K. Wichmann for the ZEUS collaboration

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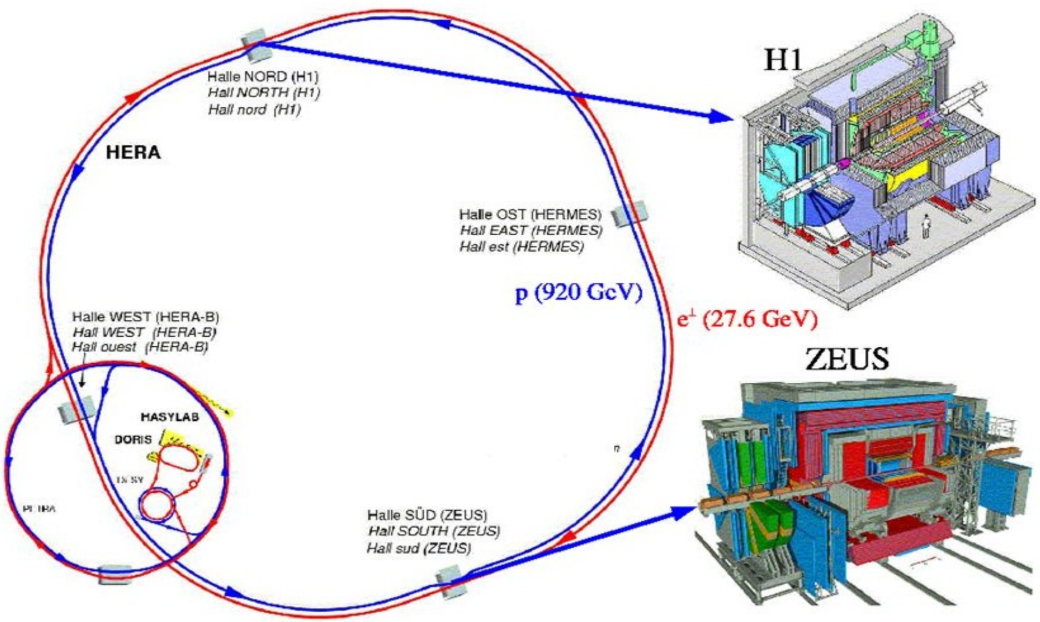
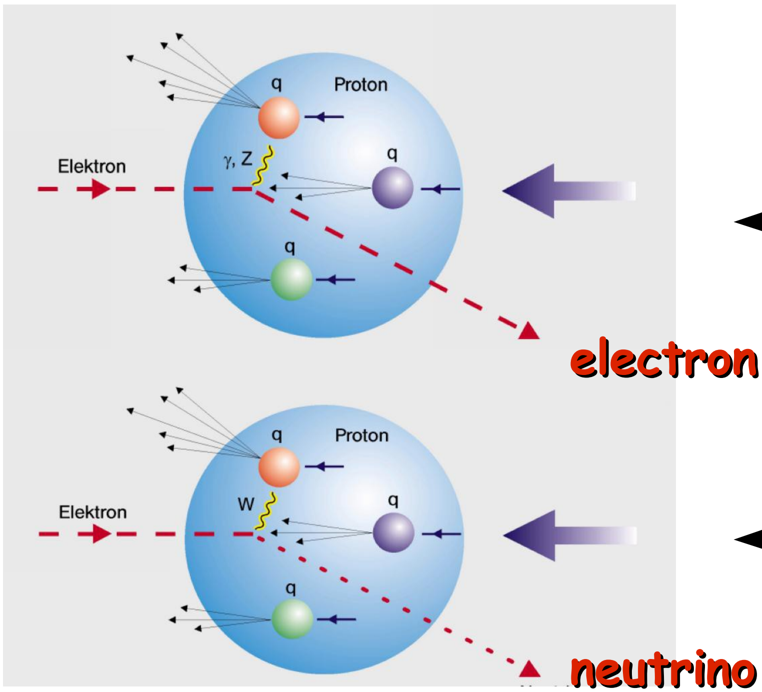
HERA and DIS



- HERA: ep collider in Hamburg
- Operation: 1992-2007
- Colliding experiments: H1 and ZEUS



Deep Inelastic Scattering

Neutral Current (NC)

γ, Z^0 exchange

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

Charged Current (CC)

$W^{\pm}$ exchange

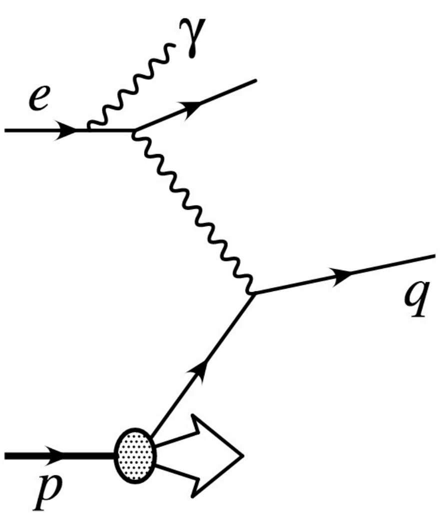
Where do isolated photons come from?

- Can be emitted from lepton (LL) or proton (quark, QQ)
- Assume lepton emission is well known

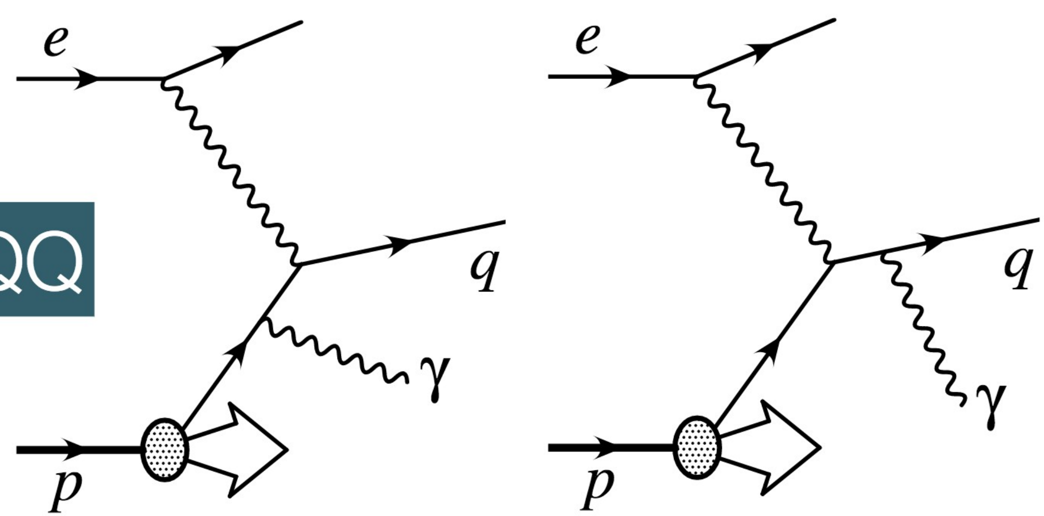
$\rightarrow$ Use photon to probe proton

Trick is to find these photons ...

LL



QQ

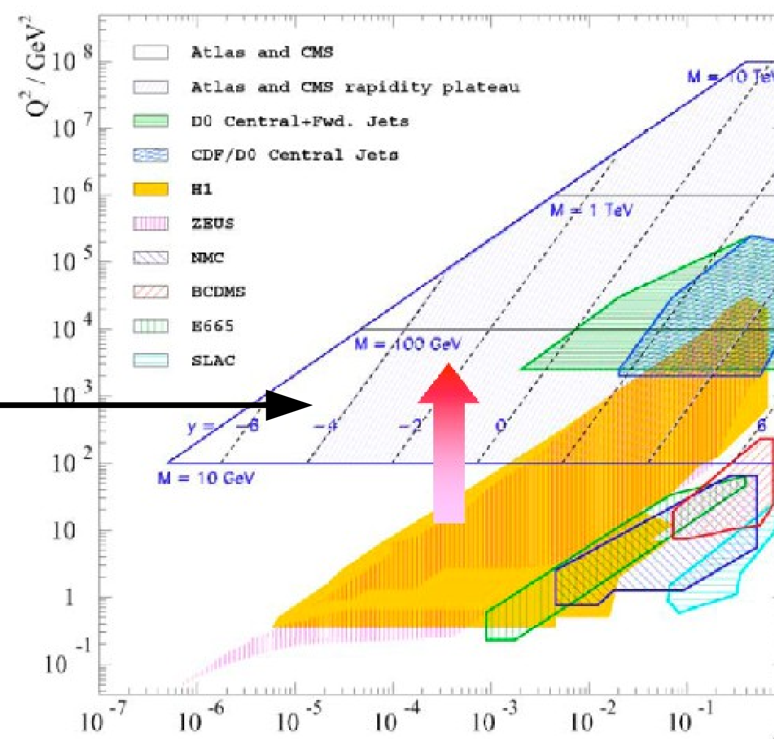


Why study prompt photons?

- Prompt photons emerge directly from the hard scattering process and give a particular view of this
- Use dynamics to probe modes such as k_t-factorisation and pQCD approaches
- See if dynamics changes with virtuality
- Combined photon/jet/electron variables give more detailed ways to test the theories than with single particles and jets

- Check proton PDFs
- Photons can be background to new physics

→ DGLAP evolves HERA scales to LHC scales



Single prompt variable already measured (Phys. Lett. B 715 (2012) 88-97), this study complements previous analysis

DIS event selection

$10 < Q^2_{el} < 350$ GeV^2

$E_{el} > 10$ GeV

$140° < \theta_{el} < 180°$

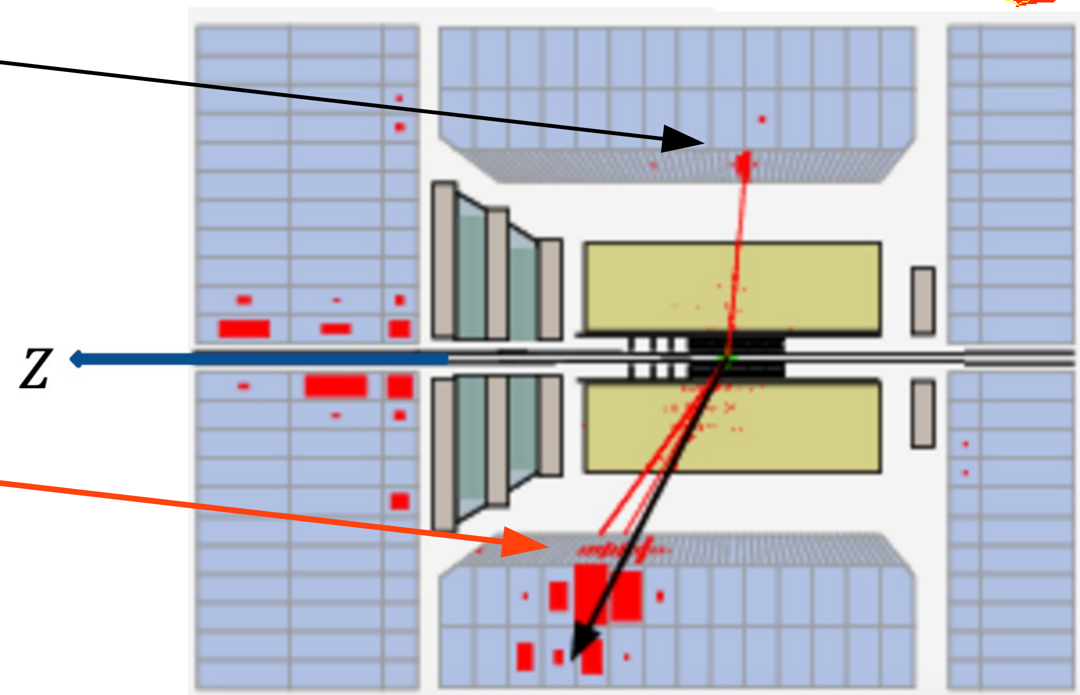
$35 < E - p_Z < 65$ GeV

Hadronic jet:

Jet with $E_{max\ T}^{jet}$

$E_T^{jet} < 2.5$ GeV

$-1.5 < \eta_{jet} < 1.8$



BCAL is finely segmented in the Z direction

Photon isolation

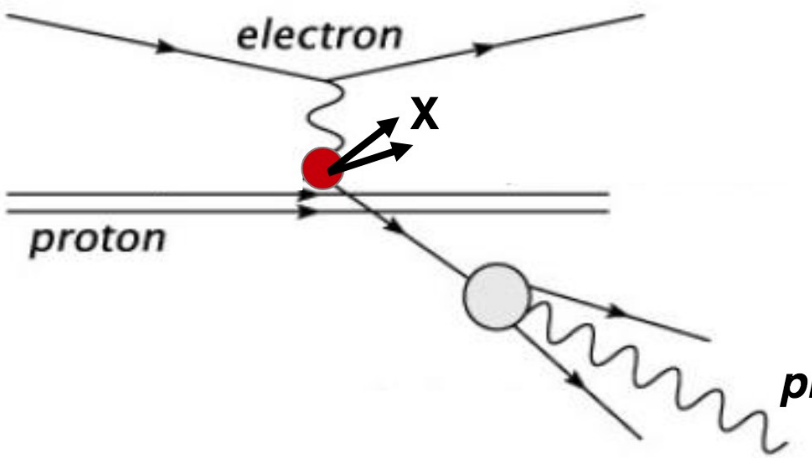
- Photon candidates are signals in BEMC without associated track

Photon selection

- $4 < E_T < 15$ GeV
- $-0.7 < \eta_\gamma < 0.9$
- Isolation:
  - $\Delta R > 0.2$ from tracks
  - >90 % jet energy
- Look in detail at shower shape in Z

What about background?

- Why do we isolate photon?



- Photons associated with jets require quark fragmentation function which is not easy to determine – requires non-perturbative input
- Reduce large background from neutral mesons

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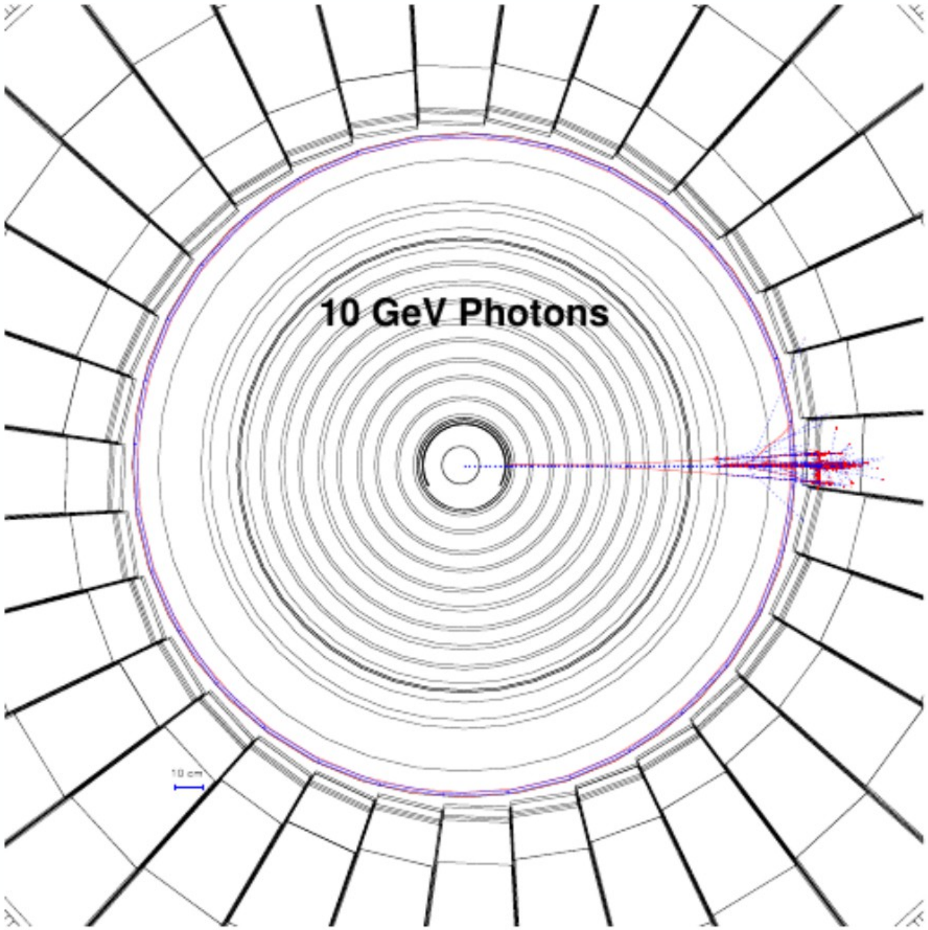
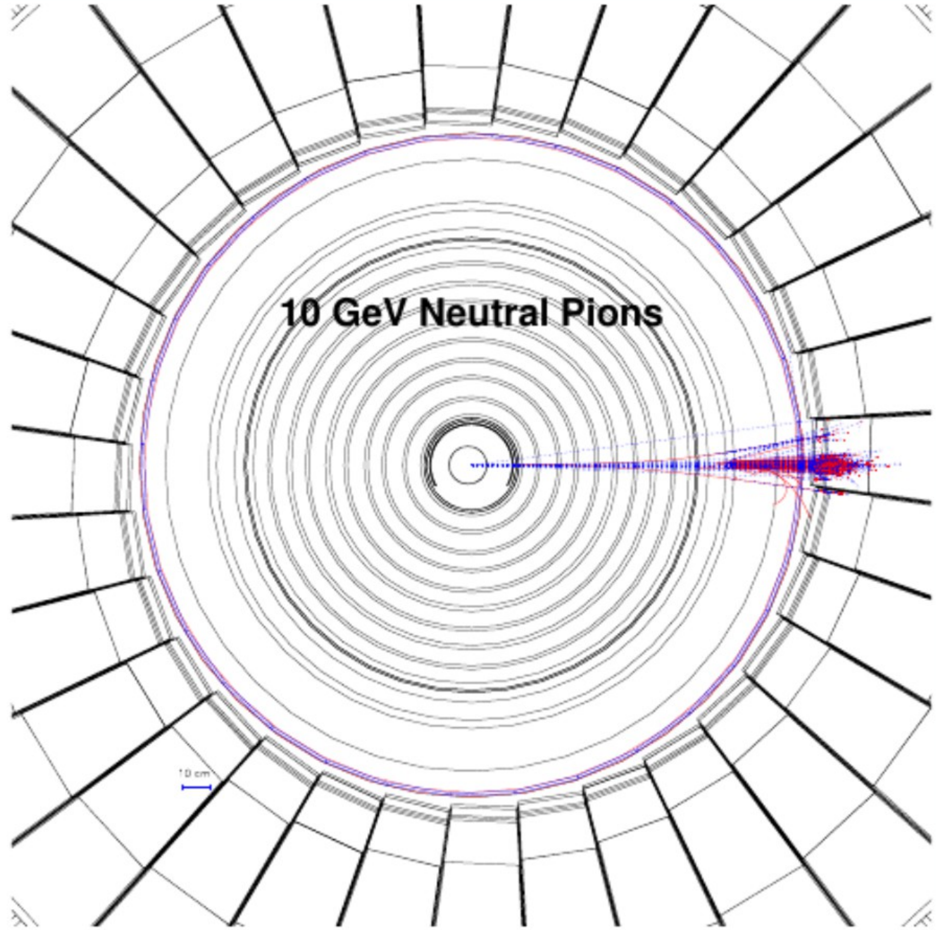
Irreducible background

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

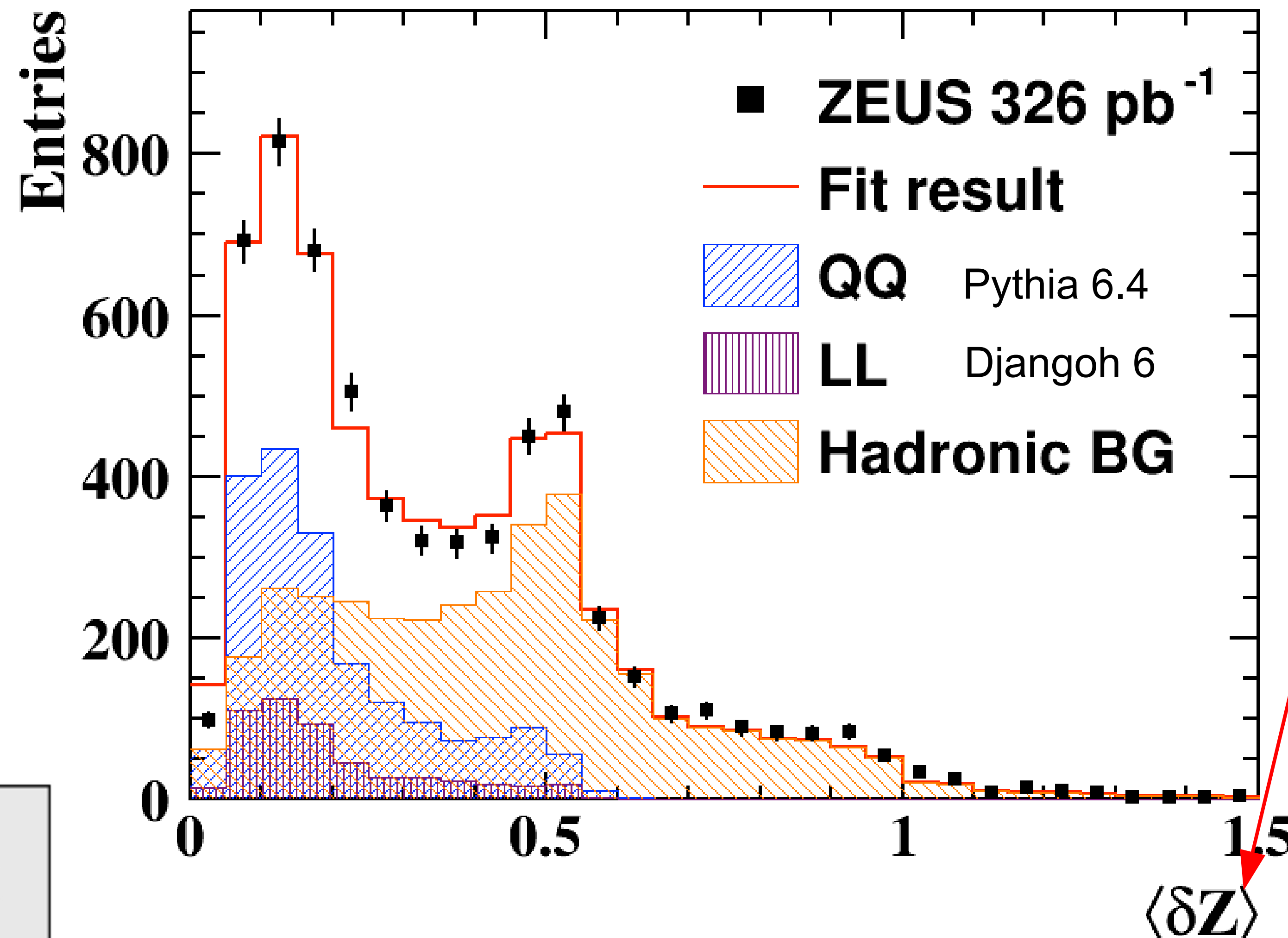


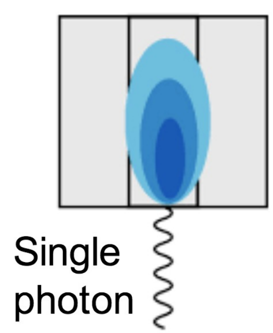


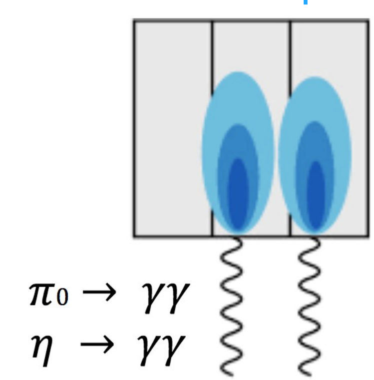
Neutral-meson produce broader energy deposits

Dealing with background

- Template fit to energy-weighted mean width of calorimeter EM cluster







Fit produced in each analyzed bin

Measurement uncertainties

- Typical statistical uncertainty is **13%**
  - ΔAcc – acceptance uncertainty, **~3-4%** effect
- Typical systematic uncertainty is **10%**
  - Dominated by the energy scale
- Fit of fraction of QQ in data
  - Δa – uncertainty of fit parameter, **~1%** effect
- $\Delta \mathcal{L}$ – 2%, but not included in the following plots

Comparison to generators

LO + LL QQ (PYTHIA) and LL (Ariadne)

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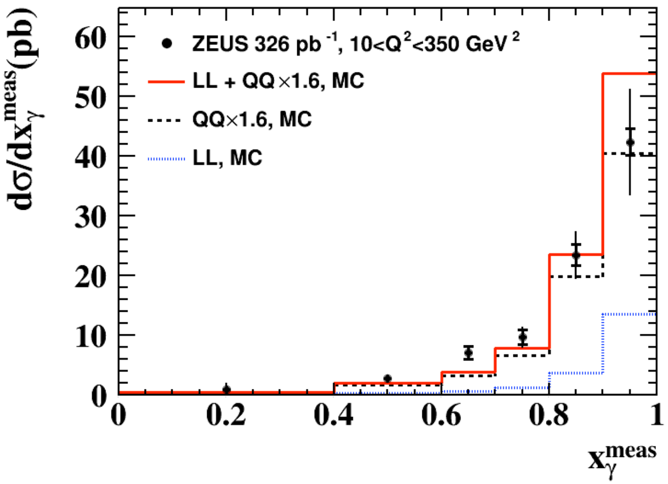
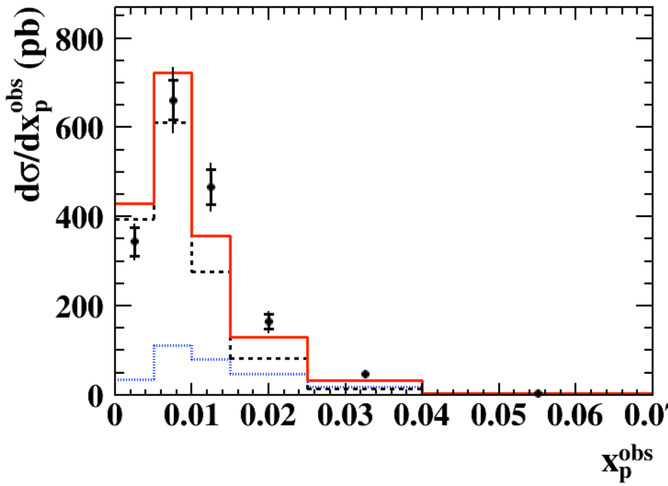
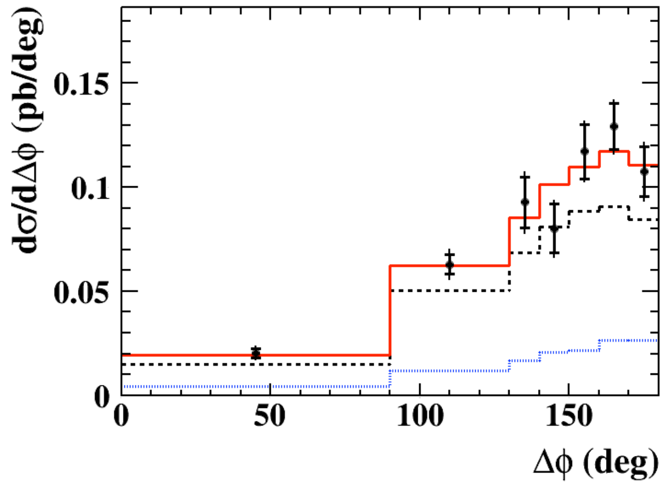
$$x_\gamma^{\text{meas}} = \frac{E^\gamma - p_Z^\gamma + E^{\text{jet}} - p_Z^{\text{jet}}}{2E_e y_{\text{JB}}}$$



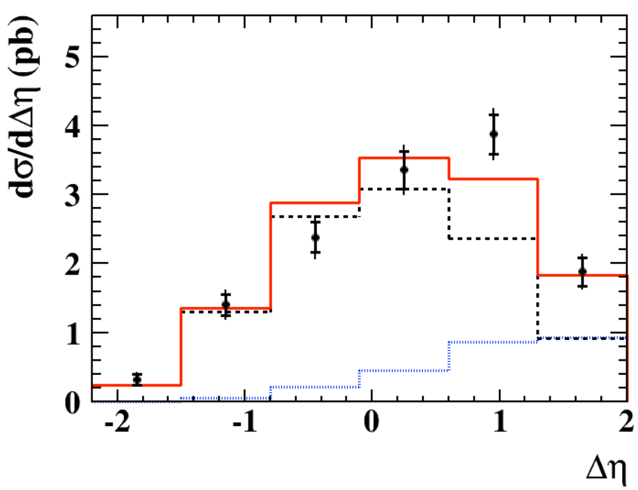
$$x_p^{\text{obs}} = \frac{E^\gamma + p_Z^\gamma + E^{\text{jet}} + p_Z^{\text{jet}}}{2E_p}$$



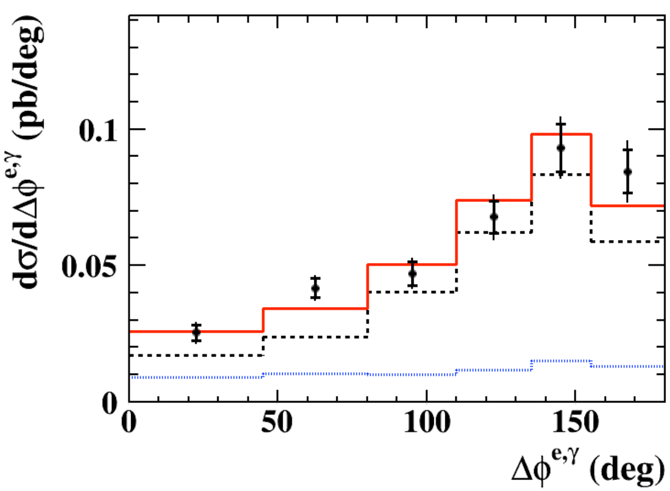
$$\Delta\phi = |\phi^{\text{jet}} - \phi^\gamma|$$



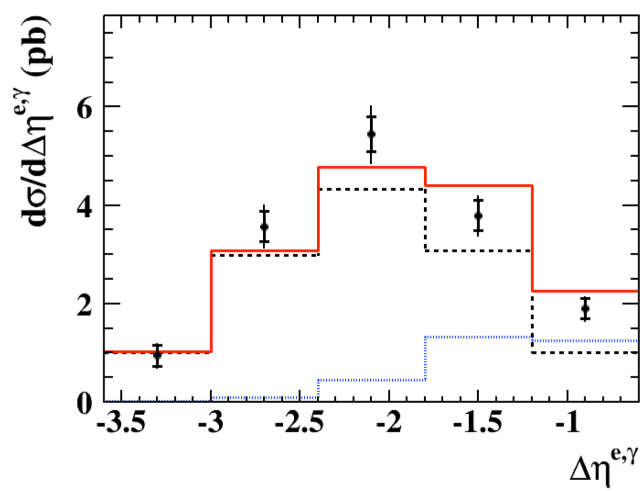
$$\Delta\eta = \eta^{\text{jet}} - \eta^\gamma$$



$$\Delta\phi^{e,\gamma} = |\phi^e - \phi^\gamma|$$

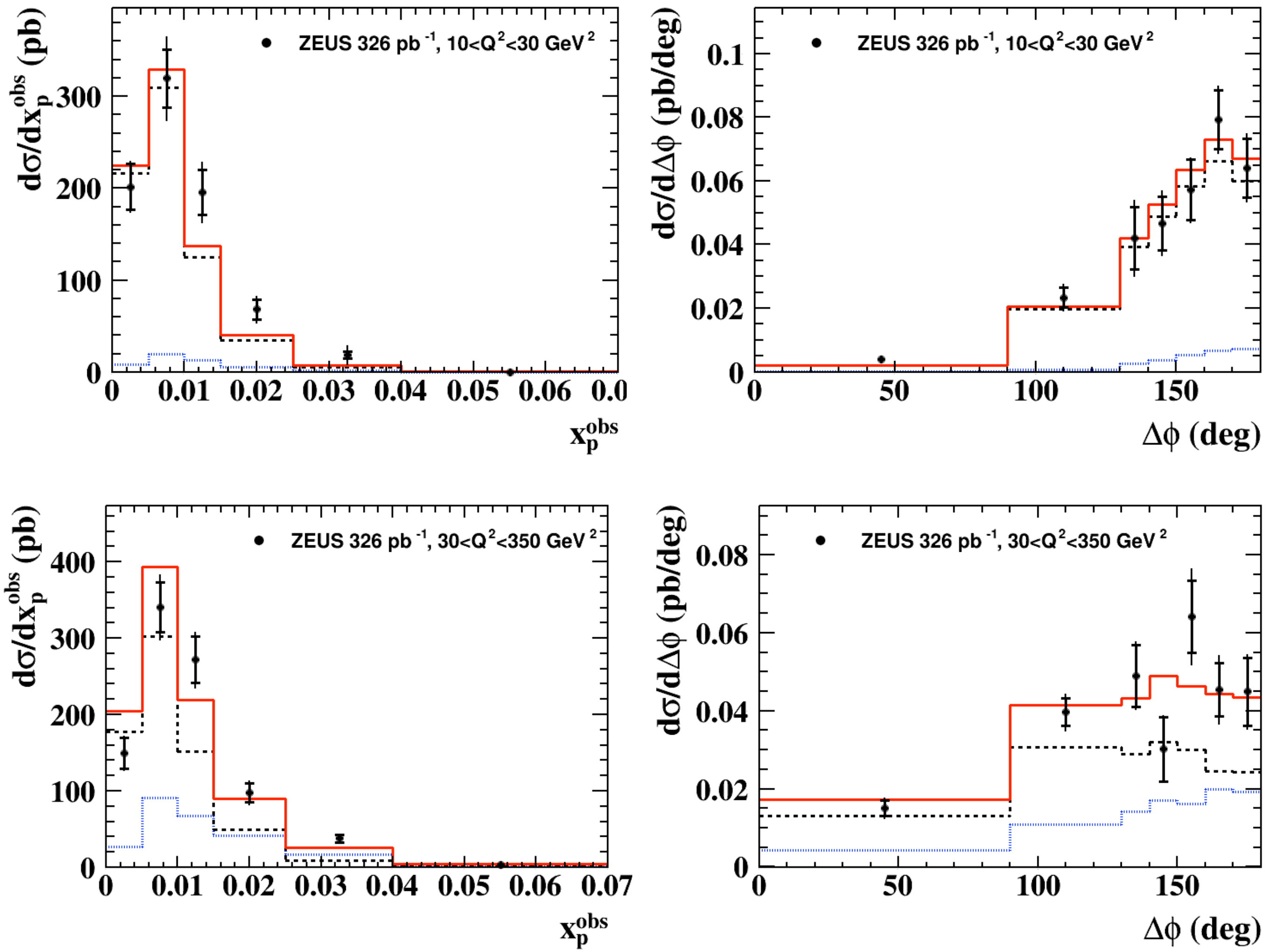


$$\Delta\eta^{e,\gamma} = \eta^e - \eta^\gamma$$



D:

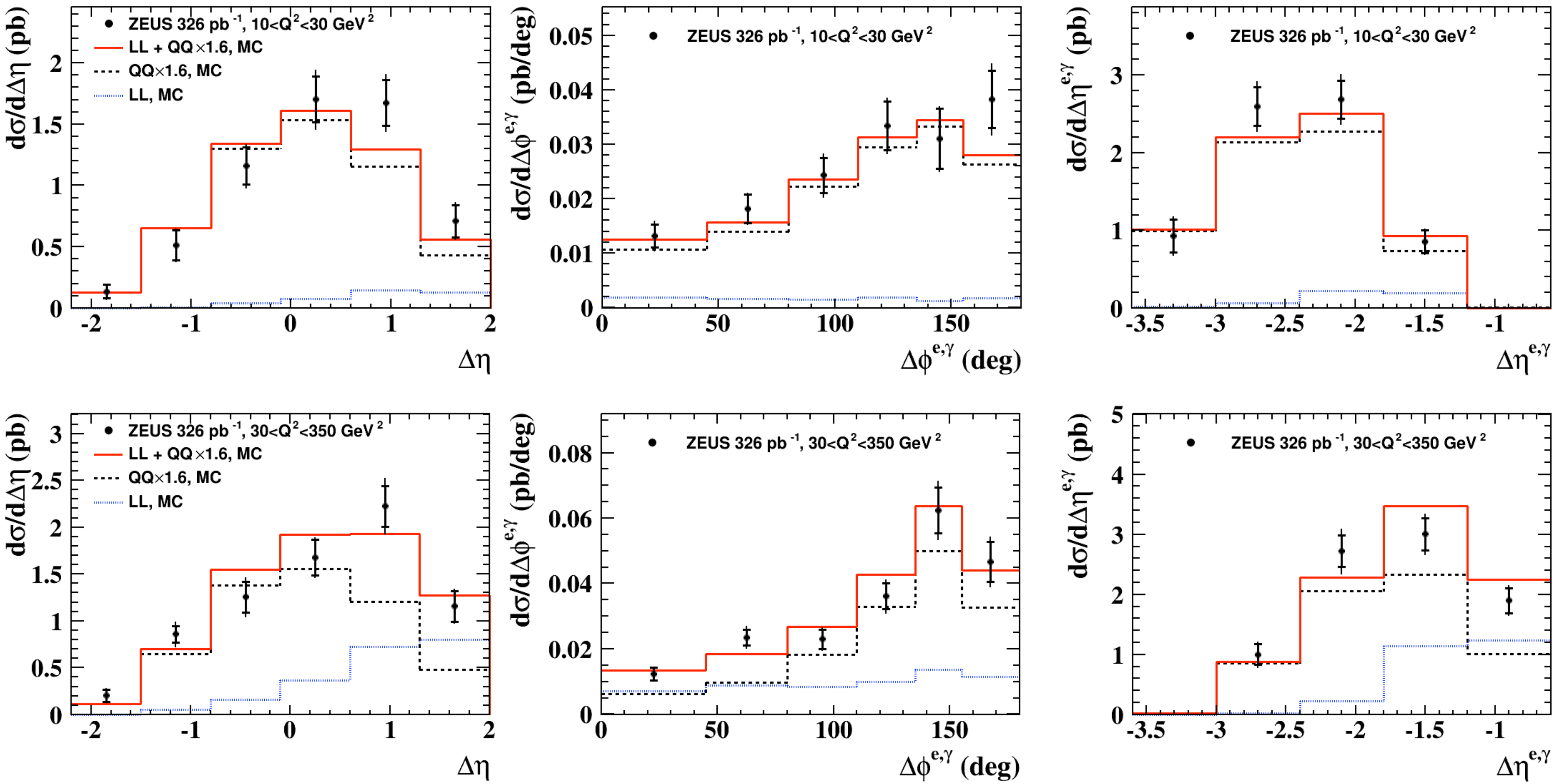
Comparison to generators: two Q^2 ranges



- Good description in both kinematic regions

At large Q^2 LL contributes significantly

Comparison to generators: two Q^2 ranges



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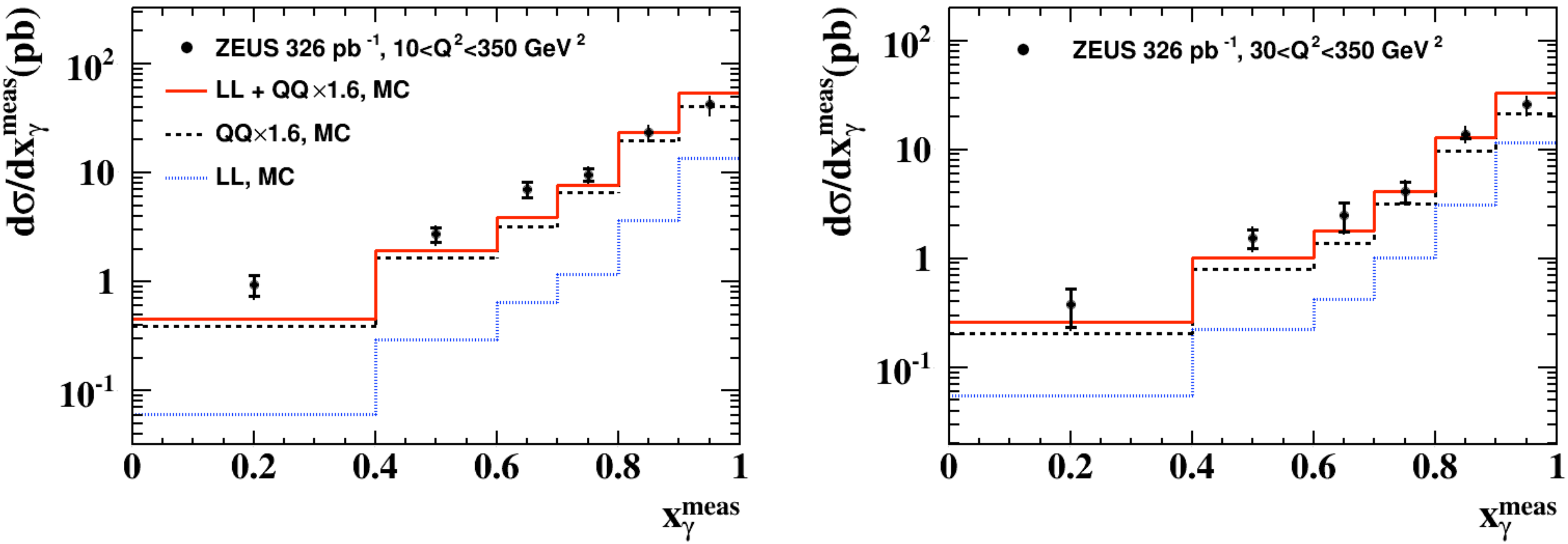
Comparison to generators: two Q^2 ranges



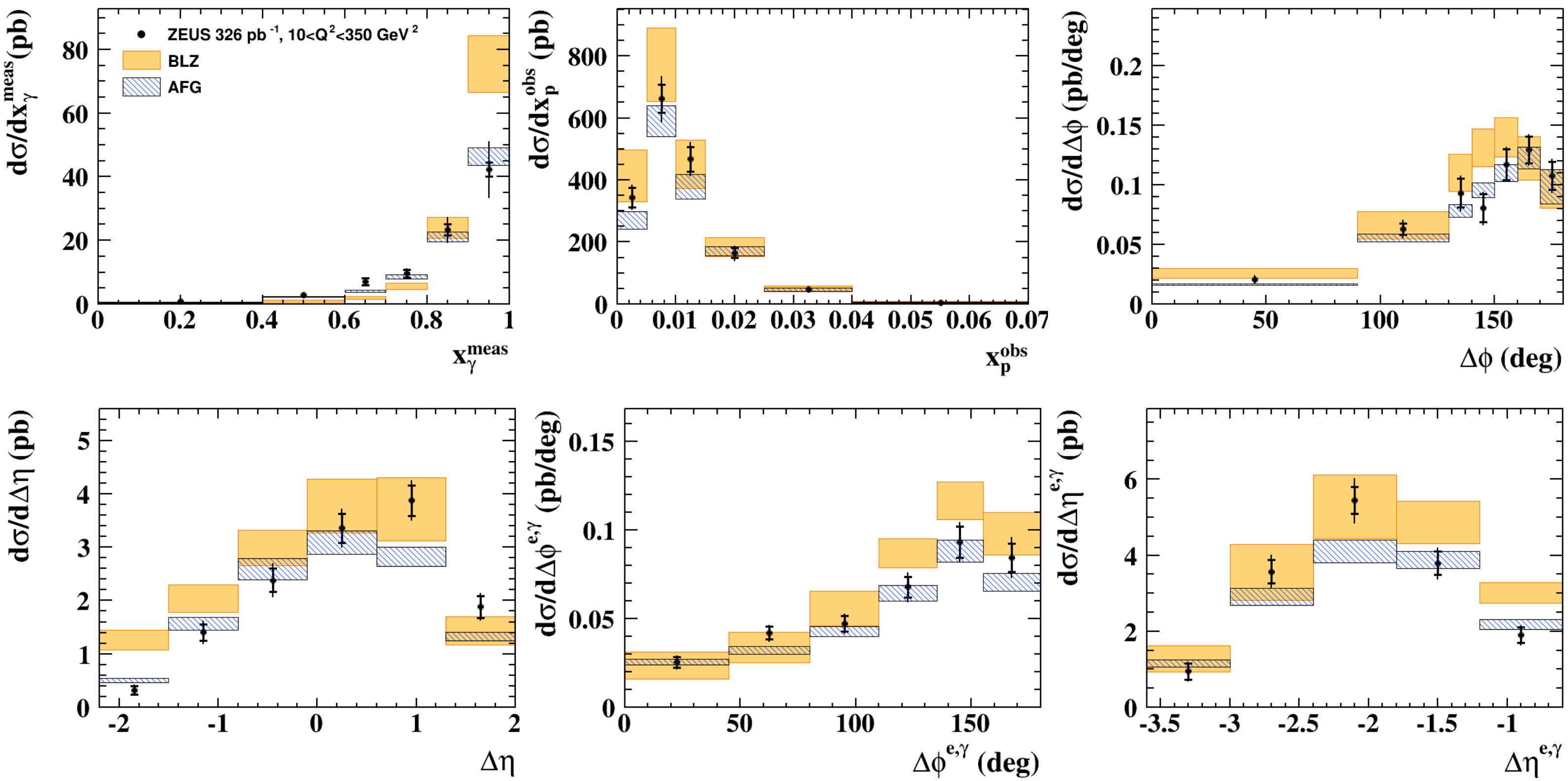
- At large Q^2 LL contributes significantly
  → improved data description

Low x_γ^{meas} region @ large Q^2 satisfactory described without higher-order corrections

Comparison with theory

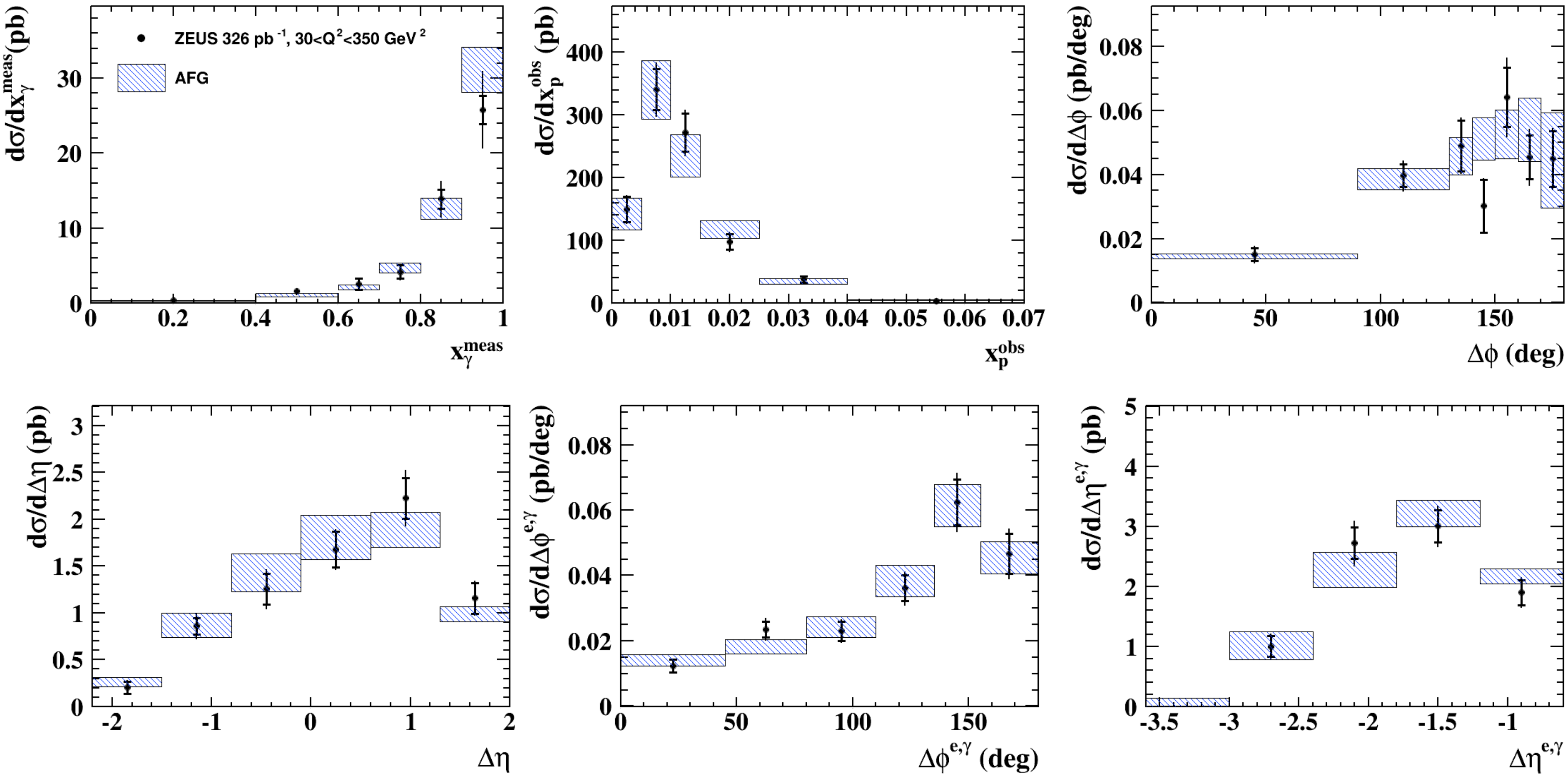
- BLZ   S. Baranov, A. Lipatov and N. Zotov, Phys. Rev. D 81 (2010) 094034.
  - K_t factorisation
- AFG: NLO   P. Aurenche, M. Fontannaz and J.Ph. Guillet, Eur. Phys. J. C 44 (2005) 395.

  P. Aurenche and M. Fontannaz, Eur. Phys. J. C 77 (2017) 324.



- BLZ: shapes fairly described, some distributions off, ~20% too high normalisation
- AFG: shapes and normalisation OK

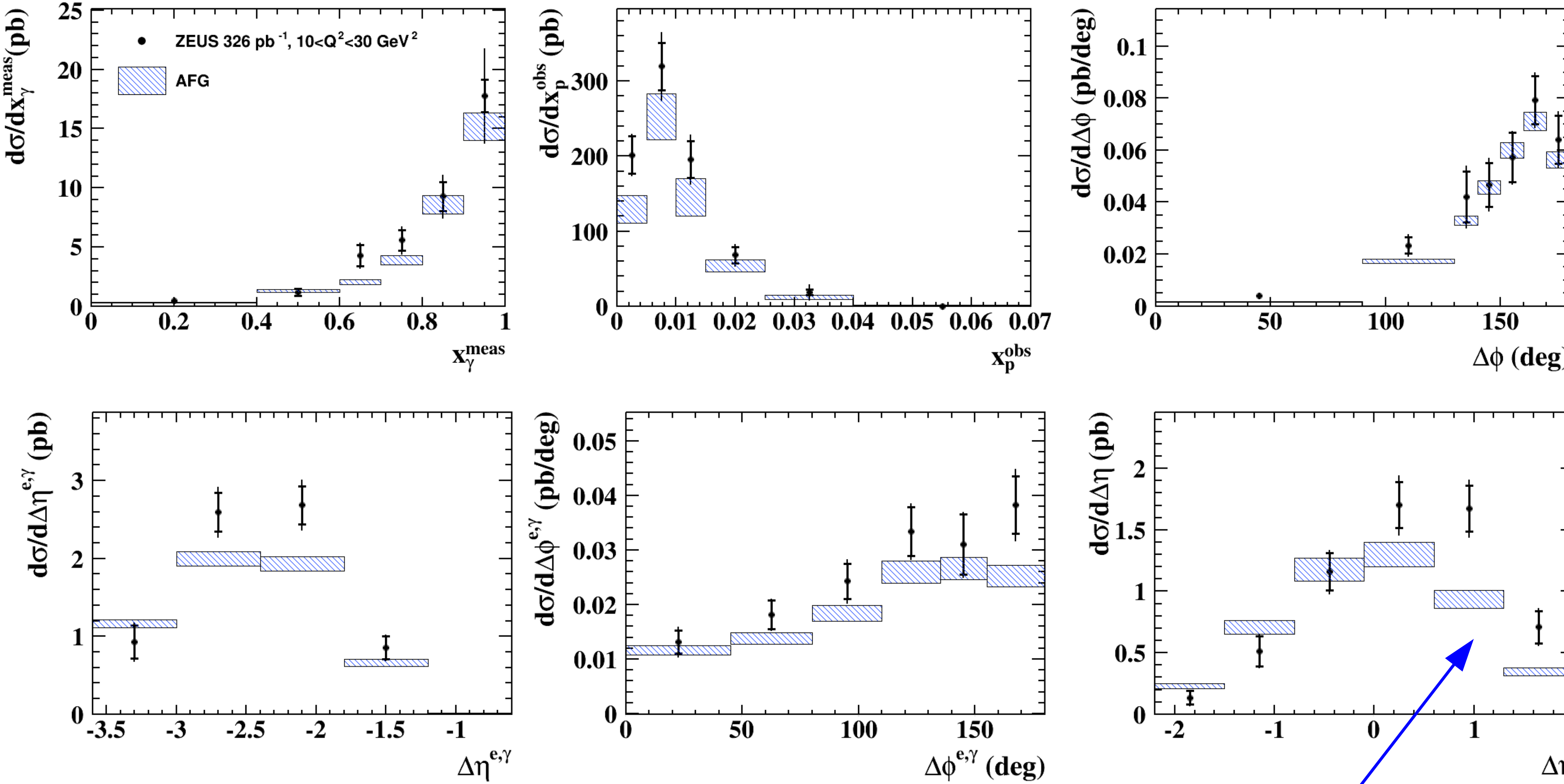
Comparison to AFG: large Q^2



- Excellent agreement in shape and normalisation for all distributions

K. Wi

Comparison to AFG: low Q^2



- Excellent agreement in shape and normalisation except for $\Delta\eta$
  - Possibly due to photon p_T cut in calculations

Summary

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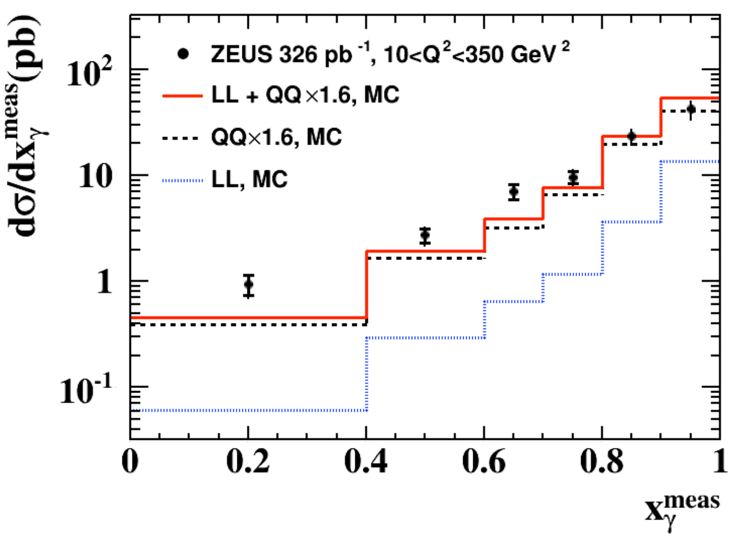
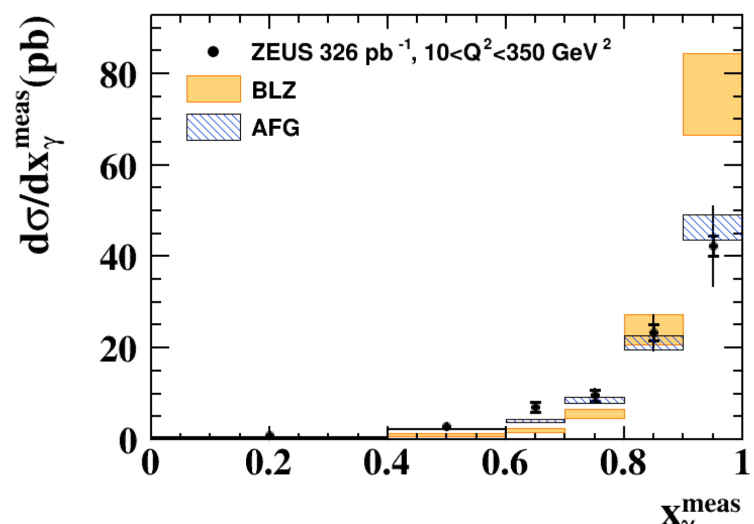
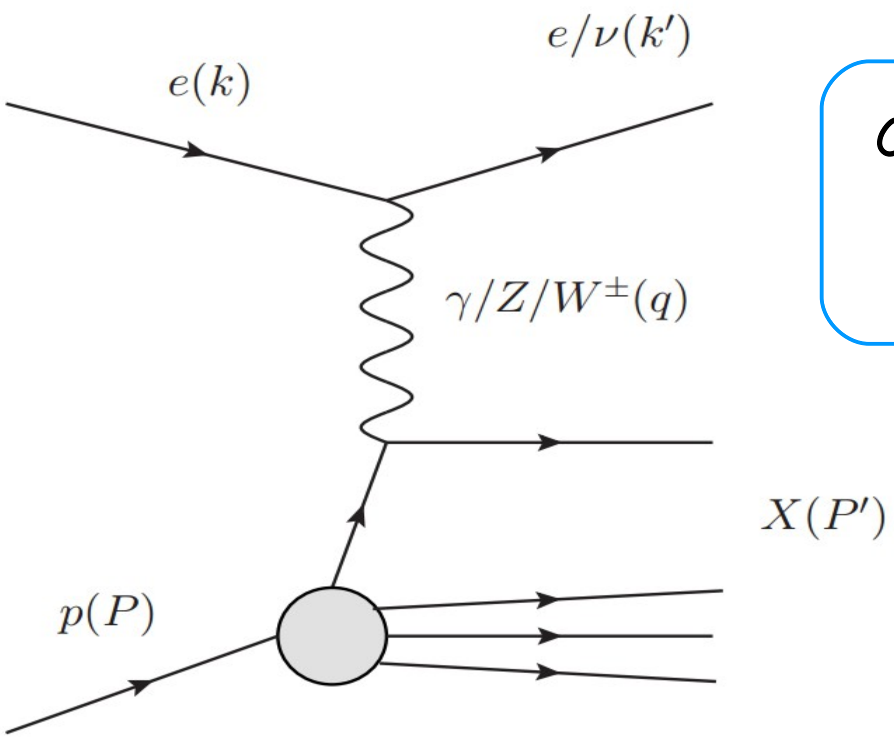
- Recent measurements complement previous studies: Phys. Lett. B 715 (2012) 88
  - Additionally studies in two Q^2 regions: below and above Q^2 of 30 GeV^2
- Extracted differential cross-sections for correlated observables: x_γ^{meas}, x_p^{obs}, $\Delta\eta$, $\Delta\phi$, $\Delta\eta_{e\gamma}$ and $\Delta\phi_{e\gamma}$
- PYTHIA x 1.6 describes data in both Q2 regions
- NLO (AFG) calculations give excellent data description, both in shape and normalisation and in both kinematic regions – low and high Q^2
- k_t-factorisation (BLZ) gives fair data description, however normalisation too high and some distributions not described in shape





Back-up slides

Deep Inelastic Scattering at HERA



Combined H1/ZEUS inclusive DIS cross sections → final word from HERA → HERA legacy

$$E_P = 920(820, 460, 575)\,GeV$$
$$E_e = 27.5\,GeV$$

$$\sqrt{s} = 318(300, 225, 252)\,GeV$$

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

$$x_{Bj} = \frac{Q^2}{2\,pq} \qquad y = \frac{pq}{pk}$$

$$s = (p + k)^2 \qquad Q^2 = xys$$

Experimental luminosity (H1 & ZEUS):

~ 0.5fb^{-1} data from each experiment