Inclusive and Dijet Diffractive Production at HERA

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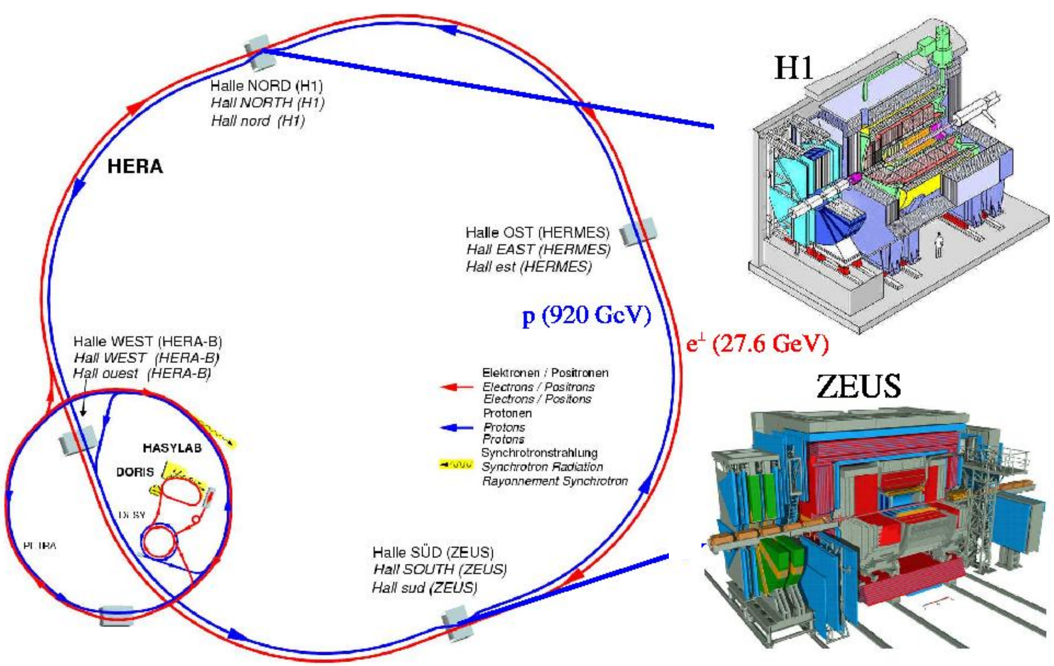
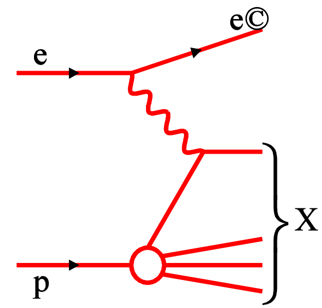
Representing H1 and ZEUS collaborations

14th EDS Workshop,Qui Nhon

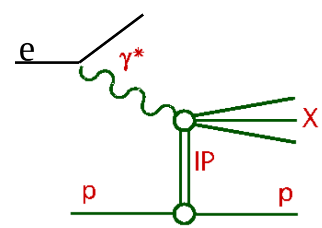
HERA collider experiments

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



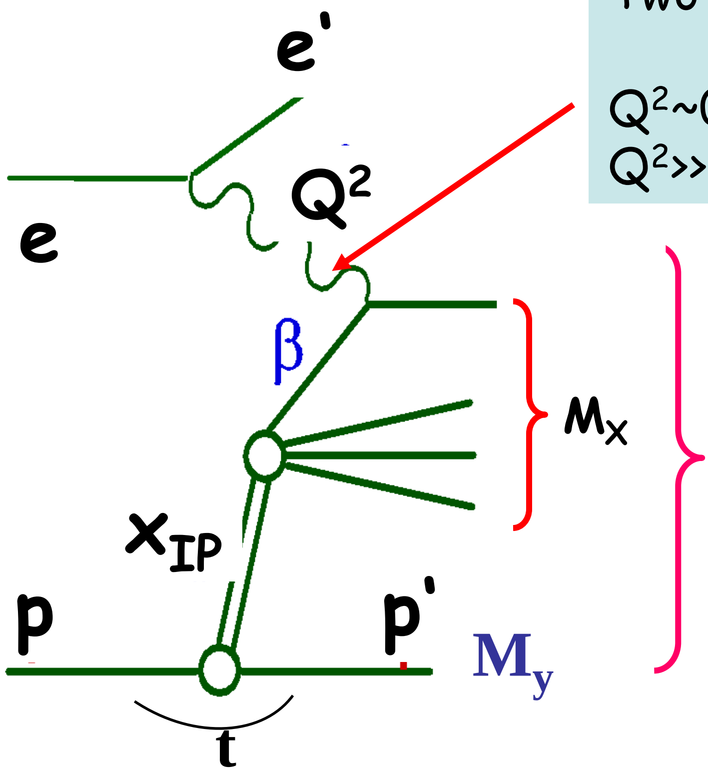


DIS: Probe structure of proton → F_2



Diffractive DIS: Probe structure of difraction → F_2^D

Diffraction and diffraction 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

W

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

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

Diffractive reduced cross section

y - inelasticity → 1-(E'$_e$/E$_e$)

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

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

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

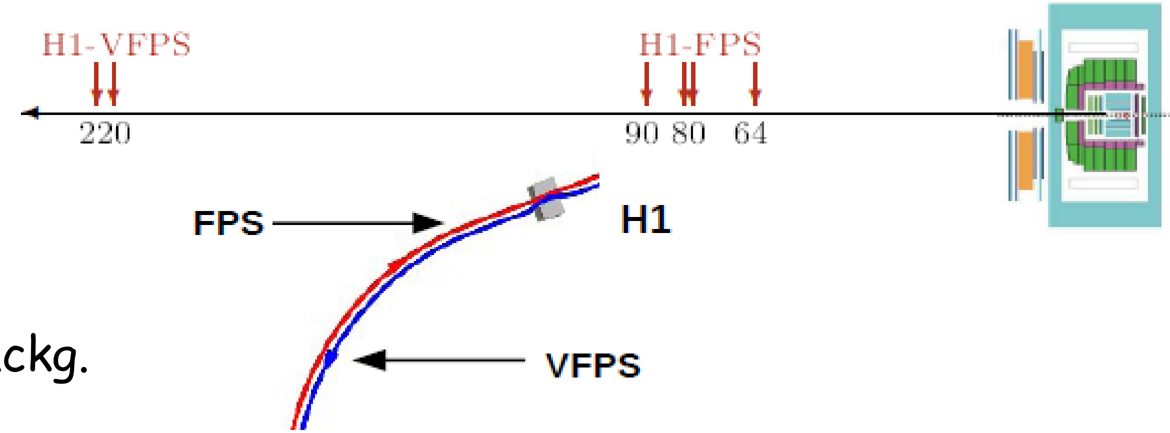
$\sigma_R^{D(4)} \approx F_2^{D(4)}$ at low and medium y

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

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

Integrate over t when proton is not tagged
→ $\sigma_R^{D(3)}(\beta,Q^2,x_P)$

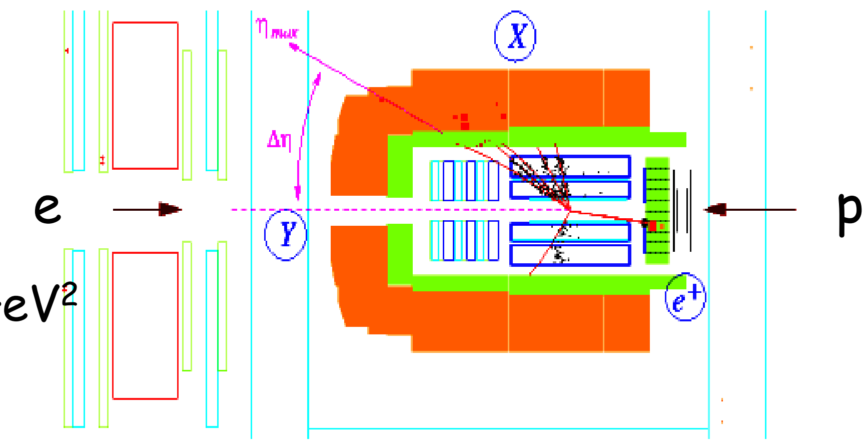
Methods of diffraction selection



Proton spectrometers

ZEUS: LPS (1993-2000)
H1: VFPS (2002-2007)
FPS (1997-2007)

- free of p-dissociation backg.
- x_{IP} and t measurements
- access to high x_{IP} range (IP and IR)



Large Rapidity Gap, H1, ZEUS:

- require no activity beyond η_{max}
- t not measured, integrated over $|t|<1$ GeV^2
- very good acceptance at low x_{IP}
- p-diss background about 20%

Different systematics – non-trivial to compare!

Comparison between methods

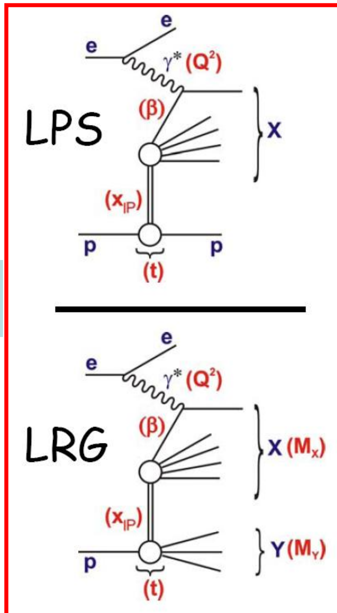
Are „rapidity gap“ and „forward proton“ methods compatible?

- LRG selection contains about 20% events of proton diss.
- no significant dependence on any variable
- well controlled, precise measurements

ZEUS, LPS/LRG = $0.76 \pm 0.01 \pm^{0.03}_{0.02} \pm^{0.08}_{0.05}$

LRG/LPS ~ 1.32

ratio



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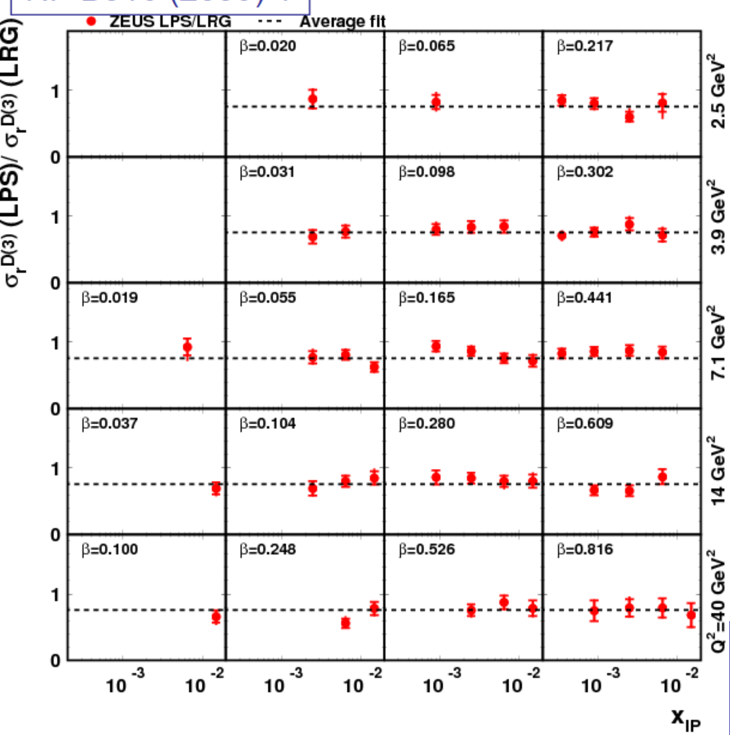
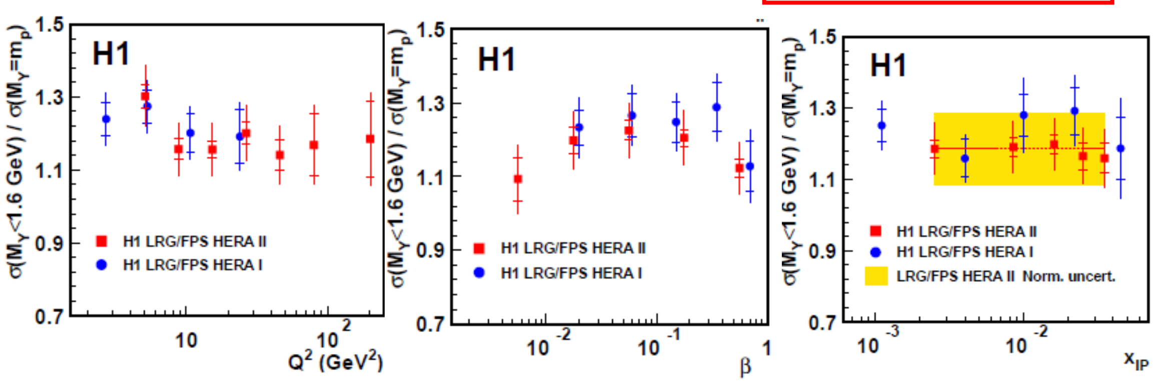


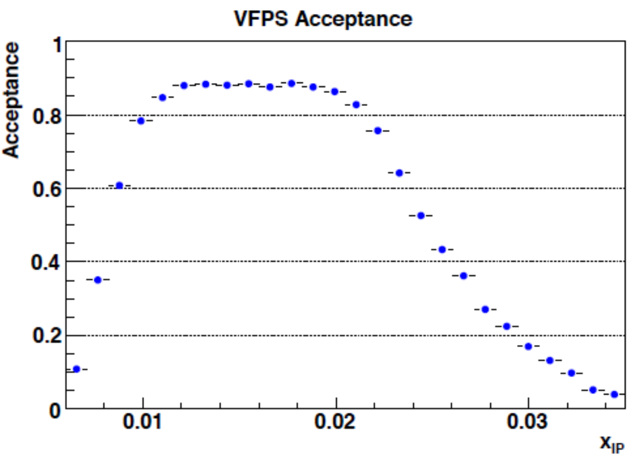
EPJ C71 (2011) 1578

H1, LRG/FPS = 1.20 ± 0.11 (exp)



Precise knowledge and corrections for proton dissociation background- key point in H1- ZEUS data comparison

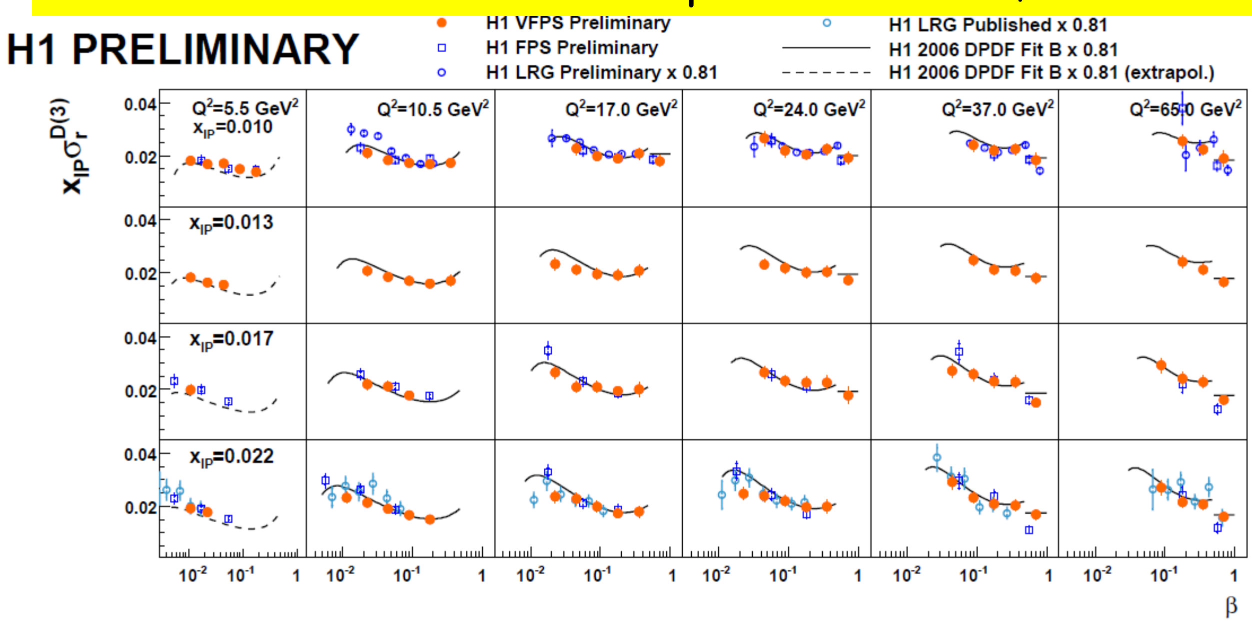
H1 VFPS



- high acceptance ~ 90% for $0.009 < x_{IP} < 0.026$ and $|t|<0.5$ GeV^2
- high track reconstruction efficiency ~ 96%
- low background < 2%

Calibrated using exclusive ρ production, resulting in a well understood high acceptance proton spectrometer

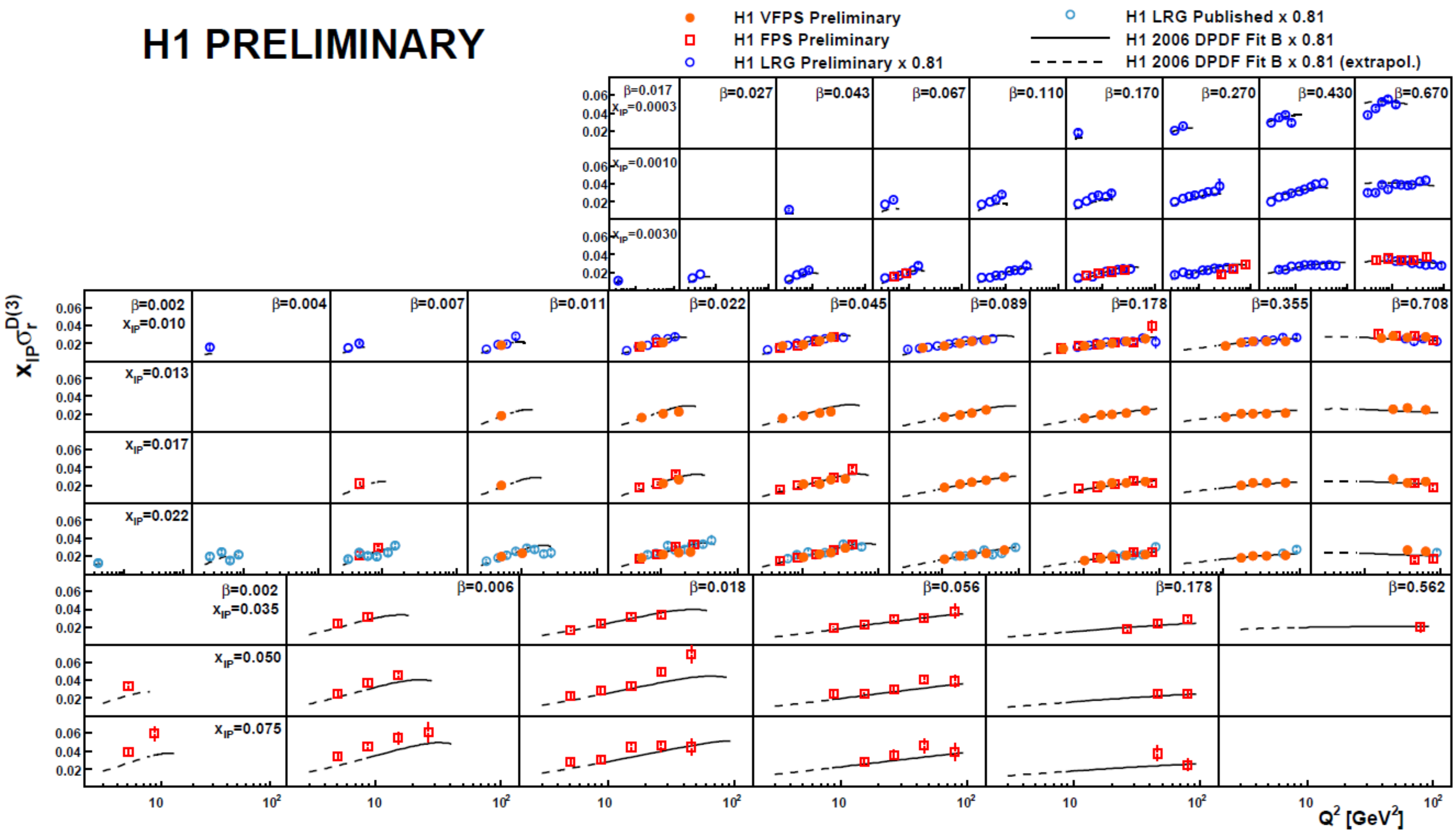
Reduced cross section – comparison of LRG, FPS VFPS methods



$\sigma_r^{D(3)}$ for $|t|<1$ GeV^2

H1 prel-10-014

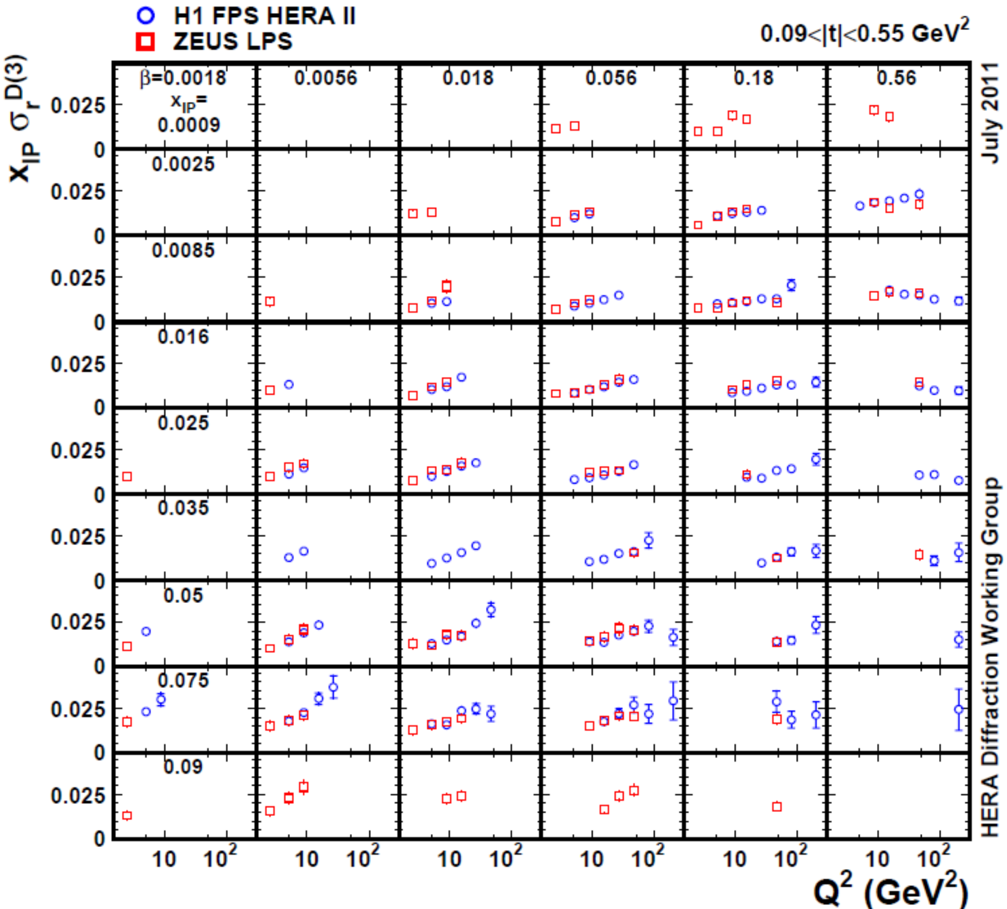
Inclusive -> VFPS & FPS & LRG



→ compilation of VFPS, FPS and LRG data vs H1 DPDF Fit B

$$\frac{\text{VFPS}}{\text{FPS}} = 0.96 \pm 0.02(\text{stat.}) \pm 0.11(\text{syst.}) \pm 0.08(\text{norm.})$$

H1 FPS & ZEUS LPS



H1 prel-11-111, ZEUS prel-11-011

Proton Spectrometer data in 0.09<|t|<0.55GeV^2

Q^2-dependence in (β,x_{IP}) bins

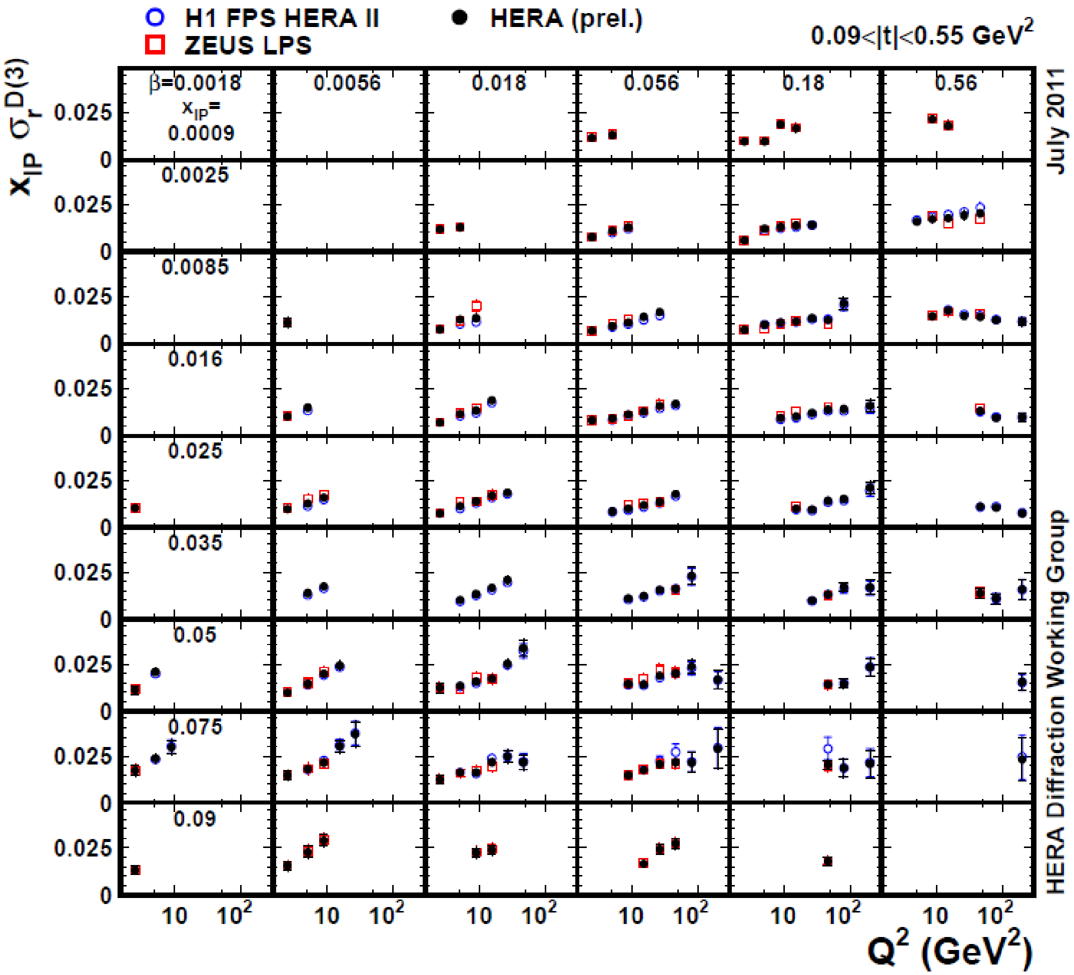
- H1 FPS norm. uncertainty 4.5%, ZEUS LPS norm. uncertainty 7%

H1 / ZEUS: = 0.91 +/- 0.01(stat.) +/- 0.03(syst.) +/- 0.08(norm.)

➔ Reasonable agreement of H1 FPS HERA-2 and ZEUS LPS data in shape & normalisation

➔ Combine H1 and ZEUS cross sections to extend phase space and reduce uncertainties

H1 FPS & ZEUS LPS



Big step forward!
First combination of H1 and ZEUS diffractive data.

Two experiments calibrate each other resulting in reduction of systematic uncertainties.

Two types of factorisation

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)

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

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

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

It allows the extraction of DPDFs from the (DIS) data

H1 and ZEUS –QCD fits assuming Regge factorisation for DPDF

For larger x_{IP} also Reggeon contribution!

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

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

pomeron flux factor

pomeron PDF

Tests of QCD factorisation

Basic strategy:

- measure a particular diffractive final state
- compare the measurement with NLO calculation using DPDFs previously extracted

What kind of final states?

- processes with a hard scale
- sensitive to gluons (gluons contribute by up to 80% to the DPDFs)

Factorisation confirmed for DIS dijet measurements, D* production in DIS and photoproduction (within large errors) by H1 and ZEUS.

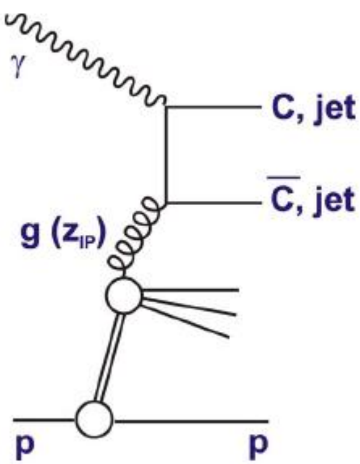
DPDFs in DIS

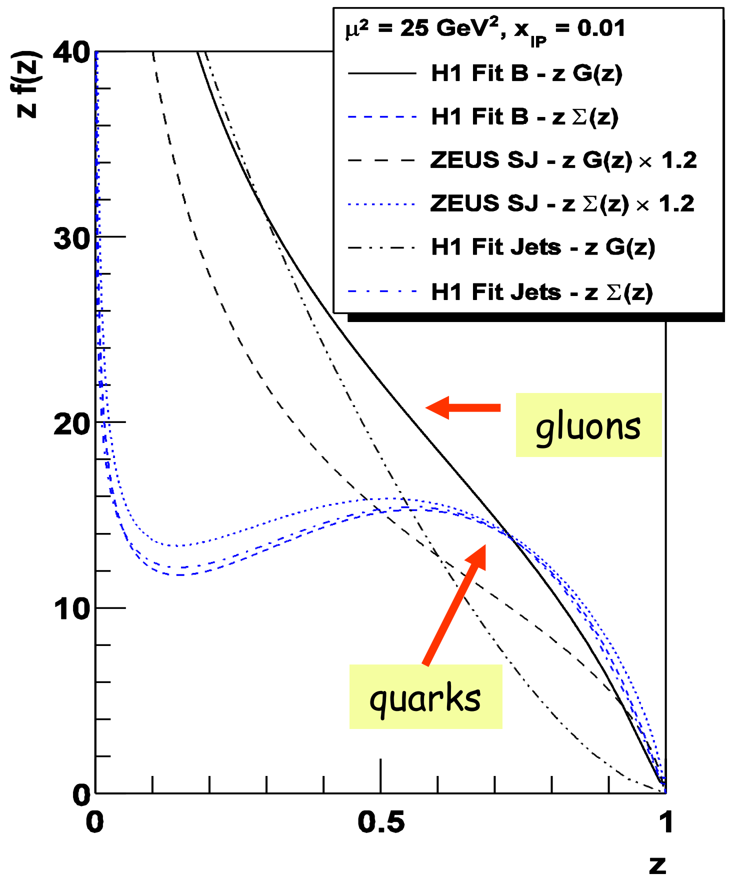
Both collaborations used in the past dijet data to improve DPDFs, mainly its gluonic part (combined inclusive & dijet QCD fits)

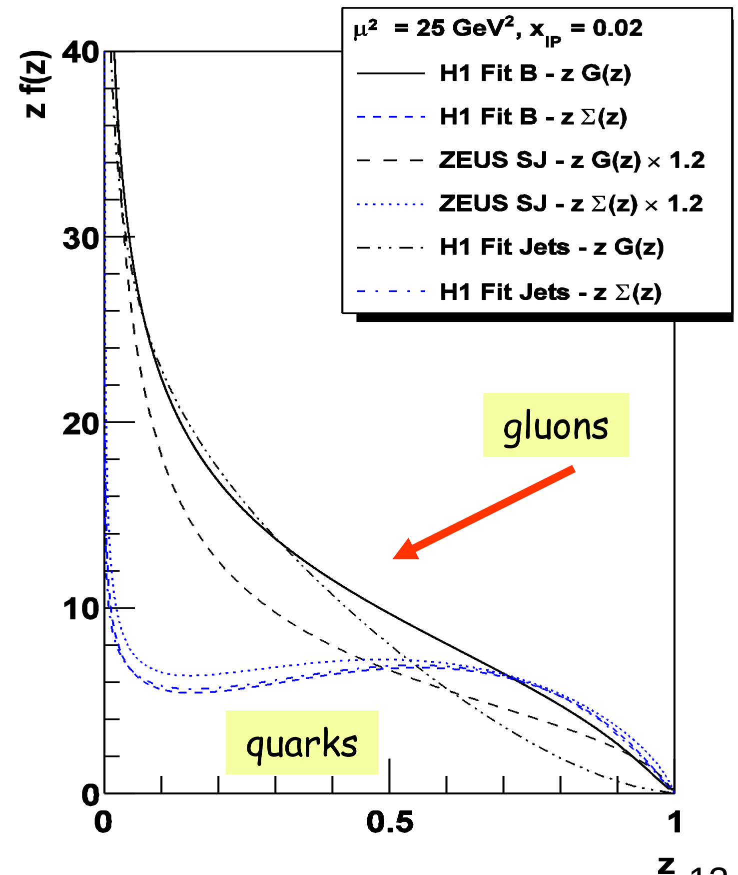
H1: JHEP,0710:042,(2007) -> H1 fit jets

ZEUS: Eur.Phys.J.C52: 83 (2007) -> ZEUS fit SJ

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



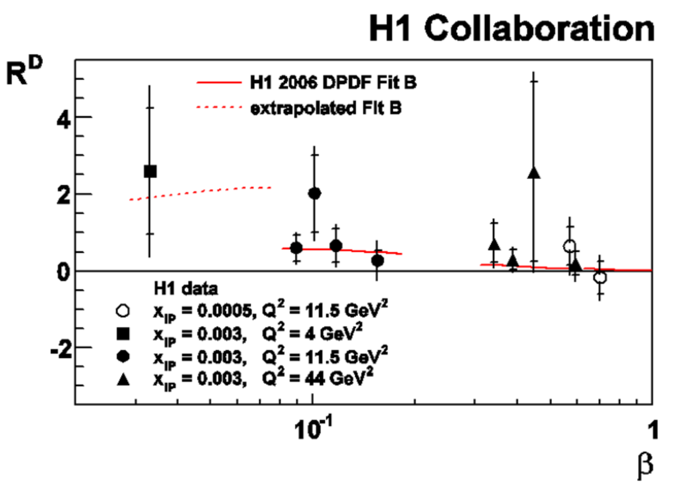


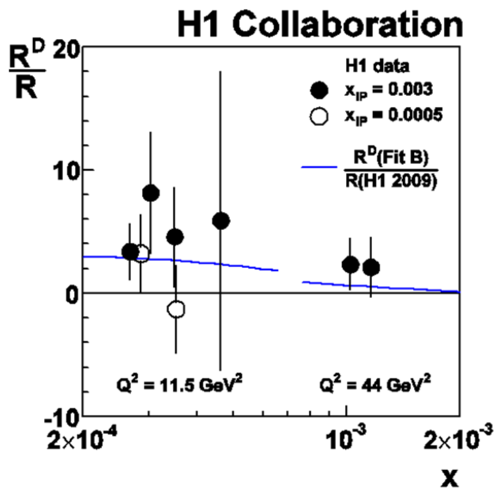


F_L^D structure function

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

$R = \sigma_L / \sigma_T \rightarrow F_L^D / (F_2^D - F_L^D)$





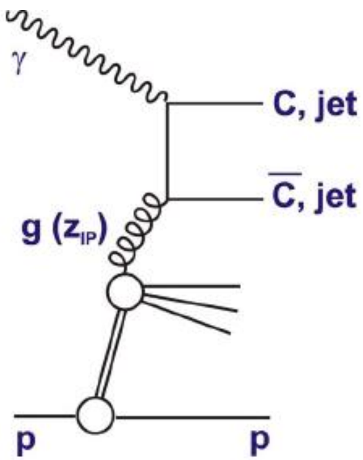
- → measure σ_R^D at fixed Q^2,x_{IP},β, but different y using LRG data at different proton energies (460 GeV,575 GeV,820 GeV,920 GeV)
- → perform linear fits at different beam energies
- → analysis published for full range Q^2> 2.5 GeV^2

- F_2^D and F_L^D extracted in bins of Q^2,x_{IP} and β
- F_2^D and F_L^D data agree with H1 DPDF fits
- Ratio R^D to R(incl.DIS) → longitudinal component is larger in diffraction

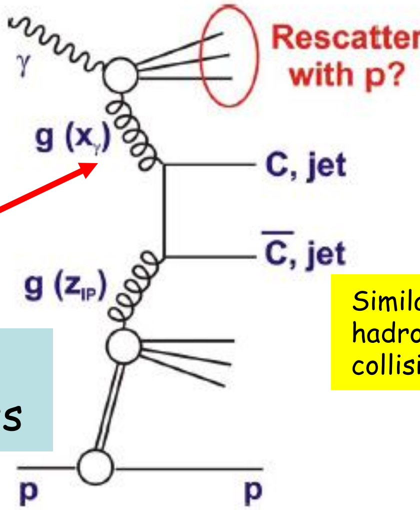
Dijets in photoproduction, $\gamma^{*}p$, $Q^2 \to 0$

In LO!

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



x_γ - fraction of photon's momentum in hard subprocess



Similarity with hadron-hadron collisions

resolved

direct

direct photoproduction

photon directly involved in hard scattering

$x_\gamma = 1$ (at parton level)

hadron –like component

photon fluctuates into hadronic system, which takes part in hadronic scattering

$x_\gamma < 0.2$ (at parton level)

point –like component of resolved photon

dominates in the region of $0.2 < x_\gamma < 1$

Factorisation in hadron-hadron collisions

Exporting DPDFs from HERA to Tevatron does not work

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

Factorisation broken by β-dependent factor ~ 10, $S^2 \sim 0.1$.

Succesfully explained in terms of rescattering and absorption
(see Kaidalov,Khoze,Martin,Ryskin:Phys.Lett.B567 (2003),61)
KKMR predicted suppression factor for HERA resolved photoproduction

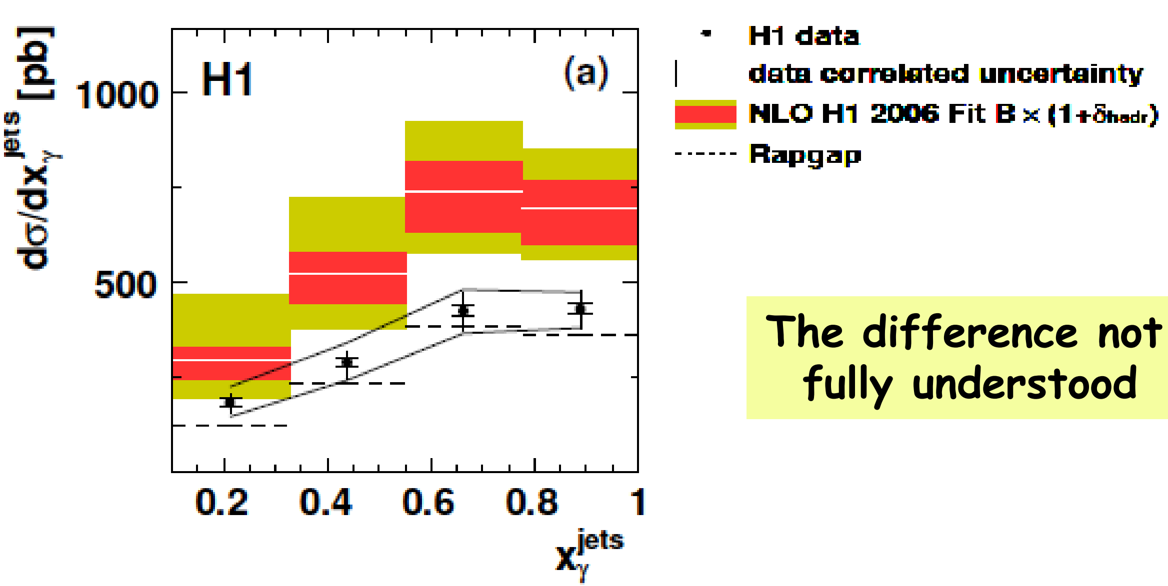
$S^2 \sim 0.34$

In 2010 new theoretical prediction by KKMR:
(European Journal of Physics 66,373 (2010))
Suppression 0.34 present only for hadronic part of photon PDF (**x_γ<0.2**),
for dominant point-like component →
suppression: quarks GRV **0.71(0.75)** E_T^{jet1} >5 (7.5) GeV
gluons GRV **0.53(0.58)** E_T^{jet1} >5 (7.5) GeV

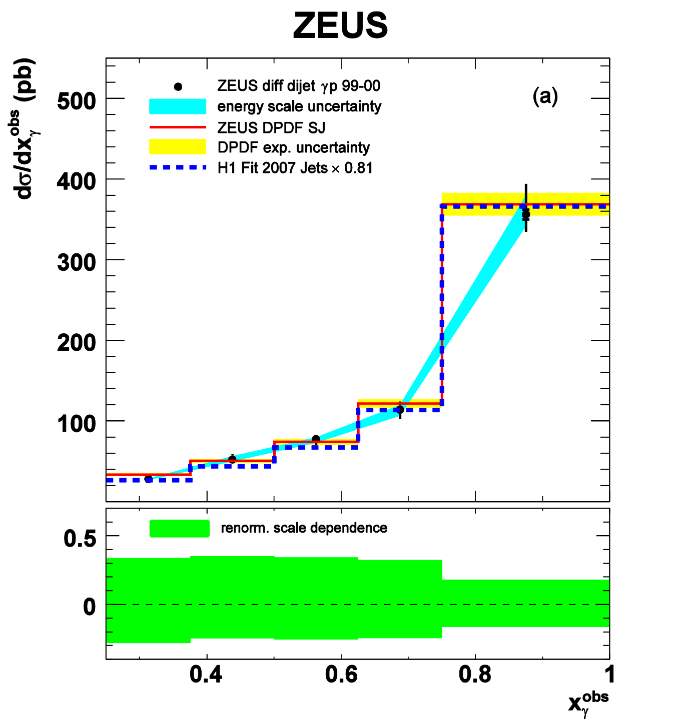
Dijets in photoproduction

Factorisation breaking observed by H1, two analyses,
EPJC C51 (2007),549, – suppression ~ **0.5**
EPJ C68 (2010),381 – suppression ~ **0.6**

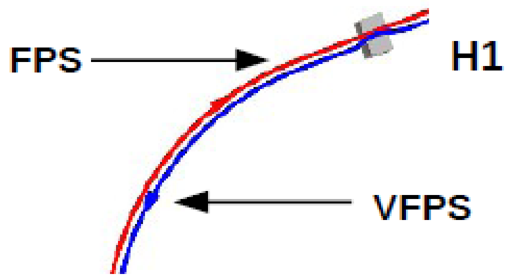
not observed by ZEUS, Nucl.Phys. B381 (2010) – no suppression ~ **1.**



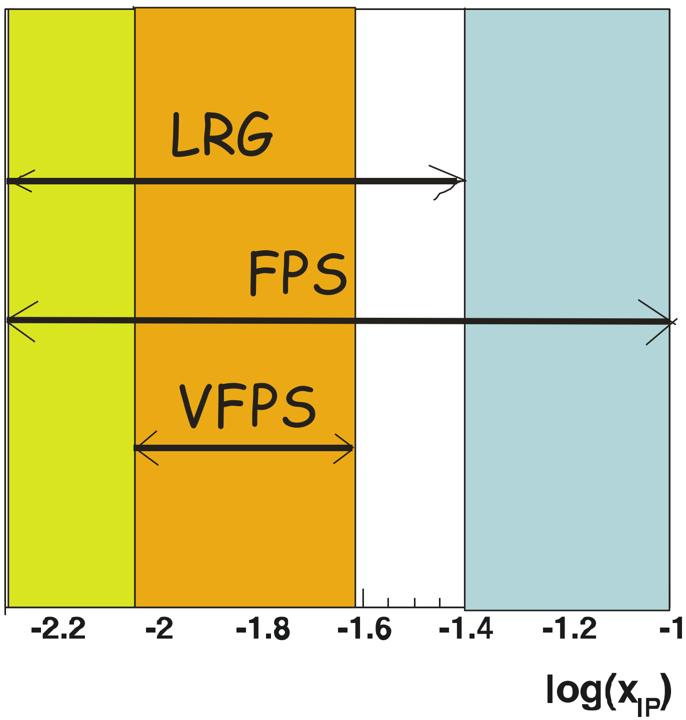
The difference not fully understood



New measurements with proton spectrometers



H1 spectrometers FPS & VFPS



H1 - phase space of Large Rapidity Gap and proton spectrometers FPS and VFPS dijet measurement in x_{IP}

Proton spectrometers cover different phase space than LRG measurements…

Dijet measurements - FPS

Forward proton spectrometer FPS - H1

Check of the consistency with published LRG dijet measurement - significant extension of the phase space (times 3 in x_{IP}).

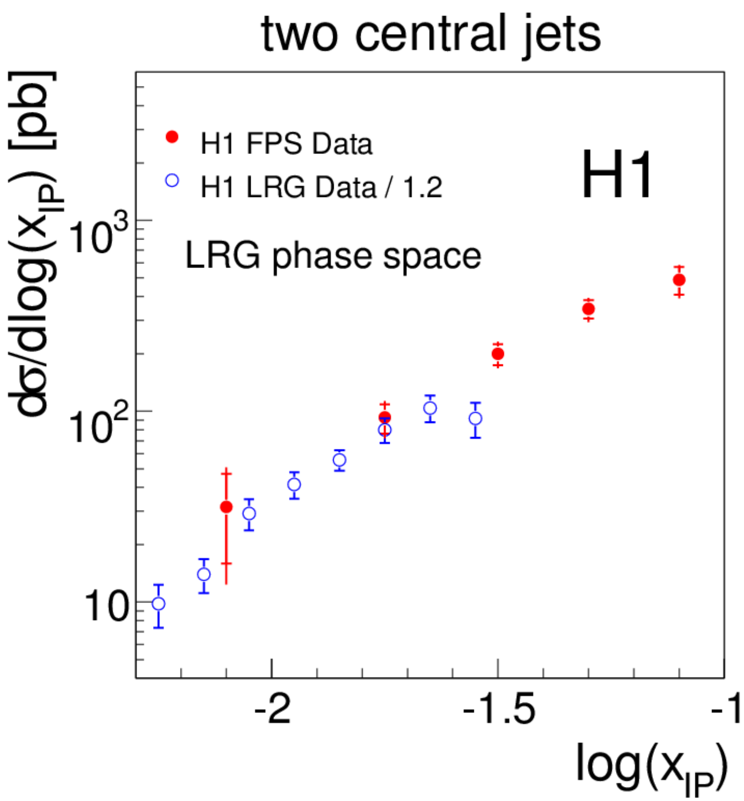
DESY-11-166

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

$0.1 < y < 0.7$

$p_{T1}^* > 5.5$ GeV

$p_{T2}^* > 4$ GeV



Both measurements are consistent in the overlapping region.

H1 FPS – two central jets -DIS

$4 < Q^2 < 110\ GeV^2$

$0.05 < y < 0.7$

$x_{IP} < 0.1$

$p_{T1}^* > 5\ GeV$

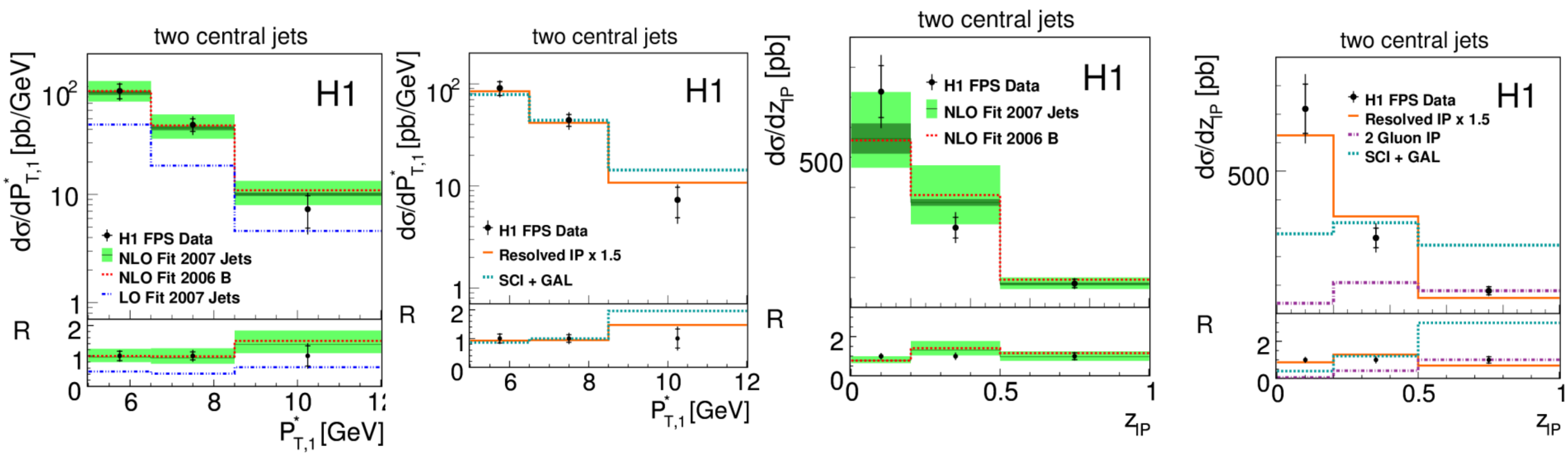
$p_{T2}^* > 4\ GeV$

$-1 < \eta_{1,2} < 2.5$

- Good general description of the data by NLO (NLOJET++) using DPDFs Fit 2006 B and 2007 Jets
- Resolved IP model in RAPGAP describes the shapes but underestimates the cross section
- Models 2 gluon IP and SCI + GAL are off

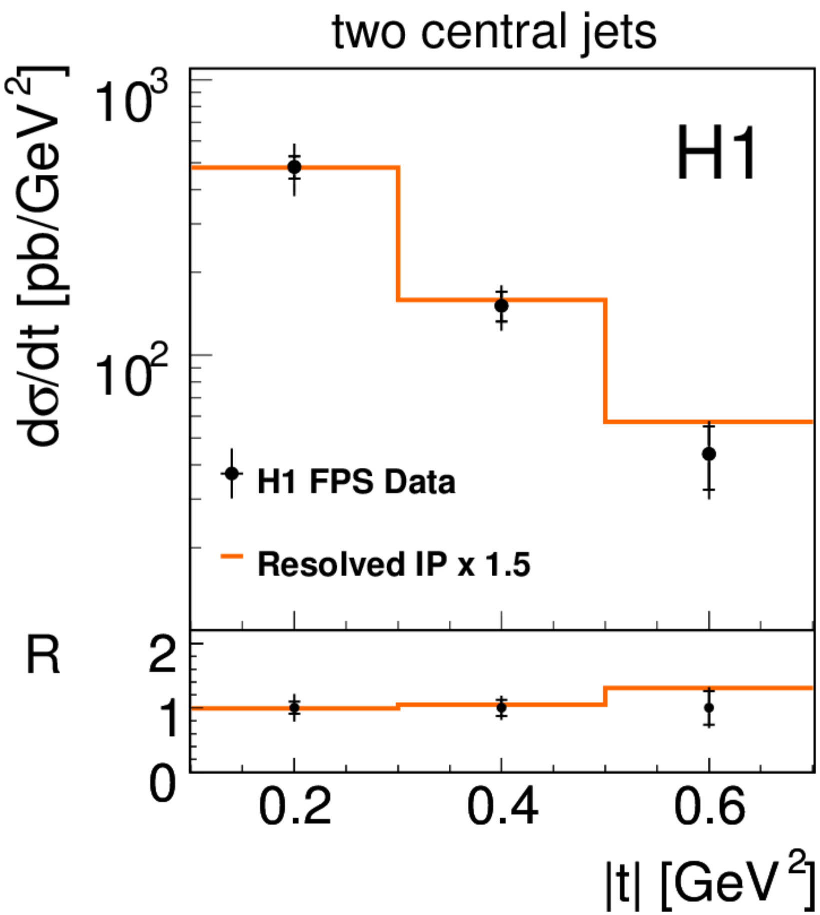
σ(data)= 254 20(stat) 27(syst) pb

σ(NLO-FitB)= 270 $^{134}_{53}$(stat) 16(syst) pb

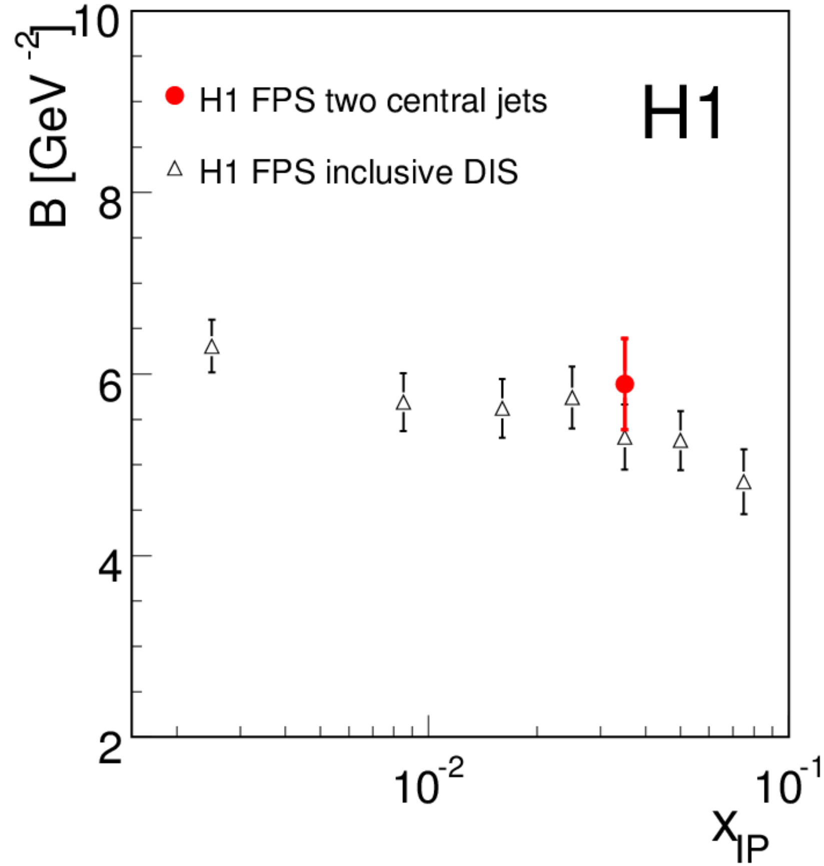


FPS – two central jets

Fit exp(Bt)   B=5.89 0.50 (exp) GeV^{-2}

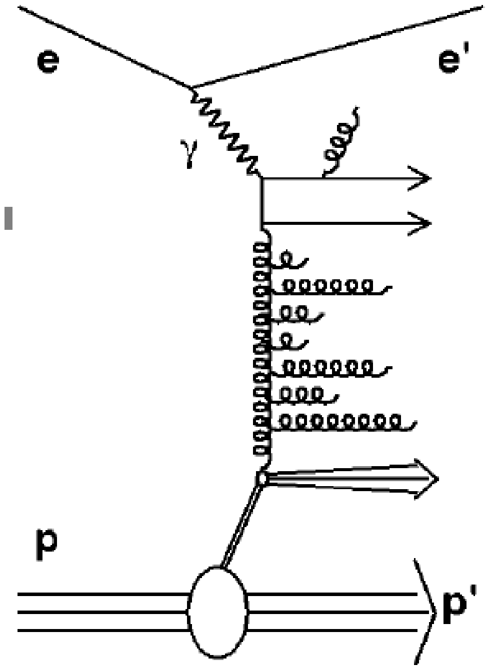


Results consistent with previous inclusive measurement – proton vertex factorisation holds



FPS – diffractive forward jets

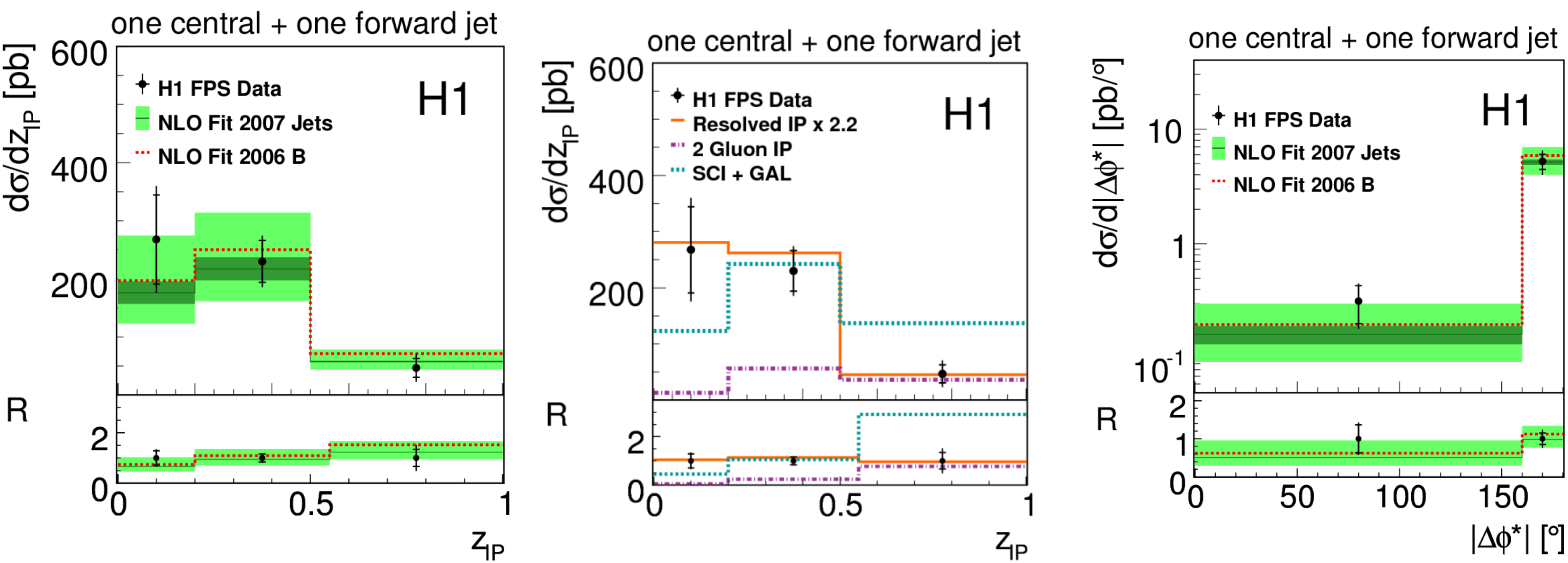
- Forward jets with leading proton in DDIS - search for physics beyond DGLAP
- the possibility to investigate the jets close to the proton direction
- the selection of 1 central + 1 forward jet
- compared with NLOJET++ with DPDF H1 fit B



$4 < Q^2 < 110$ GeV^2
$0.05 < y < 0.7$
$x_{IP} < 0.1$
$|t| < 1$ GeV^2

$P^*_{T,cent}, P^*_{T,forw} > 3.5$ GeV
$M_{jj} > 12$ GeV
$-1 < \eta_{cent} < 2.5$, $1 < \eta_{forw} < 2.8$, $\eta_{forw} > \eta_{cent}$

H1 FPS – diffractive forward jets



NLO based on the DGLAP approach describes data well,
LO MC models are again off….(see DESY-11-166).

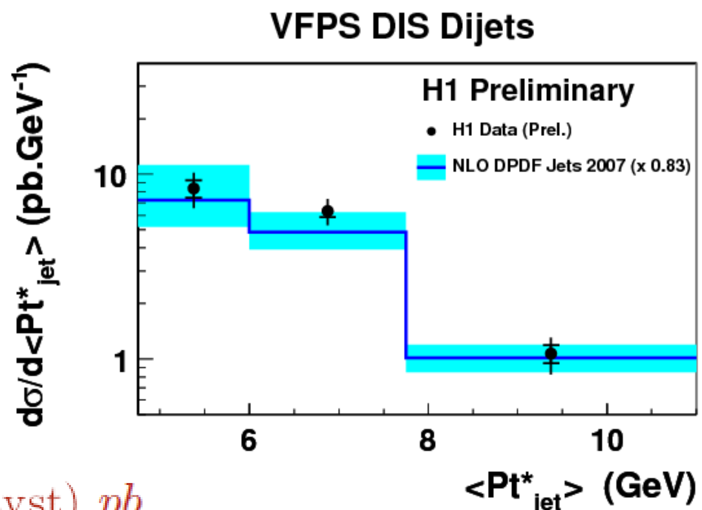
DIS - VFPS dijets

$$0.009 < x_{\mathbb{P}} < 0.024$$
$$5 < Q^2 < 80\ GeV^2$$
$$0.1 < y < 0.65$$
$$-3 < \eta^*_{j1,j2} < 0$$

- At least 2 central jets
- Jets selected in $\gamma^* - p$ frame
- $P^*_{t,jet1} > 5.5 GeV$
- $P^*_{t,jet2} > 4 GeV$

1400 events selected…

NLOjet++ calculations with H1 2007 jets DPDF
(times 0.83 to account for diff.dissociation)



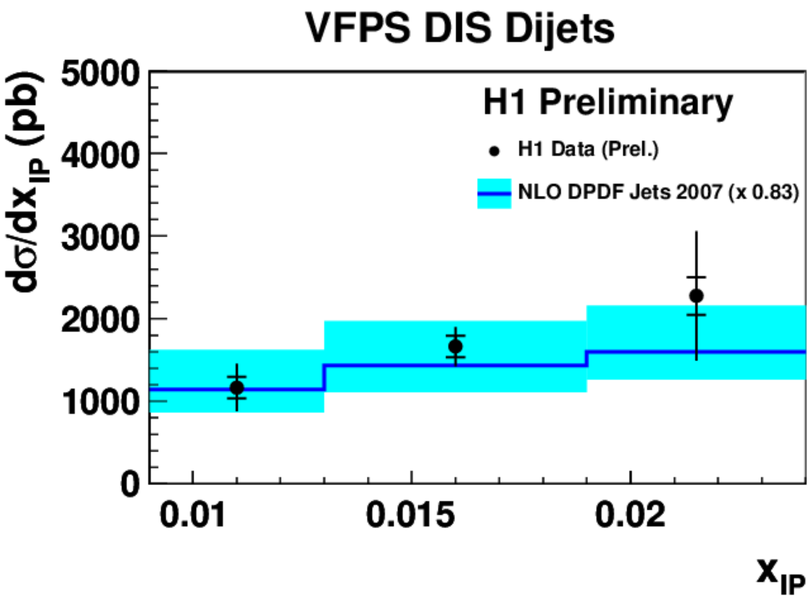
The total cross section:

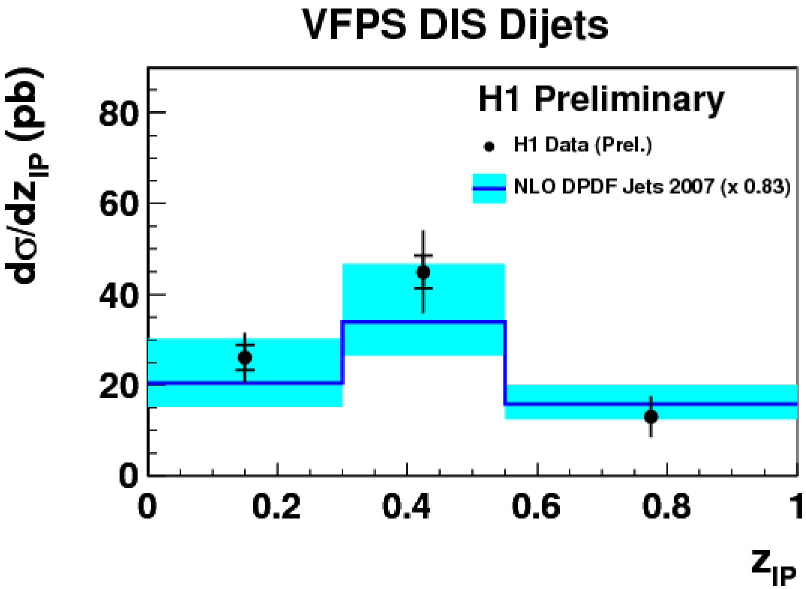
$$\text{H1 VFPS Preliminary}: 25.3 \pm 1.4\ (\text{stat.}) \pm 6.5\ (\text{syst})\ pb$$

$$\text{NLO DPDF Fit Jet 2007}: 19.9^{+7.4}_{-4.4} \pm 0.5(had.)\ pb$$

DIS -VFPS dijets

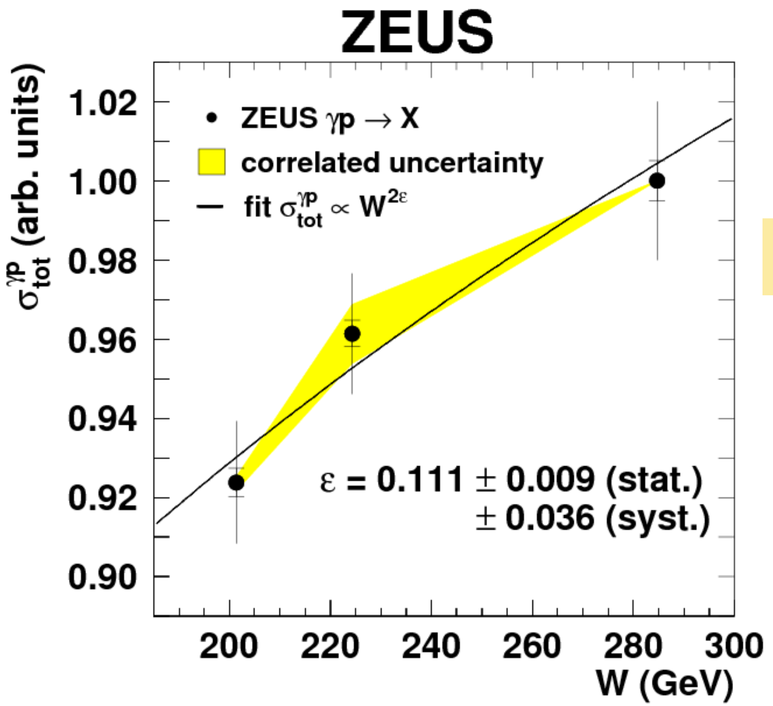
Very good agreement of data distributions with NLO calculations in normalization and the shape.





γ^*p total cross section

γ^*p total cross section measured by ZEUS for 3 values of centre-of-mass energy W, (Phys.Lett.B 697 (2011),184)



Parametrisation $\sigma_{tot}^{\gamma p} \sim W^{2\varepsilon}$

$\varepsilon = 0.111 \pm 0.009$ (stat) ± 0.036(syst)

Reggeon contribution on the level of few percent,
ε is compatible with the energy dependence measured in hh collisions (0.0959 ± 0.0021)
Donachie - Landshof

Conclusions

- HERA continues to provide unique diffractive data..........
- agreement in detail between different analysis methods
- combination of H1 and ZEUS diffractive data with tagged proton gives consistent results
- H1 - first measurement of F_L^D
- H1 and ZEUS results for factorisation breaking in diffractive dijet photoproduction are not conclusive, new analyses desirable...

- new DIS inclusive and diffractive dijets measurements with H1 proton spectrometers FPS and VFPS:
  - ★ dijets in the central region described by NLO
  - ★ forward jets described by NLO, no evidence for beyond DGLAP contributions
- ZEUS - W dependence of the total γ*p cross section in agreement with hh collisions

Backup

Comparison with KKMR models

NLO calculations

Model KKMR 2003:
resolved part suppressed by 0.34.

Model KKMR 2010:
quarks suppressed by 0.71
gluons suppressed by 0.53

Model KKMR 2010 agrees with H1 data better than model 2003 but shape description is still better with **global suppression**.