PROCEEDINGS OF SCIENCE

Development of a thin-wall straw-tube tracker for COMET experiment

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The COMET experiment at J-PARC aims to search for the charged lepton flavor violating process of neutrinoless muon to electron conversion with an improvement of a sensitivity by a factor of 10000 to the current limit, in order to explore the parameter region predicted by most of well-motivated theoretical models beyond the Standard Model. When the muon to electron conversion occurs, almost all the energy of the muon mass is carried out by the electron which is expected to have the monochromatic energy of about 105 MeV. The experiment requires to detect such electron with an excellent momentum resolution, better than 200 keV/c, in order to achieve the goal sensitivity. Thus the very light material detector which is operational in vacuum is indispensable. On the basis of the requirement, we have developed the thin-wall straw-tube tracker which is operational in the vacuum and constructed by the extremely light material. The prototype straw-tube tracker has been developed, which consists of 9.8 mm diameter tube, longer than 1 m length, with 20 μm thickness Mylar foil and 70 nm aluminum deposition, and its performance evaluation using radioactive source, cosmic ray, and electron beam has been performed. In this paper, we introduce the straw-tube tracker and report the current status of the performance evaluation for the prototype tracker.

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1. Introduction

The COherent Muon to Electron Transition (COMET) experiment at J-PARC aims to search for the charged lepton flavor violating process of neutrinoless muon to electron conversion in the presence of a nucleus. This process is strongly restricted by the Standard Model (SM) even if the neutrino oscillation is considered. However, the most of well-motivated theoretical models beyond the SM predict that a branching ratio of this process is to be $\sim 10^{-15}$ [1, 2]. The COMET experiment searches this process at a single-event sensitivity of $\sim 10^{-17}$ which is 4 order of magnitude better than that of the experimental limit given by SINDRUM-II at PSI [3].

The event signature of muon to electron conversion in a muonic atom is a monochromatic electron with an energy of $E_e \sim m_\mu - B_\mu \sim 105$ MeV, where m_μ and B_μ are the muon mass and the binding energy of the 1*s* muonic atom, respectively. The most of electron backgrounds coming from muon-stopping target is the Decay In Orbit (DIO) electron, $\mu^- \rightarrow e^- \nu_\mu \overline{\nu_e}$. The endpoint of the spectrum of the DIO coincides with the energy of E_e due to the recoil effect of the nuclear field[4]. In order to suppress this background, an excellent momentum resolution of better than 200 keV/c is required. In this momentum range around 105 MeV, the momentum resolution is primarily limited by the multiple scattering effect, then the light material for the detector component is essential. To satisfy the requirement, the extremely thin-wall straw-tube tracker which is operational in vacuum has been developed.

2. Straw tube tracker

The tracker consists of 5 tracker layers, which are called stations. Each station consists of 4 straw-tube planes: 2 planes for x-coordinate and 2 planes for y-coordinate. Each pair of planes is staggered by half a cell to solve the left-right ambiguity. The thickness of straw wall made by Mylar is extremely thin, 20 μm, and the gap between each stations is vacuum. Figure 1 shows the design of straw tracker. Each station is constructed as a stand-alone module and installed in the detector solenoid by the rail on the detector frame. A gas manifold is constructed in the outer border of straw-tube volume. The manifold does not only provide the gas supply but also contains the front-end electronics and high voltage supply lines, which makes the tracker to be operational in a vacuum. Anode wires made of gold-coated tungsten are extracted via a feedthrough into the gas manifold. More details are described in [5].

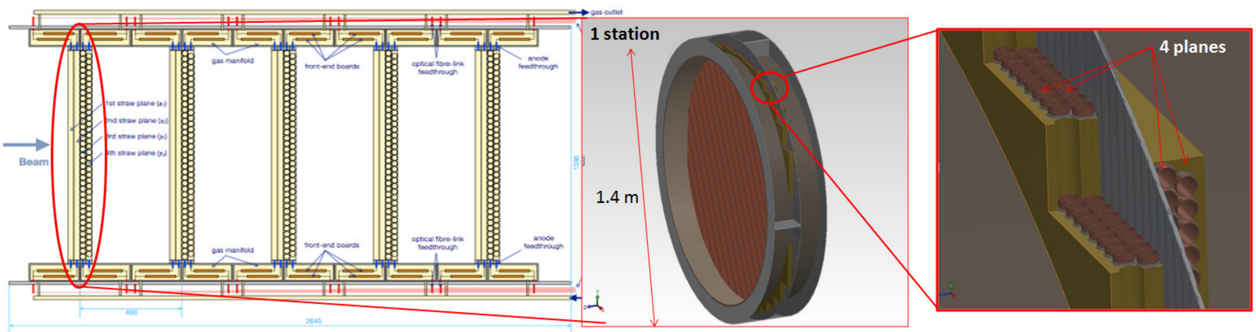

Figure 1: Schematic view of straw tracker.

3. Performance evaluation

In order to develop the COMET straw tracker, the prototypings and those evaluations have been done. It was already found that the fundamental properties of the straw tube itself such as mechanical strength, elongation, gas tightness, and so on were reliable for the COMET experiment [5]. Some performances as a detector have also been investigated using the full scale prototype which is shown in Fig. 2 and good resolution was obtained with general Amplifier-Shaper-Discriminator (ASD) [5]. In parallel, own readout electronics has been developed, which is called “ROESTI”[6]. Pre-amplification, shaping, and discrimination are done by ASD[7] and waveform digitization is done by DRS4[8], and those signals are controlled by FPGA. The new version of ROESTI was developed (Fig. 3) and its performance evaluation was almost done.

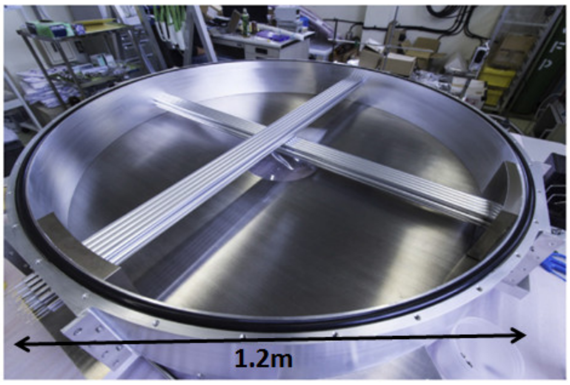

Figure 2: Photograph of prototype straw tracker.

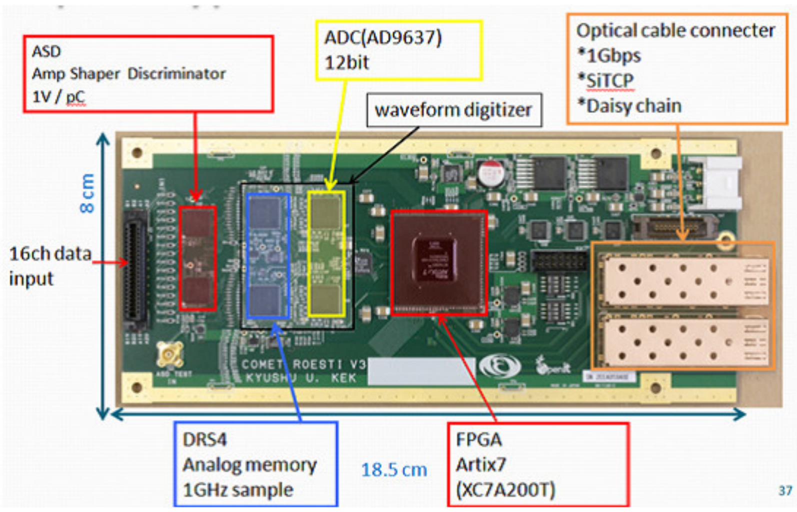

Figure 3: Photograph of newly developed readout electronics, “ROESTI”.

As the fundamental performance evaluation of the straw tracker with ROESTI, test-beam experiment was carried out with the 100 MeV/c electron beam at the Research Center for Electron Photon Science (ELPH), Tohoku University. The obtained detection efficiency as a function of applied HV and the spatial resolution as a function of drift distance are shown in Fig. 4 (left) and

Fig. 4 (right), respectively. It was found that good enough detection efficiency can be obtained with the applied HV of more than 1850 V. The obtained spatial resolution includes uncertainties of multiple-scattering effect and tracking uncertainty, but it is already better than the requirement of COMET experiment (better than 200 μm). Detailed analysis is ongoing and more improved resolution is expected.

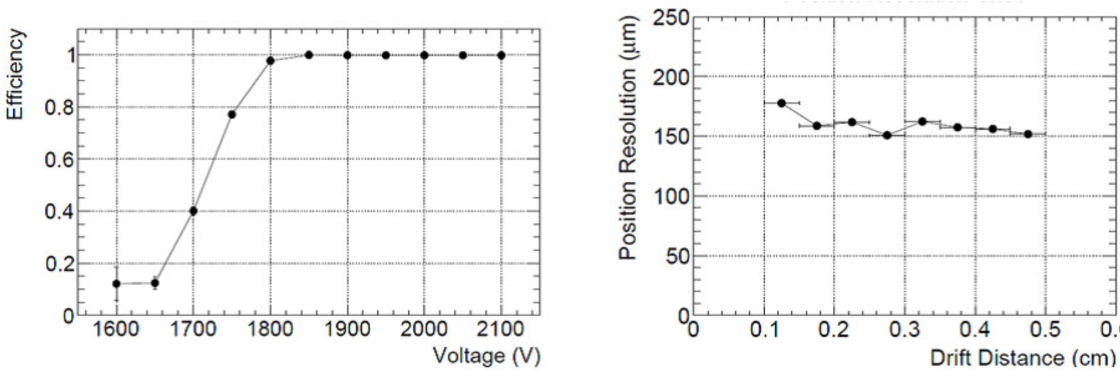

Figure 4: Detection efficiency as a function of applied HV (left) and spatial resolution as a function of drift distance at applied HV of 1900 V(right) (Gas mixture Ar : C_2H_6 = 50 : 50).

4. Summary

Extremely thin-wall straw-tube tracker has been developed for COMET experiment. The thickness of the straw tube made by Mylar is 20 μm and this straw tube is operational in vacuum. Almost all the fundamental properties were investigated and reliability for the experiment was confirmed. Fundamental performance evaluation of the prototype tracker with newly developed readout electronics has been performed using 100 MeV/c electron beam and good enough performances are demonstrated.

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