PAUL SCHERRER INSTITUT

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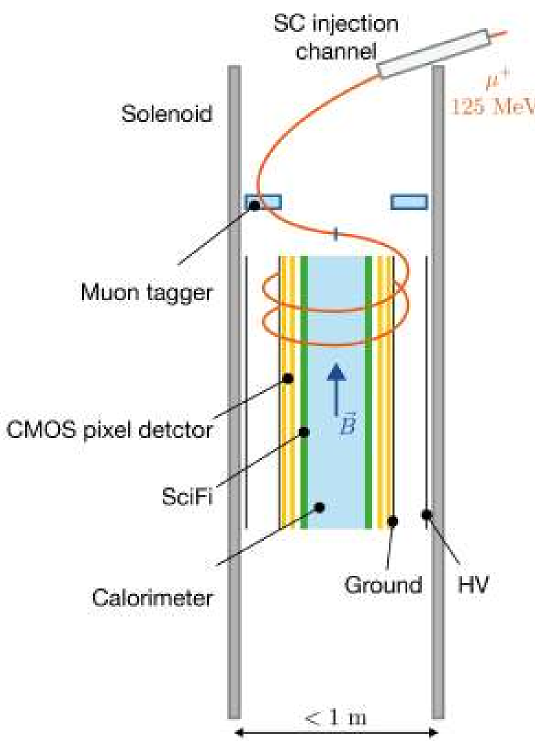
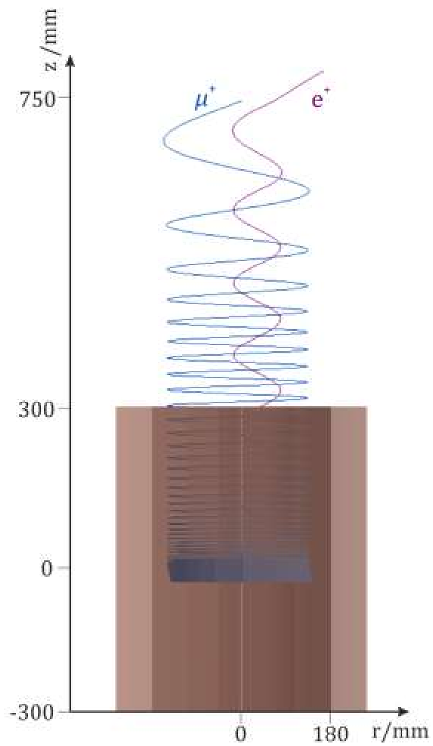
Beam Tests of an Entrance Detector for the MuonEDM Experiment at PSI

16.05.2023 New Frontiers in Lepton Flavor Pisa

The MuonEDM Experiment

Aim: measure (a possible) electric dipole moment (EDM) of the muon.
Why: **N**on-zero EDM → direct sign of CP violation
How: Frozen spin technique
Muons orbit in an electromagnetic field tuned to "freeze" the spin to the momentum vector, so that the only spin precession is due to the EDM term.





- Injection into solenoid on helical trajectory
- Magnetic kick stops vertical movement and forces muon on stable orbit

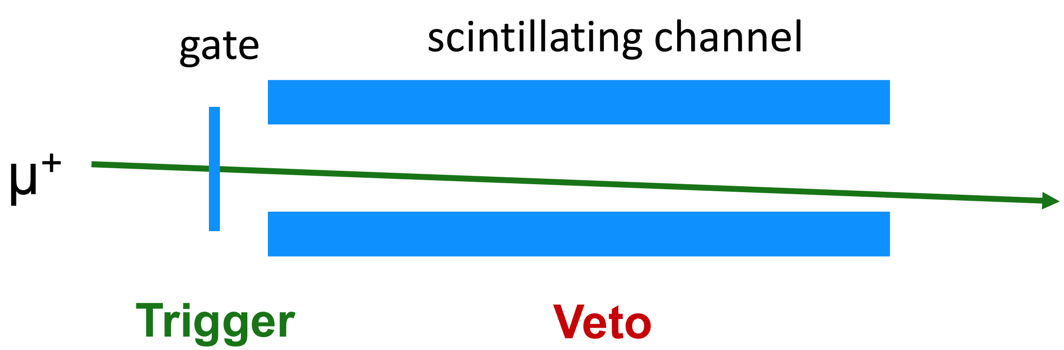
→ An Entrance detector is needed to trigger the magnetic kick.

Entrance Detector Wishlist

Trigger magnetic kick **only if** muon injected along right trajectory for storage!

1. Detect the arrival of a muon
2. Check that muon follows the right trajectory for injection into storage orbit

A possible detector:

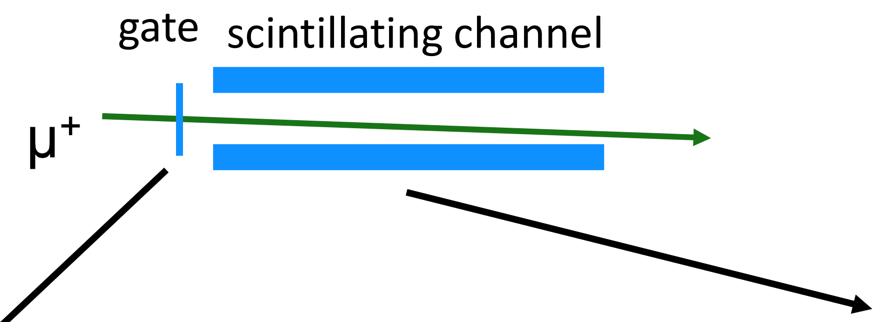


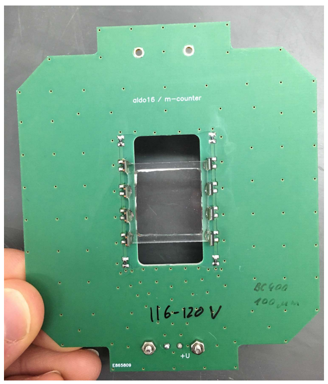
Gate scintillator: must be **very thin to reduce multiple scattering!**

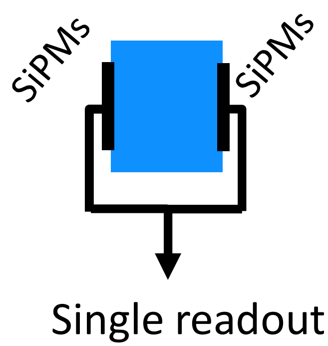
At same time, require: Full efficiency at no thermal noise contamination

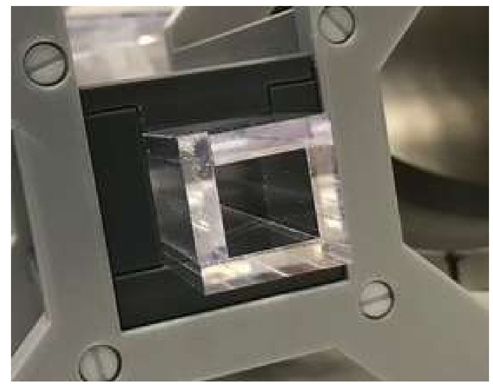
→ Learn how to operate such a thin scintillator with muons!

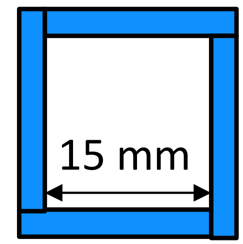
A First Prototype…











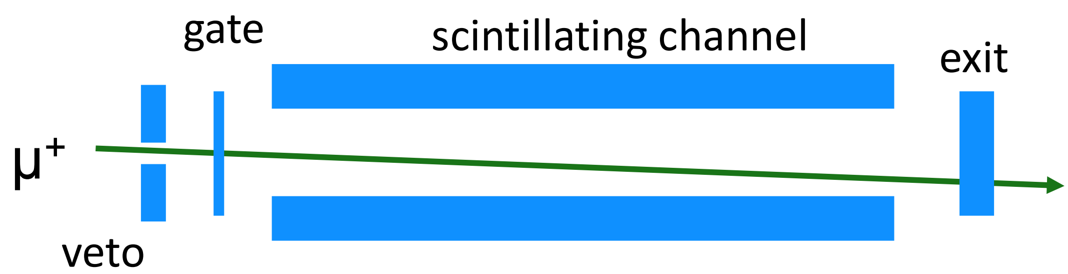
- 100 μm thick, 20 mm x 20 mm
- Two sided SiPM readout combined into a single channel

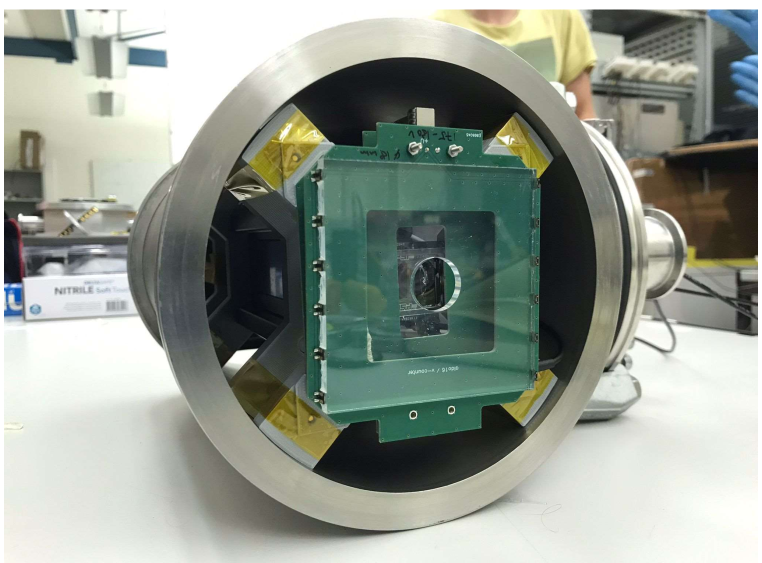
- Four thick (5 mm) rectangular, scintillating tiles (200 mm x 20 mm)
- Upstream and Downstream SiPM readout → **8 channels**
- Air gaps between tiles to prevent optical crosstalk

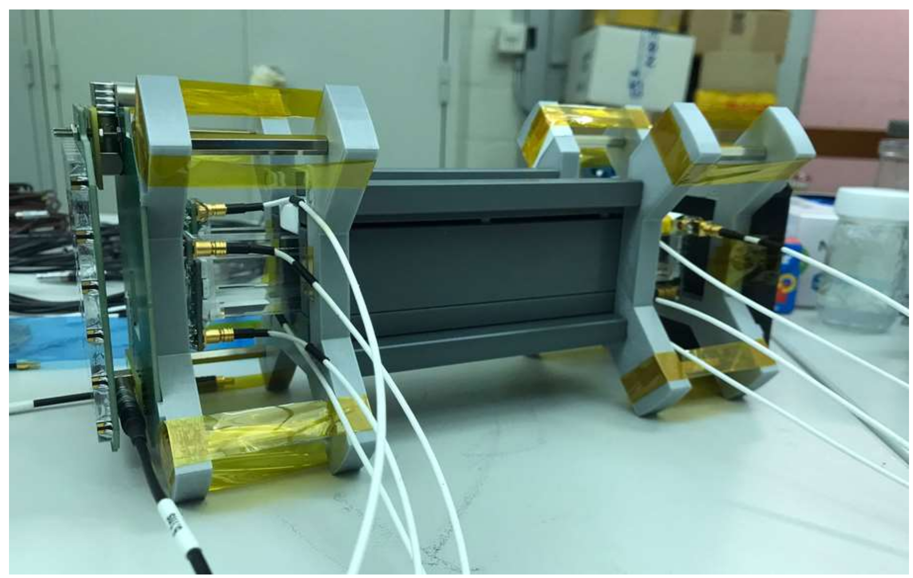
....equipped with additional detectors.

For measurements with beam: **added veto & exit detector**

Silicon Photomultipliers (SiPMs) used for light readout of all scintillators.



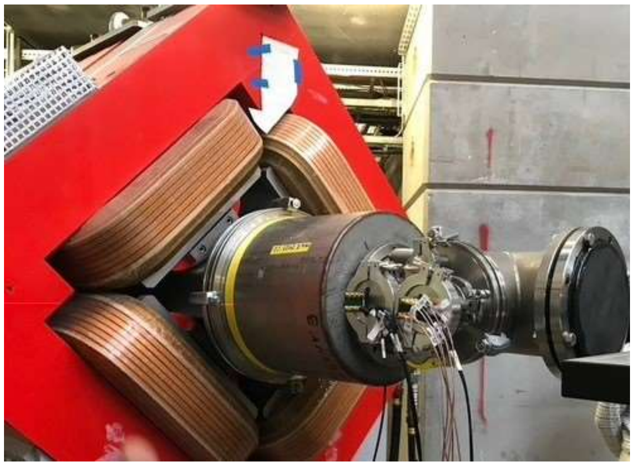




Tests with the Beam in Dec 2022

Aim: Evaluate performance of subdetectors (gate, scintillating channel)

- At the πE1 beamline at the Paul Scherrer Institute (PSI), Switzerland
- Muons with p≈28 MeV/c



- WaveDREAM boards to record waveforms and power SiPMs
- Offline waveform analysis after beamtime

Gate Scintillator Characteristics

Trigger threshold? Efficiency ? Thermal noise contamination?

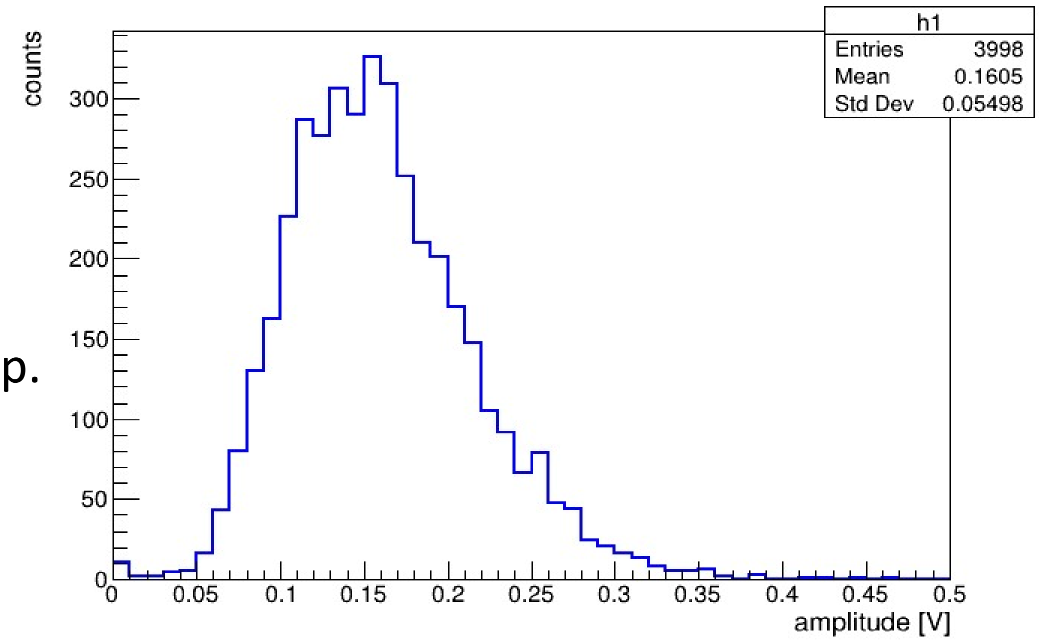
→ Amplitude distribution of 28 MeV/c muons in the gate scintillator (Trigger: Exit)

Efficient Trigger Threshold: ~ 50 mV

But at 50 mV: **Thermal noise rate of SiPMs is a few kHz**

→ Very thin scintillator:
Signal amplitude ~ thermal noise amp.

→ How to get rid of thermal noise counts?

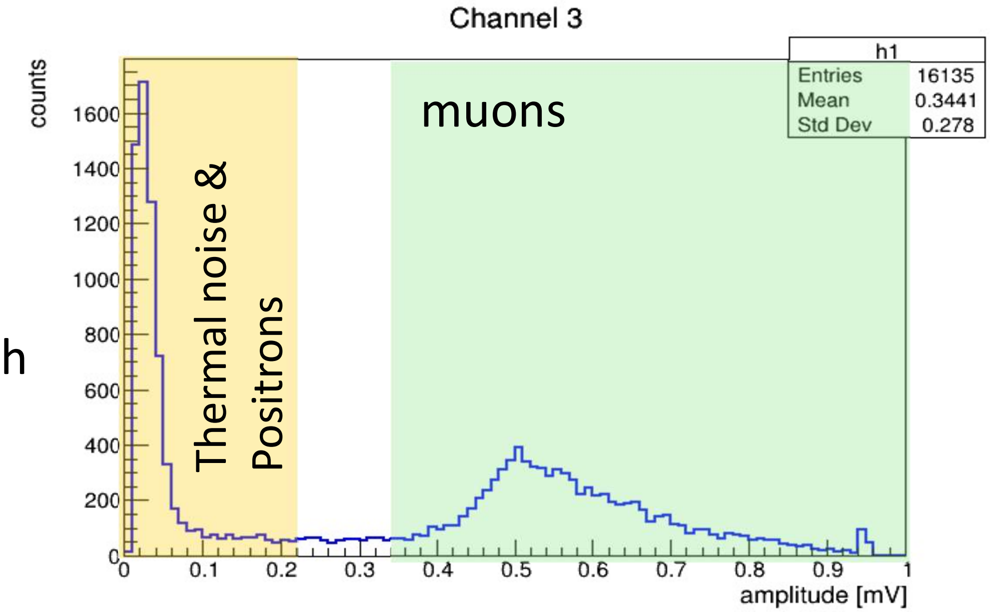


Strategy: Reject thermal noise by coincidence trigger on different SiPM readouts

Conclusion: To be fully efficient with a low dark noise contamination, a multi-channel readout is necessary for the 100 µm thin gate scintillator.

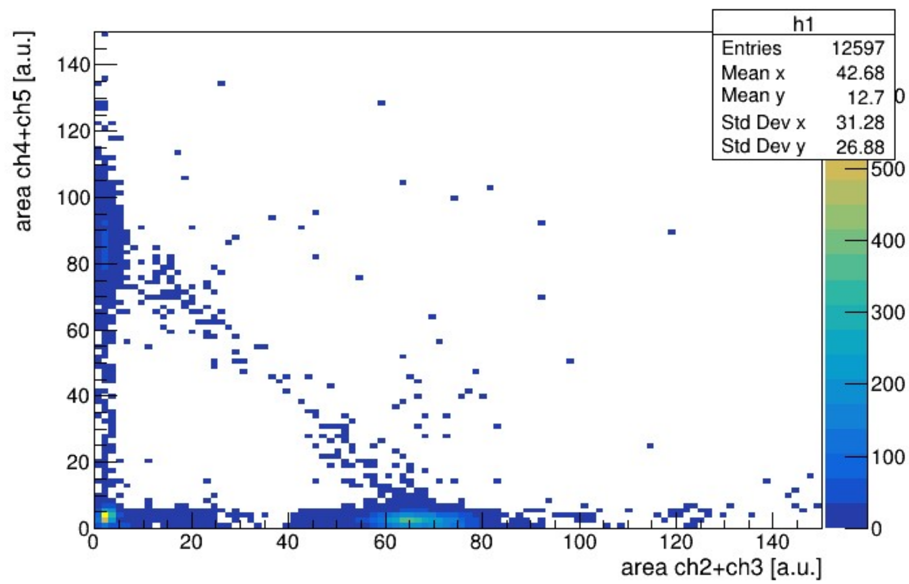
Scintillating Channel Characteristics

Amplitude of muon hits well separated from noise
→ A single readout per tile is enough



Almost no correlations in the deposited charge between different channels

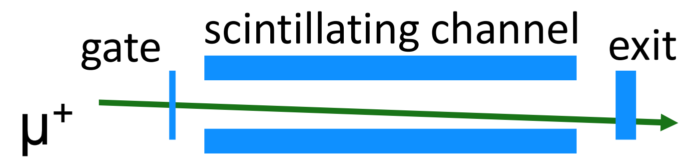
→ Not much optical crosstalk



Scintillator Timing Properties

Trigger magnetic kick to stop muons: tight timing constraints (~ 60 ns)
→ Time resolution of scintillators?

Measure **time of flight** between gate and exit (200 µm): $\Delta t = t_{exit} - t_{entrance}$

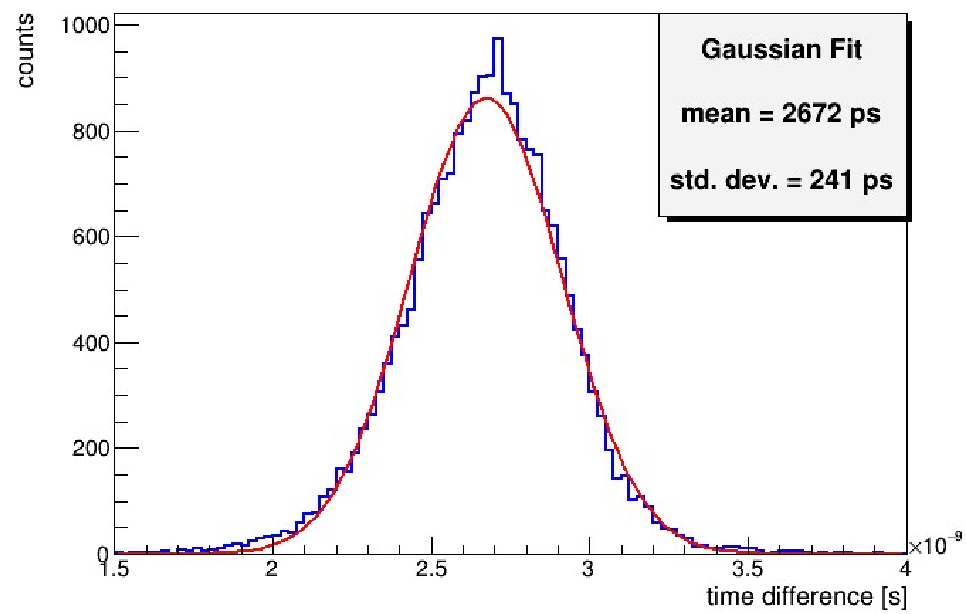


$$\sigma_{\Delta t}^2 = \sigma_{scintillators}^2 + \sigma_{beam}^2$$

From MC: $\sigma_{beam} \approx 78\,ps$

Combined time resolution of gate & exit:

$$\boldsymbol{\sigma_{scintillators} \approx 228\,ps}$$



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What We Learned

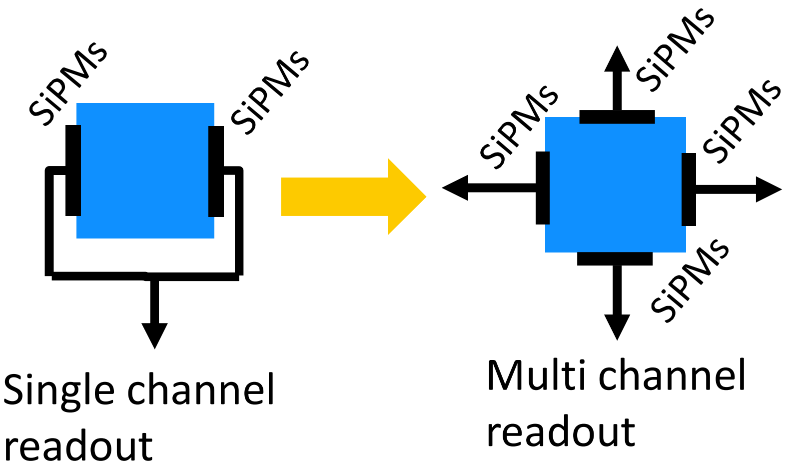
- In case we need to use very thin scintillators (~ few 100 µm)
  → multi-channel readout necessary to reject thermal noise pulses
- Thick scintillators (few mm): muon signal well separated from thermal noise in SiPMs
- The combined time resolution of a 100 µm gate and 200 µm exit scintillator is on the order of 230 ps.

Next Step:
Towards an Even Thinner Gate Scintillator

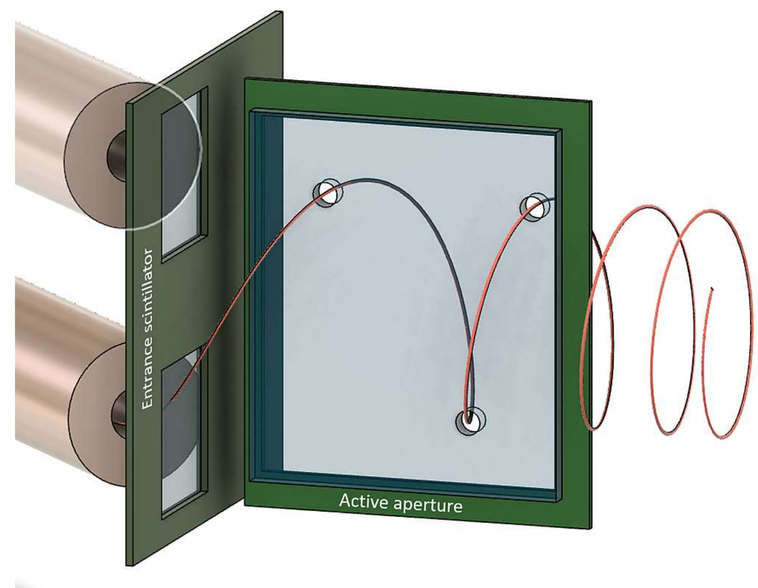
Use an even thinner gate scintillator (~ 50 µm) to further reduce multiple coulomb scattering!

→ multi-channel readout to reject thermal noise counts crucial!

→ test during 2023 beamtime



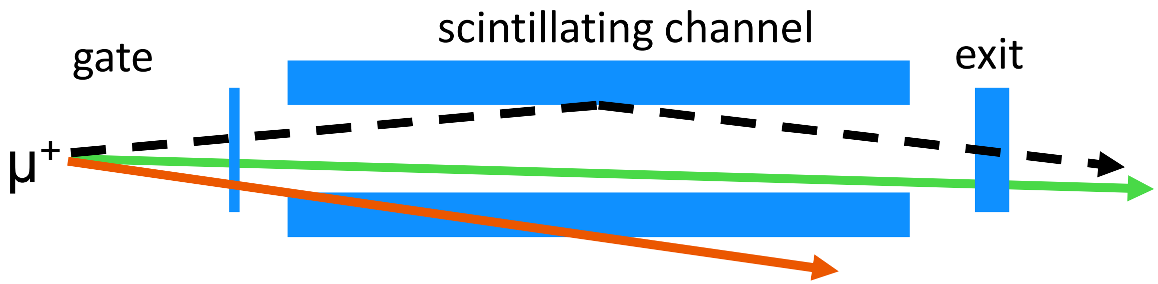
→ scintillating channel will be replaced by a scintillating plate with holes to monitor the trajectory more precisely.



Thanks a lot for your Attention! Questions?

Some other studies and slides

Muon Trajectories in the Telescope



Trigger on Entrance & (!Veto), Rate = 2.8 kHz

In Entrance: 32’529 counts = 100 %

Path	# hits	Fraction [%]
Entrance → scintillating channel, NOT exit	**14’265**	**43.9**
Entrance → Exit, NOT scintillating channel	**7’589**	**23.3**
Entrance → scintillating channel → Exit	**1’209**	**3.7**
Entrance only	9’466	29.1

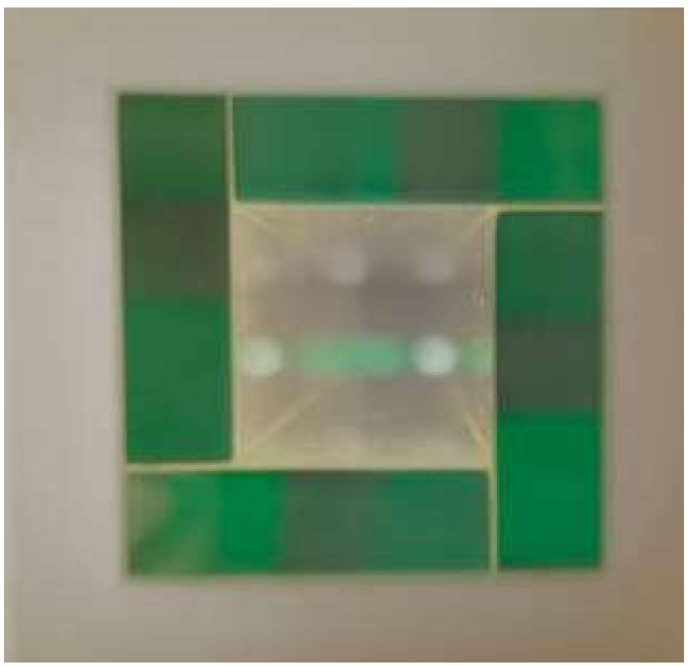
→ In this beam configuration, about 23 % of the muons entering the detector follow the desired trajectory

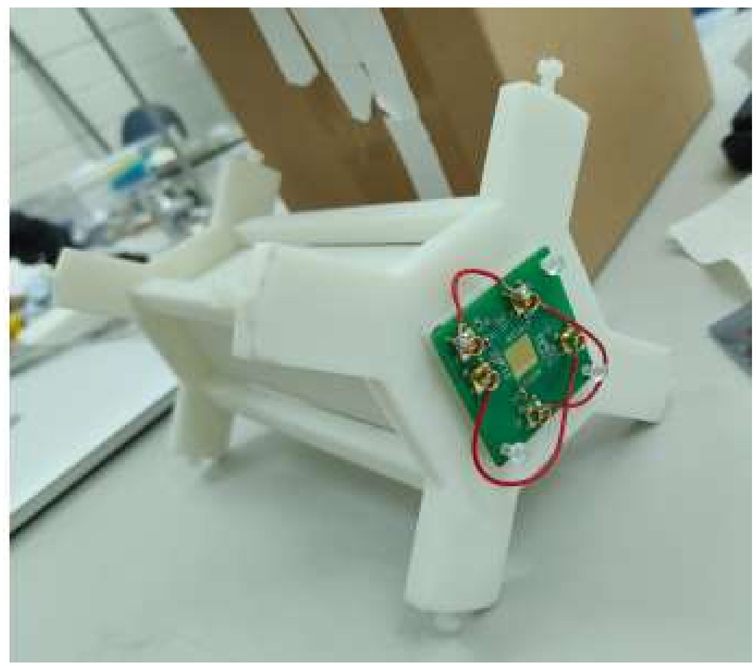
→ Still ongoing: What happens to the muons leaving a hit in the entrance only, i.e. which “disappear” in the telescope?

Scintillating Channel: Optical Crosstalk

But we also tested another scintillating channel prototype! (University of Shanghai)

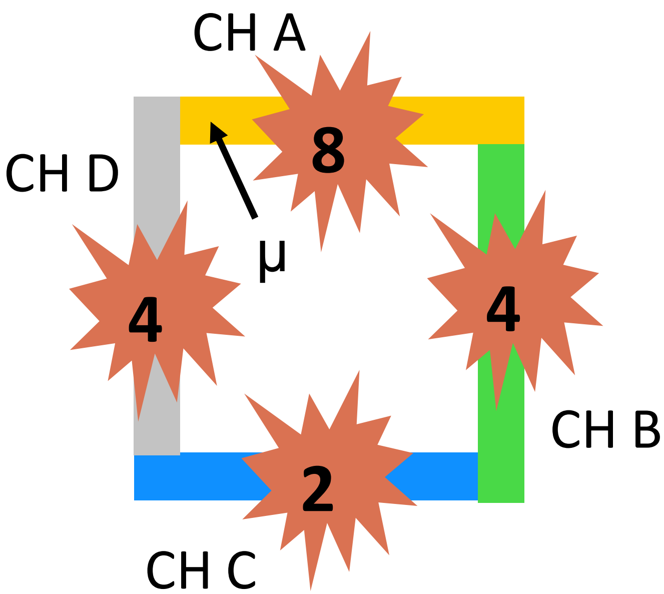
- Scintillators tightly packed
- 1 readout per scintillator tile



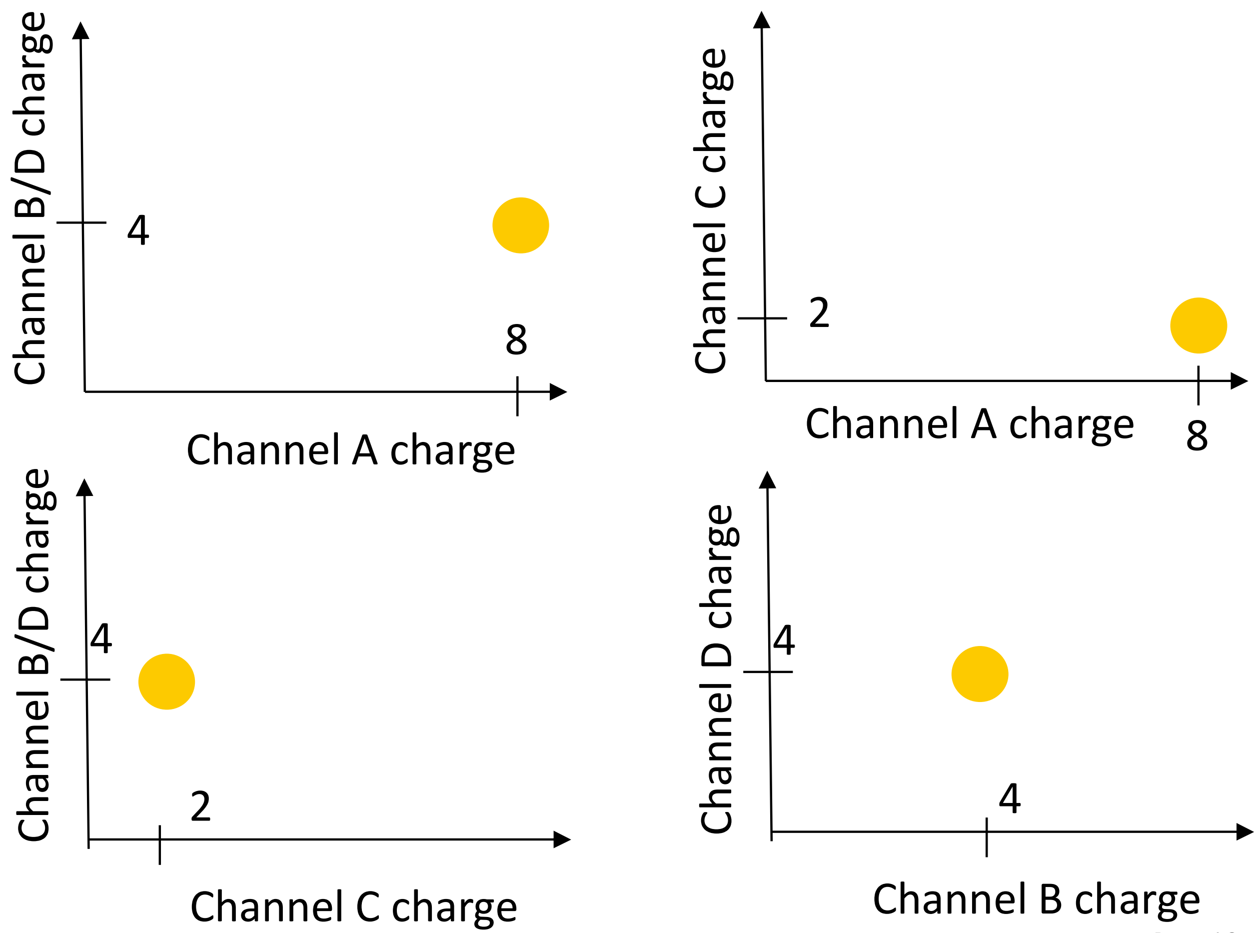


Scintillating Channel: Optical Crosstalk

Touching scintillators in ideal setup → expect optical crosstalk.



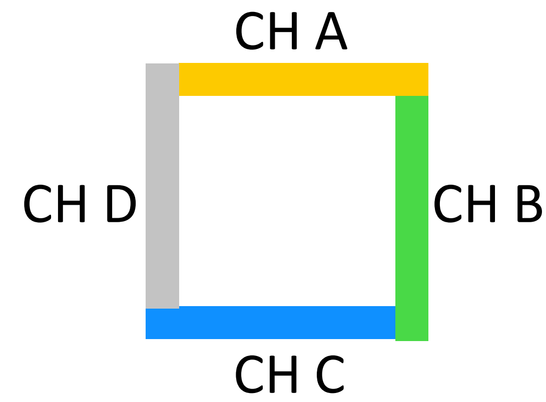
Expected correlation patterns between different channels when considering only hits in channel A:



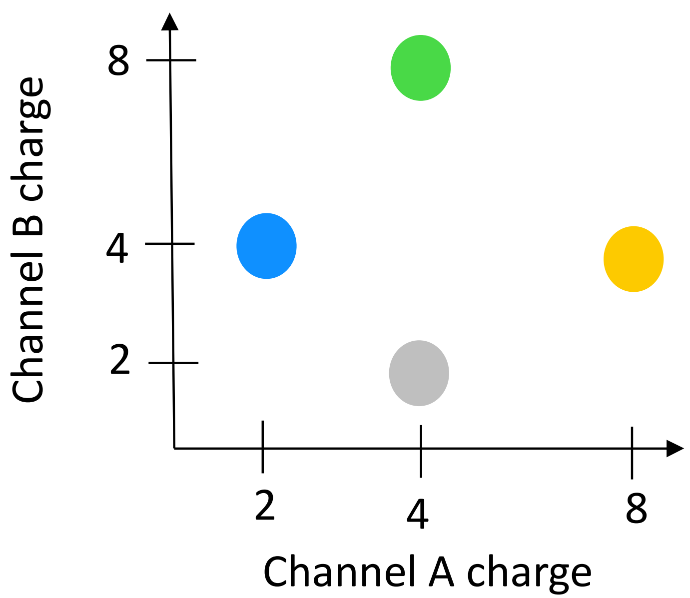
Scintillating Channel: Optical Crosstalk

Fix two channels, plot charge deposit of hits in all four channels.

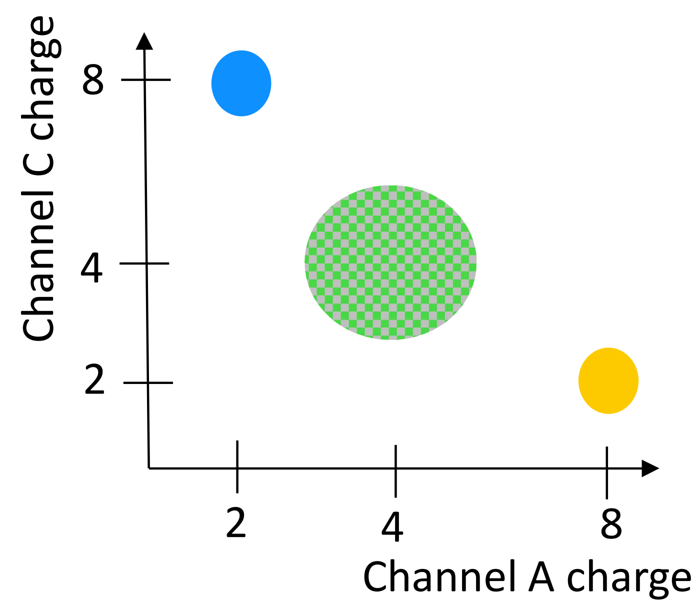
Expected correlation plots:



Correlation between channels next to each other



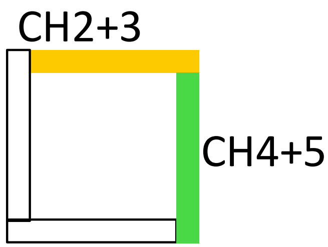
Correlation between channels opposite to each other

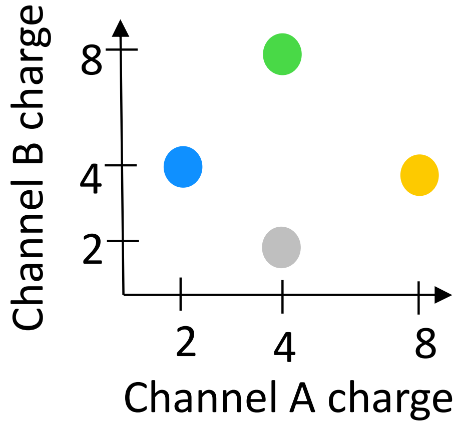


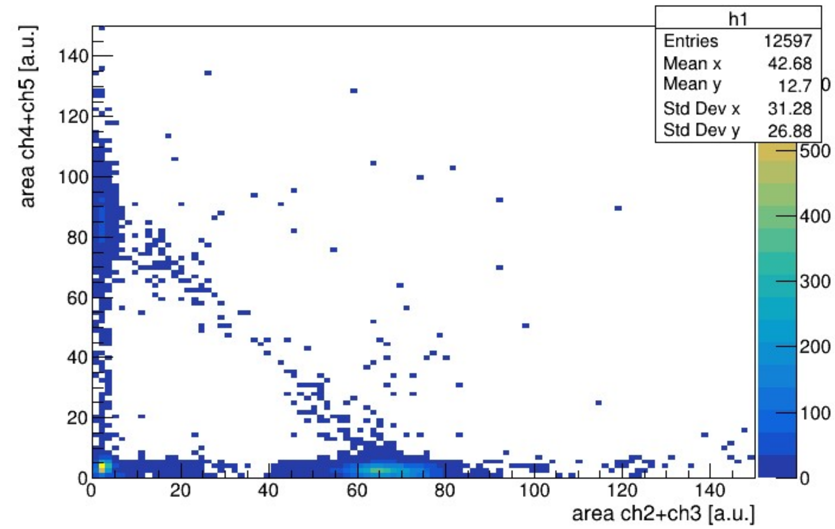
Scintillating Channel: Optical Crosstalk

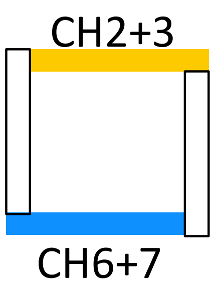
Measured correlations between the scintillator tiles

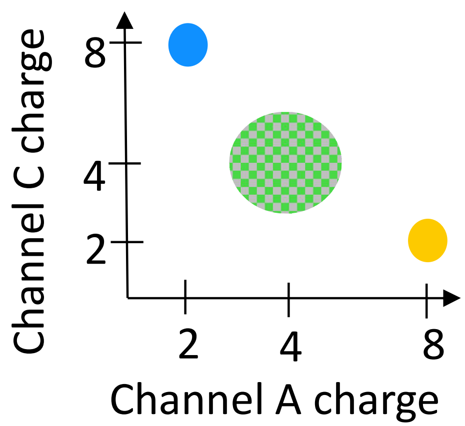
Trigger: Hit in gate and in one of the sides of the scintillating channel

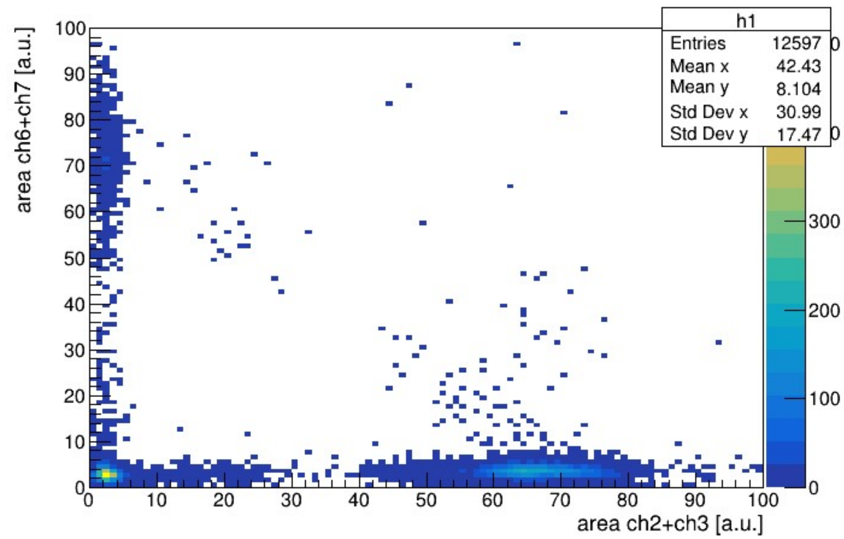










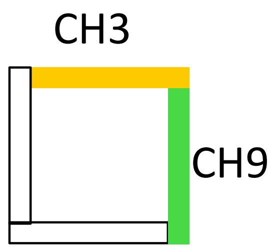


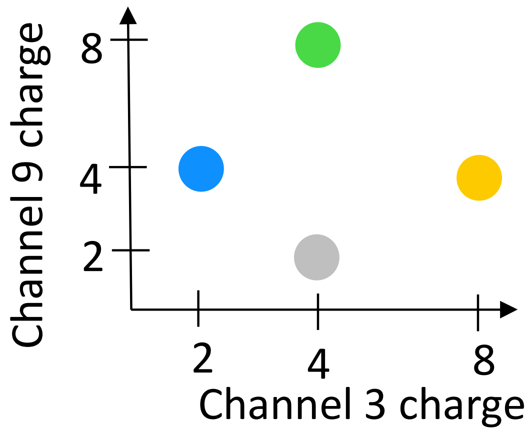
→ **Almost no crosstalk observable!**

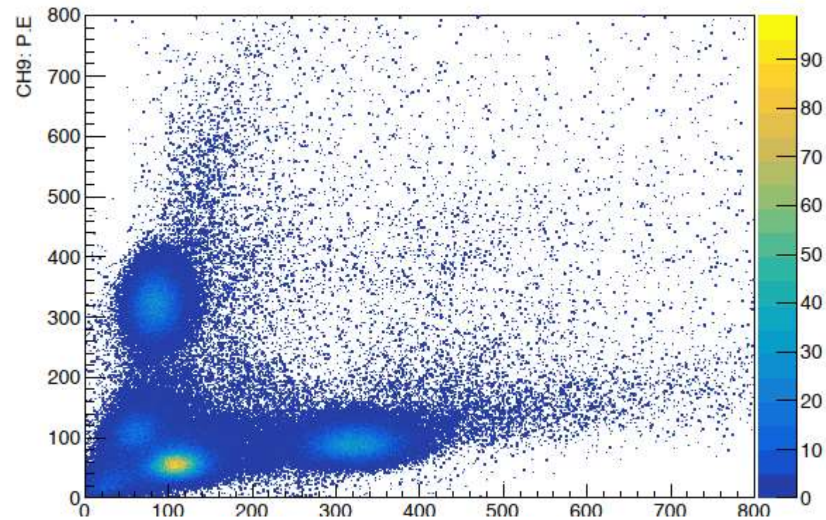
Scintillating Channel: Optical Crosstalk

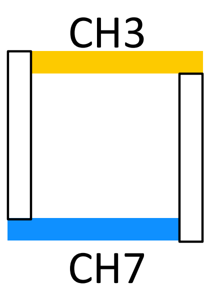
In **Shanghai prototype**, we find the expected correlation patterns!

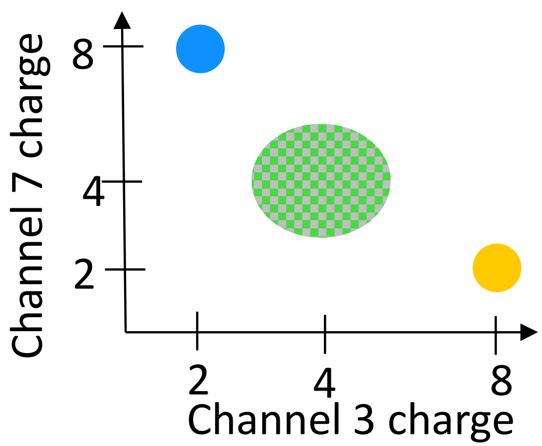
Source: Tianqi Hu

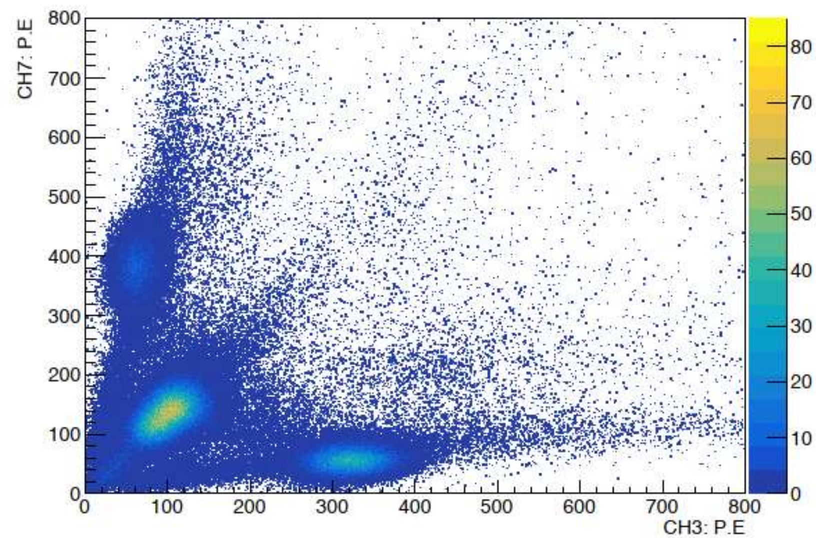












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Scintillating Channel: Optical Crosstalk

After Inspection of tiles: Residual glue from glueing SiPMs to scintillators→ Air gaps between scintillating tiles!

Air gaps in the Pisa telescope prevent optical crosstalk.
In Shanghai telescope: Expected optical crosstalk patterns found!

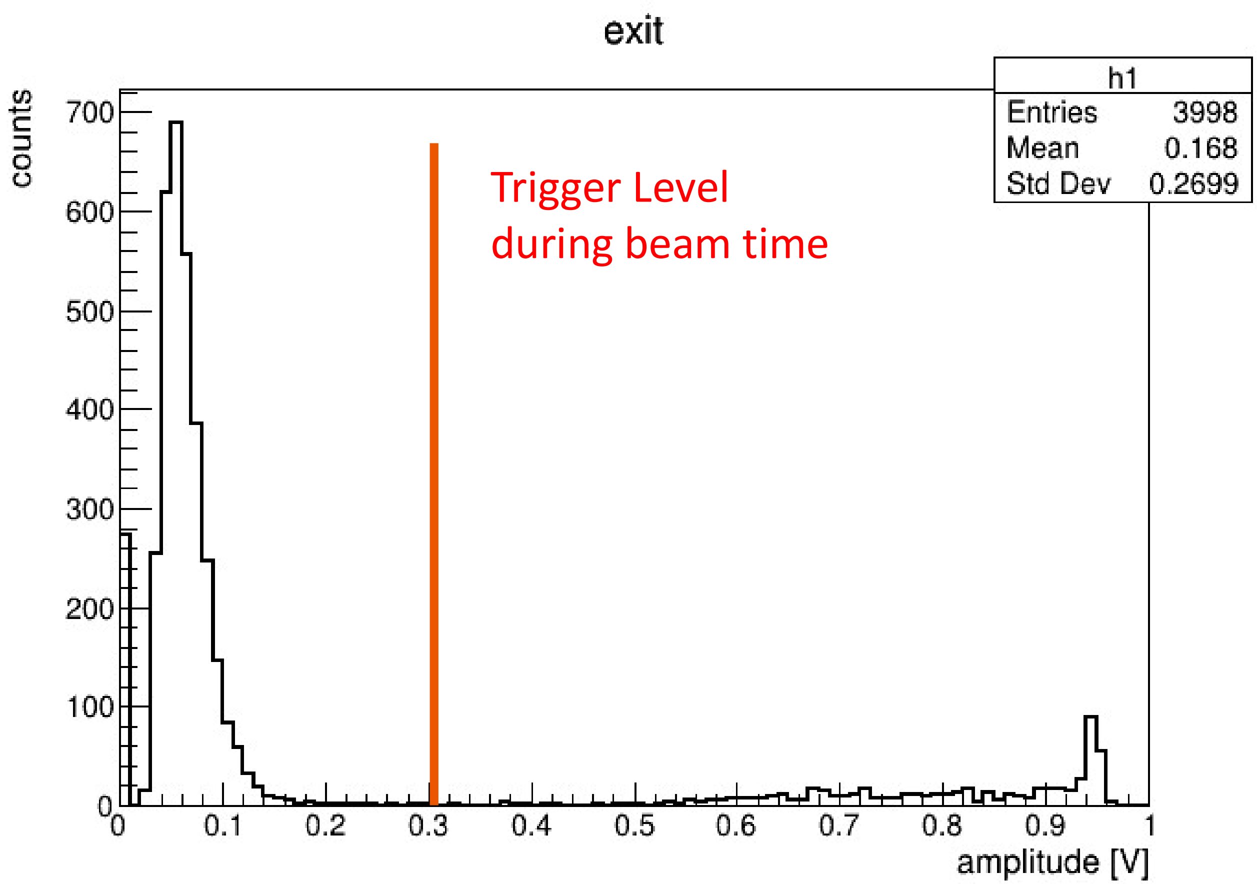
To avoid optical cross talk:
→ Separate tiles by air
→ Deposit few hundred nm of aluminium on side where they touch

Exit Scintillator

Trigger on Entrance detector. Two different populations visible:

Peak Below Trigger Level: Positrons + Thermal Noise (84.5 %)

Events Above Trigger Level: Muons (15.5 %)



Many muon events above WaveDream range (1 V) due to too high gain.