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Multifunctional Detector of Muons for Investigations of the Vertical Muon Flux of Extensive Air Showers at High Energies

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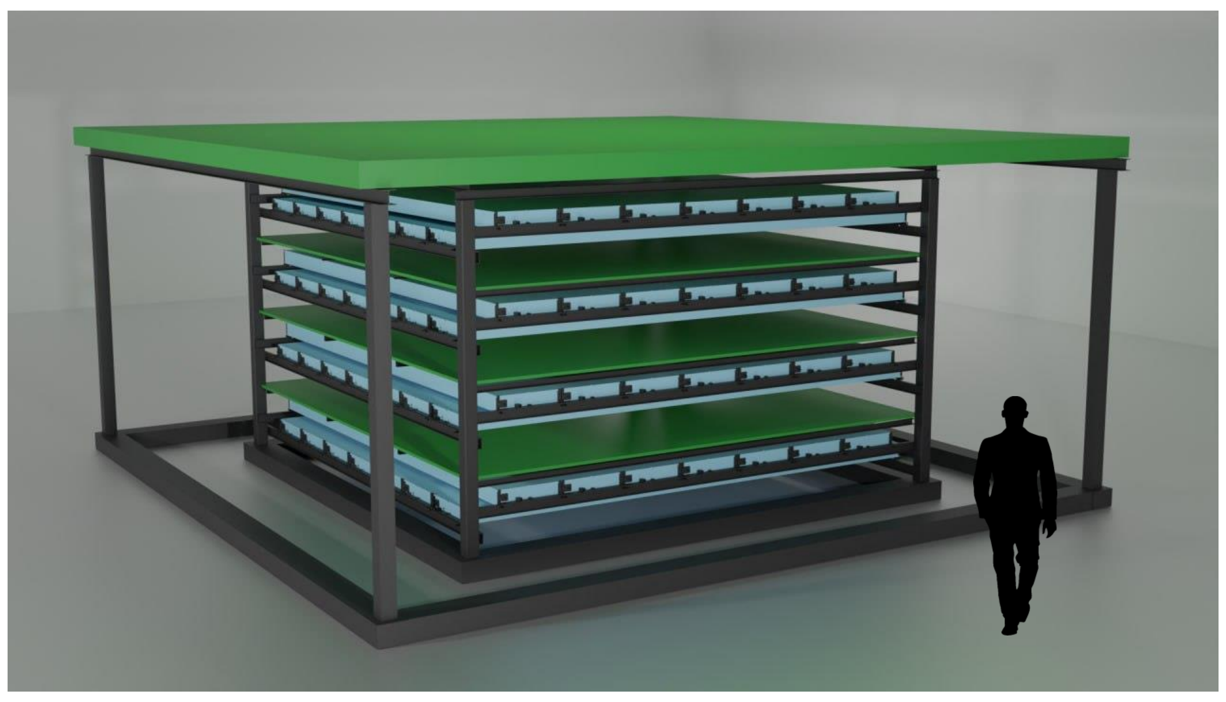
Multifunctional Detector of Muons (MDM)

The detector MDM is designed to study high energy muons in extensive air showers (EAS) – avalanches of elementary particles generated by primary cosmic rays (PCR) in the atmosphere.



Model of the MDM detector

The detector consists of an array of the multiwire drift chambers forming several coordinate planes, the upper thick absorber and thin absorbers between the planes.

There are 14 drift chambers in each coordinate plane, seven drift chambers per X-projection and seven per Y-projection.

The detector is shielded with a thick absorber layer on top and thin ones between the planes. Such configuration allows to distinguish muons from electrons and investigate EAS with the method of local muon density [1] (LMDS) in 0°-60° range of zenith angles.

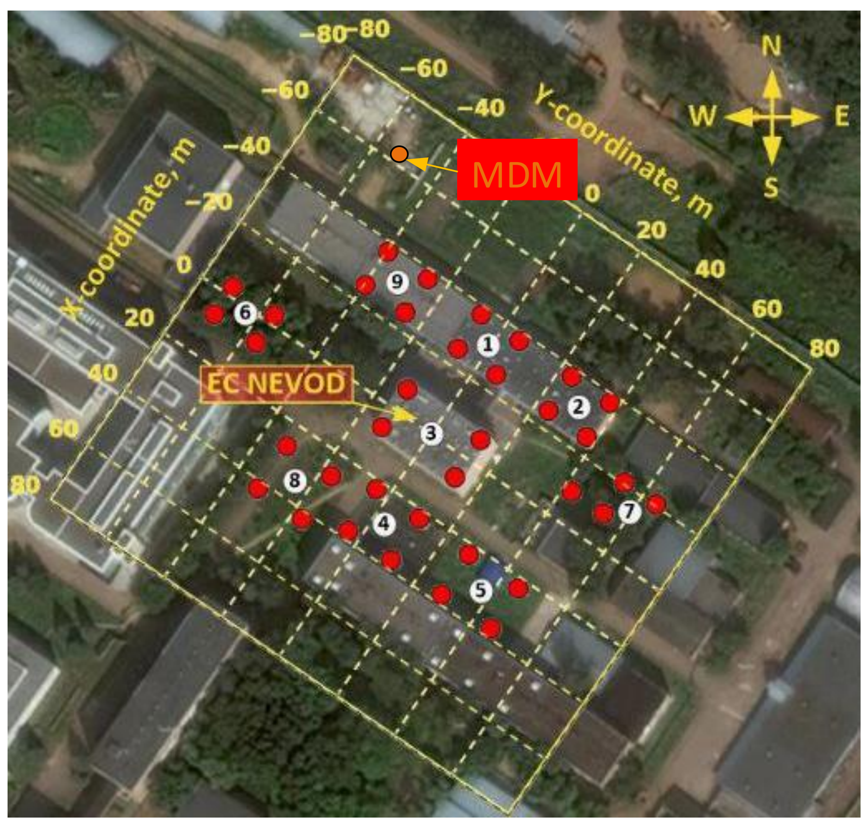
Detector can be operated with trigger from scintillation counters or in self-triggering mode with GPS-timestamp for each event that allows to match them with the response of other detectors of the Experimental complex NEVOD.

The objectives of the MDM detector

- Local muon density spectra for the near-vertical muons.
- Muon densities at different distances from the axis of the extensive air showers.
- Lateral distribution function of muons in joint operation of MDM with NEVOD-EAS, PRISMA, URAN [2].
- Anisotropy of single and multi-muon events.
- Search for events from gamma-rays. Joint operation with all detectors of the NEVOD complex.
- Operation as a test-bench for investigation of spatial response of other particle detectors. The installation has a good spatial accuracy of 1 mm.

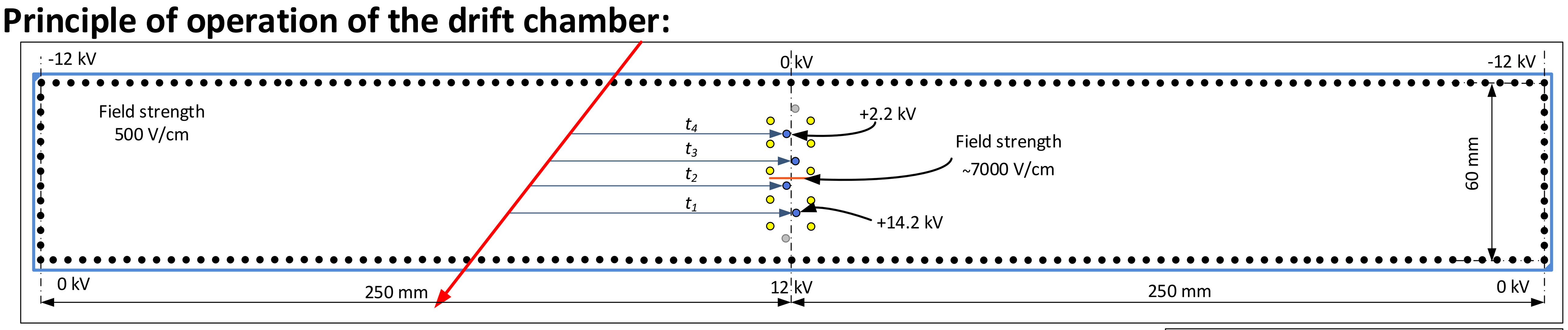
MDM, NEVOD-EAS, NEVOD

NEVOD-EAS determines the EAS axis, MDM measures the muon density at a point, combining these data to construct the function of lateral distribution.



The location of the MDM detector on the territory of MEPhI and within the experimental complex NEVOD.

Principle of operation of the drift chamber:



- ● – field-forming wires,
- ● – signal wires,
- ● – cathode wires,
- ● – security wires.

The drift chamber (DC) is a device for detection of charged particles and reconstruction of their tracks. These drift chambers were developed at the Institute for High Energy Physics in Protvino for neutrino experiment at U-70 accelerator.

DC [3] is an aluminum box with a volume of 4000×508×112 mm^3, bounded at the ends by two 15 cm plexiglas plugs. The DC volume (200 l) is filled with a mixture of 94% Ar and 6% CO_2. Hundreds of field-forming wires are stretched along the entire chamber, creating a homogeneous electric field with a strength of 480 V/cm across the DC in the range from 12 kV to 0. During the passage of the particle, the gas of the working mixture is ionized, the released electrons drift at a constant velocity under the electric-field to the center of the chamber, where two rows of cathode wires and 4 signal wires are located. A voltage of 2.2 kV is created between the cathode and signal wires at a distance of about 1 mm, which provides a gas amplification of the order of 10^5. According to the electron drift time, the position of the gas ionization points is determined and the particle track is reconstructed.

Characteristics of drift chambers:

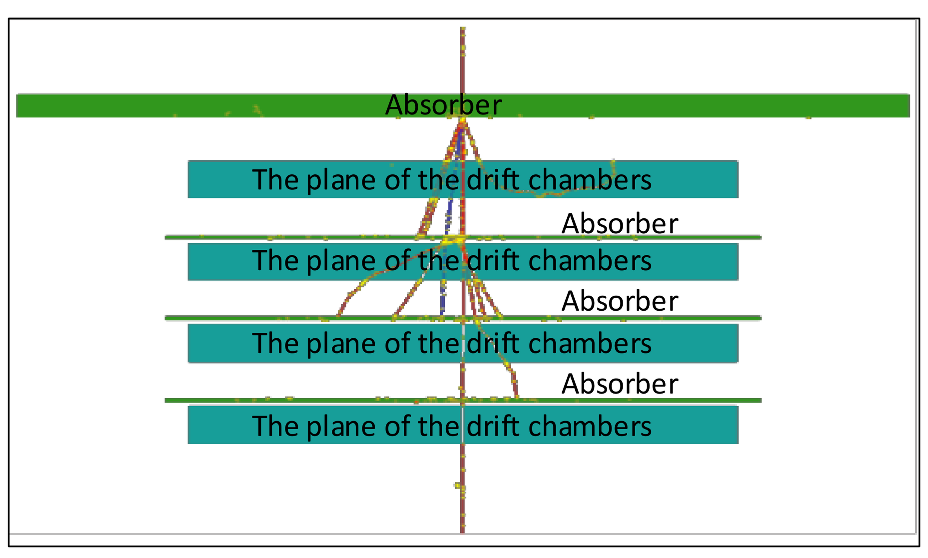
- The gas mixture: 94% Ar + 6% CO_2
- Spatial accuracy ≈ 1 mm
- Angular accuracy ≈ 1.7°
- Two-track resolution ≈ 3 mm
- Electron drift time up to 6 µs
- Drift velocity ≈ 42 mm/µs

Simulation of passage of vertical particles through the detector

In order to design the detector structure and the thickness of the absorber, a detector model in Geant4 was created and a simulation of the registration of single muons and electrons in a wide energy range was performed.

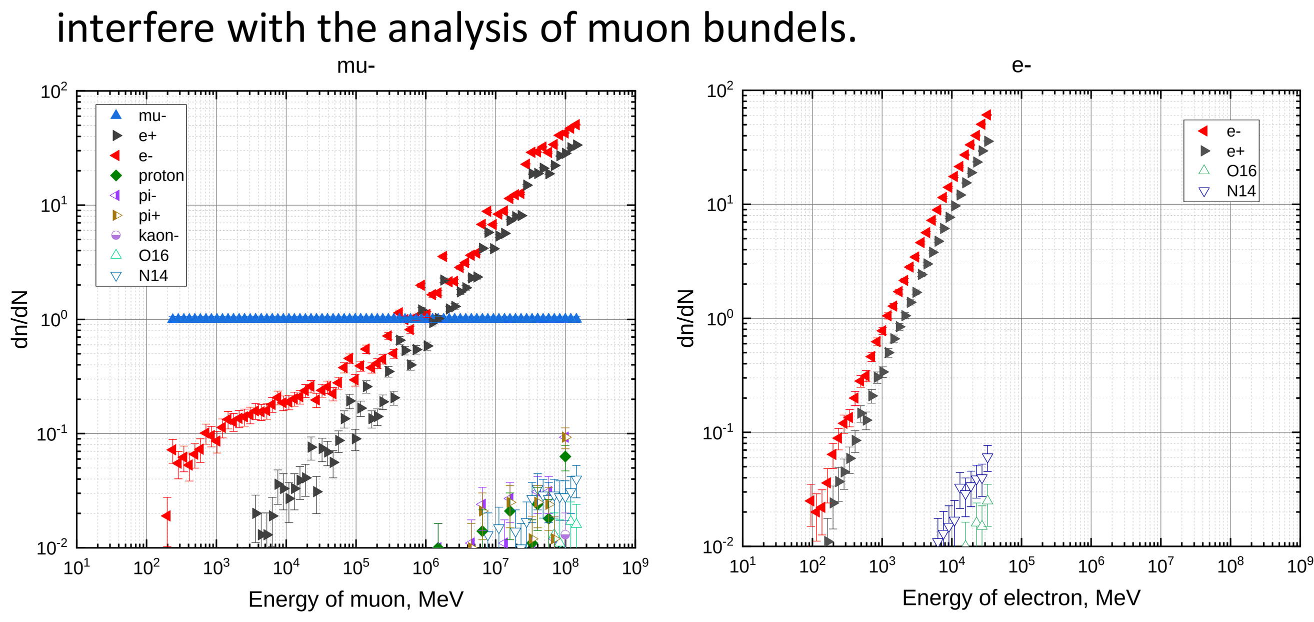
The MDM detector model consists of an upper 150 mm thick steel absorber, four DC planes and a 20 mm steel absorber between the planes of the drift chambers. In reality, the thickness of the absorbers may be changed.

In the simulation, a particle was launched from above the detector and moved towards it. Most of the particles in EAS are in the energy range from 10 MeV to 10 TeV, therefore, in the simulation the first particles were muons and electrons, with energies from 1 MeV to 100 TeV and with a geometric constant logarithmic step $E_{i+1}/E_i = 1.2$.



A model of the MDM detector in Geant4 with characteristic dimensions during the passage of a muon with an energy of 10 GeV.

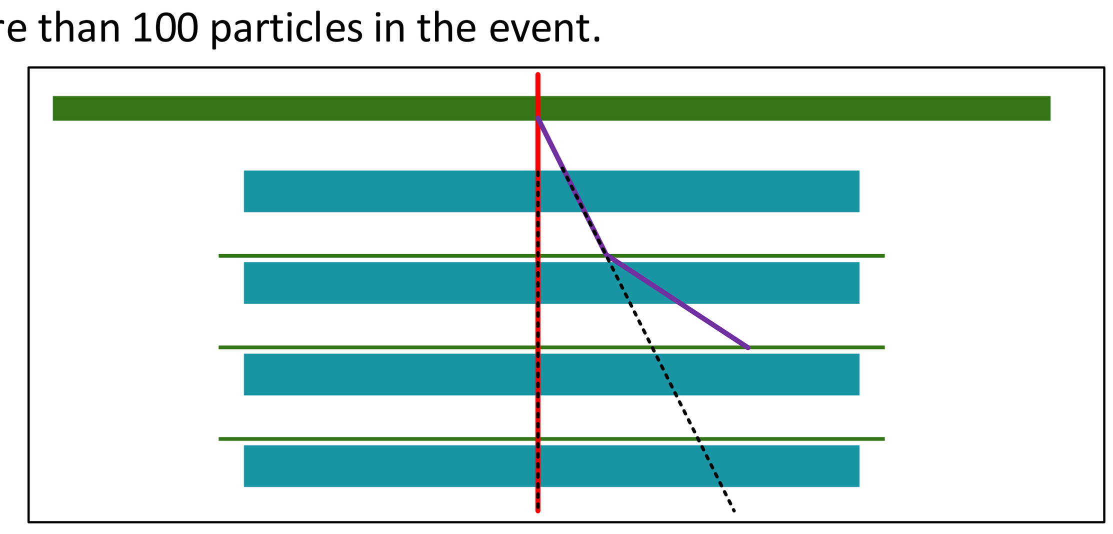
After the particle passes through the absorber, it can produce a cascade of other particles. The plots show all the particles registered in the upper plane of the drift chambers. This secondary particles interfere with the analysis of muon bundels.



All particles registered in the upper level of the drift chambers from the muon, electron.

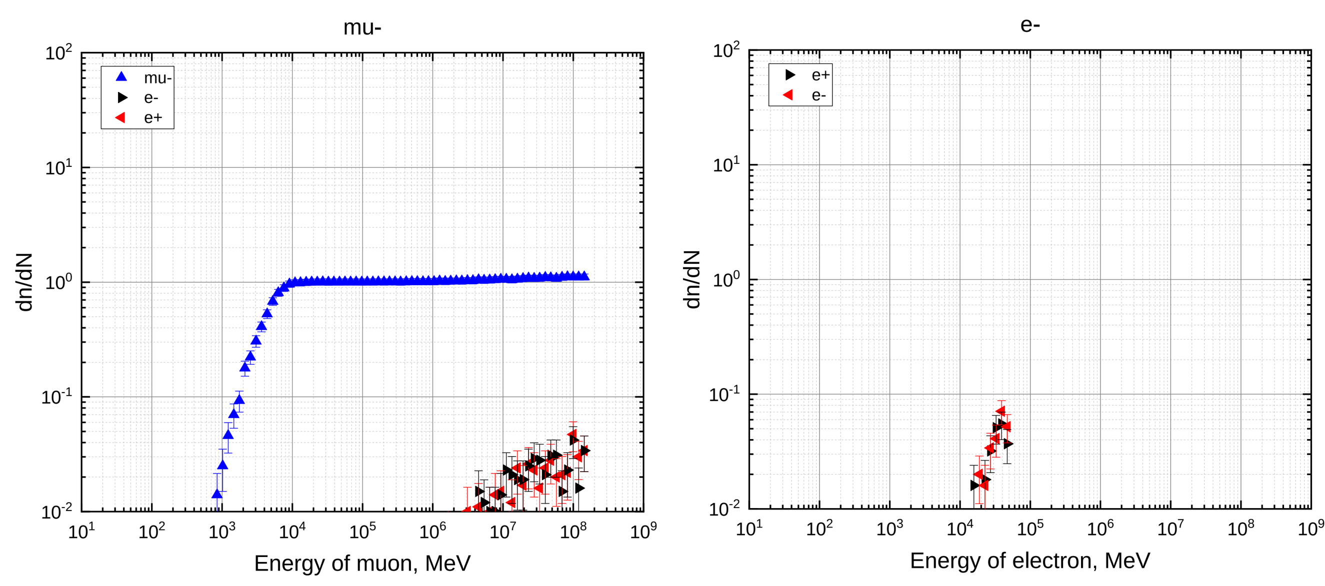
Secondary and low-energy particles, in addition to physical absorption, can be deflected. During reconstruction, such tracks will differ markably in angle from the direction of the main particles.

The deviation of the trace is the basis of the reconstruction method. The method looks at the deviations of the particle track in the upper from the lower planes, if the deviation is large, the track is discarded from the analysis. Criteria for the selection by zenith angle of 5 degrees, at the coordinate of 5 mm, and there are no more than 100 particles in the event.



Example of event reconstruction: red line is a muon track, purple line is a electron track, dotted line is a track extrapolation to other planes of drift chambers.

After the reconstruction of the tracks, it was possible to reject most of the secondary particles and electrons, the degree of clipping is shown in the plots.



Particles after using the reconstruction method.

Conclusion

To sum up, the design of the MDM detector makes it possible to investigate muon bundles in EAS, to reject electrons and secondary particles. Such detector configuration makes it possible to distinguish single muons with energies from 5 GeV to 20 TeV.

Multifunctional Detector of Muons will allow for the first time to study near-vertical muons using the LMDS method.

References

[1] Bogdanov A. G., et al. Investigation of the properties of the flux and interaction of ultrahigh-energy cosmic rays by the method of local-muon-density spectra // Elementary particles and pields. – Moscow:2010. - volume 73, pages 1852–1869.

[2] Yashin I.I. et al. NEVOD — An experimental complex for multicomponent investigations of cosmic rays and their interactions in the energy range 1–10^{10} GeV // Journal of Instrumentation. - Moscow:2021. - volume 16.

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