PROCEEDINGS OF SCIENCE

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Radon contamination measurement in the SuperNEMO demonstrator

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The neutrino, as a neutral particle can be identical to its antiparticle, i.e, a Majorana particle. SuperNEMO aims at searching for the neutrinoless double beta decay ($0\nu\beta\beta$), whose observation would prove that the neutrino is a Majorana particle.
The $0\nu\beta\beta$ process, beyond the Standard Model, is very rare and the level of background should be extremely small.
One source of background comes from the ^{222}Rn emanation from the detector components or diffusion from the air of the laboratory towards the tracker. The daughter isotope, of ^{222}Rn, the ^{214}Bi can by (β,γ) disintegration produce two electrons with an energy around 3 MeV and therefore constitute a source of background for $0\nu\beta\beta$. The SuperNEMO demonstrator should prove the capacity to reduce the ^{222}Rn activity to to a level less than 0.15 mBq/m^3. Here, I present the preliminary measurement of the ^{222}Rn activity in the demonstrator, based on first data acquired without shieldings, without injection of Radon free air in the antiradon tent, and purification of the tracker gas by the Radon trap.

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1. Majorana neutrino and Double-beta decay

As a neutral particle, the neutrino can be identical to its antiparticle, i.e. a Majorana particle. This is introduced by the most simple extension of the Standard Model, and it could explain the matter-antimatter asymmetry by leptogenesis and also the smallness of the neutrino masses through the seesaw mechanism.

The most sensitive way to test the Majorana nature of the neutrino is the search for the neutrinoless double-beta decay ($0\nu\beta\beta$). This process has never been observed and is extremely rare ($T_{1/2} > 10^{24} - 10^{26}$ years). In this process, two neutrons simultaneously undergo beta-decays, without emitting neutrinos. This process is beyond the Standard Model and violates the conservation of the lepton number.

Another process than the $0\nu\beta\beta$ process is the double-beta decay with two-neutrinos emission. It consists in a radioactive decay in which two neutrons are simultaneously transformed into two protons inside an atomic nucleus, as a result two electrons and two electron antineutrinos are emitted from the decaying nucleus (or two positrons and two electron neutrinos). This process of second order in the weak interaction, is allowed by the Standard Model and, though rare, has been observed with half-lives $T_{1/2} \sim 10^{18} - 10^{24}$ years. The precise measurement of the observables of $2\nu\beta\beta$ could constrain on one hand the effective axial-vector coupling constant, and on the other hand processes beyond the Standard Model (Majoron, bosonic neutrino, Lorentz invariance violation) [1] [2] [3] [4].

The SuperNEMO experiment was design both to observe the $0\nu\beta\beta$ decay and measure precisely the $2\nu\beta\beta$ decay, showing the capabilities of a tracker-calorimeter detector.

2. SuperNEMO demonstrator module description

The techniques of detection of SuperNEMO are similar to its predecessor, NEMO-3. The double-beta electrons are first tracked by a tracker and then their energies and arrival times are individually measured by a segmented calorimeter [5], see Fig. 1.

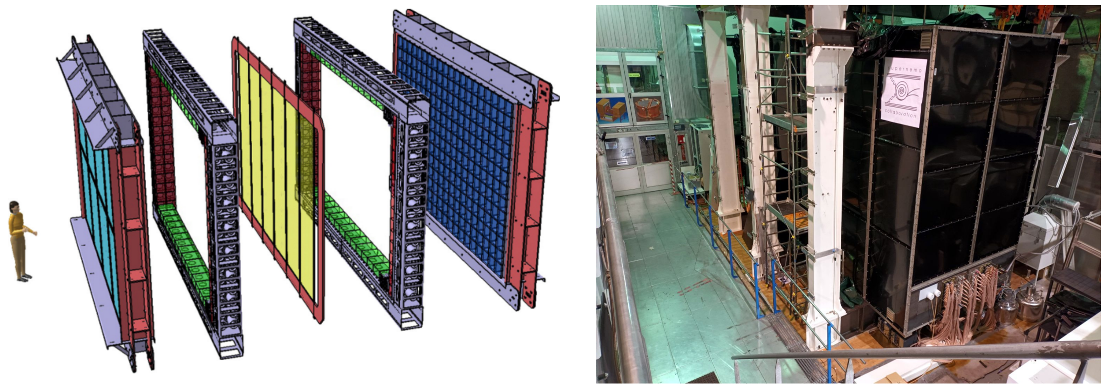

Figure 1: Left: An exploded view of a SuperNEMO demonstrator, showing (from left to right) one calorimeter wall, one tracker volume, the source foil, another tracker volume and another calorimeter wall [6]. Right: SuperNEMO demonstrator with antiradon tent installed.

The SuperNEMO demonstrator module, should prove the performance of tracking-calorimetry principle for precise double-beta measurements, is 6 m in length, 4 m in height and 2 m in width. In the middle it contains a thin segmented source foils (≈40 mg/cm^2) with 6.3 kg of vertically suspended enriched in 96-99% in ^{82}Se sources, regarding on the segment of the foil [7], surrounded by 2034 drift cells operating in Geiger mode (for particle tracking) and enclosed by calorimeter walls consisting of 712 optical modules (for energy and time of flight measurements) [6]. Each optical module is a square-faced plastic scintillator block coupled to a low radioactivity 8-in. or 5-in. photomultiplier tubes (PMTs) [6].

SuperNEMO focuses on high background rejection techniques. Main background suppression strategies consist in the use of radiopure materials, antiradon tent, iron (gamma) shielding and water + polyethylene (neutron) shielding.

Demonstrator is installed in Modane underground laboratory (LSM) and full tracker and calorimeter are operational since December 2022. Remaining part to be installed are: gamma and neutron shieldings.

Gamma and neutron shieldings are designed to suppress the external background and should be installed in spring 2024. Antiradon tent is designed to prevent leaking of Radon into the SuperNEMO tracker.

3. Internal background sources

Internal background takes origin from contamination of the source foils and tracker gas by natural radioactive decay chains and comes mainly due to β decay of ^{214}Bi with Q_β = 3.27 MeV and ^{208}Tl with Q_β = 4.99 MeV, the two (β,γ) decay isotopes with the largest energy release in the ^{238}U and ^{232}Th natural radioactivity decay chains, respectively. ^{214}Bi and ^{208}Tl beta decays can mimic double-β event, for example, by β which is accompanied by an internal conversion electron process.

^{214}Bi can have two origins: either it is located in the source foils and is part of the internal background, or it comes from the ^{222}Rn decay, where the ^{222}Rn gas is located in the tracking chamber (and after disintegration can produce ^{214}Bi nuclei close to the foil), see Fig. 2.

The rock of the Modane underground laboratory can be contaminated with ^{226}Ra, the parent of ^{222}Rn. Then, due to its relatively large half-life (3.8 days) it has enough time to emanate and diffuse towards the tracking detector. The main sources of ^{222}Rn are the emanation of Radon from the detector constituents, the contamination of the gas flushed inside the tracker and the emanation of Radon from the rock of the laboratory with further diffusion towards the tracker.

In order to reduce the Radon background, several techniques will be used: the antiradon tent of the tracking chamber (already installed), the Radon trap will be applied to the gas flushed to the tracker and the gas flux could be increased.

4. ^{222}Rn background measurement

In order to estimate the ^{222}Rn activity inside the tracker it is convenient to use the ^{214}Bi-^{214}Po cascades: a ^{214}Bi (β, γ) decay followed in a short time by ^{214}Po slightly delayed alpha decay which occur near the source foil. The half-life of ^{214}Po is 164 μs.

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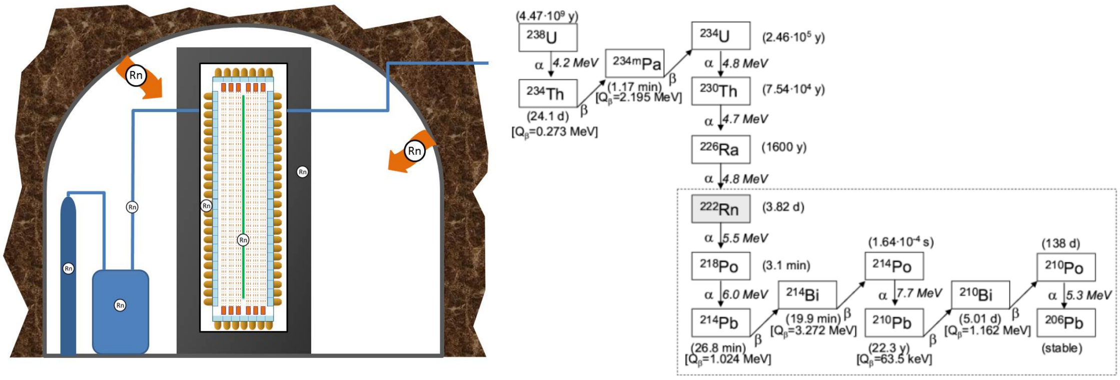

Figure 2: Left: Schematic view of possible Radon origins inside the SuperNEMO tracker volume. Right: Natural decay chain of the radioactive family of ^{238}U [8]. One can note the presence of the gaseous Radon ^{222}Rn and of ^{214}Bi, which constitutes a background for the $0\nu\beta\beta$ search.

Bi-Po cascades can be observed by SuperNEMO as an electron track inside the drift chamber associated with a scintillator hit, eventually some unassociated scintillator hits due to gamma(s) interaction(s) and at least one delayed short track in the tracking chamber close to the emission point of the electron, due to the delayed α particle.

In order to obtain the preliminary value of the ^{222}Rn activity inside tracker, the dedicated analysis has been performed. In 47 hours of data taking in March 2023, 575 Bi-Po candidates have been selected with the efficiency of selection $\approx$3%. The delay time between the electron emitted by ^{214}Bi decay and the alpha emitted by ^{214}Po decay is fitted by an exponential + constant function, see Fig. 3. The Radon activity is obtained from the contribution of the exponential component and, taking into account a possible contribution from a random coincidence background, the ^{214}Po decay half-life (164 μs) was reproduced within uncertainty.

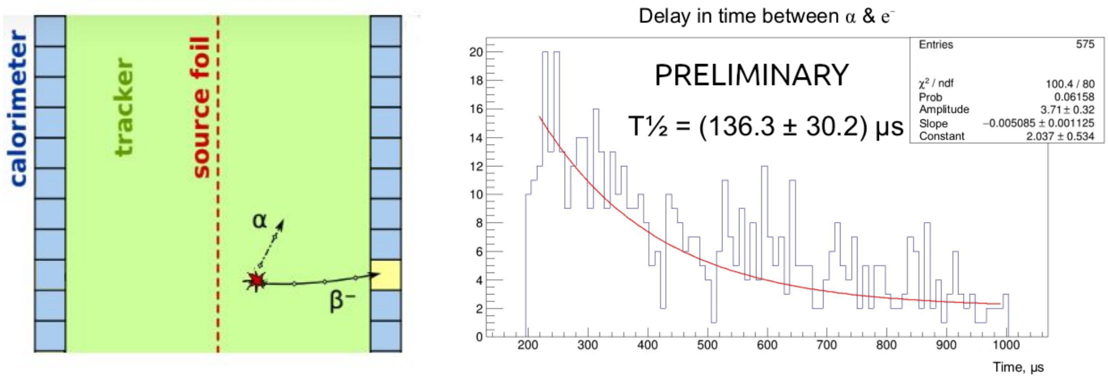

Figure 3: Left: Schematic view of a Bi-Po event. Right: Delayed time between electron and alpha, fitted by a constant plus exponential function.

The estimated activity is at the level (6 ± 2) mBq/m^3, which is already at the level of the NEMO-3, the predecessor of SuperNEMO. However this activity was reached without flushing Radon-free air inside the antiradon tent, whereas for NEMO-3 this activity was obtained when flushing Radon-free air inside the tent. With further Radon suppression strategies used, the Radon activity inside the SuperNEMO demonstrator will become even less. The goal is to have ^{222}Rn activity at the level < 0.15 mBq/m^3.

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