Development of fTOF detector with SiPM sensors for HIEPA experiment – simulations

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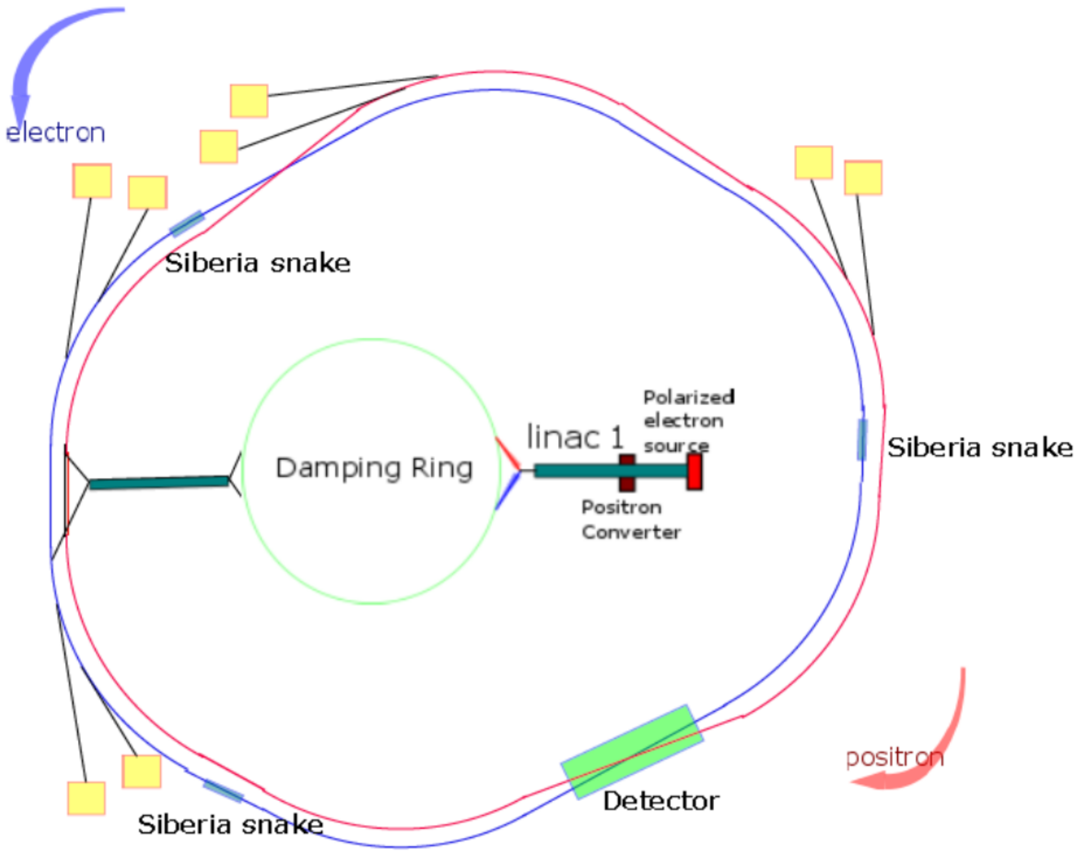
Outline

- HIEPA experiment
- fTOF PID approach
- fTOF sector simulation: SuperB approach and implementation for HIEPA
- Time properties research
- Realistic light amount simulations (different SiPM types)
- K/pi separation with detector resolution
- Endcap ring and multilayer approach
- LAL quartz prototype test

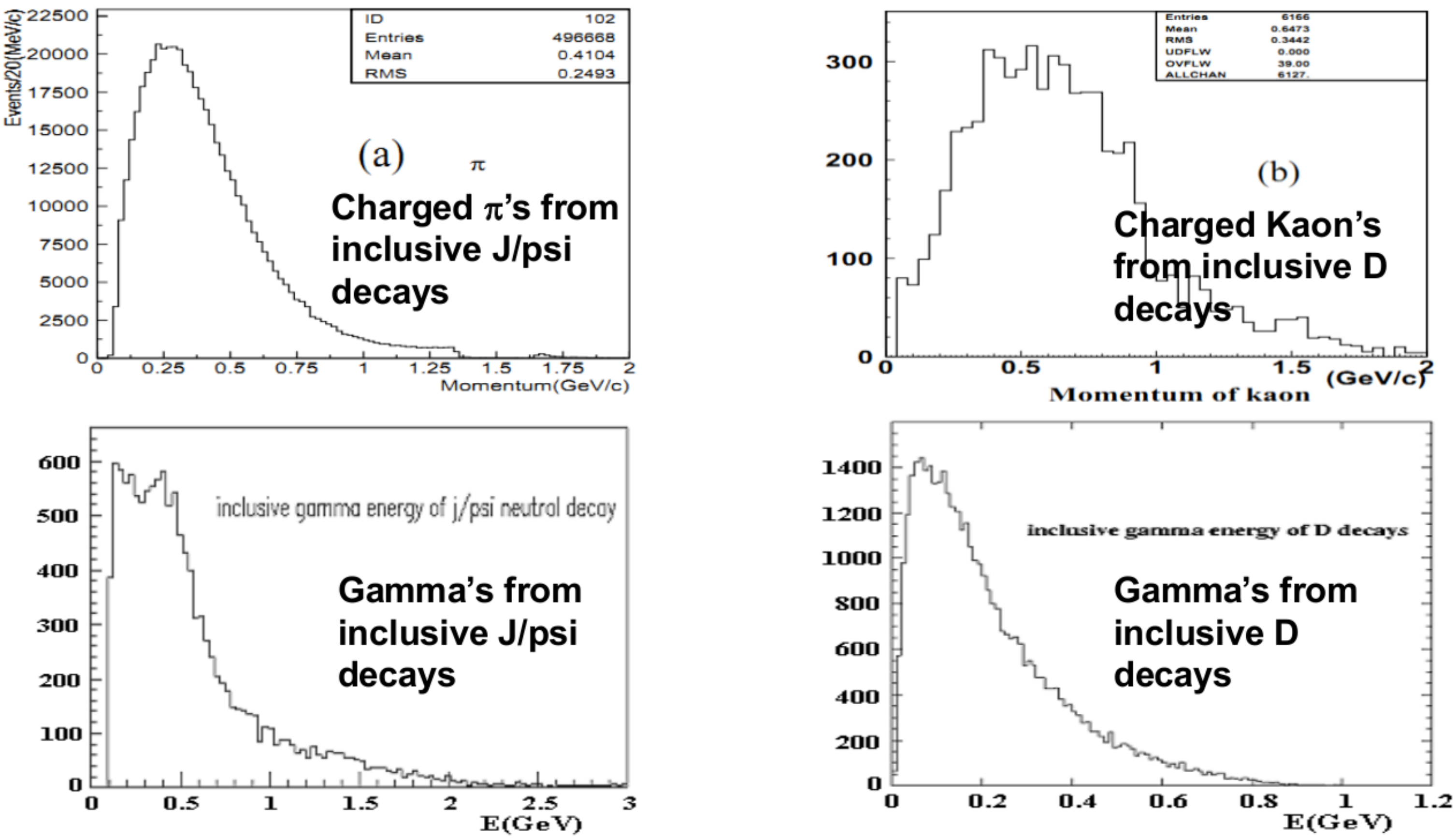
High **I**ntensity **E**lectron **P**ositron **A**ccelerator

- Extension of BEPCII and a viable option for a post-BEPCII HEP project in China.



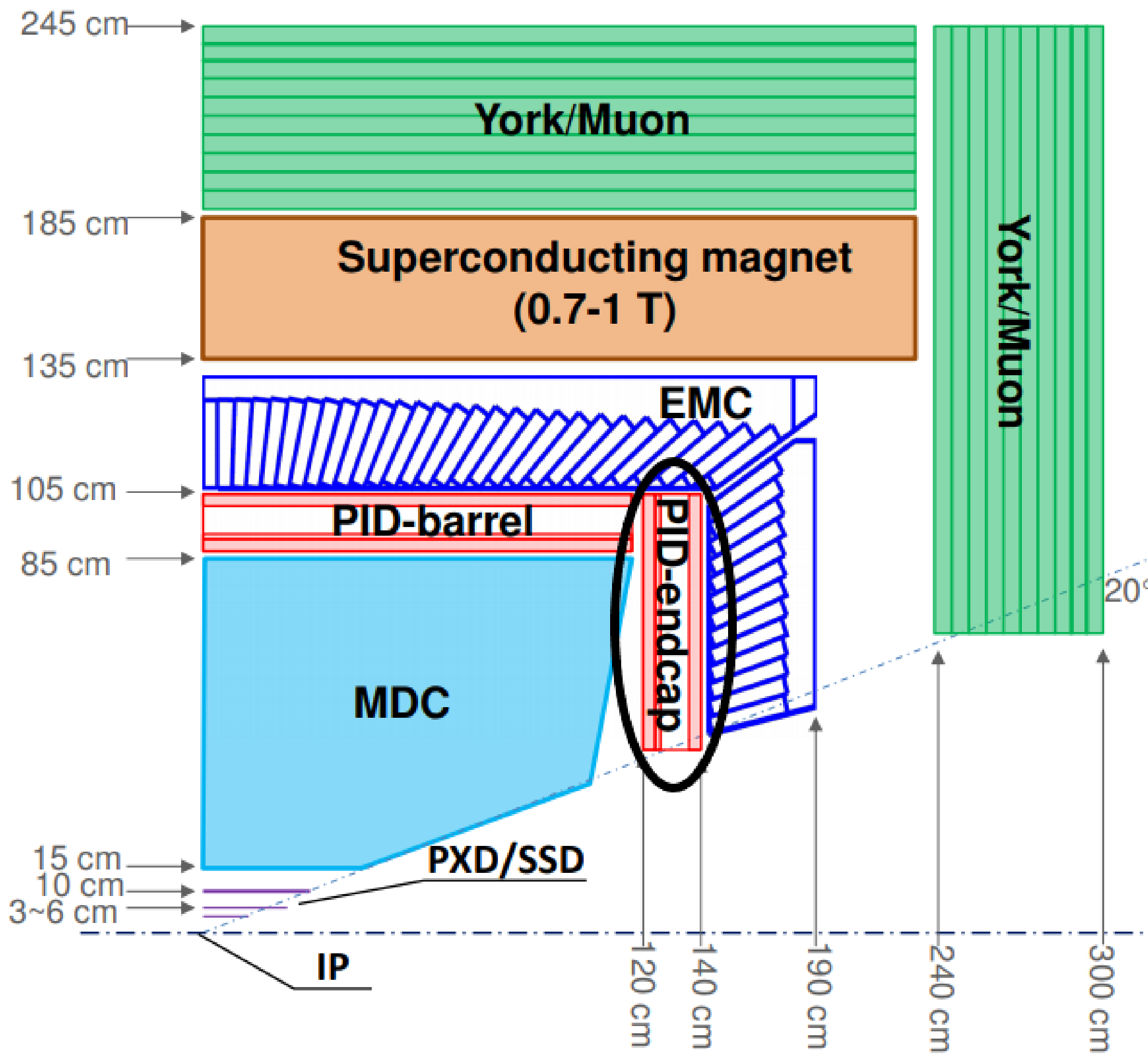
- E_{cm} = 2-7 GeV
  $L=1*10^{35}\ cm^{-2}s^{-1}$ at 4 GeV
- Symmetrical collision
- Double-ring, 600-1000m
- Crab waist scheme
- Single beam polarized

Low momentum mesurements



- Final-state particles are largely of low momentum/energy (< 1GeV/c)
- Designs of the HIEPA detector have to match this important feature of final states.

HIEPA endcap PID



PXD
- Material budget ~0.15%X_0 / layer
- σ_{xy}=50 μm

MDC
- σ_{xy}=130 μm
- σ_p/p =0.5% at 1 GeV
- dE/dx<7%

PID
- π/K (and K/p) 3-4σ separation up to 2GeV/c

EMC

Energy range: 0.02-2GeV

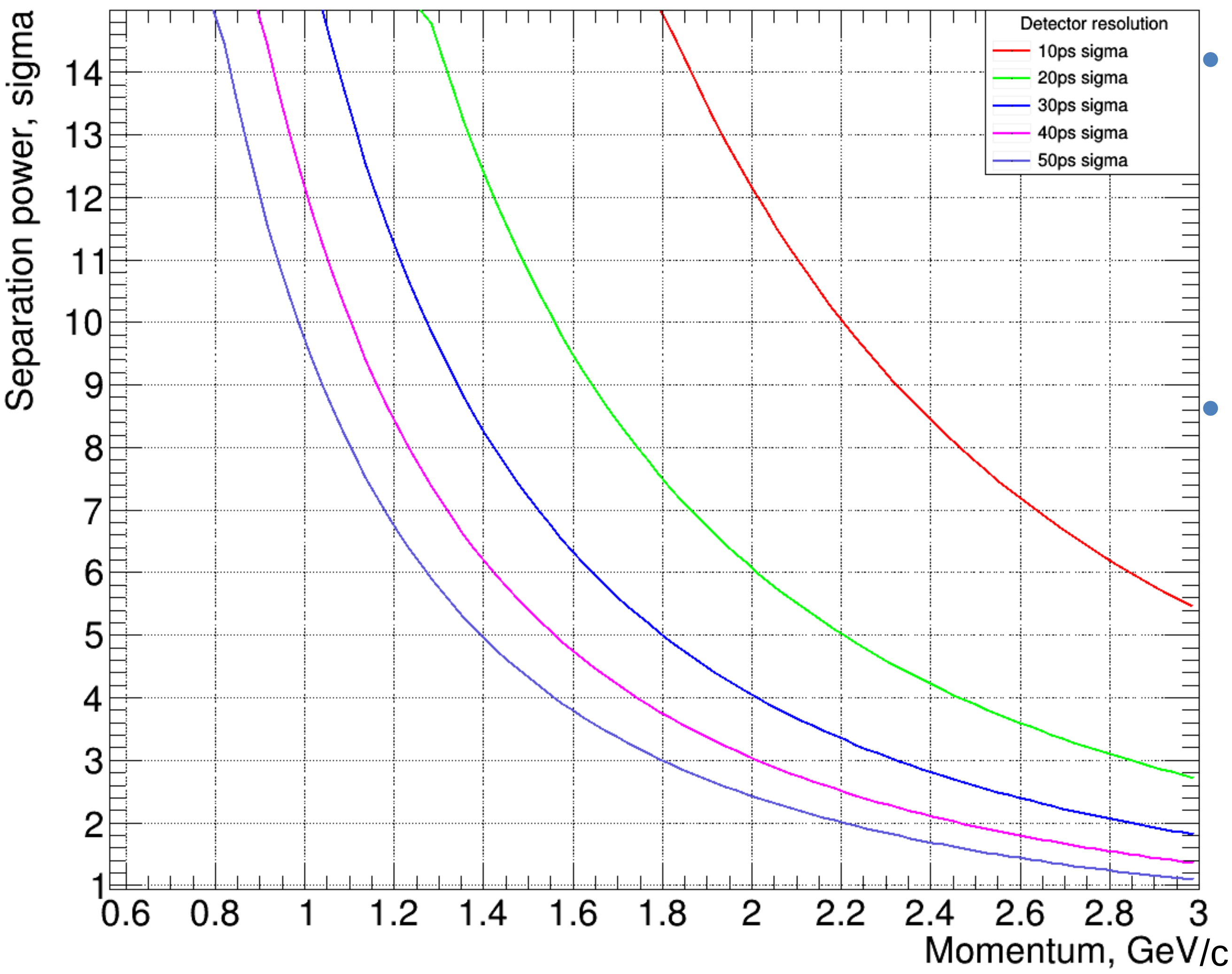
At 1 GeV	σ_E (%)
Barrel(Cs(I)):	2
Endcap (Cs):	4

MUD
- μ/π suppression power >10

Endcap ring:

Inner radius :	47	cm
Outer radius:	105	cm
Max thickness:	20	cm

K/pi separation



- Time of flight for distance L, momentum p and mass m:

$$t = \frac{L}{c}\sqrt{1 + \left(\frac{mc}{p}\right)^2}$$

- The difference in time of flight (K /π):

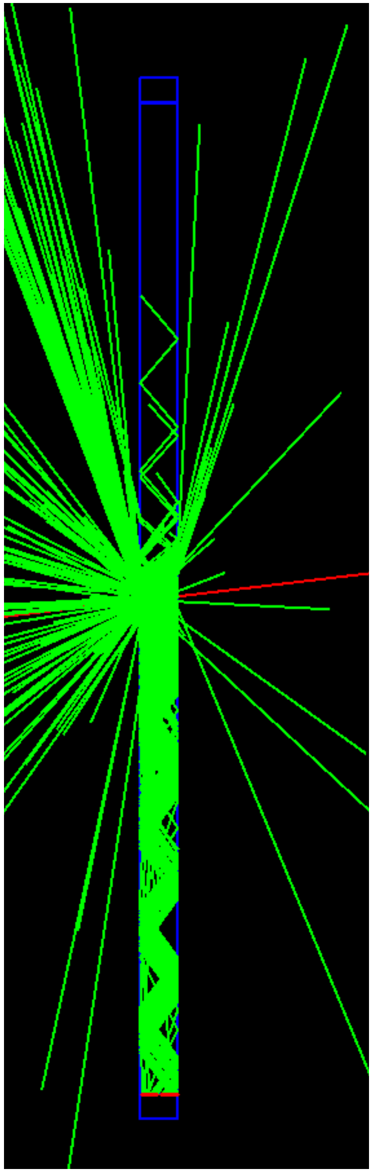
$$\Delta t = \frac{Lc}{2p^2}\left({m_K}^2 - {m_\pi}^2\right)$$

$$separation\ power = \frac{|\Delta t|}{\sigma}$$

Due to this calculations, we need ~**30ps** detector resolution for **4σ** K/pi separation at p = **2 GeV/c** and L = 130 cm path length

DIRC-like TOF approach

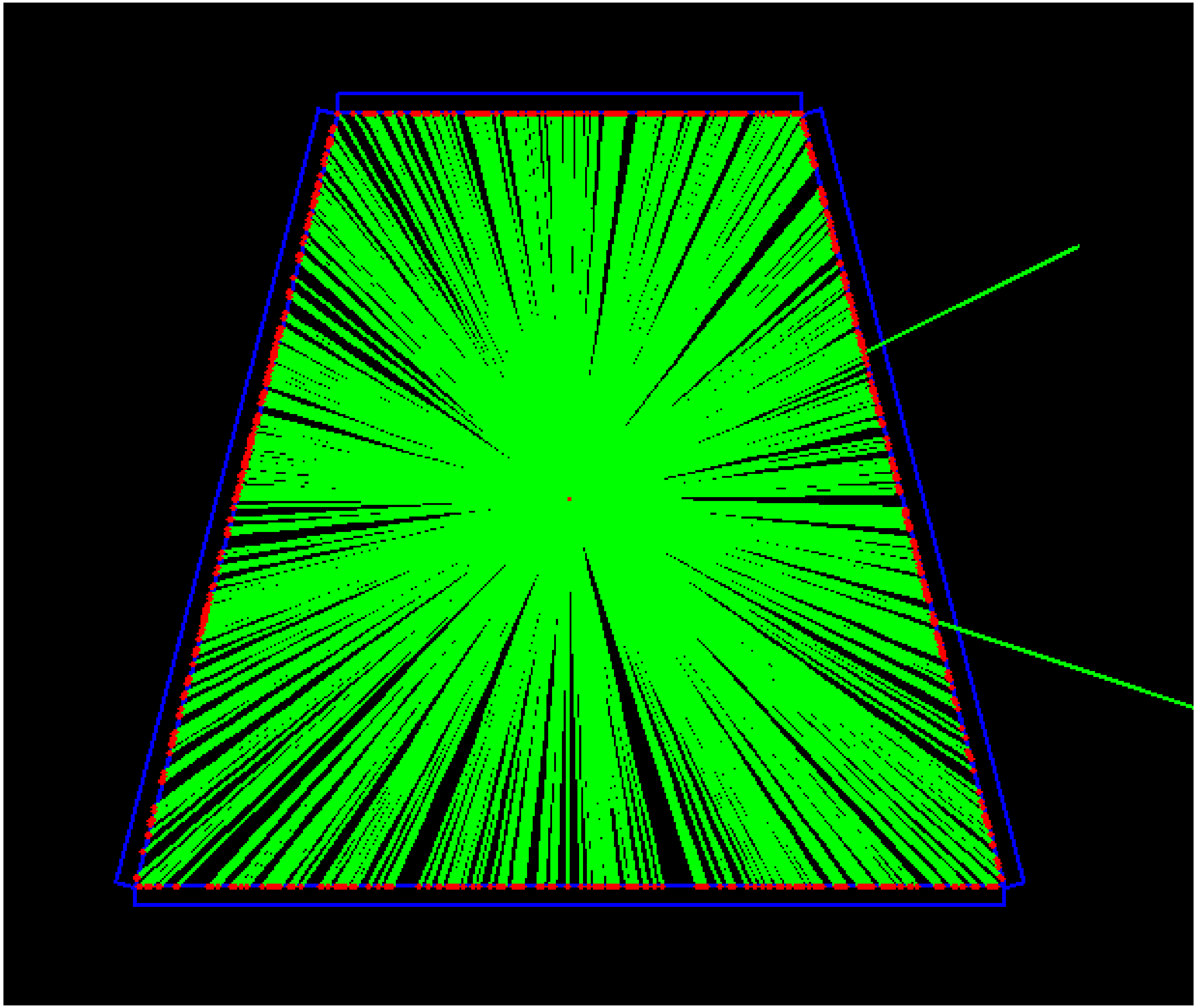
Quartz bar at the same time both the Cherenkov radiator and light guide (from the impact point to the photodetector on the outer edge)



Time-of-flight detector of internal reflected Cherenkov light (DIRC-like) has following advantages:

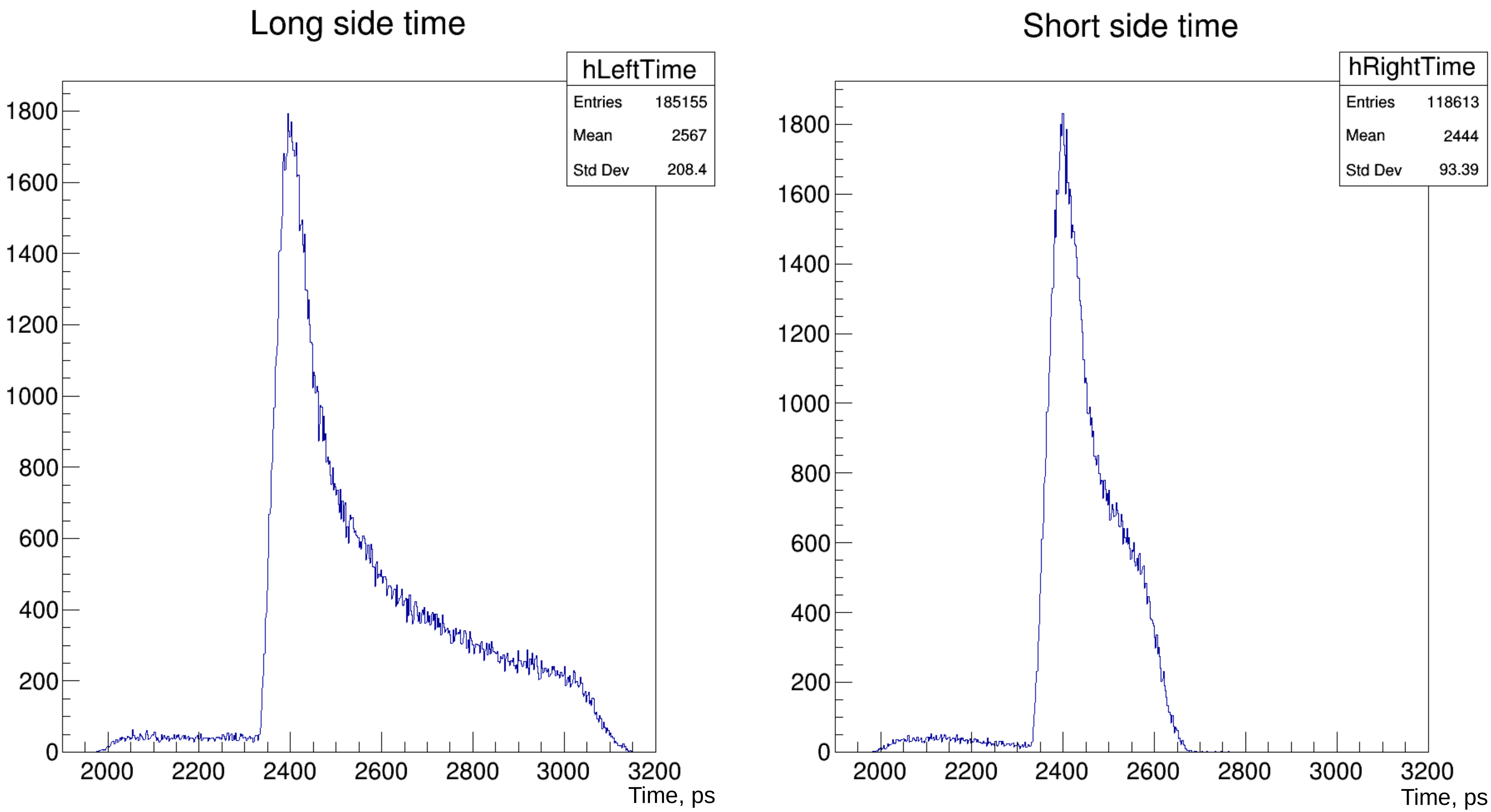
- Small size
- Minimized amount of PMTs and electronics channels
- Low $\int \frac{dE}{dx} dx$

fTOF big trapeze sector



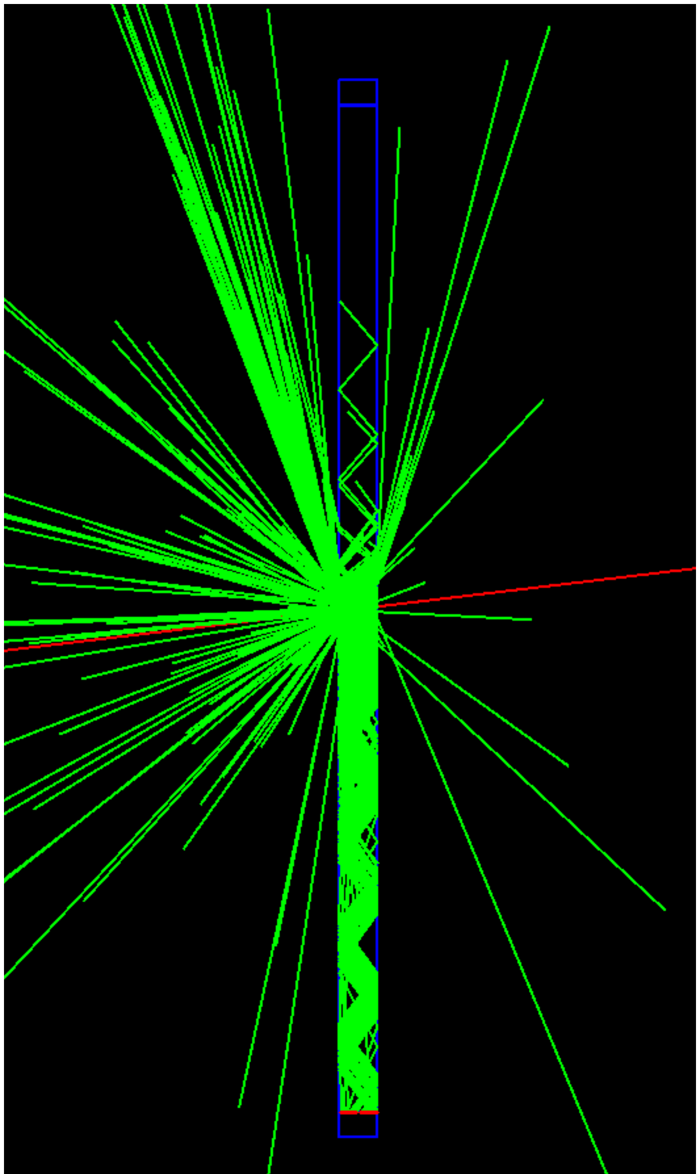
Short side: 24 cm
Long side: 45 cm
Height: 40 cm
Thickness: 1.5 cm

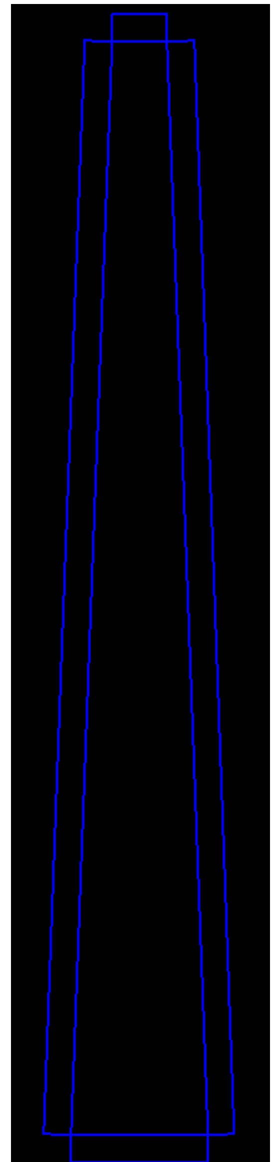
Time distributions, 1000 muons



Wide time distribution is dependent on the side length
If side length is much bigger then thickness, shape of distribution: $n \sim 1/t$

Small trapeze

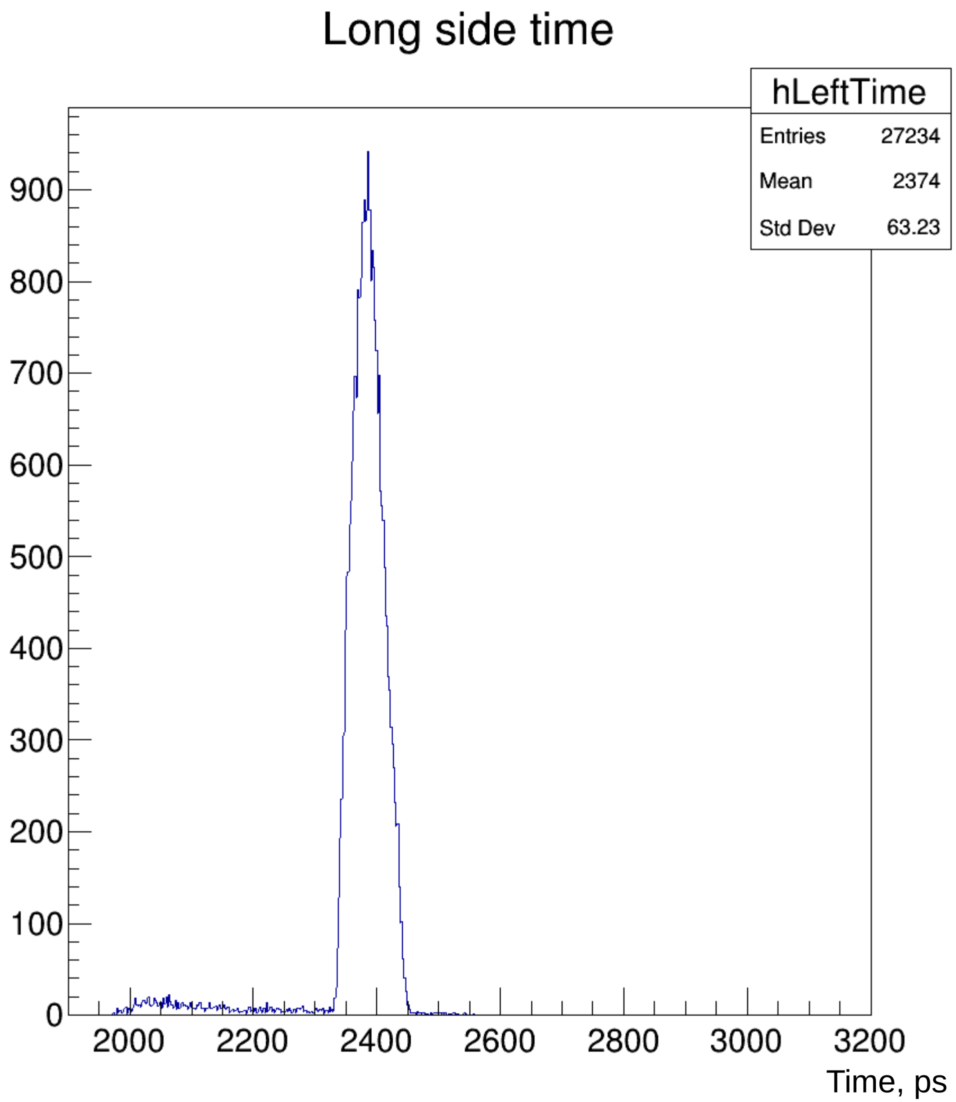


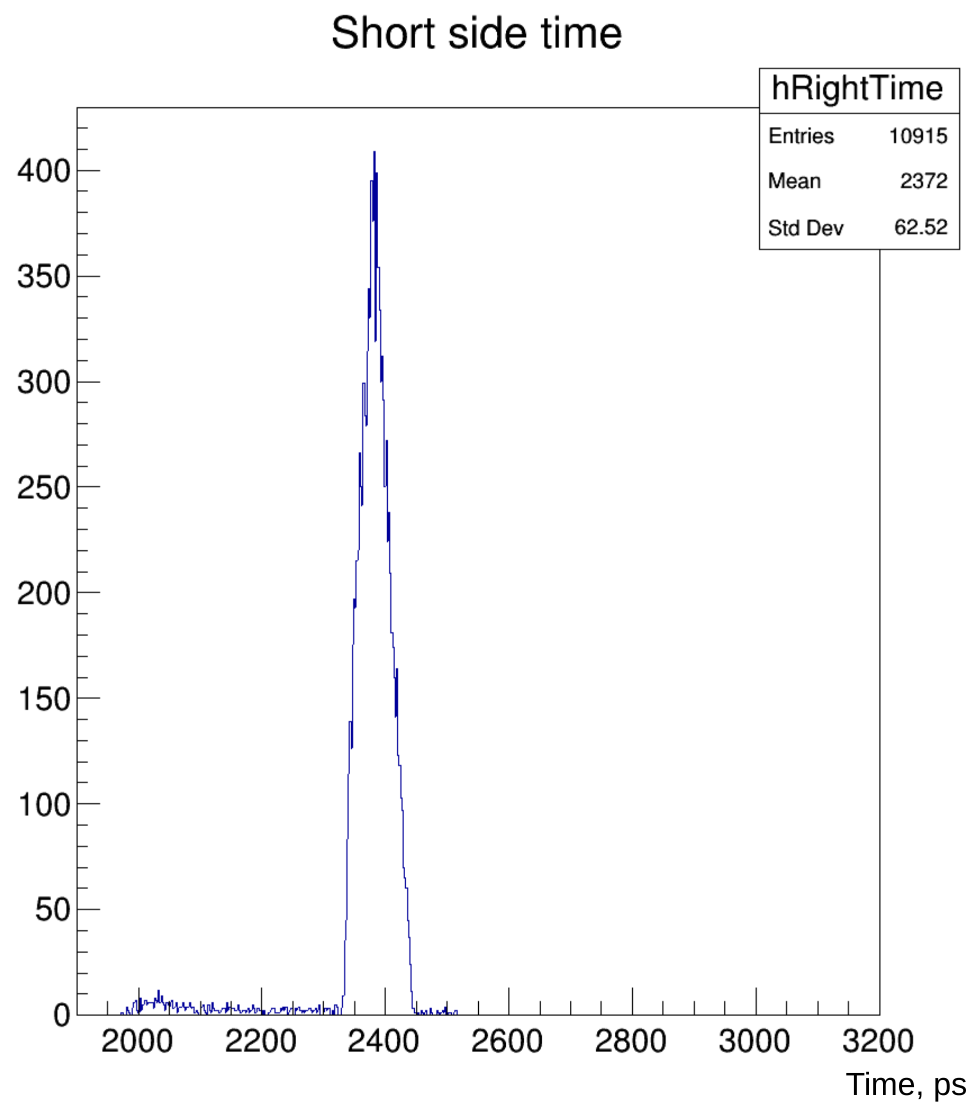


Simulation of the muon hitting detector at the angle of 25° (to the detector from the interaction point)

Short side: 2 cm
Long side: 5 cm
Height: 20 cm
Thickness: 1.5 cm

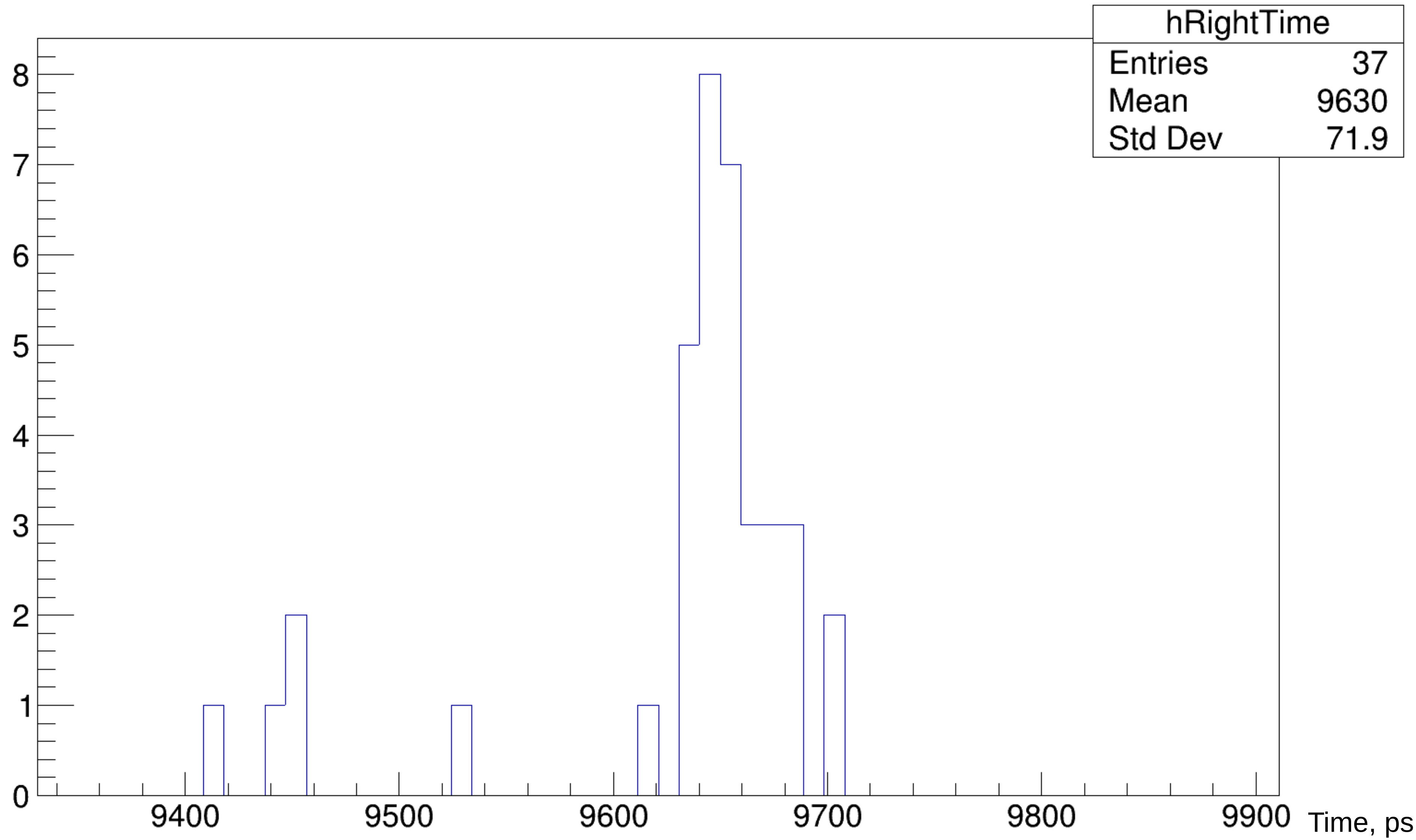
Time distribution, 1000 muons



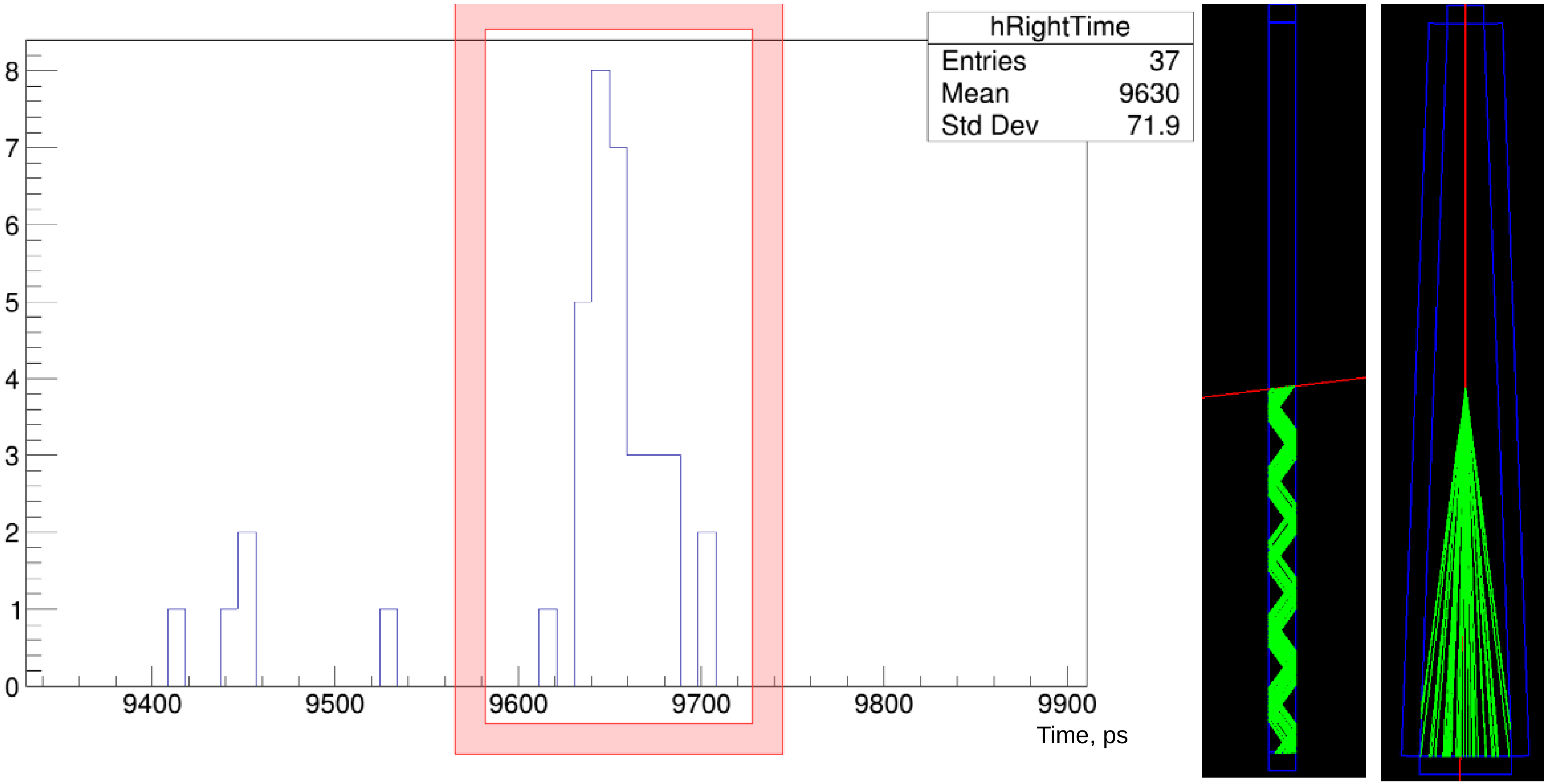


So as predicted, we have much narrower distributions because of less side length

Time distribution of the photons from a single muon on the longer side (outer radius)

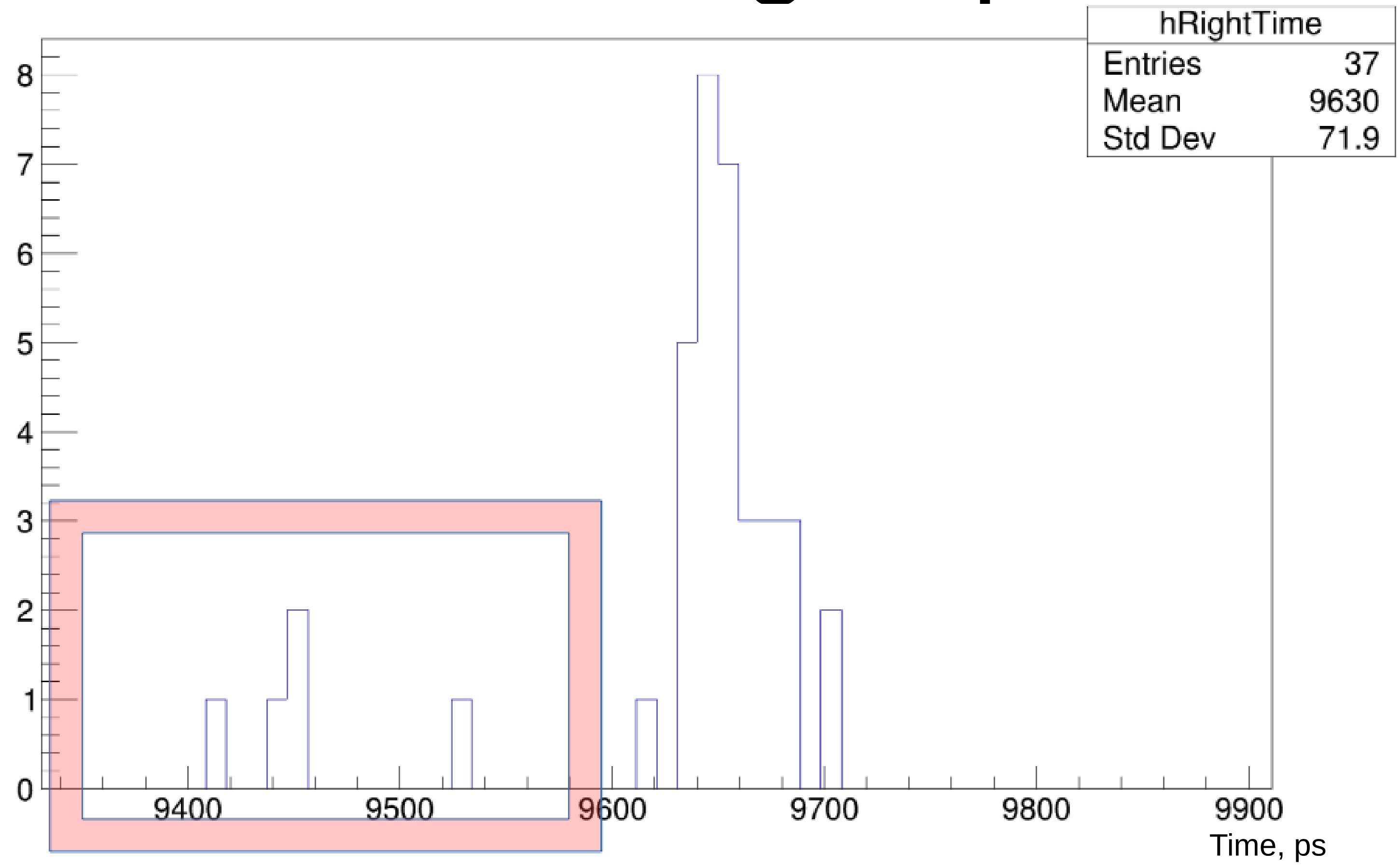


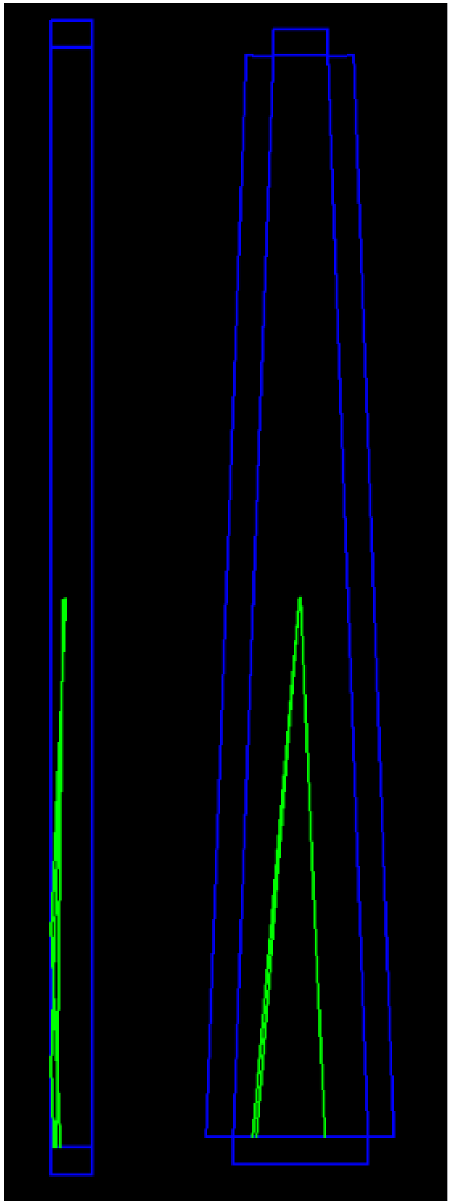
Main peak



The main peak describes the time distribution of photons from the Cherenkov radiation of muon

"Straight" photons



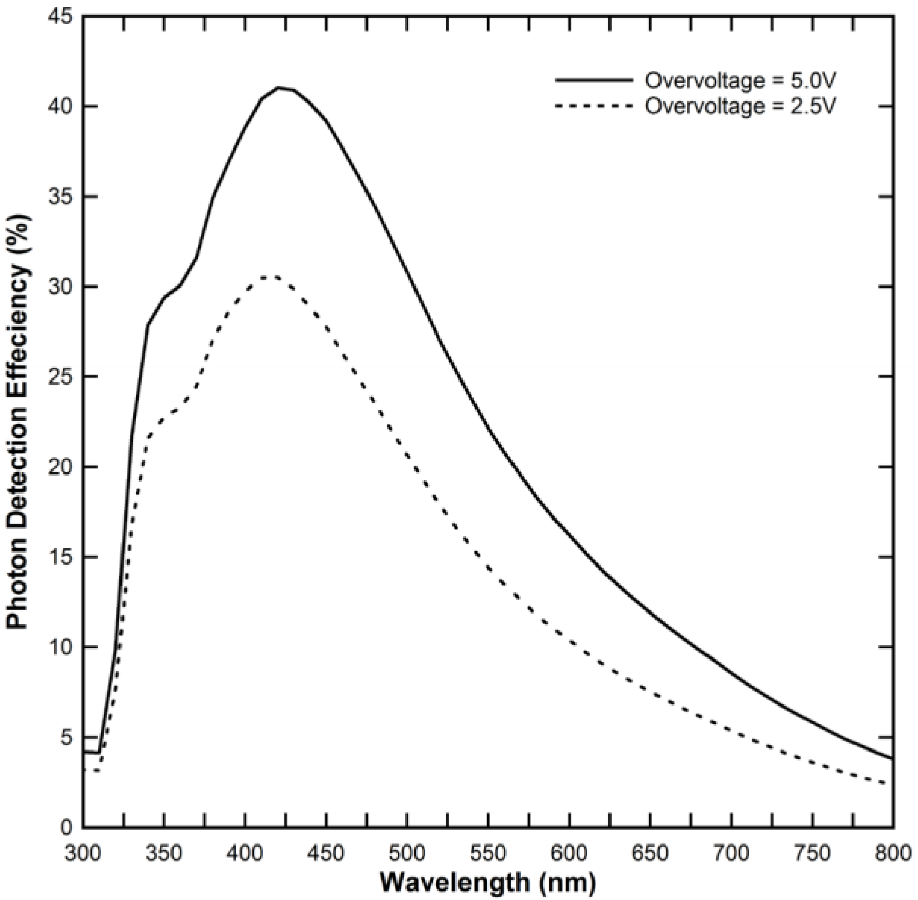


As we can see, there're photons which are emitted at the angle which allows them to move straight to the detector with very few reflections (~1 vs ~8-10)

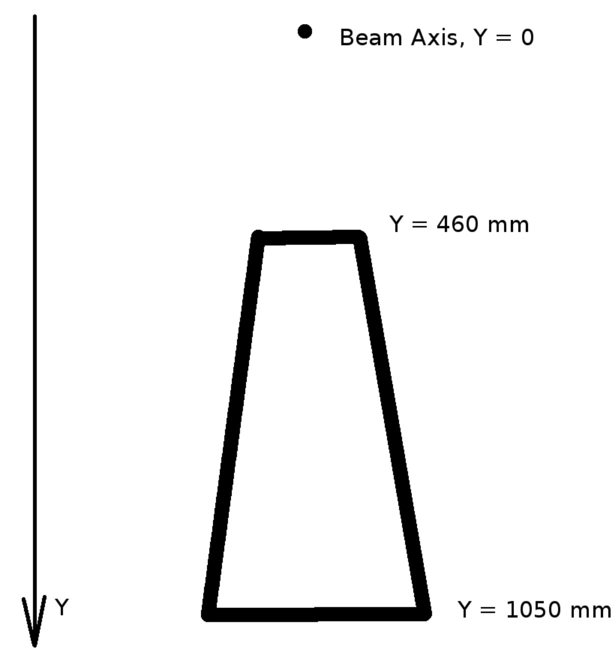
But how does it happen?

Light amount detected by SiPM

Regular SiPM with 42% peak PDE (5V overvoltage)
(Photon detection efficiency)

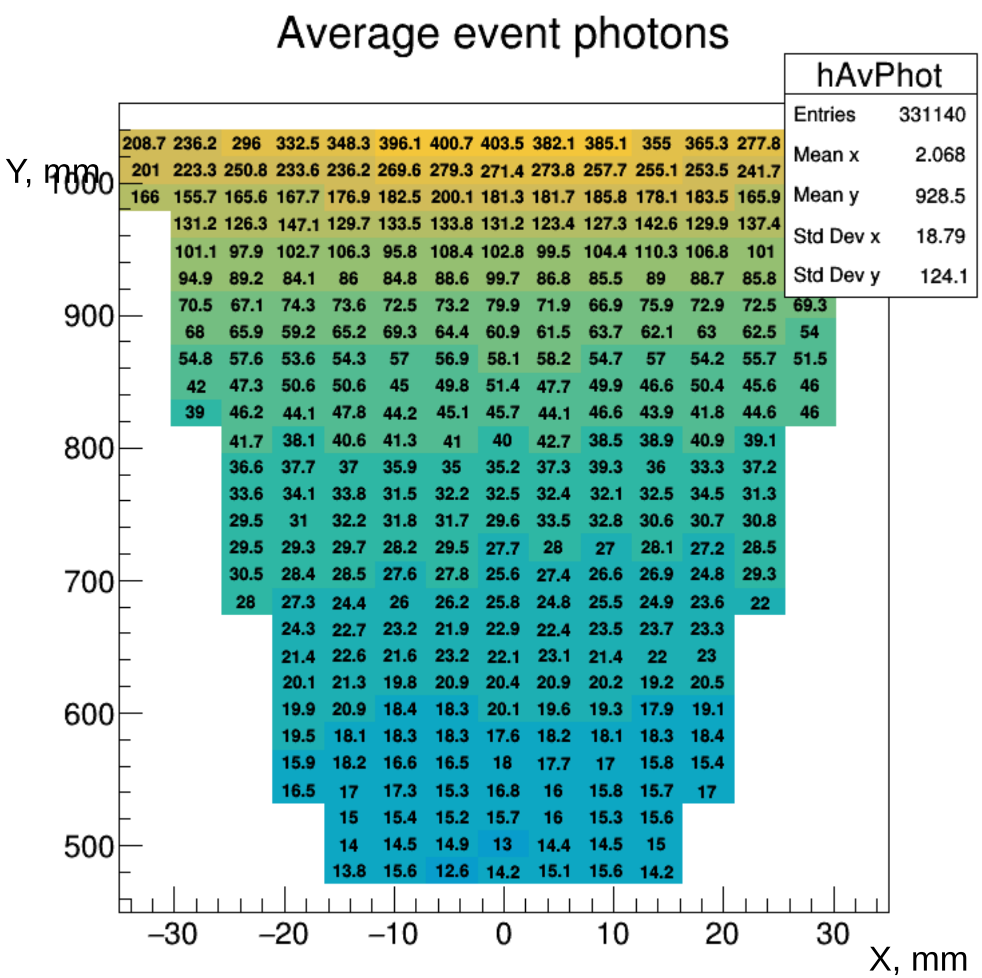


Simulation geometry.
Particles are isotropically distributed from interaction point and the single sector of the fTOF endcap is tested.

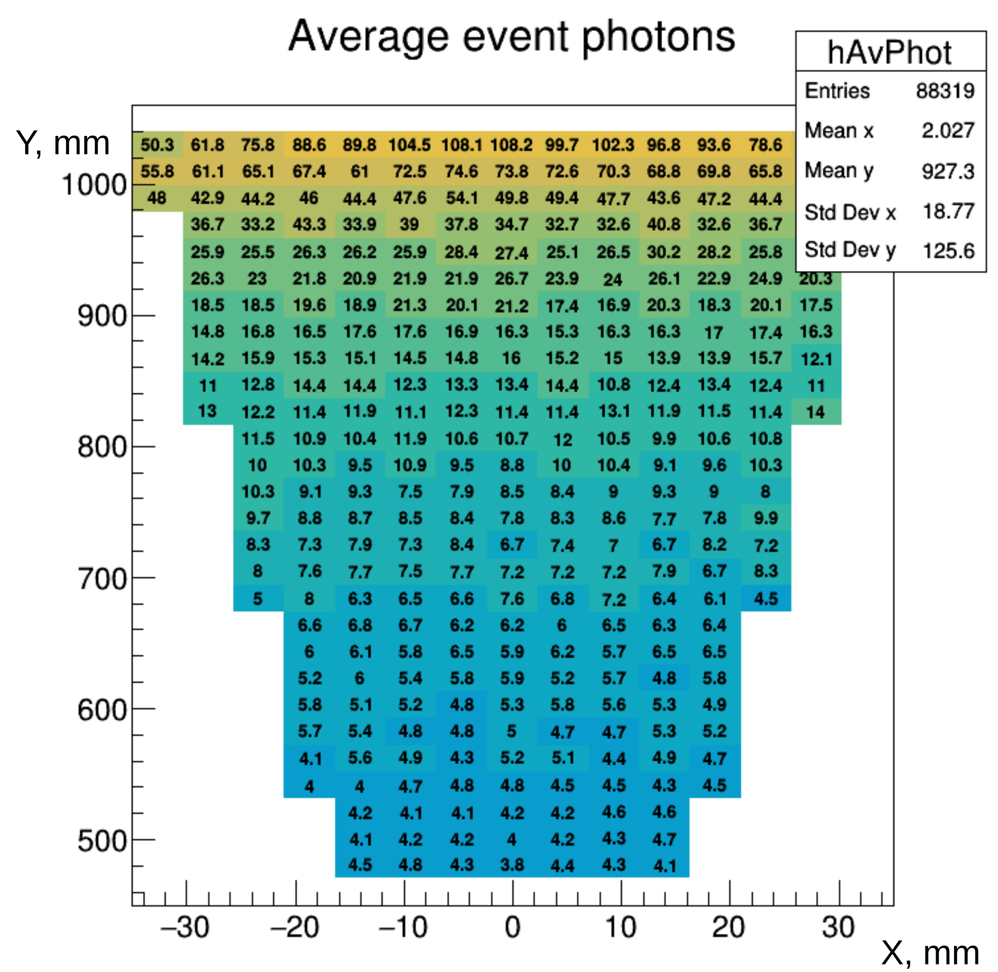


2 GeV/c Kaons isotropicaly distributed from primary vertex (no magnetic field)

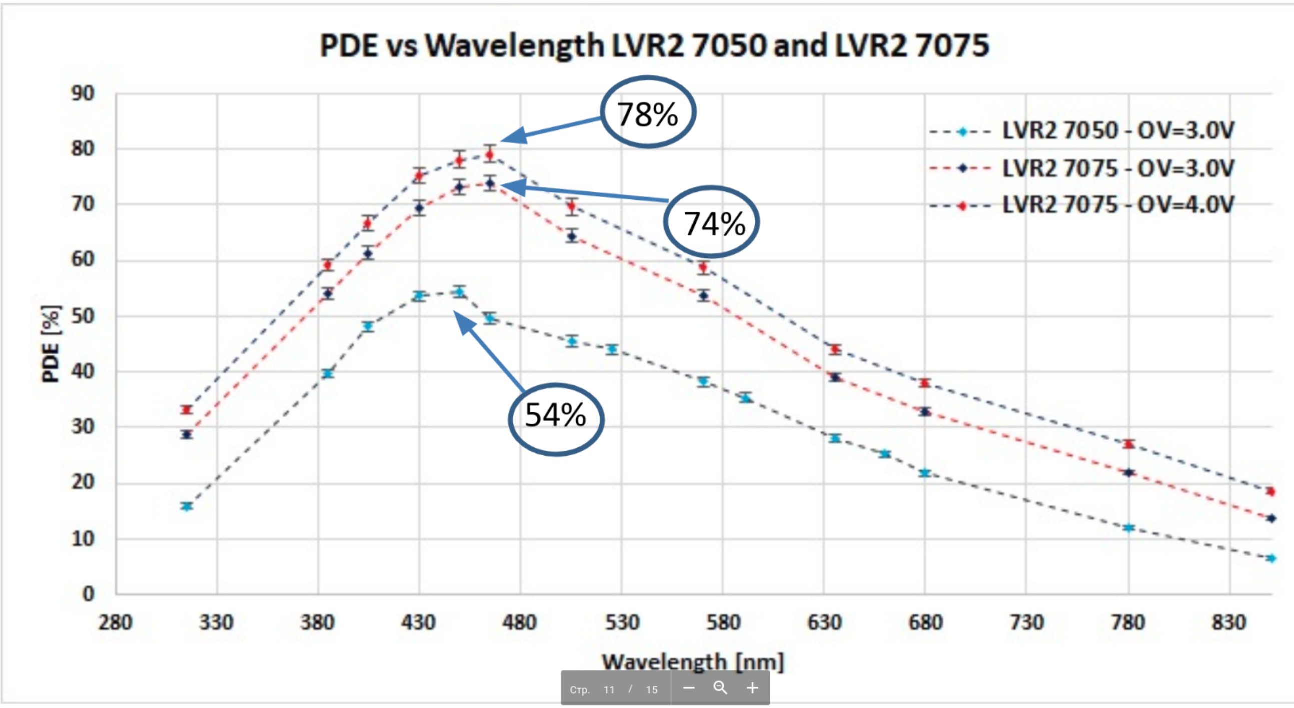
Number of photons arrived to detector vs kaon entering position



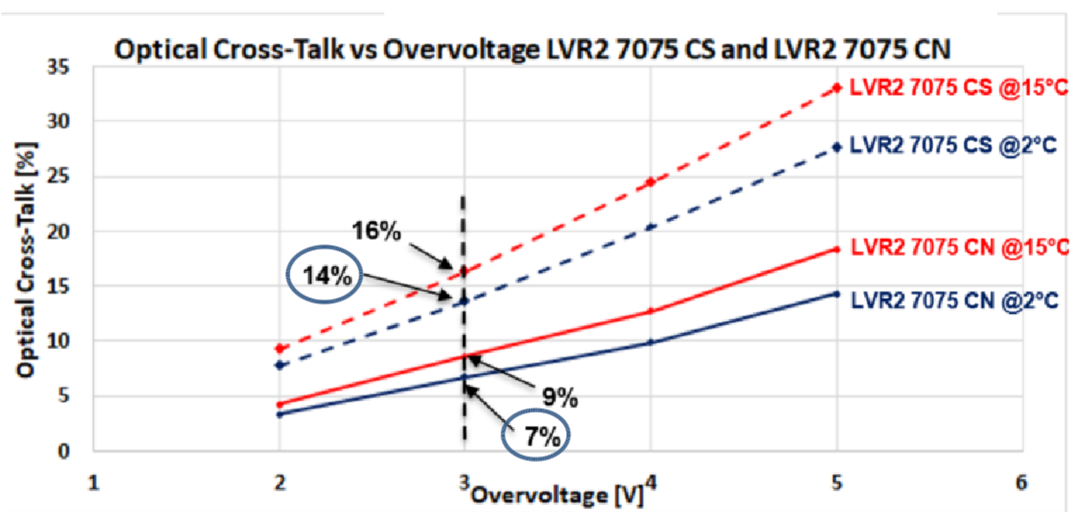
Number of “photoelectrons” in photodetector (including PDE) (without surface filling factor)



SiPM with 78% peak PDE (LVR2 7075 with 4V overvoltage)



Wavelength, nm	PDE, %
301.912	28.8171
313.672	33.3843
325.042	36.9531
350.522	46.5159
375.218	55.9360
384.235	59.0762
400.700	65.0710
404.620	66.3556
414.420	70.2092
425.397	74.0631
429.318	75.2052
449.712	77.9204
463.832	78.9225
475.998	76.7862
499.940	70.6593
505.042	69.6622
525.448	66.1017
550.562	62.3998
569.007	58.8388
575.286	57.5568
600.798	51.4303
625.130	46.5871
635.334	44.0224
650.245	42.1721
675.360	38.4702
700.472	35.7667
729.115	32.7789
780.517	27.2297
849.970	18.8324

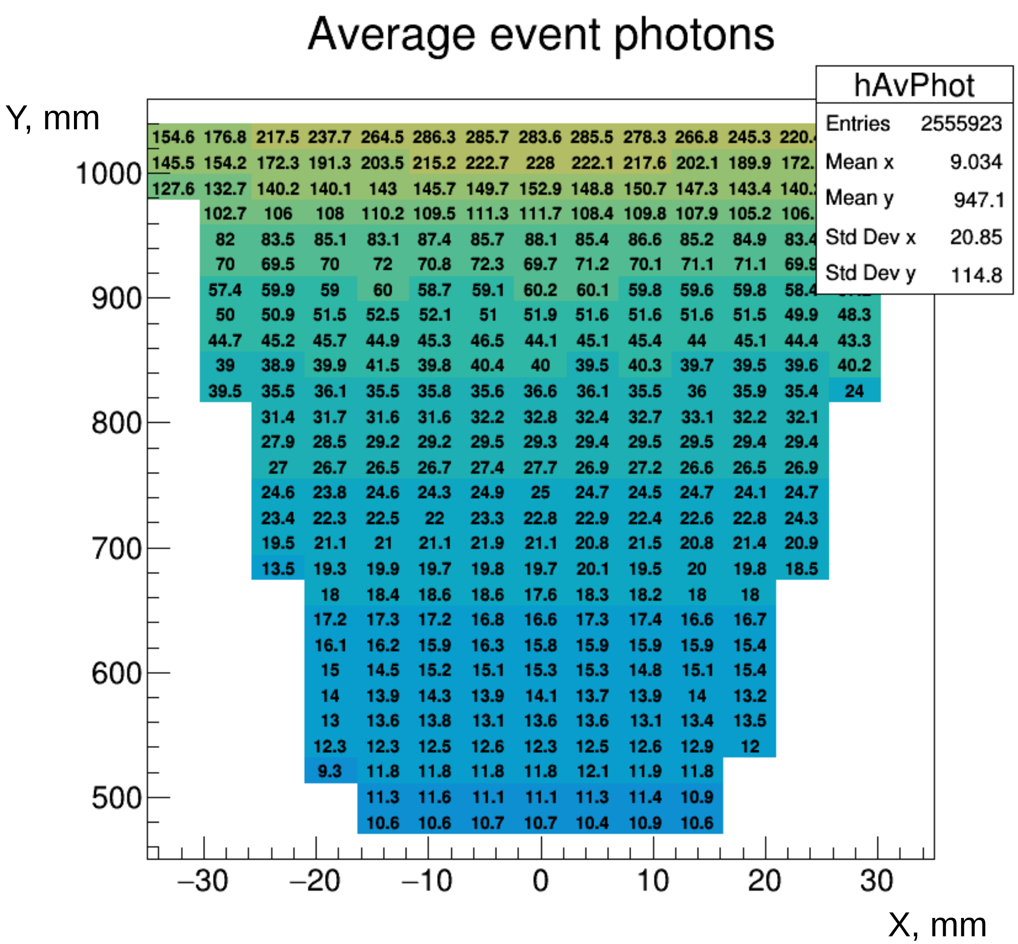


CS – with silicon coating
CN – without silicon coating

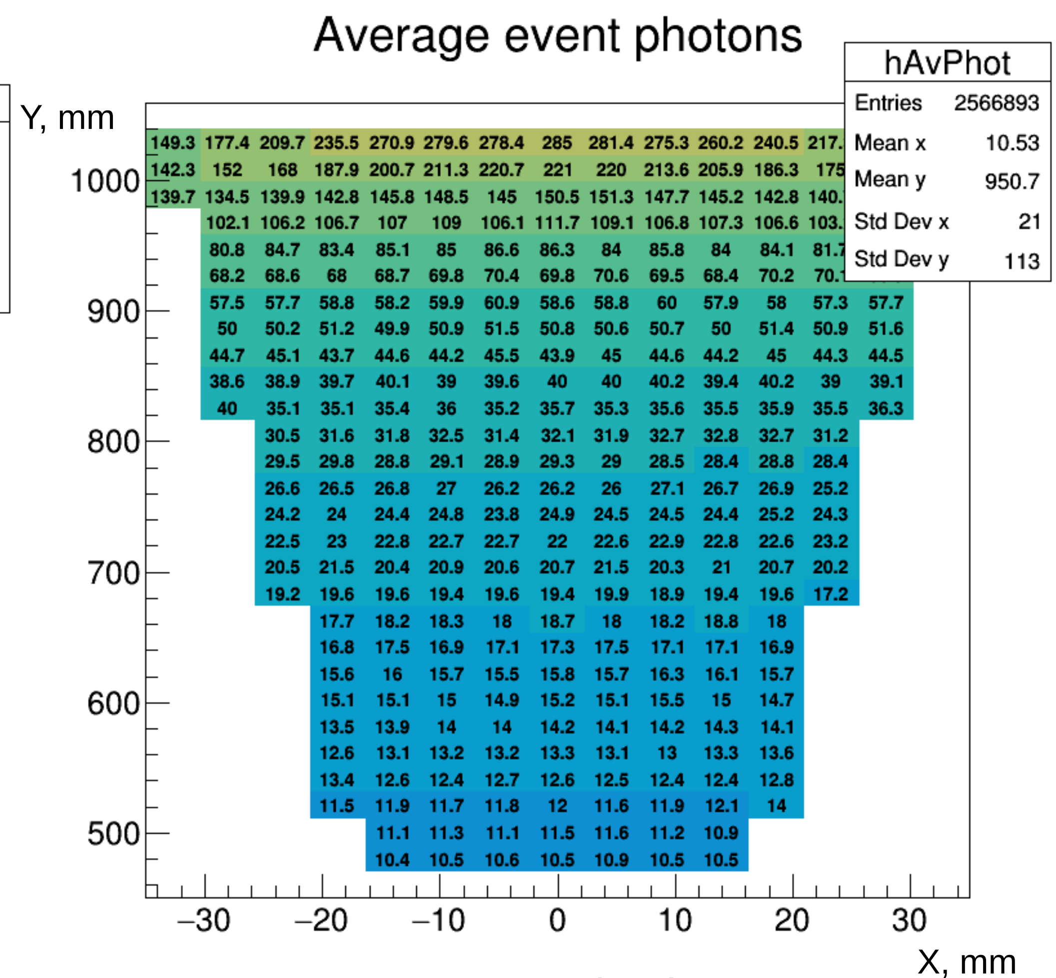
78% SiPM, low-energy K and pi (without magnetic field)

Number of “photoelectrons” in photodetector
(without surface filling factor)

Filling factor ~85%
(65*15 mm^2 side vs 18
7*7 mm^2 SiPM

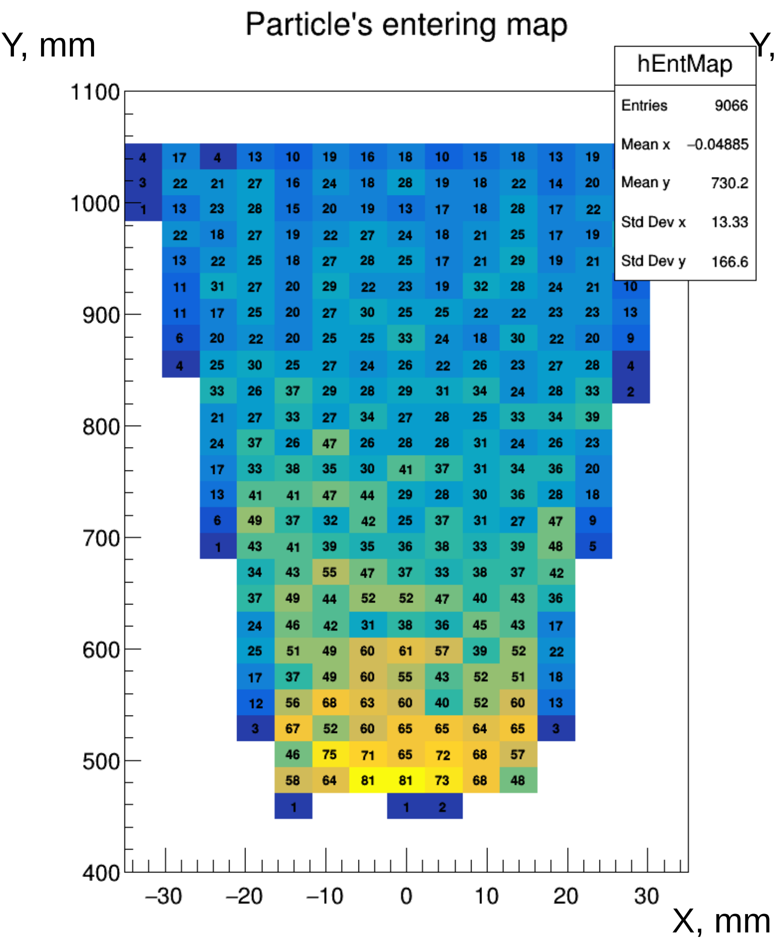


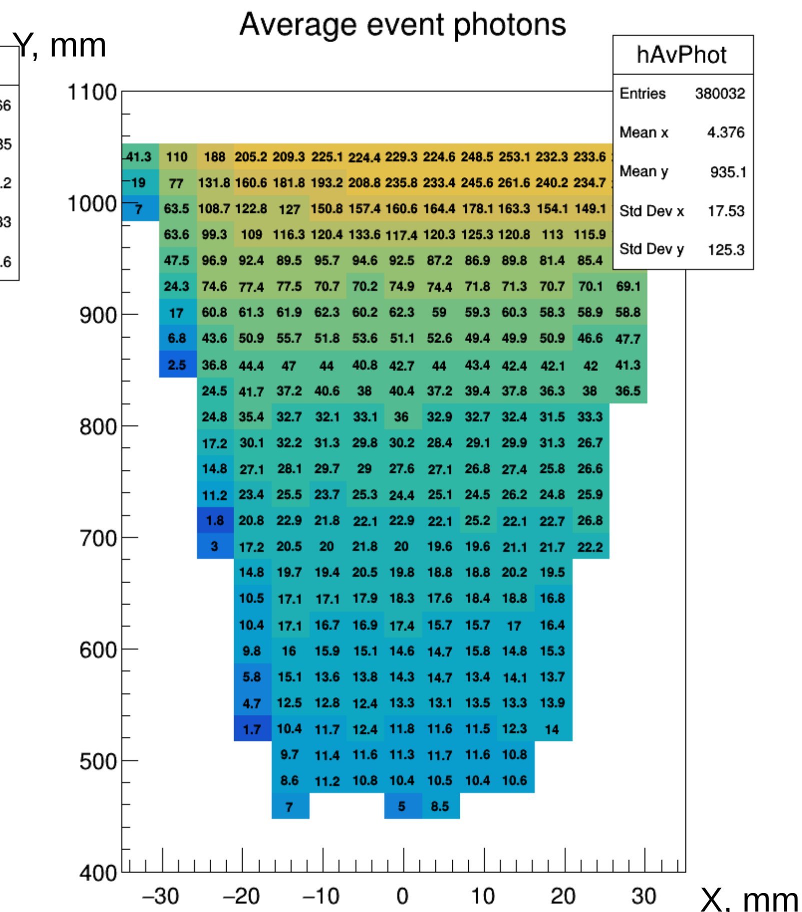
700 MeV/c Kaons
(~670 MeV/c threshold)



200 MeV/c pions
(~190 MeV/c threshold)

The same, but with 1Tl homogeneous magnetic field along the beam



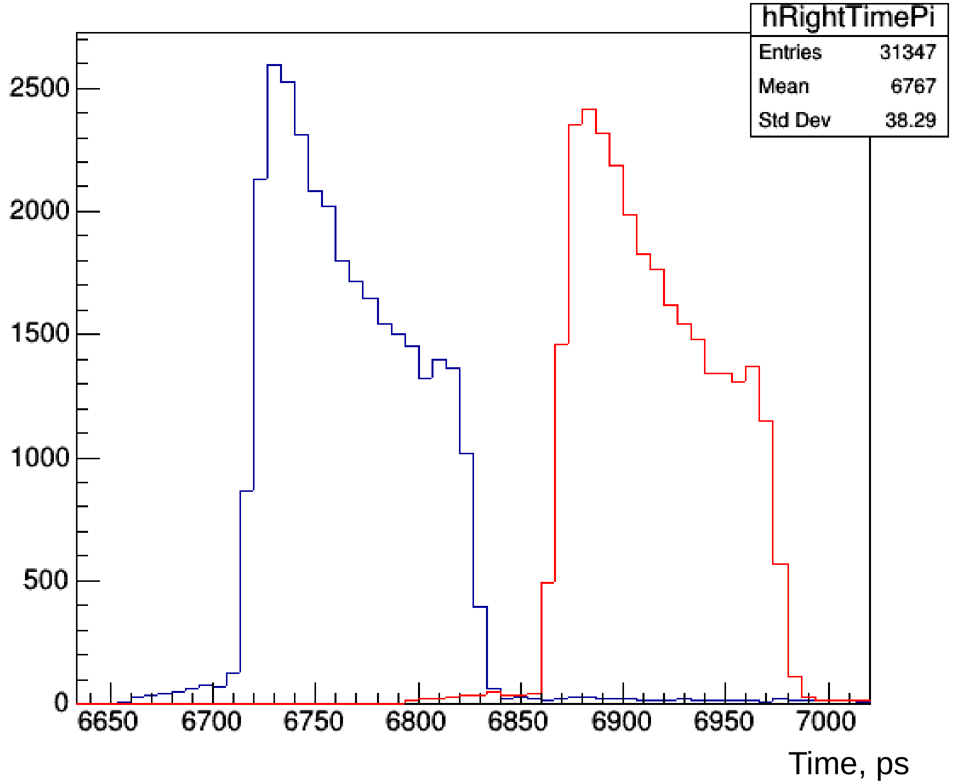


700 MeV/c Kaons
(~670 MeV/c threshold)

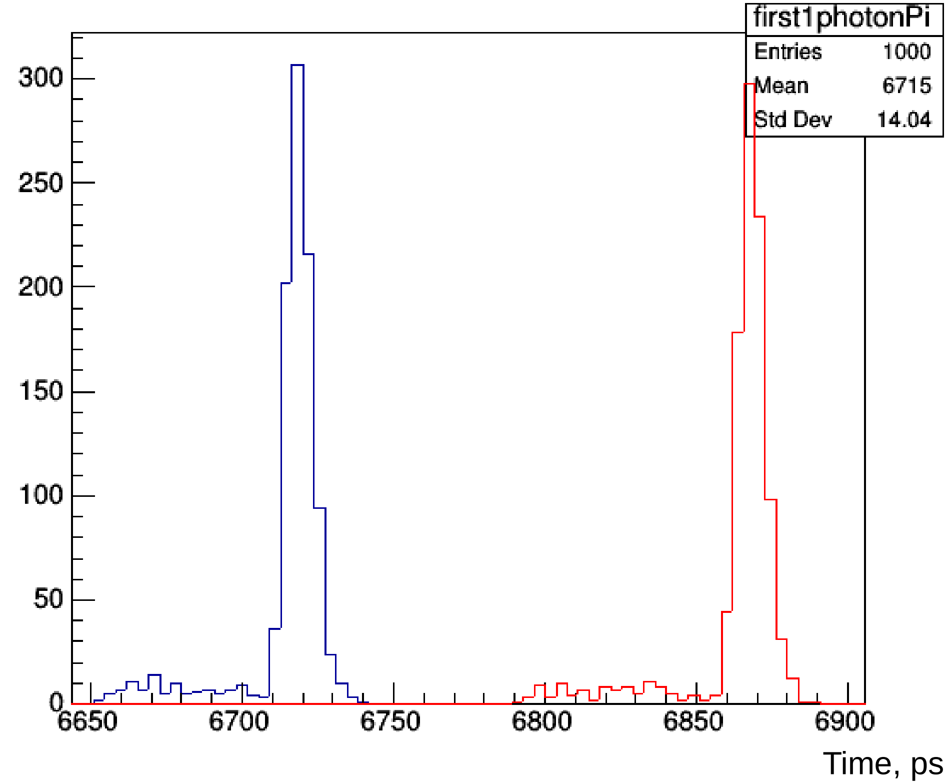
Number of particles entered the detector

Number of “photoelectrons” in photodetector (without surface filling factor ~84%)

Time distribution for 2 GeV/c Kaos (red) and pions (blue) with ideal photodetector (1000 event statistics)

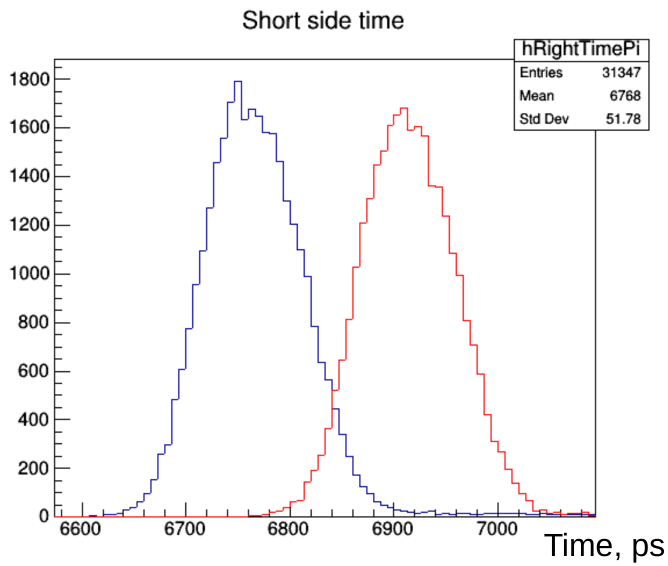


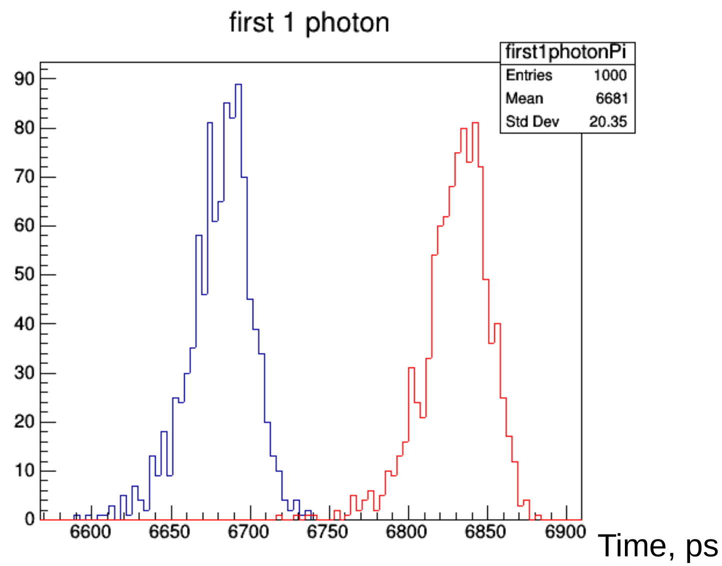
Time of all photons



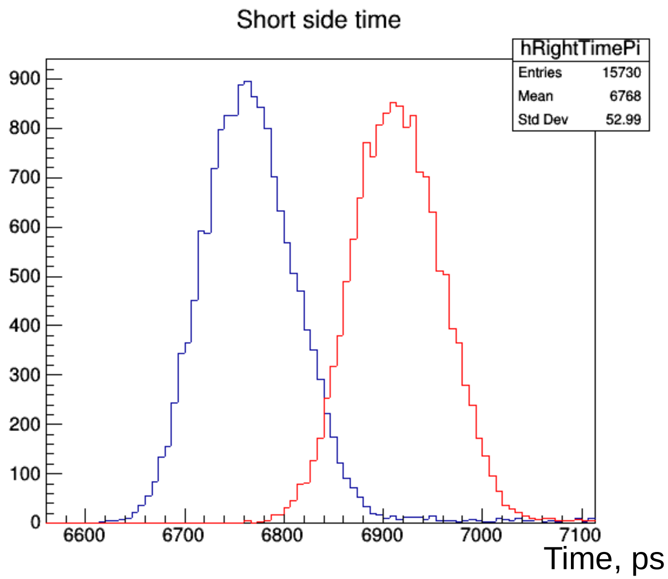
Time of the first photons

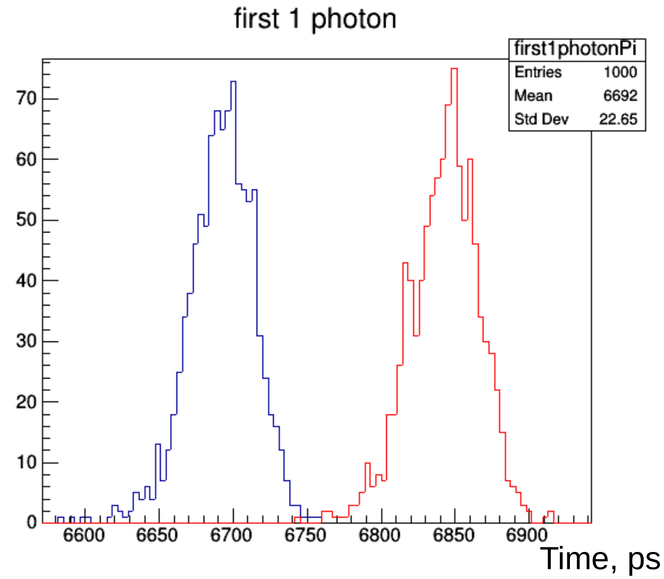
30 ps time resulution
(1000 event statistics)





30 ps sigma
100% efficiency





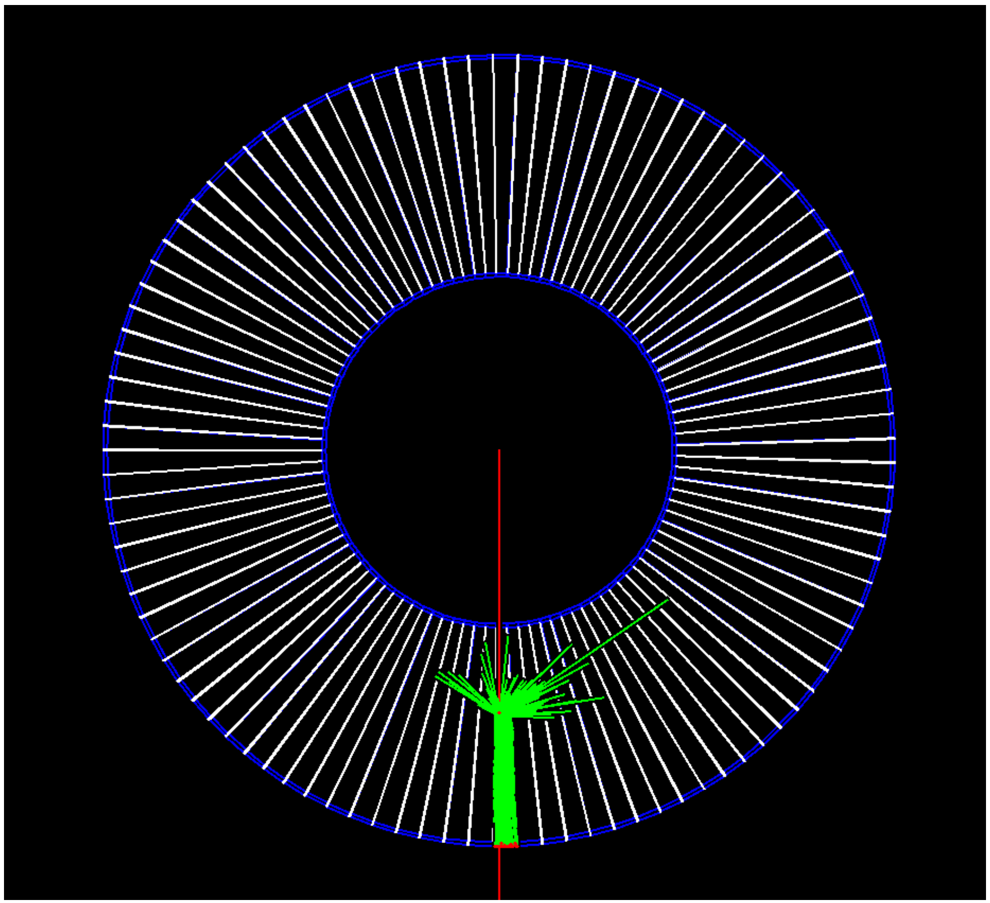
30 ps sigma
50% efficiency (average)

Time of all photons

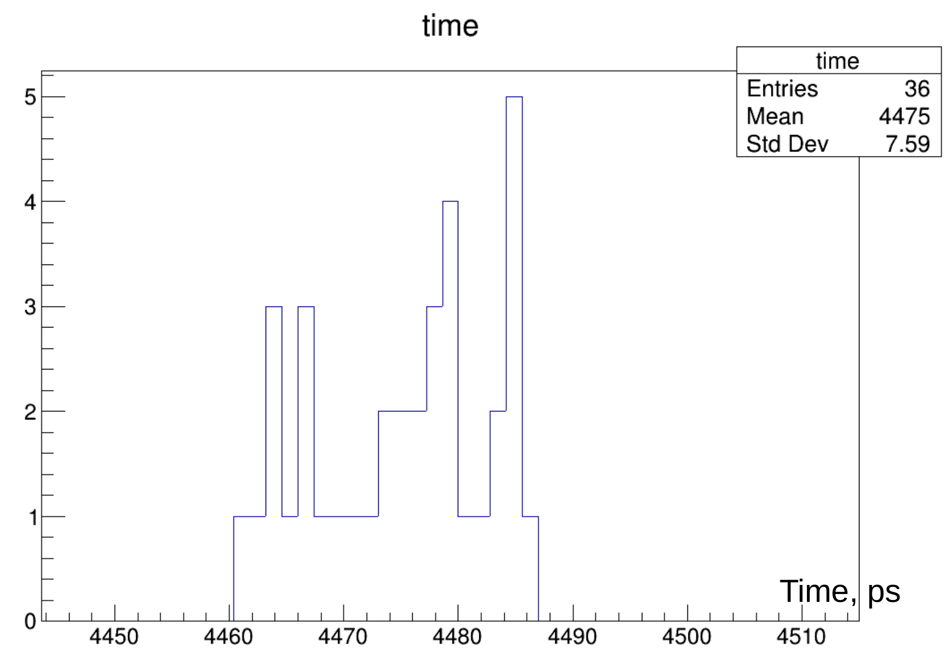
Time of the first photons

100 parts (small trapeze)

This kind of fragmentation gives us small enough trapezes and good time characteristics.
Also it's much easier to manufacture and to service.

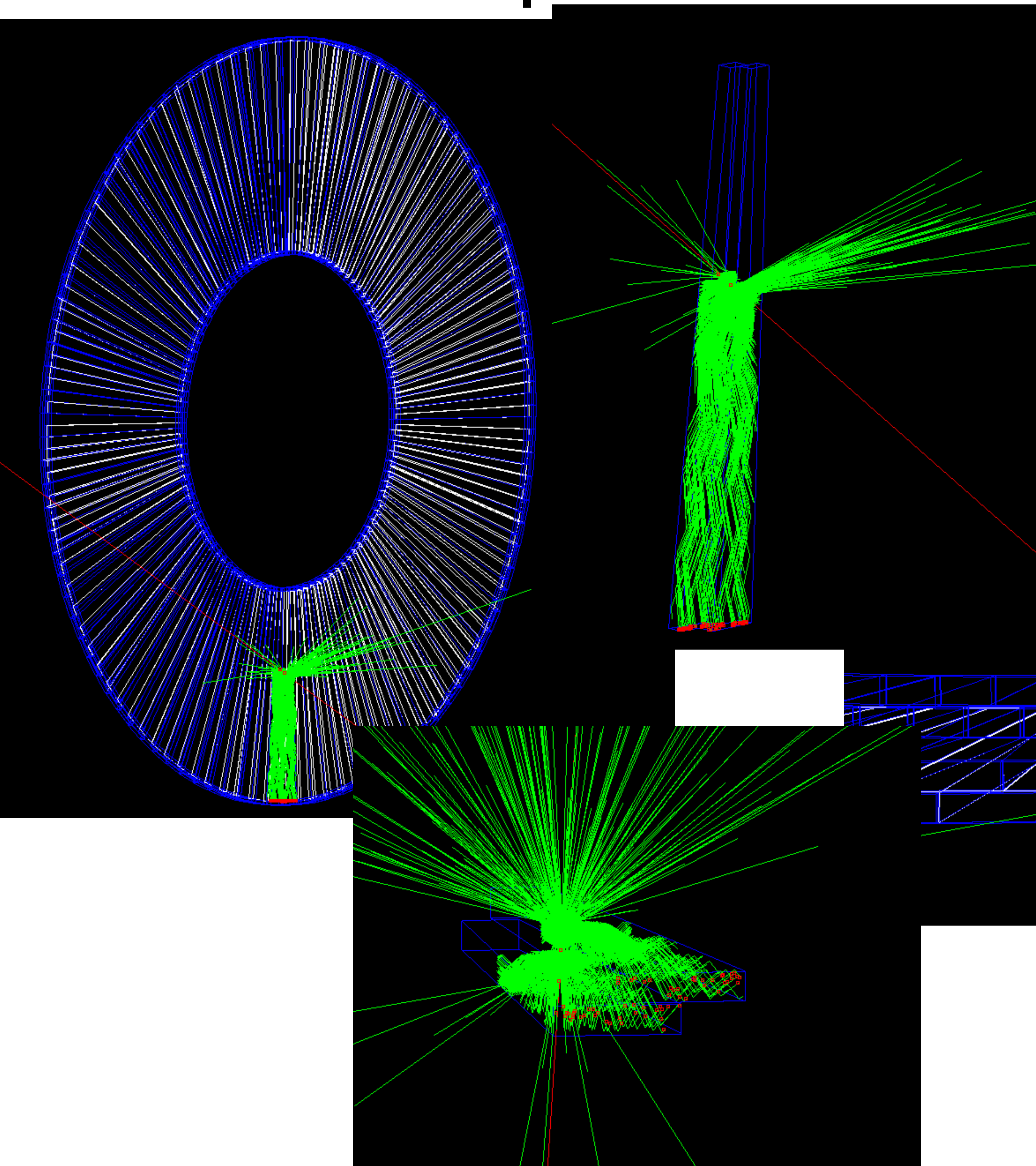


Short side = 2.9 cm
Long side = 6.5 cm



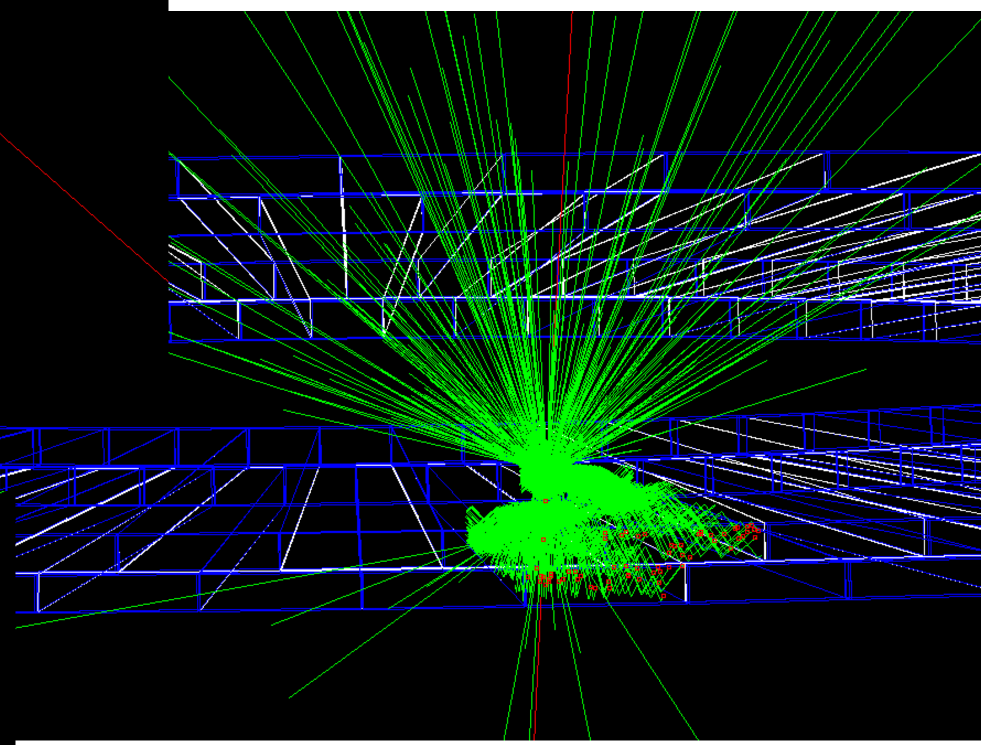
But this kind of geometry has a lot of **blind space** between sectors.

100 parts and two layers

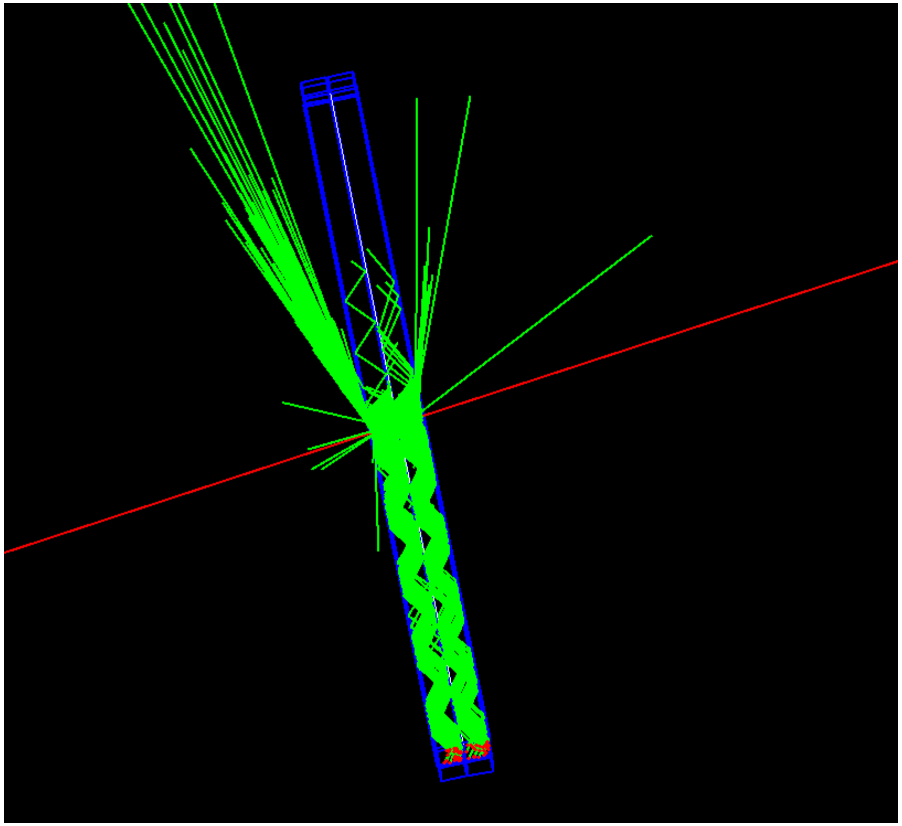


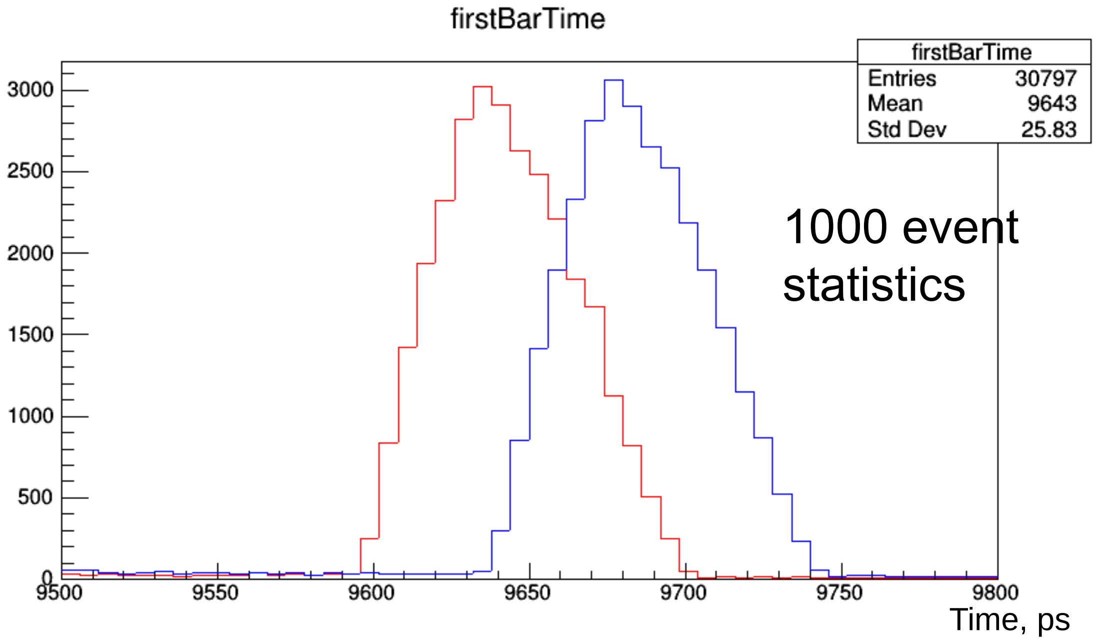
The solution could be two layers, shifted by half of the sector size.

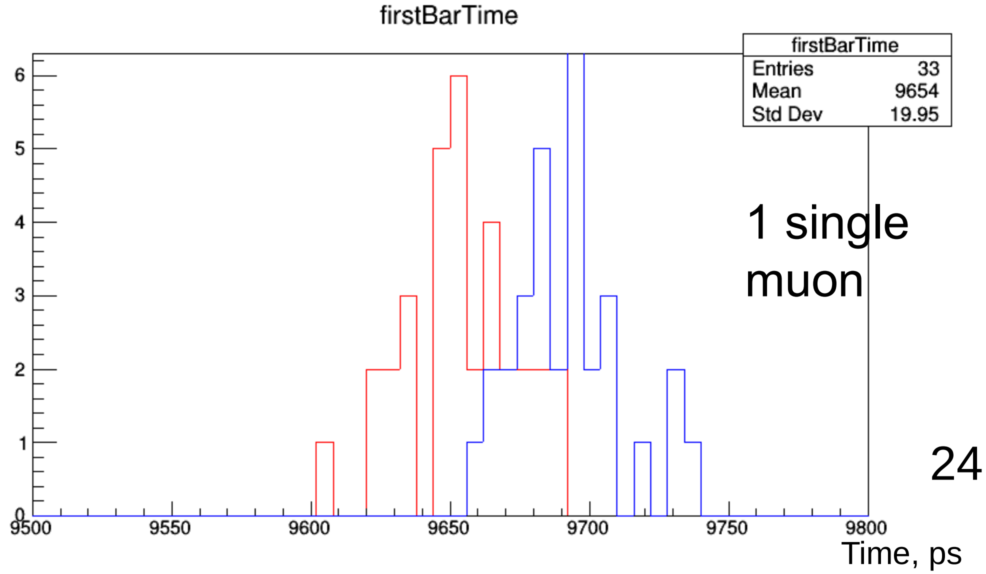
In this case one layer covers blind space of another layer.



Two layers (center hit)



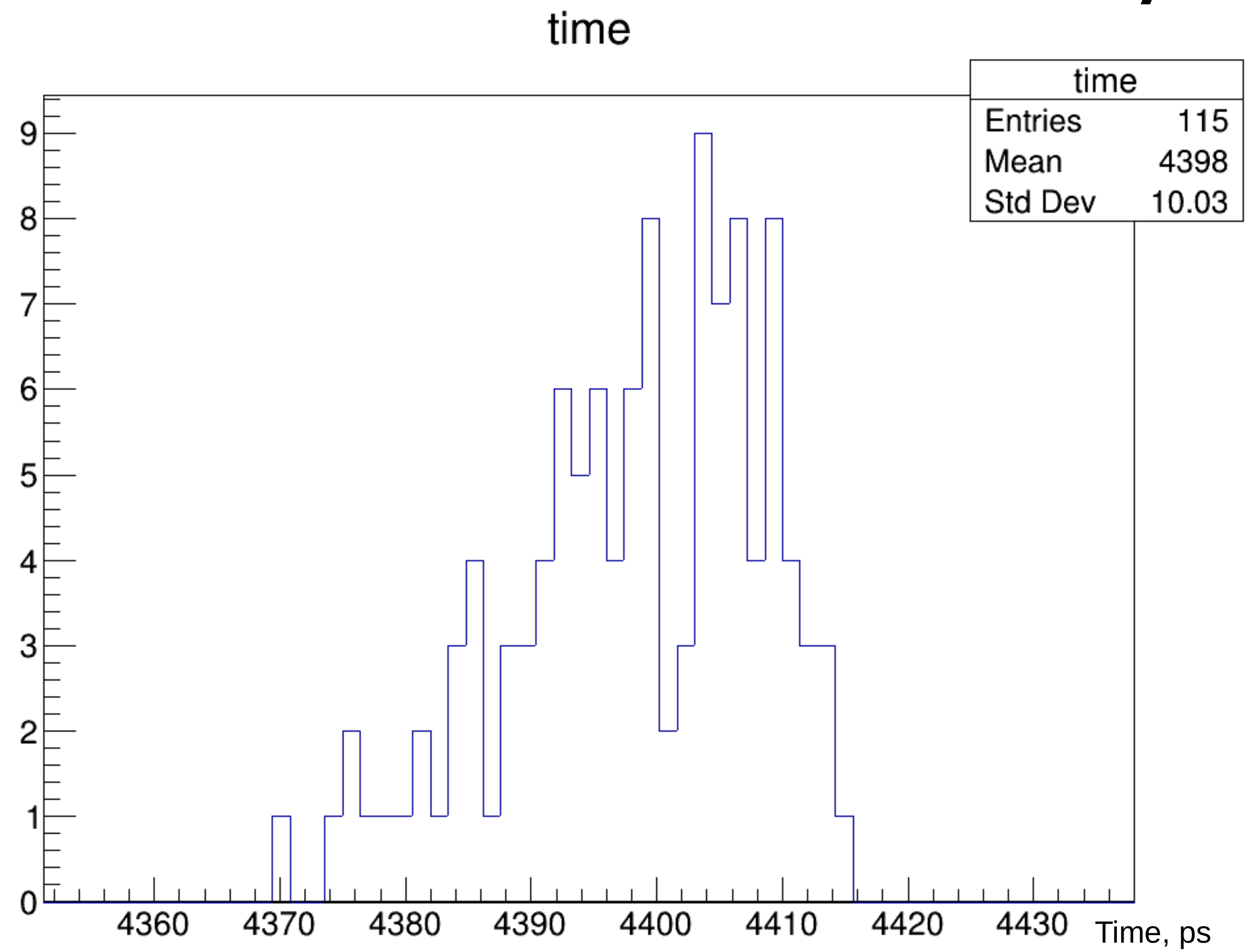




Also we can get time from fTOF detector more precisely if we have few thinner layers against one thick.

Also bigger light detection probability due to the Poisson distribution.

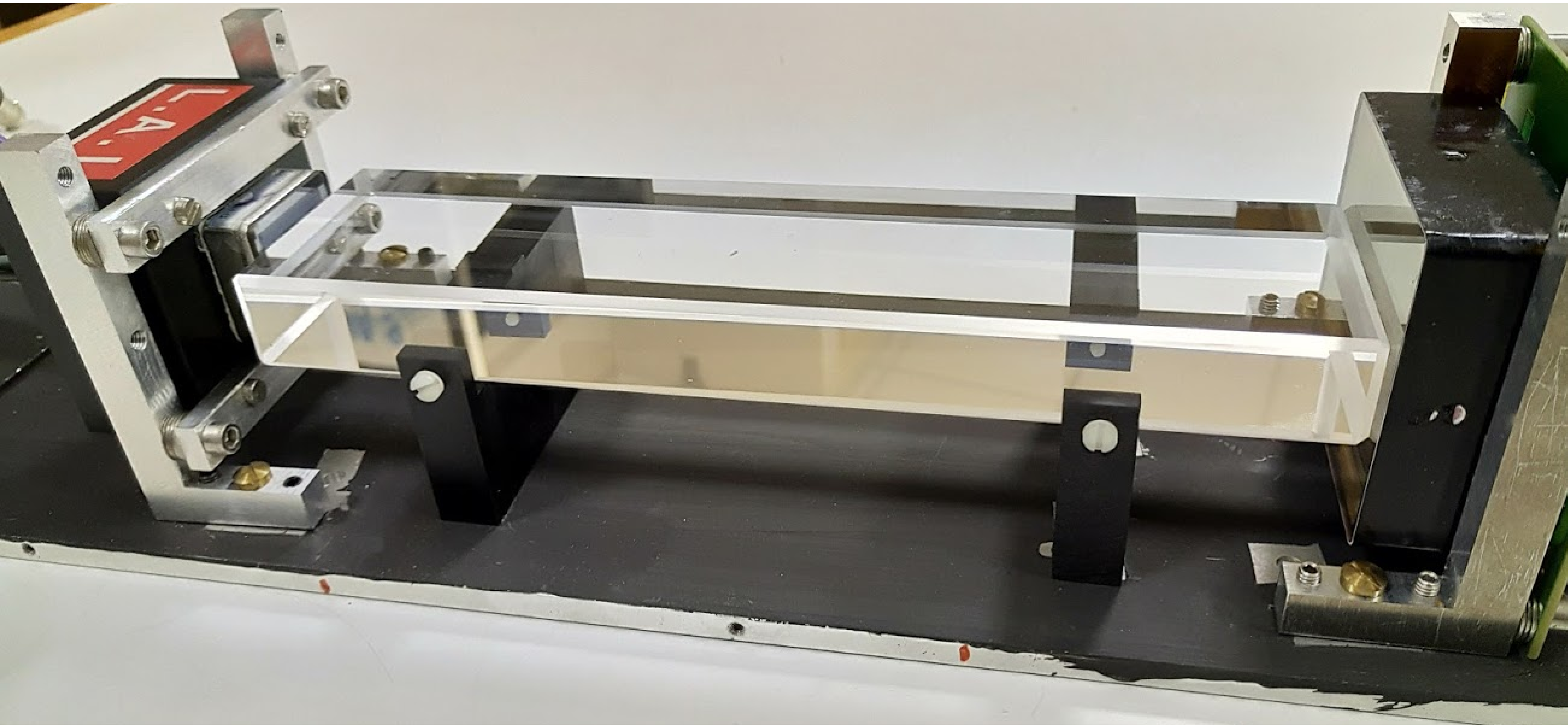
Time distribution for two layers



Time distribution for both layers on one histogram.

- Both layers will have separate photodetecting channel for distinguishing light from different layers.
- An advanced reconstruction algorithm can improve timing by including this factor into analysis.

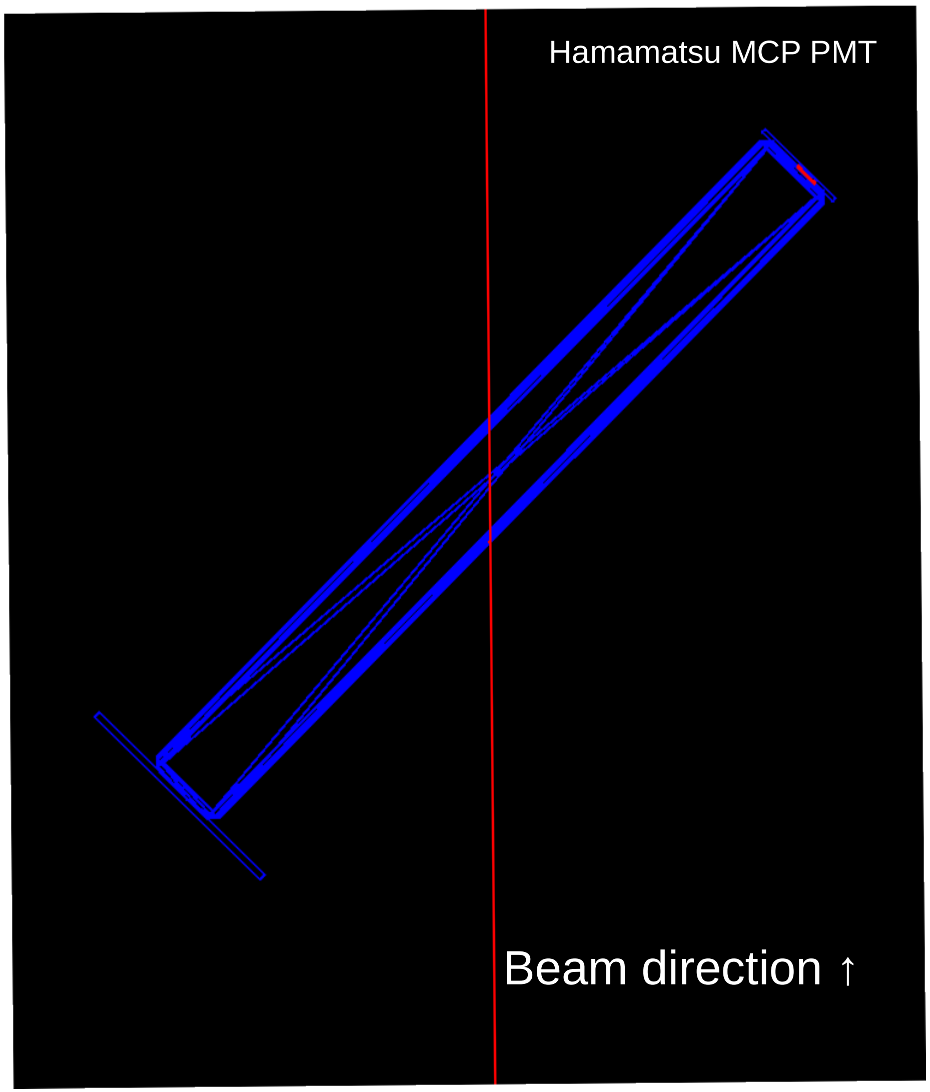
Prototype at LAL for quartz and MCP PMT's properties research



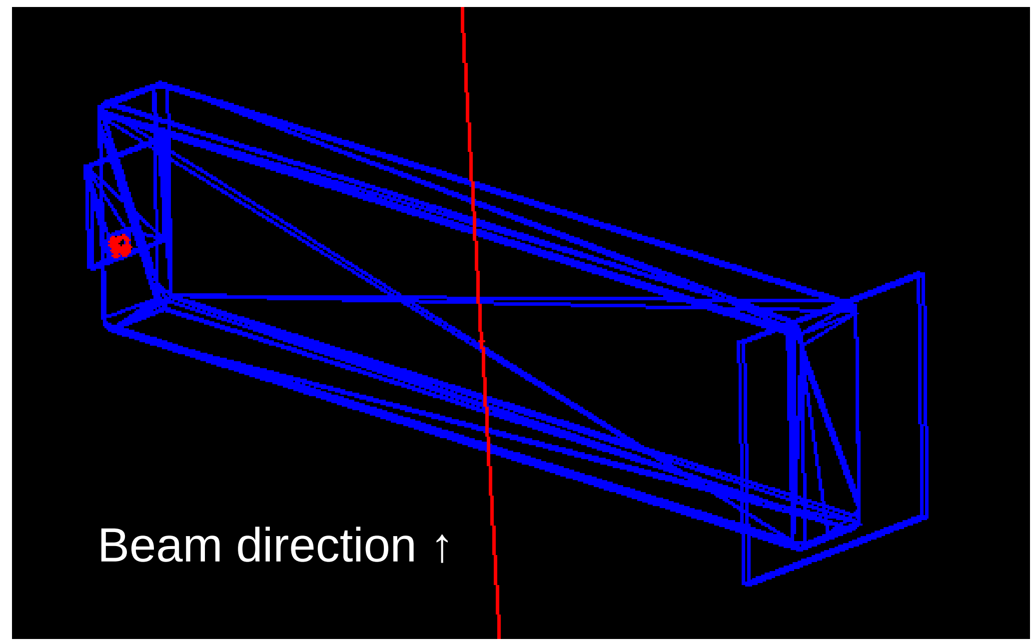
Length: 200 mm
Width: 50 mm
Thickness: 20 mm

Chamfer: 2 mm
(technological aspect)

H8 pion test at CERN



180 GeV pion+ beam for detector tests, made by 450 GeV protons, extracted from SPS, hit the target.



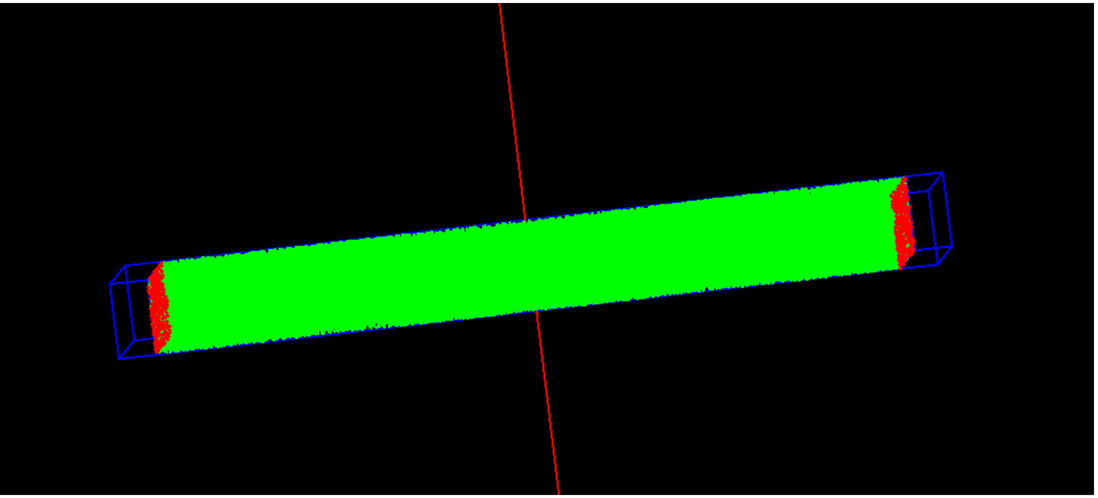
The complex data analysis and photodetectors' time resolution measurements **will be performed soon** to estimate the contribution of all factors in the system.

Summary

- fTOF which was designed for the SuperB projects is promising for the forward PID at the HIEPA.
- So far the simulation includes idealistic description of materials and processes.
- SiPM time characteristics to be tested for HIEPA fTOF detector.
- Multilayer model can help us to improve time precision (20 cm of space is available vs ~1.5 cm layer thickness)
- Reconstruction algorithm can improve time properties, but requires advanced R&D.
- The quartz fTOF prototype was tested on CERN’s H8 test facility. The Geant4 simulation and experiment data to be analyzed to determine real detector performance.

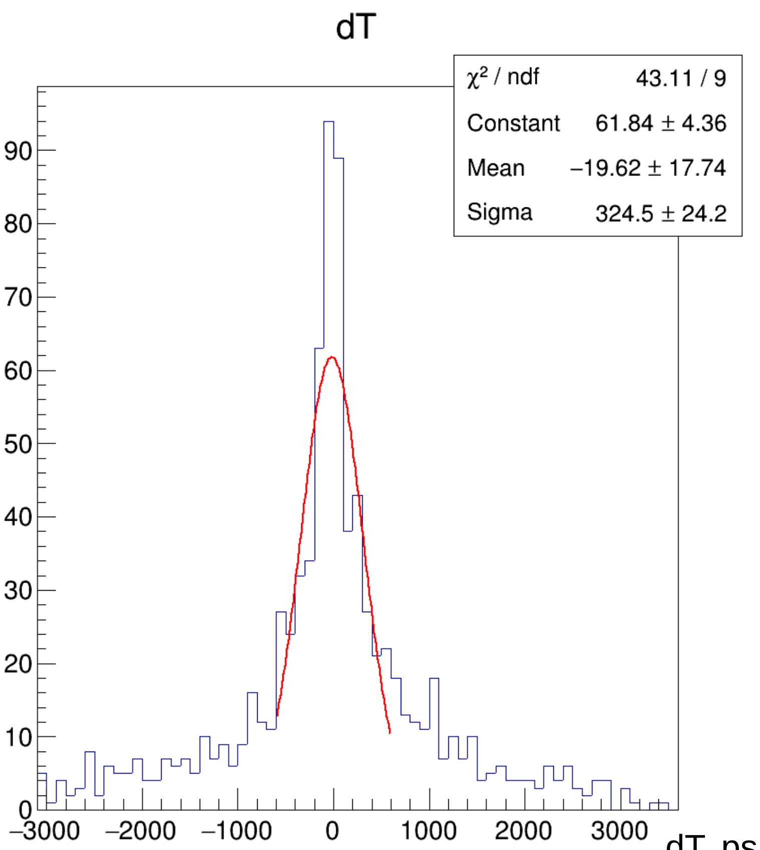
Backup

Rectangular cuboid without chamfers



2 GeV/c muon hit at the middle, zero angle

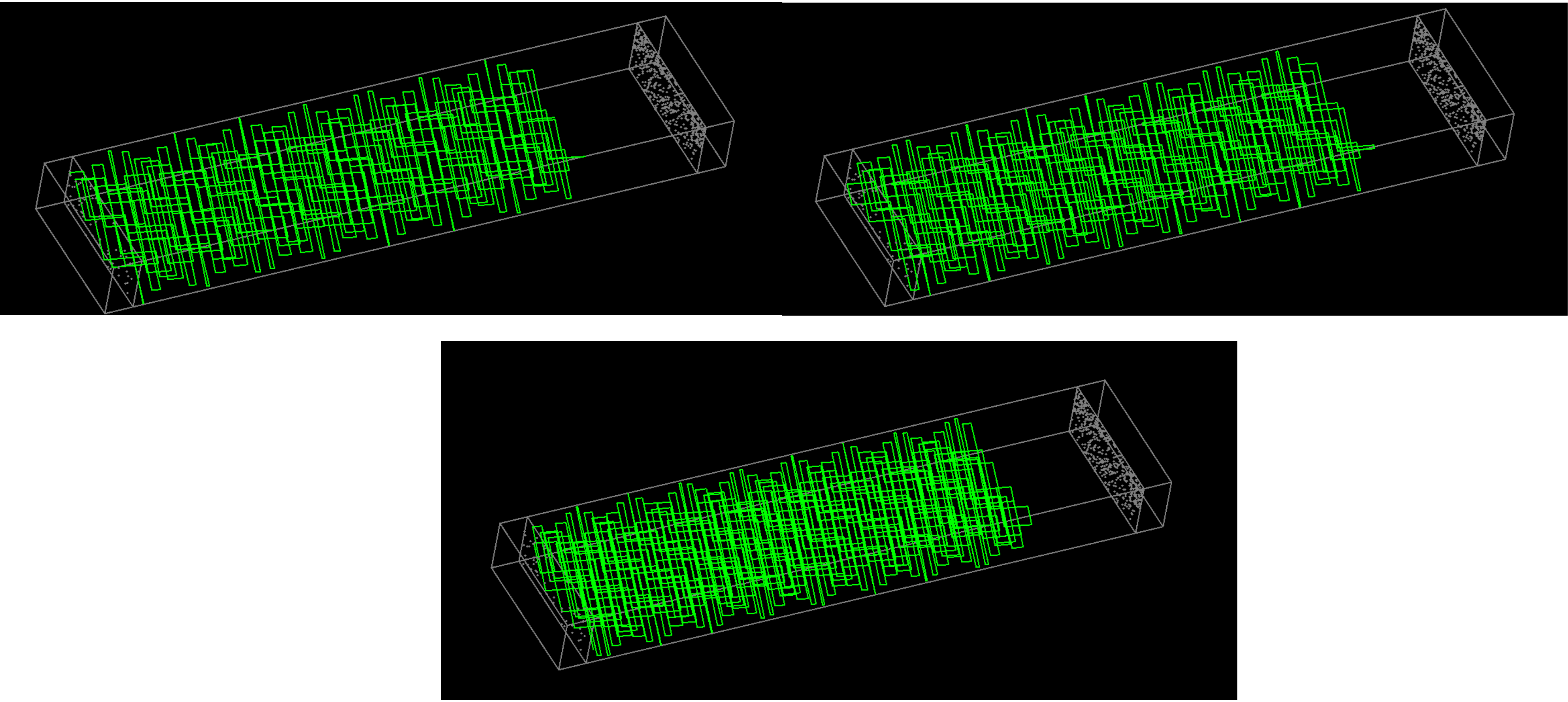
Ideal senstitve photodetectors on the left and right sides



Difference in time (ps) between photons arrived to the left and right side (1000 muons)

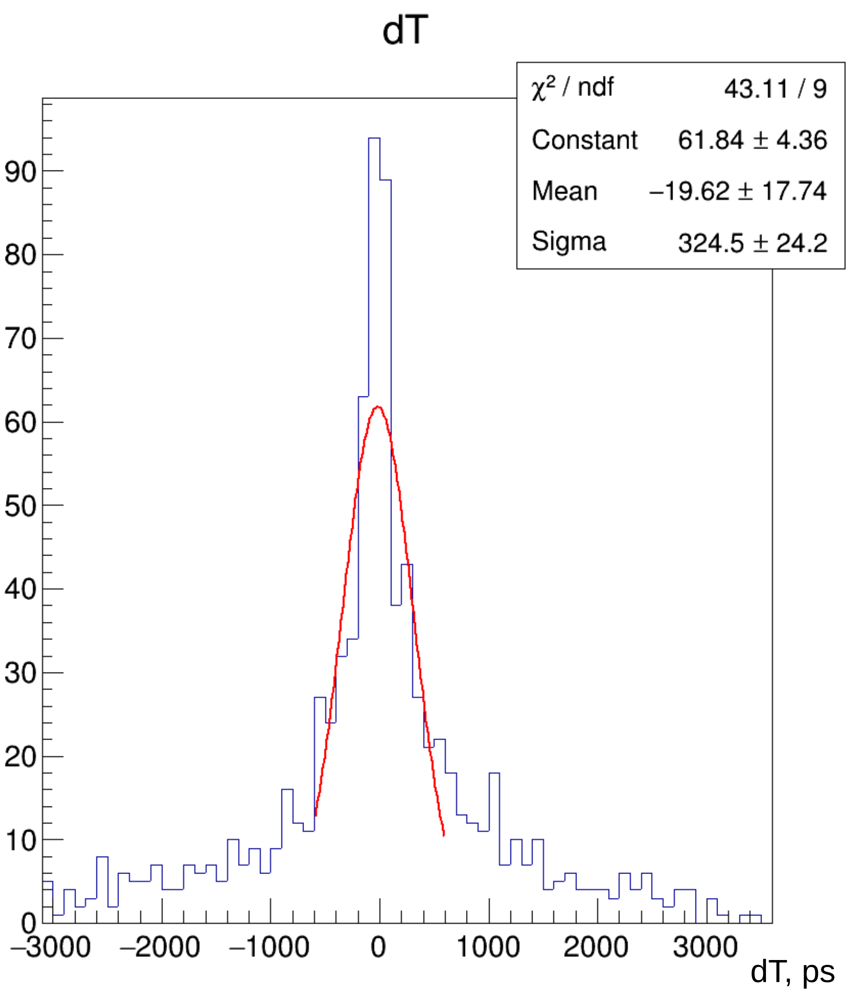
As we can see, in this case light doesn't escape from the quartz and it is fully collected by detectors. But the signal is spread in few nanoseconds interval.

This kind of photons gives us the huge width of the distribution from previous slide.

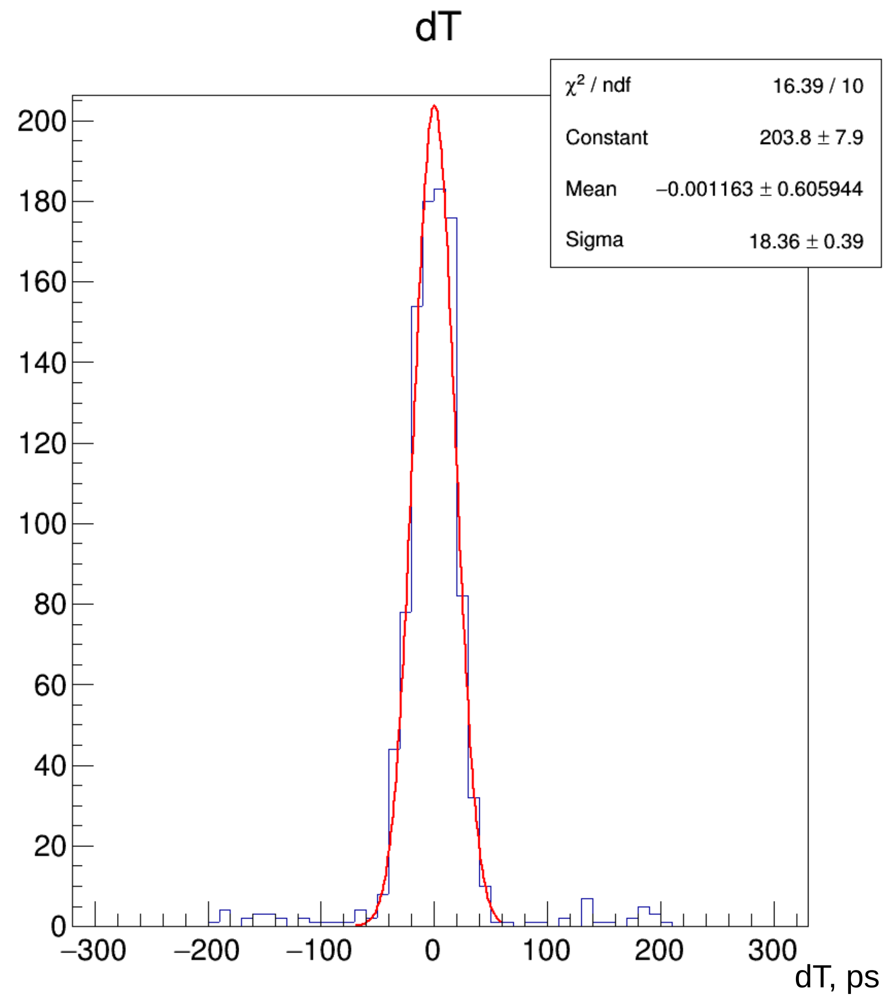


1000 muons, hit to the center, zero angle. Time is given in ps.

Without absorbers
(~440 photons/event on each side)

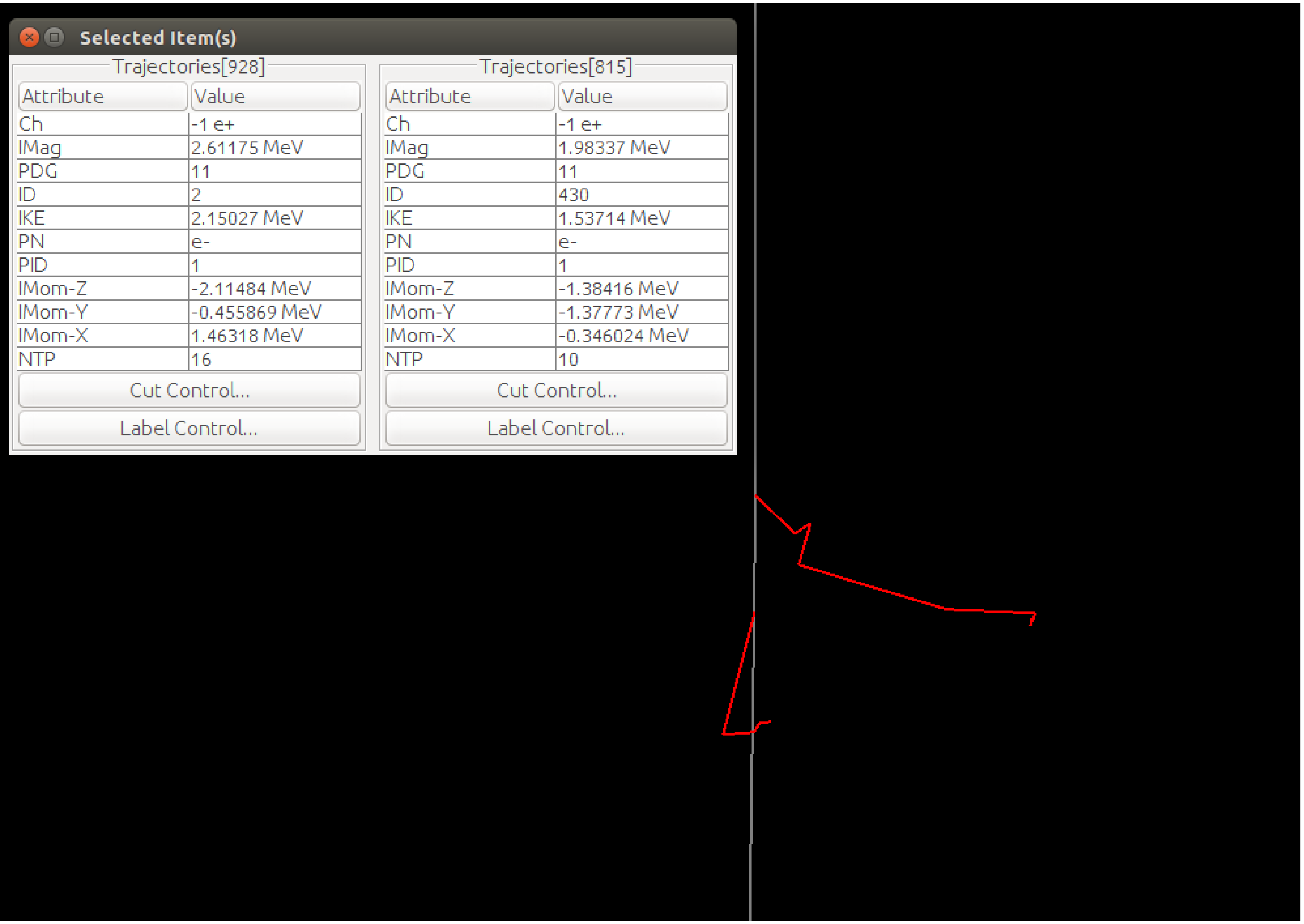


With absorbers
(~75 photons/event on each side)



We have much narrower peak, but less light collected

Delta-electrons

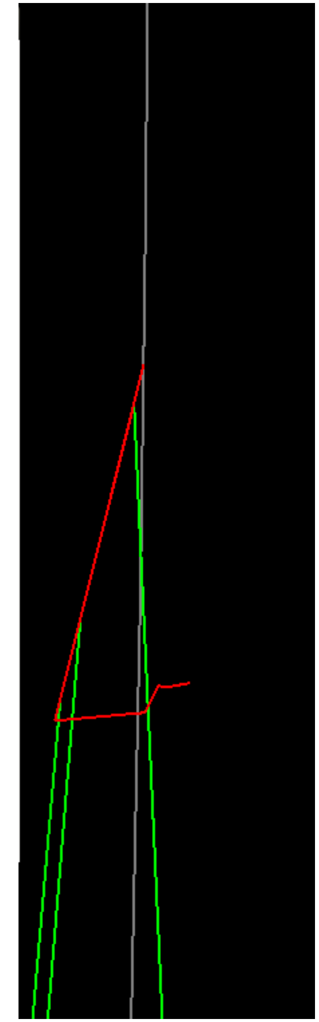


Trajectories[928]

Attribute	Value
Ch	-1 e+
IMag	2.61175 MeV
PDG	11
ID	2
IKE	2.15027 MeV
PN	e-
PID	1
IMom-Z	-2.11484 MeV
IMom-Y	-0.455869 MeV
IMom-X	1.46318 MeV
NTP	16

Trajectories[815]

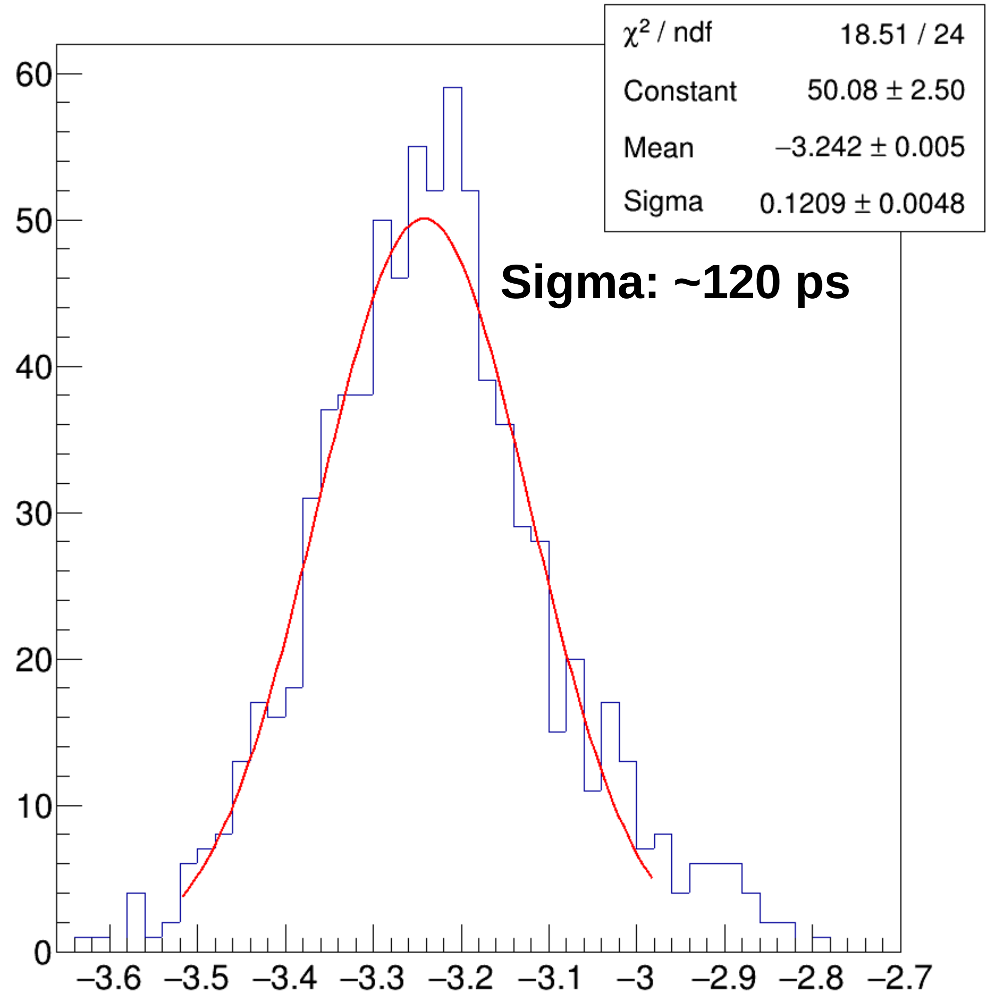
Attribute	Value
Ch	-1 e+
IMag	1.98337 MeV
PDG	11
ID	430
IKE	1.53714 MeV
PN	e-
PID	1
IMom-Z	-1.38416 MeV
IMom-Y	-1.37773 MeV
IMom-X	-0.346024 MeV
NTP	10



Delta-electrons (red) from muon (grey) ionizing matter. Both are above cherenkov treshold (~0.2 MeV for an electron in quartz)

“Straight” photons from delta-electrons which were detected

Time distribution width estimation



Supposed factors of this width:

- MCP-PMT time resolution
- SiPM trigger time resolution
- Electronics impact (cables, amplifiers, USB WaveCatcher, etc.)
- Showers from 180 GeV pions passing through matter

The complex data analysis and photodetectors' time resolution measurements **will be performed soon** to estimate the contribution of all factors in the system.