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A Low Mass Straw Tube Tracker for the Mu2e Experiment

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The Mu2e Tracker is a state of the art low mass straw tube detector that will look for charged lepton flavor violation (CLFV) by measuring the position and the momentum of the monochromatic 105 MeV/c electron from the $\mu^- N \rightarrow e^- N$ neutrinoless electron conversion in the presence of aluminum nucleus. To achieve this goal, the tracker needs to have momentum resolution of less than 180 keV/c [1] for the conversion electron spectrum. The tracker is still under construction with the joint effort of several institutes. This paper will detail technical information about the Mu2e tracker and show early cosmics data taken with a production tracker plane.

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1. Tracker Mechanical Construction

The Mu2e tracker's smallest module is called a panel. A panel has 96 aluminized Mylar straws with a diameter of 5 mm and 15 μm walls, that are positioned in a two layered configuration and covers a 120° arc. A 25 μm tungsten wire strung through each straw acts as the sense wire for the detector. Straws covers the radial area from 300 mm to 700 mm where the detector is sensitive to conversion electrons with a significant portion of lower energy electrons passing through the hollow middle section. Panels are designed to run $ArCO_2$ drift gas at 15 psid with respect to Detector Solenoid vacuum of 10^{-4} Torr. They are then configured into a unit called a tracker plane that houses six panels. The Mu2e tracker will have 36 such planes when it is completed. The two layer straw configuration with highly modular tracker plane design improves track finding and reconstruction efficiency. Some of the tracker planes produced can be seen in Figure 1.

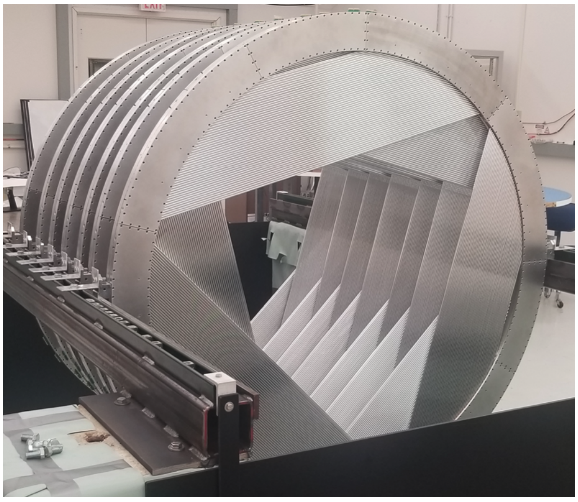

Figure 1: Completed production tracker planes stored for future commissioning. Each plane consist of 6 tracker panels.

2. Tracker Electronics

A Mu2e tracker wire kept at 1500 V is read through both ends with preamps on each side connecting to TDCs (Time-to-Digital Converter) found in the DRAC (Digital Readout Controller) board. Coincidences within 40 ns of TDCs firing is kept to do a time division measurement of the signal to calculate hit location along the straw. The signals are also summed through an ADC (Analog-to-Digital Converter) that separates between electron tracks and highly ionizing beam protons. The ADC provides the micro controller with a sample window in case of a coincidence to form a hit and readout is brought to the tracker DAQ (Data Acquisition) through optical links. The goal is for time division to be at 4 cm positional accuracy and dE/dx separation to be less than 20% of the charge resolution, with an overall momentum resolution of less than 180 keV/c for the conversion electrons with 105 MeV/c momenta. In addition, all electronics are within the tracker panel volume and they are exposed to radiation. Therefore all electronics also have to work up to the 150 kRad lifetime expectancy of Mu2e while passing other physics requirements.

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3. Cosmic Tracks with Production Plane

The first production plane was constructed in March 2020. This plane met all design parameters and quality checks in place and was assigned for long term testing, referred to as a vertical slice test (VST). The VST plane was tested in three configurations; horizontal with cosmics, horizontal with ^{55}Fe source and vertical with cosmics as shown in Figure 2.

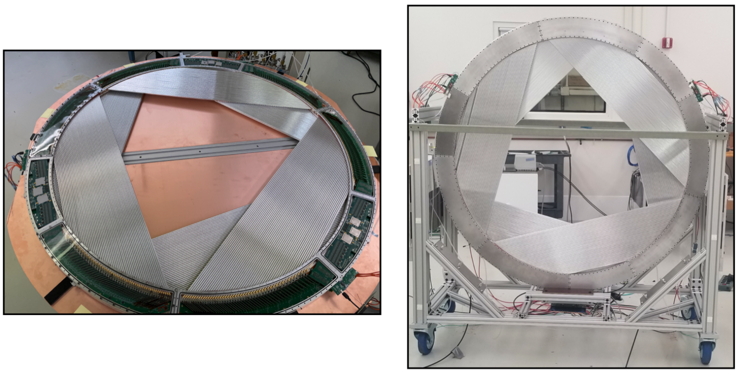

Figure 2: First production plane going under a vertical slice test. Left: Vertical slice test plane on the test table with all production electronics installed. Cosmics and ^{55}Fe runs were taken in this configuration. Right: Vertical slice test taking cosmics data in the vertical configuration with all readout chain in place and running to tracker DAQ through optical fibers.

A fine grid scan of the VST plane was done with the ^{55}Fe source placed 1 cm away from the top layer straws. An example of the ^{55}Fe peak seen by the target straw and its neighboring straws is shown in Figure 3. For each straw the source was taken along the straw in 5 cm steps and data was collected at 15 mV threshold. For the analysis of the data, an amplitude cut was implemented to separate 5.9 keV photon peak to improve Δt measurement. Next effective propagation velocities were calculated from the Δt distribution, also factoring the trace length differences in the PCB layout. Resulting Δt mean of 2.33 ns corresponds to 3 cm longitudinal resolution in the average, which falls within detector expectancy. Switching to the second configuration, the VST plane was run in a vertical configuration that mirrors its natural state in the detector solenoid. In this state the VST plane reconstruction efficiency is increased as each track has a higher chance of intersecting multiple straws and tracker panels. Drift velocities and distance of closest approach is calculated using hit Δt information and tracks are formed. A cosmic track passing through one of the VST panels can be seen in Figure 4.

4. Summary

We demonstrated that the VST plane populated with production electronics operates within design parameters and is able to find cosmic muon tracks. The Mu2e tracker is on schedule for completion during 2022. Nine tracker planes out of 36 are now constructed up to design specifications and testing is underway, with transition into commissioning in the near future.

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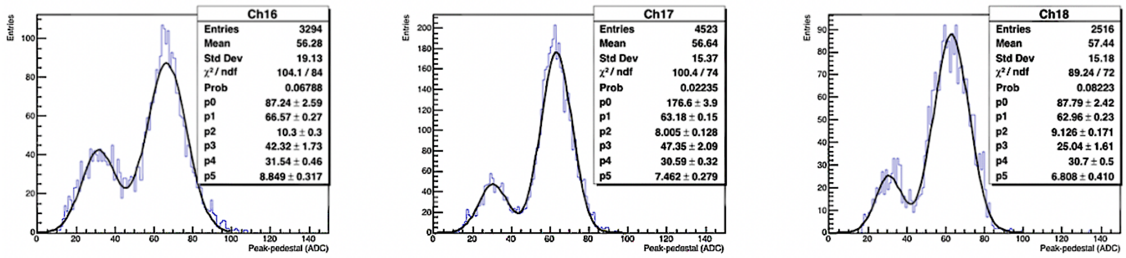

Figure 3: ^{55}Fe spectrum as seen by the target straw and its neighboring straws. 5.9 keV ^{55}Fe peak and smaller Argon escape peak is identifiable on all the straws that are shown.

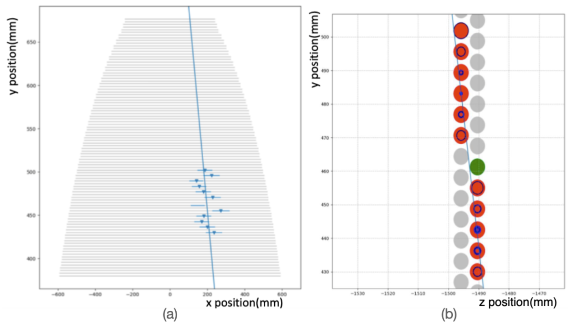

Figure 4: Cosmic track reconstruction with a VST panel. a) Hit straws and positions are shown in the tracker panel illustration. b) Reconstructed track and the distant of closest approach approximation is drawn for each individual straw that is hit (highlighted in red).

5. Acknowledgments

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