

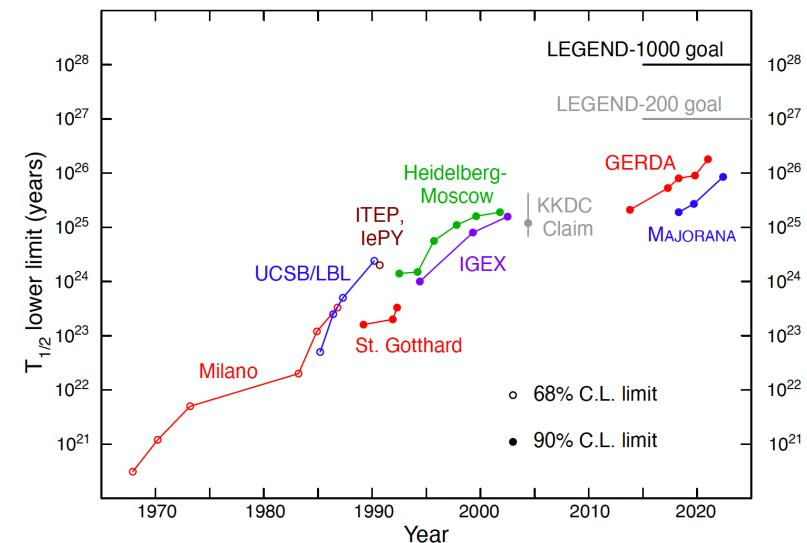
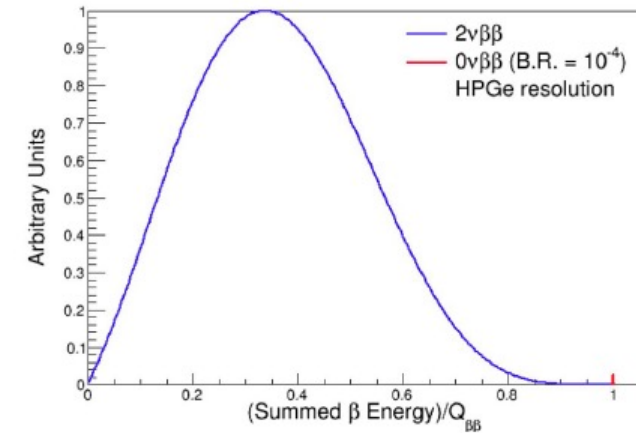
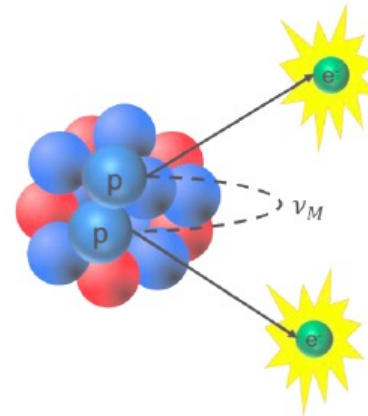
# Current status of MJD, MJD-Ta, and LEGEND

Ralph Massarczyk,  
Los Alamos National Laboratory

LA-UR 22-31285

# Neutrinoless double beta decay in $^{76}\text{Ge}$

- Search for a peak at the Q-value for double-beta decay (2.039 MeV)
- Long history of searches in germanium
- Use the strengths of Ge as detector material
  - Source = detector (high efficiency)
  - Excellent energy resolution
  - Well established, no extrapolation from current detector performance



More on double-beta decay under:  
[legend-exp.org](http://legend-exp.org)

# MAJORANA DEMONSTRATOR Timeline



## Module 1

16.8 kg (20) <sup>enr</sup>Ge  
5.6 kg (9) <sup>nat</sup>Ge



Deploy Module 1 in shield

**Mar. 2021:**  
Stopped <sup>enr</sup>Ge Operation  
Removed all <sup>enr</sup>Ge for LEGEND-200

2015

2016

2017

2018

2019

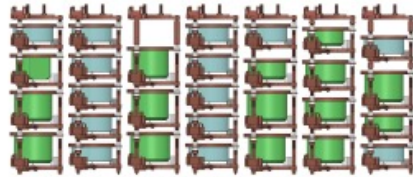
2020

2021

2022

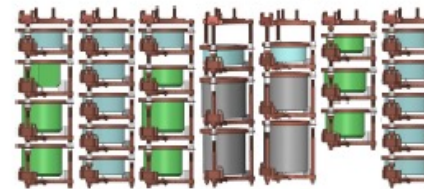
## Module 2

12.9 kg (15) <sup>enr</sup>Ge  
8.8 kg (14) <sup>nat</sup>Ge



Deploy Module 2 in shield

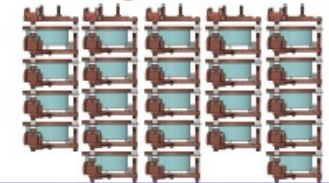
14.1 kg (13) <sup>enr</sup>Ge  
8.8 kg (14) <sup>nat</sup>Ge



6.7 kg (4) as ICPC

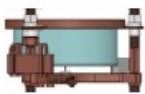
Cable/Connector Upgrade of Module 2  
Removed 5 PPC detectors for LEGEND Testing  
Installed 4 LEGEND ICPC Detectors

14.3 kg (23) <sup>nat</sup>Ge

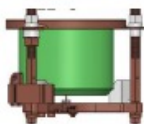


Continuing operation of Module 2 only with natural Ge detectors.  
Since April '22 with <sup>180m</sup>Ta

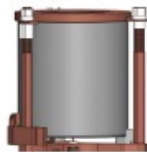
Mirion/Canberra  
BEGe  
<sup>nat</sup>Ge



Ortec  
PPC  
<sup>enr</sup>Ge



Ortec ICPC  
<sup>enr</sup>Ge

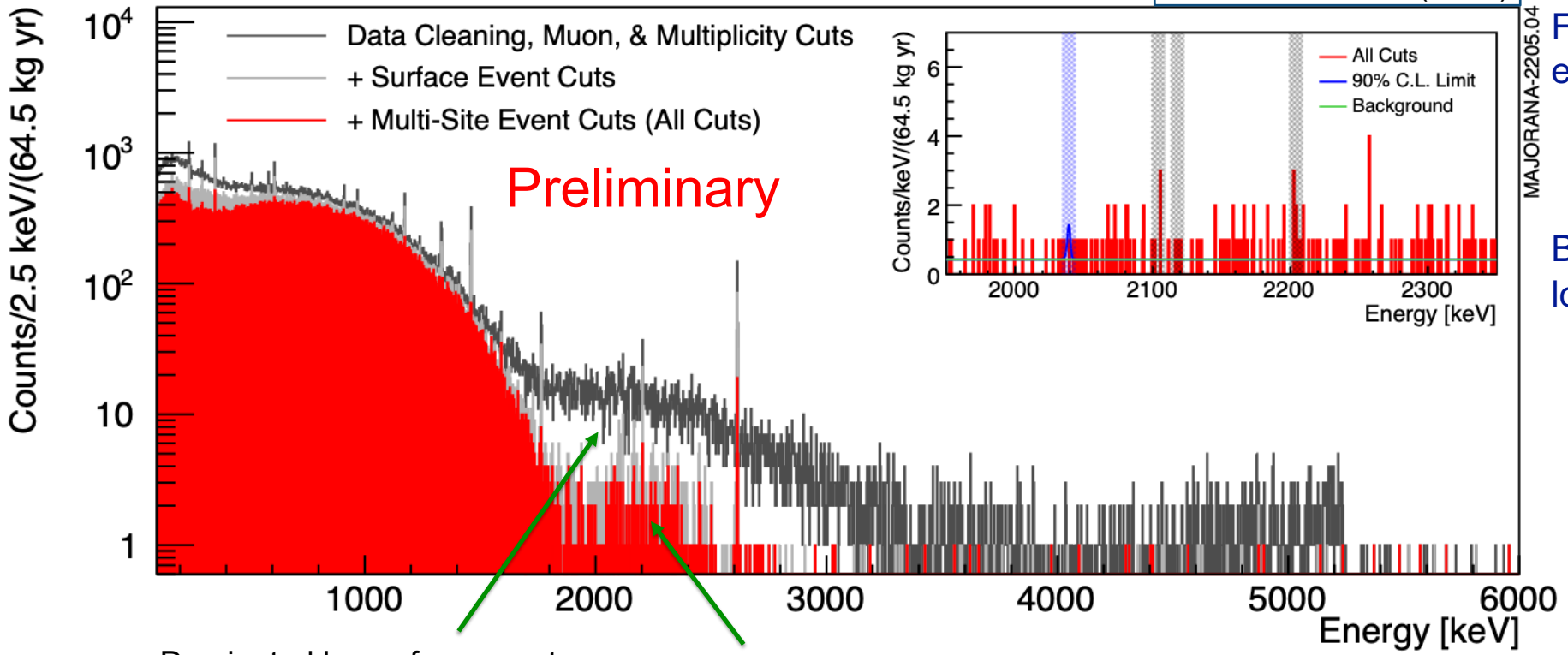


# MAJORANA DEMONSTRATOR Final $0\nu\beta\beta$ Result



Operating in a low background regime and benefiting from excellent energy resolution

arXiv:2207.07638 (2022)



Final enriched detector active exposure:

$$64.5 \pm 0.9 \text{ kg-yr}$$

Background index at 2039 keV in lowest background configuration

$$15.7 \pm 1.4 \text{ cts}/(\text{FWHM t yr})$$

Background index in Module 1

$$18.6 \pm 1.8 \text{ cts}/(\text{FWHM t yr})$$

Background index in Module 2

$$8.4^{+1.9}_{-1.7} \text{ cts}/(\text{FWHM t yr})$$

Dominated by surface events before cuts

$^{208}\text{Tl}$  ( $^{232}\text{Th}$ )-like after cuts

- Median  $T_{1/2}$  Sensitivity:  $8.1 \times 10^{25}$  yr (90% C.I.)
- Limit:  $T_{1/2} > 8.3 \times 10^{25}$  yr (90% C.I.)

# Rich and Broad Physics Programs



## Tests of Fundamental Symmetries and Conservations

Lepton number violation via neutrinoless double beta decay  
Baryon number violation  
Pauli Exclusion Principle violation

arXiv:2207.07638 (2022)

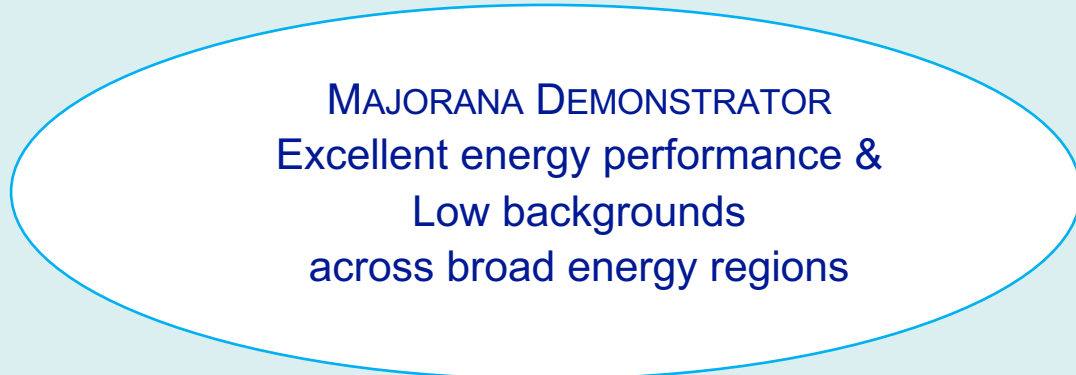
PRC **100** 025501 (2019)

PRD **99** 072004 (2019)

arXiv:2203.02033 (2022)

## Standard Model Physics

## BSM Physics



Standard Model Physics,  
particular backgrounds

$2\nu\beta\beta$  to excited states  
In situ cosmogenics  
(alpha, n) reactions

PRC **103** 015501 (2021)

PRC **105** 014617 (2022)

PRC **105** 064610 (2022)

Low-mass dark matter signatures

Pseudoscalar dark matter  
Vector dark matter  
Fermionic dark matter  
Sterile neutrino  
Primakoff solar axion  
14.4-keV solar axion

PRL **118** 161801 (2017)

PRL **129** 081803 (2022)

arXiv:2206.10638 (2022)

## Exotic Physics

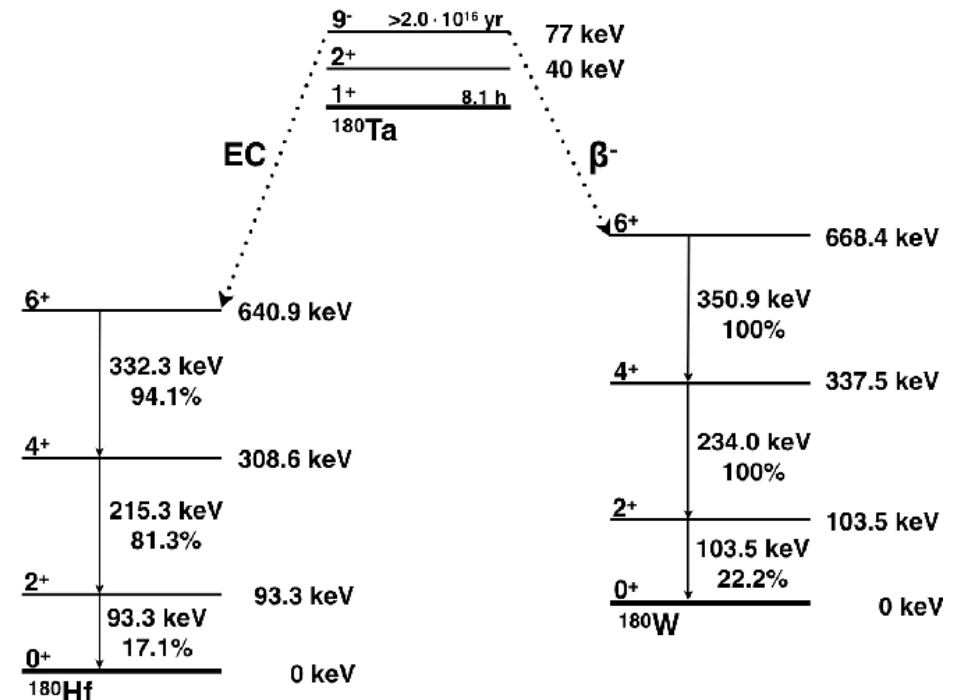
Quantum Wavefunction collapse  
Lightly ionization particle

PRL **129** 080401 (2022)

PRL **120** 211804 (2018)

# Ta Study – a new purpose for MAJORANA

- $^{180\text{m}}\text{Ta}$  is the only unobserved long-lived isomeric decay ( $T_{1/2} > 10^{16}$  yrs)
- with MJD at SURF:
  - Cleaner setup ( $\sim \times 10$ )
  - More mass ( $\times 12$ )
  - More detectors ( $\times 12$ )than any previous attempt
- In addition searches for dark matter interacting with nuclei (DM induced deexcitation)

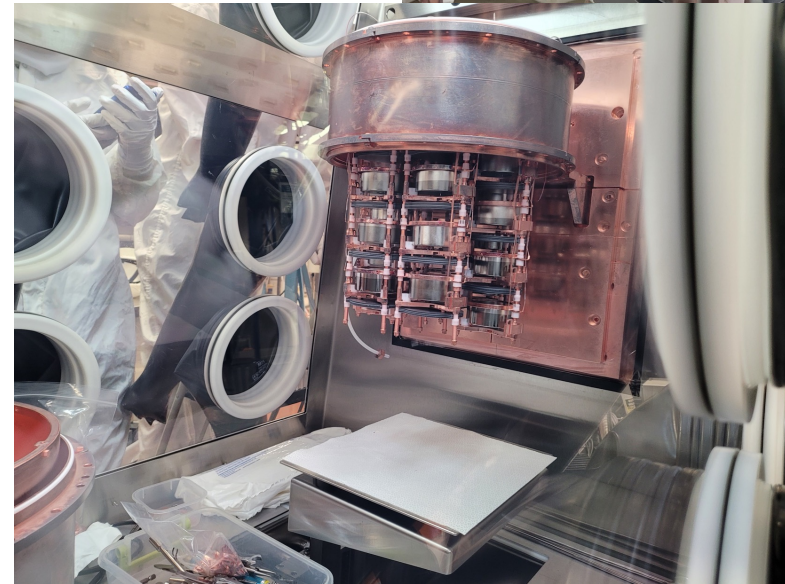




# Ta Study – status

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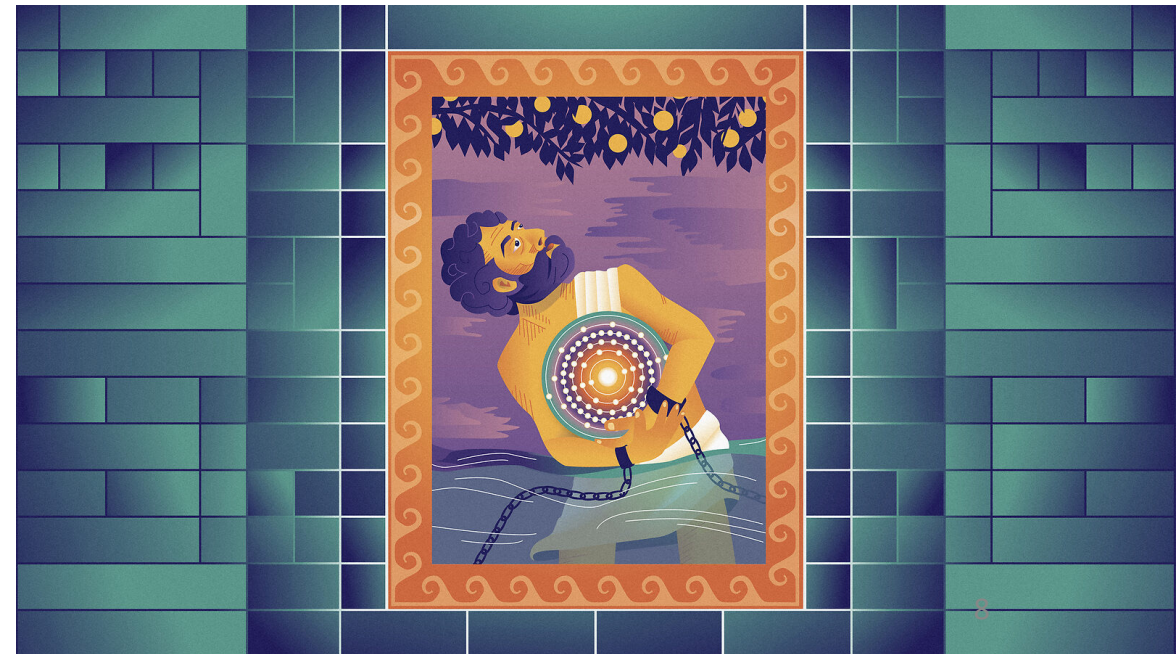
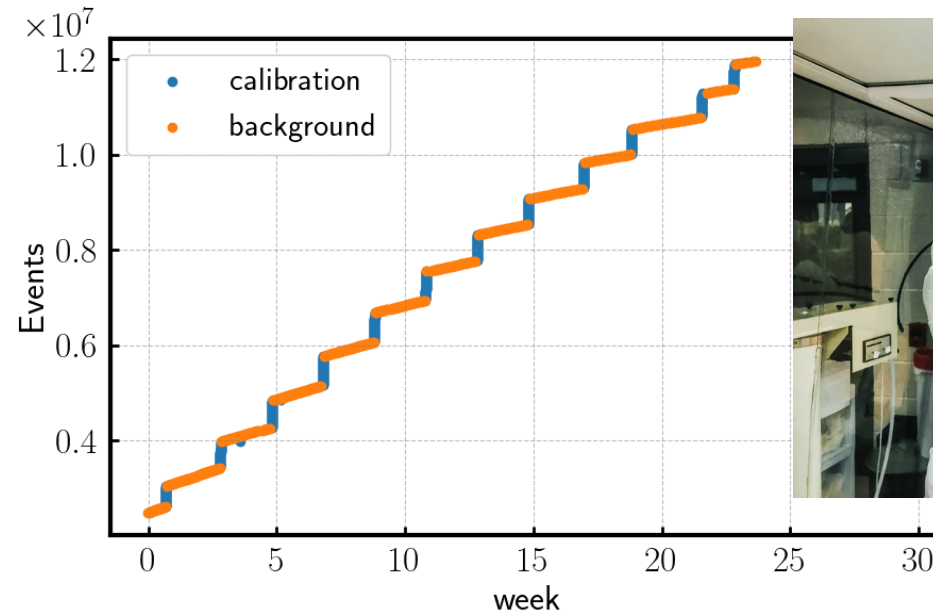
- 17.4 kg installed in Mar / Apr following established SURF and MJD procedures
- Operation smoothly, analysis ongoing (first week of data improved old limit by factor 2)
- New possibilities for local students
- Triggered wide interest from science, e.g. Symmetry Magazine



# Ta Study – status

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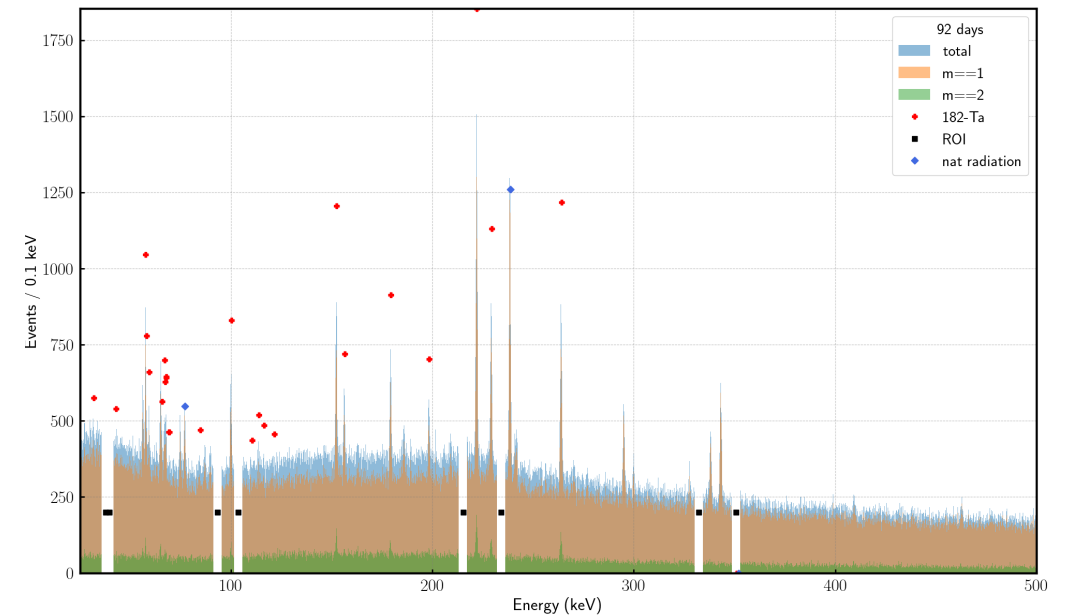
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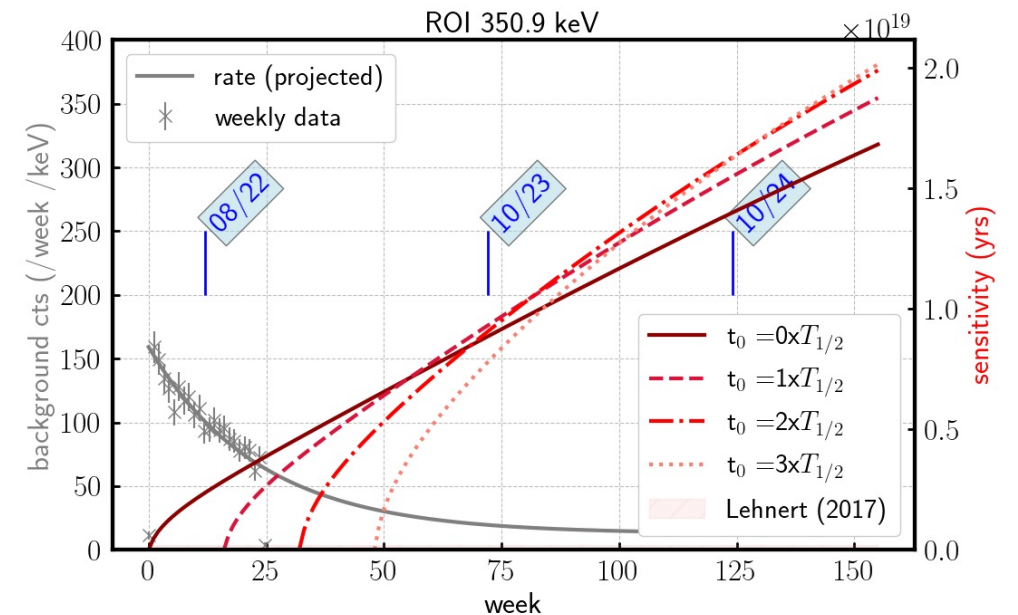


# Ta study – plans

- **Current data set (5 months)**
  - shows no hint of a Ta-decay
  - Covers already the predicted theory range (mid  $10^{18}$  yrs,  $1\sigma$ )
- A run until Oct 2024
  - Background improving ( $^{182}\text{Ta}$ -decay)
  - Allows study beyond the  $10^{19}$  yrs in different decay channels and improved DM searches
  - Additional studies of cosmogenic background in-situ



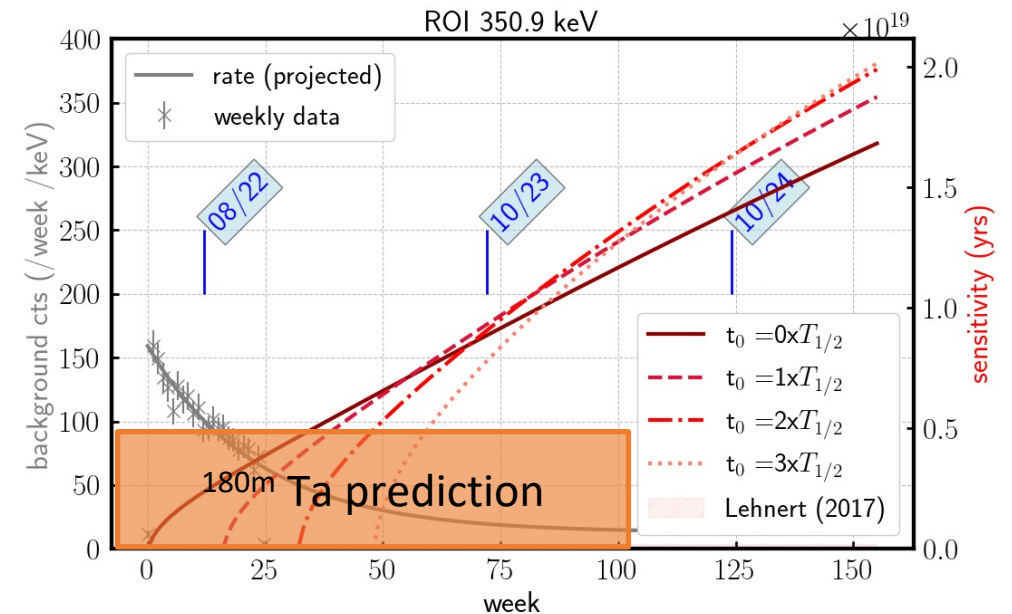
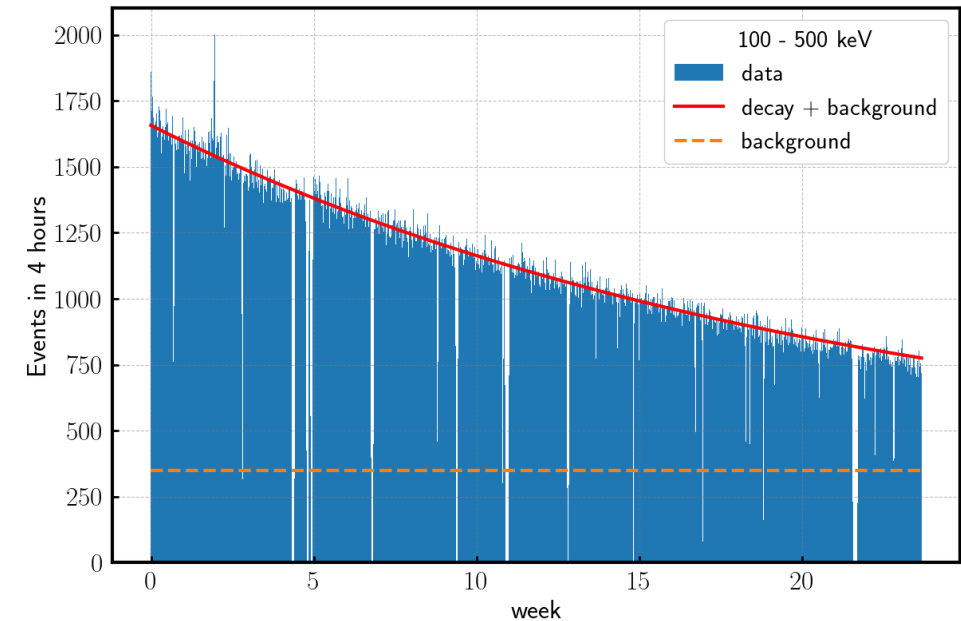
Energy spectrum after 14 weeks



Detection Sensitivity vs measurement time

# Ta study – plans

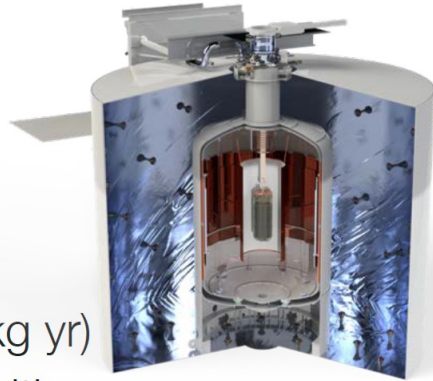
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# LEGEND a phased approach

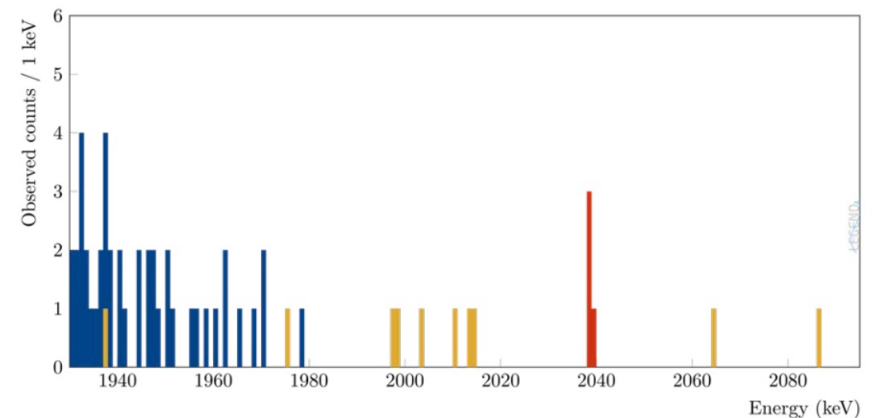
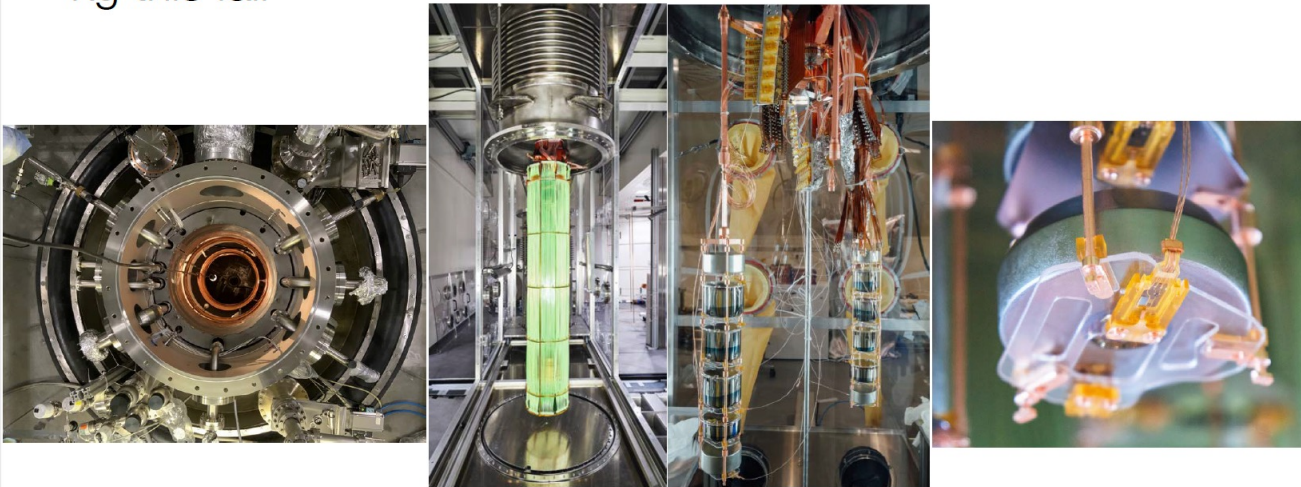
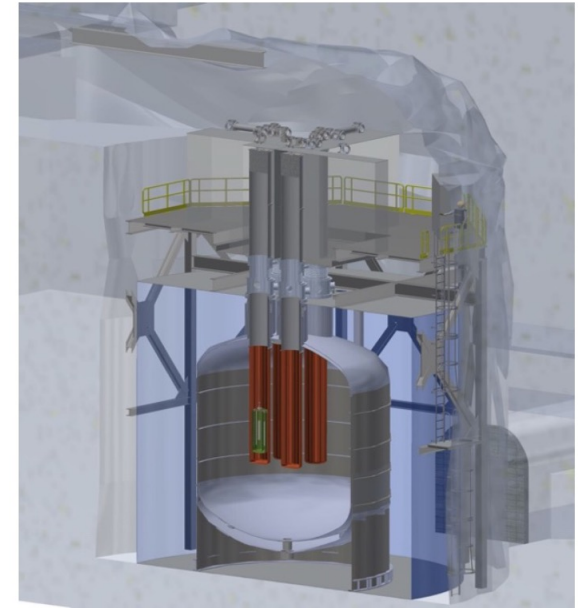
## LEGEND-200

- 200 kg  $^{76}\text{Ge}$  in upgrade of existing infrastructure at LNGS
- BG goal
  - < 0.6 cts/(FWHM t yr)
  - <  $2.5 \times 10^{-4}$  counts/(keV kg yr)
- Has been commissioning with 60 kg June - Oct.
- Initial physics running with 140 kg this fall



## LEGEND-1000

- 1000 kg  $^{76}\text{Ge}$  (staged)
- BG goal
  - < 0.025 cts/(FWHM t yr)
  - <  $1 \times 10^{-5}$  counts/(keV kg yr)
- Location: SNOLAB or LNGS
- Proceeding towards “CD-1”



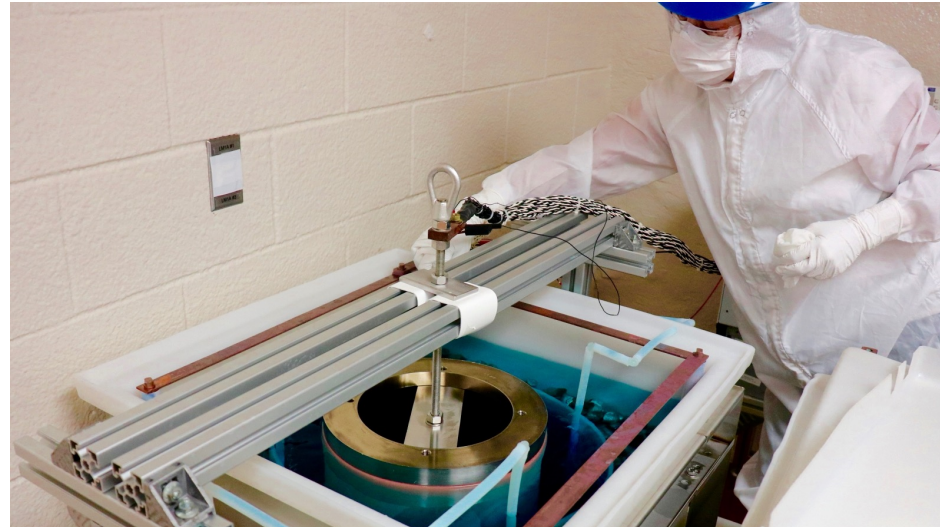


# LEGEND activities @SURF

## Support of the LEGEND program @ SURF

*unique expertise for clean materials*

- Electroforming
- Machining
- Clean Handling and Validation
- R&D for rolling and welding of cryostat Cu





# Summary

## **MAJORANA DEMONSTRATOR**

- Enriched detector taking ended
- Achieved best energy resolution and 2<sup>nd</sup> best background of all double-beta decay efforts
- Excluded neutrinoless double-beta decay in Ge with half-life less than  $8.3 \times 10^{25}$  yrs

## **Tantalum study**

- Makes use of the excellent conditions of the DEMONSTRATOR
- Most sensitive search for isomeric decay world-wide

## **LEGEND**

- Electroforming and Machining of clean copper parts
- Clean environment at SURF plays vital roles for LEGEND-1000 material handling and testing