Particle Trackers Based on 1 mm and 0.7 mm Scintillating Fibres Readout by a Multi-anode Photomultiplier

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Abstract

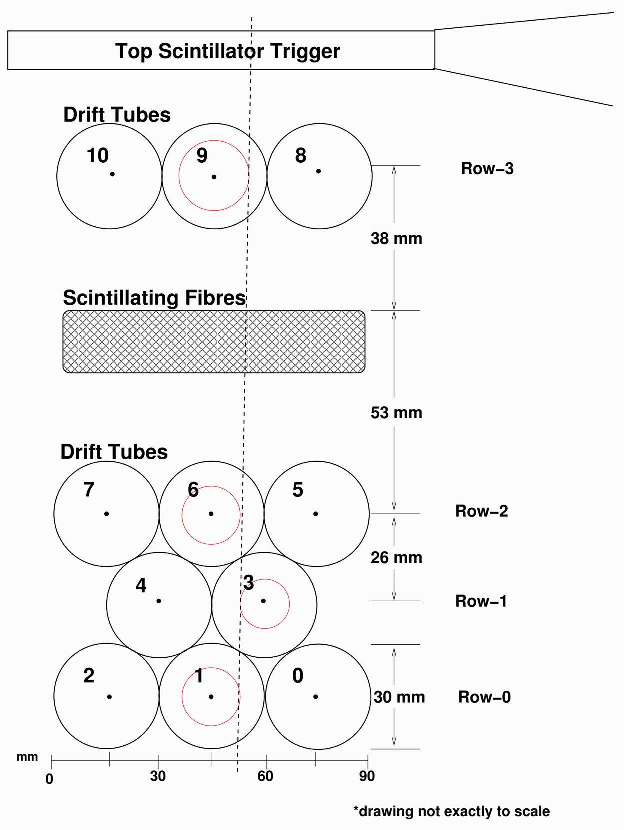
This poster describes a prototype particle tracking detector constructed with 1 mm and 0.7 mm plastic scintillating fibres with a 64 channel Hamamatsu H7546A-200 Ultra-bialkali flat-panel multi-anode photomultiplier readout. Cosmic ray tracks from an array of 11 gas-filled drift tubes were matched to signals in the scintillating fibres in order to measure the resolution and efficiency of tracks reconstructed in the fibre-based tracker. The fibres allow for two possible readout methods, a hit-based (digital) and an amplitude-based (analog) mode. A GEANT4 detector simulation was also developed to compare cosmic ray data with Monte Carlo results. These fibre tracker designs are suggested as a way to meet the resolution and efficiency goals of modern detectors, such as an upgraded LHCb Outer Tracker.

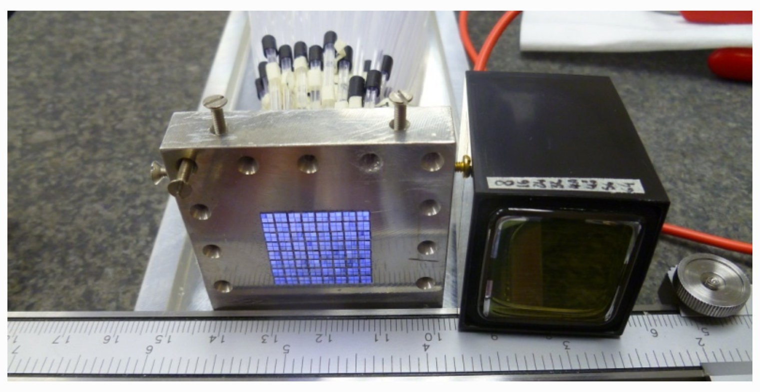
Motivation and Requirements

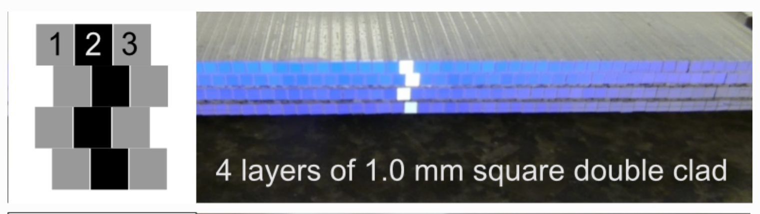
The current straw tube Outer Tracker of LHCb is expected to be upgraded with an improved design [1] due to the expected radiation damage and rate requirements[2, 3]. A design imagined for this upgrade uses plastic scintillating fibres with a photodetector readout was tested to determine its suitability, based on other experimental efforts[4]. A detector for the upgraded LHCb Outer Tracker should meet the following requirements:

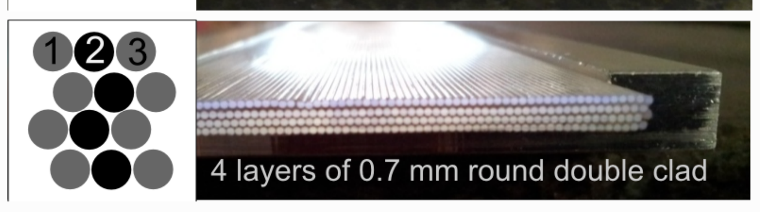
- **a position resolution better than 0.2 mm**
- withstand irradiation levels in the hottest region from an 10x increase in luminosity up to $2 \times 10^{33}\ cm^{-2}s^{-1}$ (transmission in fibres decreases with damage for $\lambda \leq$500 nm [5],[6])
- good spatial resolution with a low material budget. Channels in a 1 mm(0.7 mm) fibre tracker provide a factor of 5(7) smaller geometric profile than the straw drift tube, decreasing occupancy.
- should cover a large area of the innermost region (i.e. 4×4.5 m^2)
- the decay time of a scintillating fibre is typically 3–7 ns with a signal delay of 5.3 ns/m [7] and could discriminate between bunches

Experimental Setup with Cosmic Rays





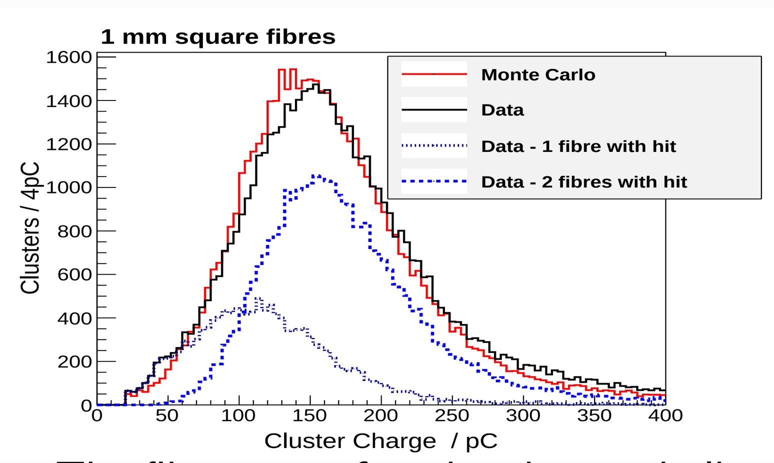


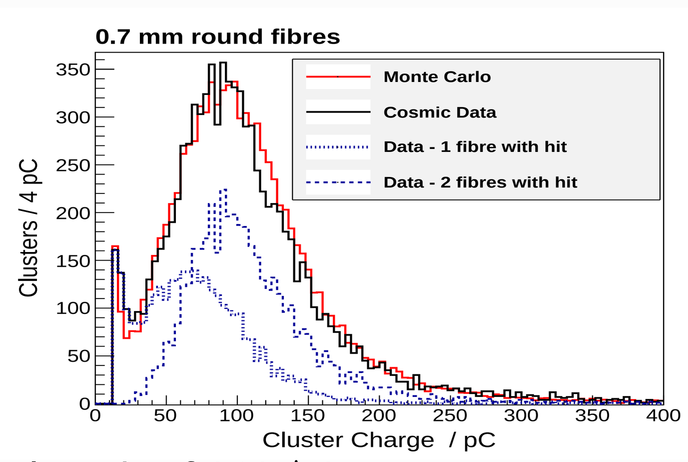


The 11 drift tubes were 3 cm in diameter, with a 30 μm diameter Au-W wire operated at HV=4600 V. A 40:60 Ar–Isobutane gas mixture in limited streamer regime ensured large amplitude signals and stable operation.

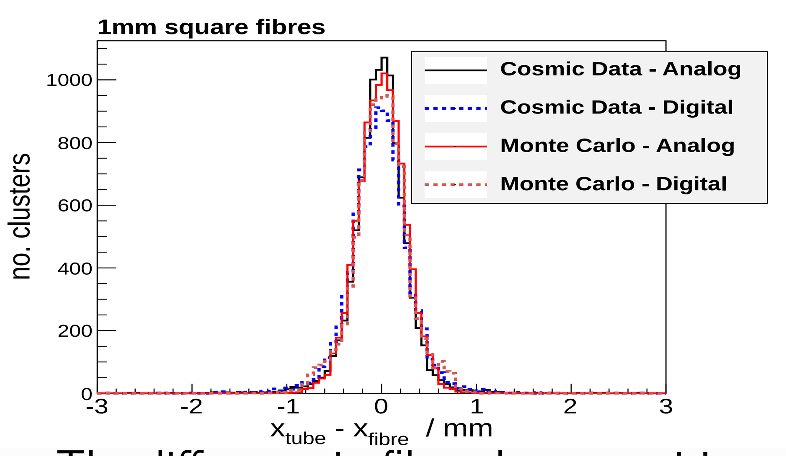
The two fibre planes tested used Bicron BCF-10 [7] double clad fibres, the first with a 1 mm square width and the second with a 0.7 mm radius The fibres in each vertical channel of 4 fibres, overlap alternating adjacent channels by 50% to improve the resolution of each fibre plane. The channels were mounted in an aluminum grid and readout with a Hamamatsu Ultra-Bialkali H7546-200 Multi-Anode photomultiplier operated at 850 V.

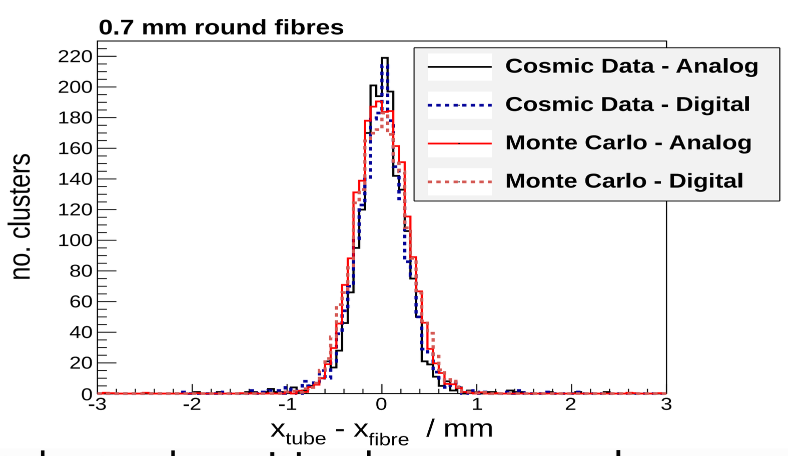
Results





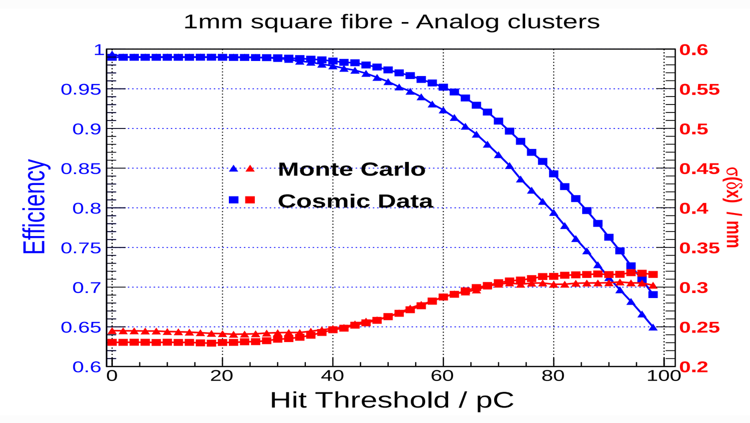
The fibres were found to have a bulk attenuation length of 210$\pm$8 cm, in agreement with the manufacturer. After calibrations, the GEANT4-based Monte Carlo produces similar cluster charge spectra. In cosmic data, 13$\pm$3 photoelectrons are measured in both fibre trackers. (15$\pm$3 and 11$\pm$3 from Monte Carlo-truth for 1 mm and 0.7 mm, respectively.)

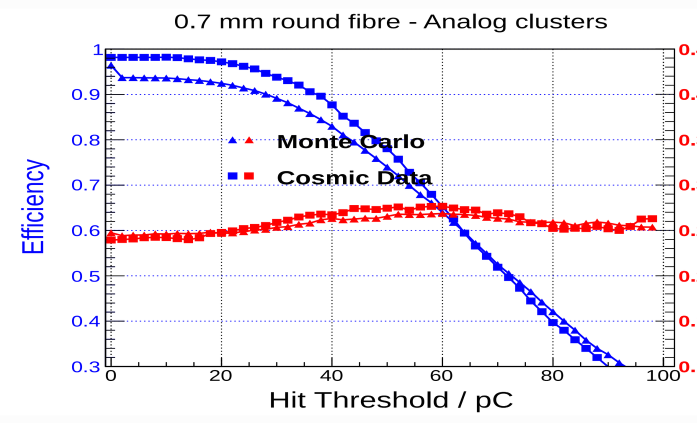


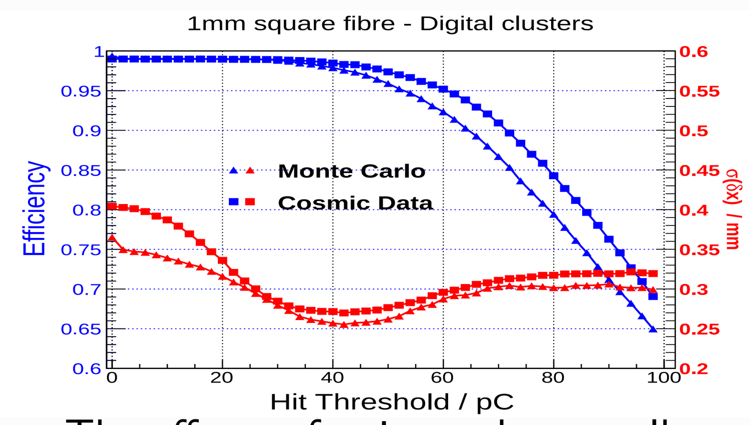


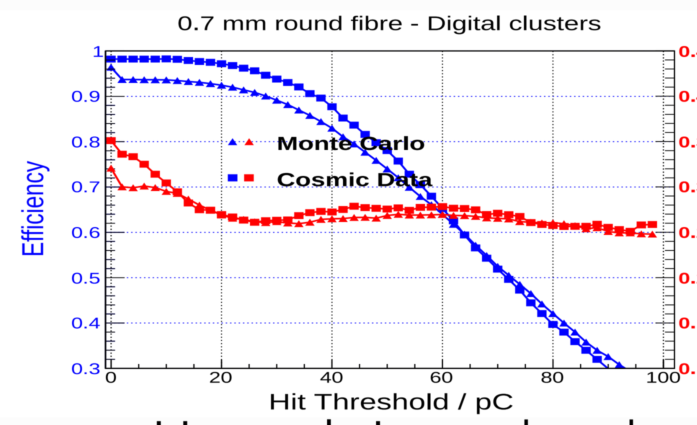
The difference in fibre cluster position and drift-tube track position have a normal distribution where the width is determined by the resolution of the fitted cosmic track from the drift tubes and the cluster position determined from hit-weighted (digital) or charge-weighted clusters (analog). The spectra shown above are for the optimal charge thresholds in a well-behaved part of the experimental setup.

Results continued...

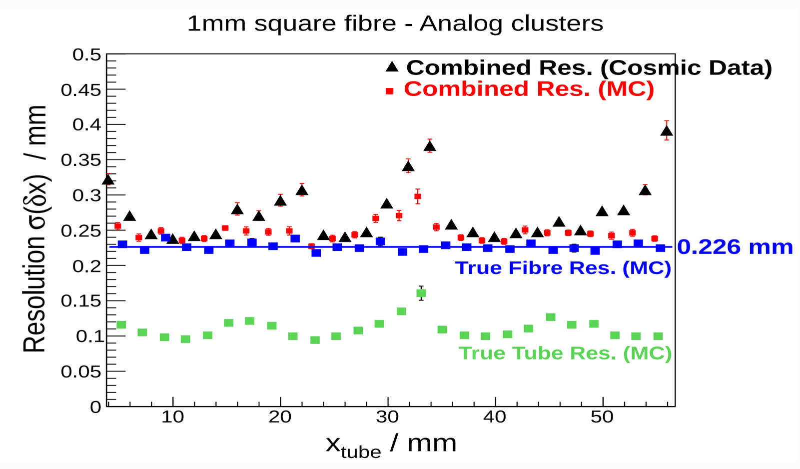


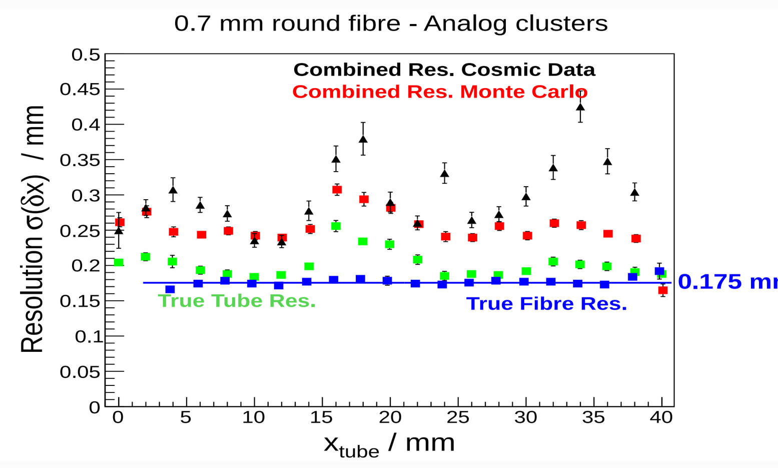


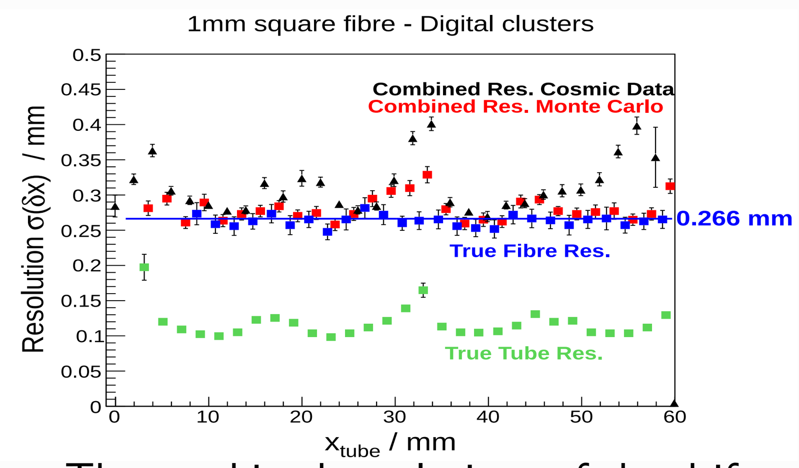


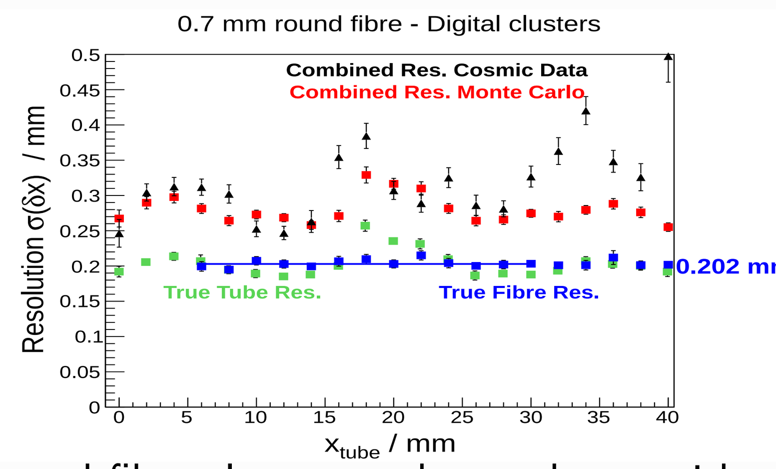


The effects of noise and crosstalk on the cosmic ray position resolution can be reduced by adjusting the charge threshold for which a channel is included in a charge-weighted (analog) or hit-weighted (digital) cluster. An increasingly large threshold eventually degrades the efficiency as well as the resolution.

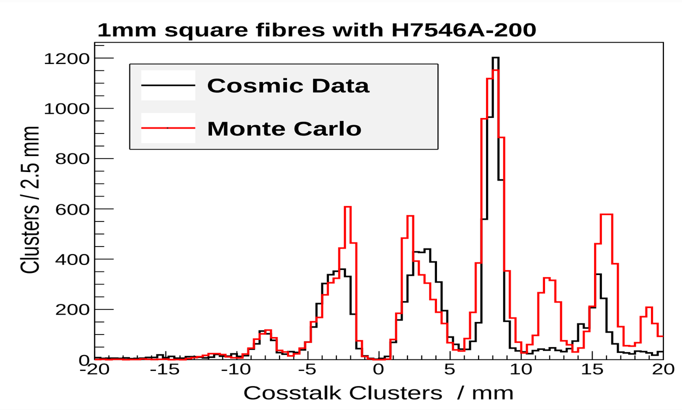


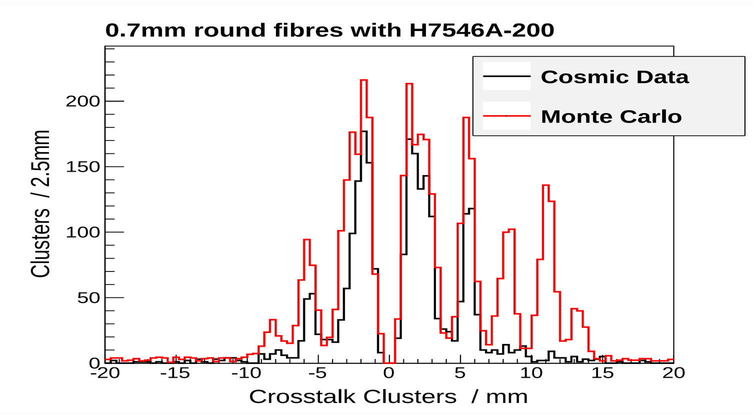


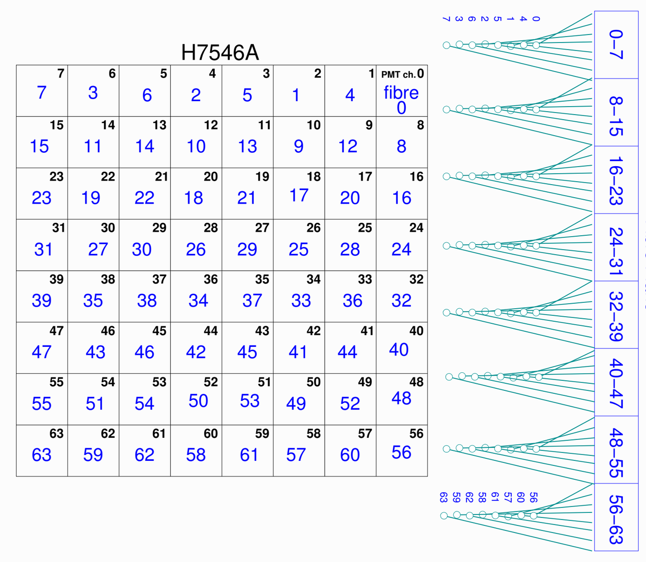




The combined resolutions of the drift tube track and fibre planes are shown above, with the resolutions extracted from the Monte Carlo truth information also shown. The cosmic data and Monte Carlo data agree well in both fibre plane tests. However, the drift tubes exhibits poor resolution in 3 regions along the edges of the tubes, as well is higher in the 0.7 mm tests due to lower statistics and residual miscalibrations.







Electronic crosstalk and crosstalk from misalignment to the MA-PMT channels are managed by the fibre arrangement on the MA-PMT plane, and will not affect the track cluster width. However, there is some evidence for shared optical light between fibre channels, possibly due to localized emissions from the primary dye in the track fibre and absorption by the secondary dye in the adjacent fibre.

Conclusion

The overlapping fibres of the 1 mm square fibre-based particle tracker produces resolutions of 0.236 mm and 0.266 mm for analog and digital clustering. The 0.7 mm round fibre-based particle tracker produces resolutions of 0.175 mm and 0.202 mm for analog and digital clustering in the Monte Carlo, with the total combined track resolution agreeing with Monte Carlo. However, the drift-tube tracker currently limits the precision with which the track can be compared in the 0.7 mm cosmic data test. Data is still being collected and improvements in calibration should be seen.

Acknowledgements

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