Review of diffraction at HERA

Karel Černý

Charles University in Prague

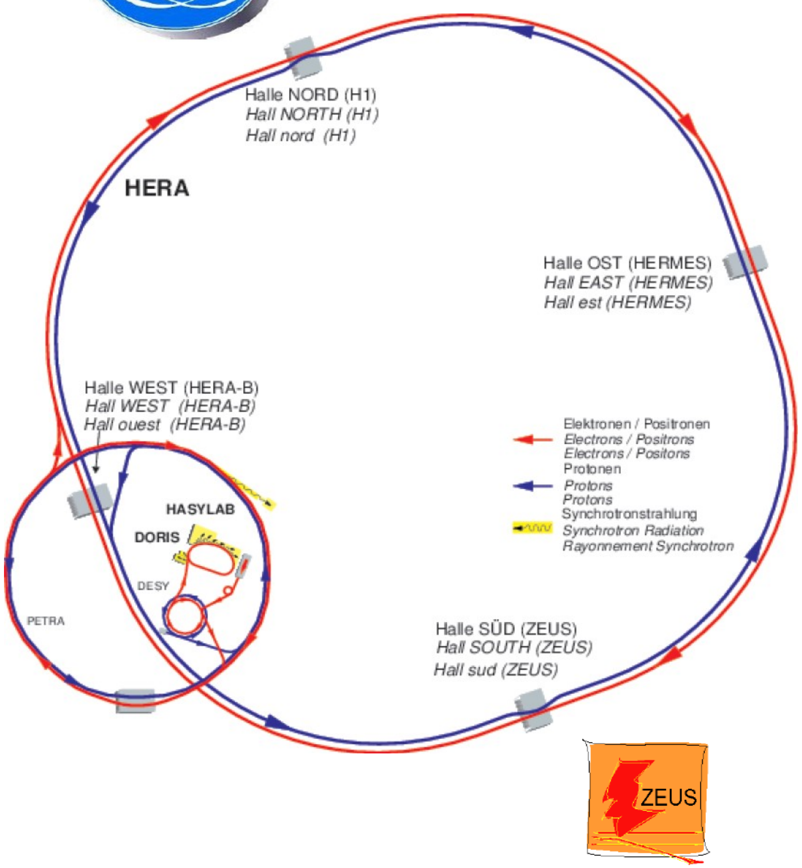
on behalf of the H1 and ZEUS Collaborations

Low-x Meeting, June 7 2016, Gyöngyös, Hungary

HERA

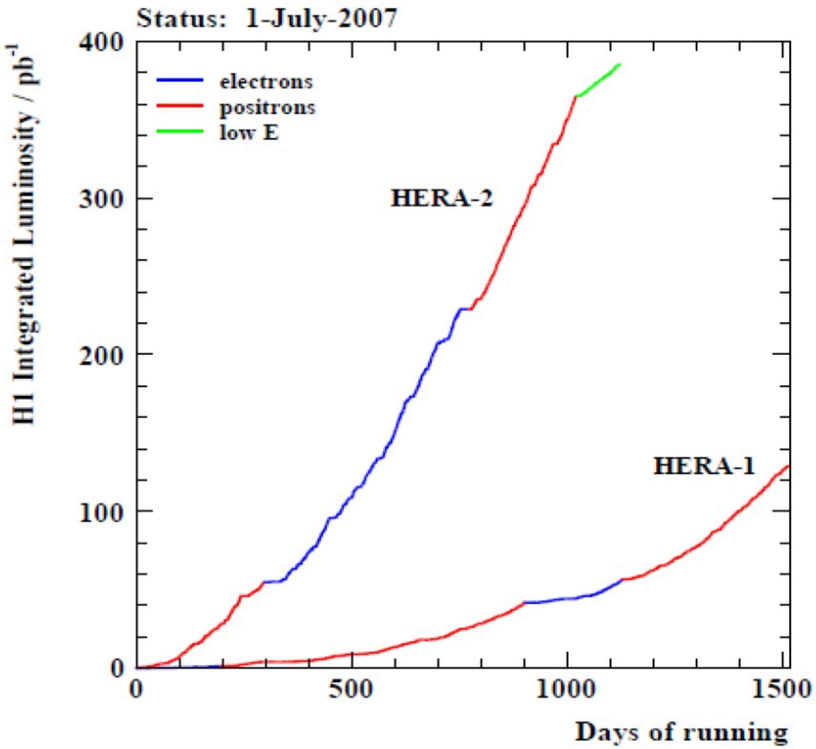
HERA (DESY, Hamburg)
ep collider, 1993-2007

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



H1 and ZEUS
two multipurpose experiments

HERA I (1993-2000) ≈ 120 pb^{-1}
HERA II (2003-2007) ≈ 380 pb^{-1}
… per experiment



Diffraction in ep

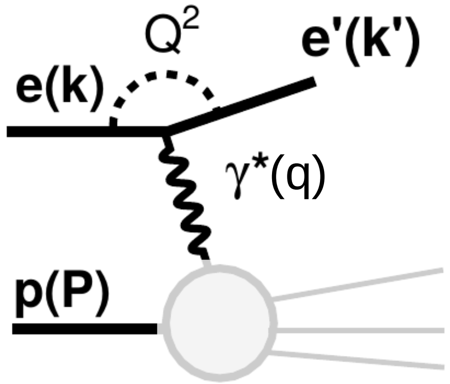
ep interactions proceed mainly via γ^* exchange

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

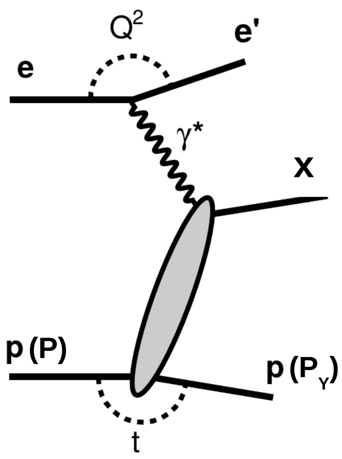
$Q^2=-q^2=-(k-k')^2$... four-momentum transfer at e vertex

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

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



diffraction



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

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

from Regge phenomenology of h-h collisions

$$\sigma_{tot} \propto \sum_k s^{2(\alpha_k(0)-1)}$$

$\alpha_k(t) = \alpha_k(0) + \alpha'_k\, t$

→ trajectory in (t, l) plane

→ l – cplx ang. momentum

$\sigma_{tot}(s)$ described only if vacuum quantum numbers' exchange is included:

→ Pomeron (IP) $\alpha_{IP}(t) = 1.08 + 0.25\ [\mathrm{GeV}^{-2}]\ .\ t$

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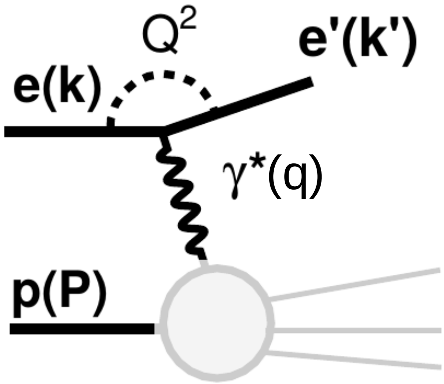

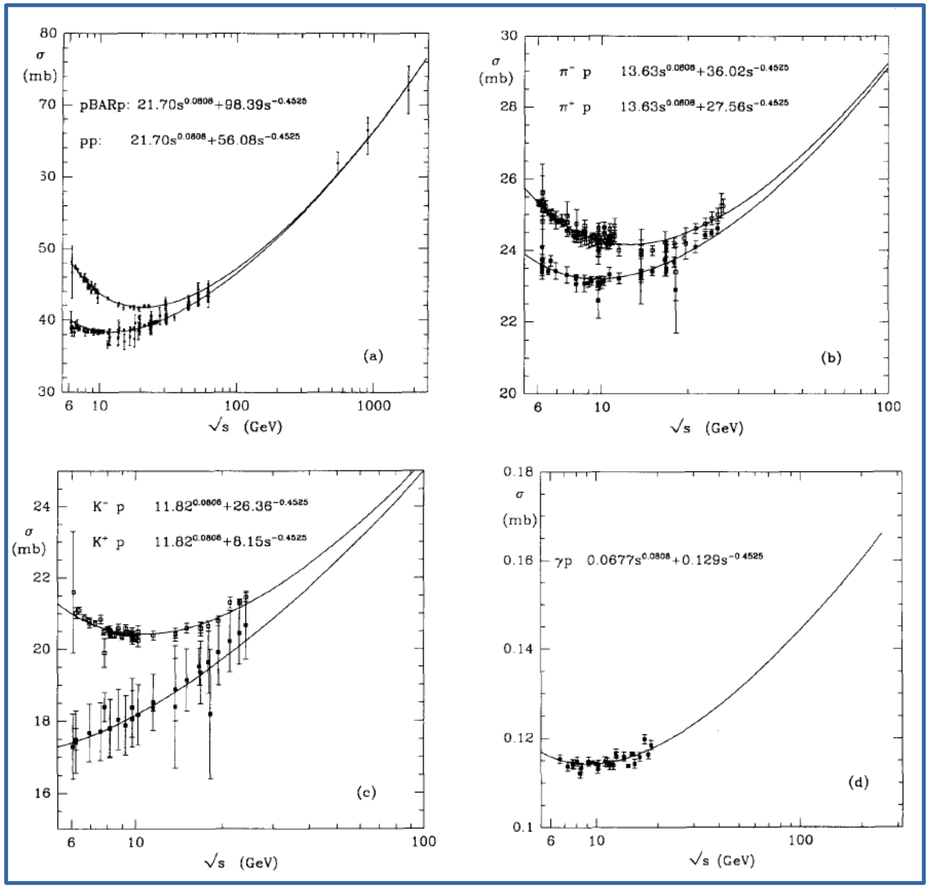

Donnachie,Landshoff - Phys. Lett. B 296 1-2

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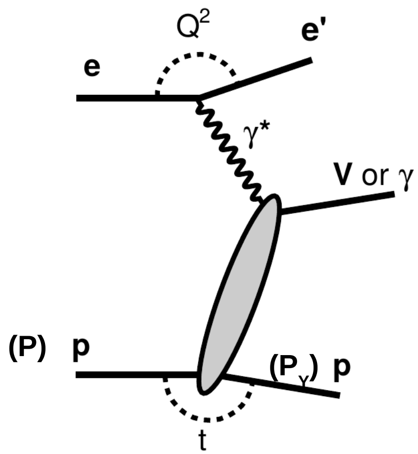
Diffraction in ep

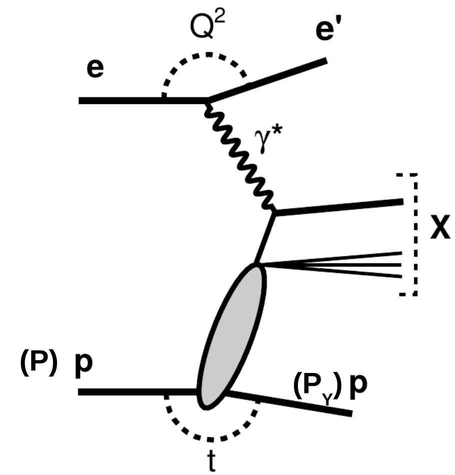
main classes of diffractive processes of interest at HERA



'elastic' VM or DVCS
partially also inclusive DDIS

in some cases with
proton dissociation

$p \rightarrow Y$, where $M_Y = P_Y^2$



diffractive dissociation

hard diffractive exchange

→whole exchange participates
→mostly ρ, ω, φ, ρ', J/ψ or γ

described in proton rest frame

→ VMD model (no hard scale)
→ color dipole model (hard scale)

HERA domain

→continuum of masses of X

diffractive exchange

→ only part of diff. exchange participates, $\beta = x / x_{IP}$

Diffraction seen in detectors

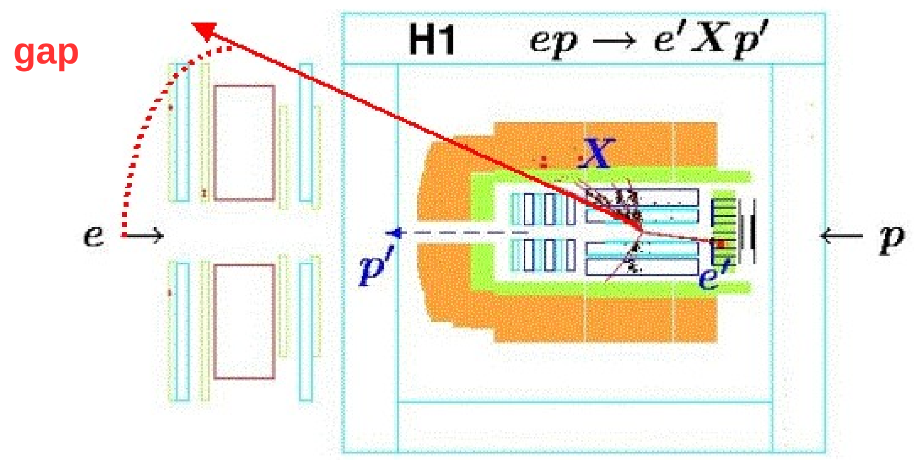
due to vacuum quantum exchange

→ 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 used in H1 and ZEUS

LRG method



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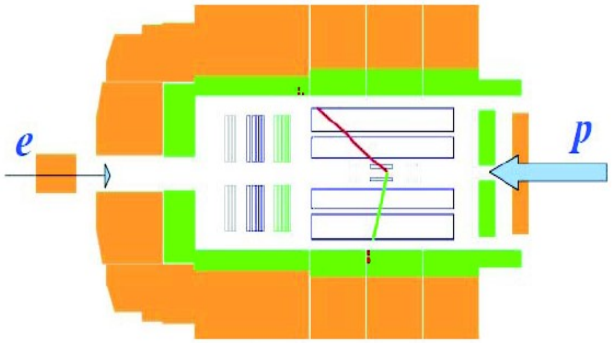

exclusive VM
empty detector otherwise

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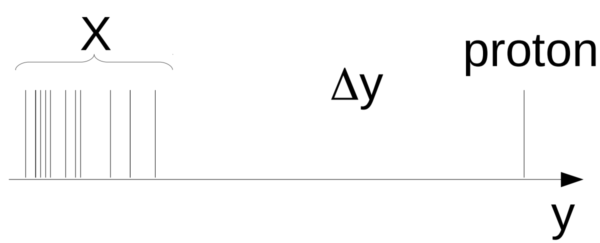

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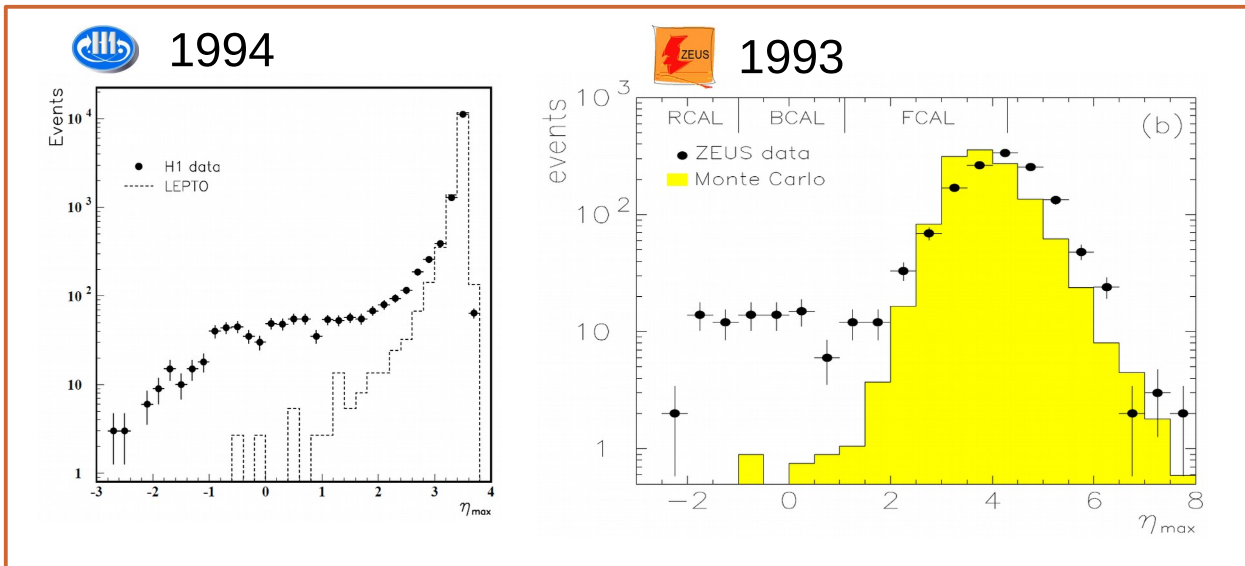

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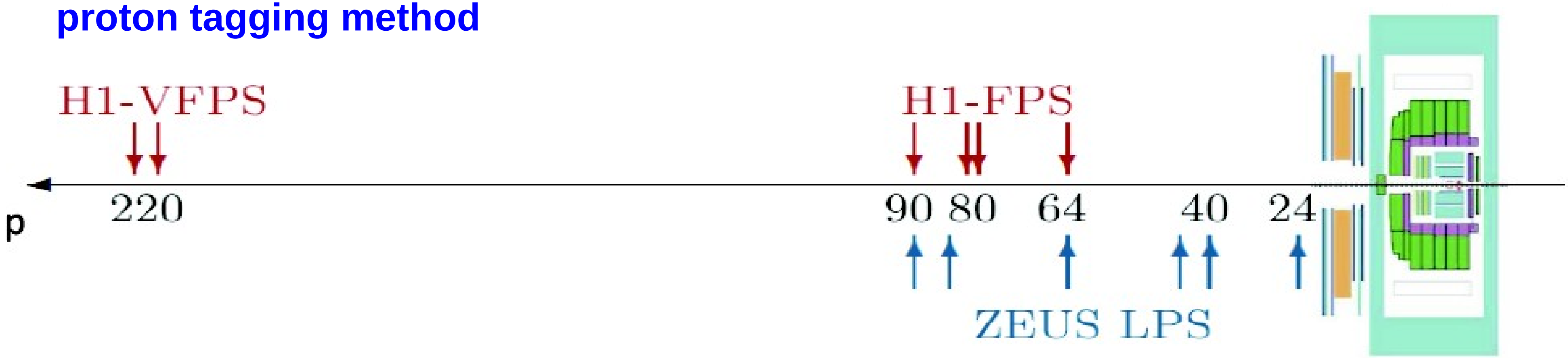

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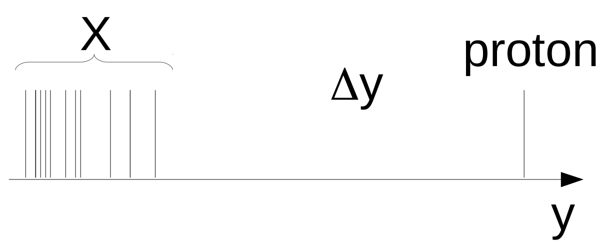

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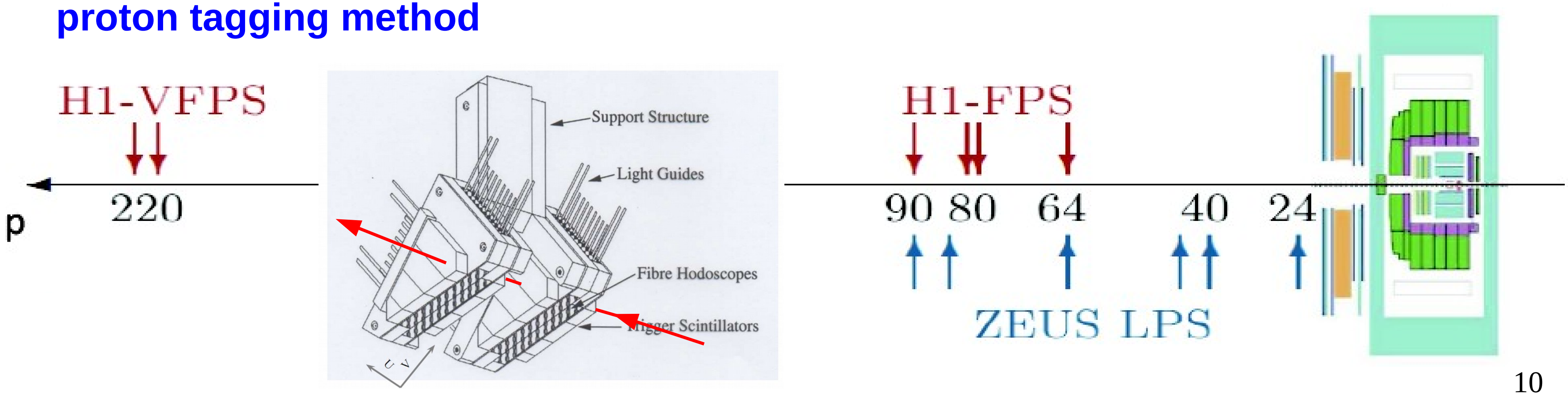
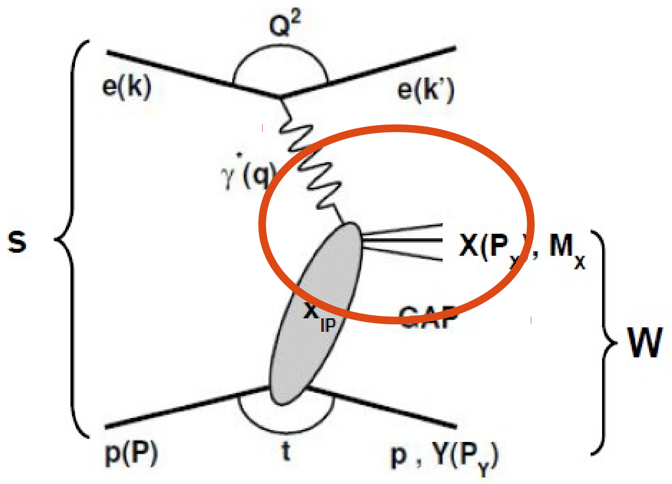


Diffractive dissociation

Diffractive dissociation in DIS

- virtual photon dissociates into system X ($M_X^2 << W^2$)
- small momentum transfer to proton, $|t| << W^2$
- proton stays intact or dissociates into system Y ($M_Y^2 << W^2$)
- 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
- represents ~10% of low x DIS σ



ep → eXY

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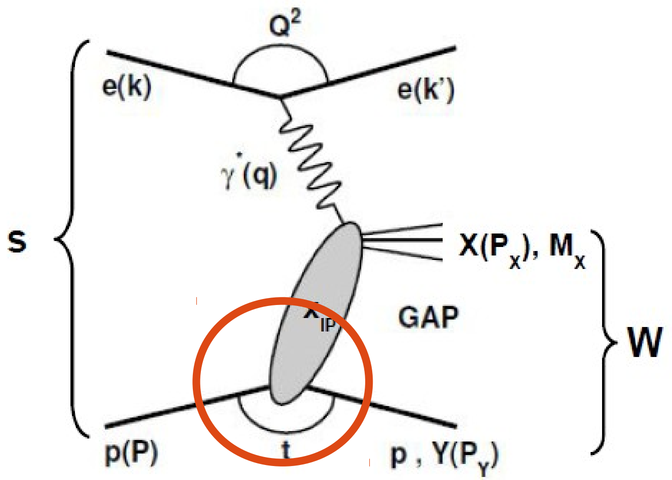

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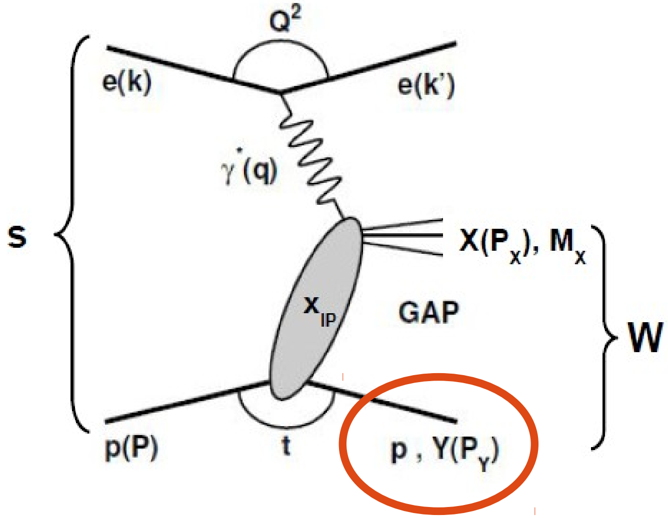

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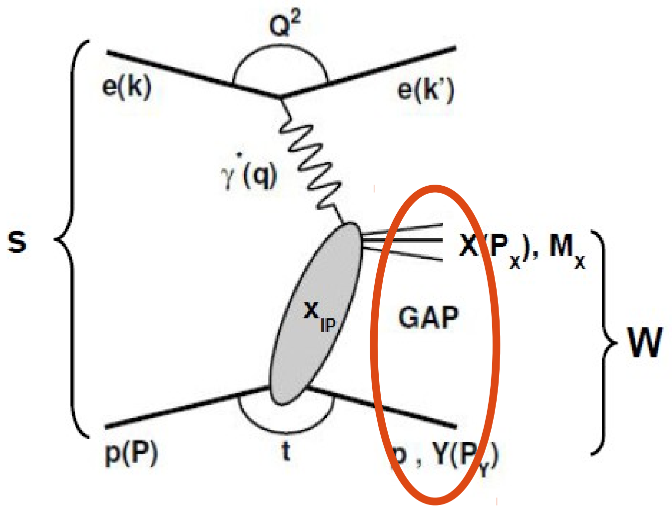

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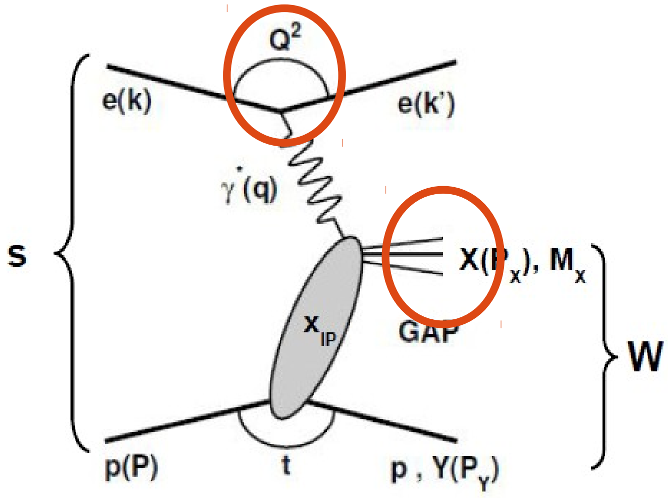

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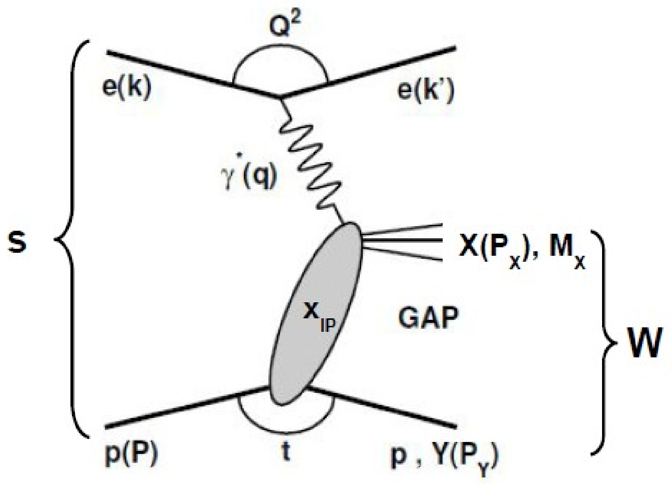


ep → eXY

Collinear factorization

Most used approach to model various features of diffractive DIS.

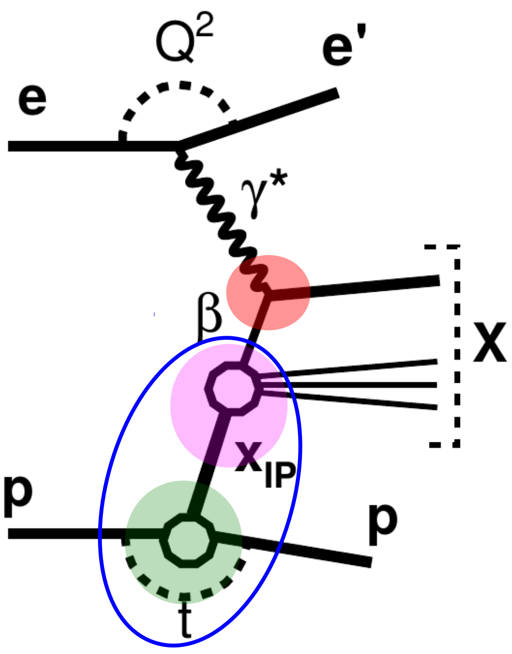
central assumption

Collinear factorization Collins, valid for diffractive DIS

→ diffractive parton distribution functions (DPDFs)

→ QCD based predictions for X states

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



optionally

Resolved Pomeron approach Ingelman and Schlein

→ virtual photon inteacts with partonic diffractive exchange

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

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

Diffractive PDFs

Parton distributions under diffractive condition → DPDFs

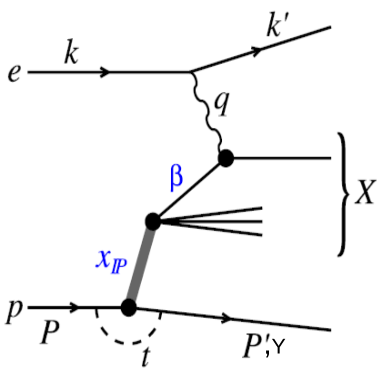
→ use of collinear factorization (+ proton vertex fact.)

→ QCD predictions of cross sections

→ parton distributions parameterized and evolved

(usually, uds democratically in a quark singlet and gluon)

→ optimal params' values from fits to measured x-sections



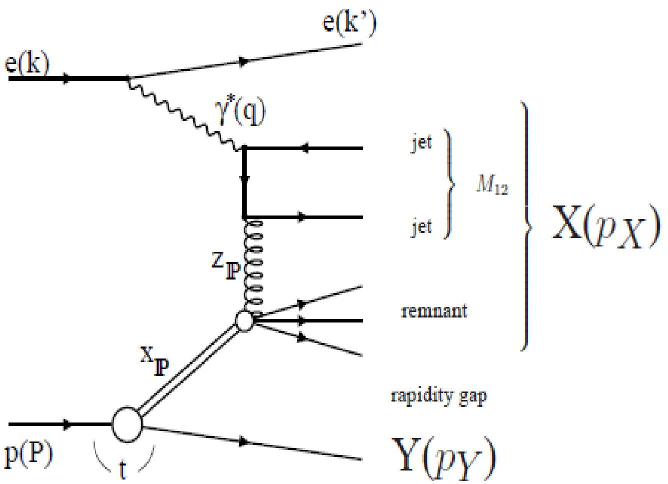
inclusive

Extracted mostly from:

→ inclusive data ep → eXY

→ ep → eXY with jets in the final state

(another constraint on gluon DPDF)



dijets

Can be improved by:

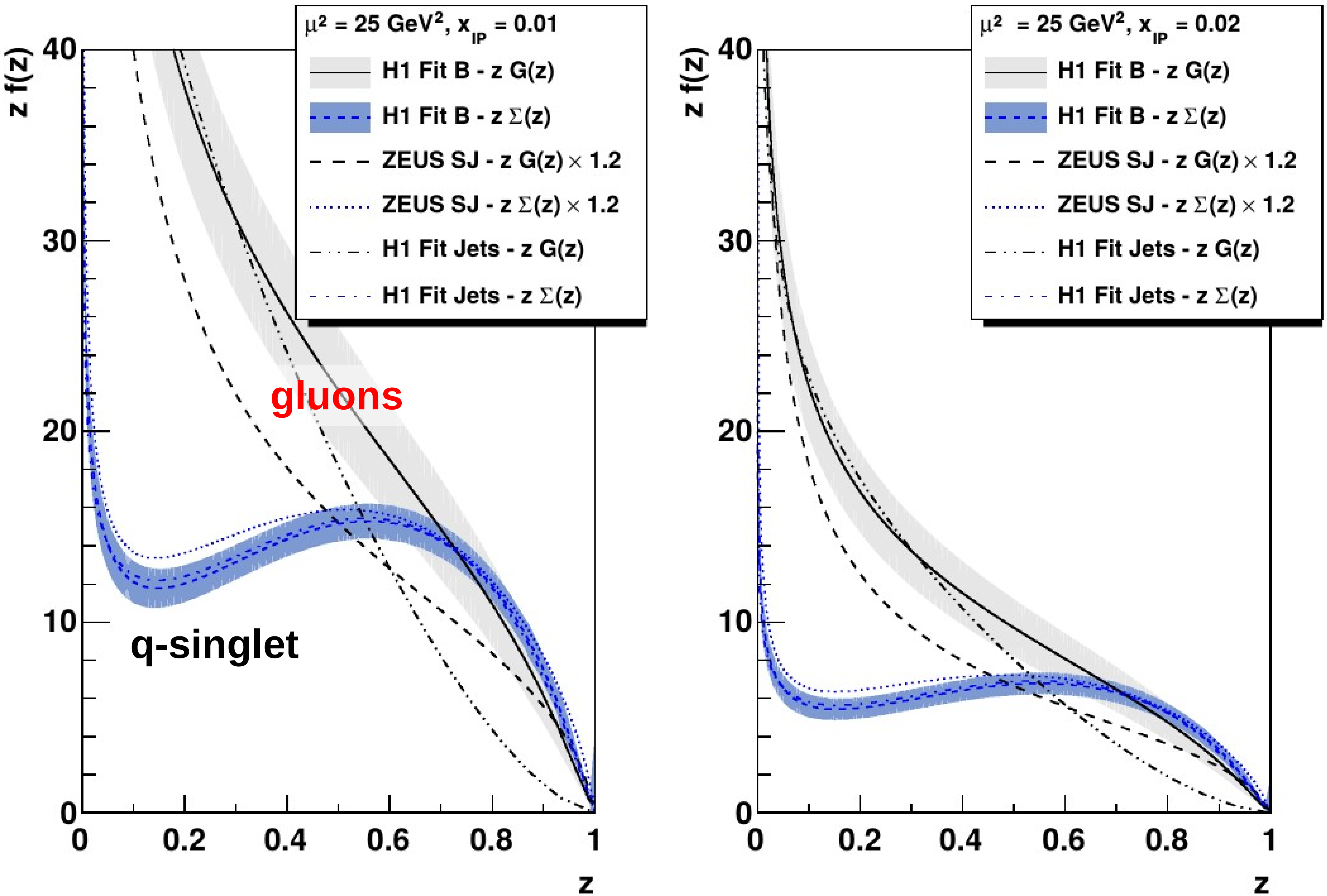
→ combination of diffraction selection methods

→ combinations of data from H1 and ZEUS

Diffractive PDFs

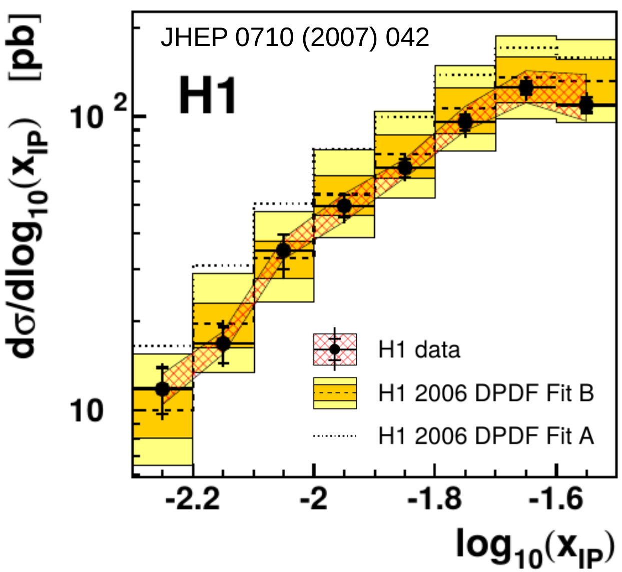
It's the gluon that dominates diffractive PDFs

a summary of recent, most used, DPDF fits from H1 and ZEUS

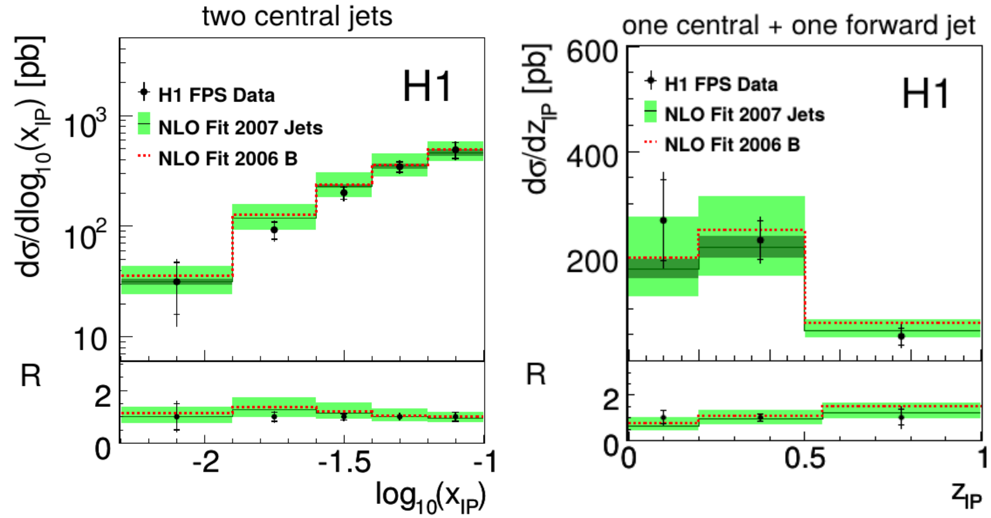


Tests of collinear factorization

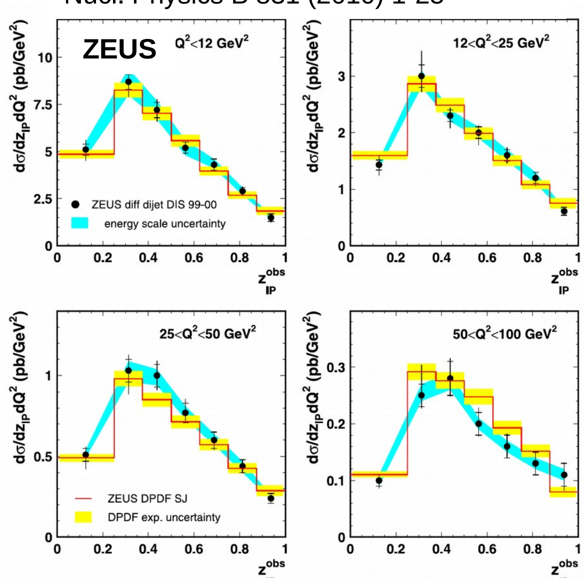
Jets in DDIS

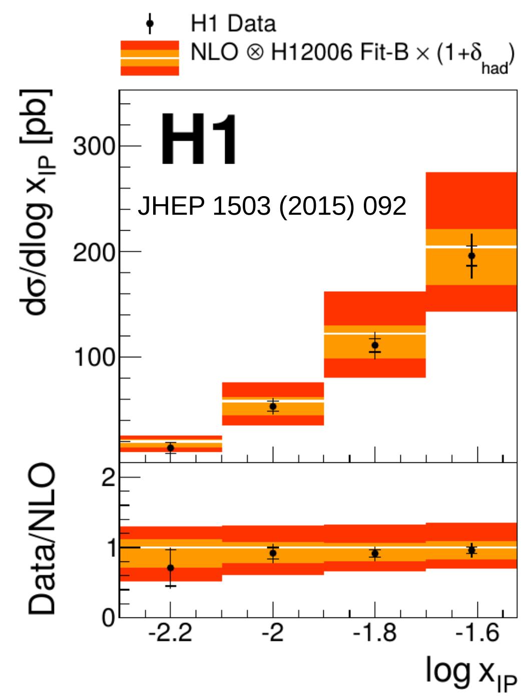


Eur.Phys.J. C72 (2012) 1970



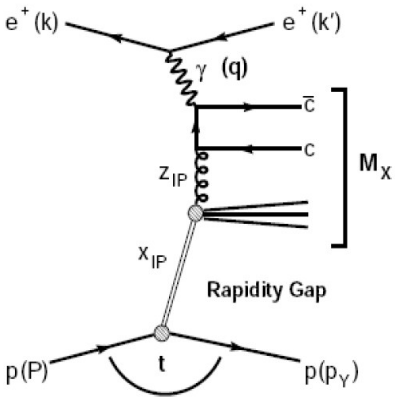
Nucl. Physics B 831 (2010) 1-25



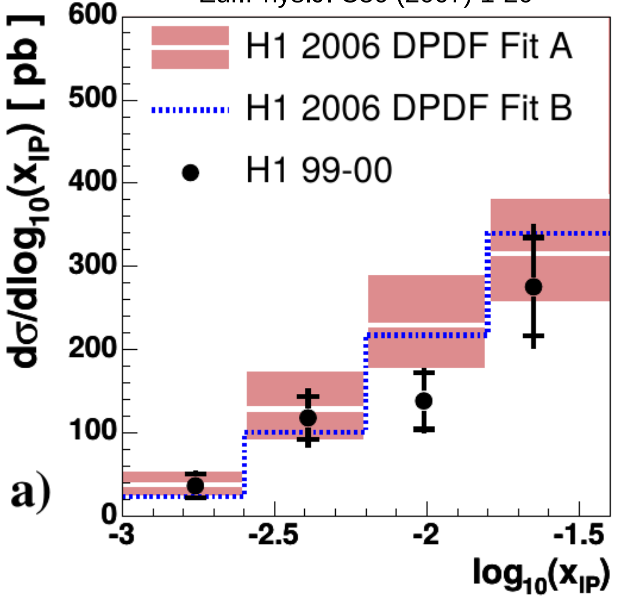


Tests of collinear factorization

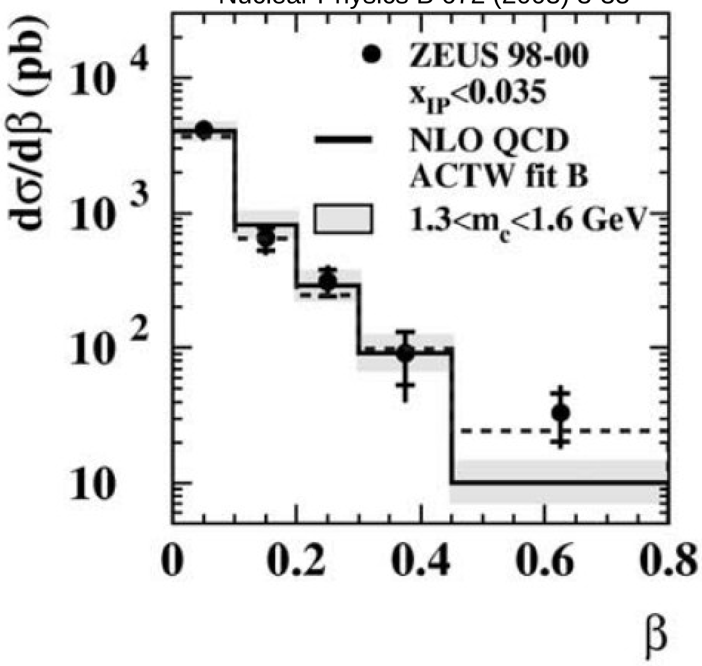
open charm with D*



Eur.Phys.J. C50 (2007) 1-20



Nuclear Physics B 672 (2003) 3-35



Tests of collinear factorization

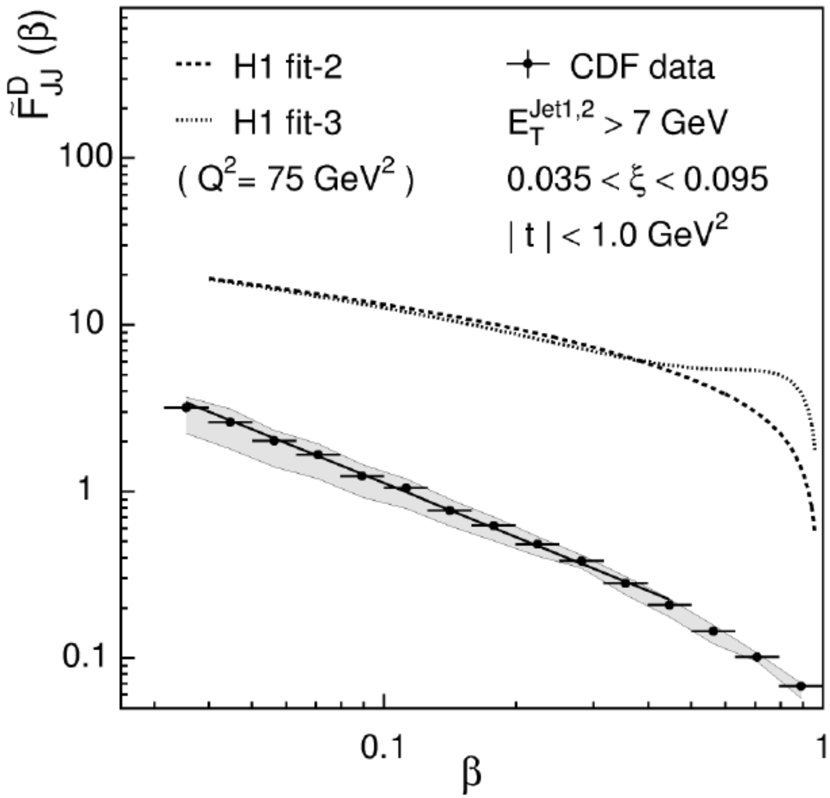
Jets in photoproduction

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

→ order of magnitude overestimation of predicted pp dijet rates

Factorization breaking in diffractive dijet production

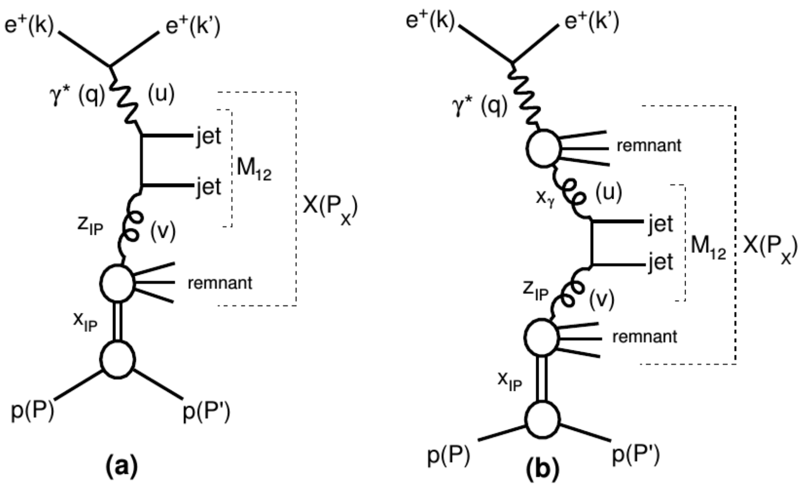
Phys. Rev. Lett. 84 5043 (2000)



Tested in diffractive dijet photoproduction at HERA

Tests of collinear factorization

Jets in photoproduction



direct
x_γ = 1

resolved
x_γ < 1

photoproduction regime

→ Q2 ~ 0 … electron at low angle

→ hard scale provided by p_T , mass

in LO

→ direct γ DIS-like

→ resolved γ pp-like

x_γ fraction $x_\gamma = \frac{P.u}{P.q}$

→ allows to classify processes … up to smearing

studies by H1 and ZEUS

→H1: LRG analyses 2007(Php,DIS), 2010(Php) … latest leading proton 2015(Php, DIS)

→ZEUS: LRG analysis 2010 (Php)

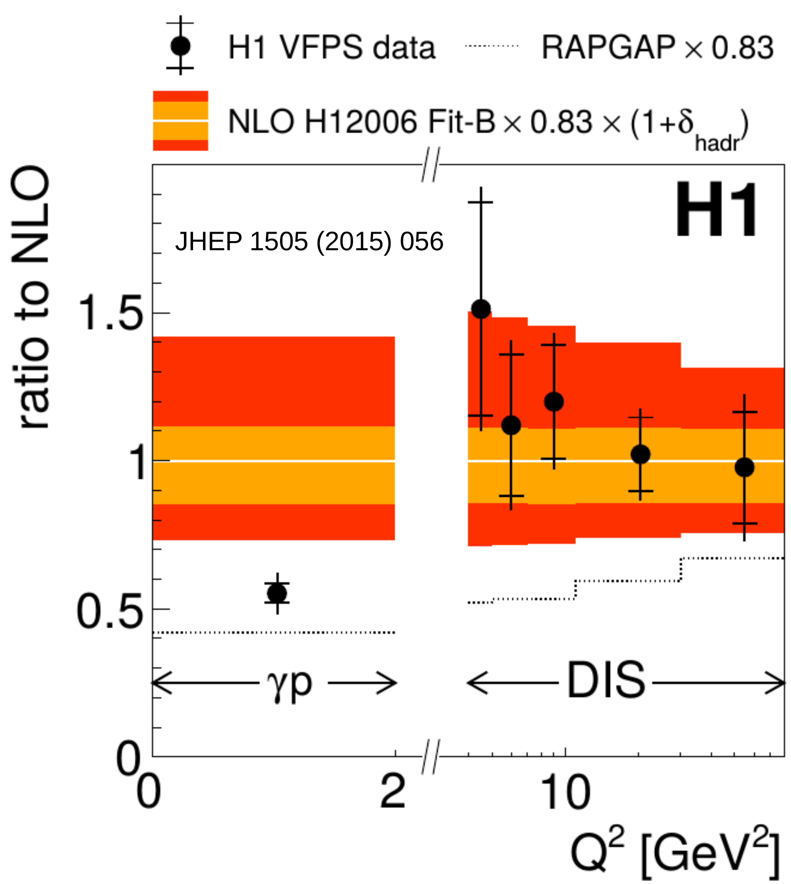
Tests of collinear factorization

Jets in photoproduction

photoproduction regime

di

x



measured suppression of data wrt theory

data/NLO

gp	$0.551 \pm 0.078\ (\text{data})^{+0.230}_{-0.149}\ (\text{theory})$
DIS	$1.08 \pm 0.11\ (\text{data})^{+0.45}_{-0.29}\ (\text{theory})$

studi

→H1: ... DIS)

→ZEUS: LRG analysis 2010 (Php)

New results from HERA

Studies of the diffractive photoproduction of isolated photons at HERA

Open charm production in diffractive deep inelastic scattering at HERA

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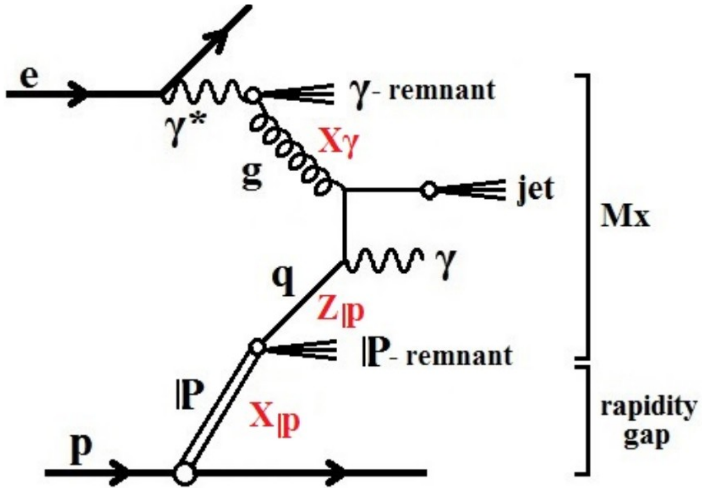
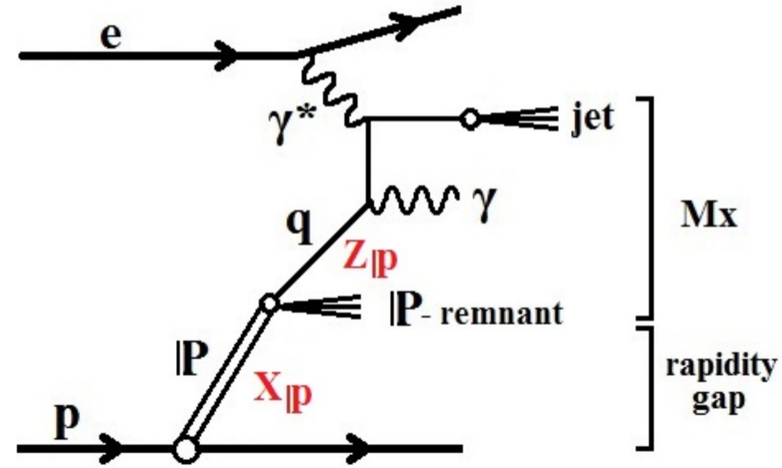


resolved



direct

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

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

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

→ sensitive to quark content of IP, “free” of hadronization for γ

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

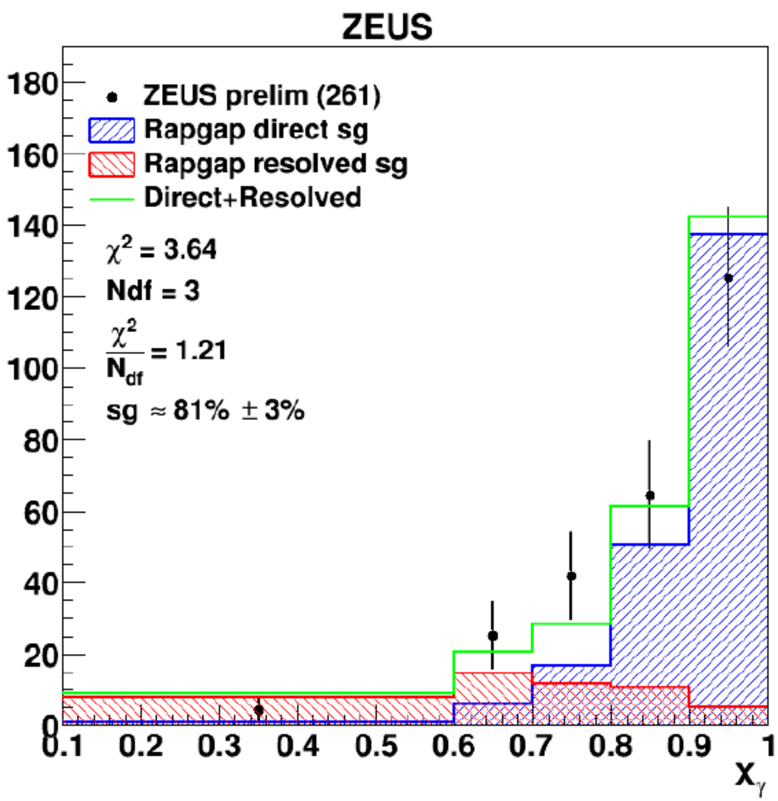
→ photoproduction $Q^2 \sim 0$ GeV^2 → resolved / direct component

→ photon isolation selection to suppress background (π^0 and DVCS)

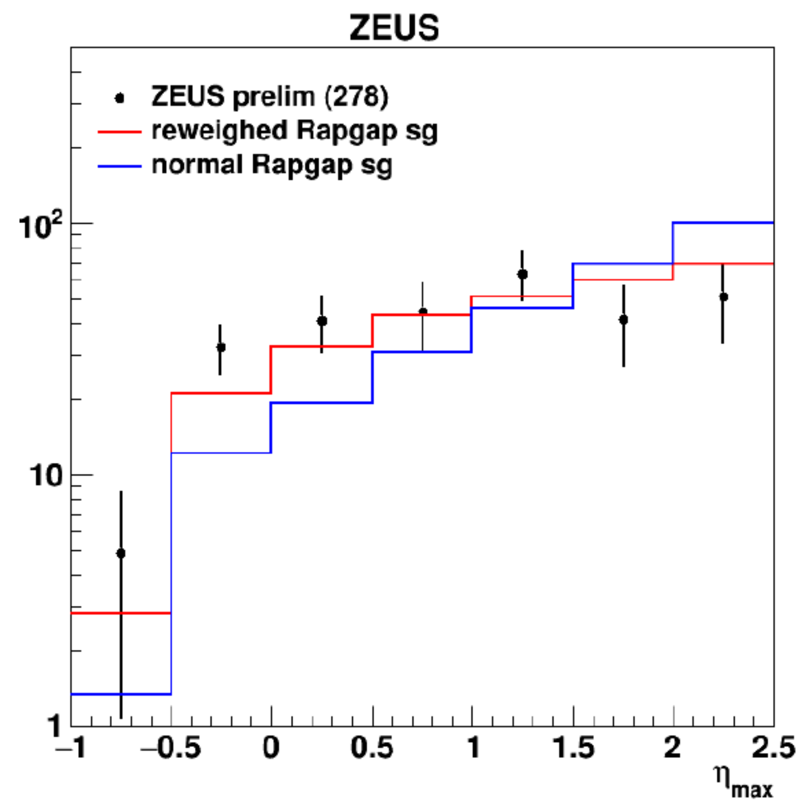
→ data corrected to hadron level and compared with theory provided by Rapgap MC

New results from HERA

Studies of the diffractive photoproduction of isolated photons at HERA.



fraction of γ in hard process



most forward calo cluster (E > 400 MeV)

→ **simulation optimized in order to describe the data at rec level**

→ **normalizations propagated to MC model predictions of x-section**

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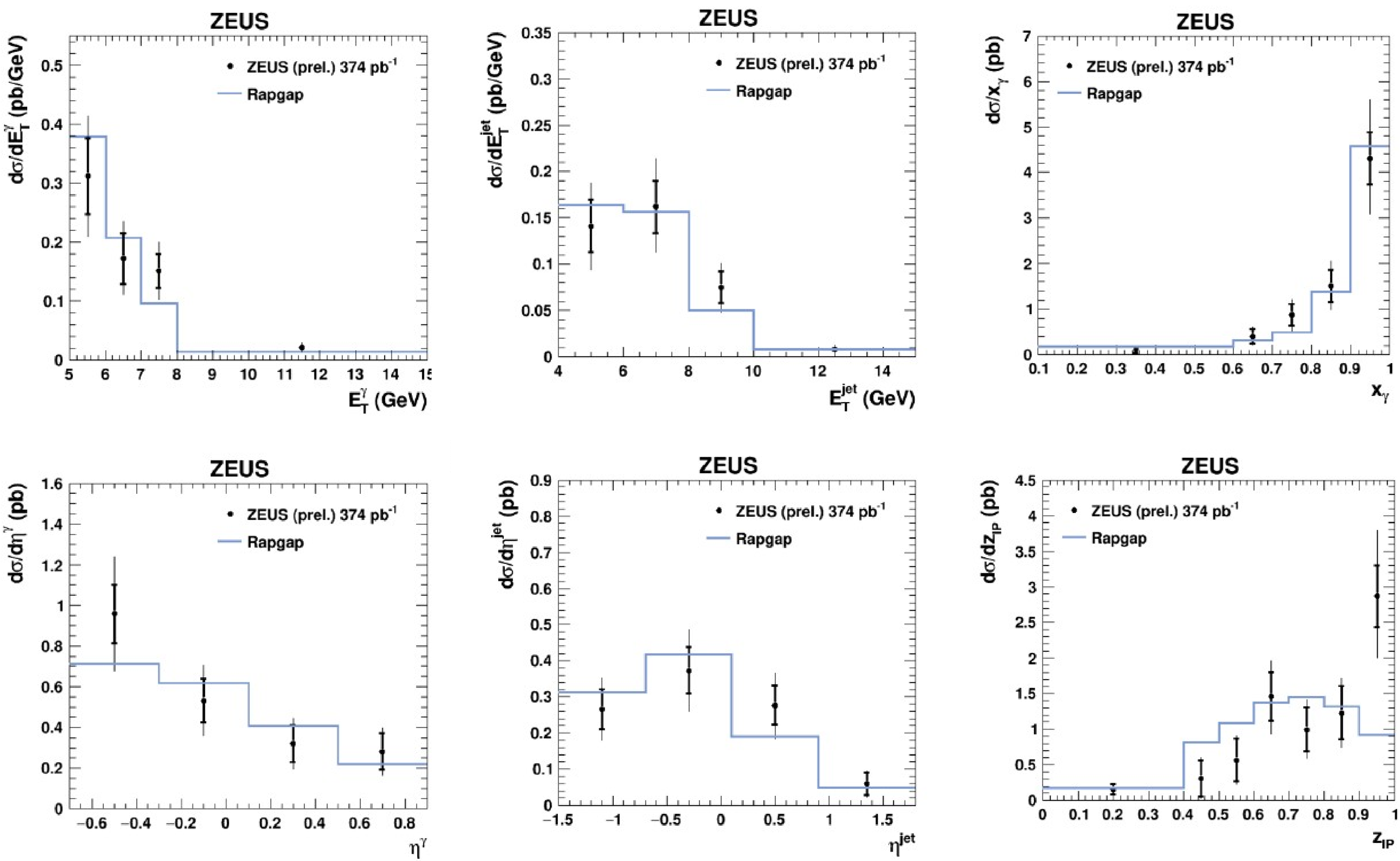

γ + jet events, Rapgap weighted and normalized

New results from HERA

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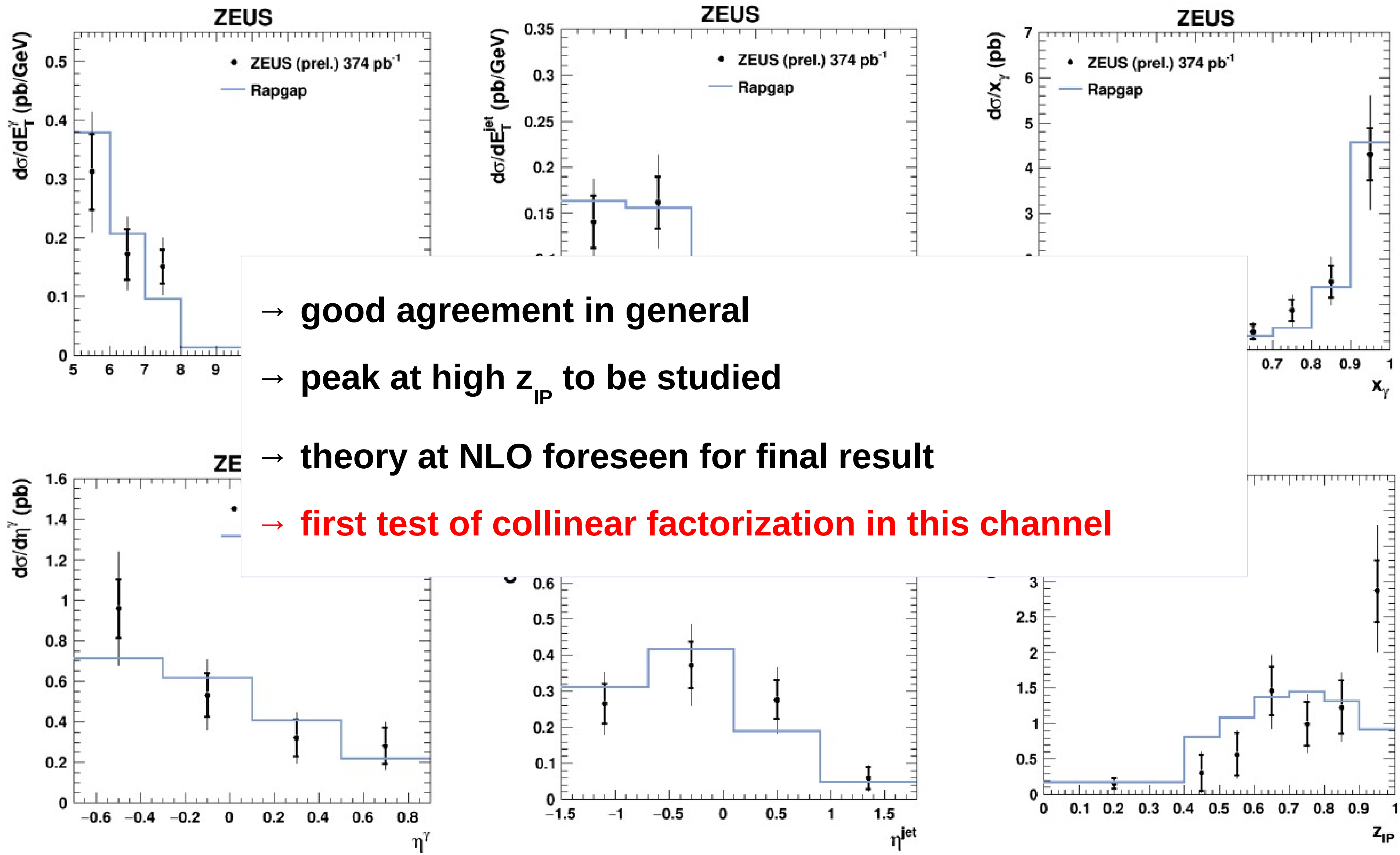


→ **good agreement in general**

→ **peak at high z_{IP} to be studied**

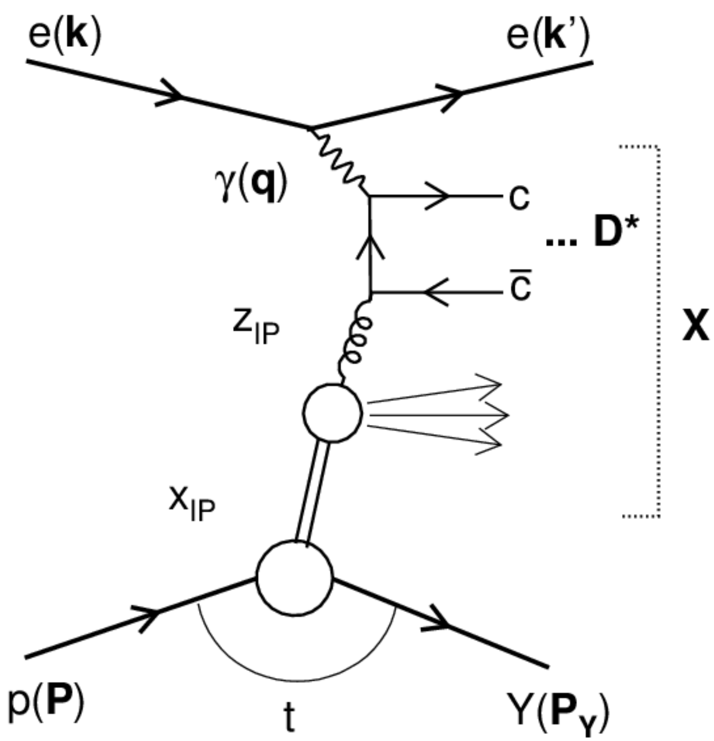
→ **theory at NLO foreseen for final result**

→ **first test of collinear factorization in this channel**

γ + jet events

New results from HERA

Open charm production in diffractive deep inelastic scattering at HERA



→ based on 280 pb^{-1} HERA 2 data
(~ 50 pb^{-1} H1 HERA 1 publ. 2007)

→ tagged with presence of D* in the final state

→ gluon initiated 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

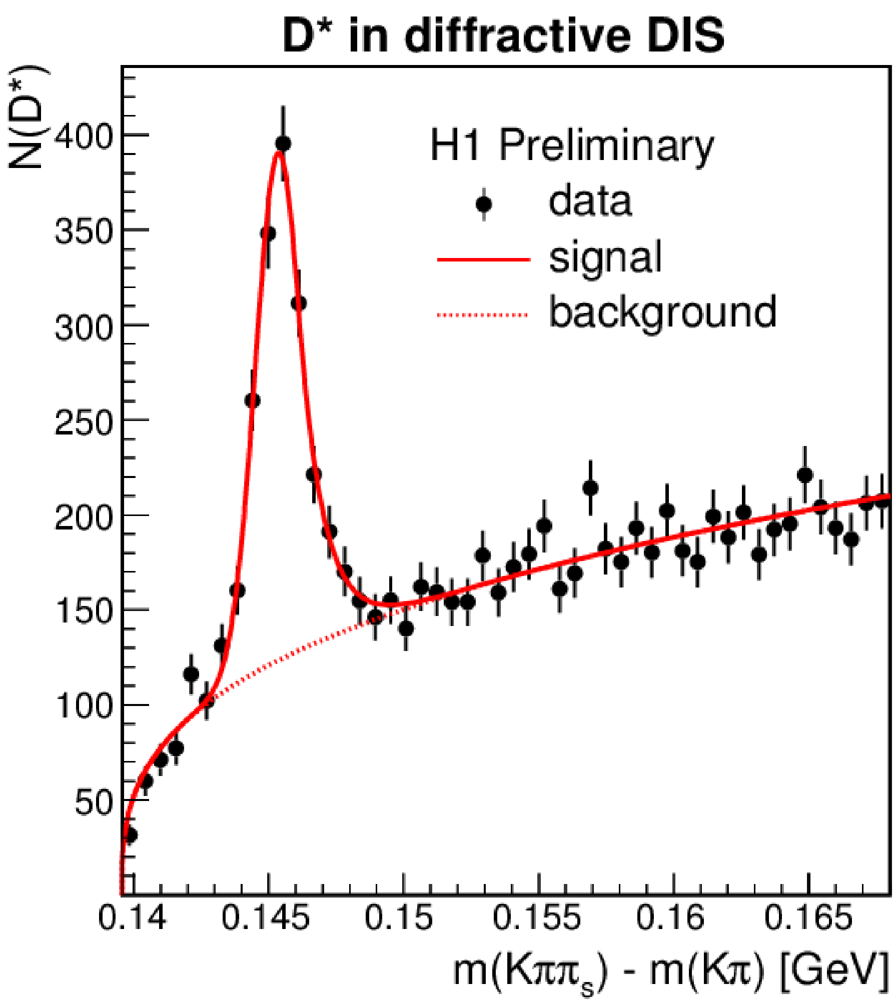
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$

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

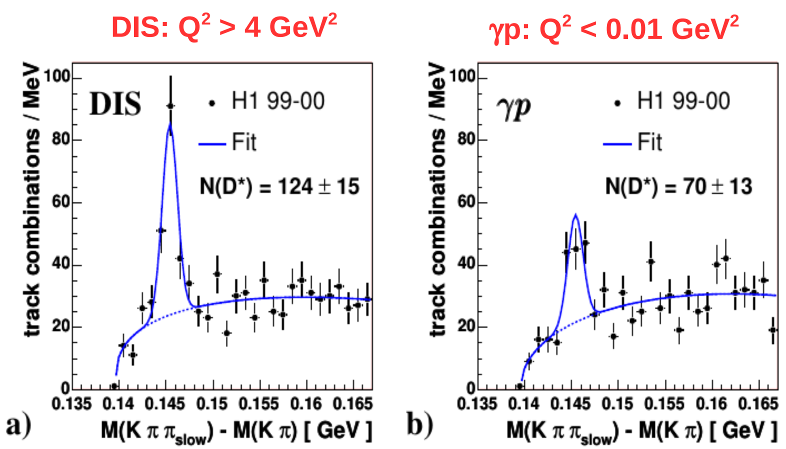
$x_{IP} < 0.03$

New results from HERA

Open charm production in diffractive deep inelastic scattering at HERA



Eur.Phys.J.C50 (2007) 1



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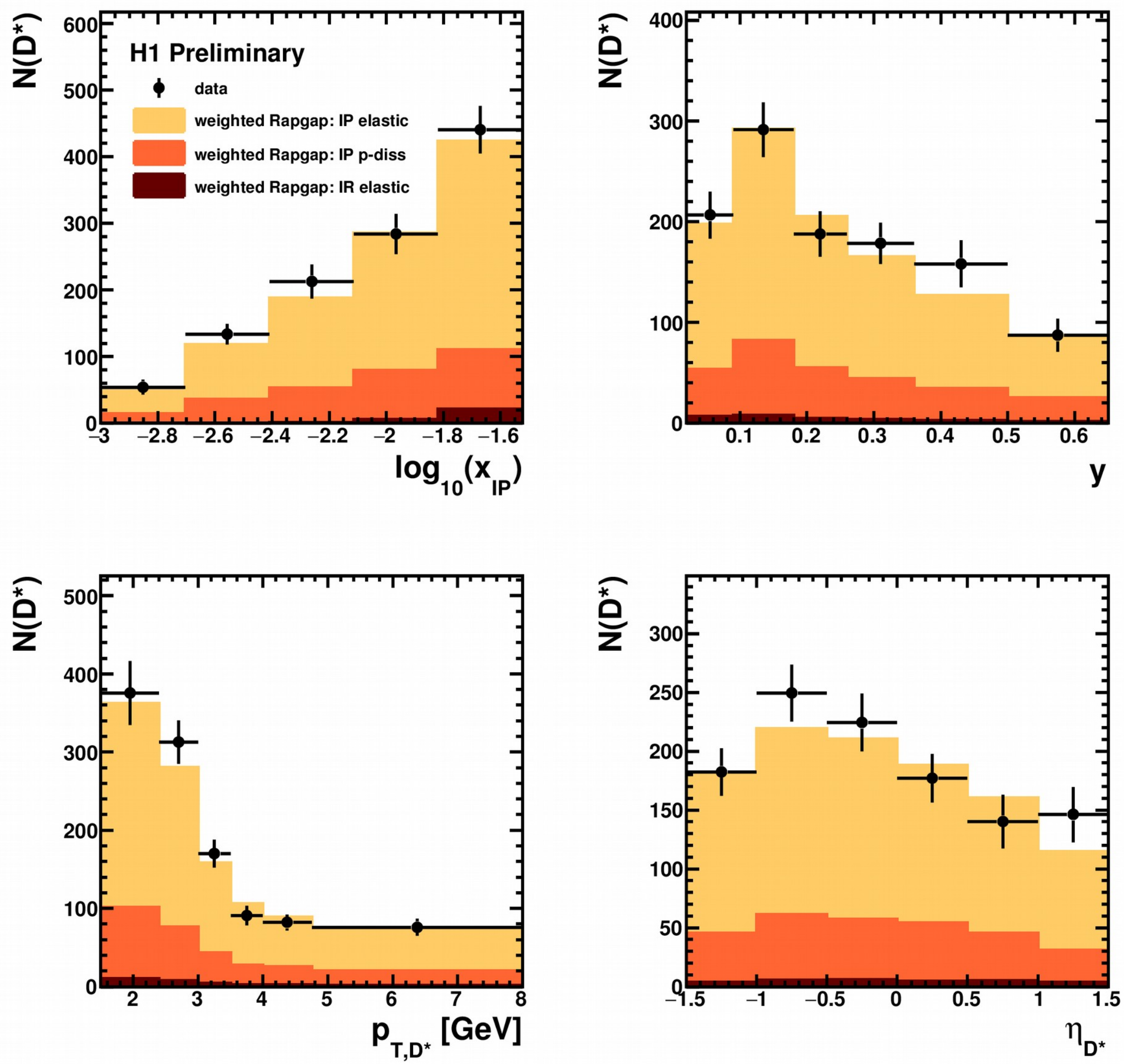
D* in diffractive DIS



detector level control distributions

- correction of the data for detector effects relies on adequate description with simulation
- fits performed in each bin for data and MC contribution
- proton dissociation contribution ($M_Y > m_p$)
- non-diffractive background negligible
- weighting applied to correct shape and normalization agreement

cross sections compared with

NLO QCD by HVQDIS in FFNS

- adapted for diffraction, using H1 2006 DPDF Fit B Eur.Phys.J.C73 (2013) 2311
- $\mu^2_r = \mu^2_f = m^2_c + 4\,Q^2$
- charm mass m_c = 1.5 GeV
- Kartvelishvili fragmentation used
  - according to H1 measurement, Eur.Phys.J.C71 (2011) 1769

Theoretical uncertainties considered at the moment

- μ_r , μ_f varied by 0.5 and 2 simultaneously for th. uncertainty
- $1.3 < m_c < 1.7$ GeV

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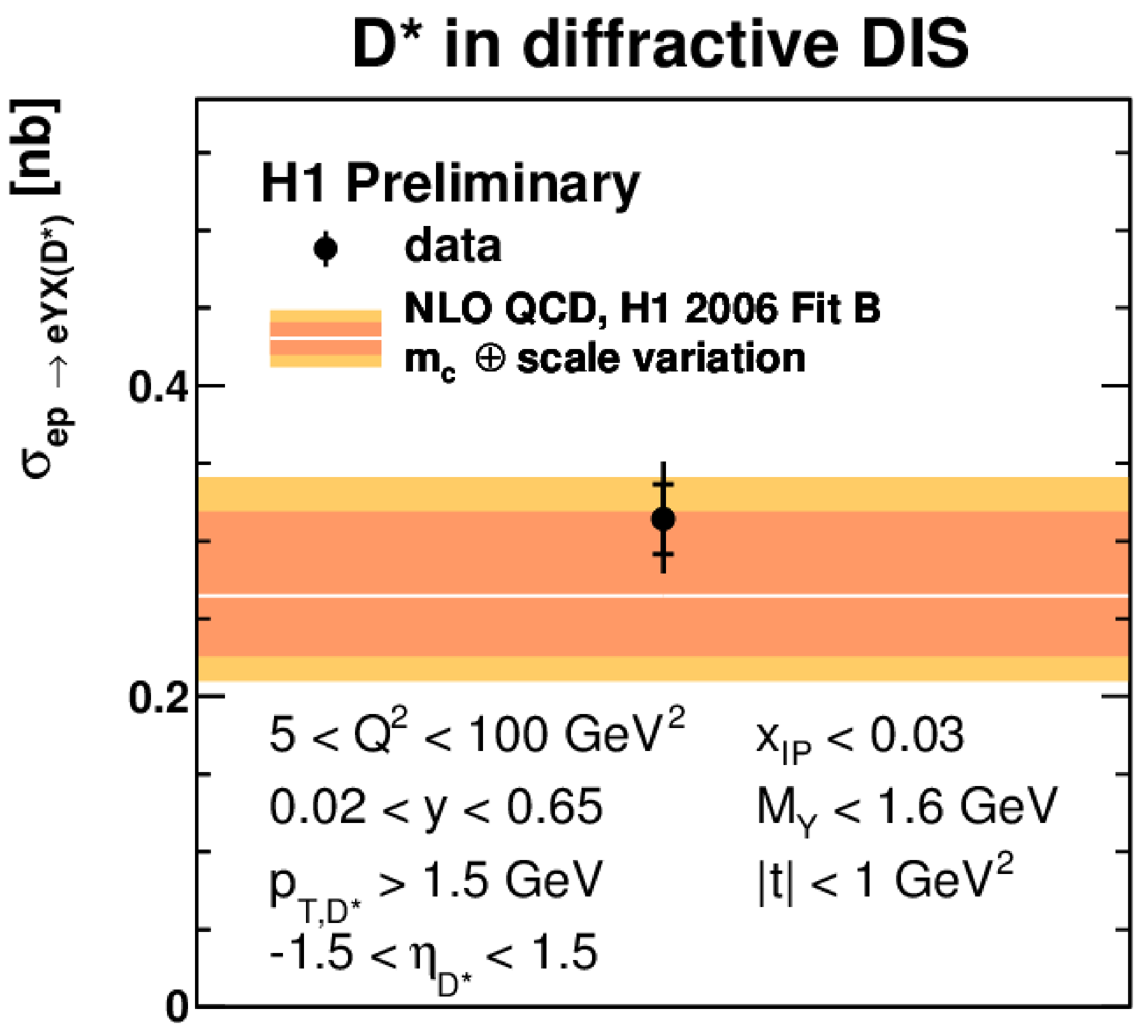

$$\sigma_{ep \to e Y X(D^*)} = 0.314 \pm 0.022(\text{stat.}) \pm 0.028(\text{syst.})\ [\text{nb}]$$

dominant sources of syst. error: gap selection
proton dissociation contribution

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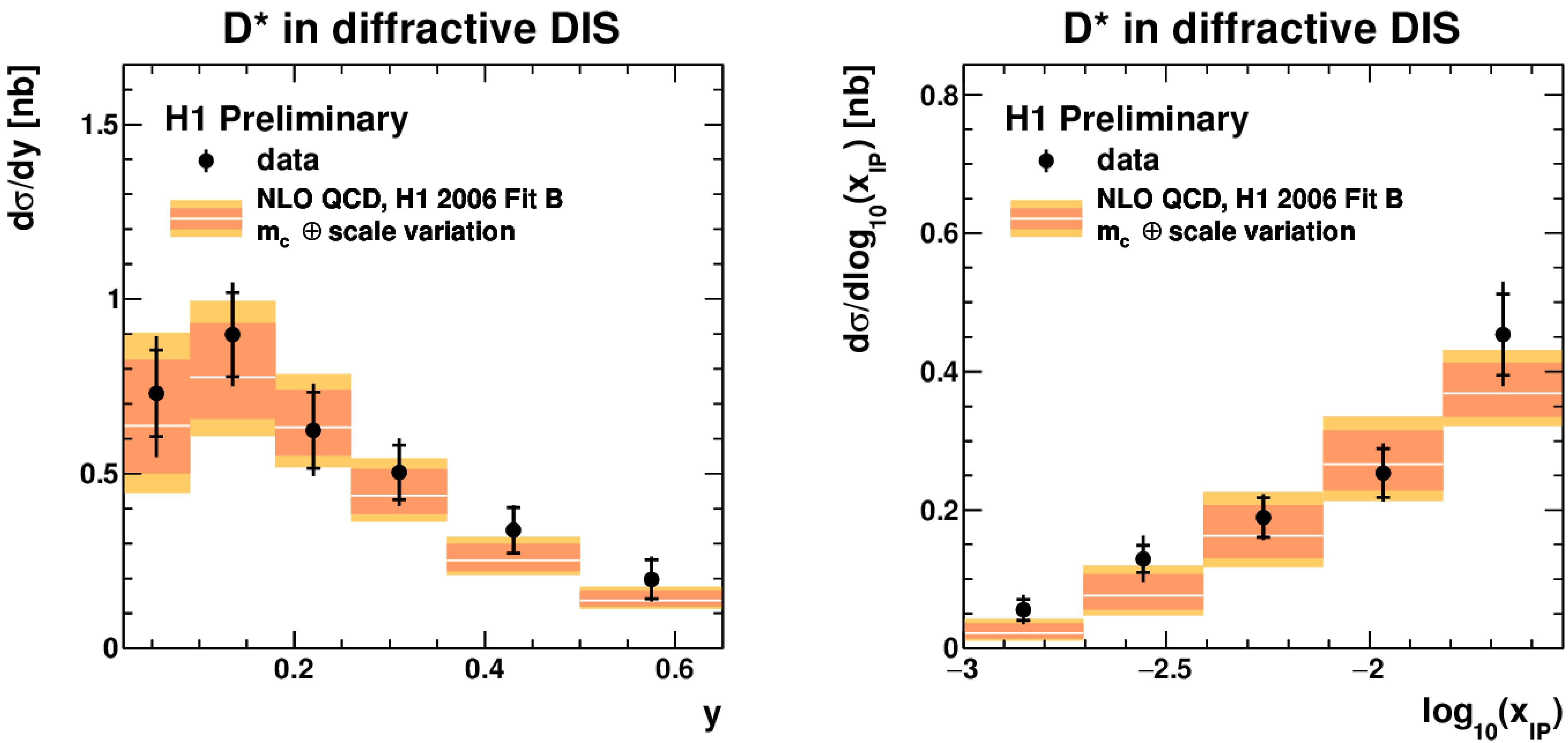

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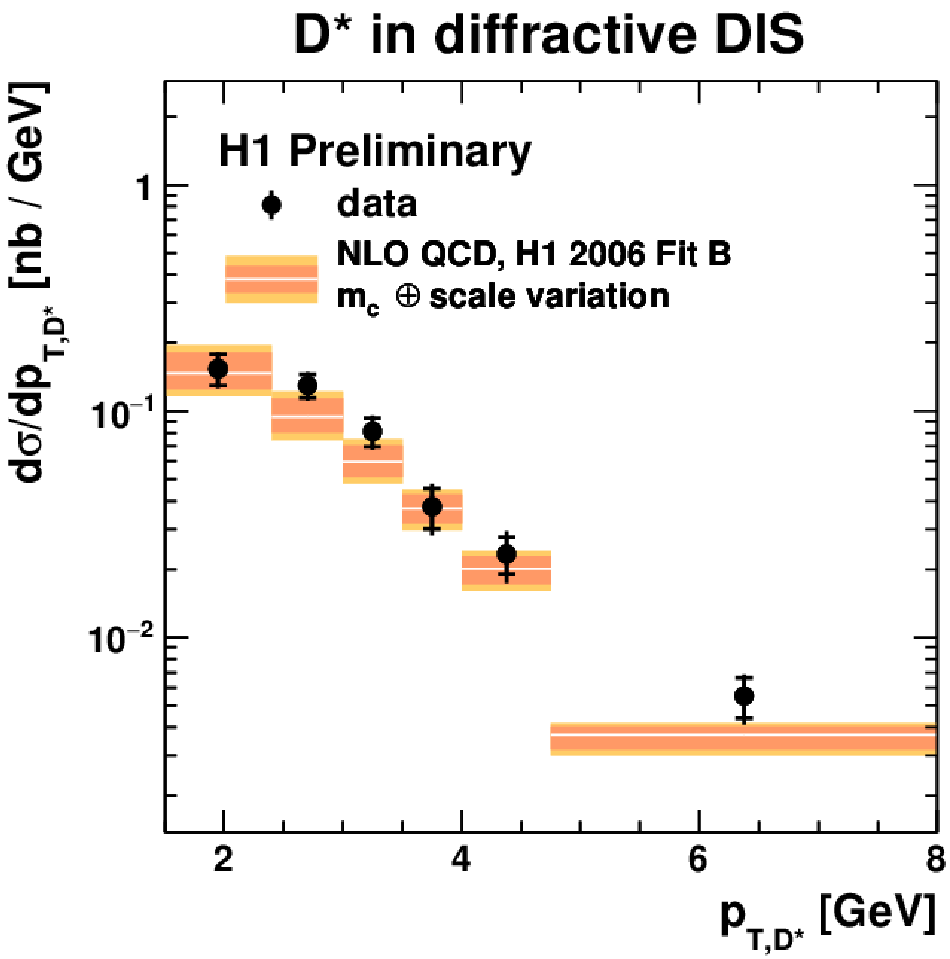

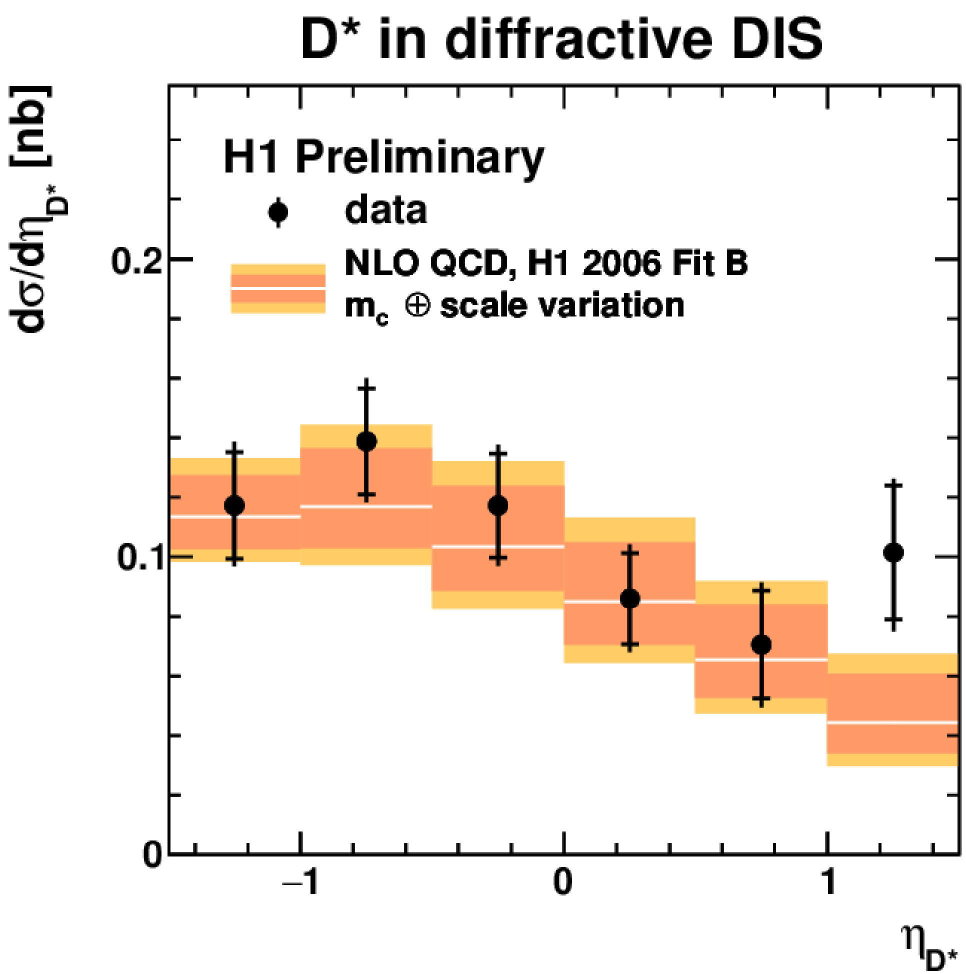

New results from HERA

Open charm production in diffractive deep inelastic scattering at HERA

(1) New measurement of open charm production in diffractive DIS with larger dataset.

(2) NLO QCD prediction (in FFNS) based on DPDFs (inclusive H1 data), agree well within errors with measured cross sections - new test of collinear factorization validity.

(3) Charm fragmentation function with Kartvelishvili parameterization determined in previous H1 (non-diffractive) analysis, supports universality of fragmentation.

(4) Final measurement of cross sections might serve as an input to DPDF fits.

Thank you for your attention!