Light (Anti)Nuclei Production via Coalescence in Electron–Proton Collisions: from HERA to EIC

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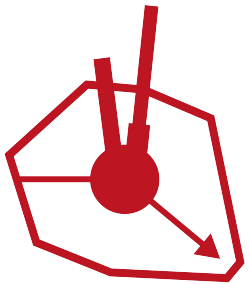


DIS2026

DIS 2026 - Bologna - 07/05/2026

Motivation

Light nuclei and antinuclei are a laboratory to study the **nuclear strong interaction**

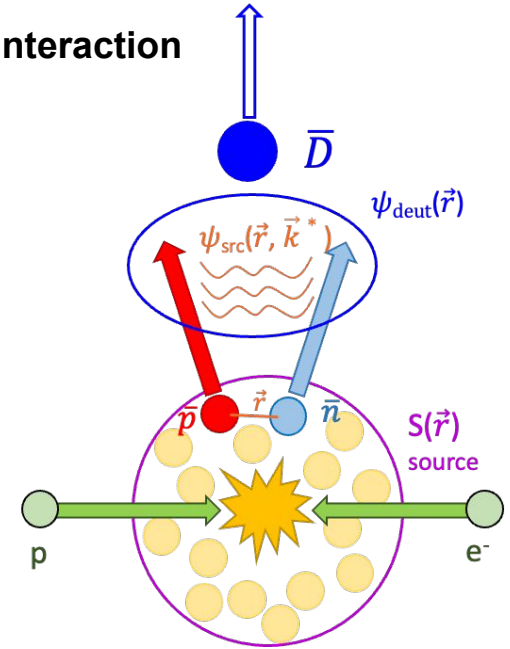
In high-energy collisions, light (anti)nuclei can be produced by nucleon fusion → modelled via **coalescence** [1, 2, 3]

The mechanism is sensitive to the distributions of protons and neutrons (*the nucleon **source***) produced in the collisions

High-energy ep, eA collisions (DIS) provide:

- a **cleaner** initial state as compared to pp, AA
- a possibility to test the **universality** of the process

Conversely the measurement of D vs $\overline{D}$ production in the proton region is sensitive to the proton and nuclear PDFs

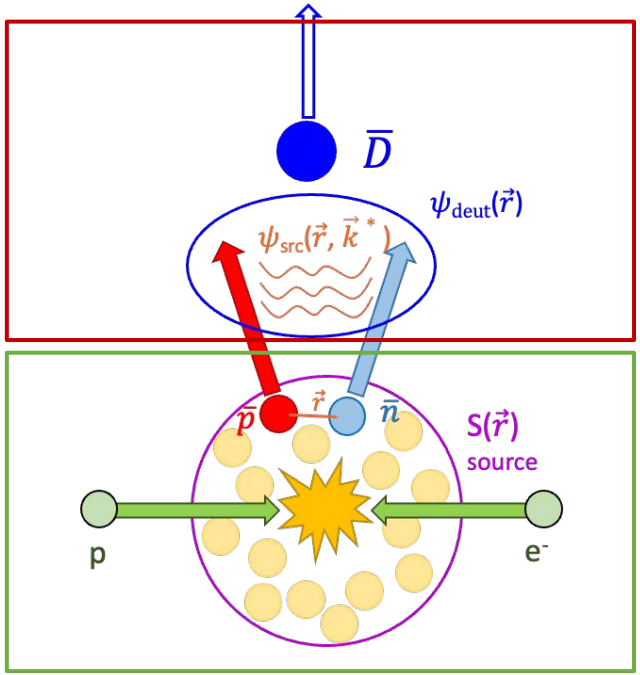


[1] Kapusta, J. I., Phys. Rev. C 21, 1301 (1980)

[2] Scheibl, R., Heinz, U., Phys. Rev. C 59:1585-1602 (1999)

[3] Blum K., Phys. Rev. D 96.10 (2017)

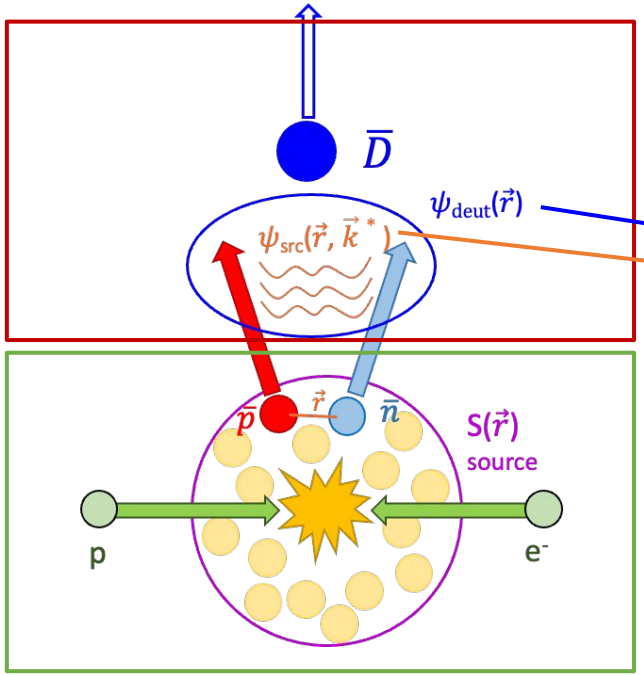
Simulation strategy



To simulate the production of nuclei, **PYTHIA8 is employed**, followed by a **custom afterburner** [4] implementing the **coalescence** model.

[4] Mahlein M., Eur. Phys. J. C 83.9 (2023)

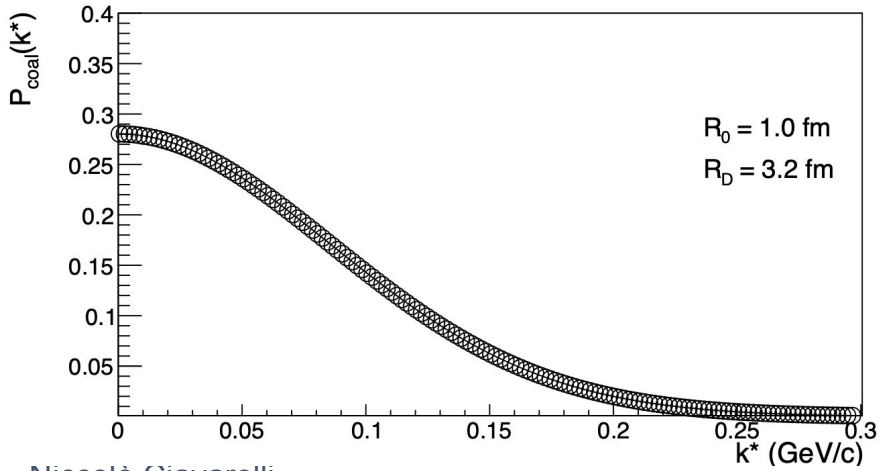
Simulation strategy



To simulate the production of nuclei, **PYTHIA8 is employed**, followed by a **custom afterburner** [4] implementing the **coalescence** model.

The coalescence probability is the scalar product of a gaussian source wave function and the (anti)deuteron (D) ground state

$$P_{coal}(k^*) = \frac{3}{8}\left|\langle \psi_{src}(\vec{r}, \vec{k}^*) \, | \, \psi_{deut}(\vec{r}) \rangle\right|^2$$



$$k^* = \frac{|\mathbf{p}_1^* - \mathbf{p}_2^*|}{2}$$

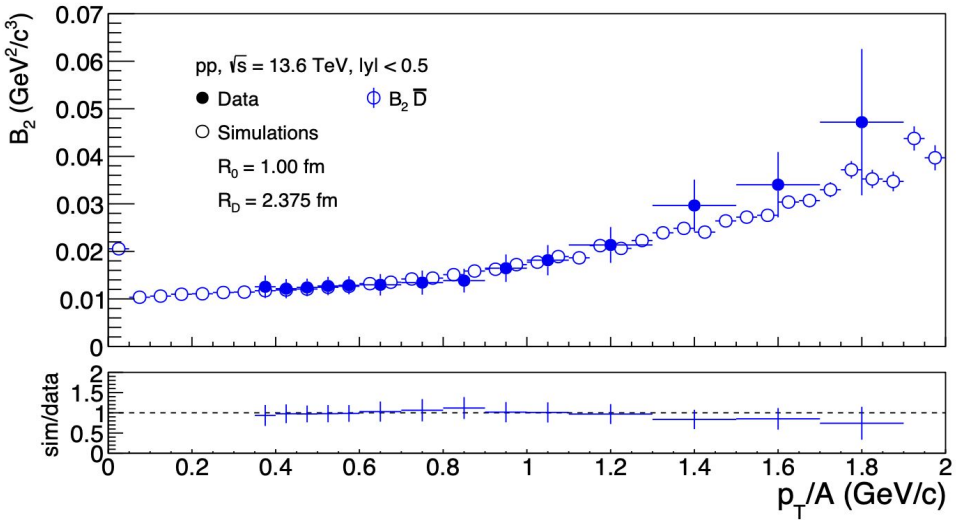
relative momentum of particle pairs in the pair rest frame

[4] Mahlein M., Eur. Phys. J. C 83.9 (2023)

Validation with pp collision data from ALICE

The model was first tuned* with pp collision and validated against ALICE data [5]

Observable: coalescence parameter B_2 $\quad B_2 = \dfrac{\bar{D}\ energy\ distribution}{(\bar{p}\ energy\ distribution)^2}$



- B_2 shows an increasing trend with p_T/A.
- Our model results are consistent with ALICE data [5] within the experimental uncertainties → ratio within the unity

Simulations: 10^9 pp collisions at √s = 13.6 TeV with PYTHIA8 Monash 2013 + **coalescence afterburner**

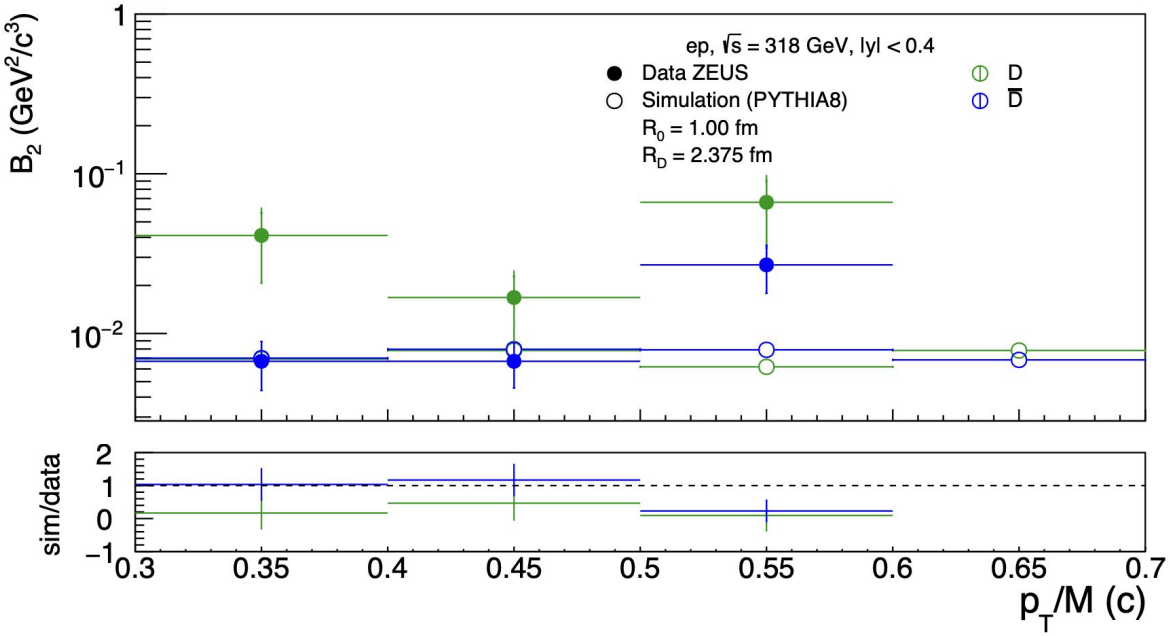
* R_0 (source) and R_D (D size) as free parameters

[5] Eur. Phys. J. C 80.9 (2020)

Validation with ep collision data from HERA

We validate the model in ep collisions first against HERA data

Simulation: 2×10^9 ep collisions at $\sqrt{s}$ = 318 GeV with PYTHIA8 Monash



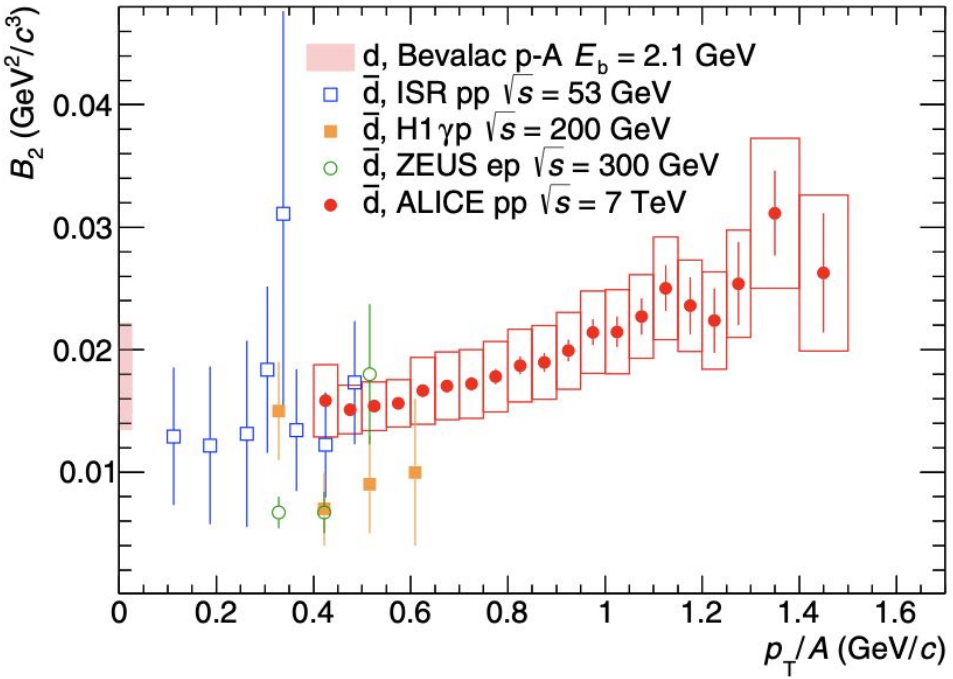
- **Consistent** with ZEUS data [6].
- The **expected symmetry at midrapidity between D and $\overline{D}$** of the coalescence parameter is preserved

[6] ZEUS, Nucl. Phys. B 786 (2007)

Validation with ep collision data from HERA

The first validation in ep collision made with HERA data

Simulation: 2×10^9 ep collisions at $\sqrt{s}$ = 318 GeV with PYTHIA8 Monash



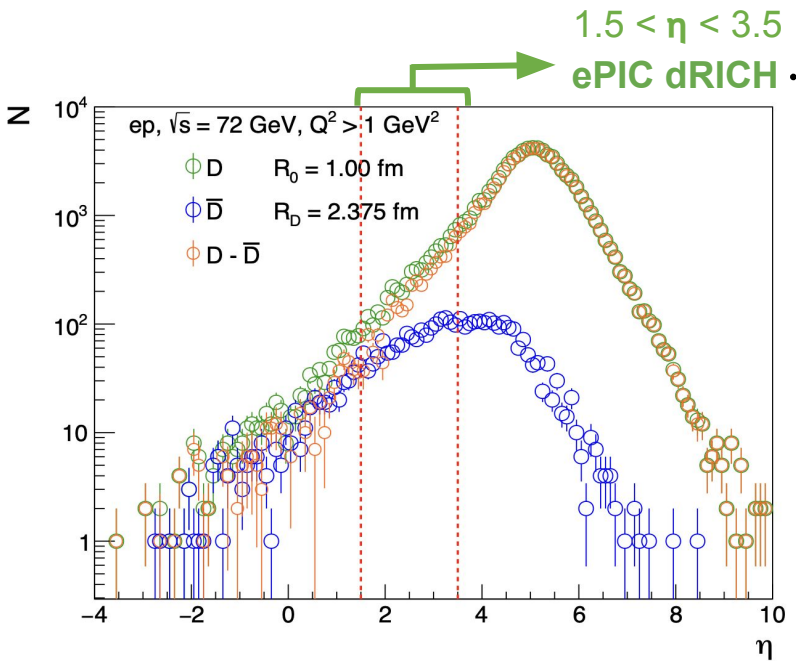
- Test the universality of the process [7] w.r.t. the collision system
  - but HERA has low statistics

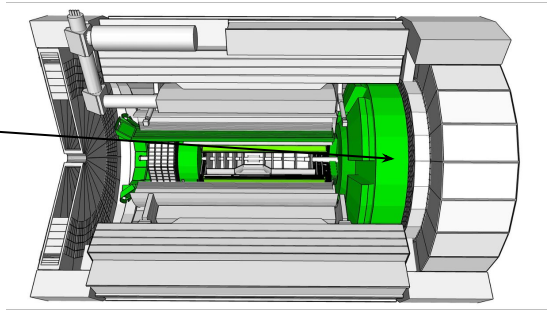
EIC will provide more statistics, improving and refining this measurement.

*[7] ALICE, Phys. Rev. C **97**, 024615*

Production of (anti)deuterons at the EIC

We propose to measure D/$\overline{D}$ production at EIC, with larger integrated luminosity + (Anti)nuclei identification in the ePIC dRICH





Considering $\mathcal{L}$ = 5.33 fb^{-1} for the first year of data taking:

D ~ 600 k
$\overline{D}$ ~ 120 k

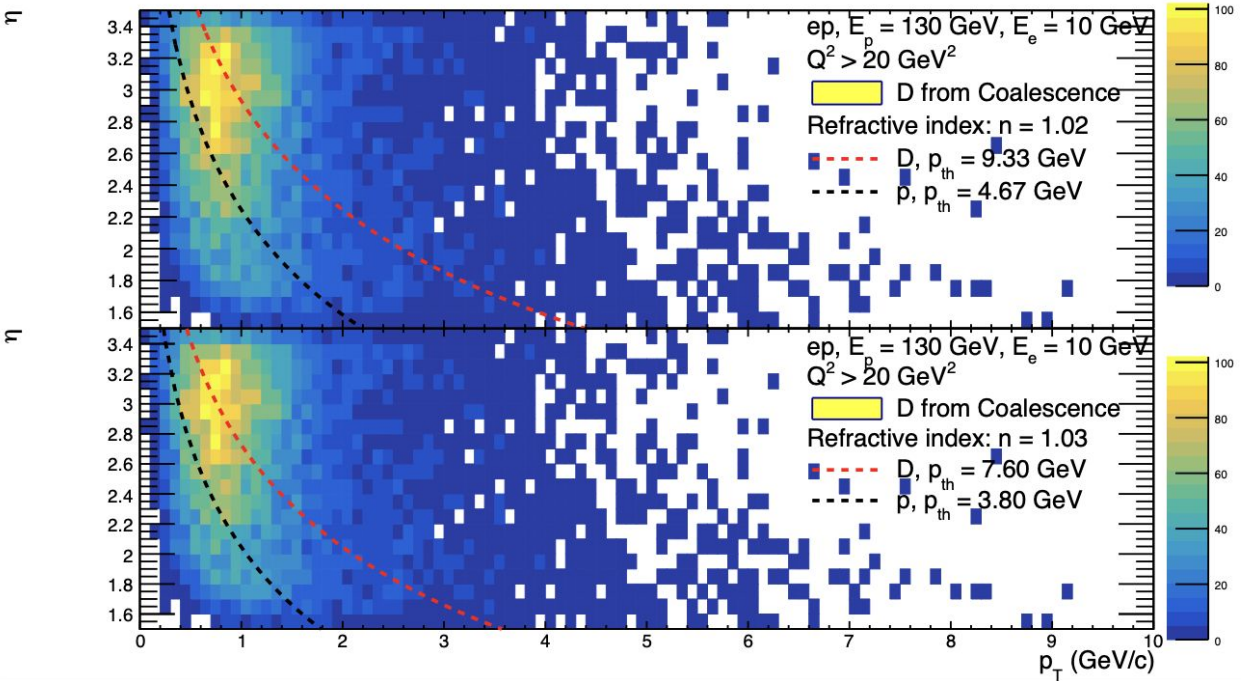
In dRICH acceptance

Forward rapidity chosen for:

- Nuclei-antinuclei asymmetry → sensitivity to PDFs
- Particle ID via dRICH

Simulation: 10^9 ep collisions at E_p = 130 GeV and E_e = 10 GeV with PYTHIA8 Monash

(Anti)Deuteron detection in the ePIC dRICH



dRICH acceptance: $1.5 < \eta < 3.5$

Aerogel radiator with refractive indice between n = 1.02 and 1.03

Two PID thresholds:

- Cherenkov angle measurement (D above threshold)
- Veting hadrons (proton above threshold) when deuteron below threshold

$$p_T = \frac{p}{\sinh(\eta)}$$

Summary

To simulate the production of light nuclei and antinuclei in pp, ep collisions

→ a **coalescence** model has been implemented as a new **custom afterburner**

- versatile implementation → employed with PYTHIA8 input
- **tuned** with ALICE data in pp collisions

Results:

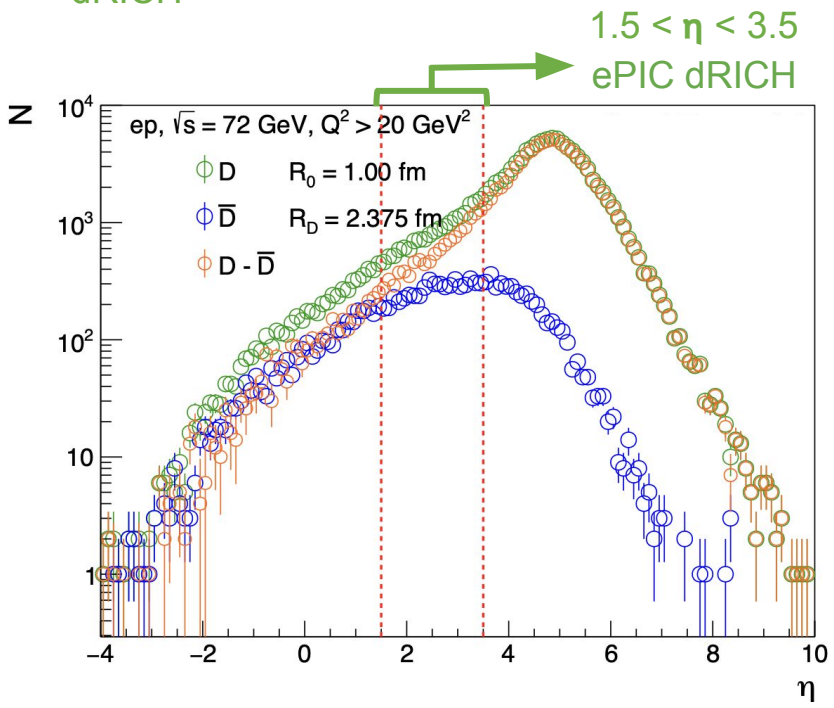
- The model **well reproduces HERA** data
- We obtained a prediction on the production of deuterons and antideuteron at EIC with $\mathcal{L}$ = 5.33 fb^{-1}
- We propose to measure deuteron and antideuteron performing PID with ePIC dRICH

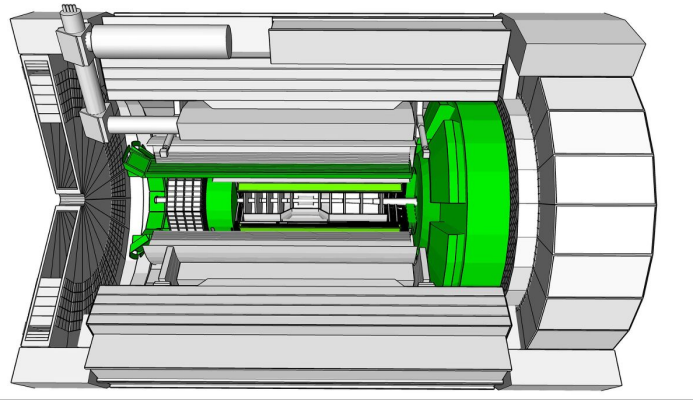
Nuclei and antinuclei production at **EIC** is expected to be **abundant** and **experimentally accessible** offering a new window into **nuclear dynamics** and **PDFs** via such a channel

Thank you

Production of (anti)deuterons at the EIC

We propose to measure D/$\overline{D}$ production at EIC, with larger integrated luminosity and using the ePIC dRICH

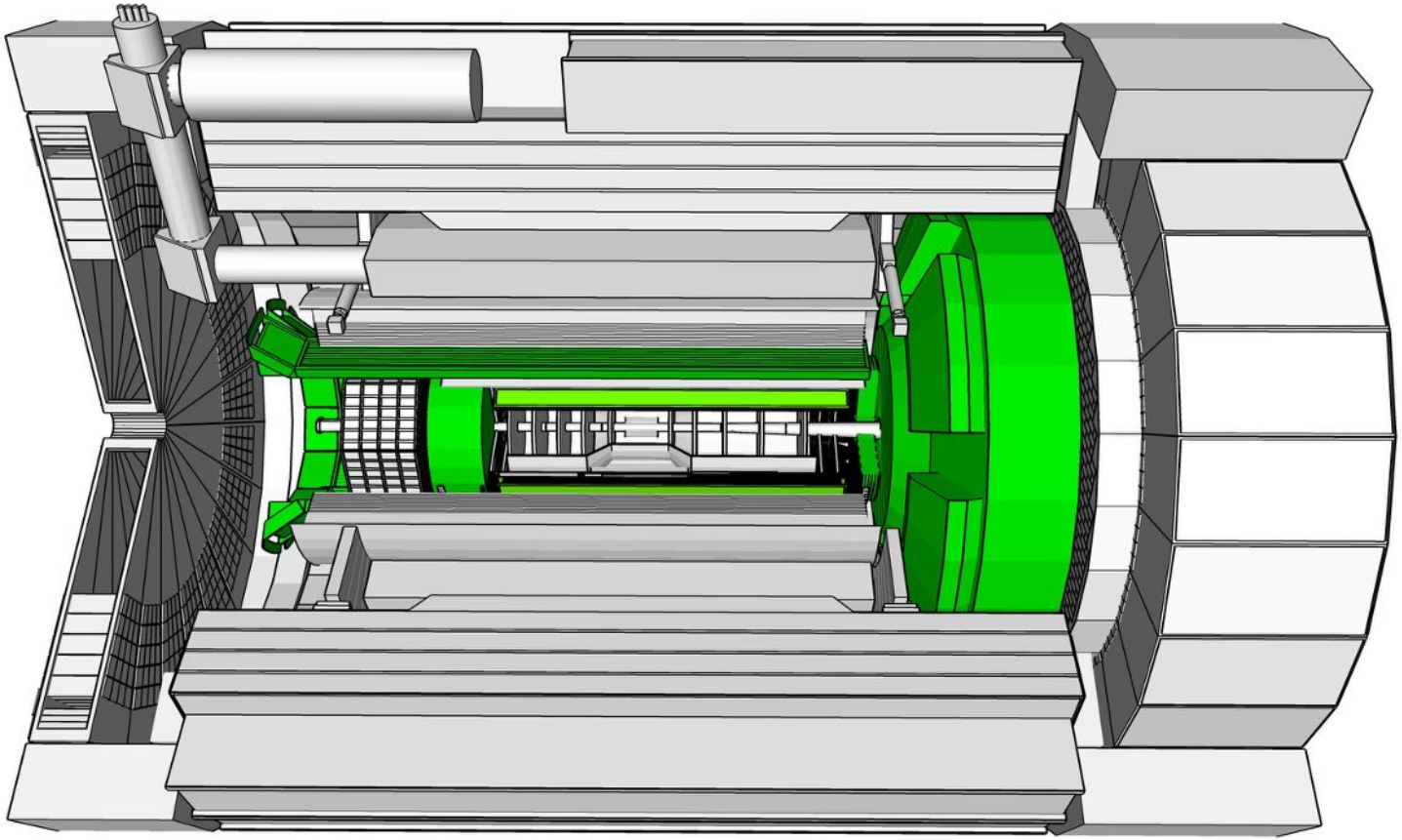




Considering $\mathcal{L}$ = 5.33 fb^{-1} for the first year of data taking:

D ~ 245 k **In dRICH**
$\overline{D}$ ~ 26 k **acceptance**

Forward rapidity chosen for:

- Nuclei-antinuclei asymmetry → sensitivity to PDFs
- Particle ID via dRICH

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