Measurement of the muon-induced neutron yield in liquid scintillator and iron at LNGS with the LVD experiment

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Introduction

A common challenge in rare-events search experiments is an accurate and precise understanding of all background components. The main sources of background for those experiments are due to gamma and neutrons. Neutrons arise in an underground laboratory either from natural radiactivity or being produced by cosmogenic muons. The latter comes from nuclear reactions induced by the muon itself or by secondary particles generated in muon-induced cascades, and they are more penetrating, indeed more dangerous, than other particles because of their harder spectrum (E>10 MeV).

Objective

Description of the measurement of the muon-induced neutron yields in liquid scintillator and iron at LNGS with the LVD experiment.

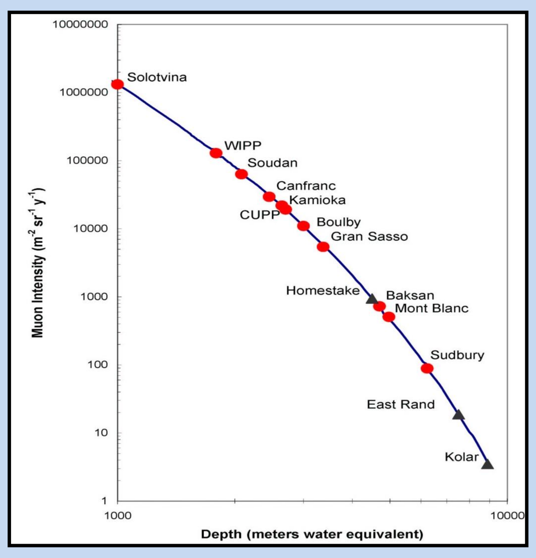
Ingredients for the calculation

The calculation of the muon-induced neutron flux needs several inputs. The required ''ingredients'' are:

A. The total muon flux at the underground site.
B. The energy spectrum and the angular distribution of muons: since in general they are correlated, depending on the particular surface profile above the underground laboratory.
C. A precise Monte Carlo code to track muons and their interactions, as well as production, propagation and possible detection of all secondaries in a very detailed detector description.

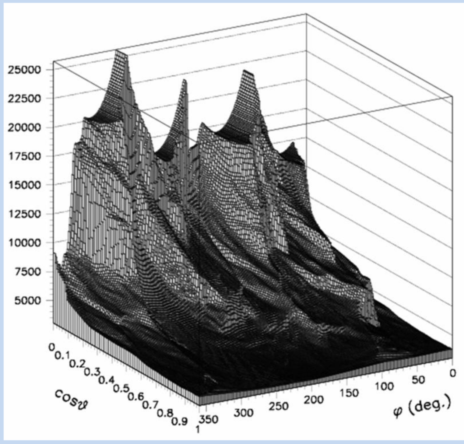
A. Muon flux

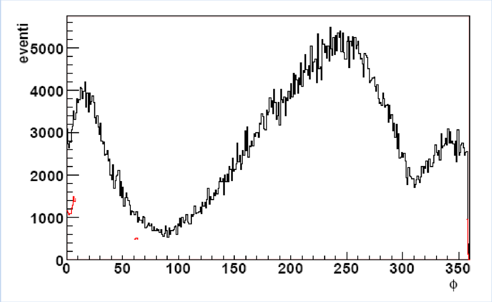
The residual underground muon flux decreases with depth and for Gran Sasso laboratory is about 1.1 μ/(m² h)

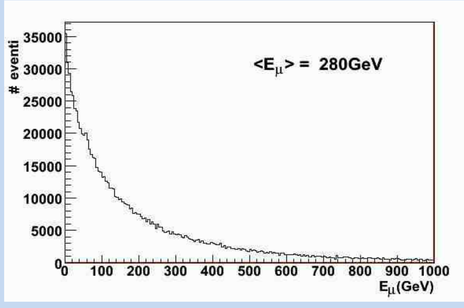


B. Muon energy spectrum and angular distribution

The energy spectrum and angular distribution, feeded into our Monte Carlo simulation were obtained with 2 fast dedicated codes: MUSIC and MUSUN

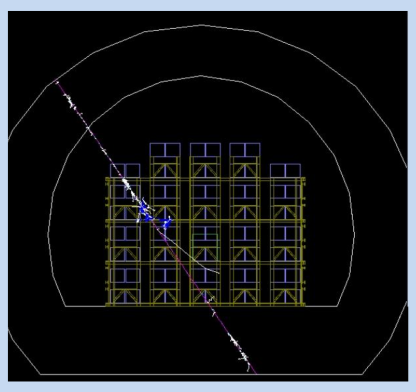


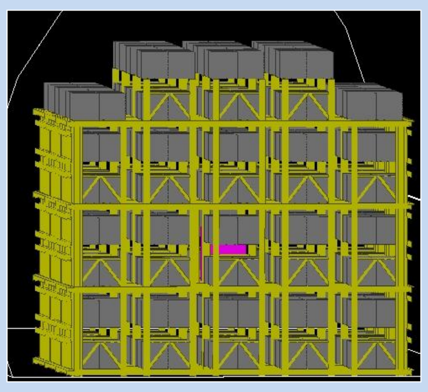




C. Monte Carlo simulation

The Monte Carlo simulation is based on GEANT4 (version 9.3) and the physics list adopted is: QGSP_BIC_HP.
We implemented a very precise geometrical description of the whole LVD detector, the support iron structure, the shape of the LNGS Hall A and the rock around it (7 m).
The trigger logic and detailed digitization of the detector has been reproduced as well.





Detector description

The Large Volume Detector (LVD) is located in Hall A of the LNGS. LVD is made of 1000 t of liquid scintillator and 1000 t of iron. The detector consists of an array of 840 liquid scintillator counters, 1.5 m³ each, arranged in a compact and modular geometry. The external dimensions of the active volume are 13x23x10 m³. The liquid scintillator (density ρ=0.78 g/cm³) is C_nH_{2n} with <n>=9.6 doped with 1 g/l of PPO and 0.03 g/l of POPOP. Each counter is viewed from the top by three 15 cm diameter photomultipliers (FEU49 and FEU125).

The electronics is designed to detect both the products of the inverse β-decay.
The trigger has a High Energy Threshold (HET) at ~4 MeV. For each HET trigger, the threshold is lowered to ~1 MeV (LET) for about 1 ms in all the counters in the same module where the HET signal has been registered.

Data selection

Muons are identified requiring at least 2 HET triggers in different counters within a time coincidence of 250 ns. We applied the following off-line selection criteria:

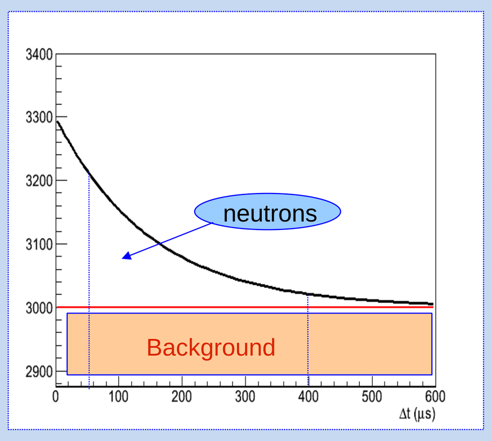
1) For HET signals:
- Two HET signals with an energy released above 10 MeV for each signal
- One of the HET signal has to be detected in an internal counter (counter shielded from the rock by at least another counter)

2) We look for neutron signals only in:
- Internal counters
- Counters with a stable and flat background over the year
- Counters not crossed by muon

3) For LET signals:
- Energy between 1 and 5 MeV
- In the time interval 20-400 μs

Background evaluation

The time delay distribution of LET signals with respect to the muon arrival has 2 components:
- Flat, due to uncorrelated background
- Exponential, due to neutron capture

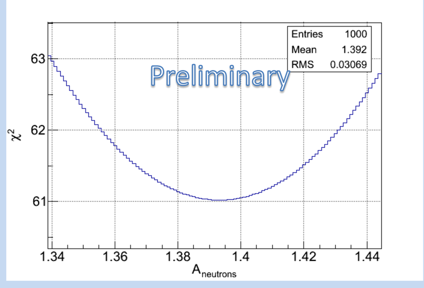


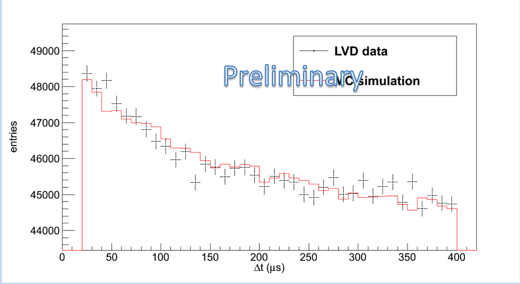
In LVD we can estimate the background component measuring the counting rate each time the gate in that counter is opened.

For this purpose, we use the single HET events to be sure that there are NO muons in the event

MC-DATA comparison

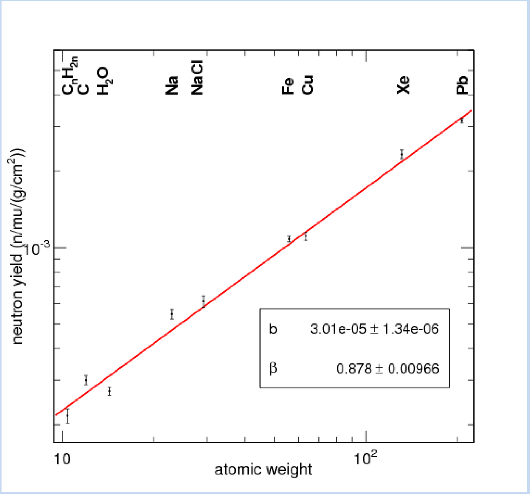
We evaluated how much GEANT4 underestimate or overestimate the muon-induced neutron yields by comparing the time delay distribution of LET signals for both DATA and MC (adding to the latter a flat background component evaluated before). Results infer that Geant4 underestimate the neutron yield by a factor 30-40%.





MC neutron yield

We evaluated the neutron yield with GEANT4 (v 9.3) firing muons, with their energy spectrum at LNGS , on homogeneous blocks of several materials, for which we considered only the neutrons produced (per unit of path lenght) in their central part.



Conclusions

The **preliminary** neutron yields obtained are:

Y_{LS} = (2.9±0.6)x10^{-4} n/(g/cm²)

Y_{Fe} = (1.5±0.3)x10^{-3} n/(g/cm²)

so stay tuned to read the paper in preparation!

References

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