



Probing Cosmic Ray Composition and Muonphilic Dark Matter via Muon Tomography

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Background and Motivation

- Although dark matter is strongly supported by cosmological observations, no dark matter particle has yet been directly detected. We explore muonphilic dark matter using muon tomography. If a muon interacts with dark matter while traversing a region, its trajectory may be deflected and recorded by surrounding tracking detectors.
- Cosmic-ray muons are used as probes, but secondary cosmic rays at sea level also contain electrons, photons, neutrons, and other particles. Precise knowledge of this composition, especially the non-muon background, is essential for dark matter searches.
- The key idea of this work is to use the scattering angle to simultaneously study near-ground cosmic-ray composition and search for muonphilic dark matter.

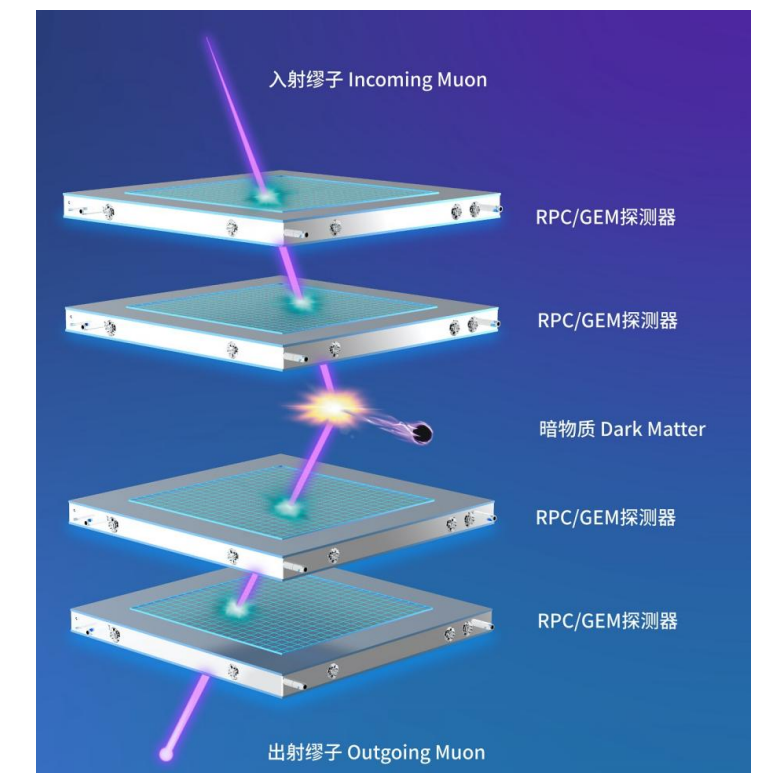


Fig.1 Schematic illustration of dark matter detection via muon tomography

Experimental Setup and Simulation

- The experiment uses a four-layer glass RPC (Resistive Plate Chamber) muon tomography system, with layer gaps of 20 cm, 50 cm, and 20 cm. Each RPC has an active area of $28 \times 28 \text{ cm}^2$, a spatial resolution better than 1 mm, and a two-dimensional position reconstruction efficiency of about 85%. The scattering angle θ is defined from the reconstructed upper and lower tracks, as shown in Fig. 2.

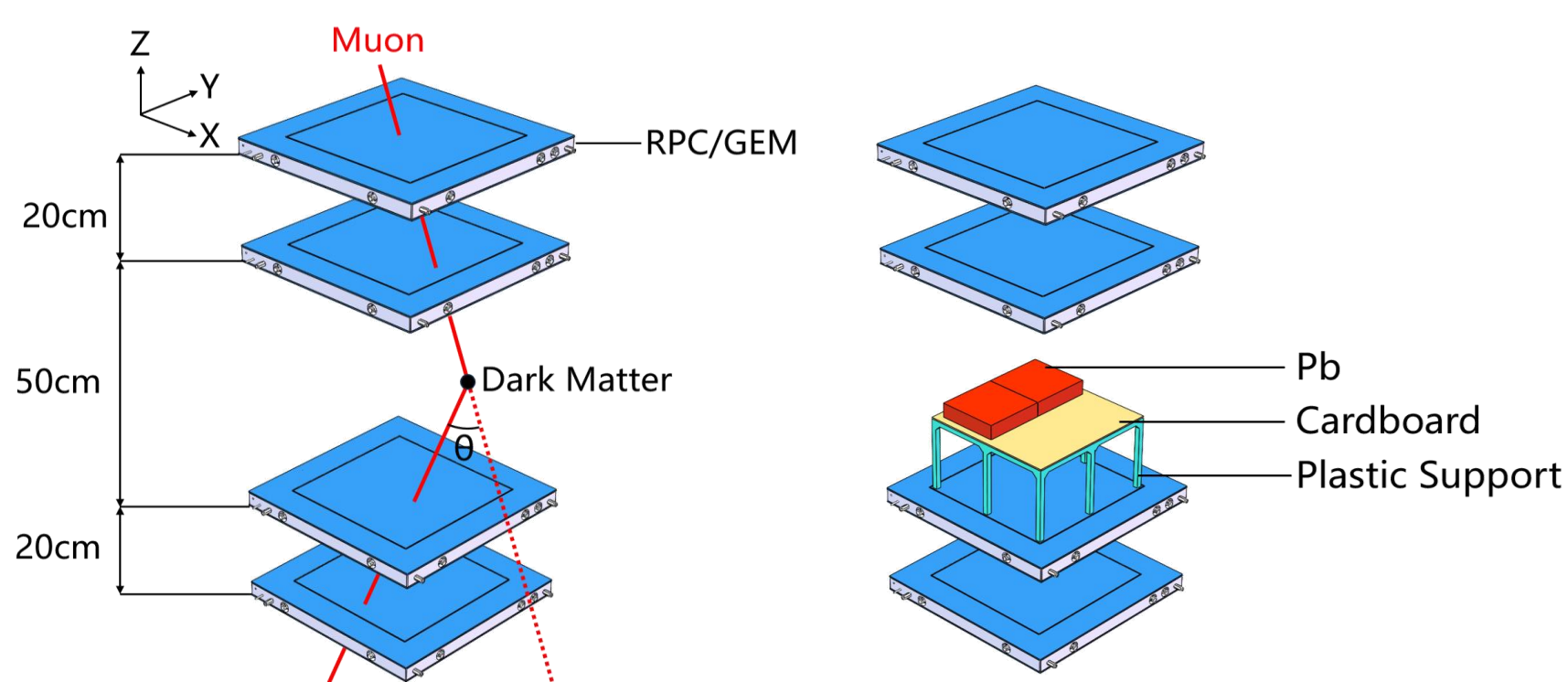


Fig.2 Experimental setup: Physics Run (Left); Control Run (Right)

- The scattering position and angle are reconstructed using the PoCA (Point of Closest Approach) method. By fitting the data with simulated templates for different particle species, the cosmic-ray composition is extracted and dark matter scattering is constrained.
- Two runs were performed: a 63-day Physics Run in air and a Control Run with lead blocks for background validation. Simulations were performed with CRY (Cosmic-Ray Shower Generator) and Geant4, including detector resolution and response effects.

Event Selection and PoCA Point Reconstruction

- To suppress background from surrounding materials, only events with valid two-dimensional hits in all four RPC layers were selected. The scattering point was reconstructed using the PoCA method, and only events within the central fiducial volume ($X, Y, Z \in (-110 \text{ mm}, 110 \text{ mm})$) were retained. The scattering angle was further restricted to 0.05–0.5 rad..

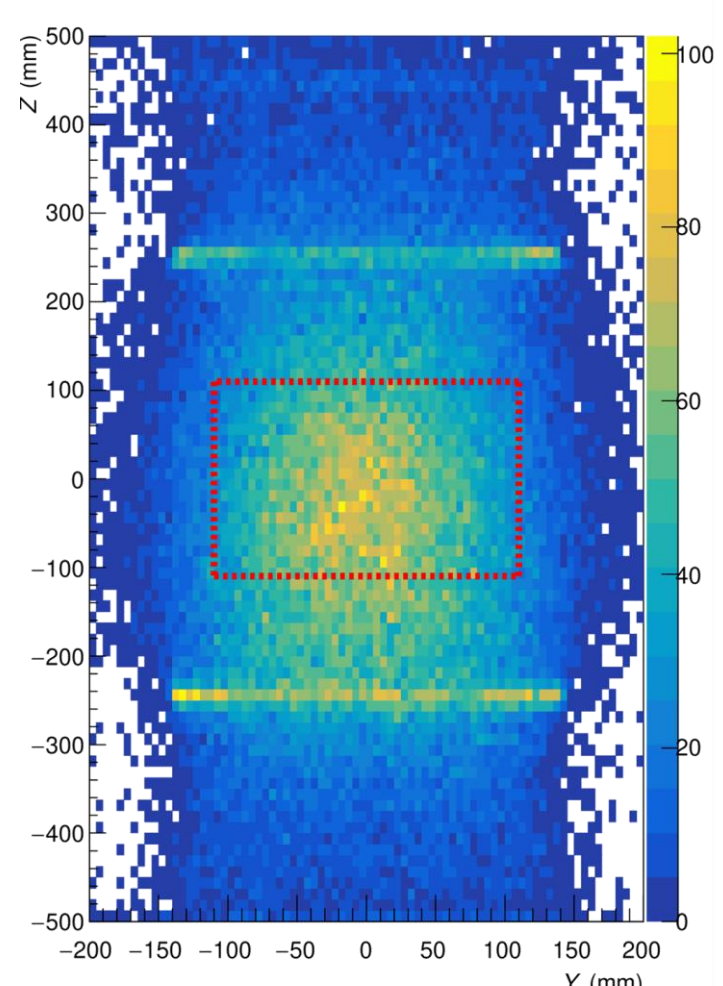


Fig.3 Distribution of PoCA points. Red dashed box: fiducial volume.

- The PoCA distribution shows enhanced large-angle scattering near the RPC surfaces and outer regions, indicating contributions from surrounding building materials. (See Rongfeng Zhang's poster)

References

- [1] C.-e. Liu, R. Zhang et al., Phys. Rev. Lett. 136, 151001 (2026)
[2] R. Zhang, Z. Qin, C.-e. Liu et al., J. Appl. Phys. 139, 014903 (2026)

Cosmic Ray Composition

- A multi-template fit to the scattering-angle distribution was performed to extract the contributions from different particle species. In the selected angular range, the Physics Run contains about $35.1\% \pm 5.2\%$ muons and $52.5\% \pm 2.5\%$ electrons. The electron fraction is measured with a precision of about 2%, as shown in Fig. 4.

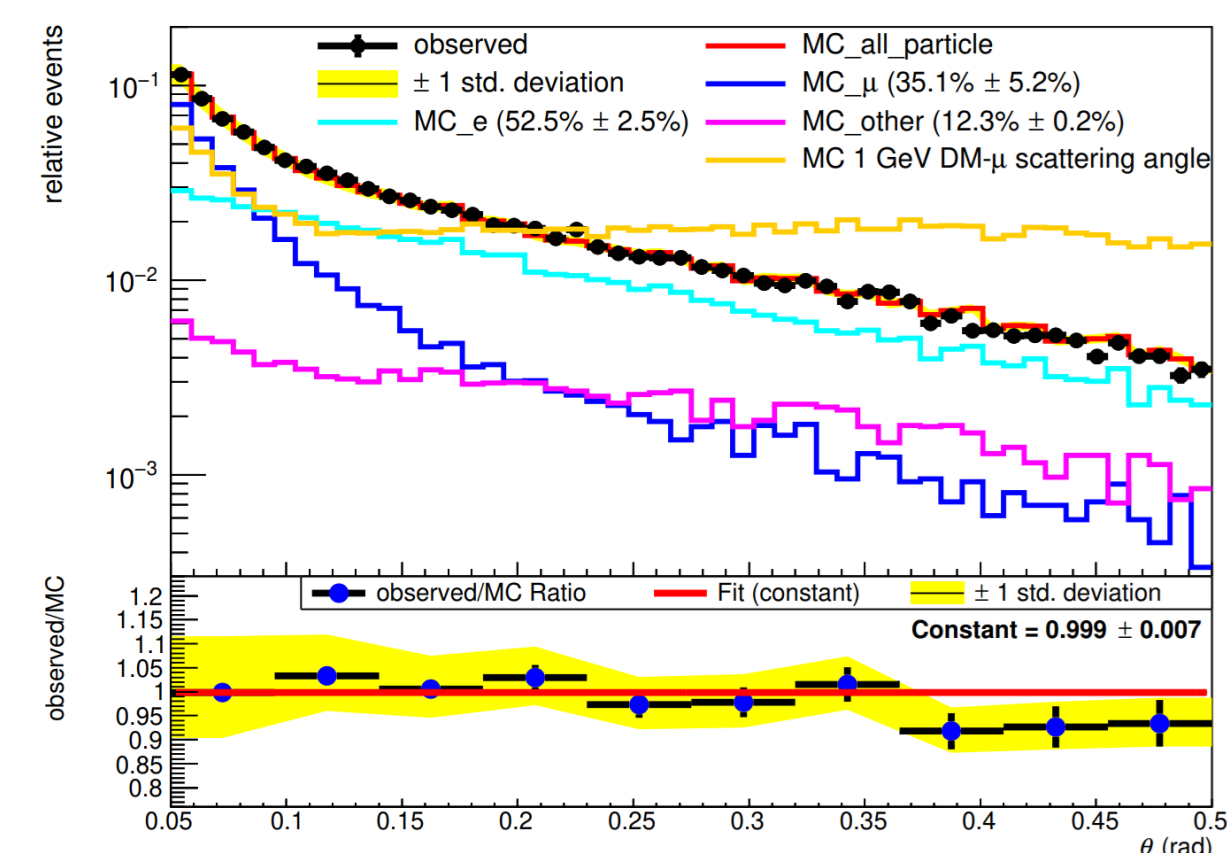


Fig.4 Fit result of the scattering-angle distribution

- These results show that RPC-based scattering measurements can distinguish different particle components and provide precise information on the near-ground cosmic-ray composition.

Muonphilic Dark Matter

- Using the same scattering-angle analysis, we constrain elastic scattering between cosmic-ray muons and slow muonphilic dark matter. A 95% C.L. upper limit on the muon-dark matter scattering cross section is derived from the data (Fig. 5). For a 1 GeV dark matter particle, the limit is about $1.61 \times 10^{-17} \text{ cm}^2$.

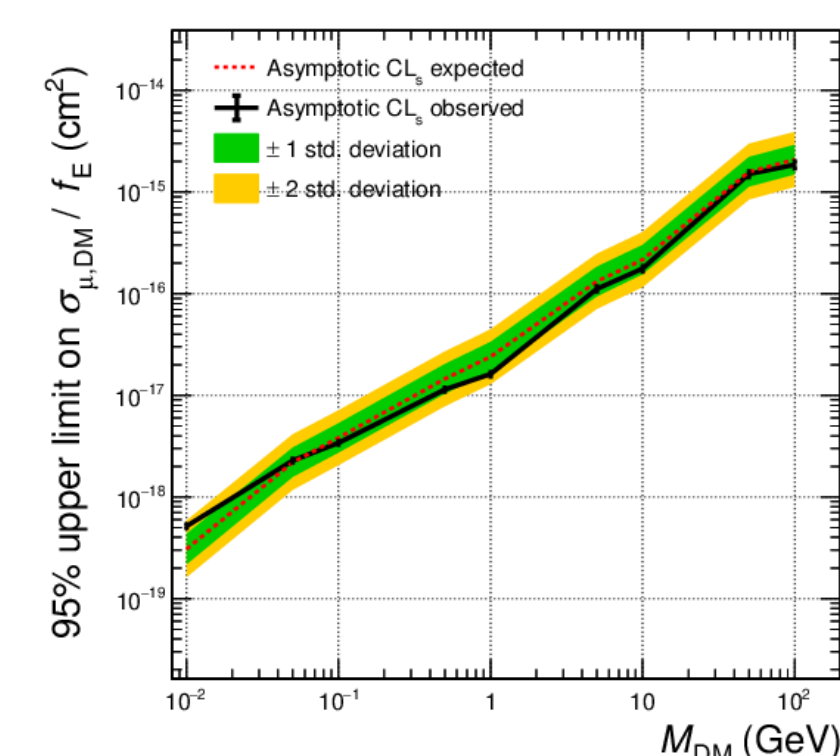


Fig.5 Upper limit on the cosmic-ray muon-dark matter scattering cross section

Summary and Outlook

- A four-layer RPC-based muon tomography system was developed and validated. Using scattering angle as a unified observable, this work measured near-ground cosmic-ray composition and constrained muonphilic dark matter.
- With larger detectors, higher statistics, and future muon sources, this method can achieve higher sensitivity.