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

Stefania Maria Beolé on behalf of the ALICE experiment

International Workshop 23rd iWoRiD on Radiation Imaging Detectors

iWoRiD 2022

23rd International Workshop on Radiation Imaging Detectors

26 – 30 June 2022

Riva del Garda, Italy

ALICE Upgrades in LS2

Motivation:

High-precision measurements of rare probes at low p_T

- Cannot be selected by hardware trigger
- Need to record large minimum-bias data sample
  - Read out all Pb-Pb interactions up to the **maximum collision rate of 50 kHz**

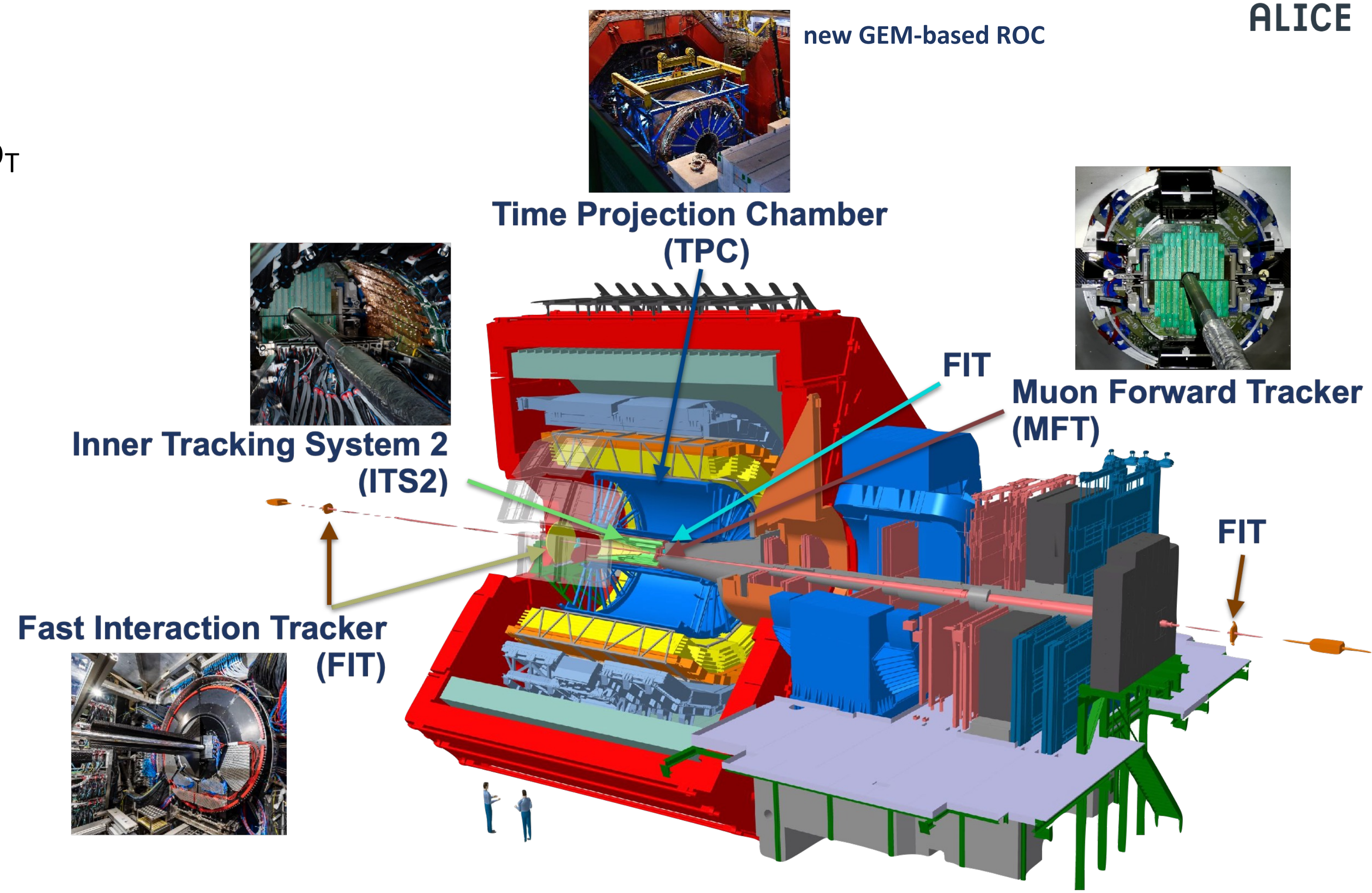
Goal:

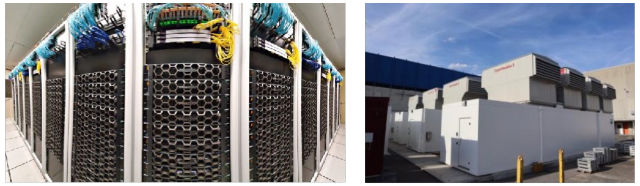
- Pb-Pb integrated luminosity 13 nb^{-1} (plus pp, pA and O-O data)

  -> Gain factor 100 in statistics for min bias sample w.r.t. runs 1+2
- Improve vertex reconstruction and tracking capabilities

Strategy:

- new ITS, MFT, FIT, TPC ROC
- update FEE of most detectors
- new integrated Online-Offline system (O^2)



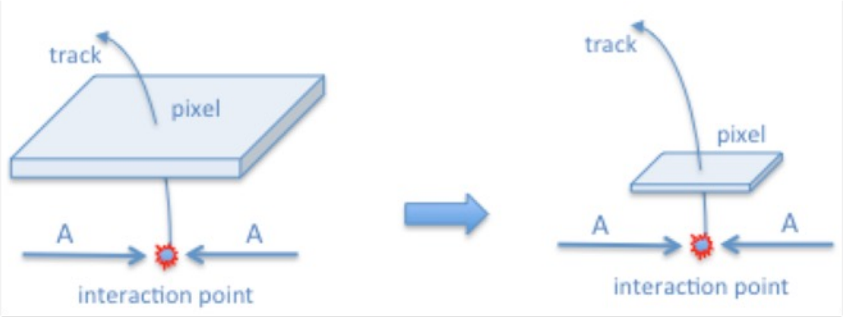


Integrated Online-Offline system (O^2)

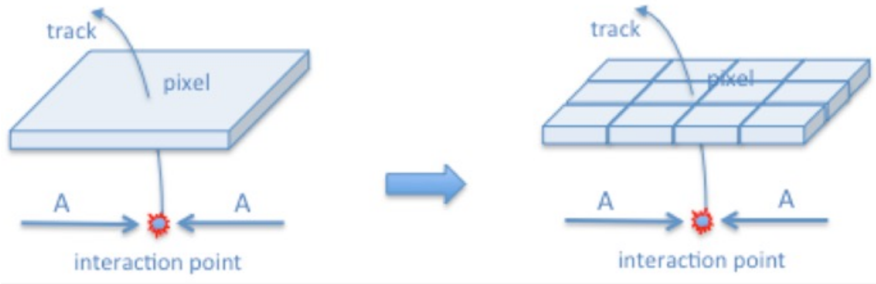
Readout upgrade
TOF, TRD, MUON, ZDC, Calorimeters

ITS2 Design Objectives

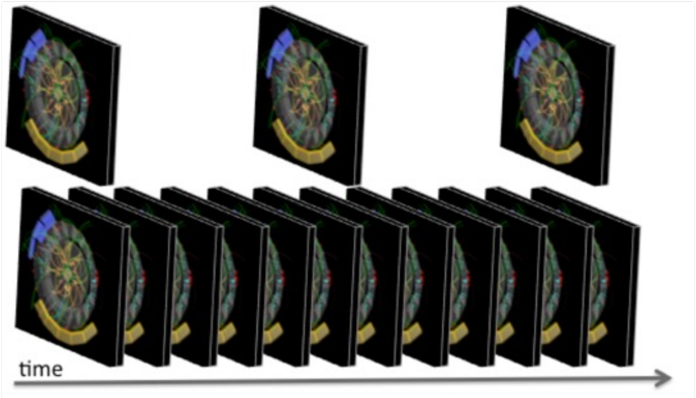
- Improve impact parameter resolution by factor ~3 in rϕ and factor ~5 in z at p_T = 500 MeV/c
  - Get closer to IP: 39 mm -> 23 mm
  - Reduce material budget: 1.14% X_0 -> 0.35% X_0 (inner layers)
  - Reduce pixel size: 50 x 425 μm^2 -> ~30 x 30 μm^2



- Improve tracking efficiency and p_T resolution at low p_T
  - Increase number of track points: 6 -> 7 layers

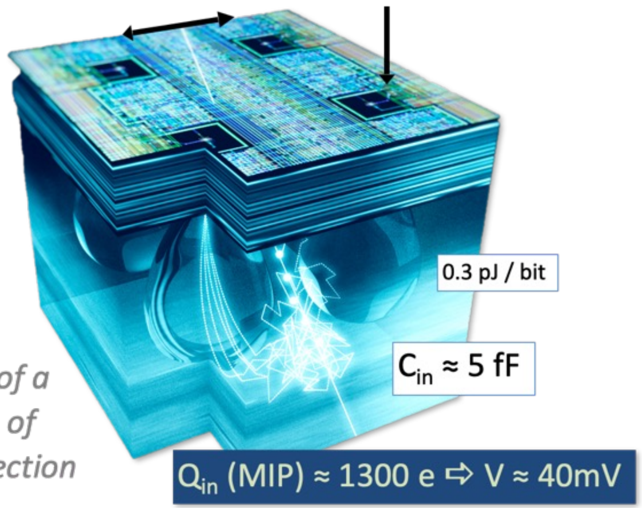


- Fast readout
  - Readout of Pb-Pb collisions at 100 kHz (ITS1: 1 kHz) and p-p at 400 kHz

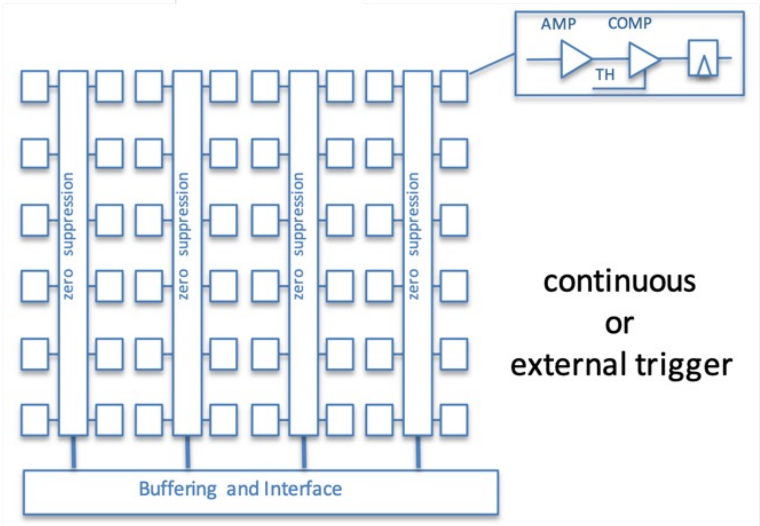


ITS TDR: J. Phys. G: Nucl. Part. Phys. 41 (2014) 087002

ITS2 pixel chip: ALPIDE



Artistic view of a SEM picture of ALPIDE cross section

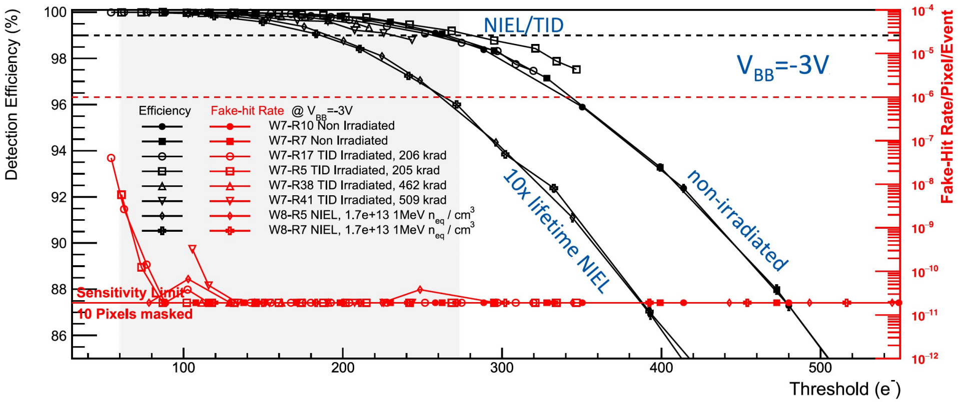


CMOS Pixel Sensor – Tower Semiconductor 180nm CMOS Imaging Sensor (CIS) Process

ALPIDE Key Features

- In-pixel: Amplification, Discrimination, multi event buffer
- In-matrix zero suppression: priority encoding
- Ultra-low power < 40mW/cm^2 (< 140mW full chip)
- Detection efficiency > 99%

- Spatial resolution ~5µm
- Low fake-hit rate: << 10^{-6}/pixel/event (10^{-8}/pixel/event measured during commissioning)
- Radiation tolerance:
  - 270 krad total ionising dose (TID),
  - > 1.7 10^{13} 1MeV/n_{eq} non-ionising energy loss (NIEL)
- Same chip used for ITS and Muon Forward Tracker (MFT)



ALPIDE detection efficiency and fake hit rate

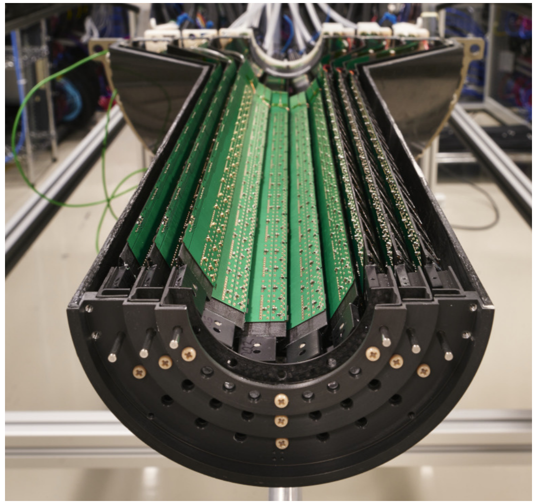
ALPIDE and other developments

With permission. Article online

ALPIDE: Tower Semiconductor 180nm CMOS Imaging Sensor (CIS) Process

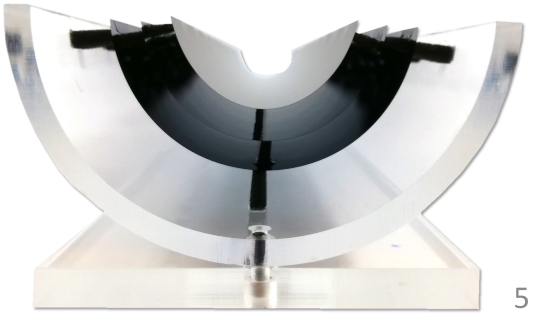
- R&D effort within the ALICE collaboration
  - excellent collaboration with foundry
  - more than 70k chips produced and tested
  - ALICE ITS pioneers large area trackers built of MAPS (ALICE 3)
- in parallel studies to optimise process to reach full depletion and improve time response and radiation hardness up to 10^{15} 1MeV/n_{eq} :
  - **More details:** NIM **A871** (2017) https://doi.org/10.1016/j.nima.2017.07.046
  - **Now being further pursued: MALTA, CLICpix, FastPix, …**

ITS2 Inner Barrel



FUTURE: TPSCo 65 nm CMOS Imaging Sensor (CIS) Process

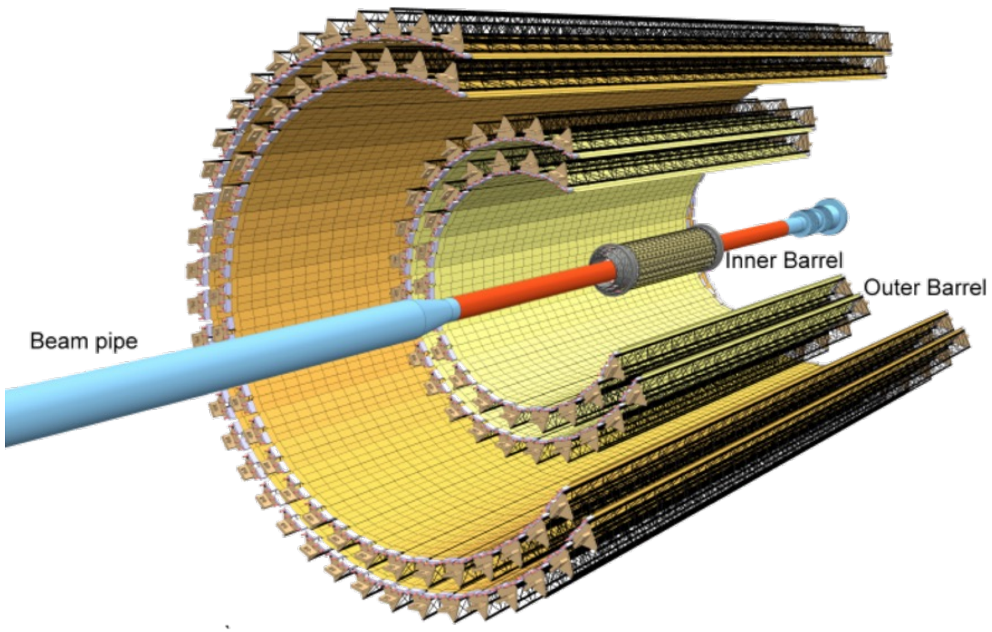
- **what next? ITS3: all silicon detector**
  - 2D stitching → large surface sensors
  - 300 mm wafers → 27×9 cm^2 sensor
  - single “chip” equips an ITS3 half-layer
  - thinned down to 20-40 µm
    -> flexible, bent to target radii

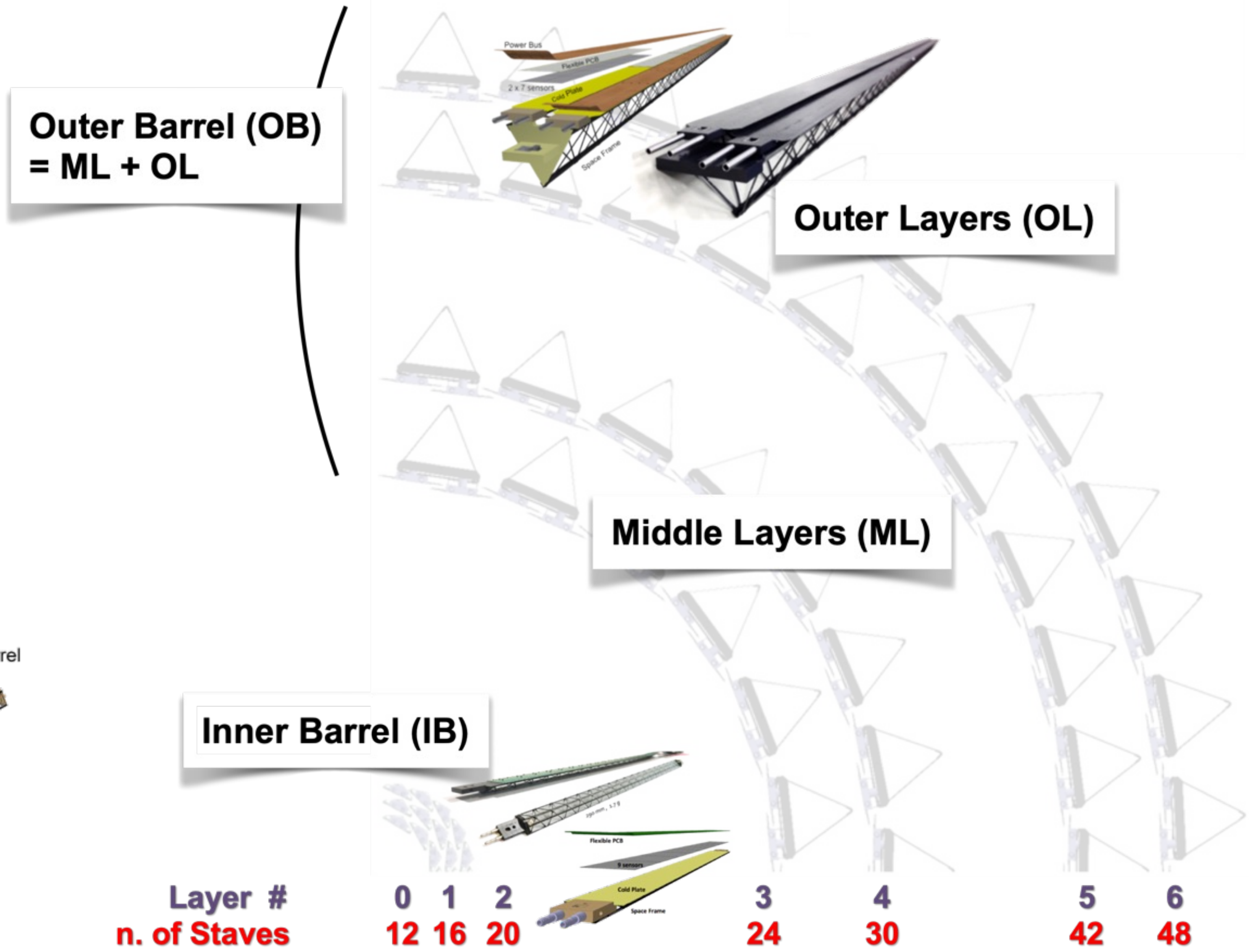


follow Serhiy Senyukov’s talk this afternoon

ITS2 Layout

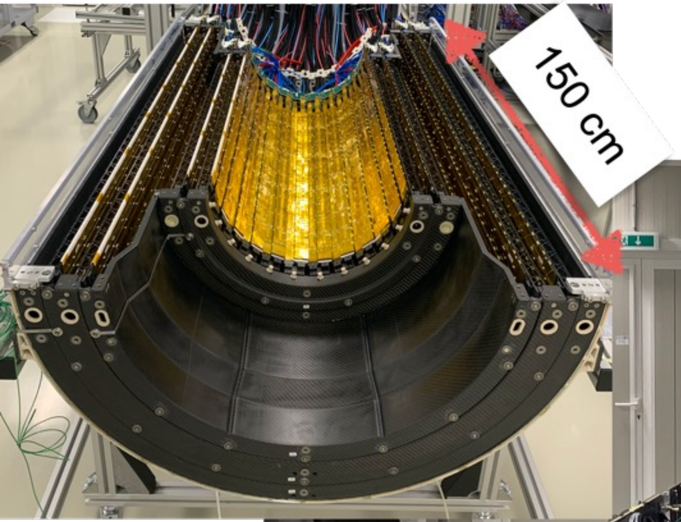
- 7 Layers (3 inner / 2 middle / 2 outer) from R = 22 mm to R = 400 mm
- 192 Staves (48 IL / 54 ML / 90 OL)
- Ultra-lightweight support structure and cooling
- 10 m^2 active silicon area, 12.5 x 10^9 pixels



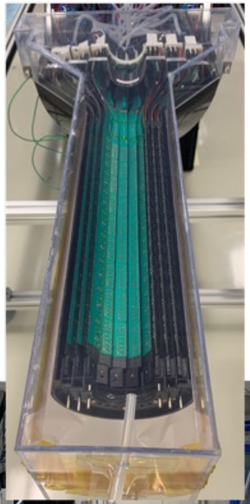


On-Surface Commissioning

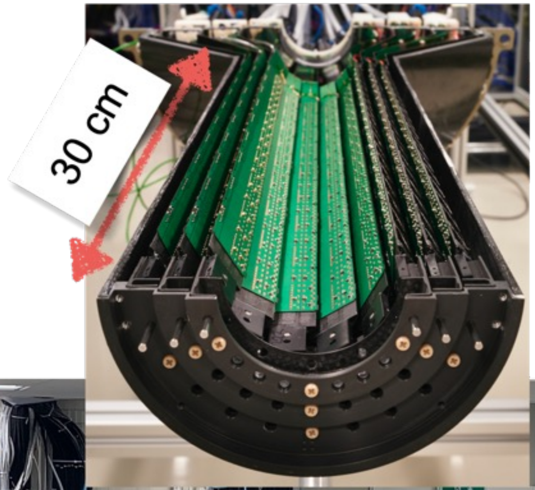
Outer Barrel Top



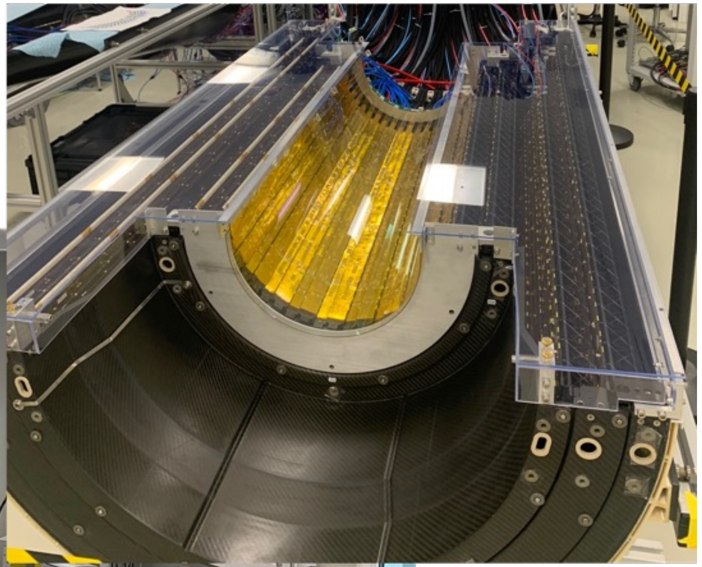
Inner Barrel Top



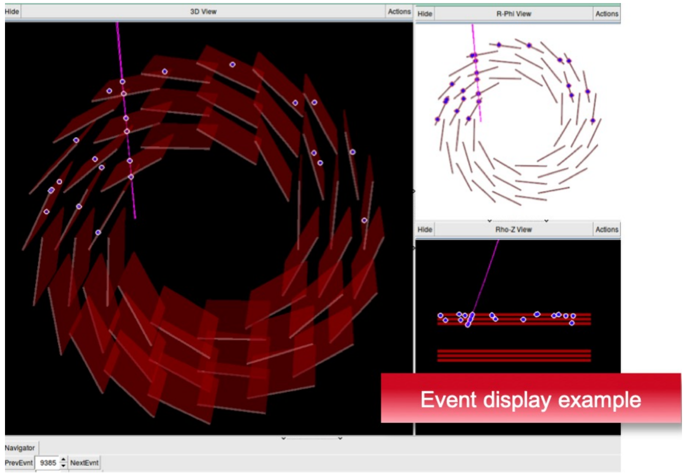
Inner Barrel Bottom

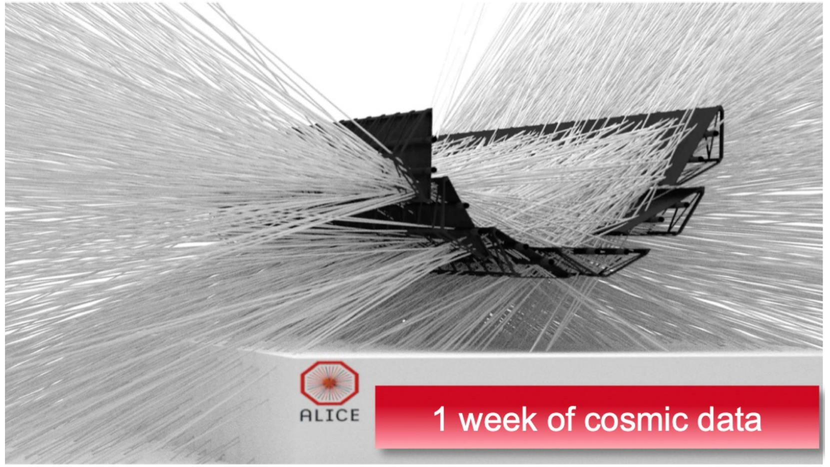


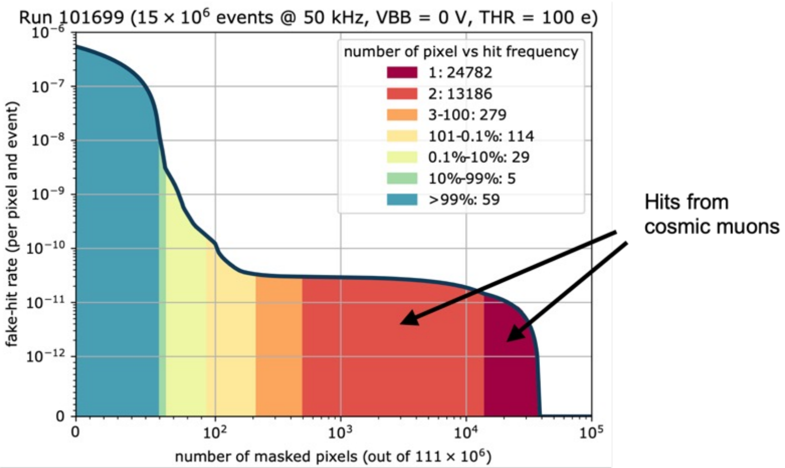
Outer Barrel Bottom



On-Surface Commissioning results

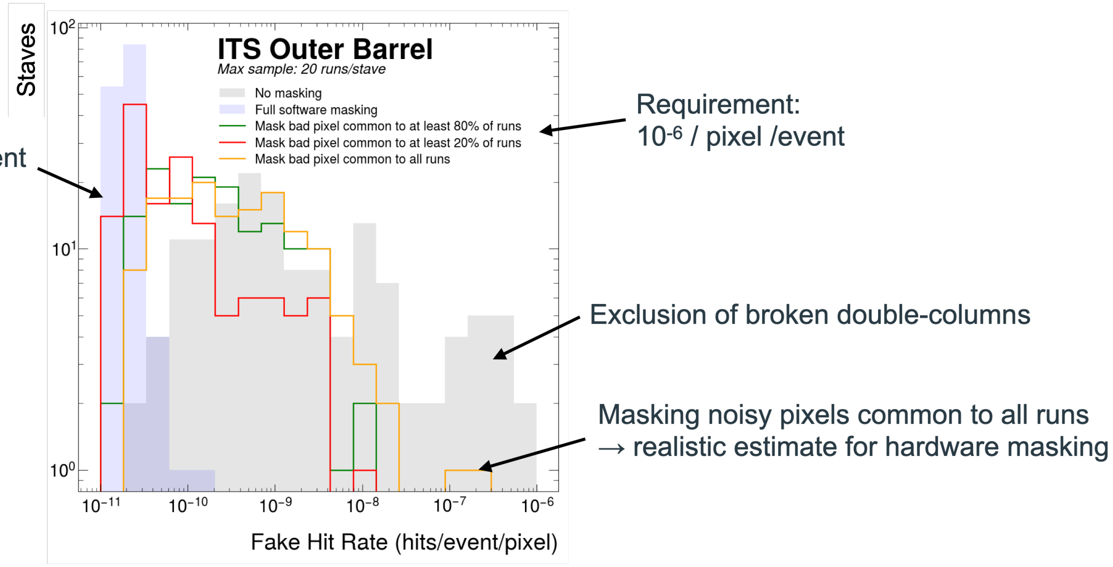






- Cosmics tracks reconstructed
- IB: fake-hit rate of 10^{-10} / pixel / event
  - Achieved by masking fraction of 10^{-8} pixels
- OB: fake-hit rate of 10^{-8} / pixel / event
  - Achieved by masking noisy pixels common to all runs
- Bit-error-free data transmission for several tens of hours at nominal operating conditions
  - Large operational margin in terms of occupancy and readout rate
  - Regular errors for extreme combinations of occupancy and trigger rate lead to negligible inefficiency (~1/s for full IB)

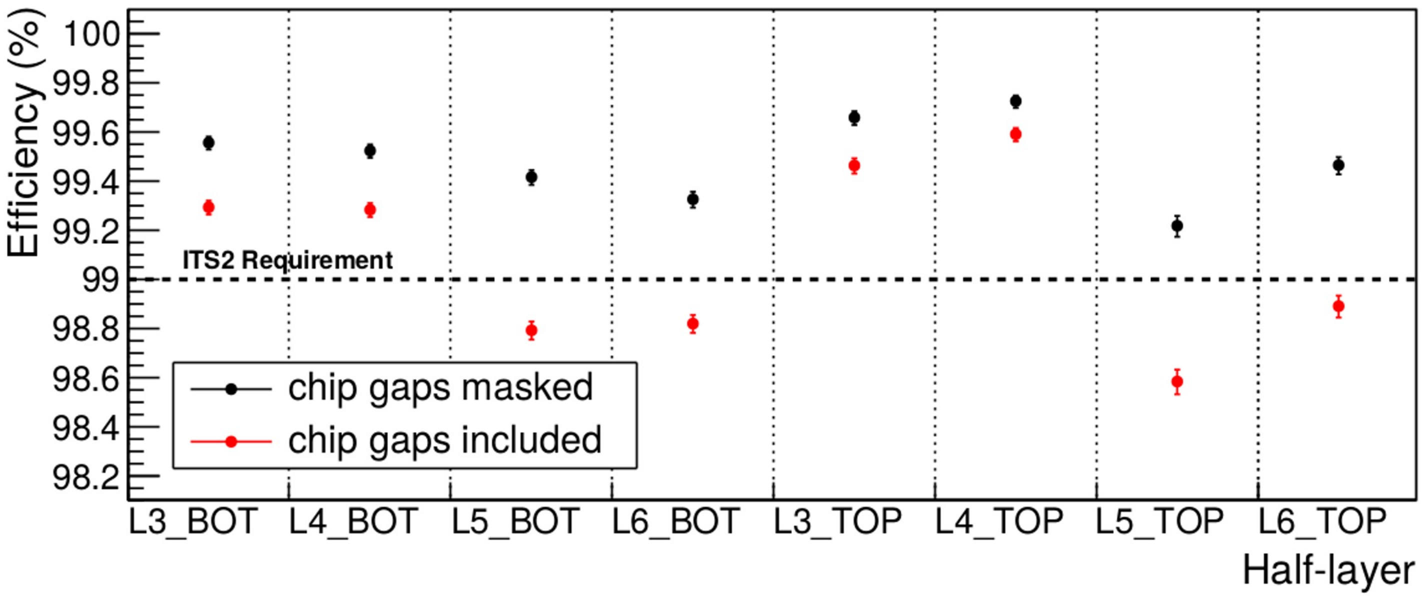
Offline masking:
FHR 10^{-10} / pixel / event

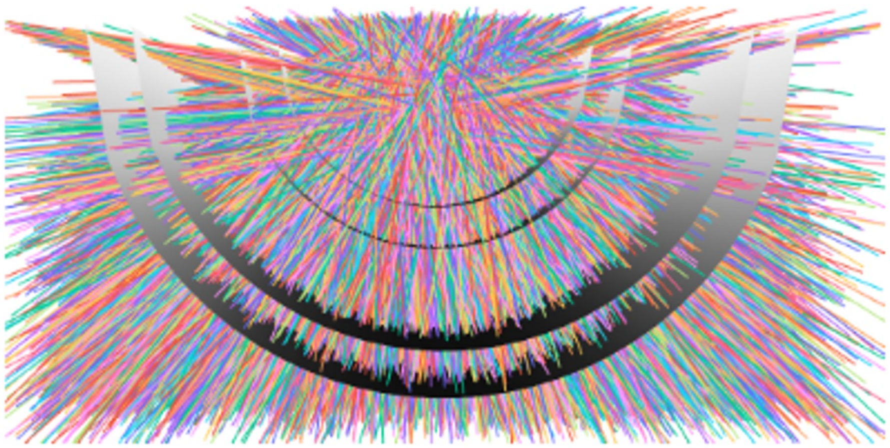


Excellent Fake-Hit Rate (FHR) in the entire OB

On-Surface Commissioning – Outer Barrel Efficiency

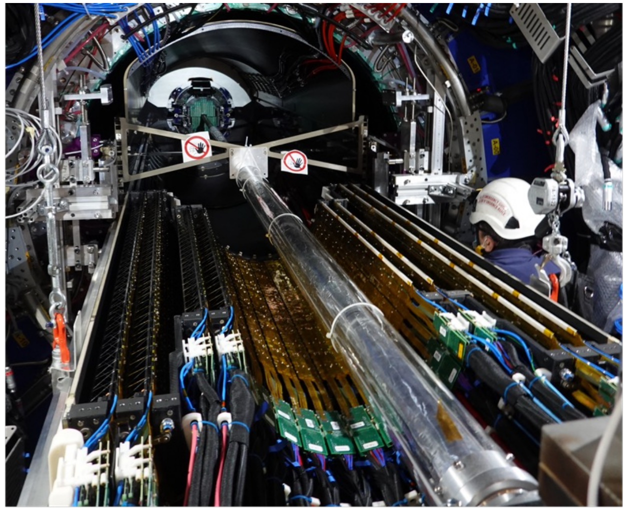
- [Preliminary study] Efficiency of OB using cosmic tracks



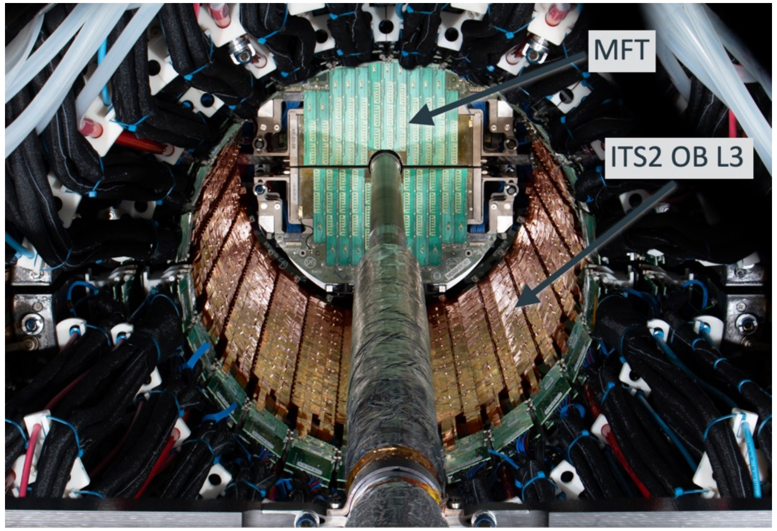


- Restricted to cosmic tracks passing through 10 cm sphere around interaction point for realistic track geometry
- Preliminary cut on chip gaps to restrict region-of-interest to sensitive area
- Measured efficiency well above 99% for all layers

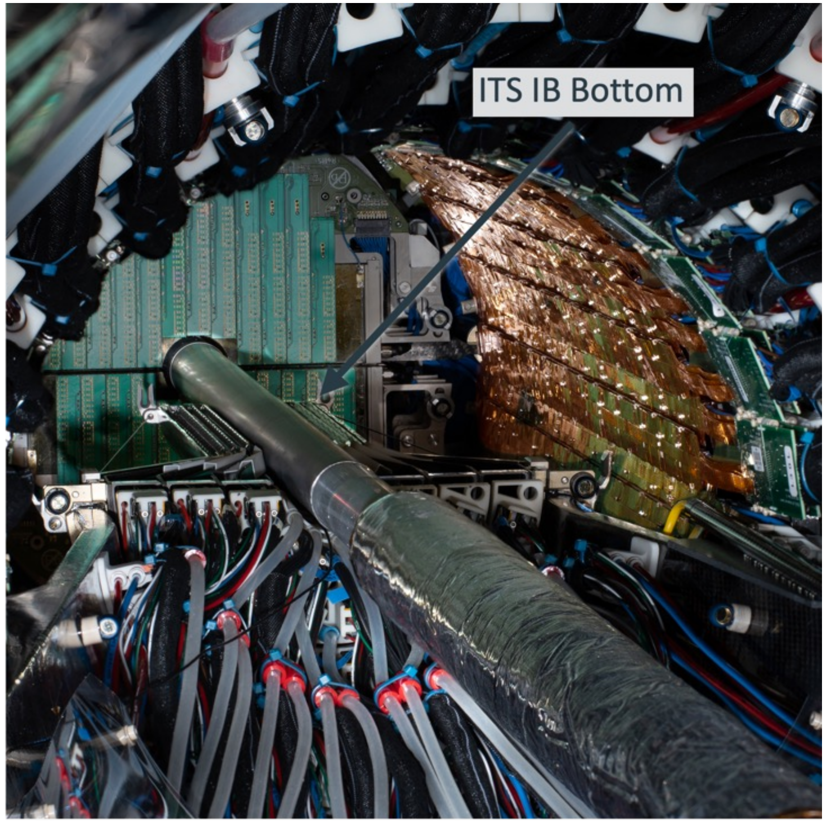
ITS installation



Outer Barrel Bottom being inserted on the rails inside the TPC



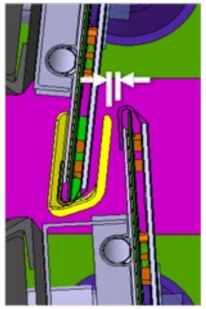
ITS Outer Barrel surrounding the beam pipe, MFT in the back



ITS Inner Barrel Bottom and Outer Barrel

- Installation challenges
  - Precise positioning around the beam pipe (nominal clearance ~ 2 mm)
  - Manipulating from 4 m distance
  - Difficult to see actual position by eye
  - precise mating of top and bottom barrel halves (clearance between adjacent staves ~ 1.2 mm)
- Dry-installation tests on the surface to test and exercise procedures
- Use of 3D scans, surveys and cameras

1.2 mm nominal clearance



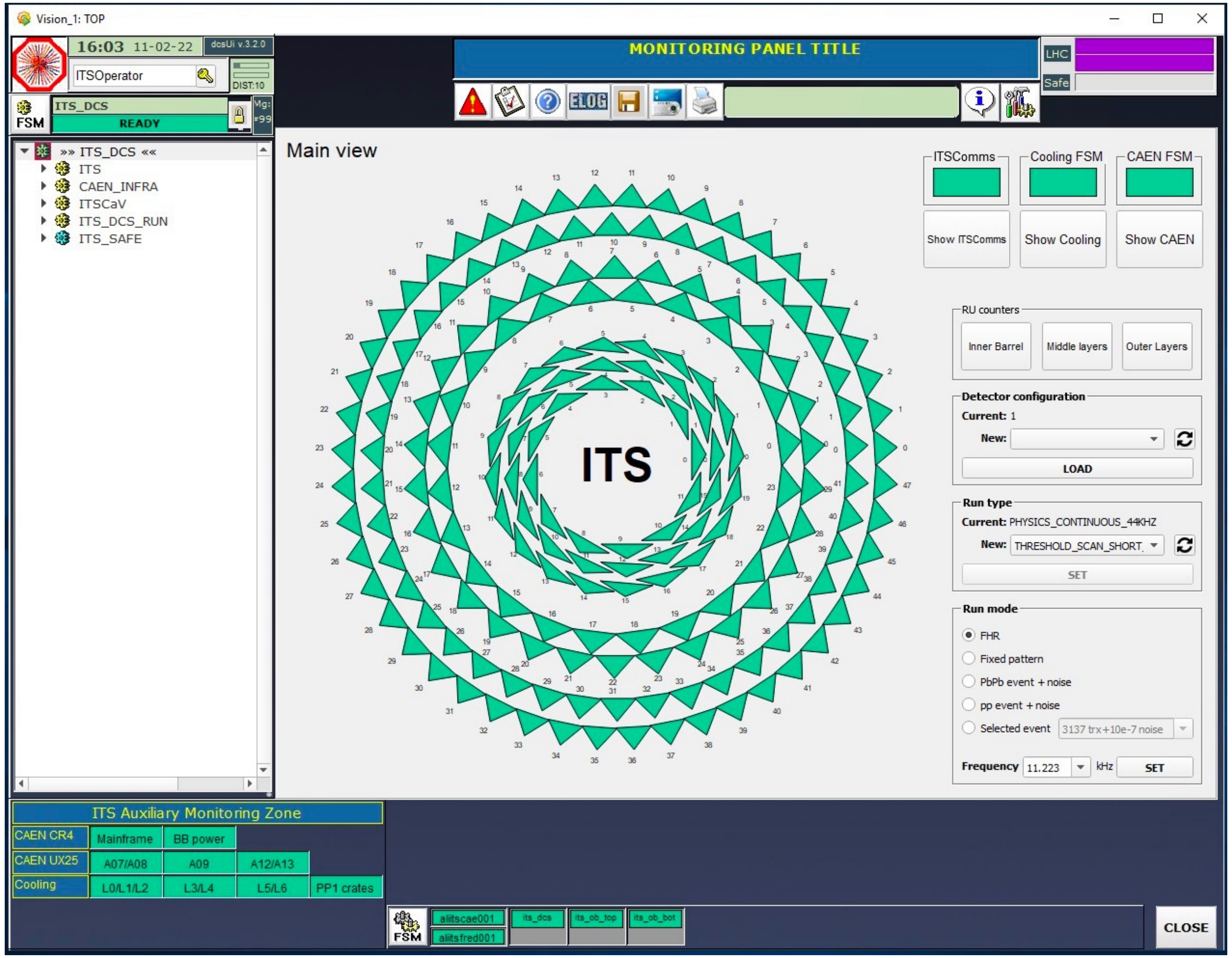
OB stave edge clearance when fully mated

Detector Control System

- DCS ready to control detector in all phases of operation:
  - Controls and configures pixel chips and entire infrastructure
  - Error recovery during a run to continue running with minimal data loss

  - Detector functionality implemented in C++ library (pixel chips, readout cards, regulator boards)
  - GUI, FSM and alarms in Siemens WinCC OA
  - fully integrated into ALICE DCS

- Routinely used during commissioning and Pilot Beams



Calibration

The Challenge:

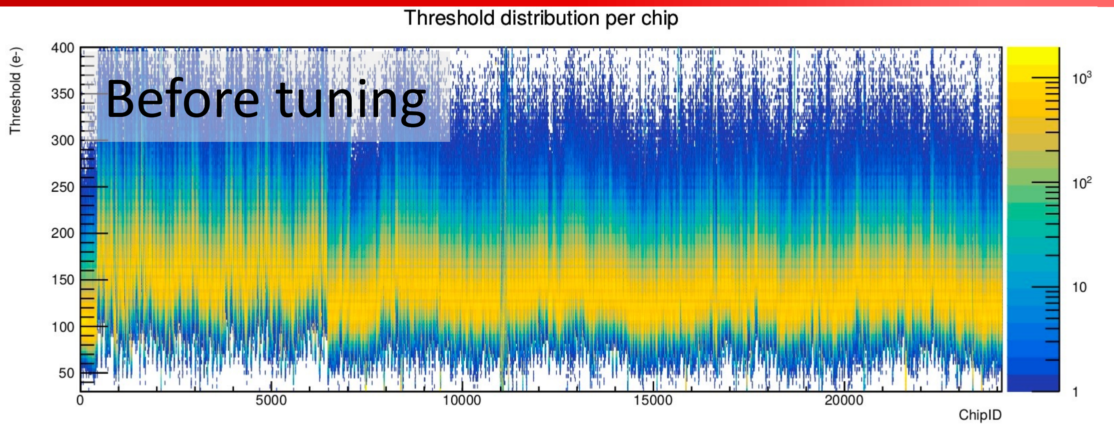
- Online calibration of 12.5 billion channels
- Threshold scan of full detector: > 50 TB of event data
- Several scans to be run sequentially
  - Threshold tuning (adjust thresholds to target)
  - Threshold scan (measure actual thresholds)

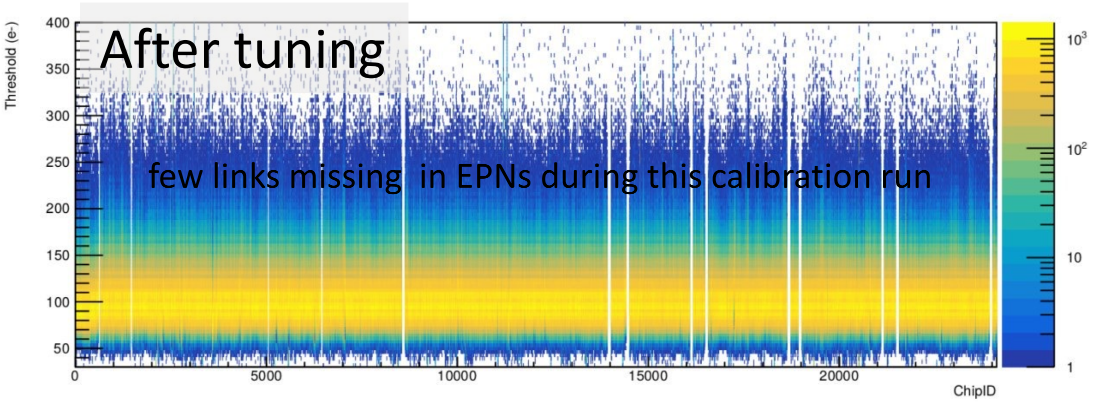
Procedure:

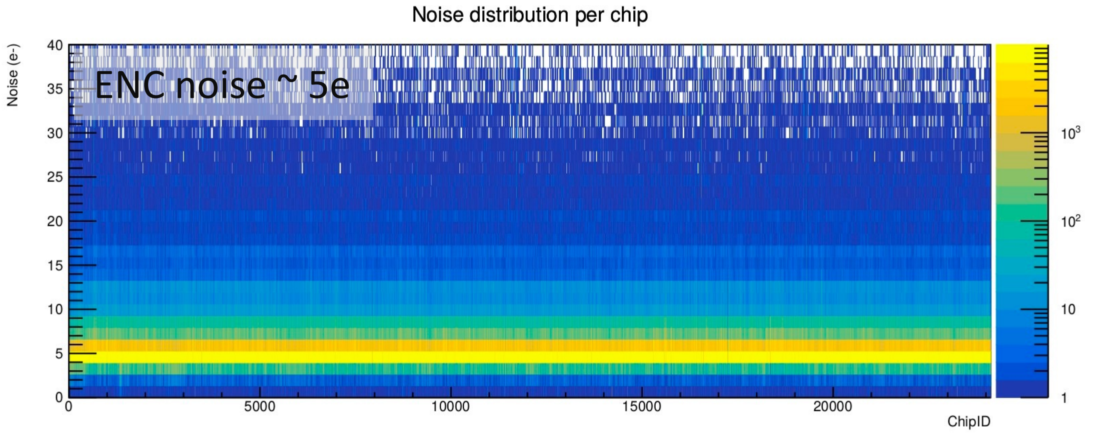
- DCS performs actual scans: configure and trigger test injections
- Scan runs in parallel but independently on all staves
- Distributed analysis on event processing nodes
- full procedure takes **less than 30 minutes**

Results:

- Scan with online analysis successfully run on full detector
- before tuning: settings used in surface commissioning: detector already fully efficient
- After tuning:
  - Thresholds very stable on all the chips: RMS of threshold distribution per chip <23 e^- (compatible with what we had during production)
- ENC noise ~ $5e^-$

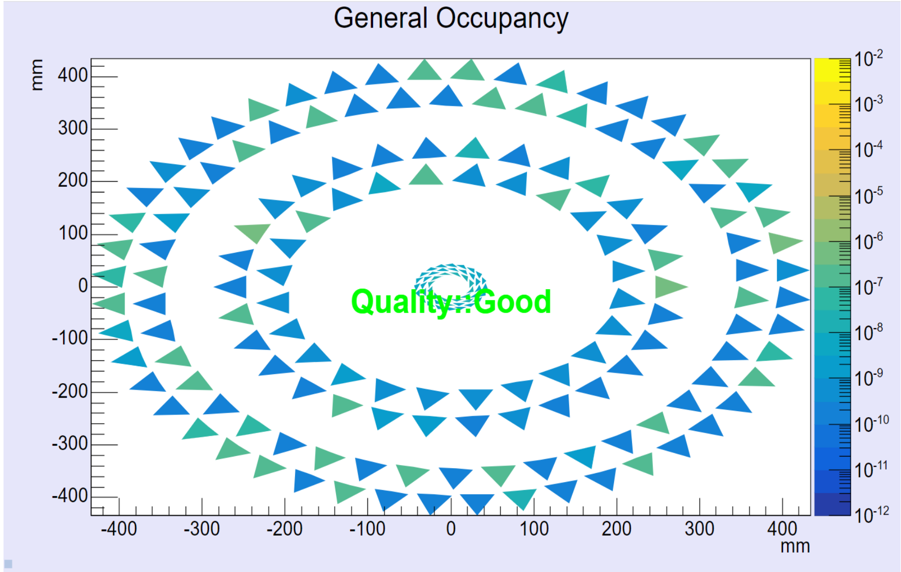






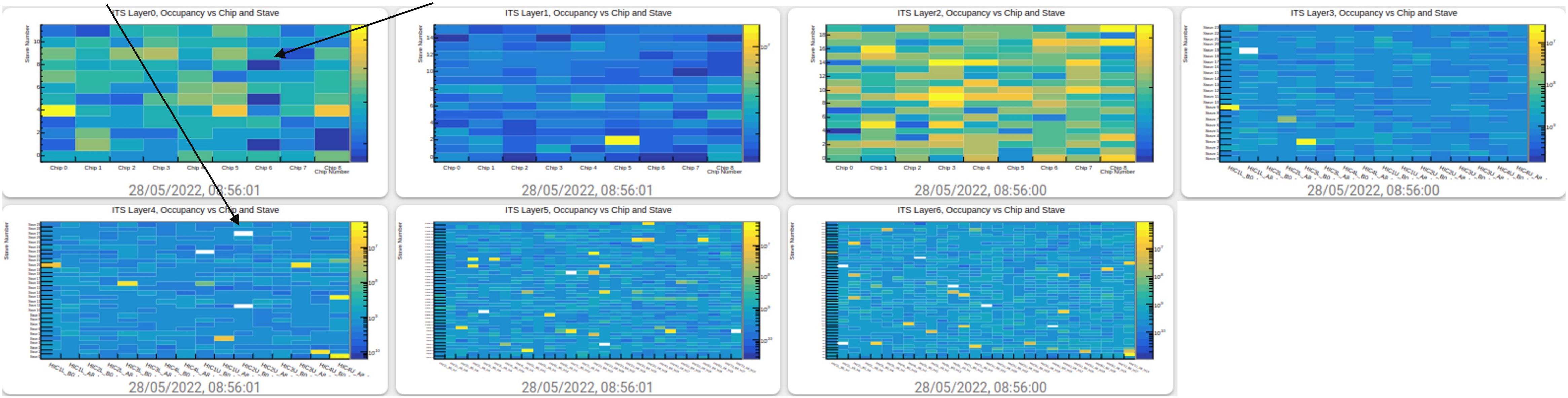
Data Quality Control (QC)

- Comprehensive online QC to check data quality and spot problems early
- 6 QC online tasks to monitor DATA/MC quality: FHR, FEE, Cluster, Track, Noisy Pix, Monte Carlo
  - *Front-end electronics:* data integrity check with payload decoding of all events
  - *Occupancy:* monitoring of detector occupancy
  - *Cluster:* monitoring cluster size, topology etc.
  - *Tracks:* monitoring of track multiplicity, angular distribution, clusters etc.
  - *Noisy pixels:* extraction of noisy pixels for offline noise masks
  - *Threshold:* monitoring during calibration scans (threshold, ENC, dead pixels)
- Offline version of track and cluster task
- QC post-processing online and offline: FHR, FEE, Tracks, Clusters, Thresholds
  - Analysis and trending of QC online plots (run by run)

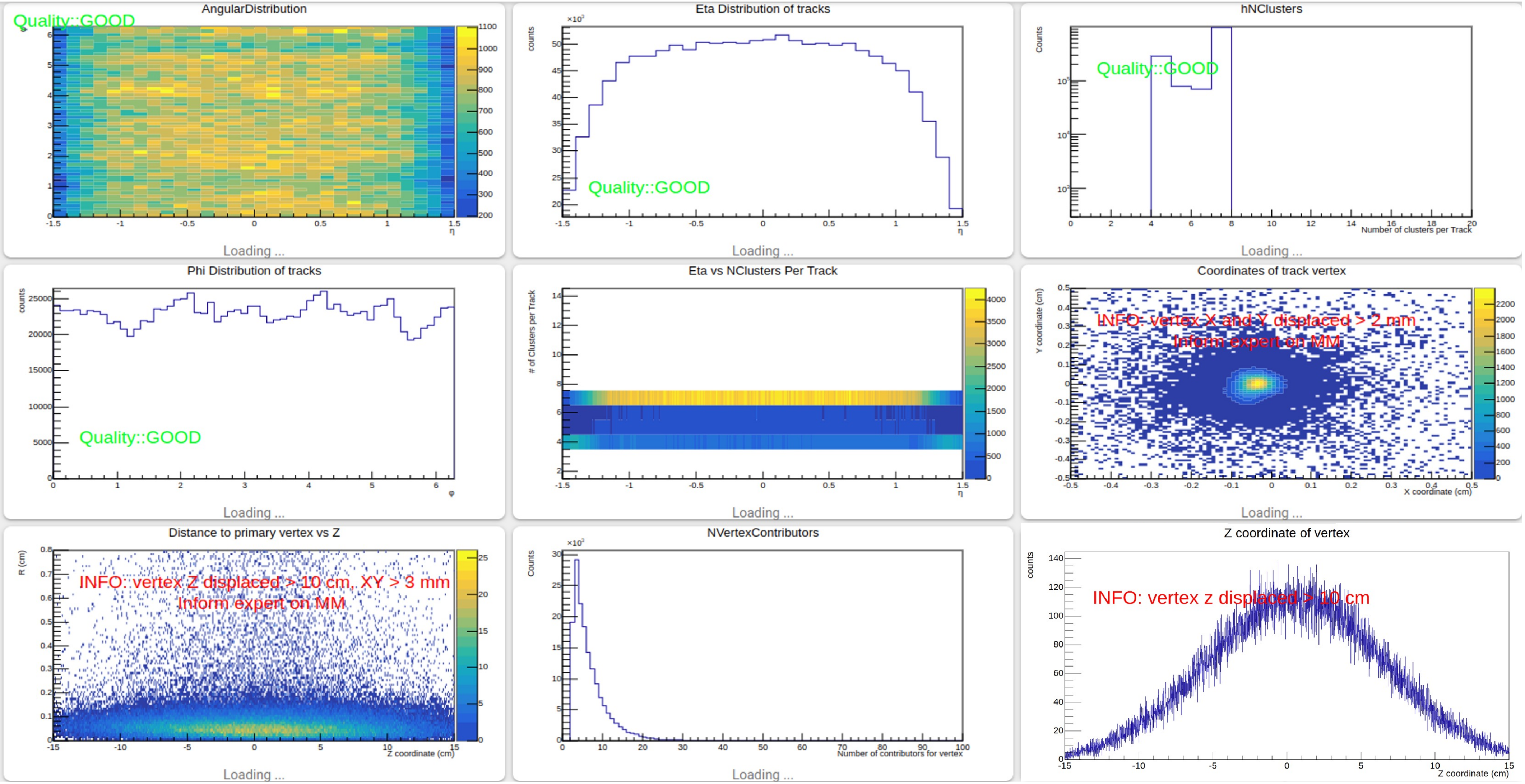


Empty lane (entire run)

Lane stopped sending data during run



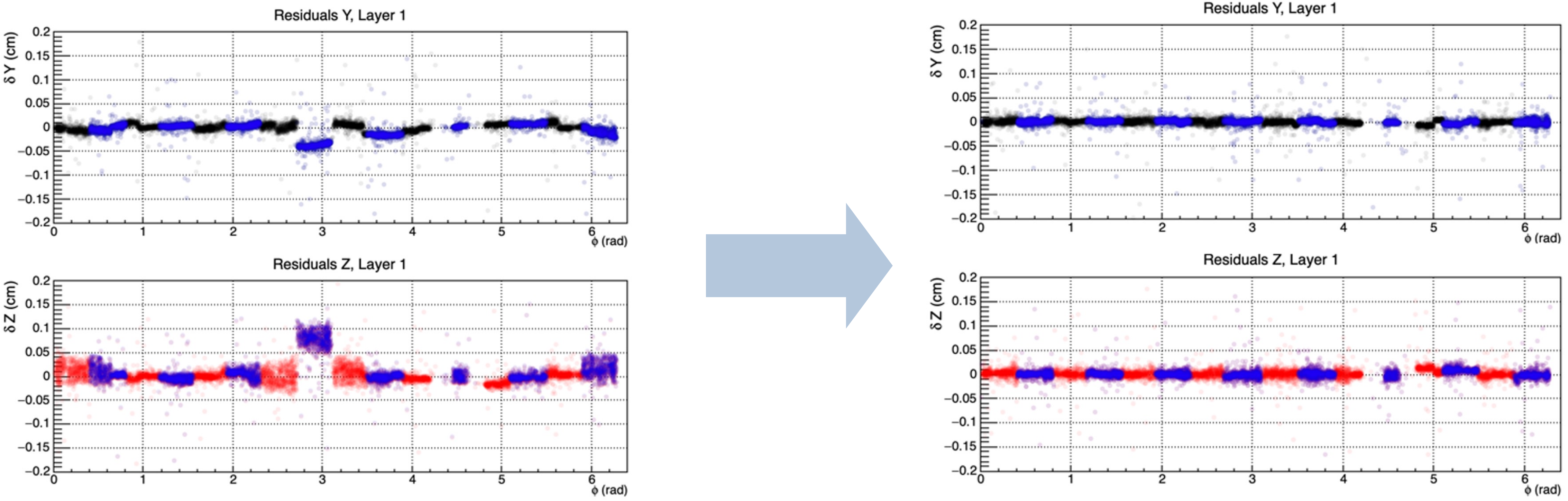
Plots from collisions (pp @900 GeV)



Data Preparation: alignment

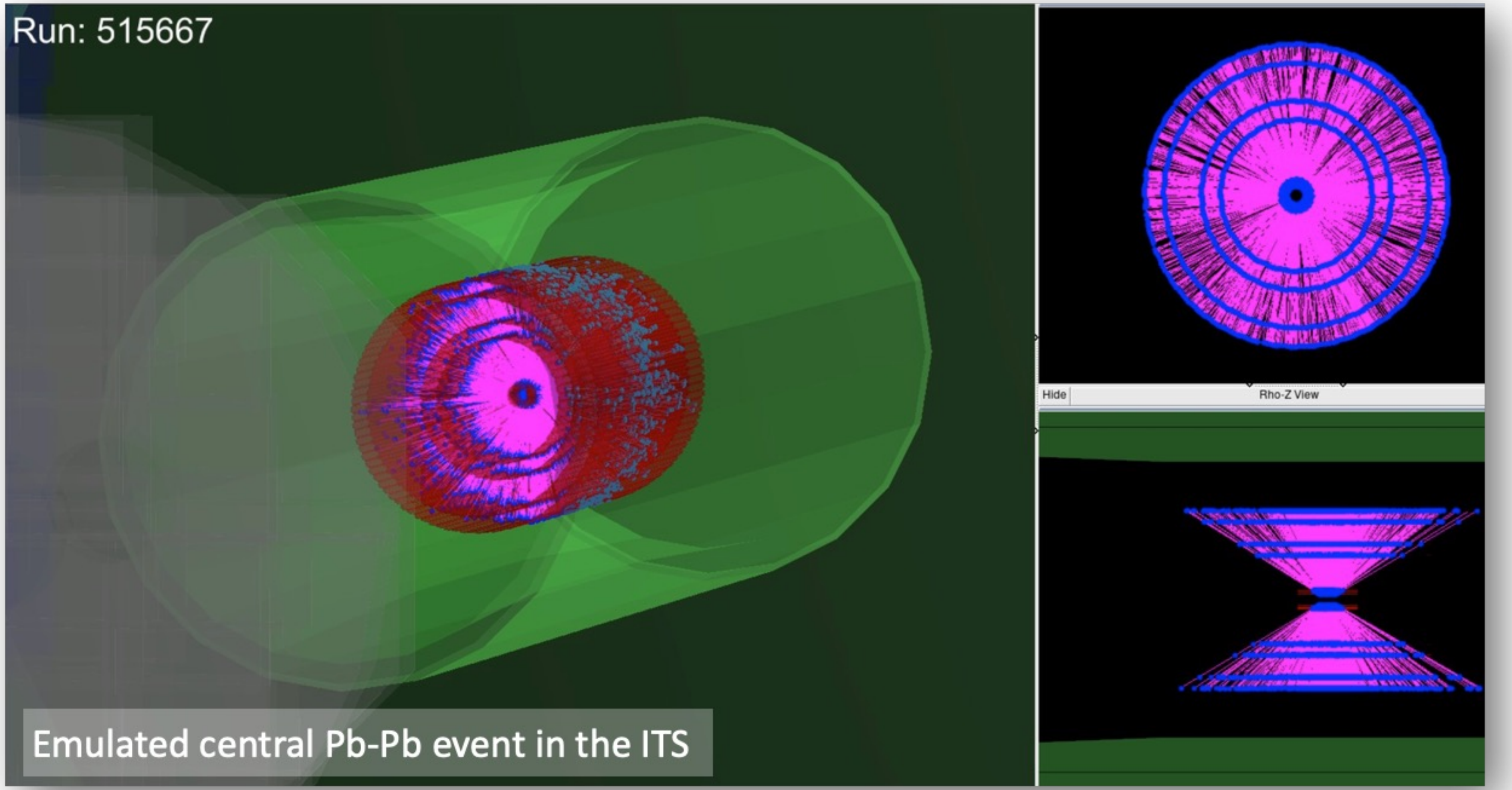
- Manual pre-alignment concluded with precision of O(100 µm)
- Ongoing: pre-alignment in R, Rf and Z using Millepede
  - currently at O(10 µm) for Inner Barrel and O(50µm) for Outer Barrel)
- Next step: fine alignment targeting a precision of a few µm (using Millepede, or AI approaches)

Below: example, Y and Z residuals in L1, before and after alignment with Millepede

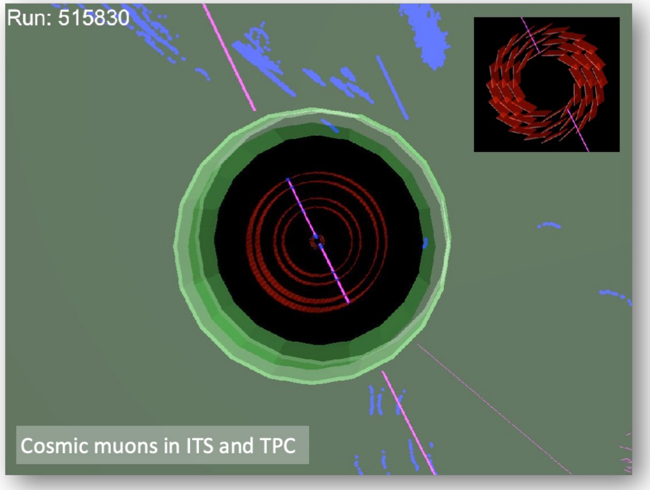


Data Taking Preparation

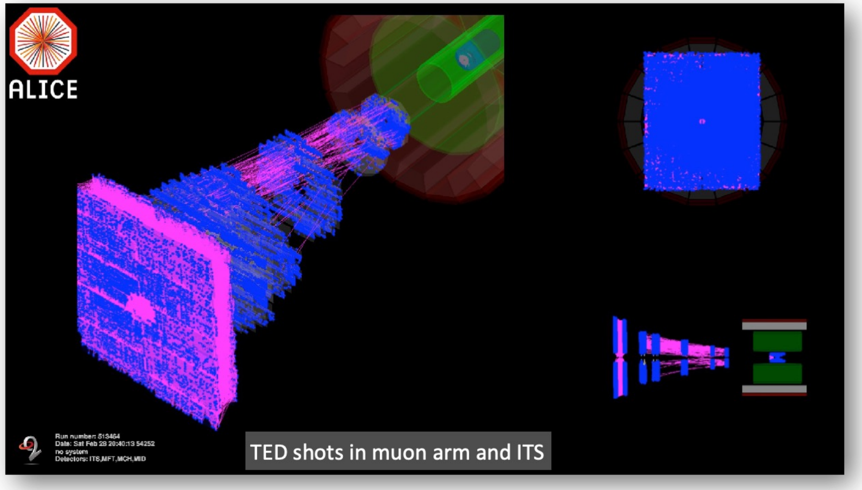
- Last part of commissioning phase devoted to prepare and test settings optimized for pp with 200 kHz framing rate (instead of 45 kHz for Pb-Pb) to achieve better time resolution reducing pile-up
  - successfully tested tested in pp Pilot Beam (2022)
- Extensive test runs with emulated Pb-Pb and pp events (injected into the detector front-end) to test detector, processing chain under realistic load



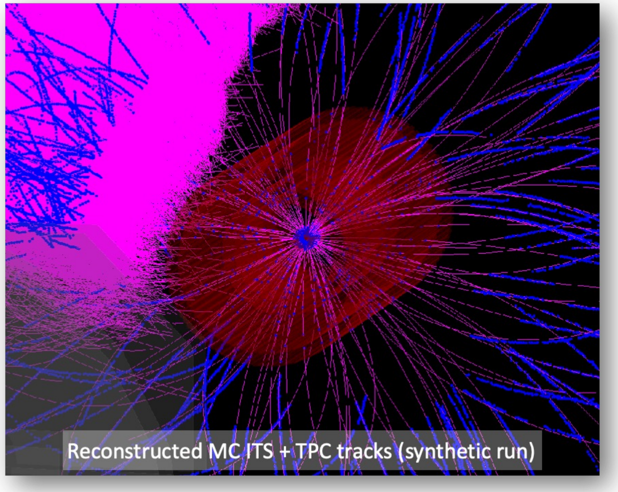
RUN 3 readiness

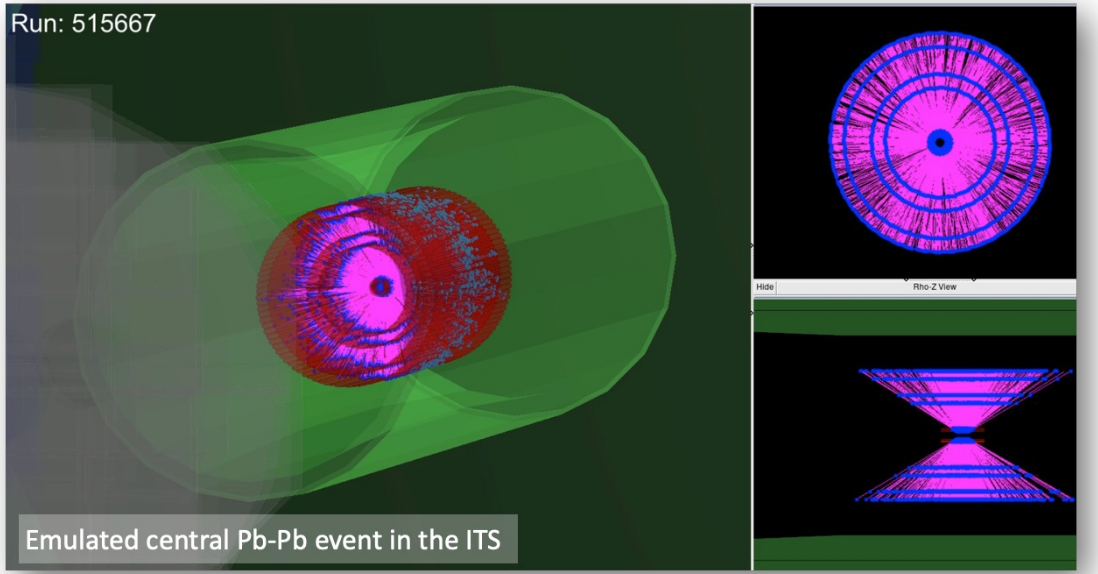


Cosmic muons in ITS and TPC

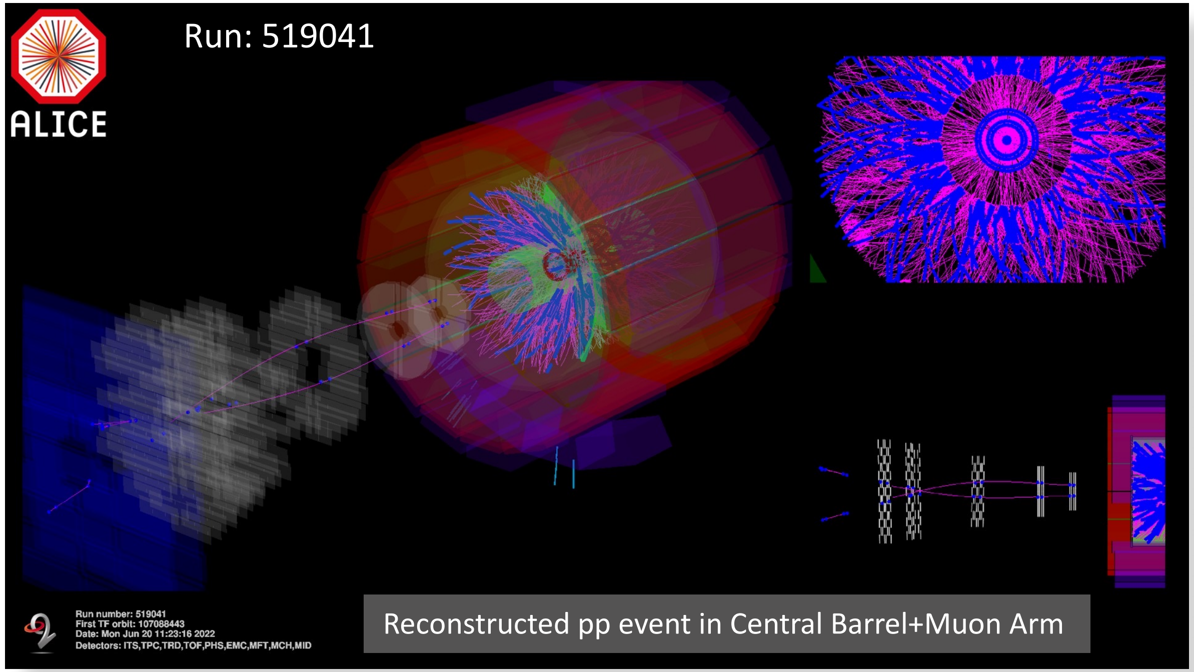


TED shots in muon arm and ITS


Reconstructed MC ITS + TPC tracks (synthetic run)



Emulated central Pb-Pb event in the ITS

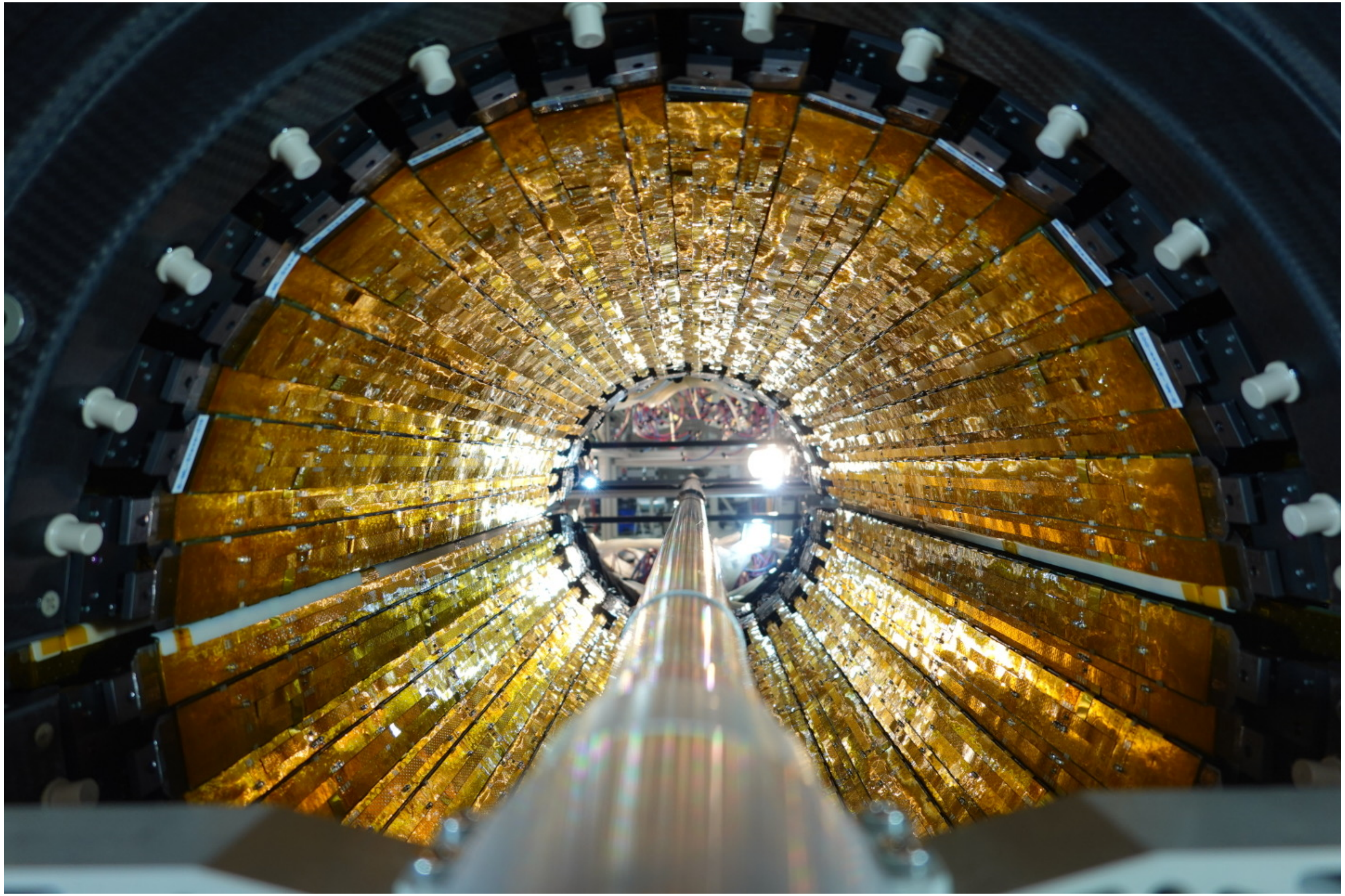


Reconstructed pp event in Central Barrel+Muon Arm

Conclusions

- ITS2 successfully installed and commissioned for LHC RUN3
- Calibration procedure established and tested
- DCS and QC tools ready for data taking
- Detector settings optimized both for pp and PbPb collisions

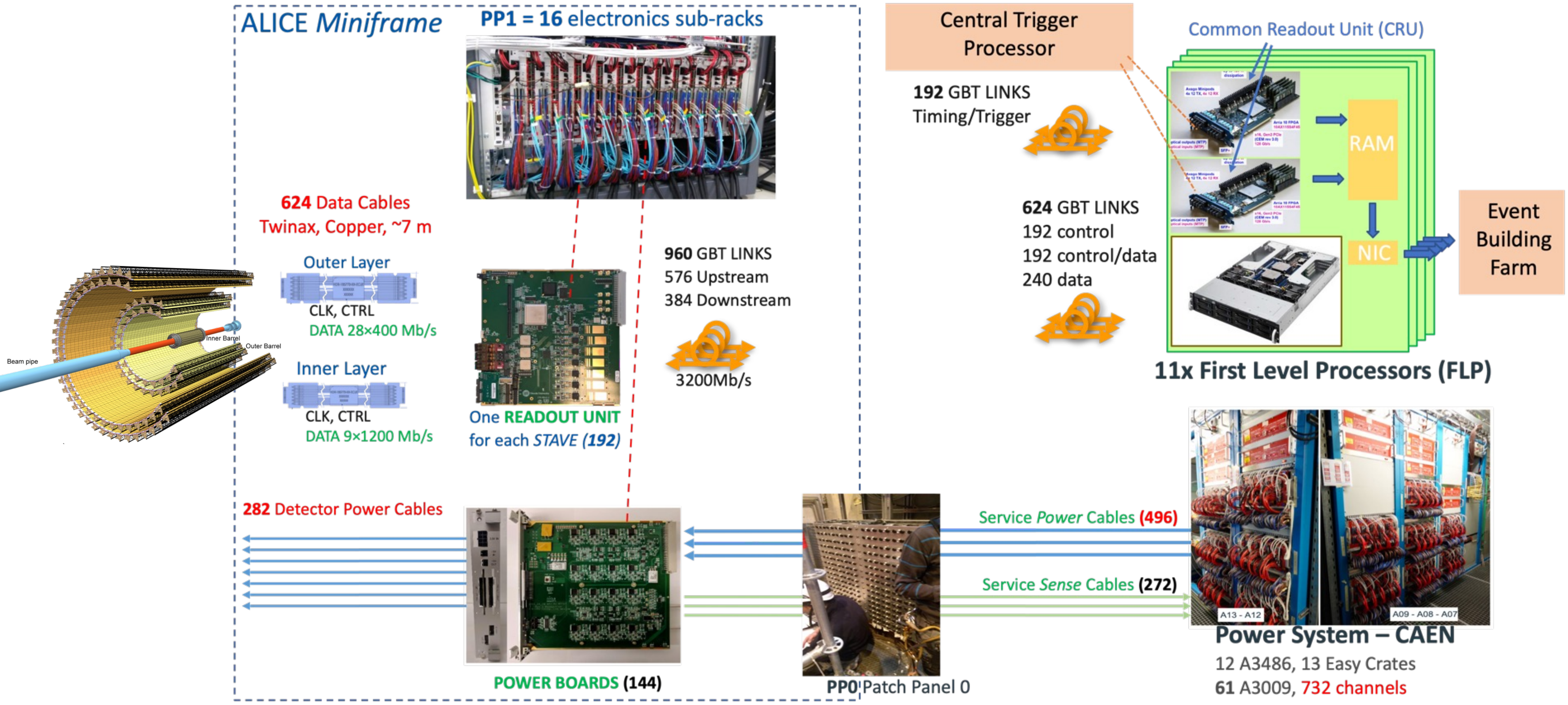
- ITS2 is ready for RUN3



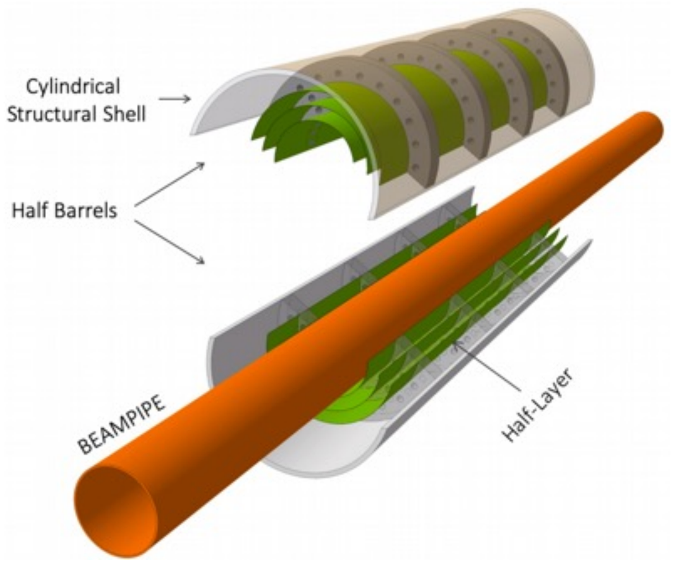
ALICE ITS2 Outer Barrel during insertion tests

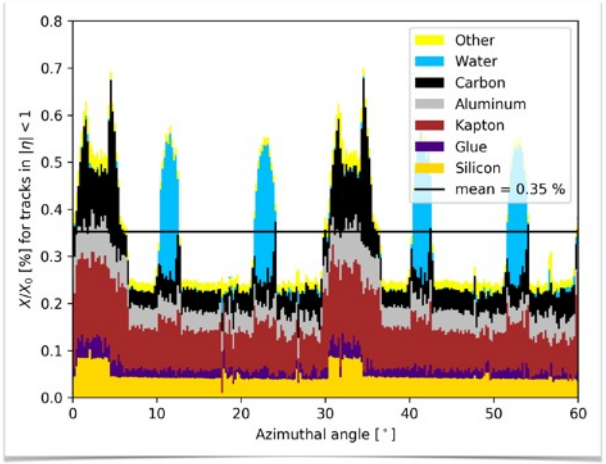
BACK UP SLIDES

Power and Readout System Overview

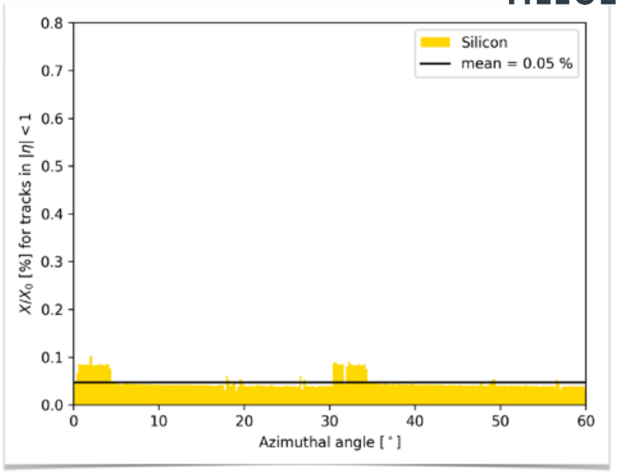


ALICE 2.1: ITS3 all silicon detector





ITS2 Layer 0: X/X0=0.35



ITS3 only silicon: X/X0=0.05

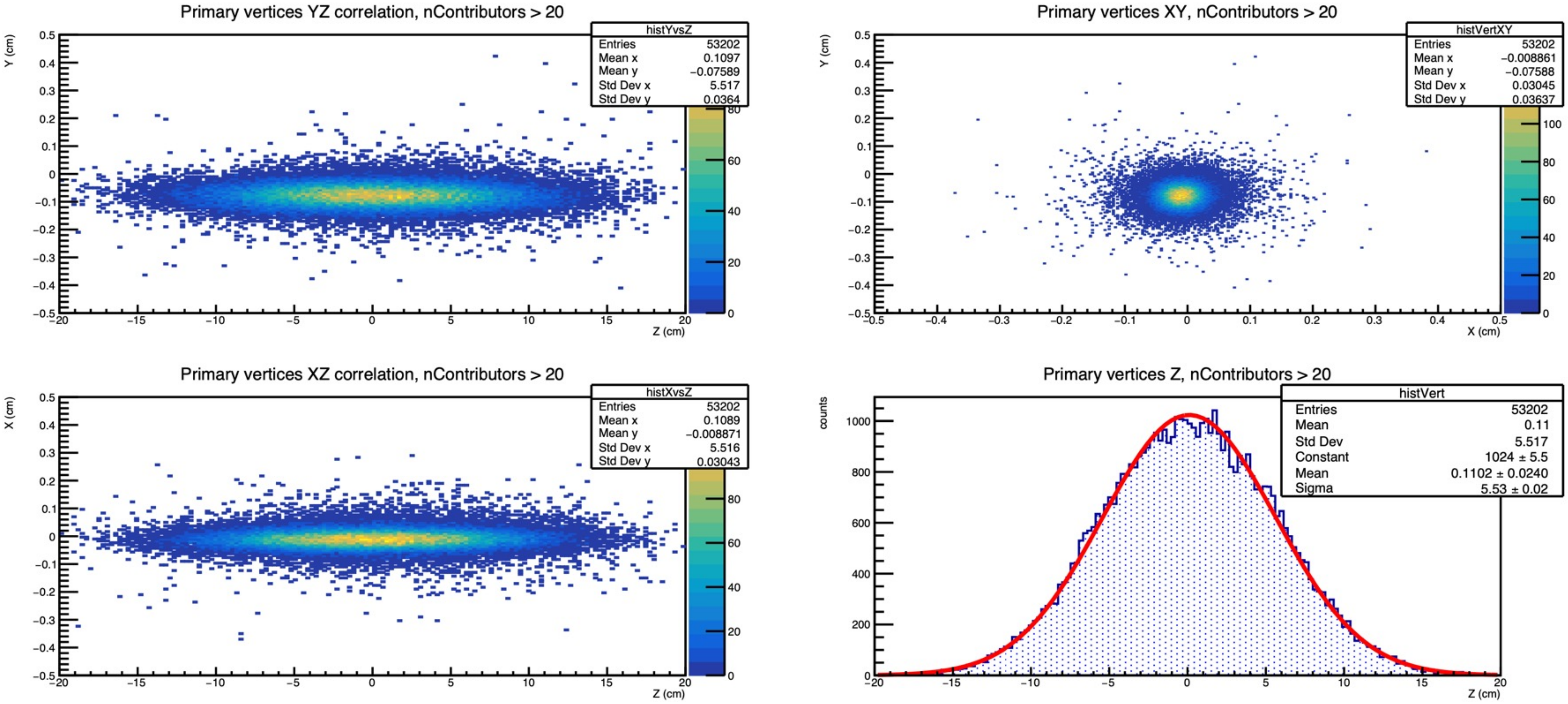
- Goal: improve vertexing at high rate

- Layout: 3 layers, replace ITS Inner Barrel,
  - beam pipe: smaller inner radius (18.2 mm to 16 mm) and reduced thickness (800 µm to 500 µm)
  - innermost layer: mounted around the beam pipe, radius 18mm (was 22 mm)
- Technology choices:
  - 65 nm CIS of Tower & Partners Semiconductor (TPSCo):
    - larger wafers: 300 mm instead of 200 mm,
    - single “chip” equips an ITS3 half-layer (through stitching technology)
    - 6 sensors in total
  - thinned down to 20-40 µm
    - -> flexible
    - bent to target radii

  - mechanically held by carbon foam ribs with low density and high thermal conductivity

Letter of Intent for an ALICE ITS Upgrade in LS3 https://cds.cern.ch/record/2703140

Vertex reconstruction



Collision systems	pp, pPb, Pb-Pb	pp, pPb, Xe-Xe, Pb-Pb	pp, pO, OO, pPb, Pb-Pb	pp, pPb, Pb-Pb	pp, pA?, AA	pp, pA?, AA
LHC schedule	RUN 1 2009-2013	RUN 2 2015-2018	RUN 3 2022-2025	RUN 4 2029-2032	RUN 5	RUN 6

High luminosity for ions (~$7 \cdot 10^{27}$ cm^{-2} s^{-1})

HL-LHC (~$5\text{-}7.5 \cdot 10^{34}$ cm^{-2} s^{-1})

Higher luminosities for ions

ATLAS	ATLAS	ATLAS phase I upgrade	ATLAS phase II upgrades	
CMS	CMS	CMS phase I upgrade	CMS phase II upgrades	
LHCb	LHCb	LHCb upgrade I(a)	LHCb upgrade I(b)	LHCb upgrade II
ALICE	ALICE 1	ALICE 2 upgrade	ALICE 2.1 upgrade	ALICE 3 upgrade

intermediate upgrade

major upgrade

ALICE2 UPGRADE: ITS + MFT

Inner Tracking System

GOALS:

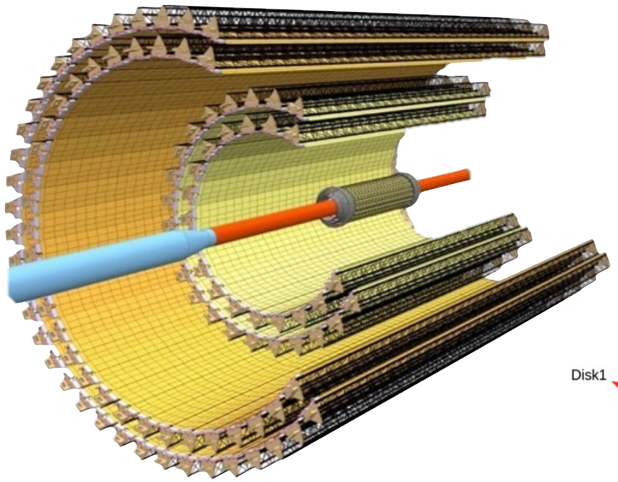
- improve pointing resolution
  - reduced material
  - closer to IP (39mm -> 22mm)
  - better spatial resolution (-> 5x5μm^2)
- faster readout (1->100kHz)

Detector layout

- Inner Barrel: 3 layers, 48 staves
- Outer Barrel: 4 layers, 144 staves

In total ~24000 chips = 12.5 Gpixels

~10m^2 of silicon pixel sensors

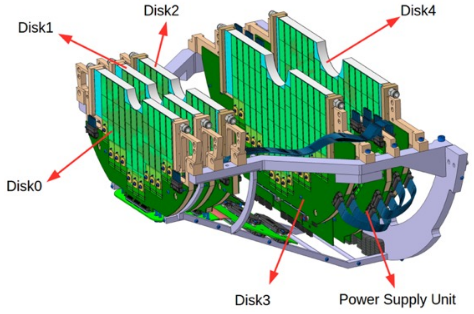


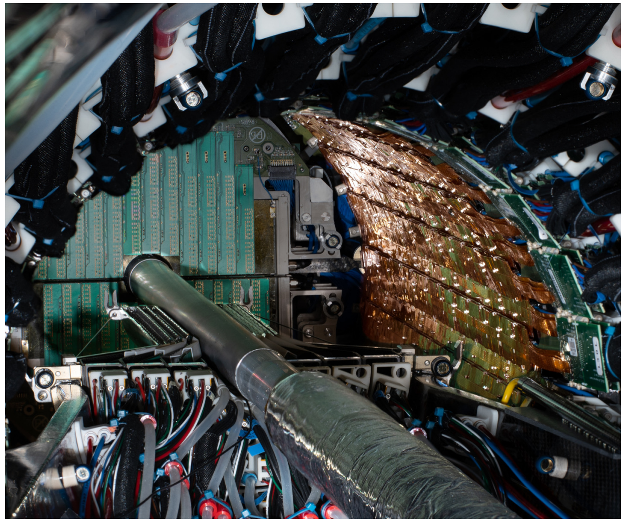
ITS

Technology:

- CMOS sensors (ALPIDE)

MFT





ITS Inner and outer barrels + MFT disk 0 during installation

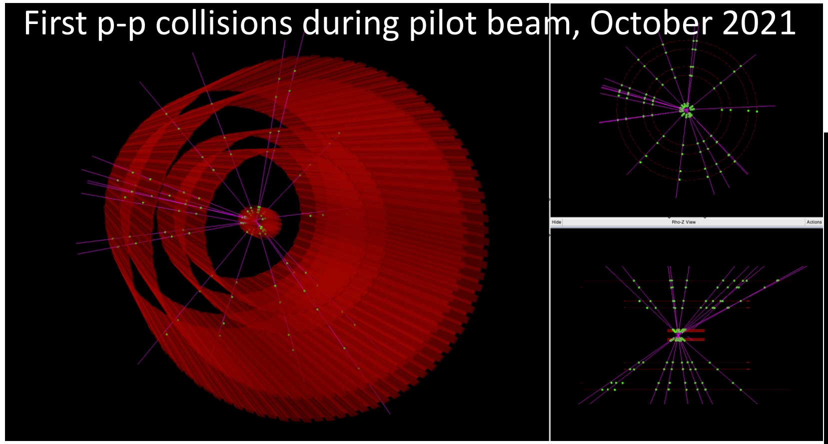
Muon Forward Tracker

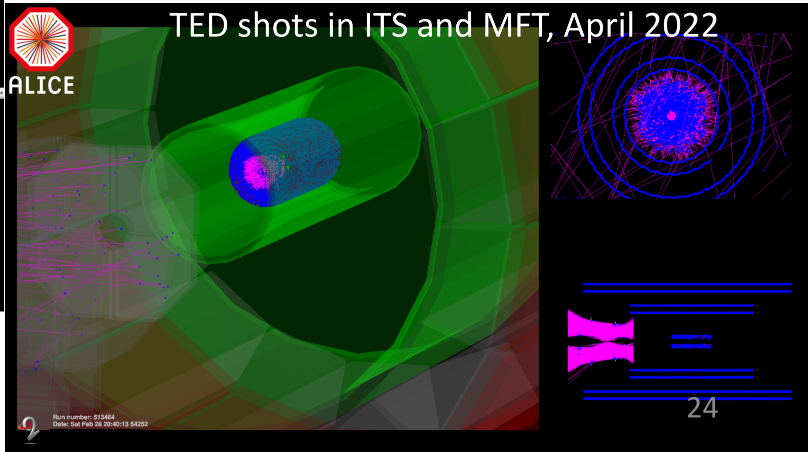
GOALS:

- add capabilities for secondary vertex measurement at forward rapidity

Detector layout

- upstream of the absorber
- 10 half-disks, 2 detection planes each
- 280 ladders of 25 sensors each: 920 chips (0.4 m^2)





ITS TDR: J. Phys. G: Nucl. Part. Phys. 41 (2014) 087002
MFT: CERN-LHCC-2015-001. ALICE-TDR-018 https://cds.cern.ch/record/1981898

Alignment in OB

Run 505413 (B = 0T)