

# Electron-Ion Collisions at the LHeC and FCC-eh

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Diffraction and Low- $x$

29th September 2022



# Motivation

- DIS is a precise process with a point-like probe
  - Clean experimental environment
  - Controlled theoretical setup:  
first-principle QCD calculations
- Collider DIS only done with a proton target
  - Possibility to study nuclear effects with  
LHeC and FCC-eh
- LHeC/FCC-eh CDR: [J.Phys.G 48 \(2021\) 11, 110501](#)

CERN-ACC-Note-2020-0002  
Geneva, July 28, 2020



The Large Hadron-Electron Collider at the HL-LHC

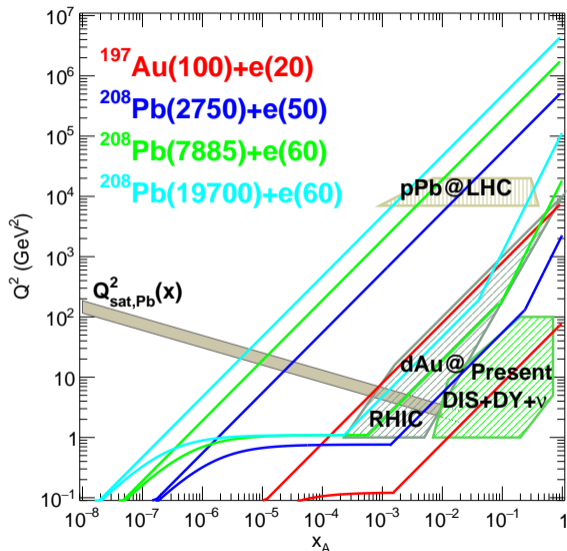
LHeC and FCC-eh Study Group



To be submitted to J. Phys. G

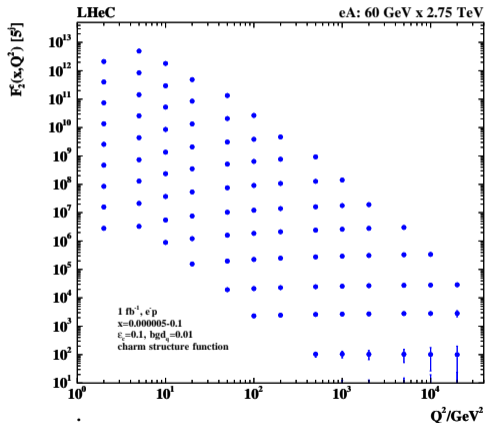
# LHeC and FCC-eh kinematics

- Large  $\sqrt{s} \Leftrightarrow$  small  $x$
- Wide range in  $x$  and  $Q^2$
- Perturbative region up to  $x \sim 10^{-7}$ 
  - Unexplored region!
- Non-linear effects important at  $Q^2 \lesssim Q_{\text{sat}}^2 \sim A^{1/3} x^{-0.2}$
- Higher  $\sqrt{s}$  than in previous DIS experiments
  - LHeC: 0.74 TeV
  - FCC-eh: 2.2 TeV

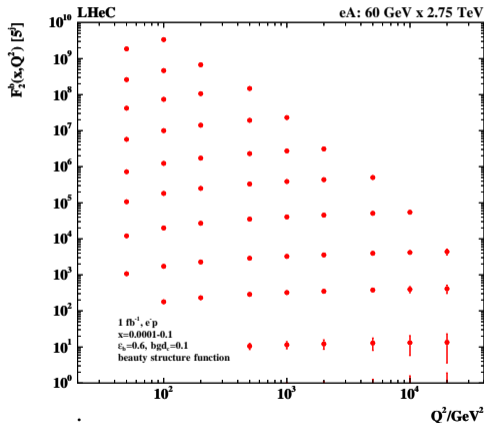


# Structure functions

Very precise structure function measurements, even for heavy quarks



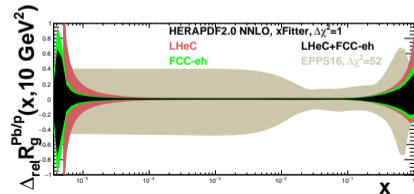
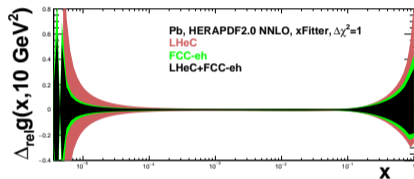
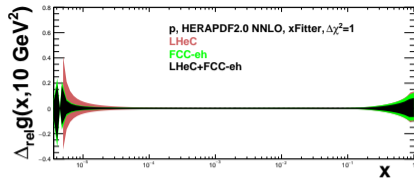
Charm:  $x = 5 \cdot 10^{-6} - 0.1$



Bottom:  $x = 5 \cdot 10^{-4} - 0.1$

# PDFs from single nucleus fit

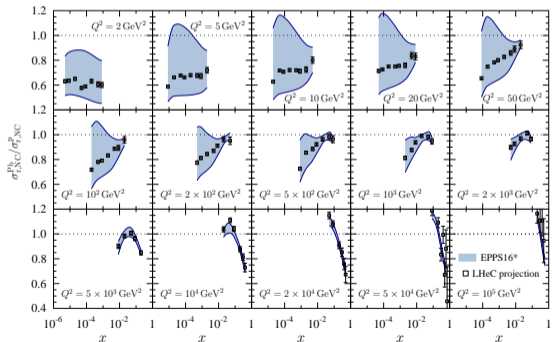
- LHeC data allows for determining PDFs separately for different nuclei
  - No need to model  $A$  dependence
- Ultimate precision for nuclear PDFs
  - Pb: uncertainty  $< 10\%$  down to  $x \sim 10^{-5}$
- Can be included in the global PDF analysis
  - Precision test for collinear factorization using nuclei



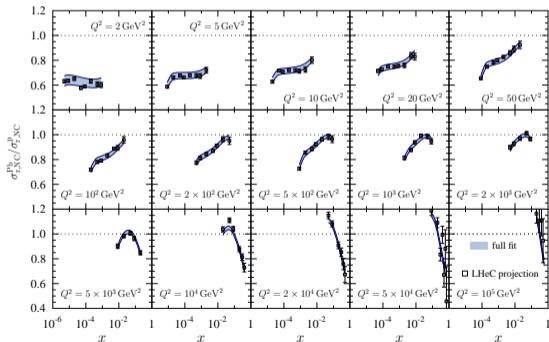
# Nuclear modification in structure functions measurements

$\sigma_r^{\text{Pb}}/(A\sigma_r^{\text{p}})$ : Pseudodata calculated assuming EPPS16 nuclear effects. High precision possible!

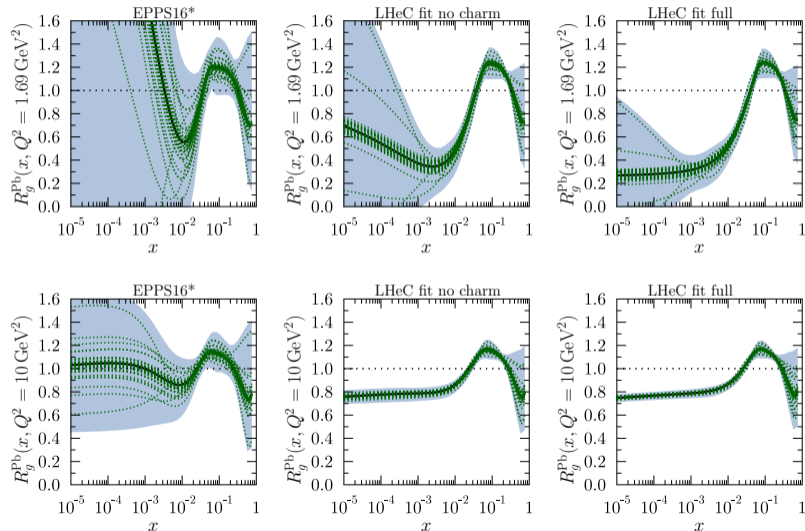
Fit without LHeC pseudodata



Fit with LHeC pseudodata

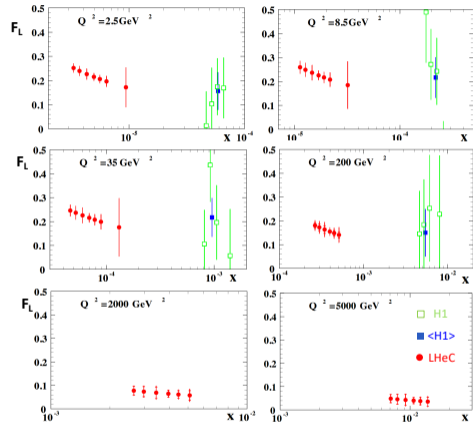
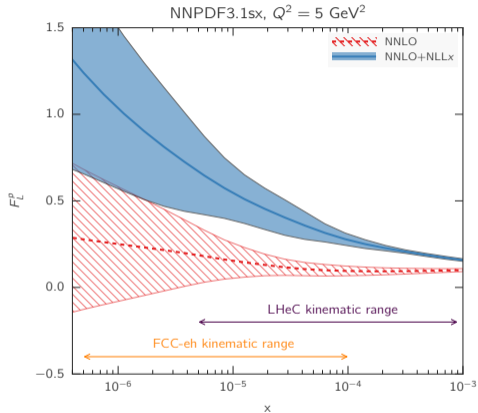


# Nuclear modification factor



- $R_i^A$  = nuclear modification to the free nucleon parton distribution
- EPPS16\*: unconstrained in the region with no data ( $x \lesssim 10^{-2}$ )
- Large improvements for uncertainties, especially for small  $x$
- Charm data important

# Proton structure function $F_L^P$

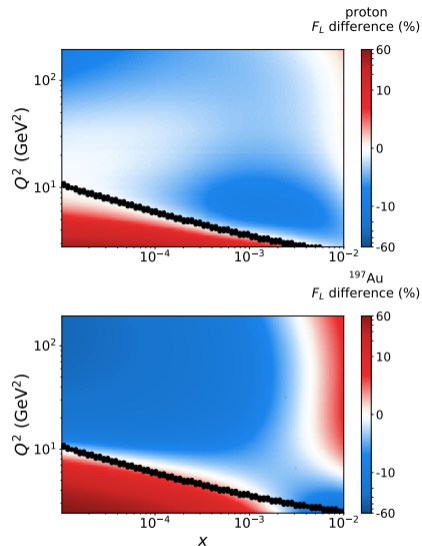


- Small  $x$  effects (BFKL resummation) important at NNLO
- LHeC/FCC-eh data: further tests beyond HERA kinematics, even with different nuclei



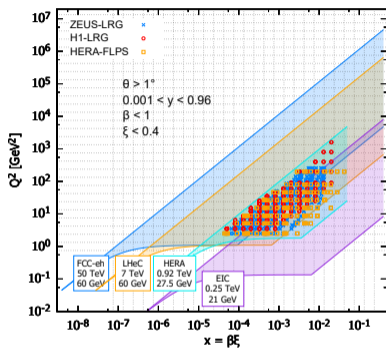
# Nuclear structure function $F_L$

- Plot: difference between DGLAP and CGC calculations
- Tens of percents in the LHeC kinematics
- Data precision at percent level  
⇒ Both linear and nonlinear calculations not expected to work at the same time
- Test of small- $x$  dynamics!



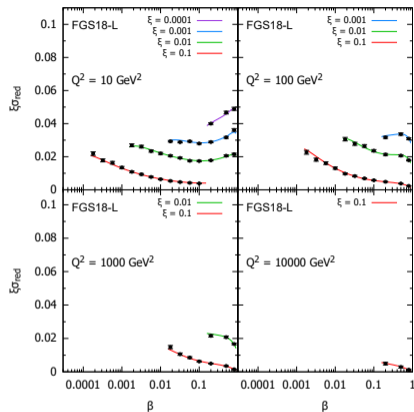
Tevio et al., Phys.Rev.D 105 (2022) 11, 114017

# Nuclear diffractive PDFs



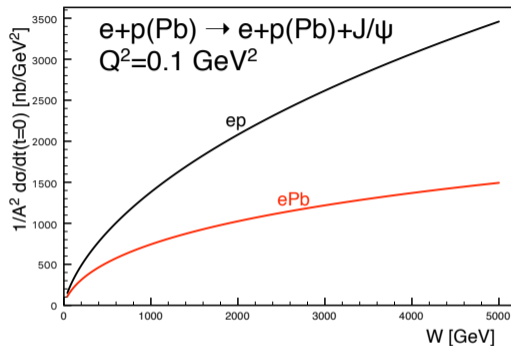
- Diffractive PDFs: measure a parton in the target with the target remaining intact
- Not previously measured for nuclei

e Pb  $E_{p_b}/A = 2.76$  TeV,  $E_e = 60$  GeV,  $L = 2$  fb<sup>-1</sup>

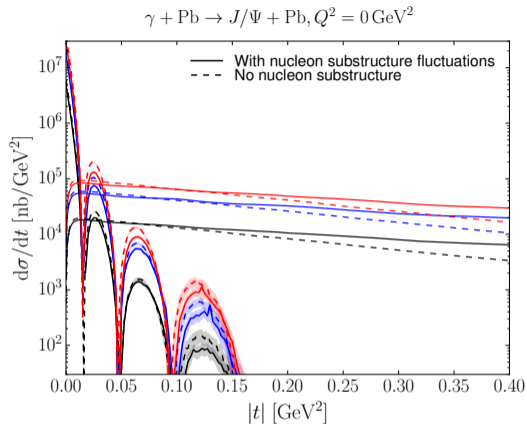


- Sensitive to nonlinear effects
- High precision measurements possible at the LHeC/FCC-eh

# Exclusive vector meson production



Large nuclear suppression: factor of  $\sim 3$   
 $\Rightarrow$  Exclusive  $J/\psi$  production sensitive to nuclear structure



$t$ -spectrum  $\Leftrightarrow$  **b**-distribution of small- $x$  gluons  
 LHeC/FCC-eh kinematical coverage:  
 study  $x$  evolution of geometry

# Summary

- The LHeC and FCC-eh will explore high-energy nuclear DIS in a completely new region in the  $x-Q^2$  plane
- Precise measurements of multiple different observables with different nuclei
  - Total and diffractive structure functions, inclusive and exclusive processes. . .
- Determination of nPDFs at an unprecedented level
- Tests of small- $x$  dynamics and search for saturation
- More information on the CDR: [J.Phys.G 48 \(2021\) 11, 110501](#)