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Beam monitoring, tracking and timing with scintillating fibres readout by SiPM

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Overview

- Introduction

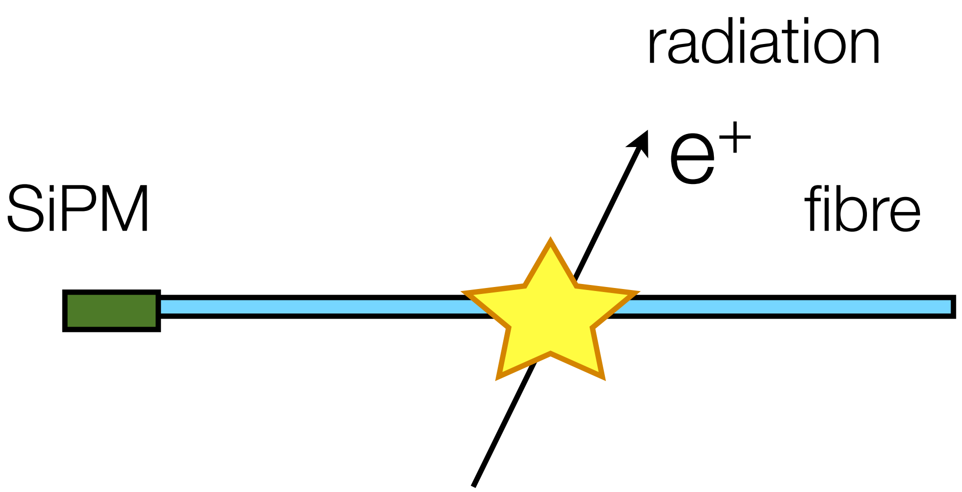
- Preliminary results of detector prototypes performances of single layer of very thin scintillating fibres (250 and 500 um) made of up to 8 fibres, each one coupled to SiPM

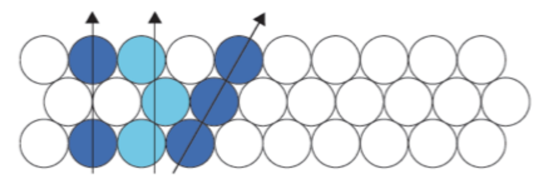
  - detector efficiency
  - spatial resolution
  - timing resolution

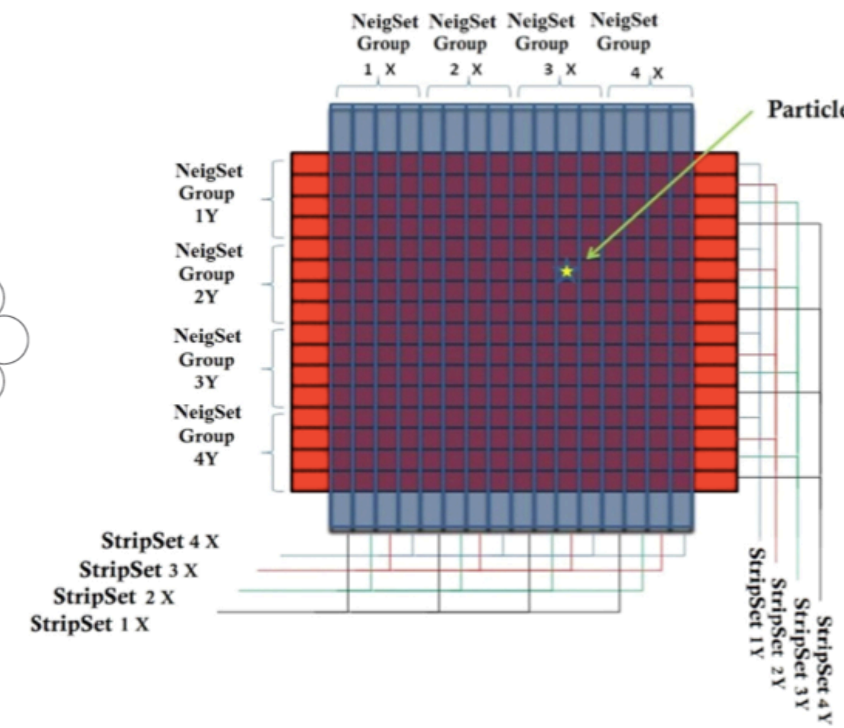
The new age of scintillating fibre coupled to SiPM

- Scintillating fibre coupled to photosensor provides flexible, fast and high spatial and high rate detectors
- The advent of the Silicon Photomultiple (SiPM, MPPC etc.) has a strong impact in the development of a new age of fibre detector based
  - higher detector performances w.r.t. the previous detector generation (spatial and timing resolution) for single fibre/layer (small detector size: single fibre coupled to each own photosensor)
  - working in magnetic field (trackers, spectrometers etc.)

Fundamental building block





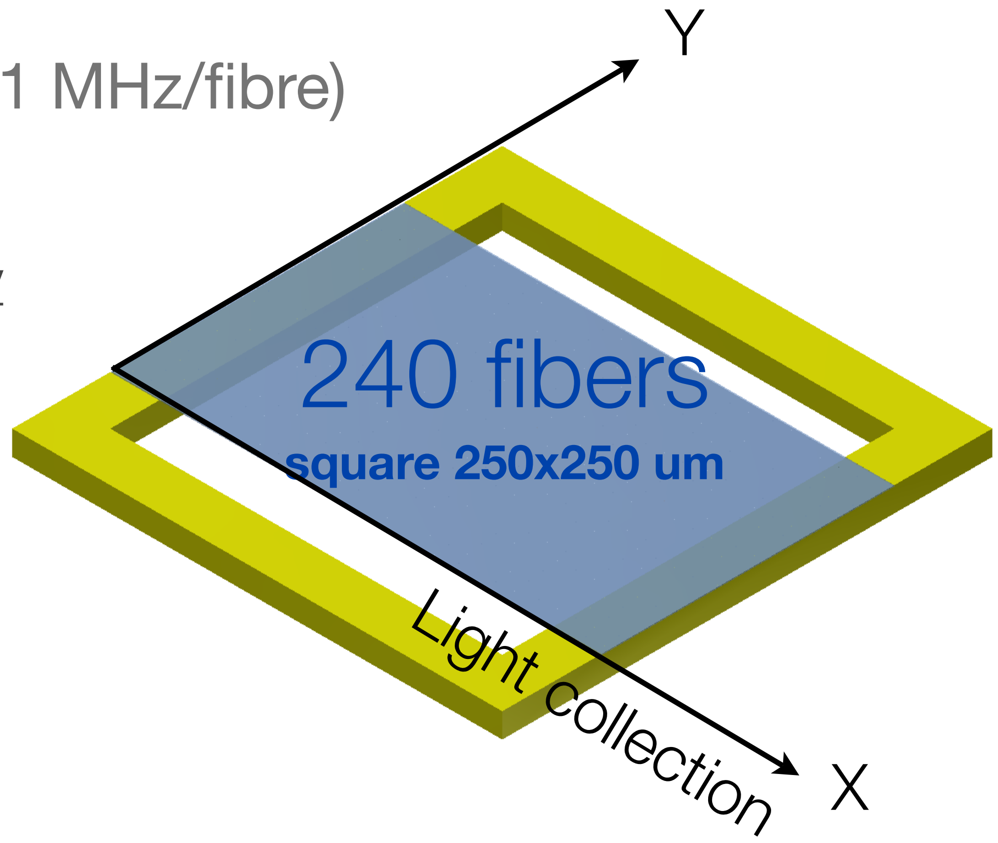


A beam monitoring and a vertex decay detector

- High and minimum ionizing particle detection
  - stopping muons and minimum ionizing positrons
- High detection efficiency at few phe (ε > 80%)
  - mean ~ 5 phe/SiPM (m.i.p.)
- High spatial resolution and minimum multiple scattering
  - $\sigma_{space} < 100$ um and $\Theta_{MS} < 5$ mrad
- High rate
  - beam intensity up to 10^8 particle/s (max 1 MHz/fibre)

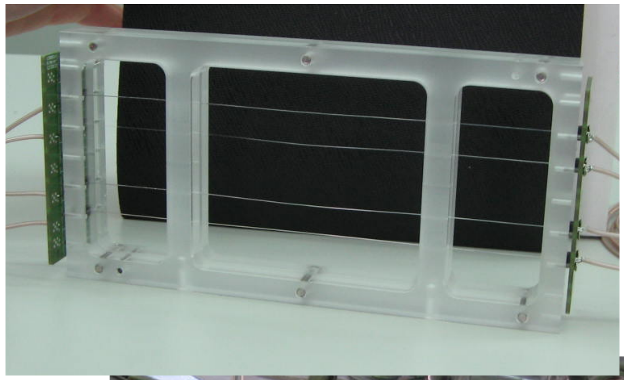
Single 250 um multi-clad fibre array
Each fibre readout by its own SiPM

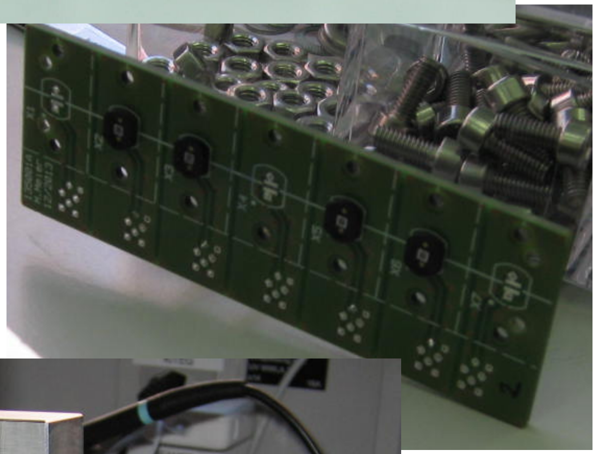
Auxiliary:
External trigger
movable/rotating support

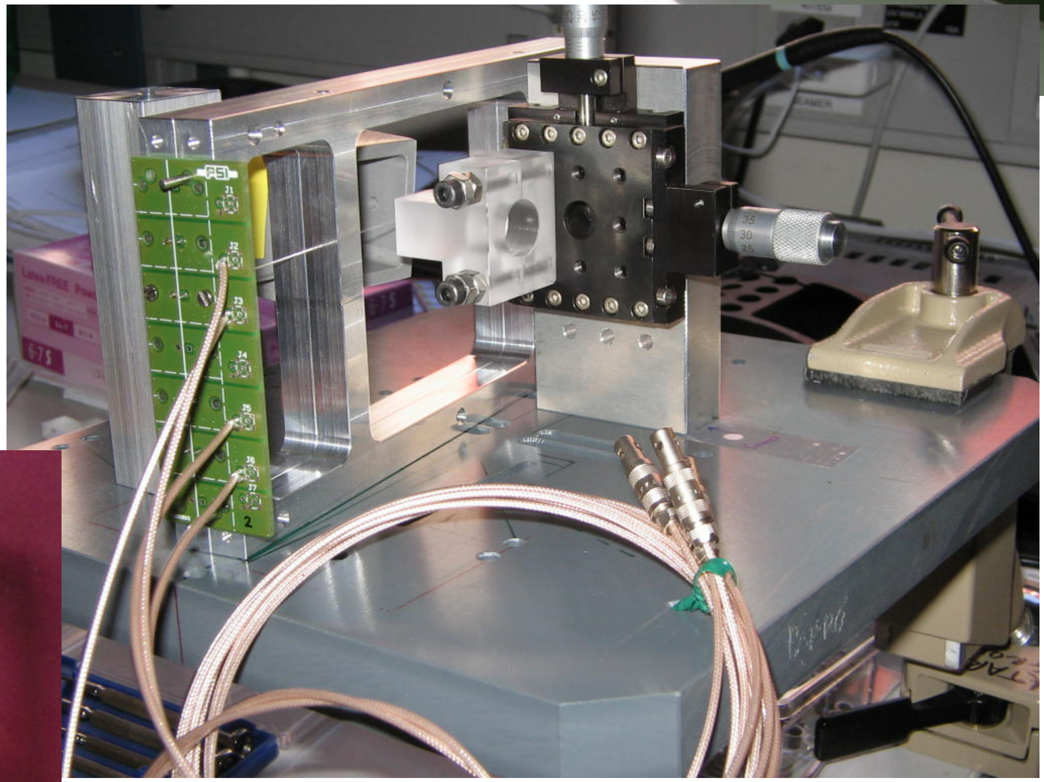


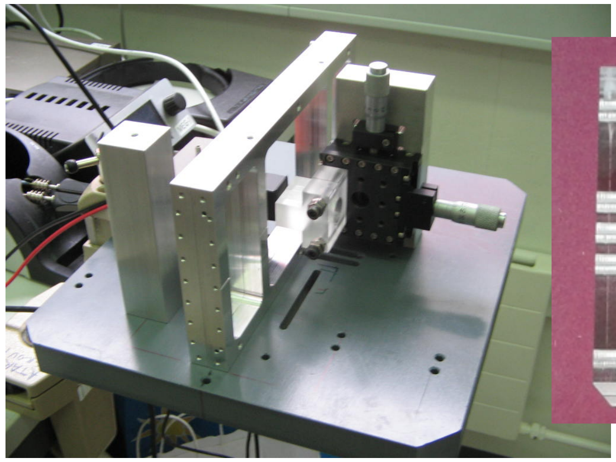
Experimantal setup

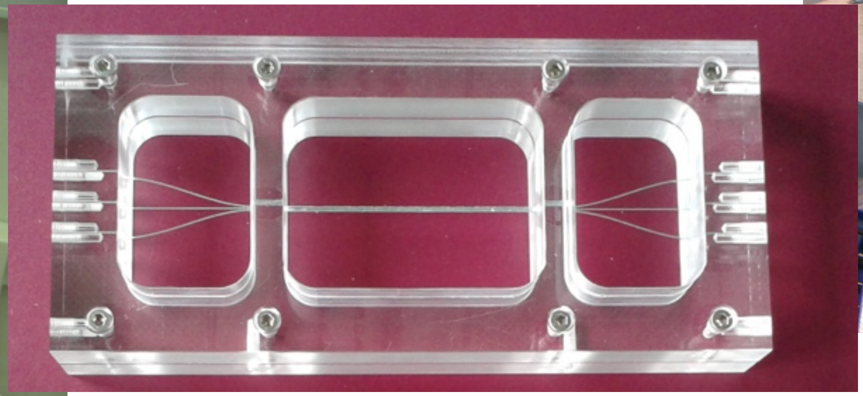
- Sr90 source
- Plexiglas collimator 0.25, 0.5, 0.75 and 1 mm
- Saint-Gobain BCF12/20 multi-cladding 0.25/0.5 mm square fiber
- Hamamatsu SiPM series S12571-100C/050C
- BC400 18x18x23 mm
- Hamamatsu PMT
- Preamplifier: PSI MAR-amplifier
- DAQ: PSI DRS evaluation board
- The external trigger role is
  - to remove SiPM thermal noise (no cooling)
  - to select minimum ionizing particles (>1.5 MeV)





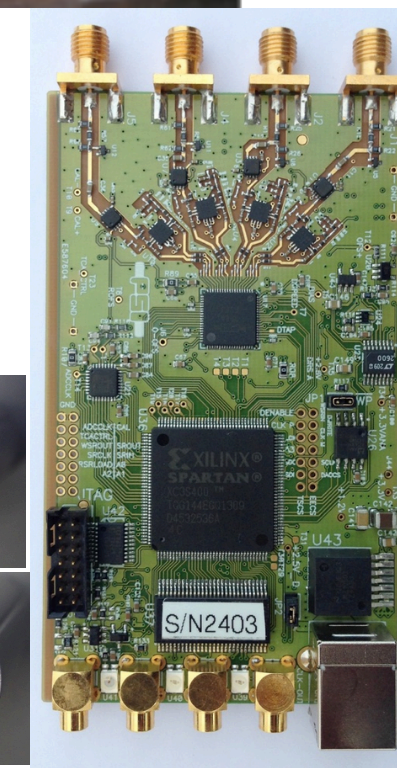


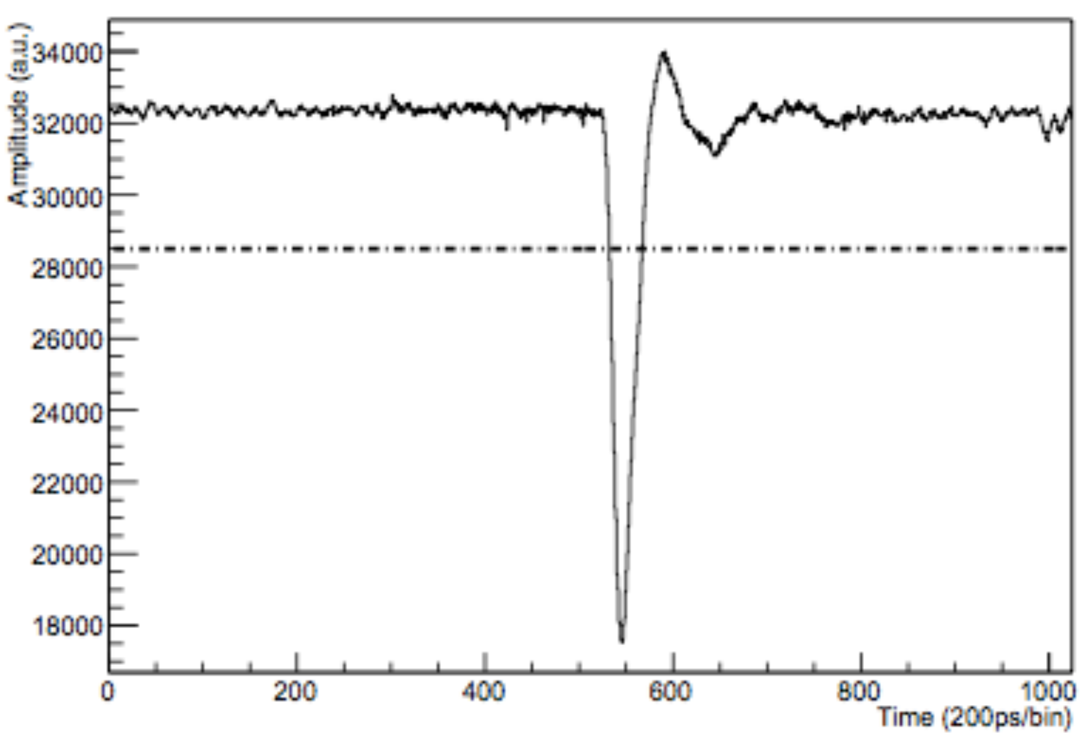


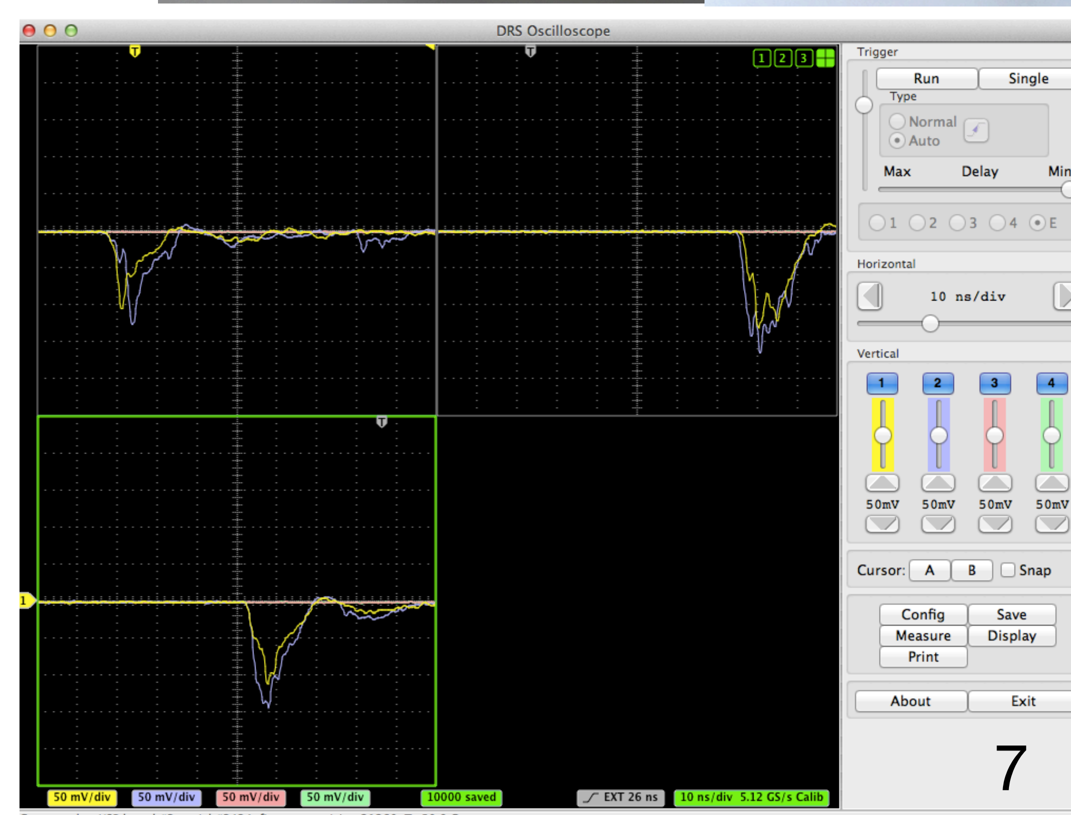


Electronics and DAQ

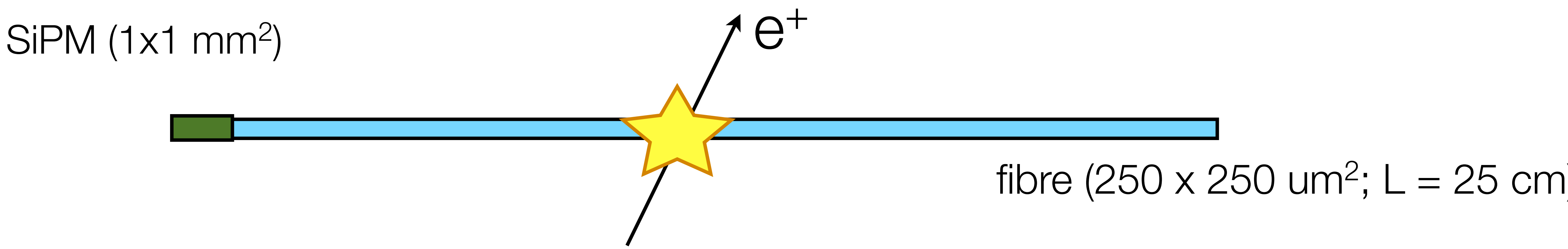
- Preamplifier from PSI MuSR group
  - A. Stoykov et al.: NIMA 695 (2012) 202
- DAQ: DRS4 evaluation board from PSI electronic pool
  - S. Ritt: NIMA 494 (2002) 520
  - http://www.psi.ch/drs/evaluation-board
  - Up to 5 Gsample/s
  - Custom waveform analysis



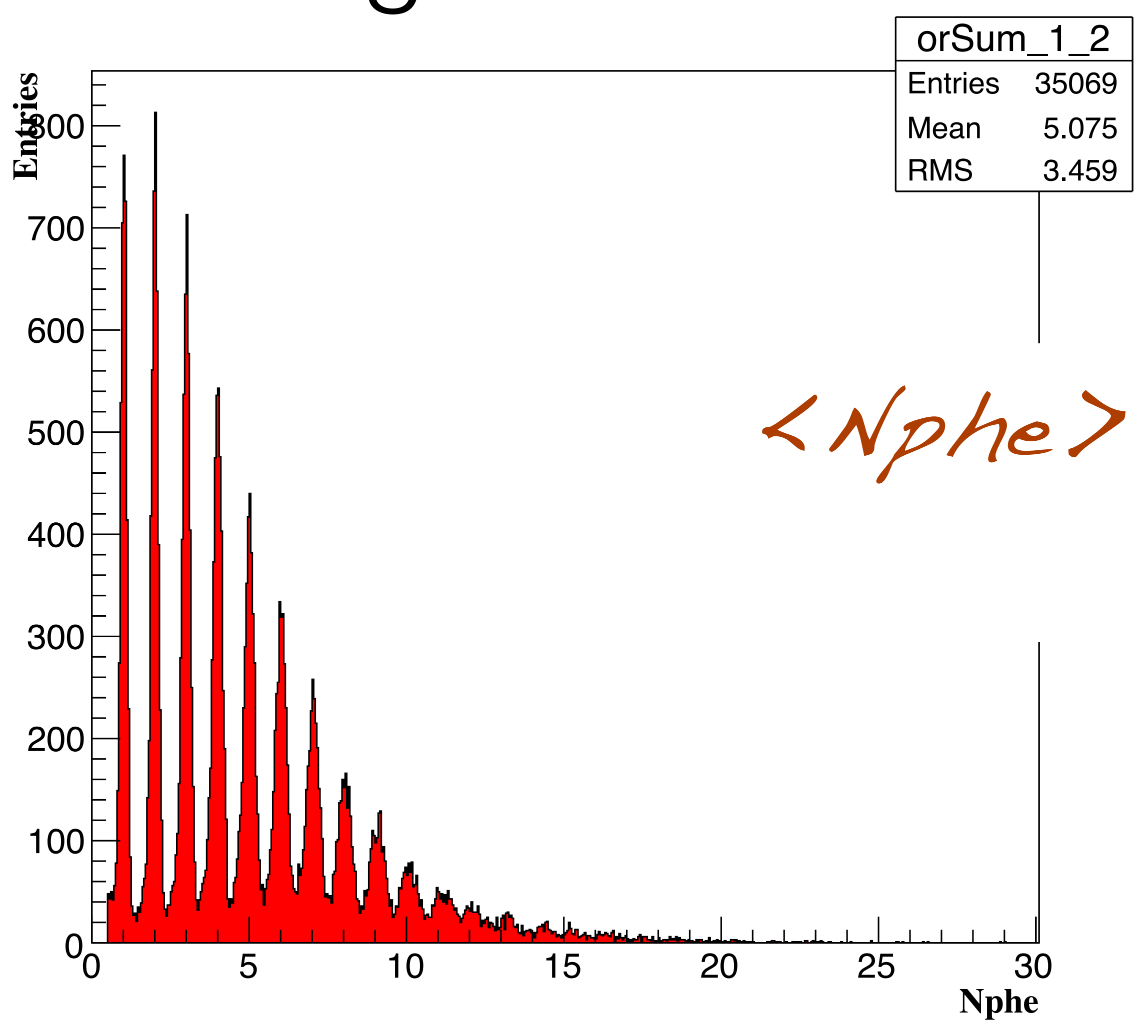




Positron spectra -- charge on one SiPM

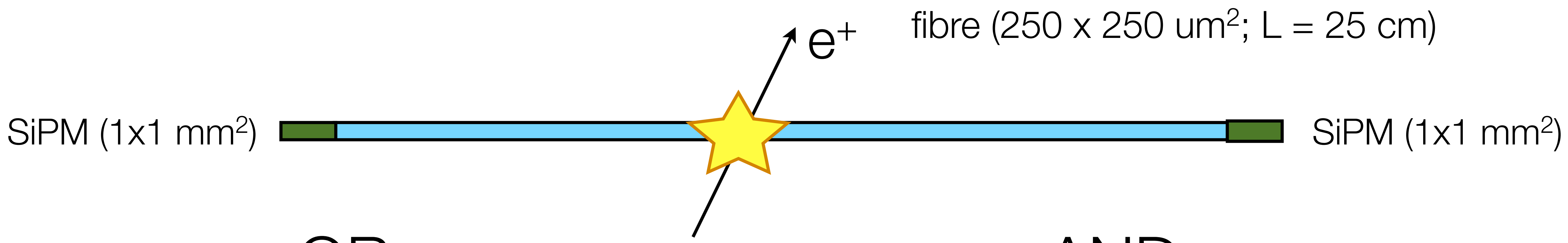


Single readout

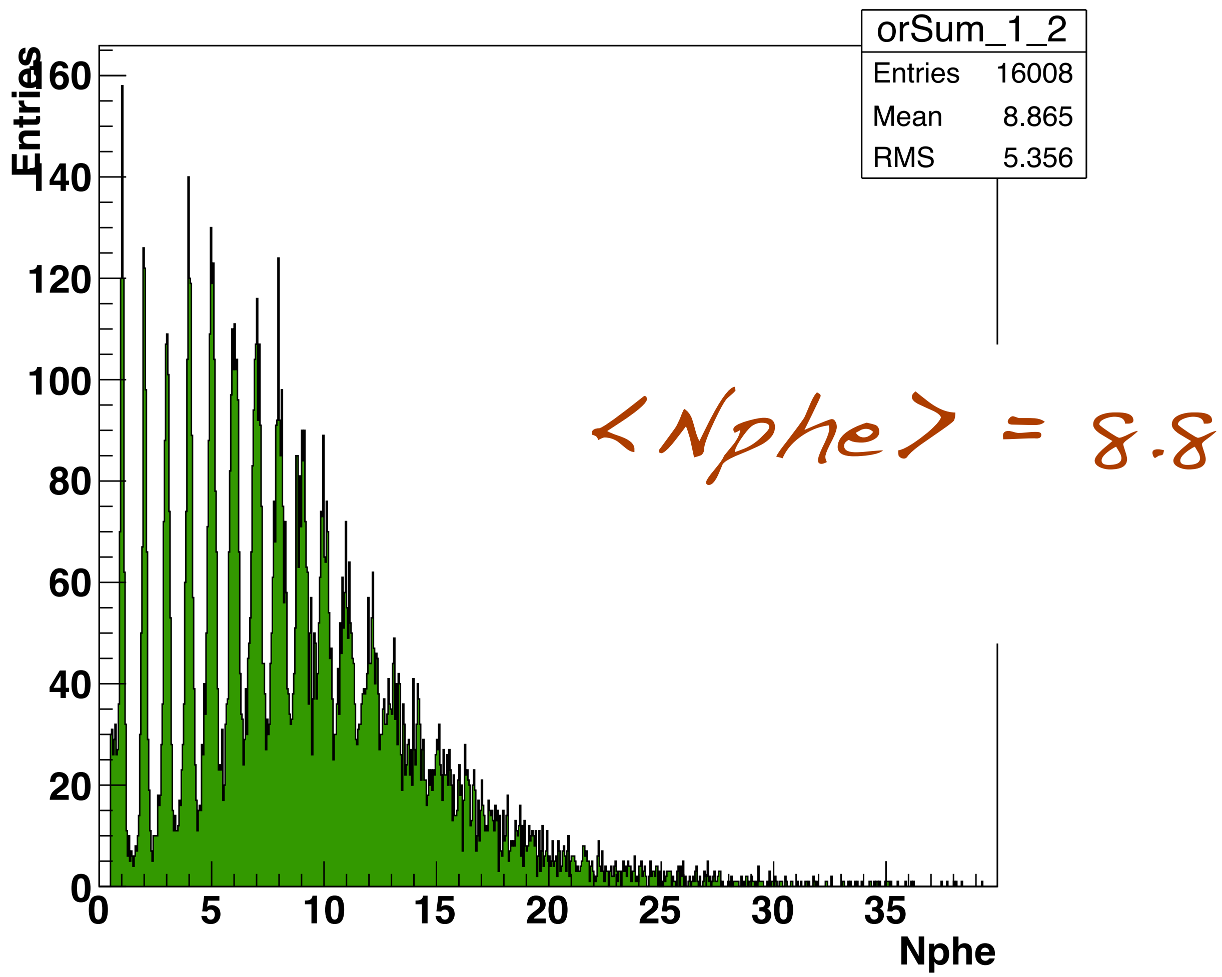


$\langle Nphe \rangle = 5$

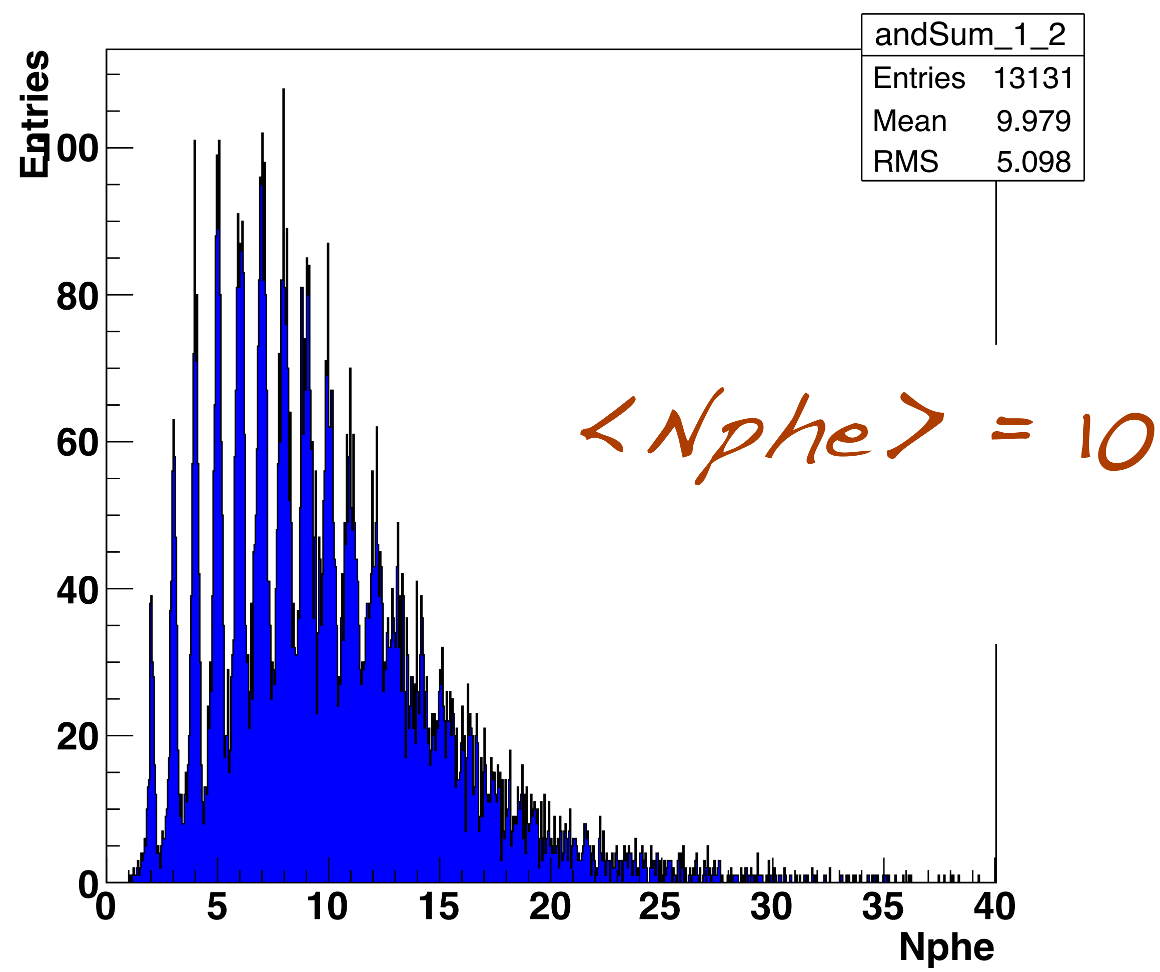
Positron spectra -- charge on both SiPMs



ORsum



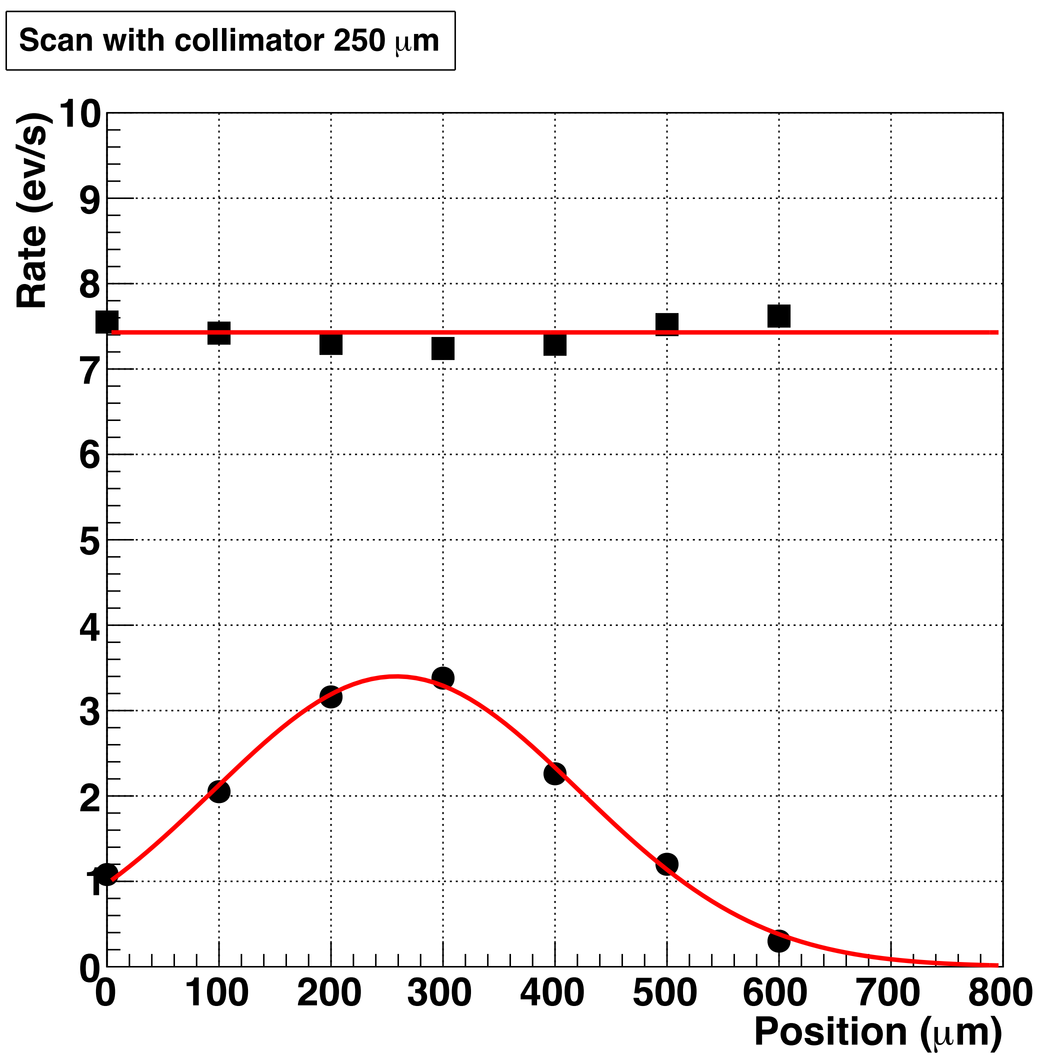
ANDsum

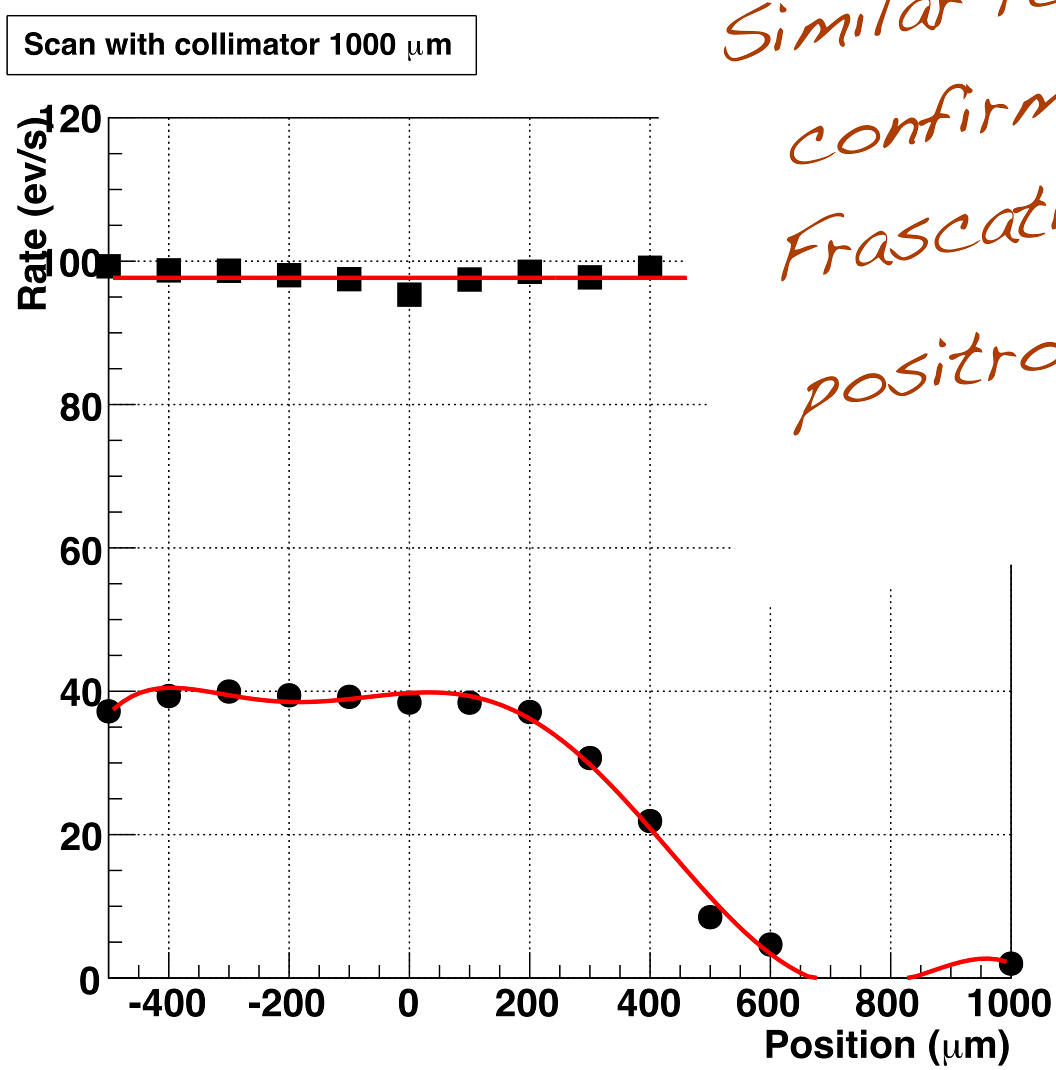


M.i.p. detection efficiency

- Scan of the relative position of the collimator hole w.r.t. the fiber was performed for each collimator (250, 500, 750, 1000 um)

■ TRG rate ● Fibre rate



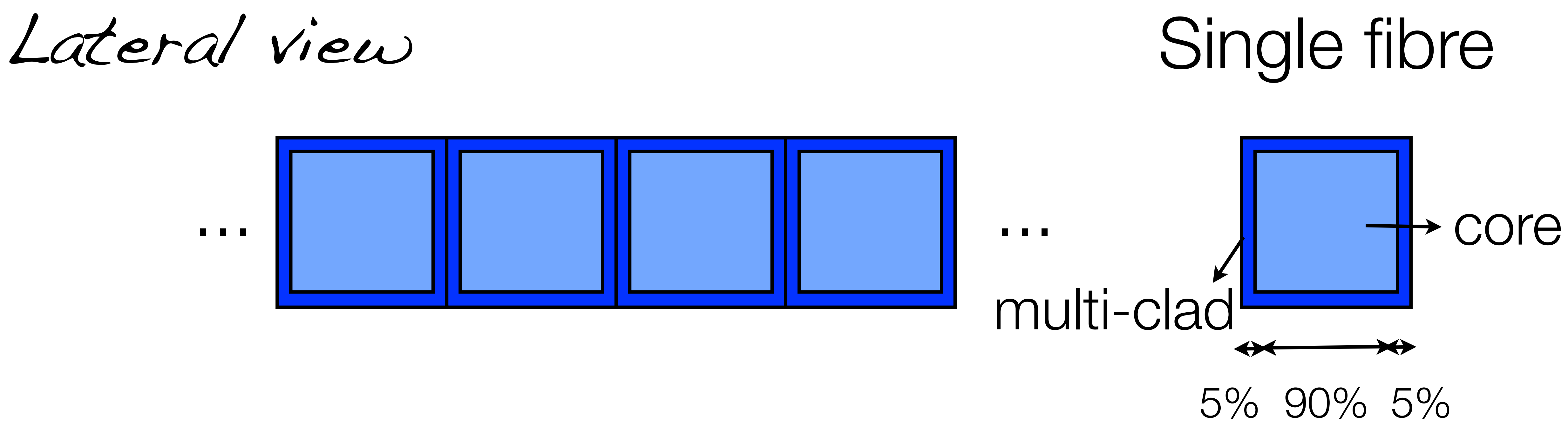


Similar results confirmed in Frascati using positron beam

ε_{dec} ~ 90% @ 0.5 phe

M.i.p. detection efficiency

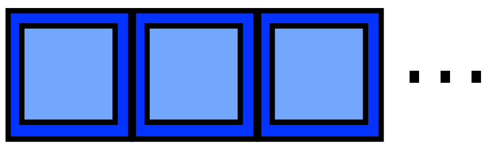
- Scan of the relative position of the collimator hole w.r.t. the fiber was performed for each collimator (250, 500, 750, 1000 um)

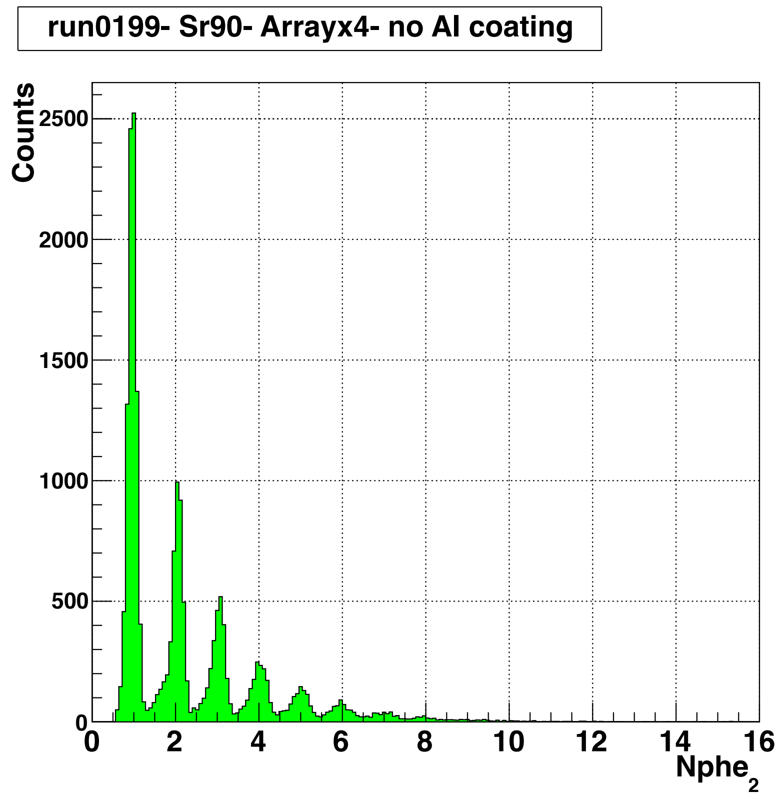


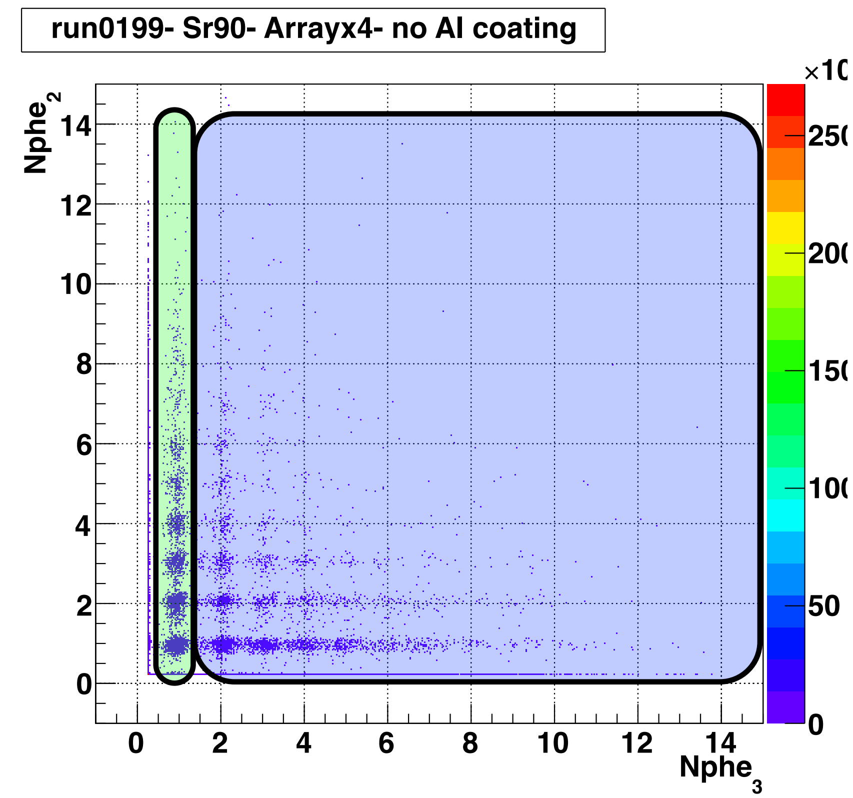
Single layer array sensitive geometrical coverage = 90%

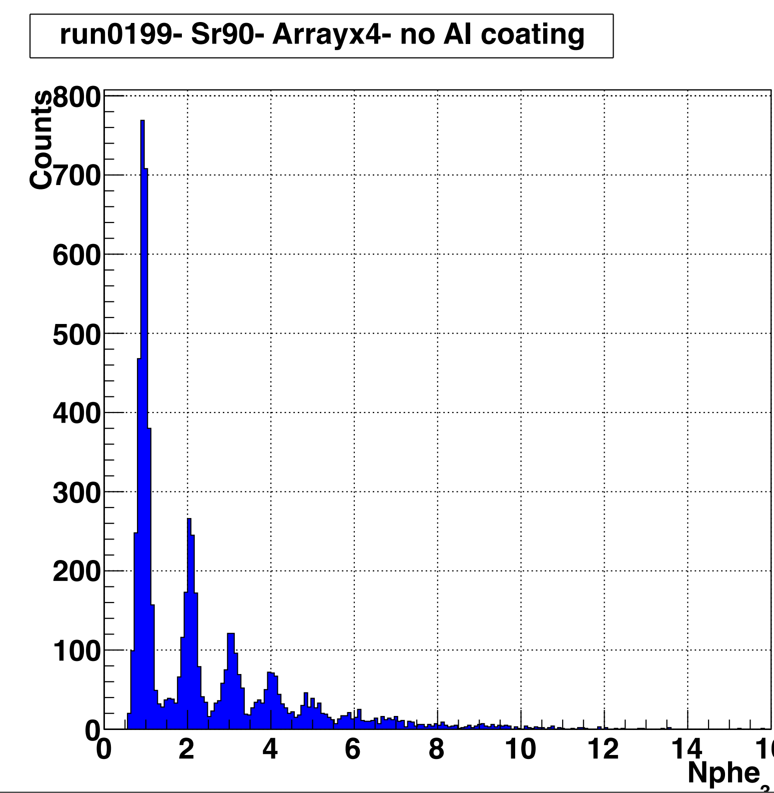
ε_{dec} ~ 90% +- few % @ 0.5 phe

The optical cross-talk -- without Al coating







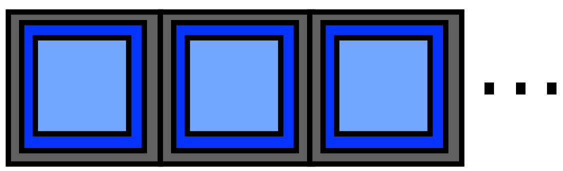


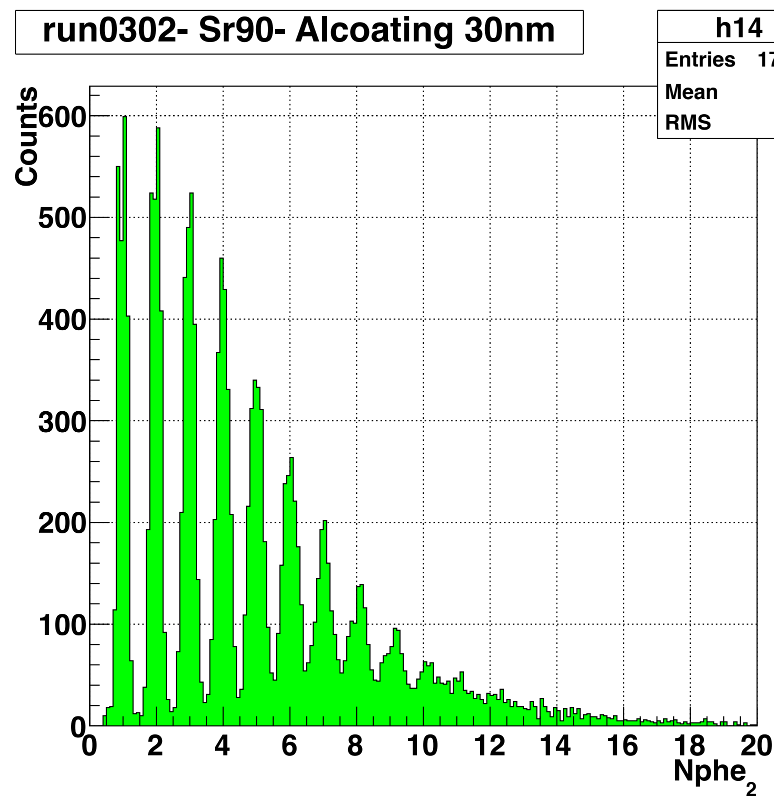
$P(Nphe_3|Nphe_2) \sim$

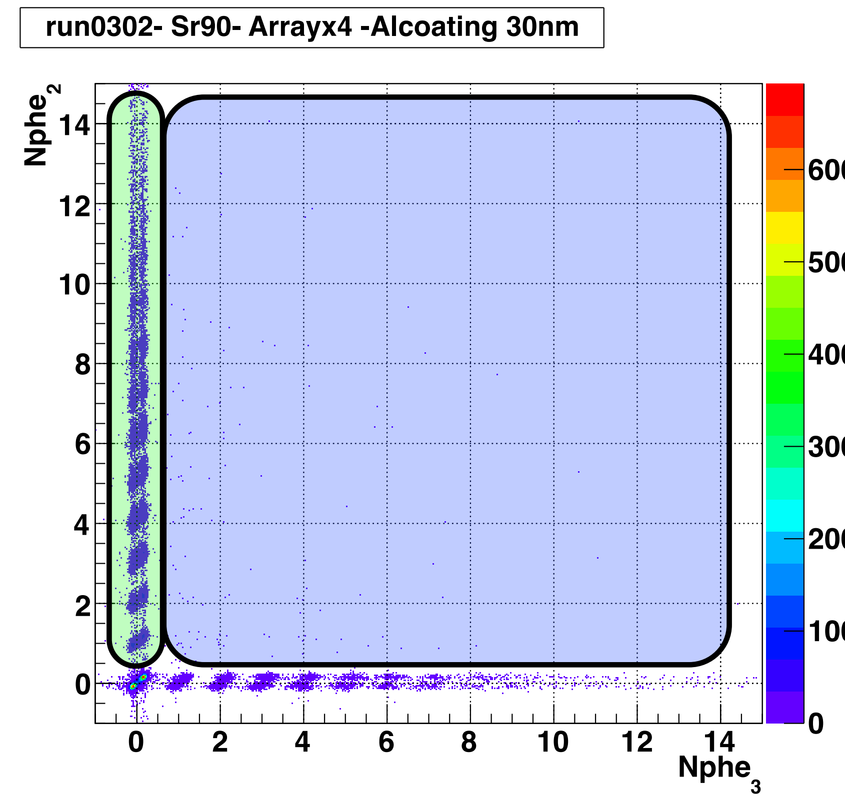
3×10^{-1}

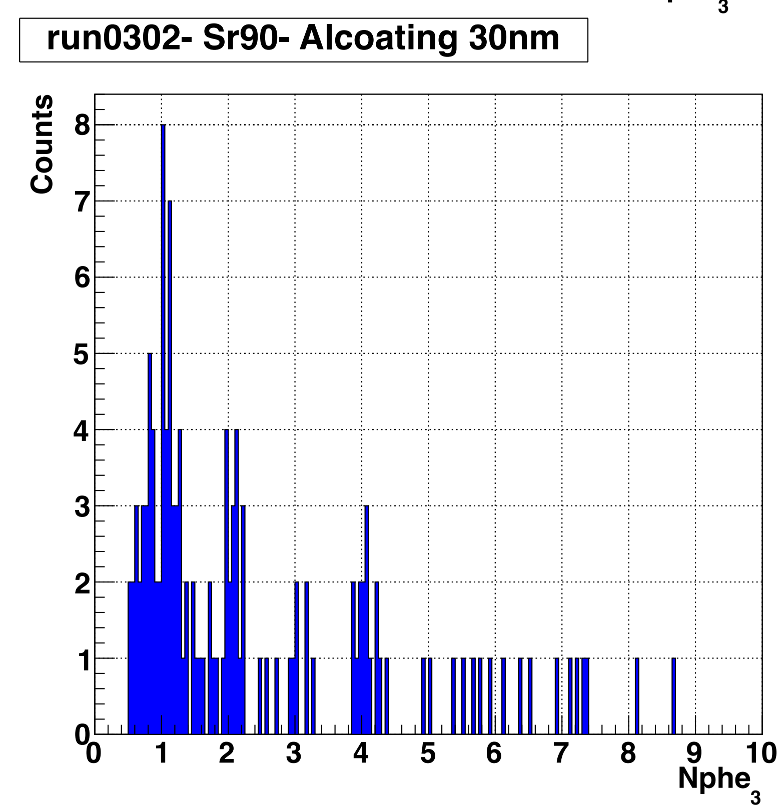
-- $Nphe_3$ in coincidence with $Nphe_2$ --

The optical cross-talk -- with 30 nm Al coating









$P(Nphe_3|Nphe_2) \sim$

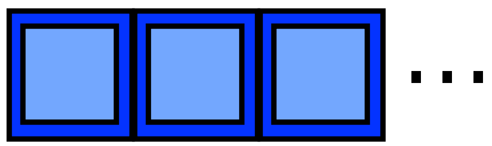
8×10^{-3}

-- $Nphe_3$ in coincidence with $Nphe_2$ --

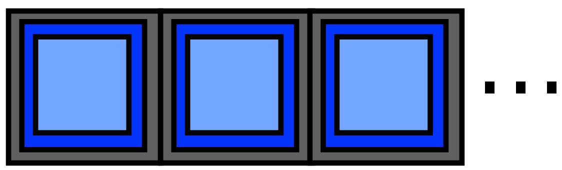
Optical cross-talk

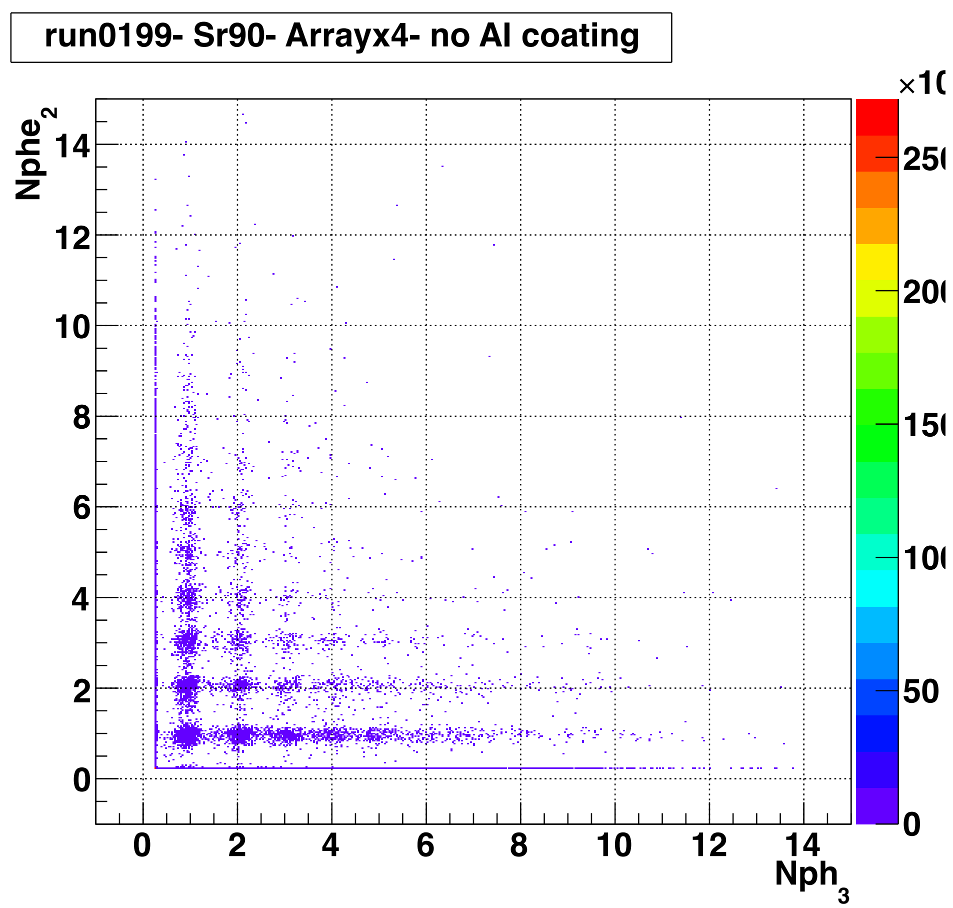
- Fibre array detector: with 30 nm sputtered Al coating

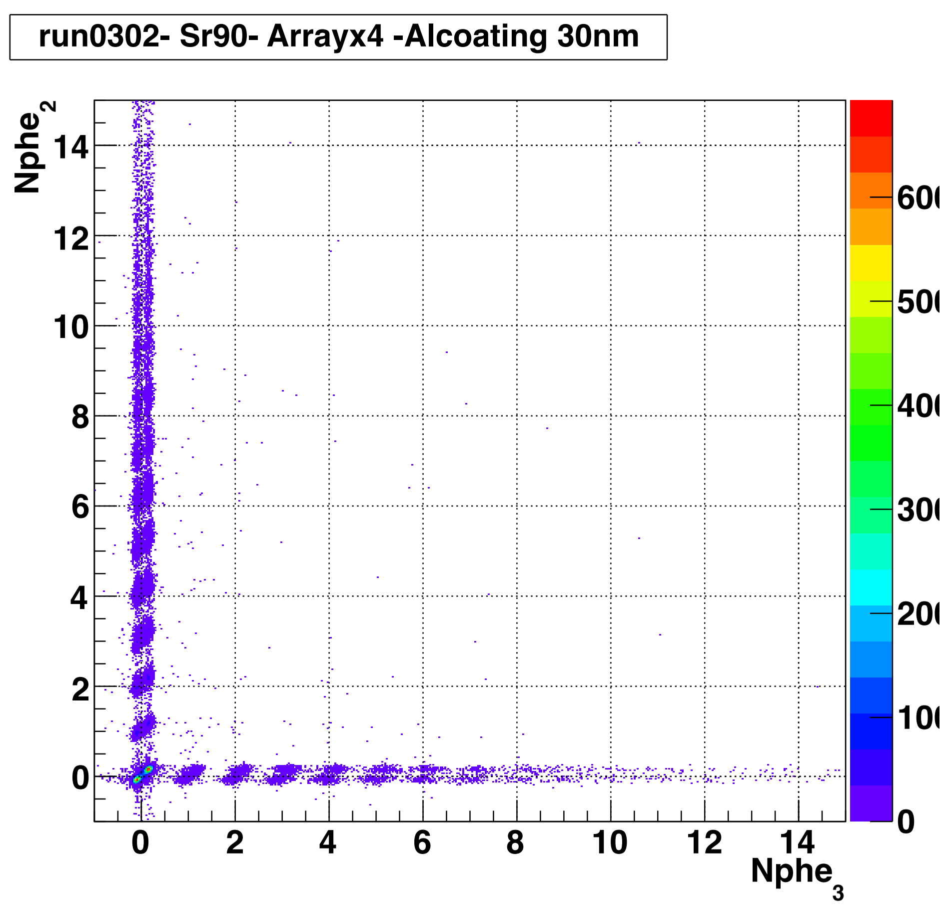
without Al coating



with 30 nm Al coating



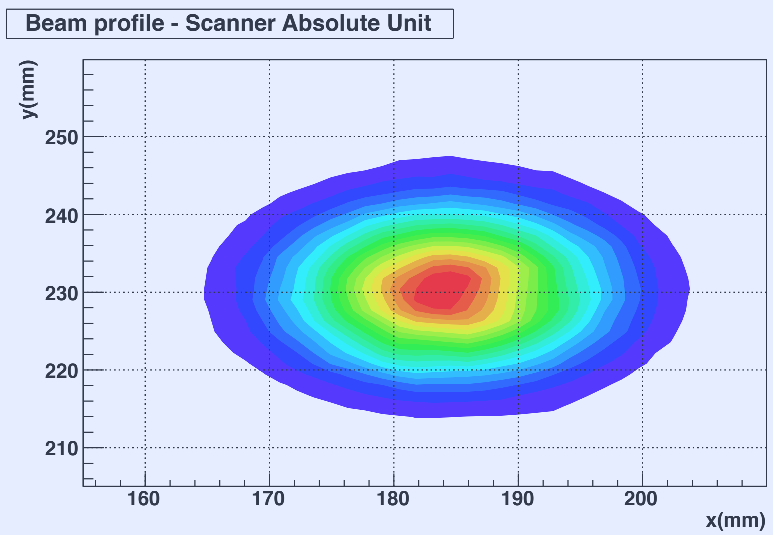


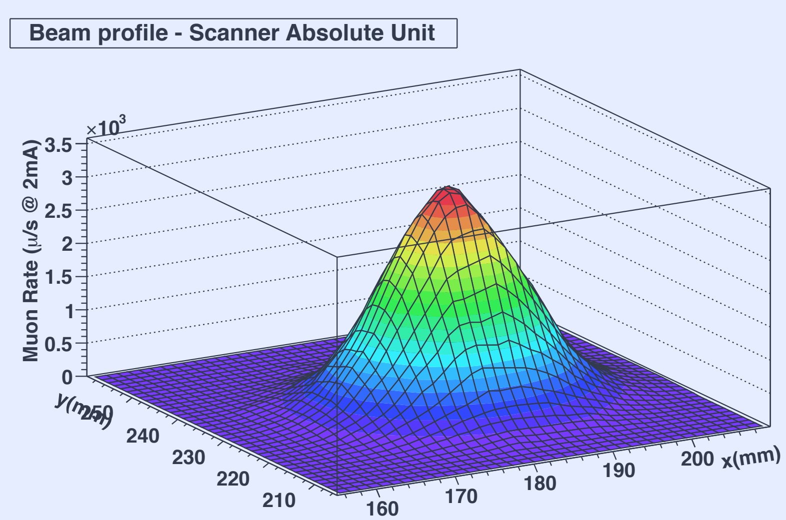


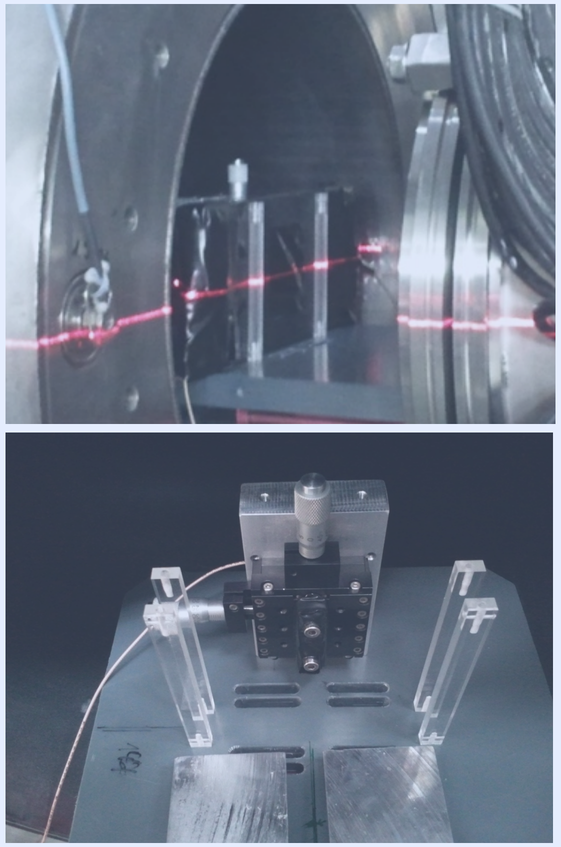
Optical crosstalk< 1%

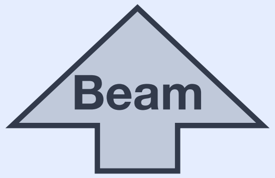
σ_{space} ~ 70 μm

Muon signal

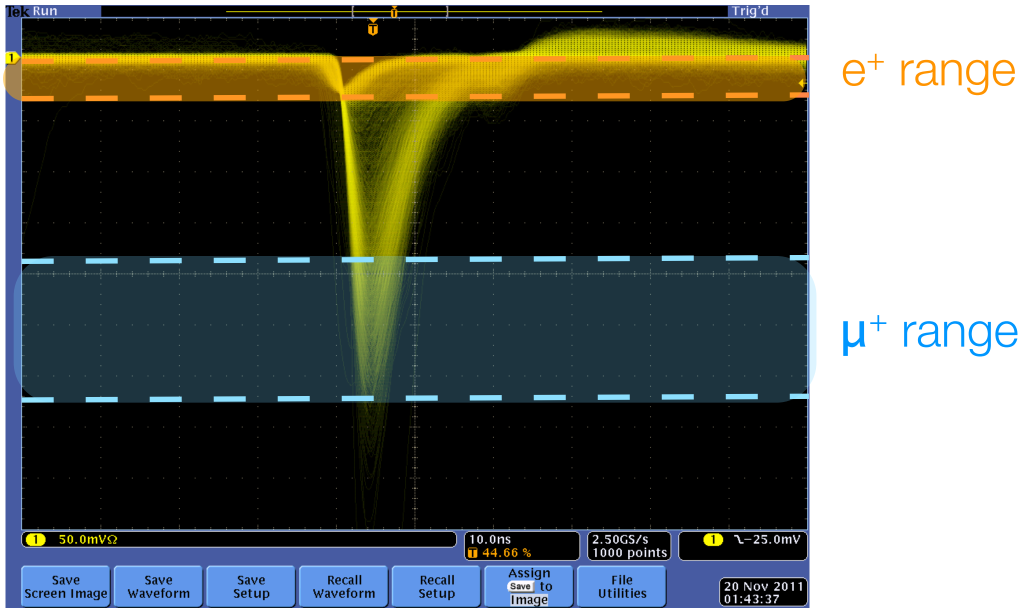








Ext. trigger:
small scint. + SiPM
(BC400 2x2x2 mm3 +
3x3 mm2 SiPM)



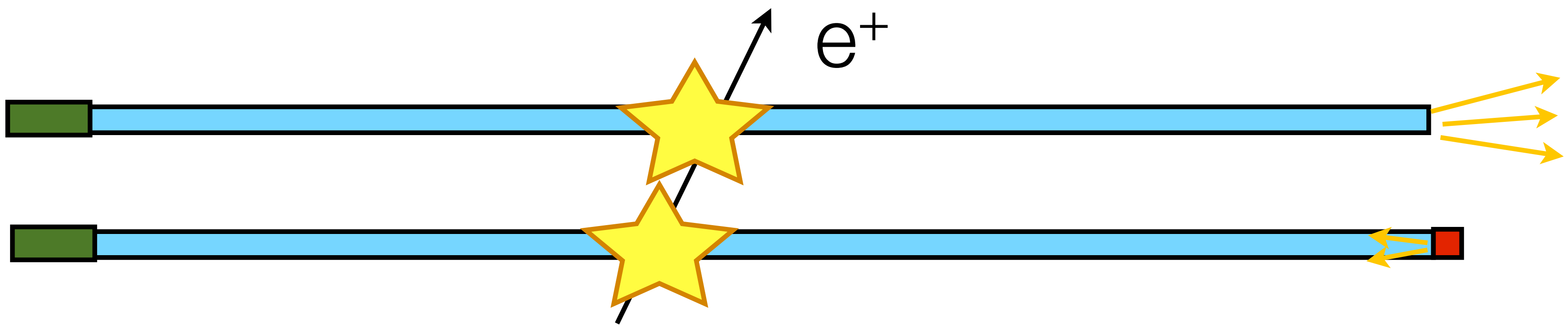
- Collected light > 30 Nphe
  - Very clean amplitude distrimination between high and minimum ionizing particle

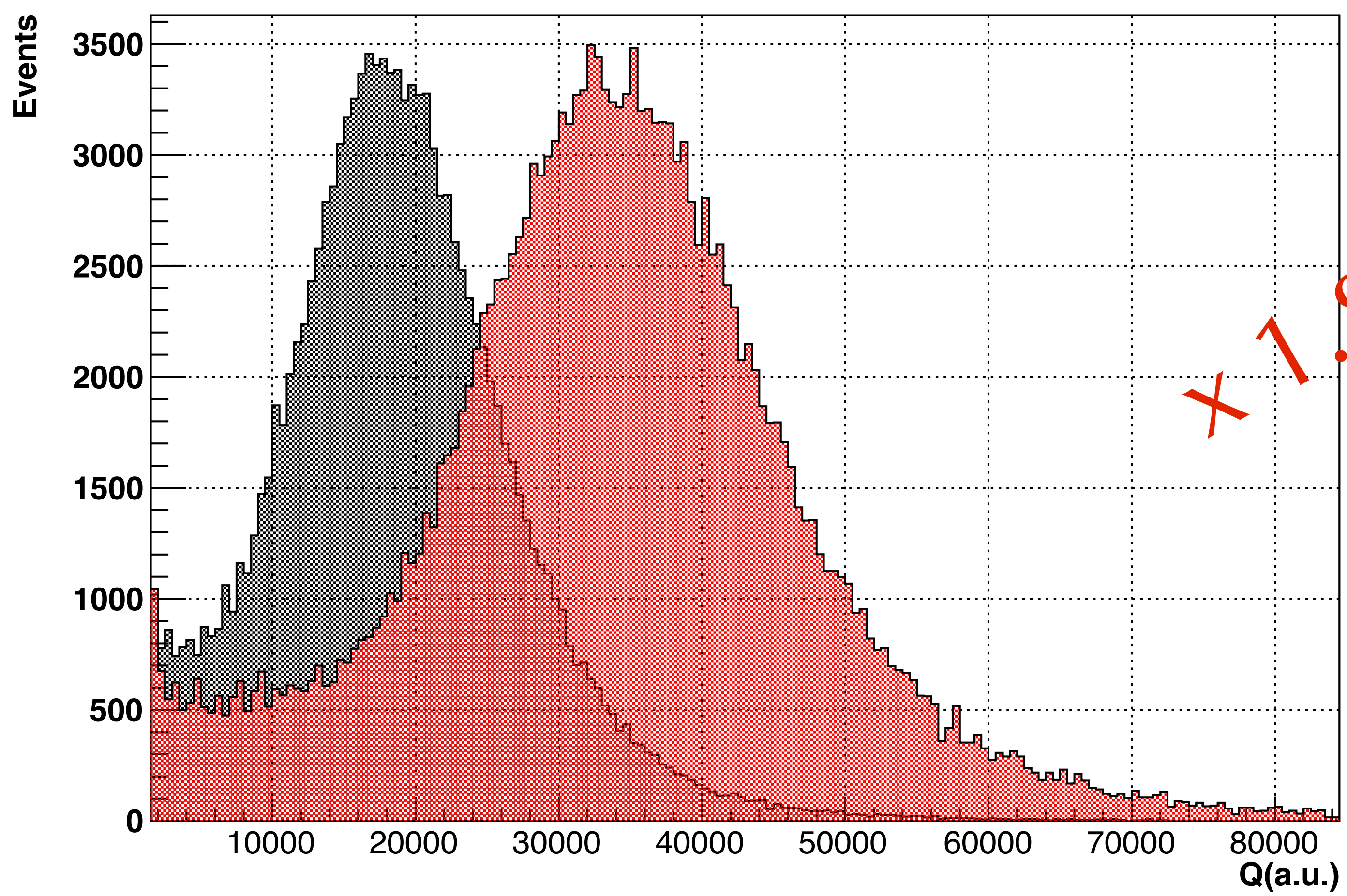
Al mirror on one end of the fibre

- Polished fibre 1x1 mm^2 without and with Sputtered/Painted Al
- Similar results with 0.5x0.5 mm^2 and 0.25x0.25 mm^2 fibre

without Al

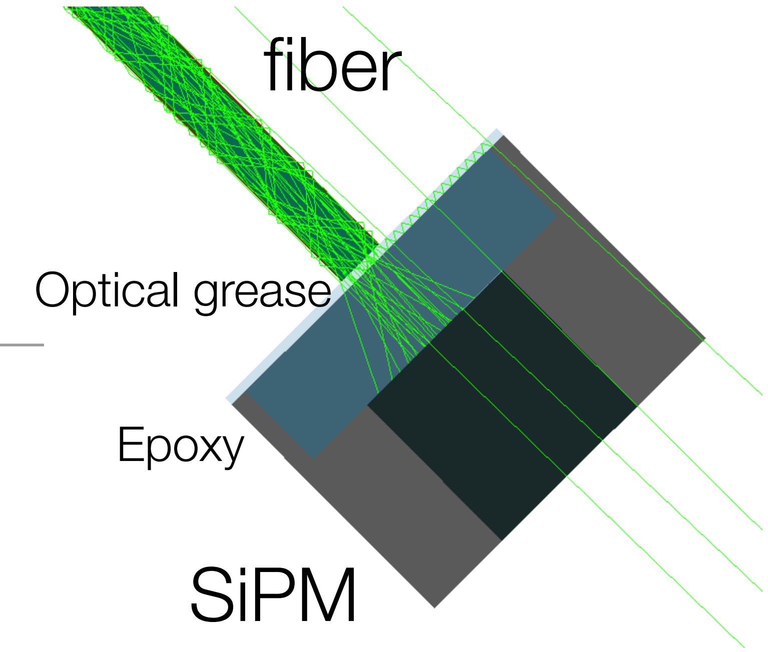
with Al



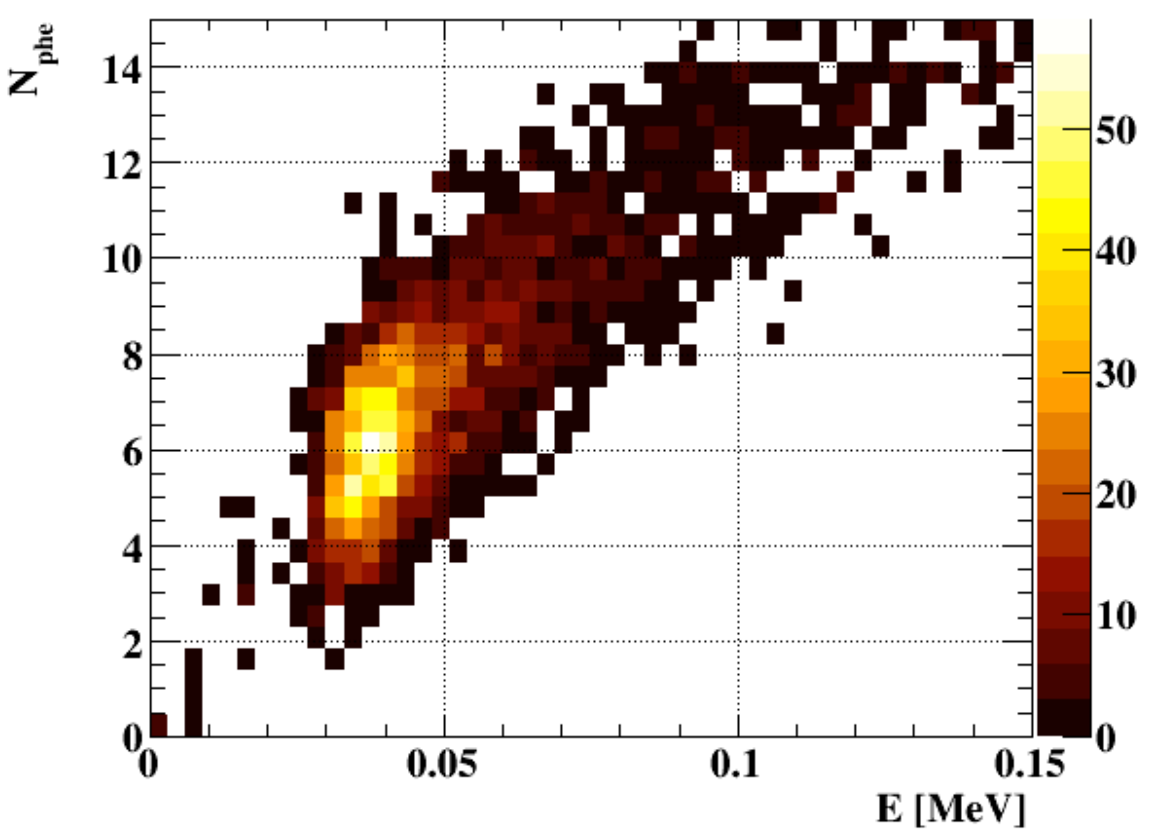


x 1.8 collected light

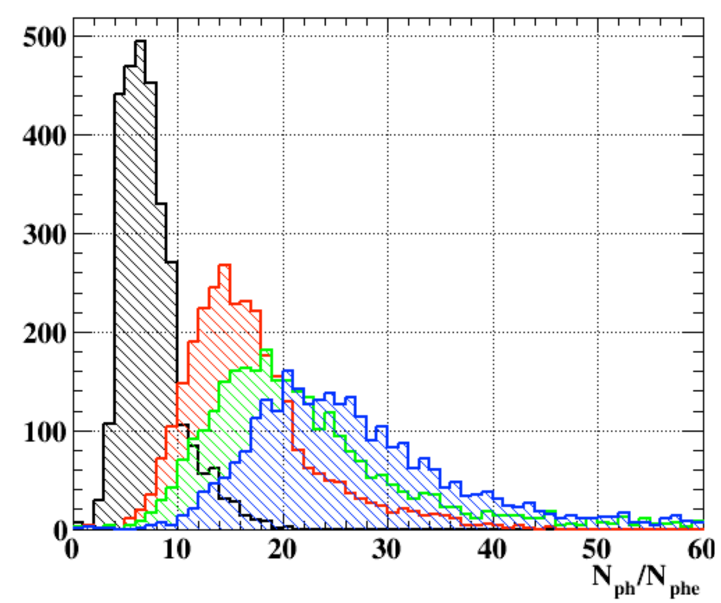
Monte-Carlo simulation



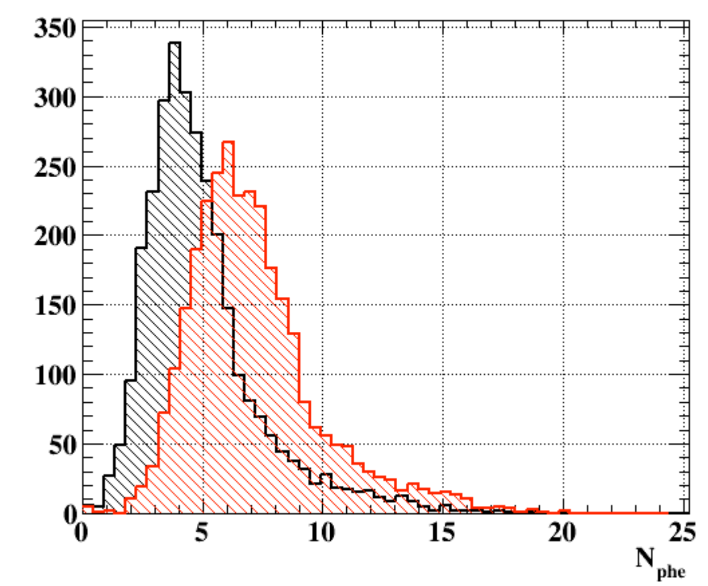
- Based on GEANT4
  - SiPM response (including the signal shaping)
- Main result:
  - MC validation using data from several fiber thicknesses (250, 500 and 1000 um) and SiPM (1x1 mm2, 3x3 mm2 /25, 50 and 100 um pixel size)
  - A very good agreement with fiber 250, 500 and 1000 um



Light at the **end of fiber**/SiPM coupling **(FF, +Occupancy, +QE)**

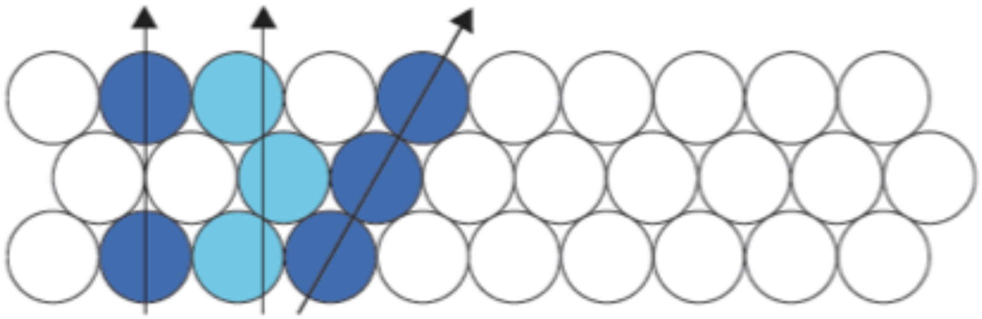


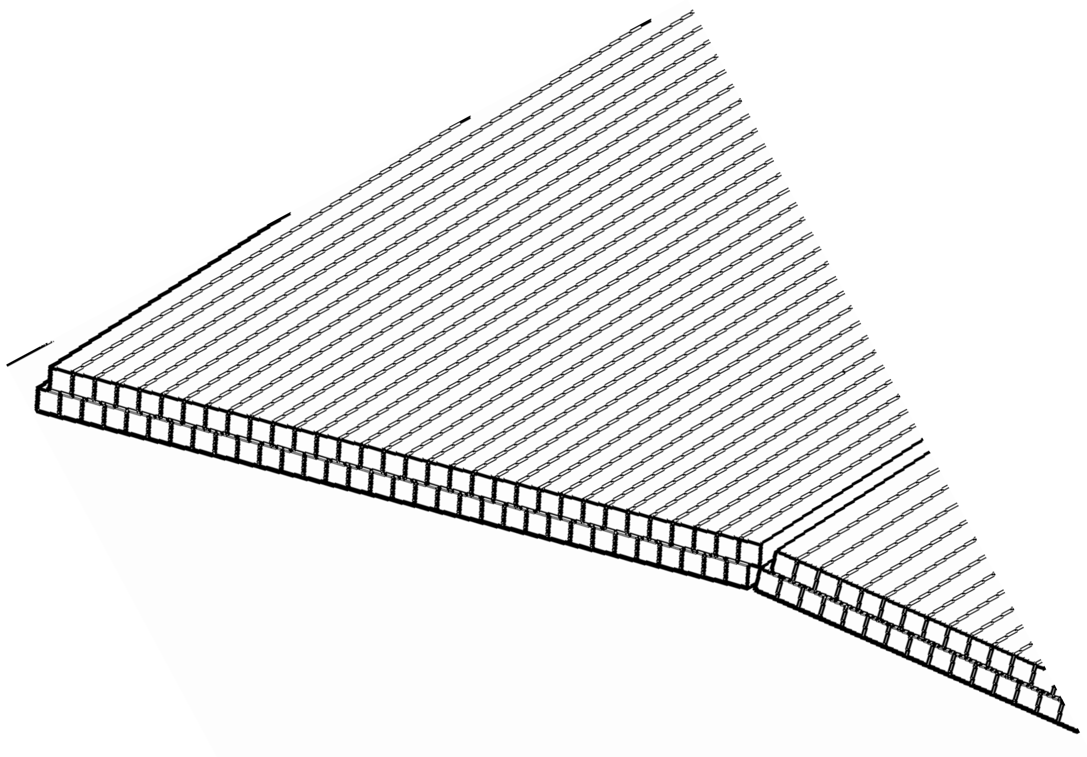
Fiber **with**/**without** Al deposit **(x1.6-1.8 more light as measured)**



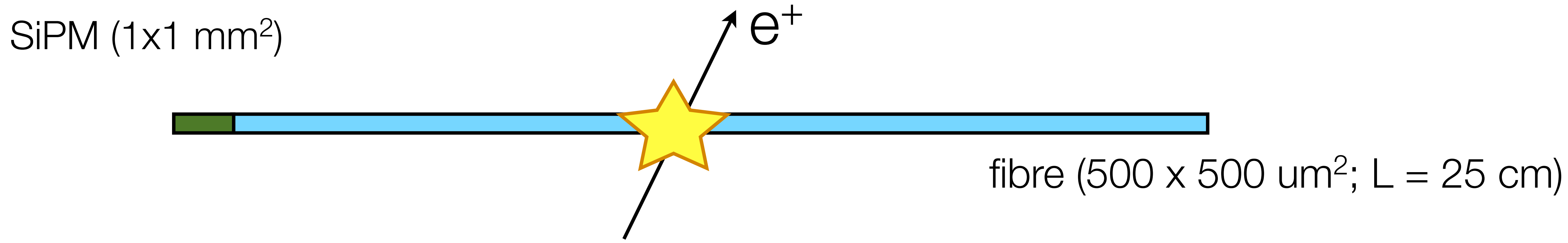
A timing detector

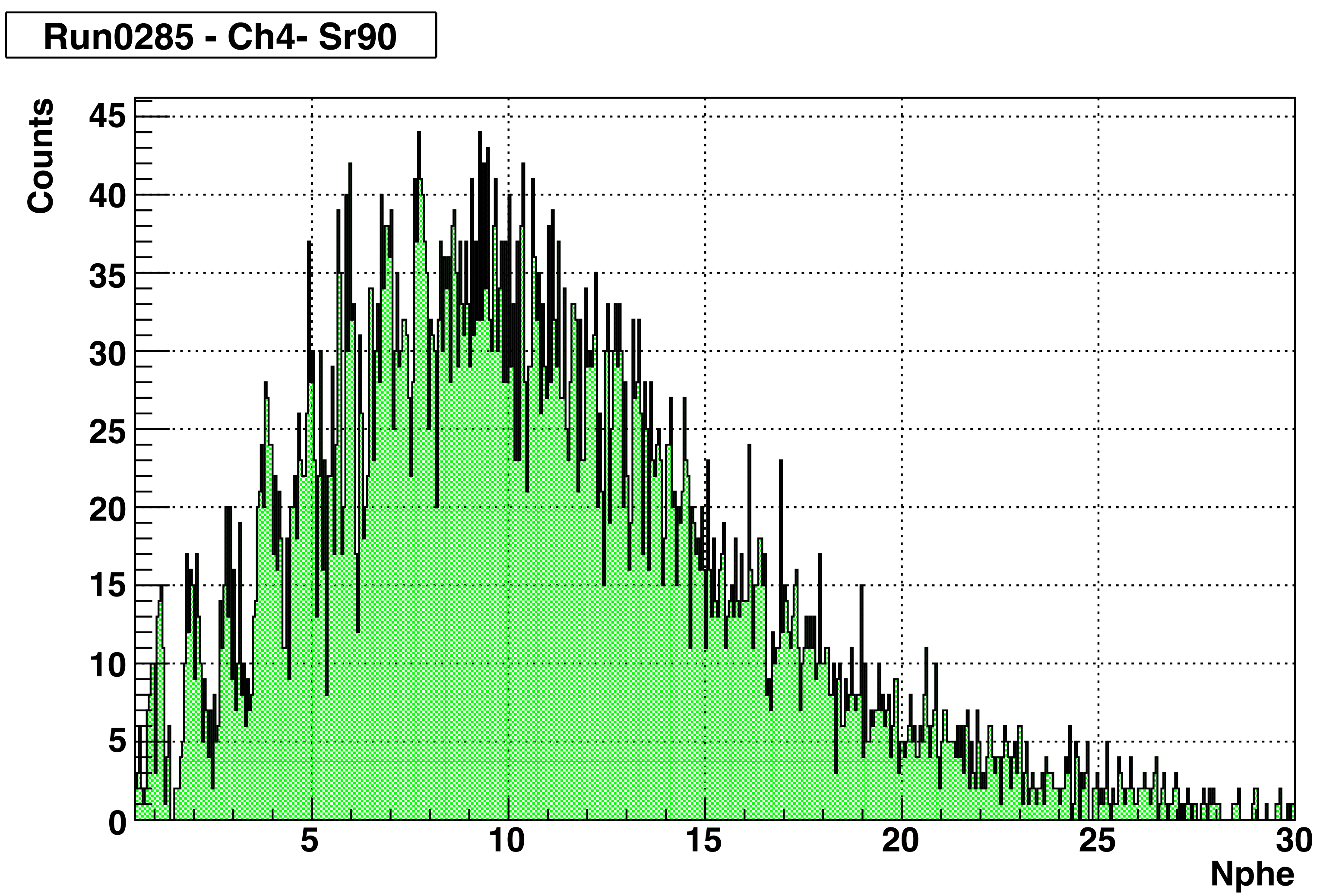
- Minimum ionizing particle detection
  - minimum ionizing positrons
- High detection efficiency at few phe
  - mean ~ 5 phe/SiPM (250 um fibre) or 10 phe/SiPM (500 um fibre)
- High spatial resolution and minimum multiple scattering
  - $\sigma_{space} < 200$ um and $\Theta_{MS} < 20$ mrad
- High rate
  - beam intensity up to 10^{10} particle/s (max 1MHz/fibre)
- Timing resolution
  - $\sigma_t < 1$ ns



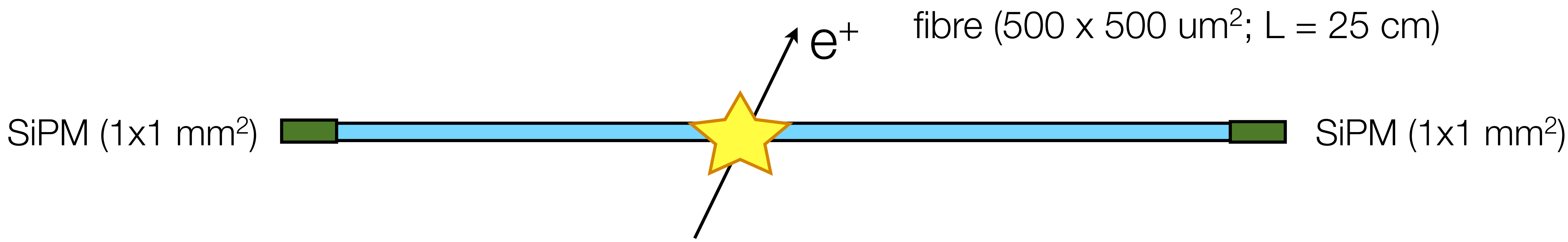


Positron spectra -- charge on one SiPM

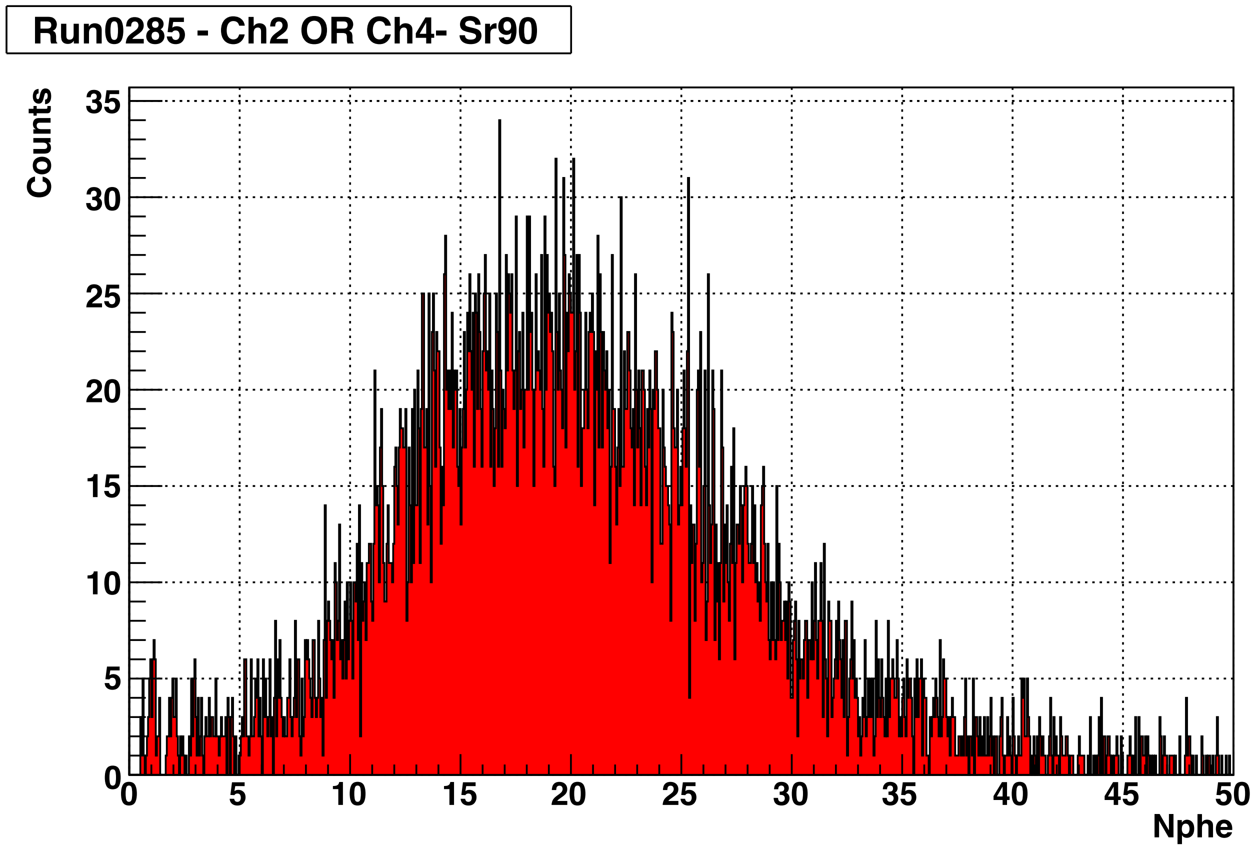




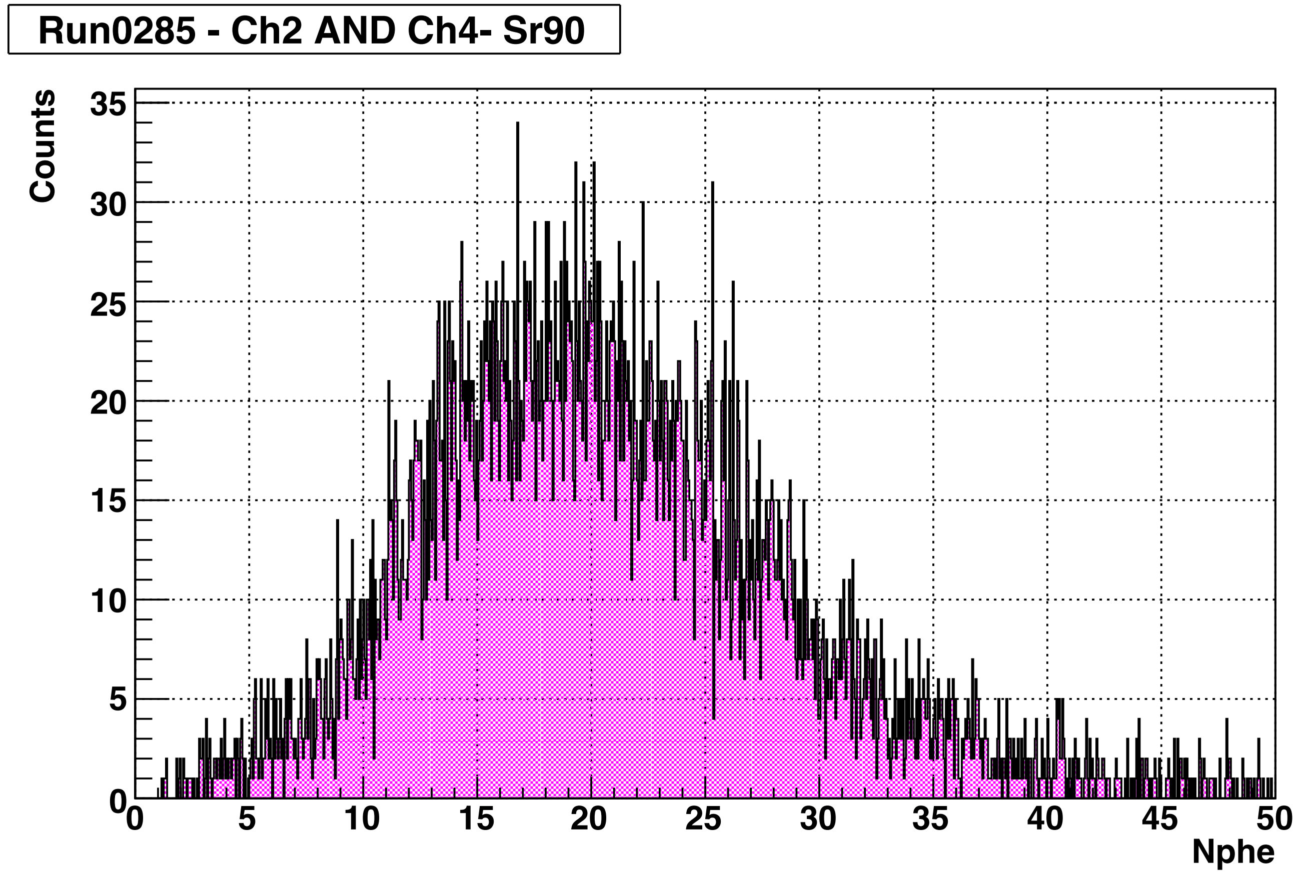
The positron spectrum -- charge on both SiPM



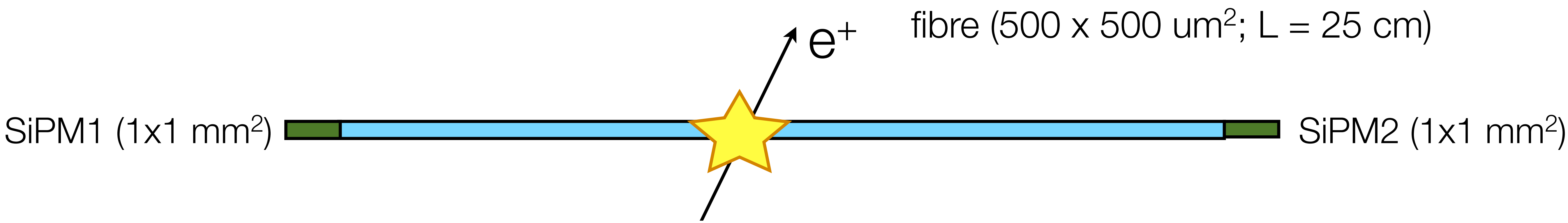
ORsum



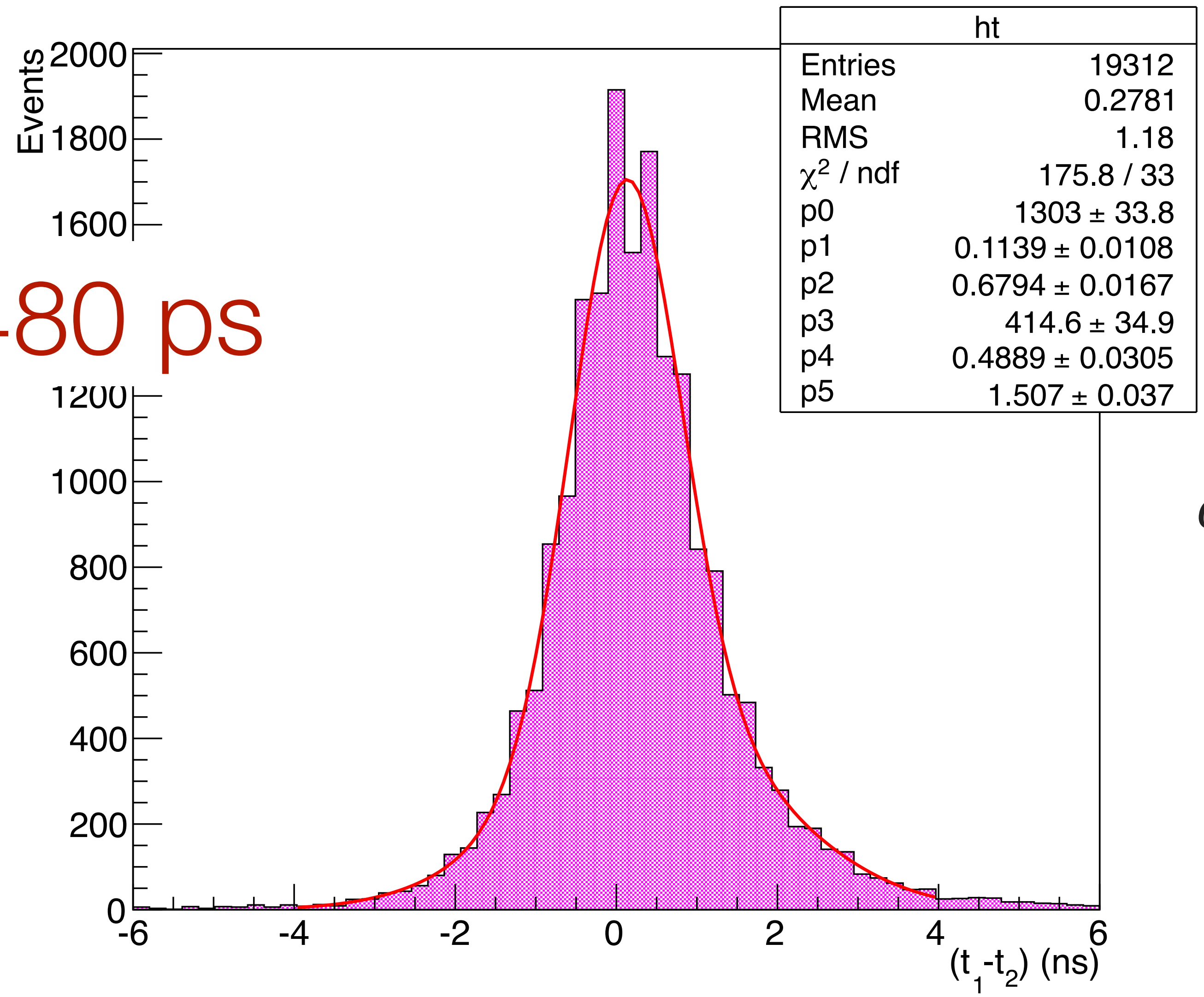
ANDsum



Timing resolution



$\sigma_t \sim 480$ ps



Legend

Plot: $\Delta t = (t_1 - t_2)$

$$\sigma^2(\Delta t) = \sigma^2(t_1) + \sigma^2(t_2) \sim$$

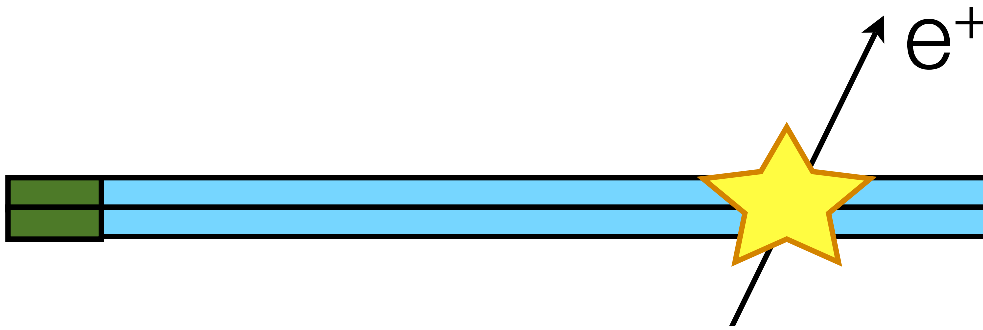
$$2\sigma^2(t) = 2\sigma^2_t$$

$$\sigma_t = \sigma(\Delta t)/\sqrt{2}$$

Timing resolution

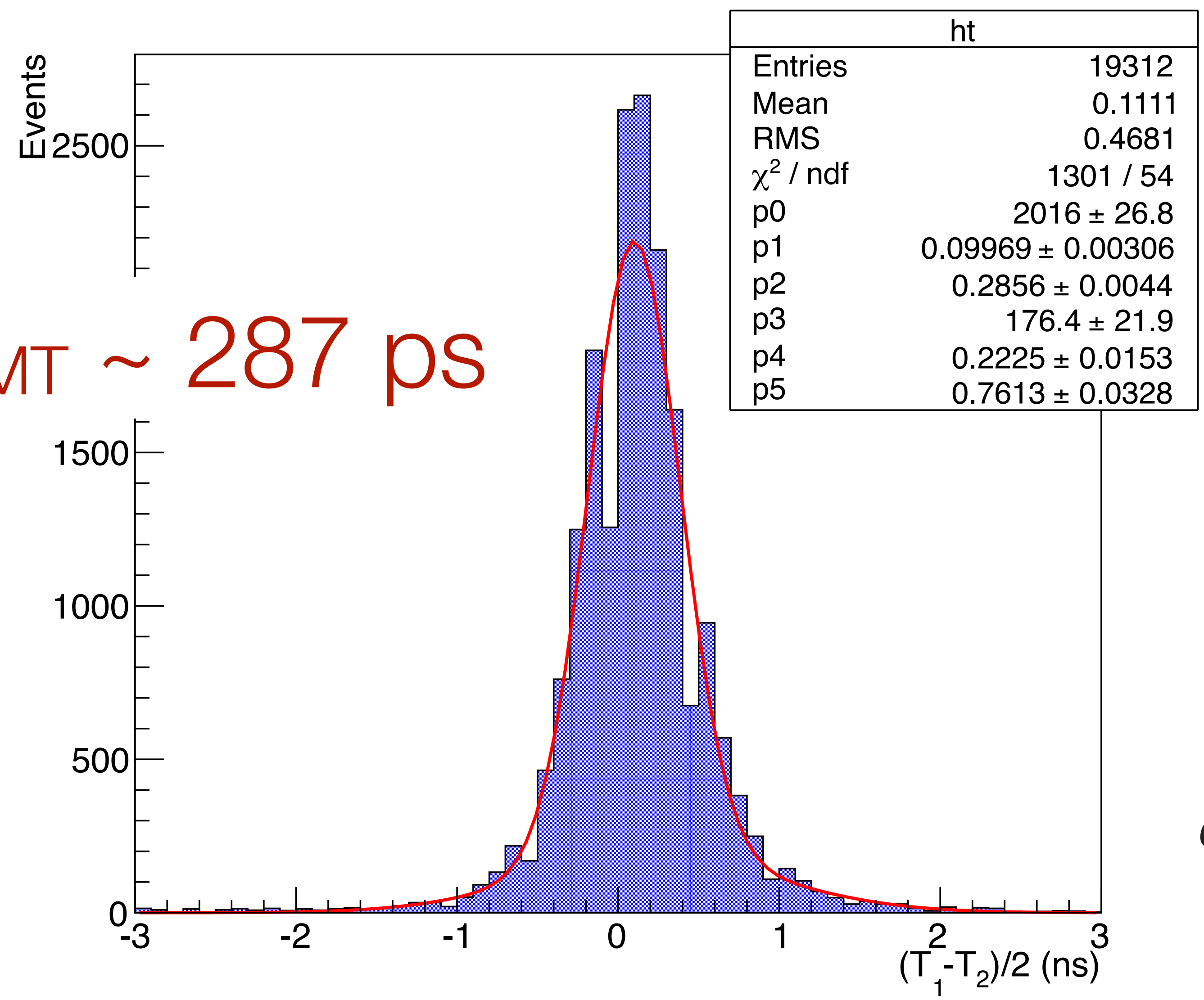
fibre ($500 \times 500\ um^2$; $L = 25$ cm)

SiPM1 ($1 \times 1\ mm^2$)
SiPM3 ($1 \times 1\ mm^2$)



SiPM2 ($1 \times 1\ mm^2$)
SiPM4 ($1 \times 1\ mm^2$)

$\sigma_{MT} \sim 287$ ps



Legend

$T_1 = (t_1 + t_2)/2$

$T_2 = (t_3 + t_4)/2$

Plot: $\Delta T = (T_1 - T_2)/2$

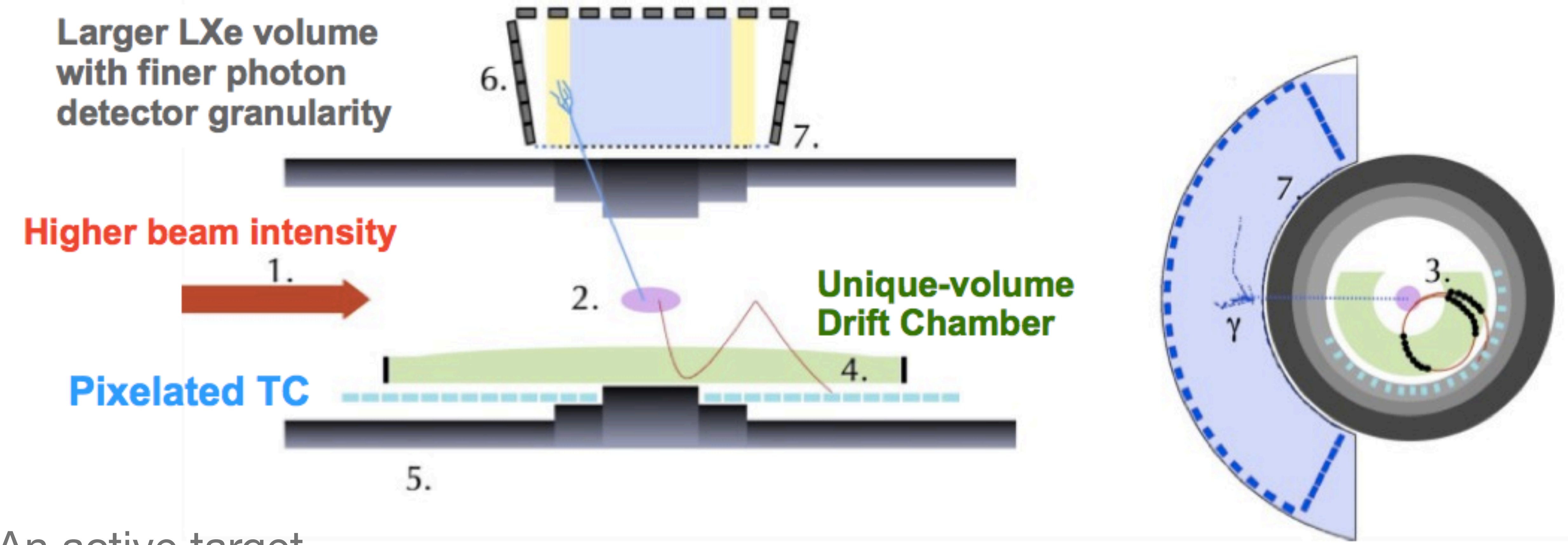
$\Sigma T = (T_1 + T_2)/2$

$\sigma^2(\Delta T) = \sigma^2(\Sigma T) = \sigma^2_{MT}$

Application

An active target for the MEGII experiment

- The MEGII experiment aims to search for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of ~10^{-14} (best upper limit $BR(\mu^+ \rightarrow e^+ \gamma) \leq 5.7 \times 10^{-13}$ @90 C.L. by the MEG experiment)

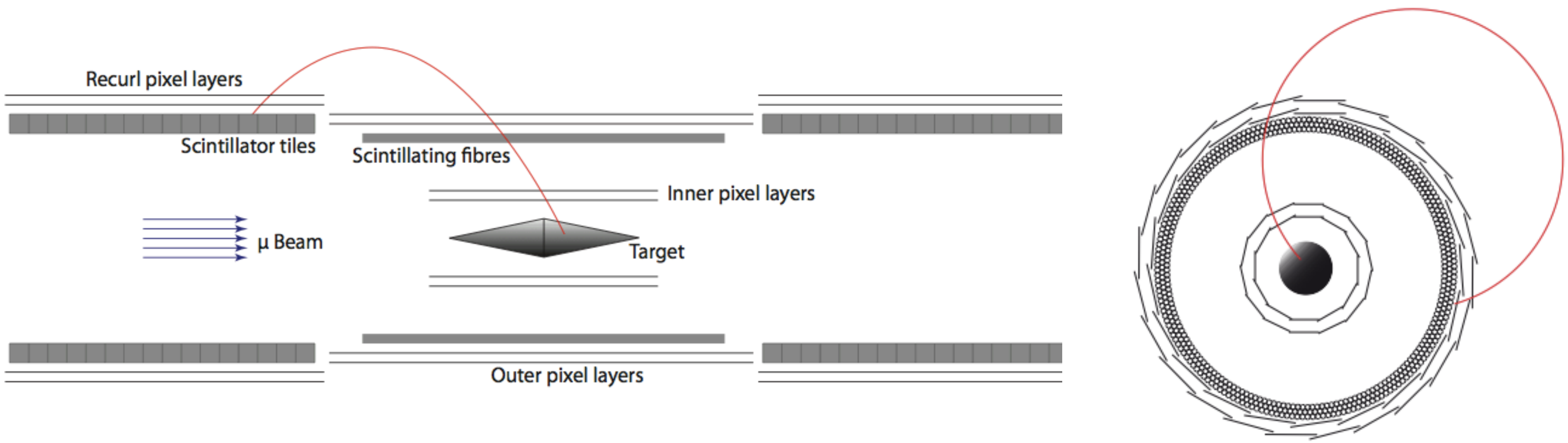


- An active target
  - beam monitoring (in loco real time beam scanning, absolute normalization etc.)
  - a vertex decay detector (to complement the spectrometer aiming at improving positron angular and momentum resolutions)

Application

A fibre hodoscope for the Mu3e experiment

- The Mu3e experiment aims to search for $\mu^+ \rightarrow e^+ e^+ e^-$ with a sensitivity of ~10^{-16} (best upper limit $BR(\mu^+ \rightarrow e^+ e^+ e^-) \leq 1 \times 10^{-12}$ @90 C.L. by the SINDRIUM experiment)



- The Mu3e hodoscope
  - a cylidrical ToF detector to complement the central silicon tracking system (hits matching and background rejection)
  - ε_{det} ~ 100% and σ_{MT} ~ few x 100 ps

Conclusions

- Working with the building block of any kind of fibre coupled to SiPM detector we get
  - for a single layer of multi-clad 250 um fibre (L= 25 cm, beam monitoring and vertex detector)
    - <Nphe> ~ 10 phe
    - negligible optical cross-talk doing a 30 nm Al coating around the fibre
    - a spatial resolution of ~70 um
    - a detection efficiency of ~ 90% (geometrical limit)
  - for a single layer of multi-clad 500 um fibre (timing detector)
    - <Nphe> ~ 20 phe
    - a timing resolution of < 300 ps (mean time precision)
  - Data and MC simulation in very good agreement

Thanks

- In collaboration with two PhD students
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