2027 R&D Proposal
for the FCC-ee Muon Detector Development

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We propose a high-precision, fast, robust and cost-effective muon detector concept for an FCC-ee experiment. This design combines precision drift tubes with fast plastic scintillator strips to enable both spatial and timing measurements. The drift tubes deliver two-dimensional position measurements perpendicular to the tubes with a resolution around 100 μm. Meanwhile, the scintillator strips, read out with the wavelength-shifting fibers and silicon photomultipliers (SiPMs), provide fast timing information with a precision of 200 ps or better and measure the third coordinate along the tubes with a resolution of about 1 mm.

Introduction

This proposal has been presented at several FCC-ee meetings, such as at the US HFCC workshop at Fermilab [1] and at the 2025 FCC Week in Vienna [2]. A detailed description is also available in Ref. [4].

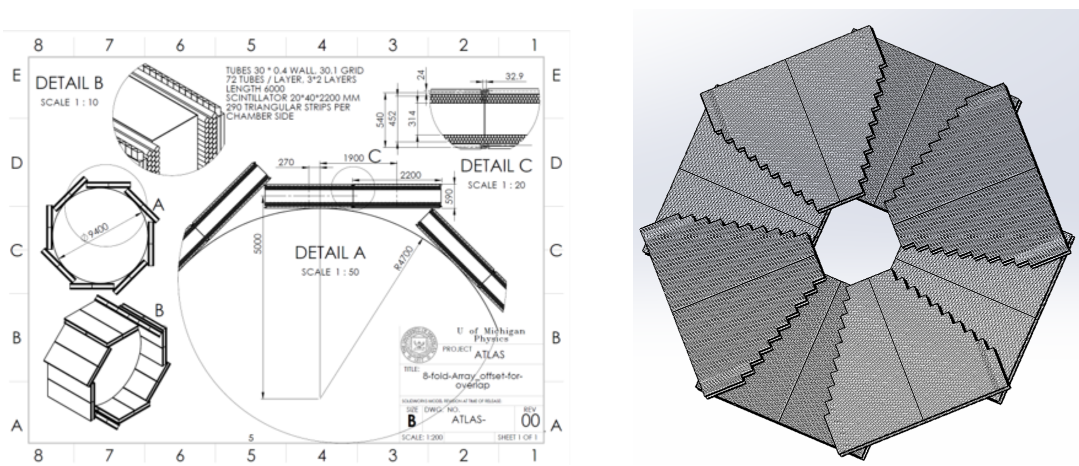

Figure 1: A potential layout for the barrel (left) and endcap (right) muon system.

We have been actively pursuing R&D since 2025. Our work includes designing and constructing prototype modules, preparing engineering drawings for the conceptual detector layout, and submitting these drawings to the FCC-ee simulation group to facilitate detailed muon detection studies. A preliminary layout of the muon system has been developed as shown in Fig. 1, with corresponding engineering documentation provided to the simulation team. Fig. 2 illustrates a basic muon detector module with drift tubes and scintillator strips.

Current R&D Activities

Building on our extensive experience with the construction and operation of the ATLAS monitored drift tubes, our current R&D efforts focus on characterizing the performance of the scintillator strips. Using FY 2026 funding and existing resources, we have constructed two small prototype modules, each containing eight

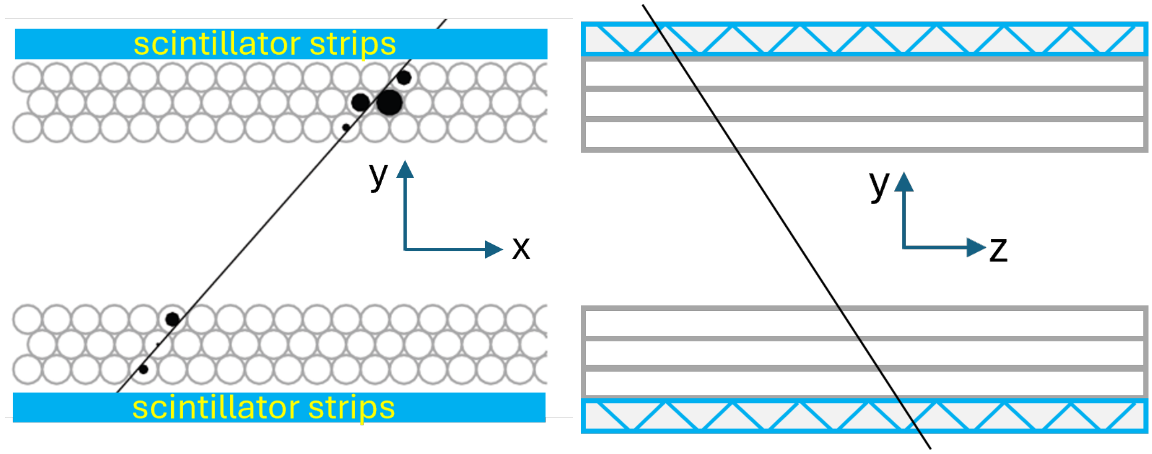

Figure 2: The proposed basic muon detector module comprises two multilayer drift tube detectors for high-precision tracking in the $x-y$ plane, along with two layers of scintillator strip detectors for fast timing and precision z-coordinate measurements.

1-meter-long triangular scintillator strips. These strips – originally developed for tomographic muon imaging measurements [3] and provided by Fermilab – have an isosceles cross section with a 4 cm base and 2 cm height. We have also received a sample of wavelength-shifting (WLS) fibers from Kuraray for evaluation. The modules are instrumented with Hamamatsu S13360-3075PE SiPMs. Figure 3 shows the modules under construction at Michigan and mounted on the assembly for the CERN test beam.

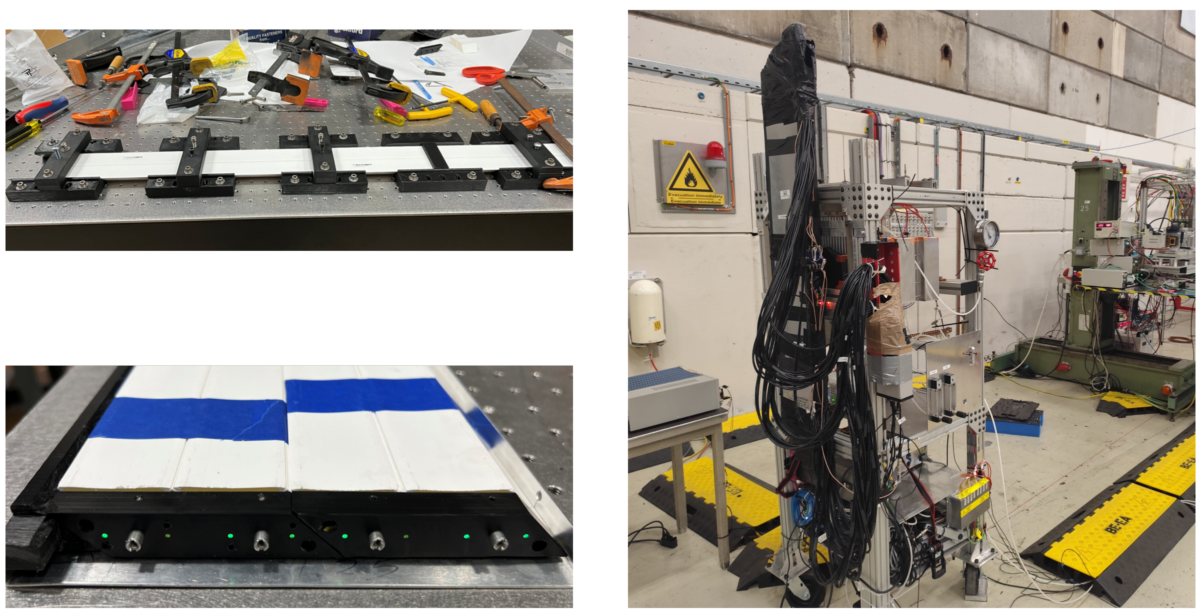

Figure 3: Left: prototype modules under construction at Michigan. Right: the cart equipped with the prototype modules and sMDT chambers at the CERN T9 beam line.

In conjunction with the straw tracker R&D program, we collected a substantial dataset during the March-April 2026 test beam campaign at CERN's T9 beam line. The setup, shown in Fig. 3 (Right), includes four small-radius Monitored Drift Tube (sMDT) chambers that provide precise tracking information. The prototype modules were readout using a borrowed CAEN DT5202 Citiroc unit. Figure 4 shows initial results on the position (perpendicular to the strips) and time-measurement performance of the prototype modules. A preliminary analysis yields resolutions of approximately 2mm in position and 500 ps in time, where the latter includes an estimated 250 ps contribution from the DAQ system. We expect these resolutions to improve through more detailed analyses.

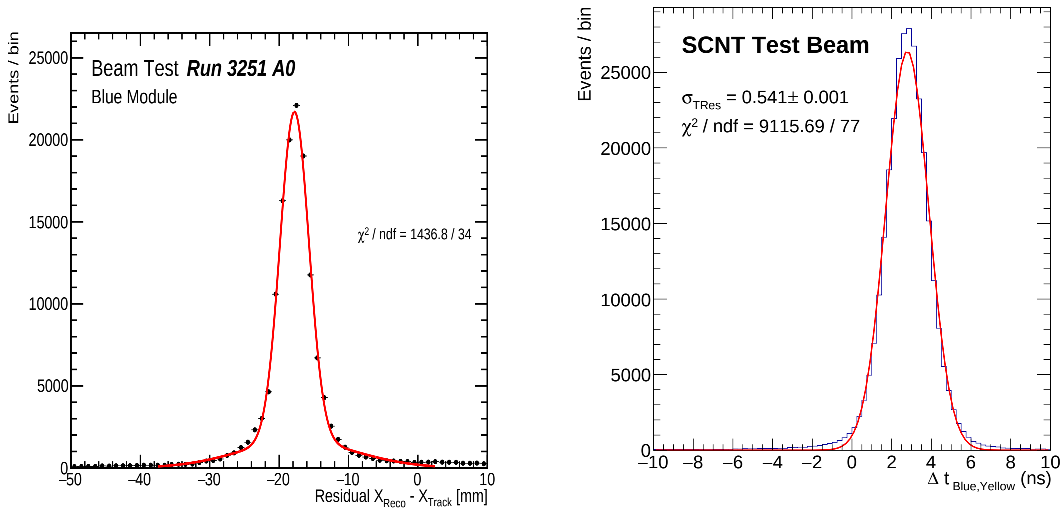

Figure 4: Left: distribution of the position difference between the scintillator module measurement and the position extrapolated from the sMDT measurement. Right: distribution of the measured time difference between the two scintillator modules.

Proposed Research and Budget Request

We request modest FY2027 funding to continue the performance characterization of the prototype modules including studies of potential scintillator aging, to advance the development of a realistic detector concept, and to investigate the performance of long-strip and long-fiber detector designs.

A major focus in the coming year will be the detailed analysis of the test-beam data. Our goal is to determine the position and timing resolutions of the prototype modules and to explore strategies for improving them. This work will include studying light yields, detection efficiencies, and position and timing resolutions both along the strips and for particles impact across the strips. We will examine various contributions to the position and timing resolutions. In parallel, we will monitor potential aging effects in the scintillator light yield of the prototype modules through dedicated cosmic-ray measurements.

In parallel, We plan to further develop the muon detector concept – both as a muon tagger and as a tracking detector with momentum measurement capability – within the broader framework of the full FCC-ee detector concepts. As part of this effort, we will implement an initial version of the muon detector design in the FCC-ee simulation framework.

Although the current prototype modules use 1-meter strips, the FCC-ee muon detector concept envisions scintillator strips up to 5 meter long to reduce channel count and simplify the mechanical integration. While the longer strips do not affect local production of scintillation light, the extended WLS fibers introduce new challenges: attenuation reduces the photo-electron yield which could degrade position resolution, and longer propagation time increase timing jitter. To understand and quantify these effects, we plan to construct a long light-box equipped with an automatic control system, readout electronics and a DAQ system. This setup will allow for dedicated measurements before we proceed to build prototype modules with long-fiber readout.

Our request for FY2027 amounts to $50,000 with the following breakdowns:

1. Personnel support: $25,700
   (2.5 month Engineer and Technician support to build the light box system and to develop a realistic

detector concept)

2. Materials and supplies: \$14,000
   (Lightbox and control system: \$7,000; Fibers: \$3,000; SiPMs: \$2,000; Supplies: \$2,000)
3. Indirect cost (26%): \$10,300

Impact and Justification:

This funding will directly advance the development of the FCC-ee muon detector by validating its spatial and timing performance–capabilities essential for identifying long-lived and slow-moving particles. We will make extensive use of our existing resources and facilities to minimize costs. For example, no funding is requested for electronics such as high- and low-voltage power supplies or data acquisition electronics, and support for graduate students and postdoctoral researchers is also covered through existing resources.

The requested funding will enable continued progress on a unique US-led detector concept that integrates precision drift tubes with fast scintillator strips – an approach made possible by Fermilab's capability to produce extruded scintillator strips and by the advancement in high-performance SiPM technology. Although the request is modest, the investment carries significant strategic value for the FCC-ee muon R&D program. It reinforces US leadership in detector technology and establishes a solid foundation for future participation in the design and construction of the FCC-ee detector. For these reasons, we strongly recommend prioritizing this proposal within the FY2027 R&D budget.

References

[1] "A High-Precision, Fast, Robust, and Cost-Effective Muon Detector Concept for the FCC-ee", Kevin Nelson, presentation at the Third Annual Higgs Factory Future Circular Collider Workshop, April 14-17, 2025, Fermilab, USA (https://indico.fnal.gov/event/67484).

[2] "A muon System Made of Drift Tubes and Scintillator Strips For FCC-ee", Bing Zhou, presentation at the FCC Week 2025, May 19-23, 2025, Vienna, Austria (https://indico.cern.ch/event/1408515).

[3] "Tomographic Muon Imaging of the Great Pyramid of Giza", A.D. Bross *et al.*, arXiv:2202.08184 (https://arxiv.org/abs/2202.08184).

[4] "A High-Precision, Fast, Robust, and Cost-Effective Muon Detector Concept for the FCC-ee", F. Anulli *et al.*, arXiv:2504.10448 (https://arxiv.org/abs/2504.10448).