GRAPPA MSc Project Presentations

Nikhef

Universiteit van Amsterdam

Dark Matter and Rare-event Experiments

- What is the particle responsible for Dark Matter in the Universe?
- What are the fundamental properties of the Neutrino?

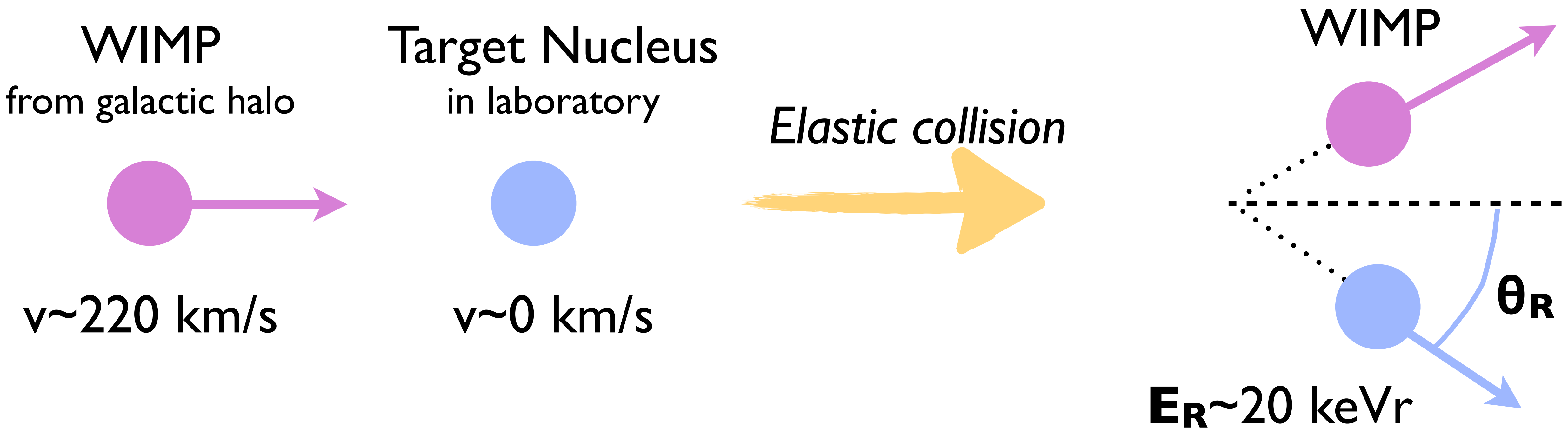
- Auke-Pieter Colijn colijn@nikhef.nl
- Tina Pollmann t.pollmann@nikhef.nl
- Patrick Decowski decowski@nikhef.nl

DM Group

- Dark Matter Group at Nikhef
  - 3 UvA Faculty Members
  - 2 Postdoc
  - 5-6 PhDs
  - 3-4 MSc students
- Experiments:
  - XENONnT/DARWIN Dark Matter
  - KamLAND-Zen Double Beta Decay
  - PTOLEMY Cosmic Neutrino Background
  - DUNE (with Neutrino Group)
  - Lab R&D

Physics Topics: Dark Matter

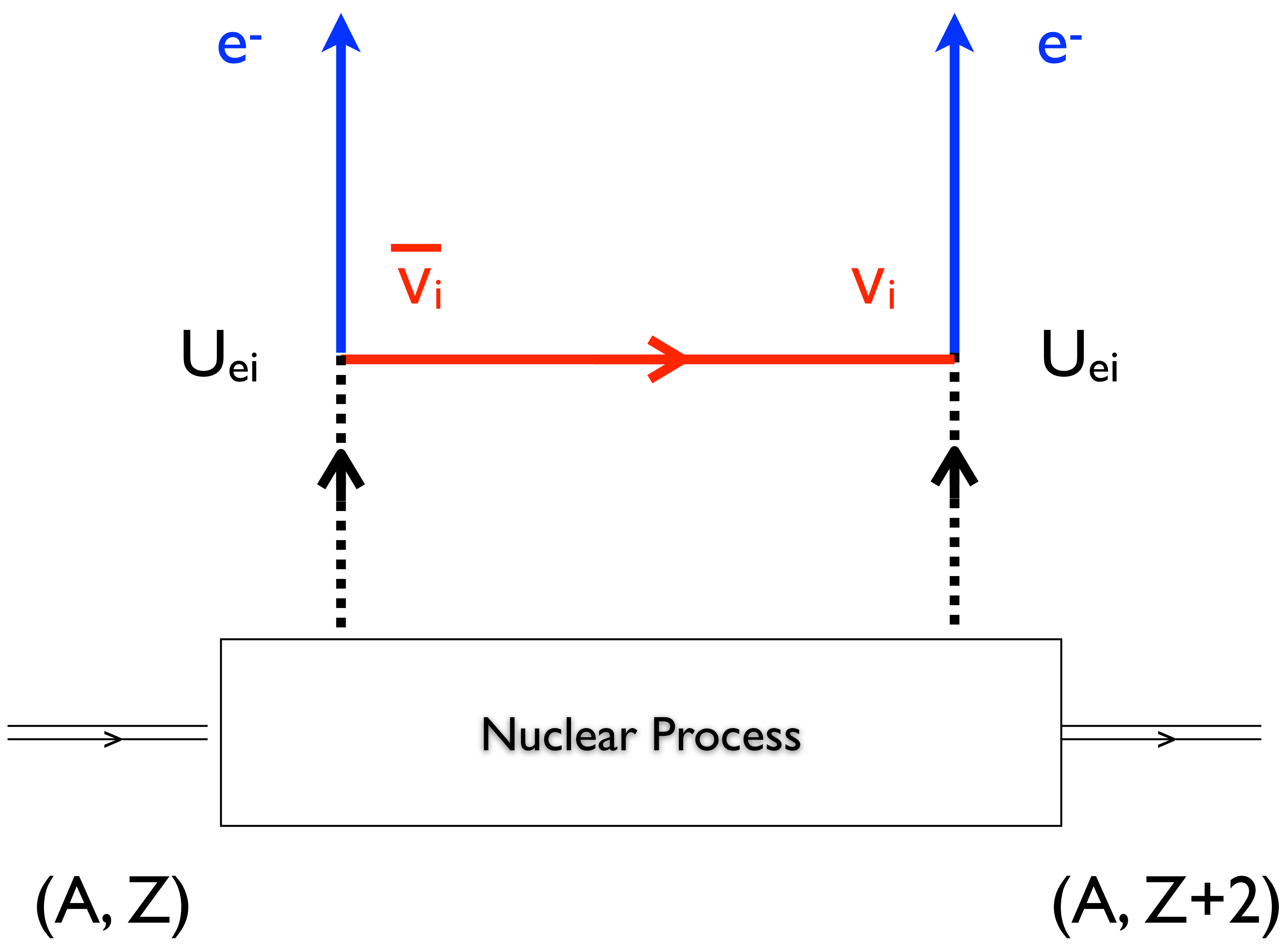
Assume WIMP is not only gravitationally interacting



But not only WIMPs! Also looking at Axions and other DM mechanisms

Physics Topics: Majorana Neutrinos

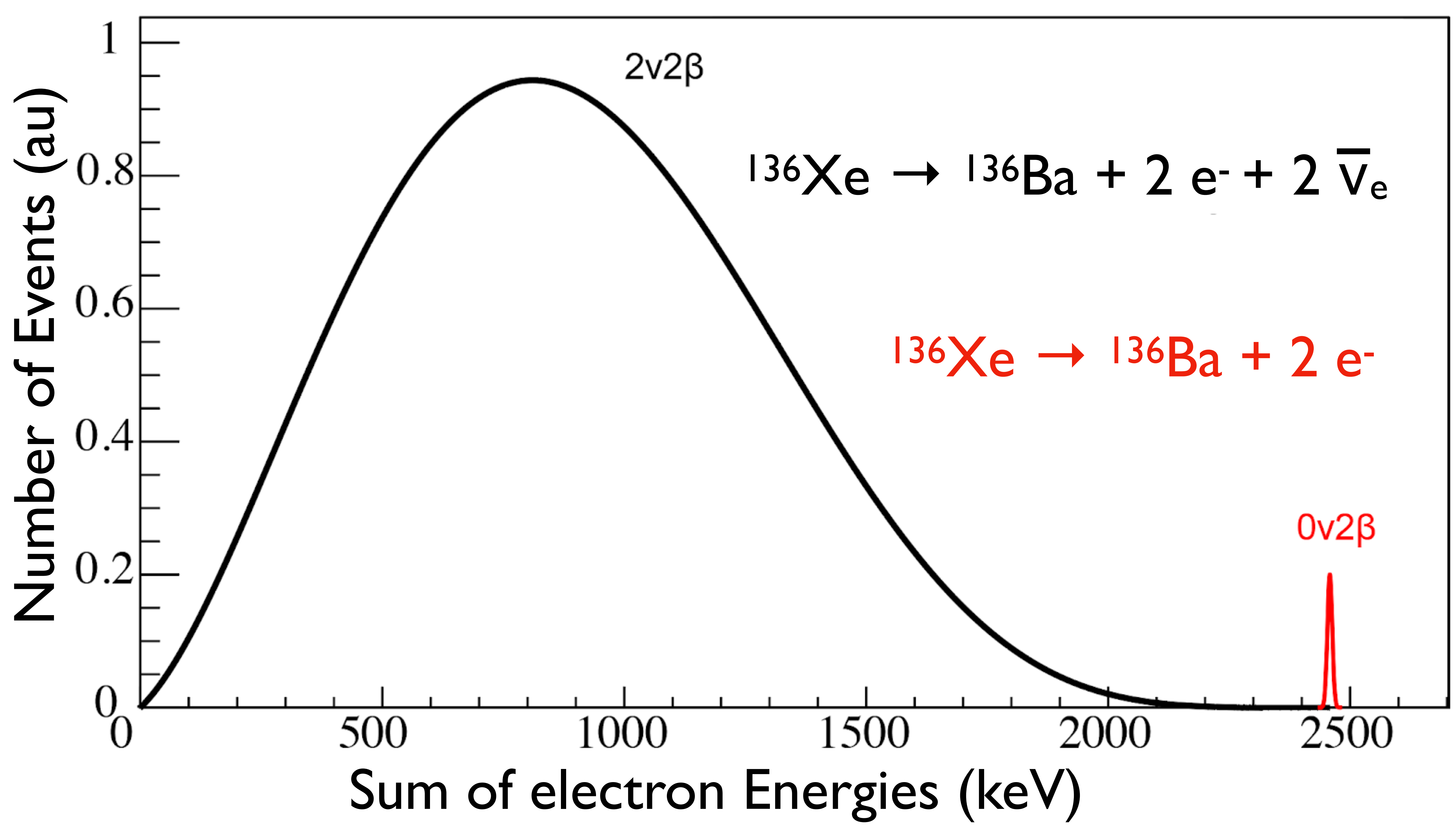
Is the neutrino its own anti-particle, i.e. Majorana?



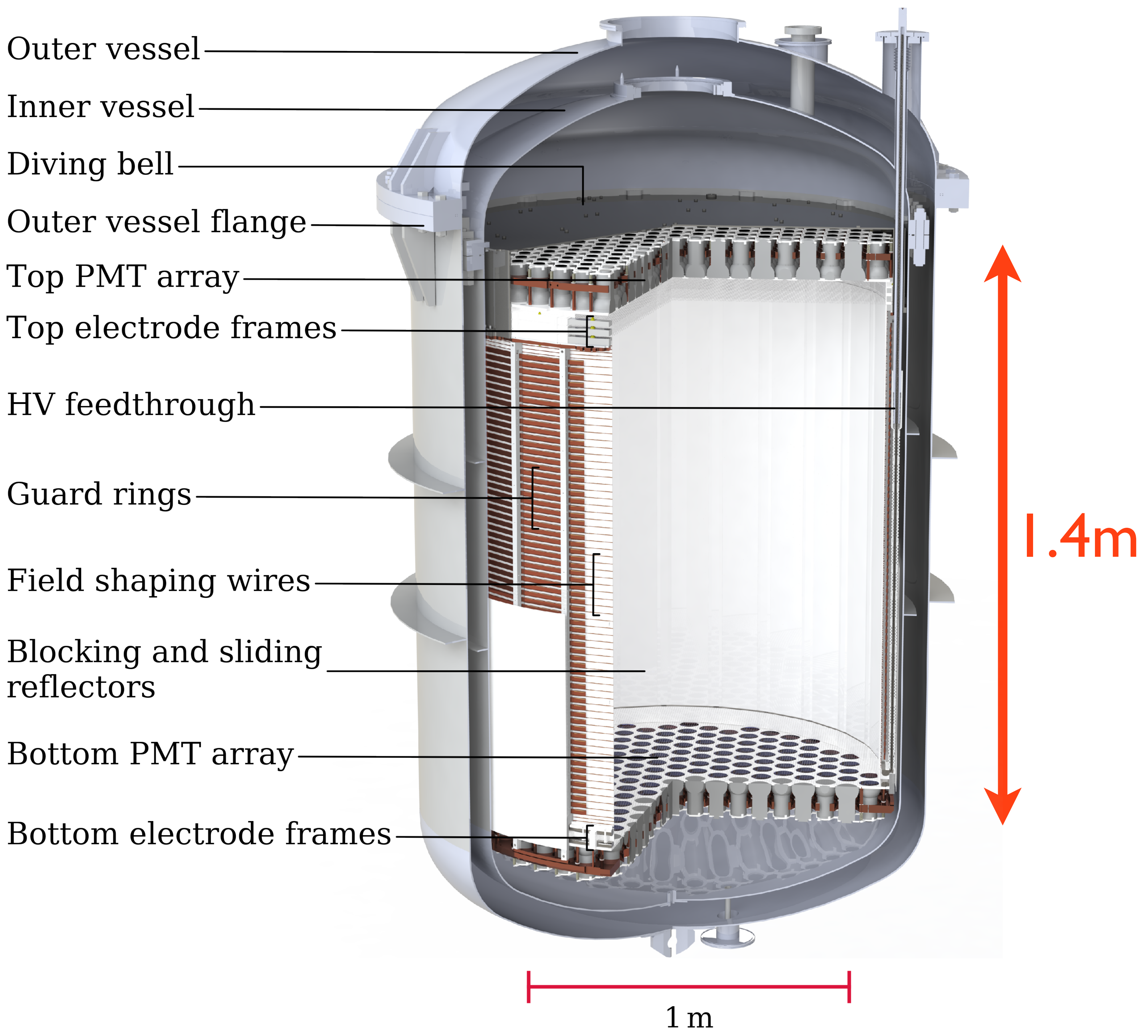
$$M_\nu \neq 0$$
$$|\Delta L| = 2$$

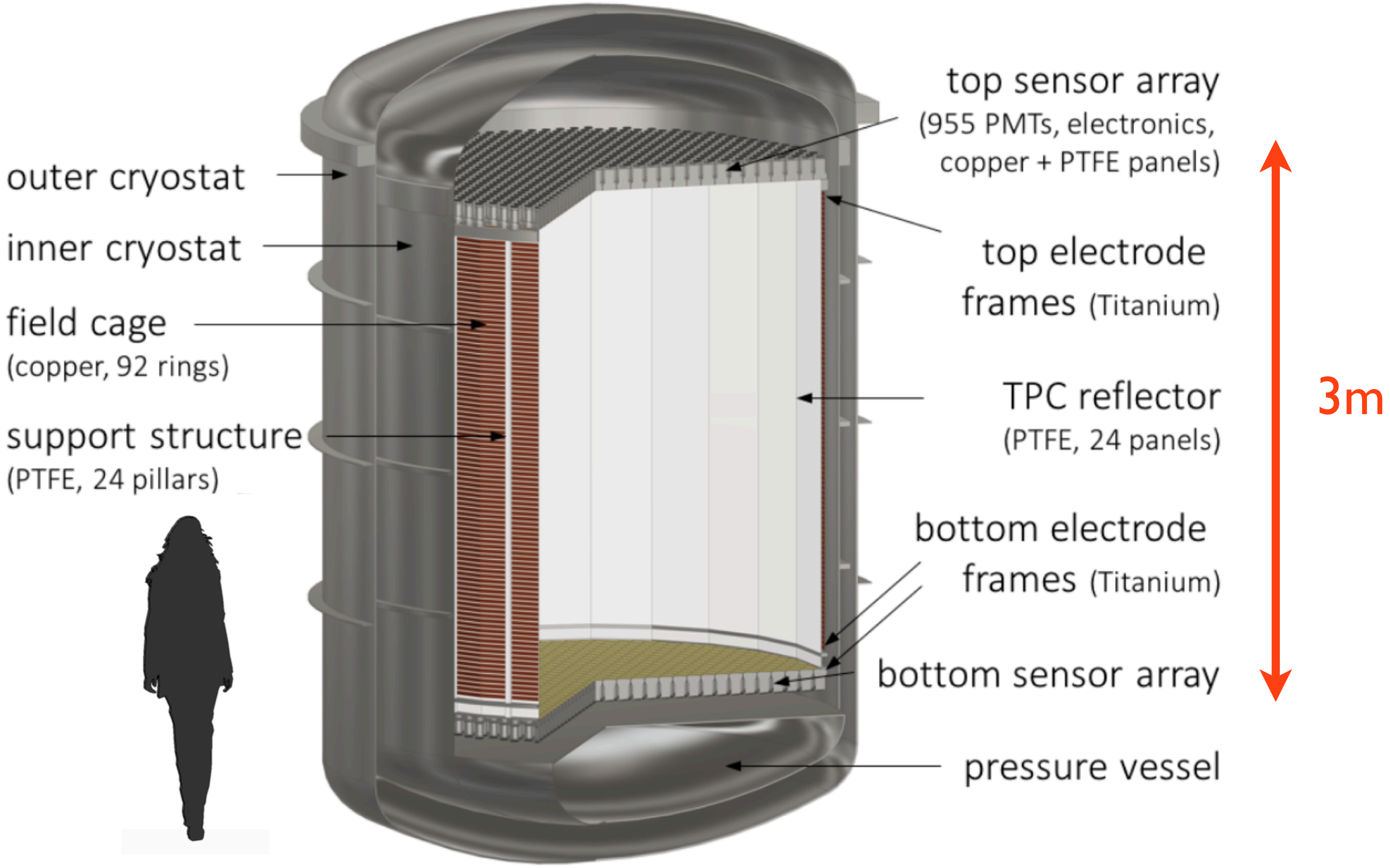
Lepton Number Violating process

Look for 0ν2β in ^{136}Xe



XENONnT and DARWIN Dark Matter Experiments





<u>XENONnT</u>

8.5t of LXe total

2021 - 2028

<u>DARWIN</u>

60t of LXe total

Global effort

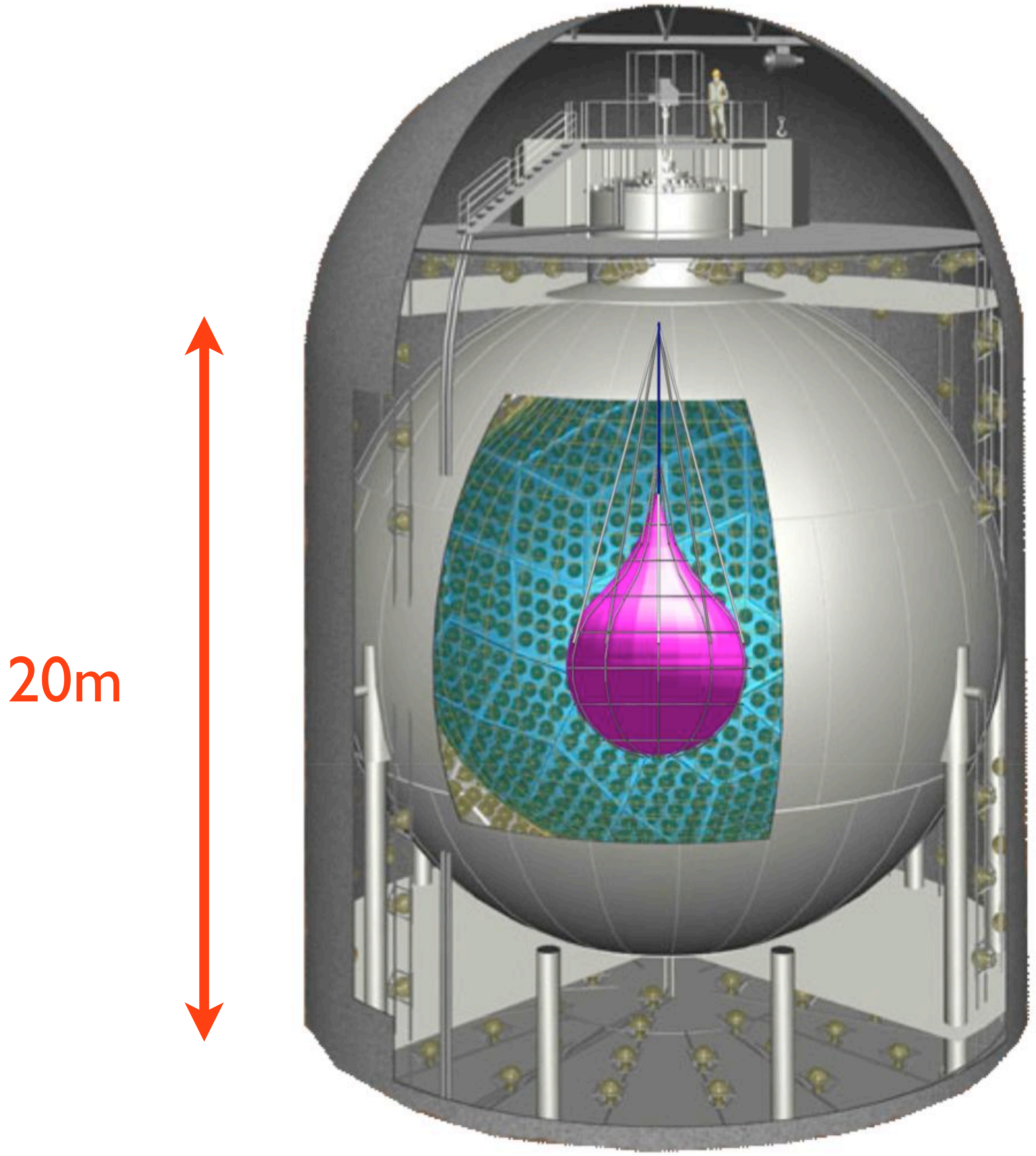
Start in 2030

https://arxiv.org/abs/2007.08796

https://arxiv.org/abs/2203.02309

KamLAND-Zen Experiment

Experiment located in Japan
750 kg of enriched Xe-136



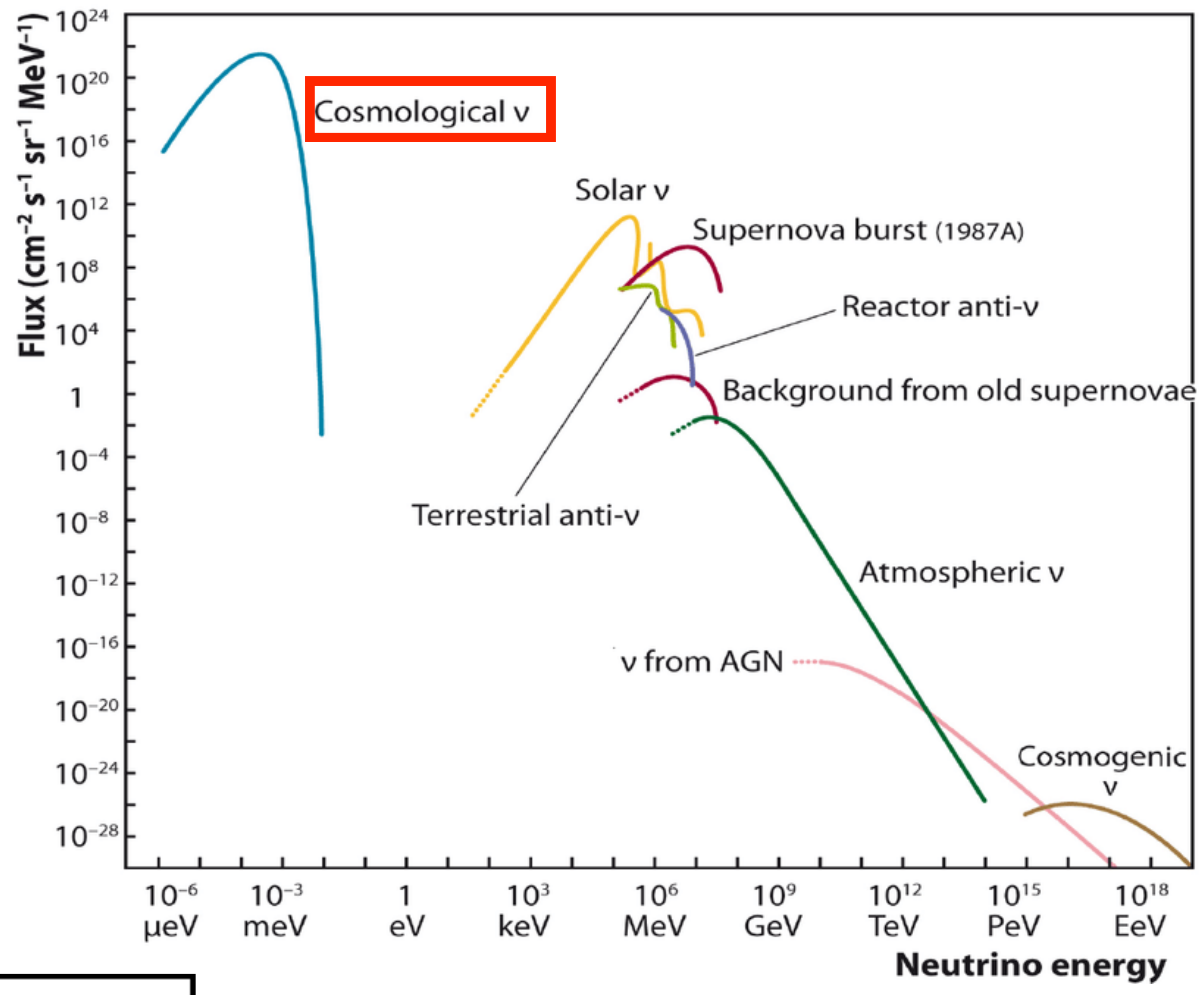
World's most sensitive detector for Majorana Neutrinos!

$$T_{1/2}^{0\nu} \propto \epsilon \frac{a}{A} \sqrt{\frac{Mt}{b\Delta E}}$$

https://arxiv.org/abs/2203.02139

PTOLEMY Experiment: Detecting Cosmic Neutrino Background

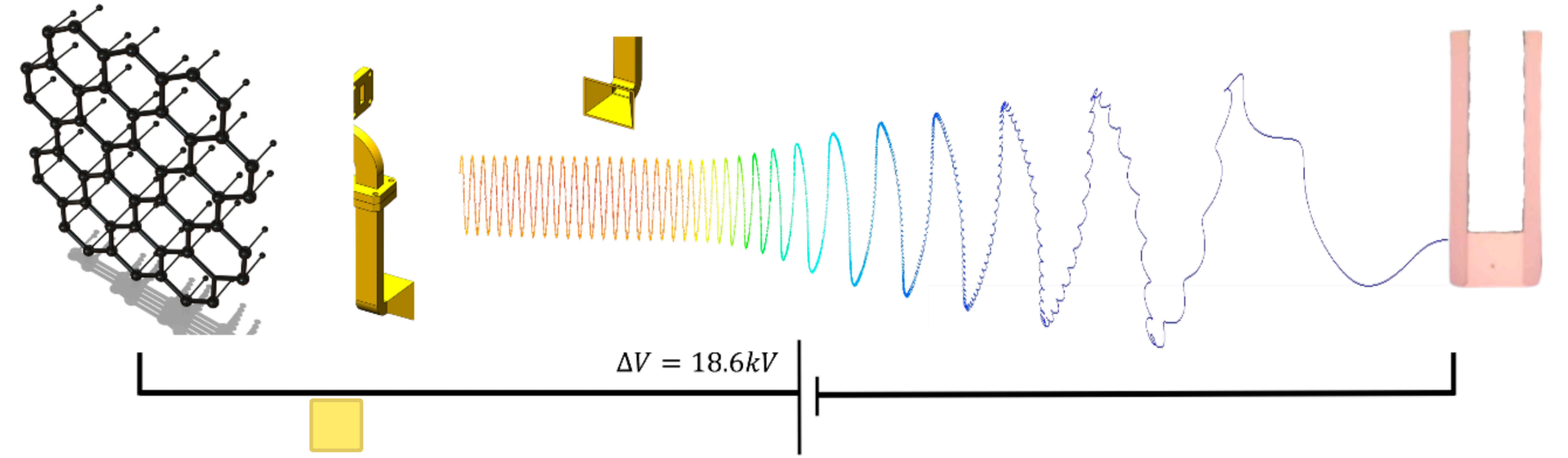
Detecting Relic Neutrinos from the Big Bang



Use neutrino capture on tritium and measure outgoing electron energy very precisely

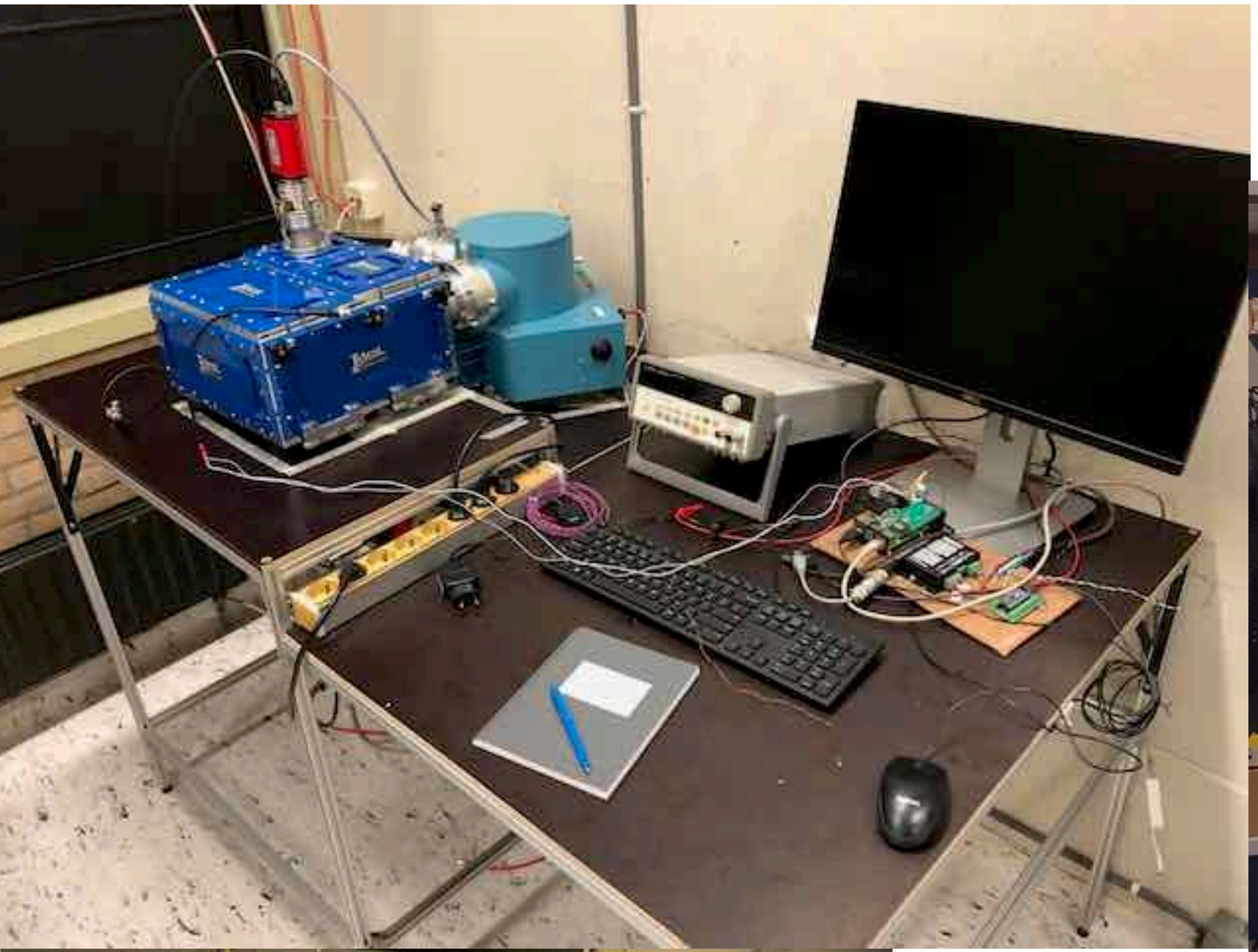
$$\nu_e + {}^3H \rightarrow {}^3He + e^-$$

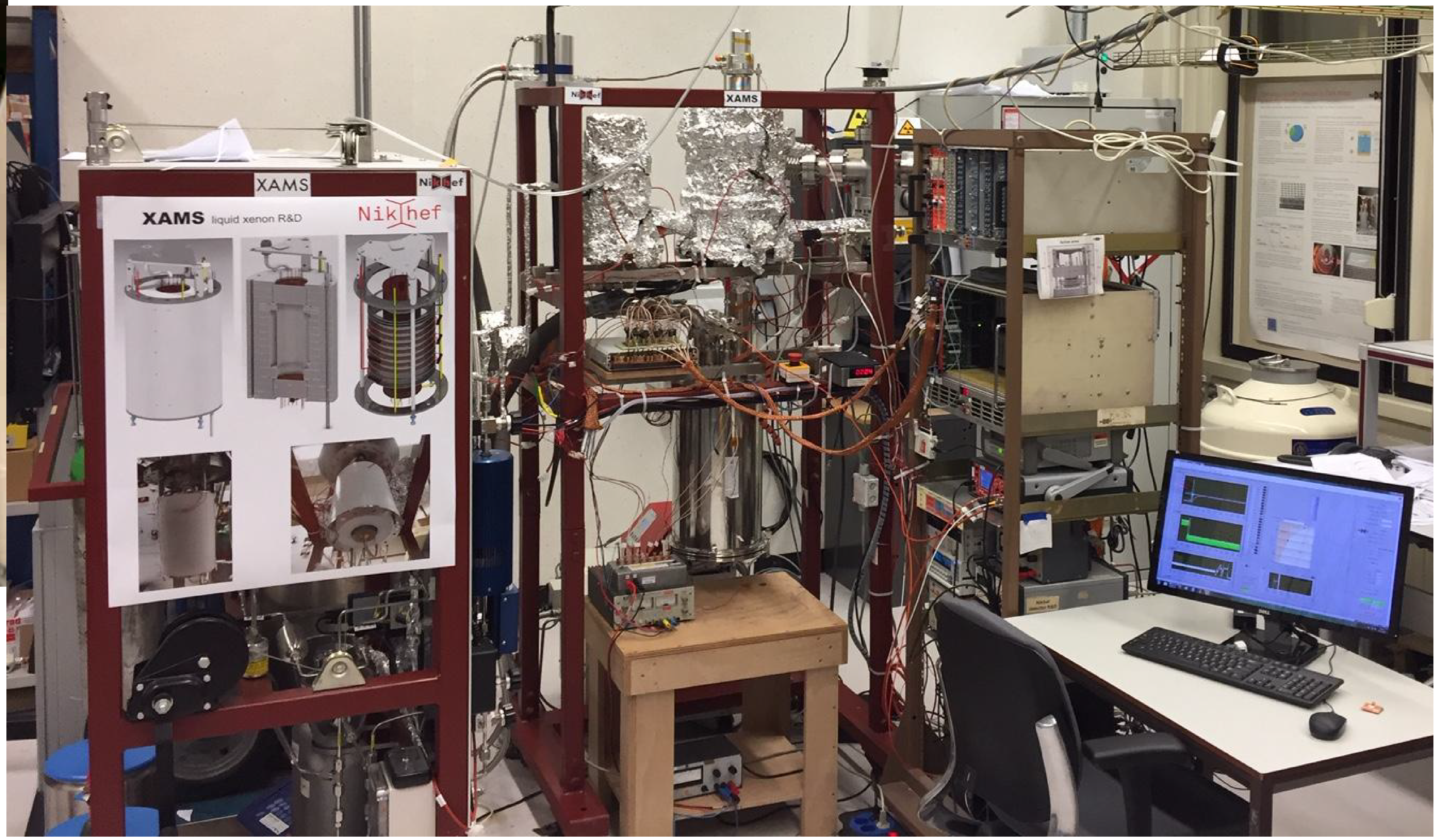
Target: Relic Neutrino Capture	→	RF Tracker: Electron Pre-Measurement	→	Dynamic Filter: Selects endpoint electron in narrow 10^{-4} energy window	→	Micro-calorimeter: Measures few eV electron to 10^{-2} energy resolution

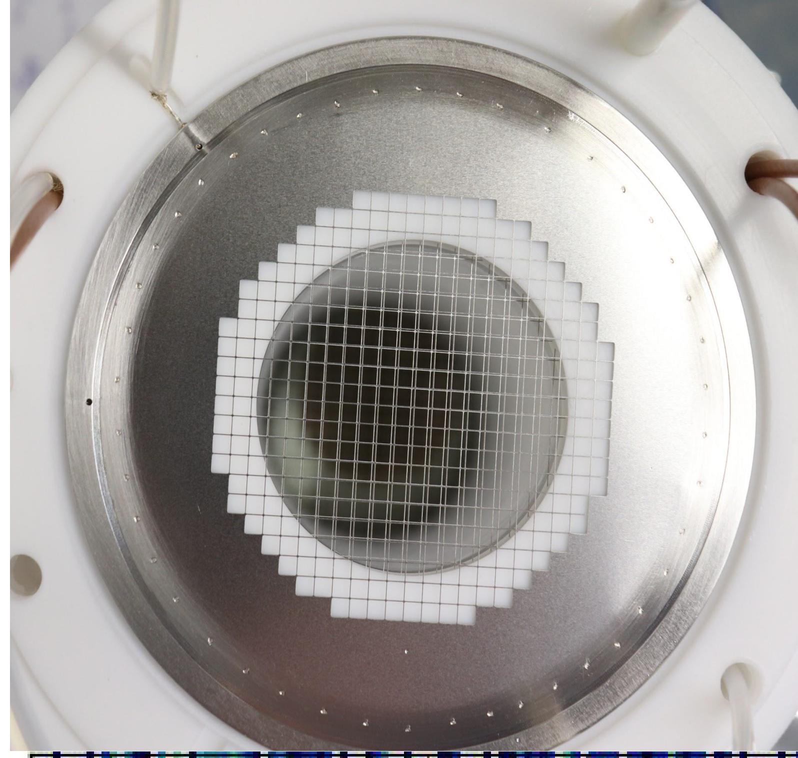


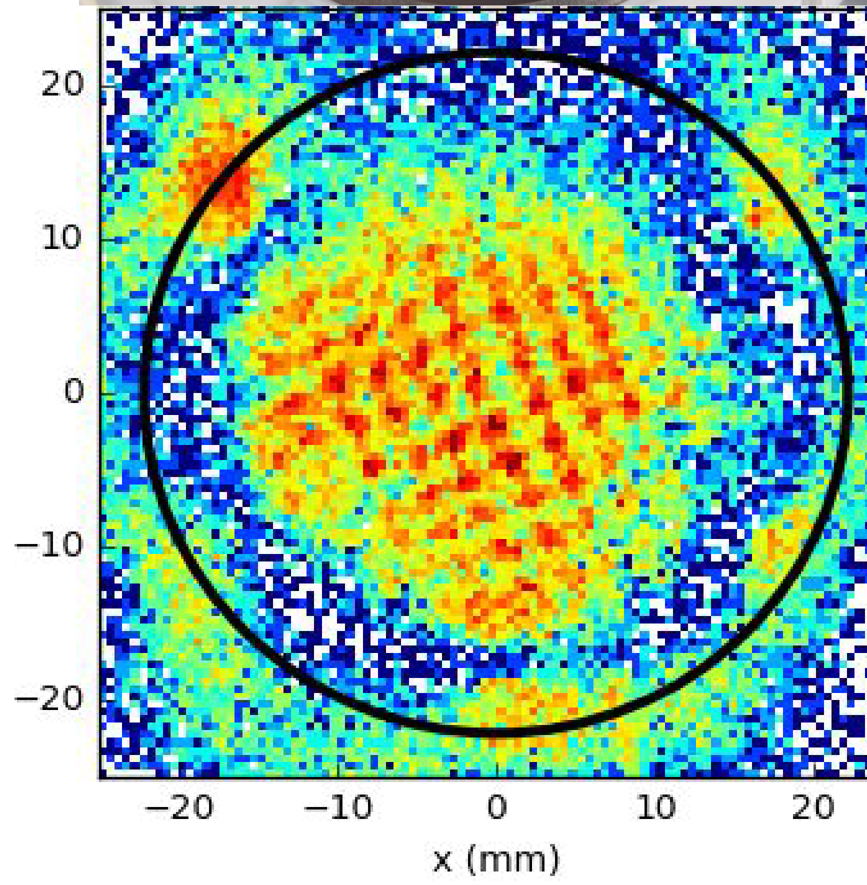
https://arxiv.org/abs/1808.01892

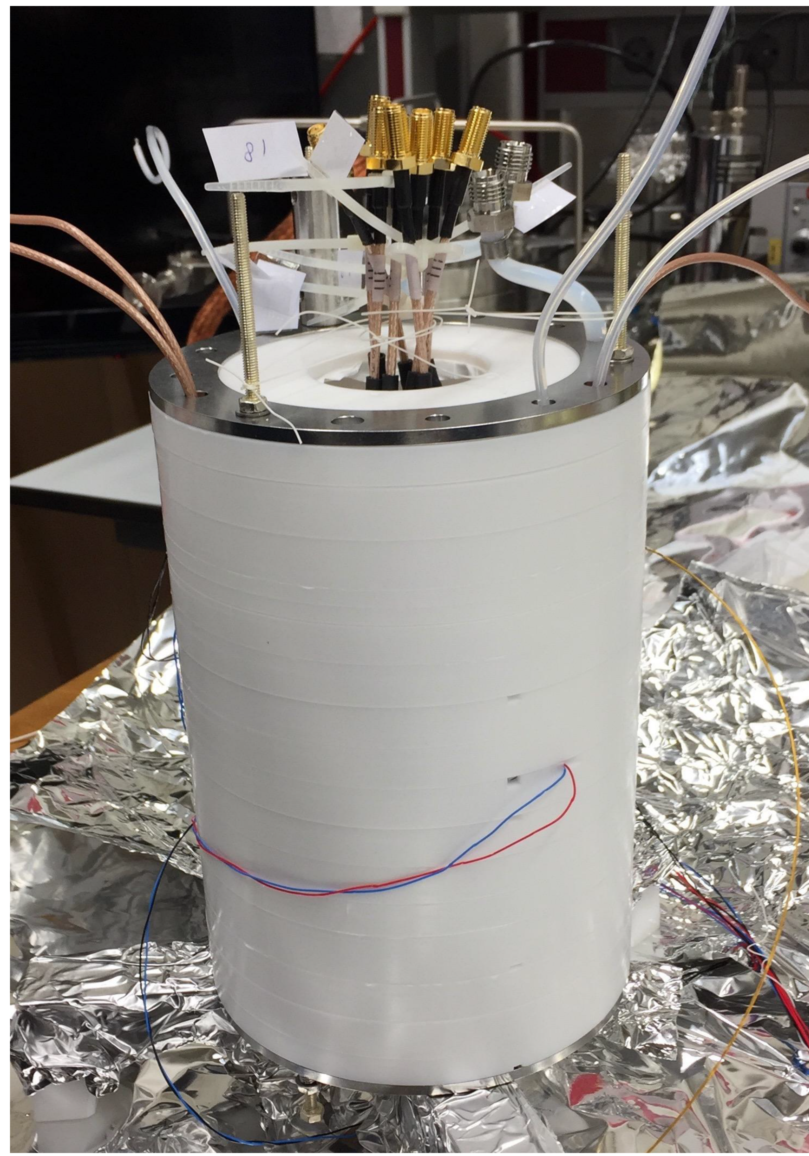
Local Lab R&D











R&D for large liquid Xe detectors:

- New light sensors
- Material reflections
- Optimizing anodes
- LXe properties
- [your own ideas!]

Available Projects

- XENONnT Data Analysis
  - Work on data to make position and particle identification reconstruction better
- DARWIN Sensitivity Studies
  - Use simulations to determine how well the ultimate dark matter experiment will work on discovering DM particles and $0\nu 2\beta$
- KamLAND-Zen Data Analysis
  - Work on KamLAND-Zen data to discover $0\nu 2\beta$
- PTOLEMY Relic Neutrino R&D
  - Building and testing GHz electronics
- R&D for the next great dark matter / neutrino detector
  - Hands-on in the lab, you “own” the setup

- Auke-Pieter Colijn colijn@nikhef.nl
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https://wiki.nikhef.nl/education/Master_Projects

From https://wiki.nikhef.nl/education/Master_Projects

Dark Matter: Building better Dark Matter Detectors - the XAMS R&D Setup

The Amsterdam Dark Matter group operates an R&D xenon detector at Nikhef. The detector is a dual-phase xenon time-projection chamber and contains about 0.5kg of ultra-pure liquid xenon in the central volume. We use this detector for the development of new detection techniques - such as utilizing our newly installed silicon photomultipliers - and to improve the understanding of the response of liquid xenon to various forms of radiation. The results could be directly used in the XENONnT experiment, the world's most sensitive direct detection dark matter experiment at the Gran Sasso underground laboratory, or for future Dark Matter experiments like DARWIN. We have several interesting projects for this facility. We are looking for someone who is interested in working in a laboratory on high-tech equipment, modifying the detector, taking data and analyzing the data themselves You will "own" this experiment.

Contact: Patrick Decowski and Auke Colijn

Dark Matter: Searching for Dark Matter Particles - XENONnT Data Analysis

The XENON collaboration has used the XENON1T detector to achieve the world's most sensitive direct detection dark matter results and is currently operating the XENONnT successor experiment. The detectors operate at the Gran Sasso underground laboratory and consist of so-called dual-phase xenon time-projection chambers filled with ultra-pure xenon. Our group has an opening for a motivated MSc student to do analysis with the new data coming from the XENONnT detector. The work will consist of understanding the detector signals and applying a deep neural network to improve the (gas-) background discrimination in our Python-based analysis tool to improve the sensitivity for low-mass dark matter particles. The work will continue a study started by a recent graduate. There will also be opportunity to do data-taking shifts at the Gran Sasso underground laboratory in Italy.

Contact: Patrick Decowski and Auke Colijn

Dark Matter: Signal reconstruction and correction in XENONnT

XENONnT is a low background experiment operating at the INFN - Gran Sasso underground laboratory with the main goal of detecting Dark Matter interactions with xenon target nuclei. The detector, consisting of a dual-phase time projection chamber, is filled with ultra-pure xenon, which acts as a target and detection medium. Understanding the detector's response to various calibration sources is a mandatory step in exploiting the scientific data acquired. This MSc thesis aims to develop new methods to improve the reconstruction and correction of scintillation/ ionization signals from calibration data. The student will work with modern analysis techniques (python-based) and will collaborate with other analysts within the international XENON Collaboration.

Contact: Maxime Pierre, Patrick Decowski

Dark Matter: The Ultimate Dark Matter Experiment - DARWIN Sensitivity Studies

DARWIN is the "ultimate" direct detection dark matter experiment, with the goal to reach the so-called "neutrino floor", when neutrinos become a hard-to-reduce background. The large and exquisitely clean xenon mass will allow DARWIN to also be sensitive to other physics signals such as solar neutrinos, double-beta decay from Xe-136, axions and axion-like particles etc. While the experiment will only start in 2027, we are in the midst of optimizing the experiment, which is driven by simulations. We have an opening for a student to work on the GEANT4 Monte Carlo simulations for DARWIN. We are also working on a "fast simulation" that could be included in this framework. It is your opportunity to steer the optimization of a large and unique experiment. This project requires good programming skills (Python and C++) and data analysis/physics interpretation skills.

Contact: Tina Pollmann, Patrick Decowski or Auke Colijn

Dark Matter: Exploring new background sources for DARWIN

Experiments based on the xenon dual-phase time projection chamber detection technology have already demonstrated their leading role in the search for Dark Matter. The unprecedented low level of background reached by the current generation, such as XENONnT, allows such experiments to be sensitive to new rare-events physics searches, broadening their physics program. The next generation of experiments is already under consideration with the DARWIN observatory, which aims to surpass its predecessors in terms of background level and mass of xenon target. With the increased sensitivity to new physics channels, such as the study of neutrino properties, new sources of backgrounds may arise. This MSc thesis aims to investigate potential new sources of background for DARWIN and is a good opportunity for the student to contribute to the design of the experiment. This project will rely on Monte Carlo simulation tools such as GEANT4 and FLUKA, and good programming skills (Python and C++) are advantageous.

Contact: Maxime Pierre, Patrick Decowski

Dark Matter: Sensitive tests of wavelength-shifting properties of materials for dark matter detectors

Rare event search experiments that look for neutrino and dark matter interactions are performed with highly sensitive detector systems, often relying on scintillators, especially liquid noble gases, to detect particle interactions. Detectors consist of structural materials that are assumed to be optically passive, and light detection systems that use reflectors, light detectors, and sometimes, wavelength-shifting materials. MSc theses are available related to measuring the efficiency of light detection systems that might be used in future detectors. Furthermore, measurements to ensure that presumably passive materials do not fluoresce, at the low level relevant to the detectors, can be done. Part of the thesis work can include Monte Carlo simulations and data analysis for current and upcoming dark matter detectors, to study the effect of different levels of desired and nuisance wavelength shifting. In this project, students will acquire skills in photon detection, wavelength shifting technologies, vacuum systems, UV and extreme-UV optics, detector design, and optionally in Python and C++ programming, data analysis, and Monte Carlo techniques.

Contact: Tina Pollmann

Neutrinos: Searching for Majorana Neutrinos with KamLAND-Zen

The KamLAND-Zen experiment, located in the Kamioka mine in Japan, is a large liquid scintillator experiment with 750kg of ultra-pure Xe-136 to search for neutrinoless double-beta decay (0n2b). The observation of the 0n2b process would be evidence for lepton number violation and the Majorana nature of neutrinos, i.e. that neutrinos are their own anti-particles. Current limits on this extraordinary rare hypothetical decay process are presented as a half-life, with a lower limit of 10^26 years. KamLAND-Zen, the world's most sensitive 0n2b experiment, is currently taking data and there is an opportunity to work on the data analysis, analyzing data with the possibility of taking part in a ground-breaking discovery. The main focus will be on developing new techniques to filter the spallation backgrounds, i.e. the production of radioactive isotopes by passing muons. There will be close collaboration with groups in the US (MIT, Berkeley, UW) and Japan (Tohoku Univ).

Contact: Patrick Decowski

Neutrinos: TRIF$\mathcal{O}$RCE (PTOLEMY)

The PTOLEMY demonstrator will place limits on the neutrino mass using the β-decay endpoint of atomic tritium. The detector will require a CRES-based (cyclotron radiation emission spectroscopy) trigger and a non-destructive tracking system. The "*TRItium-endpoint From $\mathcal{O}$(fW) Radio-frequency Cyclotron Emissions*" group is developing radio-frequency cavities for the simultaneous transport of endpoint electrons and the extraction of their kinematic information. This is essential to providing a fast online trigger and precise energy-loss corrections to electrons reconstructed near the tritium endpoint. The cryogenic low-noise, high-frequency analogue electronics developed at Nikhef combined with FPGA-based front-end analysis capabilities will provide the PTOLEMY demonstrator with its CRES readout and a testbed to be hosted at the Gran Sasso National Laboratory for the full CvB detector. The focus of this project will be modelling CR in RF cavities and its detection for the purposes of single electron spectroscopy and optimised trajectory reconstruction for prototype and demonstrator setups. This may extend to firmware-based fast tagging and reconstruction algorithm development with the RF-SoC.

Contact: James Vincent Mead]