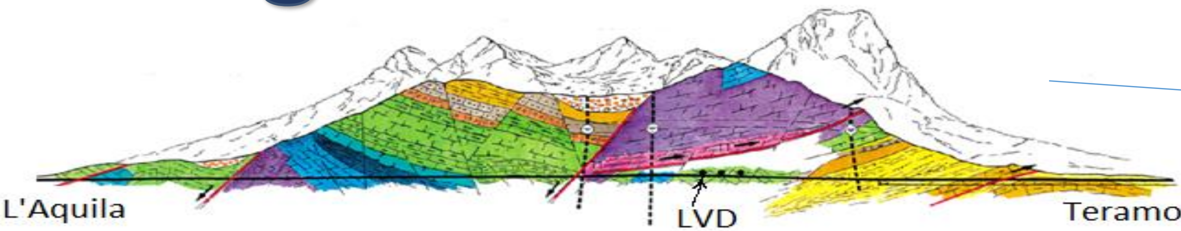
Seasonal variations of the near-horizontal muon flux measured with the LVD underground detector

Natalia Agafonova (INR RAS)

ISCRA -2019, 25-28 June 2019, MEPhI, Moscow, Russia

Large Volume Detector at LNGS

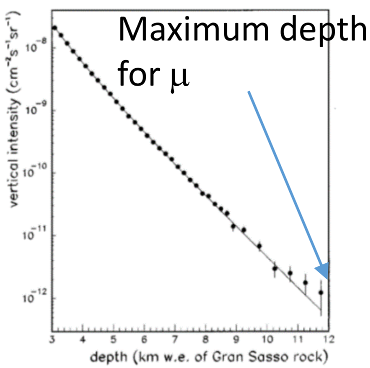


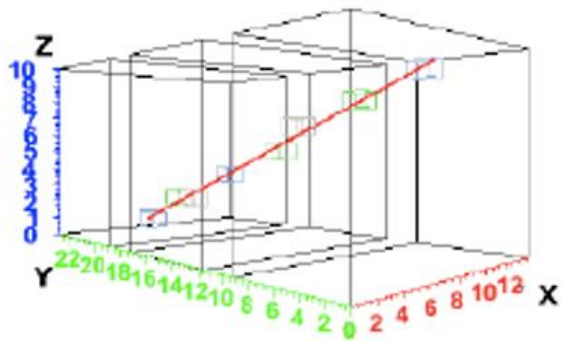
Length ×Width ×Height	22.7×13.2×10 m
Iron mass	1020 t
Scintillator mass	1008 t
Amount of scintillation counters	840
Average depth minimal	3650 m w.e. 3000 m w.e.
Mean muon energy	280 GeV
E_μ on see level (min.)	1.3 TeV
Muon rate (on 1 tower)	~ 120 h^{-1}
Threshold ε_{th}	5 MeV

The main goal of LVD is searching for neutrino radiation from stellar core collapse.

Muon events in LVD

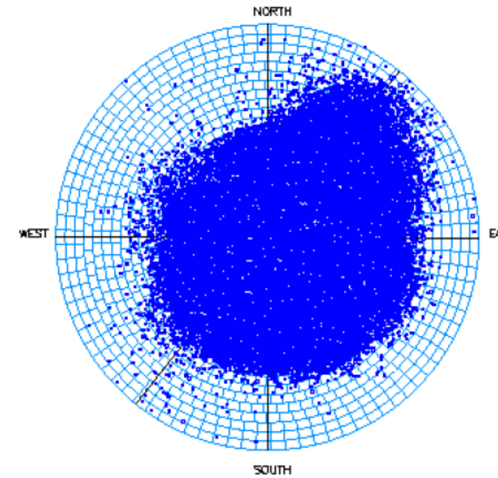
Depth-intensity curve



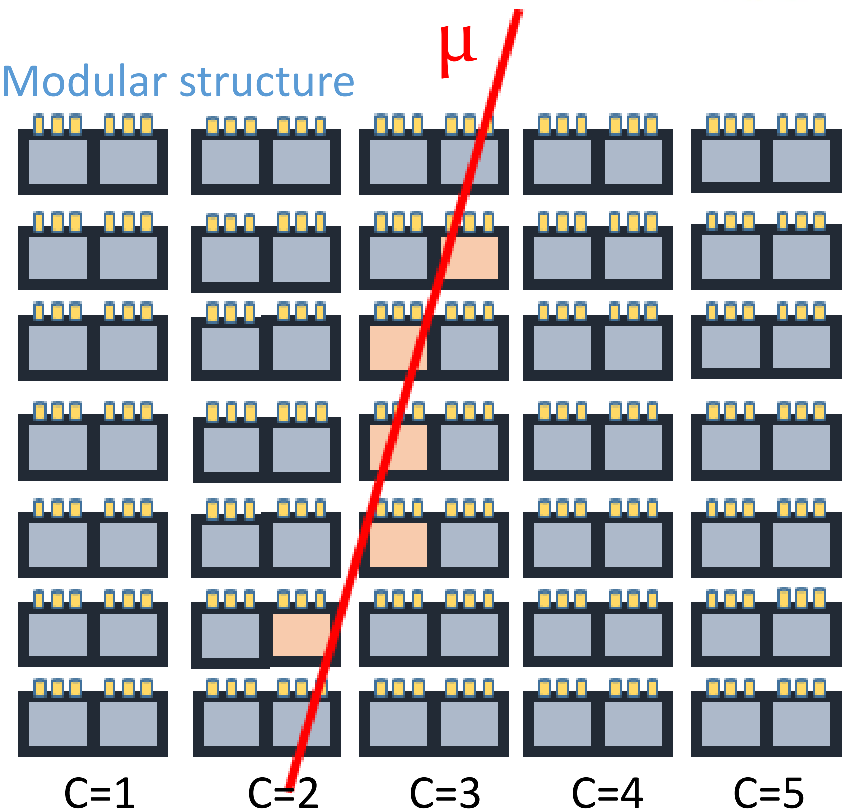


Angular distribution

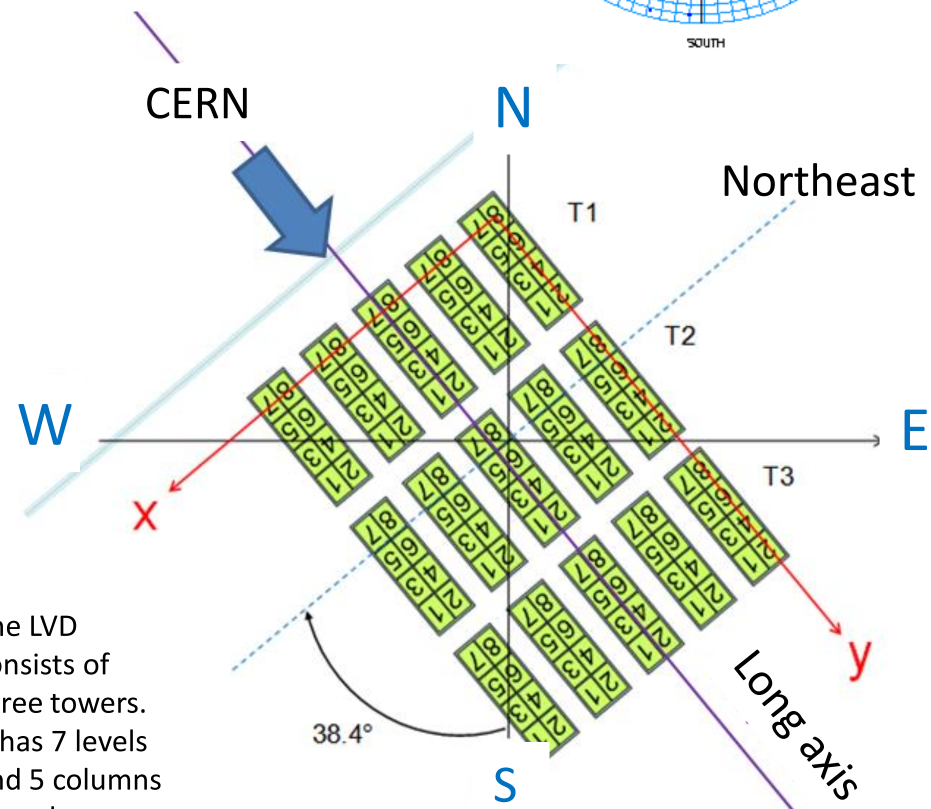
Large θ angles toward the northeast correspond to depths of about 5 km w.e.



Modular structure



The LVD consists of three towers. It has 7 levels and 5 columns in each tower.



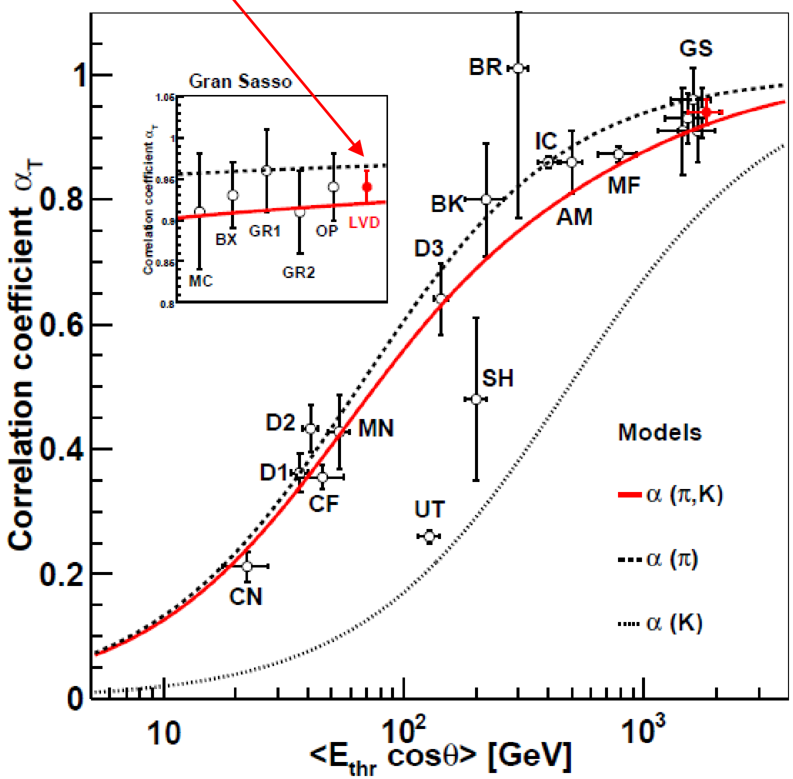
Scheme of the setup

Temperature effect

For high-energy muons (~ 280 GeV), which we are detecting underground, there is a positive temperature effect.

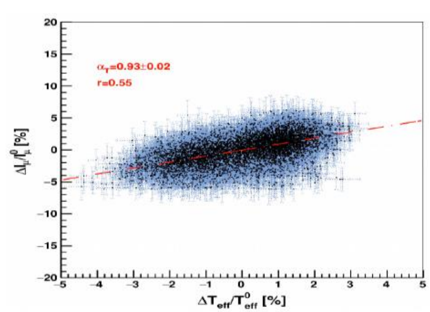
Muons that reach great depths are produced, generally, in the decays of pions of the first generation. The number of these decays increases with the expansion of the atmosphere and the fall of its density in the upper layers (at an altitude of ~ 30 km).

$\alpha_T = 0.93 \pm 0.02$

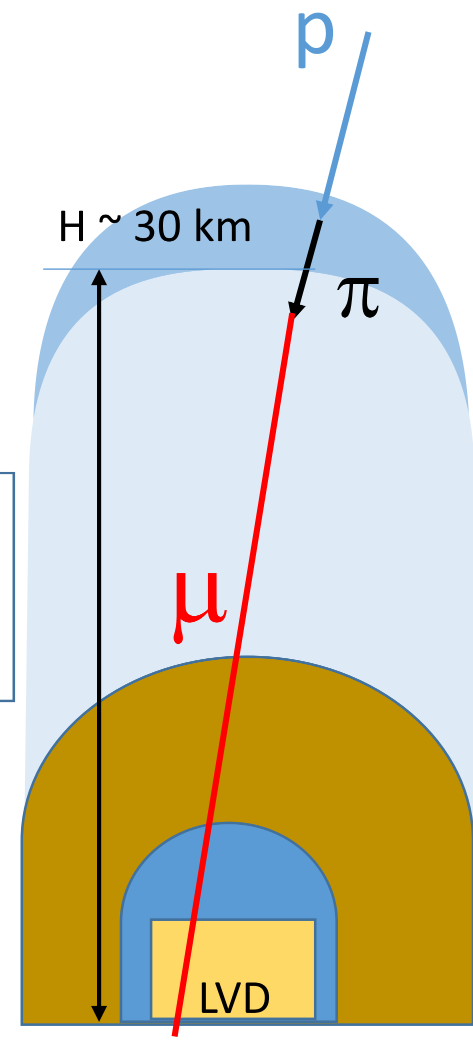


The correlation of the change in the muons intensity and the change in temperature

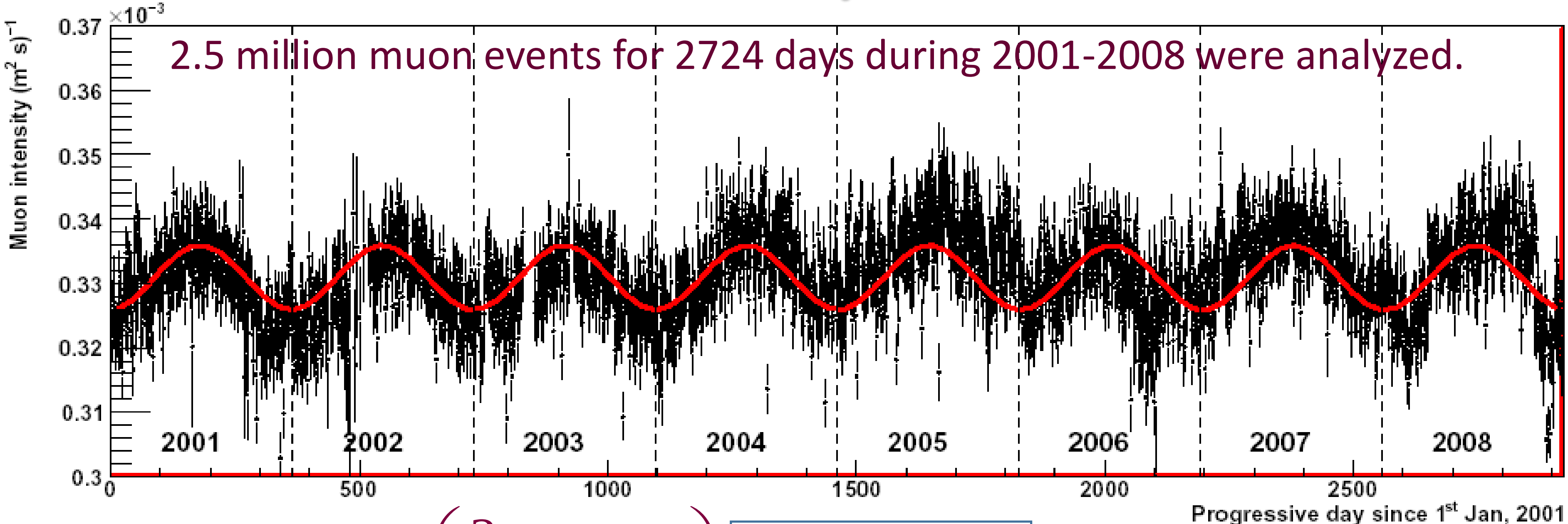
$$\Delta I_\mu / I_\mu^0 = \alpha_T \frac{\Delta T_{eff}}{T_{eff}^0}$$



correlation between muon flux and temperature changes



Variations of the intensity of the total muon flux



$$I_\mu = I_0^\mu + \delta I^\mu \cos\left(\frac{2\pi}{T}(t - t_0)\right)$$

Modulation phase

t_0= 185±15 дней

Average intensity

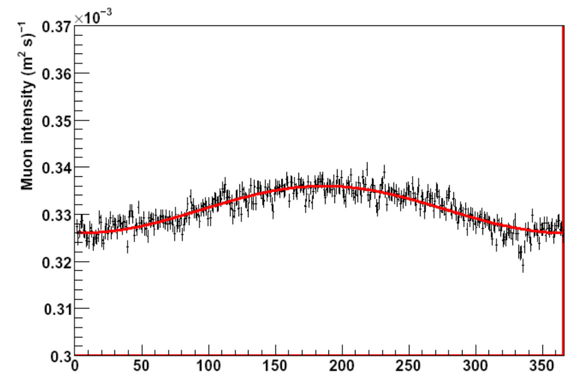
$I_0^\mu = (3.31 \pm 0.03)\cdot 10^{-4} м^{-2} с^{-1}$

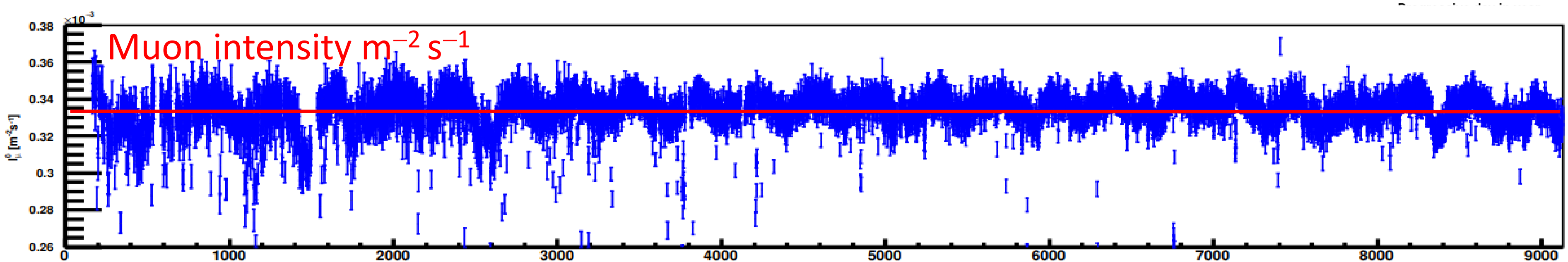
Modulation value

δI = (1.5±0.1)%

Modulation period

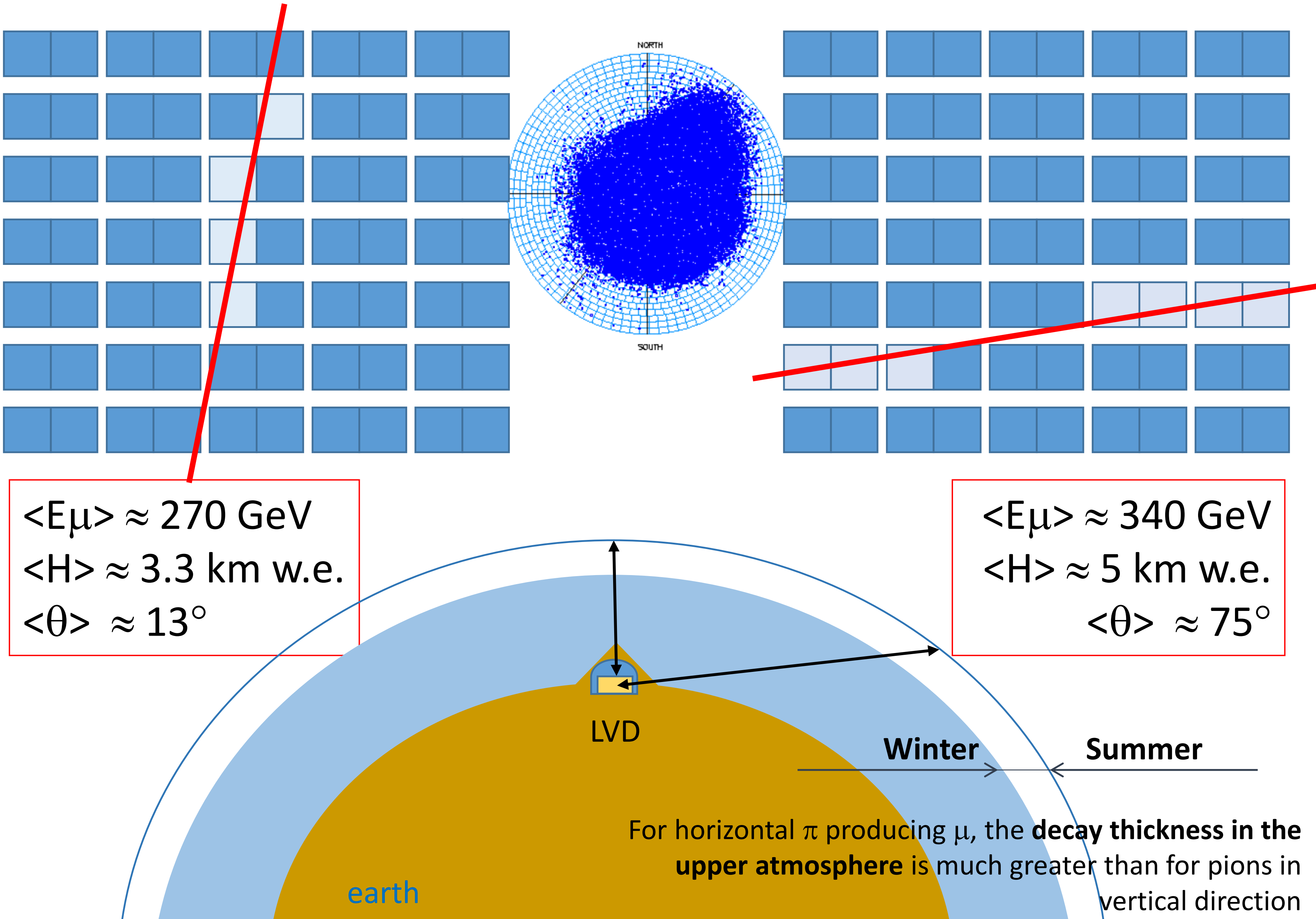
T= 367±15 дней





Near Vertical Muons

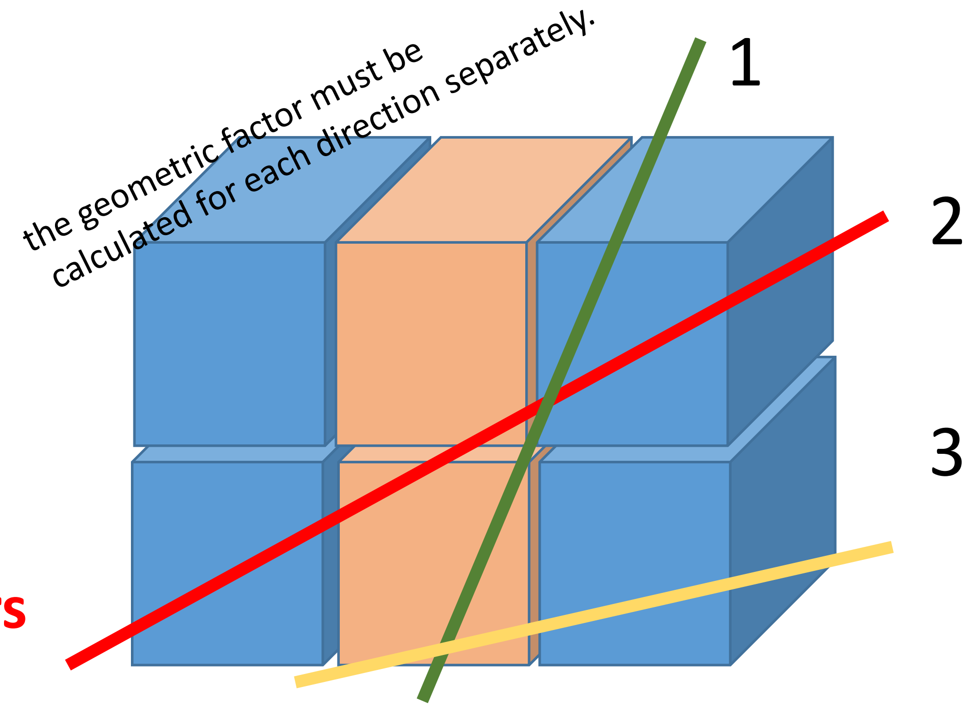
Near horizontal muons



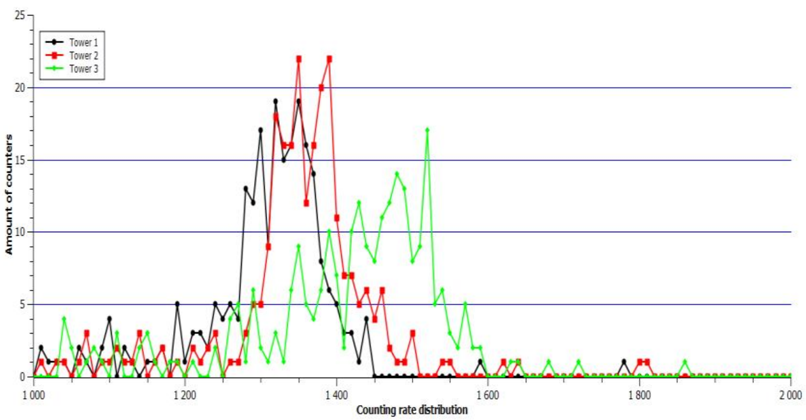
Determination of the geometric factor

<u>Event selection:</u>
Muon hits at least 2 counters in detector.

<u>An example of the passage of a muon in construction of 6 counters :</u>
№1 – muon will not detect
№2 – muon will detect
№3 – muon will not detect

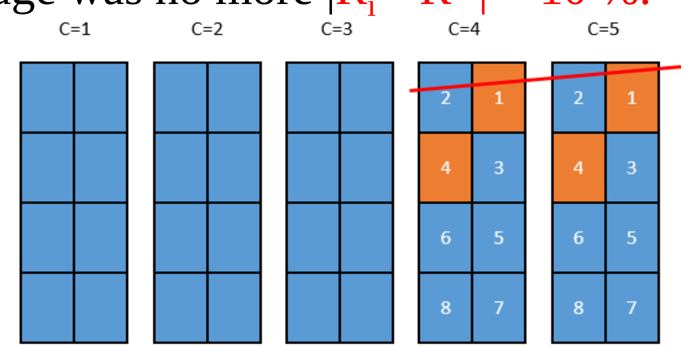


Muon hodoscope of two counters = equal acceptance method

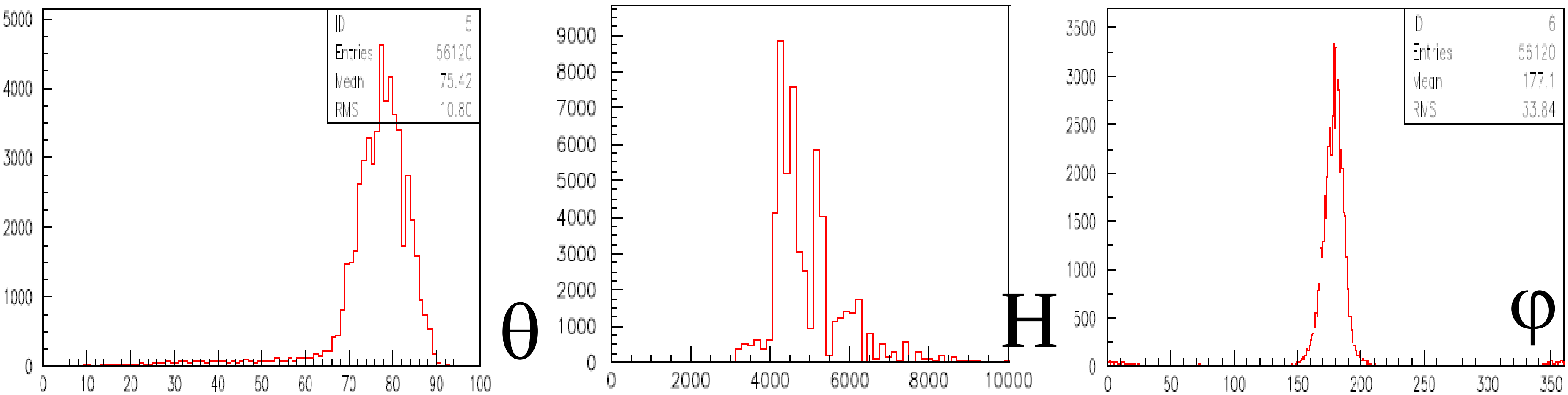


Distribution of counting rates of muon pulse counters with energy E> 50 MeV

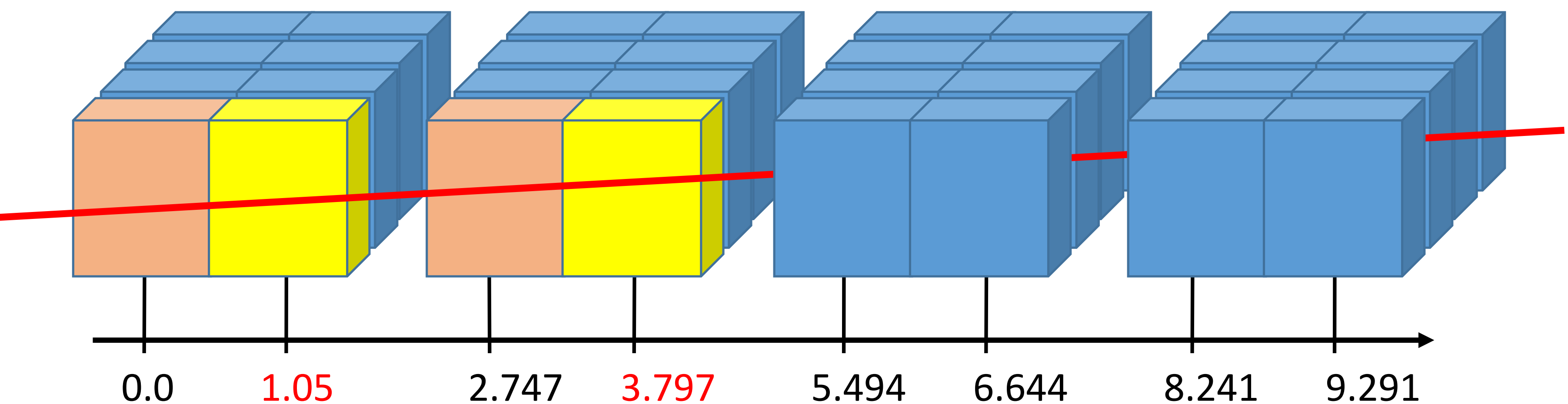
In each month, pairs of counters were selected, so that the difference in the counting rate of the counter from the average was no more $|R_i - \langle R \rangle| = 10\ \%$.



Muon hodoscope of two counters



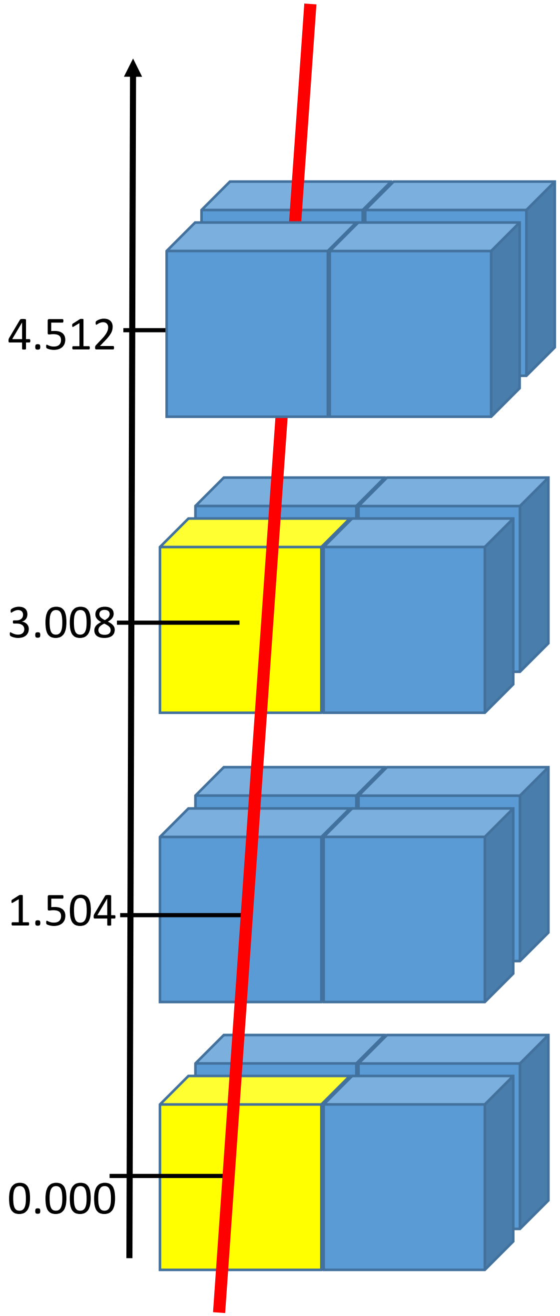
horizontal direction θ: 65° – 90°

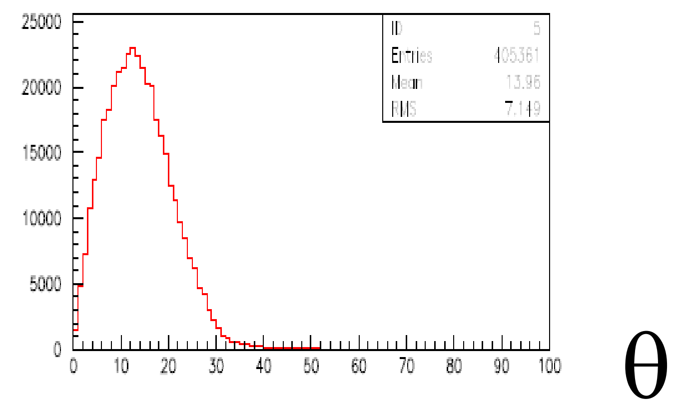


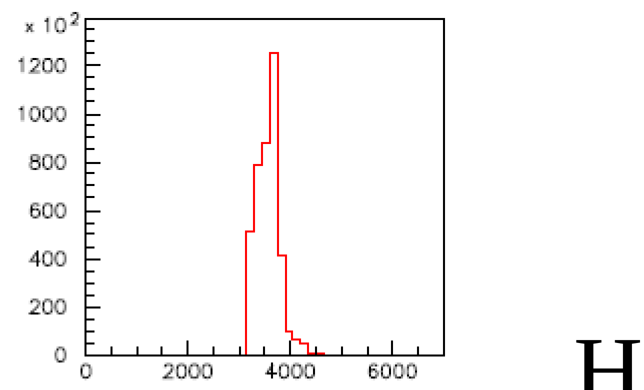
The muon hodoscope of the horizontal direction forms the counters of the same level, standing through one. We linked the counters in pairs. Such coupled pairs in the detector can be 672 max.

Muon hodoscope of two counters

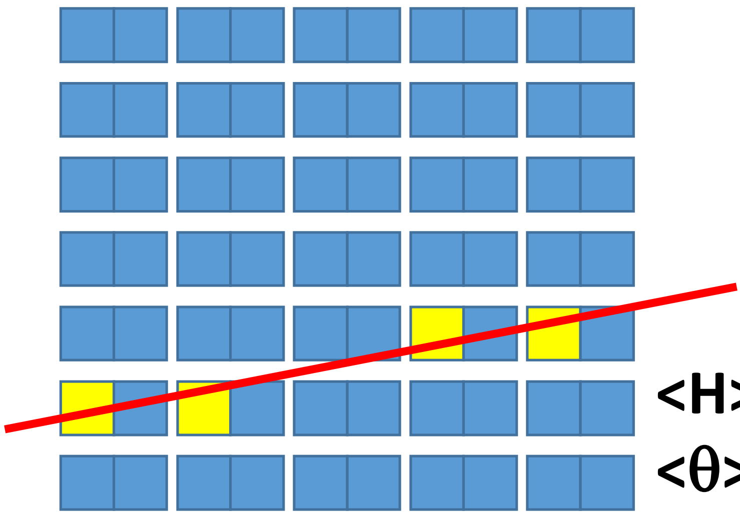
vertical direction θ: 0° – 30°







variation of horizontal muons



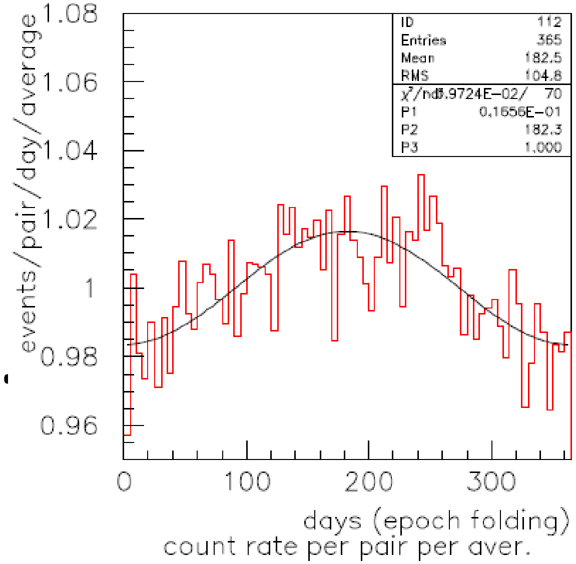
E_{tr} > 50 МэВ
Nсч > 2

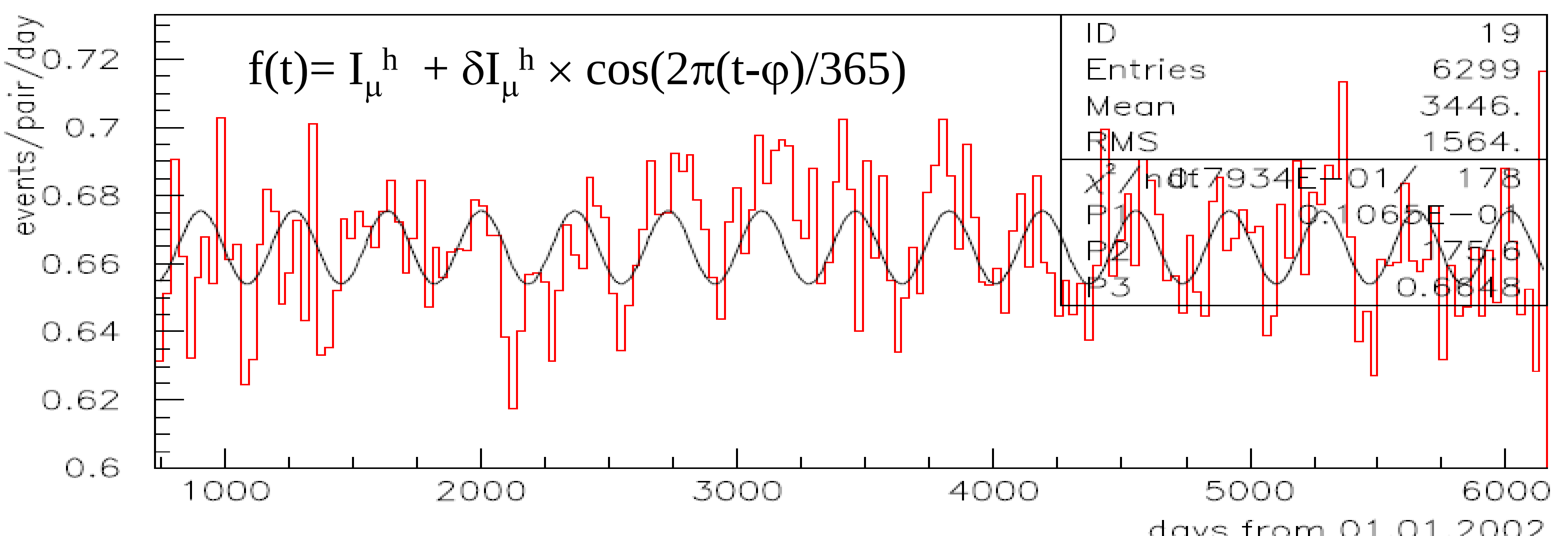
$\langle H\rangle = 4980 \pm 250$ m w.e.

$\langle\theta\rangle = 76 \pm 2$

$N_{hor} = 2.6\% \; N_{tot}$

Epoch folding method





The seasonal variations of horizontal muons

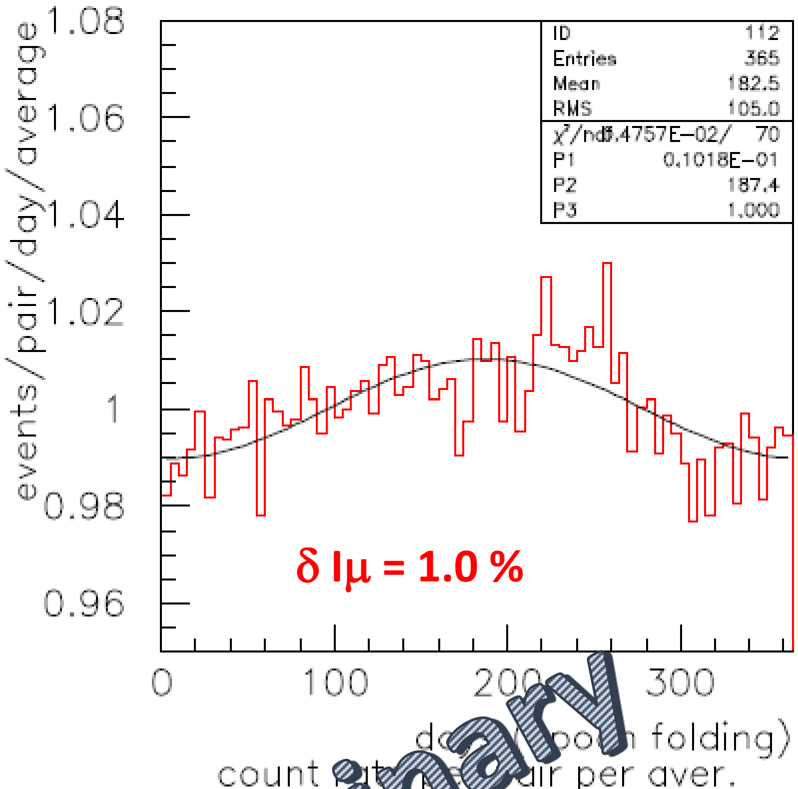
N_{hor} = 0.66 d^{-1} $pair^{-1}$

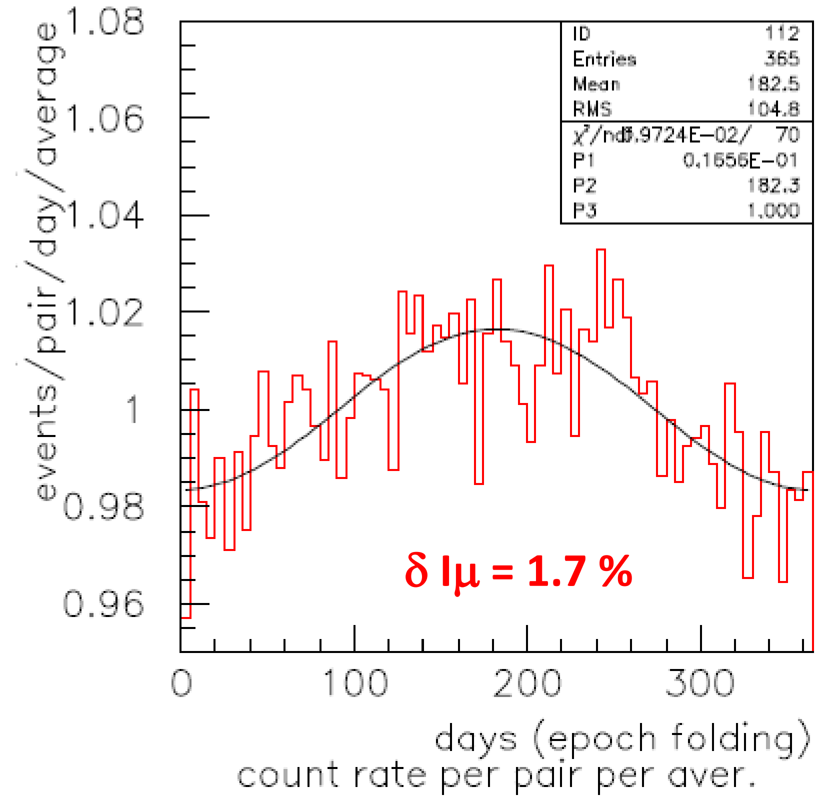
t_{max}=182 d

δ = 0.011/0.66 = 0.017

Near-vertical muons | **Near-horizontal muons**

Epoch folding method





Residual method

Near-vertical muons:

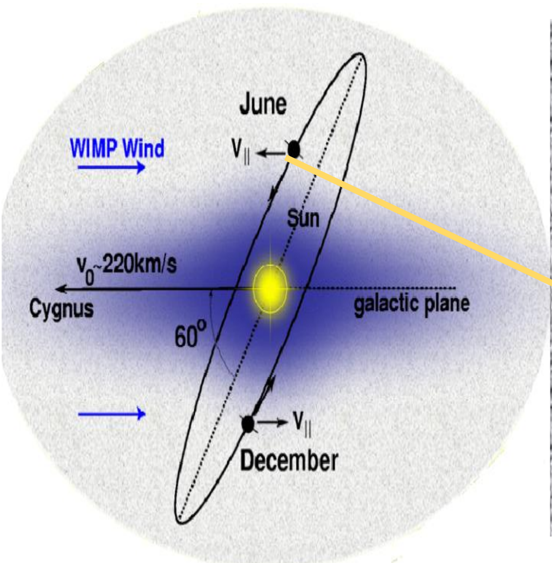
summer: 3731 ev./c.
winter: 3647 ev./c.
δ Iμ= 1.1 ± 0.06stat ± 0.2sys %

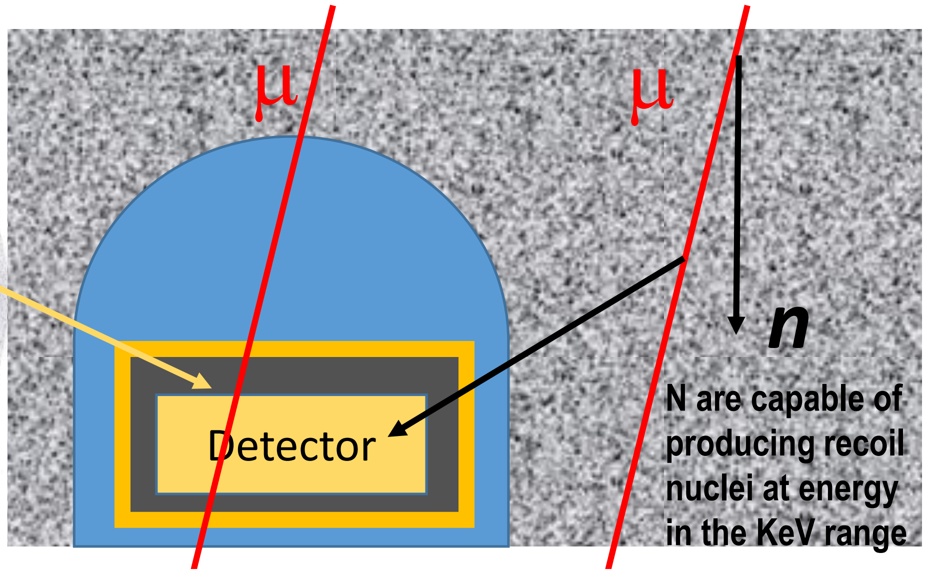
Near-horizontal muons:

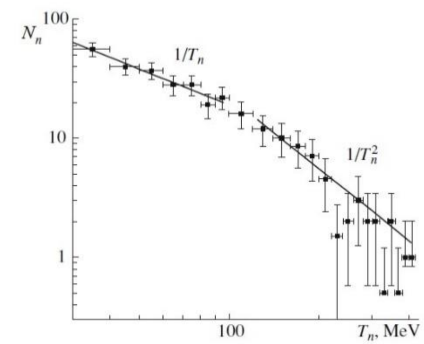
summer: 763 ev./c.
winter: 736 ev./c.
δ Iμ = 1.8 ± 0.2stat ± 0.2sys %

Direct search for dark matter particles

In the case of elastic scattering on the nuclei of the substance of the detector, WIMPs can give recoil nuclei with energies from 1 to 100 KeV. The rate of WIMP detection should be modulated due to seasonal variations in the speed of the Earth relative to the center of the Galaxy and the galactic WIMP- “gas”. Due to the rotation of the Earth around the Sun and the movement of the Solar System in the Galaxy, the registration rate in summer exceeds the winter rate.



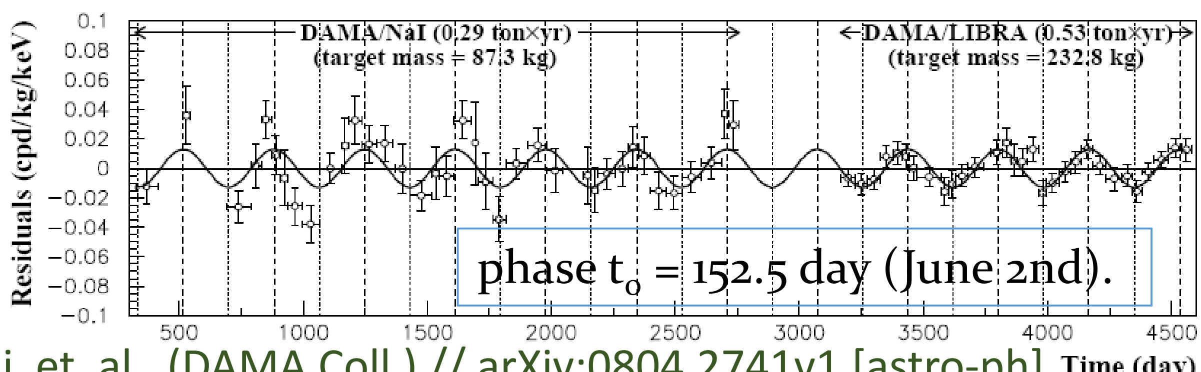




Cosmogenic neutron energy spectrum

The counting rate of neutron producing by μ has seasonal variation, like WIMP !

DAMA/LIBRA, XENON100, XMASS Direct detection of cold dark matter - hypothetical particles of WIMPs



R. Bernabei et. al., (DAMA Coll.) // arXiv:0804.2741v1 [astro-ph]

Conclusion:

1. With the LVD data the characteristics of seasonal variations in the muon fluxes of different directions in the period from 2001 to 2018 were obtained. Using independent simple hodoscopes the amplitude and phase of seasonal variations for horizontal and vertical muons were determined.

Modulation amplitude for horizontal muons is δI_{μ}^{hor} = 1.7±0.3 %

Modulation amplitude for vertical muons is δI_{μ}^{ver} = 1.0±0.2 %.

2. This studies refer to high-energy muons: the threshold energy (50% probability of survival) of muons at sea level for vertical muons is E_{th}^{ver} = 1.8 TeV, for horizontal muons is E_{th}^{hor} = 4.7 TeV.

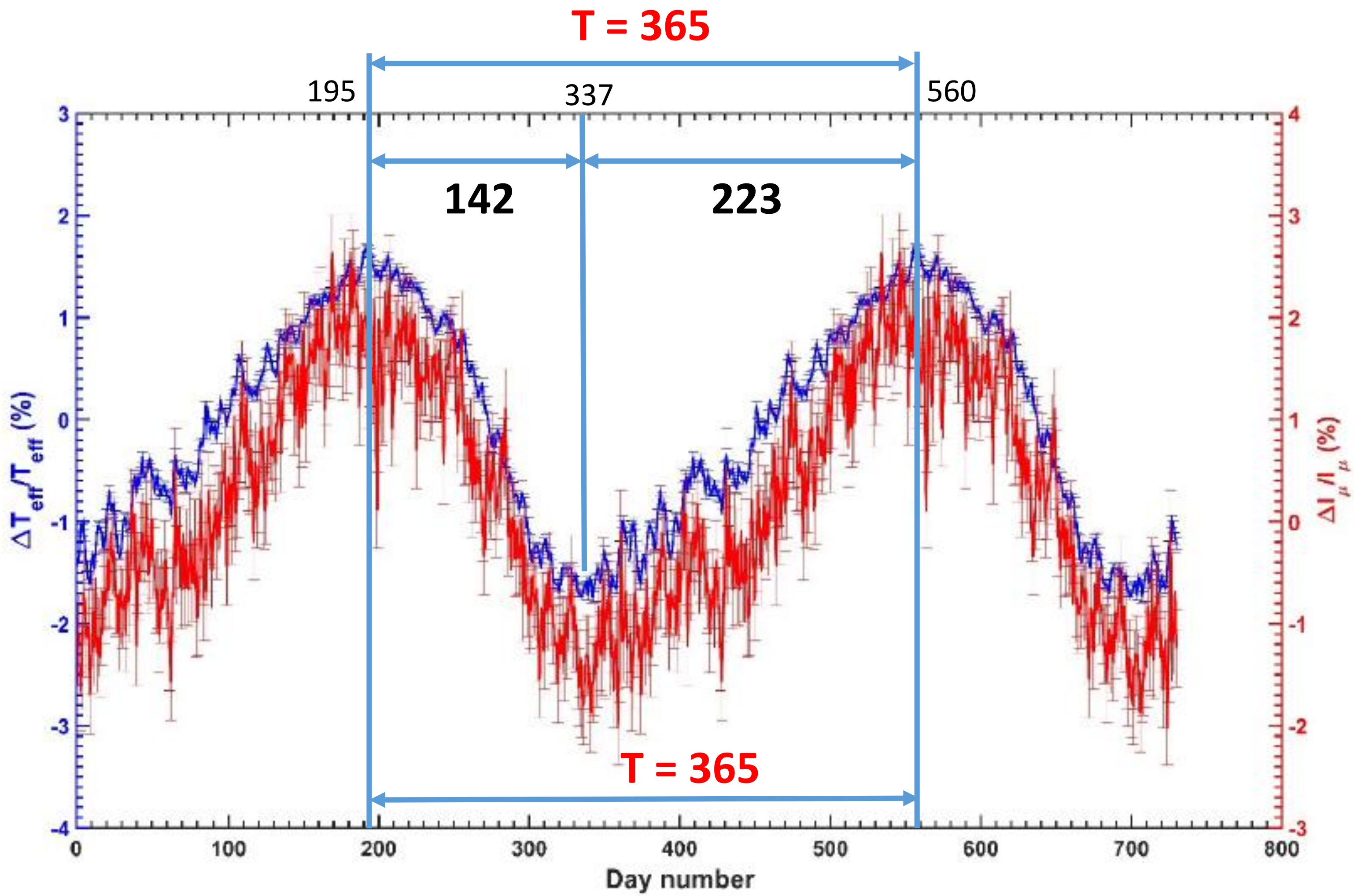
3. In the future, it is planned to determine the temporal characteristics of the neutrons produced by muons in vertical direction and horizontal one.

Thanks!

comparison table

	All muons	Near Vertical Muons	Near horizontal muons
δI_{μ}	1.5%	1.1%	1.7%
<H>, km w.e.	3.72	3.57	4.98
$<\theta>$	28	13	75
<E>, ГэВ	280	260	340
I^{max}	185	182	178
δN_n	7.7%	6.4%	14%

Variations of muon intensity: features - not a sinusoid



Вариации нейтронов, образованные горизонтальными мюонами