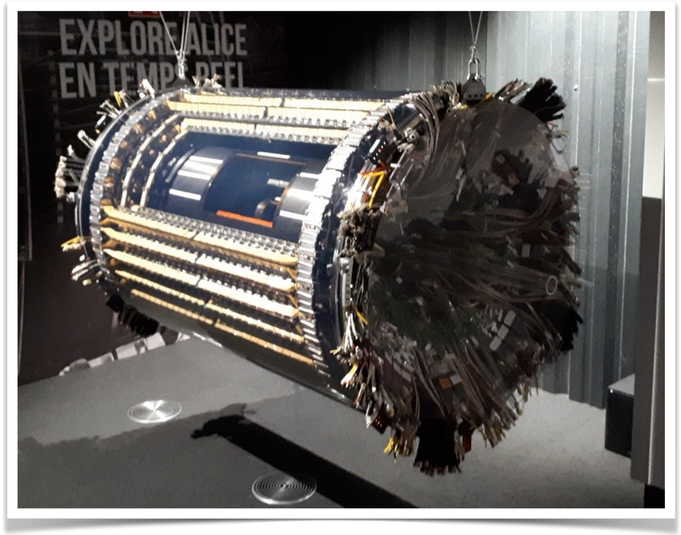
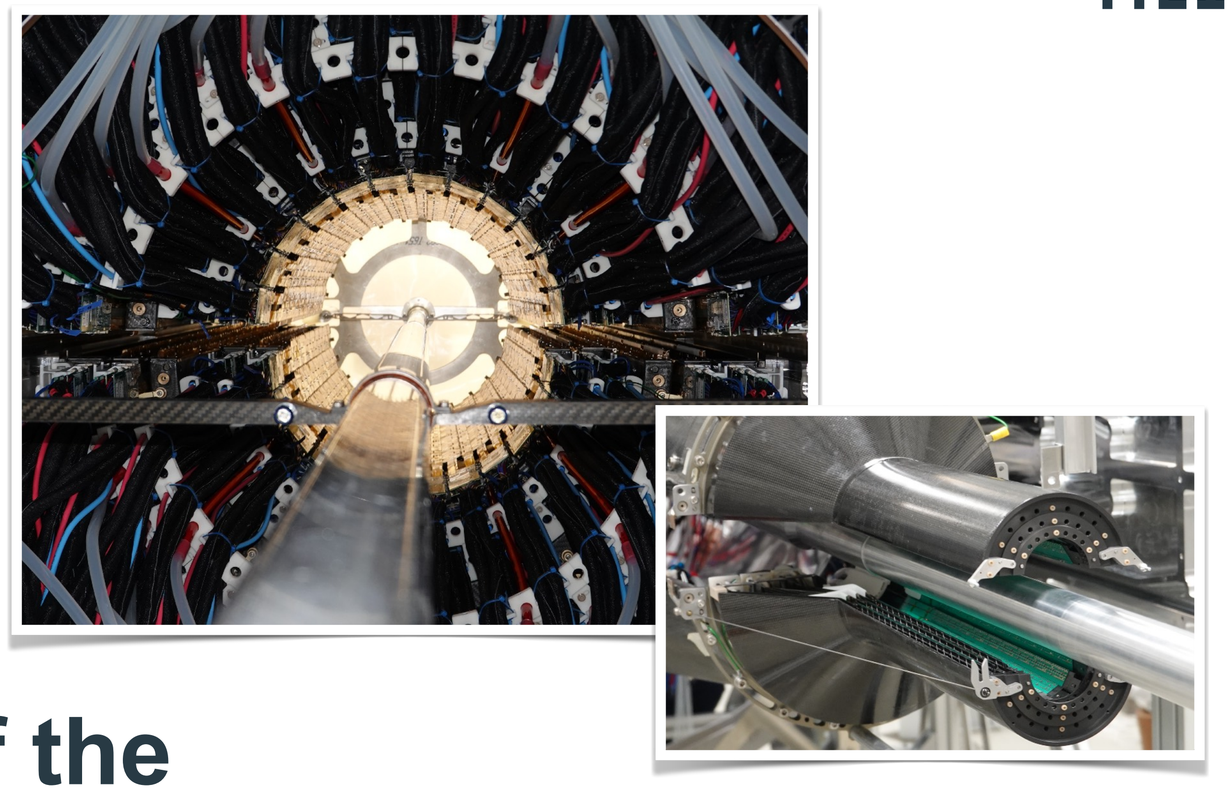
ITS1



ITS2



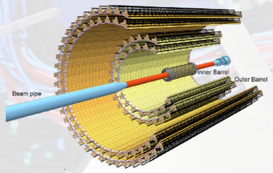
Upgrade of the ALICE ITS detector

Felix Reidt
felix.reidt@cern.ch

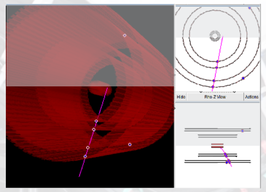
on behalf of the ALICE collaboration

Outline

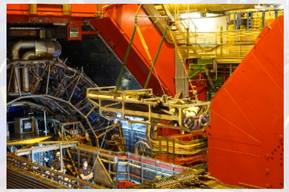
- Introduction

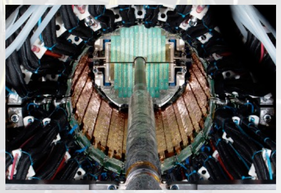


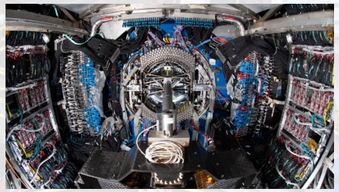
- On-surface commissioning



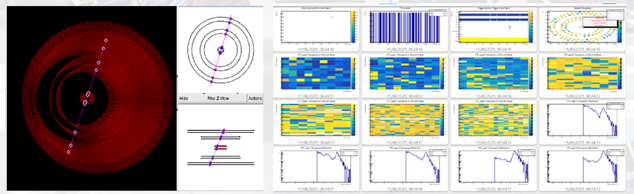
- Detector Installation



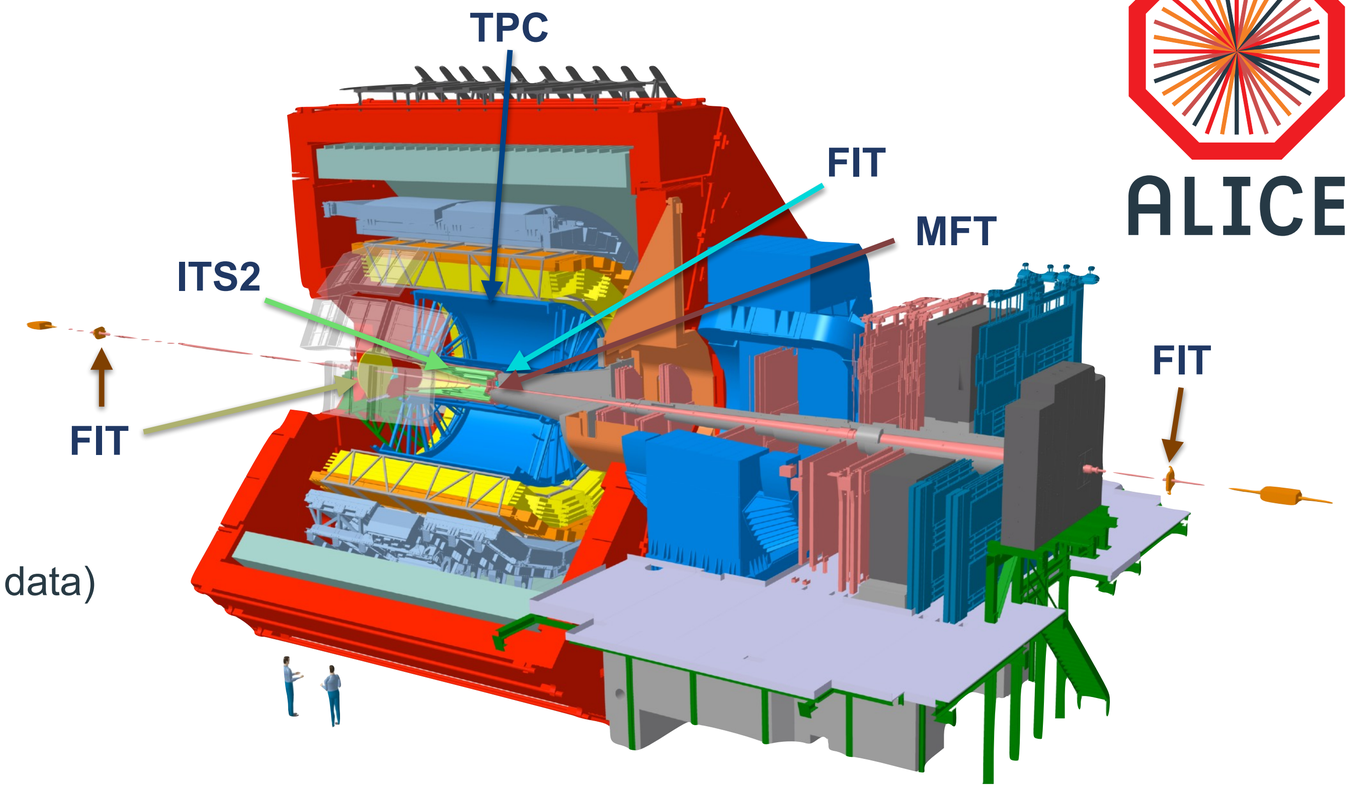




- Commissioning in the experimental apparatus



Upgrade Strategy for LS2 (2019 - 2021)



Motivation:

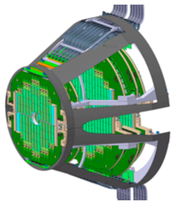
High-precision measurements of rare probes at low p_T
- Cannot be selected by hardware triggers
- Need to record large minimum-bias data sample
  ⇒ read out all Pb-Pb interactions up to the maximum LHC Pb-Pb collision rate of 50 kHz

Goal:

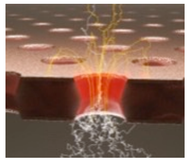
- Pb-Pb recorded luminosity: 10 nb^{-1} (plus pp, p-A and O-O data)
  → gain factor 100 in statistics for minimum-bias trigger
- Improved vertex reconstruction and tracking capabilities

Strategy:

New Inner Tracking System (ITS2)

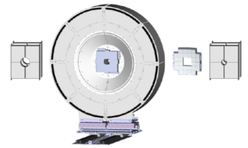


New Muon Forward Tracker (MFT)



New TPC Readout Chambers (ROCs)

New Fast Interaction Trigger (FIT) Detector



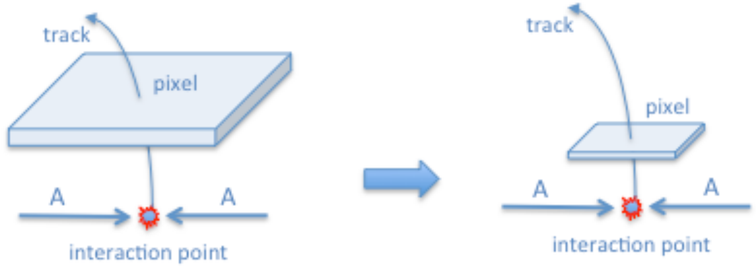
Readout upgrade

Integrated Online-Offline system (O^2)

ITS2 Design Objectives

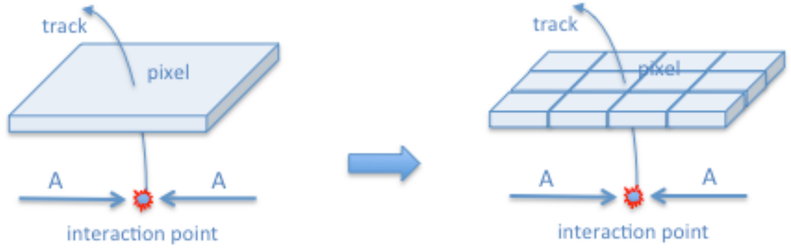
Improve impact parameter resolution by a factor ~3 in rφ and ~5 in z at p_T=500MeV/c

- get closer to IP: 39mm ➔ 23mm (innermost layer)
- reduce material budget: ~1.14% X_0 ➔ ~0.35% X_0 (inner layers)
- reduce pixel size: 50x425μm² ➔ O(30x30μm²)



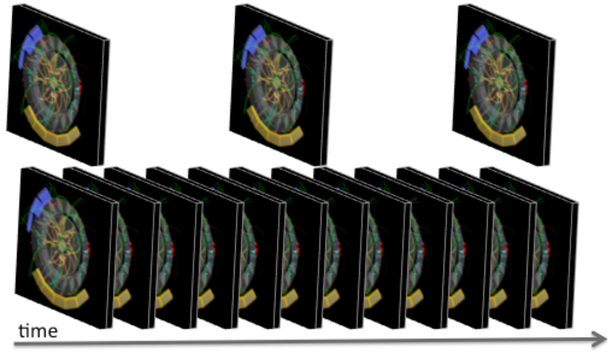
Improve tracking efficiency and p_T resolution at low p_T

- increase granularity: 6 layers ➔ 7 pixel layers



Fast readout

- readout of Pb-Pb at up to 100 kHz (presently 1 kHz) and 400 kHz for pp

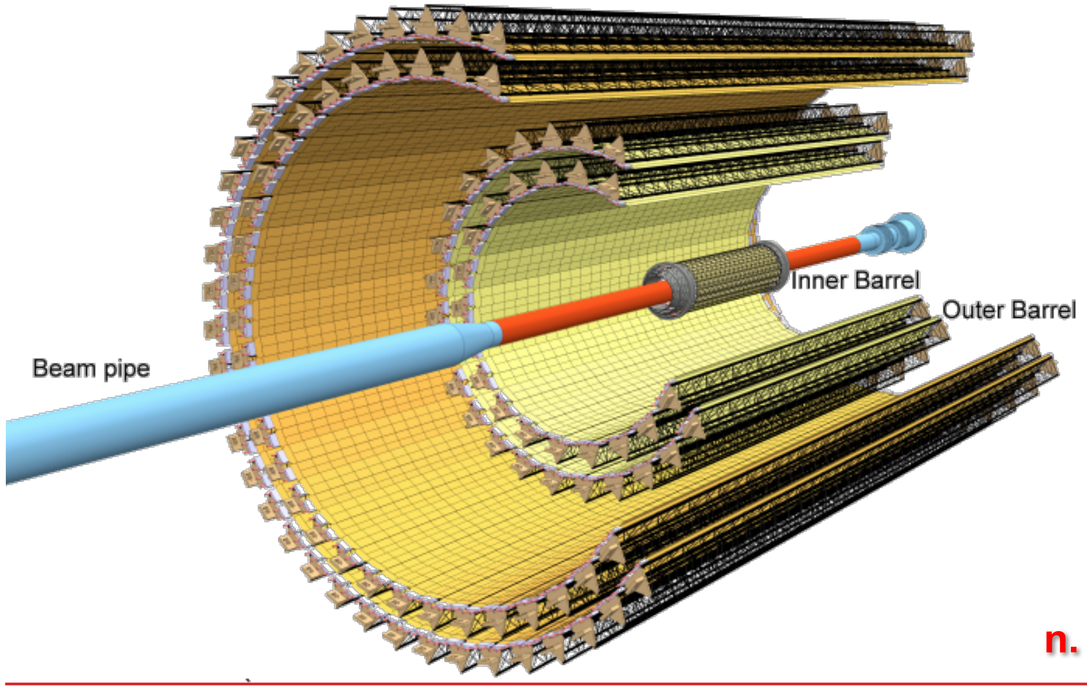


➔ ITS1 will be fully replaced!

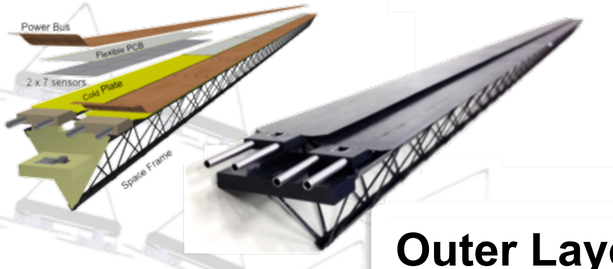
ITS2 Layout

- 7 layers (inner/middle/outer): 3/2/2 from R = 22 mm to R = 400 mm
- 192 staves (IL/ML/OL): 48/54/90
- Ultra-lightweight support structure and cooling

10 m² active silicon area, 12.5×10⁹ pixels



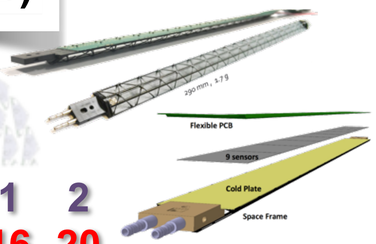
Outer Barrel (OB) = ML + OL



Outer Layers (OL)

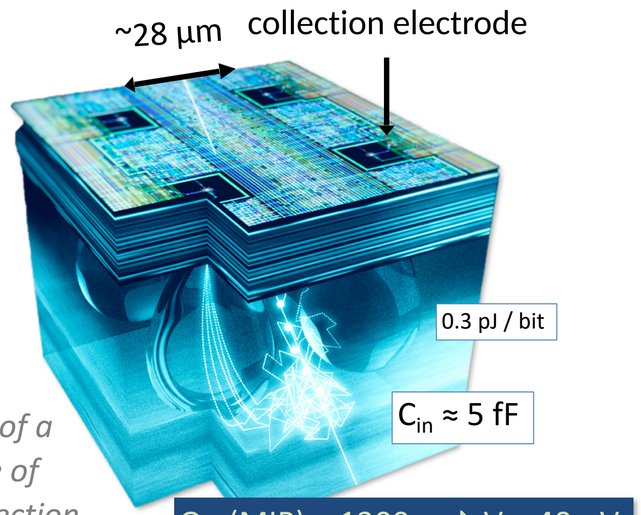
Middle Layers (ML)

Inner Barrel (IB)

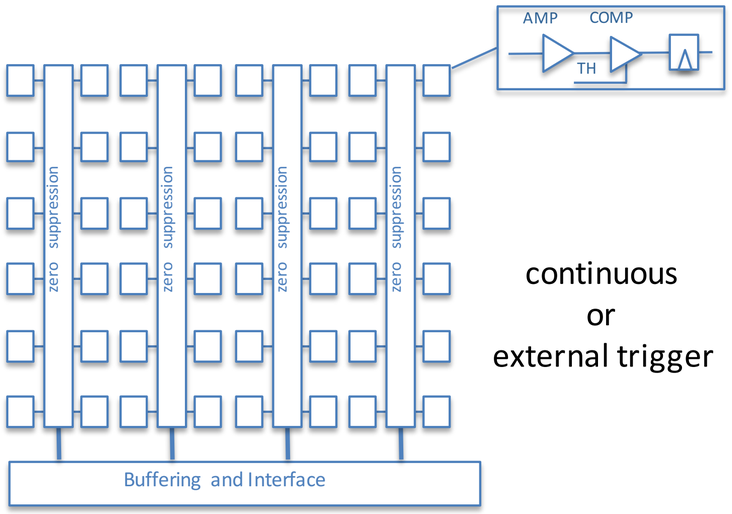


Layer #	0	1	2	3	4	5	6
n. of Staves	12	16	20	24	30	42	48

Pixel chip characteristics



Artistic view of a SEM picture of ALPIDE cross section



continuous
or
external trigger

- Based on the **ALPIDE Monolithic Active Pixel Sensor**
  - In-pixel amplification, shaping, discrimination and Multiple-Event Buffers (MEB)
  - In-matrix data sparsification
  - High detection efficiency: > 99% and low fake-hit rate: << 10^{-6}/pixel/event
  - Radiation tolerant: > 270 krad Total Ionising Dose (TID),
    > 1.7×10^{12} 1 MeV/n_{eq} Non-Ionising Energy Loss (NIEL)
  - Low power: < 40mW / cm^2

	Previous ITS	New ITS2
Distance to IP (mm)	39	22
X_0 (innermost layer) (%)	~ 1.14	~ 0.35
Pixel pitch (µm^2)	50 x 425	27 x 29
Readout rate (kHz)	1	100
Spatial resolution (rφ x z) (µm^2)	11 x 100	5 x 5

Improved resolution, less material, faster readout

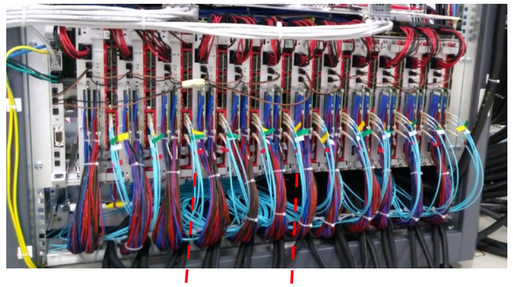
ITS2 System Overview

ALICE

ALICE *Miniframe*

Inside the magnet

PP1 = 16 electronics sub-racks



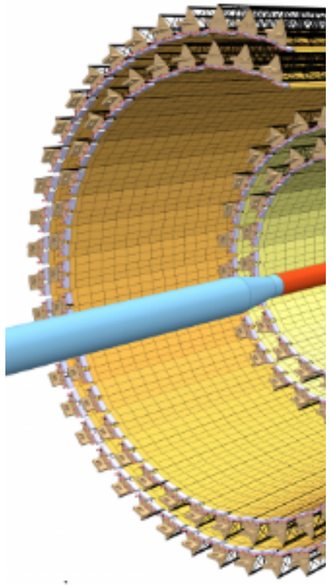
624 Data Cables
Twinax, Copper, ~7 m

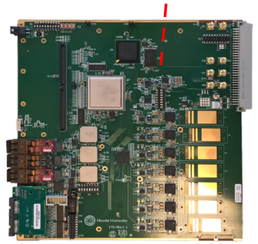
Outer Layer

CLK, CTRL
DATA 28×400 Mb/s

Inner Layer

CLK, CTRL
DATA 9×1200 Mb/s





One **READOUT UNIT**
for each *STAVE* (***192***)

960 GBT LINKS
576 Upstream
384 Downstream

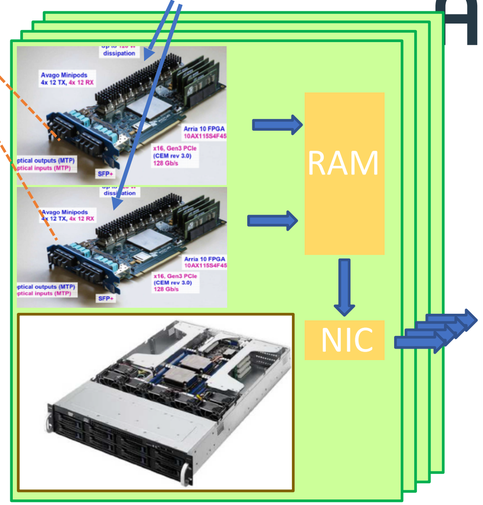
3200Mb/s

Central Trigger Processor

192 GBT LINKS
Timing/Trigger

624 GBT LINKS
192 control
192 control/data
240 data

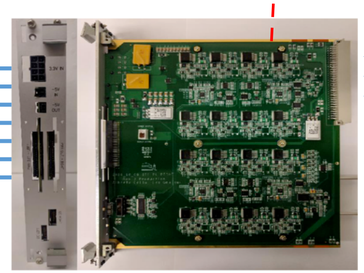
Common Readout Unit (CRU)



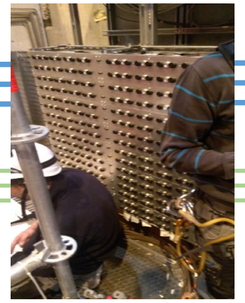
Event Building Farm

11x First Level Processors (FLP)

282 Detector Power Cables



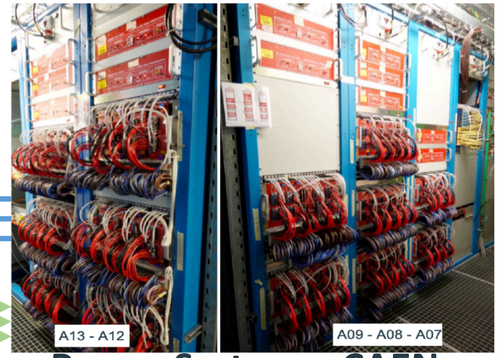
POWER BOARDS (144)



PP0 Patch Panel 0

Service *Power* Cables **(496)**

Service *Sense* Cables **(272)**



Power System – CAEN

12 A3486, 13 Easy Crates
61 A3009, 732 channels

Construction installation and commissioning timeline*

Dec ‘16 — **Detector construction and assembly**
- ~72000 chips —> ~2600 Hybrid Integrated Circuits (HICs) —> ~280 Staves
- > 10 production sites worldwide
- ~ 30 institutes involved

May ‘19 — **On-surface commissioning w/ final services**
- 24/7 operation w/ ~200 shifters from ~30 institutes
- Calibration runs, cosmic muon data taking
- Key to spot potential issues early

Dec ‘20

Jan ‘21 — Services installation in the cavern

Mar ‘21 — Outer Barrel installation

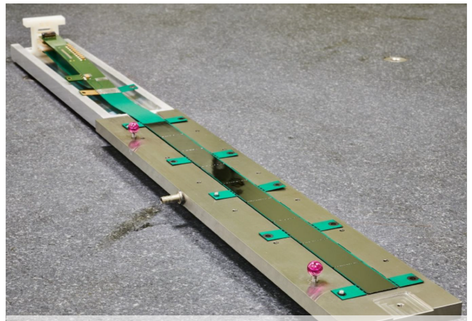
May ‘21 — Inner Barrel installation

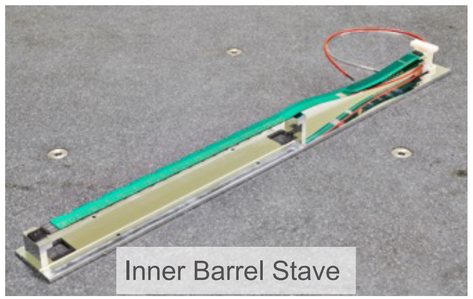
Verification of the detector

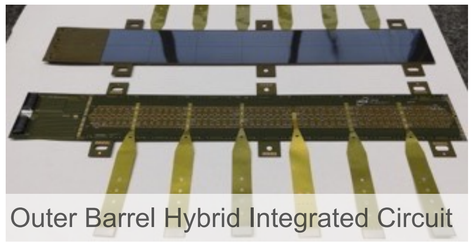
Jul ‘21 — Global commissioning

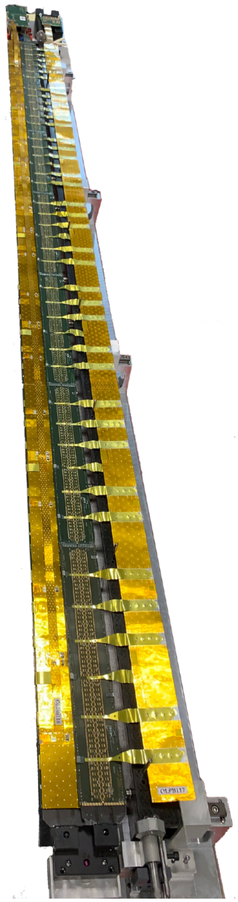
Oct ‘21 — Pilot beam test

* Schedule was changed significantly due to COVID-19; installation in the cavern was carried out with a significantly reduced crew


Inner Barrel Hybrid Integrated Circuit


Inner Barrel Stave


Outer Barrel Hybrid Integrated Circuit


Outer Barrel Stave

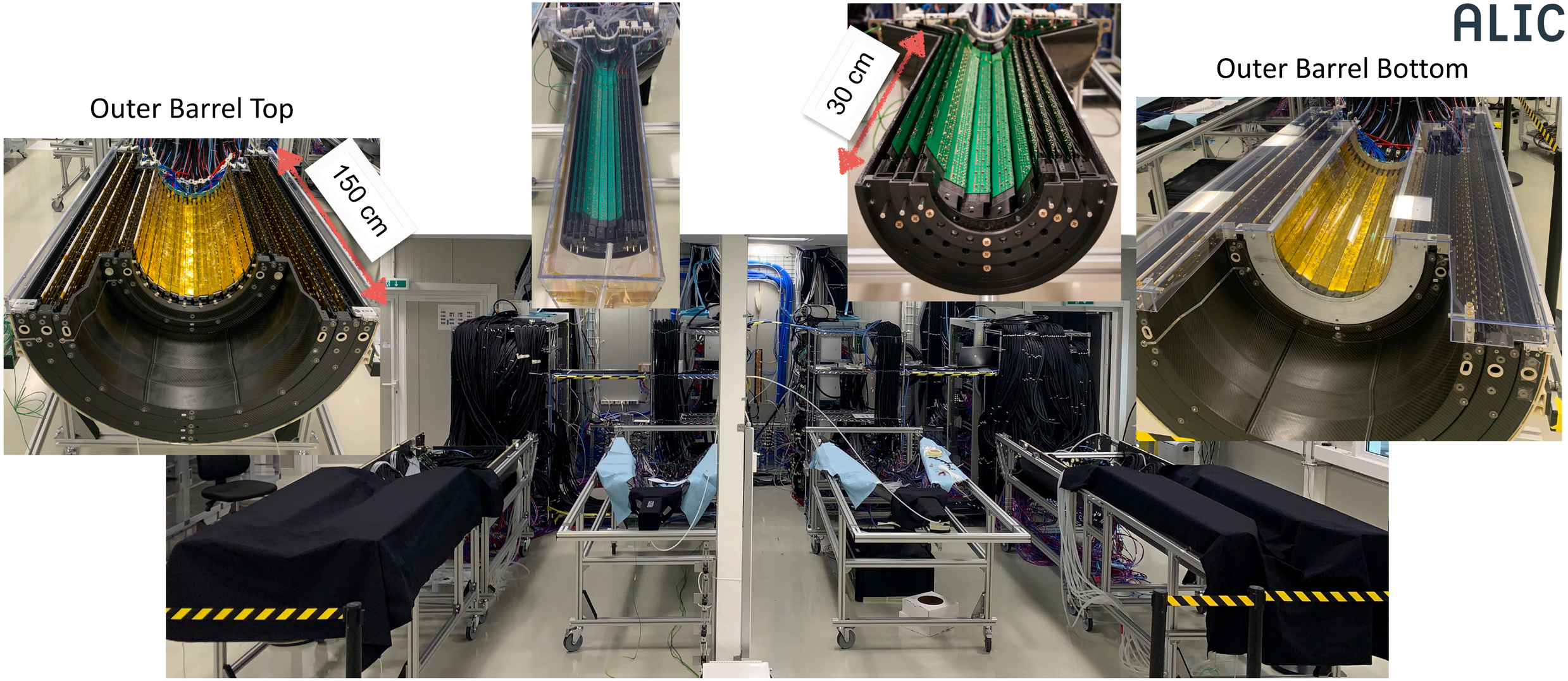
On-surface commissioning - clean room

Inner Barrel Top

Inner Barrel Bottom

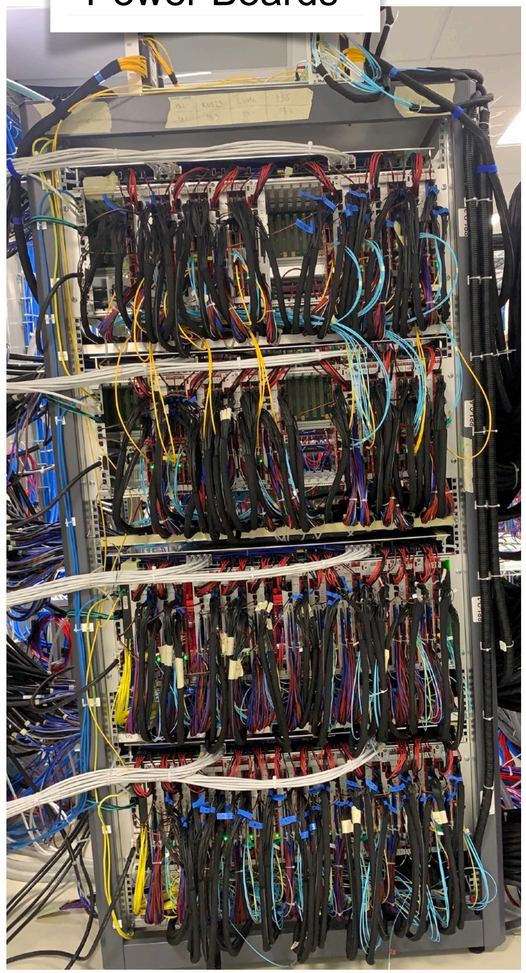
Outer Barrel Top

Outer Barrel Bottom



On-surface commissioning - services

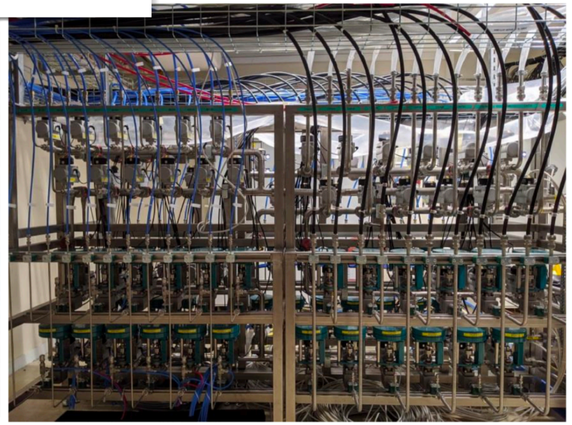
Readout Units / Power Boards



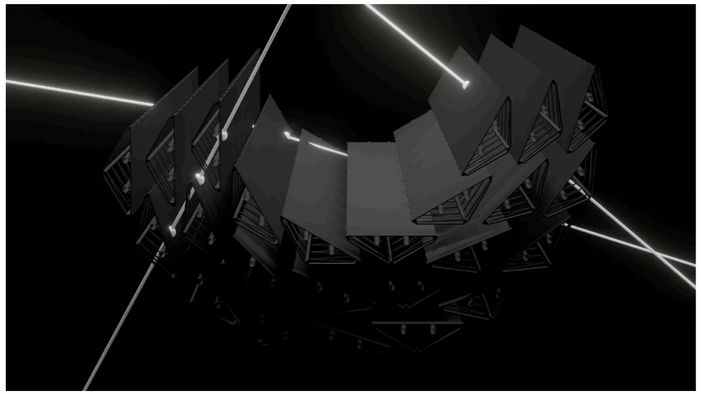
Readout / Control Servers

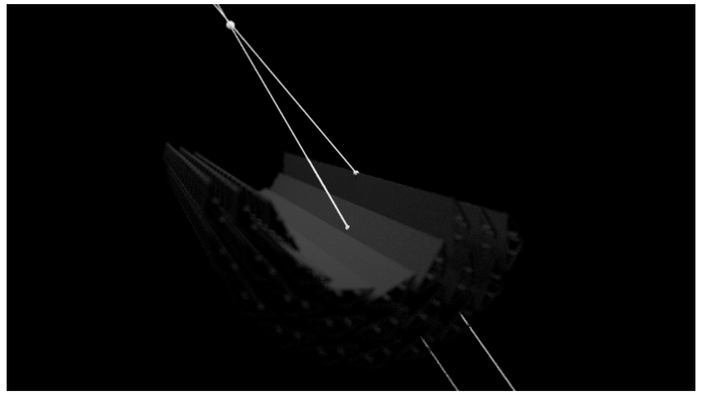
Power supplies

Cooling Plant

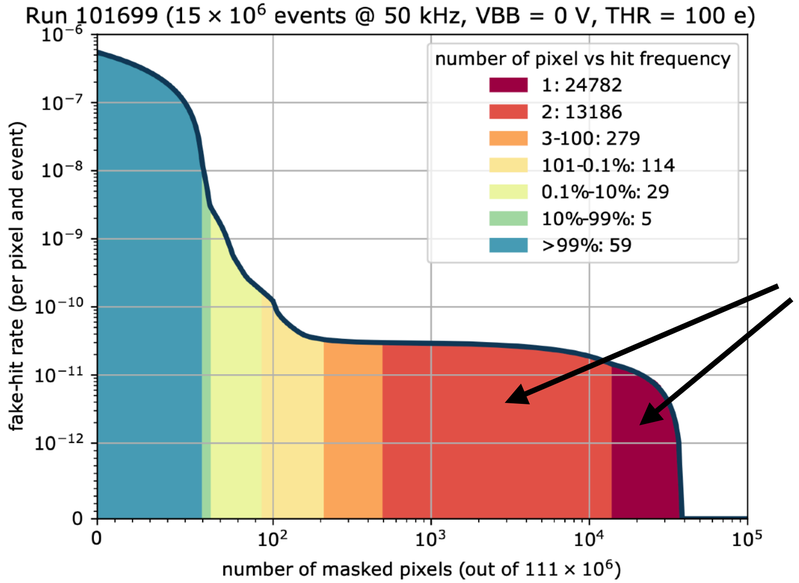


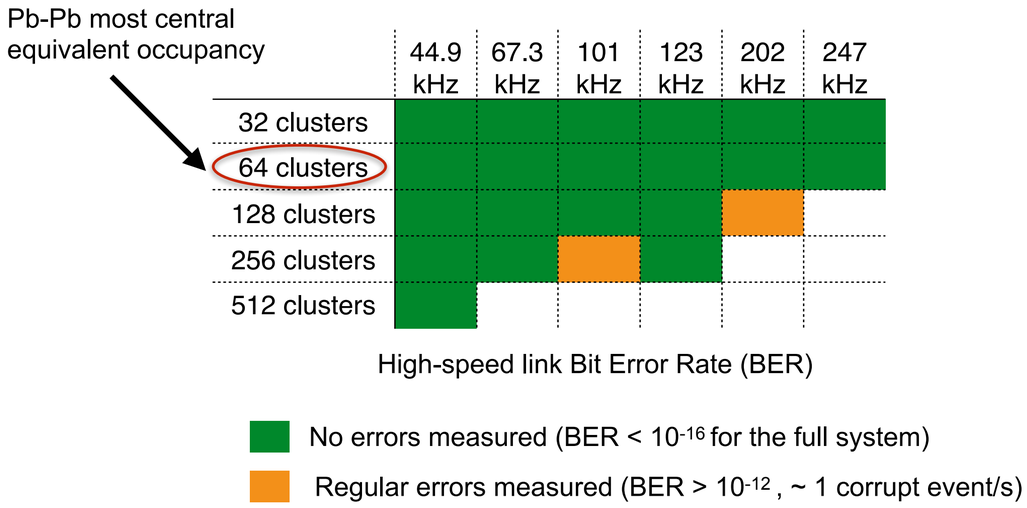
On-surface commissioning - Inner Barrel - highlights



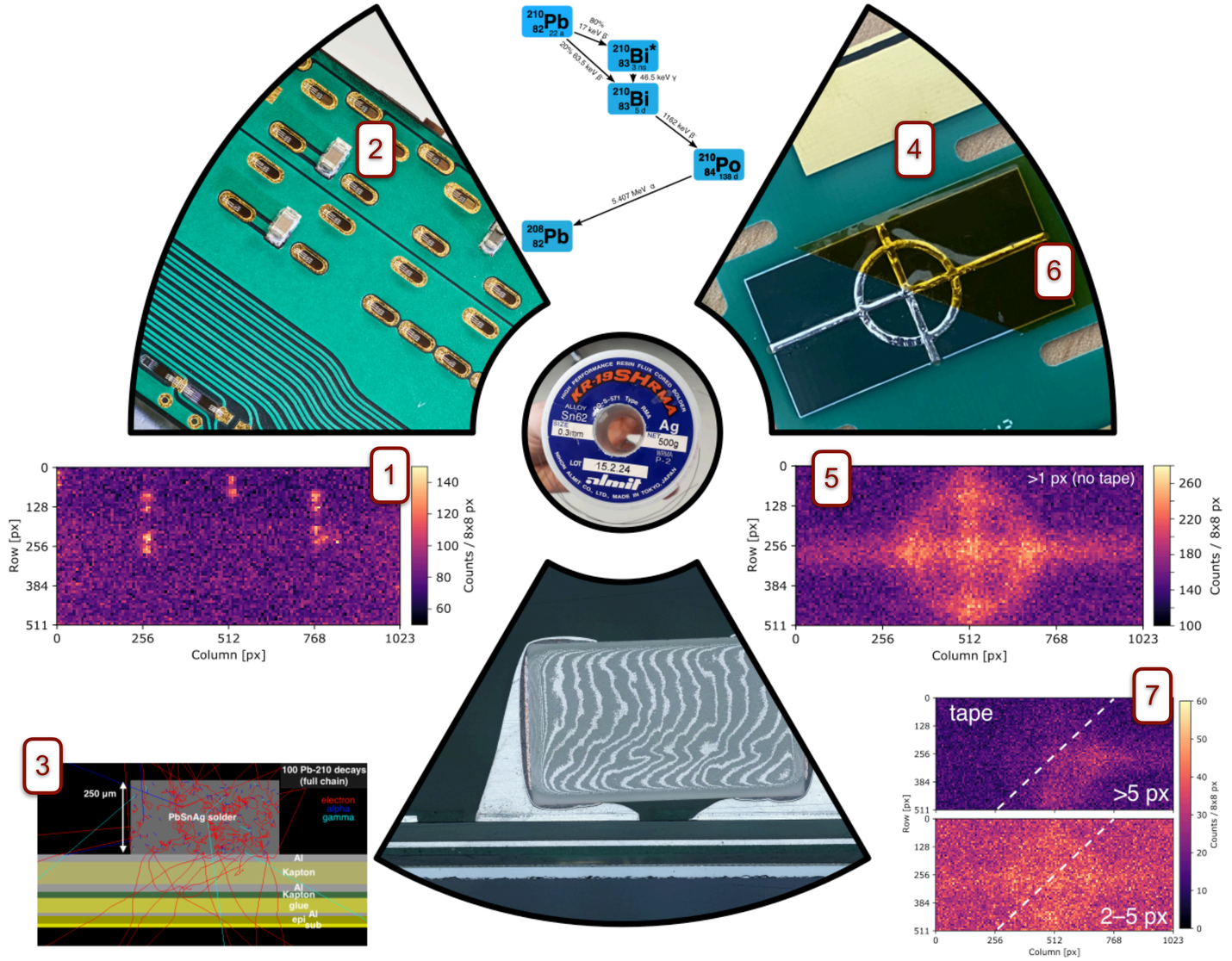


- Tracks and vertices reconstructed
- Excellent fake-hit rate of 10^{-10} / pixel / event
  - Achieved by masking a fraction of 10^{-6} pixels
- Bit error free data transmission:
  - Large operation margin in terms of occupancy and readout rate
  - Error free for several tens of hours at nominal operating conditions
  - Even regular errors *O*(1 / s / 432 chips) for extreme combinations trigger rate and occupancy of lead only to negligible inefficiency





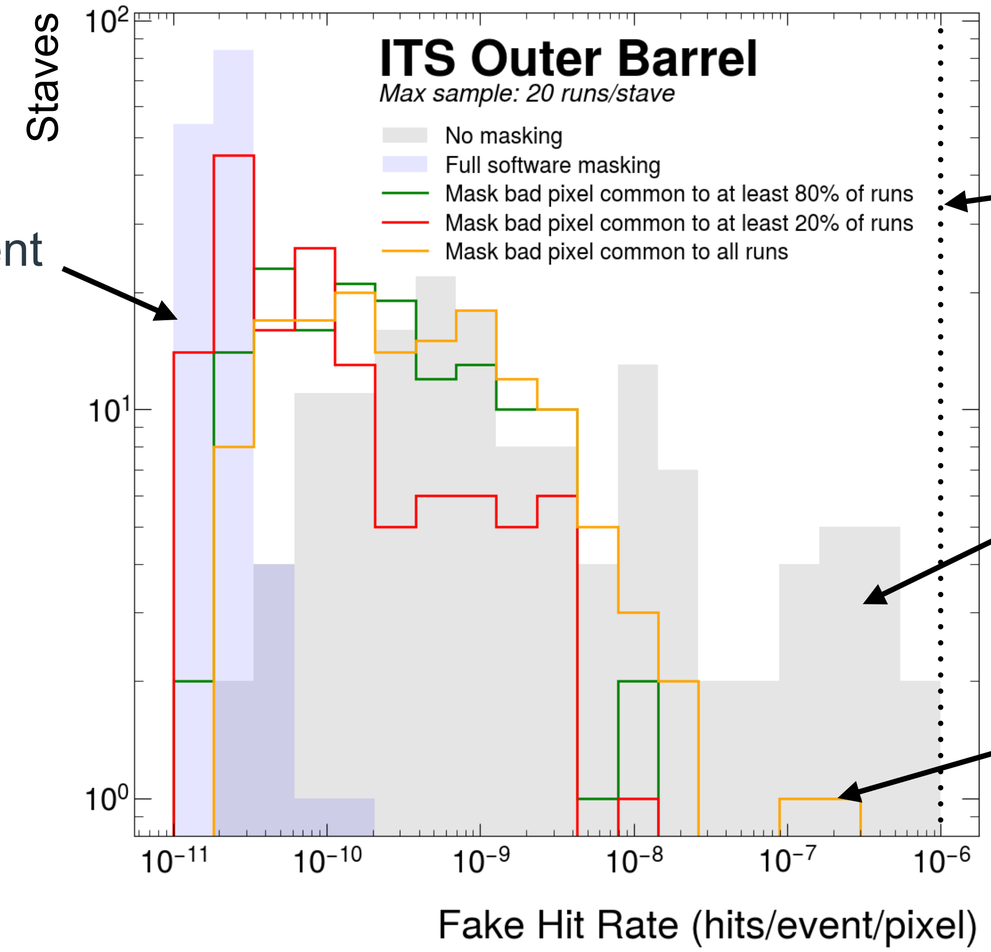
On-surface commissioning - Inner Barrel - closer look into the noise



- Excluded hits clusters assigned to tracks to investigate residual noise
- Superimposed hit maps of 216 ALPIDEs → effective **exposure time** of **204 days**
- **Pattern** 1 correlating with capacitors on the FPC 2
- Components loaded using **leaded solder tin**
- Geant-4 **simulation** 3 to confirm ^{210}Pb decay chain as potential source → control measurement with tin sample 4
- **Tin crosshair** well visible in the control measurement 5
- Used Polyamide tape on a part of the sample to shield Po-210 (α) while letting Bi-210 (β) through 6
- Cluster size analysis confirmed hypothesis: noise pattern originates from Bi-210 (β) 7

On-surface commissioning - Outer Barrel - fake-hit rate

Offline masking:
FHR 10^{-10} / pixel / event



Requirement:
10^{-6} / pixel /event

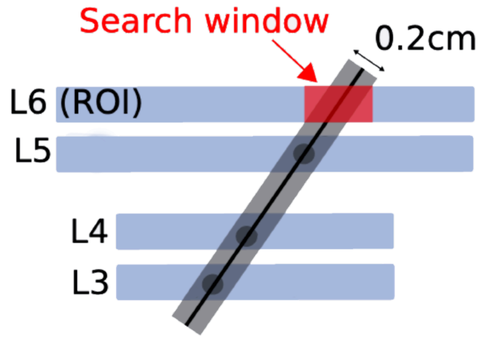
Exclusion of broken double-columns

Masking noisy pixels common to all runs
→ realistic estimate for hardware masking

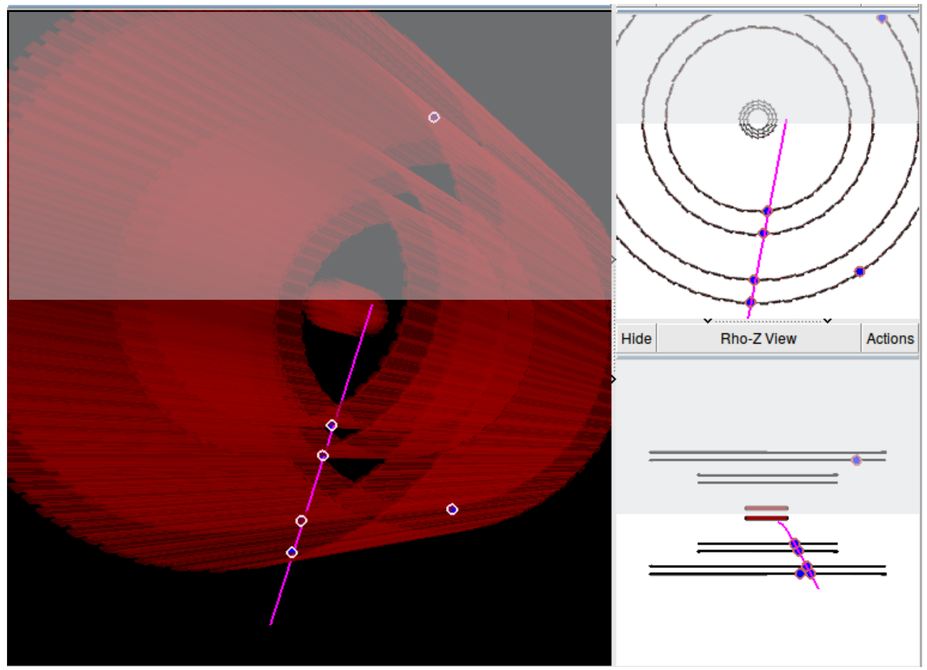
Excellent Fake-Hit Rate (FHR) in the entire OB

On-surface commissioning - Outer Barrel - tracking efficiency

Layer	TOP	BOT
3	98.92 + 0.02 - 0.02	98.95 + 0.02 - 0.02
4	99.30 + 0.01 - 0.01	99.64 + 0.01 - 0.01
5	99.30 + 0.01 - 0.01	98.54 + 0.02 - 0.02
6	99.20 + 0.01 - 0.01	99.38 + 0.02 - 0.02

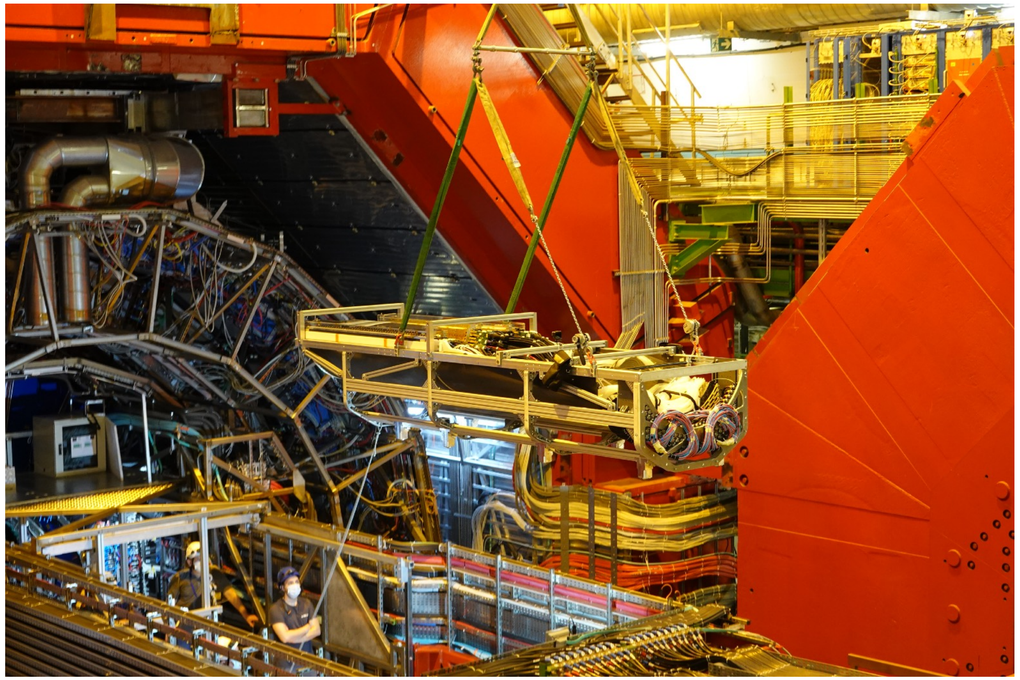


- Analysis prior to software alignment
- Hardware alignment sufficient for first studies
- Based on straight line fits through 3 out of 4 layers
- **Preliminary results** close to **99%**
- Study continues to understand efficiency loss

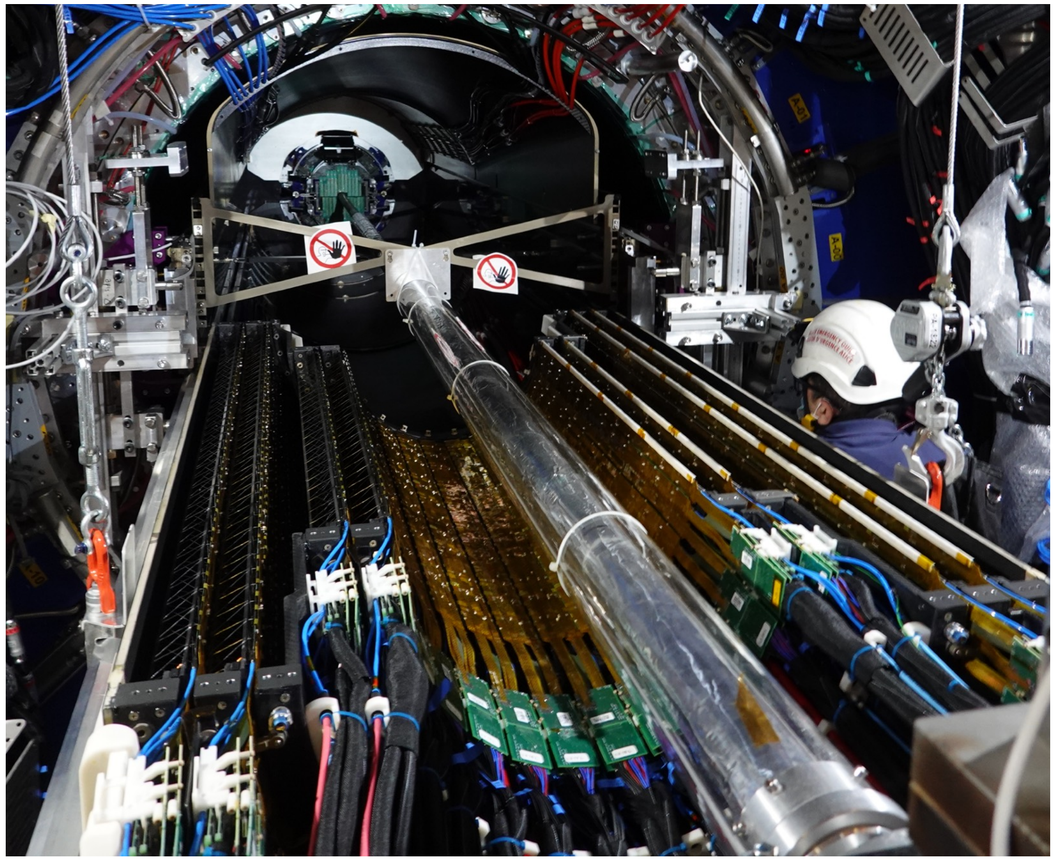


Track candidate in OB Bottom Half-Barrel

Detector installation



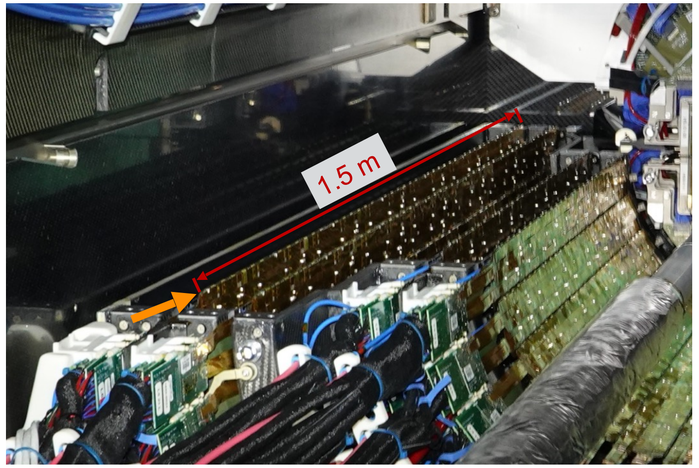
Outer Barrel Bottom lifted to the Mini-Frame by crane



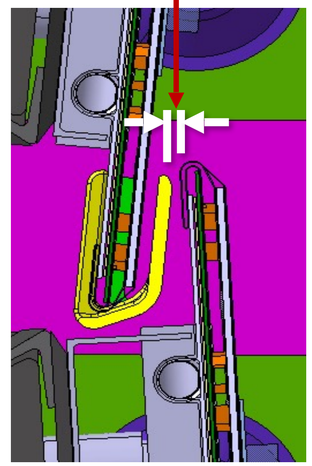
Outer Barrel Bottom being inserted on the rails inside the TPC

Installation - challenges

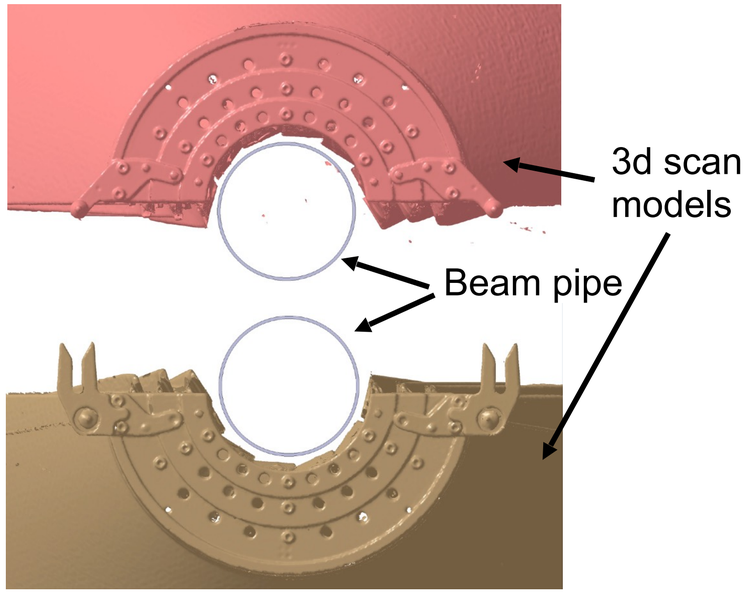
- Precise positioning of fragile objects inside the TPC bore
  → manipulating from a few meters distances
  → difficult to actually see the position by eye
- Dry installation tests on-surface to exercise and test the procures
- Use of 3d scans, surveys and cameras



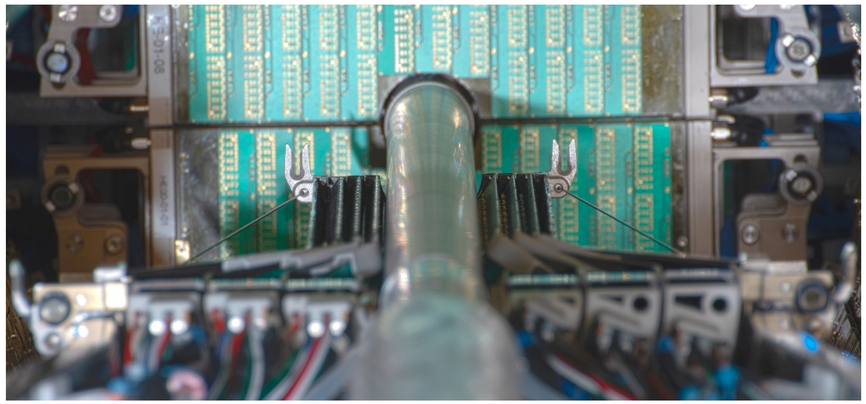
OB stave edge



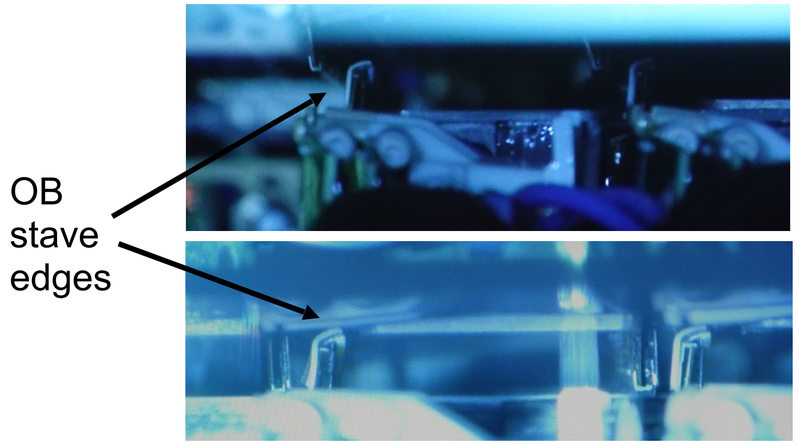
OB stave edge clearance when fully mated



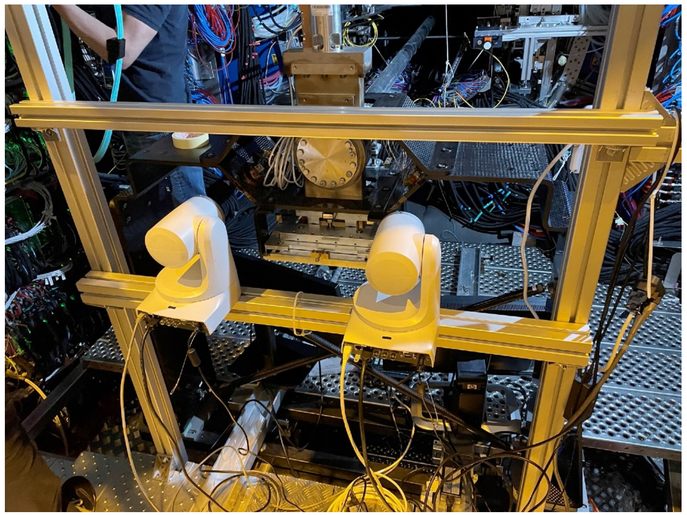
3d scans of IB Half-Barrels next to beam pipe, based on survey

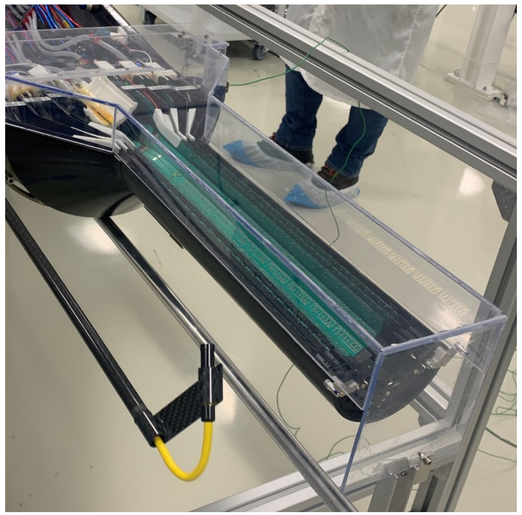


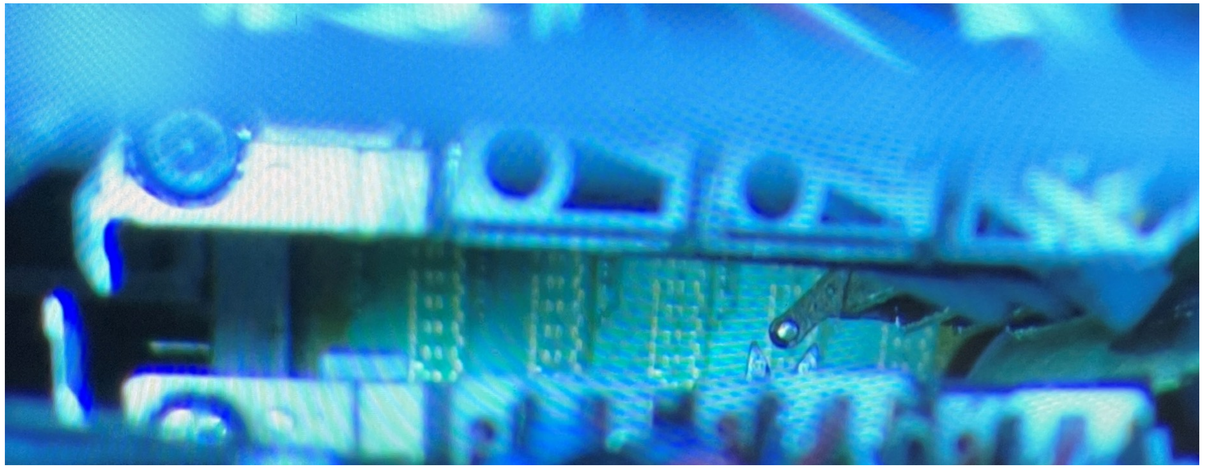
IB Bottom in the final position

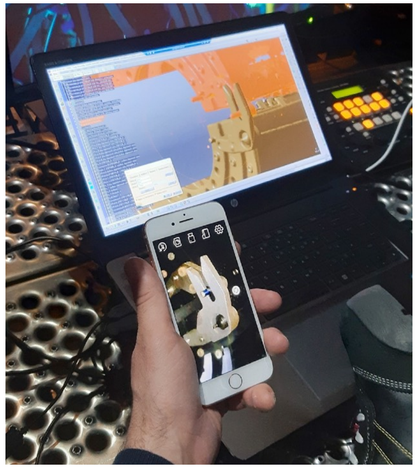


Inner Barrel final positioning



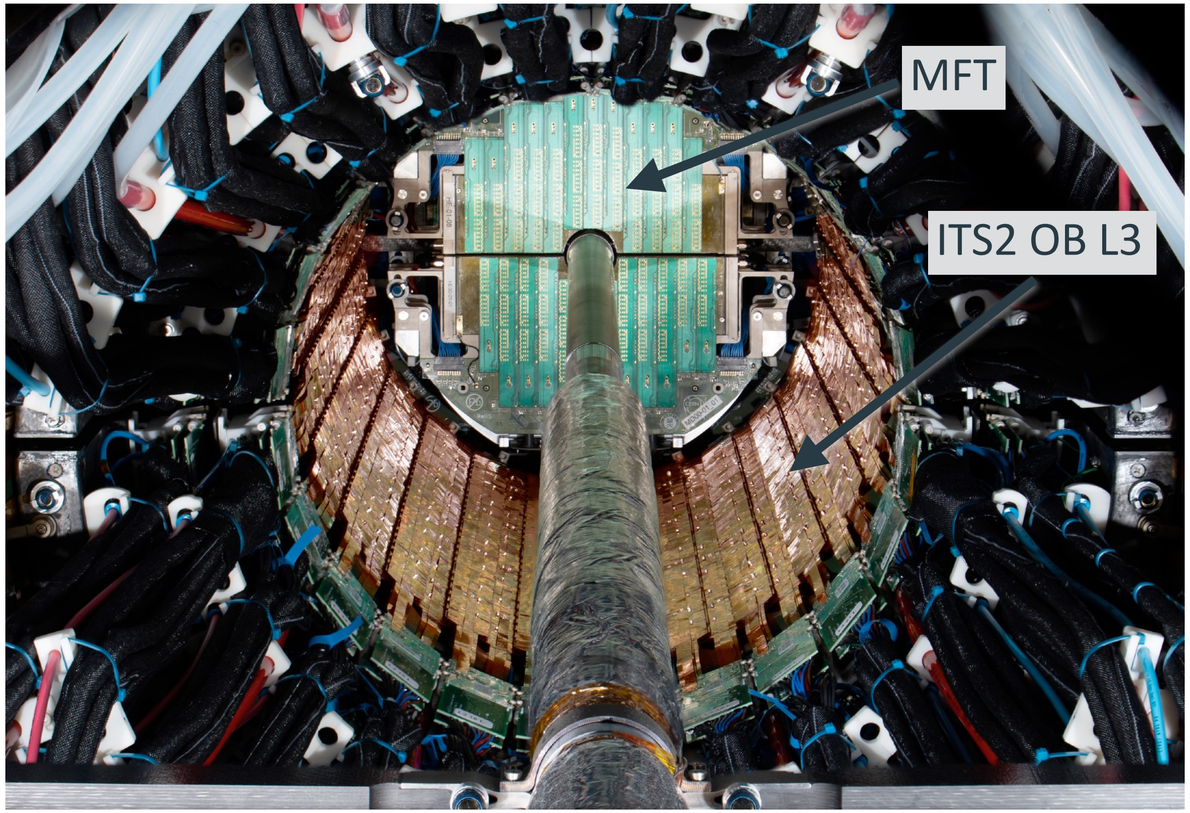




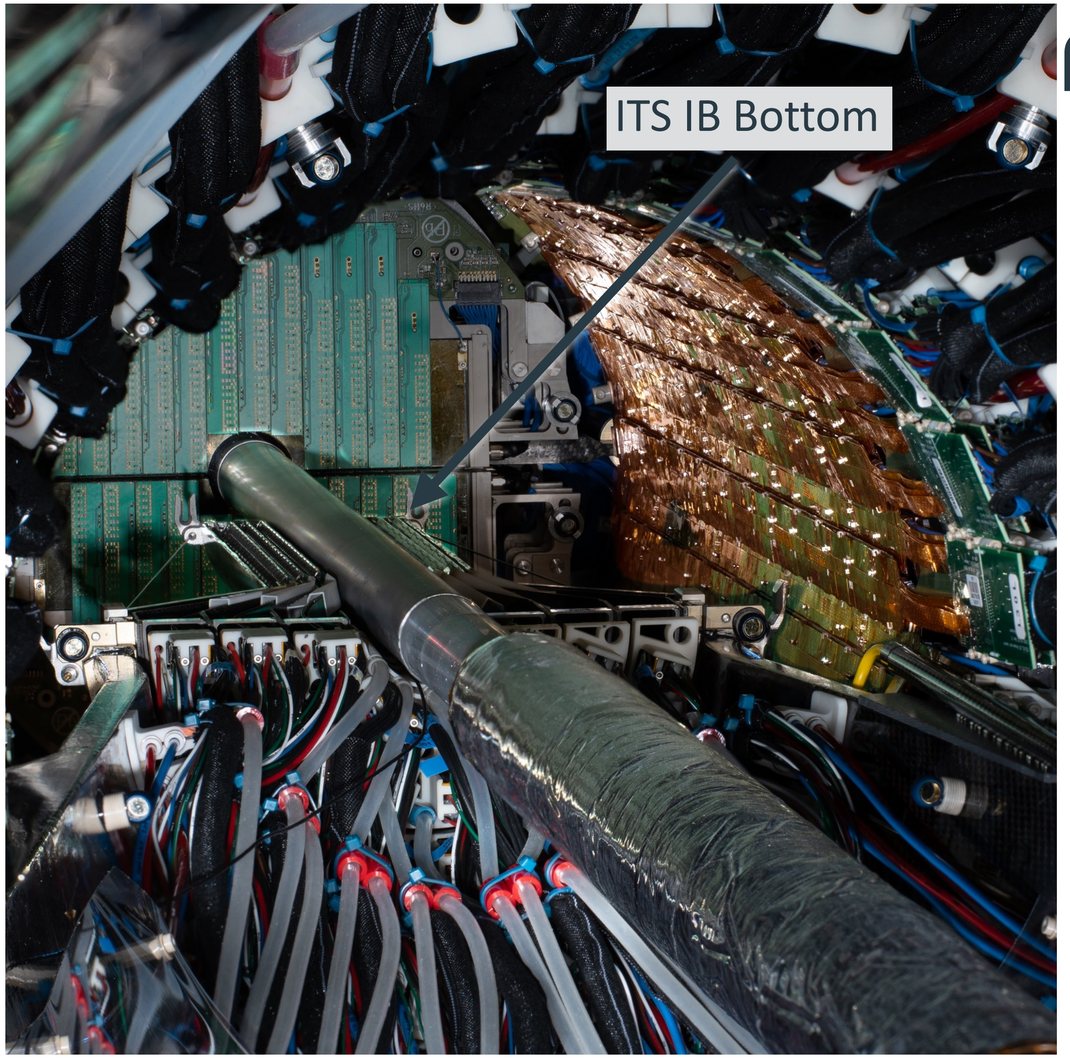


Real time verification using 6 cameras
+ comparison to 3D CAD scans

ITS2 in the ALICE experimental apparatus

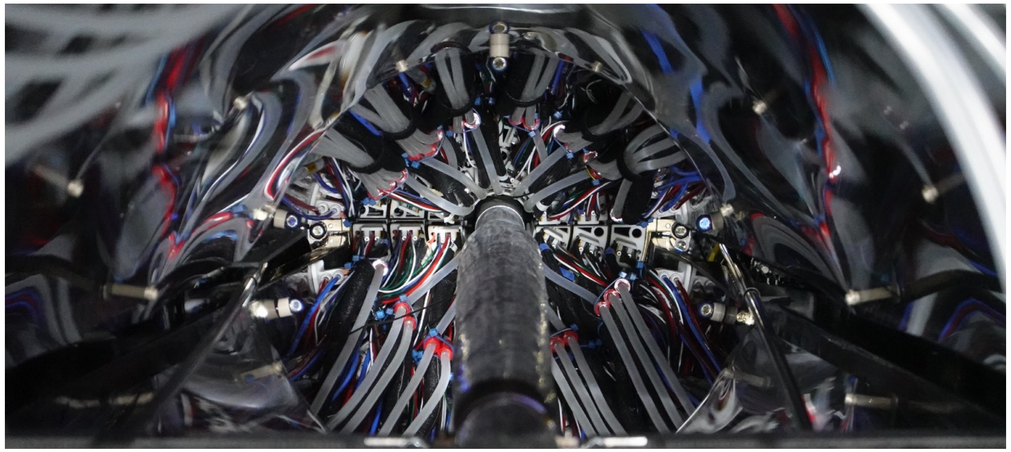


ITS Outer Barrel surrounding the beam pipe, MFT in the back

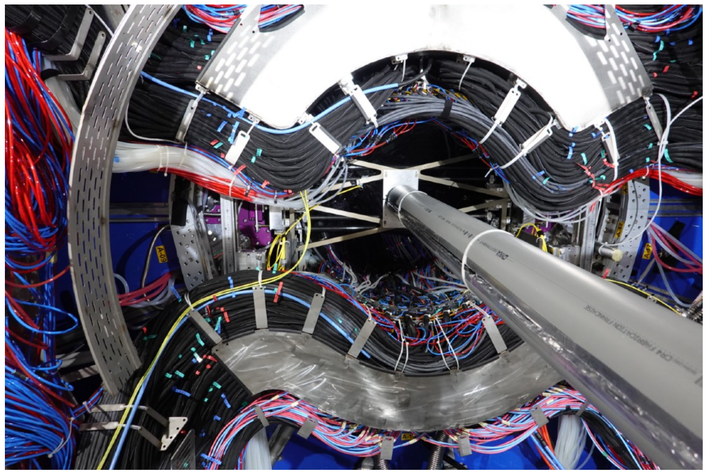


ITS Inner Barrel Bottom and Outer Barrel

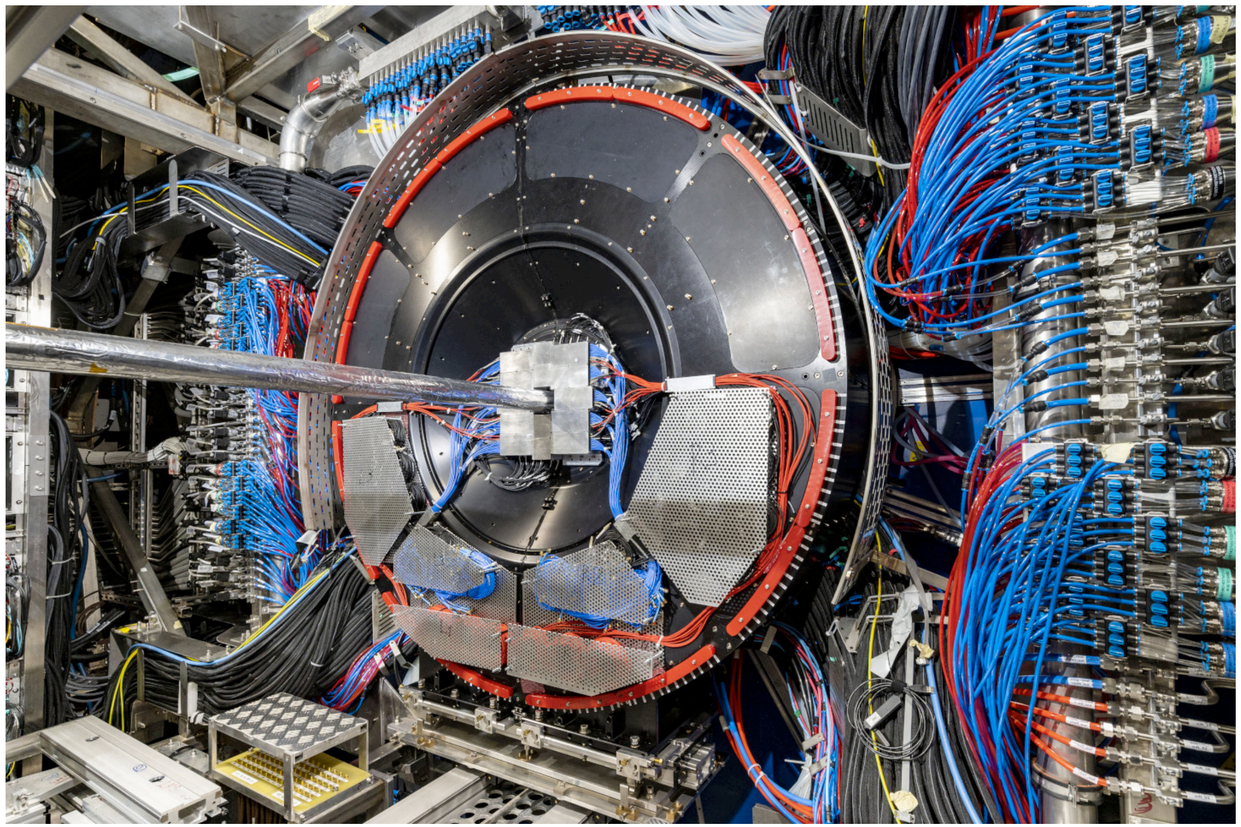
ITS2 in the ALICE experimental apparatus now



Inner Barrel fully mated - only services visible



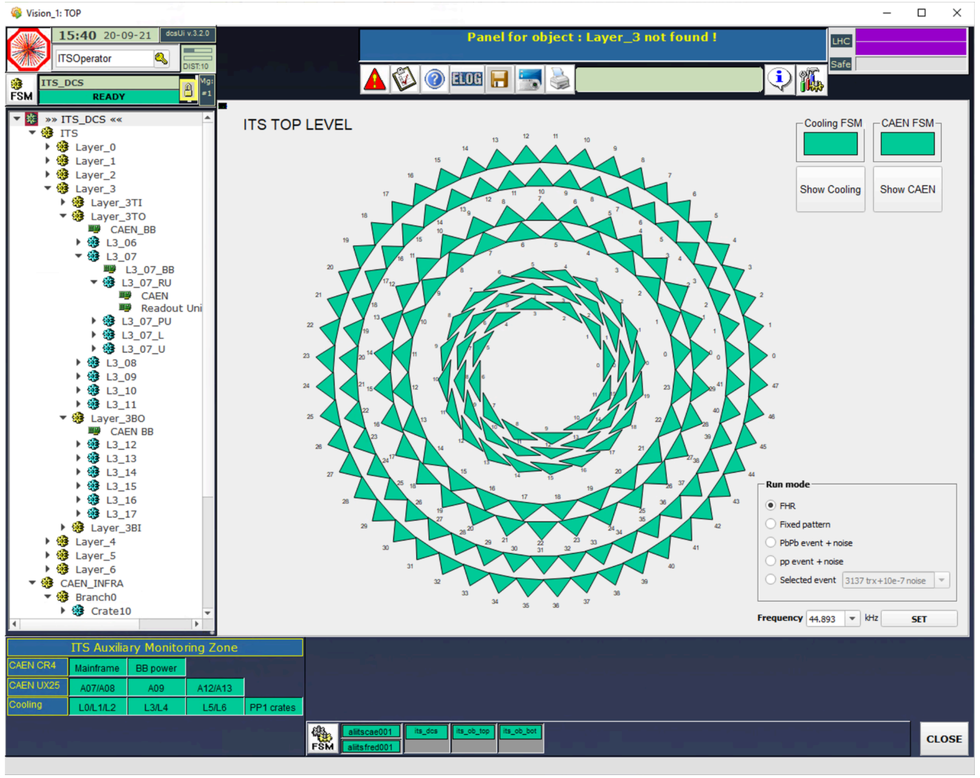
Full services connected (data, power, cooling, ventilation)



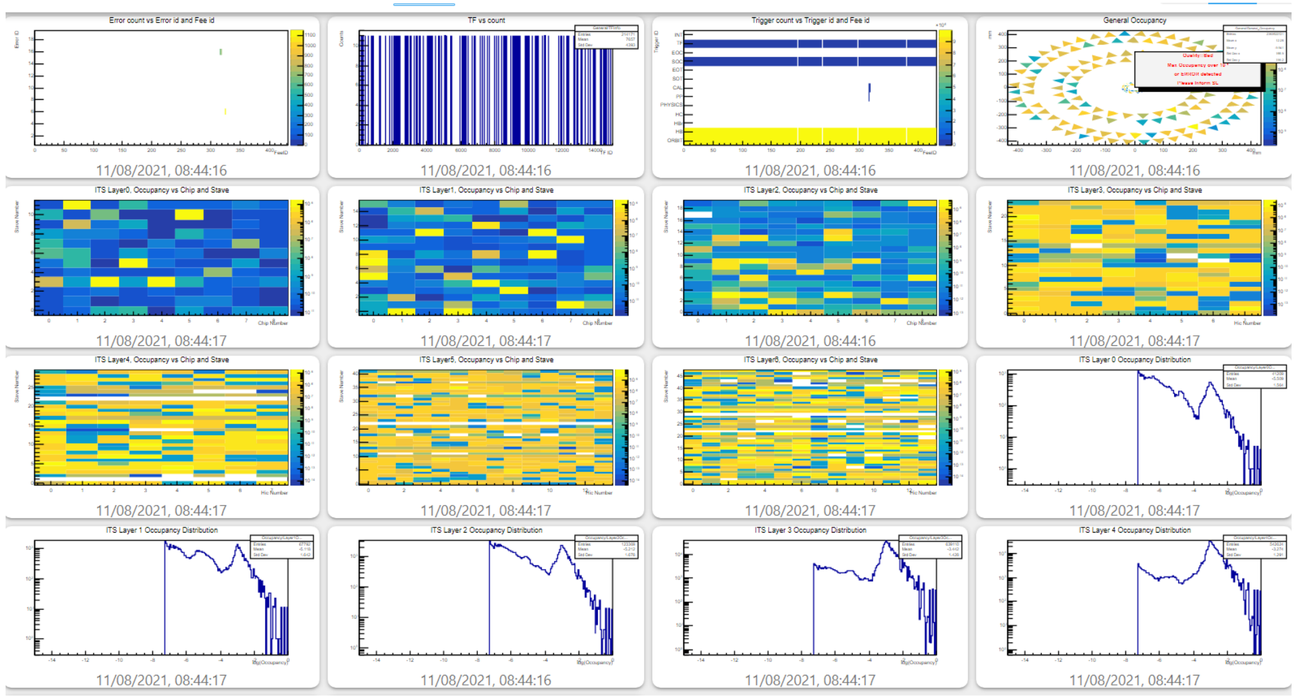
Fast Interaction Trigger (FIT) installed in from of the ITS and its services

Verification and commissioning in the cavern

- Tested connectivity and stability (running 24/7) after every integration step
- Focus on central system integration and operational experience with the final tools
- Detector Control System (DCS) and QC well advanced



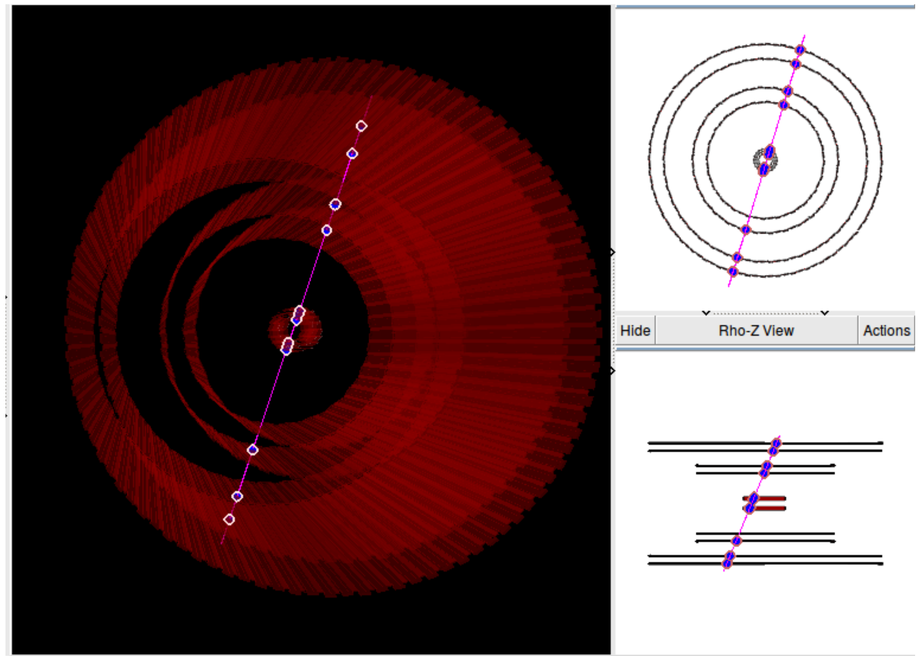
DCS main panel

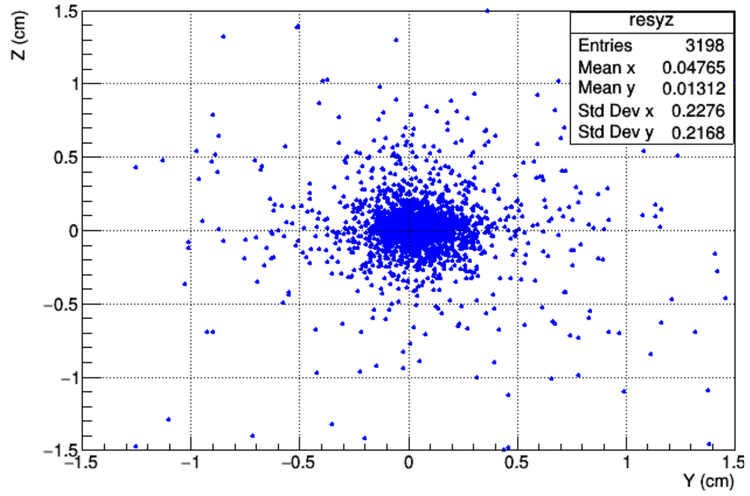


Occupancy view of the ITS2 QC

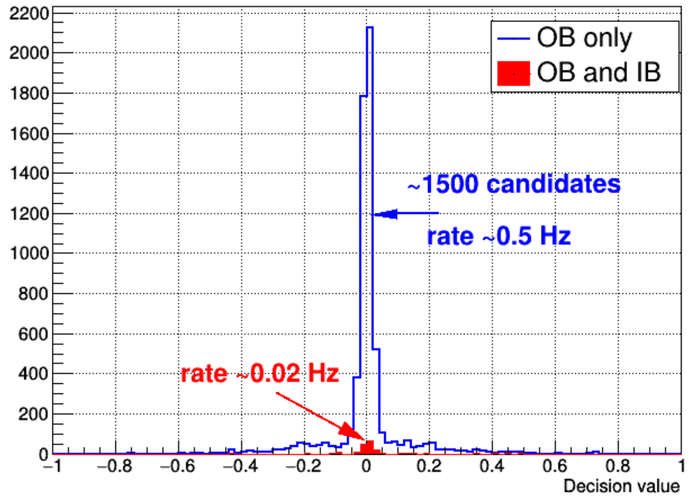
Cosmic muons in the cavern

- Data taking in the final system
  (services, trigger network, readout chain)
- Analysis of first tracks ongoing
- Cosmic track rate:
  - Outer Barrel: 0.5 Hz
  - Full detector (Outer Barrel + Inner Barrel): 0.02 Hz
- Residuals prior alignment of *O*(1 mm)
  → Excellent hardware alignment
  → Mapping of chips correct
- Next steps:
  - Detector alignment
  - Track reconstruction





Residual of a straight line extrapolation to L6 before alignment

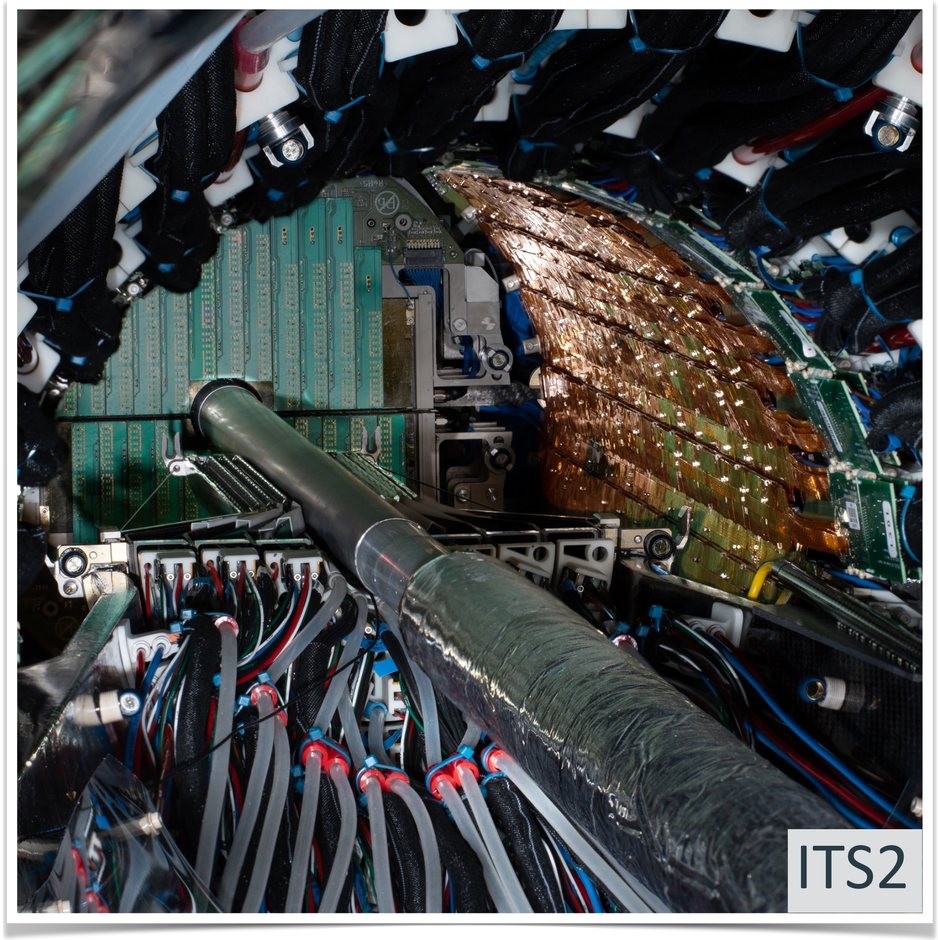


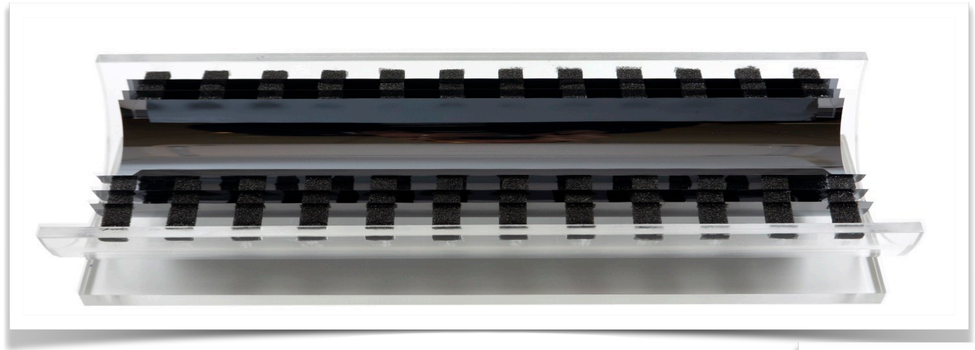
Track straightness based on hits in layers 4, 5 and 6

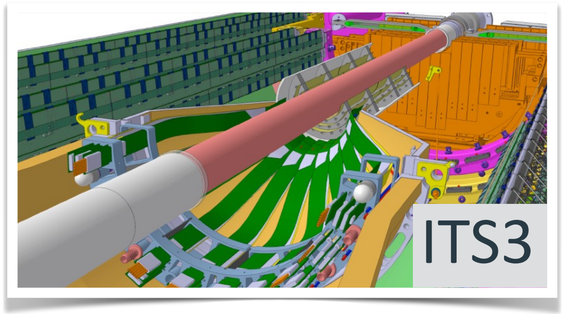
Summary

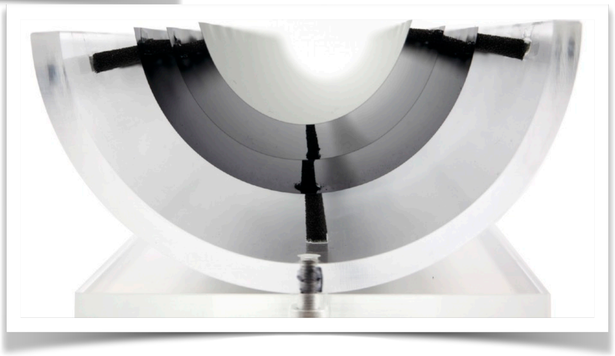
- Single chip performance confirmed during on-surface commissioning
- Detector fully installed
- Detector verified after installation
- First cosmic tracks observed
- Getting ready for the pilot beam test in October

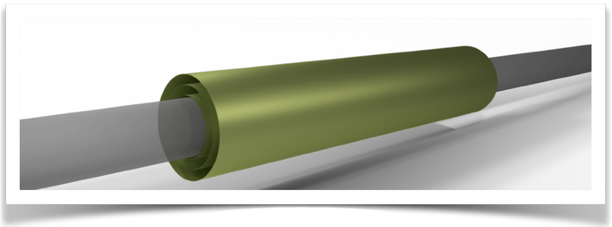
ITS Outer Barrel during insertion tests











Thank you for your attention!

ITS3 talks:

Development of bent silicon vertex detectors for ALICE in the LHC Run 4 - Matthew Buckland - on Tuesday 28th

Analysis of test beam data with bent MAPS sensors for the ALICE upgrade - Nicolo Jacazio - on Tuesday 28th