First results of the newly installed, MAPS based, ALICE Inner Tracking System

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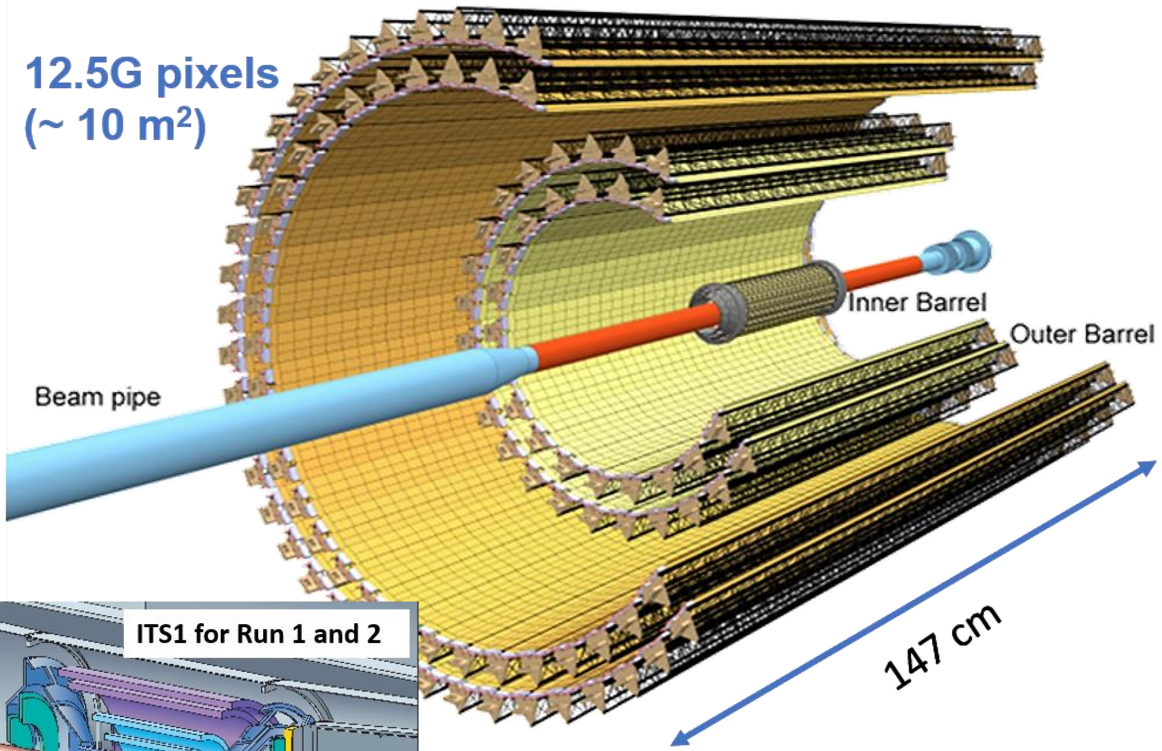
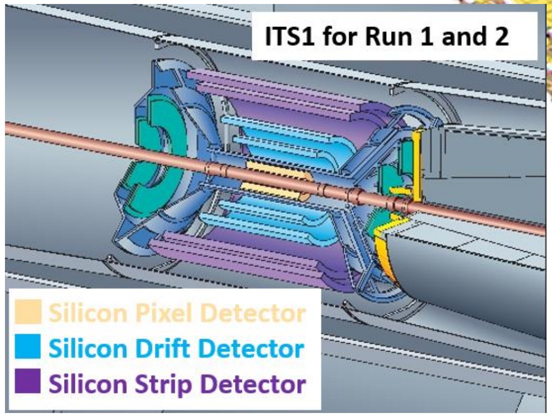
on behalf of the ALICE Collaboration

European Physical Society Conference on High Energy Physics 2021

26-30 July 2021, Online Event

Inner Tracking System Upgrade – ITS2



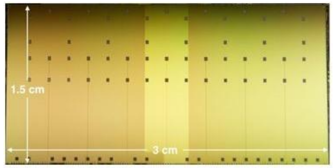


Sensor specification:

- TowerJazz 180 nm CiS Process, full CMOS
- Sensor size: 1.5 cm x 3 cm
- Pixel pitch: 27 µm x 29 µm
- Thickness: 50 µm (IB), 100 µm (OB)

Radiation hardness:

- TID: ~ 270 krad
- NIEL: ~ 1.7×10^{13} n_{eq}



Entirely Monolithic Active Pixel Sensor (MAPS) based

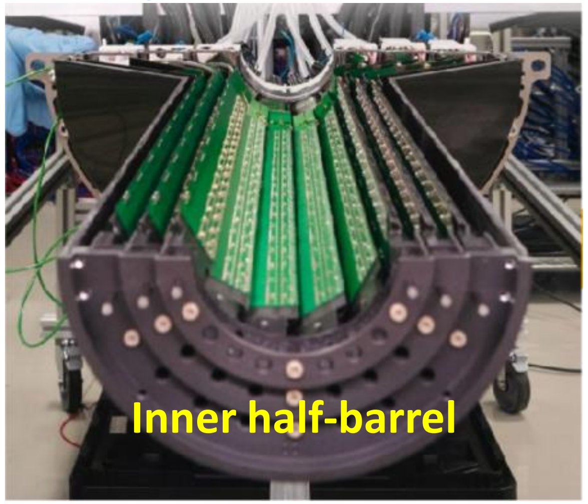
- 7 cylinders covering ~ 10 m^2 area
  - Inner Barrel (IB): 3 Inner Layers (48 staves)
  - Outer Barrel (OB): 2 Middle Layers (54 staves) + 2 Outer Layers (90 staves)
- Fake-hit rate (FHR) requirement: < 10^{-6} /event/pixel
- Detection efficiency requirement: > 99%
- Fast removal/insertion of inner barrel for yearly maintenance

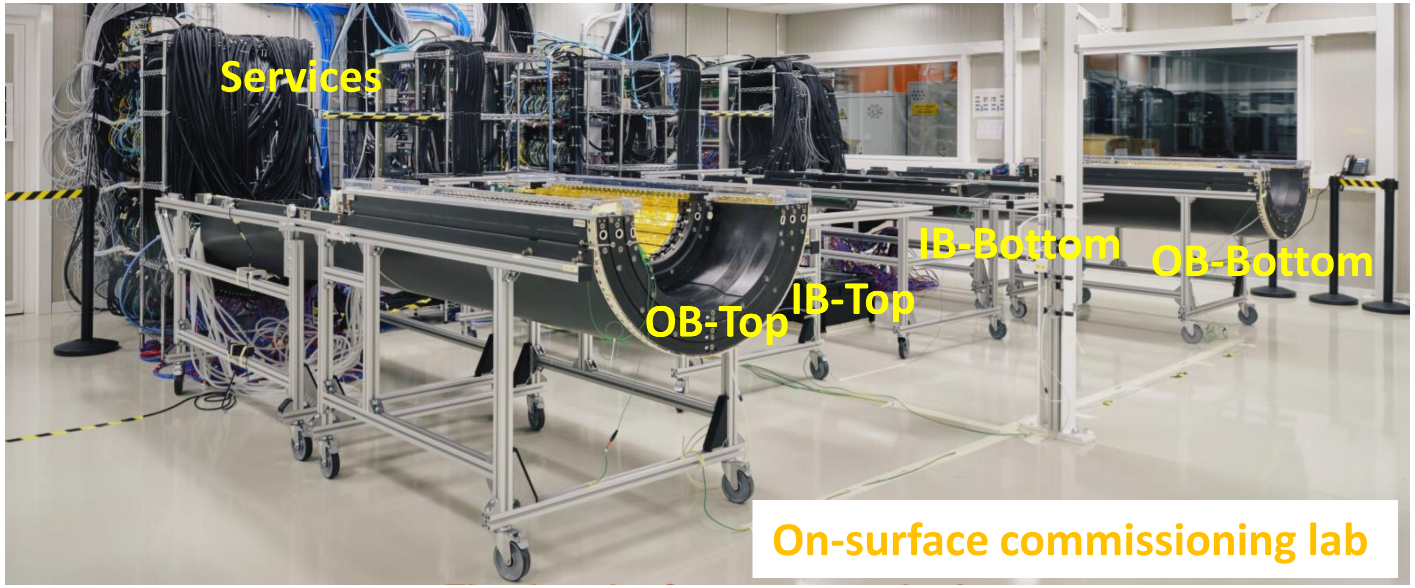
	ITS1	ITS2
Technology	Hybrid, drift, strip	MAPS
Layers	6	7
Spatial resolution	12 µm x 100 µm	5 µm x 5 µm
Radius	39 – 430 mm	22 mm – 400 mm
Pseudorapidity	$-1 \le \eta \le 1$	$-1.4 \le \eta \le 1.4$
Material budget	~ 1.14% X_0	~ 0.3% X_0 (inner barrel), ~ 1% X_0 (outer barrel)
Readout capability	1 kHz	>100 kHz (Pb-Pb), >1 MHz (pp)

"Technical Design Report for the Upgrade of the ALICE Inner Tracking System"
ALICE Collaboration, J.Phys. G41 (2014) 087002, CERN-LHCC-2013-024

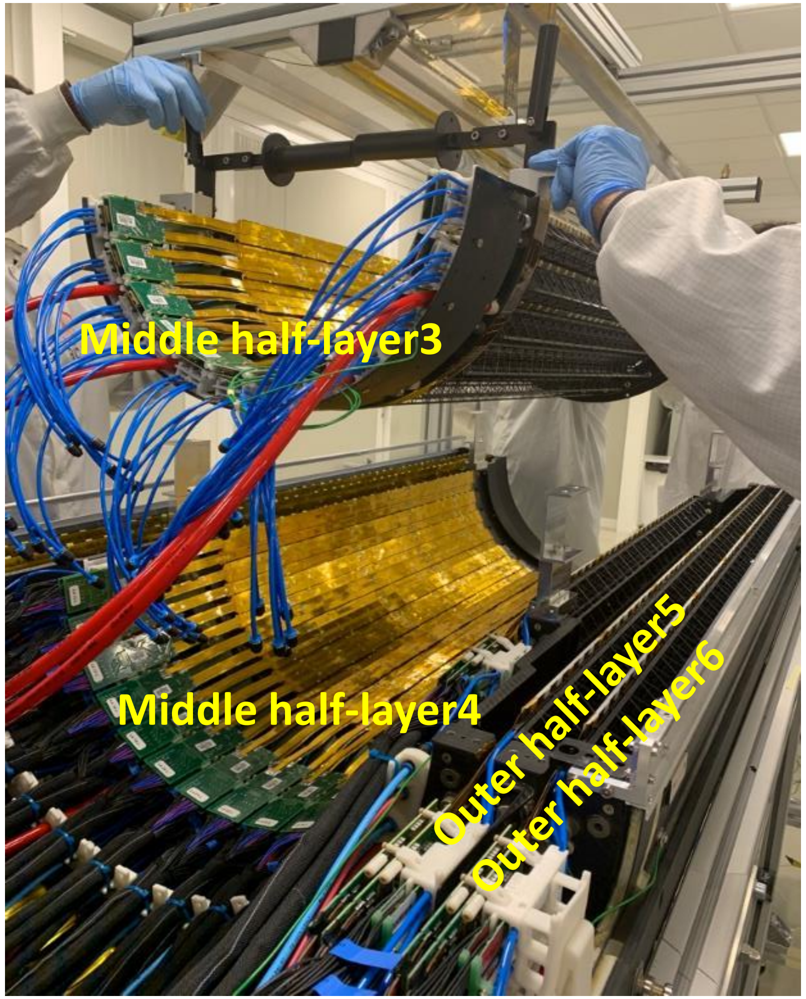
Layer and Barrel Assembly

Inner Barrel assembly



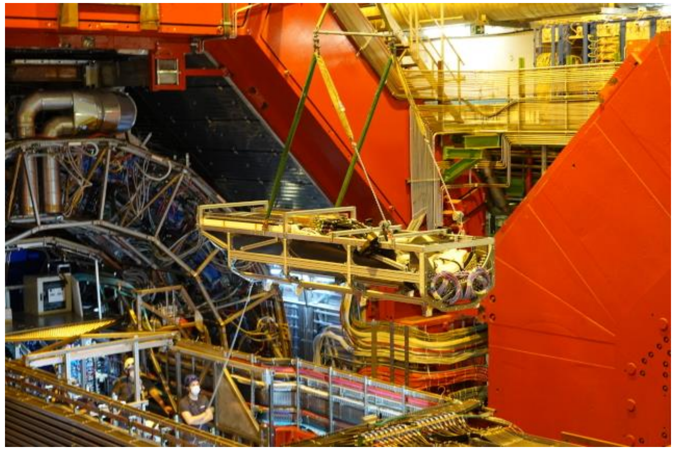


Outer Barrel assembly

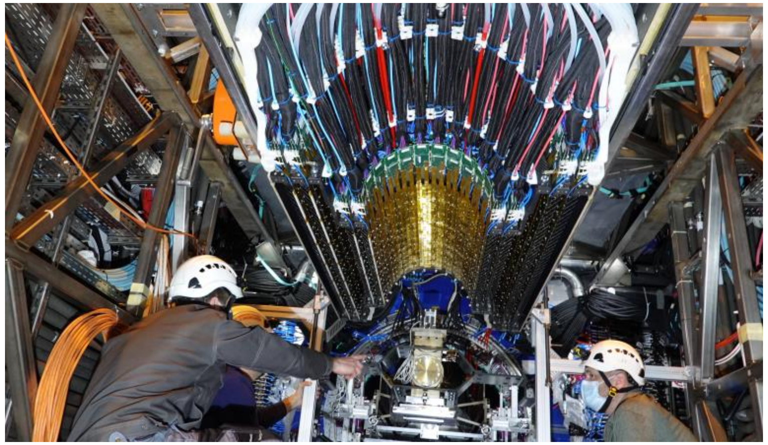


Detector fully assembled in Dec. 2019

Installation

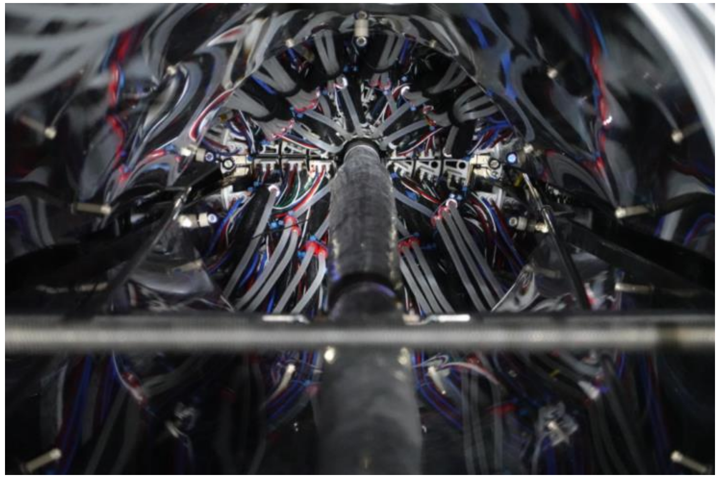


OB-Bottom being loaded to mini-frame

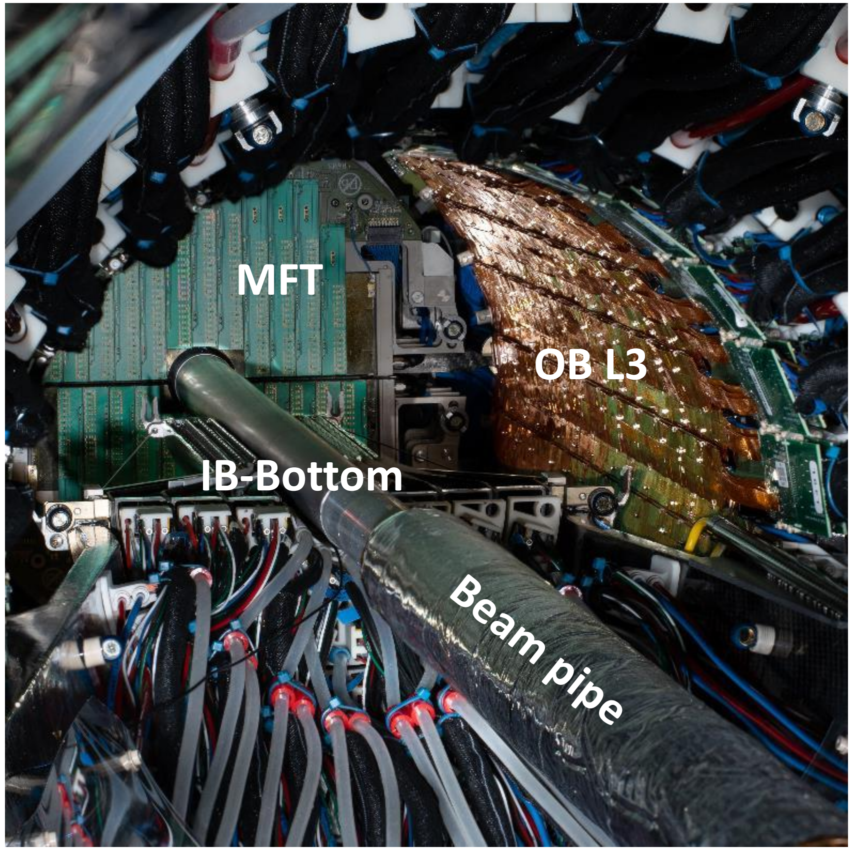


OB-Bottom being positioned

IB being installed



IB installed



OB installation completed – mid March 2021
IB installation completed – mid May 2021

Commissioning - Overall Status (1/2)

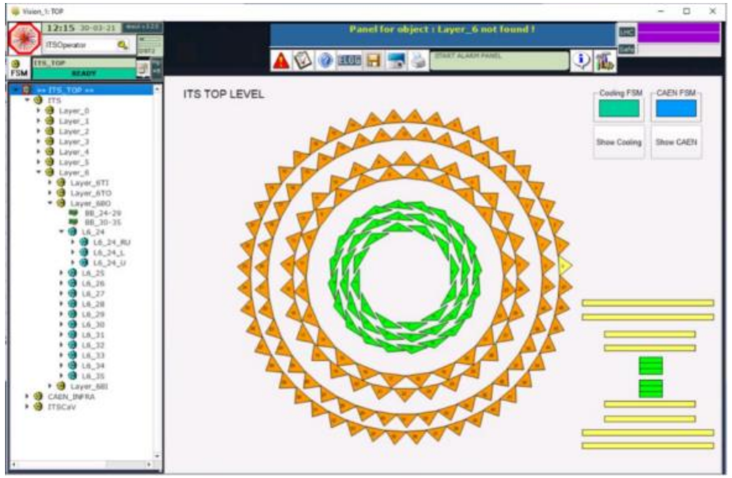
On-surface commissioning

- Commissioning shifts 24/7 started in July 2019
- 3 daily slots with 2 shifters + 1 shifter leader
- Completed in December 2020
- Verification of detector performance and long stability of parameters
- Detector status monitoring: voltage, current and temperature monitoring
- Standalone data taking: threshold scans, fake-hit rate runs and readout tests
- Offline data quality control

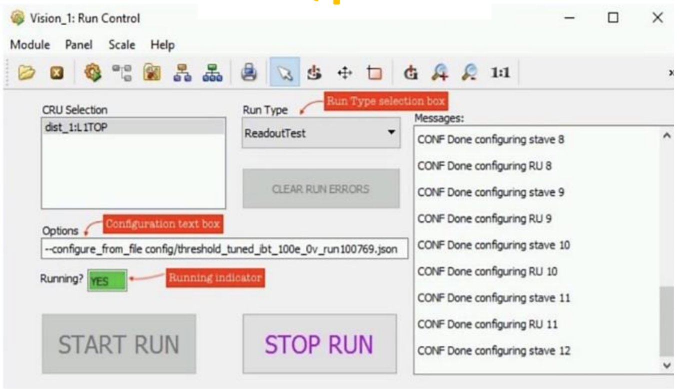
	Half IB	Full IB	OB
Cosmics	~2000 runs ~7 days	~1600 runs ~6 days	~10 hours
Threshold scan	~2000 runs ~15.5 days	~1600 runs ~8.5 days	$O(10^2)$ runs $O(10)$ days
Readout test	~2000 runs ~30 days	~2700 runs ~55 days	$O(10^2)$ runs

DCS: Detector Control System
DAQ: Data Acquisition
QC: Quality Control

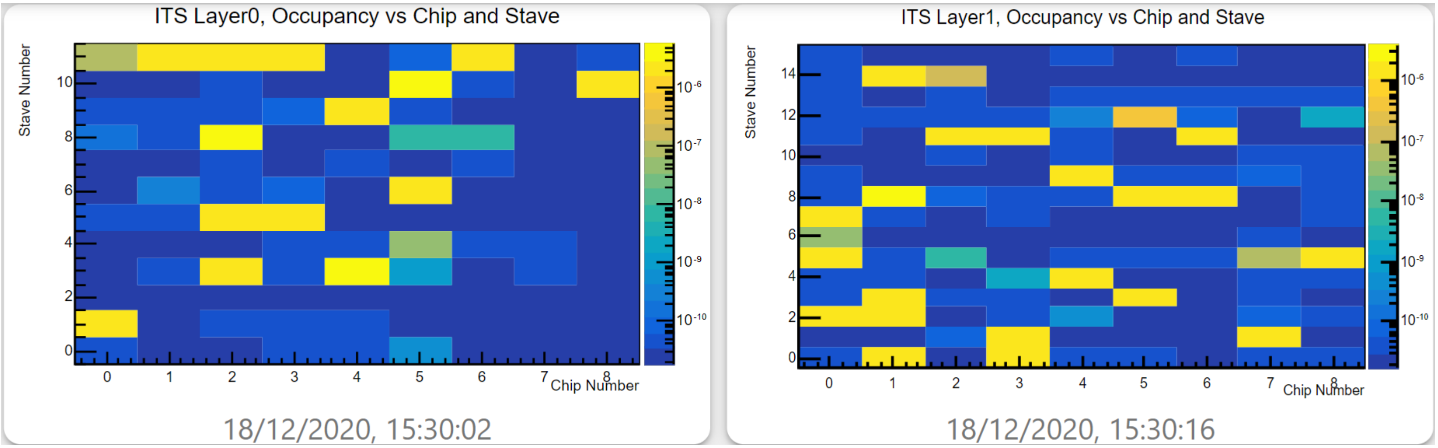
DCS panel



DAQ panel



QC panel (Fake-hit rate)

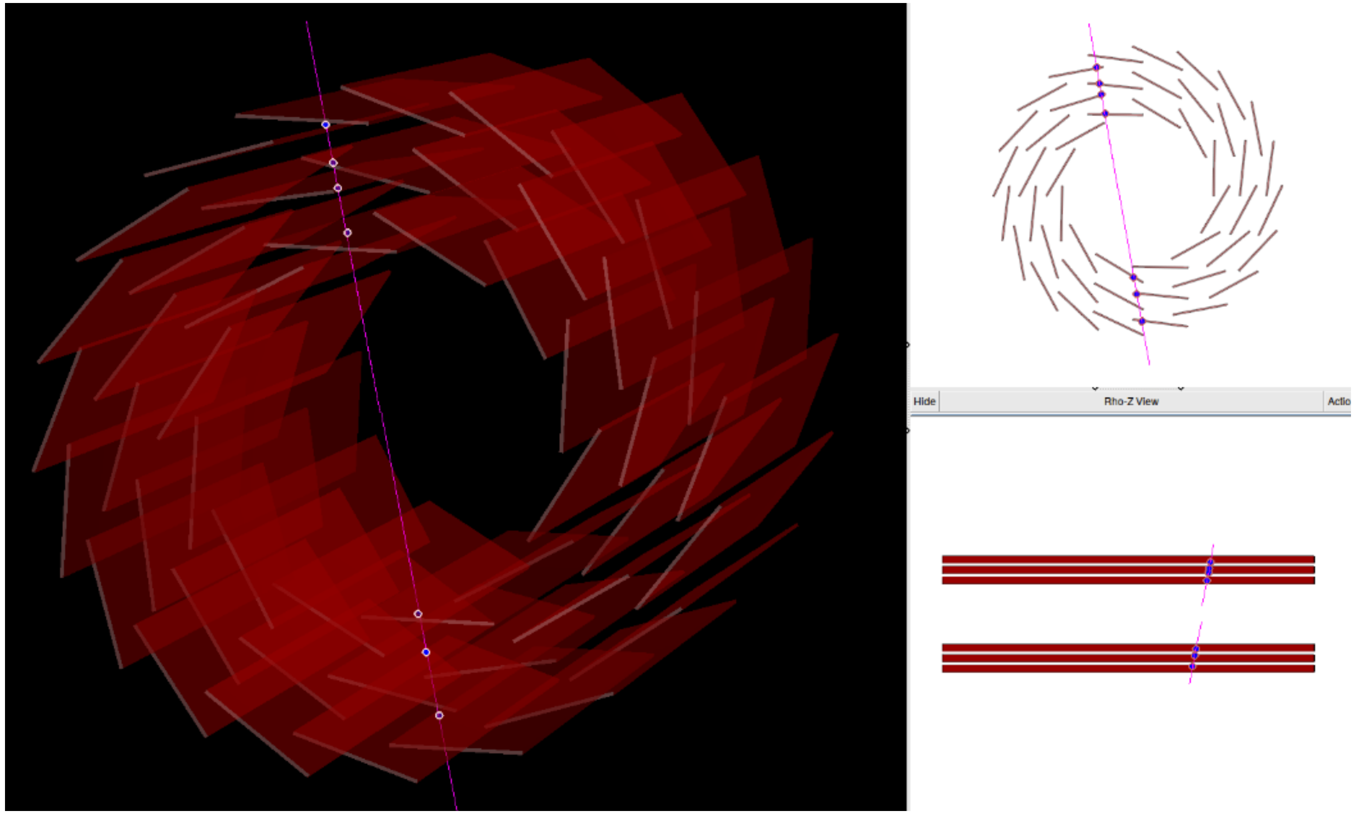


Commissioning - Overall Status (2/2)

***In-situ* commissioning**

- Standalone (April – June 2021)
  - Similar shift configuration as the on-surface commissioning
  - Central system integration
  - Detector status monitoring + expert tests
  - Detector validated after the installation in the cavern
- Global (July – December 2021)
  - Shifts organized by ALICE + ITS on-call shifts
  - Central system integration/benchmarking
  - Validation/finalization of the online data processing/monitoring chain
  - Detector alignment + calibration
  - Technical + physics (cosmics + pilot beams, etc) runs

A cosmic track from the full IB

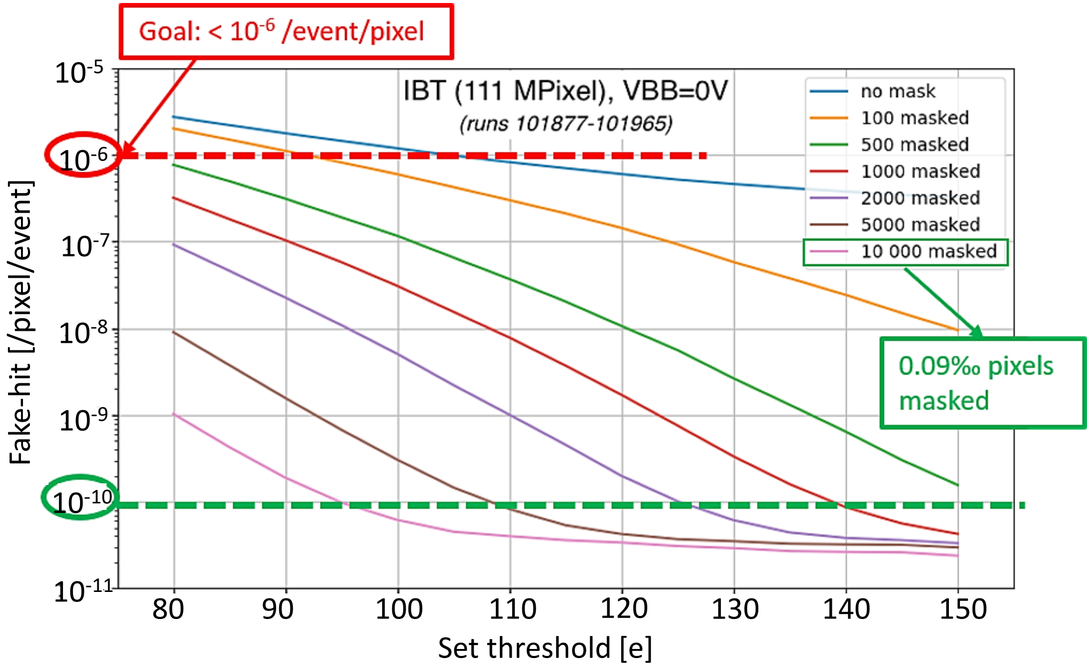


See Giulio Eulisse's talk: "O2/PDP: Preparation for data processing and analysis in LHC Run 3"

Commissioning – Fake-hit rate

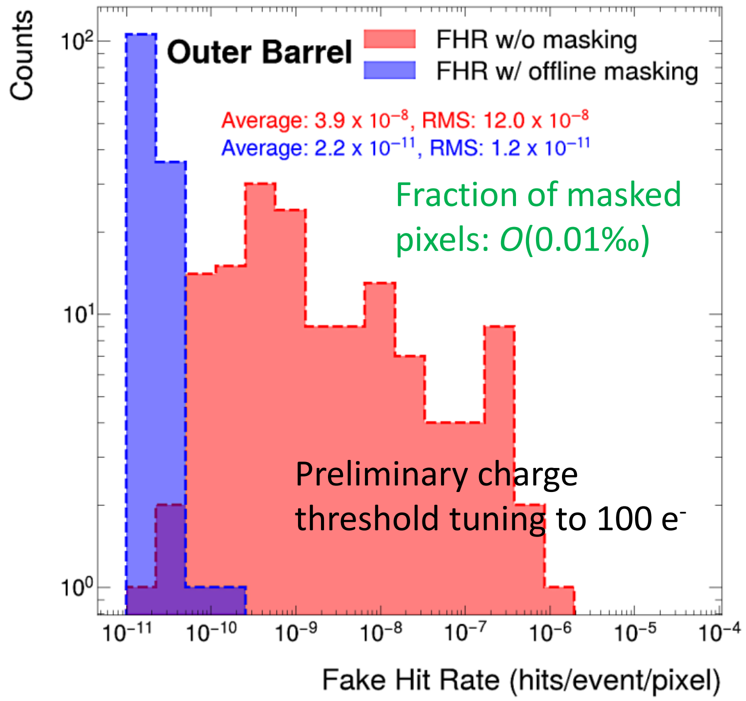
Inner Barrel:

- Measurement performed on half IBs
- Noisy pixels stay stable over time
- Running the IB at a fake-hit rate below 10^{-10}/pixel/event seems feasible



Outer Barrel:

- Fake-hit rate runs using fixed settings
- Slight variations in the voltage applied to chips require 5-10 runs to detect all the hot pixels
- Masking the noisy pixels in each run, the average FHR reaches ~10^{-11}/event/pixel for all staves over 23688 chips (12.4G pixels)



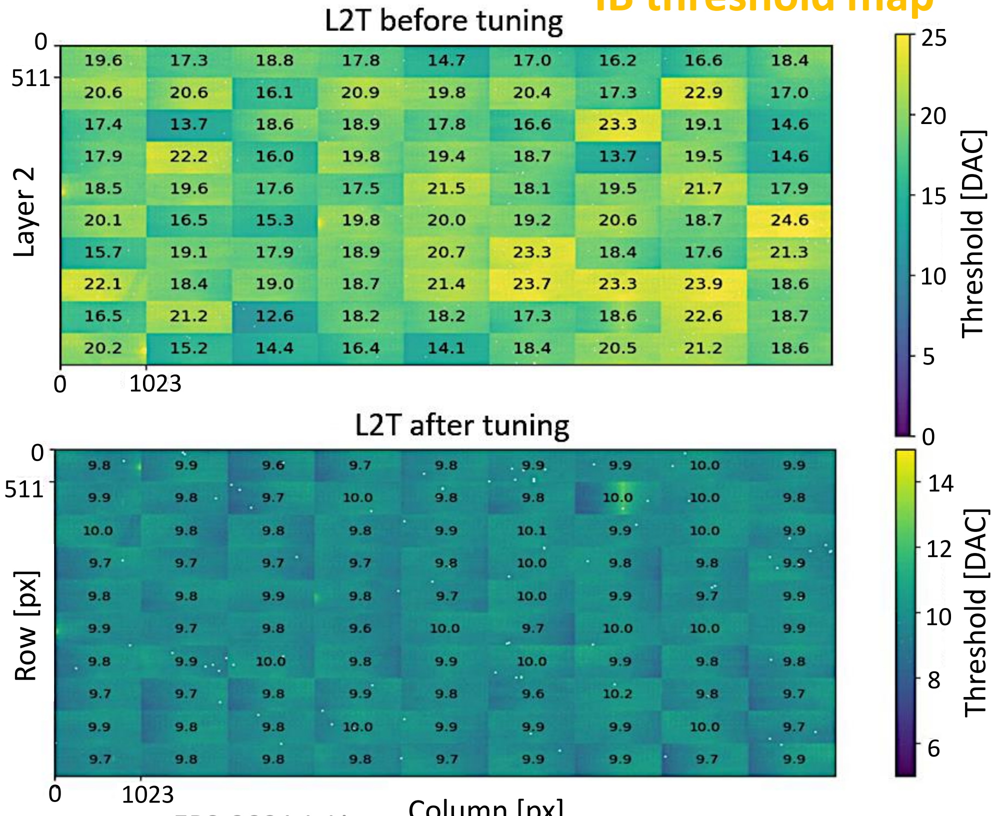
Extremely quiet detector!

Commissioning – Threshold

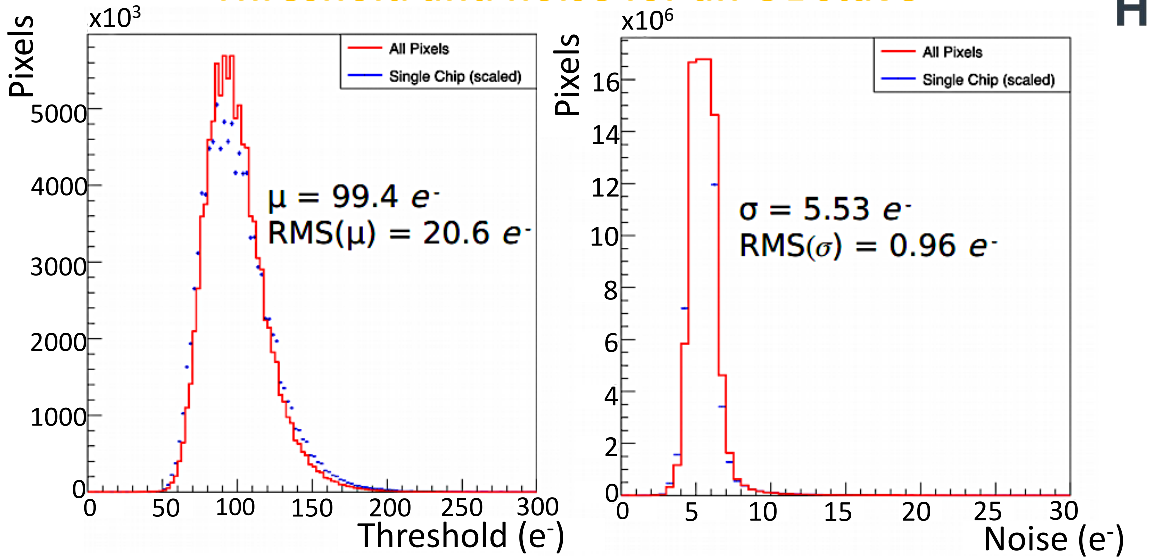
Threshold

- Chip-wide adjustment of front-end parameters to optimize the charge thresholds
- Achieving uniform response across the detector
- Very satisfying threshold stability over time

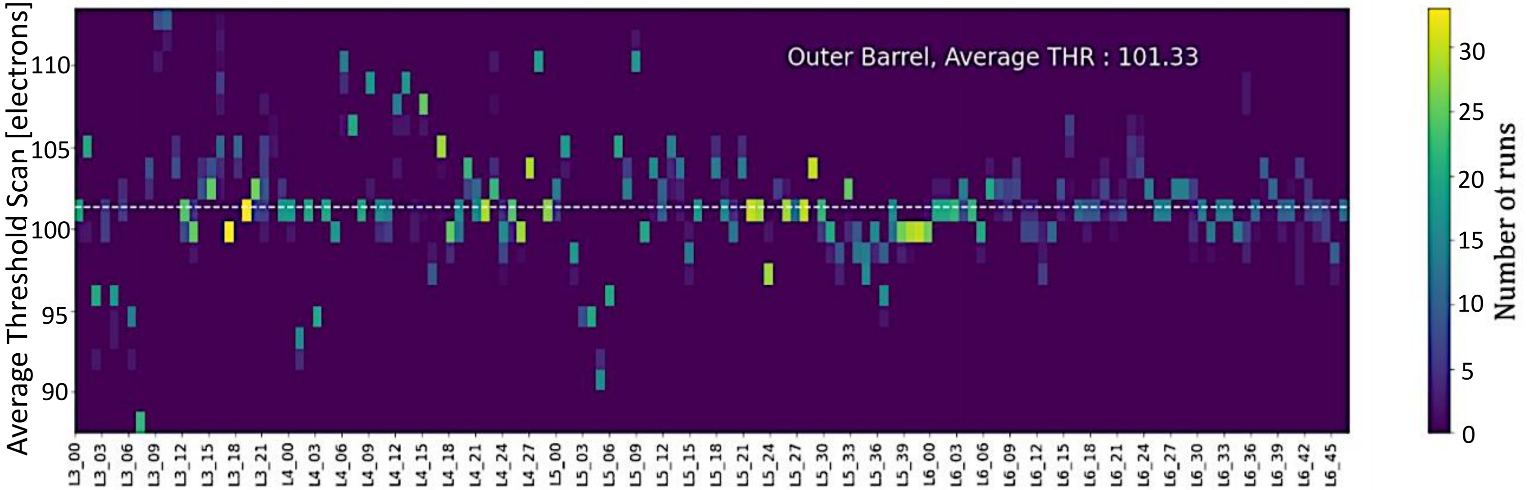
IB threshold map



Threshold and noise for an OL stave



Average threshold for OB staves



Commissioning – Reconstruction

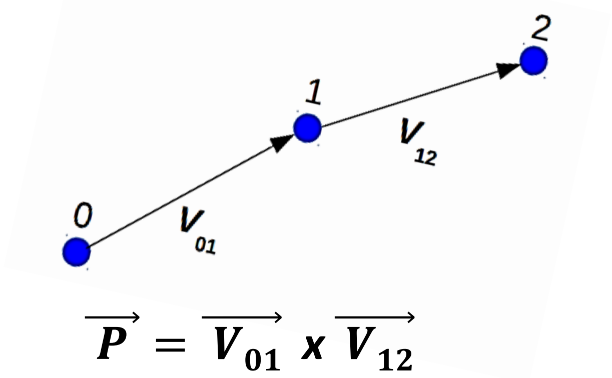
Goals: study track and cluster parameters, alignment

- Excellent training for readout chain, raw-data decoding, geometry, calibration and cluster finding
- Fully reconstructed in March 2021
- IB and OB misalignment O(100 µm)
- OB efficiency > 99.5% (see next slide)

Preliminary

	Period	Eff. exposure (@44 kHz)	Num. of track candidates
IBT	Sep. – Dec. 2020	72 h	1.4×10^6
IBB	Feb.– Dec. 2020	105 h	1.7×10^6

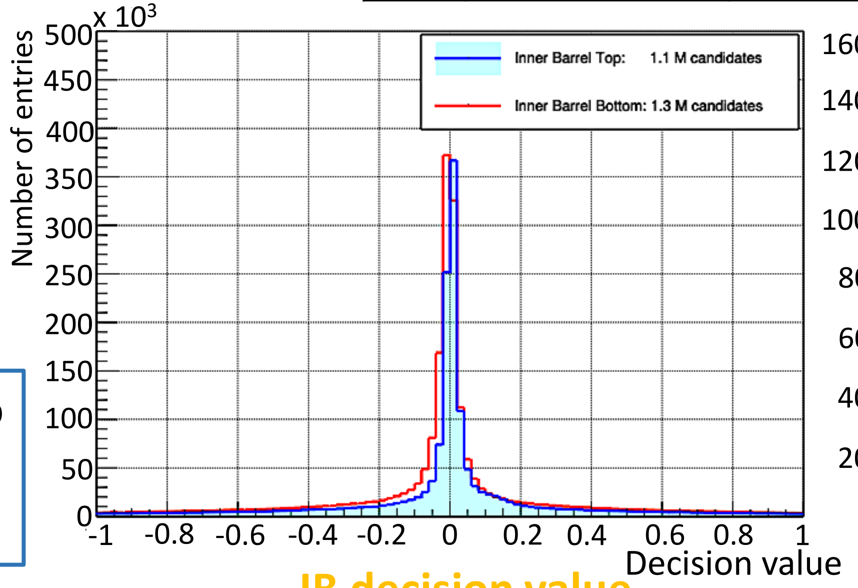
	Period	Eff. exposure (@11 kHz)	Num. of track candidates
OBT	Nov. – Dec. 2020	10.7 h	2.5×10^6
OBB	Nov. – Dec. 2020	14.5 h	2.7×10^6



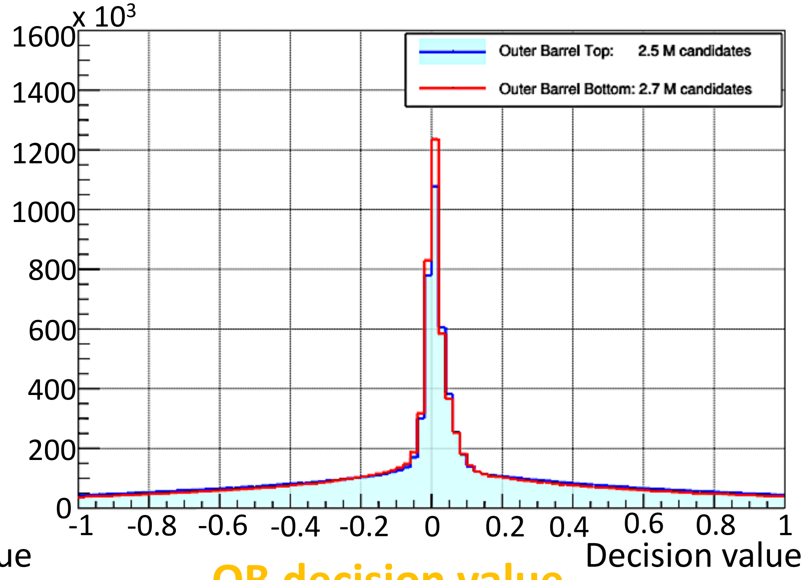
$$\vec{P} = \vec{V}_{01} \times \vec{V}_{12}$$

$$\text{Decision value} = \sin^2(\theta_{v01\text{-}12})$$

Decision value: the vector product of the two vectors connecting the three clusters in the seed candidate



IB decision value

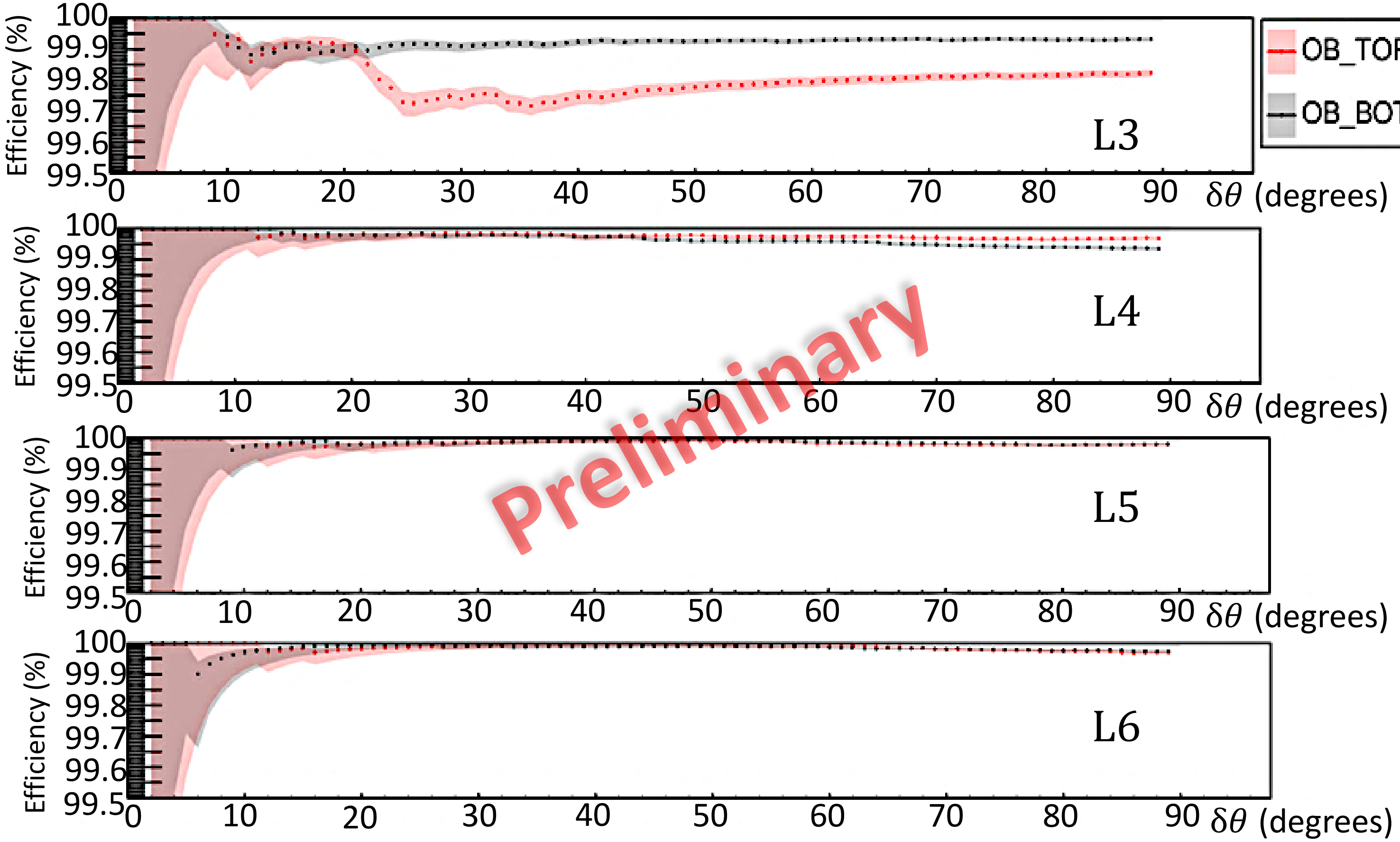


OB decision value

Commissioning – Efficiency

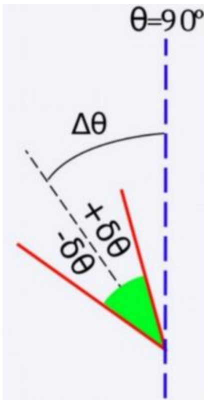
Detection efficiency

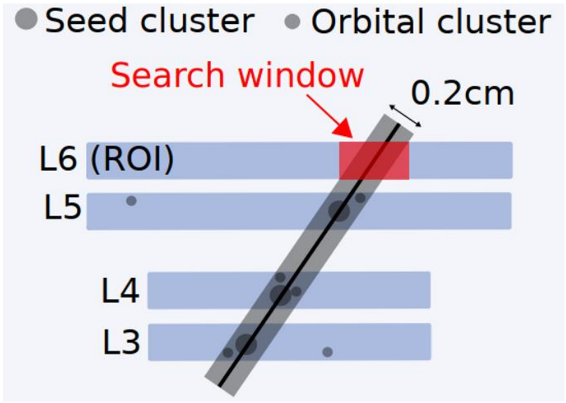
- Cosmic tracks during the on-surface commissioning
- Efficiency >99.5% (±0.3%) → requirement satisfied



Conditions

- Decision value < 0.1
- $\Delta\theta = 90^o$, $\delta\theta = 10^o$ (~vertical tracks)
- $\chi^2 < 1$ for fit to clusters

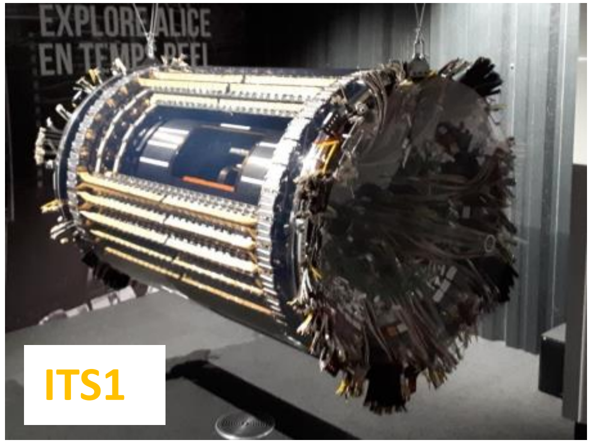


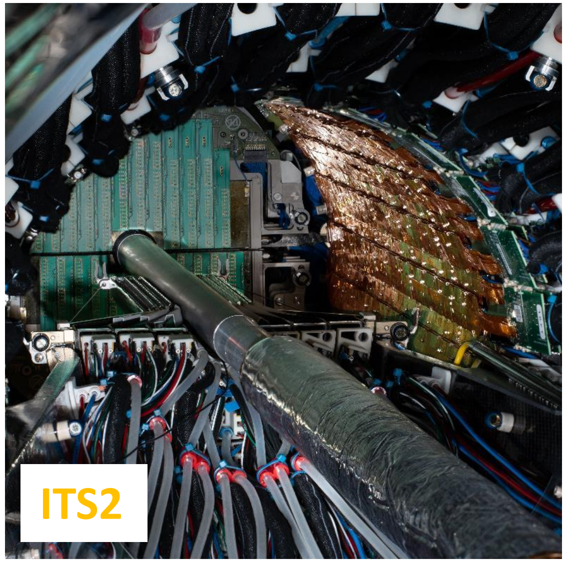


- Cosmic track candidate extrapolated onto the fourth layer
- Straight line fit to the clusters
- Refit the track by taking into account the clusters which lie < 0.2 cm away from the track

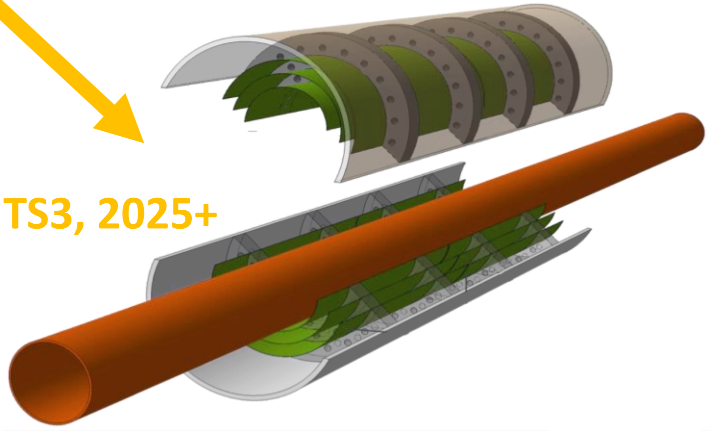
Summary

- ITS2, an all-pixel version based on MAPS, fully installed in the ALICE experiment as part of the ALICE upgrade in May 2021
- Commissioning in the laboratory completed in December 2020, shows excellent performance
- *In-situ* commissioning started from mid April (standalone + global commissioning)
- ALICE cavern closure expected in February 2022 → LHC Run 3
- A further upgrade of the ITS Inner Barrel (ITS3), based on TowerJazz CMOS 65 nm technology with bent wafer-scale stitched sensors, is approved for the LHC Long Shutdown 3 and R&D is on-going





ITS3, 2025+



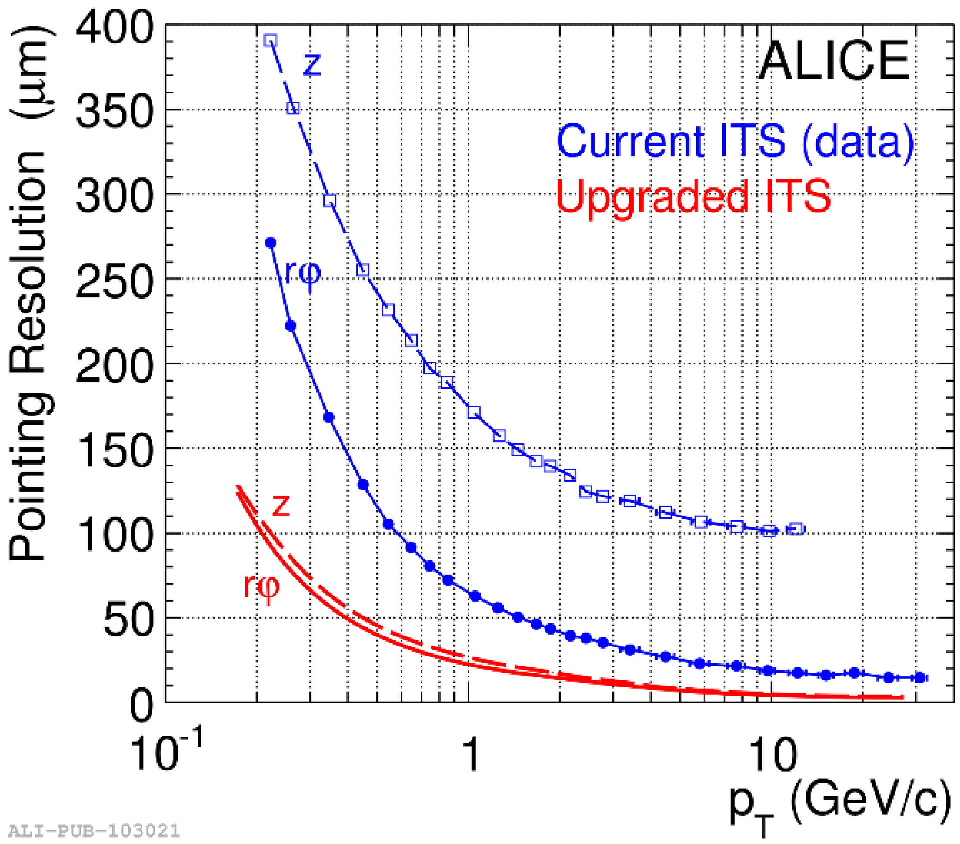
See Filip Krizek's talk: "Future upgrades of ALICE for Run 4"

Backup

ITS Upgrade Simulated Performance

Pointing resolution

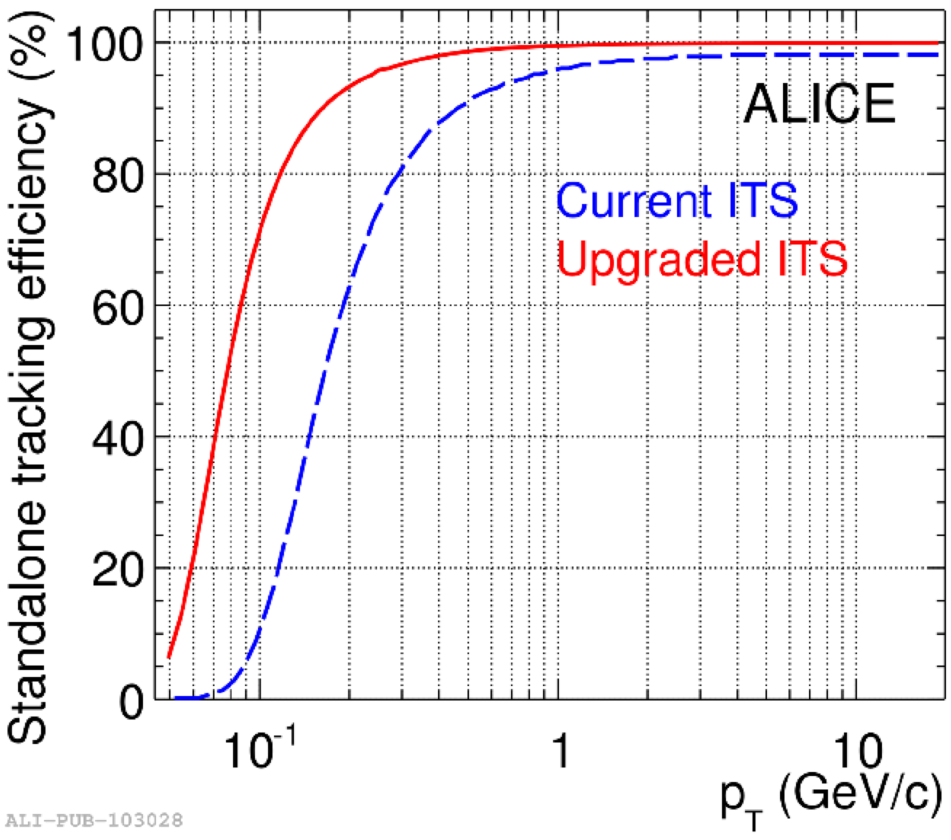
- *x3* and *x6* improvement in rφ and z for 0.5 GeV/c π
- 40 μm for 0.5 GeV/c π



ALI-PUB-103021

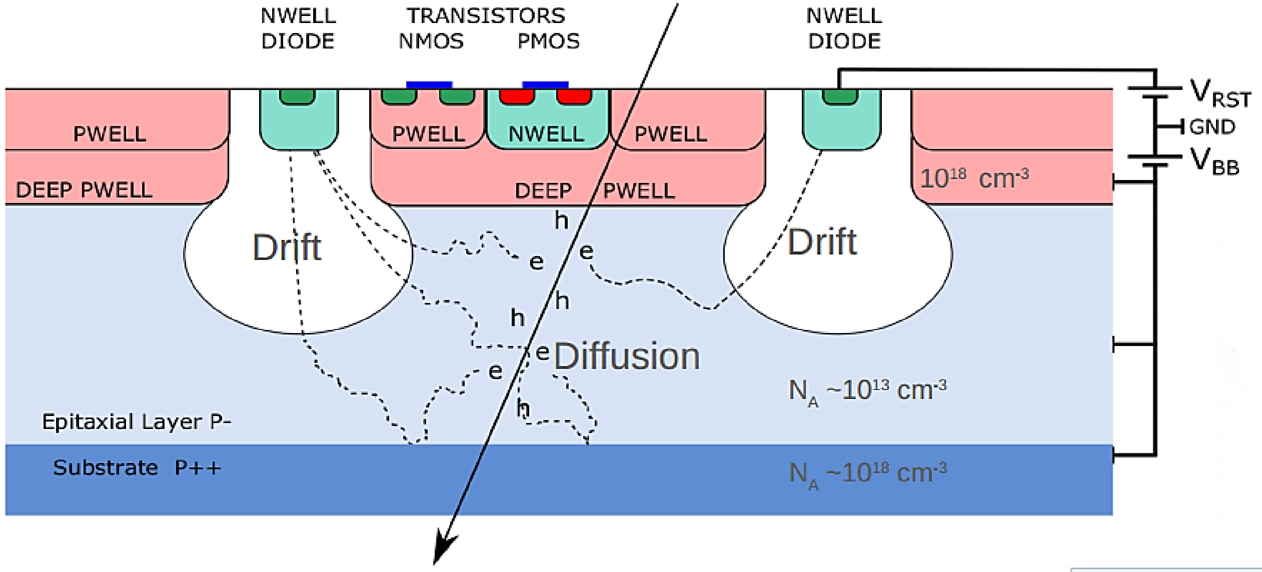
Standalone tracking efficiency

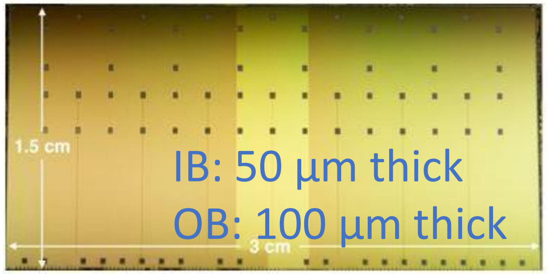
- > 60% for 0.1 GeV/c π
- > 95% for π with p_T > 0.3 GeV/c

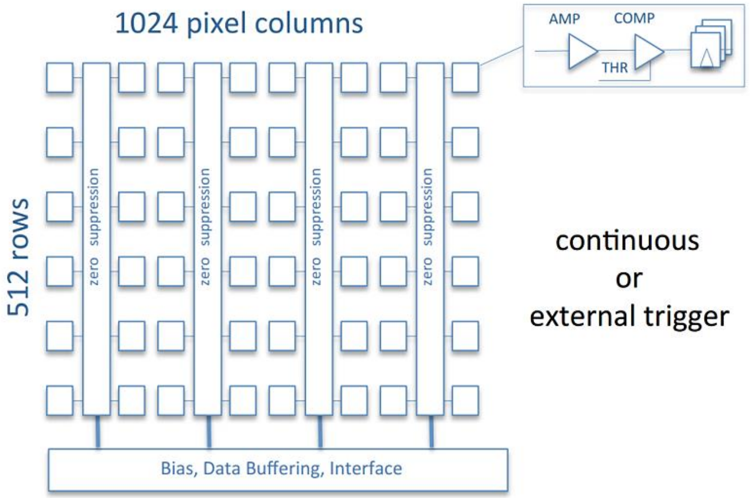


ALI-PUB-103028

ALPIDE: ALICE PIxel DEtector







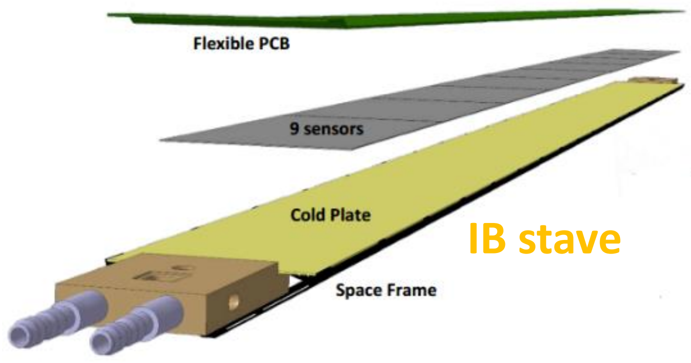
ALPIDE technology features:

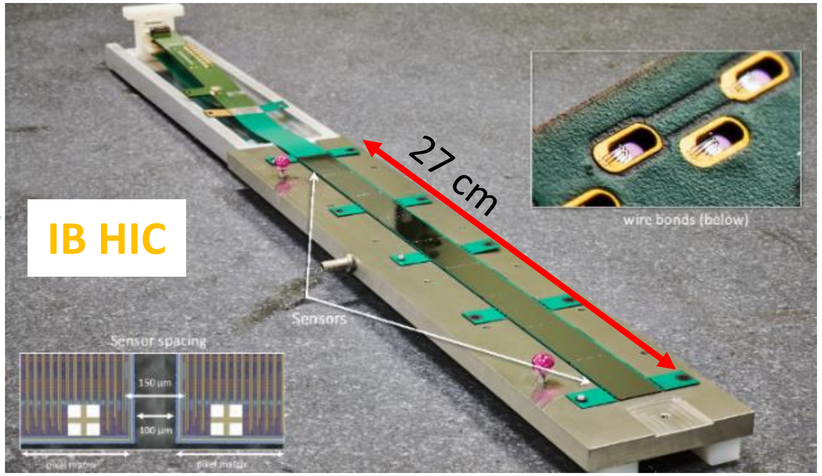
- TowerJazz 180 nm CiS Process, full CMOS
- Deep P-well implementation available
- High resistivity epi-layer (>1 kΩ·cm) p-type, thickness 25 µm
- Smaller charge collection diode → lower capacitance → higher S/N
- Possibility of reverse biasing
- Substrate can be thinned down

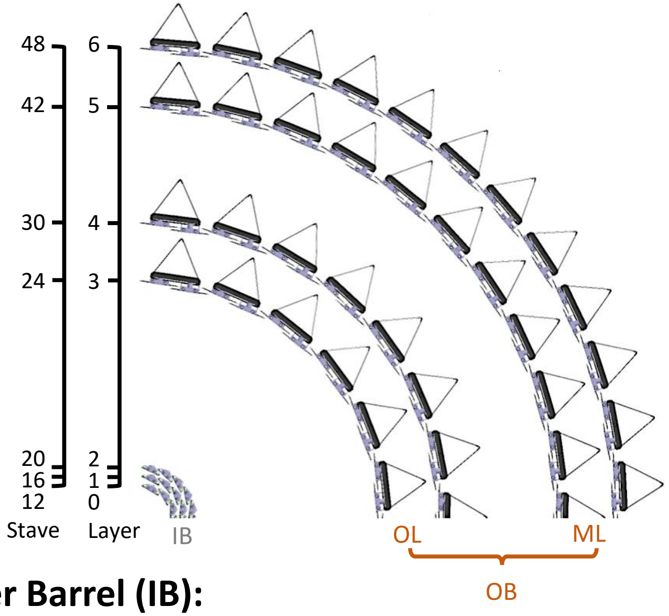
Sensor specification:

- Pixel pitch 27 µm x 29 µm → spatial resolution 5 µm x 5 µm
- Priority Encoder Readout
- Power: 40 mW/cm^2
- Trigger rate: 100 kHz
- Integration time: < 10 µs
- Read out up to 1.2 Gbit/s
- Continuous or triggered read-out

ITS2 Barrels

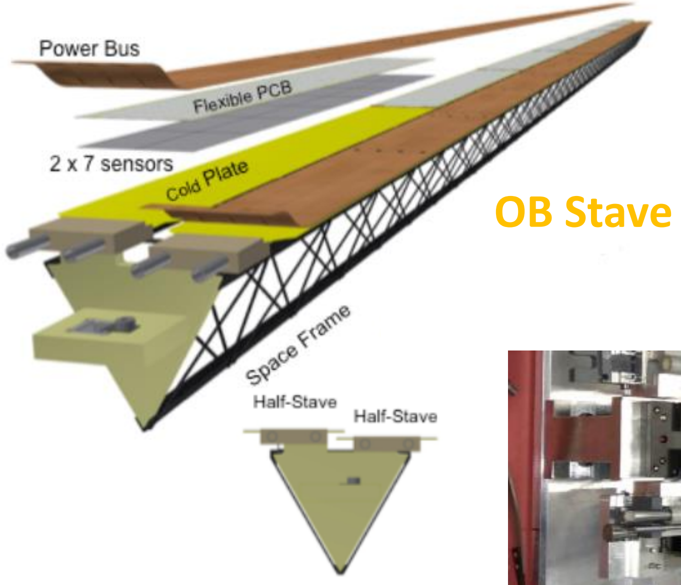


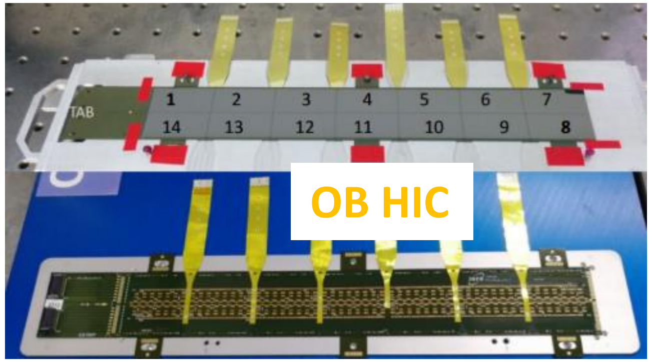


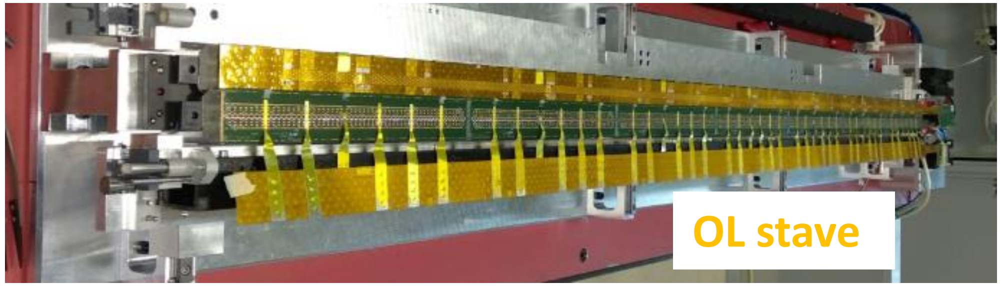


Inner Barrel (IB):

- Hybrid Integrated Circuit (HIC): 9 sensors glued onto Al Flexible Printed Circuit (FPC)
- Wirebonds electrically connect FPC to chips
- Stave: a HIC glued onto cold plate and space frame
- Each sensor is read out individually







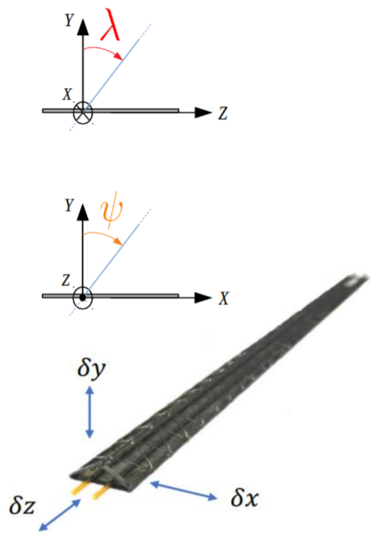
Outer Barrel (OB):

- OB HIC:
  - 7x2 sensors (2 rows) glued onto Cu FPC
  - Power delivered via 6 Al cross-cables soldered to the FPC
  - Data and control are transferred through 1 master chip per row
- OB stave:
  - 4x2 HICs (for ML) or 7x2 HICs (for OL) glued onto cold plate and space frame

Commissioning – Cluster

Cluster shape

- Hit position resolution depends on cluster shape
- Clusters become more elongated in the direction of track inclination
- Similar evolution of cluster shapes for both angles
- Slightly more pixels in the direction of ψ (pixels are shorter along columns)



The tracks selected in λ