From double to single beta decays – the search for the isomeric decay of ^{180m}Ta in the MAJORANA DEMONSTRATOR

Ralph Massarczyk on behalf of the MAJORANA Collaboration

Introduction

The MAJORANA DEMONSTRATOR was a neutrinoless double-beta ($0\nu\beta\beta$) decay experiment that ran until March 2021. After the removal of the enriched detector material and additional background studies the ultra-clean facility was available for additional studies.

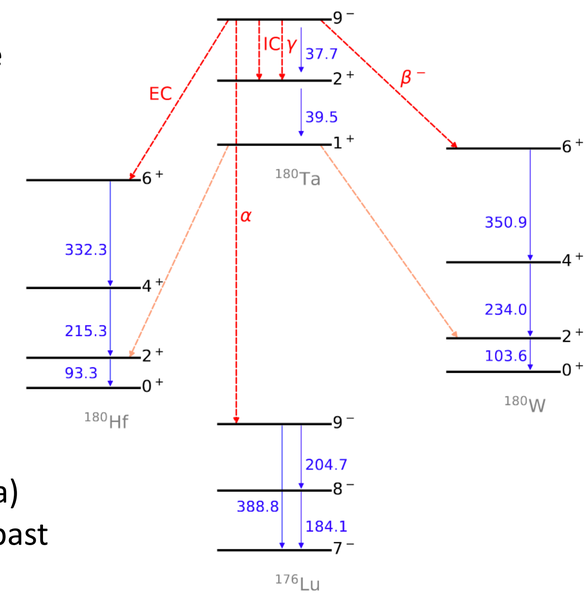
Key Features

- Detector array of HpGe detectors in ultra-high vacuum
- Compact graded shield and active muon veto deep underground
- All materials ultra-clean
- Excellent energy resolution
- Low background

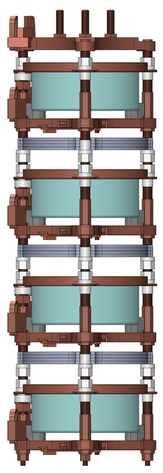
Motivation

- Longest living isomer in nature
- Most extreme case to study the nature of nuclear spin traps
- Variety of decay schemes possible
- Half-life and decay of interest to understand production and abundance in the universe
  e.g. by
  - ➢ *ν-interactions,*
  - ➢ *thermal excitation in early universe*
  - ➢ *Deexcitation by dark matter ?*
- Natural abundance (0.012% ^{180m}Ta) prohibited larger searches in the past

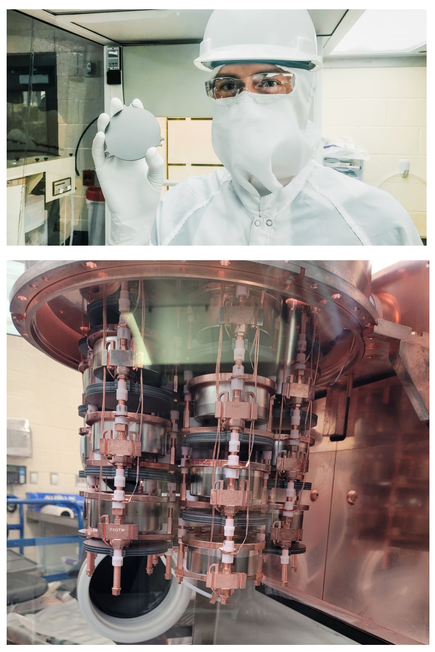
$$\lambda_{total} = \lambda_{EC} + \lambda_{\beta-} + \lambda_{\gamma} + \lambda_{IC} + \lambda_{\alpha} + \lambda_{DM}$$



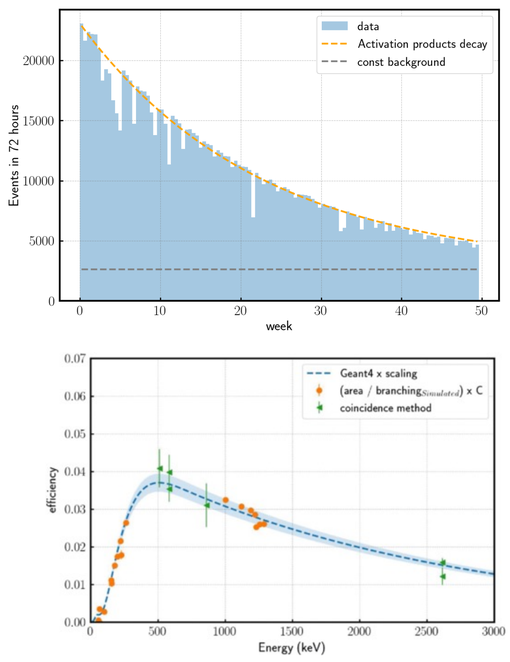
Experiment and analysis



- Detector array with 23 active detectors
- 17.4 kg of ^{nat}Ta installed *(~**2g ^{180m}Ta**)*
- Close geometry and no structural material between detector and sample
- Sample thickness optimized by simulation to maximize detection efficiency and minimize self-shielding
- Stable data taking since May 2022 (>92% live)

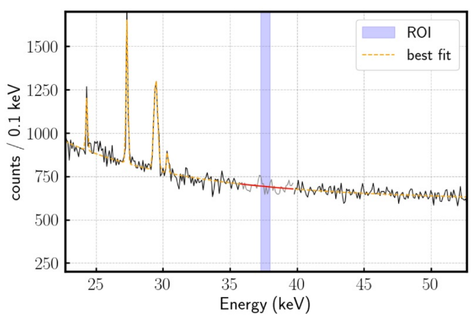


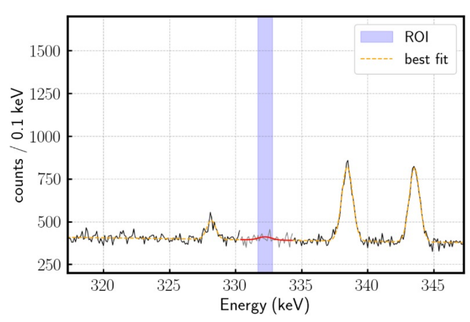
- Analysis using established routines on recorded waveform signals from the MAJORANA DEMONSTRATOR (MJD)
- Background consists of
  - Signatures of surface activation like decays from ^{182}Ta or ^{175}Hf
  - Natural Radioactivity from within the sample
    (x 10-20 above MJD levels)
- Efficiency and detector resolution verified using ɣ-rays from ^{182}Ta-decay emitted from within the samples



First results

- Search for peak-like structures in energy histograms for single- and multi-detector events

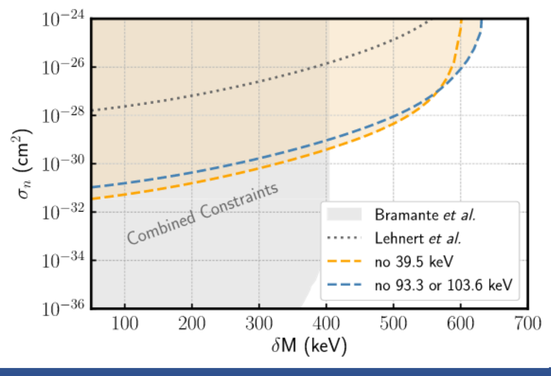




- **Most sensitive search** given improvements in mass (x12), efficiency (x2-3), and background (in higher multiplicity signatures
- In addition, low threshold allows direct search for the predicted most prominent channel (Internal conversion to the first excited state)

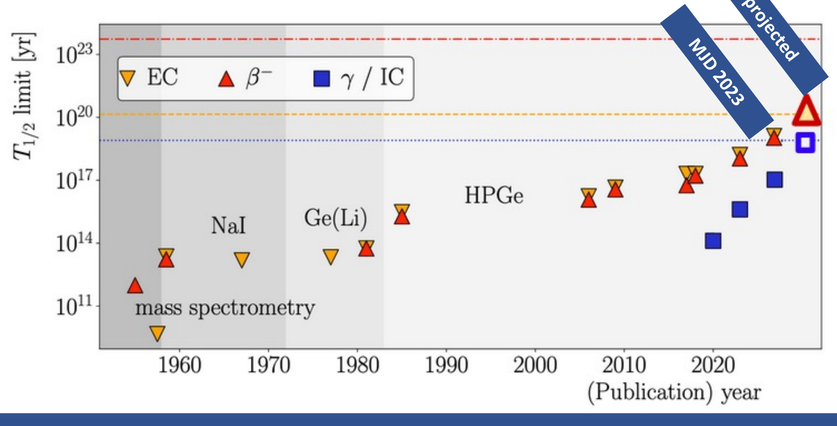
	EC	β^-	ɣ	IC	α
Previous limits	1.6 x 10^{18} yrs	1.1 x 10^{18} yrs	4.5 x 10^{15} yrs	4.5 x 10^{15} yrs	---
This work	**13.3 x 10^{18} yrs**	**15.4 x 10^{18} yrs**	**0.6 x 10^{18} yrs**	**0.3 x 10^{18} yrs**	**11.3 x 10^{18} yrs**
Expected $T_{1/2}$	10^{20} yrs	10^{23} yrs	10^{20} yrs	10^{18} yrs	10^{28} yrs

- **Non**-observation of signatures allows the **exclusion** of dark-matter induced deexcitation e.g. by inelastic dark matter scattering
- **Details: PRL131 152501 (2023)**



Outlook and Summary

- Improvements in analysis
  - Multidimensional fitting routines in time-and-energy
  - Began search and simulations for signatures that are summing up, which improves the efficiency for the decay channels involving cascades
- Continuous data takings with lower background conditions planned until Fall 2025
- Background by Surface activation minor in latest data sets
- Estimates based on current performance predict sensitivities for the most prominent channel that are for the first time ever within the predicted



The Majorana Collaboration: I. J. Arnquist, F. T. Avignone III, A. S. Barabash, C. J. Barton, K. H. Bhimani, E. Blalock, B. Bos, M. Busch, M. Buuck, T. S. Caldwell, C. D. Christofferson, P.-H. Chu, M. L. Clark, C. Cuesta, J. A. Detwiler, Yu. Efremenko, H. Ejiri, S. R. Elliott, G. K. Giovanetti, J. Goett, M. P. Green, J. Gruszko, I. S. Guinn, V. E. Guiseppe, C. R. Haufe, R. Henning, D. Hervas Aguilar, E. W. Hoppe, A. Hostiuc,I. Kim, R. T. Kouzes, T. E. Lannen V., A. Li, J. M. López-Castaño, R. Massarczyk, S. J. Meijer, T. K. Oli, L. S. Paudel, W. Pettus, A. W. P. Poon, D. C. Radford, A. L. Reine, K. Rielage, A. Rouyer, N. W. Ruof, D. C. Schaper, S. J. Schleich, T. A. Smith-Gandy, D. Tedeschi, J. D. Thompson, R. L. Varner, S. Vasilyev, S. L. Watkins, J. F. Wilkerson, C. Wiseman, W. Xu, and C.-H. Yu
Additional contributors: D. S. M. Alves, L. Hebenstiel, W. Meijer, H. Ramani

This material is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, the Particle Astrophysics and Nuclear Physics Programs of the National Science Foundation, and the Sanford Underground Research Facility, LA-UR-24-25547