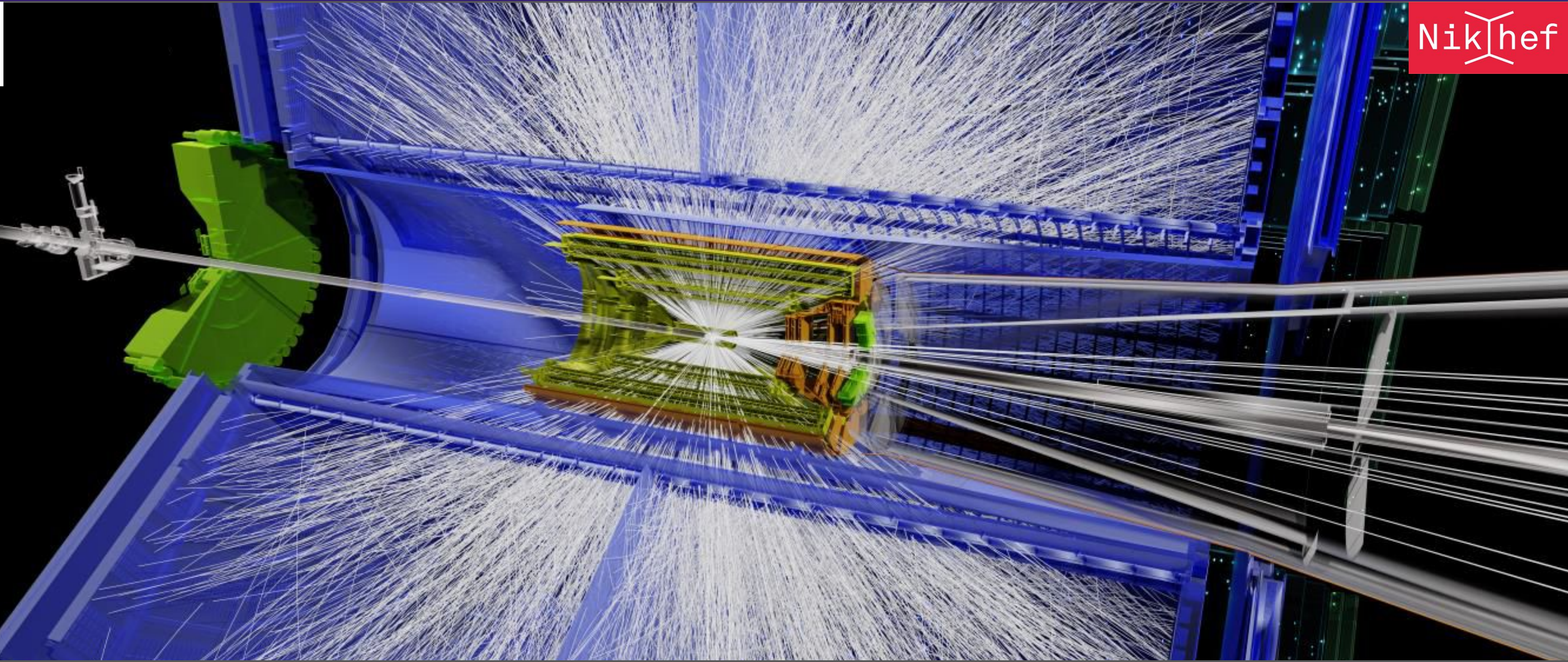


ALICE ITS2: overview and performance

Artem Isakov*, on behalf of the ALICE collaboration

[*] Nikhef, Netherlands

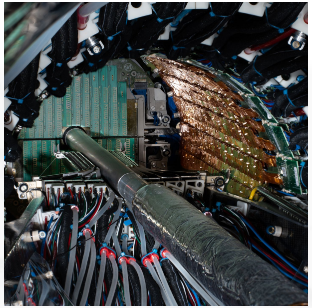
Outlook

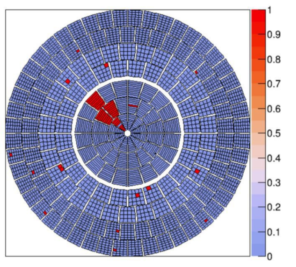
ALICE experiment in Run 3

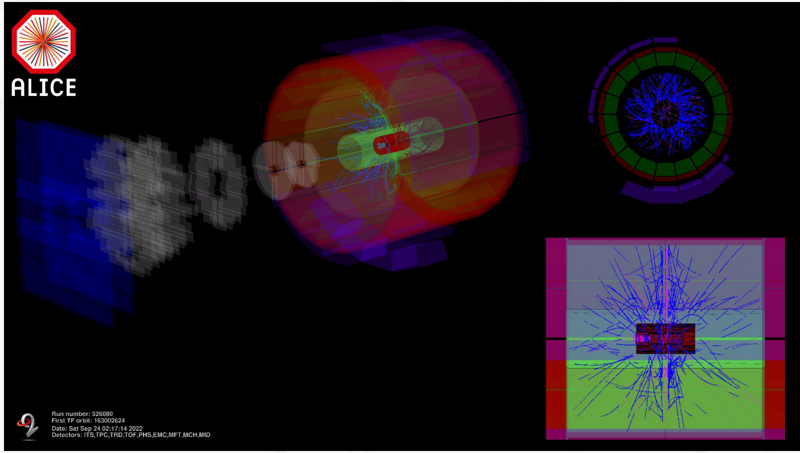
Inner Tracking System 2 upgrade

ITS Performance in Run 3 with pp and Pb-Pb

Summary and outlook





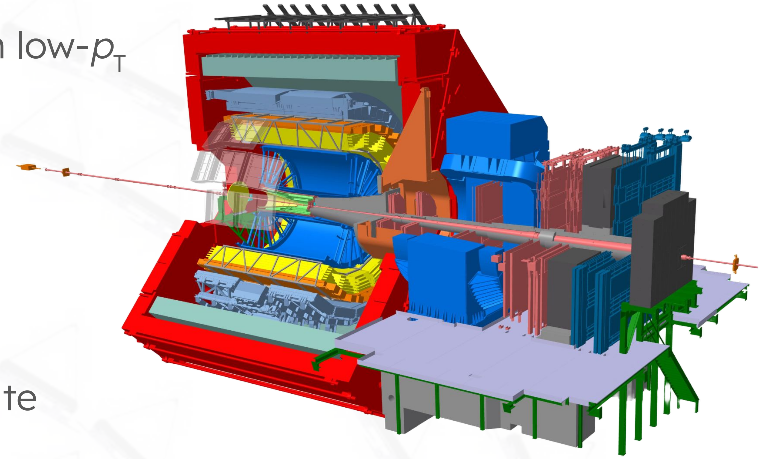


ALICE in Run 3

ALICE

Study of Quark Gluon Plasma in heavy-ion collisions at LHC:

- Particle identification in large p_T range, a special interest in low-p_T
- Reconstruction of beauty and charm hadrons
- Operations in high-multiplicity environment

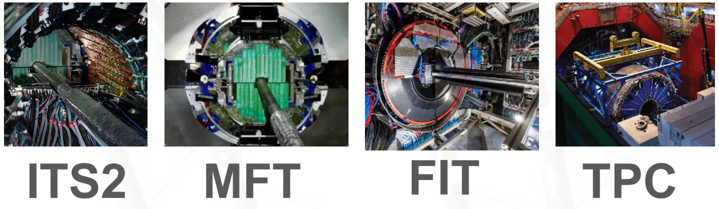


Goals of ALICE upgrade in Long Shutdown 2

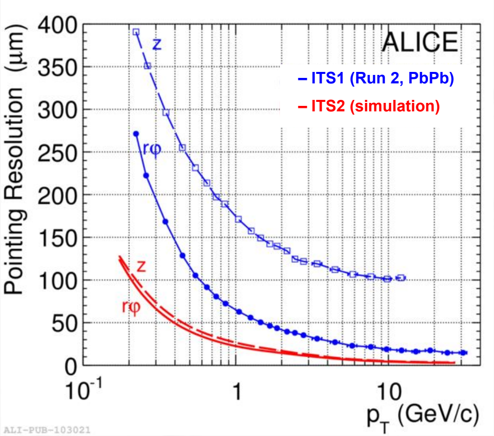
- 13 nb^{-1} Pb-Pb collisions (x100 w.r.t Run1+2)
- Data-taking of Pb-Pb collisions at 50 kHz of interaction rate
- Improved vertex reconstruction and tracking capabilities

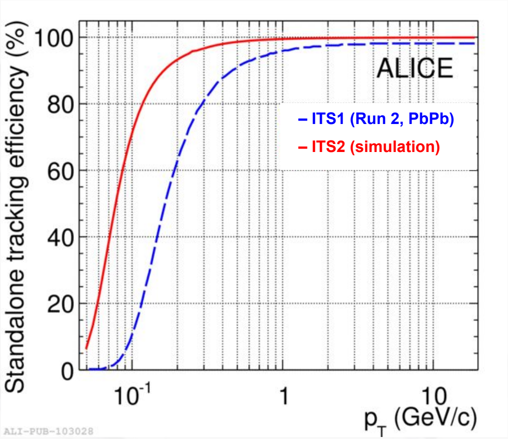
↓

- Upgrade of several detector systems: ITS, MFT, TPC, FIT
- New framework for online/offline analysis (O^2)



Inner Tracking System 2 (ITS2) design goals



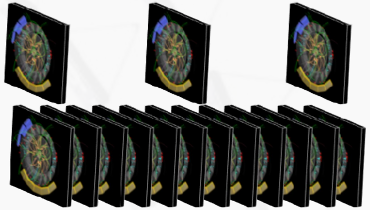


Improved position resolution for low momenta particles
(6 times in *z* direction, 3 times in *rφ* direction):

- First layer is closer to Interaction Point: 39 mm ➔ 23 mm
- Smaller material budget: ~1.14% X_0 ➔ ~0.36% X_0 per layer (for the inner layers)

Improved tracking efficiency:

- Increased granularity: 6 layers ➔ 7 pixel layers
- Smaller pixel size: 50 x 425 μm^2 ➔ O(30 x 30 μm^2)

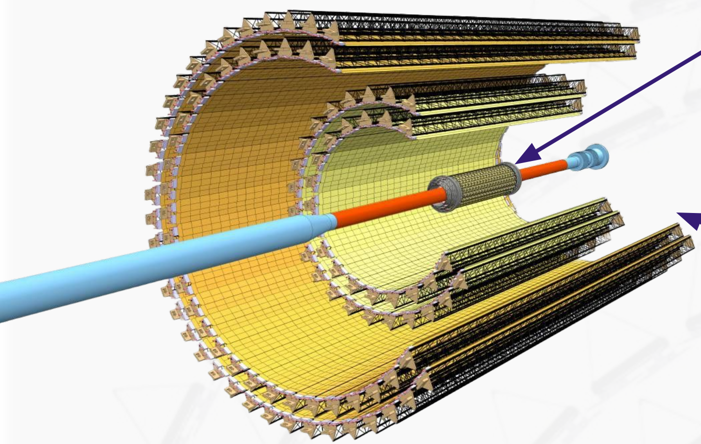


Faster readout:

- Pb-Pb 1 kHz ➔ 67 kHz, 202 kHz for pp

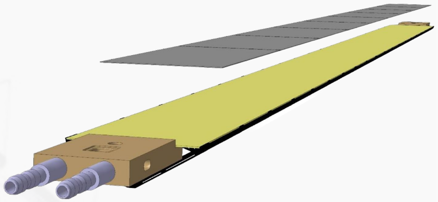
ITS2 layout

ALICE



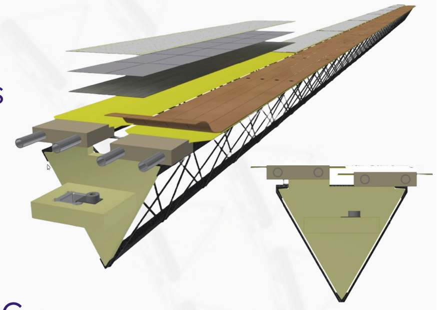
Inner Barrel (IB) — Layers 0 - 2:

- **Stave** Built from 9 ALPIDE chips
- **Length:** 27 cm
- **Sensor thickness:** 50 µm
- **Material budget:** ~ 0.36 % X_0/layer
- 1 high-speed link of 1.2 Gbit/s per chip



Outer Barrel (OB) — Layers 3 - 6:

- Stave built from HICs: 2 rows by 7 chips
- **Length:** 84 cm (middle layer),
  150 cm (outer layer)
- **Sensor thickness:** 100 µm
- **Material budget:** ~ 1.1 % X_0/layer
- 2 high-speed links of 400 Mbit/s per HIC

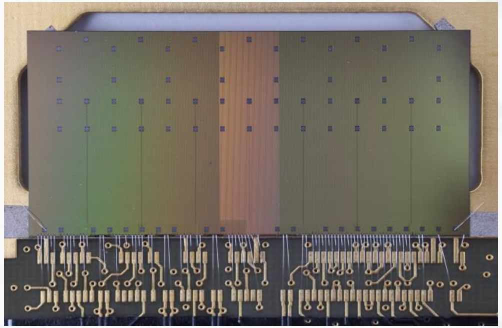


- **7 layers** (inner/middle/outer): 3/2/2
- **192 staves** (inner/middle/outer): 48/54/90
- Ultra-lightweight support structure and cooling
- 10 m^2 active silicon area
- 12.5×10^9 pixels

MAPS for ITS2

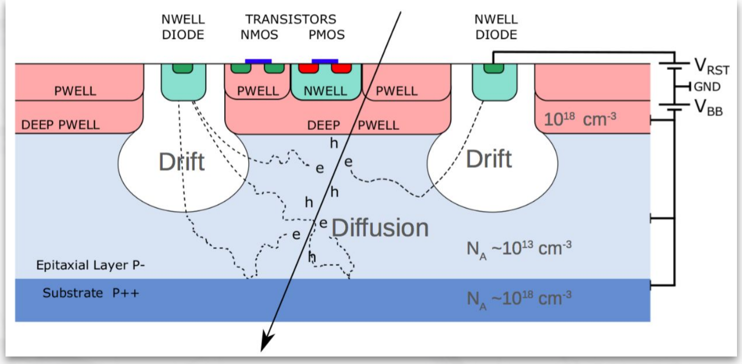
1024 pixels / 30 mm

512 pixels / 15 mm



ALICE PIXEL DETECTOR (ALPIDE)

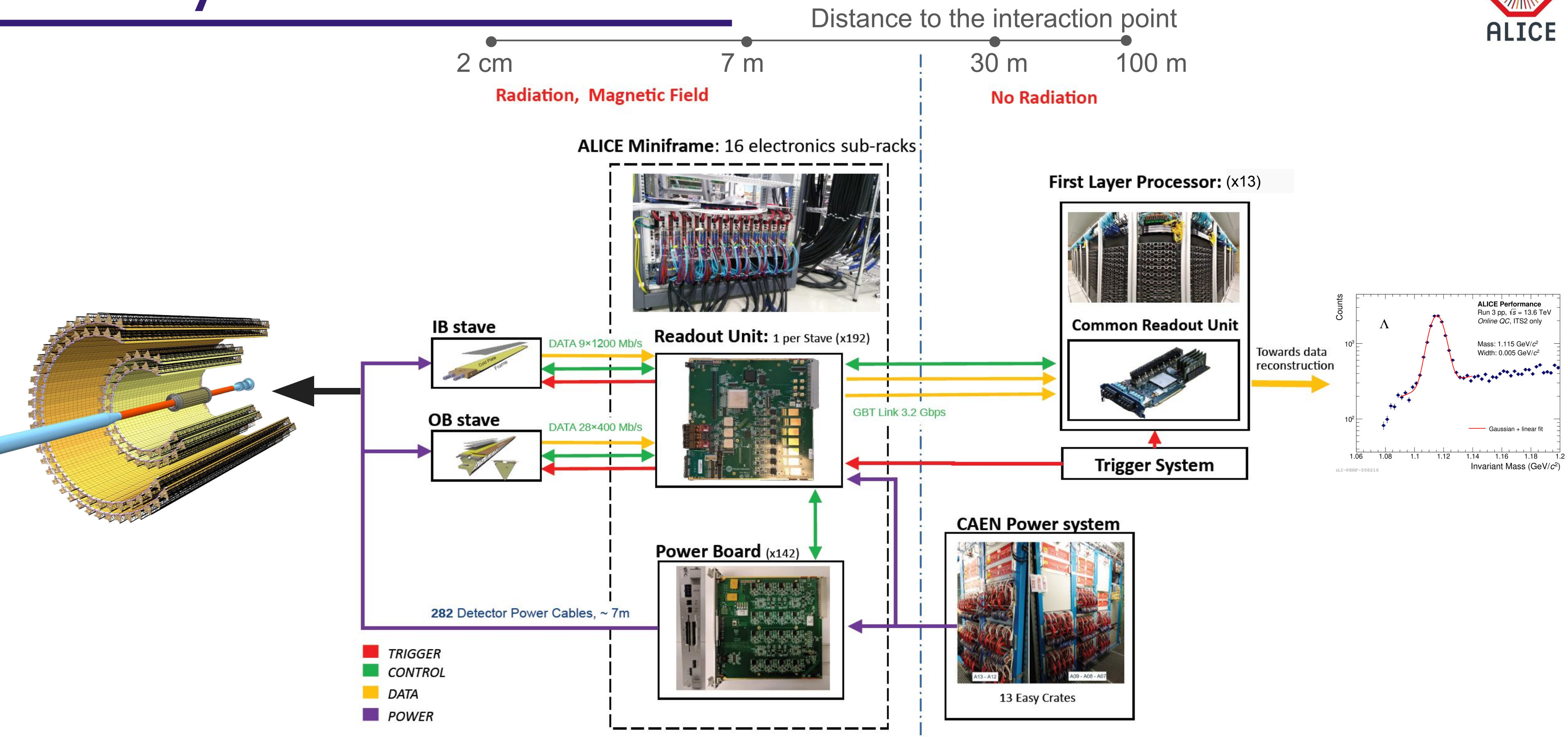
- In-pixel amplification and shaping, discrimination and Multiple-Event Buffers
- Analog DACs for front-end biasing
- Power consumption < ~47 mW/cm^{-2}
- Fake-hit rate << 10^{-6} /hits/cm^{2}
- 1.2 Gbit/s on-chip high-speed link
- **Radiation hardness for MAPS:**
  - Total Ionizing Dose > 270 kRad
  - Non Ionizing Energy Losses > ~ 1.7·10^{12} 1 MeV n_{eq} cm^{-2}



Pixel Technology:

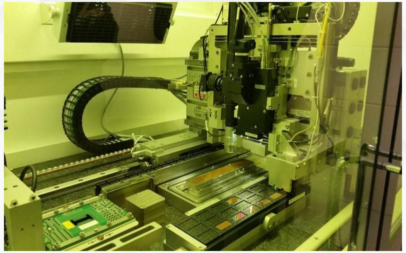
- 180 nm CMOS imaging process by TowerJazz with Pixel pitch 29 µm × 27 µm
- High-resistivity (> 1kΩ cm) p-type epitaxial layer (25 µm) on p-type substrate
- Low capacitance (~fF) thanks to small n-well diode (2 µm diameter)
- Reverse bias voltage (-6 V < V_{BB} < 0 V) to vary depletion zone, default V_{BB} = 0 V
- Deep P_{WELL} shields N_{WELL} of PMOS transistors

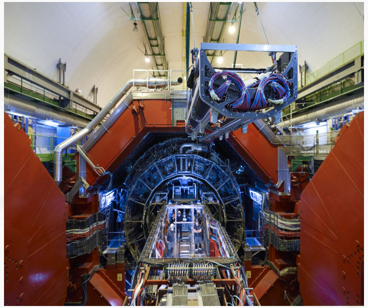
ITS2 system overview

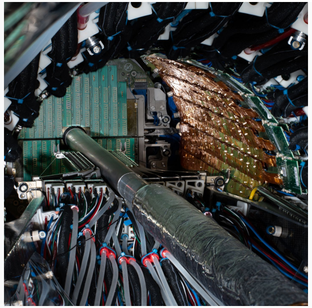


General timeline of the project

- **2011:** Start of the ALPIDE sensor R&D
- **12/2016:** Sensor production started
- **01/2021:** ITS installation in the cavern
- **10/2021:** First pp pilot beam test
- **11/2023:** First heavy ion run
- **09/2024:** 80 pb^{-1} of pp data is taken

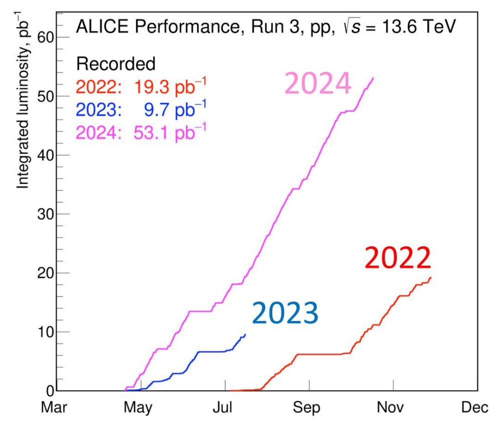

Module Assembly Machine


OB installation


OB + bottom half-barrel of IB

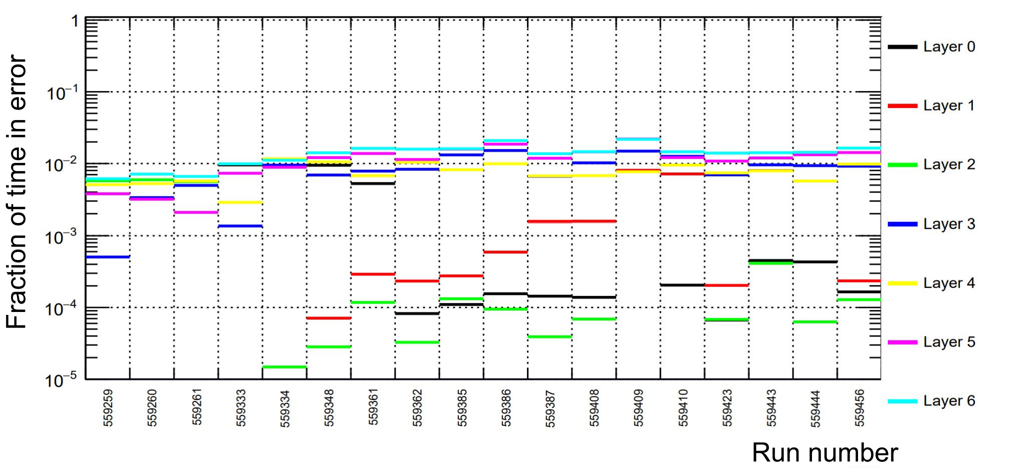
Run 3 started on 5th July 2022 with pp collisions at $\sqrt{s}$=13.6 TeV:

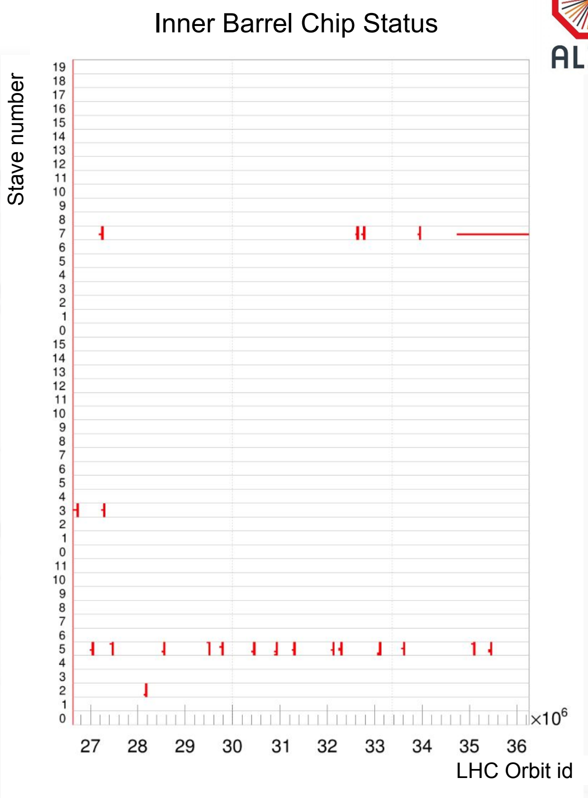
- ITS participated in more than 2000 hours of data taking
- Crucial detector for data-taking - 100% participation in physics runs
- Recorded data:
  - **Total pp** ($\sqrt{s}$ = 13.76 TeV) : **82 pb^{-1}**
  - **Total Pb-Pb** ($\sqrt{s_{NN}}$ = 5.36 TeV: **2.16 nb^{-1}**
  - pp reference ($\sqrt{s}$ = 5.36 TeV): 5.3 pb^{-1}
- Estimation of total absorbed dose for L0 / L1 / L2 / L3:
  - TID: ~43 / 25 / 15 / 0.5 kRad
  - NIEL: ~$4.3 \cdot 10^{11}$ / $2.9 \cdot 10^{11}$ / $1.8 \cdot 10^{11}$ / $1.6 \cdot 10^{10}$ 1 MeV n_{eq} cm^{-2}



ITS2 performance in RUN3

- Continuous operation of 24k chips: loss of ITS acceptance due to lane errors < 1%
- Advanced system for auto-recovery during data-taking:
  - **Corrupted data:** filtering out problematic data + detection in QC
  - **Clock issues on GBT Links:** automatic re-configuration of lane
  - **Radiation induced errors:** RU scrubbing + firmware update
- Tools to monitor and record status of each ITS chip over time -> Important input for MC anchoring

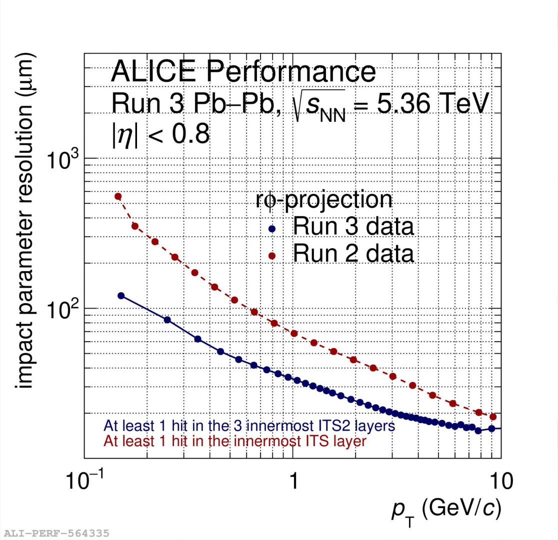




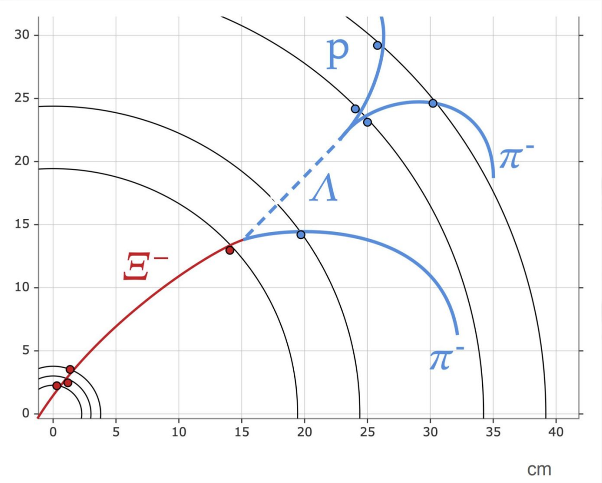
Status of the IB chips during data-taking of Pb-Pb collisions at 5.36 TeV with time resolution of 1 sec

Detector performance: Tracking

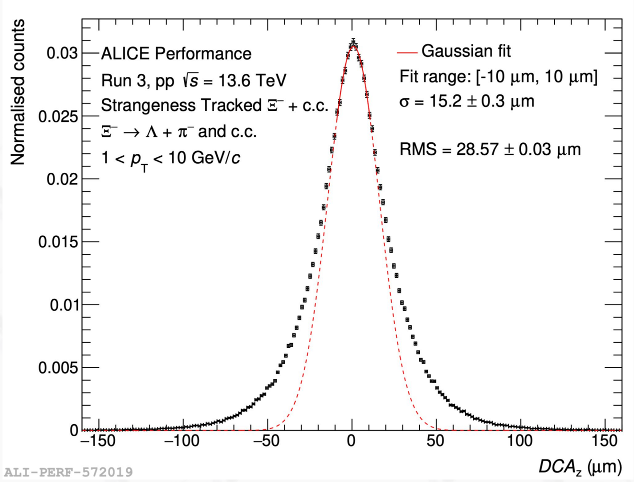
Impact parameter resolution on a base of Pb-Pb Run 3 data: 2x improvement at p_T = 1 GeV/c



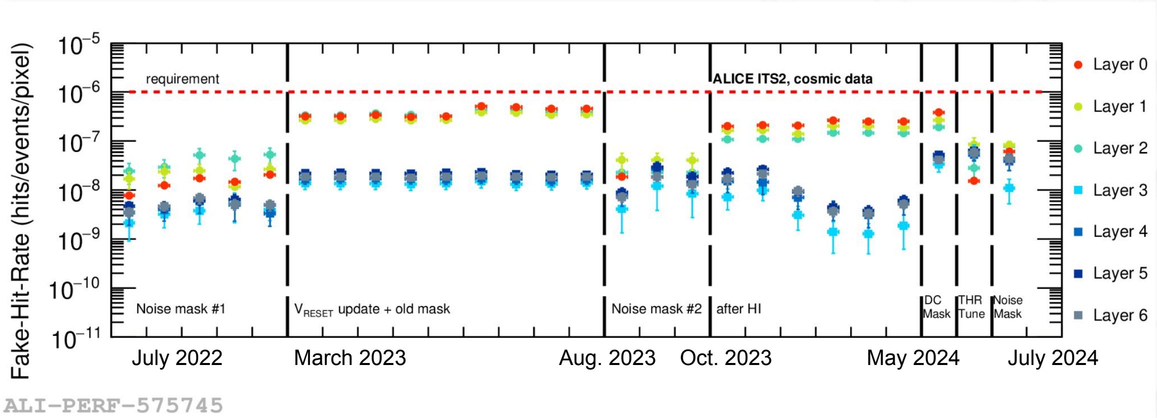
IB spans from 2.2 to 4 cm:
ITS can track particles before their weak decay



Possibility to measure non-prompt cascades with ITS

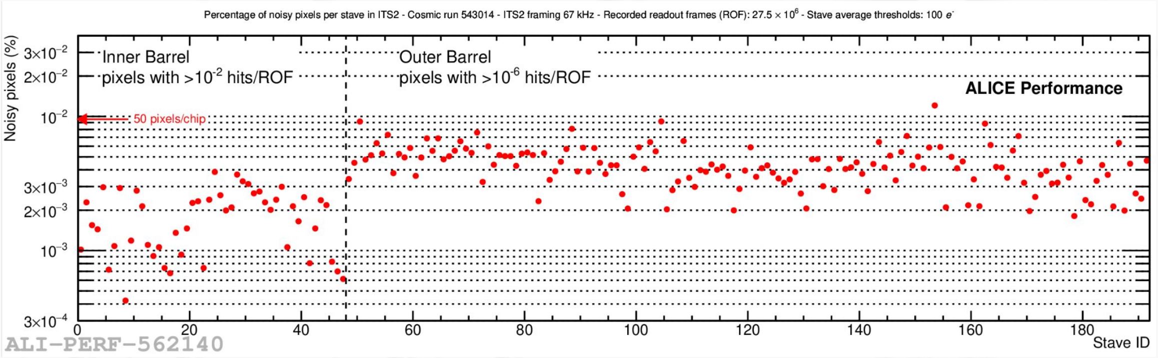


Detector performance: Fake-hit rate (FHR)



Level of the fake-hit rate always below at least by factor of 10 from project requirements and could be controlled by:

- Noise-pixel masking
- Threshold re-tuning

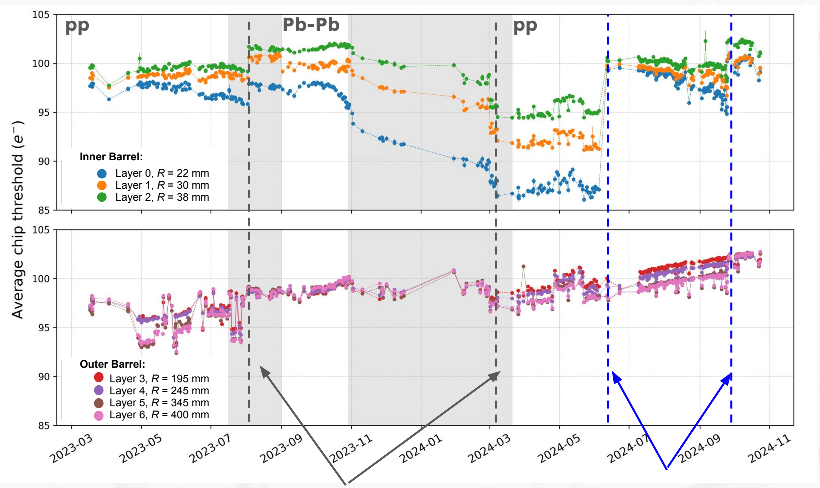


0.15 ‰ of pixel are masked in total on the full detector

- OB: stricter masking of noise pixels due limited bandwidth
- IB: priority on detection efficiency

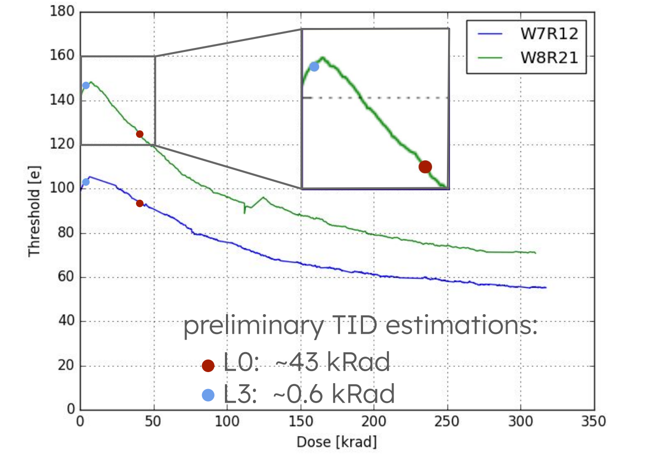
Detector performance: Threshold level

No beam #1 No beam #2



Update in voltage-drop correction New 100 e^- tune

Threshold changes during X-ray radiation of two ALPIDE chips at V_{BB} = -3 V



December 2022: Detector was tuned to 100 e^-

Pb-Pb Run 2023: a mild decrease in the average THR in IB:

- Magnitude depends on the radiation load
- FHR level is under control during all that period

June 2024: Detector was tuned again to 100 e^-

THR trend corresponds to the R&D observations:

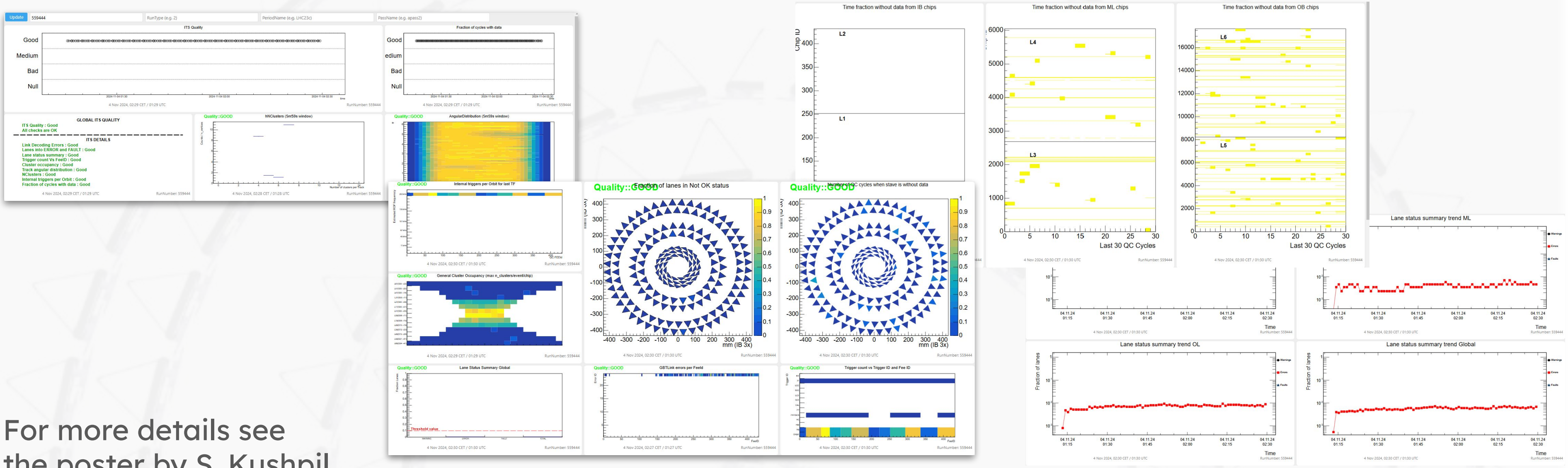
- R&D: Initial increase in THR followed by its decay with increase of absorbed TID
- ITS: Inner layers (higher dose) → decrease of THR
  Outer layers (lower dose) → slight rise of THR

Detector performance: Quality Control

Several QC online tasks to monitor data and MC simulation quality:

- **Front-end electronics:** triggering issues, status of lanes and payload
- **Hit Occupancy:** level of FHR, detection of hit anomalies
- **Clusterization:** monitoring cluster size, topology etc.
- **Track properties:** reconstruction issues
- **Calibration quality:** noise, THR, biases
- **Decoding/ Chip Status:** missing chips and corrupted data

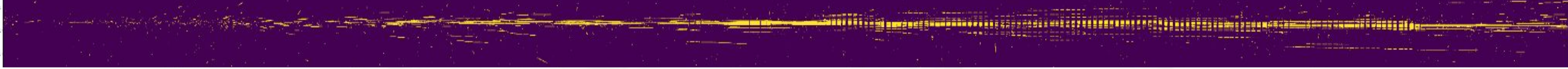
Plus, **QC post-processing online and offline**: long term stability of the detector parameters



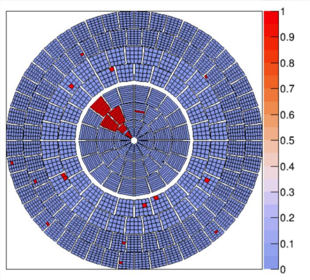
For more details see the poster by S. Kushpil

Detector performance: Pb-Pb beam background in 2023

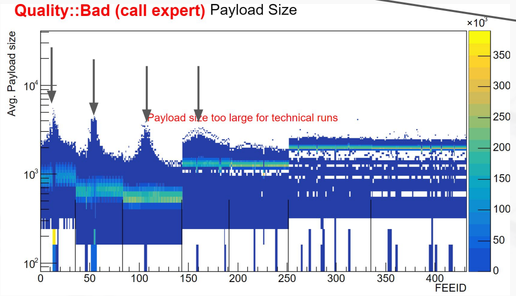
Example of L0_04 stave hitmap with a shower produced by particle hitting beam pipe



QC indicated problematic region at φ = 2.4, and r = 2 to 3 cm during the first minutes of the Pb-Pb beam



ITS Lanes status during Pb-Pb background event



Background also visible in the data rate of the neighboring staves and reaching L3

This region was not instrumented by previous generation of ITS where L0 started at $r \sim 4$ cm

- The source was promptly identified and largely mitigated (see report by R. Bruce) → only first 10% of the statistics affected
- The inflicted radiation damages due to the background was estimated to ~1.5% of the entire lifetime dose
- Readout Unit firmware improved to better cope with such large events by dropping the next events

Similar long tracks could be detected during pp collisions with much rare frequency: hitmap of L0_04

Detector performance: dE/dx - color run

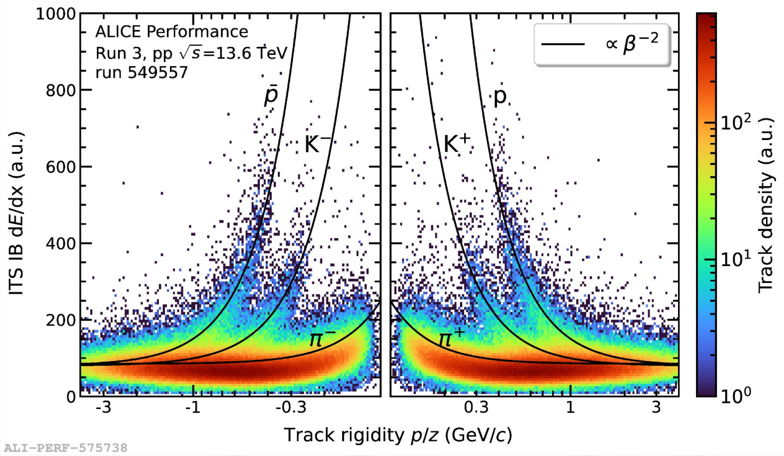
ITS Color run: usage of Time over Threshold information to access the particle energy loss in ALPIDE sensitive layer

Special detector parameters during color run:

- Analogue front-end configured to achieve analogue pulse length proportional to deposited charge
- High readout rate (2.2 MHz) to oversample analogue front-end response
- Only feasible at < 1 kHz of pp collisions

Proof of concept of PID with binary readout MAPS and a 25 µm thick sensitive layer

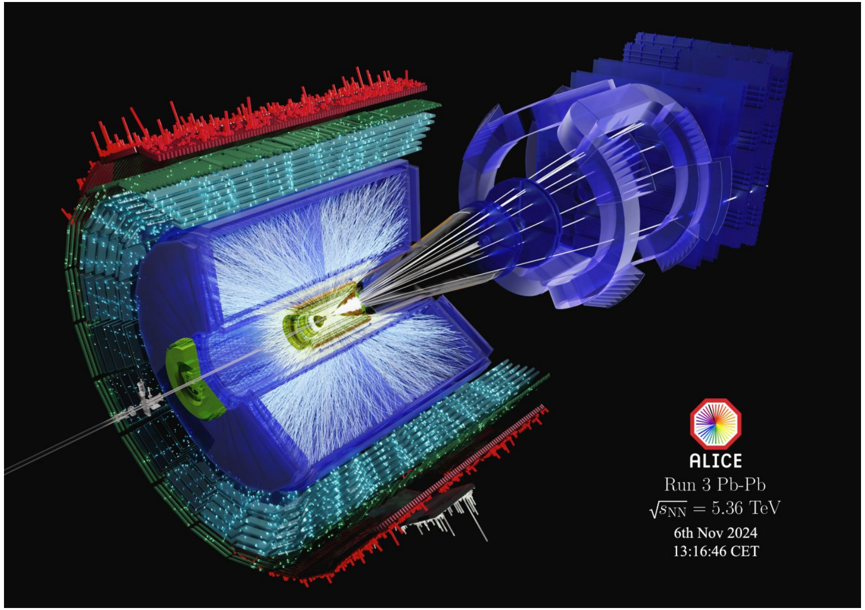
dE/dx spectrum versus track rigidity in the ALICE ITS2 Inner Barrel



Summary

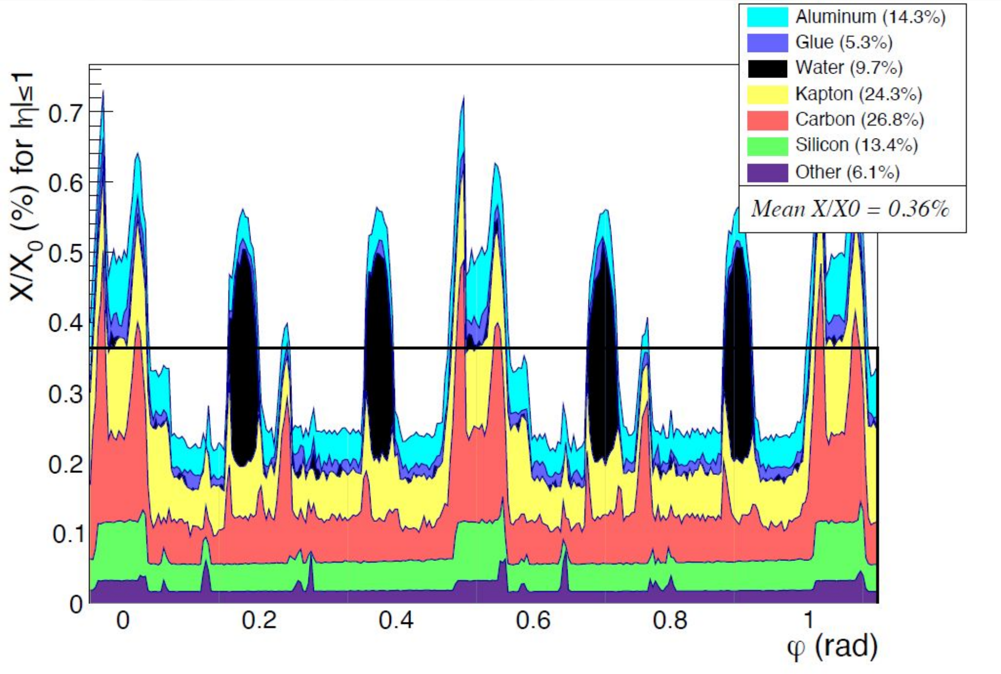
ITS2 successfully operated in pp and Pb-Pb collisions:

- First fully MAPS based tracking detector at the LHC
- Largest and most granular pixel detector to date with impact parameter resolution ~50 μm for particles with p_T < 1 GeV/c
- Recorded more than 80 pb^{-1} of pp collisions at $\sqrt{s}$ = 13.6 TeV and 500 kHz of interaction rate
- Stable performance with less than 1% loss of acceptance due to detector errors
- Many lessons learned during Run 3 operations → important inputs for ITS3 and ALICE 3



Additional Slides

ITS material budget for IB

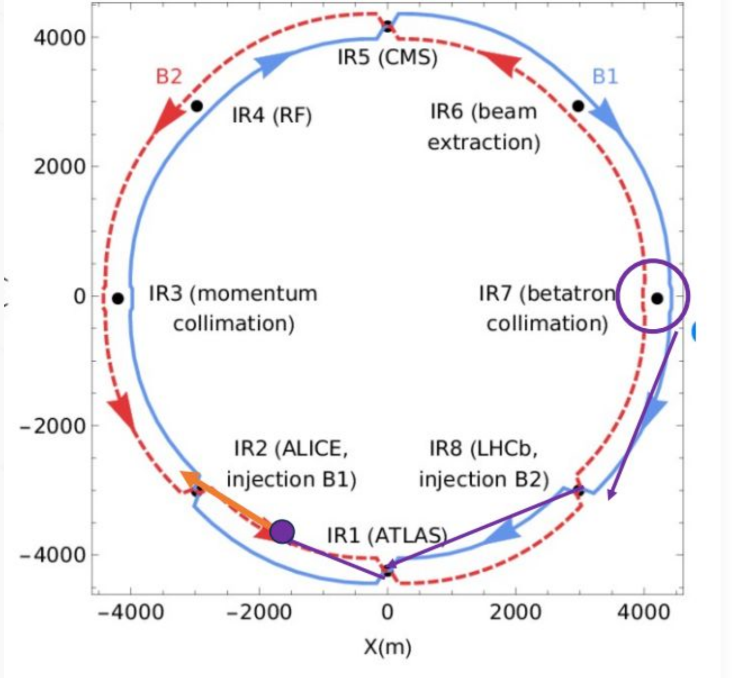


LHC background in Pb-Pb Run 2023

Confirmed by MFT and ZDC via off-time signals from Beam 1

Explanation: Shower created from ion fragments traveling inside the beam, hitting IP2 TCT collimators, ~114 m from IP2

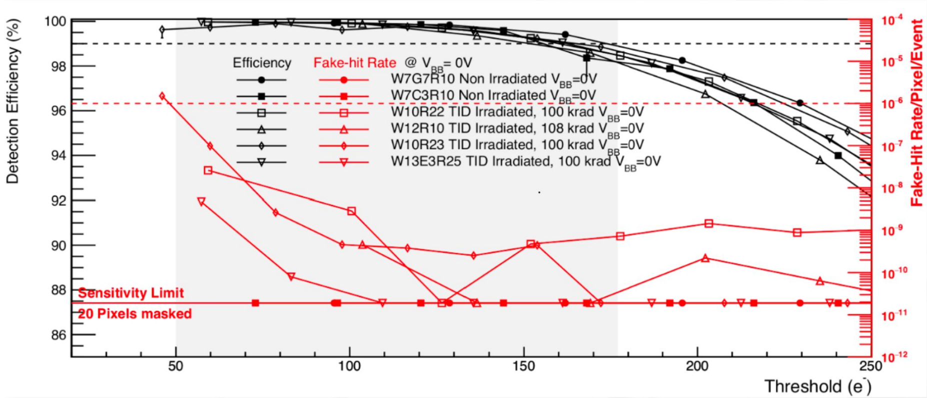
Mitigated on October 4th by adding an orbit bump at the ALICE TCTs

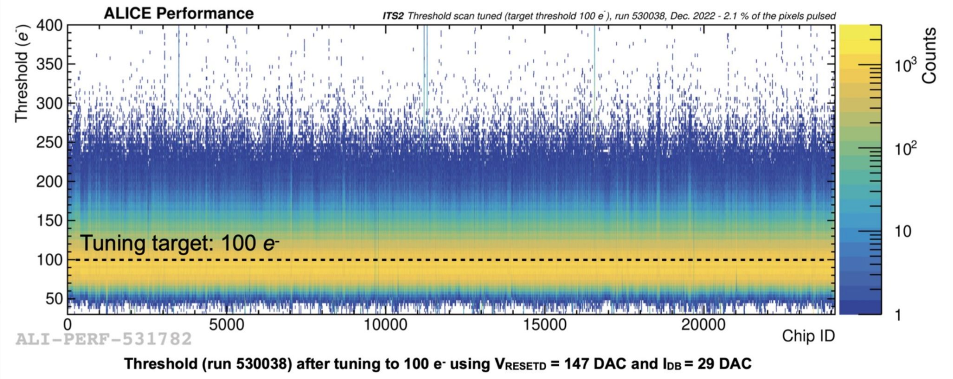


Taken from

Detector performance: Threshold level

Measurements of detection efficiency and FHR level as a function of Threshold charge for different ALPIDE prototypes.





- Choice of operational margins for THR is driven by FHR level (< 10^{-6}/pixel/event) and detection efficiency >99%
- Minimal observed THR of 85 e^- on L0 still lies within optimal ranges → no excessive noise during data-taking

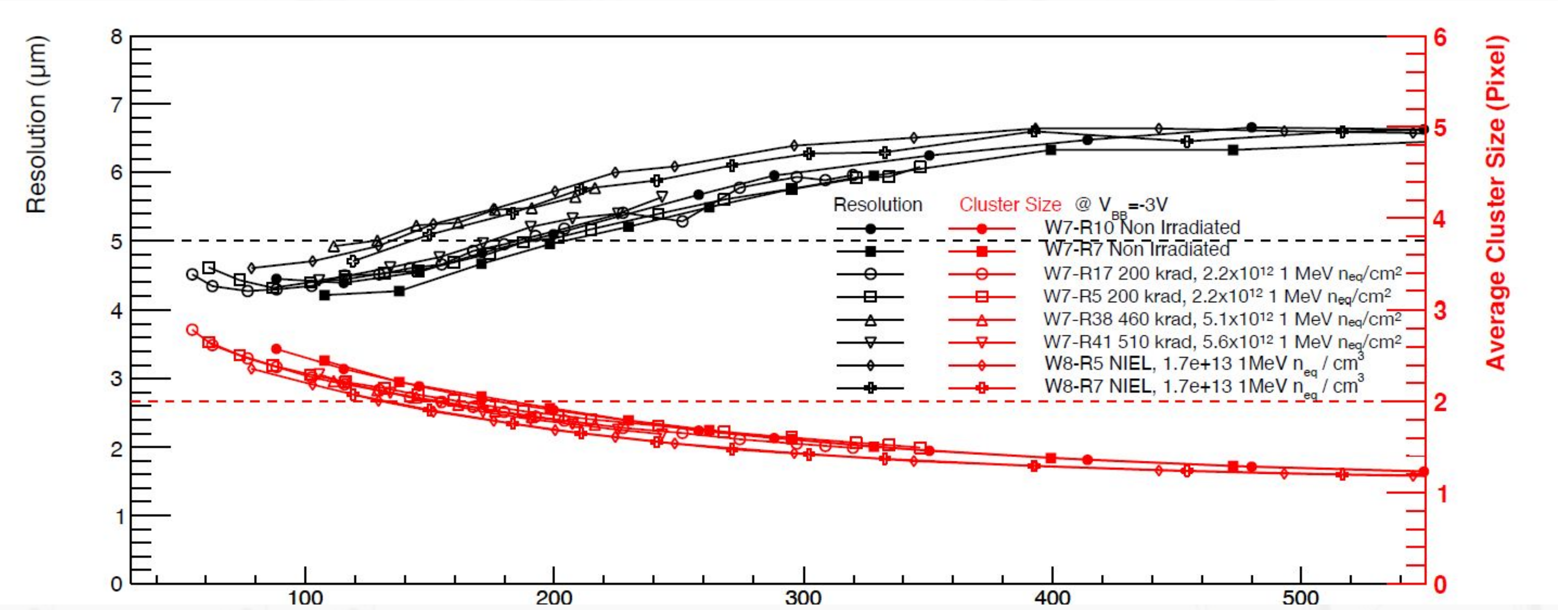
Stability of threshold values across all chips after tuning to 100 e^-:

- In-chip RMS of ~20 e^- -> in line with R&D measurements
- Chip-by-chip variations are a lot smaller than the pixel-by-pixel variations inside one chip
- Total ENC noise is of 5 e^-

Performance of ALPIDE: hit resolution

Beam test studies of irradiated ALPIDEs:

- Hit-position resolution 4-5 μm for thresholds below 140 e⁻ < 8 μm
- Cluster size depends on the threshold setting due to charge sharing



ITS Readout system