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Selection of optimal parameters of the scintillation hodoscope model for the muonography method

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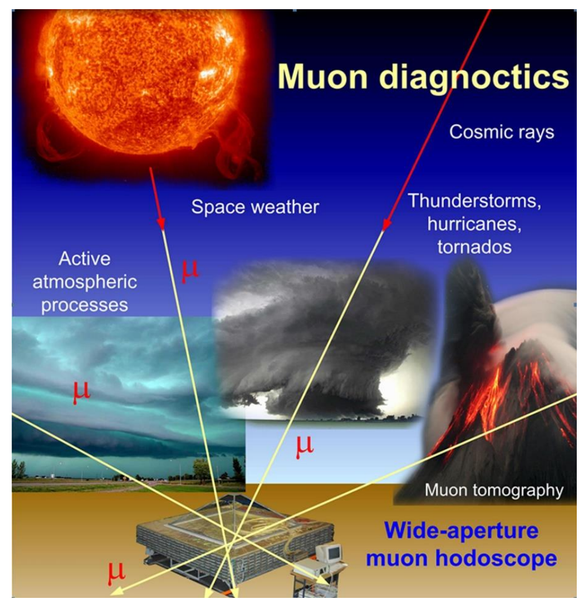
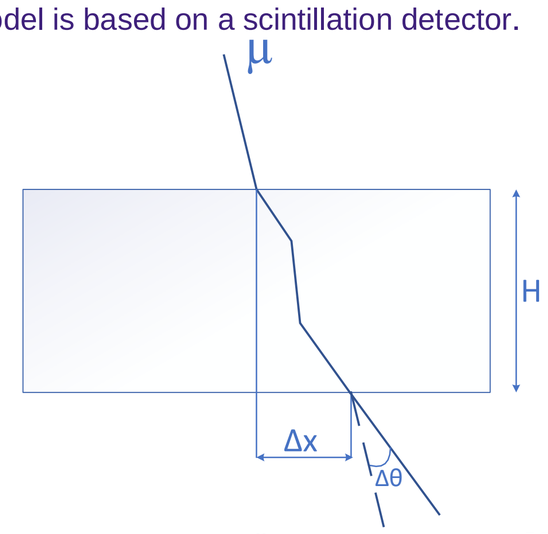
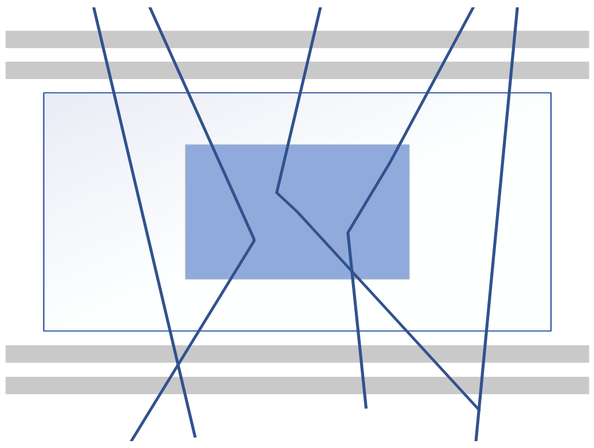
Variations of the muon flux on the Earth surface arise as a result of influence of various processes in the heliosphere on primary cosmic ray flux, as well as during the passage of muons through the atmosphere. A high penetrating ability makes muons an attractive tool for muonography. The method that applies the effects associated with the loss of muon energy or muon scattering in a substance is called muon tomography. The task of this work is to create a model of a new scintillation muon hodoscope for the development of the method of muonography of large-sized objects. The model is based on a scintillation detector.



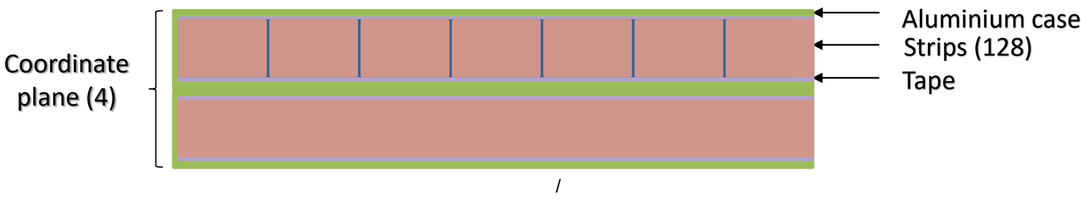
$$p + N \rightarrow \pi^{\pm} + n + N + \ldots$$
$$p + N \rightarrow K^{\pm} + n + N + \ldots$$
$$\downarrow$$
$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}),\ \sim 100\%$$
$$K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}),\ \sim 63.5\%$$





Geometry of the scintillation muon hodoscope model

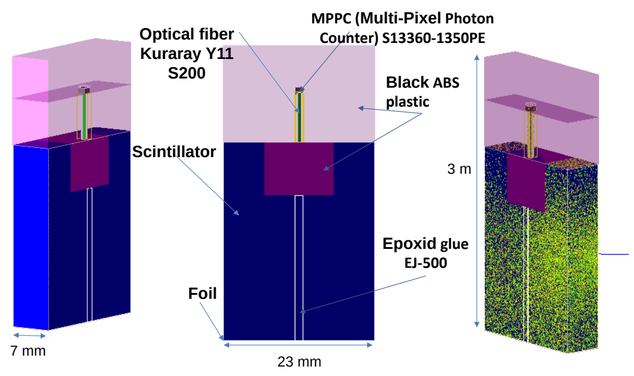
The supermodule consists of eight layers. Each layer contains 128 strips, which are located inside a special protective case and fastened with double-sided tape. The case provides rigidity, additional light insulation and protection of strips from damage. Layers overlap each other perpendicularly, forming a coordinate plane. Thus, four coordinate planes are formed from eight layers. The hodoscope final parameters are the strip width of 23 mm and the distance between adjacent layers of 65 cm.

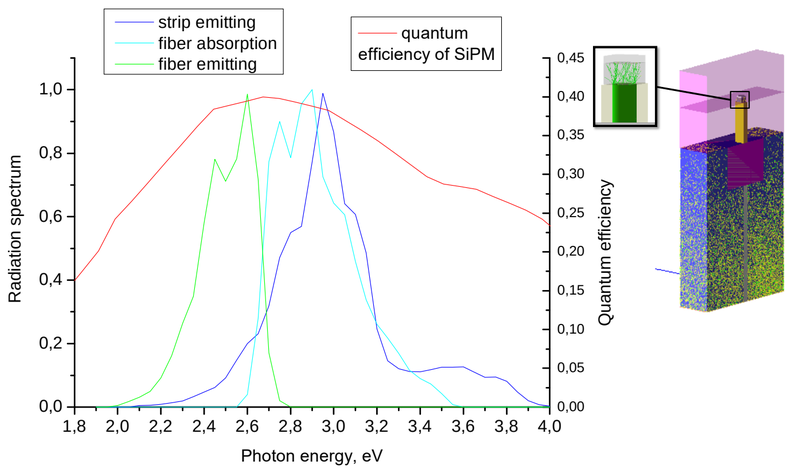


General characteristics of the strip model

The registration of muon tracks is carried out by several layers of narrow long scintillation strips with fiber-optic light collection on silicon photomultipliers. The model of future scintillation muon hodoscope strip was created in the Geant4 program package, and all necessary optical properties were included.

Most of the scintillations emitted are absorbed by the optical fiber and re-emitted in a another energy range. The maximum quantum efficiency of SiPM is in the same energy range.

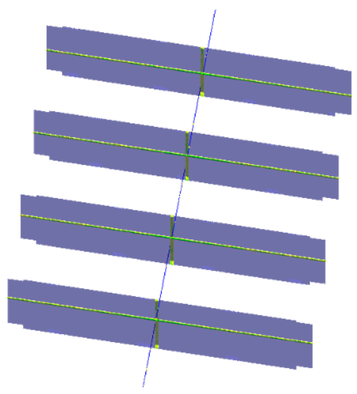




Modeling response of scintillation muon hodoscope to passage of particle

The figure shows the passage of a muon with an energy of 3 GeV through the scintillation muon hodoscope model. The triggered strips are lit in green. This confirms that the developed model works correctly.

Layer number	Strip number	Number of photons	Number of photoelectrons
7	53	97	37
6	62	22	10
5	53	77	26
4	64	96	33
3	53	151	55
1	53	119	47
0	63	16	4
0	64	143	62
0	63	91	32
0	64	20	5



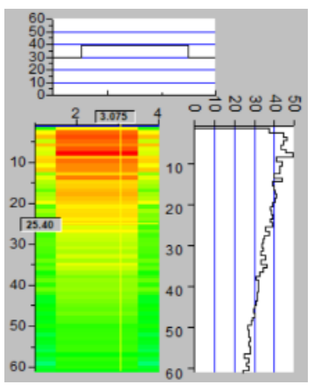
Calibration of the strip using experimental data

The strip model was calibrated according to experimental data, and more accurate parameters of muon hodoscope model were obtained from calibration results.

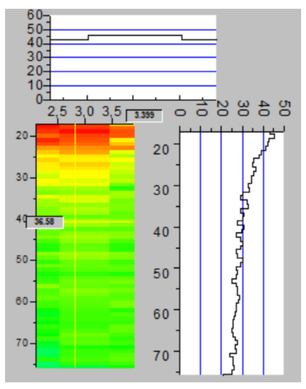
The final parameters of the strip for modeling:

1) light output 11500/MeV
2) absorption length 10 cm
3) reflection from the inner surface of the strip 0.98
4) foil reflection 0.98

Modeling

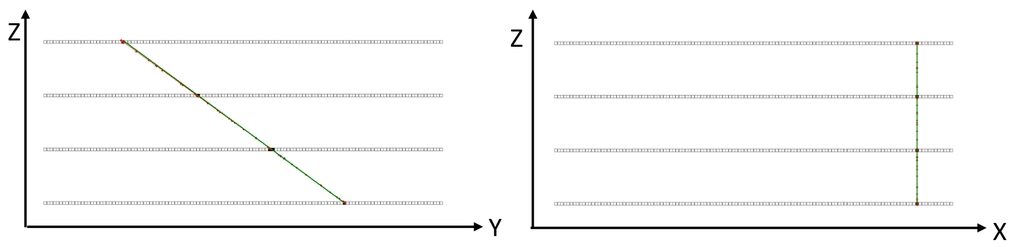


Experiment



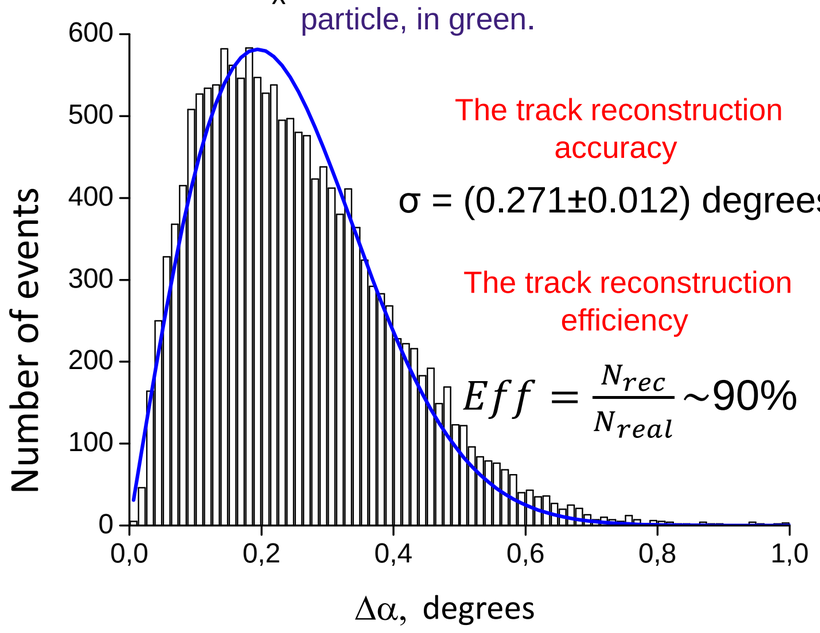
Determination of the accuracy and efficiency of muon tracks reconstruction

Muon track recovery example



The on-line track reconstruction program draws the coordinates of the particle passage, the reconstructed track based on the triggered strips (using the “straight” section method) in red, and the real track obtained by applying the least squares method to the exact coordinates of the passed particle, in green.

For simulation of muon hodoscope response to cosmic-ray particles passing through it, in order to obtain dependences most consistent with the experiment, the spectrum of cosmic-ray particles was simulated, which is close to a real one. The tracks of muons were reconstructed and accuracy of their reconstruction was estimated. The figure shows a histogram of the angles Δα between the reconstructed and “real” tracks. The blue line on the histogram is a Rayleigh fit. The track reconstruction accuracy is determined by the root-mean-square deviation σ.



Conclusion

1. A strip model was created in the Geant4 software package, physical and optical processes were connected, and the reliability of the resulting model was checked.
2. A model of a scintillation muon hodoscope has been created and the response of a MH to the passage of a muon with an energy of 3 GeV has been simulated.
3. The developed strip model was calibrated according to the experimental data obtained with the URAGAN muon hodoscope. The optimal parameters of the strip model are selected and the created model of the scintillation muon hodoscope is refined.
4. The efficiency and accuracy of muon registration by a scintillation muon hodoscope are estimated. The error in the reconstructing of the track angles is less than one degree, and the reconstruction efficiency for muon tracks is about 90%.

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