

Open kick-off meeting of the ep/eA@CERN Study  
October 31<sup>st</sup> 2023

# Proton and nuclear structure from EIC and HERA (and LHC) to LHeC and FCC-eh

WG Conveners:

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Paul Newman (*Birmingham*, [paul.newman@cern.ch](mailto:paul.newman@cern.ch))

WG indico page: <https://indico.cern.ch/category/17307/>

# The ep/eA study at the LHC and FCC – new impactful goals for the community

**WG1**

2023

WS

2024

WS

2025

TWS

input to ESPP

**proton and nuclear structure from EIC and HERA to LHeC and FCC-eh**

*novel QCD with high-energy DIS physics: what do we discover when breaking protons and nuclear matter in smaller pieces*

**general-purpose high-energy physics programme: precision physics and searches**

*enabling direct discoveries and measurements in EW, Higgs and top physics with high-energy DIS collisions*

**ep-physics empowering pp/pA/AA-physics (LHC and FCC)**

*improving the ATLAS, CMS, LHCb and ALICE discovery potential with results from a high-energy DIS physics programme*

**developing a general-purpose ep/eA detector for LHeC and FCC-eh**

*critical detector R&D (DRD collaborations), integrate in the FCC framework, one detector for joint ep/pp/eA/pA/AA physics*

**developing a sustainable LHeC and FCC-eh collider programme**

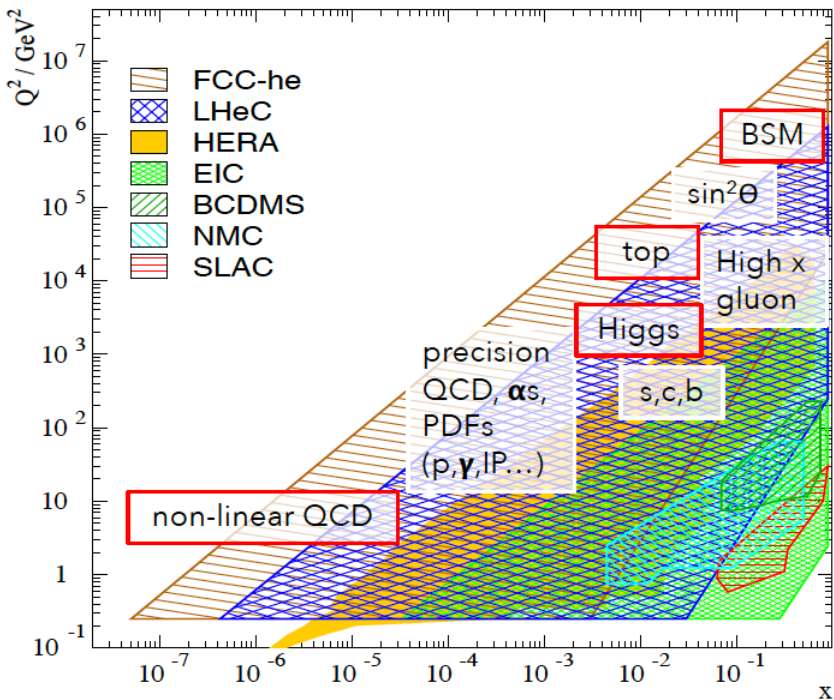
*design the interaction region, power and cost, coherent collider parameters & run plan, beam optimization, ...*

- typically 2-3 conveners per theme
- annual ep/eA workshops (WS)
- **final thematic workshop with closing reports to inform the upcoming Strategy process with impactful information (TWS)**
- inform the community with regular ep/eA Newsletters
- everybody is welcome to join

**Coordination Panel:** N. Armesto, M. Boonekamp, O. Brüning, D. Britzger, J. D'Hondt (spokesperson), M. D'Onofrio, C. Gwenlan, U. Klein, P. Newman, Y. Papaphilippou, C. Schwanenberger, Y. Yamazaki

# Proton & Nuclear Structure – Opportunities and Impact

**Large extension of the kinematic plane  $\Rightarrow$   
unprecedented possibilities for precise understanding of p/A structure and q/g dynamics**



**x15/120 extension in  $Q^2$ ,  $1/x$  reach wrt HERA**

## Open questions:

- Precise PDFs without uncertainties inherent of pp/pA/AA (e.g., factorization, additional physics,...).
- Complete unfolding of all parton species.
- Existence and characterization of a new, non-linear, regime of QCD.
- 3D structure in the region of interest for future hadronic colliders.
- Complementarity/synergy with EIC and LHC.

Note: plots taken from the CDR Update, 2007.14491, unless otherwise stated.

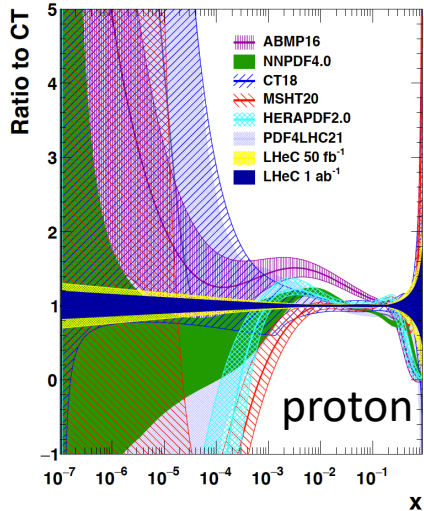
# Proton & Nuclear Structure – Objectives and Challenges

→ Precise determination of collinear PDFs in ep and eA, and  $\alpha_s$ :

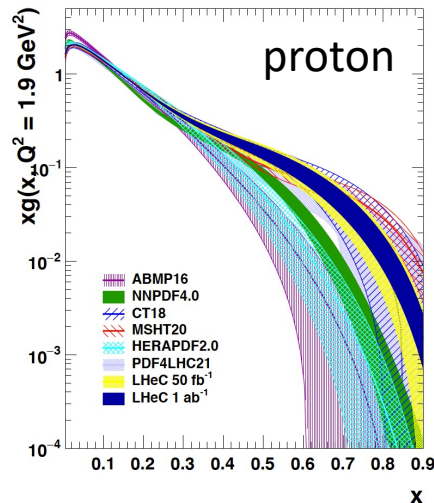
- Highlight the role of DIS versus hadronic collisions.
- Establish the complementarity with the EIC and the LHC.
- Need to go to N<sup>3</sup>LO and include EW corrections, and beyond.

DIS offers the cleaner EXP & TH environment, possibility for single experiment/system for complete determination; required for precise SM and BSM prediction for hadronic colliders.

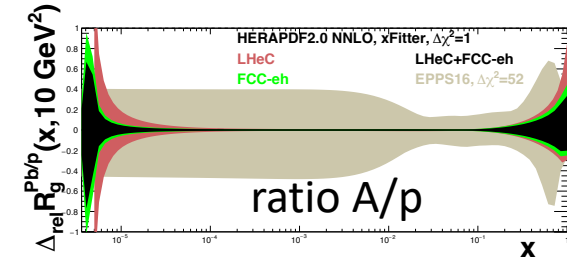
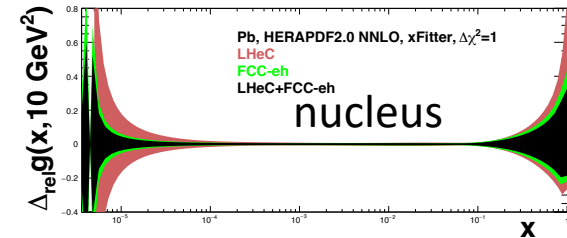
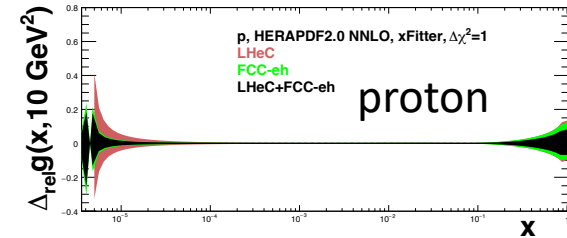
gluon distribution at  $Q^2 = 1.9 \text{ GeV}^2$



gluon distribution at  $Q^2 = 1.9 \text{ GeV}^2$



Uncertainties on the gluon

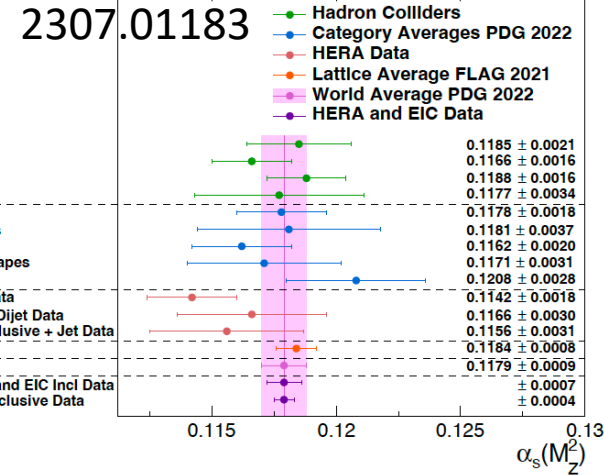
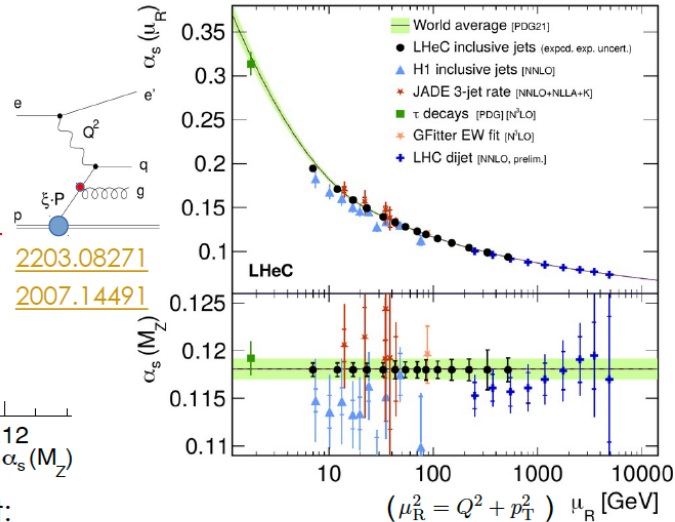
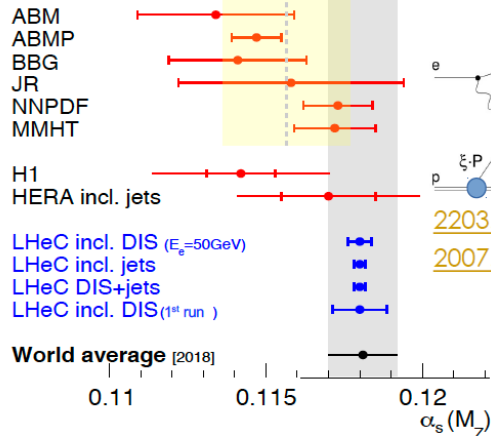


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$\alpha_s$  determinations at NNLO QCD:



➤ LHeC simultaneous PDF+ $\alpha_s$  fit:

- $\Delta\alpha_s(m_Z) = \pm 0.00022_{(\text{exp.}+\text{PDF})}$
- $\Delta\alpha_s(m_Z) = \pm 0.00018$  (with ep jets)

➤  $\alpha_s$  from fits to ep jet production (LHeC)

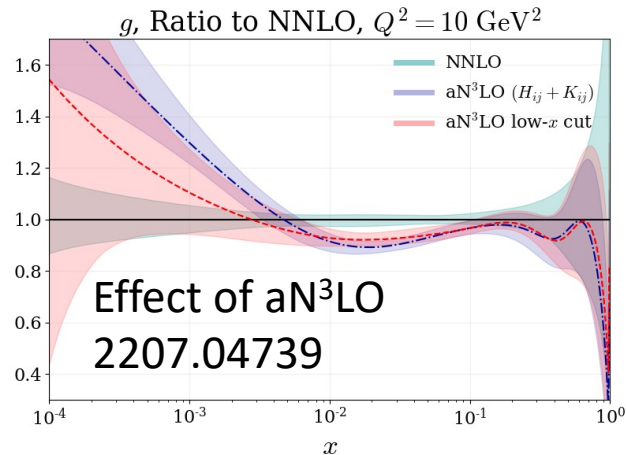
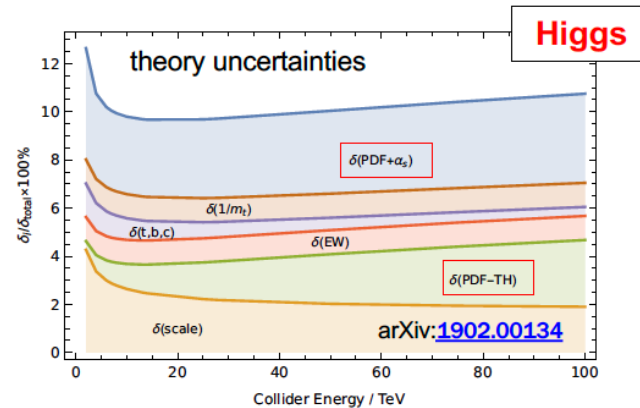
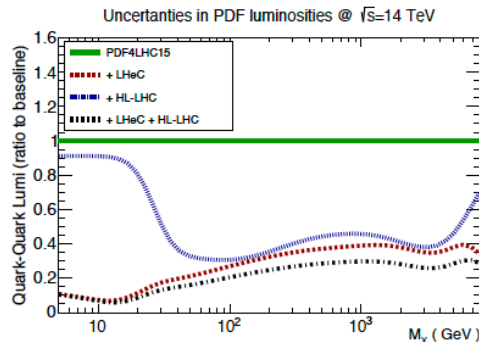
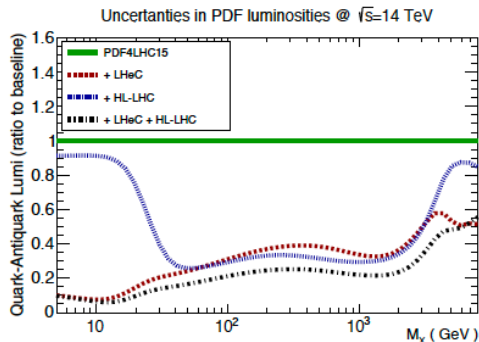
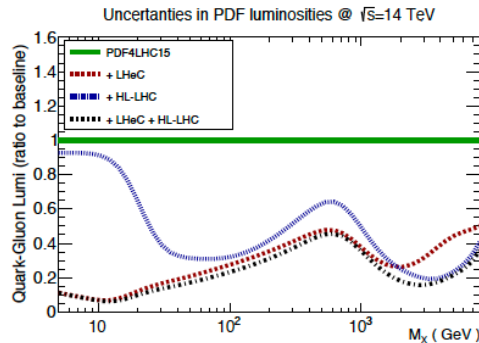
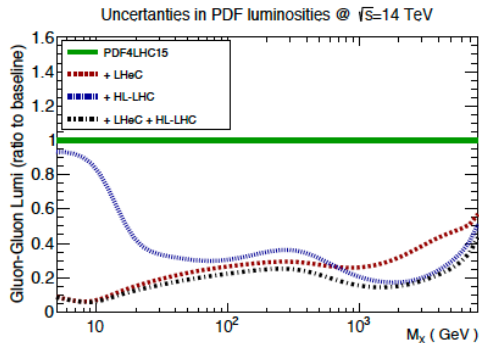
➤ Achievable precision: **0(0.1%)** - **x5-10** better than today

➤ FCC-eh further increases precision and range

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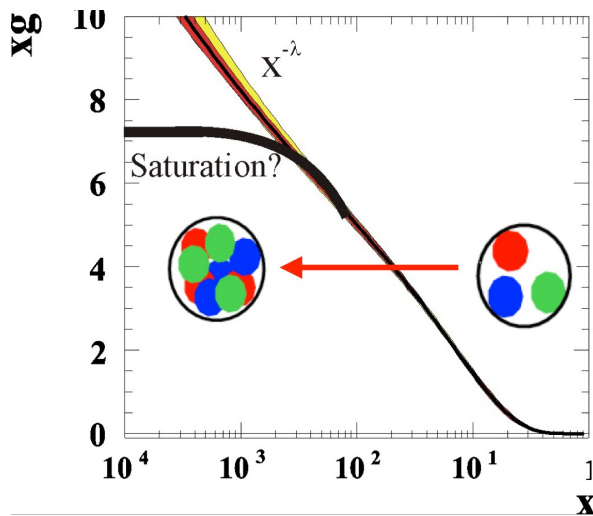


# Proton & Nuclear Structure – Objectives and Challenges

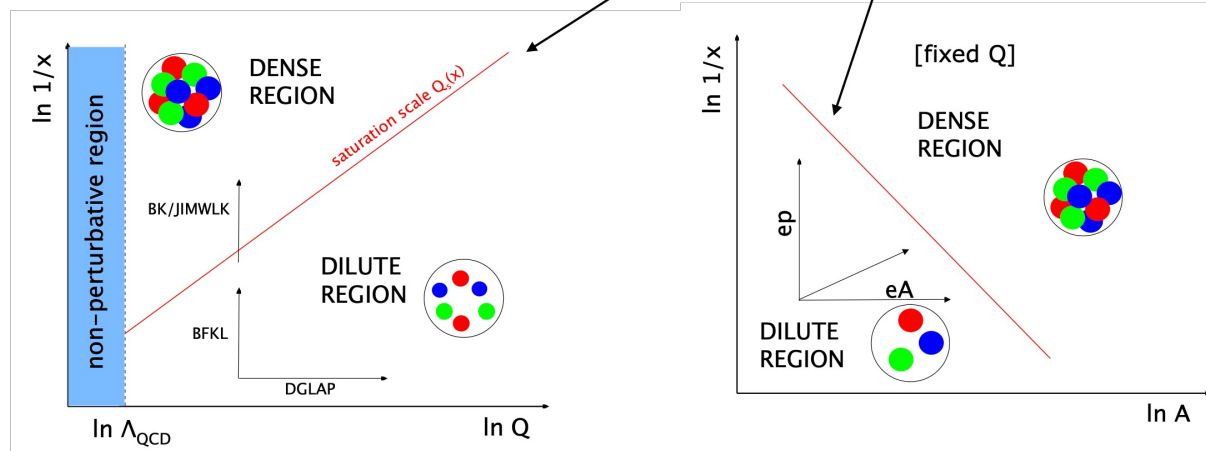
## → New non-linear regime of QCD at small $x$ :

- Use of observables beyond inclusive ones.
- Complementarity with UPCs and pA at the LHC, and the EIC.

DIS offers the cleaner EXP & TH with both protons and nuclei; essential for complete understanding of QCD; relevant for observables in hh/AA at available and higher energies.



$$\frac{xG_A(x, Q_s^2)}{\pi R_A^2 Q_s^2} \sim 1 \implies Q_s^2 \propto A^{1/3} x^{-0.3}$$



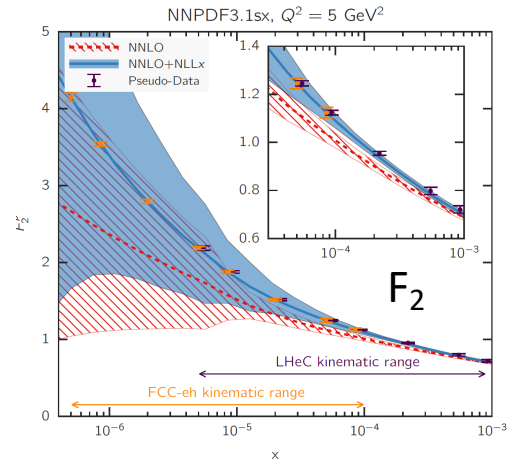


# Proton & Nuclear Structure – Objectives and Challenges

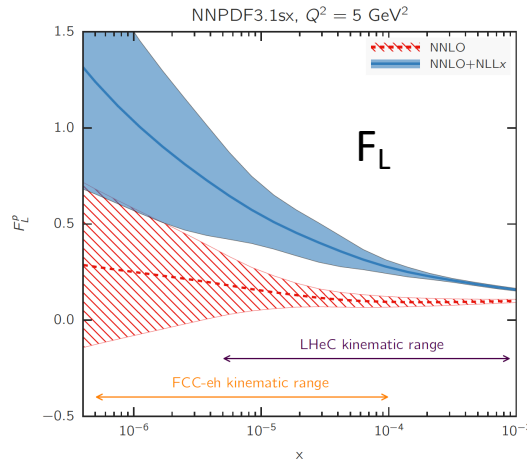
→ **New non-linear regime of QCD at small  $x$ :**

- Use of observables beyond inclusive ones (e.g., diffraction, exclusive production) .
- Complementarity with UPCs and pA at the LHC, and the EIC.

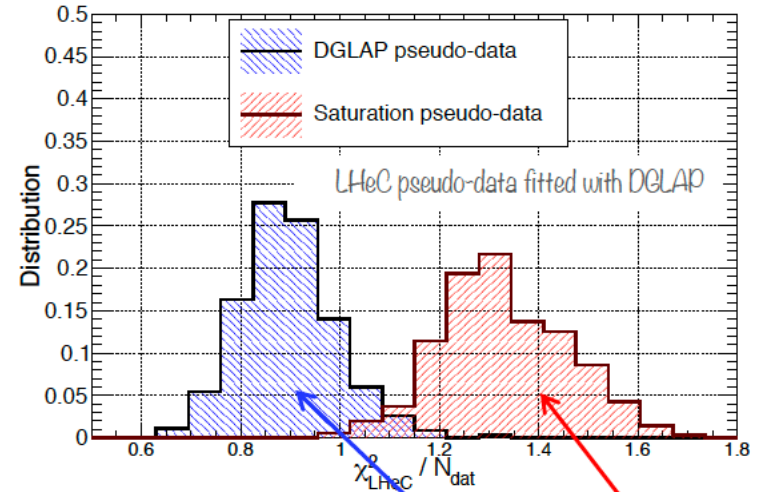
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Effect of resummation



Post-fit results to LHeC (500 pseudo-experiments)



LHeC can distinguish **DGLAP** and **saturation**  
(also 2203.05846)

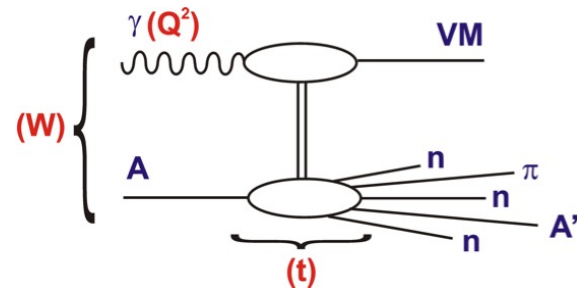
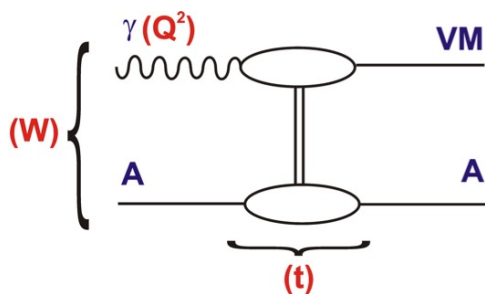
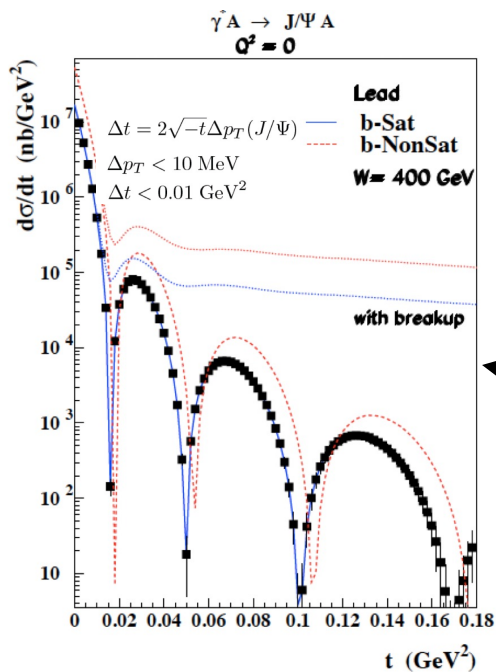


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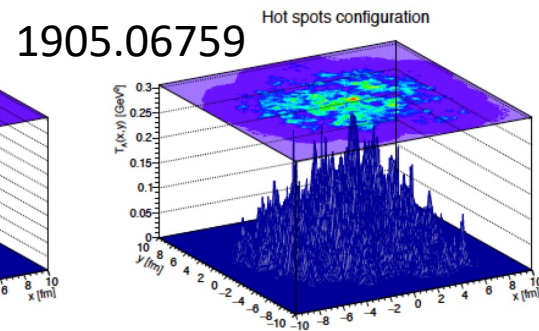
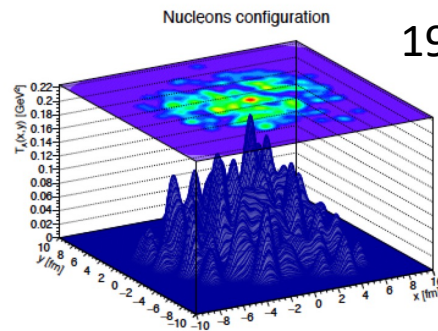
➔ Proton/nucleus structure beyond 1D with diffraction and semi-inclusive observables:

- Establishing a clear path between theoretical concepts and experimental observables.
- Need for dedicated studies in eA to distinguish coherent from incoherent diffraction.
- Elaborate with the TMD community the advantages of large lever arms in  $x$  and  $Q^2$ .

Intrinsic interest in QCD; relevant for MC models, and initial conditions in HIC and small systems.



FT: spatial distribution of gluons (DVCS for quarks)

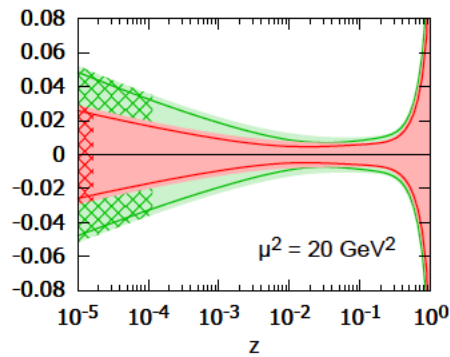
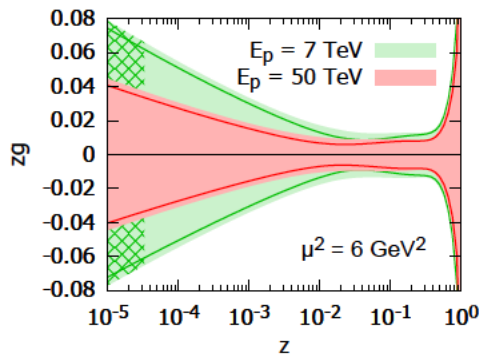
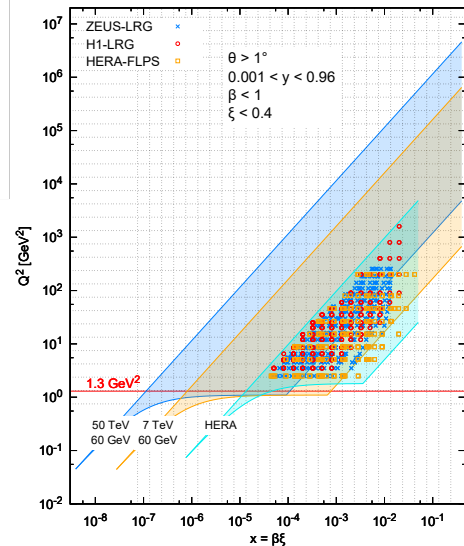
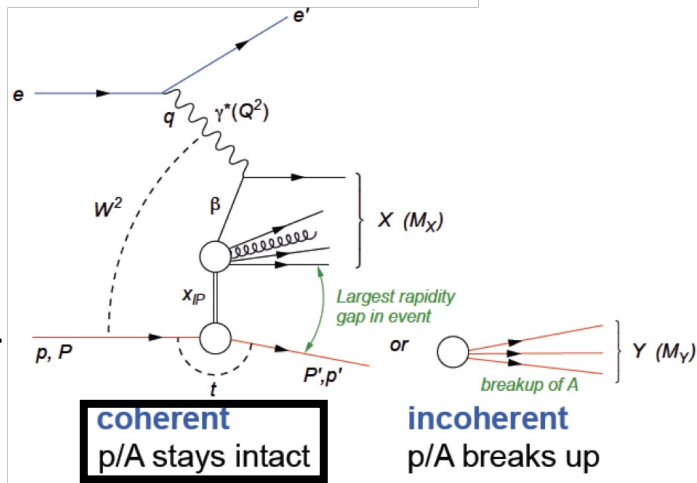


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# Proton & Nuclear Structure – Organisation

## → Collaborations:

- MC community to include LHeC/FCC-eh energies in their plans.
- TH community on radiative corrections for the need of N<sup>3</sup>LO and beyond.
- TH TMD community for studies at small x.
- EIC community about diffraction, 3D structure and PDFs.
- LHC community about PDFs and small x (UPCs and pA).
- Detector WG about detector needs, specifically for diffraction and semi-inclusive measurements.

## → Organisation:

- One subgroup per item (three in total).
- Regular (~ monthly meetings ) of the subgroups.
- One workshop per year, all three subgroups together.

**Self-subscribe to the WG mailing list:** [ep-eA-WG1-structure@cern.ch](mailto:ep-eA-WG1-structure@cern.ch).

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