

Commissioning and performance of the new ALICE Inner Tracking System in the first phase of LHC Run 3

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for the ALICE Collaboration

¹CERN (Geneva, CH)

24th-28th October

VERTEX 2022

Tateyama Resort Hotel, Japan

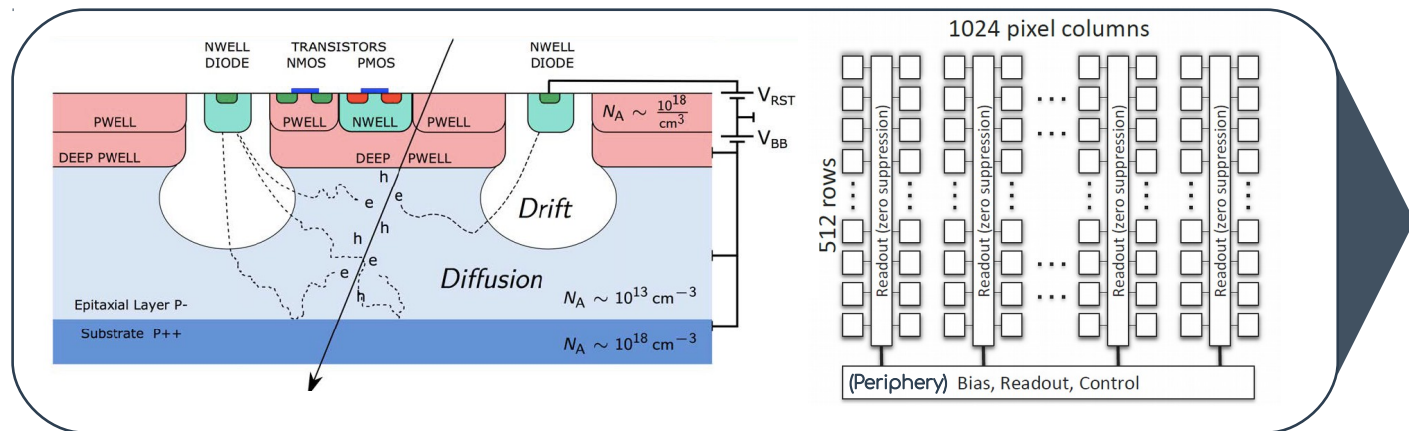


ALPIDE chip – the detector core

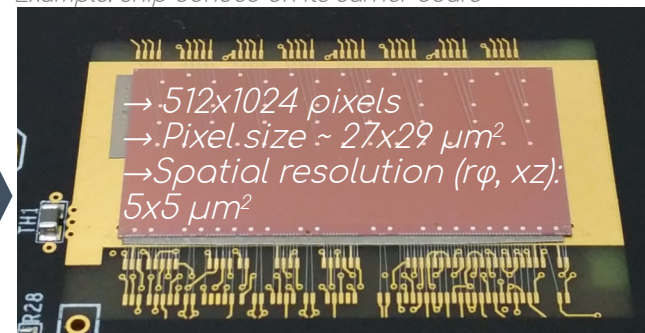
→ ALice P_lxel DEtector



ALICE



Example: chip bonded on its carrier board



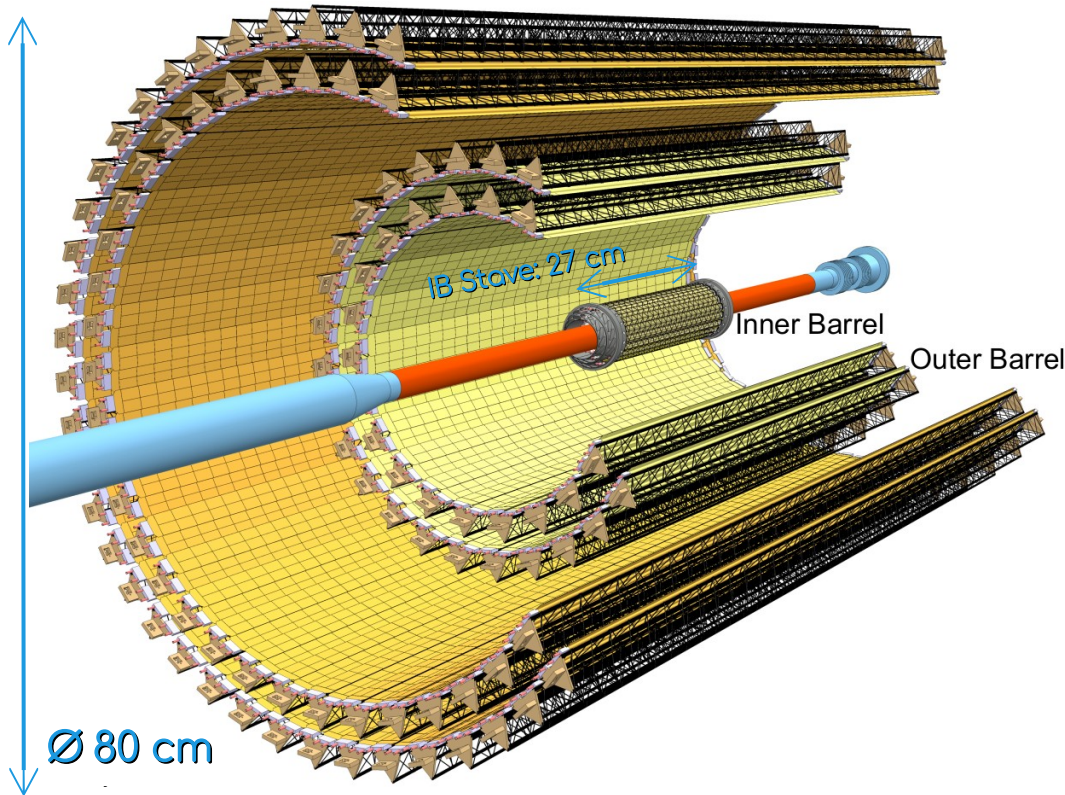
ALPIDE chip – 1.5 x 3.0 cm²

- TowerJazz 0.18 μm CMOS imaging process – a Monolithic Active Pixel Sensor (MAPS)
 - High resistivity ($1 \div 6 \text{ k}\Omega\text{cm}$) p-type epitaxial layer (25 μm) on p-type substrate
 - Small n-well diode ($\varnothing = 2 \text{ }\mu\text{m}$), ~100 times smaller than pixel → small capacitance ~fF
 - Reverse bias voltage to substrate: $-6 < V_{\text{BB}} < 0 \text{ V}$
 - Deep PWELL shields NWELL of PMOS transistor → full CMOS circuitry within active area
 - Fast data driven encoder for pixel matrix readout
 - Pixel signal amplified and digitized at a pixel level → Low power consumption ($< 40 \text{ mW/cm}^2$)
 - Pixel data sent towards periphery to the Data Transmission Unit (Serializer + PLL + LVDS driver)

- The ITS2 detector
- Readout chain and detector control system
- Data quality control
- Highlights from surface commissioning
- Highlights from commissioning in the cavern
- Start of Run 3 – detector performance
- Conclusions

Introduction – The Upgraded Tracker (ITS2)

→ 10 m² of monolithic active pixel sensors (12.5 GPixels)



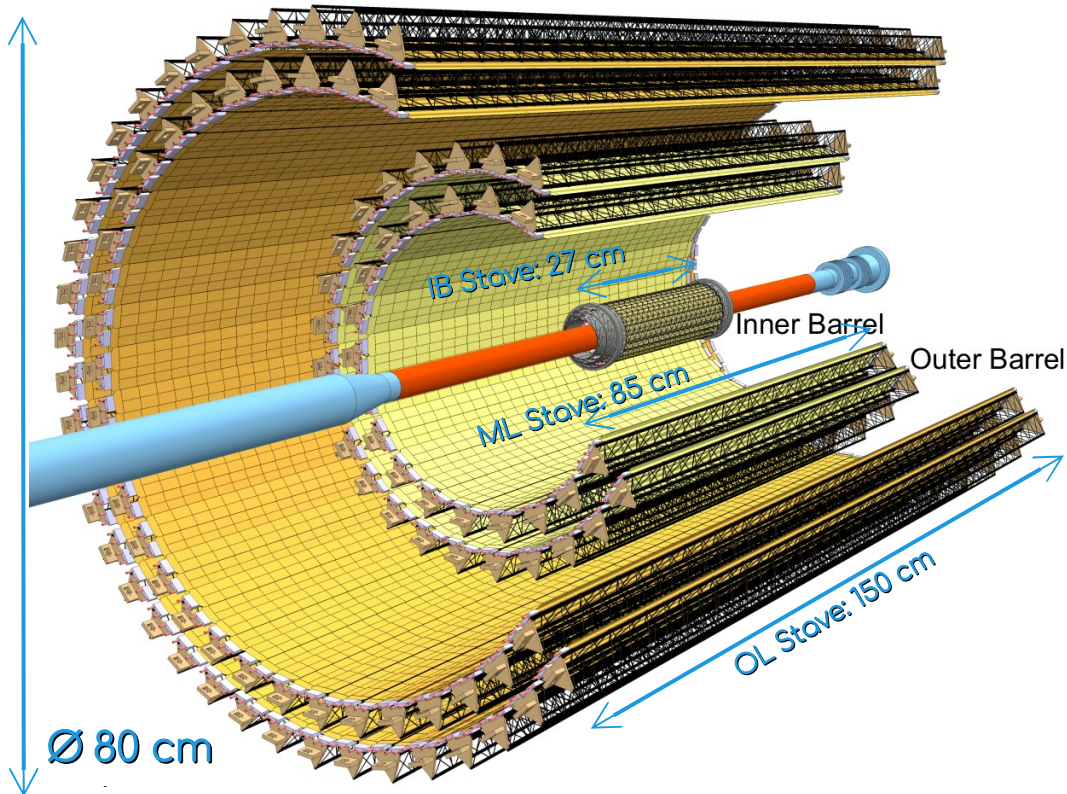
Inner Barrel (IB)

- 3 layers (L0 → L2)
- Staff length: ~27 cm
- 48 Staves made of 9 ALPIDE chips each
- Material budget: 0.36% X_0
- Readout at 1200 Mb/s per chip

Inner Tracking System (ITS)

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Inner Tracking System (ITS)

Inner Barrel (IB)

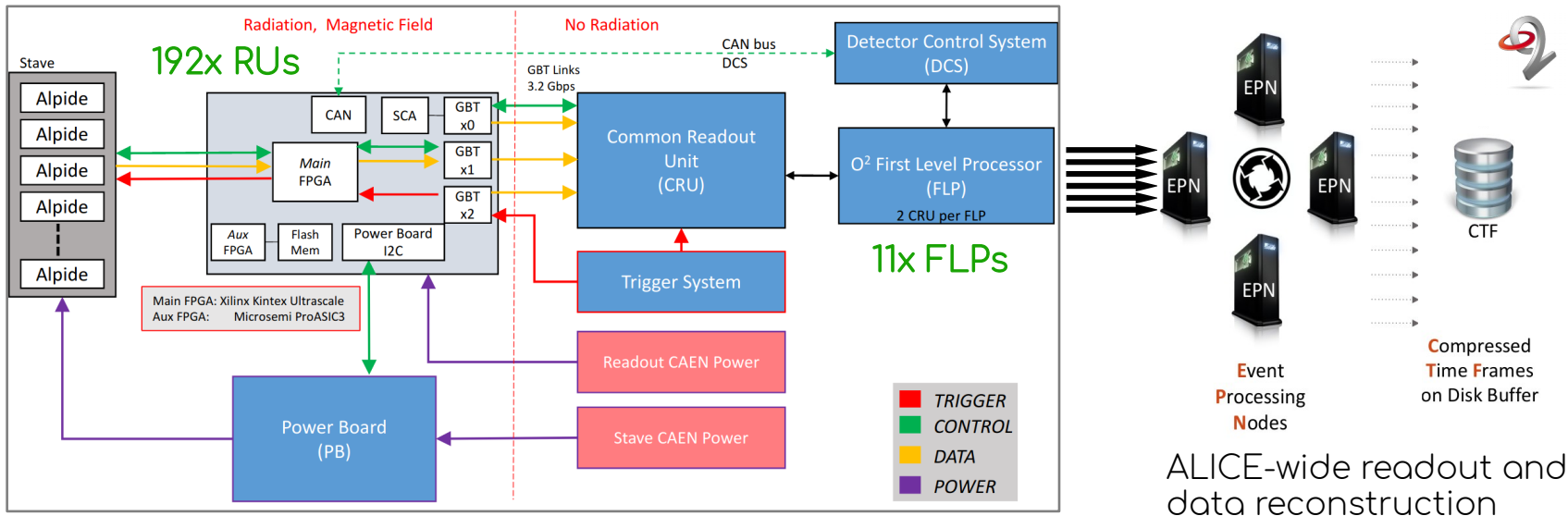
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24k chips
12.5 Gpix

Outer Barrel (OB)

- 4 layers – 2 Middle + 2 Outer Layers (L3 → L6)
- Stave length: ~85 cm (ML), ~150 cm (OL)
- ML(OL): 54(90) Staves with 112(196) ALPIDE chips each
- Material budget: ~1.14% X_0
- Readout of 7 chips with single link at 400 Mb/s

Data readout architecture

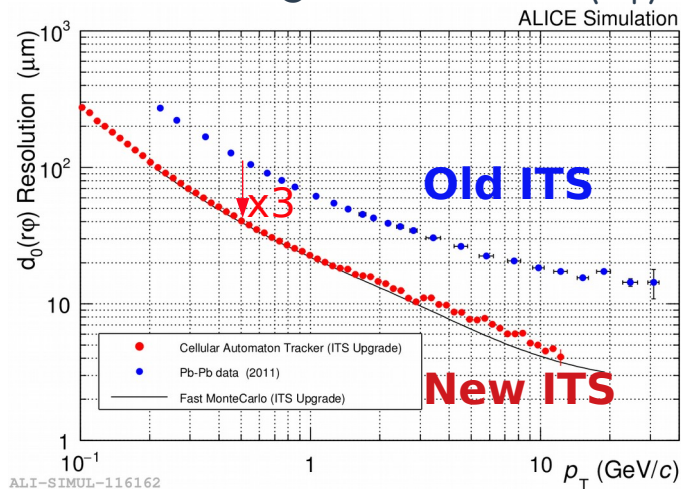


ITS2-specific readout

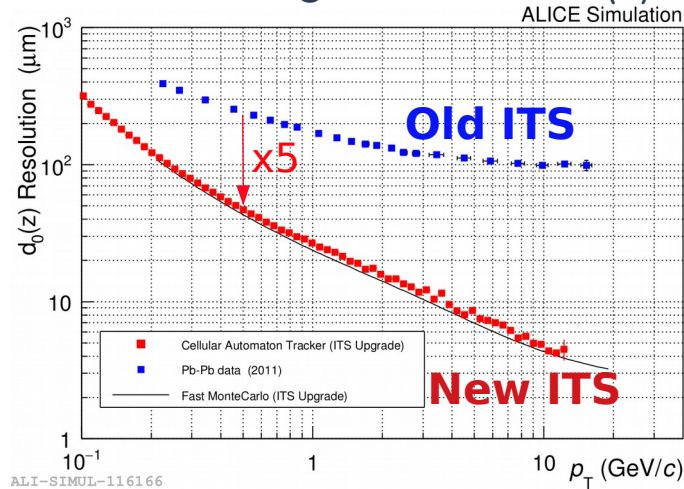
- 1500 Event Processing Nodes (EPN from ALICE farm) → sub-timeframes → time frames
- Synchronous reconstruction, calibration and data compression (→ GPUs)
- Asynchronous stage: reconstruction with final calibration → final Analysis Object Data (AOD)

Expected improvements with ITS2

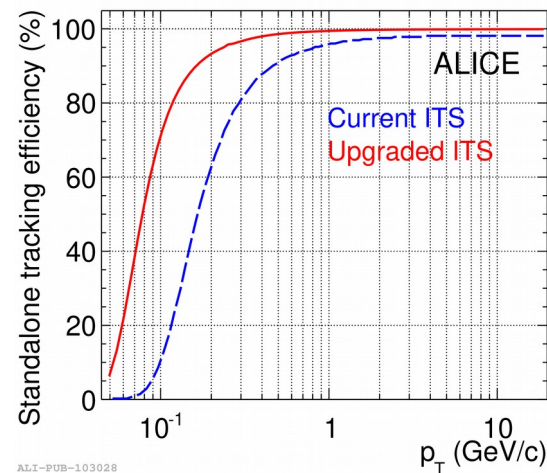
Pointing resolution ($r\phi$)



Pointing resolution (z)



Tracking efficiency



- Improved impact parameter resolution: factor ~ 5 (z), factor ~ 3 ($r\phi$) at $p_T = 500$ MeV/c
- Improved standalone tracking efficiency: 60% \rightarrow 90% at $p_T = 200$ MeV/c

Detector Control System (DCS)

Finite State Machine (FSM):
detector status
and operations

Click: **stave**
status (voltages,
currents,
temperatures,
readout
electronics)

Auxiliary
monitoring:
CAEN, cooling, ...

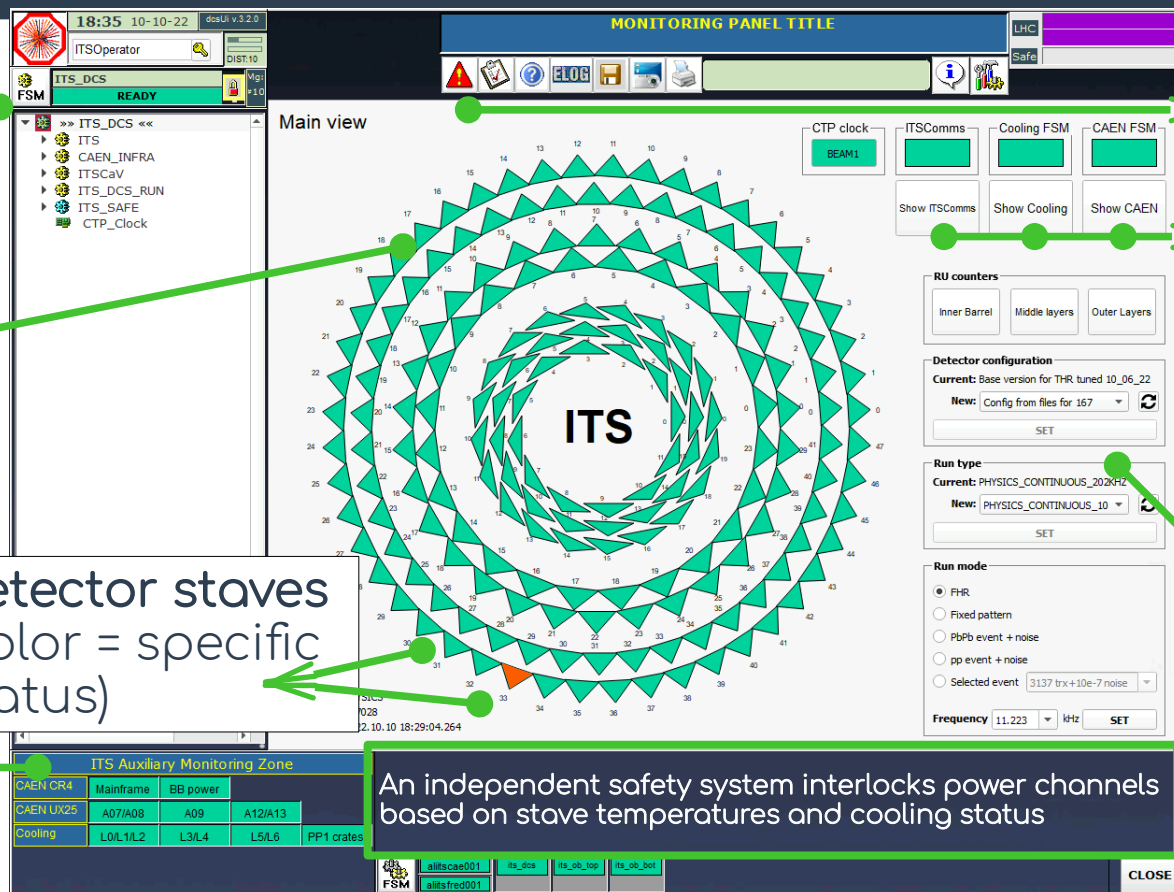
Alarm screen:
list of alarms

CAEN, Cooling
and monitoring
software
statuses

Detector
configuration
and selection of
run types
(physics,
calibration)

Detector staves
(color = specific
status)

An independent safety system interlocks power channels
based on stave temperatures and cooling status



(Data) Quality Control (QC)



7 QC online tasks

(online monitoring on data subsets)

- **Fake-hit rate:** monitoring of detector FHR and noisy pixels
- **Noisy pixels:** for detector noise calibration
- **Calibration:** monitoring of pixel threshold and dead pixels.
- **Cluster:** monitoring cluster size, topology, etc.
- **Tracks:** monitoring of track multiplicity, angular track distribution, clusters, etc.
- **Front-end Electronics:** chips in error, trigger flags
- **Decoding errors:** summary of decoding errors per chip

... and

5 online post-processing tasks + offline post-processing framework/macros → trending vs run

(Data) Quality Control (QC)

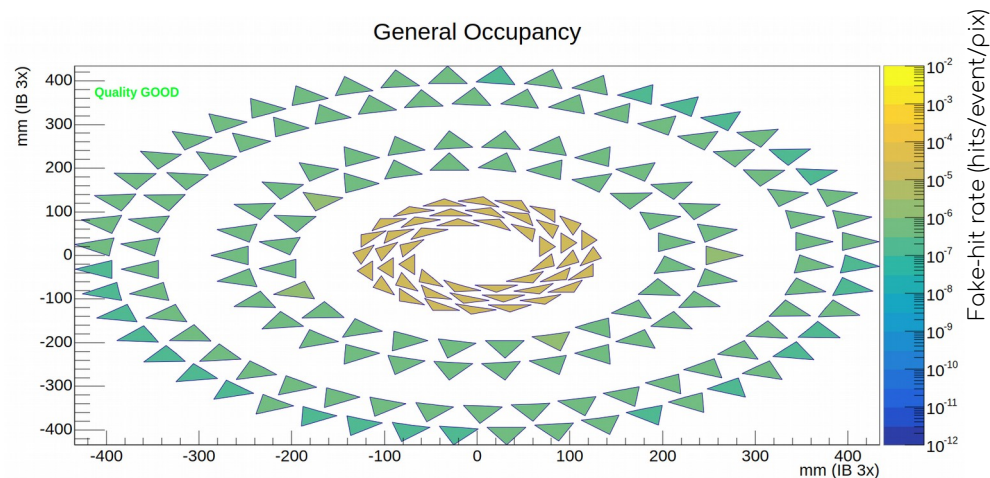
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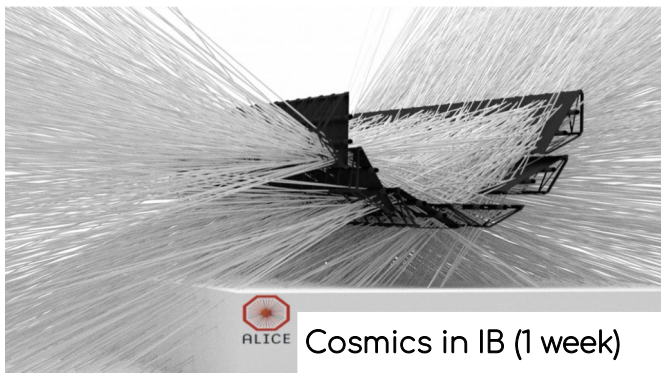
➡ QA of data done on a daily basis

On-surface commissioning overview - 2019/2020

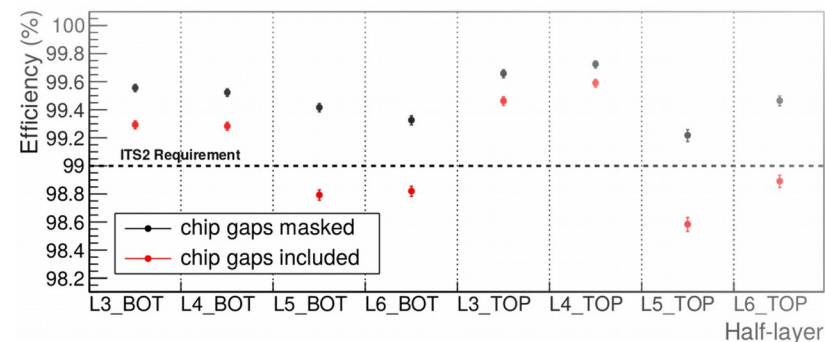
- Commissioning of the full detector in the laboratory before installation in the ALICE cavern
 - Sept 2019 → Dec 2020
- Continuous data taking: cosmic + calibration runs
 - 24/7 shifts + operations by detector experts



Half-barrels in the CERN cleanroom



Cosmics in IB (1 week)



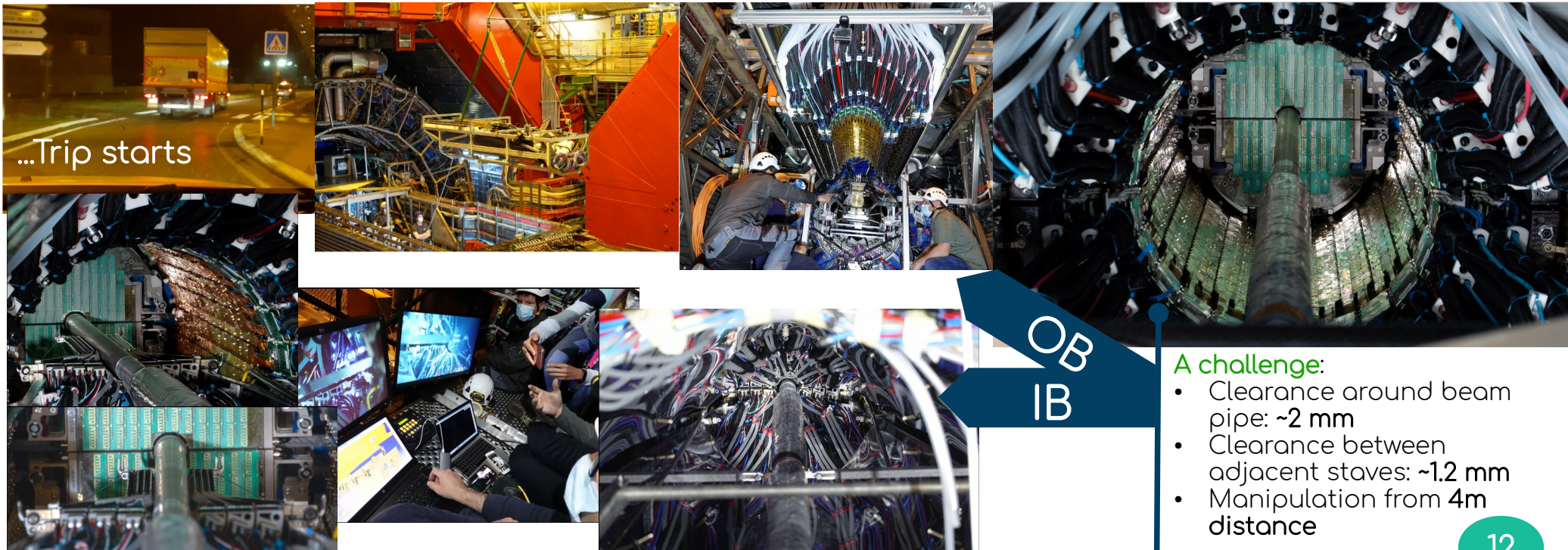
Efficiency with cosmic tracks (OB)

ITS installation inside ALICE cavern - 2021

→ a trip from lab to ALICE cavern



- OB installation completed in March 2021
- IB installation completed in May 2021



A challenge:

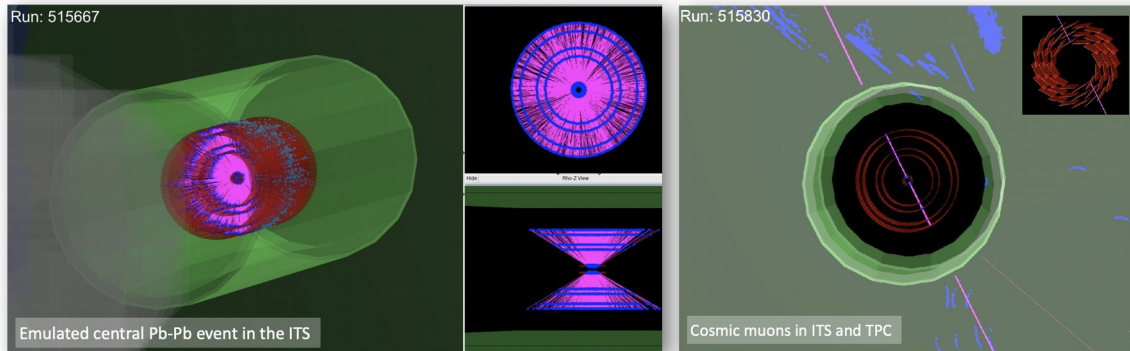
- Clearance around beam pipe: ~2 mm
- Clearance between adjacent staves: ~1.2 mm
- Manipulation from 4m distance

Verification of barrels after installation and preparation for data taking - 2021



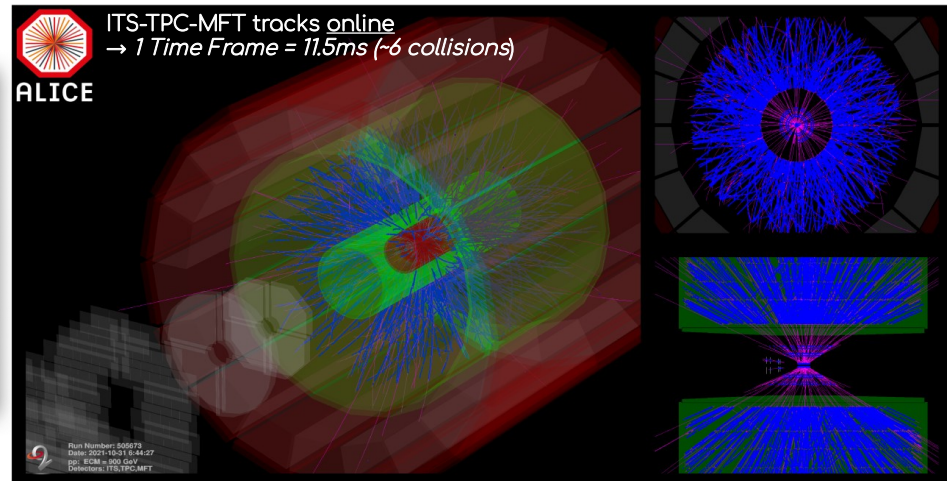
- OB installation (March 2021)
 - Full detector powered and monitored till mid-April
 - Various issues spotted and solved:
 - Problematic cables giving loose contacts or with wrong wire configuration (replaced)
 - Unstable power supplies (replaced)
 - Optimization of cooling for staves and electronics
 - Resolution of bugs into control-system user interface and code.
- IB installation (May 2021)
 - Basic verification of IB: readout tests + resistance measurement to check connections.
 - Basic verification of OB after IB installation: power and communication tests
- ITS standalone commissioning in the cavern (till July 2021)
 - Full verification of the detector: cosmic runs, data taking with emulated data patterns (pp, Pb-Pb), calibration runs.

Verification of barrels after installation and preparation for data taking - 2021 / 2022



Data taking preparation

- pp @ 202 kHz
- Pb-Pb @ 45 kHz
- cosmits



Successful data taking

- pp @ $\sqrt{s} = 900$ GeV

19/07/2021: start of ALICE global commissioning with central shifts
End October 2021: first pilot collisions (pp $\sqrt{s} = 900$ GeV)
January 2022 – June 2022: pilot collisions, cosmits, software validation with emulated data

Start of Run 3 overview – July 2022

- Official start on July 5th with first pp collisions at $\sqrt{s} = 13.6$ TeV (stable beams):
<https://alice-collaboration.web.cern.ch/run3>
- Since then, ~400h of data taking:
 - Nominal ITS framing rate: 202 kHz
 - ALICE standard luminosity: 500 kHz interaction rate with rate scans up to 4 MHz.
 - Loss of acceptance during runs: <1% (within requirements)
- Main issues related to ITS during runs:
 - Corrupted data
 - High-load of the First Level Processors
 - Mis-configuration of detector
 - Loss of clock (~ 1 event / day)
- At every beam dump: ITS threshold scan to evaluate the goodness of the detector calibration



- Main events till end of the year
 - pp collisions at 500kHz with regular tests at 1-2 or 4-5 MHz
 - 17-18/11: Pb-Pb ion tests → ion run moved to 2023
 - From 28/11: Year-End Technical Stop (no beam)

Preliminary performance results in Run 3

→ ITS2 full calibration (1)



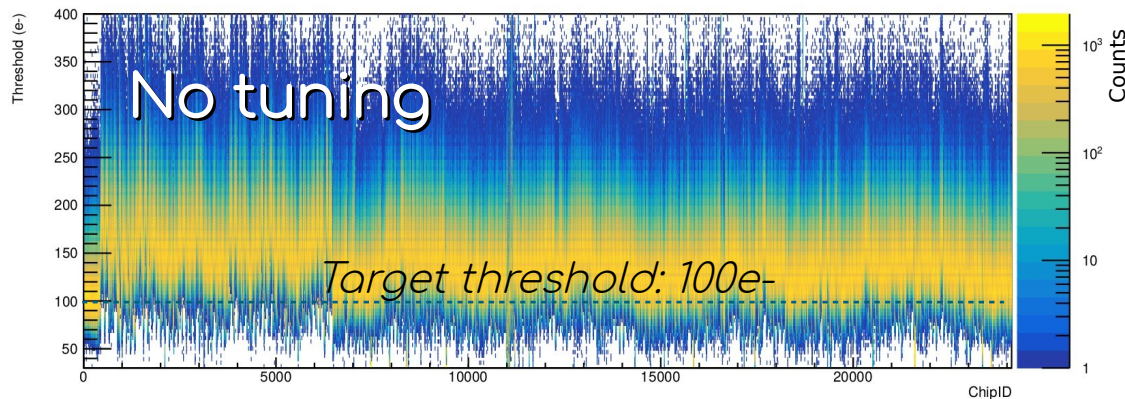
- ITS calibration parameters:
 - Masking of noisy pixels: occupancy $> 10^{-6}$ (10^{-2}) hits/event (IB)
 - Masking of problematic pixels: firing more than the number of injections done in calibration scans.
 - Tuning of discriminating thresholds
 - Power supply voltage
 - Temperature (ITS-dedicated water cooling)
- Numbers at hand:
 - Masked pixels on the full detector: ~0.15‰
 - Dead chips (OB): ~40
 - Thresholds: tuned to 100e- (in-layer RMS $< 5e^-$)
- Threshold calibration of 24120 chips is challenging:
 - Online calibration workflow runs on 40 Event Processing Nodes (EPN)
 - 5 parallel calibration processes + 6 decoding processes per EPN
 - Pulsing of ~1% of the pixels: ~252Ghits to be decoded → per-pixel calculations → final chip-by-chip threshold calibration/settings (average on pixels)

Preliminary performance results in Run 3

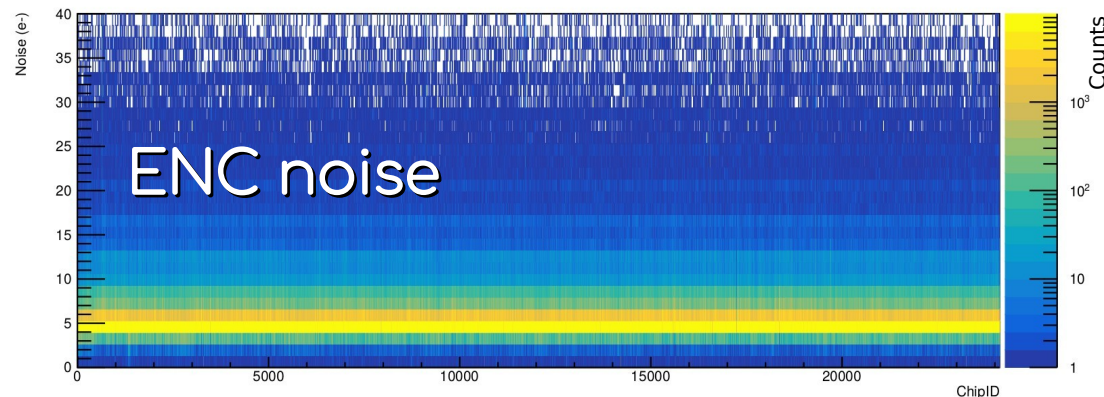
→ ITS2 full calibration (2)



ALICE



- Distribution of pixel thresholds per chip
- Thresholds not tuned: detector already ~100% efficient
- ENC noise: ~5e- (stable for 24k chips)

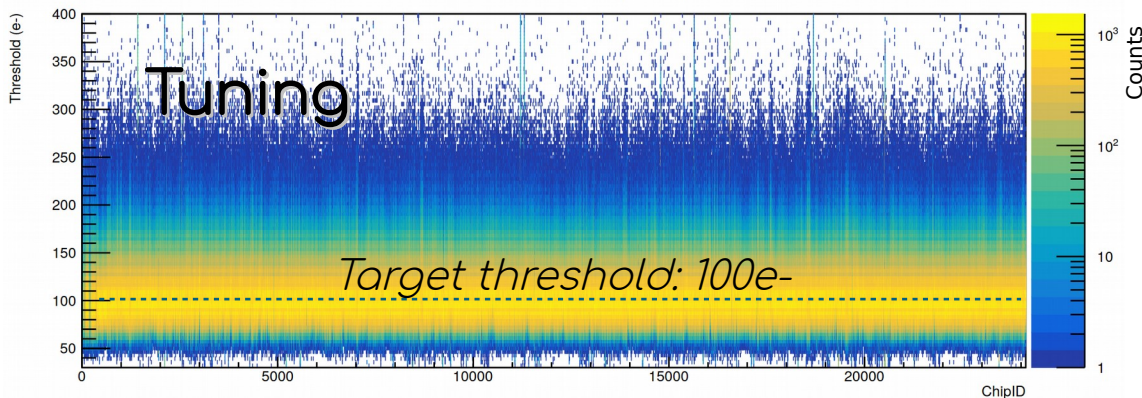


Preliminary performance results in Run 3

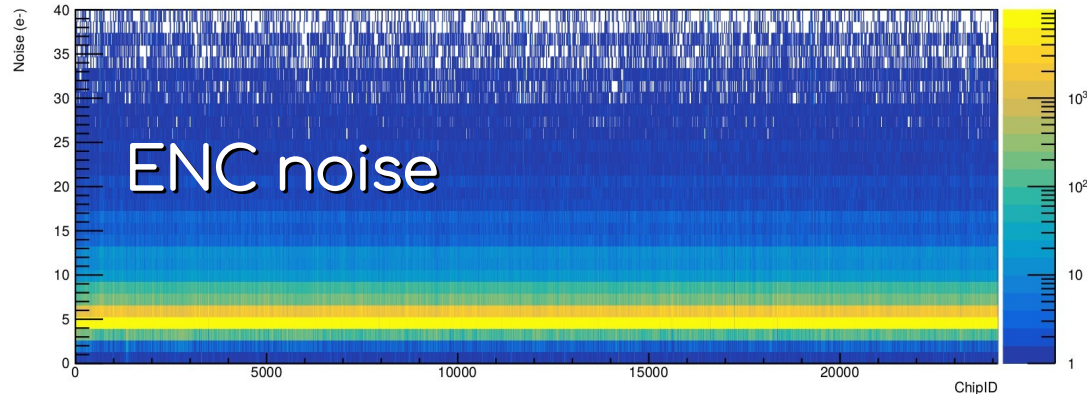
→ ITS2 full calibration (3)



ALICE



- Distribution of pixel thresholds per chip
- Thresholds not tuned: detector already ~100% efficient
- ENC noise: ~5e- (stable for 24k chips)
- Threshold tuned: 100e- (stable for 24k chips)
- RMS ~20e- (compatible with what measured during production)

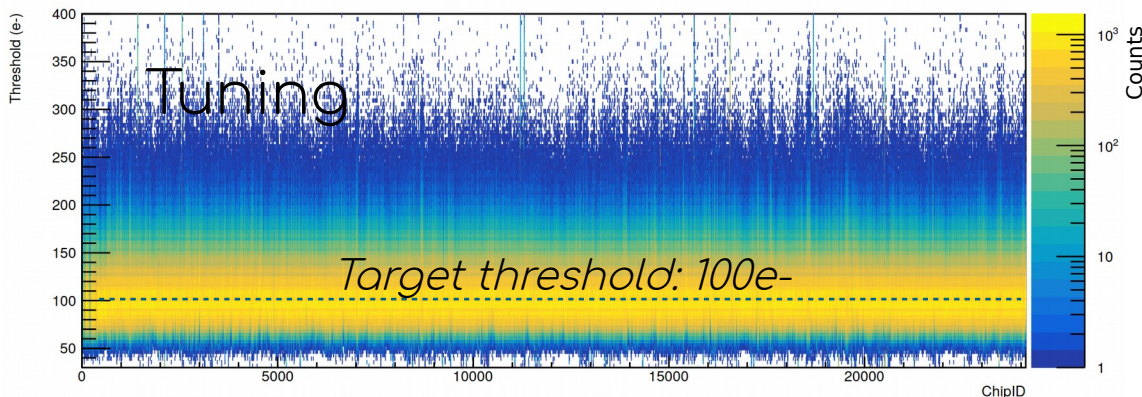


Preliminary performance results in Run 3

→ ITS2 full calibration (4)



ALICE

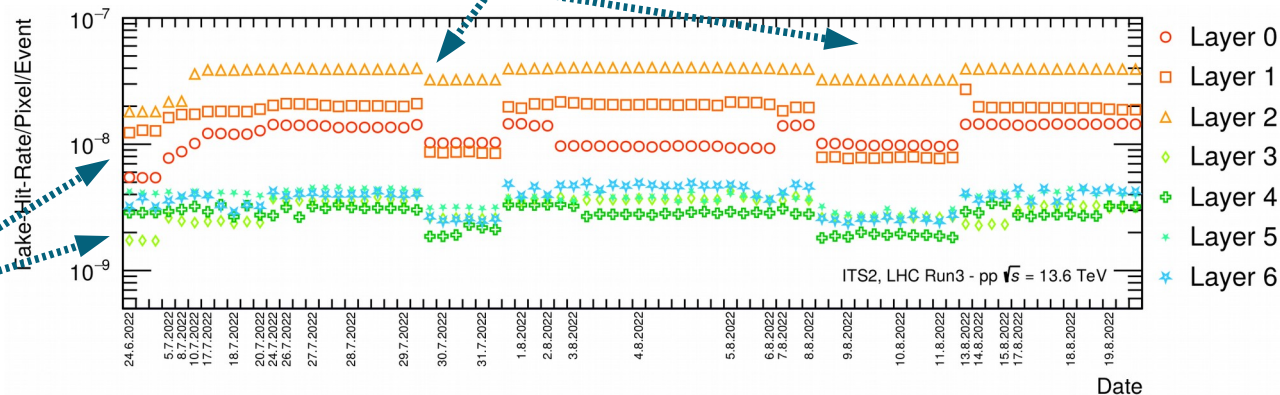


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- RMS ~20e- (compatible with what measured during production)

Fluctuations: due to <1% of chips where single noisy pixels might appear/disappear after power cycles or intensive detector tests

- Fake-hit rate trend during cosmic runs (tuned thresholds + noise masks)
- **Stable and $\ll 10^{-6}$ hits/event/pixel** (design requirement) by masking only ~0.15% of the pixels

Different noise masks
between IB and OB

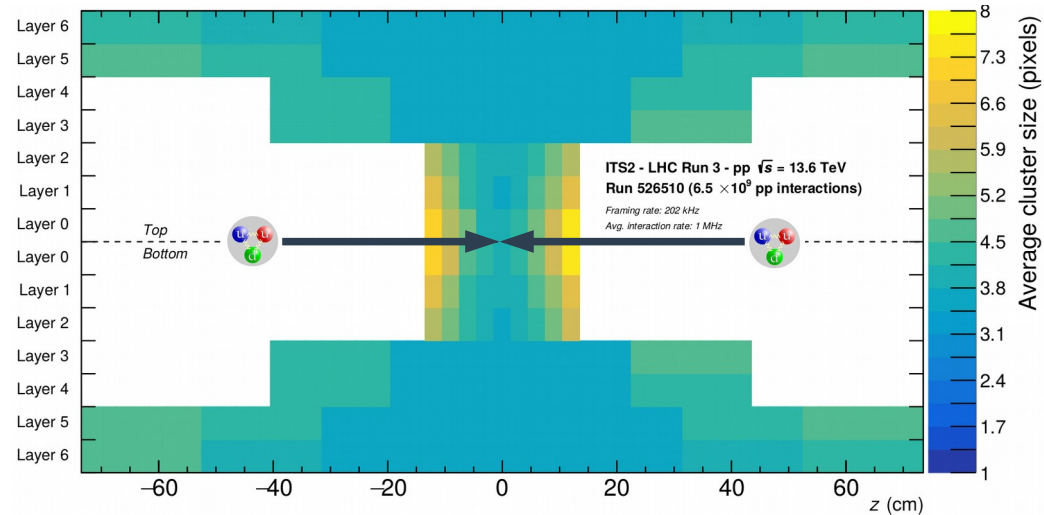


Preliminary performance results in Run 3

→ Cluster size and simulation

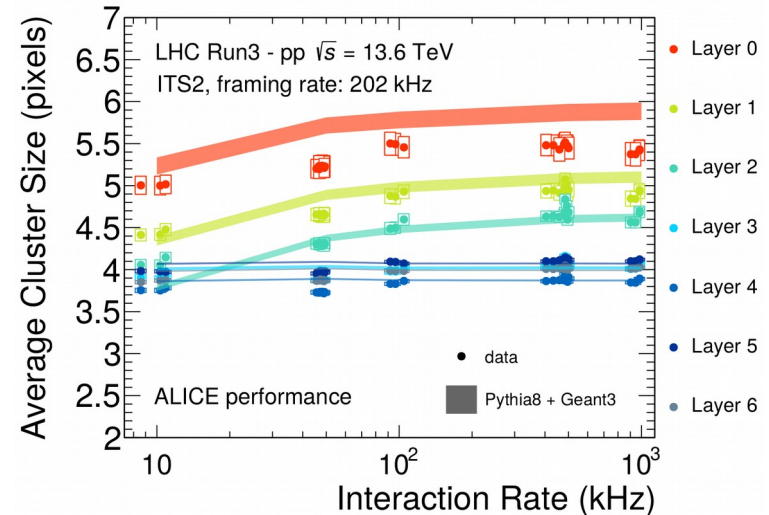


- Cluster size averaged for half barrels
 - Between 3 and 8 pixels depending on η
 - RMS ranging on the same interval
 - Observed to be stable over time
 - Independent of the interaction rate
 - PID studies with machine learning techniques are ongoing



Cluster size (pix)

- Simulation with Pythia 8 + Geant 3
 - Simulated noise: 2×10^{-8} hits/event/pix (IB), 3×10^{-9} hits/event/pix (OB)
 - Good agreement with data considering approximations:
 - Average noise per barrel and not per stave/chip.
 - Limited statistics in MC: ~20k events.



Cluster size vs IR

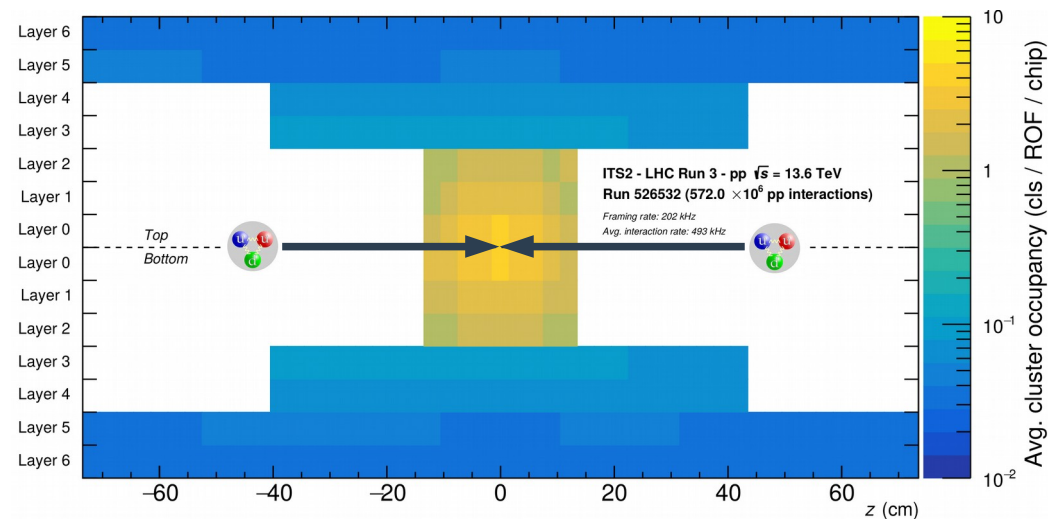
Preliminary performance results in Run 3

→ Cluster occupancy and simulation

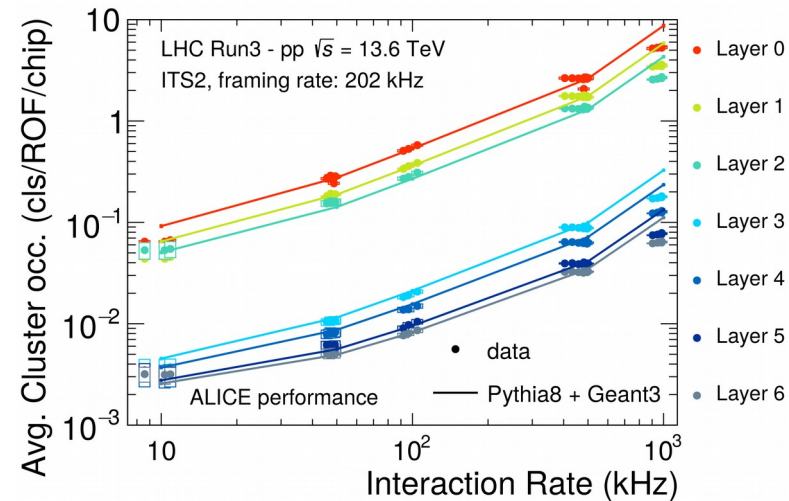


- Cluster occupancy per readout frame (ROF) and per chip
 - Between 0.1 and 10 clusters/ROF/chip @ 1 MHz (202 kHz framing rate)
 - Observed to be stable over time (at the same IR)
 - Dependent on the interaction rate

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 - Simulated noise: 2×10^{-8} hits/event/pix (IB), 3×10^{-9} hits/event/pix (OB)
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Cluster occupancy

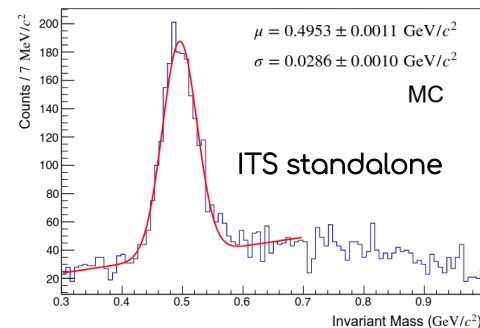
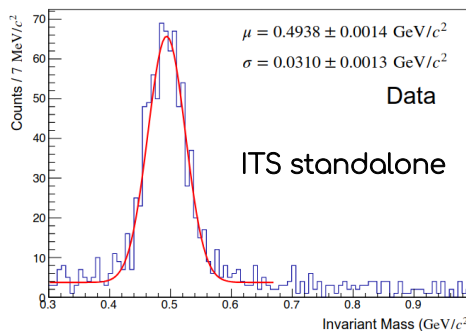
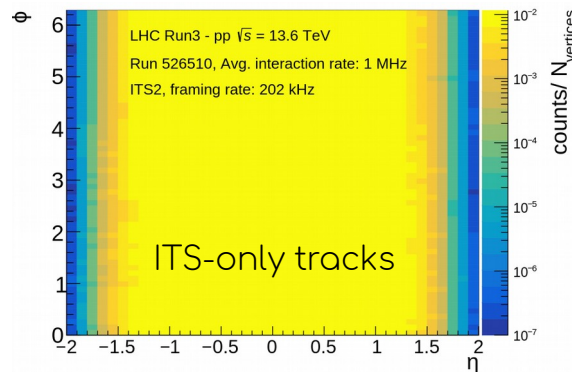


Cluster occ. vs IR

Preliminary performance results in Run 3

→ Detector alignment and reconstructed tracks

- Current detector (pre-)alignment
 - Effective pointing resolution: $\sim 80 \mu\text{m}$
 - Residual misalignment @50% track loss: $\sim 100 \mu\text{m}$
- ITS tracking numbers/features based on current alignment
 - Cellular automaton algorithm
 - Online tracking for quick QA of the data
 - % of tracks with 7 clusters (crossing all layers): $\sim 50\%$
 - Angular distribution of tracks of good quality
 - Vertexing: ITS tracklets (IB, input for tracking) or with global tracks
- Pre-alignment benchmarking with K^0_s (data vs MC)
 - Mean differs by a few per mille
 - Peak width increases by $<10\%$



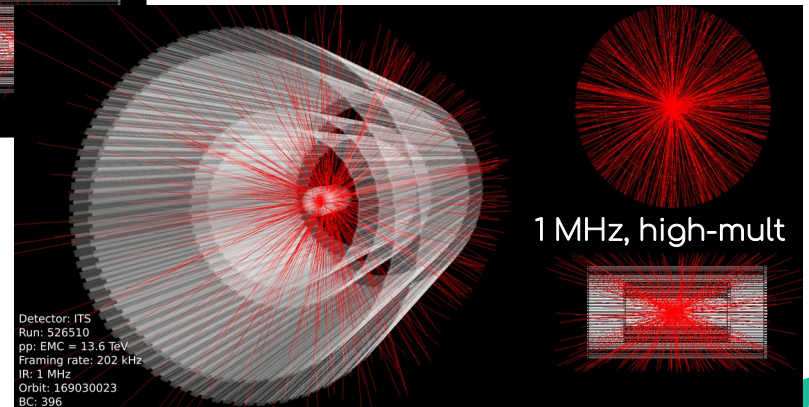
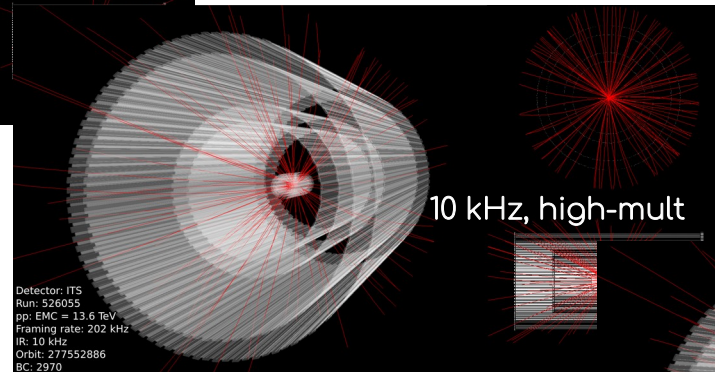
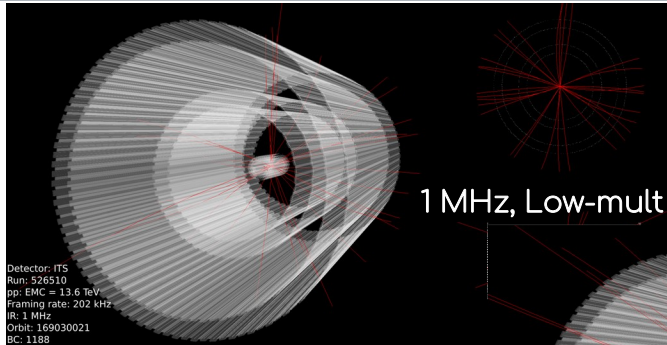
K^0_s invariant mass

Preliminary performance results in Run 3

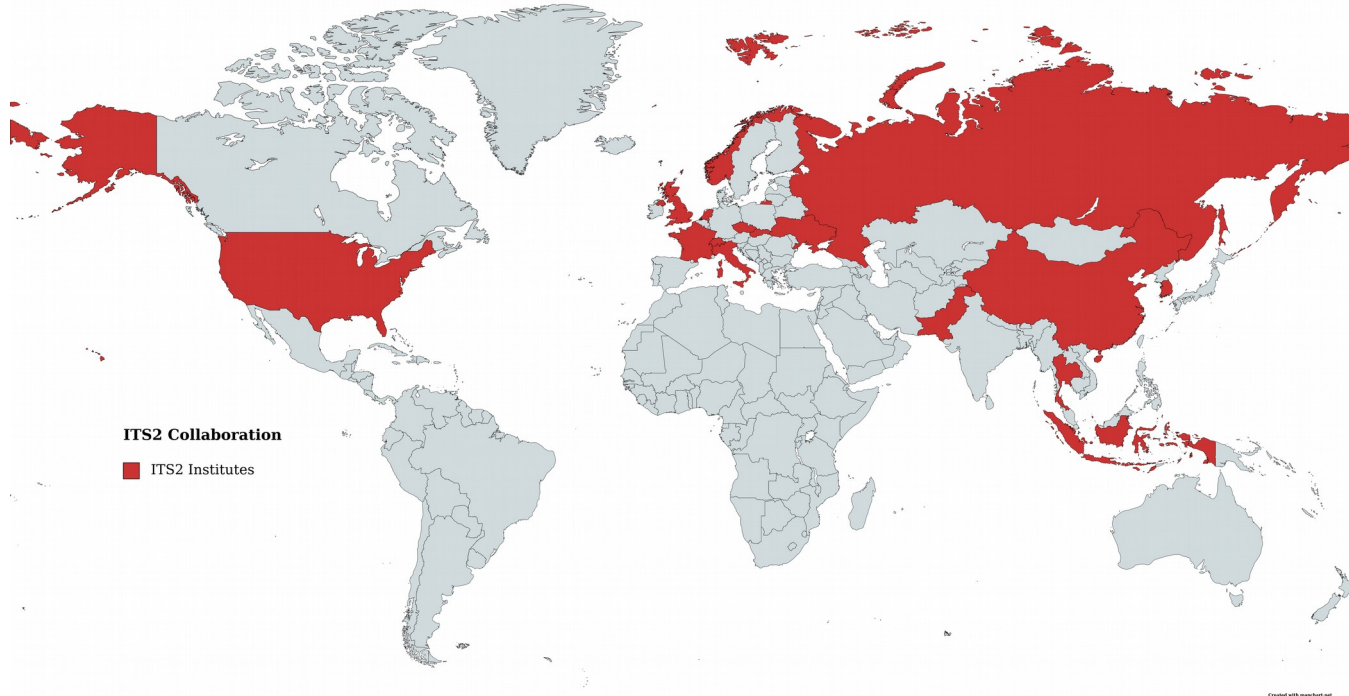
→ ITS2 event displays from Run 3



ALICE



ITS2 – a world-wide collaboration



CERN (Switzerland), CCNU (China), Řež u Prahy (Czech Republic), Strasbourg (France), LIPI (Indonesia), Alessandria (Italy), Bari (Italy), Cagliari (Italy), Catania (Italy), LNF (Italy), Messina (Italy), Padova (Italy), Pavia (Italy), Torino (Italy), Trieste (Italy), Nikhef (The Netherlands), UoB/BUC (Bergen, Norway), Oslo (Norway), COMSATS (Pakistan), Inha (Republic of Korea), Yonsei (Republic of Korea), PNU (Republic of Korea), St. Petersburg (Russia), Kosice TU (Slovakia), Kosice Slovak Academy (Slovakia), SUT (Thailand), Kiev BITP (Ukraine), Liverpool (United Kingdom), Daresbury (United Kingdom), Austin (United States), LBNL (United States), ORNL (United States)

Commissioning

Run 3

- **On-surface commissioning**
 - Successfully completed in December 2020.
- **Detector installation**
 - Successfully completed in May 2021.
- **Commissioning in the cavern**
 - Successfully completed in June 2022.
- **Run 3 started on July 5th 2022**
 - pp collisions at $\sqrt{s} = 13.6$ TeV, nominal interaction rate at 500 kHz.
- **Run 3 performance studies**
 - ITS2 performance is within expectations.
- **Detector Control System and Quality Control system**
 - Ready to monitor the detector hardware and data in Run 3

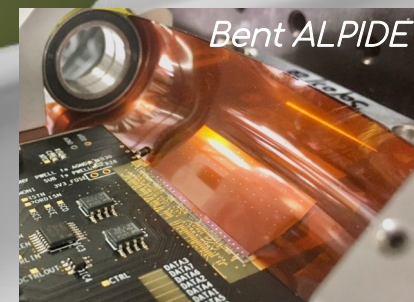
Conclusions

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- On-surface commissioning

Interested into the future of ITS2?
Don't miss these talks!

- [Tue 10.35] F. Carnesecchi – ITS Upgrade for Run4
- [Tue 11.05] L. Lautner – Beam tests with bent MAPS
- [Tue 15.20] P. Becht – Neutron-irradiated DPTS



Backup slides



ALICE

(Data) Quality Control (QC)

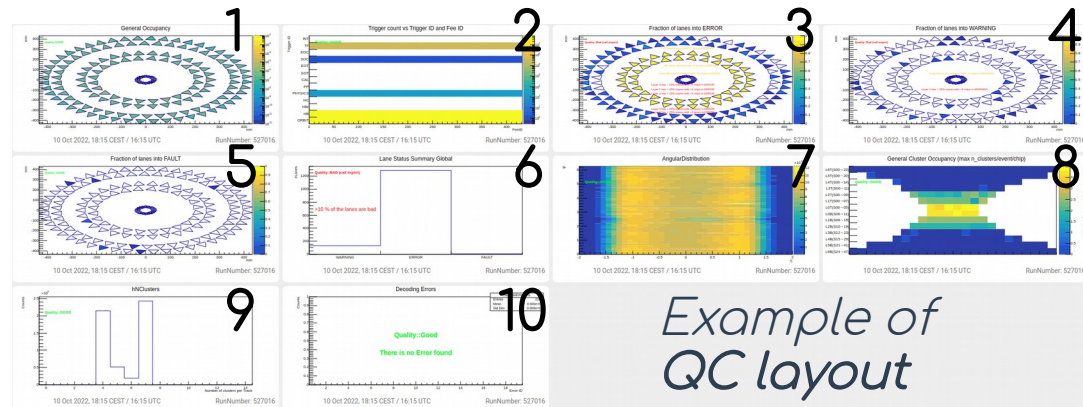
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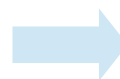
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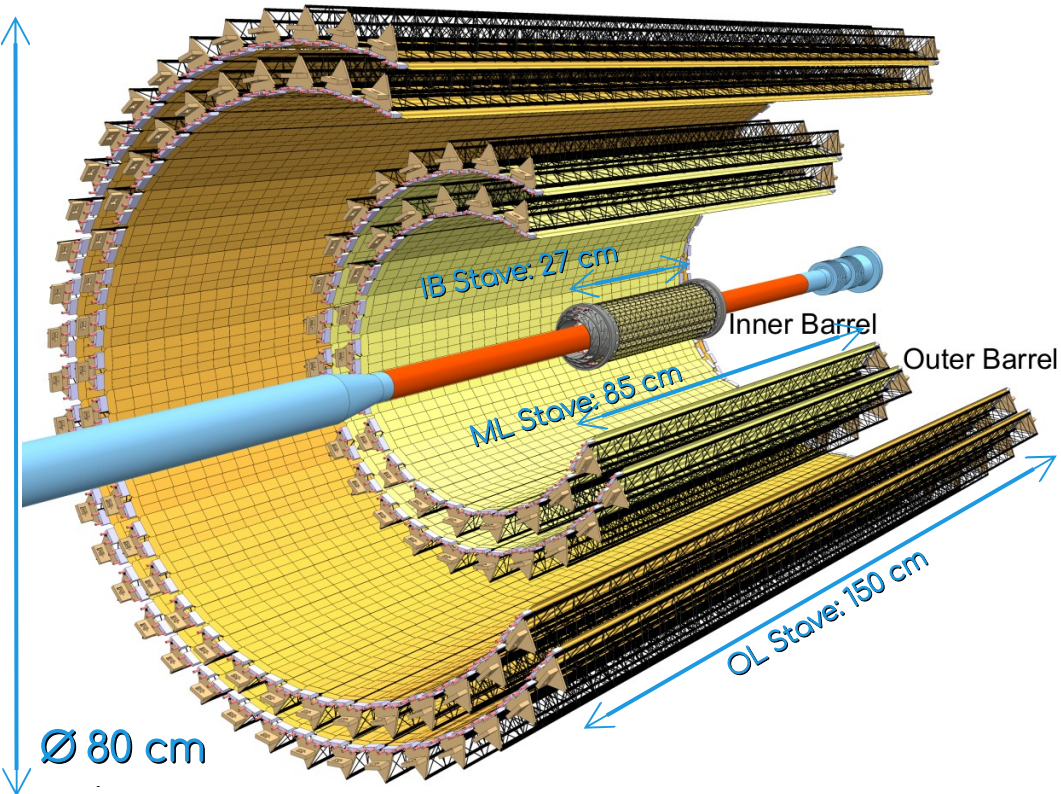


- 1 – Maximum fake-hit rate per stave
- 2 – Trigger types
- 3,4,5 – Fraction of chips in error (3 flags defined)
- 6 – Total number of chips in error
- 7 – ϕ vs η or reco ITS tracks
- 8 – Maximum cluster occupancy per stave
- 9 – Clusters per track
- 10 – Count of decoding errors



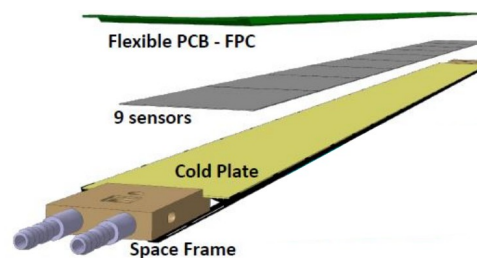
QA of data done on a daily base

ITS2 – details on components

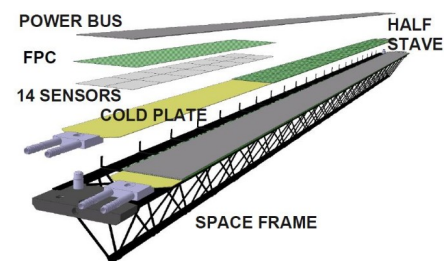


Inner Tracking System (ITS)

Inner Barrel Stave



Outer Barrel Stave

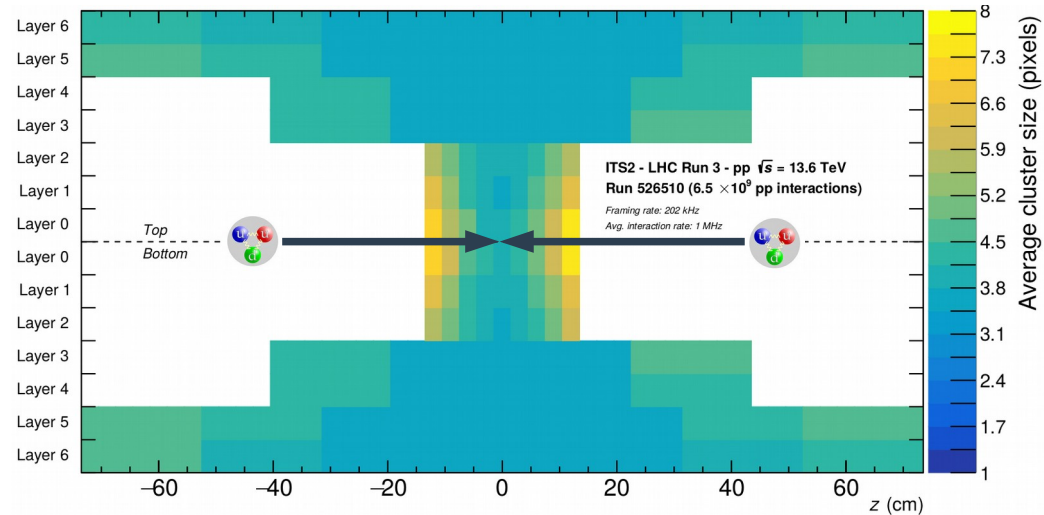


Preliminary performance plots in Run 3

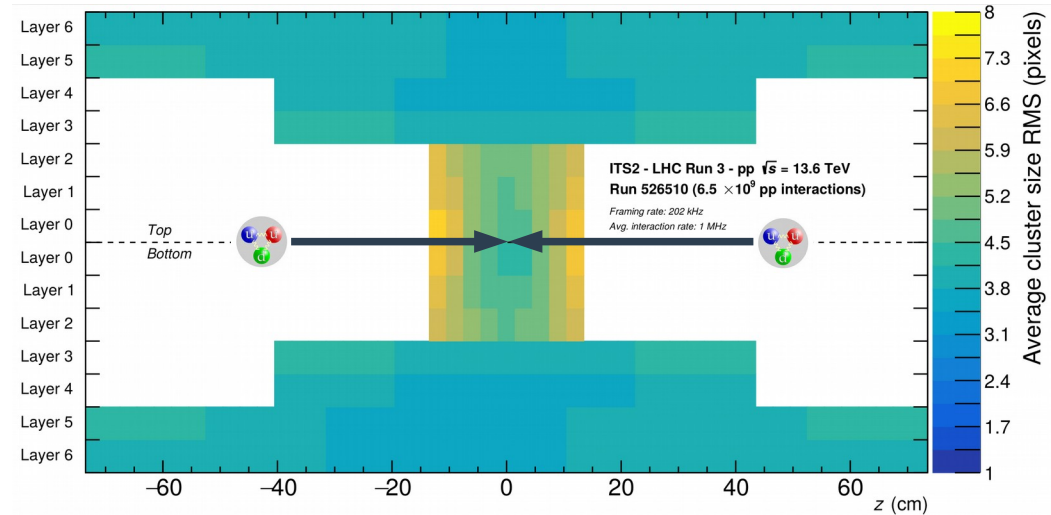
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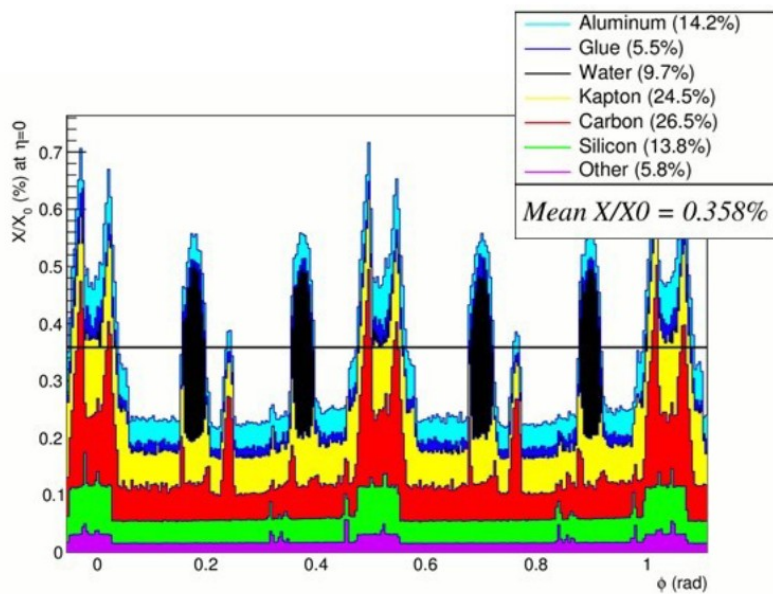


Cluster size (pix)



Cluster size RMS (pix)

Inner Barrel



Outer Barrel

