ETH
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Prototype Studies for the Mu3e Scintillating Fiber Detector

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on behalf of the Mu3e Collaboration

PhD Seminar 2015

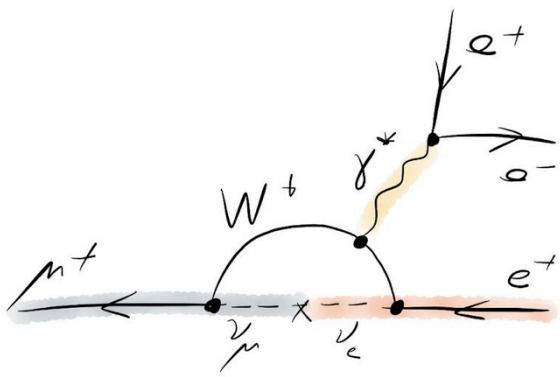
The Mu3e Experiment

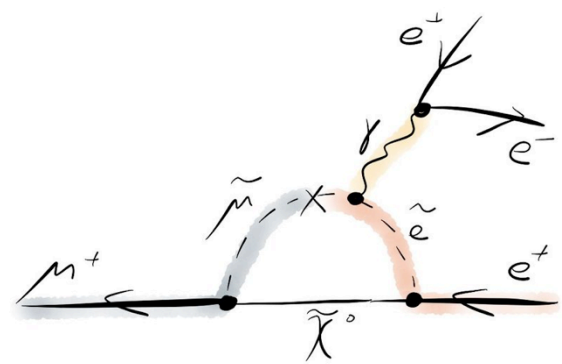
Search for the charged lepton flavor violating decay

$\mu^+ \rightarrow e^+e^-e^+$

with an aimed single event sensitivity of $O(10^{-16})$

(staged approach: Phase I SES 10^{-15}, Phase II SES $<10^{-16}$)

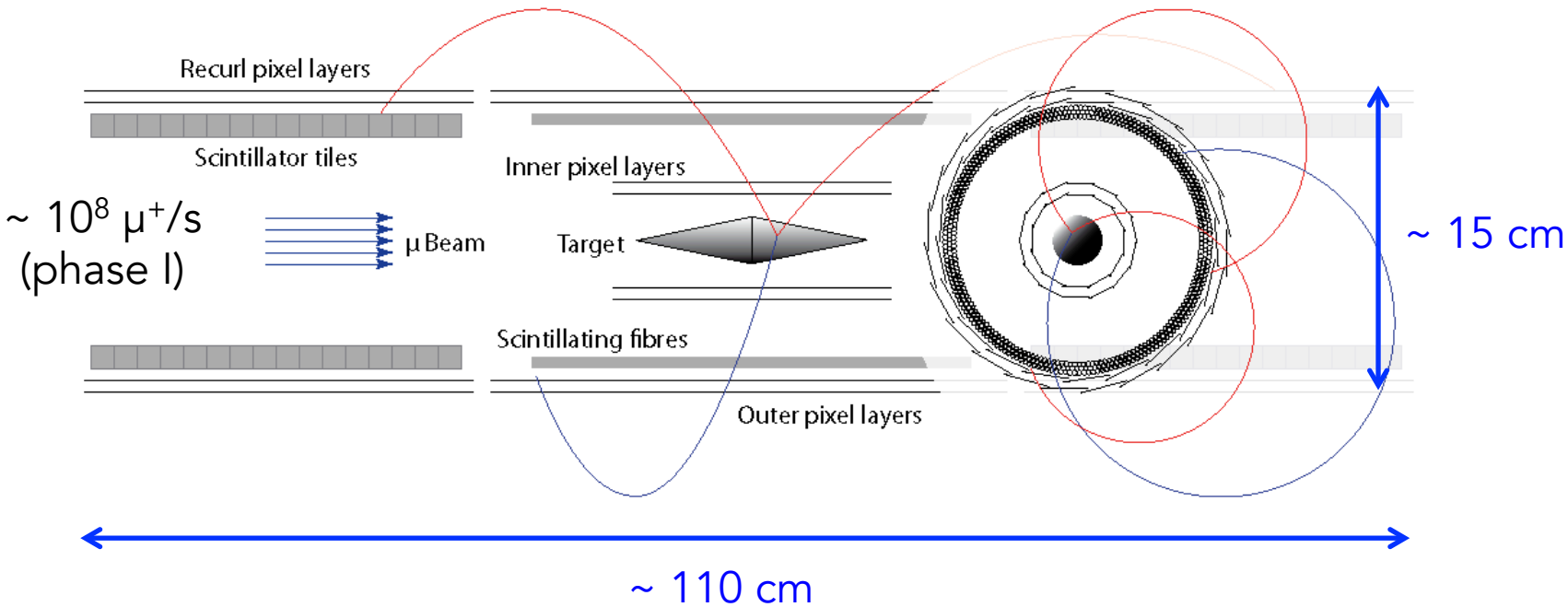




Standard Model: BR < $O(10^{-50})$

→ $\mu \rightarrow e^+e^-e^+$ is sensitive to new physics

Experimental Layout (Phase I)



$\sigma_{Meee} \leq 0.5$ MeV
$\sigma_{time} \leq 1$ ns
$\sigma_{vertex} \sim$ 200-300 μm

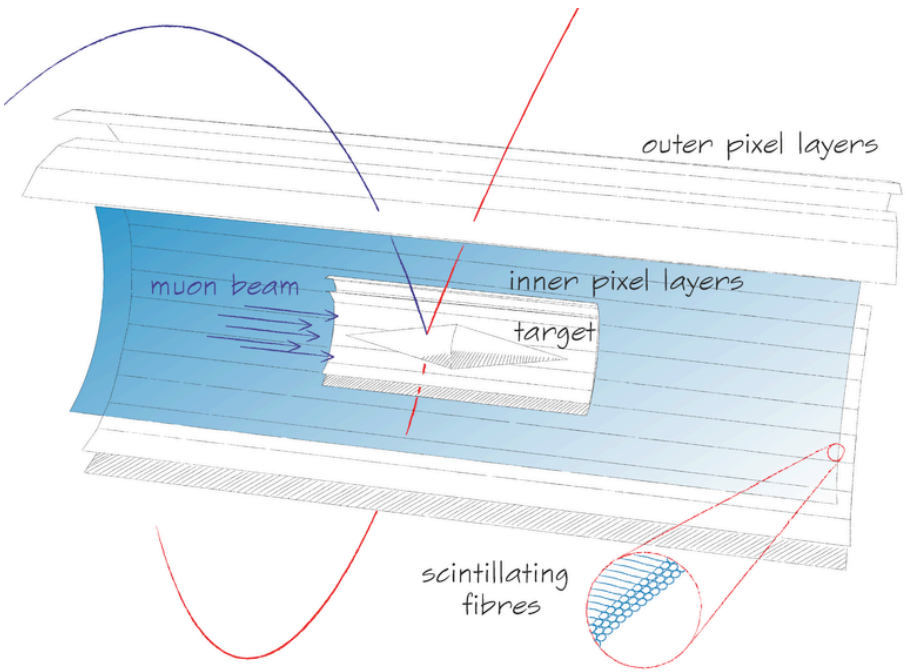
Proposal: http://www.psi.ch/mu3e/DocumentsEN/ResearchProposal.pdf

Scintillating Fiber Detector

Purpose:
Complement the silicon tracker (unambiguous silicon hit assignment to tracks)

Requirements:
- timing resolution < 1 ns
- detection efficiency ~100 %
- as little material as possible (multiple scattering)

Baseline design:
~4'500 fibers of 250 μm thickness and ~ 35 cm length arranged in three-layer-ribbons, read out by Silicon Photomultipliers (SiPMs) at both fiber ends



central part of the detector

Scintillating Fiber Detector

Challenge: Achieve good timing resolutions (< 1 ns) with high detection efficiency using so little (< 1 mm) scintillation material

expected energy deposit (MIP) ~ 30 keV ≅
O(10) detected photons per fiber

Measurement goals with PSI prototypes:

- timing resolution in single- and multi-hit event
- detection efficiency

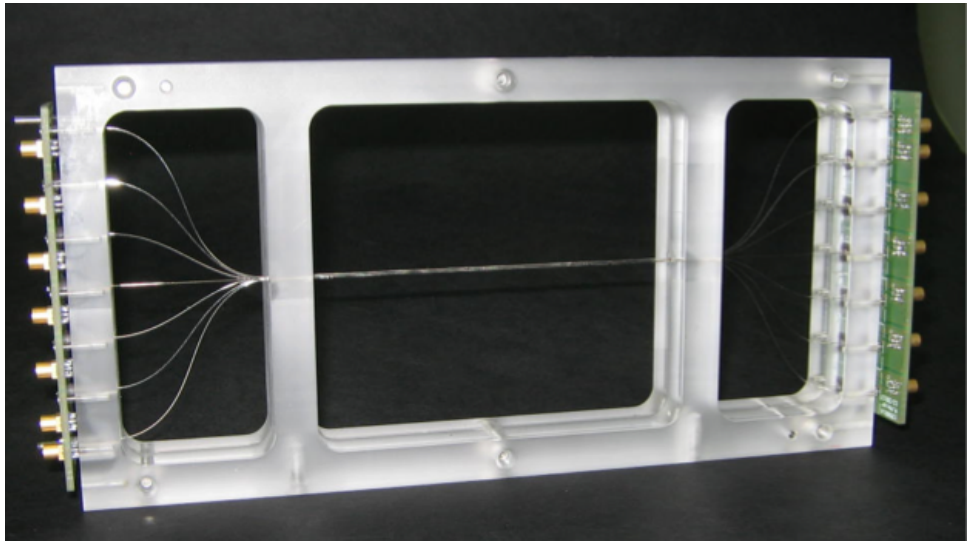
for both **250 μm** and 500 μm squared fibers

Tests…

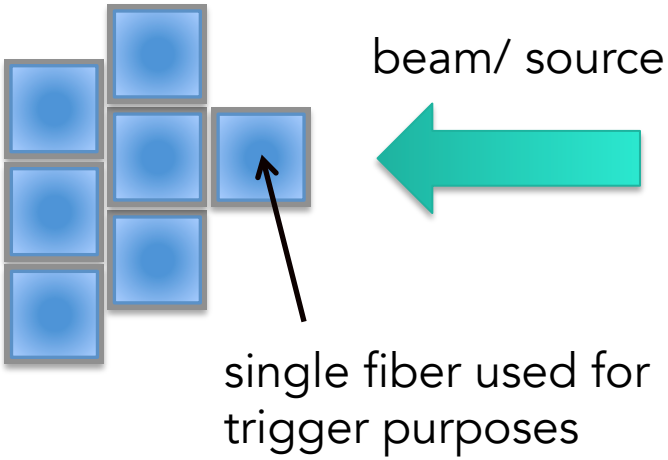
…in the lab (Sr90 source)
…in PiE5 area @ PSI (28 MeV/c e^+, older version of the 250 μm prototype)
…in PiM1 area @ PSI (115 MeV/c e^+, newer version of the 250 μm prototype)

The Prototypes

- Telescope structure
  - 3 layers
  - 14 channels (7 fibers read out at both ends)



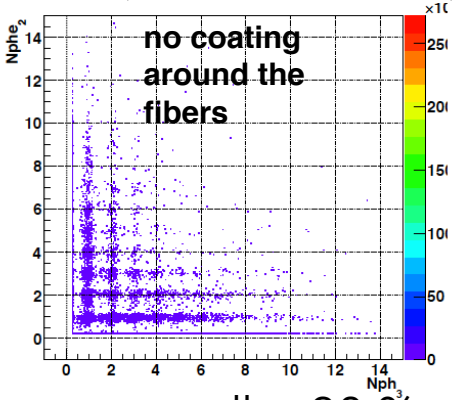
Arrangement of the fibers



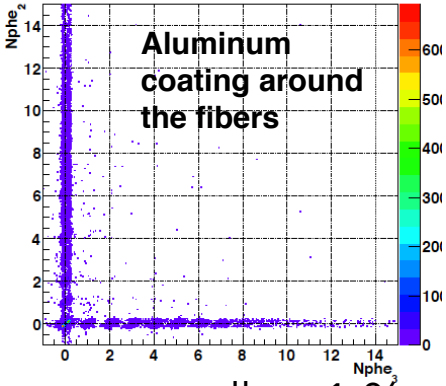
The Prototypes

- Telescope structure
  - 3 layers
  - 14 channels (7 fibers read out at both ends)
- Squared **250 µm** fibers
  - Saint-Gobain BCF-12 multiclad
  - 25 cm length
  - coated with 100 nm of aluminum to suppress crosstalk between fibers
  - fibers mounted on a plexiglass frame

cross talk between adjacent fibers (Sr90 electrons)

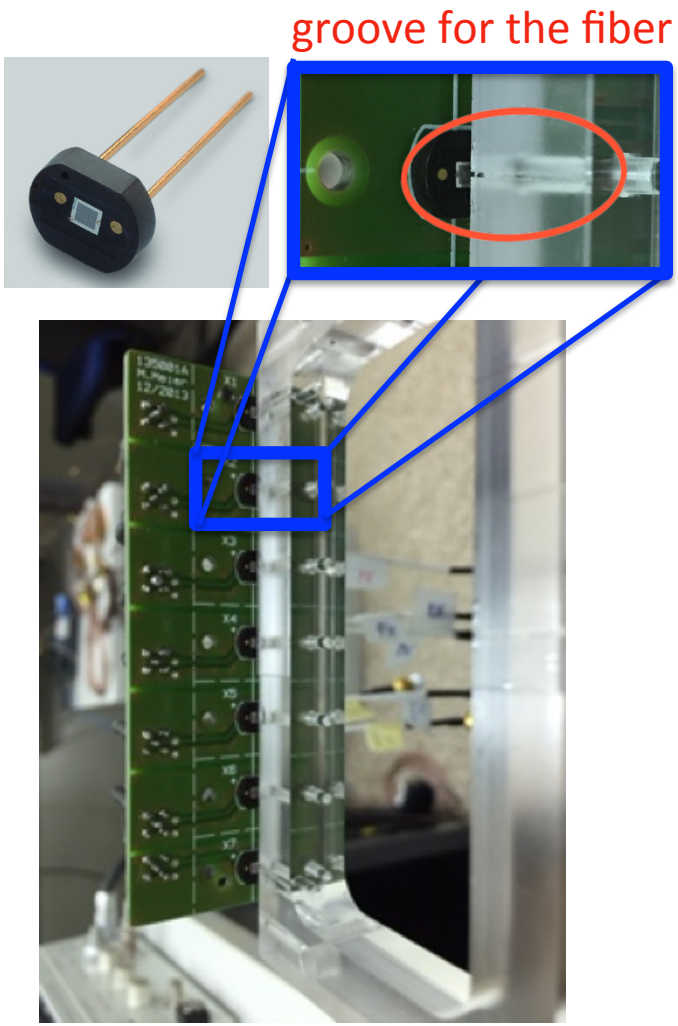


cross talk ~30 %



cross talk < 1 %

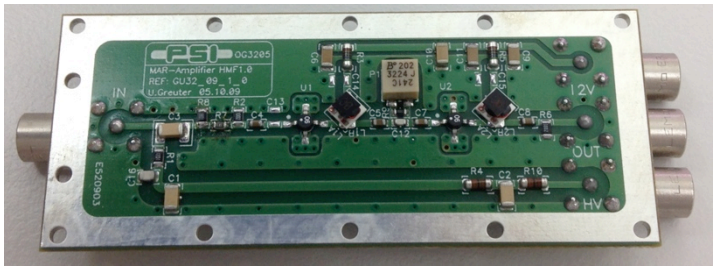
The Prototypes



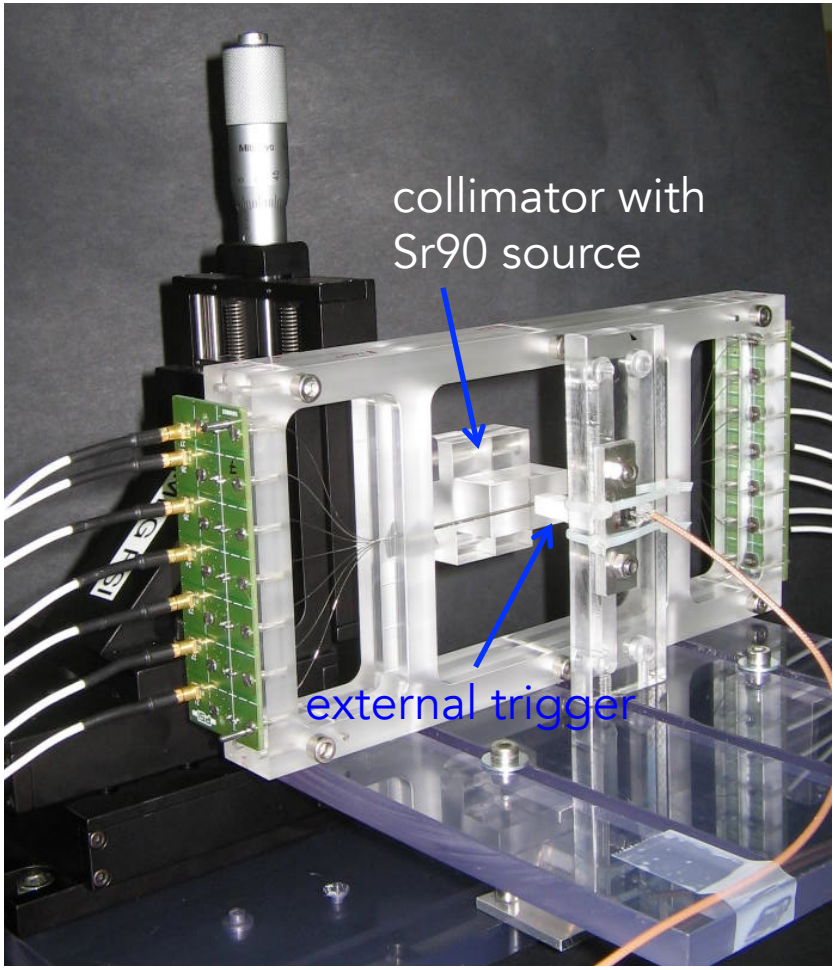
- Light detection: SiPM coupled at both fiber ends
  - Hamamatsu S12815-050C
  - 50 μm pixel size, sensitive area 1.3 x 1.3 mm^2
  - Coupling fiber – SiPM with optical grease

Electronics

- Preamplifiers:
  - MAR-amplifiers developed at PSI (and optimized for small amount of detected photons)
- DAQ: PSI DRS evaluation boards (daisy-chained)
  - Waveform digitization @ 5 GSPS
  - 4 channels per board
  - Max. acquisition rate for one single evaluation board: 500 Acq./ sec



The Lab-Setup

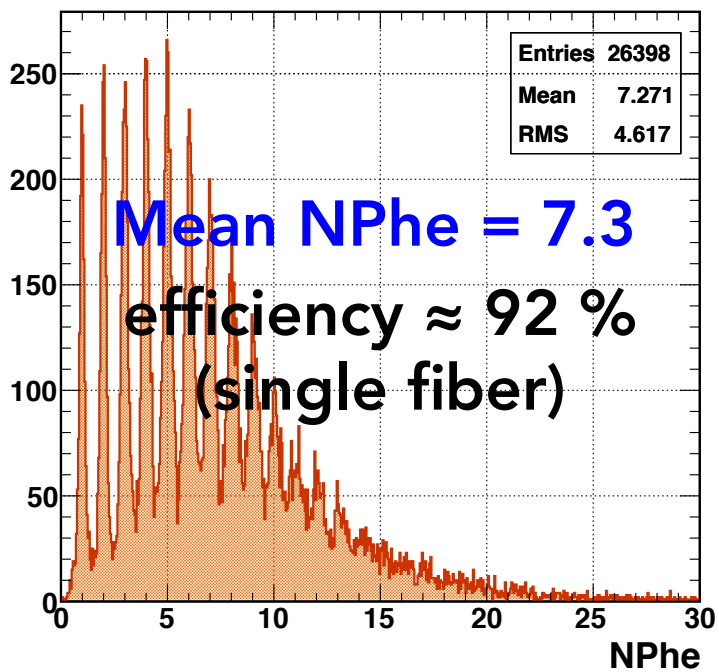


- Sr90 source
  - Collimator mounted on a moving stage
- External trigger:
  - Plastic scintillator (4 x 4 x 20 mm^3) coupled to
  - SiPM (Hamamatsu 3 x 3 mm^2 active area)
  - Select MIPs (E_e> 1.5 MeV)
  - Get rid of thermal noise (no cooling)

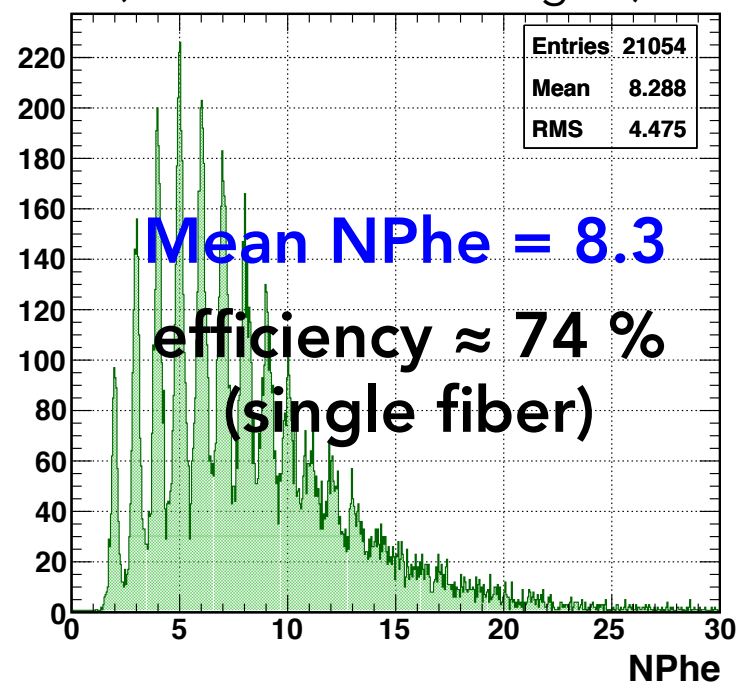
Results 250 µm – Source

- Collected light – Sum of both SiPM (readout of both fiber ends) – Threshold 0.5 NPhe

SiPMs in "OR" logic
(at least 1 SiPMs sees a signal)



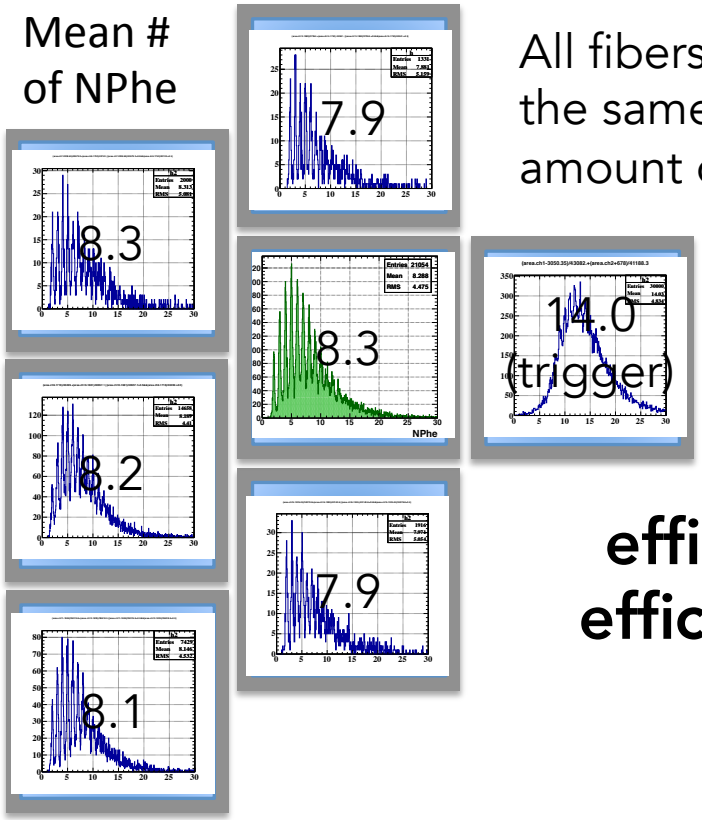
SiPMs in "AND" logic
(both SiPMs see a signal)



Results 250 μm – Source

- Collected light – Homogeneous response of the detector – Threshold 0.5 NPhe (AND logic)

Mean # of NPhe



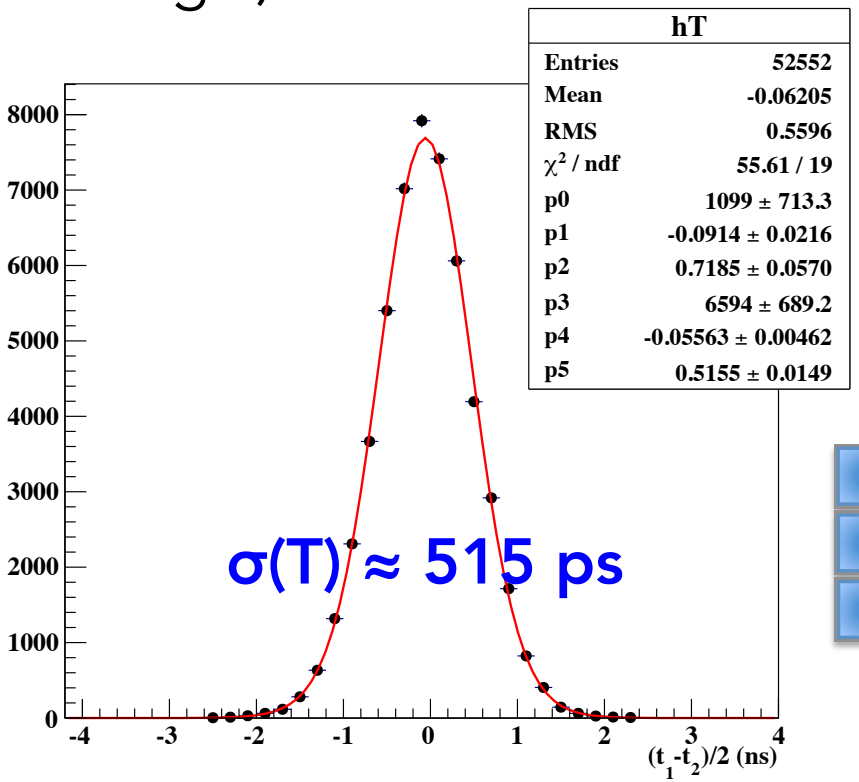
All fibers see ~ the same amount of light

source e⁻

efficiency (OR) ≈ 97 %
efficiency (AND) ≈ 79 %
(fiber layer)

Results 250 µm – Source

- Timing: Custom waveform analysis with offline constant fraction discrimination – Threshold 0.5 NPhe (AND logic)



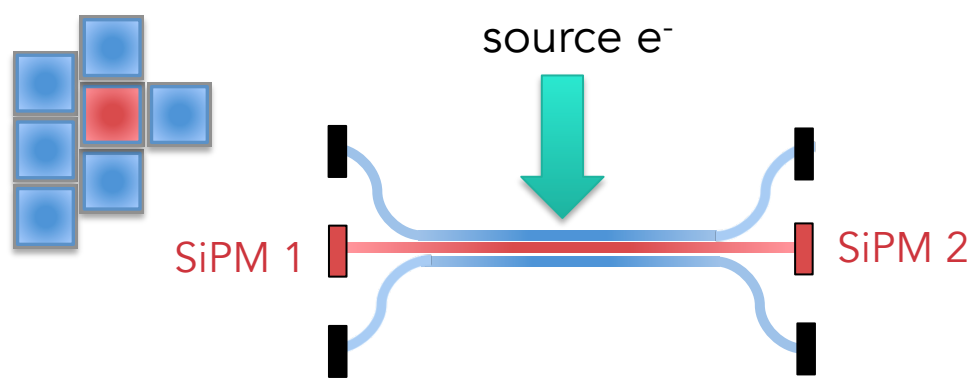
Single hit timing resolution

$$\sigma(T) = \sigma((t_1 - t_2)/2)$$

time measured by SiPM 1

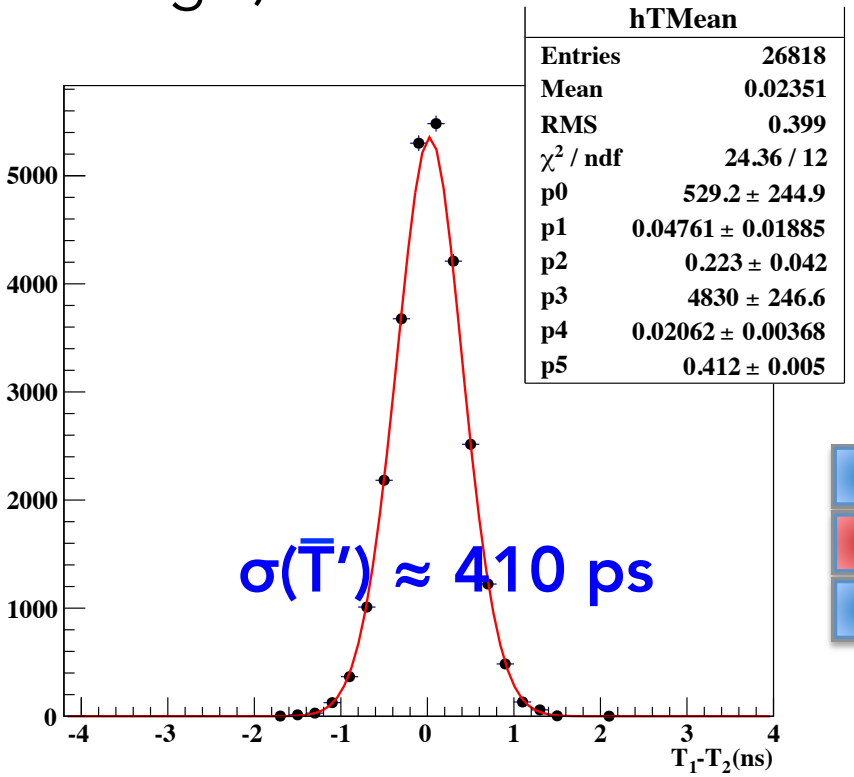
time measured by SiPM 2

fibers under consideration



Results 250 µm – Source

- Timing: Custom waveform analysis with offline constant fraction discrimination – Threshold 0.5 NPhe (AND logic)



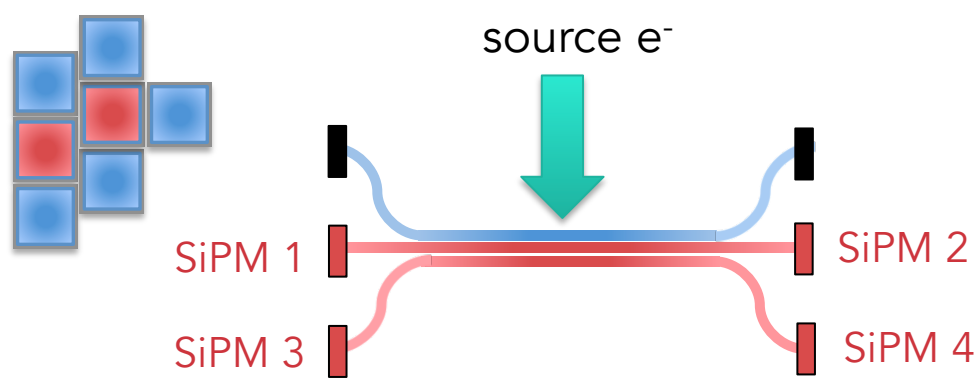
Double hit timing resolution

$$\sigma(\bar{T}') = \sigma((T_{12}-T_{34})/2) = \sigma(T)/\sqrt{2}$$

Note:

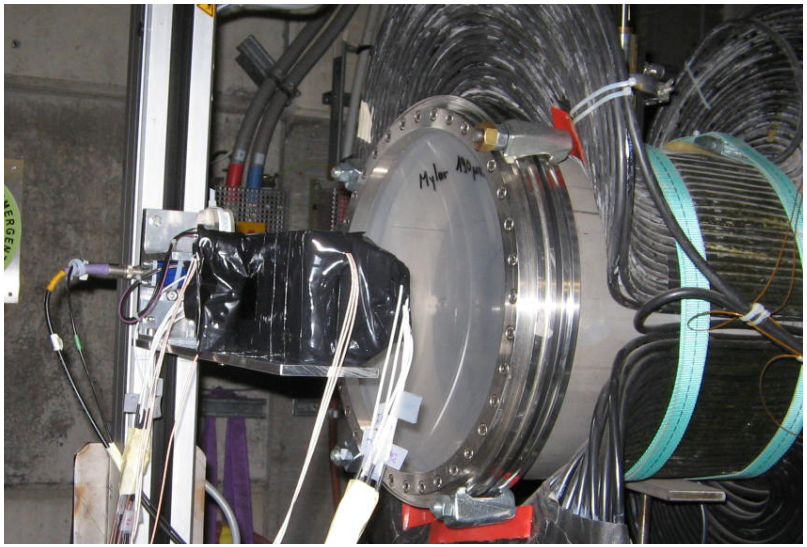
$$\sigma(\bar{T}') = \sigma((T_{12}-T_{34})/2) = \sigma((T_{12}+T_{34})/2) = \sigma(\bar{T})$$

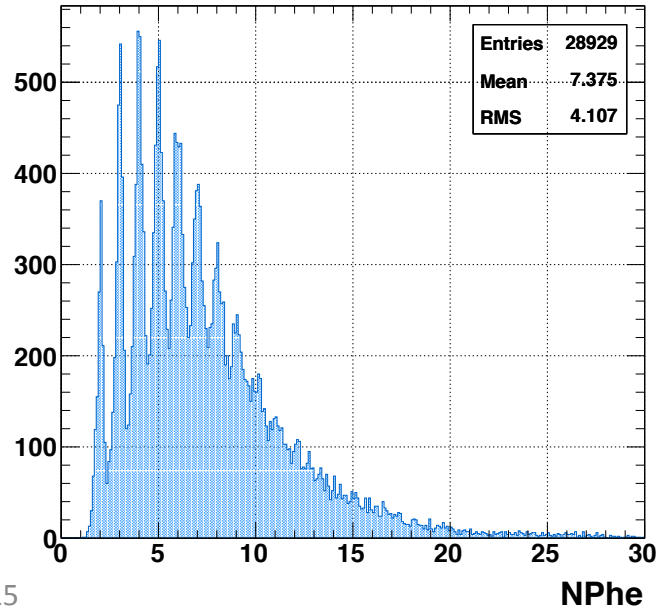
fibers under consideration



Test Beam PiE5

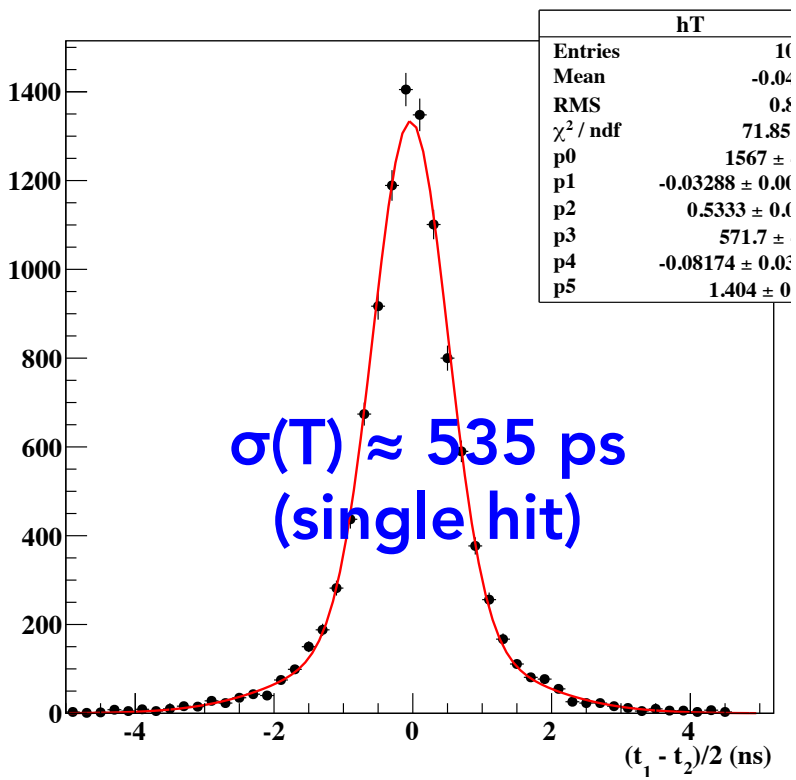
- Test of a **previous version** of the 250 μm prototype
  - Difference w.r.t. new version: **Al coating** via sputtering instead of PVD ➔ slightly less performing fibers (mean collected number of photons 7.4 NPhe instead of 8.3 NPhe)
- Beam Momentum: p = 28 MeV/c positrons

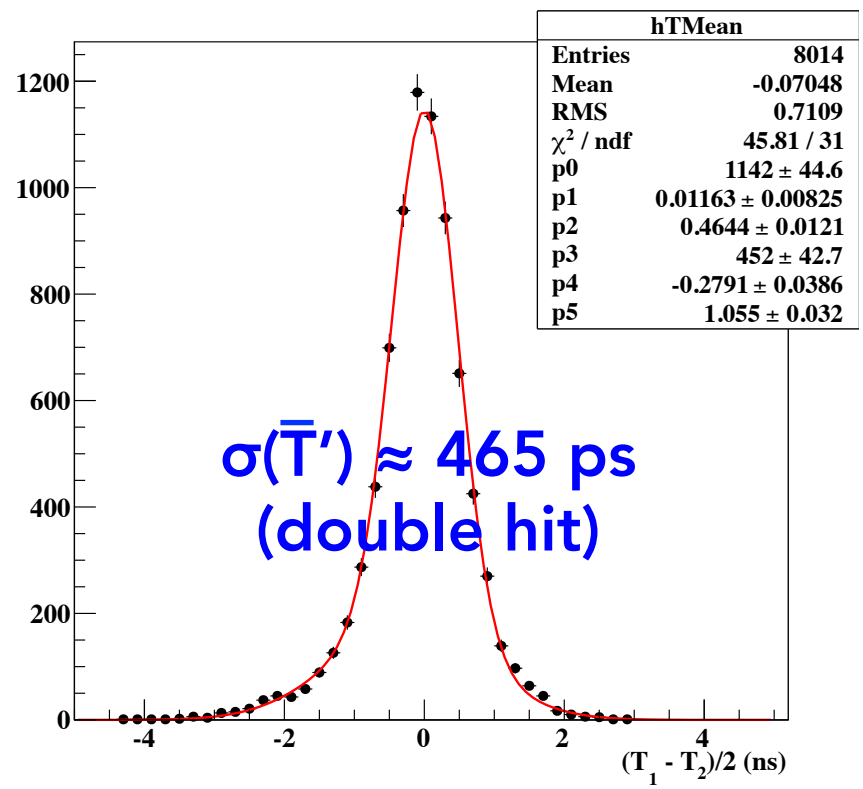




Results 250 µm – Test Beam PiE5

- Timing: Custom waveform analysis with offline constant fraction discrimination – Threshold 0.5 NPhe (AND logic)



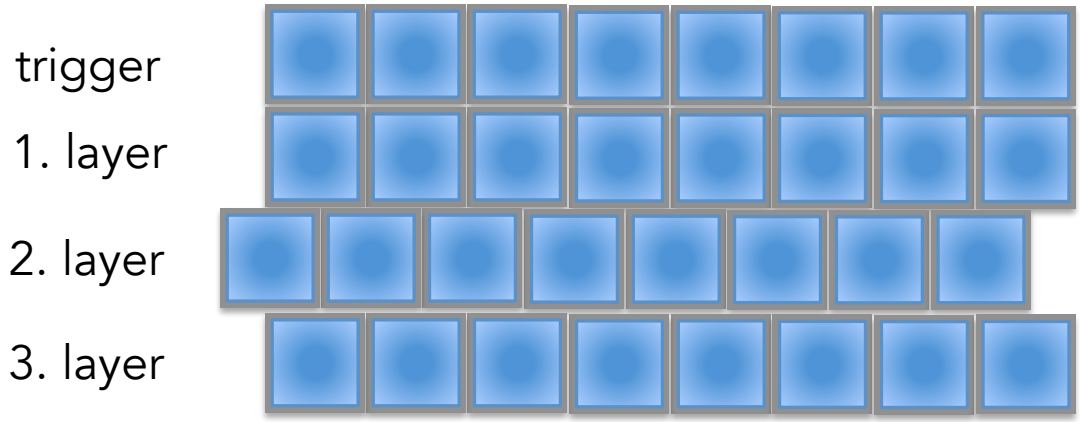


Conclusion

- Prototype studies with a telescopic structure of 250 μm squared multiclad scintillating fibers have shown the following performances:
  - ca**. 8 (mean) collected photons per fiber**, observed for all fibers of the prototype (homogeneous detector response)
  - **cross talk** < 1 %
  - **single fiber efficiency** of **92 %** (OR-logic) and **74 %** (AND-logic)
  - **fiber layer efficiency** of **97 %** (OR-logic) and **79 %** (AND-logic)
  - **timing resolution** of ca. **515 ps** (single hit) and ca. **410 ps** (double hit)
- Performances in the lab and test beam are consistent
- Analysis of the PiM1 test beam data underway
  - Time-of-flight measurement
  - Improvements on the timing algorithm

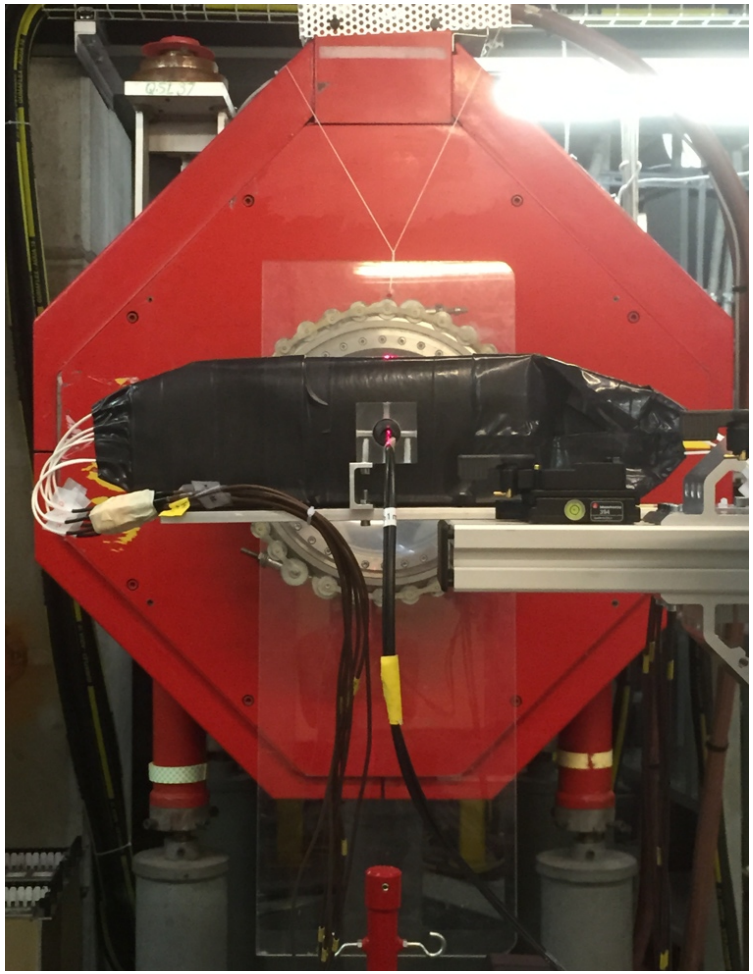
Outlook

- Preparation of a "large prototype" ongoing
  - confirmation of detector performances (collected light, efficiencies, timing resolutions)
  - first "small" 32 fibers, 64 channels module (measure multi-layer efficiency, study clustering algorithms)
  - to be tested in October 2015 in PiM1 @ PSI



Backup

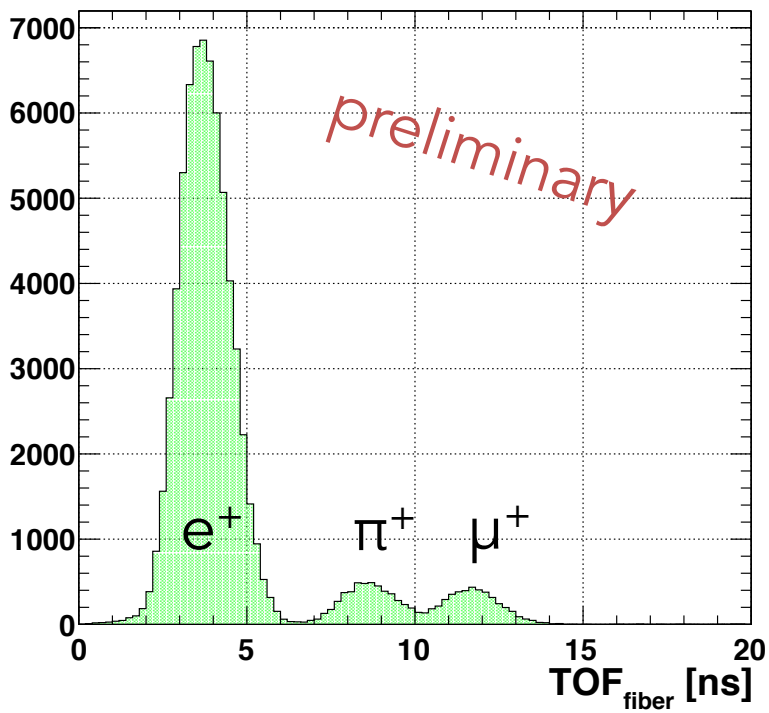
Test Beam - PiM1

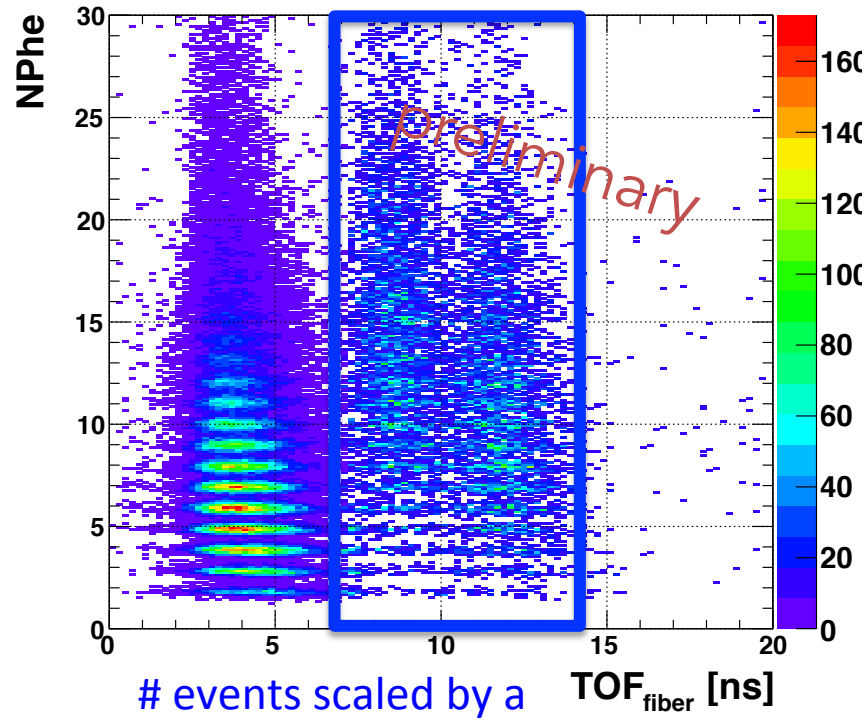


- **Momentum:** p = 115 MeV/c (e^+, μ^+, π^+)
- **Beam size:** (σ_x,σ_y) = (6.6 mm, 9.4 mm)
- **Total rate:** ~ 5.8 10^5 particles/ s @ 2.2 mA proton current
- Particle separation by time-of-flight

Results – Test Beam PiM1

- Time-of-flight measurement

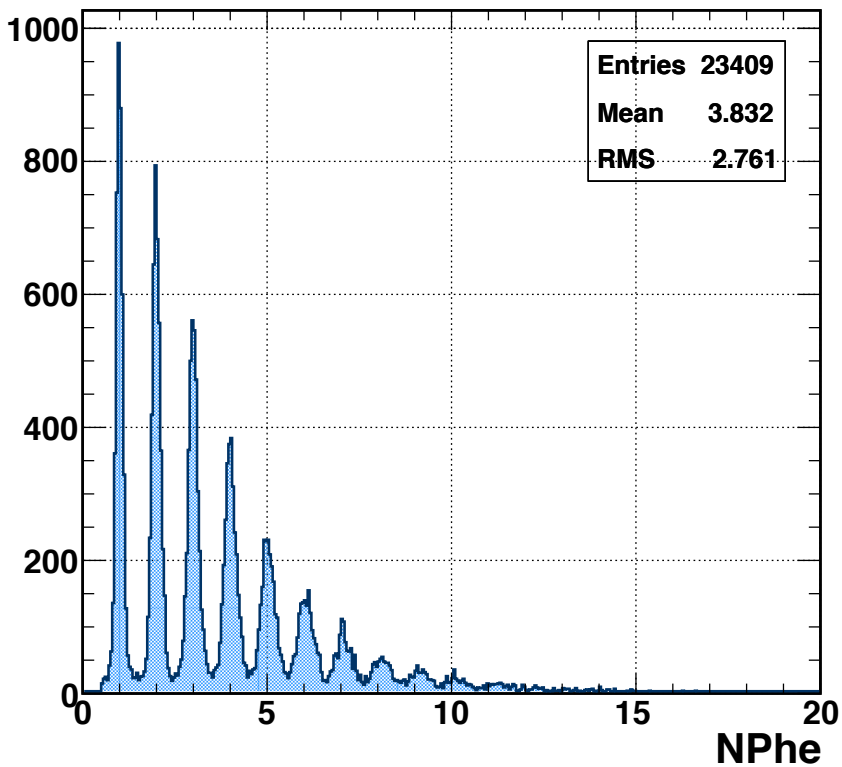




events scaled by a factor 10 for π^+, μ^+

Results 250 µm – Source

- Collected light (NPhe) – Single SiPM (readout of one fiber end) – Threshold 0.5 NPhe



Results 250 µm – Source

- Timing: Custom waveform analysis with offline constant fraction discrimination – Threshold 0.5 Nphe (AND logic)

Single Gaussian Fit