ALICE 3 Inner Tracker Design And Developments

Kshitij Agarwal[1], on behalf of the ALICE Collaboration

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PSD14: The 14th International Conference on Position Sensitive Detectors

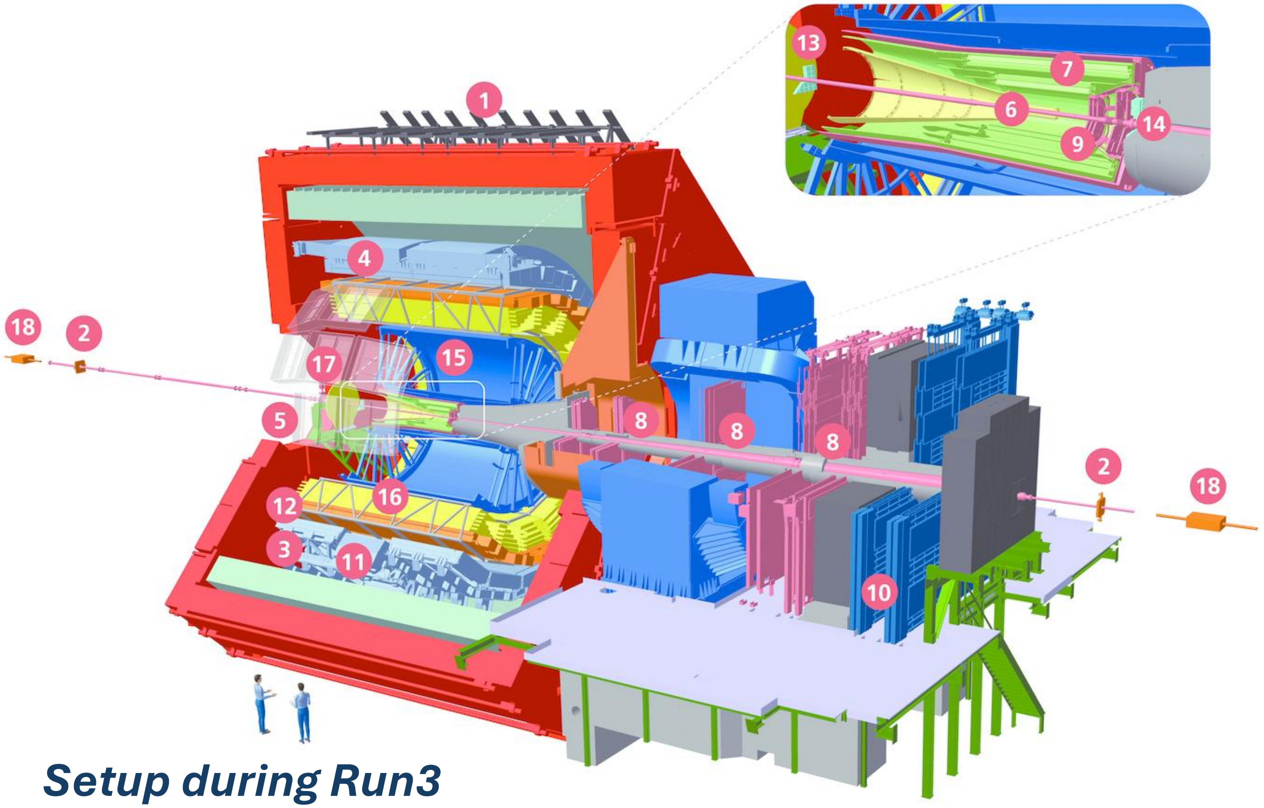
Queen Mary University of London (UK); 01 – 04.09.2026

OVERVIEW

Introduction

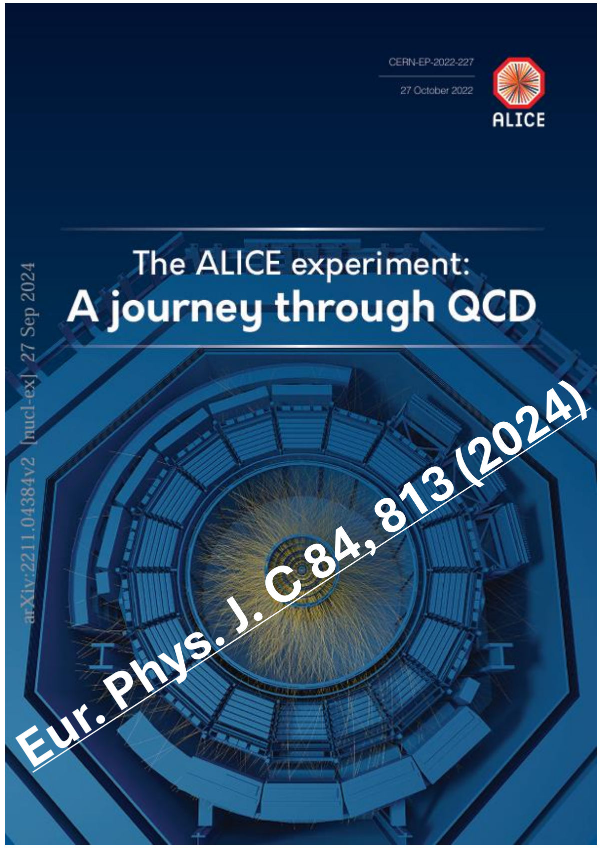
ALICE Evolution (Run 1 … 4)

LHC Run 1 2009 – 2013	LHC Run 2 2015 – 2018	LHC Run 3 2022 – 2026	LHC Run 4 2030 – 2033	LHC Run 5 2036 – 2041
ALICE 1 Pb-Pb: 1 kHz, pp: 200 kHz		ALICE 2 Pb-Pb: 50 kHz, pp: 750 kHz	ALICE 2.1 Pb-Pb: 50 kHz, pp: 750 kHz	ALICE 3 Pb-Pb: 100 kHz, pp: 24 MHz



Setup during Run3

1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter



ALICE Silicon Tracker Evolution (Run 1 … 4)

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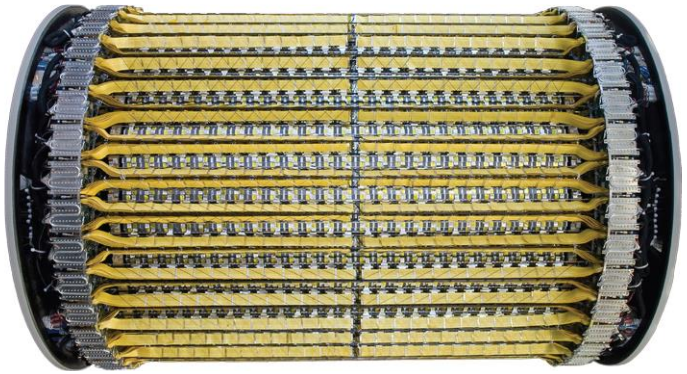
ITS1 @ Run 1, 2 (Pixel, Drift, Strip)



ITS2 @ Run 3 (MAPS)

J. Liu, 03.09 | Link
S. Kushpil, Poster | Link

ITS3 @ Run 4 (Wafer-Scale, Curved MAPS)

U. Savino, 02.09 | Link

ALICE silicon tracker upgrades are aimed to improve the impact parameter resolution (Δd_0), while increasing the Pb-Pb interaction rate

- Position Resolution ($\sigma_{r\varphi}$)
- Innermost Radius (r_0)
- Material Budget (X/X_0)
- Radiation Tolerance
- Readout Speed
- Detector Acceptance

$$\Delta d_0 = a \cdot \sigma_{r\varphi} \oplus b \cdot \frac{r_0 \cdot \cosh^{1/2}\eta}{p_T} \cdot \sqrt{\frac{X}{X_0}}$$

Z. Drasal and W. Riegler, Nucl.Instrum.Meth.A 910 (2018) 127-132

ALICE 3 (RUN 5)

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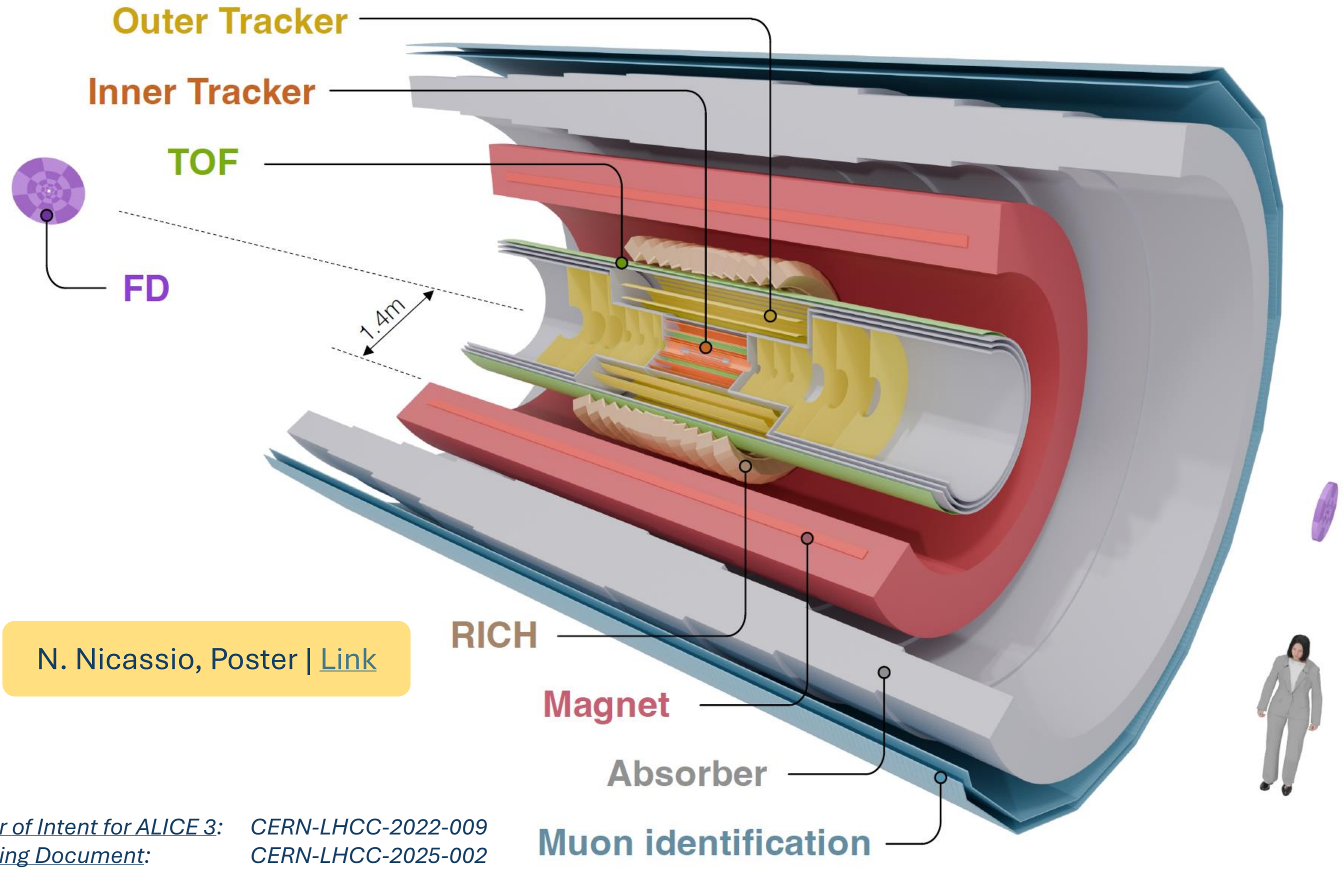
Physics Goals -

- Thermalisation of heavy quarks in QGP
- Evolution of QGP temperature as function of time
- Fundamental aspects of the QCD phase transition
- Laboratory for hadron physics

Key Detector Features -

- Compact, ultra-light silicon tracker
- PID capabilities over $|\eta| \leq 2.5$:
  Time-Of-Flight + Ring Imaging Cherenkov + Muon ID
- Superconducting 2T solenoid magnet
- Continuous read-out and online processing



N. Nicassio, Poster | Link

Letter of Intent for ALICE 3: *CERN-LHCC-2022-009*
Scoping Document: *CERN-LHCC-2025-002*

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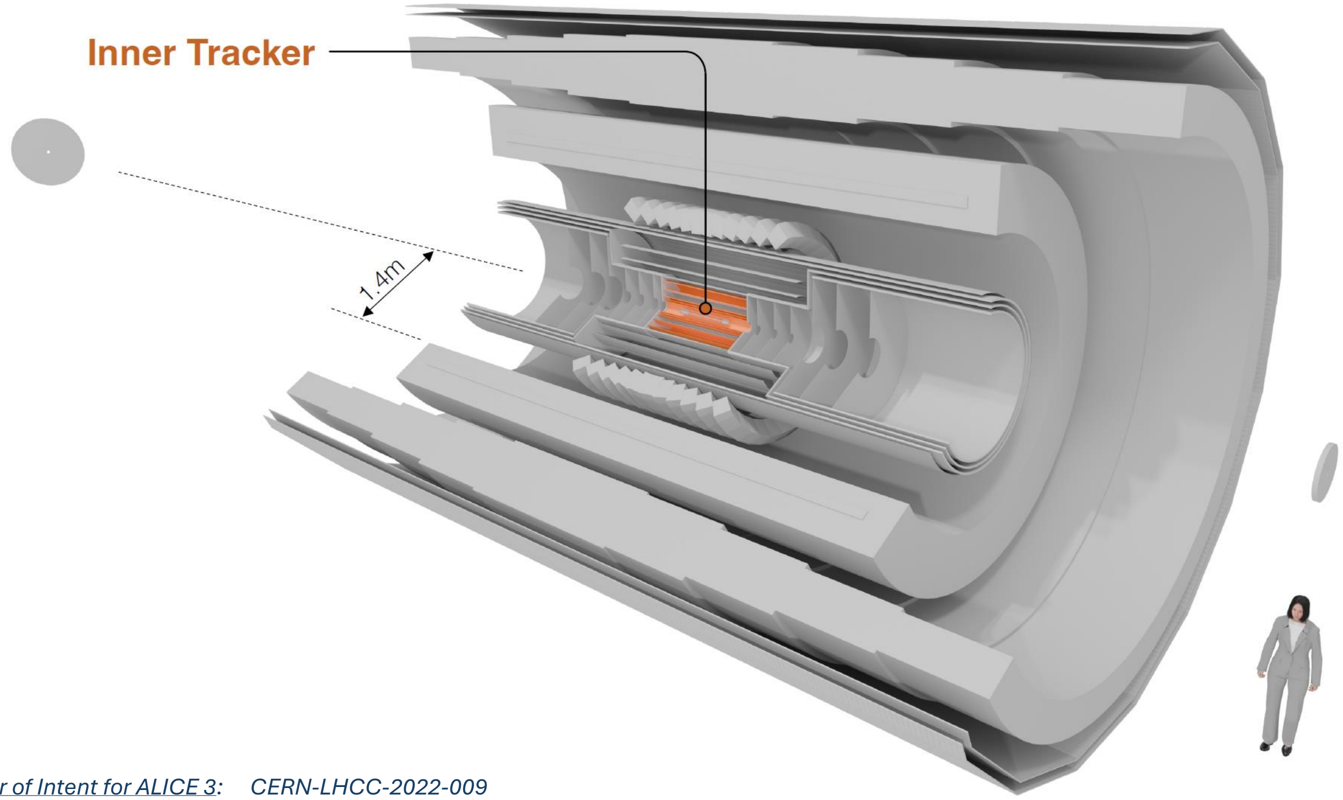

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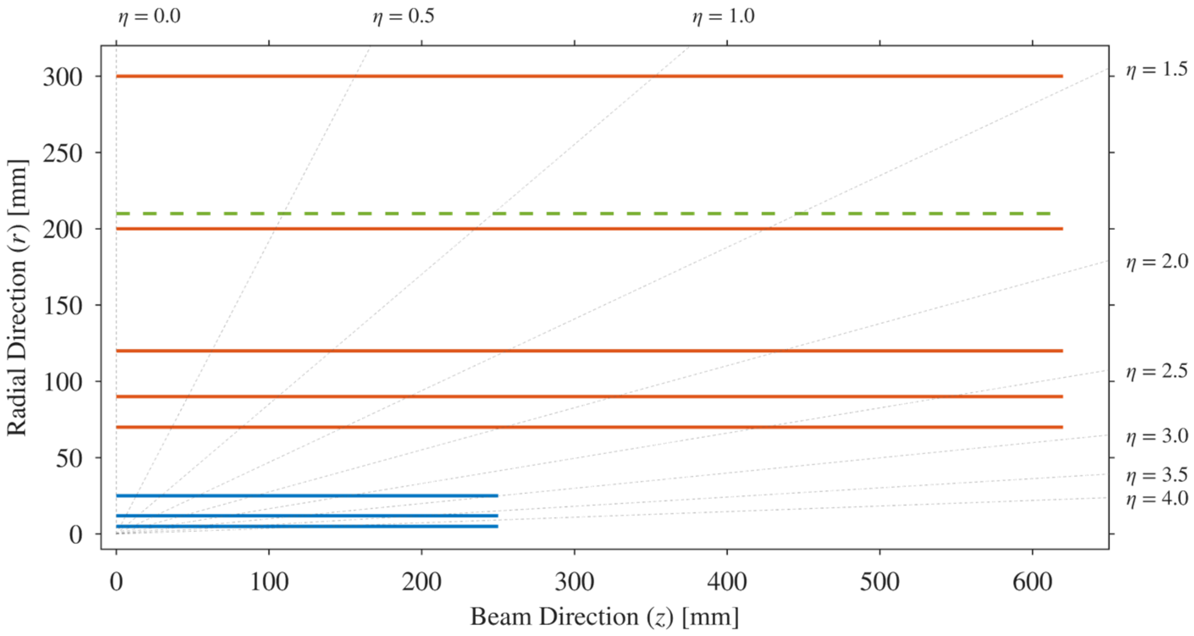
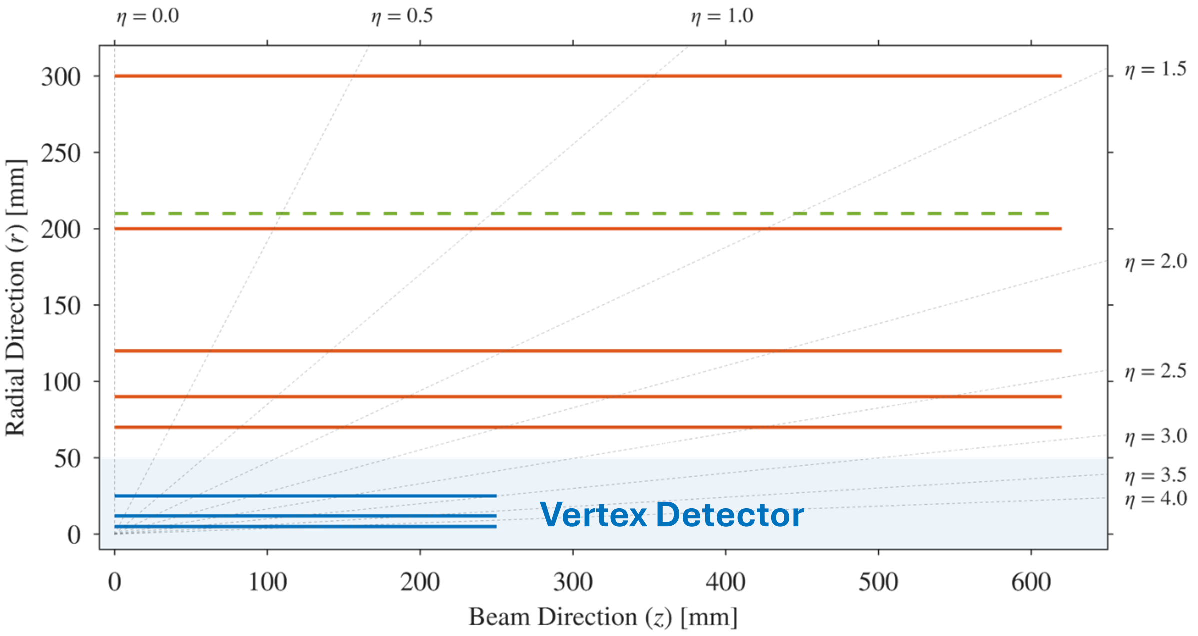
General Design Features And Requirements

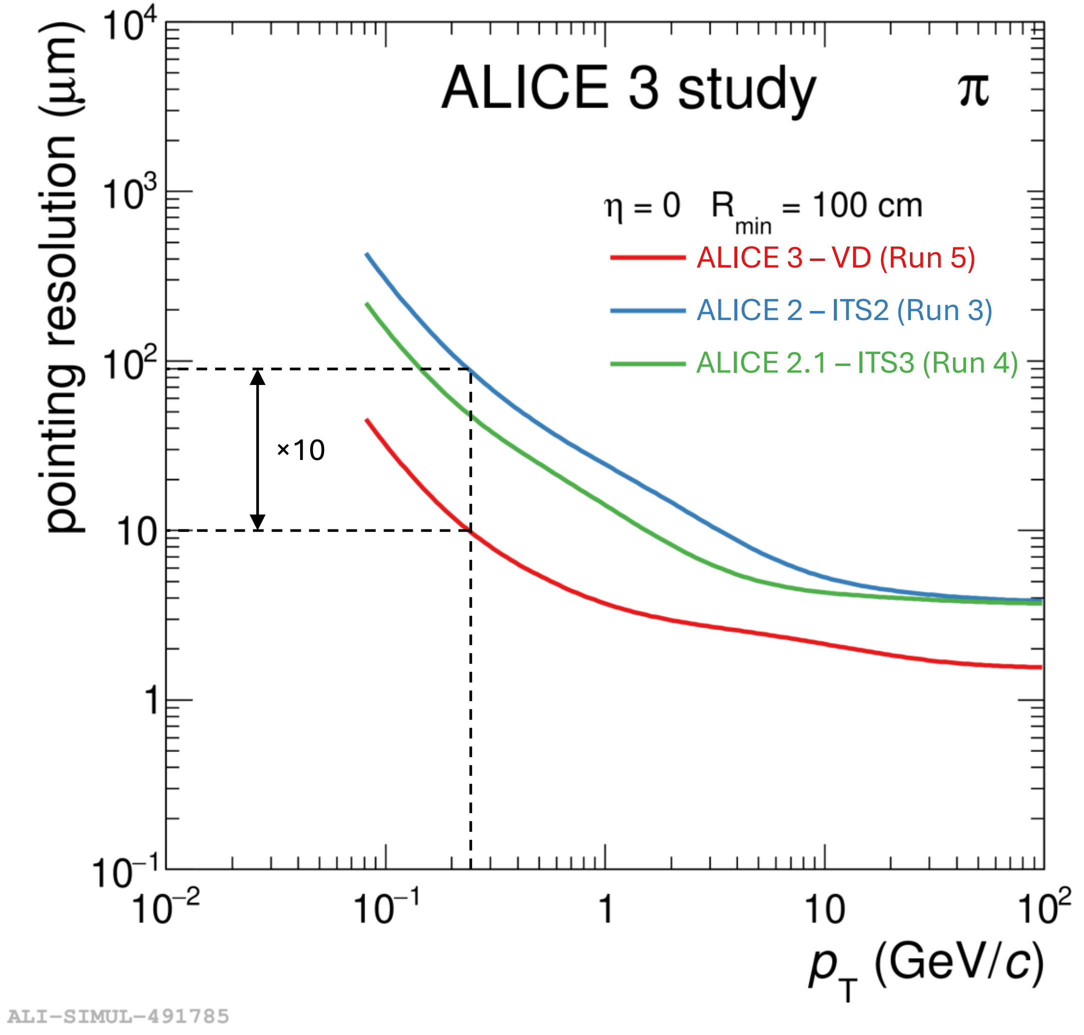
ALICE 3 Inner Tracker (IT) – Layout



- CMOS MAPS for all 8 barrel layers, covering ≈ 6.2 m^2

Vertex Detector (VD)





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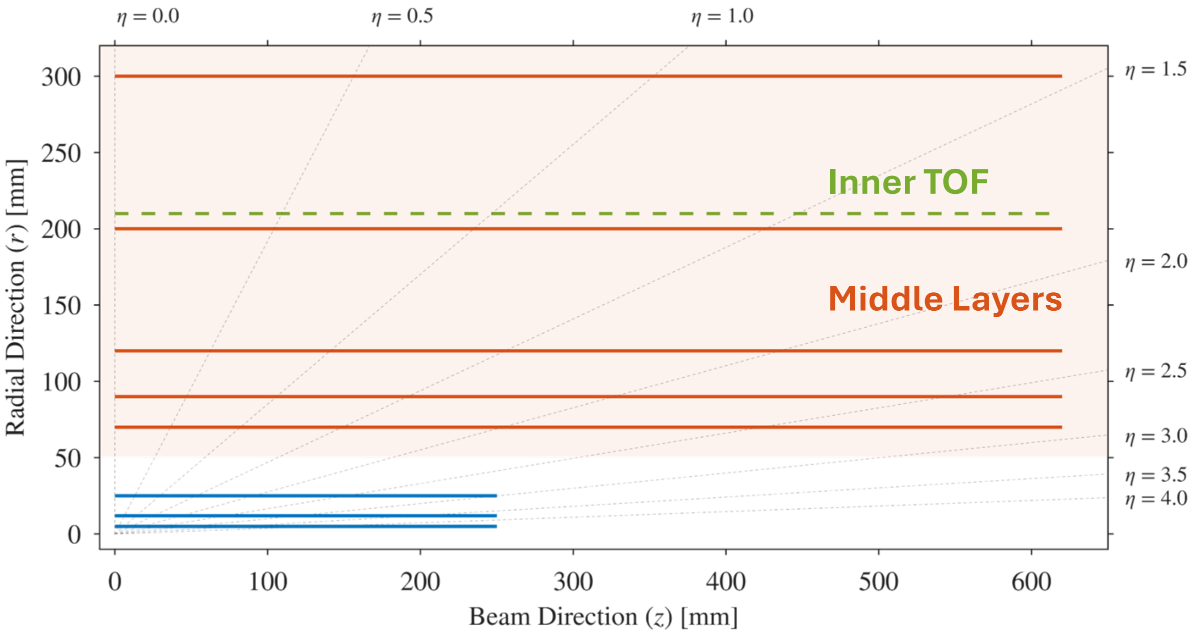
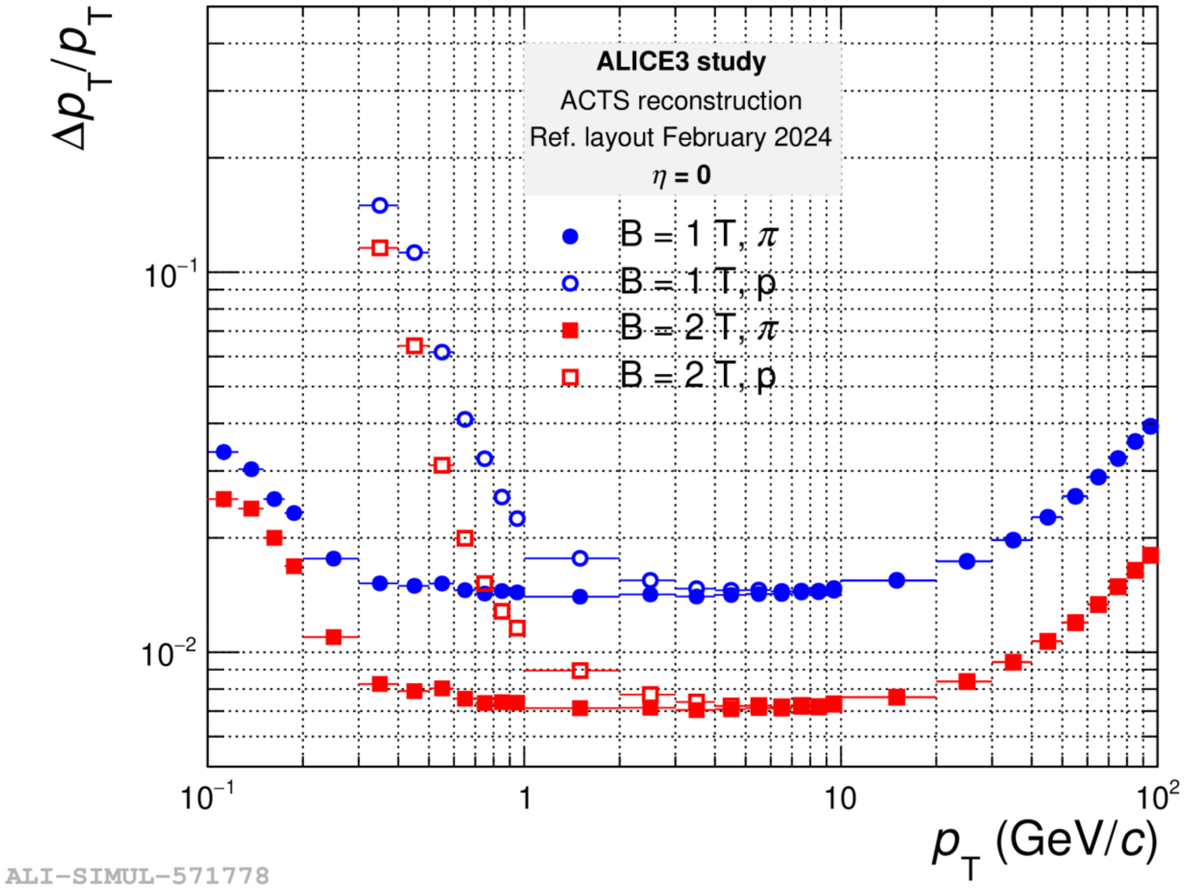
- **Vertex Detector (VD):** 3 barrel layers inside the beam pipe (r_0 = 5 mm)
  $\sigma_{xy} \approx$ 10 μm @ p_T = 0.25 GeV/c

Middle Layers (ML)





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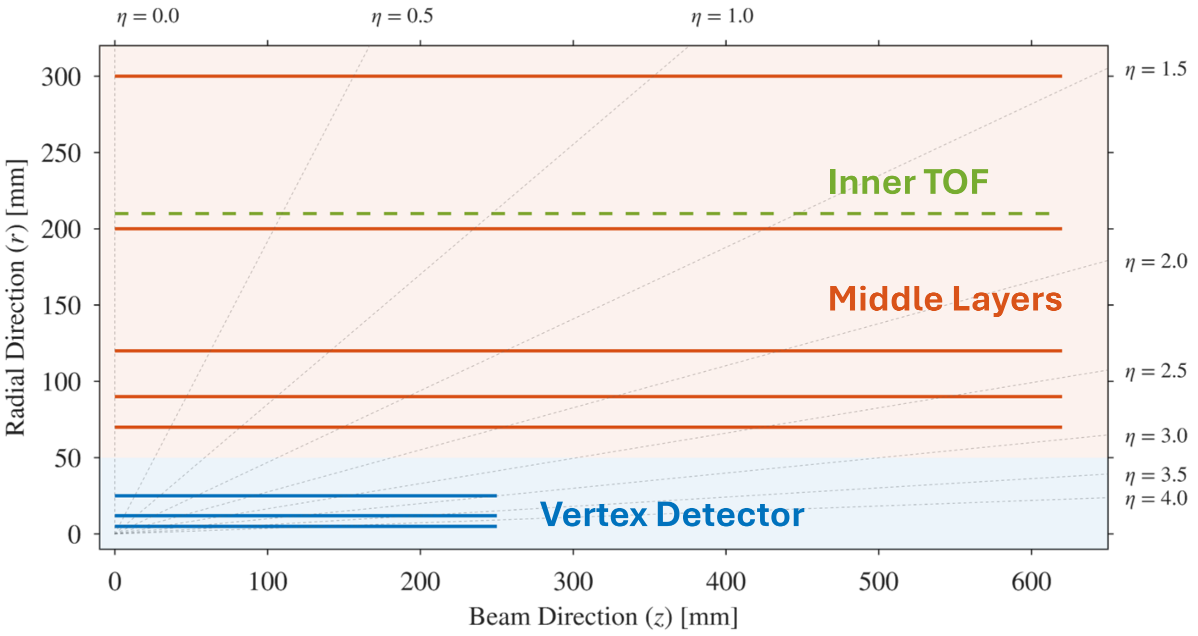
  $\sigma_{xy} \approx 10$ μm @ p_T = 0.25 GeV/c
- **Middle Layers (ML):** 5 barrel layers outside the beam pipe
  $\Delta p_T/p_T < 2\%$ @ $p_T > 0.20$ GeV/c and 2T
  Shared mechanics with **Inner TOF** barrel layer

Requirements



- ALICE 3 IT requirements spanning wide ranges for each parameter

	ALICE 2.1 ITS3	ALICE 3 Inner Tracker	
		Vertex Detector	Middle Layers
Intrinsic Position resolution [μm]	5	2.5	10
Pixel Pitch [μm]	20	10	< 50 (20)
Time Resolution [μs RMS]	*O*(1)	*O*(0.1)	*O*(0.1)
In-Pixel Hit Rate [Hz]	54	94	42
Fake-Hit Rate [/pixel/event]	$< 10^{-7}$	$< 10^{-7}$	$< 10^{-7}$
Power Consumption [mW/cm^2]	35	70	20 ... 30
Particle Hit Density [MHz/cm^2]	8.5	94	0.6
X/X_0 per Layer [%]	0.09	0.1	1.0
Total Sensor Area [m^2]	0.1	0.1	6.1

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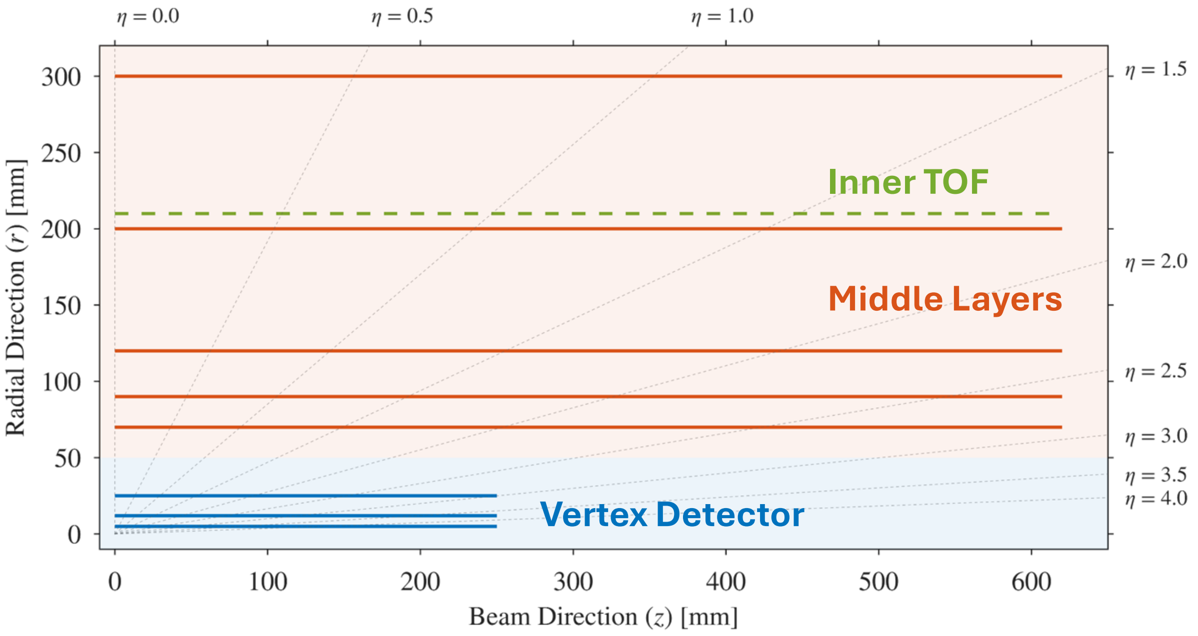

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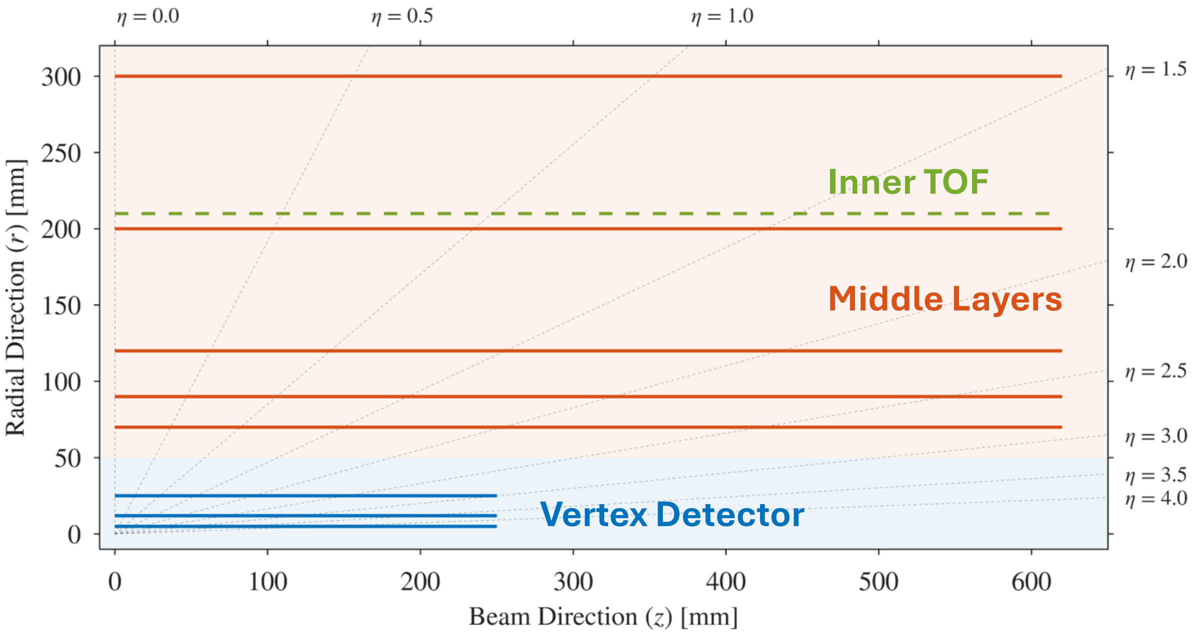

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- **Middle Layers (ML):** Module design for high-yield industrial production
  Low power consumption while maintaining timing

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Sensor Development And Characterisation

ALMIRA – ALICE 3 Monolithic Integrated Tracker Asics

- Common design approach for all ALICE 3 tracker layers
- Modular design with **Pixel Macros** ($80 \times 80\ \mu m^2$) as basic unit

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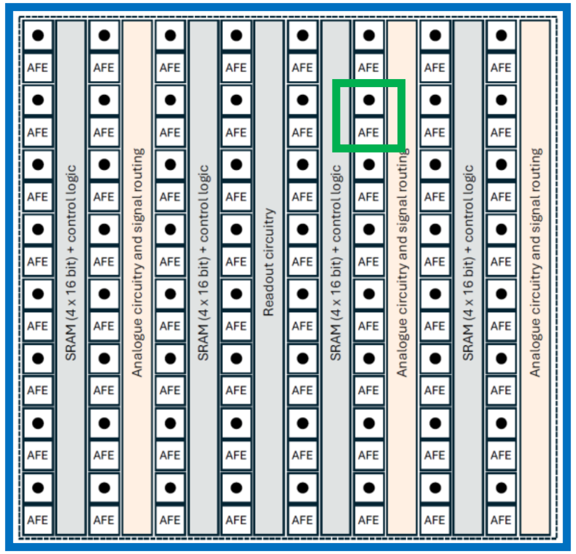
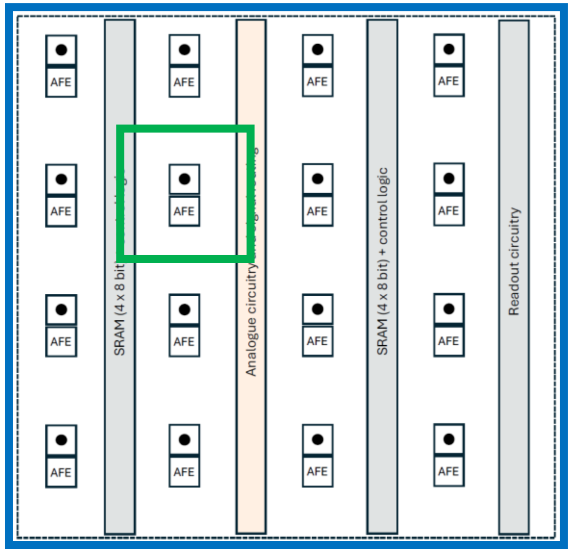
  ALMIRA-V: a larger format chip 10 μm pitch for the VD

  ALMIRA-T: a reticle-size ≥ 20 μm pitch for tracking layers

Pixel Macro for 10 μm pixels



Pixel Macro for 20 μm pixels



● ***Charge Collection Electrode***

AFE ***Analog Front End***

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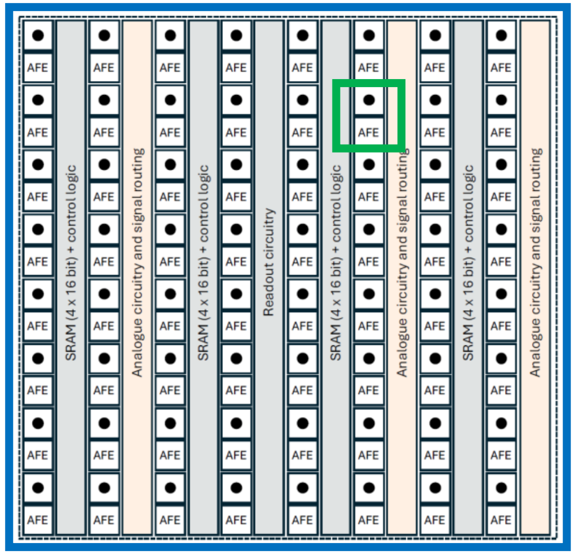
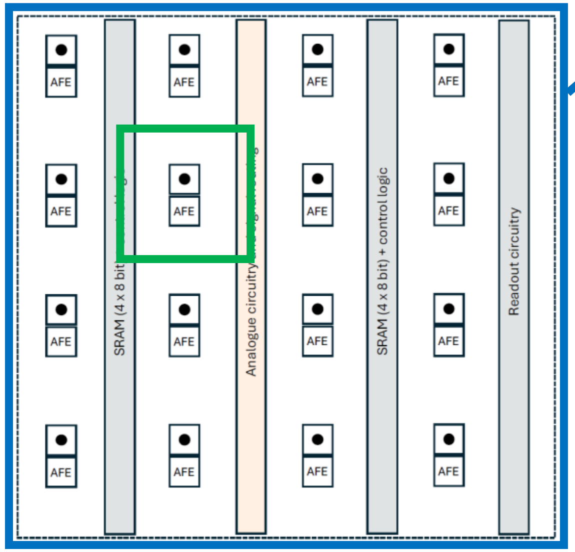
  - ALMIRA-V: a larger format chip 10 µm pitch for the VD
  - ALMIRA-T: a reticle-size ≥ 20 µm pitch for tracking layers
- **Matrix Core** of 128 pixel macros arrays (1 × 1 cm^2) with peripheral interface for control, aggregation, serialisation
- Detailed designing and simulations ongoing, with first submission targeted in 2027

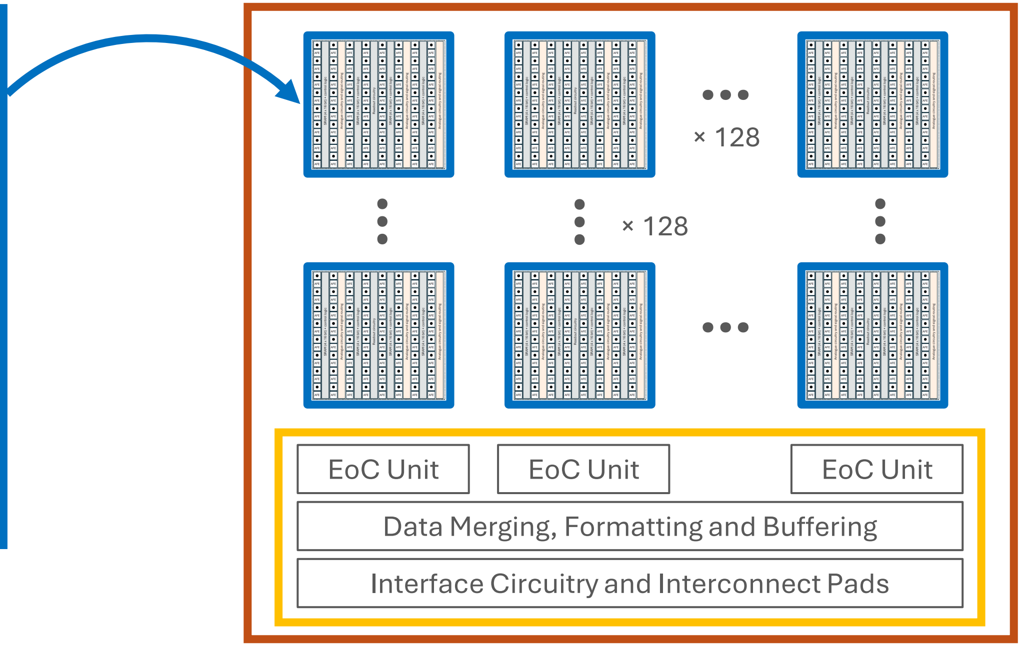
Pixel Macro for 10 µm pixels



Pixel Macro for 20 µm pixels



Pixel Matrix Core



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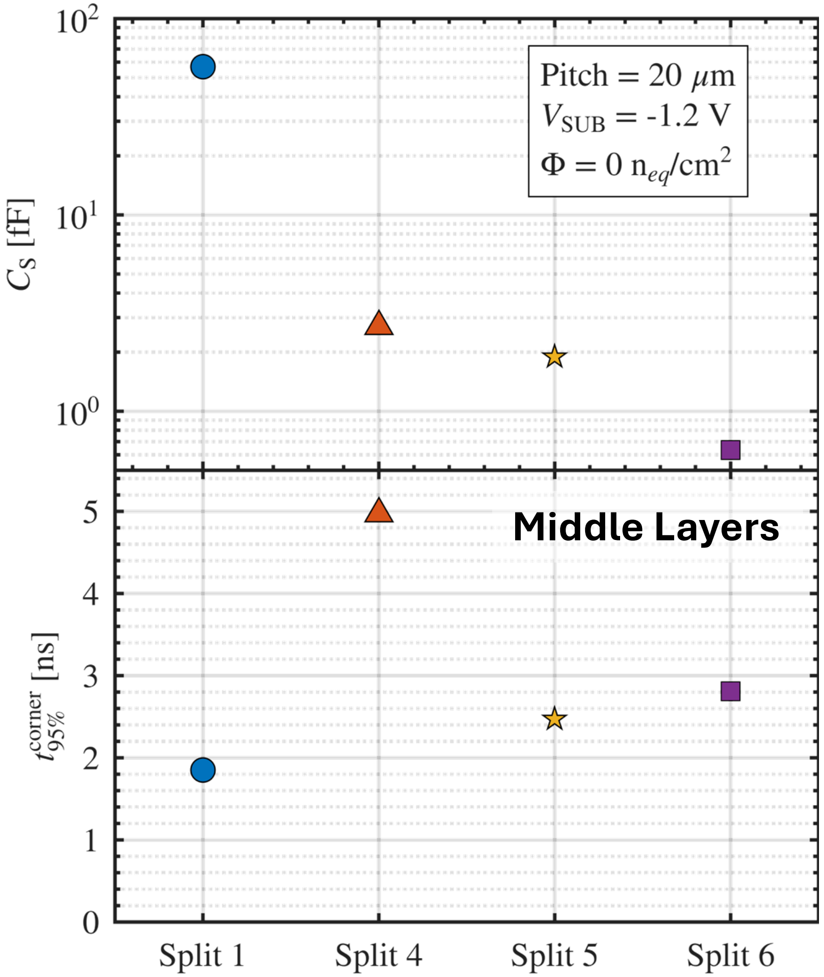
- **Middle Layers:**
  - Split 4-6:   -1.2 V bias and 20 µm pitch
  - Optimised to lower sensor capacitance (C_S) for higher signal-to-noise ratio and lower analog power consumption
  - Further split optimisation ongoing for 0 V bias



C. Lemoine et al., JINST 19 (2024) 02, C02033
G. Borghello et al., JINST 20 (2025) 07, C07053

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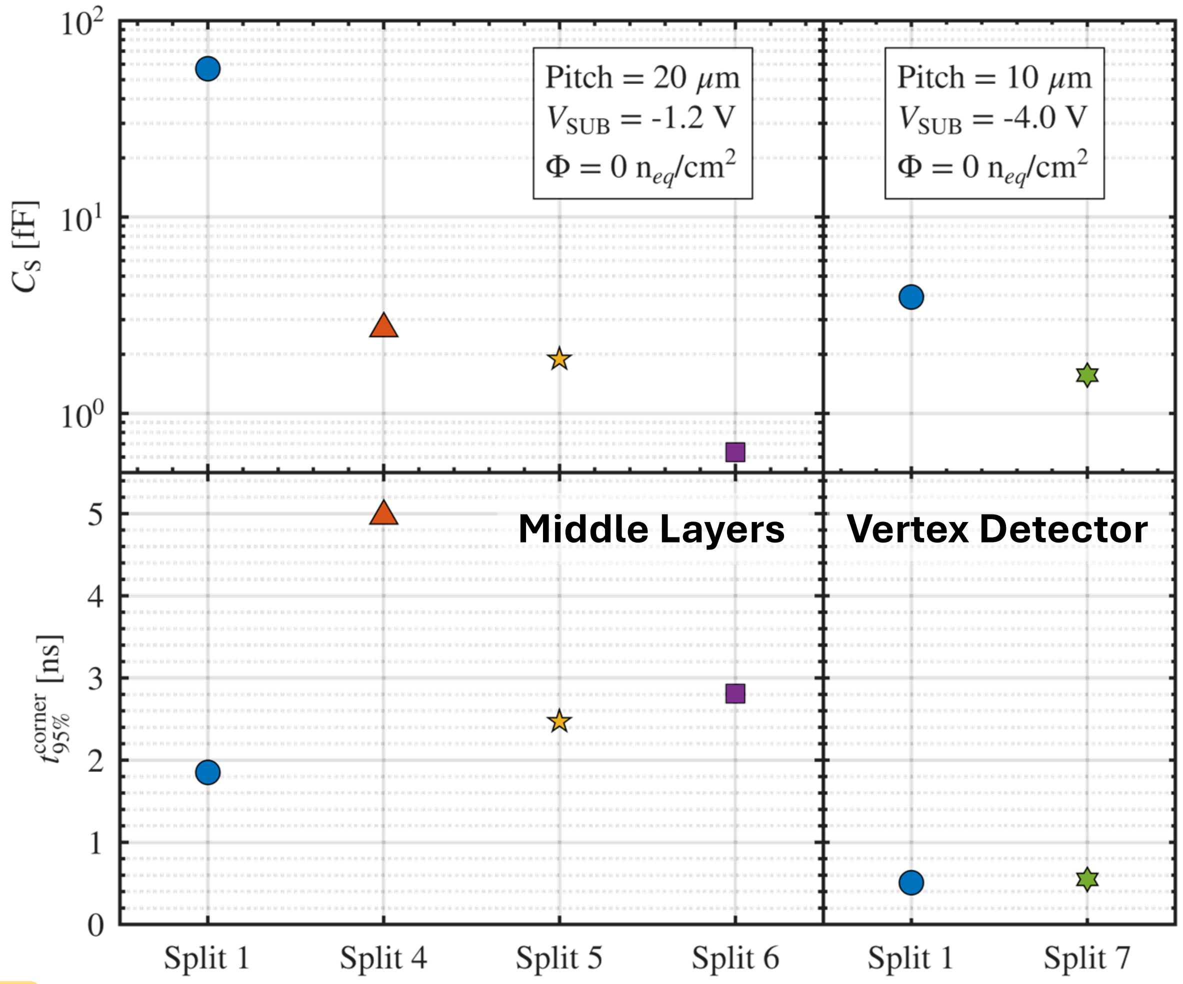
- **Vertex Detector:**
  - Split 7:   -4.0 V bias and 10 µm pitch
  - Optimised for faster charge collection time ($t^{corner}_{95\%}$) to improve radiation hardness

- Analog Pixel Test Structures (APTS) of various splits produced during ITS3 Engineering Run 2 (ER2)

U. Savino, 02.09 | Link



C. Lemoine et al., JINST 19 (2024) 02, C02033
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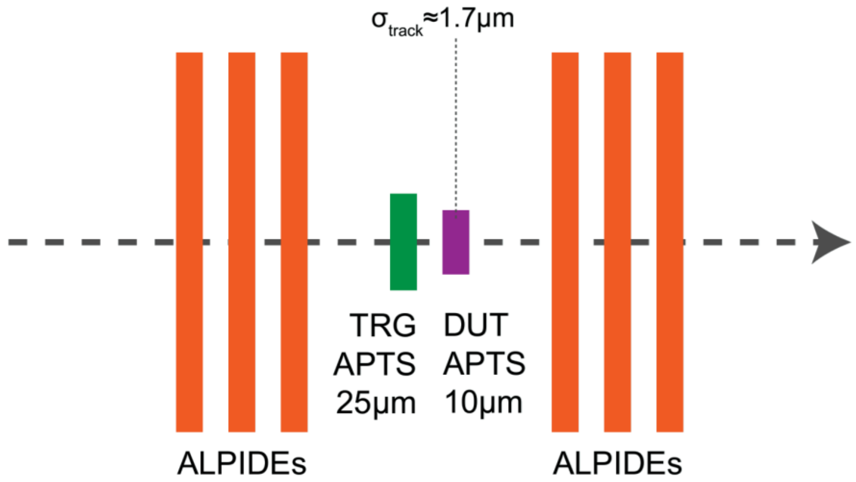
Characterisation Of Sensor Prototypes

- Cold DUT setup with ALPIDE telescope to test irradiated APTS chips as function of temperature in lab and in beam
- Analysis ongoing for > 30 APTS variants (pitch, split, layout)



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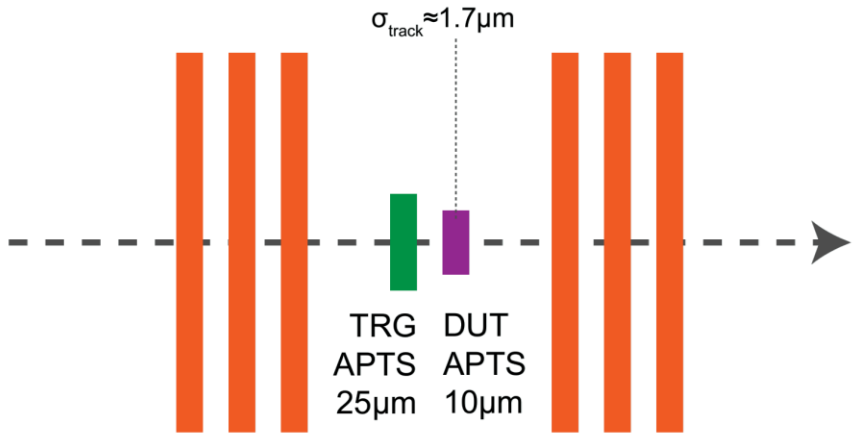
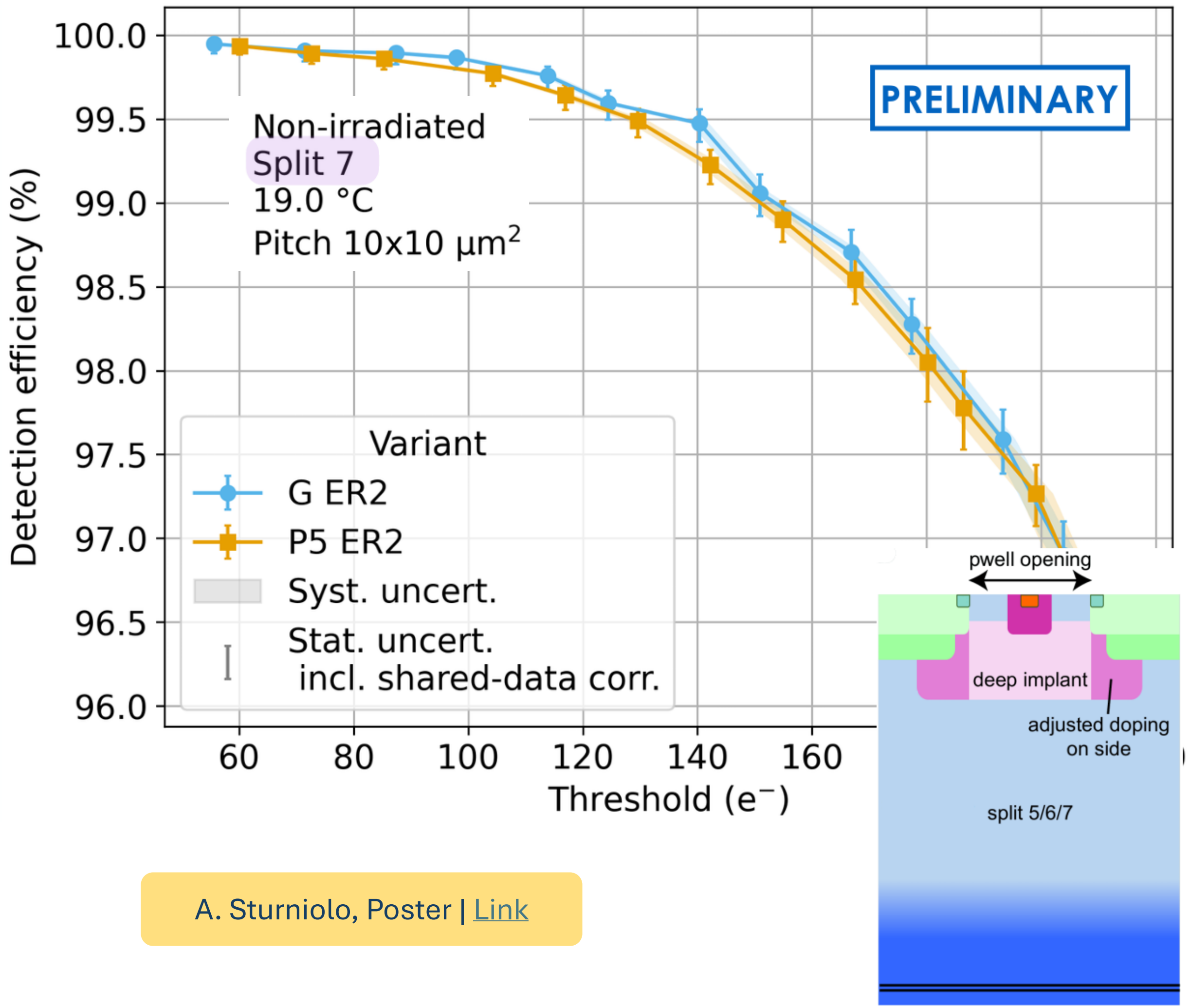
- Analysis ongoing for > 30 APTS variants (pitch, split, layout)
- **Freeing space for FE design in 10 µm pixel pitch**

  Variant with **smaller opening (P5)** around the electrode exhibits comparable performance to the **default (G)**



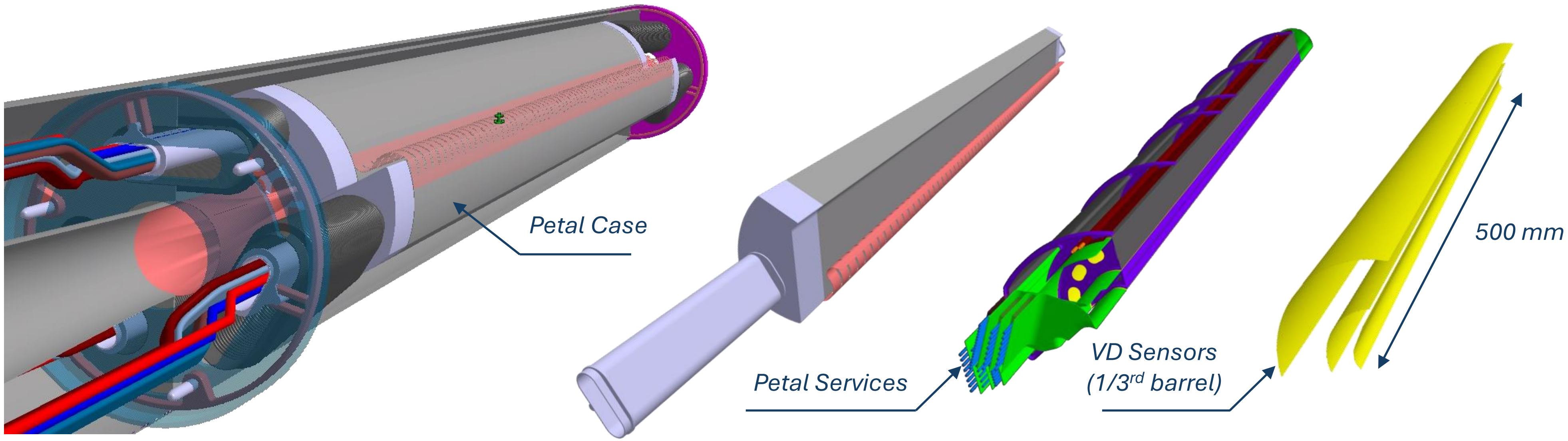


A. Sturniolo, Poster | Link

MODULES AND MECHANICS R&D

Vertex Detector

- Wafer-scale, curved MAPS barrel layers inside beampipe
- Detection layers enclosed in beryllium case “petals”



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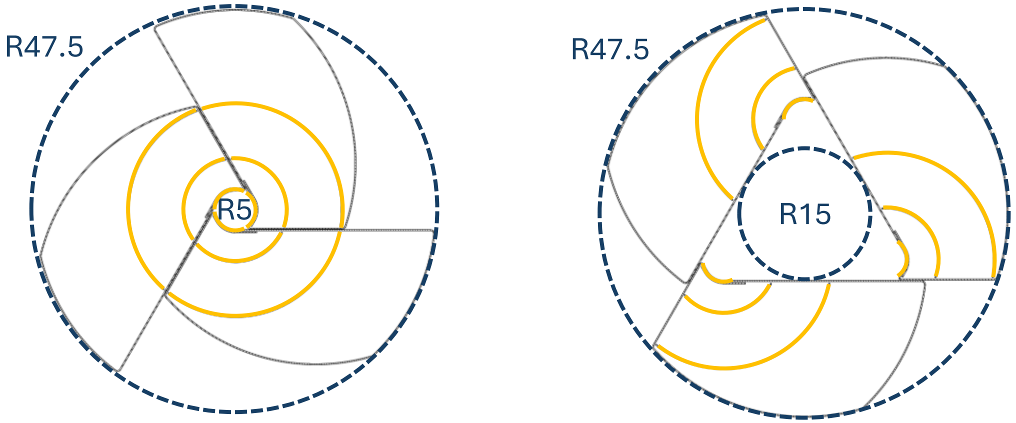
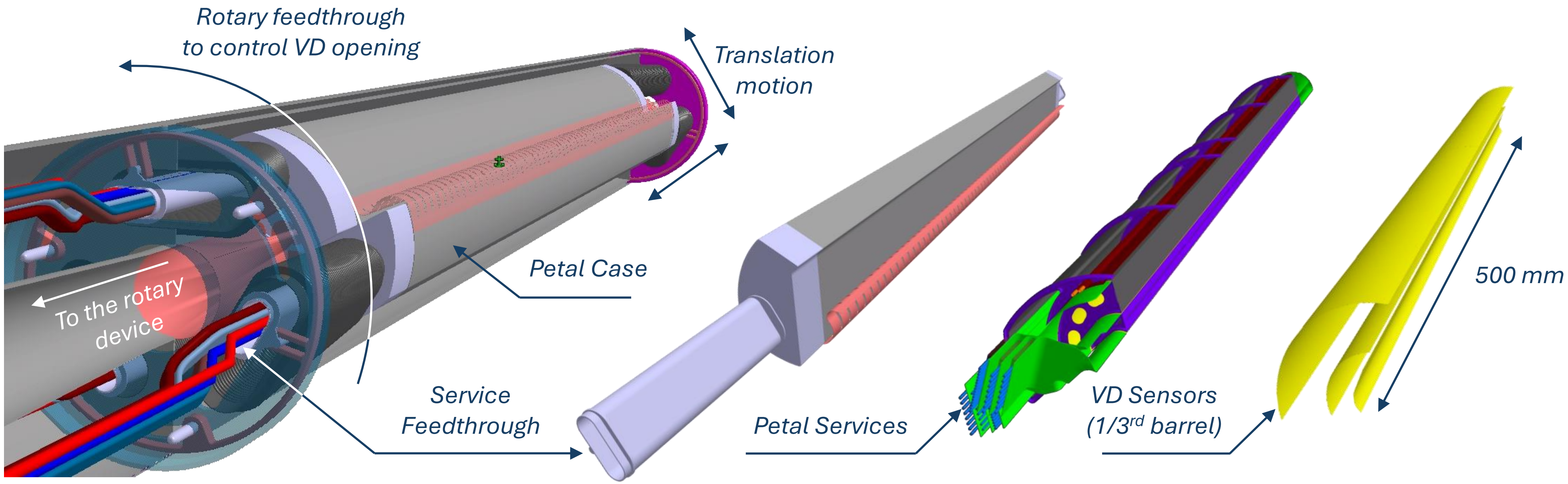


At top beam energy (r_0 ≈ 5 mm) ***At beam injection energy (r_0 ≈ 15 mm)***



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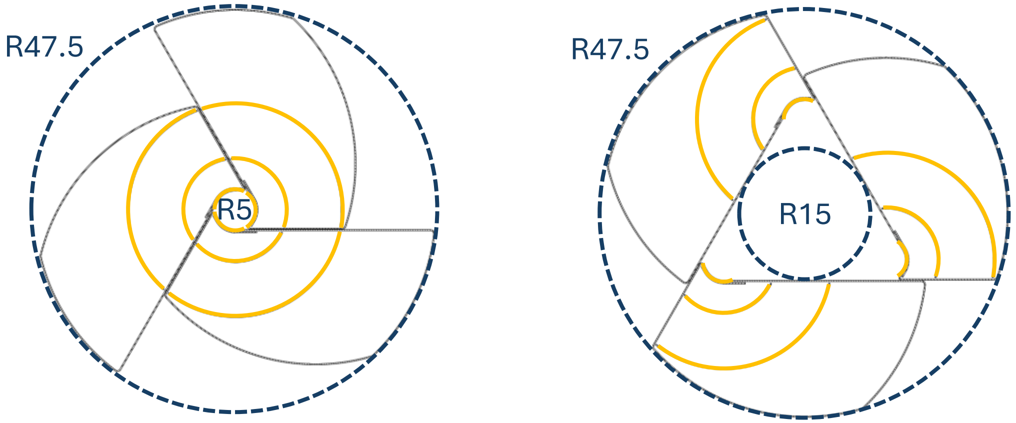
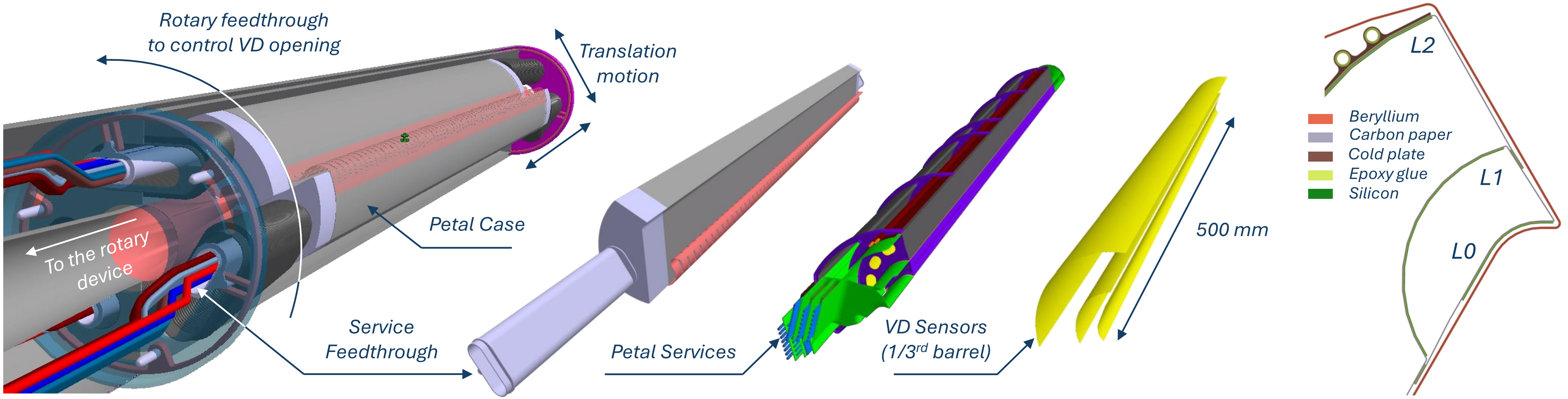
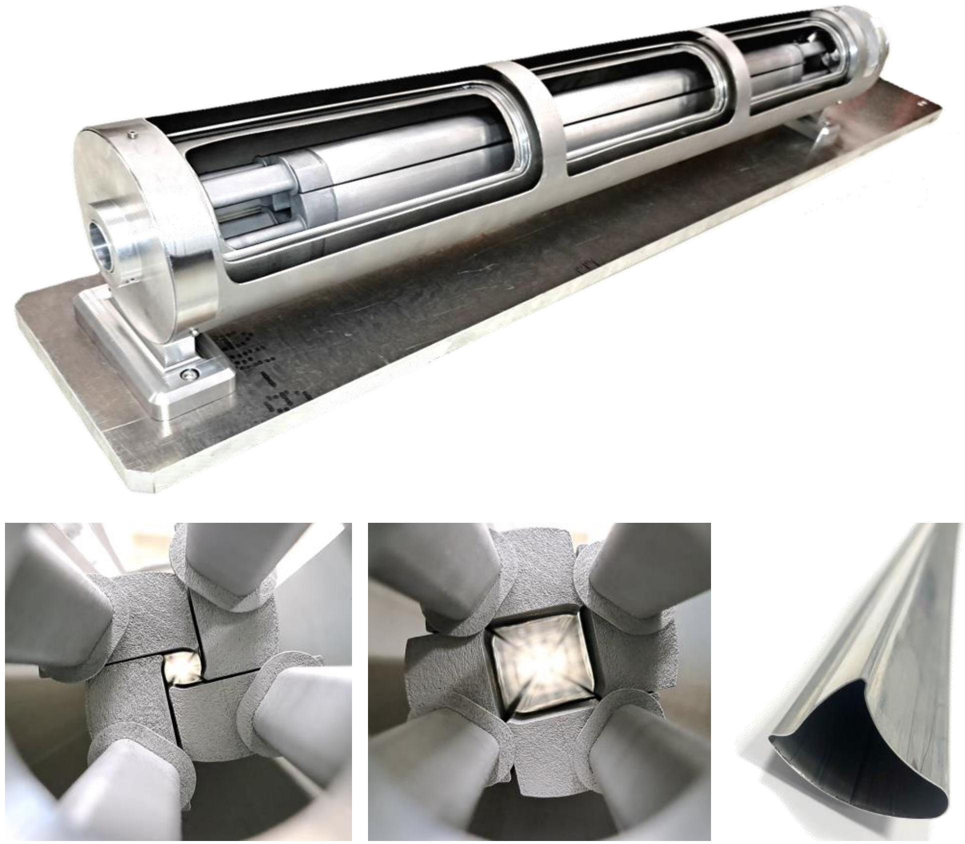
- Carbon cold plate with bi-phase CO_2 to remove sensor and beam-induced power dissipation



At top beam energy ($r_0 \approx$ 5 mm) *At beam injection energy ($r_0 \approx$ 15 mm)*



VERTEX DETECTOR : PROTOTYPING



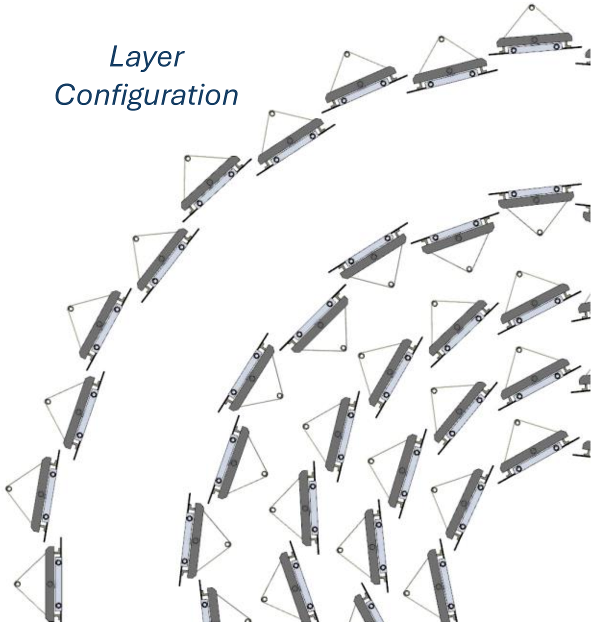
Full Engineering Model #1
(4 aluminium petals, 0.3 mm thick)

Ultra-High Vacuum Test Setup
(4.0 $\times 10^{-10}$ Torr $\approx$ 5.33 $\times$ 10^{-10} mbar)

Carbon cold plate with polyimide tubes
(burst pressure 150 bar)

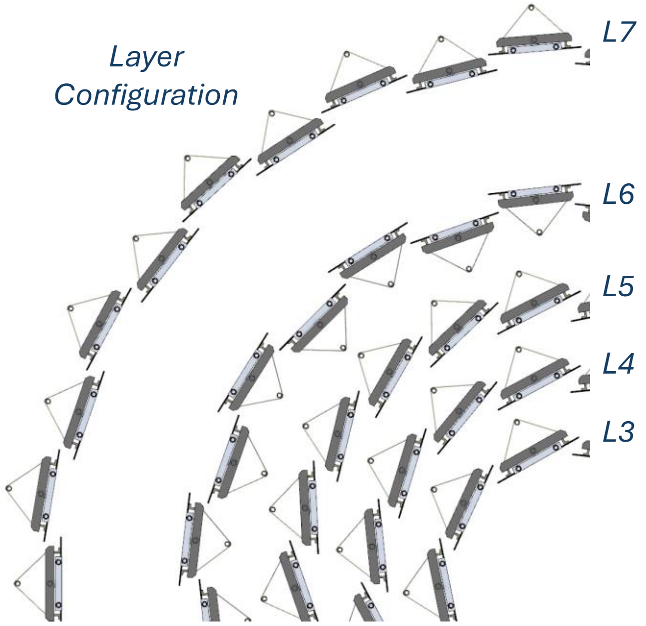
Middle Layers

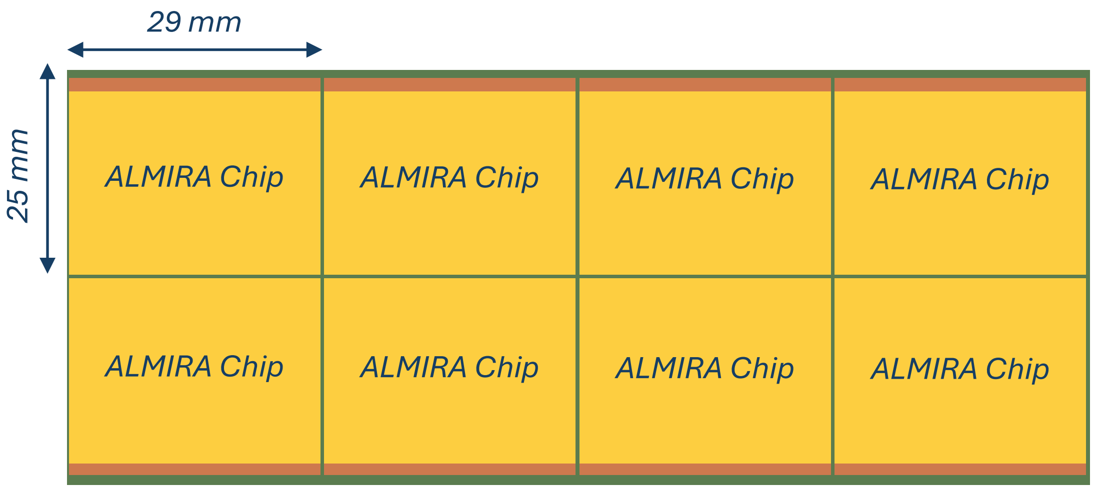
- **Reticle-sized MAPS** to cover ≈ 6 m^2 over 5 layers outside the beampipe



MIDDLE LAYERS

- **Reticle-sized MAPS** to cover ≈ 6 m^2 over 5 layers outside the beampipe
- **Evaluation ongoing to establish baseline module design**
  - Interconnection and FPC technologies
  - Powering concepts beyond parallel powering (DC-DC conversion, serial powering)
  - On- and off-module data aggregation scheme
  - R&D in synergy with ALICE 3 Outer Tracker module production (≈ 50 m^2)





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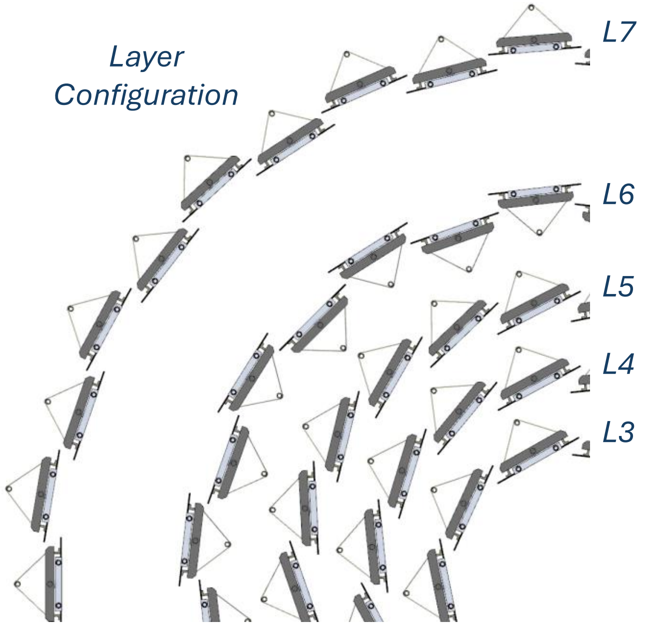
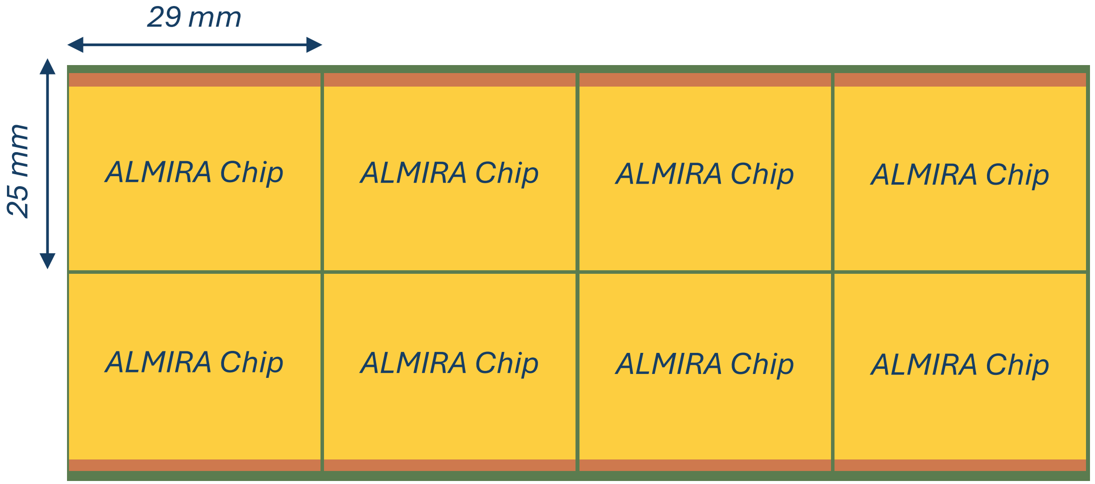
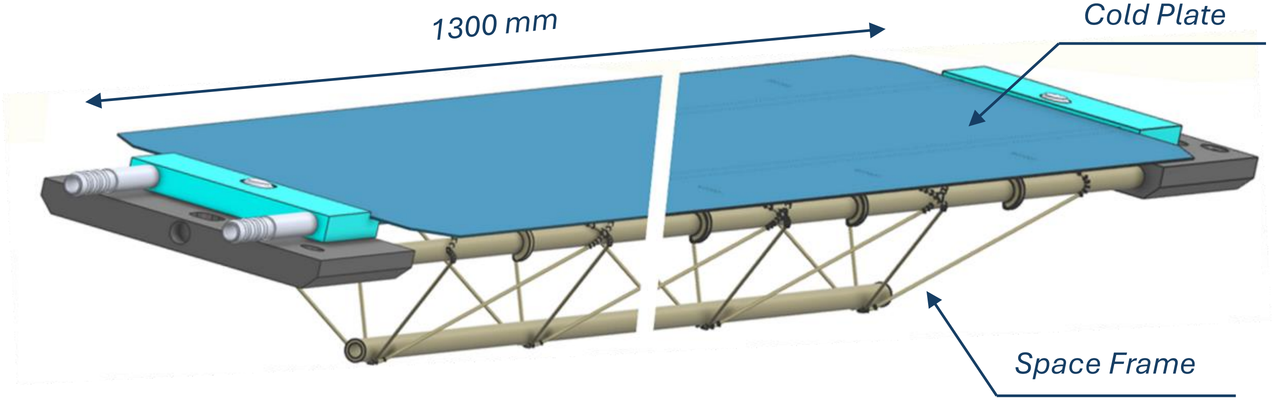
  - On- and off-module data aggregation scheme
  - R&D in synergy with ALICE 3 Outer Tracker module production (≈ 50 m^2)
- **Studying stave design inspired by existing solutions** (ALICE ITS2, CBM STS)







Summary And Outlook

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- Improve radiation hardness and rate capabilities
- Achieve smaller pixel pitches and spatial resolution
- Retractable mechanics and operation in beam pipe
- Reduce power consumption
- Industrial and automatised module assembly methods

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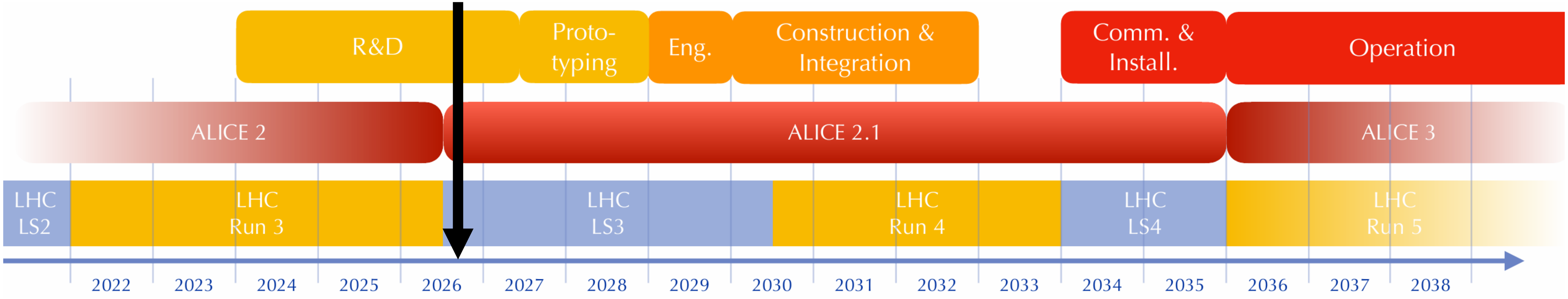
Extensive R&D underway towards the Technical Design Report (TDR) phase

- Common sensor development for all silicon layers
- Baseline concepts established for mechanics and cooling
- Prototyping and testing ongoing, with concurrent transition to more realistic and larger objects
- Physics simulations with detailed modelling of sensor response and detector geometry



THANK YOU

EXTRA SLIDES

ALICE 3 Physics Programme

[Letter of Intent for ALICE 3:](#) CERN-LHCC-2022-009
[Scoping Document:](#) CERN-LHCC-2025-002

ALICE

Access to temperature as function of time

- di-electron mass spectra, p_T dependence, elliptic flow

Understanding thermalisation in the QGP

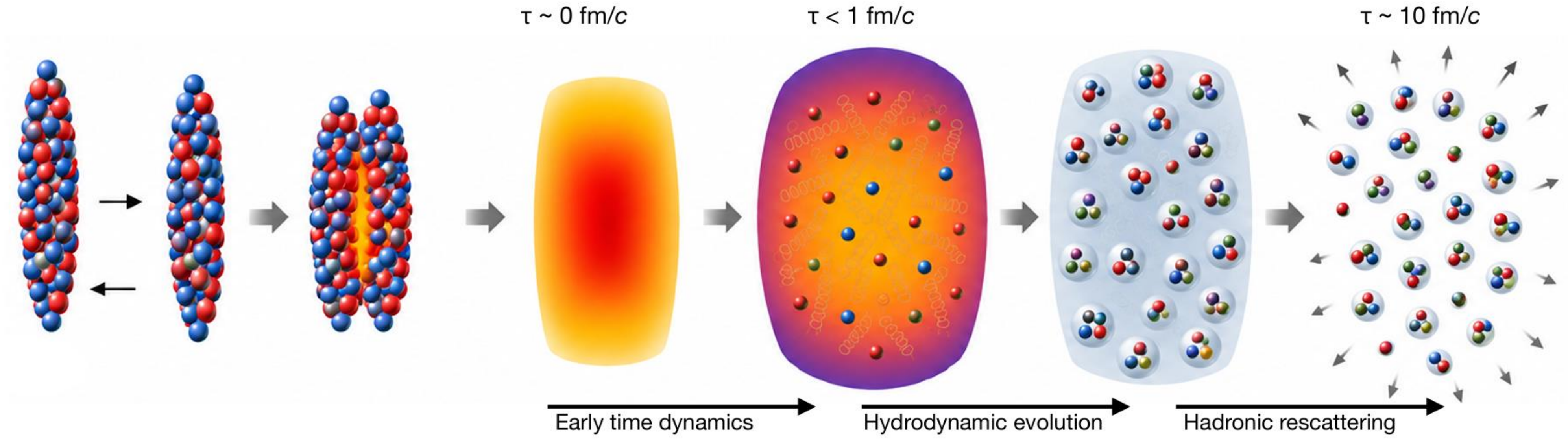
- charm diffusion: D-Dbar azimuthal correlations
- beauty thermalisation: high-precision beauty measurements
- approach to chemical equilibrium: multi-charm hadrons

Fundamental aspects of the QCD phase transition

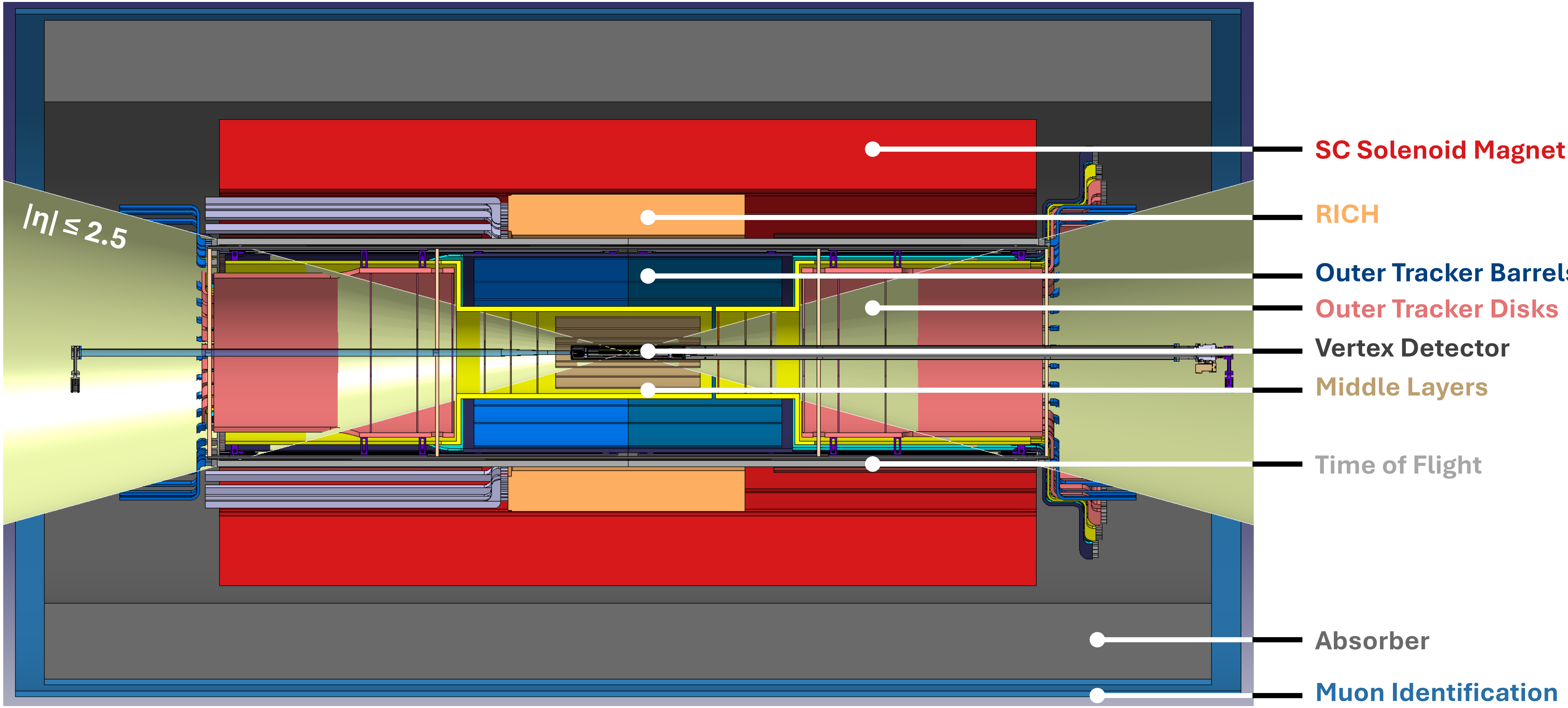
- net-baryon and net-charm fluctuations
- chiral symmetry restoration in QGP: di-electron mass spectra

Laboratory for hadron physics

- hadron-hadron interaction potentials
- explore nature of exotic hadrons (tetraquarks)

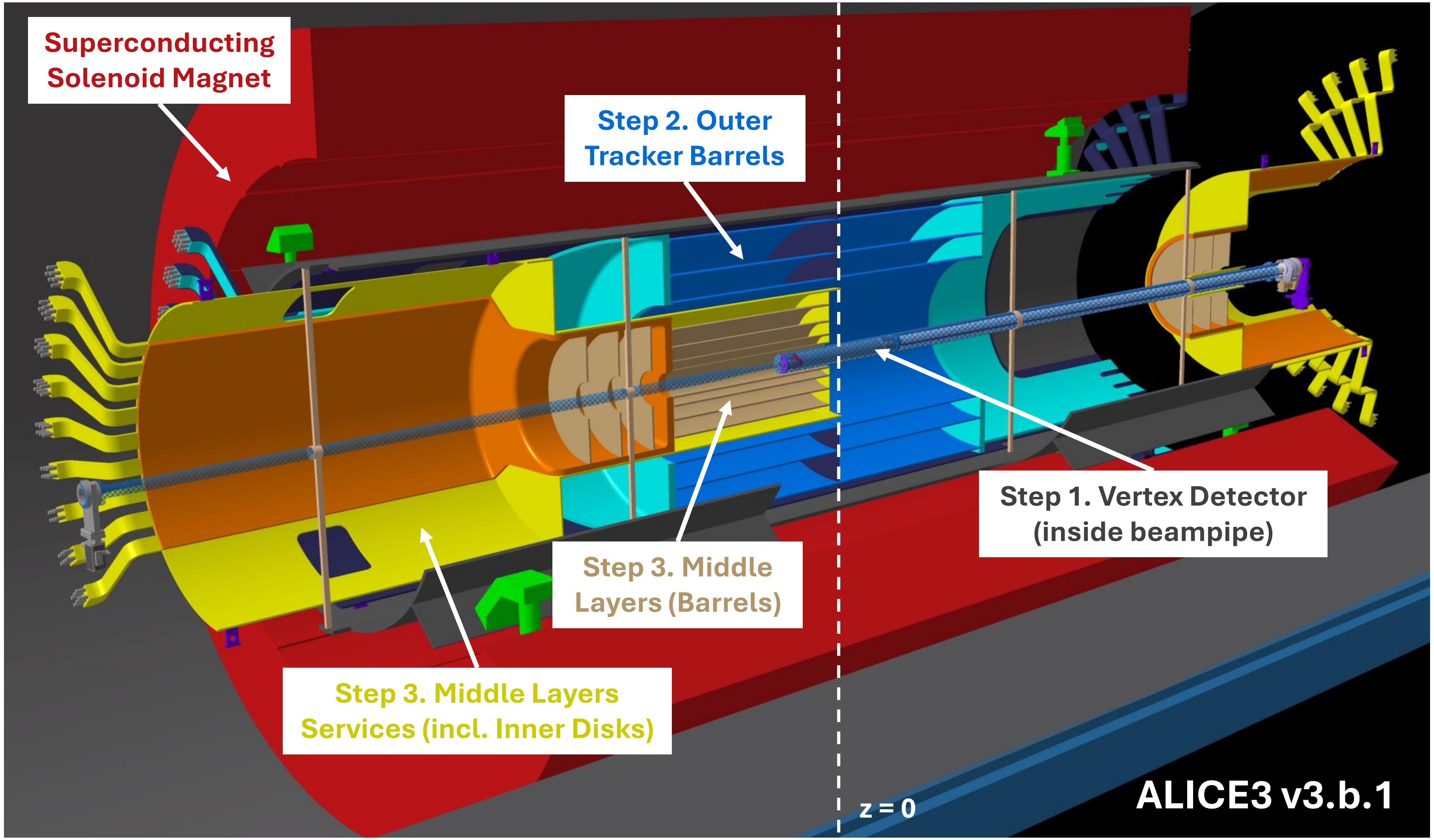


ALICE 3 v3.B.1

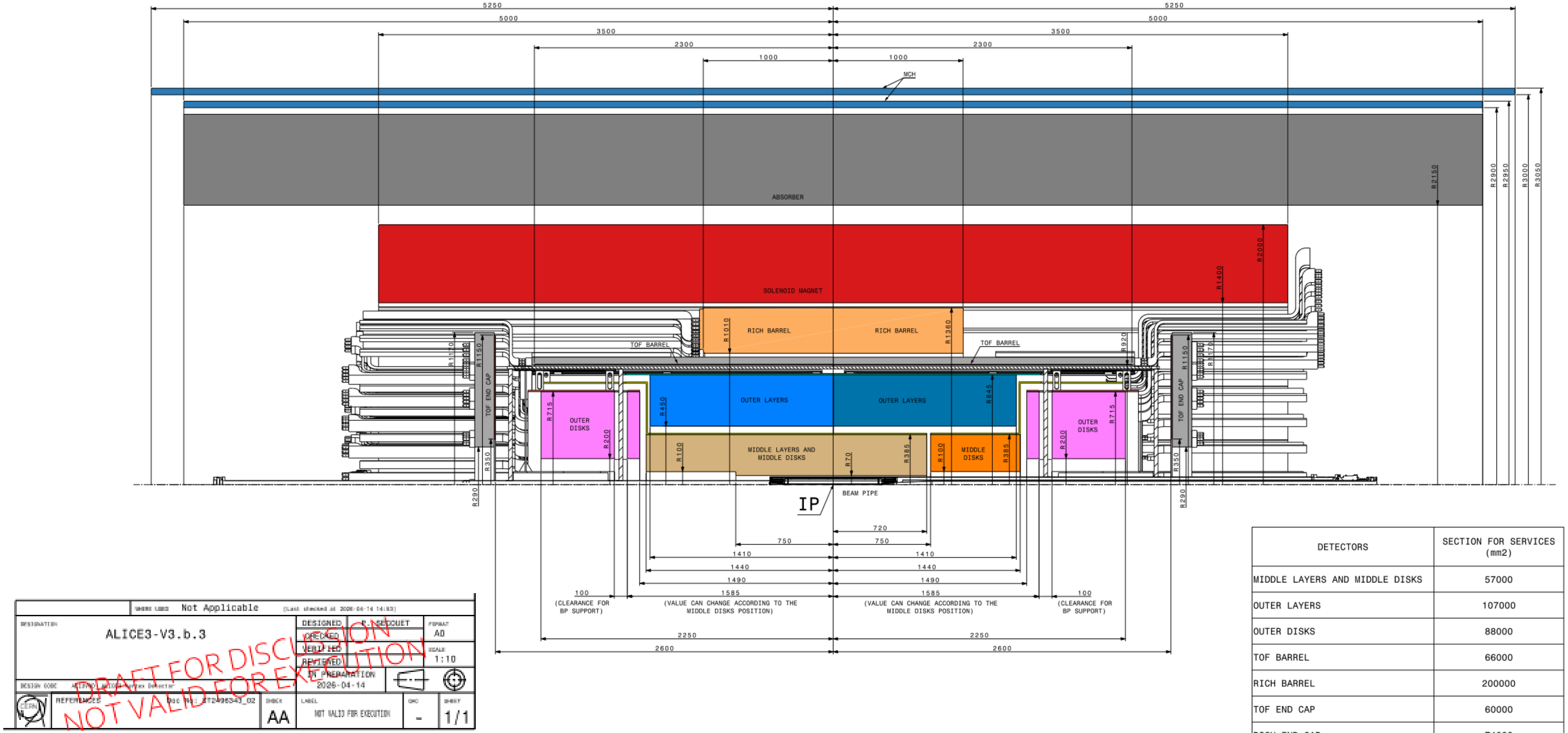


|η| ≤ 2.5
SC Solenoid Magnet
RICH
Outer Tracker Barrels
Outer Tracker Disks
Vertex Detector
Middle Layers
Time of Flight
Absorber
Muon Identification

SILICON TRACKER : INSERTION SEQUENCE



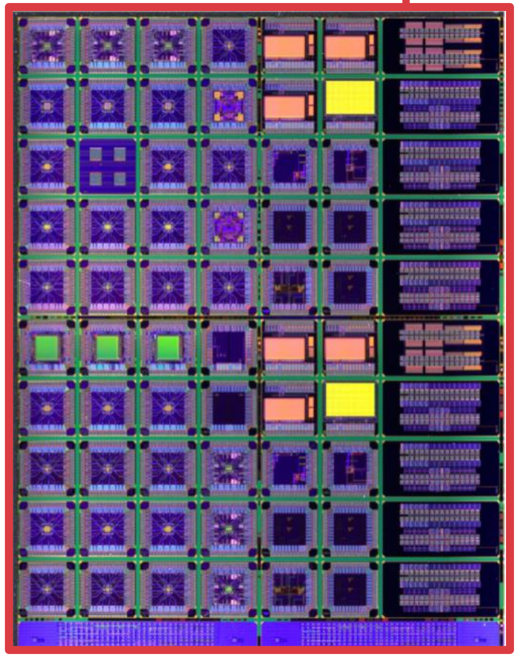
INTERFACE CONTROL DRAWING : SERVICES

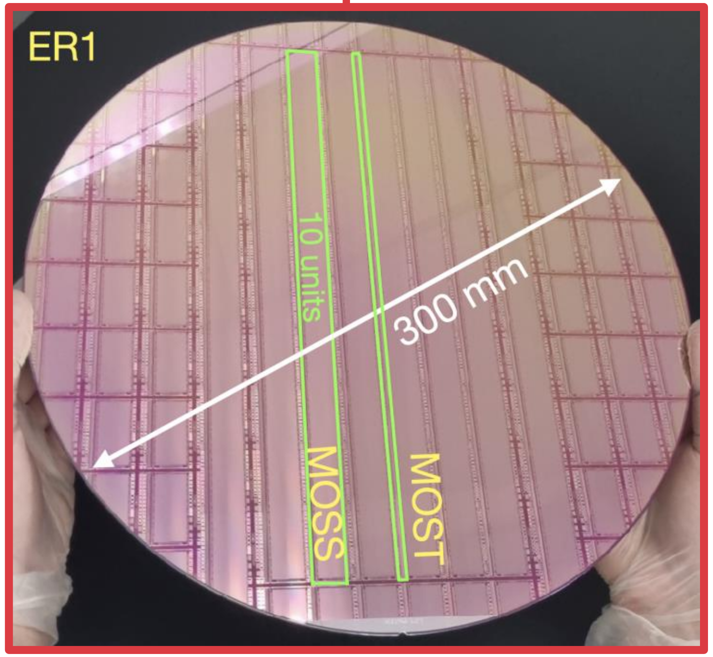


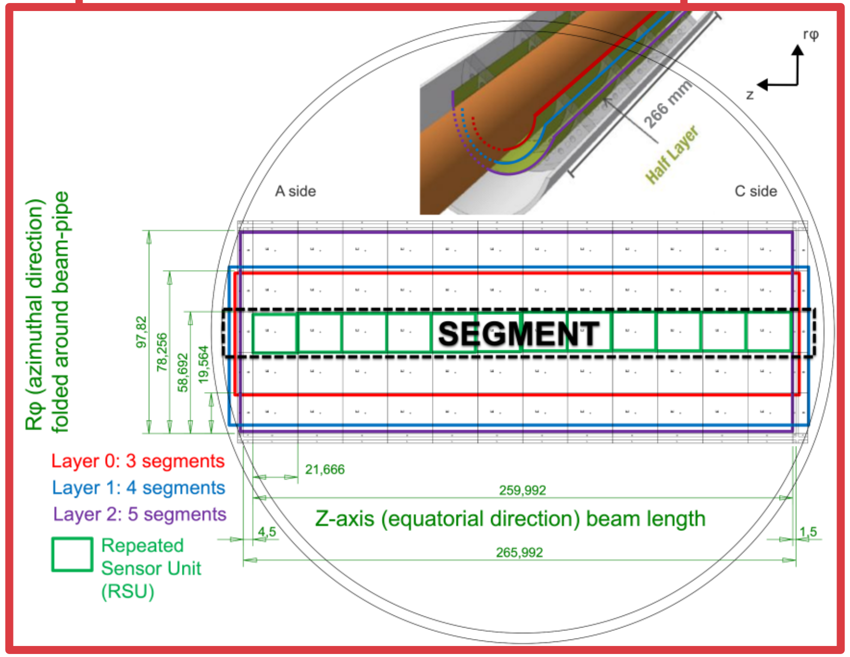
DETECTORS	SECTION FOR SERVICES (mm2)
MIDDLE LAYERS AND MIDDLE DISKS	57000
OUTER LAYERS	107000
OUTER DISKS	88000
TOF BARREL	66000
RICH BARREL	200000
TOF END CAP	60000
RICH END CAP	74000

ITS3 Sensor Development Roadmap

Multi Layer Reticle 1 MLR1 – 2021	Engineering Run 1 ER1 – 2023	Engineering Run 2 ER2 – 2025	Engineering Run 3 ER3 – 2027
65 nm MAPS Qualification	Stitched MAPS (MOSS, MOST)	Full scale ITS3 prot. (MOSAIX)	ITS3 Final Sensor Production







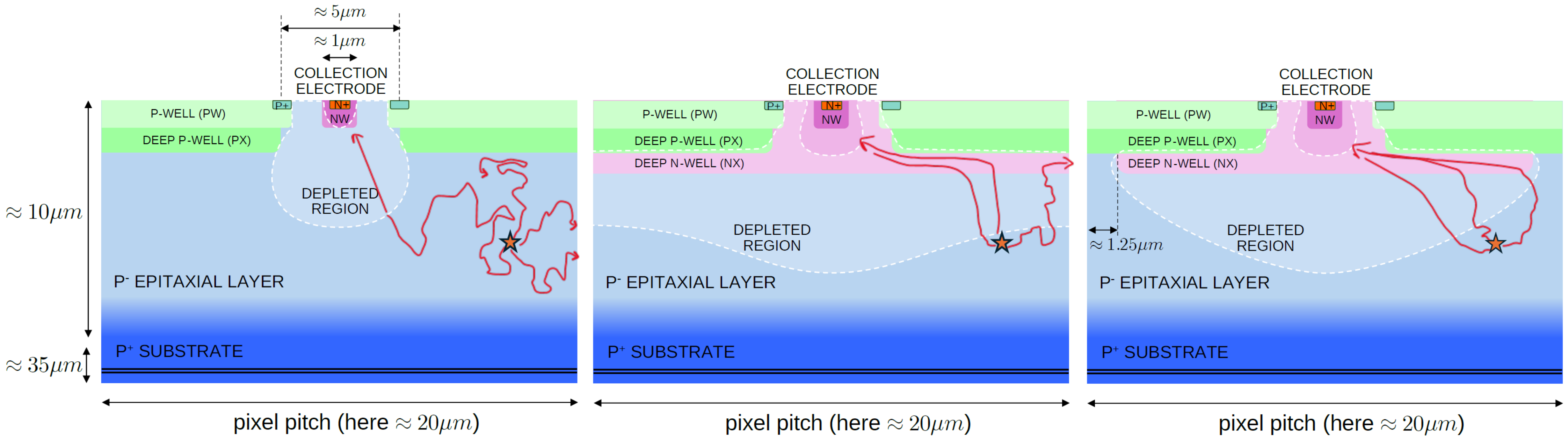
DPTS: *Nucl.Instrum.Meth.A 1056 (2023) 168589*
Nucl.Instrum.Meth.A 1083 (2026) 171082
APTS-SF: *Nucl.Instrum.Meth.A 1069 (2024) 169896*
APTS-OA: *Nucl.Instrum.Meth.A 1070 (2025) 170034*

MOSS: *e-Print: 2510.11463 [physics.ins-det]*

ITS3 Technical Design Report, CERN-LHCC-2024-003 | Link

Sensor Flavour Evolution (MLR1)

Nucl.Instrum.Meth.A 871 (2017) 90-96
Nucl.Instrum.Meth.A 1056 (2023) 168589
Nucl.Instrum.Meth.A 1069 (2024) 169896



Standard | **Modified** | **Modified with Gap**

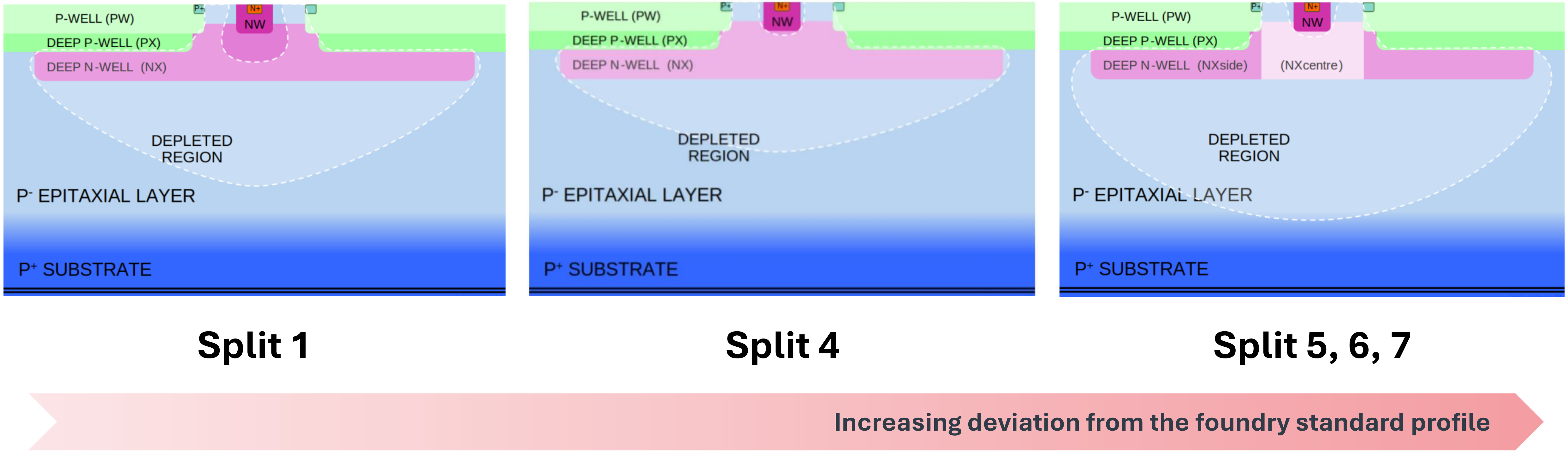
Higher cluster size and spatial resolution

Higher seed signal, efficiency and radiation tolerance

Illustrations from: Corentin Lemoine, PhD Thesis, Uni. Strasbourg (2025)

Process Split Evolution

C. Lemoine et al., JINST 19 (2024) 02, C02033
G. Borghello et al., JINST 20 (2025) 07, C07053



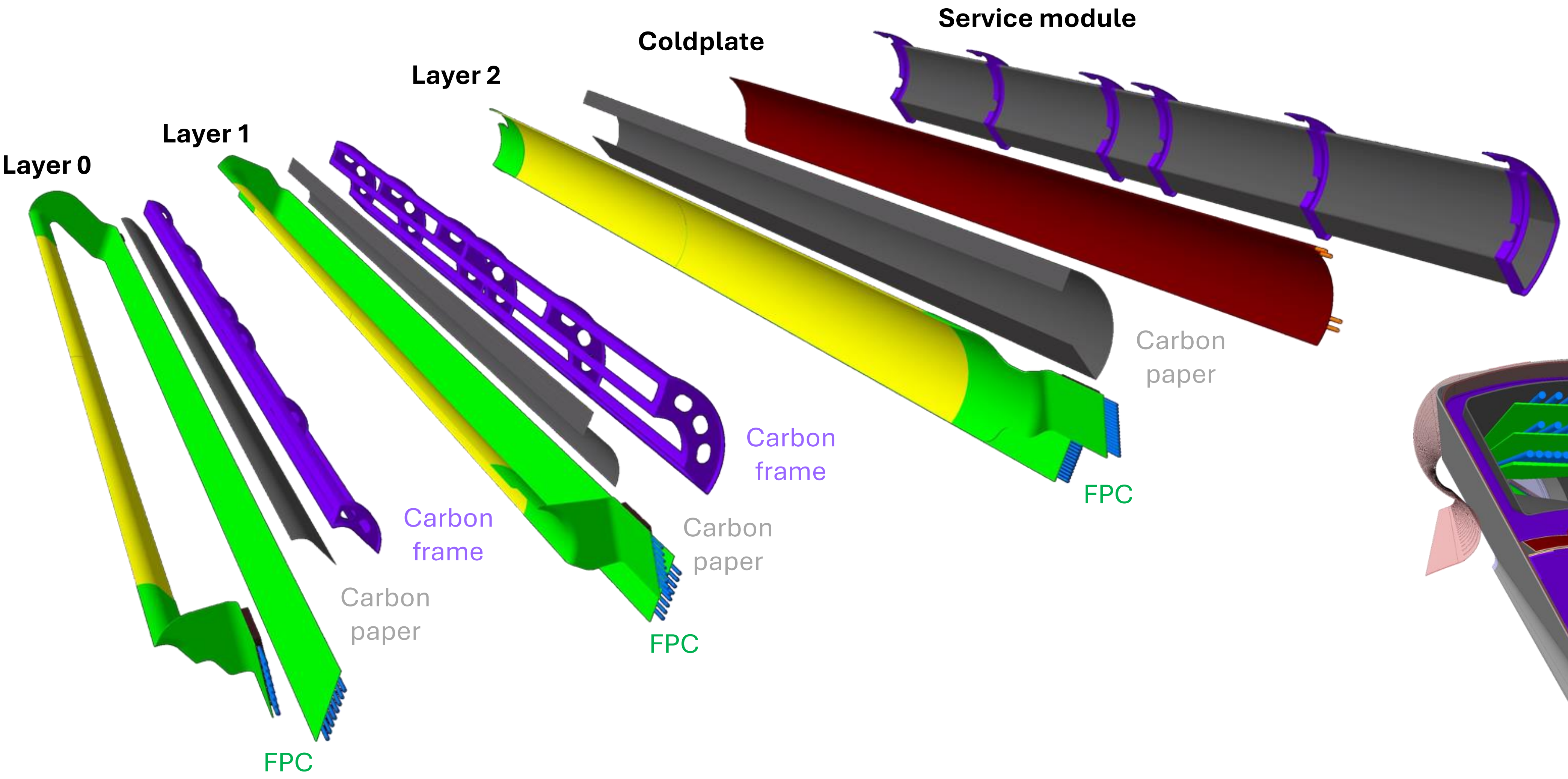
Split 1: Foundry standard profiles

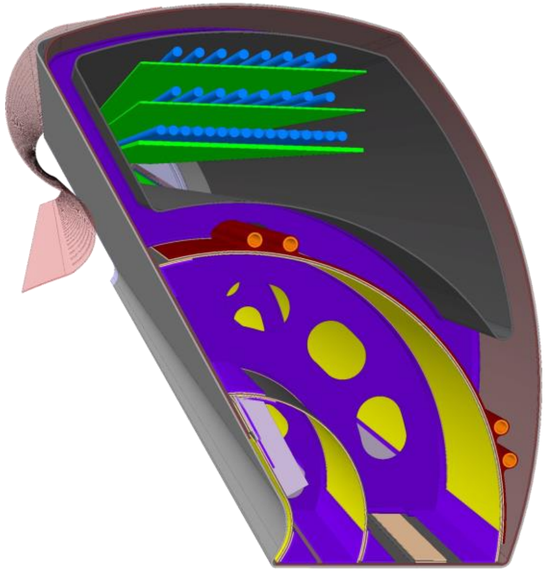
Split 4: Reduced doping in n-type implant (NX)
Reduces sensor capacitance
Increases radiation sensitivity

Split 5, 6: NXside to increase charge collection
NXcentre to reduce sensor capacitance

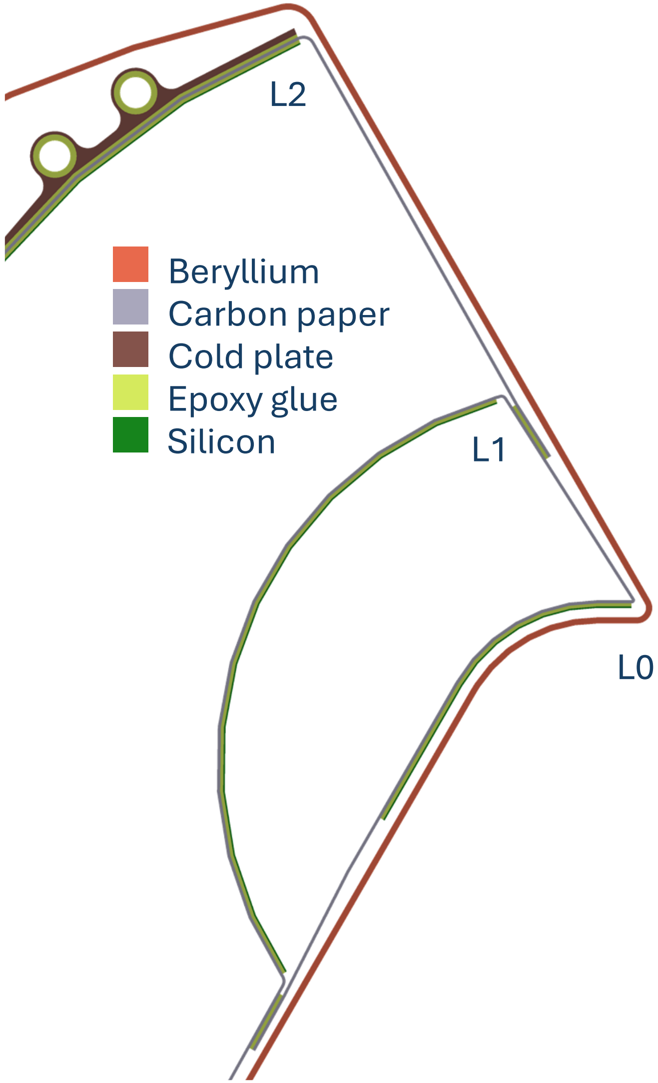
Split 7: Similar to process split 5, 6 but for 10 μm
Higher doping for smaller NXside

VERTEX DETECTOR : PETAL COMPONENTS

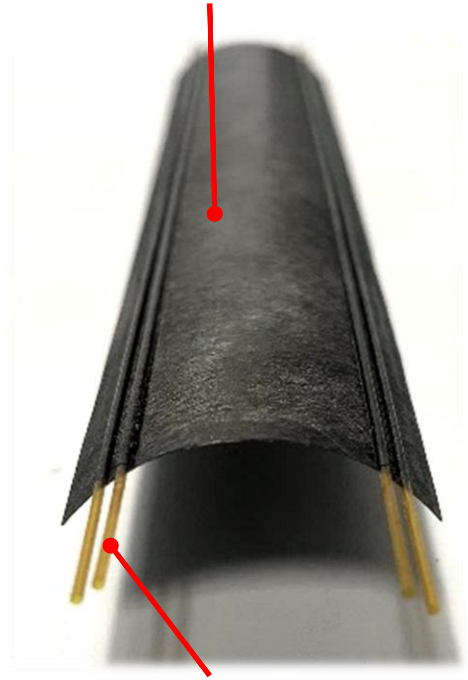




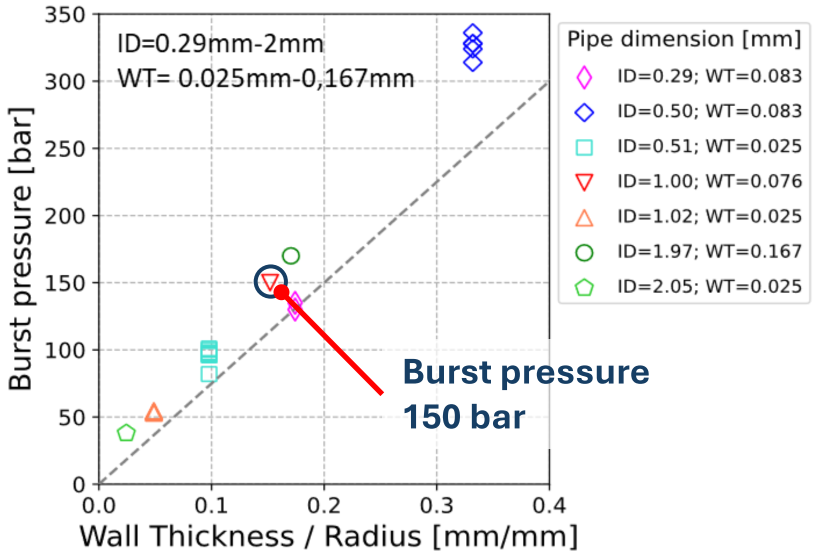
VERTEX DETECTOR : THERMAL MANAGEMENT

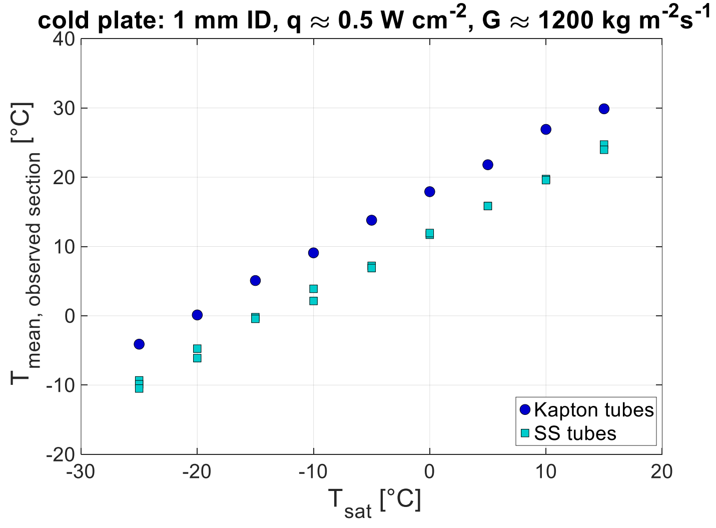


Carbon laminate
K13D2U UD prepreg,
graphite foil, carbon veil.
Thickness < 0.2mm
Inner radius = 25.1 mm



Polyimide pipe
Inner diameter = 1.024 mm
Wall thickness = 0.076mm





VERTEX DETECTOR : ALIGNMENT STRATEGY

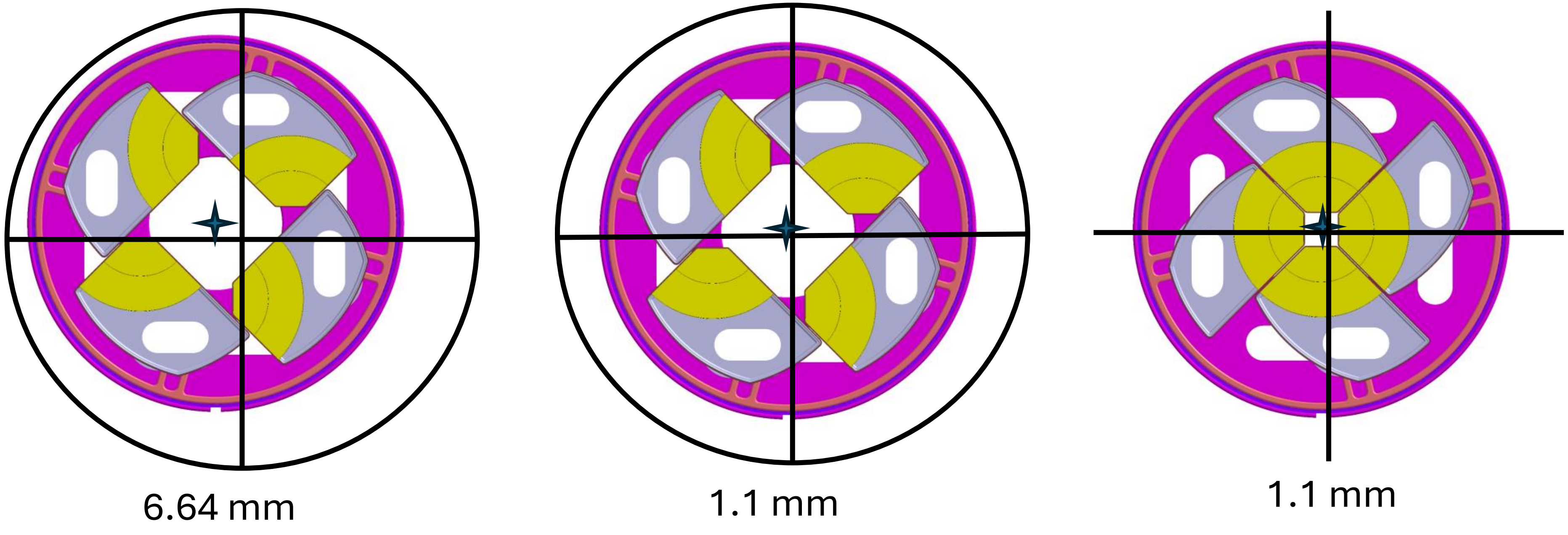
FIRST CLOSURE AFTER INSTALLATION

- Install the Vertex Detector in open position,
- Keep it open (can be off by 6.64 mm)
- Move beampipe by reconstructed vertex (1.10 mm)
- Close and align (1.10 mm)

NEXT CLOSURES

- No need to realign (move) VD
- Only need to identify VD w.r.t. beam.

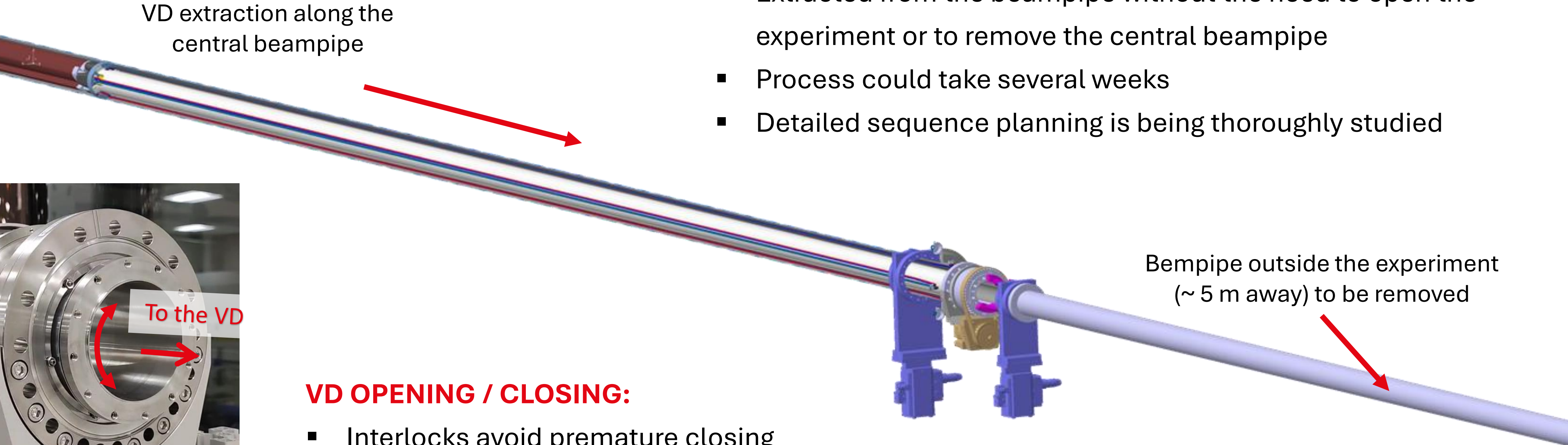
Beam movement normal to beam line is of low magnitude between injections



VERTEX DETECTOR : SAFETY ISSUES

IN CASE FULL VD SHOULD BE EXTRACTED:

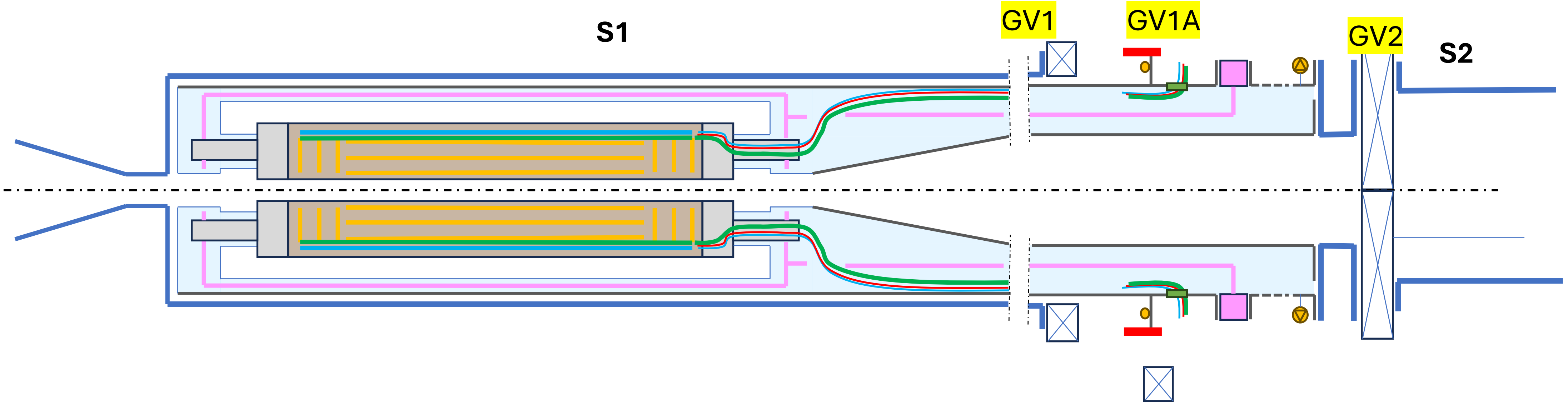
- Requires vacuum opening
- Extracted from the beampipe without the need to open the experiment or to remove the central beampipe
- Process could take several weeks
- Detailed sequence planning is being thoroughly studied

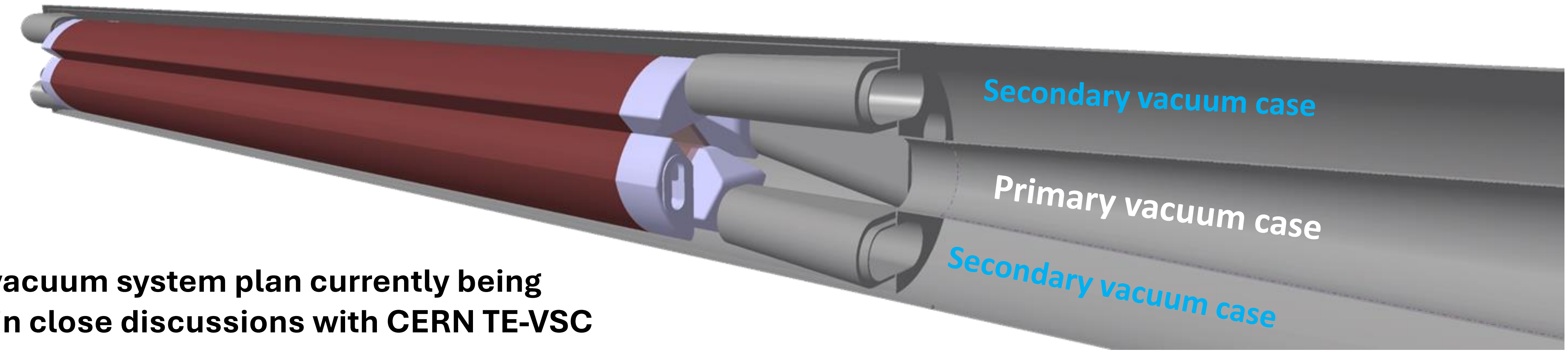


VD OPENING / CLOSING:

- Interlocks avoid premature closing
- Only to be closed as soon as Stable Beams are declared
- Long-term cycling of the motion system under test
- Manual operation will be integrated in the design

VERTEX DETECTOR : VACUUM ENVELOPE





ALICE3 vacuum system plan currently being defined in close discussions with CERN TE-VSC