Thin scintillating fibers coupled to SiPMs for fast beam monitoring and timing purposes

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Objective Target

Development of detectors based on thin scintillating fibers (250 x 250 μm² size, smallest size available on the market) and SiPMs for:

- **Vertex tagging** (MEG: Active TARget)
- **Beam monitoring** (MEG, beamlines @ PSI in general)
- **Timing purposes** (Mu3e scintillating fiber hodoscope)

Versatile, modular and comparably cheap technology, applicable in magnetic fields and vacuum environments.

Challenge: Ability to detect minimum ionizing particles with high efficiency using so little scintillating material (expected energy deposit O(50 keV) / fiber ≅ O(10 detected photons)/ fiber).

Scintillating Fibers

- Saint-Gobain BCF-12 squared multiclad fibers
  - Squared: Higher trapping efficiency (7.3%) compared to round fibers (5.6%)
- Emission color peaks in the blue (where the photon detection efficiency of the SiPM is approximately maximal)
- Attenuation length L > 2.7 m
- Aluminum coating around every single fiber (two methods investigated: Physical Vapor Deposition (CERN) and sputtering (PSI))
- Coupling to SiPMs by optical grease

Silicon PhotoMultipliers („Multi-Pixel Photon Counters")

Pixelized single photon counting devices, where every pixel consists of a Geiger avalanche photodiode and a quenching resistor. Pixels are connected in parallel and arranged in a rectangular manner.

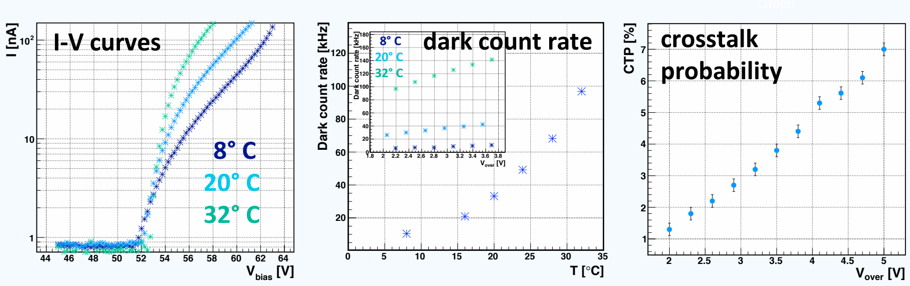
Advantages w.r.t to photomultiplier tubes:

- insensitive to magnetic fields
- relatively low HV supply
- competitive photon detection efficiency (30-40 %)

Hamamatsu 13360-1350CS

SiPMs used here: Hamamatsu 13360-1350CS and 12825-050C - 50 μm pixel size, active area 1.3x1.3 mm².

Detailed characterization of important properties (dark count rate, optical crosstalk probability, gain etc.) as a function of temperature and bias voltage



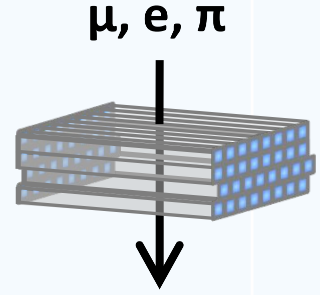
Prototype Construction

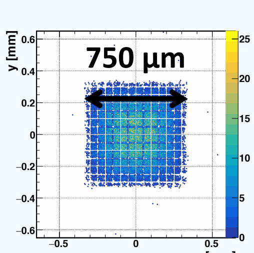
Large Prototype

32 fibers arranged in four layers and read out indivdually by SiPMs on both fiber ends

Key points:

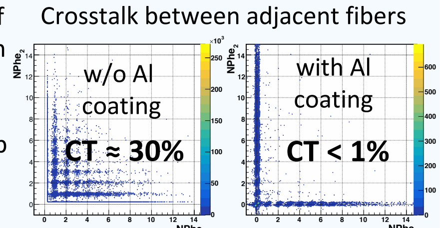
- Fiber quality control (geometry and visible defects)
- Aluminum coating (100 nm) around every fiber to reduce fiber crosstalk < 1%
- Glueing of fibers to layers of uniform thickness of ca. 265-270 μm
- Mechanics for individual fiber readout guaranteeing a good fiber – SiPM alignment

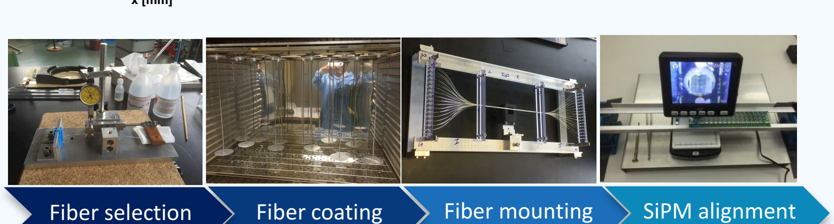




Simulated distribution of photons originating from a 250 μm fiber centered on a SiPM active area of 1.3x1.3 mm². Shifts of up to 300 μm affordable without any light loss.

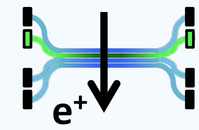
Crosstalk between adjacent fibers





Achievements

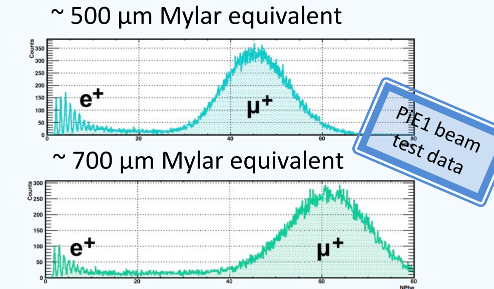
- **Efficiencies for Minimum Ionizing Particles**
  AND/OR logic: Both SiPM/ at least one SiPM connected to a fiber see at least one photon (threshold at 0.5 NPhe)

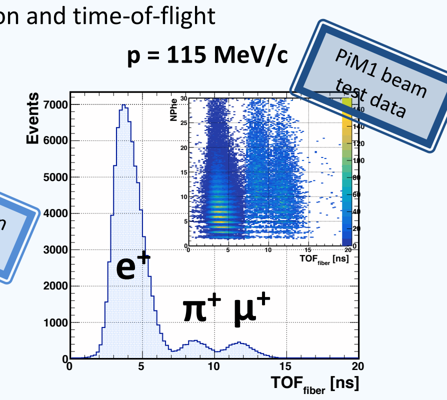


PiM1 beam test data

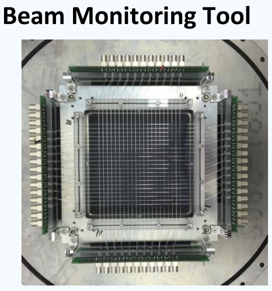
	Single fiber	Double layer	Triple layer
AND	(72 ± 2) %	(89 ± 2) %	(95 ± 2) %
OR	(96 ± 2) %	(99 ± 2) %	(98 ± 2) %

- **Particle ID** through charge discrimination and time-of-flight





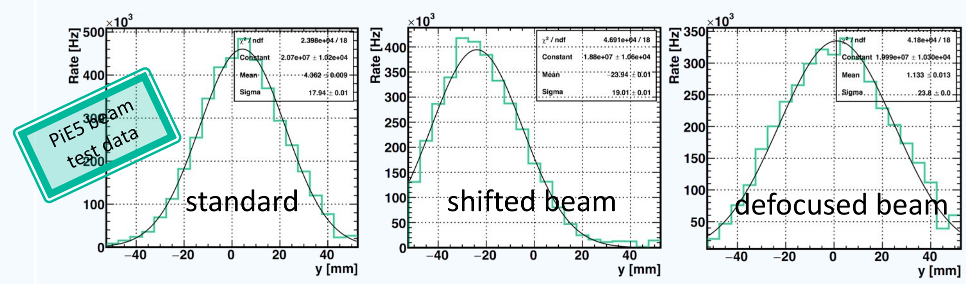
- **Beam Monitoring Tool**



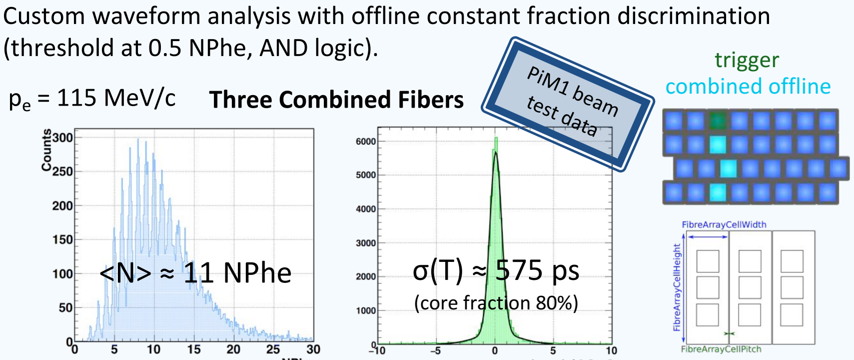
- Grid made of two layers (x,y) à 21 fibers of 250 μm size each, covering an area of 10x10 cm²
- Pitch: 5 mm; Fiber Length: ca. 20 cm
- 84 channels (every fiber read out on both ends)
- Trigger + DAQ: WaveDREAM boards (waveform digitizer running @ 2 GHz), dedicated trigger system (MEGII)

Quasi non-invasive, fast, capable of particle ID

Measurements show good agreement (within better than 10 %) with the standard beam measurement device (pill counter) for both rates and beam sizes.

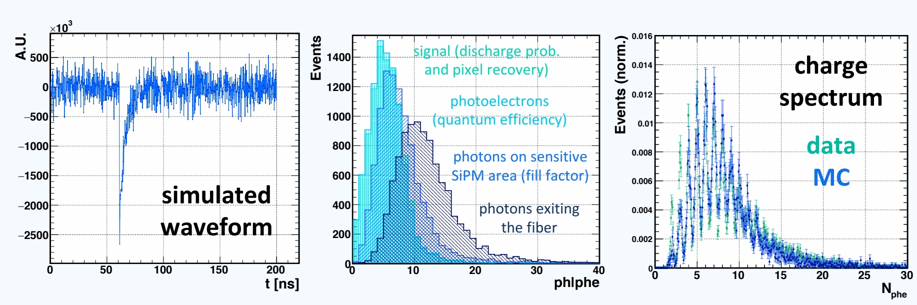


- **Array Configuration: Light Yield and Timing Resolution**
  Custom waveform analysis with offline constant fraction discrimination (threshold at 0.5 NPhe, AND logic).



Note: Three layers of 250 μm fibers are equivalent to < 0.3 % X_0

- **Stand-alone Monte Carlo Simulation**
  based on Geant4 and custom SiPM simulation.



References

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