Study of Scintillation Photon Propagation in a Polystyrene ECal Plate (SPD)

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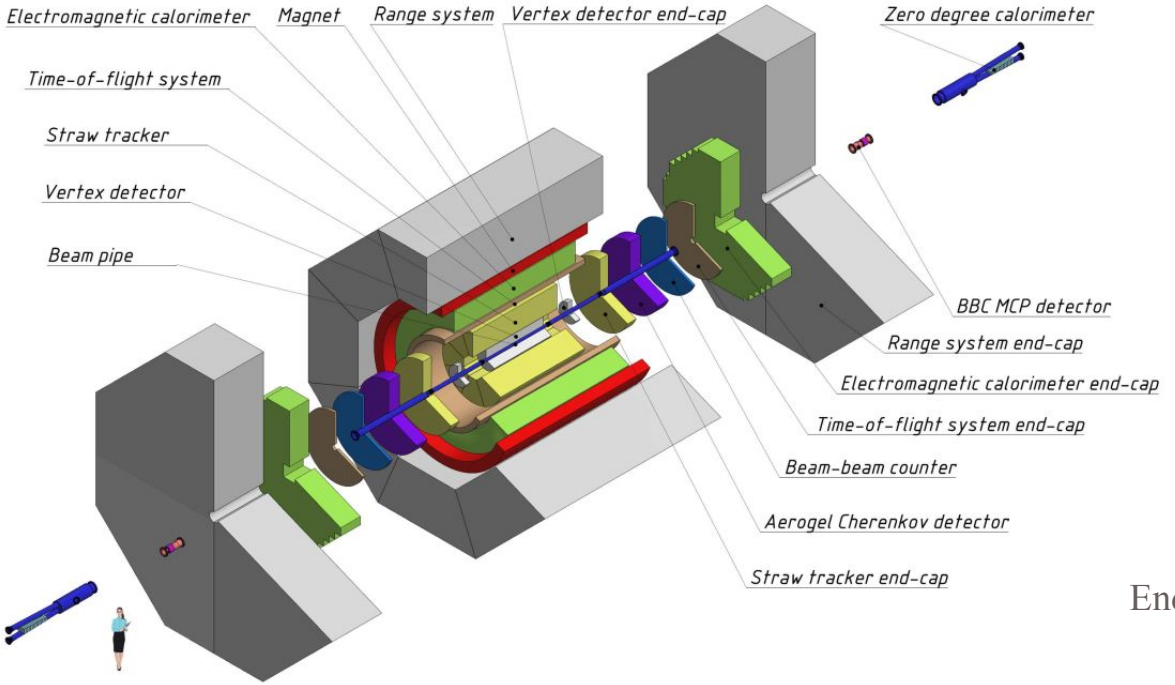
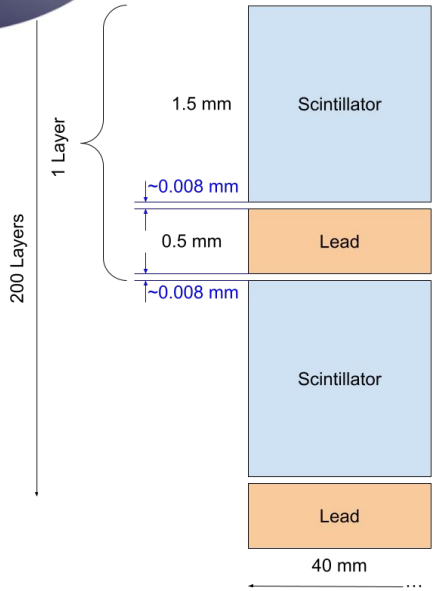
Electromagnetic Calorimeter (SPD)





End-cup



Some conclusions from previous presentation:

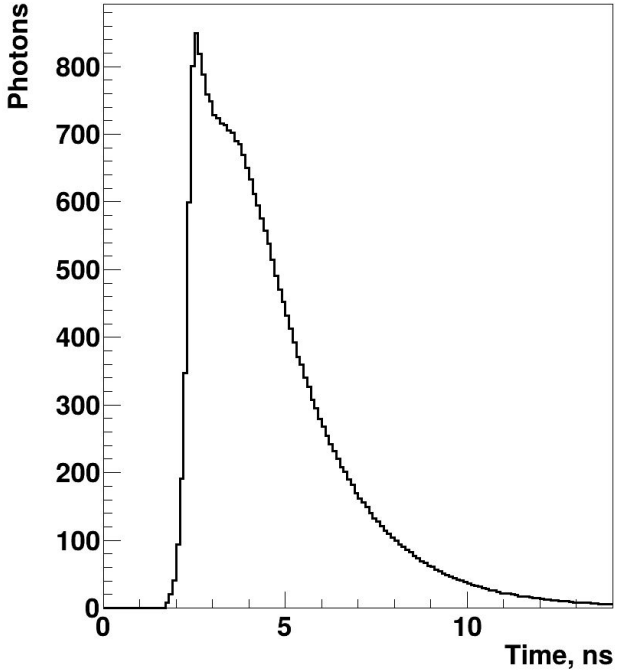
"Experimentally, it was found that there are 200 photoelectrons per 1 muon. And we calculated using the Monte Carlo model that 27500 photons reach the SiPM ***without taking into account losses in the scintillation plates (1-β).***

Photon Detection Efficiency (PDE) of EQR15-11-6060D-S for 500 nm is ~33%. Thus simulation shows us that we have 9075 · β photoelectrons. Using experimental data it was found that ***β is 0.022*** *which is satisfactory for this geometry."*

Actually $\beta = \delta \cdot \theta$, where $1-\delta$ is losses in the scintillation plates, $1-\theta$ is other losses of the scintillation photons in the calorimeter.

Our goals:

- estimate photons losses in the scintillation plates (**1-δ**).
- estimate the linearity of response of SiPM.



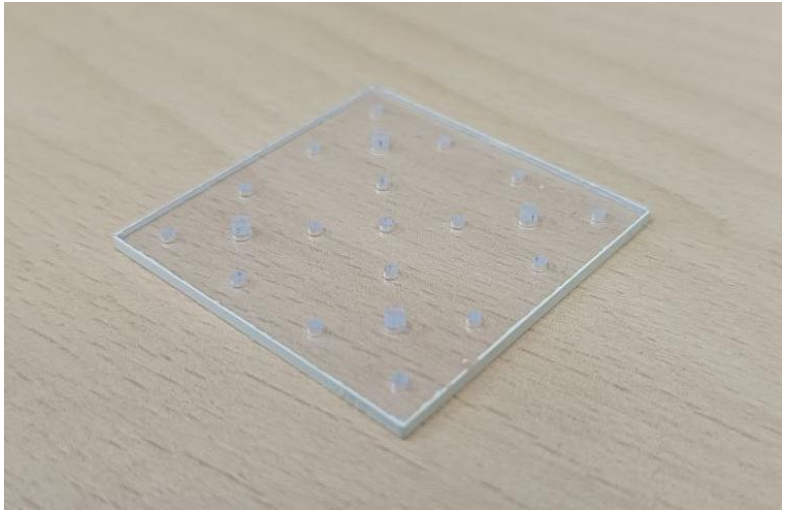
Average pulse from 1 GeV muon (Monte Carlo model)

Simulated processes in the scintillation plate

The whole module was simulated, not only one plate!

List of simulated processes:

1) Interaction between particles with material and calculation deposited energy.
2) Production scintillation photons.
3) Propagation of the photons in the layer:
   a) Absorption of the photons in the plate.
   b) Refraction.
   c) Reflection photons by paint, lead.
   d) Total internal reflection and ect.
4) Caption of photons by WLS fiber lightguide.



Transportation of the optical photons in the WLS fiber lightguide is not simulated! It was discussed in the previous report.

Parameters for optical Monte Carlo model

Parameters available in the literature:

1) Lightyield of polystyrene scintillator (8-10 photons per keV).
2) Emission spectra of polystyrene scintillators with POPOP.
3) Refraction coefficient of the plate (1.59).
4) Absorption length of the WLS fiber (Kuraray Y11).
5) Refraction coefficients of the fiber core and cladding.

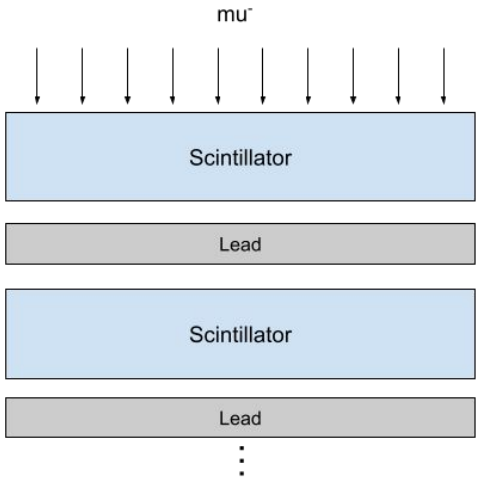
Parameters needing further definition:

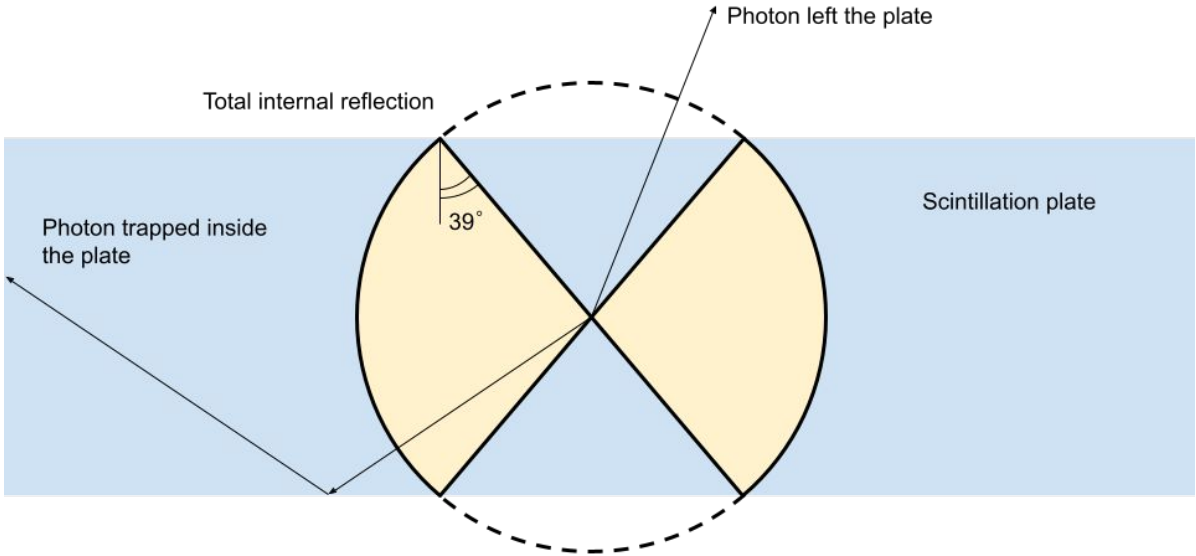
1) Absorption length of the polystyrene (30-300 mm).
2) Paint reflection efficiency at plate edge: 80–98%.
3) Lead plate reflection efficiency: 30–50%

A **1 GeV muon** beam at **normal incidence** with a **uniform spatial distribution** entered the module.

The number of photons exiting the plate and, after that, absorbed by lead was estimated. Two approaches were used: theoretical calculation (see Picture) and Monte Carlo simulation.

The results are very close: the theoretical calculation gives 22.2%, while the Monte Carlo simulation yields 23.4%. This small discrepancy is due to simplifications in the theoretical model.





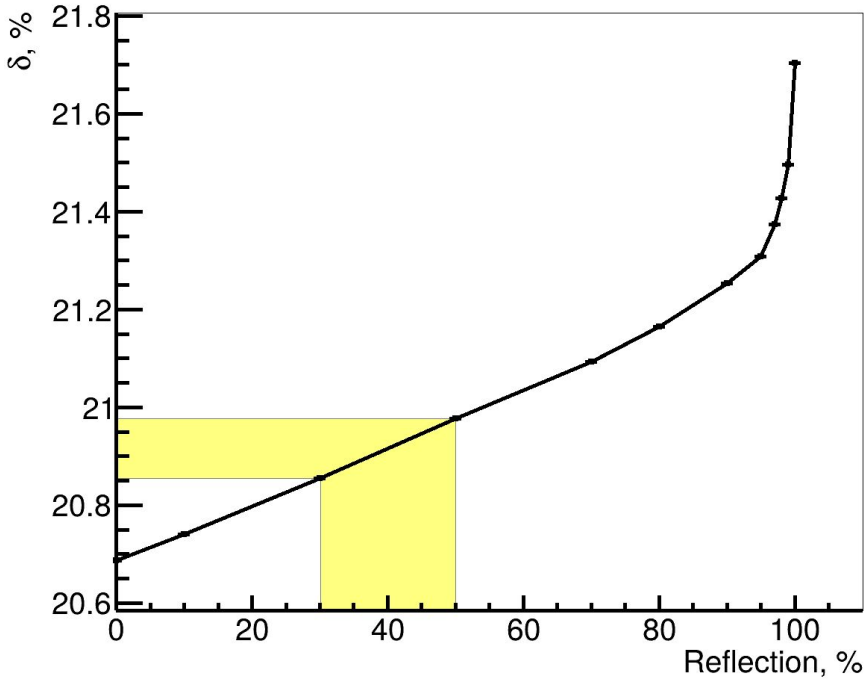
Lead plate reflection efficiency

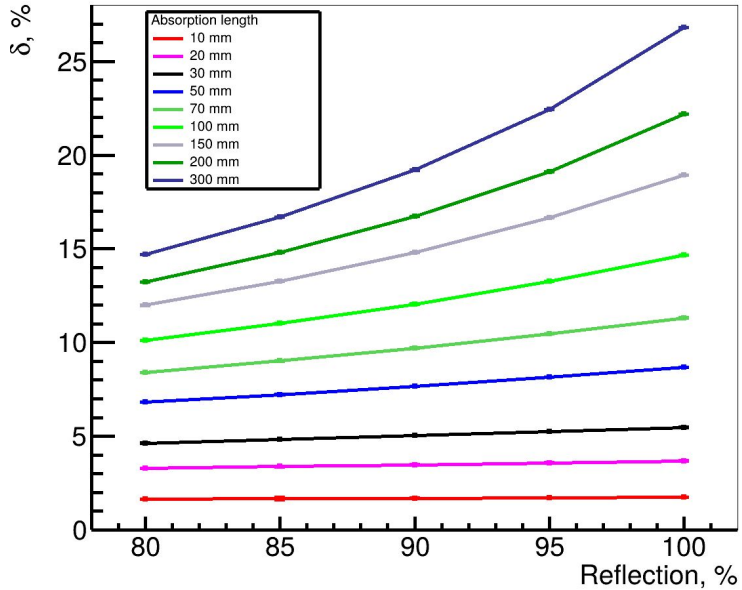
δ is the fraction of scintillation photons captured by the WLS fiber. (1-δ is losses in the scintillation plates).

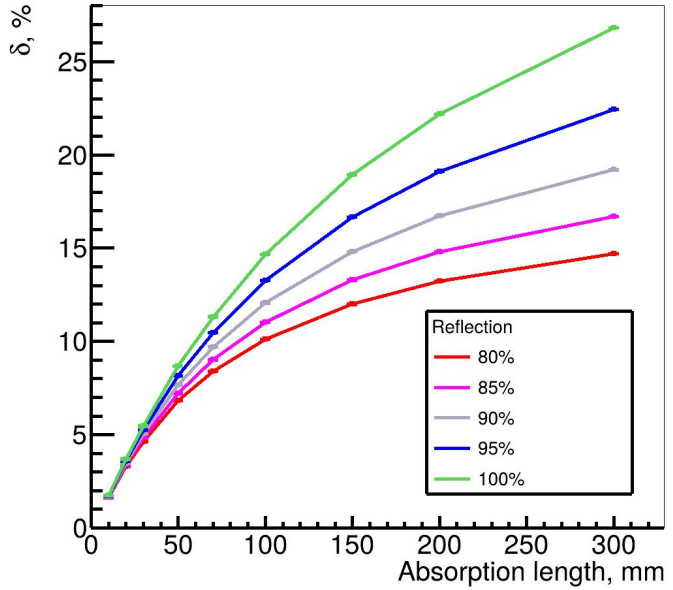
The white paint reflection efficiency is set to 98%, and the polystyrene absorption length is set to 200 mm.

Lead plate reflection efficiency usually is from 30 to 50%.

Within this range, δ shows a relatively weak dependence on the reflection efficiency (Δδ<0.15%). **For it is not necessary to know the exact lead plate reflection efficiency.**







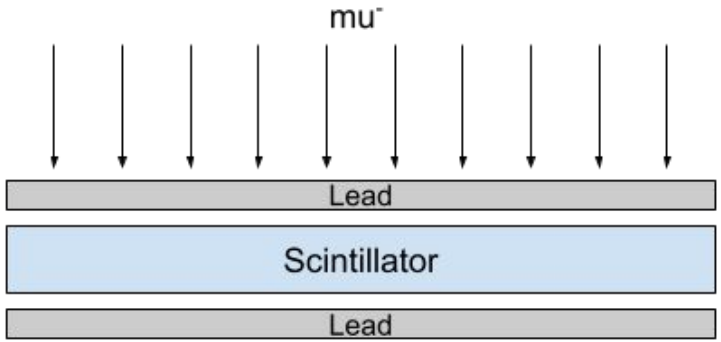
Lead plate reflection efficiency is set as 30%. White paint reflection efficiency usually is from 80 to 98%. Absorption length of the polystyrene is from 30 to 300 mm.

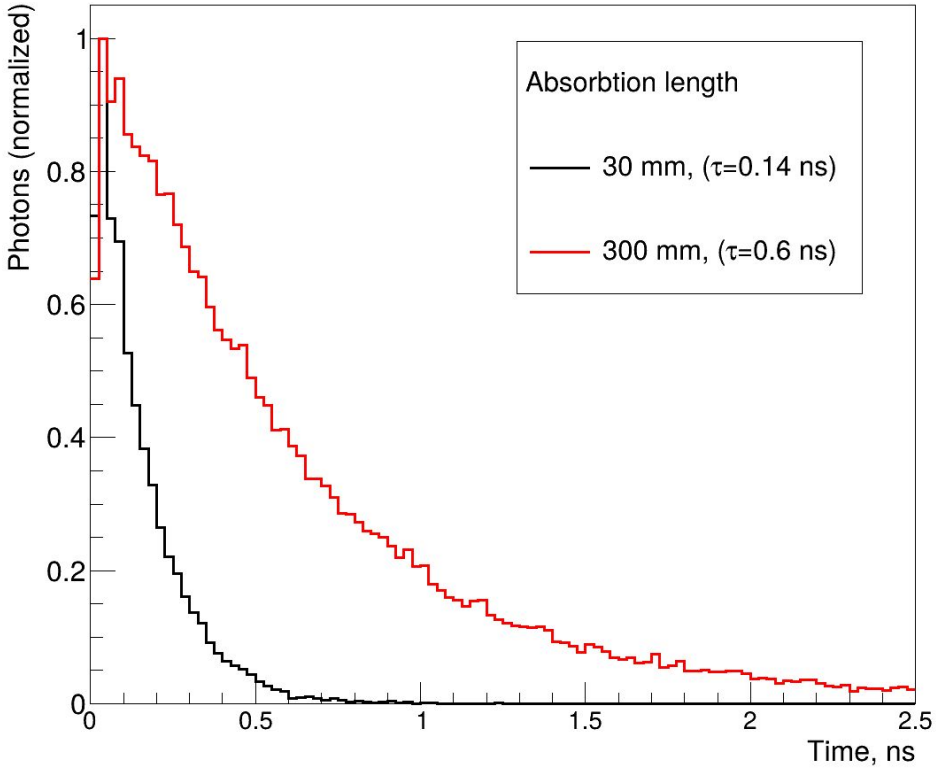
δ shows a strong dependence on the reflection efficiency and absorption length. **Therefore it is necessary to determine the values of these parameters with good accuracy.**

Scintillation photons propagation time

In this simulation, only one scintillation plate with two lead plates was considered (see picture below). A normal-incidence muon beam entered the layer. It had a uniform spatial distribution over its cross-section . Muon energy was 1 GeV.

Propagation time shows a strong dependence on the absorption length.





Other losses (θ)

$\beta = \delta \cdot \theta$, where δ is losses in the scintillation plates, θ is other losses of the scintillation photons in the calorimeter.

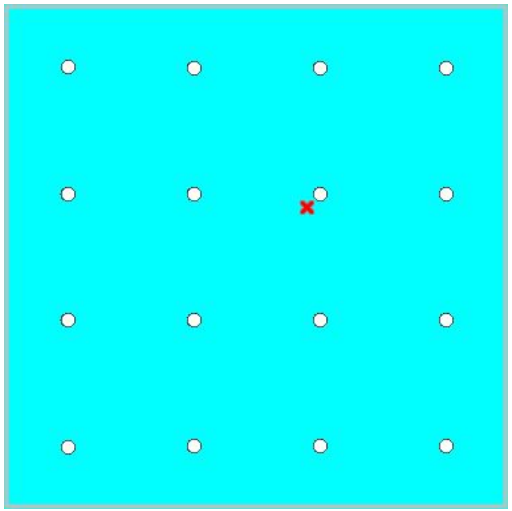
What is included in the parameter θ that we have not considered yet?

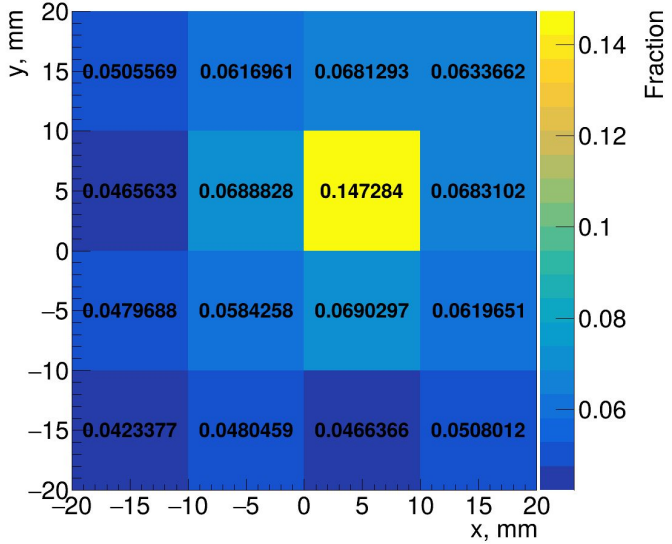
1) Fluorescence Quantum Yield. Now in MC model 1, but in one paper 0.7.
2) Photon Detection Efficiency (PDE). Now in MC model 33%, but in the datasheet ~30%.
3) Scintillation light yield. Now in MC model 10 ph/keV, but in papers 8-10 ph/keV.
4) Maybe something more.

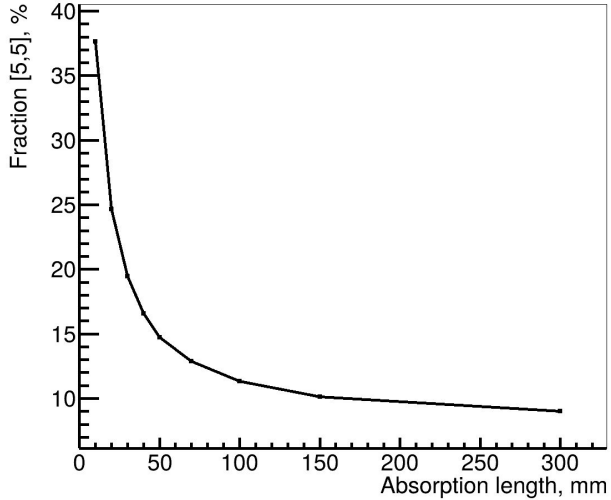
Linearity

The whole module was simulated, not only one plate!

A **10 GeV gamma-ray** beam enters at the point shown in the left figure. Lead plate reflection efficiency is set as 30% and paint reflection efficiency as 98%.





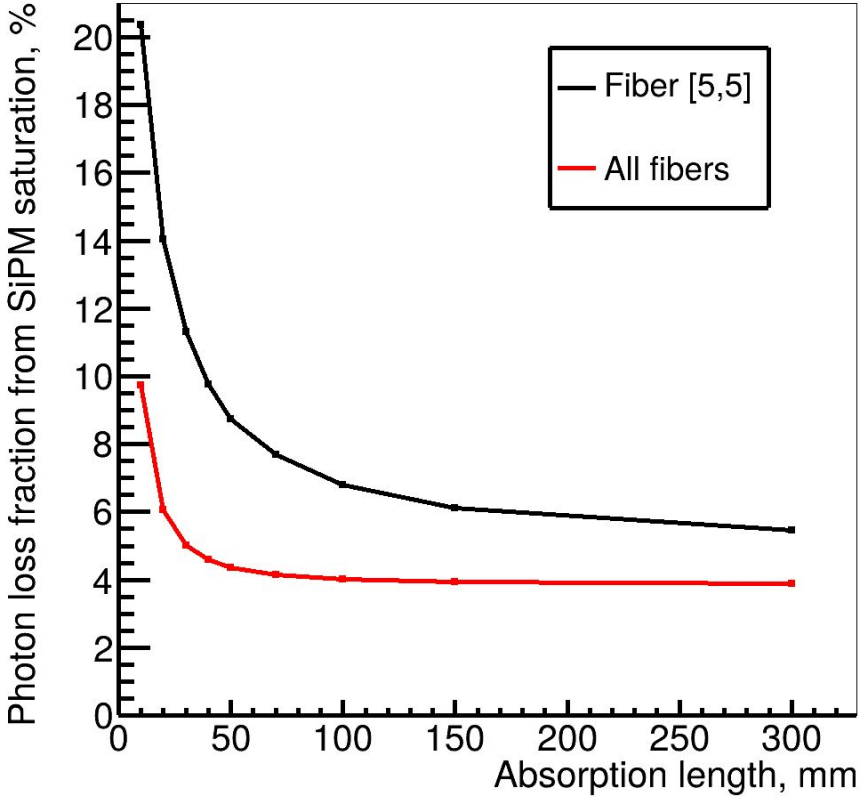


A long absorption length leads to a more even distribution of photons in the fibers.

$$F_{loss} = 1 - \frac{M}{N_{ph}PDE}\left[1 - exp\left(-\frac{N_{ph}PDE}{M}\right)\right]$$

where M is the number of microcells, N_{ph} is the number of incident photons on the SiPM and PDE is the photon detection efficiency.

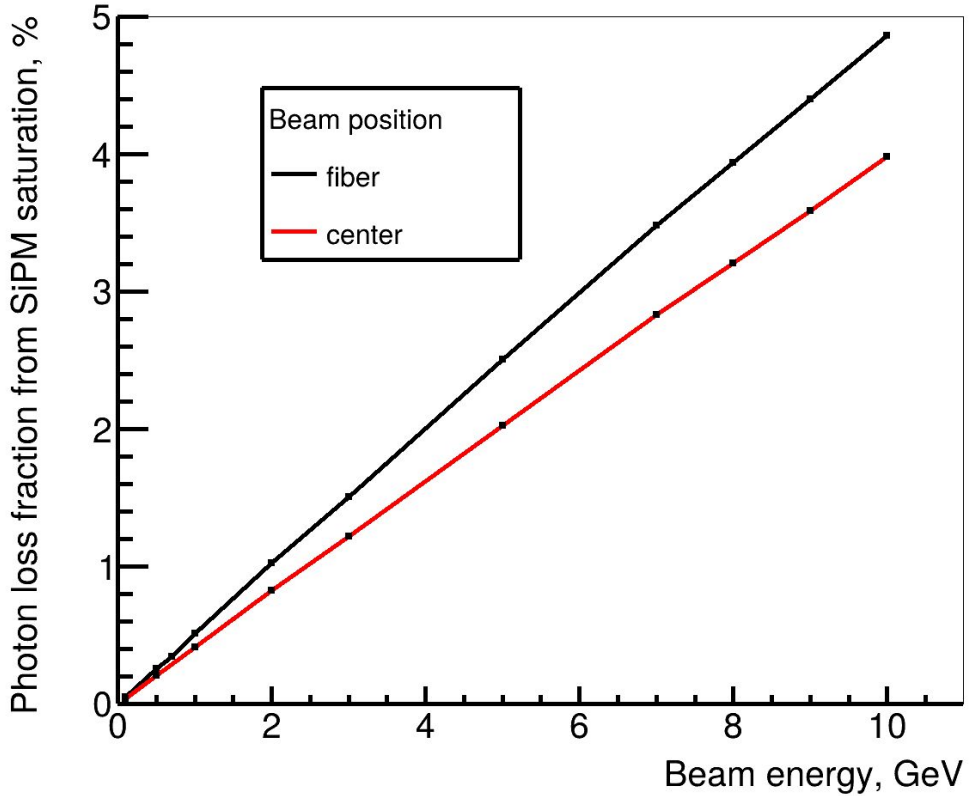
Some photon loss occurs in the fiber [5,5] due to SiPM saturation. **However, for all fibers, this loss is negligible. Therefore, the SiPM response remains linear.**



Linearity vs energy and beam position

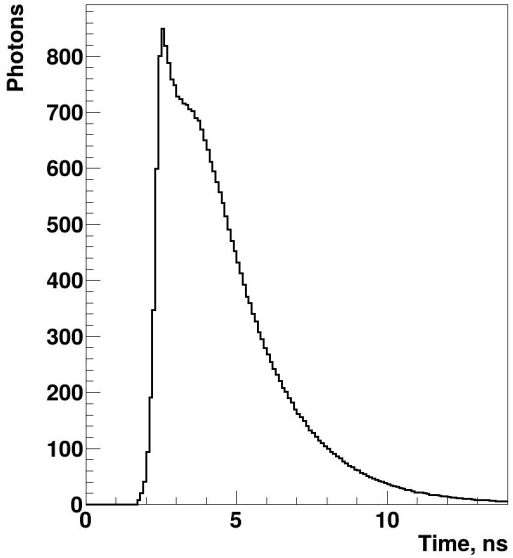
The polystyrene absorption length is set to 30 mm.

In conclusion, the main cause of nonlinearity in the SiPM response is the total number of scintillation photons, not their distribution among the fibers.

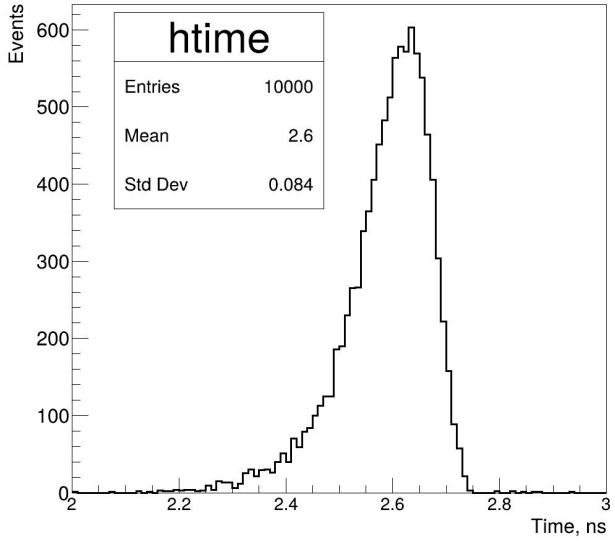


We used the constant fraction discriminator method to determine the registration time.

Please note these are preliminary results, as the Monte Carlo model is currently under development!



Average pulse (MC)



Jitter (MC)

Recommended Measurements

Cell:

1) The number photoelectrons from 1 cosmic muon.
2) Electron/gamma beam test? (800 MeV+)

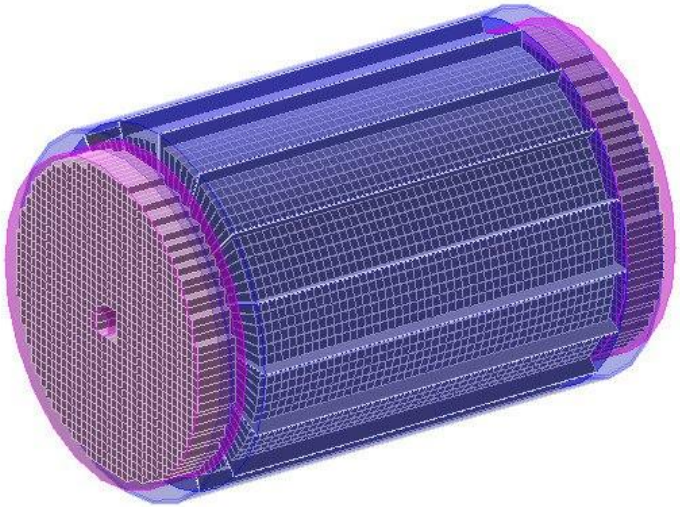
WLS fiber:

3) Photons vs coordinate.
4) Fiber fluorescence decay time.
5) Fiber fluorescence Quantum Yield.

Scintillator:

6) Scintillator absorption length.
7) Scintillator light yield.
8) Paint reflection efficiency at plate edge.

- SPDGeoModel is complete.
- Next: project support.



Sampo:

- Standalone simulation is under development but already available for use.
- Id Encoder and Id Decoder is developed.
- Algorithm for transformation MCHits to ECalHits is developed.
- ECalHits sorter is developed.
- Algorithm for transformation ECalHits to ECalDigit is developed.

Plans:

- Further development of standalone simulation.
- The development of electronics simulation.

Conclusions

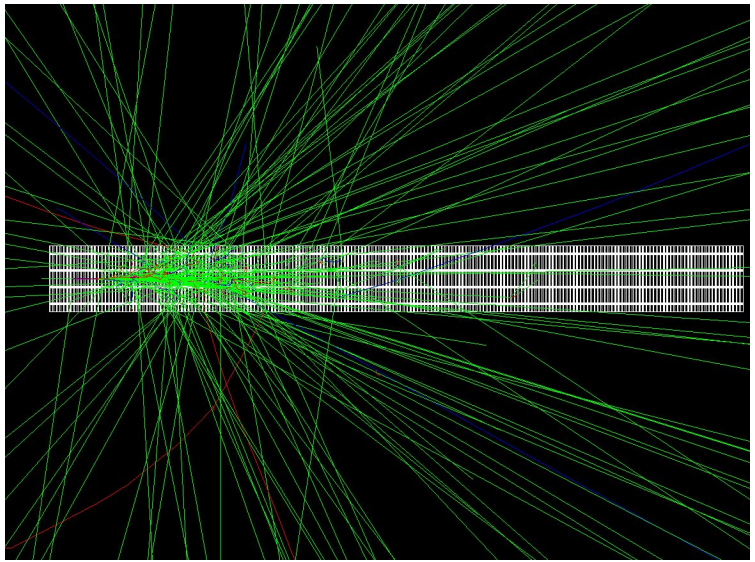
- Monte Carlo model of cell is created.
- The reflectivity of the lead plate does not significantly affect photon losses ($\Delta\delta<0.15\%$), whereas the reflectivity of the paint on the plate edge and the absorption length of the polystyrene have a strong effect (δ = 4-27%). Therefore, it is better to know the exact values of the last two parameters.
- The absorption length of the polystyrene affects how the photons distribute among the fibers, but it does not cause the SiPM response to become nonlinear.
- The electronic jitter at this stage of the Monte Carlo model is estimated.
- The ECal SPDGeoModel is complete for the current state.

We are going to:

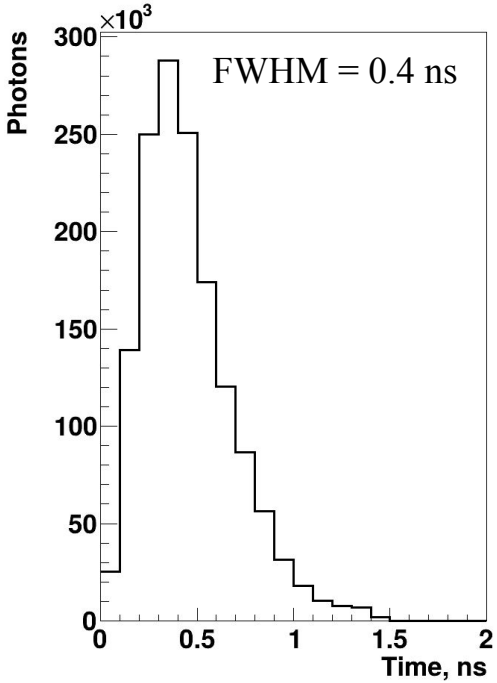
- improve the Monte Carlo model by using more accurate and reliable experimental data,
- estimate the impact of Cherenkov photons,
- use this MC model for the ECal parameterization (SAMPO).

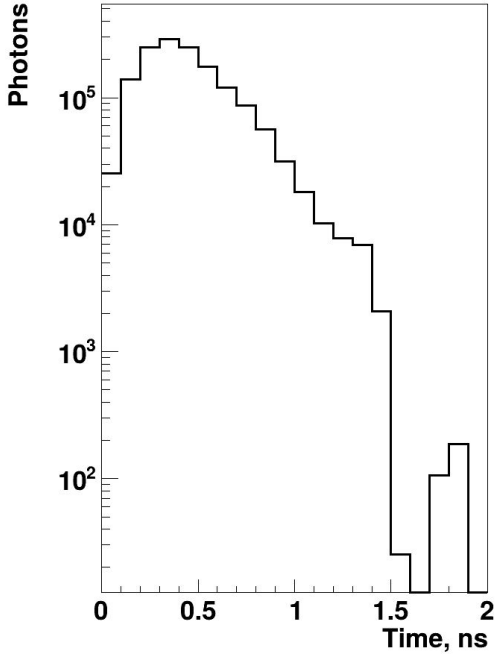
Do you have any suggestions?

Thank you for your attention!

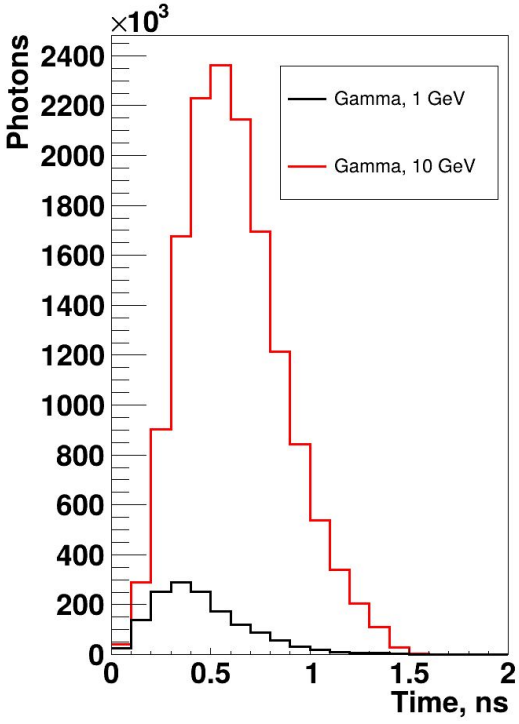


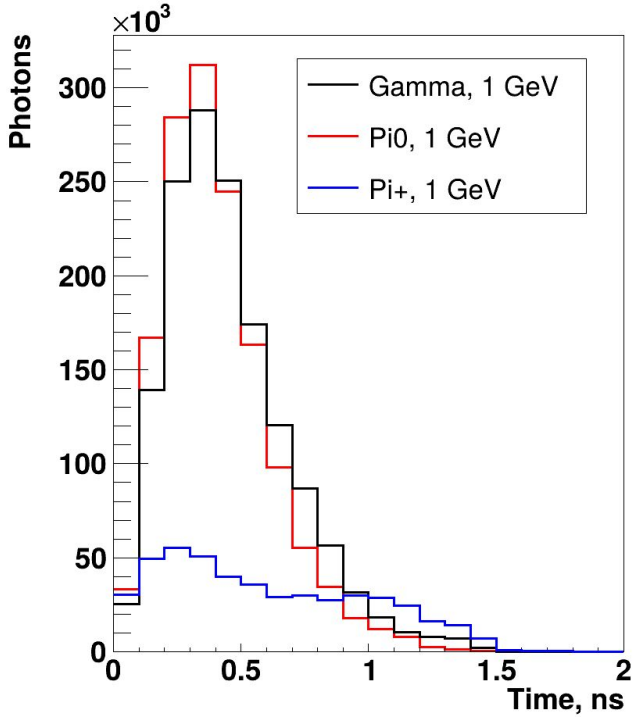
Gamma 1 GeV

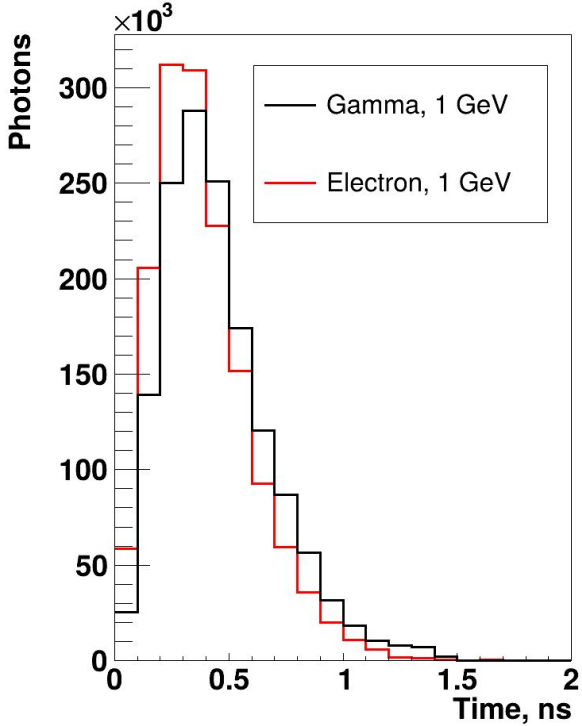


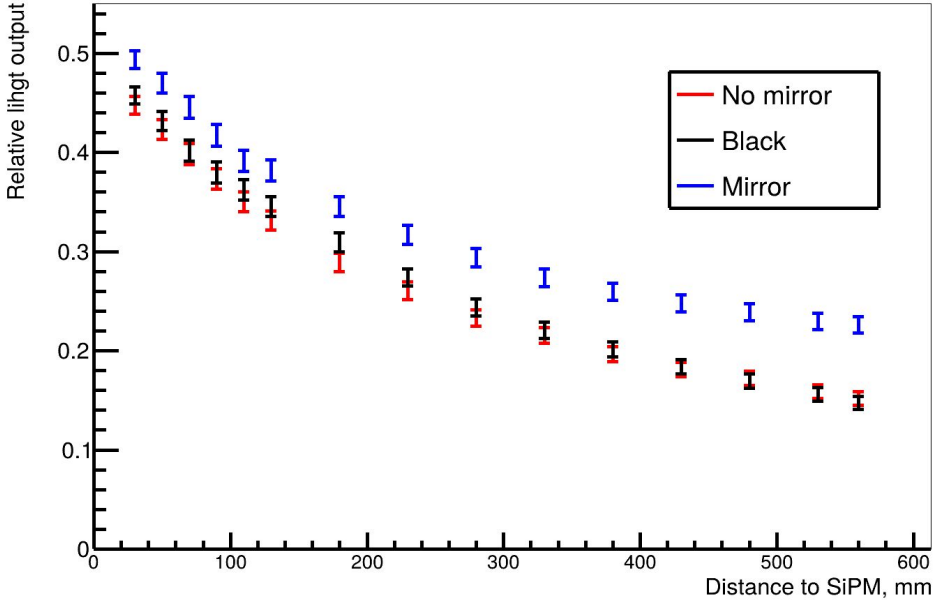


Scintillation constant = 0 ns


×10^3
Photons
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
0.5
1
1.5
2
Time, ns
Gamma, 1 GeV
Gamma, 10 GeV

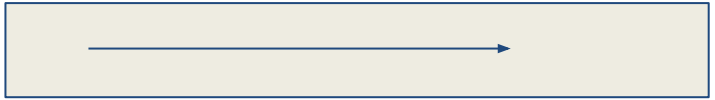

×10^3
Photons
300
250
200
150
100
50
0
0
0.5
1
1.5
2
Time, ns
Gamma, 1 GeV
Pi0, 1 GeV
Pi+, 1 GeV


×10^3
Photons
300
250
200
150
100
50
0
0
0.5
1
1.5
2
Time, ns
Gamma, 1 GeV
Electron, 1 GeV



Obtained with data measured by Vladimir Baranov and Eduard Ginya. OSL-8 (Tver, Russia).

Attenuation length of the WLS fibers

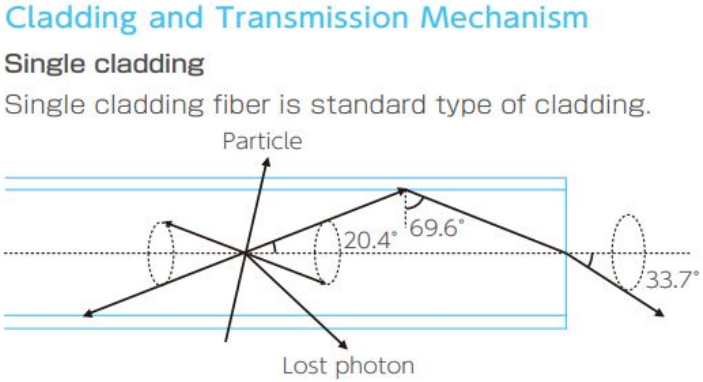


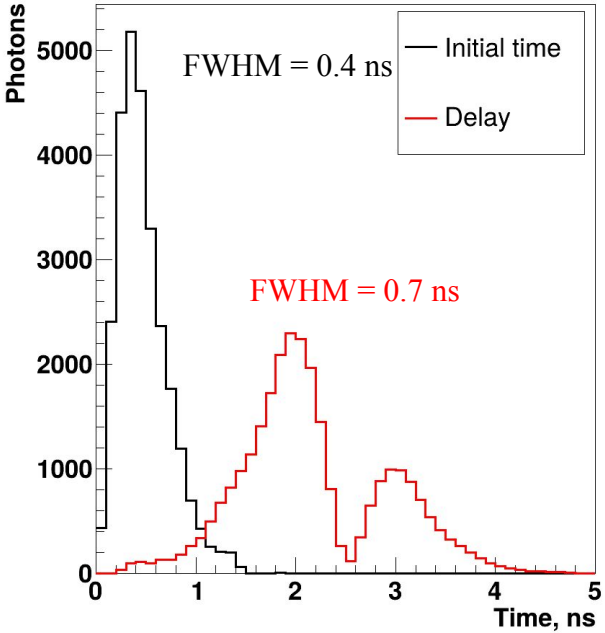
Absorption length of the material (polystyrene)



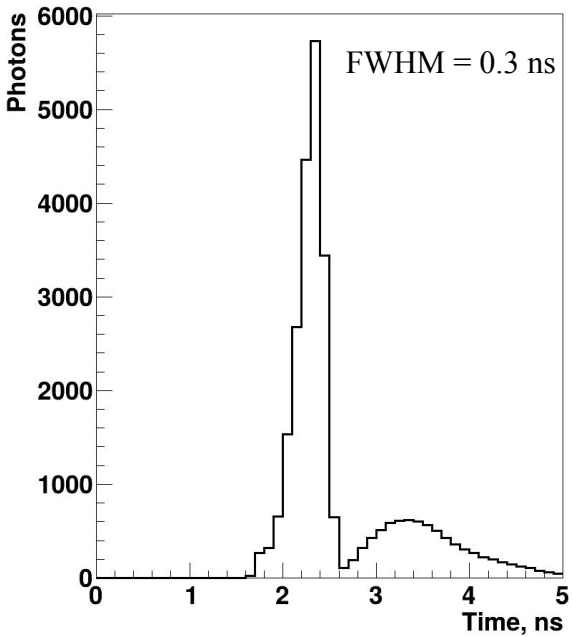
What affects the transportation time of photons in the WLS fiber?

- Absorption length of the material (polystyrene),
- Angle,
- Direction of the photon (mirror),
- Short or long components.

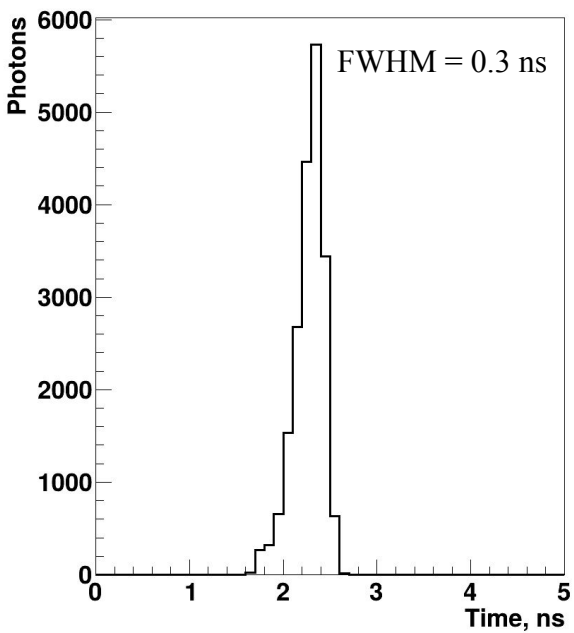




Time of the scintillation of the photons (black) and delay in the WLS fiber light guide with mirror (red)

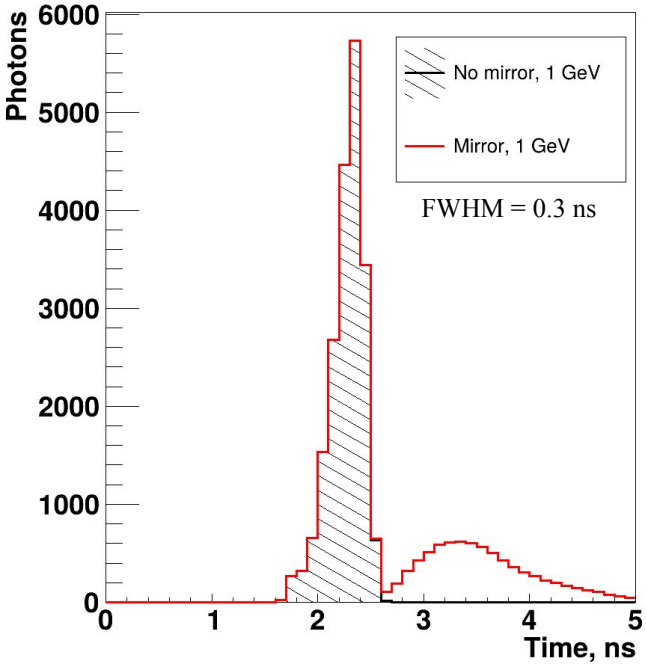


Delayed signal by the WLS fiber light guide with the mirror



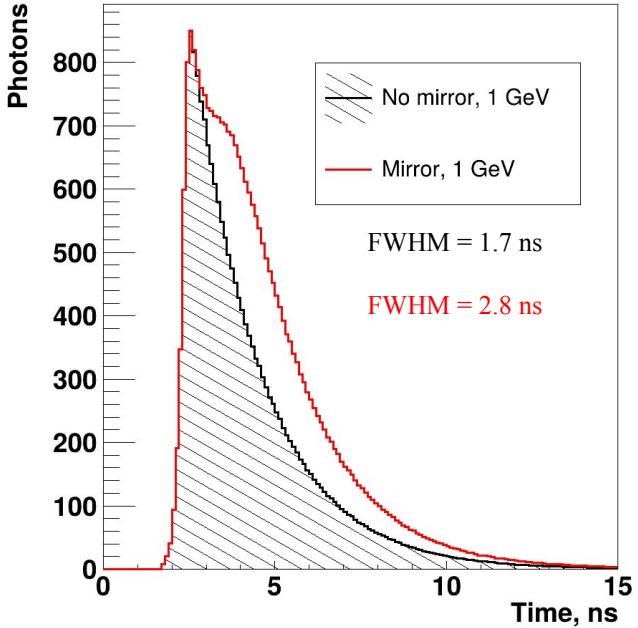
Delayed signal by the WLS fiber light guide without the mirror

Scintillation in the scintillation plate



Delayed signal by the WLS fiber light guide with the mirror (scintillation time constant = **0 ns**)

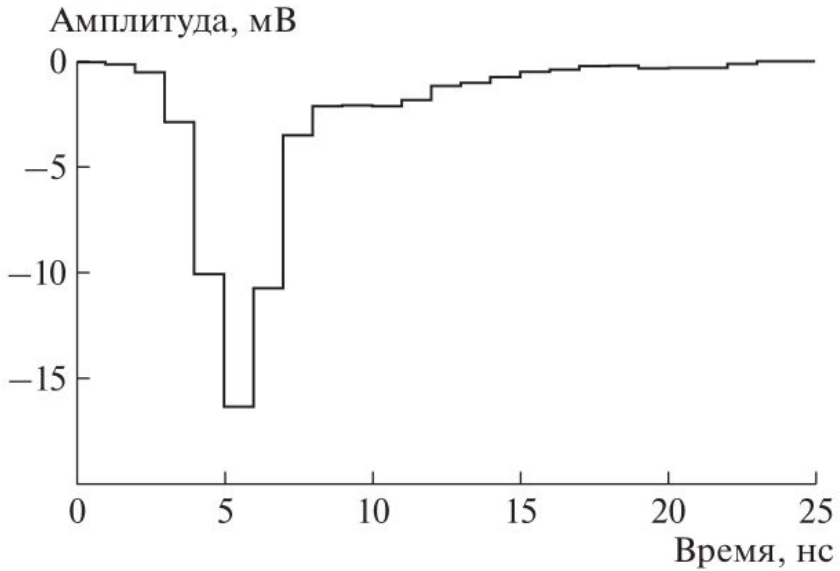




Delayed signal by the WLS fiber light guide with the mirror (scintillation time constant = **2 ns**)

Plans:

- Get Average Single Photoelectron Pulse.
- Perform a convolution of the distribution of the photons with the Average Single Photoelectron Pulse



It’s just example, not real data!

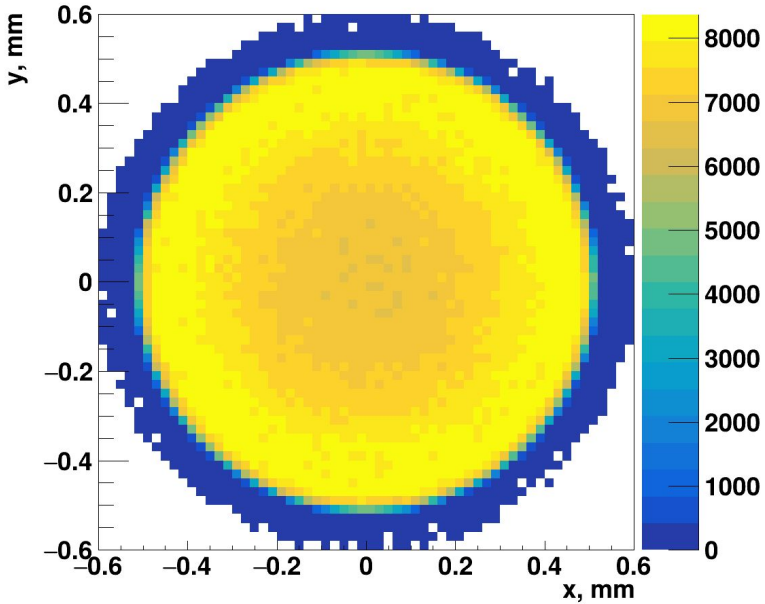
Linearity of the response of the SiPM (in progress)

Do the SiPMs have a linear response to high-energy gamma (10 GeV)?

We expect ~6300 photoelectrons from 10 GeV gamma. One WLS fiber covers an area of ~5000 cells of the SiPM, and we have 16 WLS fibers.

How do the photons distribute among the fibers?

Simulation is necessary to answer this question. If all the photons are captured by one fiber we will get a non-linear response. If they spread more evenly we will get a linear response.



Distribution of the photons at the end of the WSL fiber (simulation)