Positron Detection System of Muonium-to-Antimuonium Conversion Experiment

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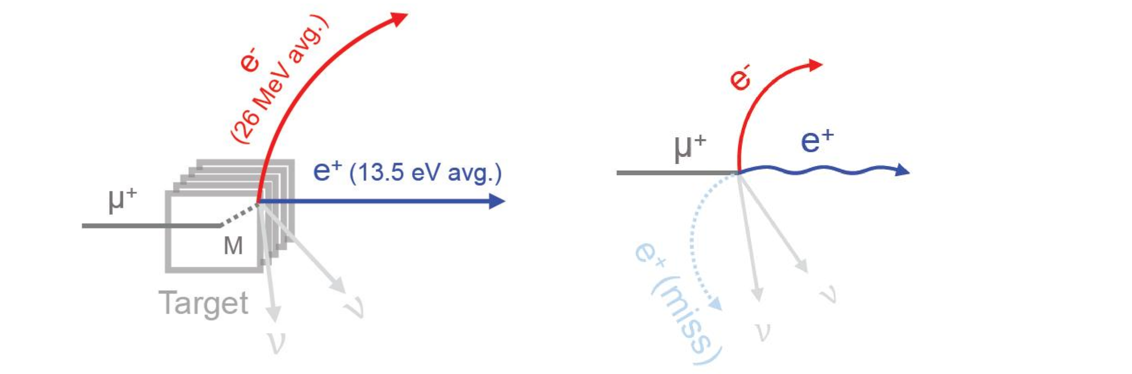
Introduction

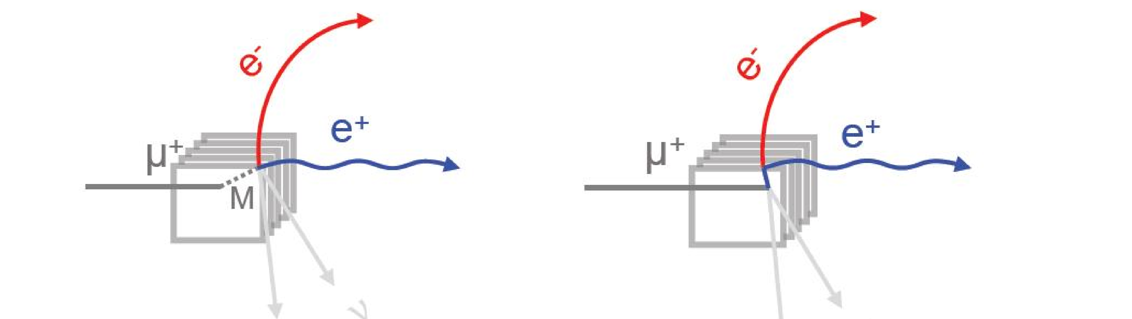
Inspired by neutrino oscillation, which is a kind of flavor mixing process, we embarked on a study to explore charged lepton flavor violation (cLFV). A novel method to probe cLFV is by investigating the spontaneous conversion from muonium to antimunonium. The original idea was first brought by Pontecorvo in 1957. In 1999, the upper limit on the muonium-to-antimuonium conversion probability, established at $P \leq 8.3\times10^{-11}$ at 90% confidence level, in the MACS experiment at PSI.

Over the past few decades, significant advancements in detector technology and muon sources will lead to new possibilities in design of lepton flavor violation experiments. We aim to improve the present upper limit of the conversion probability by more than two orders of magnitude in the proposed Muonium-to-Antimuonium Conversion Experiment(MACE).

A critical component of the MACE detector system is the positron detection system (PDS), which consists of s a MCP and a spherical ECAL. The MCP will provide an accurate start time and detection initial position of electron or positron event. Subsequently, the ECAL is employed to detect the characteristic 0.511 MeV gamma from positron annihilation. By reconstructing the signals from the MCP and ECAL, the system can effectively identify and confirm positron events.



(a) M-to-$\overline{M}$ conversion **signal.** (b) **Background**: SM allow rare decay $\mu^+ \to e^+e^-e^+\nu_e\overline{\nu_\mu}$.



(c) **Background**: muonium decay with Bhabha scattering. (d) Accidental **backgrounds.**

Fig. 1 Event topologies for signals and backgrounds.

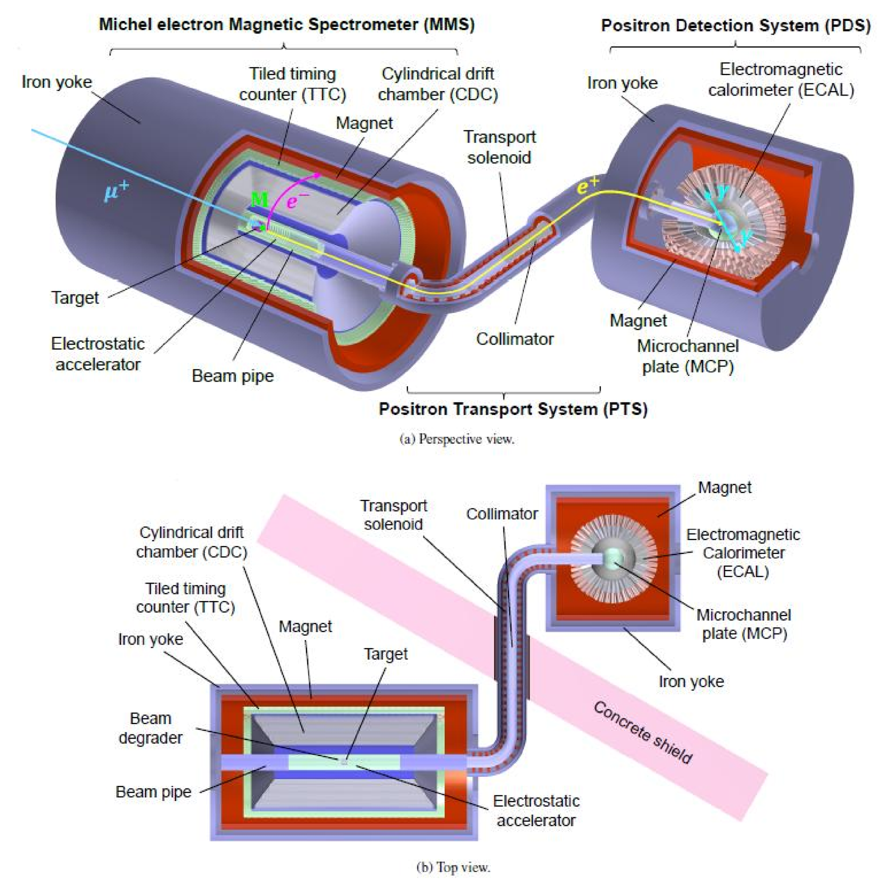


Fig. 2 Overview of MACE detector system[1]. In this poster, we mainly focus on the positron detection system.

Experiment setup and method

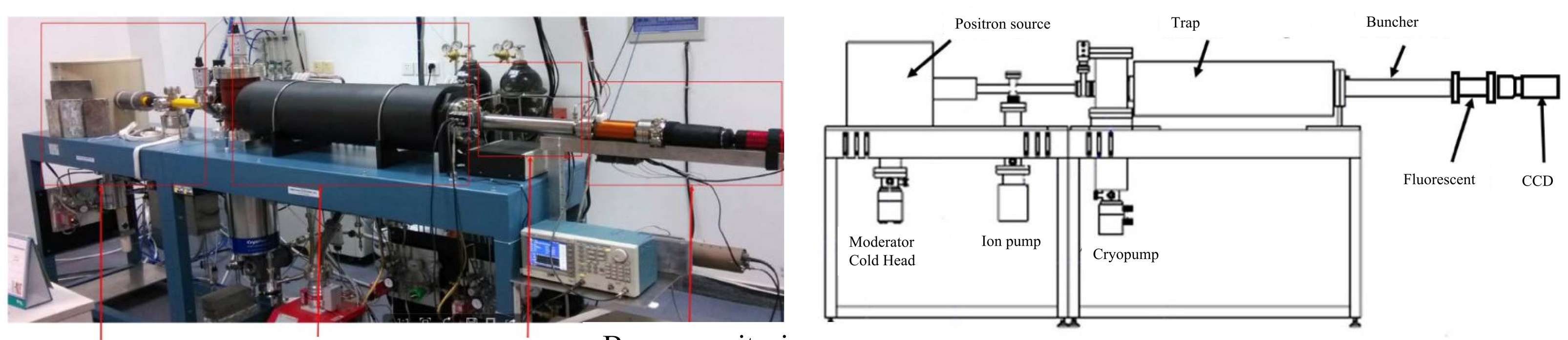


Fig.3 Positron beam based on solid neon moderator[2].

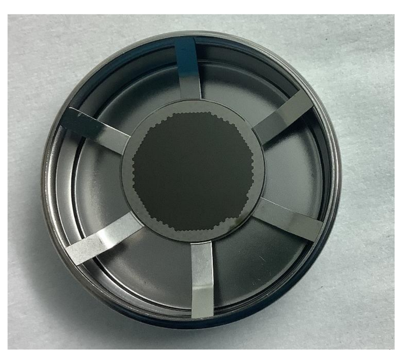
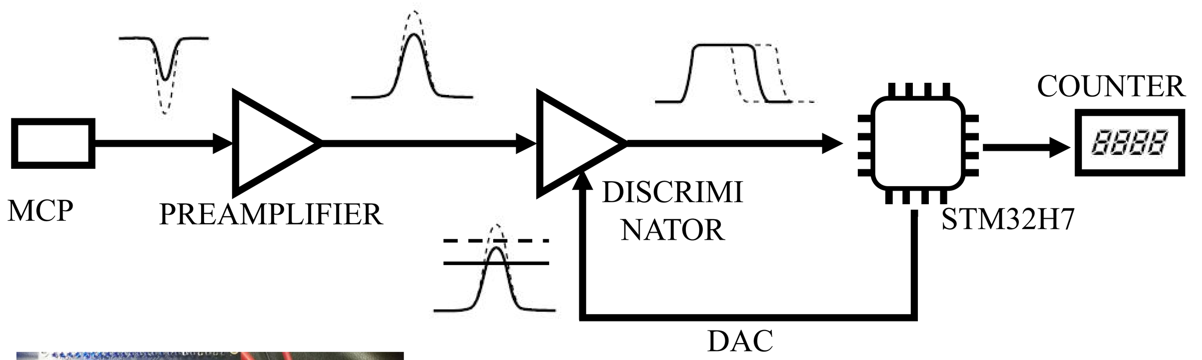


Fig. 4 Φ25 Lead free MCP enhances the efficiency of the positron coincidence system.



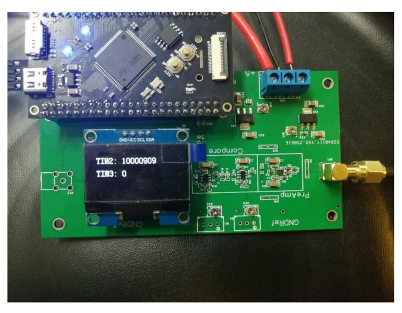


Fig. 5 A pulse counting system for the output signal of MCP is implemented using the STM32H7, which offers a cost-effective and user-friendly solution.

Wavelength	Decay Time	Light Output	Energy Resolution	Radiation length for 0.511MeV
480 nm	300 ns	8000–10000 photons/MeV	10.00 % @0.511MeV	1.1 cm

Fig. 6 We select BGO scintillator crystals for the electromagnetic calorimeter, as the table above shows BGO crystals excellent performance[3].

Conclusion

- A preliminary test was conducted on the positron detection system. The BGO-PMT achieve a good time resolution for the coincidence of the annihilation gamma-ray process, which is approximately 2.9 ns in our experiment.
- The lead-free MCP achieves a detection efficiency of approximately 30% for positrons with impact energies ranging from 400 eV to 1200 eV. The positron detection efficiency increases with higher impact energies. In the future experiments, a delay line anode or multi-anode will be used to acquire the spacial information of the detected particles.

Performance testing of the positron detection system

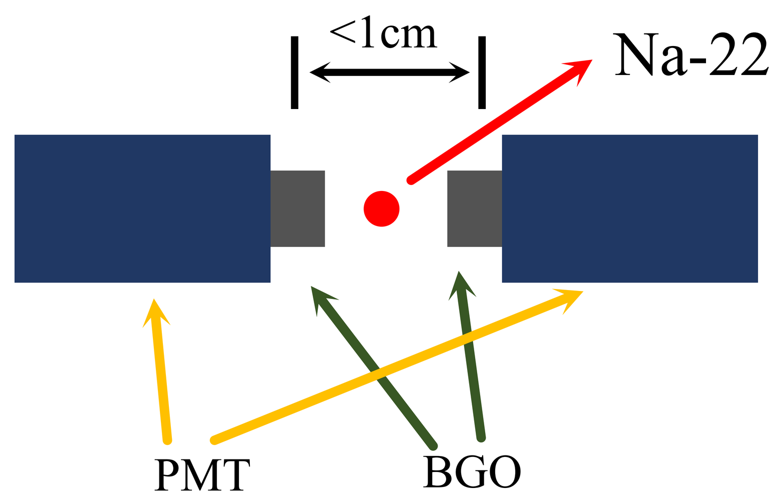


Fig. 7 The time resolution measurement system for BGO scintillation coupled with a PMT

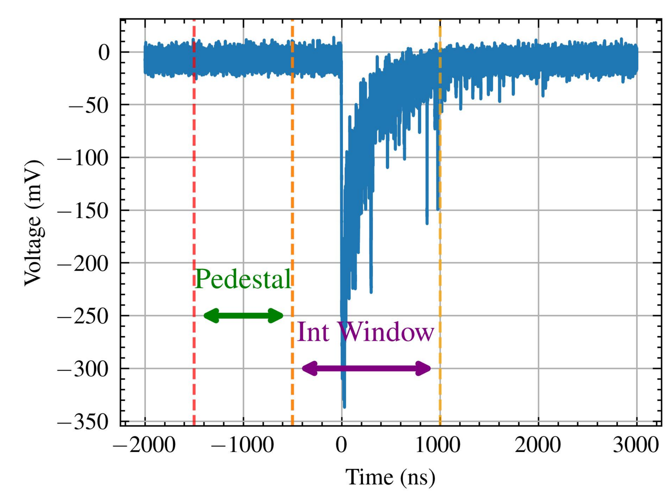


Fig. 8 Output signal of the PMT

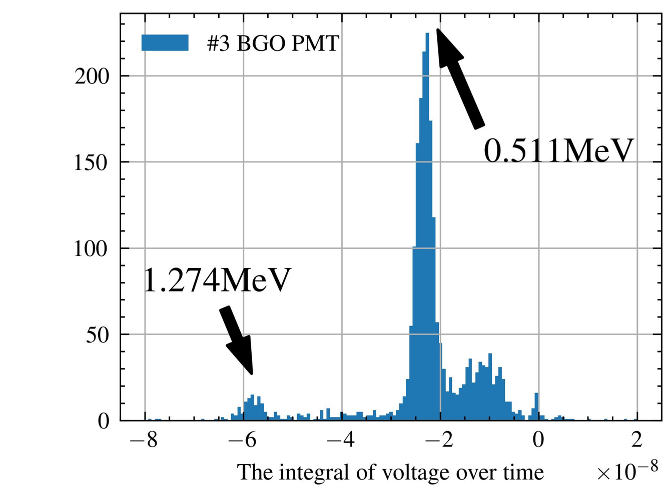


Fig. 9 Energy Spectrum of Na-22 Decay Measured by BGO-PMT.

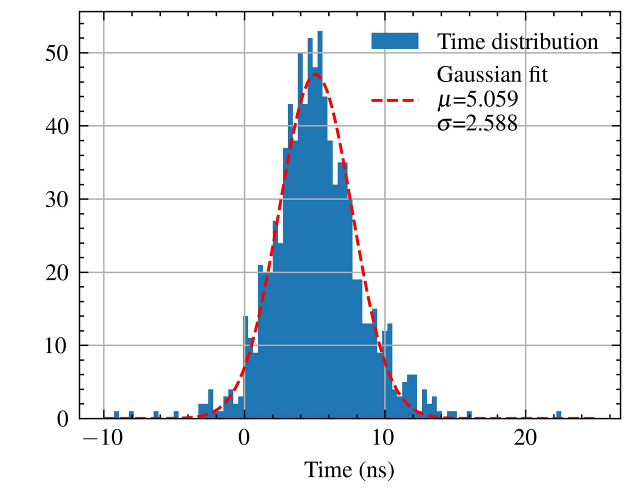


Fig. 10 Time diffidence between the two coincidence PMT. Gaussian function fit curve shows that the time resolution is about 2.6 ns.

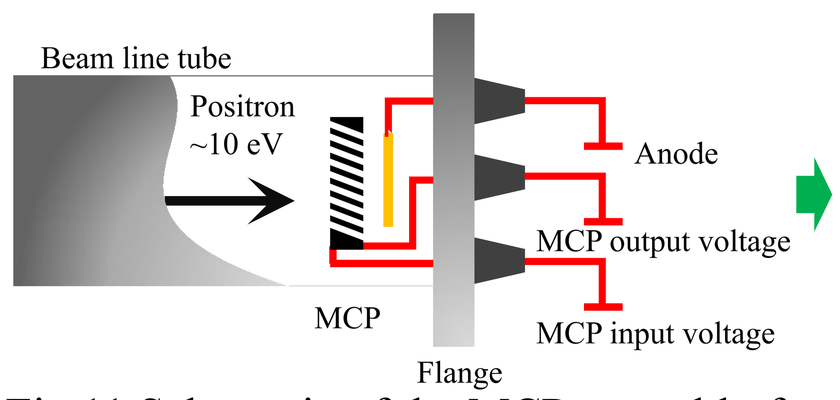


Fig.11 Schematic of the MCP assembly for positron detection efficiency measurement. By varying the MCP input voltage, the positron impact energy can be adjusted.

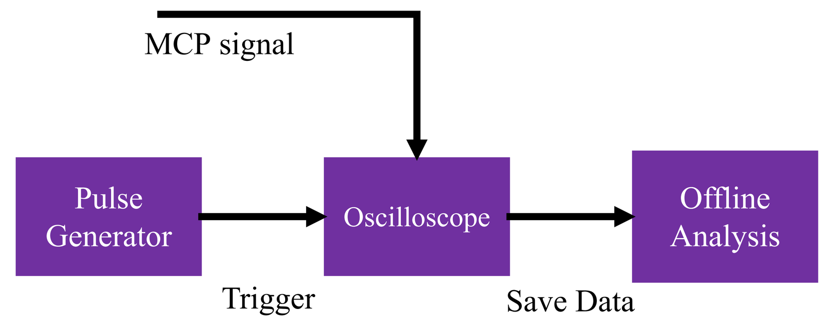


Fig. 12. Block diagram of MCP positron detection efficiency measurement.

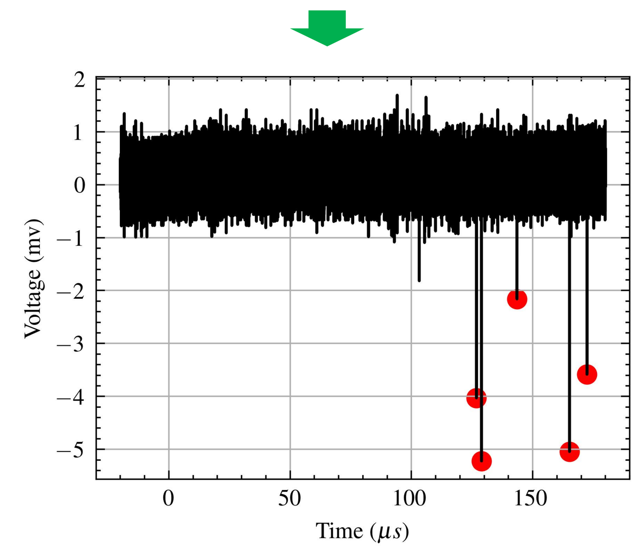


Fig. 13 The signal of positron in a waveform snapshot.

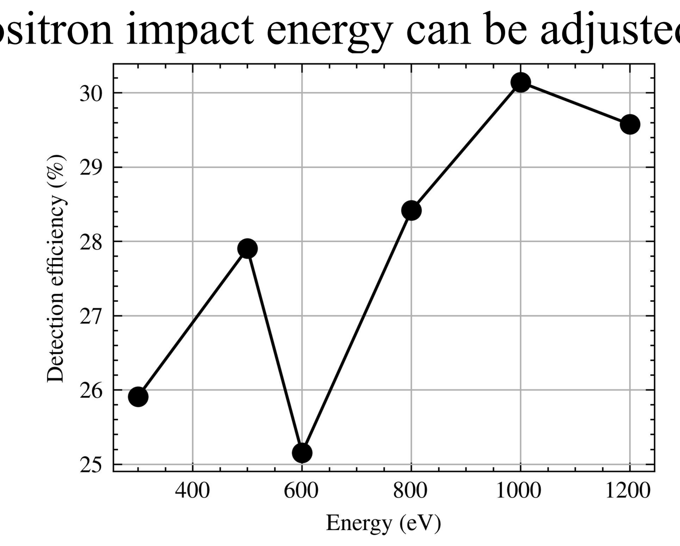


Fig. 14 The positron detection efficiency of MCP under the different impact energy.

Reference

[1] Bai A Y, Cai H, Chen C L, et al. Conceptual design of the muonium-to-antimuonium conversion experiment (MACE)[J]. arXiv preprint arXiv:2410.18817. To appear in Nuclear Science and Techniques.
[2] Bao-Yi W, Yan-Yun M, Ping W, et al. Development and application of the intense slow positron beam at IHEP[J]. Chinese Physics C, 2008, 32(2): 156.
[3] Crylink, BGO scintillator crystals, https://www.scintillator-crylink.com/wp-content/uploads/BGO-scintillator-crystals.pdf (2025).