PROCEEDINGS OF SCIENCE

Construction status and performance evaluation of the Straw-Tube Tracker for the COMET experiment

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The COMET experiment at J-PARC aims to search for muon-to-electron conversion in aluminium with a target sensitivity of 10^{-17}. To measure 105 MeV/c signal electrons with a momentum resolution better than 200 keV/c, COMET employs a low-mass Straw-Tube Tracker consisting of five stations read out by dedicated electronics. Three stations have been constructed, and the first station has been commissioned with the COMET beamline, successfully recording the first signals. A full-scale prototype previously demonstrated a spatial resolution of ~110 μm, exceeding the required performance of better than 200 μm. For the first station, baseline noise was resolved through improvements to the grounding and cabling, reducing the noise by 90%. Spatial-resolution studies with the improved setup are now in progress.

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1. Introduction

The muon-to-electron conversion is a charged lepton flavor-violating process. In this process, a muon captured by an atom will decay into a single electron with a fixed momentum of about 105 MeV/c in the case of aluminium. This process is strictly prohibited in the Standard Model, and even when considering the neutrino oscillation, its branching ratio is severely constrained to $\mathcal{O}(10^{-54})$. However, according to some theories [1] beyond the Standard Model, this branching ratio can reach up to 10^{-15}, meaning that the discovery of the muon-to-electron conversion would directly indicate the presence of new physics.

The COMET experiment [2] at J-PARC aims to search for the muon-to-electron conversion in aluminium atoms with the highest single event sensitivity in the world. The experiment will be conducted in two stages (Phase-I and II), with the Phase-II single-event sensitivity goal set at 10^{-17}, 10000 times better than that of the preceding SINDRUM-II experiment [3]. Fig. 1 shows the layout of the COMET phase-II setup. Protons delivered by the J-PARC Main Ring accelerator are directed to the pion production target. The pions produced at the target are transported through the transport solenoid, where they decay into muons; the magnetic field in this bent solenoid provides momentum selection, which reduces beam-related backgrounds before the muons reach the downstream muon stopping target. Electrons emitted from the stopping target are further transported through a 180°-bent solenoid, which suppresses low-momentum particles, and their momentum and energy are finally measured by the detectors located at the most downstream position.

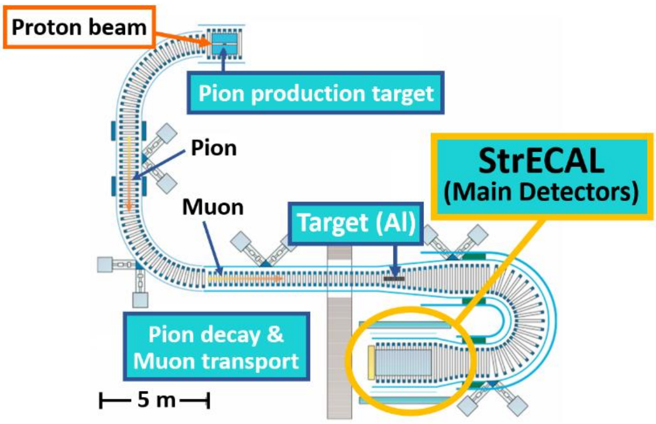


Fig. 1: A schematic layout of the COMET phase-II experimental setup.

2. Straw-Tube Tracker

The main detector system, so-called StrECAL, consist of Straw-Tube Tracker and Electromagnetic Calorimeter (ECAL). The ECAL measures the energy of charged particles, provides particle identification, and generates trigger signals that define the timing reference (T0) for the Straw-Tube Tracker.

The Straw-Tube Tracker (Fig. 2) is used for momentum measurement [4]. It consists of five stations and operates in a vacuum and a 1 T magnetic field. Each station consists of four layers of two-dimensionally aligned straw tubes, which are made of ultra-thin aluminized Mylar (20 µm aluminium and 70 nm Mylar) and function as proportional counters. The inside of the straw tubes is filled with chamber gas composed of Ar:C_2H_6 (50:50), and the sense wire is made of gold-plated tungsten with a diameter of 25 µm. By using this low-mass detector in a vacuum, the Straw-Tube Tracker strongly suppresses Coulomb multiple scattering and achieves a high momentum resolution of better than 200 keV/c.

Three of the five stations have already been constructed, and work toward completing the full detector is progressing.

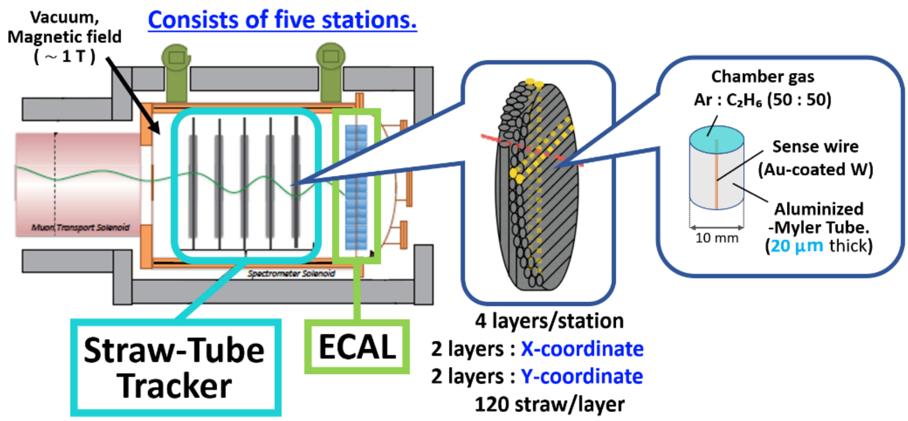


Fig. 2: Layouts of the Straw-Tube Tracker and the electromagnetic calorimeter (ECAL).

3. Read-out electronics

The frontend electronics for the Straw-Tube Tracker is called ROESTI [7] (Read-Out Electronics for Straw Tube Instrument). ROESTI was developed by the COMET group for the Straw-Tube Tracker. Fig. 3 shows the ROESTI board along with the signal processing flow.

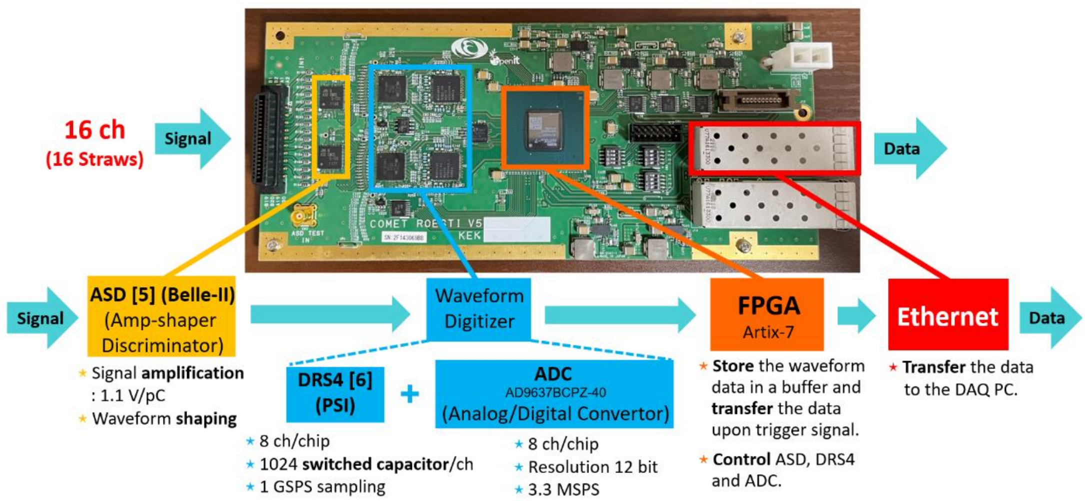
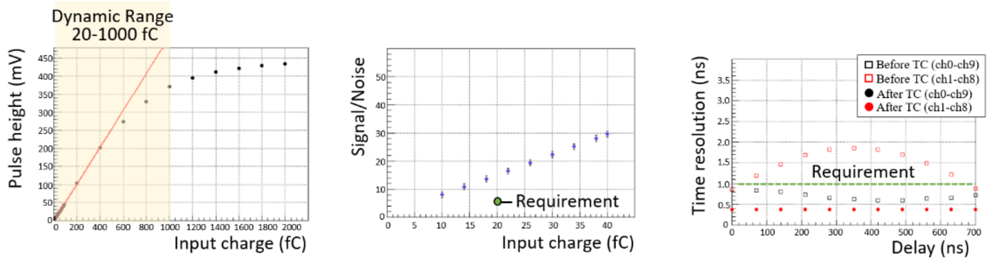


Fig. 3: The frontend electronics (ROESTI) and its signal processing flow.

3.1 Quality check of the ROESTI boards

A total of 30 mass-produced ROESTI boards—corresponding to the number required to read out all straws in one station—were manufactured, and quality-check tests were performed to ensure that they meet the required specifications. The ROESTI boards must satisfy three main performance criteria: the signal amplitude linearity must be maintained within the dynamic range of 20–1000 fC; the signal-to-noise (S/N) ratio must be at least 5 for an input charge of 20 fC; the time resolution must be better than 1 ns.

Charges of 10–2000 fC were injected from a function generator into ROESTI boards to evaluate linearity and S/N. The corresponding results are shown in Fig. 4 (a) and (b). Within the required dynamic range of 20–1000 fC, linearity is maintained up to about 400 fC, with deviations from the linear fit remaining within approximately 2%. Although the response starts deviating from linearity at ~600 fC, the response remains usable after calibration. The S/N ratio exceeds the required value of over 5 at 20 fC. The time resolution was measured by injecting identical periodic signals into each channel and evaluating the phase differences. After applying time calibration (TC), all channels achieved the required resolution of better than 1 ns, as shown in Fig. 4 (c).



(a) (b) (c)

Fig. 4: Performance test results of the ROESTI. (a) Pulse height linearity for injected charges of 10–2000 fC, with deviations < 2% up to ~400 fC. (b) S/N ratio exceeding 5 at 20 fC. (c) Time resolution before and after TC, achieving < 1 ns after the TC.

3.2 ROESTI integration and cooling

Inside each station, there is a gas-manifold region that surrounds the active detector volume. Since the ROESTI boards are installed inside the gas-manifold region without room for additional cooling structures, the system relies on the chamber gas flow for heat dissipation.
Fig. 5 shows a schematic view of the cooling system. Preparations are in progress for a cooling circulation test using the first station to assess the ROESTI cooling performance.

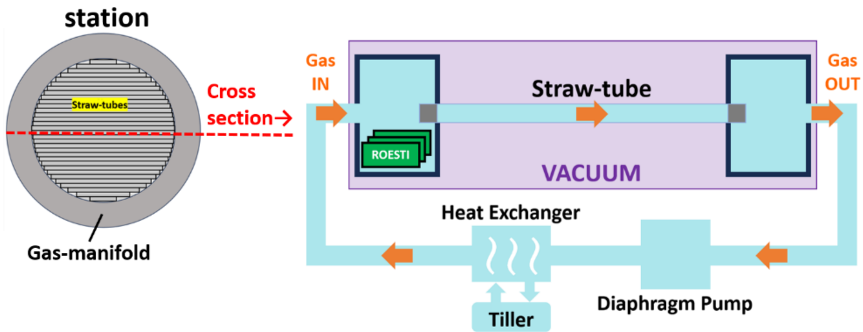


Fig. 5: Schematic view of the ROESTI cooling system inside the station.

4. Construction

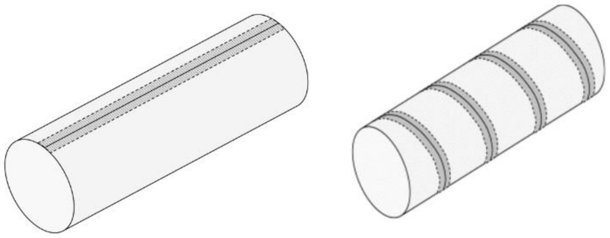
The construction of the first, second, and third stations has been completed. To achieve the low-material design required for the detector, a fabrication technique for 20-µm-thick straw tubes was developed by the JINR-COMET collaboration, and reliable procedures for installing both the straw tubes and the sense wires have also been established.

4.1 Production of the straw tubes

The construction of the Straw-Tube Tracker relies on the production of ultra-thin straw tubes. The experiment employs straight-adhesion type straws (Fig. 6), which enable extremely thin walls but require careful control of circularity. These straws are fabricated using an ultrasonic welding technique originally pioneered by the JINR–NA62 group, and the JINR–COMET collaboration has succeeded in producing 20 µm-thick tubes with excellent uniformity.

4.2 Pre-tensioning of the straw tubes and installation of the sense wires

Each straw was mounted into the plate and pre-tensioned using screw-type end plugs (Fig. 7). A tension of 1 kg was applied to the straw tubes to prevent deformation during operation. The sense wires are then threaded and fixed while maintaining the proper wire tension, ensuring mechanical stability and accurate alignment.



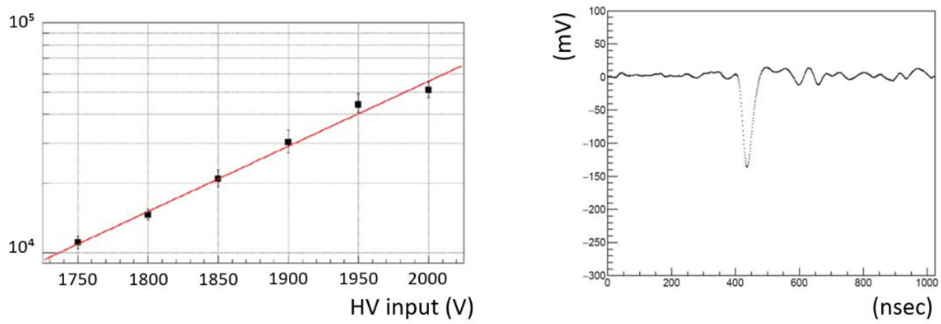
(a) (b)

Fig. 6: Fabrication methods of the straw tubes.
(a) Straight-adhesion type adopted by COMET.
(b) Double-wound type.

Fig. 7: Screw-type end plug and plate used for pre-tensioning the straw tubes.

5. Commissioning

For the first station, the full readout system including the ROESTI boards was installed, and basic operational checks such as gain measurements were performed. Fig.8 (a) shows the gain curve measured with a ^{55}Fe source. Beam irradiation tests using the COMET beamline (COMET Phase-α) were also conducted, resulting in the successful acquisition of the first signals (Fig.8 (b)).



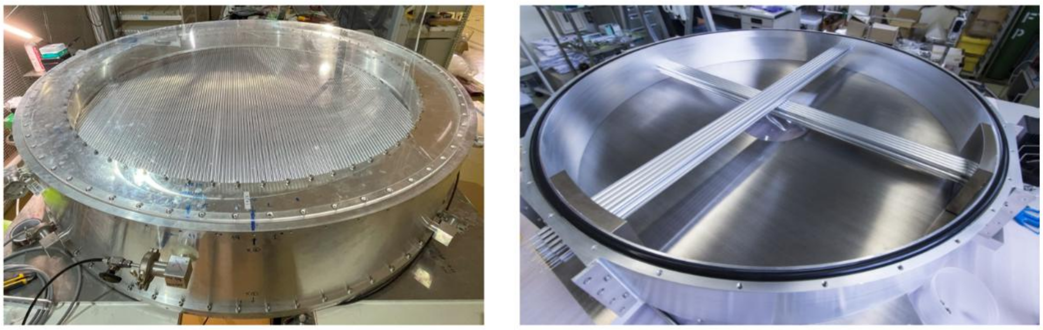
(a) (b)

Fig. 8: (a) Gain curve measured with a ^{55}Fe checking source. (b) The first signal obtained by the first station in the beam irradiation test (COMET Phase-α).

6. Performance evaluation and modification

Fundamental performance evaluation of the first station (Fig.9 (a)) is currently in progress. To achieve the required momentum resolution of better than 200 keV/c, the Straw-Tube Tracker must provide a spatial resolution below 200 μm. The spatial resolution had previously been evaluated using a full-scale prototype (Fig.9 (b)). This prototype had the same dimensions as the final detector and employed the same straw tubes and the ROESTI readout electronics, differing only in the reduced number of straws. Beam tests with 50–300 MeV/c electrons at Tohoku University [8] demonstrated that the prototype achieved a spatial resolution of approximately 110 μm.

A spatial-resolution study using the first station with a checking source is currently in progress. In contrast to the prototype, the first station exhibited baseline noise that hindered accurate evaluation. Unlike the prototype configuration, the first station requires the installation of thirty ROESTI boards within a limited space, making cable design and grounding conditions critical for noise suppression. By revising the cabling layout and reinforcing the grounding scheme, the S/N ratio was significantly improved from 26.5 to 262.5 (Fig. 10). This noise level is comparable to that observed in the prototype waveforms. With this improved setup, the spatial-resolution measurement of the first station is going to be carried forward.



(a) (b)

Fig. 9: (a) The first station of the Straw-Tube Tracker. (b) The full-scale prototype of the Straw-Tube Tracker [8].

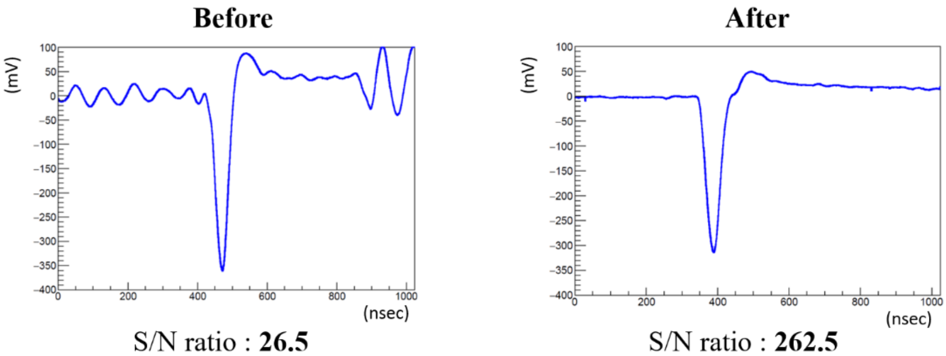


Fig. 10: Signal waveforms and their S/N ratio obtained with the first station before and after the improvements.

7. Conclusion

The Straw-Tube Tracker for the COMET experiment has reached significant milestones toward its full deployment. Three of the five stations have been constructed, incorporating 20-μm-thick straw tubes developed through the JINR–COMET collaboration and assembled using established wire-installation procedures. The dedicated readout electronics, ROESTI, have been mass-produced, validated, and integrated into the first station. Commissioning with the COMET beamline resulted in the successful acquisition of the first signals. Although coherent baseline noise initially hindered spatial-resolution studies, improvements to the grounding scheme and cabling layout reduced the noise level by 90%, matching the performance observed in the full-scale prototype. With the improved readout stability, spatial-resolution measurements of the first station are now underway. The construction and evaluation of the remaining stations will continue toward the completion of the full detector system by the middle of 2026.

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References

[1] H. Chiang, E. Oset, T. Kosmas, A. Faessler, and J. Vergados, Coherent and incoherent (μ −, e −) conversion in nuclei, Nuclear Physics A 559, 526 (1993).

[2] COMET Collaboration, "COMET Phase-I technical design report," Prog. Theor. Exp. Phys., vol. 2020, no. 3, p. 033C01, Mar. 2020. doi: 10.1093/ptep/ptz125.

[3] W. Bertl et al., "A search for μ − e conversion in muonic gold," Eur. Phys. J. C, vol. 47, pp. 337-346, 2006. doi: 10.1140/epjc/s2006-02582-x.

[4] H. Nishiguchi et al., “Construction on vacuum-compatible straw tracker for COMET Phase-I,” Nucl. Instrum. Methods A 958 (2020) 162800. https://doi.org/10.1016/j.nima.2019.162800

[5] S. Shimazaki et al., “Front-end electronics of the Belle II drift chamber,” Nucl. Instrum. Methods Phys. Res. A, vol. 735, pp. 193-198, 2014. doi: 10.1016/j.nima.2013.09.050

[6] S. Ritt, "Development of high speed waveform sampling ASICs," Paul Scherrer Institute, Villigen, Switzerland, 2010.

[7] K. Ueno et al., "Design and performance evaluation of front-end electronics for COMET straw tracker," Nucl. Instrum. Methods Phys. Res., Sect. A, vol. 936, pp. 297-299, Aug. 2019. doi: 10.1016/j.nima.2018.08.027.

[8] K. Oishi et al., “Study of Sensitivity to Search for a Charged Lepton Flavor Violating Process,” Kyushu University, 2021, Kyushu University, https://cir.nii.ac.jp/crid/1910020910685740416