

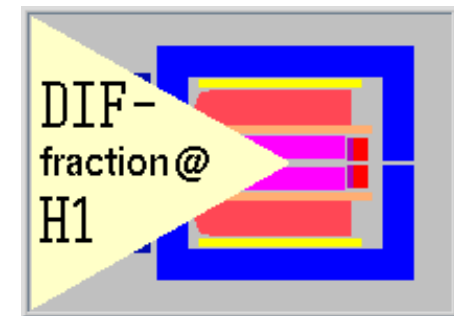


Recent H1 results on Diffraction

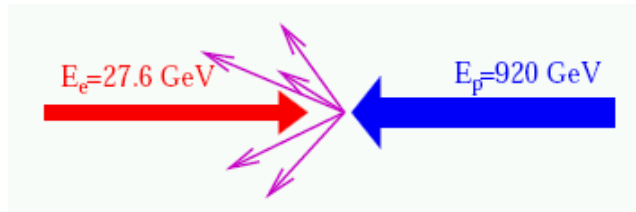
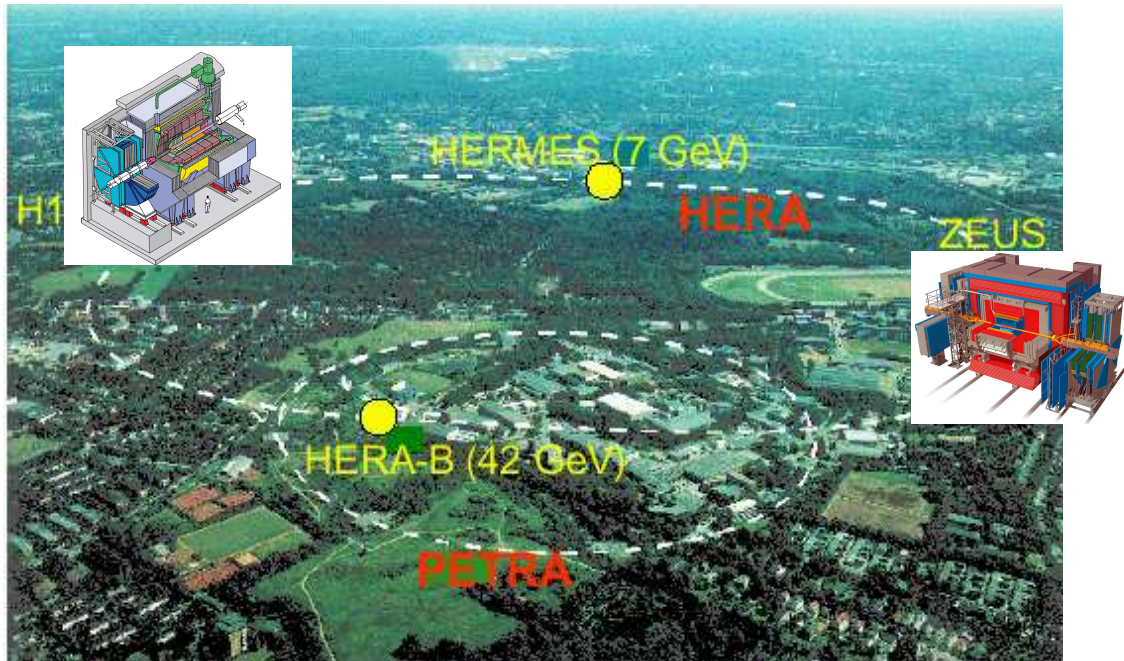
S. Levonian, DESY



- Measurement of Inclusive Diffraction in DIS
(abstract 53)
- Diffractive Dijets and QCD Factorisation
(abstracts 50,65)



HERA: The World's Only ep Collider



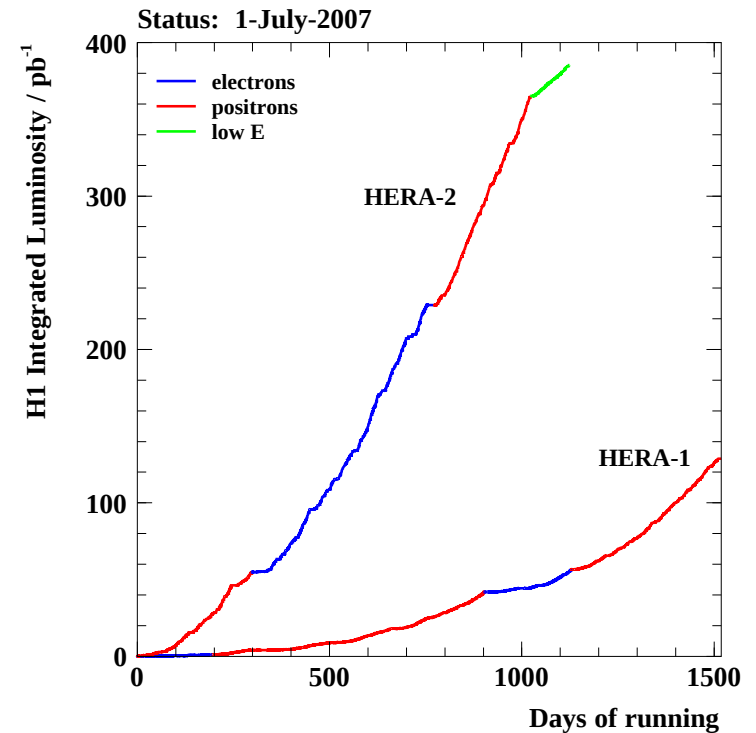
- 1998 E_p upgrade: $820 \Rightarrow 920$ GeV
($\sqrt{s}$: $301 \Rightarrow 319$ GeV)
- 2001 HERA-2 upgrade: $\mathcal{L} \times 3$, Polarised e^+/e^-
($\langle P \rangle = 40\%$)

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

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

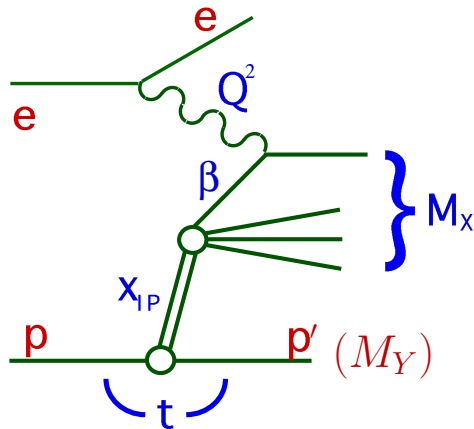
Final Data samples

H1+ZEUS: $2 \times 0.5 \text{ fb}^{-1}$



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)



$$x_P = \xi = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

(momentum fraction of colour singlet exchange)

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

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

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

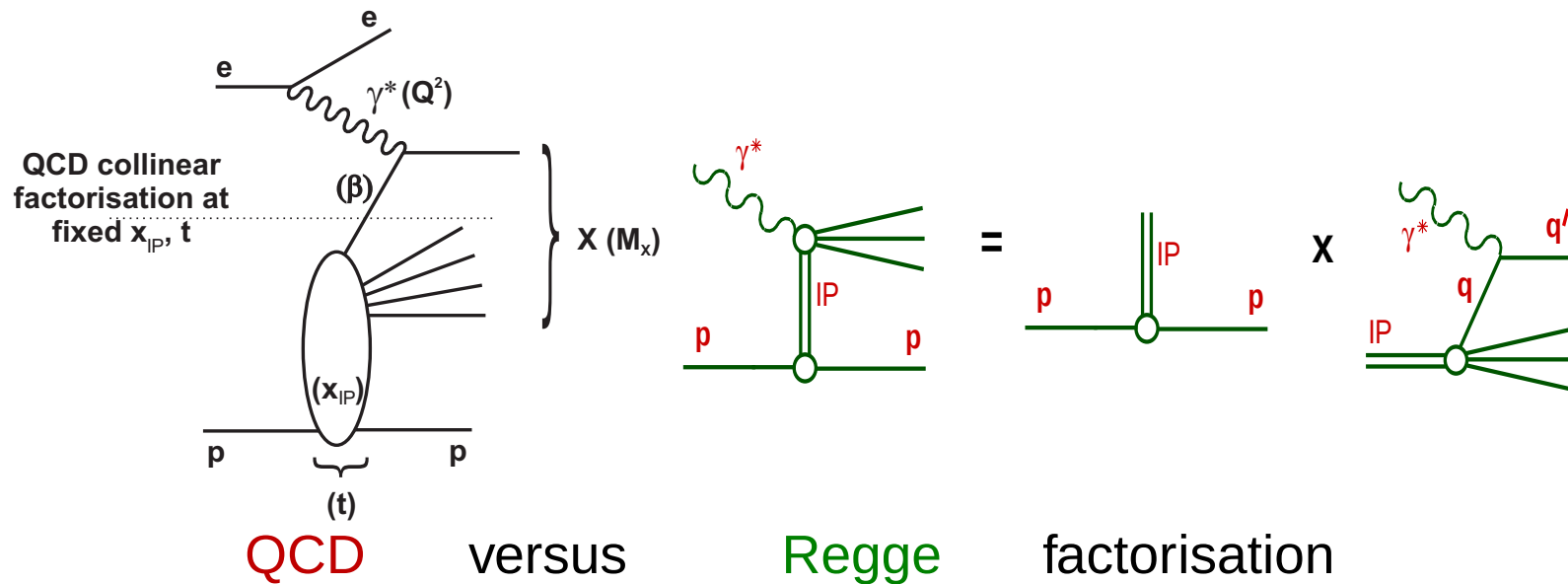
(4-momentum transfer squared)

Experimental methods:

- 1) selecting LRG events
- 2) detecting p in Roman Pots (60 – 220 m from IP)



Factorisation properties in diffraction



QCD factorisation

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

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

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

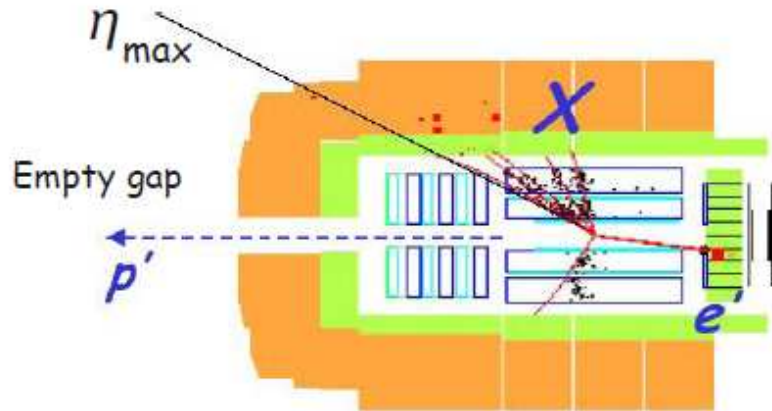
Regge factorisation

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

$$F_2^{D(4)}(x_{\text{IP}}, t, \beta, Q^2) = \Phi(x_{\text{IP}}, t) \cdot F_2^{\text{IP}}(\beta, Q^2)$$

- In this case shape of diffractive PDF's is independent of x_{IP}, t while normalization is controlled by Regge flux $\Phi(x_{\text{IP}}, t)$

Inclusive DDIS: H1 LRG Data Samples

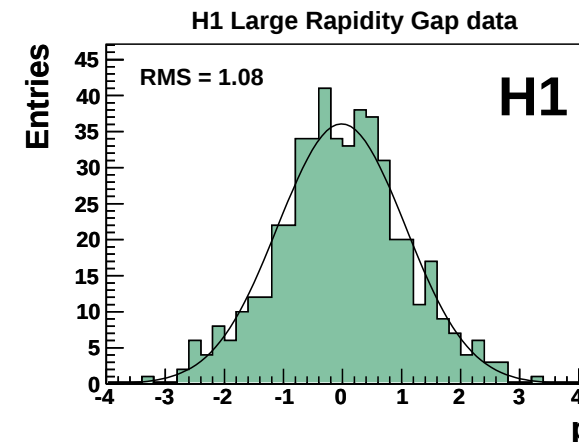


Data Set	Q^2 range (GeV ²)	Proton Energy E_p (GeV)	Luminosity (pb ⁻¹)
New data samples			
1999 MB	$3 < Q^2 < 25$	920	3.5
1999-2000	$10 < Q^2 < 105$	920	34.3
2004-2007	$10 < Q^2 < 105$	920	336.6
Previously published data samples			
1997 MB	$3 < Q^2 < 13.5$	820	2.0
1997	$13.5 < Q^2 < 105$	820	10.6
1999-2000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

[H1 Coll. EPJC28 (2006) 715]

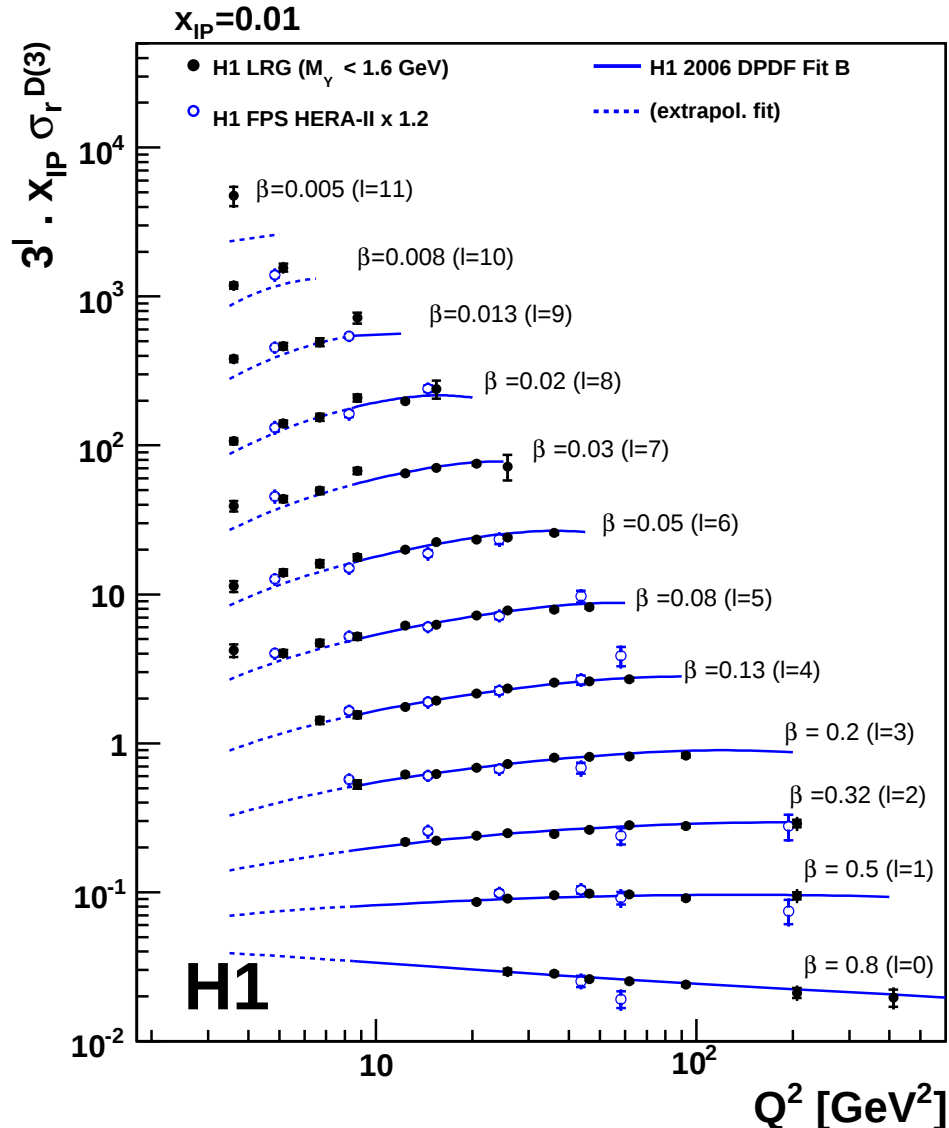
- Statistics increase: 3 to 33
Typical precision: 1%(stat) $\oplus$ 5%(syst) $\oplus$ 4%(norm)
- 597 data points averaged to 277 measurements
Iterative χ^2 minimisation with full error correlations
 $\chi^2/\text{NDF} = 371/320$
- Total kinematic range:

$$\begin{aligned}
 &3.5 < Q^2 < 1600 \text{ GeV}^2 \\
 &0.0017 < \beta < 0.8 \\
 &0.0003 < x_F < 0.03
 \end{aligned}$$



➡ No large tension between data sets

Inclusive DDIS: LRG vs p-tagged methods



Compare LRG and FPS cross sections

Ratio LRG/FPS:

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

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

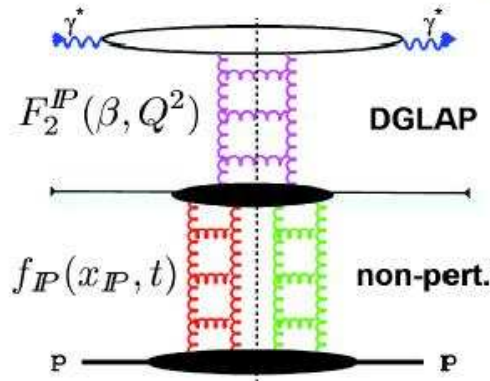
(1.6%) (7.2%)

➡ 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**



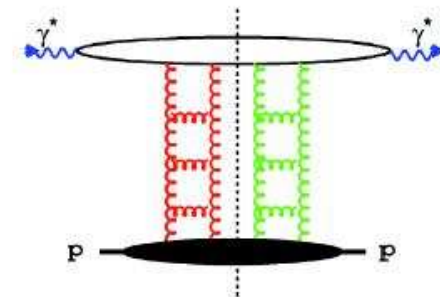
- Factorization is assumed.

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

$$f_{IP} = \frac{e^{bt}}{x_{IP}^{2\alpha_{IP}-1}}$$

- Diffractive parton densities can be derived.

- Proton rest frame: **dipoles**

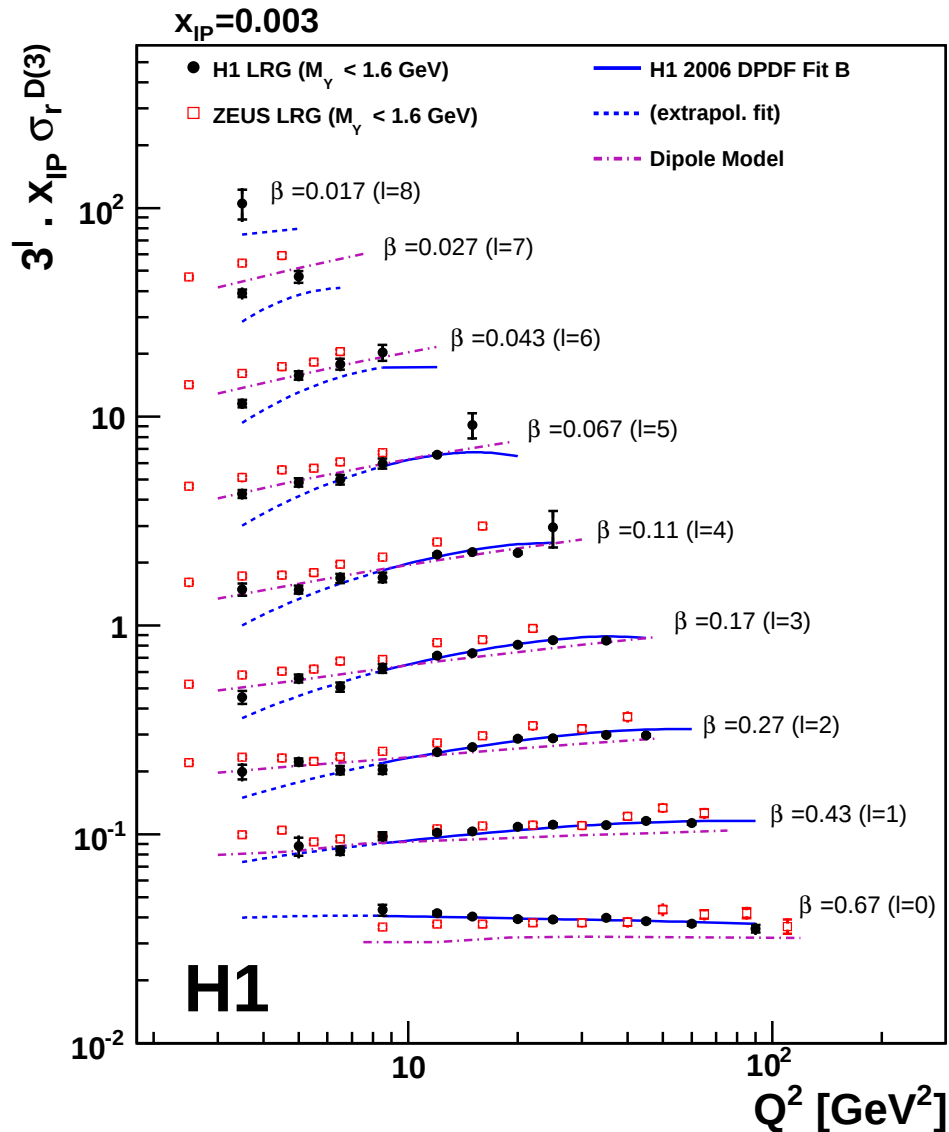


- Long-living quark pair interacts with the gluons from the proton.

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

- Direct relation to inclusive DIS.
- Incorporates saturation dynamics.
- No extra parameters 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:

$$F_2^{D(3)}(Q^2, \beta, x_P) = f_{IP/p}(x_P) F_2^{IP}(Q^2, \beta) + n_R f_{R/p}(x_P) F_2^R(Q^2, \beta)$$

$$f_{IP/p, R/p}(x_P) = \int_{t_{cut}}^{t_{min}} \frac{e^{B_{IP, R} t}}{x_P^{2\alpha_{IP, R}(t)-1}} dt$$

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

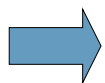
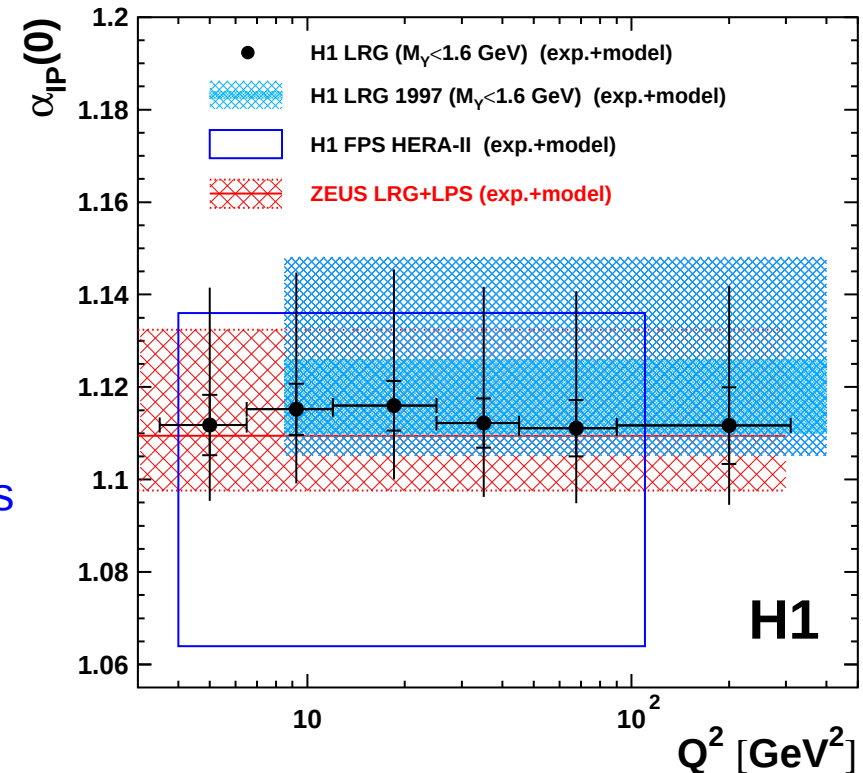
- Mean value of the Pomeron intercept:

$$\alpha_P(0) = 1.113 \pm 0.002(\text{exp})_{-0.015}^{+0.029}(\text{model})$$

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

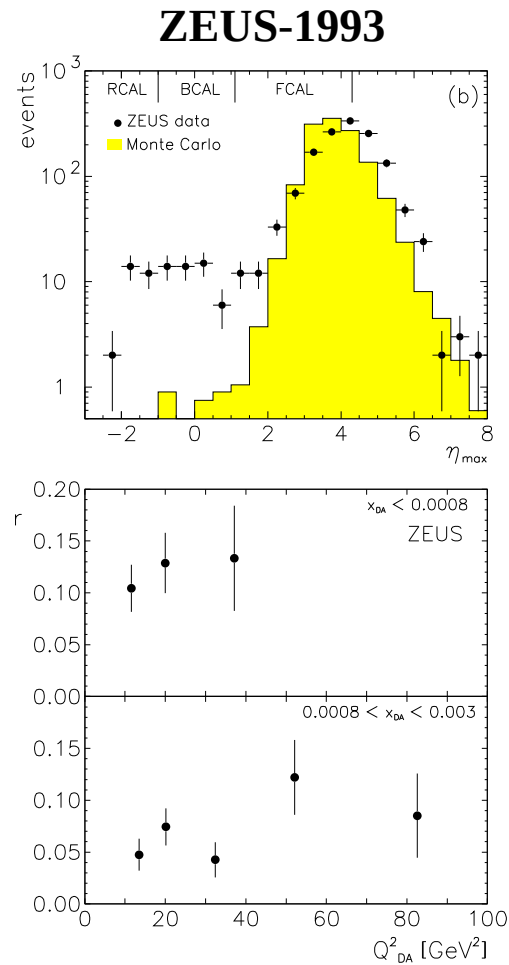
$\alpha_P(0)$ – consistent with ‘soft IP ’

$\alpha'_{IP} \leq 0.1$ is typical for ‘hard IP ’



Complicated interplay of hard and soft phenomena

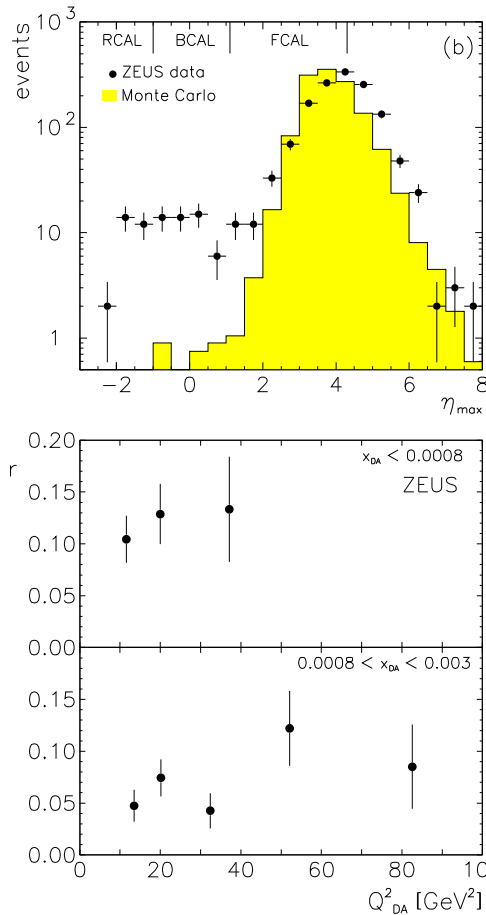
20 years of Diffraction in DIS



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

20 years of Diffraction in DIS

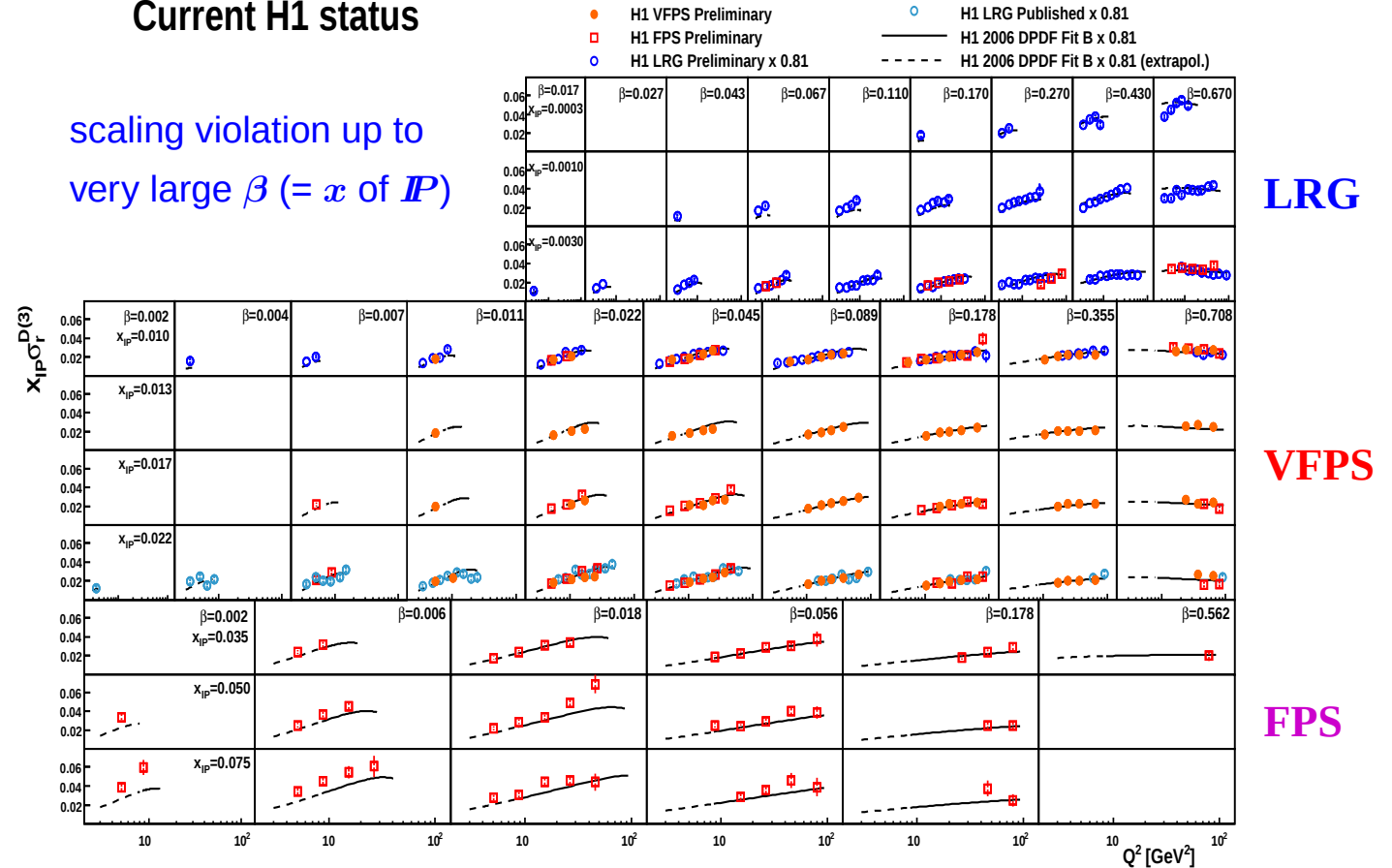
ZEUS-1993



First observation
of diffraction in DIS
1992 data, 24.7 nb⁻¹

Current H1 status

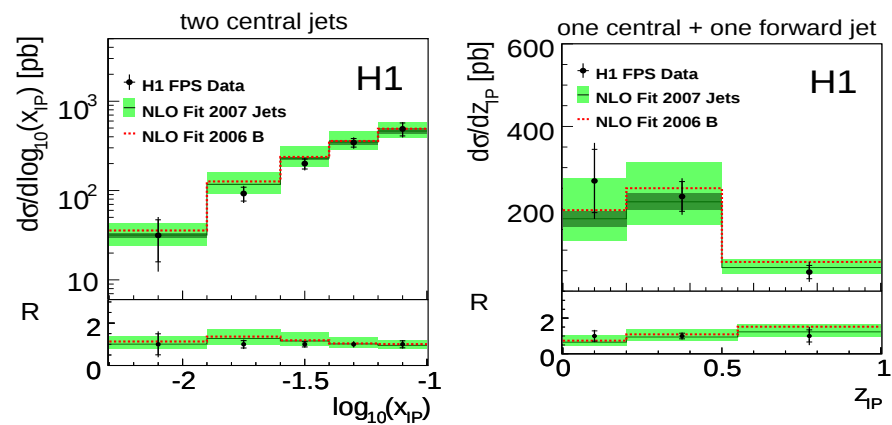
scaling violation up to
very large β ($= x$ of IP)



- 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?

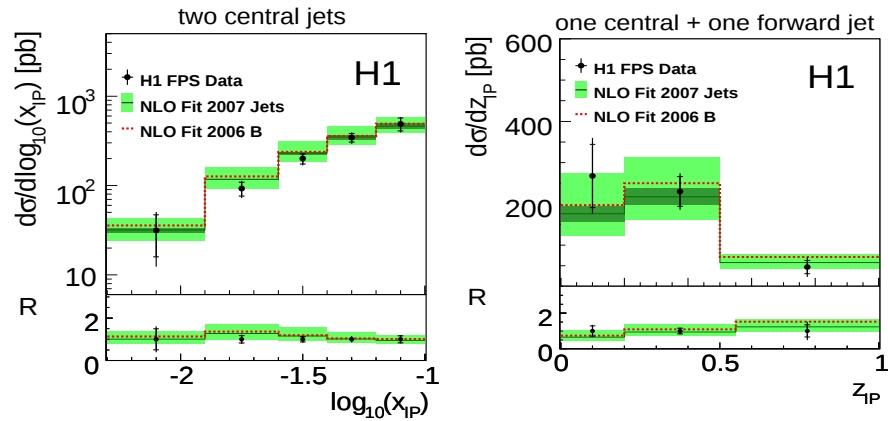
QCD Factorisation Tests in Diffraction at HERA

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



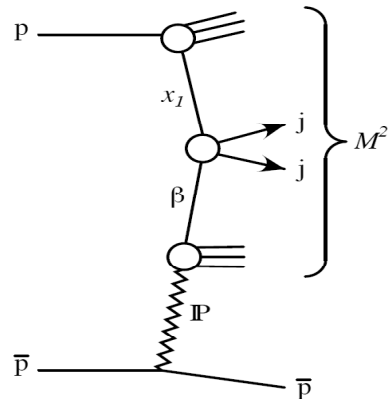
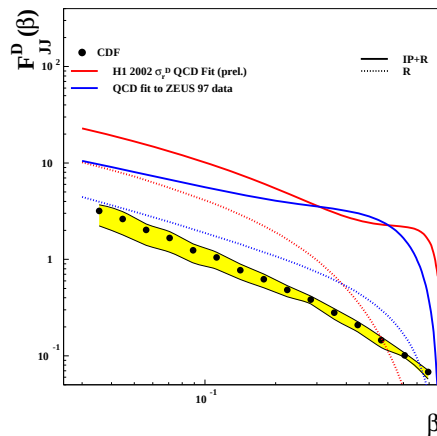
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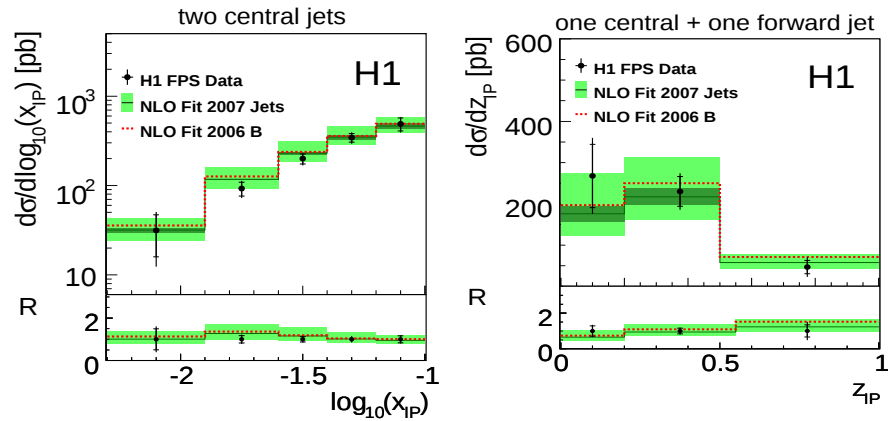
However, it breaks down at Tevatron ...

Tevatron vs HERA



QCD Factorisation Tests in Diffraction at HERA

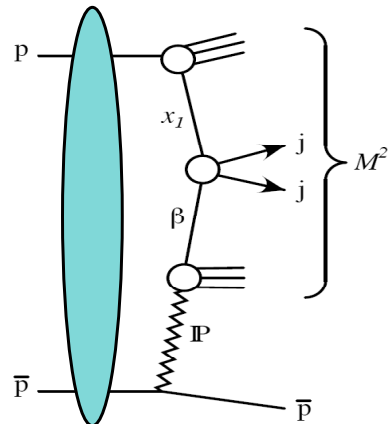
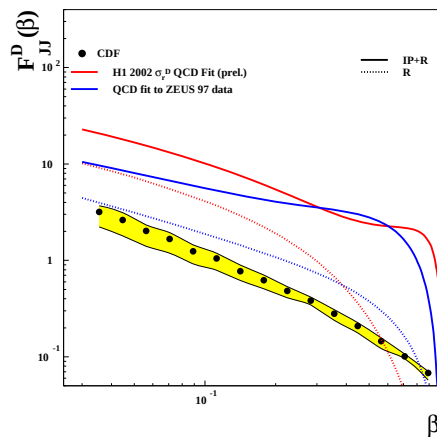
QCD Factorisation holds in DIS regime (*EPJ*, C72, 2012)



However, it breaks down at Tevatron ...

...due to soft remnant rescattering ($S \sim 0.15$)

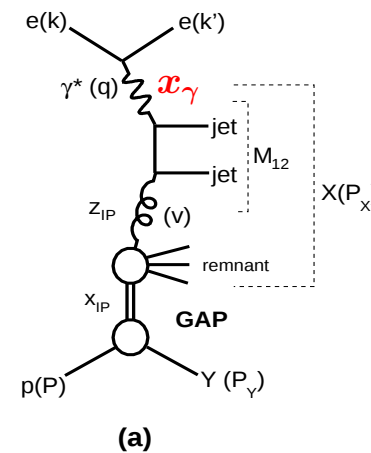
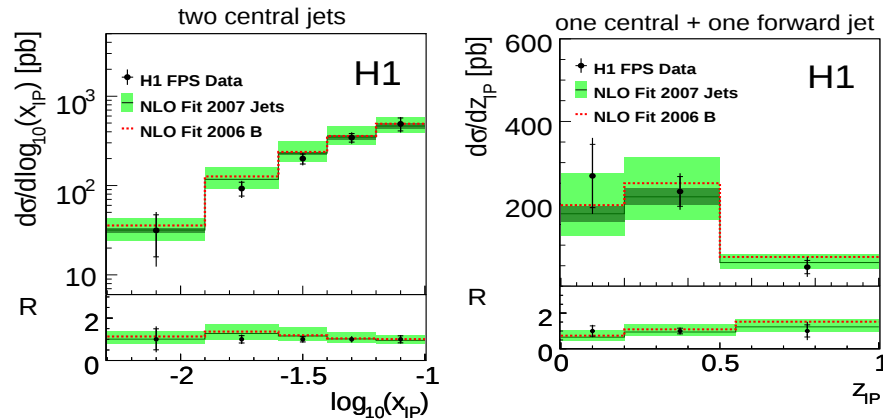
Tevatron vs HERA



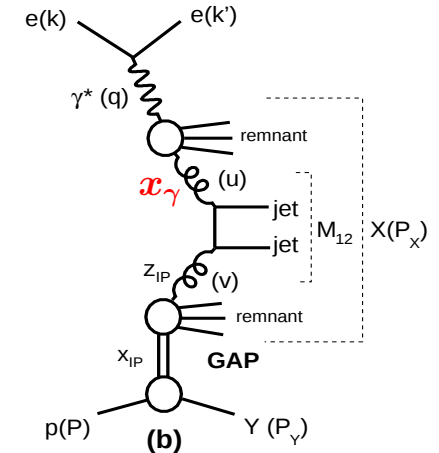
QCD Factorisation Tests in Diffraction at HERA

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

⇒ Test it in photoproduction:



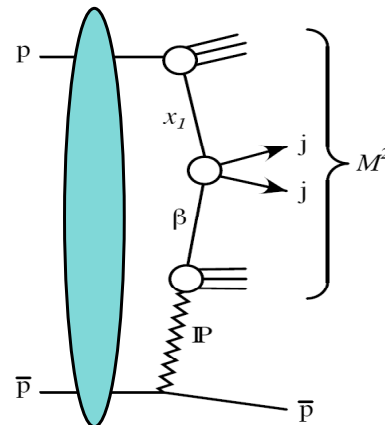
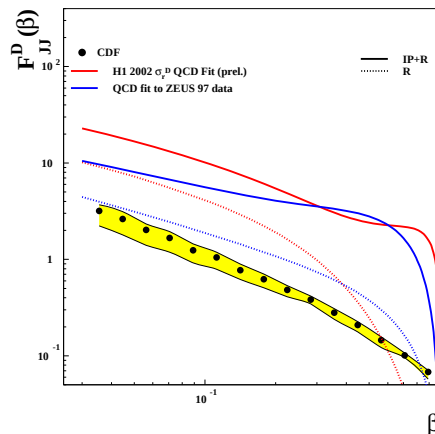
direct, $x_\gamma = 1$ (DIS-like)



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

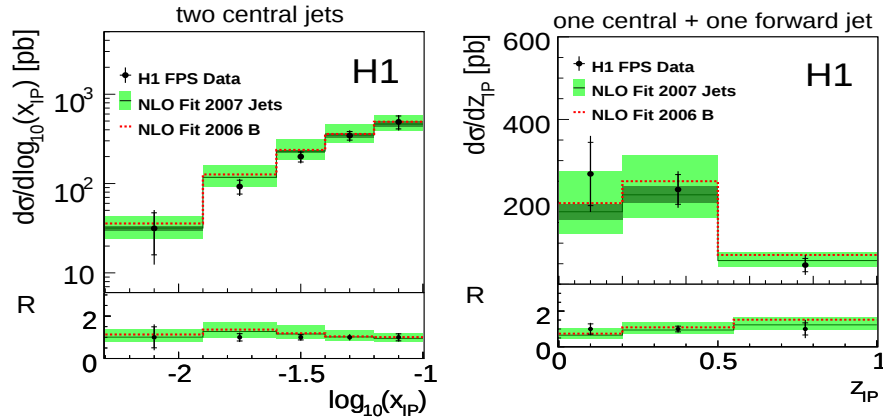
However, it breaks down at Tevatron ...
...due to soft remnant rescattering ($S \sim 0.15$)

Tevatron vs HERA

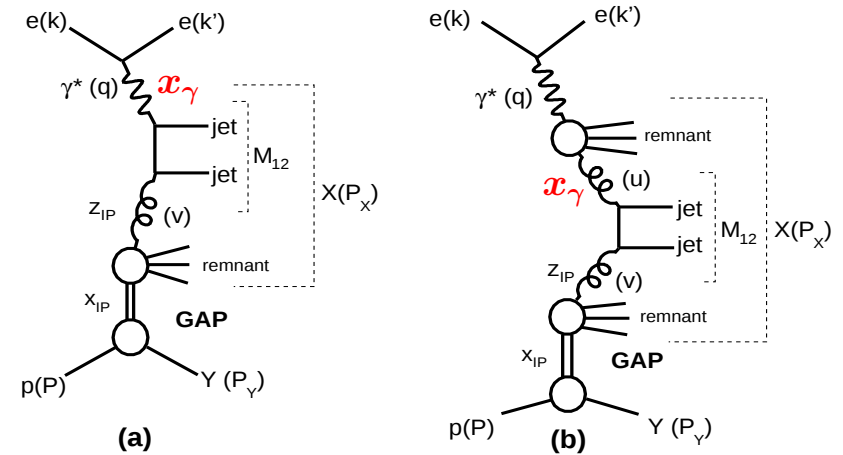


QCD Factorisation Tests in Diffraction at HERA

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



⇒ Test it in photoproduction:

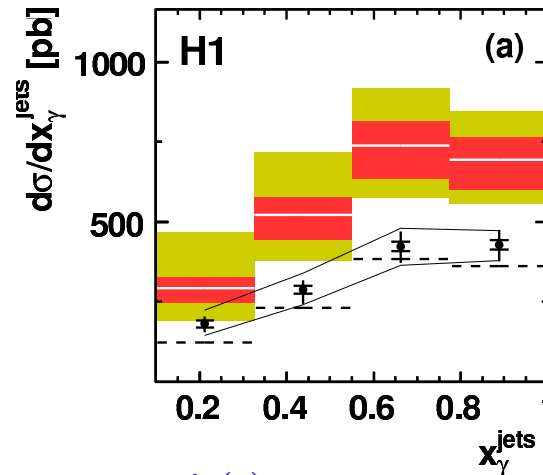
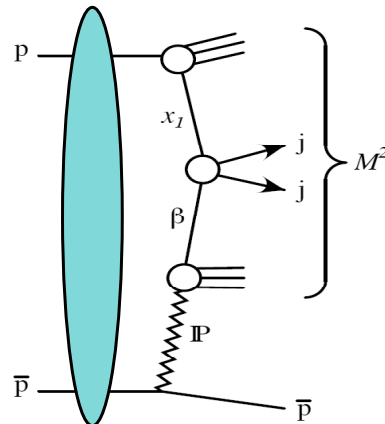
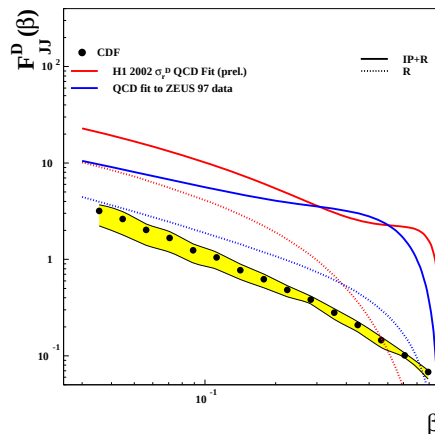


direct, $x_\gamma = 1$ (DIS-like) resolved, $x_\gamma < 1$ (hadron-like)

2010 publications

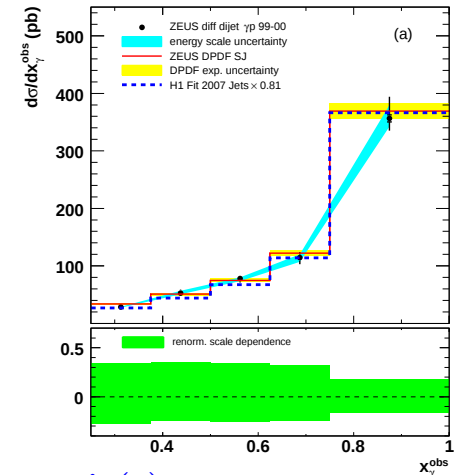
ZEUS

Tevatron vs HERA



$E_T^{j(2)} > 5(4) \text{ GeV}$

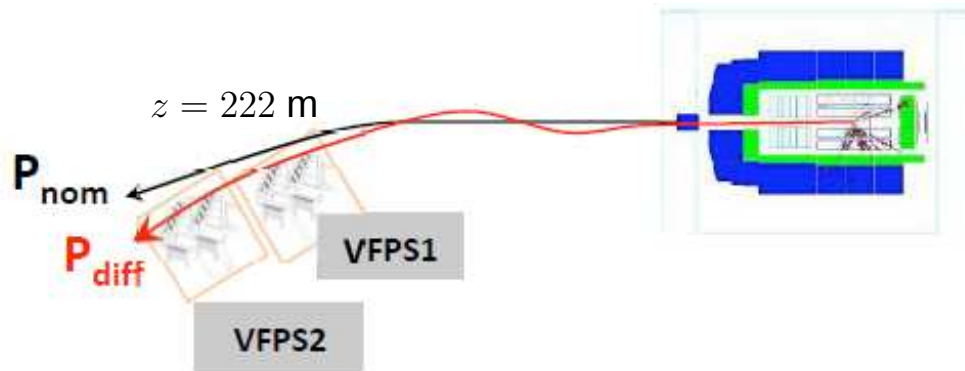
$S \approx 0.6$



$E_T^{j(2)} > 7.5(6.5) \text{ GeV}$

$S \approx 1.0$

VFPS Dijets: Data Sample



Statistics: **4800** dijet events after all cuts

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

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

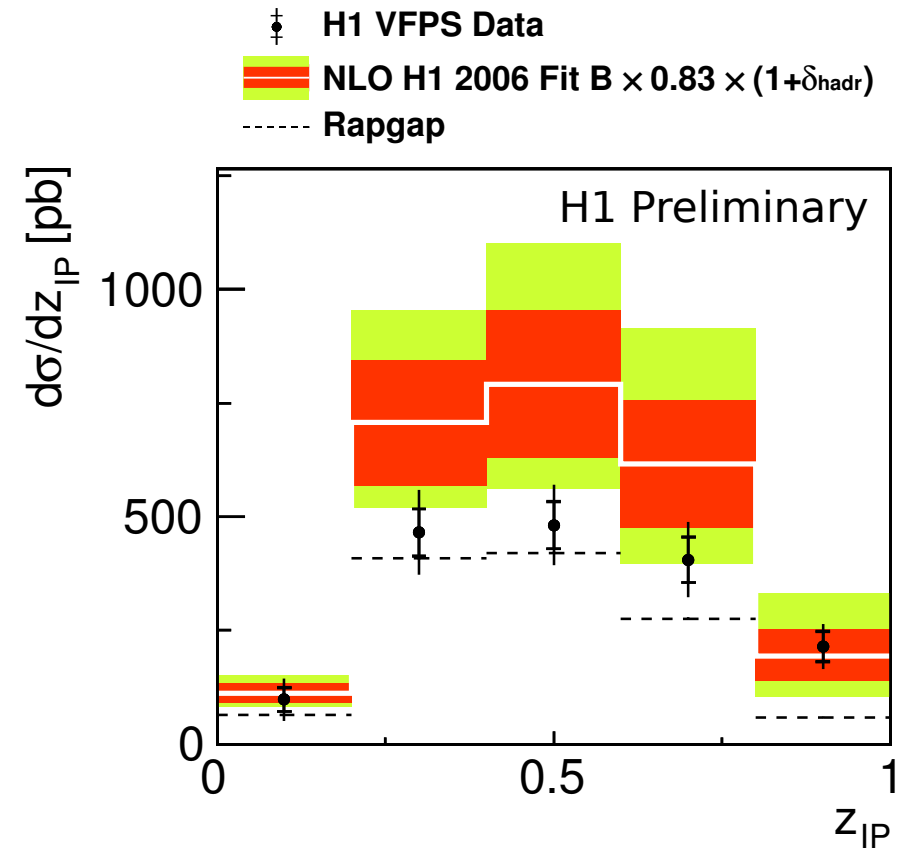
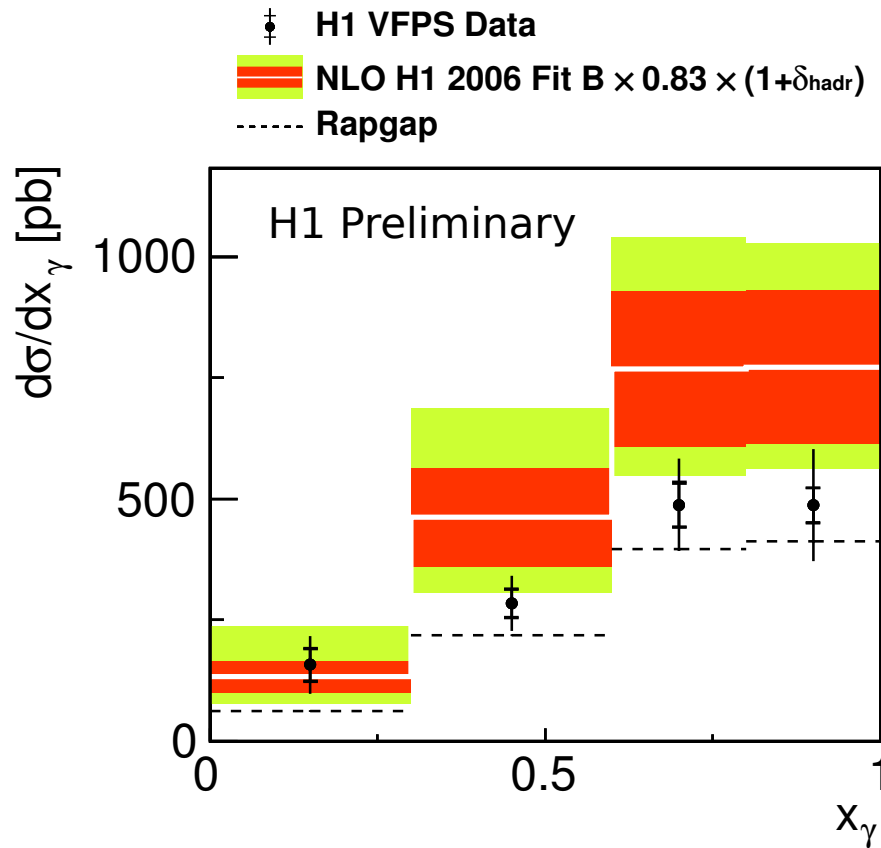
- Scales: $\mu_r = \mu_f = E_T^{\text{jet1}}$
- DPDF H1 2006 Fit B and GRV-HO γ -PDF used

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

Phase-space definition

$$\begin{aligned}
 &Q^2 < 2 \text{ GeV}^2 \\
 &0.2 < y < 0.8 \\
 &k_T \text{ jet algorithm:} \\
 &E_T^{\text{jet1(2)}} > 5.5(4) \text{ GeV} \\
 &-1 < \eta^{\text{jet1,2}} < 2.5 \\
 &\text{Diffractive:} \\
 &0.010 < x_{IP} < 0.024 \\
 &|t| < 0.6 \text{ GeV}^2 \\
 &M_Y = M_p
 \end{aligned}$$

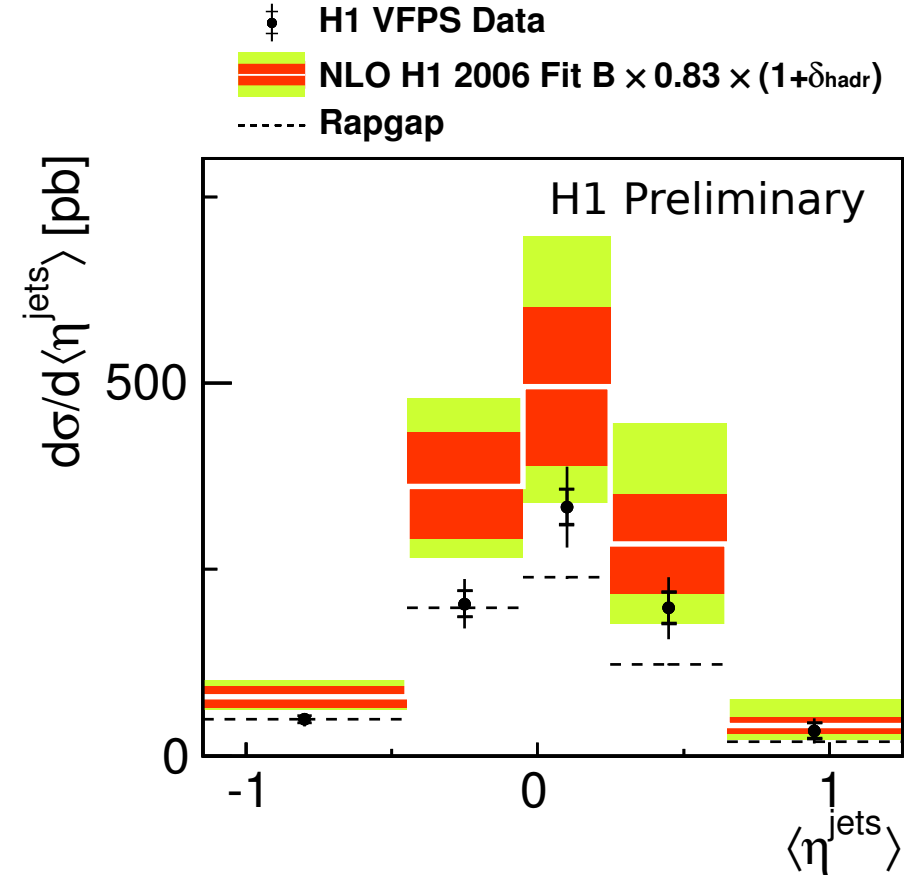
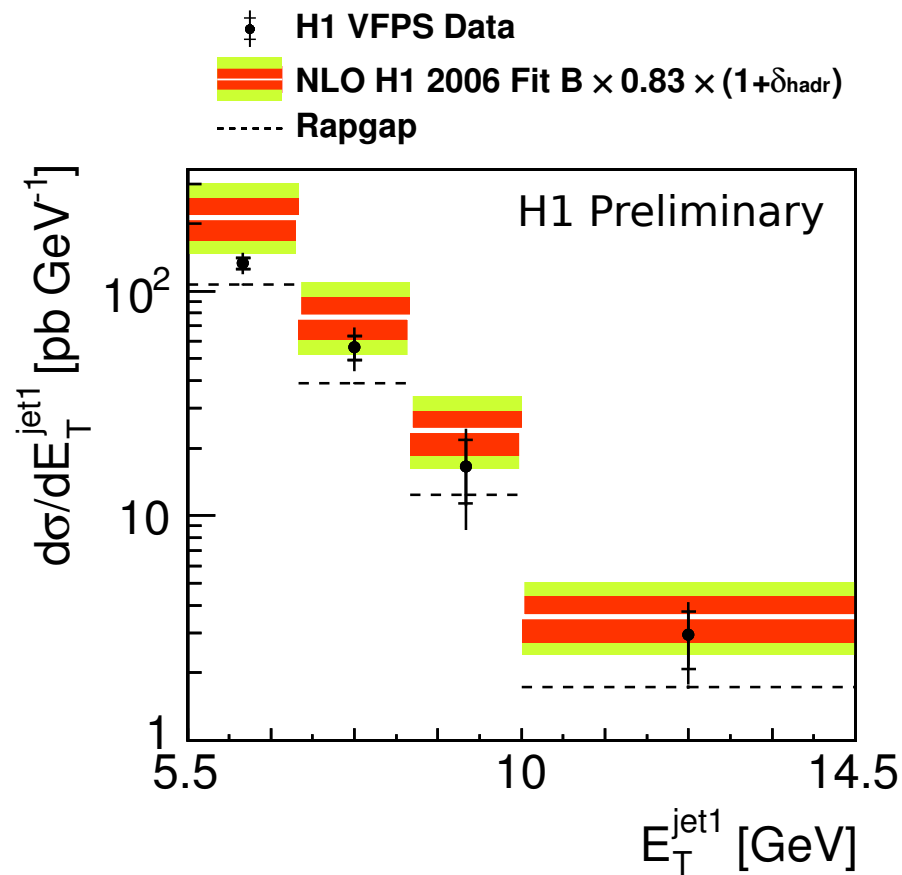
VFPS Dijets: Differential cross section in x_γ and z_{IP}



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

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

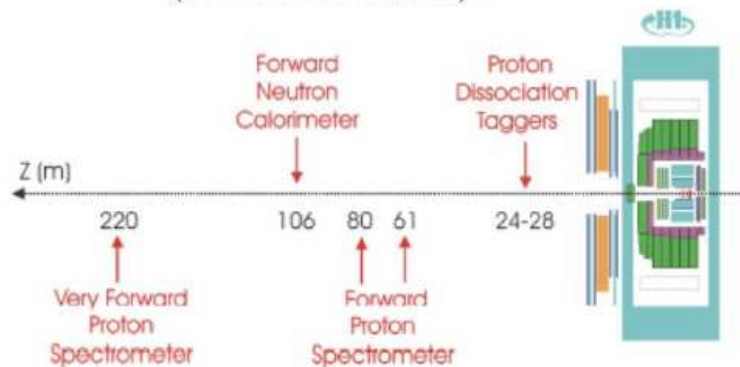
- Precision measurement representing a final H1 word on inclusive LRG cross sections in DIS is published based on full HERA I+II data
- These data provide new constraints to QCD models and support proton-vertex factorisation hypothesis
- Dijet diffractive photoproduction cross sections with proton tagged in VFPS are measured, and found consistent with previous (LRG) measurement.
- Gap survival probability = $0.67 \pm 0.10(\text{exp}) \pm 0.24(\text{th})$ with no evidence for the difference between resolved and direct processes
- Some features of these new measurements reveal a complicated interplay of soft and hard phenomena which still represent a challenge for theoretical models of ep diffraction.

Extra slides

Selection of Diffractive Events

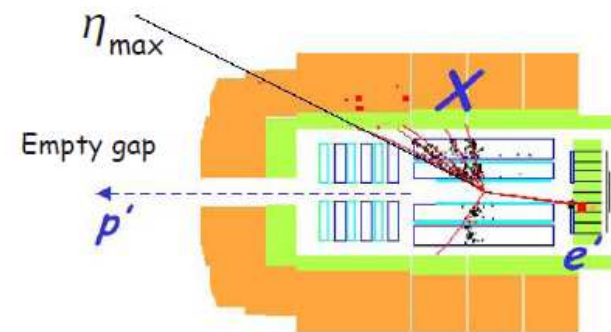
Measure the leading proton

→ Forward spectrometers
(H1 FPS/VFPS)



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

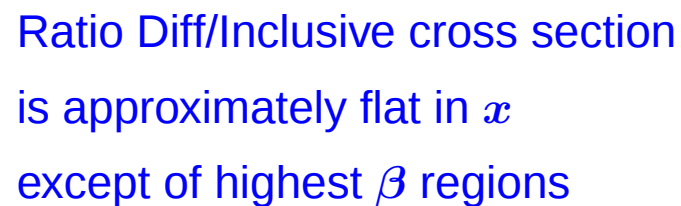
Measure a Large Rapidity Gap



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

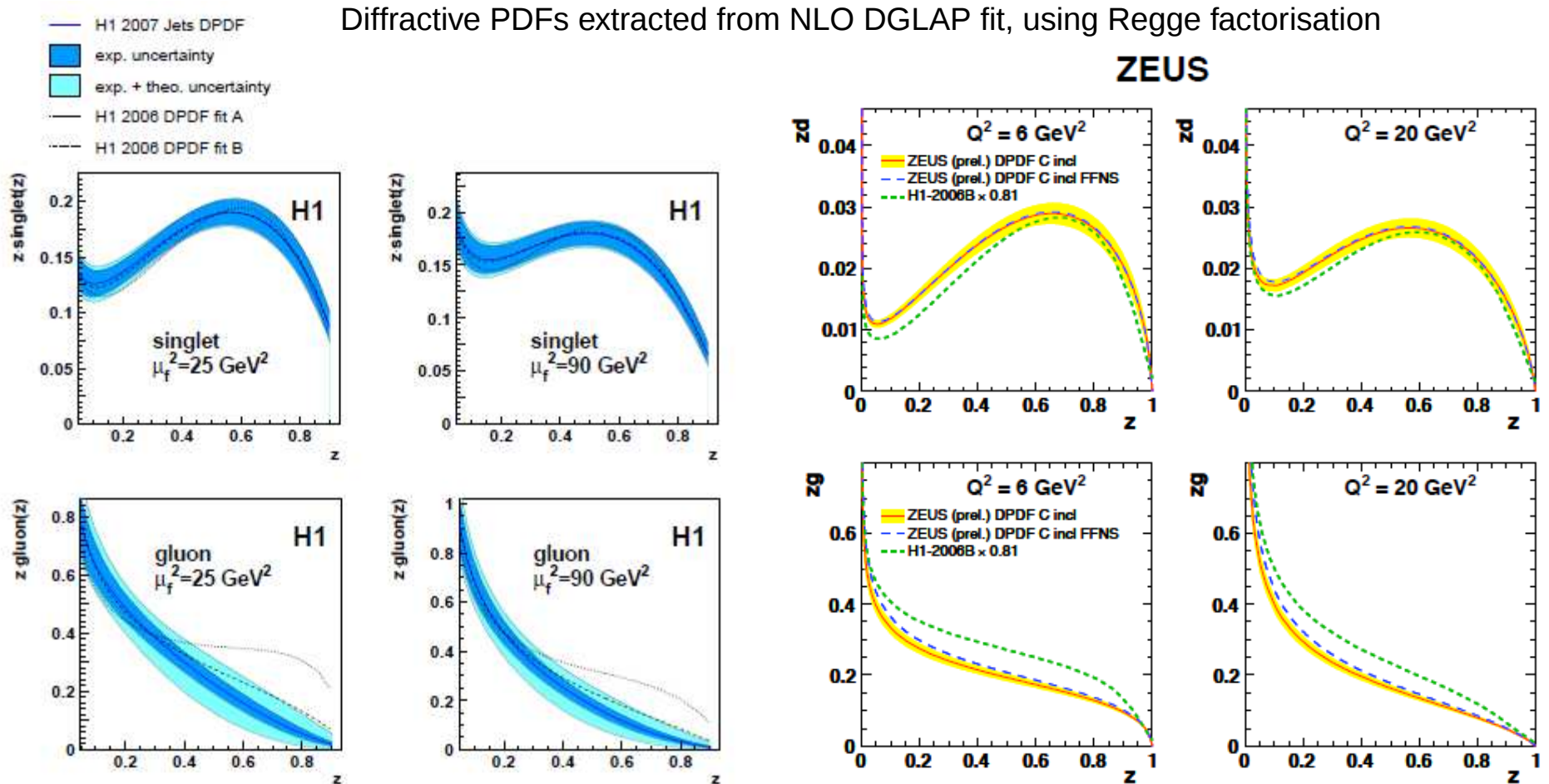
→ Needs to be controlled

- ↘ Different systematics
- ↘ Different kinematic coverage



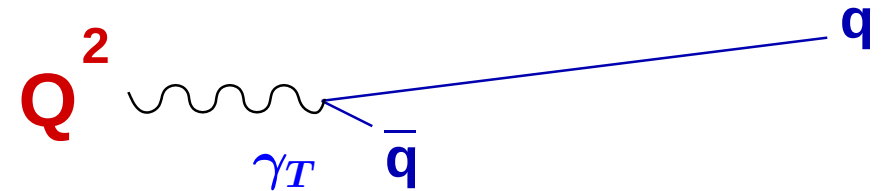
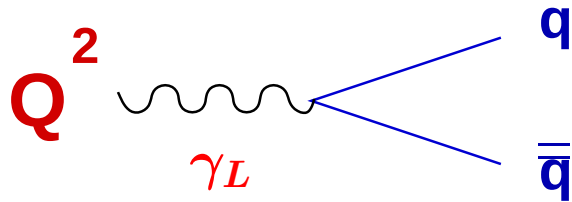
Ratio of quarks to gluons
is similar in diffractive
and inclusive DIS

Diffractive PDFs as determined by H1 and ZEUS



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

Interplay of soft and hard contributions



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

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

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	$\sim \frac{m_q^2}{Q^2}$	$\sim \frac{1}{m_q^2}$	$\sim \frac{1}{Q^2}$	$\sim \frac{1}{m_q^2 Q^2}$