Scintillating Fibre Detector for the Mu3e Experiment

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What is the Mu3e Experiment?

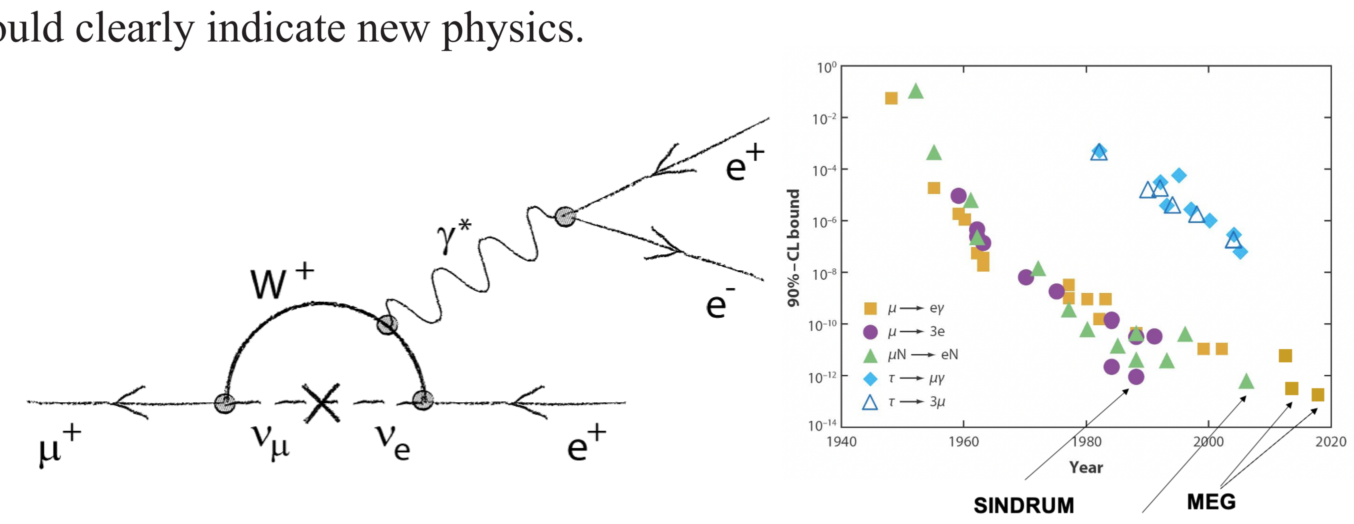
Mu3e is an experiment under construction at PSI, Switzerland looking for the charged lepton flavor violating decay μ+->e+e+e-. Mu3e's experimental goal is to reach a sensitivity for a branching ratio of 10^{-15}. To achieve this, Mu3e uses the world highest intensity continuous surface muon beam, together with precise tracking and timing devices.

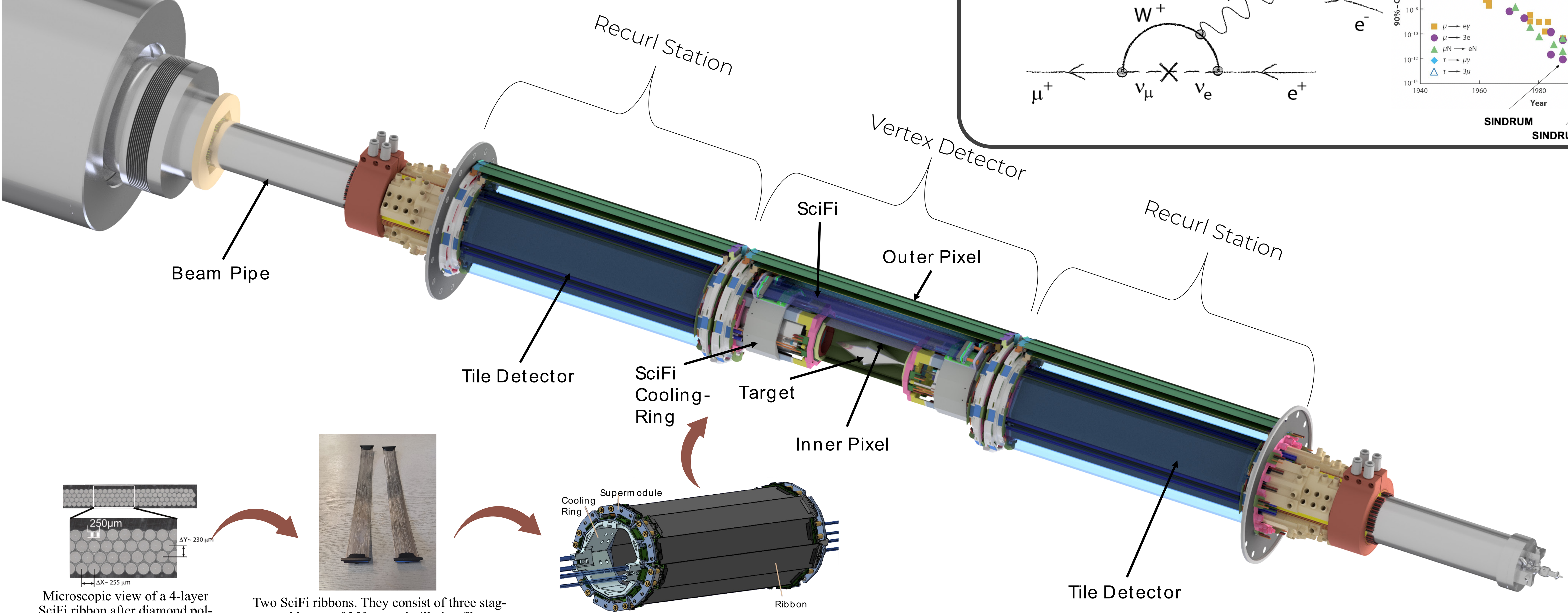
The University of Geneva is developing a Scintillating (SciFi) Fibre detector, with the fixed aim of timing particles with a better resolution than 500 ps. As SciFi is positioned in a central zone (the second closest to vertex) the detector needs to be very thin. SciFi consists of three layers of 250 μm fibres, resulting in a thickness of less than 0.2% radiation length, and it can achieve a time resolution of 300 ps while still maintaining an efficiency > 97%.

What can we learn from the μ→ eee decay?

The discovery of neutrino oscillations has clearly shown that neutrinos are massive particles, something previously unaccounted for in the Standard Model (SM). This opened the door to many lepton flavour violation experiments, as in principle, even though with a small probability, neutrino oscillations allow for processes that violate lepton flavour conservation.

An example is the μ+->e+e+e- decay, in principle possible but with a branching ratio of $\mathscr{B}<10^{-54}$. With today's experimental capabilities, finding such a decay would clearly indicate new physics.





Microscopic view of a 4-layer SciFi ribbon after diamond polishing.

Two SciFi ribbons. They consist of three staggered layers of 250 μm scintillating fibres, glued together with a black epoxy. SciFi comprises 12 ribbons in total.

CAD of full SciFi Detector

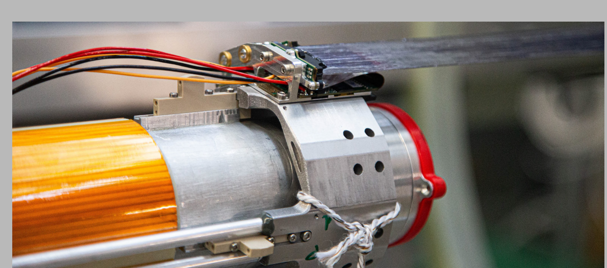
Experimental Overview

A continuous beam of muons is stopped at a central target and the muons subsequently decay at rest. The decay particles are detected through a series of detectors, based on pixel (space resolution ~ 23 μm) and scintillation technologies (< 100 ps time resolution). Since the whole experiment is inside a 1 T magnetic field, charged particles follow curved tracks and they can curl back and be detected a second time at the vertex or at the recurl stations. The main background of this experiment is the radiative muon decay μ+->e+e+e- ν $\bar{\nu}$. Since neutrinos are indirectly detected through missing mass, the momentum resolution of the Mu3e detector needs to be better than 0.5 MeV/c. The momentum resolution is strongly affected by multiple Coulomb scattering, and it is therefore imperative that all detectors have a material budget as small as possible.

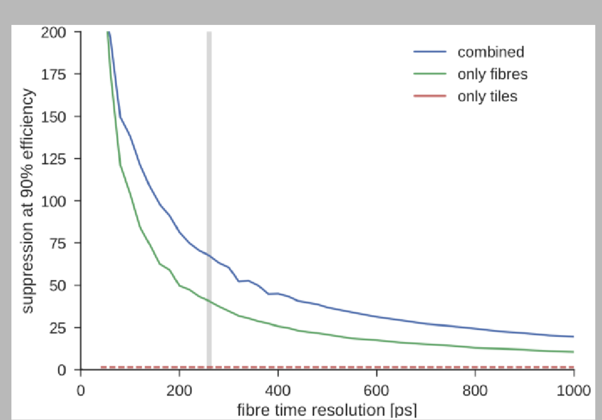
SciFi Detector

The job of the SciFi detector is to assign a very precise time stamp to the tracks of the decay electrons. This is needed to suppress the various sources of background. The SciFi system is essential to the Mu3e detector, as without it, the other timing detector (Tiles) could not effectively suppress background. The SciFi detector will also help determine the charge of the particles by measuring the sense of rotation of the tracks in the magnetic field.

The final SciFi detector consists of twelve fibre ribbons made from three staggered layers of 250 μm thick SCSF-78MJ fibres. Particles crossing the fibres will produce light, which propagates along the fibre to the two ends of the ribbon. There, the light is detected by a 128 channel silicon photomultiplier (SIPM) array, which is read out by a specially designed ASIC called MuTRiG.



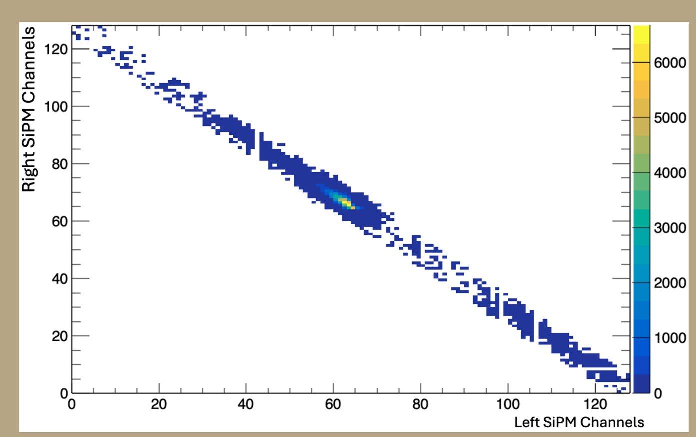
Close up of a SciFi module and some of its cooling mechanics.



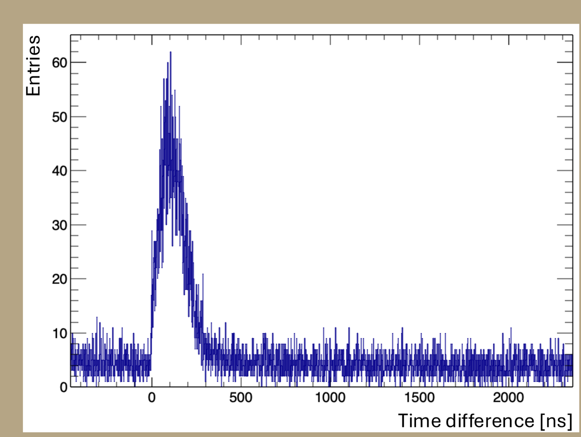
Suppression power of the SciFi alone or together with the Tile detector.

Current Status of SciFi

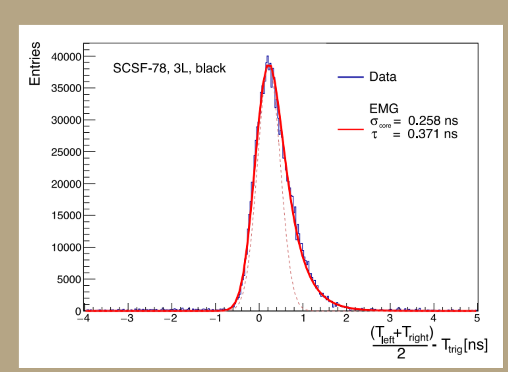
Our current design has been shown to achieve a time resolution of 250 ps at an efficiency of 97% while only having a thickness of 0.2% of a radiation length. With the final version of the electronics and data acquisition system in place, the SciFi detector has undergone extensive beam tests, which confirmed the validity of its original design choices. Notably, for the first time, the SciFi successfully operated in tandem with the pixel detector, successfully acquiring data. At the moment, the SciFi detector is complete, currently in installation on the Mu3e detector cage.



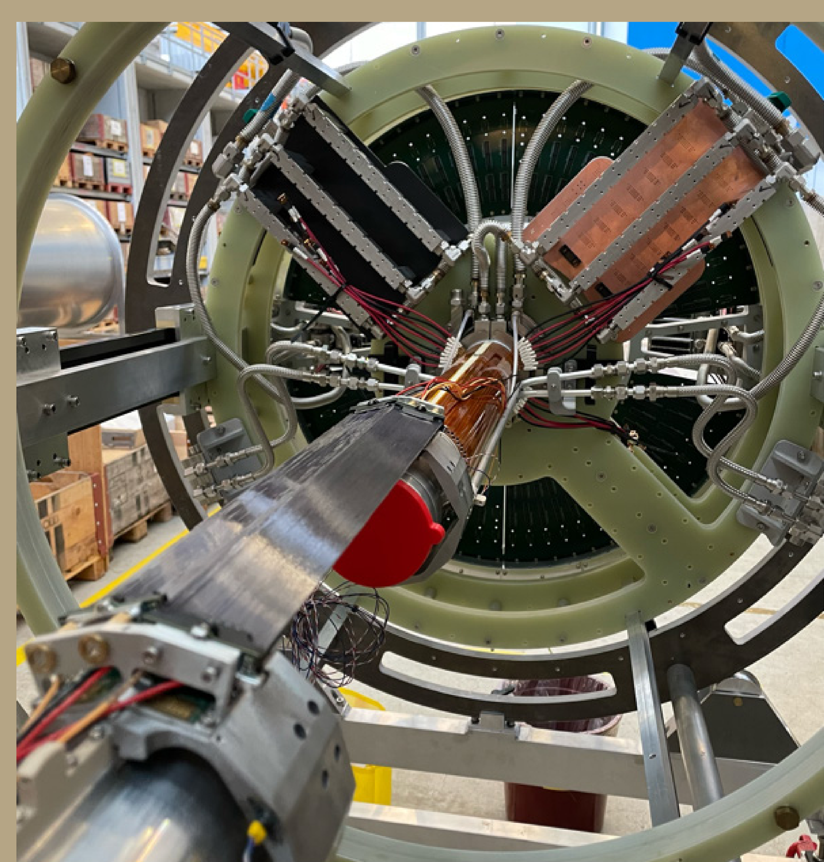
Electron beam reconstructed with the SciFi. The concentration at the middle shows that the electron beam hits the SciFi in its center.



Time difference between hits from a SciFi and a Pixel detector. This is the first time a coincidence has beam measured with the two key detectors of the Mu3e



Time resolution (258 ps) of a SciFi ribbon.



Installation in progress. Two SciFi ribbons installed on the Mu3e beam pipe. The mechanics on which the ribbons are installed contain inner channels through which cooling liquid is actively flowing. In the background, part of the SciFi cooling system can also be seen. The Mu3e detector is being prepared for a cosmic-ray run at the end of this year.