Measurement and modeling of muon-induced neutrons in LSM

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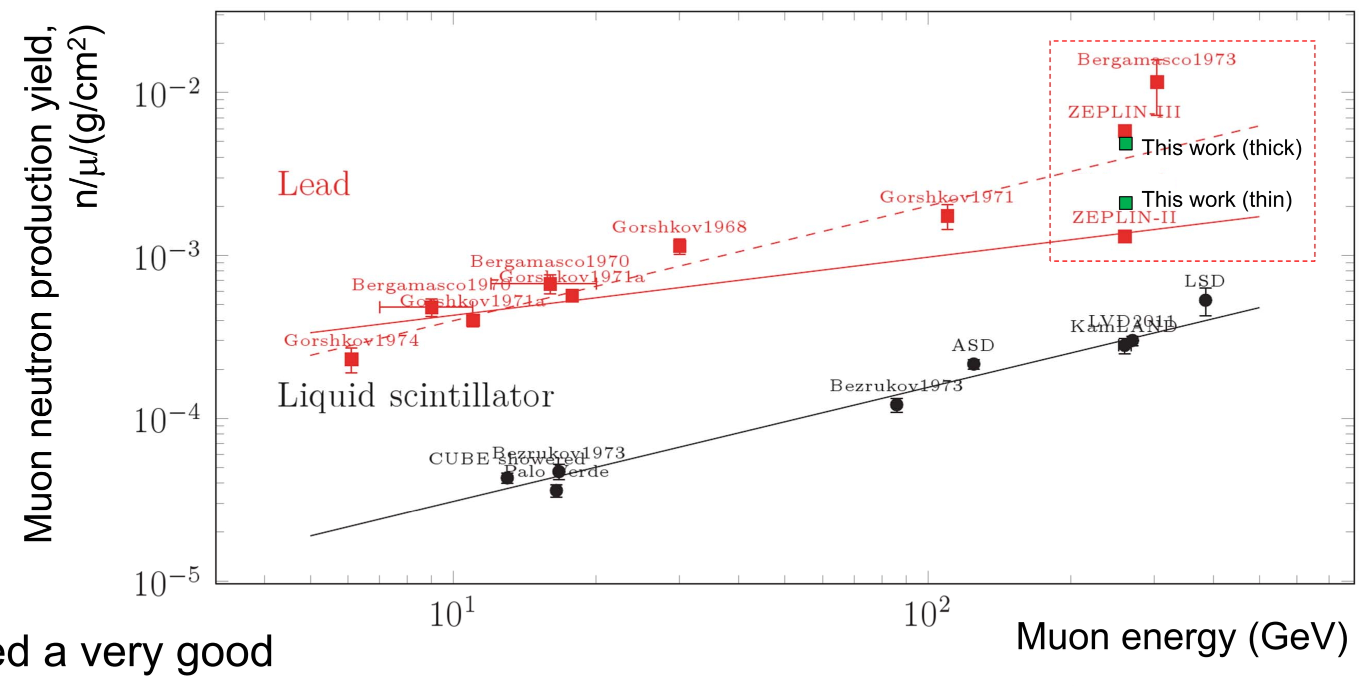
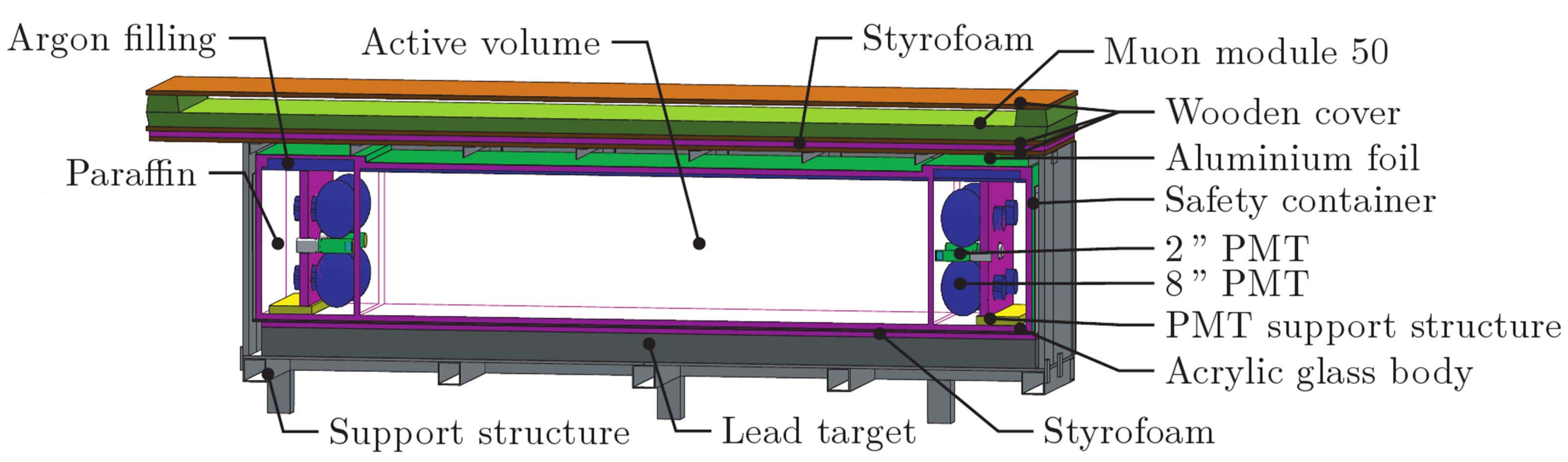
Physics motivation in context of Dark Matter searches

	EDELWEISS-2	EDELWEISS-3	EURECA
Goal	$4.4\cdot10^{-8}$ pb	a few 10^{-9} pb	10^{-10} .. 10^{-11} pb
Signal, ROI [20,200] keV	$<10^{-2}$ /kg.d	$<10^{-3}$ /kg.d	$<10^{-5}$ /kg.d
Irriducable muon-induced neutron background, ROI	<0.72 evt per 481 kg.d	<0.6 evt per 3000 kg.d	<0.3 evt per $3.65\cdot10^{5}$ kg.d

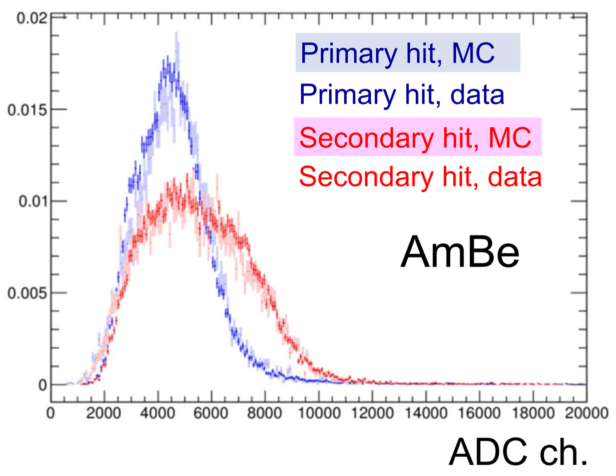


Muon-induced neutrons constitute a prominent background for direct Dark Matter searches, as neutrons can mimic a potential Dark Matter signal. With ever increasing sensitivity of experiments (see table), we need a very good understanding of this background in order to suppress it. However, for some materials, e.g. lead, currently available data and simulations can vary up to an order of magnitude.

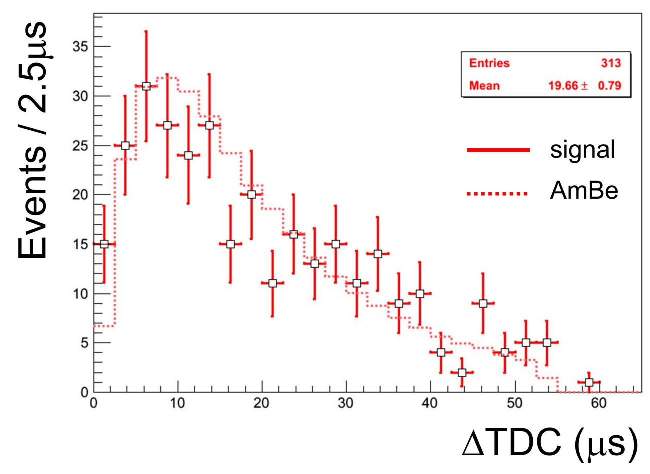
Measuring μ-n coincidences with a system of scintillators



We have built and operated in 2009 - 2012 in Laboratoire Souterrain de Modane (LSM, 4800 mwe) a Neutron Counter (NC) detector based on 1 m³ of Gd-loaded liquid scintillator viewed by 16 PMTs of 8-inch diameter. The system was coupled to a muon telescope to tag original muons. Underneath the detector there was 10-cm layer of Pb. The details can be found in Astropart. Phys. 34 (2010) 97.

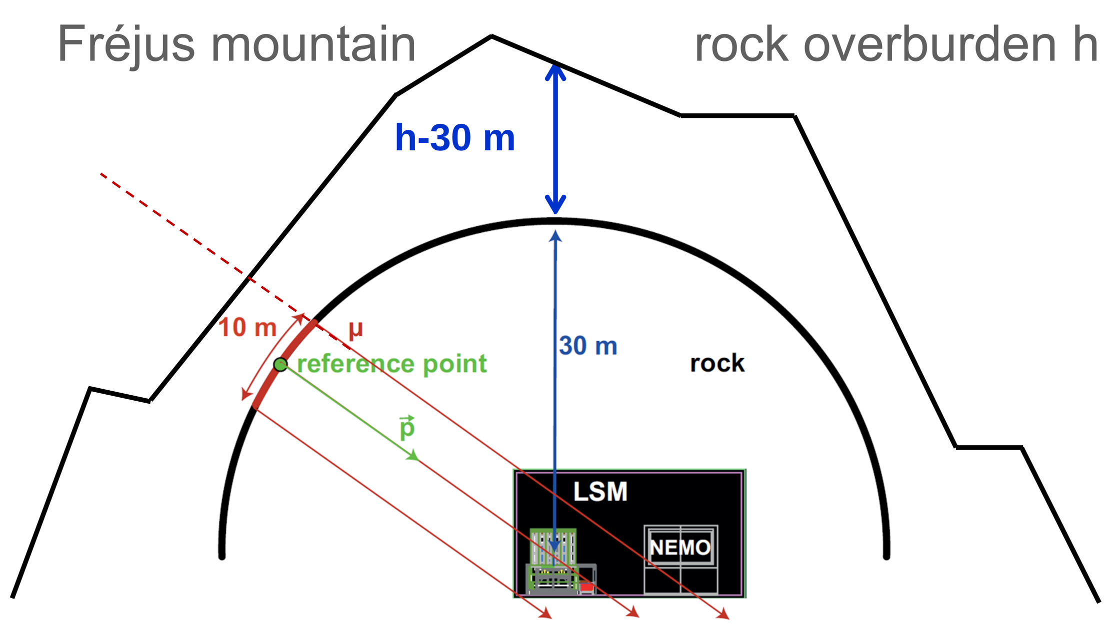


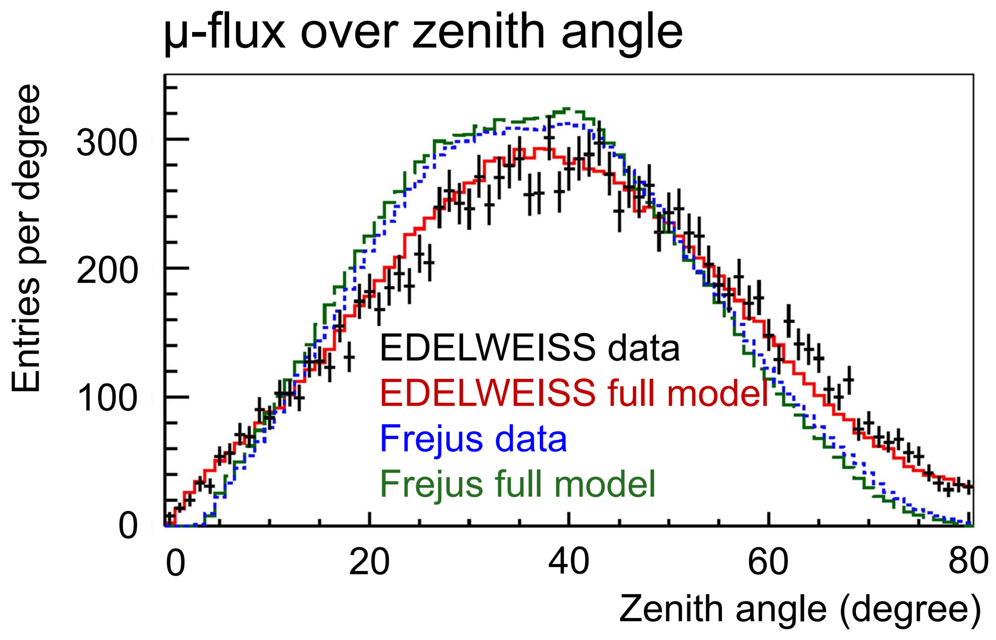
Regular AmBe source calibrations were used to monitor behavior of the detector and to normalize a Monte-Carlo description of the detector response.

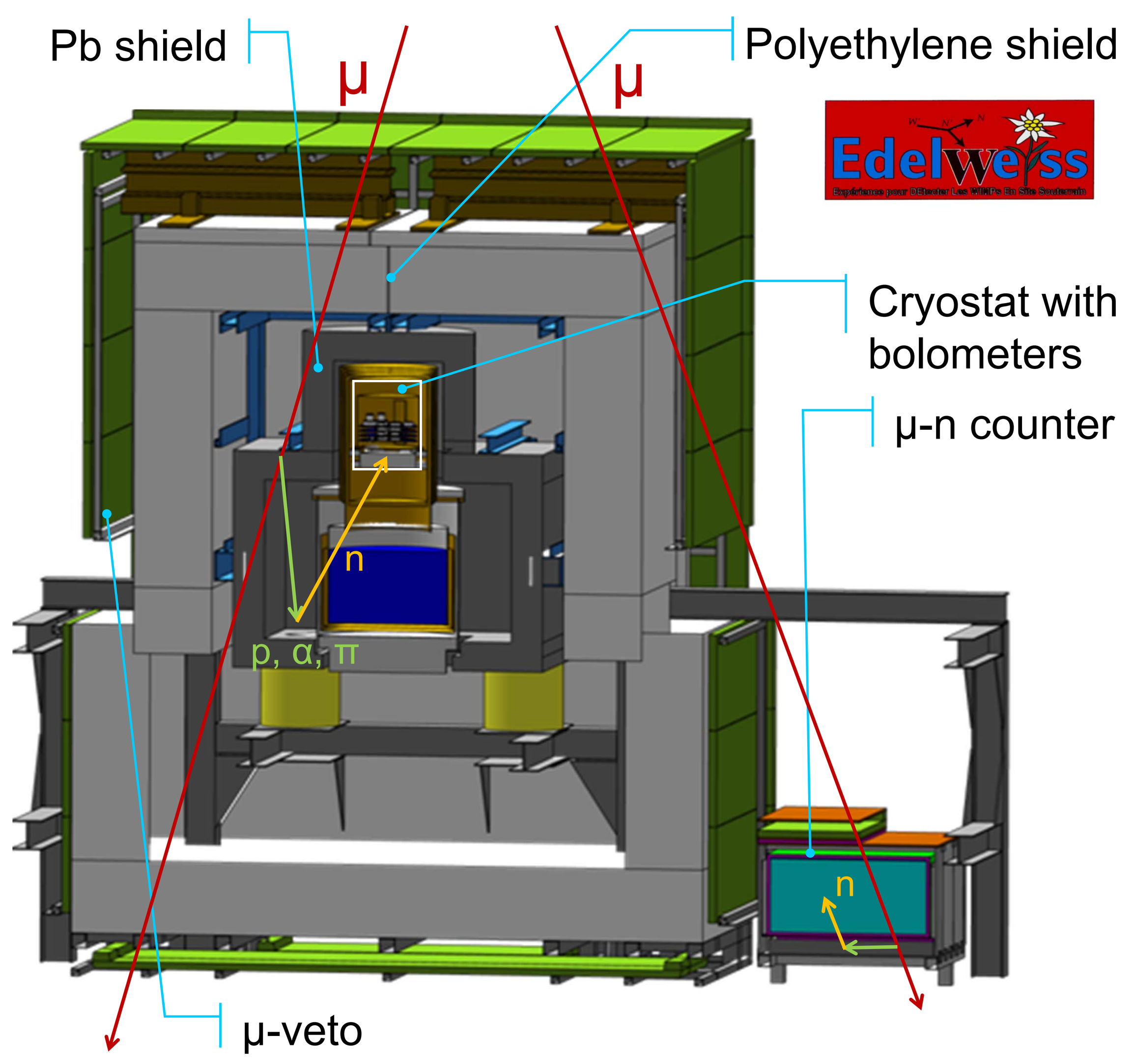


For each event a number of secondary hits within the DAQ window (60 μs), hit time and energy were recorded. Time distribution of secondary hits was compared to AmBe data.

Monte-Carlo model (Geant4)







'End-to-end' Monte-Carlo model based on Geant4 9.2p01 was built to deduce a muon-induced neutron production in Pb. It allows to calculate properly the muon flux in the underground lab (e.g. it covers >99.9% of the local muon spectrum and reproduces well both EDELWEISS and Frejus data), uses custom defined Physics list (based on QGSP_BIC_HP) to propagate muons and to describe the neutron production, and includes the full description of the neutron counter detector, as well as surrounding systems such as the full EDELWEISS setup. In addition, the model uses custom Gd neutron capture spectrum (GdNeutronHPCapture from Double CHOOZ) and permits to apply same cuts as in real measurement.

Comparing MC model and the measurement

	Measurement	MC model ('end-to-end')
Muon rate, day^{-1}	5.79 ± 0.08	$5.71 \pm 0.01 \pm 0.03\ ^{+1.49}_{-0.47}$
Secondaries / muon	$(5.5 \pm 0.3)\cdot10^{-2}$	$(6.57 \pm 0.04 \pm 0.12\ ^{+1.49}_{-1.83})\cdot10^{-2}$
In more details:		
NC Events / muon	$(3.2 \pm 0.2)\cdot10^{-2}$	$(2.71 \pm 0.02 \pm 0.04\ ^{+0.46}_{-0.64})\cdot10^{-2}$
Secondaries / NC Event	1.75 ± 0.16	$2.42 \pm 0.05 \pm 0.09\ ^{+1.47}_{-0.93}$

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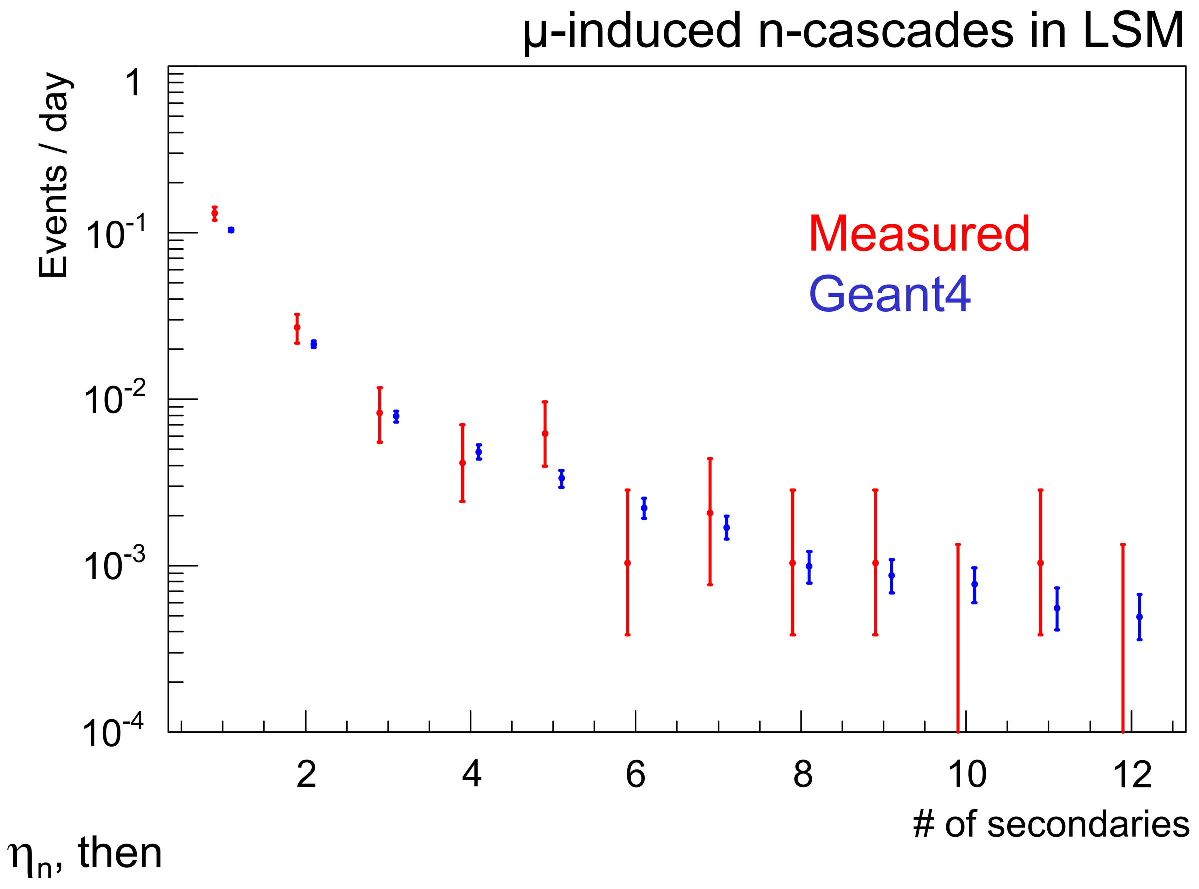

After 3 years of data-taking the Monte-Carlo model is compared to the acquired data. Overall a good agreement is found: the rate of neutron production per detected muon agrees within 20% with the model. Though, there might be an indication of underproduction of primary neutrons and overproduction of secondary neutrons compared to the data. If these numbers are interpreted in terms of muon-induced neutron production yield in lead, η_n, then

$\Rightarrow$ $\eta_n = 2.2\times10^{-3}$ n/μ/(g/cm²) (thin Pb target) and $\eta_n = 4.9\times10^{-3}$ n/μ/(g/cm²) (thick Pb target) for $E_\mu \sim 260$ GeV