Inclusive diffraction at future electron-ion colliders

Studies for LHeC, FCC-eh colliders with outlook for EIC

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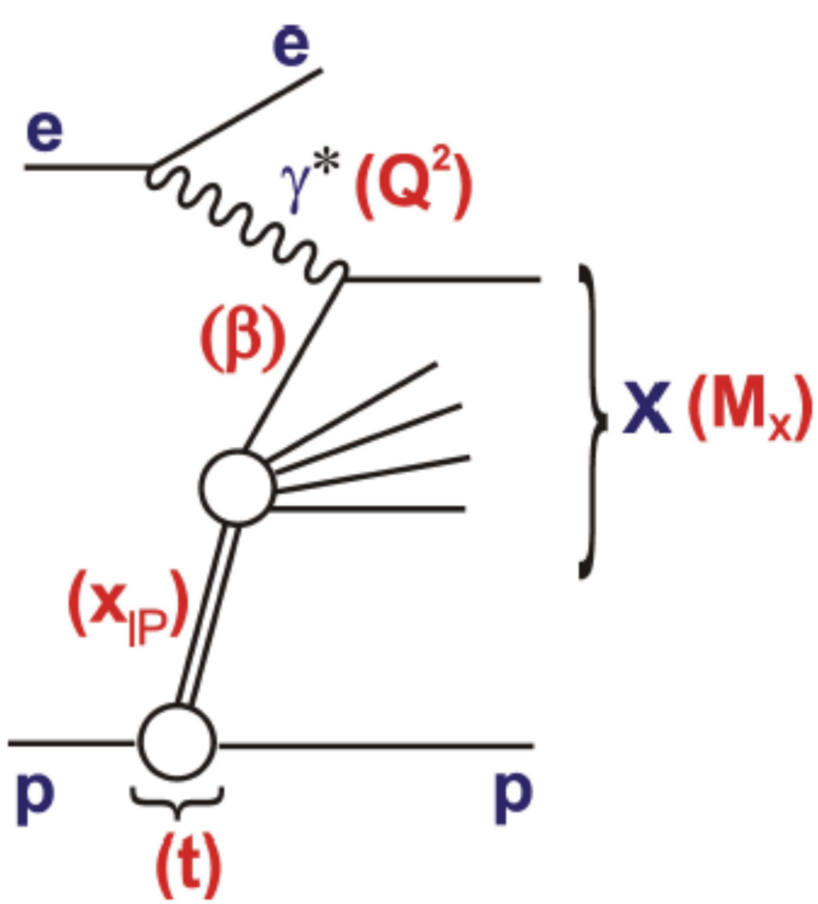
Outline

- Introduction: DIS at CERN and diffraction at HERA
- Phase space for inclusive diffraction at future electron-ion colliders.
- Reduced diffractive cross section - pseudodata simulation. This talk: case study for LHeC and FCC-eh, which could be extended to EIC
- Impact on diffractive parton distribution functions in ep (preliminary plots for EIC)
- Diffraction on nuclei (LHeC, FCC-eh, EIC)

Nestor Armesto, Paul Newman and Wojciech Słomiński, A.S.
PRD100 (2019) no.7, 074022, arXiv:1901.09076

Diffractive kinematics in DIS



$$x_{Bj} = x_{IP}\beta$$

Standard DIS variables:

electron-proton cms energy squared:

$$s = (k+p)^2$$

photon-proton cms energy squared:

$$W^2 = (q+p)^2$$

inelasticity

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

Bjorken x

$$x = \frac{-q^2}{2p \cdot q}$$

(minus) photon virtuality

$$Q^2 = -q^2$$

Diffractive DIS variables:

$$\xi \equiv x_{IP} = \frac{Q^2 + M_X^2 - t}{Q^2 + W^2}$$

momentum fraction of the Pomeron w.r.t hadron

$$\beta = \frac{Q^2}{Q^2 + M_X^2 - t}$$

momentum fraction of parton w.r.t Pomeron

$$t = (p - p')^2$$

4-momentum transfer squared

Two classes of diffractive events in DIS:

$Q^2 \sim 0$ photoproduction

$Q^2 \gg 0$ deep inelastic scattering

Diffractive structure functions

$$\boxed{\frac{d^3\sigma^D}{dx_{IP}\,dx\,dQ^2} = \frac{2\pi\alpha_{\rm em}^2}{xQ^4}\,Y_+\,\sigma_r^{D(3)}(x_{IP},x,Q^2)}$$

$$Y_+ = 1 + (1-y)^2$$

Reduced diffractive cross section depends on two structure functions

$$\boxed{\sigma_r^{D(3)} = F_2^{D(3)} - \frac{y^2}{Y_+} F_L^{D(3)}}$$

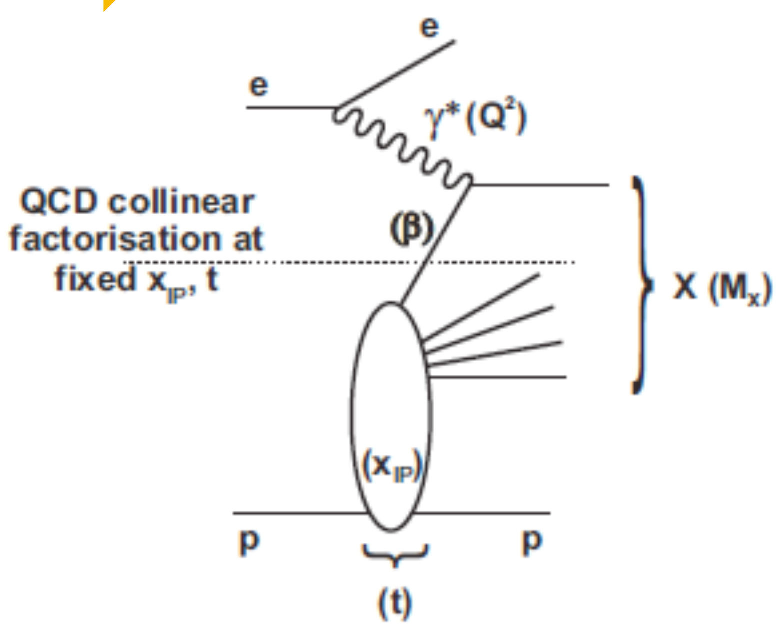
For y not to close to unity we have: $\sigma_r^{D(3)} \simeq F_2^{D(3)}$

Integrated vs unintegrated structure functions over t:

$$F_{T,L}^{D(3)}(x,Q^2,x_{IP}) = \int_{-\infty}^{0} dt F_{T,L}^{D(4)}(x,Q^2,x_{IP},t)$$

$$F_2^{D(4)} = F_T^{D(4)} + F_L^{D(4)}$$

Collinear factorization in diffraction



Collins

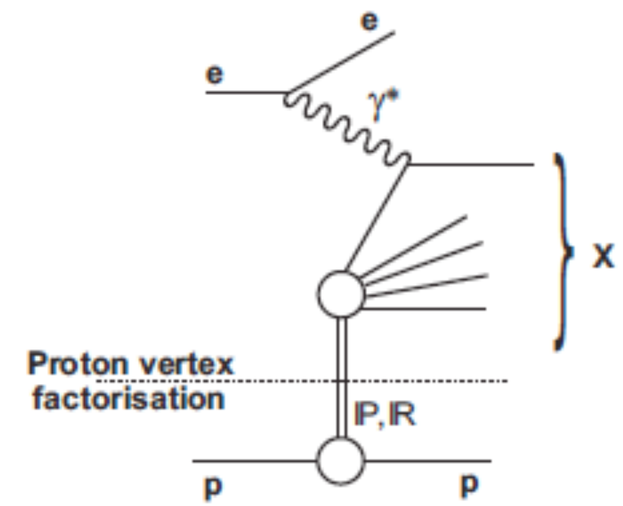
Collinear factorization in diffractive DIS

$$d\sigma^{ep\to eXY}(x,Q^2,x_{IP},t) = \sum_i f_i^D \otimes d\hat{\sigma}^{ei} + \mathcal{O}(\Lambda^2/Q^2)$$

- Diffractive cross section can be factorized into the convolution of the perturbatively calculable partonic cross sections and diffractive parton distributions (DPDFs).
- Partonic cross sections are the same as for the inclusive DIS.
- The DPDFs represent the probability distributions for partons i in the proton under the constraint that the proton is scattered into the system Y with a specified 4-momentum.
- Factorization should be valid for sufficiently(?) large Q^2 (and fixed t and x_{IP}).

DPDF parametrization

Regge factorization (additional assumption)



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

Pomeron flux is parametrized as

$$f_{IP/p}(x_{IP}, t) = A_{IP} \frac{e^{B_{IP} t}}{x^{2\alpha_{IP}(t)-1}}$$

$$\alpha_{IP}(t) = \alpha_{IP}(0) + \alpha'_{IP} t$$

parton distributions in the Pomeron

$$f_k(z) = A_k z^{B_k} (1-z)^{C_k}$$

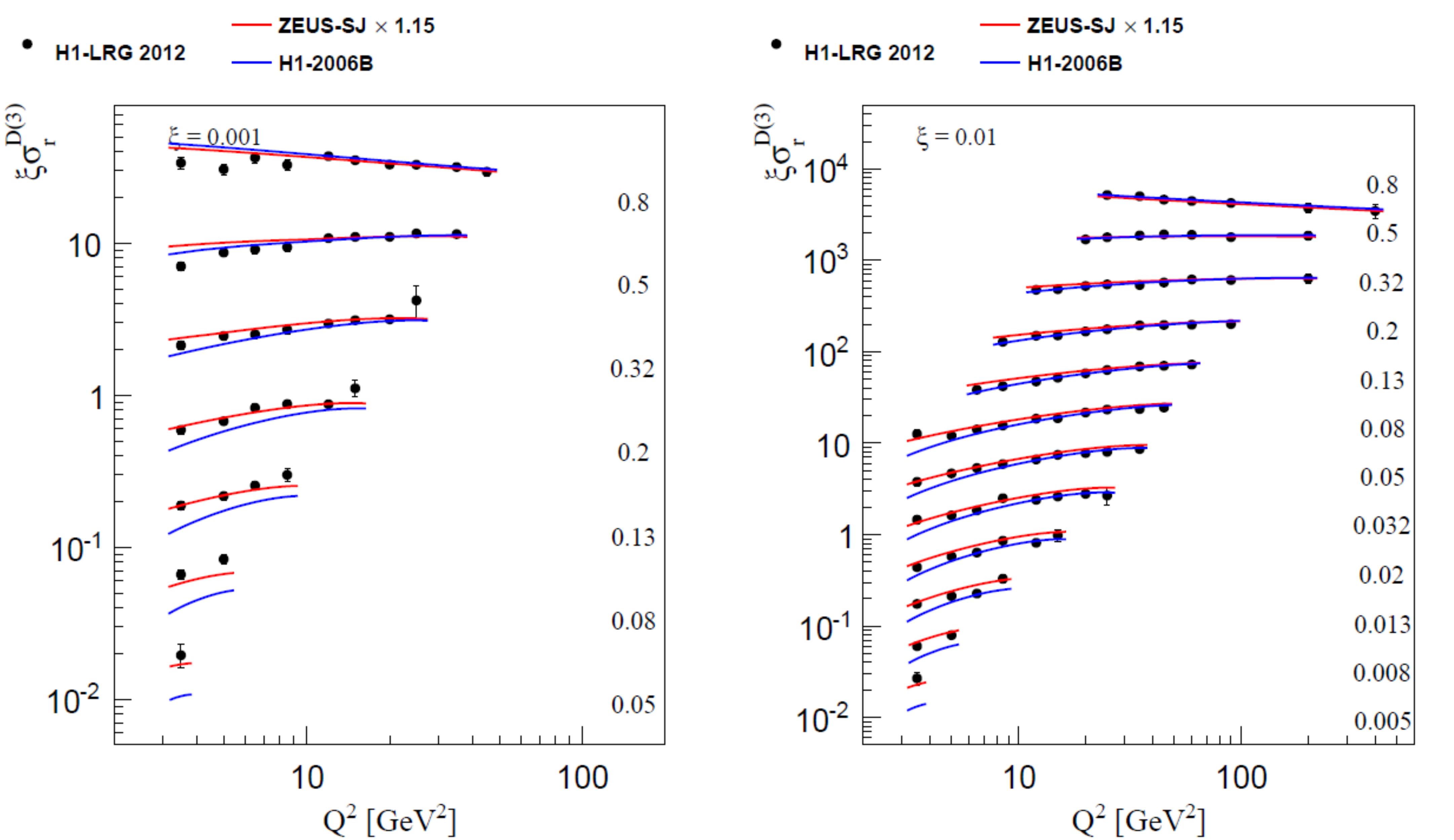
where k=g,d. Light quarks equal u=d=s.

For good description of the data usually subleading Reggeons are included

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

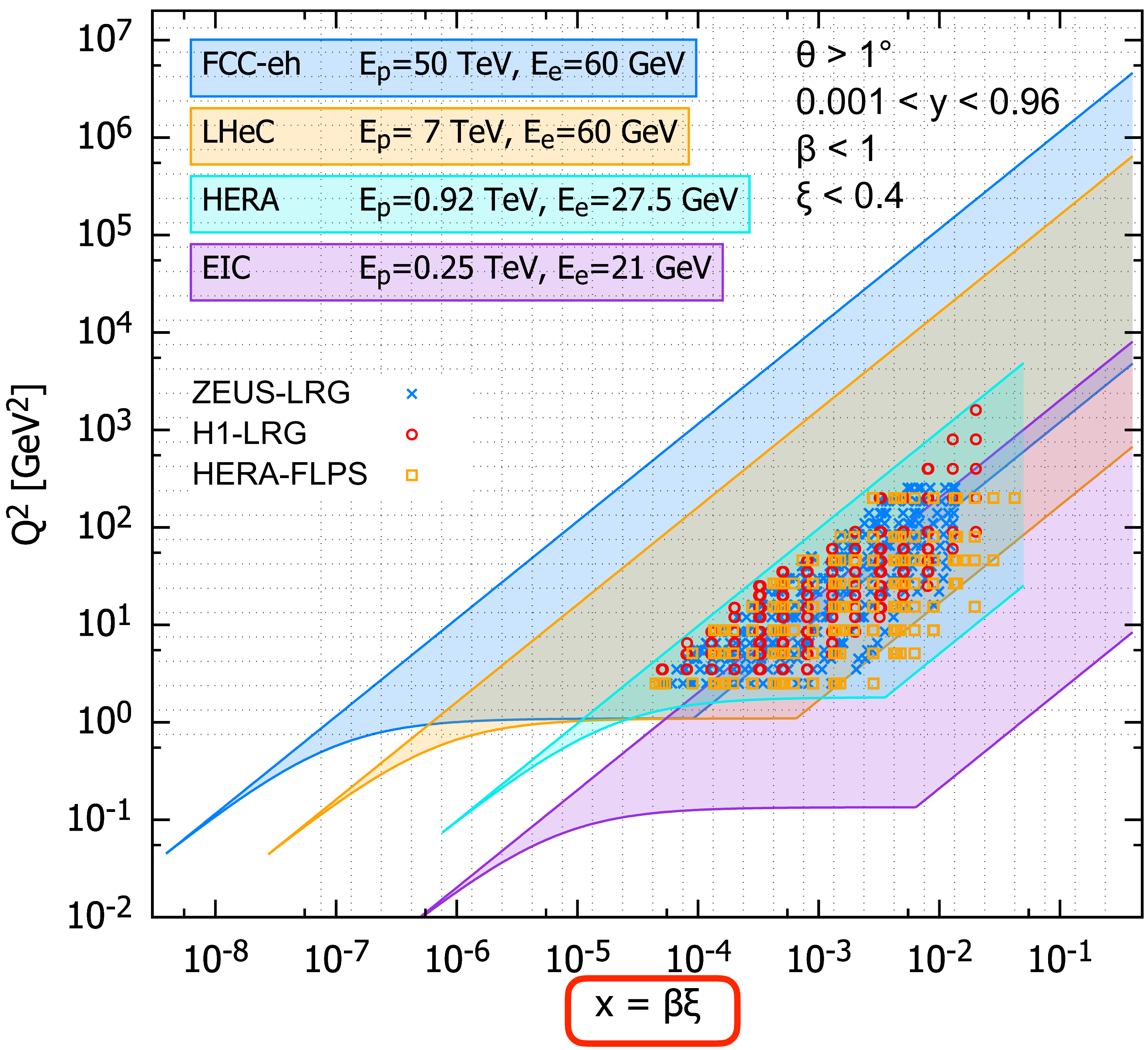
Diffractive fits

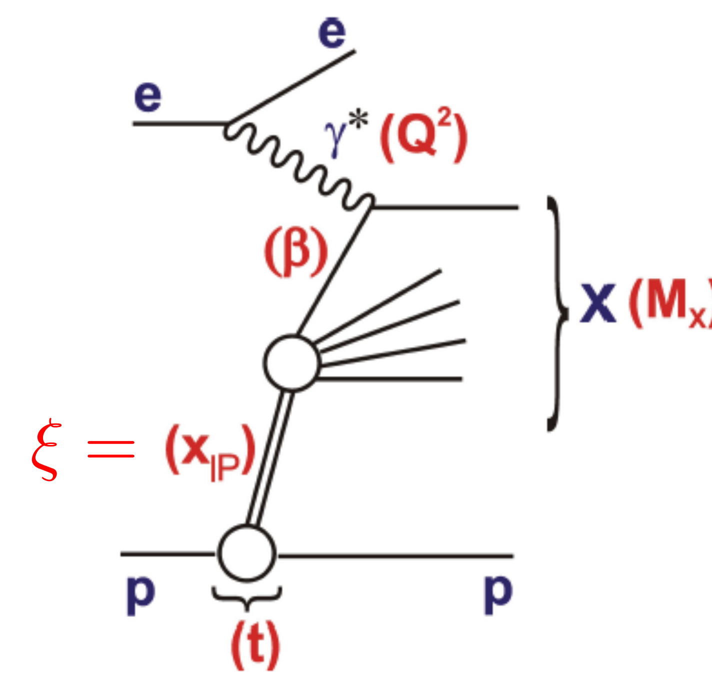
$\xi = x_{IP}$ Example of the DGLAP fit to the diffractive data



Comparison of H1-2006B and ZEUS-SJ fits to the H1-LRG 2012 data
ZEUS-SJ fit seems to better describe the data in the low β region

Phase space: LHeC, FCC-eh,EIC



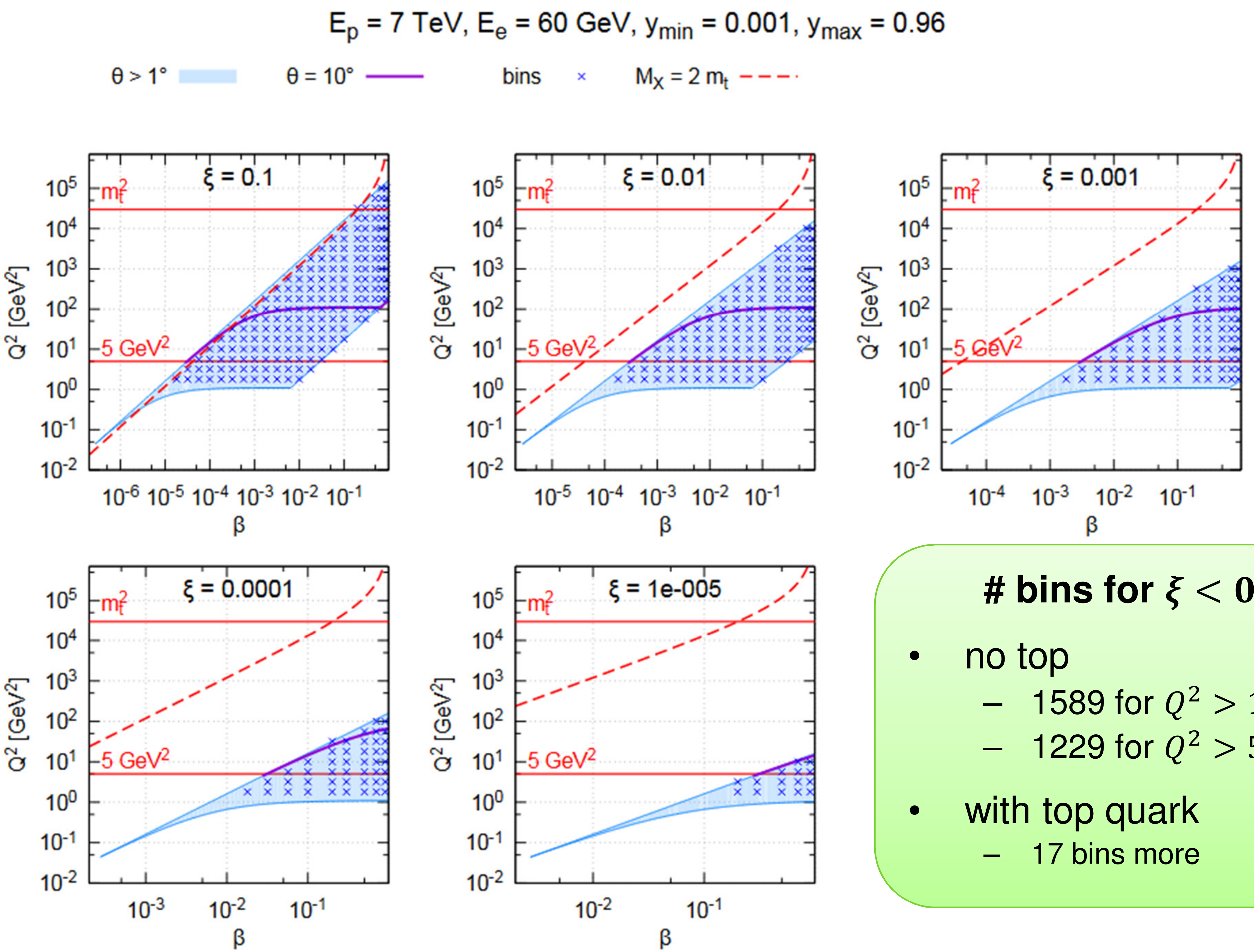


$E_e = 60\ GeV$

- $E_p = 7\ \mathrm{TeV}$ vs. HERA
  - $x_{\min}$ down by factor ~20
  - $Q^2_{\max}$ up by factor ~100
- $E_p = 50\ \mathrm{TeV}$ vs. $7\ \mathrm{TeV}$
  - $x_{\min}$ down by factor ~10
  - $Q^2_{\max}$ up by factor ~10

For the EIC: better than HERA coverage of the large x region

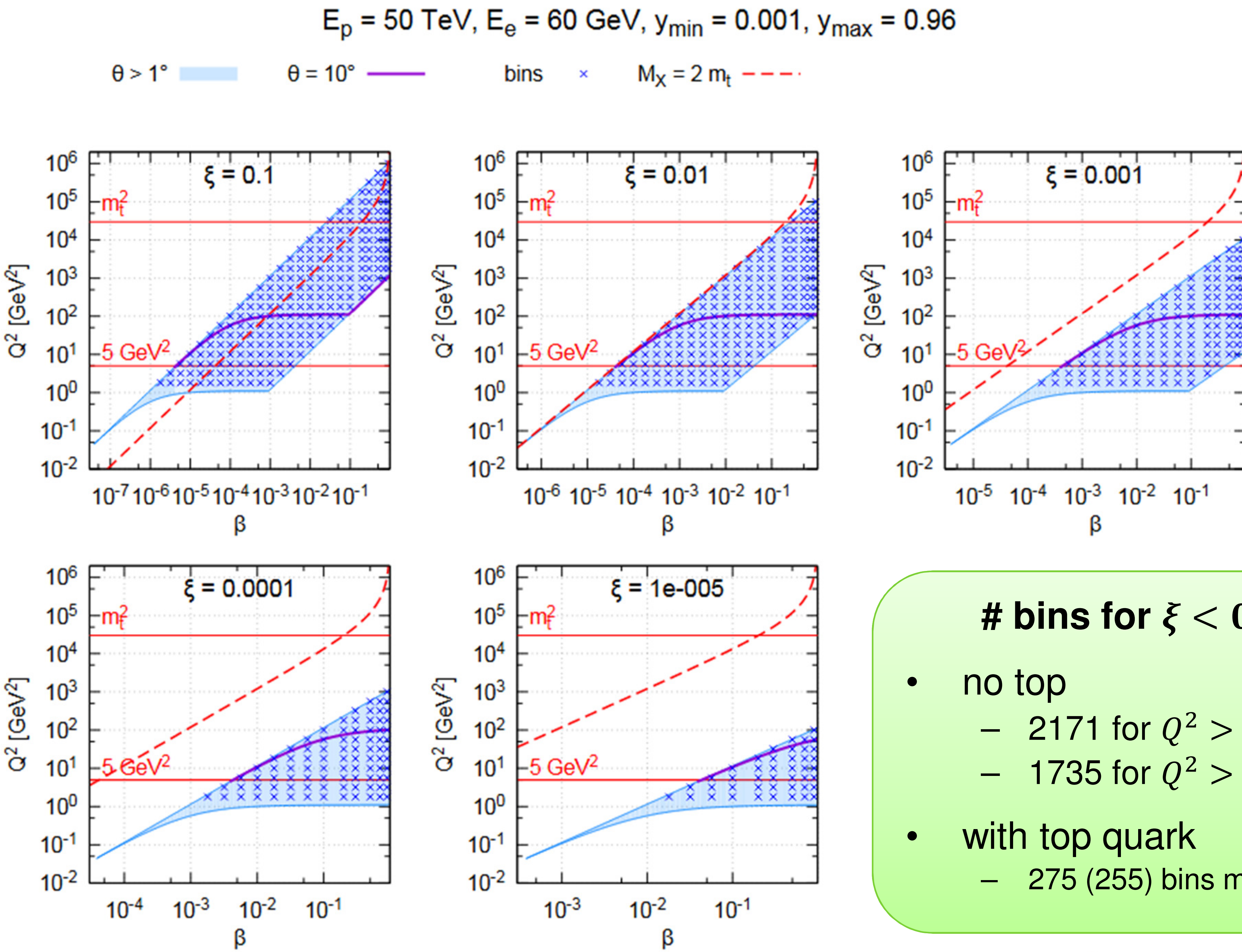
LHeC phase space: (β,Q²) fixed ξ



 # bins for $\xi < 0.15$

- no top
  - 1589 for $Q^2 > 1.3\ \mathrm{GeV}^2$
  - 1229 for $Q^2 > 5\ \mathrm{GeV}^2$
- with top quark
  - 17 bins more

FCC-eh phase space: (β,Q²) fixed ξ



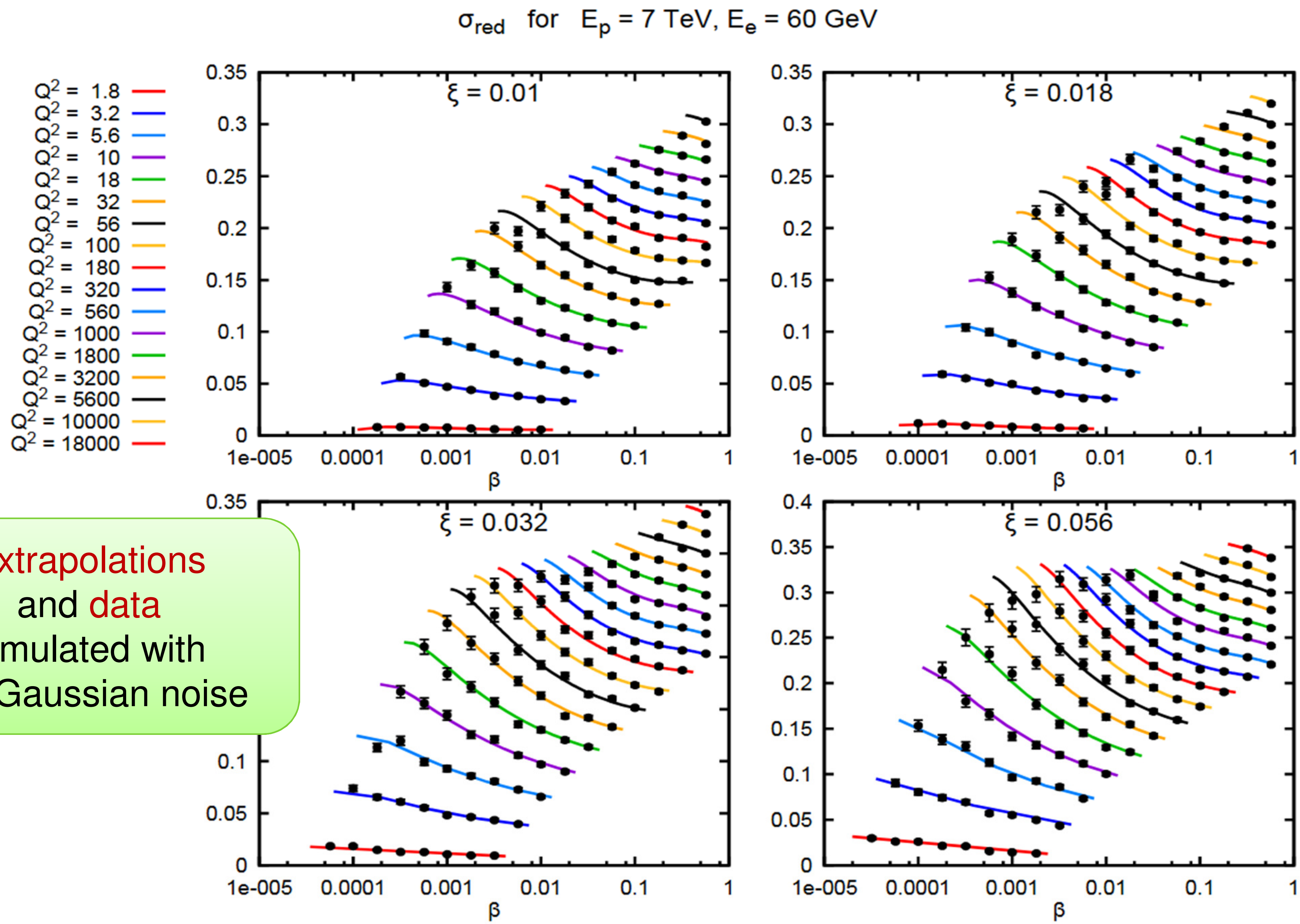
 # bins for $\xi < 0.15$

- no top
  - 2171 for $Q^2 > 1.3\ \mathrm{GeV}^2$
  - 1735 for $Q^2 > 5\ \mathrm{GeV}^2$
- with top quark
  - 275 (255) bins more

Data simulations

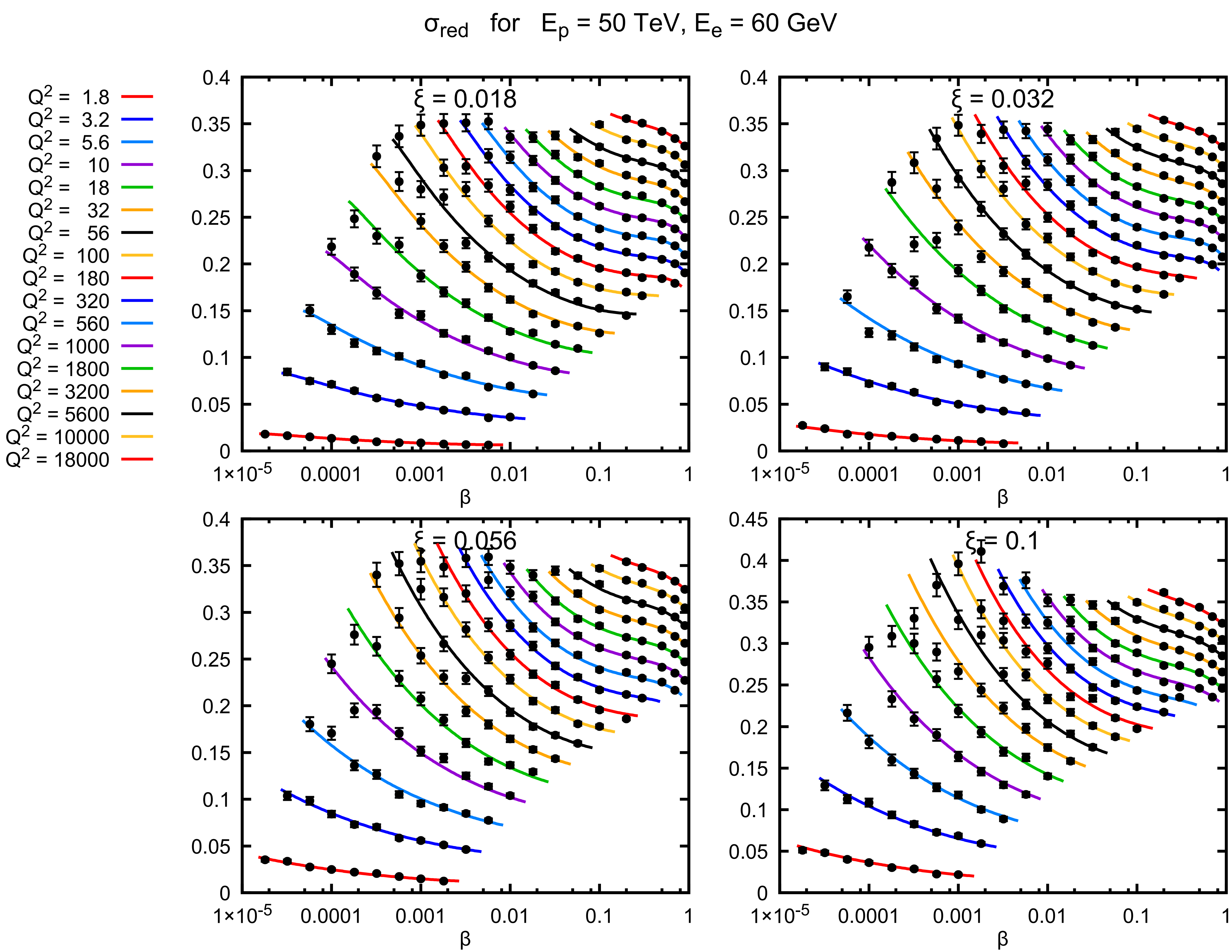
- Simulations based on extrapolation from ZEUS-SJ DPDFs
- VFNS scheme but no top at HERA so top contribution neglected in the simulation
- Errors simulated with 5% Gaussian noise
- Reggeon contribution is included but hard to constrain at HERA, could lead to large uncertainty in the extrapolation at $\xi>0.01$
- Binning to assume negligible statistical errors

Pseudodata: large ξ, LHeC



Extrapolations
and data
simulated with
5% Gaussian noise

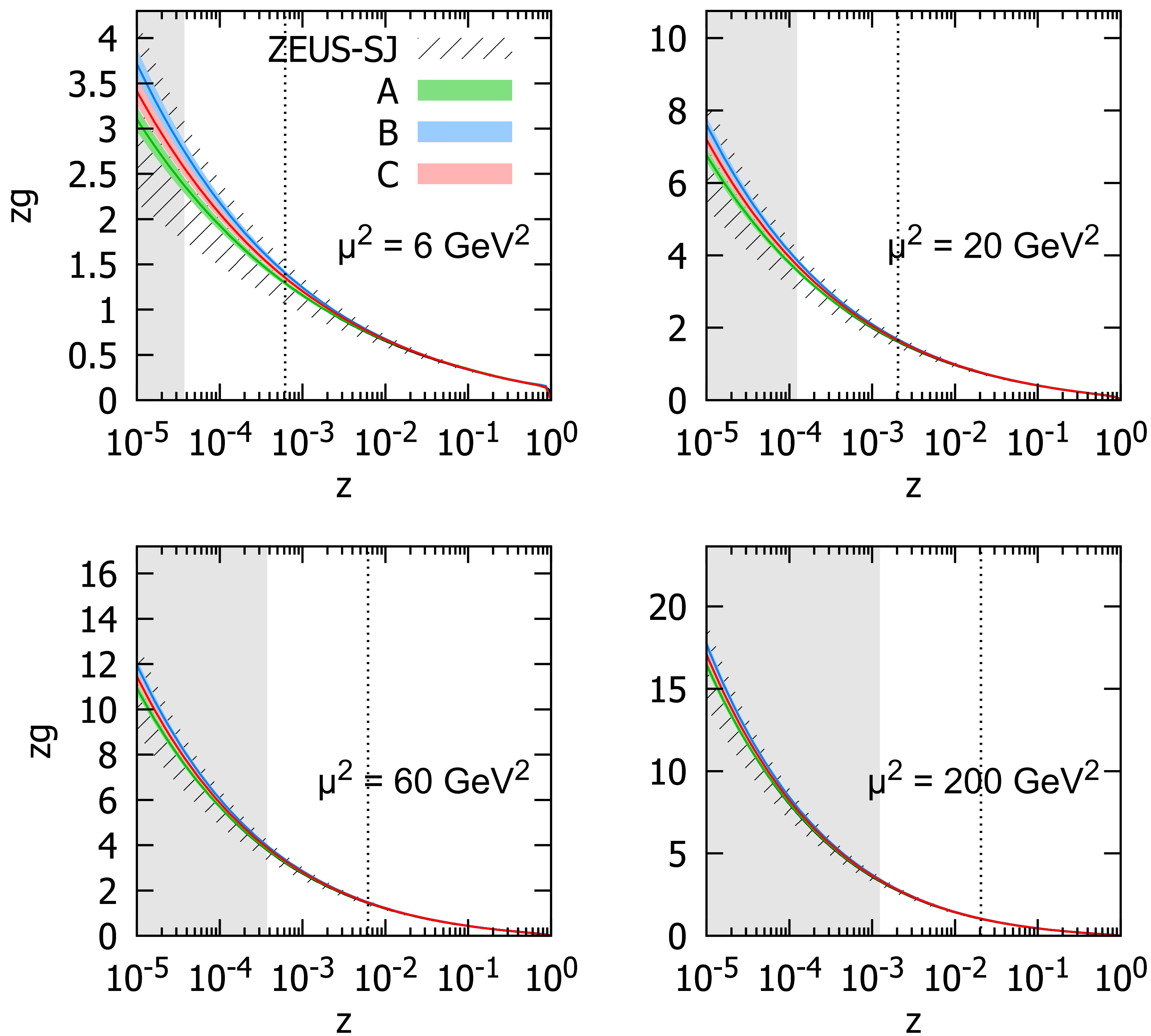
Pseudodata: large ξ, FCC-eh



DPDFs from simulations: LHeC

Gluon

Gluon DPDFs from the 5% simulations
E_p = 7 TeV, Q^2 > 4.2 GeV^2, 1229 data points.



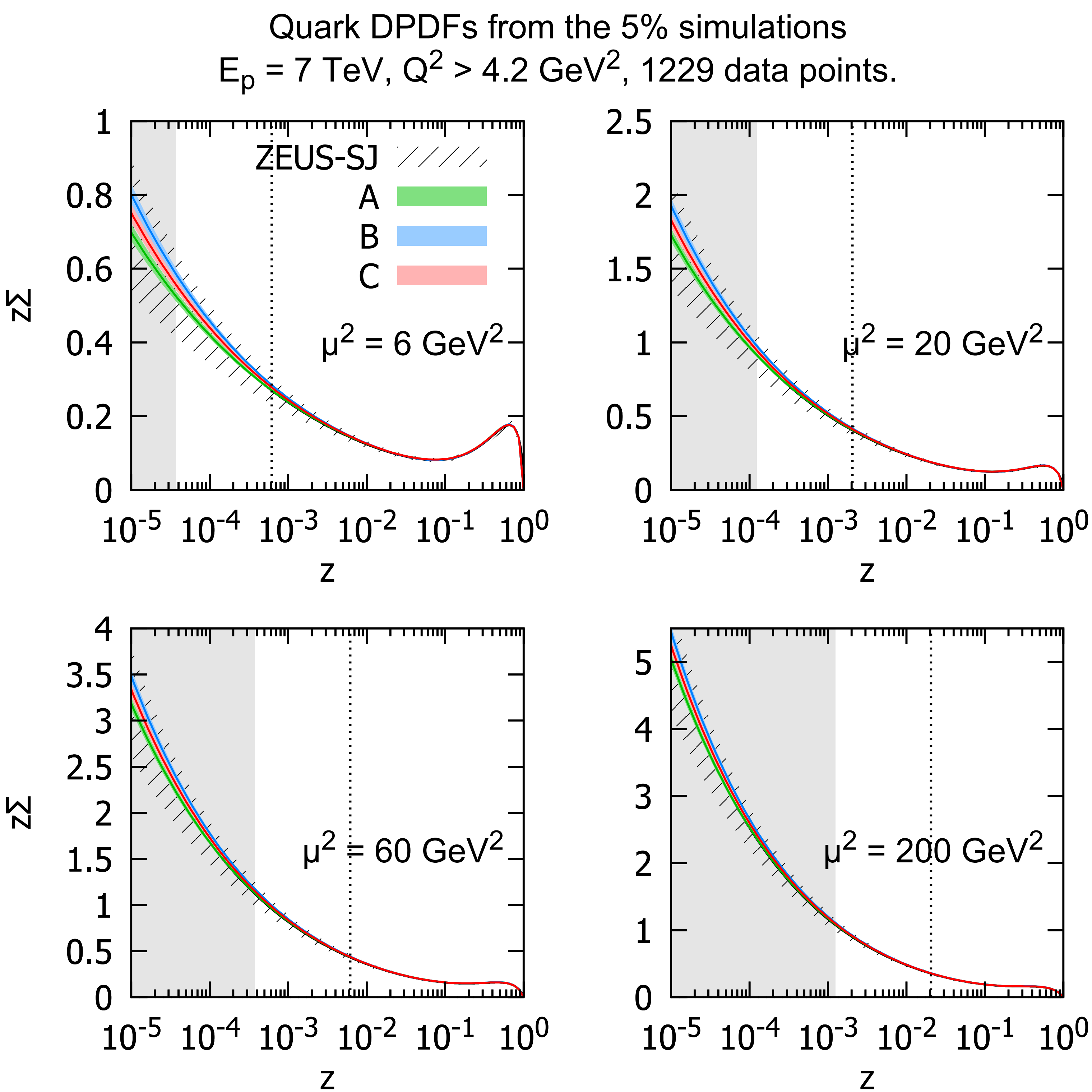
$Q^2_{\mathrm{min}} \approx 5\ \mathrm{GeV}^2$

$E_p = 7\ \mathrm{TeV}$

- Substantially improved accuracy wrt. HERA
- Statistical spread ~ 2 × error-band

DPDFs from simulations: LHeC

Quark



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- Substantially improved accuracy wrt. HERA
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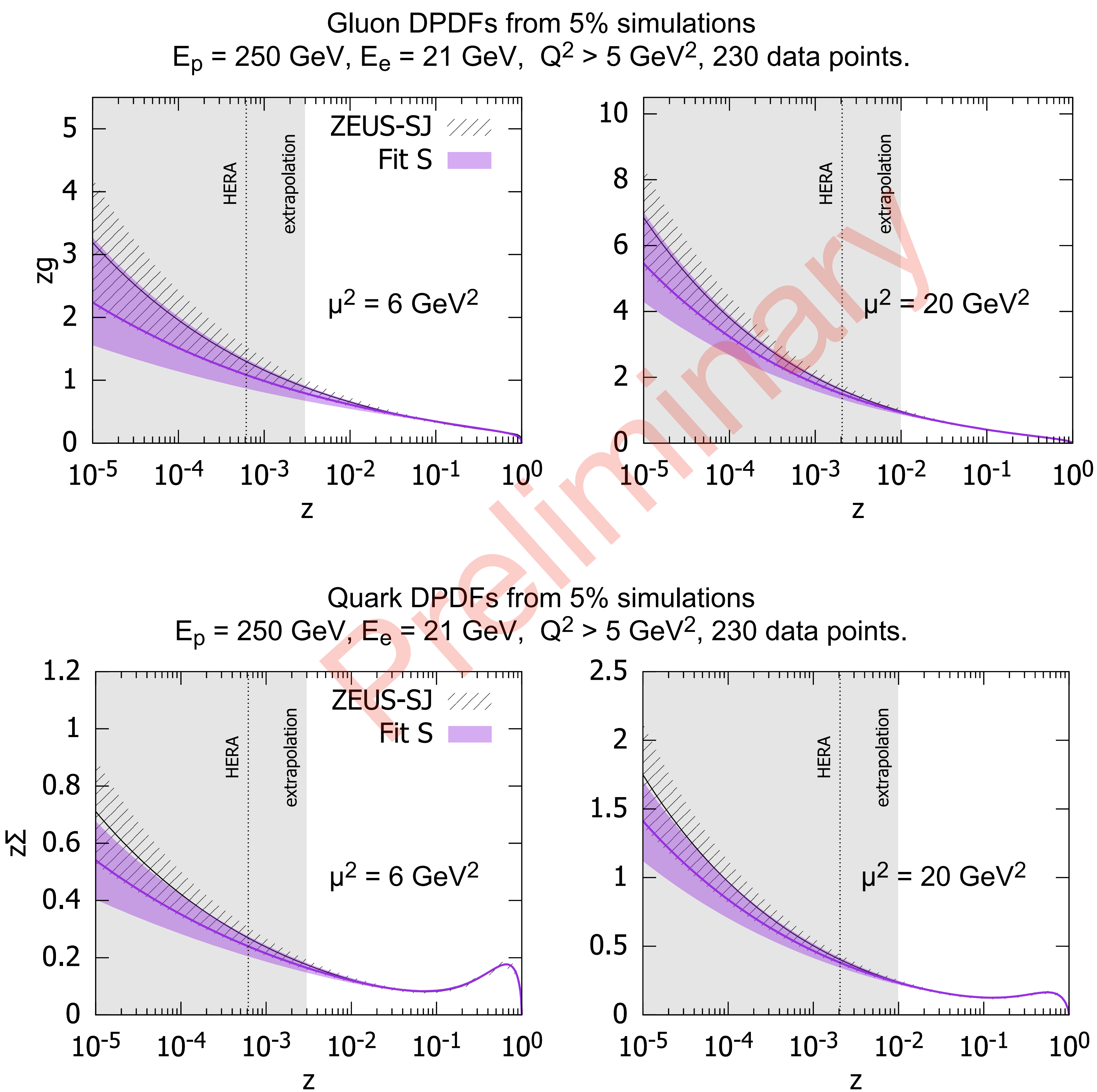
DPDFs from simulations: EIC



Simulated data points: 568

$$y_{\max} = 0.96,\ Q^2_{\min} = 2\,\mathrm{GeV}^2$$

Data in fit after cuts: 230

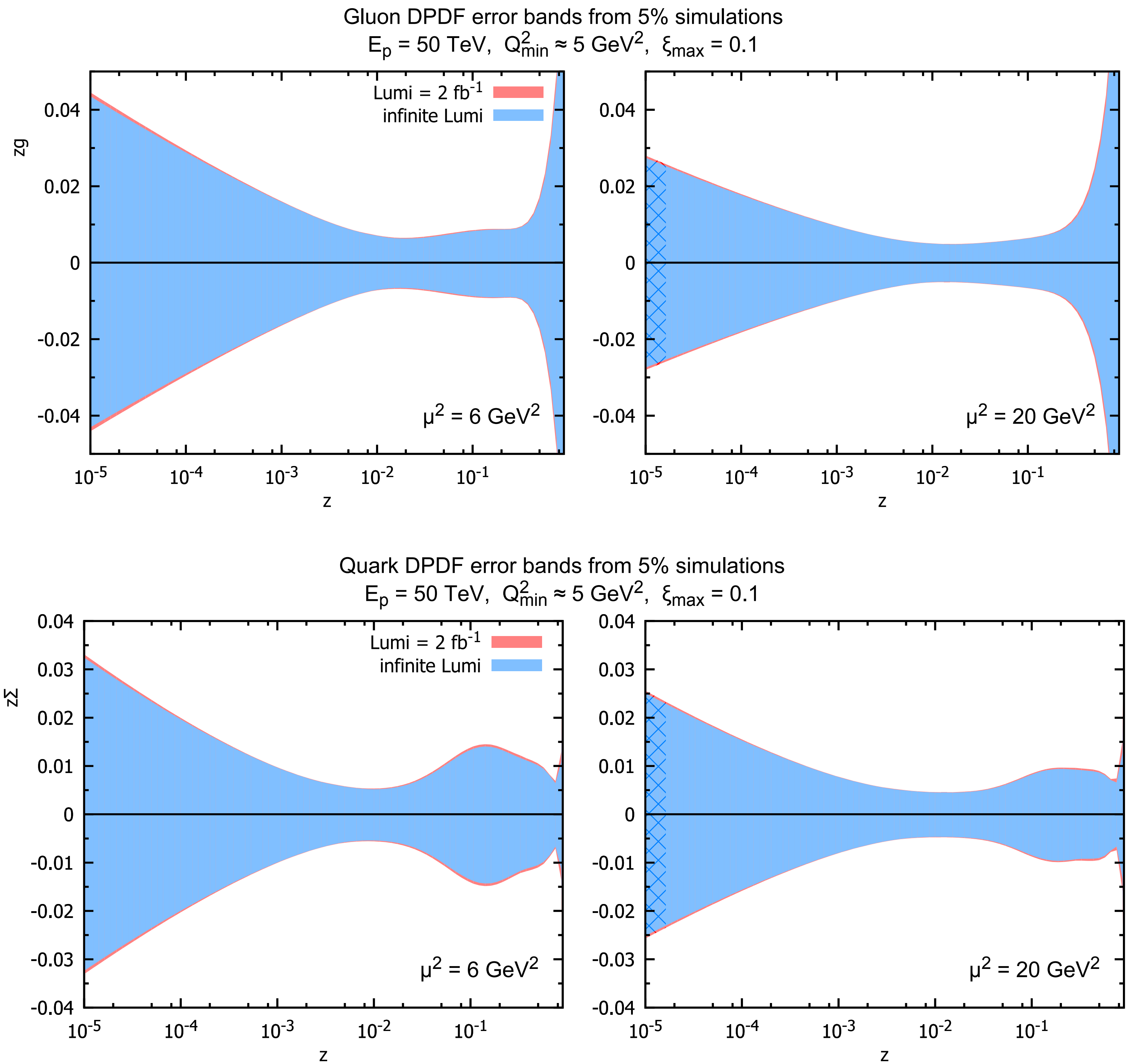
$$Q^2 > 5\ \mathrm{GeV}^2, \xi < 0.1$$

Small z gluon and quark cannot be constrain better than at HERA.

EIC offers access to large z may be better constrained than at HERA (which was unconstrained)

Possibility of measurement of Reggeon contribution

Luminosity study: FCC-eh case

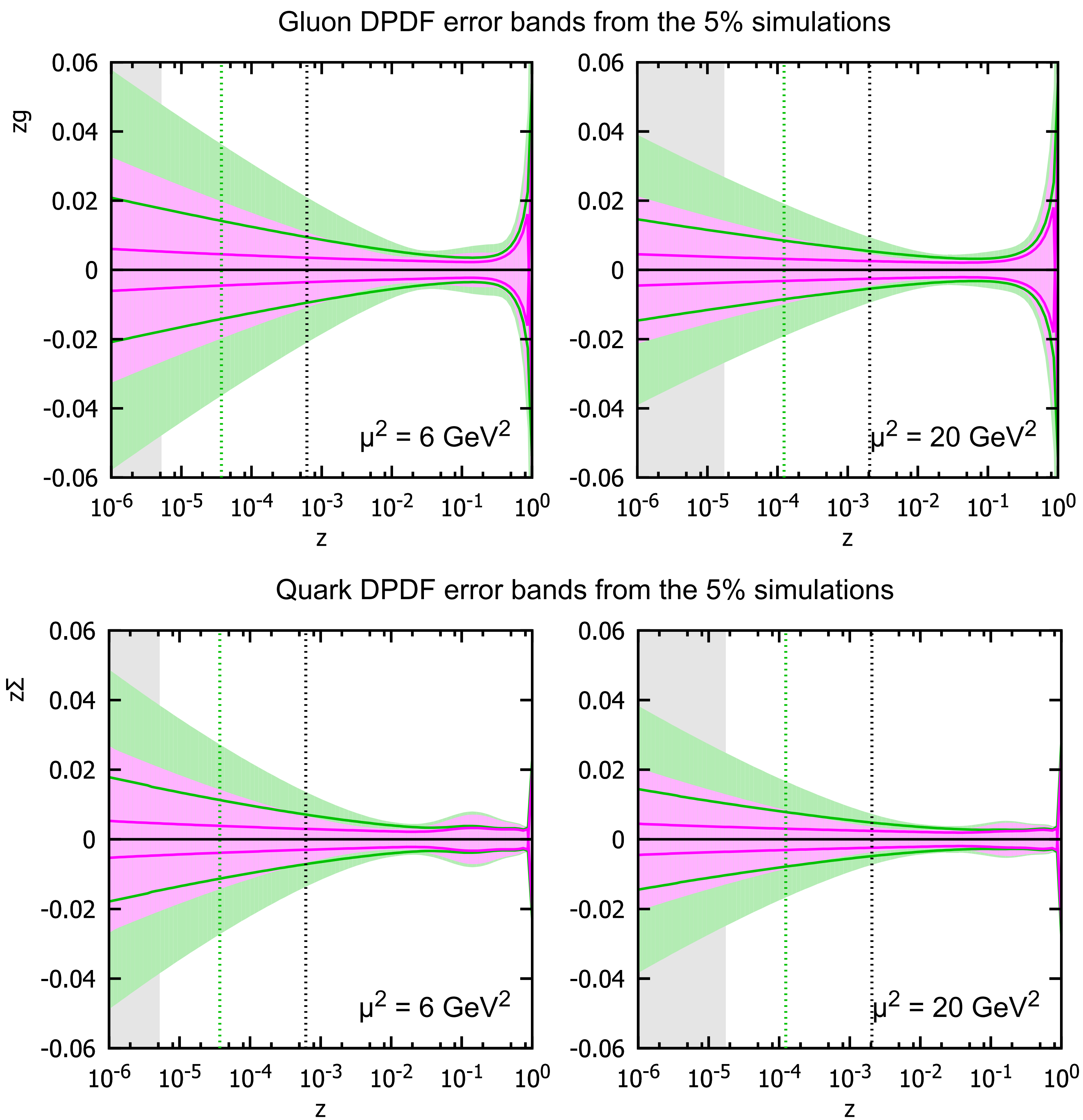


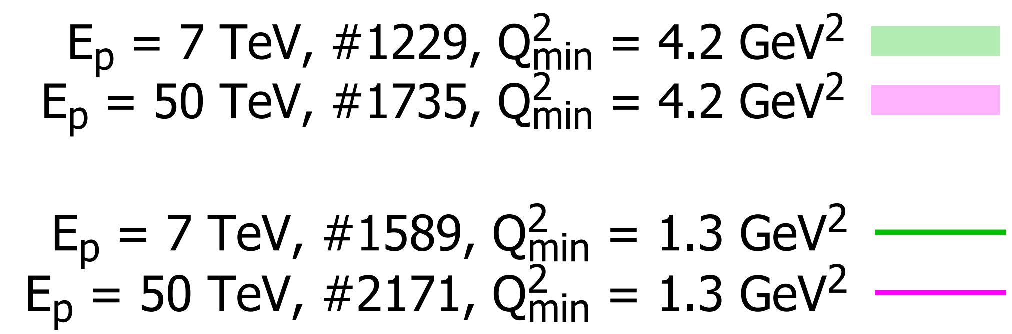
$$E_e = 60 \text{ GeV}$$
$$E_p = 50 \text{ TeV}$$
$$Q^2_{\text{min}} \simeq 5 \text{ GeV}^2$$

Comparison of ‘infinite’ Lumi simulation and Lumi=2 fb^{-1}

For this measurement there is negligible difference

Dependence on Q_{min}^2 and E_p

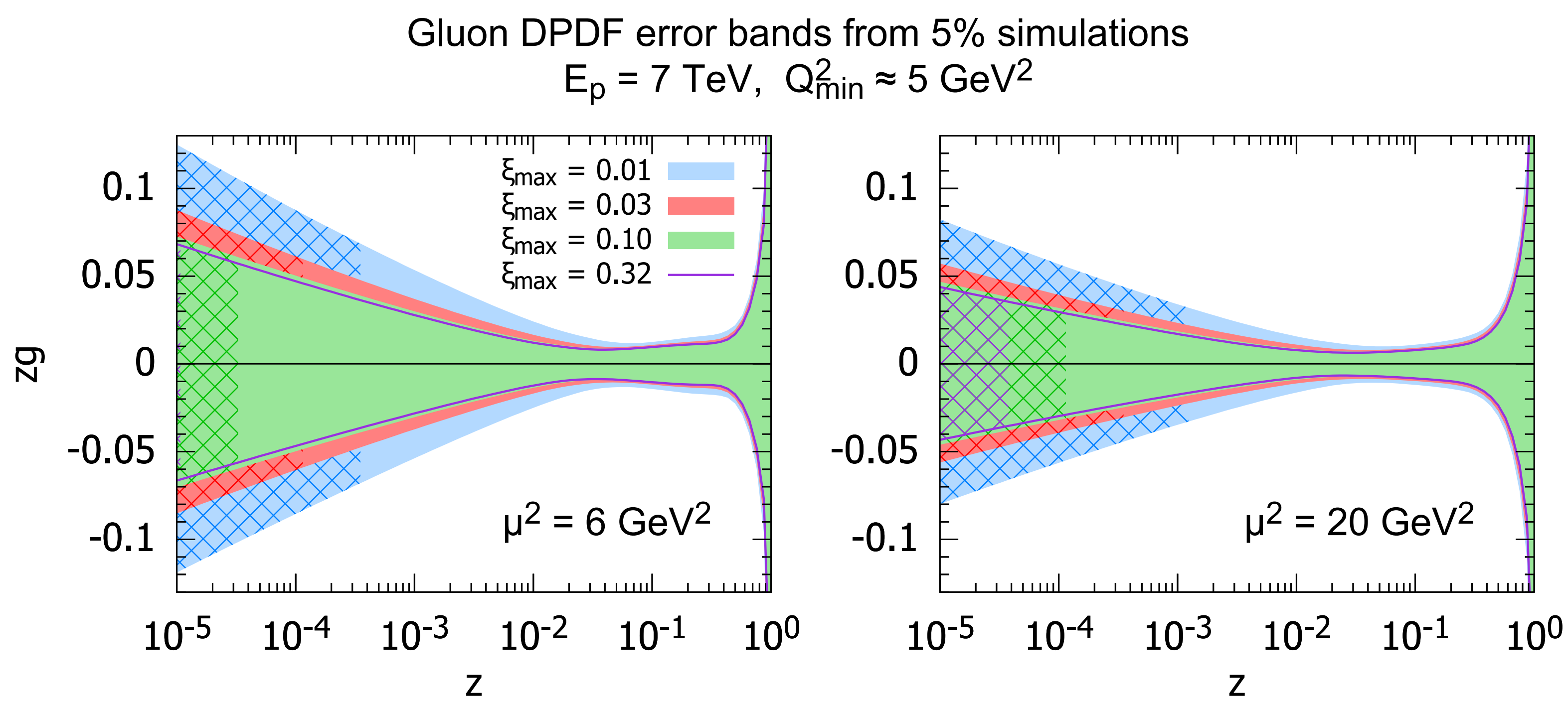




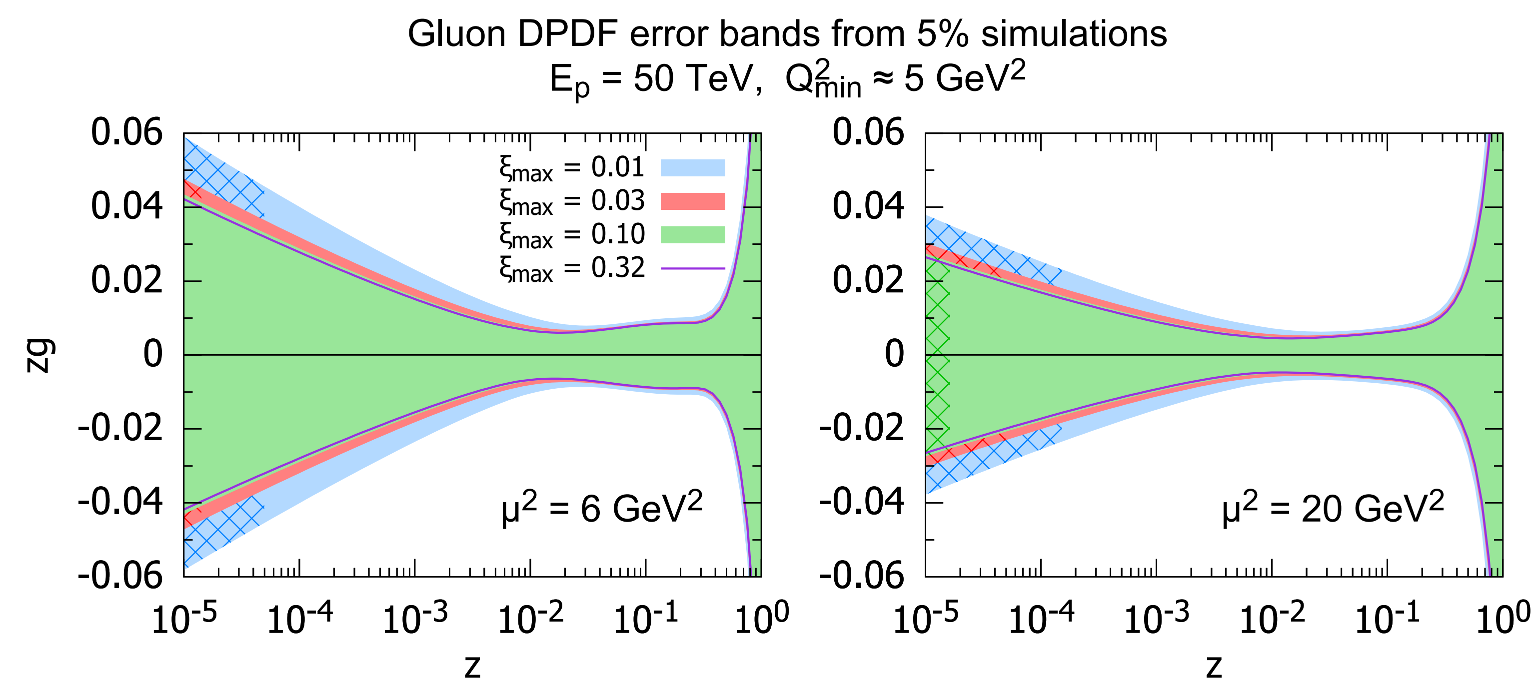
Improvement of accuracy of factor about 3 ÷ 5 for low Q_{min}^2

Low Q^2 region sensitive to higher twists, saturation etc especially in diffraction. DGLAP fits may not work/ be reliable in this region.

Dependence on maximal ξ



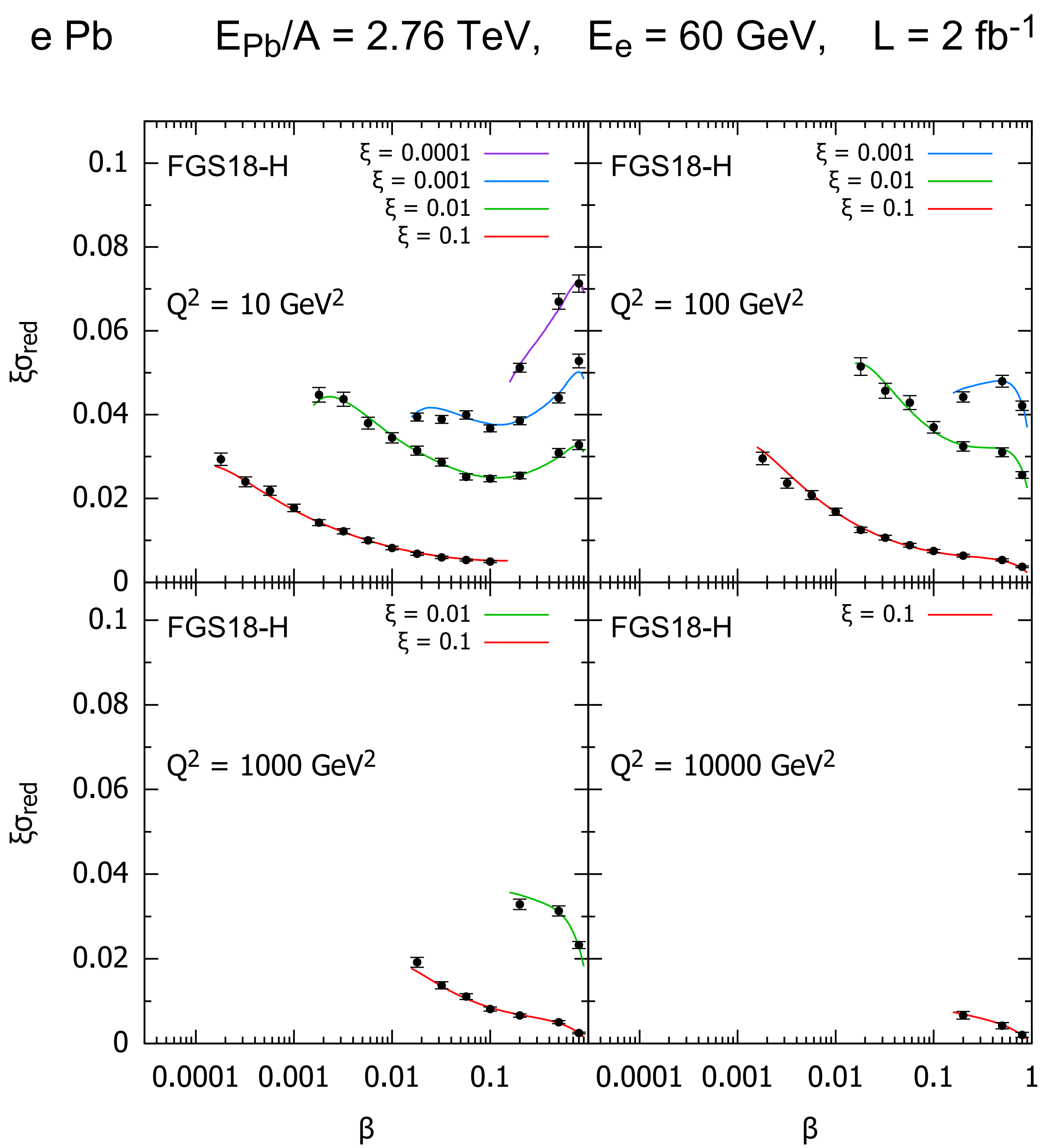
Large ξ region is challenging experimentally.

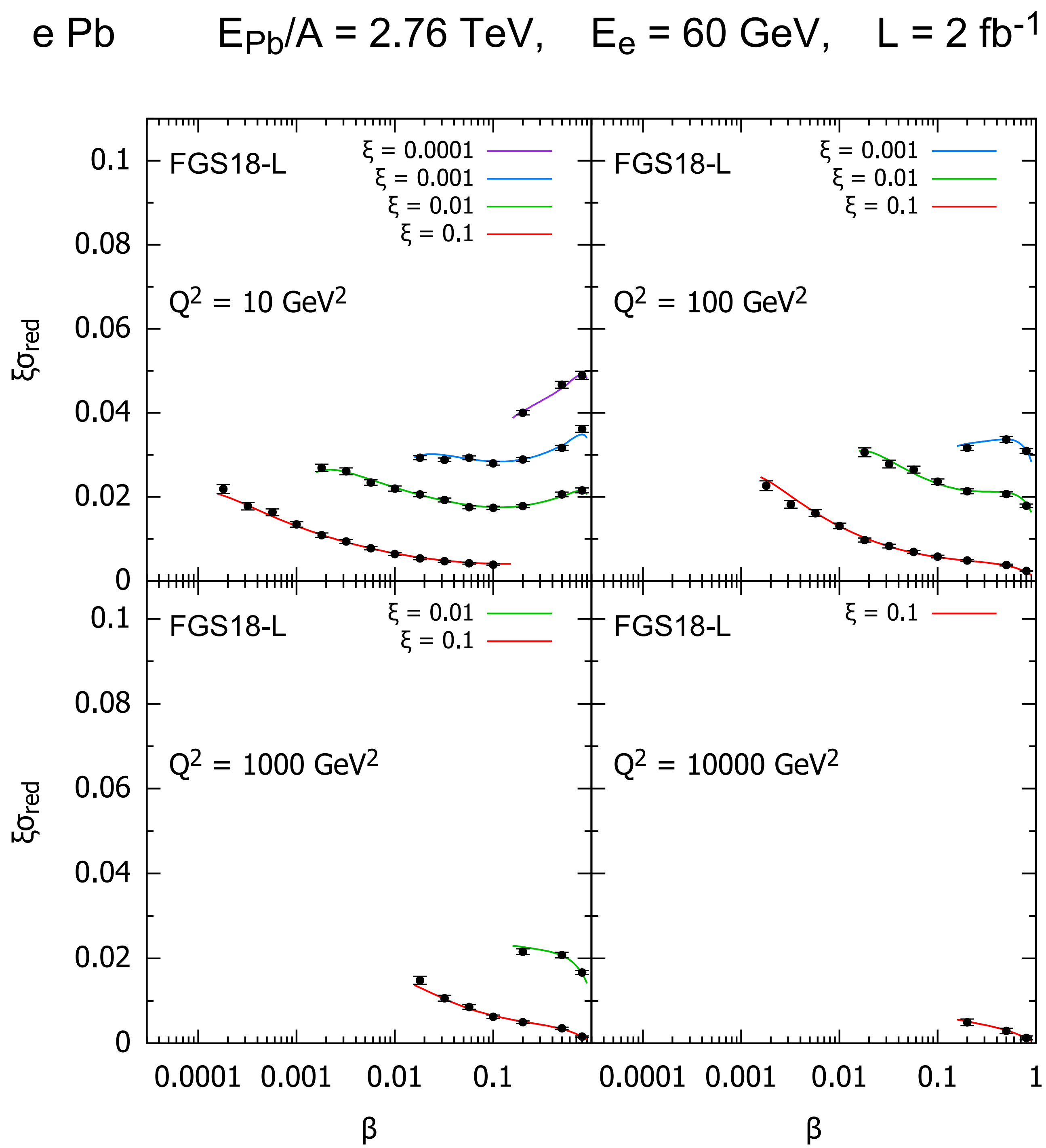


Modest sensitivity to the variation of the maximal cutoff on ξ.

Nuclear cross sections: LHeC

Reduced cross section





Nuclear cross sections: EIC

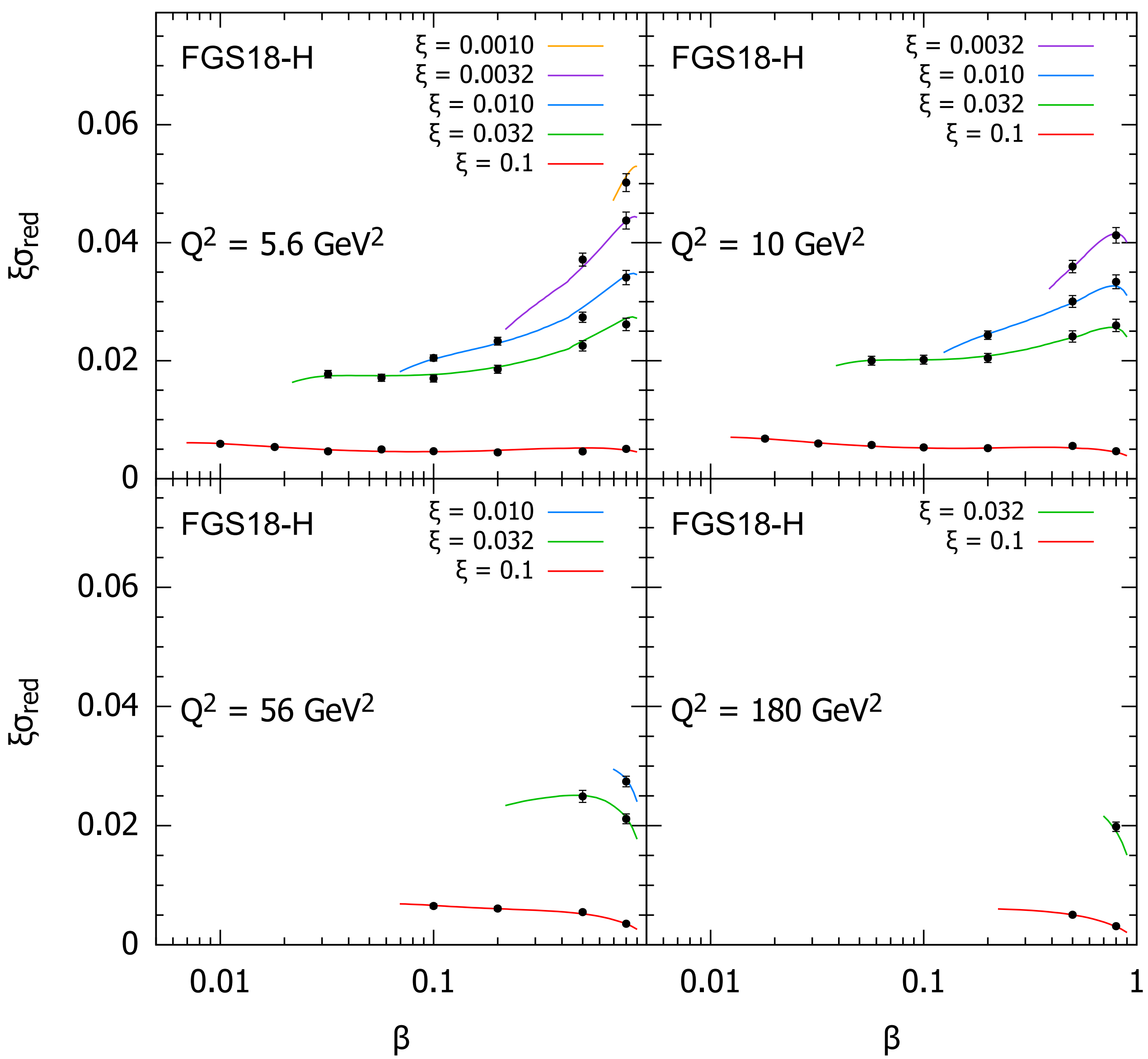
Frankfurt, Guzey, Strikman model: high and low shadowing model predictions

Pseudodata simulated under the same assumptions: 5% systematics, luminosity 2 fb^{-1}

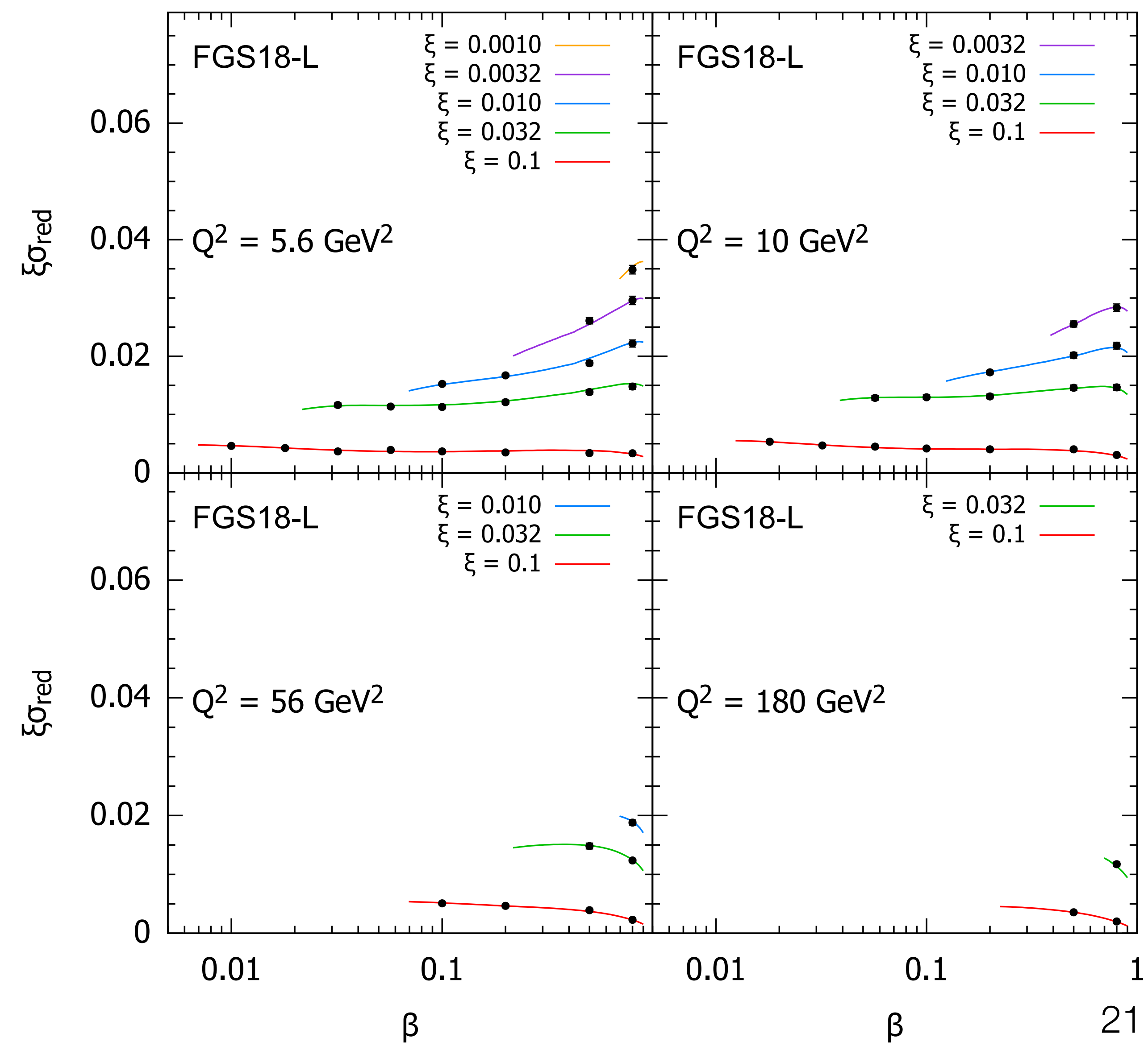
Illustration of the possible reach in (Q^2,β,ξ) kinematics

Reduced cross section

e-Au E_{Au}/A = 100 GeV, E_e = 21 GeV, L = 2 fb^{-1}



e-Au E_{Au}/A = 100 GeV, E_e = 21 GeV, L = 2 fb^{-1}



Summary

- Case study performed for LHeC and FCC-eh kinematics. Working on the extension for the EIC kinematics

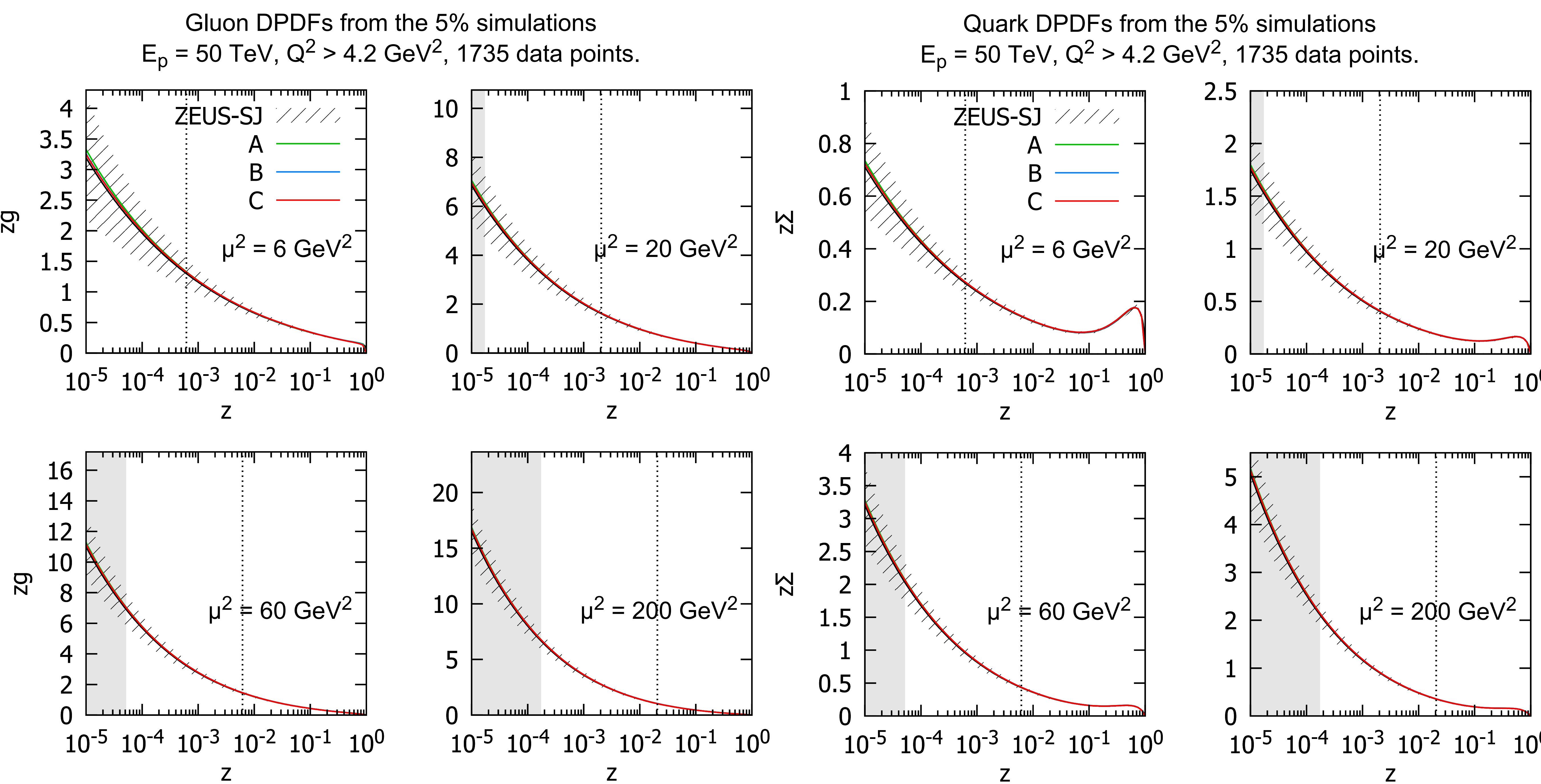
- Preliminary study of quark and gluon diffractive parton distribution extraction using EIC pseudodata. Focus on the large z gluon: possibility of constraining (unlike HERA), disentangling Pomeron/Reggeon ?

- Lowering initial Q^2 increases the accuracy. This is the region that is expected to be very sensitive to higher twists in diffraction. Further analysis with better modeling of this region is necessary to estimate the impact of such correction.

- Pseudodata for e-Pb at EIC. Nuclear diffraction measurement would be first of that kind at EIC.

- Prospect for extraction of nuclear PDFs at EIC: similar precision to that in ep

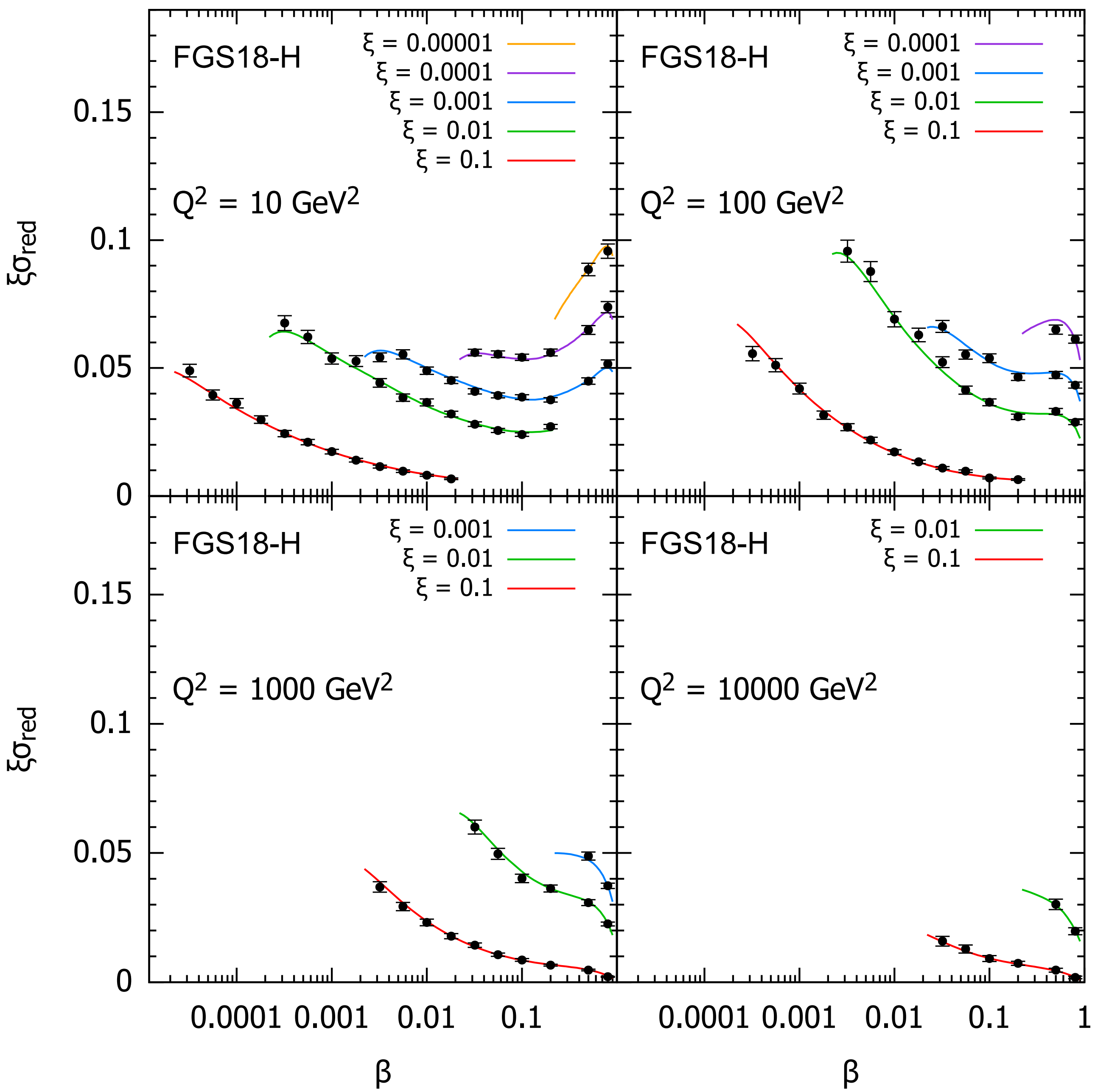
DPDFs from simulations: FCC-eh



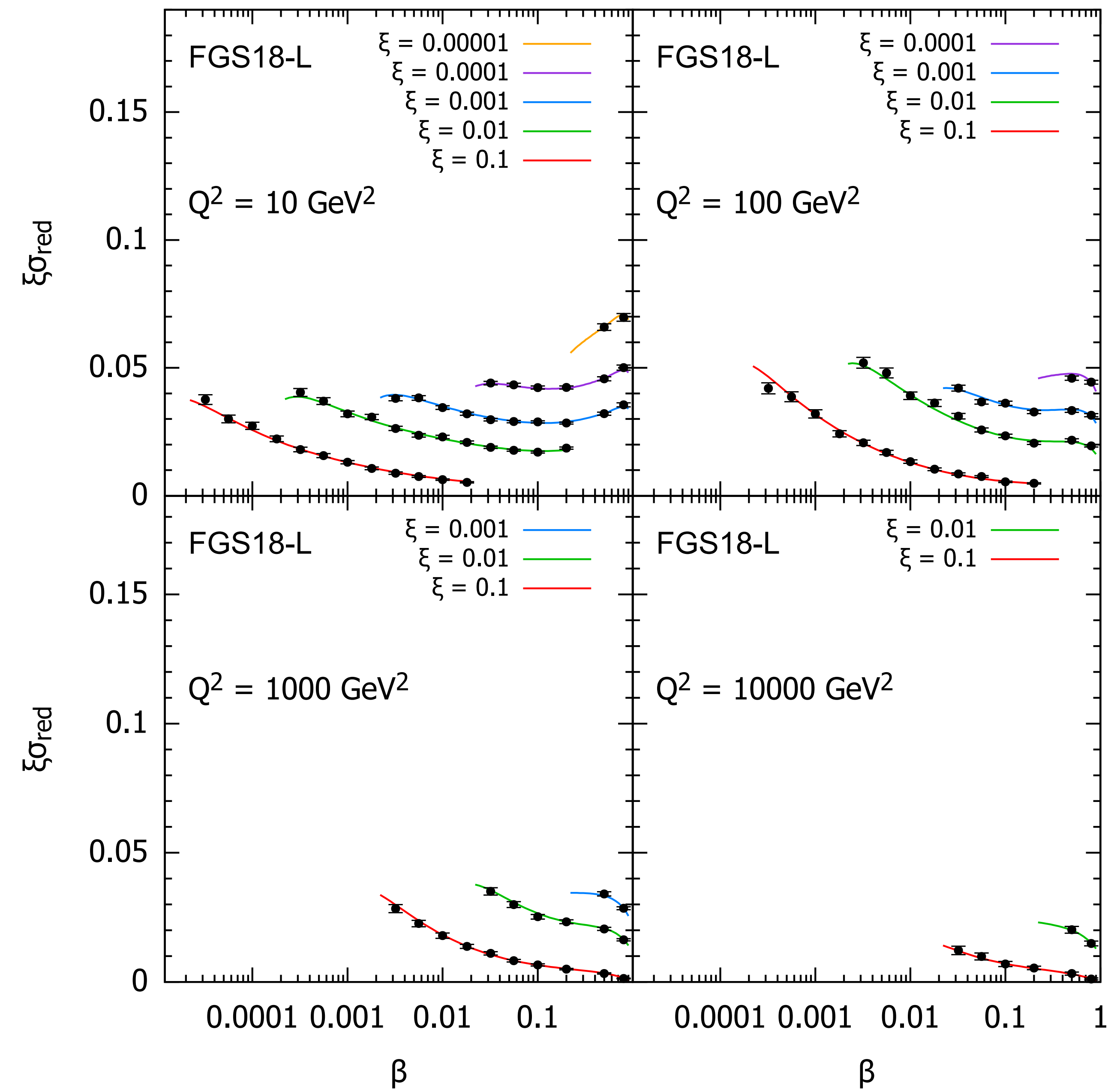
Nuclear cross sections: FCC-eh

Reduced cross section

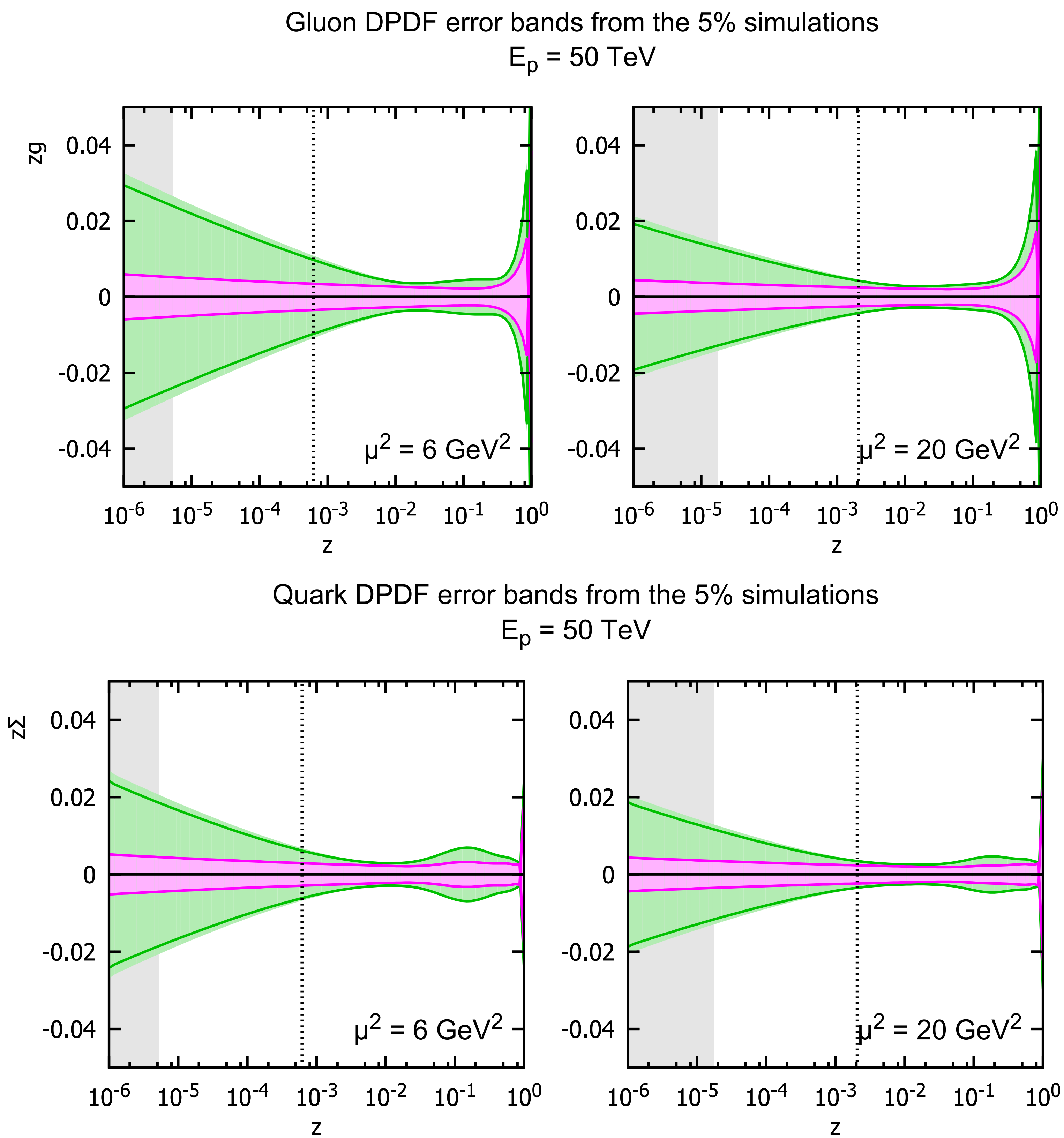
e Pb E_{Pb}/A = 19.7 TeV, E_e = 60 GeV, L = 2 fb^{-1}

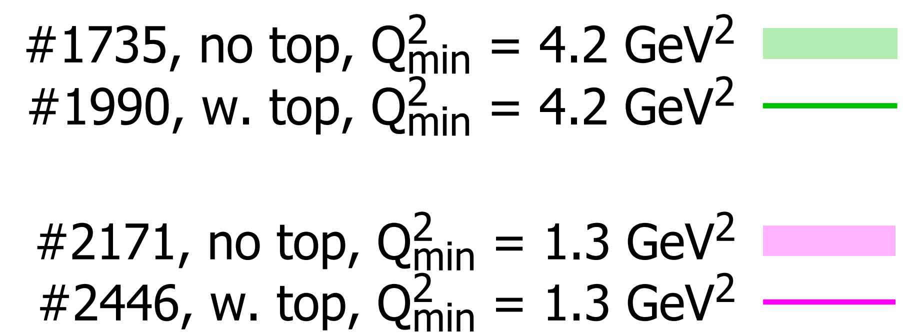


e Pb E_{Pb}/A = 19.7 TeV, E_e = 60 GeV, L = 2 fb^{-1}



Top contribution





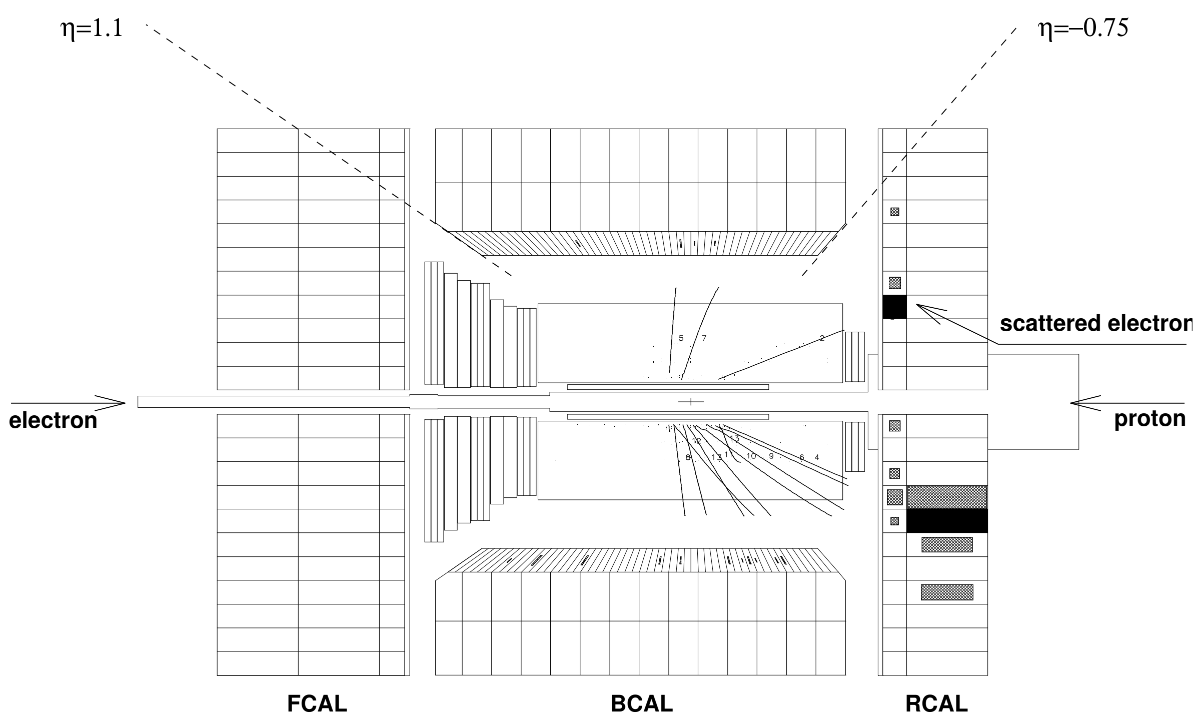
Top quark phase space region does not have big effect on the DPDF extraction

Introduction to diffraction

What is diffraction ?

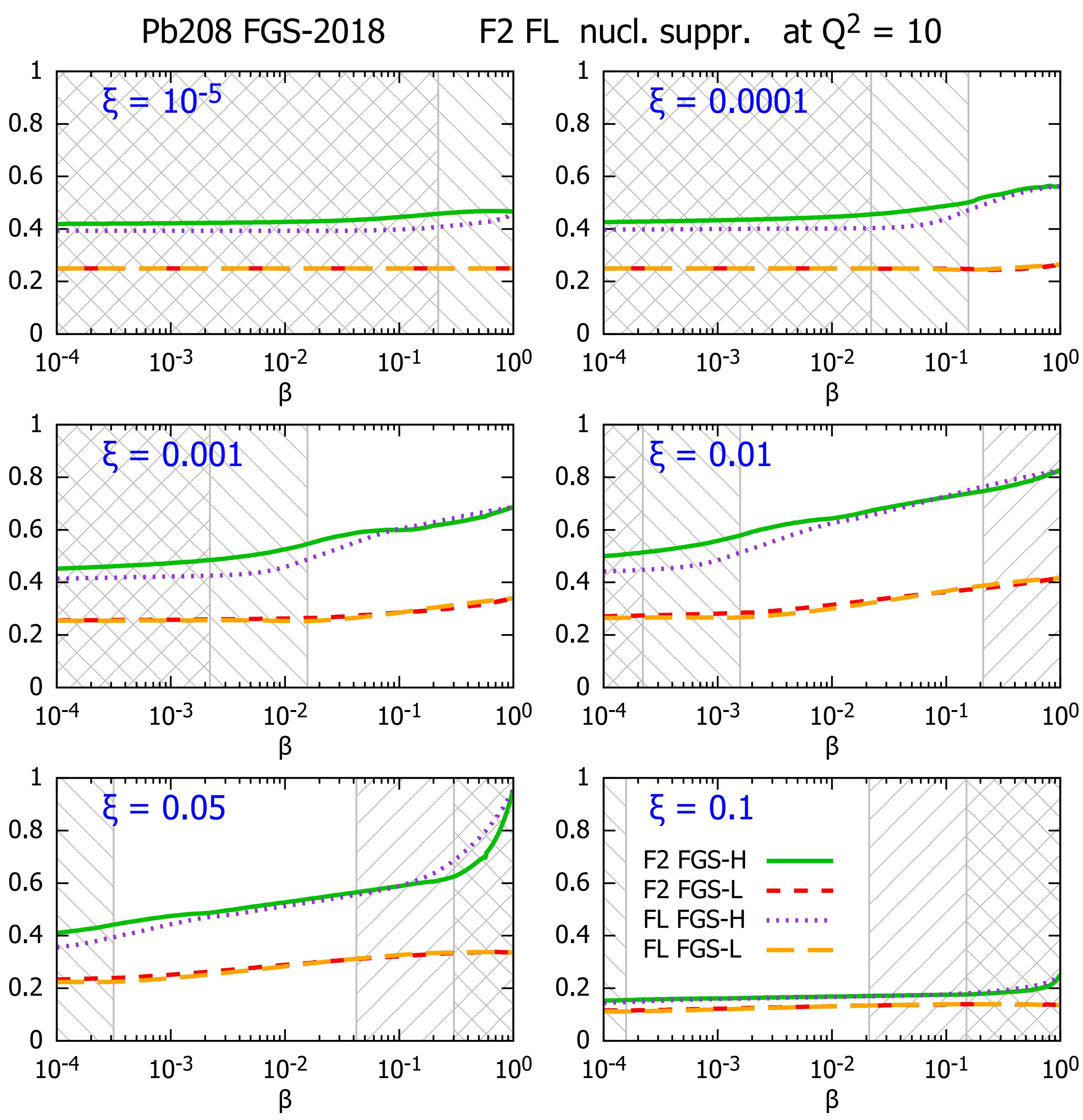
- Diffractive processes are characterized by the rapidity gap: absence of any activity in part of the detector.
- One interpretation of diffraction : it is mediated by the exchange of an ‘object’ with vacuum quantum numbers - usually referred to as the *Pomeron*.

At HERA in electron-proton collisions: about 10% events diffractive



Diffractive event in ZEUS at HERA

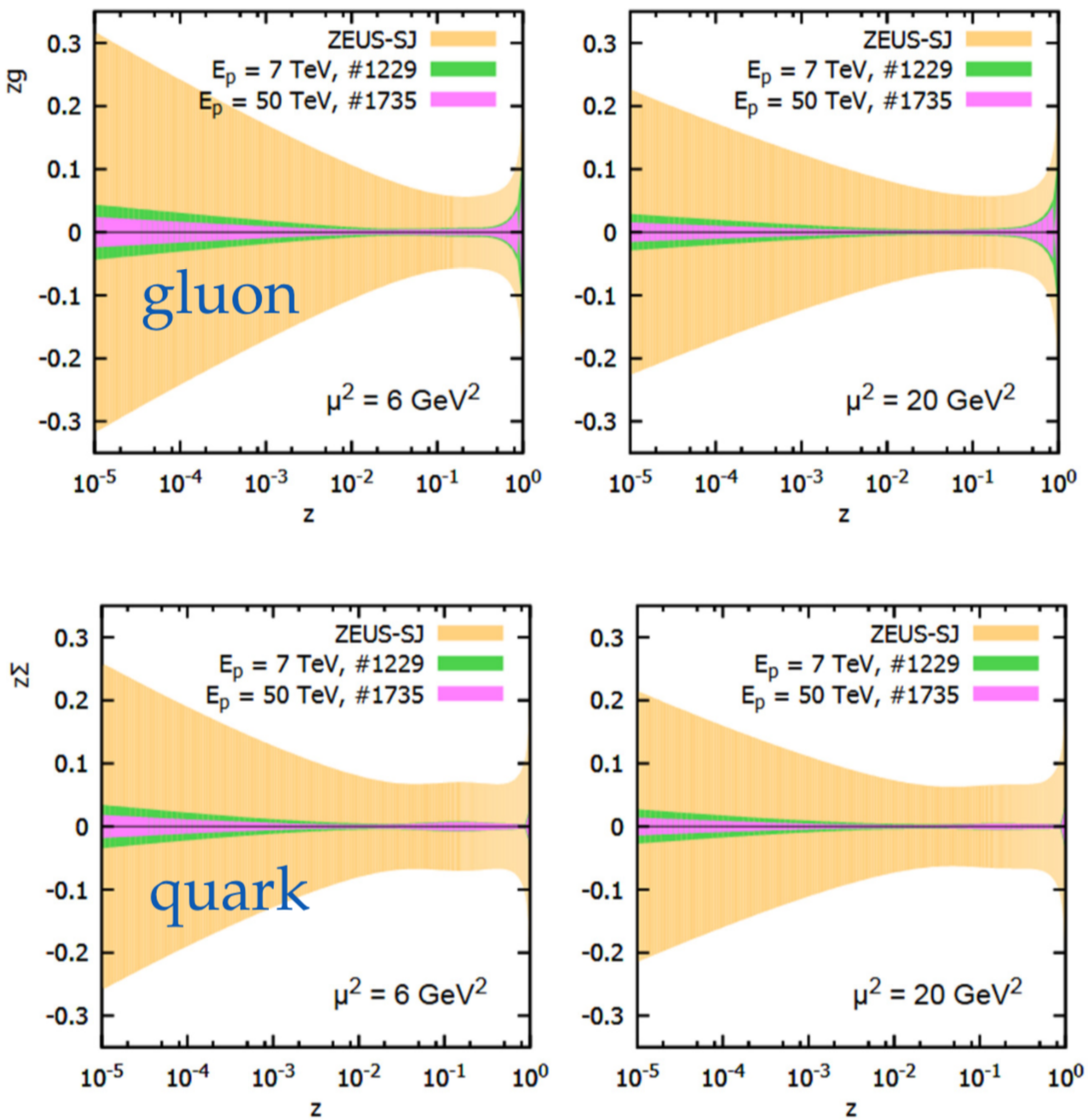
Nuclear diffractive structure functions



- Model for nuclear shadowing: Frankfurt,Guzey,Strikman
- Two models: high and low shadowing
- Results for nuclear ratio:

$$R_k(\beta, \xi, Q^2) = \frac{f_{k/A}^{D(3)}(\beta, \xi, Q^2)}{A\, f_{k/p}^{D(3)}(\beta, \xi, Q^2)}$$

DPDFs error bands



$Q^2_{\min} \approx 5\ \mathrm{GeV}^2$

Accuracy increased by

- ✓ factor ~10 for LHeC
- ✓ factor ~20 for FCC-he