Hard diffraction and factorization breaking

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on behalf of the H1 and ZEUS Collaborations

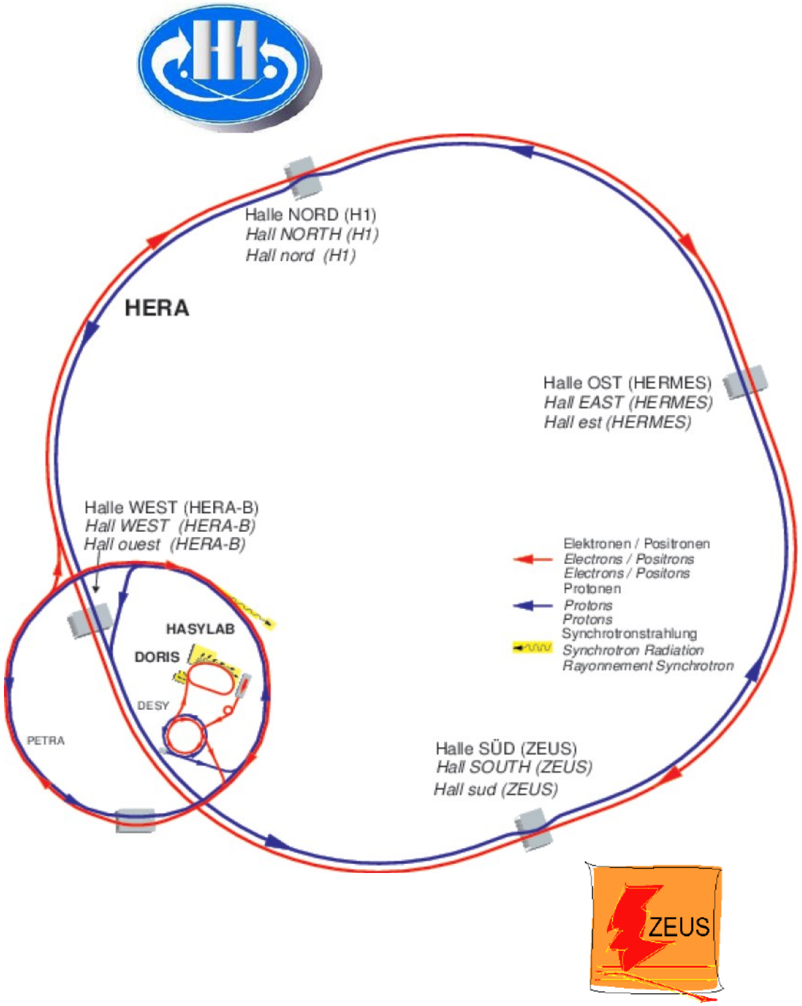
Diffraction 2016, Acireale, Catania, Sicily

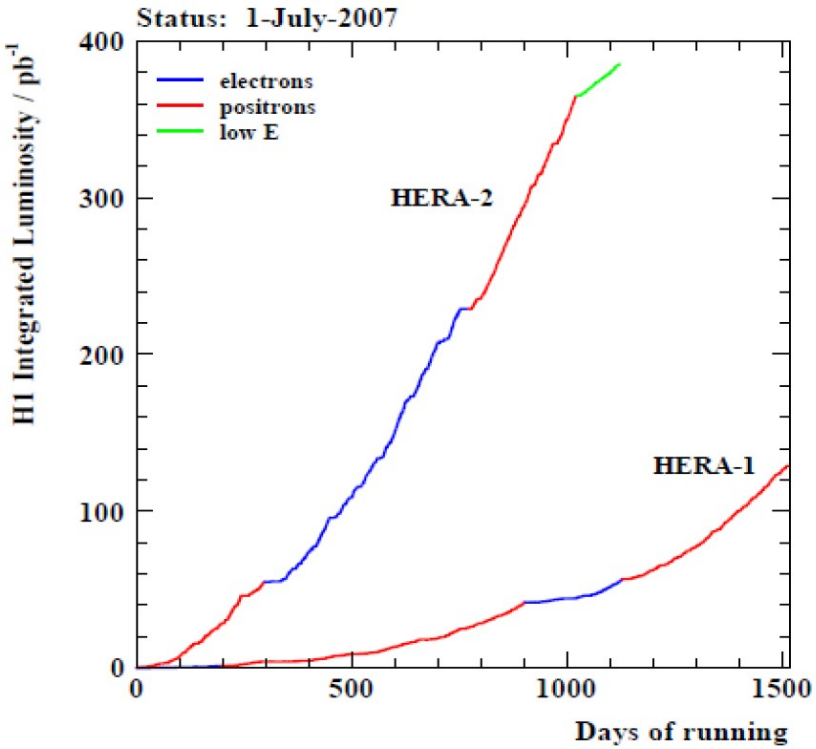
HERA

HERA, ep collider
(DESY, Hamburg, 1993-2007)

E_p = 920 GeV $E_{e\pm}$ = 27.5 GeV

0.5 fb^{-1}… per experiment

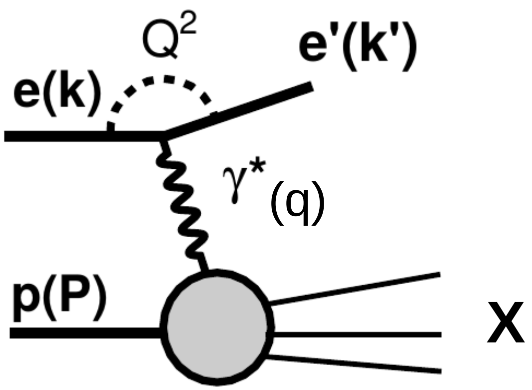




Diffraction with hard scale in ep

ep interactions proceed mainly via γ* exchange

ep → eX



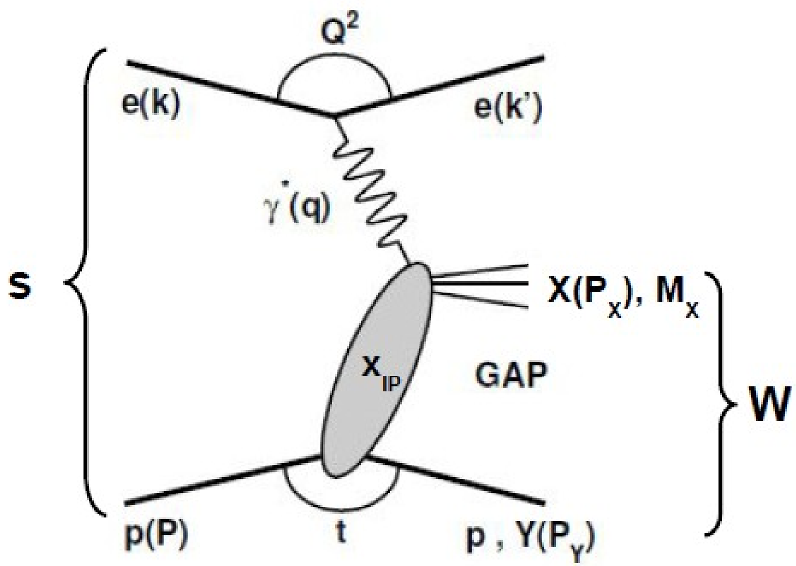
$s=(k+P)^2$ ... CMS energy of collision

$Q^2=-q^2=-(k-k')^2$... four-momentum transfer at e vertex

$W=\sqrt{(q+P)^2}$... hadronic c.m.s. energy

$x=\frac{Q^2}{2q.P}$... Bjorken x

Diffractive dissociation



HERA domain

→ continuum of masses of X

Diffractive exchange (IP)

→ quantum numbers of vacuum

→ $\beta = x / x_{IP}$ … mom. fraction of IP participating

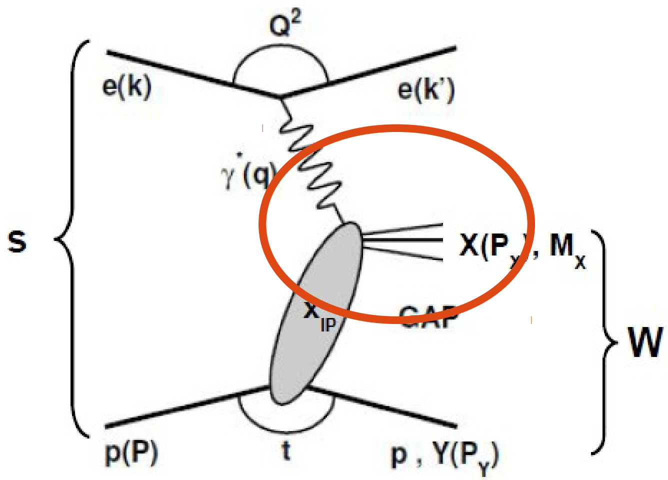
$t = (P-P_Y)^2$ ... four-momentum transfer at p vertex

$x_{IP} = \frac{q.(P-P_Y)}{q.P}$ ... fractional long. mom. loss of proton

Diffractive dissociation

Diffractive dissociation in DIS

- **virtual photon dissociates into system X ($M_x^2 \ll W^2$)**
- small momentum transfer to proton, $|t| \ll W^2$
- proton stays intact or dissociates into system Y ($M_Y^2 \ll W^2$)
- large rapidity gap (non-exponentially suppressed) between Y and X
- hard scale present (Q^2, p_T^2, m_Q^2)
  - inclusive
  - jet data
  - open charm / beauty
  - γ
- represents ~10% of low x DIS σ



ep → eXY

Diffractive dissociation

Diffractive dissociation in DIS

- virtual photon dissociates into system X ($M_x^2 << W^2$)
- **small momentum transfer to proton, $|t| << W^2$**
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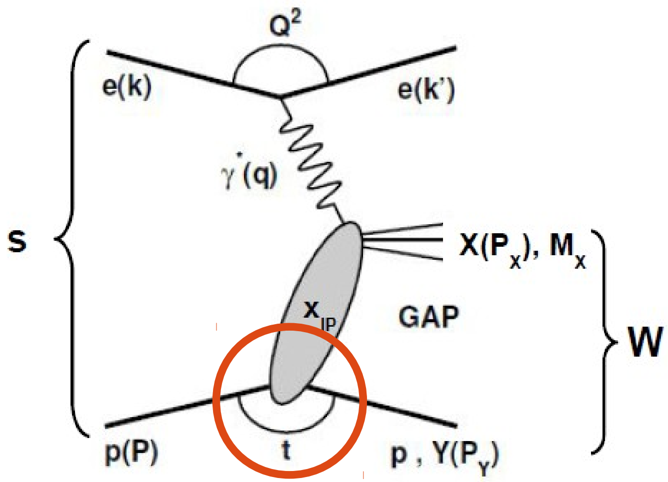

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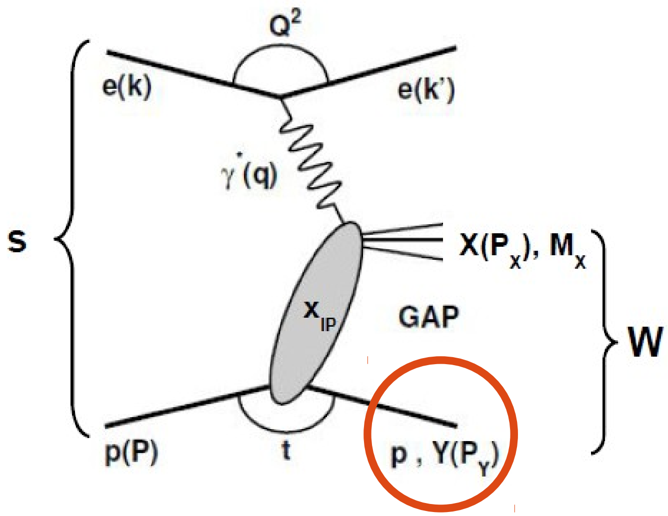

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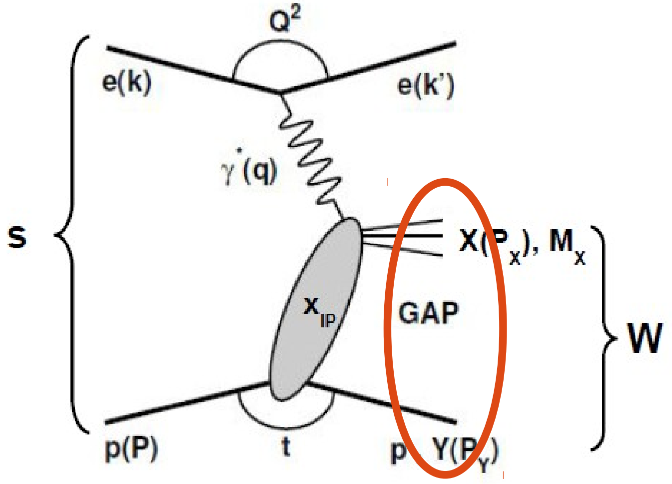

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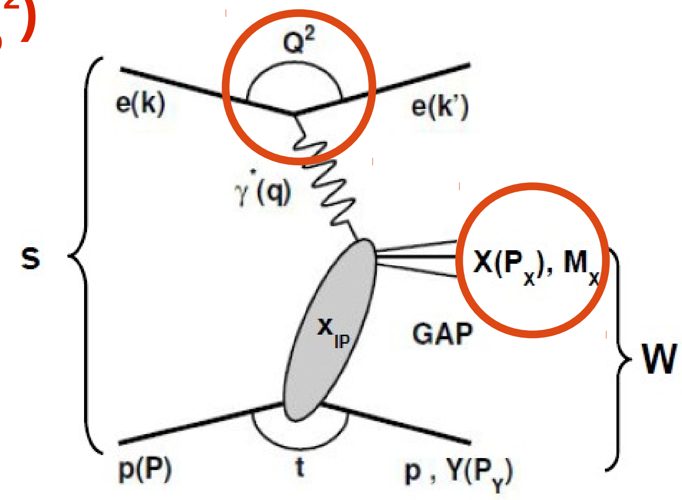


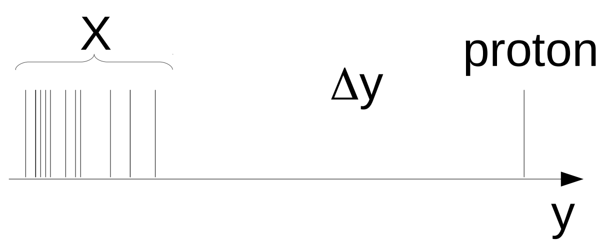
ep → eXY

Diffraction seen in detectors

Due to vacuum quantum number exchange

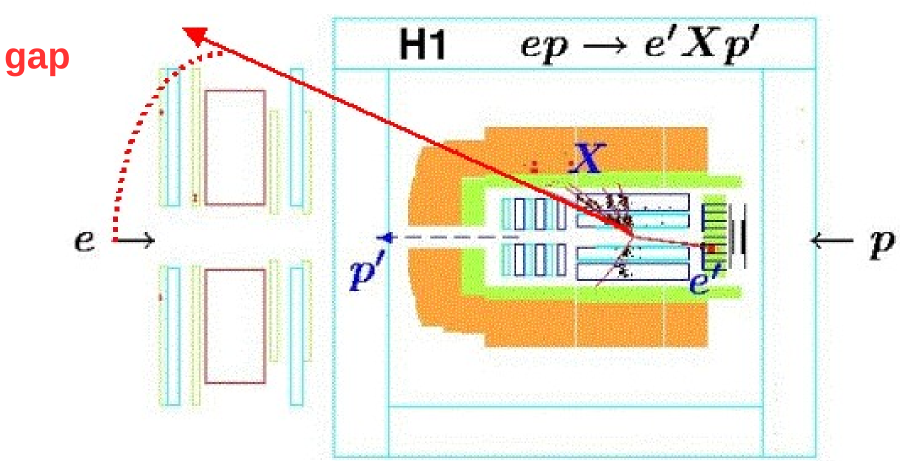
→ leading particle at relatively small t

→ rapidity distributions of final state (VM, X) separated from leading particle by non-exponentially suppressed gaps – **Large Rapidity Gap (LRG)**



Both leading proton tagging or LRG detection used in H1 and ZEUS

LRG method



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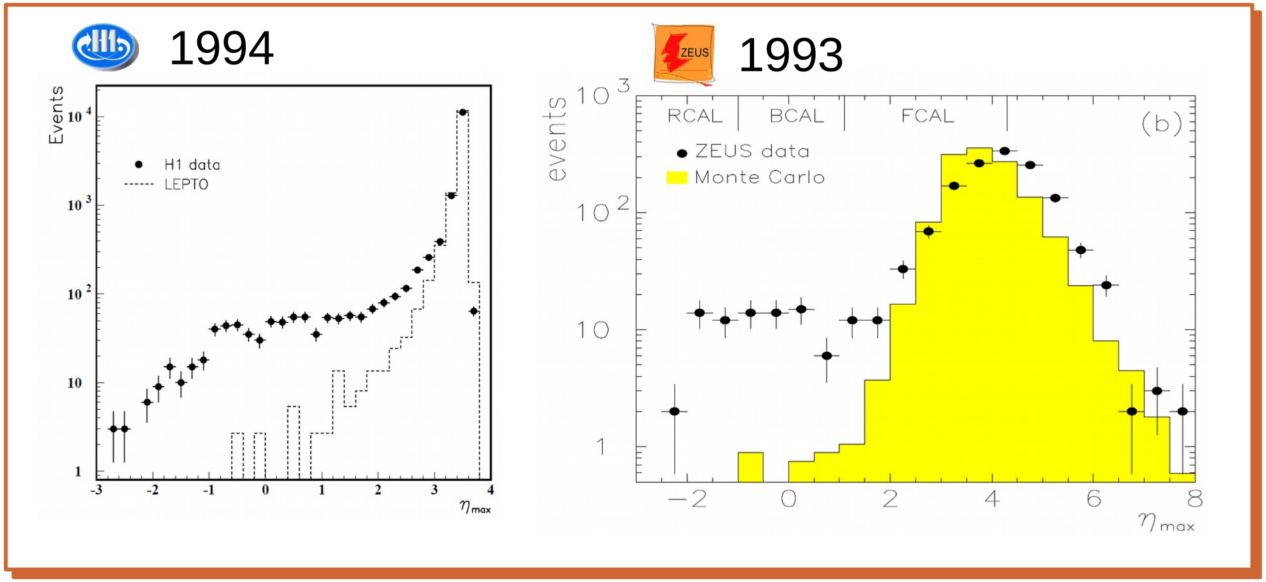

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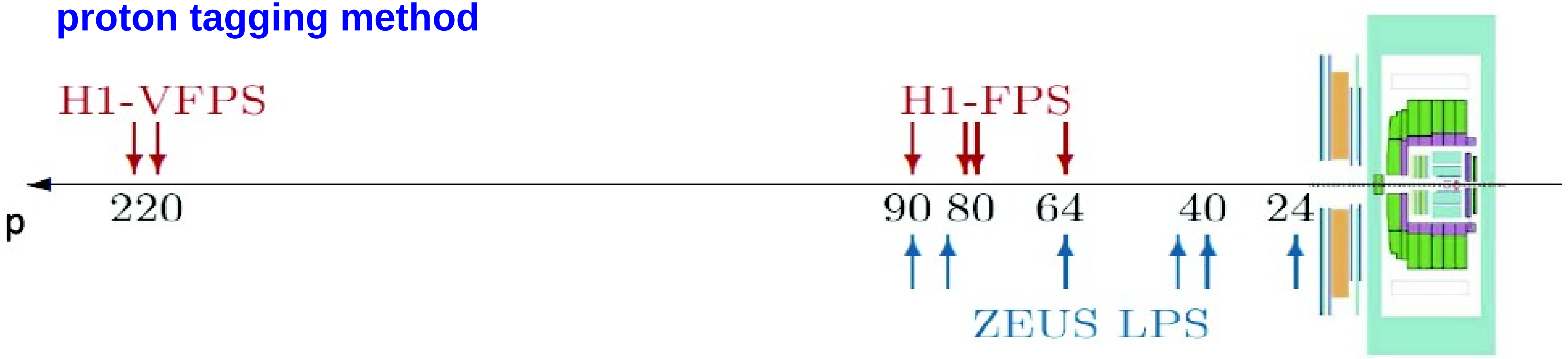
proton tagging method



Diffraction seen in detectors

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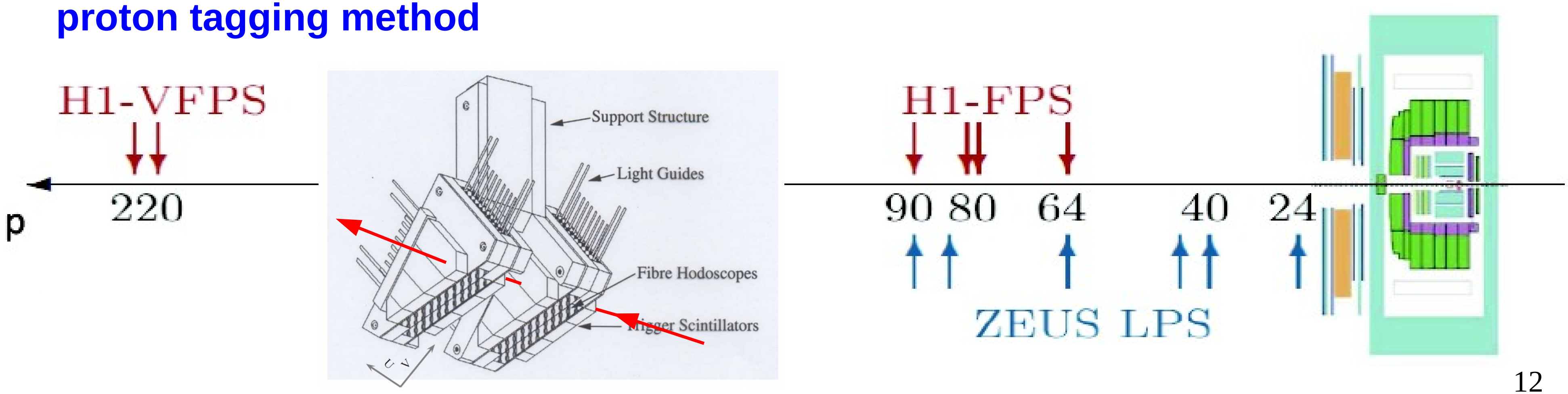


Collinear factorization

Most used approach to model various features of diffractive DIS.

Central assumption: *Collinear factorization* *valid for diffractive DIS, Collins*

→ diffractive parton distribution functions (DPDFs) factorized from predictions of hard X states cross sections

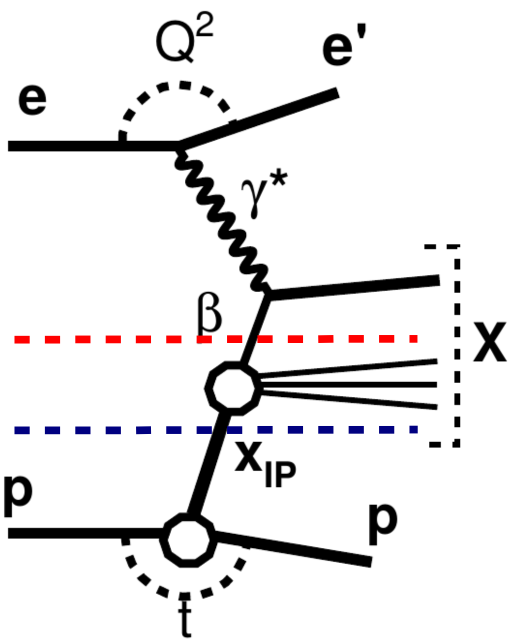
$$d\sigma^{ep\to eXp}(x,Q^2,x_{IP},t)=\sum_i f_i^D(x,Q^2,x_{IP},t)\otimes d\hat{\sigma}(x,Q^2)$$

Optionally: *Resolved Pomeron approach* *Ingelman and Schlein*

→ virtual photon inteacts with partonic diffractive exchange

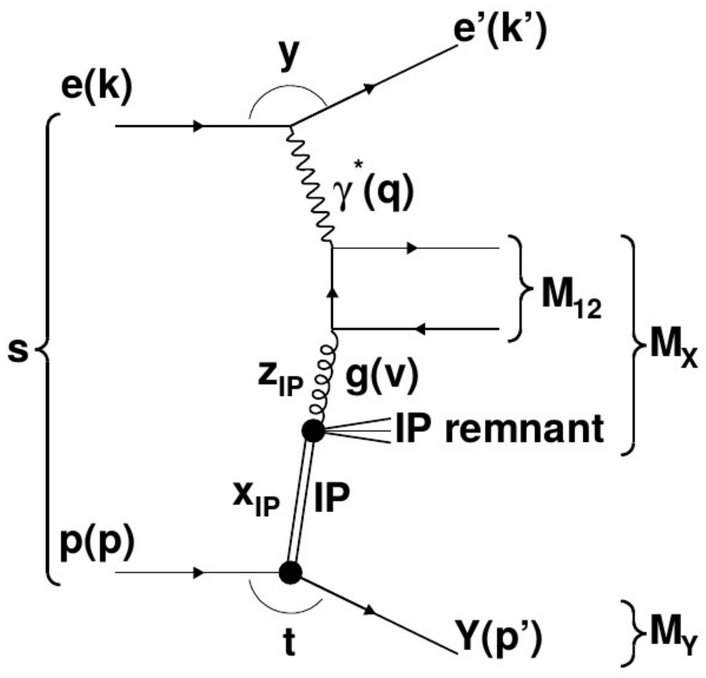
→ leading proton (t , x_{IP}) treated separately aka Proton vertex factorization

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



Dijets in diffractive DIS

JHEP 1503 (2015) 092



z_{IP} variable

→ fraction of IP momentum participating in the hard process giving rise to jets

DIS	***2-jets***	***diffraction***
$4 < Q^2 < 100\ \mathrm{GeV}^2$	$p^*_{\mathrm{T},1} > 5.5\ \mathrm{GeV}$	$x_{P} < 0.03$
$0.1 < y < 0.7$	$p^*_{\mathrm{T},2} > 4.0\ \mathrm{GeV}$	$\lvert t \rvert < 1\ \mathrm{GeV}^2$
	$-1 < \eta^{\mathrm{lab}}_{1,2} < 2$	$M_Y < 1.6\ \mathrm{GeV}$

Most precise DDIS dijet measurement from HERA

→ based on ~ 290 pb^{-1} of HERA-2 H1 data

→ LRG selection used

→ proton dissociation contribution up to M_Y < 1.6 GeV

→ detector effects controlled very well by simulation

→ data corrected with regularized unfolding (TUnfold)

→ single and double-differential x-sections measured

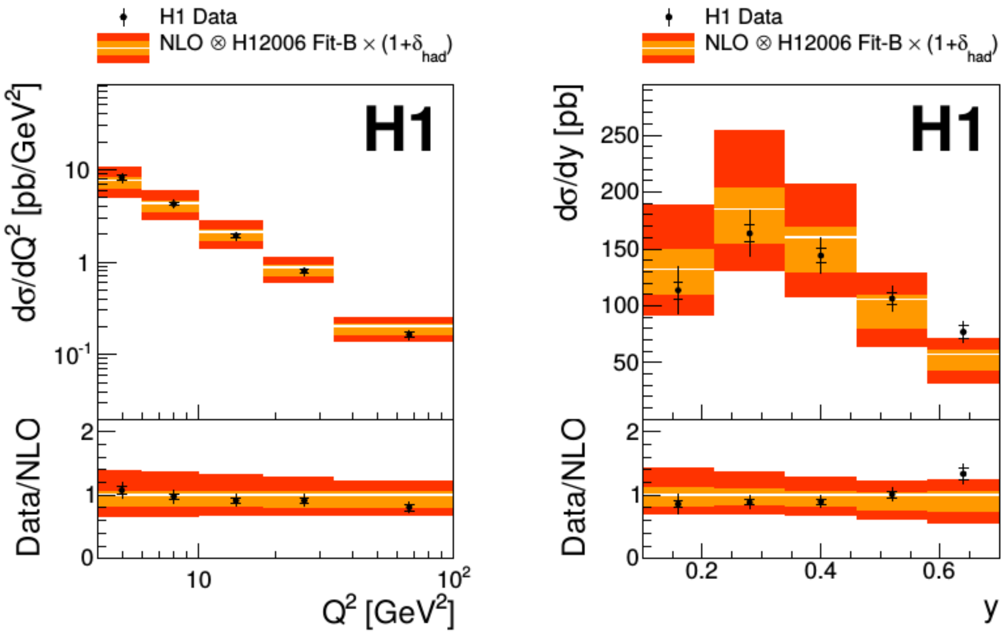
Compared with theory

→ in NLO QCD (nlojet++)

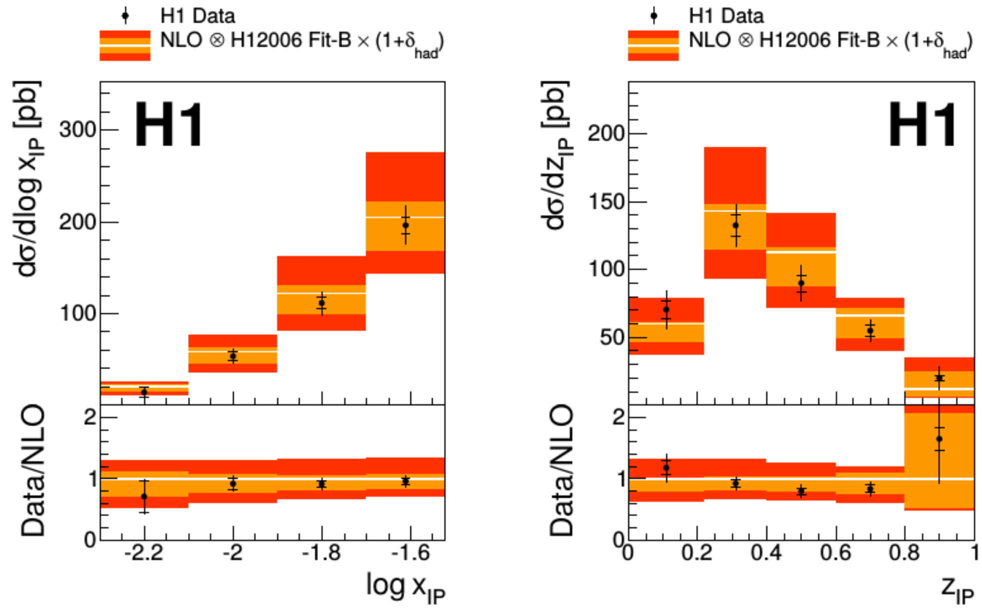
→ hadronization corrections from MC

→ using H1 2006 DPDF Fit B

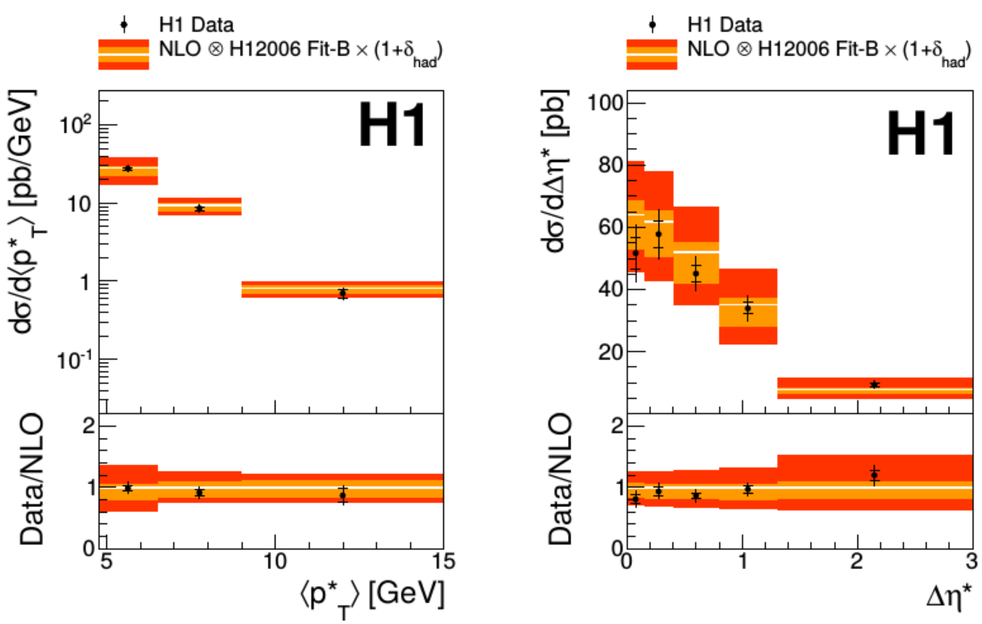
DIS variables



Diffractive variables



Jet variables



Data more precise than theory

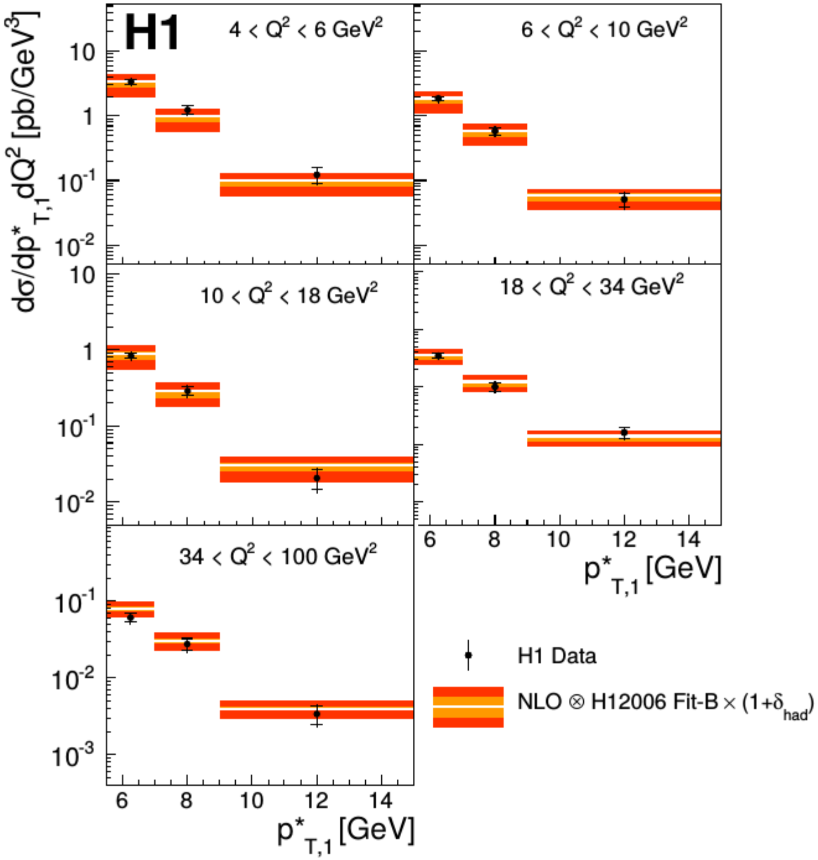
DPDF uncertainties

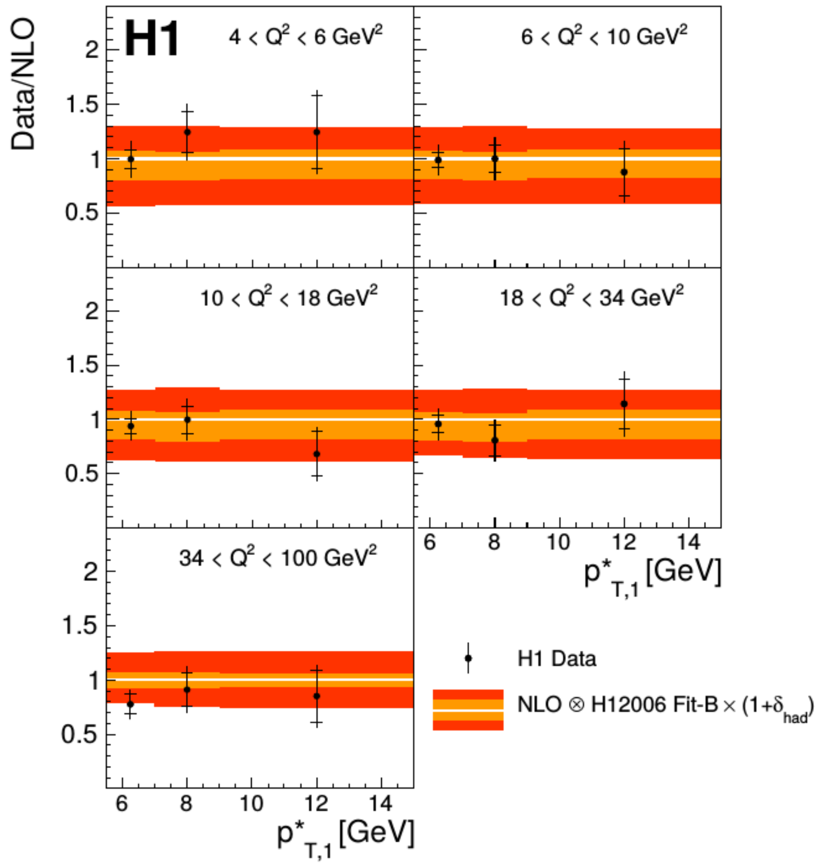
DPDF & scale uncertainties

Data well described by theory

$$\sigma^{dijet}_{meas}(ep \to eXY) = 73 \pm 2\ (\text{stat.})\ \pm 7\ (\text{syst.})\ \text{pb}$$

$$\sigma^{dijet}_{theo}(ep \to eXY) = 77\ ^{+25}_{-20}\ (\text{scale})\ ^{+4}_{-14}\ (\text{DPDF})\ \pm 3\ (\text{had})\ \text{pb}$$





Double-differential cross sections

→ agreement with QCD at NLO

→ precision of the data allows the extraction of α_s ... in agreement with world average

… not a competitive means for α_s extraction

… supports readiness of the data for DPDF fits

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

Dijets in diffractive photoproduction and DIS with leading proton

JHEP 1505 (2015) 056

Independent of previous analyses from HERA

→ leading proton detected in VFPS

Photoproduction regime

→ $Q^2 < 2$ GeV^2

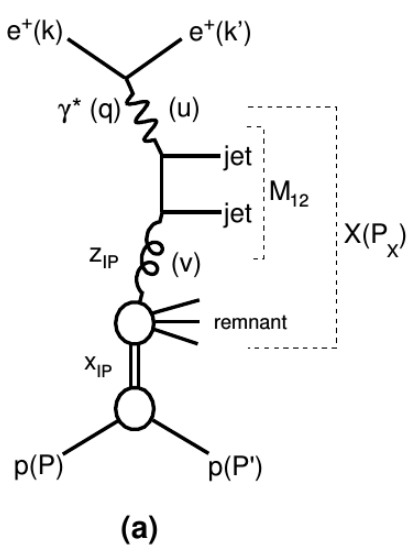
→ direct γ DIS-like

→ resolved γ pp-like

→ $\mathbf{x_\gamma}$ **fraction** $x_\gamma = \frac{P.u}{P.q}$ … dir/res classification

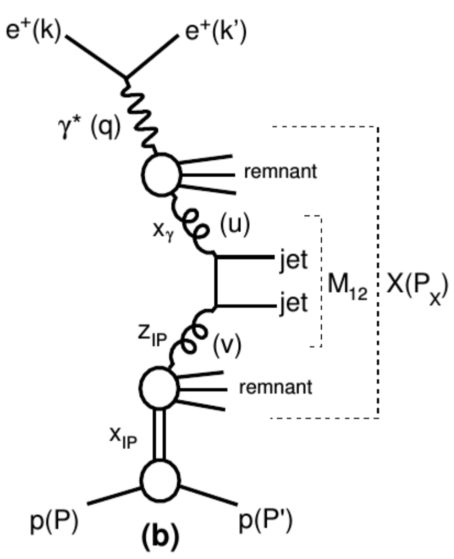
Performed also in DIS regime

→ 4 GeV^2 $< Q^2 < 80$ GeV^2



direct

$\mathbf{x_\gamma = 1}$



resolved

$\mathbf{x_\gamma < 1}$

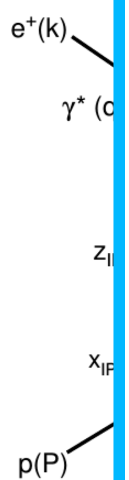
$$0.010 < x_{I\!P} < 0.024 \qquad E_T^{*\mathrm{jet1}} > 5.5\,\mathrm{GeV}$$
$$|t| < 0.6\,\mathrm{GeV}^2 \qquad E_T^{*\mathrm{jet2}} > 4.0\,\mathrm{GeV}$$
$$z_{I\!P} < 0.8 \qquad -1 < \eta^{\mathrm{jet1,2}} < 2.5$$

Dijets in diffractive photoproduction and DIS with leading proton

JHEP 1505 (2015) 056

Independent of previous analyses from HERA

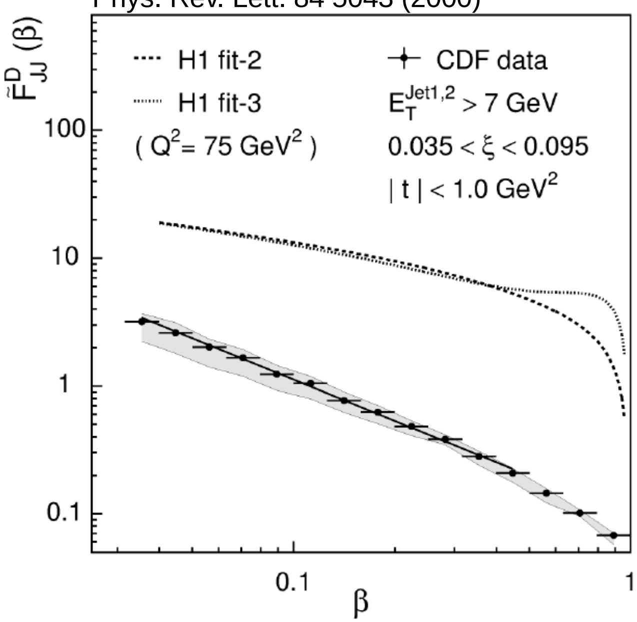
→ leading proton detected in VFPS



! DPDFs are not portable to diffractive hadron-hadron (pp) processes !

→ order of magnitude overestimation of predicted pp dijet rates first observed by CDF → **Factorization breaking**

Phys. Rev. Lett. 84 5043 (2000)



Absorptive effects occur

→ change of event kinematics

→ rescattering or unitarity corrections

→ several approaches exist to calculate so called **Survival probability $\langle S^2 \rangle$**

… i.e. probability of diffractive event to retain the diffractive signature

Tested in diffractive dijet photoproduction at HERA due to γ's partonic fluctuations (hadron-like object)

on

$z_{I\!P} < 0.8$ $\quad -1 < \eta^{\mathrm{jet1,2}} < 2.5$

Dijets in diffractive photoproduction and DIS with leading proton

JHEP 1505 (2015) 056

Independent of previous analyses from HERA

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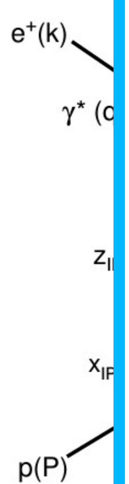
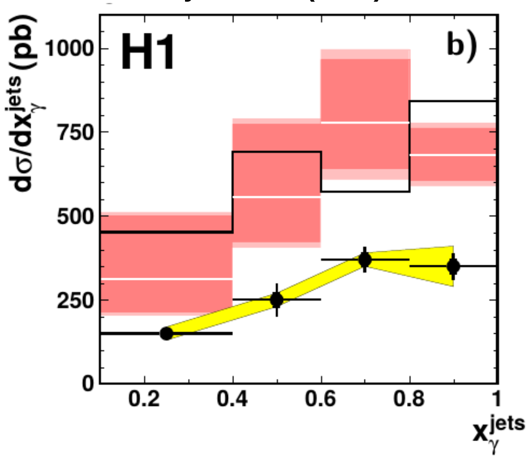
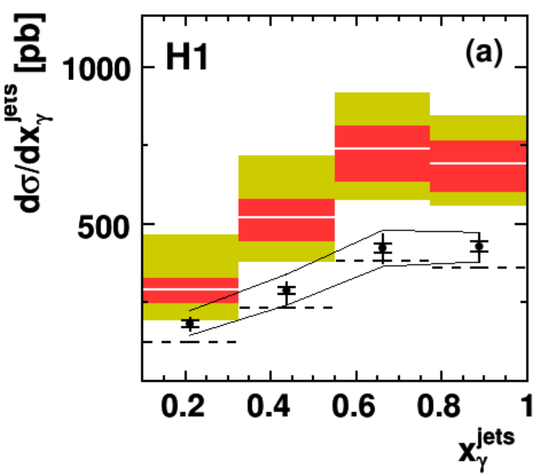


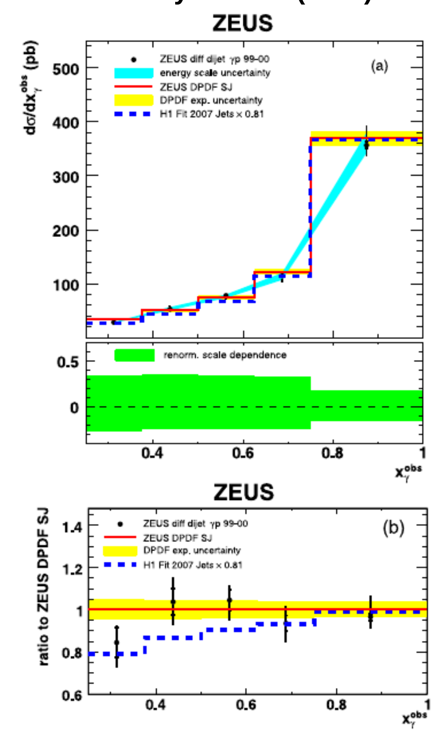
Eur.Phys.J.C 51 (2007) 549



Eur.Phys.J.C70 (2010) 15



Nucl. Phys. B 831 (2010) 1-25



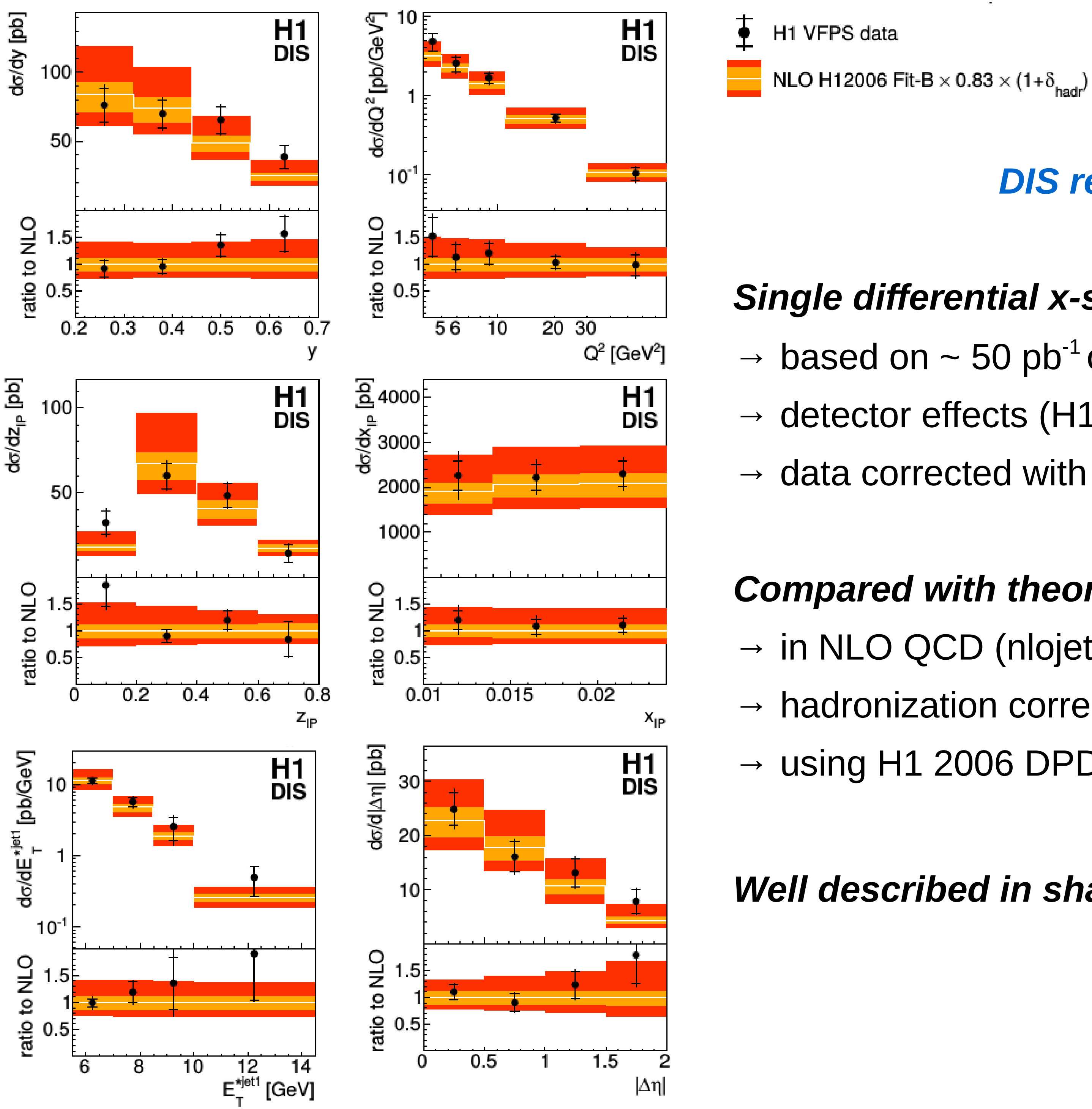
Previous H1 and ZEUS (LRG) analyses

→ H1: 2007 (S^2 ~ 0.5), 2010 (S^2 ~ 0.6)

→ ZEUS: 2010 (S^2 ~ 1)

on

$z_{I\!P} < 0.8$ $\qquad -1 < \eta^{\mathrm{jet1,2}} < 2.5$



DIS results

Single differential x-sections

→ based on ~ 50 pb^{-1} of HERA-2 H1 data

→ detector effects (H1 and VFPS) well simulated

→ data corrected with regularized unfolding

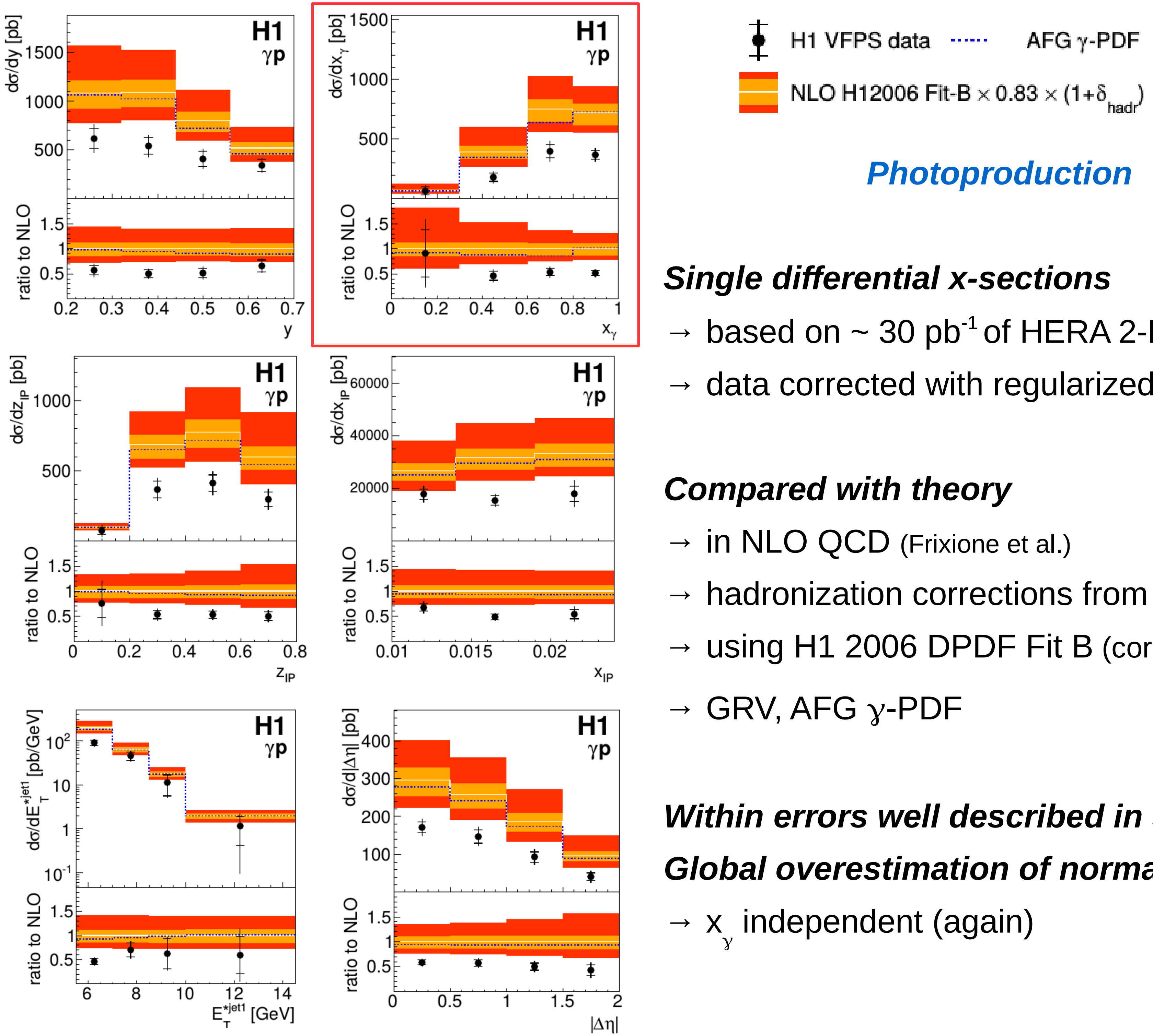
Compared with theory

→ in NLO QCD (nlojet++)

→ hadronization corrections from MC

→ using H1 2006 DPDF Fit B (corrected to $M_Y = m_p$)

Well described in shape and normalization



Photoproduction

Single differential x-sections

→ based on ~ 30 pb^{-1} of HERA 2-H1 data

→ data corrected with regularized unfolding

Compared with theory

→ in NLO QCD (Frixione et al.)

→ hadronization corrections from MC

→ using H1 2006 DPDF Fit B (corrected to $M_Y = m_p$)

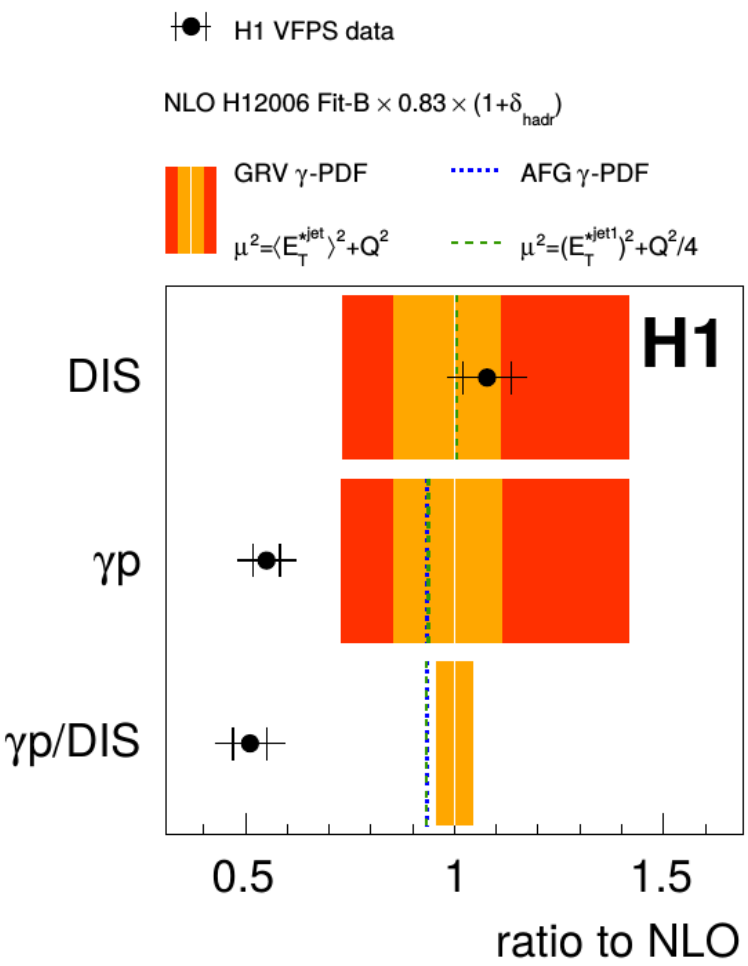
→ GRV, AFG γ-PDF

Within errors well described in shape

Global overestimation of normalization

→ x_γ independent (again)

Ratios of γp / DIS



Profits from cancellations of scale uncertainties

→ theory / theory, if varied simultaneously

No significant dependence on kinematics

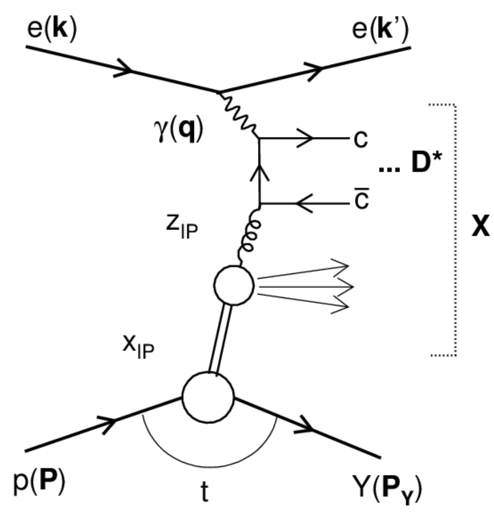
→ only global ratios are shown

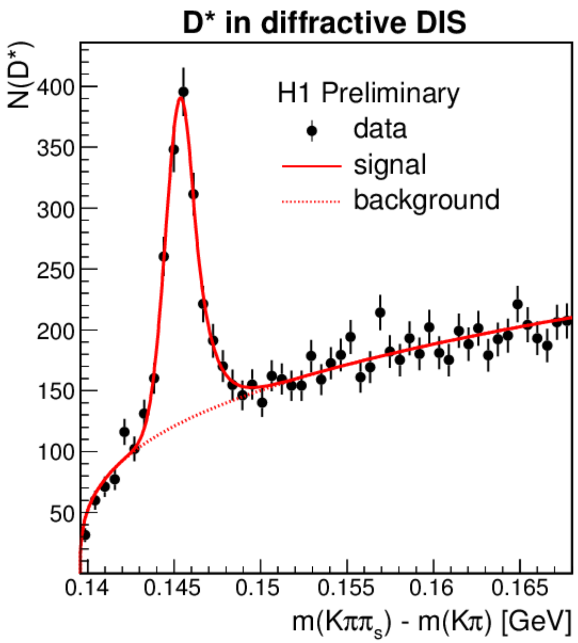
$$1.08 \pm 0.11\ (\mathrm{data})^{+0.45}_{-0.29}\ (\mathrm{theory})$$

$$0.551 \pm 0.078\ (\mathrm{data})^{+0.230}_{-0.149}\ (\mathrm{theory})$$

$$0.511 \pm 0.085\ (\mathrm{data})\ ^{+0.022}_{-0.021}\ (\mathrm{theory})$$

Open charm production in diffractive deep inelastic scattering at HERA





Open charm from c → with D* fragmentation

→ based on 280 pb^{-1} HERA-2 data

(previous H1 publ. at 50 pb^{-1} H1 HERA 1)

→ gluon initiated process at LO

→ open charm tagged with D*

$$D^{*+} \rightarrow D^0 \pi^+_{slow} \rightarrow (K^- \pi^+) \pi^+_{slow} + C.C.$$

→ fits of $\Delta m = m(D^*_{cand}) - m(D^0_{cand})$

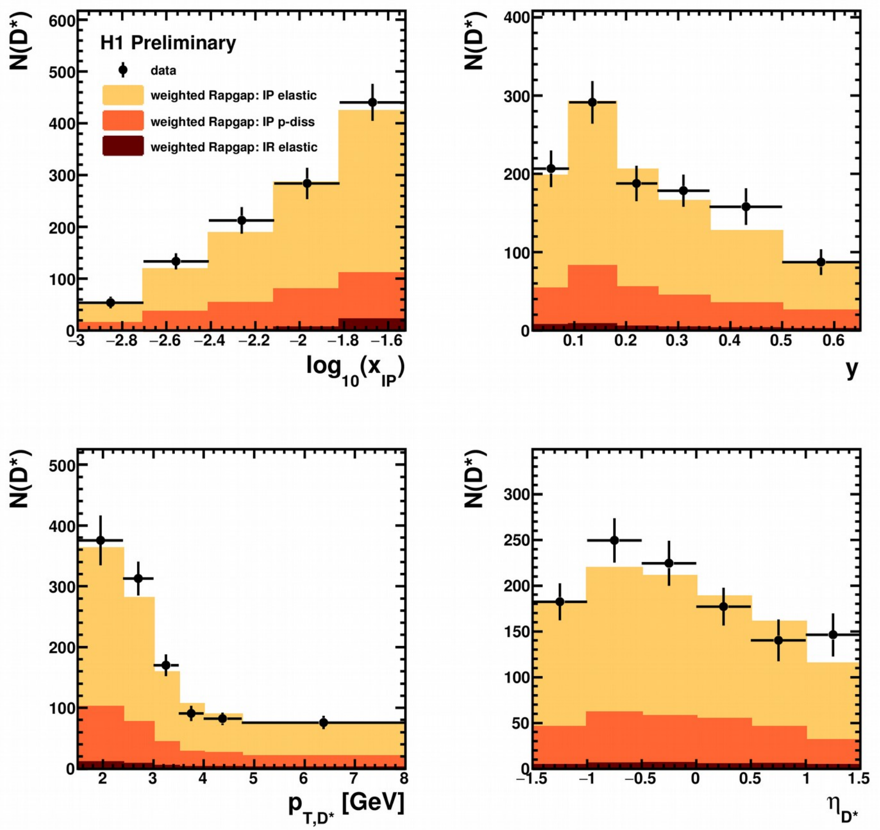
→ large rapidity gap selection

$5 < Q^2 < 100$ GeV^2 $\quad 0.02 < y < 0.65$

$p_{t,D^*} > 1.5$ GeV $\quad |\eta_{D^*}| < 1.5$ … in lab

$x_{IP} < 0.03$

D* in diffractive DIS



Detector level distributions

→ satisfactory description with simulation

→ inv. mass fits performed in each bin

→ proton dissociation contr. simulated

→ non-diffractive background negligible

→ corrected for detector effects

Measurement compared with theory

→ NLO QCD (HVQDIS in FFNS)

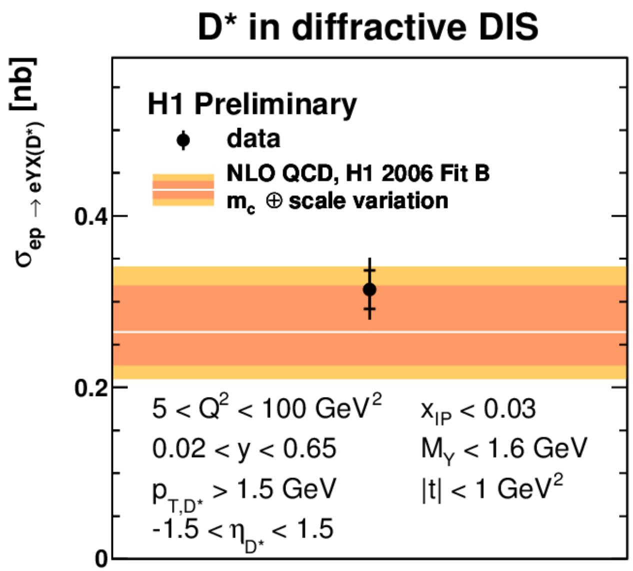
→ using H1 2006 DPDF Fit B

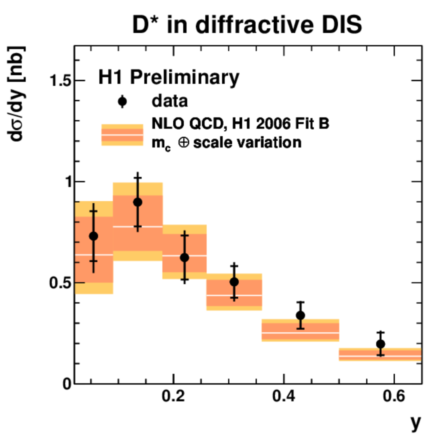
→ H1 tune of fragmentation Eur.Phys.J.C71 (2011) 1769

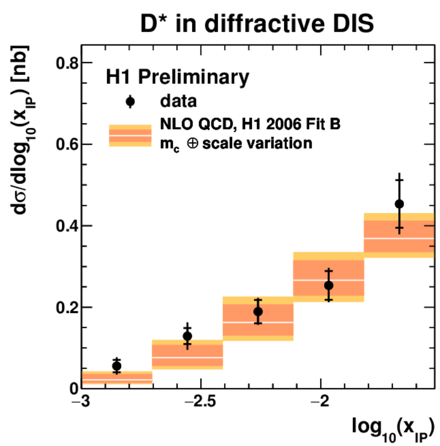
→ theoretical uncertainties (scale, m_c)

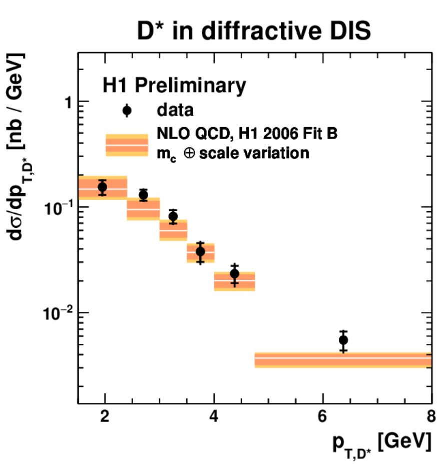
… $\mu = \mu_r = \mu_f$ varied by 0.5 and 2

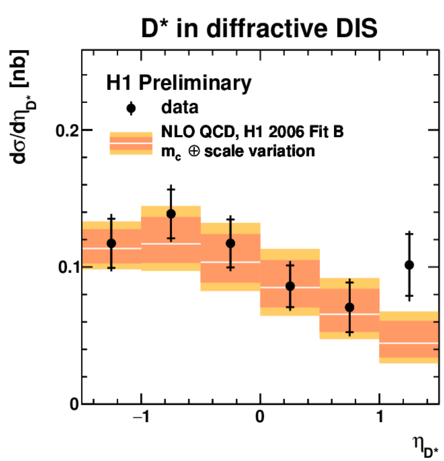
… $1.3 < m_c < 1.7$ GeV











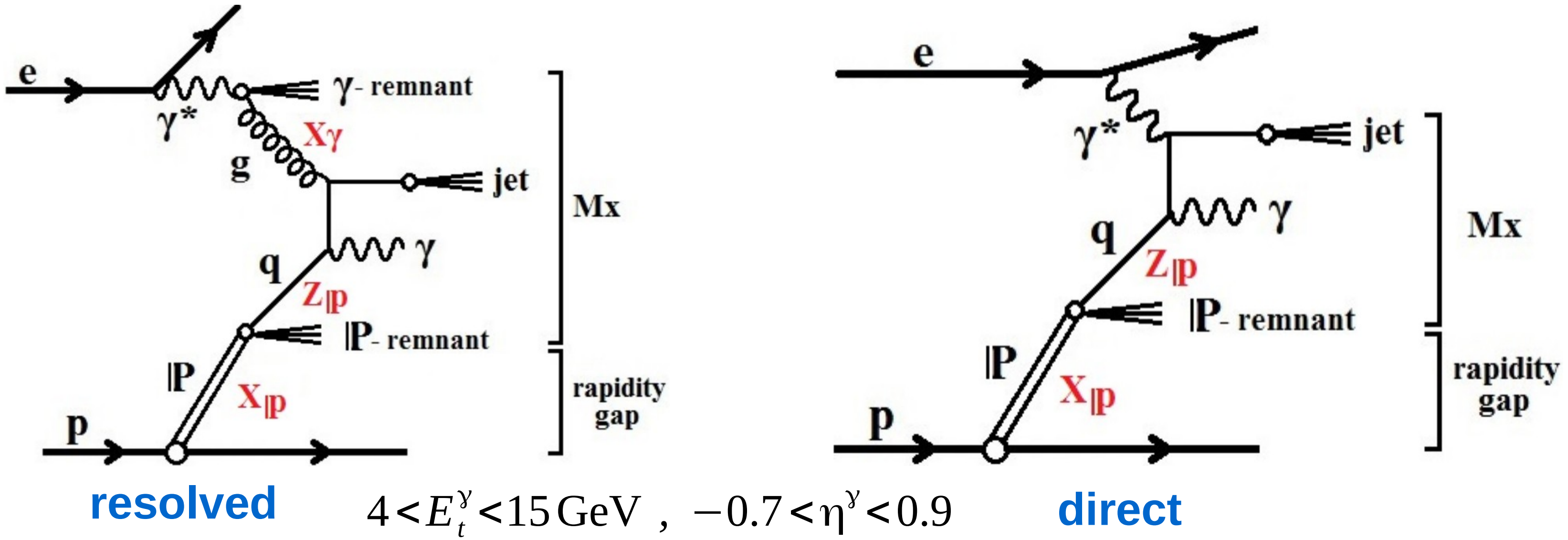
New preliminary measurement with a larger statistics

NLO QCD prediction agree well within errors with measured cross sections

→ new test of factorization

Final measurement might serve as an input to DPDF fits

Studies of the diffractive photoproduction of isolated photons at HERA.



$$4 < E_t^{\gamma} < 15\,\mathrm{GeV}\ ,\ -0.7 < \eta^{\gamma} < 0.9$$

$$4 < E_t^{jet} < 35\,\mathrm{GeV}\ ,\ -1.5 < \eta^{jet} < 1.8$$

$$Q^2 < 1\,\mathrm{GeV}^2\ ,\ 0.2 < y < 0.7\ ,\ x_{IP} < 0.03$$

First diffractive analysis of isolated (prompt) photon production

→ based on 91 pb^{-1} and 374 pb^{-1} HERA-1 and HERA-2 data, respectively

→ photons directly from hard process

→ sensitive to quark content of IP

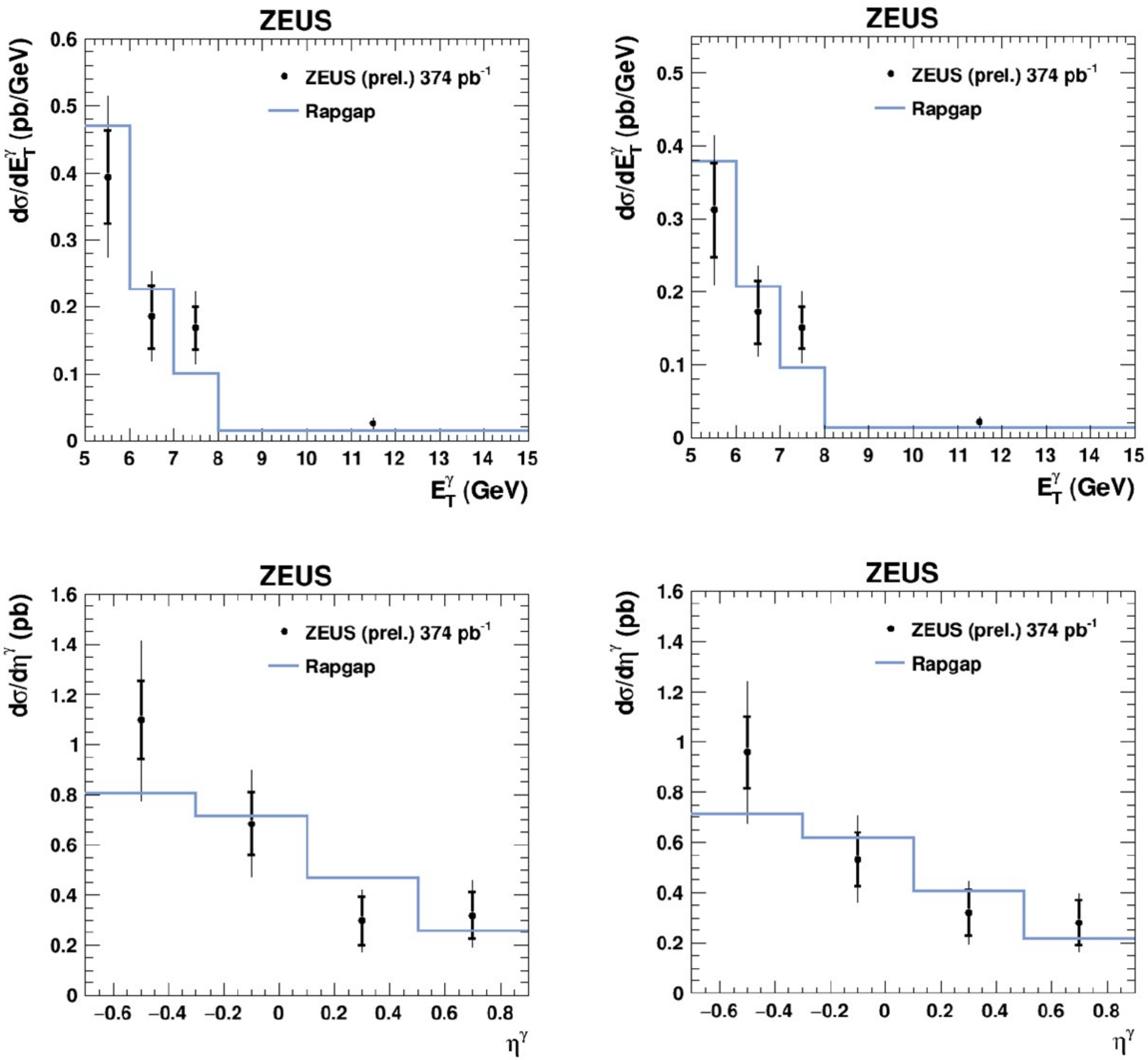
→ photoproduction → resolved / direct component

→ photon isolation selection to suppress background

→ data corrected to hadron level and compared with theory provided by Rapgap MC

→ inclusive photon and photon+jet measurements performed

inclusive γ ***γ + jet events***

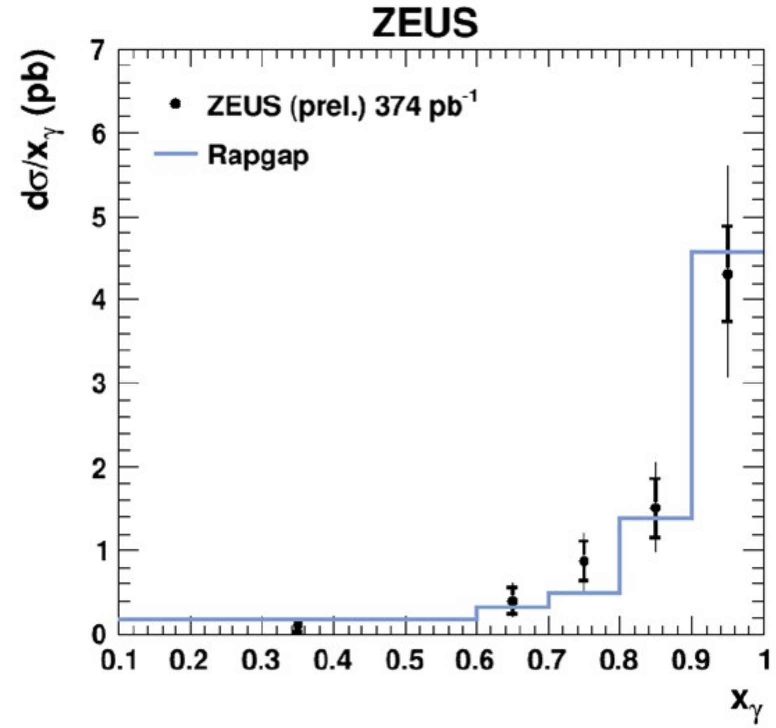


Most photon events accompanied by jet

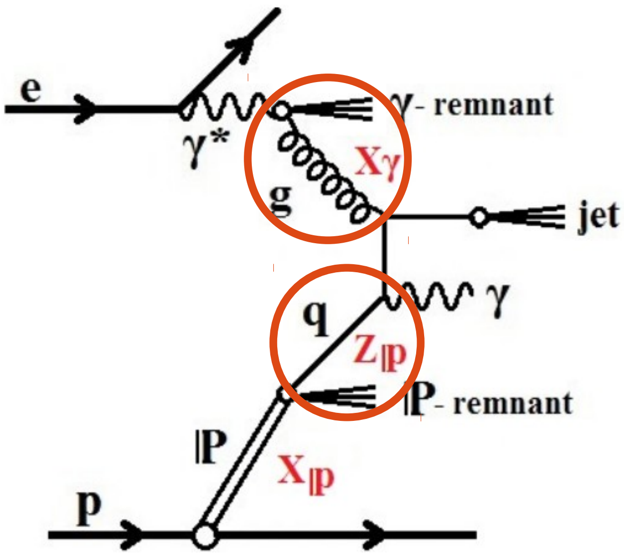
MC prediction normalised to the data

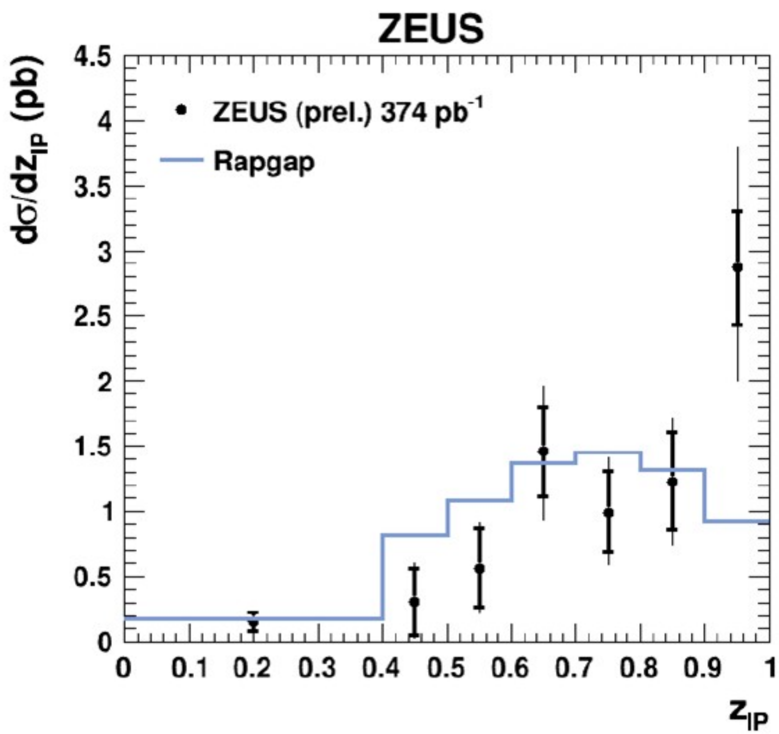
Reasonable description of shapes MC

NLO needed to test factorization in this channel



x_γ: ***Direct proccesses dominate***





z_{IP}: ***models at high z_{IP} do not peak***

→ seen at detector level already

→ to be studied

Production of exclusive dijets in diffractive deep inelastic scattering at HERA

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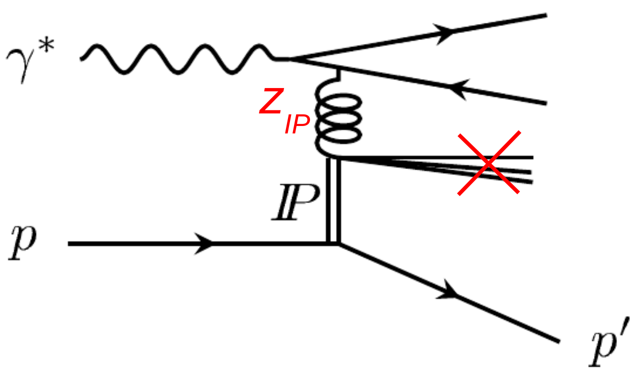
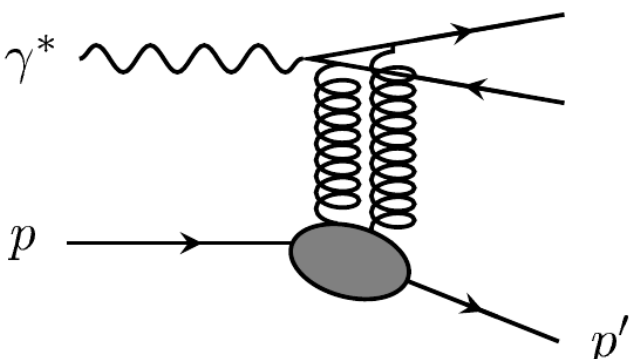
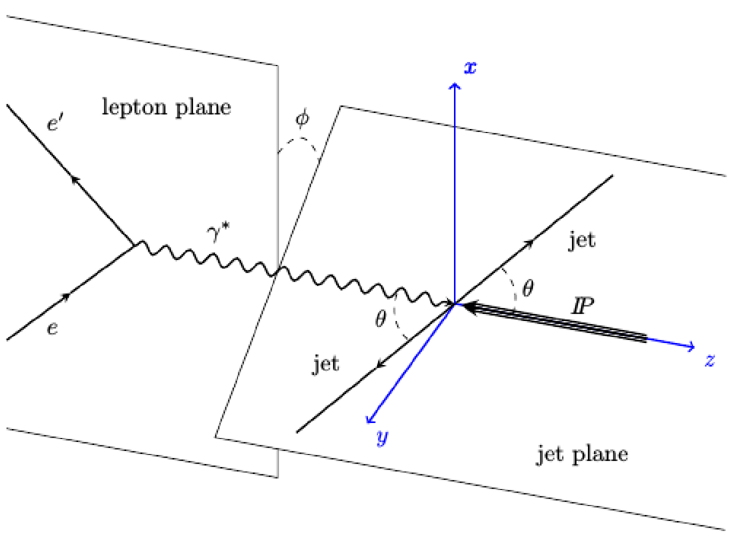






Resolved pomeron models in DDIS for dijet analyses describes well various event observables

→ in limit of large z_{IP} all energy exclusively in jets

… no IP remnant

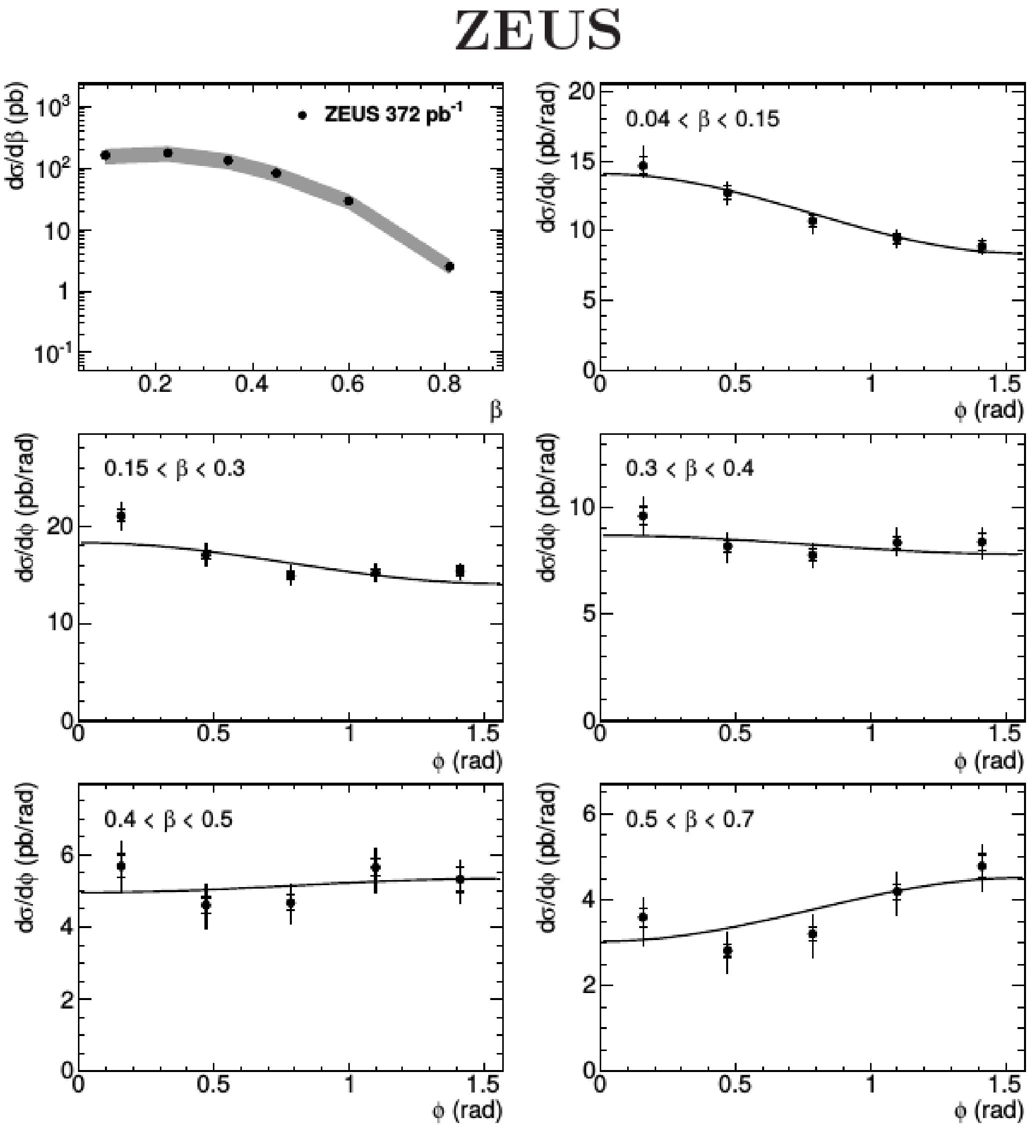
Two-gluon exchange well suited for exclusive dijets

Distribution of lepton-dijet angle plane differs for both theoretical approaches

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

A > 0 … resolved IP

A < 0 … two-gluon exchange



Measurement performed corrected to hadron level

→ control distributions well described

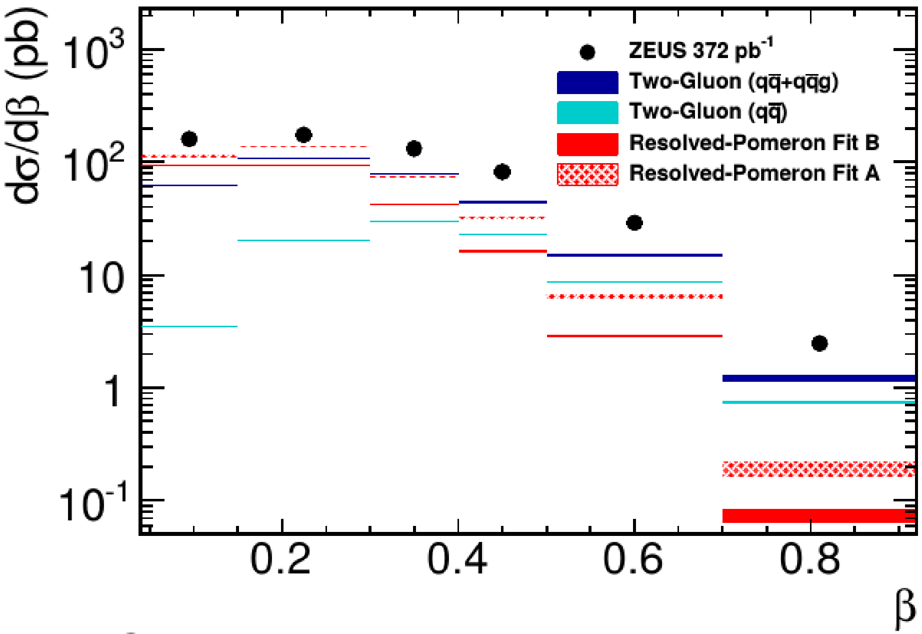
→ unfolding with TSVDUnfold

$Q^2 > 25$ GeV^2
$90 < W < 250$ GeV
$x_{IP} < 0.01$
$M_X > 5$ GeV
$N_{jets} = 2$
$p_{T;jet} > 2$ GeV.

ϕ distribution obey 1 + A cos2ϕ

in bins of $\beta = x / x_{IP}$

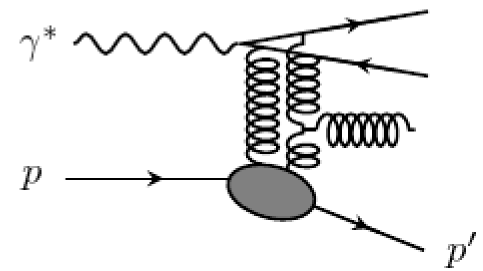
→ fitted A parameters β dependence extracted

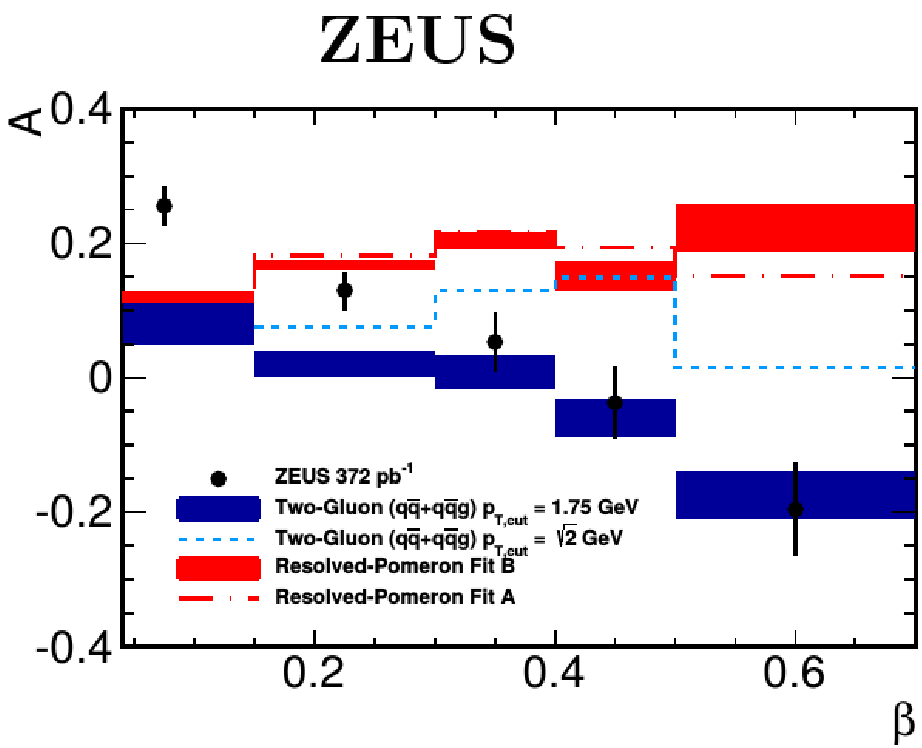


None of the models does particularly well as to the normalization of dσ / dβ

→ NLO ?

→ $q\bar{q}g$ final state included in two-gluon exchange model





Study of A indicates two-gluon exchange may be relevant for β > 0.3

Resolved IP does not reproduce A(β)

Discussion

***Collinear factorization tested** by H1 and ZEUS in diffractive DIS*

1) Factorization approach with QCD NLO predictions successfully describes diffractive DIS dijet data

   → most recent dijet measurement precise enough to contribute in DPDF fits

2) Recent preliminary result on D* production (together with previous ZEUS and H1 results) results supports validity of collinear factorization

3) Prompt photons in diffractive photoproduction measured for the first time indicating reasonable description of x-section shapes with LO prediction

***Collinear factorization breaking** repeatedly tested in diffractive photoproduction of dijets at HERA*

→ inconsistency remains in the size of the survival probablity between H1 and ZEUS

→ H1 and ZEUS consistently observe lack of dependence of the s.p. on kinematics

→ most recent H1 result experimentally “orthogonal” to previous H1 results

Recent result of ZEUS on exclusive dijet production in diffractive DIS provide indication of applicability of two gluon exchange

Thank you for your attention!

Double ratios php/DIS diffractive dijets