Hard diffraction at HERA

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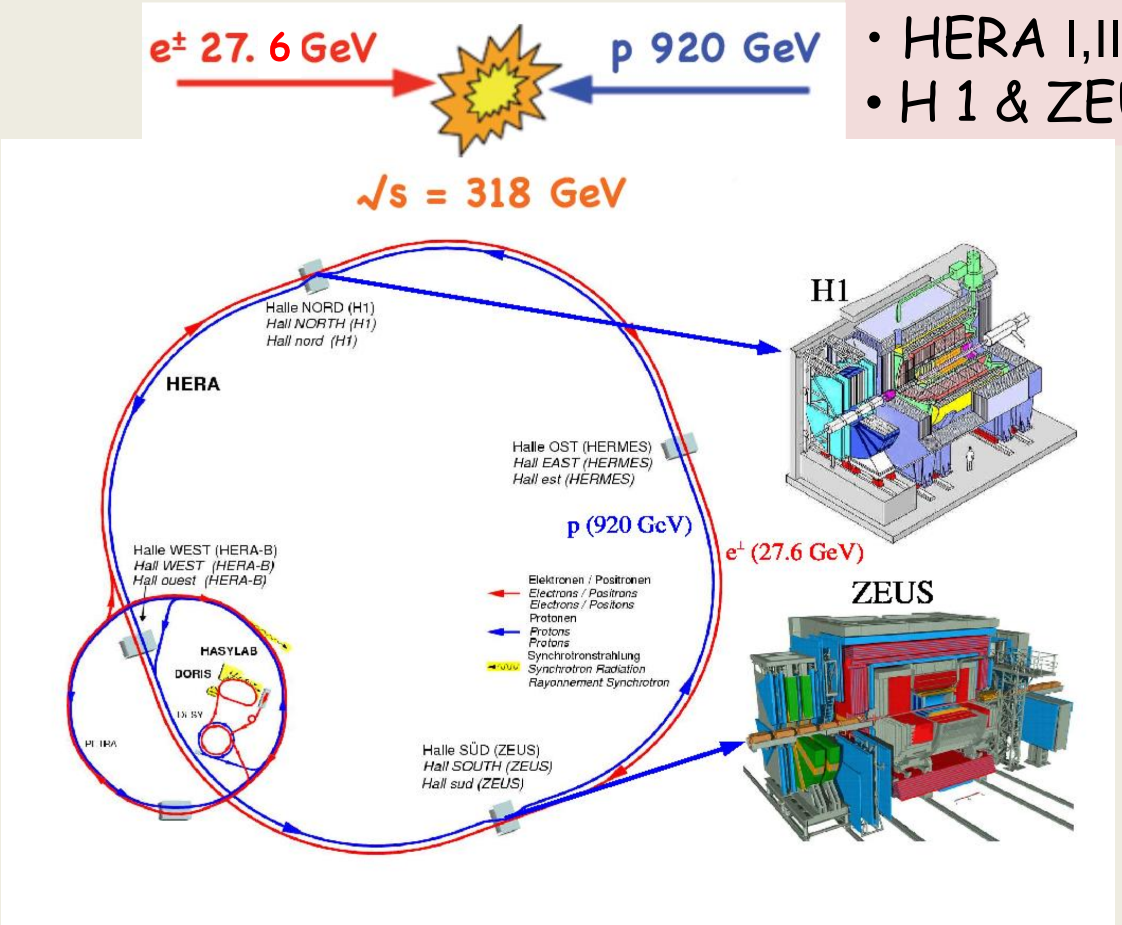
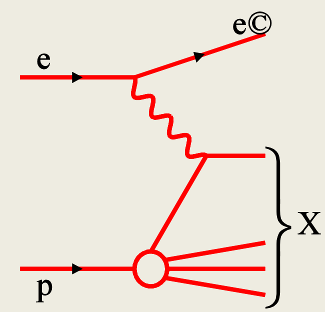
on behalf of H1 and ZEUS Collaborations

HERA collider experiments

- data taken in 1992-2007
- HERA I,II: ~ 500 pb^{-1} per experiment
- H 1 & ZEUS - 4π detectors





DIS: Probe structure of proton → F_2

One of first HERA surprises:
~10% of DIS events have no activity in proton region → diffractive interactions

Historical reminder

- **20 years** after the observation of diffractive DIS events at HERA!
- First publications describing **hard diffraction in 1995**

1995

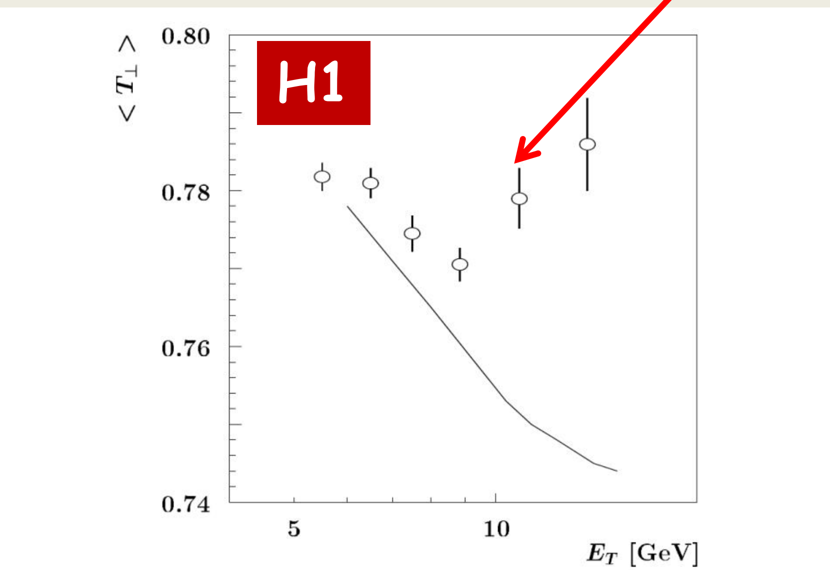
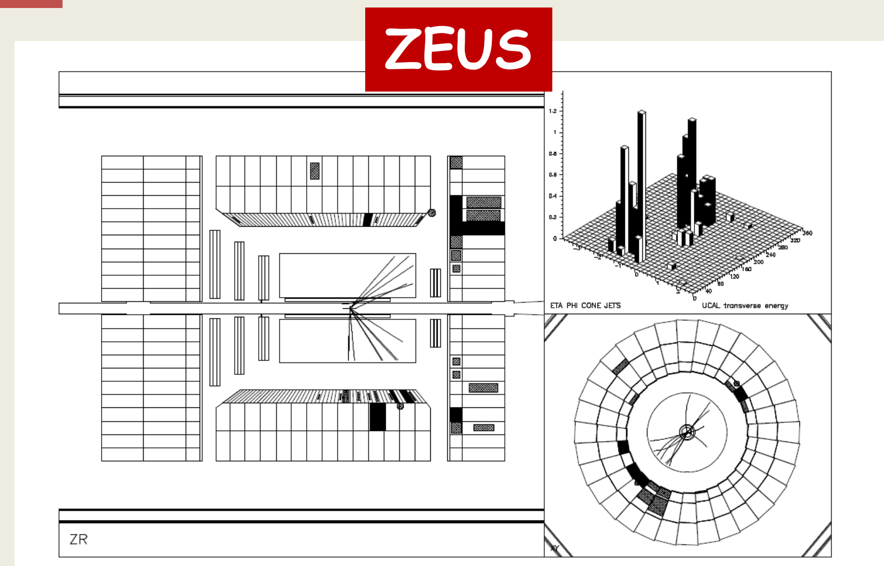


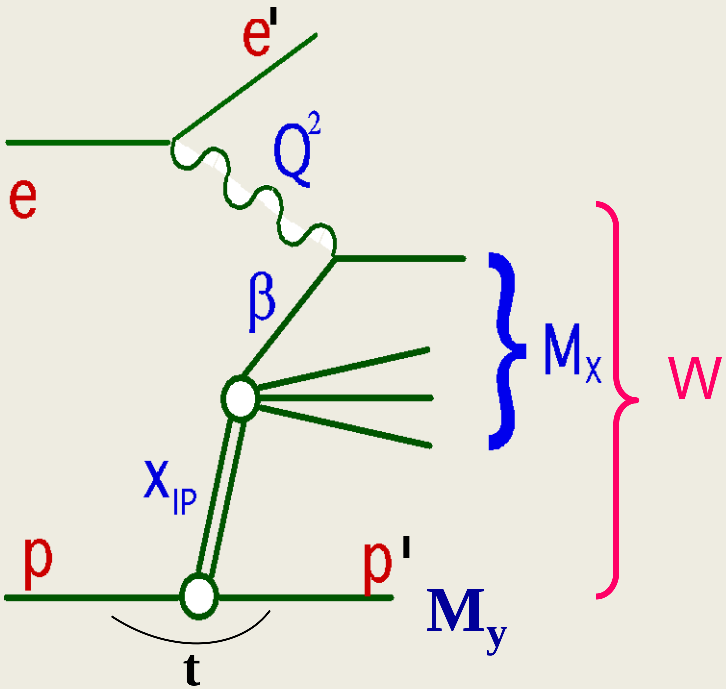
Figure 3: Average observed transverse thrust as function of event E_T. Data (points) and expectation for azimuthally isotropic events (line) with the same average multiplicity as the data points for a given E_T.

Observation of Hard Processes in Rapidity Gap Events in gamma-p Interactions at HERA, Nucl. Phys. B435 (1995) 3



Observation of Hard Scattering in Photoproduction Events with a Large Rapidity Gap at HERA, PL B 346 (1995) 399

Diffractive kinematics



Q²~0 GeV²→ photoproduction
Q²>>0 GeV²→ deep inelastic scattering (DIS)

$$x_{I\!P} = \xi = \frac{Q^2+M_X^2}{Q^2+W^2}$$ → momentum fraction of color singlet exchange

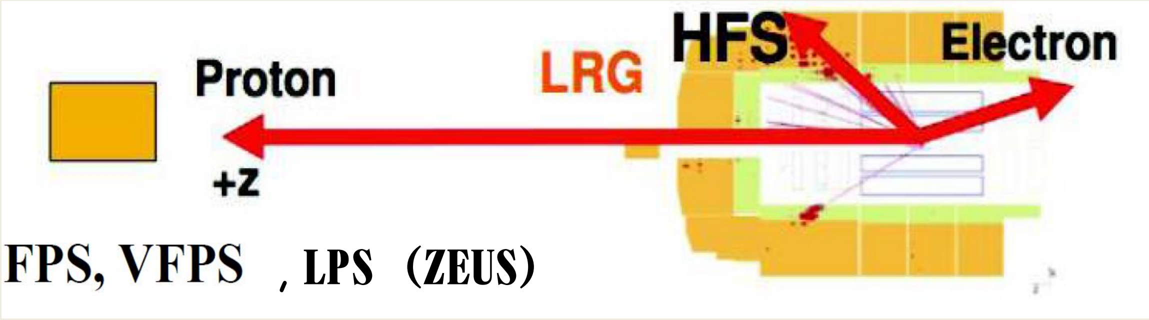
$$\beta = \frac{Q^2}{Q^2+M_X^2} = x_{q/I\!P} = \frac{x}{x_{I\!P}}$$ → fraction of exchange momentum, coupling to γ

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

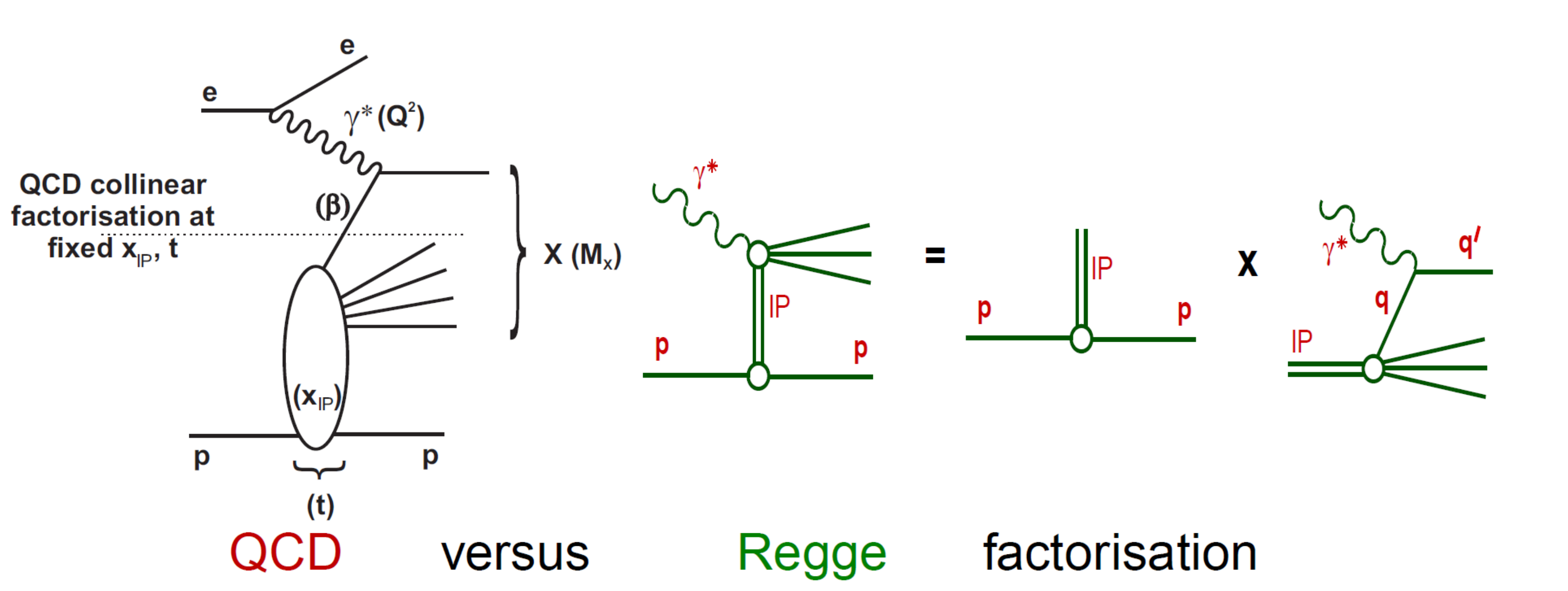
$M_y = m_p$ proton stays intact, needs detector setup to detect protons
$M_y > m_p$ proton dissociates, contribution should be understood

Experimental methods:

- selecting LRG events
- measuring p in Roman pots (60-220m from IP)



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

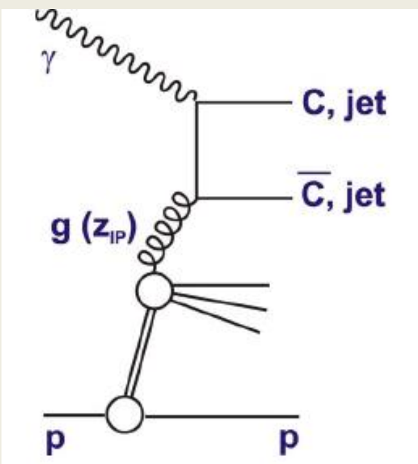
Get PDF from inclusive diffraction ➡ predict cross sections for exclusive diffraction

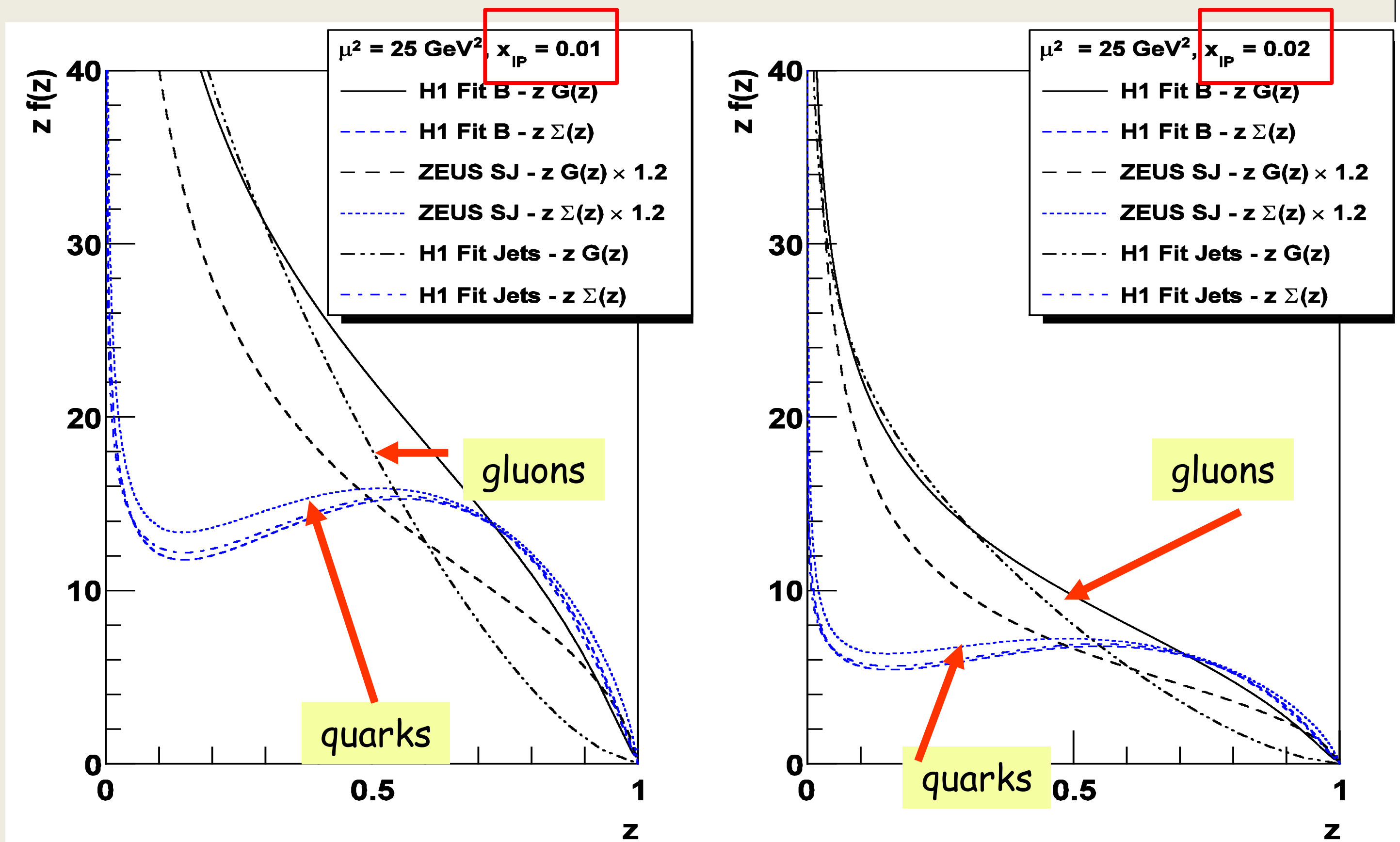
DPDFs in DIS

DPDFs obtained by H1 and ZEUS from inclusive, dijet (and D* measurements….)
DPDFs used in HERA analyses – **H1 fit B, H1 fit Jets, ZEUS fit SJ**

Main differences are in gluonic part.

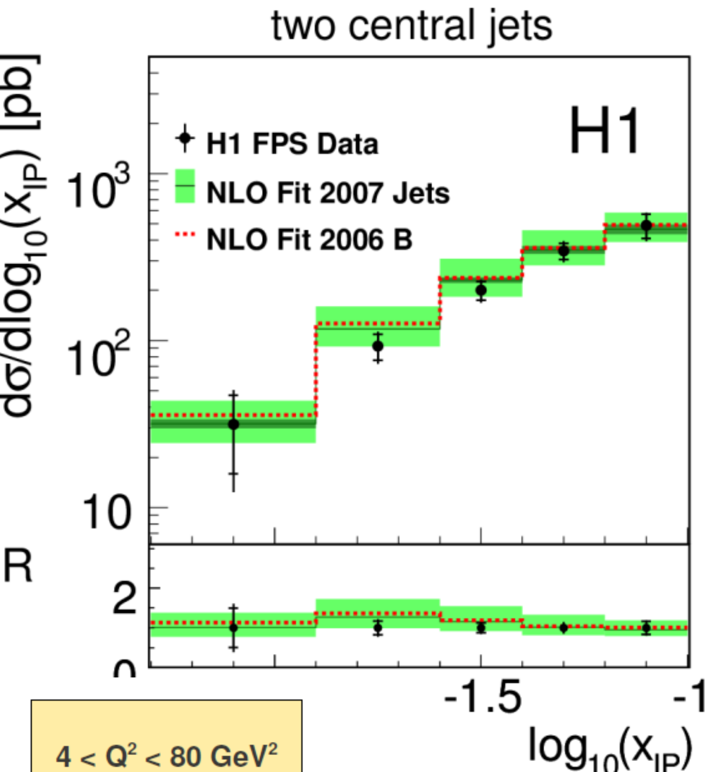
$$z_{IP} = \frac{Q^2+M_{12}^2}{Q^2+M_X^2}$$

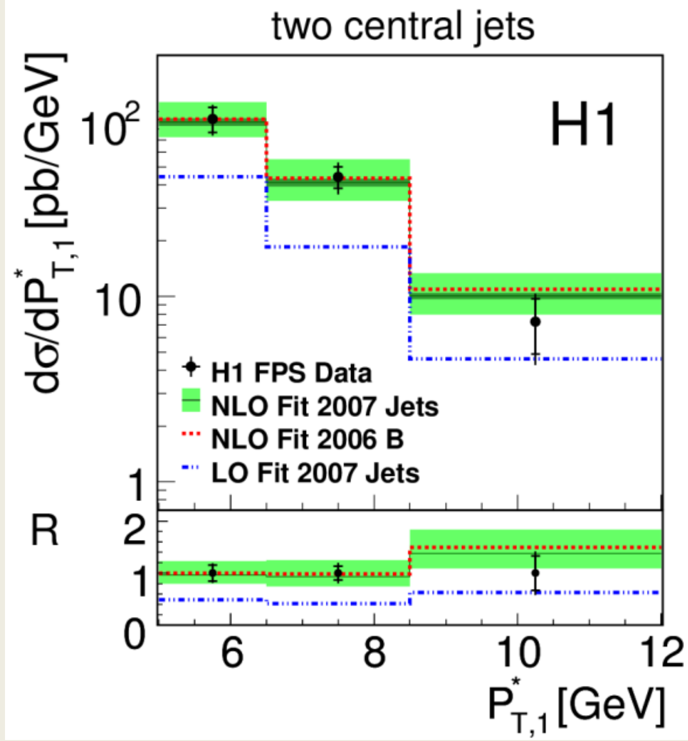




Dijet DIS production in FPS spectrometer

Eur. Phys. J. C72 (2012) 1970





$4 < Q^2 < 80$ GeV^2

$0.1 < y < 0.7$

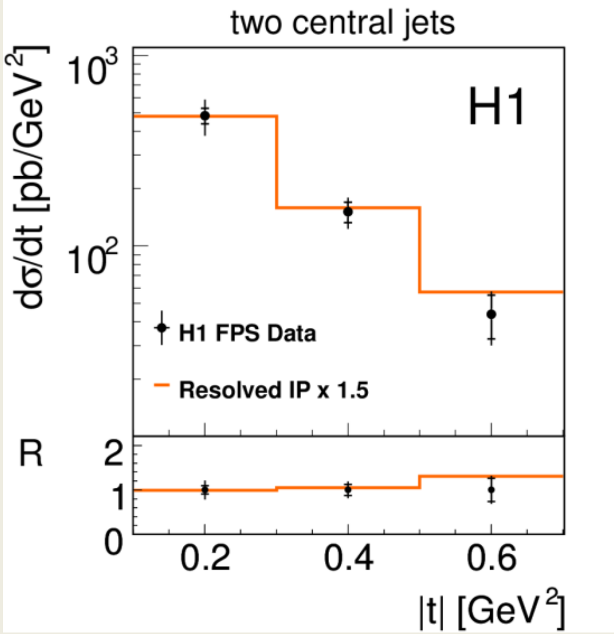
$p_{T1}^* > 5.5$ GeV

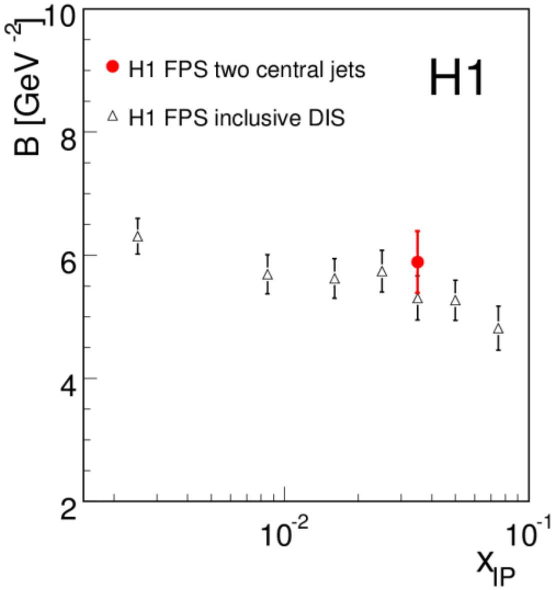
$p_{T2}^* > 4$ GeV

Data well described by NLO predictions ->
QCD factorization confirmed

Dijet DIS production in FPS spectrometer

Regge factorization





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

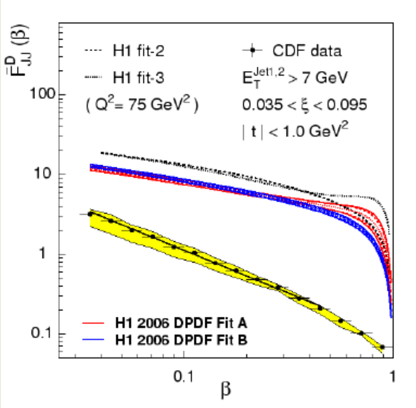
$$f_{IP/p}(x_{IP}, t) = \frac{e^{Bt}}{x_{IP}^{2\alpha(t)-1}}$$

B = 5.89 ± 0.50 GeV^{-2}

B-slope consistent with inclusive measurements

ep and hadron-hadron collisions

- In diffractive DIS **factorization experimentally confirmed** by H1 and ZEUS (dijets in DIS, D* in DIS…).

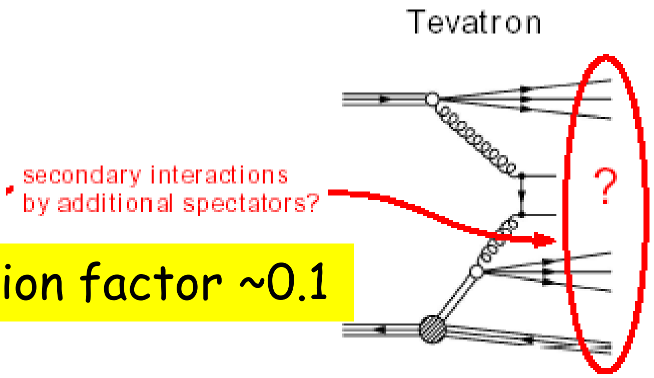


- Exporting DPDFs from HERA to Tevatron does not work

$$S^2 = \frac{\sigma\,(\text{data})}{\sigma\,(\text{theory})}$$

→ suppression factor

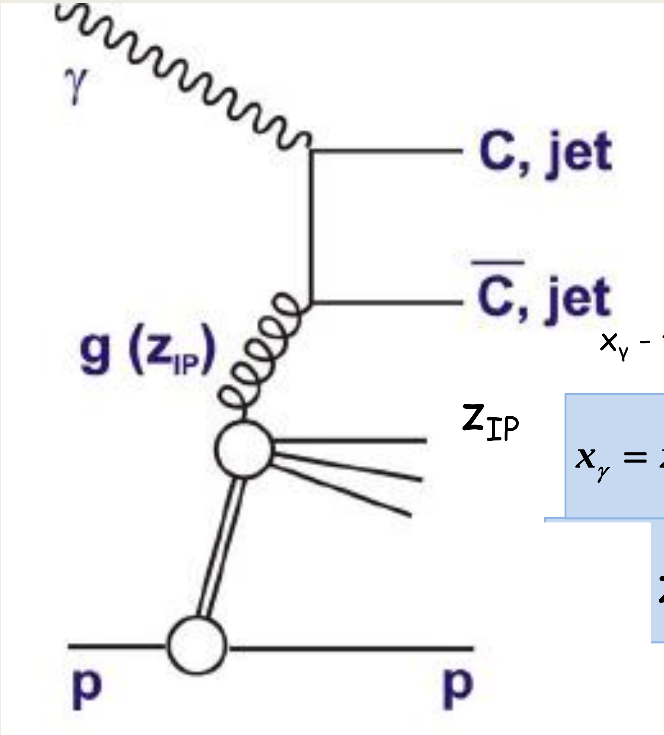
Rescattering leads to factorization breaking and rapidity gap fill up



Suppression factor ~0.1

suppression of cross section ~ 1 – (rapidity gap survival probability)

Photoproduction, γ*p, $Q^2 \to 0$



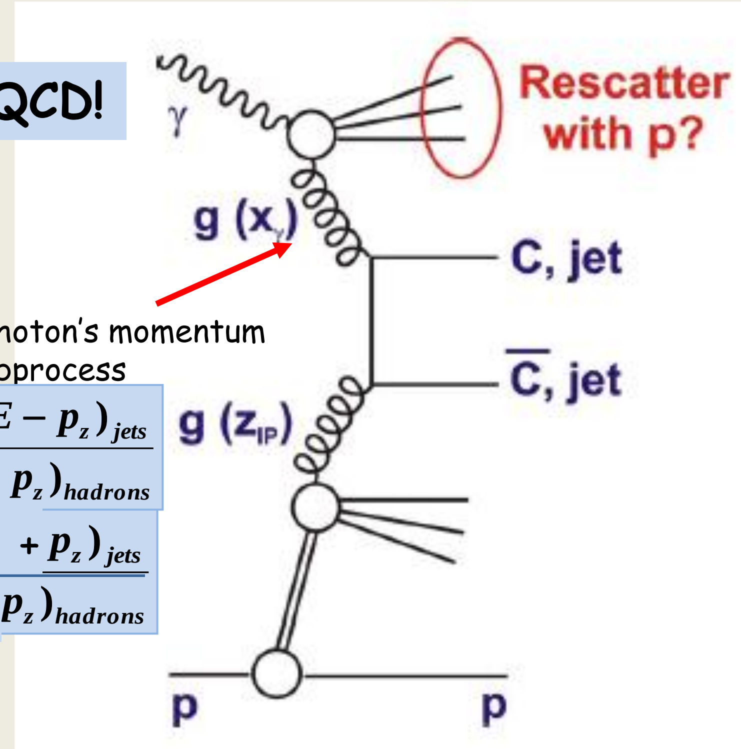
In LO QCD!

x_γ - fraction of photon's momentum in hard subprocess

z_{IP}

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

$$z_{IP} = \frac{\sum (E + p_z)_{jets}}{(E + p_z)_{hadrons}}$$



direct photoproduction:

-> $x_\gamma = 1$

resolved photoproduction:

dominant at $Q^2 \simeq 0$ -> $x_\gamma < 1$

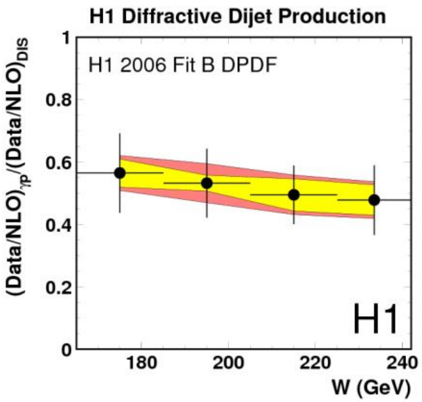
Theor.prediction of Kaidalov,Khoze,Martin,Ryskin (European Journal of Physics 66,373 (2010))

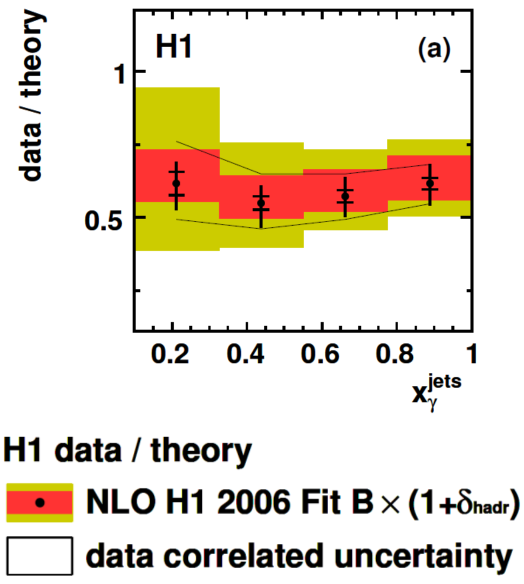
no suppression

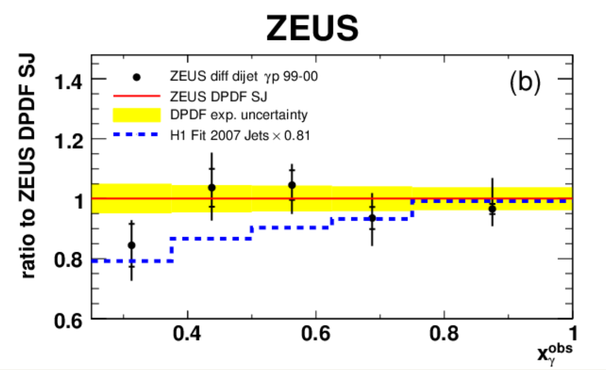
suppression: quarks **0.71(0.75)** $E_T^{jet1} > 5$ (7.5) GeV
gluons **0.53(0.58)** $E_T^{jet1} > 5$ (7.5) GeV

Dijets in photoproduction-history

Double ratio data/NLO
for PH and DIS,
-> small uncertainties!







EPJC C51 (2007),549, – suppression **0.5 ± 0.1**

EPJ C68 (2010),381 – suppression – **0.58 ±0.01±0.12(exp) ±0.14±0.09(th)**

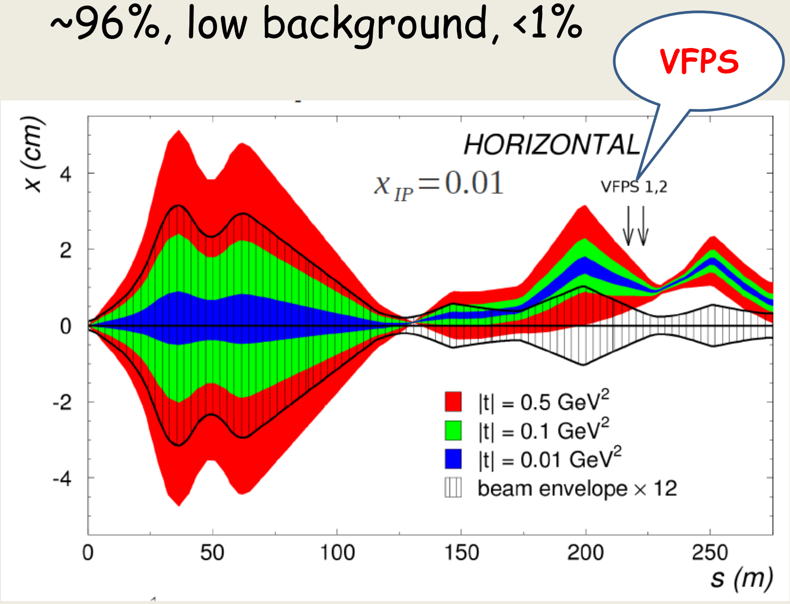
Nucl.Phys. B381 (2010) – suppression **~ 1**

Different phase space in H1 and ZEUS analyses,
H1 tagged photoproduction,
ZEUS untagged ph, ZEUS larger E_T of jets, E_T dependence of suppression?
No dependence on $\mathbf{x}_\gamma$ (both H1 and ZEUS)!

New analysis –dijets in PH with a leading proton

- 2006/07 $e^{+}p$ H1 data, integrated lumi ~ 30pb^{-1}
- Proton measured in Very Forward Proton Spectrometer -> $M_Y = M_p$
- Untagged photoproduction (events without visible electron)

- 2 stations - 218 and 222m from the interaction point
- High track reconstruction efficiency ~96%, low background, <1%

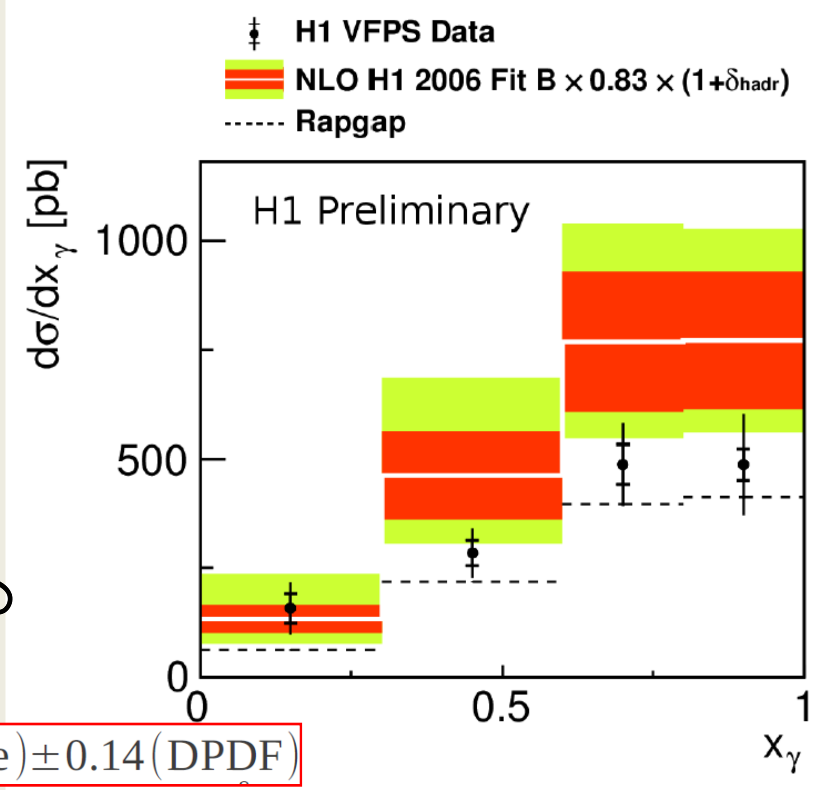


Phase-space definition
$Q^2 < 2\,\mathrm{GeV}^2$
$0.2 < y < 0.8$
k_T jet algorithm:
$E_T^{jet1(2)} > 5.5(4)\,\mathrm{GeV}$
$-1 < \eta^{jet1,2} < 2.5$
Diffractive:
$0.010 < x_{IP} < 0.024$
$\lvert t \rvert < 0.6\,\mathrm{GeV}^2$
$M_Y = M_p$

~ 4800 events

Differential cross sections - x_γ

- Data unfolded to hadron level using Singular Value Decomposition of the response matrix
- NLO QCD Frixione-Ridolfi program (DPDF H1 Fit B x 0.83 (proton dissociation factor))
- Hadronization corrections calculated using MC RAPGAP



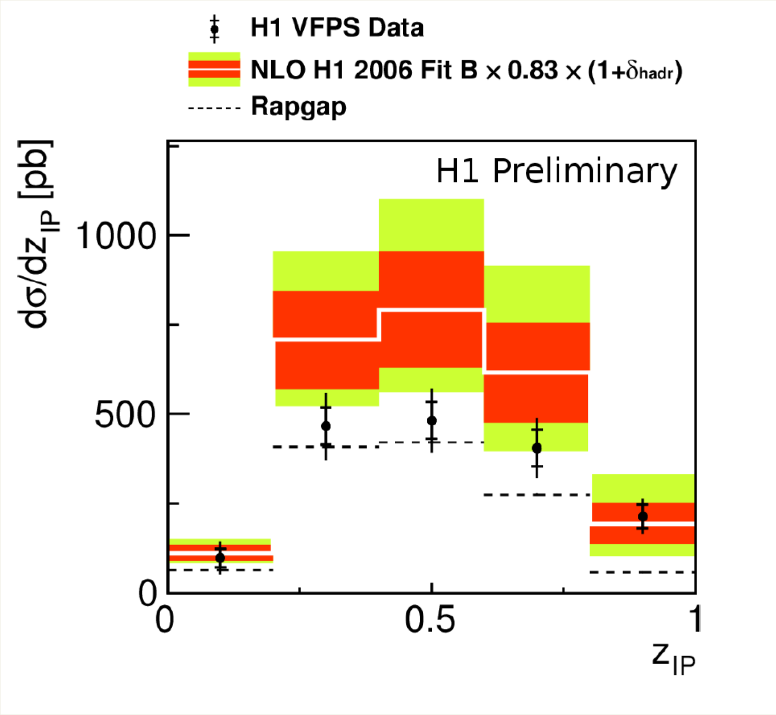
Data suppressed in comparison with NLO QCD by factor:

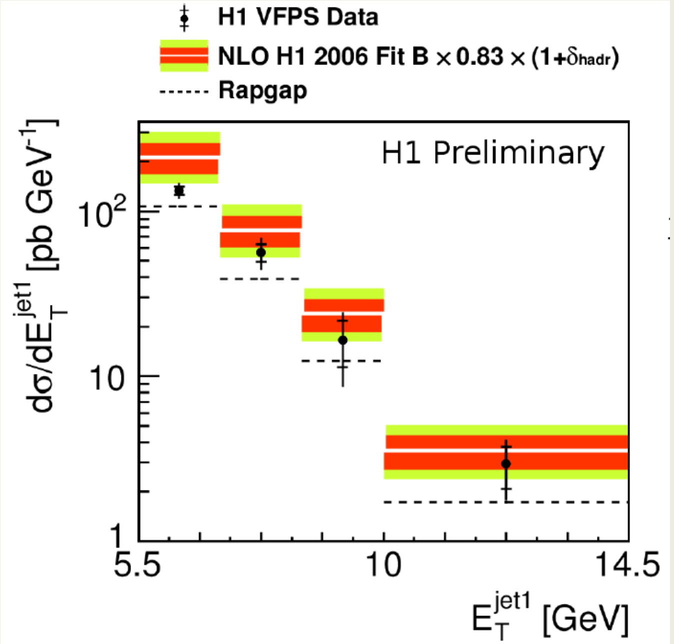
$$\sigma_{DATA}/\sigma_{NLO} = 0.67 \pm 0.04(\text{stat.}) \pm 0.09(\text{syst.}) \pm 0.20(\text{scale}) \pm 0.14(\text{DPDF})$$

No obvious dependence of suppression on x_γ

Large theoretical uncertainties connected with the DPDF uncertainty and scale variation.

Differential cross sections $-z_{IP}, E_T^{jet1}$





MC RAPGAP describes the shape quite well but it is too low

The NLO QCD prediction for last z_{IP} bin should be taken with caution – DPDF was not evaluated for $z_{IP} > 0.8$, here only extrapolation!

Dependence on E_T cannot be excluded, within large theor. uncertainties

Conclusions

- Differential cross section of dijet production in DIS and photoproduction for events with leading proton in forward spectrometers (FPS and VFPS) measured.
- DIS dijets – data agree with NLO predictions – previous H1 results and QCD factorisation confirmed
- Photoproduction dijets – data suppressed by factor 0.67 in comparison to NLO calculations, previous H1 results confirmed but large uncertainties
  -> possible way out -> measure the double ratio data/NLO for DIS and photoproduction, many uncertainties will cancel