FY2027 R&D Plan on Drift-tubes+ Scintillator Strip Muon system for HFCC-ee

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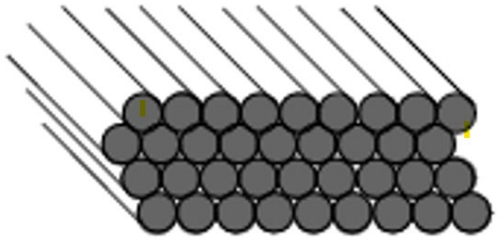
May 1, 2026

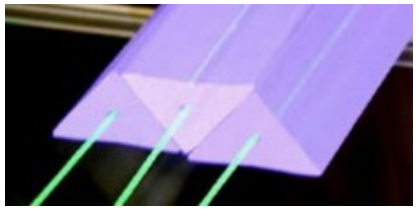
A muon system with drift tubes and scintillator strips to satisfy the requirements

- **High precision:** Precision position measurements from **drift tubes**
- **Fast:** Fast timing information from **scintillator strips**
- **Cost-effective:** Inexpensive to construct and with a low channel count
- **Robust:** Reliable and robust to operate for long term

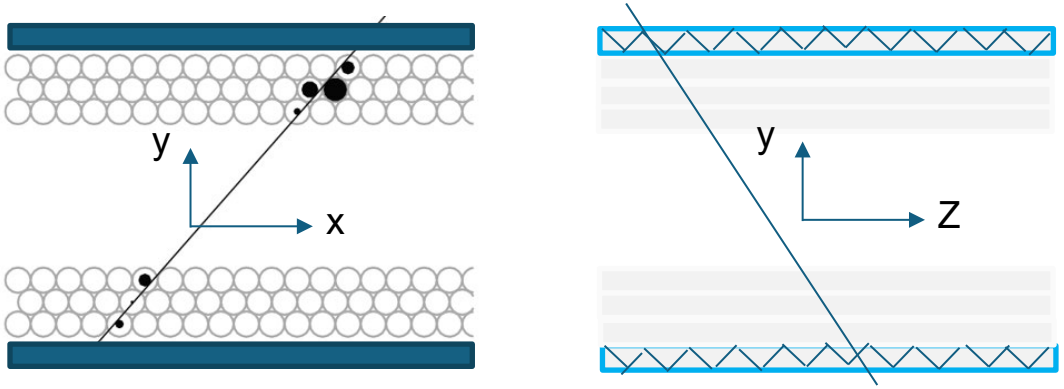
Drift tube area



Scintillator strips



An example of a muon detector module



spatial measurements with a resolution of σ_{xy}**~100µm per tube**

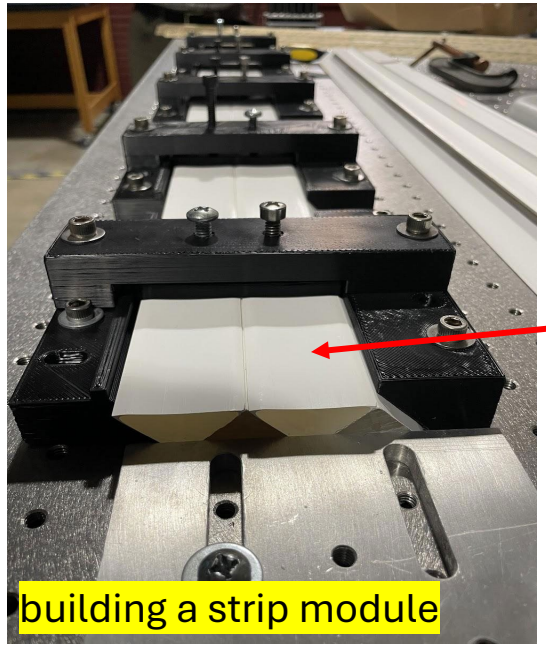
with σ_z**~1mm** and σ_t**~200ps**

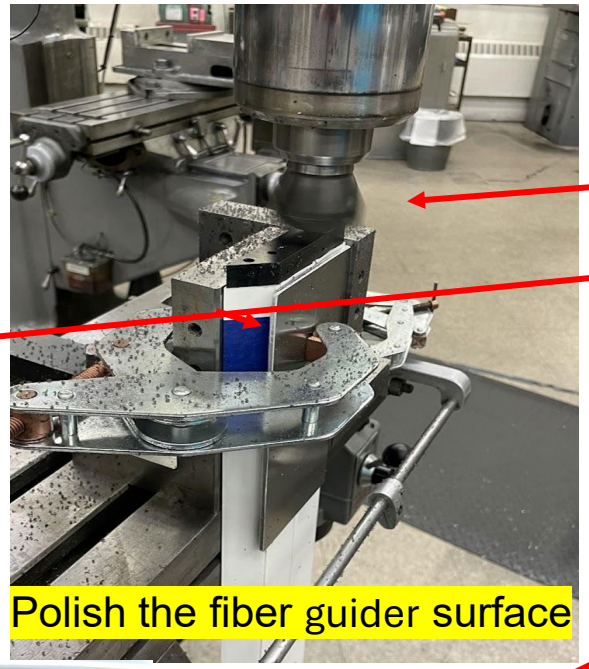
- Reconstruction of track segments,
- Reconstruction of decay vertices of long-lived particles

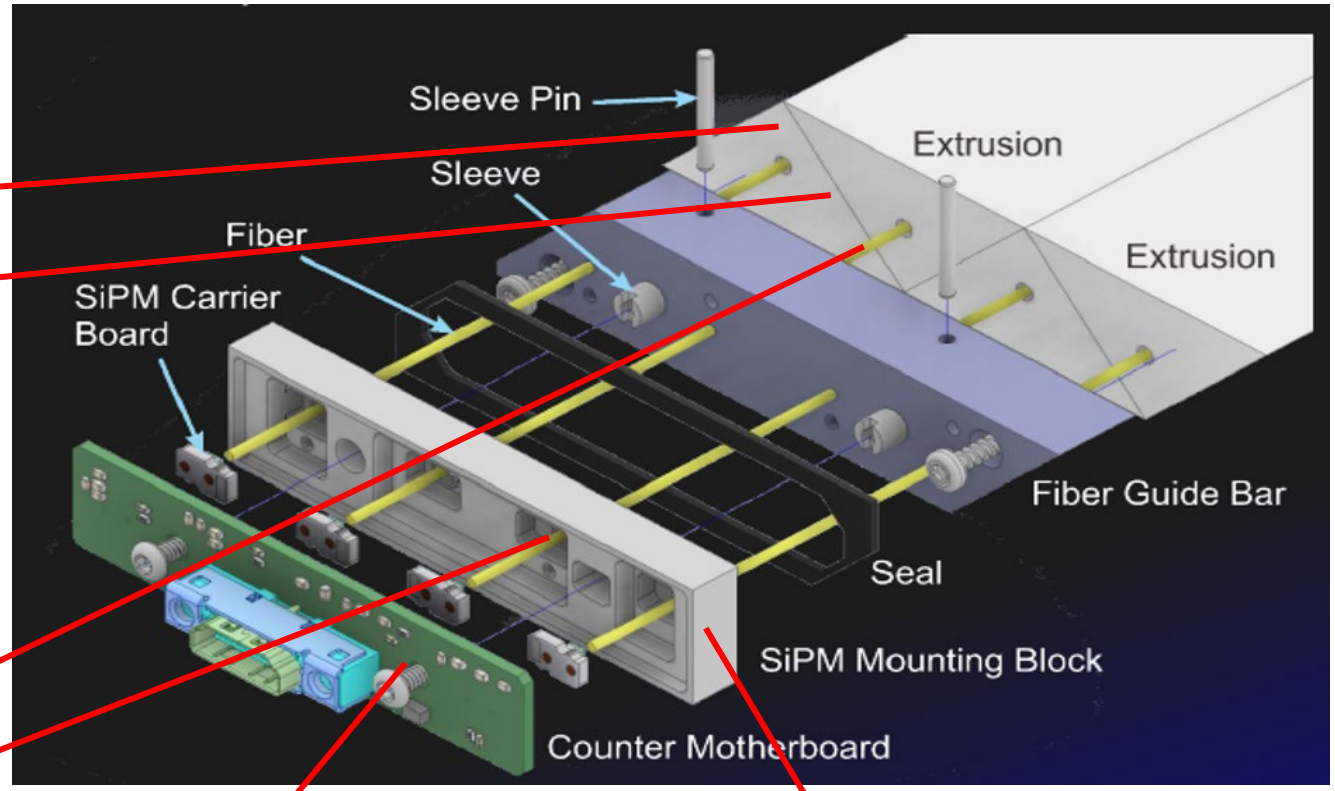
- Triggers
- Time-of-flight information for massive stable particles, …

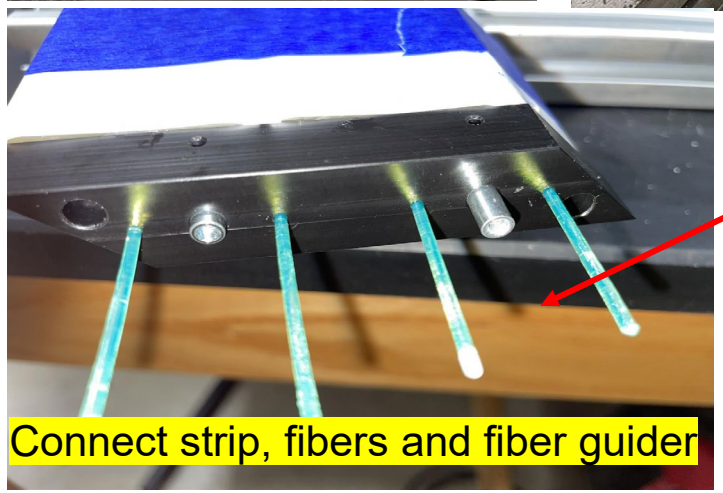
R&D Progress in FY2026 (1) built prototypes

Triangular scintillator strips: 4 cm base, 2 cm height, and 1 m long, from Fermilab, **WLS fibers**: Kuraray YS-2M and YS-4M, 1.5mm diameters; **Hamamatsu S13360-3075PE SiPMs** on both ends.

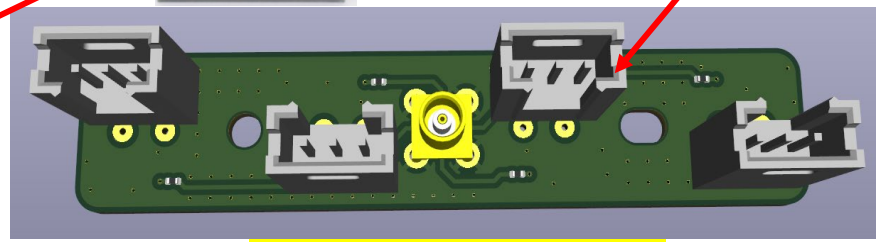

building a strip module


Polish the fiber guider surface




Connect strip, fibers and fiber guider

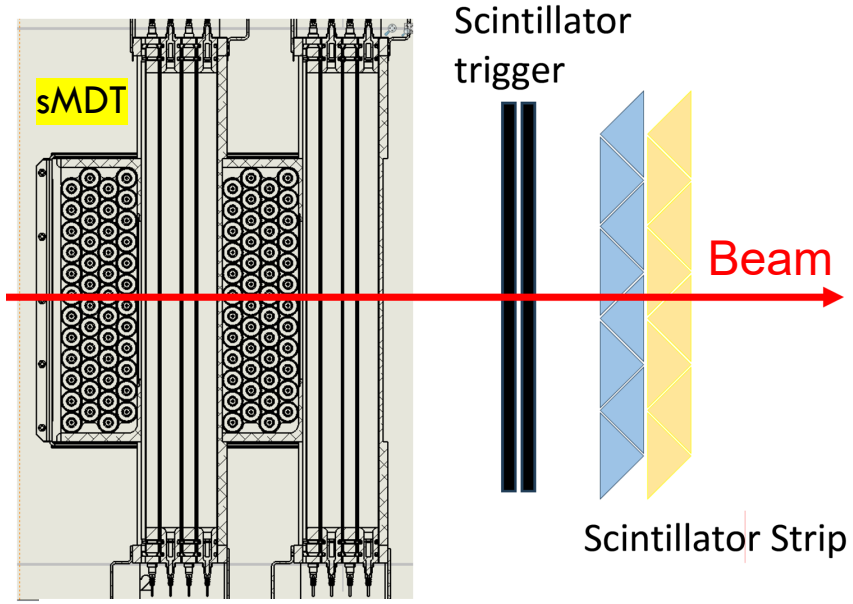
SiPM


RO PCB Motherboard

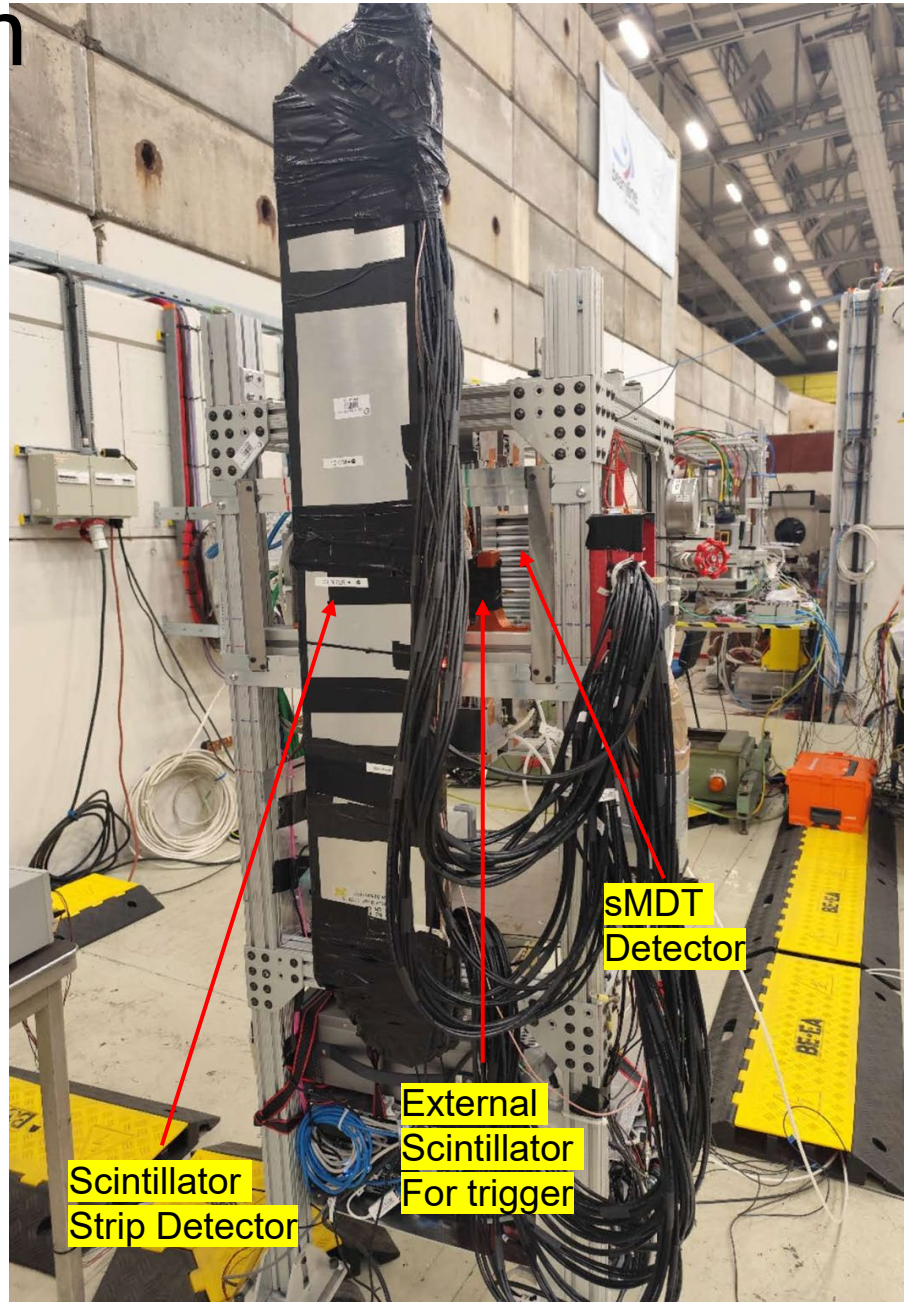

SiPM holder

R&D Progress in FY2026 (2) Test beam

- Joined two test beam campaigns at CERN PS T9 using miniDAQ systems developed at University of Michigan
- Four drift tube chambers provide 3D reference tracks with precision ~85 microns per tube
- Two scintillation strip detectors with total of 16 strips with 32 channel readout in both ends of the strips.
- Study the performance using with 10 Gev Hadron beams.

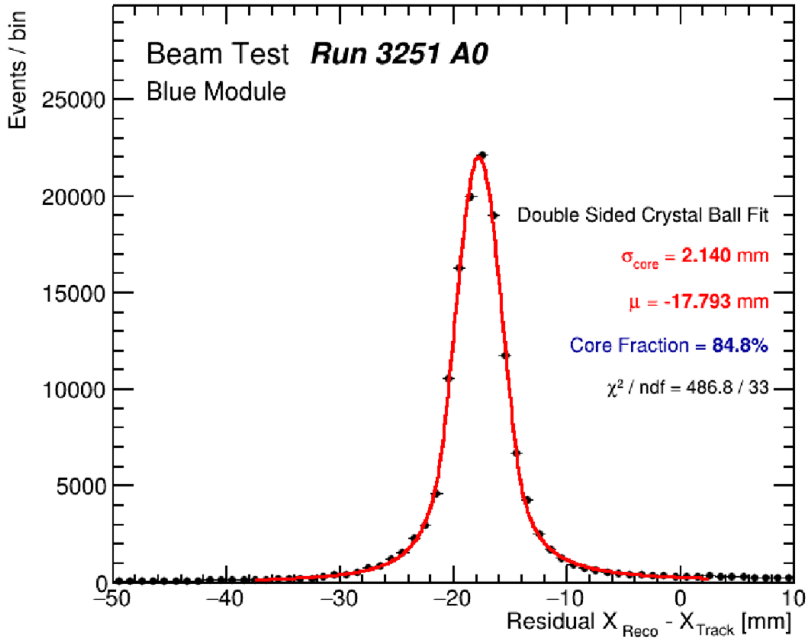


Test beam setup (Top view)

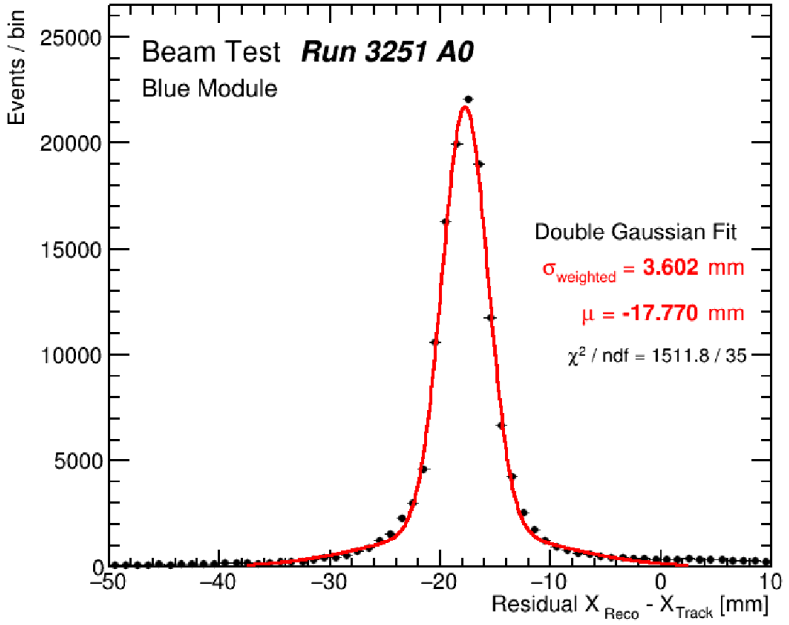


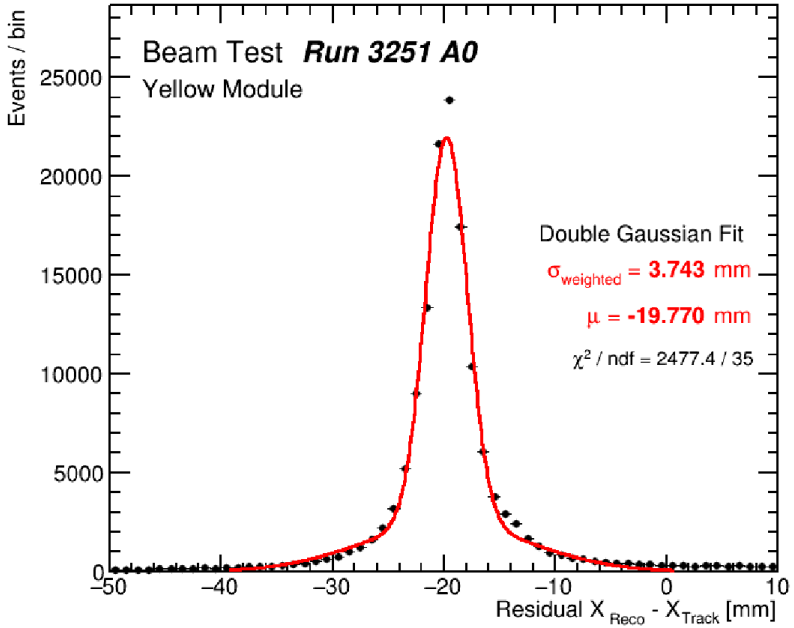
Preliminary Test Beam Results

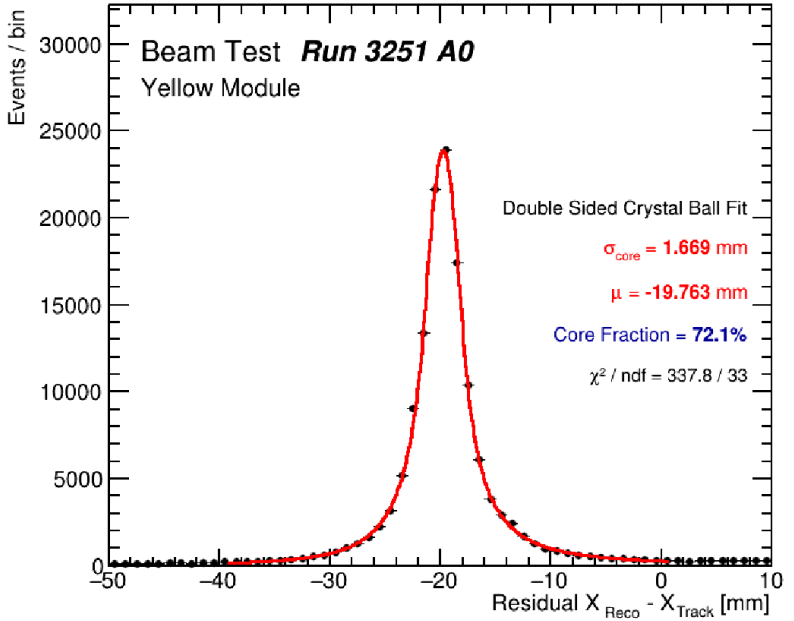
- Cross-Strip spatial resolution study (Nov 2025 test beam data)
  - Reference tracking position from sMDT compared to the centroid of the scintillator strip charge collection.
  - PE calibration with HG/LG
- Special resolution (core): 1.7 – 2.1 mm (see plots right)
- Special resolution (from one end readout) from double Gaussian fit: 3.6 – 3.7 mm (including the tail contributions) → see plots below.
- With better calibration method and equal cable lengths used for 2026 test beam to improve the resolution.



the core has a resolution 1.6~2.1mm

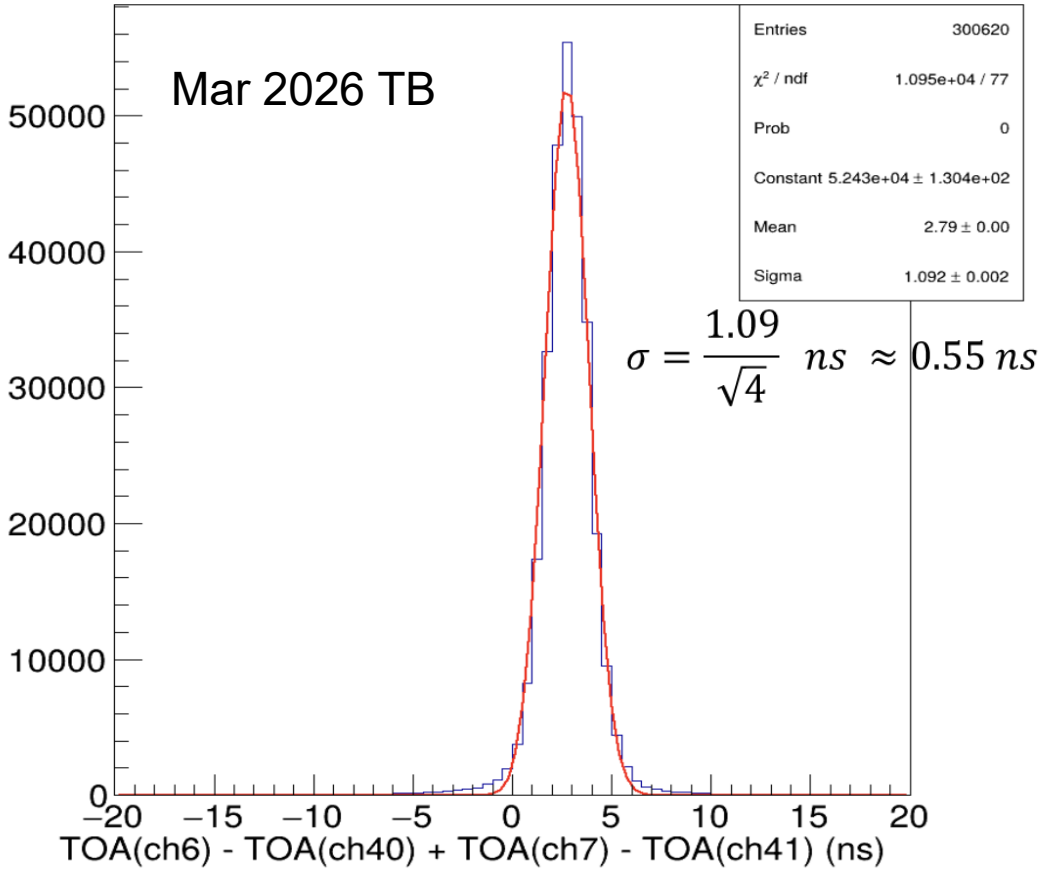


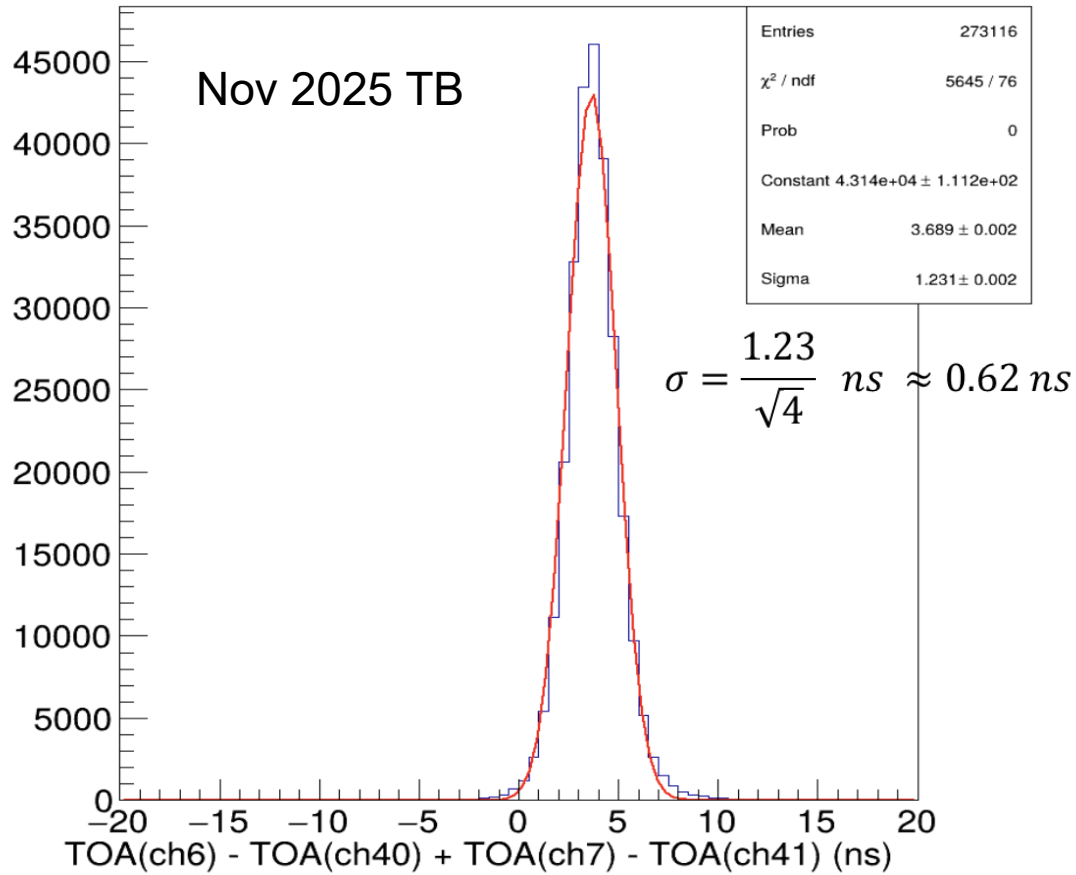




Preliminary Test Beam Results

- The intrinsic time resolution of CAEN DT5202 was measured to be around **280 ps**.
- Single channel time resolution from Mar 2026 test beam is 0.55 ns, corresponding **473 ps** detector resolution, it has been improved compared to the results from Nov 2025 test beam with better calibration and eq. cable length
- We have a large room to improve time with slew correction, calibration, reference track selection.





On-going/Planned Test-beam Data Analysis

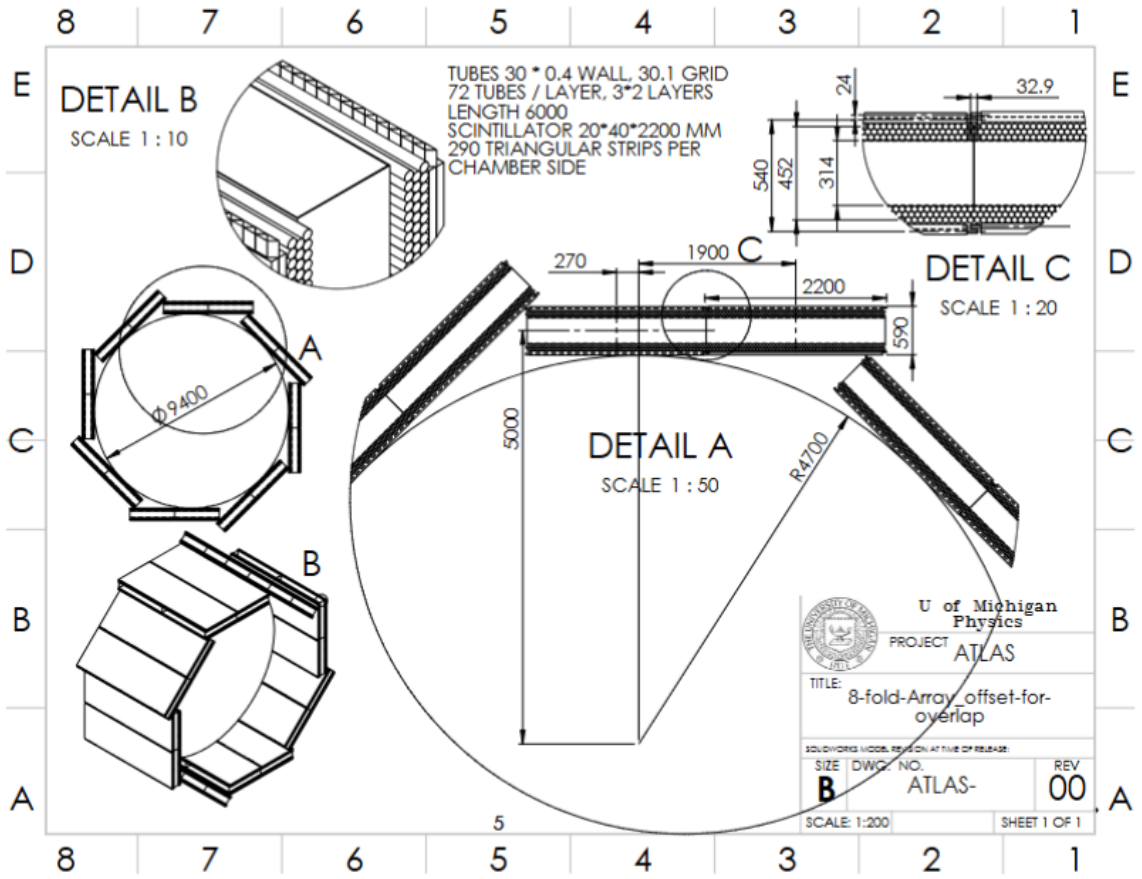
Large high-quality test beam data sets enable us to study detailed detector response

- Charge Particle **Track Reconstruction**
- sMDT and SCNT-strip **DAQ event synchronization** and sMDT reference tracker for SCNT-strip in sMDT coordinate system
- **SCNT Strip calibrations:** all channels with same gains
- SCNT-strip Precision **position measurements and efficiency** determinations strip by strip
- SCNT-strip **time measurements and efficiency** determinations strip by strip
- SCNT-strip **2nd coordinator along SCNT-strip** by using charge and time separately and efficiency determinations strip by strip
- SCNT-strip **signal attenuation studies** strip by strip
- SCNT-strip **trigger studies**
- SCNT-strip **GEANT4 simulation**

R&D Progress in FY2026 (3)

Detector Layout Study with ALLEGRO Concept

Engineering Drawing



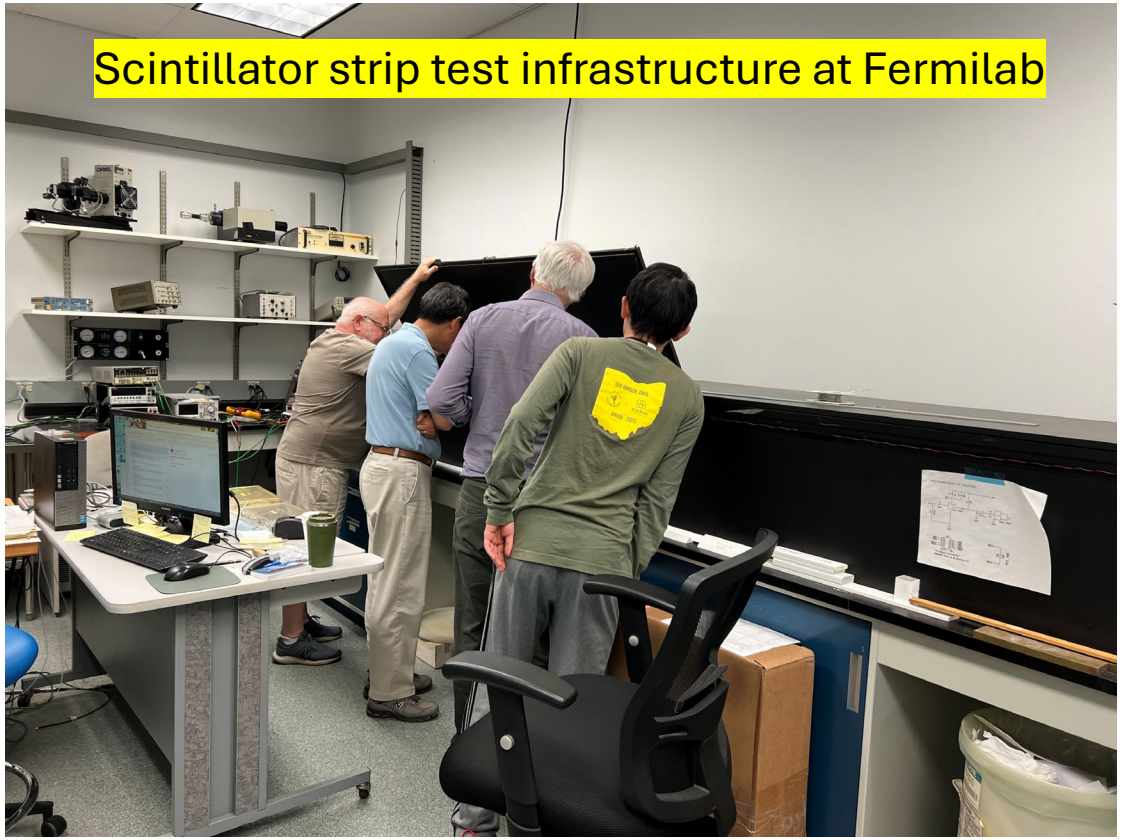
Key parameters of the muon detector
In put to GEANT4 muon detector simulation

Component	Parameters
Drift-tube	Length: 6000 mm Outer Diameter: 30.0 mm Gas Material: Ar:CO_2 (93%:7%) Wall Thickness: 0.4 mm Wall Material: Aluminum Wire Diameter: 35 μm Wire Material: Tungsten Configuration: 72 tubes/layer, 6 layers/module
Scintillator	Length: 2200 mm Cross-section: Triangular (40 × 20 mm) Scintillator Material: Polystyrene plastic Configuration: 290 strips per chamber side
Module Gap	Spacer thickness: 314 mm

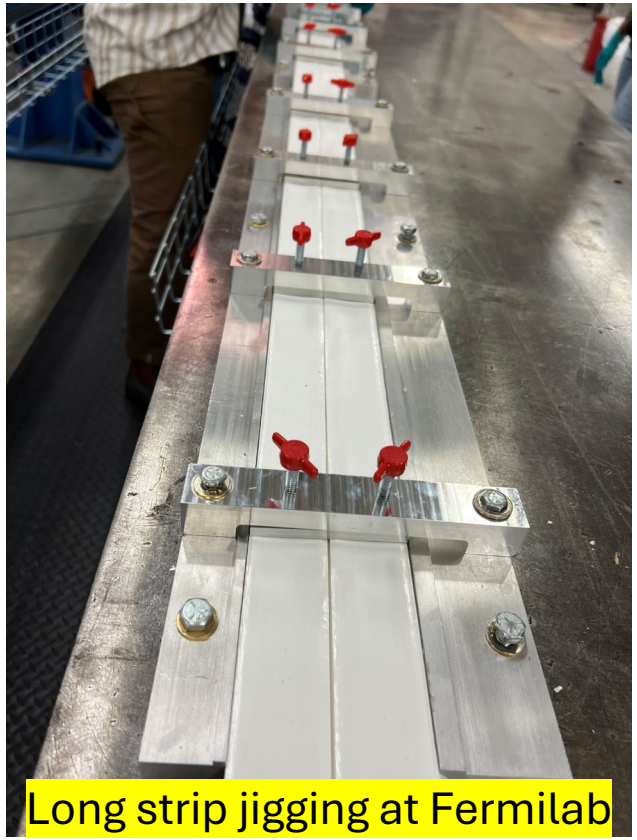
R&D Plan in FY2027

Proposal attached in indico page

1) Complete test beam data analysis, and publish the results
2) Building long precision strip module construction jigging
3) Building a long black box with internal detector supporting structure, and trigger/light source moving system
4) Design electric boards using HPTDC to readout timing signal from SiOM with 100 – 200 ps timing resolution
5) Participate in ALLEGRO Muon System concept development with engineering/GEANT4 simulations



Scintillator strip test infrastructure at Fermilab



Long strip jigging at Fermilab

HFCC-ee Muon detector R&D FY 2026 Funding and FY 2027 Request

FY 2026 proposed work and funding spending status

Constructed two small prototype modules with 8 triangular strips each, for a total 32 readout channels, characterize their performances through test beams at CERN and cosmic studies at Michigan

Received R&D funding for FY2026: $50k

- Engineer and Technician support: $30.6k (salary, $23.6k, and fringe benefits, $7.0 k)
- Materials & Supplies: $9.0k (module construction jigging, fiber holder, SiPM holder, PCB boards, module shipping box)
- Indirect cost (26%): $10.3k

The FY26 R&D funds are spent or committed in this FY. Expect to be all spent by September 30, 2026

FY 2027 Proposal and funding request

Continue the study of the performance of the prototype modules, focusing on improving the timing and spatial resolutions. We need to construct a 5m long lightbox to study the performance of long scintillator/fiber detector and develop realistic detector concept.

FY2027 Funding Request: $50k

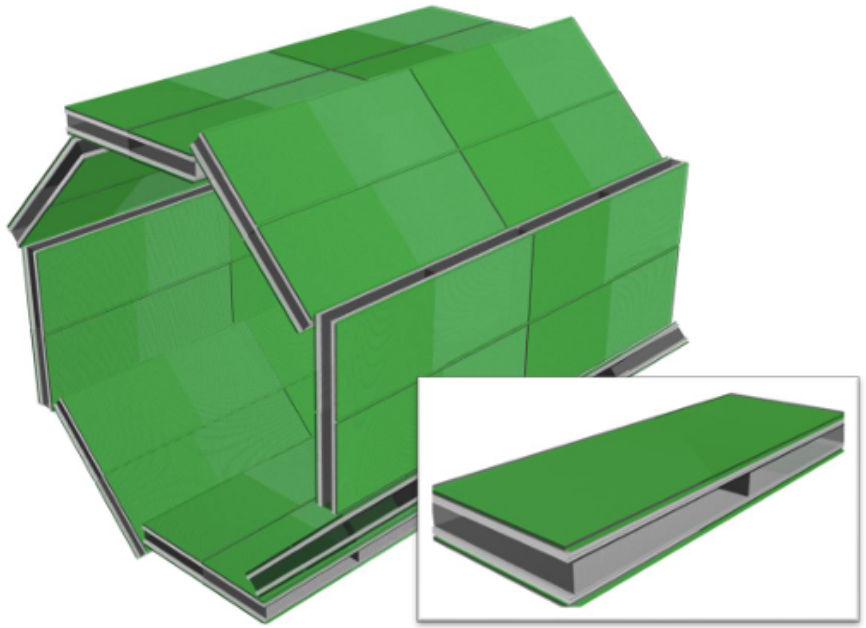
- Engineer and Technician support: $25.7k (Salary: $20.6k, Fringe: $5.1k)
- Materials and supplies: $14.0k
  Lightbox and the light source control system: $7k, Fibers: $3k (with minimum order requirement), SiPMs: $2k, Supplies: $2k
- Indirect cost (26%): $10.3k

Additional slides

GEANT4 Simulation of Muon System

Geometry in DD4hep

- **Muon System**
  - Barrel



Muon Barrel (module)

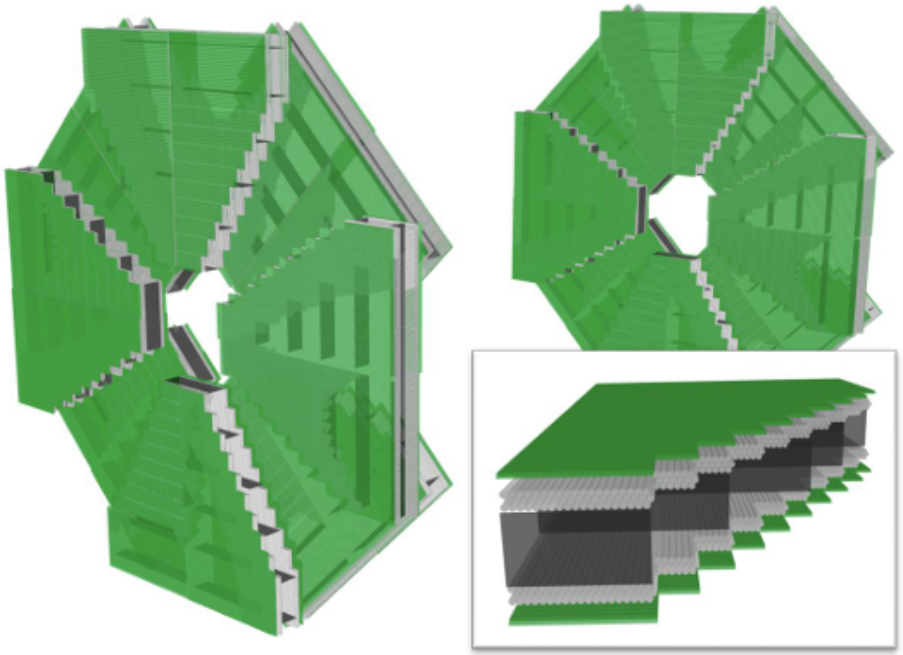
- **Main parameters**
  - **Tube** Use ATLAS BOL MDT as a model
    - **Length 6000mm**
    - **Outer diameter 30mm**
    - **Inner diameter 29.2mm**
  - **Scintillator**
    - **Length 2200mm**
    - **Hypotenuse 40mm**
  - **Center gap thickness 317mm**

Additional stations can be easily added for muon momentum measurement combining with magnet design of ALLEGRO detector concept

GEANT4 Simulation of Muon System

Geometry in DD4hep

- **Muon System**
  - EndCap



Muon EndCap (module)

- **Main parameters**
  - **Tube**
    - **Length 1000~3700mm**
    - **Outer diameter 30mm**
    - **Inner diameter 29.2mm**
  - **Scintillator**
    - **Length 586~2170mm**
    - **Hypotenuse 40mm**
  - **Center gap thickness 300mm**

Geometric acceptance > 98% with the layout of the muon system