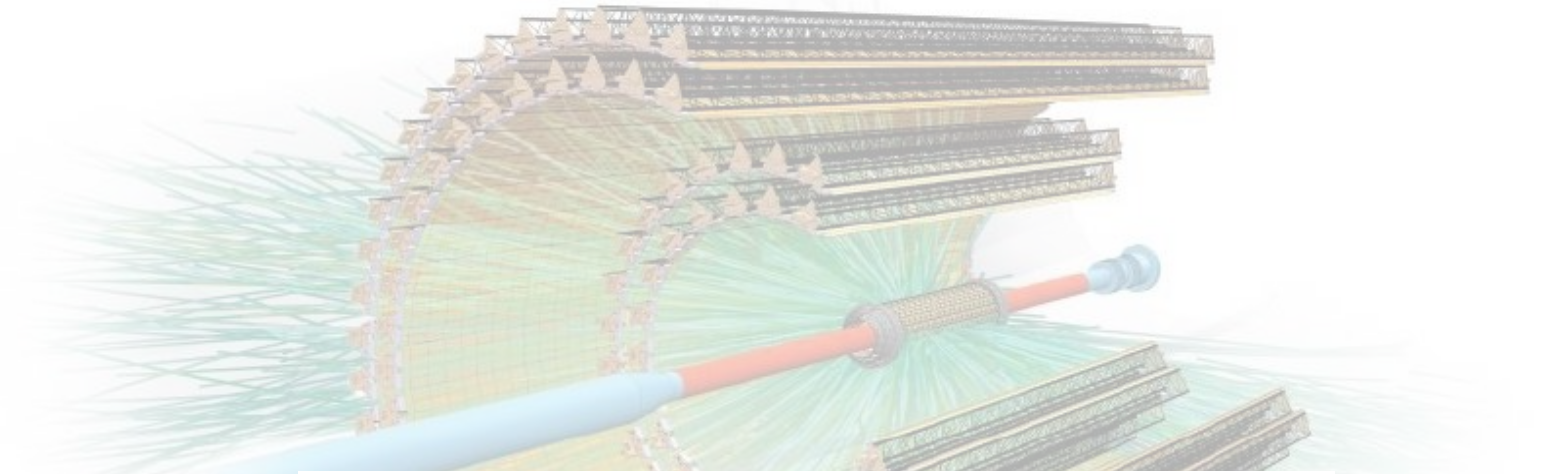
The Inner Tracking System Upgrade for ALICE



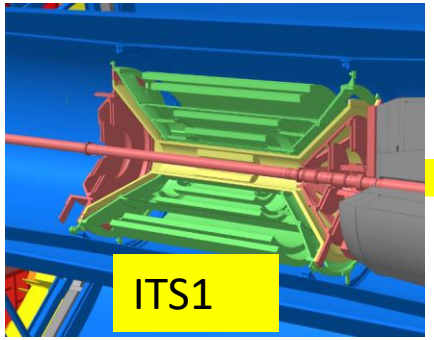
Jian Liu (University of Liverpool)
on behalf of the ALICE Collaboration

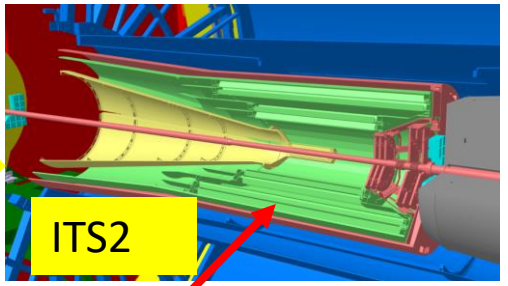
TREDI2020: 15th "Trento" Workshop on Advanced Silicon Radiation Detectors

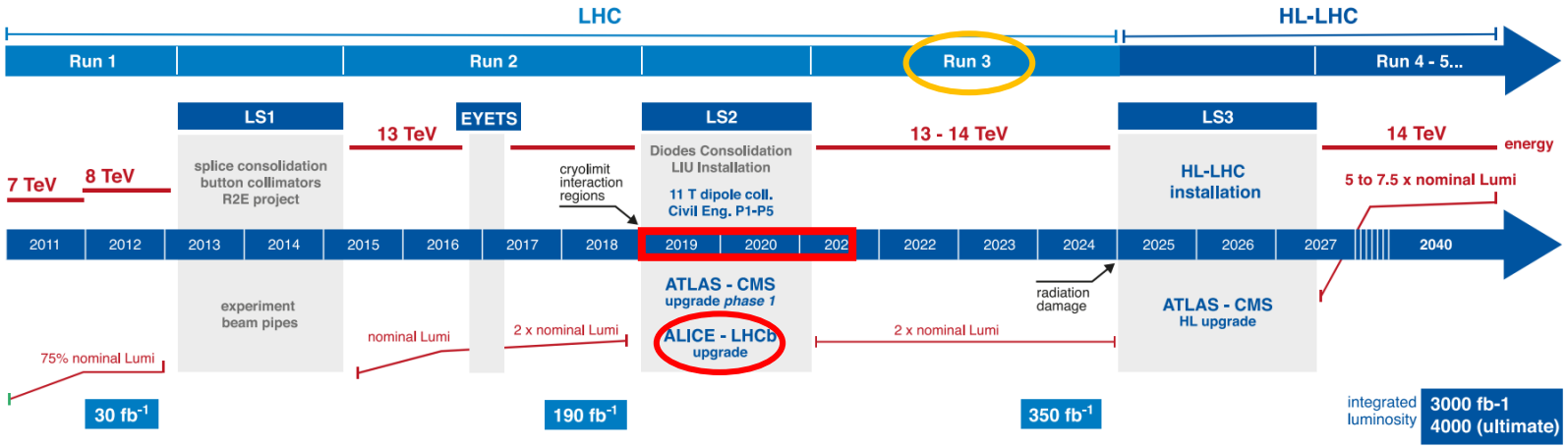
17-19 February 2020, TU Wien

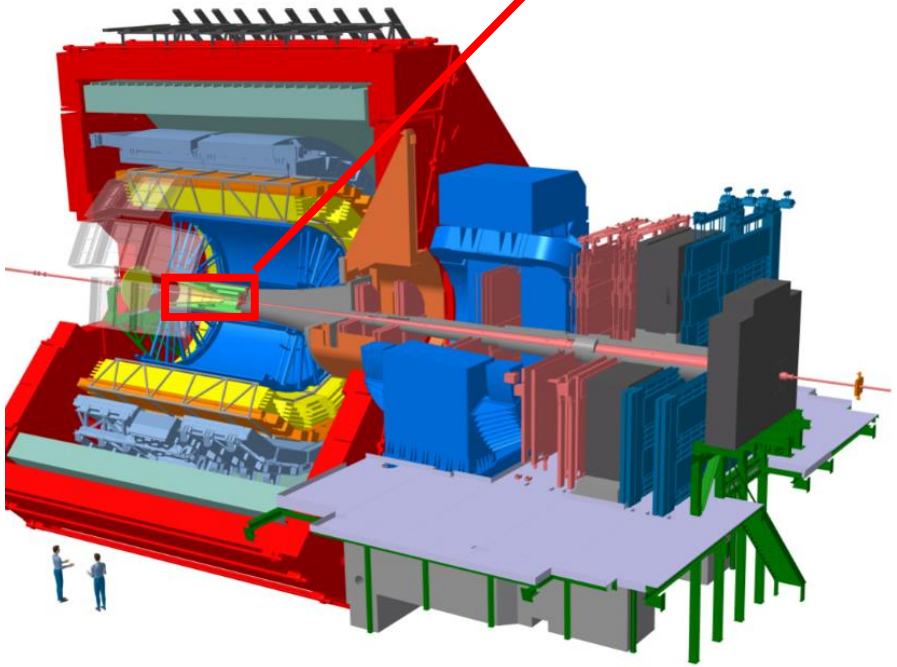
ALICE Upgrade for Run 3

- **Major upgrades** are underway for **ALICE** during LHC long shutdown 2(LS2)
- Physics goals → high-precision measurements of QGP properties
  - Heavy-flavor hadrons and quarkonia at very low p_T
  - Vector mesons and low-mass di-leptons
  - High-precision measurements of light nuclei and hypernuclei
- Main detector requirements for the new Inner Tracking System (ITS2)
  - High tracking efficiency and resolution at low p_T
    - Increased spatial resolution, reduced material budget
  - High statistics
    - Increased readout rate, online data reduction

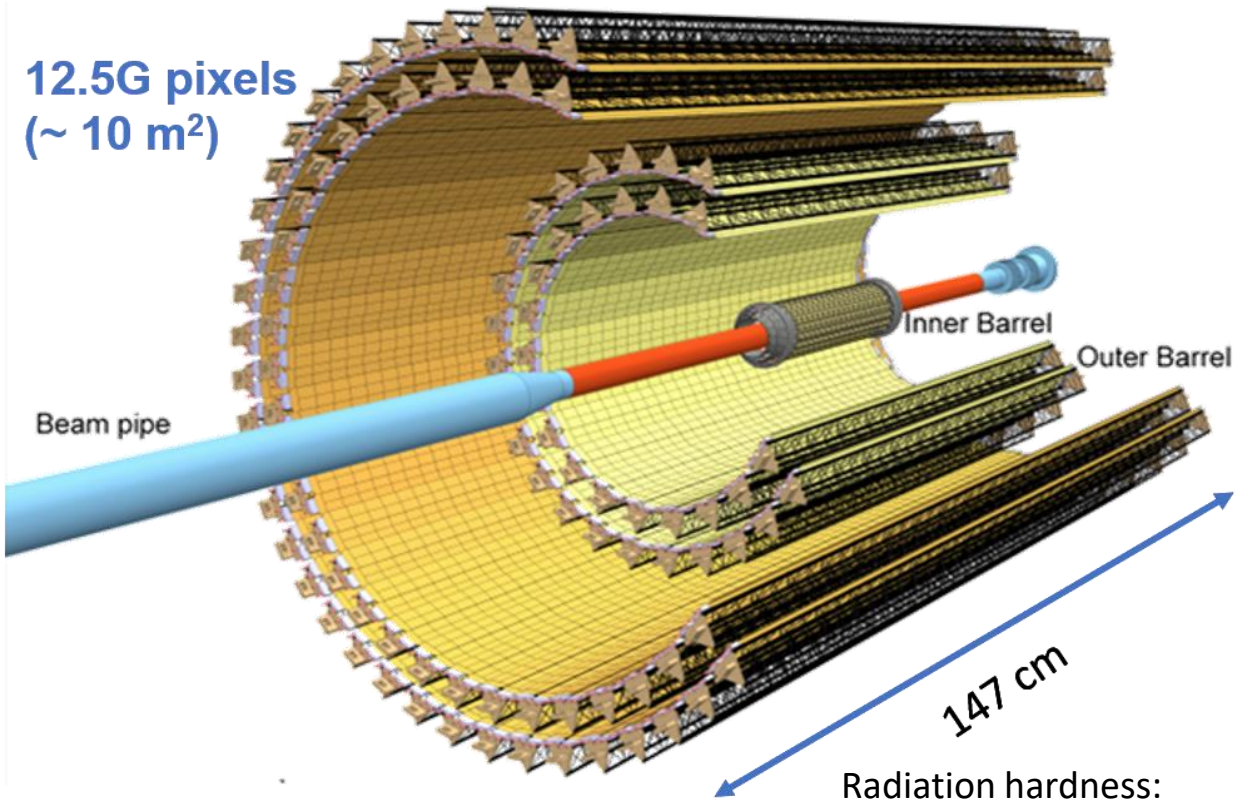








Inner Tracking System Upgrade – ITS2



Radiation hardness:
- TID: ~ 270 krad
- NIEL: ~1.7x10^{13} n_{eq}

Entirely Monolithic Active Pixel Sensor (MAPS) based complete silicon pixel detector

- 7 cylinders covering ~ 10 m^2 area
  - Inner barrel: 3 inner layers
  - Outer barrel: 2 middle layers + 2 outer layers
- Fake-hit rate: < 10^{-6} /event/pixel
- Detection efficiency: > 99%
- Fast removal/insertion for yearly maintenance

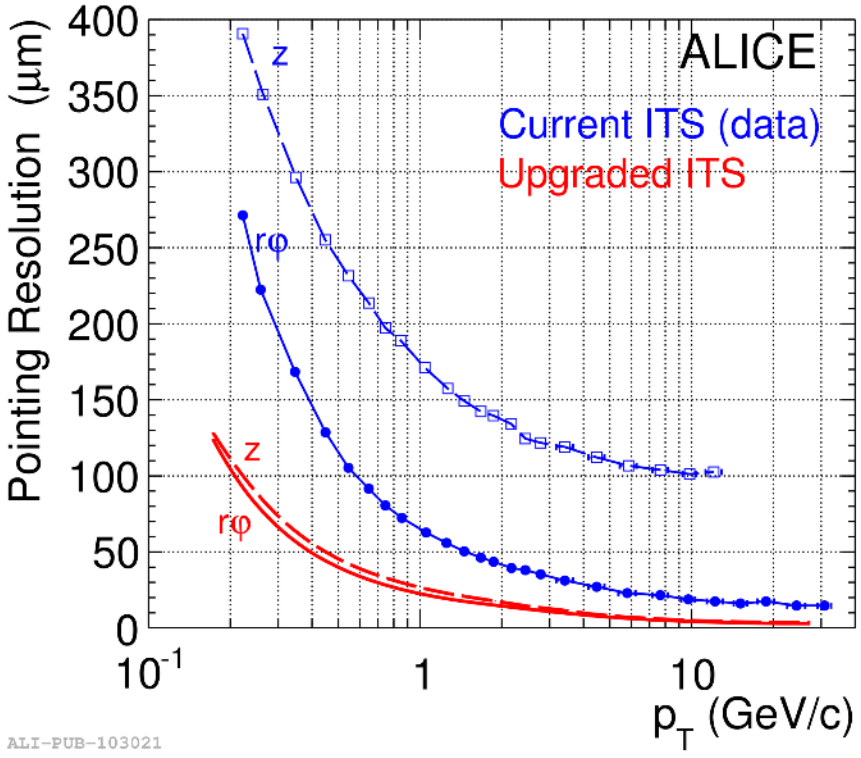
	ITS1	ITS2
Technology	Hybrid, drift, strip	MAPS
Layers	6	7
Spatial resolution	12 µm x 100 µm	5 µm x 5 µm
Radius	39 – 430 mm	22 mm – 400 mm
Pseudorapidity	-1 ≤ η ≤ 1	-1.4 ≤ η ≤ 1.4
Material budget	~ 1.14% X_0	~ 0.3% X_0 (inner barrel), ~ 1% X_0 (outer barrel)
Readout capability	1 kHz	>100 kHz (Pb-Pb),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

ITS Upgrade Simulated Performance

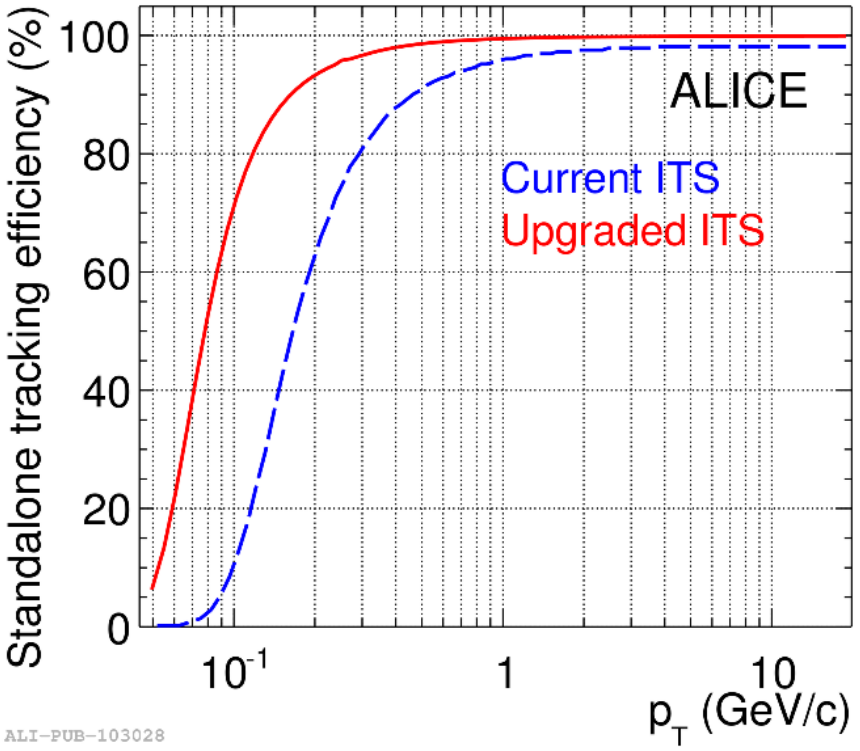
Pointing resolution

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

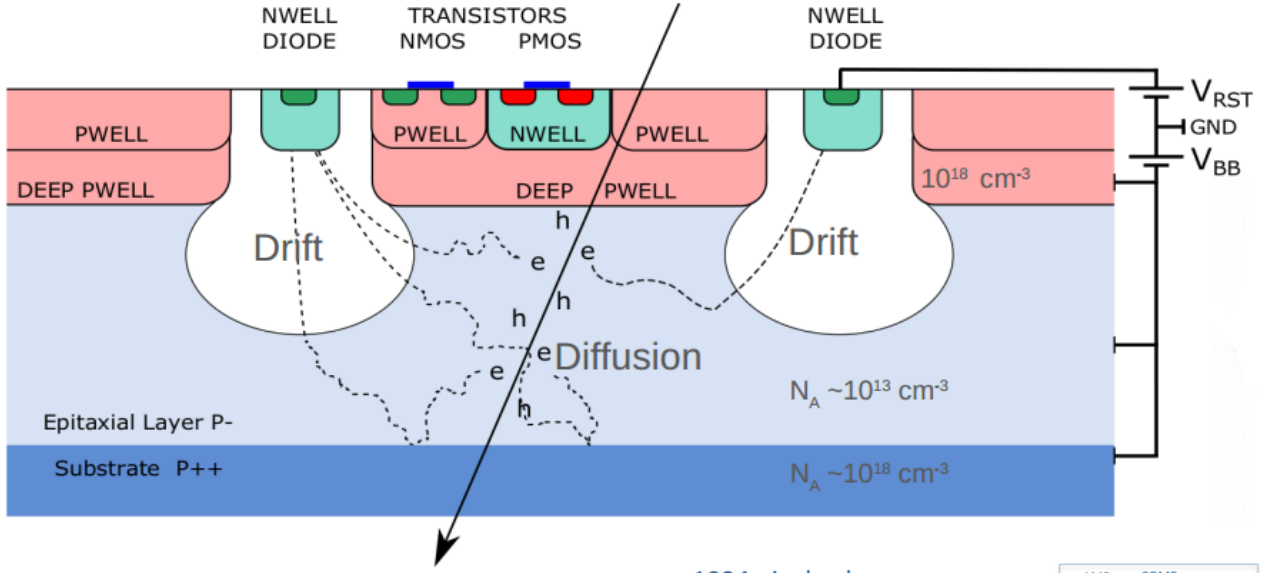


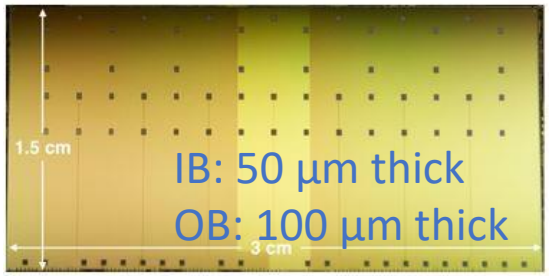
Standalone tracking efficiency

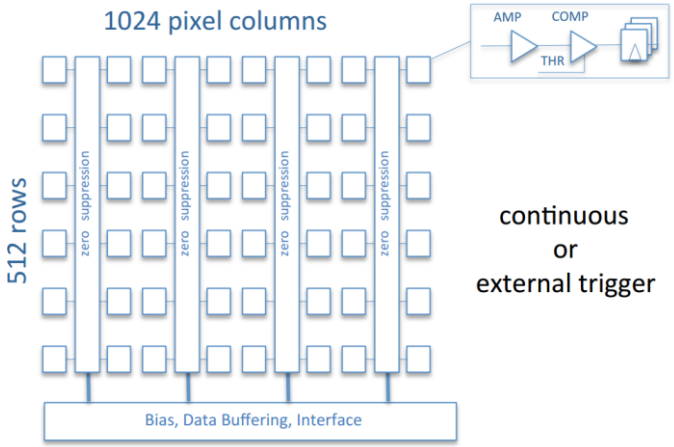
- > 60% for 0.1 GeV/c π
- > 95% for π with p_T > 0.3 GeV/c



ALPIDE: MONOLITHIC ACTIVE PIXEL SENSOR







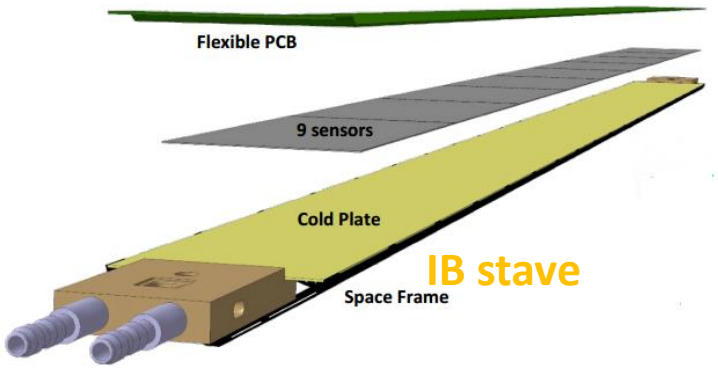
ALPIDE technology features:

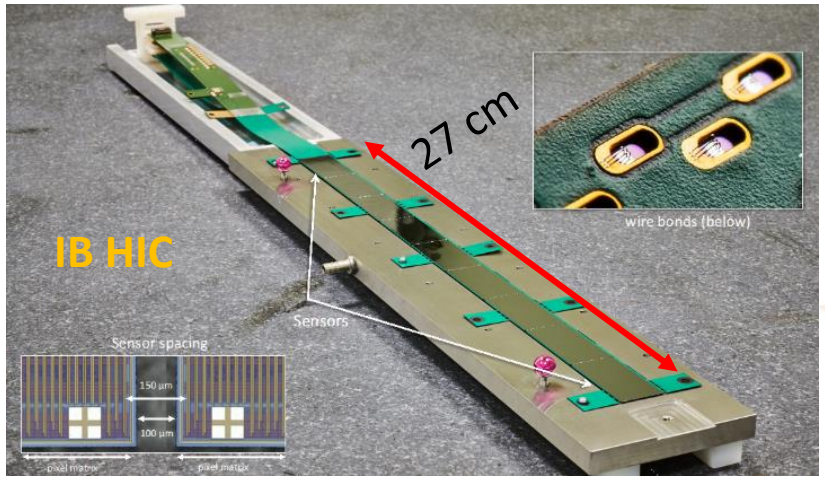
- TowerJazz 180 nm CiS Process, full CMOS
- Deep P-well implementation available
- High resistivity epi-layer (>1 kΩ·cm) p-type, thickness 25 µm
- Smaller charge collection diode → lower capacitance → higher S/N
- Possibility of reverse biasing
- Substrate can be thinned down

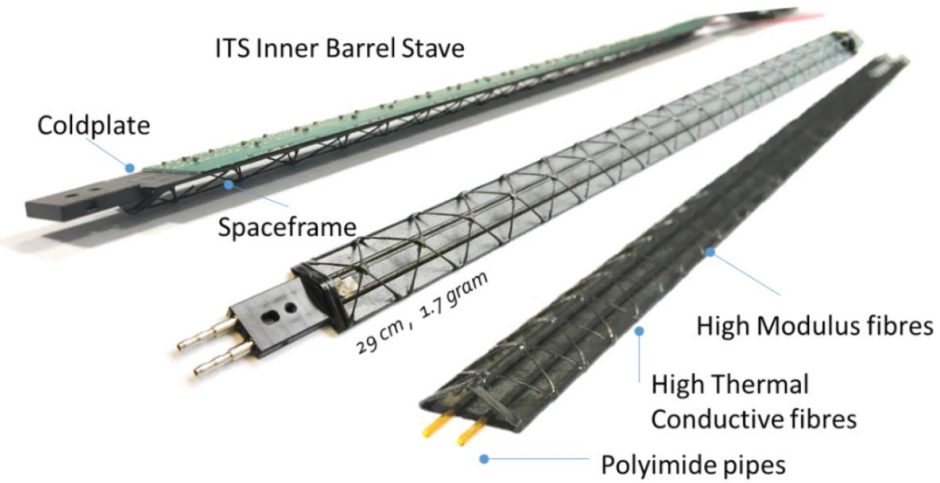
Sensor specification:

- 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 Inner Barrel





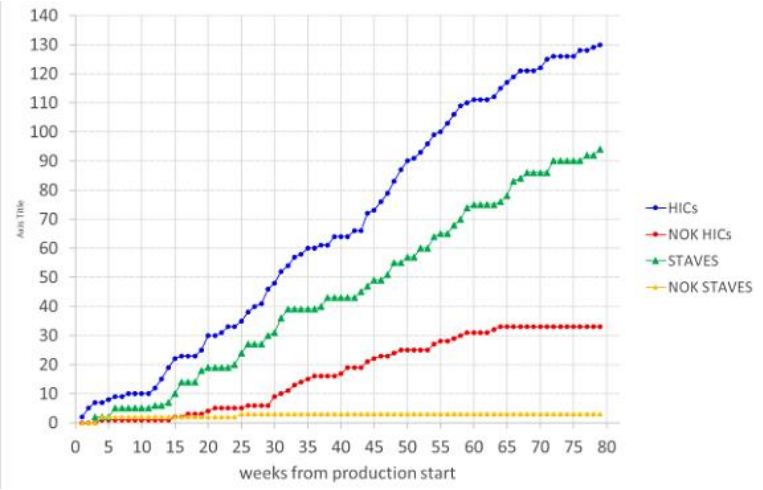


Inner Barrel (IB):

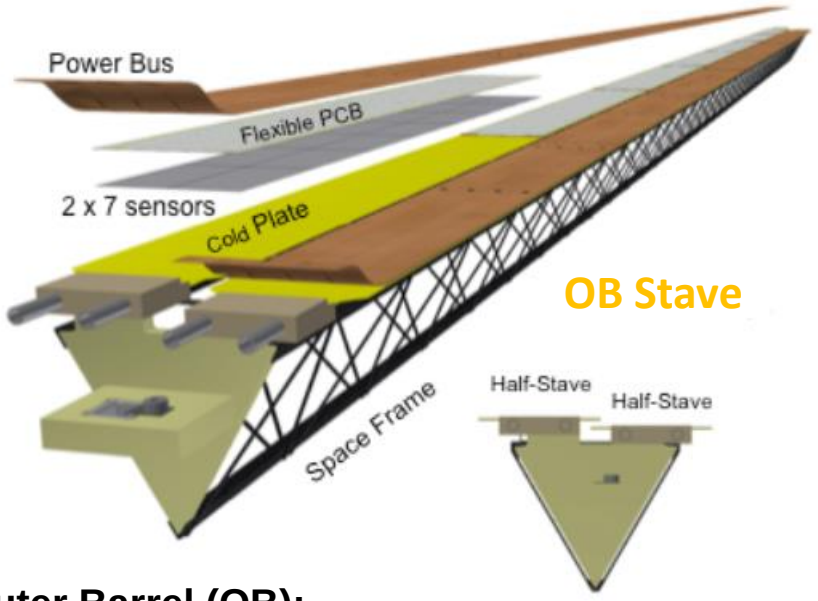
- Three layers
  - Layer0: 12 staves
  - Layer1: 16 staves
  - Layer2: 20 staves
- Hybrid Integrated Circuit (HIC): 9 sensors glued onto Al Flexible Printed Circuit (FPC)
- Wirebonds electrically connect FPC to chips
- Stave: a HIC glued onto cold plate and space frame
- Each sensor is read out individually

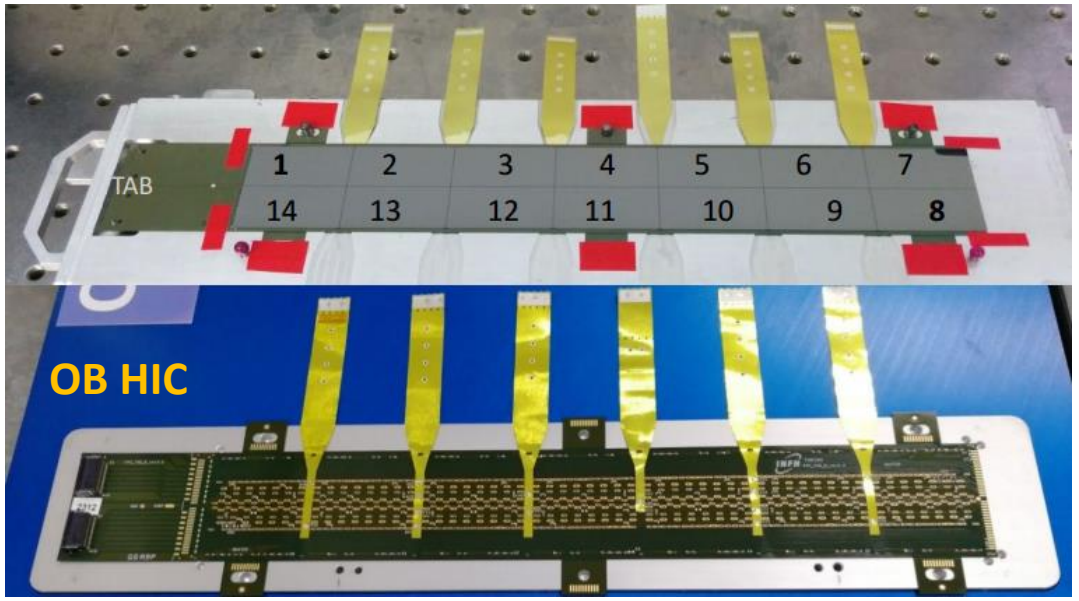
HIC & stave production:

- Production site: CERN
- 140 staves assembled
- Yield 73%
- **Production completed** and enough for two IB sets plus spares



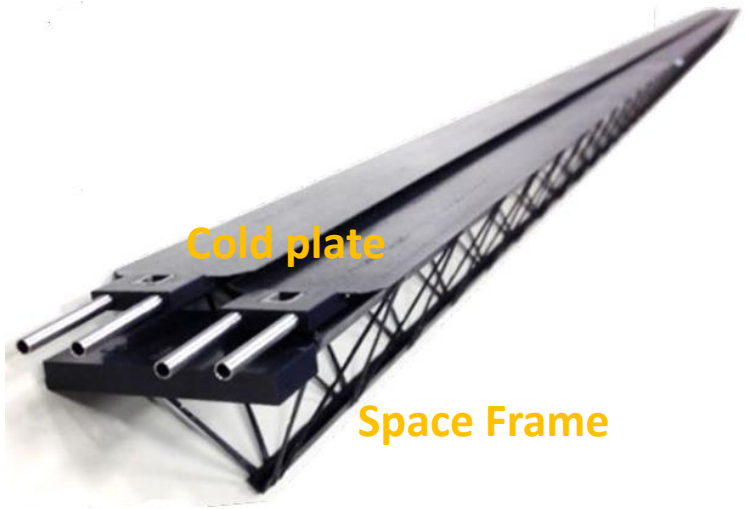
ITS2 Outer Barrel



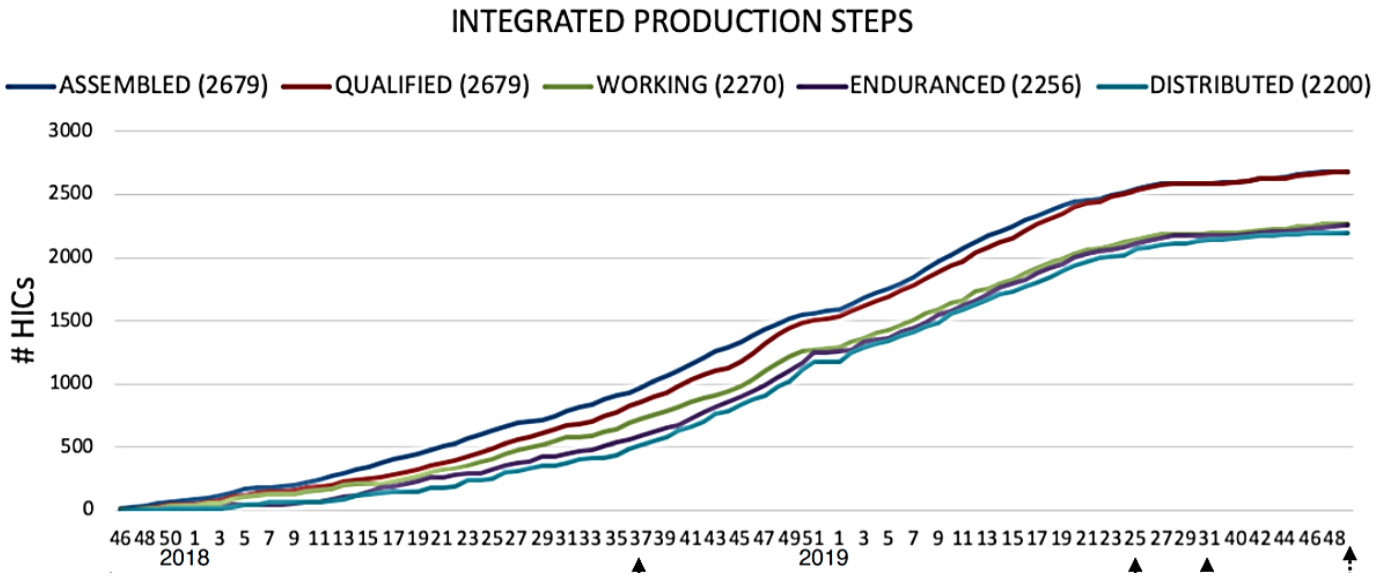


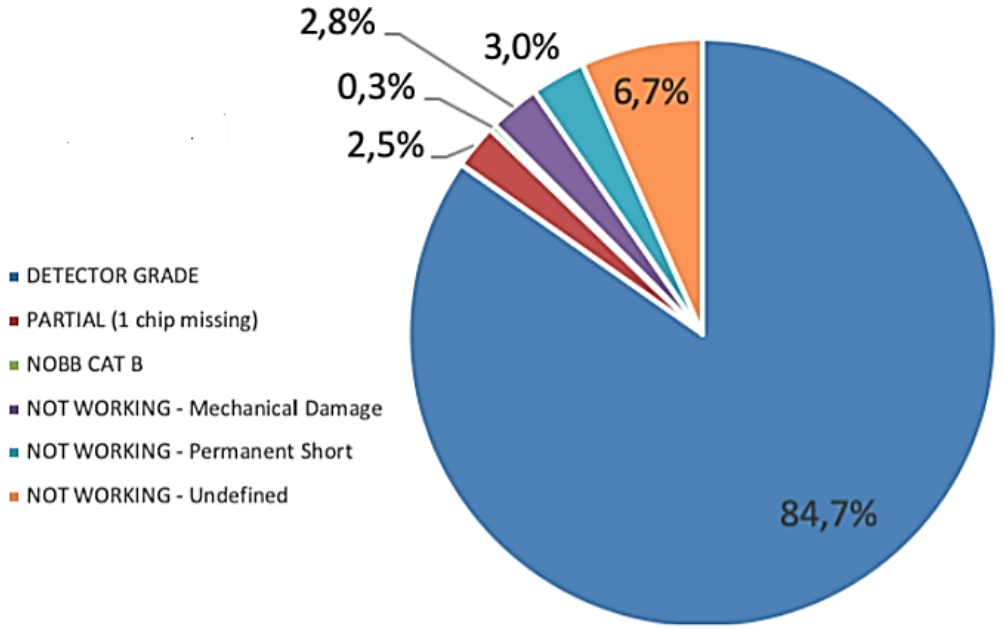
Outer Barrel (OB):

- OB HIC:
  - 7x2 sensors (2 rows) glued onto Cu FPC
  - Wirebonds electrically connect FPC to chips
  - 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
- 54 ML staves (24 + 30) + 90 OL staves (42 + 48)



ITS2 OB HIC Production Summary





OB HIC production:

- HIC assembly sites: Bari, Liverpool, Pusan/Inha, Strasbourg, Wuhan
- FPC test and preparation sites: Trieste, Catania
- 1692 working HICs needed to build OB staves
- 2679 HICs assembled and 2270 HICs qualified as Detector Grade (DG)
- 2200 HICs distributed to OB stave production sites

OB HIC YIELD

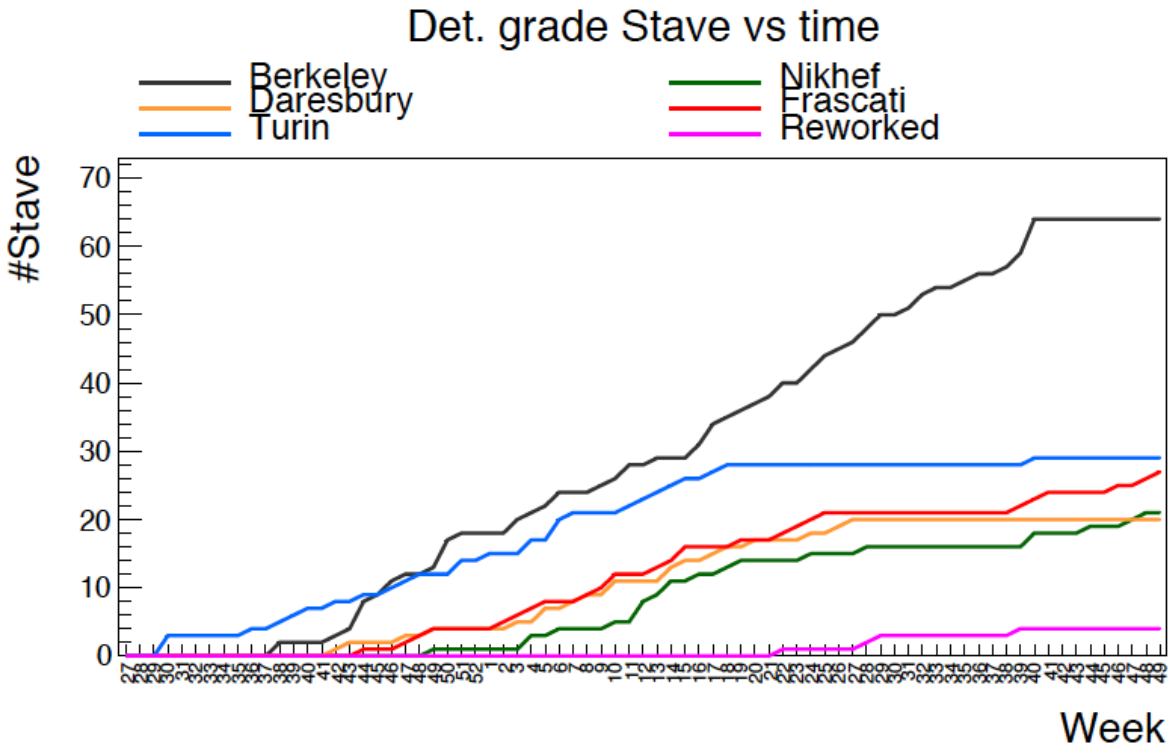
Gold/Silver + Bronze + Burnt through + NO Backbias

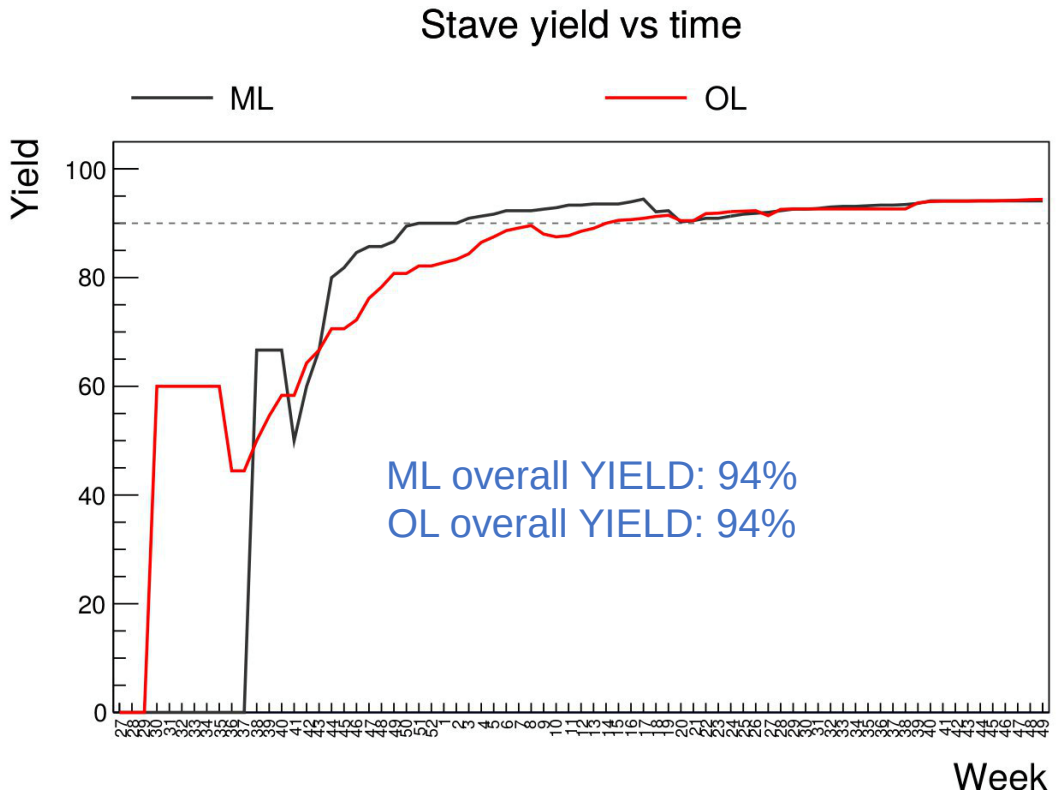
58.7%+11.1%+5.5%+9.4%

84.7%

Production completed on 25/11/2019

ITS2 OB Stave Production Summary





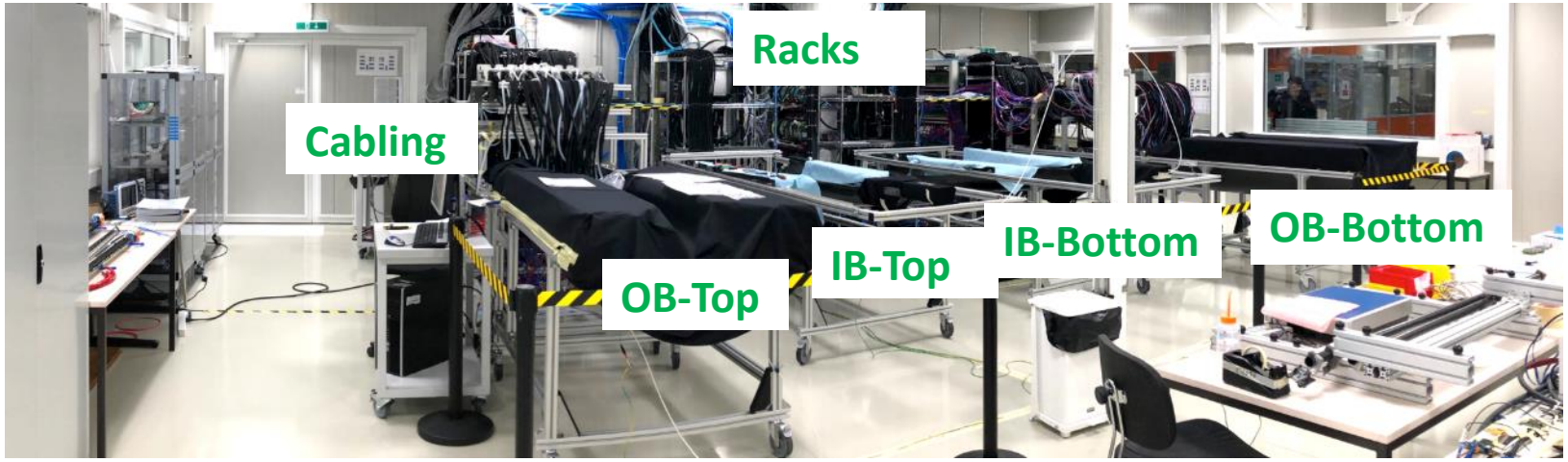
OB stave production:

- production sites: Torino, Frascati, Daresbury and Nikhef (for OL), Berkeley (for ML)
- 68 (64 DG) ML staves + 107 (101 DG, including 4 reworked) OL staves assembled

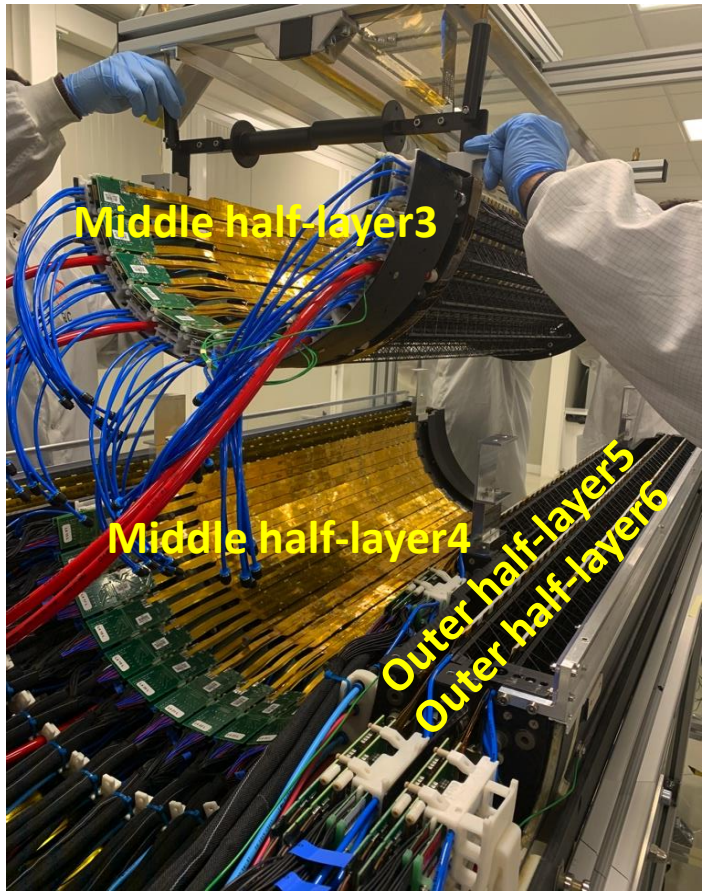
ML production completed in October 2019
OL production completed in December 2019

Layer and Barrel Assembly

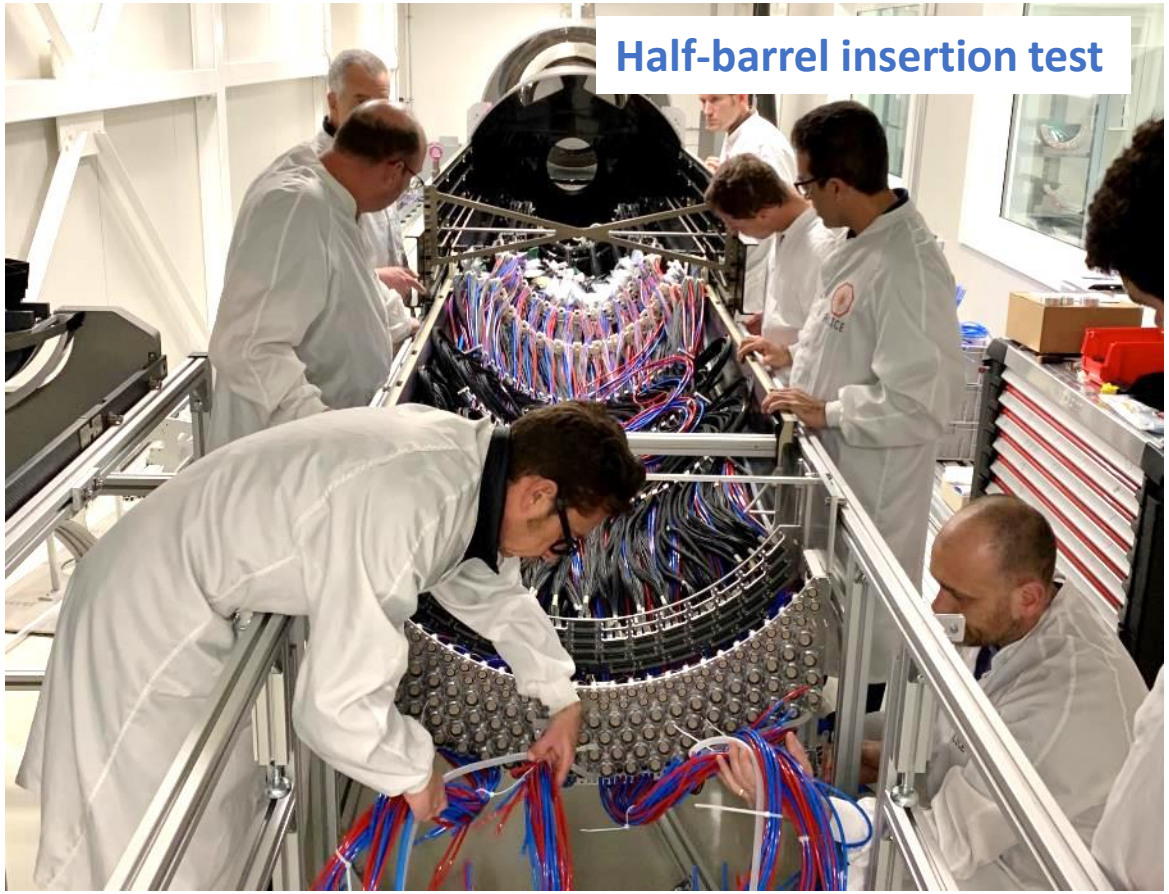
Inner Barrel assembly completed: fully functional



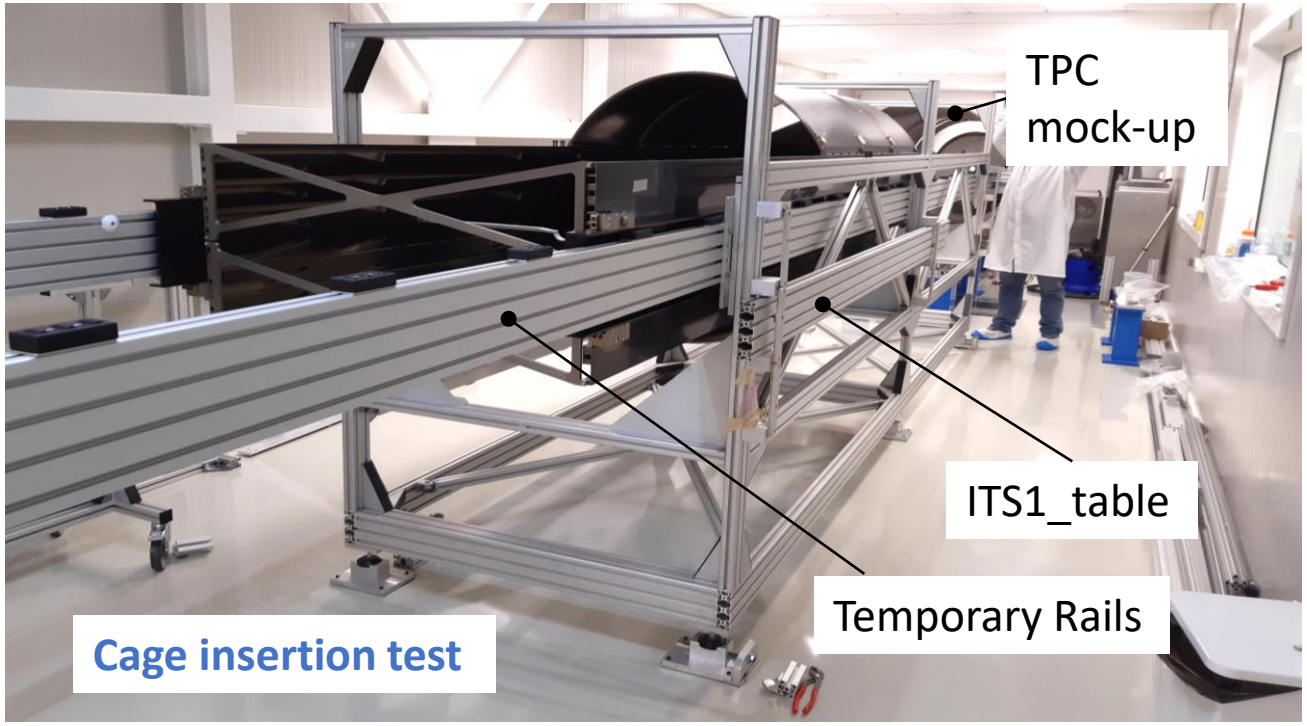
Outer barrel assembly completed



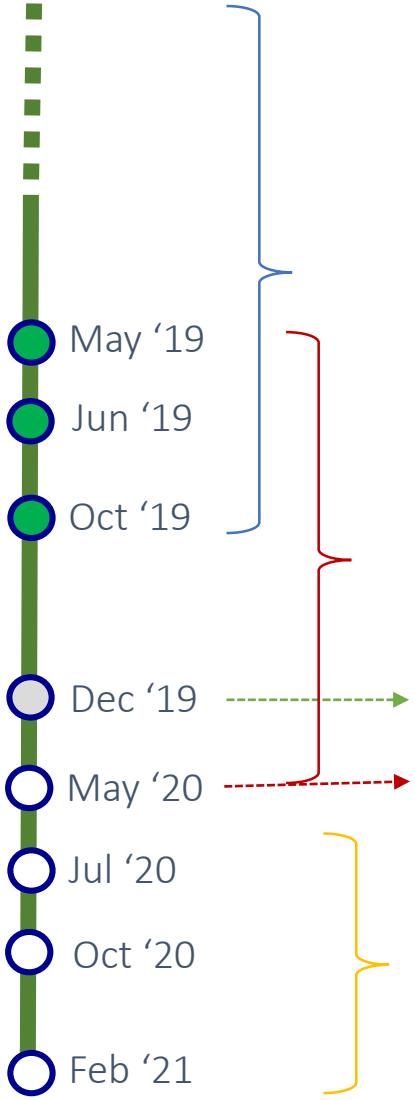
Detector Insertion Test



Detector barrels and cage insertion test in TPC mock-up ongoing



ITS2: Assembly and Commissioning Timeline



Detector Construction and Assembly

- Module production: done!
- Stave production: done!
- Electronics production: done!

Assembly and Commissioning

Commissioning ongoing
(operation 24/7)

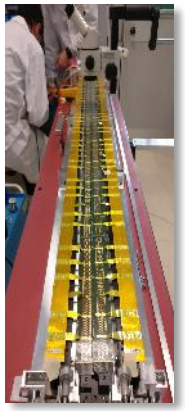
OB Assembly End: done

End of commissioning in lab

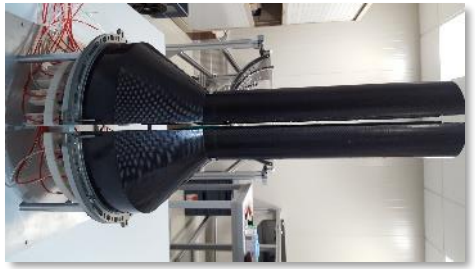
Installation

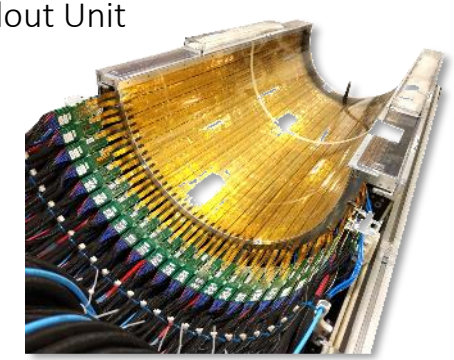
Global Commissioning

→ 6 months

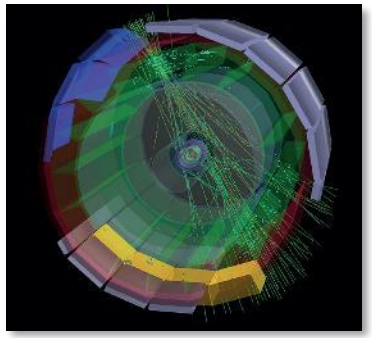

Stave


Readout Unit


Inner Barrel Assembly


Outer Barrel Assembly

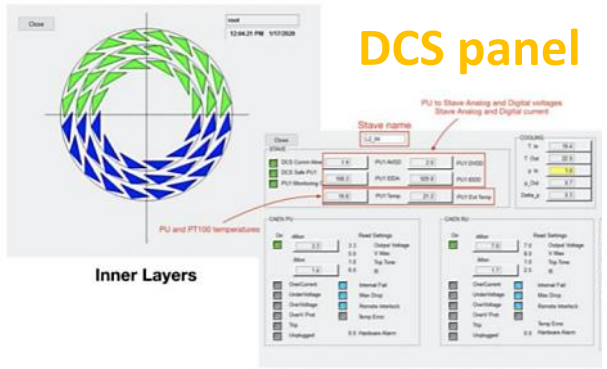

Installation

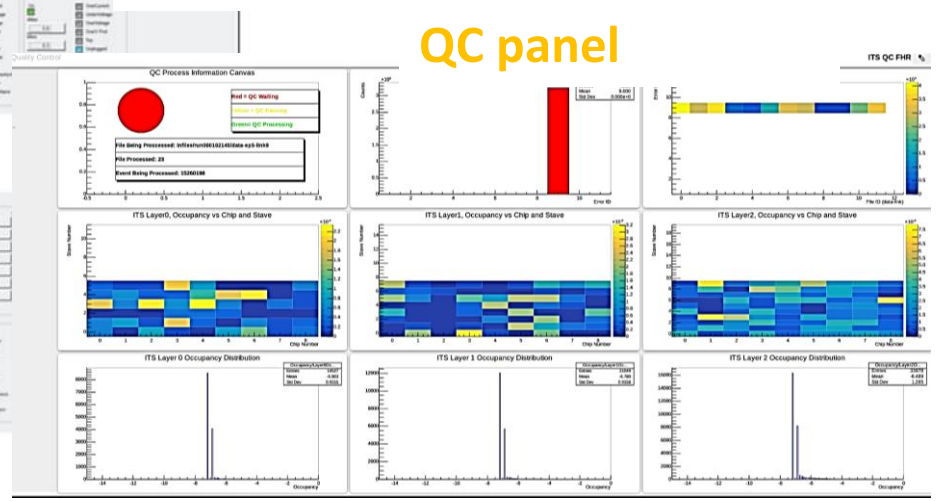

Global commissioning

Commissioning Overall Status

- Commissioning of the detector on surface is underway
- Aim to obtain the detector performance and long stability of parameters before installation inside the cavern
- Commissioning shifts 24/7 started from 1/07/2019, 3 daily teams with 2 shifters + 1 shifter leader
- Detector status monitoring: voltage, current and temperature
- Data taking: threshold scan, fake-hit rate and readout test
- Data Quality control (QC)

- IB: IB-Top and IB-Bottom data taking, cosmic track studies ongoing
- OB: ML and OL fully powered on, basic verification ongoing

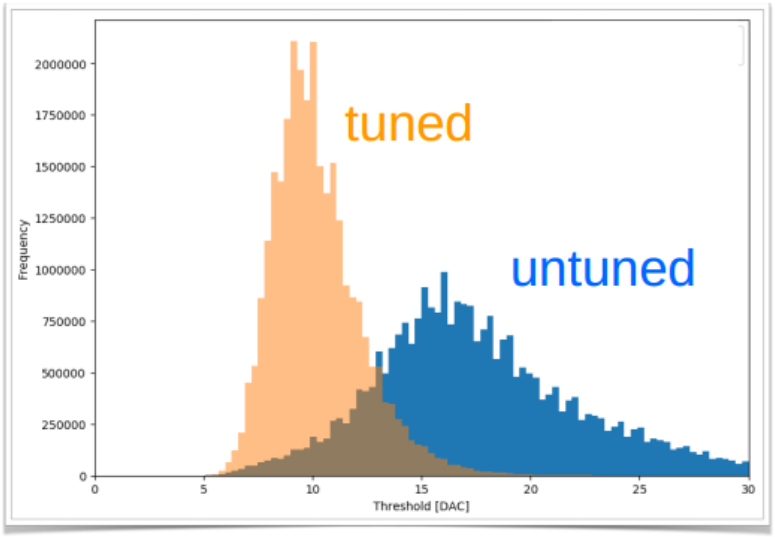




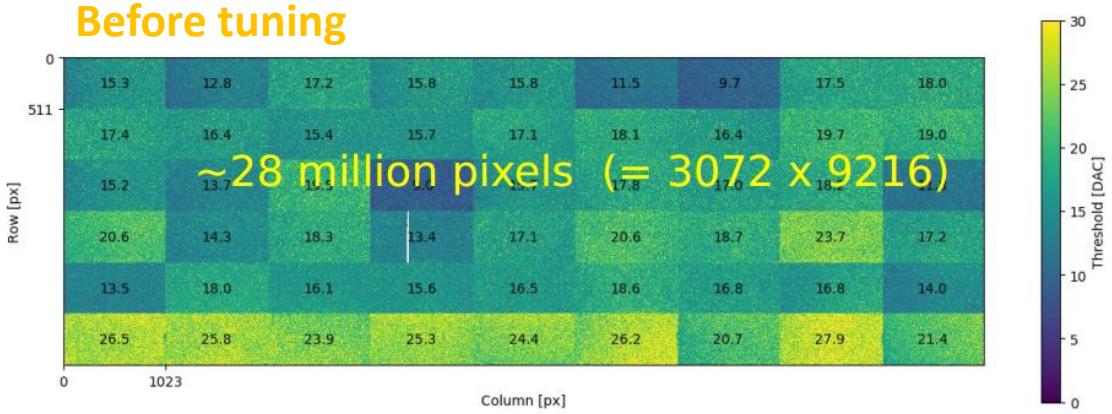
Commissioning –Threshold Tuning

Threshold tuning on IB Half-layer (Debug Layer)

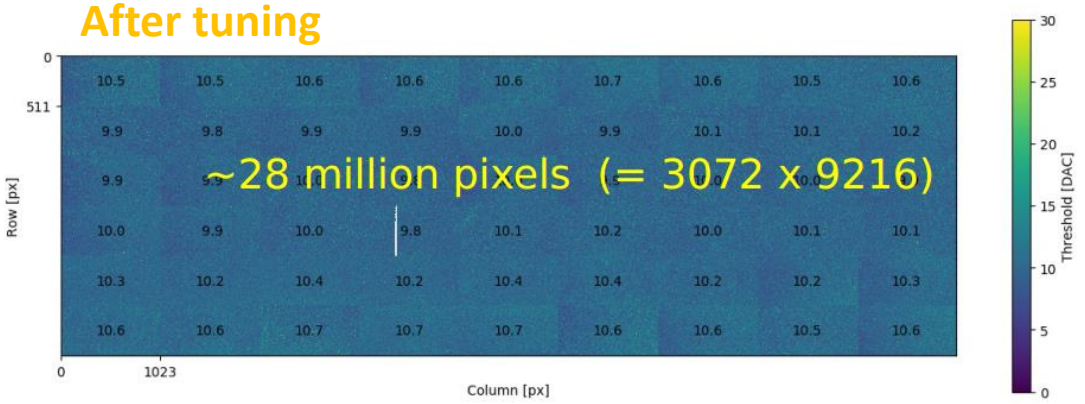
- Adjustment of front-end parameters to equilibrate the charge thresholds
- Achieving uniform response across the detector
- Very satisfying threshold stability over time



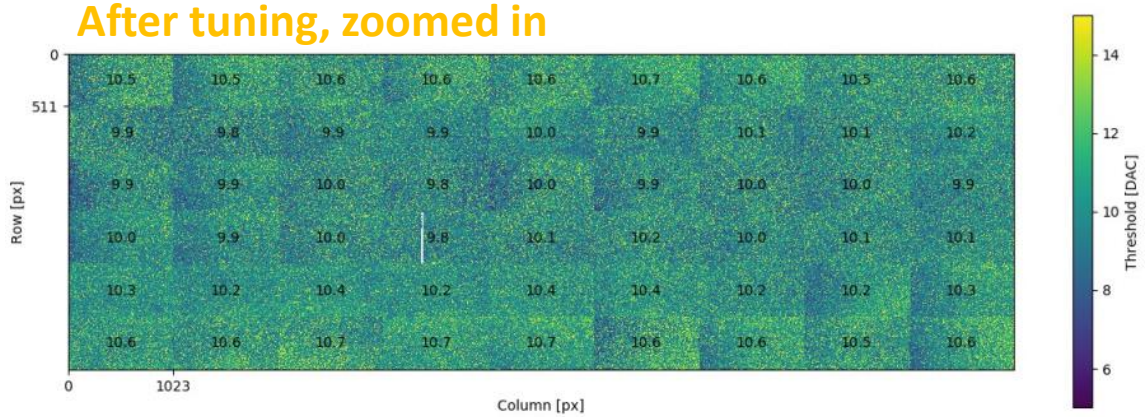
Before tuning



After tuning

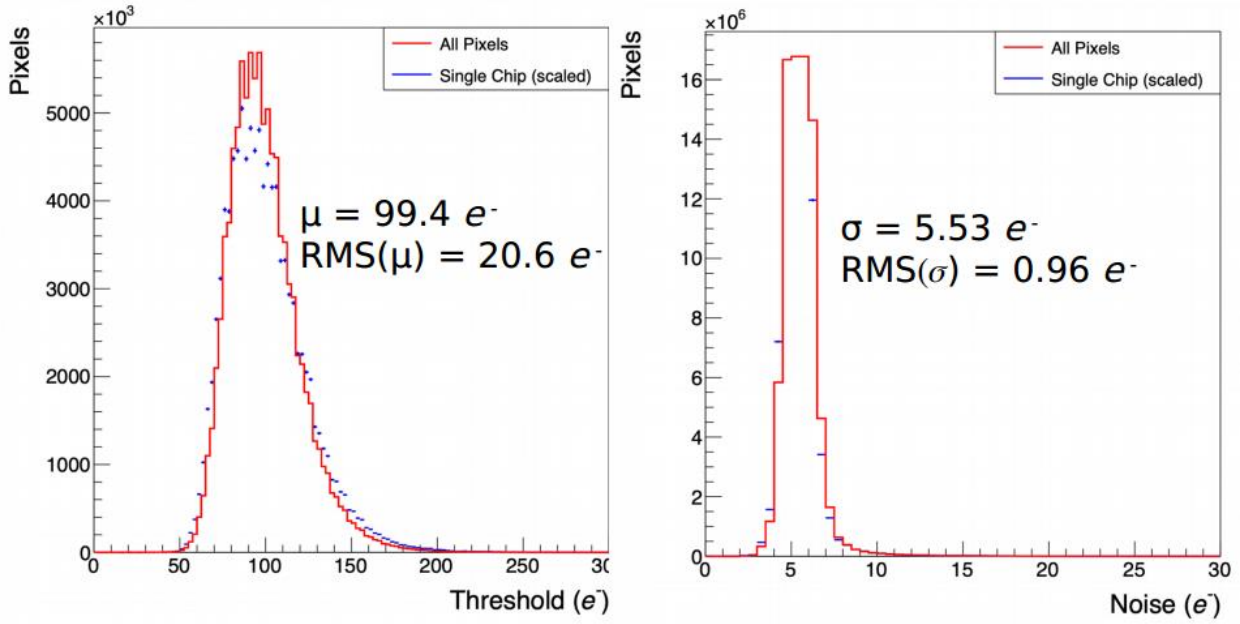


After tuning, zoomed in



Commissioning – Threshold and Noise

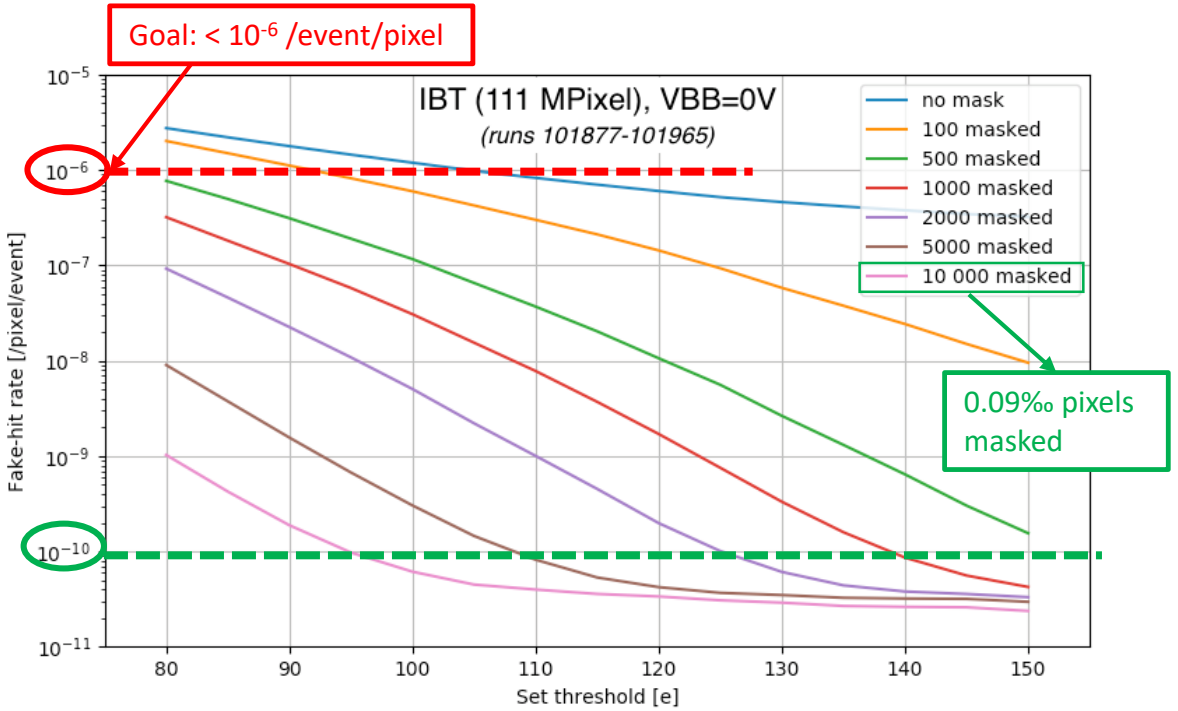
OB threshold and noise:
Threshold and noise after tuning an OL Stave (~100M pixels) compared with test data from a single chip



Threshold is a trade-off between:

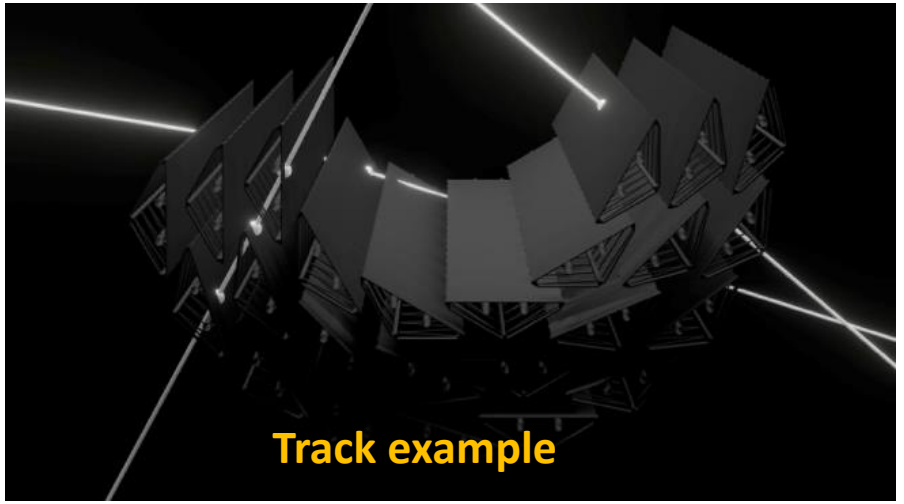
- Detection efficiency : Threshold < Charge QMIP (~225 *e*-)
- Fake-hit rate : Threshold >> Noise

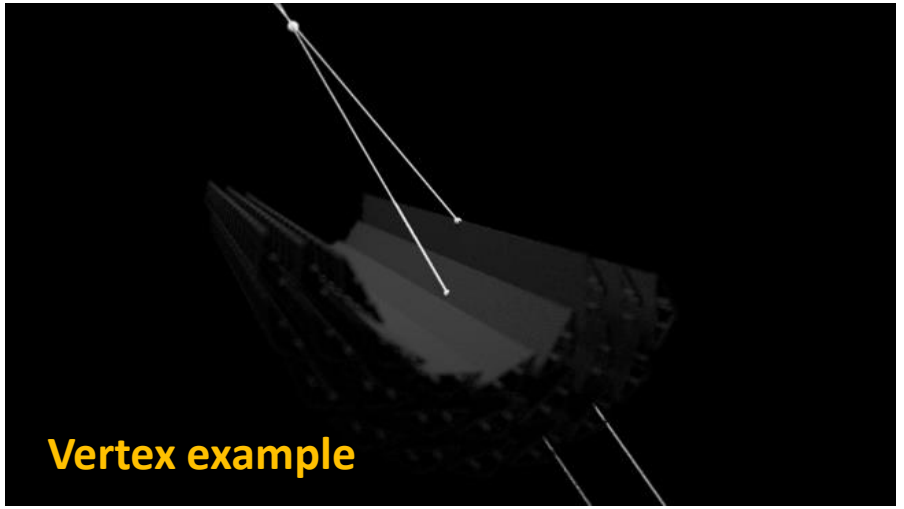
Fake-hit rate for IB-Top (half IB):
From tests performed on half IB, running the IB at fake-hit rate below 10^{-10}/pixel/event seems feasible



Extremely quiet detector!

Commissioning – Cosmic Track





Goals: study track and cluster parameters, alignment

- Get around 1 cosmic track per second
- Along with cosmic tracks have seen vertexes (rates of ~ 1/min)
- Commissioning data analysis ongoing

Summary

- ALICE upgrade during LS2 to enhance physics performance is underway
- One key part is the upgrade of the ITS to ITS2 (an all pixel version based on MAPS)
- The ITS upgrade will dramatically improve performance: impact parameter resolution, efficiency and readout rate capabilities
- Component production, assembly of detector and services are completed
- Commissioning in laboratory is ongoing and shows excellent performance, due to finish beginning of May 2020
- The detector will be transferred to the ALICE cavern starting in May and installed in the experiment in July 2020, followed by 6 months of global commissioning
- Plan to take data in 2021
- A further upgrade of the fully-cylindrical ITS Inner Barrel (ITS3) for the LHC Long Shutdown 3 has been proposed and the kick-off meeting was held at CERN on 04/12/2019

See Magnus Mager's talk: "The LS3 upgrade of the ALICE Inner Tracking System based on ultra-thin, wafer-scale, bent Monolithic Active Pixel Sensors"