Status on the ALICE 3 Inner Tracker in China

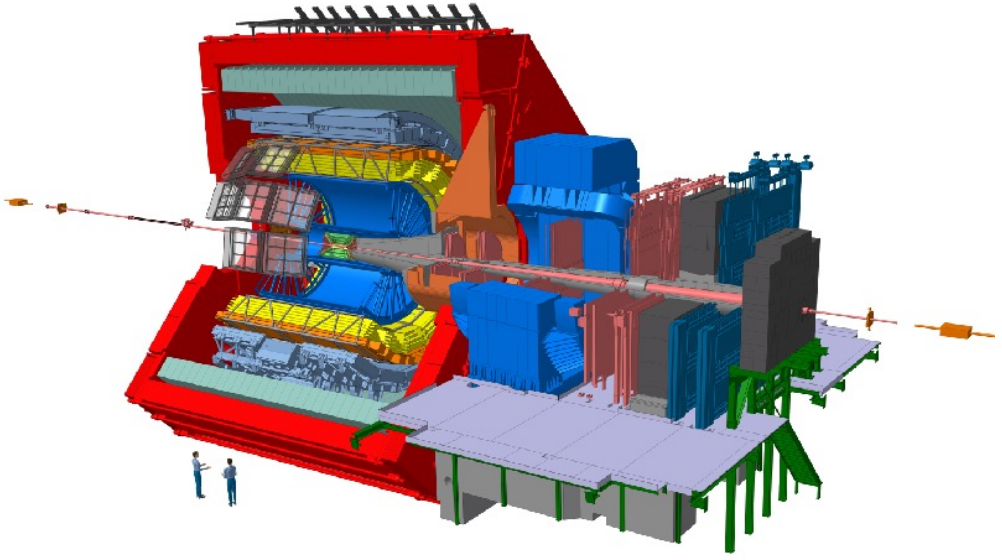
Yaping Wang

Central China Normal University (CCNU)

Outline

- ALICE Upgrade Overview
- ALICE 3 Experiment (*ref.: Jesper Karlsson Gumprecht, SQM2026*)
- ALICE 3 Inner Tracker (*ref.: Jochen Klein, INSTR2026*)
- Status of ALICE 3 Inner Tracker in China (*ref.: YPW, ALICE 3 IT Plenaries*)
- Summary and Outlook

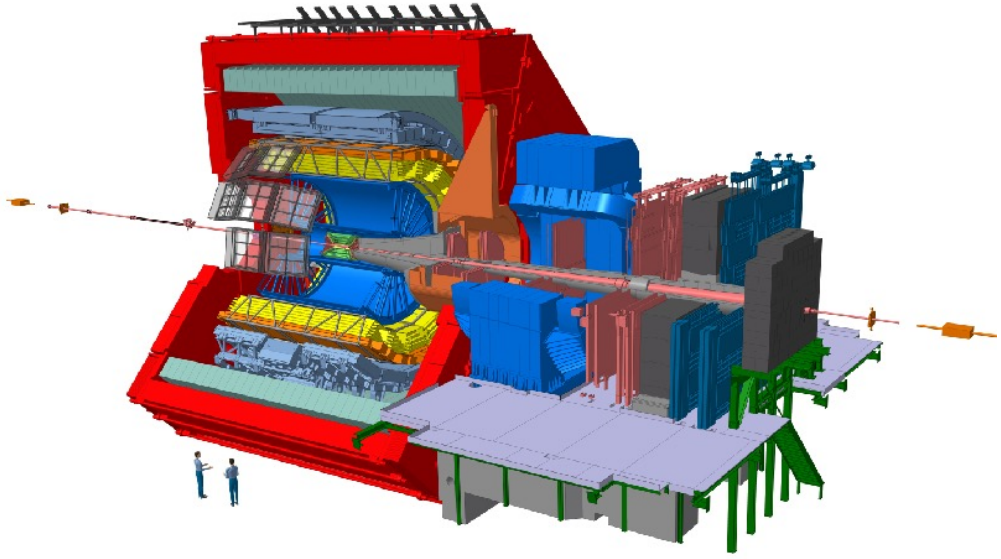
ALICE Upgrade Overview

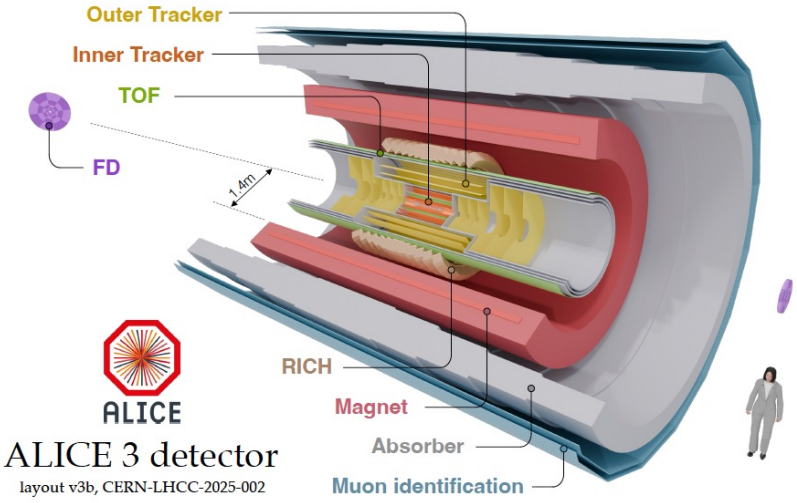


High luminosity for ions | HL-LHC | Higher luminosities for ions

Run 1 2009 - 2013	Run 2 2015 - 2018	Run 3 2022 - 2026	Run 4 2030 - 2033	Run 5
ALICE 1		ALICE 2	ALICE 2.1 upgrade	ALICE 3 upgrade
ITS		(ITS2, MFT, TPC)	(ITS3, FoCal)	

ALICE Upgrade Overview

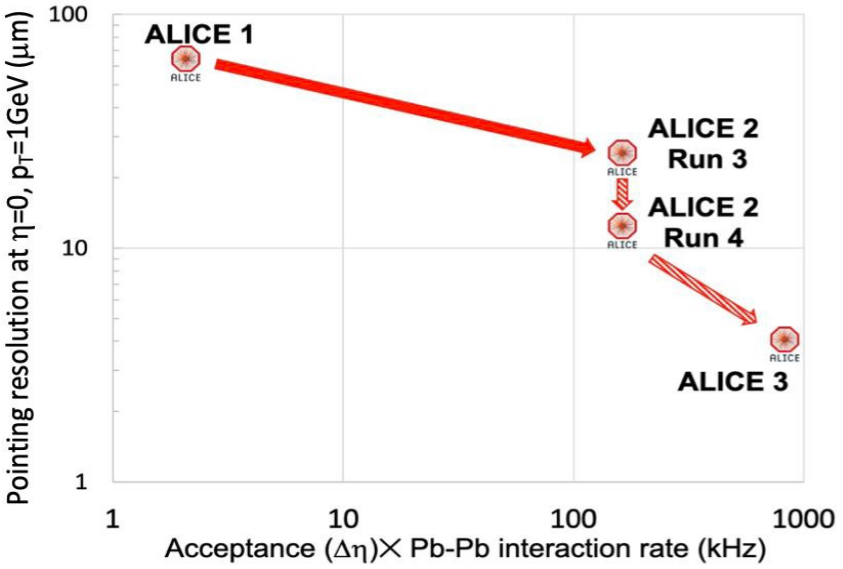


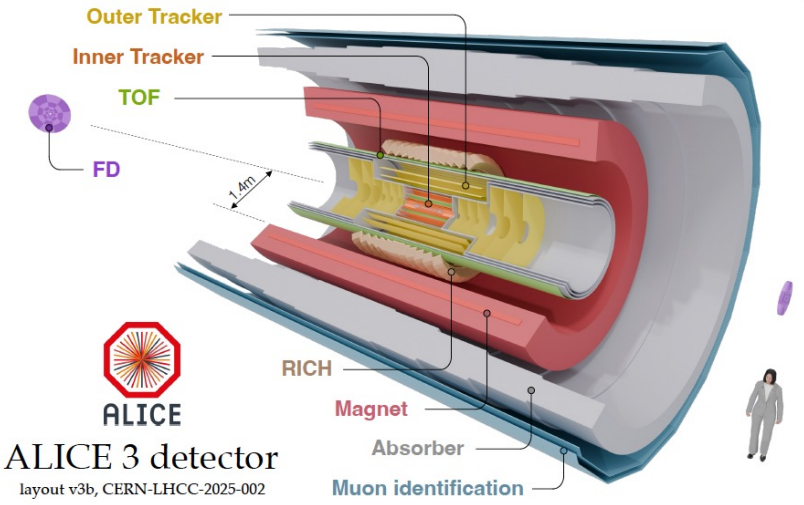


High luminosity for ions — HL-LHC — Higher luminosities for ions

Run 1 2009 - 2013	Run 2 2015 - 2018	Run 3 2022 - 2026	Run 4 2030 - 2033	Run 5
ALICE 1		ALICE 2	ALICE 2.1 upgrade	ALICE 3 upgrade
ITS		(ITS2, MFT, TPC)	(ITS3, FoCal)	

ALICE 3 Experiment – Introduction



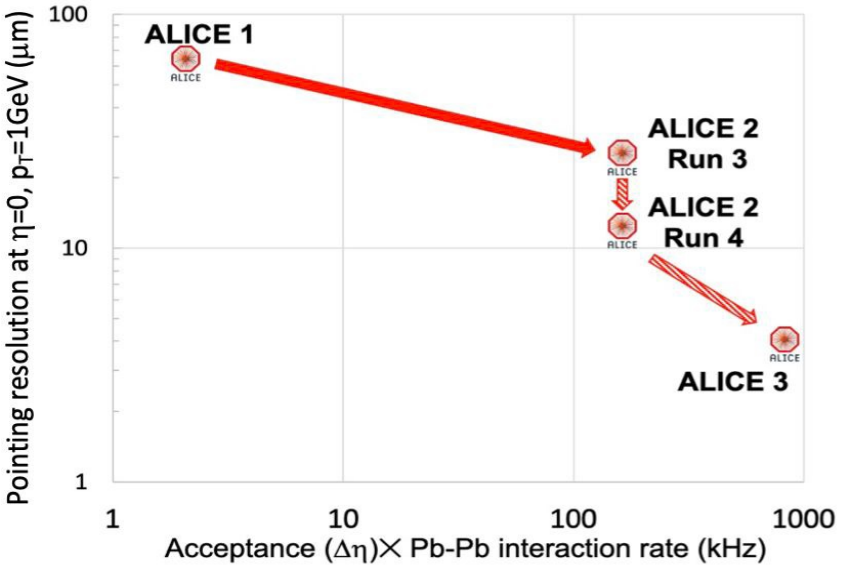


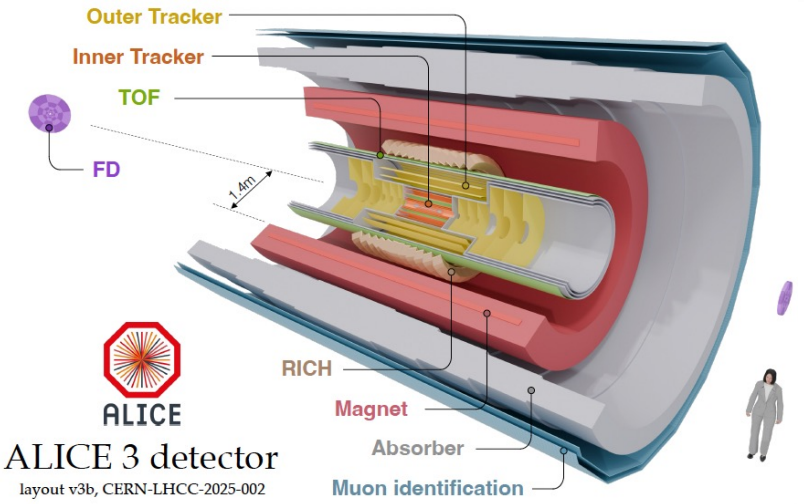
- 100 kHz Pb-Pb (dN/dη ~400)
- 24 MHz pp (dN/dη ~7)

A next-generation experiment for the LHC Run 5

- ✓ superconducting magnet system → p_T resolution
- ✓ compact, lightweight tracker → efficient down to $p_T \approx 0$
- ✓ retractable vertex detector → pointing resolution
- ✓ complementary techniques → excellent particle ID
- ✓ high rate and large acceptance → large data samples

ALICE 3 Experiment – Introduction





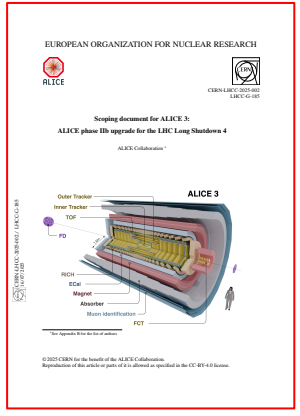
Expression of Interest (EoI), 2019



Letter of Intent (LoI), 2022



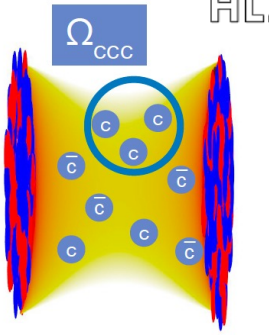
Scoping Document (SD), 2025



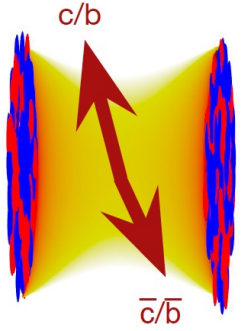
Technical Design report (TDR), 2026

ALICE 3 Experiment – Physics beyond Run 4

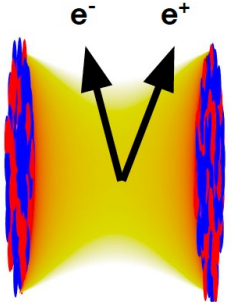
- **Systematic measurements of (multi-)heavy-flavour hadrons**
  - ✓ Propagation and hadronisation mechanisms in the QGP
  - ✓ Study heavy quark equilibrium and diffusion



- **Hadron correlations and fluctuations**
  - ✓ Hadron-hadron interaction potentials
  - ✓ Net-baryon and net-charm fluctuations



- **Precise measurements of dileptons**
  - ✓ Evolution of the quark–gluon plasma temperature
  - ✓ Mechanisms of chiral symmetry restoration in the QGP

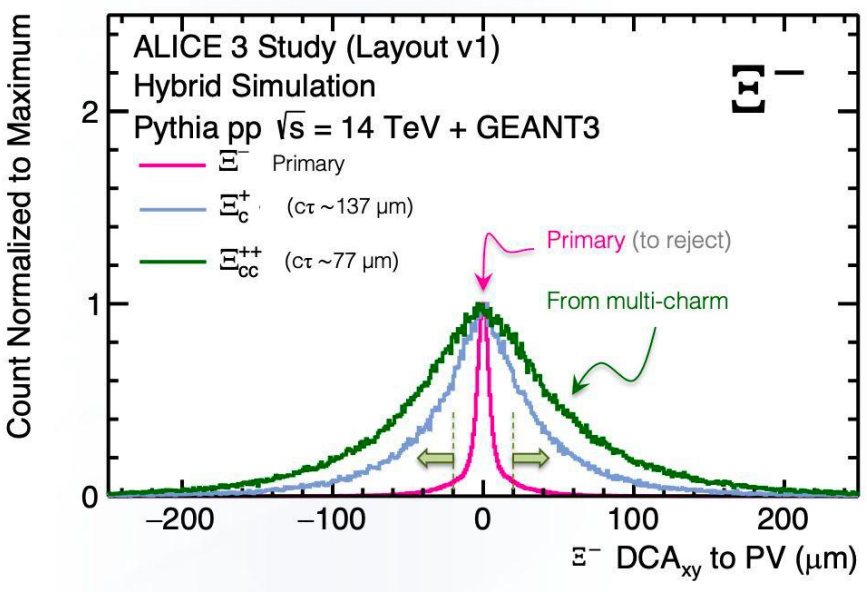


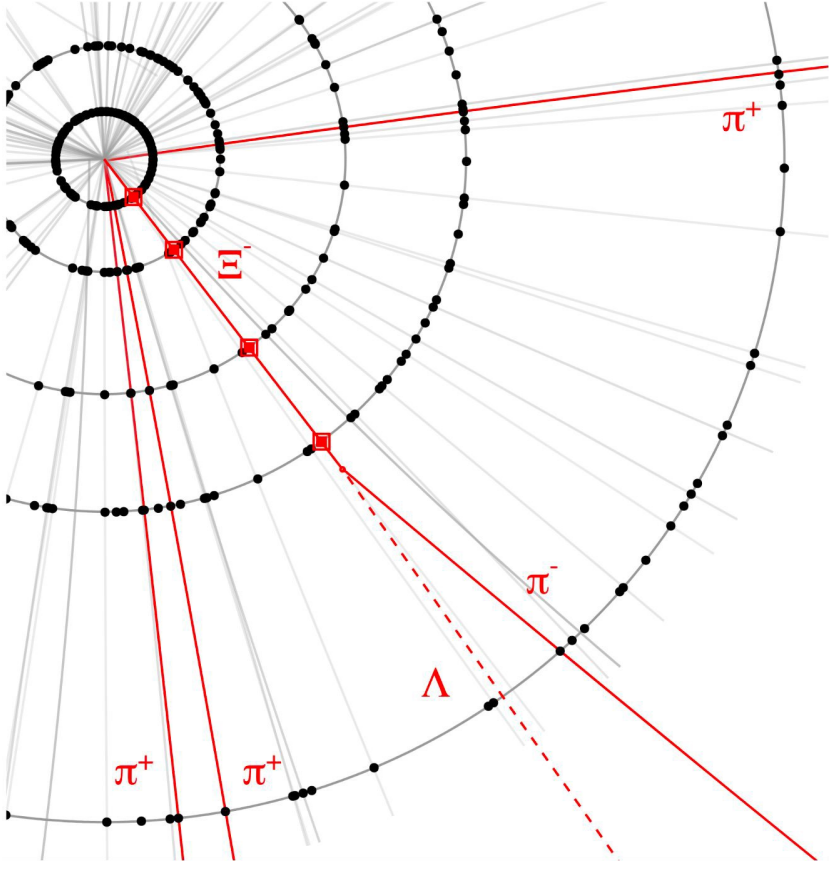
ALICE 3 Experiment – Access to multi-charm hadrons

- **Direct detection of weakly decaying particles**
  - ✓ Charged hyperons can leave hits in tracking layers before decay
  - ✓ Match corresponding hits to topologically reconstructed candidate to greatly improve precision

$$\Xi_{cc}^{++} \rightarrow \Xi_c^+ + \pi^+ \rightarrow \Xi^- + 3\pi^+$$

$$\Xi^- \rightarrow \Lambda + \pi^- \rightarrow p + 2\pi^-$$



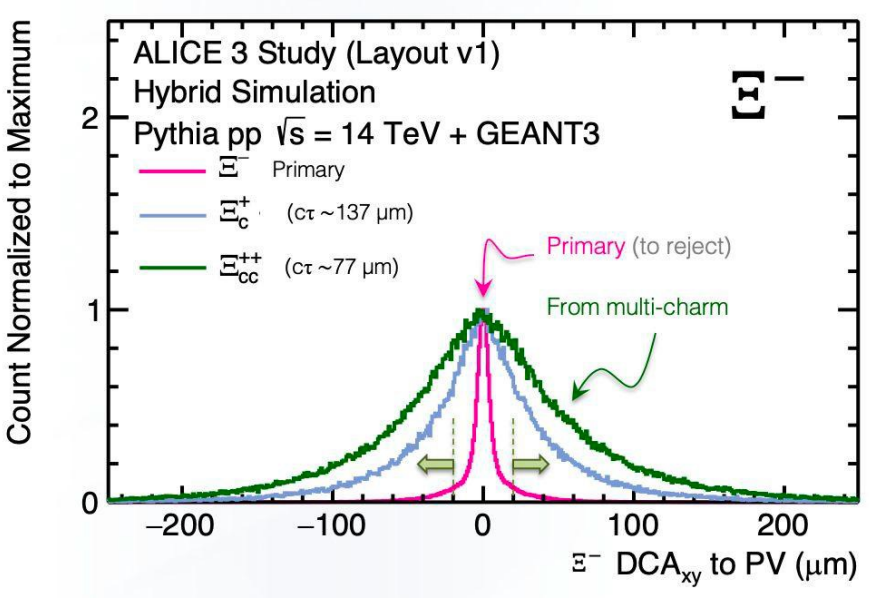


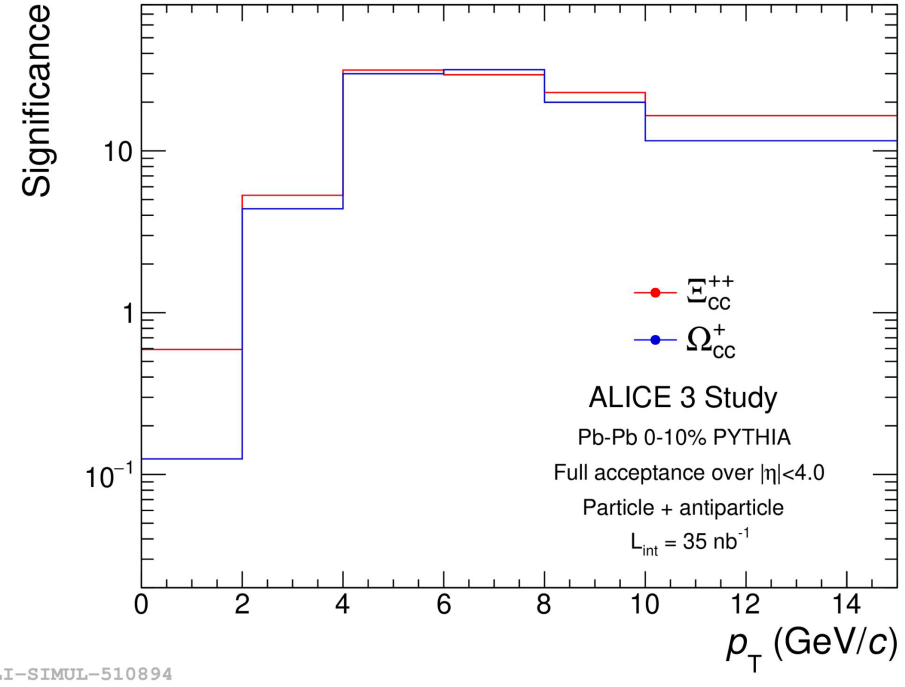
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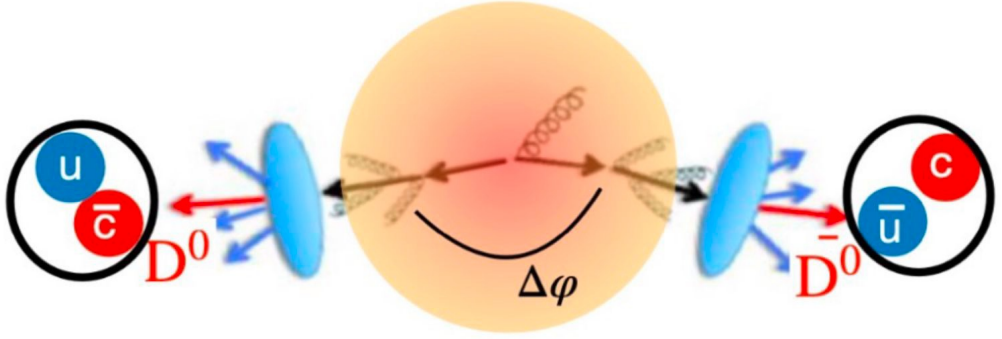
$$\Xi^- \rightarrow \Lambda + \pi^- \rightarrow p + 2\pi^-$$

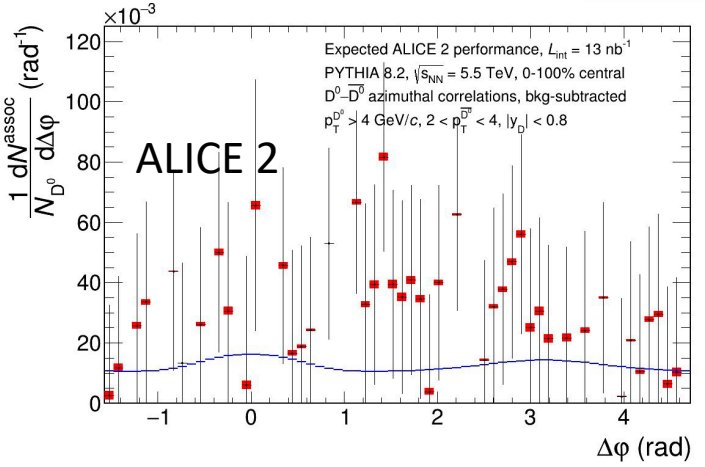


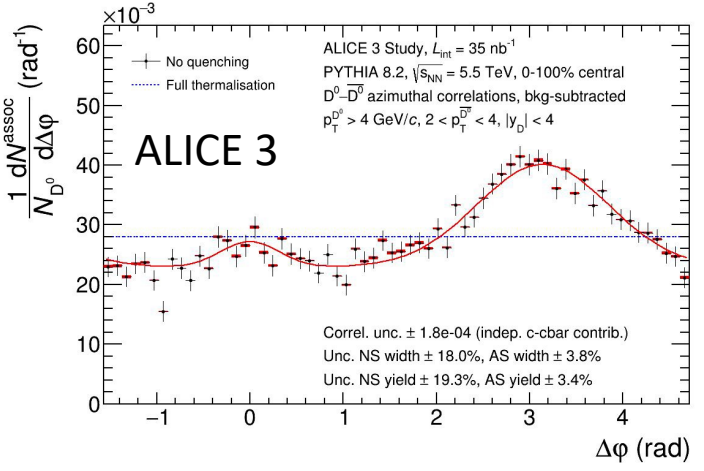


ALICE 3 Experiment – Heavy quark correlations

- **Angular decorrelation of heavy-flavour hadrons**
  - ✓ Sensitive to energy loss and degree of thermalization
  - ✓ Requires high purity, efficiency and large η coverage
  - ✓ Strongest signal at low p_T

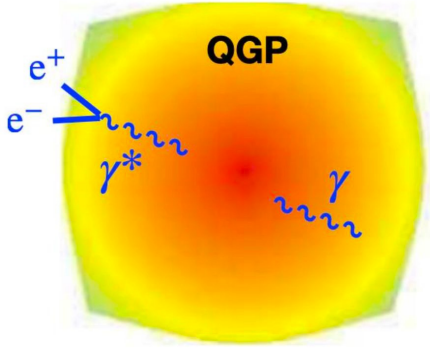


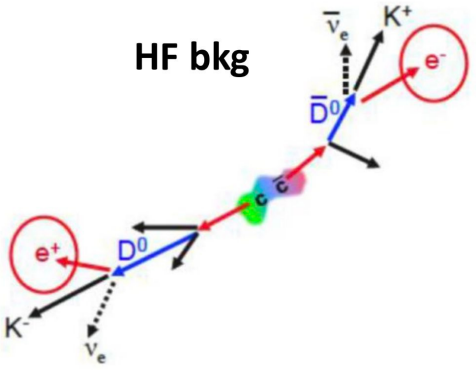


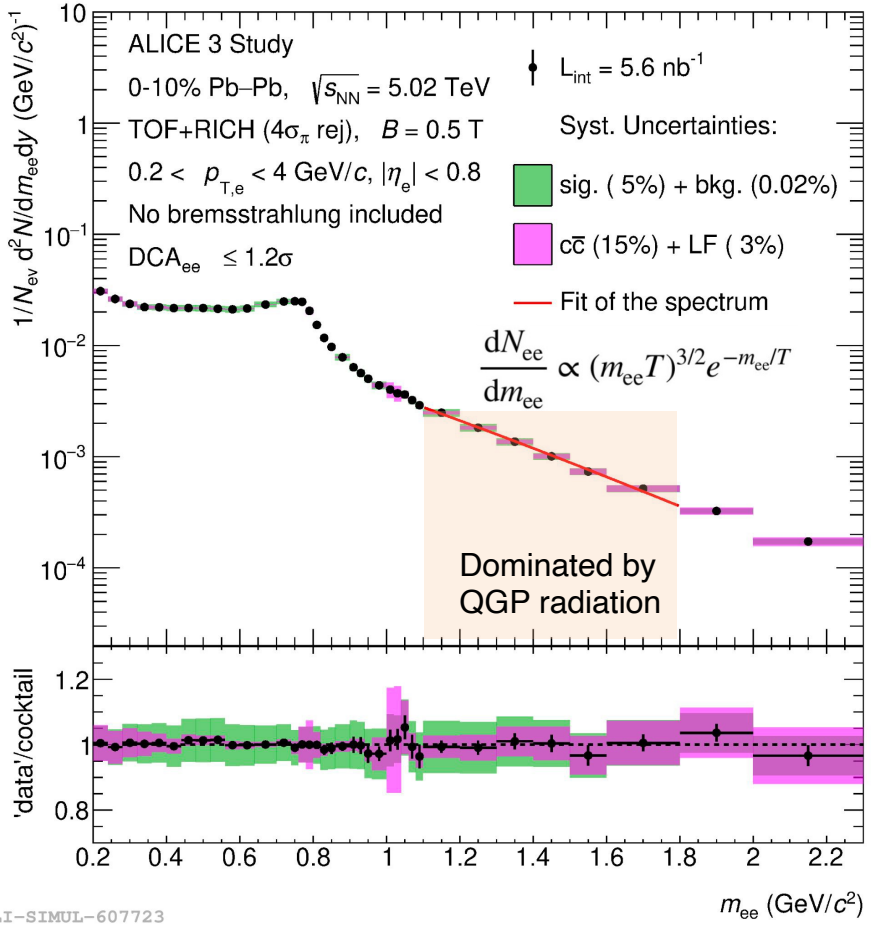


ALICE 3 Experiment – Precise measurements of dileptons

- **Accessing QGP temperature**
  - ✓ Excellent pointing resolution for HF rejection
  - ✓ Exceptionally low material budget
    → Little background from gamma conversion
  - ✓ Very good electron identification down to low p_T

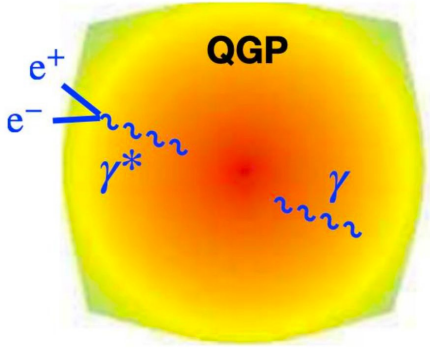


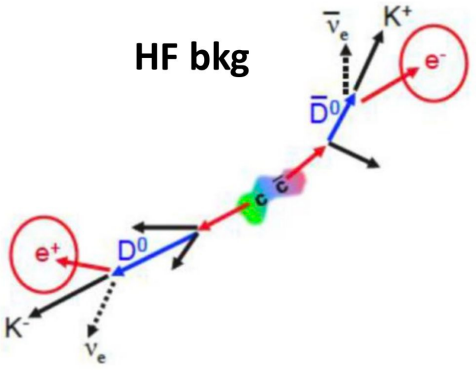


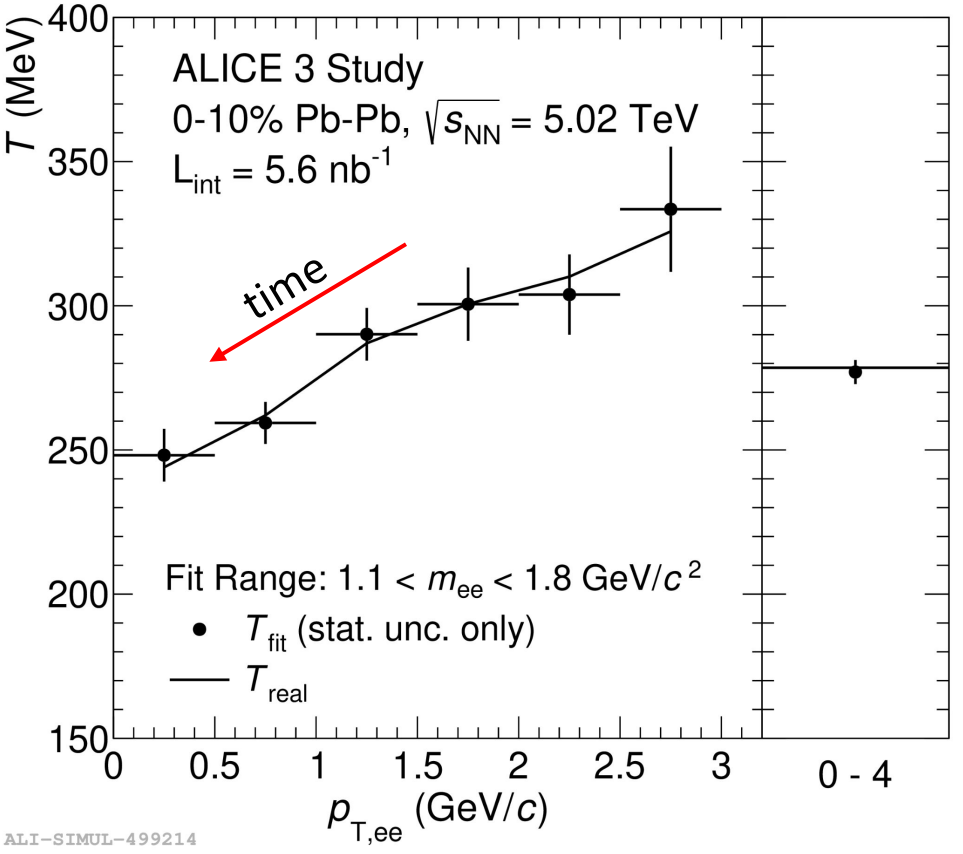


ALICE 3 Experiment – Precise measurements of dileptons

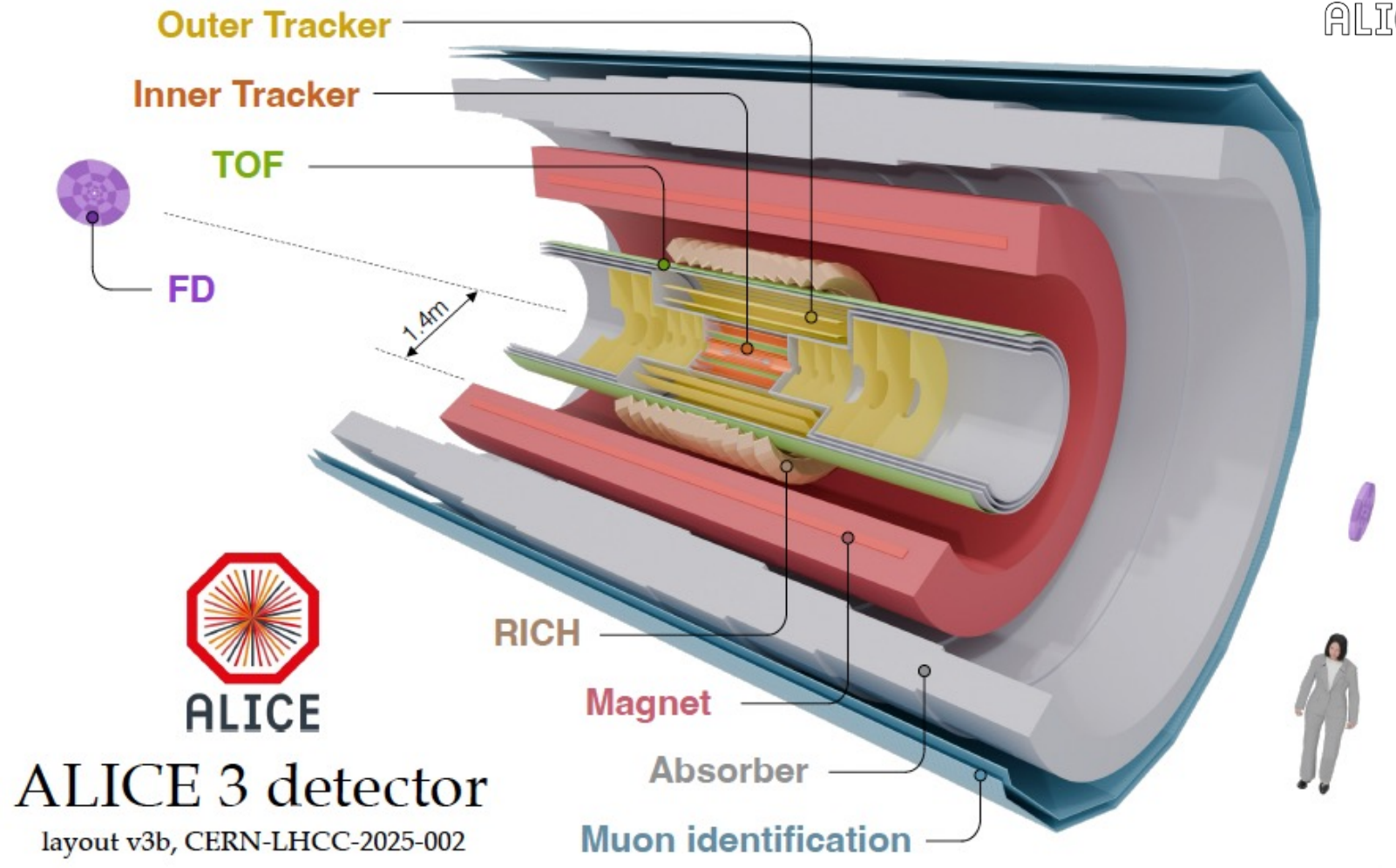
- **Accessing QGP temperature**
  - ✓ Excellent pointing resolution for HF rejection
  - ✓ Exceptionally low material budget
    → Little background from gamma conversion
  - ✓ Very good electron identification down to low p_T
- **Probe time dependence of temperature**
  - ✓ With ALICE 3 precision: differential in p_T







ALICE 3 Detector

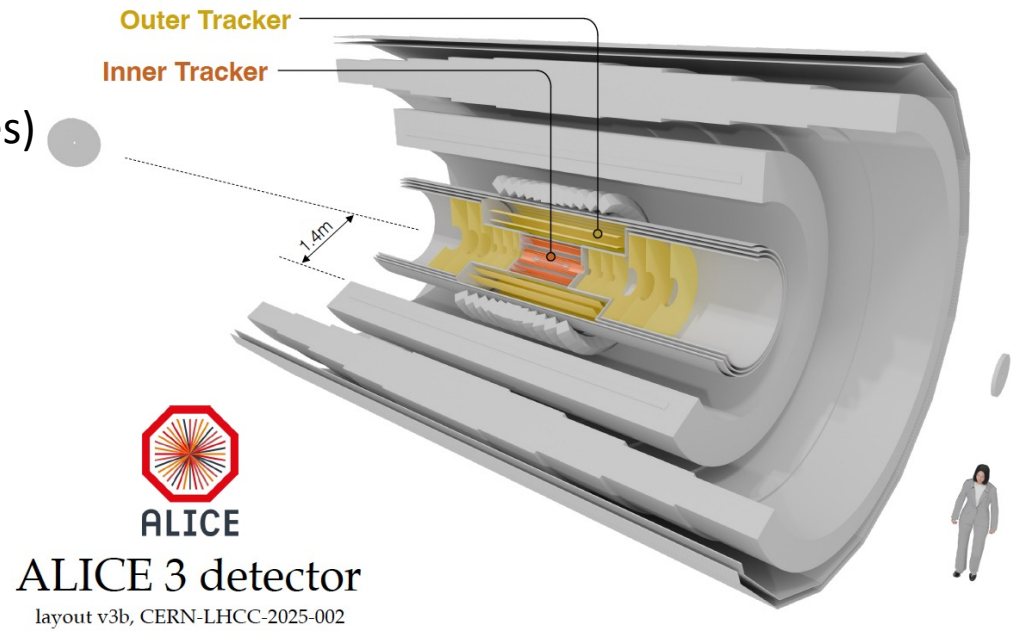


ALICE 3 Tracker

- **Significant step in instrumented surface**
  (Inner Tracker ~6 m^2, Outer Tracker ~40 m^2)
  - ✓ sensor design & production (yield, cost, synergies)
  - ✓ modularisation (yield, industrialisation)
  - ✓ fault tolerance (redundancy)

- **Challenging for integration and maintainability**
  - ✓ mechanical concept with minimal material
  - ✓ maintainable integration

- **New concepts for power distribution**
  - ✓ current reduction, e.g. through serial powering
  - ✓ granularity
  - ✓ failure handling

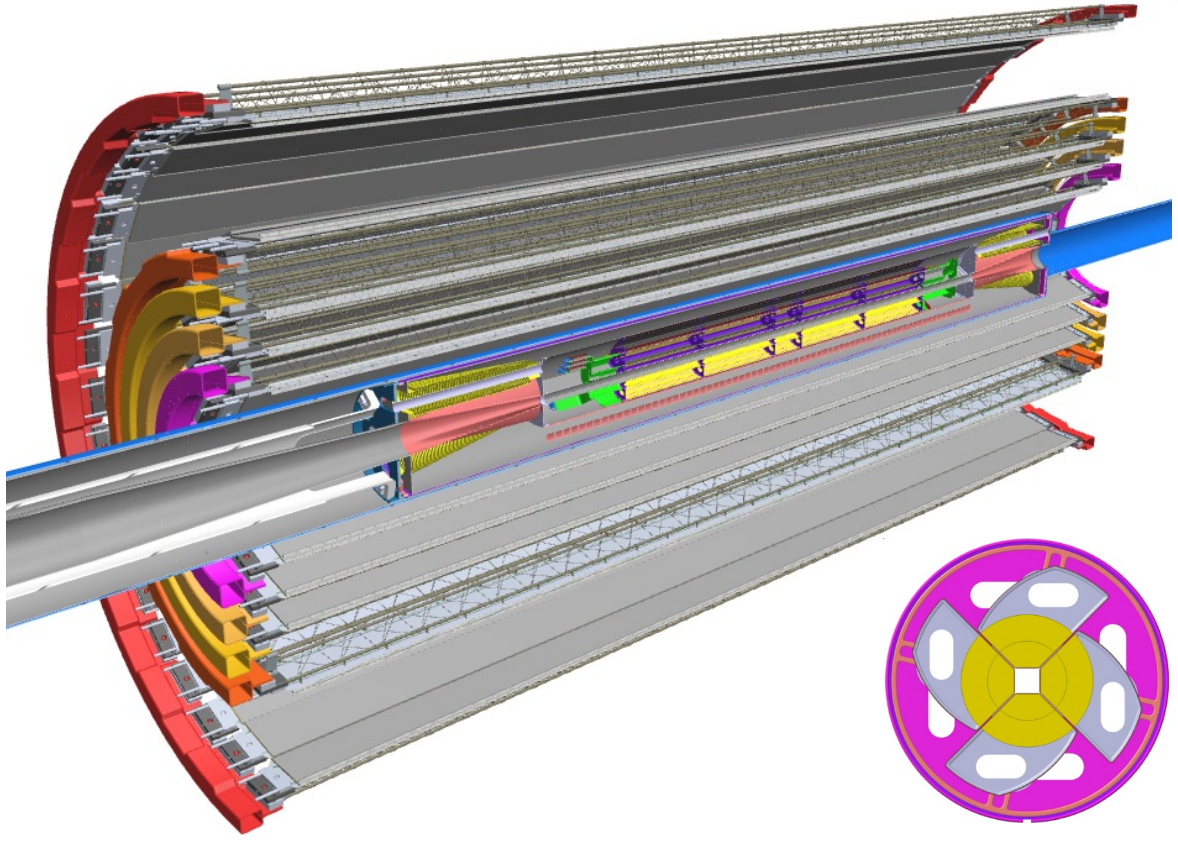


Inner Tracker: **Vertex Detector + Middle Layer**
Outer Tracker: **Outer Layers + Forward Disks**

ALICE 3 Inner Tracker

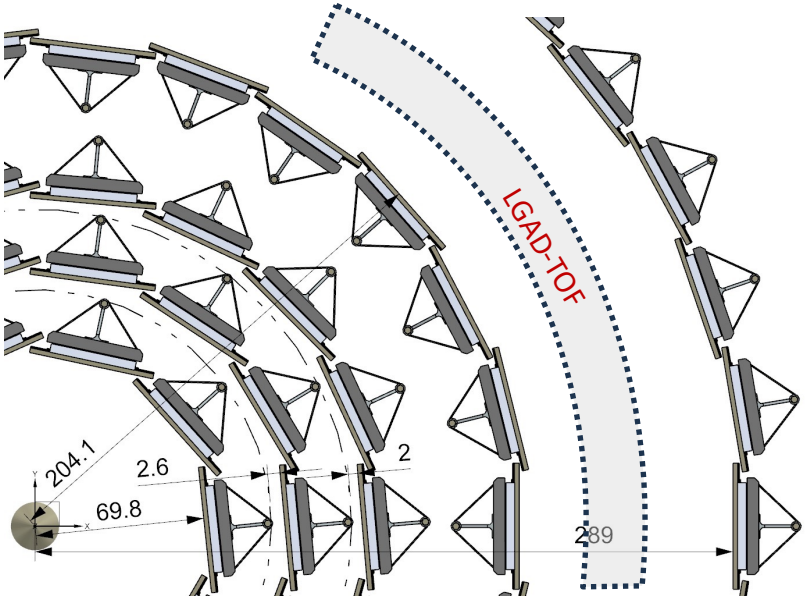
- **5 Middle Layers in barrel configuration**
  - ✓ radii between 9 and 30 cm
  - ✓ ~1% X_0 per layer
  - ✓ σ_{pos} ~10 µm
  - ✓ lightweight staves

- **3 cylindrical layers (Vertex Detector) inside beam pipe**
  - ✓ radii between 5 and 25 mm
  - ✓ 0.1 % X_0 per layer
  - ✓ σ_{pos} ~2.5 µm
  - ✓ petals for secondary vacuum



MAPS chip → Module → Integration → Powering → Readout

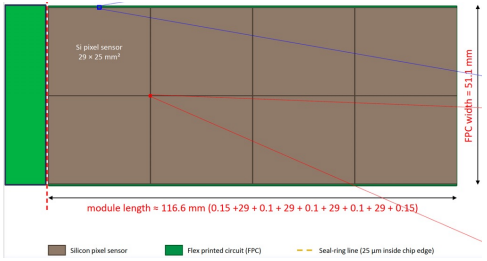
ALICE 3 Inner Tracker – Layout



ALICE IT middle layers: 5 stave layers, ~6.1 m^2 (or 6.7 m^2)

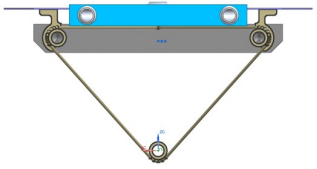
Layer	Radius (mm)	Length (mm)	No. staves	No. chips	Area (cm^2)
L3	72.8	1166	10	800	5800
L4	106	1166	14	1120	8120
L5	138	1166	18	1440	10440
L6	198	1166	26	2080	15080
L7	291	1166	38	3040	22040

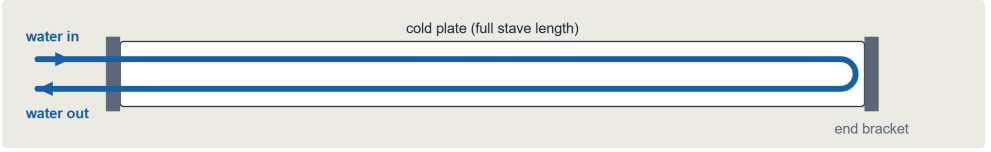
module

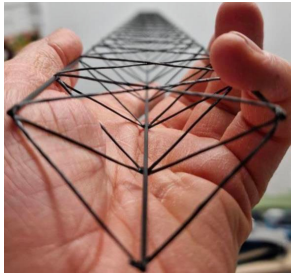




Stave







ALICE 3 Inner Tracker – Pixel chip

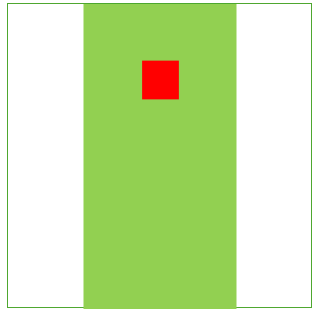
- **Common R&D line for VD, ML, OL**
  → ALMIRA as joint technology project

- **Pixel with different pitches** down to **10x10 µm²**
  ✓ collection electrode
  ✓ analogue front-end

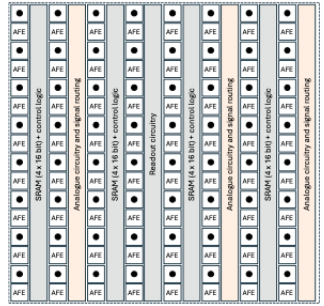
- **Pixel macro**
  → modular architecture with two variants
  ✓ discrimination and fast-OR
  ✓ memory for multi-event buffering (controlled by periphery)
  ✓ analogue circuitry
  ✓ control logic

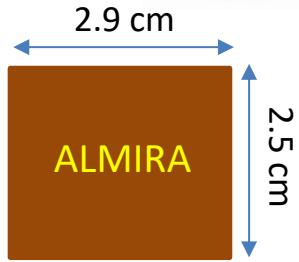
- **Analogue Pixel Test Structures (APTS)** from ITS3 ER-2 extensively tested

Single pixel (10x10 µm²)

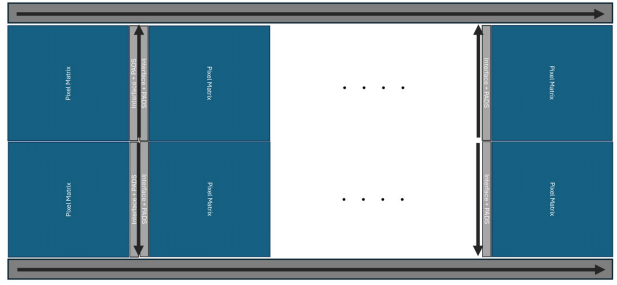


Pixel macro

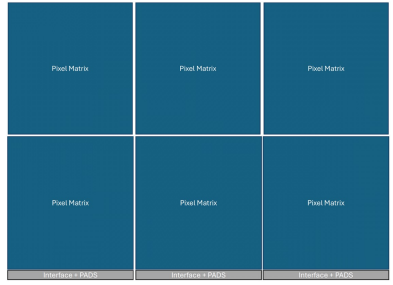




Ex. of stitched sensor



Ex. of reticle-size chip

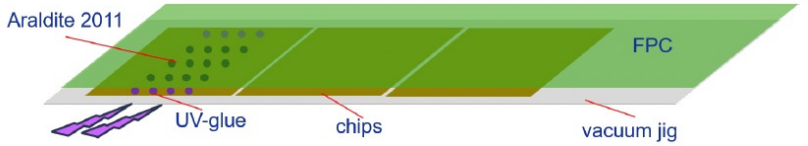


- **ALMIRA submission in preparation**
  ✓ pixel with (new) analogue front-end
  ✓ pixel macro with buffering and fast-OR
  ✓ periphery with control and readout
  ✓ design needs to consider sensor assembly

ALICE 3 Inner Tracker – Chip module

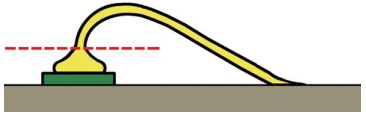
- **Requirements**
  - ✓ **Small-scale but complex VD layer assembly**
    → bending, in-vacuum, bake-out procedure, …
  - ✓ **Large-scale production of ML modules**
    → scaling, yield, material budget

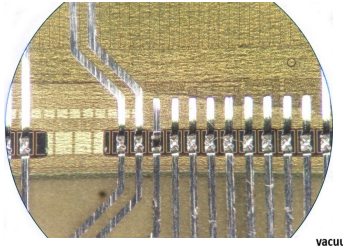
UV curing

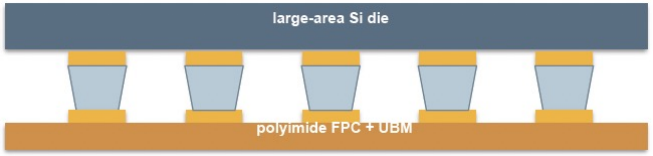


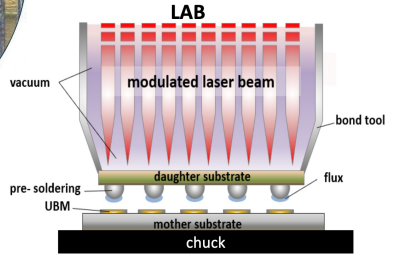
- **R&D to identify ideal interconnect**
  - ✓ **Wire bonding** (established)
  - ✓ **Au-stud bonding** (R&D ongoing)
    → high temperatures, mechanical stress
  - ✓ **Indium bump bonding** (R&D starting)
    → low temperature, flexible, oxide formation
  - ✓ **TAB bonding** (R&D ongoing)
  - ✓ **Laser-assisted bonding** (R&D starting)
    → properties of process to be understood

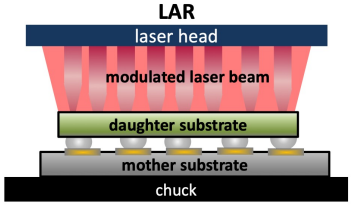
Au stud creation





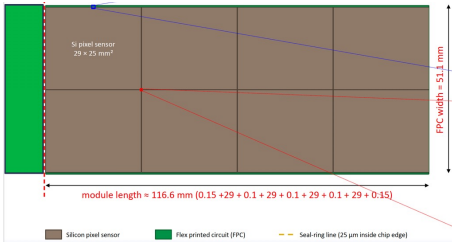


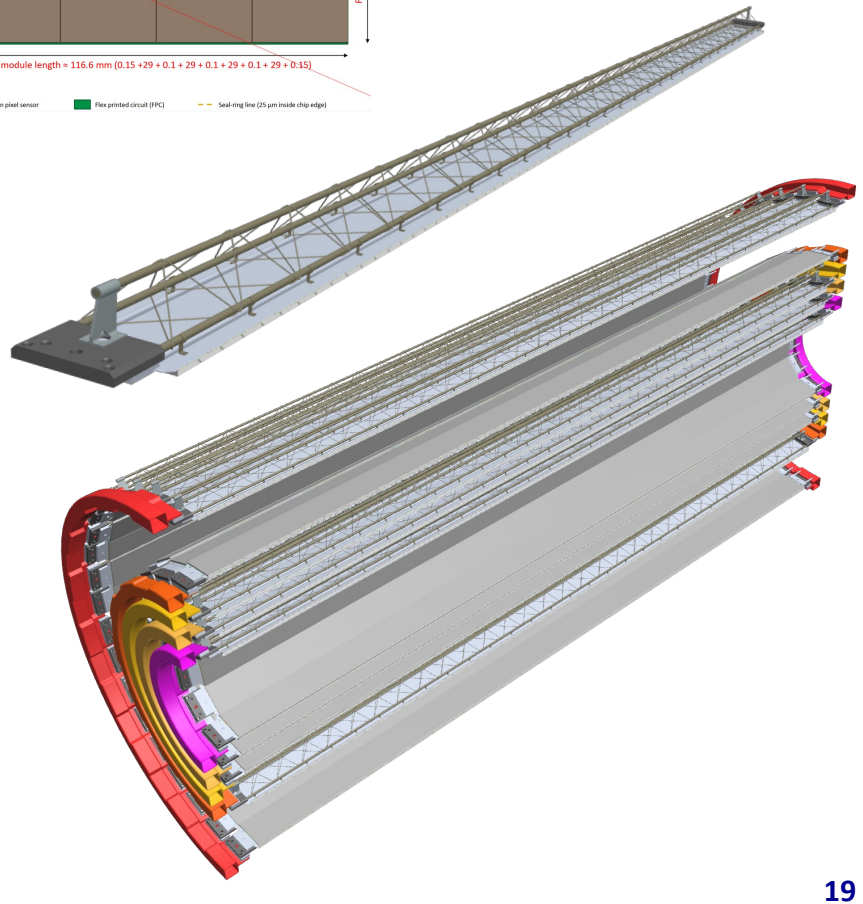




ALICE 3 Inner Tracker – Stave module

- **Modules** to host 2x4 reticle-size chips
  - ✓ FPC for power distribution and readout
- **Staves** to host modules
  - ✓ spaceframe based on
    → pultruded longerons and continuous winding
  - ✓ coldplate with embedded tubes for water cooling
- **End wheels** to host staves
- **Service barrels**
  - ✓ joint structure for installation

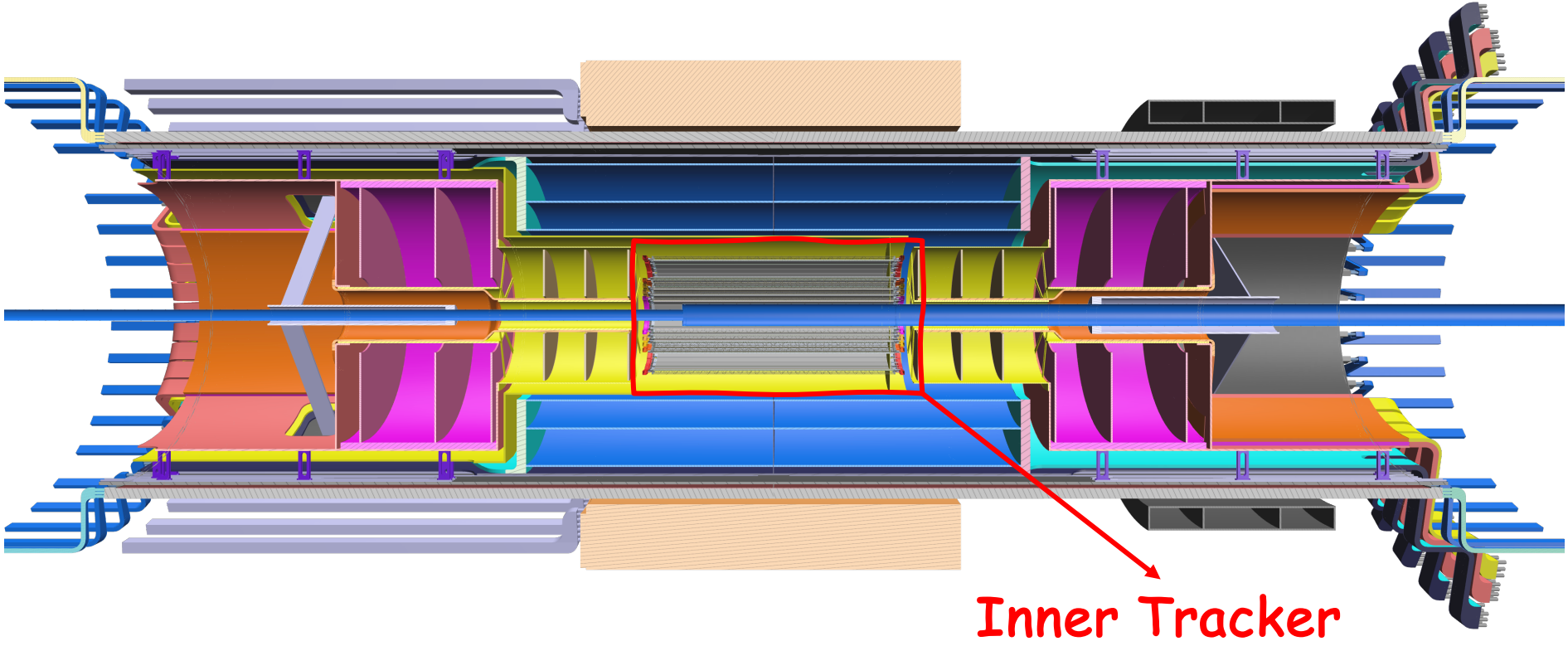




Need to consider reworkability and effective installation!

ALICE 3 Inner Tracker – Integration

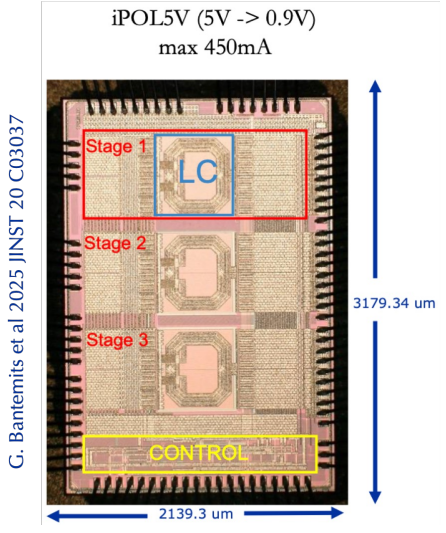
- Peacock structure for sequential installation of fully prepared detectors
  → installation in short period of Long Shutdown 4 (~2 years)
  ✓ careful planning and preparation of service routing required

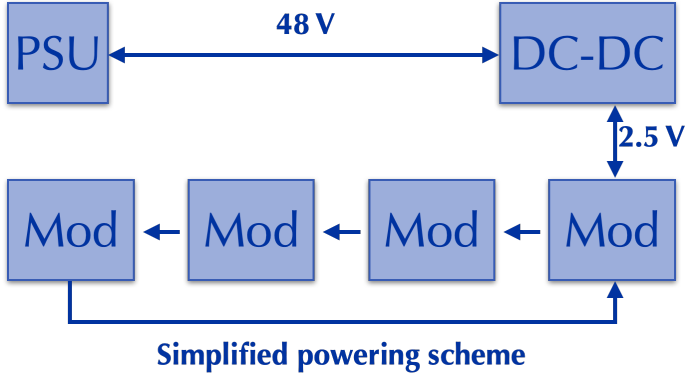


ALICE 3 Inner Tracker – Powering

- **Parallel powering** → parallel voltage supplies for each module
  - conceptually simple and easy to control
  - prohibitive in terms of material
- **DC-DC conversion** → higher voltage → reduce current
  - rad. hard buck converters available (bPOL…)
  - ongoing R&D for higher currents (50 A), including new processes
  - iPol developments could be well suited
- **Serial powering** → reuse and reduce current
  - requires (integrated) shunt regulators
  - complex system architecture
- **Consider all aspects:** integration, stability, availability
  - study concrete concepts
  - plan relevant tests

Fully integrated DC-DC converter (28 nm)



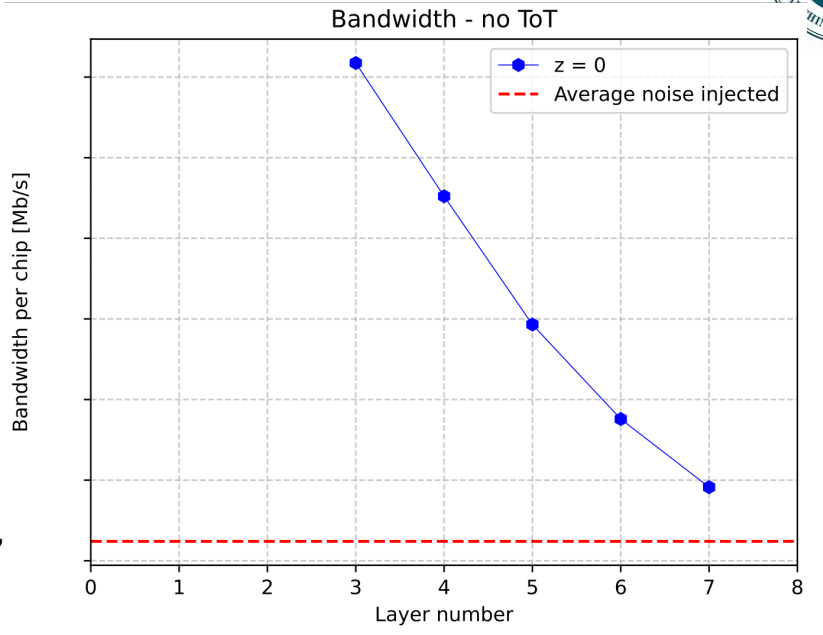


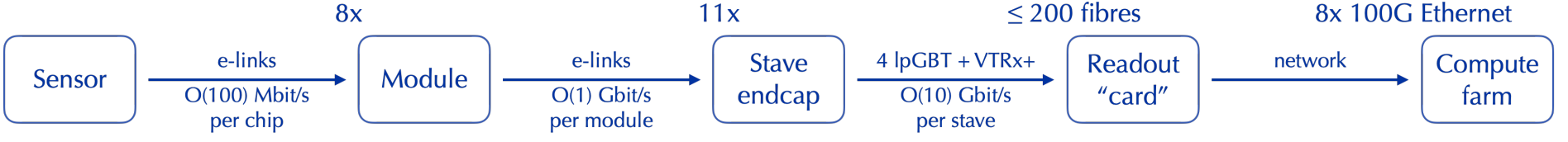
Simplified powering scheme

ALICE 3 Inner Tracker – Readout

- **Continuous, trigger-less read-out**
  - highly parallel processing exploiting GPUs
- **Data aggregation and buffering**

  with large spread of required readout bandwidth
  - consider total bandwidths to judge feasibility
  - consider different schemes for data aggregation and buffering in different regions
  - Versatile Link (lpGBT and VTRX+) used as example, alternatives to be evaluated





individual sensors

module with or without data aggregation

stave interface aggregating data from a given stave

interface between optical links and compute farm (netFELIX, …)

event building event processing compression

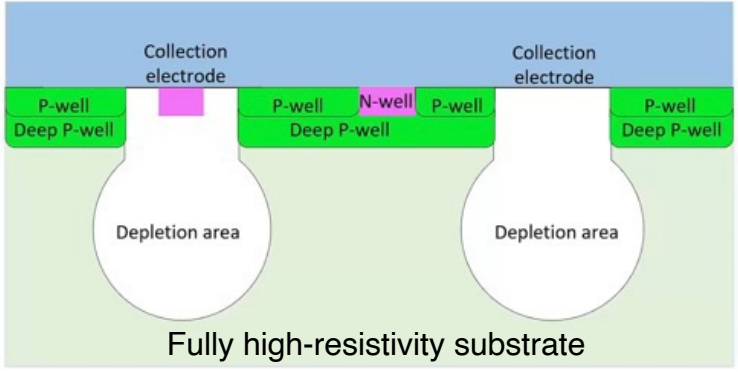
Status of ALICE 3 Inner Tracker in China

Activities and institutes

	CH	CN	CZ	IT	NO	UK
Performance	CERN	FDU, CCNU, CUG, UCAS		BA, PD, PV, TS		
Chip design	CERN	CCNU, USTC, SDU		BA, FG, PD		
Sensor characterisation	CERN	CCNU, USTC	Rez	BA, CA, CT+ME, FG, LNF, PD, PV, PI, TS	UIB	Daresbury, Liverpool
Modules	CERN (R&D)	CCNU, CIAE, IMP		BA, TS		
Vertex Detector	CERN			BA		
ML barrel		CCNU, CIAE, IMP, SDU		BA, LNF, PD, PI, TS		Daresbury, Liverpool
Readout, Control, Power	CERN	CCNU, CIAE, USTC		CA, PD, TS	UIB, UIO, USN	

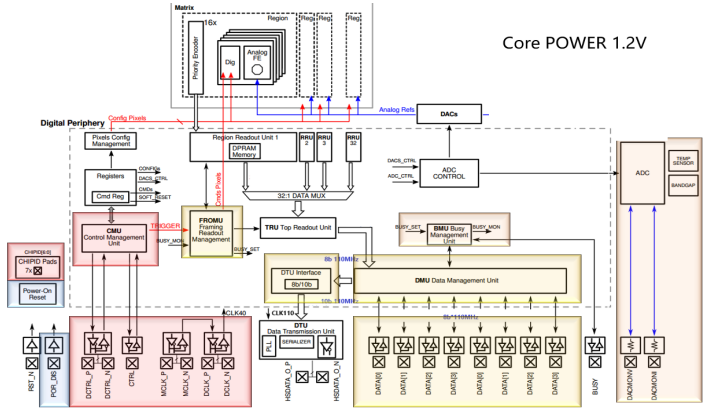
Status of ALICE 3 Inner Tracker in China

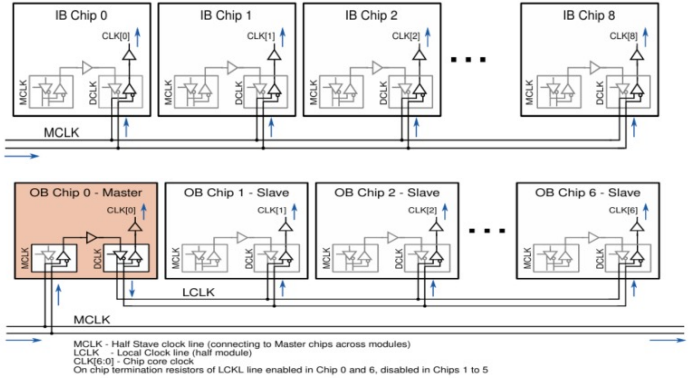
(CCNU)



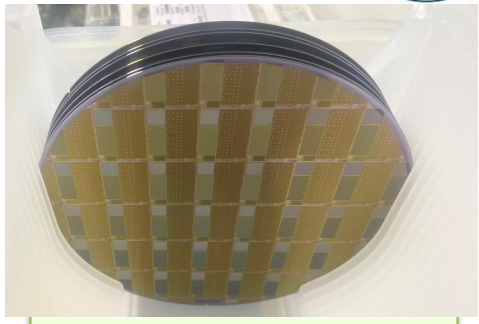
MIC6_V4 Features	
Process	130 nm
Core Voltage	1.2V
Chip Size	30 mm × 15 mm
Pixel Array	980 × 497
Pixel Size	30.53 um × 26.8 um
Readout	AERD
Output Rate	1.2 Gbps
Encoder	8B10B
Slow Control	MLVDS Control Bus
Parallel Data Interface	master-slave data aggregation and transmission

Architecture

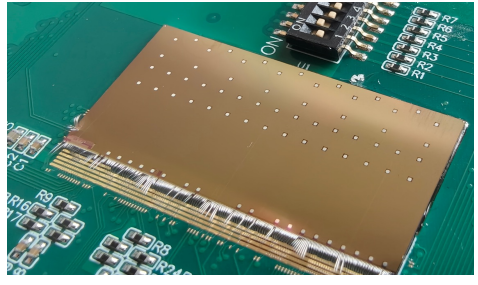


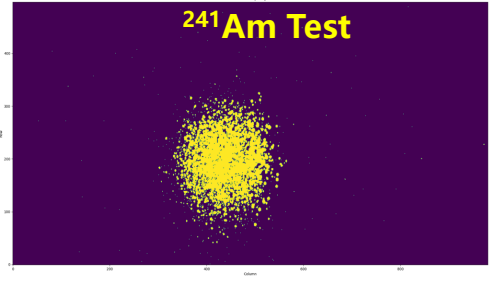


Master-Slave Mode



Chip layout

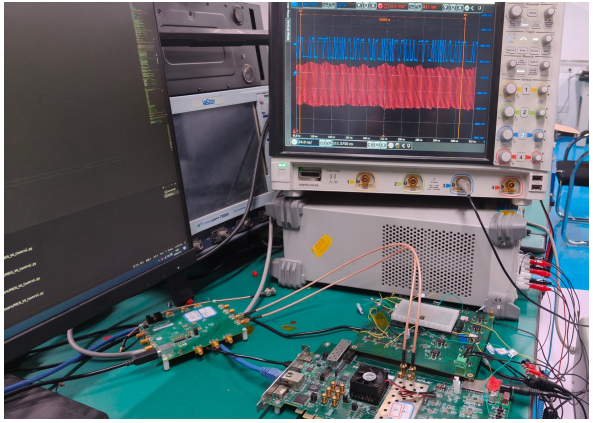




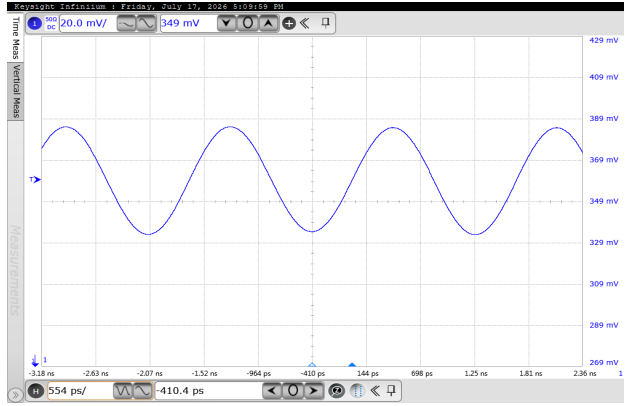
Status of ALICE 3 Inner Tracker in China

(CCNU)

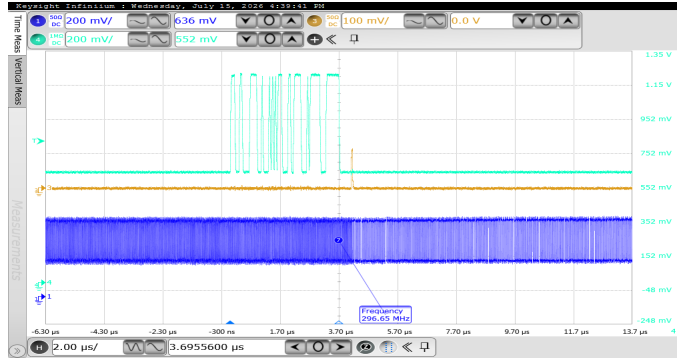
MIC6_V4 Test System



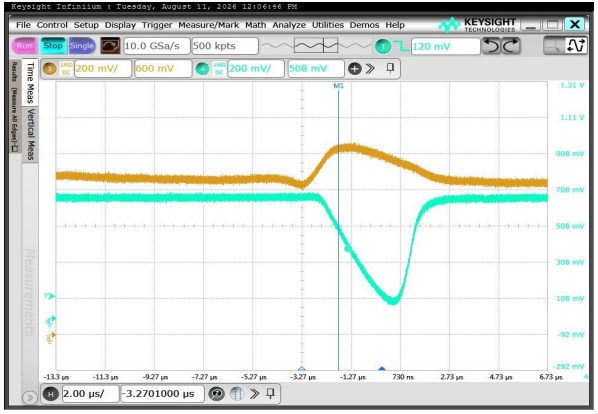
PLL Output 600MHz Clock



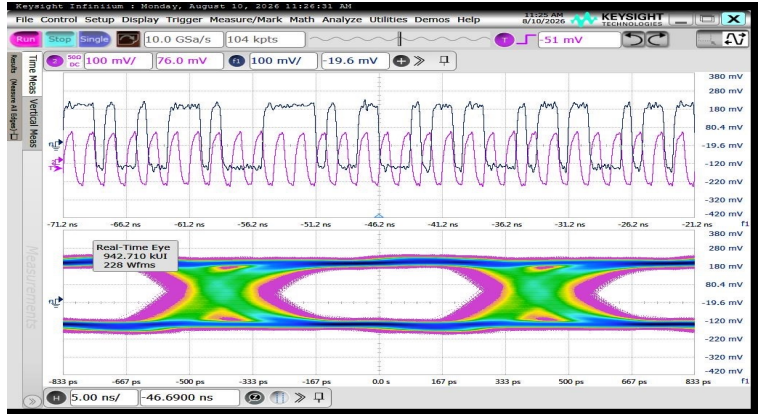
CMU Configure PLL Clock



Pixel Out_A & Out_D



Serial Data Eye Diagram @ 1.2Gbps

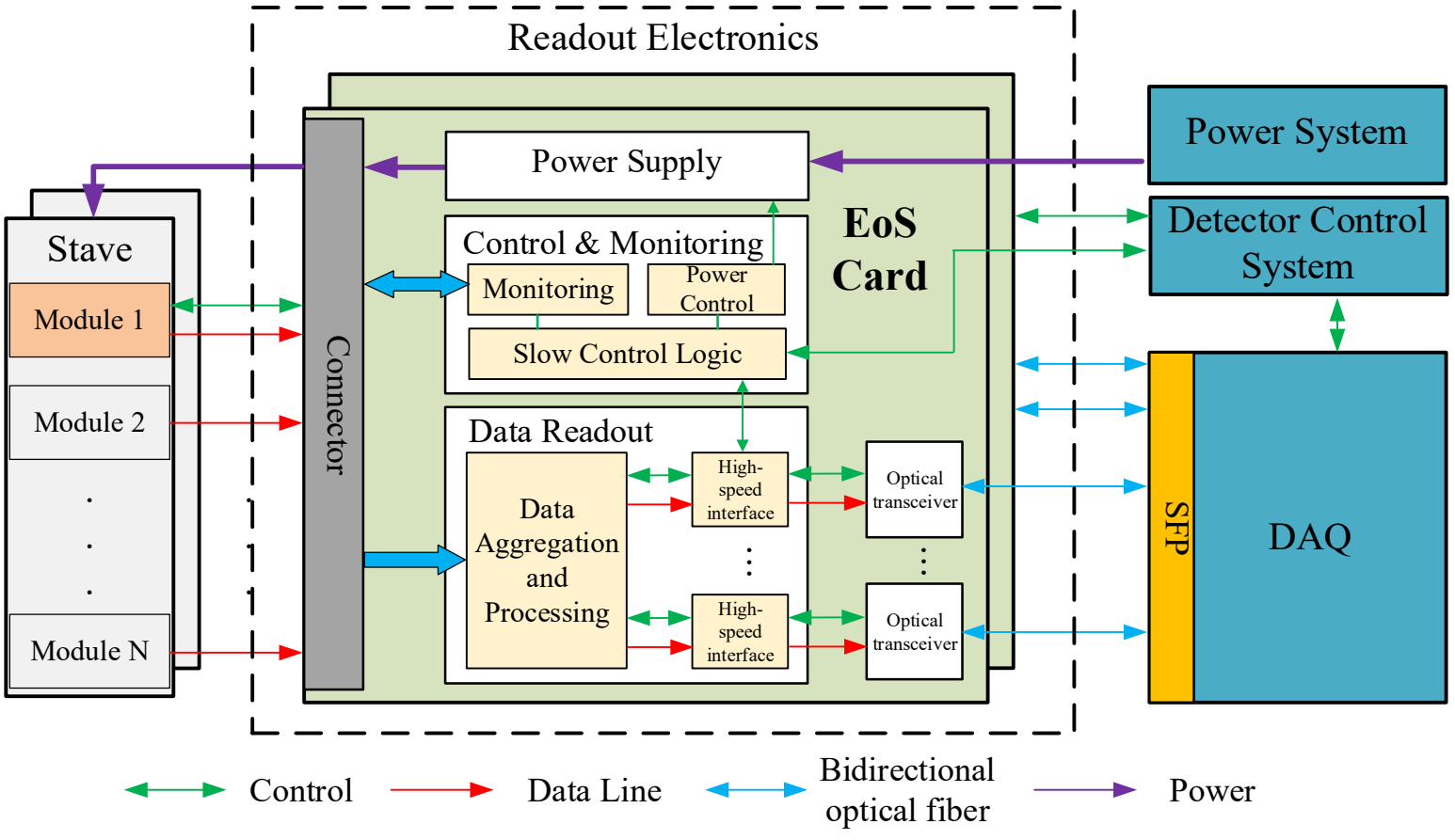


- MLVDS Module ✓
- PLL Module ✓
- Control Management Unit ✓
- DAC ✓
- Pixel Front-end ✓
- Serializer ✓
- Frame Builder and 8b10B Encoder ✓
- Pixel Configuration Module ✓
- AERD for Pixel Array Readout ✓

Status of ALICE 3 Inner Tracker in China

(USTC)

- Proposed full-functional prototype design for ALICE3 tracker

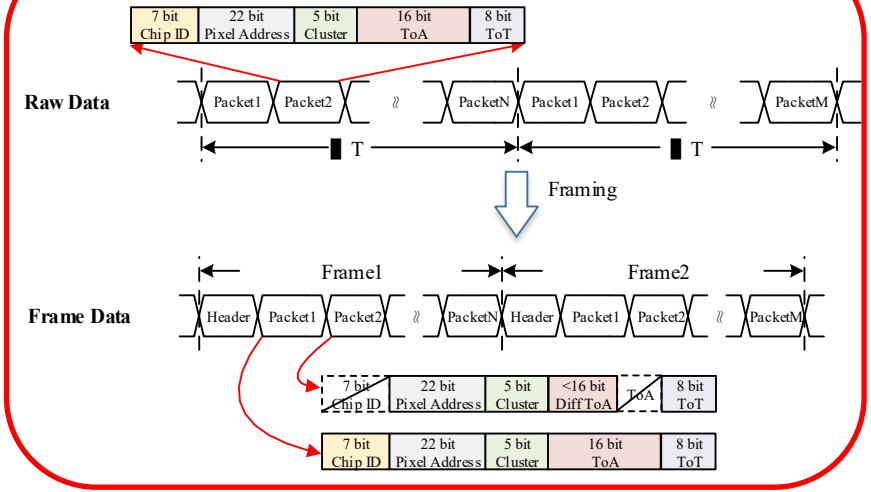


Status of ALICE 3 Inner Tracker in China

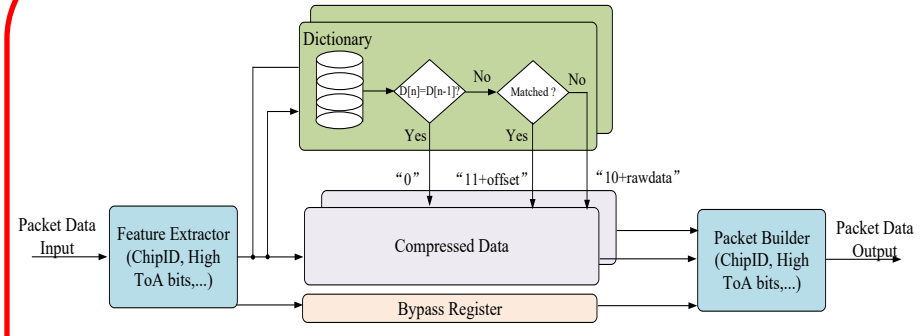
(USTC)

- High-speed trigger-less data aggregation & transmission
  - ✓ High-speed reception → parallel data stream recovery and alignment
  - ✓ Pre-processing & shared buffering → lossless data compression
  - ✓ Configurable on-chip routing (X-bar)
  - ✓ High-speed transmission

Frame-based incremental data compression



Dictionary-based data compression

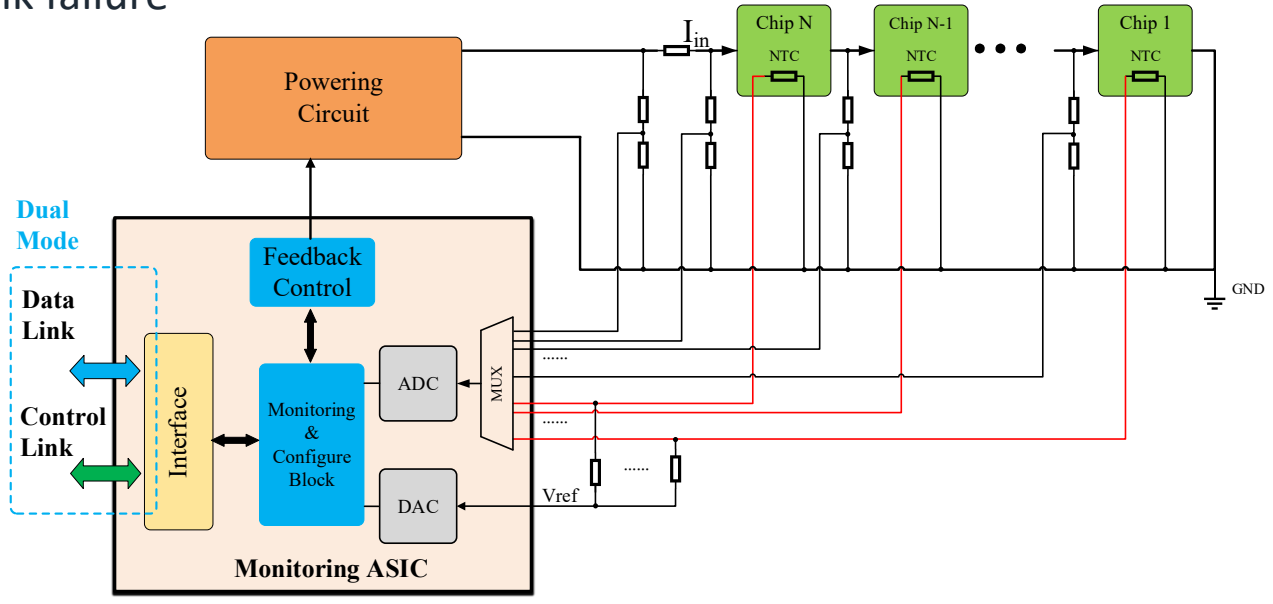


- Dynamically constructs symbol dictionaries and replaces repeated data with compact indices

Status of ALICE 3 Inner Tracker in China

(USTC)

- Monitoring ASIC with local protection & dual-mode communication
  - ✓ Unified monitoring: V / I / T to voltage
  - ✓ Shared high-precision ADC + time-division multiplexing
  - ✓ Local automatic protection: fast fault response, improve reliability
  - ✓ Dual-mode communication: monitoring over data link normally; independent slow-control interface on link failure



Status of ALICE 3 Inner Tracker in China

- Challenging for the pixel tracker design and integration
  - ✓ Positioning accuracy for reticle-size (> several cm^2) & thin chip (~50 μm): < 5 μm
  - ✓ Lightweight supporting structure: carbon fiber mechanics, flexible PCB
  - ✓ Powering & cooling: limited space, low material requirements
  - ✓ Semi-automatic assembly to full automatic assembly/testing for large-scale area:
    - 0.16 m^2 (STAR/HFT) → 10 m^2 (ALICE/ITS2) → ~50 m^2 (ALICE 3),
  - ✓ Modular design for reworkablity, effective installation and period maintainability

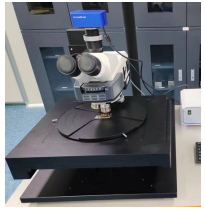
- To the ALICE3 IT construction, Chinese institutions are interested to:
  - ✓ Chip modules: R&D, mass production (assembly, testing, QA)
  - ✓ Mechanics & integration (space frame, cold plate, FPC…): R&D, production
  - ✓ Stave module: R&D, production (assembly, testing, QA)

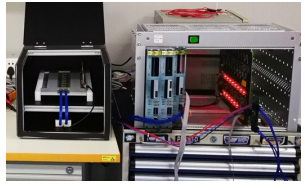
Status of ALICE 3 Inner Tracker in China

(CCNU)

- Production lines available for chip module and stave module assembly and testing
- Equipped with module QA instruments (wire pull tester, peel force tester, measurement microscopes, …)
- Well-trained technicians during the ALICE ITS2 project for the pixel detector assembly & testing





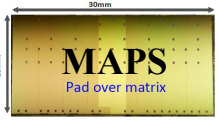

Module assembly & testing @ ISO6 clean room, 75 m^2


Stave assembly & testing @ ISO7 clean room, 60 m^2

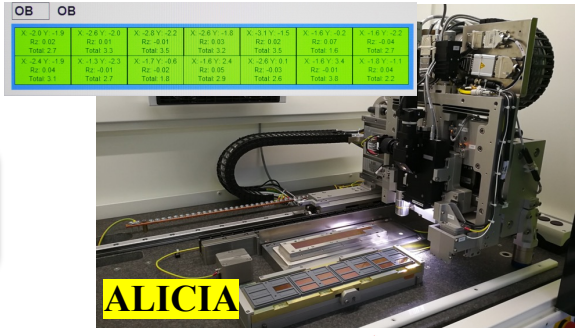
Status of ALICE 3 Inner Tracker in China

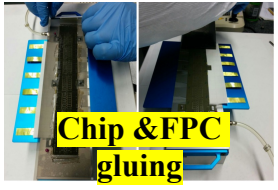
(CCNU)

- Participated in ALICE ITS2 OB HIC mass production and completed 450 HIC modules (yield ratio ~85%, ~2.8m^2 in 2 years), the module production line in working status



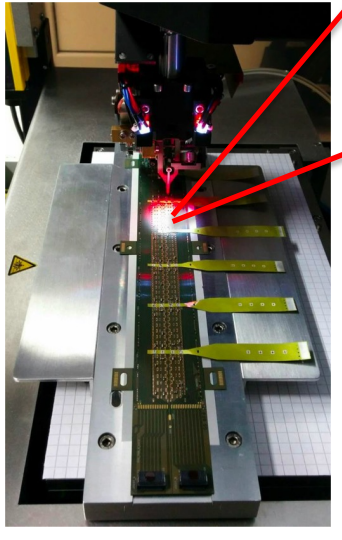
Chip inspection & positioning

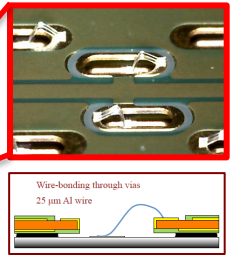




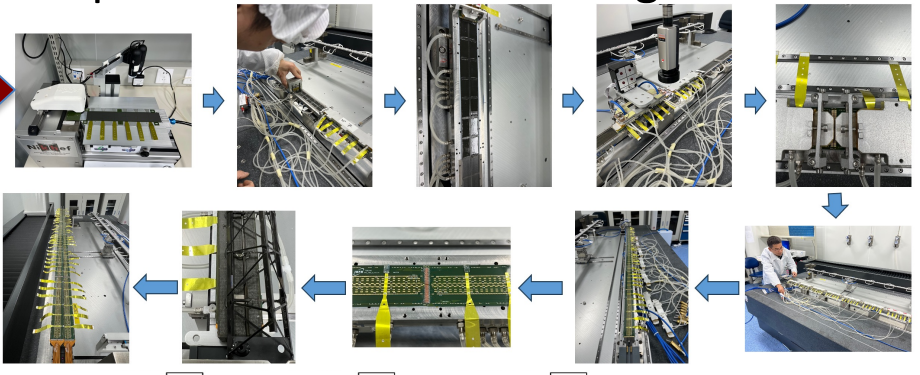
curing

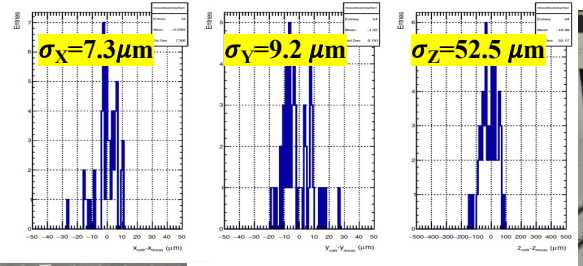
Wire-bonding

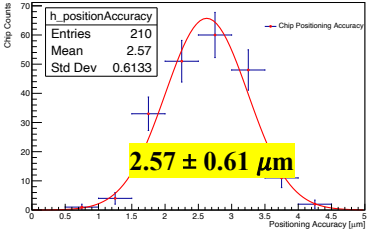


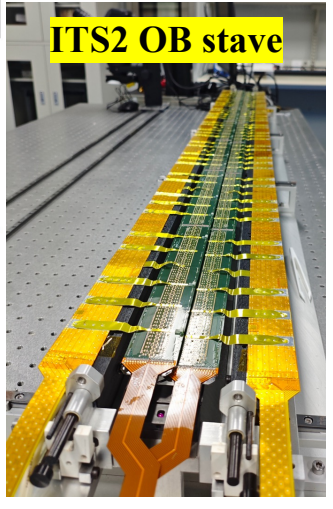












Status of ALICE 3 Inner Tracker in China

(CCNU)

- CCNU is upgradeing the infrastructure for pixel detector development in coming years.

Wafer dicing machine





Wafer inspection machine

High-Precision Flip-Chip Bonder

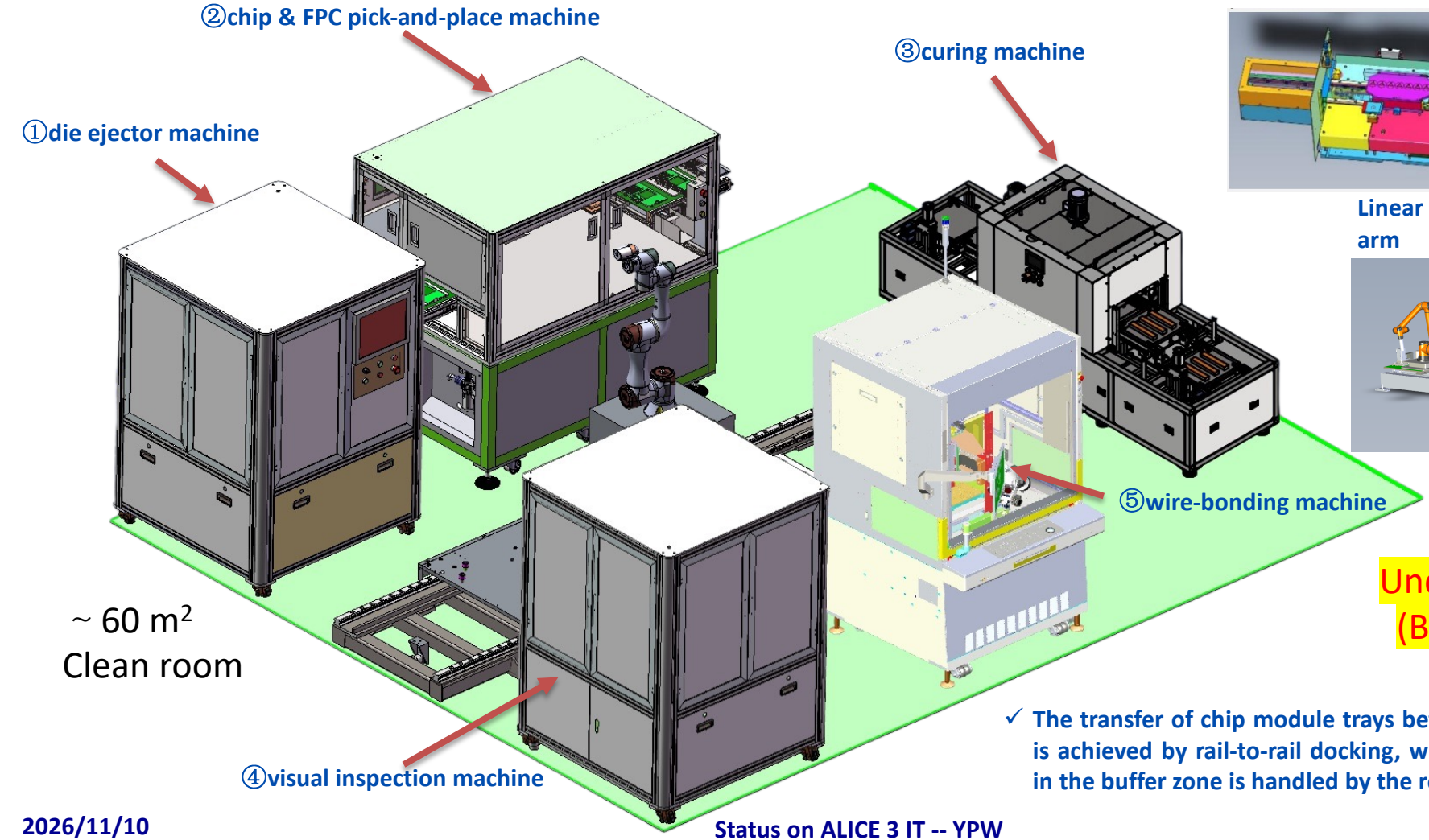




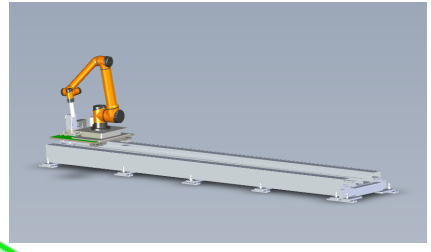


Status of ALICE 3 Inner Tracker in China

(CCNU)



Linear guide rail and robotic arm



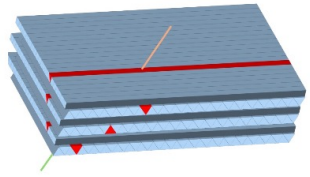
Under construction
(Be ready in 2027)

✓ The transfer of chip module trays between different devices is achieved by rail-to-rail docking, while the tray placement in the buffer zone is handled by the robotic arm.

Status of ALICE 3 Inner Tracker in China

(CIAE)

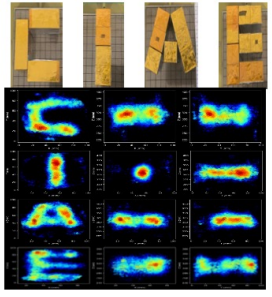
- Detector development



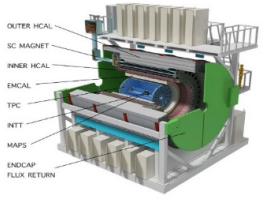


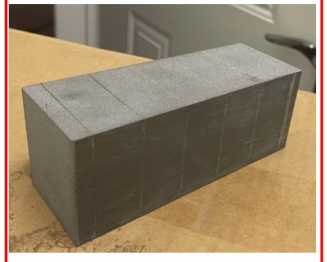
Plastic Scintillator





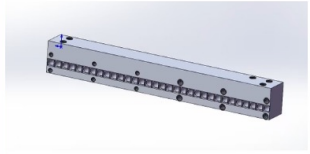
Photolithography Micromegas

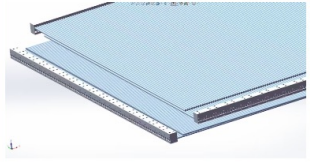


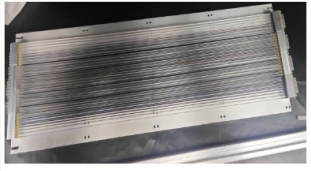




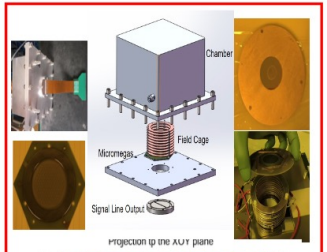
sPHENIX EMCAL

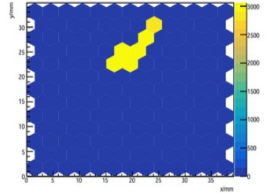


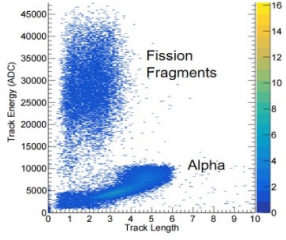




Scintillating fiber







Multi-purpose TPC

- Readout electronics (ALICE FoCal, gas detector, SiPM readout, Trigger & MCA system)

Status of ALICE 3 Inner Tracker in China

(CIAE)

Interest

- Detectors:
  - Detector modules design, assembly and test
  - Cooling and mechanical design
- Electronics:
  - High speed readout electronics for high luminosity
  - Radiation hardening strategy
  - Intelligent triggering and readout

What we already have

- Lab: 600m^2+400m^2, including ~100m^2 clean room
- Funding for manpower and technology
- Full group： 3 Professors

  2 Asisstant Professors

  3 Technicians

  8+2 Ph.D Students

  4+ Master Students
- Experience on pixel sensor readout system

What we need

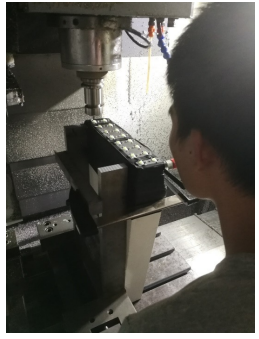
- Funding for large equipments

Status of ALICE 3 Inner Tracker in China

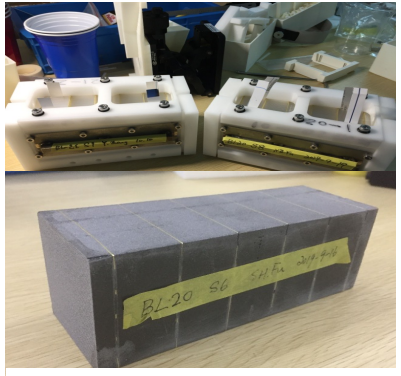
(FDU)

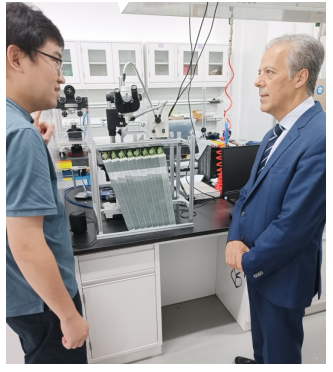
- **Previous experience on EMCal**





Shashlyk, Mass production





Spaghetti Calorimeter (SPACAL), Mass Production

- **Previous experience on ITS3**
  - **Geometry alignment design**
  - **MOSS characterization test**
  - **Beam test at CERN**





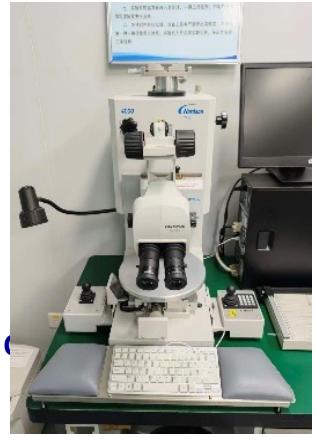
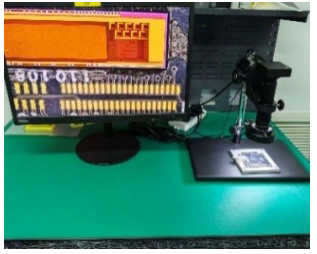
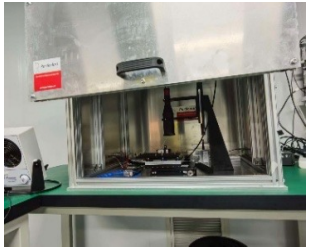
Status of ALICE 3 Inner Tracker in China

(IMP/CAS)

- Institute of Moder Physics (IMP) is part of the Chinese Academy of Sciences (CAS). It operates accelerator research facilities HIRFL and HIAF.
- The Silicon Lab at IMP has participated the development of pixel detectors for experiments at the accelerators of IMP.
- Equipped with machines for pixel chip development and testing (wire bonding machine, optical microscope, laser equipment, etc.).
- A team of experts with the experience of pixel chip development and electronics.





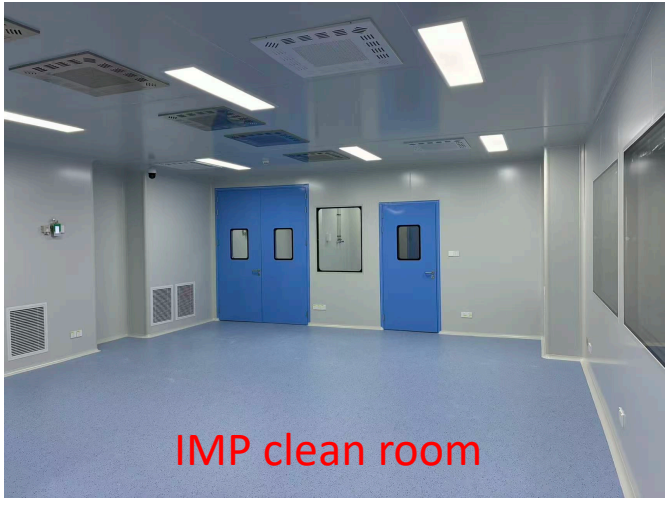






Status of ALICE 3 Inner Tracker in China

(IMP/CAS)

- A new clean room (~70m^2 for 1,000 class cleanliness and ~60m^2 for 10,000 class cleanliness) has been constructed for pixel detector module assembly.
- Planning to build production line to assemble and test modules from pixel detector chips, including chip positioning machine, wire bonding machine, optical inspection equipment, CMM, etc.
- It will equip with module quality assurance instruments (wire pull tester, peel force tester, semiconductor inspection microscopes, etc.) and module testing systems.
- A team is building for the pixel detector module assembly & testing.
- Will upgrade to general-purpose automated assembly and testing platform together with CCNU.











Status of ALICE 3 Inner Tracker in China

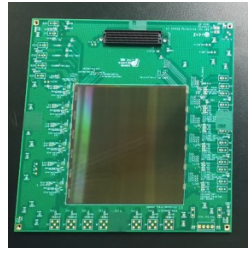
(SDU)

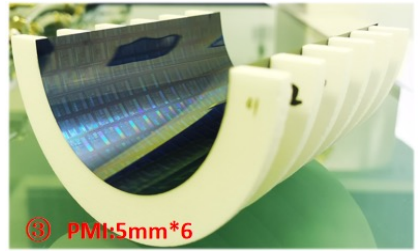
- **Previous project experience**
  - ✓ **CMOS Pixel Sensor Design**

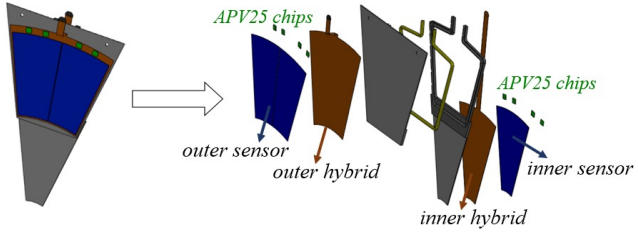
    CMOS Pixel Sensors: Developed Supix sensors and wafer-scale sensor designs.

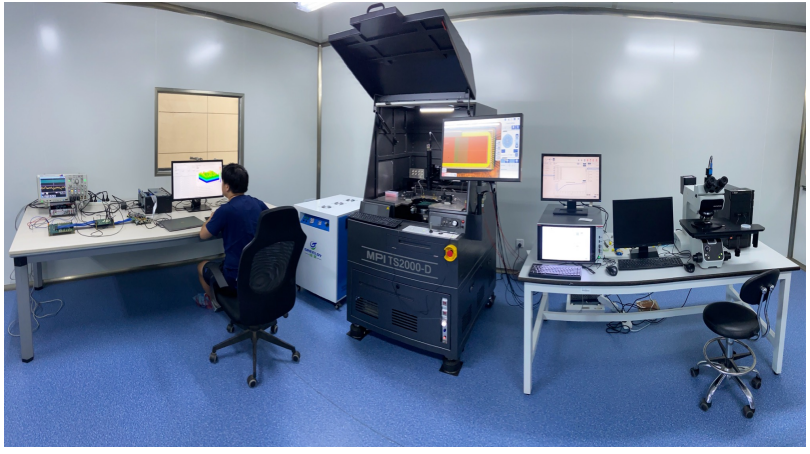
    Collaborative Projects: Participated in design/test of Taichupix/Jadepix3 (CEPC) and MAPS (STCF).

  - ✓ **STAR FST: Flexible Hybrid Boards Design**
  - ✓ **CMS Timing system: MUX64 chip Testing**















Status of ALICE 3 Inner Tracker in China

(SDU)

- **Available Resources & Expected Role**

Small Batch Test System for chip

- Source Meters: Keithley 2636B
- DMM(6 ½): Keithley DMM6500
- Oscilloscopes: Tektronix MSO64B
- AFG: Tekrtonix AFG31252
- Low-Voltage Power Supplies

Micro/Nano Fabrication & Packaging

- Probe station available：MPI TS2000-D
- Wire-bonding capability
- ~150m² clean room is planned for the near future.

Human Resources

Sensor design：

- 1 faculty
- 2 PhD students
- 1-2 graduate students

Assembly and testing：

- 1 faculty
- 1-2 graduate students
- 1-2 full-time engineers (in need of training)

Expected Role in ALICE3-IT

We hope to contribute to:

- Sensor design
- the assembly and testing phases of the ALICE3-IT detector construction

Status of ALICE 3 Inner Tracker in China

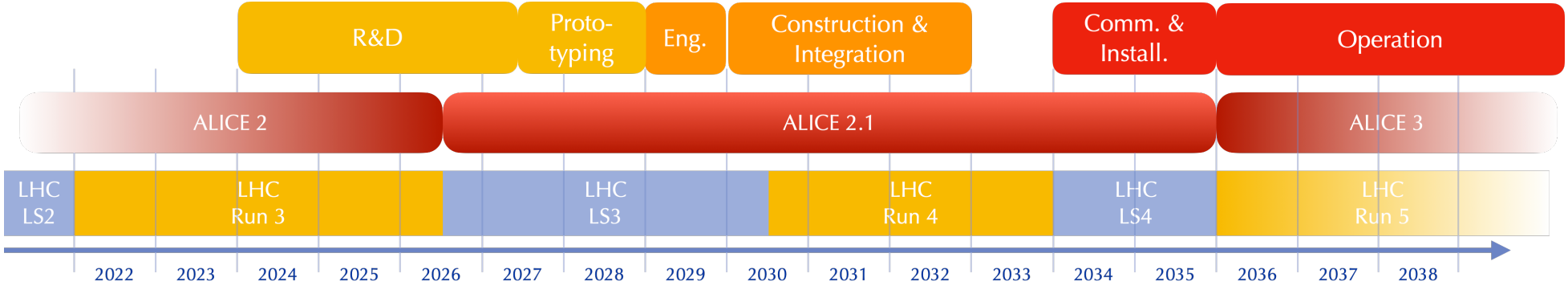
(UCAS, UCG)

- UCAS and UCG expressed interests to the simulation, performance, et al.
- UCAS also plans to make efforts to hardware contribution, lab is under preparation

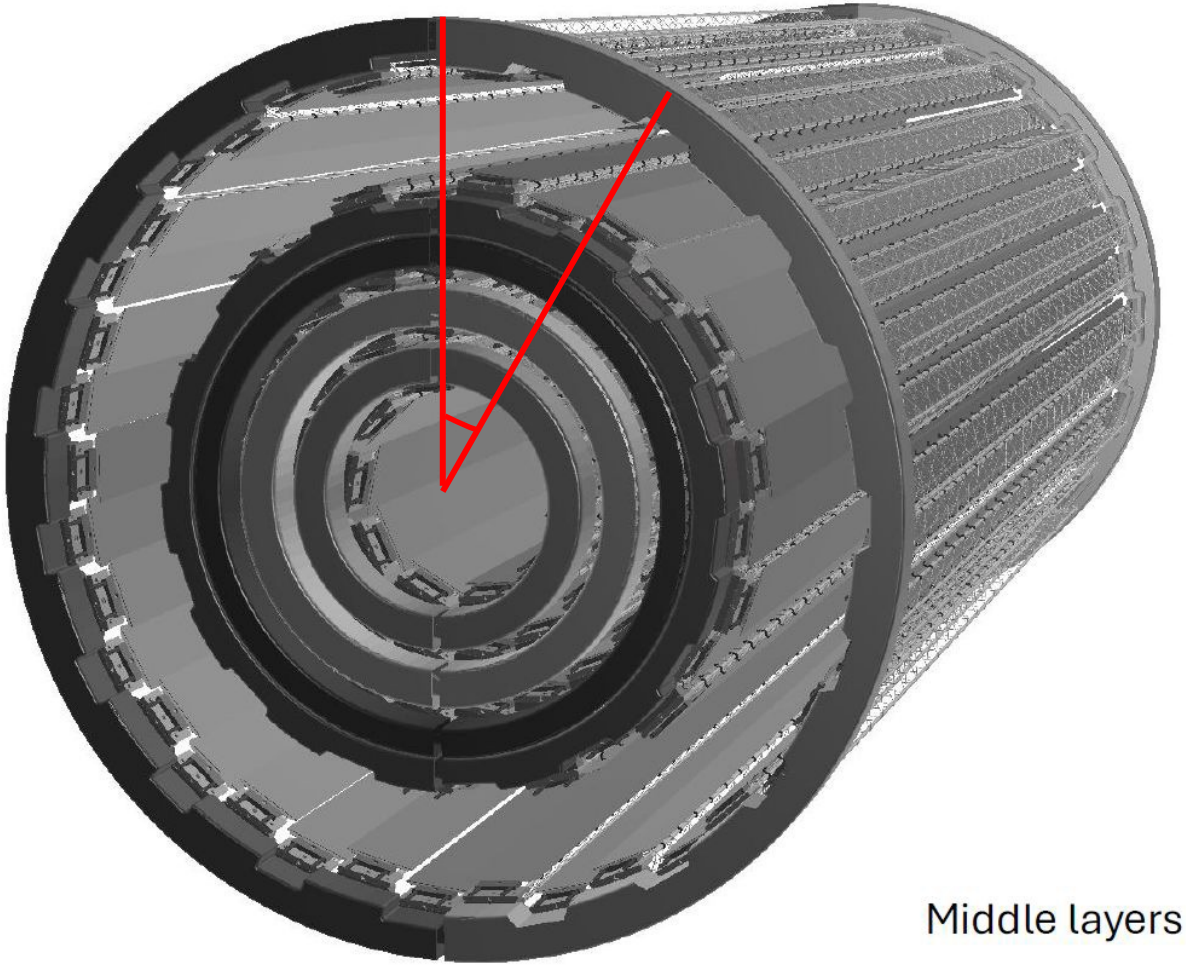
Summary & Outlook

- ✓ ALICE 3: Advanced detector technology and extremely low material budget, designed to study and address open questions in QCD physics left to be studied at the LHC
- ✓ 8 Chinses institutes express strong interests to the ALICE 3 Inner Tracker project, and all of them have HEP experimental project experiences.
- ✓ Among these institutions, available infrastructure and manpower resources are ready for the ALICE 3 IT project, and the needed infrastructure construction and/or upgrade is underway.

Thanks for your attention!



Summary & Outlook



Middle layers

China side: construct 1/12th of the full system (ALICE 3 IT)

MAPS chip → Module → Integration/Cooling → Powering → Readout/DAQ → Alignment/Calibration