Study of processes caused by stopped muons for the energy scale determination in the DANSS experiment

Alexandra Yakovleva, MIPT Natalia Skrobova, LPI RAS

Moscow International School of Physics 2020

08.03.20

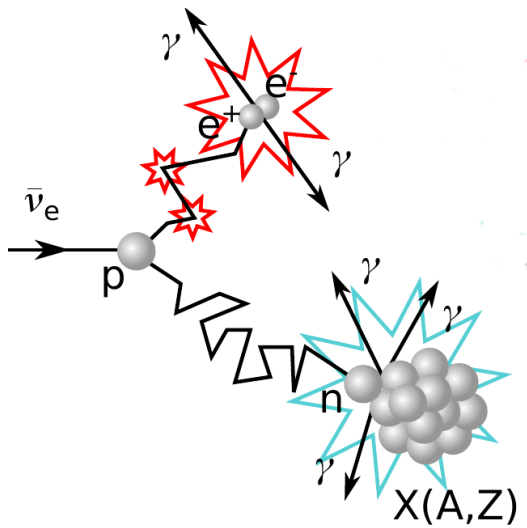
DANSS experiment

The experiment goal is the search for sterile neutrinos. To achieve this goal, the inverse beta decay (IBD) process is used.

Antineutrino energy is determined by measuring energy of produced positrons. Therefore the detector energy scale is a key parameter of the experiment.

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

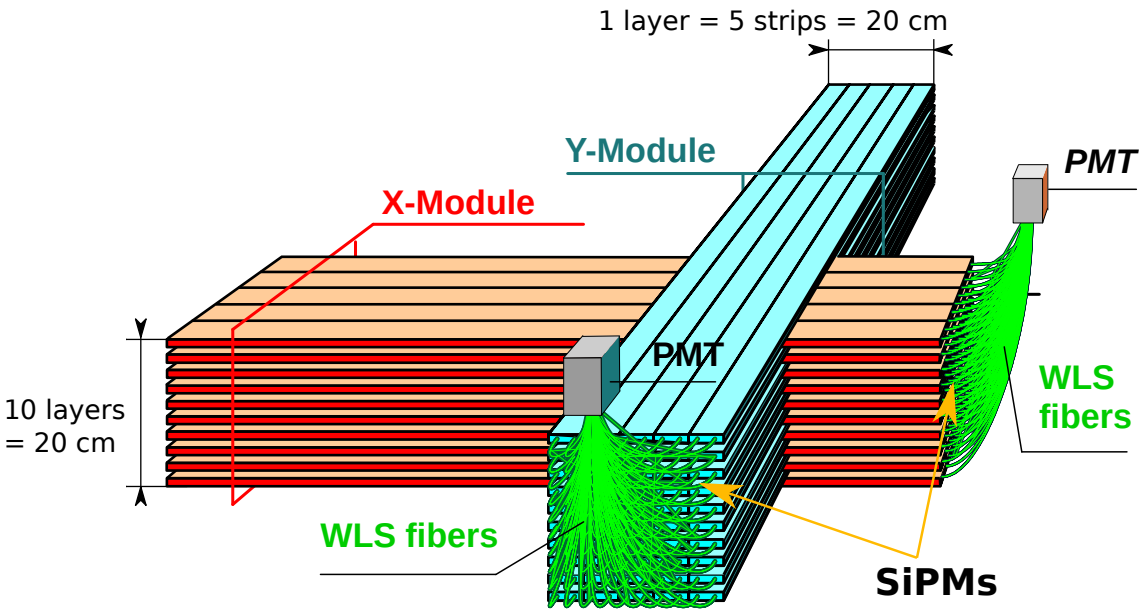
$$E_{\overline{\nu}} = E_{e^+} + 1.806 \text{ MeV}$$

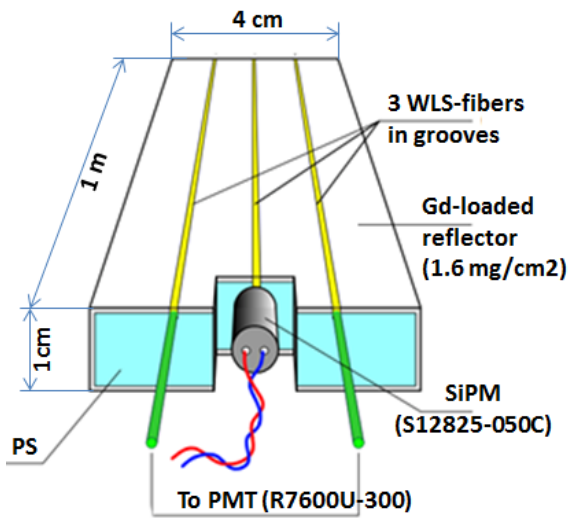


We use processes with muons stopped inside the detector to determine the energy scale.

DANSS experiment

DANSS consists of 2500 scintillator strips arranged in 100 layers of 25 strips. The strips in the adjacent layers are orthogonal. Light from the strips is collected with wavelength shifting fibers read out with SiPMs and PMTs.





Processes caused by stopped muons

DANSS detects cosmic muons.

- Muon stopped inside the detector could **decay**:

  $$\mu^+ \to e^+ + \nu_e + \overline{\nu}_\mu \qquad \mu^- \to e^- + \overline{\nu}_e + \nu_\mu$$

  or **be captured**:

  $$\mu^- + p \to n + \nu_\mu$$

  Muons mean lifetime: ≈ 2.2 μs

- Muons captured on carbon could **produce boron**:

  $$\mu^- + {}^{12}C \to {}^{12}B + \nu_\mu$$

  Then boron decays:

  $${}^{12}B \to e^- + \overline{\nu}_e + {}^{12}C$$

  ${}^{12}B$ mean lifetime: ≈ 29 ms

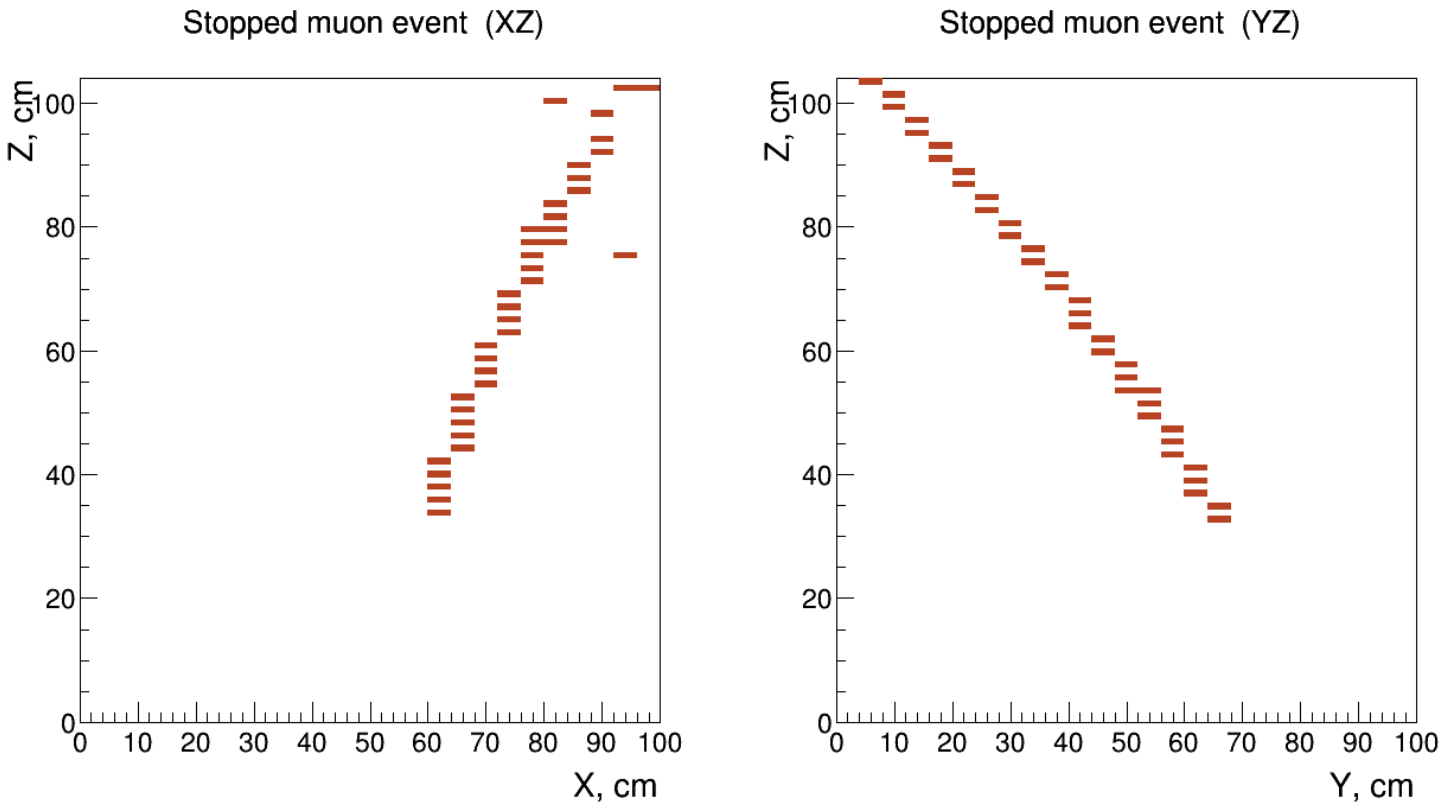
DANSS registers e^- and e^+ produced in these processes, which have recognizable spectra and can be used for the energy scale determination.

Search for stopped muons

Algorithm of the search:

- search for the lowest strip of the muon event (Z is considered);
- X, Y coordinates reconstruction by parameters of the previously built track line

We do not consider muons stopped close to the boundary.

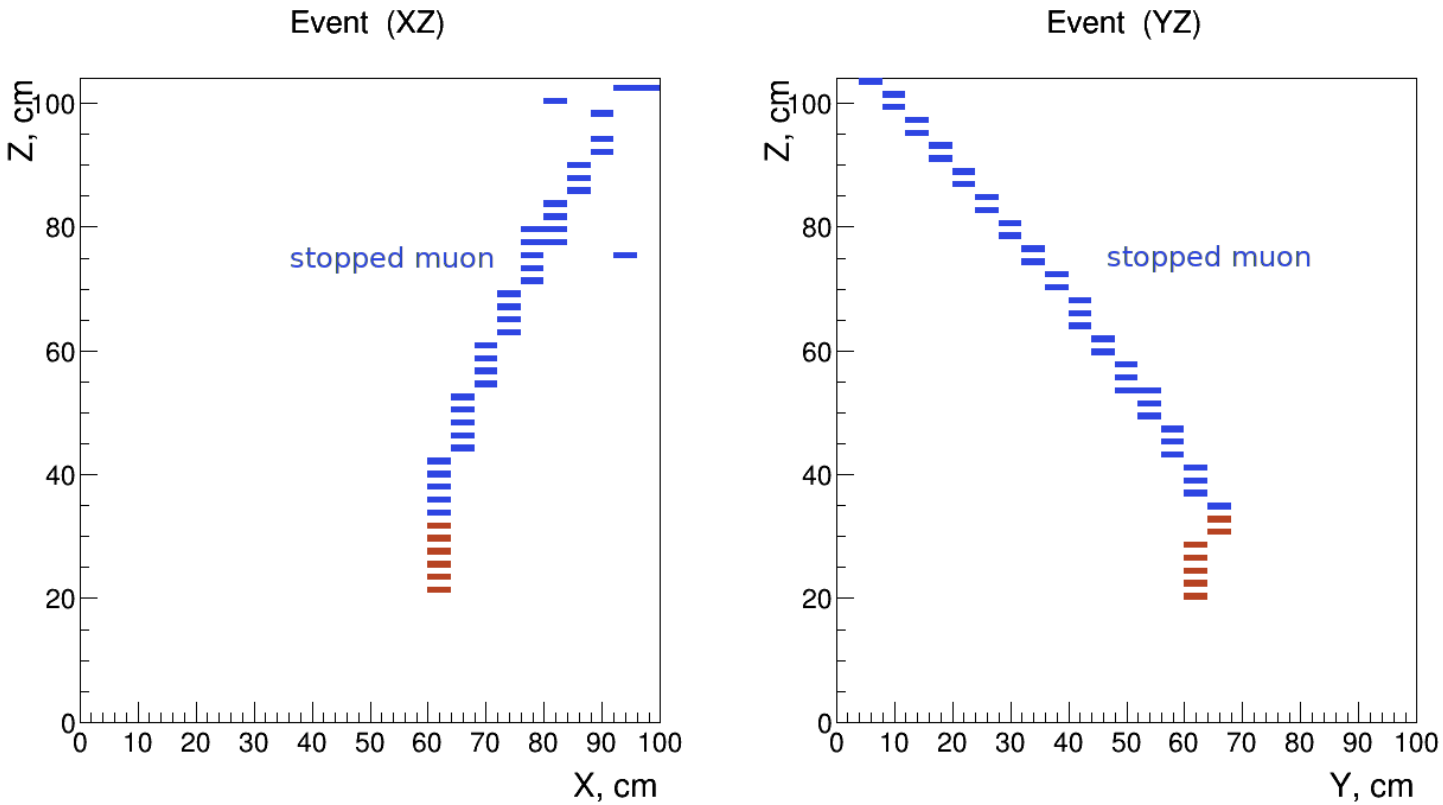


Example of a stopped muon

Decays and captures of stopped muons selection criteria

Decays and captures events criteria:

- time span between the event and the muon stop is less than 8 μs (muon mean lifetime ≈ 2.2 μs);
- at least one strip close to the stop point responded;
- energy of each hit is less than 10 MeV (to avoid saturation effect in each channel)



Example of a decay or capture event

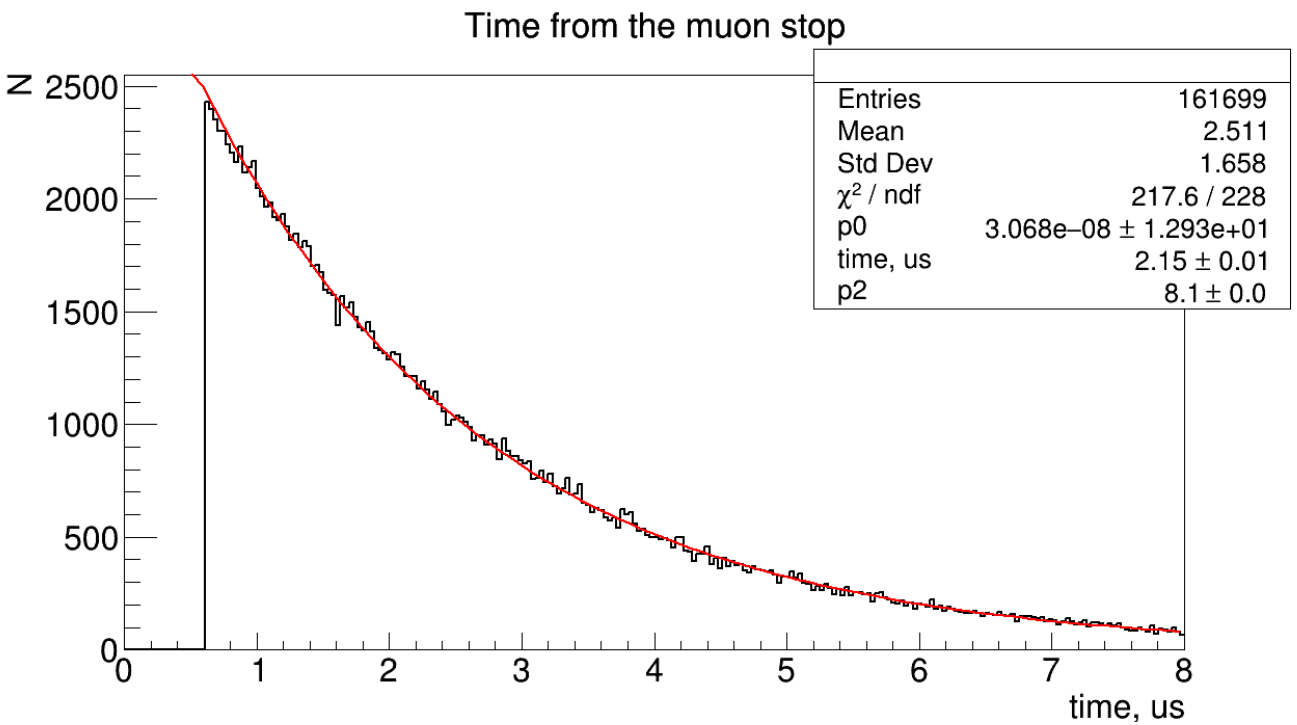
Decays and captures distributions

The distributions of time from the muon stops were fitted with the following function: $f(t) = p_0 + \exp(p_1 \cdot t + p_2)$. Data is perfectly described by the fit function.

Measured muon lifetime:
2.150 ± 0.007 μs

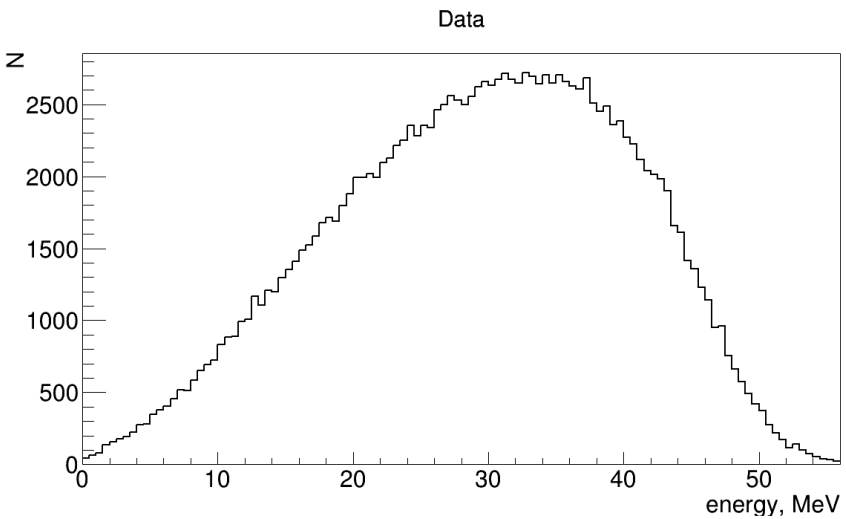
Free muon lifetime (PDG):
2.196981 ± 0.000002 μs

The measured lifetime is slightly smaller than the free muon one because of captures of negative muons.



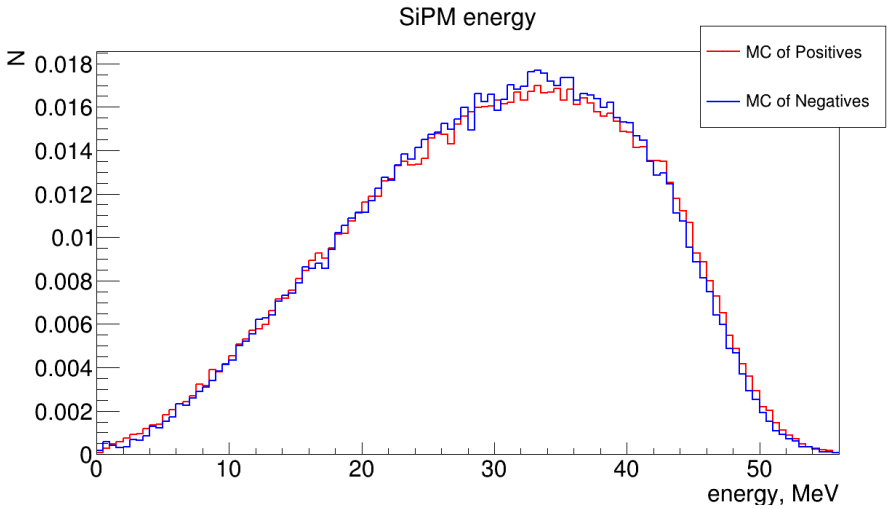
Decays and captures distributions

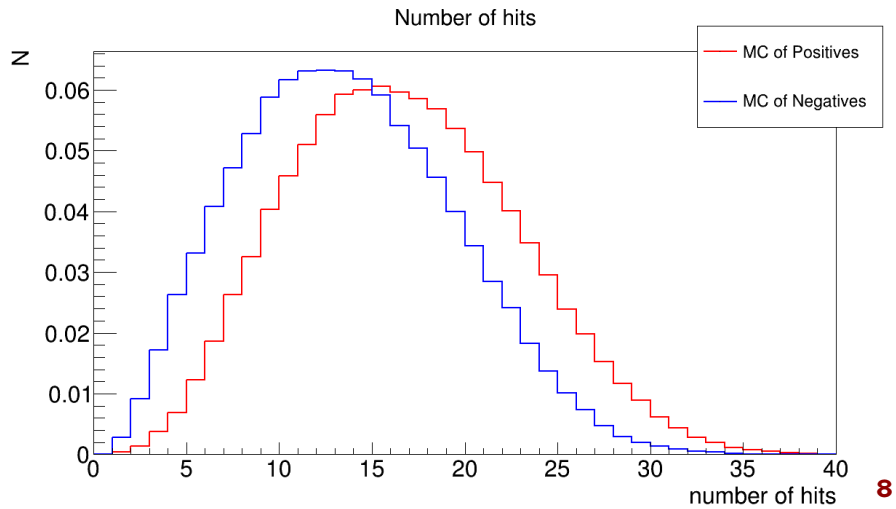
We use only decays spectra from the simulation because captures is hard to describe. The comparison is carrying out at high energies (≥ 24 MeV) where the contribution of captures is almost zero.



Measured energy spectrum (top), simulated spectra of positive and negative muons decays (left), simulated distribution of number of hits in positive and negative muons decays events (right)

Positive muons spectrum is shifted and has larger hits multiplicity than negative muons spectrum due to positrons annihilation.



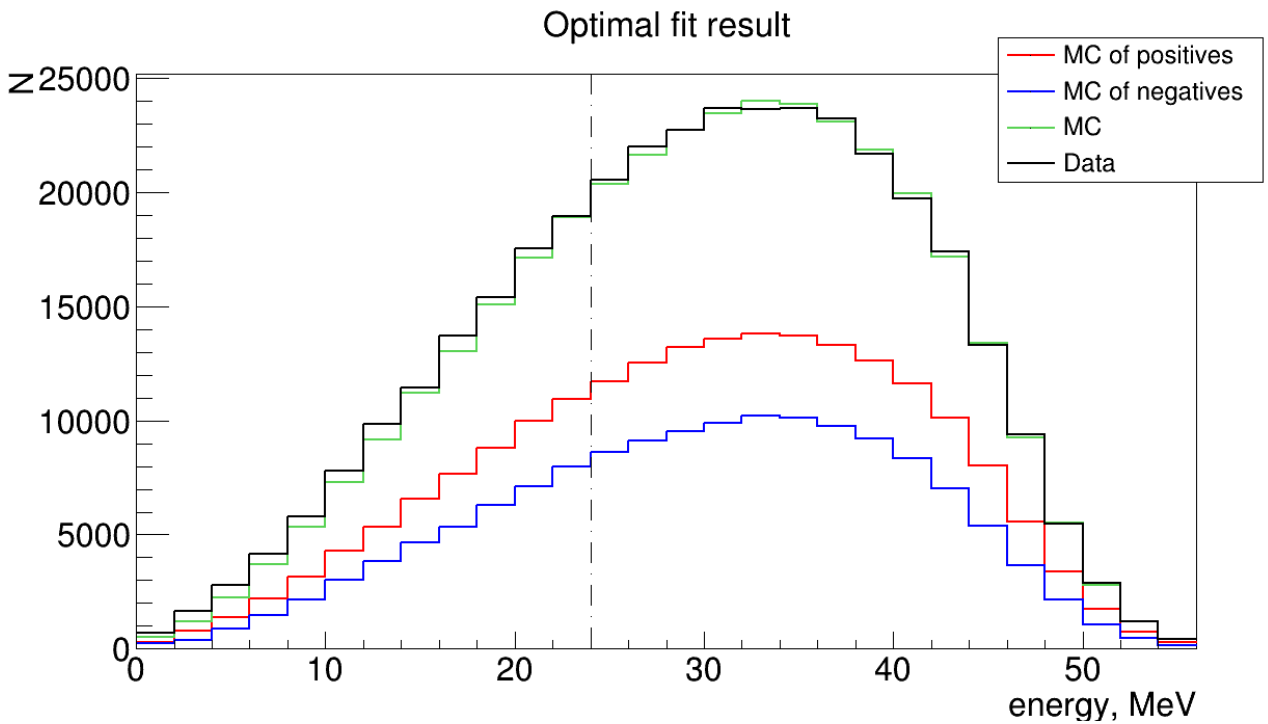


Comparison with Monte Carlo simulation

To determine the corrections to the energy scale and the detector resolution,

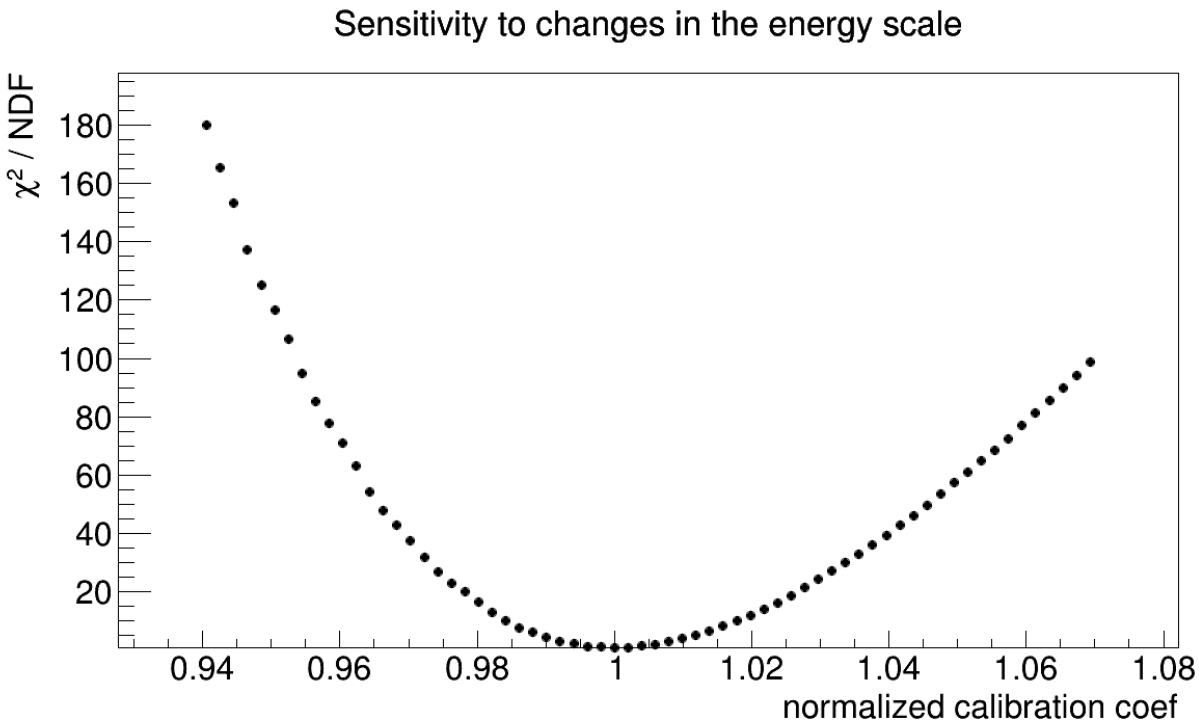
- the measured energy spectrum is scaled with an additional calibration coefficient;
- the spectrum from the simulation is blurred;
- these spectra are compared for different calibration and blur coefficients

The DANSS collaboration decided not to reveal the coefficients this time.



Comparison with Monte Carlo simulation

The detector energy scale can be determined with a statistical accuracy of 0.5%.



Boron decays selection criteria

Decays of boron events criteria:

- time span between the event and the muon stop is more than 80 μs (to suppress neutron capture) and less than 100 ms (boron mean lifetime ≈ 29 ms);
- at least one strip close to the muon stop point responded;
- energy of the event is more than 4 MeV (there is too much background at lower energies);
- energy outside the continuous cluster of strips is less than 250 keV (almost zero)

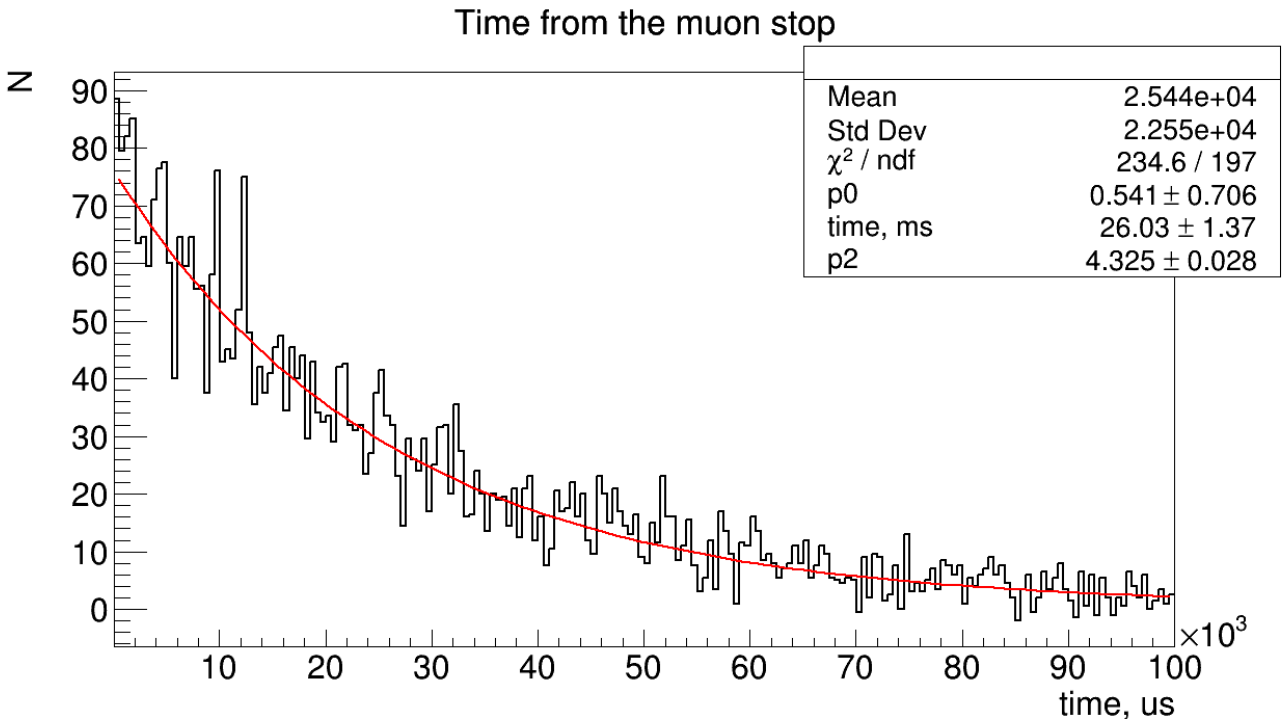
The continuous cluster includes stopped point of the muon and adjacent strips no further than 12 cm (the maximum electron track length ≈ 10 cm) from the point. Accidental background is subtracted.

Boron decays selection criteria

The distributions of time from the muon stops were fitted with the following function: $f(t) = p_0 + \exp(p_1 \cdot t + p_2)$. It's in a roughly agreement with data.

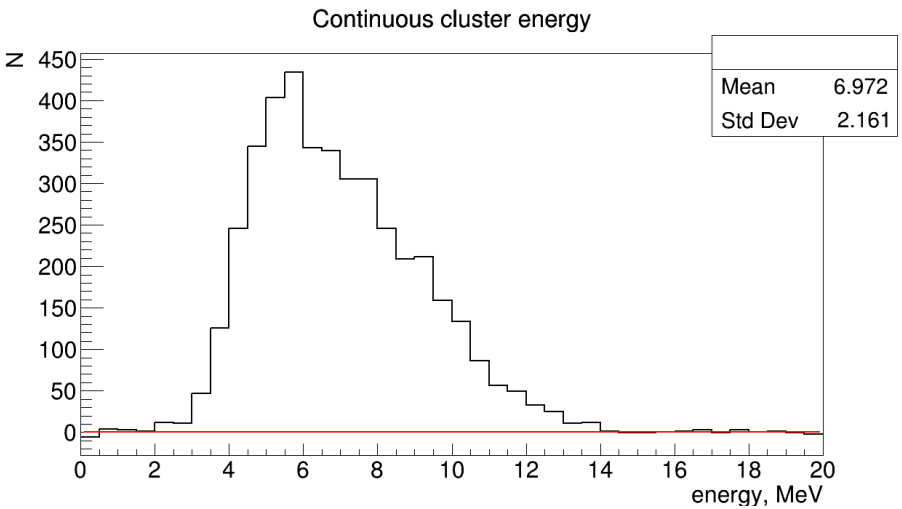
Measured boron lifetime:
26.0 ± 1.4 ms

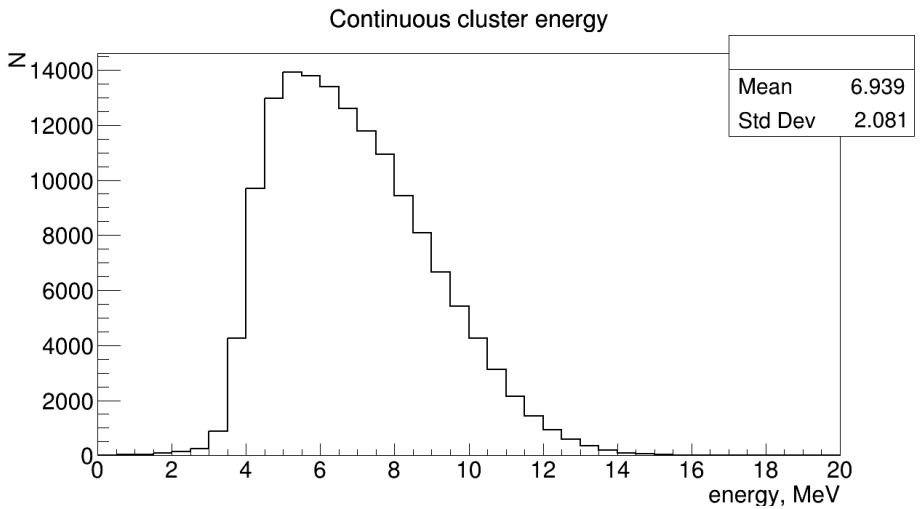
Mean boron lifetime:
29.17 ± 0.06 ms



Boron decays distributions

We plan to compare the measured boron decay energy spectrum with the Monte Carlo simulation.





The continuous cluster energy: measured data (left), simulated decays of boron (right)

Summary

- muons stopped inside the detector were identified;

Muon decays and captures

- decays and captures of stopped muons were selected;
- the measured spectrum was compared with the Monte Carlo simulation and the results consistent with the expected were obtained;
- the energy scale can be determined with a statistical accuracy of 0.5%

Boron decays

- beta decays of boron produced in stopped muon capture on carbon were selected;
- comparison of the measured spectrum and the Monte Carlo simulation started

We will continue this study to achieve a better description of the experimental data.

Thank you for you attention!