Efficiency measurement of the Outer Barrel of the ALICE Inner Tracking System Using Cosmic Muons

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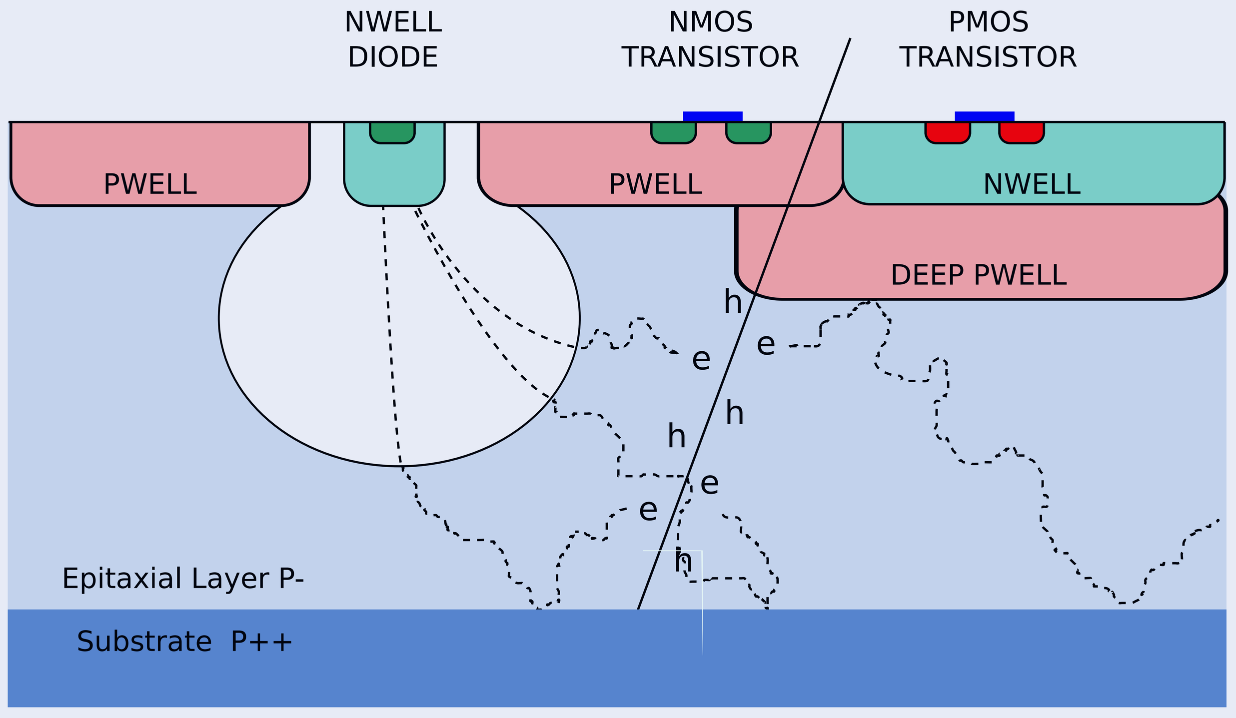
Introduction

The new ALICE Inner Tracking System (ITS) consists of 7 concentric layers of a custom Monolithic Active Pixel Sensor (MAPS) design known as ALPIDE (see Box 1). The outermost four layers (the Outer Barrel) were constructed by the end of 2019 and integrated into the readout electronics (see Box 2). In the first half of 2020, each stave in the Outer Barrel was verified individually with the readout electronics. By the end of 2020, a campaign to gather cosmic muon data was completed, from which a measurement of the detection efficiency was made.

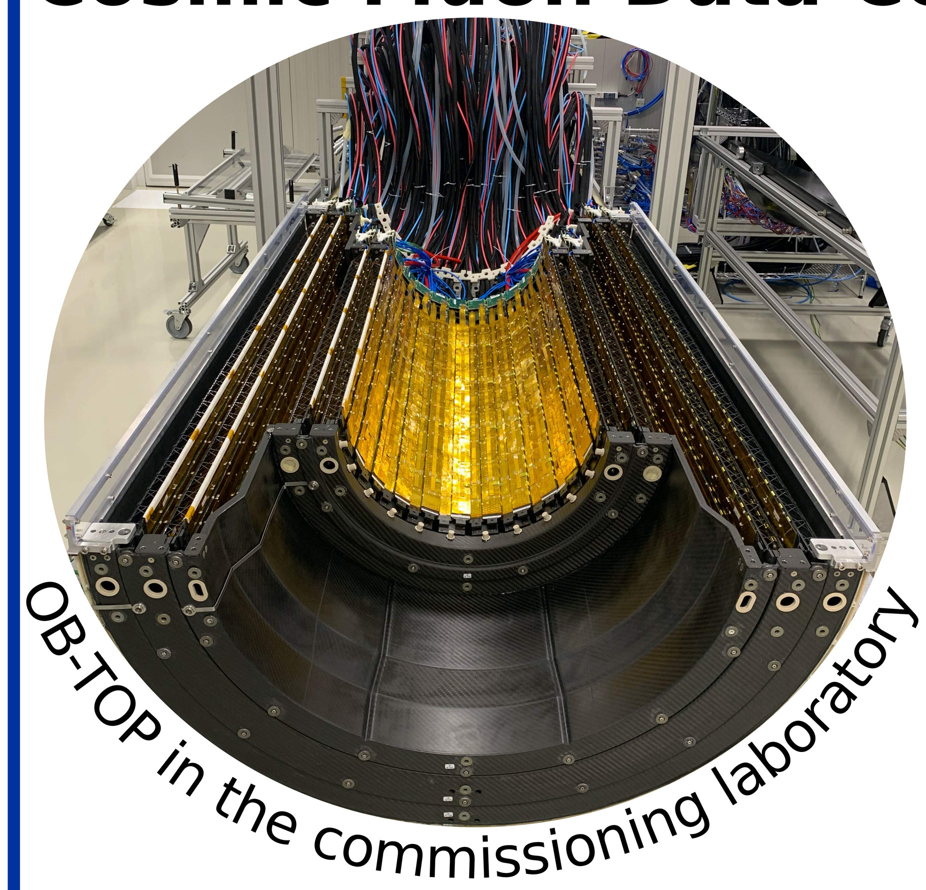
BOX 1 - ALPIDE



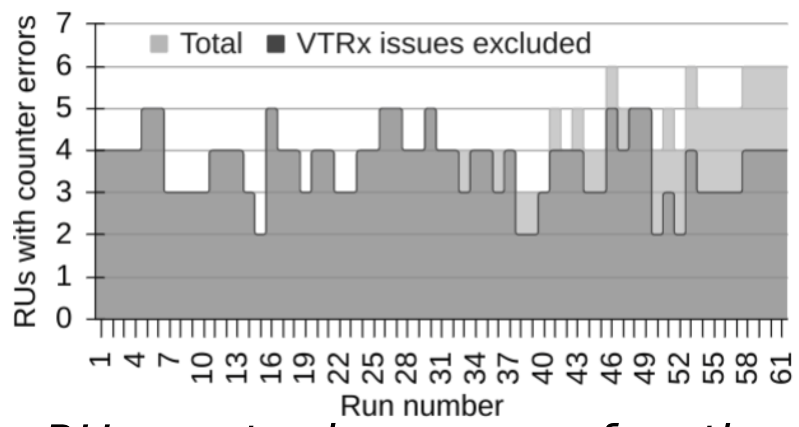
A single ALPIDE chip measures 15mm x 30mm and consists of 512 x 1024 pixels. A deep PWELL shields the NWELL permitting the use of PMOS transistors within the pixel matrix and therefore full CMOS logic. This makes it possible to have an amplifier, signal-shaper, discriminator and multiple event buffers in-pixel [1].

- 130,000 pixels / cm^2
- Spatial resolution: ≈ 5µm
- Power: ≈ 40nW / pixel
- Fake hit rate << 10^{-6} /pixel/event

Cosmic Muon Data Collection



- Data collection time: 10 hours
- Active time: 100%
- Pixels included: 98 %
- Pixel threshold: 100 e-
- Trigger frequency: 11.2 kHz



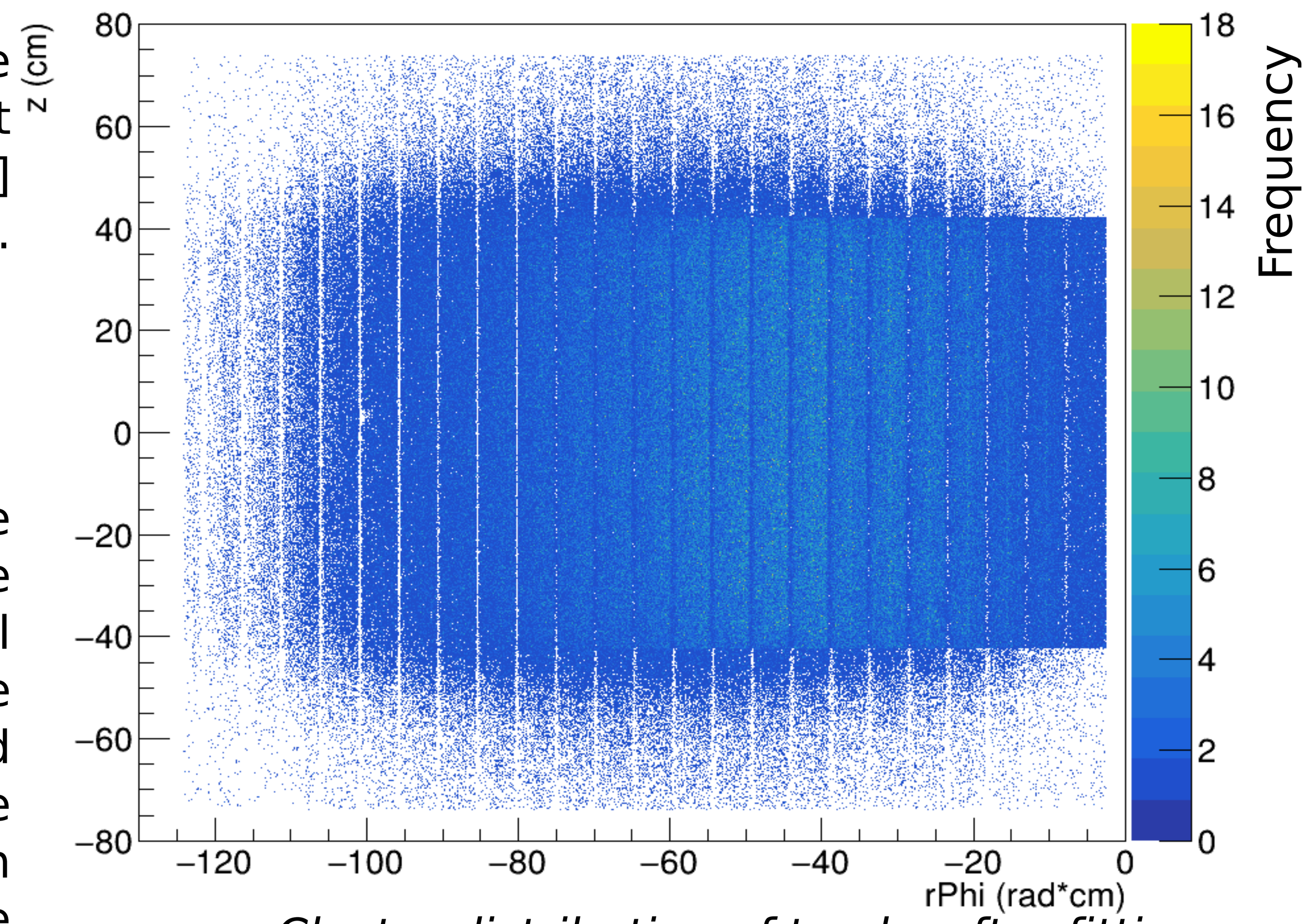
RU counter issues as a function of run number.

No significant increase in Readout unit issues if VTRx issues are excluded. VTRx issues are known and under control (see Box 2).

Fit clusters in a single frame with a straight line using MIGRAD [3] with χ2 minimisation.

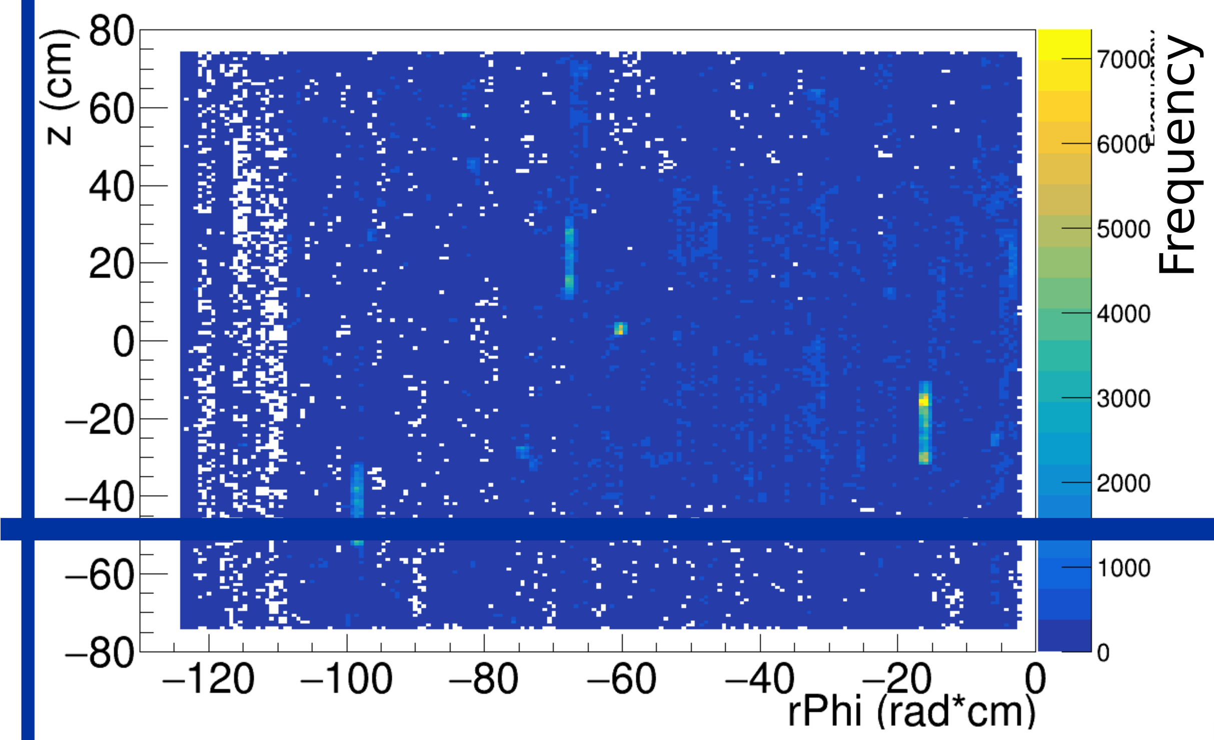
$$\chi^2 = \sum \left[\frac{d}{\sigma}\right]^2$$

where d is the distance from the cluster to the line and σ is the spacial resolution of the detector. The estimated missalignment of the sensors is 0.2mm, which is used as an estimate for σ.



Cluster distribution of tracks after fitting with χ2 minimisation.

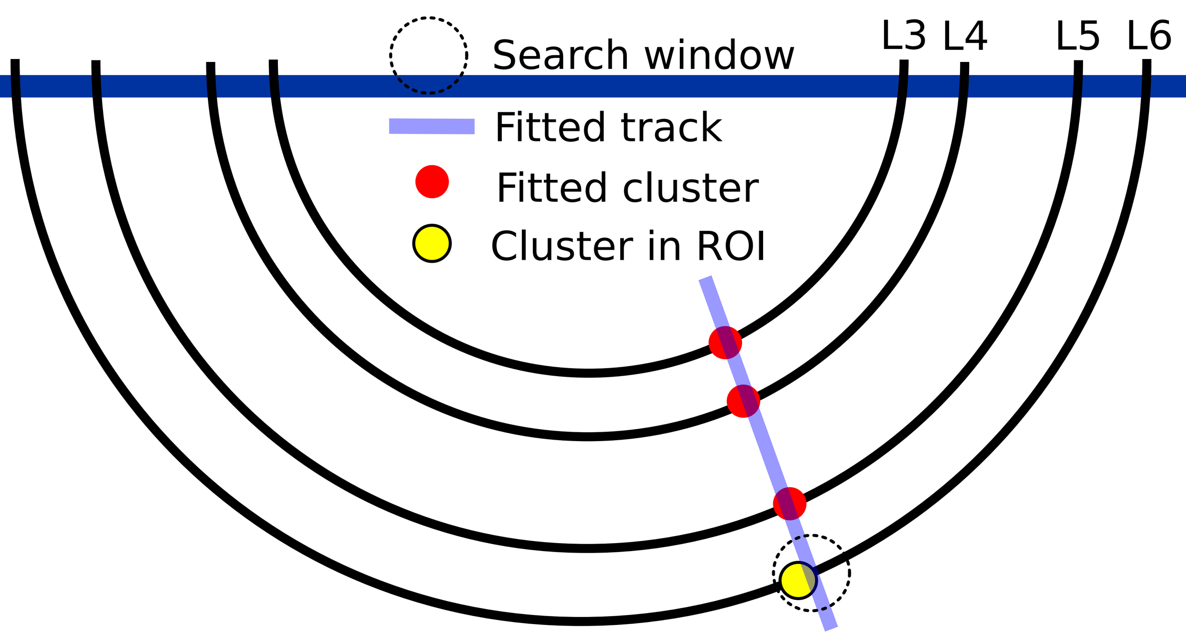
Detection Efficiency

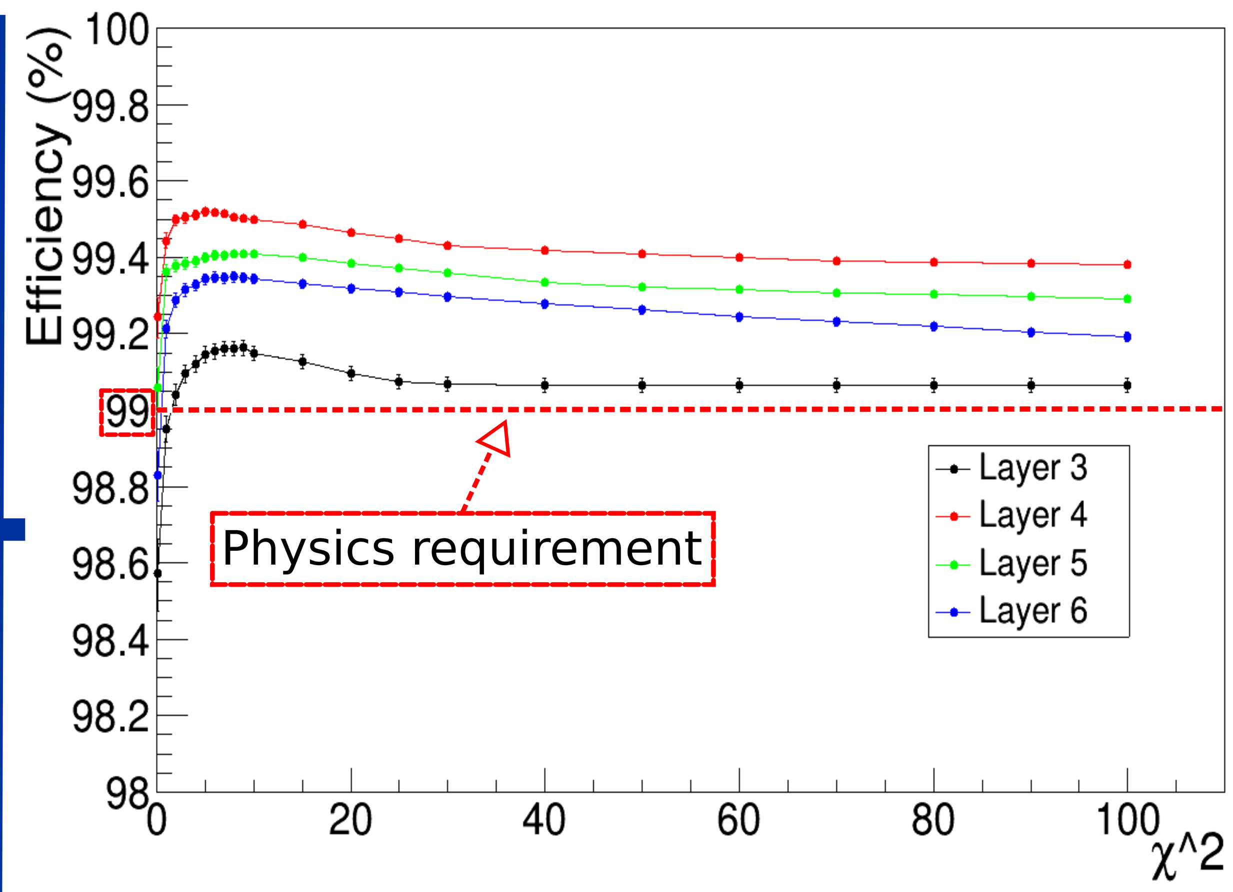


The distribution of noisy pixels. The distribution is fairly uniform across the detector apart from three modules with a lower pixel threshold.

Pixels which fire more than twice per run are masked from the efficiency calculation.

- The track is extrapolated to determine where on the Range Of Interest (ROI) the track is expected to hit.
- If there is a cluster on the ROI within a search window, the track is **efficient**, otherwise, the track is **inefficient**.
- Each layer is independently used as the ROI. In the illustration below, layer 6 is the ROI.





Efficiency as a function of χ2. Each layer is shown with a different colour.

Conclusions

The Outer Barrel of the upgraded ITS has been constructed, assembled and verified. During the verification, a measurement of the Fake Hit Rate of the detector was made and found to be < 3.8×10^{-9} hits/event/pixel, which is in agreement with the FHR of the ALPIDE chip. The first particle tracks were detected in the form of a cosmic muon data collection campaign at the end of 2020.

From this data set, a first measurement of the detection efficiency strongly suggests the detection efficiency of the Outer Barrel is above the physics requirement of 99%.

BOX 2 - Readout Unit

One FPGA-based Readout Unit (RU) connects to each stave [2]. The RU provides unidirectional, 40MHz clock and data signals, as well as bidirectional, 40Mbit/s differential control signals to the ALPIDE chips. Data is aquired from the staves via 28 400 Mbit/s high-speed links, and the RU is cabable of providing an indication of the quality of those data. The RU is also responsible for monitoring and control of the powering of the staves, as well as the distribution of triggers from the Local Trigger Unit to the ALPIDE chips.

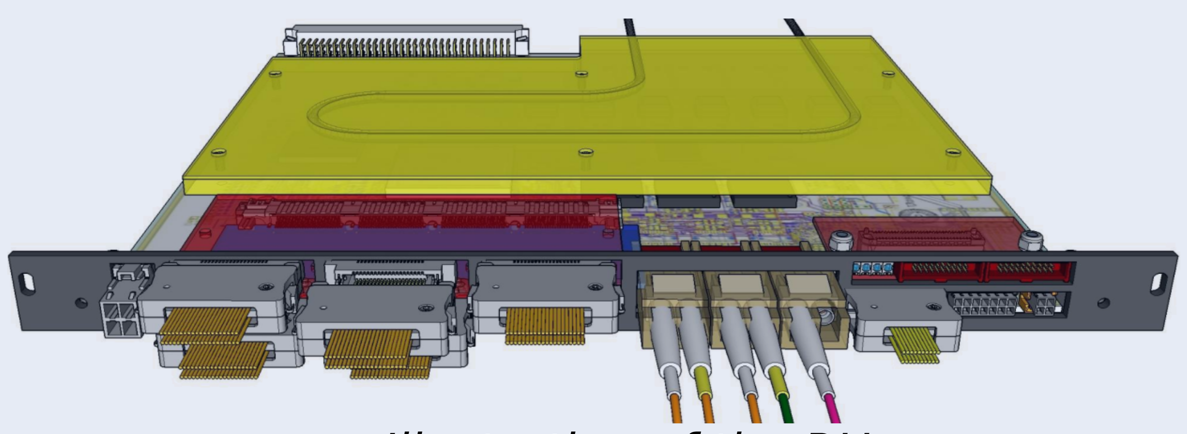


Illustration of the RU.

Triggers are received by the RU via optical link using a unidirectional **VTRx** transceiver. During the cosmic data collection campaign, reliability issues affecting the VTRx module resulted in a sub-optimal signal strength. The reliability issues have been understood and solved since the cosmic data taking campaign.

References

[1] The ALICE Collaboration. Technical Design Report of the ITS Upgrade. J Phys. G Nucl. Part. Phys. 41, 1–181 (2014).
[2] Lupi, M. Design, development, and experimental assessment of a highly-reliable, radiation-tolerant readout system for the upgrade of the ALICE inner tracker (2020).
[3] James, F. MINUIT Function Minimization and Error Analysis Reference Manual. https://root.cern.ch/download/minuit.pdf. (1994).

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