Extended studies of isolated photon production in deep inelastic scattering at HERA

Ian C. Brock on behalf of the ZEUS collaboration
University of Bonn

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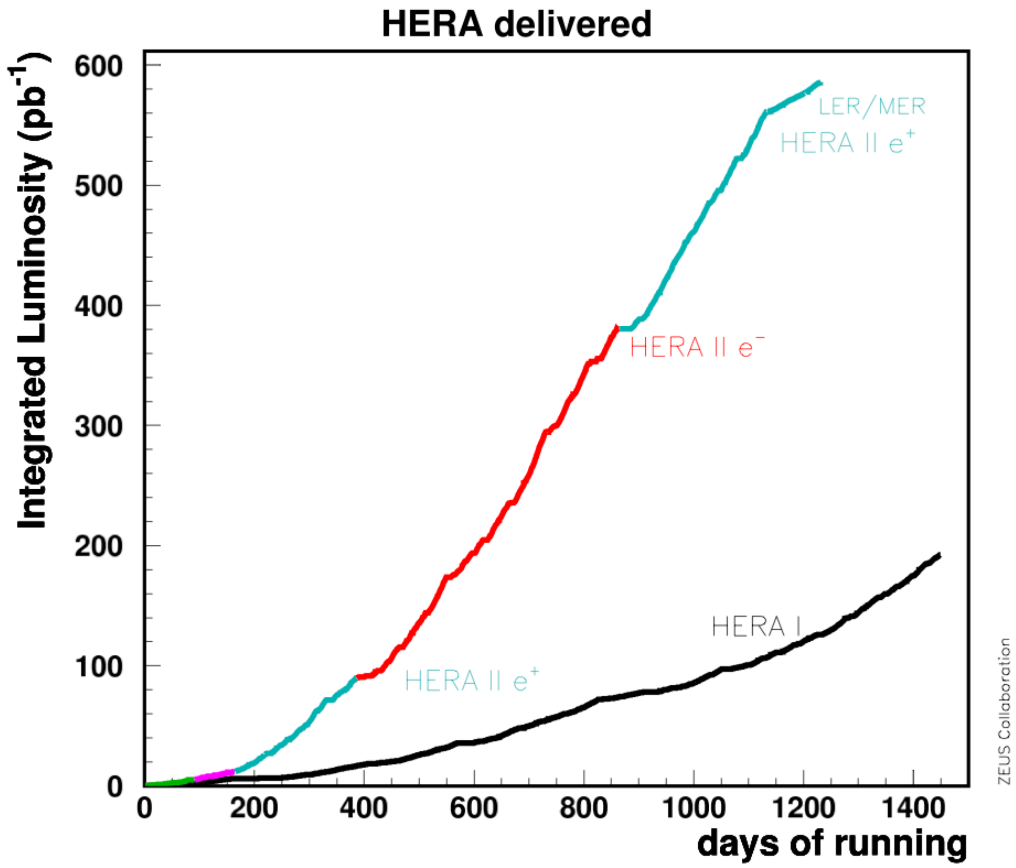
Outline

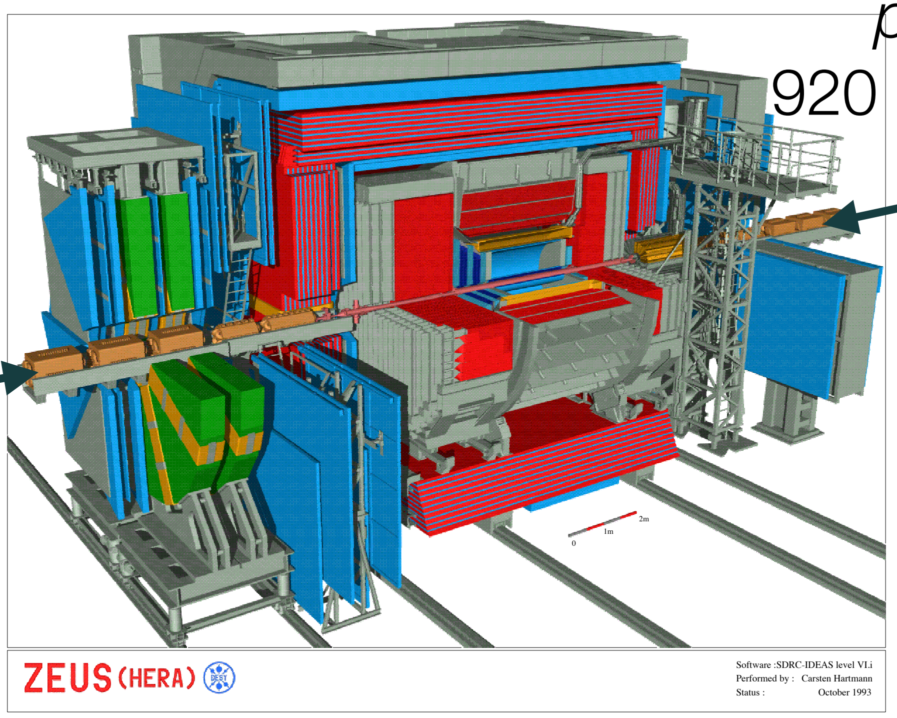
- Introduction
- Event selection
  - Separating direct photons from other sources
- Differential cross-section measurements
- Summary

HERA and ZEUS

- $e^{\pm}p$ collisions at $\sqrt{s}$ = 318 GeV
  - ~0.5 fb^{-1} per experiment
- HERA 1:
  - 1996 - 2000
- HERA 2 (longitudinal e$^{\pm}$ polarisation)
  - 2004 - 2007

Measurement uses 326 pb^{-1} from HERA 2





p
920 GeV

e$^{\pm}$
27.5 GeV

θ w.r.t. p beam
η = -ln tan θ/2

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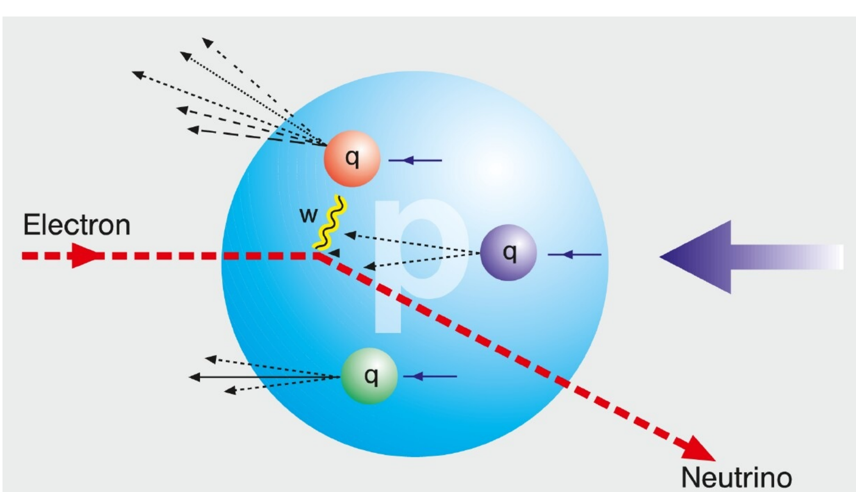
DIS events and kinematics

- Characterise events:
  - Q^2 $Q^2 = s\,x\,y$
  - Bjorken x, $(0 < x < 1)$
  - Inelasticity y, $(0 < y < 1)$

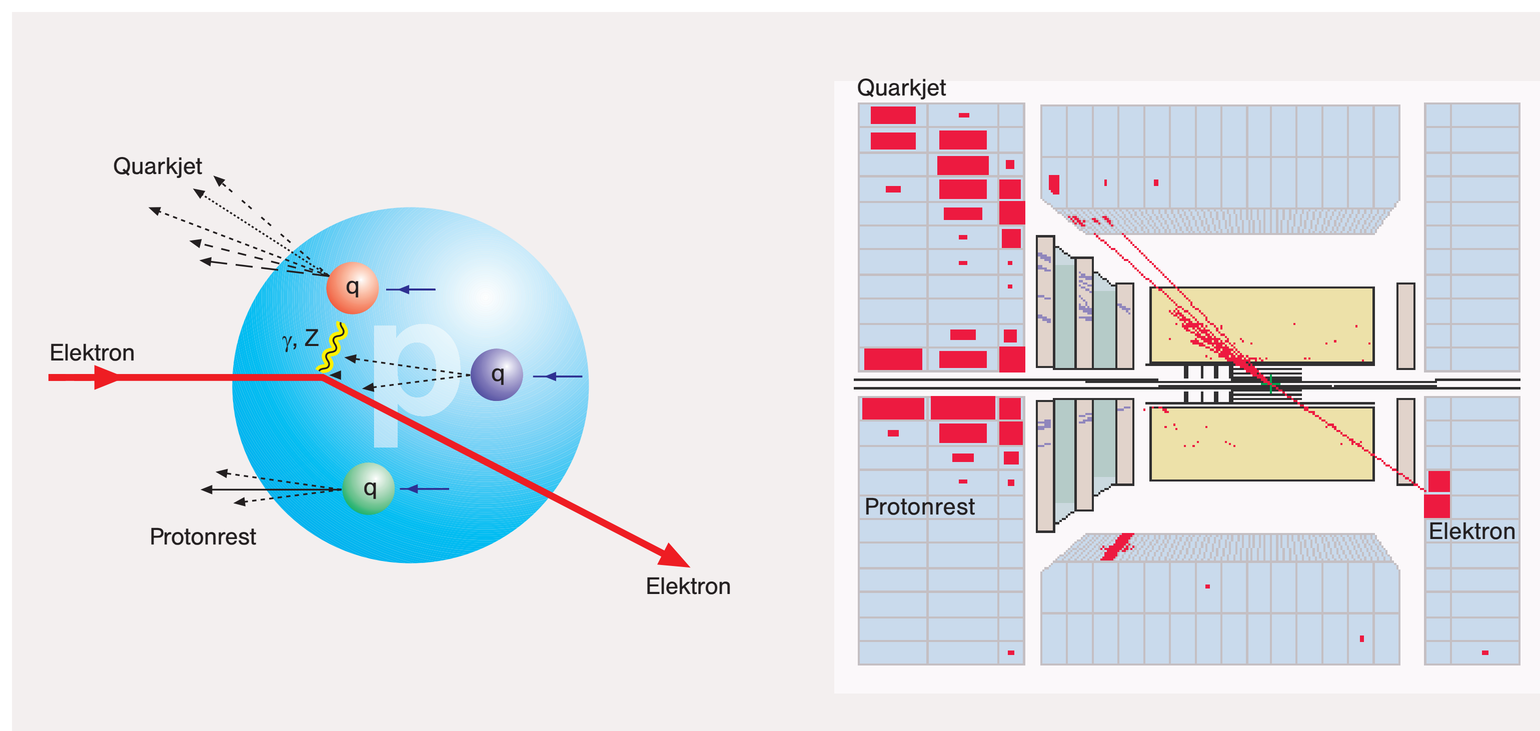
DIS ⇒ scattered e in detector

$Q^2 \gtrsim 1\ \text{GeV}^2$

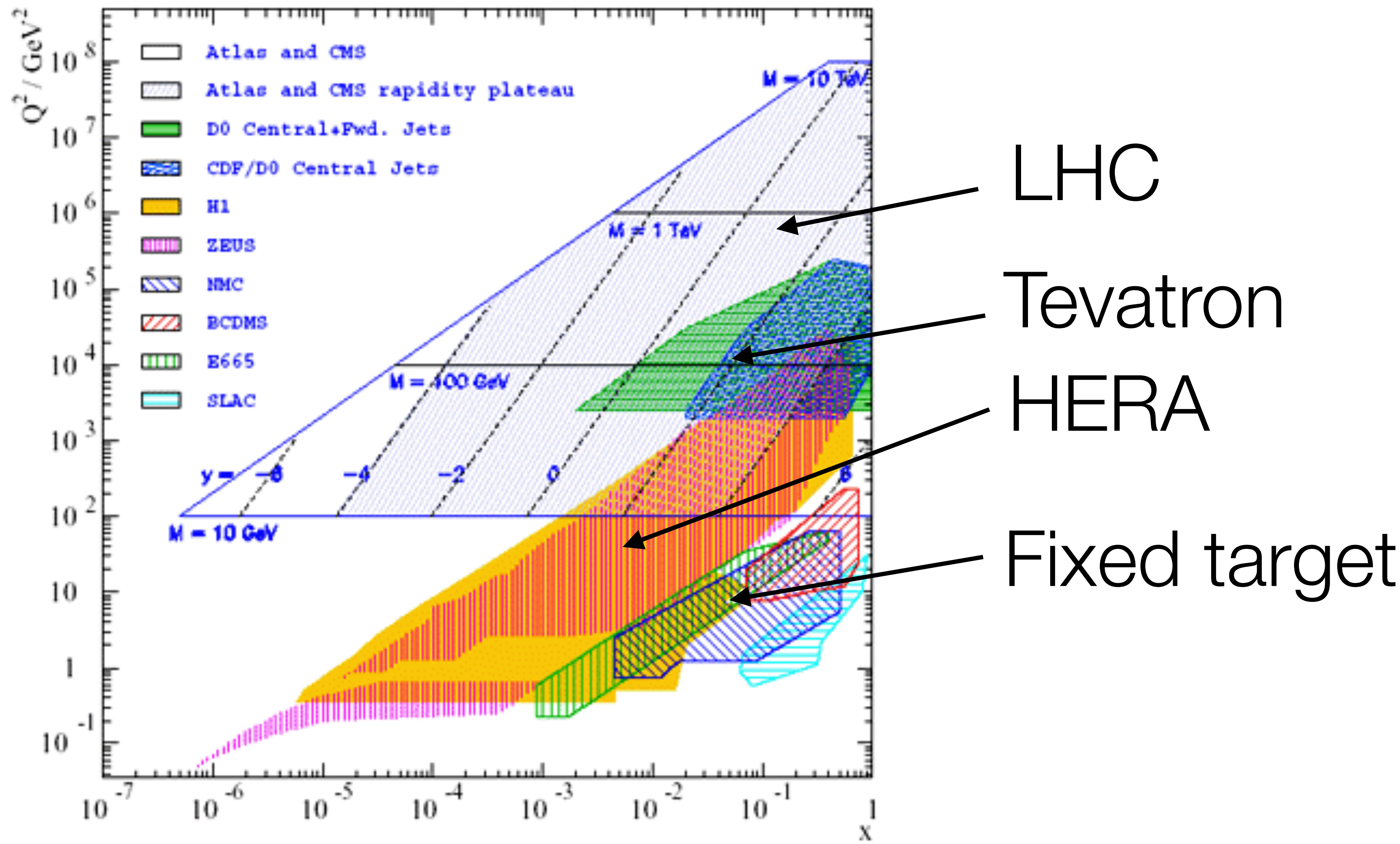
CC - scattered ν



NC - scattered e



Kinematic regions



Parameterise structure functions as a function of *x*
Use DGLAP equations to evolve from HERA to LHC

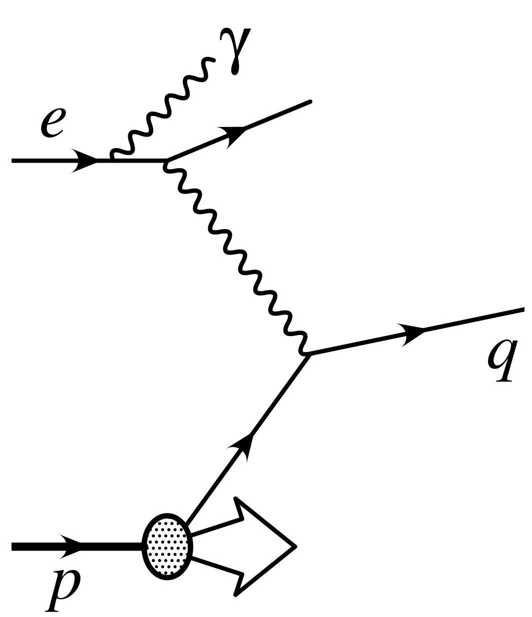
Why isolated photons?

- Use dynamics to probe modes such as k_t-factorisation and pQCD approaches
- See if dynamics changes with virtuality
- Check proton PDFs
- Photons can be a background to new physics

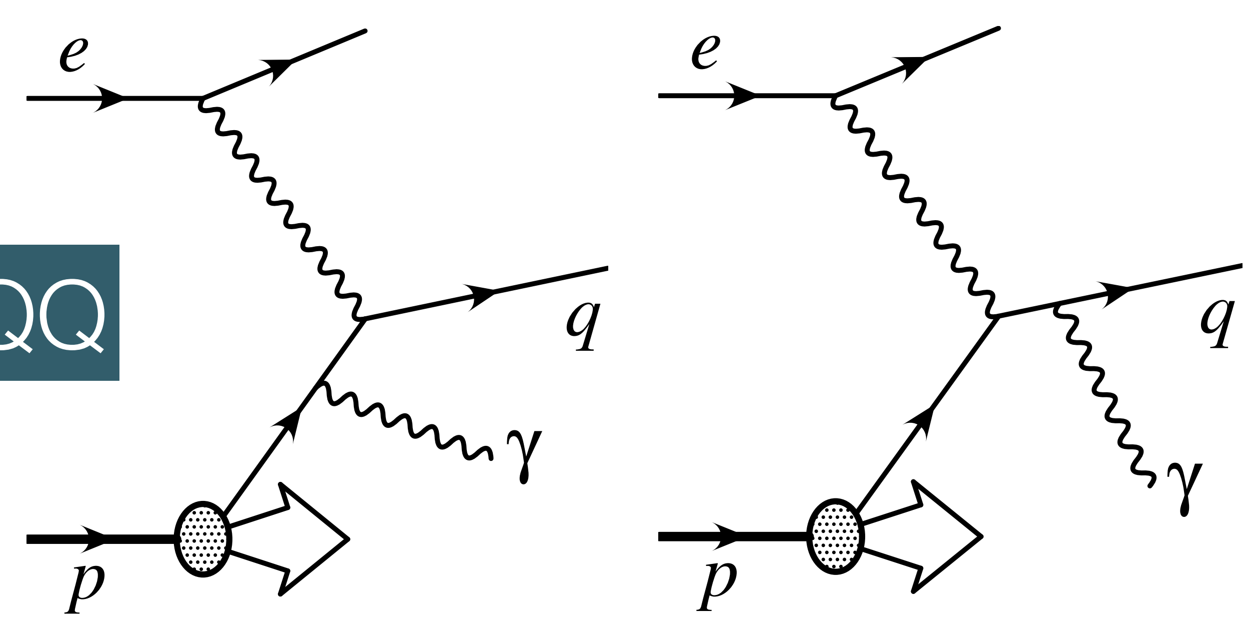
Where do isolated photons come from?

- Can be emitted from lepton (LL) or proton (quark, QQ)
- Assume lepton emission is well known
- Use photon to probe proton
- Trick is to find these photons

LL



QQ



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Selection criteria

- Event
  - $10 < Q^2 < 350$ GeV^2
  - $E_e > 10$ GeV and $\theta_e > 140°$
  - $35 < E - p_Z < 65$ GeV
- Jets
  - k_t clustering, R=1.0
  - $E_{jet} > 2.5$ GeV
  - $-1.5 < \eta_{jet} < 1.8$

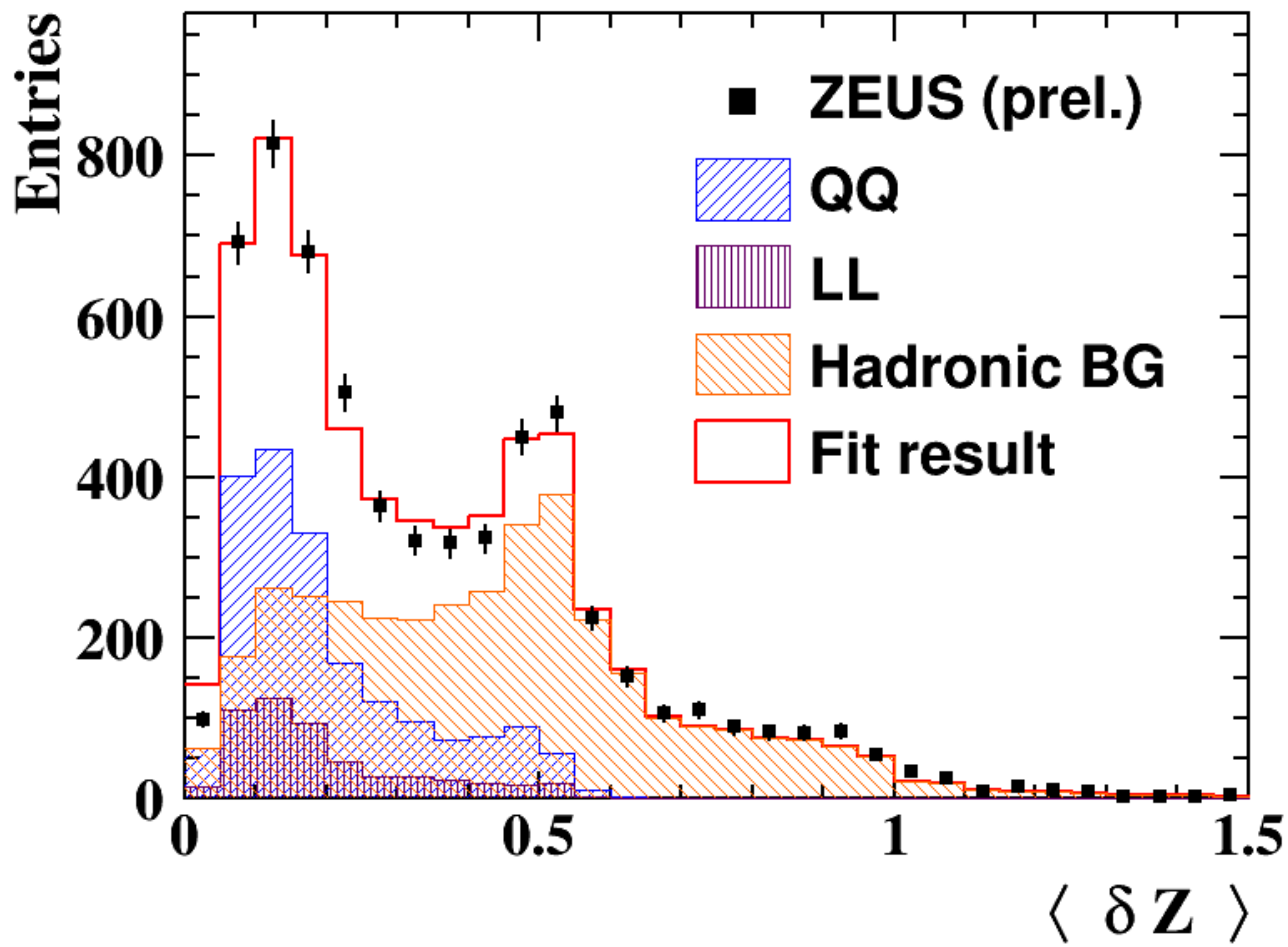
Photon selection

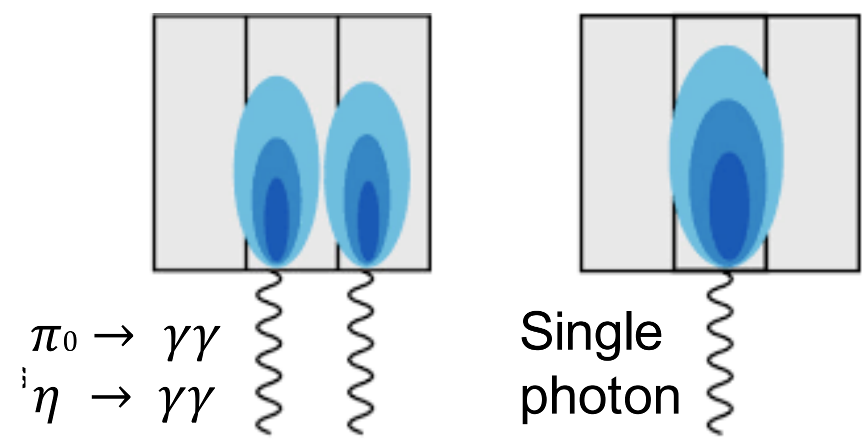
- $4 < E_T < 15$ GeV
- $-0.7 < \eta_\gamma < 0.9$
- Isolation:
  - $\Delta R > 0.2$ from tracks
  - >90 % jet energy
- Look in detail at shower shape in Z

≈6000 events selected

Separating photons from hadrons

- ZEUS barrel electromagnetic calorimeter finely segmented in *Z*





<δZ> is energy-weighted width of EM shower in *Z*

Uncertainties (typical sizes)

- Statistics: 13 %
- Acceptance: 3-4 %
- Systematics: 10 %
  - Dominated by energy scale
- Fraction of QQ events: 1 %
- Luminosity: 2 % (not included in plots)

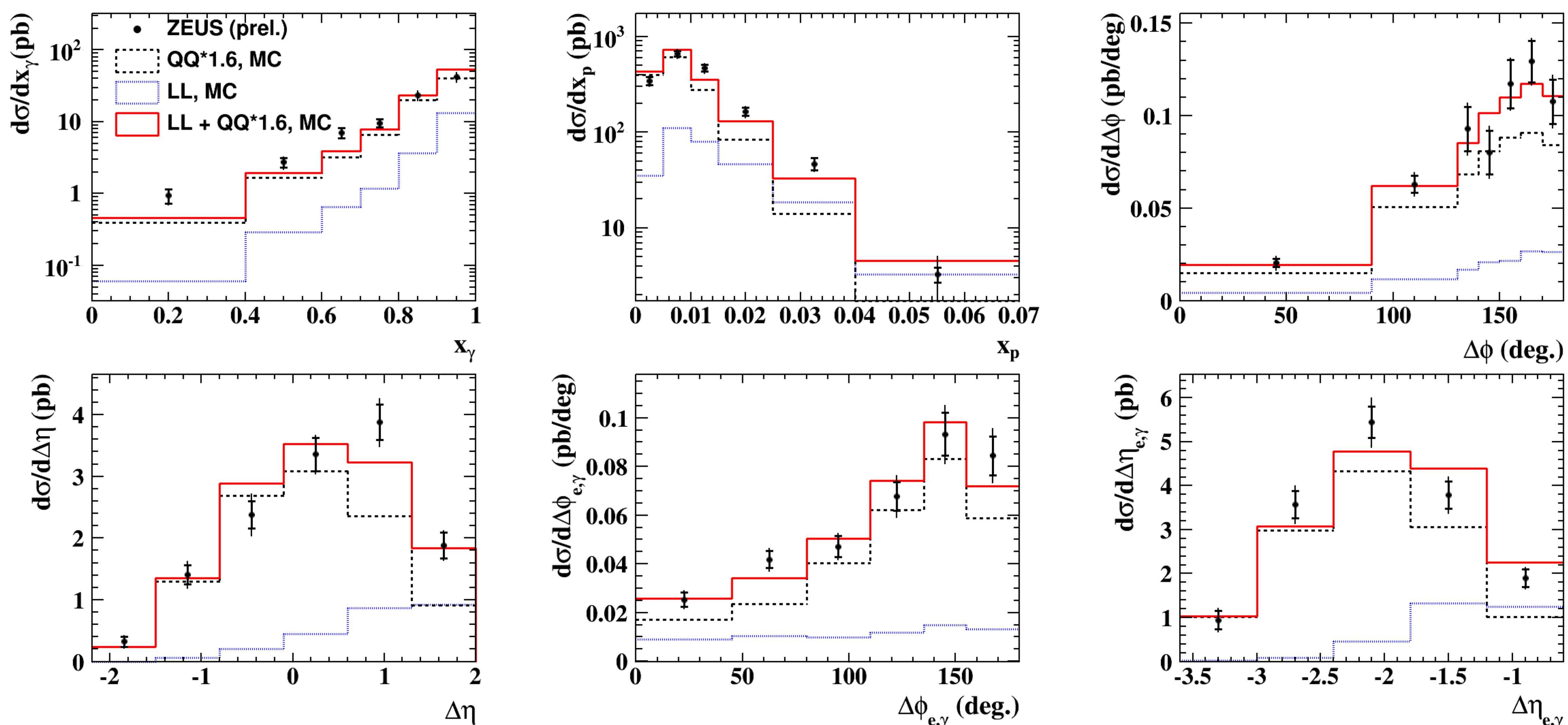
Comparison with generators

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

$$x_\gamma = \frac{\sum_{\text{jet},\gamma}(E - p_z)}{2y_{\text{JB}}E_e}$$

$$x_p = \frac{\sum_{\text{jet},\gamma}(E + p_z)}{2E_p}$$

$$\Delta\phi = \phi_{\text{jet}} - \phi_\gamma$$



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

$$\Delta\phi_{e,\gamma} = \phi_e - \phi_\gamma$$

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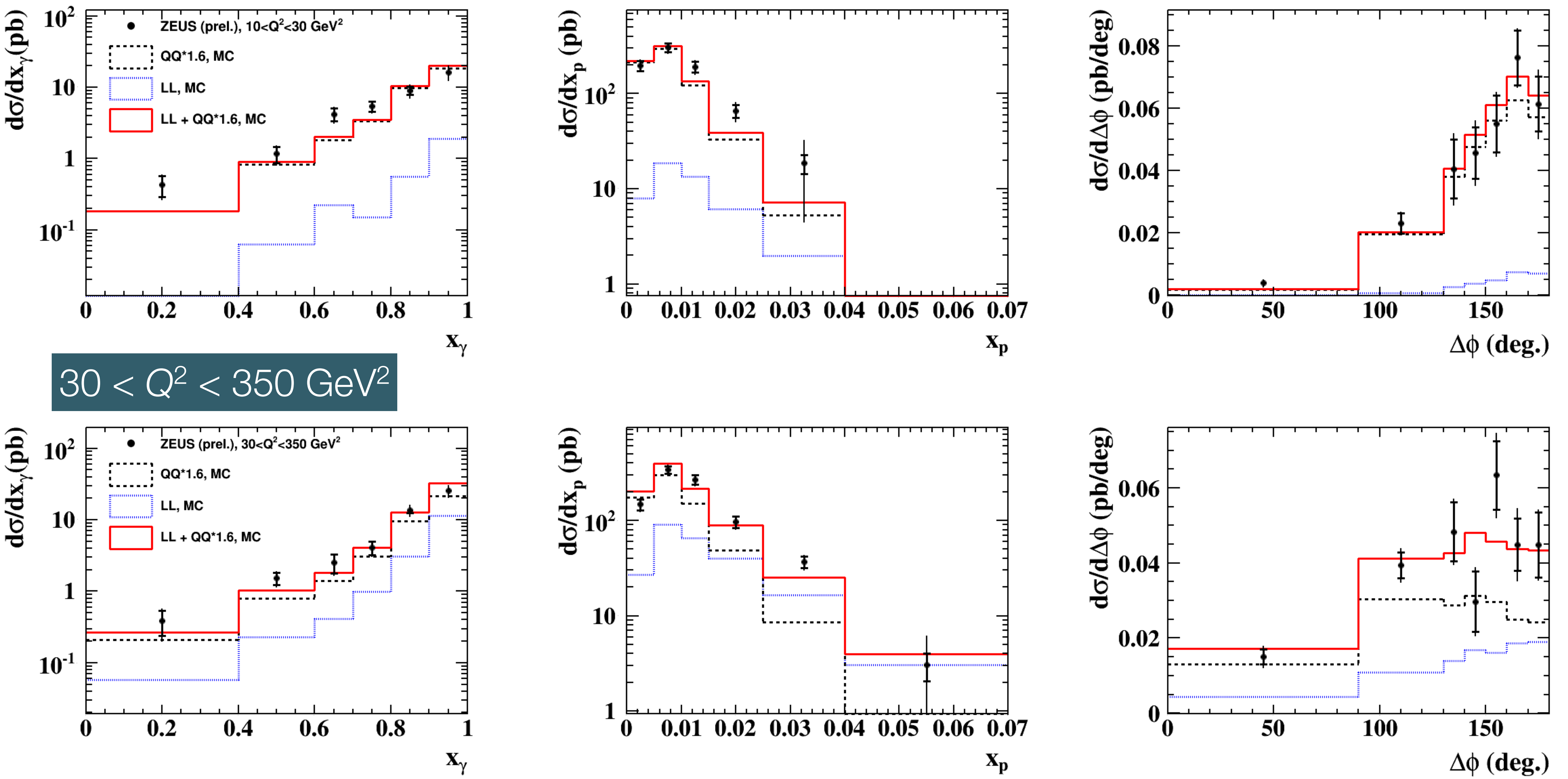

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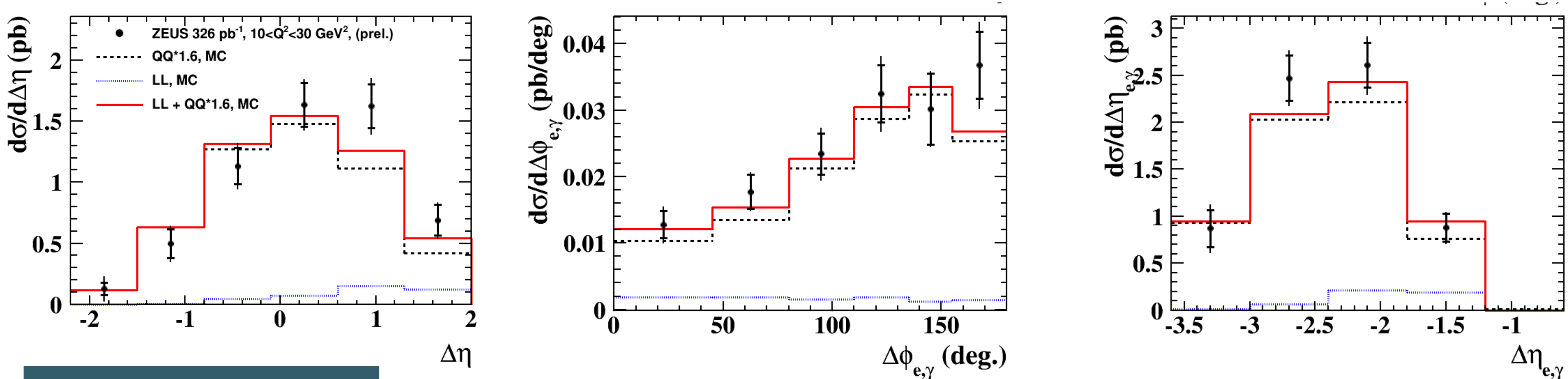

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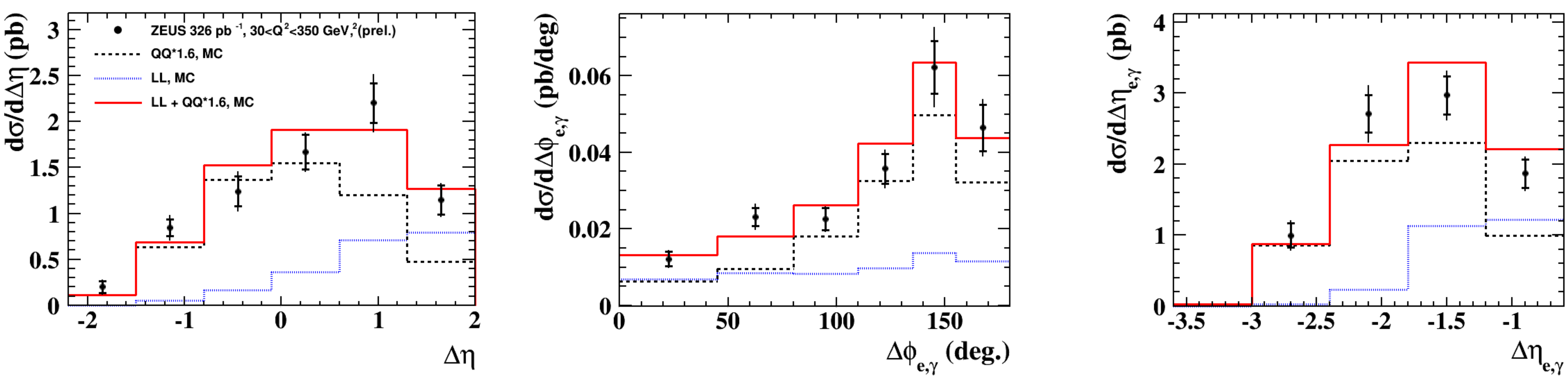
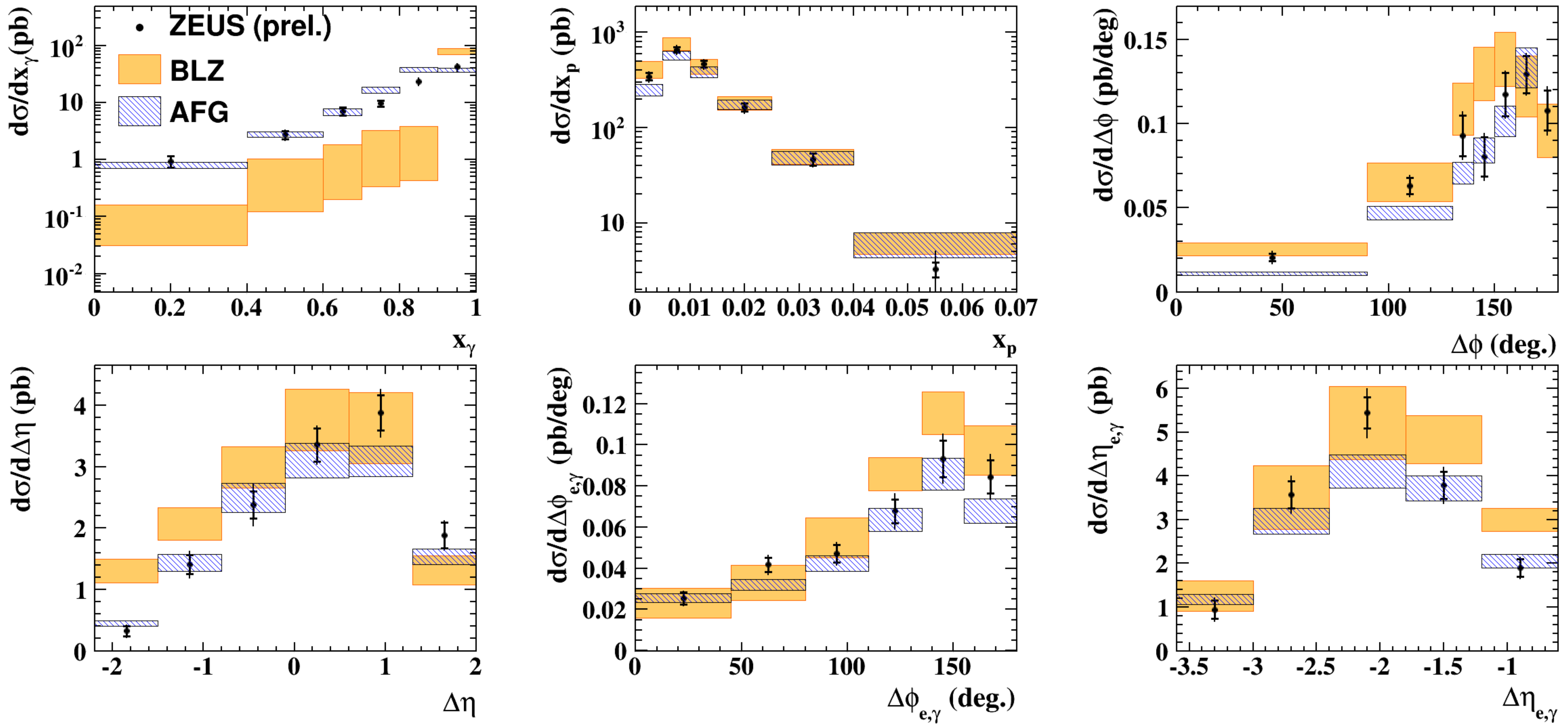


Comparison with theory



k_t-factorisation: BLZ: Baranov, Lipatov, Zotov - PRD 81 (2010) 094034
Collinear: AFG: Aurenche, Fontonnaz, Guillet - LAPTH-005/17 LPT-Orsay 16-88

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Summary

- Recent measurements complement previous studies: Phys. Lett. B 715 (2012) 88
- Extracted differential cross-sections for correlated observables: x_γ, x_p, $\Delta\eta$, $\Delta\varphi$, $\Delta\eta_{e\gamma}$ and $\Delta\varphi_{e\gamma}$
- PYTHIA x 1.6 describes data in both Q^2 regions
- AFG (NLO) calculations describe data well
- k_t-factorisation (BLZ) does OK except for x_γ and $\Delta\eta$

Backup

Cross-section calculation

- Production cross-section for variable *Y*:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}Y} = \frac{N(\gamma_{\mathrm{QQ}})}{A_{\mathrm{QQ}} \cdot \mathcal{L} \cdot \Delta Y} + \frac{\mathrm{d}\sigma_{\mathrm{LL}}^{\mathrm{MC}}}{\mathrm{d}Y}$$

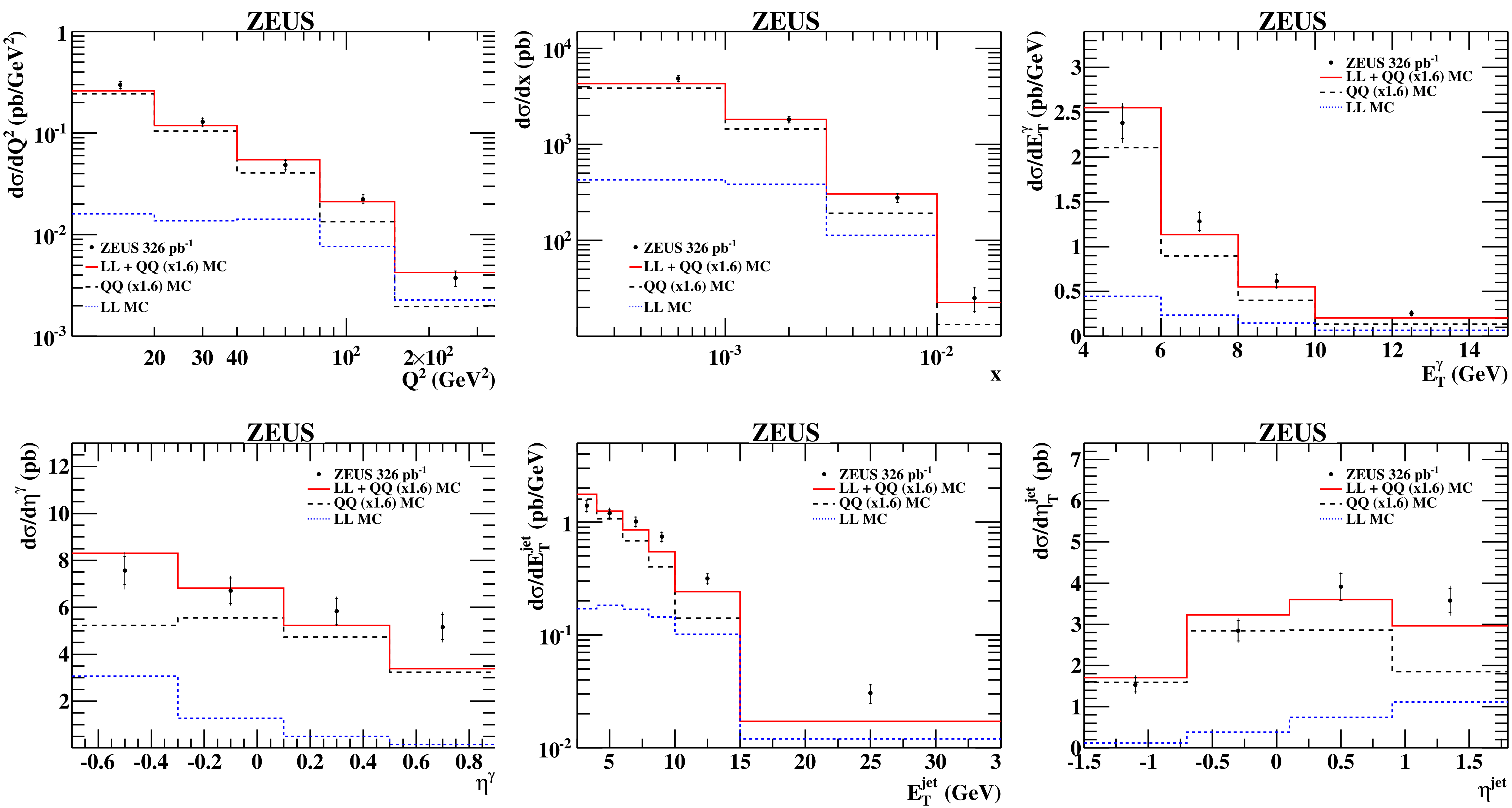
  - $N(\gamma_{QQ})$: number of QQ photons from fit
  - ΔY: bin width
  - $\mathscr{L}$: integrated luminosity
  - $d\sigma_{LL}^{MC}/dY$: cross-section for LL photons
  - A_{QQ}: events reconstructed / events generated in bin

Theory models

- Baranov, Lipatov, Zotov (BLZ)
  - Calculation of cross-section based on convolution of off-shell matrix element and unintegrated parton densities (k_t-factorisation)
  - Some final-state jets can come from parton evolution cascade - model uses approximations (especially for y)
  - Λ_{QCD} = 200 MeV, NF=4, $\mu_R^2 = \mu_F^2 = Q^2$, MSTW2008 PDF
- Aurenche, Fontannaz, Guillet (AFG)
  - NLO theory with conventional PDFs

Phys. Lett. B 715 (2012) 88

Previous results



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Phys. Lett. B 715 (2012) 88

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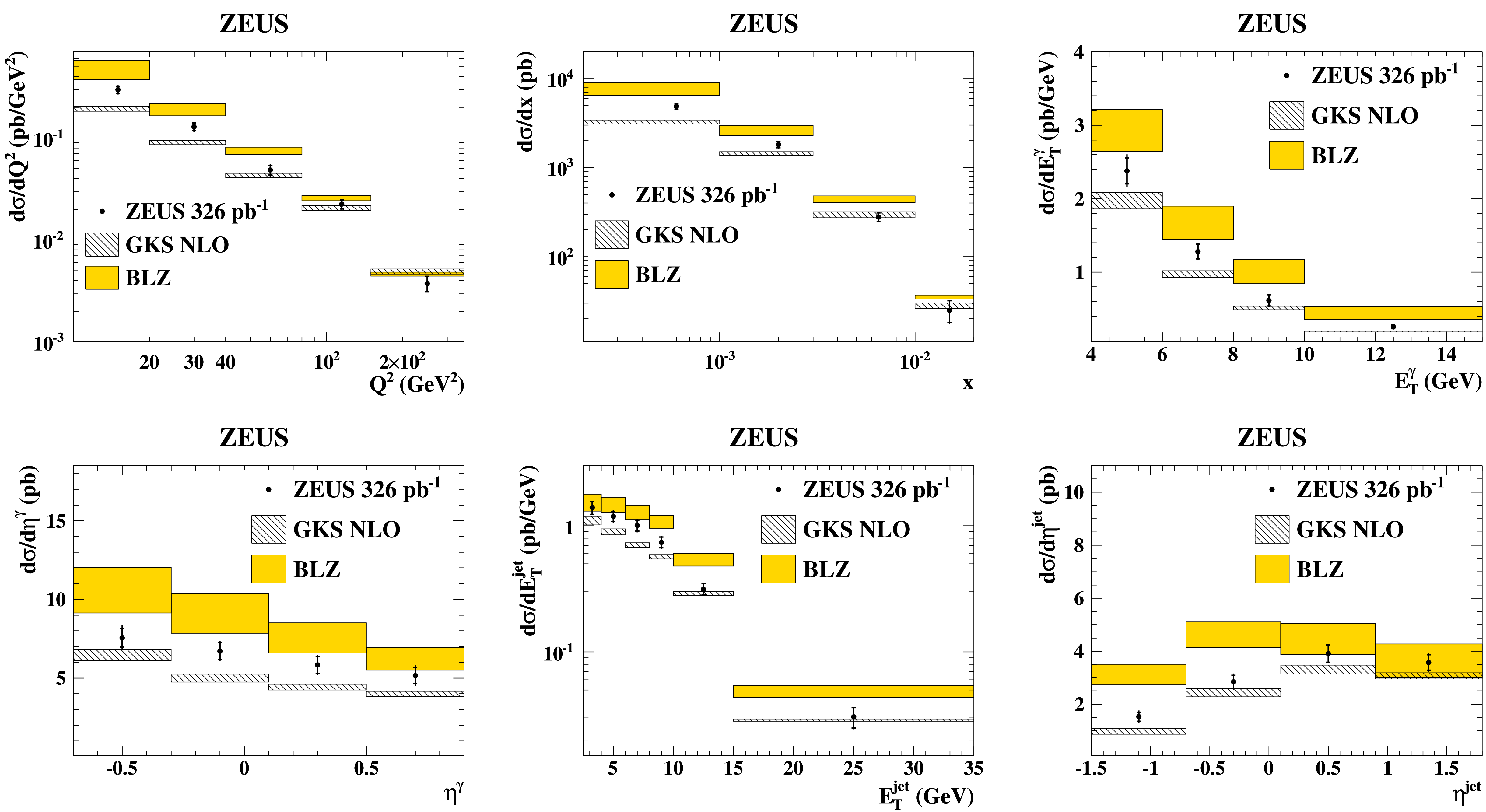

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Basic equations

- $e^{\pm}p$ cross-section and structure functions $Y_{\pm} = 1 \pm (1-y)^2$

$$\frac{\mathrm{d}^2\sigma(e^{\pm}p)}{\mathrm{d}x\,\mathrm{d}Q^2} = \frac{2\pi\alpha^2}{xQ^4}\left[Y_+ F_2(x,Q^2) \mp Y_- xF_3(x,Q^2) - y^2 F_L(x,Q^2)\right]$$

- (Unpolarised) reduced cross-sections often used:

$$\sigma_{\mathrm{r}}(\mathrm{or}\ \tilde{\sigma}) = \frac{\mathrm{d}^2\sigma}{\mathrm{d}x\,\mathrm{d}Q^2}\cdot\frac{xQ^4}{2\pi\alpha^2 Y_+} = F_2(x,Q^2) - \frac{y^2}{Y_+}F_L(x,Q^2)$$