Lomonosov Moscow State University
Faculty of physics

Determination of the photon detection efficiency, time and spatial resolution of the light collecting system in the near liquid argon detector (ND-LAr) of the DUNE experiment

Petr Lenskii, Artem Chukanov (DLNP JINR)

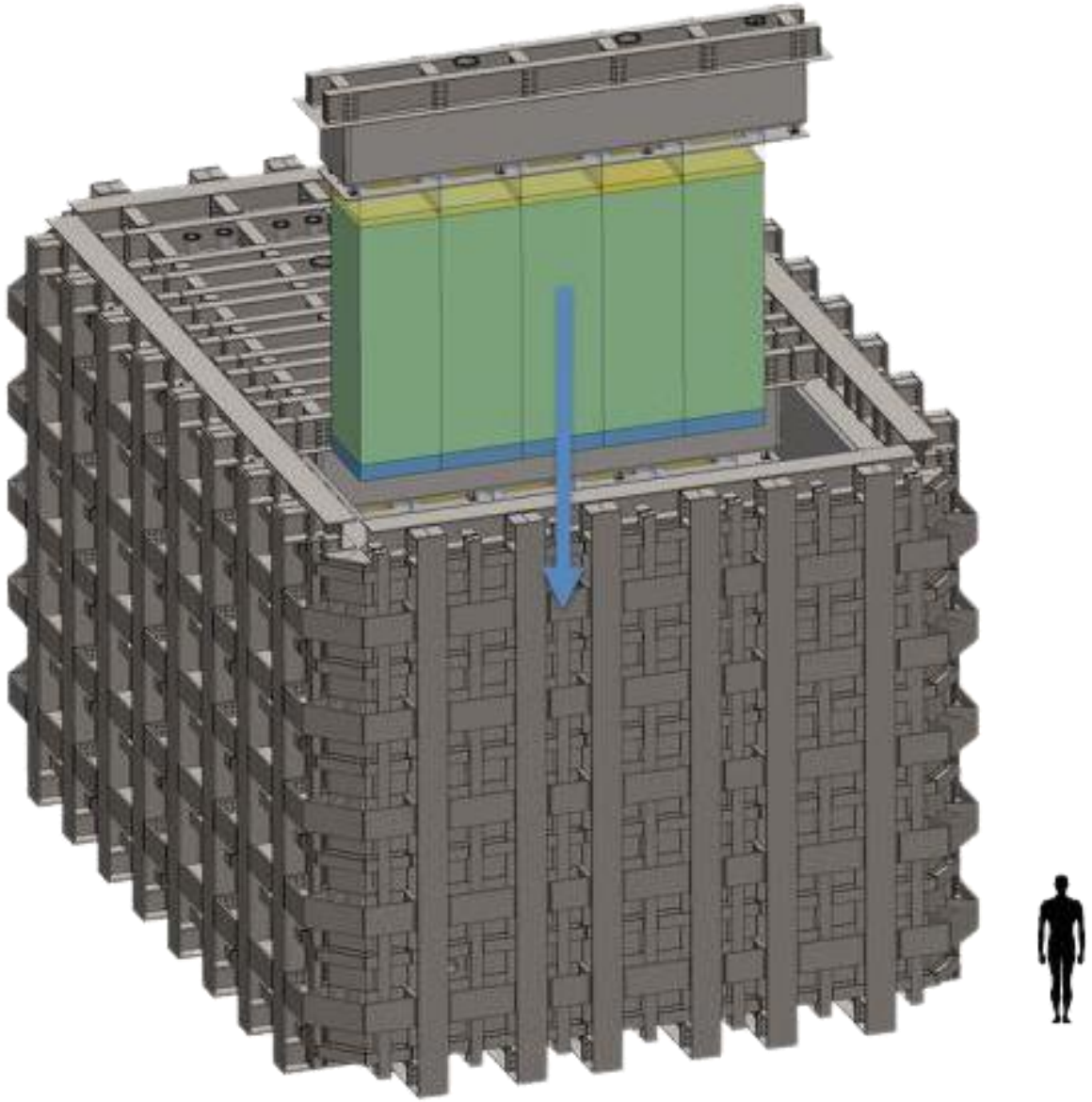
Structure of my talk

- Few words about ND-LAr
- Determination of PDE of its light collecting system using data obtained from Module 0 prototype
  - Determination of LAr scintillation parameters
  - Event selection in Module 0 data
  - Geant4 simulation of identical events
- Simulation of two-particle events in Geant4
  - Determination of minimal time and spatial shifts between tracks when they can be separated
  - Determination of time and spatial resolution for separated tracks
- Conclusion & further plans

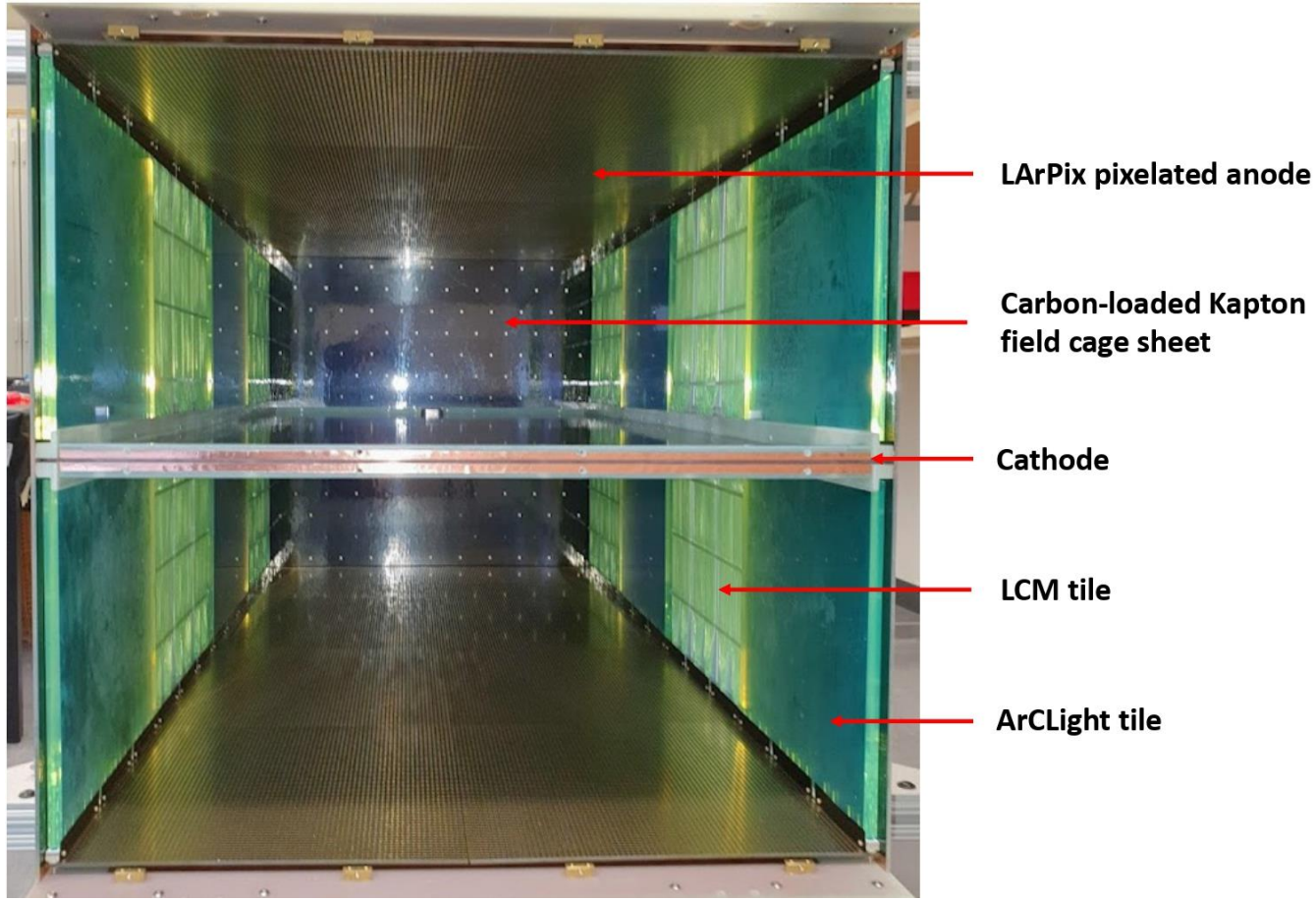
Near liquid argon detector of the DUNE experiment

Near liquid argon detector

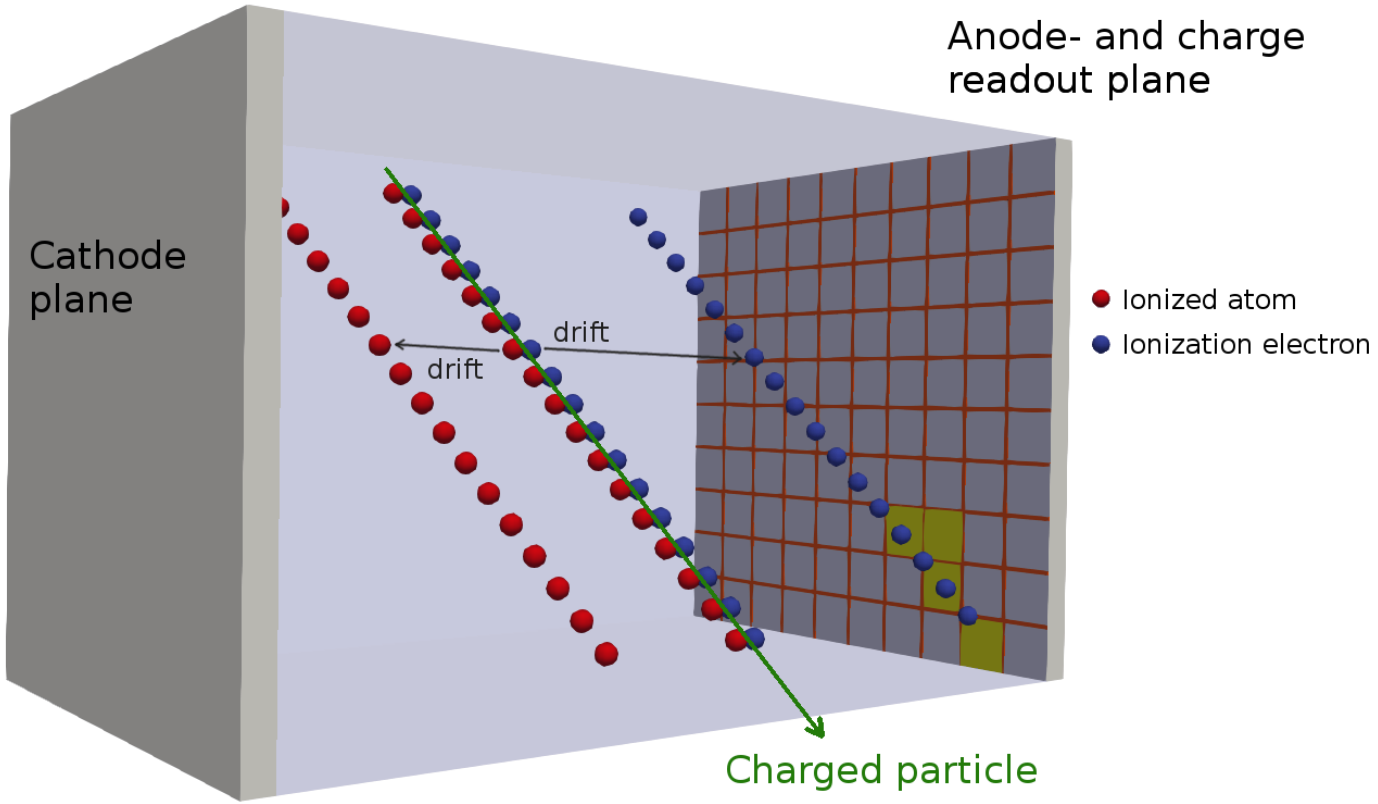
- ND-LAr consists of 35 modules (5 along X 7 transversely the beam axis)
- Every module is split by the cathode plane to two optically isolated TPCs

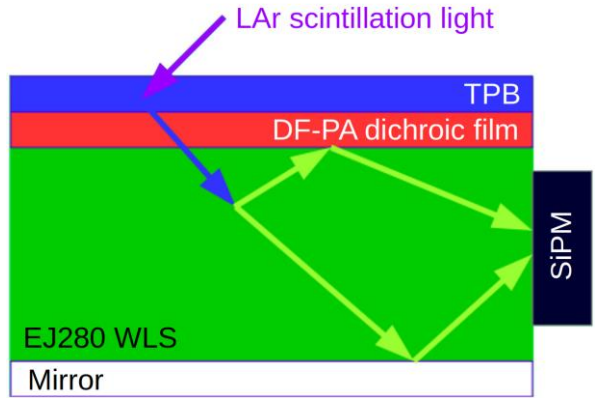


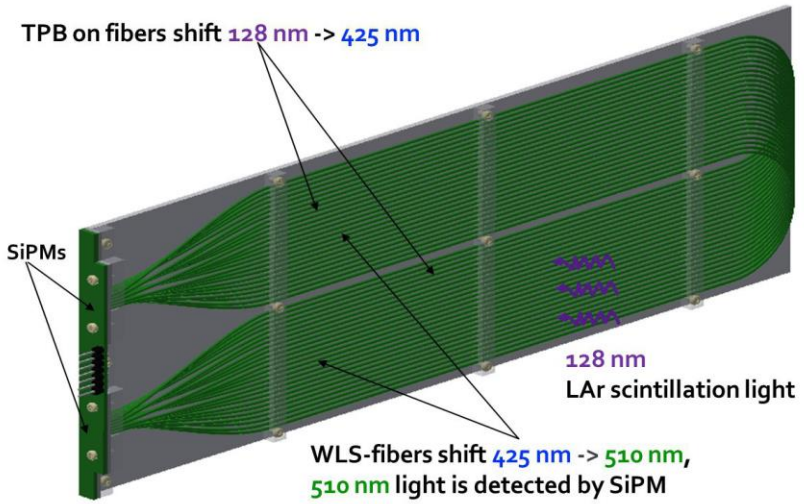
ND-LAr single module



ND-Lar single module







Determination of PDE of the ND-LAr LCS using data obtained from Module 0 prototype

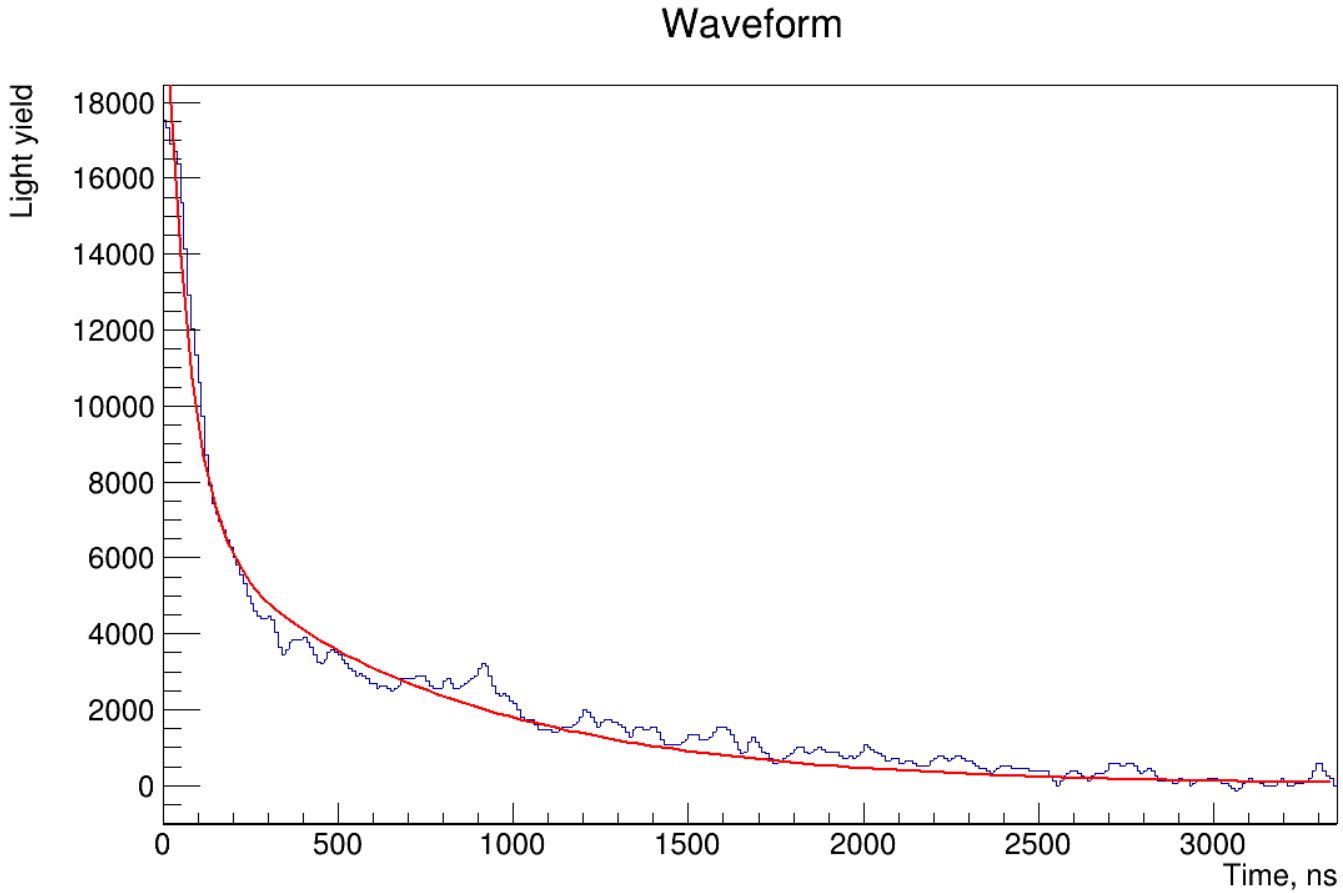
Scintillation parameters in Geant4

The following parameters were obtained from Module0 prototype:

- “fast” (66,4 ns) and “slow” (735,8 ns) time components;
- fraction of photons in “fast” component (0,171).

Light yield (number of photons per 1 MeV deposited energy) in LAr with 500 V/cm electric field is 24000 (arXiv: 2203.16134 [physics.ins-det]).

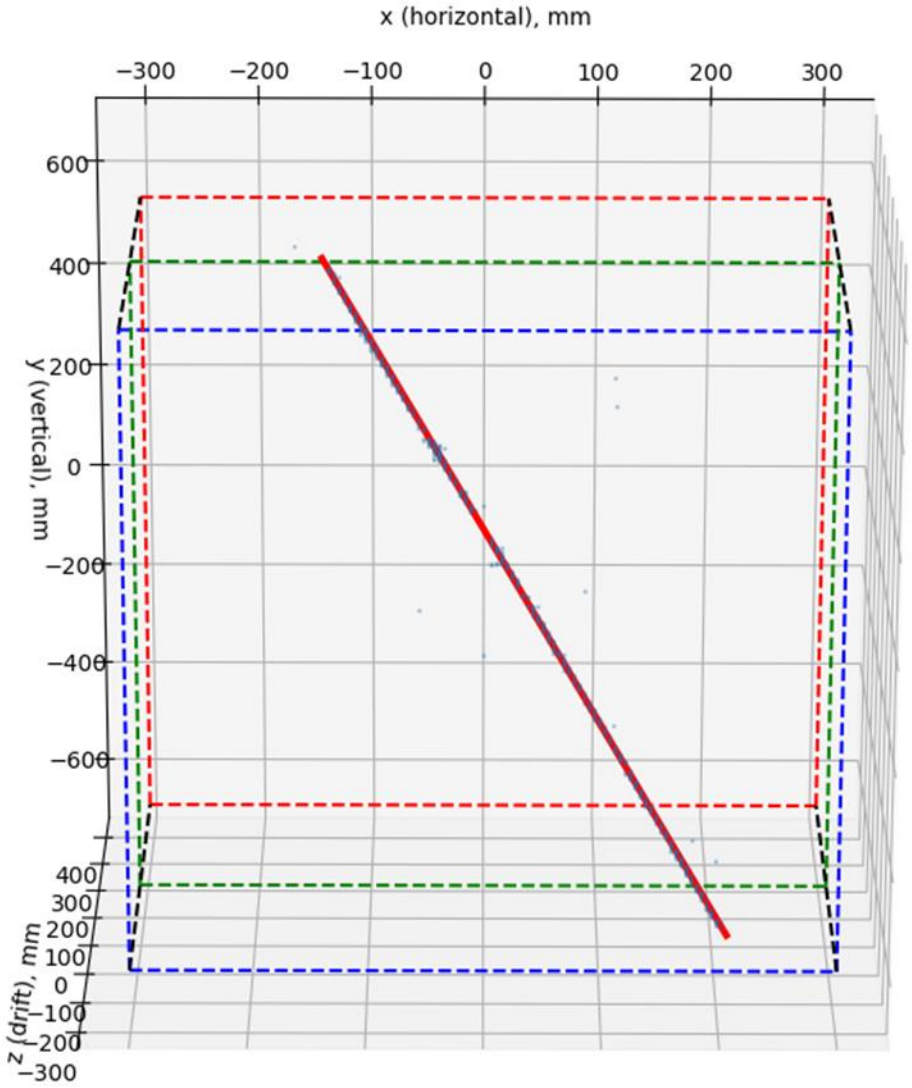
$$I = A\exp\left(-\frac{t}{\tau_f}\right) + B\exp\left(-\frac{t}{\tau_s}\right)$$



Response of the LCS of Module0 to cosmic muon flying through the chamber

Event selection in the charge system of Module0

- Single-particle events with straight tracks were selected (muons with few-GeV energies)
- In each event the track was approximated with a straight line to get the start point and the direction vector for simulation of this event



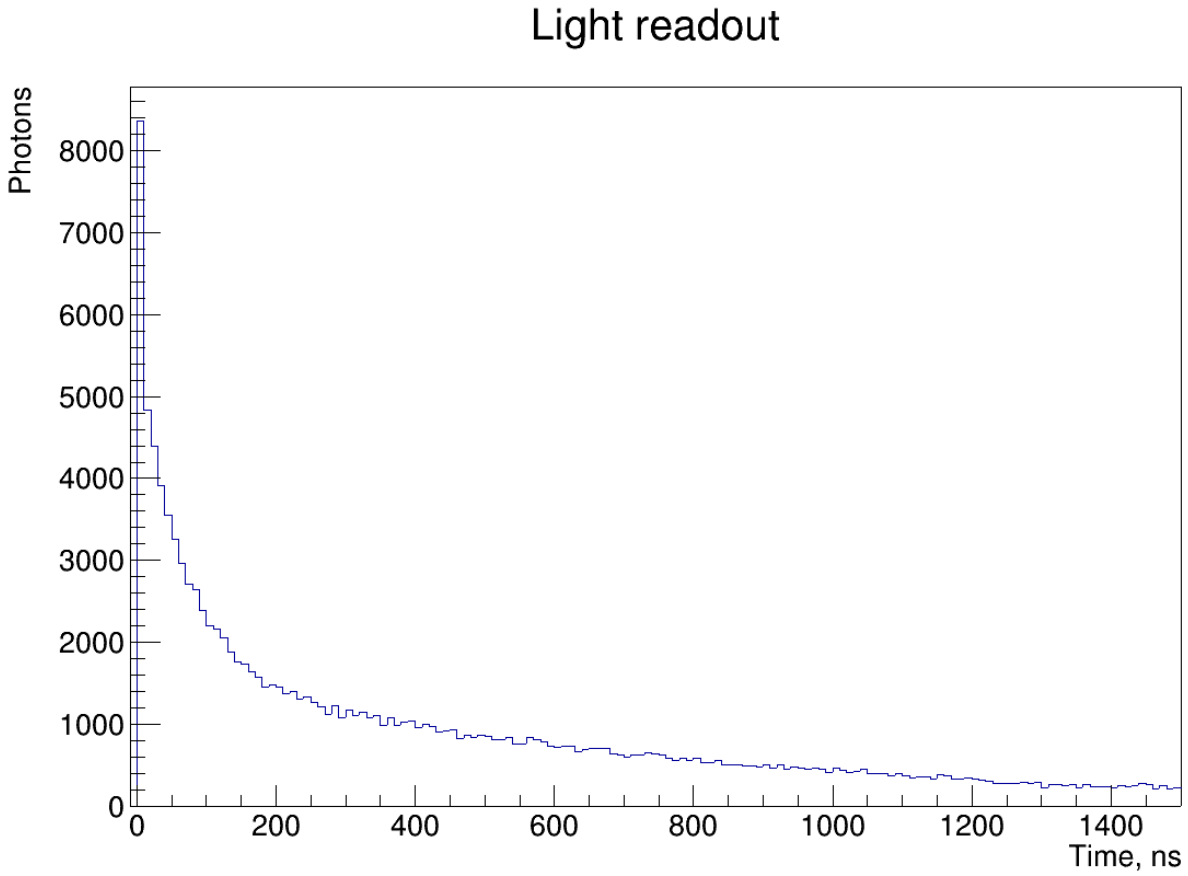
Example of the selected event

Evaluation of photon detection efficiency (PDE) of the ND-LAr LCS

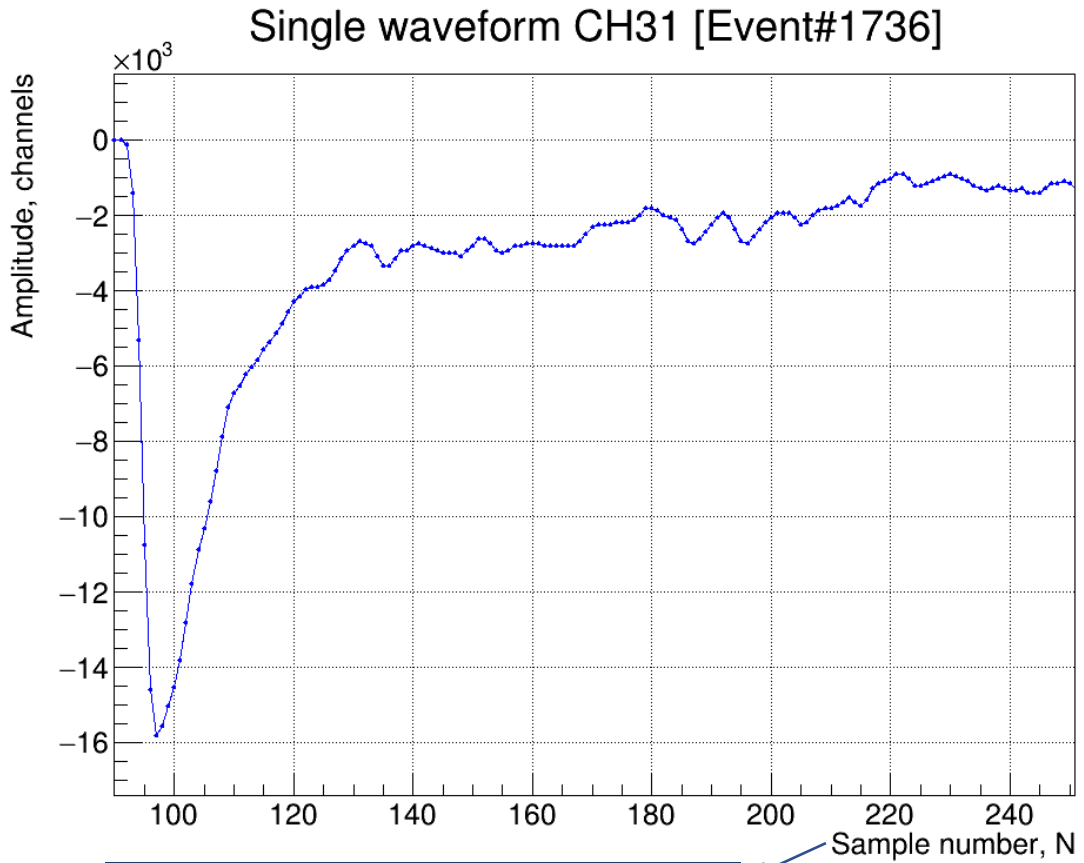
- Single-particle events with cosmic muon in Module0 were selected
- Identical events were simulated in Geant4
- In simulation, for each module of LCS the number of photons hitting its surface was calculated
- The efficiency of each module in current event was calculated as ratio between number of photons detected by this module in prototype and number of photons hitting its surface in simulation

Evaluation of PDE

Distribution of number of photons hitting the surface of one photodetector



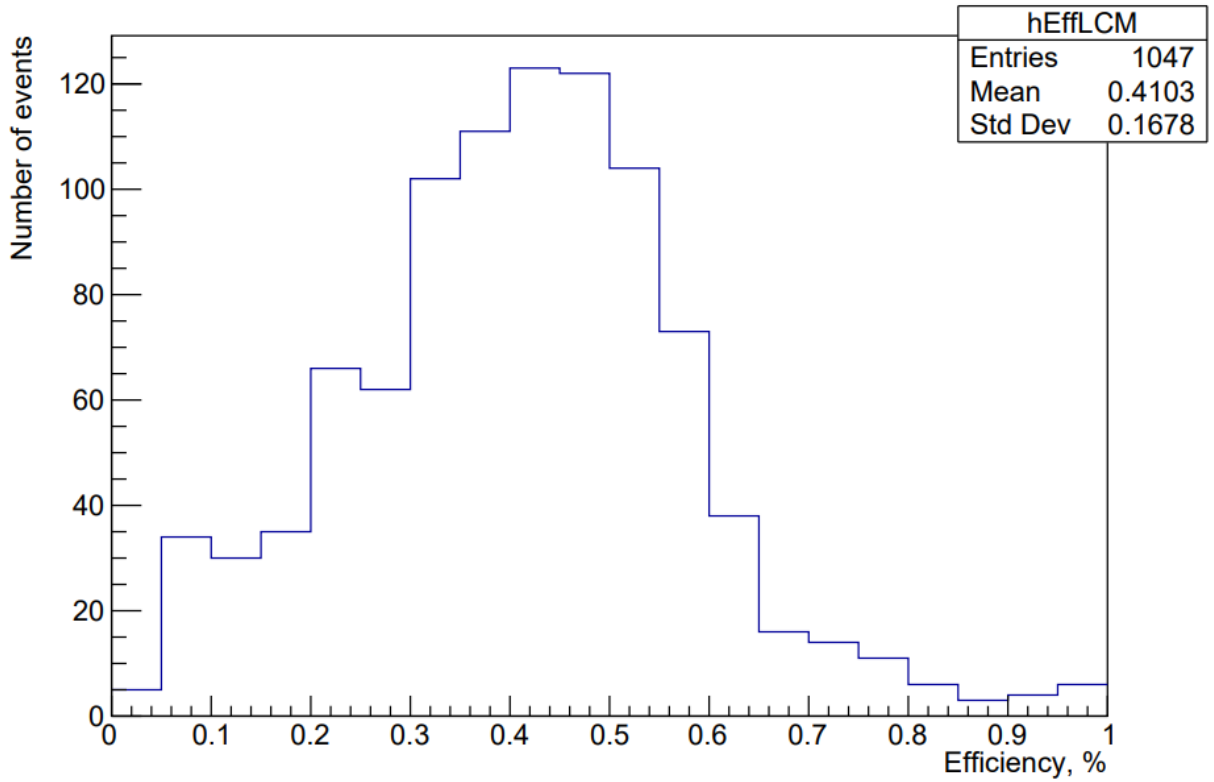
Signal in the ADC channel corresponding to this detector in the prototype chamber



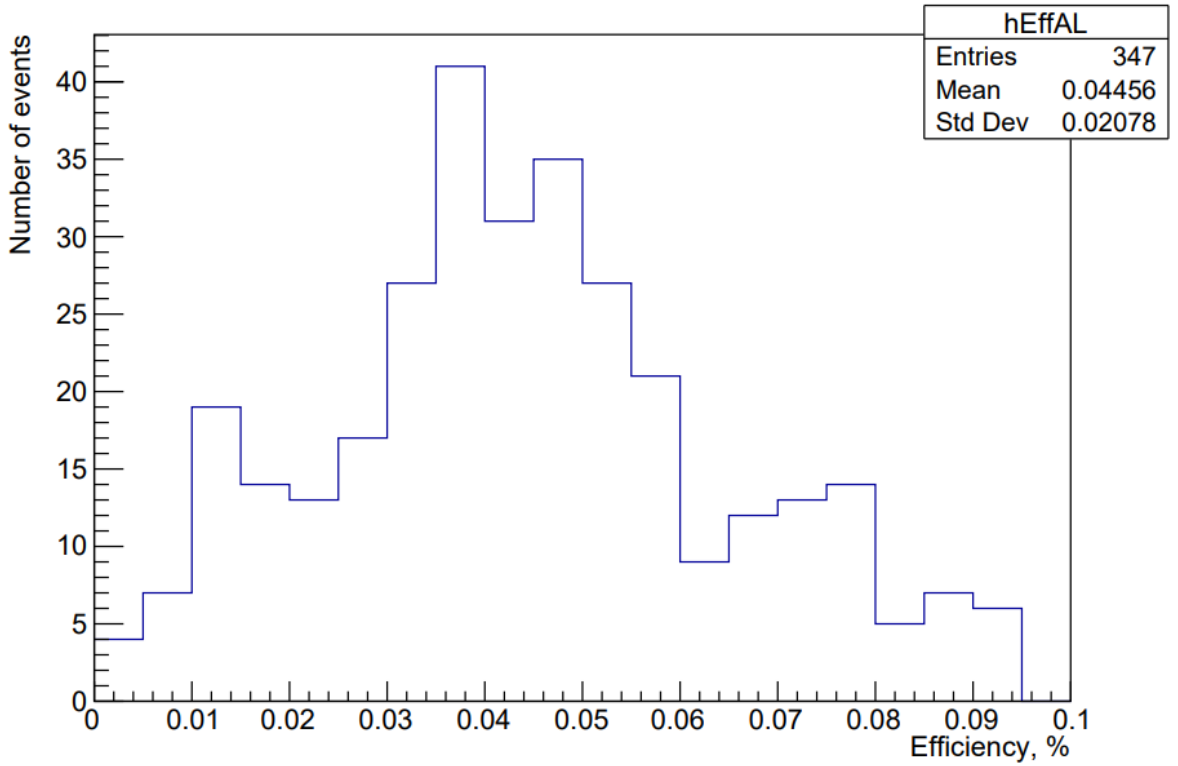
1 sample = 10 ns

PDE of LCM and ArCLight photodetectors

LCM: (0,41±0,17)%



ArCLight: (0,045±0,021)%



Simulation of two-particle events in Geant4

Requirements to the ND-LAr LCS

- For one beam spull lasting about 9.6 microseconds, about 80 events are expected in the near detector.
- The electron drift velocity in the volume of the TPC is 1.648 mm/ms, and the maximum drift length is 300 mm, that is, events in the charge system can overlap.
- Since the optical system generates triggers for the charging system, it is necessary to separate events with its help.
- The near detector in cross-section is divided into 14 optically isolated TPCs with size 0.3 ×1.2 m (x and y, respectively).
- Assuming the uniformity of the distribution of events over the cross-sectional area of the detector, about 6 events are expected in each TPC, that is, to separate them, an optical system resolution of at least 200 mm along the y axis is required.

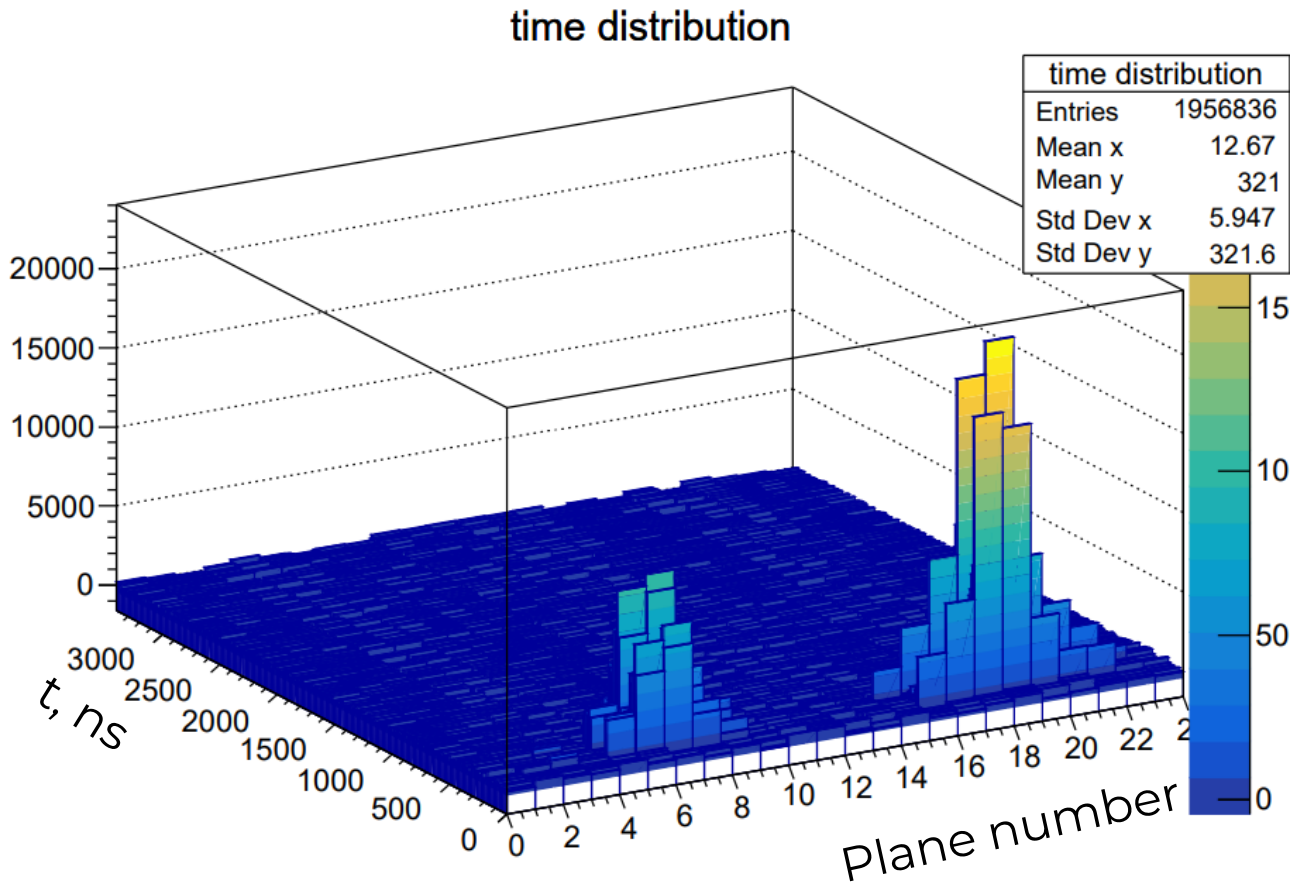
Two muons passing through the chamber along the beam axis (z axis)

Events with Δy from 0 to 900 mm and Δt from 0 to 300 ns were simulated.

Example: Δy = 0 mm, Δt = 120 ns

Algorithm for event separation:

- Draw projections of the histogram on x (plane number) and y (time) axes
- Find peaks in projection
- If number of peaks =1 in both projections, we cannot separate the events
- Otherwise we can separate them and find y coordinate and start time of the track.

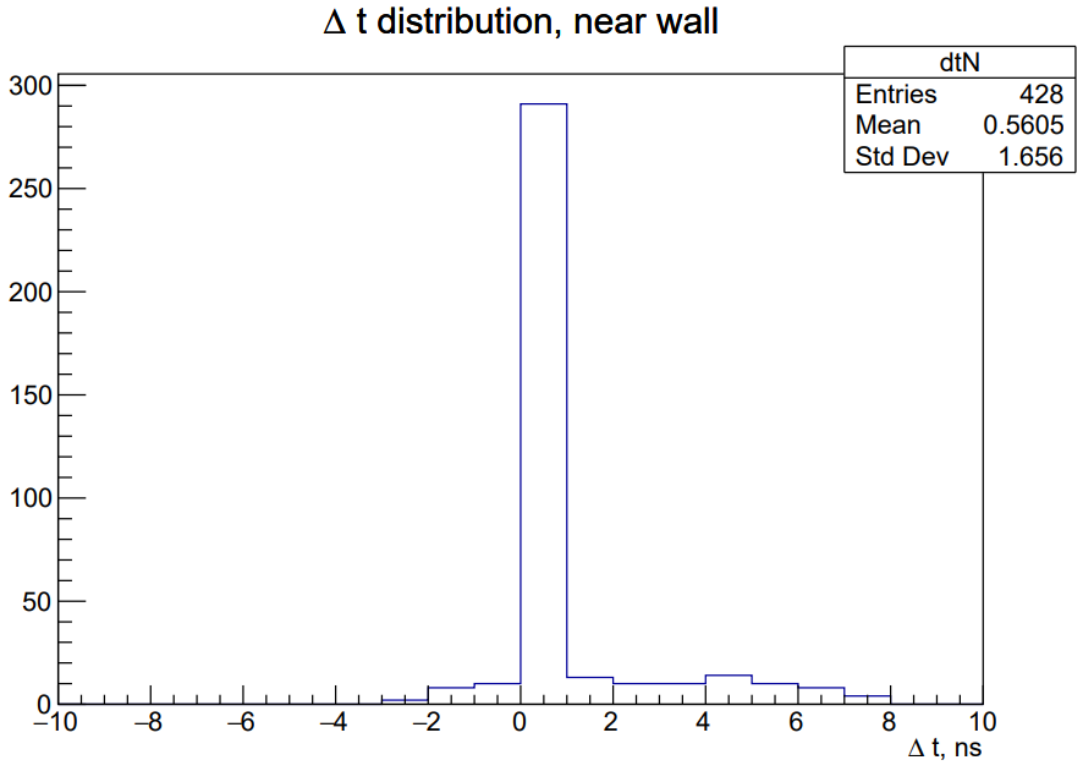


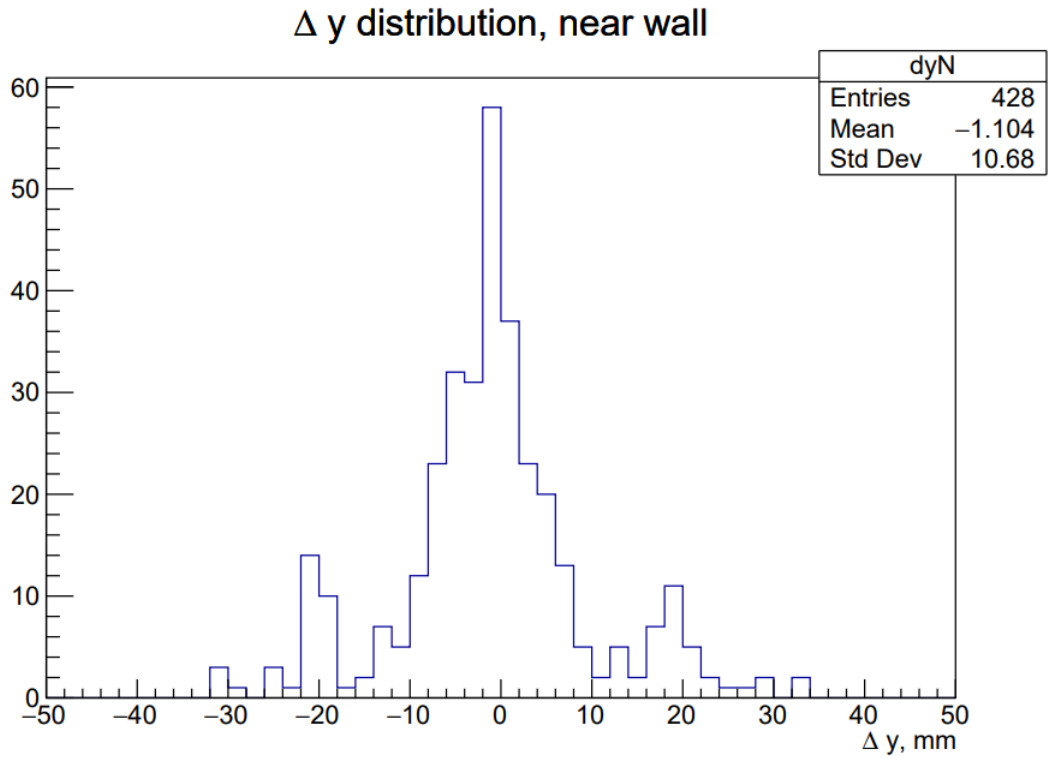
Results obtained in two-particle events simulation

- Time and space shifts when events become separable:
  - $\Delta t = 29 \pm 3$ ns
  - $\Delta y = 128 \pm 12$ mm

Results obtained in two-particle events simulation

- Time and spatial resolution for separated tracks (here Δt and Δy are the differences between real and reconstructed coordinates):





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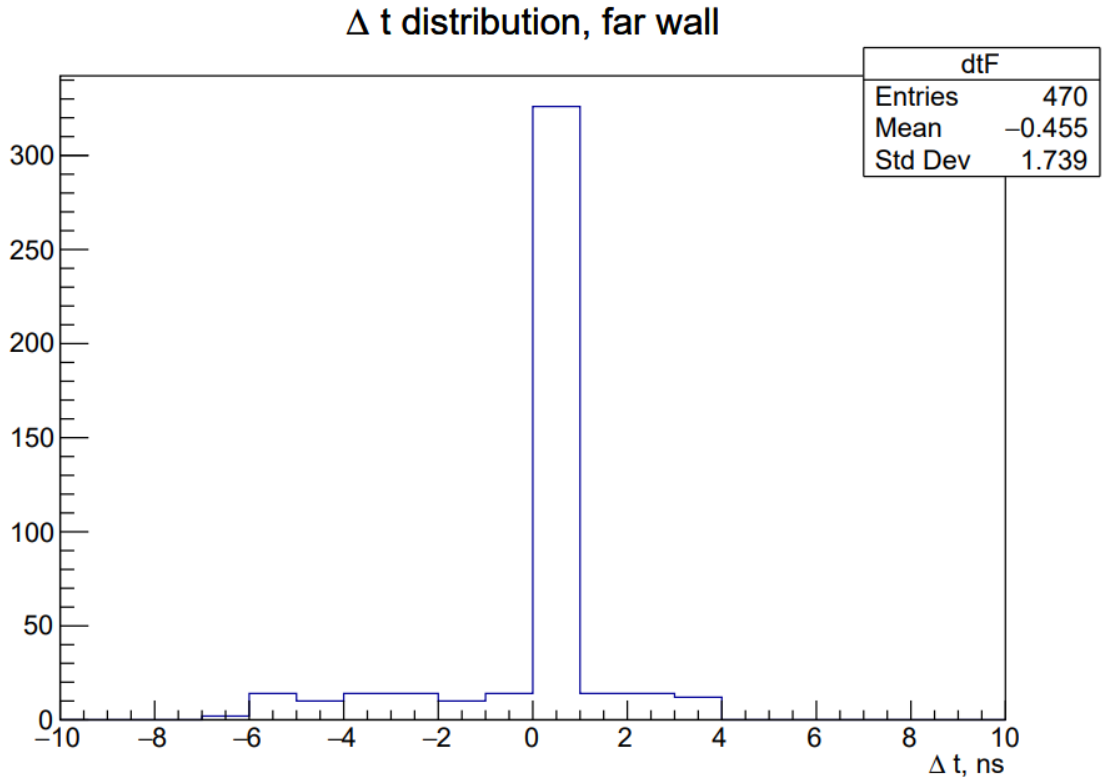
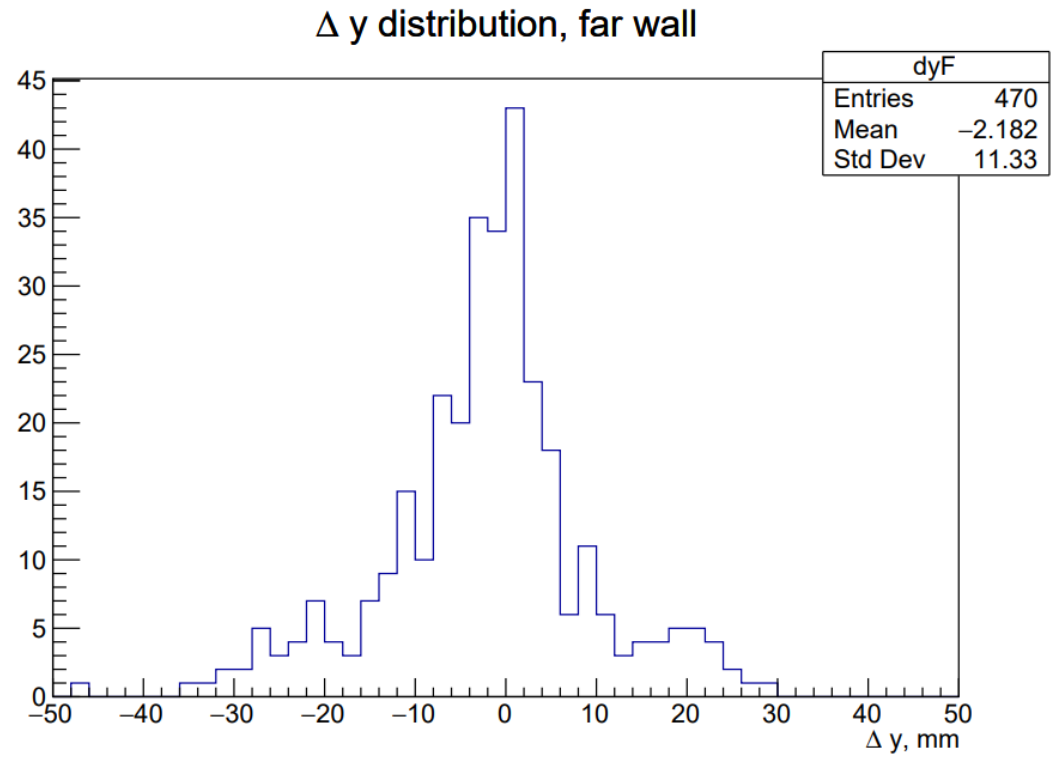




Conclusion and further plans

- To evaluate the PDE of the ND-LAr LCS, muon events registered by the prototype detector were selected and processed, after which identical events were simulated using the Geant4 software package. Comparison of model and real data showed that the PDE of LCM and ArCLight detectors is (0,41±0,17)% and (0,045±0,021)% respectively.
- Time and space shifts when events become separable were evaluated:
  - $\Delta t = 29 \pm 3$ ns
  - $\Delta y = 128 \pm 12$ mm

- For separated events time and spatial resolution is 1,7 ns and 11 mm, respectively.
- The capabilities of the detector satisfy the experimental requirements.

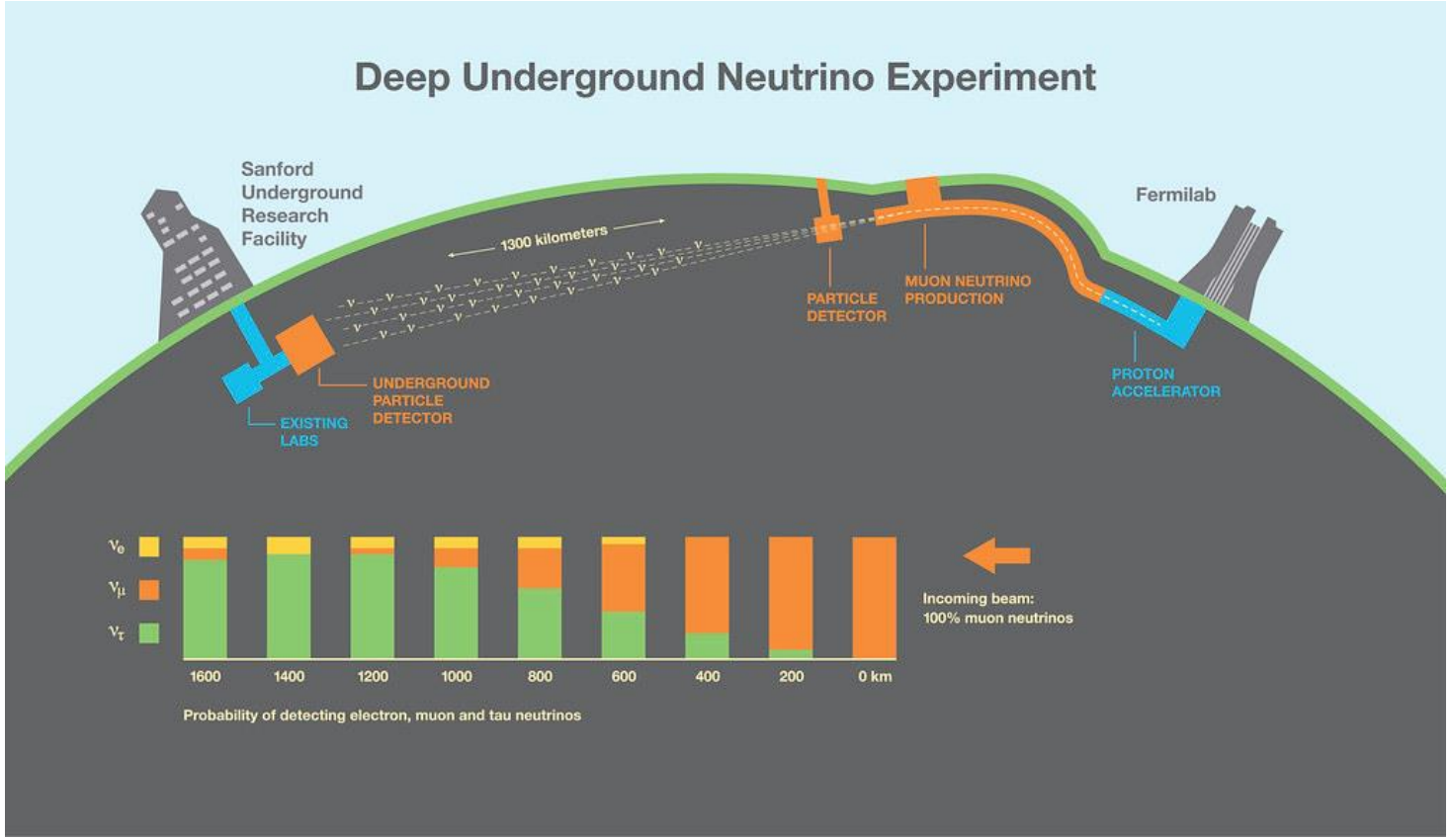
Further plans (now in progress):

- Refine the Geant4 model of the detector
- Simulate and process more events to improve accuracy of PDE values.

Thank you for your attention!

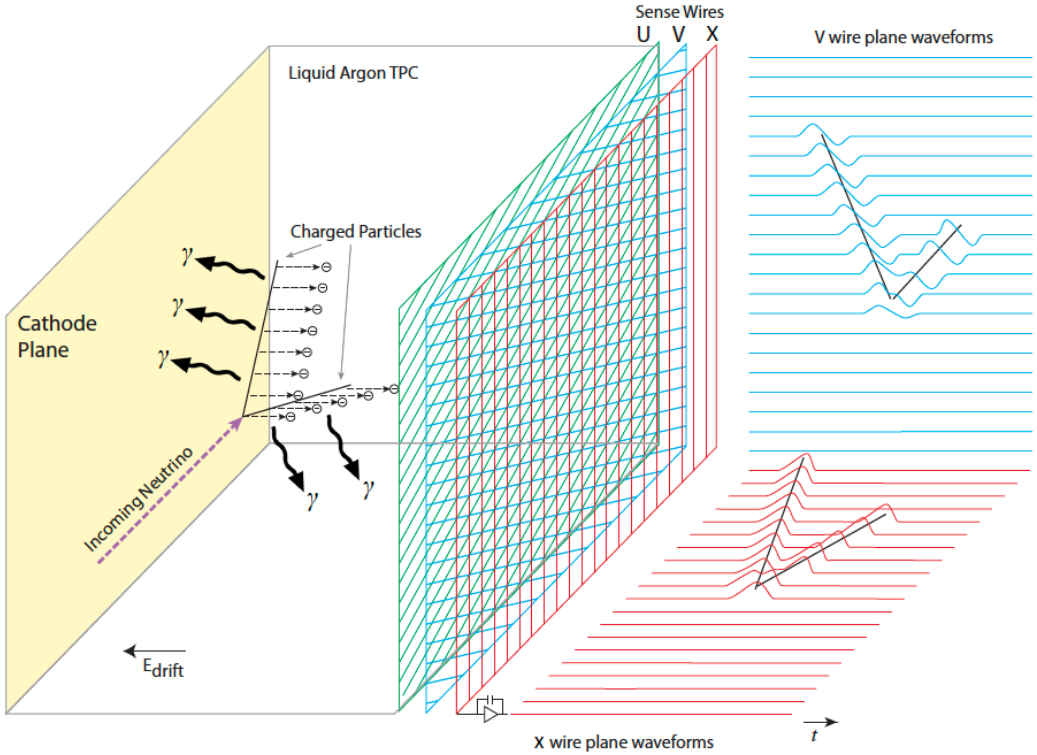
The DUNE experiment

- Long baseline of oscillations (1285 km).
- Large effective volumes of detectors. Far detector will consist of 40 kt of ^{40}Ar.
- Wide neutrino energy spectrum (0,5 – 8 GeV).

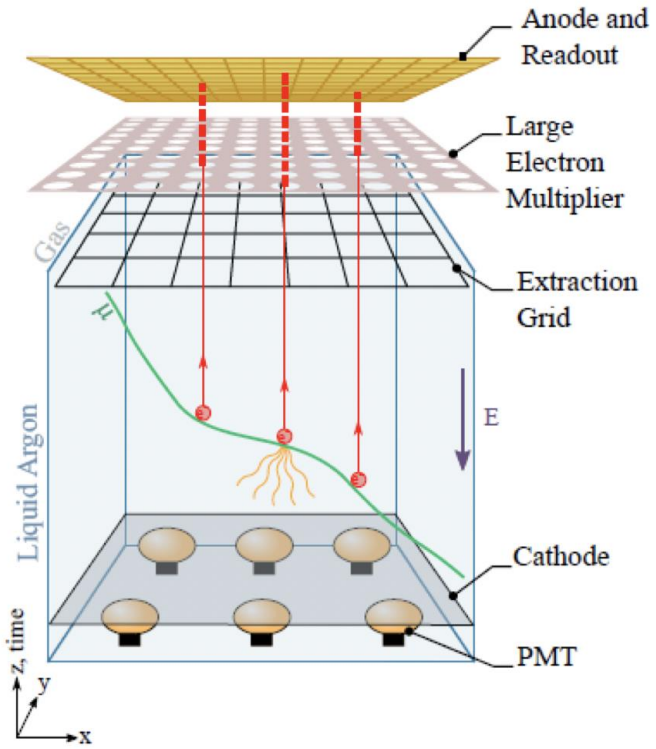


Far detector complex

Single-phase technology (only liquid argon)



Dual-phase technology (liquid and gaseous argon)



Near detector complex

Near detector complex consists of:

- ND-LAr – liquid argon time projection chamber;
- ND-GAr – gaseous argon detector will determine the momentum and the charge sign of particles flying out of the ND-LAr
- SAND – system of axial beam monitoring.

ND-LAr and ND-GAr form the movable module called DUNE-Prism for off-axis measurement for prediction of the beam spectrum in the far detector.