# Diffractive dijet photoproduction with a leading proton at HERA


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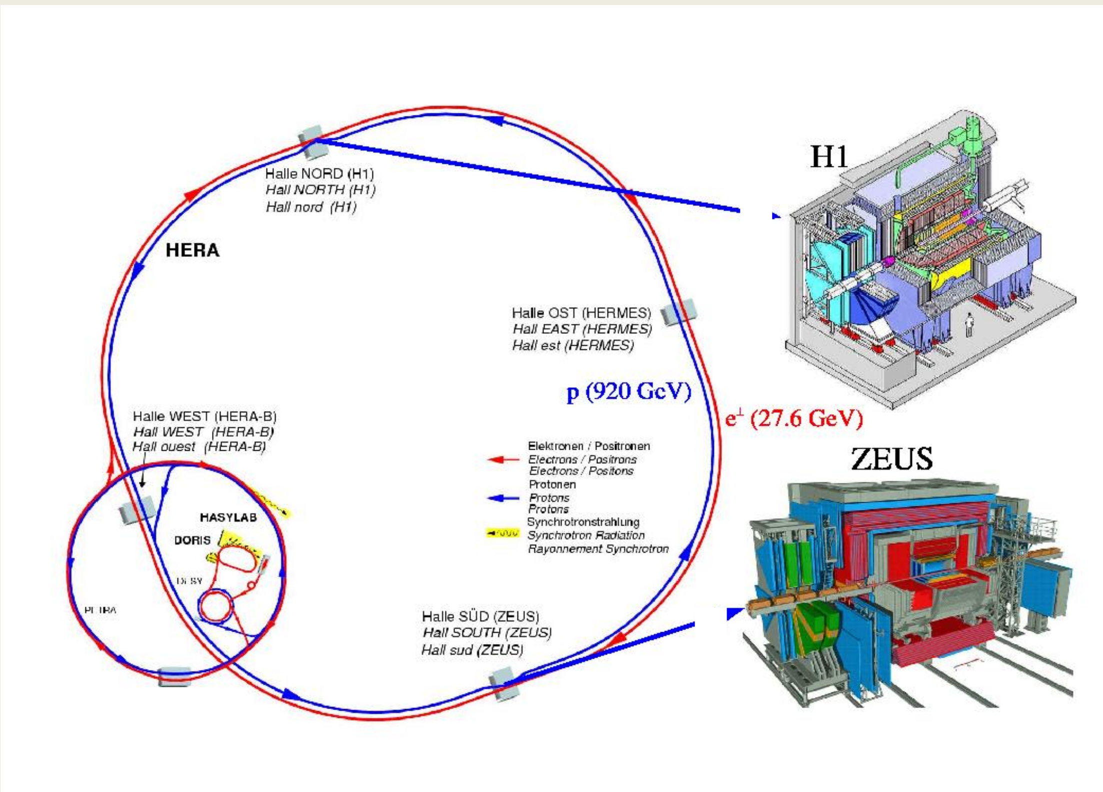
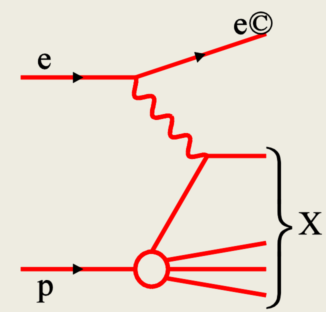
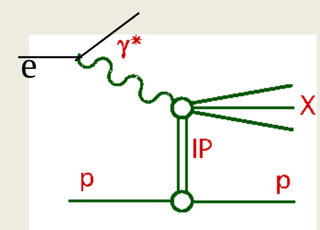
# HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons $\rightarrow \sqrt{s}$=318 GeV
- two experiments on colliding beams: H1 and ZEUS
- HERA I,II: ~ 500 $pb^{-1}$ per experiment
- closed July 2007, still data to analyse……



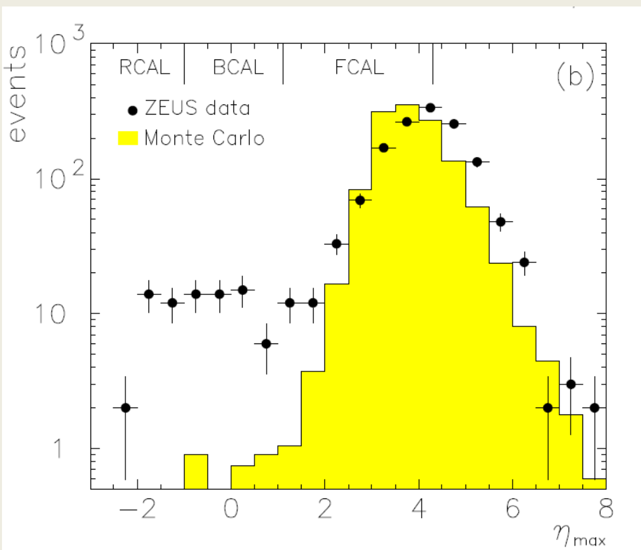

DIS: Probe structure of proton → $F_2$




Diffractive DIS: Probe structure of difraction → $F_2^D$

# Historical reminder

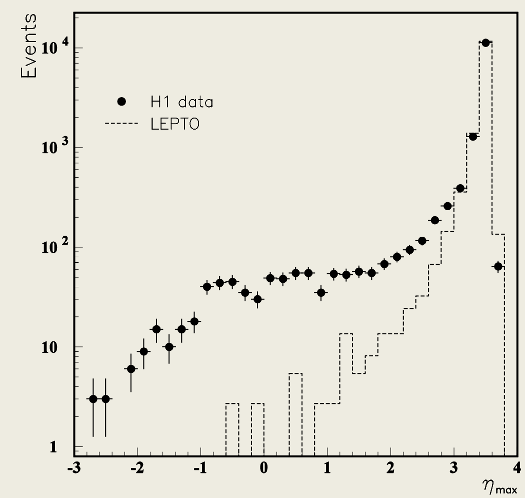
- 20 years after the observation of diffractive DIS events at HERA!
- HERA opened **new era of diffraction studies**




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

1993-1994

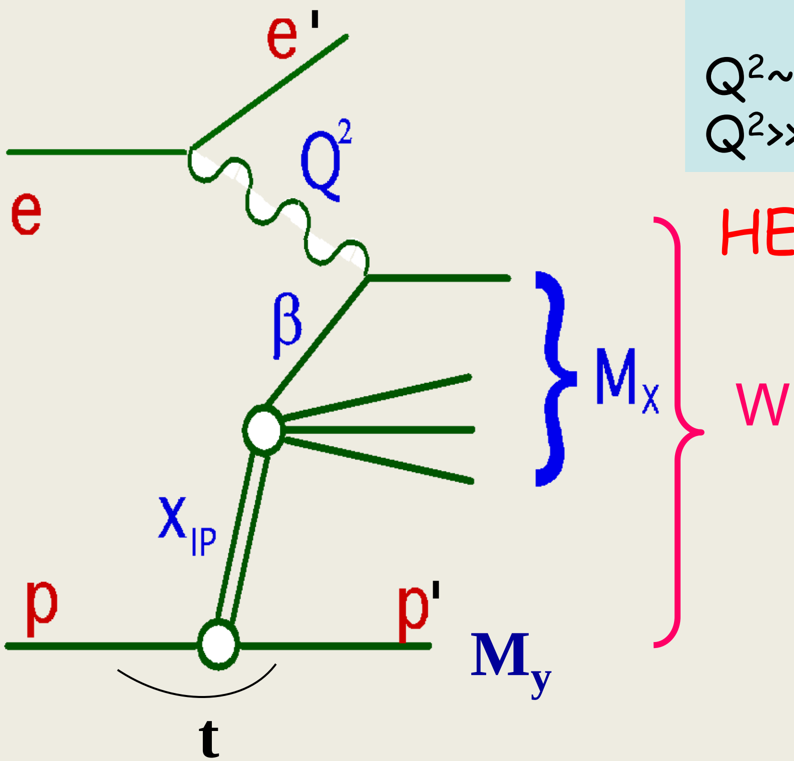
HISTORY




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

# Diffractive kinematics






Two kinematic regions of diffractive events:

$Q^2 \sim 0\ GeV^2 \rightarrow$ photoproduction
$Q^2 \gg 0\ GeV^2 \rightarrow$ deep inelastic scattering (DIS)

HERA: ~10% of events diffractive

$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2} \longrightarrow$$

momentum fraction of color singlet exchange

$$\beta = \frac{x}{x_{IP}} \approx \frac{Q^2}{Q^2 + M_X^2} \longrightarrow$$

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

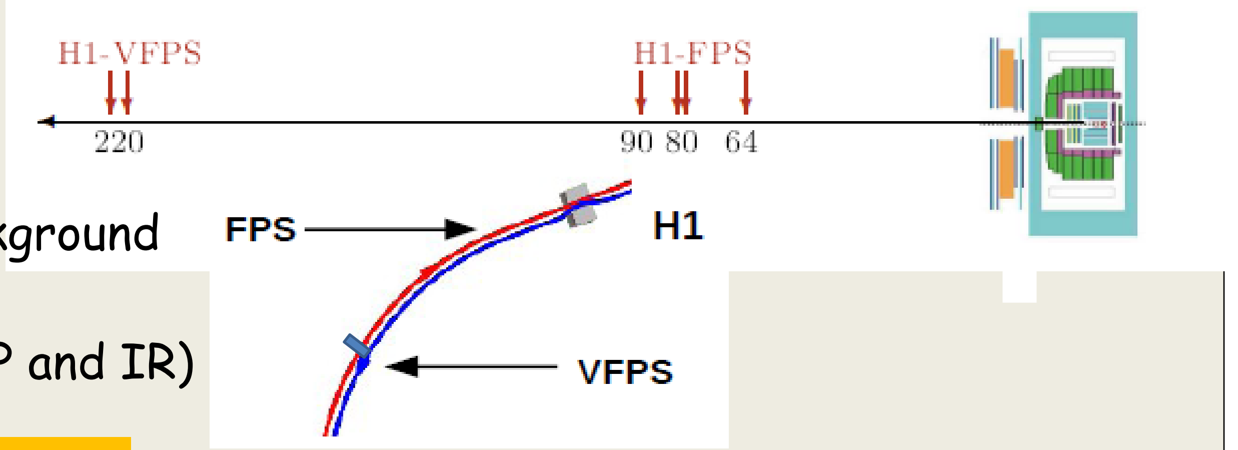
# Methods of diffraction selection

**Proton spectrometers**

H1: VFPS (2005-2007)
FPS (1997-2007)

- ☺ free of p-dissociation background
- ☺ $x_{IP}$ and $t$ measurements
- ☺ access to high $x_{IP}$ range (IP and IR)
- ☹ small acceptance

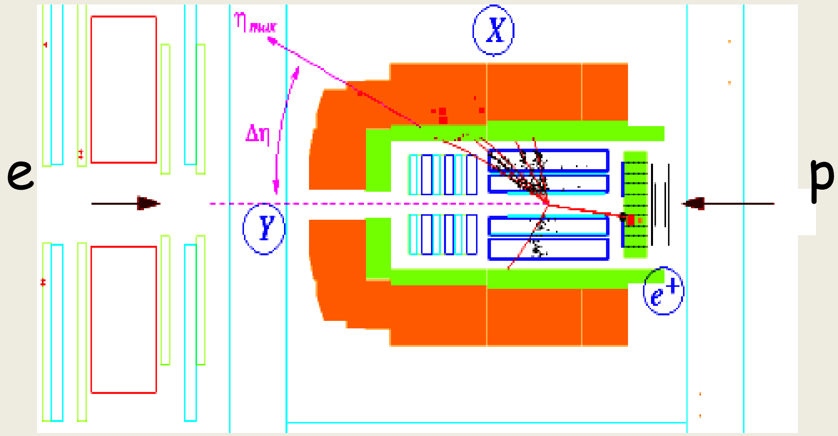
This analysis.




**Large Rapidity Gap, H1, ZEUS:**

require no activity beyond $\eta_{max}$

- ☹ $t$ not measured,integrated over $|t|<1GeV^2$
- ☺ very good acceptance at low $x_{IP}$
- ☹ p-diss background about 20% ☠



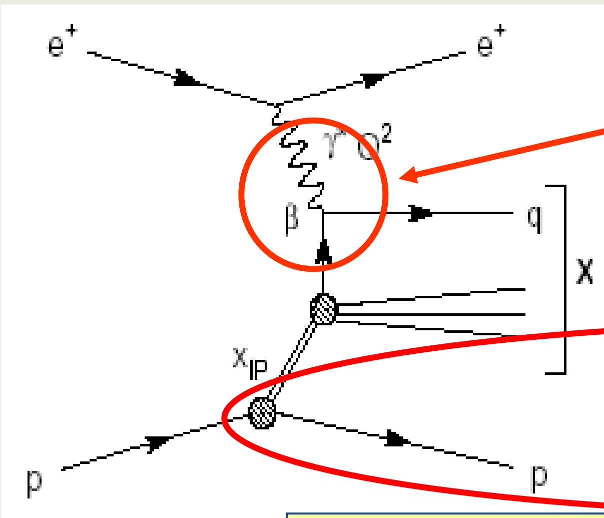

Different phase space and systematics – non-trivial to compare!

# QCD factorization

QCD factorisation holds for inclusive and non-inclusive processes:

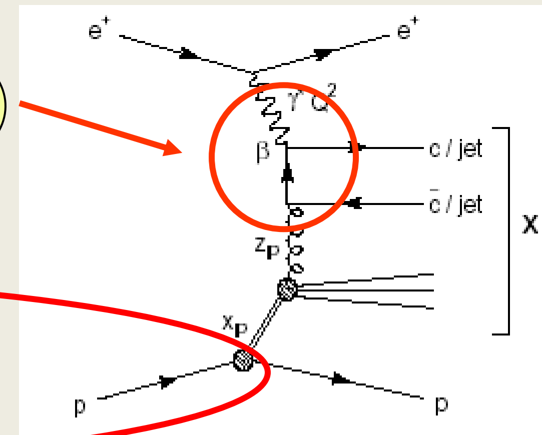
- photon is point-like ($Q^2$ is high enough)
- higher twist corrections are negligible ($M_x$ is high enough)

QCD factorisation theoretically proven for DIS (Collins 1998)




Hard scattering QCD matrix element,perturbatively calculated, process dependent

Universal diffractive parton densities, identical for all diffractive processes




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

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

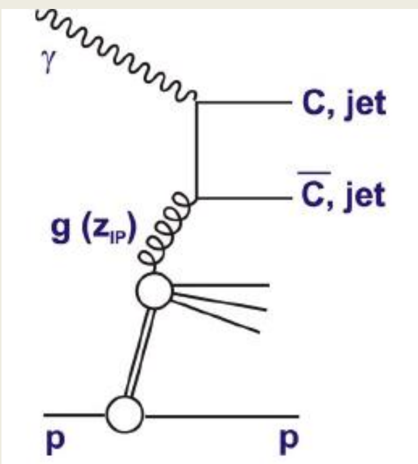
$\sigma^{\gamma^* i} \to$ hard scattering cross section (same as in non-diffractive DIS)

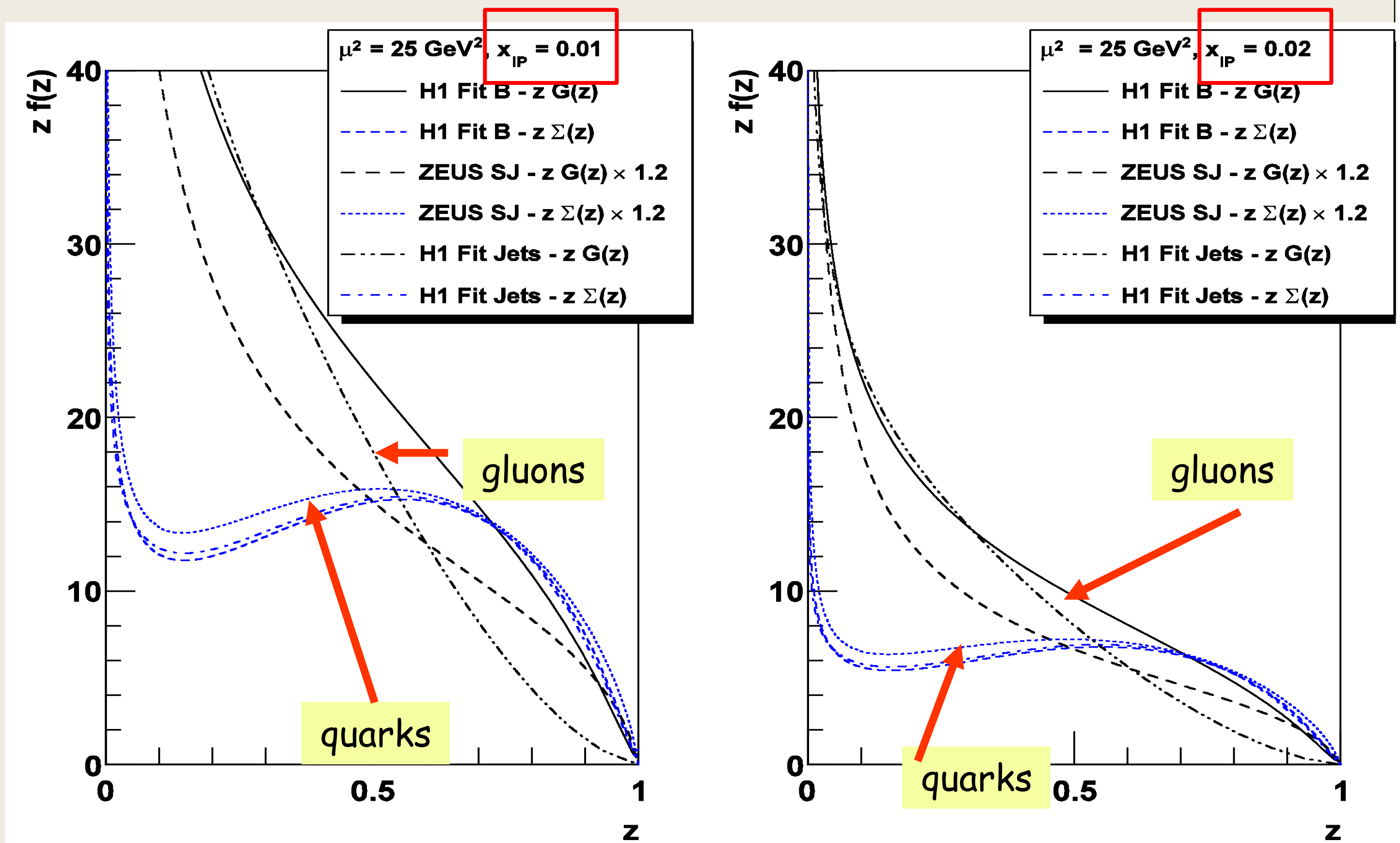
Get PDF from inclusive diffraction ➡ predict cross sections for exclusive diffraction

# 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.

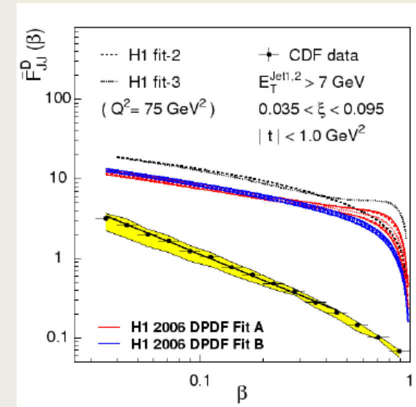
$$z_{IP} = \frac{\sum (E + p_z)_{jets}}{(E + p_z)_{hadrons}}$$



# ep and hadron-hadron collisions

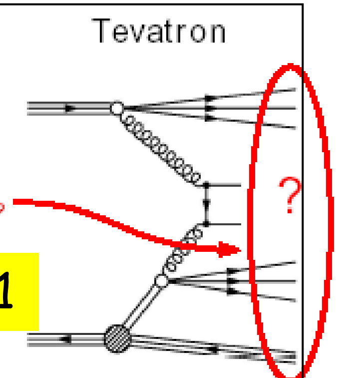
- In diffractive DIS factorization experimentally confirmed by H1 and ZEUS (dijets in DIS, D* in DIS…).
  - Exporting DPDFs from HERA to Tevatron does not work




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

Rescattering leads to factorization breaking and rapidity gap fill up

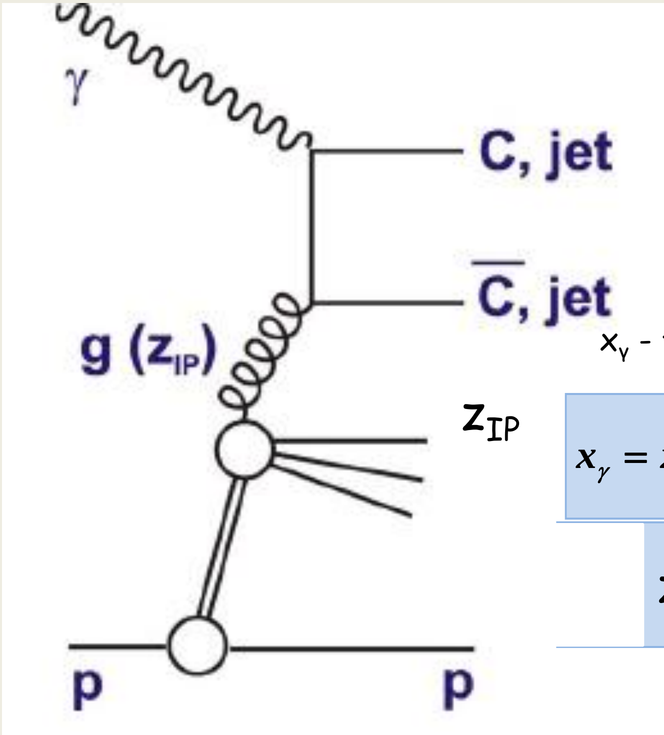
secondary interactions by additional spectators?




Suppression factor ~0.1

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

# Photoproduction, γ*p, $Q^2 \to 0$



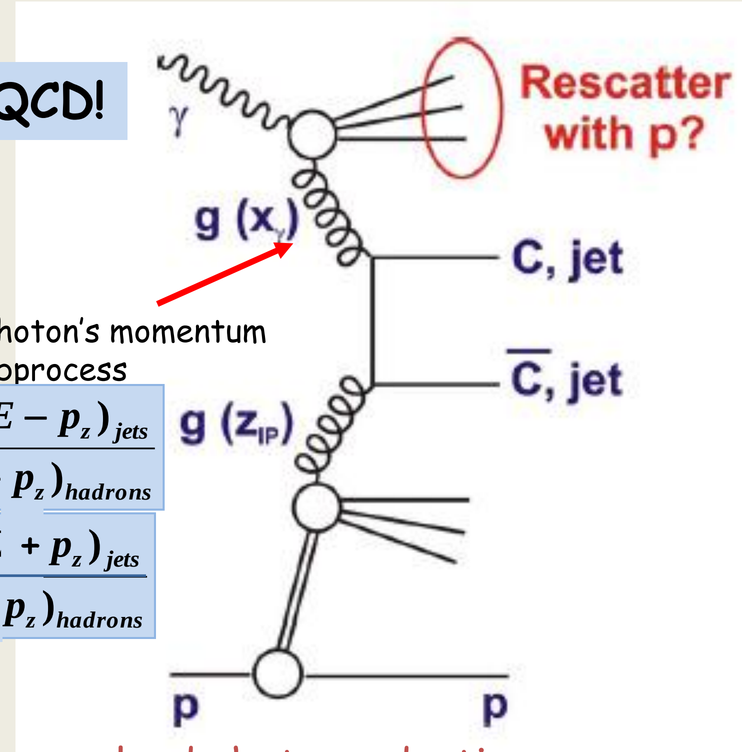

In LO QCD!

$z_{IP}$

$x_\gamma$ - fraction of photon's momentum in hard subprocess

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

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




direct photoproduction:

photon directly involved in hard scattering -> $x_\gamma=1$

resolved photoproduction:

photon fluctuates into hadronic system, which takes part in hadronic scattering,dominant at $Q^2 \simeq 0$ -> $x_\gamma < 1$

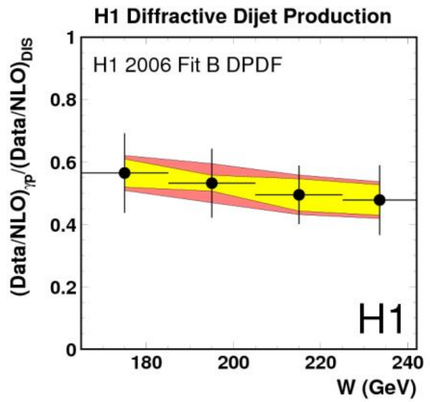
Theor.prediction of Kaidalov,Khoze,Martin,Ryskin (European Journal of Physics 66,373 (2010))

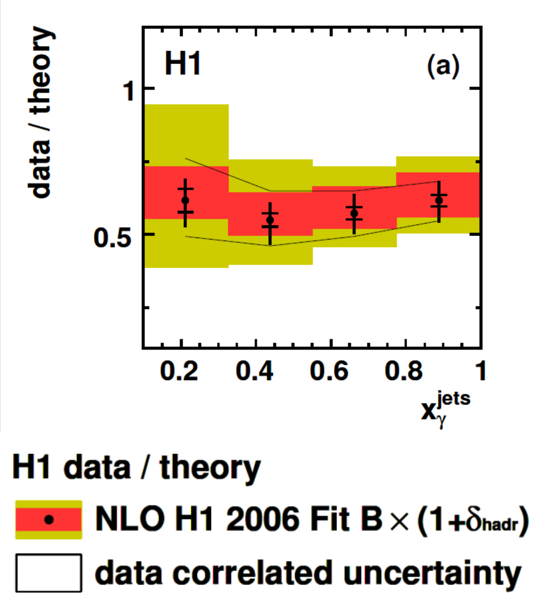
no suppression

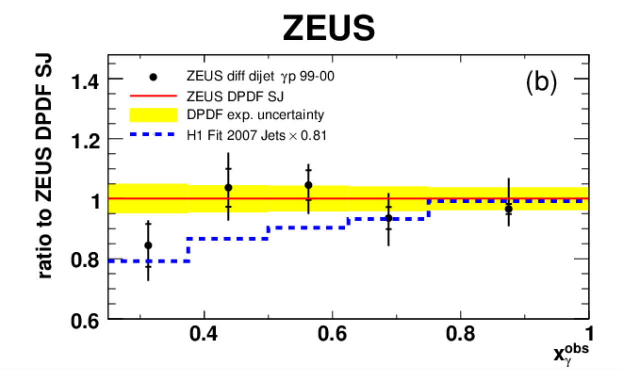
suppression: quarks **0.71(0.75)** $E_T^{jet1}$ >5 (7.5) GeV
gluons **0.53(0.58)** $E_T^{jet1}$ >5 (7.5) GeV

# 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)**

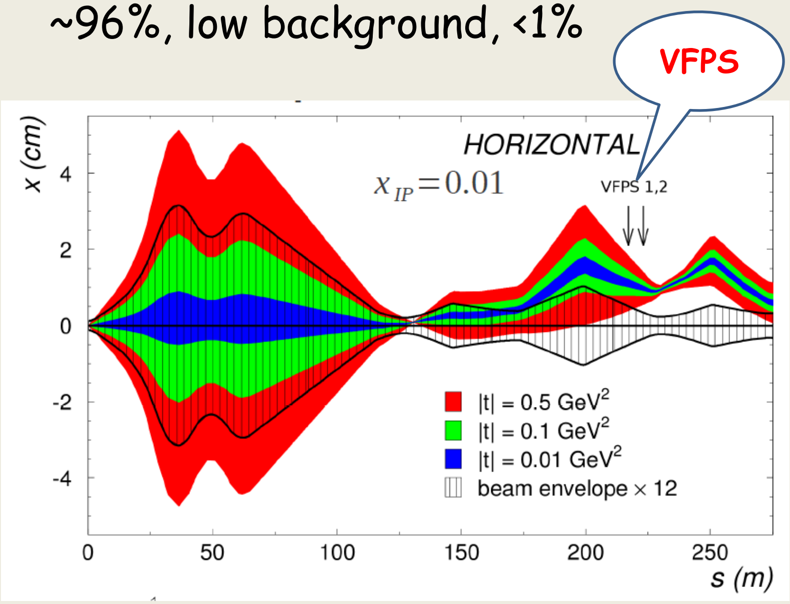
Nucl.Phys. B381 (2010) –
suppression **~ 1**

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 $x_\gamma$ !

# 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%



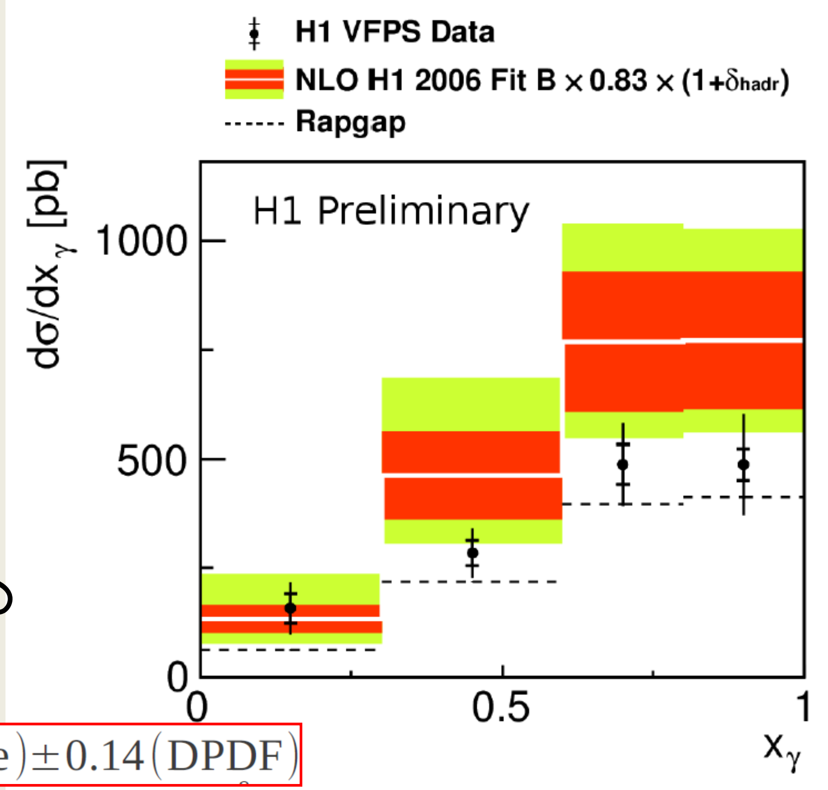

**Phase-space definition**

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

**~ 4800 events**

# Differential cross sections - $x_\gamma$

- 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:

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

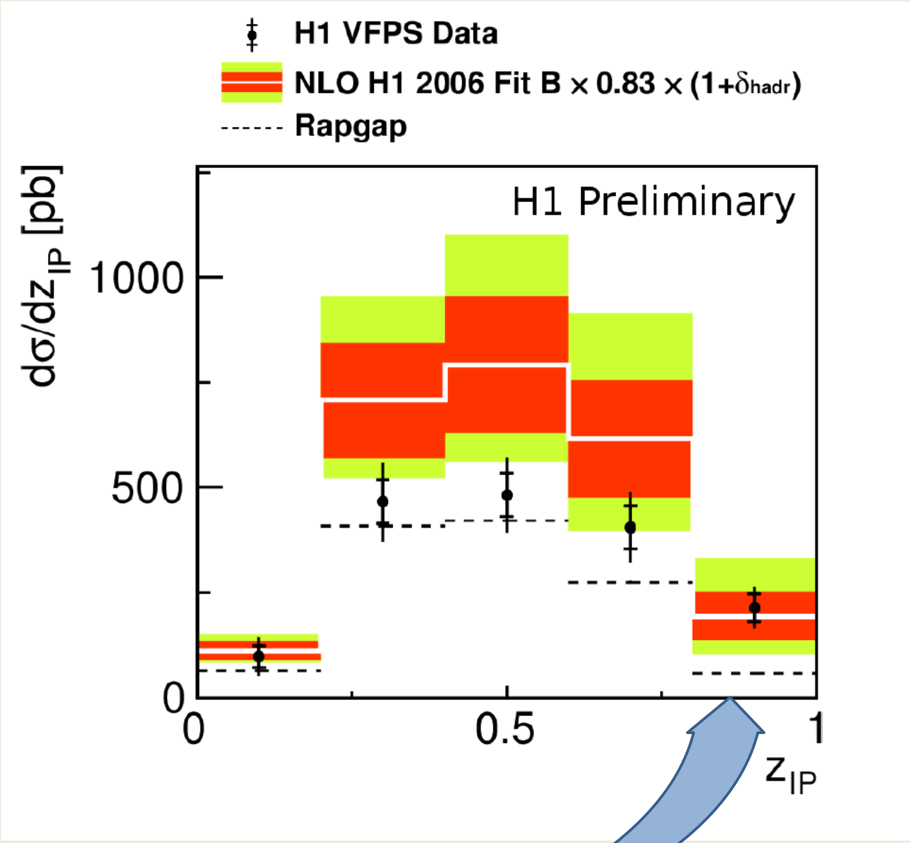
No obvious dependence of suppression on $x_\gamma$

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

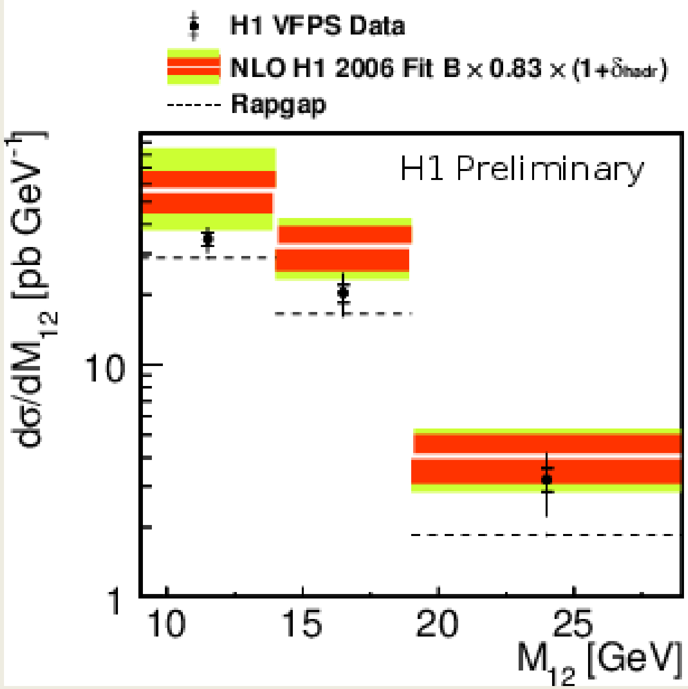
# Differential cross sections - $z_{IP}$

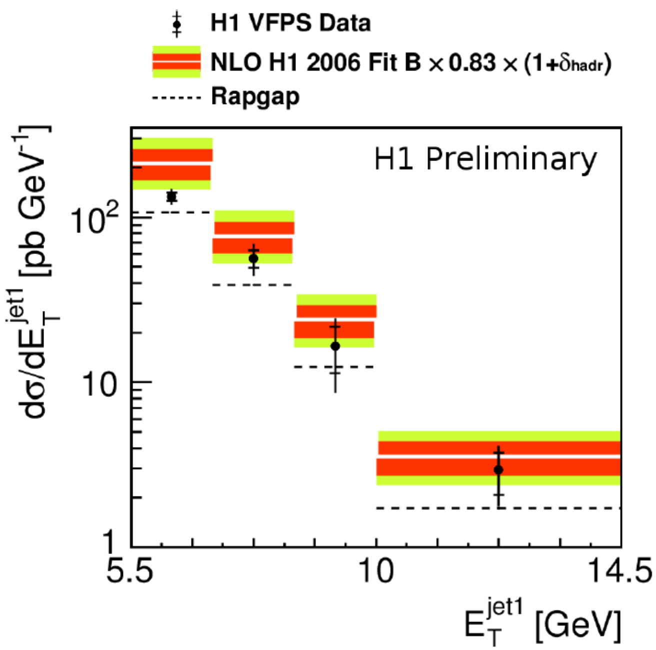
MC RAPGAP describes the shape quite well but it is too low

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!



# Differential cross sections – $M_{12}$, $E_T^{jet1}$




LO MC RAPGAP prediction too low.....

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

# Conclusions

- Differential cross section of dijet diffractive photoproduction for events with leading proton measured.
- Data cross section suppressed by factor about 0.67 in comparison to NLO QCD calculations.
- Previous H1 results confirmed however theoretical uncertainties too large to draw any final conclusions.
- Suppression in agreement with predictions of KKMR but there suppression should depend on $x_\gamma$ - it was not confirmed in any analysis (H1,ZEUS).
- Do we overestimate the role of LO picture?