First muon-induced neutron yields from NEMESIS experiment

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NEMESIS

New EMMA measurement with neutrons in cosmic showers

The EUL Project

- EU program Interreg Baltic Sea Region co-funded project Empowering Underground Laboratories network usage (EUL) continues the work done during the Baltic Sea Underground Innovation Network (BSUIN) project.
- Underground laboratories in the Baltic Sea region are not utilized to their full potential even though world-leading research organizations and industrial companies are nearby. In order to use the available underground space better, the BSUIN project has developed service concepts for the underground laboratories and an open-access platform that characterizes them. These concepts and the platform will be further tested, evaluated, and improved within the EUL project. Better information about the laboratories and their business opportunities is provided to regional development agencies and potential new customers from academia and business.

EMPOWERING UNDERGROUND LABORATORIES NETWORK USAGE

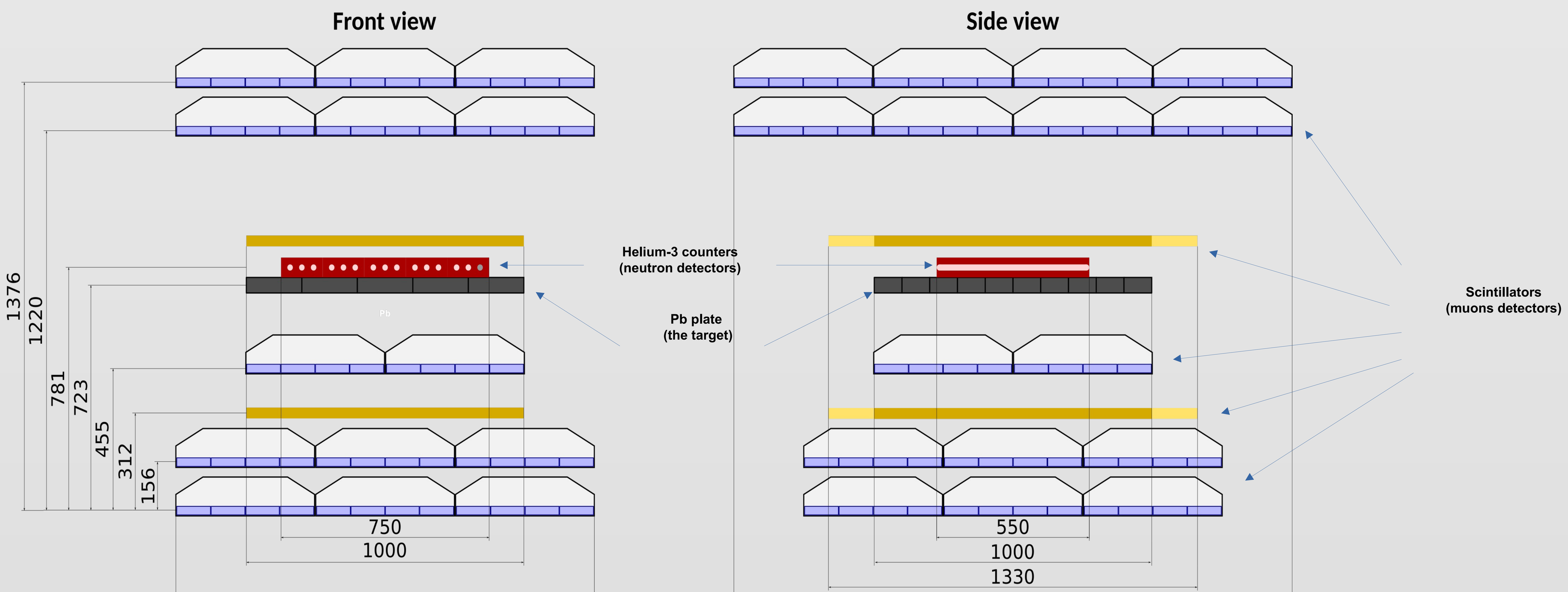
Interreg Baltic Sea Region — EUROPEAN UNION — EUROPEAN REGIONAL DEVELOPMENT FUND

- http://bsuin.eu
- https://undergroundlabs.network/about/https://undergroundlabs.network/about/

the case study: the NEMESIS experiment

- The collaboration was created thanks to contacts made during the work on the BSUIN project
- The experiment uses the infrastructure previously existing at the Pyhasalmi mine - the EMMA underground muon telescope, and a measurement set-up originally designed for pilot measurements for the BSUIN project
- But NEMESIS is not simply a combination of two existing apparatus is a new experiment pursuing their own goals

the case study: the NEMESIS experiment

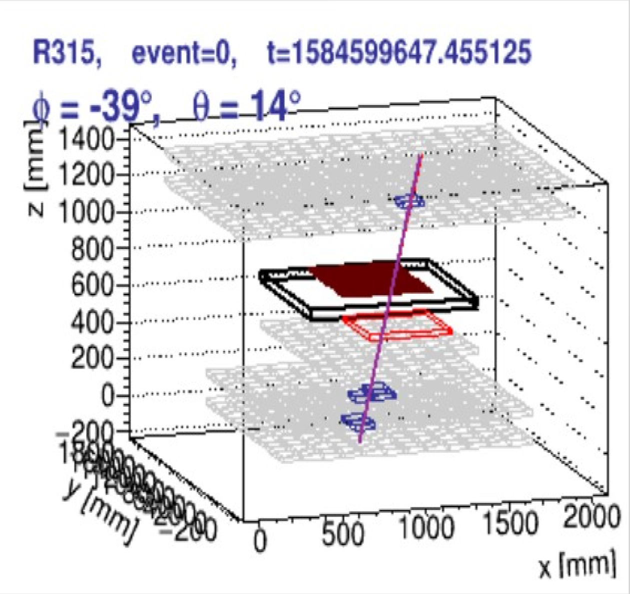


Idea:

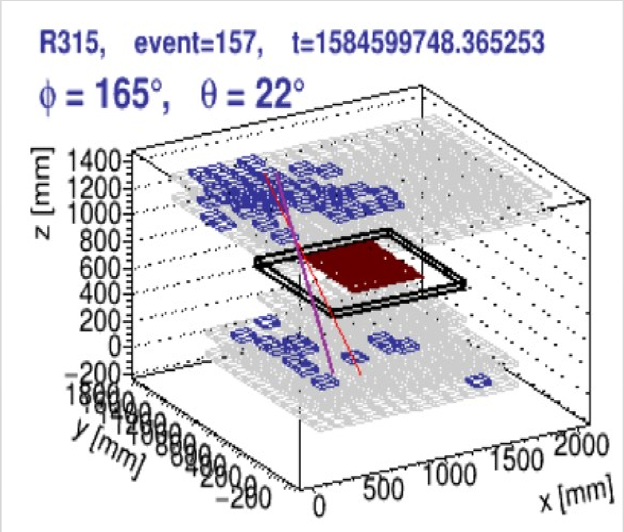
- Pb target (plate 1m² x 5cm) in which muons of cosmic rays (or other particles) produce neutrons
- tray of detectors (helium counters) detecting the produced neutrons
- target and tray are surrounded by a telescope detecting cosmic muons

The experiment is located in the Pyhasalmi mine (Finland) at a depth of 75 m (240 m H_2O)
Average cosmic muons energy = 50 GeV

Muon track reconstruction problem

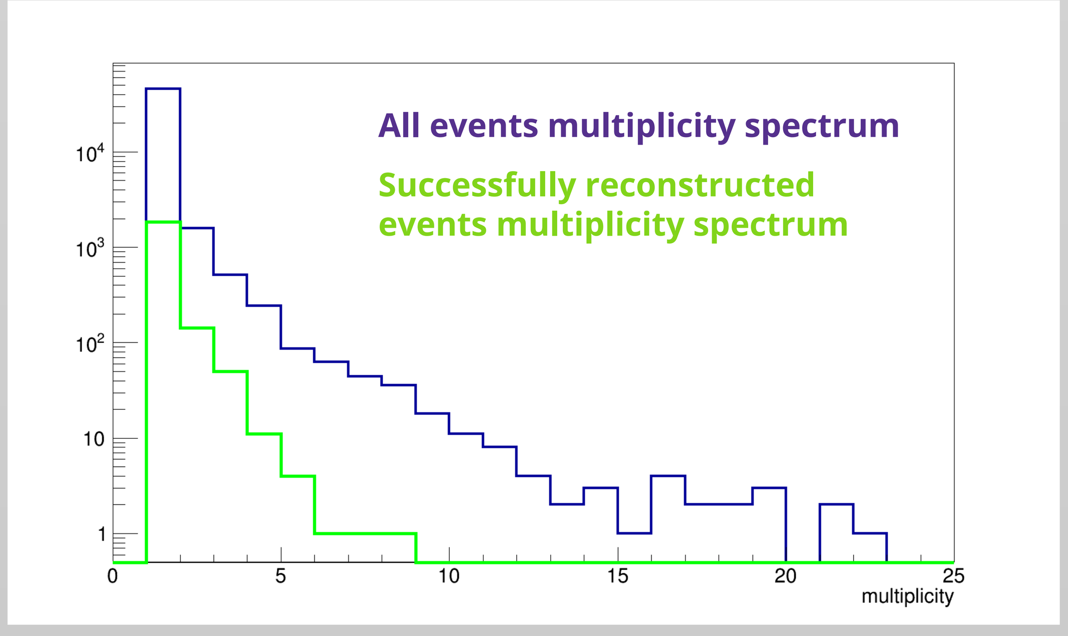


reconstructable event



non-reconstructable event

Only in 52 % of registered events, the muon track is successfully reconstructed.



- **Selection of successfully reconstructed events prefer events with lover neutron multiplicity**

$$f_{all}/f_{rec}=8.86\pm0.2$$

Neutron production yield

$$Y=N_n/(N_\mu €_n X)$$

Y – Yield
N_n – registered neutron number
N_μ – muon number
X – target thick [g/cm²]
$€_n$ – neutron registration efficiency

Neutron production yield, calculation procedure

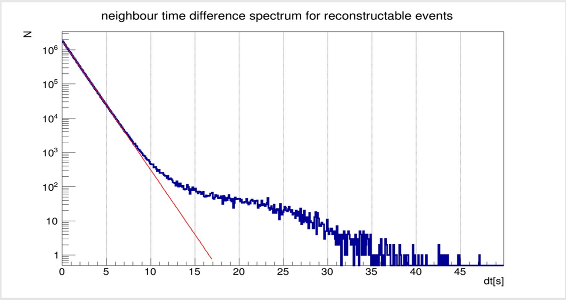
1) Determinate what part of reconstructable muons produced neutrons ($\mathbf{f_{\mu+n}/f_\mu}$)
2) Determine the average neutron production yield for the single reconstructable muon that produced the neutrons ($\mathbf{Y_{1\mu}}$). To do this, for each such muon one has to:
   1) a) determine the number of registered neutrons ($\mathbf{n_{1\mu}}$)
   2) b) determine the length of the muon path in the lead target ($\mathbf{l_{1\mu}}$)
   3) c) using Monte Carlo simulation to determine the efficiency of registration of the neutron formed
   4) at the muon impact site in the lead target ($\mathbf{€_{1\mu}}$)
3) then

$$Y_{1\mu} = n_{1\mu} / €_{1\mu} * l_{1\mu}$$

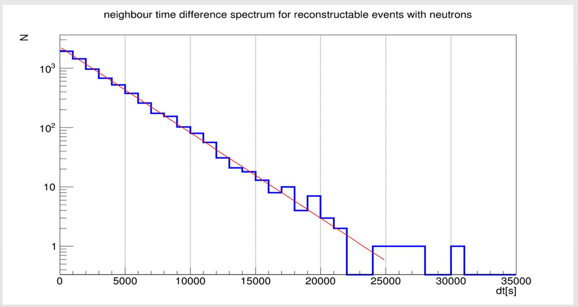
4) finally, the production yield (Y) neutron is:

$$Y = f_{all}/f_{rec} * f_{\mu+n}/f_\mu * \langle Y_{1\mu}\rangle$$

Muons with neutrons



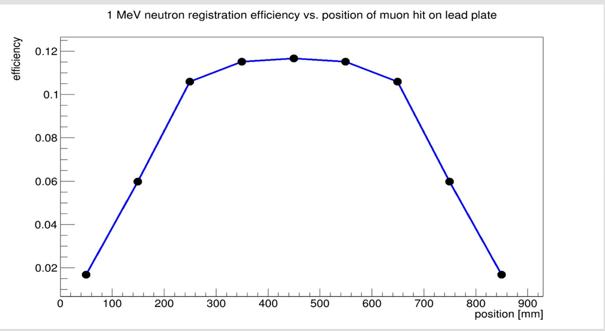
f_μ=0.8696 ± 0.0002 Hz

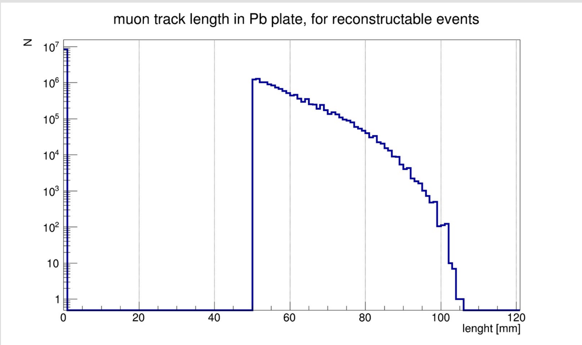


$f_{\mu+n}$= 3.32 ± 0.05 ×10⁻⁴ Hz

$$f_{\mu+n}/f_\mu = 3.81 \pm 0.07 \times 10^{-4}$$

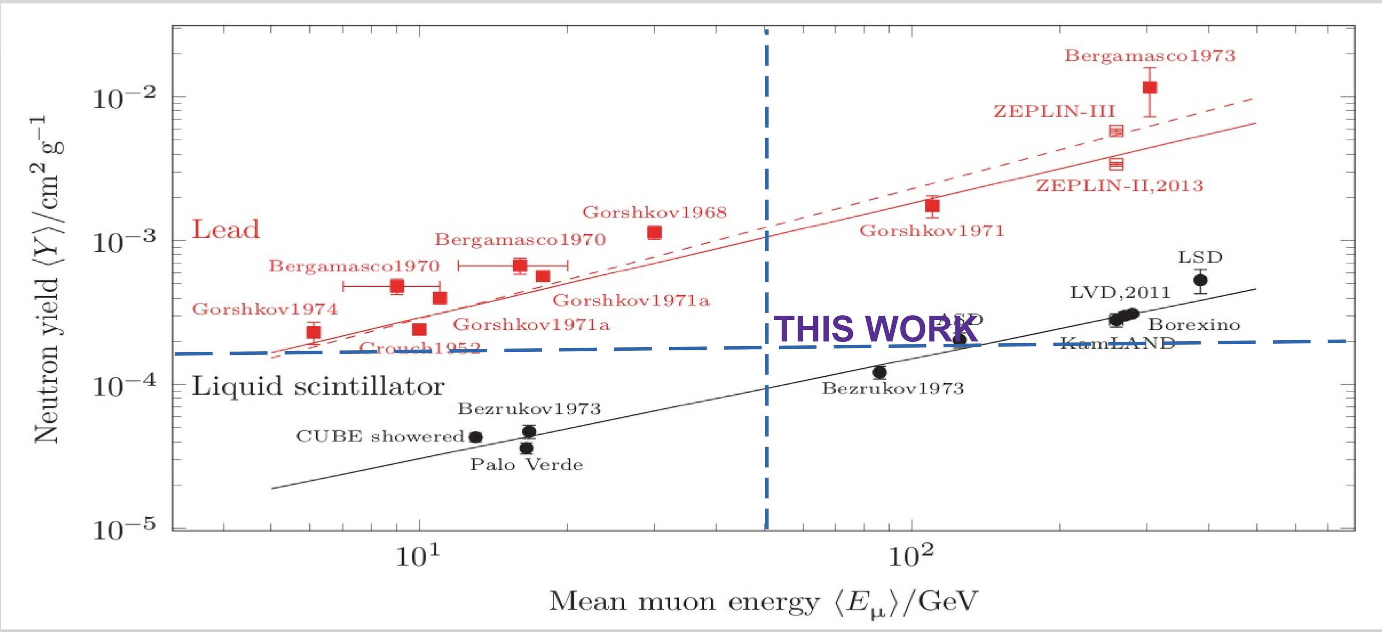
Efficiency of neutron registration & path length in Pb





- For reconstructable events, it is possible to determine the path length Pb and the efficiency of neutron registration for each event separately
- Efficiencies calculated using Geant4 simulation for 1 MeV neutron energy, most likely for spallation in lead Efficiencies calculated using Geant4 simulation for 1 MeV neutron energy, most likely for spallation in lead

The yield



$Y=1.64\times10^{-4}$
neutron per muon per g/cm² Pb

Orginal figure from H. M. Kluck „Measurement of the cosmic induced neutron yield at the Modane underground laboratory" PHD thesis

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