Diffraction at LHeC and FCC-eh

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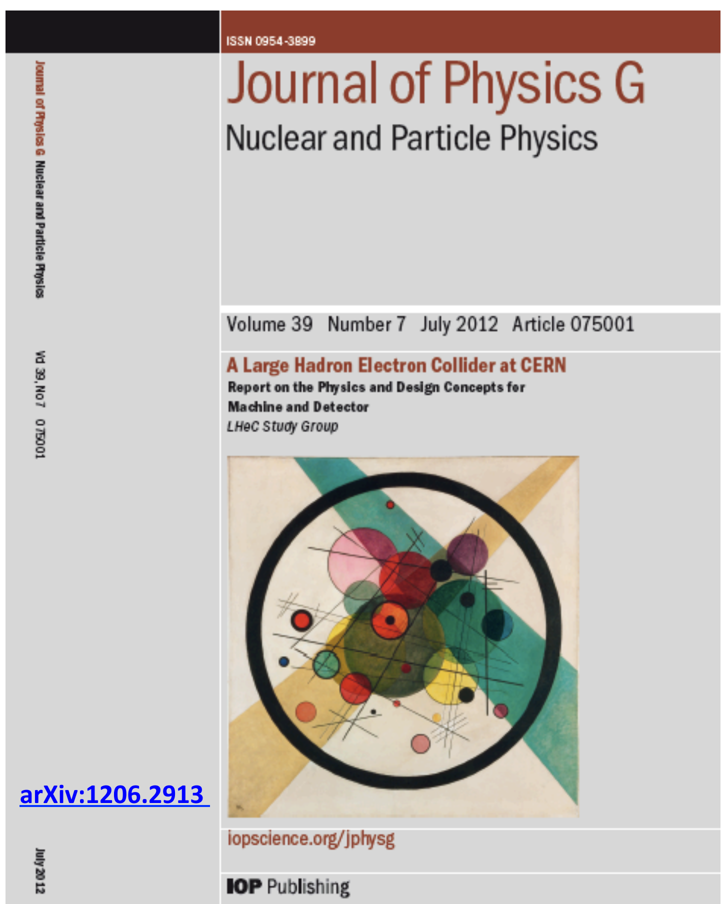
Outline

- Introduction: LHeC and FCC-eh parameters and kinematics
- Inclusive diffraction: cross sections
- Prospects for extraction of diffractive PDFs
- Inclusive diffraction in eA
- Exclusive diffraction: elastic vector meson production

LHeC Conceptual Design Report and beyond

CDR 2012: commissioned by
CERN, ECFA, NuPECC
200 authors, 69 institutions



arXiv:1206.2913

Further selected references:

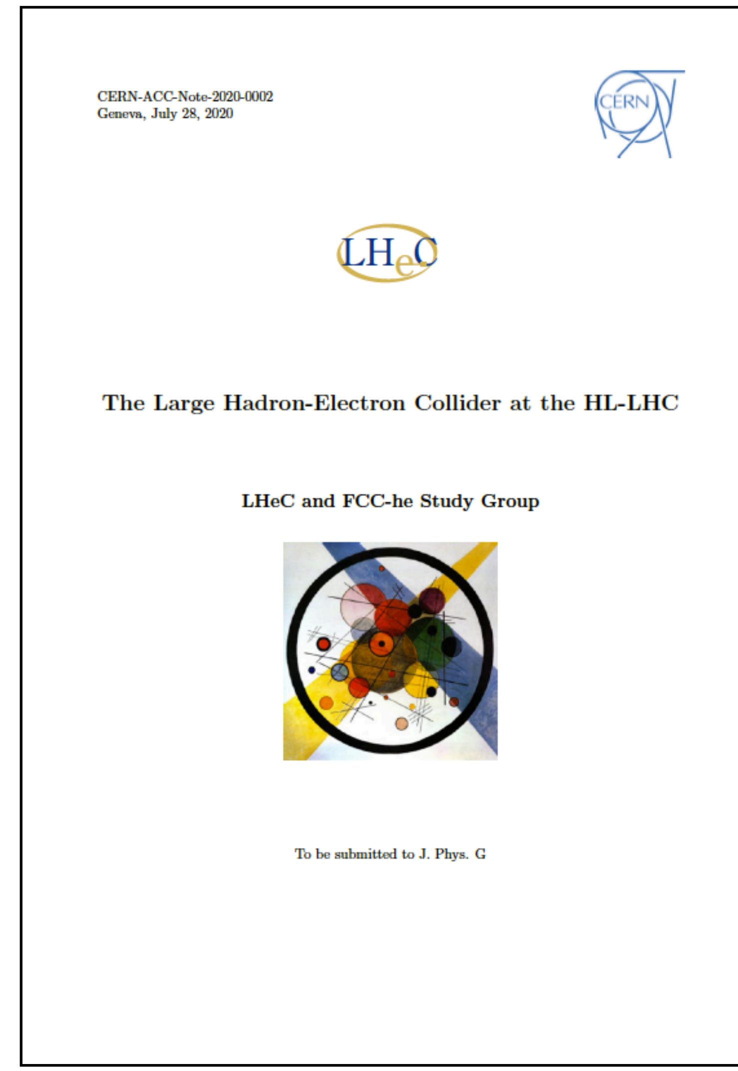
On the relation of the LHeC and the LHC
arXiv:1211.5102

The Large Hadron Electron Collider
arXiv:1305.2090

Dig Deeper
Nature Physics 9 (2013) 448

Future Deep Inelastic Scattering with the LHeC
arXiv:1802.04317

CDR update 2020
300 authors, 156 institutions



arXiv:2007.14491

Accelerator concepts for electron-proton collisions

LHeC, PERLE and FCC-eh

50 x 7000 GeV^2: 1.2 TeV ep collider

Operation: 2035+, Cost: O(1) BCHF

CDR: 1206.2913 J.Phys.G (550 citations)

Upgrade to 10^{34} $cm^{-2}s^{-1}$, for Higgs, BSM

CERN-ACC-Note-2018-0084 (ESSP)

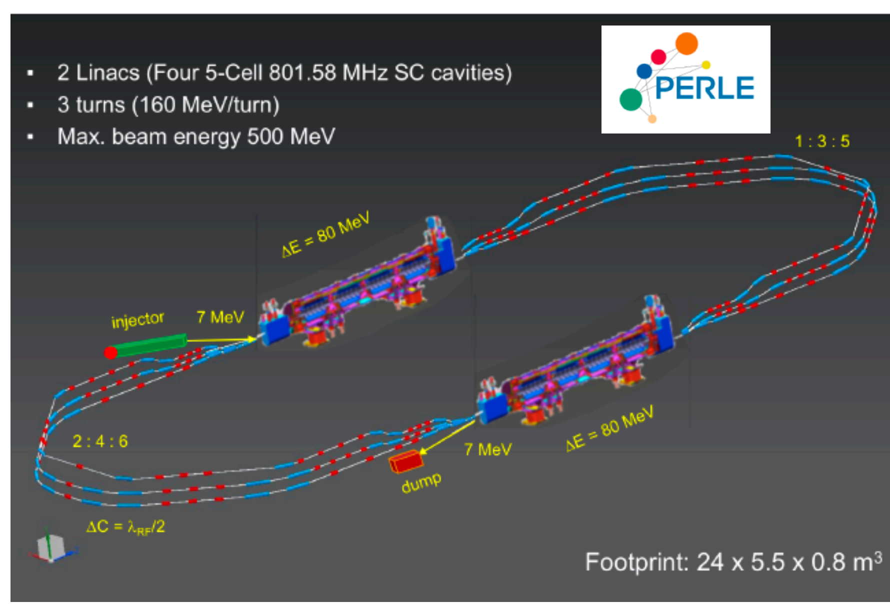
arXiv:2007.14491, subm J.Phys.G

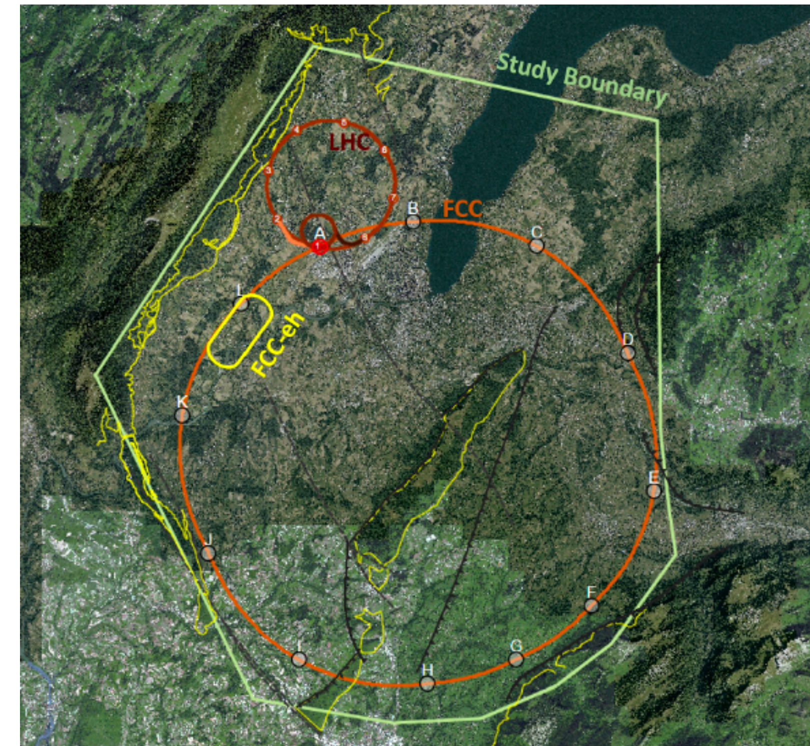
Powerful ERL for Experiments @ Orsay
CDR: 1705.08783 J.Phys.G
CERN-ACC-Note-2018-0086 (ESSP)

Operation: 2025+, Cost: O(20) MEuro

LHeC ERL Parameters and Configuration
I_e=20mA, 802 MHz SRF, 3 turns →
E_e=500 MeV → first 10 MW ERL facility

BINP, CERN, Daresbury, Jlab, Liverpool, Orsay (IJC), +





60 x 50000 GeV^2: 3.5 TeV ep collider

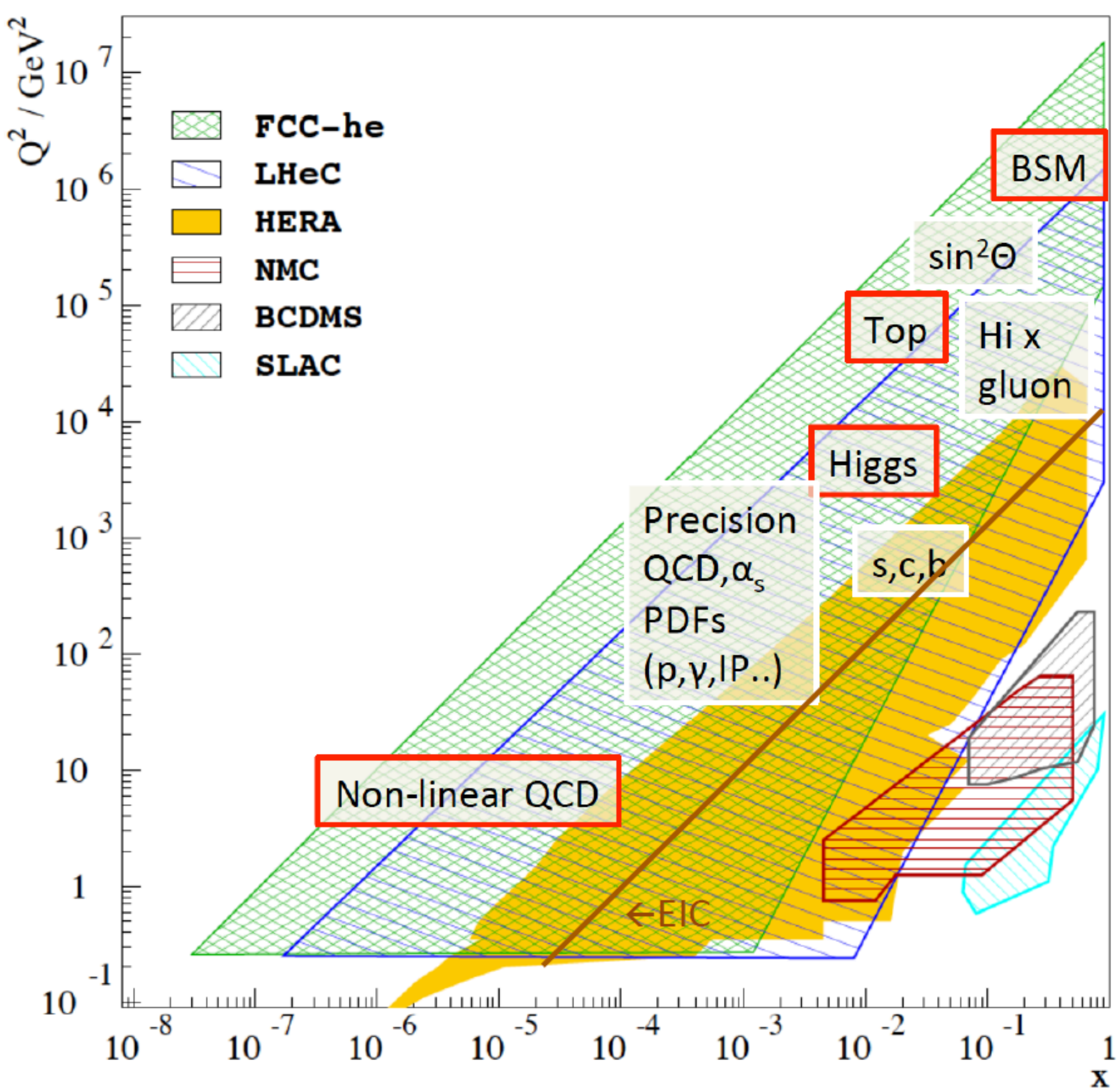
Operation: 2050+, Cost (of ep) O(1-2) BCHF

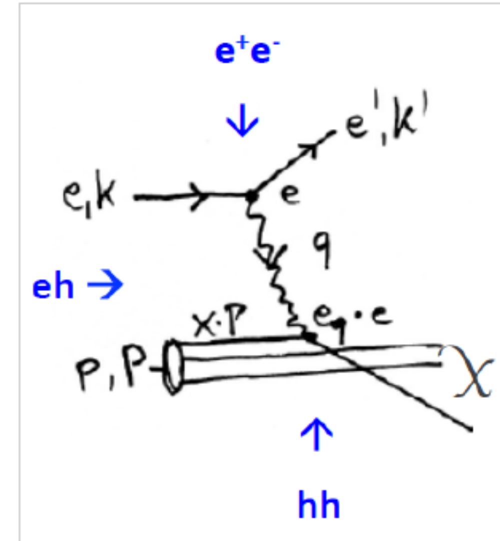
Concurrent Operation with FCC-hh

FCC CDR:
Eur.Phys.J.ST 228 (2019) 6, 474 Physics
Eur.Phys.J.ST 228 (2019) 4, 755 FCC-hh/eh

Future CERN Colliders: 1810.13022 Bordry+

Physics with Energy Frontier DIS





ep/eA collider: cleanest high resolution microscope

Precision and discovery in QCD

Study of EW physics, multi-jet final states

Transform the LHC/FCC into a high precision Higgs facility

Unique and complementary potential for the BSM studies

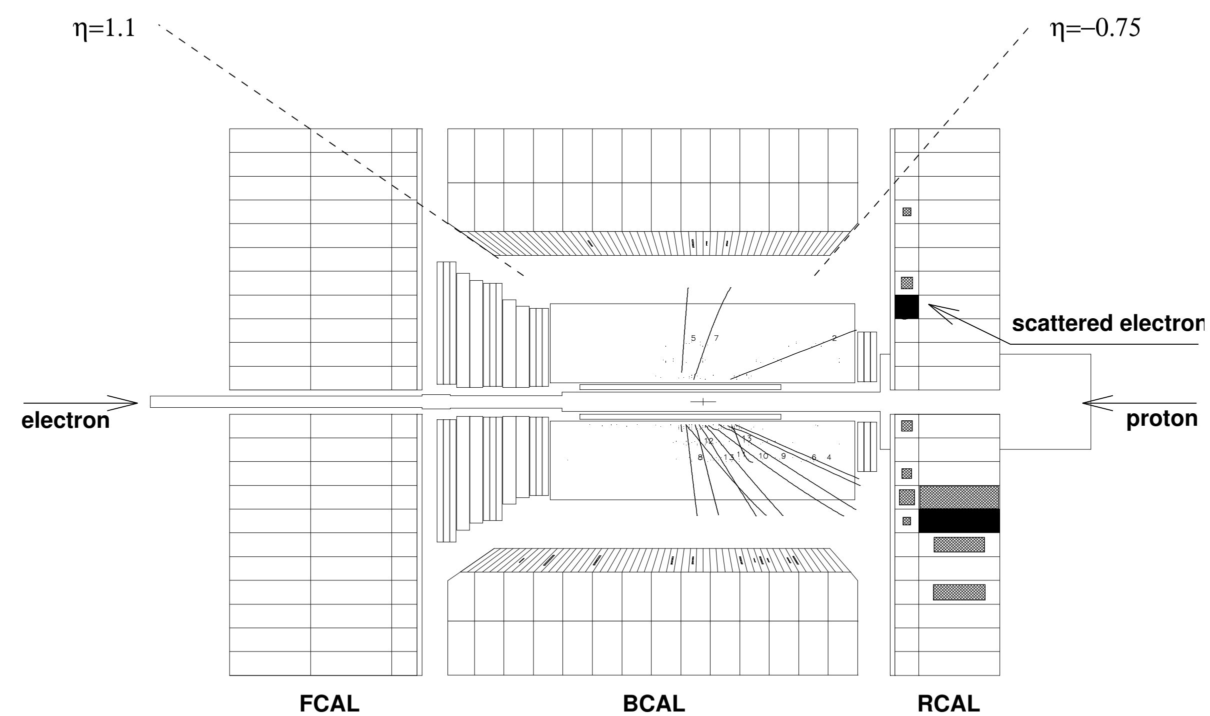
Empower the LHC/FCC search programme

Overall: a unique Particle and Nuclear Physics Facility

What is Diffraction?

- Diffractive processes are characterized by the rapidity gap: absence of any activity in part of the detector.
- Diffraction is interpreted as to be mediated by the exchange of an 'object' with vacuum quantum numbers - usually referred to as the **Pomeron**.

HERA: 10% events diffractive: **rapidity gap**



Diffractive event in ZEUS at HERA

Importance of diffraction for :

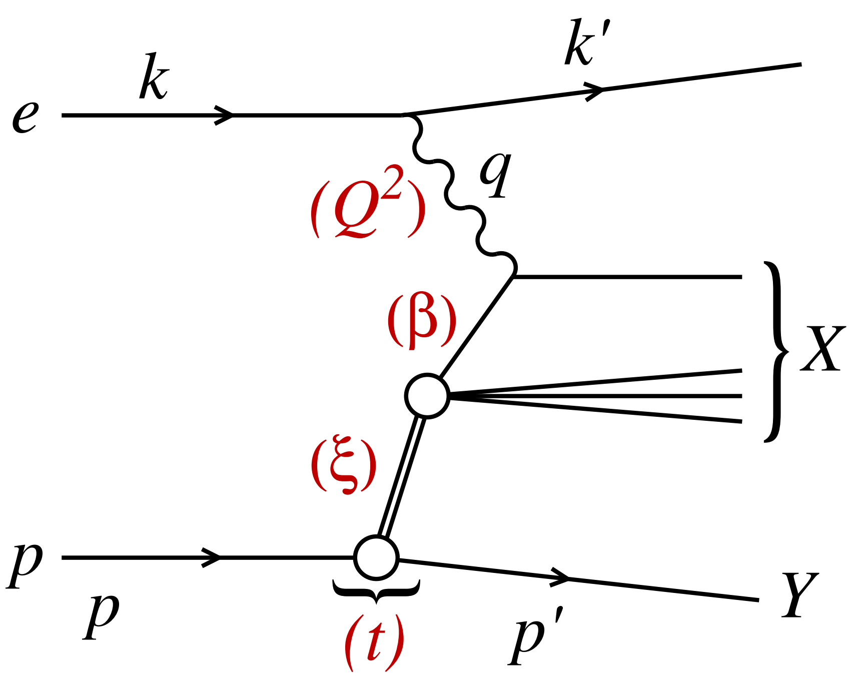
small x dynamics

shadowing

confinement,

soft and collinear factorization

Diffractive kinematics in DIS



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

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

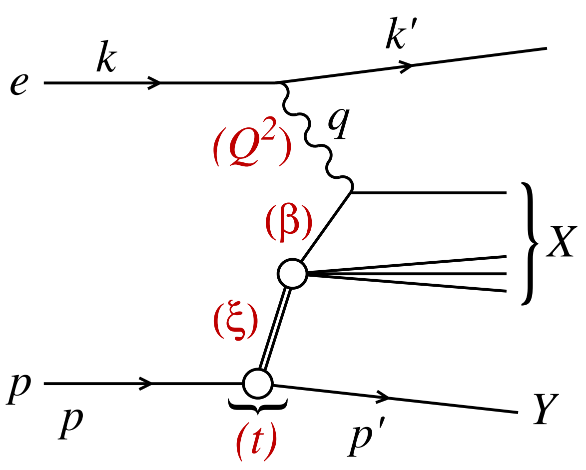
momentum fraction of parton w.r.t Pomeron

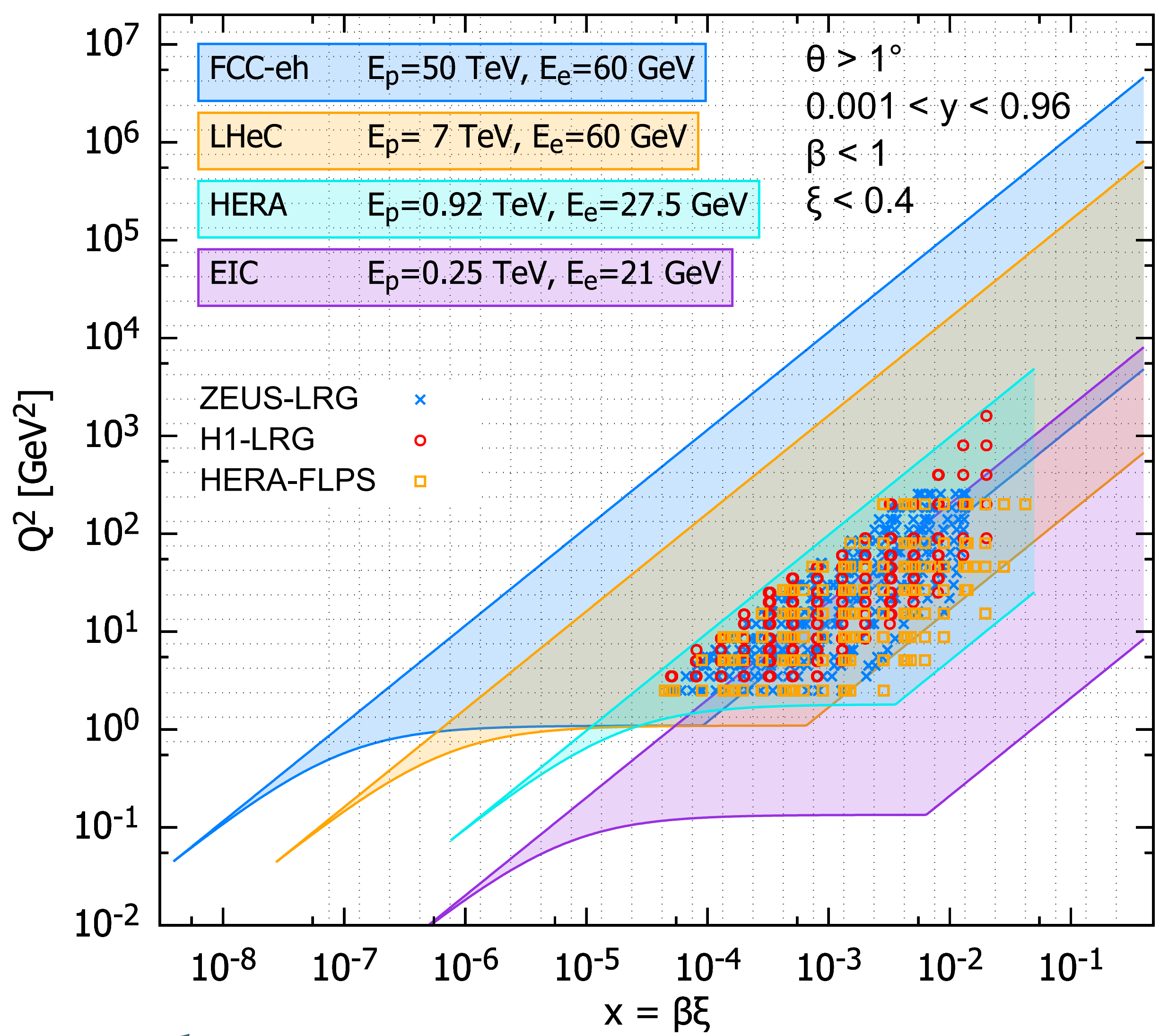
$$t = (p - p')^2$$

4-momentum transfer squared

$$x = \xi \beta$$

Phase space (x,Q²) EIC-HERA-LHeC-FCC-eh





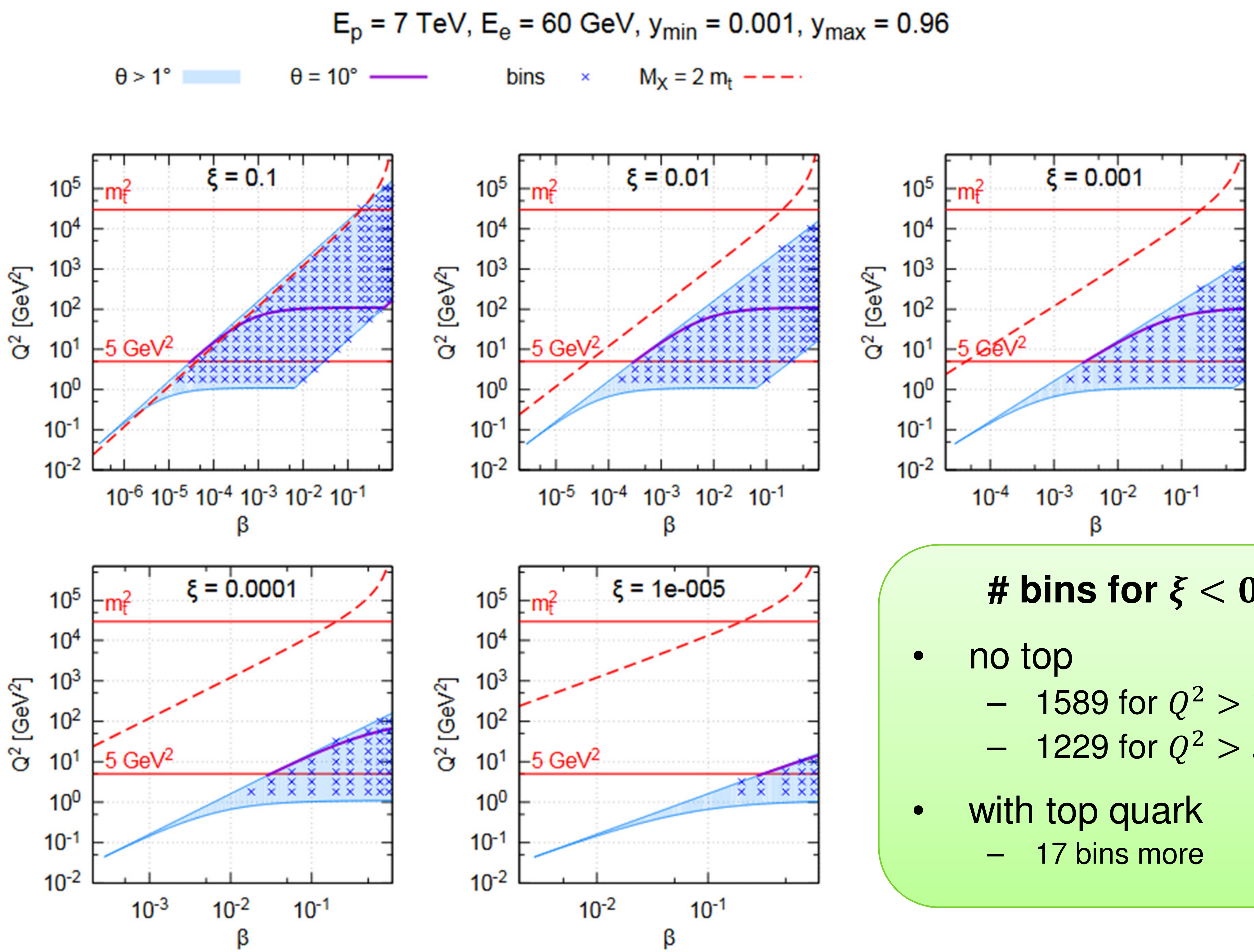
$E_e = 60\ GeV$

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

Prospects for LHeC and FCC-eh:

Low ξ: cleanly separate diffraction
Low β: novel low x effects
High Q^2: lever-arm for gluon, flavor decomposition. Tests of DGLAP evolution
Large M_X: diffractive jets, heavy flavors, W/Z
Large E_T: Precision QCD with jets

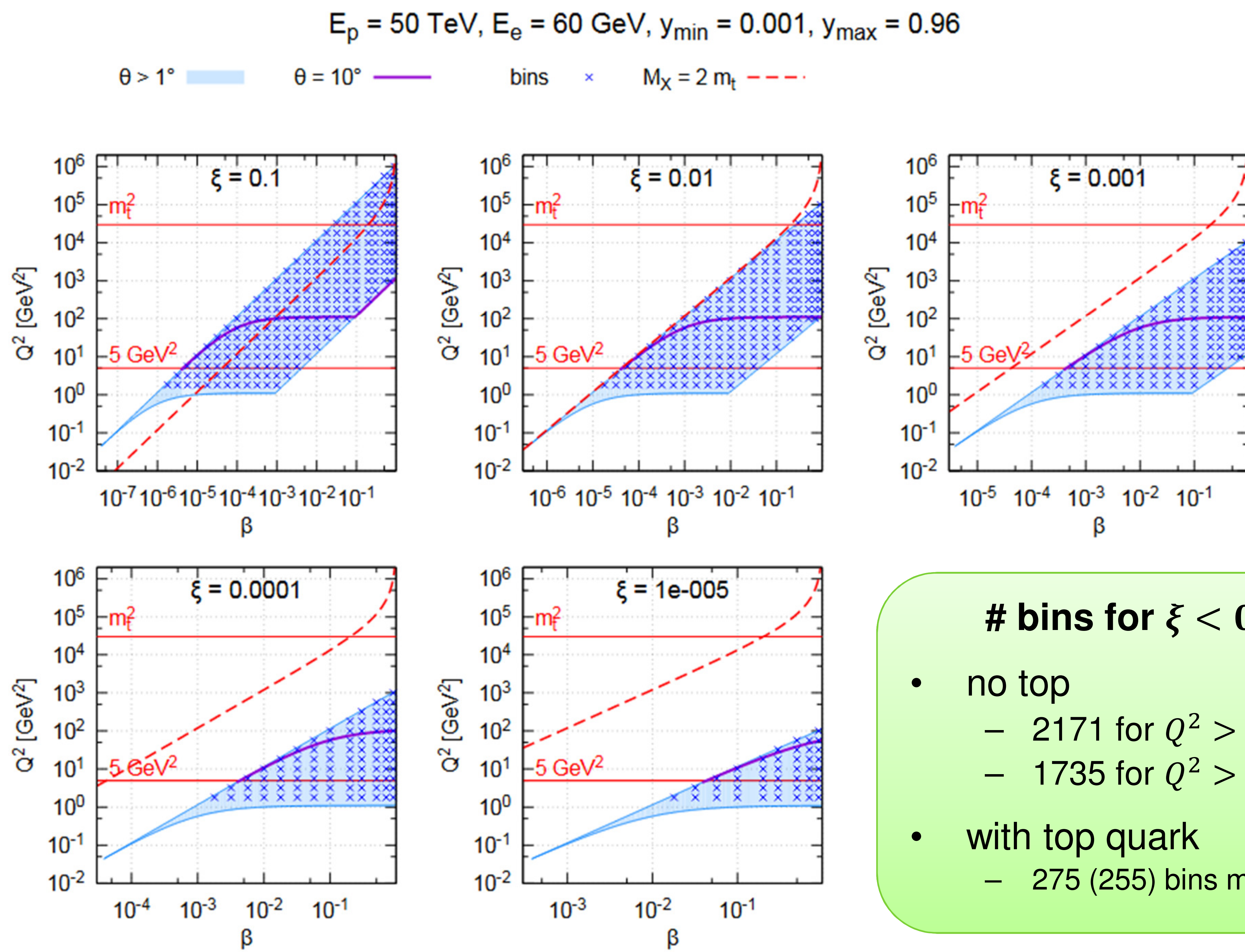
LHeC phase space: (β,Q²) fixed ξ



 # 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

Pseudodata for σ_{red}

Simulations based on extrapolation of ZEUS-SJ DPDFs

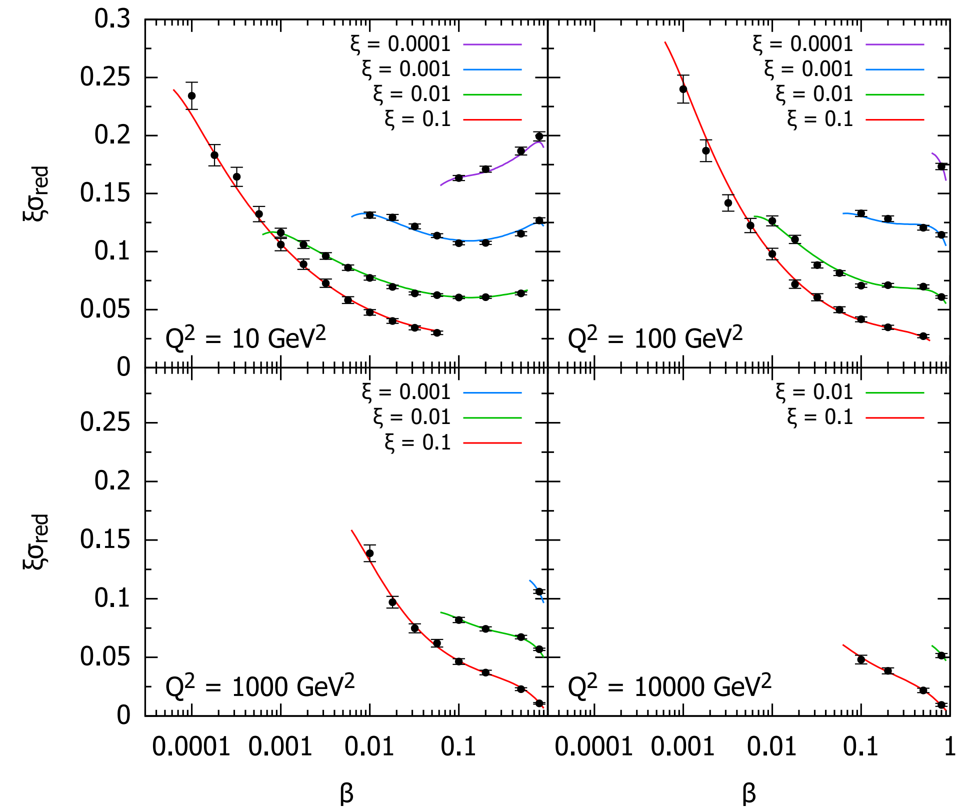
Variable Flavor Number scheme without top

Binning to assume negligible statistical errors

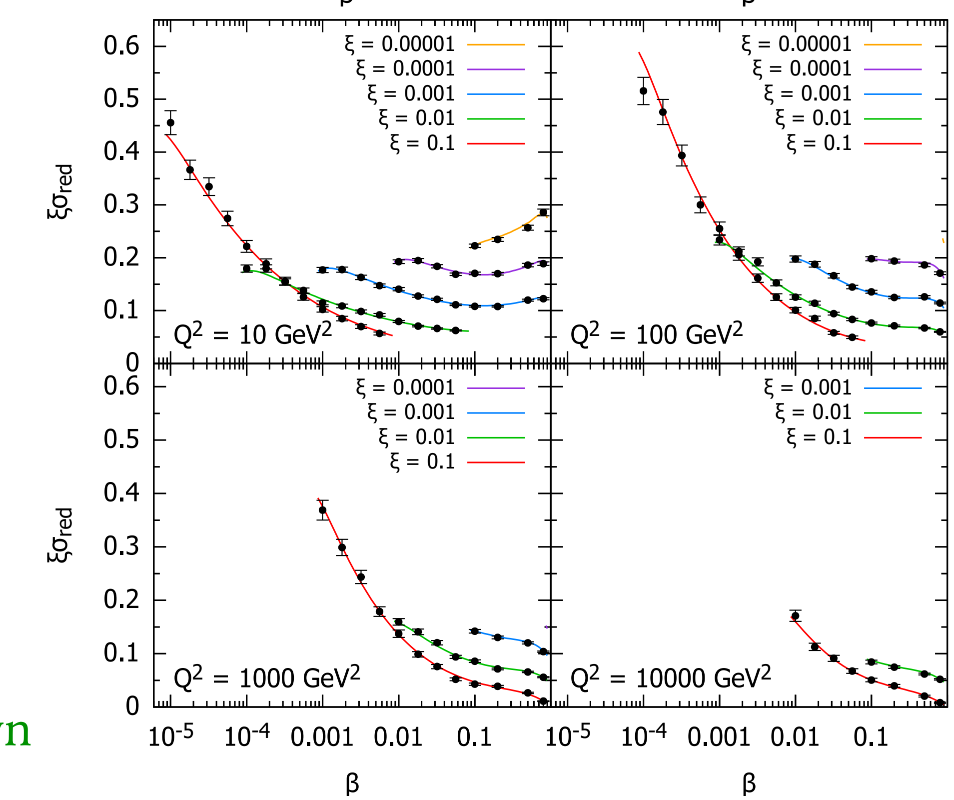
5% systematic error, dominates the total error

Potential for high quality data for inclusive diffraction at LHeC/FCC-eh

Prospects for precise extraction of diffractive PDFs, tests of factorization breaking (collinear and soft)



LHeC



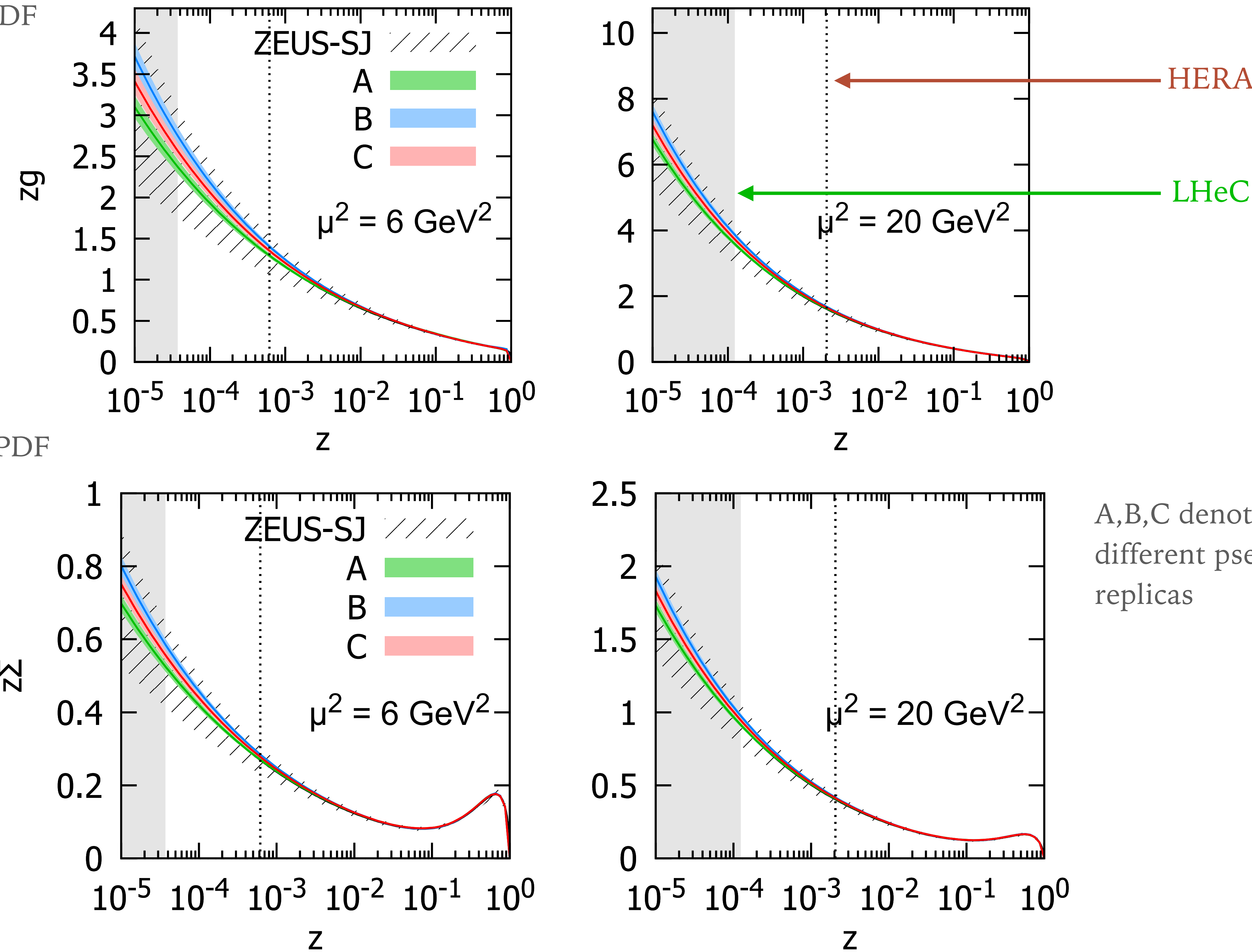
FCC-eh

Only small subset of simulated data is shown

Diffractive PDFs from LHeC pseudodata

Diffractive gluon PDF

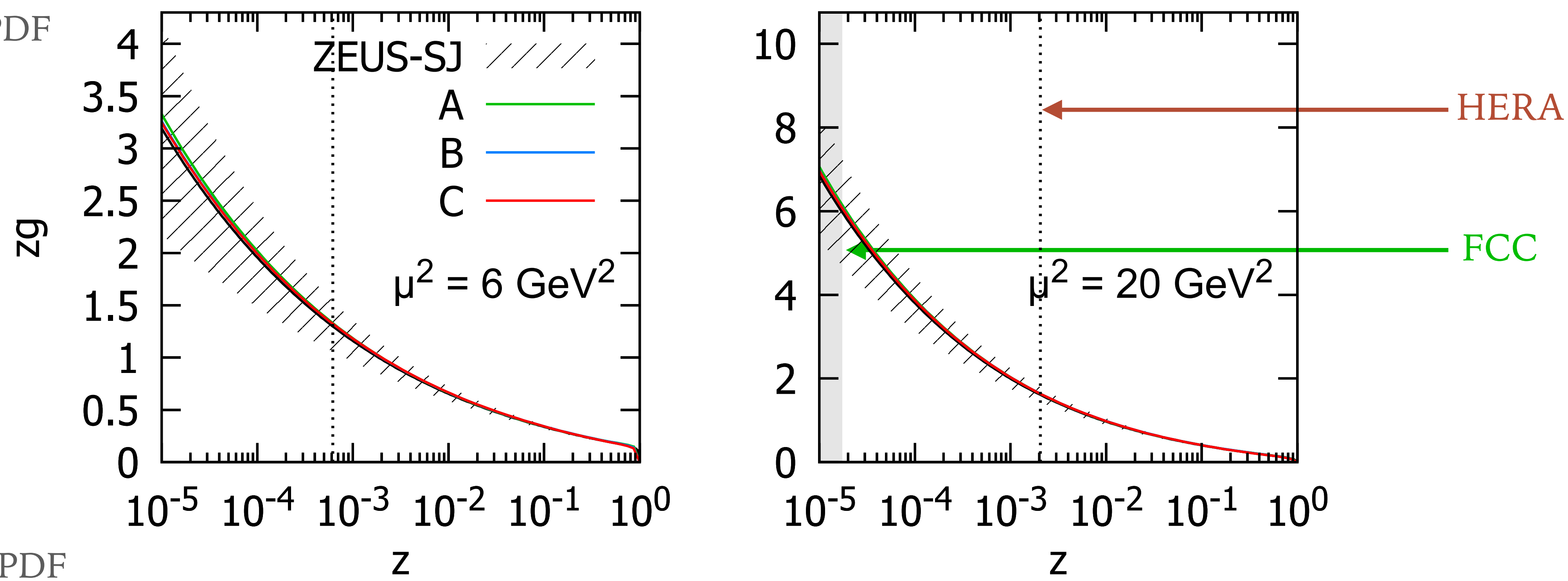
Diffractive quark PDF



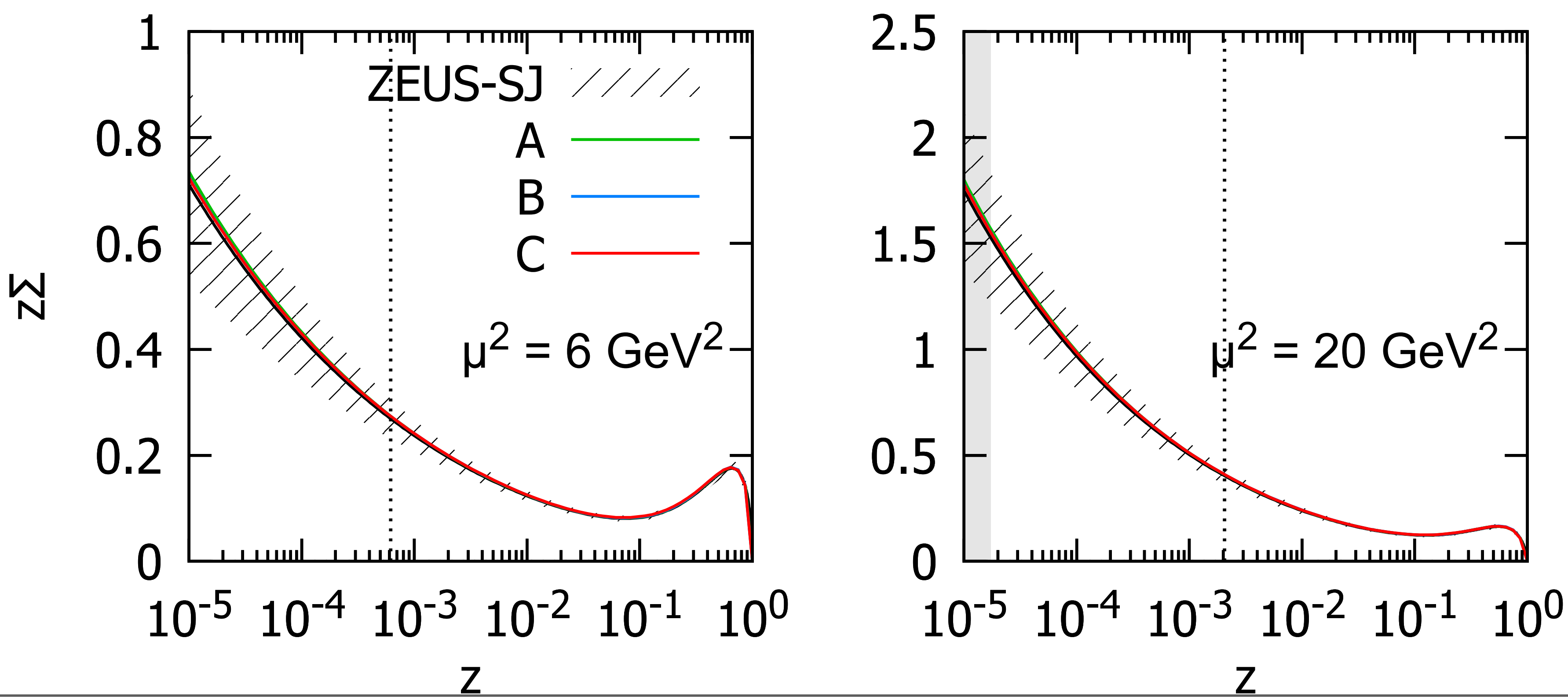
A,B,C denote fits to different pseudodata replicas

Diffractive PDFs from FCC-he pseudodata

Diffractive gluon PDF



Diffractive quark PDF



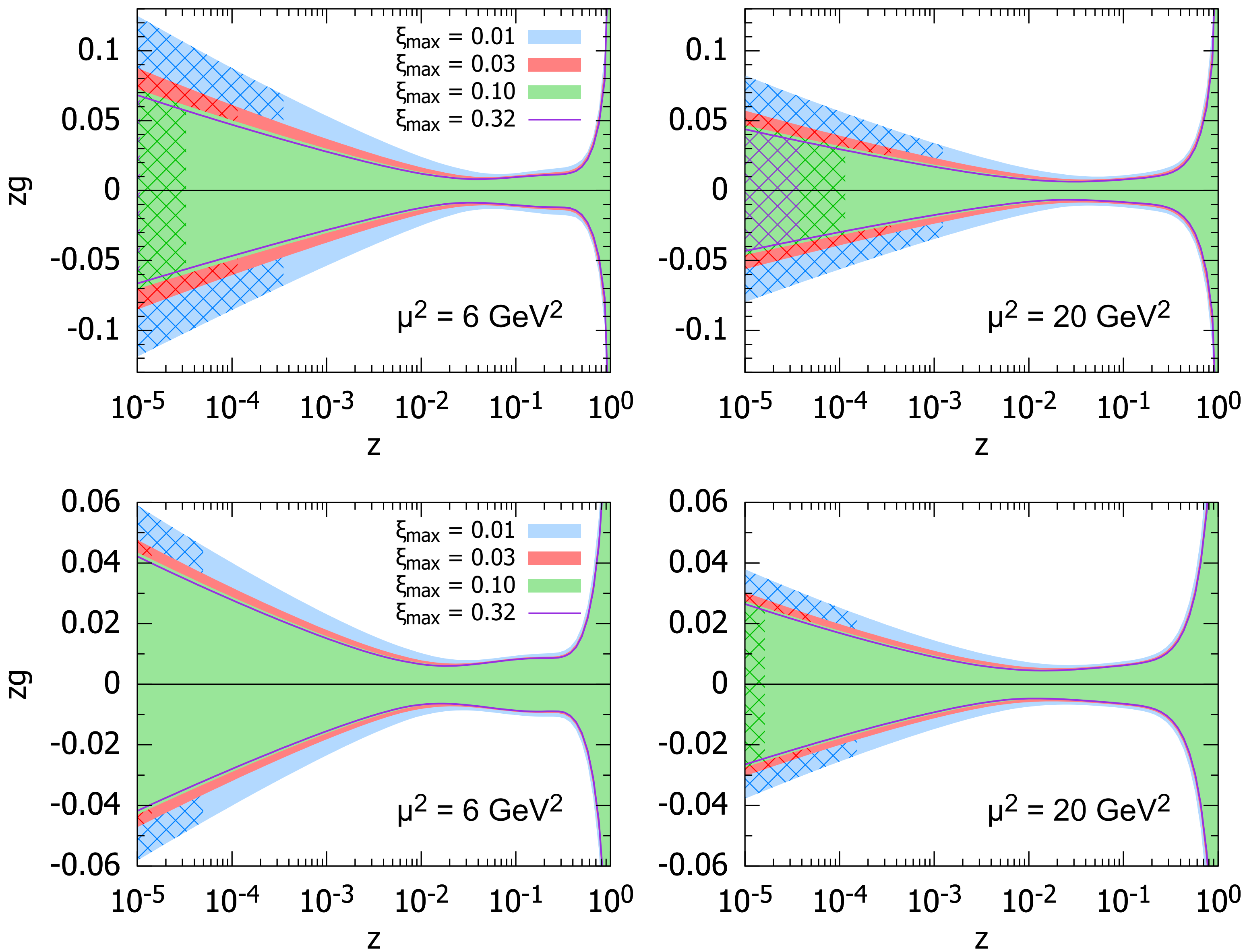
A,B,C denote fits to different pseudodata replicas

Relative uncertainties for LHeC and FCC-eh

LHeC

FCC-eh

(note reduction of scale)



Reduction of DPDF uncertainty by factor 5 — 7 at LHeC and 10 — 15 at FCC-eh with inclusive data alone. Small sensitivity to the large ξ cut

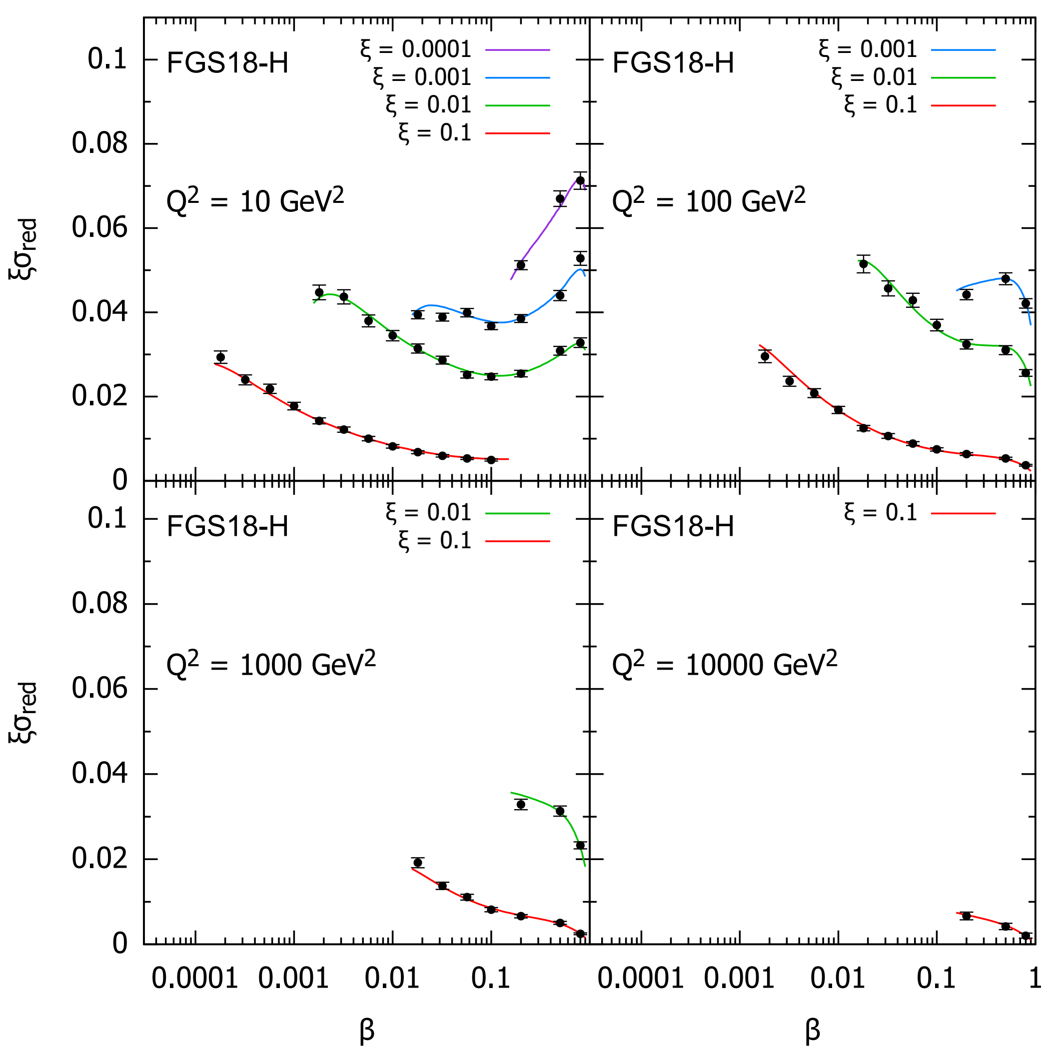
Prospects for precise extraction of diffractive PDFs, tests of factorization breaking (collinear and soft)

Inclusive diffraction on nuclei

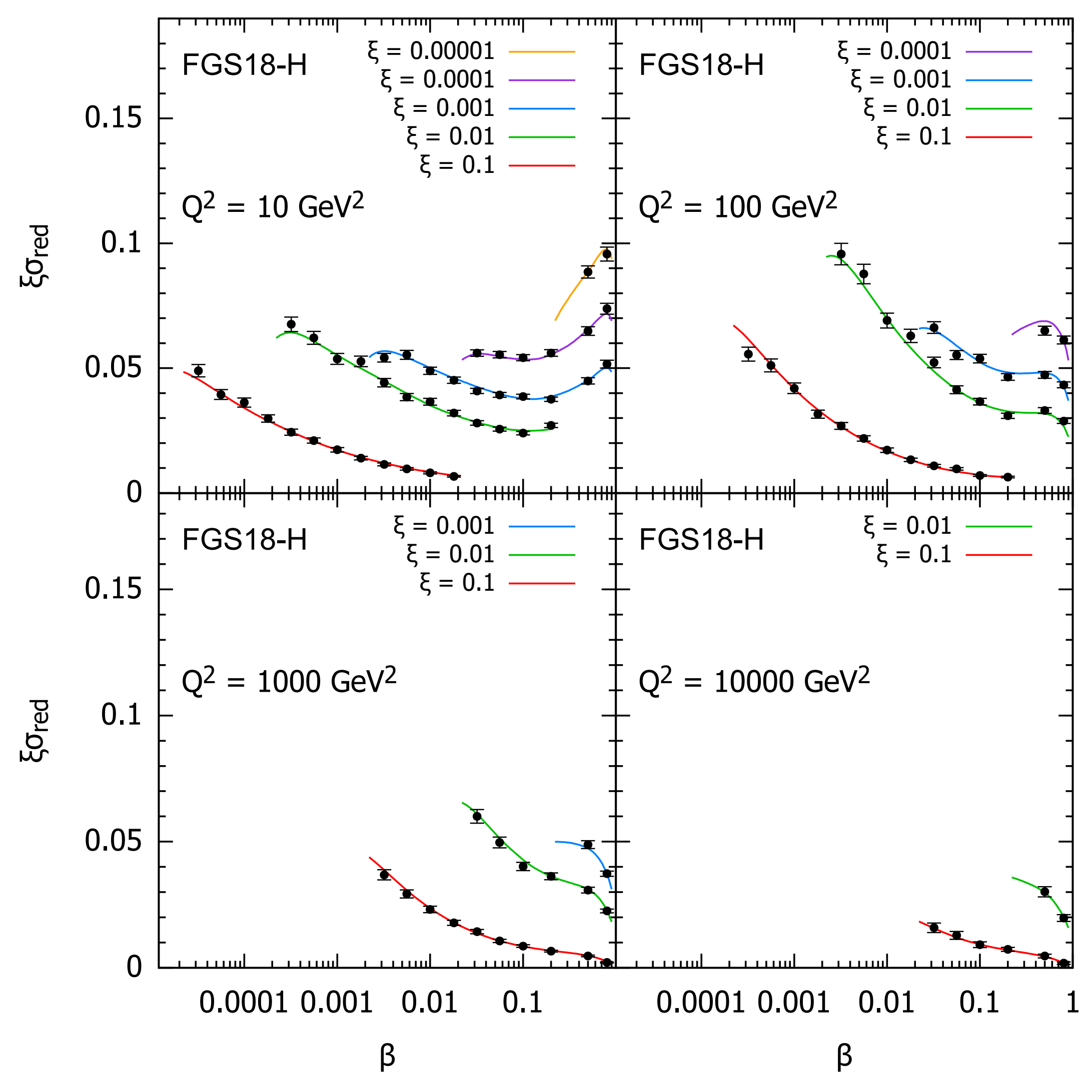
Reduced cross section from Frankfurt, Guzey, Strikman model

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

e Pb E_{Pb}/A = 2.76 TeV, E_e = 60 GeV, L = 2 fb^{-1}



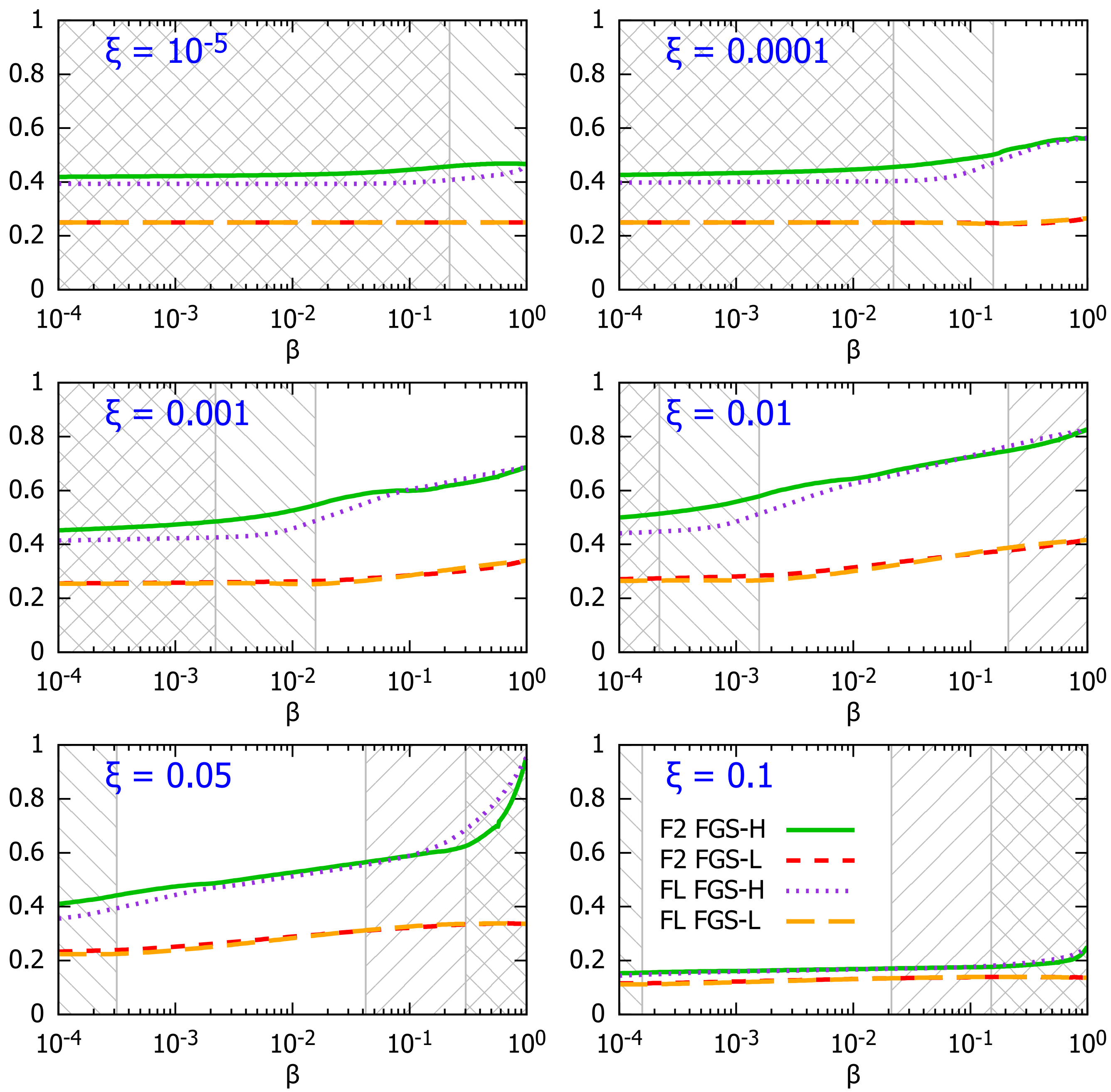
e Pb E_{Pb}/A = 19.7 TeV, E_e = 60 GeV, L = 2 fb^{-1}



High precision data would allow to extract the nuclear DPDFs with similar accuracy to the proton case

Inclusive diffraction on nuclei: nuclear ratio

$Q^2 = 10\ \mathrm{GeV}^2$ Frankfurt, Guzey, Strikman model

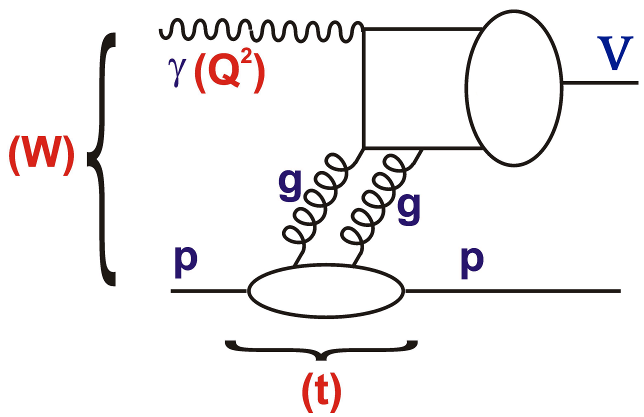


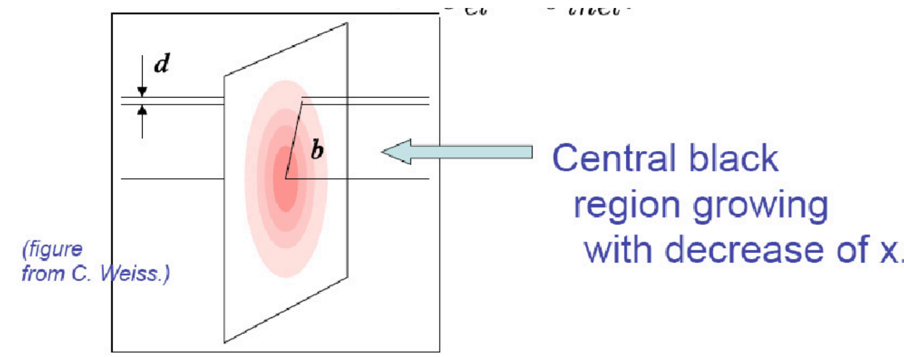
$$R_k^A(\beta, \xi, Q^2) = \frac{F_{k,A}^{D(3)}(\beta, \xi, Q^2)}{A F_{k,p}^{D(3)}(\beta, \xi, Q^2)}$$

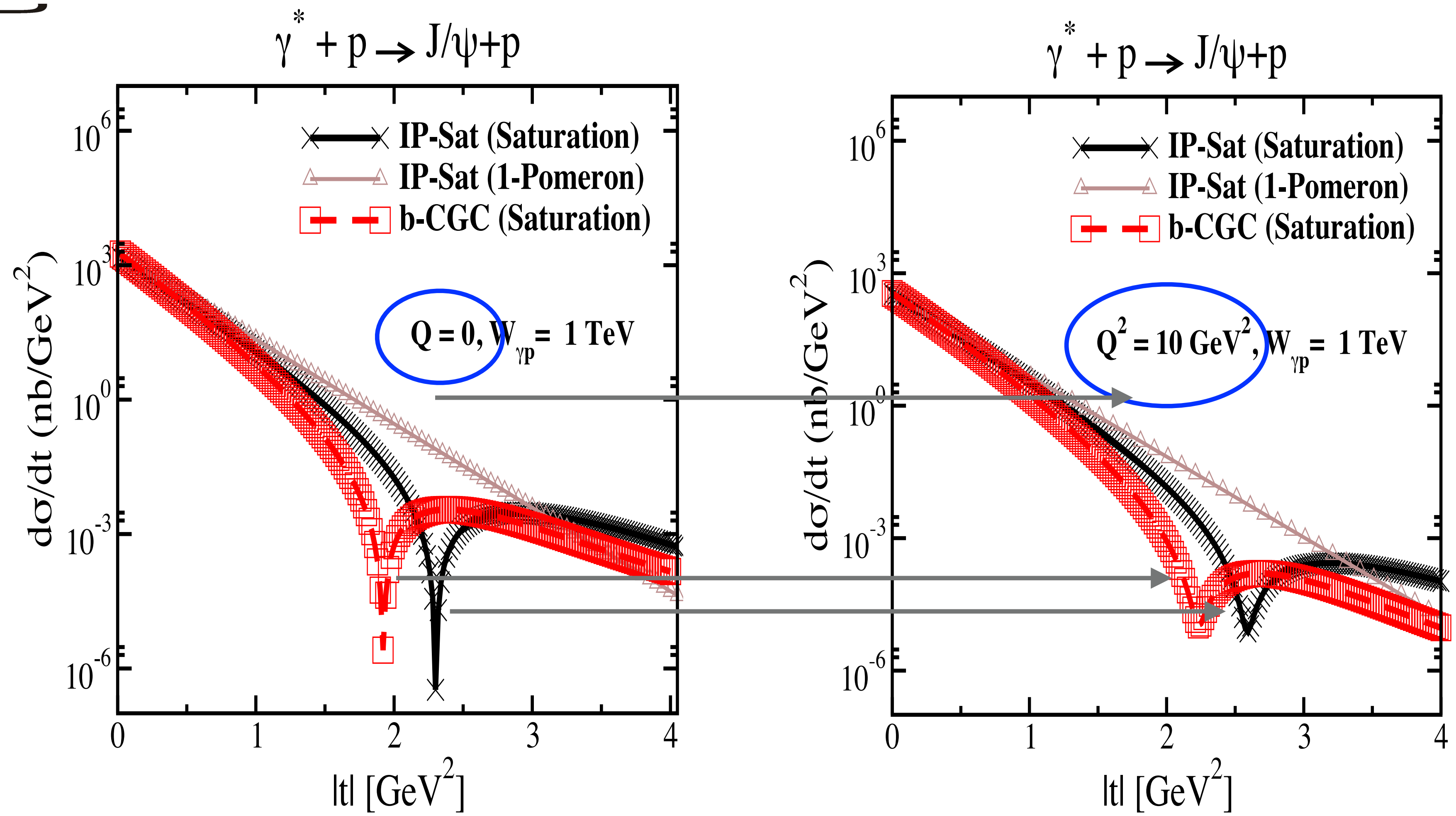
Predictions for nuclear ratios for diffractive structure functions F_2 and F_L

LHeC and FCC-eh could extract these quantities for the first time

Elastic diffraction of vector mesons: LHeC







Advantage over UPC:

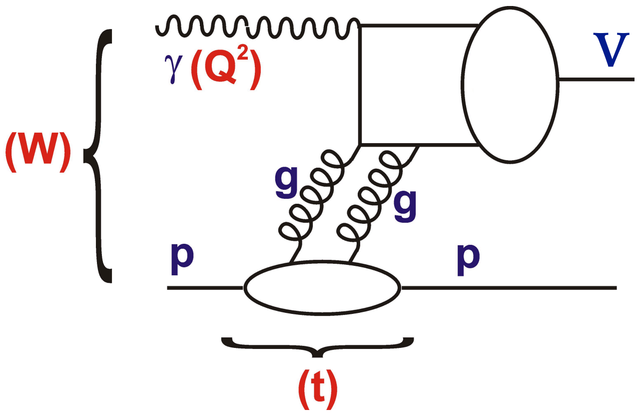
Q^2 dependence

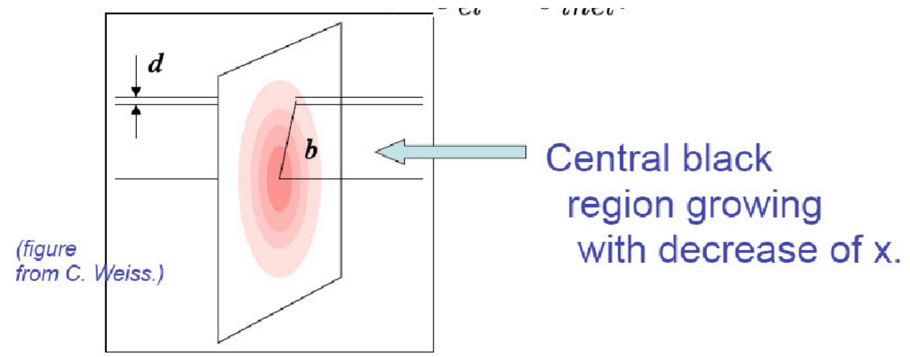
Precision t, W and Q^2 dependence of vector mesons

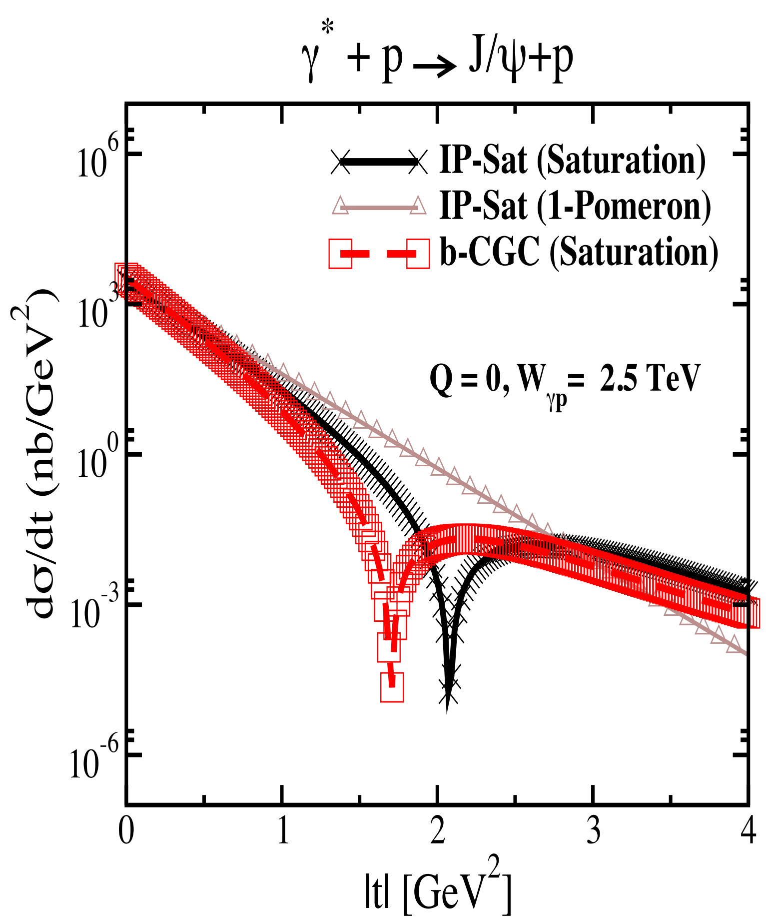
Example : tests of saturation from the slope in t

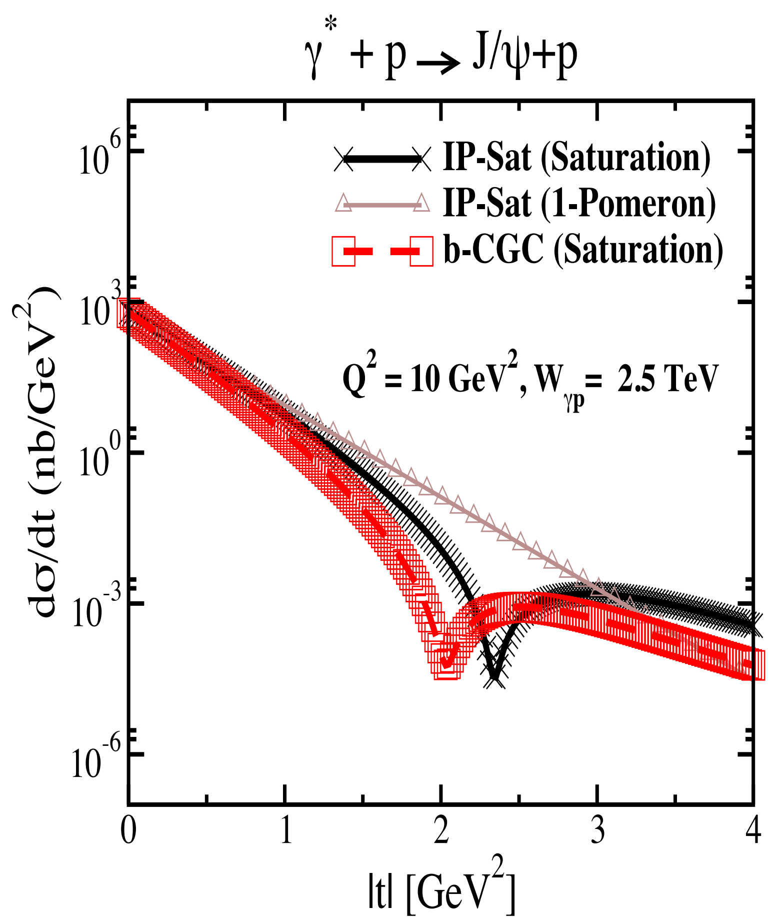
One of the best processes to test for novel small *x* dynamics

Elastic diffraction of vector mesons: FCC-he









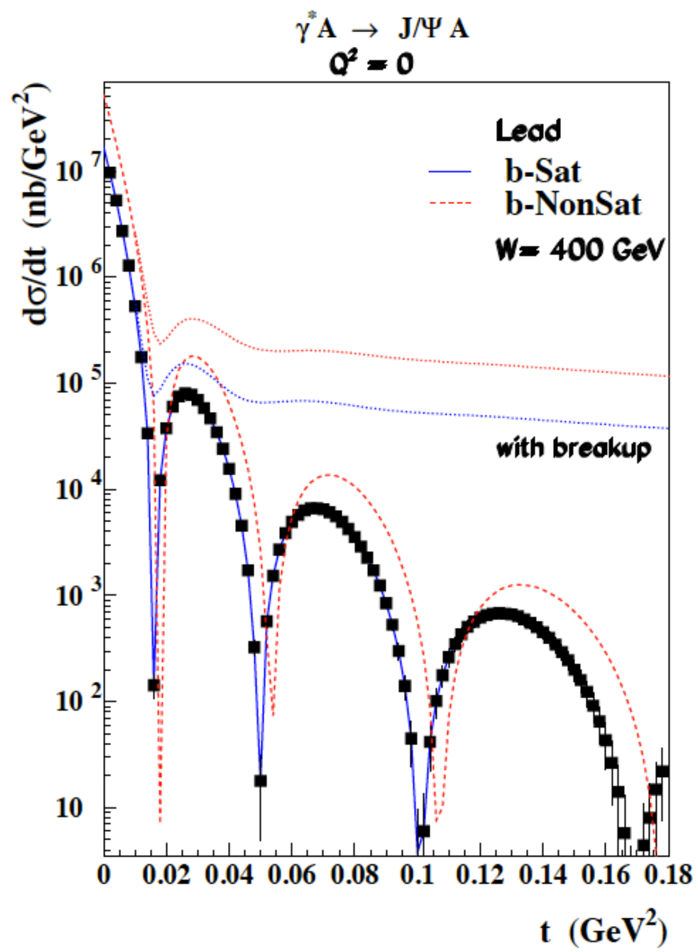
Dips move to lower |t| with higher energy

Boundary between dilute and dense region moves to large impact parameters

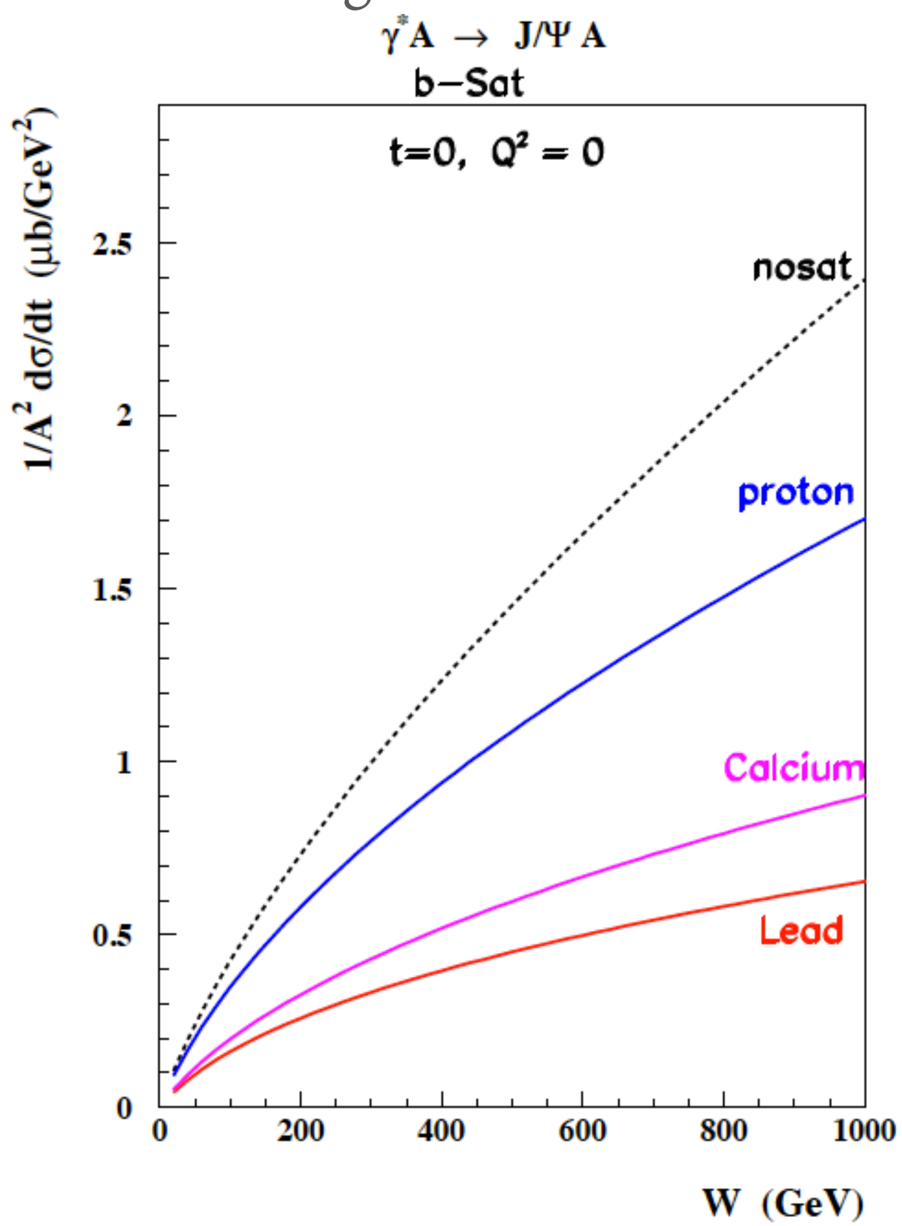
Could be explored at FCC-he

Exclusive diffraction on nuclei

Possibility of using the same principle to learn about the gluon distribution in the nucleus.
Possible nuclear resonances at small t?



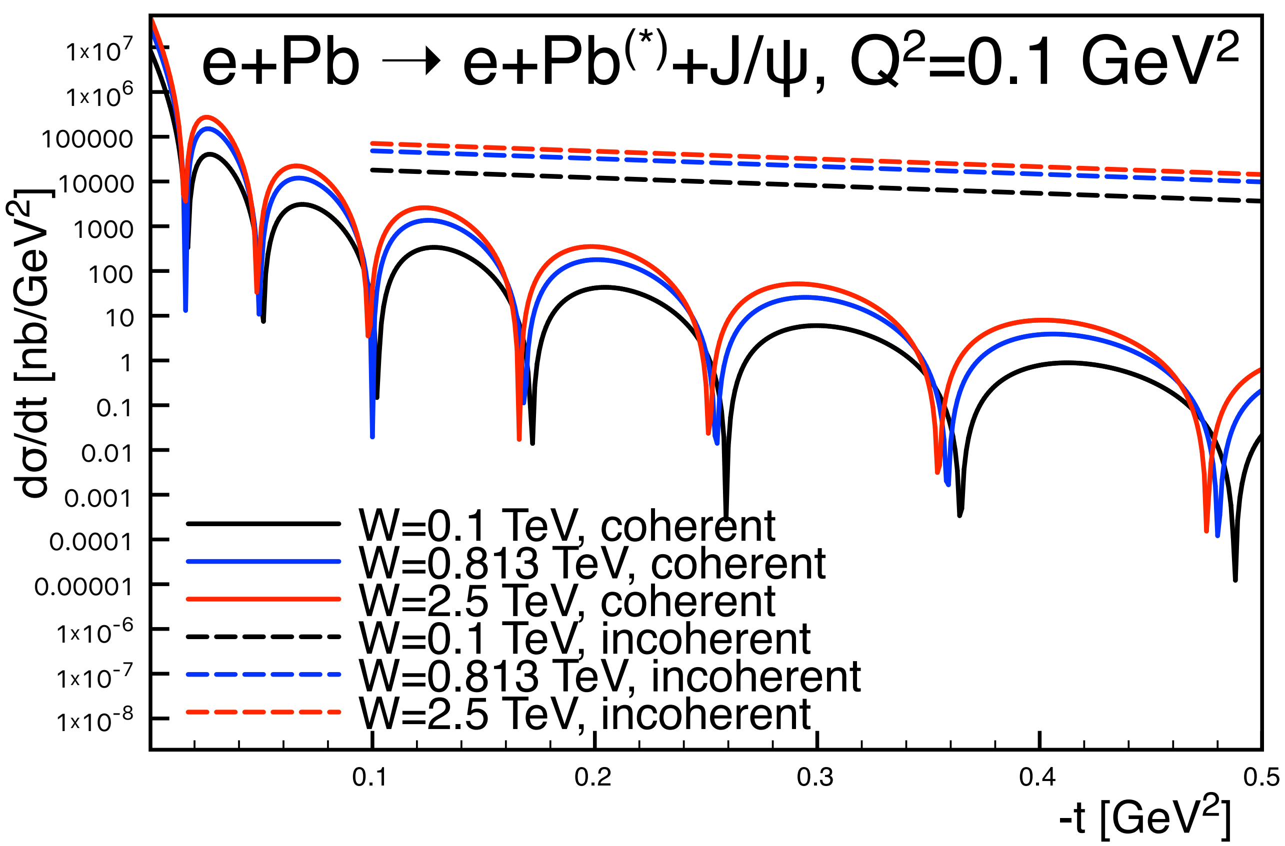
Energy dependence for different targets.

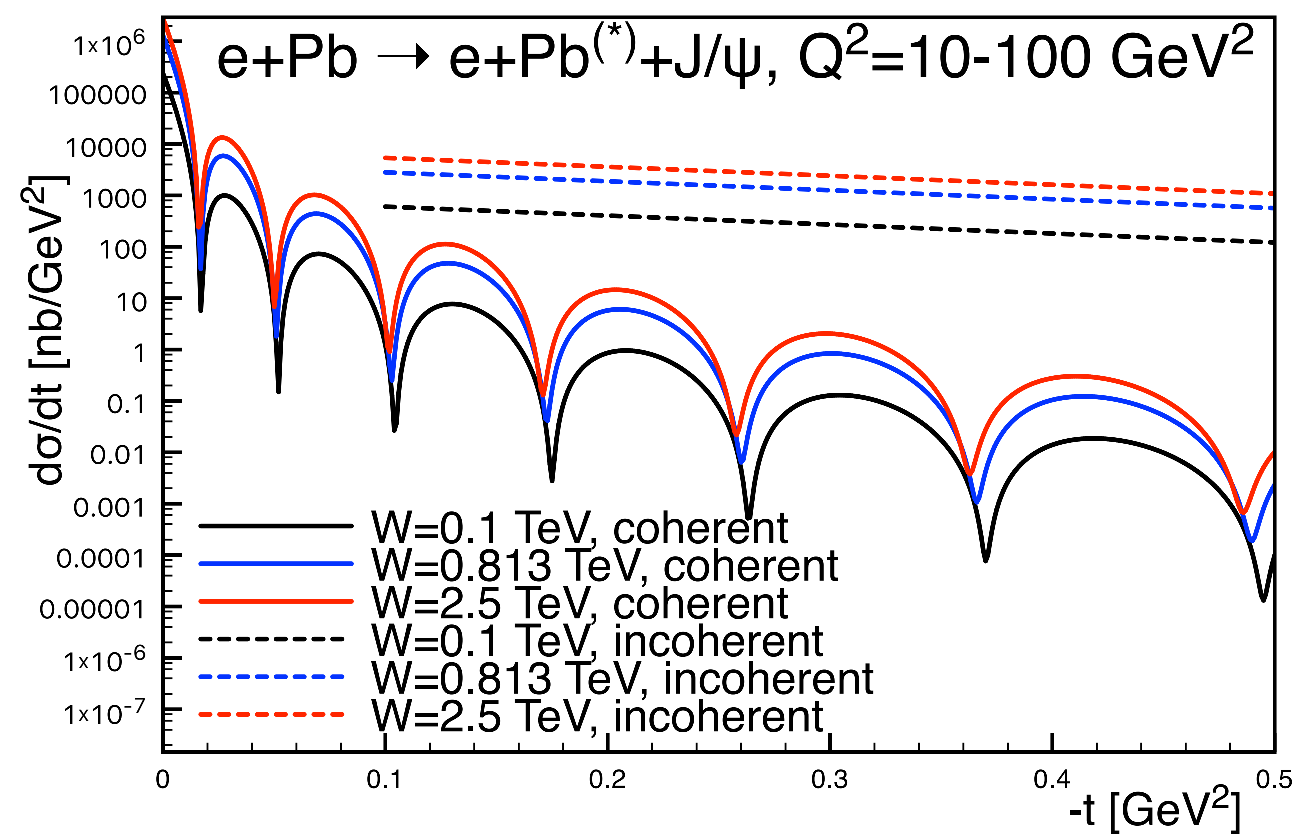


t-dependence: characteristic dips.

Challenges: need to distinguish between coherent and incoherent diffraction. Need dedicated instrumentation, zero degree calorimeter.

Exclusive diffraction on nuclei





Energy and scale dependence of the position of dips in $|t|$. Provides information about nuclear structure. Can perform similar measurements on proton target to estimate the saturation in proton vs nuclei. Challenging experimentally.

Summary

- LHeC and FCC-eh are electron-proton facilities which represent seminal opportunity to advance particle physics
- Broad physics potential: QCD studies, both precision and discovery, precision Higgs and EW, expand prospects for BSM, physics with nuclei
- New possibilities for diffraction at LHeC and FCC-he:
  - Inclusive diffraction, constraints on diffractive PDFs, increased accuracy by factor 10 at LHeC and 20 at FCC-eh
  - New final states in diffraction, possibility of producing diffractive top. Also EW exchange. Relation between diffraction and shadowing
  - First extraction of diffractive nuclear PDFs would be possible
  - Exclusive diffraction, vector meson production, t-dependence provides information about the spatial structure. Also DVCS