# ALICE upgrades for Run 4 and Run 5

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on behalf of the **ALICE collaboration**

**25th International Conference in Quantum Chromodynamics (QCD 22)**
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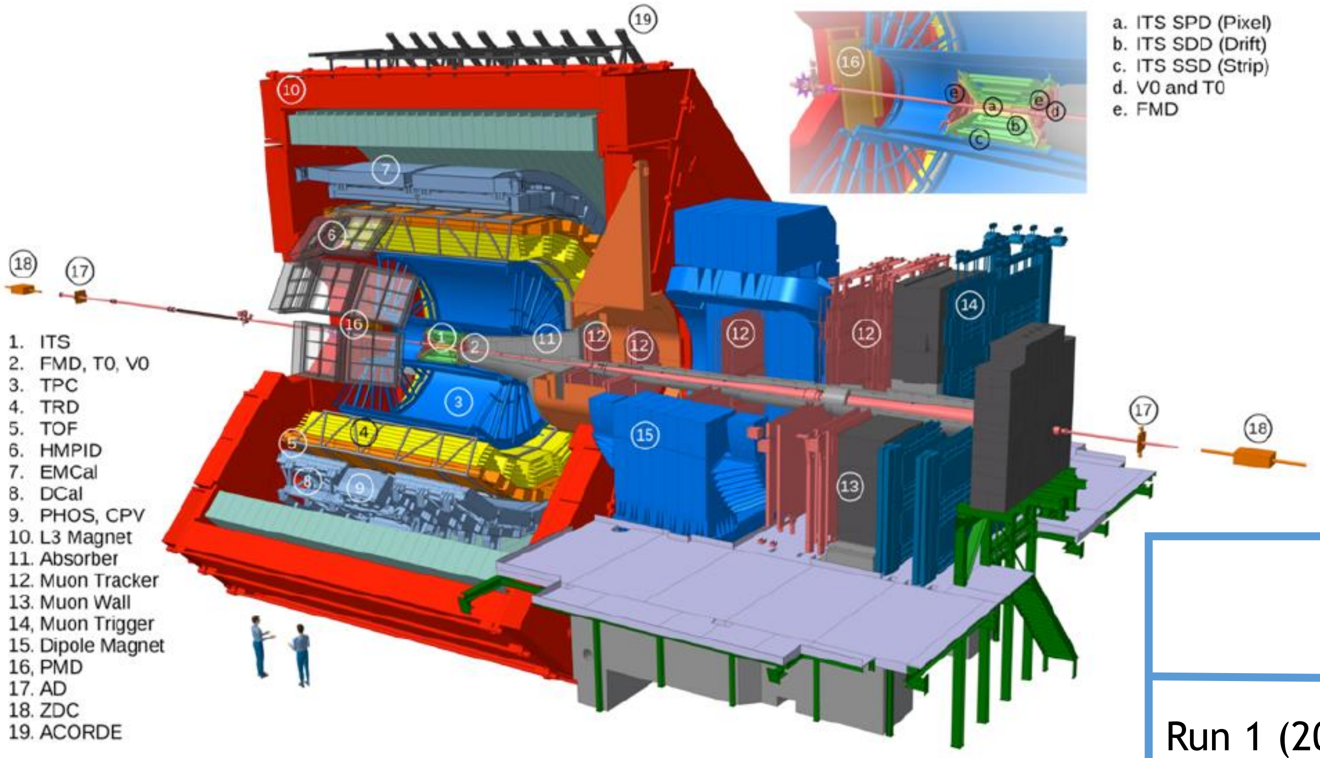
# ALICE in Run 1 and Run 2




- **ALICE** is one of the experiments at the LHC and it is mainly devoted to heavy-ion physics studies.
- Detailed characterization of strongly interacting quark-gluon plasma (QGP)
- **ALICE** is designed to carry out comprehensive studies of hadrons, electrons, muons, heavy flavors, photons and jets produced in the heavy-ion collisions

- Tracking and PID over large kinematic range
- High resolution vertex reconstruction
- Central barrel: -0.9 < $\eta$ < 0.9
- Muon spectrometer: -4.0 < $\eta$ < -2.5
- Forward detectors: trigger, centrality, luminosity, reaction plane

## ALICE data taking history

Run 1 (2009 – 2013):

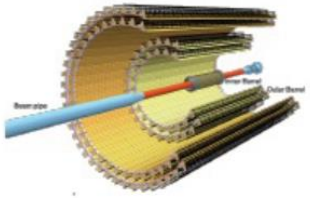
- Pb-Pb @ $\sqrt{s_{NN}}$= 2.76 TeV
- p-Pb @ $\sqrt{s_{NN}}$= 5.02 TeV
- pp @ $\sqrt{s}$ = 0.9, 2.76, 7 and 8 TeV

Run 2 (2015 – 2018)

- Pb-Pb @ $\sqrt{s_{NN}}$= 5.02 TeV
- Xe-Xe @ $\sqrt{s_{NN}}$= 5.44 TeV
- p-Pb @ $\sqrt{s_{NN}}$= 5.02 and 8.16 TeV
- pp @$\sqrt{s}$= 5 and 13 TeV

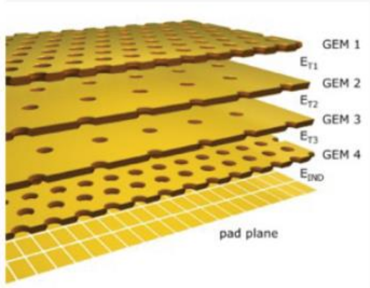
# Evolution of the ALICE set-up in Run 3

## Inner Tracking System



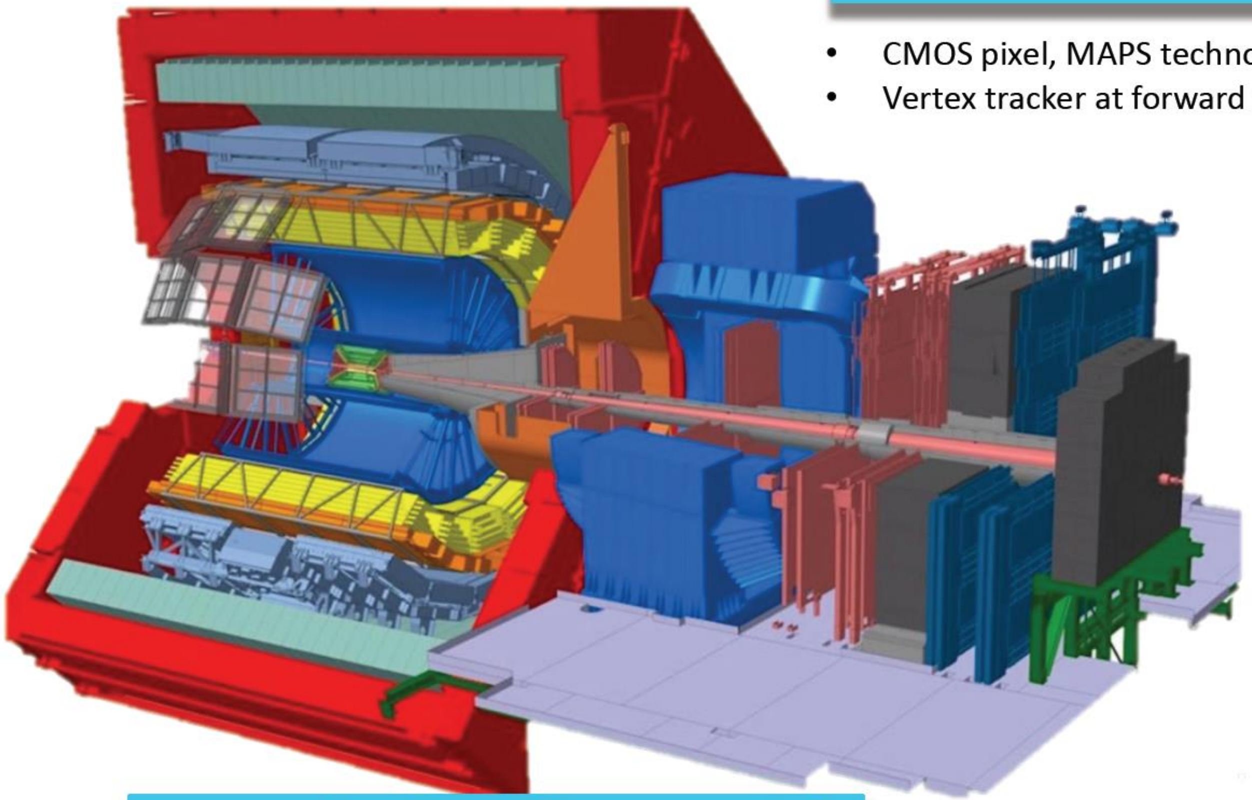
- CMOS monolithic active pixel sensors (10m$^2$ surface)
- Improved resolution, less material, faster readout

## Time Projection Chamber



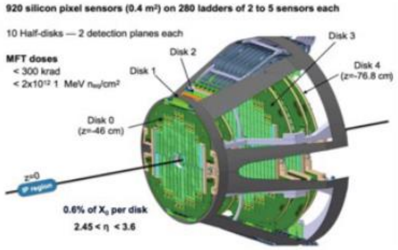

New Readout Chambers (ROCs)

- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout



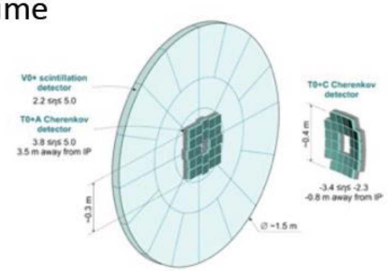
## Muon Forward Tracker

- CMOS pixel, MAPS technology
- Vertex tracker at forward rapidity



## Fast Interaction Trigger

- Centrality, event plane, luminosity, interaction time

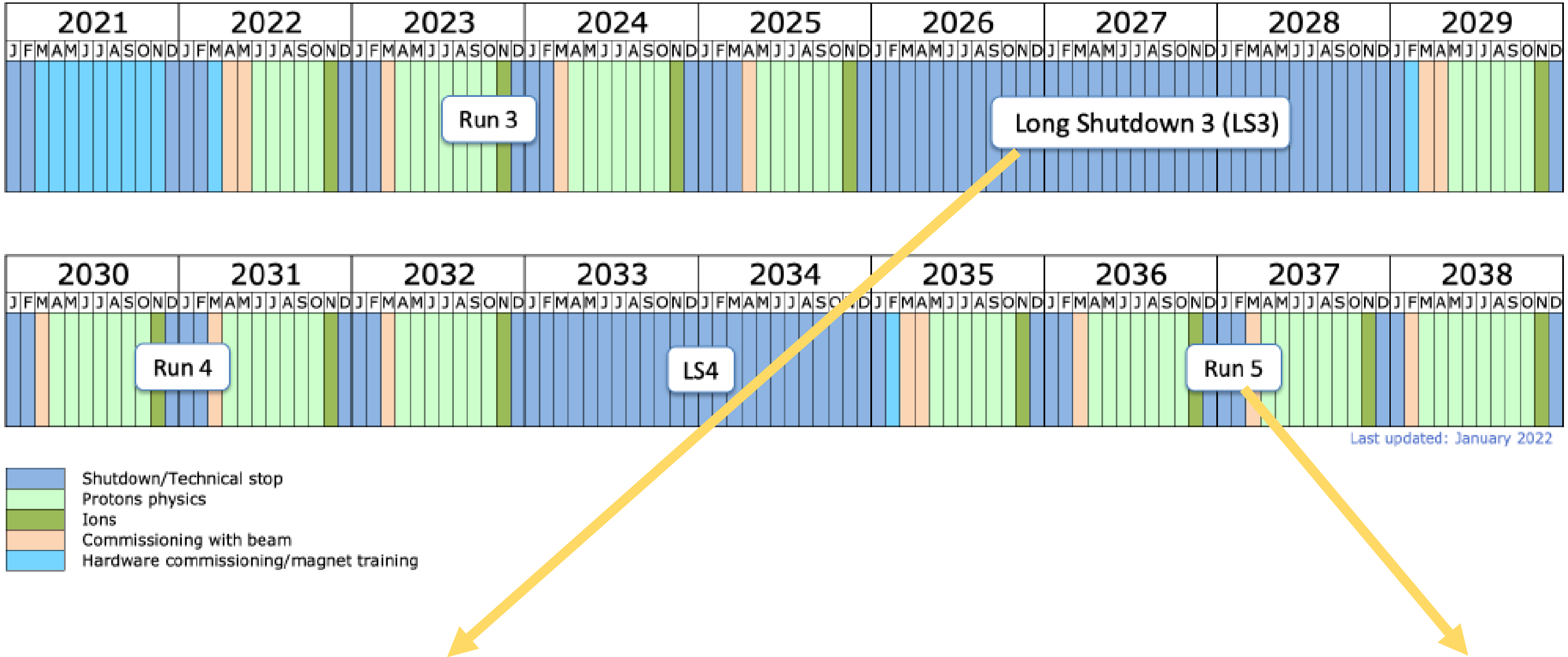


## Integrated Online-Offline system (O$^2$)

- Calibrate and reconstruct minimum-bias Pb-Pb data at 50 kHz

## Upgrades readout for TOF, TRD, MUON, ZDC, Calorimeters

# ALICE upgrade timeline




**ALICE upgrades in LS3 (2026-2028):**

- **ITS3**: a free-standing silicon vertex detector
- **FoCal**: a high-granularity forward calorimeter

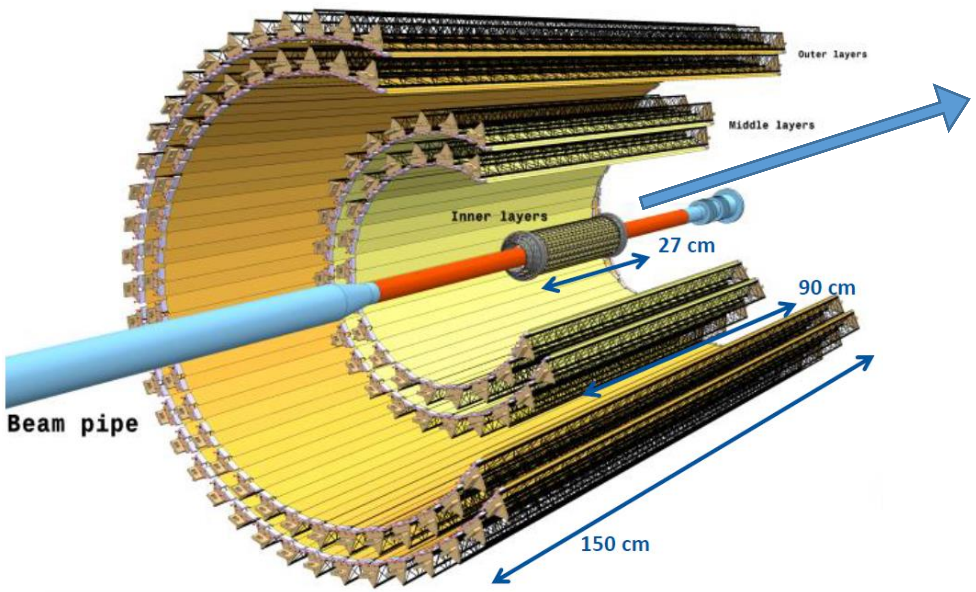
**ALICE 3: a next-generation detector for Run 5 and Run 6**

- Increased rate capabilities
- Improved vertexing
- Tracking over a wide momentum range and rapidity coverage

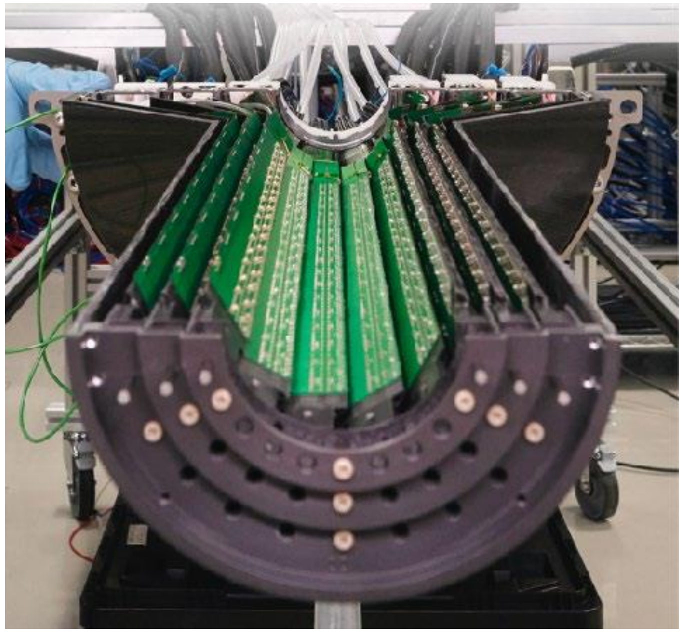
# ITS3 for Run 4
(from 2029)

# From ITS2 to ITS3

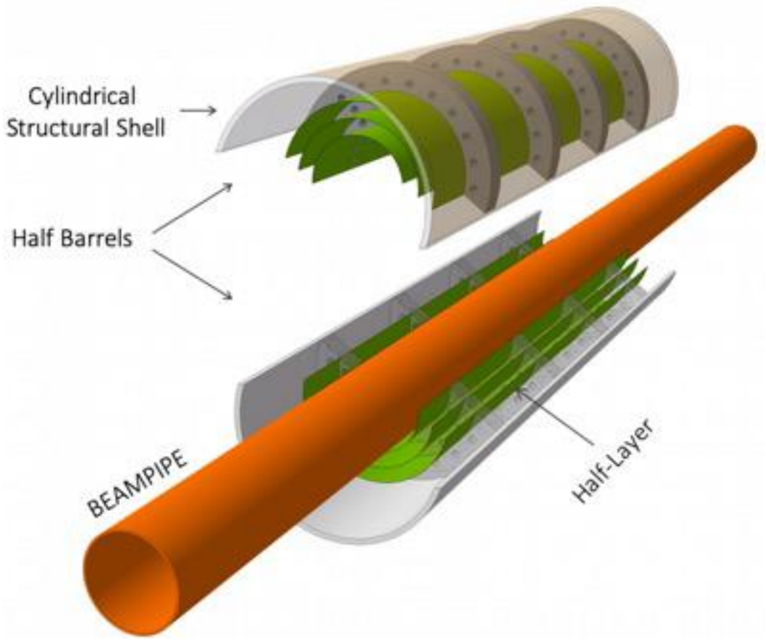
- The Inner Tracking System was completely redone during LS2 in order to improve vertex and tracking precision
- In view of Run 4, ALICE plans to further improve ITS performance by replacing the 3 innermost layers




ITS2

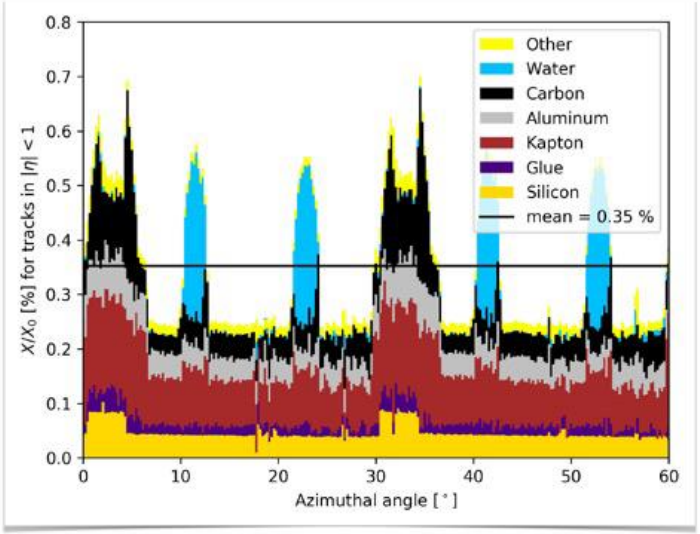


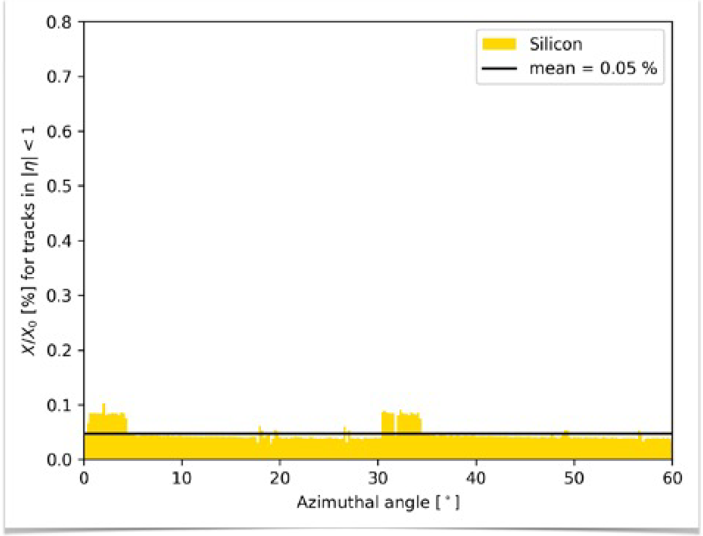
ITS2 inner layers




ITS3 upgrade

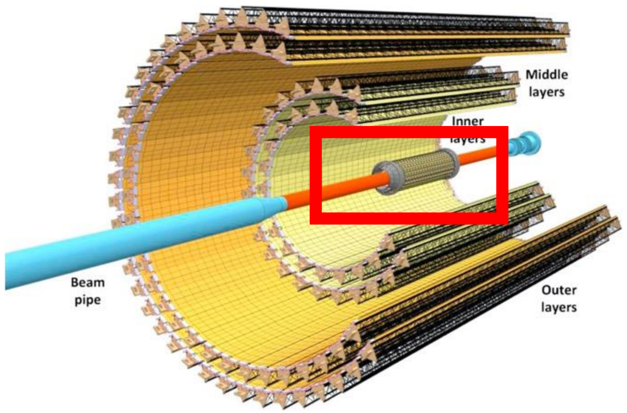
# ITS3 for Run 4

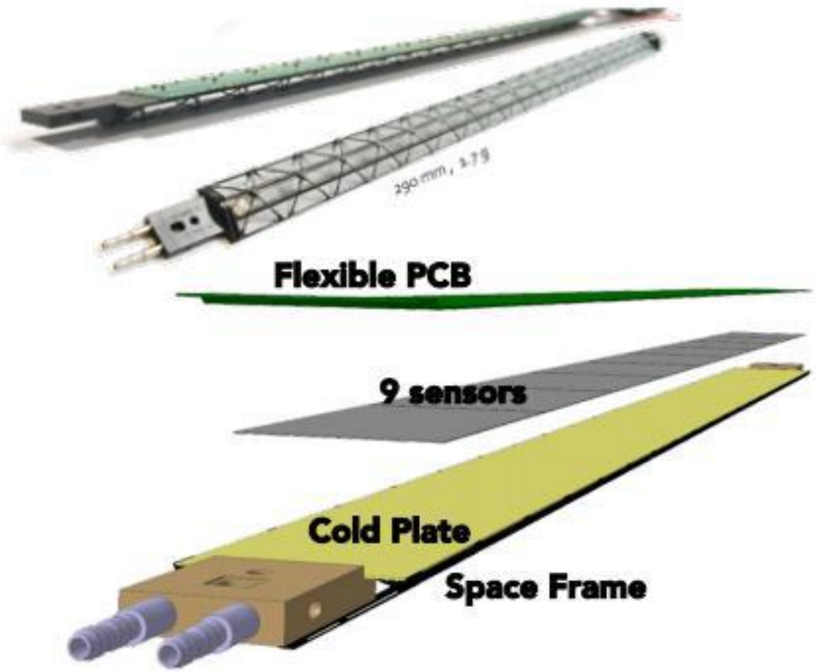



New Inner Barrel (IB): closer to the Interaction Point.

New beam pipe: smaller inner radius (from 18.2 mm to 16 mm) and reduced thickness (from 800 μm to 500 μm)

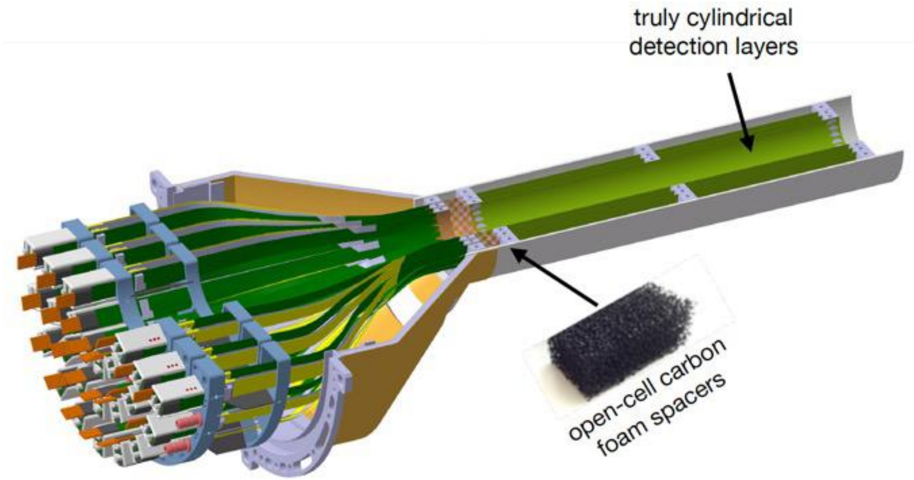


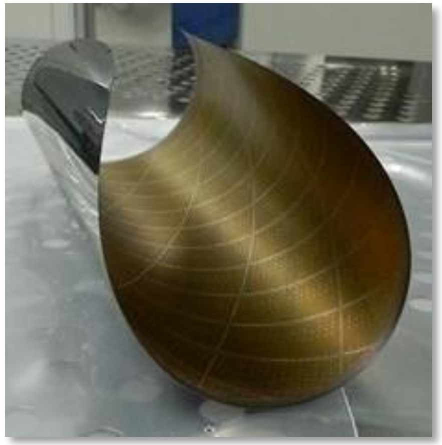



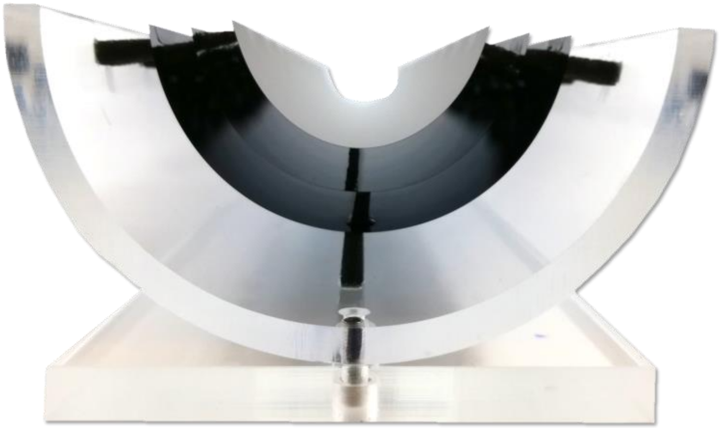

Removal of water cooling: power consumption below 20 mW/cm$^2$ (65 nm technology)
Removal of circuit board: integrate power and data buses on chip
Removal of mechanical support: benefit from increased stiffness of bent Si wafers
Ultra-thin and flexible sensors

$X/X_0$ ratio down to below 0.05%

# ITS3 detector concept





- **Key characteristics:**

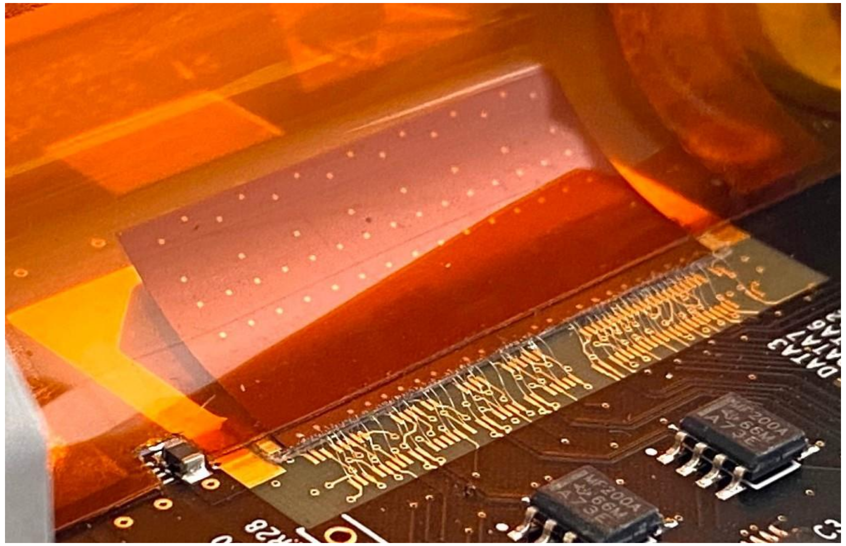
- 65 nm CMOS, up to 300mm large sensors enabled through stitching technology, thinned down to (flexible) 20-40µm
- 6 sensors in total (1 for each half layer)
- bent to target radii
- mechanically held by low-density carbon foam ribs

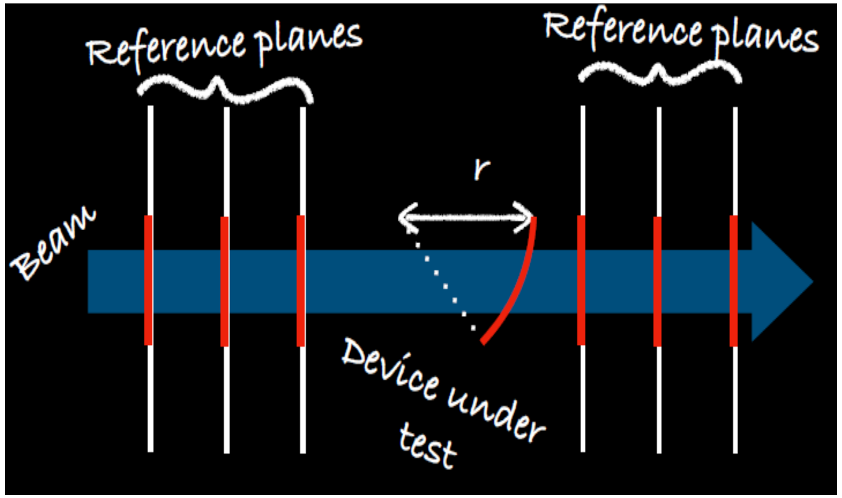
- **Main benefits:**

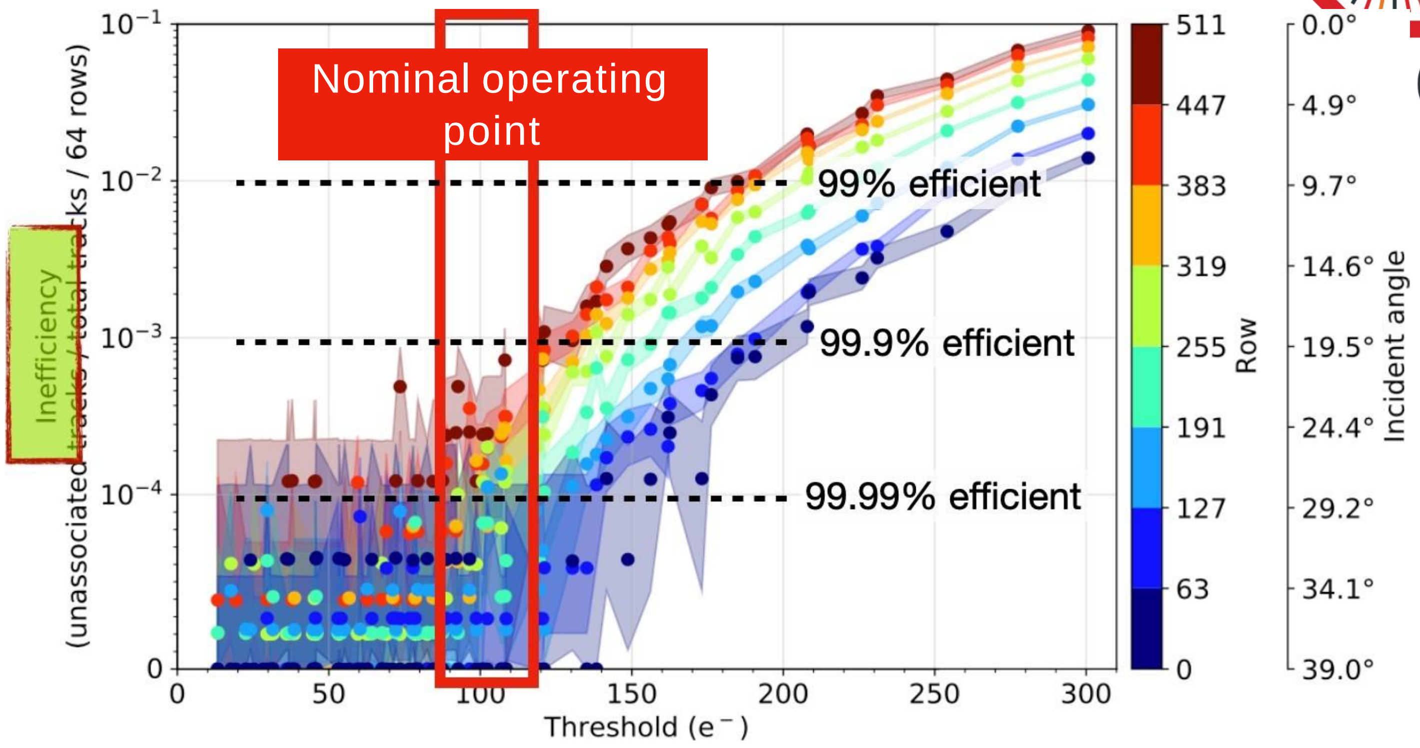
- very low material budget (below 0.05% $X_0$)
- very homogeneous material distribution (negligible systematic error)

| IB Layer Parameters | L0 | L1 | L2 |
|---|---|---|---|
| Radial Position [mm] | 18 | 24 | 30 |
| Length (sensitive area)[mm] | 300 | | |
| Pseudo-rapidity coverage | ±2.5 | ±2.3 | ±2.0 |
| Active area [cm$^2$] | 610 | 816 | 1016 |
| Pixel sensor dimensions [mm$^2$] | 280x56.5 | 280x75.5 | 280x94 |
| Number of sensors per layer | 2 | | |
| Pixels size [µm$^2$] | O(10x10) | | |
| Beam Pipe Inner/Outer Radius [mm] | 16/16.5 | | |

# Beam test with bent ALPIDE sensor





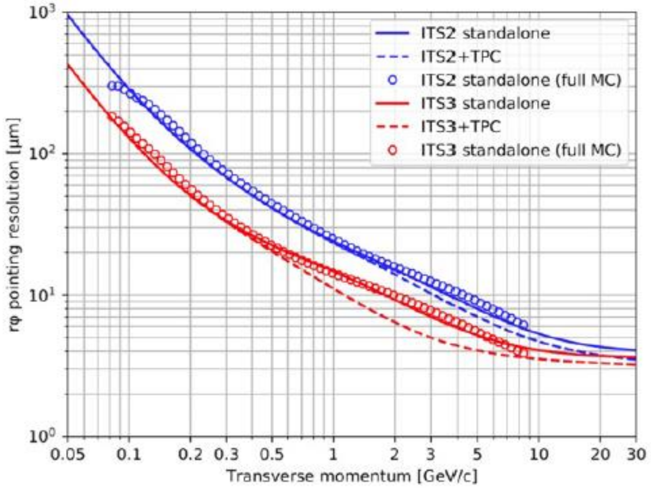



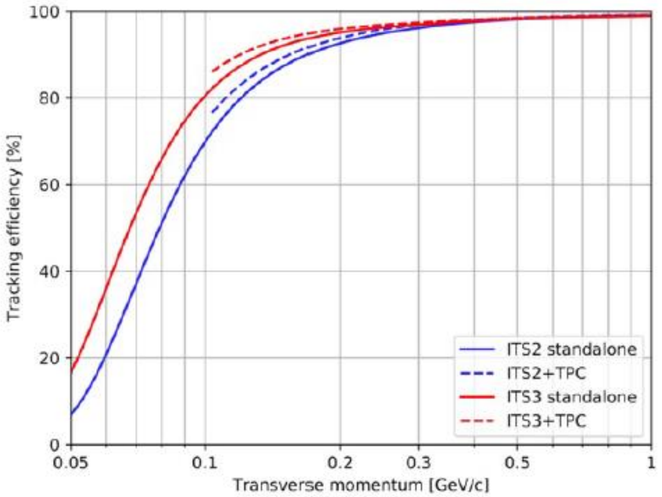

- 50 µm thick ALPIDE sensors bent to ITS3 radius along the short side
- **Mechanical and electrical characterization in laboratory**
- **Full performance characterization in test beam**
- No deviation from flat performance observed

# ITS3 physics performance

**Key improvements:**

- Pointing resolution enhanced by a factor of 2 over all momenta
- Increase of tracking efficiency for low-$p_T$ particles and extension of the low-$p_T$ reach




## $\Lambda_c$ in Pb-Pb collisions

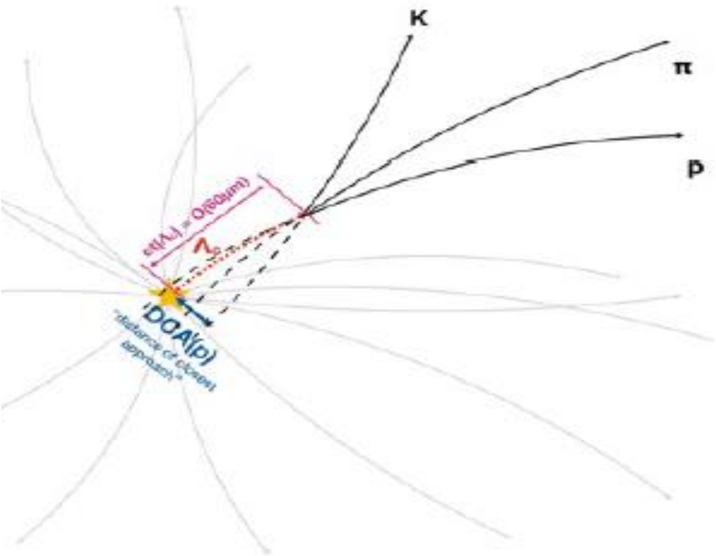
Analysis difficult due to large combinatorial background

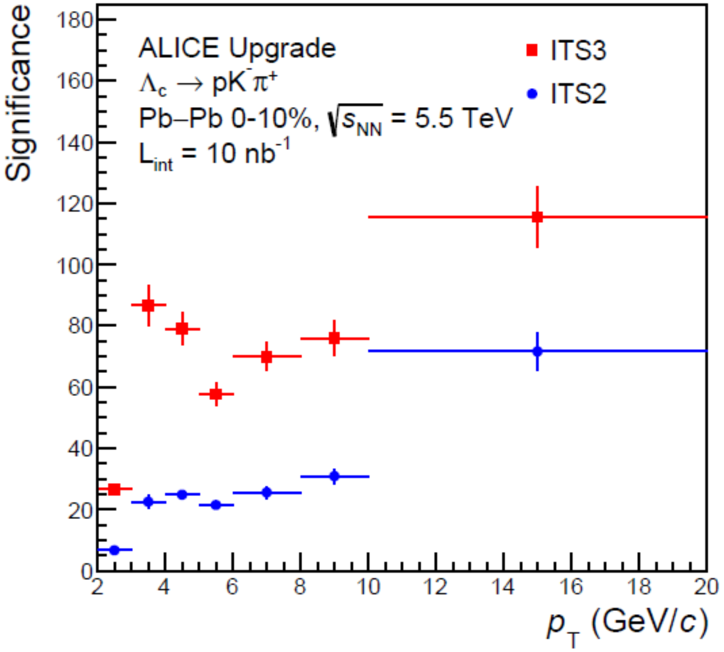
- O(10k) charged particles in central Pb-Pb collision

Discrimination of background via:

- Particle identification (relatively low yield of protons and Kaons wrt. pions

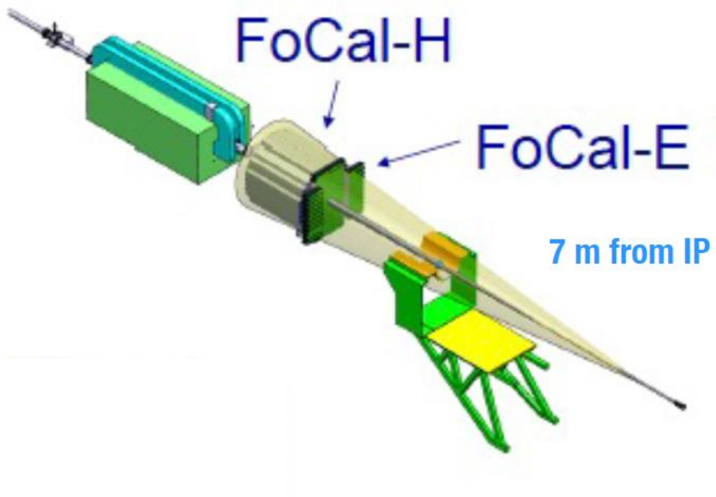
- Topology: cut on DCA of single tracks (before making the combinations) and decay vertex position (need combinations)



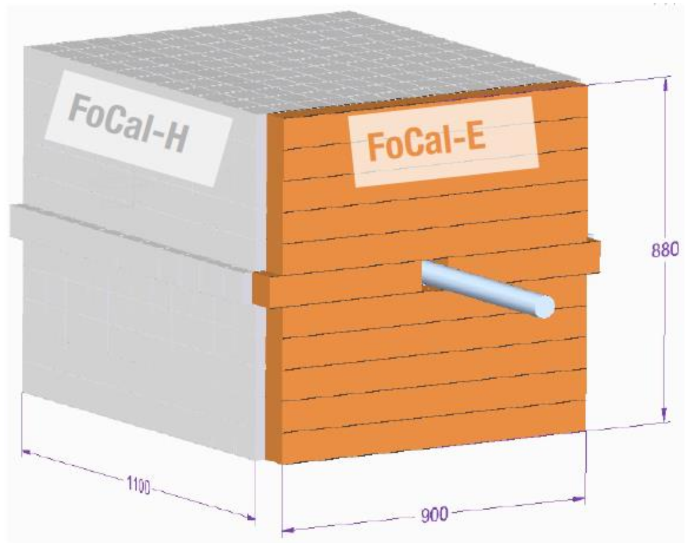
# FoCal for Run 4
(from 2029)

# FOrward CALorimeter

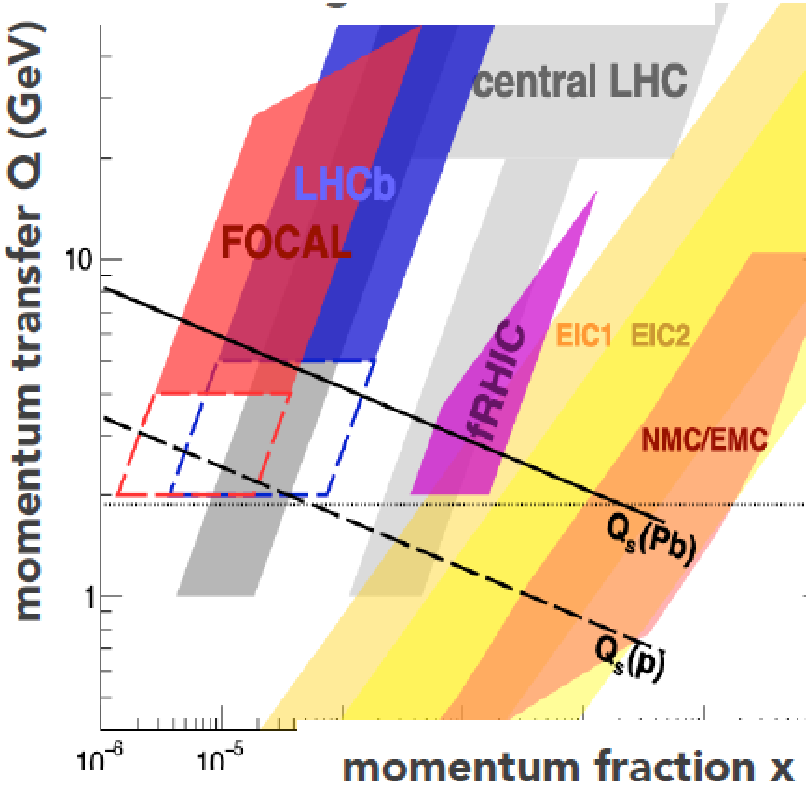



**A new high granularity Forward Calorimeter**

- High-precision inclusive measurement of direct photons and jets
- Coincident γ-jet and jet-jet measurements
- **7 m from interaction point, $3.4 \le \eta \le 5.8$**




- **FoCal-E: high-granularity (~1 mm²** ) Si-W sampling sandwich calorimeter for photons and $\pi^0$ (w/ pads and 2 high-granularity pixel layers)
- **FoCal-H:** A conventional sampling calorimeter (Cu + scintillating fibres) for photon isolation and jets

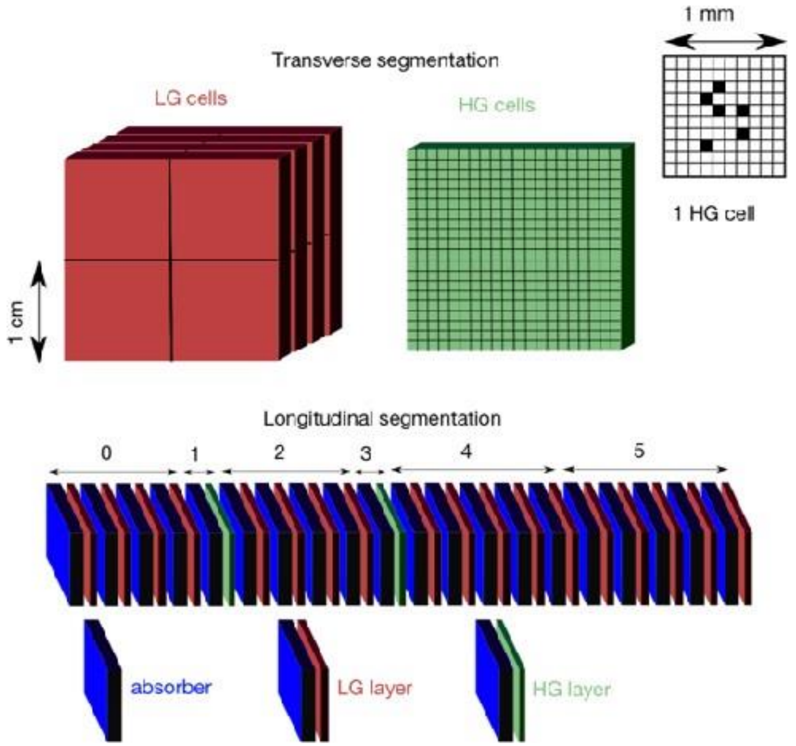



Approximate (x,Q) coverage of various experiments for regions explored by deep inelastic scattering measurements and EM probes

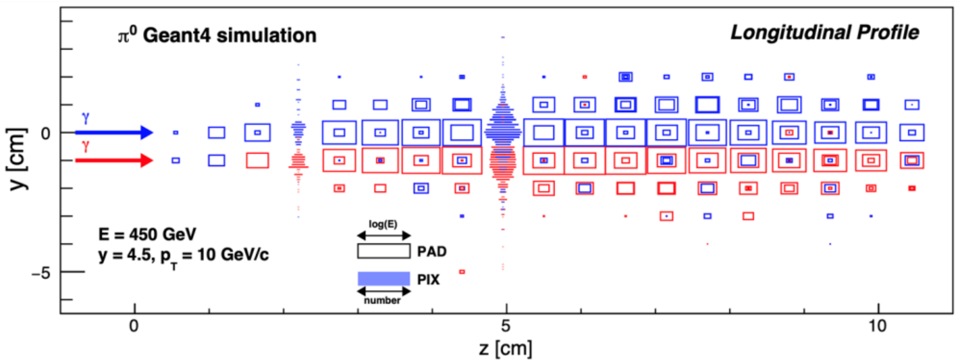
# FoCal-E detector technologies

**Main challenge** for Focal-E: $\gamma/\pi_0$ separation at high energy

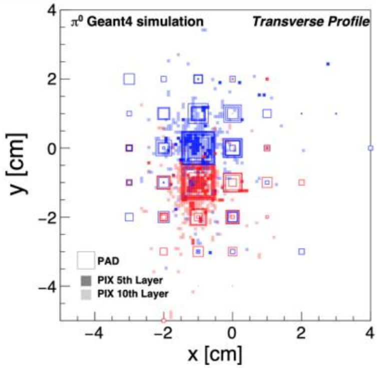
- two photon separation from $\pi^0$ decay: ~2 mm
- needs small Molière radius and high granularity readout
- Si-W calorimeter with effective granularity of ~1 mm$^2$

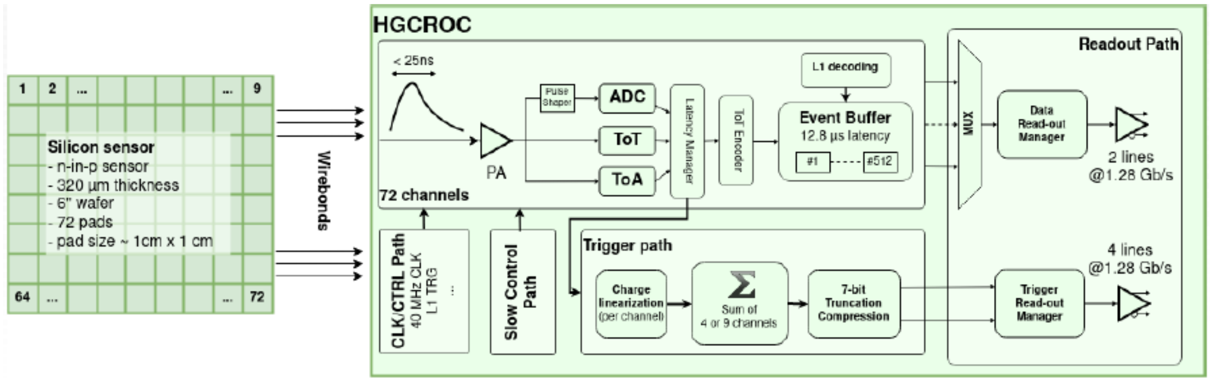



Longitudinal profile (2γ showers)




Trans. profile

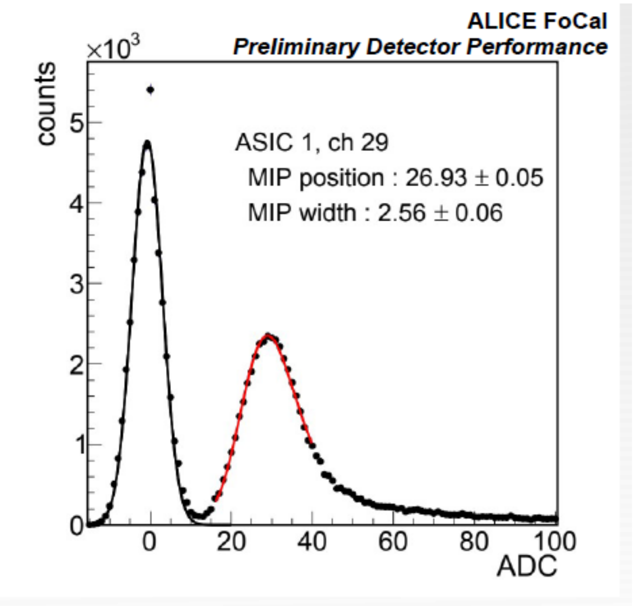


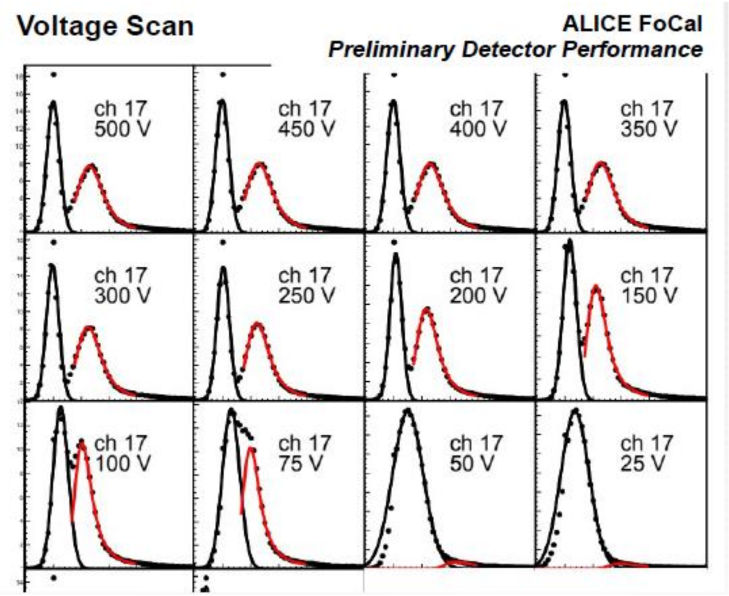



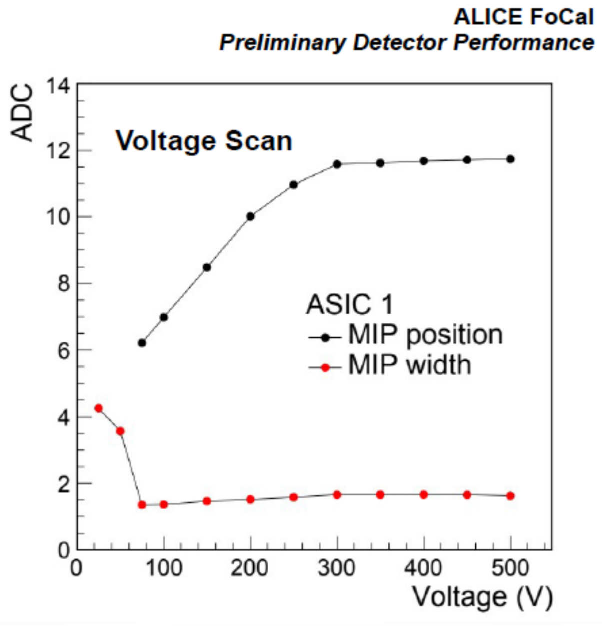

Studied in simulations: 20 layers W (3.5 mm ~ 1$X_0$) + silicon

- 18 Pad layers
  - Low granularity (LG), provide shower profile and total energy
- 2 Pixel layers (ALPIDE)
  - High granularity (HG), provide position resolution to resolve overlapping showers

# FOCAL-E pads results – Beam test CERN PS 2022



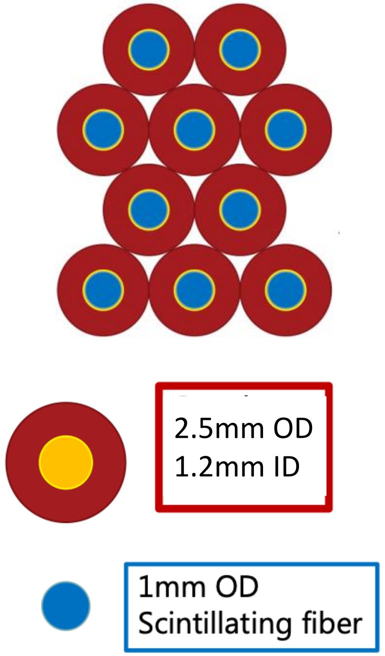

Test of 18 FoCal-E pad layer system

- Clear separation of MIP peak and pedestal noise measured in ADC distribution
- Separation measured in HV scan from 0 V to 500 V

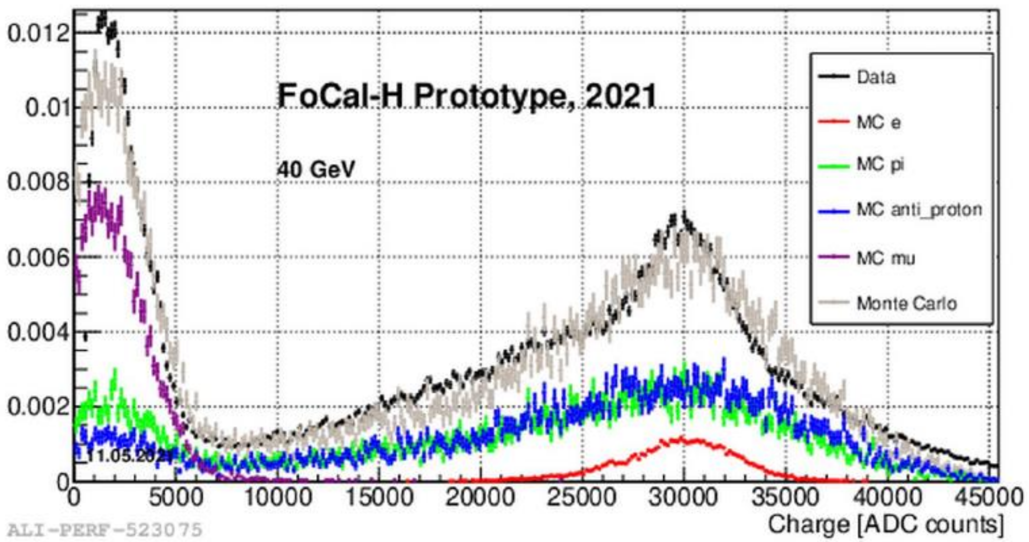
PS tests at low-energy range

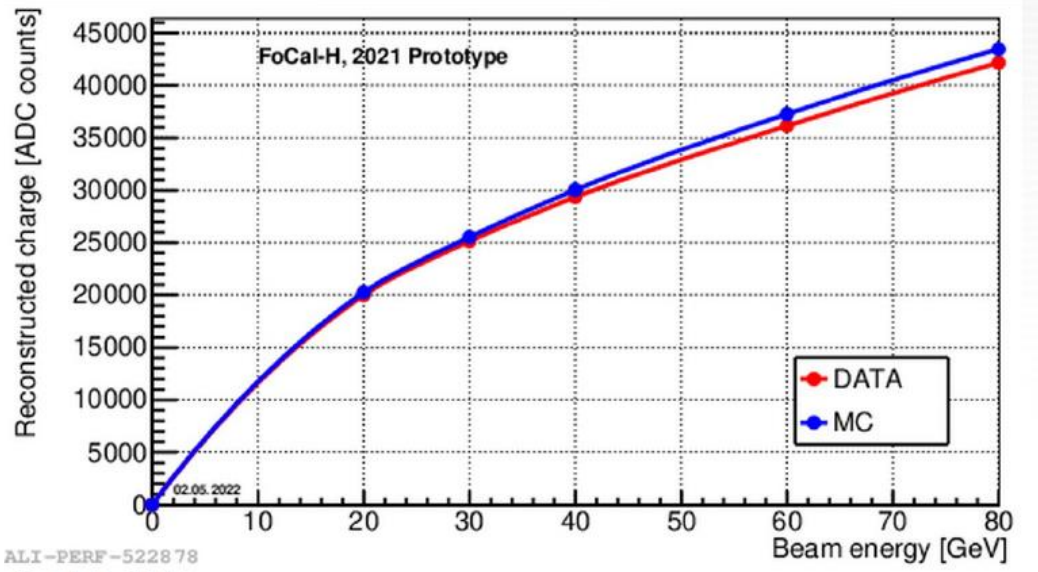
- further tests planned at SPS for autumn 2022

# FOCAL- H prototype 1 (test SPS 2021)





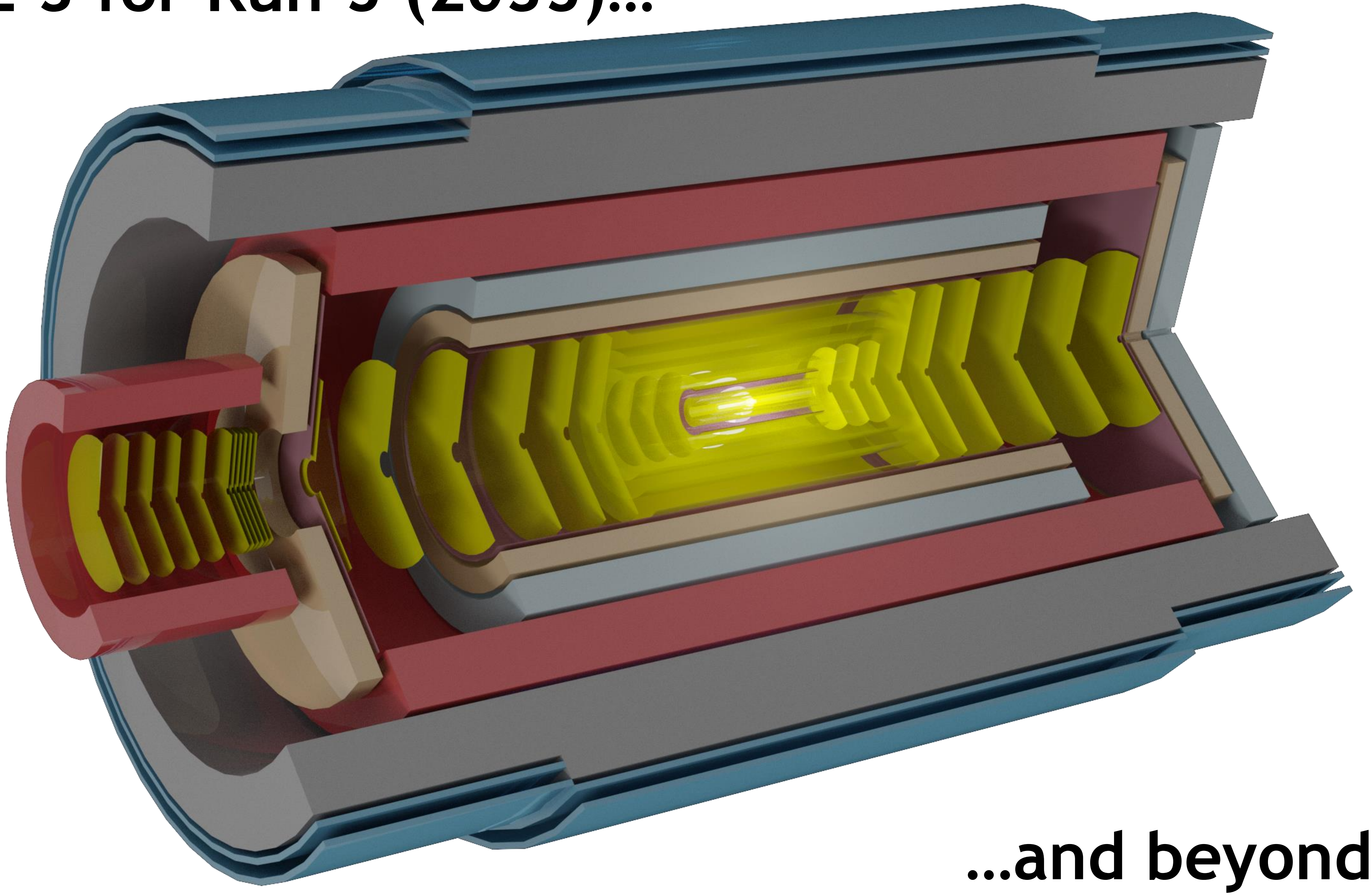



- 1440 copper tubes parallel to beam pipe, filled with scintillating fibers
- Fibers coupled to silicon photomultipliers
- Energy measured by sum of charge signal from SiPMs (in units of ADC counts)

Prototype 2 (from 2022): modular structure
- 65 x 65 x 1100 mm$^3$
- 668 copper tubes per module
- 9 modules planned

# ALICE 3 for Run 5 (2035)…



…and beyond

# ALICE 3 selection of physics goals

**Precision measurements of dileptons**

➟ evolution of the quark-gluon plasma

➟ mechanisms of chiral symmetry restoration

**Systematic measurements of (multi-)heavy-flavour hadrons**

➟ transport properties in the quark-gluon plasma

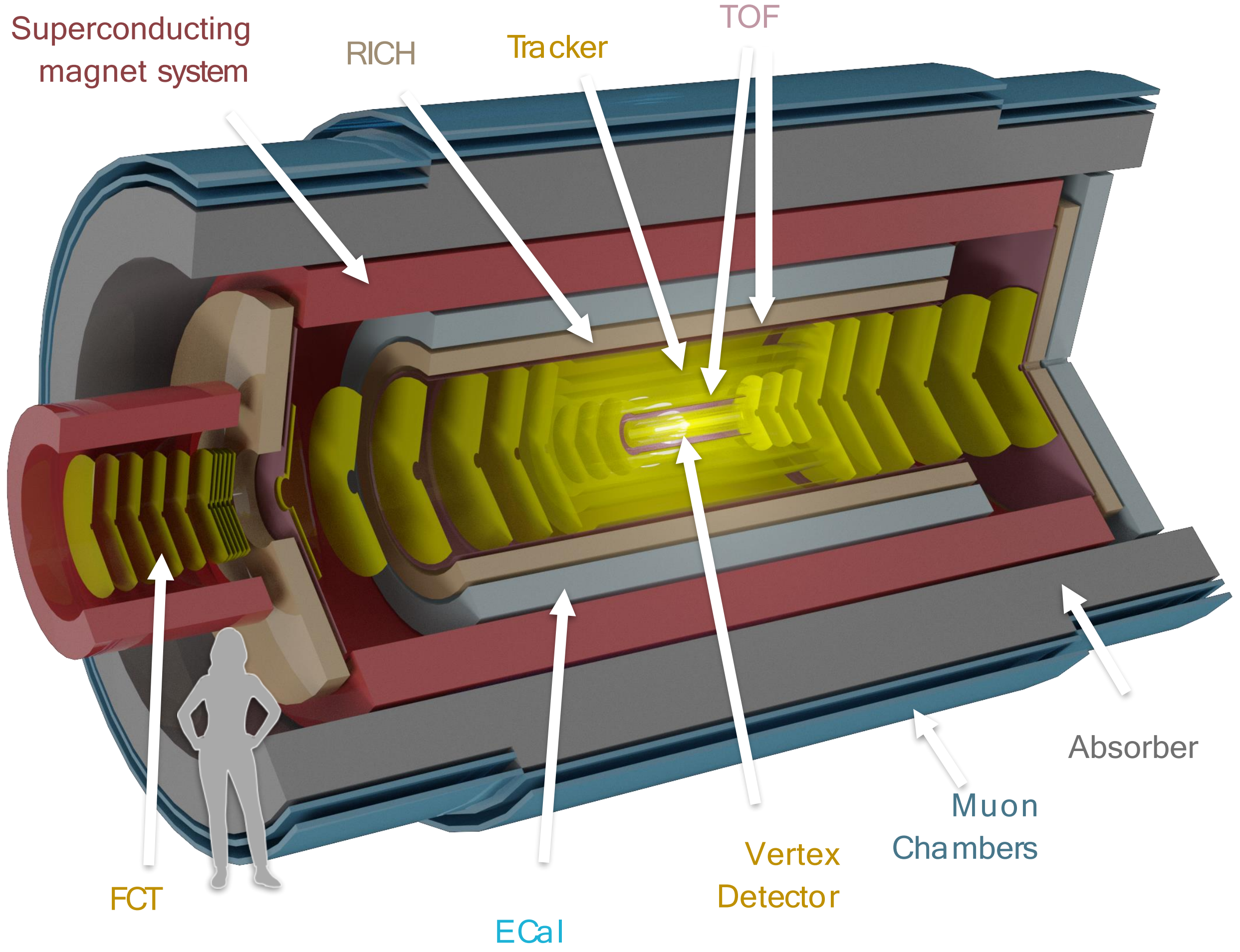
➟ mechanisms of hadronisation from the quark-gluon plasma

**Hadron correlations**

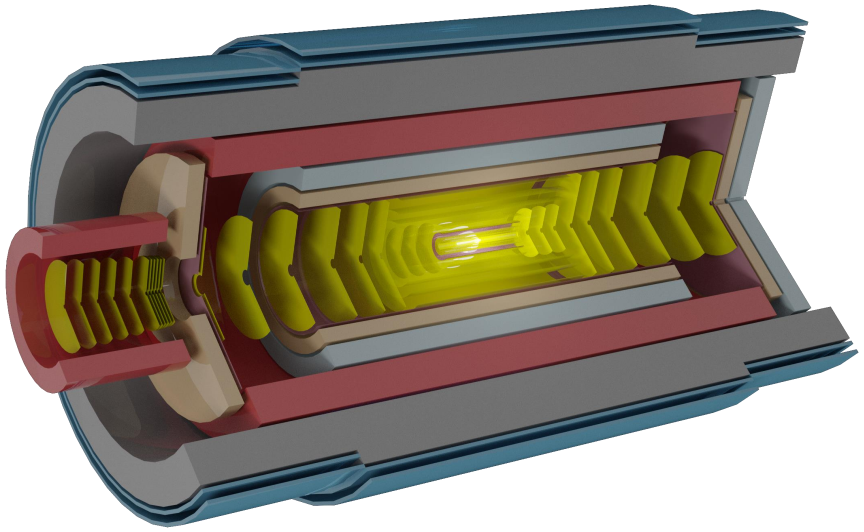
➟ interaction potentials

➟ susceptibility to conserved charges

CERN-LHCC-2020-009



# Possible ALICE3 layout

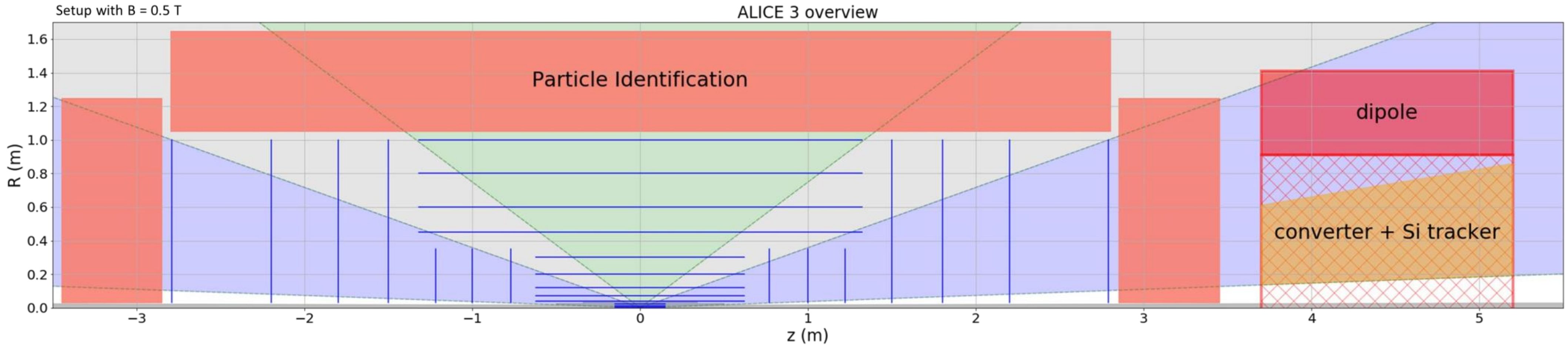


~12 tracking barrel layers + disks based on MAPS

Particle identification (TOF, Cherenkov, EM shower)

Dedicated forward detector for soft photons (conversion + Si tracker)

Further detectors under study (e.g. muon ID)



# Vertex tracker

Pointing resolution improves with smaller $r_0$ and $\sqrt{X/X_0}$

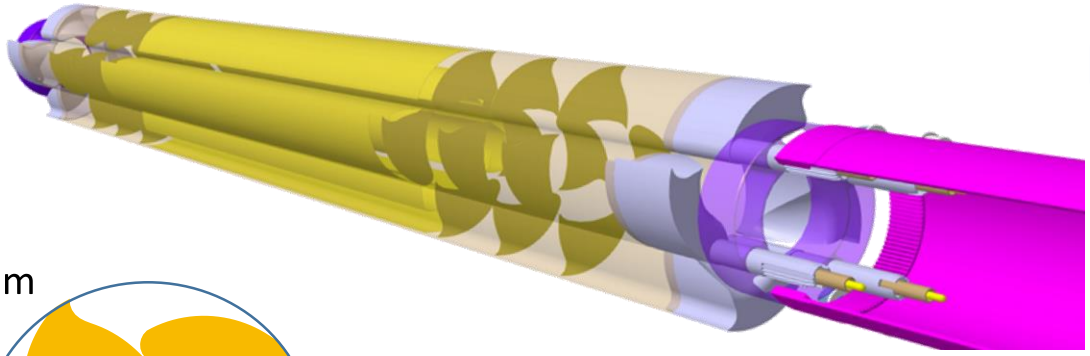
Potential improvements wrt ITS3

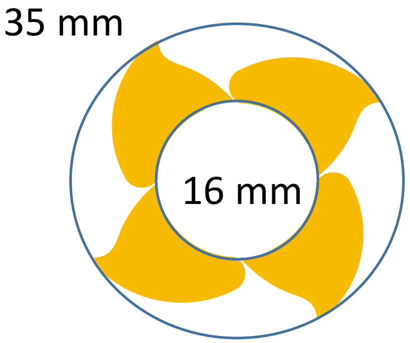
➟ Remove material in front of 1st layer by moving detector into beam pipe

➟ Move closer to interaction point

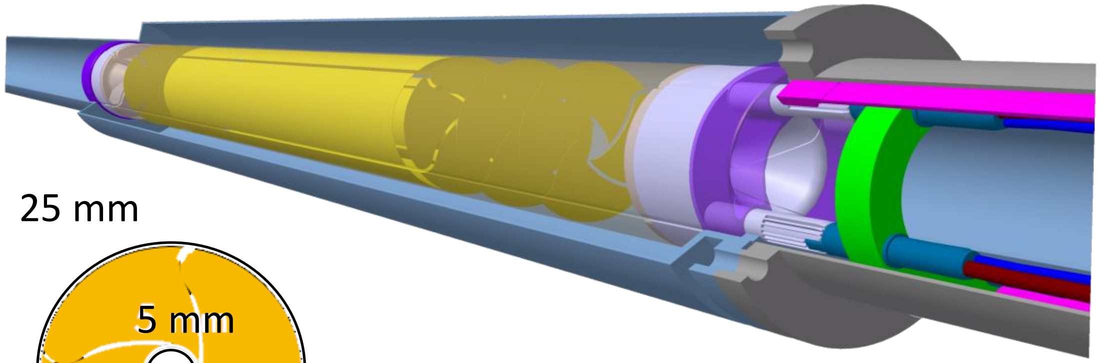
Limited by LHC beam aperture at injection energy (16 mm)

➟ Place detector in secondary vacuum, move into position for data taking (5 mm)






Retractable iris design



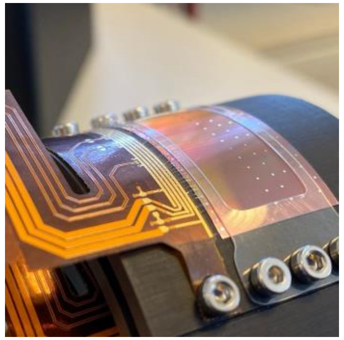
25 mm

# ALICE 3 silicon detectors: main R&D challenges

- Inner tracker
  - ultra-thin layout: flexible wafer-scale sensors (MAPS/ITS3)
  - minimal distance from IP requires retractable detector
  - position resolution O(1 μm) requires small pixel pitch

- Position resolution ~1 μm,
- $X/X_0$ ~0.1%/layer
- MAPS: pitch < 10 μm
- Innermost radius = 5 mm

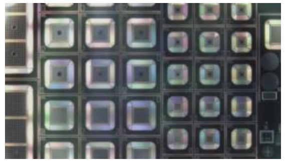
*Flexible MAPS*



- Outer tracker
  - large areas to instrument: develop cost-effective sensors
  - low material budget requires low-weight support and services

- Position resolution ~10 μm,
- $X/X_0$ ~1%/layer
- MAPS: pitch ~ 30-50 μm

*AC-LGAD*

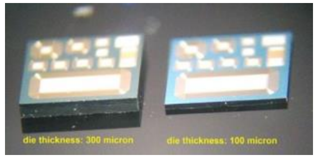


*SPAD*


- Time of Flight
  - TOF resolution < 20 ps needed on the system level requires advances both on sensors and microelectronics
  - large areas to instrument: develop cost-effective sensors

- 20 and 100 cm radii
- ~ 20 ps timing resolution
- $X/X_0$ 1-3%/layer
- Cell pitch ~ 1 mm

*DMAPS*



# Summary

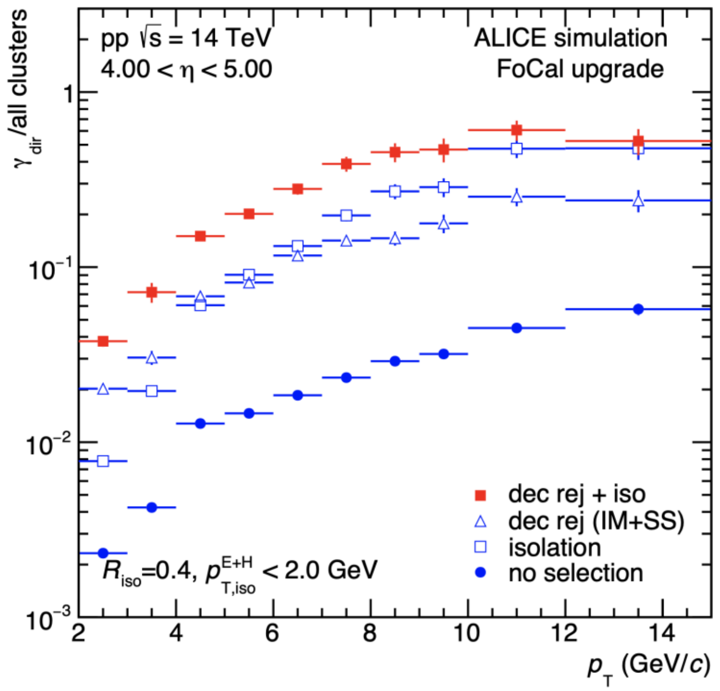
- ALICE upgrade proposals for Run 4
  - Development and prototyping phase
    - ITS3: flexible wafer-size MAPS sensors
    - FoCal: MAPS-based electromagnetic calorimeter

- ALICE 3: a new generation, heavy-ion experiment for Run 5 and Run 6
  - Letter of Intent prepared
    - Physics performance studies
    - Definition of detector requirements
    - Detector technology survey and development

# Backup slides

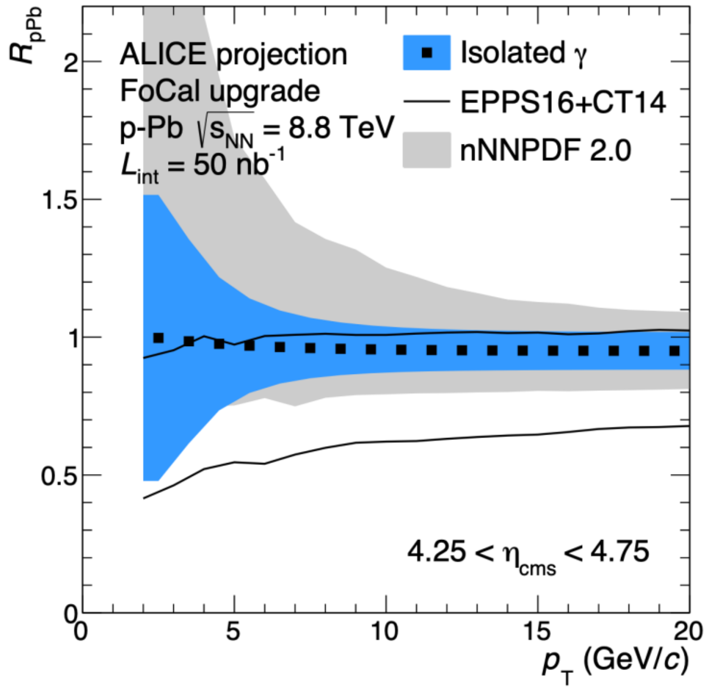
# FOCAL expected performance and impact on nPDF

### Direct γ/all cluster ratio



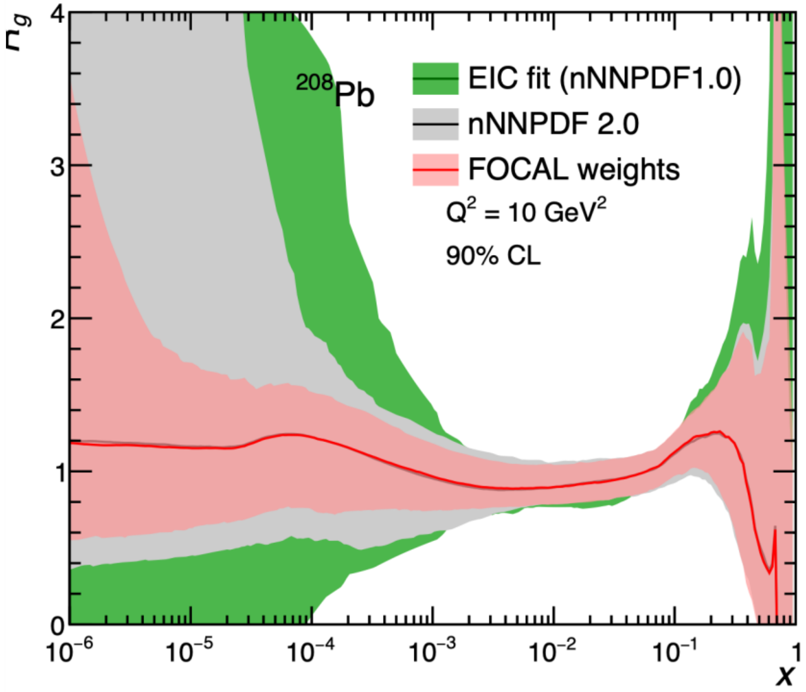

- Systematic uncertainty ~20% at ~4 GeV
- Below ~6 GeV, uncertainty rises due to remaining background

### Projected uncertainty on $R_{pPbtr}$




- Significant improvement (up to factor 2) on EPPS16, nNNDF 2.0 uncertainties
- Compare to e.g. open charm: test factorization/universality

### Reweighted nuclear PDFs




nNNPDF 2.0 from DIS + LHC (minimal theoretical assumptions)

- No constraints for $x < 10^{-2}$ from DIS
- LHC: high-$Q^2$ constraints down to $10^{-4}$
- FOCAL adds constraints over a broad range: ~$10^{-5}$ - $10^{-2}$ at small $Q^2$