PART 03

Beam Test Detector and DAQ Development

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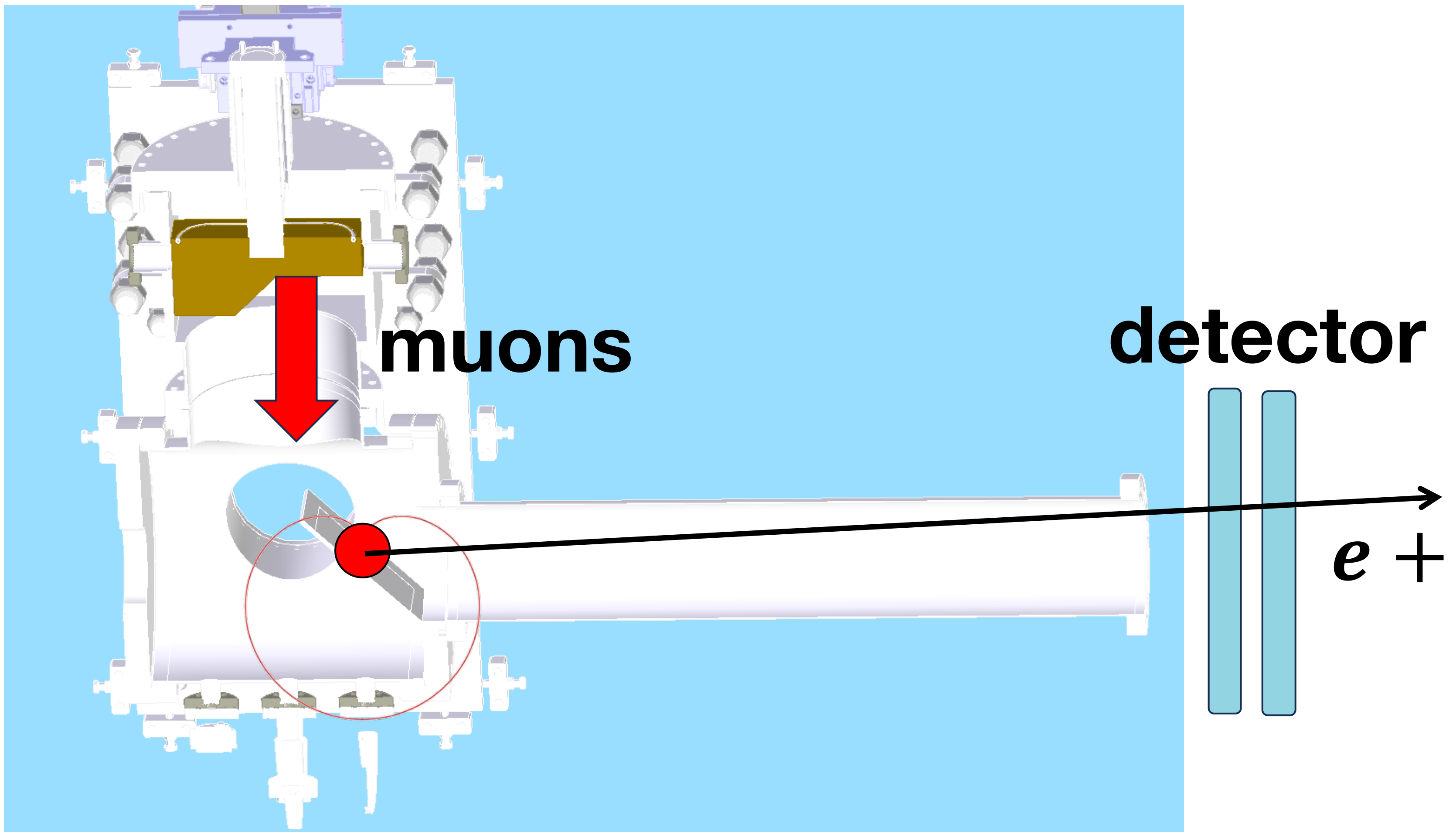
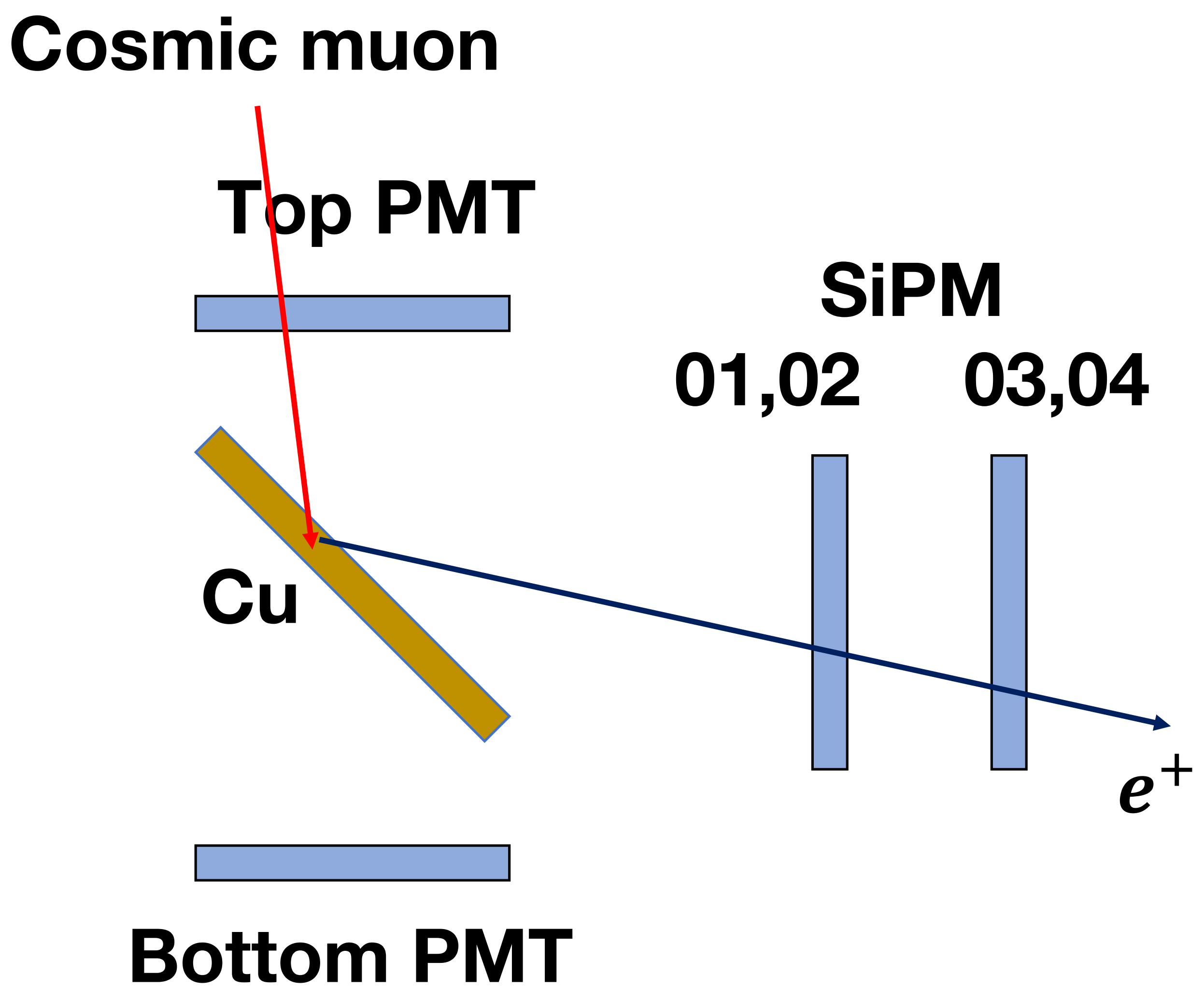
Dectecting Positrons From Muon Decay

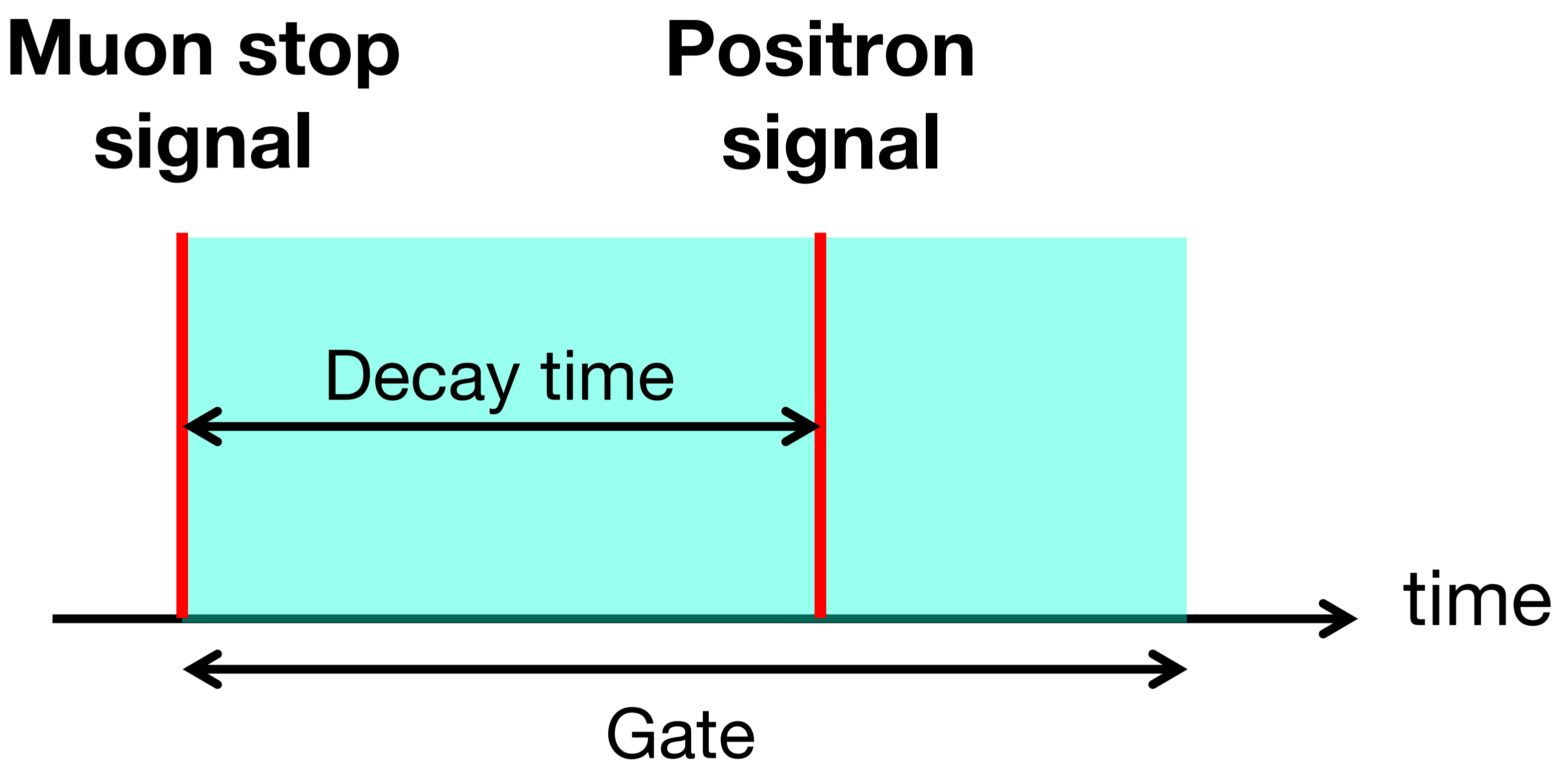
- We need a positron detector + DAQ for SHINE beam test.
  - Laboratory test was done with cosmic muons. Geometry slightly modified to balance muon stopping rate and positrons detection rate.
  - A top PMT activity initiates a time gate. All photodetector waveforms of were recorded and stored within this time window.
  - Offline analysis to select muon decay event candidates.



Beam test schematic @ SHINE

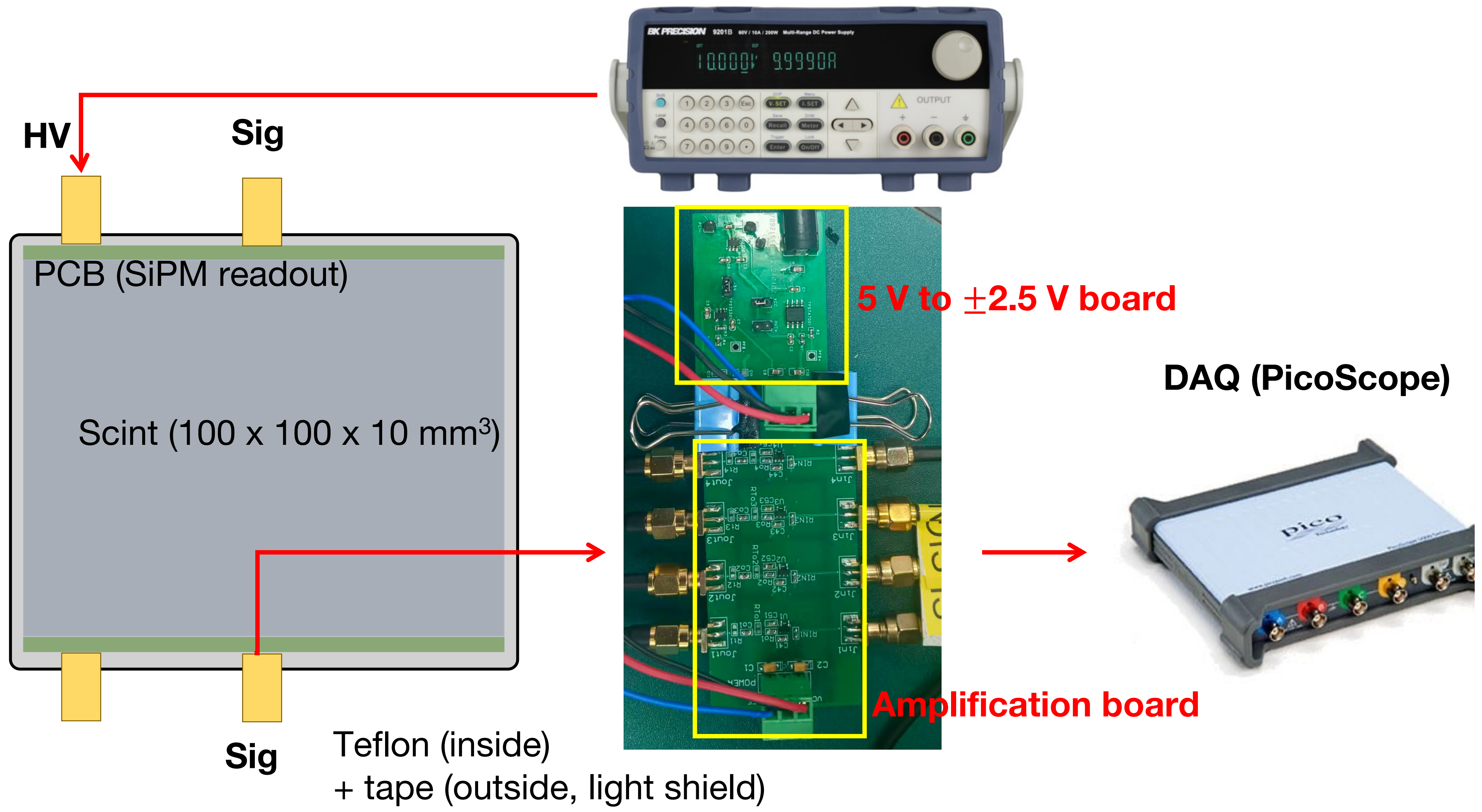


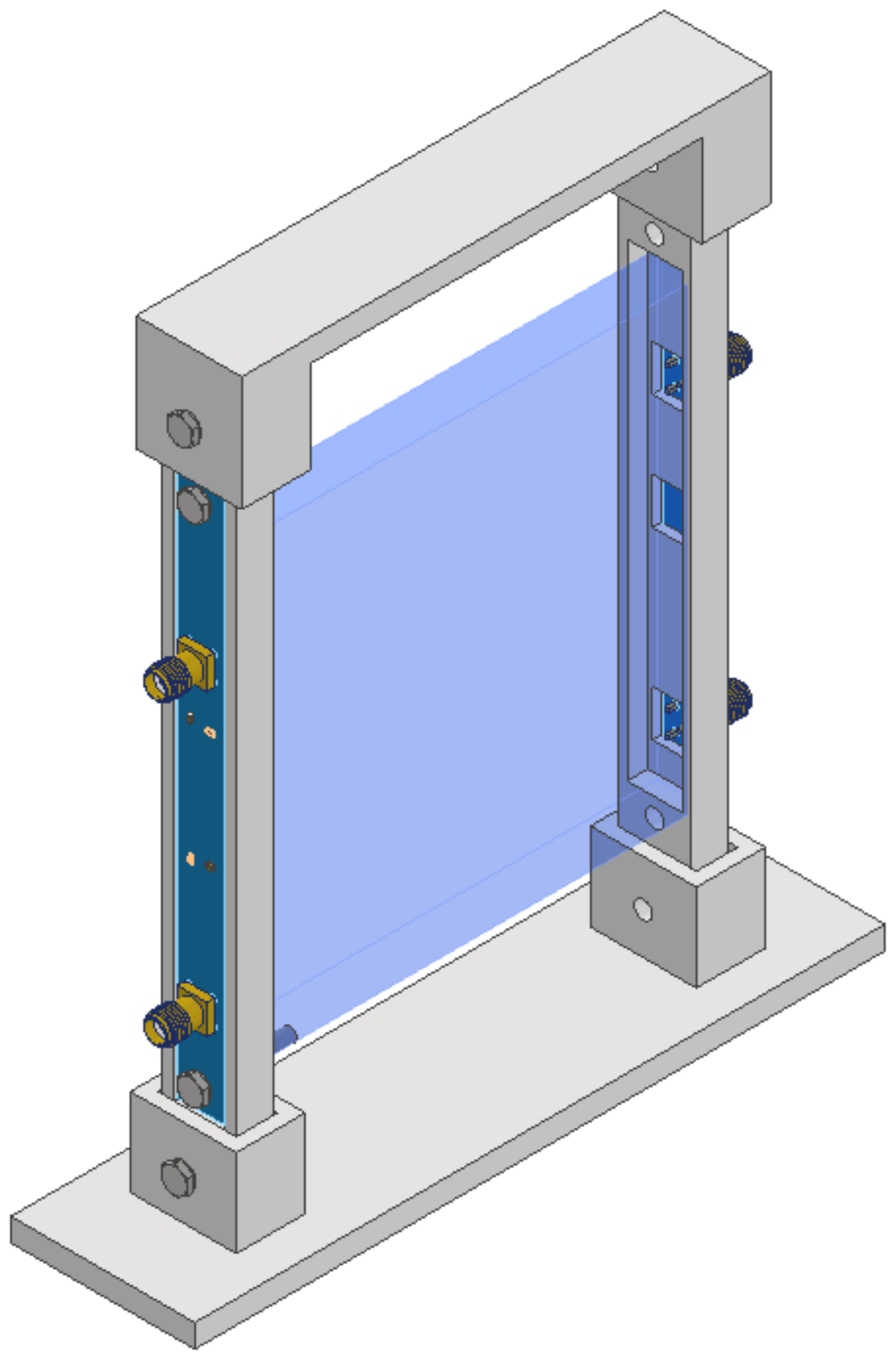
Detector schematic @ Muon Lab



Scintillator-based Positron Detector Module

- The scintillator (Beijing **GaoNengKeDi**) was redout by SiPM (Beijing **NDL**) from both sides to reject SiPM dark noise of rate ~ O(100 kHz) vs cosmic muons O(10 Hz).
- Two scintillator modules were used to further reject false positron events during offline analysis.
- The SiPM output was coupled to amplifier circuit based on Texas Instruments LMH6629MF.





3D Printed Holder

Assembly @ Muon Lab

DAQ Development and Data Runs

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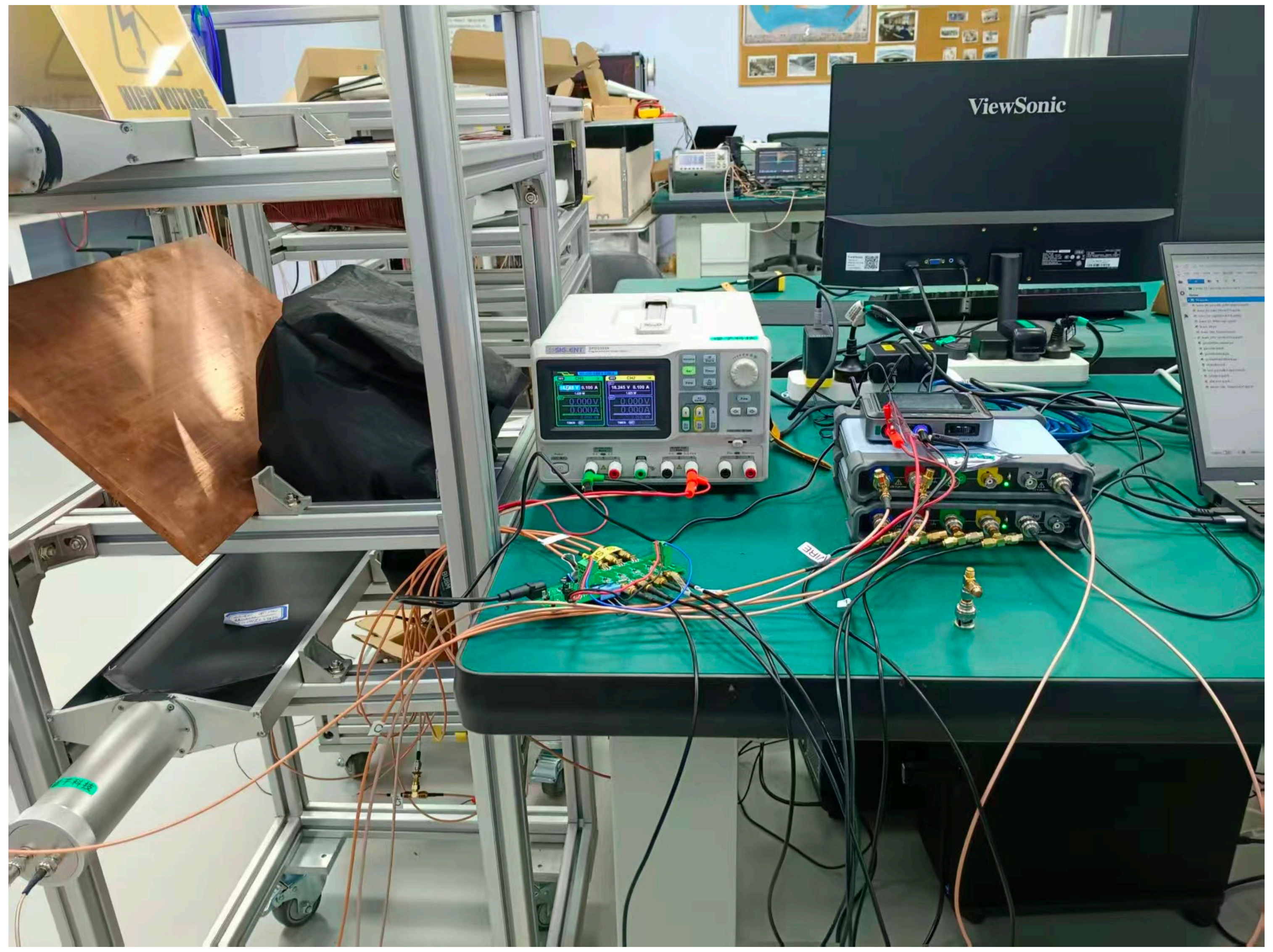
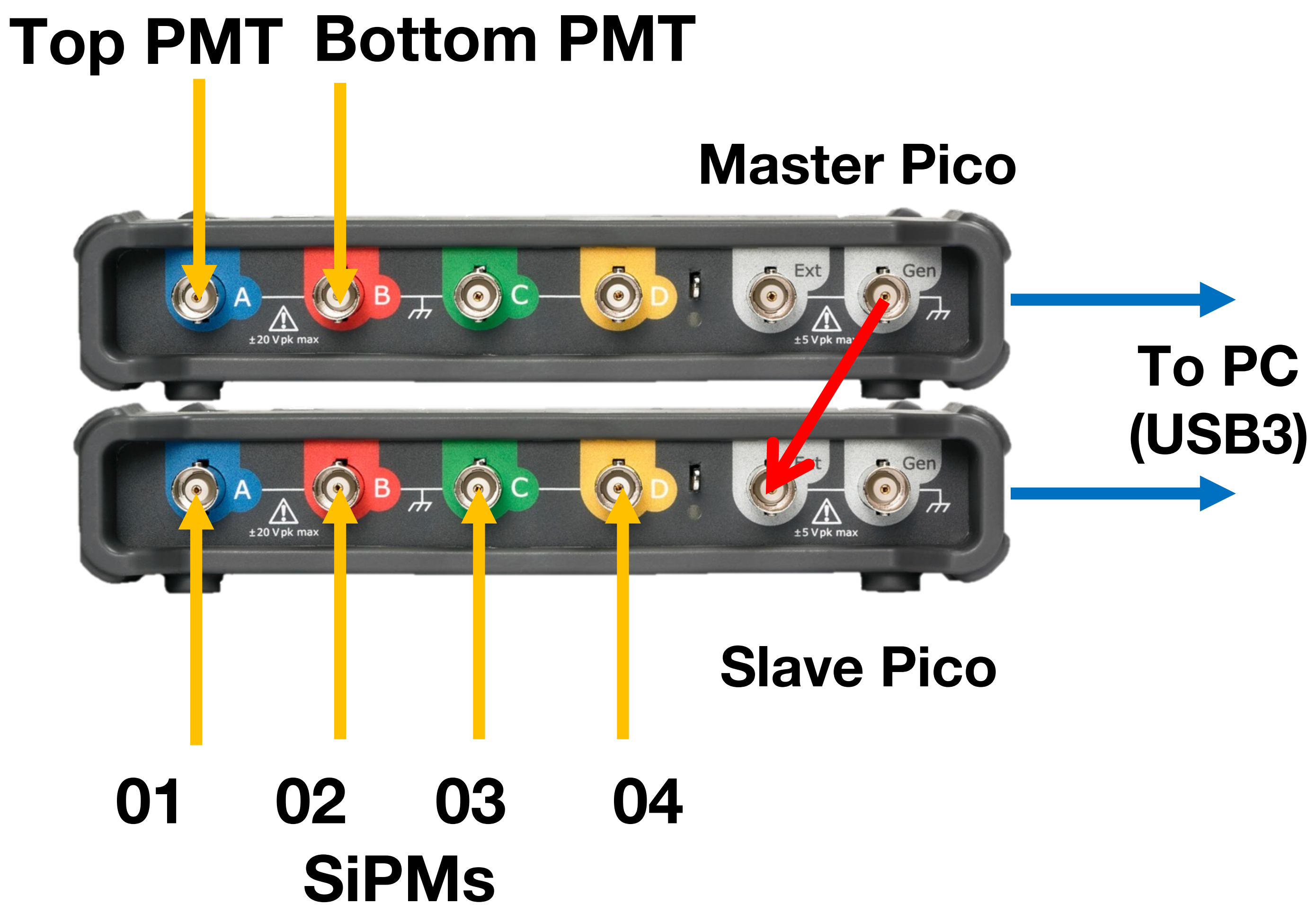
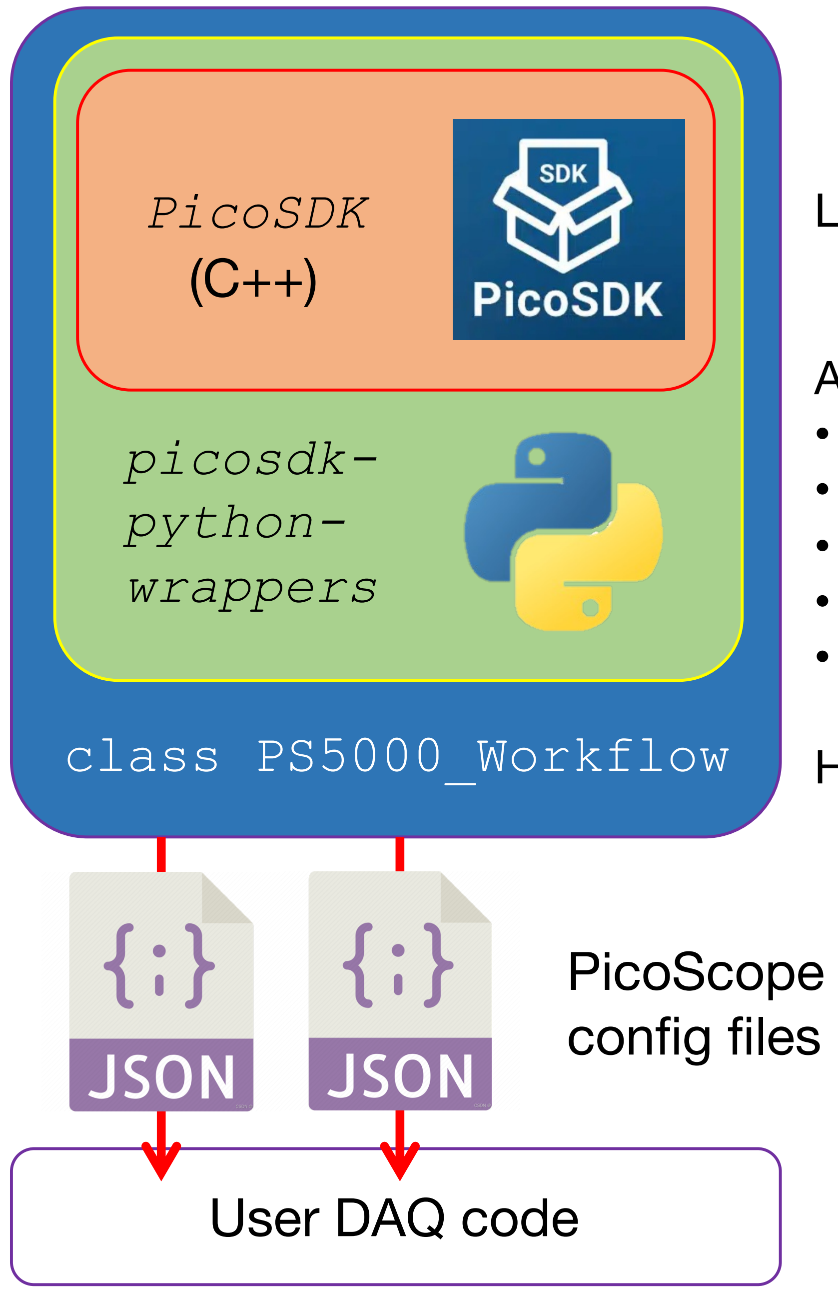
- The PicoScope 5444D is able to digitize waveform over 10 τ_μ at 4 ns/8-bit (time/ADC) resolution.
  - A python code on top of PicoSDK (C++ & python wrapper) was written to handle device communication and data-taking runs.
  - In the event of Top PMT activity, the master PicoScope triggers digitalization in both devices.
  - Raw waveforms are stored in ROOT files.







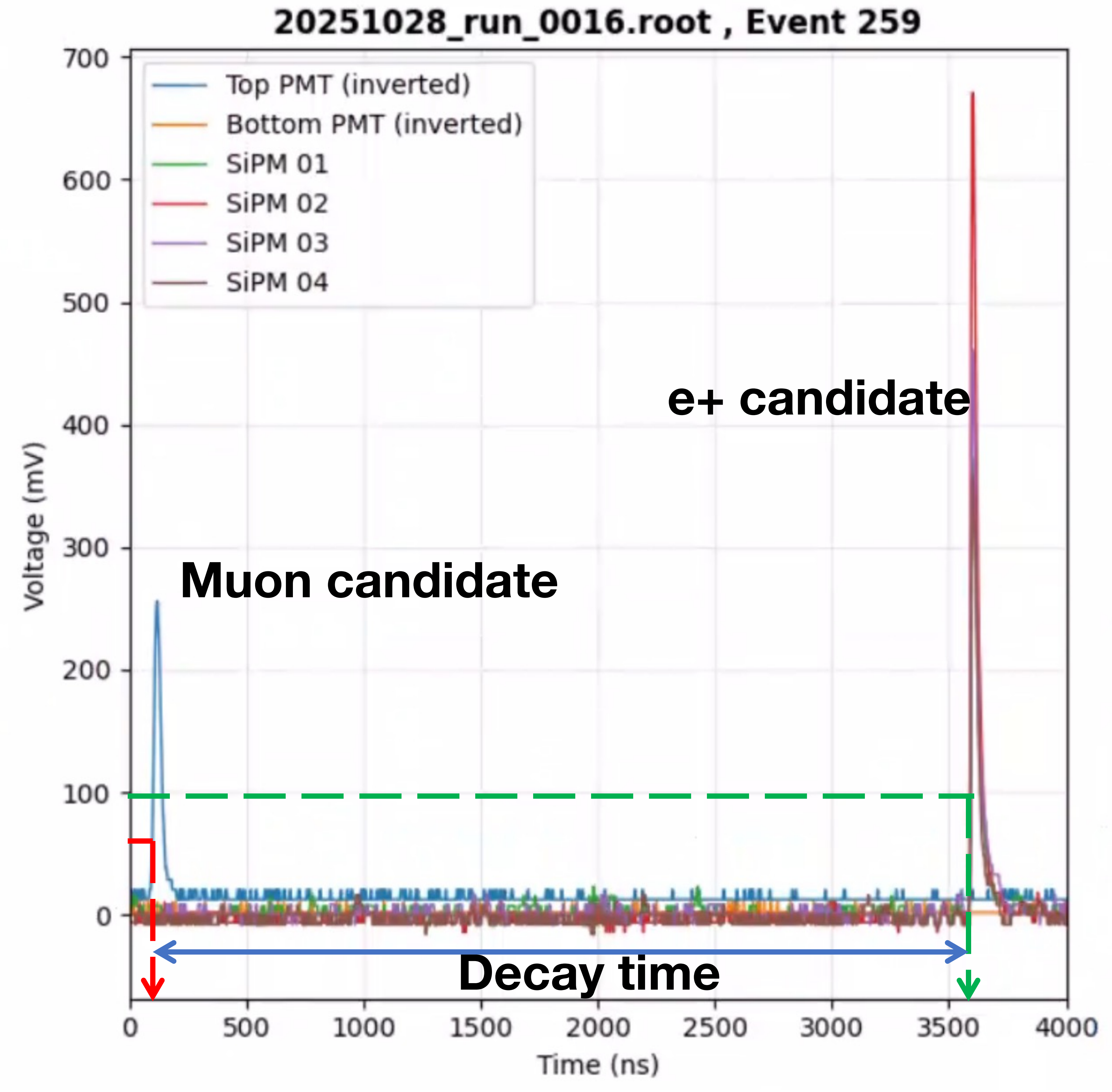
Low-level communications

APIs for
- Connecting single device, setup ADC bit-depth
- Setup channel (coupling, range, offset, etc.)
- Setup trigger and signal generator
- Memory allocation (for *Rapid Block* capture mode)
- Start and stop run, data transfer from device to host

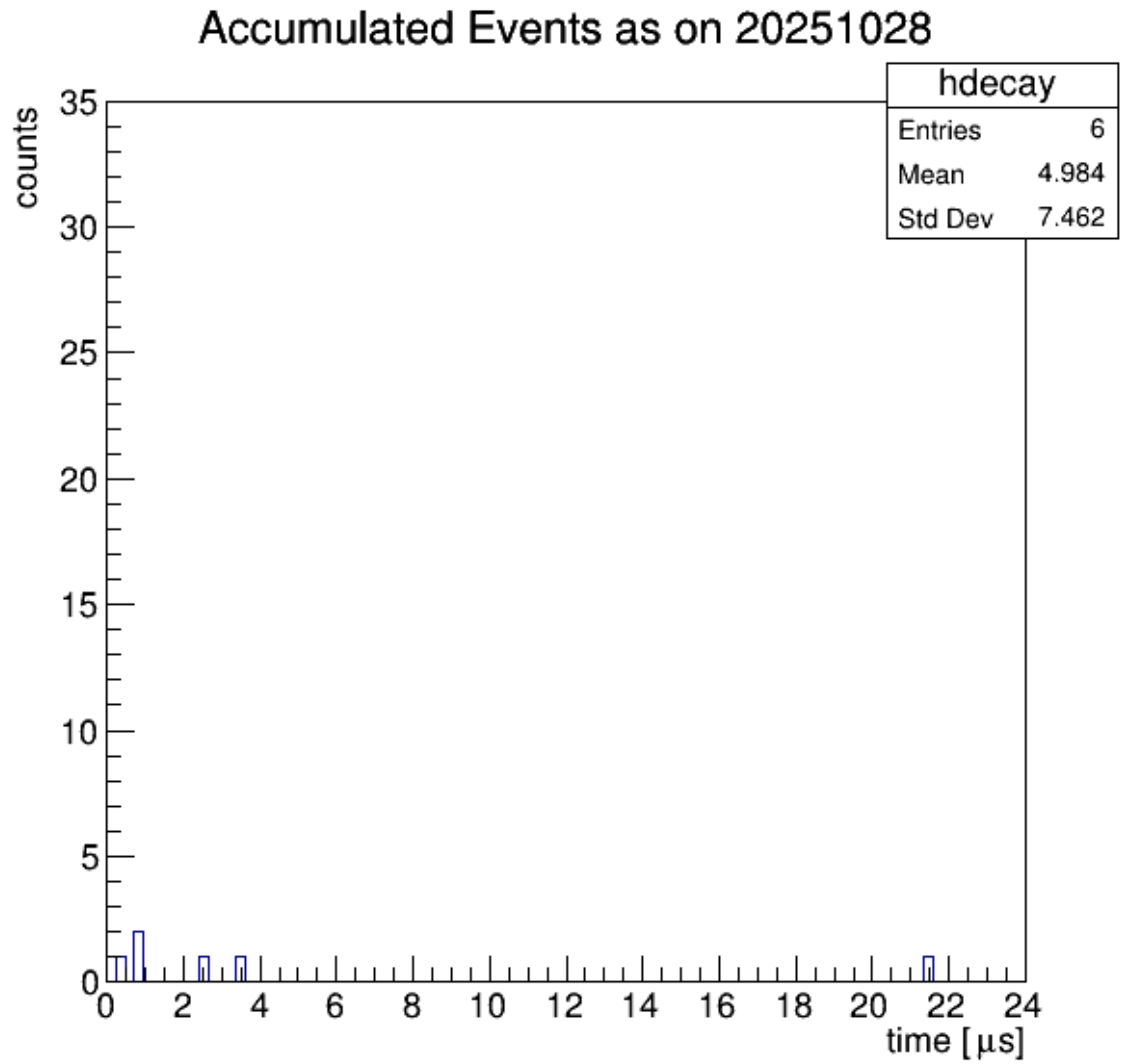
Handle multiple devices

Muon Decay Time Analysis

- Step the raw waveforms to find muon decay event candidates
  - Look for simple rising-edge activities. Need SiPMs 4-fold coincidence, with bottom PMT as veto
  - Decay time for the muon candidate was derived from the time of voltage rising-edge.



Fill time histogram



Muon Lifetime (Preliminary Result)

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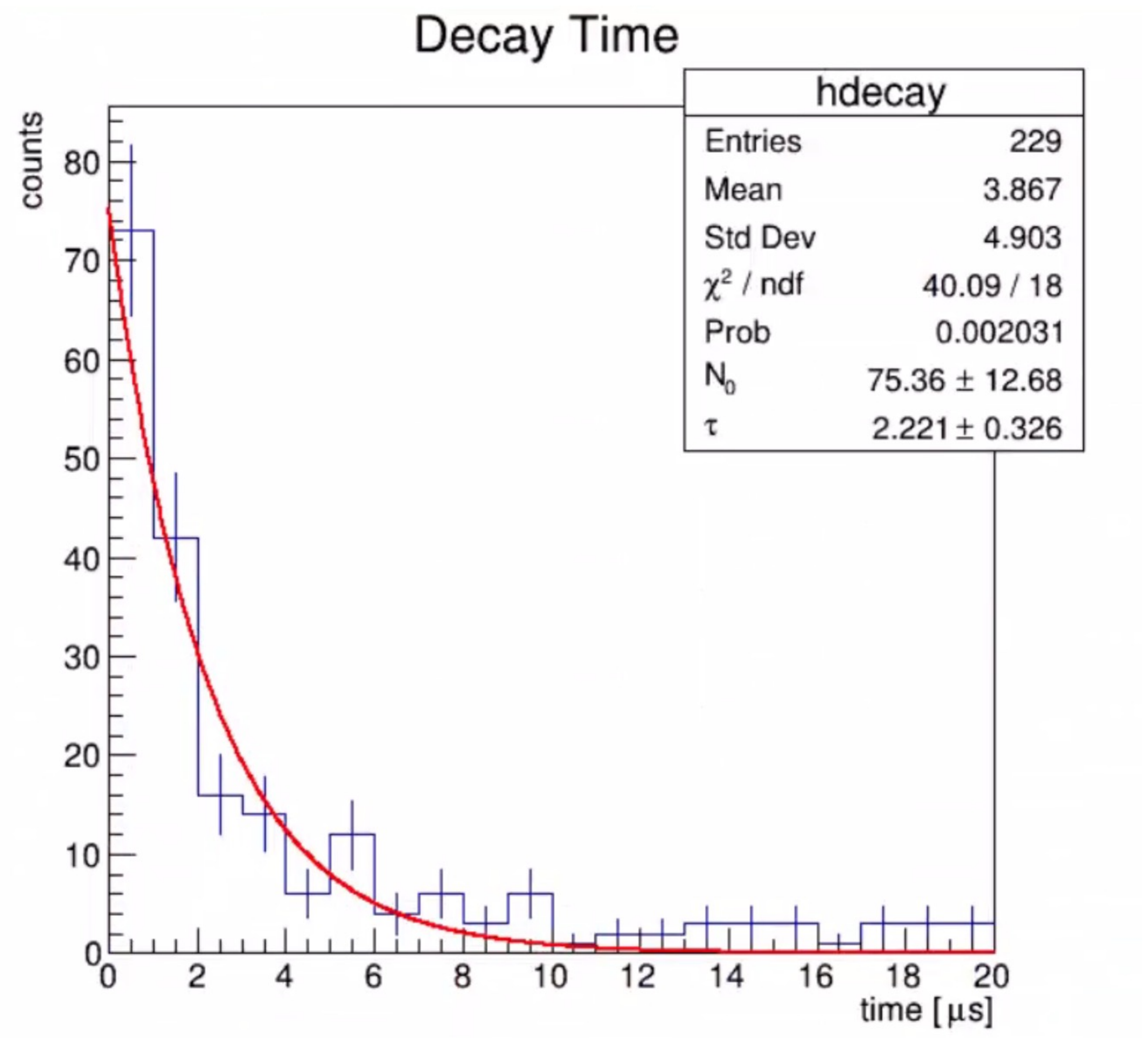
- Data from 28 Oct to 16 Nov
  - Muon decay events are 0.002 % out of 700,000 events/day, consistent with the g4bl model
  - 229 events are accumulated
- The fit result to the time histogram is consistent with muon lifetime at rest. We are still statistically limited
- Ongoing studies are in progress
  - Remove events with electrical noise
  - Inspect SiPM pulse areas to perform e+/muon separation.



PART 04

Beam Test Simulation

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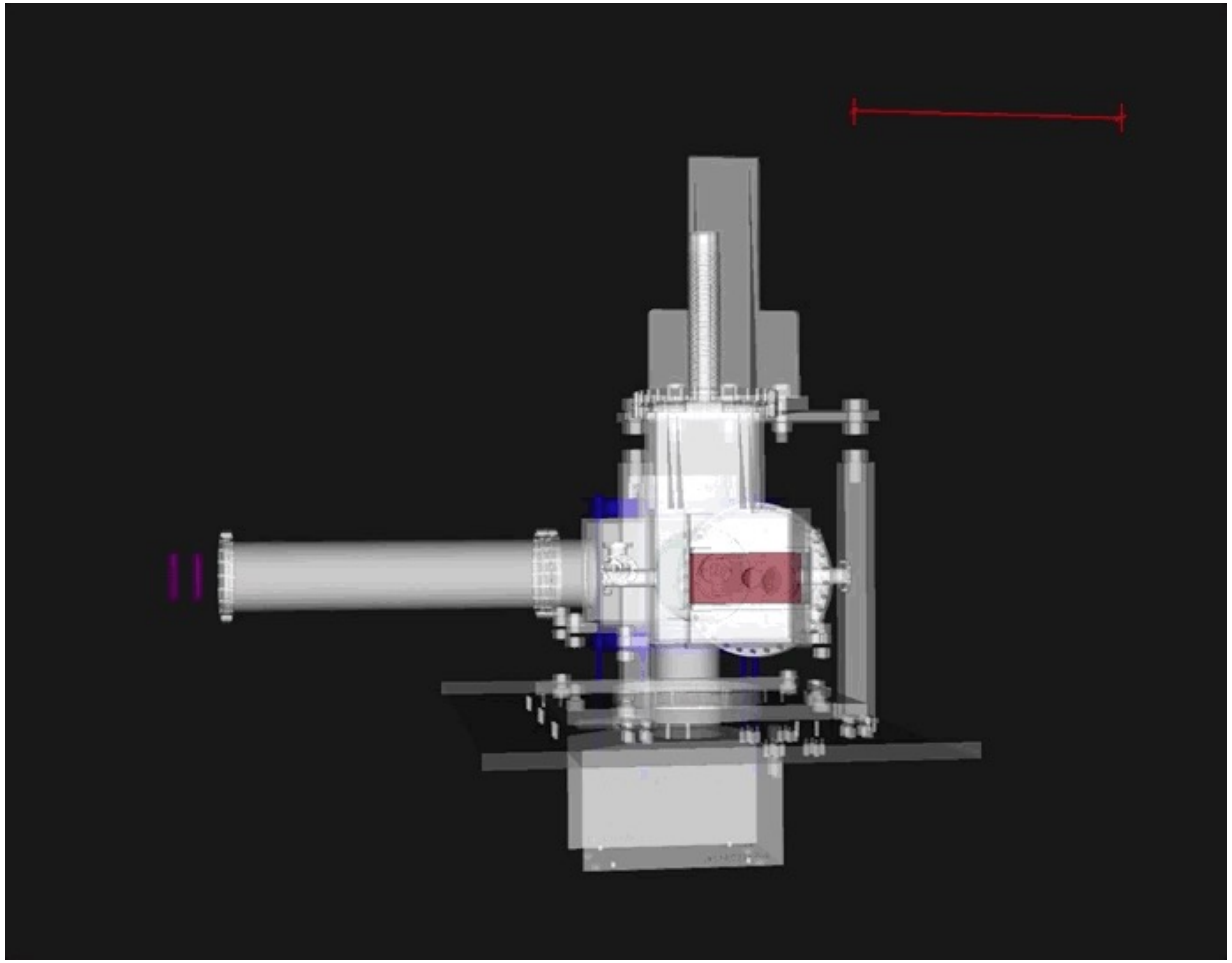
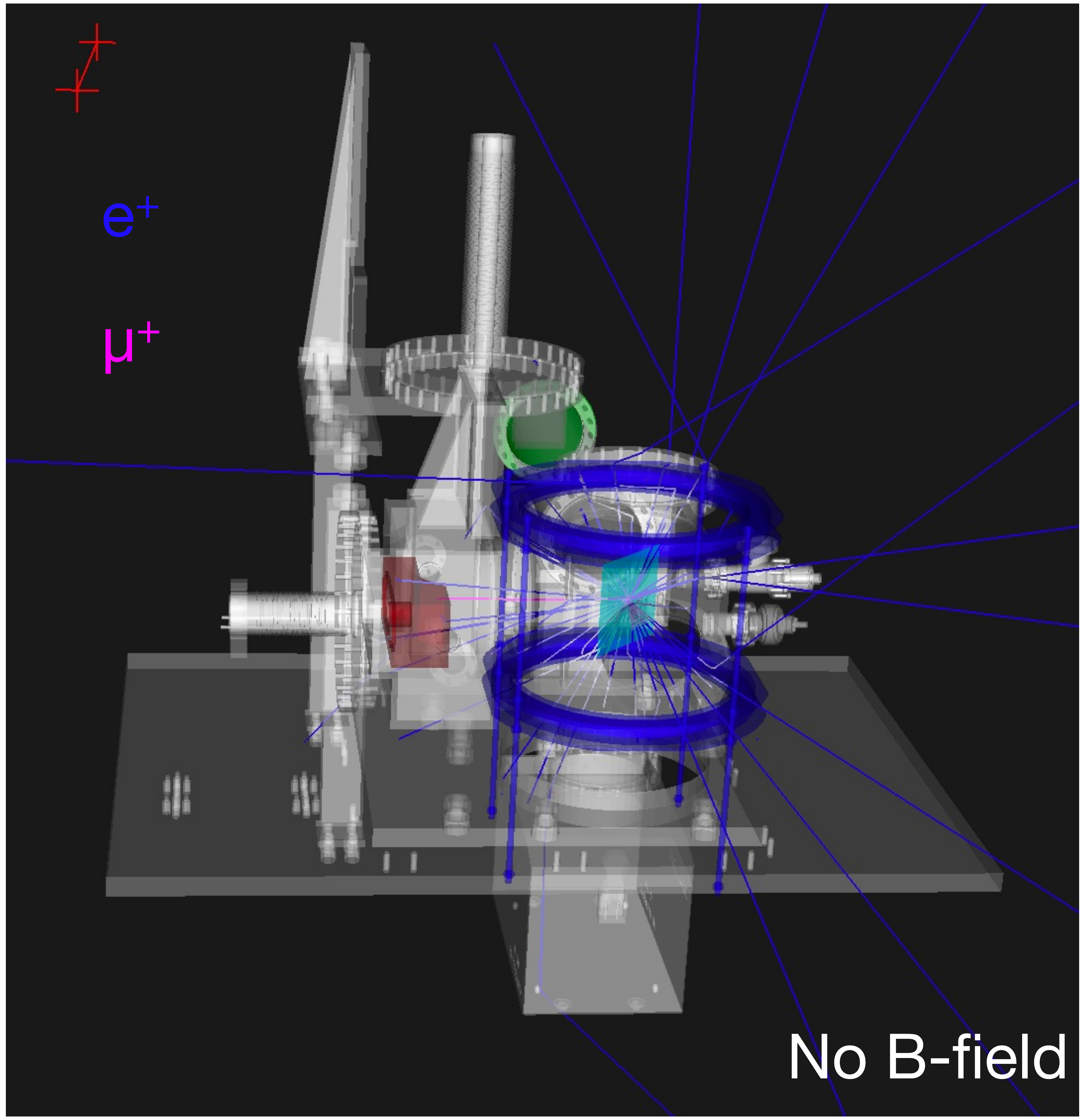
Beam Test musrSim model

- Tang's preliminary model (5 Nov 2025) were implemented in geant4-based musrSim.
  - CAD -> STL -> GMDL via CADMesh
- The following features are implemented
  - Muon distribution at the Cu target
  - Grey: Chamber and peripherals (Steel)
  - Red: Muon production target (Cu)
  - Cyan: Muon stopping target (Al)
  - Blue: Coils (Fe)
  - Green: Beam window (Ti)
  - Magenta: Positron detectors (Virtual)
- Yet-to-be implemented
  - Some complex parts (threads) have been removed to reduce memory usage
  - The magnetic field will be implemented from the measured field map

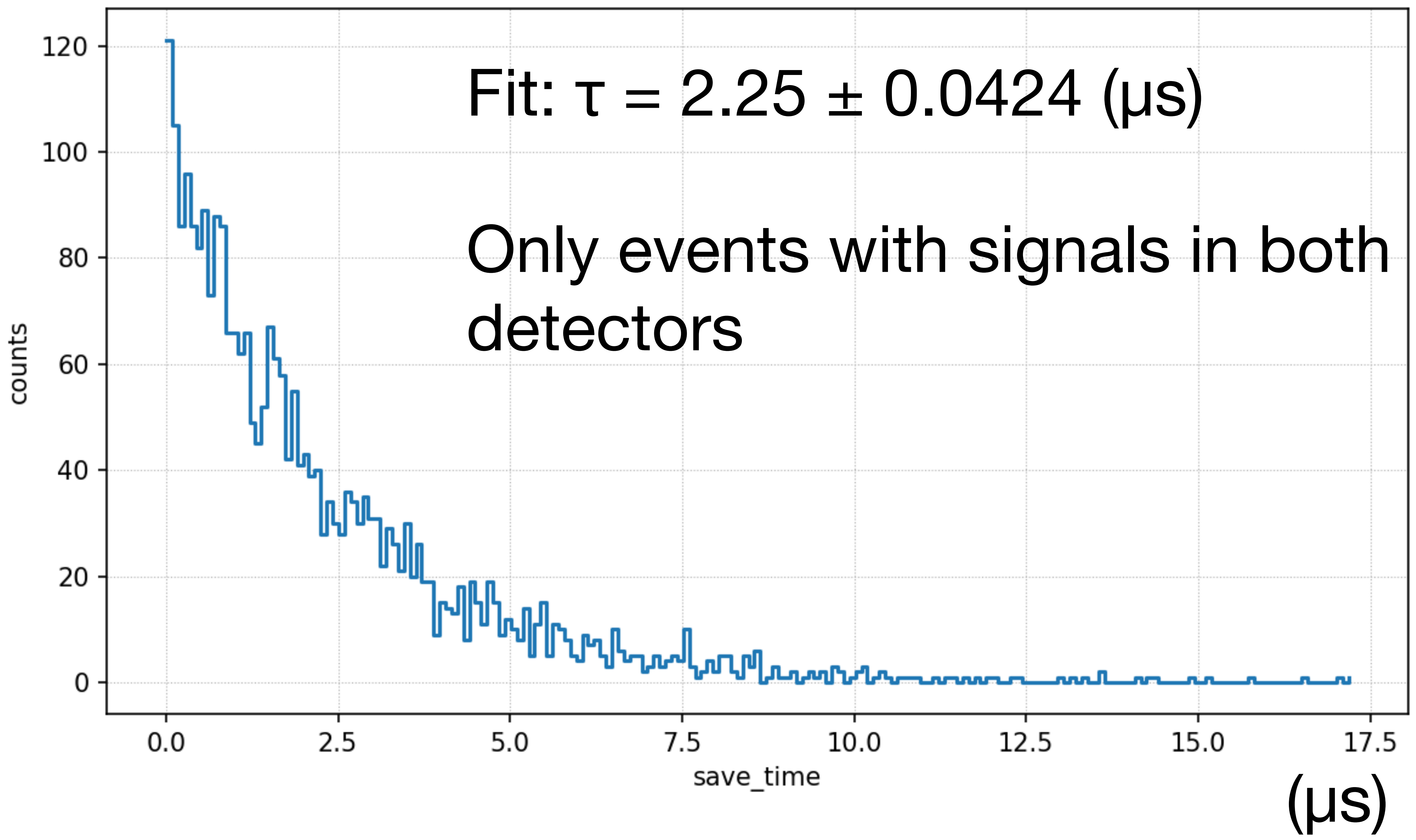


musrSim output to VRML

Beam Test musrSim model



(Pencil beam is used for vis. purpose, only e⁺, μ⁺)



Shielding and background particles will be implemented

Summary

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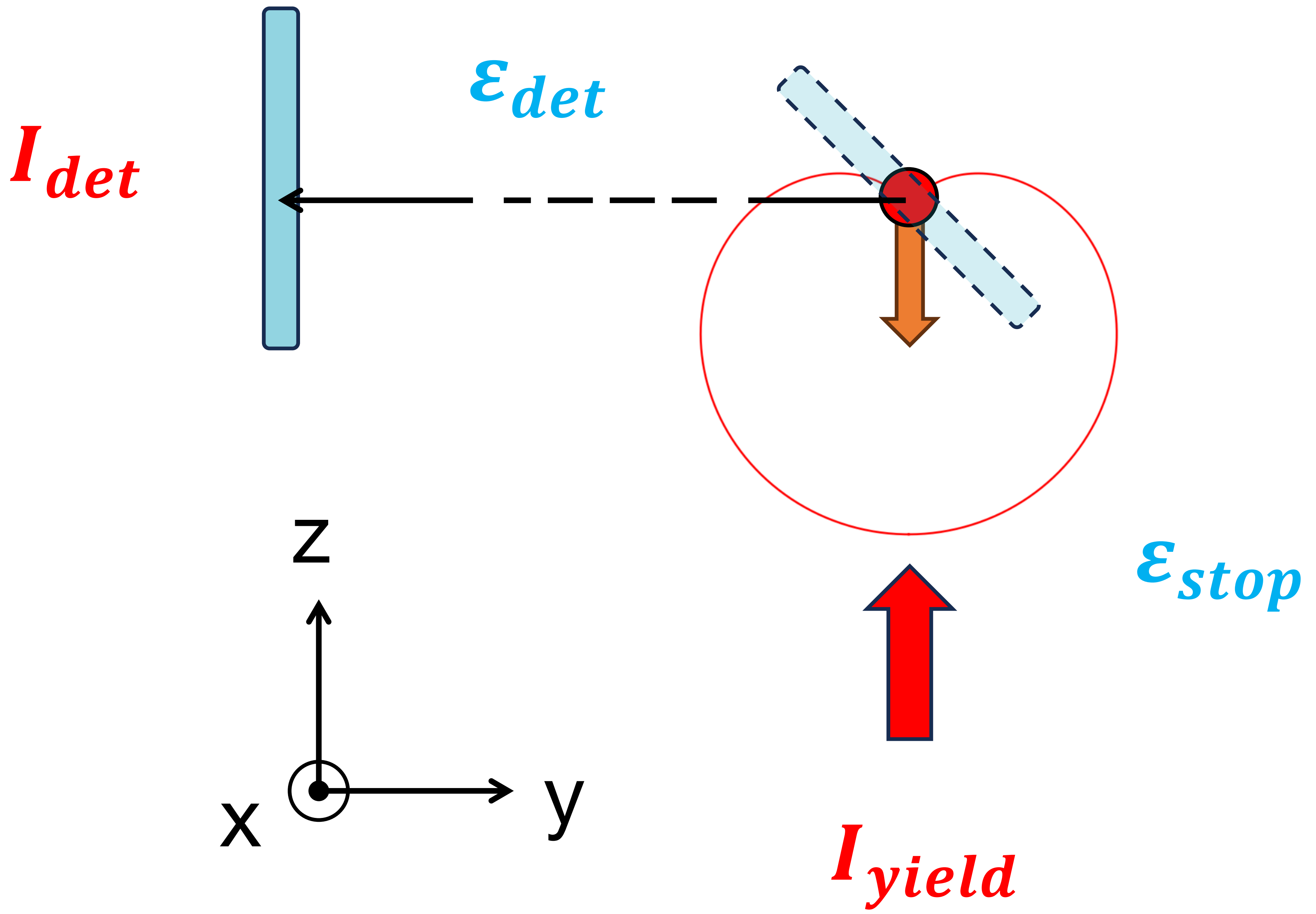
- SHINE electron beamline status: Injector & L1 commissioning finished as on 2025. Installation of Linac/Switchyard/FEL section in progress. Commissioning is expected to start on May 2026.
- A beam test to validate electron driven surface muon yield is planned at shaft#2 area at FEL-II. The planned electron beam parameters are 2 GeV, 50 pC @ 10 Hz. Vacuum chamber, targets (Cu, Al) and coil for the beam test has been designed and are ready for production.
- The positron detector for the beam test has been developed in the laboratory. The feasibility of the detection scheme was tested with cosmic muons. Further works to understand the PID.
- A musrSim model of the beam test with geometry and muon distribution is in development. The simulation will be used to cross check the beam test results.

Backup Slides

Estimating μ^+ yield from e^+

- Number of detected e^+ / sec

$$I_{det} = \underbrace{\overbrace{I_{yield} \times \varepsilon_{stop}}^{\text{Stopped } \mu^+} \times \varepsilon_{det}}_{\text{Detected } e^+} \times f_{rep}$$



I_{yield} : Surface μ^+/ bunch, intensity" (MC) : **790 μ^+/ bunch**
ε_{stop} : Surface μ^+ stopping efficiency (MC) : **0.18**
ε_{det} : acceptance (geometrical, MC) : $\mathbf{8\times10^{-4}}$
f_{rep} : Beam repetition rate

Data taking time --> 1 hour for 10,000 events with 10 Hz repetition rate

Effects of background , scintillator detection efficiency not yet taken into account

- Number of detected e+ / sec

$$I_{det} = \underbrace{\overbrace{I_{yield} \times \varepsilon_{stop}}^{\text{Stopped } \mu^+} \times \varepsilon_{det}}_{\text{Detected } e^+} \times f_{rep}$$

I_{yield} : Surface μ^+/ bunch, intensity” (MC) : **790 μ^+ / bunch**
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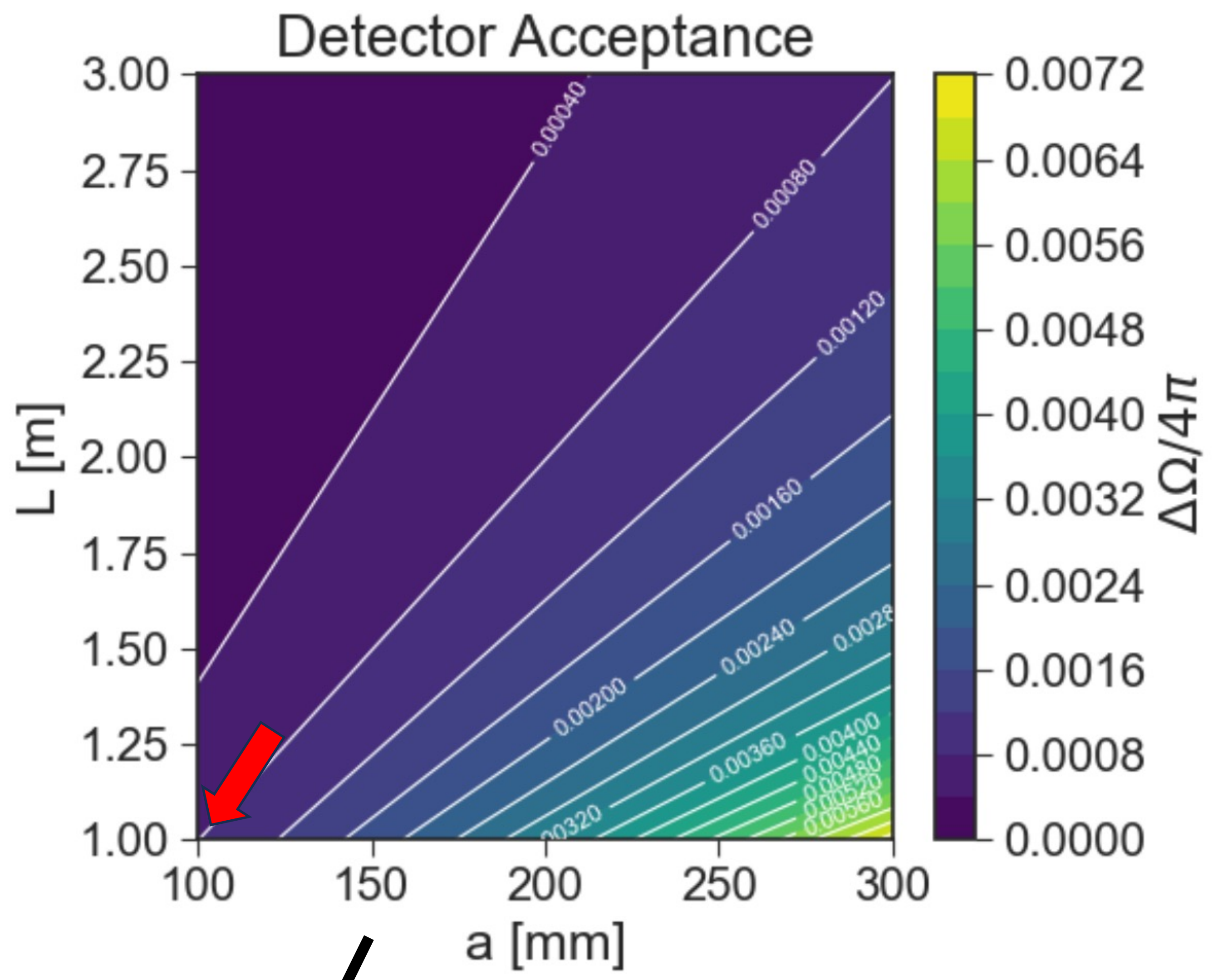
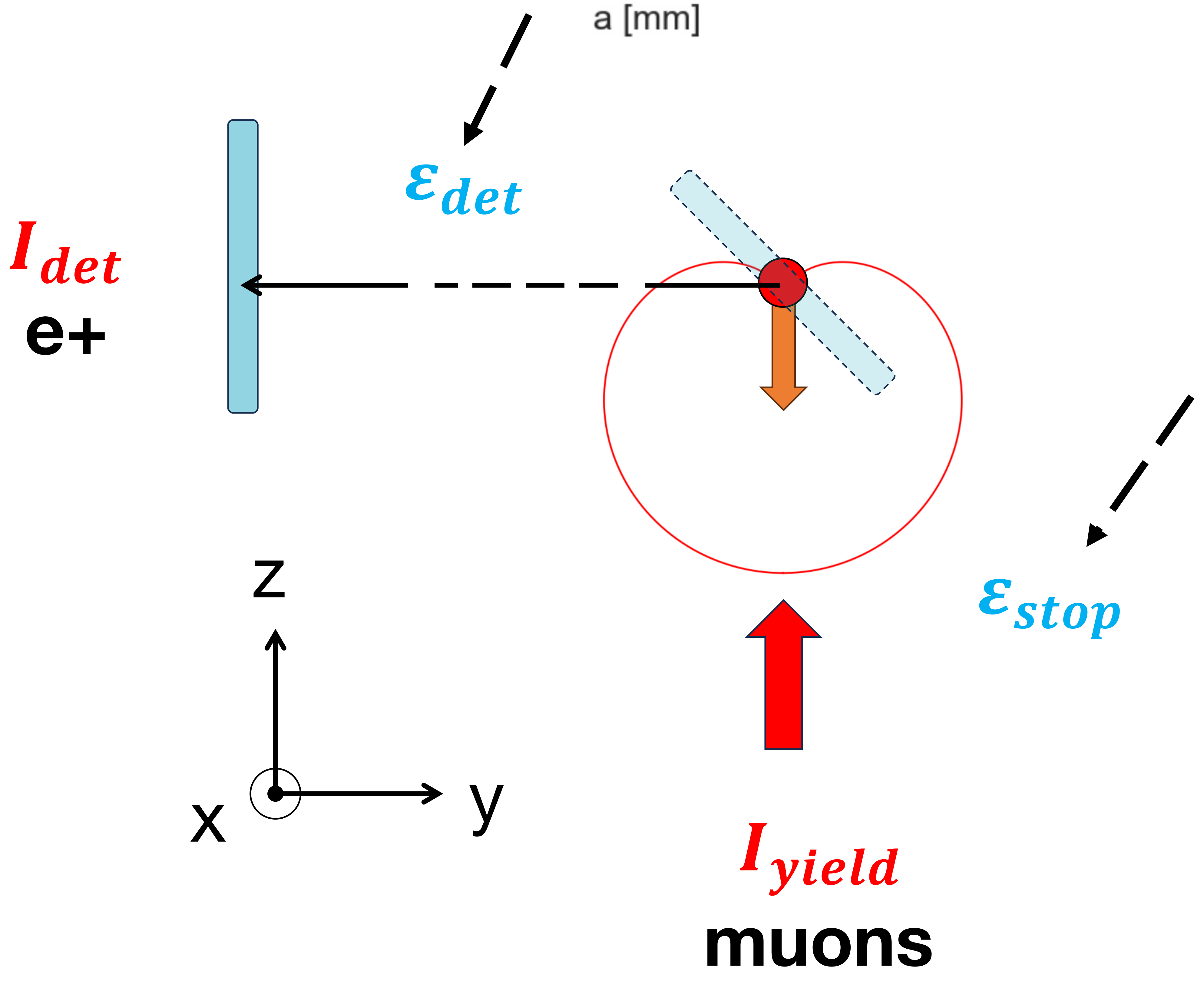
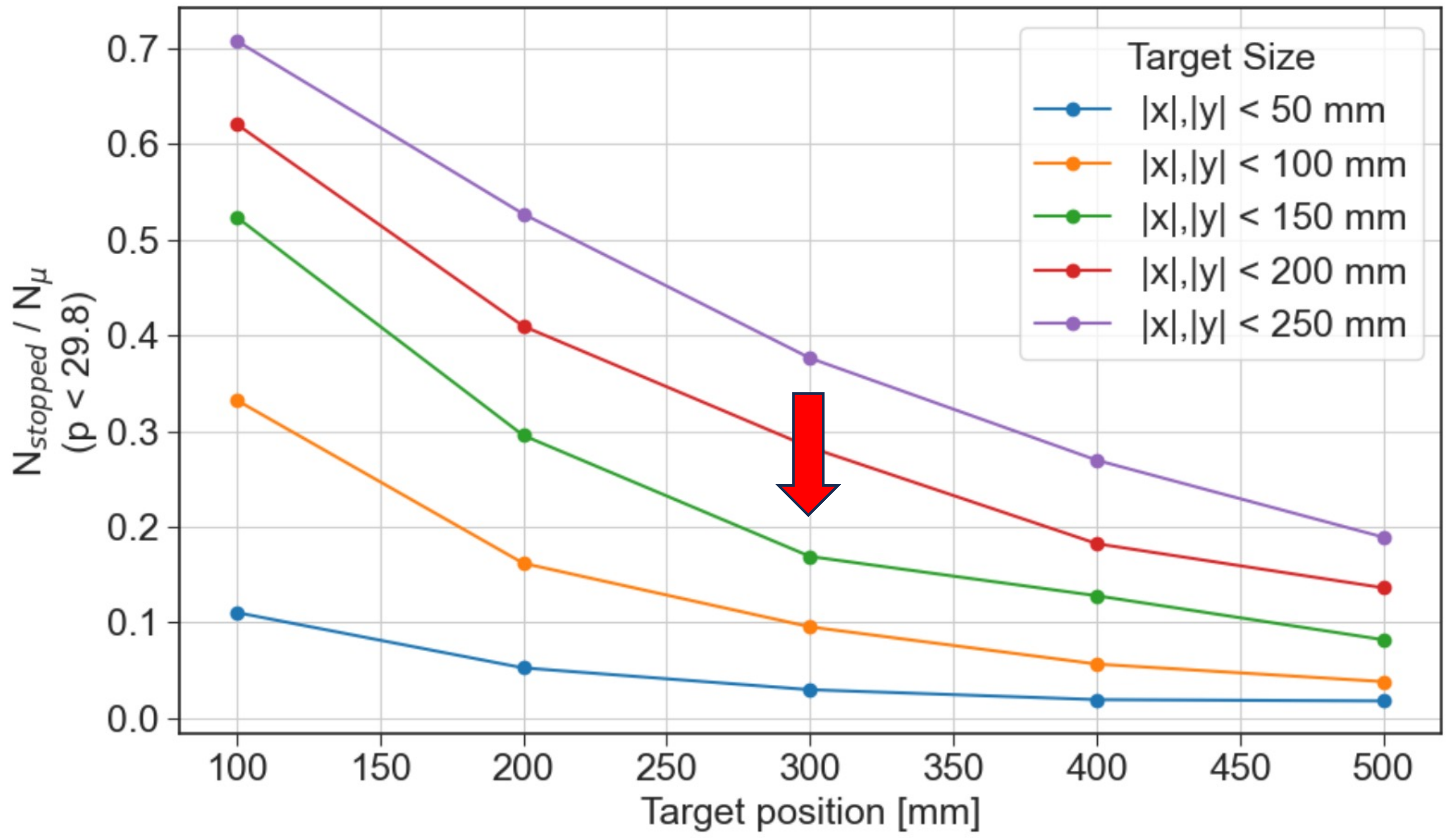


detector acceptance as a function of scitillator dimension and Al-Scint distance



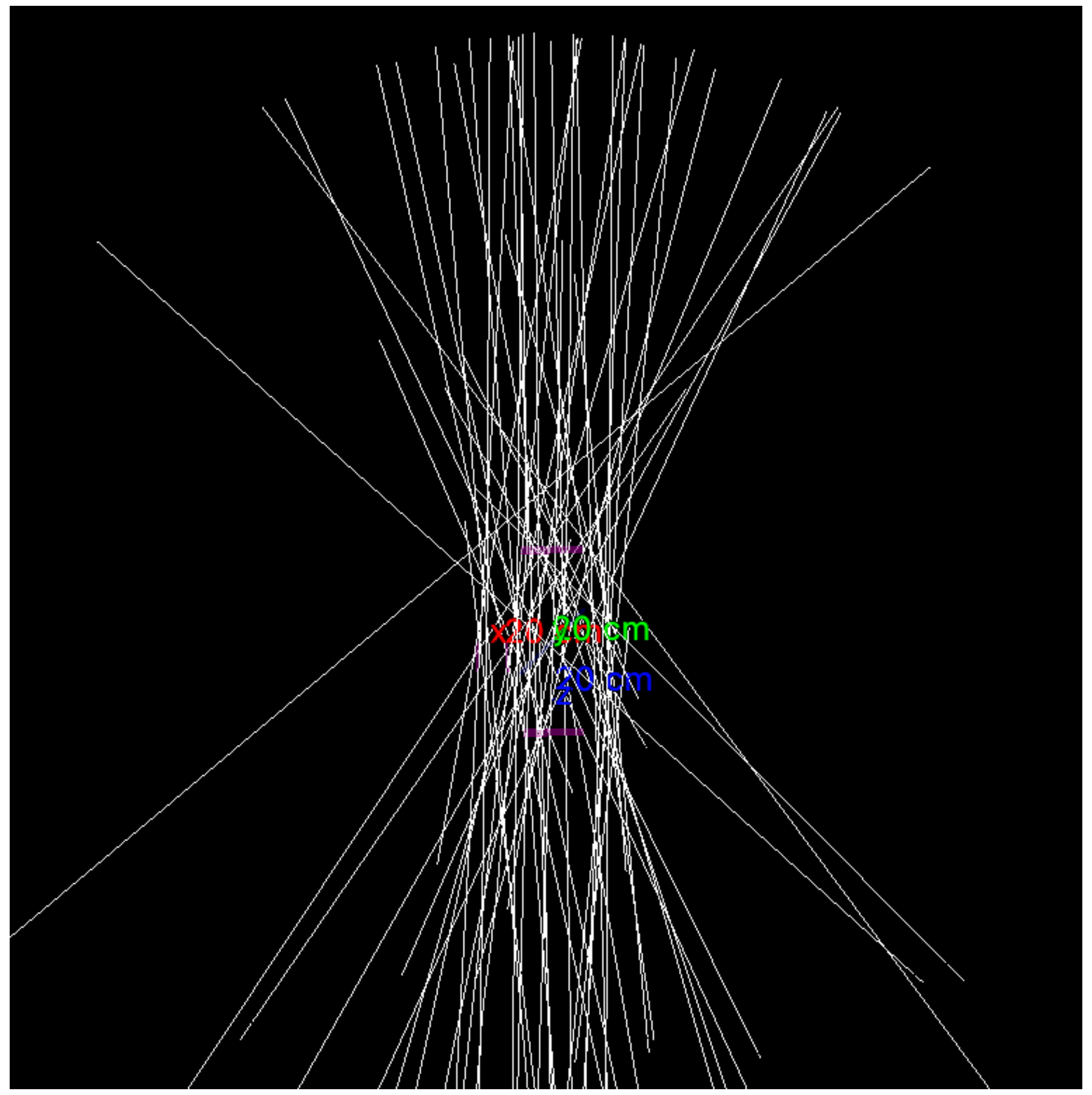


Muon stopping efficiency as a function of the Al target dimension and Cu-Al distance

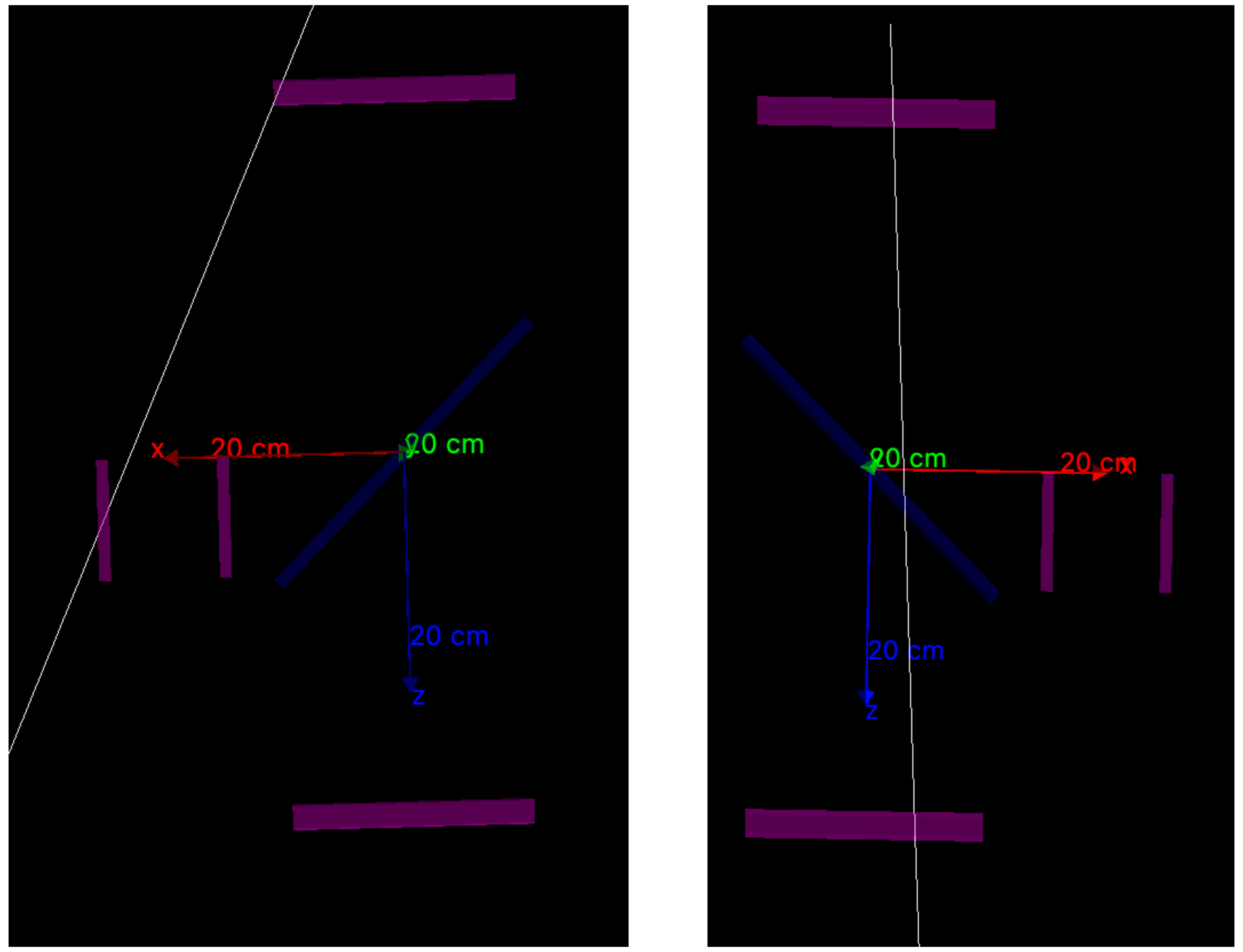
Lab Test Simulation

- A crude g4bl model of the lab test was setup to estimate the expected rate of detected muon decay events. Cosmic ray muon distribution was implemented in g4bl.
    - Implemented : Exact detector, target dimensions, position (not precisely measured)
    - Not implemented: Detector response (the simulation is at truth-level)
- We analyzed events with 1/2/3 hits
    - The detection rate is 0.002 %, consistent with observed lab test rate (later)

CR in g4bl



Two hits events



A muon decay event