Novel detector concepts for ALICE for Run 4 and beyond

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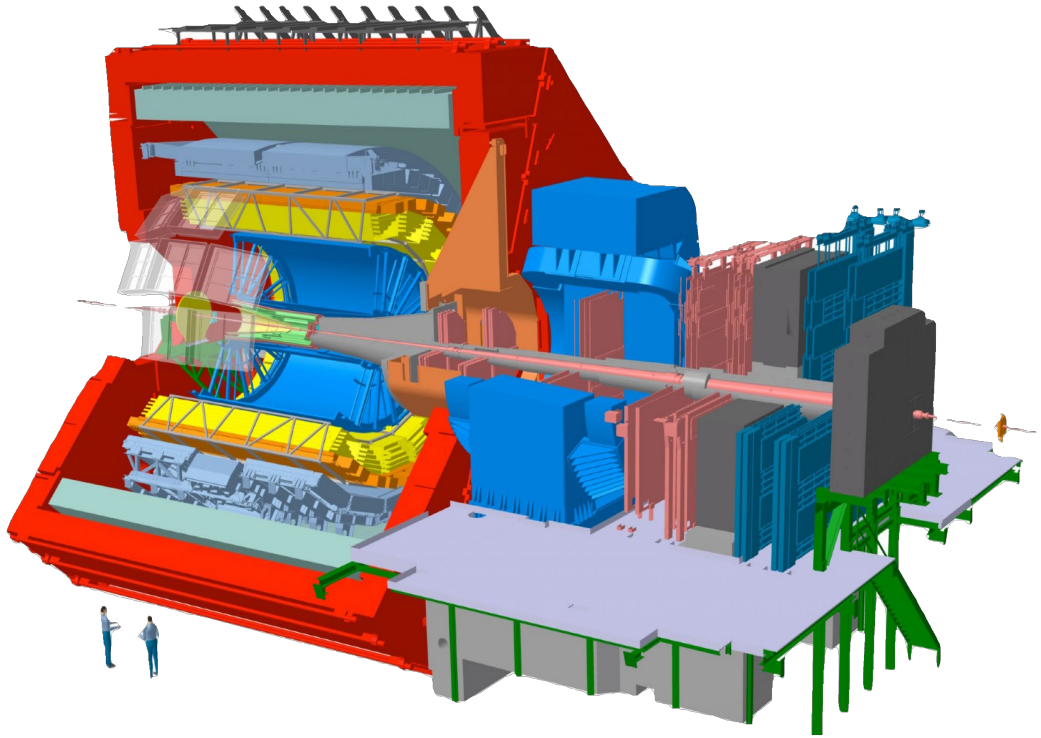
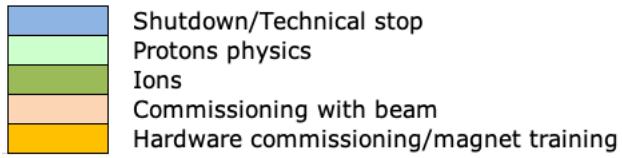
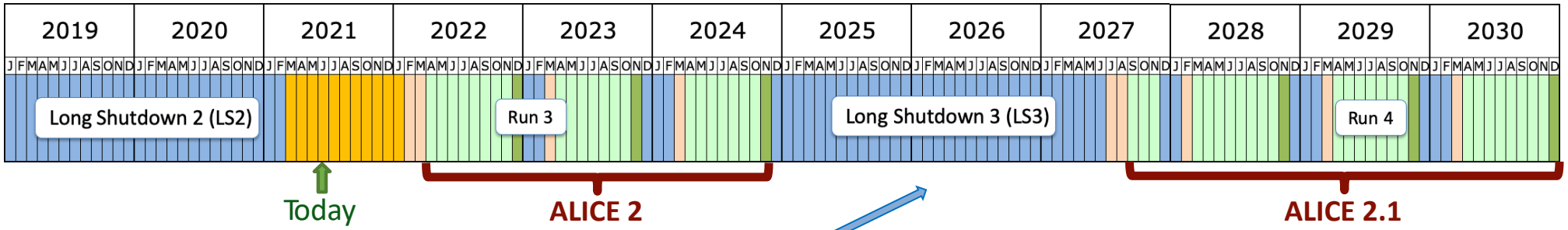
on behalf of the ALICE Collaboration



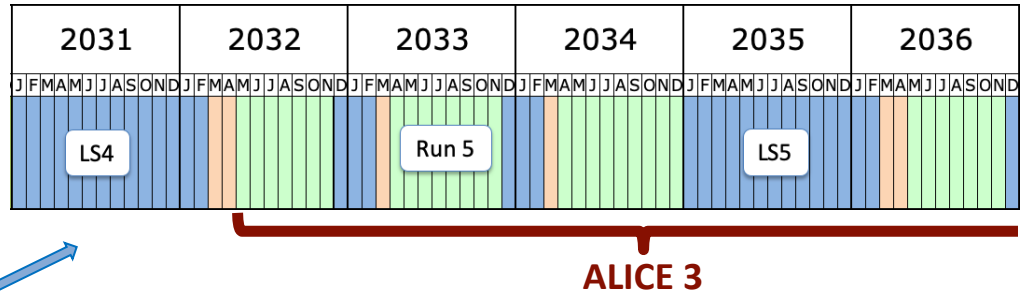
ALICE upgrade timeline





ALICE upgrades in LS3:

- **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

Programme after LS3 is included in the CERN Yellow Report arXiv:1812.06772

See C. Lippmann's talk: *"Upgrades for ALICE"*

ITS3

ITS3 detector layout

ITS3 LoI - CERN-LHCC-2019-018

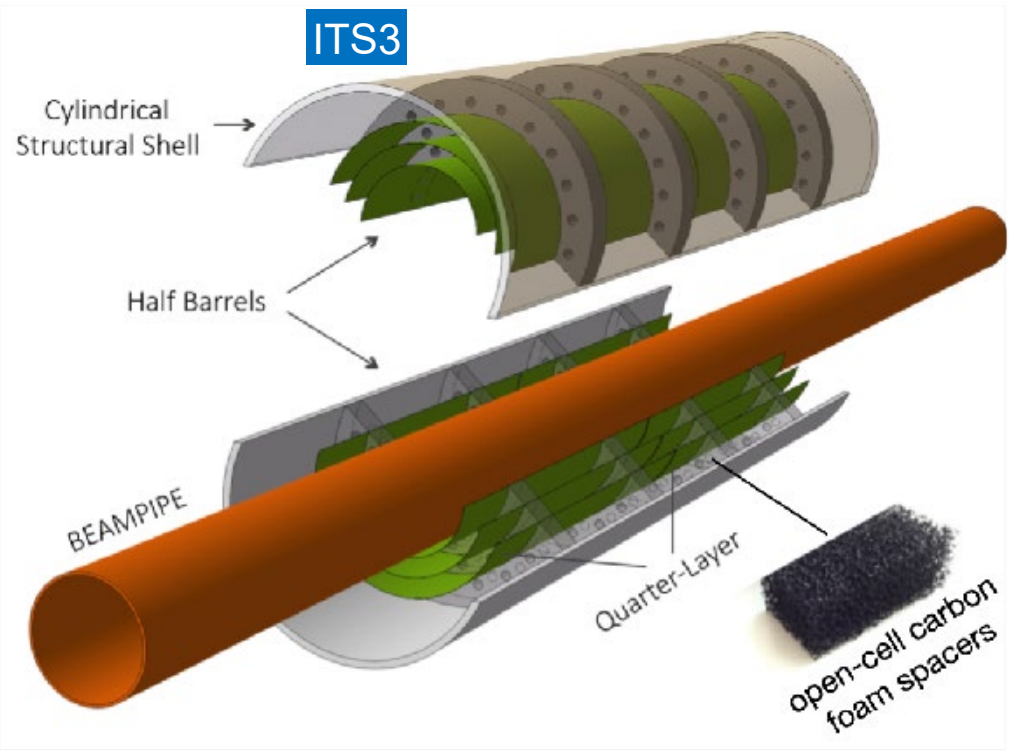
ALICE

replace

ITS2 Inner Barrel

with

ITS3



in LS3

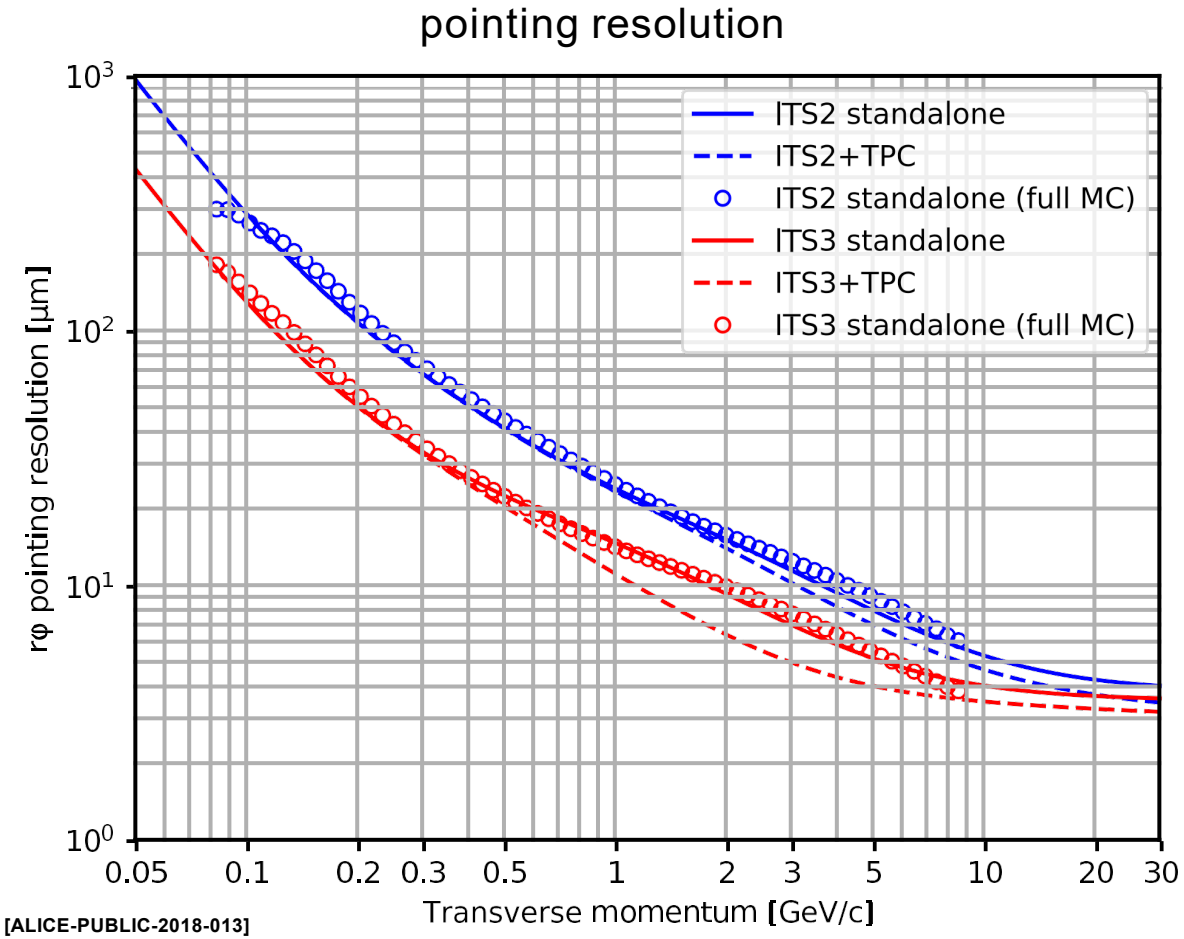
key improvements:
- closer to beam pipe: 23→18 mm
- less material: 0.3 → ~0.03 %X_0

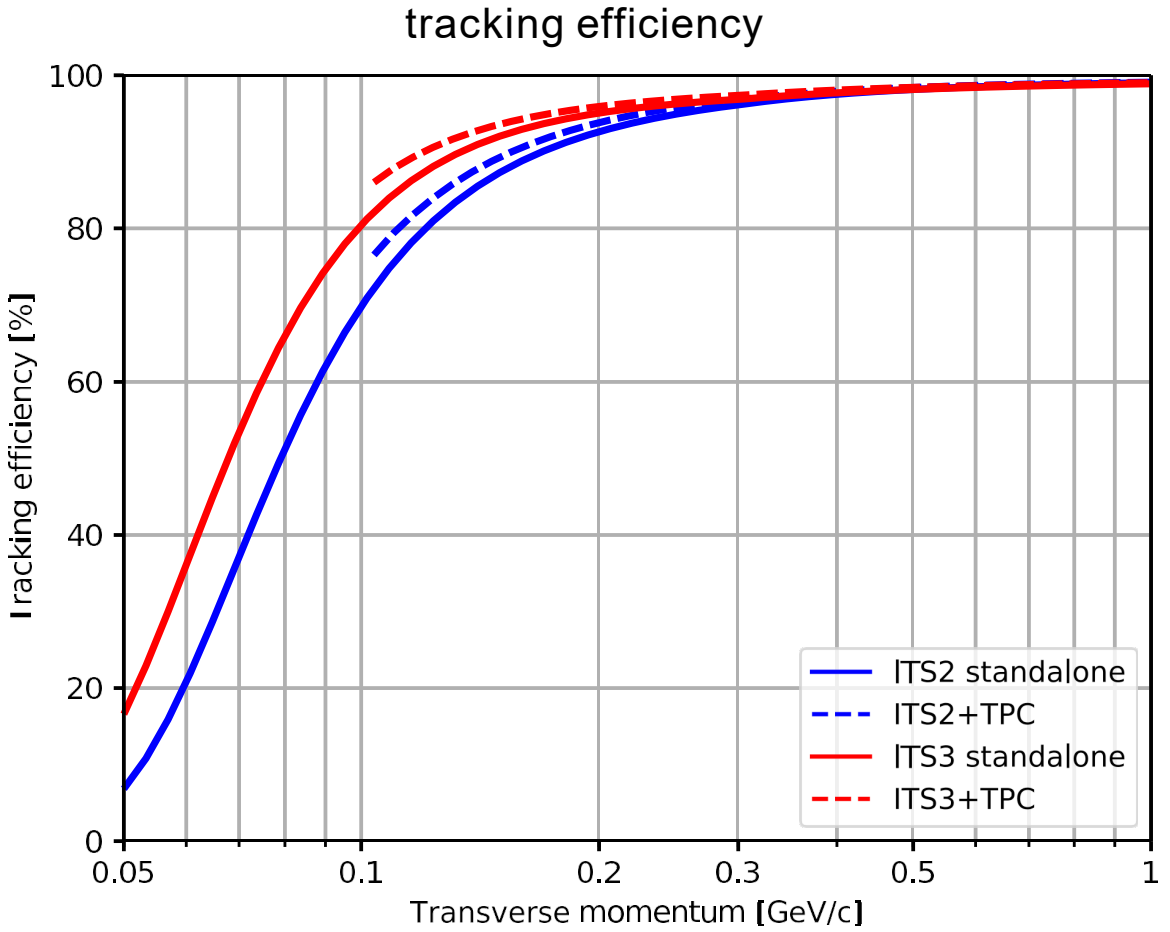
main benefit:
- better tracking performance
- especially at low p_T

based on:
- wafer-scale (up to ~28x10 cm),
- ultra-thin (20-40 μm),
- bent (R=18, 24, 30 mm)

Si sensors (MAPS) → 65 nm CMOS process

ITS3 projected performance

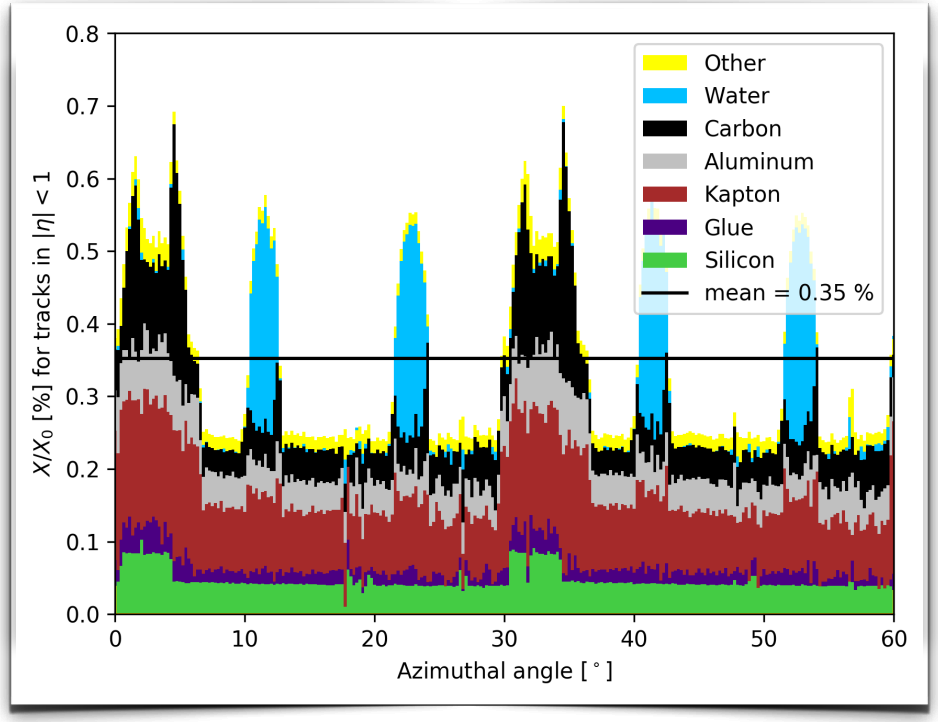


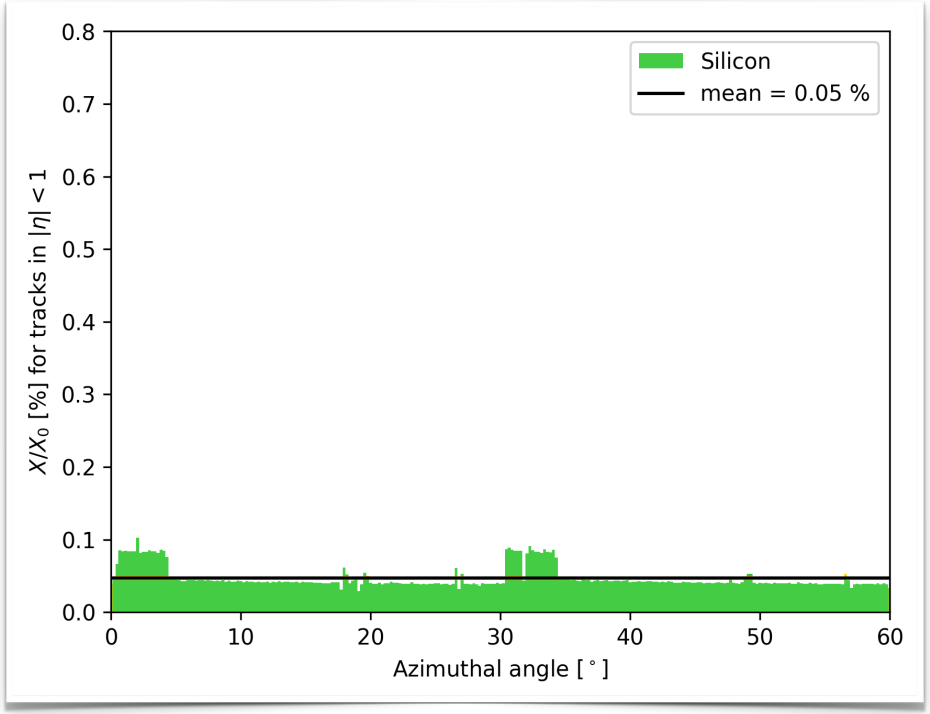


improvement of factor 2 over all momenta

large improvement for low transverse momenta

ITS3 idea: material budget minimization

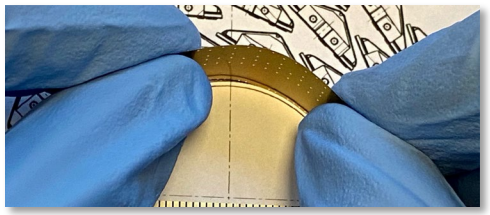


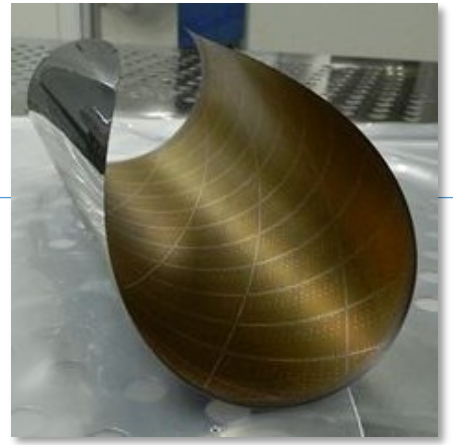


- **Silicon makes only 1/7-th** of total material budget
- **Relevant non-uniformity** due to support and cooling infrastructure, and overlaps

- Removal of water cooling:
  - If **power consumption < 20 mW/cm²**
- Removal of the circuit board for power & data:
  - If **integrated on chip**
- Removal of mechanical support:
  - **Self-supporting arched structure**

ITS3 truly-cylindrical layers

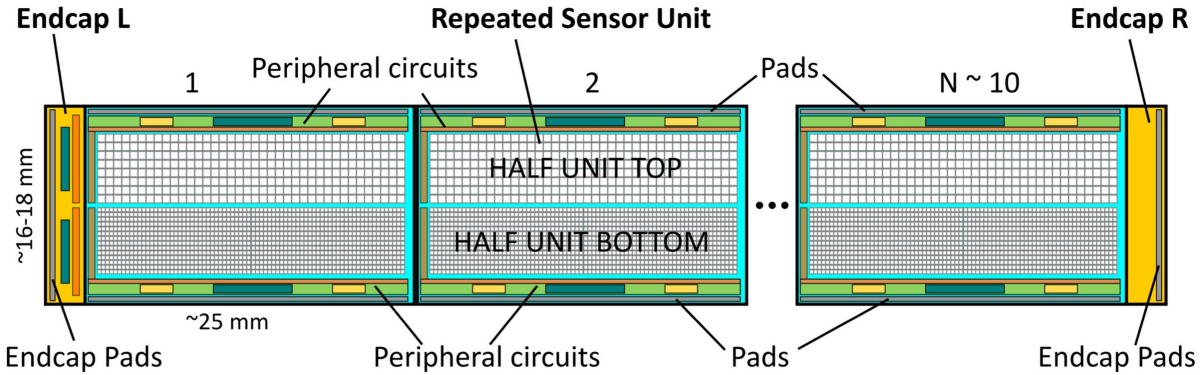




- Curved geometry
  - Silicon becomes flexible below 50 µm thickness

- Large area chips to reduce segmentation and interconnections
  - 30 cm wafers
  - Stitched design:
    - abutting identical but functionally independent units
    - connect metal traces for power distribution and long range on-chip interconnect busses
    - repeat in vertical direction to match layer size

possible architecture →



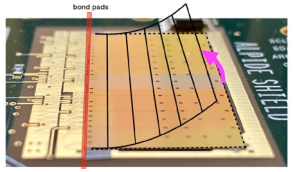
➢ TowerJazz 65 nm CMOS process exploration

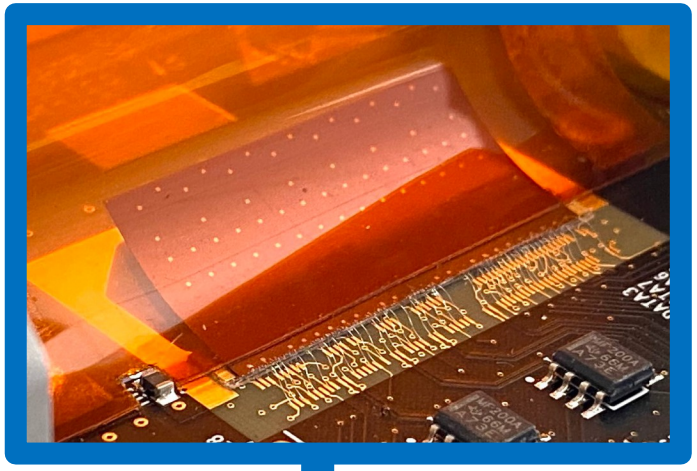
- First submission containing test structures in Dec ’20
- Wafers are now back – preparing for testing campaign

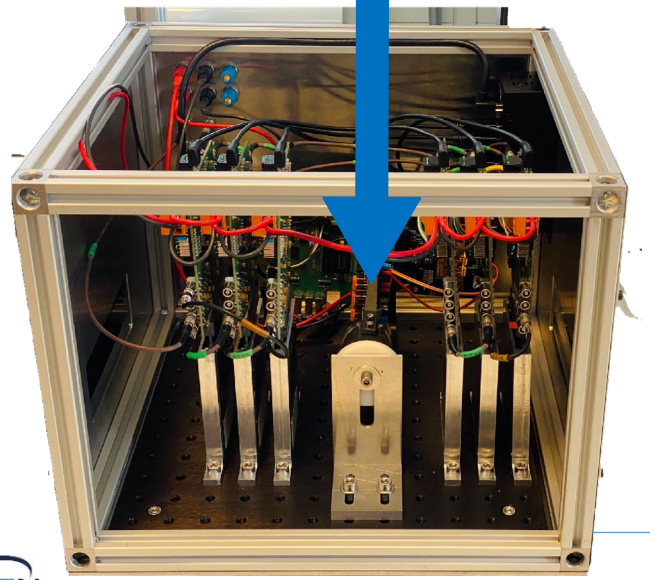
featuring: →

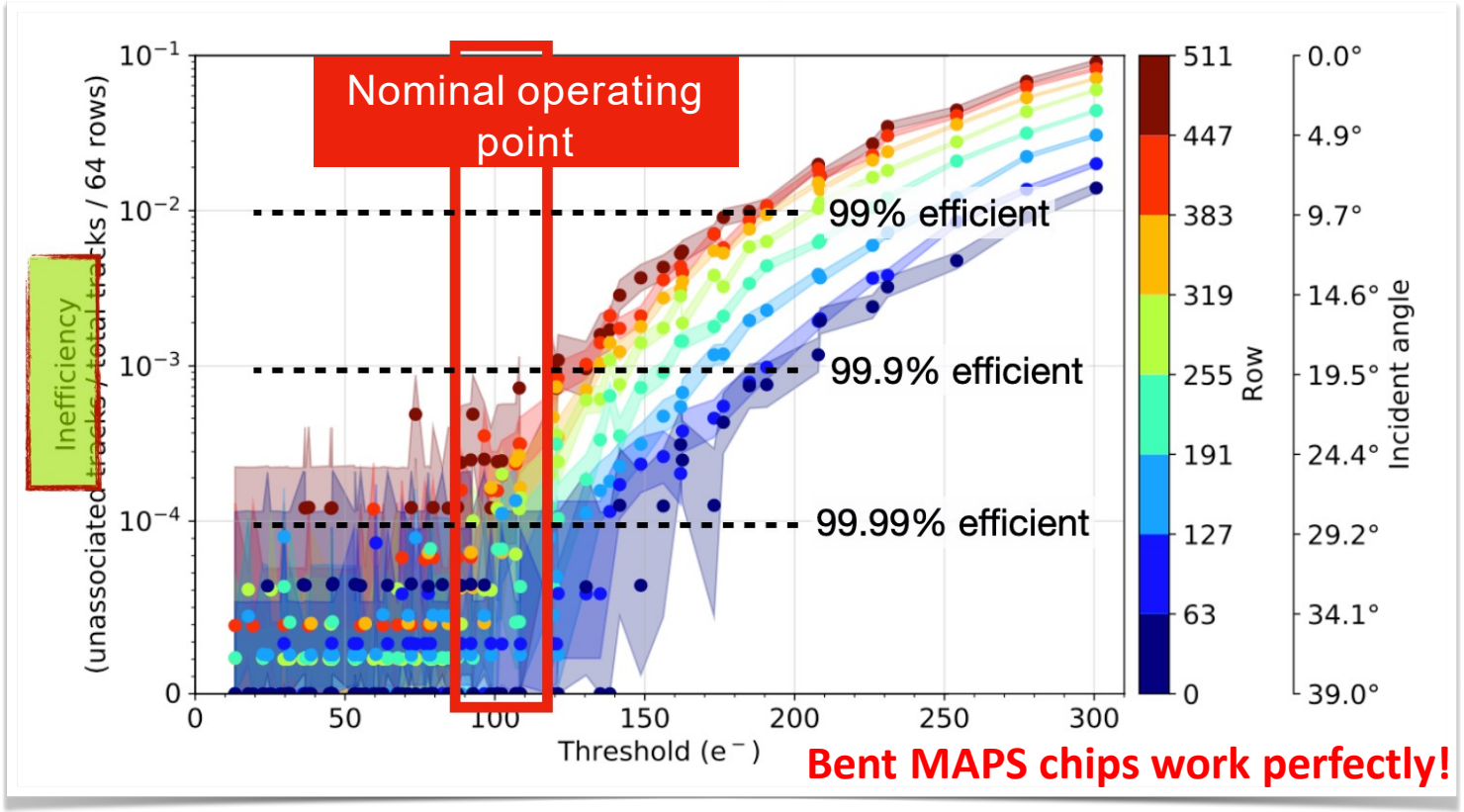
- ❖ 30 cm wafers (vs 20 cm in 180 nm)
- ❖ 2D stitching experience
- ❖ Smaller feature size → smaller pixels

Proof of concept of bent silicon sensors







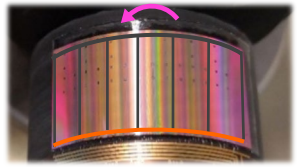


Bent MAPS chips work perfectly!

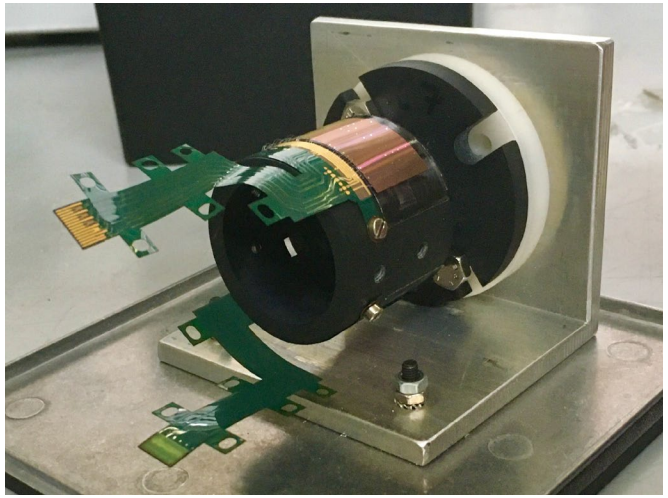
- 50 µm thick ALPIDE sensors bent to ITS3 radius along the short side
- **Mechanical and electrical characterization in laboratory**
- **Full performance characterization in test beam**
  - no deviation from flat performance observed

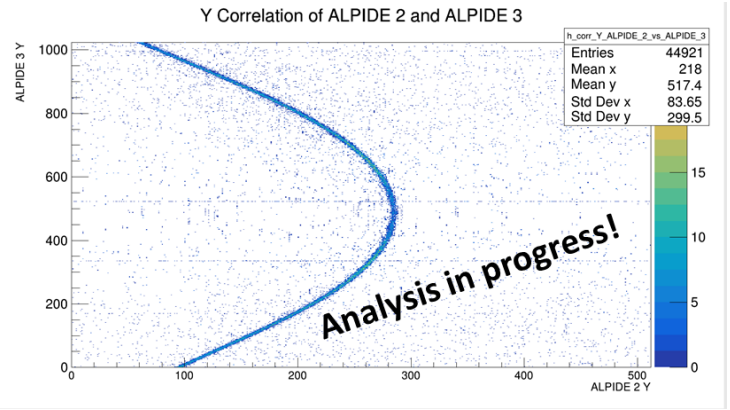
arXiv:2105.13000

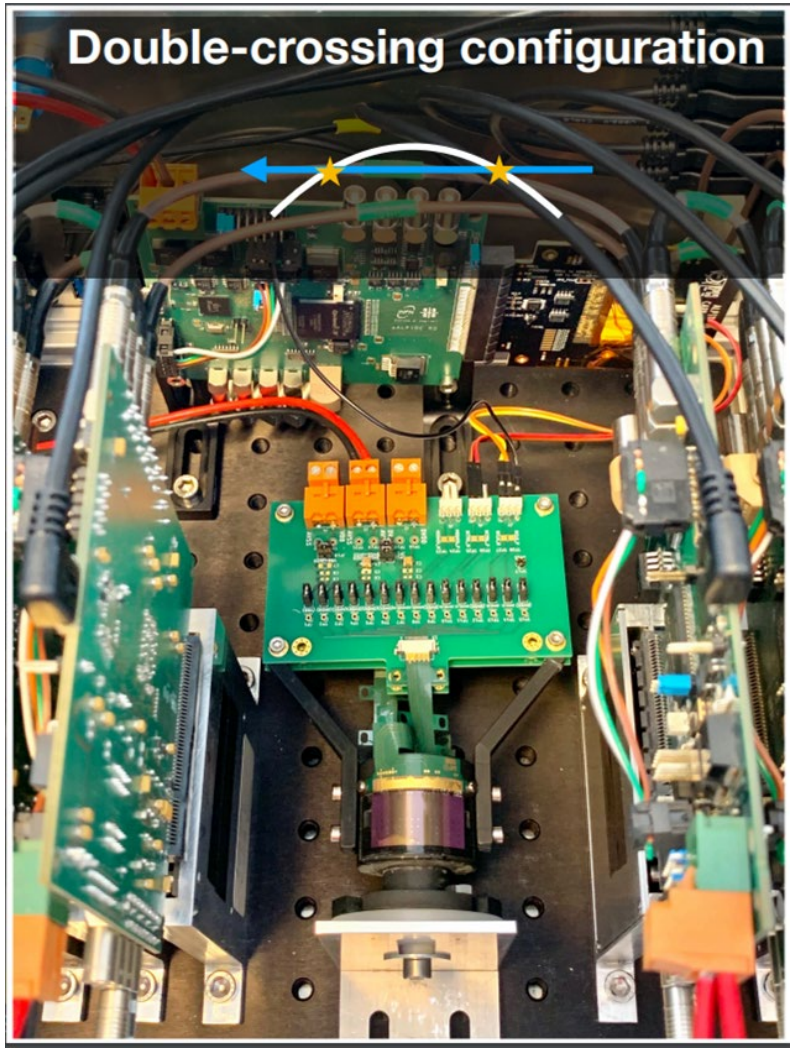
Further test beams for bent ALPIDEs



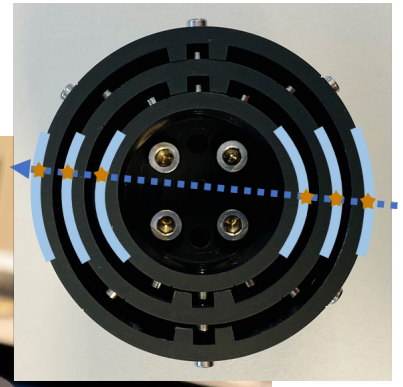
Long side bending: pixel matrix and logic are curved

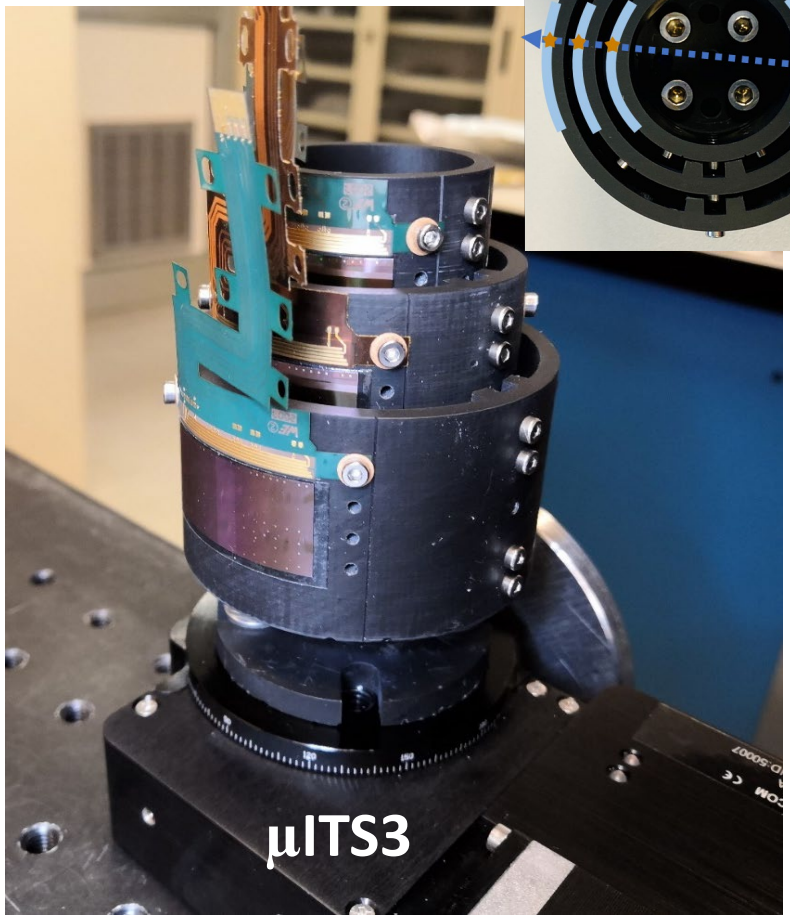






µITS3: 3 ALPIDE layers at nominal ITS3 radii

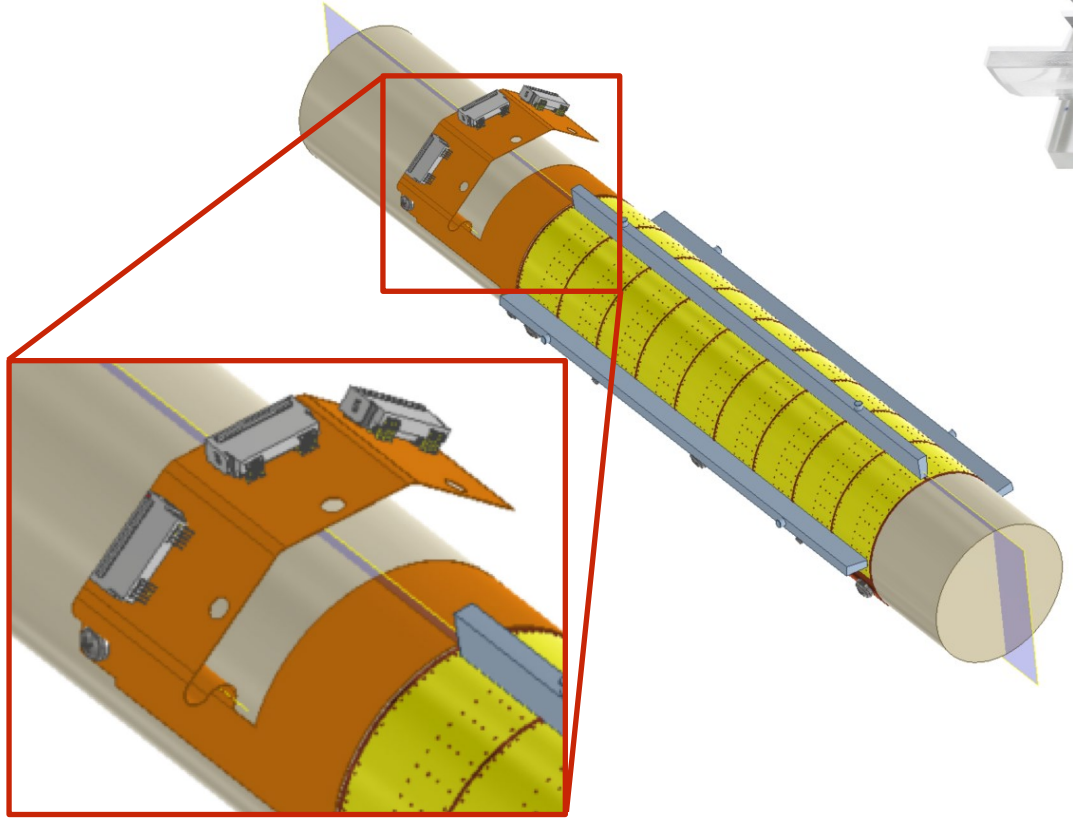


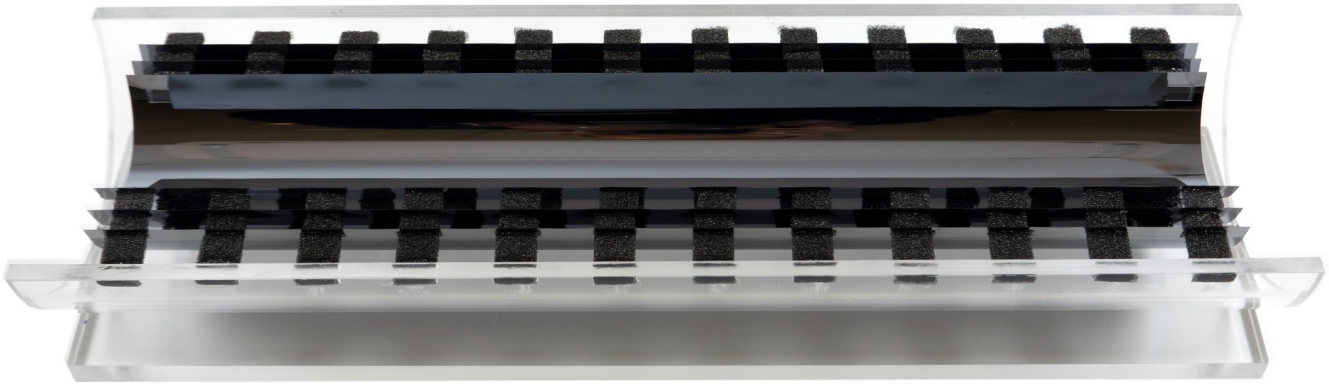


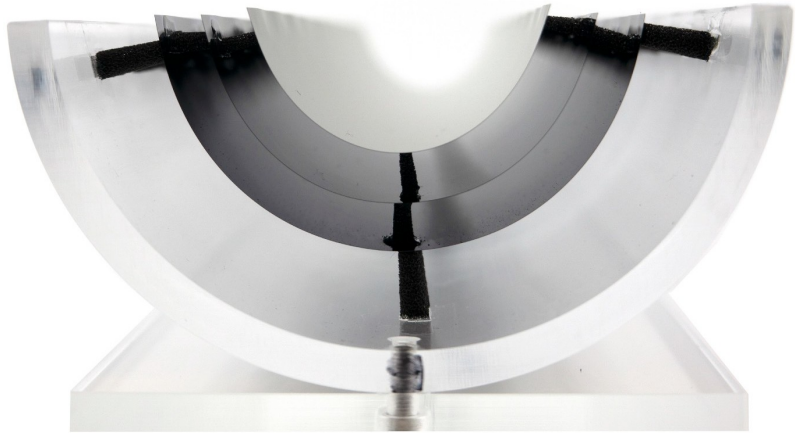
Functional mock-up half-layer based on ALPIDEs and full-size ITS3 mechanical prototype

Thinned and bent 9x2 ALPIDE matrix

- Front-edge ITS3 connection prototype
- Large area functional chip







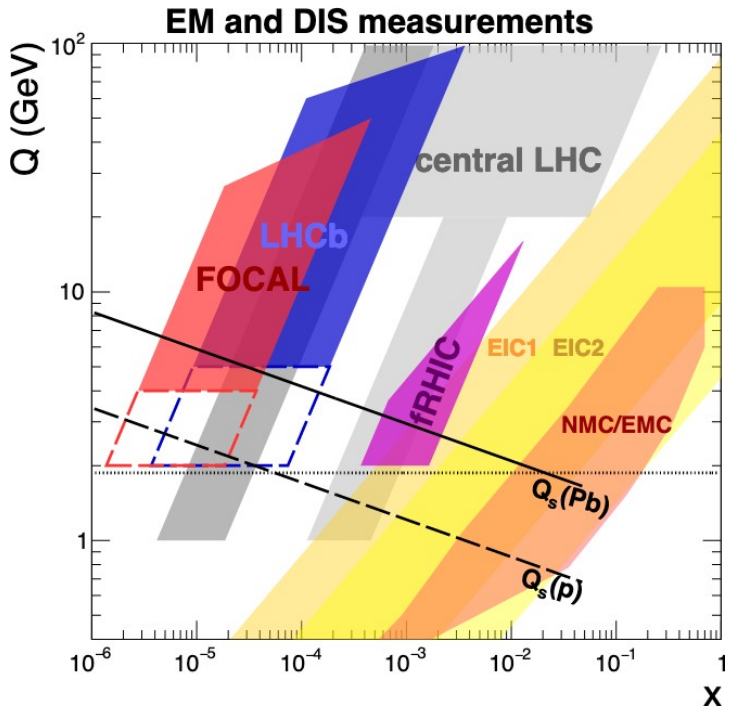
Full-size mechanical prototype

3 layers with carbon foam spacers

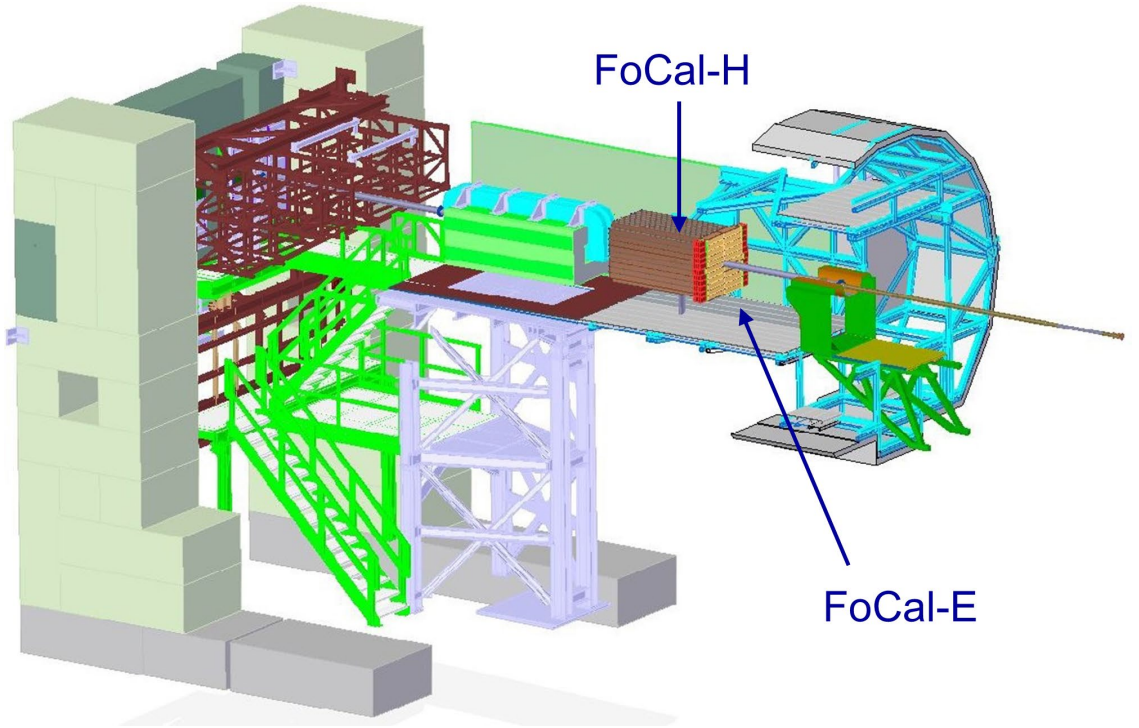
FoCal

Forward Calorimeter

- Physics Goal: unravel nucleus structure at small-x
  - Unique capabilities to measure **direct photons** in pp and p-Pb
  - Study the **gluon distributions** at **small-x** scale and **low Q**



FoCal LoI - CERN-LHCC-2020-009



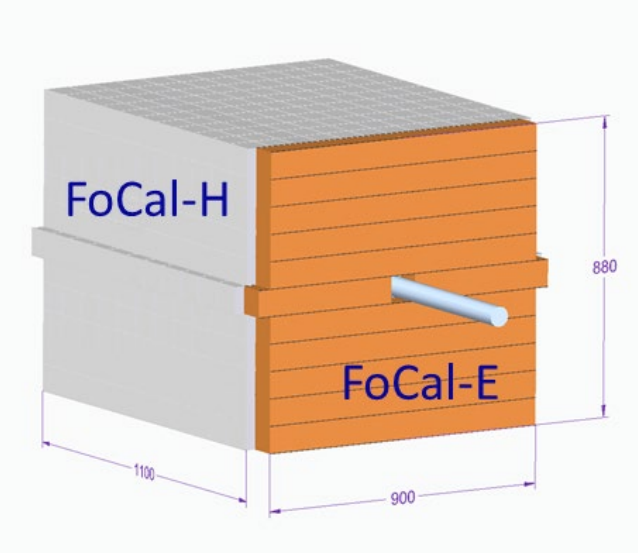
$3.4 < \eta < 5.8$
(baseline design @ 7 m from IP)

FoCal-H and FoCal-E

FoCal-H: Conventional sampling hadronic calorimeter (Cu + scintillating fibres)

- Providing γ isolation through direct detection of high energy hadrons

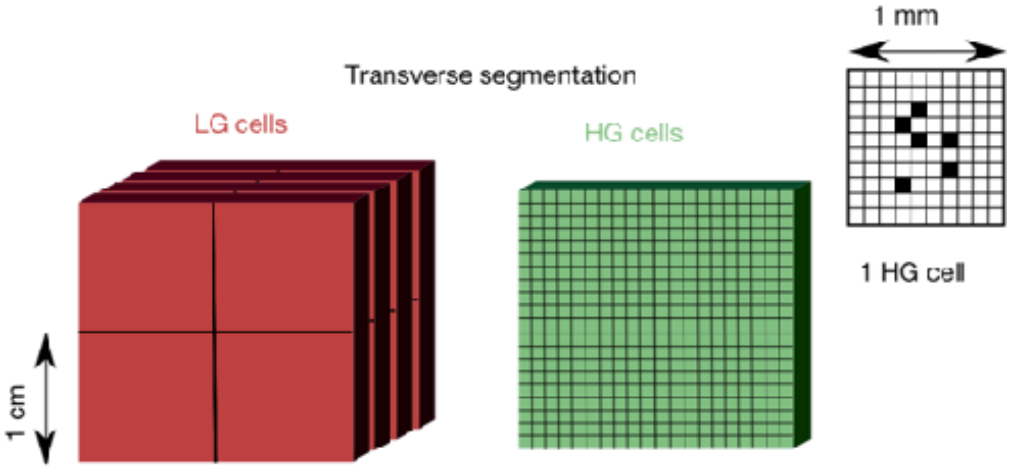
FoCal-E: high-granularity Si-W electromagnetic calorimeter for γ and π_0

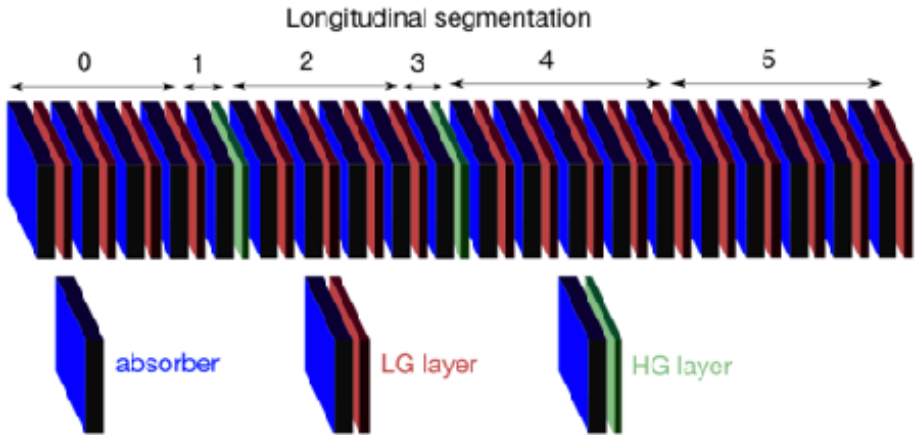


- **Main challenge** for FoCal-E: γ/π_0 separation at high energy
  - two photon separation from π^0 decay: ~2 mm
  - needs small Molière radius and high granularity readout

  ➔ Si-W calorimeter with effective granularity of ~1 mm^2

FoCal-E detector technologies



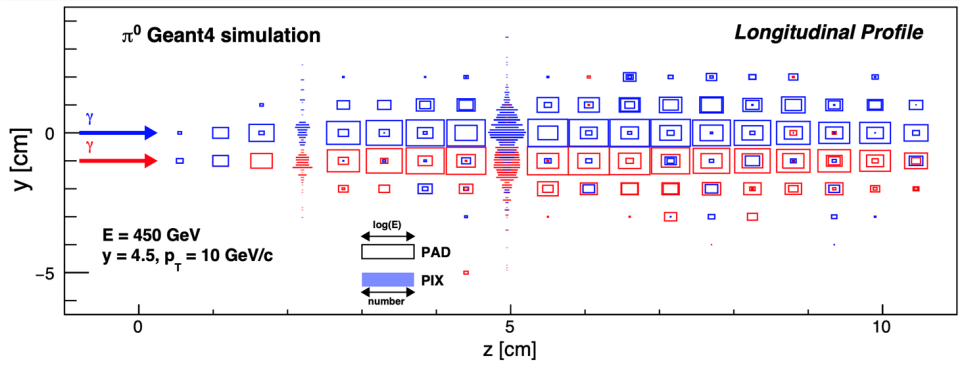


Studied in simulations: 20 layers

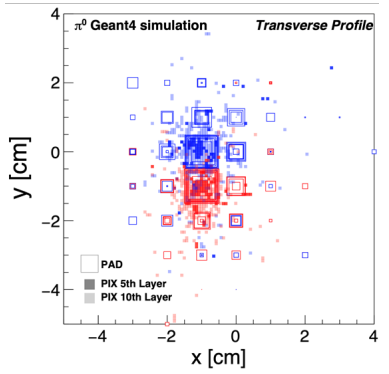
W (3.5 mm ~ $1X_0$) + silicon

- 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

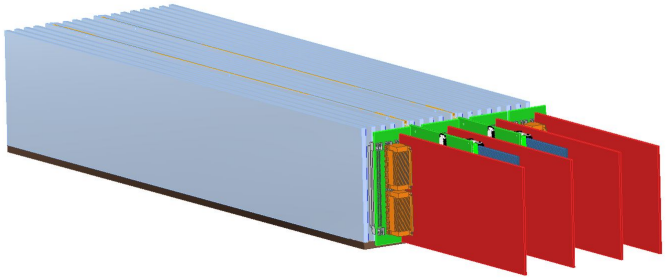
Longitudinal profile (2γ showers)



Trans. profile

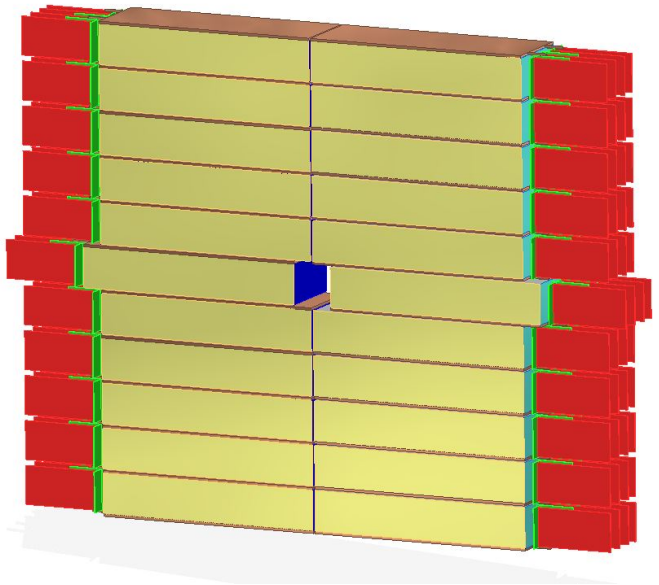


FoCal-E layout and prototypes

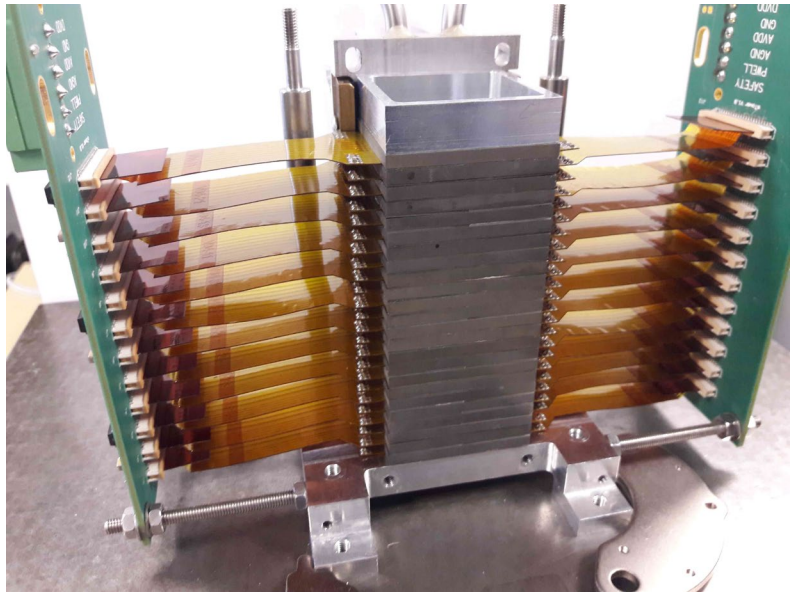


Module: 18 pad layers + 2 pixel layers

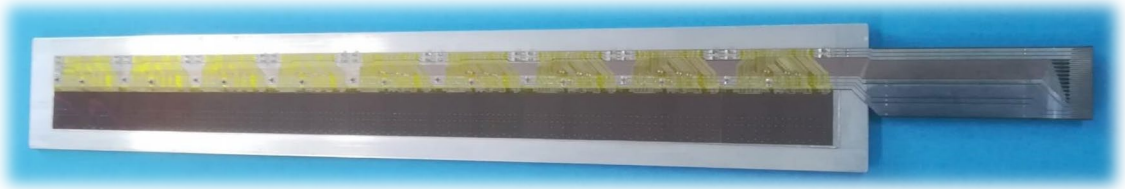
- Readout, power, cooling connected on one side



FoCal-E:
22 modules



EPICAL
all-pixel small E-cal

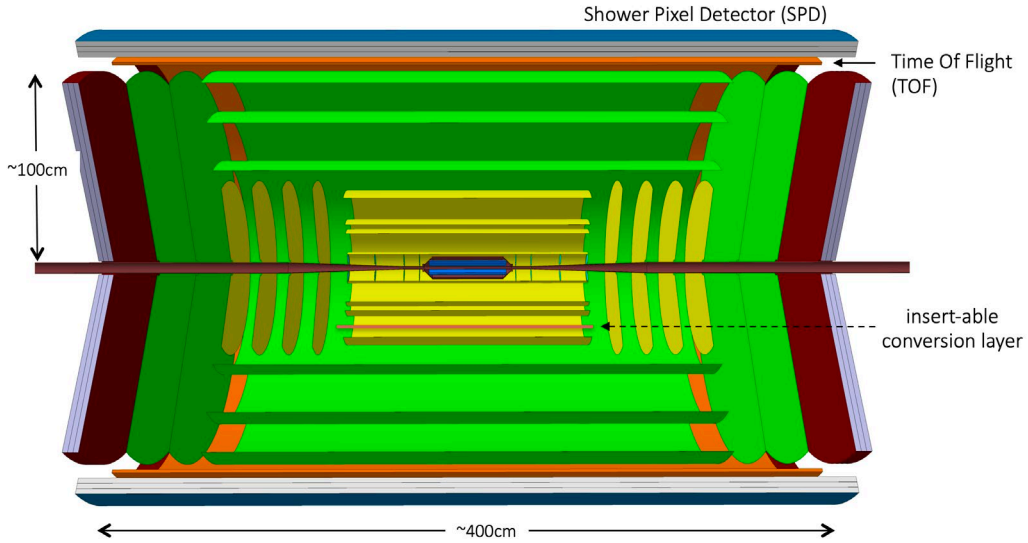


Pixel string prototype: 9x SpTAB bonded ALPIDE
Final pixel layer will have 3x 15-ALPIDEs strings

ALICE 3

ALICE 3: a heavy-ion experiment for Run 5/6

- "Ambition to design a new experiment to continue with a rich heavy-ion programme at the HL-LHC" mentioned in the Update of the European strategy for particle physics



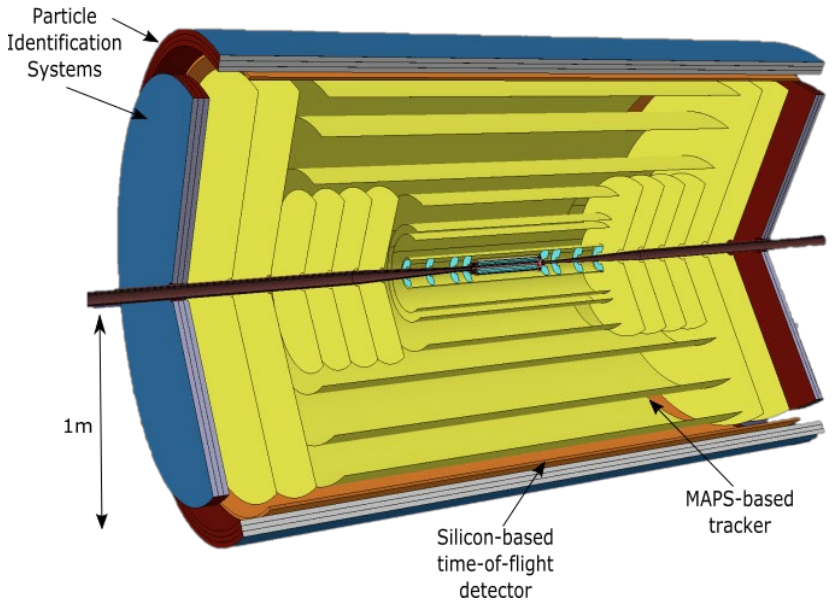
- **ALICE 3** studies organized in Working Groups towards the preparation of a Letter of Intent

See A. Uras's talk: *"Physics prospects ALICE in Run 5 and beyond"*

See S. Bufalino's talk: *"UPGRADE: PID and tracking with timing detectors in ALICE and LHCb in Run 5"*

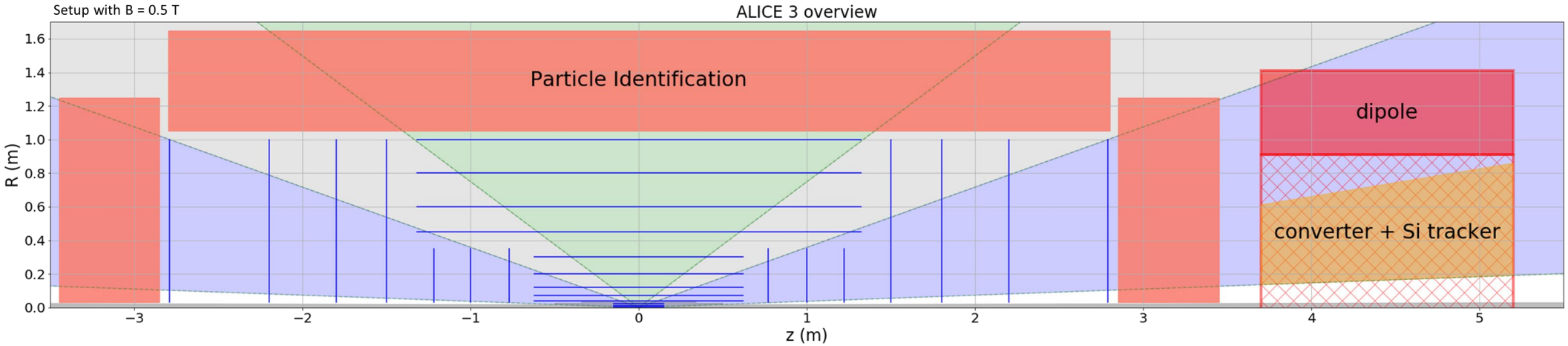
- Fast and ultra-thin detector with precise tracking and particle identification
  - Ultra-lightweight silicon tracker with excellent vertexing
  - Fast to profit from higher luminosity (also with nuclei lighter than Pb): 50-100x Run 3/4
  - Particle Identification: TOF determination (20 ps time resolution), Cherenkov, pre-shower/calorimetry
  - Kinematic range down to very low p_T: 50 MeV/c (central barrel), 10 MeV/c forward (dedicated detector)
  - Large acceptance ⇒ barrel + end caps $\Delta\eta = 8$

Possible ALICE 3 detector 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)

Si tracker of ~100 m²

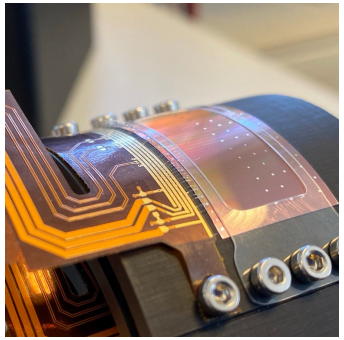


ALICE 3 silicon detectors: main R&D challenges

- 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

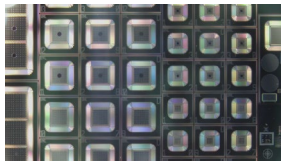
Flexible MAPS



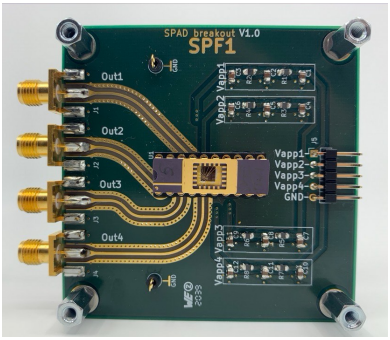
- Outer tracker
  - large areas to instrument: develop cost-effective sensors
  - low material budget requires low-weight support and services

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

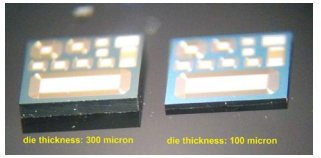
AC-LGAD



SPAD



DMAPS



- 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

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
  - Preparation of the Letter of Intent
    - Physics performance studies
    - Definition of detector requirements
    - Detector technology survey and development

Thank you for your attention!