Monte Carlo Simulation of External Background in the SuperNEMO Experiment

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Weak Interactions and Neutrinos 2021

https://supernemo.org/

1. Neutrinoless Double Beta Decay $0\nu\beta\beta$

- The most sensitive experimental probe of Majorana nature of ν

Double beta decay without emission of antineutrinos:

$$^{A}_{Z}X \rightarrow^{A}_{Z+2} Y + 2e^{-} \quad (1)$$

Experiments searching for the $0\nu\beta\beta$ signal are sensitive to:

$$T^{0\nu}_{1/2} \propto a\sqrt{\frac{Mt}{b\Delta E}} \quad (2)$$

a - abundance of the $\beta\beta$ emitting isotope,
M - source mass,
t - measurement time,
b - number of background counts
ΔE - energy resolution

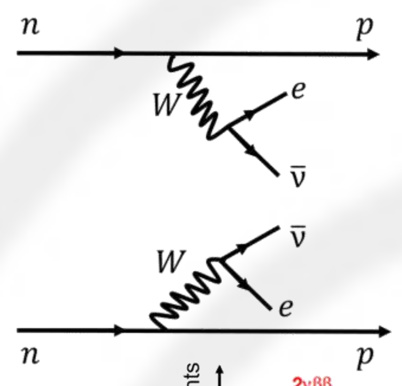
→

Requirements:

- large detector masses
- **ultra-low background noise**
- good energy resolution

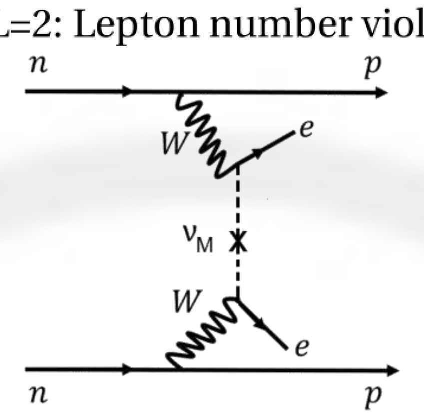
$2\nu\beta\beta$:

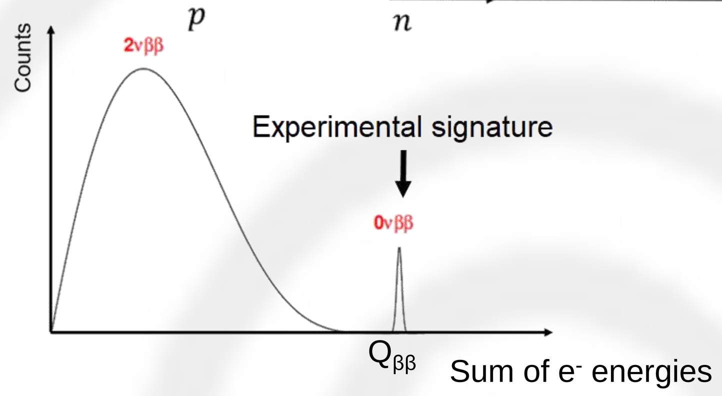
- observed in a number of experiments



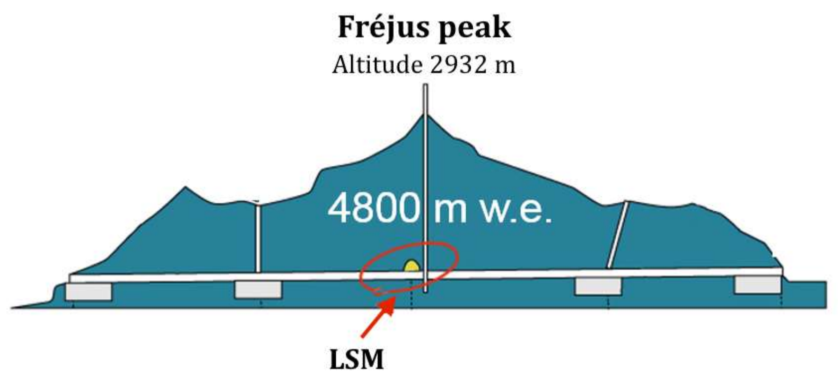
$0\nu\beta\beta$ - never seen before:

- $\bar{\nu} \equiv \nu$: Majorana particle
- Δ L=2: Lepton number violation





2. SuperNEMO Experiment



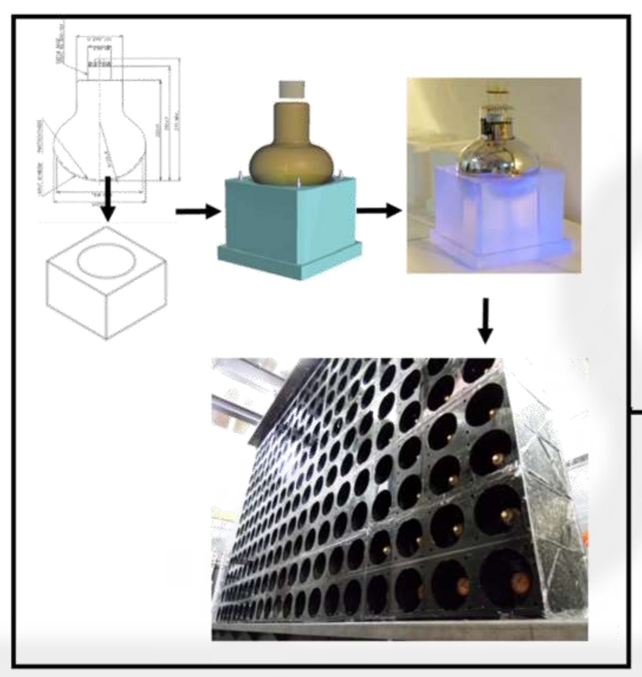
- One-of-a-kind experiment searching for $0\nu\beta\beta$ in the Modane Underground Laboratory (LSM) combining tracker and calorimetry techniques:

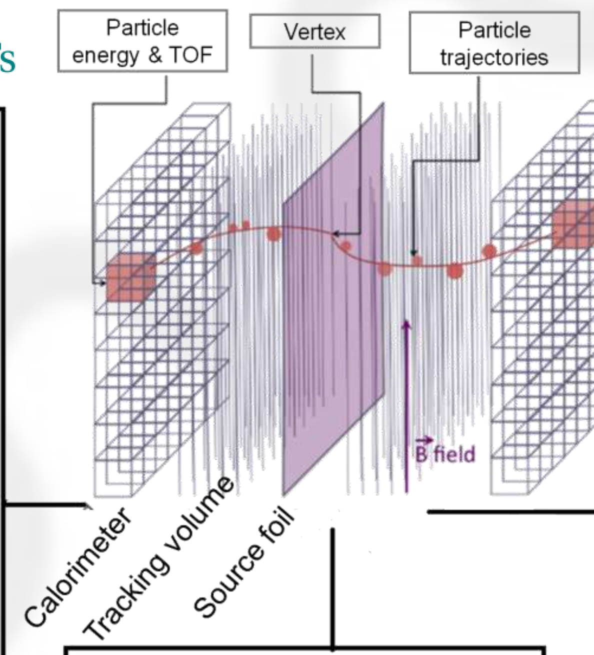
→ can detect each electron individually, measure its energy and direction

Detector properties and target levels:

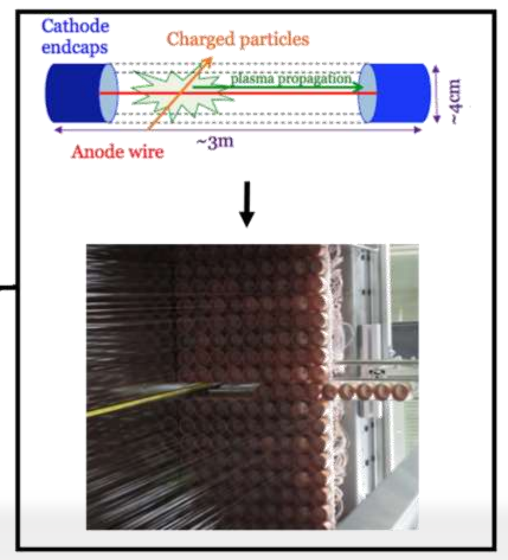
Detector property	Demonstrator	Full scale
Isotope	^{82}Se	^{82}Se / ^{150}Nd / ^{48}Ca.
Source mass	7 kg	100 kg
$T^{\beta\beta0\nu}_{1/2}$ sensitivity	10^{24} years	$> 10^{26}$ years
$\langle m_{\beta\beta}\rangle$ sensitivity	0.2 - 0.4 eV	0.05 - 0.1 eV
Energy resolution	8% (FWHM) @ 1 MeV, 4% @ 3 MeV	
Time resolution	< 400 ps @ 1 MeV	
Foil radiopurity	^{208}Tl < 2 μBq/kg , ^{214}Bi < 10 μBq/kg	
Tracker radon concentration	< 0.15 mBq/m^3	
PMT radiopurity	^{40}K= 150 mBq/kg, ^{214}Bi= 65 mBq/kg, ^{208}Tl= 4 mBq/kg	
Scintillator radiopurity	^{40}K= 2.2 mBq/kg, ^{214}Bi < 0.3 mBq/kg, ^{208}Tl< 0.1 mBq/kg	

Calorimeter:
- plastic scintillator blocks with PMTs





Tracker:
- a wire-chamber tracker with octagonal drift cells operated in Geiger mode
- drift gas: He + 1% Ar + 4% ethanol



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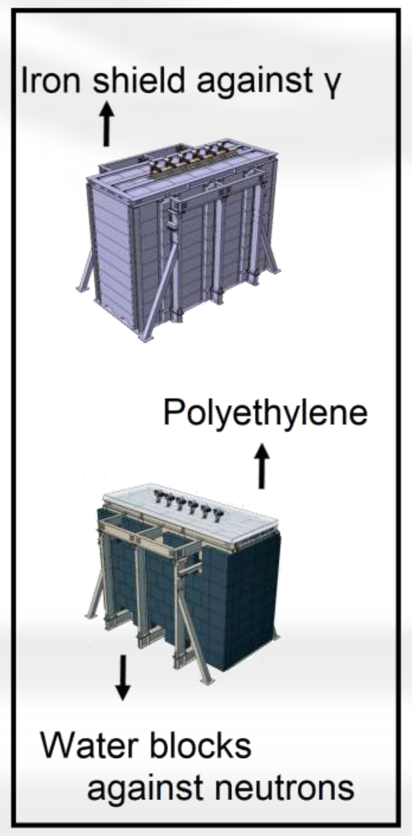
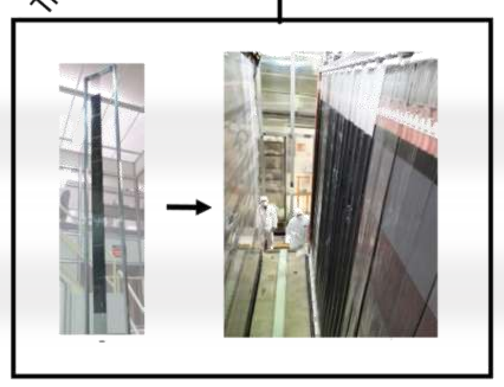




Source:
- foils composed of enriched ^{82}Se isotope
- $Q_{\beta\beta} = 2.99 MeV$

Background of the experiment
- All events that mimic two electrons emitted from a common vertex in the source foil with sum energy around the $Q_{\beta\beta}$ value of ^{82}Se.

Shielding adds to SuperNEMO's excellent reconstruction and radiopurity to minimize backgrounds in our $0\nu\beta\beta$ candidate sample.

3. High-Energy External Background

- High-energy γ-rays originating from de-excitations of radionuclides in ^{238}U and ^{232}Th decay chains and from neutron capture reactions on metals in construction materials - primarily iron and copper.

Sources of γs and neutrons:

- Ambient - from the laboratory environment
- Internal to the detector - from material contamination

Ambient γ flux > 4 MeV in LSM[1]:

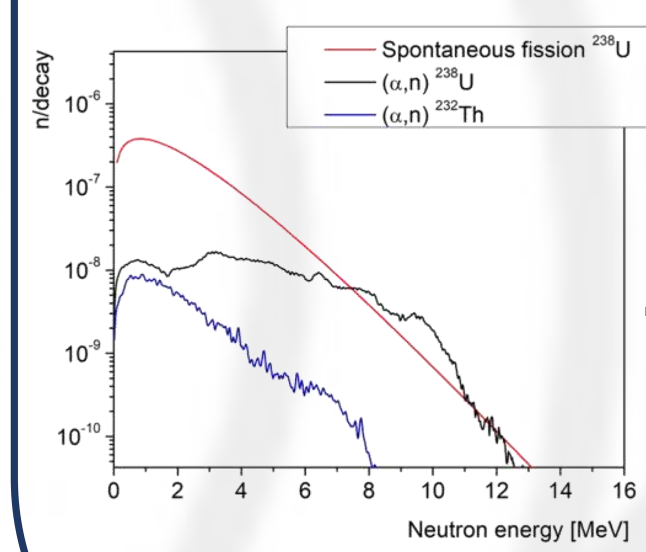
$\Phi_{\gamma} = (7.02 \pm 2.10) \times 10^{-6} \gamma s^{-1} cm^{-2}$

Ambient neutron fluxes in LSM[2,3]:

$\Phi_{n,thermal} = (2.9 \pm 0.4) \times 10^{-6}\ ns^{-1}cm^{-2}$

$\Phi_{n,fast} = (4.0 \pm 1.0) \times 10^{-6}\ ns^{-1}cm^{-2}$

(α,n) and SF produce fast n → fast n thermalize → thermal neutrons get captured → γs knock $2e^-$ out of the foil



Internal radiogenic neutrons

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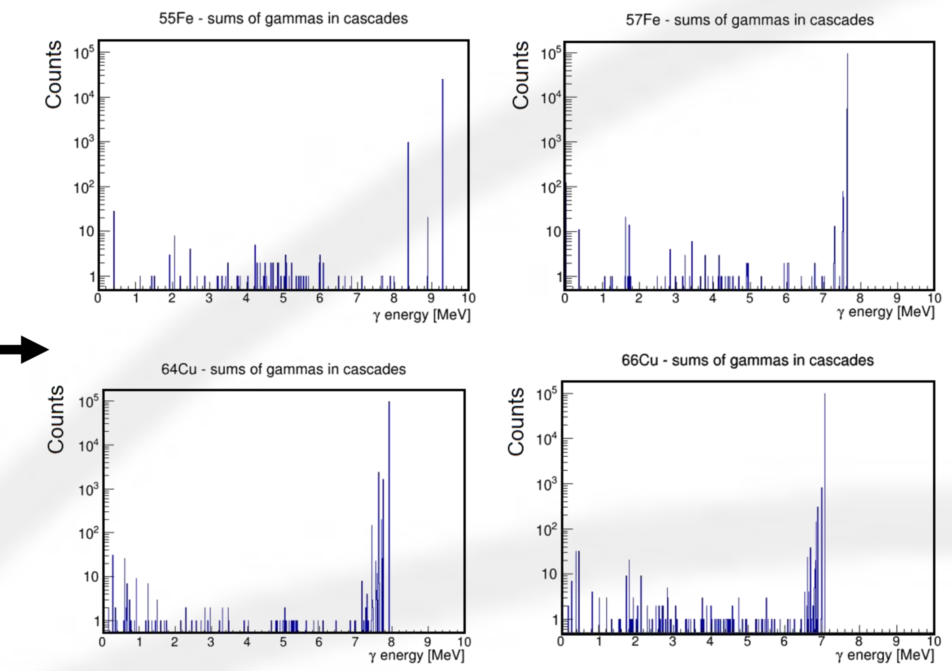

Fe and Cu thermal neutron capture gamma cascades (counts per 10^5 n captures, simulated in DICEBOX[4])

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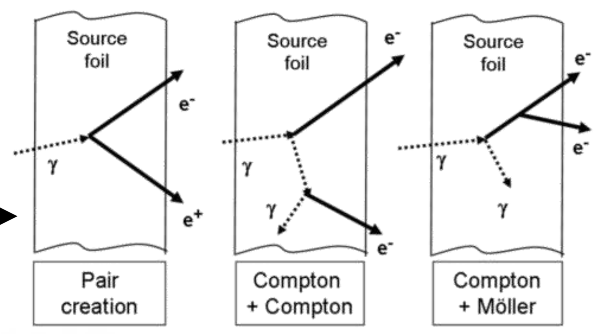


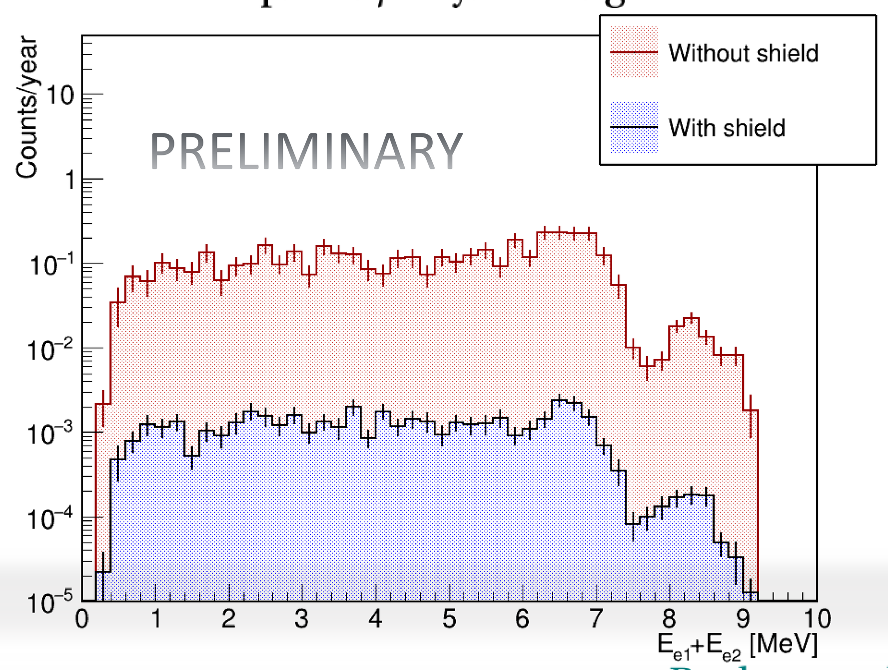
Mechanisms of external background events production

4. Analysis and Results

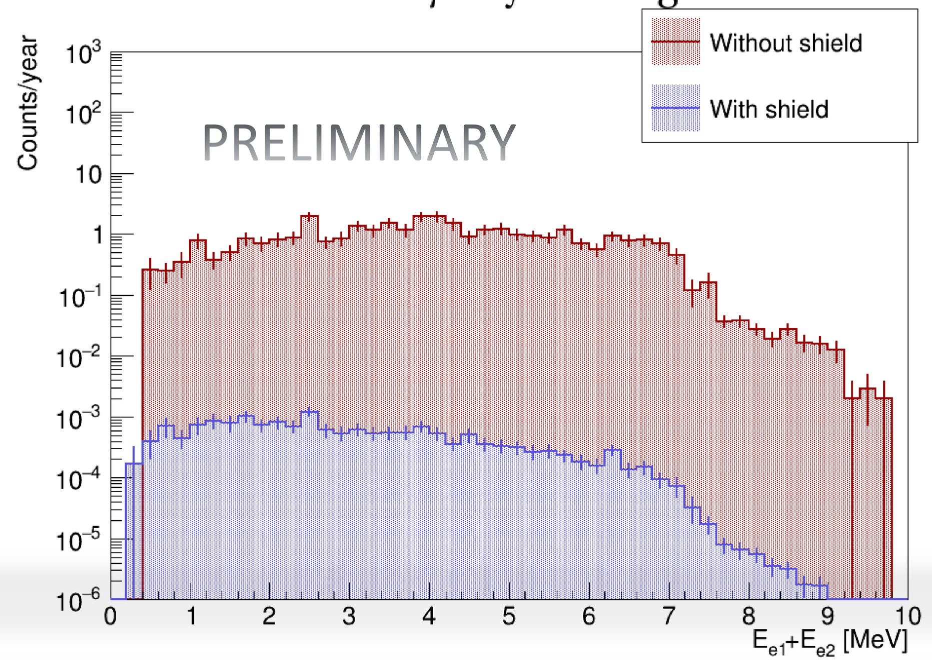
- The analysis method is based on simulating gamma and neutron fluxes from their source positions according to their energy spectra and analyzing the detector's response.

Event reconstruction-Background events are reduced to $2e^-$ topology

Neutron capture γ-rays -background events



External ambient γ-rays -background events



Background rate obtained in the $2e^-$ channel - total event counts per year

[1] H. Ohsumi et al., Nuclear Instruments and Methods in Physics Research A: Volume: 482.3, pp. 832–839, 2002;

[2] S. Rozov et al., arXiv: 1001.4383, 2010; [3] V. Chazal et al., Astroparticle Physics 9.2, pp. 163–172., 1998;

[4] DICEBOX: Nuclear Instruments and Methods in Physics Research A, Volume: 417, Issue: 2-3, pp. 434-449, Nov 11 1998; https://www-nds.iaea.org/dicebox/