Diffraction at HERA-overview II

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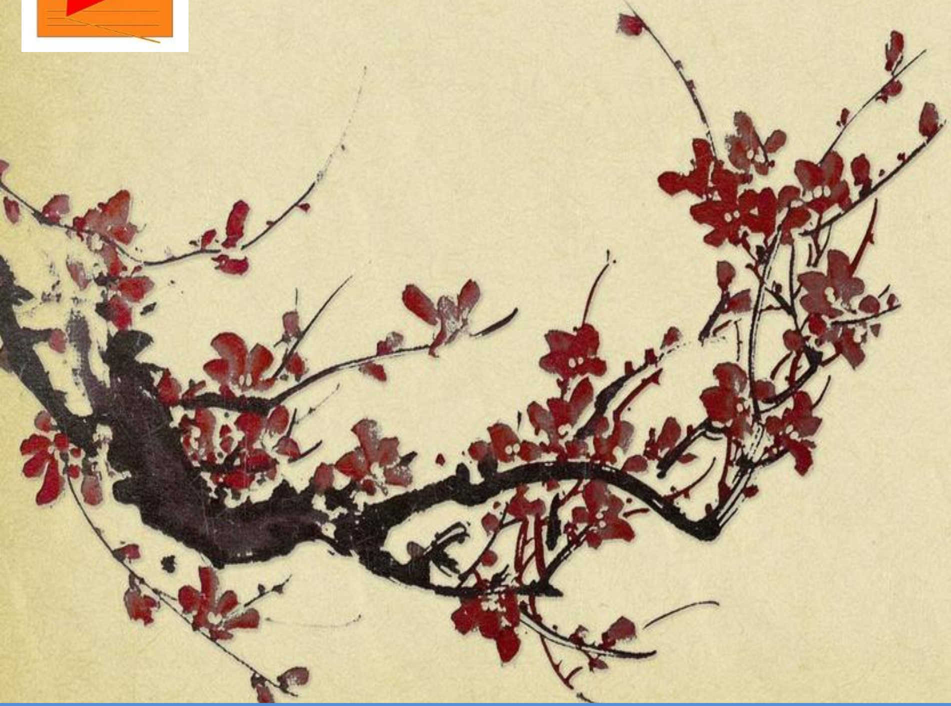


on behalf of H1 and ZEUS Collaborations

HERA collider experiments

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

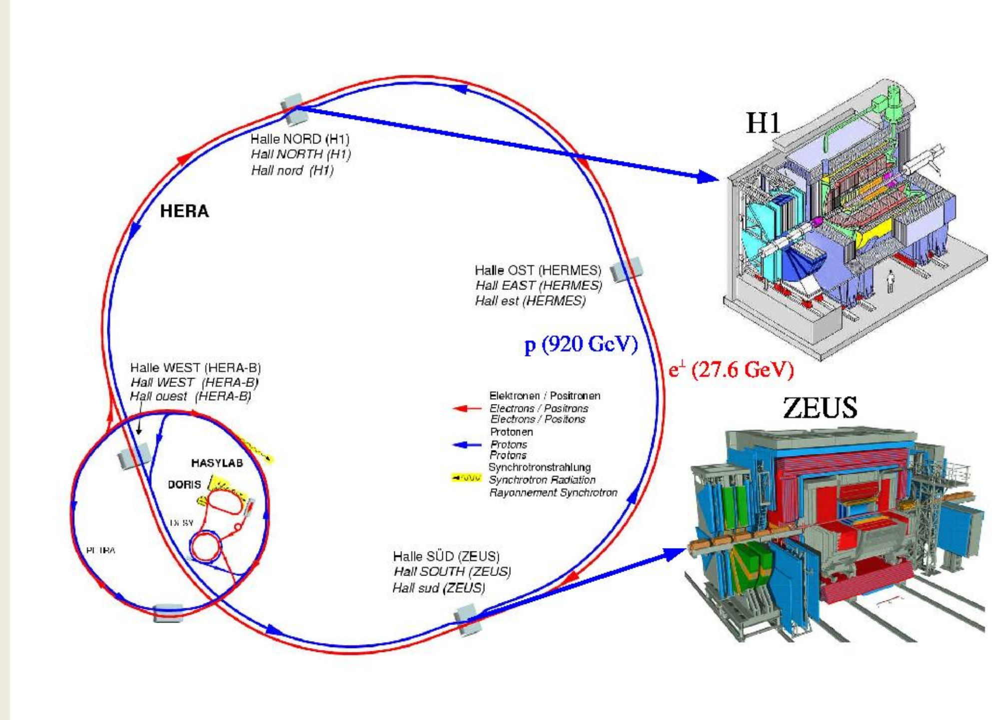
Diffraction

New era started with HERA:

H1: 31 publications about diffraction

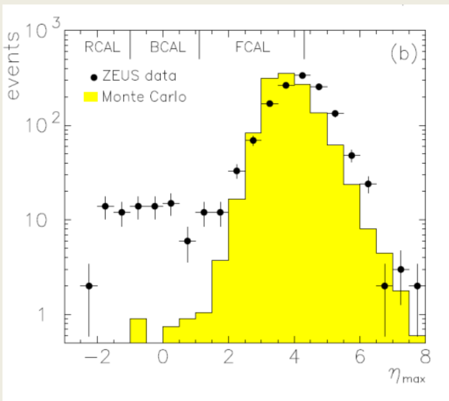
ZEUS: 31 publications about diffraction

+ one common H1/ZEUS publication



Historical reminder

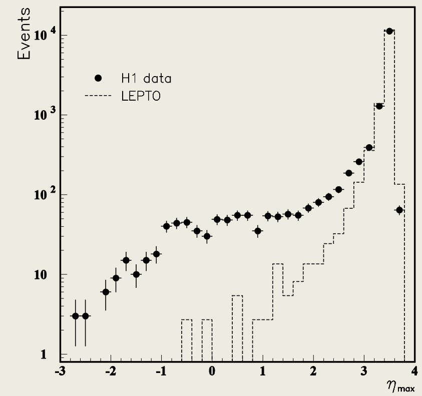
- **20 years** after the observation of diffractive DIS events at HERA!
- HERA opened **new era of diffraction studies**



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

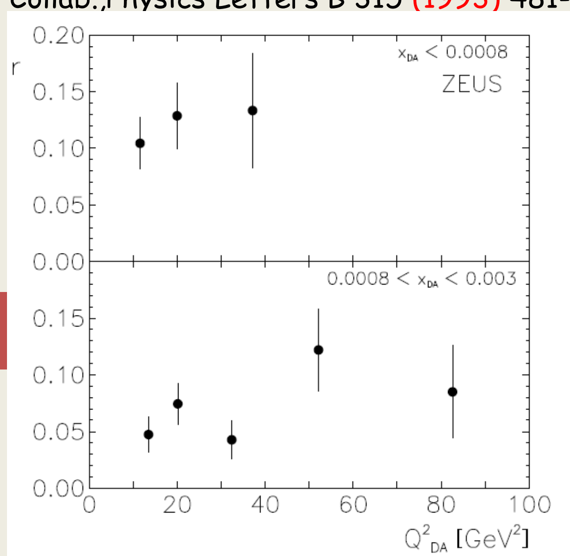
1993-1994

HISTORY

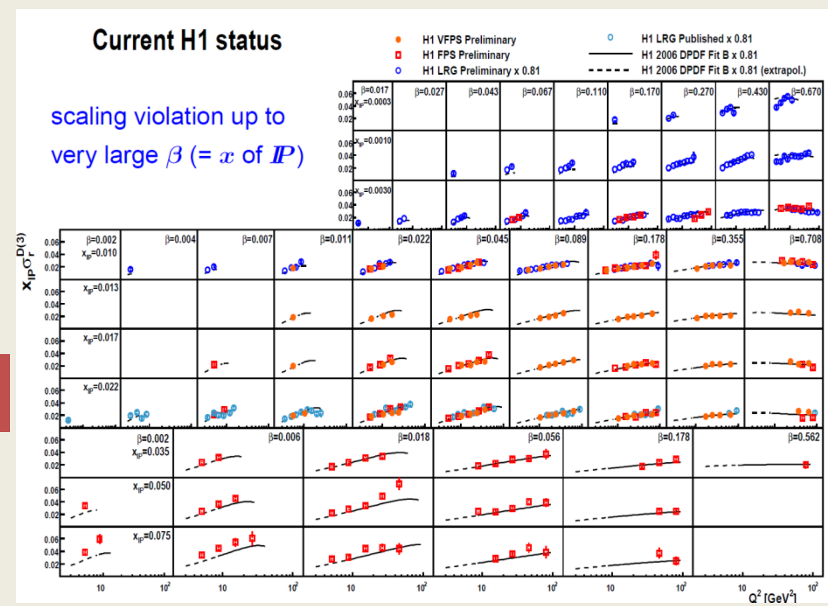


H1 Collab., Nucl. Phys. B429 (1994) 477

1993



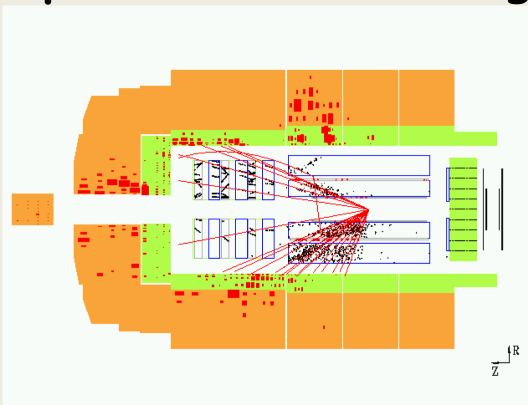
2013



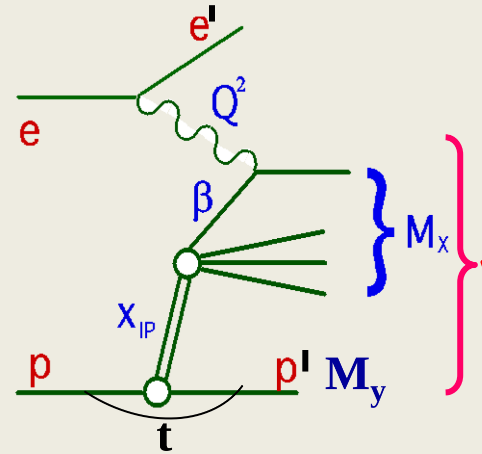
HERA: ~10% of events diffractive

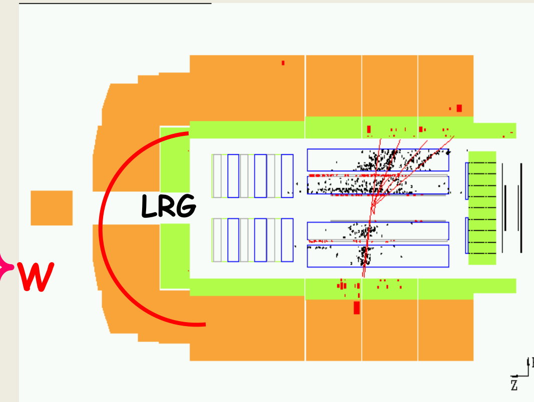
Diffractive kinematics

Deep inelastic scattering - DIS



Diffractive scattering





- Q^2- virtuality of the photon
- Q^2~0 GeV^2→ photoproduction
- Q^2>>0 GeV^2→ DIS
- W – total hadronic energy

- momentum fraction of color singlet exchange

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

- fraction of exchange momentum, coupling to γ

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

- 4-momentum transfer squared (if proton is measured)

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

$M_y = m_p$ proton stays intact

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

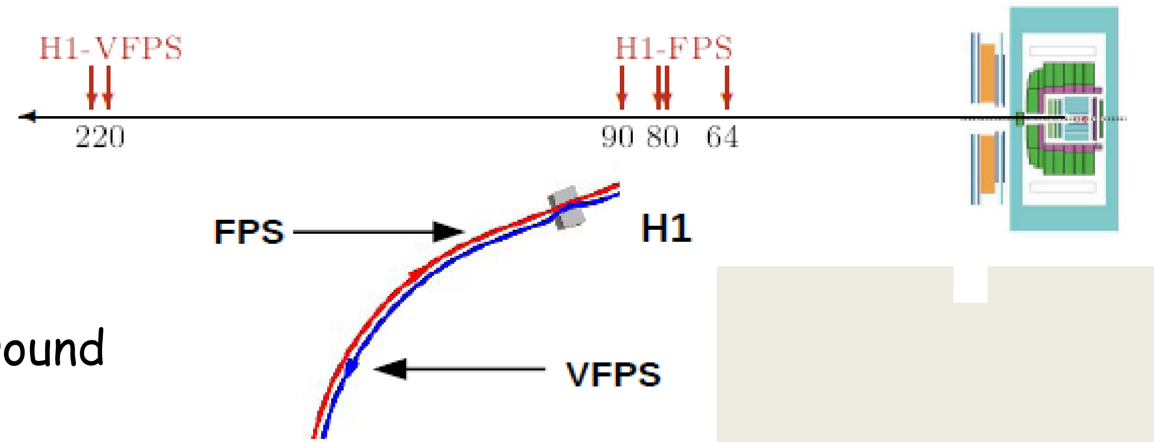
10.9.2015

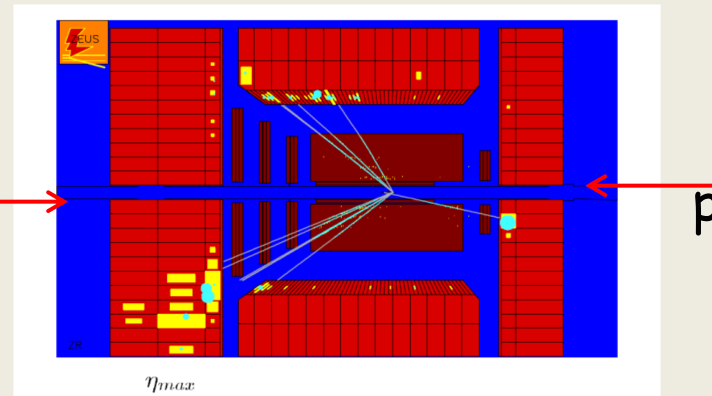
Methods of diffraction selection

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

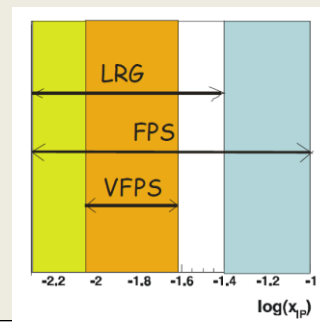




Large Rapidity Gap

require no activity beyond η_{max}

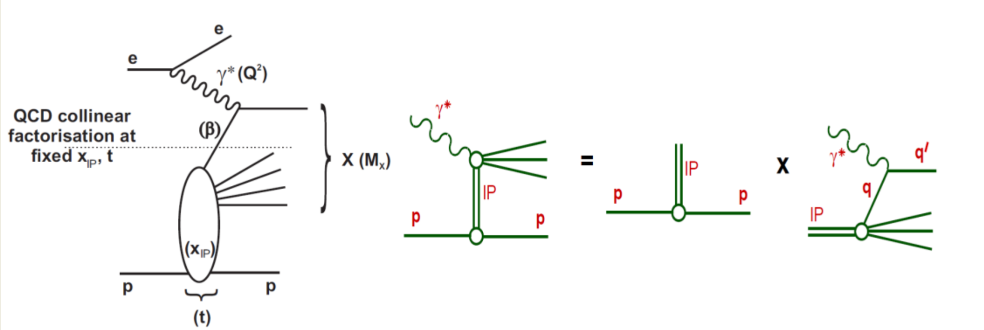
- ☹ t not measured,integrated over $|t|<1GeV^2$
- ☺ very good acceptance at low x_{IP}
- ☹ p-diss background about 20% ☠



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

Modelling of diffraction

QCD collinear factorisation theorem



QCD versus Regge factorisation

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

DPDFs – obey DGLAP universal for diff. ep DIS

hard scattering cross section

Proton vertex factorisation (conjecture, e.g. Resolved Pomeron Model by Ingelman&Schlein)

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

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

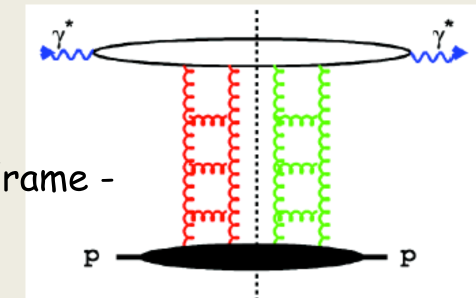
Pomeron flux factor

diffractive DPDF

Then DPDFs extracted from DIS data

Dipole model

Proton rest frame - dipoles



[C. Marquet PRD76 (2007) 094017]

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

Long living quark pairs interact with gluons of the proton

No extra parameters needed for DDIS

Diffractive reduced cross section

- select diffractive events
- correct for detector effects
- derive cross sections -> F_2^D

$$\frac{d^4\sigma(ep \rightarrow eXp)}{d\beta\, dQ^2 dx_P dt} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}(1-y+\frac{y^2}{2})\ \sigma_R^{D(4)}(\beta, Q^2, x_P, t)$$

y - inelasticity → 1-(E'$_e$/E$_e$)

$\sigma_R^{D(4)}$ → diffractive reduced cross section

$$\sigma_R^{D(4)} \approx F_2^{D(4)}$$

at low and medium *y*

$$\sigma_R^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y-\frac{y^2}{2})} F_L^{D(4)}$$

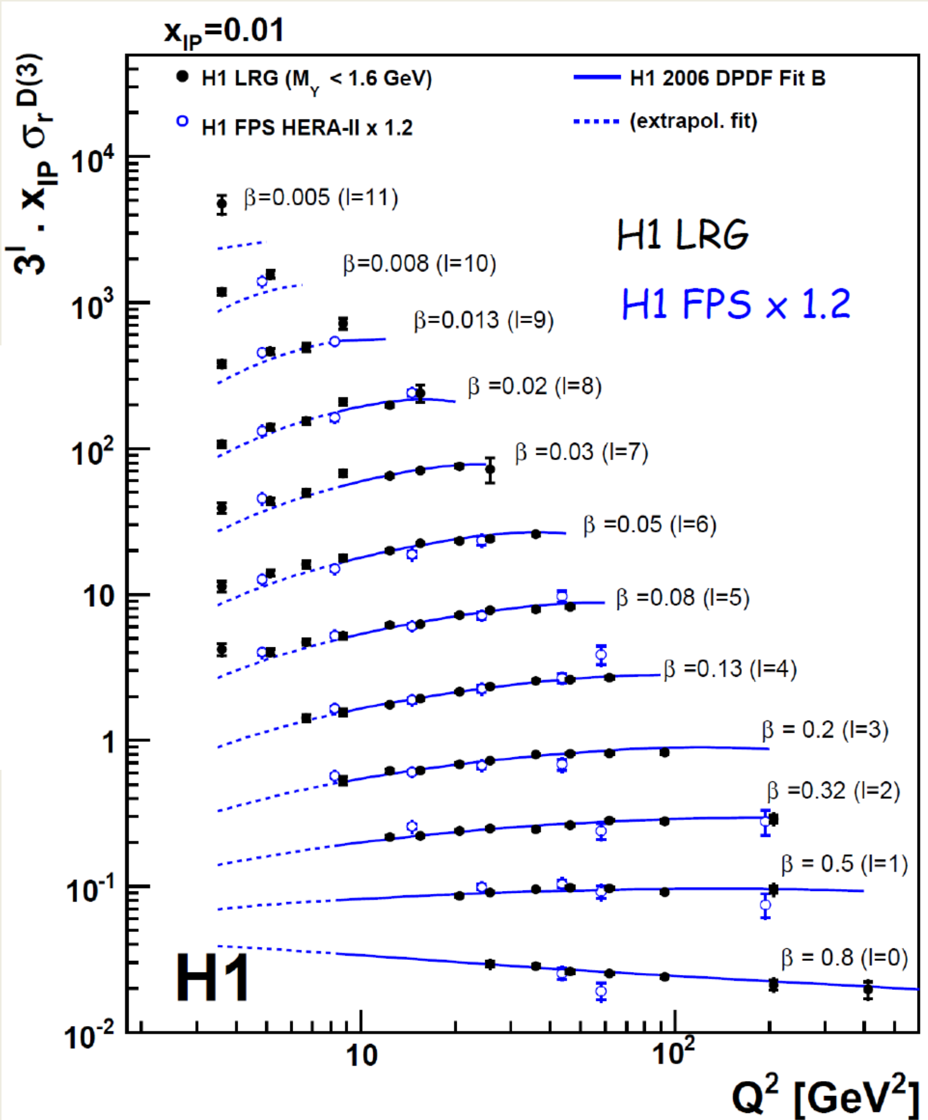
$$\sigma_R^{D(4)} = F_2^{D(4)}$$ if

$$F_L^{D(4)} = 0$$

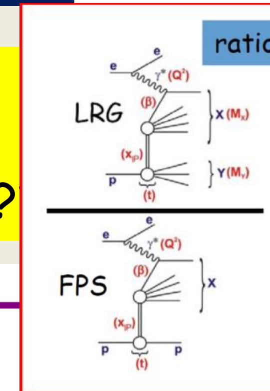
Integrate over *t* when proton is not tagged

$$\rightarrow \sigma_R^{D(3)}(\beta, Q^2, x_P)$$

Combined H1 LRG & FPS



What is the contribution of diffractive dissociation in LRG method?



The ratio LRG/FPS :

$$\frac{\sigma\,(M_Y < 1.6\,\mathrm{GeV})}{\sigma\,(Y = p)} = 1.203 \pm 0.019(\mathrm{exp.}) \pm 0.087(\mathrm{norm.})$$

(1.6%) (7.2%)

EPJC 72, (2012),2074.

FPS cross sections are multiplied by factor 1.2 to take into account the dissociation admixture in LRG sample

Agreement with previous results, no Q^2 or β dependence for the factor observed !

ZEUS

LPS/LRG=0.76 ± 0.01(st) ± $^{0.03}_{0.02}$(sy)±$^{0.08}_{0.05}$(norm)

LRG/LPS=1.31 in fair agreement with H1 within uncertainties

HERA combined $\sigma_r^{D(3)}$ - proton spectrometers

H1 FPS

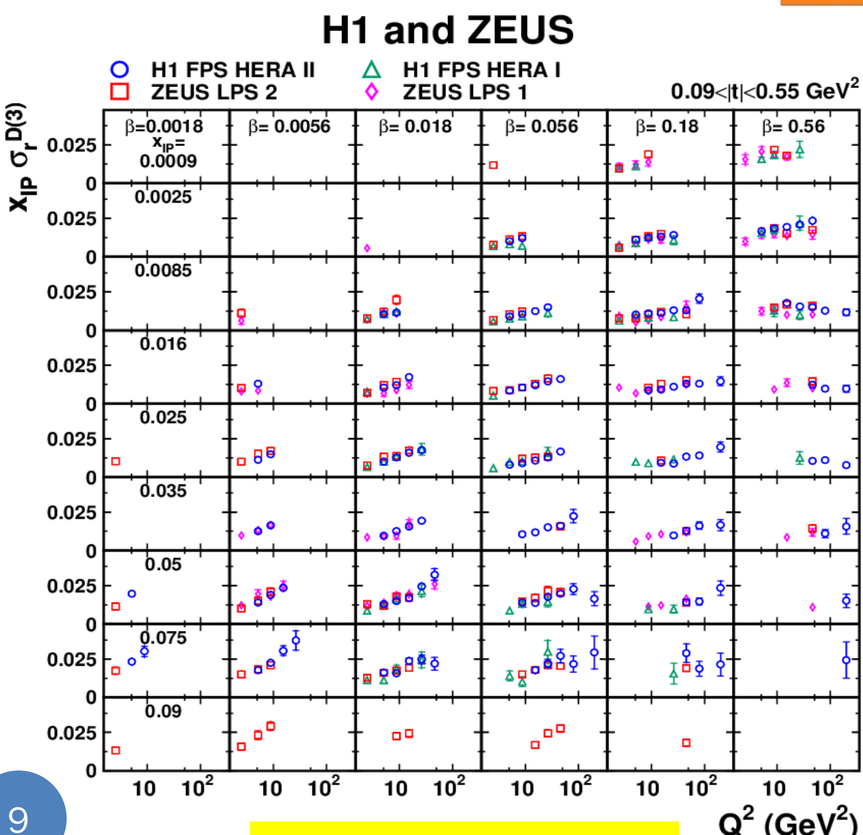
H1 Collab., Eur. Phys. J. C71 (2011) 1578
H1 Collab., Eur. Phys. J. C48 (2006) 749

ZEUS LPS

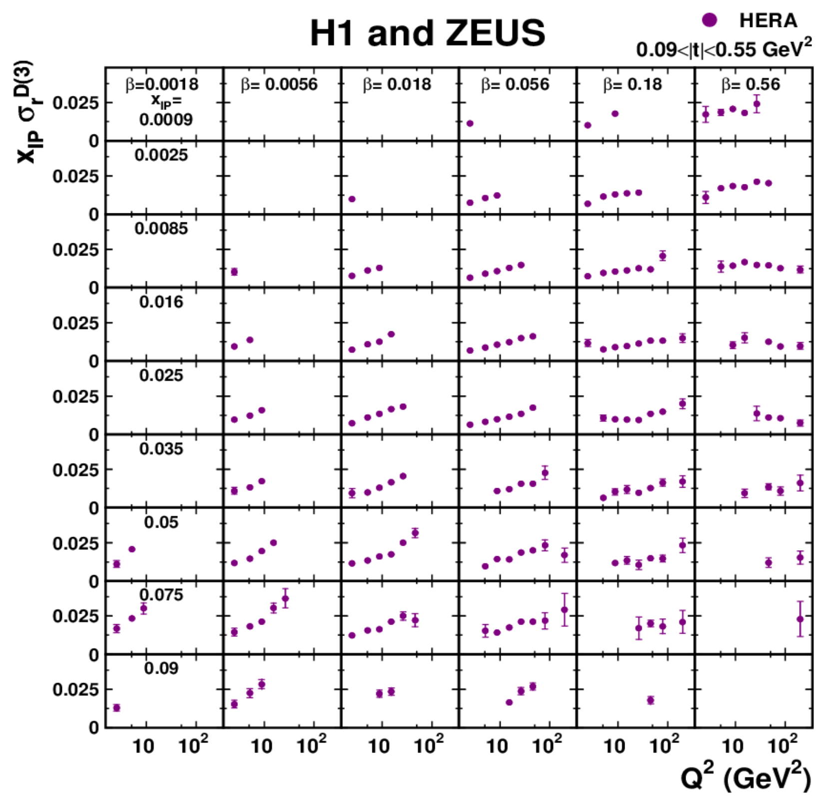
ZEUS Collab., Nucl. Phys. B816 (2009) 1
ZEUS Collab., Eur. Phys. J. C38 (2004) 43

Kinematic range

Q^2 = 2.5 - 200 GeV^2
β = 0.0018 - 0.816
x_{IP} = 0.00035 - 0.09
$|t|$ = 0.09 - 0.55

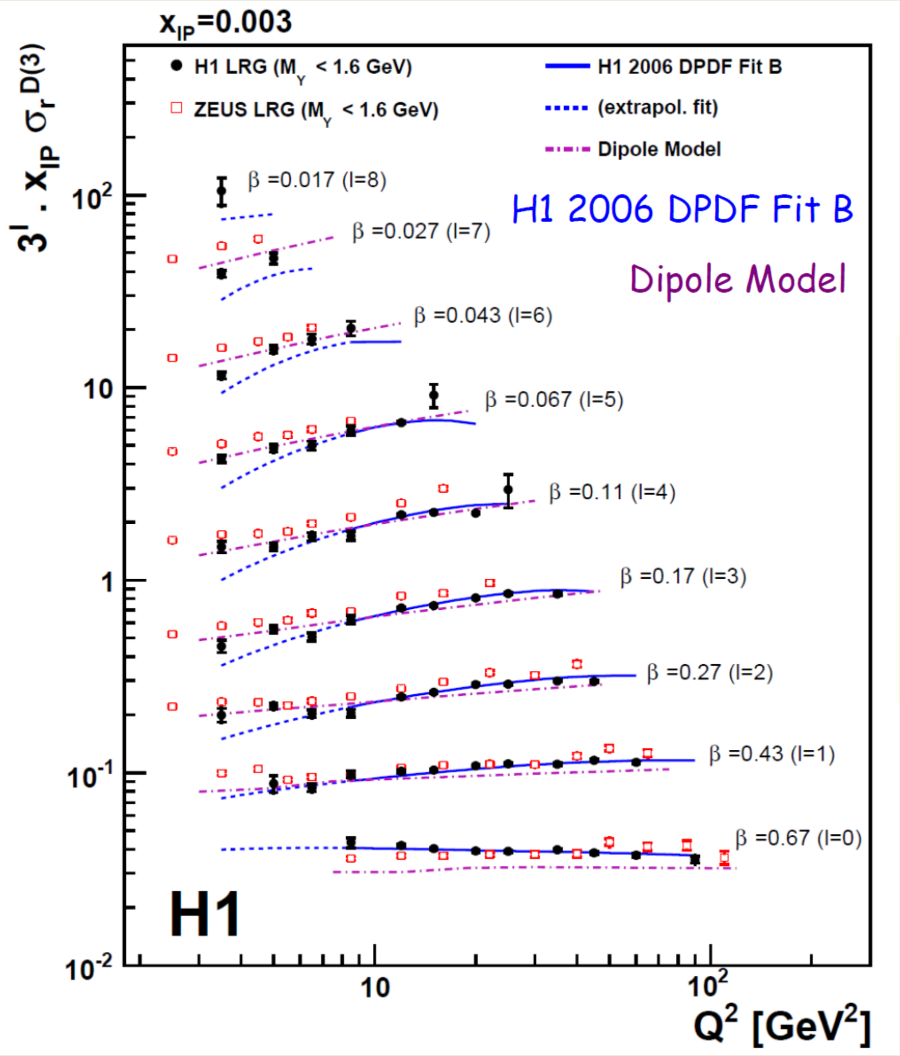


$\sigma_r^{D(3)}$ for combination



EPJC C72 (2012),2175

H1 & ZEUS-LRG, comparison with models



Normalization difference of ~ 10% between H1 nad ZEUS is within normalization uncertainties of each experiment

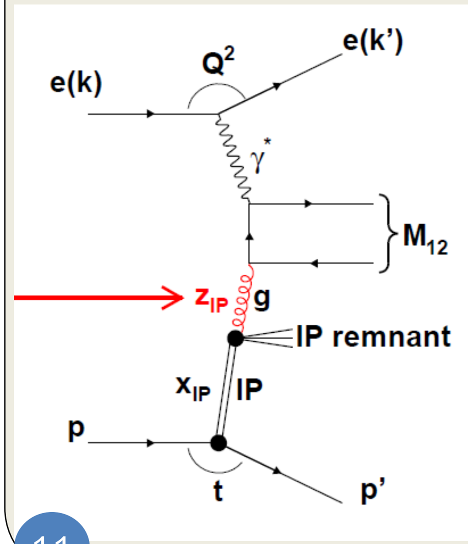
- low Q^2 – better description by dipole model, higher twist contributions?
- high Q^2 – better description by H1 fit B DPDF
- no unique tool to describe all data

Data available for comparison with models

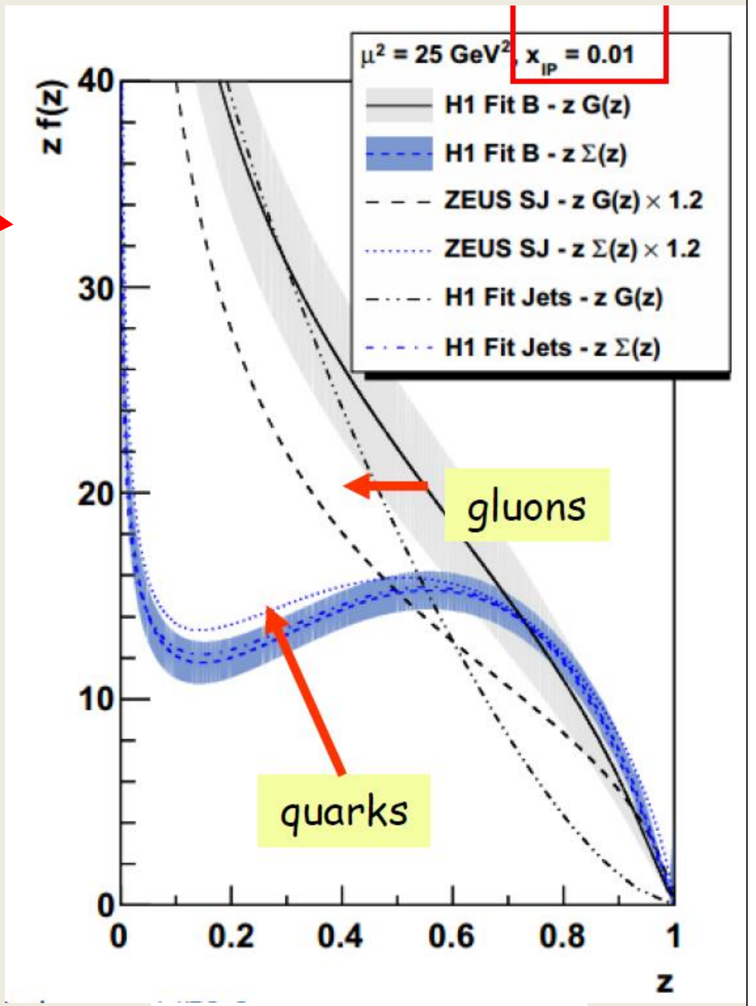
HERA LRG data combination……

DPDFs in DIS

- DPDFs obtained by H1 and ZEUS from inclusive, dijet (and D*) measurements
- **DPDFs: H1 fit B, H1 fit Jets, ZEUS fit SJ**
- Gluon exchange dominates, main differencies in fits
- **DPDFs used in NLO calculations to predict diffractive production of charm and dijets**



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



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

Factorisation tests in diffractive production

Motivation:
Factorisation was found to be broken in hadron-hadron collisions at Tevatron (D0) and LHC (CMS and ATLAS).

Measurements using HERA DPDFs compared to NLO QCD predictions.

suppression factor

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

Suppression factors $S^2 \sim 0.1$ at Tevatron and LHC.

Several theories expect factorisation breaking in diffractive ep photoproduction, due to multiple scattering, or 'absorptive' effects, which occur in the presence of beam remnants.

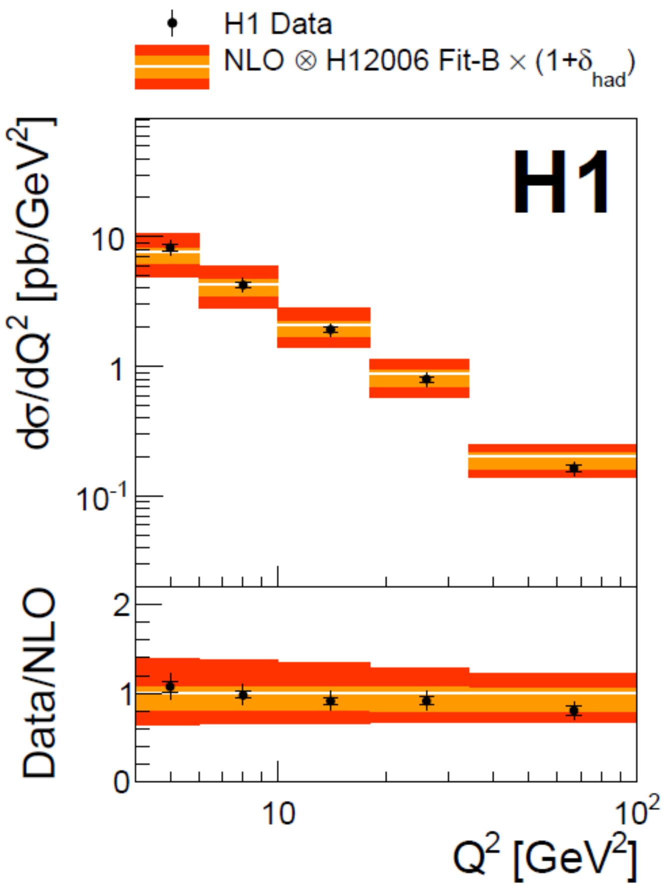
Diffractive dijet production in DIS

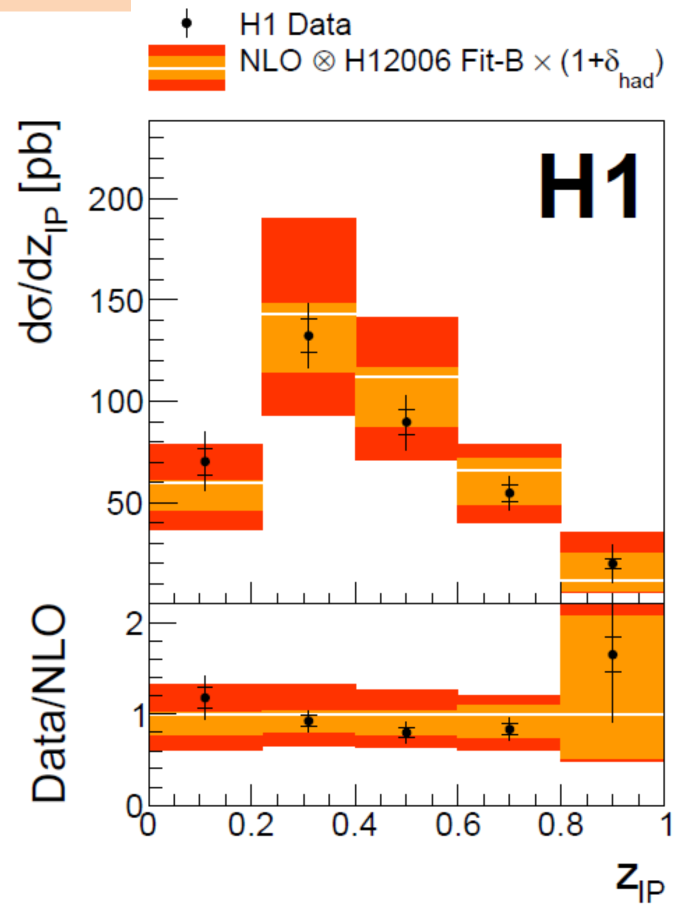
	method	Q^2 [GeV^2]	$E_{T\,jet1(2)}$[GeV]	NLO	published	suppression factor S^2
H1	LRG	<4,80>	5,(4)	DISENT	JHEP 0710:042, (2007)	~ 1
H1	LRG	<4,80>	5.5,(4)	NLOJET++	EPJC 51 (2007) 507	~ 1
ZEUS	LRG	<5,100>	5,(4)	NLOJET++ DISENT	EPJC 52 (2007),813 Nucl.Phys B831 (2010) 1	~ 1
H1	Proton detected, FPS	<4,110>	5,(4)	NLOJET++	EPJC 72, (2012),1970	~ 1
H1 new	LRG	<4,100>	5.5,(4)	NLOJET++	JHEP 1503 (2015) 092	0.95 ±0.09(exp) ±0.3(th)
H1 new	Proton detected, VFPS	<4,80>	5.5,(4)	NLOJET++	JHEP 1505 (2015) 056	1.08 ±0.11(exp) ±0.4(th)

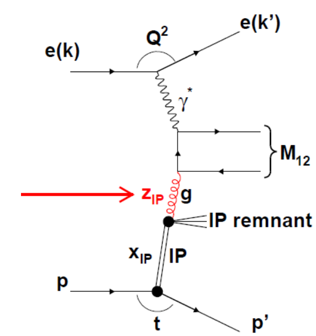
All measurements in agreement with NLO QCD calculations within uncertainties, factorisation confirmed.

Most recent -diffractive dijet production in DIS

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

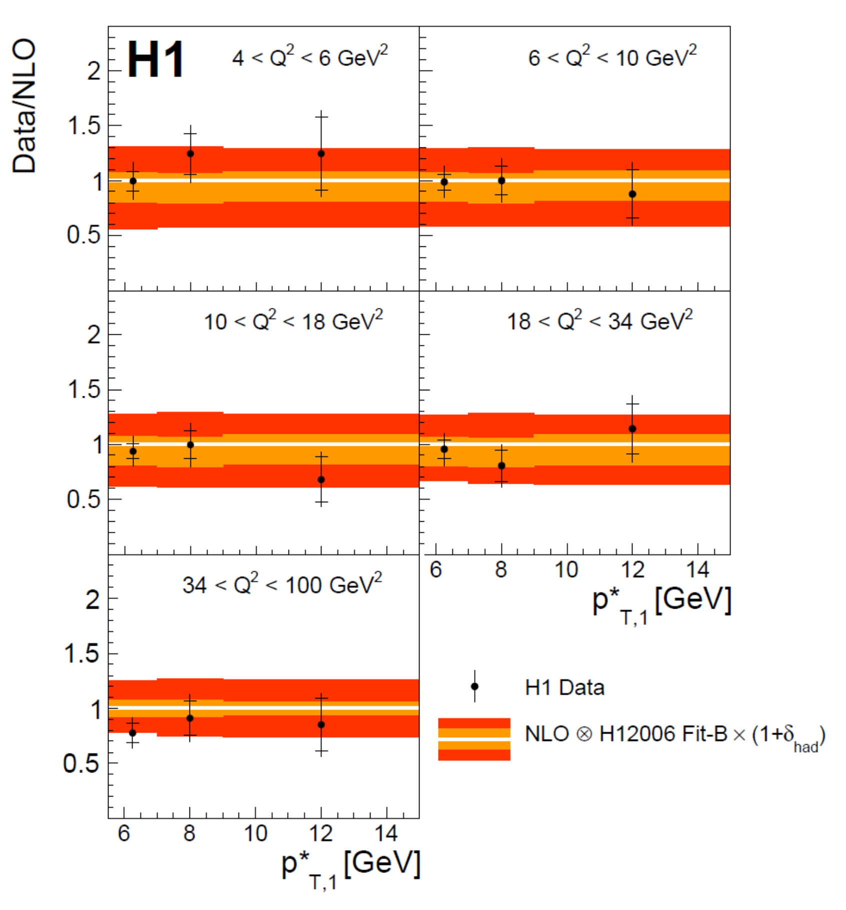


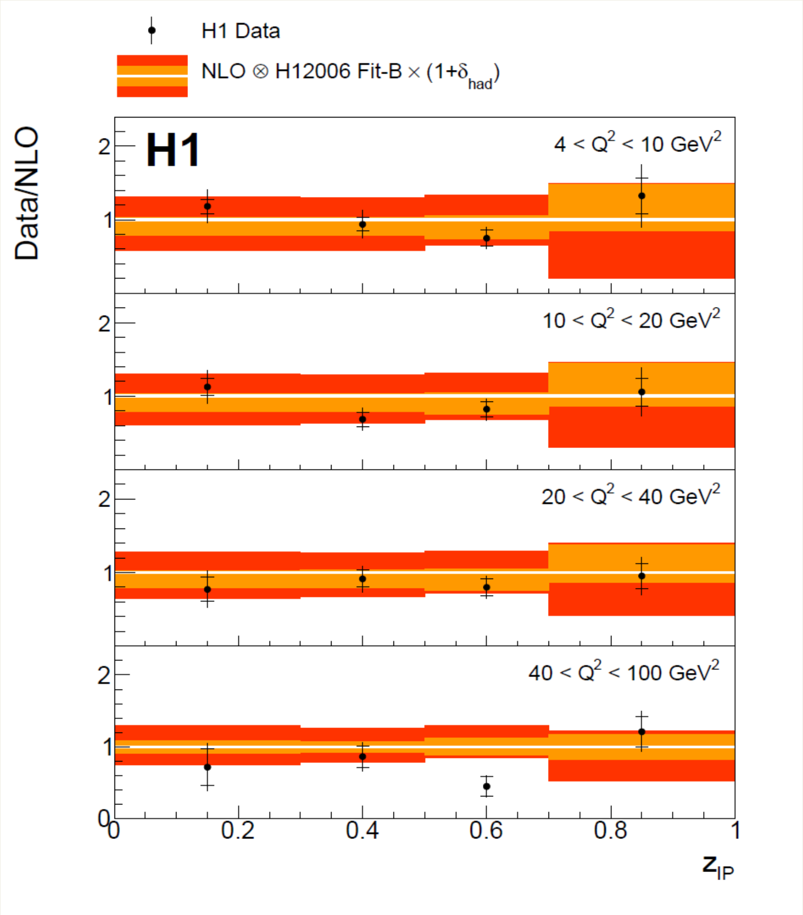




Measurements in agreement with NLO QCD calculations, factorisation confirmed.

Most recent -diffractive dijet production in DIS



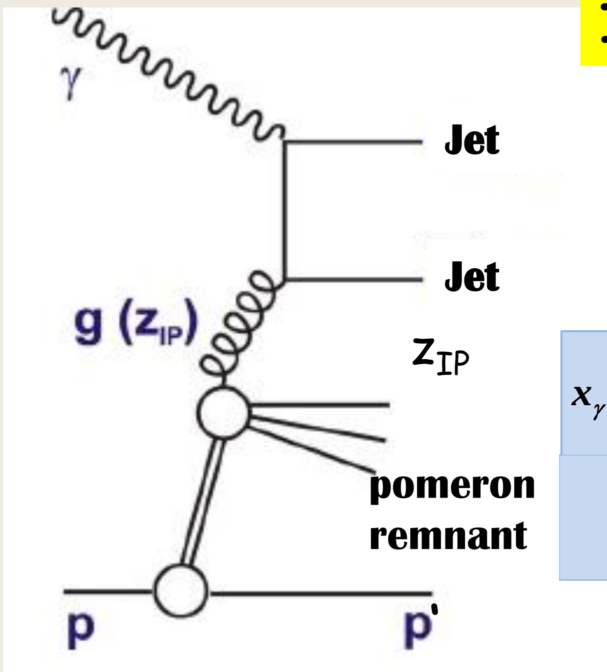


$$\alpha_s(M_Z) = 0.119 \pm 0.004\,(\mathrm{exp}) \pm 0.012\,(\mathrm{DPDF,theo})$$

Result is consistent within uncertanties with the world average

Factorisation tests in diffractive dijet photoproduction

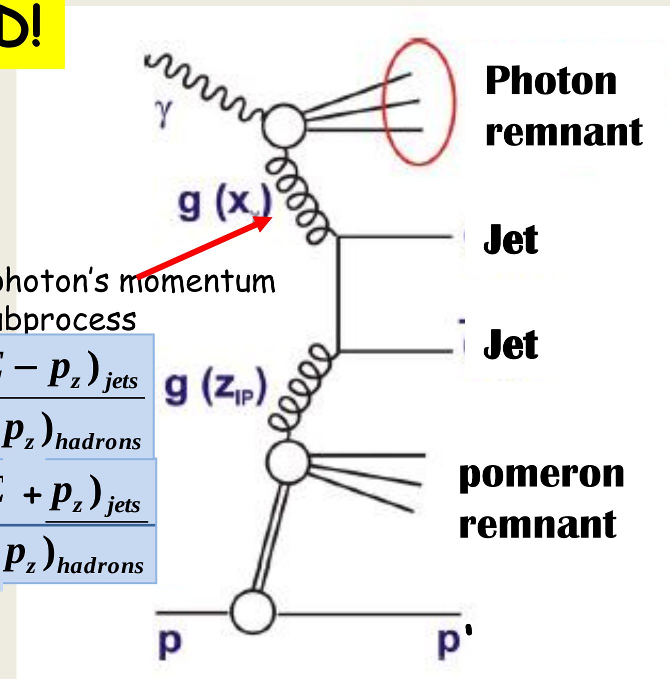
In LO QCD!



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 production in photoproduction

	method	Q^2[GeV^2]	$E_{T\ jet1(2)}$[GeV]	NLO	published	suppression factor
H1	LRG	tagged	5,(4)	Frixione	JHEP 0710:042, (2007)	0.5 ± 0.1
ZEUS	LRG	untagged	7.5,(6.5)	Klasen,Kramer Frixione	EPJC 55 (2008) 177 Nucl.Phys B831 (2010) 1	~ 0.9-1
H1	LRG	tagged	5,(4)	Frixione Klasen,Kramer	EPJC 52 (2010),15	0.58 ±0.01±0.12(exp) ±0.14±0.09(th)
H1 new	Proton detected, VFPS	untagged	5.5,(4)	Frixione	JHEP 1505 (2015) 056	0.511 ±0.085(exp) ±0.02(th)

In NLO calculations used mostly H1 2006 fit B.
H1 observed factorisation breaking by a factor 0.5, ZEUS results compatible with no suppression

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

DIS	&	photoproduction
$4 < Q^2 < 80\ GeV^2$		$Q^2 < 2\ GeV^2$

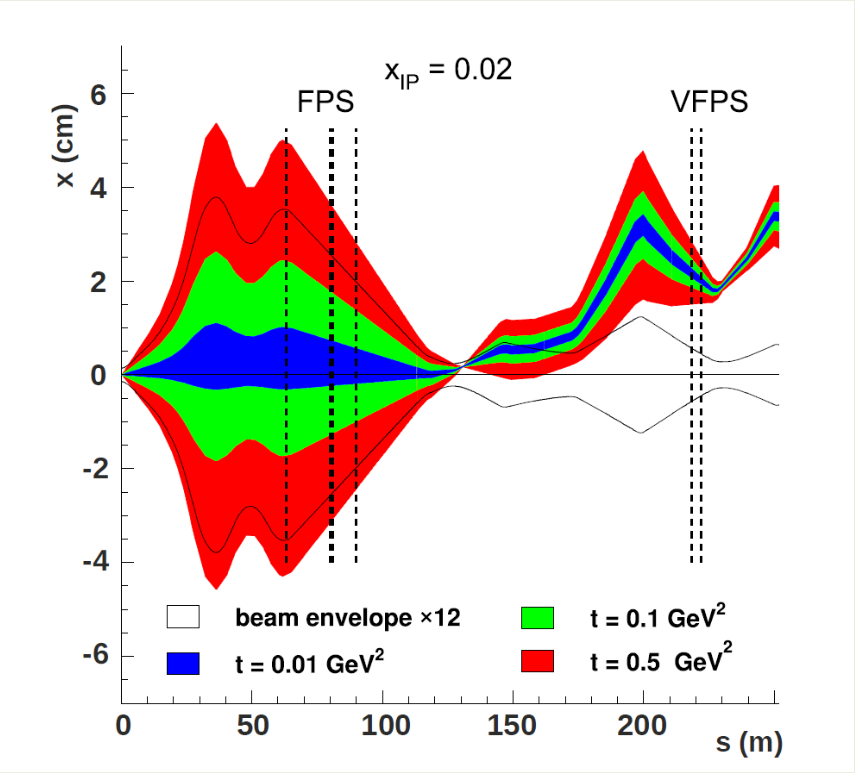
other cuts identical:

$0.01 < x_{IP} < 0.024$

$|t| < 0.6\ GeV^2$

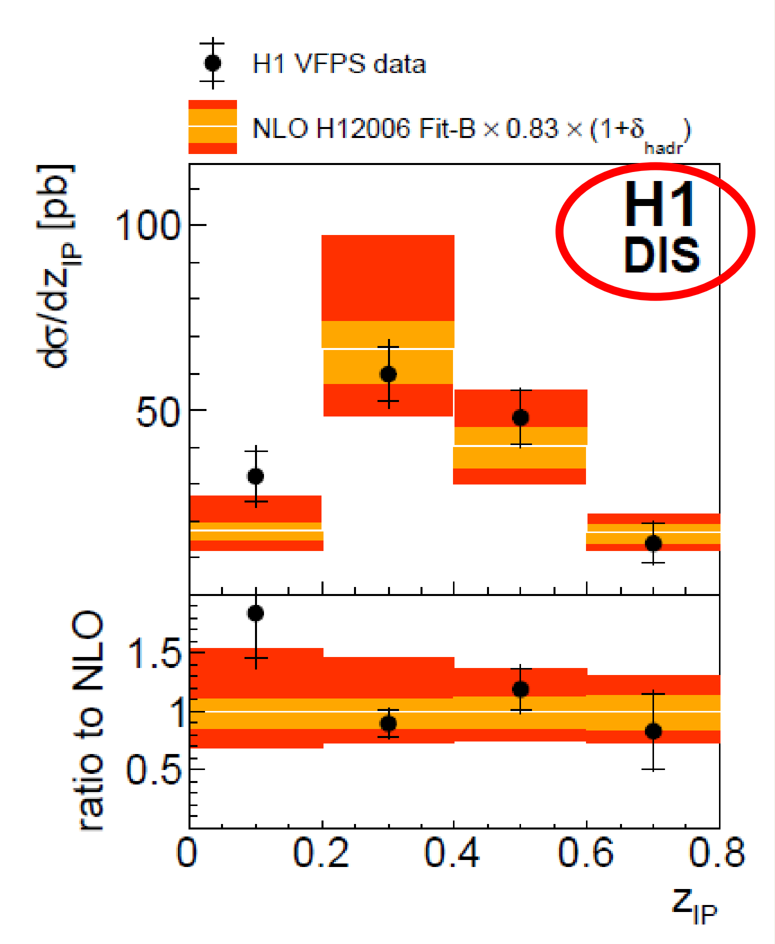
$z_{IP} < 0.8$

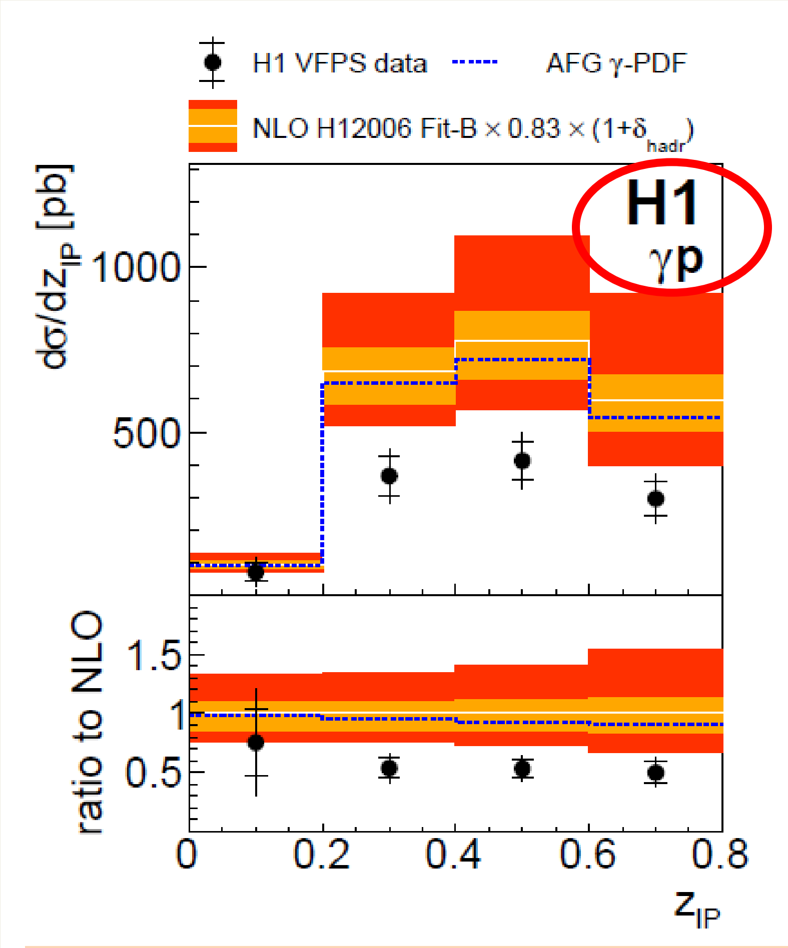
$E_T^*{}_{jet1(2)} > 5.5(4)\ GeV$
$-1 < \eta_{jet1(2)} < 2.5$



Independent cross-check of LRG measurements – without proton dissociation!

Diffractive dijet photoproduction & DIS

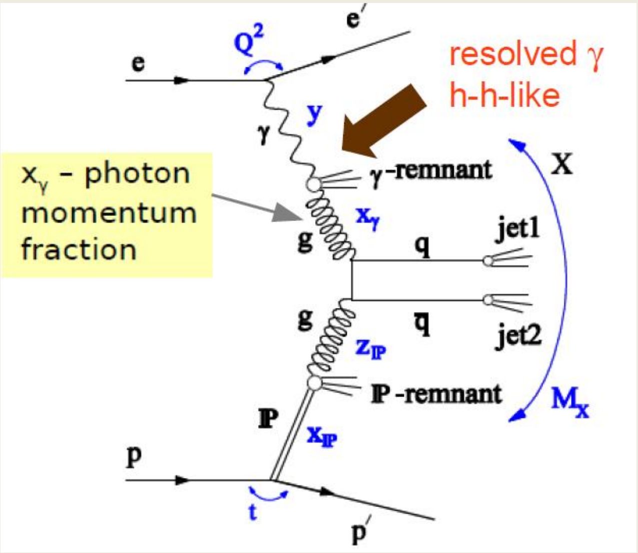




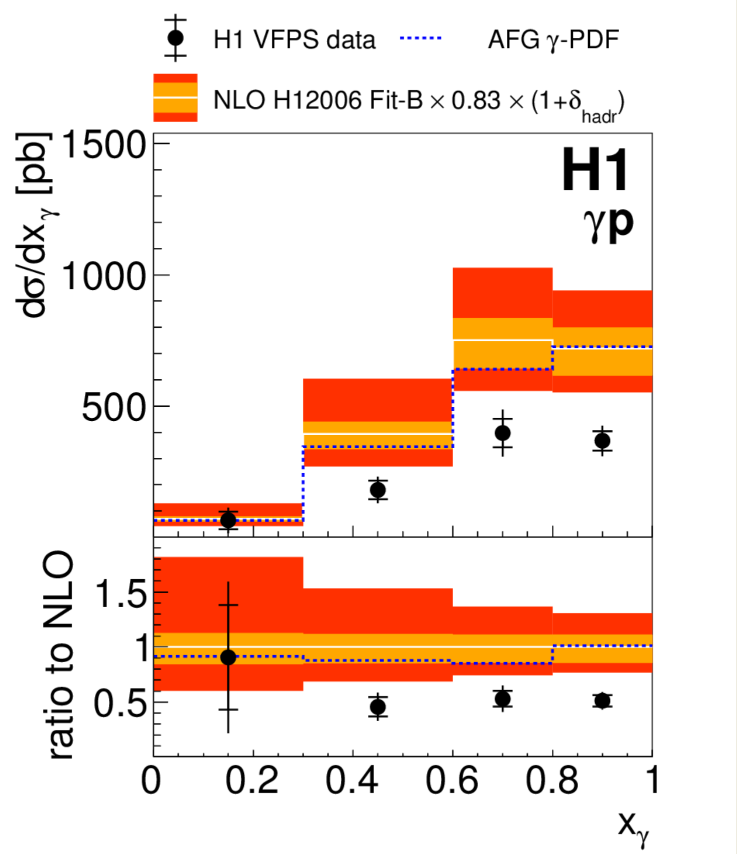
Data in agreement with NLO in DIS, within uncertainites

Data suppressed in comparison with NLO in photoproduction

Diffractive dijet photoproduction

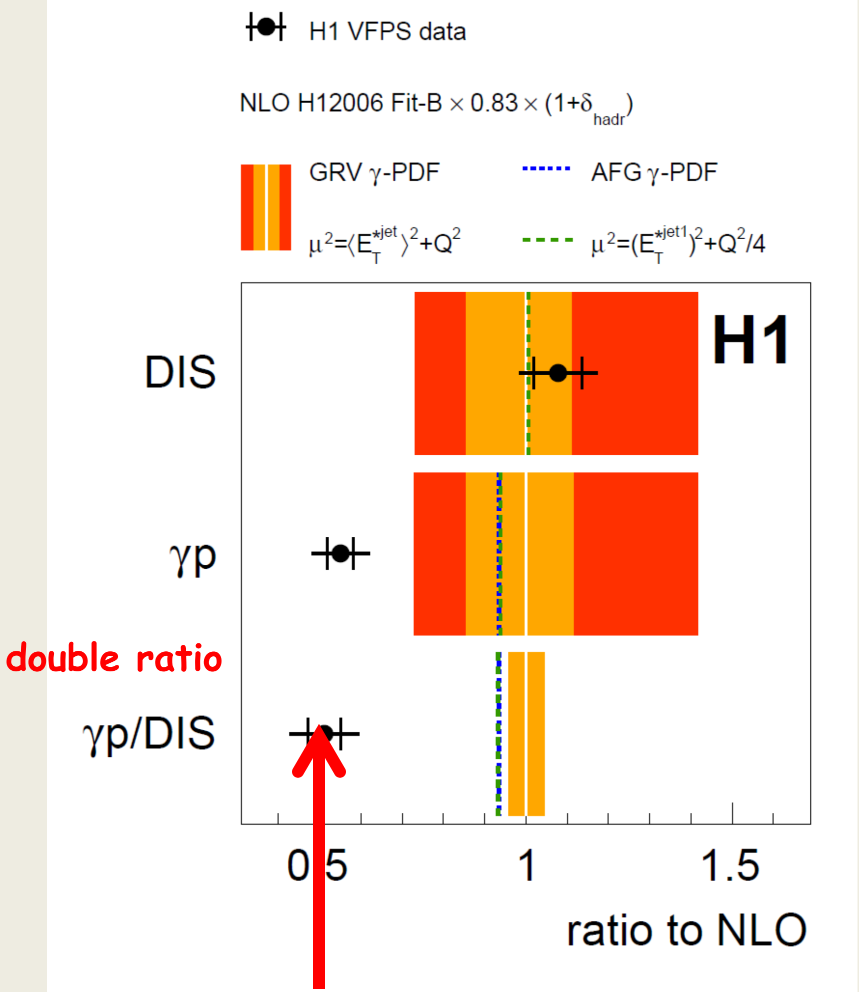


$$x_\gamma = x_\gamma^{OBS} = \frac{\sum (E - p_z)_{jets}}{(E - p_z)_{hadrons}}$$



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

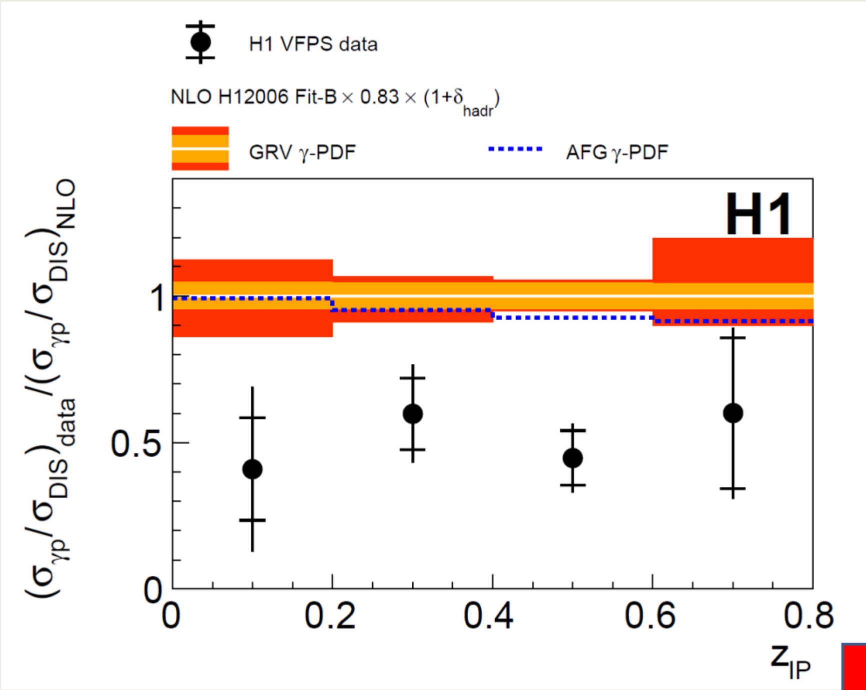
Diffractive dijet photoproduction & DIS

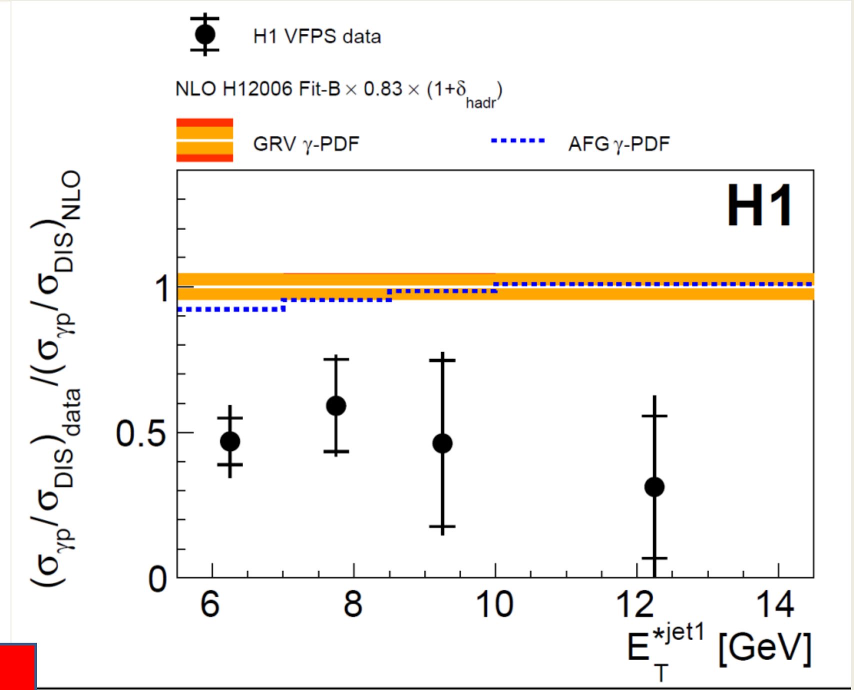


Previous H1 measurements confirmed, factorisation breaking in diffractive dijet photoproduction by factor ~ 0.5 observed

Diffractive dijet photoproduction & DIS

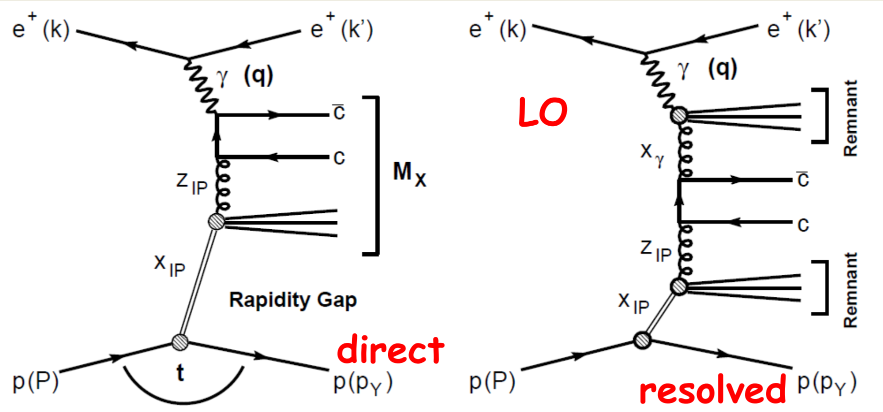
Double ratio photoproduction/DIS



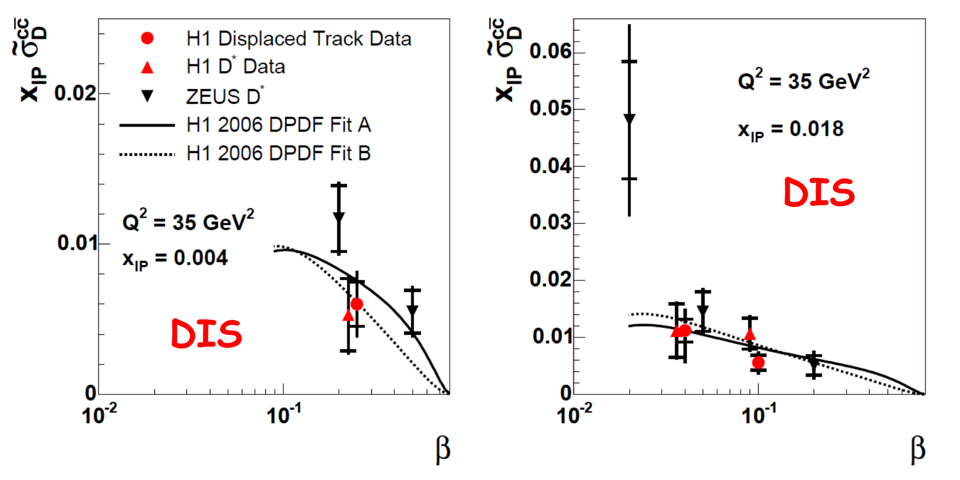


Dependence of the suppression on E_T^* of the leading jet and z_{IP} not observed!
The reason of the difference of suppression for H1 and ZEUS is not connected with different phase space in E_T of jets

Diffractive D* production in DIS & photoproduction



- hard scale -> mass of D*
- sensitive to gluon content
- direct production dominates -> not so sensitive test of possible factorisation breaking



EPJC 50 (2007) 1

Good agreement with NLO QCD calculations

Charm contribution to F_2^D ~ 20% - similar as for inclusive DIS

10.9.2015

Diffractive D* production in DIS & photoproduction

	method	Q^2[GeV^2]	fragmentation	NLO	published:	factorisation
ZEUS	LRG	DIS <1.5,200>	Peterson	HVQDIS	NuclPhys B672 (2003) 3	OK
H1	LRG	DIS <2,100> <15,100>	Peterson	HVQDIS	EPJC 50 (2007) 1	OK
ZEUS	LRG	photoproduction untagged	Peterson	FMNR	EPJC 51 (2010),15	OK
H1	LRG	photoproduction tagged	Peterson	FMNR	EPJC 50 (2007) 1	1.15 ±0.50(exp) ±0.08(th)

H1 measured double ratio

$$R^{\gamma p}_{\mathrm{DIS}} = \frac{\left(\sigma^{\mathrm{meas}}/\sigma^{\mathrm{theo}}\right)_{\gamma p}}{\left(\sigma^{\mathrm{meas}}/\sigma^{\mathrm{theo}}\right)_{\mathrm{DIS}}}$$

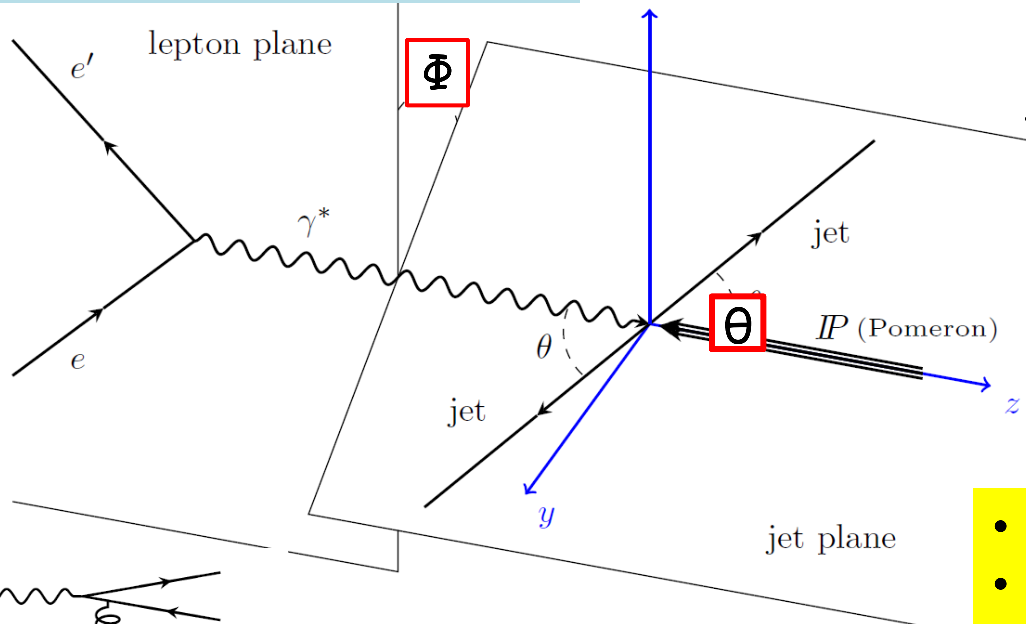
Consistent with factorisation within large uncertainies

New -exclusive dijets in diffractive DIS

How to distinguish between diffractive models???

e + p → e' + p' + jet + jet

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



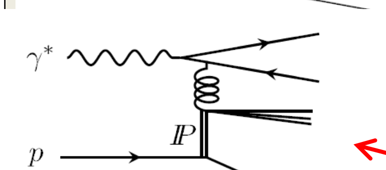
J.Bartels et al.,Phys.Lett.B386,(1996)389

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

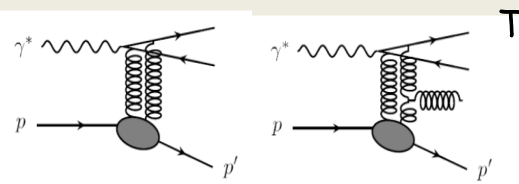


2 jets

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

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

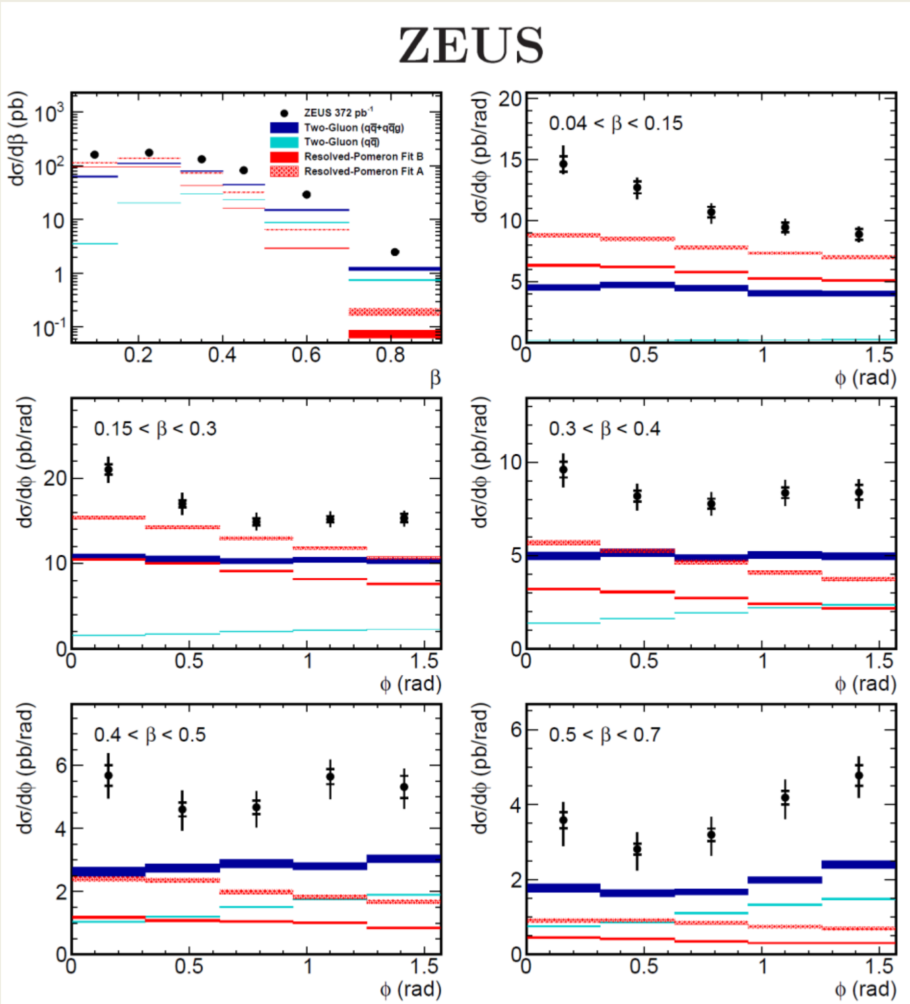
RAPGAP



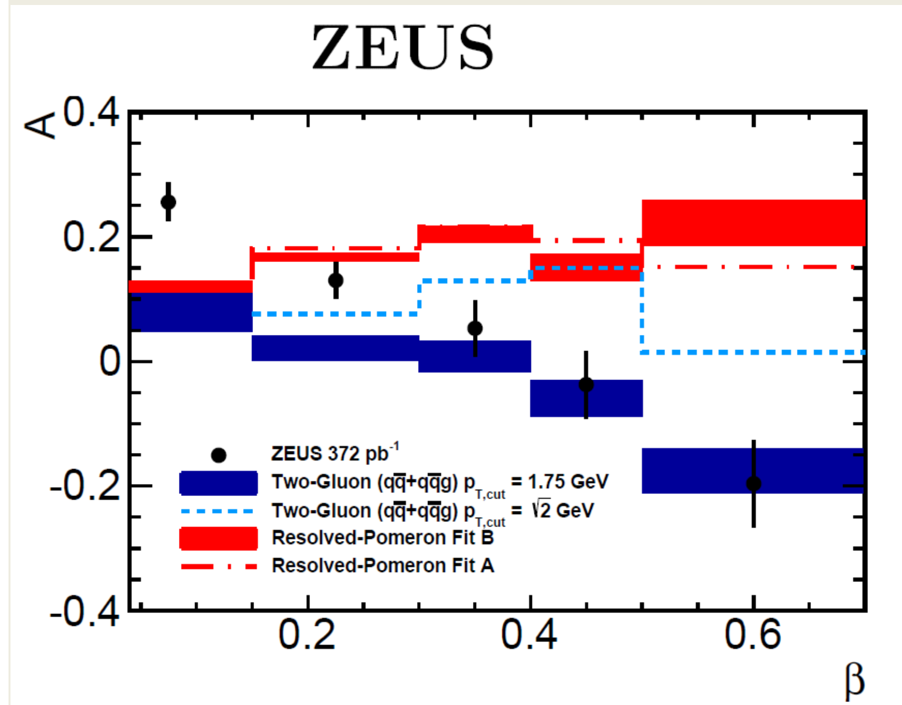
2 jets 3 jets

2.7.2015

New-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 β > 0.3) than Resolved Pomeron model (large uncertainty due to p-diss subtraction, is not shown here)

Conclusions

- H1 and ZEUS measured inclusive diffractive cross sections using different methods of diffraction selection and determined Diffractive Parton Density Functions (DPDFs).

- Measured DPDFs were applied in NLO calculations to wide variety of observables for DIS and photoproduction – tests of QCD collinear factorisation.

- In diffractive DIS QCD factorisation confirmed
- In dijet photoproduction ZEUS results consistent with factorisation, H1 measured suppression factor S^2~0.5 using both LRG and proton detection selection
- In diffractive D* production within large uncertainties QCD factorisation confirmed for both DIS and photoproduction
- Measurements of exclusive dijet production (ZEUS) prefer in LO Two Gluon exchange model to Resolved Pomeron model