The TINY experiment: search for 0ν2β decay with Nd and Zr bolometers

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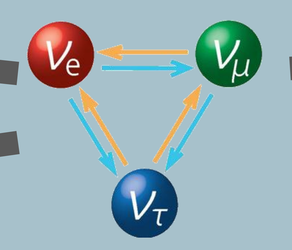
Investigating neutrino nature with neutrinoless double beta decay

Oscillations require massive neutrinos

Nature: Dirac or Majorana?

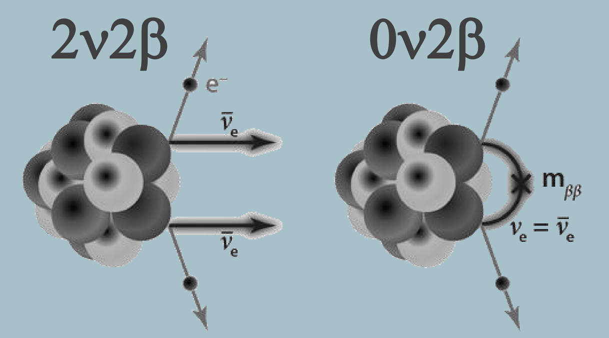


Small unknown masses

Mass hierarchy unknown

Neutrinoless double beta decay (0ν2β):

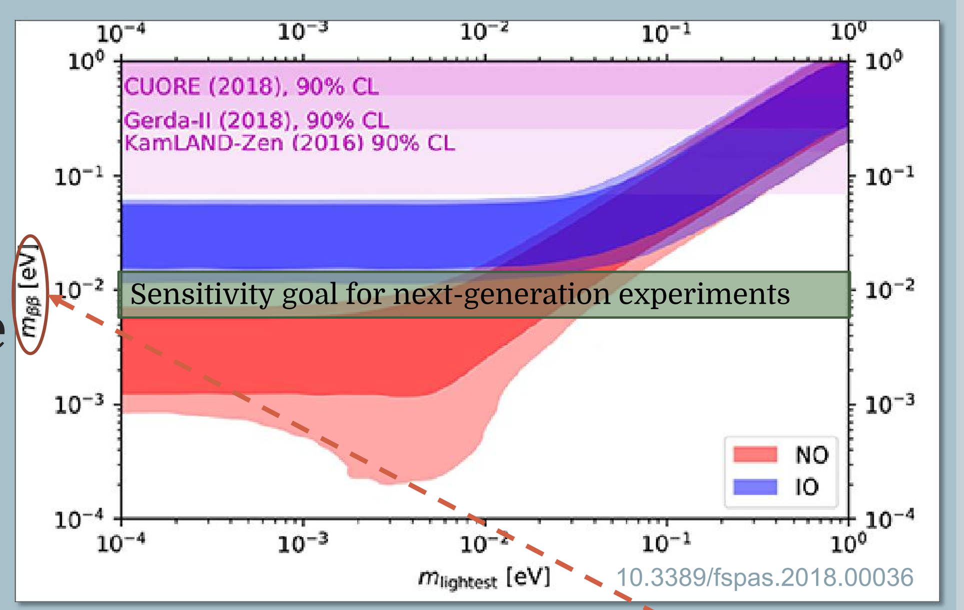
- If observed, neutrino is a Majorana particle ($\nu \equiv \bar{\nu}$)
- Lepton number violation gives clues on leptogenesis (matter-antimatter asymmetry)



- Absolute neutrino mass scale determination and information on mass hierarchy

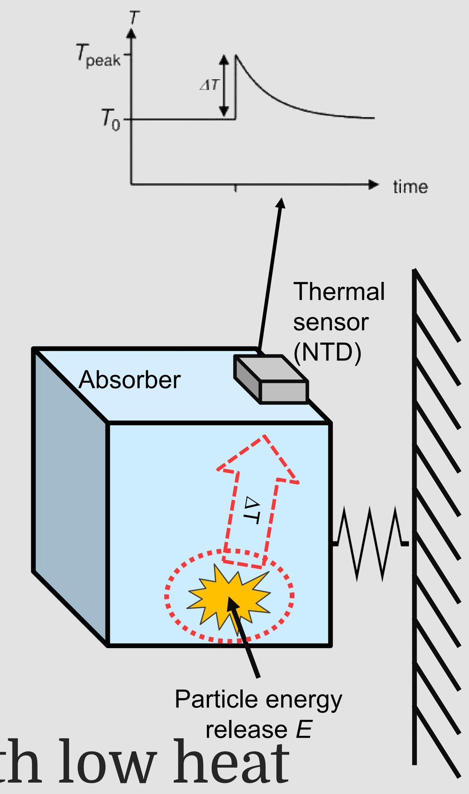
Experimental challenge:

- Very rare decay: $T_{1/2}$ (0ν2β) > 10^{26} yr
- Few isotopes are suitable for experiments
- Extremely low levels of background are required



$$(T_{1/2}^{0\nu2\beta})^{-1} = G^{0\nu}(Q,Z)\,|M^{0\nu}|^2 \frac{m_{\beta\beta}^2}{m_e^2}$$

Bolometers for 0ν2β searches



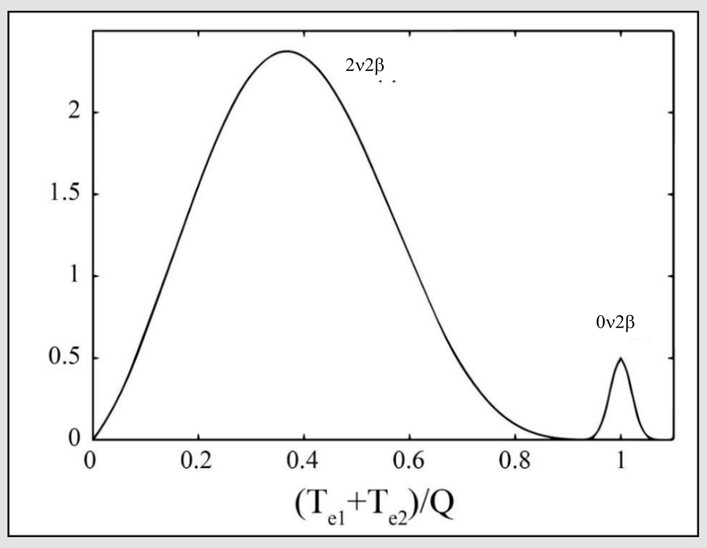
The isotope of interest is embedded in a crystal → **High detection efficiency**

High energy resolution:
5-10 keV (~0.2%) FWHM in the ROI

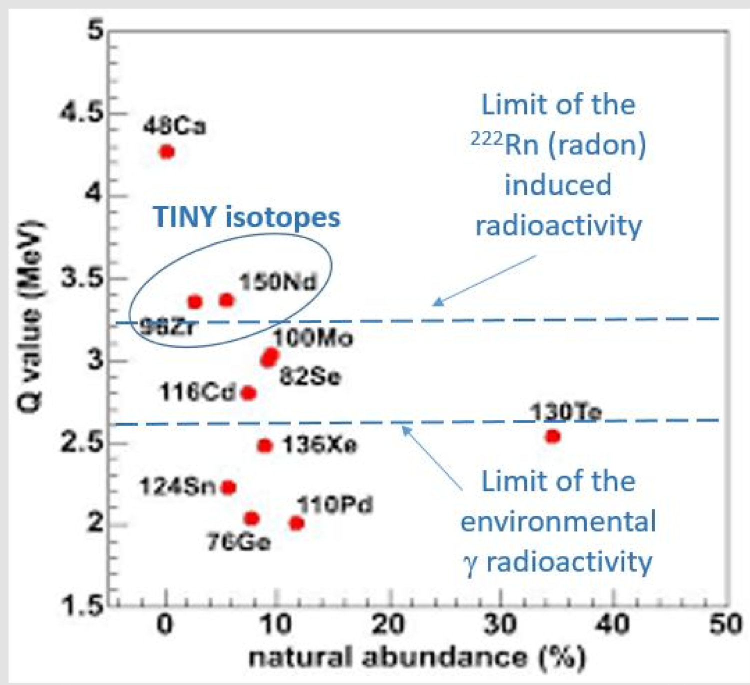
0.1-1 kg typical crystal mass: scalability to large masses is possible through arrays

Flexible composition: dielectric crystals with low heat capacity

Particle discrimination using scintillation light or pulse-shape for a rejection



Experimental signature: narrow peak in ROI



The 11 most experimentally-promising isotopes for double beta decay searches

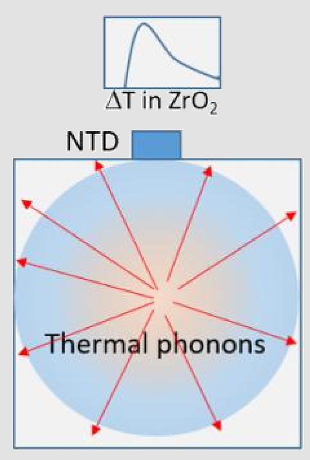
TINY detector technology

Two Isotopes for Neutrinoless double beta decaY search - **exploratory project** to largely impact experimental 0ν2β searches - cryogenic detectors with **^{150}Nd and ^{96}Zr**: zero-background and "detector=source" concept

Both **^{96}Zr and ^{150}Nd** have the crucial advantage of **very high transition energy** -> higher sensitivity to the effective Majorana mass

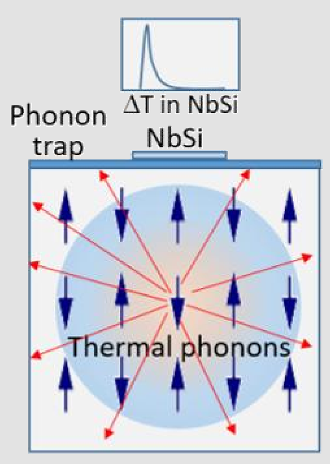
Zr-containing detectors:

- Crystal compound: ZrO_2 (75% Zr)
- **Scintillating bolometers** as a baseline
- Thermal sensors (Neutron Transmutation Doped thermistors) - robust and reproducible
- Target energy resolution: <10 keV FWHM at $Q_{\beta\beta}$
- Target a discrimination by light: >99.9%



Nd-containing detectors:

- Crystal compound: $NdGaO_3$(55%)
- Proof-of-concept: measurement of magnetic compounds with **athermal sensors**
- Use large surface athermal phonon sensors
- Target energy resolution: <20 keV FWHM at $Q_{\beta\beta}$
- Particle **discrimination by the pulse-shape**



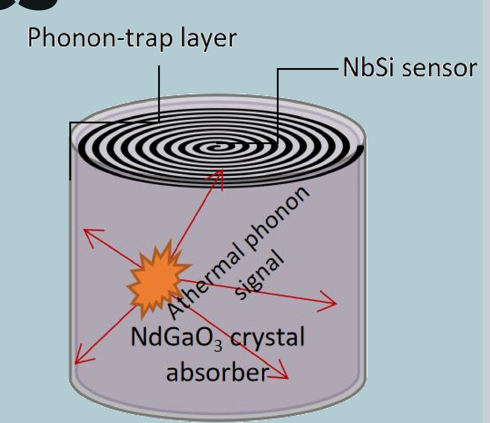
R&D planning:

- **Dedicated cryogenic facility (shallow site) in CEA-Saclay, France to be installed in 2025**
- **Collaboration with C2N and IJCLab for production of athermal phonon sensors**
- ***Tests will include search for best alternatives for crystal compounds/crystal growth methods***

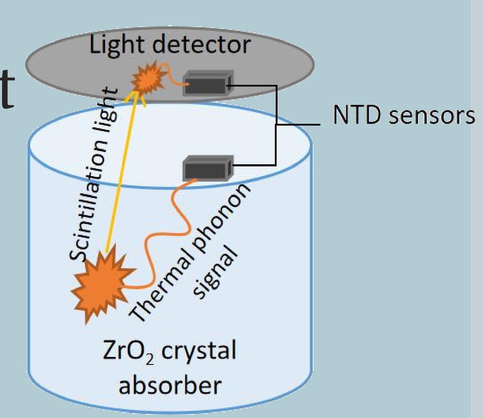
TINY demonstrator: perspectives

TINY underground installation:

- 5×400 g **ZrO_2 double read-out** scintillating bolometers
- 5×400 g natural **$NdGaO_3$ single read-out** magnetic bolometers



Precision measurement of 2ν2β spectrums: nuclear spectroscopy, NME calculations, information on axial-vector coupling constant



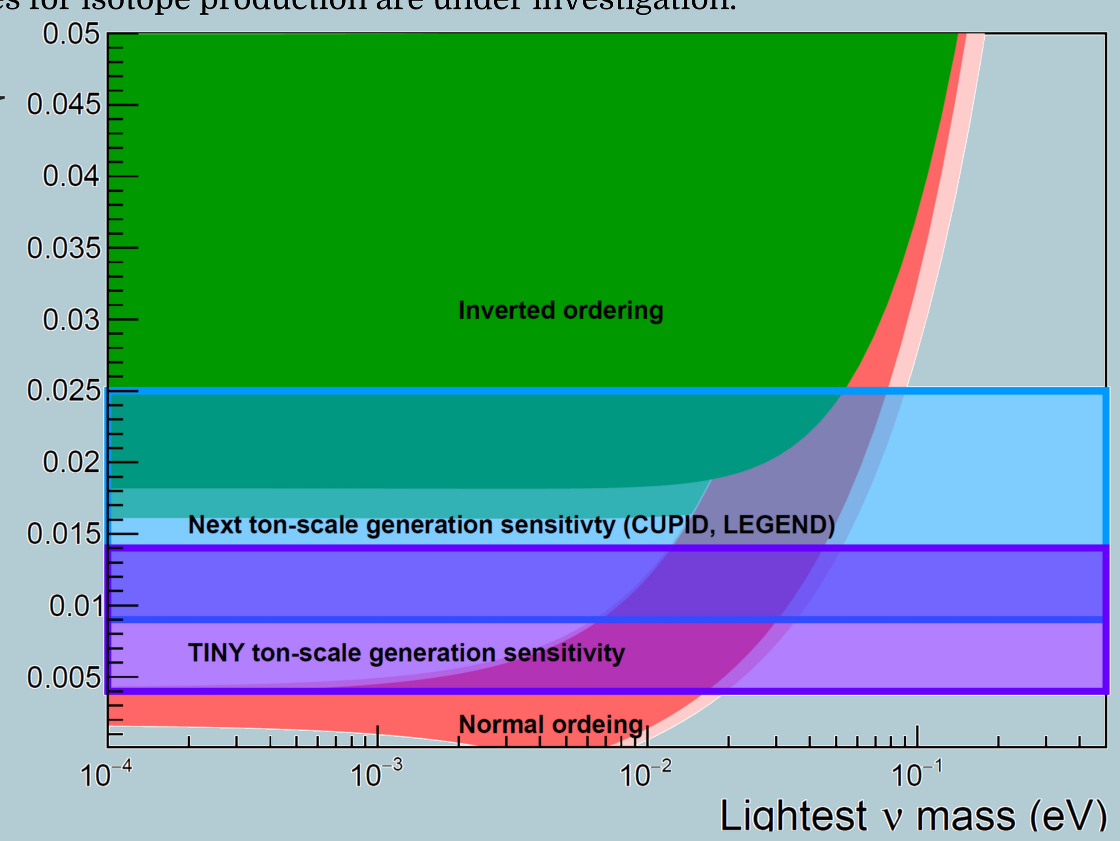
New limits in 1 year of measurements and background **10^{-3} cnts/keV/kg/yr** for both isotopes even in abcence of enrichment:

Isotope	NEMO-3		TINY	
	Exposure, kg×yr	Present limits, yr	Planned exposure, kg×yr	Projected limits, yr
^{96}Zr	0.031	9.2×10^{21}	0.042	**6×10^{22}**
^{150}Nd	0.191	2×10^{22}	0.062	**5.7×10^{22}**

Zr enrichment with gas centrifugation was initaly considered, but impacted by the Russian invasion in Ukraine. Alternative possibilities for isotope production are under investigation.

Application of TINY technology on the large scale:

Significant improvement in sensitivity with the same volume thanks to high $Q_{\beta\beta}$



The full TINY technology could be used for future generations of double beta decay experiments