# The ALICE FoCal upgrade and ALICE 3

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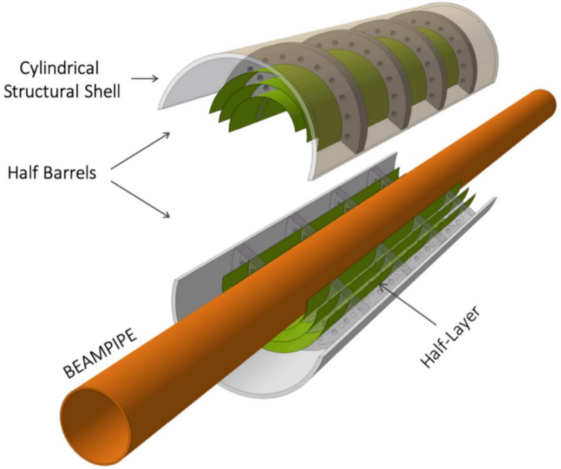
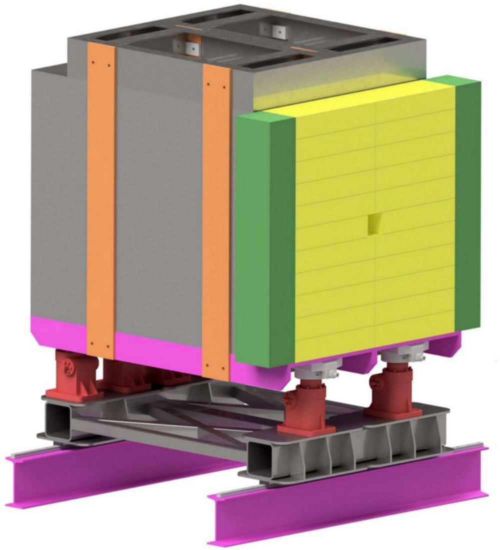
on behalf of the ALICE Collaboration

**Synergies between the EIC and the LHC, 22-24 Sept 2025, Krakow**

# ALICE upgrades timeline: ITS3 and FoCal

| Run 3 | LS3 | Run 4 | LS4 | Run 5 |
|---|---|---|---|---|
| | 2026-2029 | 2030-2033 | 2034-2035 | 2036 - |



- TDRs approved in 2024
- To be installed during LS3
- Moving towards production phase

ITS3 TDR: CERN-LHCC-2024-003

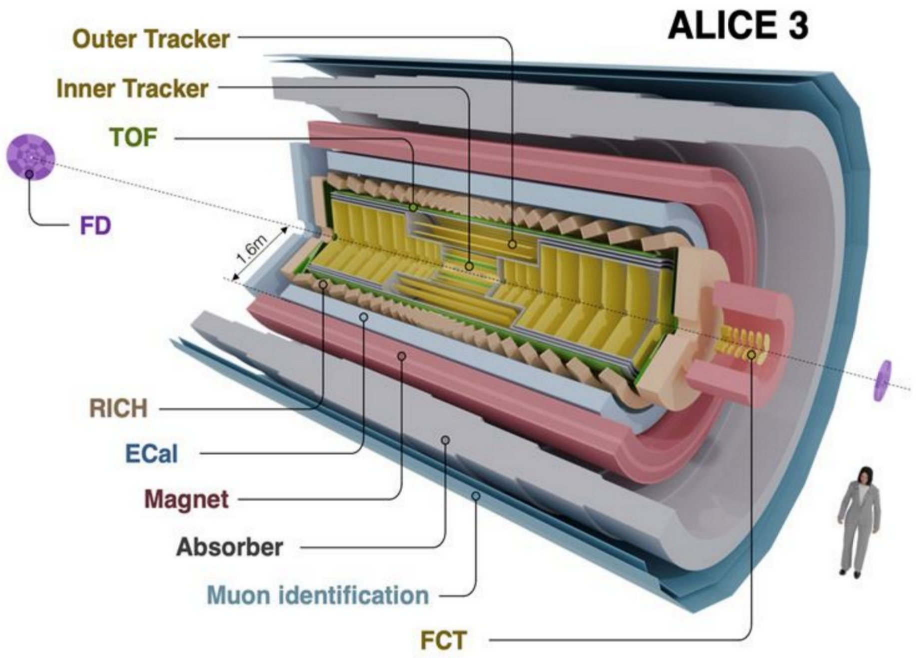
FoCal TDR: CERN-LHCC-2024-004

# ALICE upgrades timeline: ALICE3

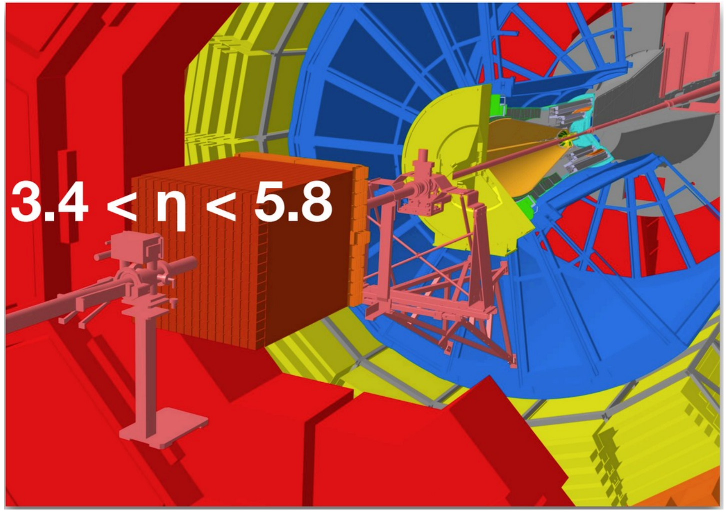
| Run 3 | LS3 | Run 4 | LS4 | Run 5 |
|---|---|---|---|---|
| | 2026-2029 | 2030-2033 | 2034-2035 | 2036 - |

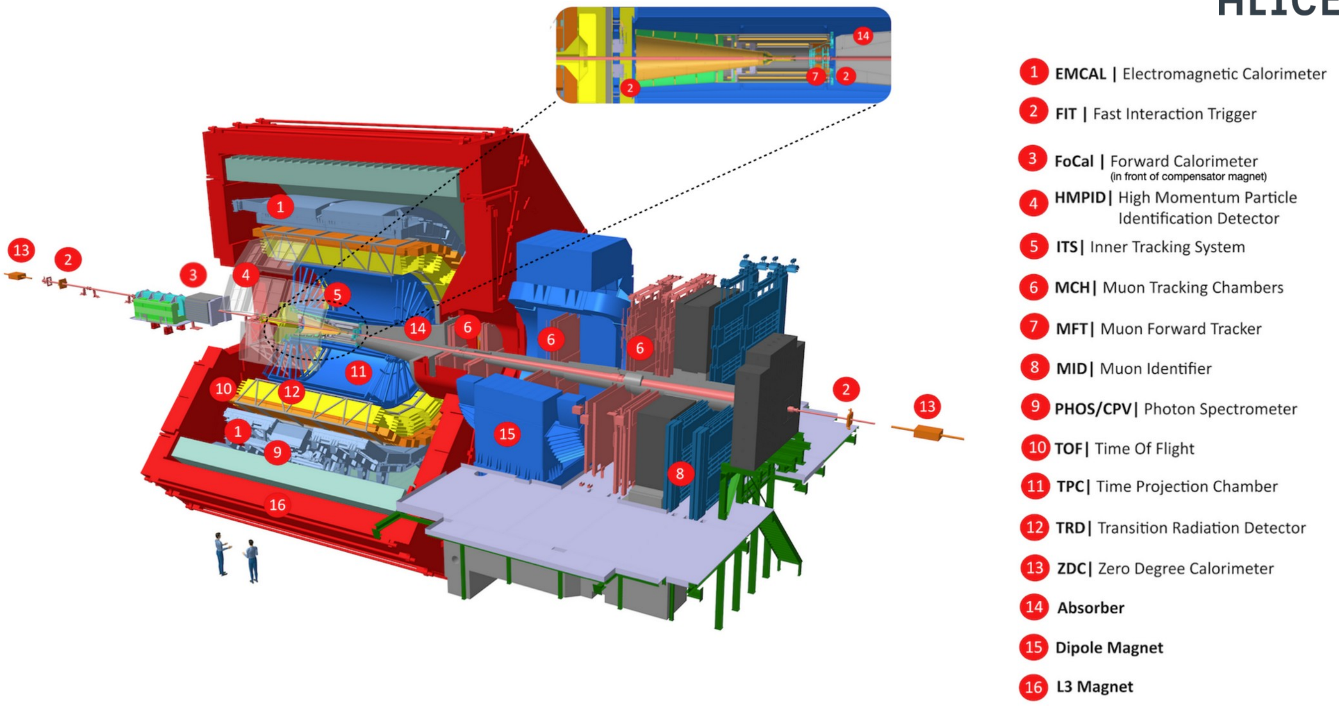
ALICE3 Loi: CERN-LHCC-2022-009
Scoping document: CERN-LHCC-2025-002

- Scoping document review completed in 2025
- Installation foreseen during LS4
- Ongoing R&D phase



# The ALICE detector + FoCal

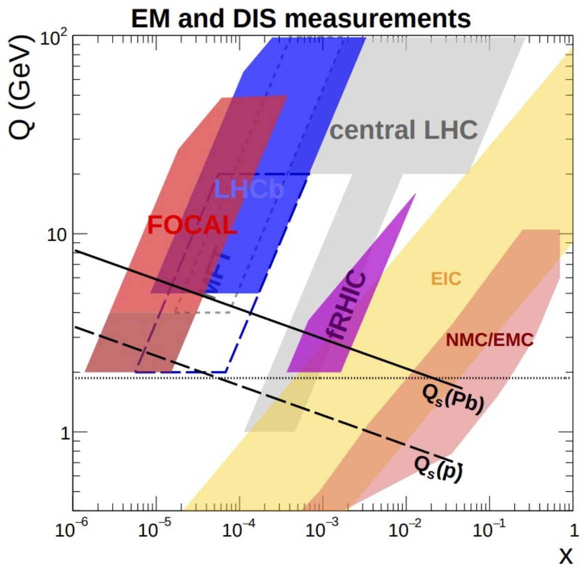


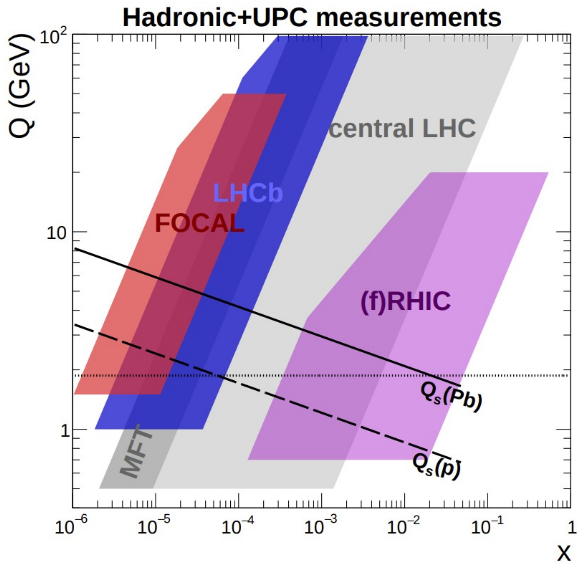




**Fo**rward **Cal**orimeter
- Electromagnetic: FoCal-E
- Hadronic: FoCal-H

- Positioned at 7m from IP2 on A-side
- Covering $3.4 < \eta < 5.8$

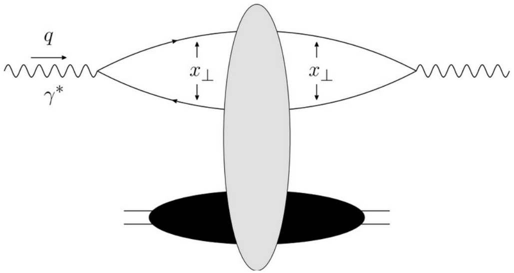
# Physics program of FoCal



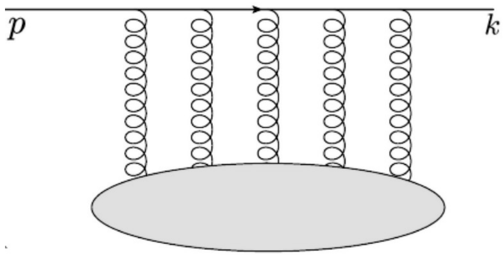

- Expand sensitivity to gluon distributions into previously unexplored regions at the LHC
- Explore non-linear evolution and nPDFs using multiple experimental observables
  - Prompt γ
  - γ – hadron correlations
  - Photoproduction in UPCs
  - Jets
  - Hadroproduction of neutral mesons, quarkonia, $Z^0$

**(e+A DIS)**




Gribov, JETP 30 (1970) 709

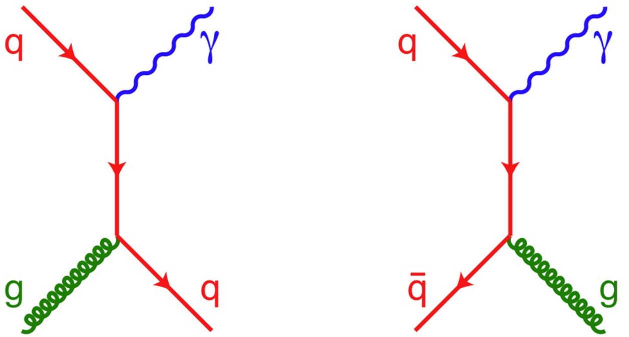
**(Forward p+A)**



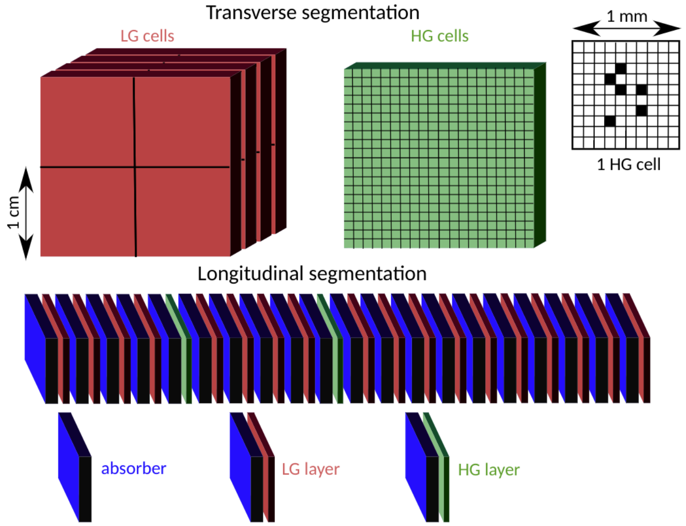

Kopeliovich, Phys.Rev.C 59 (1999) 1609

- Complementarity with the EIC
  - Multiple processes in e-A and forward p-A are theoretically described using the same scattering amplitudes
  - Test universality of the description of gluon distributions in hadrons

# FoCal design and challenges: FoCal-E




a) Compton b) annihilation




Design optimized for direct γ measurements

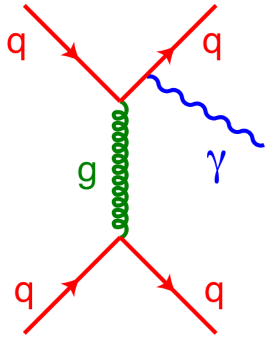
**Challenges:**

- Discriminate direct and decay photon showers (requires small Molière radius and high granularity readout)

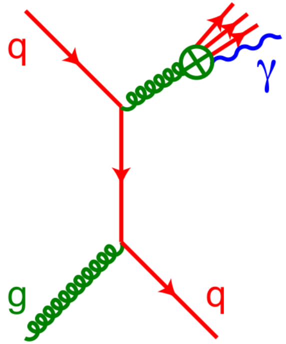
**FoCal-E**

- High granularity Si-W calorimeter
- Longitudinal segmentation (20 layers)
  - 3.5mm W in each layer (1 $X_0$)
  - 18 pad layers (1x1 cm$^2$)
    - Energy measurement
  - 2 pixel layers (30x30 μm$^2$)
    - Two shower separation

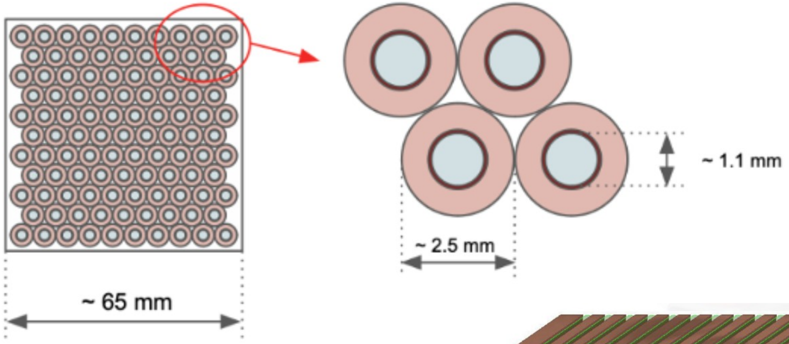
# FoCal design and challenges: FoCal-H

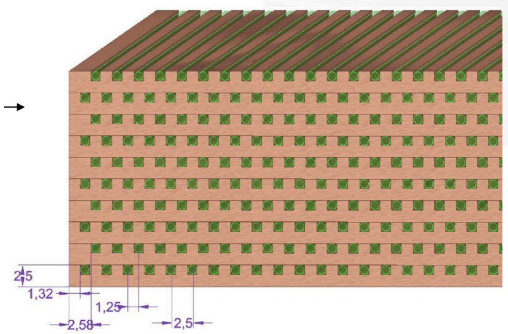



c) bremsstrahlung




d) fragmentation




Design optimized for direct γ measurements

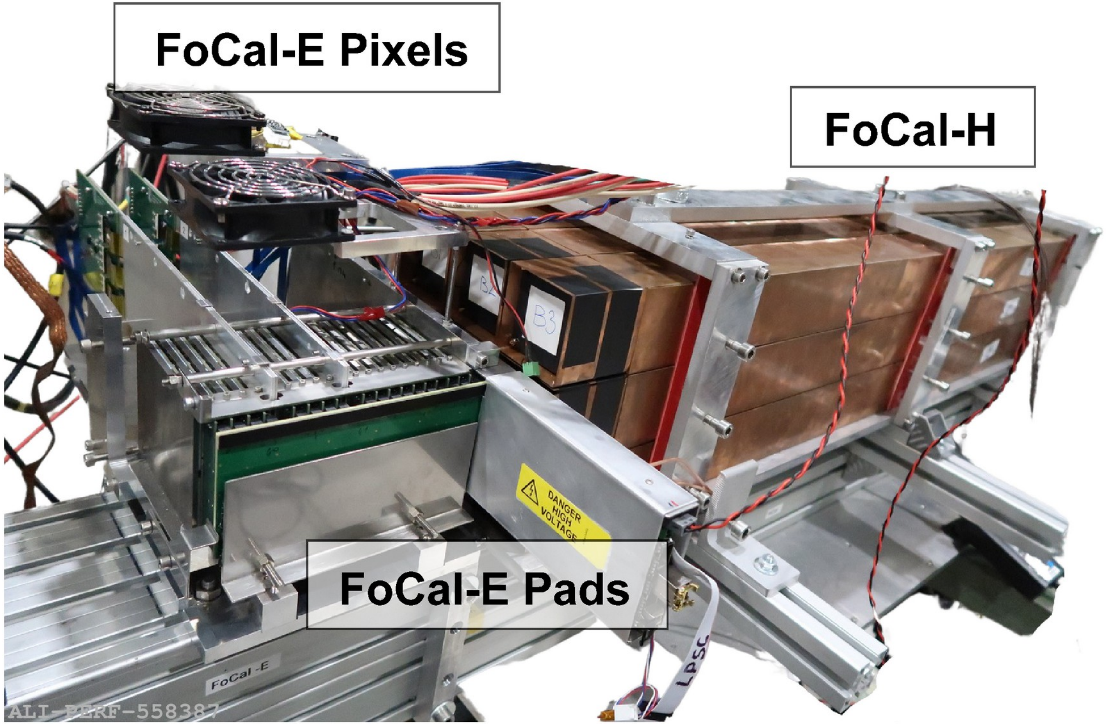
**Challenges:**

- Suppress bremsstrahlung and fragmentation γ (requires measurement of hadronic showers)

**FoCal-H**

- Spaghetti hadronic calorimeter (Cu + fibers)
  - Photon isolation, hadronic jet components
- Design A: capillary tubes
- Design B (since 2025): grooved plates

# FoCal prototype

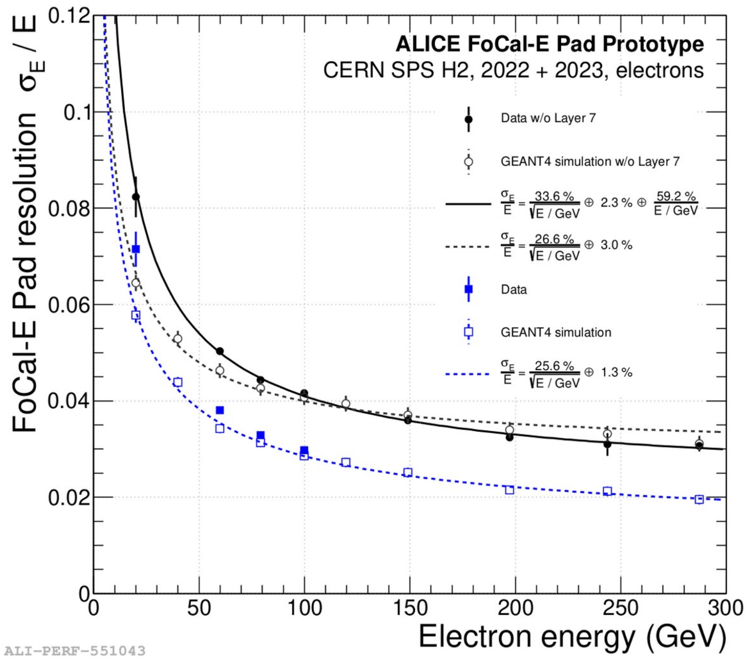


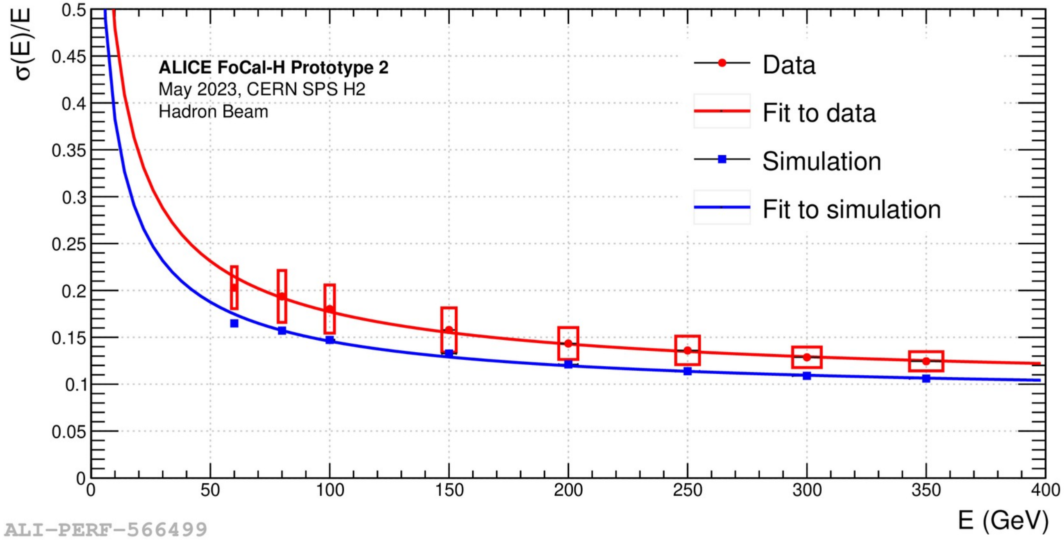

Small prototype built for performance tests

- FoCal-E
  - ~ 9 x 8 $cm^2$ transverse size
  - 18 pad layers
  - 2 pixel layers
- FoCal-H
  - 9 Cu-scintillator towers
  - ~ 20 x 20 $cm^2$ transverse size

FoCal prototype tested in several electron/hadron beams at PS and SPS
Performance in test beams M.Aehle et al., arXiv: 2311.07413

# Energy resolution in beam tests



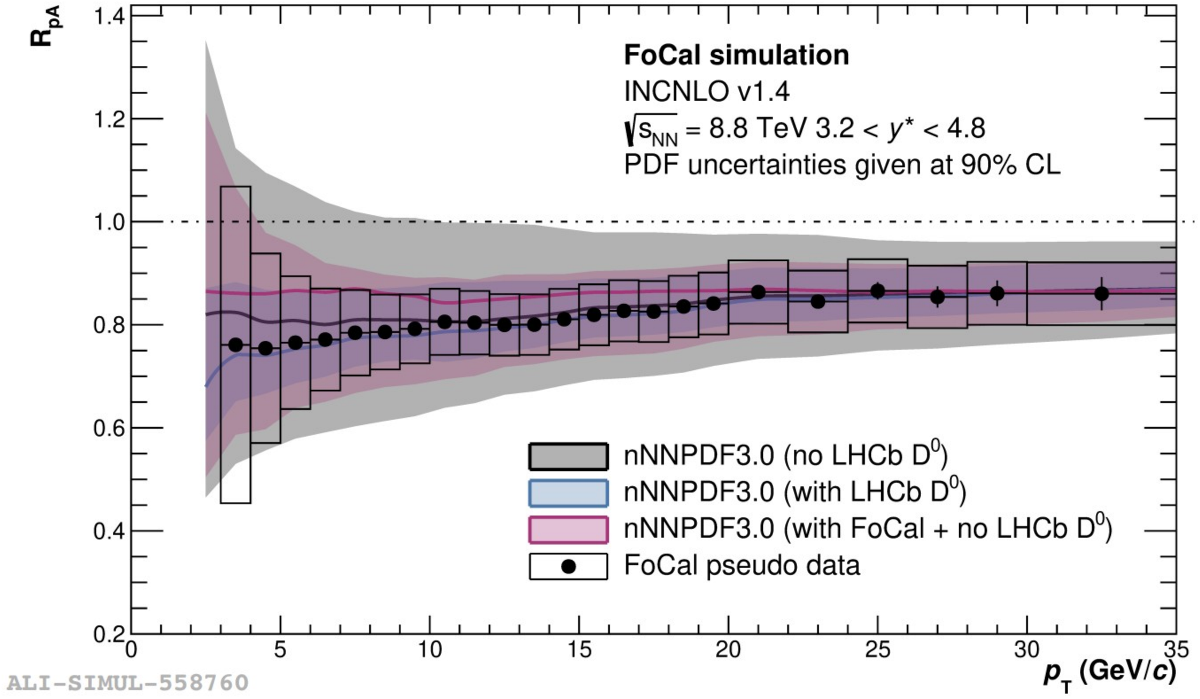



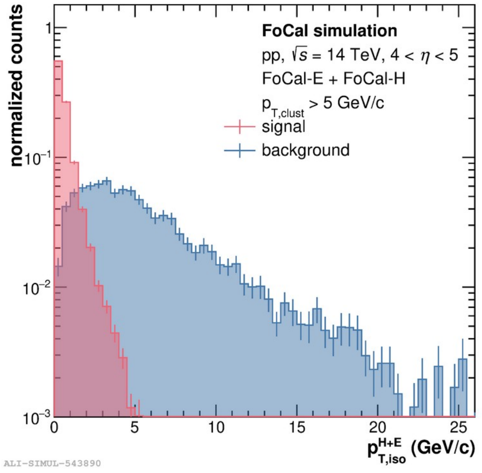

Shower energy resolution

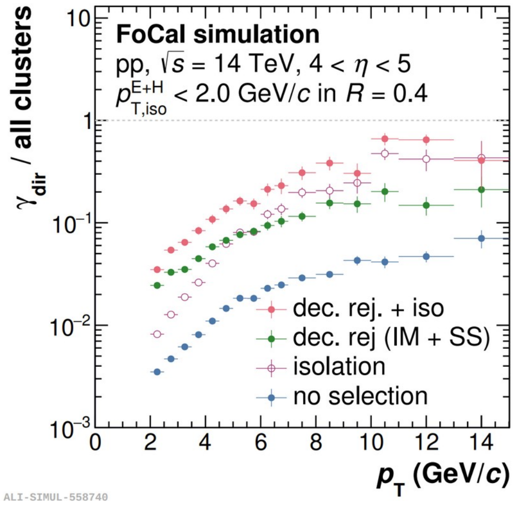
- FoCal-E: below 3% at high energy
- FoCal-H: below 15% at high energy

FoCal performance: arXiv: 2311.07413

# Constraining PDFs with isolated photons



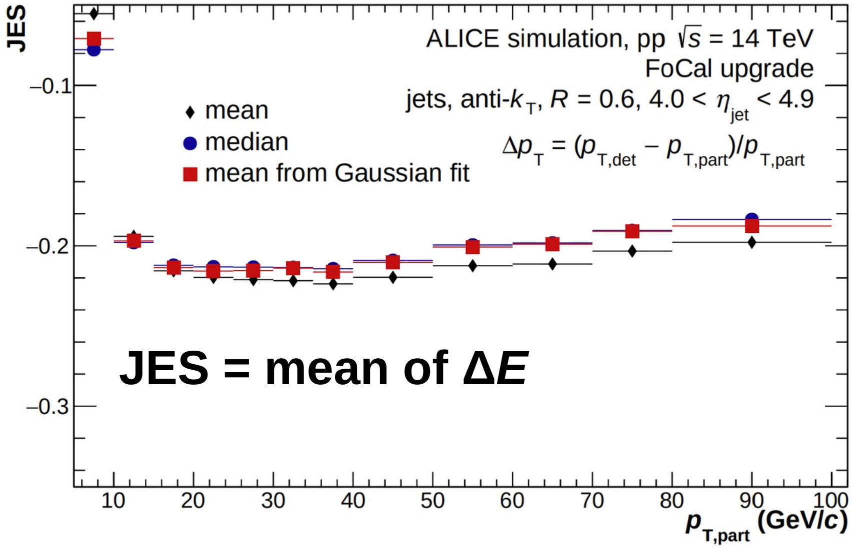



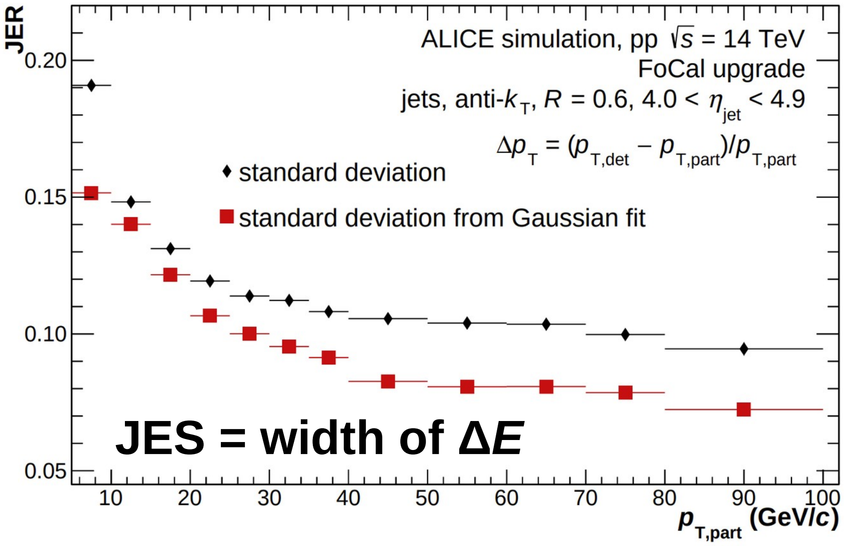




Isolated photons

- Advantage: no final state fragmentation
- Reconstructed using rej. of decay photons and isolation cuts
  - Still untapped potential using more sophisticated methods
- Similar, but independent, constraints to nuclear PDFs as LHCb data using D$^0$s

# Jets

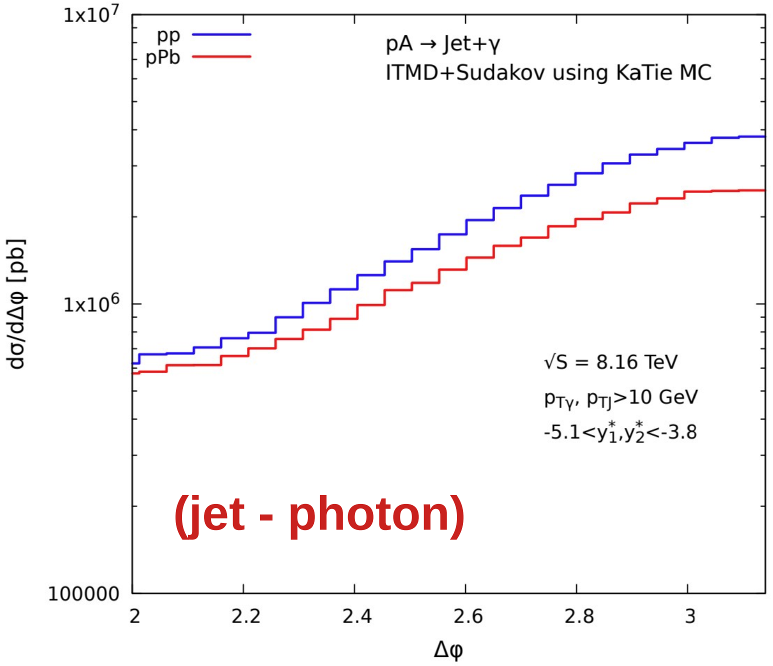


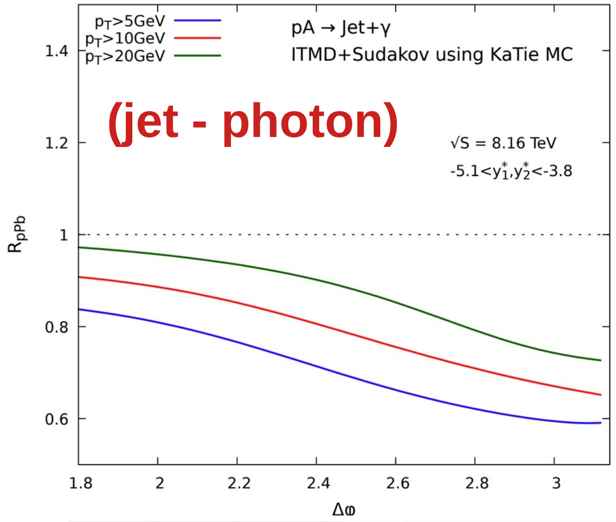



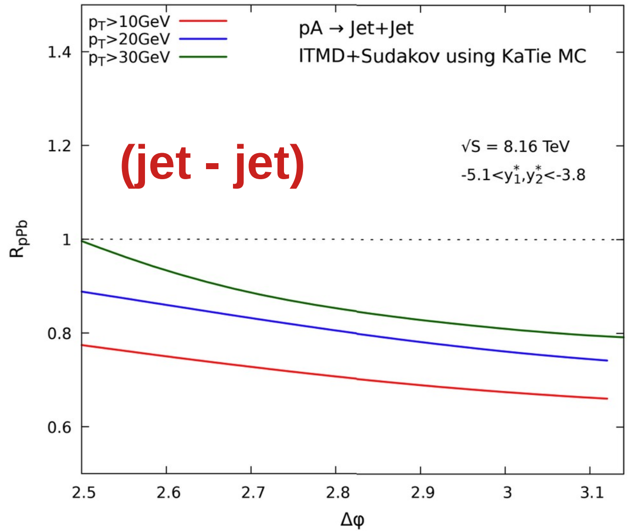

$$\Delta E = (E_{\mathbf{det}} - E_{\mathbf{part}})/E_{\mathbf{part}}$$

- Jet energy scale (JES) and jet energy resolution (JER) quantified using Pythia + GEANT for $R$=0.6 anti-$k_T$ jets

# Two-particle correlations in pp and p-Pb



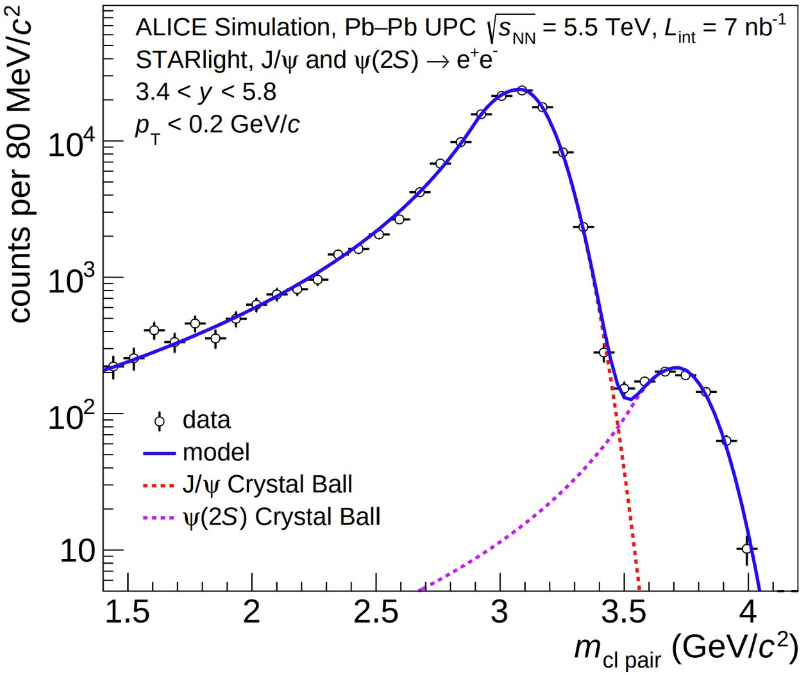



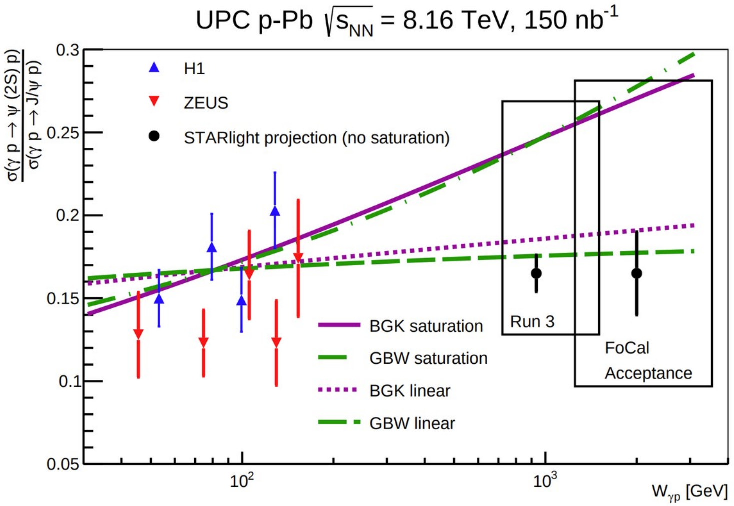

Forward dijet observables

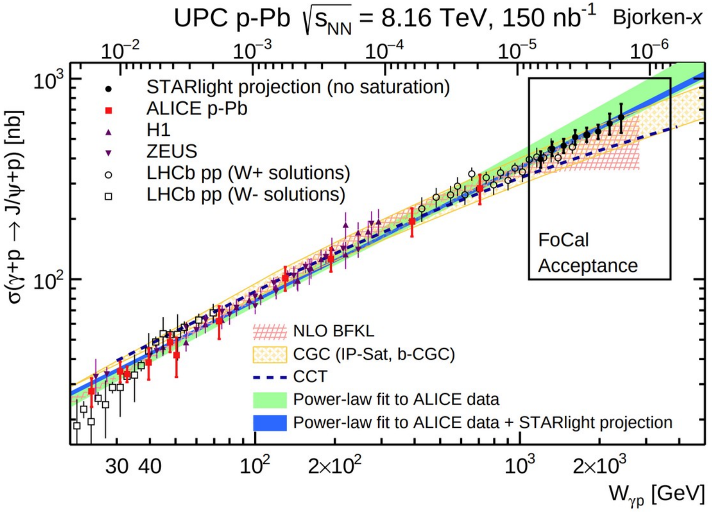
- jet-jet and γ-jet, sensitive to saturation effects at small-*x*
- Long-range correlations (FoCal – barrel) possible

ALICE-PUBLIC-2023-001

# Photoproduction in UPC (p-A and A-A)



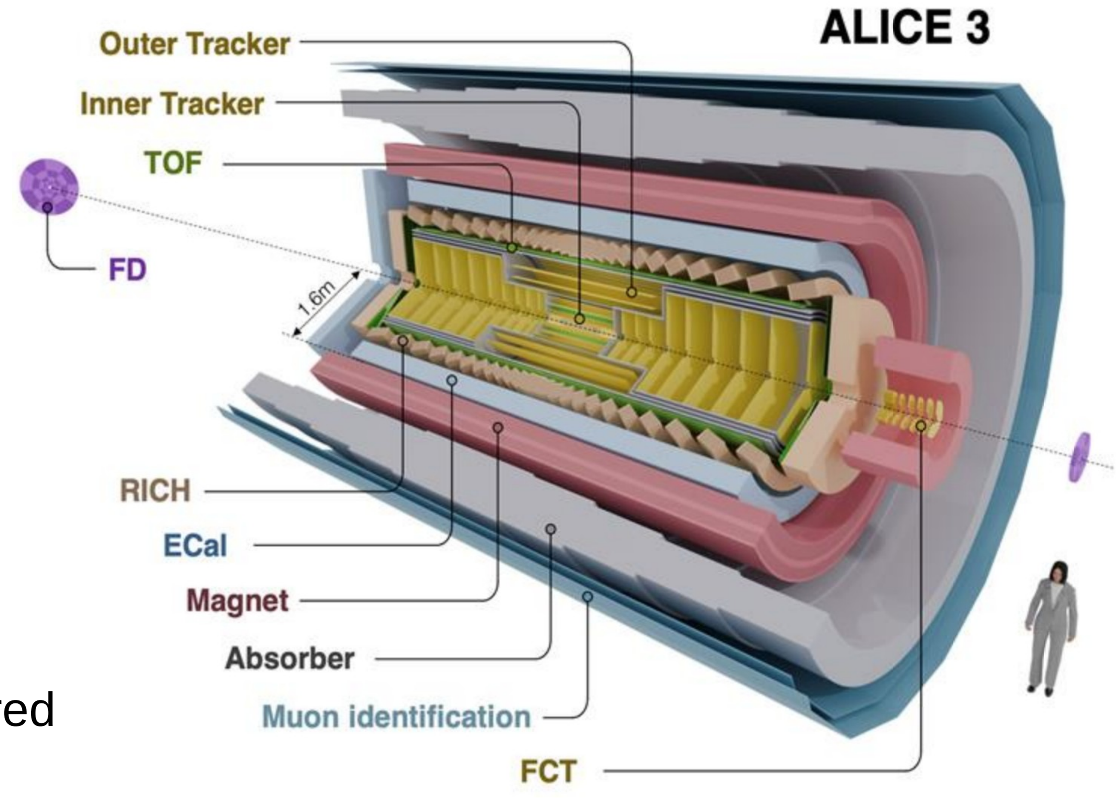

Quarkonia production in ultra-peripheral collisions

- Extending coverage in $W_{\gamma p}$ up to 2 TeV
- Large lever arm for discriminating linear vs saturation scenarios

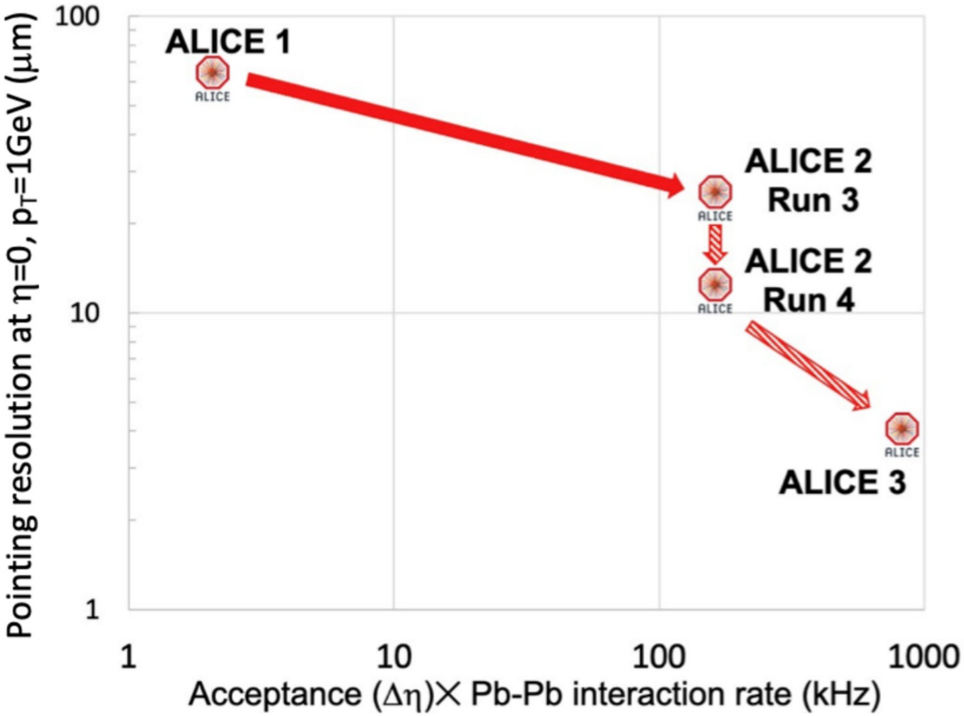
*Bylinkin, Nystrand, Tapia Takaki, arXiv:2211.16107*

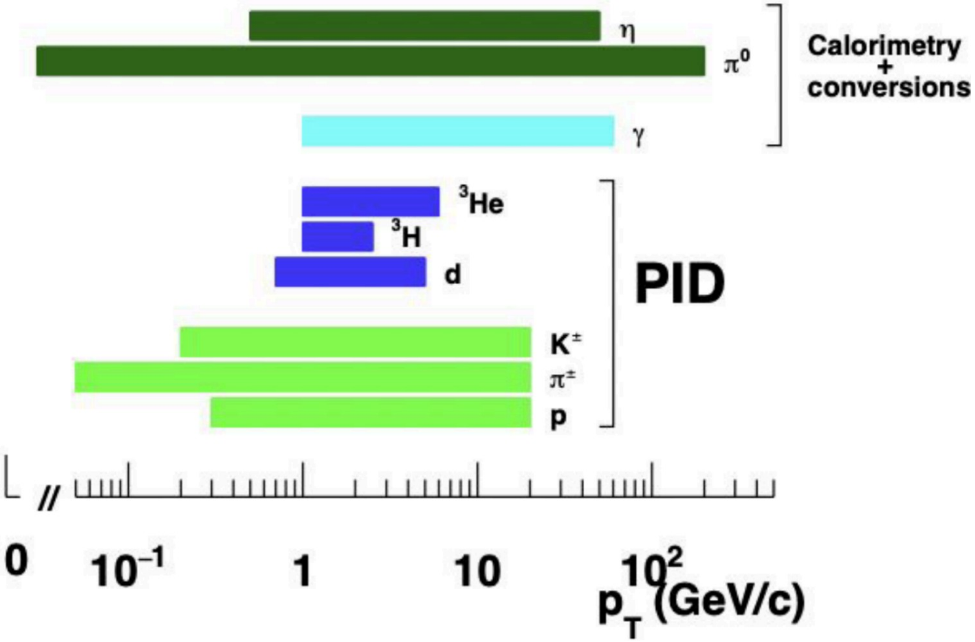
# ALICE 3

- Compact and ultra-light silicon tracker
- Retractable vertex detector with very high pointing resolution
- Extensive particle identification
- Large acceptance: $|\eta|<4$, $p_T>0.02$ GeV/$c$
- Superconducting magnet system, $B$=2T
- Continuous readout and online processing
- Possibility of including FoCal  being explored



# ALICE 3 performance

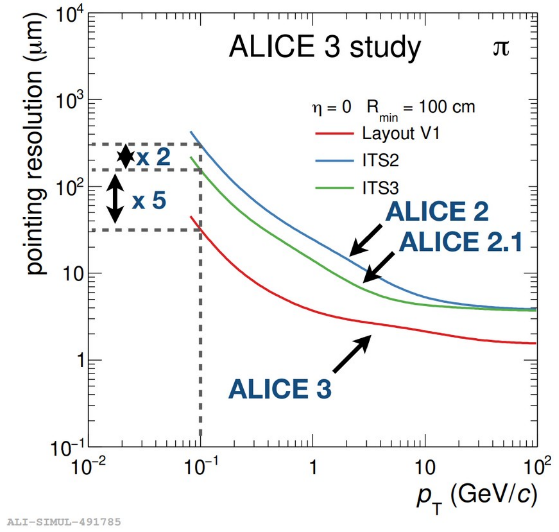


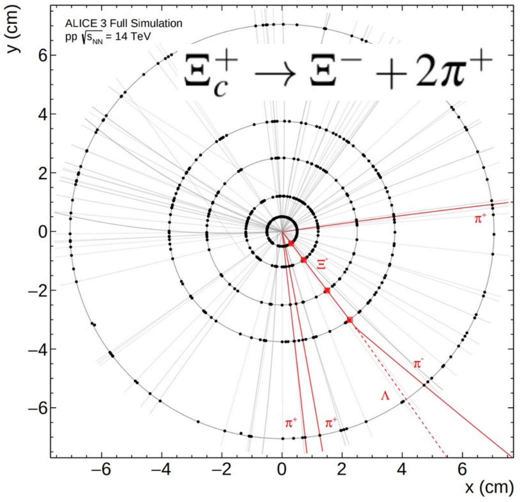



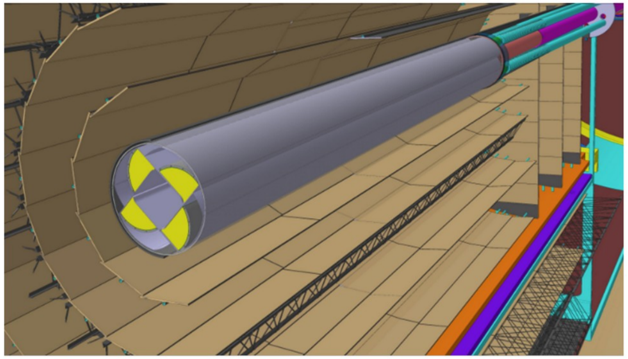

Unprecedented pointing resolution: 3-4 μm

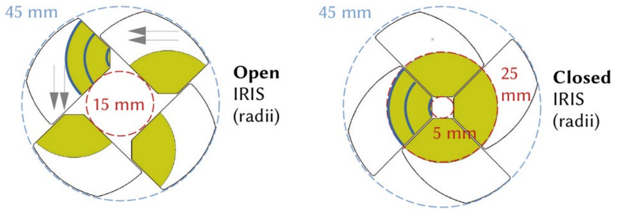
Maintain PID performance in a wide kinematic range

# Tracking



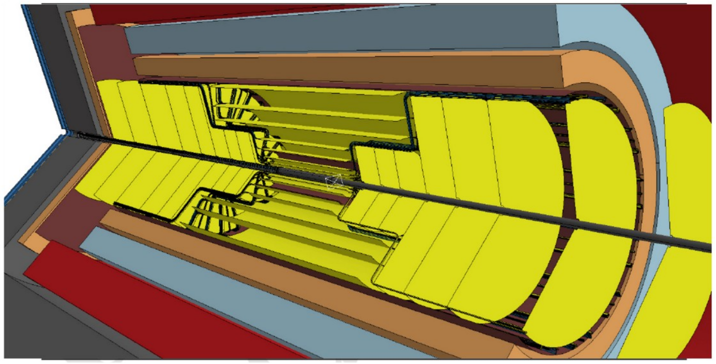



**Inner tracker**

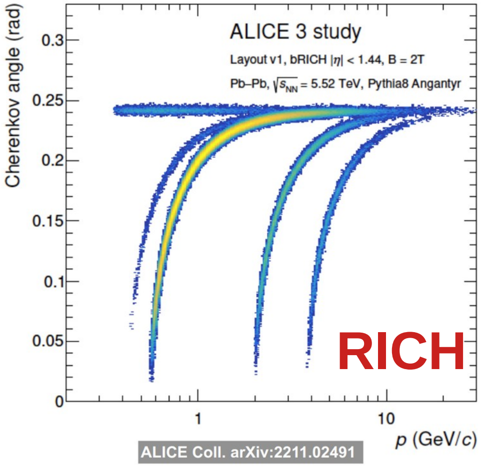
- Wafer-size, ultra-thin, bent CMOS MAPS sensors
- Retractable vertex detector (IRIS): 3 barrel + 3x2 disk layers within the beam pipe
- Middle layers: 4 barrel at R<20cm, 3x2 disks

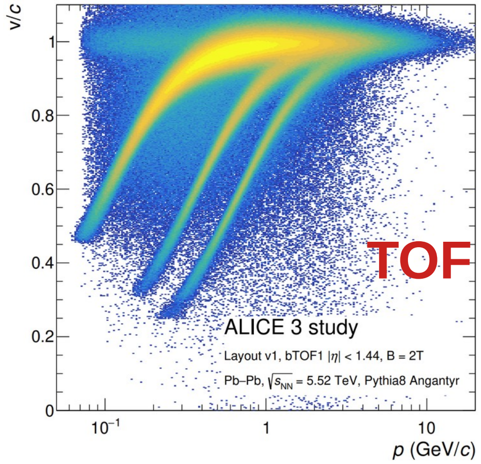
**Outer tracker**

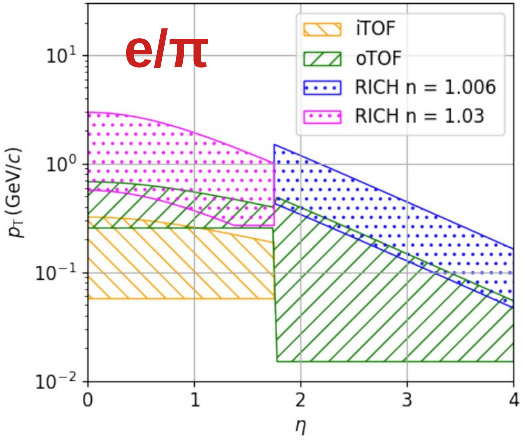
- MAPS detector with an area of 60 $m^2$
- 4 barrel layers at R > 20 cm, 6x2 disk layers

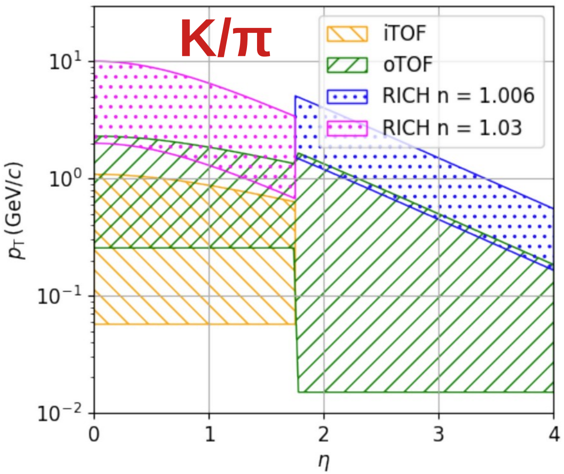


# Particle identification systems




**Barrel Time-of-Flight (TOF)**

- 2 barrel + 2 disk layers
- Technology options
  - Monolithic CMOS LGADs
  - Hybrid LGADs
  - SiPMs

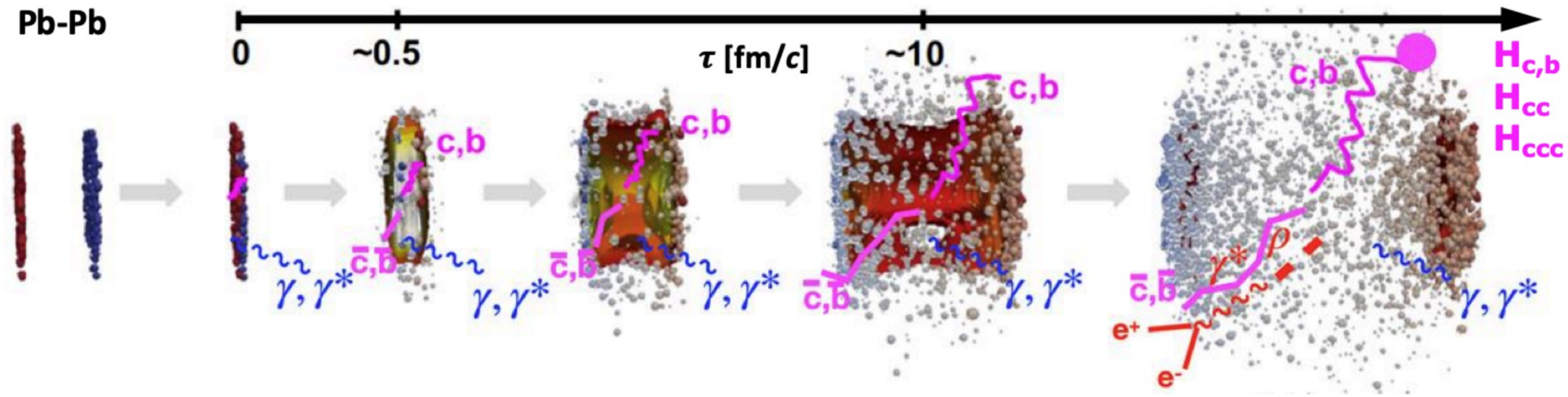
**Ring Imaging Cherenkov (RICH)**

- One barrel bRICH: aerogel + SiPMs
- 2 forward fRICH: aerogel + HRPPDs

**Muon ID**

- Standard magnetic steel absorber + two MID layers
- Technology options
  - Plastic scintillators
  - Multiwire proportional chambers
  - Resistive plate chambers (RPCs)

# ALICE 3 physics goals




Early stages: temperature, chiral symmetry restoration
- Dilepton and photon production

Heavy flavour diffusion and thermalization in QGP
- Precise beauty flow at low $p_T$, $D\overline{D}$ correlations

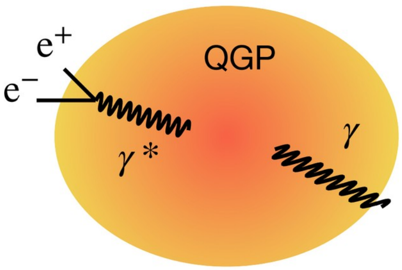
Hadronization in heavy-ion collisions
- Multi-charm production
- Excited quarkonium states: dissociation and regeneration

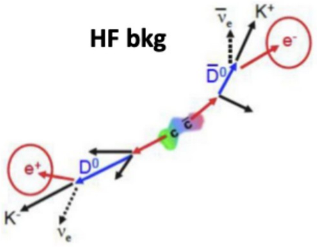
Fluctuations of conserved charges
- Hadron correlations and fluctuations

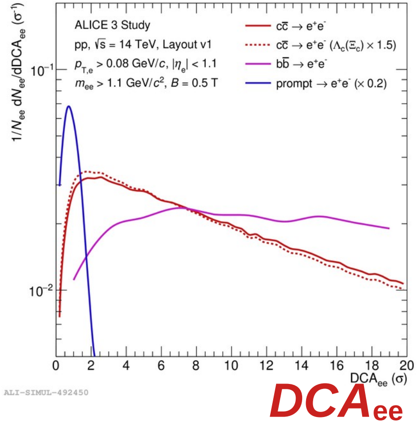
Nature of exotic hadrons
- DD femtoscopy, production yields

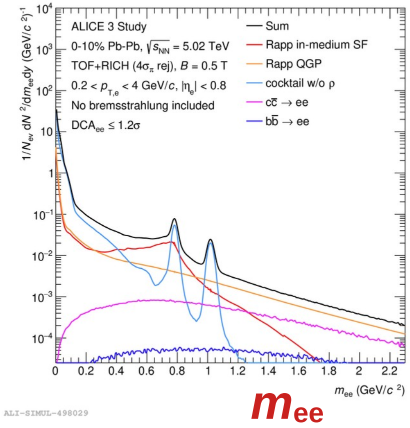
Beyond QGP physics
- Ultra-soft photon production (Low’s theorem)
- Search for ALPs in ultra-peripheral Pb-Pb
- Search for super-nuclei (c-deuterium, c-tritium)

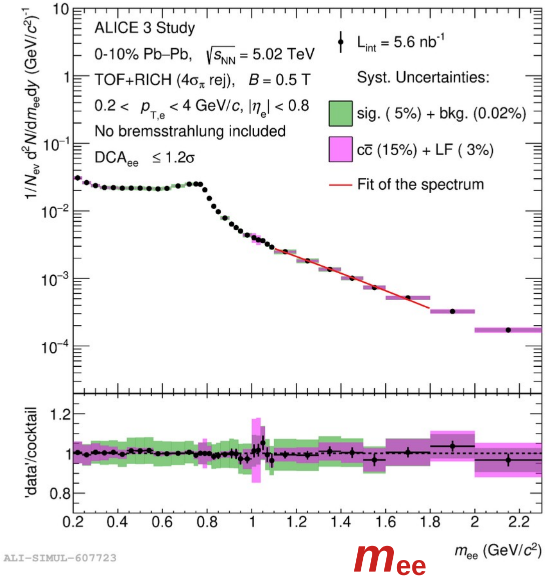
# Dilepton measurements

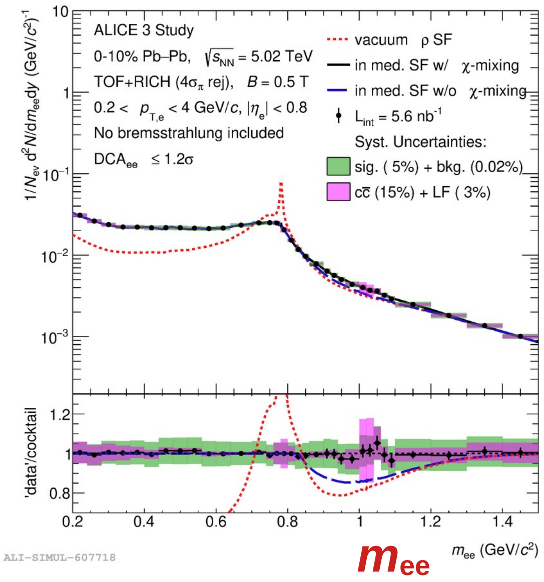


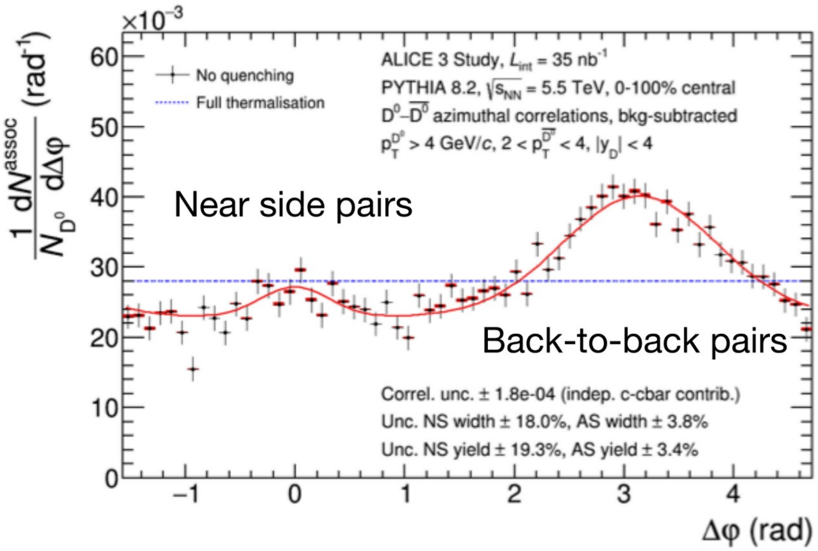



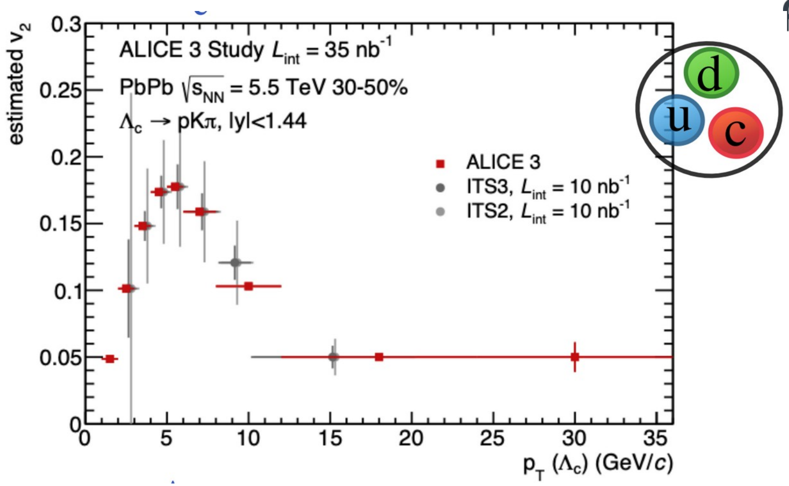

- Very good electron ID down to low $p_T$
- Small material budget
- Good pointing resolution (HF decays)

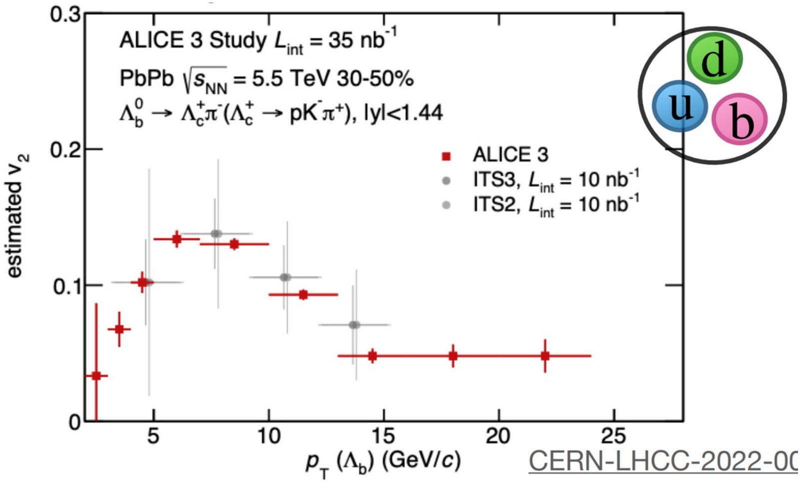
Early QGP temperature
- Mass above 1 GeV/$c^2$
- Differential studies: probe of time dependence

Chiral symmetry
- Lattice QCD indicates strong broadening of vector mesons

# Heavy quark transport




CERN-LHCC-2022-0(

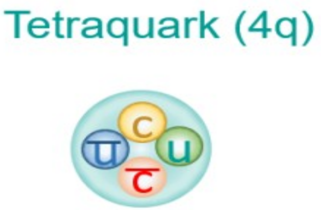
Angular decorrelation of heavy-flavour hadrons

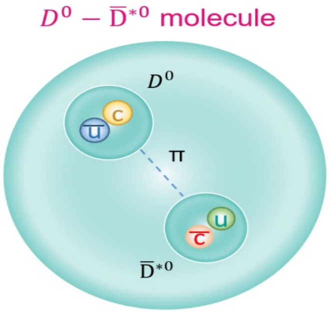
- Direct measurement of momentum broadening in QGP via D$\overline{D}$ correlations

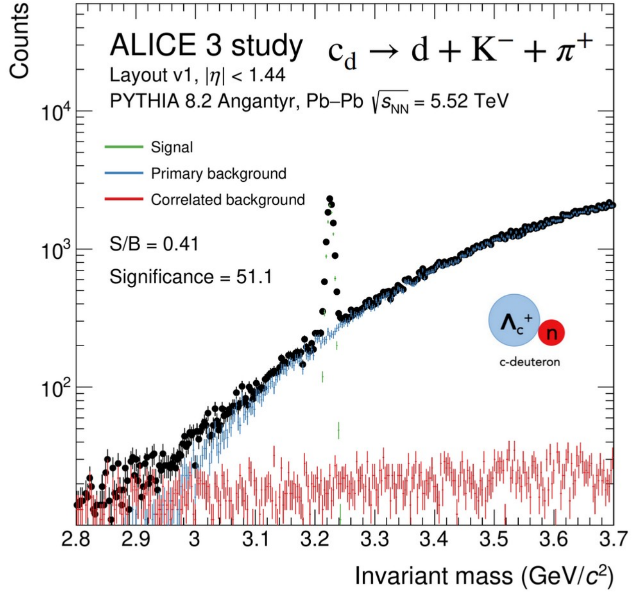
Differential production measurements (flow and $R_{AA}$)

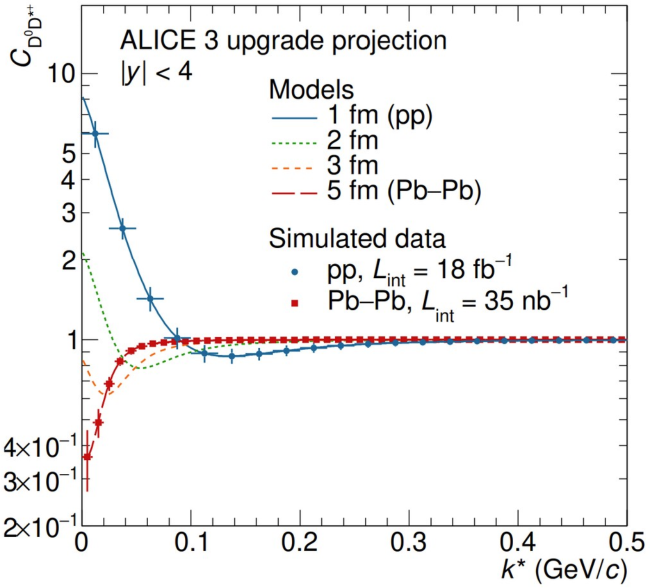
- Heavy-quark transport properties in QGP
- Probe degree of beauty thermalization

# Exotic bound states




High mass charm-nuclei

- Sensitivity to c-deuterium and c-tritium
- Search for anti-(hyper)nuclei with A>5

Search for DD bound states using femtoscopy

- Unique tests of long range strong interactions
- Nature of exotic states

# Summary and conclusions

**FoCal**

- Explore an unprecedented region in low-*x* physics, probing gluon evolution in the saturation regime
- Unique measurements of prompt photons, vector mesons and jets
- Very good performance confirmed by test beams
- Currently moving towards construction phase

**ALICE 3 is a unique experiment**

- Outstanding detector capabilities
- Main scientific goal is to expand knowledge of the microscopic dynamics of QGP beyond current limits
- Innovative design based on silicon technologies with broader impact for future high-energy and nuclear physics experiments
- ALICE3 is a very prominent project in the NuPECC long range plan and input to the European Strategy for Particle Physics