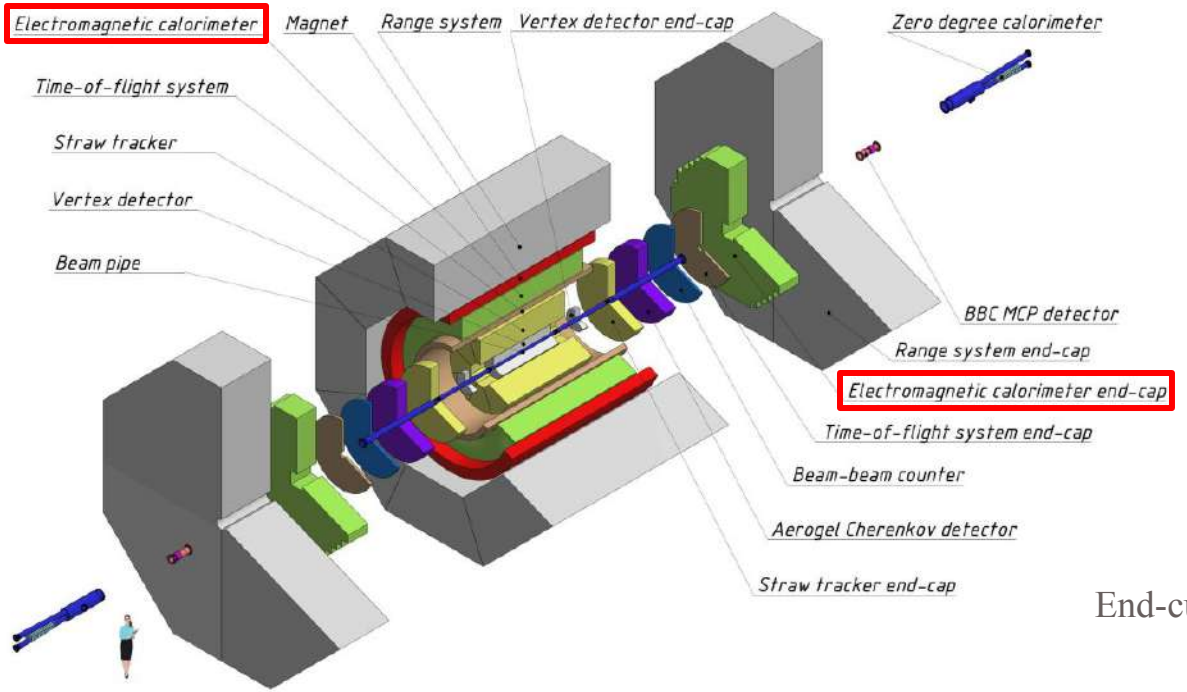
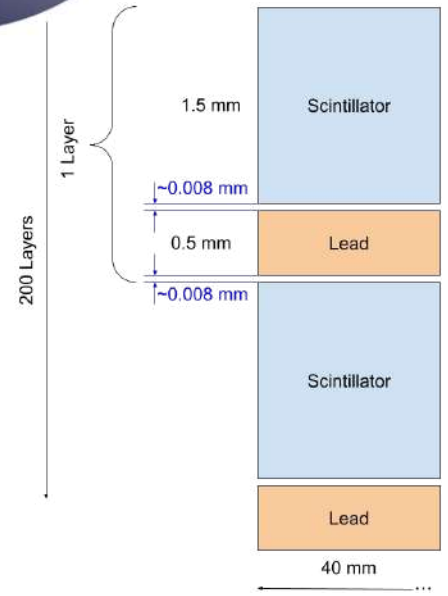
Status of development and implementation of algorithms for simulating electromagnetic calorimeter (SPD ECal) using Sampo software platform

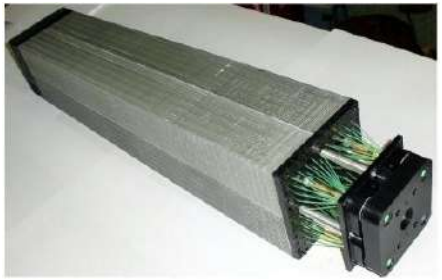
Zimin I.

Electromagnetic Calorimeter (NICA SPD)

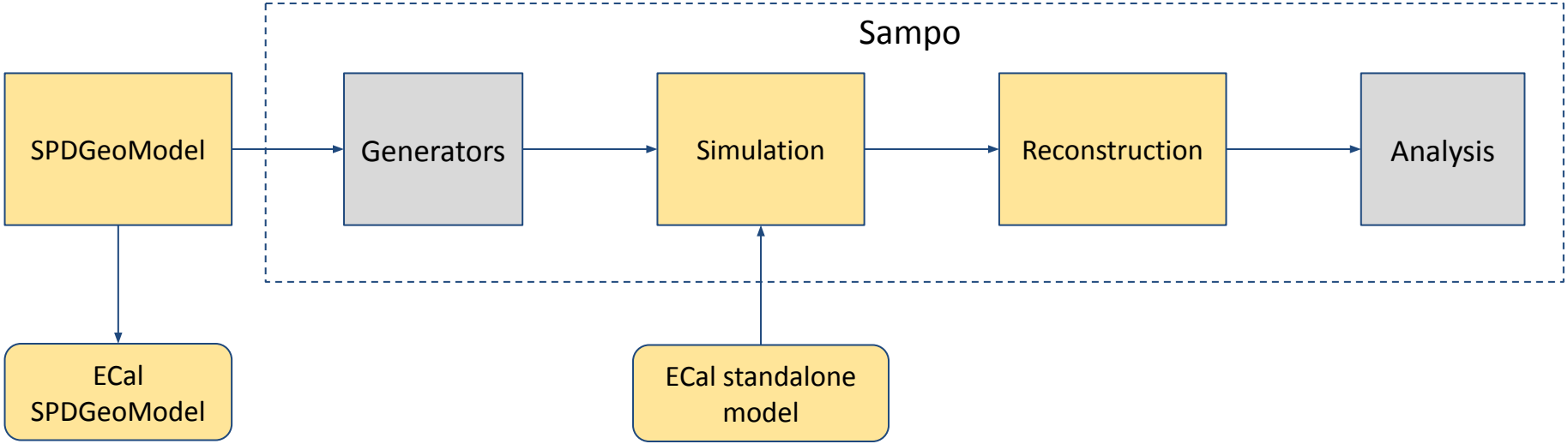




End-cup



- **Sampo** is Gaudi-based offline software for full simulation of SPD. Sampo serves as a substitute for SPDRoot.
- **SPDGeoModel** is offline software based on GeoModel and is used for creating the geometry of the detectors.





We, together with Evgeny Chernyaev, have created the GeoModel of the SPD ECal, which is used in SAMPO.

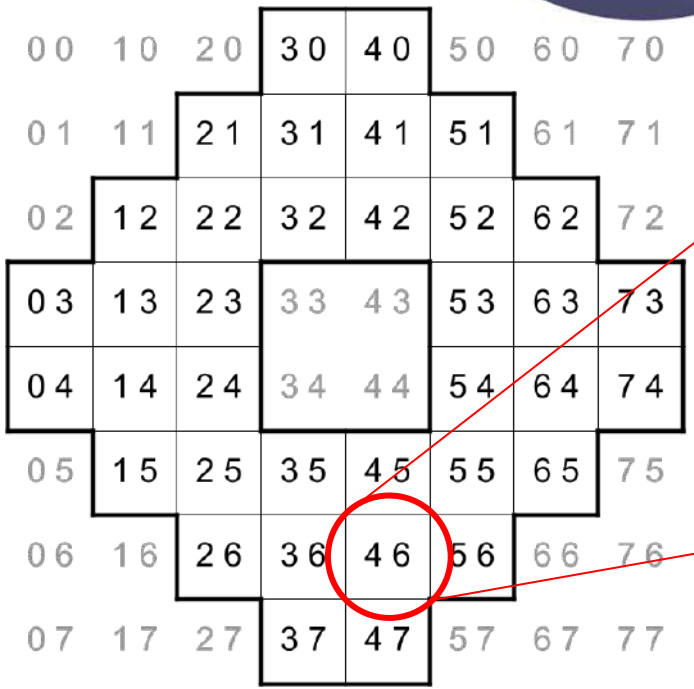
ID Encoder and ID Decoder

ID (EndCap):

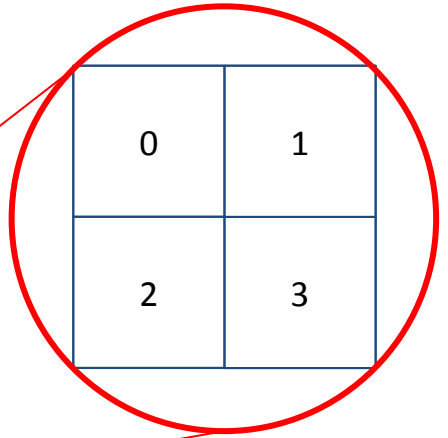
- SubSystem ID (21 or 22)
- X module ID (0..35)
- Y module ID (0..35)
- Cell ID (0..4)

ID (Barrel):

- SubSystem ID (20)
- Sector ID (0..16)
- Azimuthal module_ID (0..6)
- Z module ID (0..46)
- Cell ID (0..4)



Simplified structure of the ECal EndCap



Structure of the ECal Module

Our goal was to create one id for each sensitive volume (cell)!

ECal in Sampo

Generators

Geant4

ECalMCSteps

Generator of the parametrization function (standalone MC model of ECal cell)

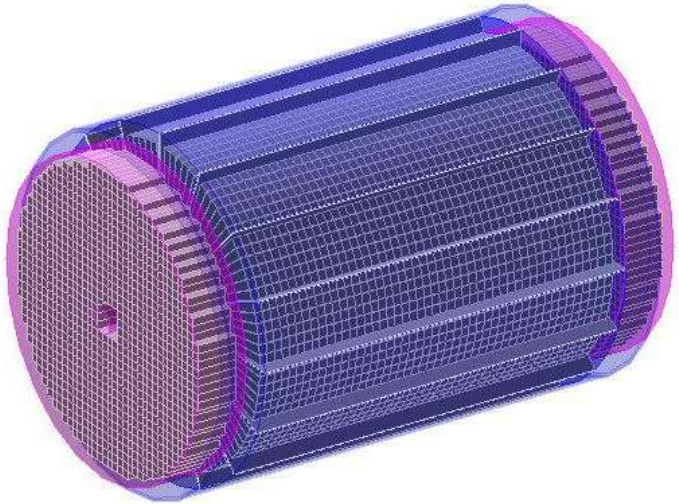
Simulation

ECalMCHit MakerAlg

ECalMCHits

ECalDigiMakerAlg

ECalDigis



Now we are nere!

Reconstruction

ECalRecoHit MakerAlg

ECalRecoHits

ECalCluster MakerAlg

ECalClusters

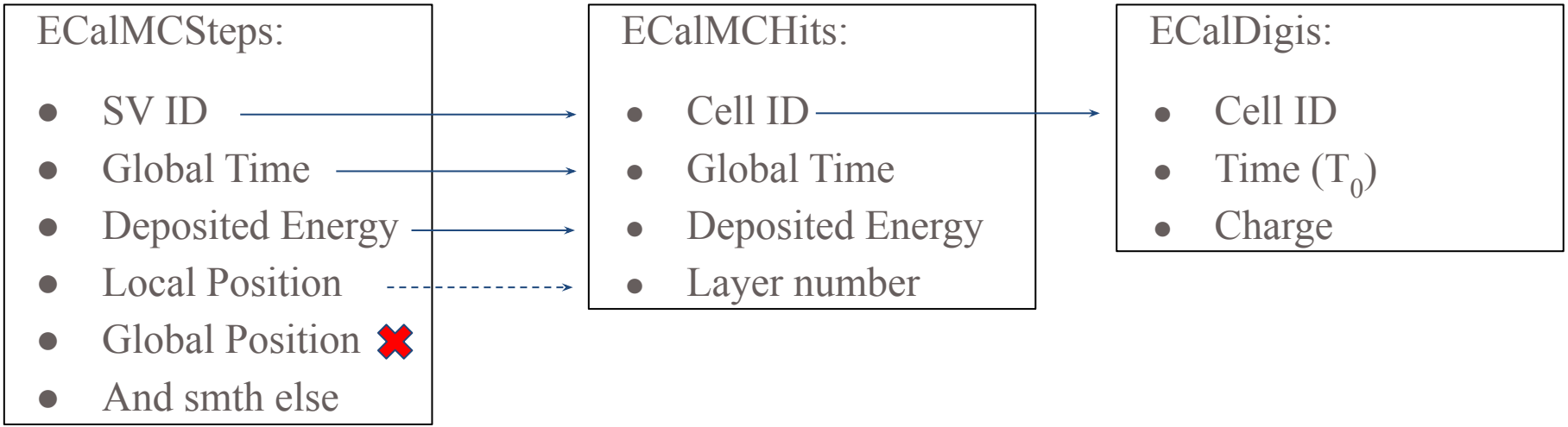
Analysis

Simulation

Geant4

The **ECalMCHit** represents all the preparation that can be done for digitization without any knowledge of electronics parameters.

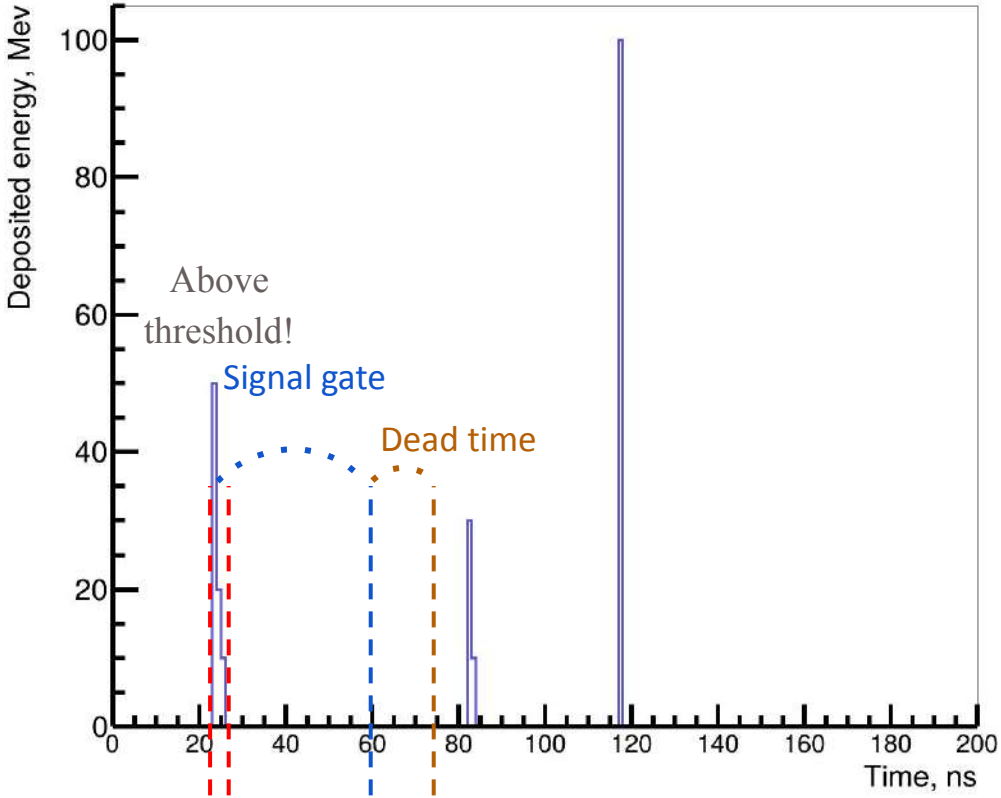
The **ECalDigi** is the simulated response of the ECal electronics.



ECalDigis: Hit sorter

Hit sorter:

1) Sort hits by cell ID.
2) For each individual cell, it finds and sorts all associated signals by their time:
   a) For each cell, a histogram is filled with all its hits, weighted by their deposited energy (see Picture).
   b) A window (3 ns) is moving to the right while energy within it reach the threshold.
   c) Perform digitization within the signal gate.
   d) The window "jumps" to the right Signal gate + Dead time.
   e) Keep going.



These are random numbers in the picture, not real data! Just for an example!

ECalDigis: Digitization

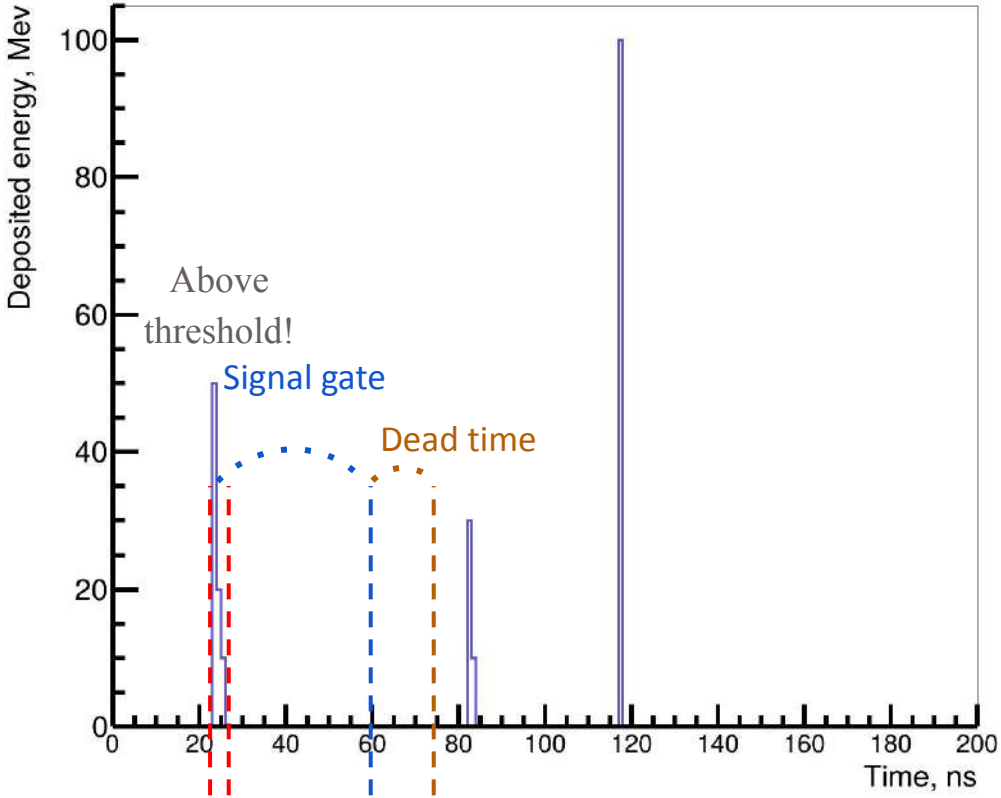
Digitization:

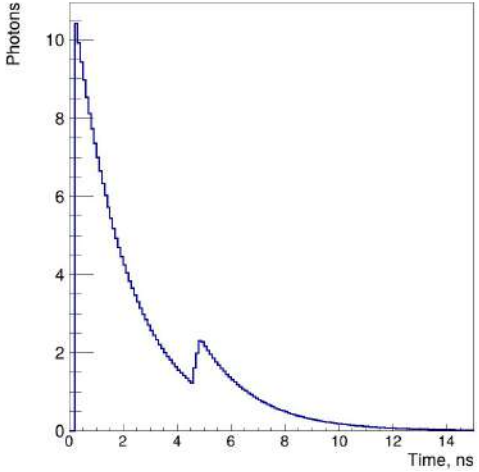
1) Set gate for charge integration and dead time for signals.
2) Sort hits by layers.
3) Perform a convolution of the hits in each layer with a parametrization function.

The parametrization function of the cell i-layer is a response of the detector when a particle deposits 1 MeV in this layer.

Where does the parametrization function come from?

It comes from a standalone Monte Carlo Model of the ECal cell.



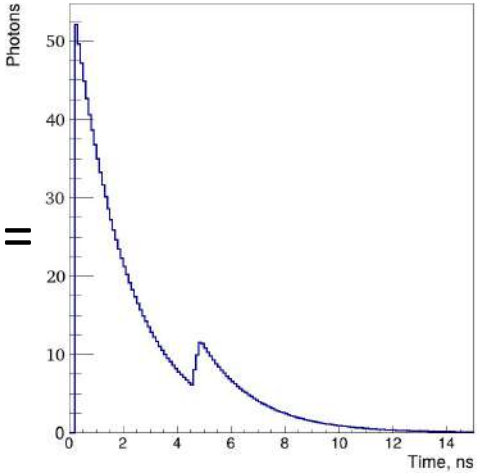


The parametrization function for i-layer (the response of the detector for the i-layer)

×

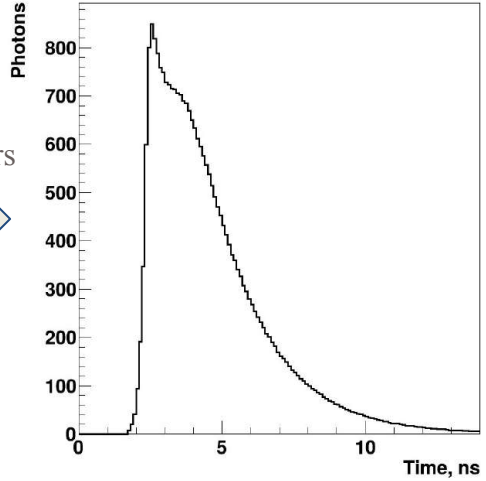
Deposited energy in the i-layer

=



Result pulse for i-layer

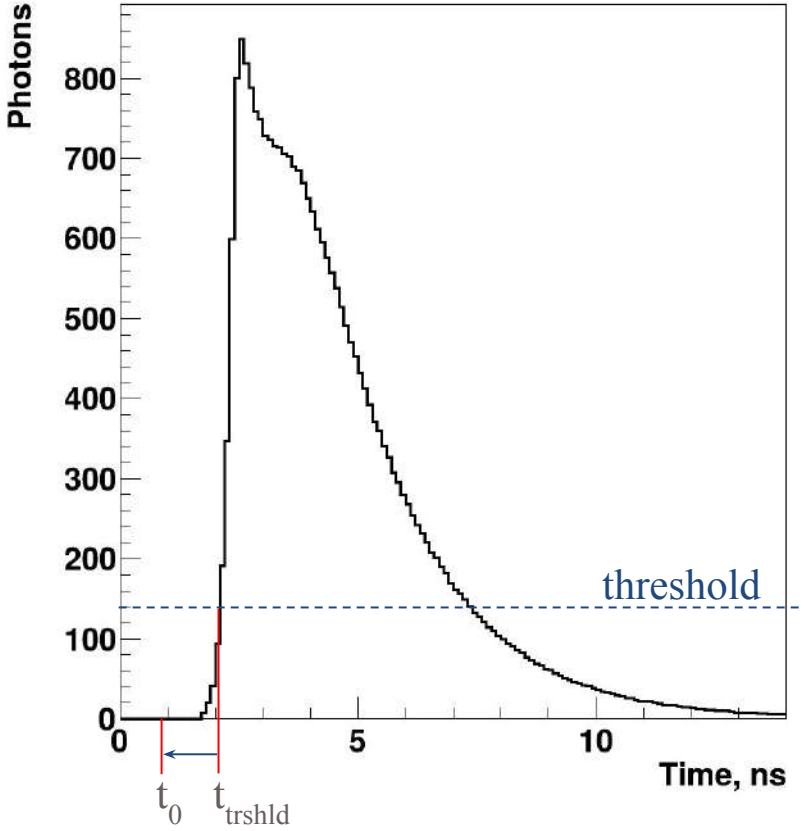
∑ all layers



Result pulse for all layers

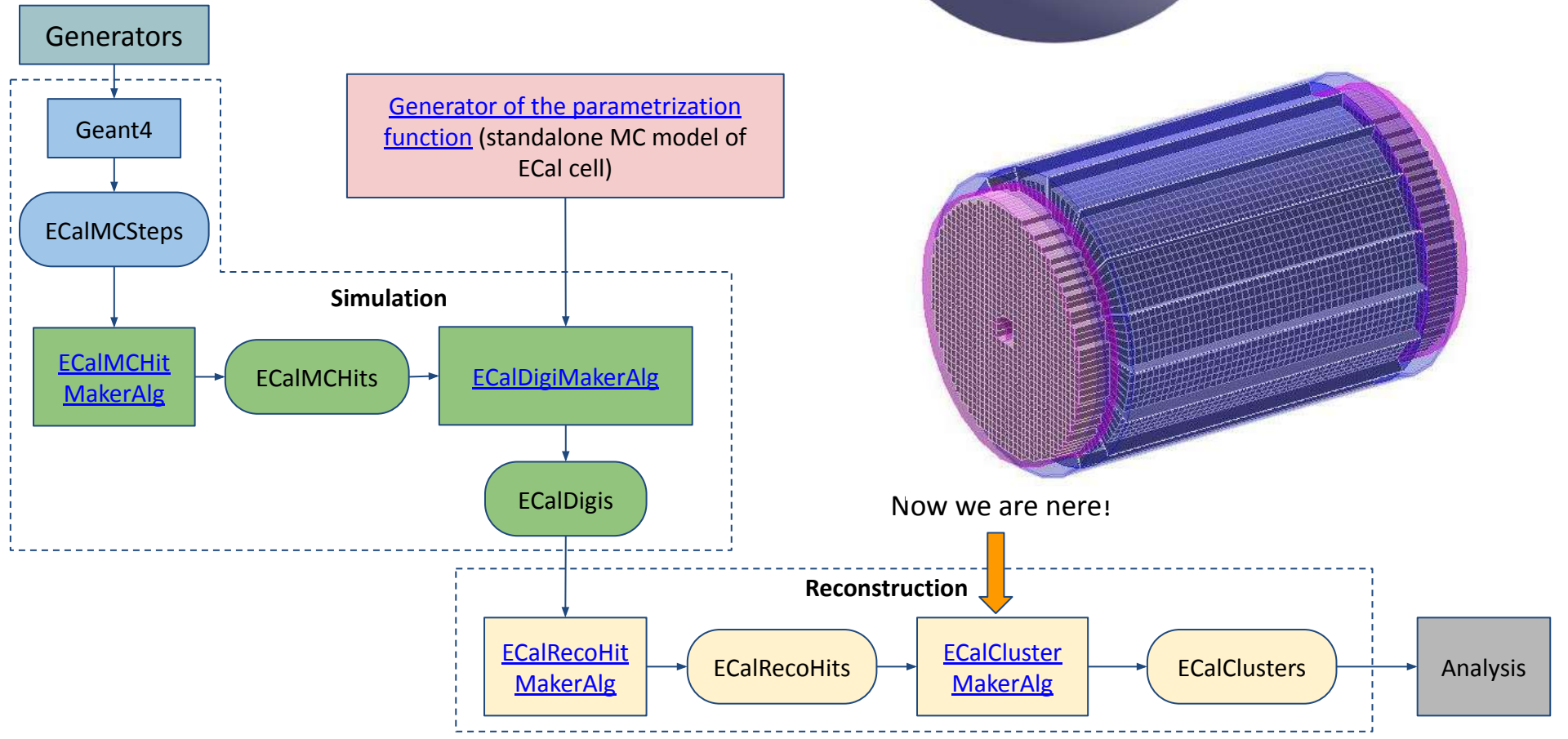
Time and charge:

1) Find t_{trshld} by threshold.
2) $t_0 = t_{trshld} - t_{prestep}$
3) Charge is integral in the signal gate

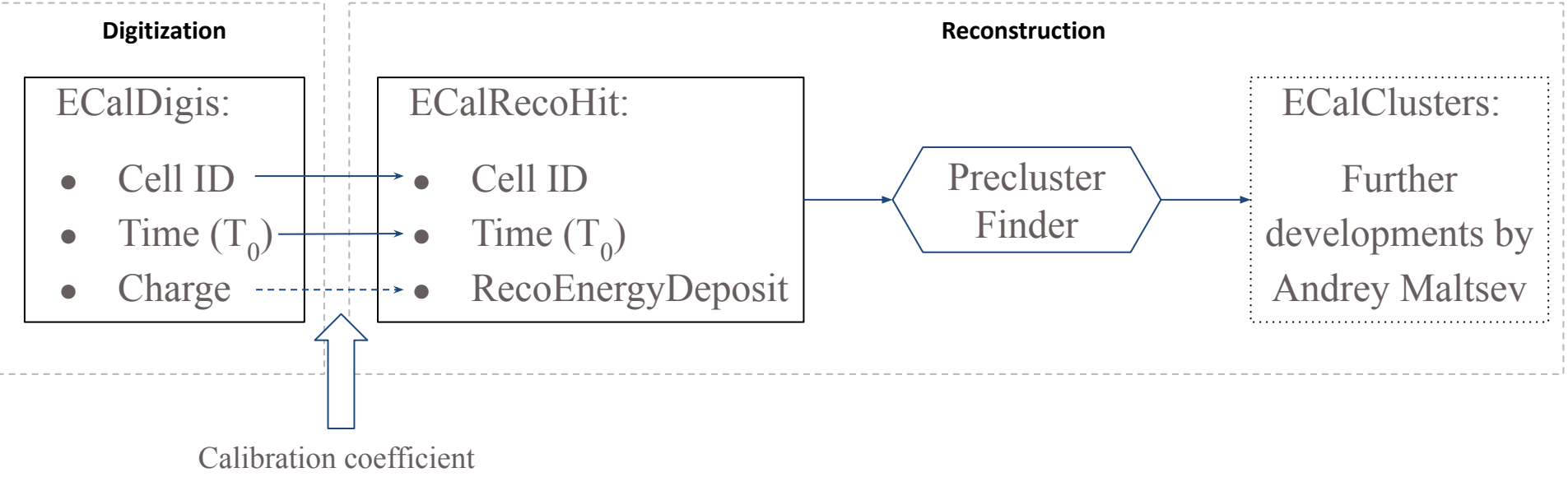


Reconstruction

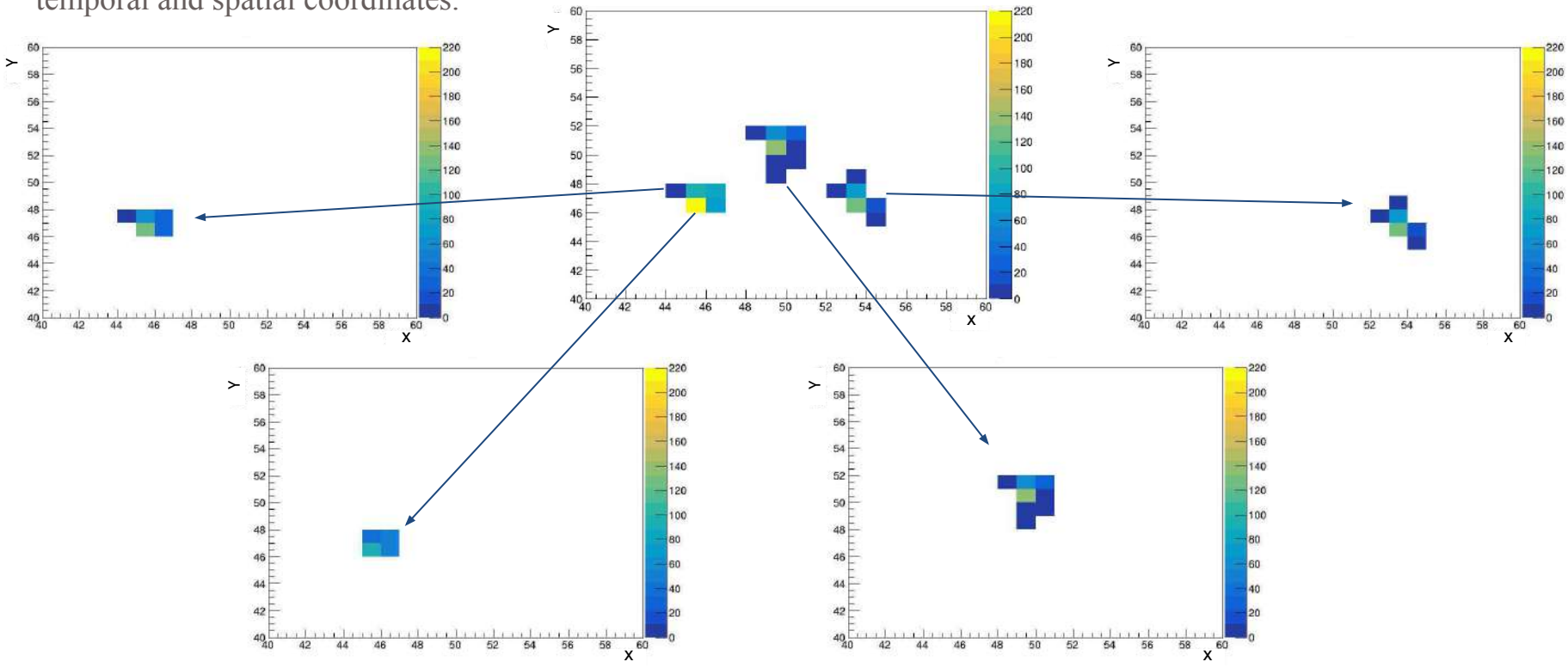
ECal in Sampo



ECalDigis to ECalRecoHit



PreclusterFinder is responsible for grouping signals from cells (ECalRecoHit) into preclusters based on temporal and spatial coordinates.



ECal standalone model

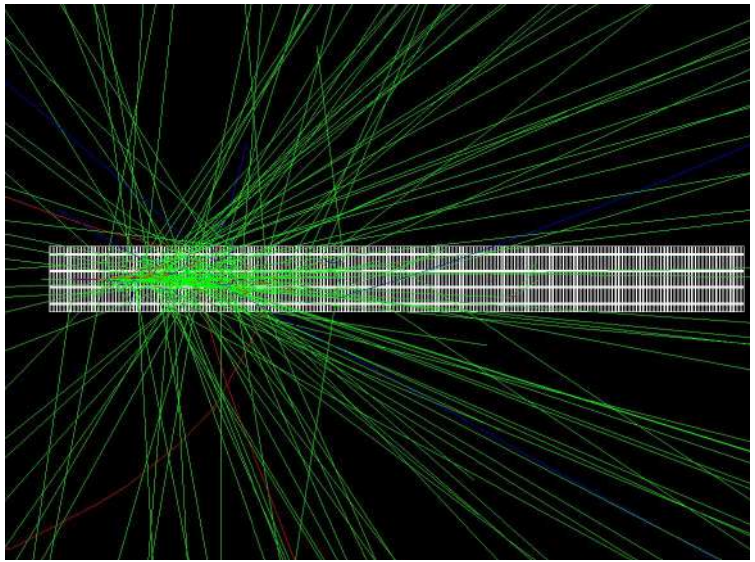
ECal standalone model

The main purpose of the **ECal standalone model** is to produce the **parametrization function**. The parametrization function of the cell i-layer is a response of the detector when a particle deposits 1 MeV in this layer.

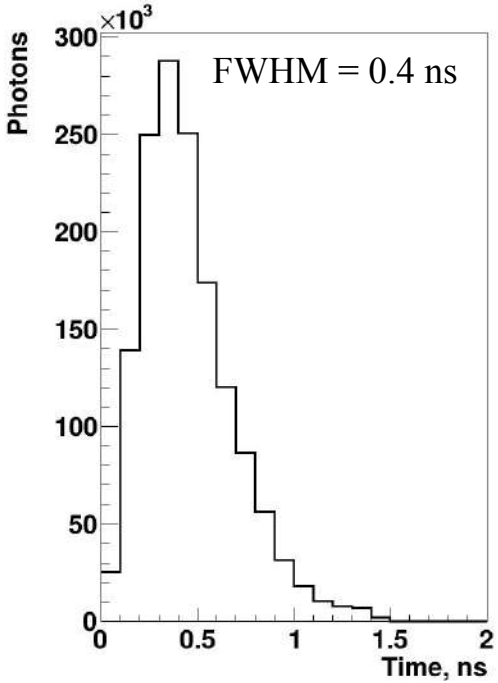
What affects the time characteristics of the signals?

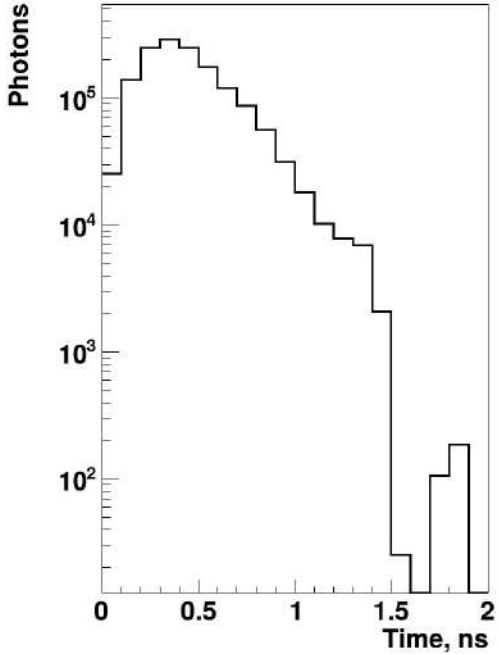
1. Longitudinal propagation of an electromagnetic shower in time.
2. Scintillation in the scintillation plate.
3. Propagation of scintillation photons in the scintillation plate.
4. Transportation of scintillation photons in the WLS fiber lightguides to the SiPM.
5. SiPM & electronics.

The EM shower propagation in time (Geant4)



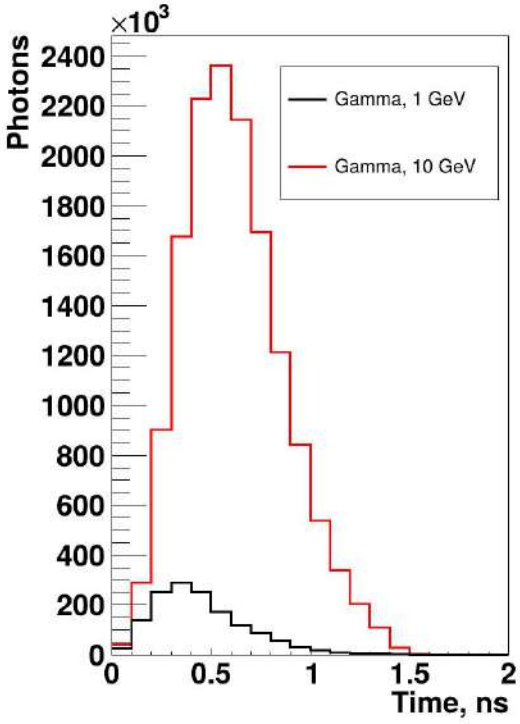
Gamma 1 GeV

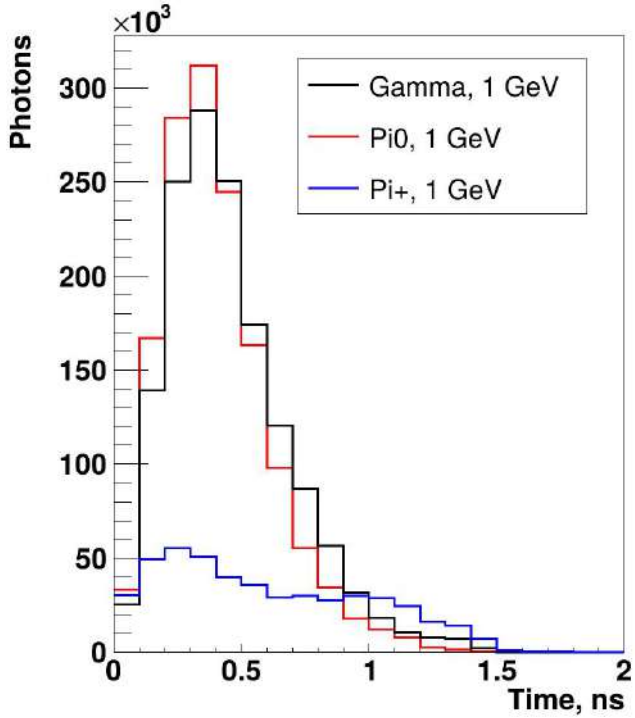


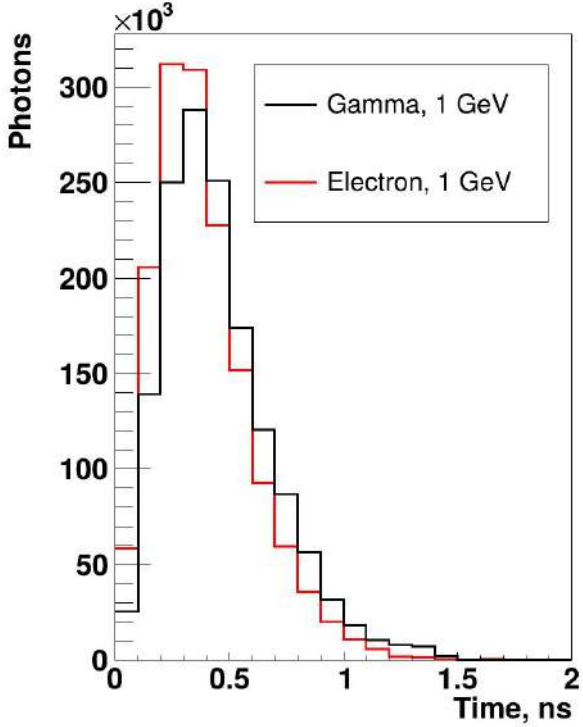


Scintillation constant = 0 ns

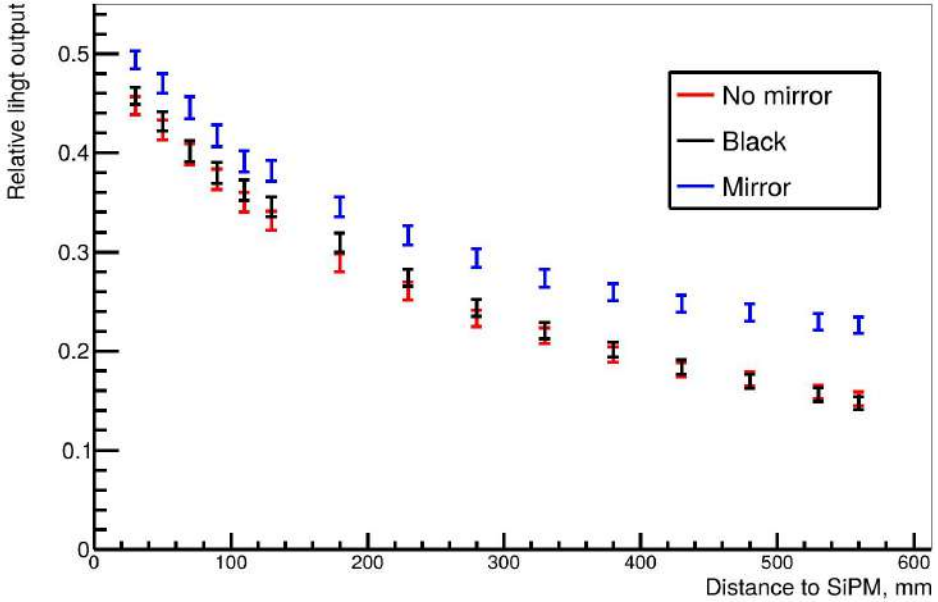
The EM shower propagation in time (Geant4)





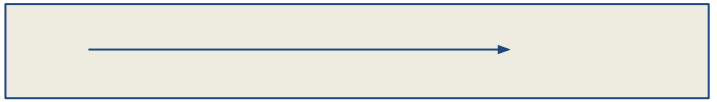


Transportation of the photons in the WLS fiber



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

Attenuation length of the WLS fibers

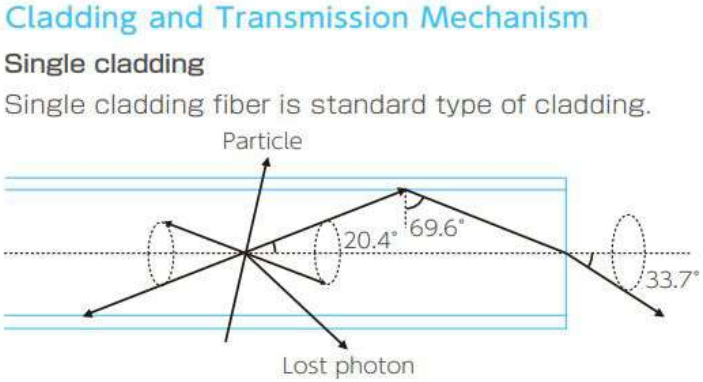


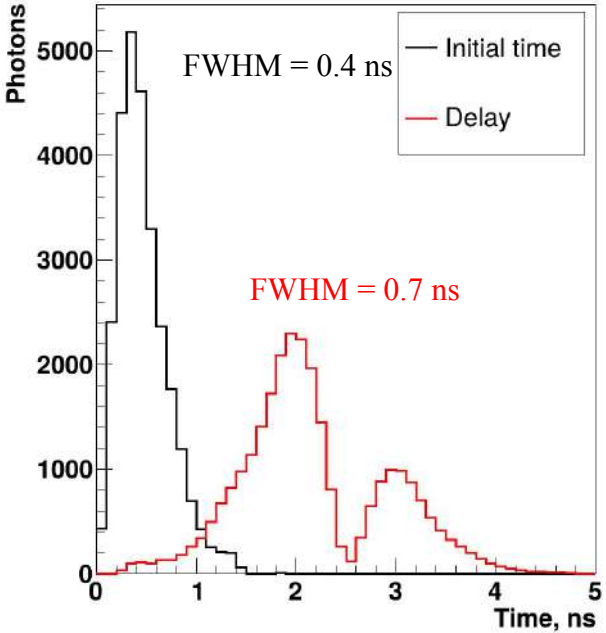
Absorption length of the material (polystyrene)



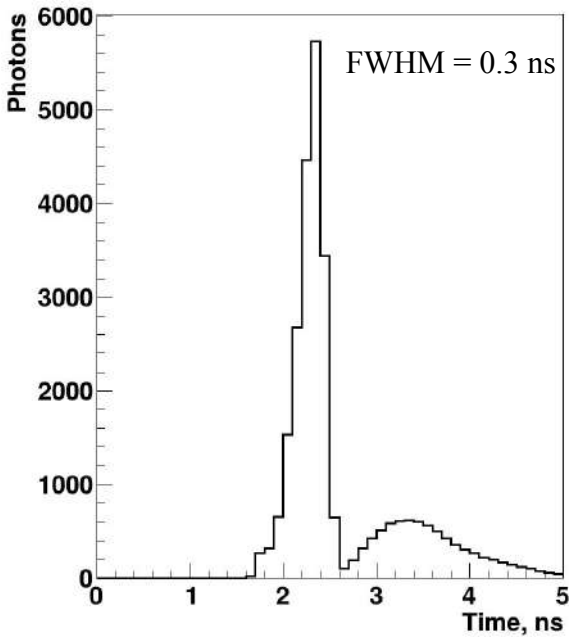
What affects the transportation time of photons in the WLS fiber?

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

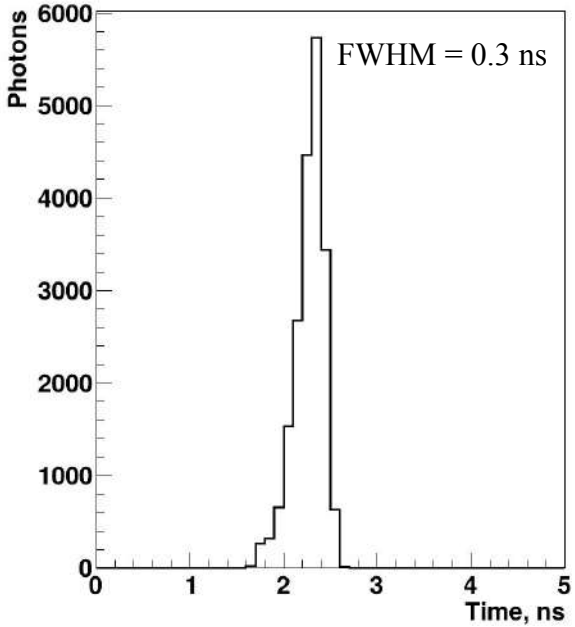




Time of the scintillation of the photons (black) and delay in the WLS fiber light guide with mirror (red)



Delayed signal by the WLS fiber light guide with the mirror



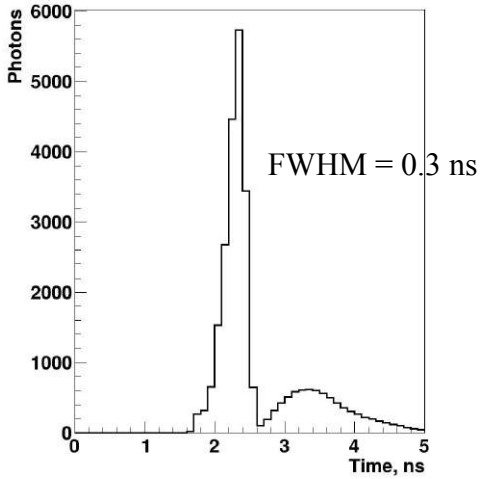
Delayed signal by the WLS fiber light guide without the mirror

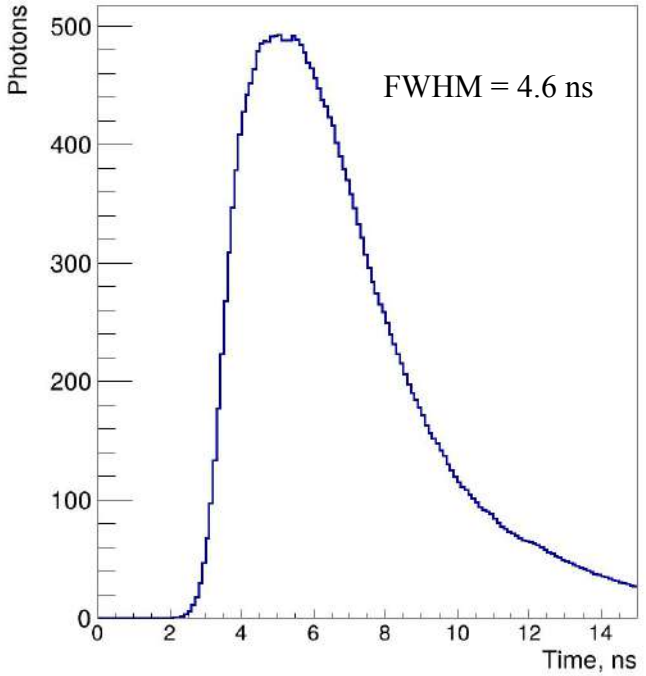
Scintillation in the scintillation plate



Data provided by N. Anphimov et al.

Delayed signal by the WLS fiber light guide with the mirror without scintillation

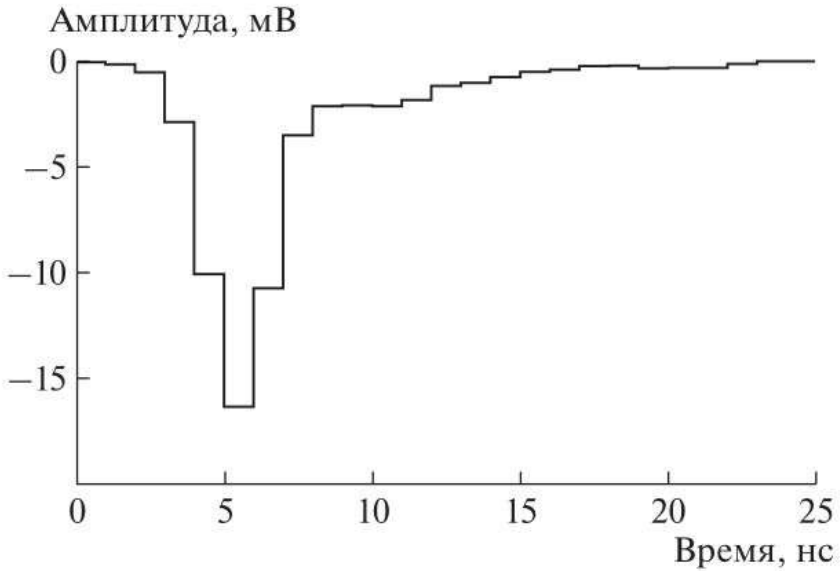




Delayed signal by the WLS fiber light guide with the mirror with scintillation

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!

The whole cell 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 lightguides was not simulated! It was discussed yet.

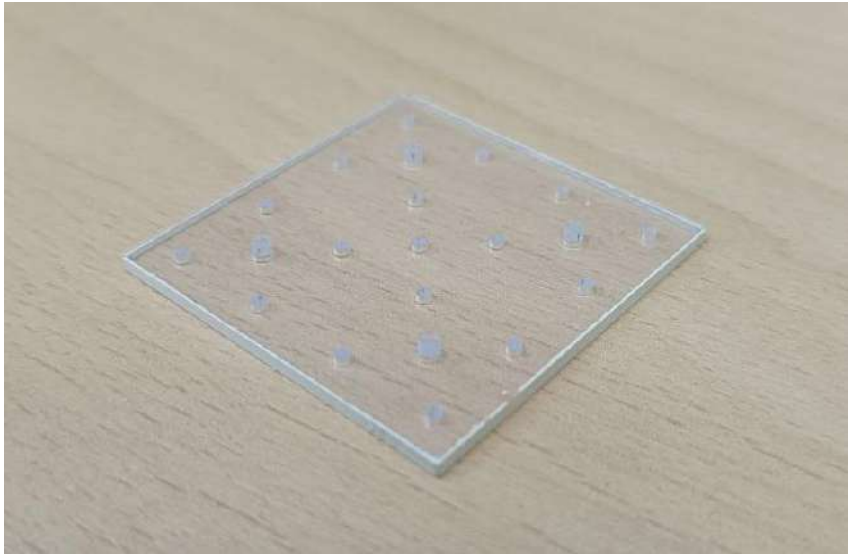
Parameters for optical Monte Carlo model

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) Refraction coefficients of the fiber core and cladding.
5) Absorption length of the WLS fiber (Kuraray Y11).

Parameters needing further definition:

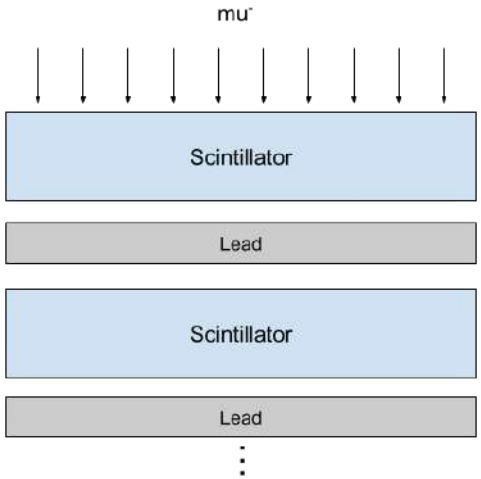
1) Absorption length of the polystyrene (30-300 mm).
2) Paint reflection efficiency at plate edge: 80–98%.
3) Lead plate reflection efficiency: 30–50%

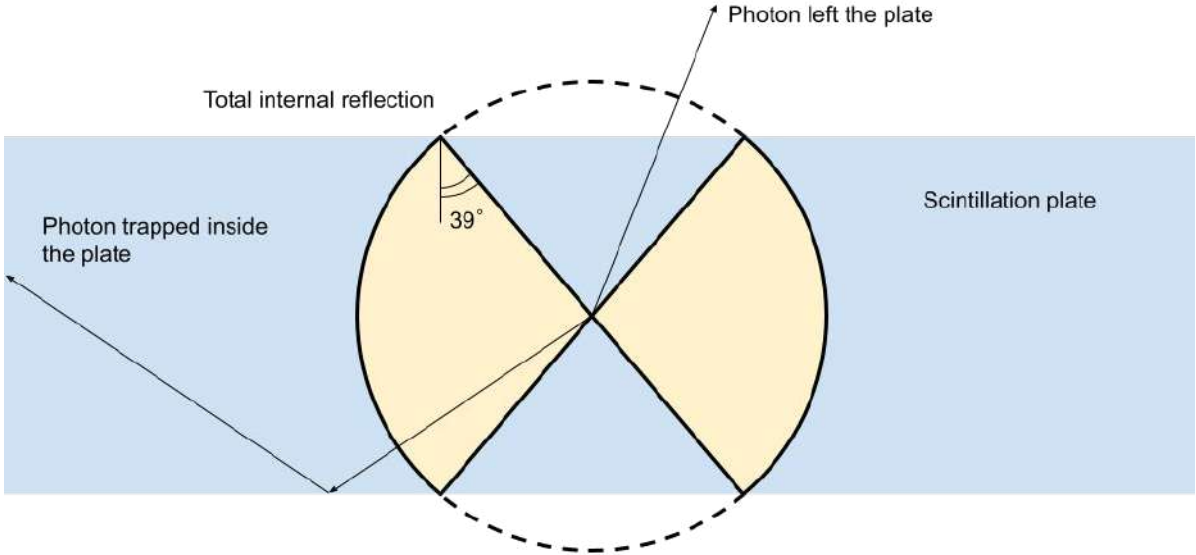


A **1 GeV muon** beam at **normal incidence** with a **uniform spatial distribution** entered the cell.

The fraction of photons exiting the plate and subsequently 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.





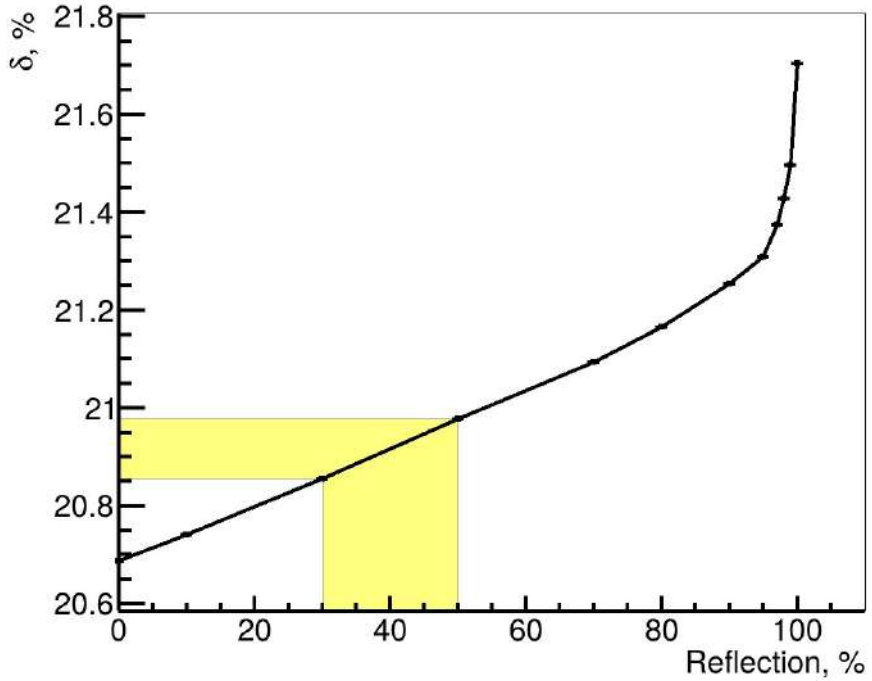
Lead plate reflection efficiency

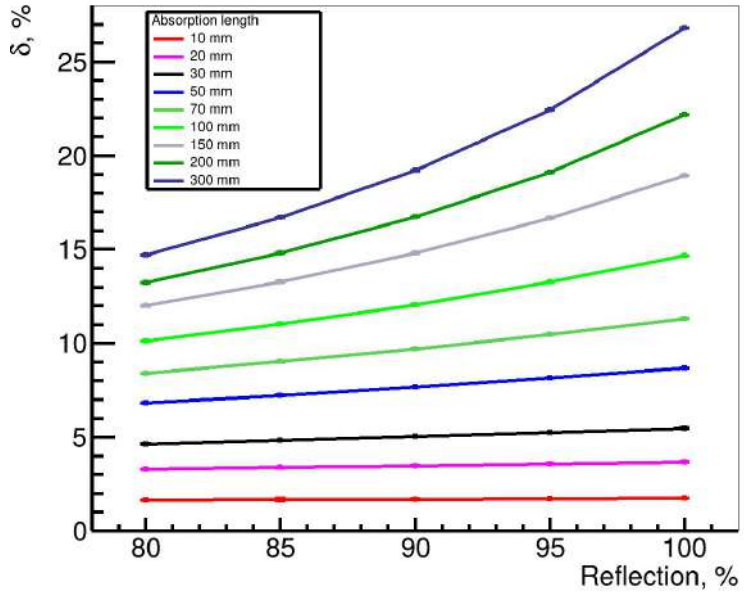
δ is the fraction of scintillation photons captured by the WLS fiber. (1-δ is losses in the layer).

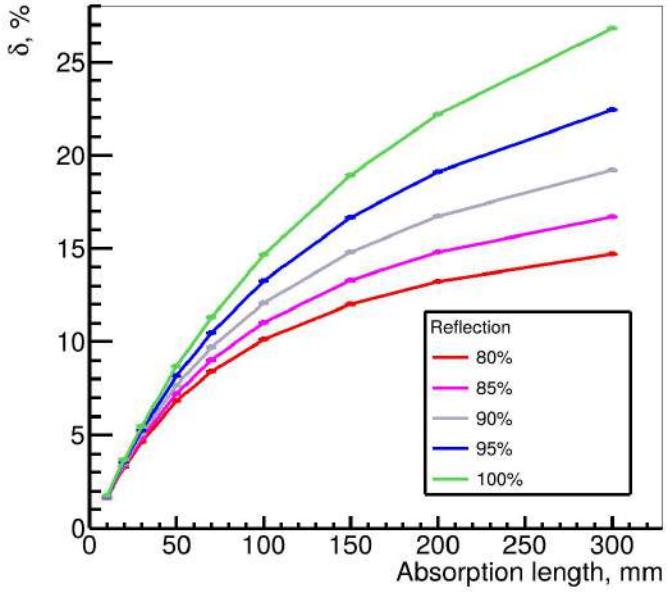
In the MC model the white paint reflection efficiency is set to **98%**, and the polystyrene absorption length is set to **200 mm**.

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.**





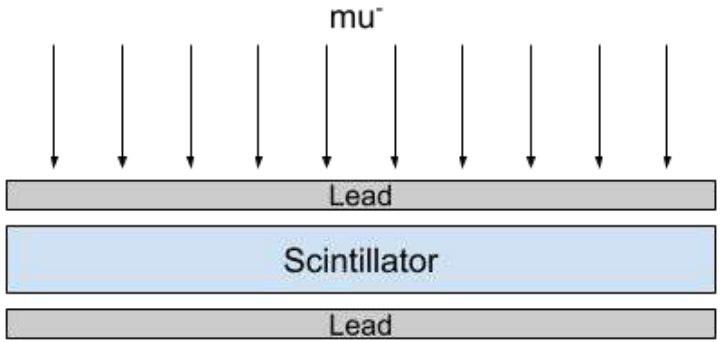


Lead plate reflection efficiency is set as **30%**. White paint reflection efficiency usually is **from 80 to 98%**. Absorption length of the polystyrene is **from 30 to 300 mm**.

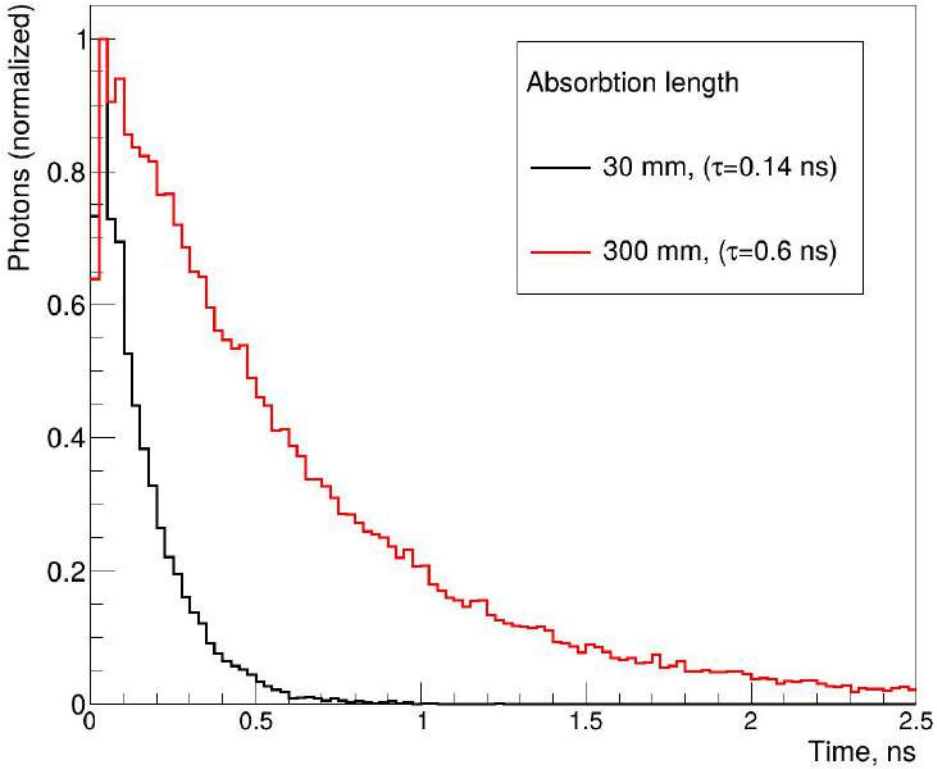
δ shows a strong dependence on the reflection efficiency and absorption length. **Therefore it is necessary to determine the values of these parameters with good accuracy.**

Scintillation photons propagation time

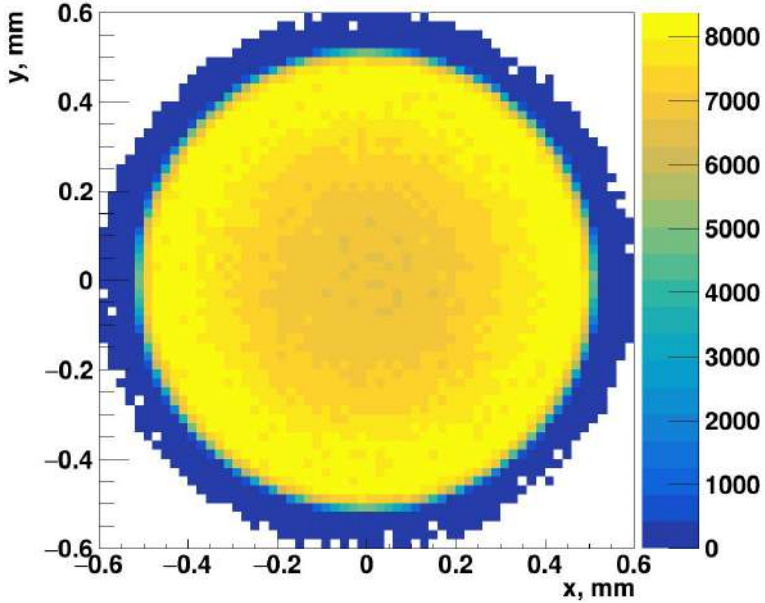
In this simulation, only one scintillation plate with two lead plates was considered (see picture below). A normal-incidence muon beam entered the layer. It had a uniform spatial distribution over its cross-section . Muon energy was 1 GeV.



Propagation time shows a strong dependence on the absorption length.



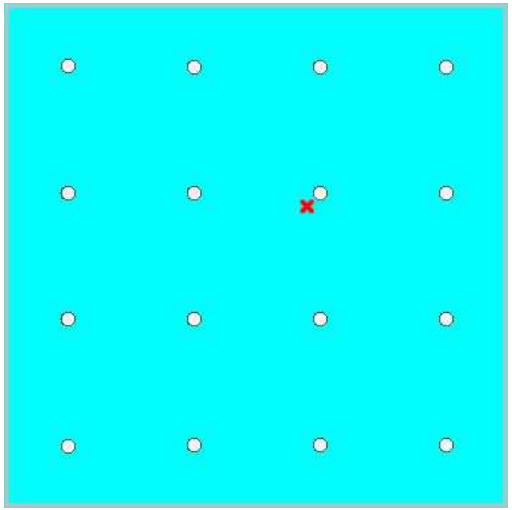
Linearity of ECal response

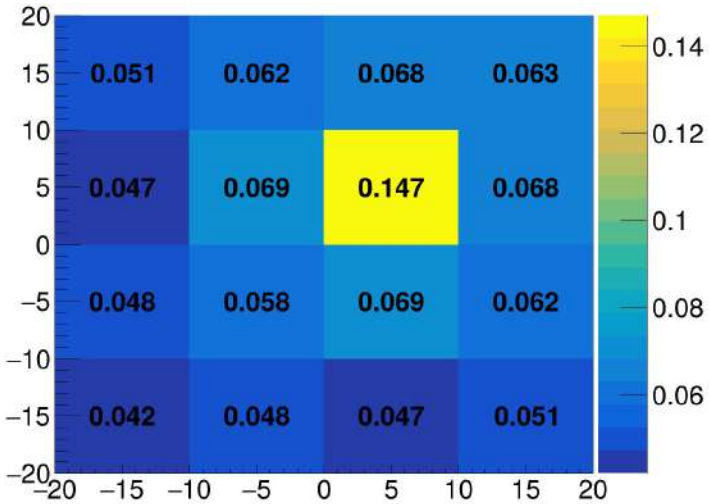


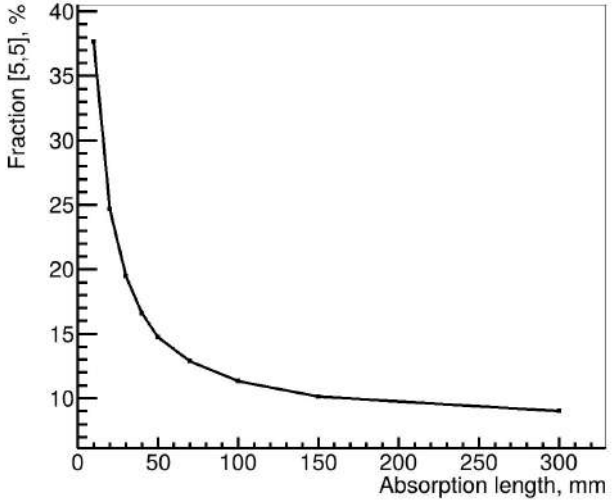
Distribution of the photons at the end of the WSL fiber (simulation)

The whole cell 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%**.





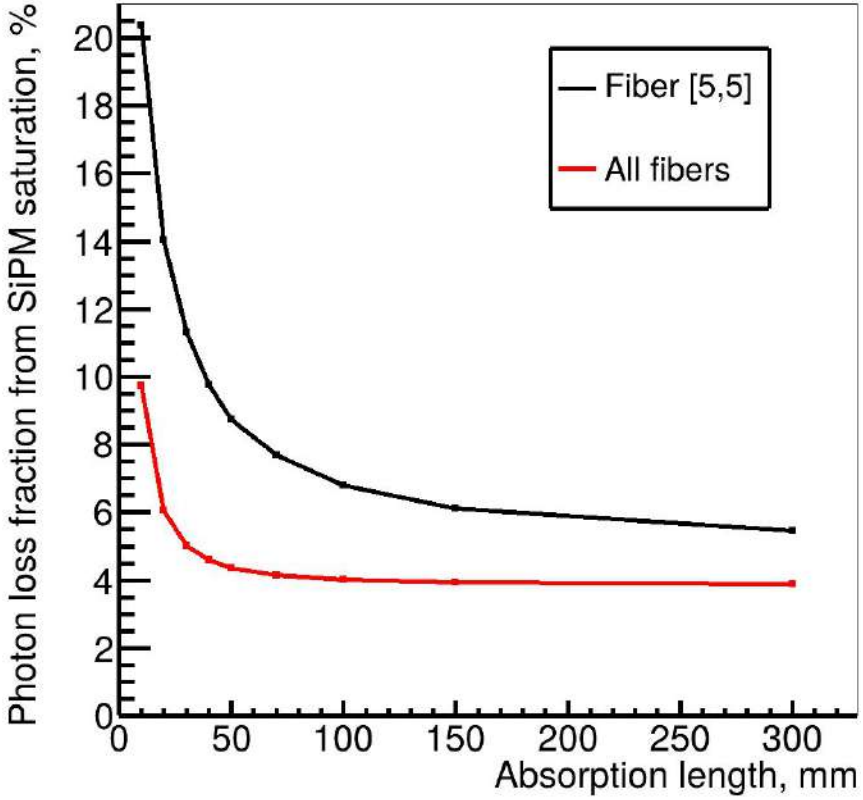


A long absorption length leads to a more even distribution of photons in the fibers.

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

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.

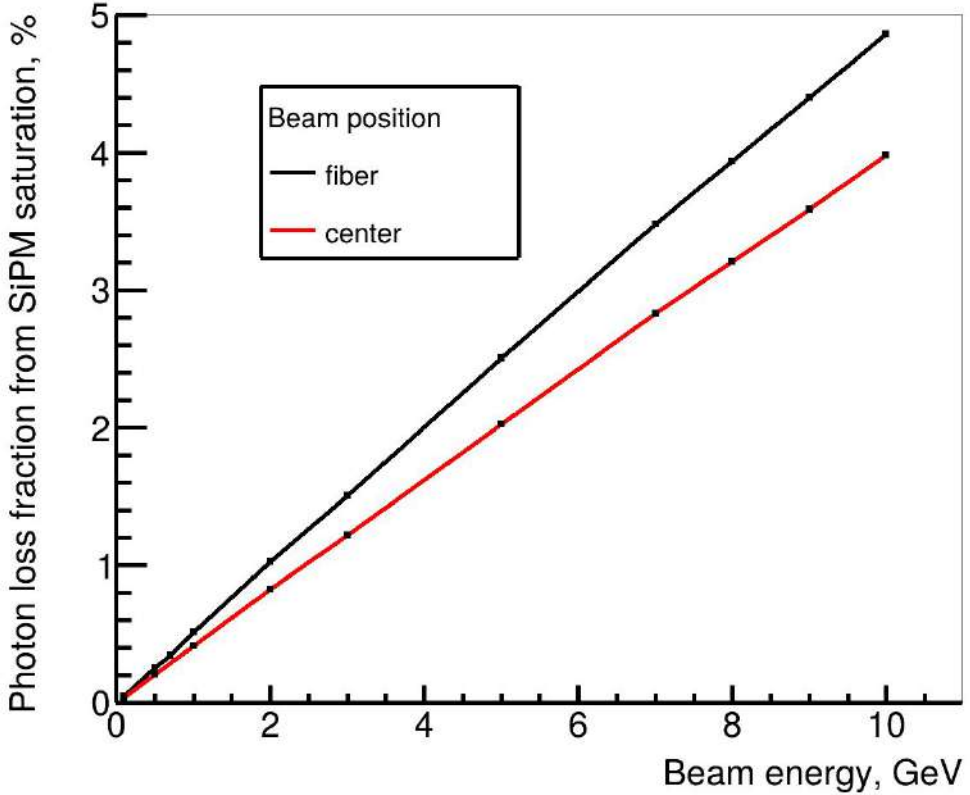
Some photon loss occurs in the fiber [5,5] due to SiPM saturation. **However, for all fibers, this loss is negligible. Therefore, the SiPM response remains linear.**



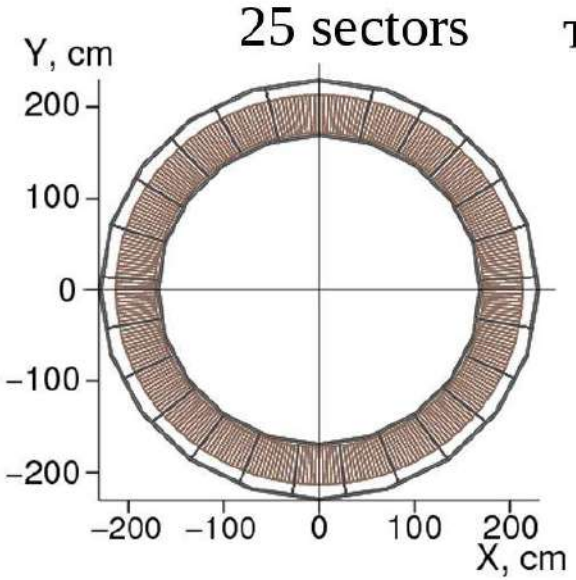
Linearity vs energy and beam position

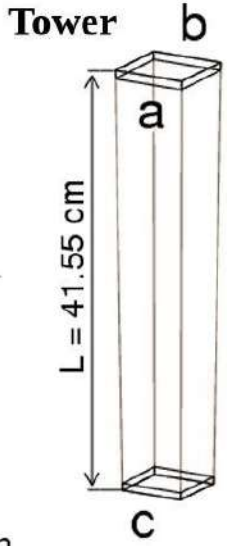
The polystyrene absorption length is set to 30 mm.

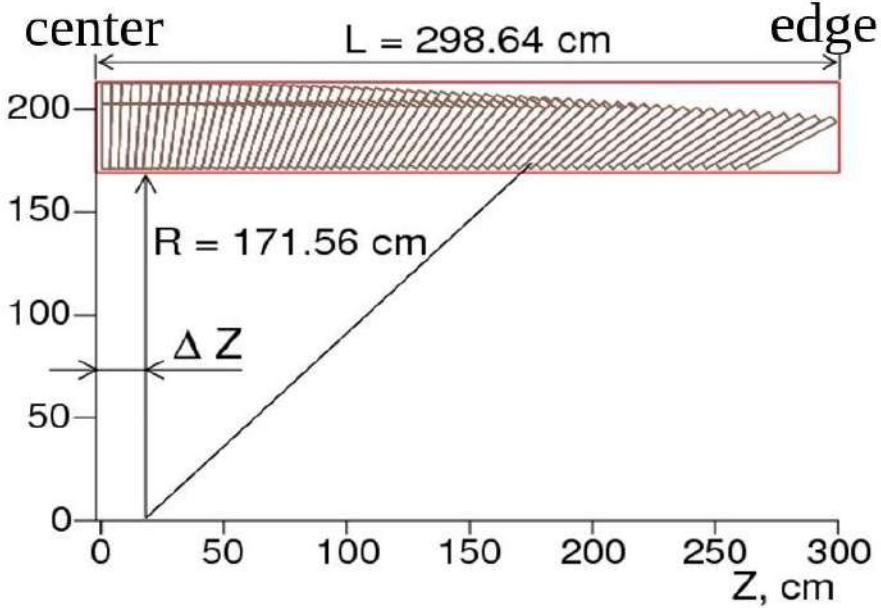
In conclusion, the main cause of nonlinearity in the SiPM response is the total number of scintillation photons, not their distribution among the fibers.



Further plans

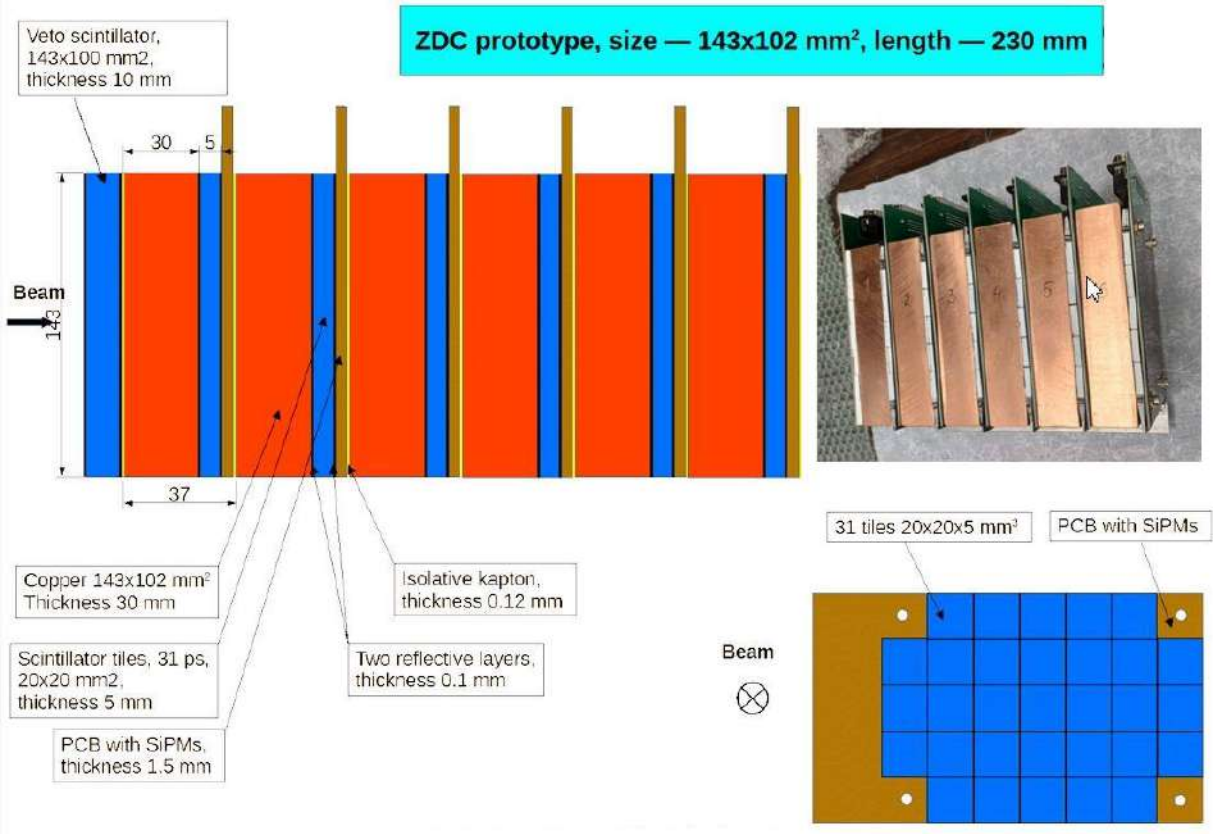






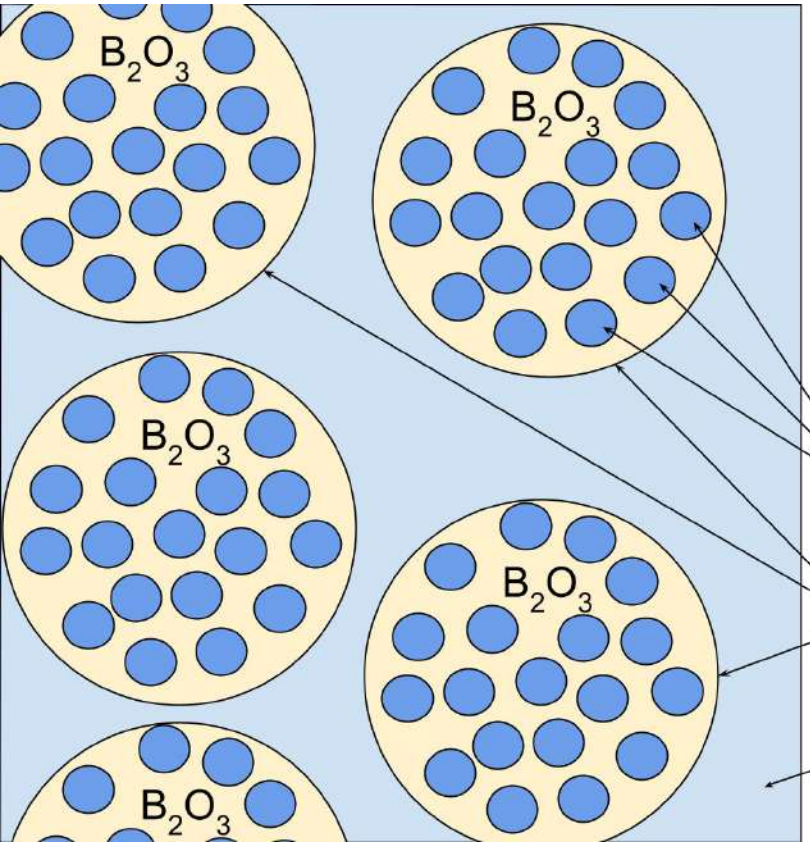
Viacheslav Kulikov on behalf of the **MPD**/ECAL group, CALIBRATION OF THE ECAL, XII MPD Collaboration Meeting, 2-6 October 2023, Serbia

Other activities



I. Alekseev (KCTEP NRC KI, Moscow), Zero Degree Calorimeter (ZDC) for SPD, XI SPD collaboration meeting, 18-22 May, Tomsk

Composite neutron detector based on LRB-2



Сцинтиллятор ЛРБ-2 (ЗАО "НПФ Люминофор", г. Ставрополь РФ) порошок состоящий:

- Кристаллы сцинтиллятора ZnS(Ag),
- B_2O_3 (ядро ^{10}B – конвертор для нейтронов).





Диаметр 38 мм, толщина 0.7 мм

Conclusions

- The geometry of the ECal in SPDGeoModel is complete for the current status.
- The pipeline from ECalMCSteps to ECalPreClusters in Sampo is ready, but it requires further improvement, particularly in the electronics domain.
- A Monte Carlo model of the SPD ECal cell has been developed; however, it still requires refinement through the incorporation of more accurate and reliable experimental data.
- The linearity of the ECal response was checked.

Thank you for your attention!

Продольные распределения энергии

Пучок: электроны

