Detector R&D for the MEG upgrade

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PSI workshop 2013
13 September

Outlook

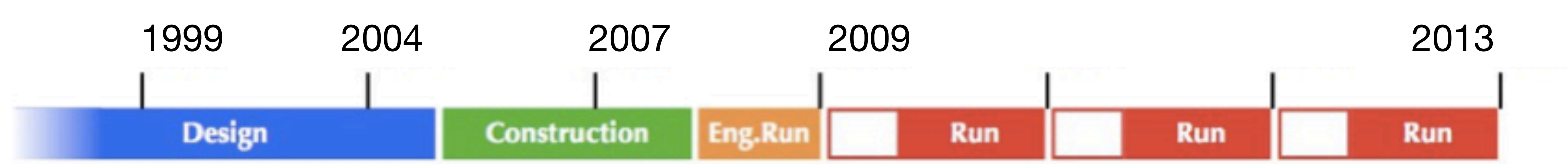
- MEG Introduction
- MEG R&D overview
- **Thin scintillating fibers coupled to SiPM for m.i.p. detection**
  - **ATAR (Active TARget) - MEG experiment**
  - Radiative counter - MEG experiment
  - Fibre hodoscope - Mu3e experiment (A. Bravar)
- **Thin scintillator foils coupled to SiPM**

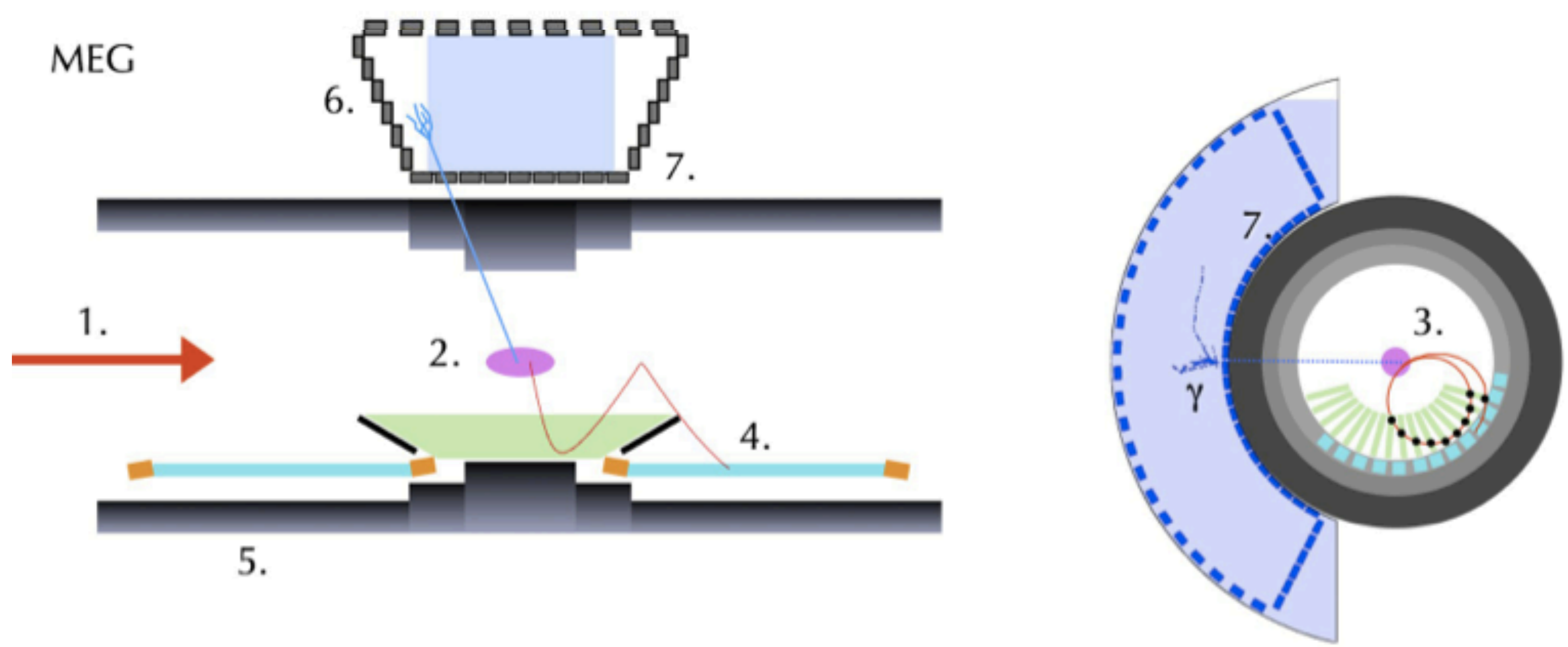
(*) Phy. Rev. Lett. 110, 201801 (2013)

(**) ArXiv:1301.7225.v2

Introduction: the MEG upgrade

- MEG is searching for lepton flavor violating decay, $\mu^+ \to e^+ \gamma$, aiming at a sensitivity of **few x10^{-13}**
- Based on 2009-11 data set, the new upper limit on the branching ratio is **5.7 x 10^{-13}** (*) -- talk: C. Voena
- An upgrade of MEG, aiming at a sensitivity improvement of one order of magnitude (**down to 5 x 10^{-14}**) approved by PSI and funding agencies (**) posters: D. kaneko, M. Nishimura





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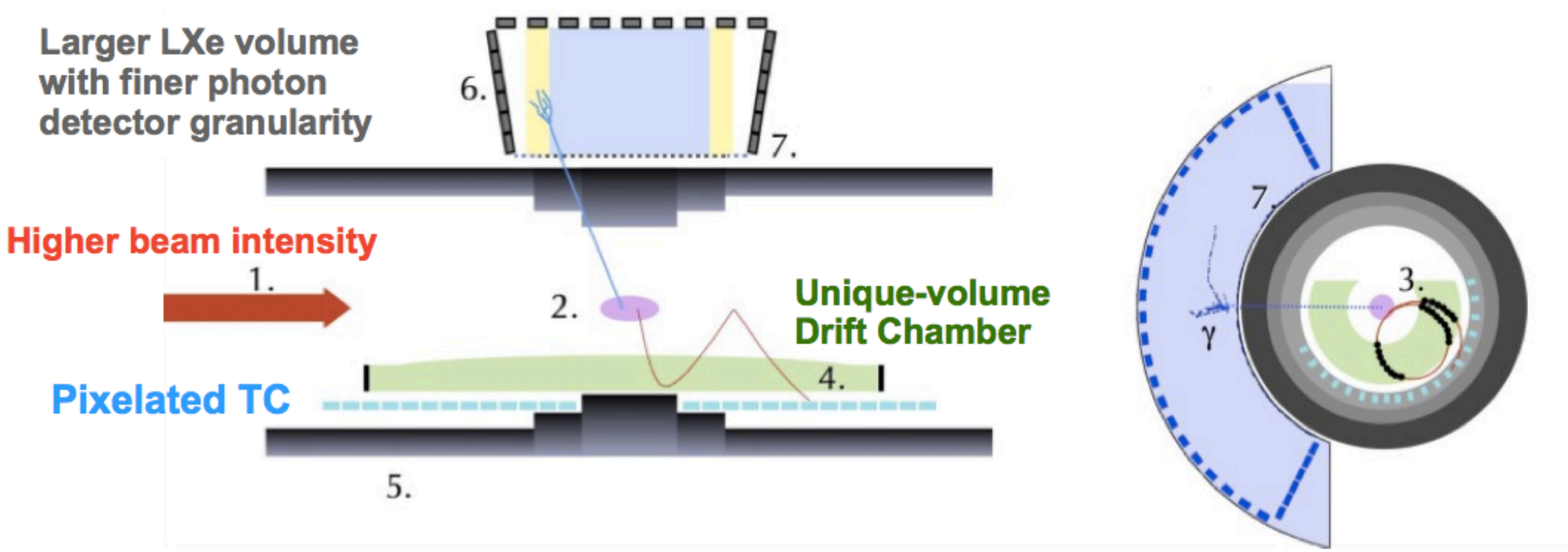


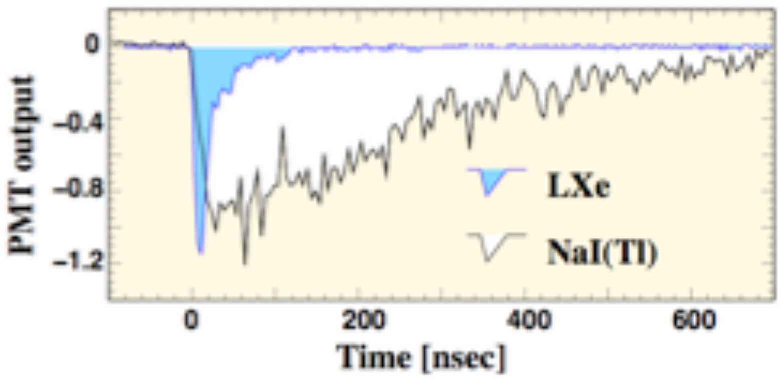
The MEG upgrade: the LXe calorimeter

The largest Omogeneuos LXe calorimeter on the World

- Volume: 0.9 m^3 LXe
- 846 PMTs immersed in LXe
- Photocathodic coverage 40%
- Solid angle coverage 10% of 4π

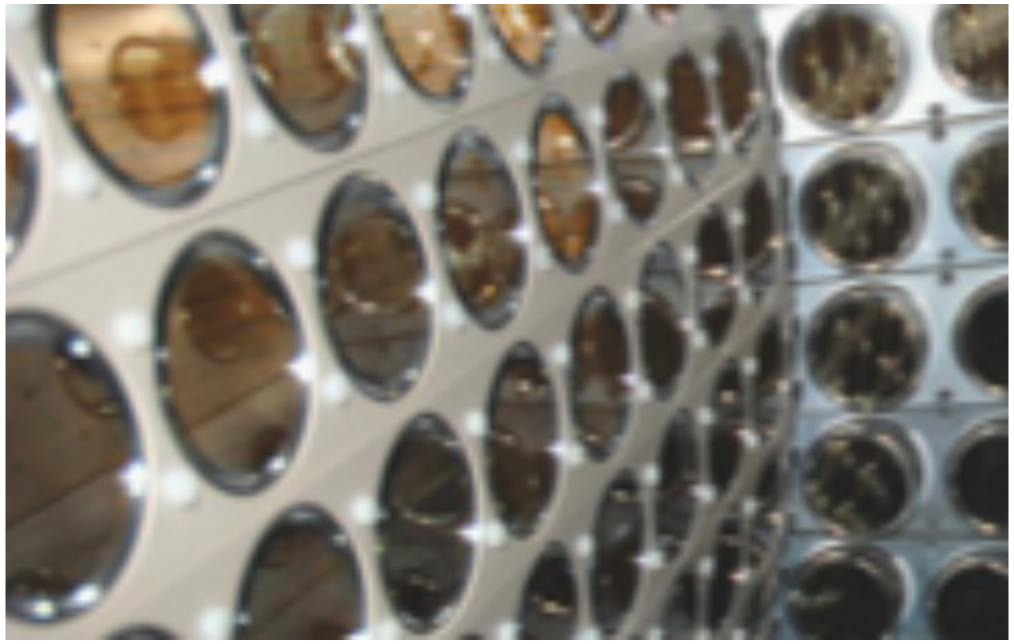
Rapid and High light yield scintillator

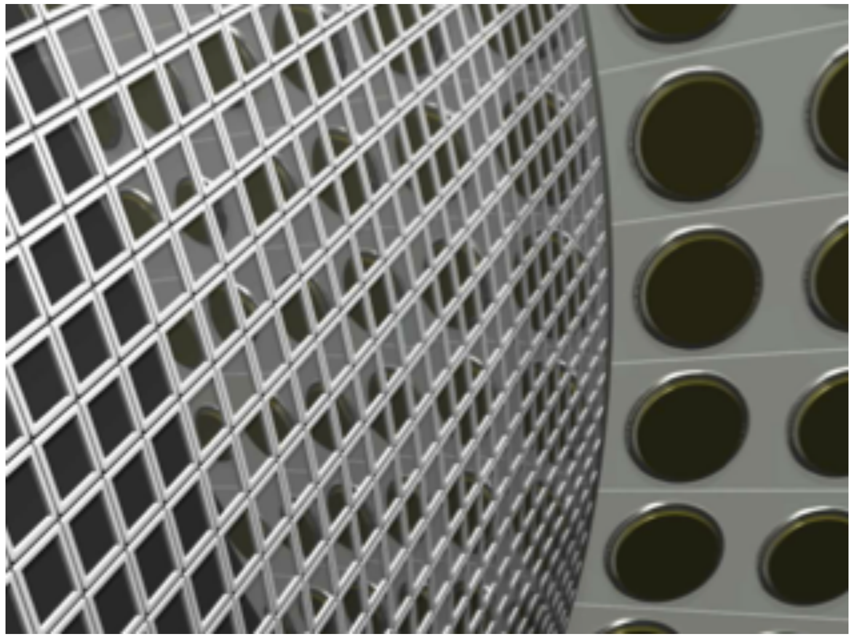
- τ = 4, 22 and 45 ns
- 40000 ph/MeV



$$\sigma(E_\gamma)/E_\gamma\ [\%] \sim 1.3\ (w<2cm)\ (2.6);\ \sim 1.0\ (w>2cm)\ (1.7)$$

$$\sigma(x_\gamma)\ [mm] \sim 2\ (w<2cm)\ (5);$$

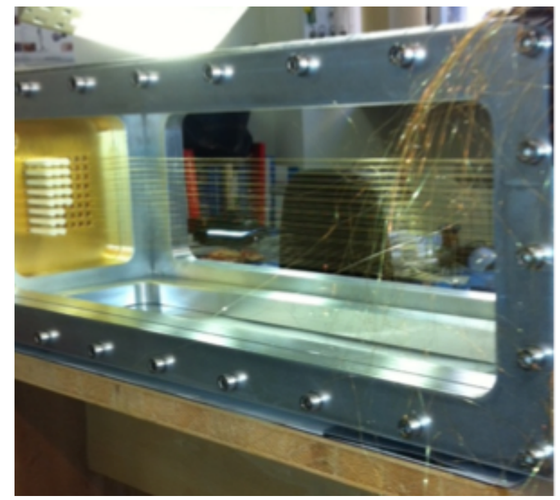




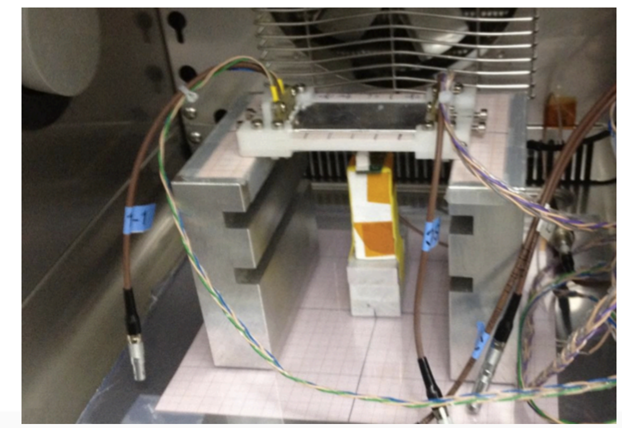
The MEG upgrade: the new spectrometer

High granularity
Less material
High Trasparency DC
towards the TC counter

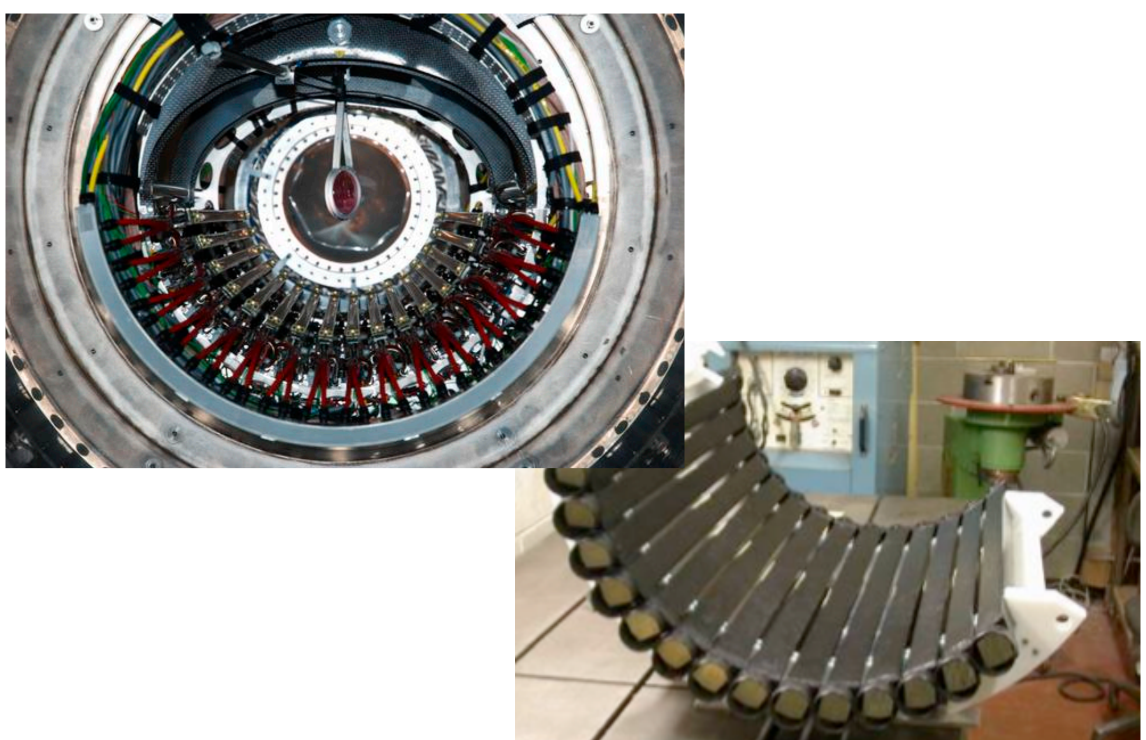
DC prototype

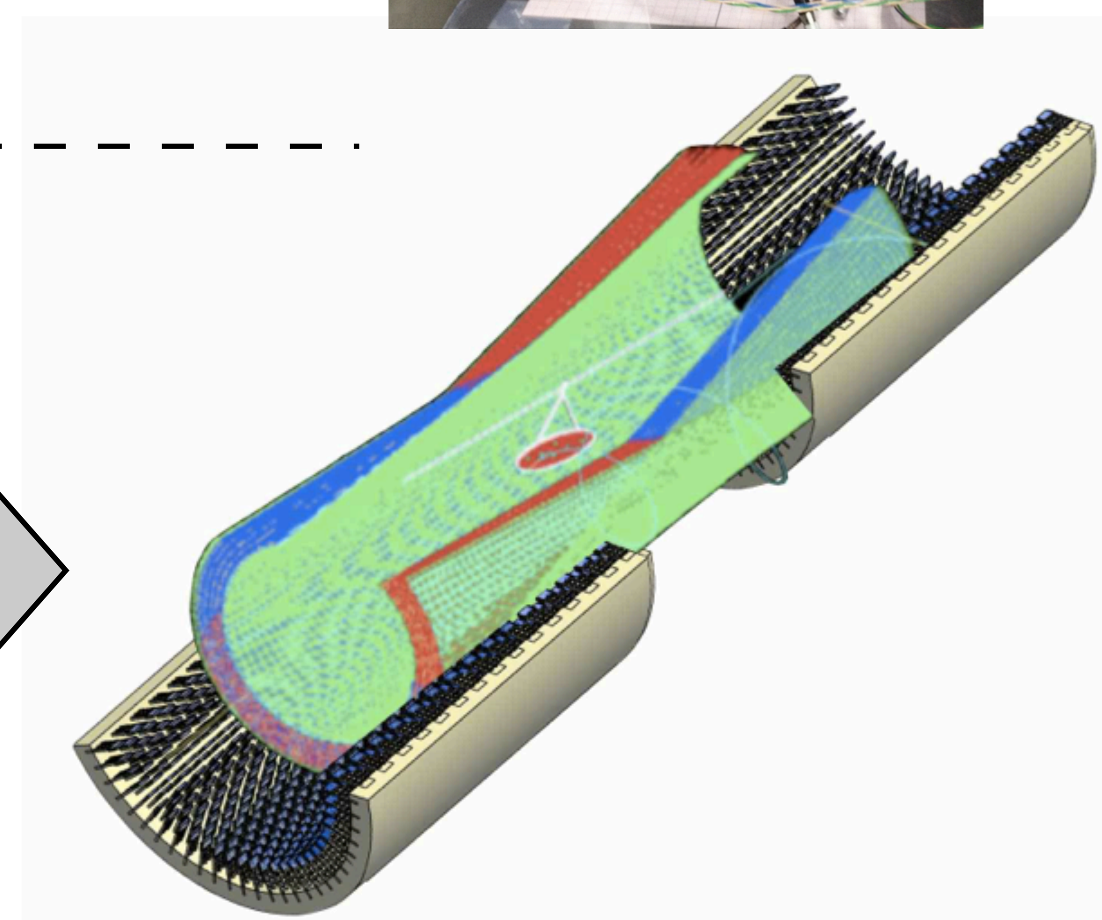


TC pixel R&D



$\sigma(E_e)$ [keV] ~ 150 (325);
$\sigma(\theta_e,\Phi_e)$ [mrad] ~ 5 (7-11);
ε(det) [%] ~ 80 (40);
$\sigma(t_e)$ [ps] ~ 30 (70);



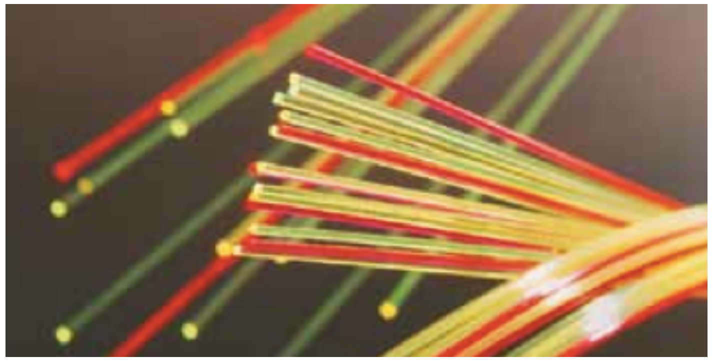


The ATAR concept

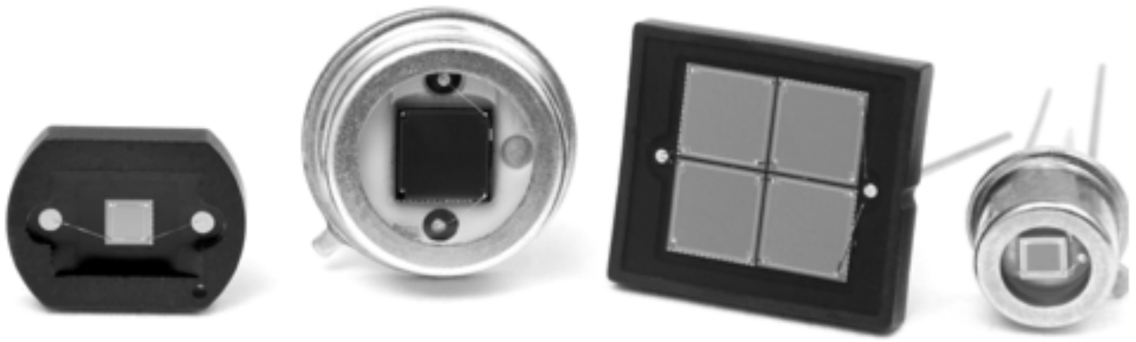
- A $\mu \Rightarrow e\gamma$ decay event is identified by four observables: **ΔE_{γ}, ΔE_{e}, $\Delta t_{e\gamma}$, $\Delta \Theta_{e\gamma}$**
- The positron momentum and direction are measured by the spectrometer after that the particle has left the target and has flown towards the detector: an additional measured point on the target plane can help the positron track fit
  - **If emerging positron is detected on the target:**
    - **improvements in both positron momentum and photon/positron angle resolutions (Better SES and bck rejection)**
  - **If the muons ranging in the target are counted: (*<<large signal compared to the positron, even if not time-correlated>>*):**
    - **beam monitoring ("absolute normalization")**

Scintillating fibers coupled to SiPM

- Since last decade scintillating fibres are a common scintillating device in particle physics
  - fast decay constant: timing measurement
  - cladding: position measurement
  - fast decay constant + cladding: tracking and beam monitoring purposes (arrays, orthogonal fibre ribbons etc.)

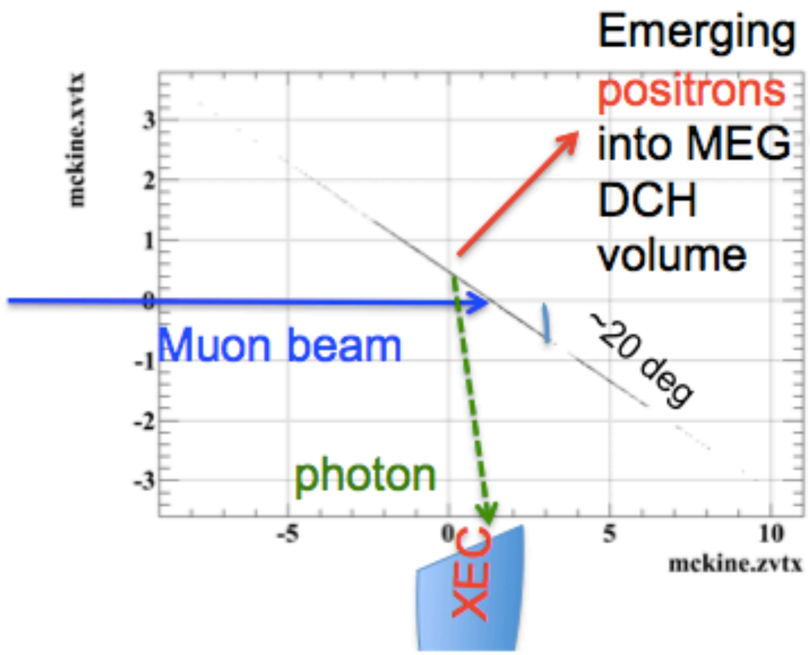


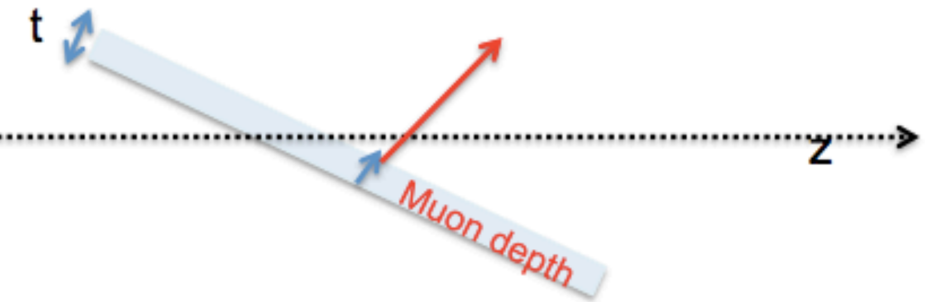
- SiPM are now an established and commercial light detector
  - excellent photon counting capability
  - insensitive to magnetic field
  - execellent time resolution
  - room temperature operation
  - low bias operation (below 100 V)
  - compact size
  - high gain



The ATAR design

Present MEG target

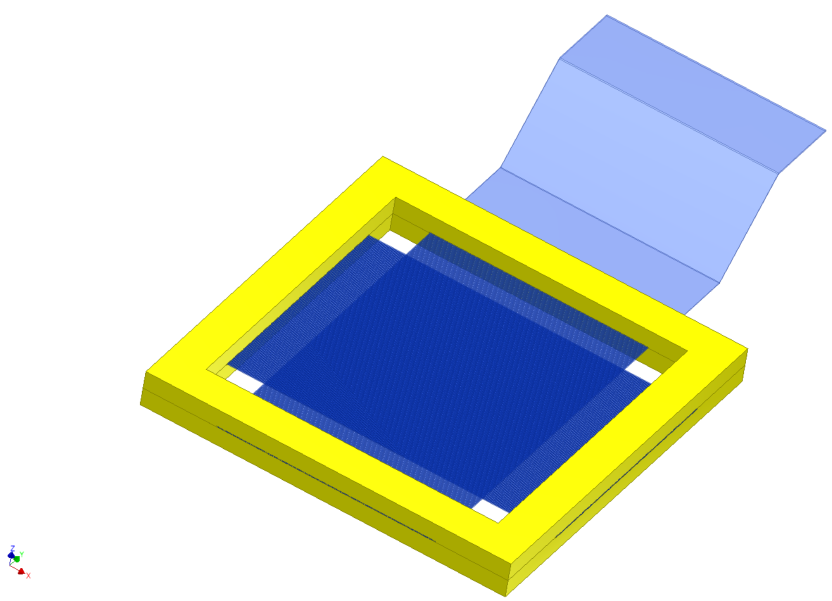




Current MEG target total thickness (t) is 205 microm polyethilene

Muon are **stopped** along z
[effective **thickness t/sin(20deg)**]

Active MEG target



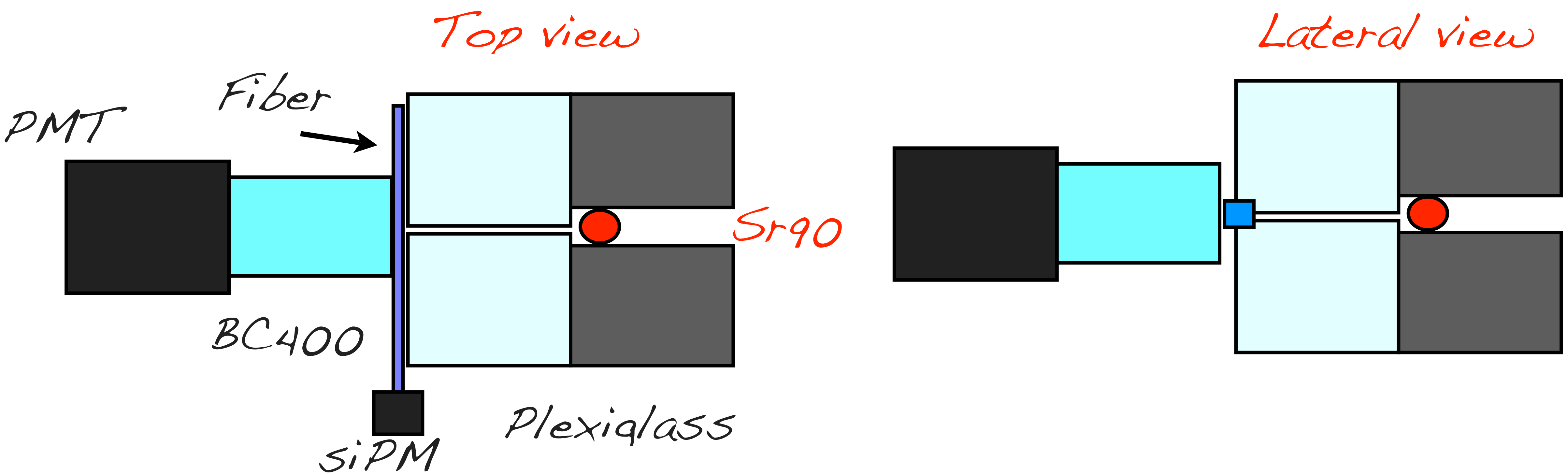
<u>Minimal fibre thickness (250 um)</u>: multiple scattering gamma background

<u>Single fibre array</u>: only the Y coordinate is measured

<u>Challenge</u>: to detect m.i.p. for which a deposit energy of ~30 keV is expected

- **maximal light collection**
  - reflection
  - multi-cladding
  - short fibre lenght (lambda) and SiPM (B field)
- **Good S/N(thermal noise)**
  - external trigger

The m.i.p. detection in lab



A large fraction of positrons is forced to go through the fiber and then stopped into the plastic scintillator

– Range of e^- @ 2.2 MeV in plastic material $\sim$ 10 mm

Collimator depth: 15 mm

Collimator hole: 1x1, 0.5 × 0.5 and 0.25×0.25 mm^2

Fibre sizes: 1 × 1 mm^2 , 0.5 × 0.5 and 0.25×0.25 mm^2

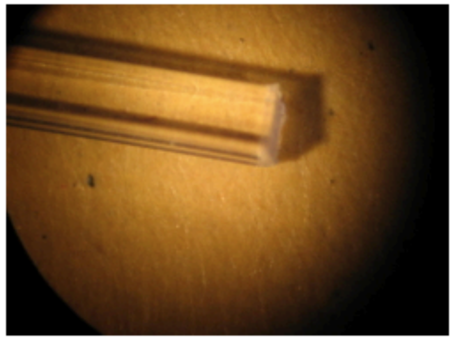
Plastic scintillator: 20×20 mm^2

The fibre optimization

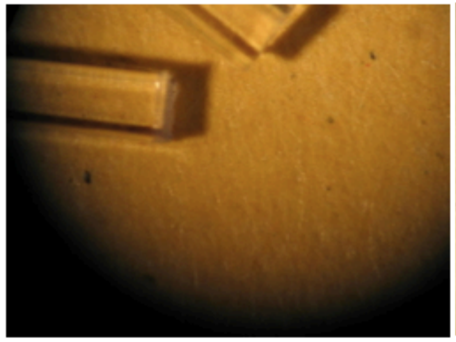
Polishing

- The fibre polishing was done using a diamond head (PSI)
  - **Samples**: 1, 0.5 and 0.25 mm2 squared fibres

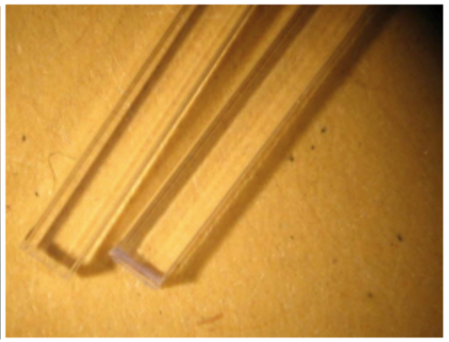
Microscope pictures:



Not polished



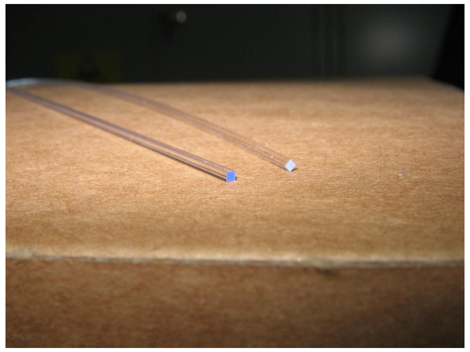
Not polished and polished



Not polished and polished

Reflective coating

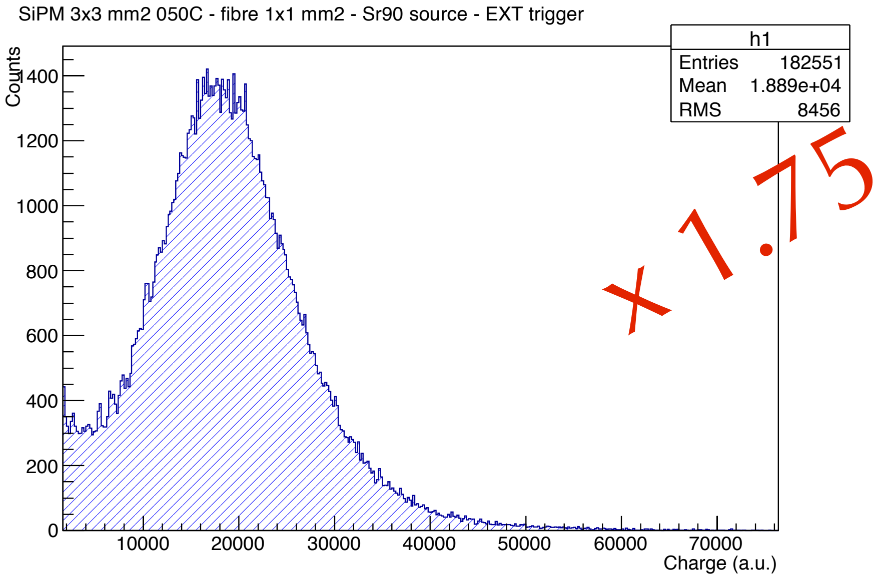
Sputtering method (PSI)



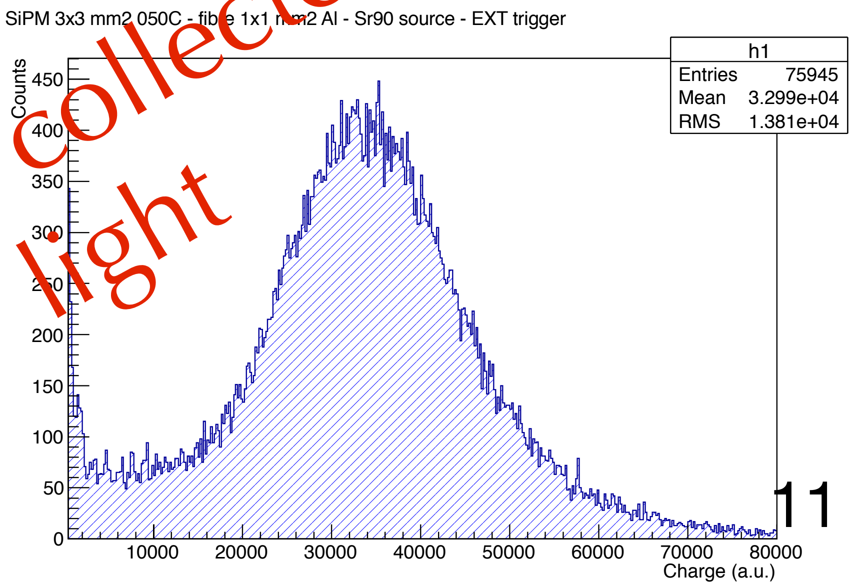
- <u>Advantages</u>
- A known and uniform deposit thickness
- Relative thin deposit (10-1000 nm)
- Metals and ceramic materials can be sputtered **(Al, TiO_2)**
- <u>Disadvantages</u>
- Time consuming

Painting method

- Polished Fibre 1x1 mm2 with/out Sputtered and Painted Al
- SiPM 3x3 mm2

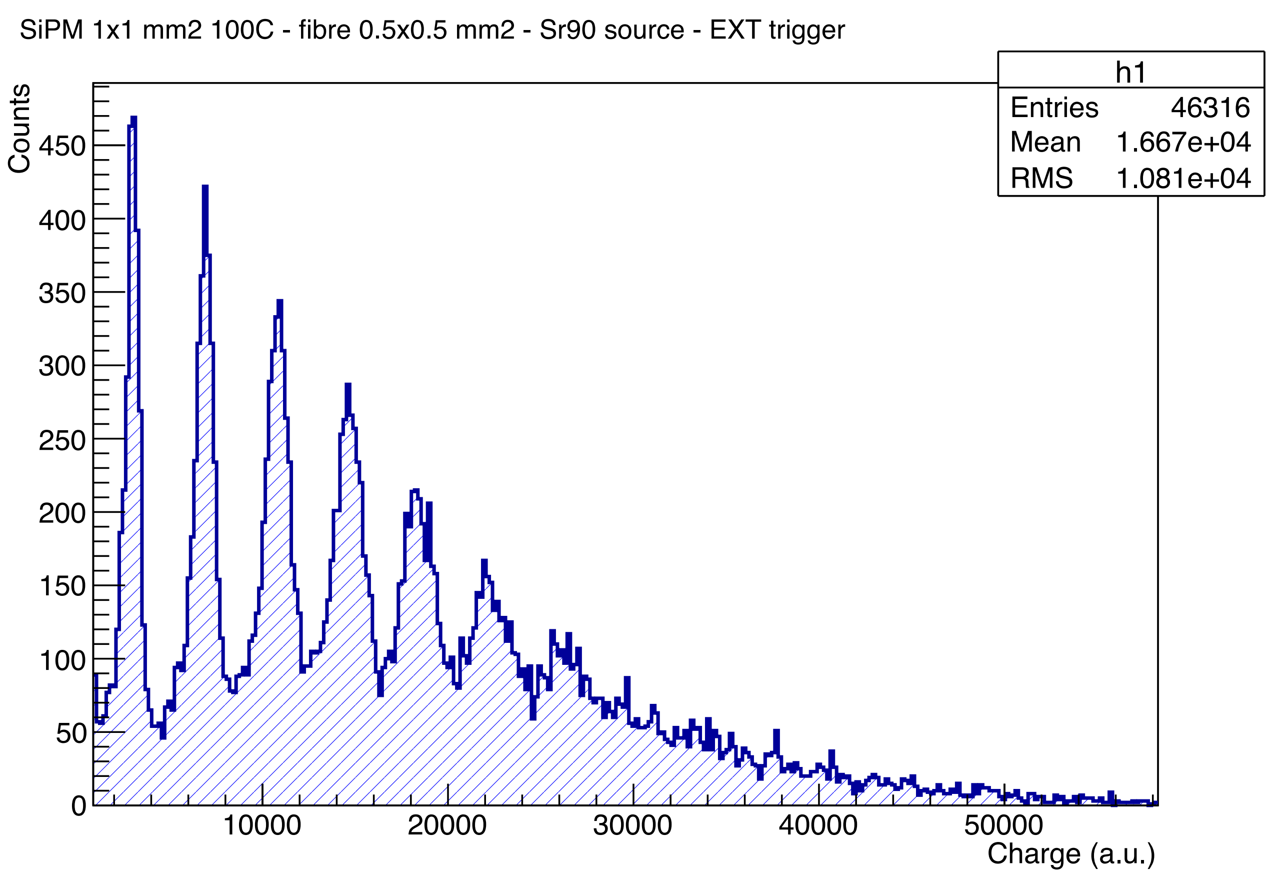


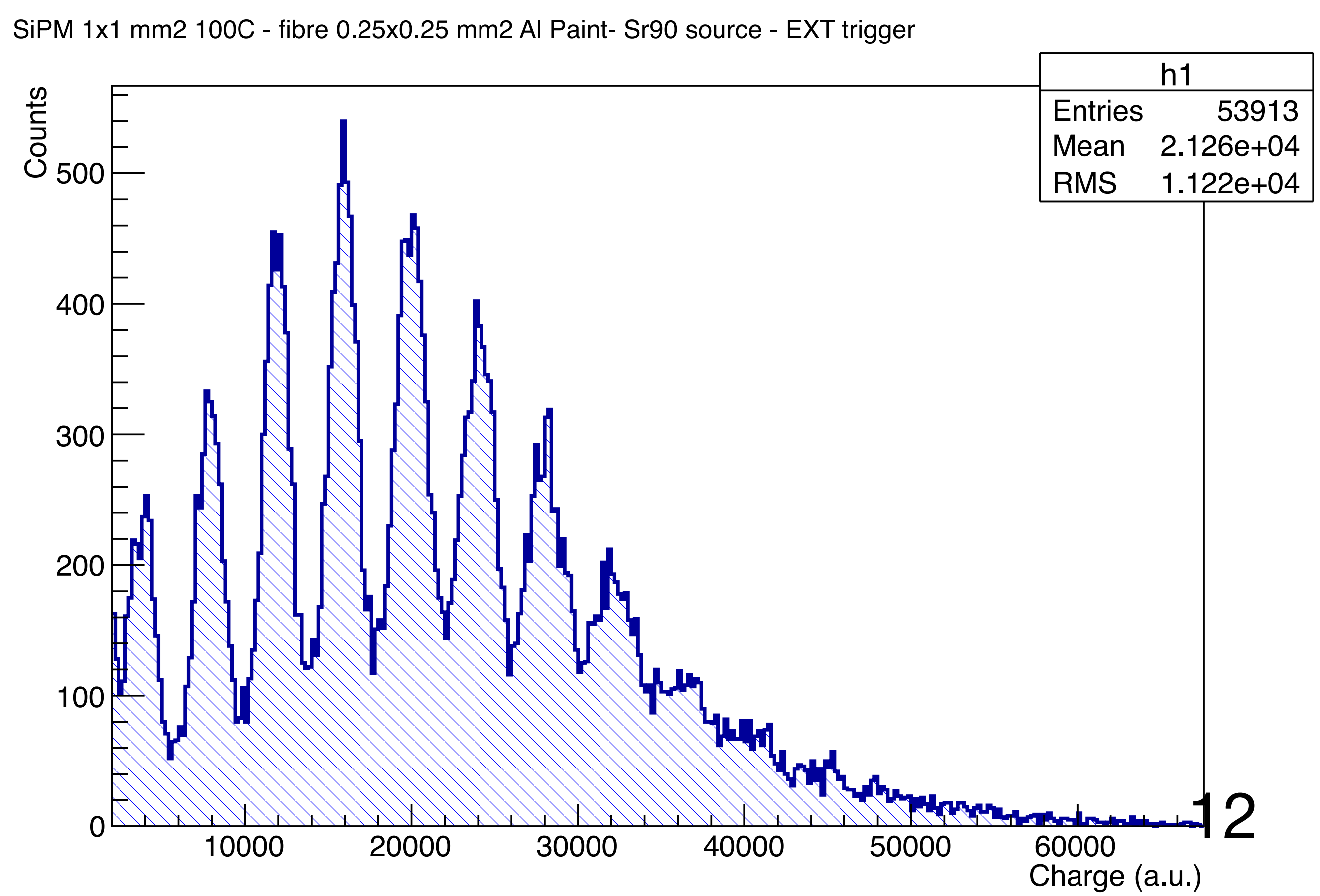
x 1.75 collected light



Our present best result

- Polished Fibre 0.25x0.25 mm2 with/out Painted Al
- SiPM 1x1 mm2 (Single readout)





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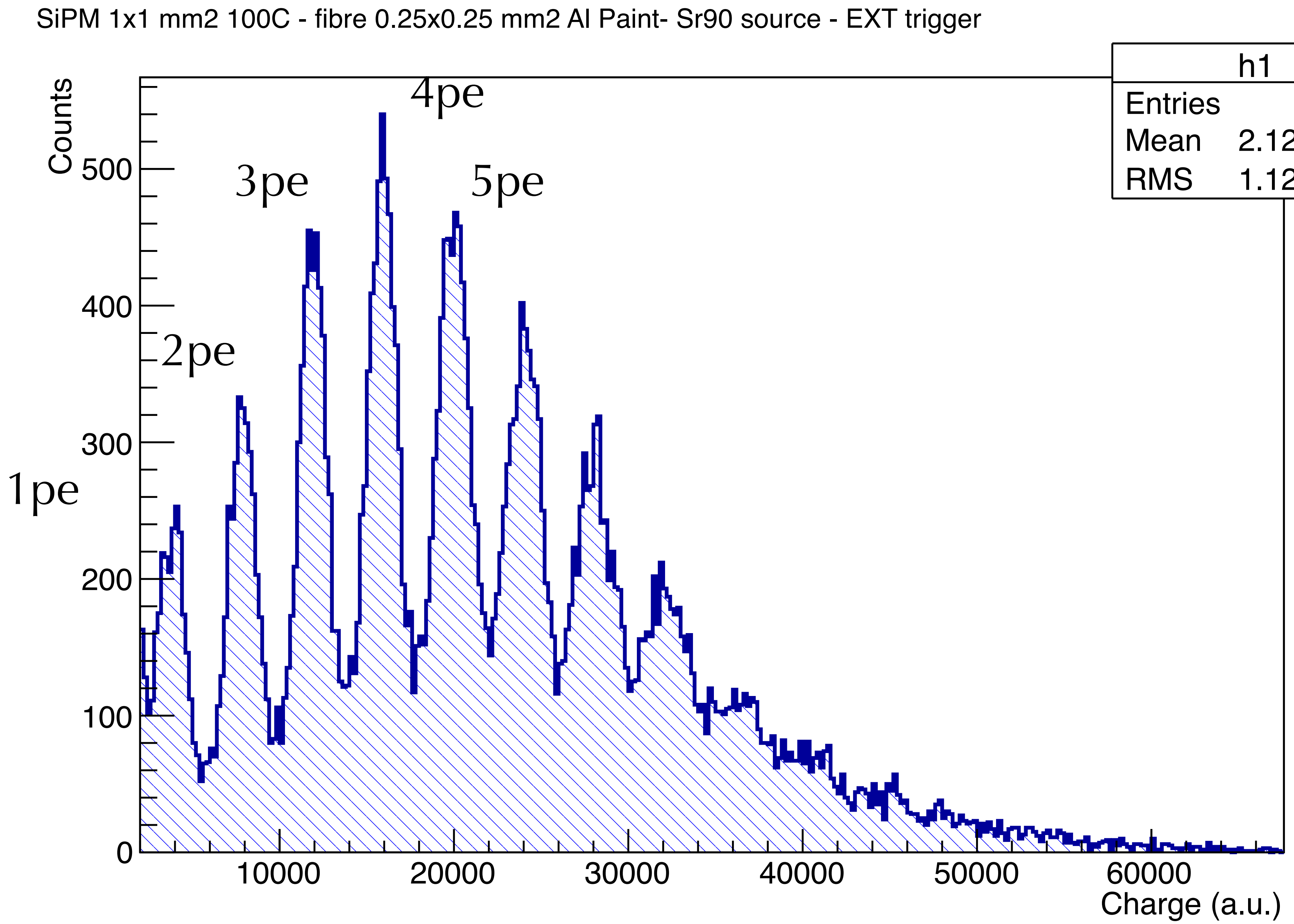


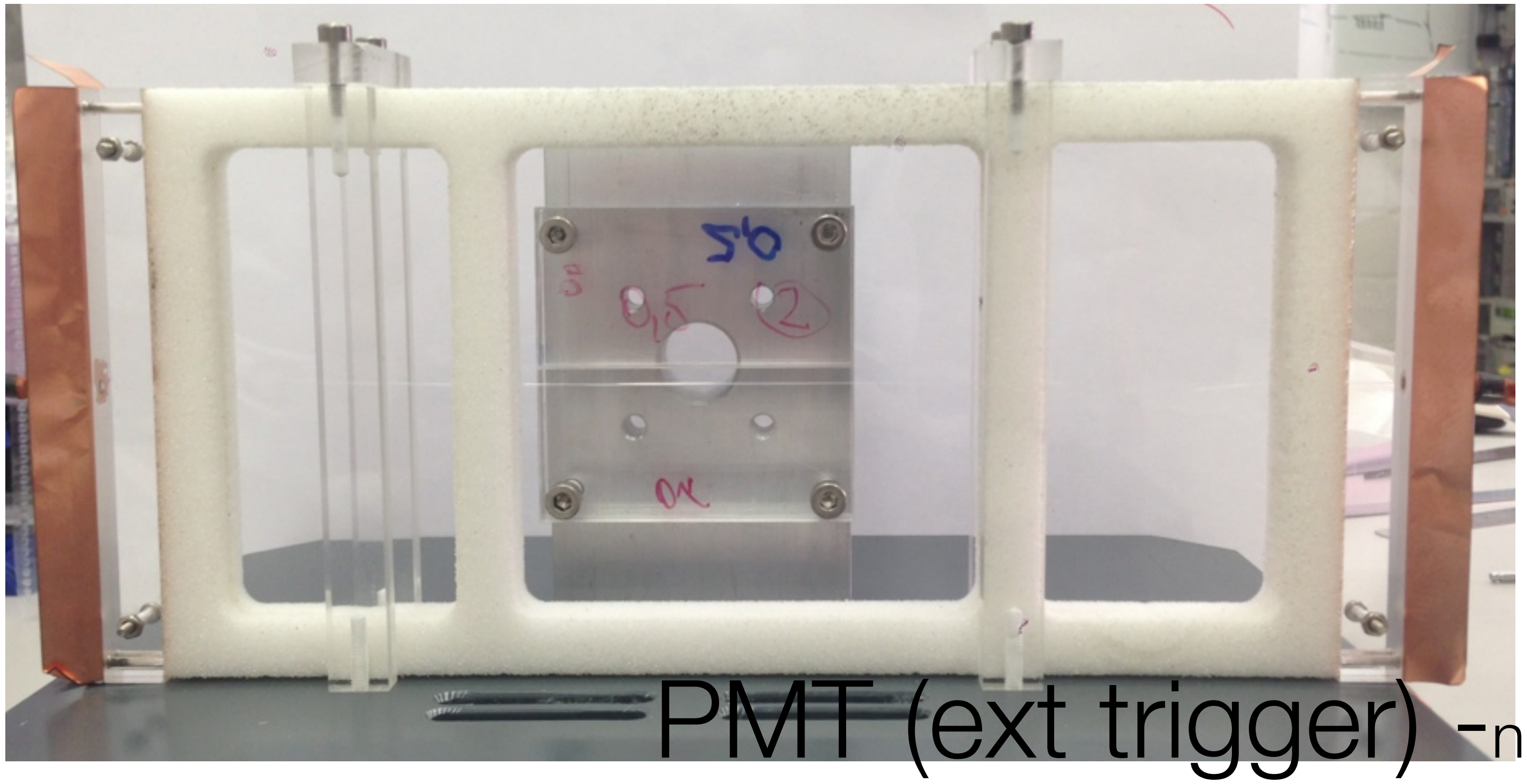
$\varepsilon_{det} \sim 76\%$

Double read-out

- A single fiber read-out by 2 SiPM at the ends of the fiber
- Q_tot = Q_1 + Q_2; expected a factor 2x in light w.r.t. to single read-out and and a factor 1.25x w.r.t. to single+Al read-out
- ...But a factor 2x in photodetector, pre-amplifier, HV bias, electronics etc.

Sr90 + Collimator

SiPM1

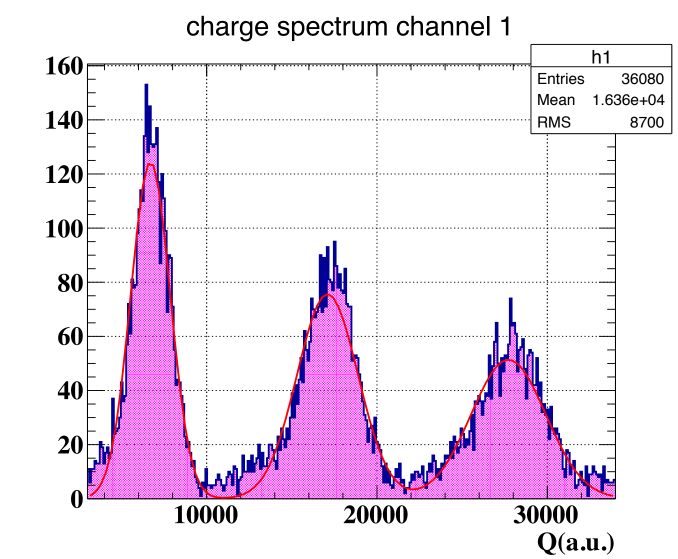


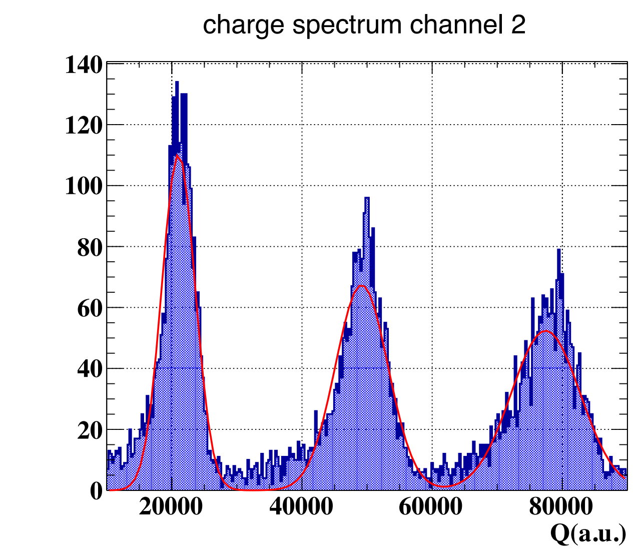
SiPM2

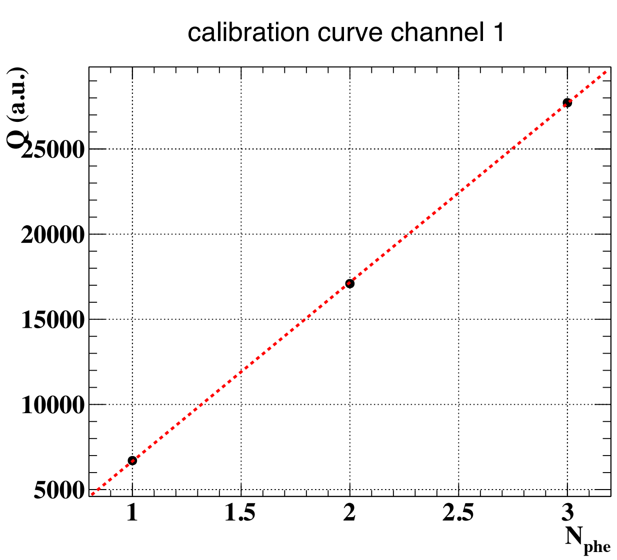
PMT (ext trigger) -not in the picture

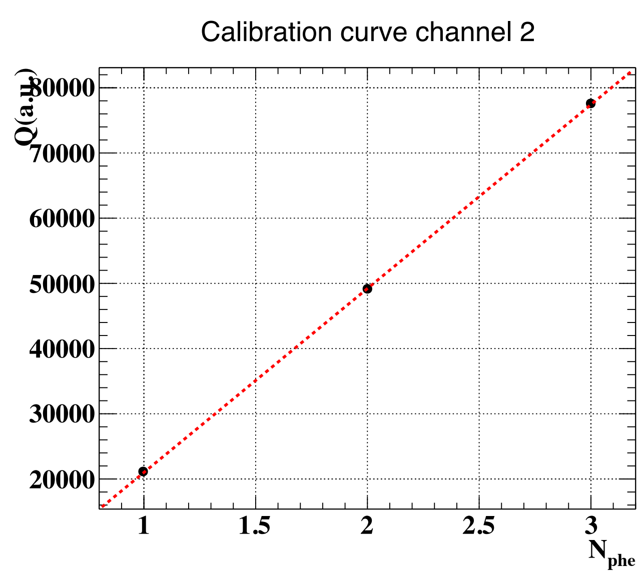
Charge Calibration

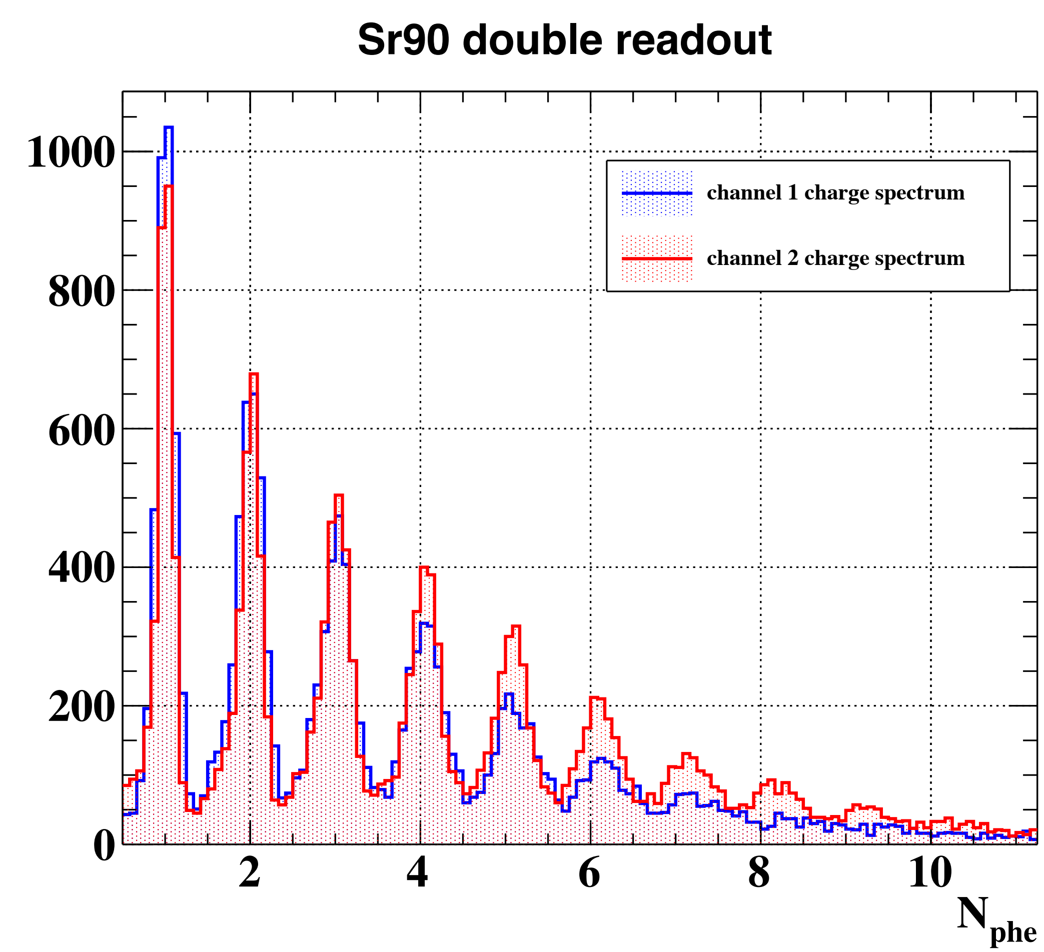
- Q_tot = Q_1 + Q_2
- A relative intercalibration between the 2 SiPM is performed (dark current and signal spectra)





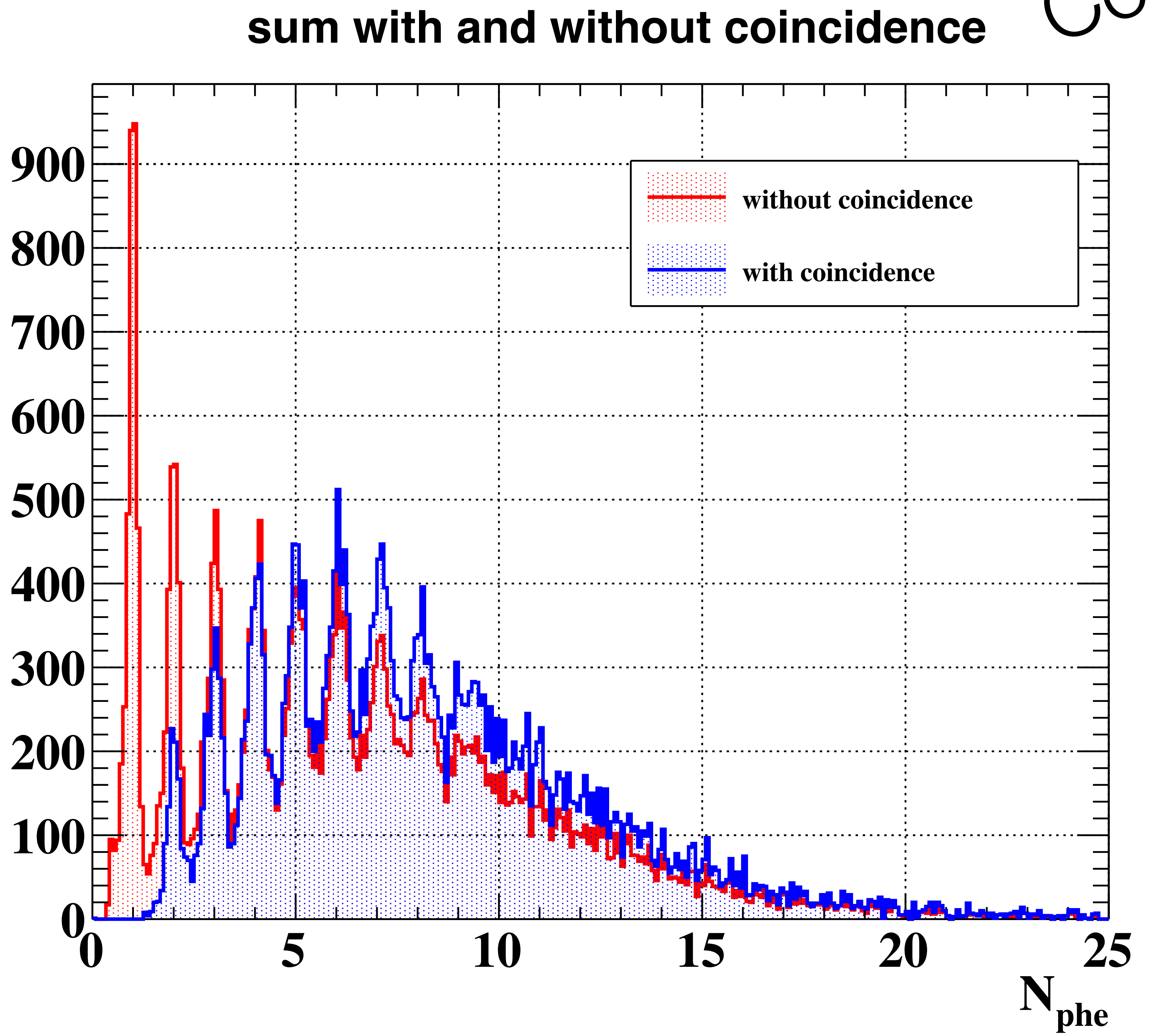






Results

Collimator system NOT optimized

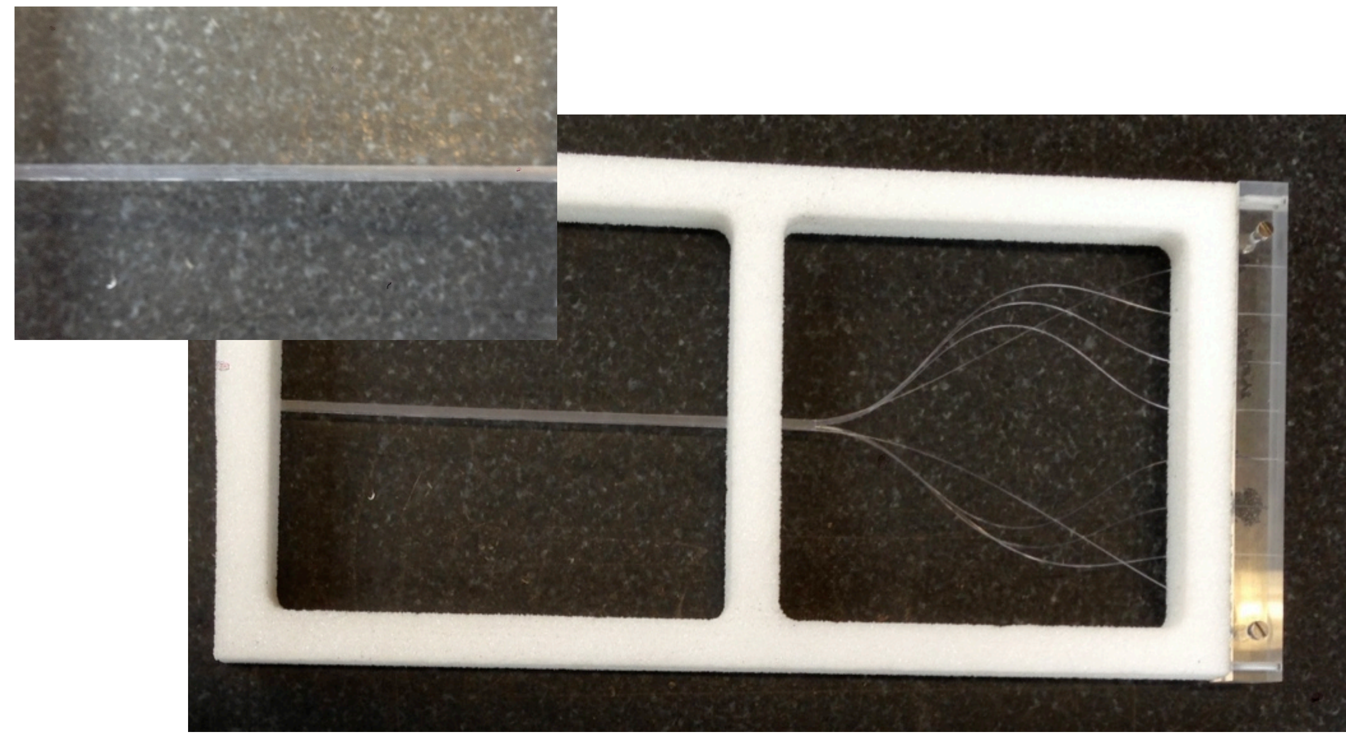


$\mu(Q_1 \text{ or } Q_2) = 6$
$\varepsilon(Q_1 \text{ or } Q_2) = 58\%$

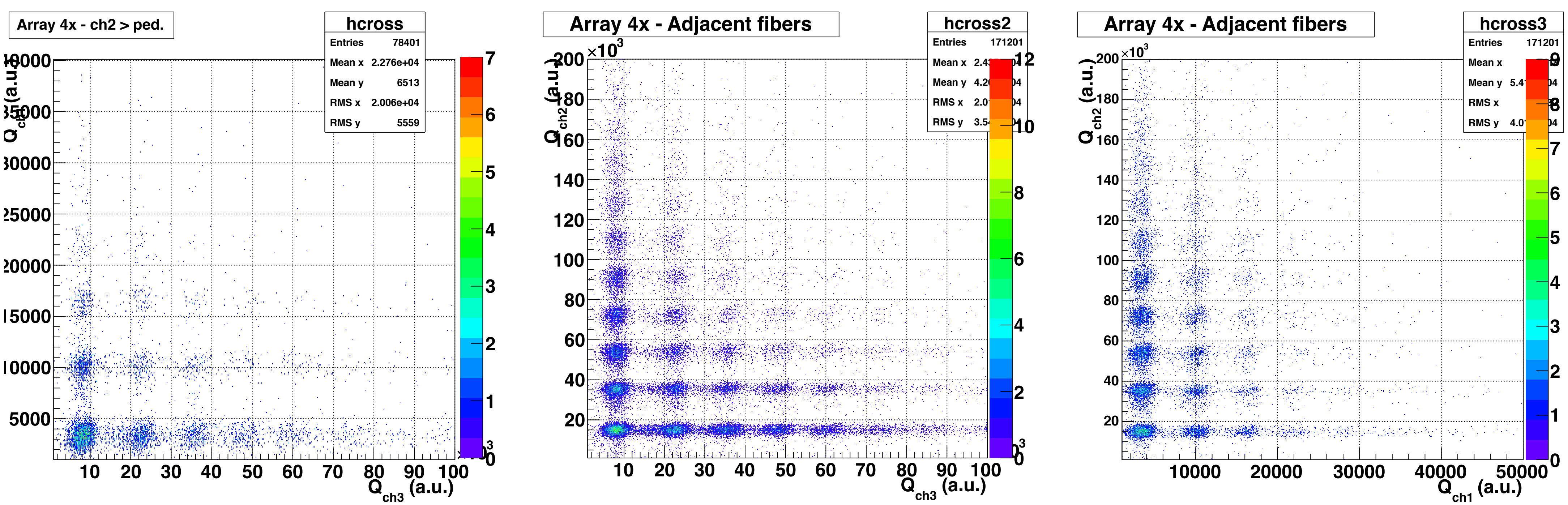
$\mu(Q_1 \text{ and } Q_2) = 8$
$\varepsilon(Q_1 \text{ and } Q_2) = 41\%$

The first array 4x: a first look at the optical cross-talk

- Collimator (0.25 x 0.25 mm^2) mounted on a micrometric linear mouver
- Sr90 source
- Scanning at step of 250 um



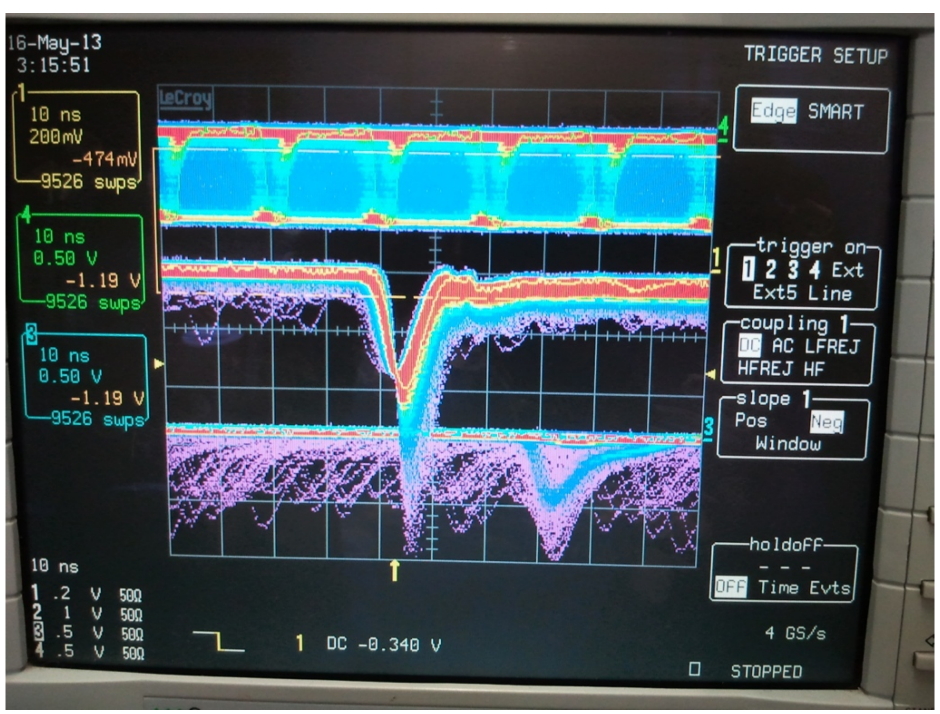
	Fiber1	Fiber2	Fiber3
X0	0.16	0.46	0.53
X0+250	0.48	0.54	0.17
X0+500	0.60	0.19	0.08
X0+750	0.25	0.10	0.05
X0+1000	0.10	0.05	0.03
X0+1250	0.05	0.03	0.02

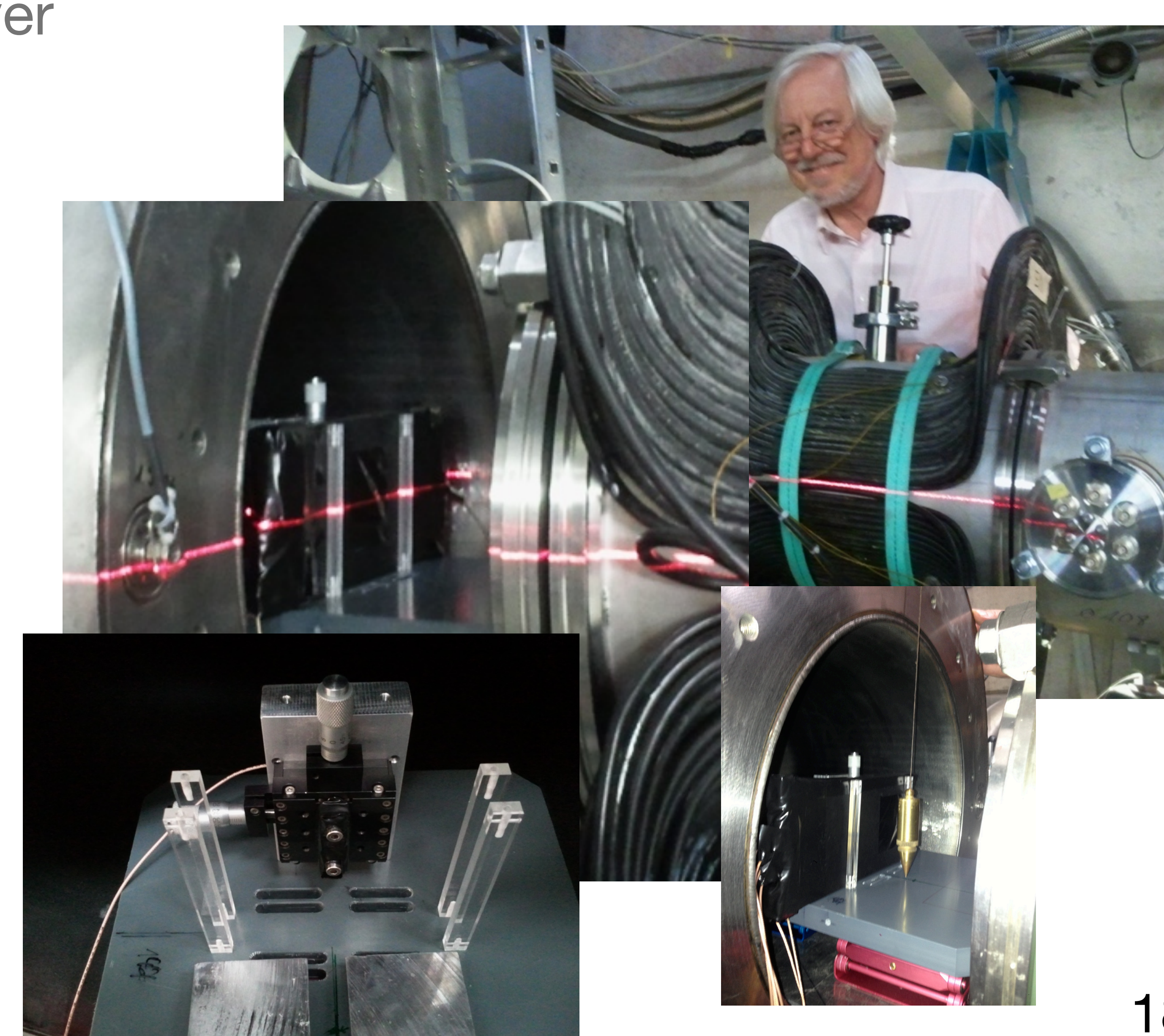


May 2013 Test beam

- Positrons at p = 28 MeV/c
- External trigger detector (BC400 2x2x2 mm^3 coupled to 3x3 mm^2 SiPM 100 um) mounted on a micrometric mover

- e^+ signal: Clear line requiring the Correlation with the RF

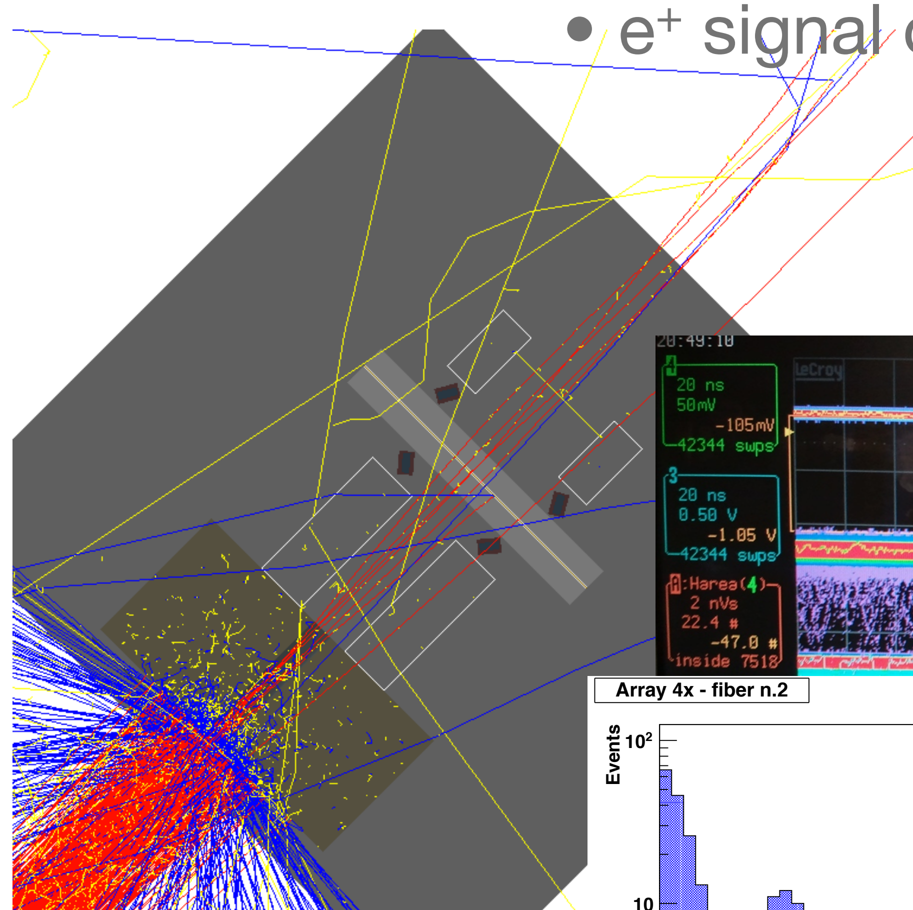


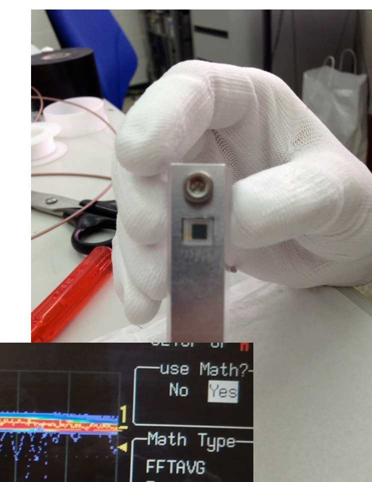


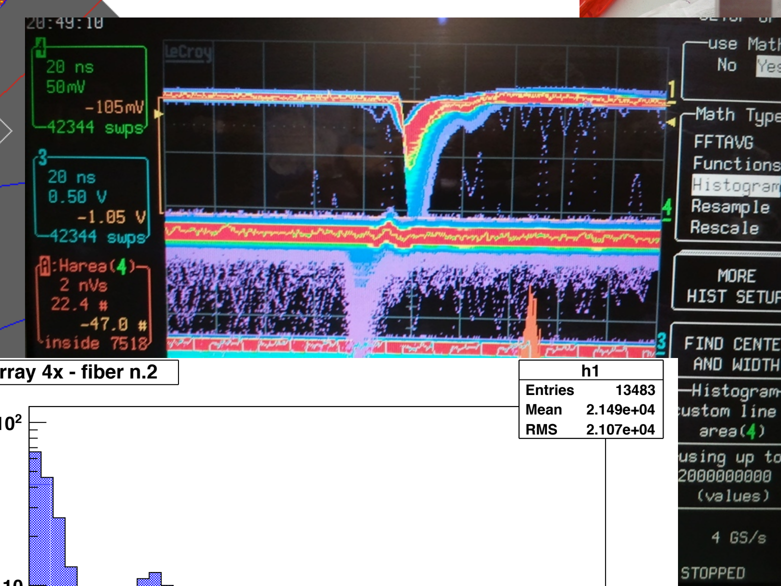
May 2013 Test beam

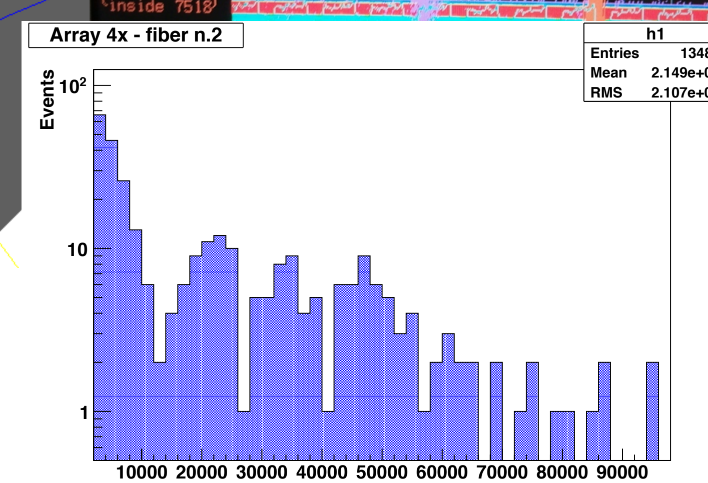
- Muons at p = 28 MeV/c and Michel positrons from muons stopped into the target
- For the selection of the Michel e^+ we used external trigger detectors (BC400 7x4x2 mm^3 coupled to 3x3 mm^2 SiPM 100 um) mounted on a micrometric mover

- e^+ signal on fiber

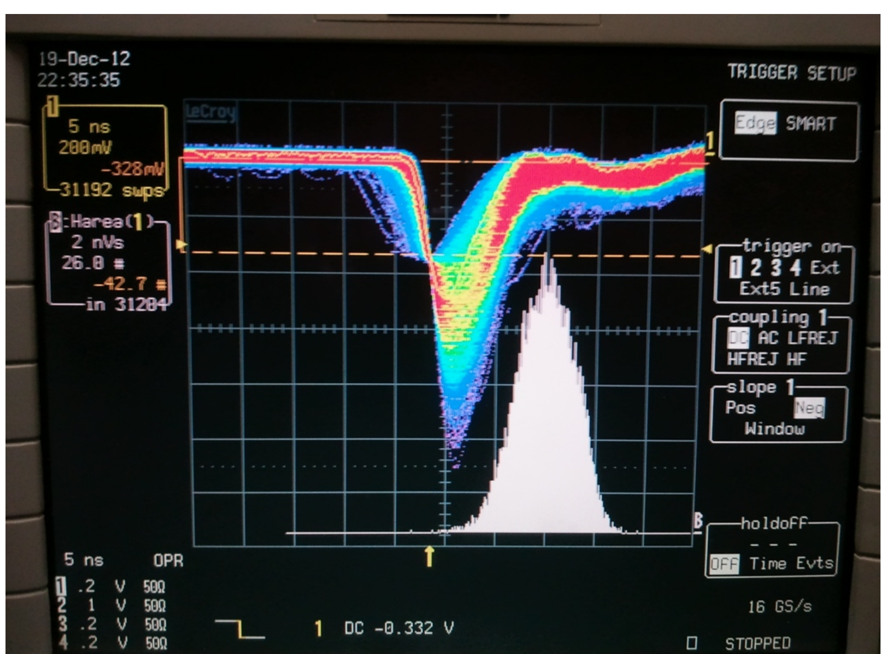








- mu+ signal on fiber



What is going on

- Comment: the μ^+ and e^+ were detected and identified with a realistc prototype
- The single fiber detectors (Aluminum fiber-single readout and fiber-double readout) worked in a satisfactory way but the requested level is not yet reached
  - more controlled couting deposit
  - more professional setup with micrometric movers
- About the fiber array we need
  - to minimize the optical cross-talk (less optical cement, Al/TiO_2 coating,glue with small refractive index)

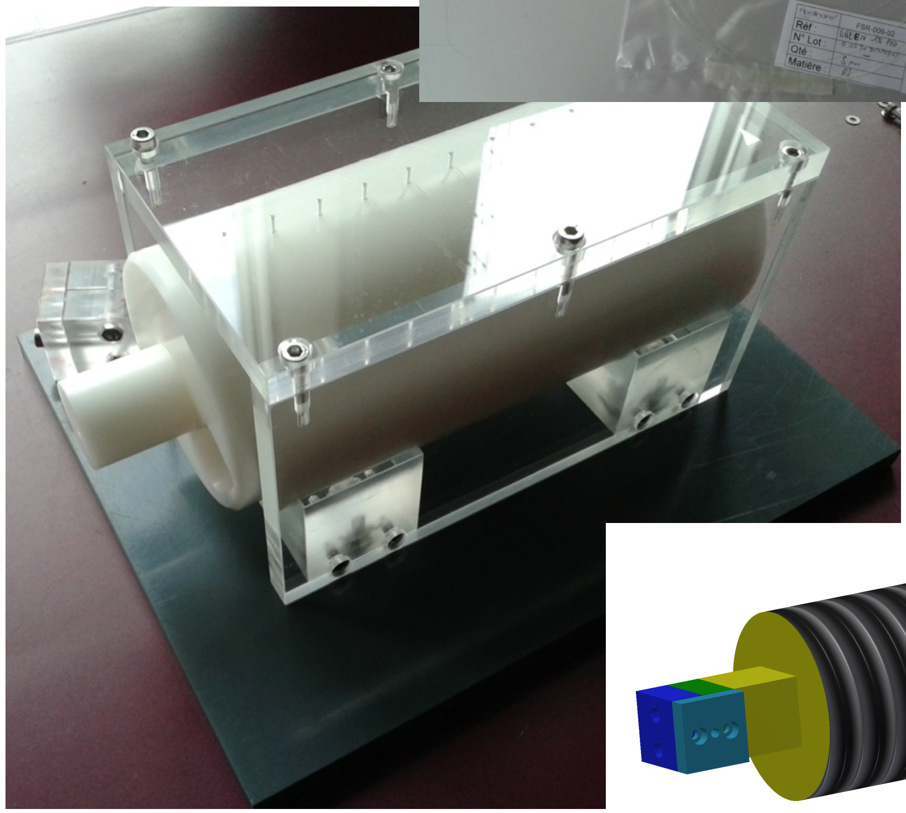
new Al samples delivered
new prototypes (4)delivered/ (1)in preparation

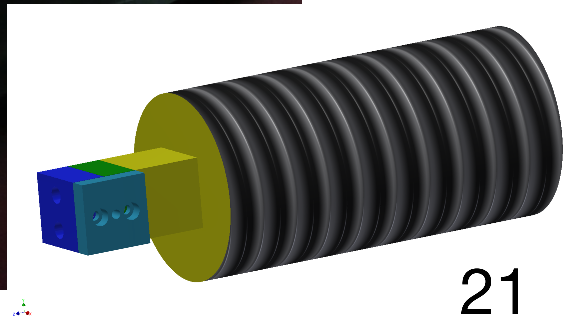
What is going on

- Investigation of fibers from others Companies (Apollinaire and Kuraray) vs Saint-Goaiban providing a full characterization (LY and λ_{att})

  - SCSF-78J (S cladding, 0.5mmSQ)
  - SCSF-3HF(1500)J (S cladding, 0.5mmSQ)

  - p-Terphenyl saturation (M cladding)
  - 1% PBD + 0.05% DMPOPOP (M cladding)
  - 1% DMPOPOP (M cladding)
  - DMPOPOP saturation (M cladding)



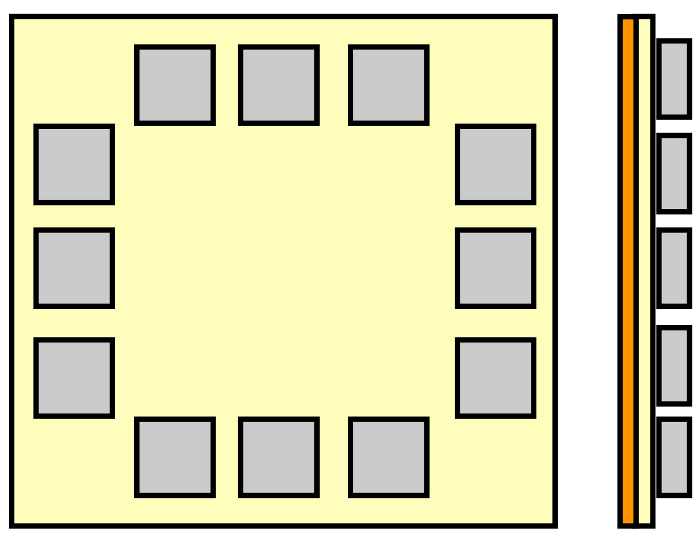


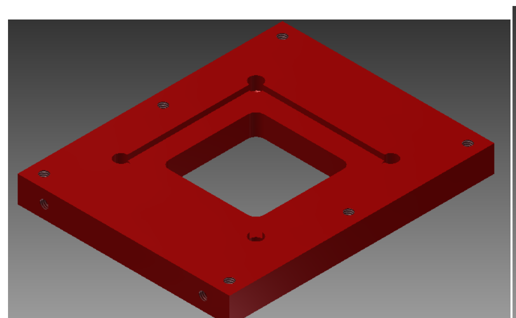
Very Thin scintillator foils with high LY

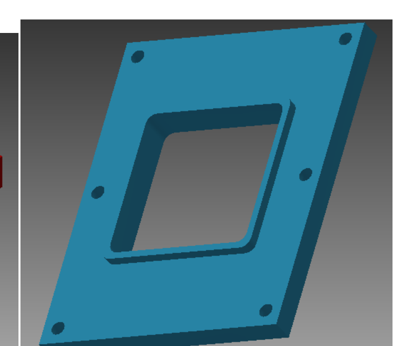
- p-Terphenyl as scintillator (instead of to be a dopant agent)
- Light Yield **~27 000 ph/MeV** (plastic scintillator ~10 000 ph/MeV)
- Attenuation length ~ few centimeter
- R&D in collaboration with the DetecEurope (no available on the market); first samples produced with a thickness < 1 mm on a 3M reflector support
  - 50 x 50 x **0.25, 0.20, 0.15 and 0.10 mm**

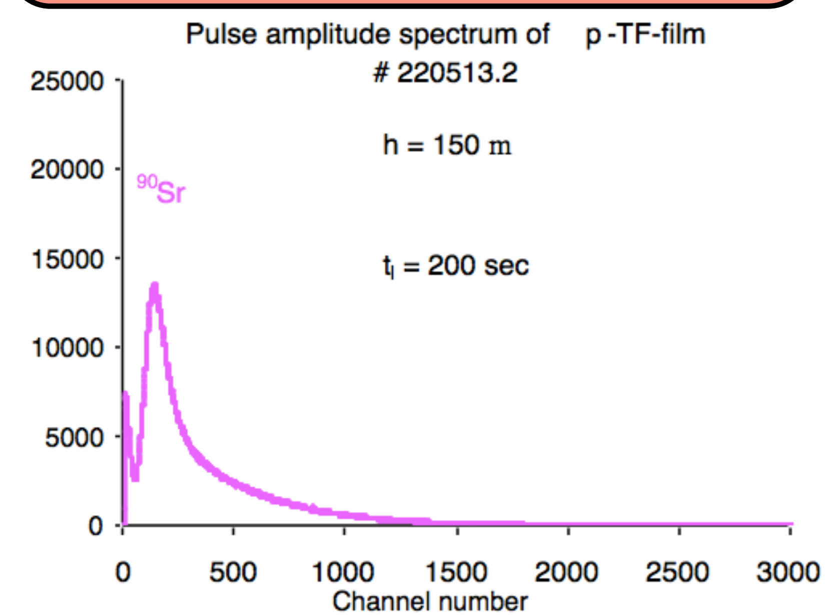
- Timing and position measurements
- Different geometrical configuration

Aiming at
Δt ~ few 100 ps
or less





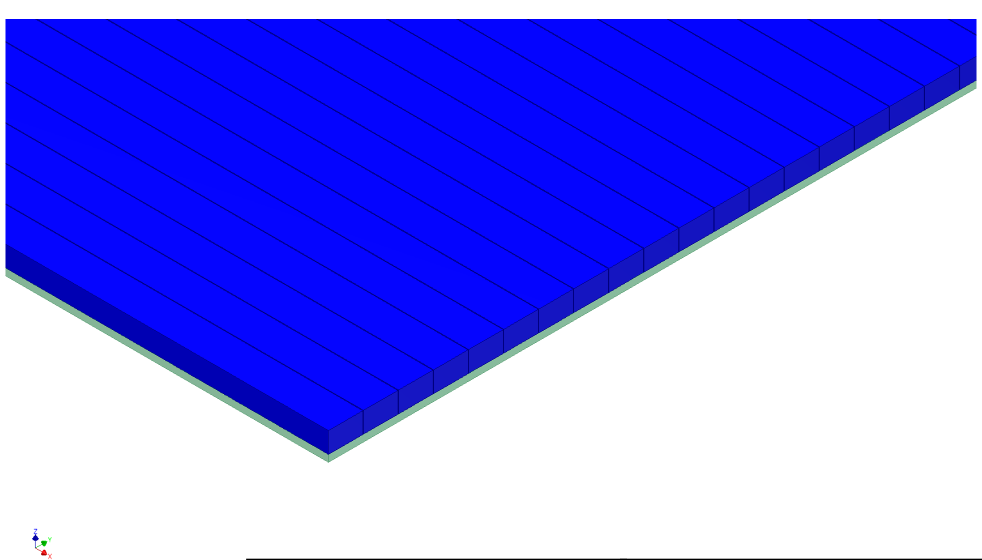


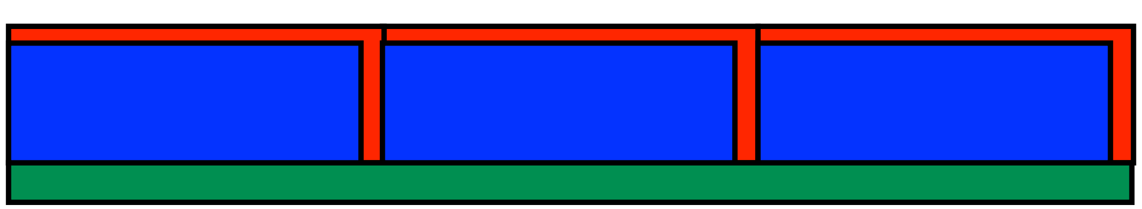


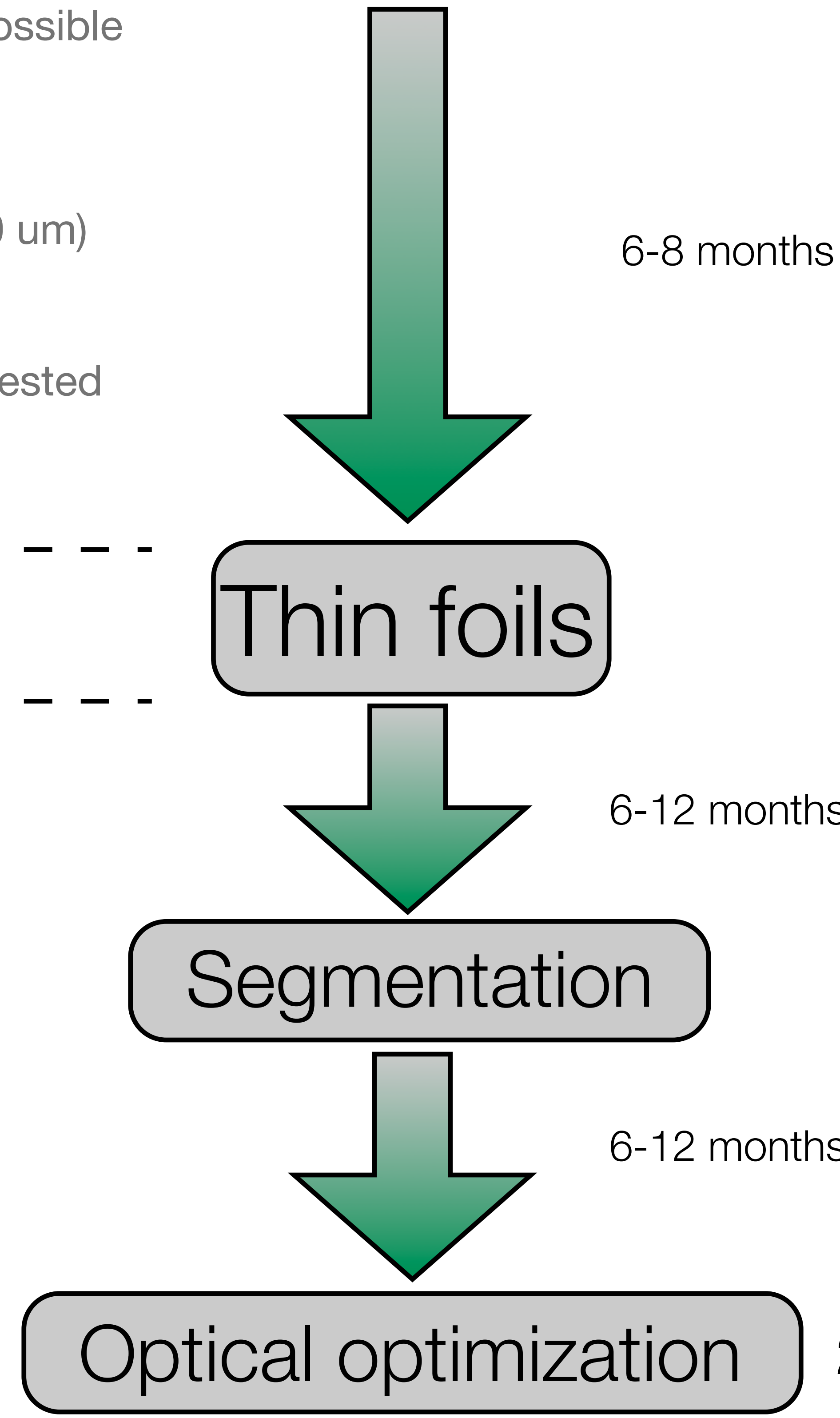
Next step

- Jan. 2013: first contact with the company/scientific motivation and possible spill-out
- Feb. 2013: starting the first production
- April 2013: a first sample with a sub mm thickness was obtained (500 um)
- May 2013: a thickness of 250 um was successfully produced
- June 2013: samples of 250,200,150 and 100 um was produced and tested
- July 2013: samples ready to be delivered

Measurements in lab.







Summary

- A rich detector R&D program for the MEG upgrade is going on ranging from noble liquid photosensor devices to a new tracking detector

- Preliminary results from the available prototypes are very promising

  - SiPM working in the VUV was tested (PDE>10%)
  - Several DC prototypes was prepared to investigate the aiging, the hit resolution, the new FE electronics, the cluster method
  - A timing resolution of 35ps was obtained using BC422 TC pixel coupled to SiPM
  - μ^+ and e^+ were detected and identified with a minimal ATAR prototype

- We are moving towards final measured resolutions and efficiencies, before starting the costruction of the detectors