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Theoretical Time Cost to Distinguish Special Nuclear Materials in Different Scenarios through MPRC-ToF based MST

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Muon scattering tomography (MST), which has gained significant attention in recent years, is a novel radiation imaging technique evolving into two research directions: rapid inspection and detailed imaging. Increasing research shows that fully utilizing the momentum information of muons is essential to achieve satisfactory results for both two directions. MRPC (Multi-gap Resistive Plate Chamber) detectors are renowned for their excellent time resolution and high detection efficiency for charged particles and are widely used in Time-of-Flight (ToF) systems in high-energy physics experiments. Our resent research shows the time resolution of very narrow gaps MRPC can reach 16 ps. Therefore, MRPC holds great potential in muon imaging where momentum information needs to be considered.

In this study, using the GEANT4 toolkit and ROOT's TMVA toolkit, focusing on rapid inspection, we conducted detailed simulations under various background conditions, including different volumes, geometrical setups, materials and shielding methods. We evaluated the rapid response capability of the MST system for typical special nuclear materials using MRPC detectors as ToF to obtain muon momentum and true muon momentum, applying unsupervised classification methods like EM-GMM and supervised classification methods like BDT, CNN and DNN. The results show that using CNN for classification, the MRPC-ToF based MST system can achieve an accuracy of over 92.8% within 45 seconds with a geometrical acceptance of 45.2%. When the geometrical acceptance is 18.8%, the accuracy is then 81.26%, which demonstrates that using MRPC detectors as ToF to acquire muon momentum information for a fast-responsive MST system is highly feasible.

Primary author: CHEN, Ziyang (Tsinghua University)

Presenter: CHEN, Ziyang (Tsinghua University)

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