EPS HEP 2013
International Europhysics Conference on High Energy Physics
Stockholm, Sweden, 18th – 24th July 2013

Recent H1 results on Diffraction

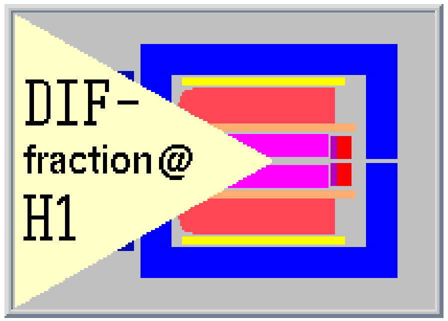
S. Levonian, DESY

- Measurement of Inclusive Diffraction in DIS

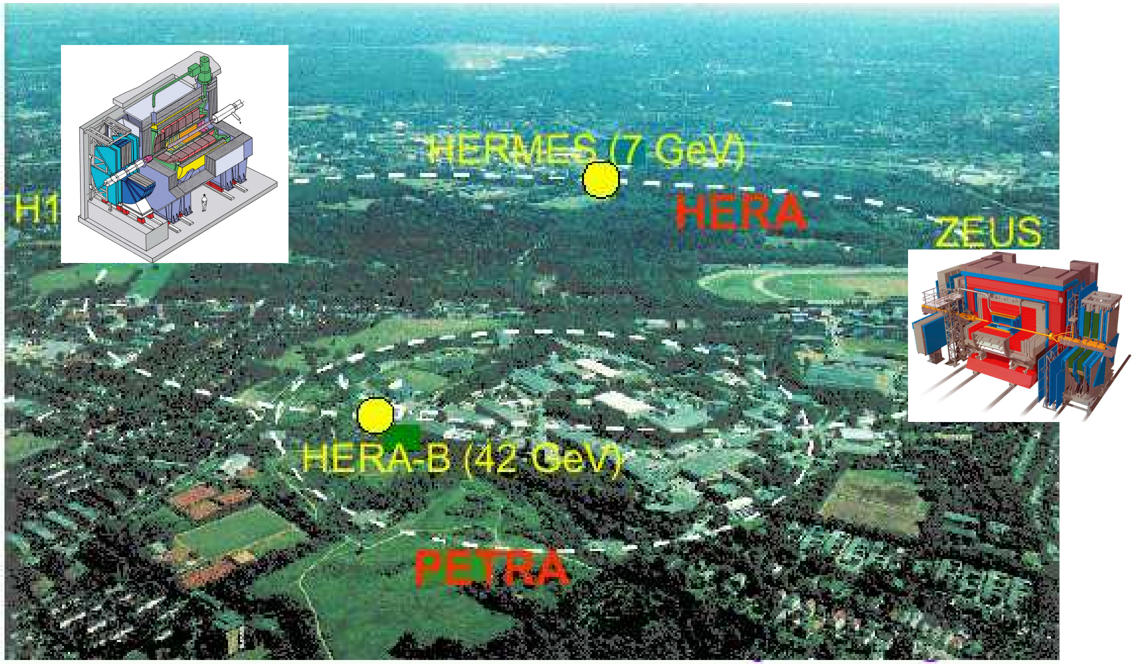
  (abstract 53)

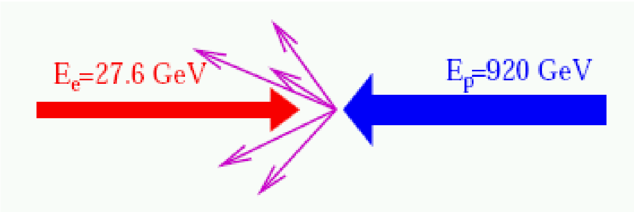
- Diffractive Dijets and QCD Factorisation

  (abstracts 50,65)



HERA: The World's Only ep Collider



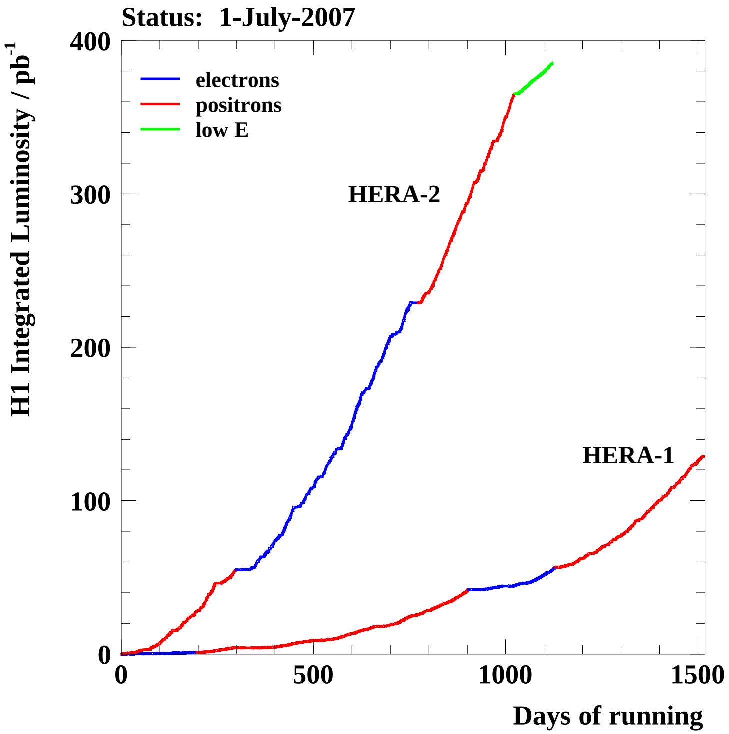


HERA-1 (1993-2000) $\simeq 120$ pb^{-1}

HERA-2 (2003-2007) $\simeq 380$ pb^{-1}

Final Data samples

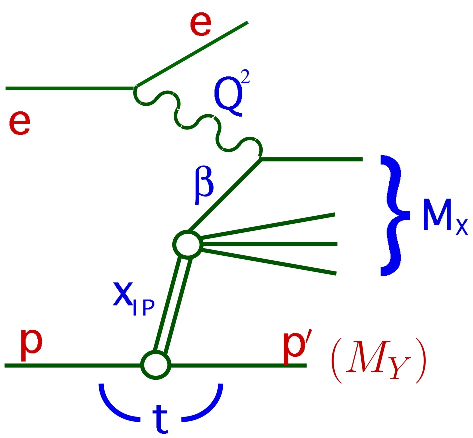
H1+ZEUS: 2×0.5 fb^{-1}



- 1998 E_p upgrade: $820 \Rightarrow 920$ GeV
  ($\sqrt{s}$: $301 \Rightarrow 319$ GeV)
- 2001 HERA-2 upgrade: $\mathcal{L} \times 3$, Polarised e^+/e^-
  ($\langle P \rangle = 40\%$)

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)

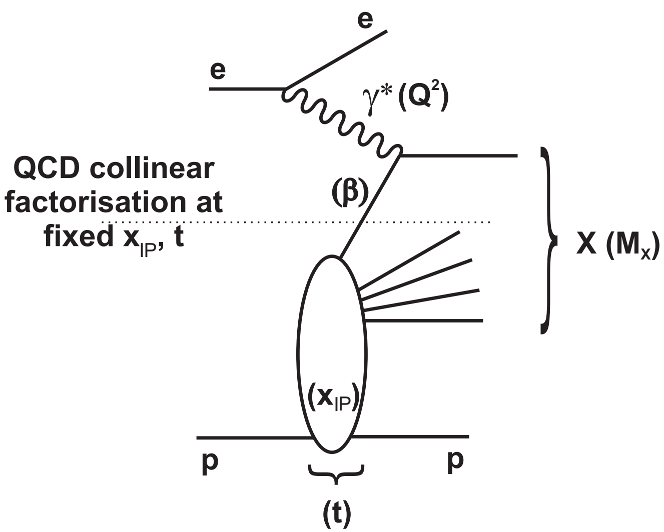
Experimental methods:

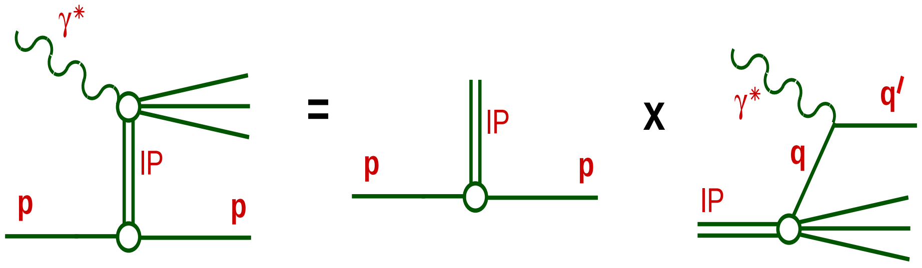
1) selecting LRG events

2) detecting p in Roman Pots ($60 - 220$ m from IP)

FPS, VFPS

Factorisation properties in diffraction





QCD versus Regge factorisation

QCD factorisation

(rigorously proven for DDIS by Collins et al.):

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

- $\hat{\sigma}^{\gamma^* i}$ – 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

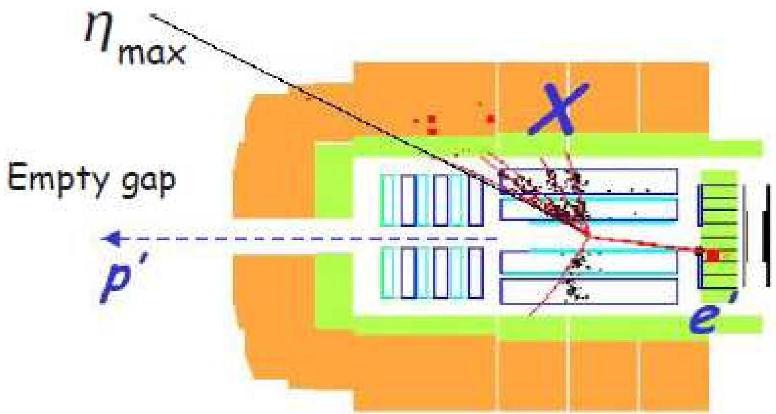
Regge factorisation

(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 $\Phi(x_{I\!P}, t)$

Inclusive DDIS: 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

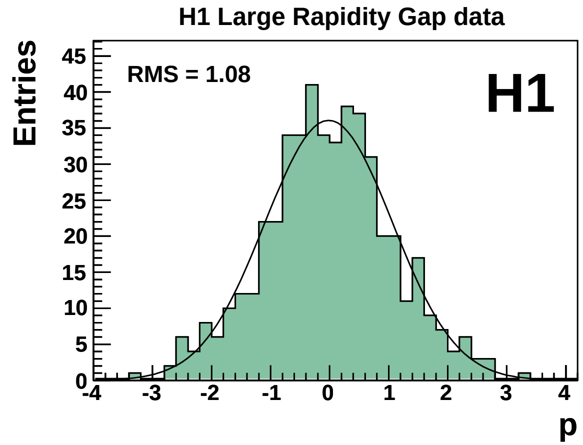
[H1 Coll. EPJC28 (2006) 715]

- Statistics increase: $\mathbf{3}$ to $\mathbf{33}$
  Typical precision: $\mathbf{1\%(stat) \oplus 5\%(syst) \oplus 4\%(norm)}$

- $\mathbf{597}$ data points averaged to $\mathbf{277}$ measurements
  Iterative χ^2 minimisation with full error correlations
  $\chi^2/\mathrm{NDF} = 371/320$

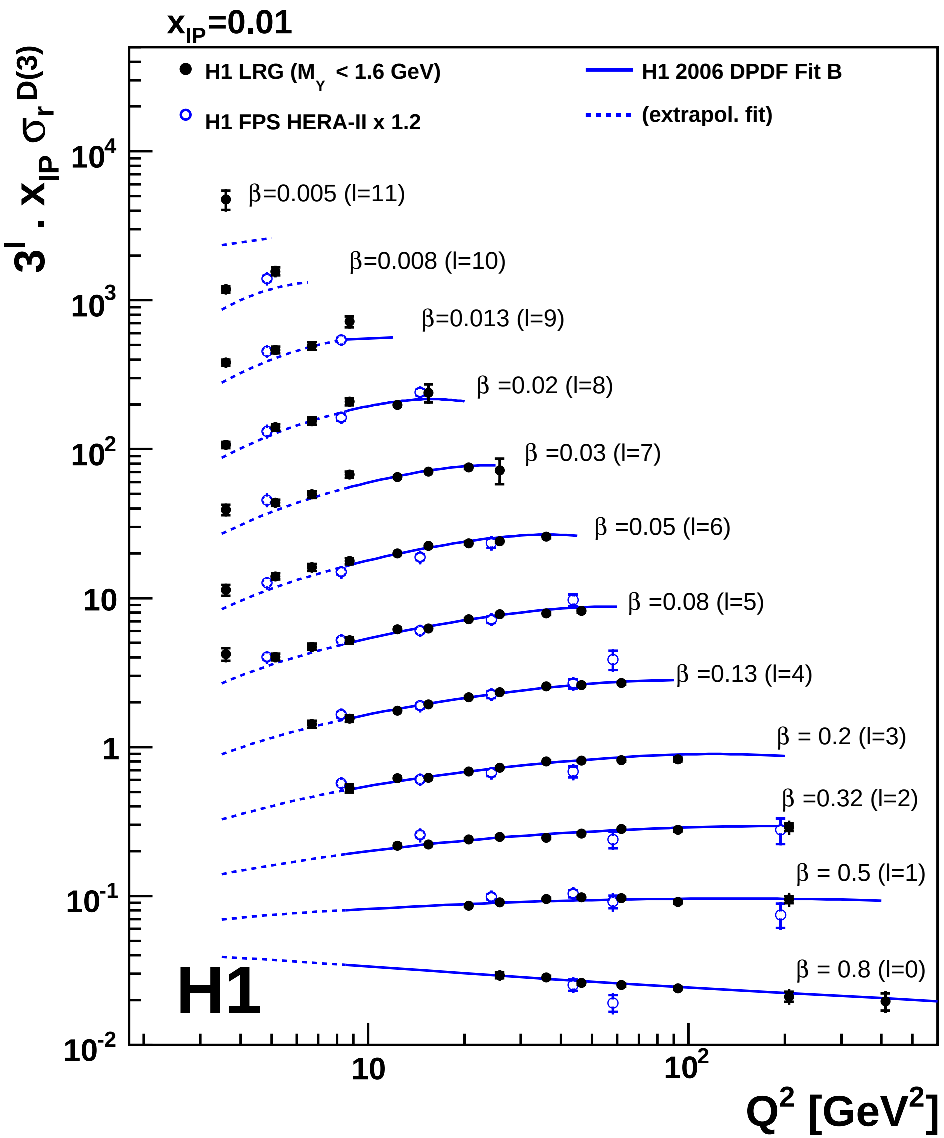
- Total kinematic range:

$$3.5 < Q^2 < 1600 \text{ GeV}^2$$
$$0.0017 < \beta < 0.8$$
$$0.0003 < x_{I\!P} < 0.03$$



→ No large tension between data sets

Inclusive DDIS: LRG vs p-tagged methods



Compare LRG and FPS cross sections

Ratio LRG/FPS:

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

$$1.203 \pm 0.019(exp) \pm 0.087(norm)$$

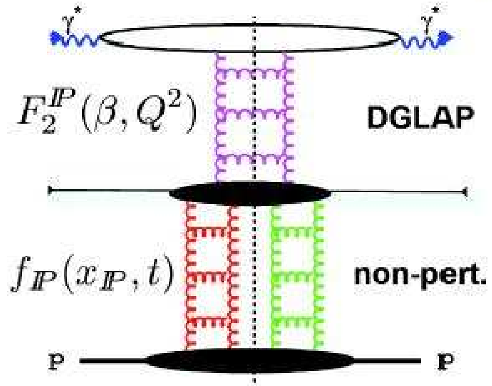
(1.6%) (7.2%)

- Experimental control on the amount of proton dissociation in LRG data

- No Q^2 or β dependent differences observed

Theoretical Approaches to DDIS: Partons vs Dipoles

- Infinite momentum frame: partons

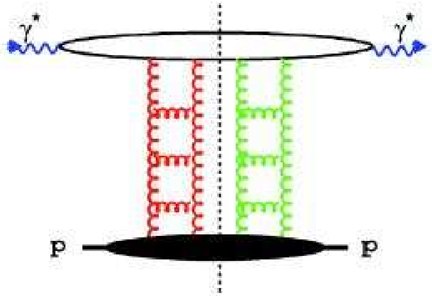


- Factorization is assumed.

$$F_2^D = f_{I\!P}(x_{I\!P}, t)\, F_2^{I\!P}(\beta, Q^2)$$
$$f_{I\!P} = \frac{e^{bt}}{x_{I\!P}^{2\alpha_{I\!P}-1}}$$

- Diffractive parton densities can be derived.

- Proton rest frame: dipoles

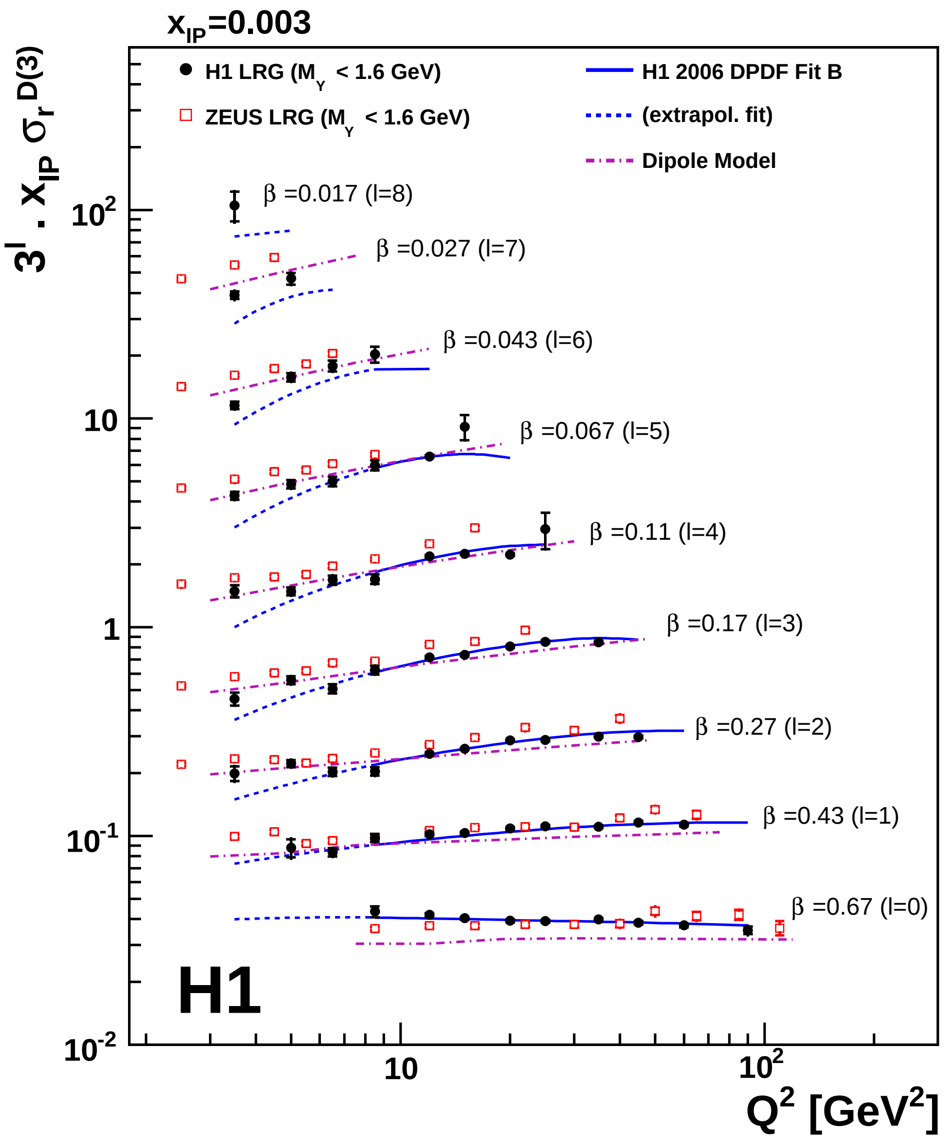


- Long-living quark pair interacts with the gluons from the proton.

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

- Direct relation to inclusive DIS.
- Incorporates saturation dynamics.
- No extra parameters for diffraction are needed.

Inclusive DDIS: Confronting Data and Models



Compare H1 and ZEUS LRG data to H1 DPDF Fit B and Dipole model

Normalisation difference of $\sim 10\%$ between **H1** and **ZEUS** – within norm. uncertainties of each experiment

Dipole model describes better low Q^2 trend

DPDF is better at higher Q^2

➡ New precise data challenge models

Inclusive DDIS: Extracting Pomeron trajectory

- Regge fit to LRG cross section:

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

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

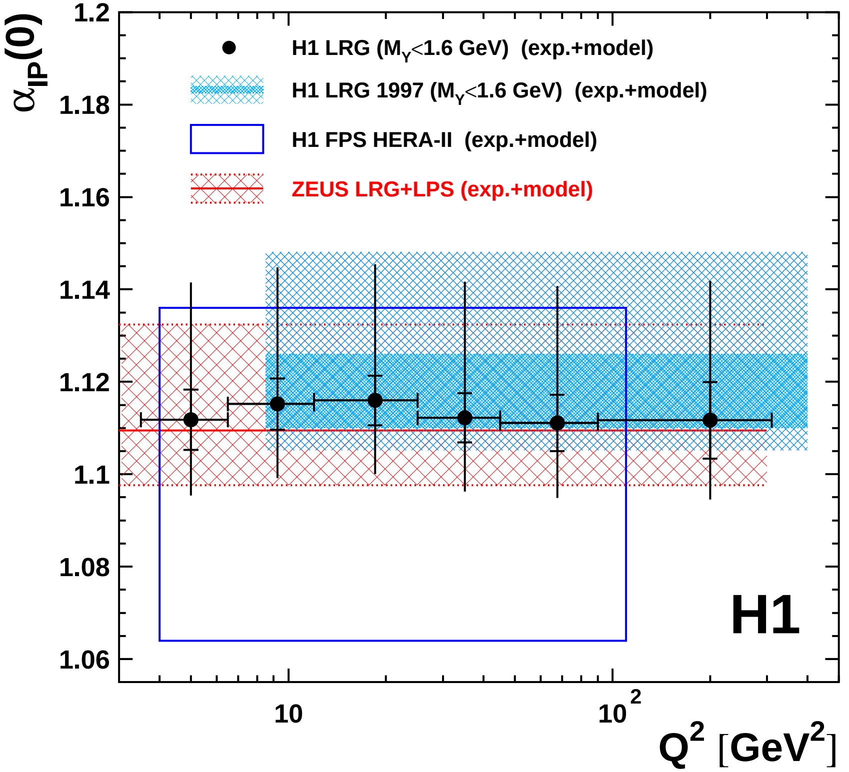
- Mean value of the Pomeron intercept:

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

- No Q^2 dependence observed
- Consistent with other determinations
- Supports proton-vertex factorisation hypothesis

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

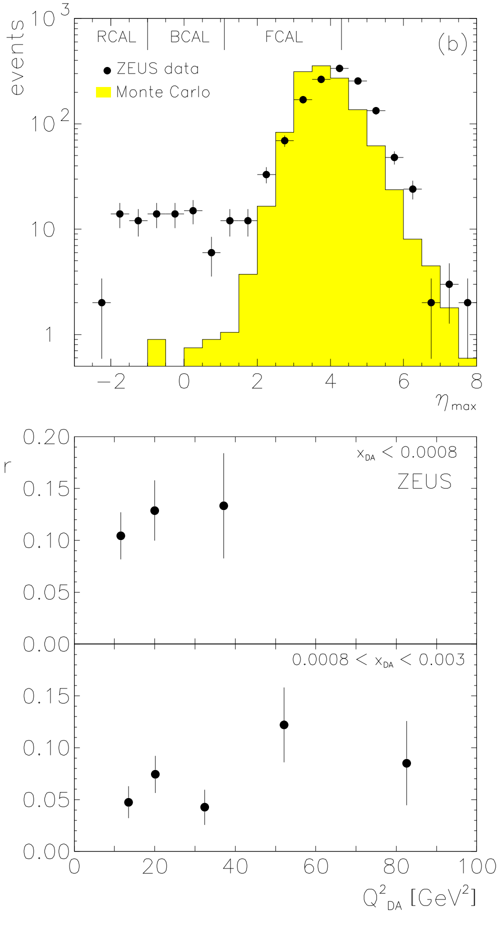
$\alpha'_{I\!P} \leq 0.1$ is typical for 'hard $I\!P$'



Complicated interplay of hard and soft phenomena

20 years of Diffraction in DIS

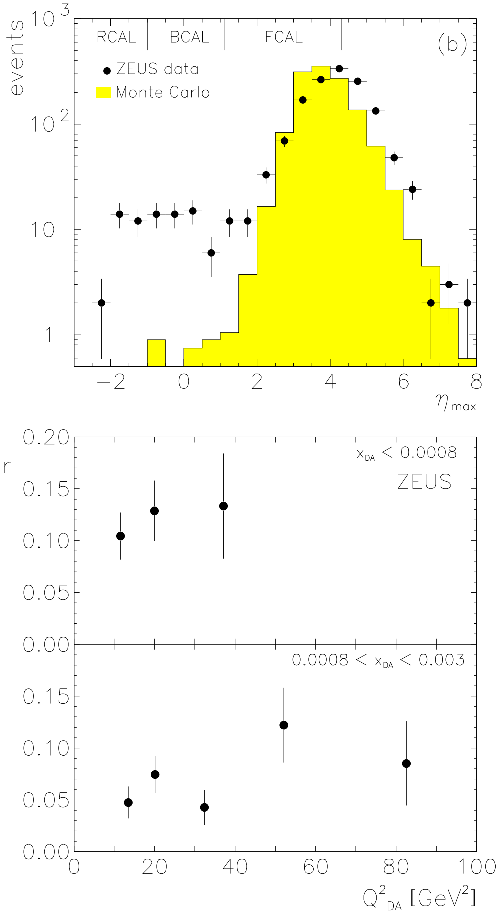
ZEUS-1993



First observation
of diffraction in DIS
1992 data, 24.7 nb^{-1}

20 years of Diffraction in DIS

ZEUS-1993



First observation
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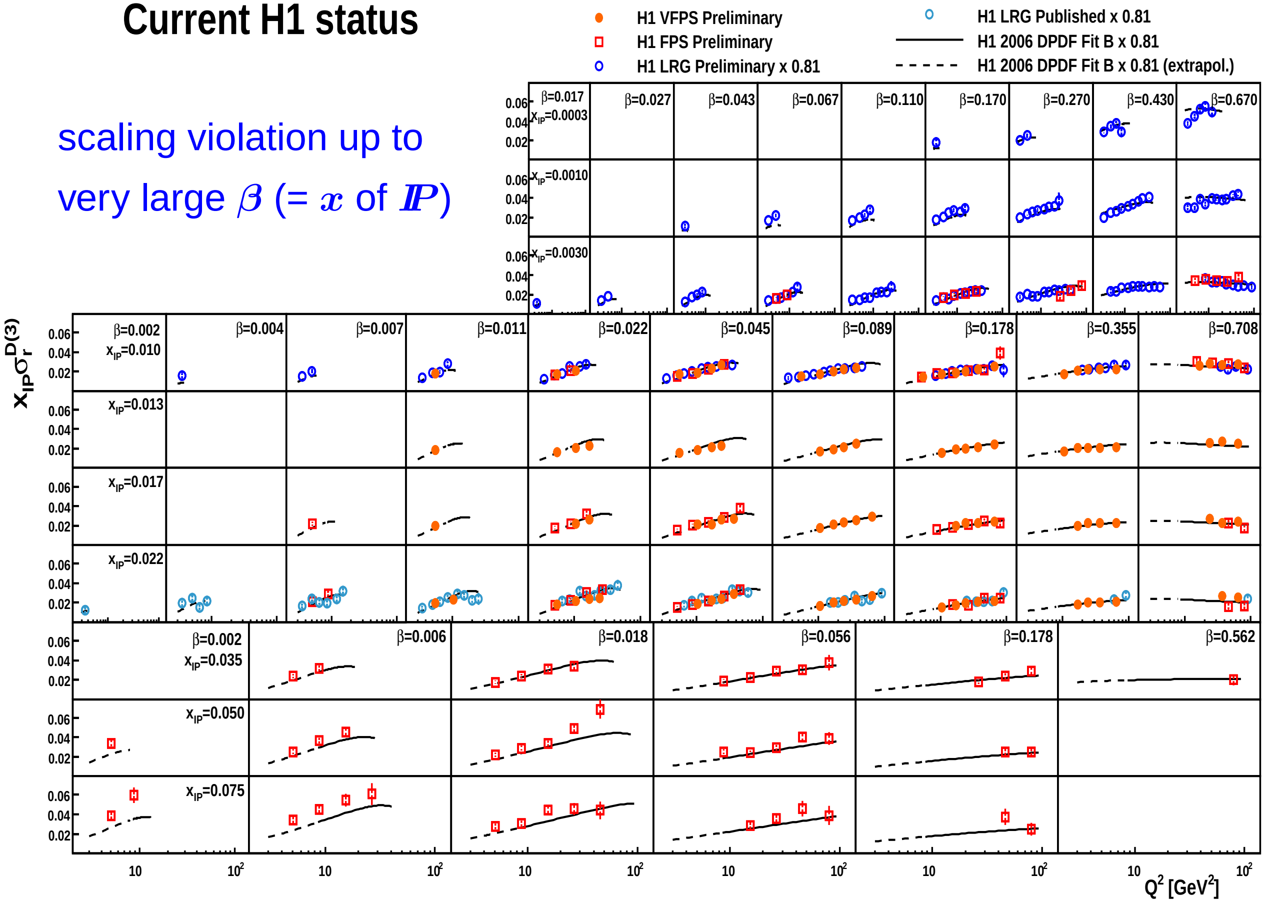
Current H1 status

scaling violation up to
very large β (= x of $I\!P$)



LRG

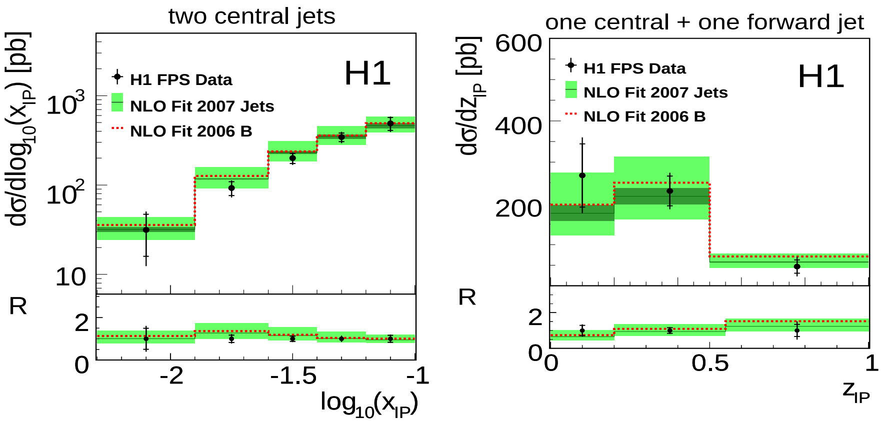
VFPS

FPS

- Compelling confirmation of the NLO QCD picture of diffraction over a wide kinematic range. Clear candidate for the textbook!
- Diffractive PDFs can be determined from these data. Are they universal?

QCD Factorisation Tests in Diffraction at HERA

QCD Factorisation holds in DIS regime *(EPJ, C72, 2012)*



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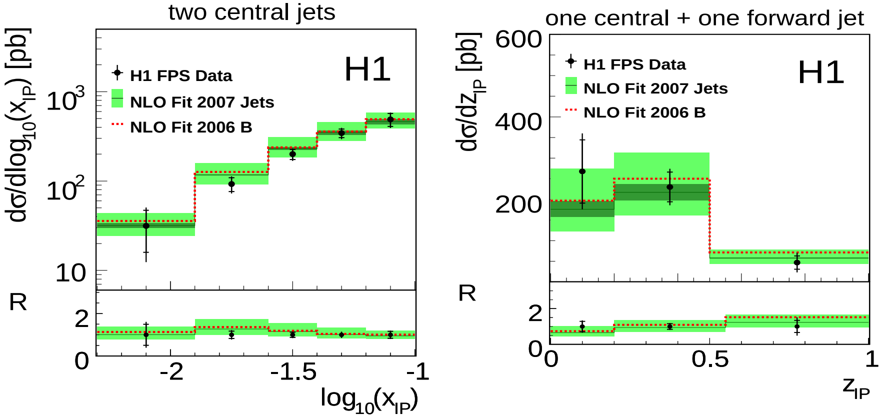
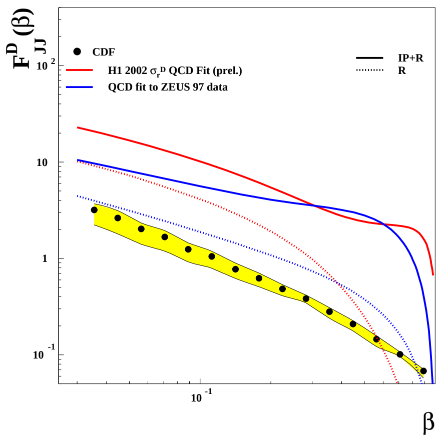
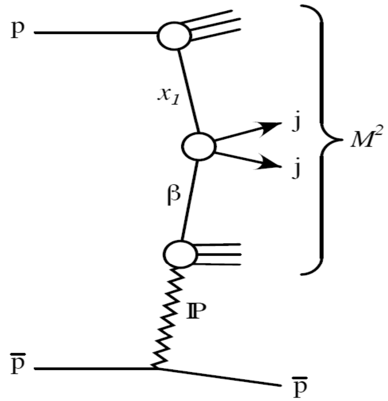


However, it breaks down at Tevatron ...

Tevatron vs HERA





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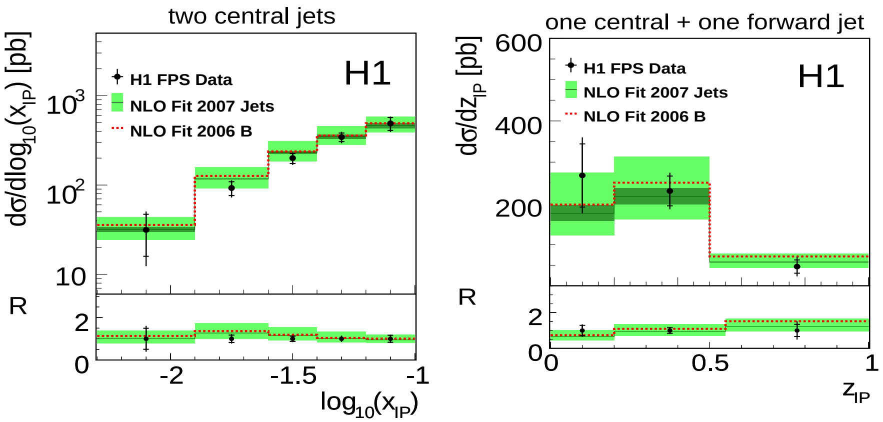
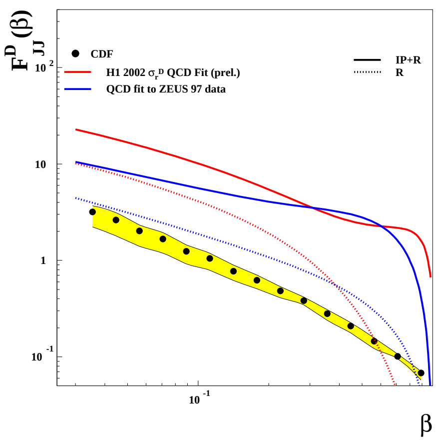
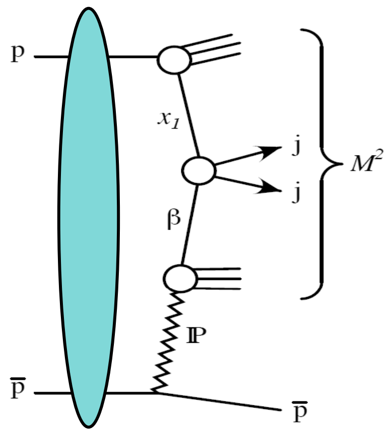


However, it breaks down at Tevatron ...
...due to soft remnant rescattering ($S \sim 0.15$)

Tevatron vs HERA





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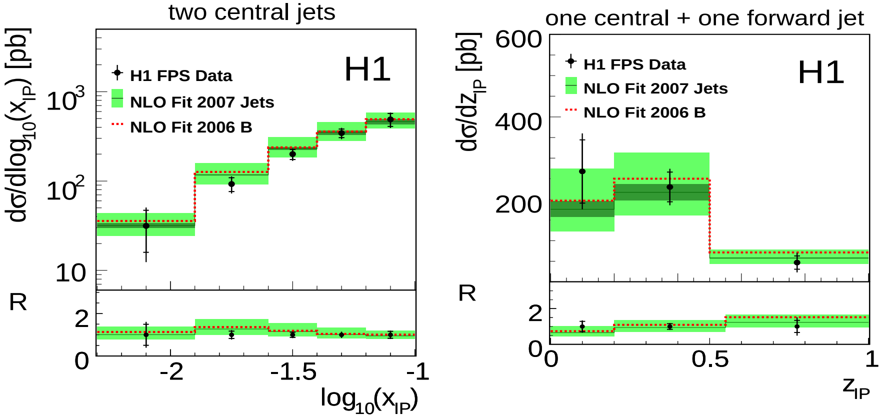
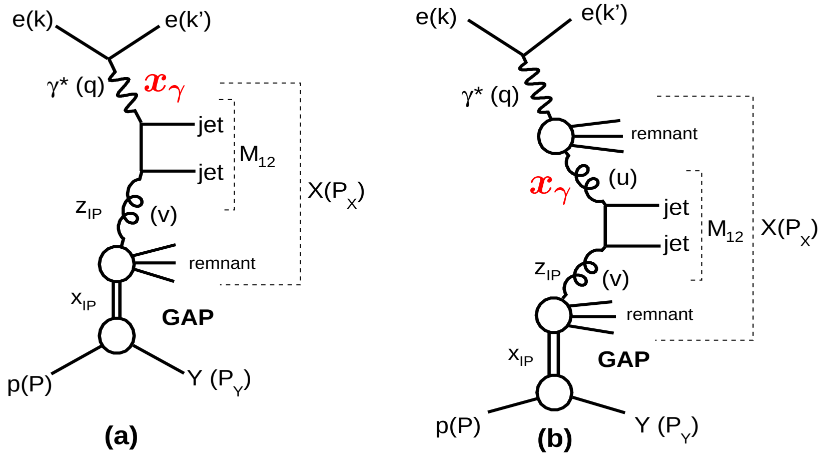


⇒ Test it in photoproduction:



direct, $x_\gamma = 1$ (DIS-like) resolved, $x_\gamma < 1$ (hadron-like)

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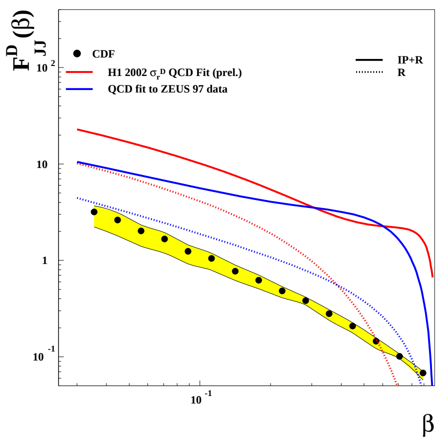
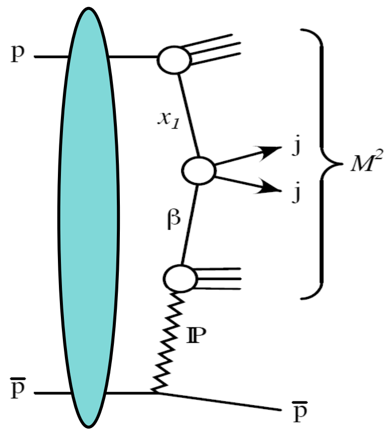
Tevatron vs HERA





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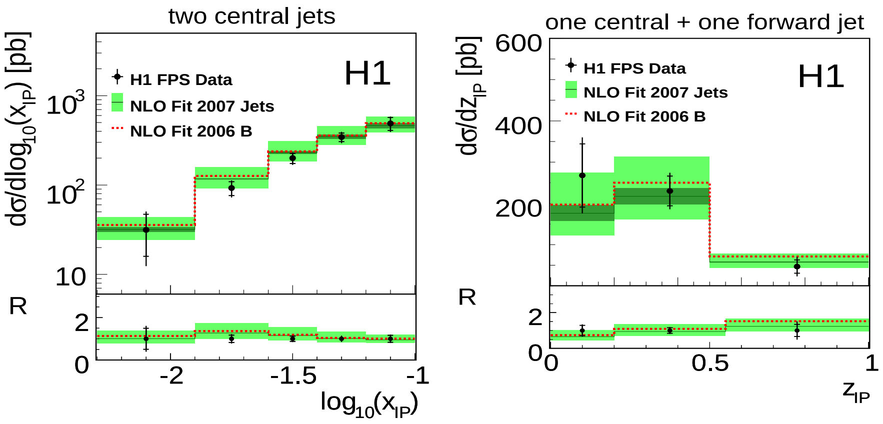

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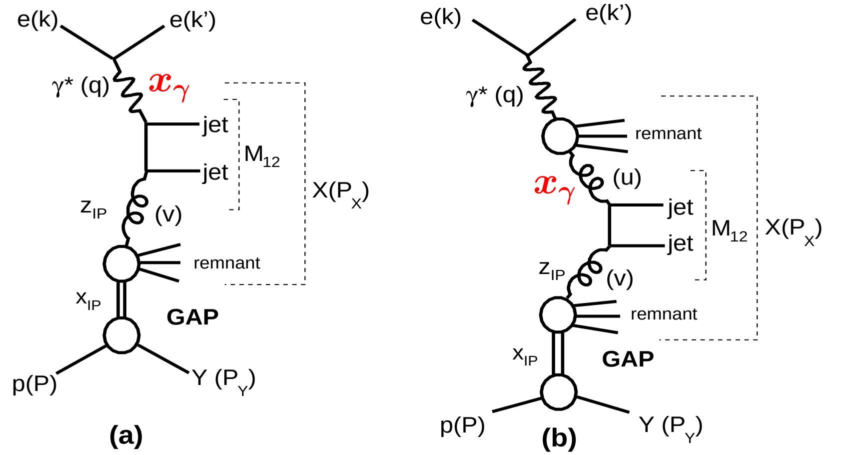

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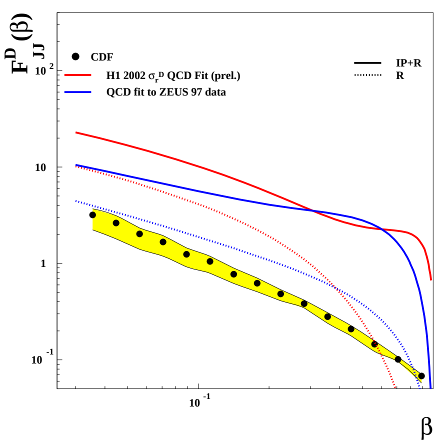
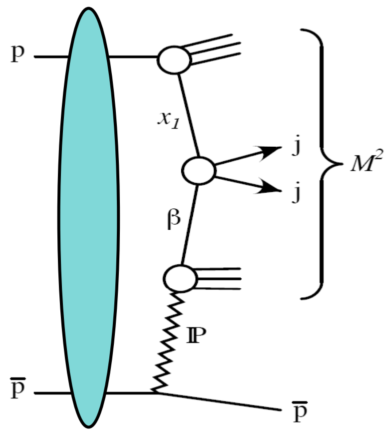
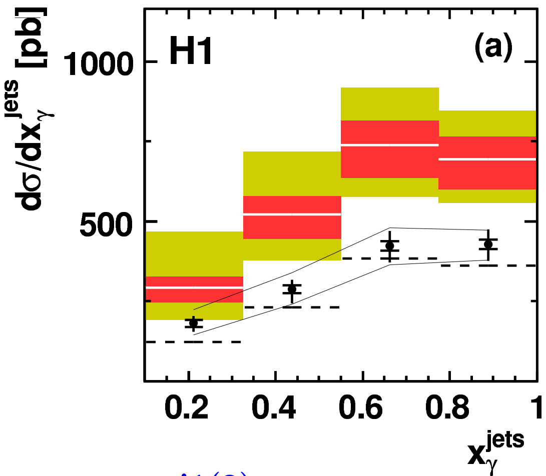
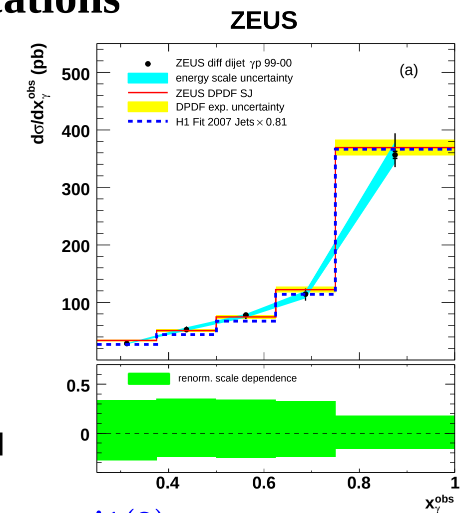




2010 publications

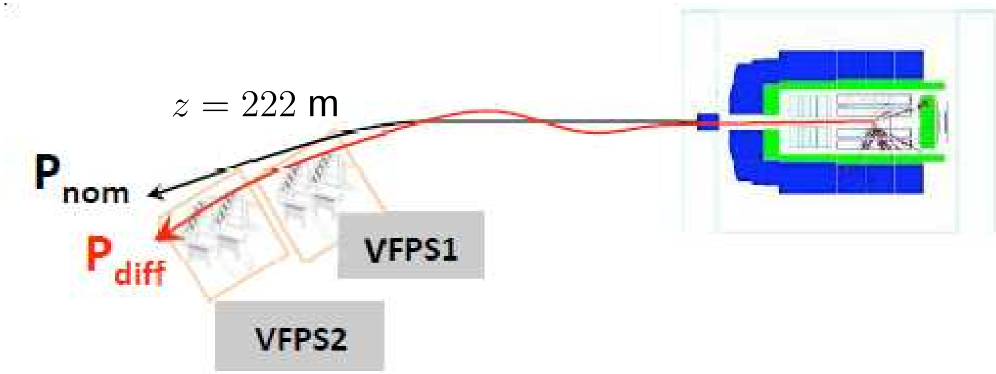




$E_T^{j1(2)} > 5(4)$ GeV $E_T^{j1(2)} > 7.5(6.5)$ GeV

$S \approx 0.6$ $S \approx 1.0$

VFPS Dijets: Data Sample



- 2006/07 e^+p data, $\mathcal{L} \approx 30$ pb^{-1}
- Leading proton measured by VFPS
- Untagged photoproduction
  (e^+ escapes in the beampipe)

Phase-space definition
$Q^2 < 2\,\mathrm{GeV}^2$
$0.2 < y < 0.8$
k_T jet algorithm:
$E_T^{\mathrm{jet1(2)}} > 5.5(4)\,\mathrm{GeV}$
$-1 < \eta^{\mathrm{jet1,2}} < 2.5$
Diffractive:
$0.010 < x_{IP} < 0.024$
$\lvert t \rvert < 0.6\,\mathrm{GeV}^2$
$M_Y = M_p$

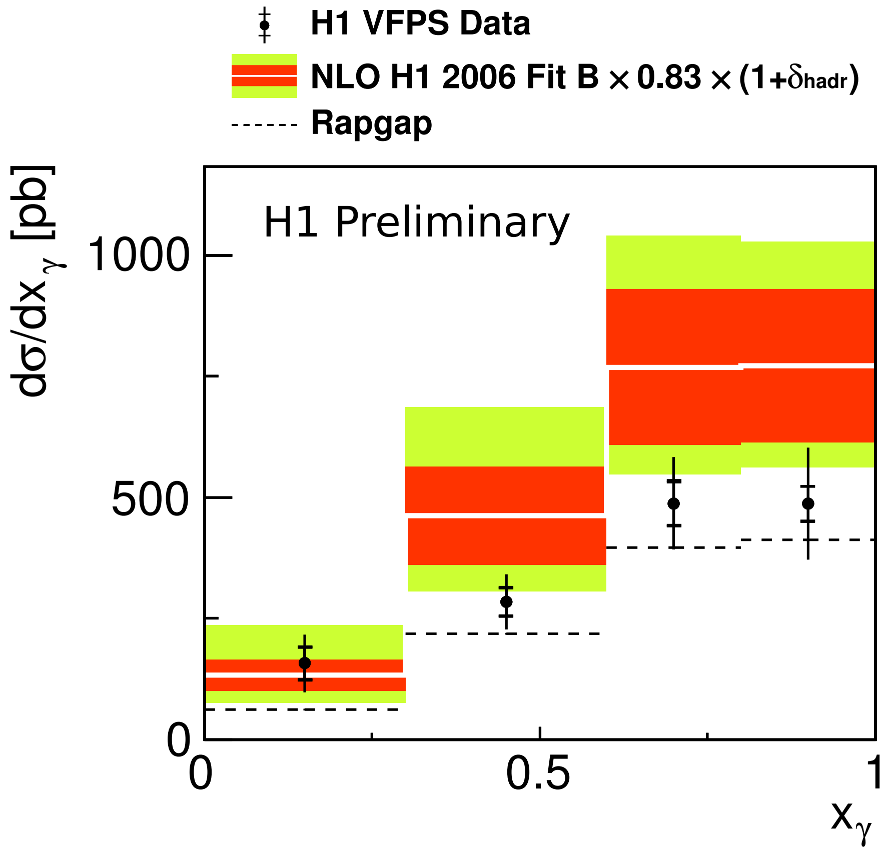
Statistics: 4800 dijet events after all cuts

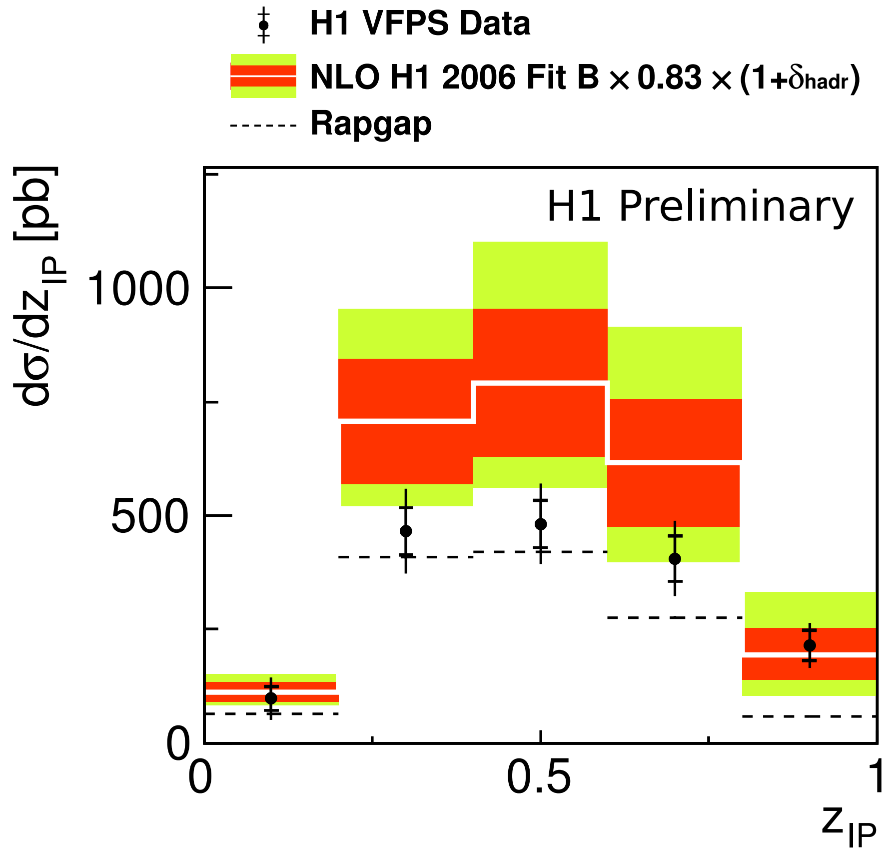
Data unfolded to the level of stable hadrons using *TUnfold* program (Singular Value Decomposition of the responce matrix)

Results are compared to LO Monte Carlo (*Rapgap*) and to NLO QCD calculations (*Frixione-Ridolfi*)

- Scales: $\mu_r = \mu_f = E_T^{\mathrm{jet1}}$
- DPDF H1 2006 Fit B and GRV-HO γ-PDF used

VFPS Dijets: Differential cross section in x_γ and $z_{I\!P}$

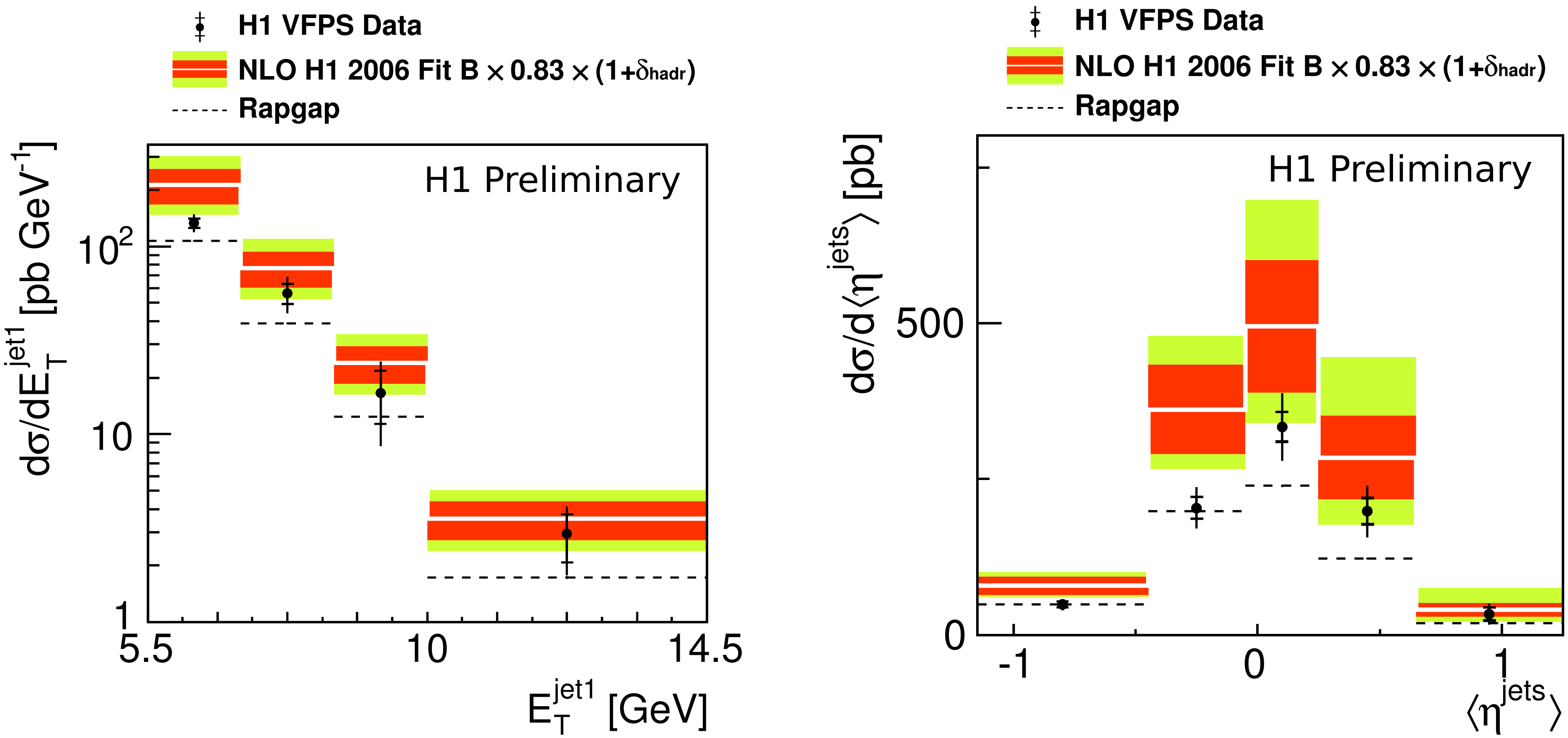




$$\sigma_{DATA}/\sigma_{NLO} = 0.67 \pm 0.04(\text{stat}) \pm 0.09(\text{sys}) \pm 0.20(\text{scale}) \pm 0.14(\text{PDF})$$

Suppression factor is independent of x_γ contrary to theoretical expectation

VFPS Dijets: Differential cross section in E_T^{jet1} and $\langle\eta^{jet}\rangle$



- E_T dependence of the suppression cannot be excluded within large uncertainties
- Rapgap MC predictions are too low as compared to the measurement

Summary

- Precision measurement representing a final H1 word on inclusive LRG cross sections in DIS is publised based on full HERA I+II data

- These data provide new constraints to QCD models and support proton-vertex factorisation hypothesis

- Dijet diffractive photoproduction cross sections with proton tagged in VFPS are measured, and found consistent with previous (LRG) measurement.

- Gap survival probability $= \mathbf{0.67 \pm 0.10(exp) \pm 0.24(th)}$ with no evidence for the difference between resolved and direct processes

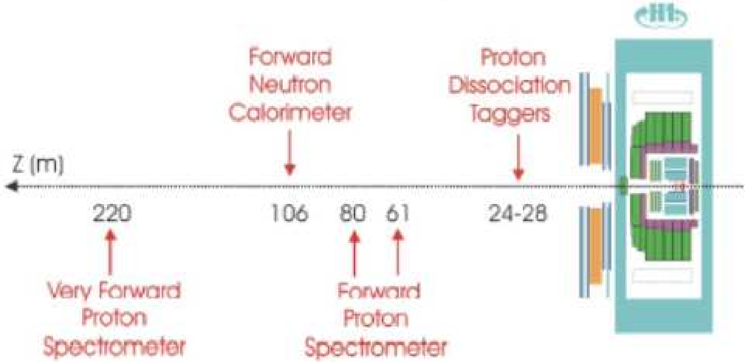
- Some features of these new measurements reveal a complicated interpay of soft and hard phenomena which still represent a challenge for theoretical models of $\boldsymbol{ep}$ diffraction.

Extra slides

Selection of Diffractive Events

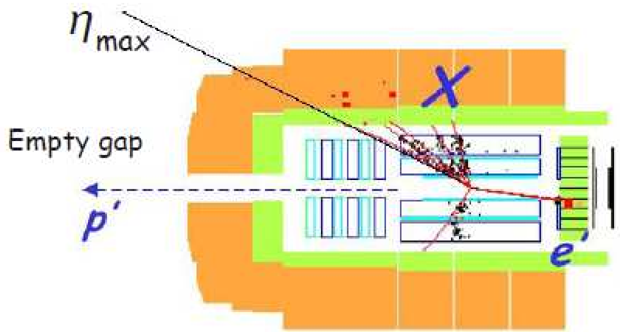
Measure the leading proton

→ Forward spectrometers (H1 FPS/VFPS)



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

Measure a Large Rapidity Gap



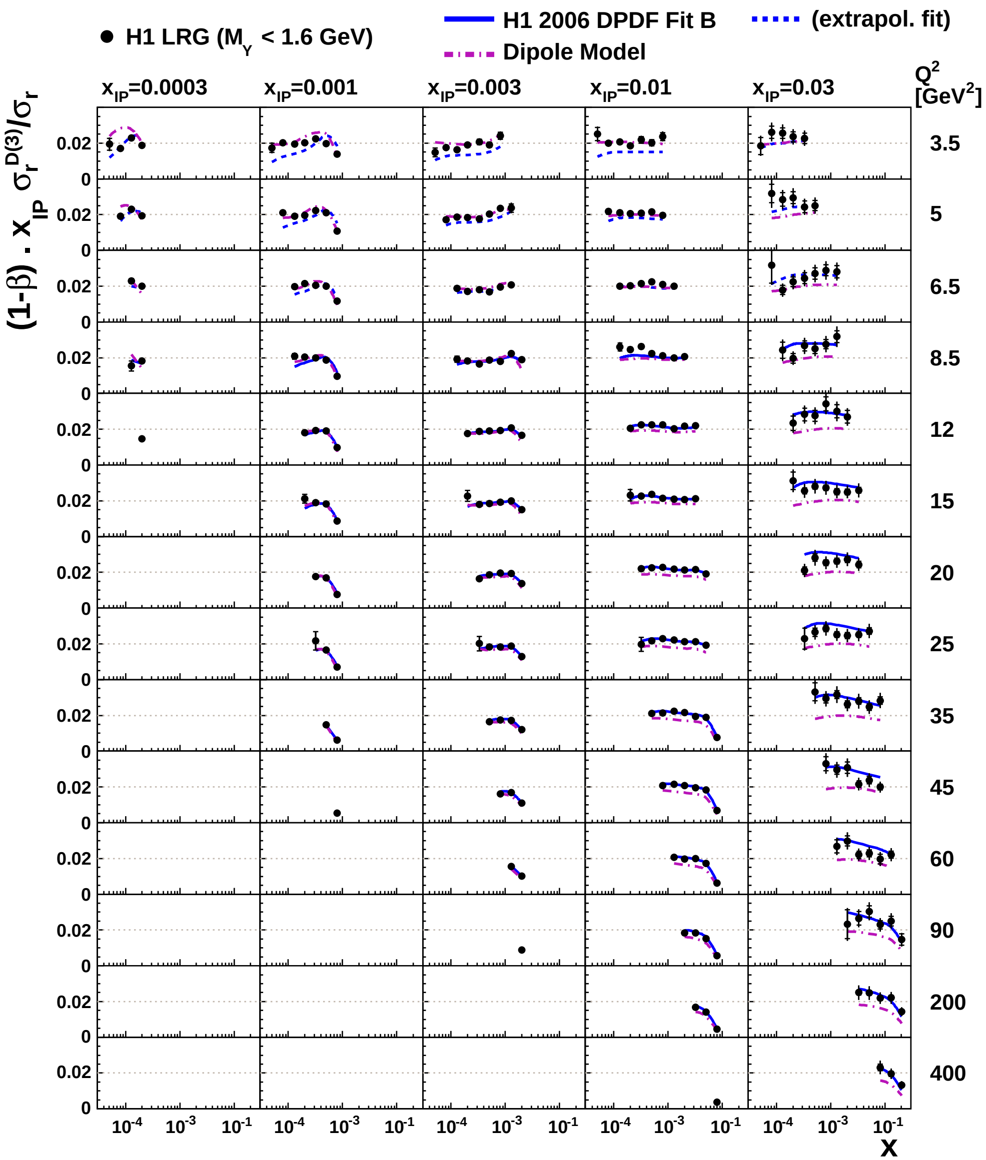
- Data integrated over $|t| < 1$ GeV^2
- High statistics
- Contamination from proton dissociation events

→ Needs to be controlled

↘ Different systematics

↘ Different kinematic coverage

Ratio of Diffractive to Inclusive cross sections

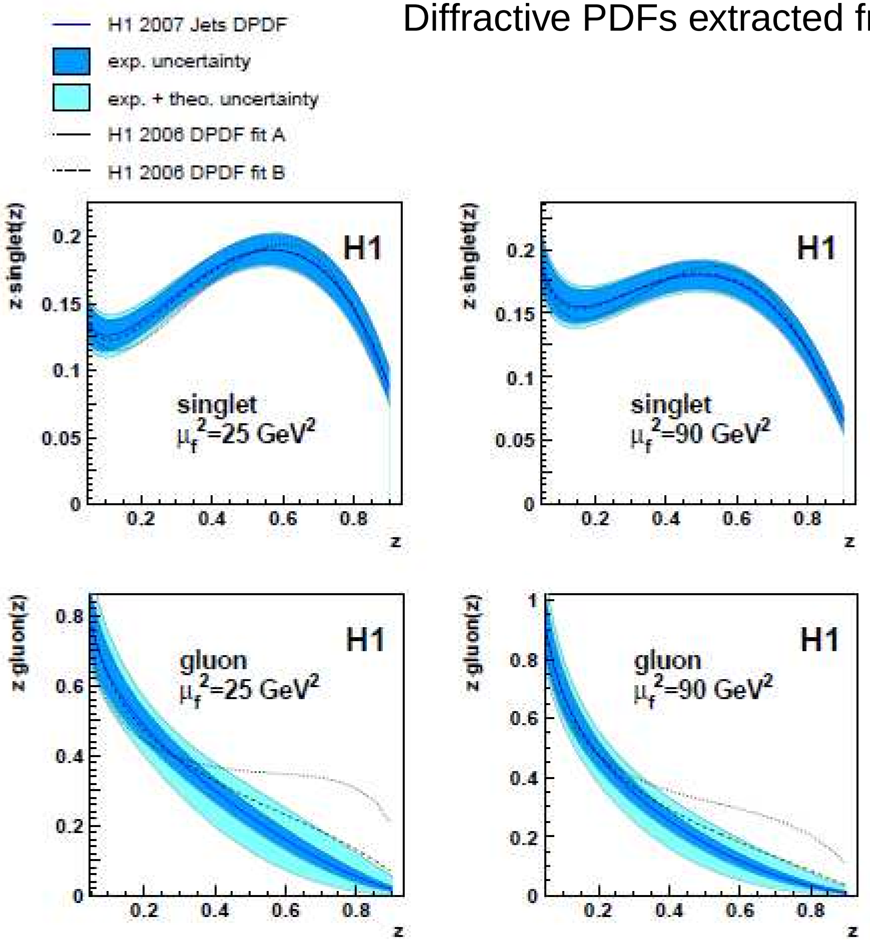


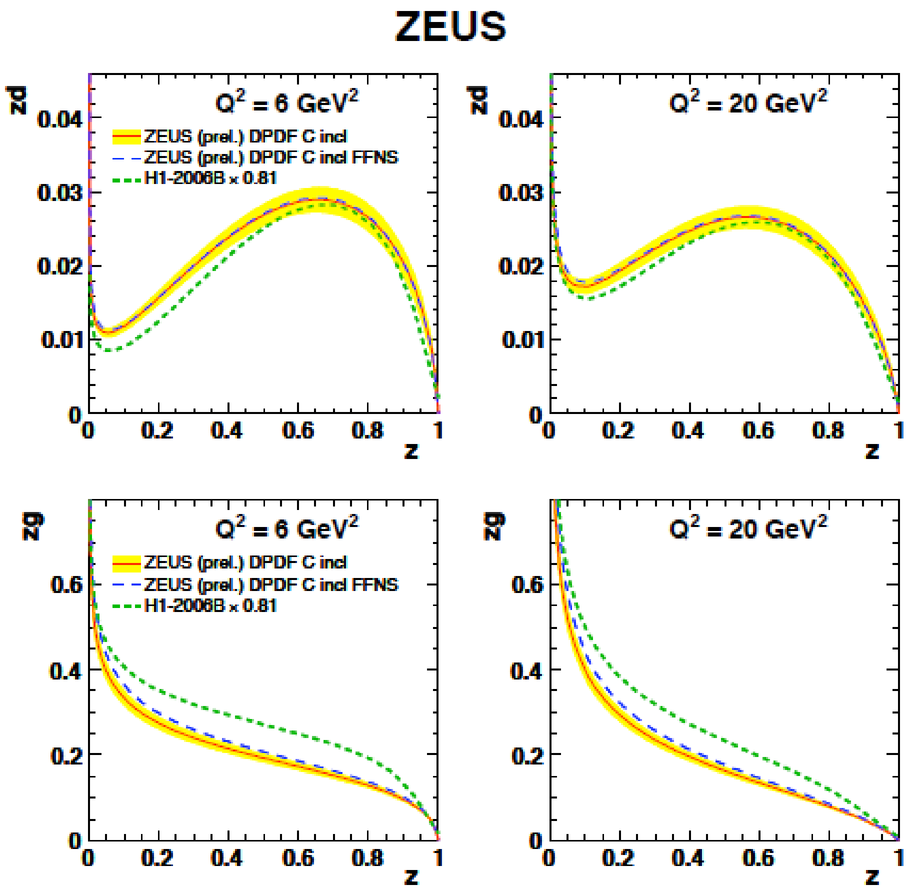
Ratio Diff/Inclusive cross section is approximately flat in x except of highest β regions

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

Diffractive PDFs as determined by H1 and ZEUS

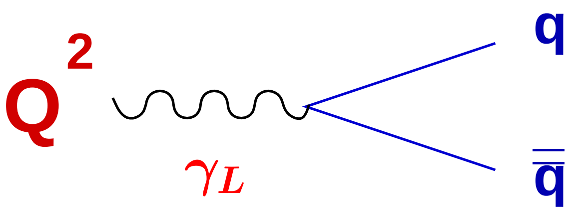
Diffractive PDFs extracted from NLO DGLAP fit, using Regge factorisation

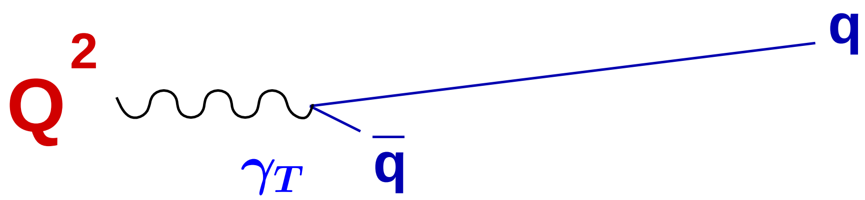




- Combine H1 and ZEUS measurements to improve precision
- Determine DPDF (eventually without Regge factorisation assumption)

Interplay of soft and hard contributions





γ_L ($z \simeq 0.5$): $\langle r_t^2 \rangle \simeq (z(1-z)Q^2 + m_q^2)^{-1} \simeq 1/[(Q/2)^2 + m_q^2]$

γ_T ($z \simeq 0; 1$): $\langle r_t^2 \rangle \simeq (z(1-z)Q^2 + m_q^2)^{-1} \simeq 1/m_q^2$

Small dipole

Large dipole

TABLE I: Interplay between the probabilities of hard and soft fluctuations in a highly virtual photon and the cross section of interaction of these fluctuations.

	$\|C_\alpha\|^2$	σ_α	$\sigma_{tot} = \sum_{\alpha=soft}^{hard} \|C_\alpha\|^2 \sigma_\alpha$	$\sigma_{sd} = \sum_{\alpha=soft}^{hard} \|C_\alpha\|^2 \sigma_\alpha^2$
Hard	~ 1	$\sim \frac{1}{Q^2}$	$\sim \frac{1}{Q^2}$	$\sim \frac{1}{Q^4}$
Soft	$\sim \frac{m_q^2}{Q^2}$	$\sim \frac{1}{m_q^2}$	$\sim \frac{1}{Q^2}$	$\sim \frac{1}{m_q^2 Q^2}$