The muon measurements at the FASER experiment

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Introduction

The FowArd Search ExpeRiment (FASER) is an experiment using the Large Hadron Collider (LHC) at CERN. Detectors of the FASER experiment are located at 480 m from ATLAS Interaction Point (Figure 1). The experiment published several papers focusing on light long-lived particles, muon neutrino, and electron neutrino. One of the main background channels for neutrino analyses is background muons. The energy distributions of these background muons are important for the background neutral hadron from the interaction of muons in the rock in front of the FASER site. Moreover, we expect background muons from the decay of hadrons produced at the IP, which can constrain the neutrino flux at the FASER detector.

Therefore, It is important to understand the muon backgrounds for systematic uncertainty of analyses. In this poster, we report the measurements of background muons at the FASER site.

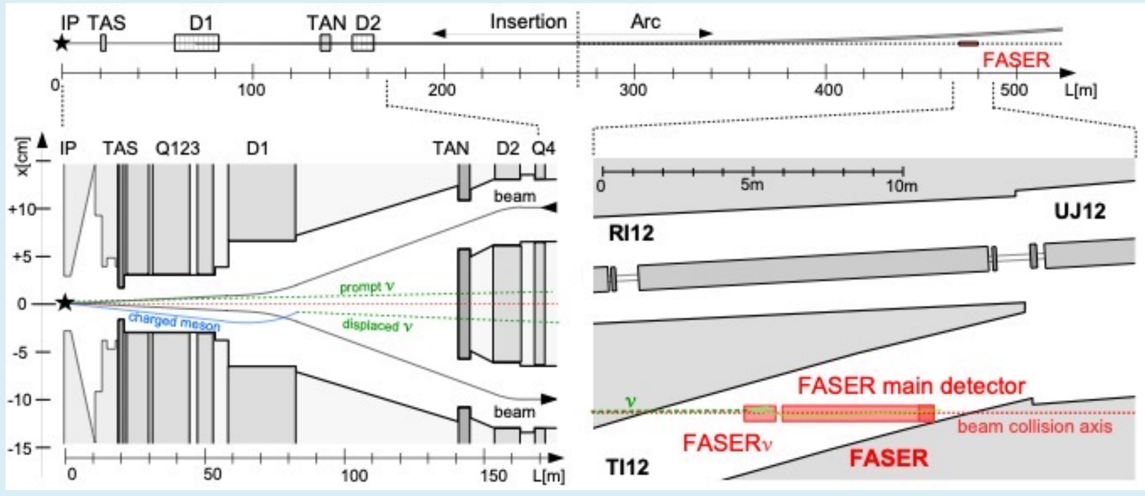

Figure 1: The schematic view of LHC and FASER detectors (Figure from arXiv:1908.02310)

FASERν detector and muon modules

The 2022 2nd module of the FASERν sub-detector was installed from July 26th to Sept. 2nd, 2022. This corresponds to 9.5 fb^{-1} of proton-proton collisions. Additionally, we installed dedicated muon flux measurement modules at the FASER site during this period. The FASERν sub-detector was made of 730 emulsion films alternating the 730 tungsten plates as shown in Figure 4.

The dedicated muon modules are made of 8 emulsion films alternating the 8 tungsten plates. Each emulsion film has a 12.5 cm width and 10 cm height. These 8 layers of emulsion films and tungsten plates are enclosed in the vacuum bag and fixed by the clamps on the pole. In total, 19 modules were installed with a 500 mm distance between each other in the x and y directions as shown in Figure 5.

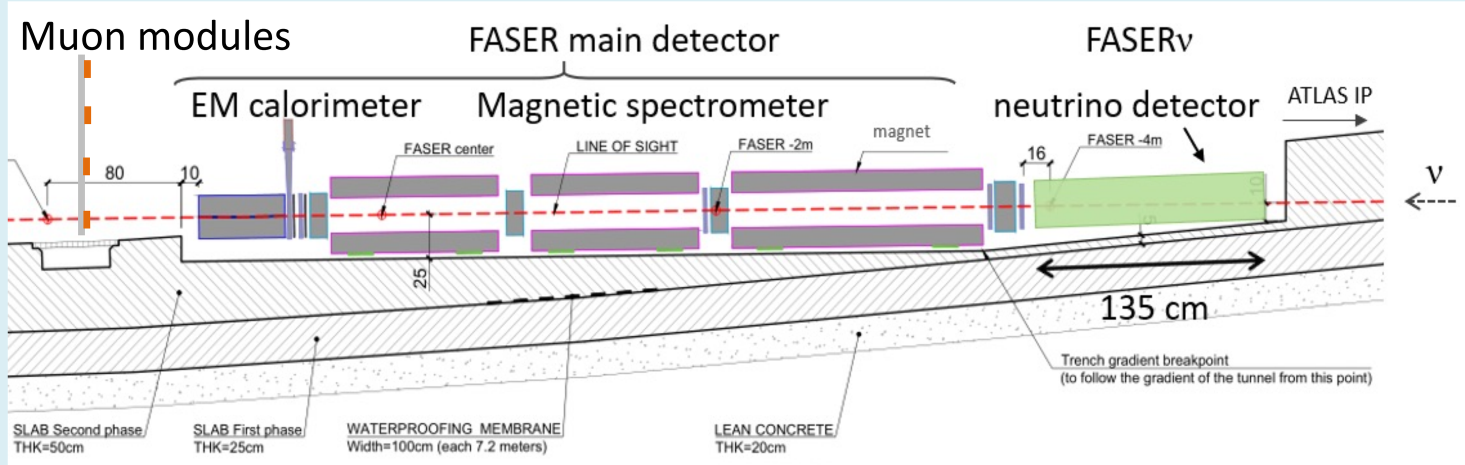

Figure 2: The schematic view of detectors (Modified from arXiv:1908.02310v1)

Detector performance

The position resolution was measured by a data-driven method. Using the tracks with hits in 6 or more films, we examined the hit position deviation Δx and Δy,which are defined by the position deviation of the track hits with respect to a linear fit line for the reconstructed tracks in the x and y directions. Figure 3 shows the distribution of Δx and Δy. The number of tracks are normalized by the size of the analysis area. The peak was fitted via the Gaussian function. The standard deviation was found to be 0.54 µm. The angular resolution of tracks penetrating 4 layers can be calculated from the position resolution as follows; (0.54×√2)/(thickness of 4 layers in µm) ~0.13 mrad.

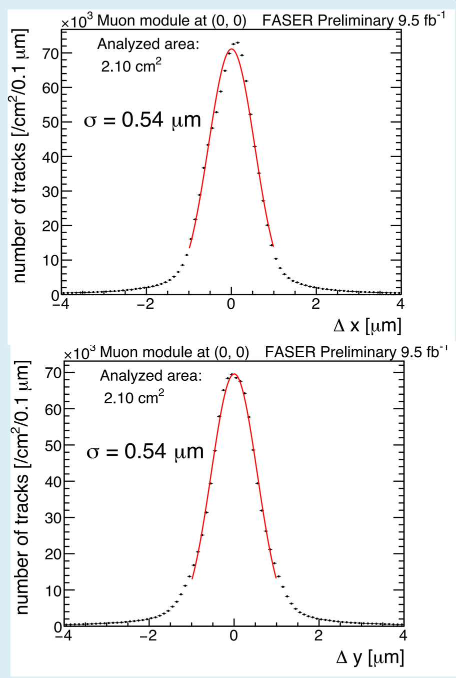

Figure 3: Distribution of Δx and Δy for the muon module at (x, y) = (0, 0) mm from the Line of Sight (LOS).

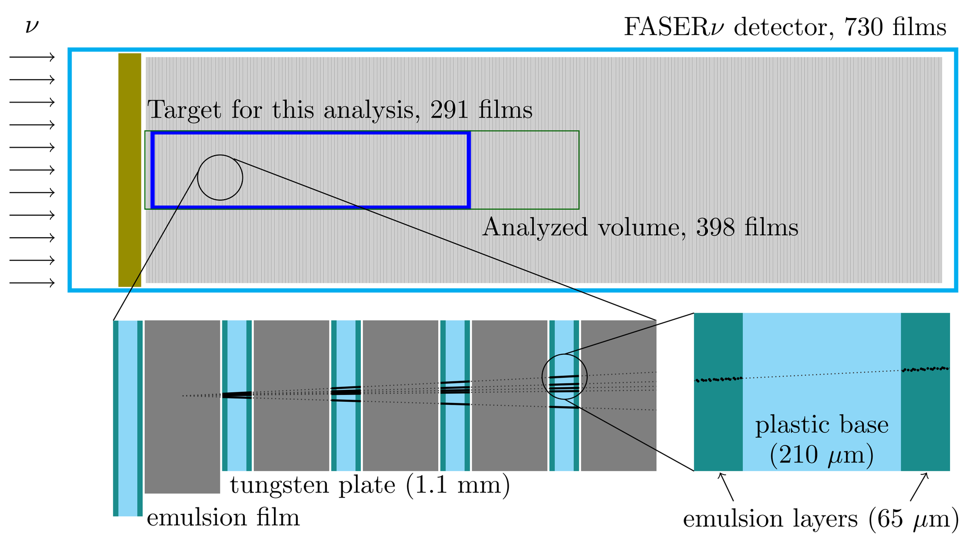

Figure 4: The schematic view of FASERν detector. (Figure from arXiv:2403.12520)

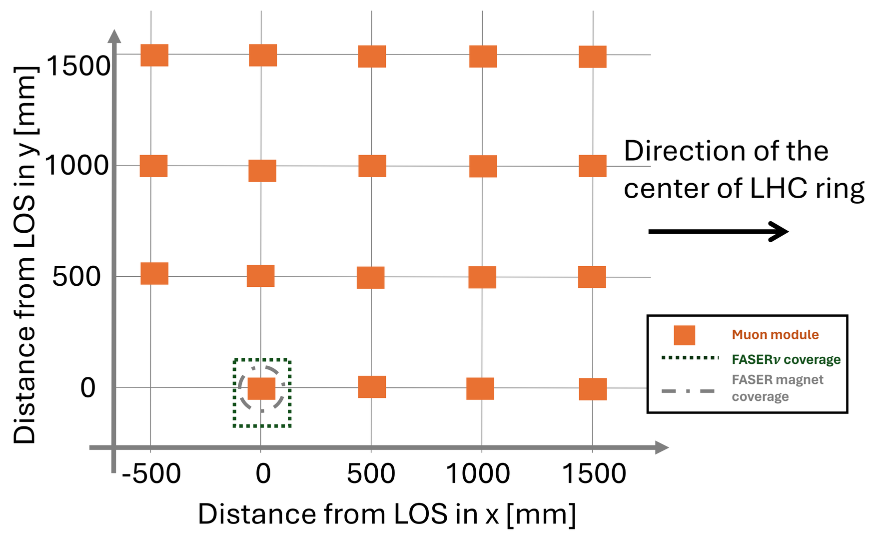

Figure 5: The schematic view of the position of the muon modules.

Wide-range angular distributions

In this poster, we focus on four muon modules located at x = 0 mm from LOS. Figure 6 shows the wide range angular distribution for muon modules.

Tracks starting in the first 4 emulsion films and penetrating 4 or more films are selected. We found a structure from θ_X = 0.1 rad to 0.3 rad. This might be caused by muons from LHC magnets in the back side of the FASER site. Figure 7 shows the schematic view of the FASER detectors and LHC beam pipes and magnets. These LHC magnets in the back side give good explanations of the structure in the angular distribution.

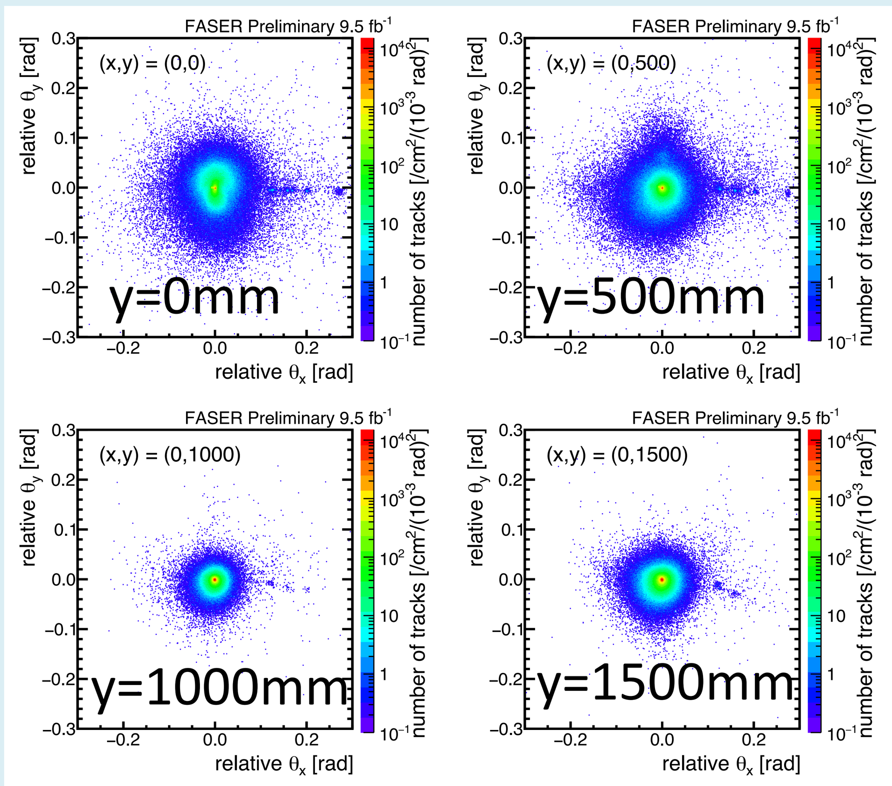

Figure 6: The wide-range angular distribution of muon modules.

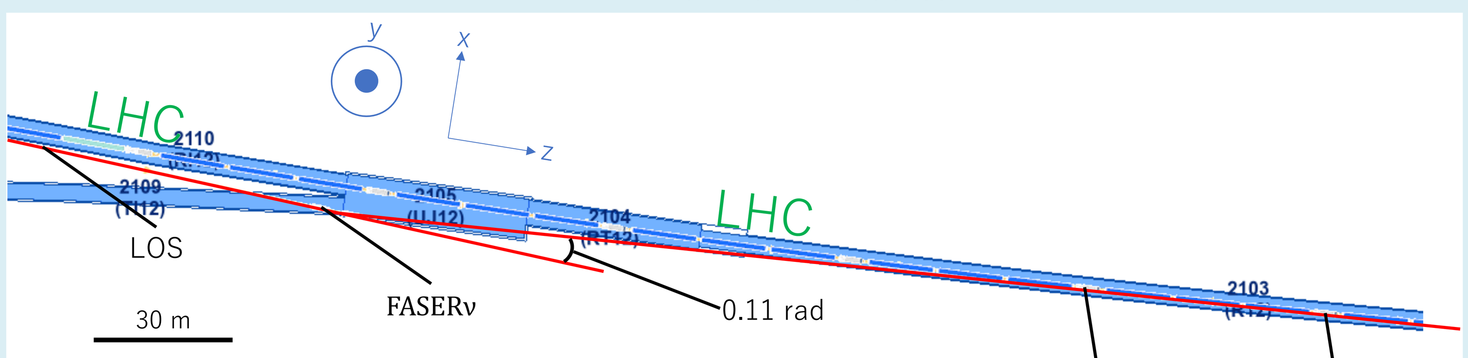

Figure 7: The LHC magnets around the FASER site. This plot was made using the GIS portal at CERN (gis.cern.ch).

Narrow-range angular distributions

Figures 8 and 9 show the angular distribution in $|\theta| < 0.02$ rad from the mean of the angular distribution. We found several peaks in θ_x for the module at LOS. The modules at higher y positions show wider peak widths.

Multiple peaks in θ_x are expected from the decay of the hadron produced at IP and the interaction with the LHC magnets in the simulation. Wider peak widths might be explained by the lower energy muons, which show more scattering in the rock in front of the FASER site. The origin of these structures are under investigation.

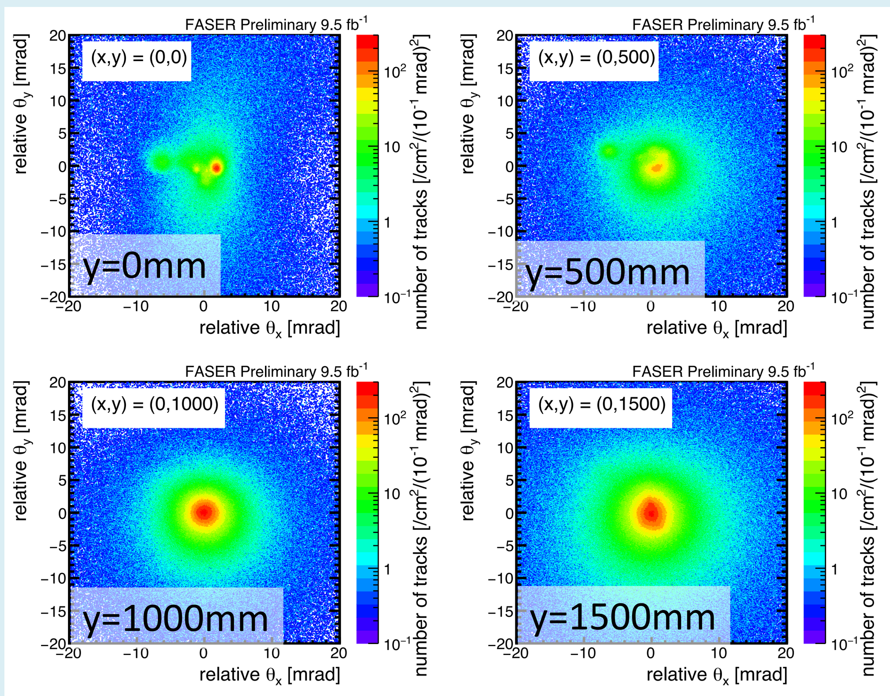

Figure 8: The narrow-range angular distributions of muon modules.

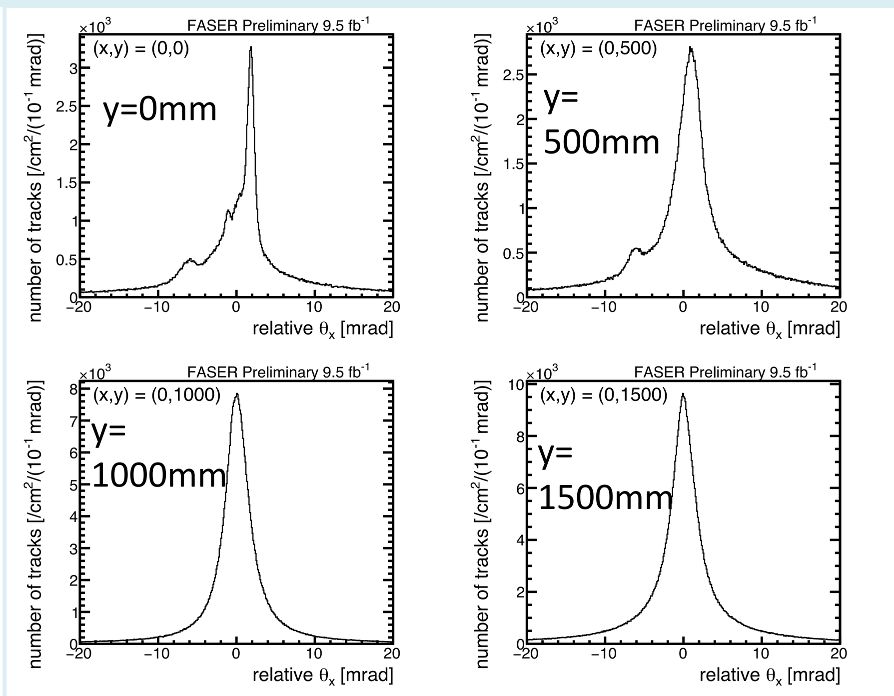

Figure 9: The narrow-range angular distributions in θ_x of muon modules.

Comparison between detectors at LOS

Figure 10 shows the angular distribution measured by the FASERν detector with the same track selections with muon modules. The FASERν detector is located before the FASER magnet while the muon module at LOS is located after the FASER magnet. Therefore, the angular peaks by μ^+ move to a lower direction in θ_Y, and those by μ^- move to a higher direction in θ_Y. We found one peak moved to the lower θ_Y, while the other peaks move to higher θ_Y. This might suggest that we have one peak with μ^+ and the other peaks with μ^-.

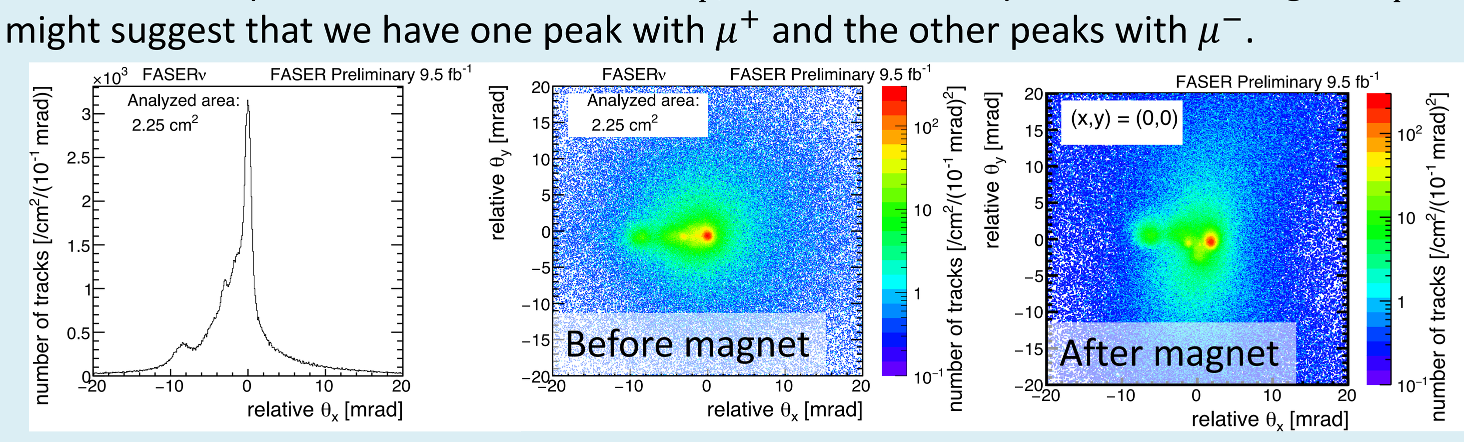

Figure 10: The 1D angular distributions of FASERν detector (left) and the 2D angular distributions of FASERν detector (middle) and muon module at LOS (right).

Summary and Prospects

In this poster, we discussed the angular distribution of the background muons measured at the FASER detector site. We found a structure that might be caused by the muons from the back side. Moreover, we found multiple peaks for the module located at LOS. The comparison of angular distributions before and after the FASER magnet suggests that we have one peak with μ^+ and the other peaks with μ^-. These measurements will be compared with the simulation to validate the simulation, and that will improve the background muon estimations.