Hard diffraction at HERA

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on behalf of H1 and ZEUS Collaborations

HERA collider experiments

- 27.5 GeV electrons/positrons on 920 GeV protons →√s=318 GeV
- data taken in 1992-2007
- HERA I,II: ~ 500 pb^{-1} per experiment
- H 1 & ZEUS - 4π detectors

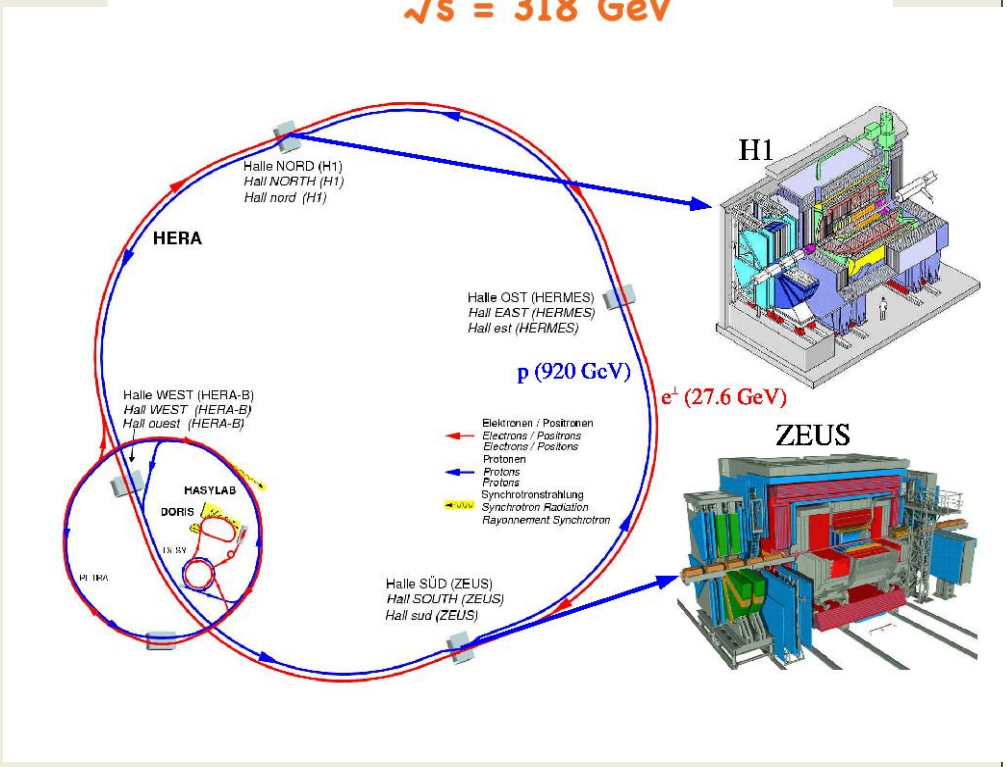
Diffraction

New era started with HERA:

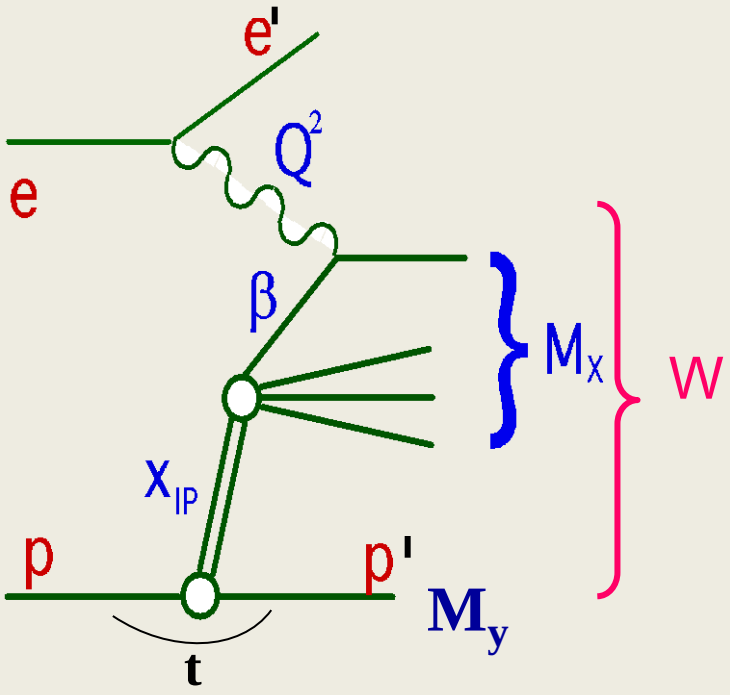
H1: 31 publications about diffraction

ZEUS: 31 publications about diffraction

+ one common H1/ZEUS publication



Diffractive kinematics



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

HERA: ~10% of events diffractive

$$x_{I\!P} = \xi = \frac{Q^2 + M_X^2}{Q^2 + W^2}$$

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

$M_y = m_p$ proton stays intact

$M_y > m_p$ proton dissociates, contribution should be understood

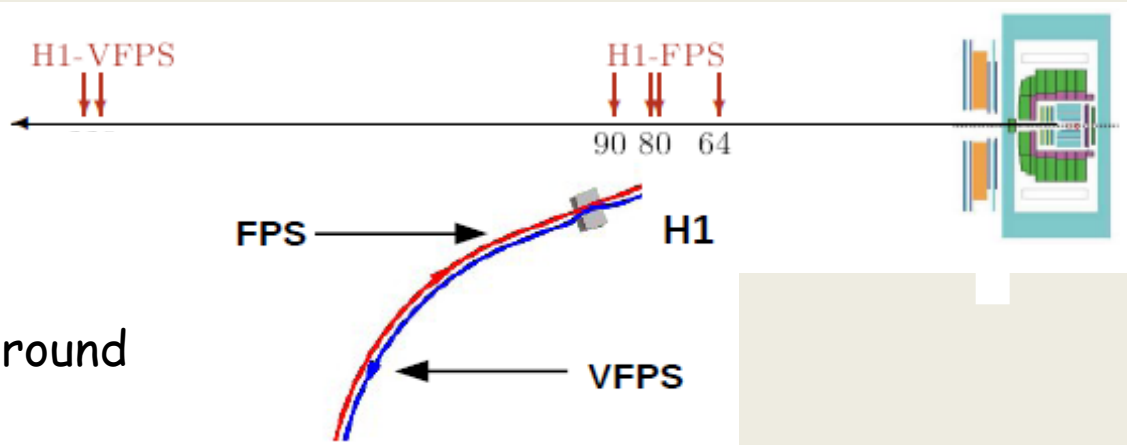
$$t = (p - p')^2 \longrightarrow$$ 4-momentum transfer squared (if proton is measured)

Methods of diffraction selection

Proton spectrometers

H1: VFPS (2005-2007)
FPS (1997-2007)
ZEUS: LPS (1997-2000)

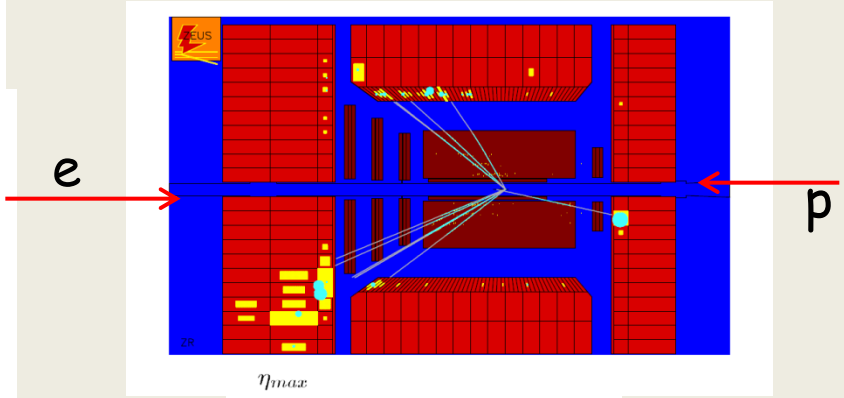
☺ free of p-dissociation background
☺ x_{IP} and t measurements
☺ access to high x_{IP} range (IP and IR)
☹ small acceptance, small statistics

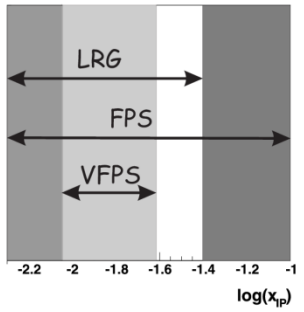


Large Rapidity Gap

require no activity beyond η_{max}

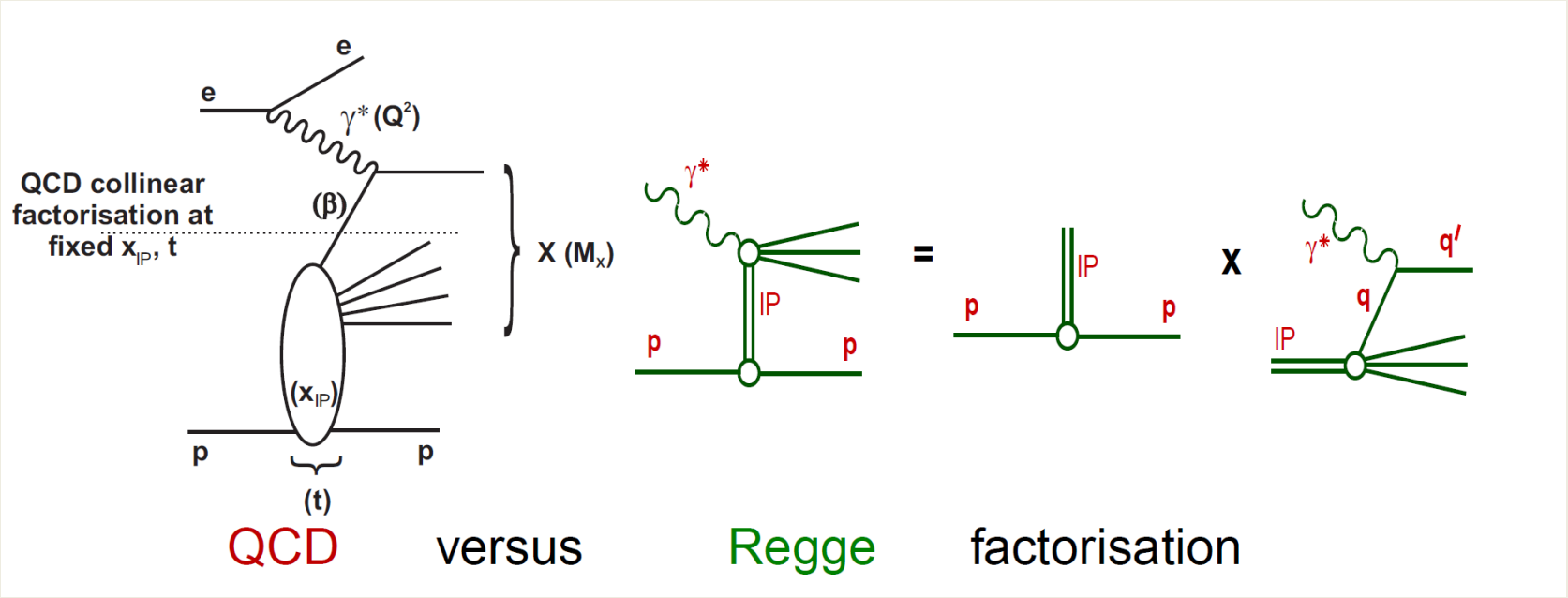
☹ t not measured, integrated over $|t|<1GeV^2$
☺ very good acceptance at low x_{IP}
☹ p-diss background about 20% ☠





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

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

Factorisation tests in diffractive dijet production

Measurements compared to NLO QCD predictions, (using HERA DPDFs).

suppression factor

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

Motivation:
Factorisation was found to be broken in hadron-hadron collissions at Tevatron and LHC (CMS and ATLAS), suppression factors $S^2 \sim 0.1$

DIS – several measurements

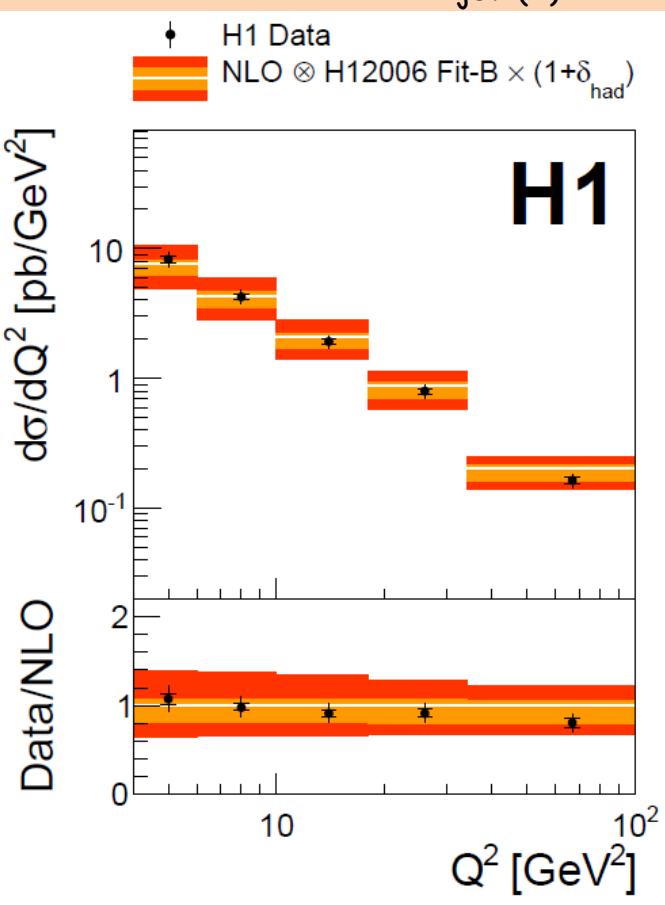
Factorisation **confirmed** by H1 and ZEUS measurements for dijets in DIS using **both** methods for diffraction selection
→ LRG and forward proton detection (H1 -> FPS)

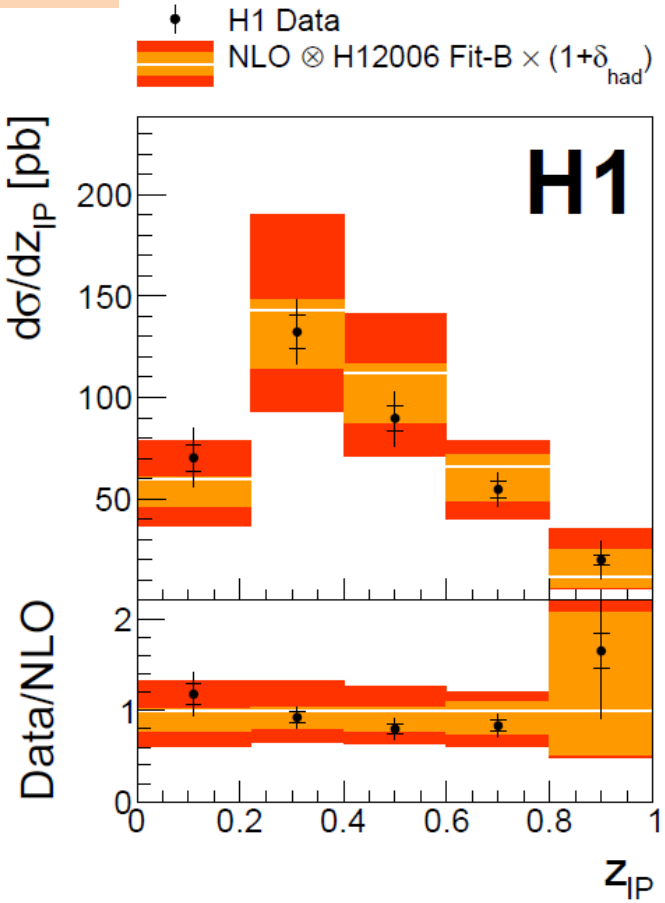
New H1 measurement with 6x larger statistics than previous measurements, LRG method, $E_T^*{}_{\text{jet1(2)}} > 5.5(4)$ GeV, sophisticated unfolding procedure

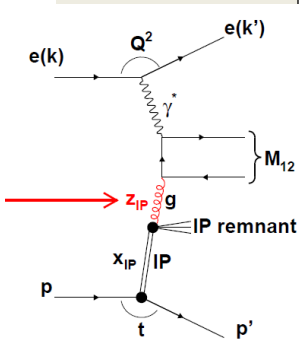
H1 Coll., JHEP 1503 (2015) 092

Diffractive dijet production in DIS

$4 < Q^2 < 100\ GeV^2$, $E_T^*{}_{jet1(2)} > 5.5(4)\ GeV$

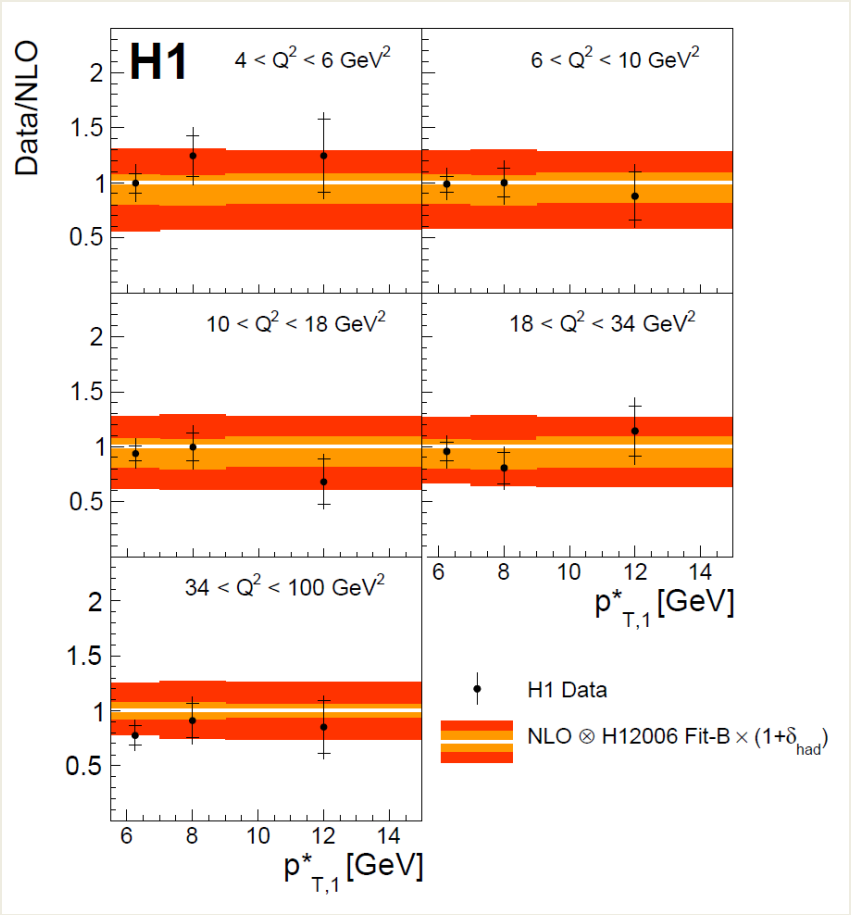


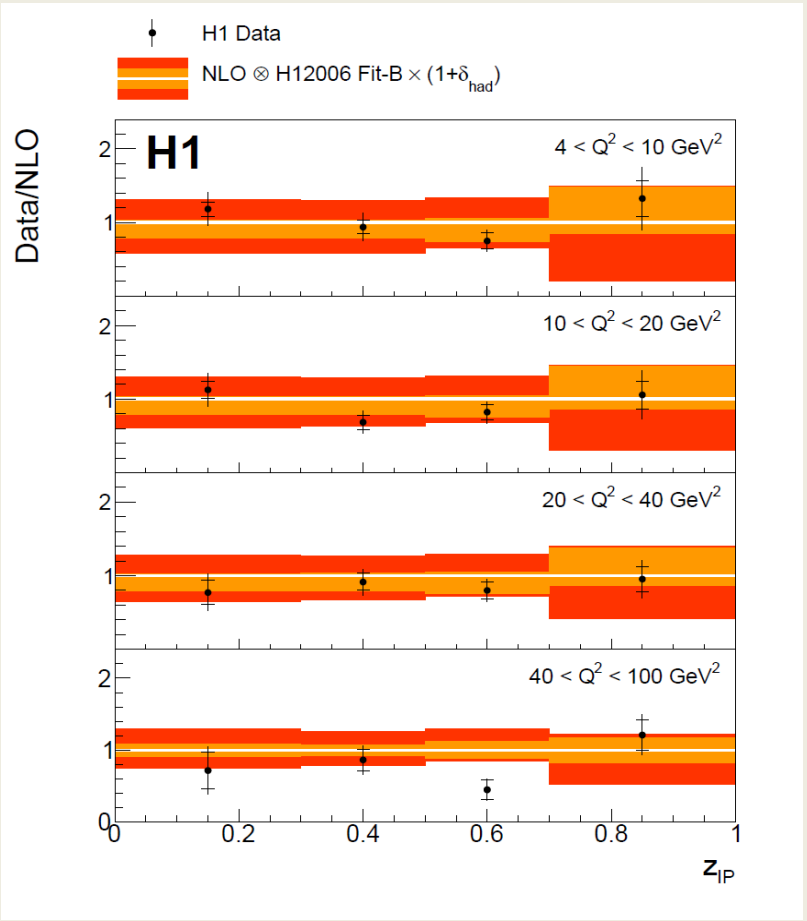




Measurements in agreement with NLO QCD calculations, factorisation confirmed.

Diffractive dijet production in DIS





$$\alpha_s(M_Z) = 0.119 \pm 0.004\,(\text{exp}) \pm 0.012\,(\text{DPDF, theo})$$

Result is consistent within uncertanties with the world average

2.7.2015

Factorisation tests in diffractive dijet production

Not evident that factorisation should be valid also for **photoproduction**, in LO photoproduction contributions of resolved photon process

History -three independent measurements

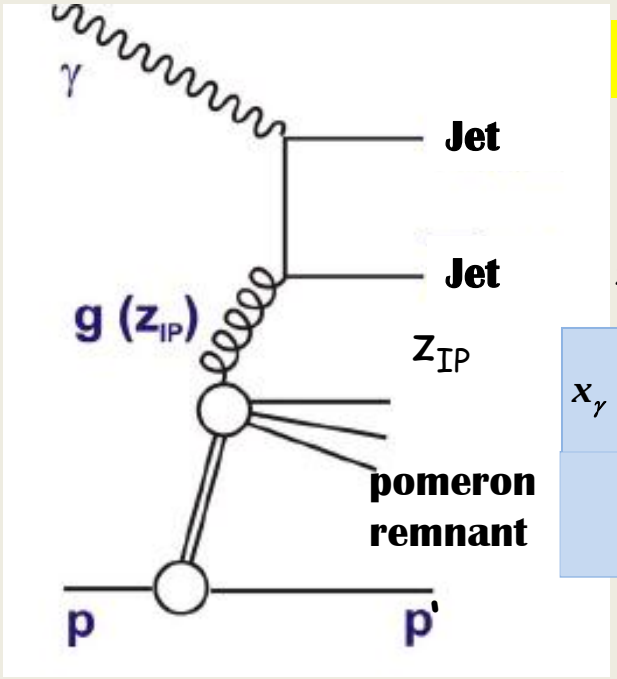
- **H1** – LRG method, tagged photoproduction, $E_T^{jet1(2)}>5(4)$ GeV,
  $S^2 = 0.5 \pm 0.1$ EPJC C51 (2007),549

- **H1** – LRG method, tagged photoproduction , $E_T^{jet1(2)}>5(4)$ GeV,
  $S^2 = 0.58 \pm 0.01 \pm 0.12(exp) \pm 0.14 \pm 0.09(th)$ EPJ C70 (2010),15

- **ZEUS** – LRG method, untagged photoproduction $E_T^{jet1(2)}>7.5(6.5)$ GeV
  $S^2 \sim 1$ Nucl.Phys. B381 (2010)

A new H1 measurement with different diffractive method selection – proton measured in forward proton spectrometer VFPS

Factorisation tests in diffractive dijet photoproduction

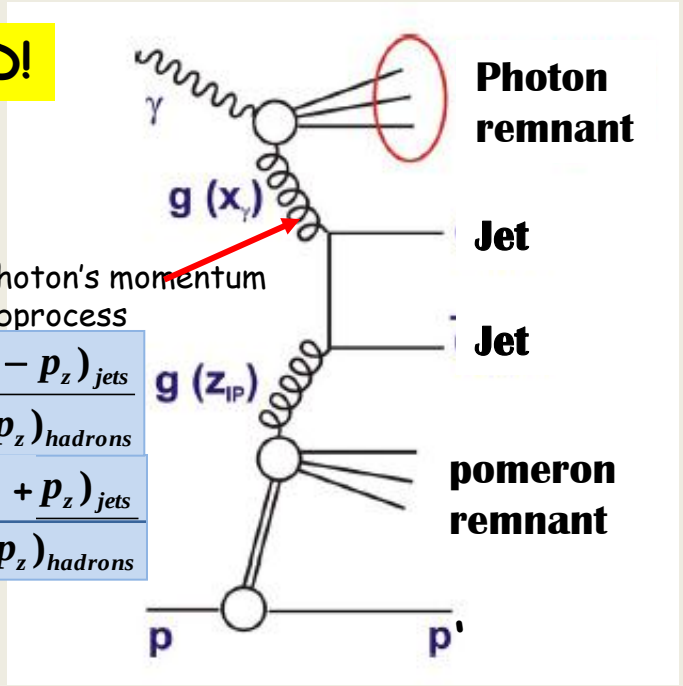


In LO QCD!

x_γ - 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

Diffractive dijet photoproduction & DIS - measurement in Very Forward Proton Detector

DIS & photoproduction

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

other cuts identical:

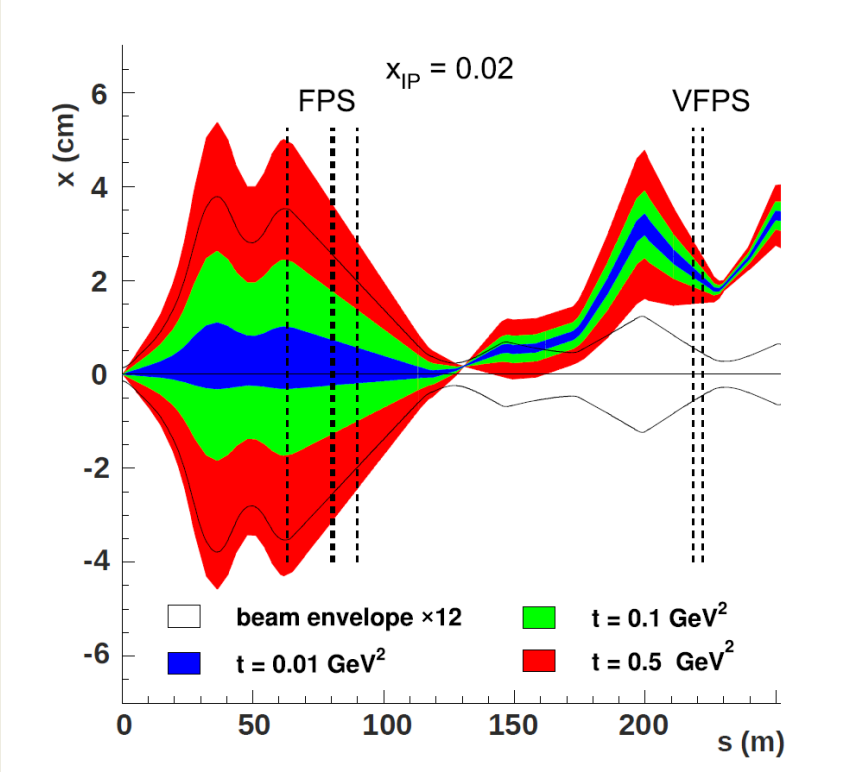
$0.01 < x_{IP} < 0.024$

$|t| < 0.6\ GeV^2$

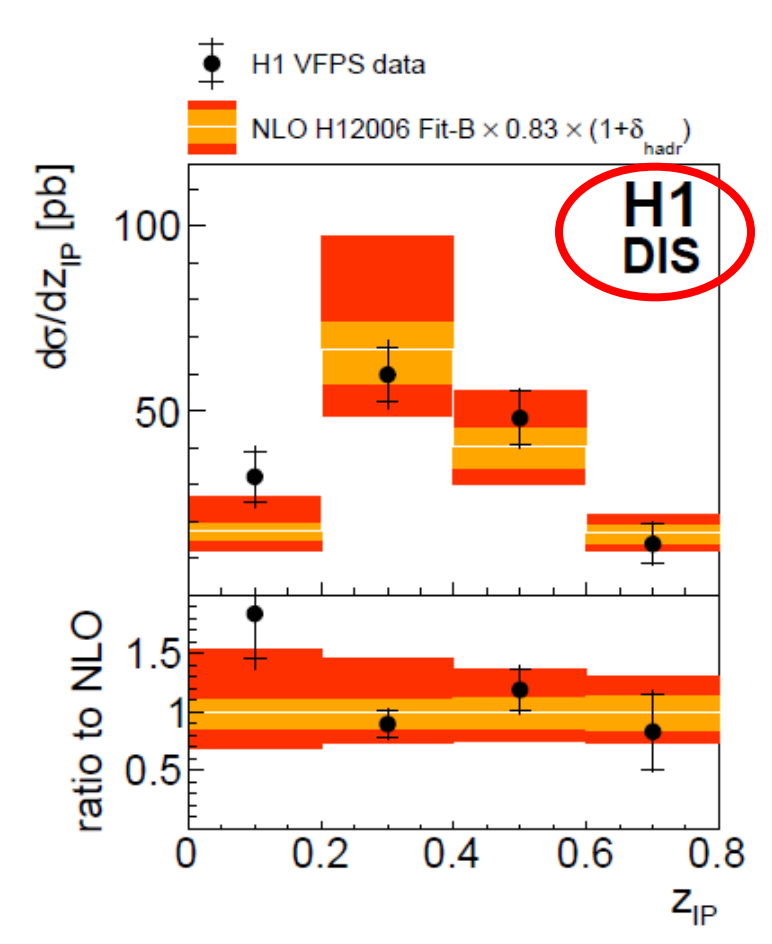
$z_{IP} < 0.8$

$E_T^*{}_{jet1(2)} > 5.5(4)\ GeV$

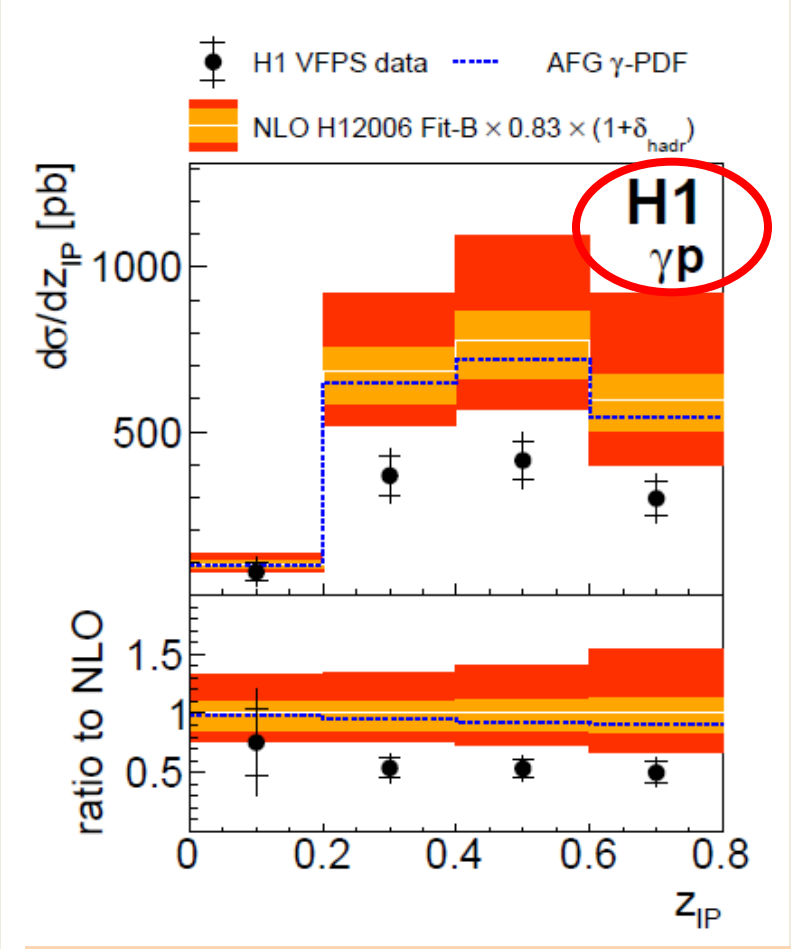
$-1 < \eta_{jet1(2)} < 2.5$



Diffractive dijet photoproduction & DIS

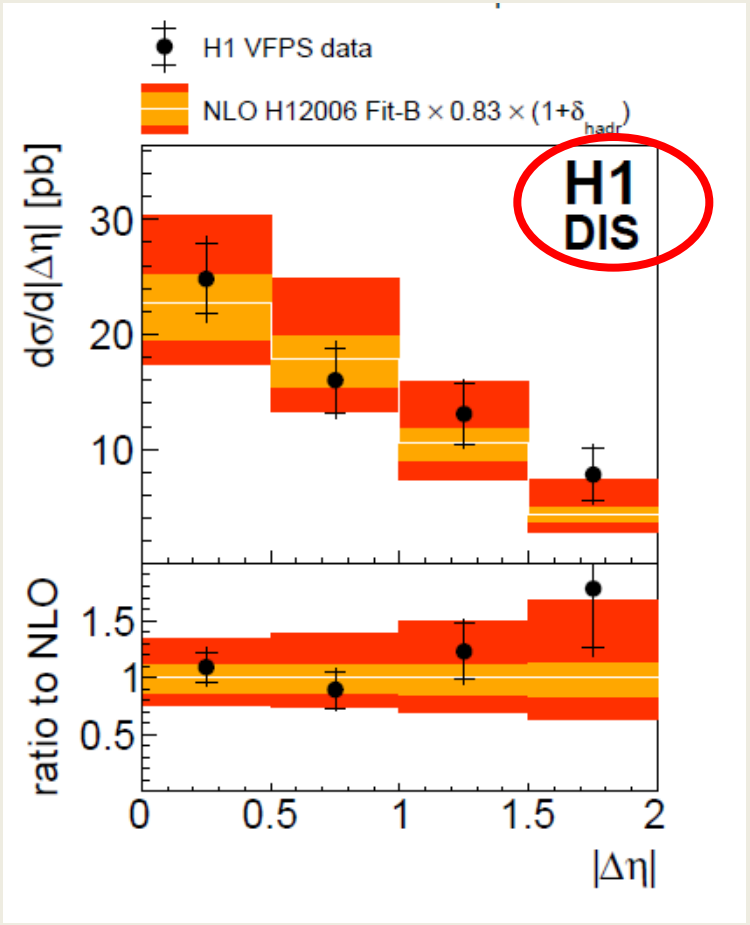


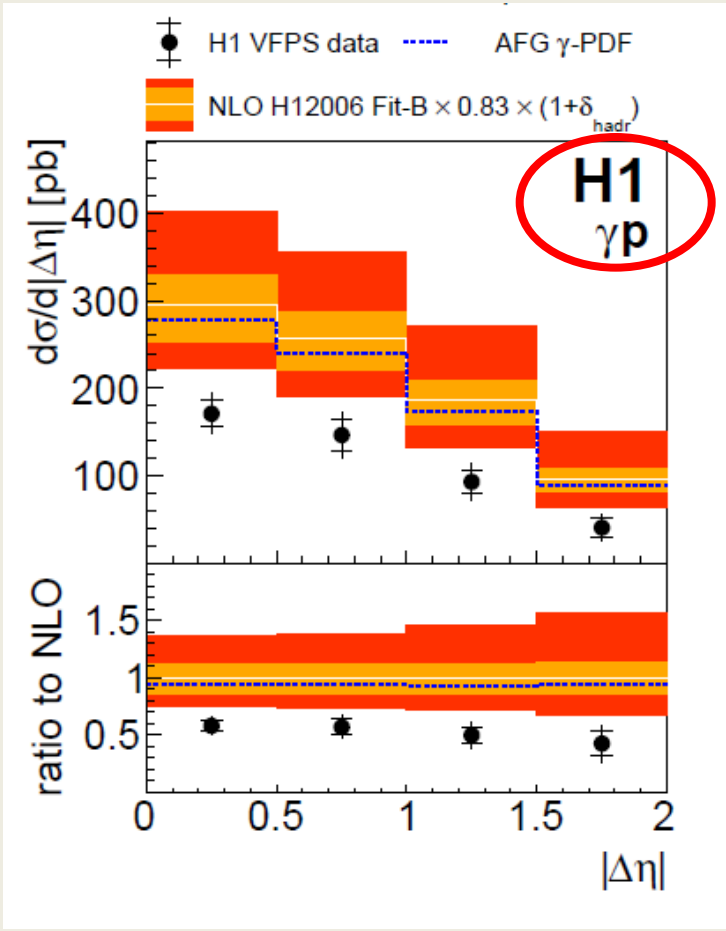
Data in agreement with NLO in DIS, within uncertainites



Data suppressed in comparison with NLO in photoproduction

Diffractive dijet photoproduction & DIS





Data in agreement with NLO in DIS, within uncertainites

Data suppressed in comparison with NLO in photoproduction

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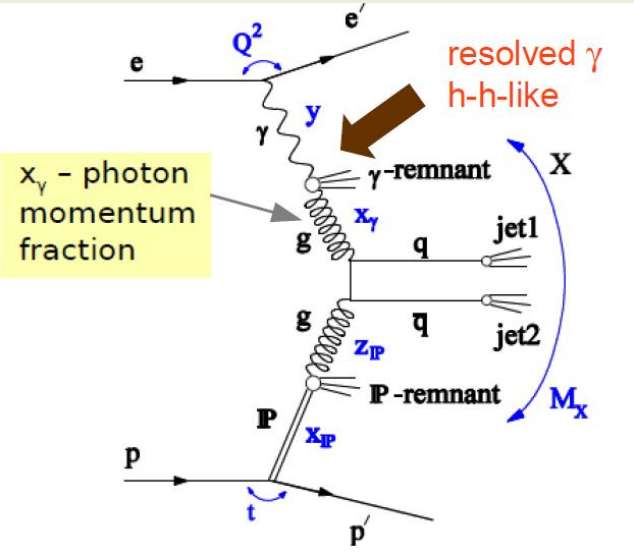
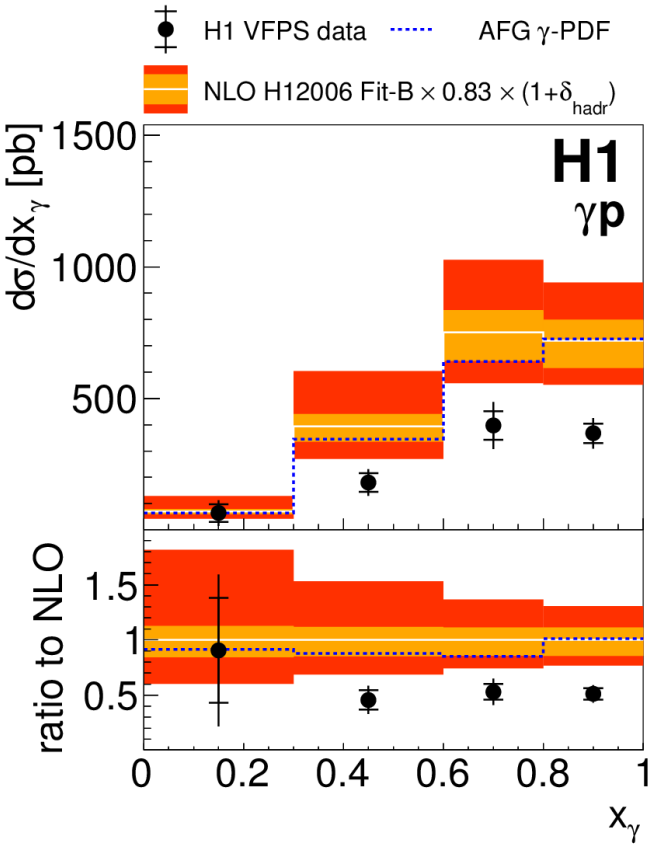
Diffractive dijet photoproduction

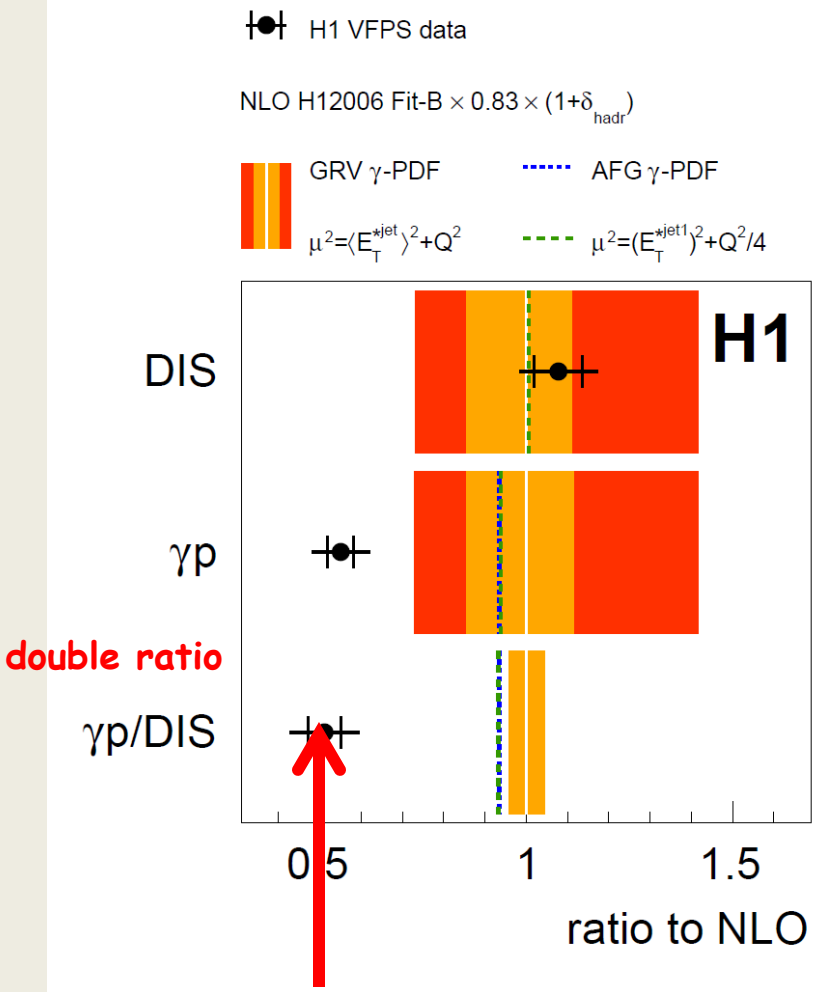


$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$



The suppression seems to be not dependent on x_γ .
It is in agreement with previous H1 and ZEUS observations!

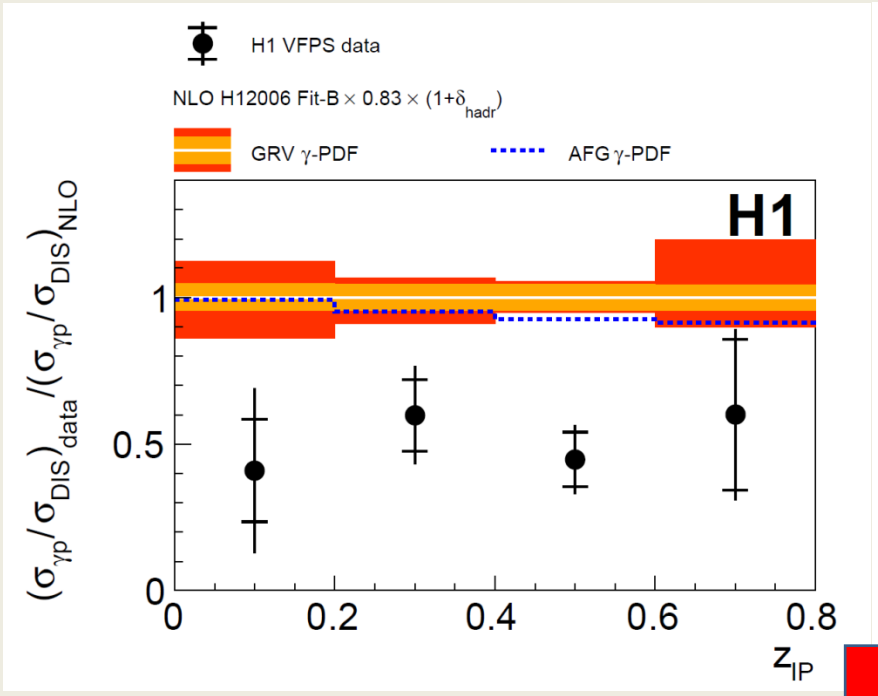
Diffractive dijet photoproduction & DIS

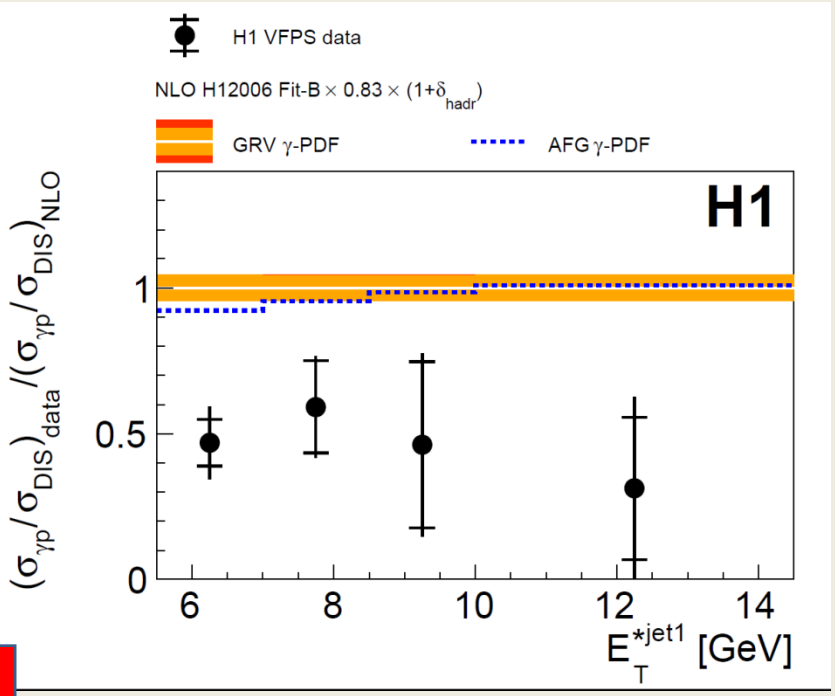


Previous H1 measurements confirmed, factorisation breaking in diffractive dijet photoproduction by factor ~ 0.5 observed

Diffractive dijet photoproduction & DIS

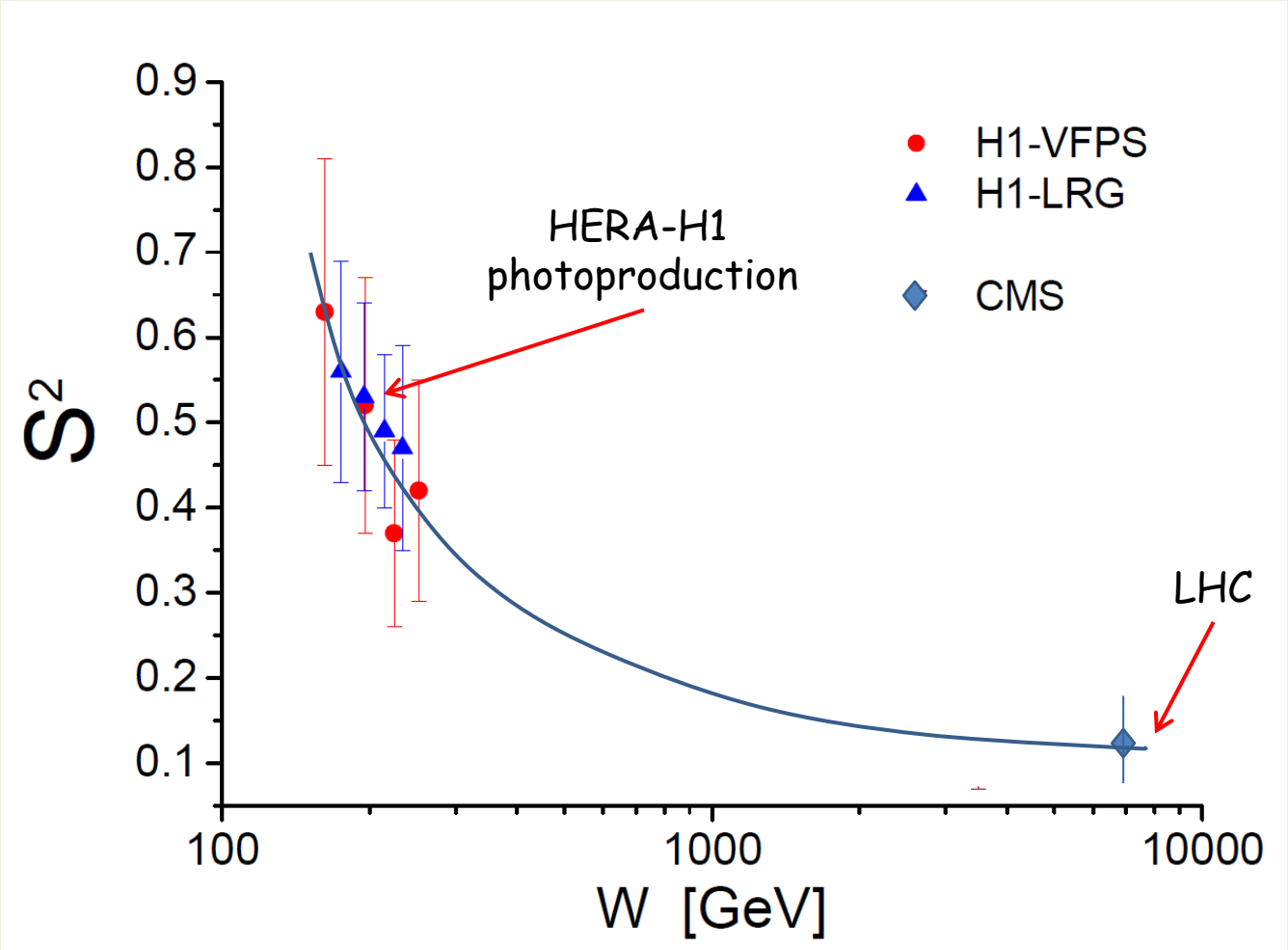
Double ratio photoproduction/DIS





Dependence of the suppression on E_T^* of the leading jet and z_{IP} not observed!
The reason of the difference of suppression for H1 and ZEUS is not connected with different phase space in E_T of jets

Dependence of the suppression factor S^2 on total hadronic energy



It is not a fit…only to guide eye…ZEUS data not shown, compatible with no suppression.

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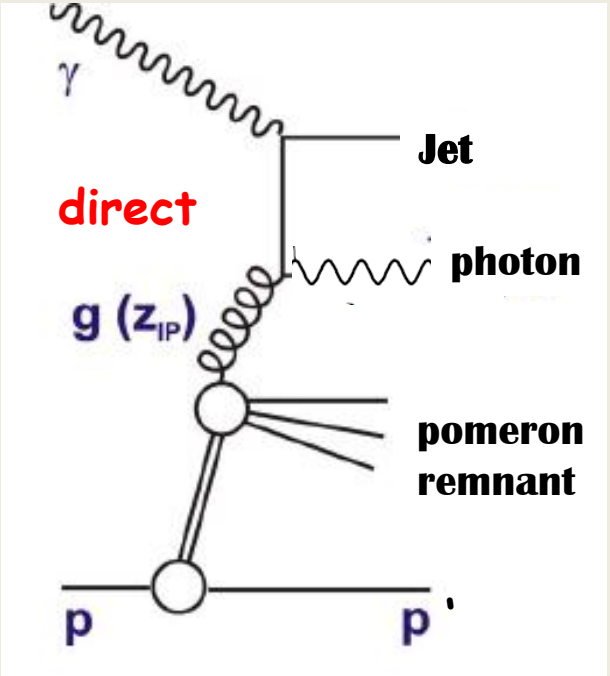
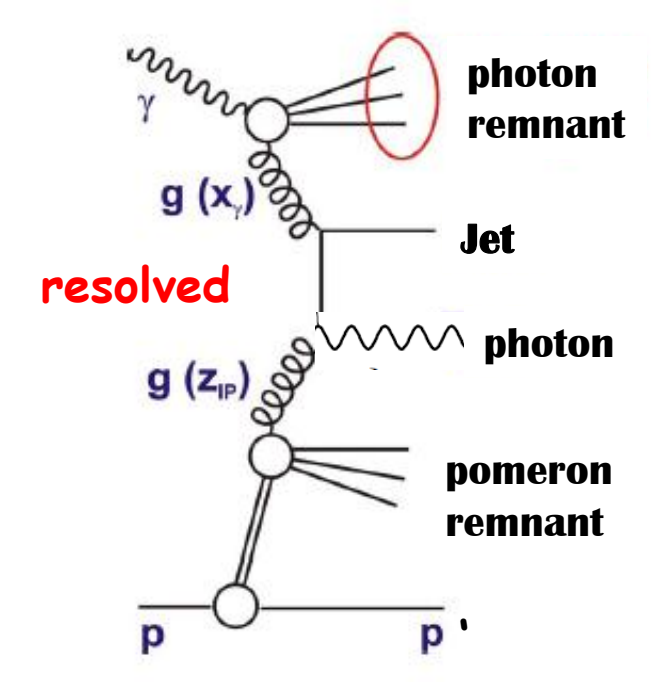
Diffractive production of prompt (isolated) photons

Previous ZEUS inclusive mesurements: Phys.Lett.730(2014), JHEP 08 (2014) 03



LO



HERA II (374pb^{-1}) and I data (91pb^{-1}, used for normalization)

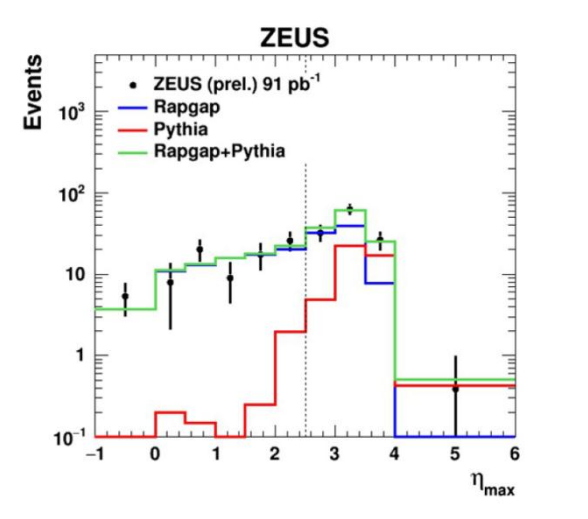
Diffractive selection – LRG, $\eta_{max} < 2.5$ $x_{IP} < 0.03$

Photons $E_T^{\gamma} > 5$ GeV, $-0.7 < \eta^{\gamma} < 0.9$

Jets use k_T-cluster algorithm, $-1.5 < \eta^{jet} < 1.8$, $E_T^{jet} > 4$ GeV.

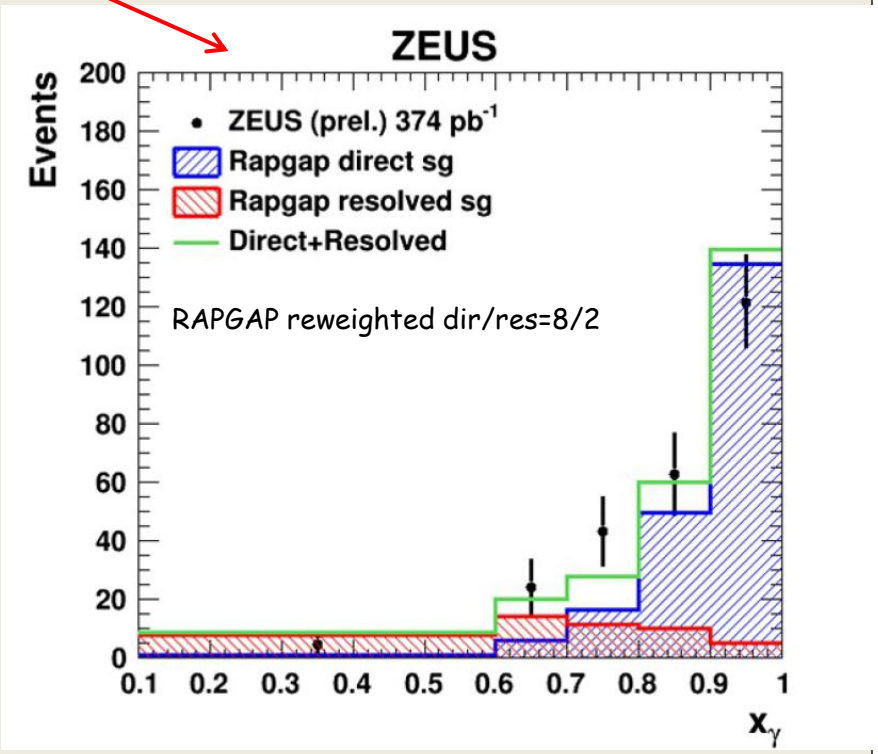
Signal MC = RAPGAP with H1 fitB DPDF and γ-PDF SASG 1D LO

Diffractive production of prompt (isolated) photons



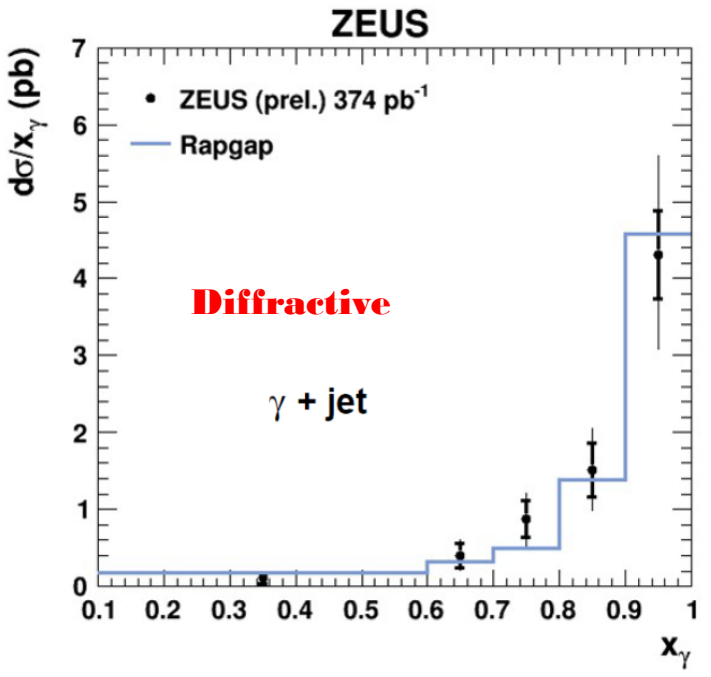
η_{max} distribution used to remove non-diffractive background

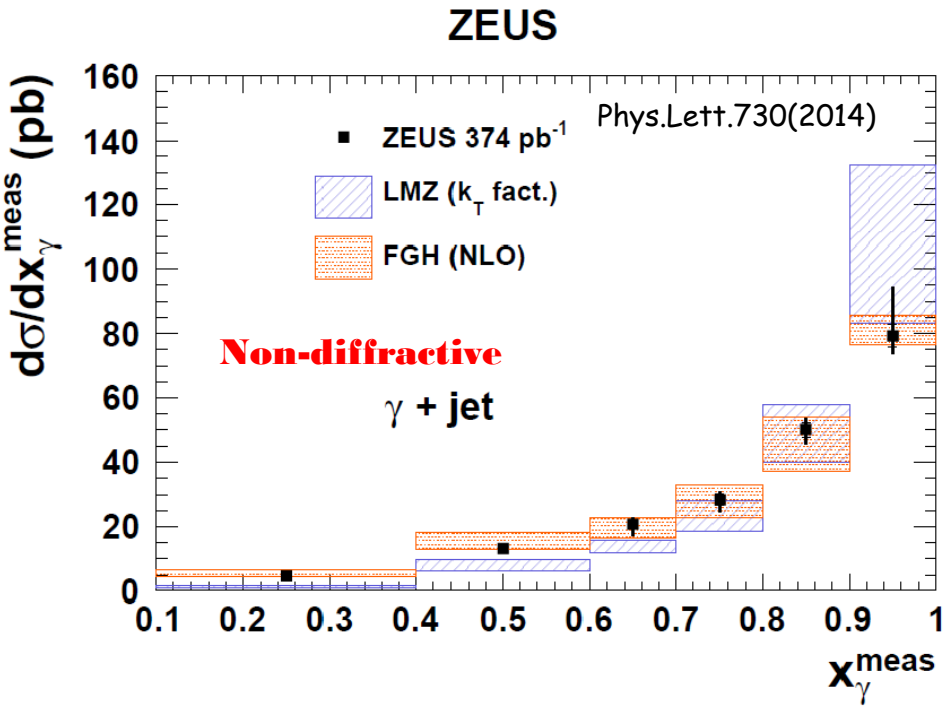
Non-diffractive background -> mean PYTHIA & HERWIG -> 23% removed



Measured x_γ distribution compared to reweighted RAPGAP

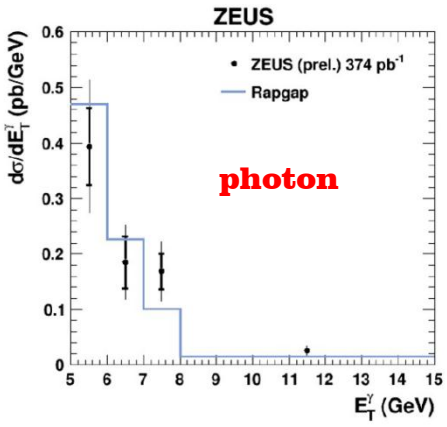
Diffractive production of prompt (isolated) photons



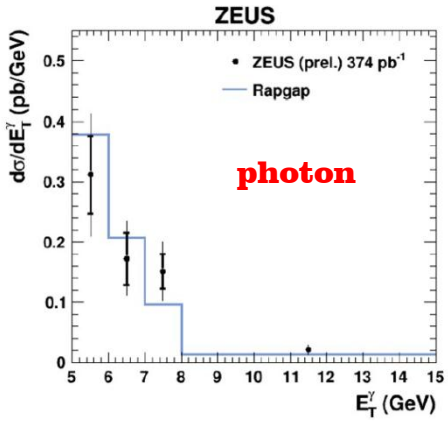


The diffractive processes seems to be more direct dominated than the non-diffractive.

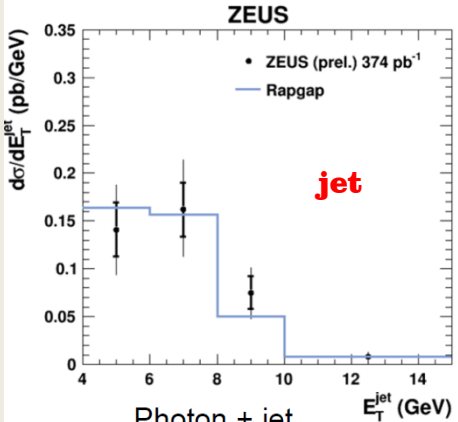
Diffractive production of prompt (isolated) photons



Inclusive photon

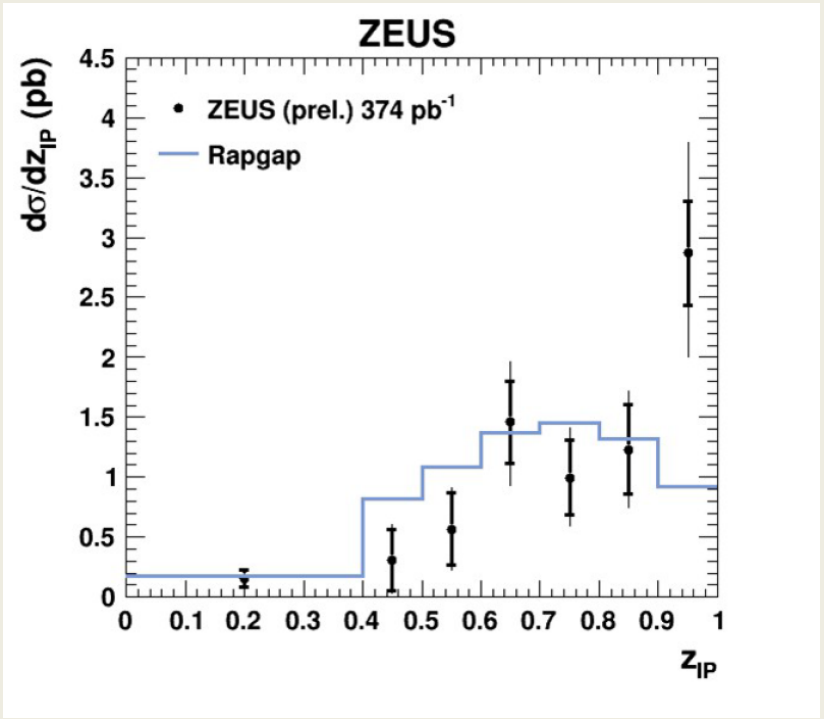


Photon + jet



Photon + jet

Fair description by RAPGAP within uncertainties



A peak at z_{IP} close to 1 is not described by RAPGAP. Note, that H1 fit B not fitted in this region, it is only exptrapolated.
Region z_{IP} ~ 1, no activity except jet and γ.

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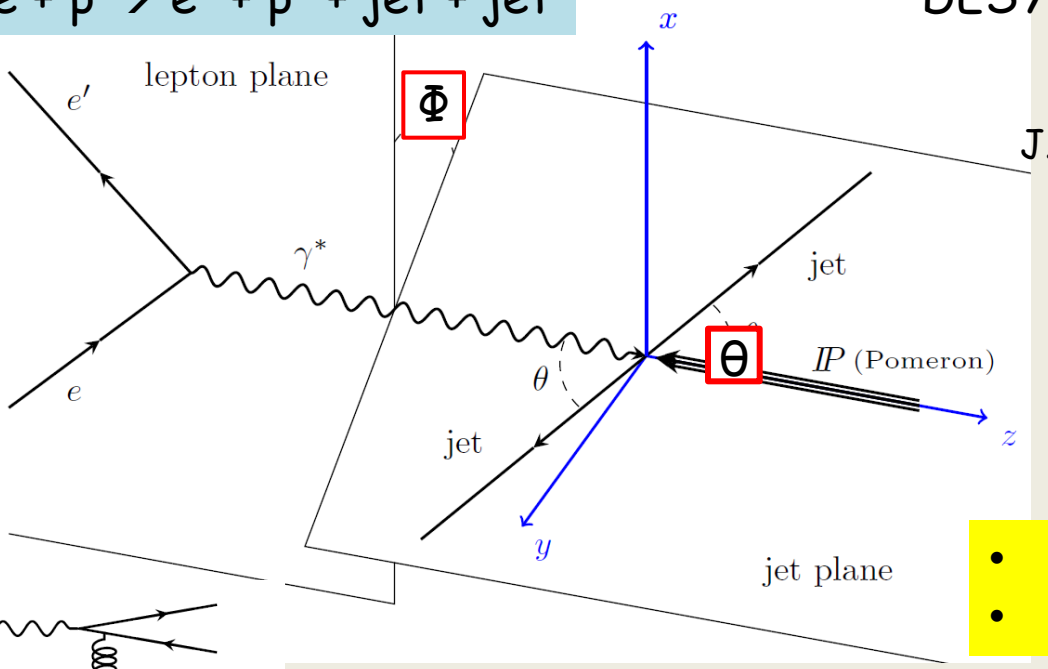
Exclusive dijets in diffractive DIS

How to distinguish between diffractive models???

e + p → e' + p' + jet + jet



DESY-15-070 (2015),sent to EPJC

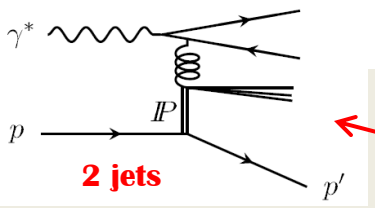
J.Bartels et al.,Phys.Lett.B386,(1996)389

Φ – angle between lepton and jet planes

Θ – polar angle of jet

$$d\sigma/d\phi \propto 1 + A\cos(2\phi)$$

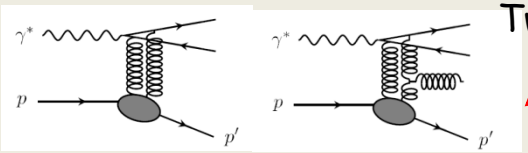
- Two gluon exchange – negative A
- Boson-Gluon fusion - positive A



BGF –Resolved-Pomeron model (Ingelman,Schlein et al.)

Two-Gluon-Exchange model (Bartels,Jung et al.)

RAPGAP



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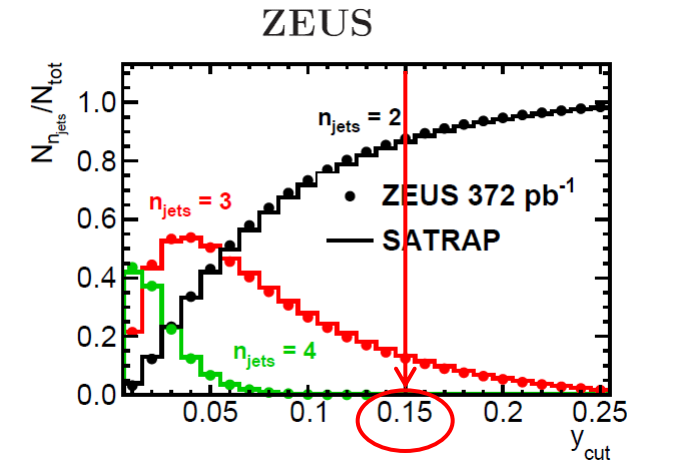
Exclusive dijets in diffractive DIS

e + p → e' + p' + jet + jet only dijet, electron and proton in the final state

Durham jet algorithm in γ*IP rest frame in exclusive mode – all objects in jets



y_{cut}=0.15

Hadron cross sections unfolded as a function of β and Φ

- $Q^2 > 25$ GeV^2
- $90 < W < 250$ GeV
- $x_{IP} < 0.01$
- $M_X > 5$ GeV
- $N_{jets} = 2$ (with $y_{cut} = 0.15$)
- $p_{T;jet} > 2$ GeV.

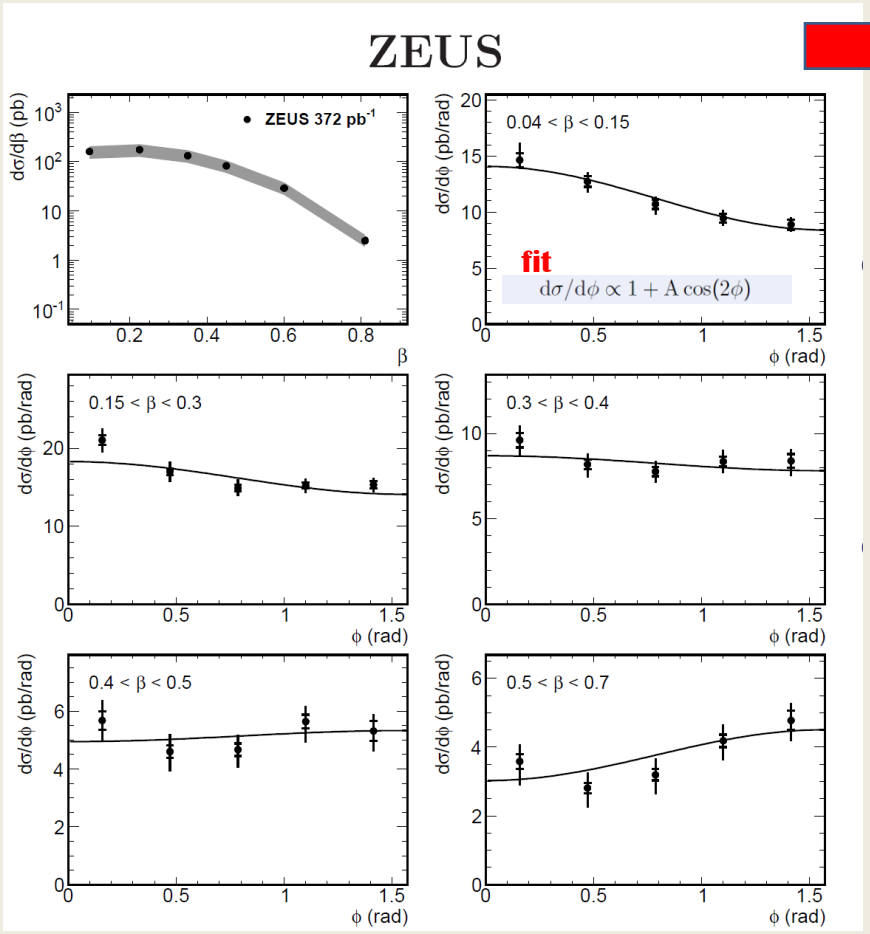
Proton dissociation background

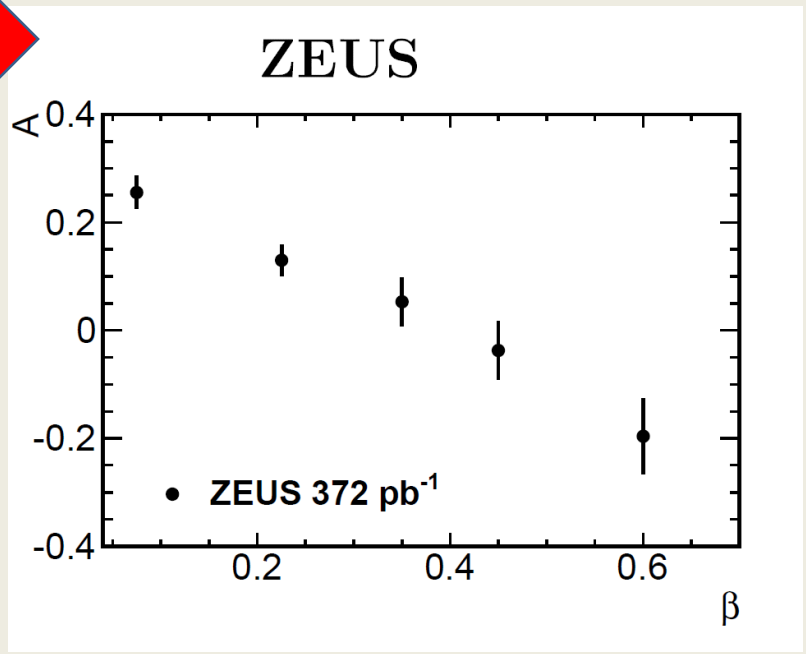
$f_{\mathrm{pdiss}} = 45\% \pm 4\%(\mathrm{stat.}) \pm 15\%(\mathrm{syst.})$

Measured cross sections reweighted by

$$(1 - f_{\mathrm{pdiss}}) = 0.55$$

Exclusive dijets in diffractive DIS



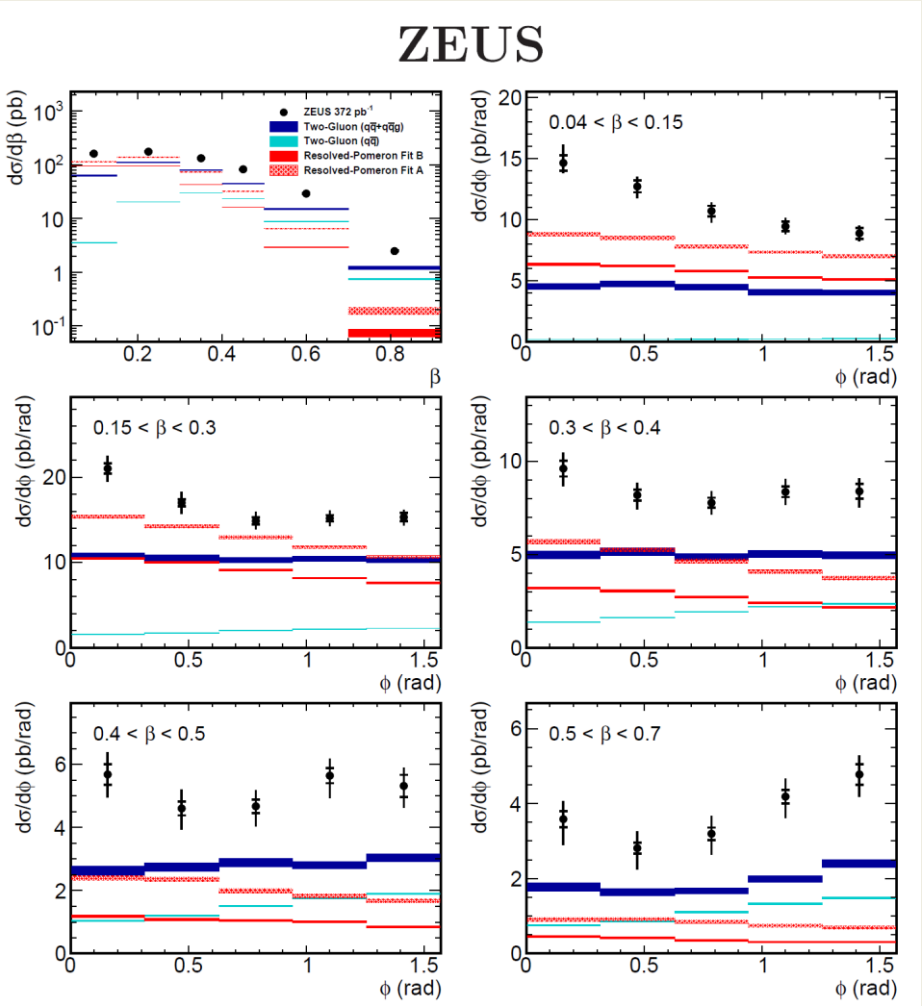


$$1 + A\cos 2\phi$$

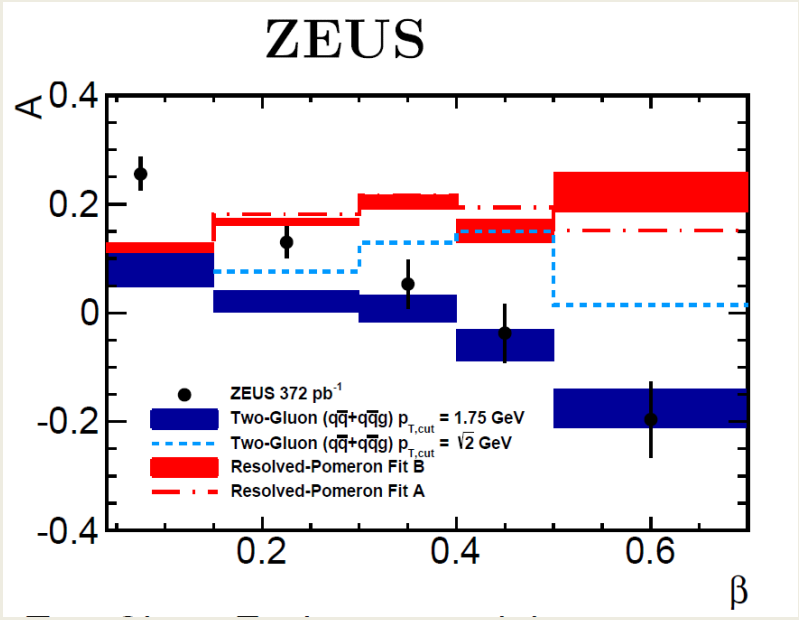
Results compared to two MC RAPGAP variants:

- Resolved Pomeron Model (DPDFs H1 FitA,B)
- Two-Gluon-Exchange Model (γ-PDF GRV)

Exclusive dijets in diffractive DIS



The measured and predicted cross sections do not agree by factor about 2.
NLO corrections large???



The Two Gluon model is more successful in describing of data (region $\beta > 0.3$) than Resolved Pomeron model (large uncertainty due to p-diss subtraction, is not shown here)

Conclusions

- New H1 measurement of diffractive dijet production in DIS → measurements described by NLO QCD predictions using H1 DPDF, value of $\alpha_s(M_Z)$ obtained from this measurement is in agreement with world average
- New H1 measurement of diffractive photoproduction & DIS dijets using VFPS proton spectrometer →
  DIS dijets in agreement with NLO QCD prediction,
  suppression factor 0.5 ± 0.1 in photoproduction dijets observed, consistent with factorisation breaking!

- New ZEUS measurement of prompt inclusive photons and photons with a jet in diffractive photoproduction. Shapes of diff.cross sections agree with RAPGAP except of z_{IP}.
- New ZEUS measurement of exclusive dijets in DIS diffraction, MC cross section significantly larger than predicted by models, Two-Gluon-Exchange model predicts reasonably well the measured value of A as a function of β for β>0.3.