Spatial-sensitive detector based on strong scattering scintillating medium

Artemiy Krapiva, Dmitriy Svirida
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Abstract

The opaque scintillator detector is a novel concept for a new generation of position-sensitive detectors. The main idea is to localize the light near the point of its scintillation via the scattering medium. The first and only published results were presented by the LiquidO collaboration, so further investigations are required.

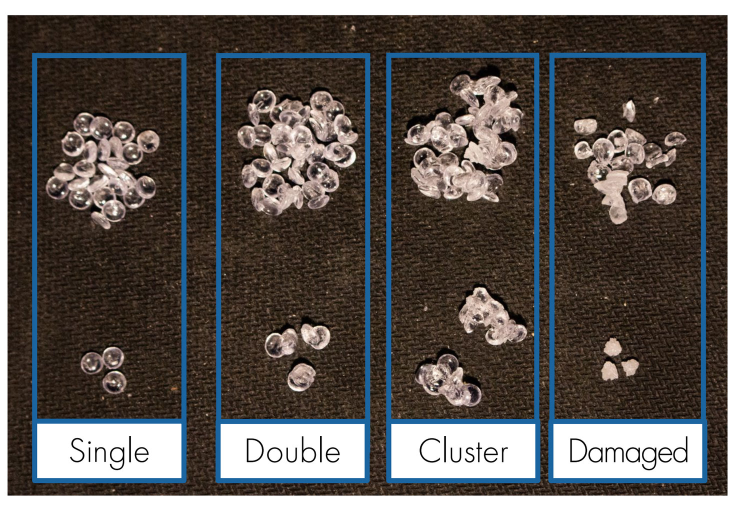
Our approach suggests the use of granular organic scintillator as a medium for the detector and an array of WLS fibers with SiPMs as a light collector. The report describes the process of calibration, the procedure of track reconstruction, and the estimation of the medium's parameters. Also, the Monte-Carlo simulations were performed in order to evaluate the immeasurable parameters of the setup and to study the possibilities of further improvements.

① Introduction

- Nowadays, organic scintillators are widely used in different experiments as easily scalable energy detectors. The array of segmented scintillator counters can be used as a detector with spatial accuracy and energy resolution. Many neutrino experiments, such as DANSS, SuperFGD, STEREO, PROSPECT, etc., have segmented organic scintillator counters as the sensitive volume.
- The LiquidO collaboration suggested a new approach based on the scattering of scintillated light by adding special wax to the LAB liquid scintillator. They reported the promising results of simulations and successful proof-of-concept experiments. However, accurate estimations of the full-scale detector's specifications are still to be conducted.
- The main idea of this approach is to localize the emitted light near its scintillation origin via light scattering. Our intention is to test the use of a differently shaped solid scintillator.

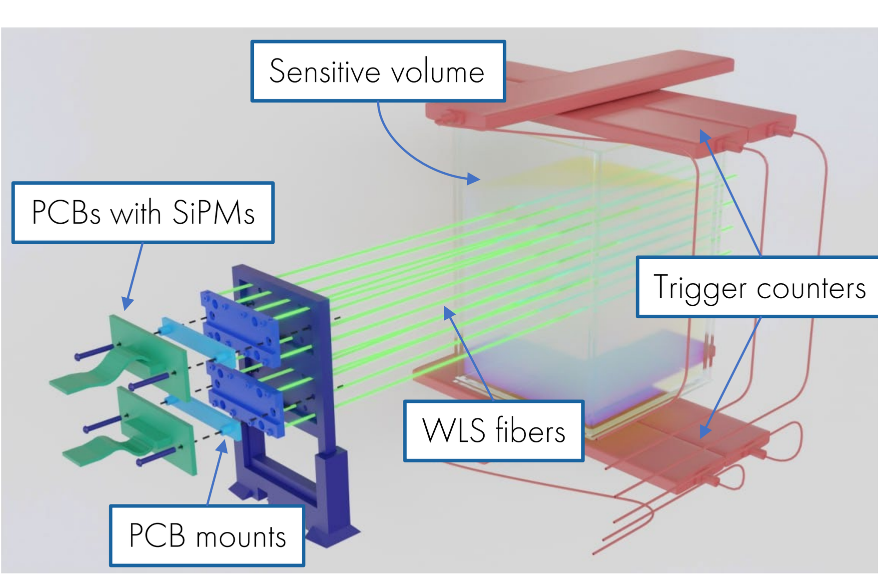
② Granules

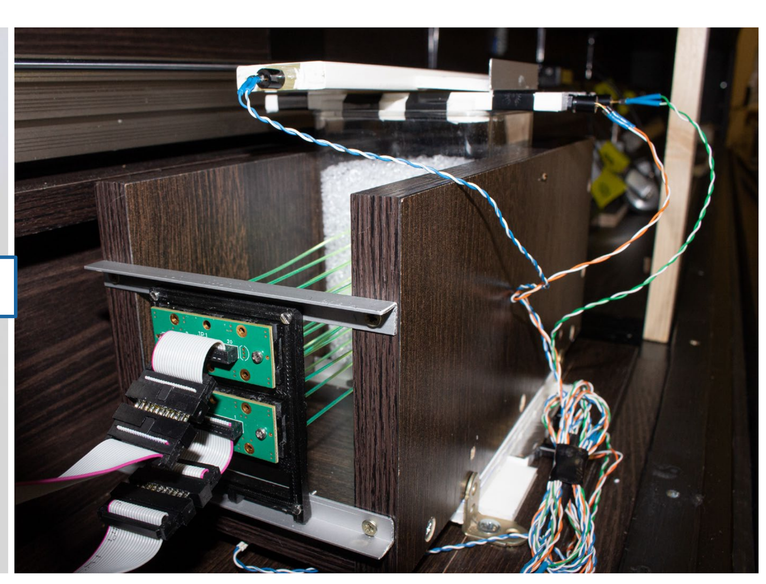
- Use of solid organic scintillator granules as a medium.
- Not flammable, don't require special conditions for stability, and don't delaminate.
- A single granule has the form of a disc 3 mm in diameter and 1 mm in thickness.
- Single and double granules were selected for the experiments.



③ Prototype Construction

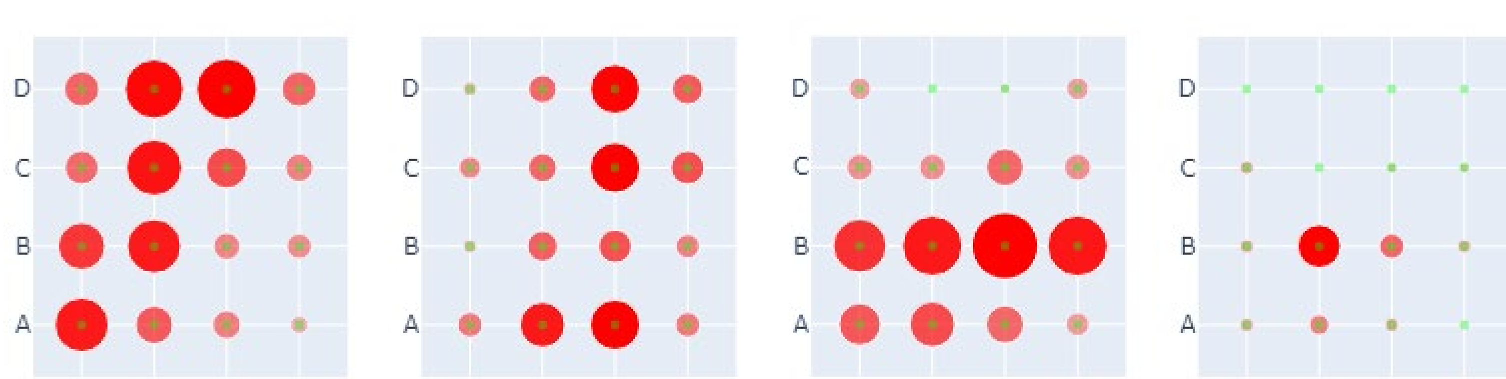
- Sensitive volume (88x88x111) mm^3 is filled with granules.
- The array 4x4 with a 15 mm step of WLS fibers Kuraray Y-11 is used for light collection.
- Each fiber is read by a Hamamtsu S13360-1350PE SiPM on one end and is painted black on the other end.
- SiPMs are mounted on the special PCBs. Voltage control and signal transmission are executed by other PCBs controlled via the RS232 interface. Reading and digitizing of SiPMs' signals are performed by a 64-channel UWFD64 module mounted to a VME crate. Then signals are transmitted to the PC for visualization and storage. The mentioned electronic scheme is similar to a scheme developed for the DANSS upgrade.
- Trigger counters are used for the trigger signal of vertical tracks by cosmic muons. Longitudinal counters can be moved transversely to study certain columns of channels.
- Also, noise spectra for each SiPM are being collected from the individual triggers for the gain calibration.





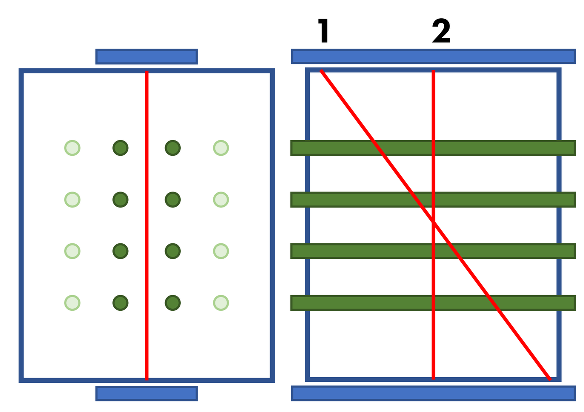
④ Events

- Events after primary calibration are presented in the figure beneath. The size and opacity of the red circles show the amplitude of the signal in the corresponding channel.
- As the data collection was conducted on cosmic rays, we were expecting mostly vertical tracks by muons, but horizontal ones and localized events are present as well.



⑤ Calibration and Spatial Accuracy

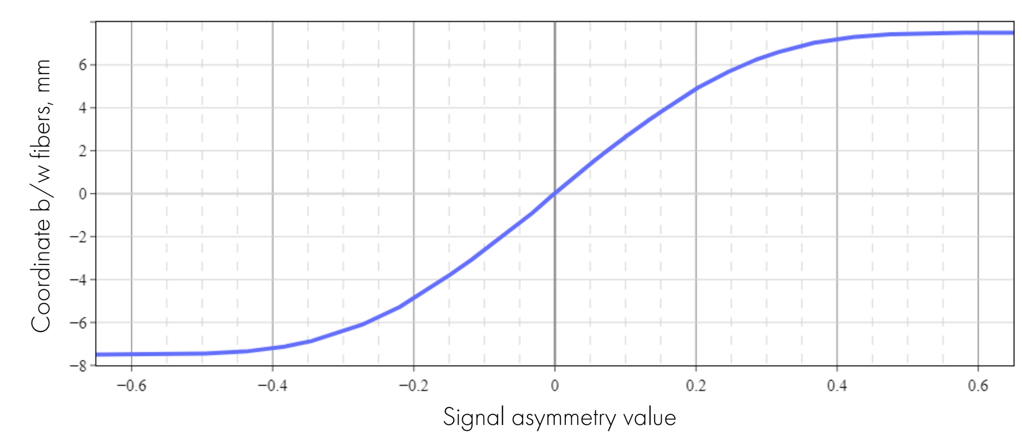
- The setup was calibrated, and the spatial accuracy was estimated with cosmic rays.
- The signal in the channel is proportional to the energy losses of the particle close to the fiber, so the 1st and 2nd tracks' signals will have different absolute values but will have the same track projections. So, *signal asymmetry* for the pair of adjacent vertical channels will be used instead of using absolute values of the signals' amplitudes.



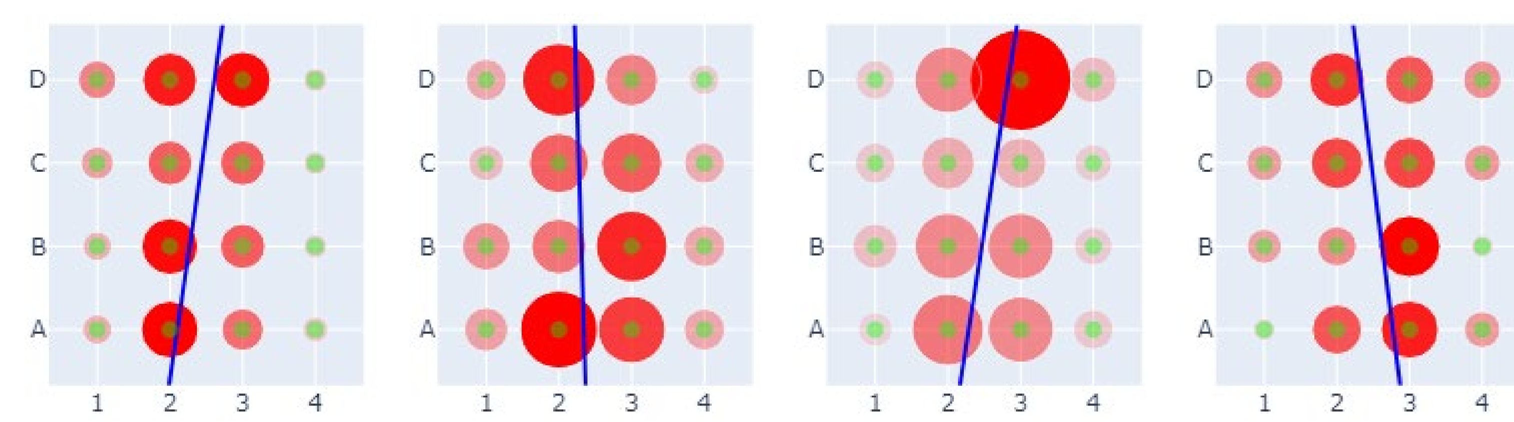
$$asym = \frac{A_{right} - A_{left}}{A_{right} + A_{left}},$$

where ***A*** is amplitude of signal

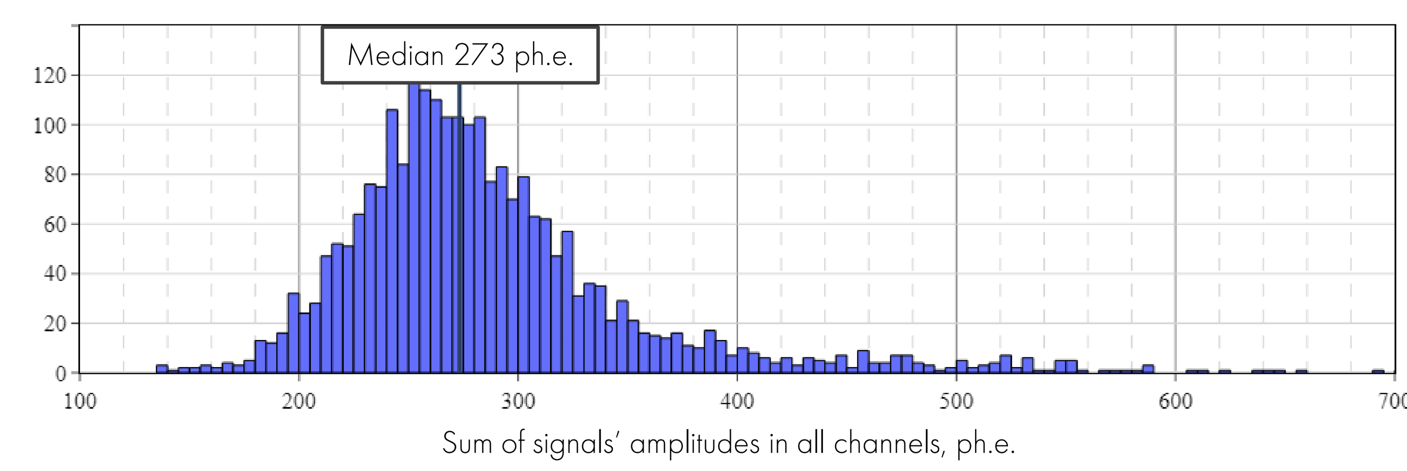
- The coordinate function of signal asymmetry is obtained by comparing the signal asymmetry distribution with the uniform coordinate distribution.



- Tracks of muons are reconstructed by 4 points of 4 vertical pairs of channels. This algorithm of testing results in a spatial accuracy of **σ**=(2.7±0.1) mm.

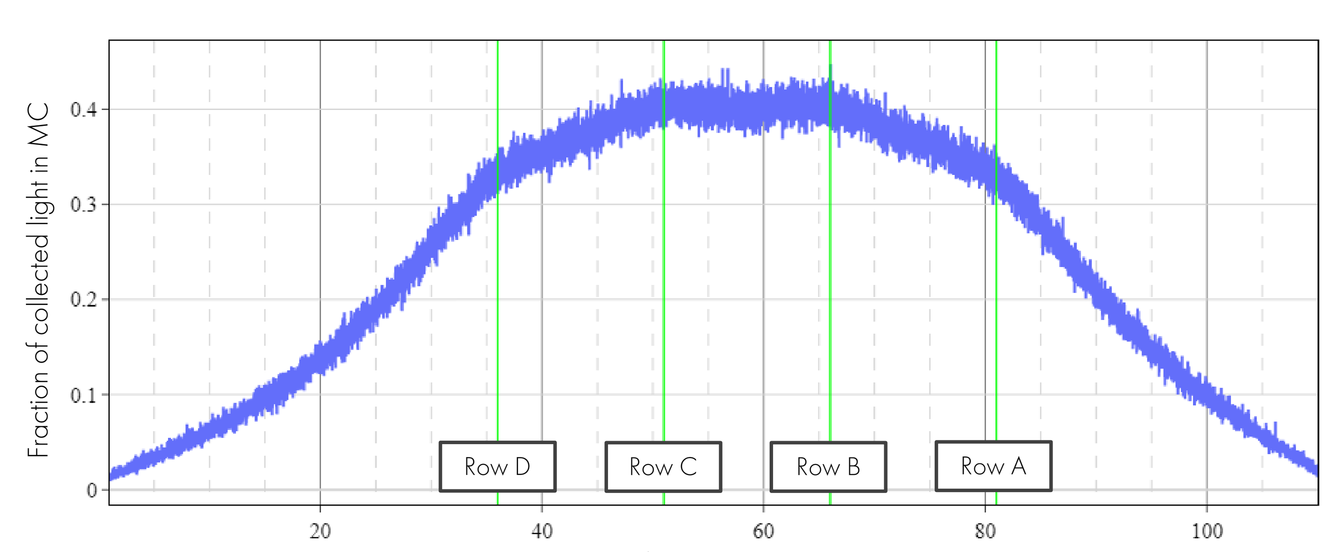


- Total light collection is 273 ph.e. in the median. Setup's light collection is 18 ph.e. @ MeV.



⑥ Simulations

- A toy Monte-Carlo simulation was conducted to study the spatial nonuniformity of light collection and to estimate the medium properties.
- Each photon emitted along the track is carried through scatters until its absorption, hitting the fiber or leaving the volume of the detector.
- The granular medium is approximated by a uniform medium characterized by absorption and scattering lengths. By varying these parameters, we estimated that experimental and simulated spectra have the same median, with absorption and scattering lengths equal to 130 mm and 3 mm, respectively.
- The vertical nonuniformity of light collection for a centered vertical muon track is shown below. Effective light collection in the central 60 mm part of the volume is 28 ph.e. @ MeV.



Conclusions

✓ The first opaque detector based on a solid scintillator was constructed and tested. Woohoo!

✓ After calibration, simulation, and data processing, the first prototype has shown effective light collection of 28 ph.e. @ MeV and spatial accuracy of 2.7 mm.

✓ Further investigations are required: light collection can be improved by medium modifications, and event identification with enhanced track reconstruction can be achieved with ML algorithms. We have forward-looking plans of future tests and upgrades!