A fast and quasi-non invasive muon beam monitoring detector working at the highest beam intensity in the world

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Introduction

A new and highly performing generation of detectors based on scintillating fibres coupled to silicon photomultipliers (SiPM) has started

The flexibility of fibres combined with the plastic scintillation properties and the new and well established silicon photomultiplier technology lead to detectors able to cover a large range of fields: high energy physics, medical physics, spacecraft-borne instrumentations etc.

We focus here on the use of such a technology as beam monitoring for high and minimum ionising particles with the following characteristics:

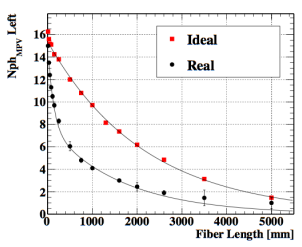
- *high granularity*
- *high detection efficiency*
- *fast timing response*
- *accurate position resolutions*
- *minimum amount of material*
- *insensitivity to magnetic field*

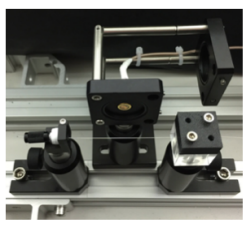
Fibre and SiPM characterisation

The SciFi detector preparation

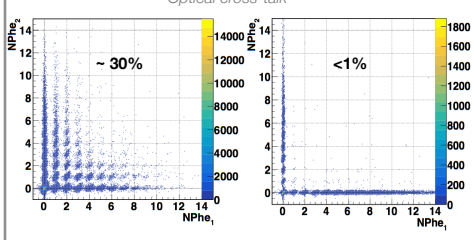
- *Fibre mechanical quality check*
- *Fibre attenuation length λ_{att} (x, λ_{scint})*
- *Fibre optical isolation with Al deposit (preserved light transmission, negligible optical cross-talk)*

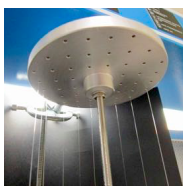
λ_{att}





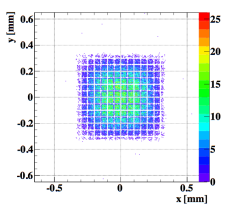
Optical cross-talk



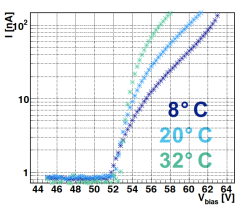


- *Fibre-SiPM alignment*
- *SiPM characterization (I-V (T), gain(V, T), DarkCount (V,T), Q spectra, ...)*
- *Pre-amplifier characterisation*
- *Full detector characterization in Laboratory with Sr90 and UV/Blue LED (detection efficiency, timing resolution, position resolution, f(x,θ,T,...))*

Fibre light spot on the SiPM surface

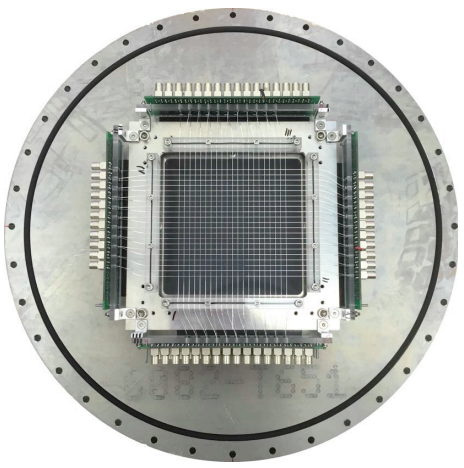


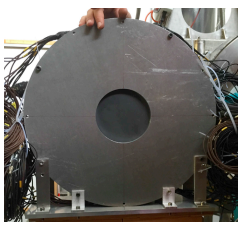
SiPM I-V curve

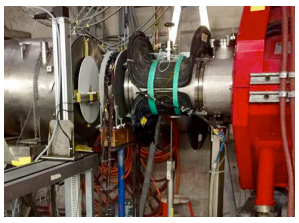


The detector

- *Fibre: Saint Gobain double clad 250 um squared BCF12 with 100 nm of evaporated Al coating*
- *A fibre grid: 2 layers (X,Y)*
- *Fibre/layer: 21*
- *Fibre length ~ 200 mm*
- *Fibre pitch: 5 mm*
- *Total number of channels (double readout): 84*
- *Photosensors: Hamamatsu MPPC S13360-1350CS*
- *Connectors: lemo*
- *Power: ~ 55.0 V*
- *Pre-amplifiers: (PSI/Wavedream) gain =100 [1]*
- *DAQ + TRG: Wavedream prototype (Waveform ditigitazion up to 5 GSample/s)+ "OR" of all"AND" from SiPM on the same fibre [2,3]*







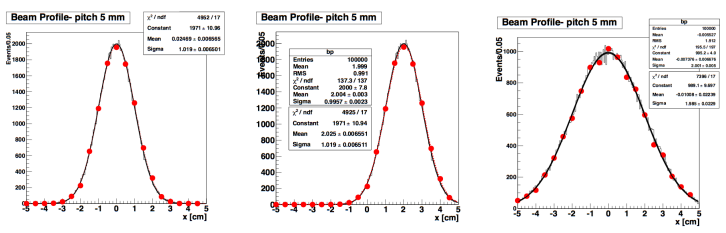
MC and TOY MC simulations: Optimised drawing

Beam reconstruction and misalignment (MC and TOY MC)

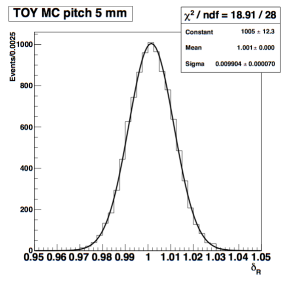
- *Studied configurations: Fibre Pitch = [2, 10] mm, Beam shifts: [1, 20] mm, Beam spot (σ) = [5, 20] mm*
- *Reconstructed beam rate and profile: **~ 1% or better***

Beam reconstruction and misalignment (MC and TOY MC)

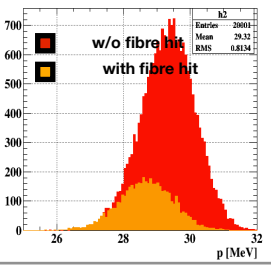
- *MC inputs: pitch = 5 mm, beam spot (σ) = 15 mm, coverage: 5 σ*
- *Transparency: (NOT hitting fibre events)/(total events) ≥ 92 %*
- *Transmission: ~ 100 %*



Example of TOY: $\delta_R = R_{rec}/R_{sim}$



Momentum distribution ($p_{initial}$ = 29.3 MeV/c)



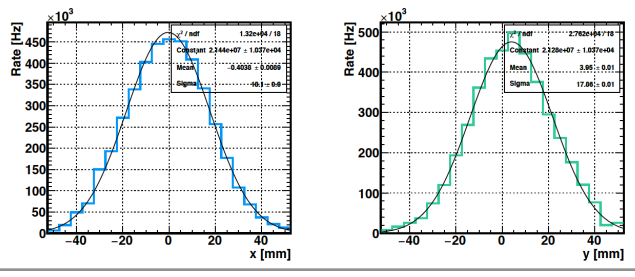
Result: Beam profile and rate, muon range

- *The detector works in an excellent way as beam diagnostic tool, providing beam profiles and rates in a few tens of seconds and being also a non-invasive monitoring method*
- *The high detector segmentation combined with the fast detector response allows to work at the highest continuous muon beam intensity in the world (**2×10^8 μ/s**) with full detection efficiency (**> 99%**)*
- *Results consistent with that obtained with standard beam monitoring methods*

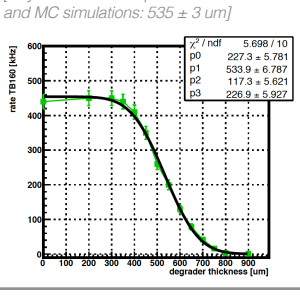
$R_\mu(@2.2\ \mathrm{mA}) = (1.11 \pm 0.01) \times 10^8\ \mu^+/\mathrm{s}$

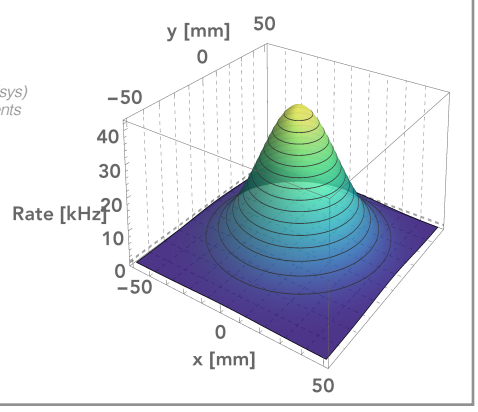
$(\sigma_x, \sigma_y) = (18.1 \pm 0.1, 17.8 \pm 0.1)\ \mathrm{mm}$

Shifted beam



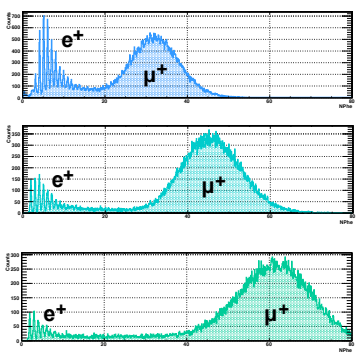
Result: (mylar equiv.) 534 ± 7 (stat) ± 3 um (sys) [fully consistent with pill counter measurements and MC simulations: 535 ± 3 um]

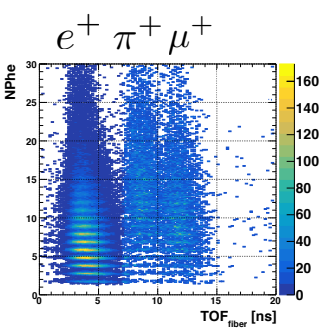


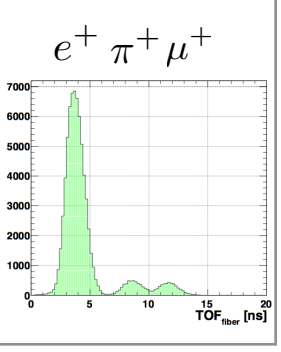


Result: Particle identification

- ***Clear separation** between minimum ionizing positrons and "low energy" muons based only on the measured charge [initial p = 29 MeV/c]*
- *Separation among minimum ionizing particles adding the time-of-flight measurement (w.r.t. the accelerator radio-frequency) [p = 115 MeV/c]*







Summary and Outlook

- *Although detectors based on scintillating fibres have been extensively used in the past in a large range of physics applications [4], the development of SiPM as photosensor and their coupling to scintillating fibres open a new era for such a detectors, with drastically improved performances [5]*
- *In this work we proved the feasibility of using that technology for high granularity beam monitoring detectors, able to sustain particle rates up to 10^8 particle/s, with full detection efficiency for high ionising particles [6]. The fast detector response allows for particle identification based on the time-of-flight technique when the charge only measurement is not sufficient. Beam profile and rate can be extracted in few seconds. All results have been checked to be consistent with measurements performed with independent methods. This technique showed great potentiality also for future high beam intensity project applications.*

References

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*[6]: A. M. Baldini et al. (MEGII collab.) EPJC **78** (2018) 380*

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