Towards a muon scattering tomography system for both low-Z and high-Z materials

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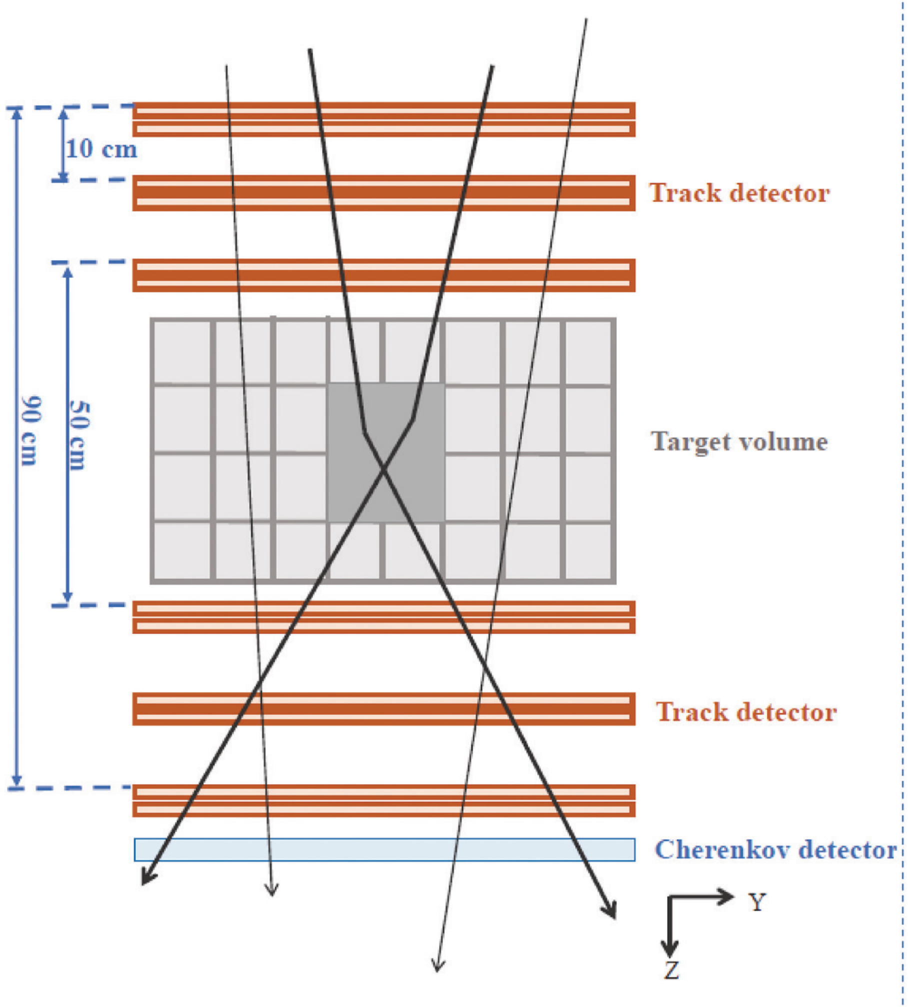
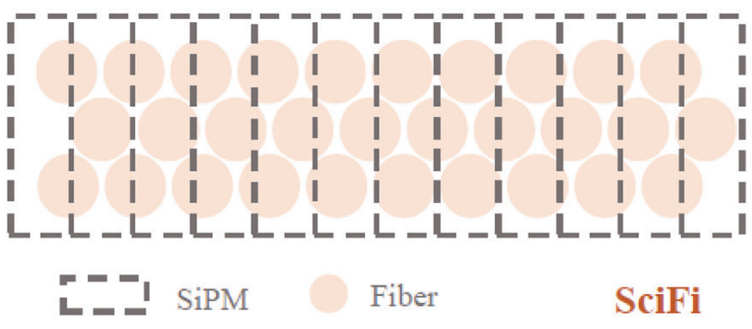
Concept of Muon Scattering Tomography

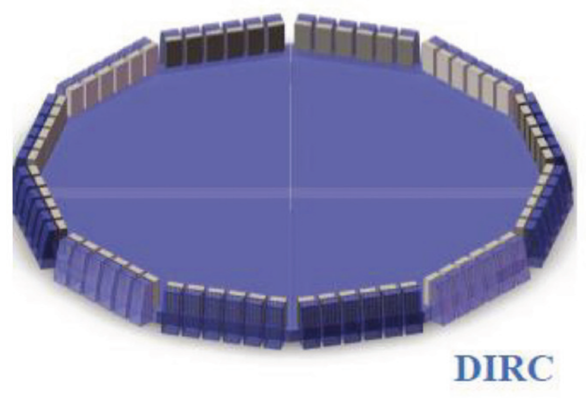
- **Muon scattering tomography** (MST) is a non-destructive technique to image various materials by utilizing cosmic ray muons as probes, particularly effective for high-Z materials
- The deviation angle of multiple Coulomb scattering effect depends on atomic number Z of target materials and muon momentum.
- A solid and compact MST system with two track detectors based on plastic scintillating fibers (SciFi) and an internally reflecting imaging Cherenkov detector (DIRC) for momentum measurement of low-energy muons is proposed to discriminate both low-Z and high-Z materials.
- The muon transport with only MCS interaction and detector response with respect to position resolution of track detectors and angle resolution of Cherenkov light are described in a toy Monte Carlo method.



Detector Techniques

The **SciFi** detector has a staggered arrangement of scintillating fibers and read out by a customized one-dimensional silicon photomultiplier (SiPM) at one end.
- Currently a fiber of 250 μm or even 125 μm diameter is achievable
- Its resolution is generally proportional to the fiber diameter d and roughly $d/\sqrt{12}$.





The **DIRC** detector makes use of internally reflected Cherenkov light in a solid radiator placed in the air. When the velocity β of a cosmic ray muon exceeds the speed of light in the radiator, the Cherenkov light will be emitted in a cone with an opening angle θ around the muon trajectory

$$\cos\theta_{\rm ch} = \frac{1}{n\beta}, \quad \beta > \beta_{\rm thr} = \frac{1}{n}$$

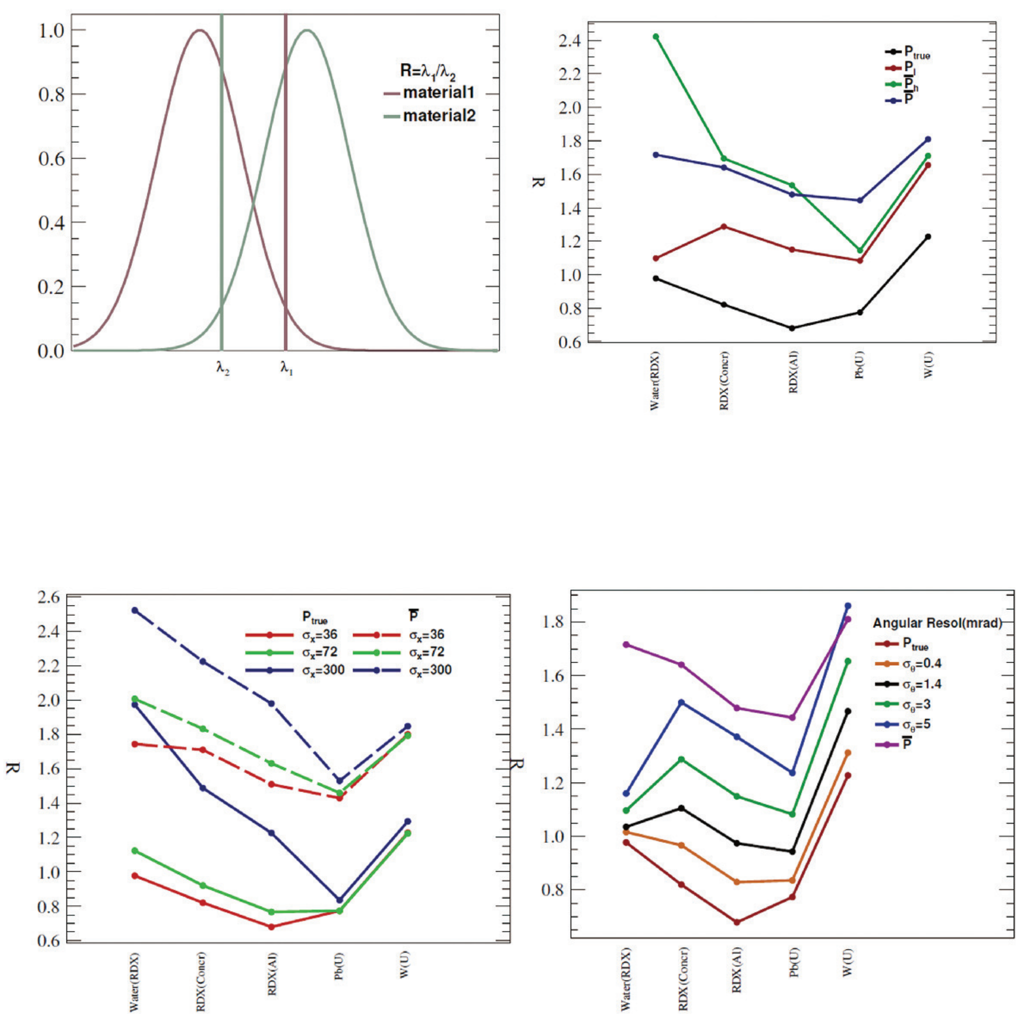
Reconstruction and Results

- Muon tracks are reconstructed with Kalman Filter algorithm taking multiple scattering effects into account.
- Scattering density of different materials is reconstructed with momentum-dependent PoCA algorithm, where momentum info is provided by DIRC detector.

$$\lambda_k^l = \frac{1}{N_k^l L_k}\sum_{i=1}^{N_k^l}\left(\frac{\beta_i c P_i}{13.6MeV}\right)^2 s_i^2 \qquad P_i \le P_{\rm thr}\,,$$

$$\lambda_k^h = \left(\frac{\bar{\beta}_h c \bar{P}_h}{13.6MeV}\right)^2 \frac{1}{N_k^h L_k}\sum_{i=1}^{N_k^h} s_i^2 \qquad P_i > P_{\rm thr}\,.$$

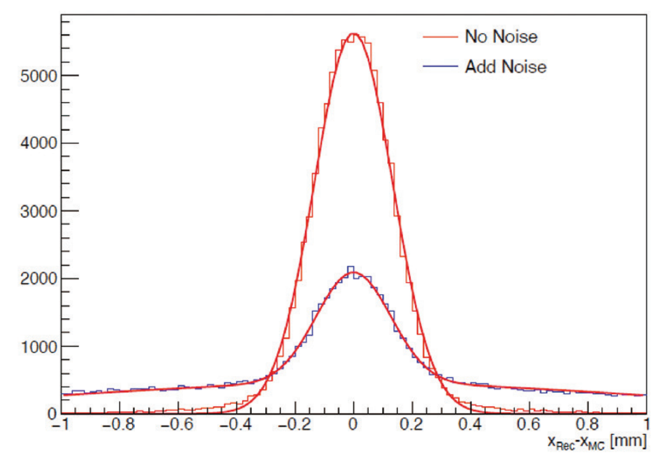
- Typical two-fold trackers and extra momentum measurement of low energy muons could enable the MST system to detect both low-Z and high-Z materials with cosmic ray muons in the whole energy range.



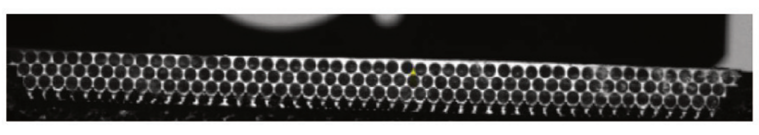
Detector Under Construction

Currently a SciFi detector with 1mm diameter is under development.

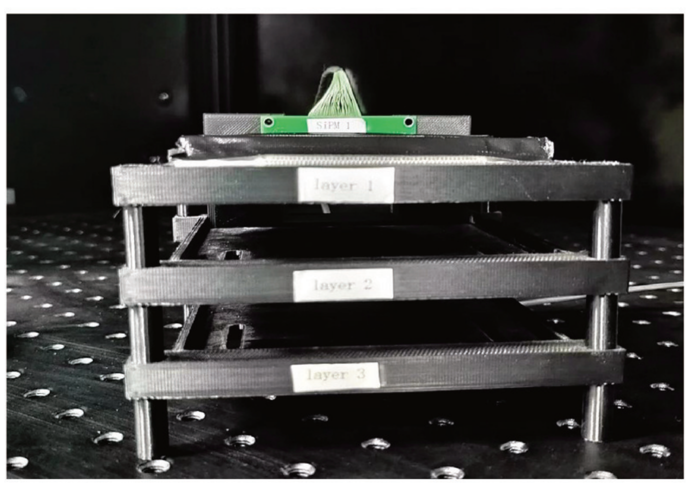
- The detector simulation of scintillating fibers and SiPM optical response is developed in Geant4. A position resolution of ~300 μm is achievable with Ø 1mm fibers.



- The process flow for arranging plastic scintillation fibers is developed by us. Compact SciFi modules with Ø 1mm fibers are fabricated.



- The modules with 1D-SiPM readout are test with cosmic ray muons locally in our lab now.



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For more details, please find our paper
arXiv:2304.09489
Jiahui Chen et al 2023 JINST 18 P08008