H1 + ZEUS diffractive results

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On behalf of H1 and ZEUS collaborations

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Physics at the Terascale
Hamburg
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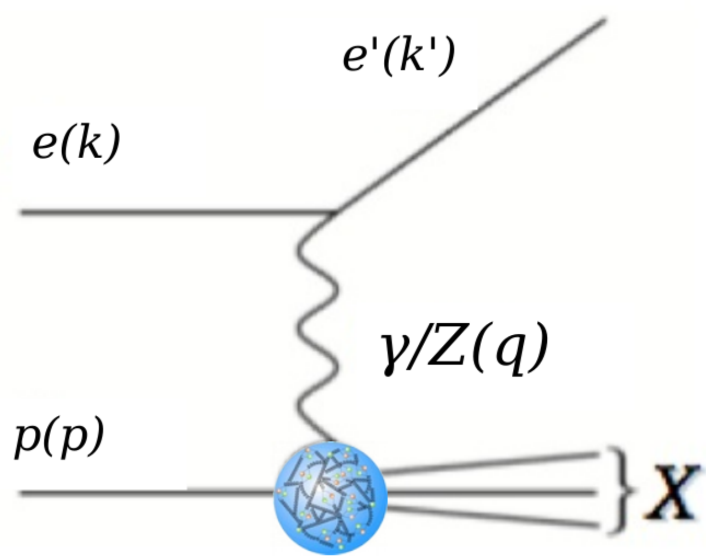
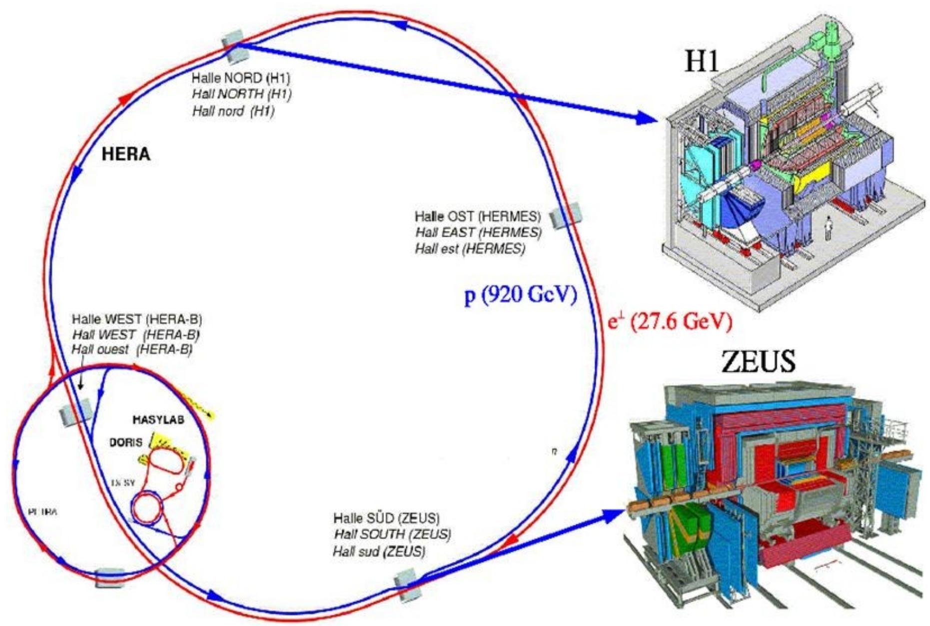
HERA Collider

- The only existing ep collider (1992 - 2007)
- About **0.5 fb^{-1}** of data per experiment
- Two multi-purpose detectors (**H1** + **ZEUS**)

$e^{\pm}$ + p
27.6 GeV + 920 GeV
$\sqrt{s} = 319\,\mathrm{GeV}$





Inelasticity

$$y = \frac{p \cdot q}{p \cdot k}$$

Photon virtuality

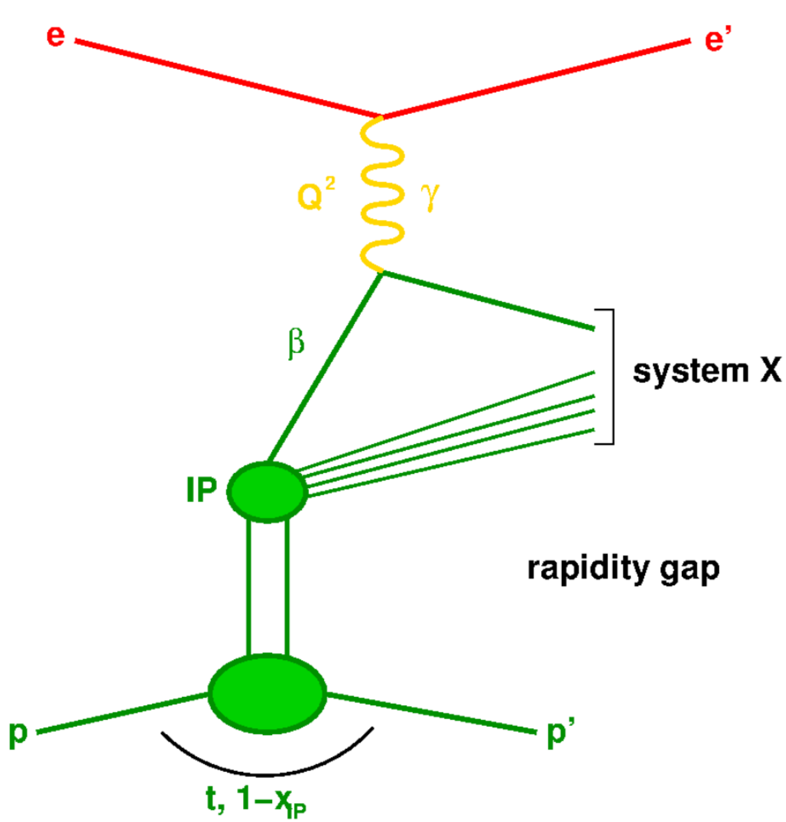
$$Q^2 = -(k - k')^2$$

$Q^2 \approx 0$ Photoproduction

$Q^2 \gg 0$ Deep-inelastic scattering (DIS)

Diffraction in ep

- The scattered proton stays intact
- Exchange of vacuum quantum numbers – Pomeron (from Regge theory)



Diffractive selection methods

- Proton spectrometer
- **Large rapidity gap method**

HERA: ~10% of low-x DIS events diffractive

$$x_{IP} = \frac{q \cdot (p - p')}{q \cdot p} = 1 - \frac{E_p'}{E_p^{beam}}$$

Fractional momentum loss of the scattered proton

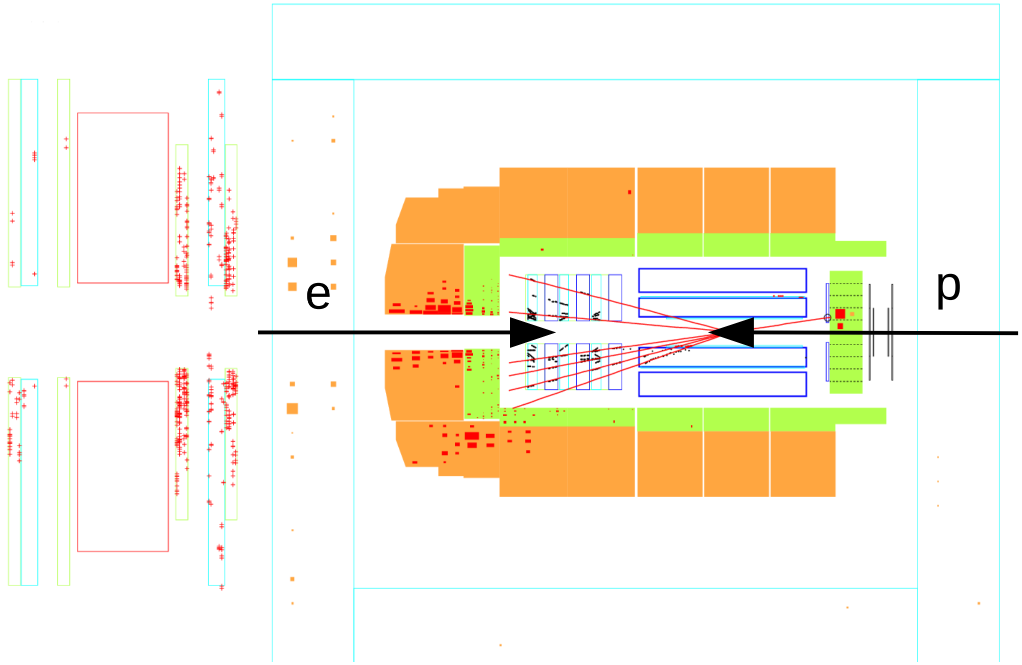
$$t = (p - p')^2 \approx -p_T^2$$

Four-momentum transfer at the proton vertex

Large Rapidity Gap

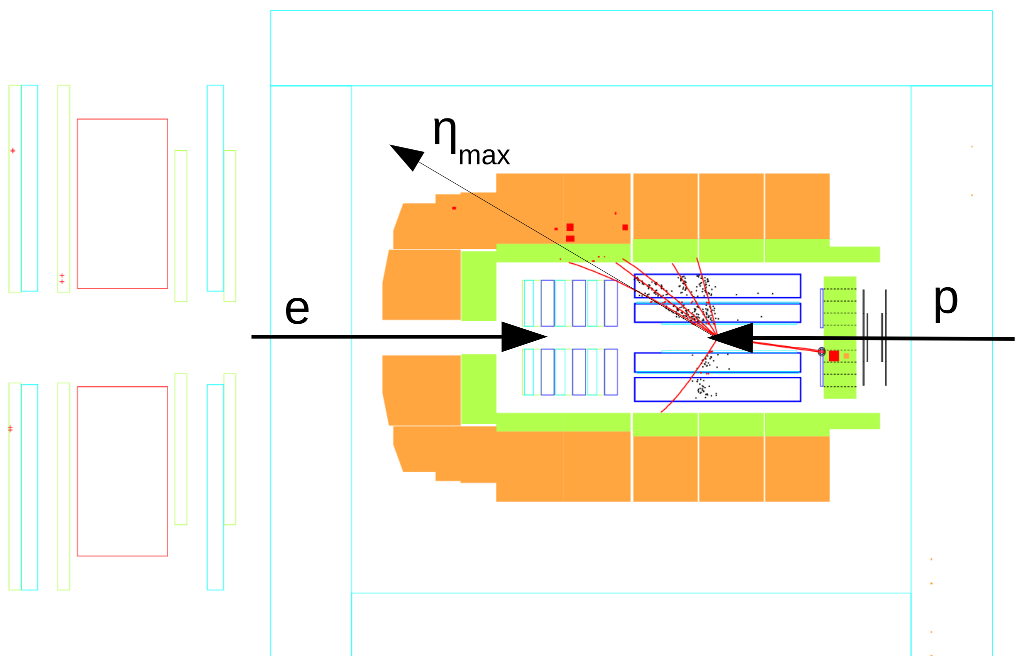
Here H1 detector

Hadronic activity in forward part of detector



Non-diffractive event

Without hadronic activity in forward part of detector

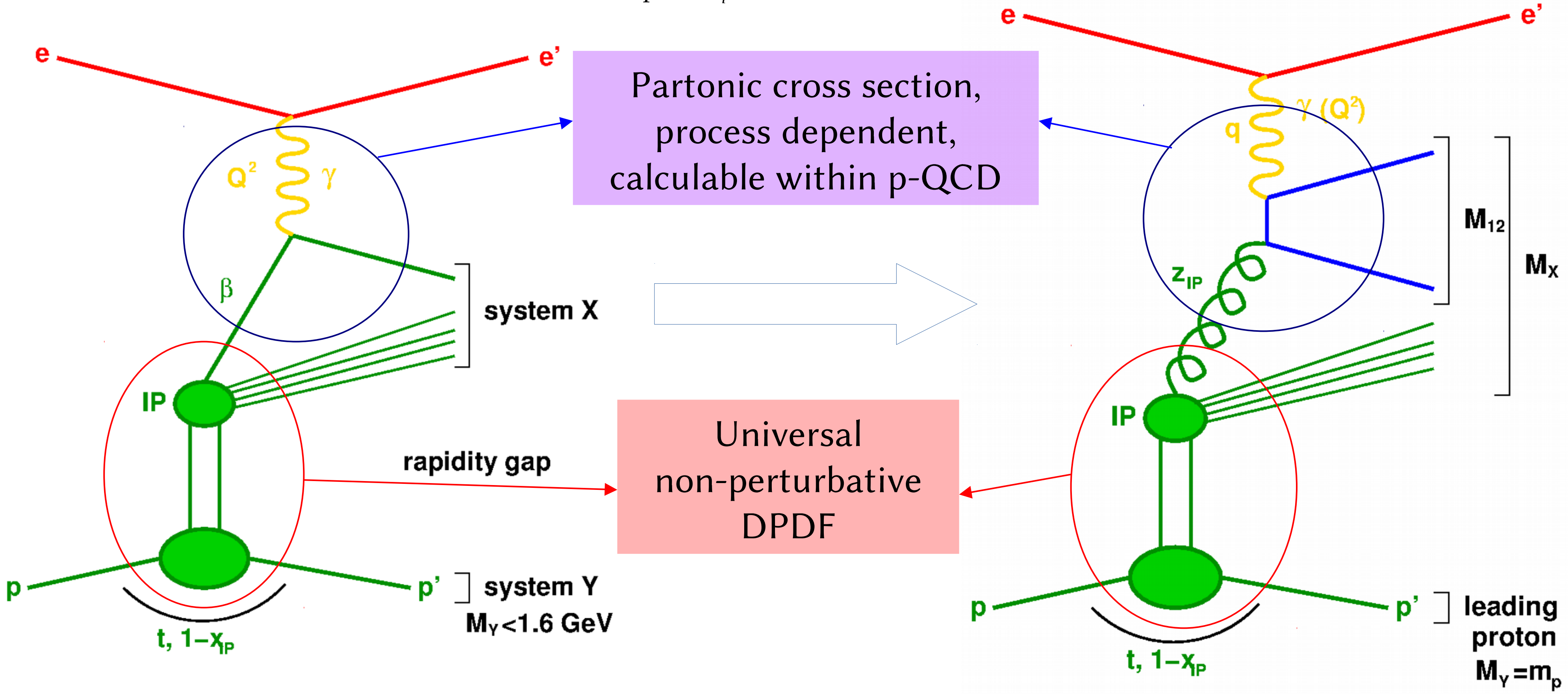


Diffractive event

Factorization in Diffraction

- DPDFs determined from inclusive measurement are capable to predict results for other, more exclusive, **D**DIS processes (dijets, D*), Collins 1997

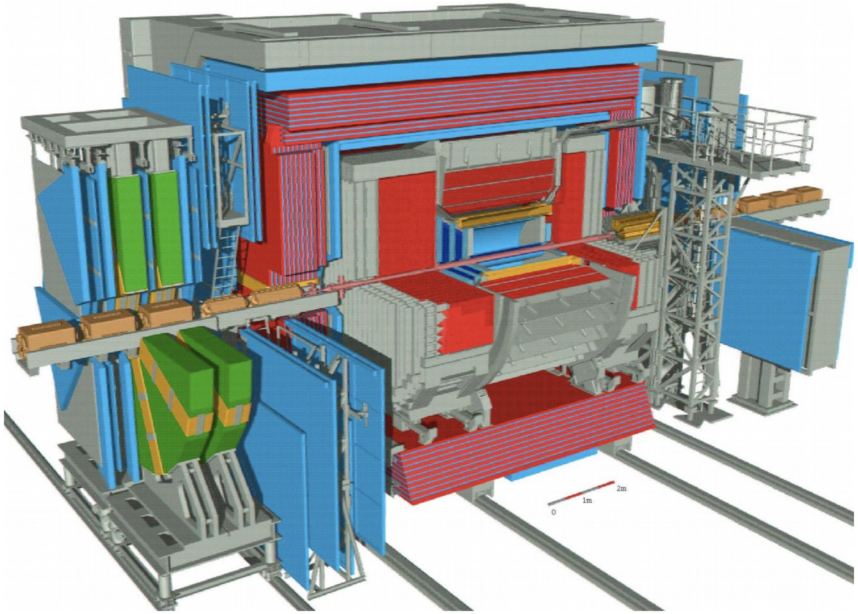
$$\sigma^D(ep \to Xp) = \sum_{parton_i} f_i^D(\beta, Q^2, x_{IP}, t)\, \sigma^{ei}(\beta, Q^2)$$



$f_i^D(\beta, Q^2, x_{IP}, t)$ DPDFs which obey DGLAP evolution

$\sigma^{ei}(\beta, Q^2)$ Partonic cross section

Diffractive photoproduction of the isolated photon (ZEUS)



DESY-17-077 [arXiv:1705.10251]
Phys. Rev. D96 (2017)

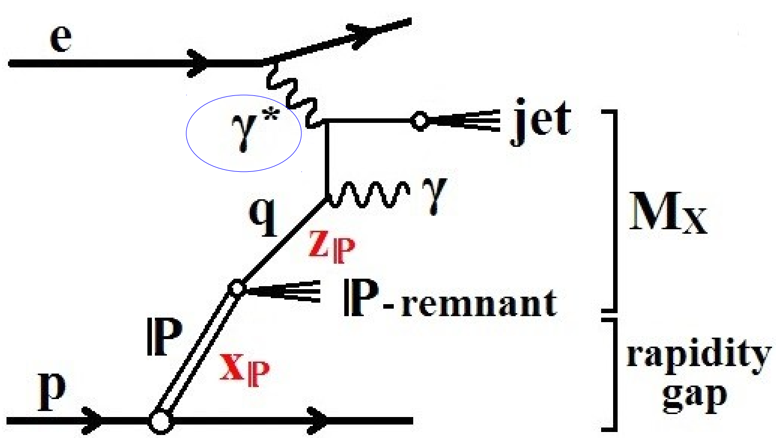
Diffractive **photoproduction** of isolated photon

- $Q^2 \approx 0 \longrightarrow$ photon may dissociate into low mass hadronic system (structure of such resolved photon described by γPDF)
- $Q^2 \approx 0 \longrightarrow \ \theta_e \approx 180^\circ$(electron leaves detector undetected)

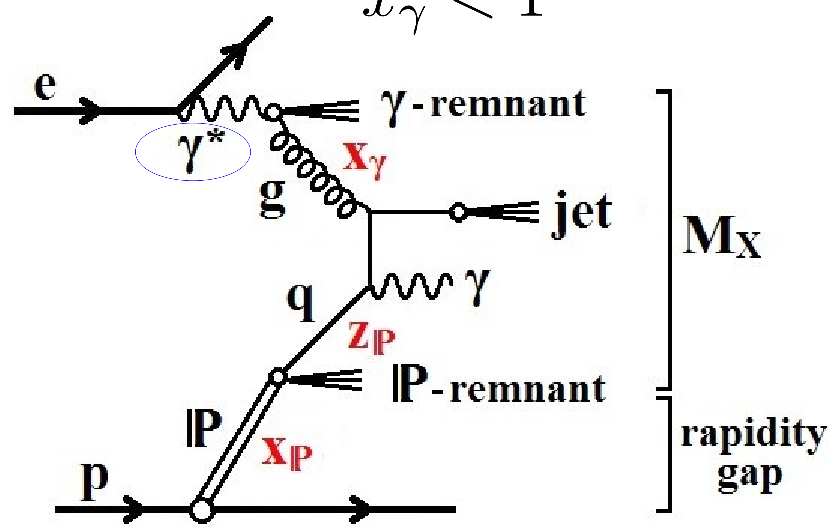
Photon momentum fraction entering the hard subprocess:

$$x_\gamma = \frac{\sum_{\gamma+\text{jet}}(E - p_z)}{\sum_{\text{EFO}}(E - p_z)}$$

Direct photon interaction
$x_\gamma = 1$



Resolved photon interaction
$x_\gamma < 1$



Diffractive photoproduction of isolated photon

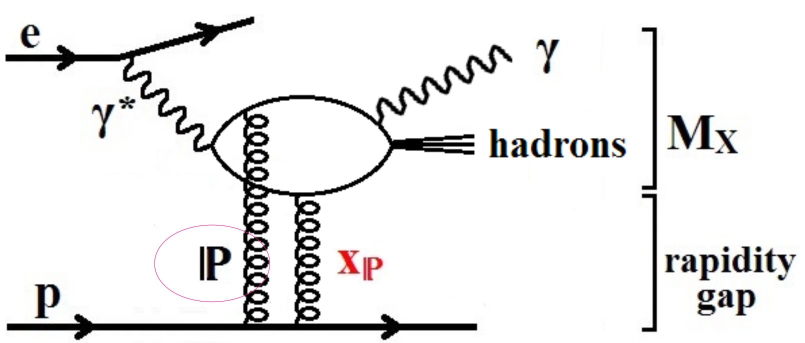
- Diffraction $\longrightarrow$ beam proton stays intact and leaves detector undetected
- Standardly described by exchange of an hadronic object with vacuum quantum numbers (pomeron)

Pomeron momentum fraction entering the hard subprocess:

$$z_{IP} = \frac{\sum_{\gamma+\text{jet}}(E+p_z)}{\sum_{\text{EFO}}(E+p_z)}$$

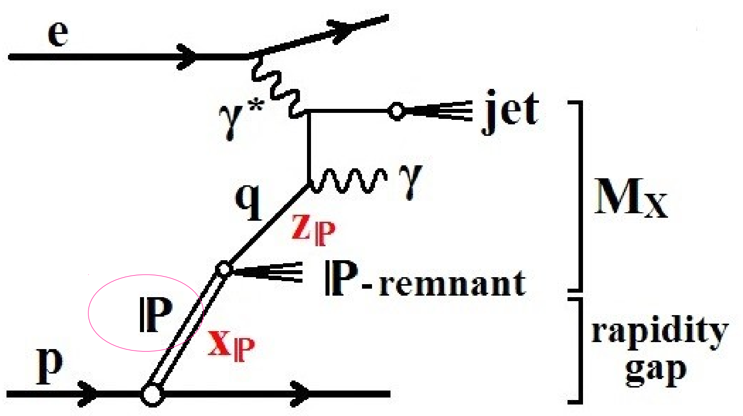
Direct Pomeron

$z_{IP} = 1$



Resolved Pomeron

$z_{IP} < 1$



Theoretical predictions

Diffractive predictions (Resolved pomeron)

- Resolved pomeron model (Ingelman, Schlein)
- Implemented in the MC generator **RAPGAP** (LO matrix element + LL parton shower + Lund string fragmentation)
- Contains direct and resolved photon processes

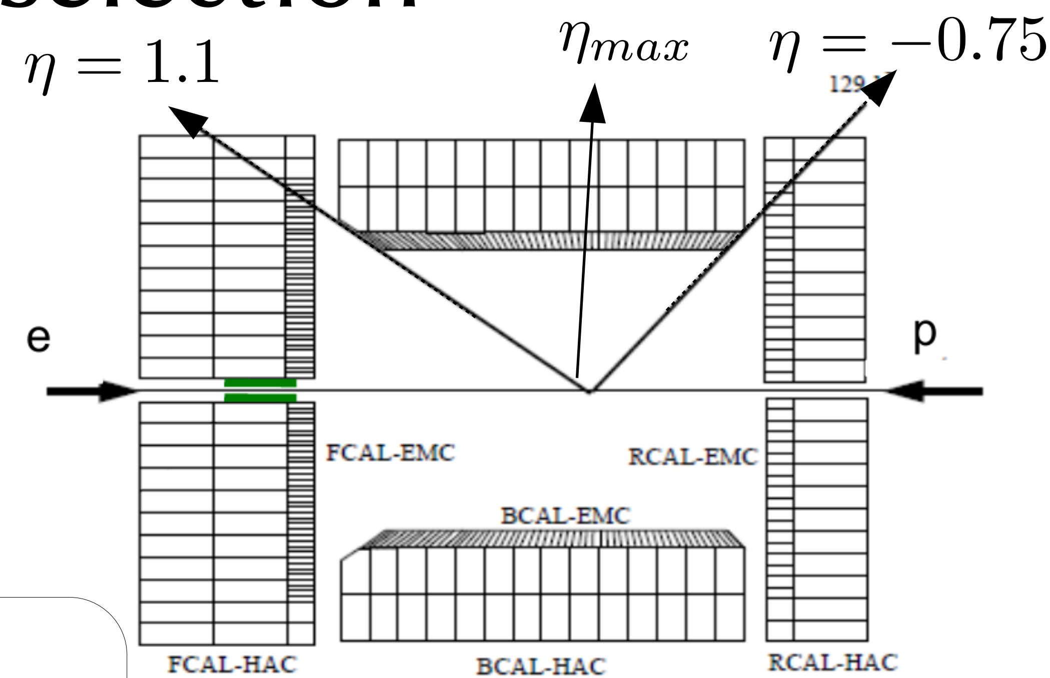
- The partonic structure of the resolved pomeron described by **H1 2006 DPDF Fit B** (from fits of inclusive diffractive DIS)
- The partonic structure of the resolved photon described by **SASGAM-2D γPDF**

- Non-diffractive background simulated by Pythia 6

No model for the possible direct pomeron interaction available

Event selection

Forward detector's region
without hadronic activity



$$e + p \rightarrow e + \gamma + X + p(Y)$$

- Veto on scattered electron
- Diffractive events dominate for small pomeron momentum fraction wrt proton x_{IP}+ **large rapidity gap**

Photon

$$5 < E_T^{\gamma} < 15\,\mathrm{GeV}$$
$$-0.7 < \eta^{\gamma} < 0.9$$

Jet

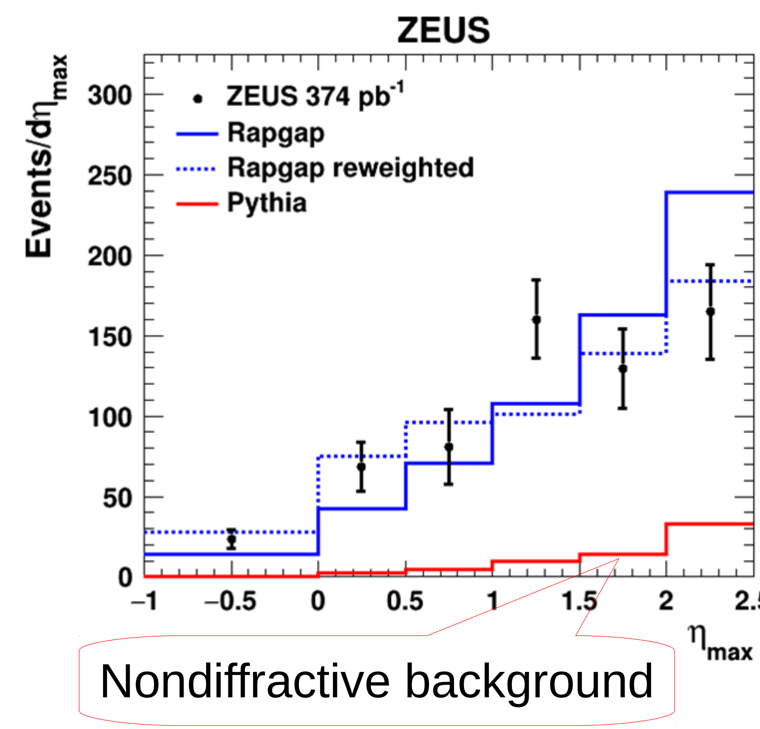
$$4 < E_T^{jet} < 35\,\mathrm{GeV}$$
$$-1.5 < \eta^{jet} < 1.8$$

Photoproduction

$$Q^2 < 1\,\mathrm{GeV}^2$$
$$0.2 < y < 0.7$$
$$y = \frac{\sum_{\mathrm{EFO}}(E - p_z)}{2E_e}$$

Diffraction

$$\eta_{max}^{E>0.4} < 2.5$$
$$x_{IP} < 0.03$$
$$x_{IP} = \frac{\sum_{\mathrm{EFO}}(E + p_z)}{2E_p}$$



Extraction of prompt photons signal

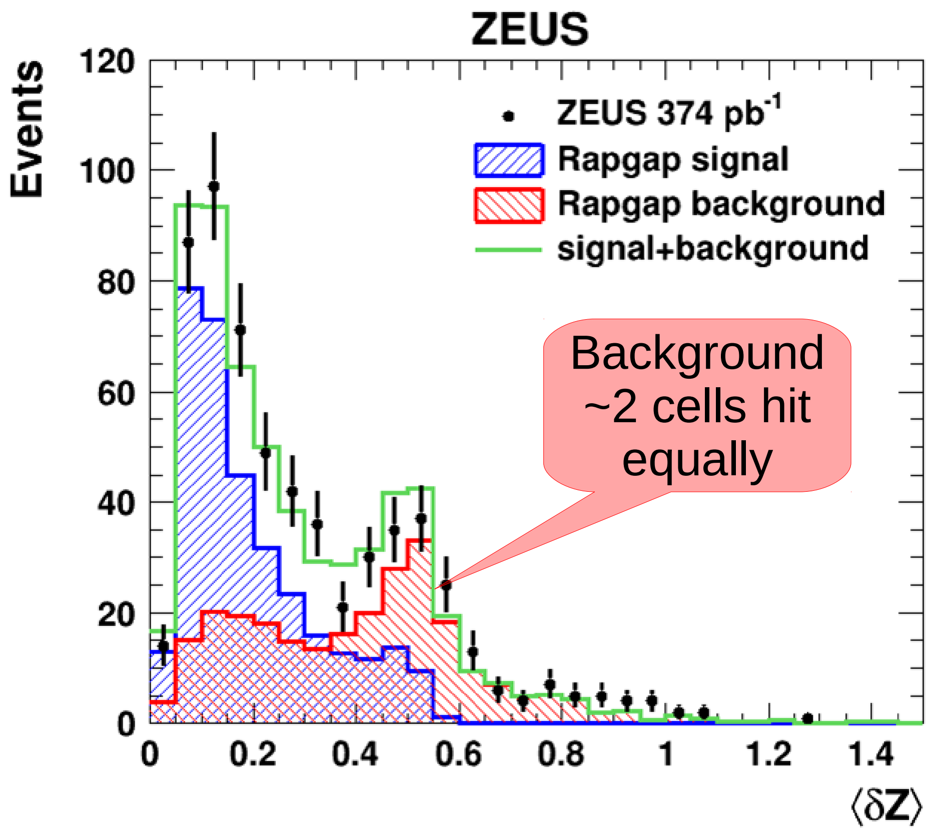
- Template fit to obtain the signal and background contribution
- Background mainly from

$$\pi^0(\eta) \rightarrow \gamma\gamma$$

- Width of the photon candidate cluster in the beam direction in units of cell width δ_{cell}

$$\langle \delta Z \rangle = \frac{\sum_i E_i |Z_i - Z_{cluster}|}{\delta_{cell} \sum_i E_i}$$

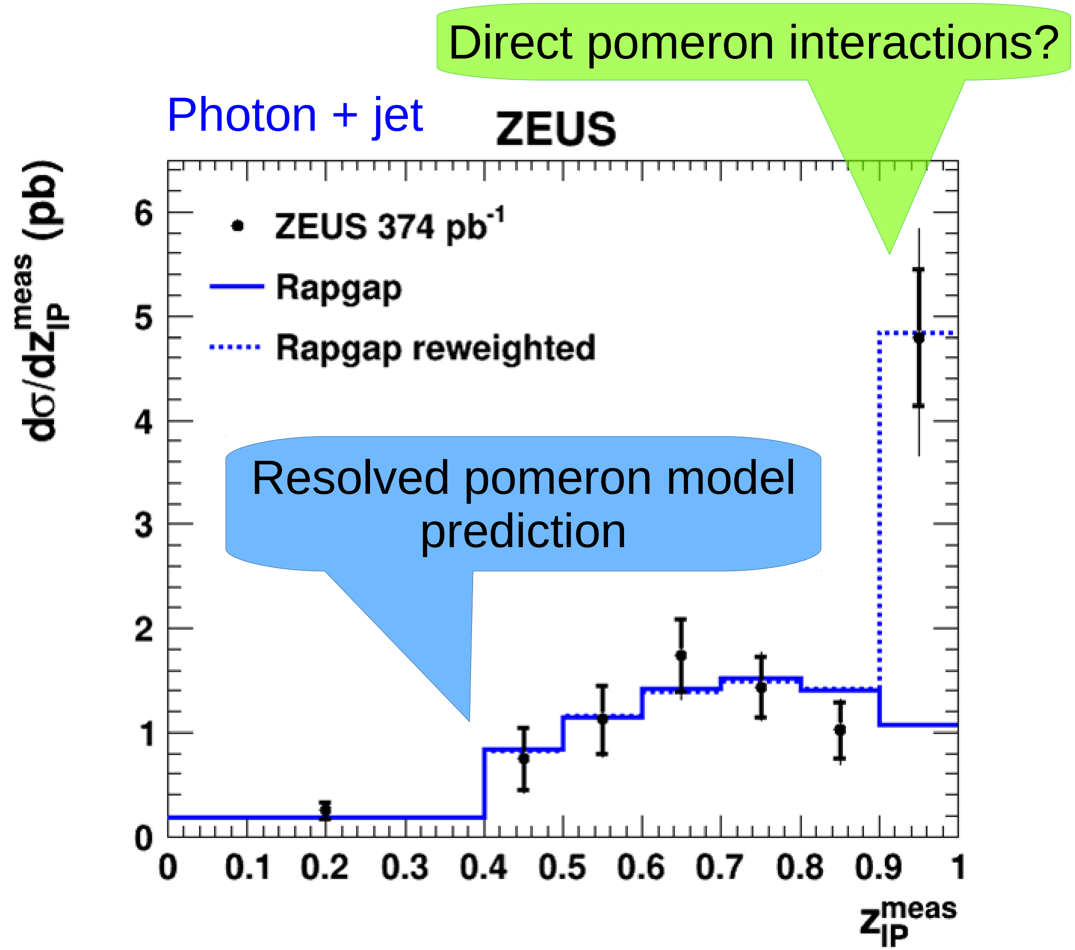
- **90%** of photon candidate energy required to be measured in EM calorimeter



	Gamma events	Gamma+jet events
HERA I (82 pb^{-1})	91	76
HERA II (374 pb^{-1})	366	311

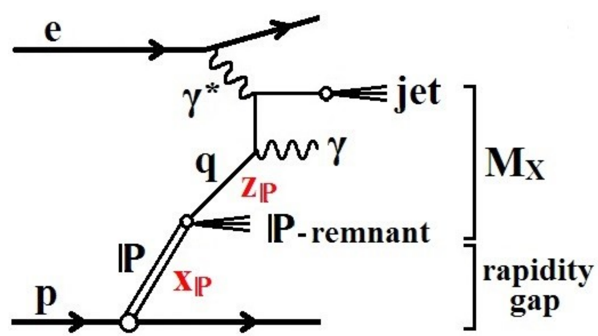
Direct pomeron exchange?

- **The $z_{IP} < 0.9$ region** well described by MC both in shape and normalization
  $$\sigma_{\text{data}}^{z_{IP}<0.9} = 0.57 \pm 0.13\,\text{pb}$$
  $$\sigma_{\text{MC}}^{z_{IP}<0.9} = 0.68\,\text{pb}$$
- **The $z_{IP} > 0.9$ region** overshot in data

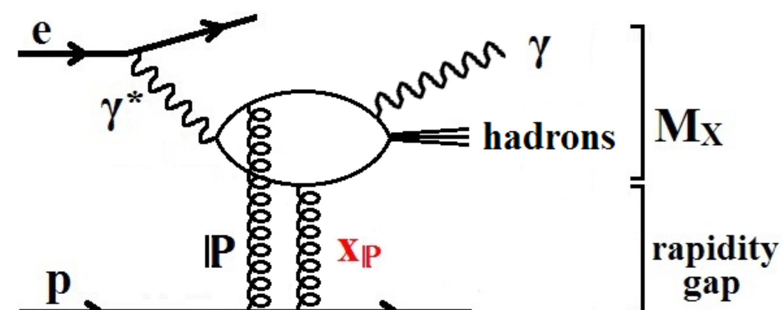


Rapgap reweighted:
MC reweighted separately for $z_{IP} < 0.9$ and $z_{IP} > 0.9$ to data

Resolved pom.



Direct pom.



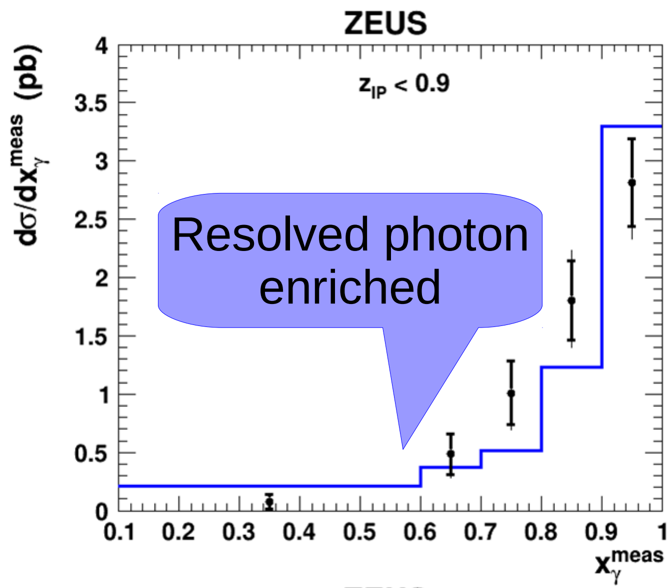
Direct vs Resolved pomeron

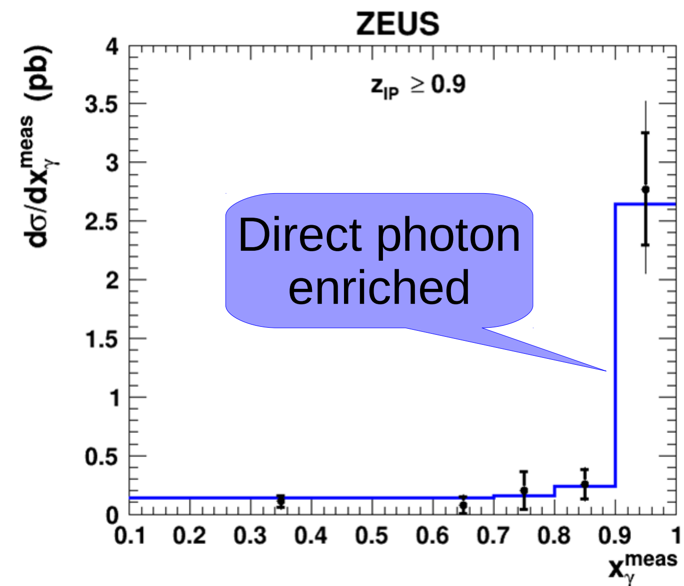
Photon + jet

Resolved pomeron enriched ($z_{IP} < 0.9$)

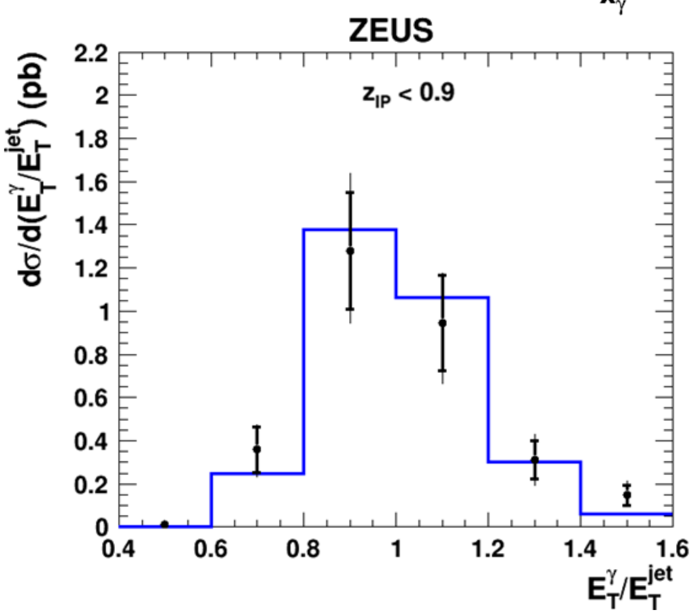
Direct pomeron enriched ($z_{IP} \geq 0.9$)

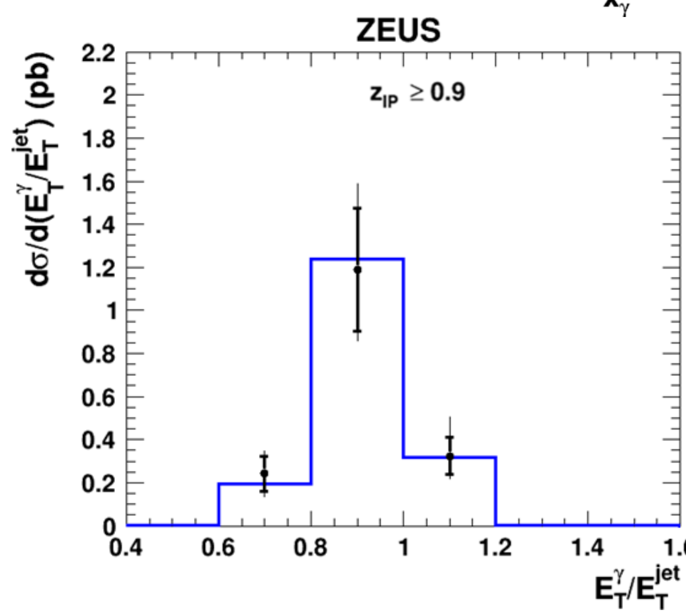
Photon momentum fraction entering hard process



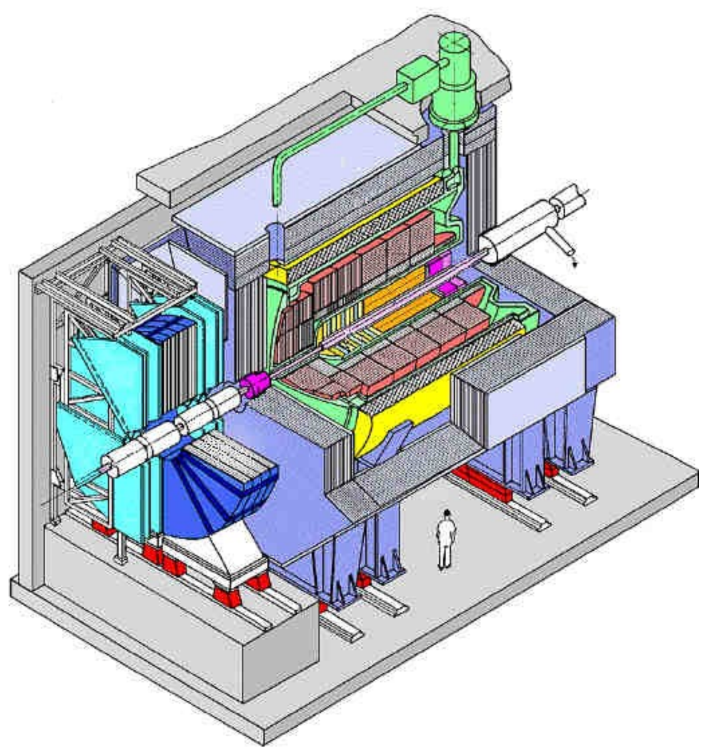


Gamma/jet p_T balance





D* Production in Diffractive DIS



DESY-17-043 [arXiv:1703.09476]
Eur. Phys. J. C77 (2017)

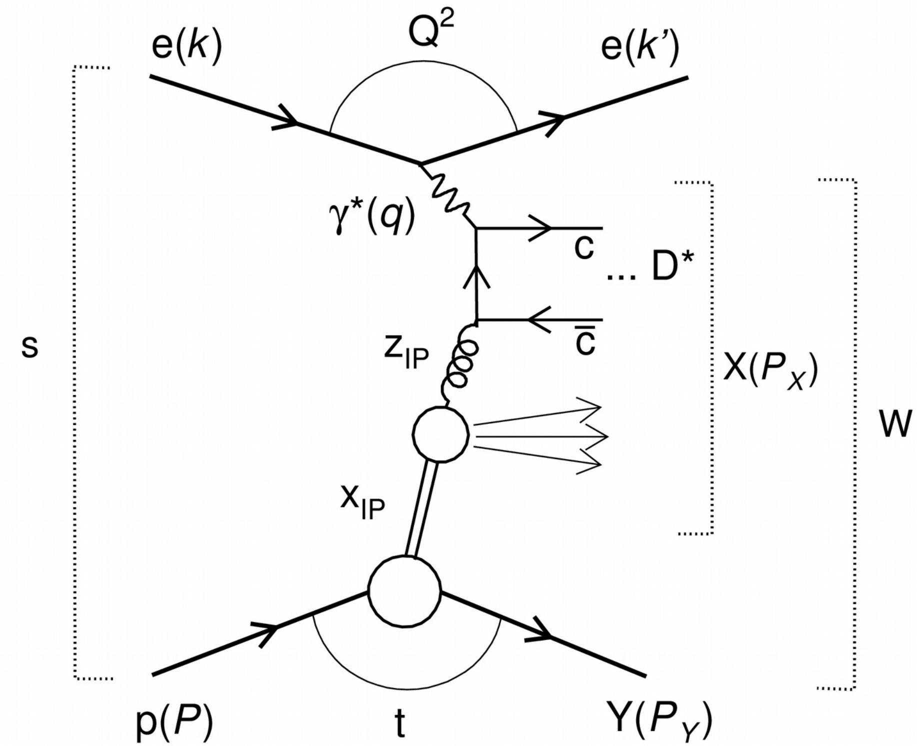
D* Production in DDIS

Why D*?

- D* is a messenger of diffractively produced charm
- At LO charm produced by γg fusion ⟶ the probe of gluonic content of Pomeron

What is studied?

- The validity of the diffractive **factorization theorem**, especially gluonic content of DPDFs
- The universality of the charm **fragmentation function**



Why now?

- Ten-fold more statistics

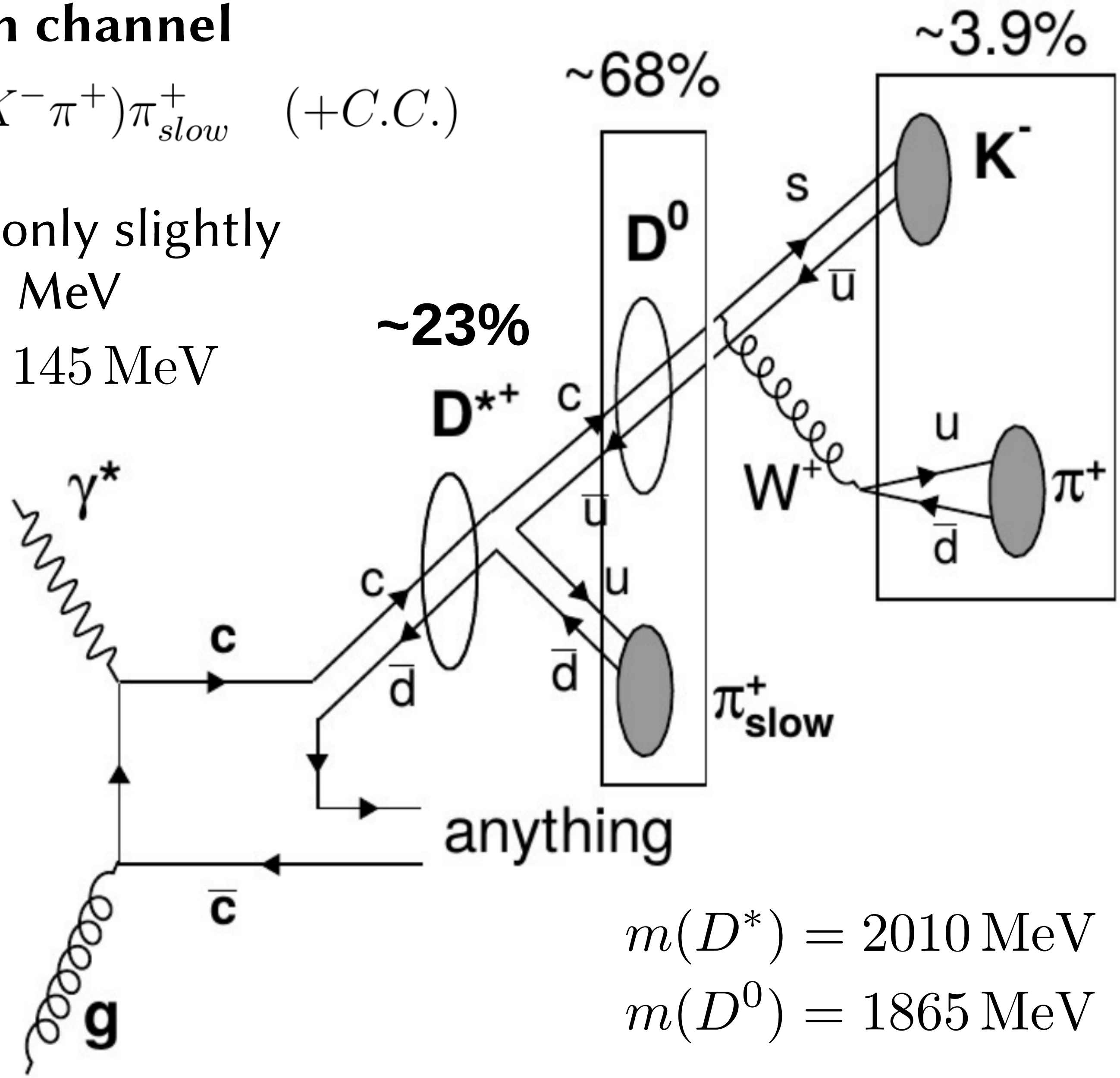
D* - Event Topology

- 0.6% of charm quarks decay to the measured D* **golden channel**

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

- The mass difference only slightly above pion mass 140 MeV

$$m(D^*) - m(D^0) = 145\,\mathrm{MeV}$$



$$m(D^*) = 2010\,\mathrm{MeV}$$
$$m(D^0) = 1865\,\mathrm{MeV}$$

D* Data sample

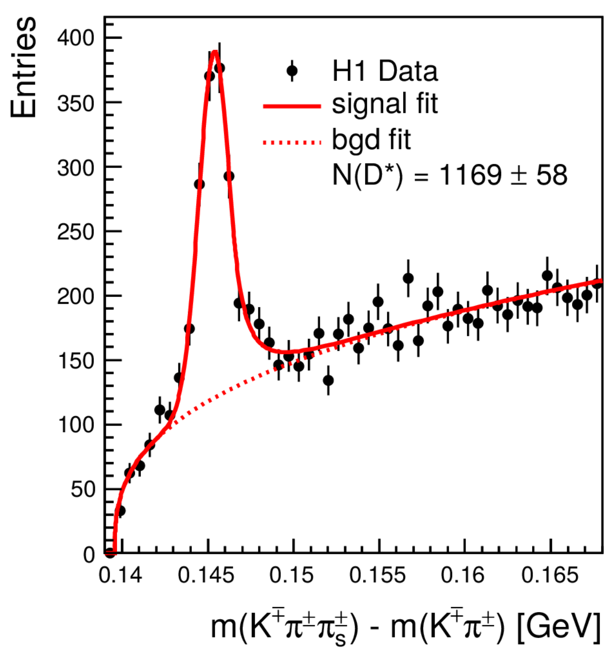
- Simultaneous fit of **right**- and **wrong** charge combination of tracks
- BG shape assumed to be identical for RC and WC

Extended ML fit
Signal: Crystal Ball (4 pars.)
Background: Granet fcn. (2 pars.)

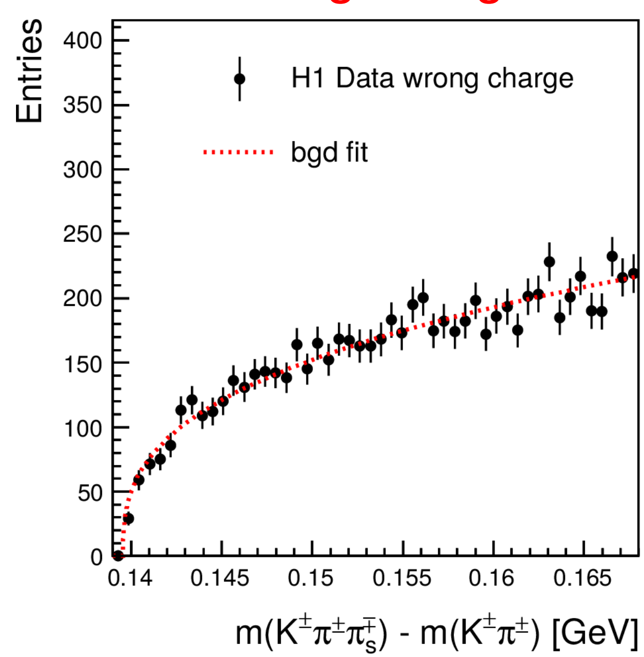
$$D^{*+} \to D^0 \pi^+_{slow} \to (K^-\pi^+)\pi^+_{slow} \quad (+C.C.)$$

287 pb^{-1} of HERA II data (2005 - 2007)

Right charge



Wrong charge



DIS phase space
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$
D^* kinematics
$p_{t,D^*} > 1.5$ GeV $-1.5 < \eta_{D^*} < 1.5$
Diffractive phase space
$x_{I\!P} < 0.03$ $M_Y < 1.6$ GeV $\lvert t \rvert < 1$ GeV^2

Data vs NLO predictions

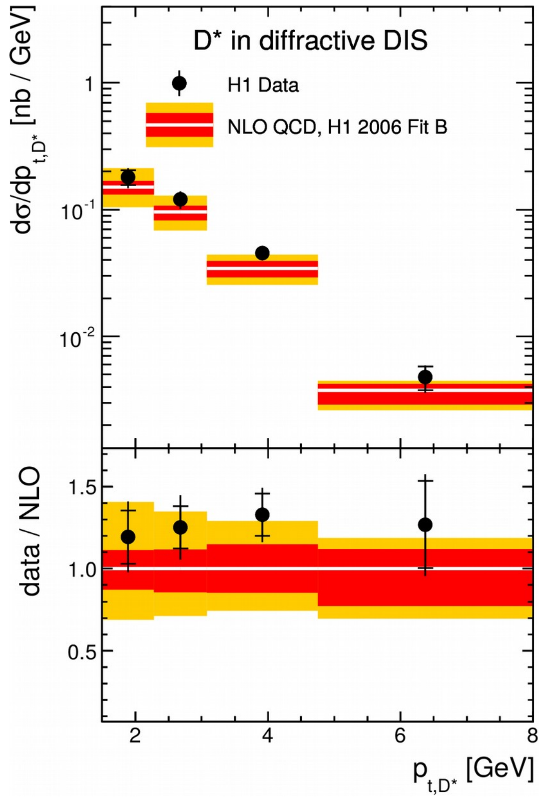
Parton-level prediction
NLO QCD in FFNS based on diffractive collinear factorization theorem (using H1 2006 Fit B DPDF)

Charm fragmentation
using Kartvellishvili parametrization

$$D(z) \sim z^{\alpha}(1-z)$$

The measured N(D*) corrected for:
- Detector effects
- D* branching ratio
- QED radiation

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}x}\right)_i = \frac{N_i^{\mathrm{data}} - N_i^{\mathrm{sim,bgr}}}{\mathcal{L}_{\mathrm{int}}\ \Delta_i^x\ B_r\ \varepsilon_{\mathrm{trigg}}\ A_i} C_{\mathrm{corr},i}^{\mathrm{QED}}$$



$$\sigma_{ep\to eYX(D^*)} = 314 \pm 23\ (\mathrm{stat.})\ \pm 35\ (\mathrm{syst.})\ \ \mathrm{pb}$$

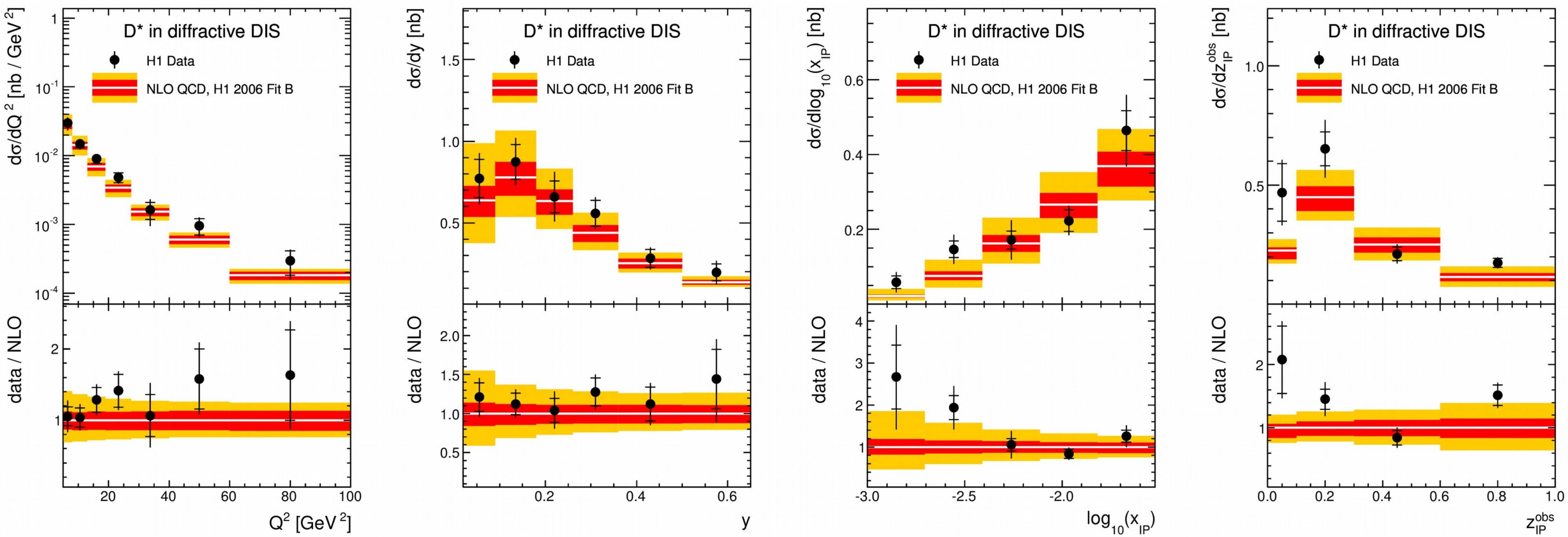
$$\sigma_{ep\to eYX(D^*)}^{\mathrm{theory}} = 265\ ^{+54}_{-40}\ (\mathrm{scale})\ ^{+68}_{-54}\ (m_c)\ ^{+7.0}_{-8.2}\ (\mathrm{frag.})\ ^{+31}_{-35}\ (\mathrm{DPDF})\ \ \mathrm{pb}$$

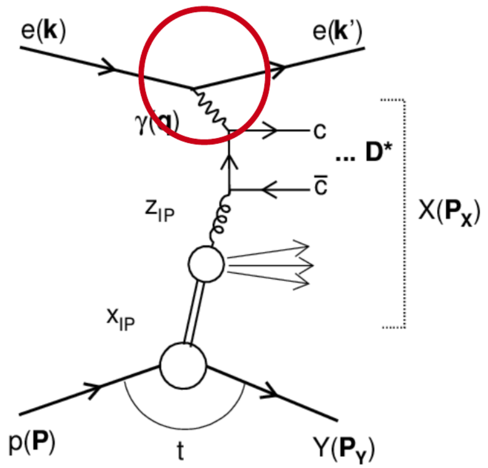
The NLO predictions compatible with the theory

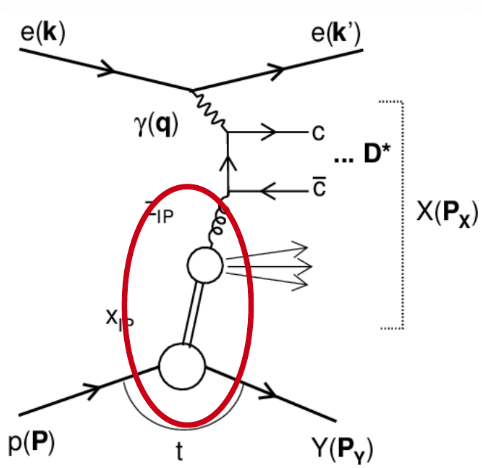
Data vs NLO predictions

Electron variables

Diffractive variables







Diffractive fraction

- We observe that **~7%** of D^* are produced diffractively
- The kinematic dependence of the diffractive fraction well described by NLO

DIS phase space
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$
D^* kinematics
$p_{t,D^*} > 1.5$ GeV $-1.5 < \eta_{D^*} < 1.5$
Diffractive phase space
$x_{I\!P} < 0.03$ $M_Y < 1.6$ GeV $\|t\| < 1$ GeV^2

/

DIS phase space
$5 < Q^2 < 100$ GeV^2 $0.02 < y < 0.65$
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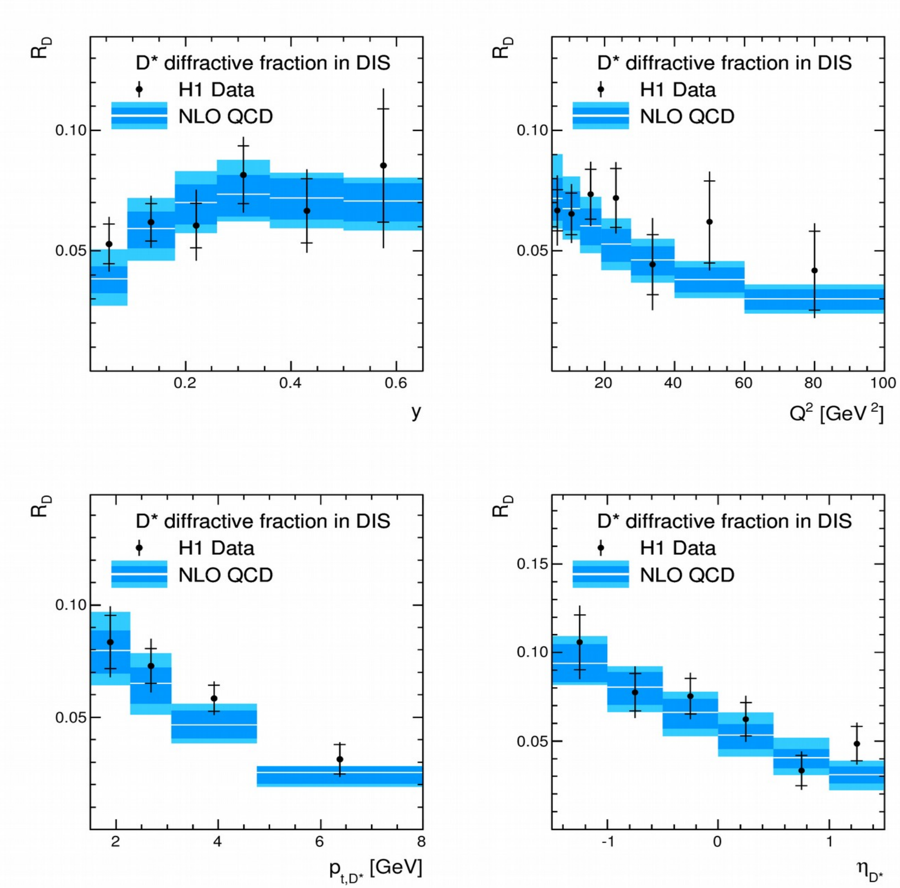
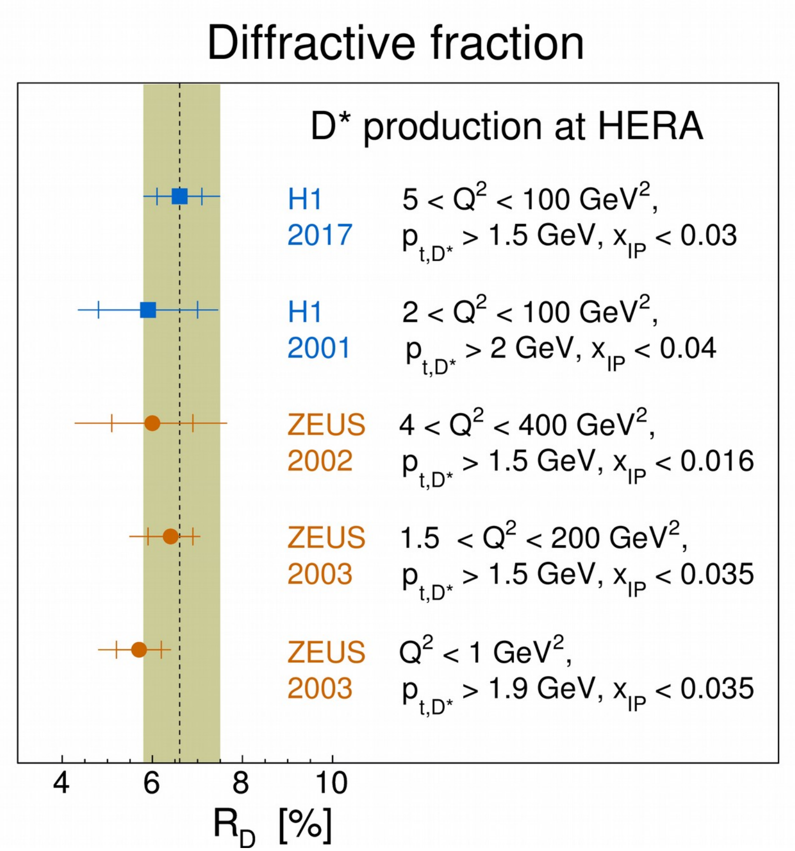
$p_{t,D^*} > 1.5$ GeV $-1.5 < \eta_{D^*} < 1.5$
~~Diffractive phase space~~
~~$x_{I\!P} < 0.03$~~ ~~$M_Y < 1.6$ GeV~~ ~~$\|t\| < 1$ GeV^2~~





Conclusion

The diffractive program at HERA has long and successful history and is still ongoing

(Predictions mostly based on QCD collinear factorization, employing DPDFs extracted from HERA DIS data)

Two recent measurements from 2017 presented

- **ZEUS**: Photon + jet in photoproduction
  $\longrightarrow$ *Indication for direct Pomeron exchange*
- **H1** : D^* production in DIS
  $\longrightarrow$ *Check of the factorization theorem and universality of charm fragmentation*

Emergence of **NNLO** calculation
$\longrightarrow$ plans for new NNLO DPDF fit