ALICE detector upgrade

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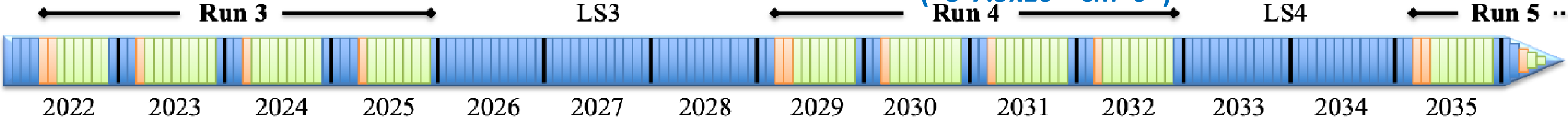
ALICE roadmap

High luminosity for ions (~7x10^{27} cm^{-2}s^{-1})

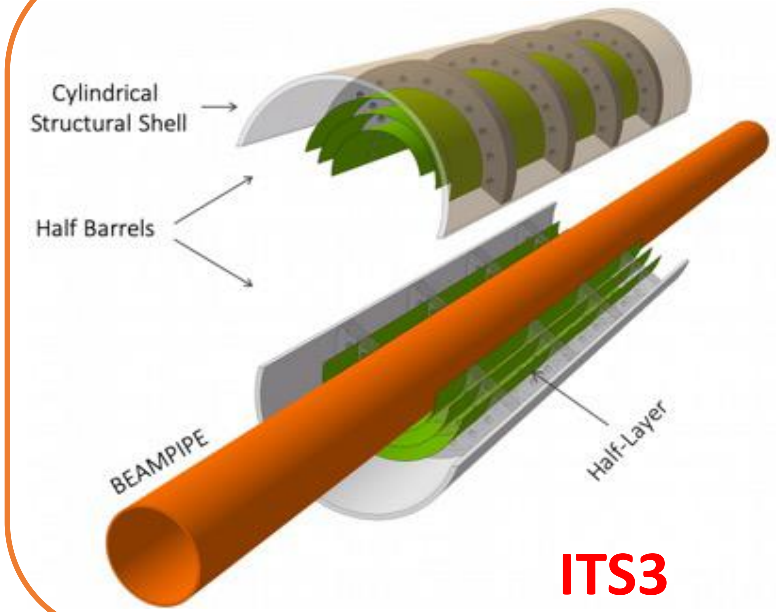
High luminosity LHC (~5-7.5x10^{34} cm^{-2}s^{-1})

Higher luminosity for ion

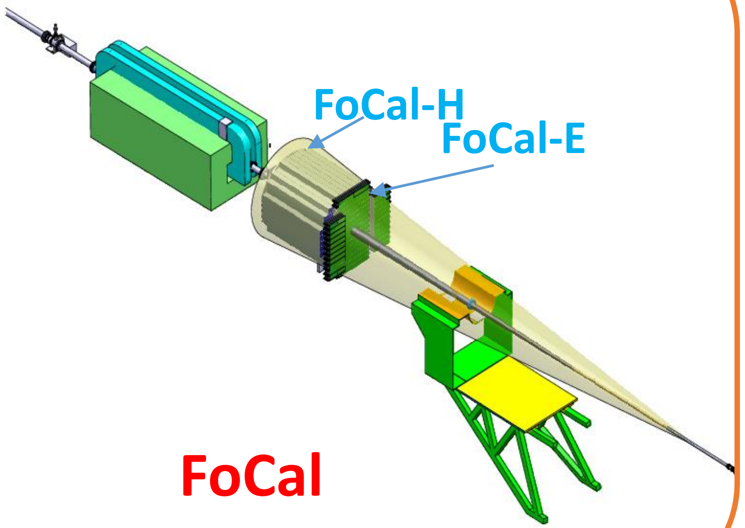


Intermediate upgrade

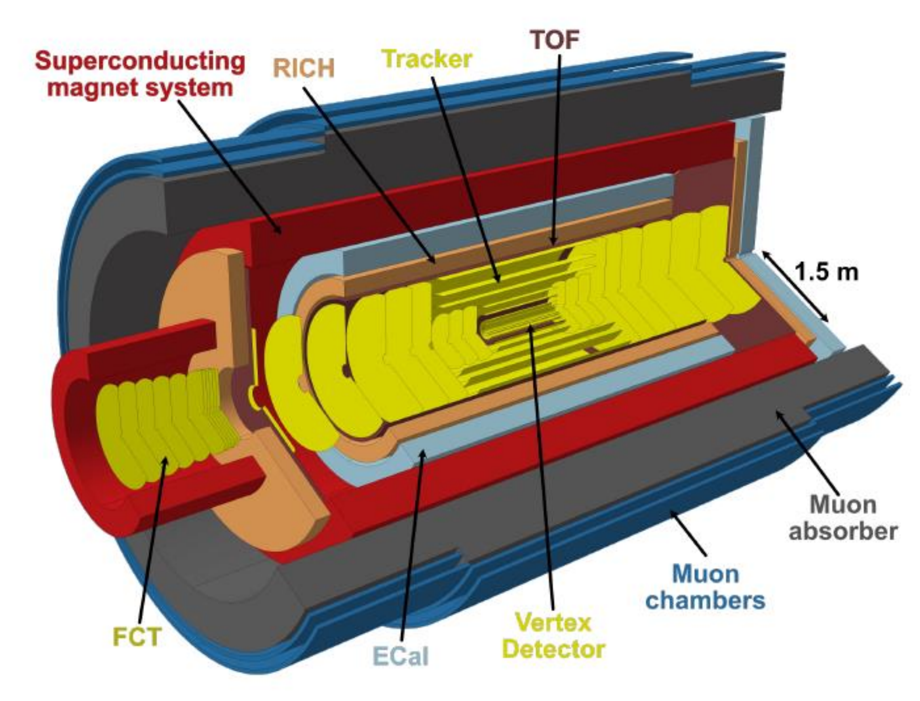
Major upgrade



ITS3



FoCal



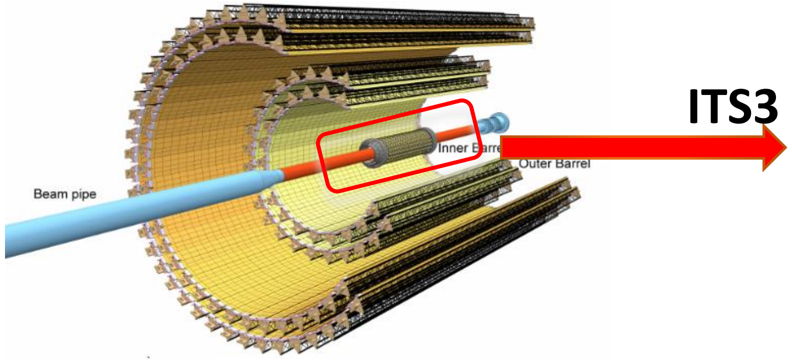
ALICE3

ITS3

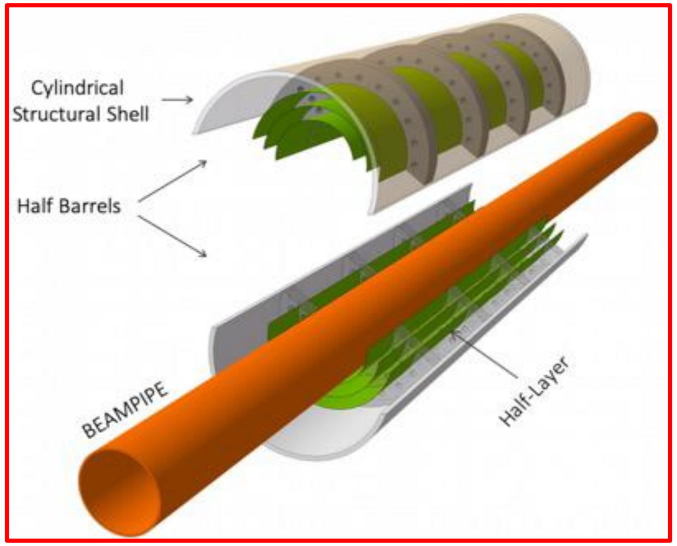
ITS1 (In exhibition)

- 6 layers
  - 2 layers of Silicon Pixel Detector
  - 2 layers of Silicon Drift Detector
  - 2 layers of Silicon Strip Detector

ITS2



- 7 layers (3 IB + 4 OB) of pixel layers
  - ALPIDE MAPS
  - 12.5G pixels
  - 10 cm^2



- 3 truly cylindrical pixel layers
  - 6 ultra-thin wafer-size curved sensors
  - Supported by carbon foam ribs
  - Air coolings

	ITS 1	ITS 2	ITS3
Distance to interaction point (mm)	39	22	18
X_0 (innermost layer) (%)	~1.14	~0.35	0.05
Pixel pitch (μm^2)	50×425	27×29	$O(15\times 15)$
Readout rate (kHz)	1	100	
Spatial resolution ($r\varphi \times z$) (μm^2)	11×100	5×5	

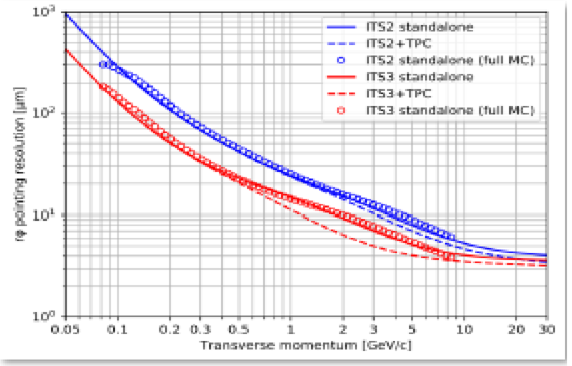
→ Closer to interaction point

→ Lower material budget

→ Improved granularity

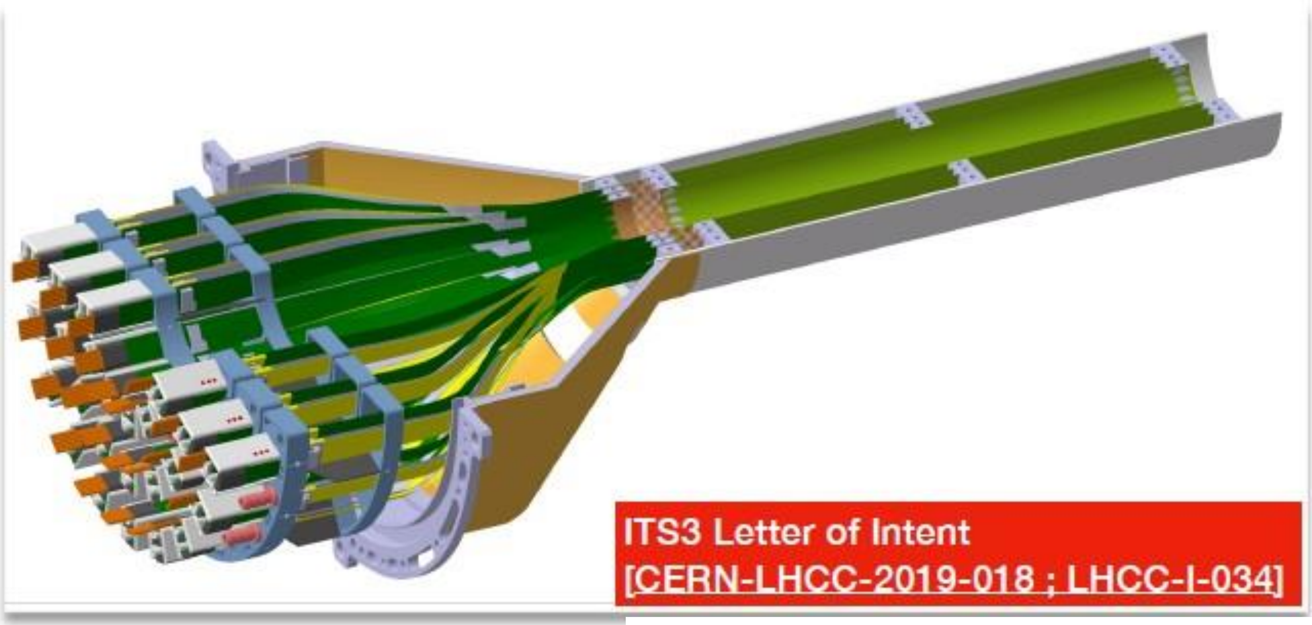
→ Faster readout

→ Improved resolution



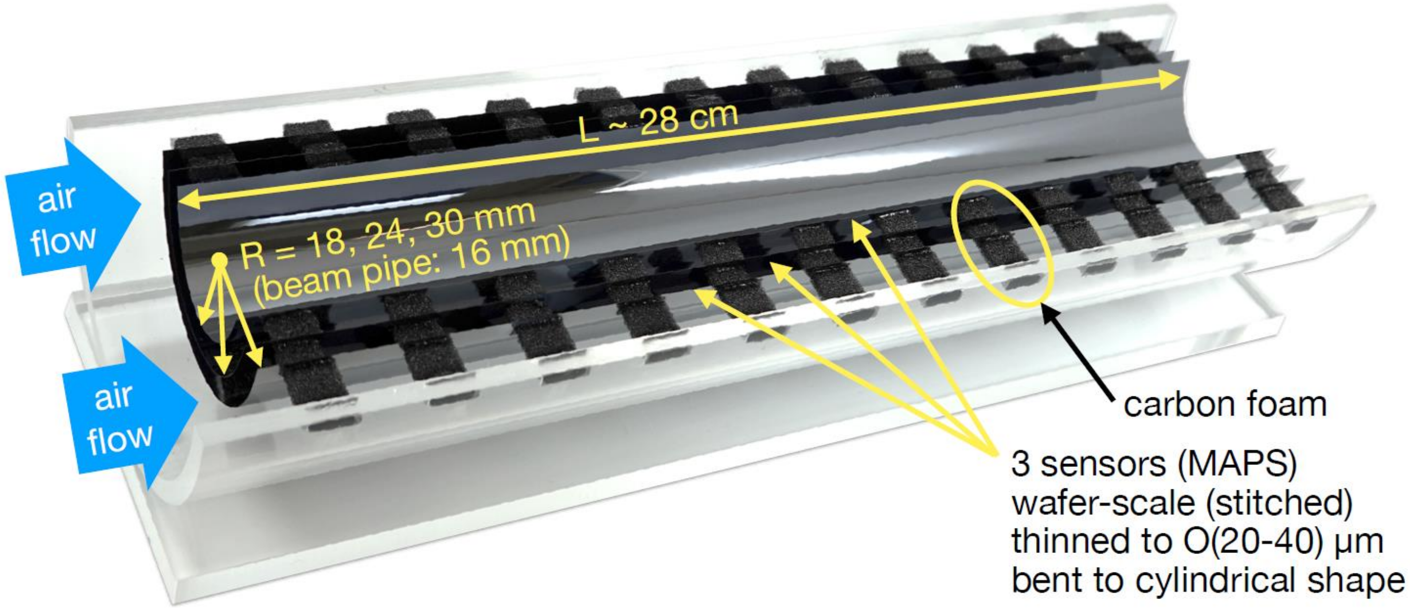
x ~2 improved in pointing resolution (ITS2 →ITS3)

ITS3 detector concept



- **Key ingredients:**
  - **300 mm wafer-scale sensors, fabricated using stitching**
  - **thinned down to 20-40 µm (0.02-0.04% X_0), making them flexible**
  - **bent to the target radii (of 18 mm, 24 mm and 30 mm)**
  - **mechanically held in place by carbon foam ribs**

Mechanical mockup using silicon dummies

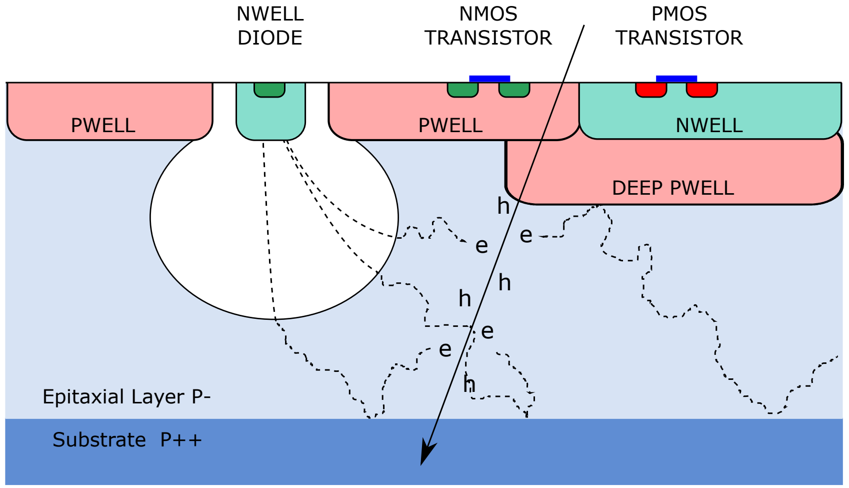


R&D on ITS3

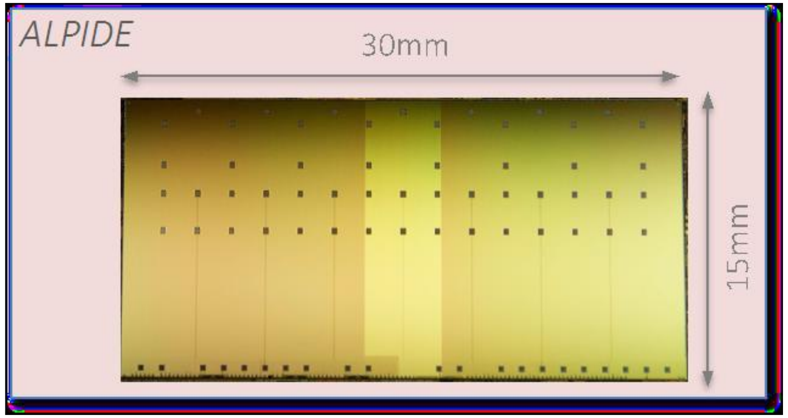
- **R&D on ultra-thin, bent Monolithic Active Pixel Sensors**
- **R&D on the 65 nm CIS process for tracking detectors**
  - **Learn technology features**
  - **Characterize charge collection efficiency**
  - **Validate radiation hardness**
- **R&D on stitching**

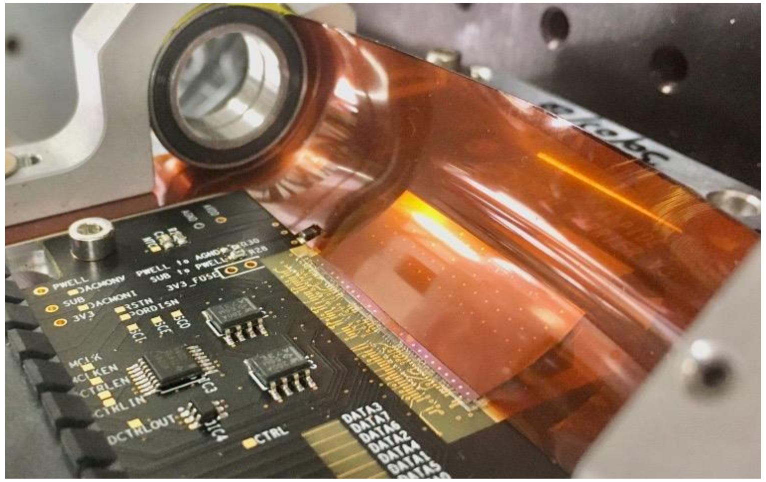
R&D on ultra-thin, bent MAPS

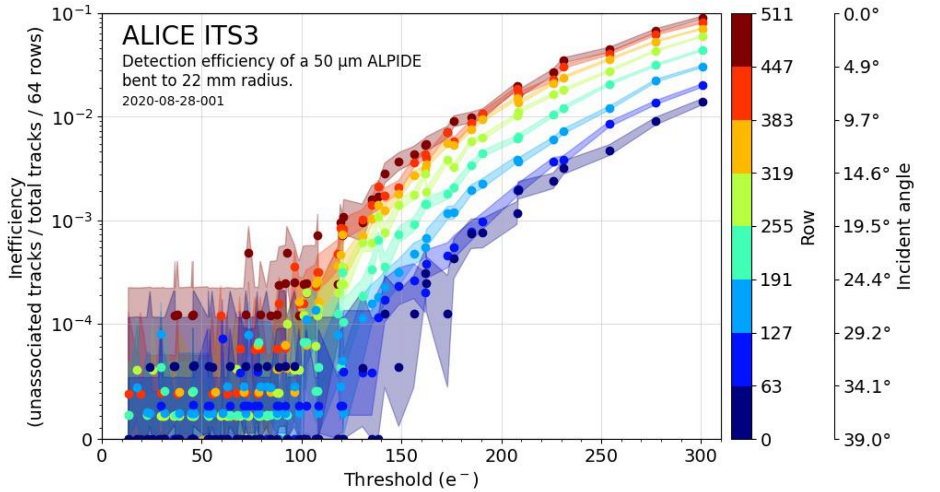
- **Carried out with ALPIDE produced using 180 nm CMOS Imaging Process**



- **High-resistivity (> 1 kΩ cm) p-type epitaxial layer (25 μm) on p-type substrate**
- **Small n-well diode (2 μm diameter), ~100 times smaller than pixel => low capacitance (~fF) and low noise**
- **Reverse-bias voltage (-6 V < V_{BB} < 0 V) to substrate (contact from the top) to increase depletion zone around n-well collection diode**
- **Deep p-well shields n-well of PMOS transistors**







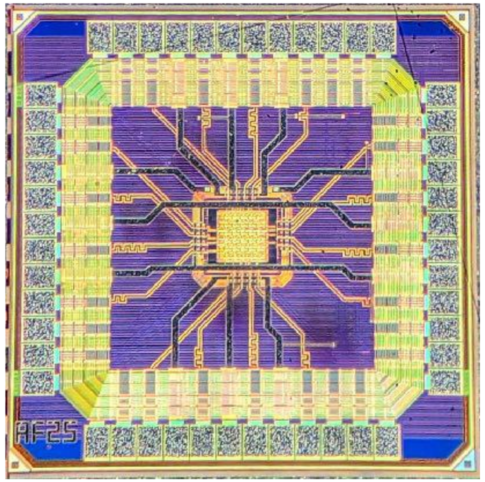
https://doi.org/10.1016/j.nima.2021.166280

50 μm thick ALPIDE bent to 22 mm showed excellent efficiency in the beam test

R&D on the 65 nm CIS process for tracking detectors

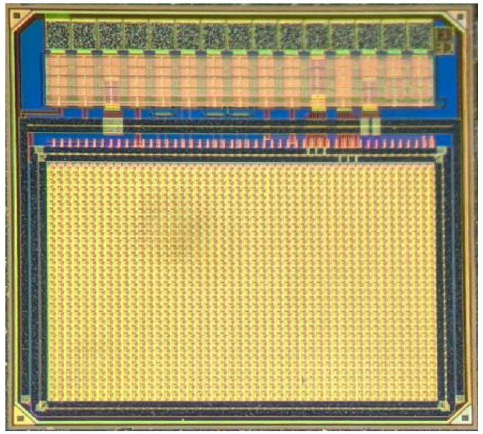
Pixel prototype chips: APTS, CE65, DPTS

APTS

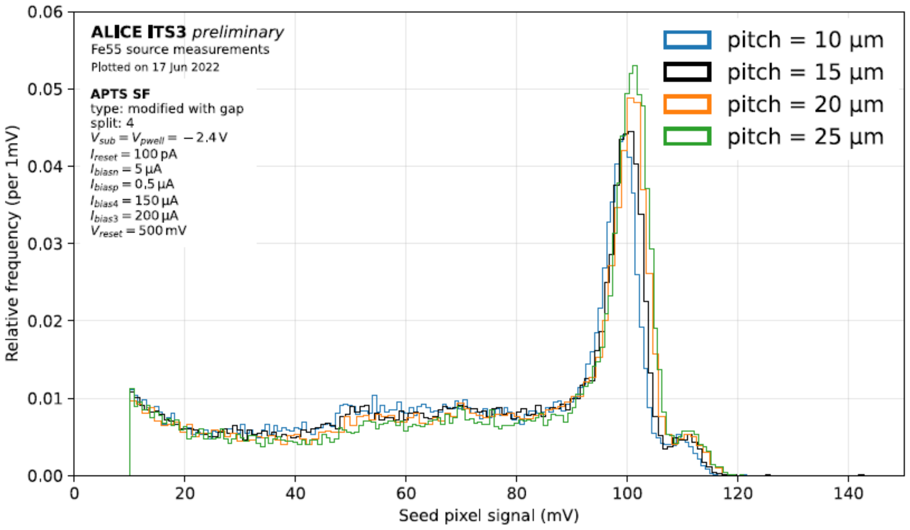


Matrix: 6x6 pixels
Readout: direct analog readout of central 4x4
Pitch: 10, 15, 20, 25 µm
Total: 34 dies

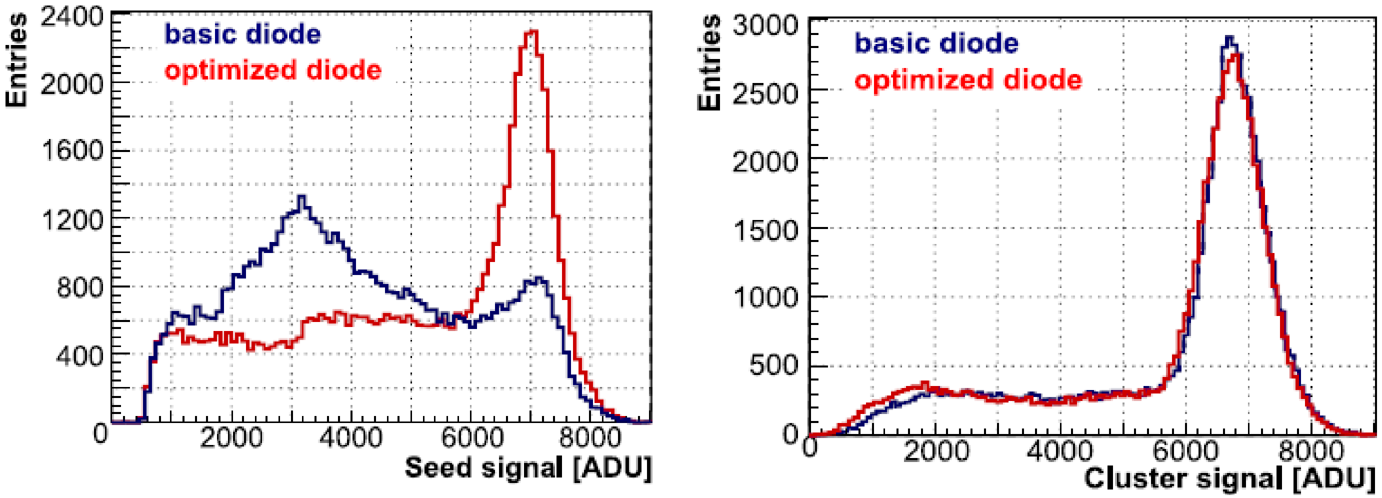
CE65



Matrix: 64x32, 48x32 pixels
Readout: rolling shutter analog
Pitch: 15, 25 µm
Total: 4 dies



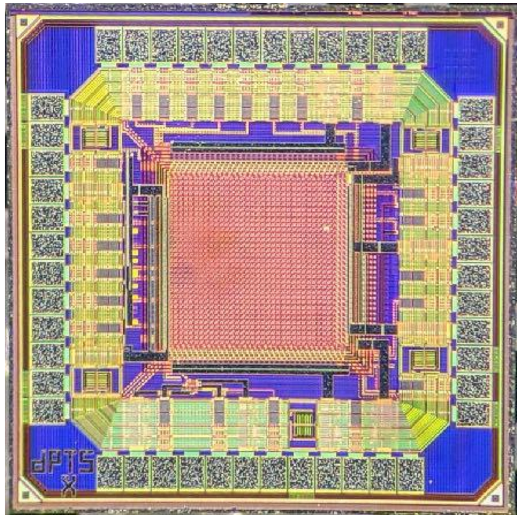
Pixels of different pitches show similar results
- the charge collection is very efficient



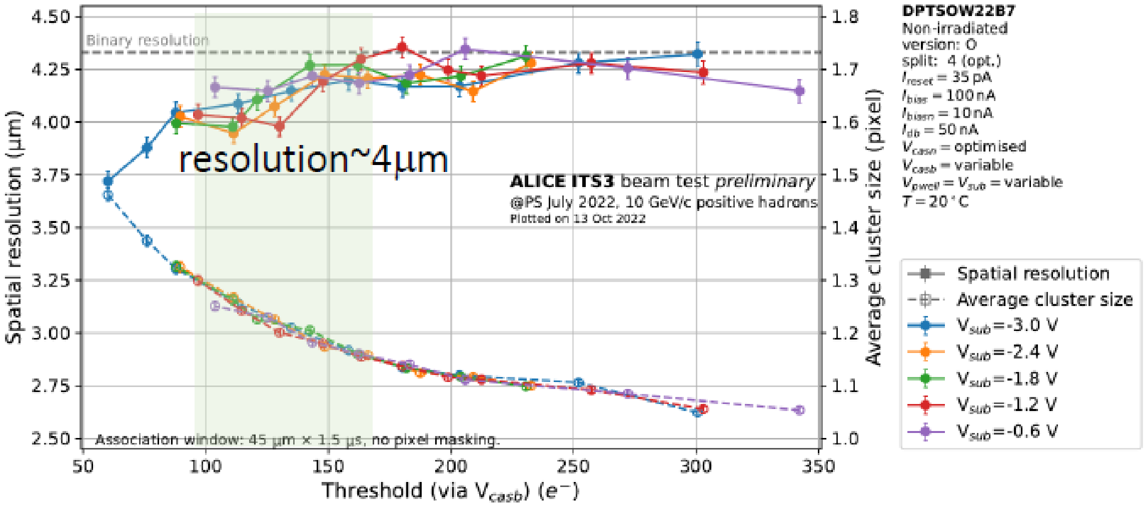
[NIM A 1040 (2022) 167213](NIM A 1040 (2022) 167213)

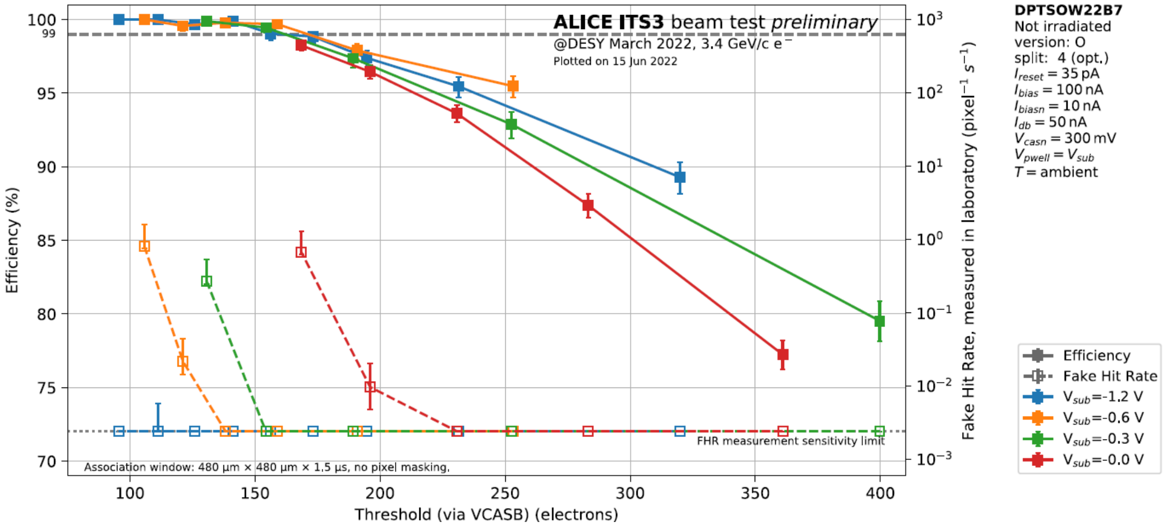
R&D on the 65 nm CIS process for tracking detectors

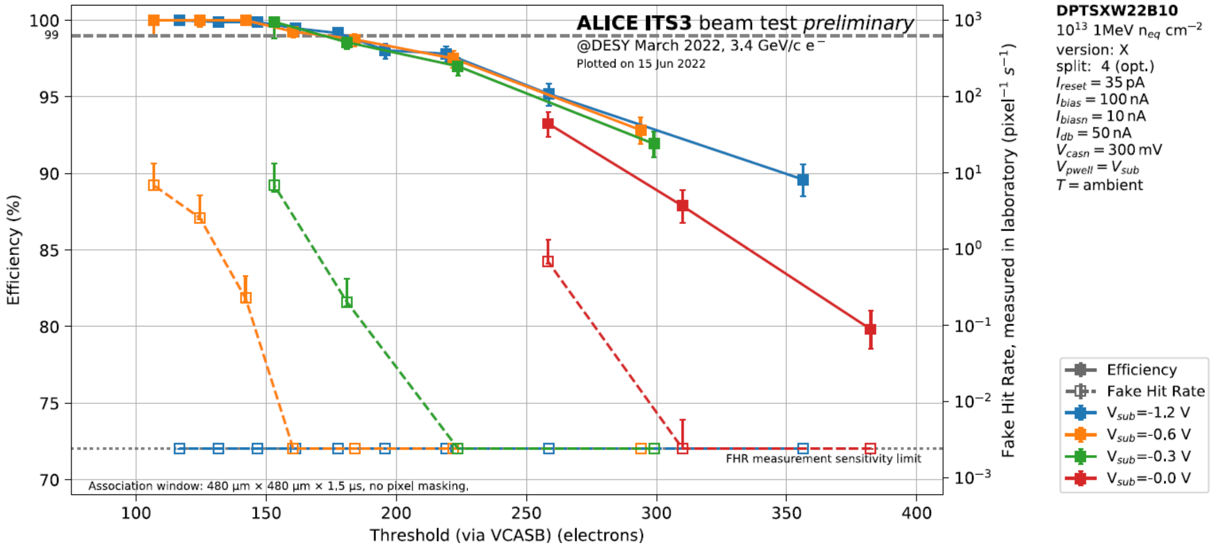
DPTS



Matrix: 32x32 pixels
Readout: async. digital with ToT
Pitch: 15 µm
Total: 3 dies





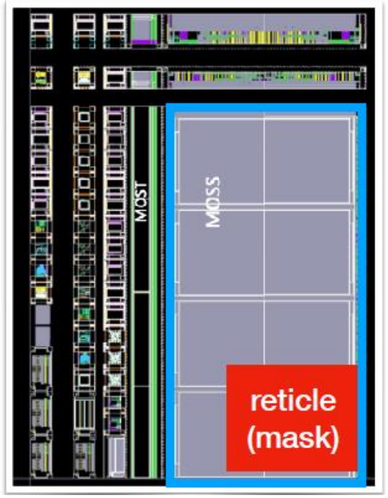


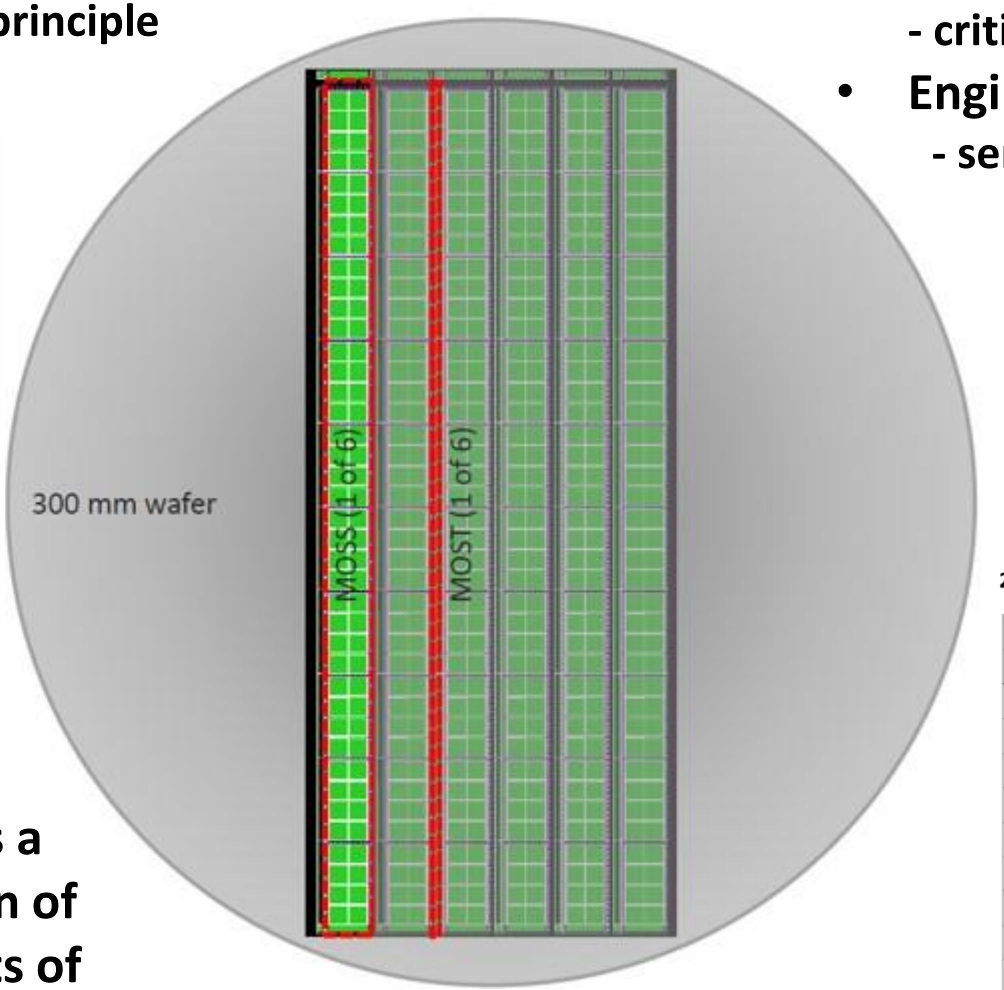
Good efficiency, but fake hit rate increases after irradiation

R&D on stitching

The simplified principle

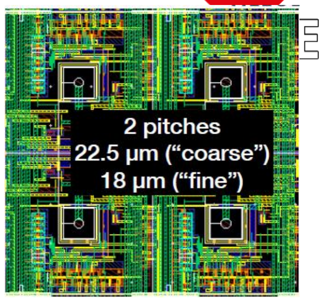
What designed

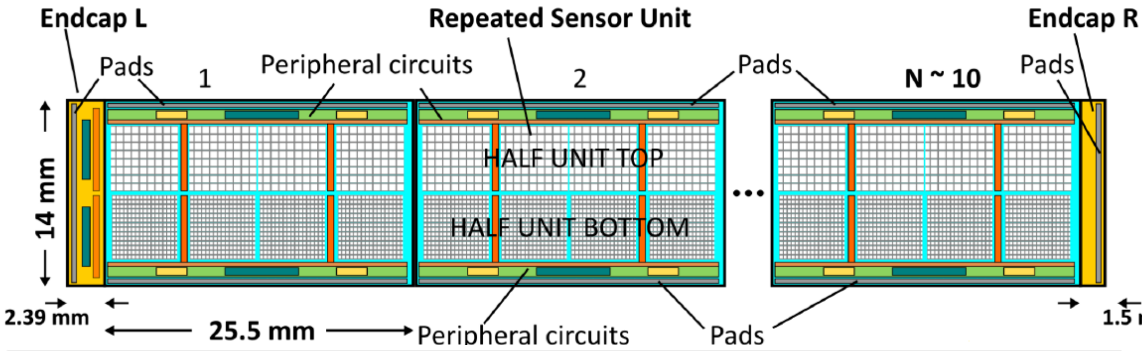


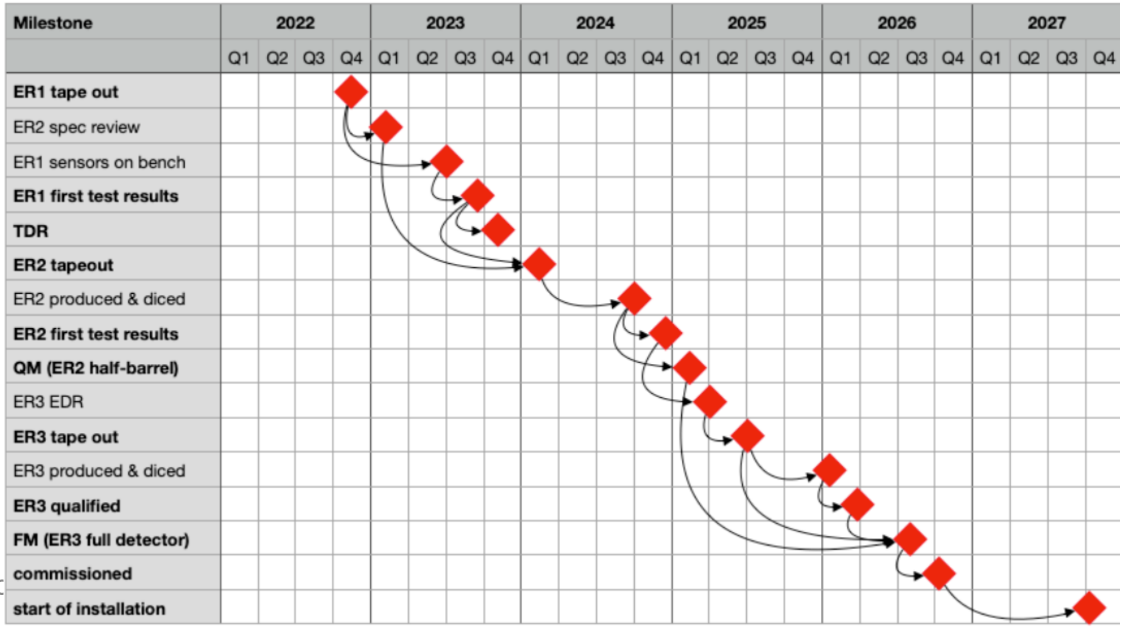


What fabricated

- **Designing this is tricky**
  - **critical aspects: yield + power distribution**
- **Engineering run to prototype is prepared**
  - **sensors expected for testing mid 2023**

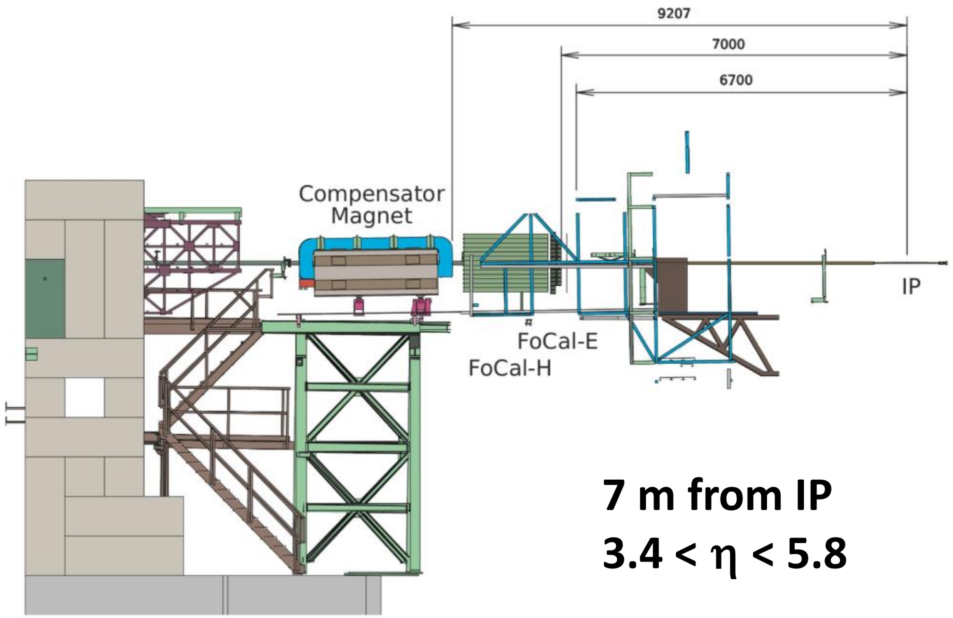




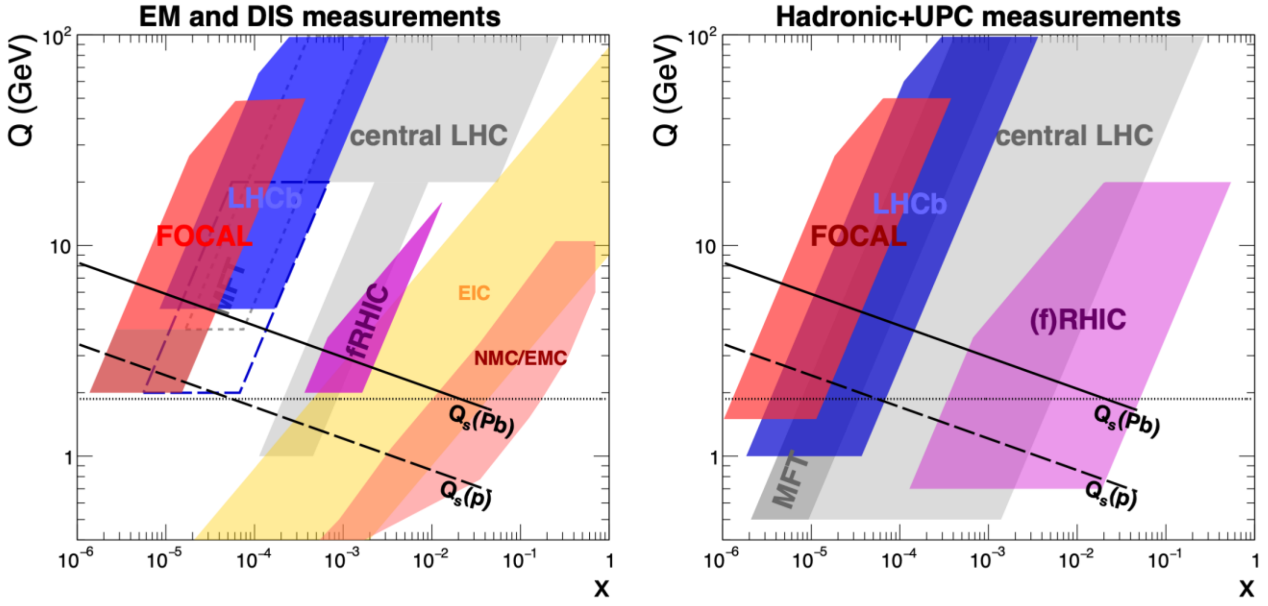


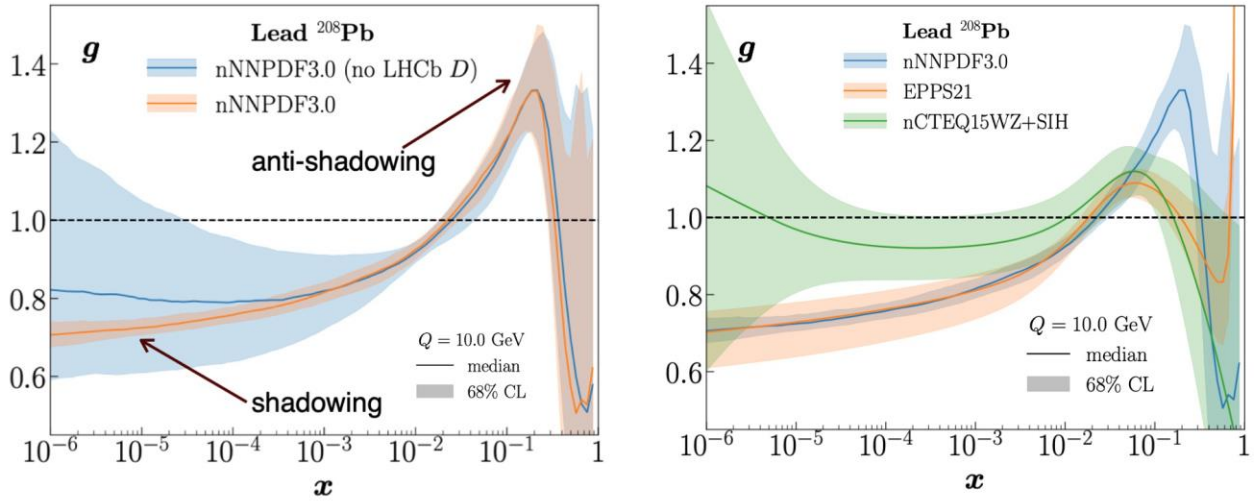
- **Final circuit is a concatenation of different parts of the masks**

FoCal



7 m from IP
3.4 < η < 5.8



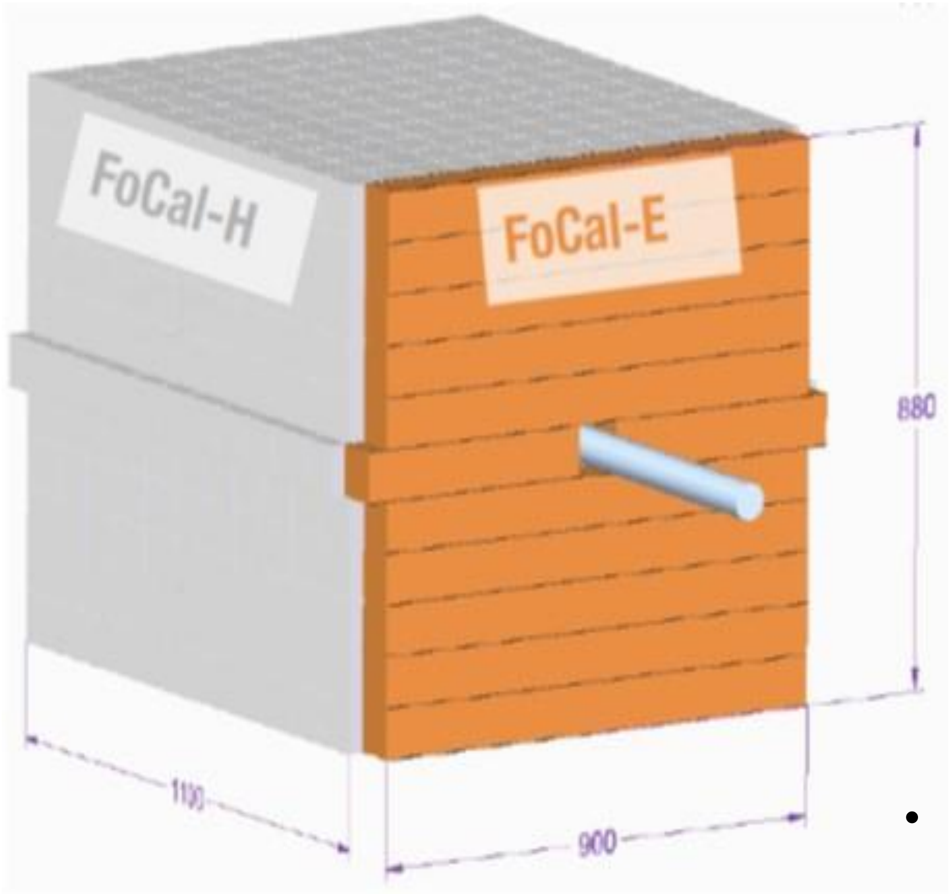


Main goal:

- measurement of direct photon production at forward rapidity in pp and pPb to probe gluon density at small x, forward π^0 in pp, pPb, PbPb
- constrain gluon nuclear PDF at small Bjorken-x ($x<10^{-4}$): structure of protons and nuclei not well constrained experimentally

FoCal will go further forward than any other LHC experiments

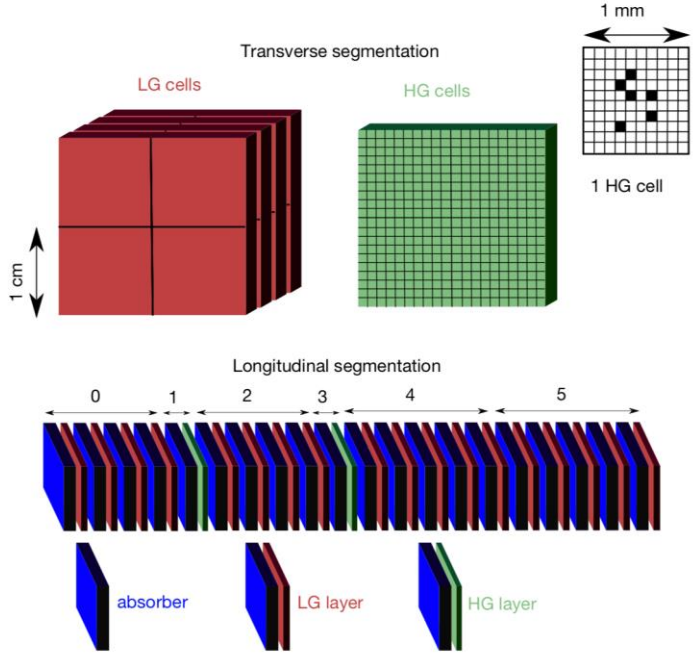
FoCal detector design



Technical Design Report planned for 2023

FoCal-E

Si-W calorimeter with effective granularity ≈ 1mm^2



- **20 layers: W(3.5 mm ≈ 1X_0) + silicon sensors**
- **Two types: Pads (LG) and Pixels (HG)**
  - **Pad layers provide shower profile**
  - **Pixel layers provide position resolution to resolve shower overlaps**

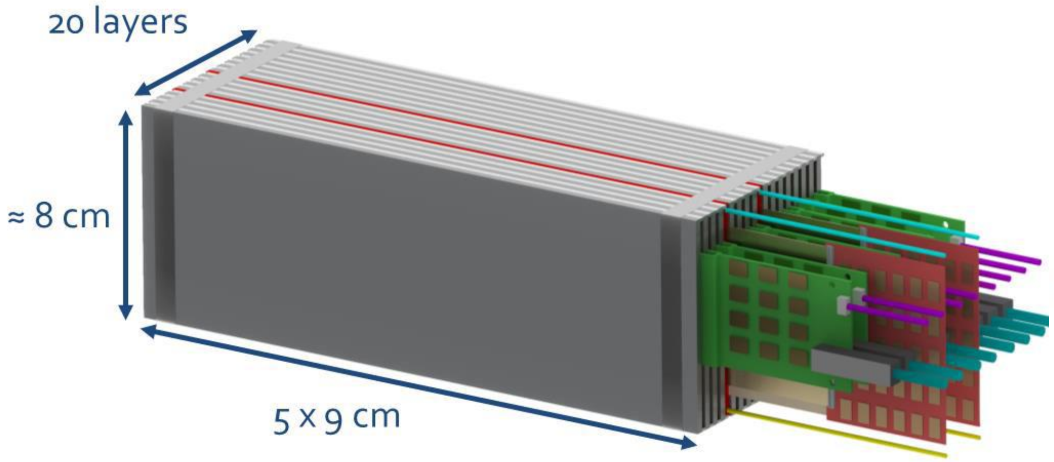
FoCal-H

Hadronic spaghetti calorimeter

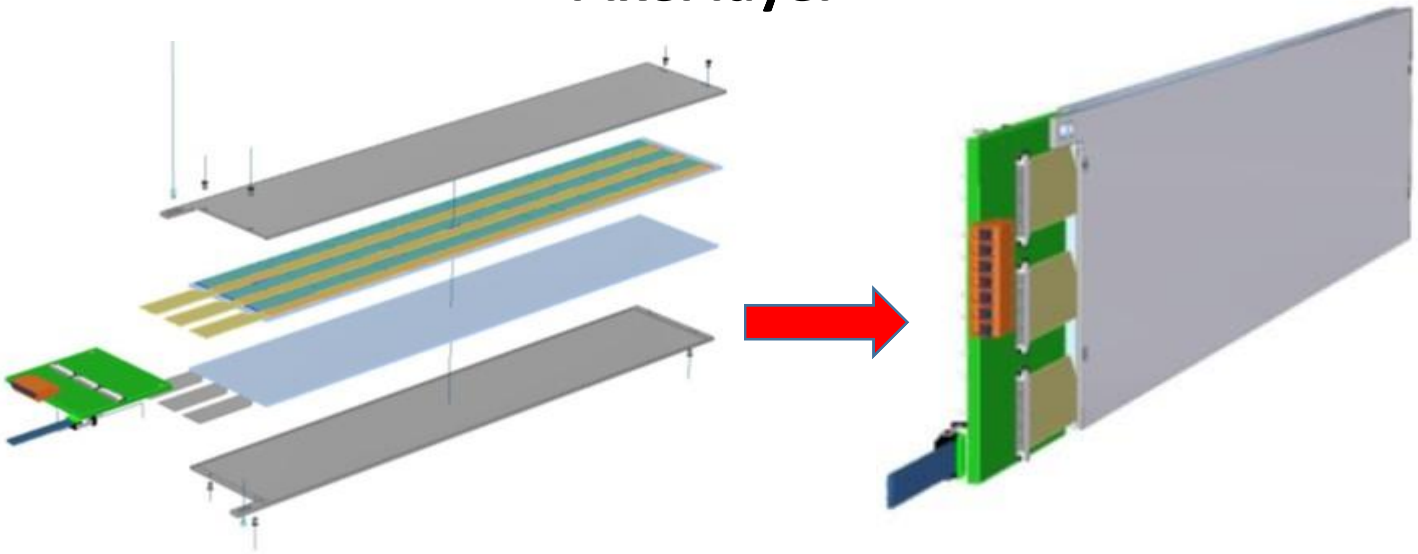
- **Copper capillary tubes, length 110 cm ~ 7λ_I (Length limited by space before compensator magnet)**
- **1 mm scintillating fibres inside 2.5 mm Cu tubes**
- **Bundle fibres and readout with SiPM**

FoCal–H prototype, 9 x (6.5 x 6.5 x 110 cm^3)

FoCal-E module

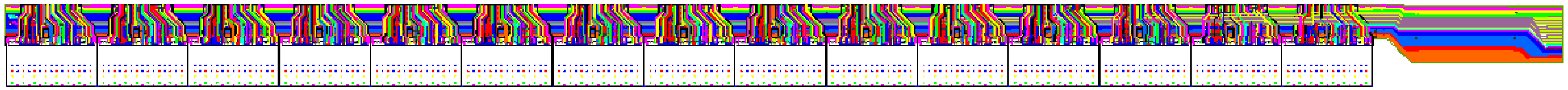


Pixel layer



Sketch

Total length of string ~50cm

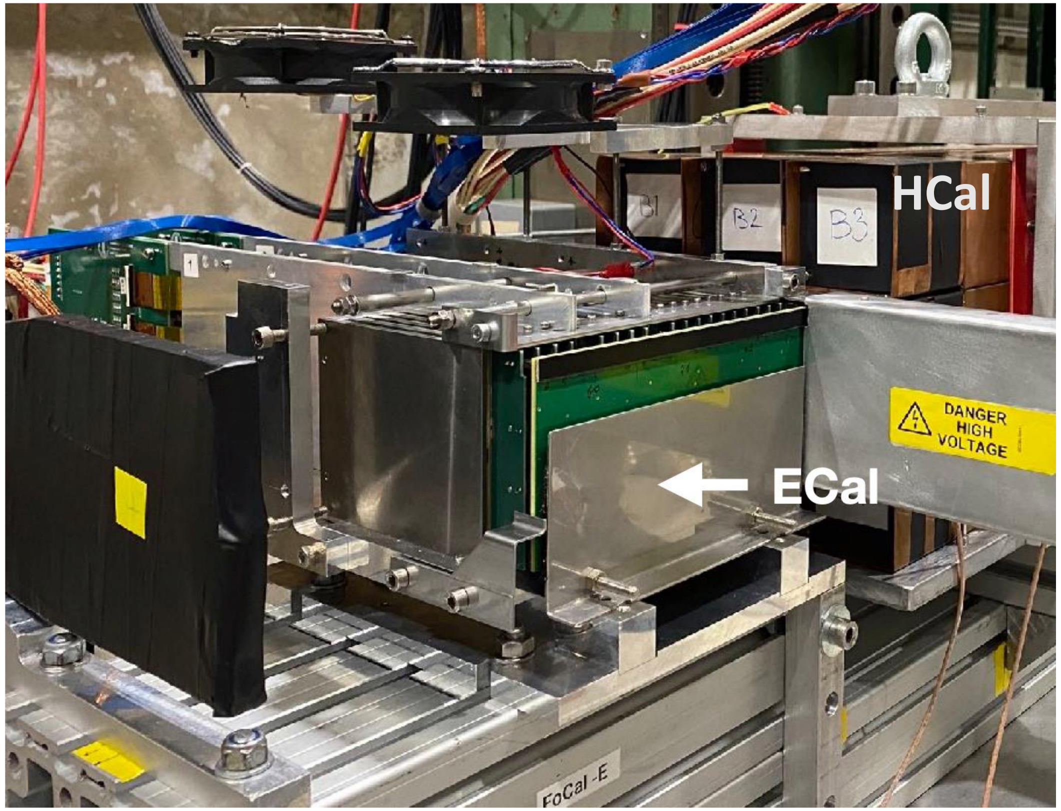


Length of active area ~45cm

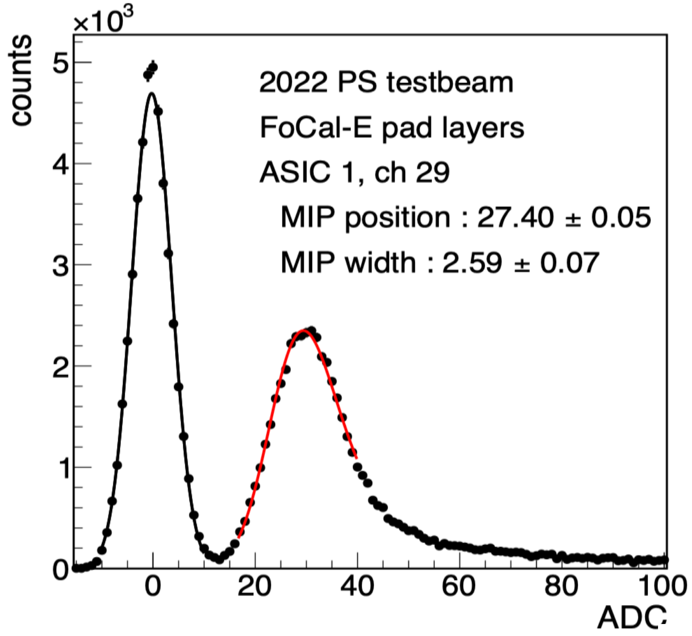
- **module of ≈ 18 pad layer and 2 pixel layers**
- **sensitive area: 45 cm x 8 cm**
- **use edge of detector for services**
- **designed to be stacked vertically for full detector setup**
- **22 modules in total**

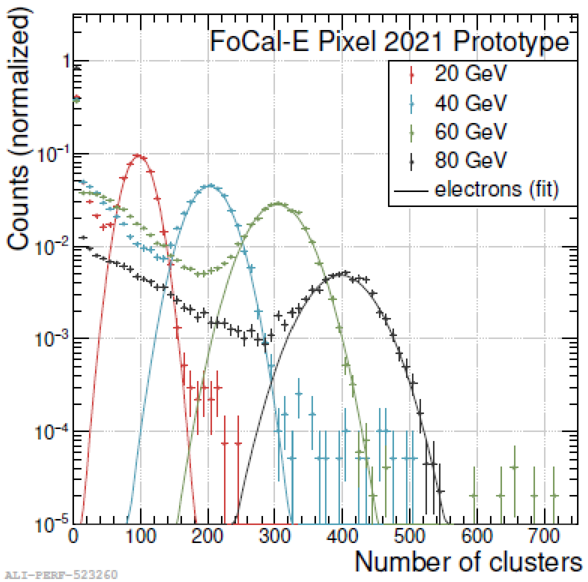
- **full area coverage with 2 x 3 strings of 15 ALPIDE sensors**
- **90 ALPIDE sensors per layer**
- **44 pixel layers, 3960 ALPIDE sensors**

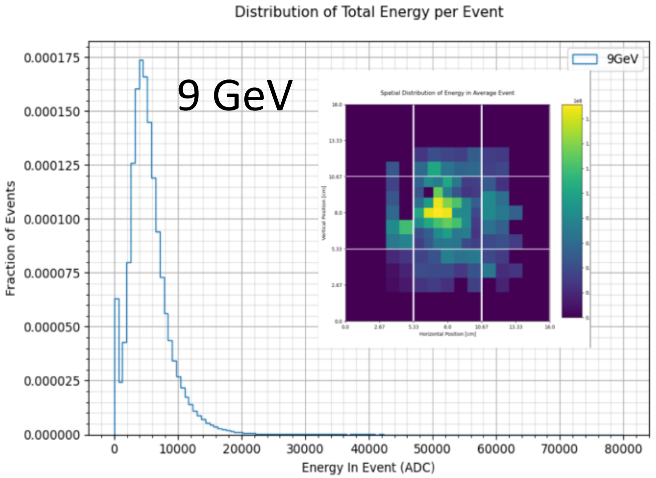
FoCal beam test results



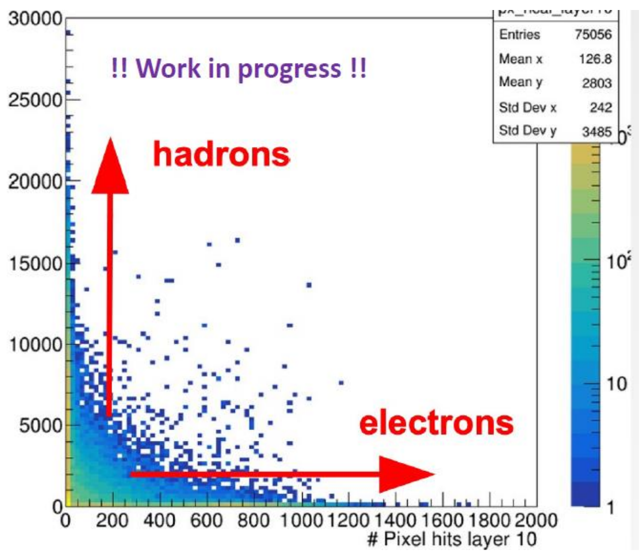
FoCal prototype, SPS test beam Sep 2022







Scintillation light by HCal vs #pixel hits



ALICE3 (beyond RUN4)

To answer the remaining fundamental questions needs:

- **precision measurements of di-leptons**

➡evolution of the quark-gluon plasma (QGP)
➡mechanisms of chiral symmetry restoration

- **systematic measurements of (multi-)heavy-flavor hadrons**

➡transport properties in the QGP
➡hadronization mechanisms from the QGP

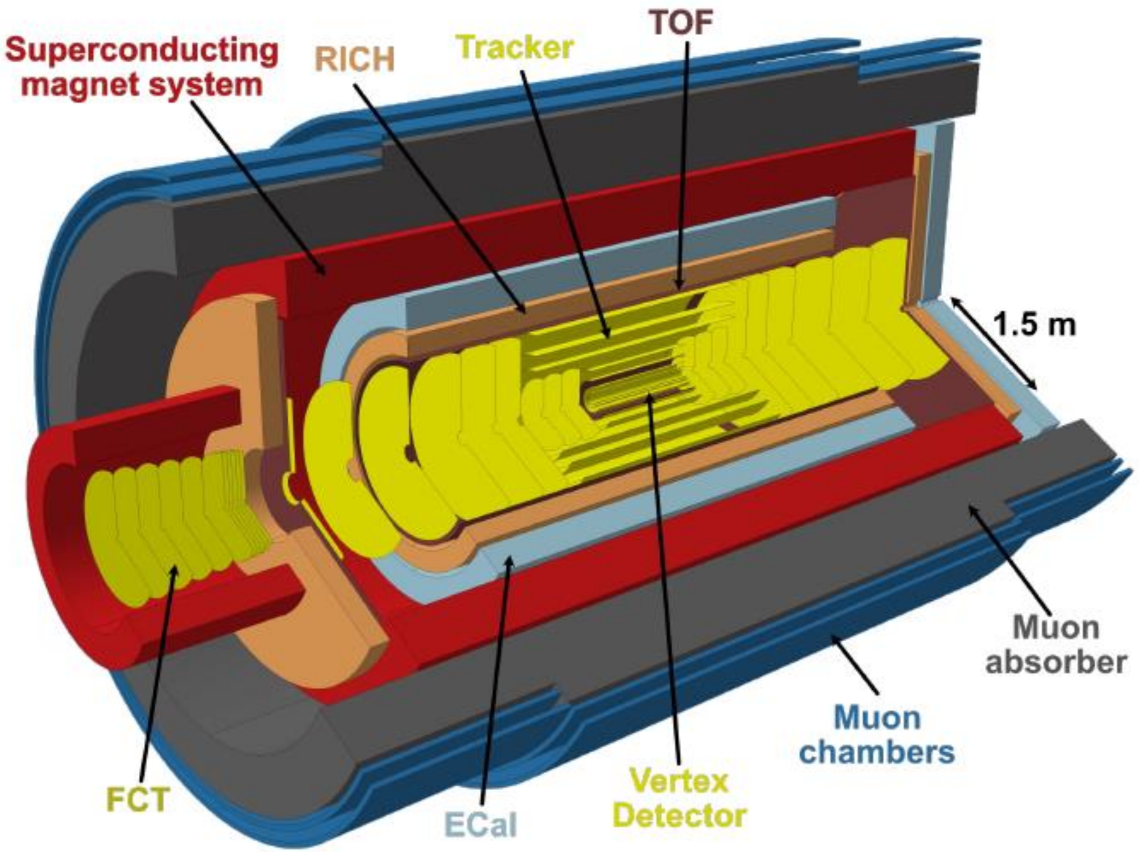
- **study of hadron interactions and fluctuations**

➡interaction potentials and c-nuclei
➡susceptibility to conserved charges

- **Novel and innovative detector concept**

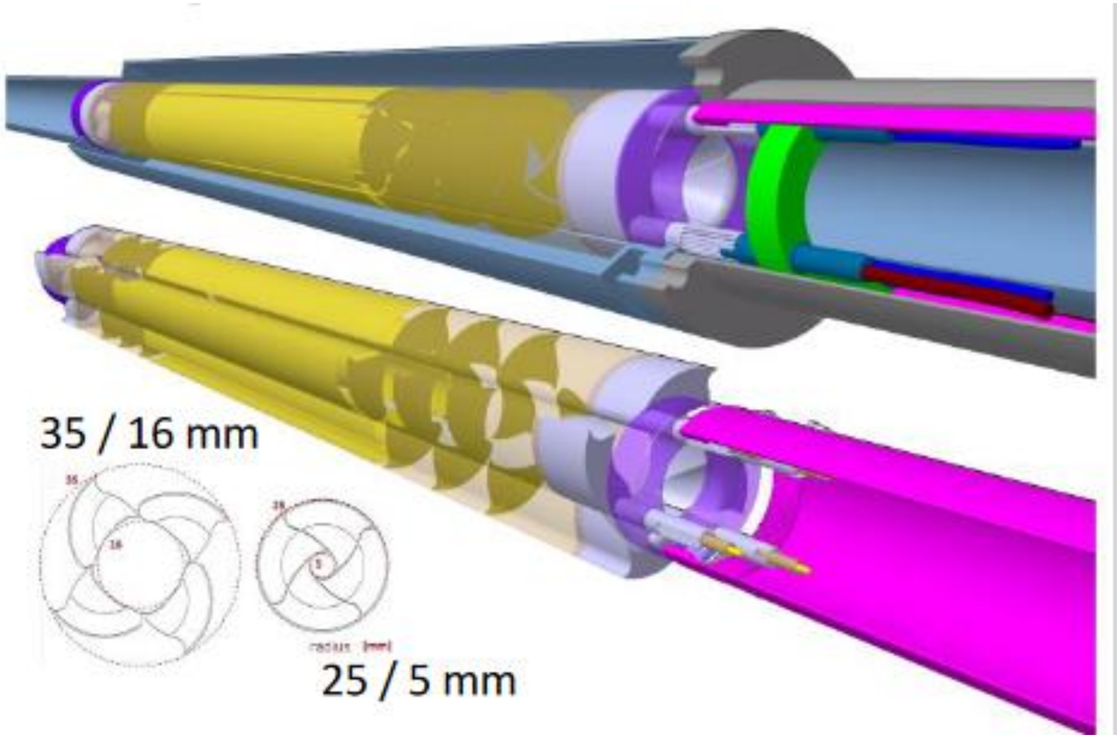
- Compact and lightweight all-silicon tracker
- Retractable vertex detector
- Particle identification systems
- Continuous read-out and online processing

- **Improvement of pointing resolution and effective statistics**



high-efficiency for heavy-quark identification and reconstruction of low-mass dielectrons
vertexing close to the beam with unprecedently low material budget
large acceptance with excellent coverage down to low p_T
excellent particle ID

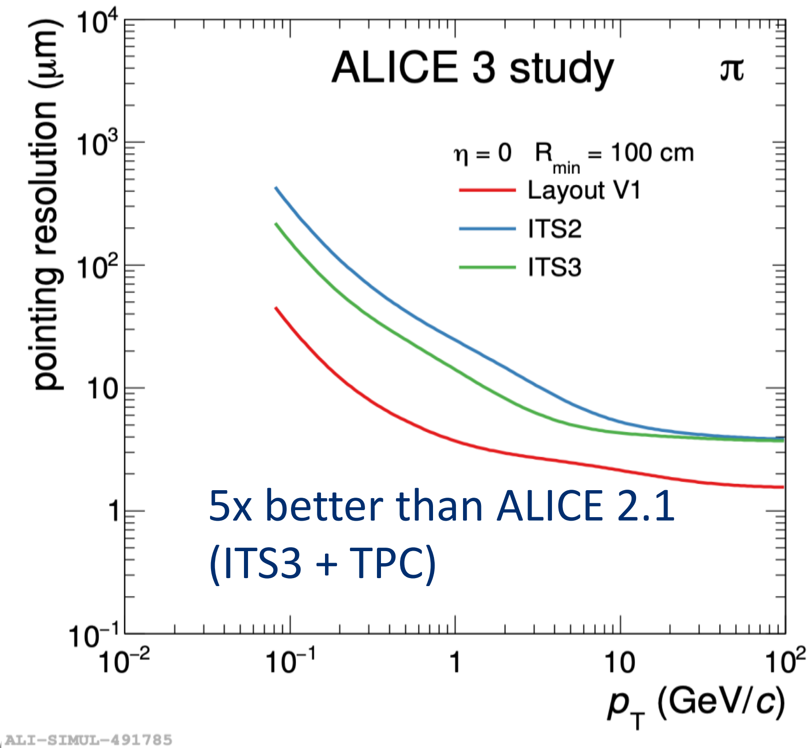
Tracker -Vertex detector



Ultimate performance

wafer-size, ultra-thin, curved, CMOS APS sensor

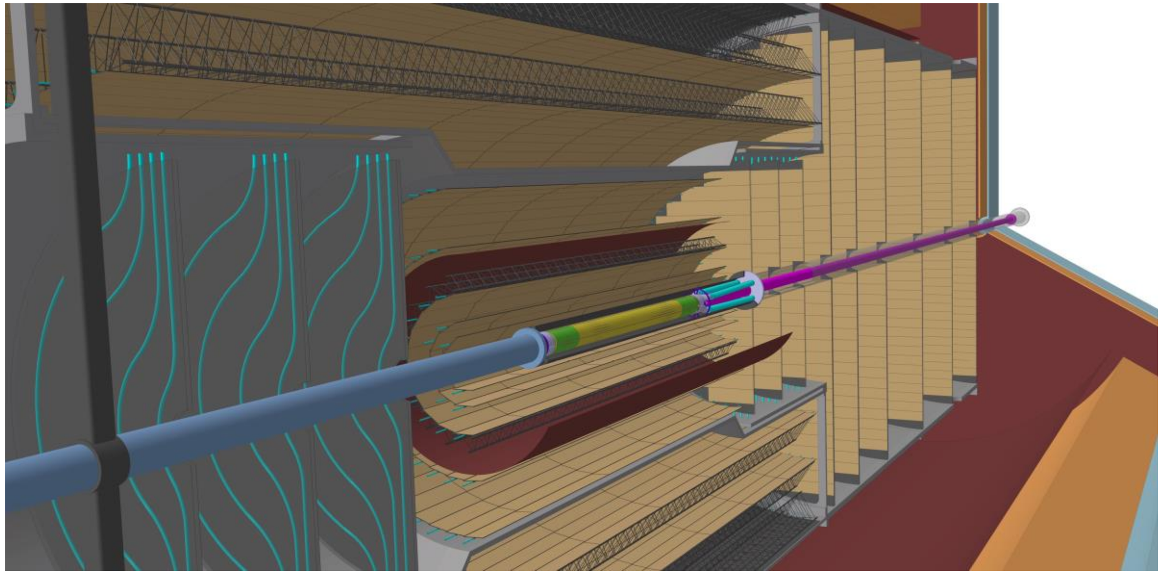
- **5mm radial distance from interaction point (inside beampipe, retractable configuration)**
- **unprecedented spatial resolution: $\sigma_{pos} \approx 2.5\ \mu m$**
- **… and material budget ≈ 0.1% X_0 / layer**



R&D focuses on

- **wafers-sized, curved sensors (same as for ITS3)**
- **advanced mechanics and cooling for integration inside beampipe (rotary petals, matching beampipe parameters, feed-through for services)**

Tracker – Outer tracker



8+2x9 tracking layers (barrel + disks)

Build on experience with ITS2 and ITS3 (same CMOS process)

R&D focuses on

- module (O(10 x 10 cm²)) concept based on **industry-standard processes for assembly and testing**
- services: **reduce** (eliminate) **interdependency** between modules (for replacement of single modules)

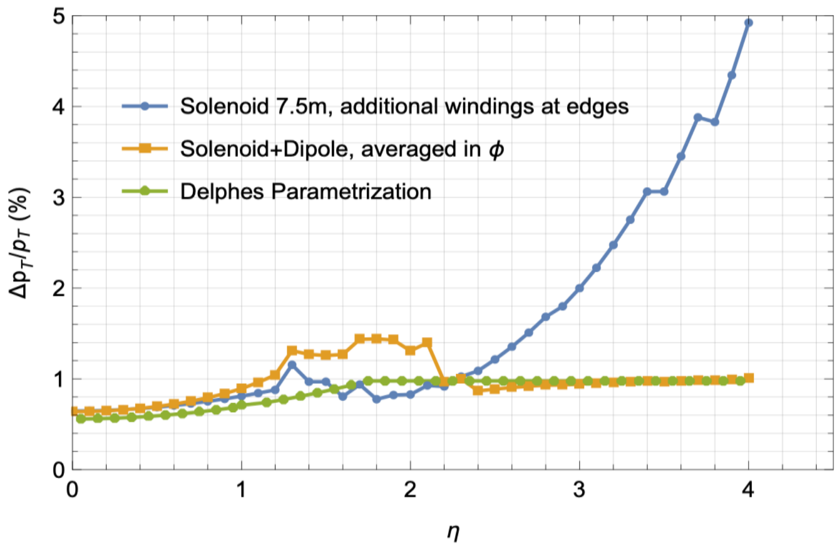
60 m² silicon pixel detector

based on CMOS Active Pixel Sensor (APS) technology

- large pseudorapidity coverage: ± 4
- compact: $R_{out} \approx 80$ cm, $z_{out} \approx \pm 400$ cm
- high-spatial resolution: $\sigma_{pos} \approx 5$ µm (req. < 10 µm)
- very low material budget: X/X_0 (total) $\lesssim 10\%$
- low power: ≈ 20 mW/cm²

$$\frac{\delta p_T}{p_T} \propto \frac{\sqrt{x/X_0}}{BL}$$

critically depends on integrated magnetic field and overall material budget



Particle identification: TOF and RICH

Barrel TOF (|η| < 1.75)

- Outer TOF radius = 85 cm

surface: 30 m^2, pitch: 5 mm

- Inner TOF, radius = 19 cm

surface: 1.5 m^2, pitch: 1 mm

Forward TOF (1.75 < |η| < 4)

- Inner radius = 15 cm
- Outer radius = 150 cm

surface = 14 m^2, pitch = 1 mm to 5 mm

$\sigma_{TOF} \lesssim 20ps$

Two R&D lines

- **CMOS LGAD (baseline):** main R&D line in ALICE
- integration of sensor and readout in a single chip
- easier system integration and significant cost reduction (save 11.5 MCHF)
- **Conventional LGADs (fallback):** R&D line in ALICE with very thin sensors

Ring-Imaging Cherenkov

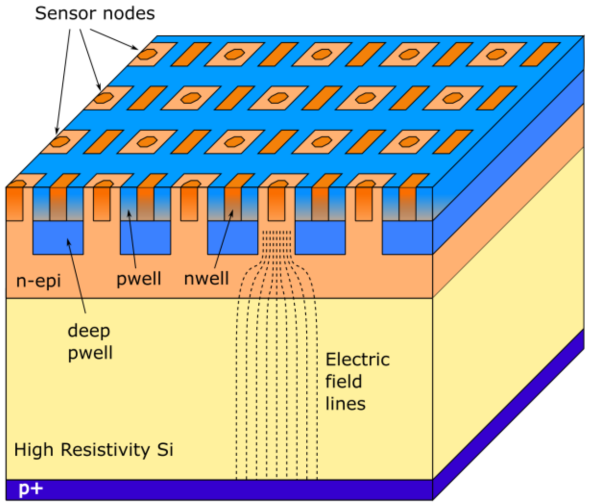
- **Extend PID reach of outer TOF to higher p_T**
- **aerogel radiator to ensure continuous coverage from TOF**

→ refractive index n = 1.03 (barrel)

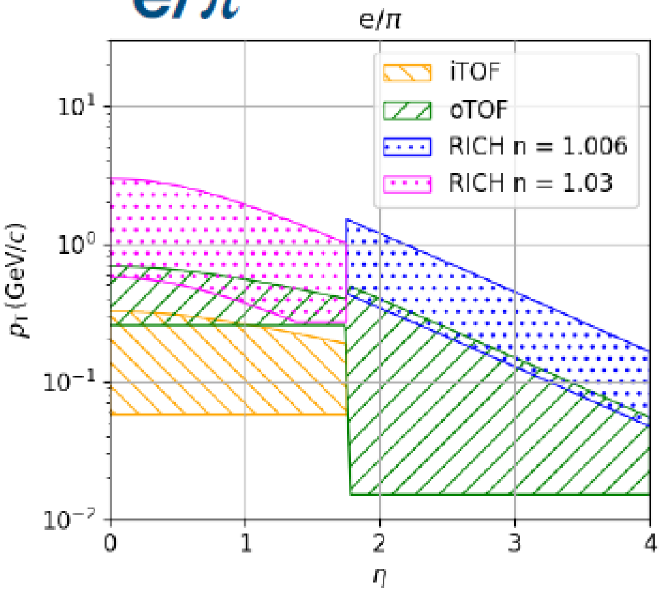
→ refractive index n = 1.006 (forward)

- **silicon photon sensors**
- **R&D on monolithic photon sensors**

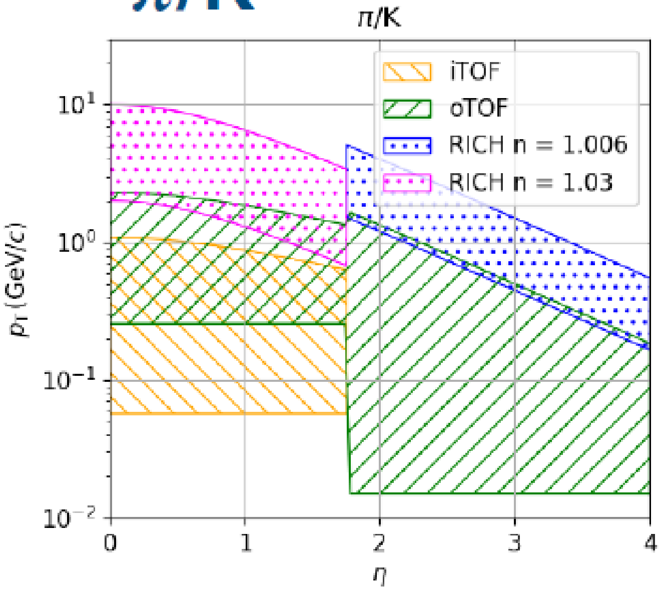
60 m^2 SiPM



e/π



π/K



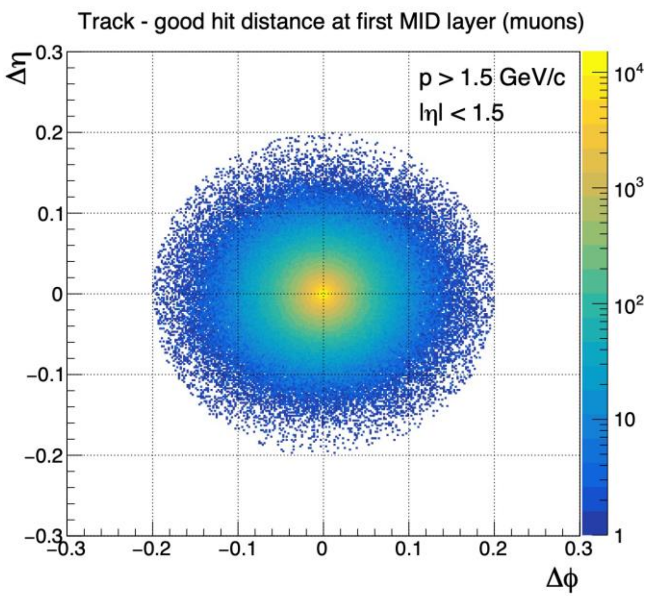
EMCal, Muon ID and FCT

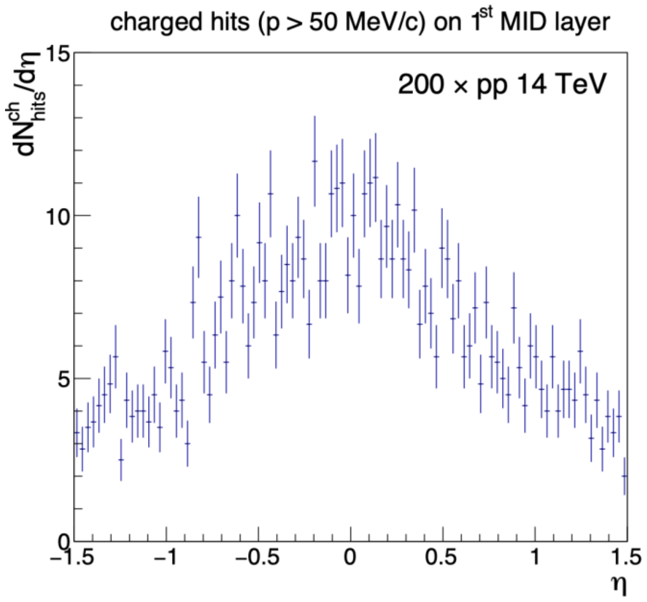
- **Electromagnetic Calorimeter**
  - **Large acceptance EMCal**
  - sampling calorimeter O(100) layers (1 mm Pb + 1.5 mm plastic scintillator)
  - **Additional high energy resolution segment** at midrapidity or forward
  - PbWO4-based

ECal module	Barrel sampling	Endcap sampling	Barrel high-precision
acceptance	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 1.5$	$\Delta\varphi = 2\pi$, $1.5 < \eta < 4$	$\Delta\varphi = 2\pi$, $\lvert\eta\rvert < 0.33$
geometry	$R_{in} = 1.15$ m, $\lvert z\rvert < 2.7$ m	$0.16 < R < 1.8$ m, $z = 4.35$ m	$R_{in} = 1.15$ m, $\lvert z\rvert < 0.64$ m
technology	sampling Pb + scint.	sampling Pb + scint.	$PbWO_4$ crystals
cell size	30×30 mm^2	40×40 mm^2	22×22 mm^2
no. of channels	30 000	6 000	20 000
energy range	$0.1 < E < 100$ GeV	$0.1 < E < 250$ GeV	$0.01 < E < 100$ GeV

- **Forward conversion tracker**
- **Thin tracking disks in $3 < \eta < 5$ in its own dipole field**
- **Very low p_T photons (≤ 10 MeV/c)**

- **Muon ID**
  - **Hadron absorber outside of the magnet**
  - ~70 cm non-magnetic steel
  - **Muon chambers**
  - search spot for muons ~0.1 x 0.1 (eta x phi) → ~5 x 5 cm^2 cell size
  - **matching demonstrated with 2 layers of muon chambers**
  - scintillator bars with SiPM read-out
  - resistive plate chambers





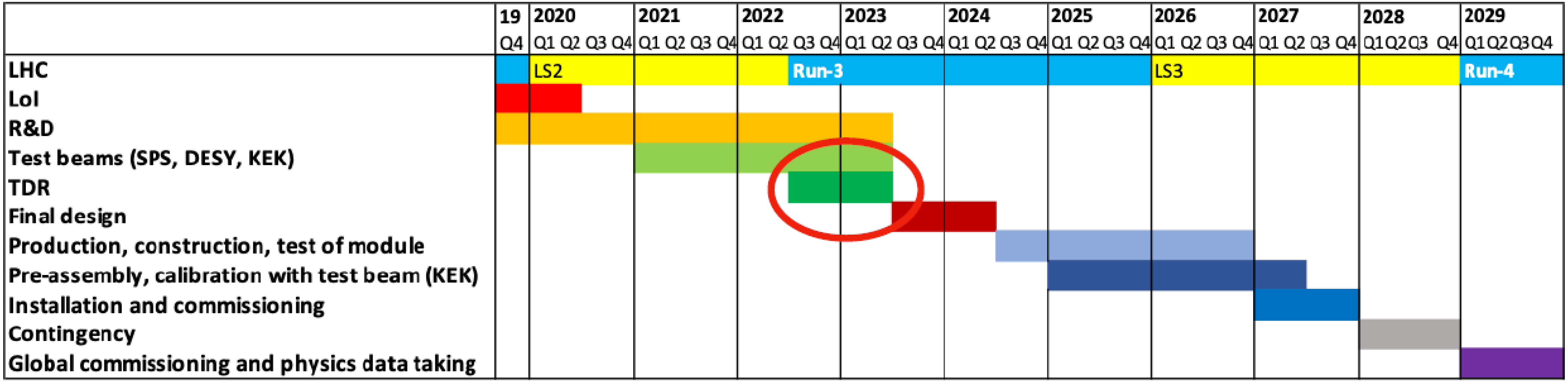
Summary

- Intermediate upgrade for the LS3 will allow higher precision measurements:
  - ITS3: better pointing resolution, R&D is onging according to schedule
  - FoCal: first prototypes being tested, very good results from beam test data
- ALICE3 is proposed as a major upgrade for Run 5 and 6 to give better insight of the microscopic dynamics of the QGP:
  - Properties of the QGP
  - Chiral symmetry restoration mechanism
  - Hadronization and nature of hadronic states
- Innovative detector concept to meet the requirements for the ALICE3 physics program:
  - building on experience with technologies pioneered in ALICE
  - requiring R&D activities in several strategic areas

Thanks a lot for your attention!

Backup

FoCal timeline



- **Schedule:**
  2023: TDR
  2023/2024: final design for production
  2024-2027: production and calibration in beam
  2027: installation

ALICE3 timeline

2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S	J M S
	RUN 3				LS3			RUN 4			LS4			RUN 5			LS5		RUN 6	
ALICE 3 LoI	ALICE3 selection of technologies, concept prototypes, R&D (25% funds)			ALICE3 engineered prototypes, R&D (75% funds), TDRs		ALICE3 construction and testing + 1 y contingency					ALICE3 installation		ALICE3 operation							

ALICE3 core cost (without labor and contingency)

- **141.5 MCHF for the baseline**
- **178.2 MCHF with present technologies**
- **Fair share for China team with 14 M&O members**
  - **2.5% compared to 1.5% core contribution up to now (ALICE1 & ALICE2)**
  - **3.5 MCHF (about 25 MCNY)**