Beam monitoring detectors for High Intensity Muon Beams

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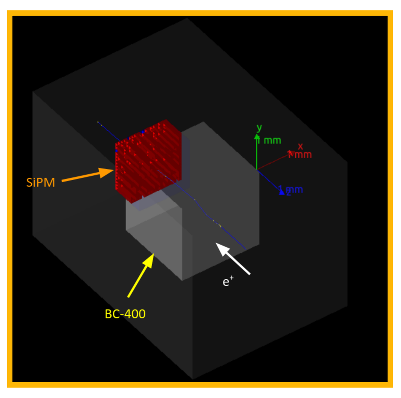
Introduction

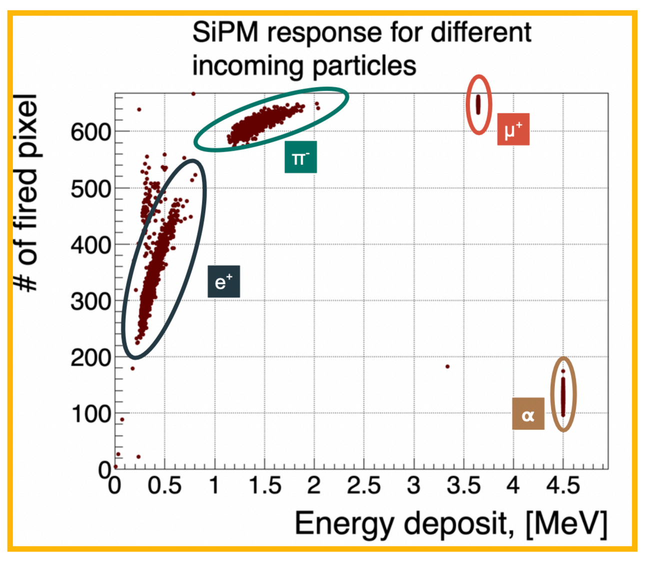
Currently PSI delivers the most intense continuous muon beam in the world with up to few 10^8 μ^+/s, and aims at reaching 10^{10} μ^+/s within the High Intensity Muon Beam (HIMB[1]) project. Usual beam monitoring tools are not suited for μ^+ beams as it is necessary to distinguish μ^+ from the particles contaminating the beam, such as e^+ and π^+.

Simulation

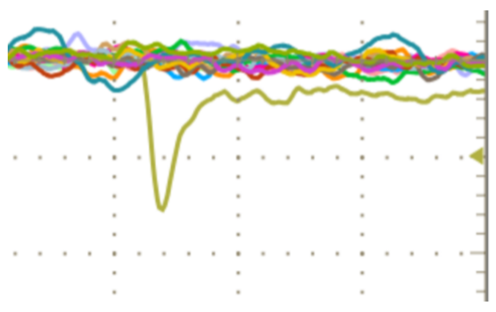
For both SciFi and MatriX a full simulation, from beam energy loss to waveform shaping has been prepared.The scintillators and the SiPMs have been modeled in Geant4.



MatriX element

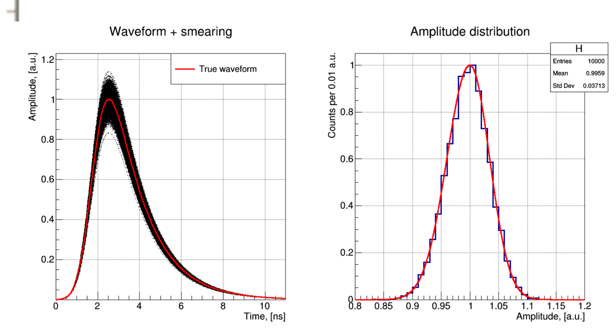


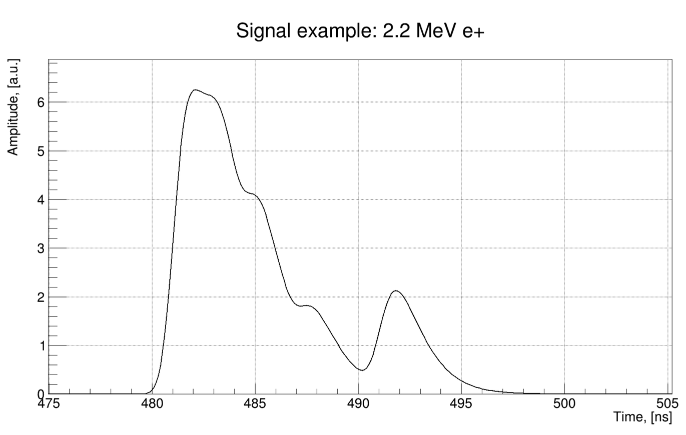
The waveforms have been modeled based on the single photon SiPM output from dark noise measurements:



The single photon waveform has been fitted and is summed up for each fired pixel based on the photon detection time

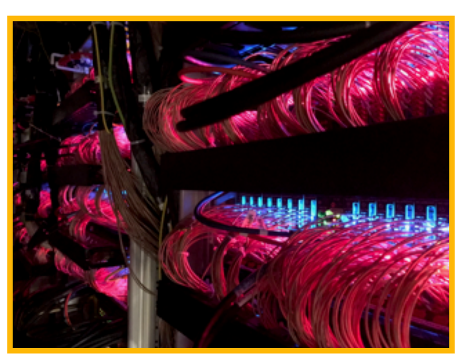
Each single-photon waveform is weighted in amplitude based on the first photo-electron amplitude distribution





TDAQ[3,4]

The SiPMs are connected to the WaveDAQ, which both supply power to the SiPMs and read them out. Thanks to the WaveDREAM boards it is possible to set different thresholds for each channel to intercalibrate them, allowing for uniform response from both detectors.



WaveDAQ racks in MEG II

Conclusions

SciFi is ready to be produced in its final version including an insertion system to have the possibility to scan beam profiles on demand.

MatriX will be now tested in an upgraded configuration with improved discrimination power between particles thanks to the new detection scheme with thinner scintillators and light-guides.

Both can provide full beam rate measurements, that can be exploited for consistently tune high intensity beamlines.

References

[1] Eichler, R., et al. (2022). *IMPACT conceptual design report*. (PSI Bericht, Report No.: 22-01). Paul Scherrer Institut.

[2] Papa A., et al. A fast and quasi non-invasive muon beam monitor working at the intensity frontier. *Nucl. Instrum. Meth. A,* 936:634.635, 2019. doi:10.1016/j.nima.2018.10.145

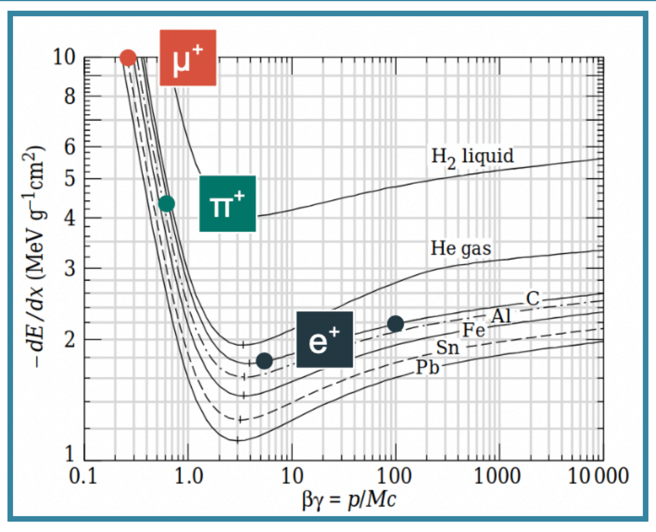
[3] S. Ritt, et al. Application of the DRS chip for fast waveform digitizing. *Nucl. Instrum. Meth. Section A* 623 (2010) 486

[4] Galli L., et al. An highly integrated trigger and data acquisition system. *Nucl. Instrum. Methods Phys. Res. Sect. A* **2019**, *936*, 399–400

[5] Baldini A.M. et al. The Search for μ+ → e+γ with 10–14 Sensitivity: The Upgrade of the MEG Experiment. *Symmetry* **2021**, *13*, 1591. https://doi.org/10.3390/sym13091591

Rate and particle ID

Particle ID is based on energy loss in matter, as we deal with low energy muons (~4 MeV), to be distinguished from ultra relativistic positrons (~53 MeV).

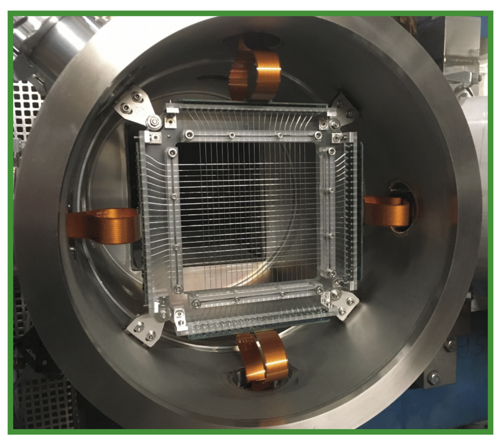


We need high responsivity from the detectors to cope with the **high rates** and **low sensitivity to high magnetic fields**.

SiPM + Plastic scintillators

The SciFi detector[2]

Geometry and characteristics



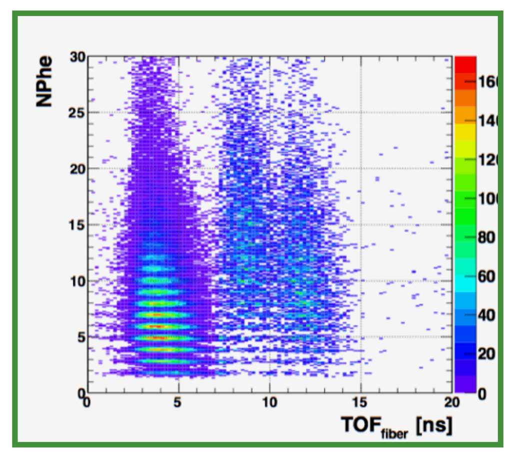
The SciFi detectors is a grid of plastic scintillating fibers coupled to SiPMs at each end:

- Fibers: square cross-section, 20 cm long, 0.5 mm thick, aluminum coated
- Layers: the fibers are 5 mm apart and divided in two perpendicular layers to measure the two transverse beam p profiles

SciFi can operate in **vacuum** under **intense magnetic fields** and it is a **non-invasive detector**, letting 80 % of the beam to be not perturbed: it can monitor the beam online if needed.

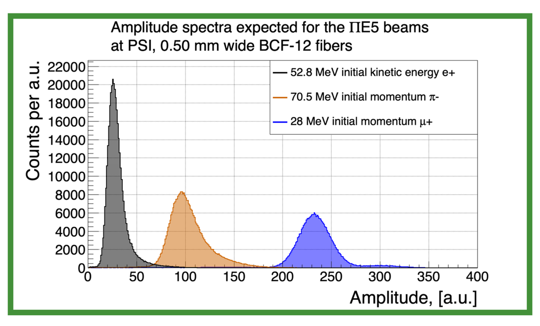
Thanks to centering the fibers on the SiPMs within few μm, transmission to photosensors is maximized, and it is possible to measure ~ 15 photons at per SiPM.

Particle ID through **time of flight** with respect to proton RF

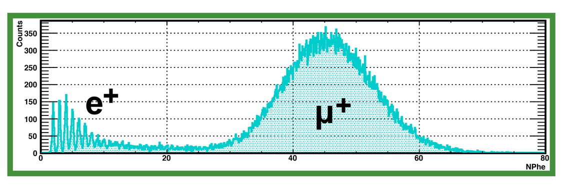


Performances

The first full prototype has been working successfully since scanning along the two transverse direction with a consistent separation between muons and positrons.



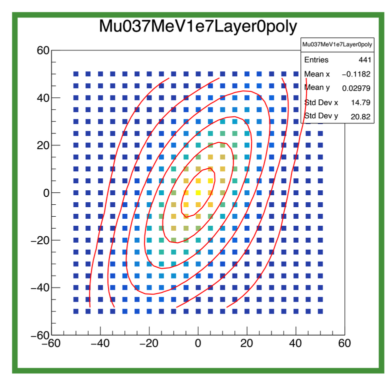
Simulation



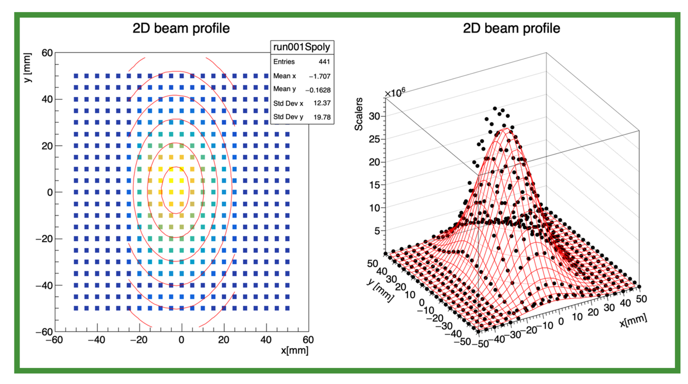
Data

We plan on assembling an upgraded version this year with an insertion system allowing to make beam measurements on demand.

Now, with WaveDAQ FPGAs, through coincidences between fibers it is possible to perform full 2D profile and measure correlation between the two transverse beam directions. Accidental coincidences provide a non-correlated background.



Simulation



Data

The MatriX detector

Geometry and characteristics

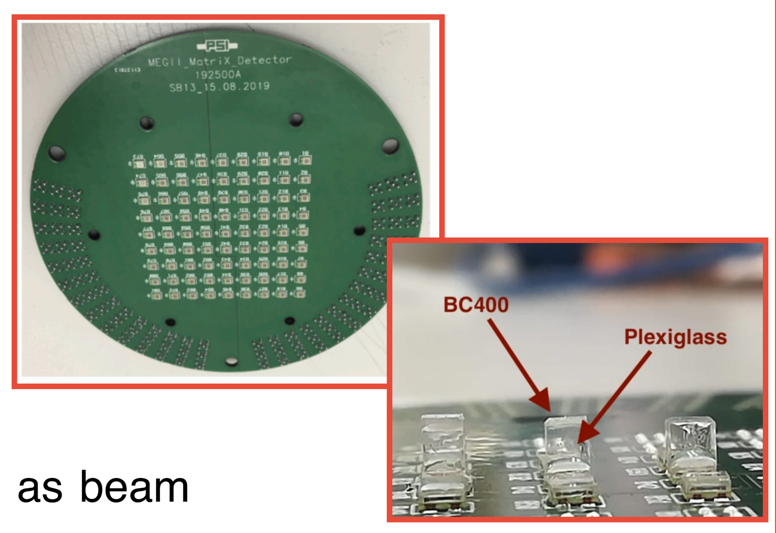
The MatriX detectors is a 9x9 matrix of plastic scintillating elements coupled to SiPMs on their back:

- Light-guide: 2-mm sized plexiglass light guide to reduce SiPM exposure to radiation
- Plastic scintillator: 0.2x2x2 mm³

MatriX can operate in **vacuum** under **intense magnetic fields**.

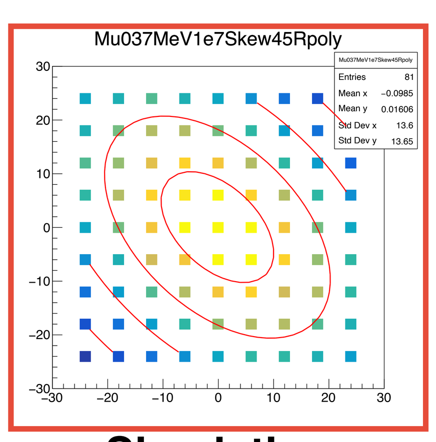
It is by design able to measure the full bi-dimensional beam profile.

It is easy to build and to adapt to different geometrical constraint (such as beam pipe sizes) or typical beam spots.

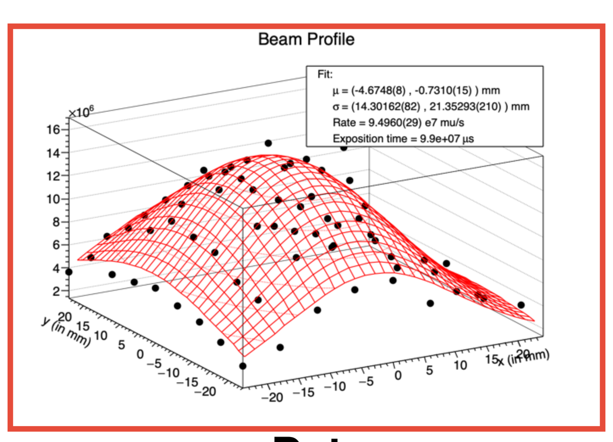


Performances

A first full prototype version was built based on plastic scintillators 2x2x2 mm big and no light guides.

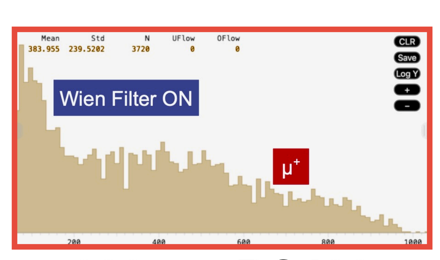


Simulation



Data

During MEG II[5] beam commissioning 2021 we reduced the thickness of the scintillators and improved the separation adding the light-guide and reducing the scintillator thickness. Here a comparison with μ^+ @ 15 MeV/c.



200 μm BC400

+ light guide