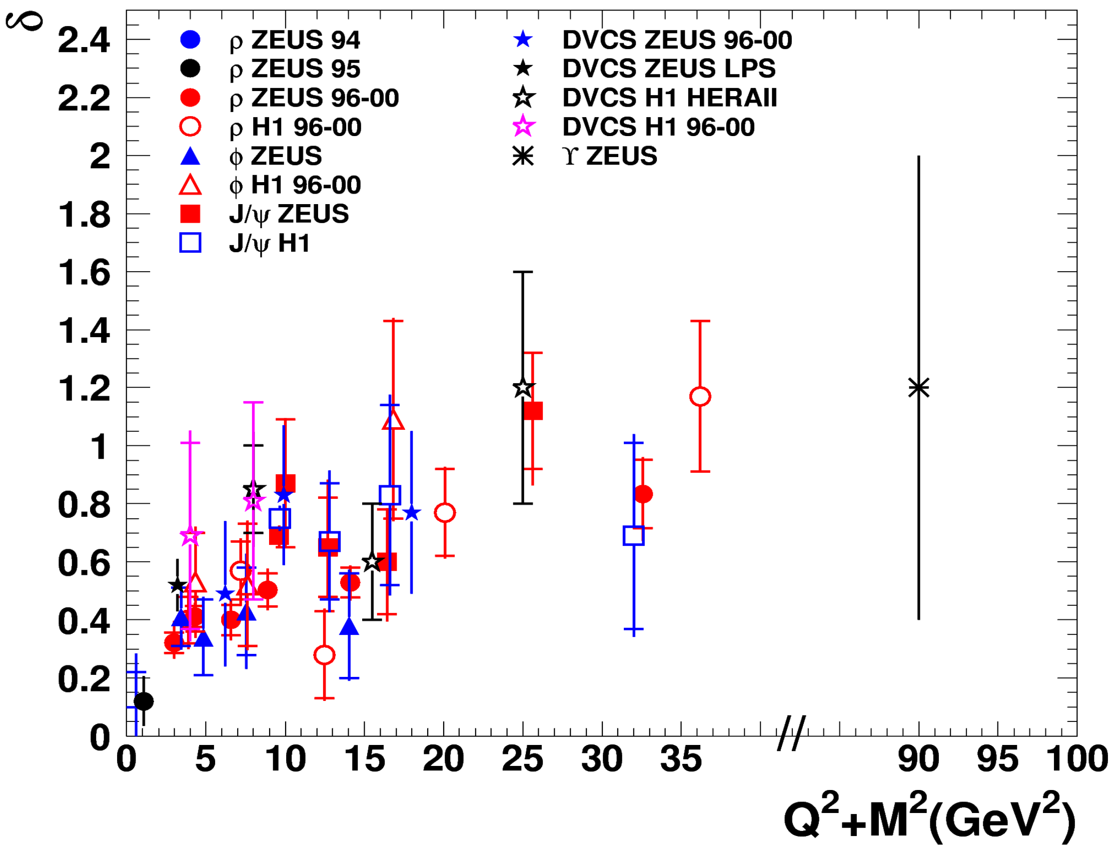
- Perturbative QCD
- Possible to calculate in presence of a scale: ***t*, Q^2 or M_{VM}**
- $\sigma \sim |x\,g(x,Q^2)|^2 \sim W^{\delta}$, $\delta_{hard} \sim 1$

$$\frac{d\sigma}{d|t|} \sim e^{-b|t|}$$

- b ~ 4-5 GeV^{-2}

Exclusive VM – W-dependence





Data consistent with different QCD models

Measurements sensitive to different MC models

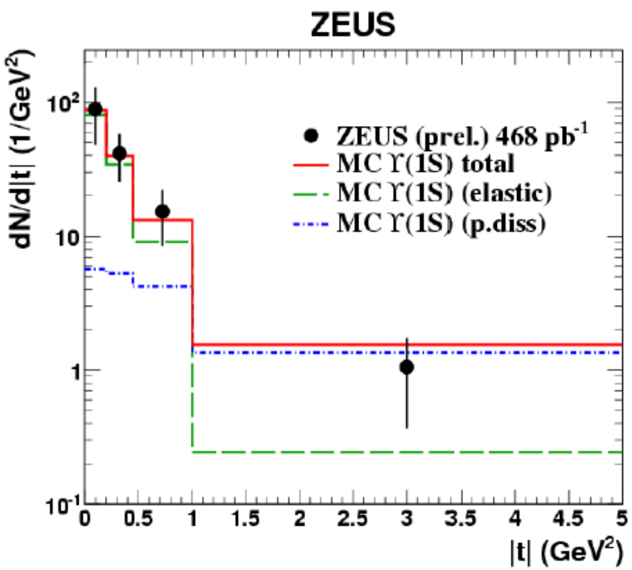
Dependence (δ) gets steeper with increasing VM mass

New Zeus Υ (DESY-09-036) measurement extends the phase space by factor of 2.5 in scale

Exlusive VM – *t* dependence

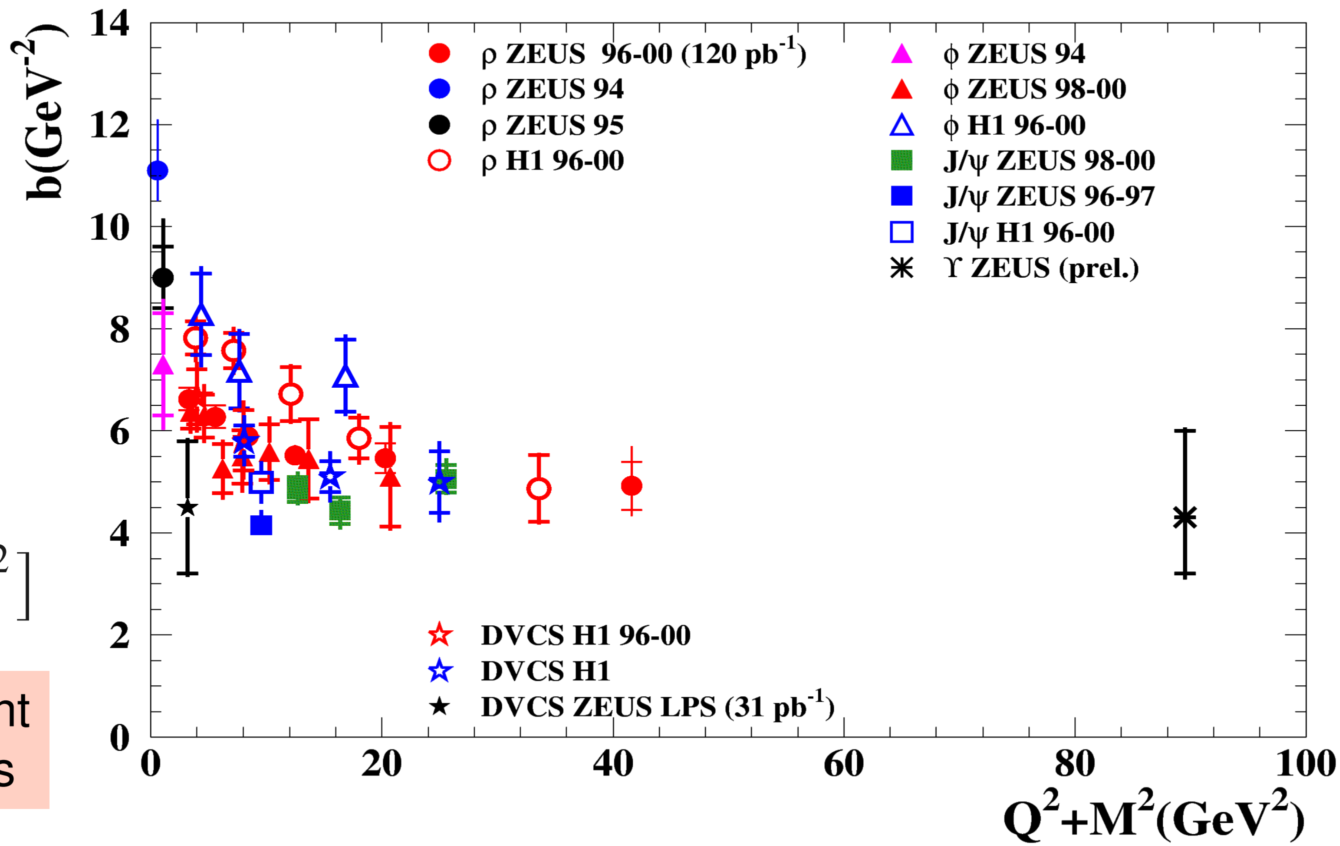
$$\frac{d\sigma}{d|t|} \sim e^{-b|t|}$$

With increasing scale *b*-slope decreases, smooth transition from soft (ρ) to hard (Υ) meson physics



$$b_\Upsilon = 4.3^{+1.7}_{-1.1} \pm 0.5 [GeV^{-2}]$$

pQCD prediction in agreement with measurement within errors



- Recent DVCS (H1, DESY-09-109), ρ and ϕ (H1, DESY-09-093) results improve precision
- *b*-slope decreases with scale as expected by smooth transition from soft to hard physics

summary

- New results from HERA-2 period have arrived and improved the measurements of diffractive structure functions
- Proton vertex factorisation with soft pomeron intercept of α_{IP} ~ 1.10 and *B*-slope of ~ 6 GeV is a suitable model for diffraction
- DPDFs tested in extended phase space wrt previous measurements
- Progress in understanding of gap survival probability in photoproduction
- New unique measurements:
  - F_L^D – independent test of QCD factorisation and gluon density
  - Jets with leading proton – no physics beyond DGLAP observed
- Extension of phase space in exclusive VM measurement fits well in the picture of interplay between soft and hard physics