ALICE Upgrades for LHC Run 4 & beyond

TCHoU Meeting, June 27th 2023, Tsukuba University
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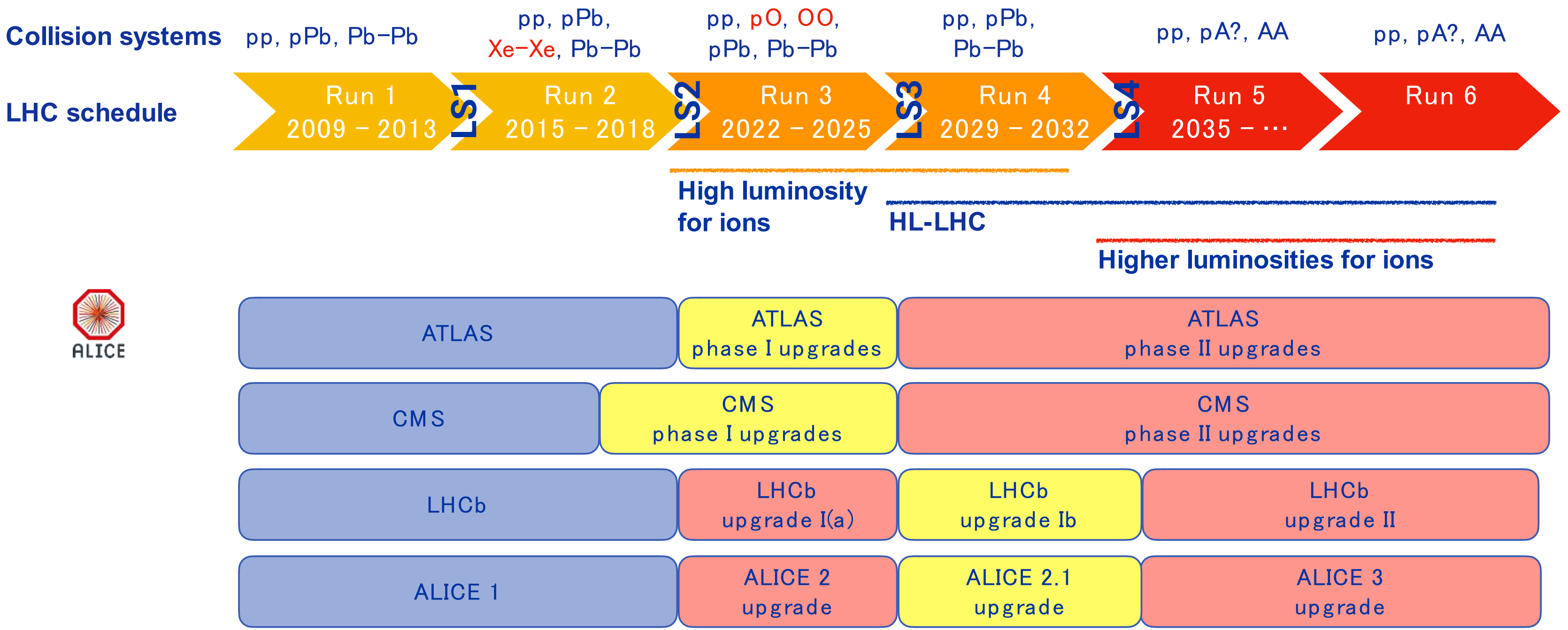
LPSC Grenoble CNRS–IN2P3/University Grenoble Alpes

- LoI CERN-LHCC-2020-009 CERN-LHCC-2019-018 CERN-LHCC-2022-009
- TDR published in 2023 for Run 4 upgrades

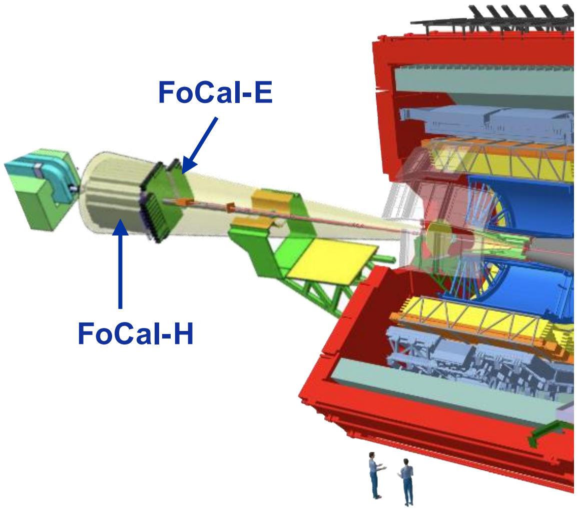
The LHC (heavy-ion) programme



FoCal
ITS3

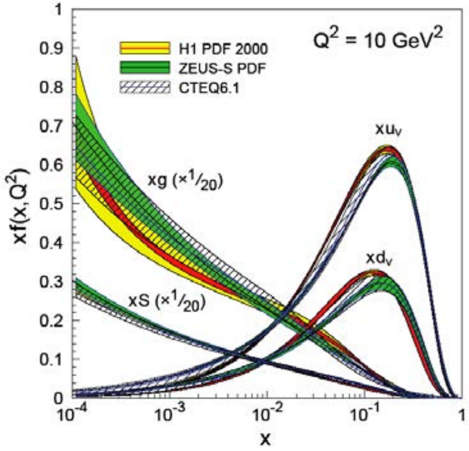
intermediate upgrade
major upgrade

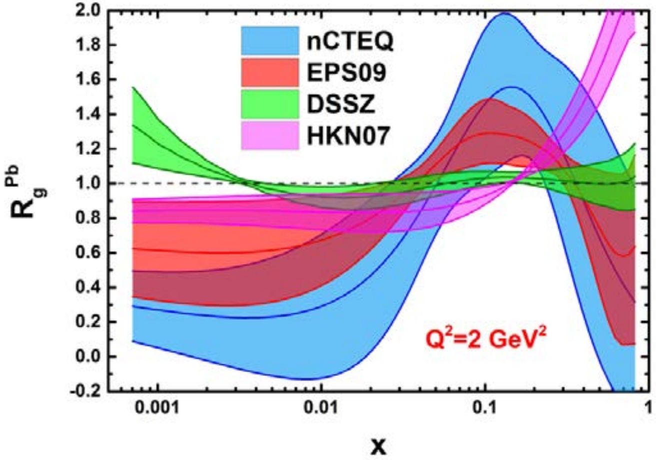
Forward Calorimeter



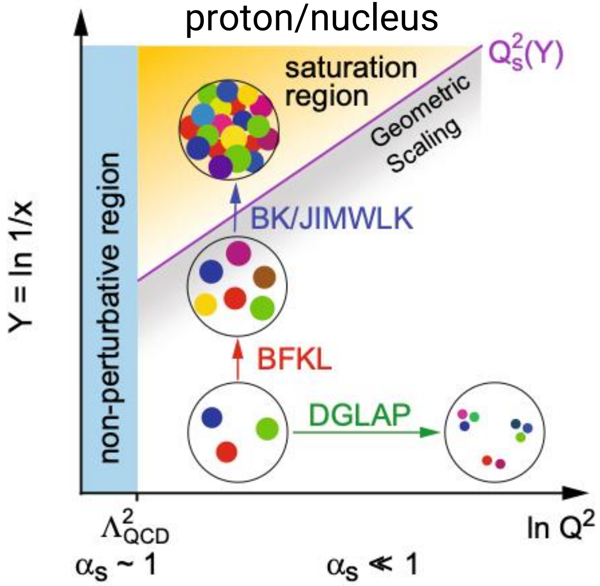
Explore the gluon structure of hadrons and nuclei

- At small x, dominant degrees of freedom of the hadrons are not valence quarks, but gluons!
  - (Exponential) growth of gluon density with increasing energy
- Larges uncertainties on gluon distributions in nuclei at small x
  - Scarce experimental data (DIS) available to constrain the gluon nPDF
    - Fit the nPDF in a global QCD analysis
    - QCD evolution equations (DGLAP & BFKL)





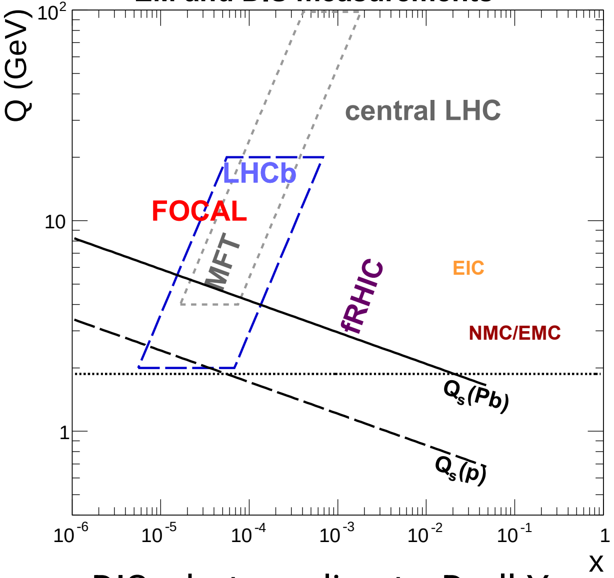
“Phase diagram” of a proton/nucleus



- Reveal gluon saturation effects at small x which is an unavoidable consequence of QCD!
- Direct photon production provides sensitivity to gluon densities in protons and nuclei
  - FoCal measurement at high rapidity ($3.4 < \eta < 5.8$) and thereby low x (down to $\sim 10^{-6}$) in nuclei

Performance of the FoCal detector

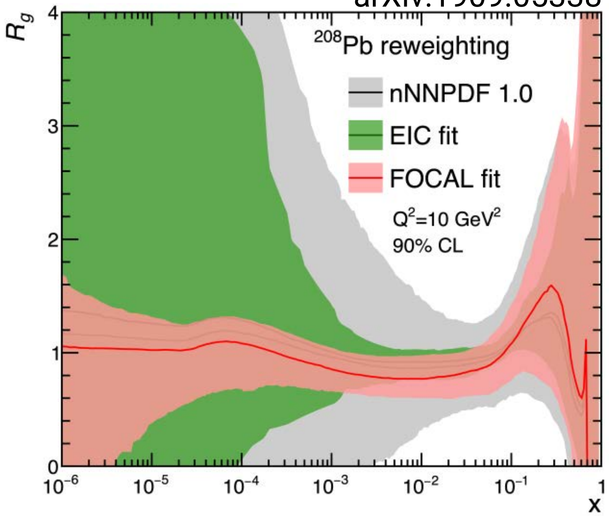
- Kinematic coverage of electromagnetic probes of current and future experiments at the LHC and other facilities



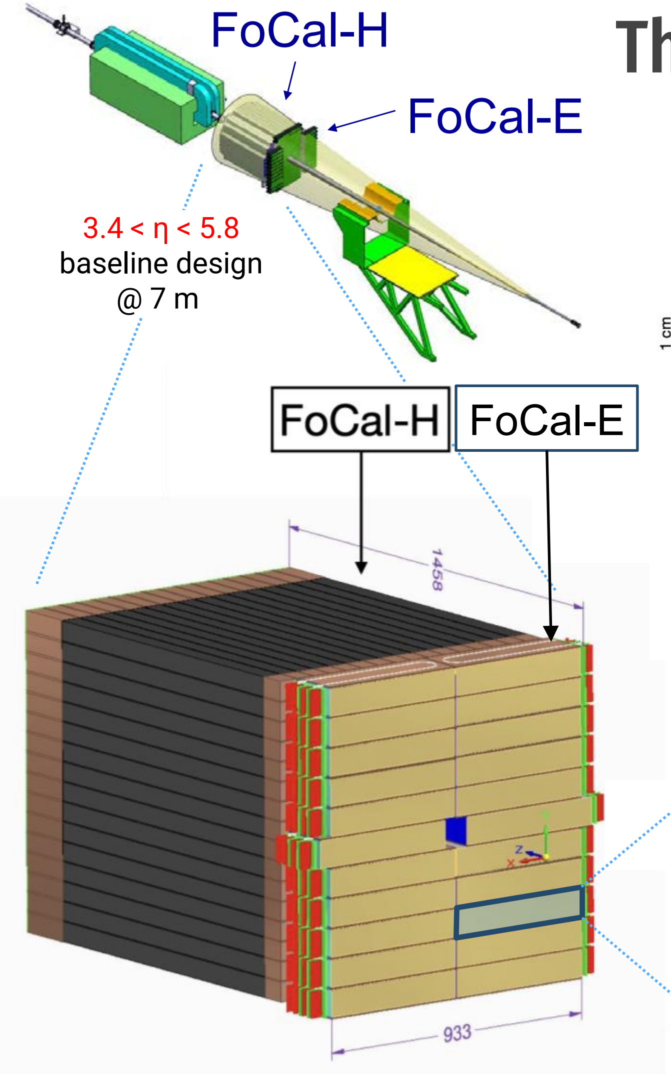
DIS, photons directs, Drell-Yan

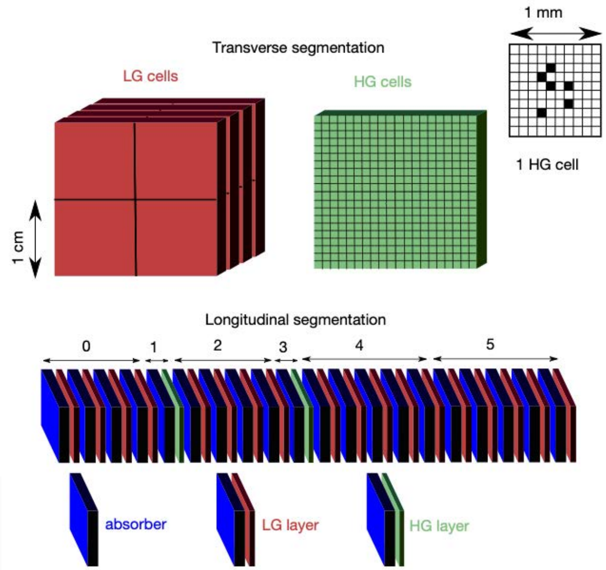
- Impact of FoCal on the gluon nPDF
  - Strong constraints over a large x region: $\sim 10^{-5}$–10^{-2}
  - Substantially outperform the expected performance of EIC for $x < 10^{-3}$

arXiv:1909.05338

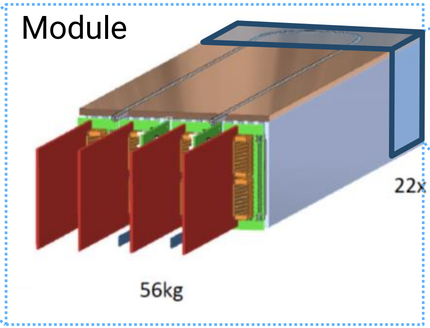


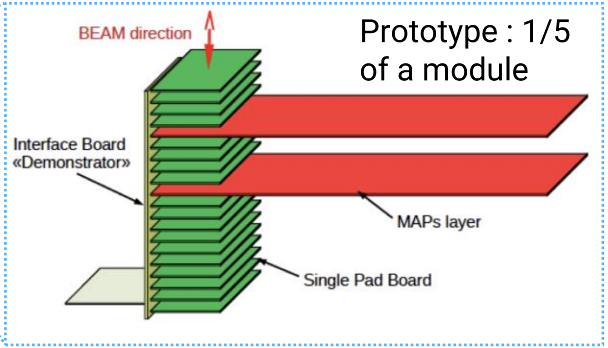
The FoCal-E detector



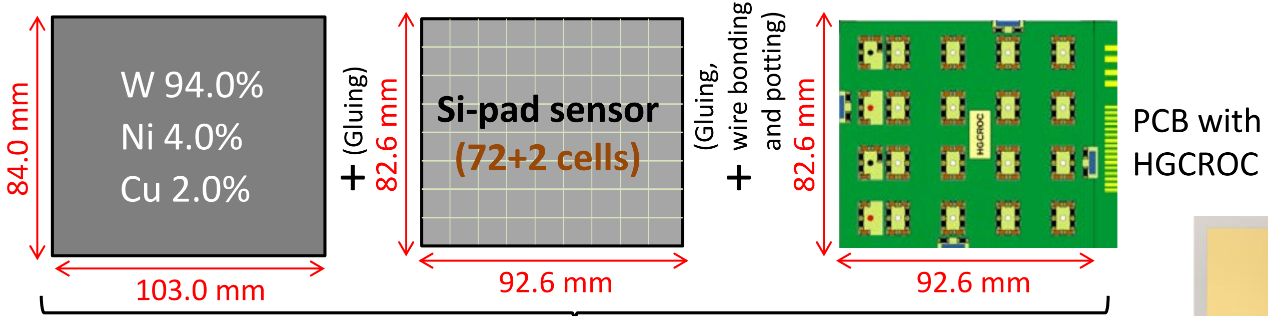


- The main challenge of direct photon production measurement at high rapidity lies in disentangling direct photons from π^0 decays at high energy
  - ~5 mm separation of photon pairs from π^0 decays (p_T = 10 GeV, η = 4.5)
  - Require a low Molière radius and high granularity → Si–W calorimeter with effective granularity ≈ 1 mm^2
- 20 layers : W(3.5 mm ≈ 1 X_0) + silicon sensors
  - 18 pad layers → shower profile and total energy
  - 2 pixels (ALPIDE) → spatial resolution essential for shower separation

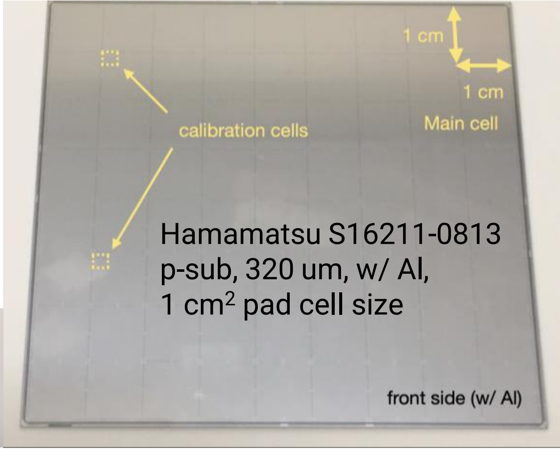


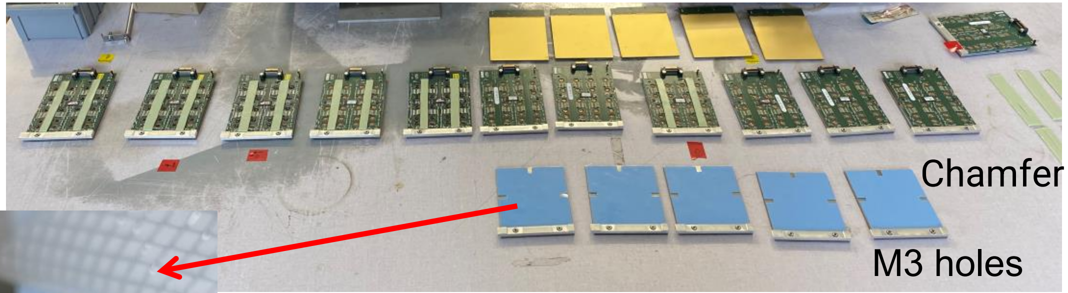


The FoCal-E PAD prototype

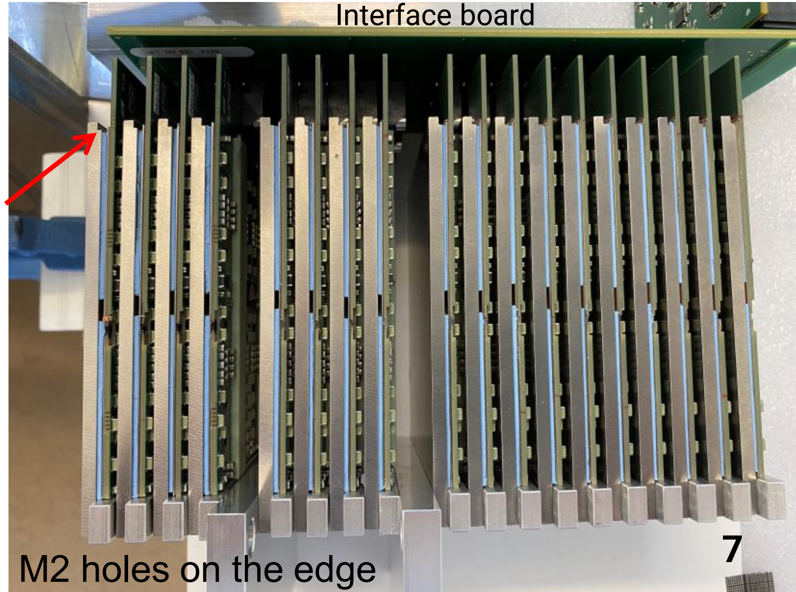


The single pad layer (x18)



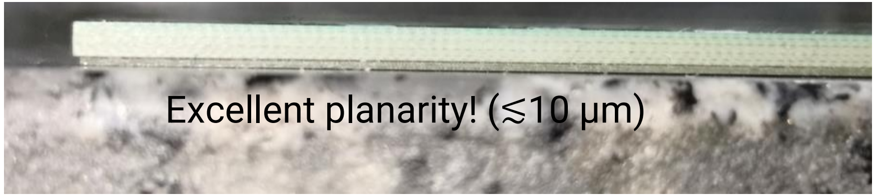


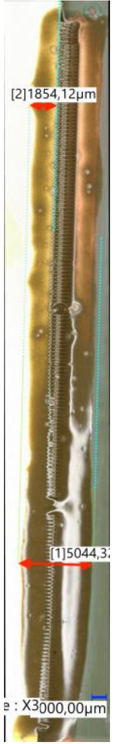
- Prototype assembly
  - W plate machining
  - Thermal foils interleaved within the Si–W sandwich
    - Ensure proper insertion of the FEE boards in the interface board by compensating the mechanical defects

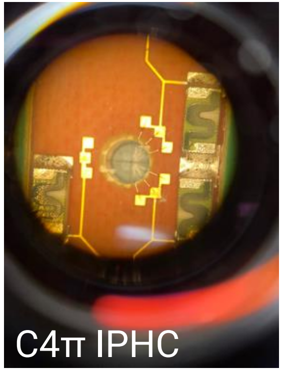


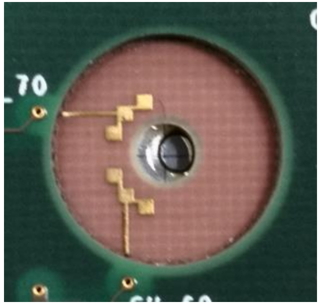
The FoCal-E PAD prototype

- Gluing and wire bonding of the silicon sensors onto the PCB
  - Provide clean biasing (to ground) on the back side of the sensor

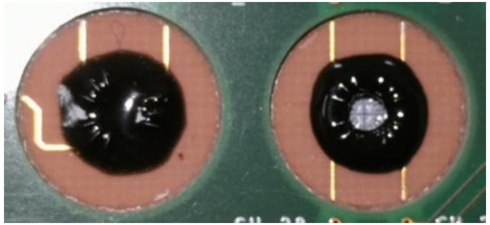








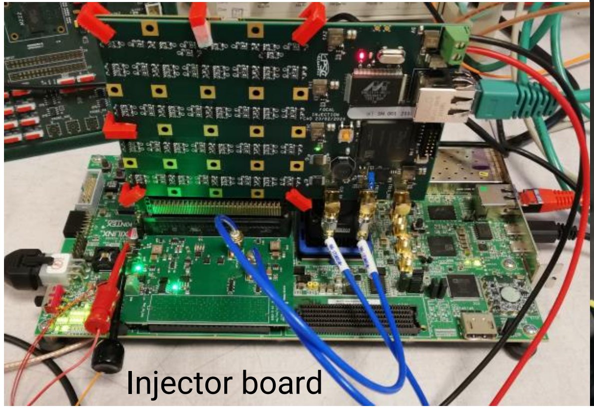
Bleeding glue
(not bonded)

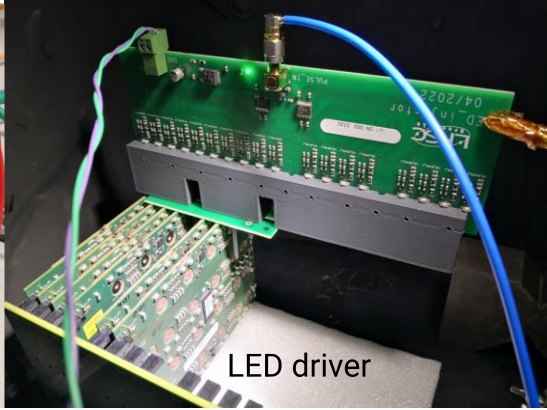


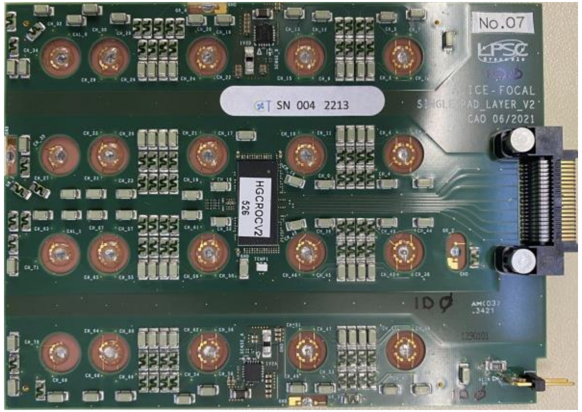
Blocked hole by the potting material
(use translucent potting later on)

Readout electronics of the FoCal-E Si–PAD layers

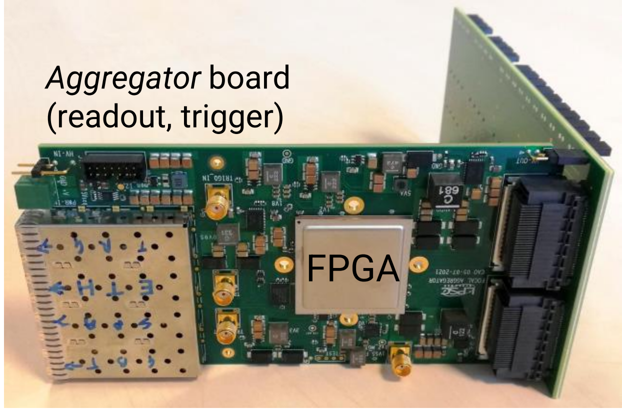
- Design, production, tests & DAQ of the whole electronic chain







FEE board (HGCROC V2 Omega LLR)



High voltage is fed to the aggregator and distributed to single pads

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Prototype electronics for the silicon pad layers of the future Forward Calorimeter (FoCal) of the ALICE experiment at the LHC

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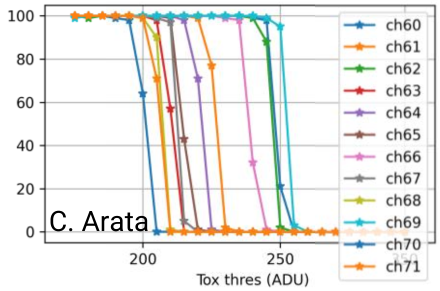
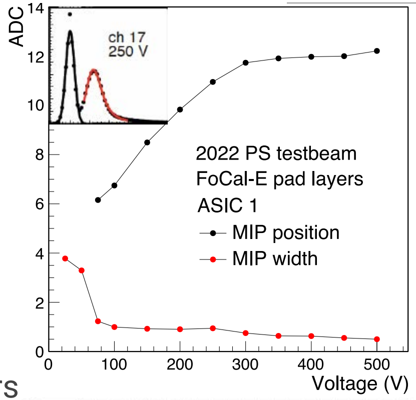
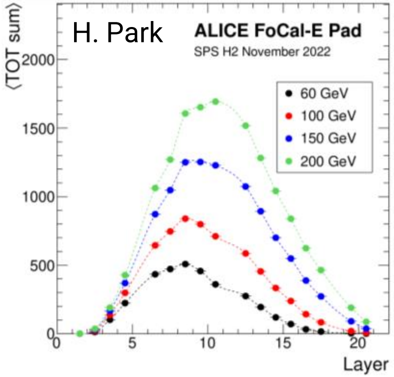
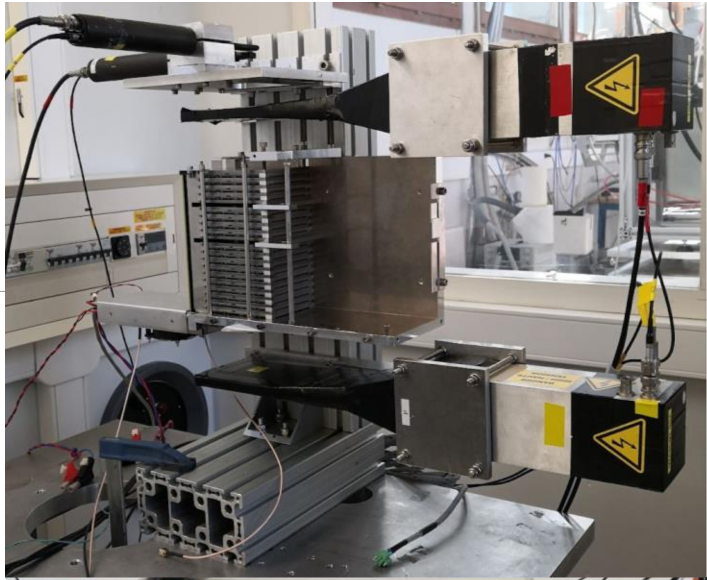
Performance of the FoCal-E PAD prototype

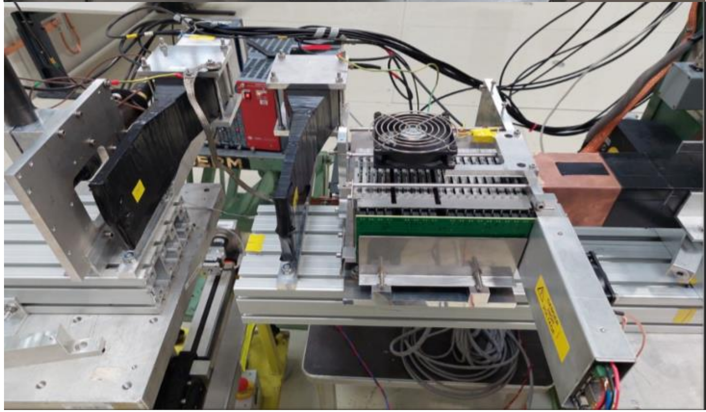
- Lab tests
  - Pedestal adjustement, calibration with internal charge injection
  - LED pulses, cosmics
  - Timing (ToA/T)
- Beam tests at CERN
  - PS T9 (June 2022)
    - Optimization of the shaper parameters with MIP (15 GeV/*c* hadrons)
    - Position & HV scans
  - SPS H6 (September 2022)
    - DAQ CRU−O2
    - Energy scan with electron beams



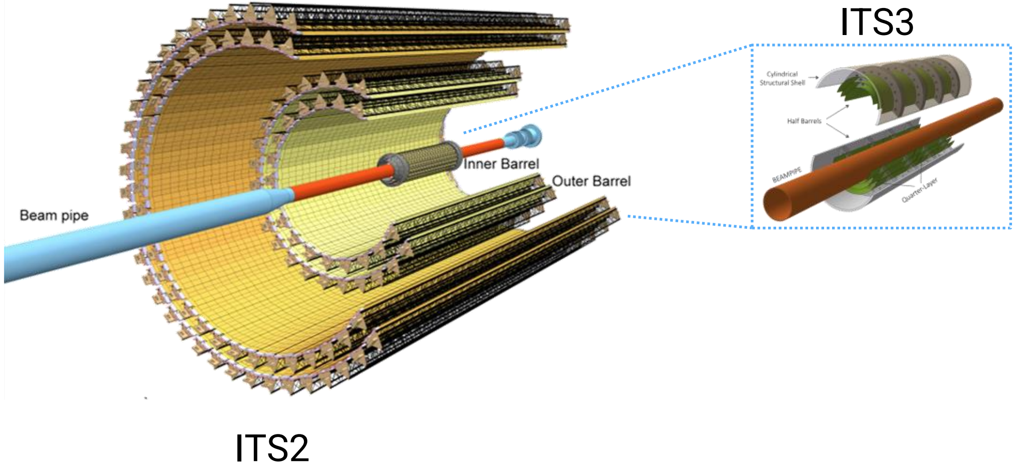








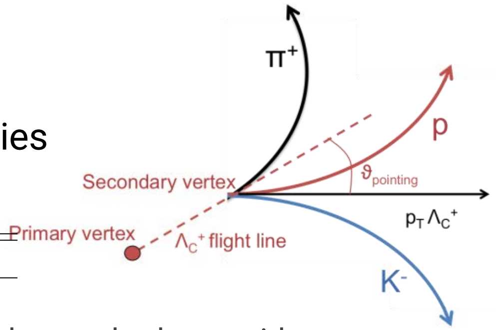
ITS3

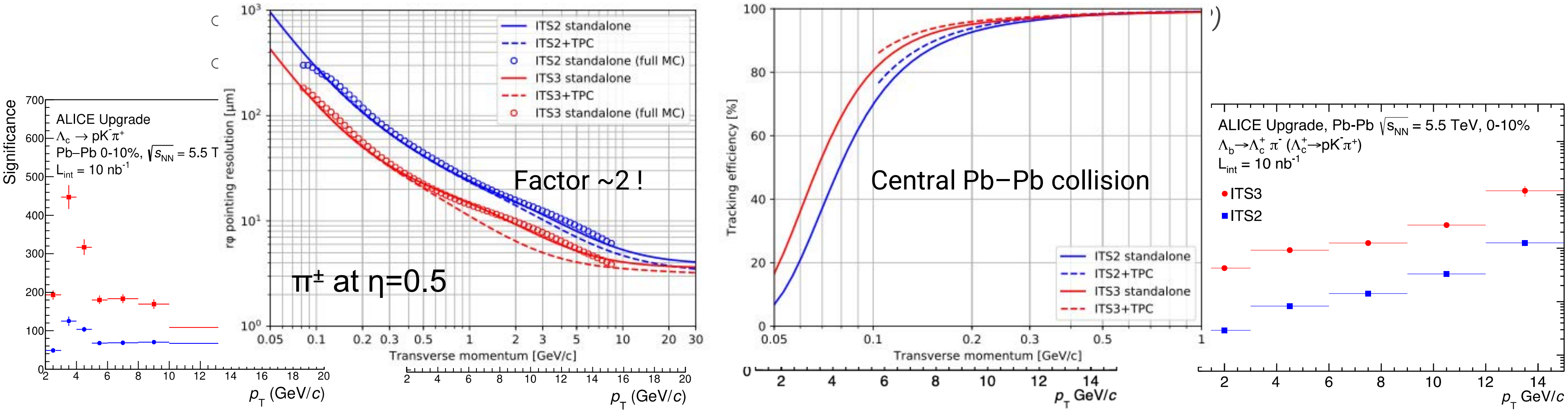


Heavy flavor physics at LHC Run 4

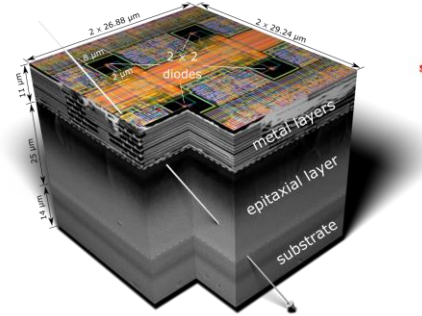
- Enhance the capabilities of the ALICE experiment for heavy quarks studies
  - Improvement of the pointing resolution
    - Stronger rejection of the combinatorial background
    - Higher efficacity of signal selection
  - Measurement of charmed and beauty baryons (Λ_c, Ξ_c, Λ_b) and charmed and beauty hadrons with a strange content (D_s, B_s)

inner layers	ITS1	ITS2	ITS3
X/X_0	1.14%	0.38%	0.05%
innermost radius	39 mm	22 mm	18 mm
pixel size	50 → 425 μm^2	30 → 30 μm^2	15 → 15 μm^2

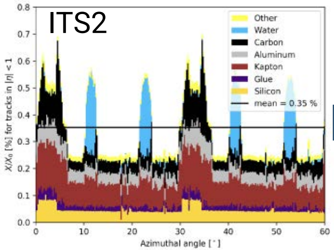


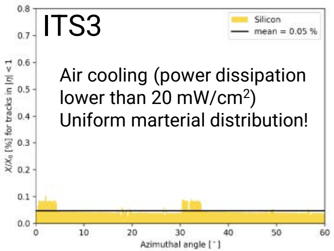


The ITS3 detector

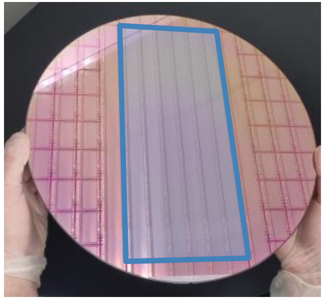


CMOS Pixel Sensor
Projet FJPPN R&D CMOS
Characterisation of the CE65 sensor on the KEK PF-AR beamline



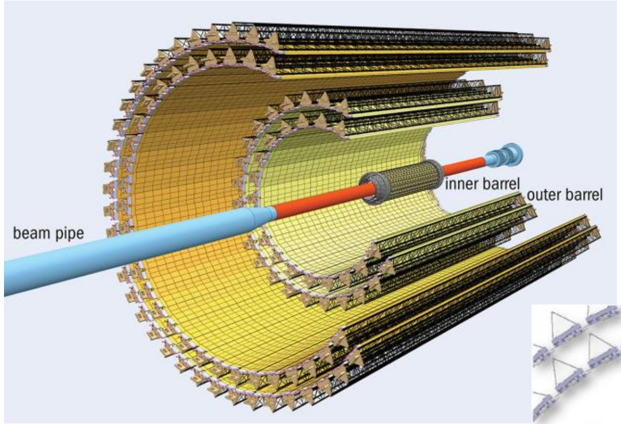


- Silicon amounts to only 1/7th of the total material thickness!
- Inhomogeneities due to the mechanical structure & cooling
- Get (even) closer to the interaction point?



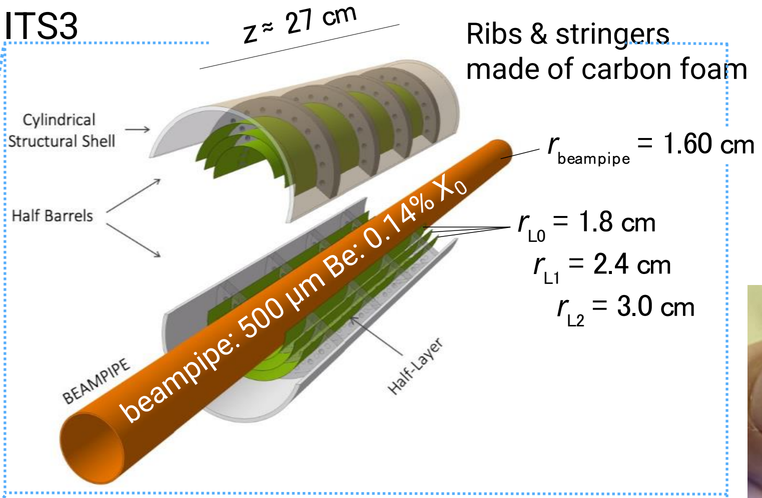
Wafer-scale chips (~27 cm long)

ITS2

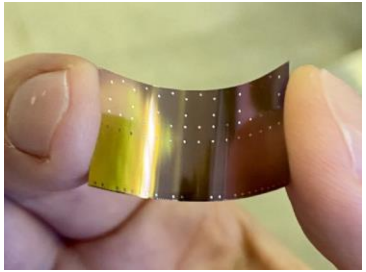


Inner Barrel
432 chips of 180 nm technology node (transistor etching size)
ALPIDE chip size limited by the dimensions of the reticule itself (~3 cm × 2 cm)

ITS3



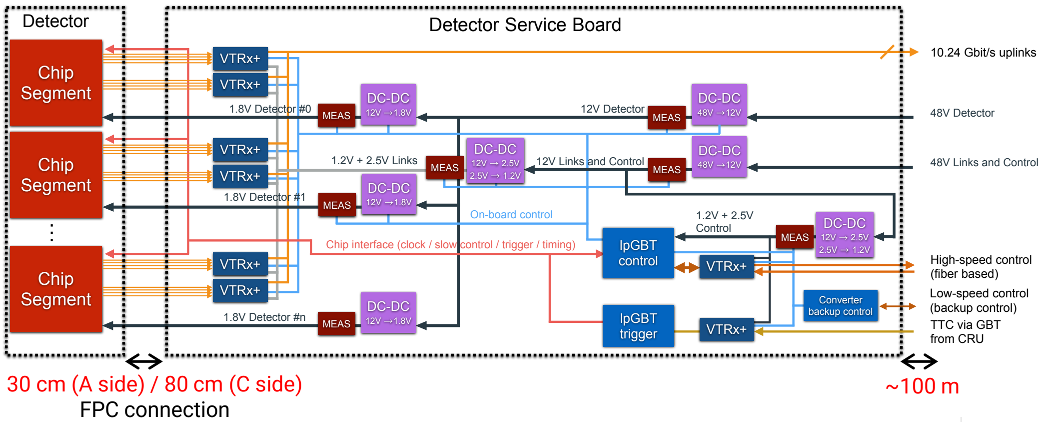
6 65 nm chips!
Stitching technique allows to produce wafer-scale chips (30 cm diameter)
→ efficiency?



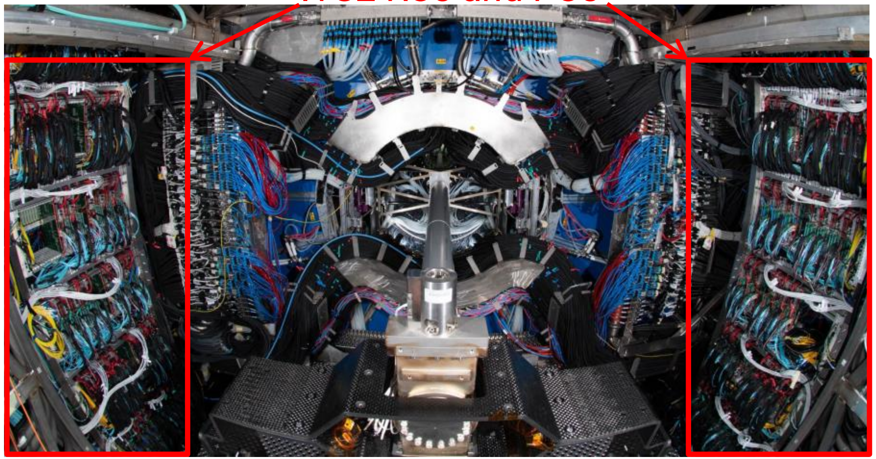
Sensors thinned down to 20−40µm (0.02−0.04 % X_0)

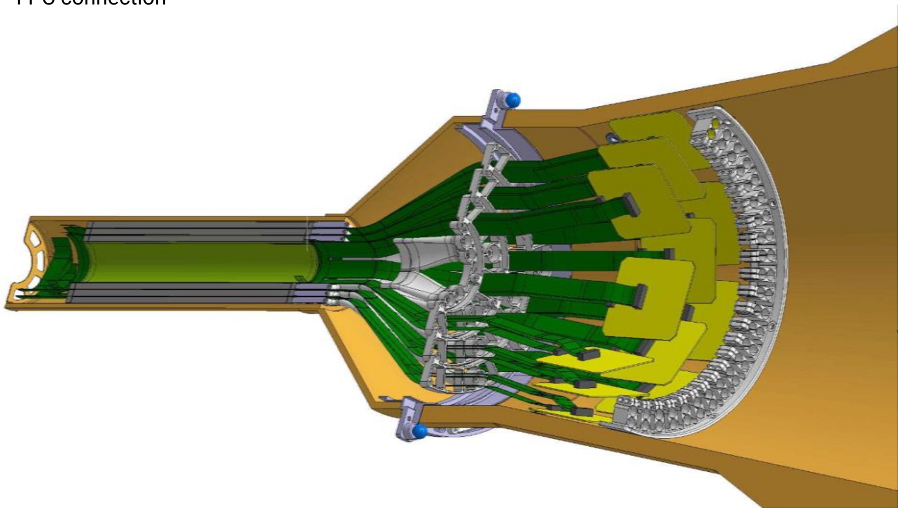
Middle-end electronics for ITS3

- System functionalities
  - Transmit data upstream at 10 Gbps
  - Supply clock and trigger signals to the detector
  - Provide power and bias to the detector
  - Slow control and monitoring
- System requirements
  - Sustain high radiation dose rates and magnetic field
    - Radiation qualified COTS or CERN-developed components
  - Fit within the limited service volume (see next slide)



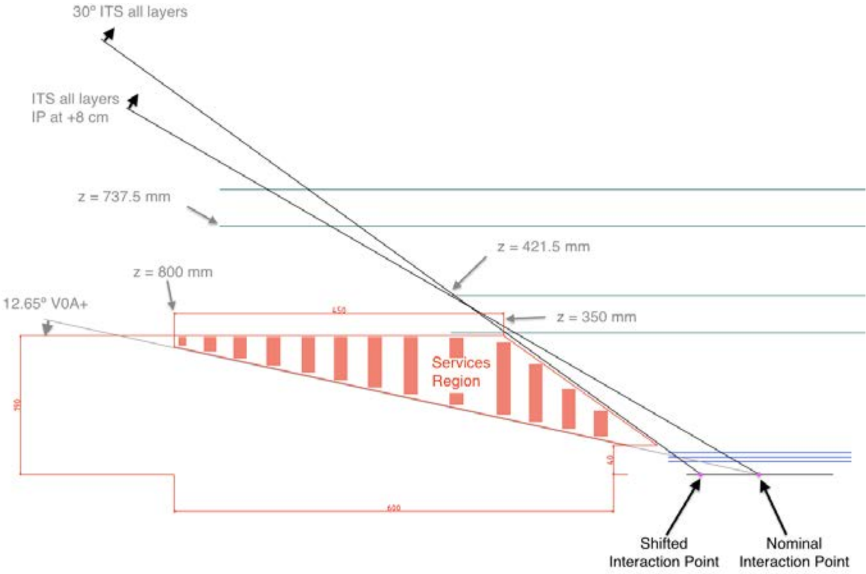
ITS2 RUs and PUs

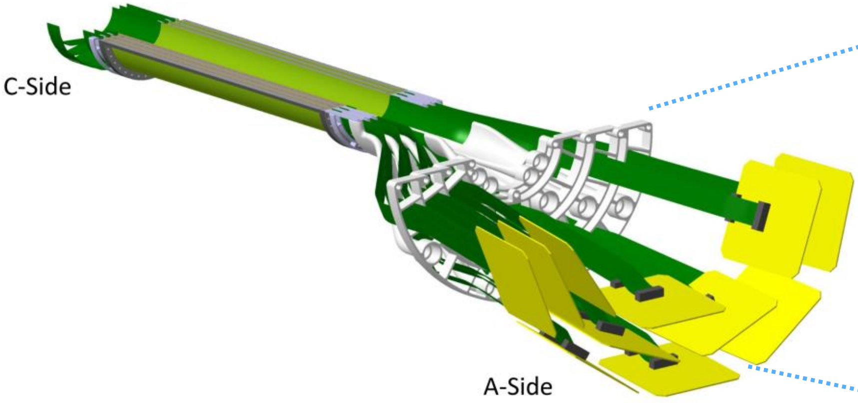


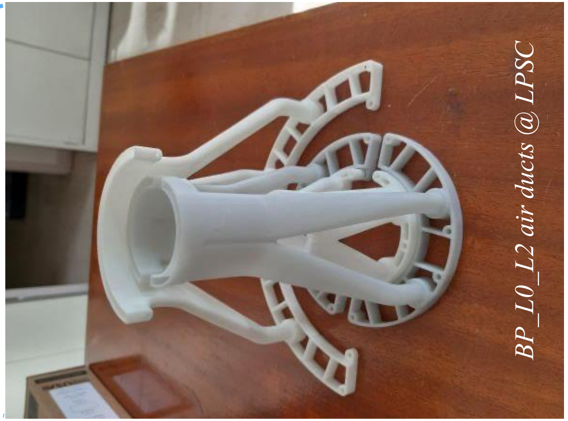


ITS3 mechanics

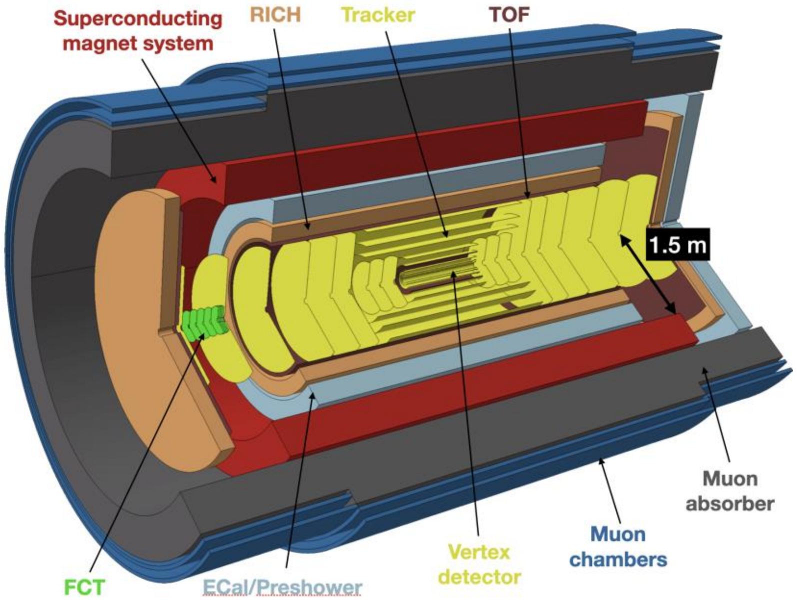
- Integration & dedicated cooling system for DSB
  - Very limited available service volume!
  - ~45 W dissipated per half-barrel (for 3 layers)
- Design & production mechanical parts for the detector air cooling system
  - First prototypes of the air cooling manifold produced by UV LCD and high-temperature FDM 3D printing with resins
  - Explore other materials for the final solution
    - Flexible bi-material monolithic components (need specific printer head)







ALICE3



Superconducting magnet system
RICH
Tracker
TOF
1.5 m
Muon absorber
Muon chambers
Vertex detector
FCT
ECal/Preshower

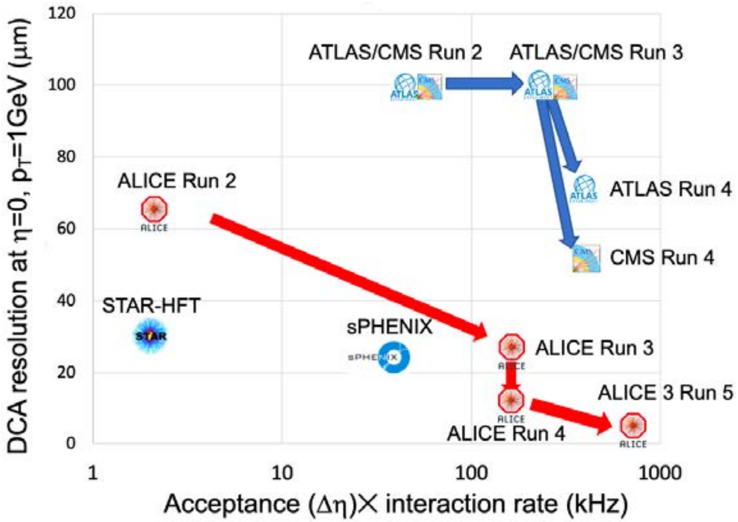
ALICE3: a next generation HI experiment for LHC Run 5 & 6

"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]

- Goal: studies of pp, pA, and AA collisions at luminosities ×20−50 higher than in ALICE in Run 3−4
- Fast and ultra-thin detector with precise tracking and timing
  - "Nearly massless" tracker based on silicon CMOS pixels (MAPS) covering ~70 m^2
  - PID via Si-based time-of-flight with ~20 ps time resolution
  - Large acceptance barrel + end caps $\Delta\eta = 8$
- Ultimate performance for HF, thermal radiation, and soft hadrons ($p_T < 50$ MeV/c)
  - Doubly and triply heavy flavour, hadron production, multi-quark states
  - Chiral symmetry restoration (e.m. probes)
  - Beyond HI (phase space complementary to other experiments)
    - Violation of fundamental properties of quantum field theories (emission of soft photons)
    - New physics in soft sector, e.g. dark photons

Summary

- **LS2** Upgrades (2019–2021)
- **LS3** (2026–2029): new upgrades for LHC Run 4
  - FoCal: γ, π^0, jets in the forward region to constrain the gluon nPDF at low *x*
  - ITS3: truly cylindrical silicon layers made of ultra-thin wafer-size MAPS
    - Low-mass dielectrons (→ QGP temperature)
    - Improve HF-particle performance + search for exotic charm nuclei



- **Beyond 2030:** continue the heavy-ion programme during the HL-LHC era
  - Possibility of a "nearly-massless" silicon detector
    - Multi-HF particles
    - Low-mass dielectrons and soft photons

Unprecedented insight into QGP world expected ahead of us!

END