

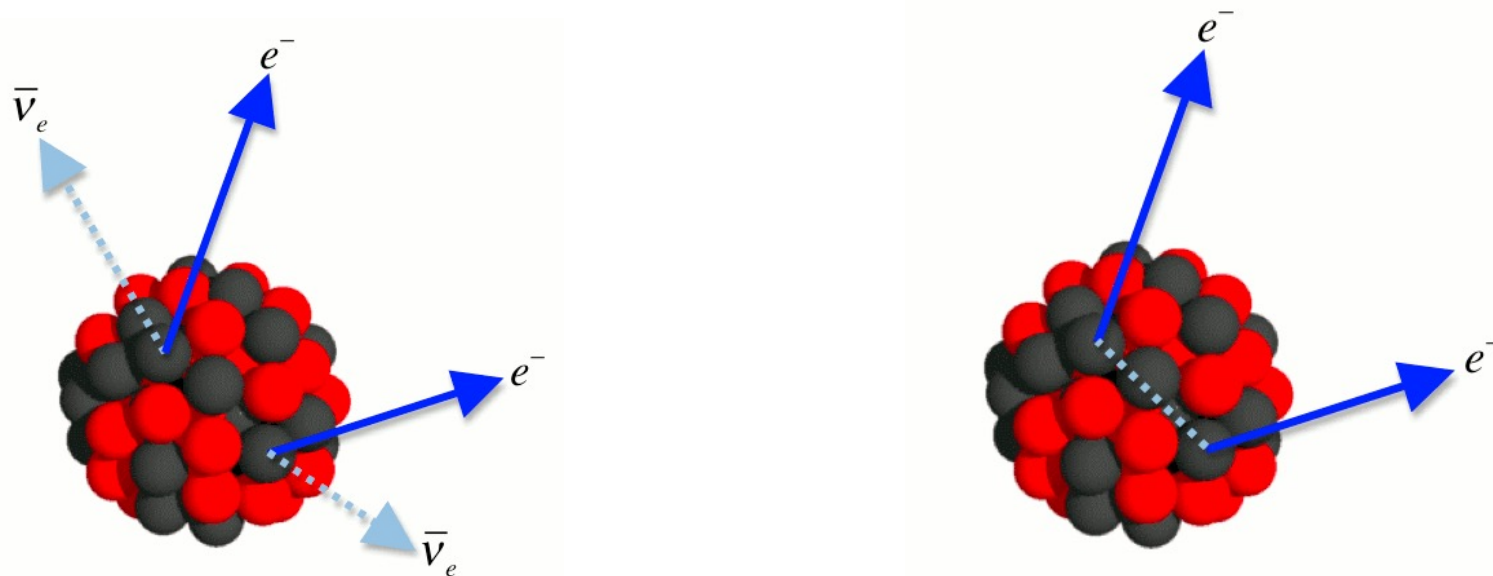
LEGEND-1000

Prof. David Waters
University College London



IoP APP, HEPP & NP Conference
10th April 2024

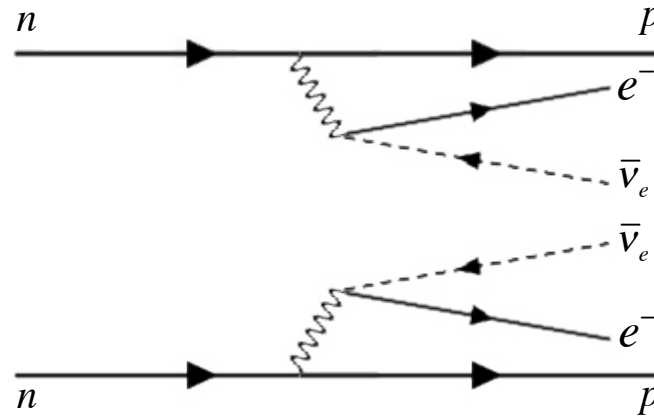
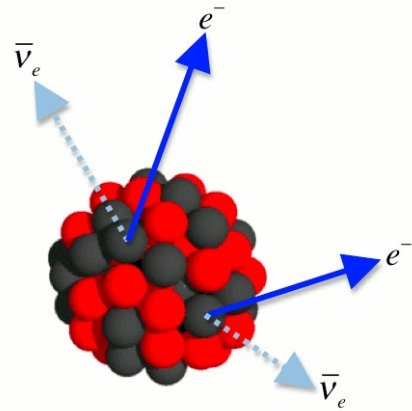
Get Well Soon Will Quinn!



Double-Beta Decay

2-Neutrino Double Beta Decay

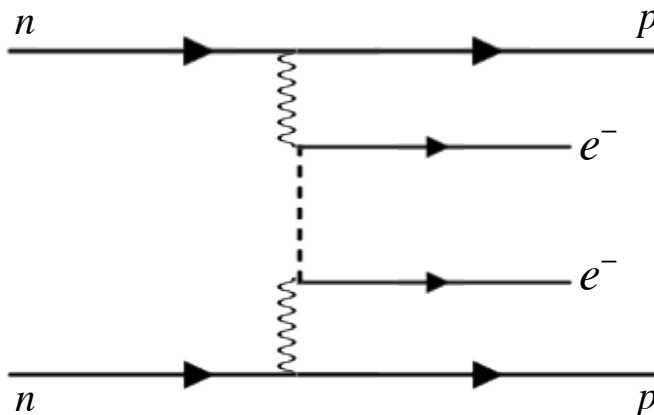
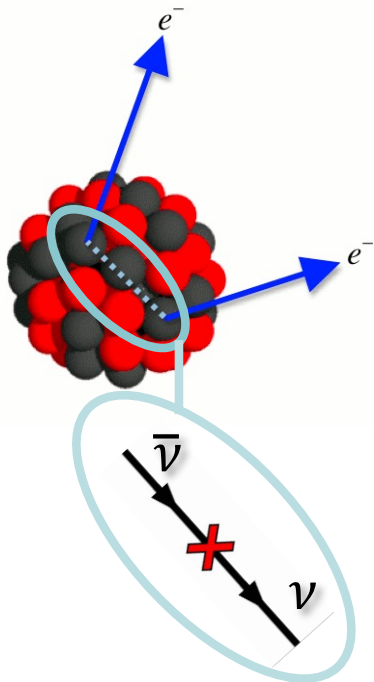
$$(A, Z) \rightarrow (A, Z + 2) + 2e^- + 2\bar{\nu}_e$$



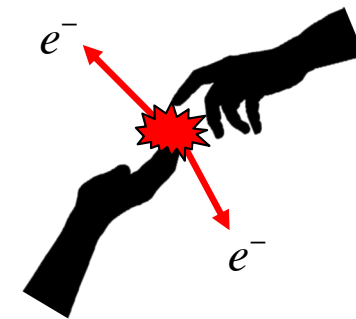
1935

0-Neutrino Double Beta Decay

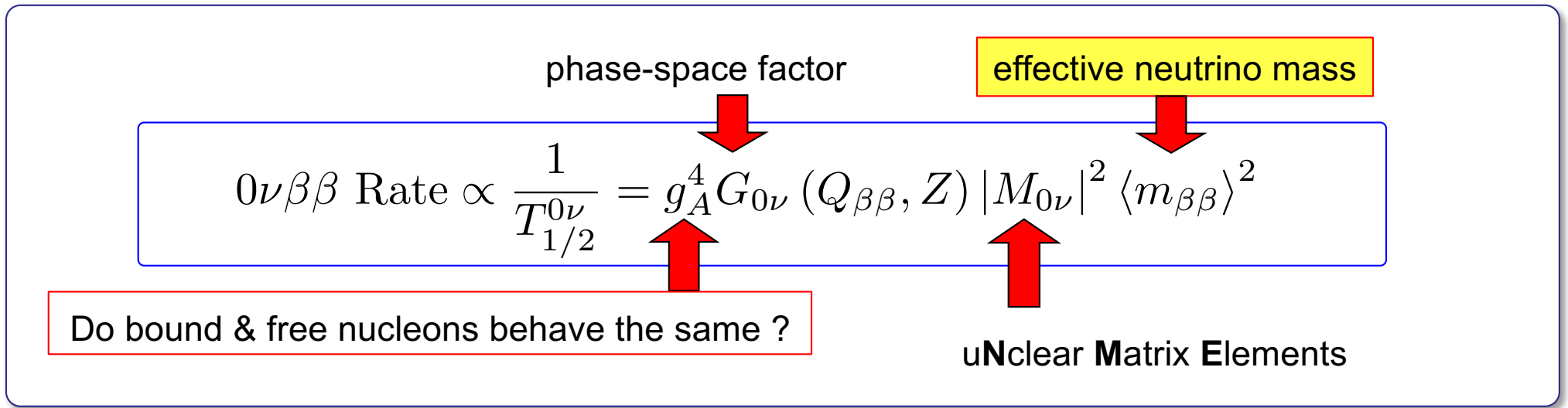
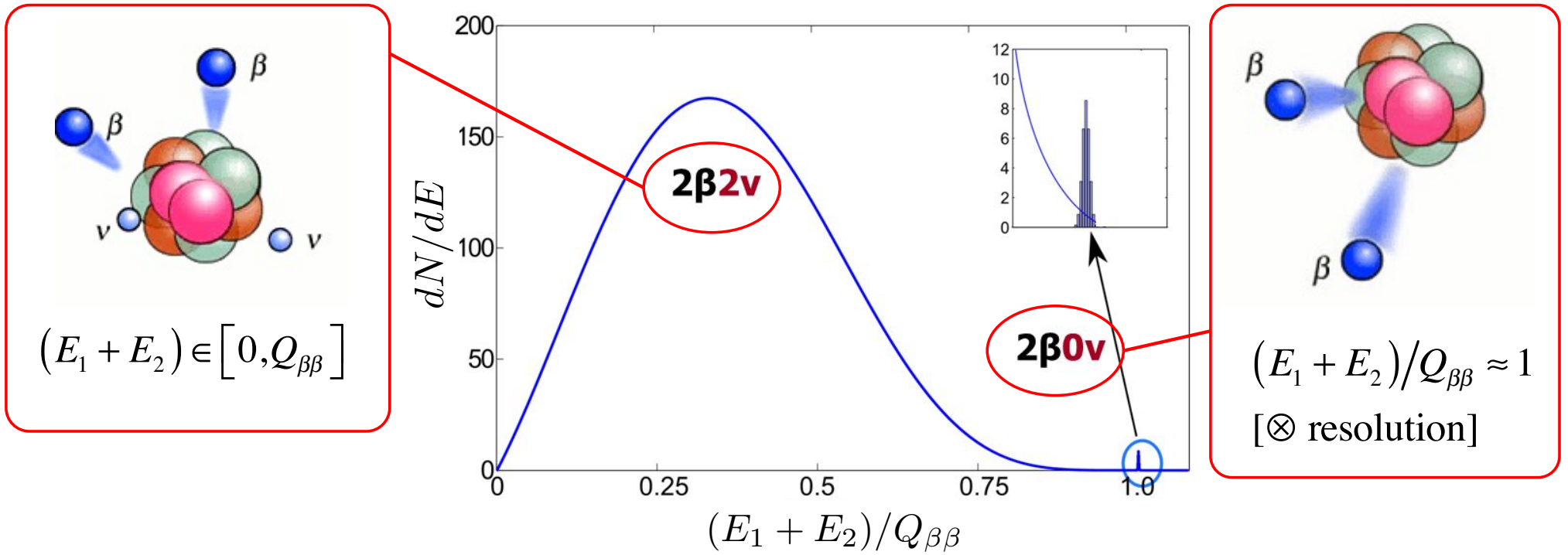
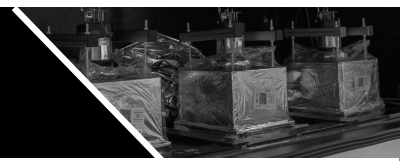
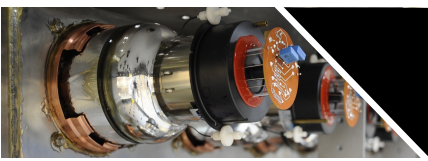
$$(A, Z) \rightarrow (A, Z + 2) + 2e^-$$



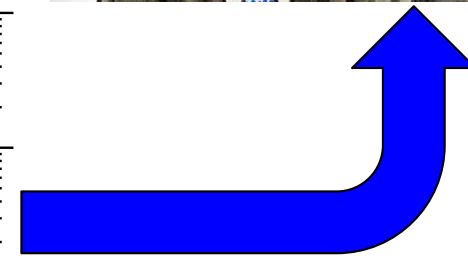
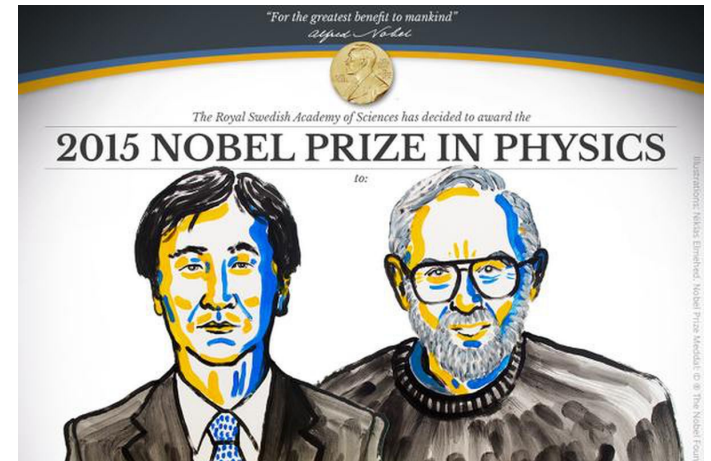
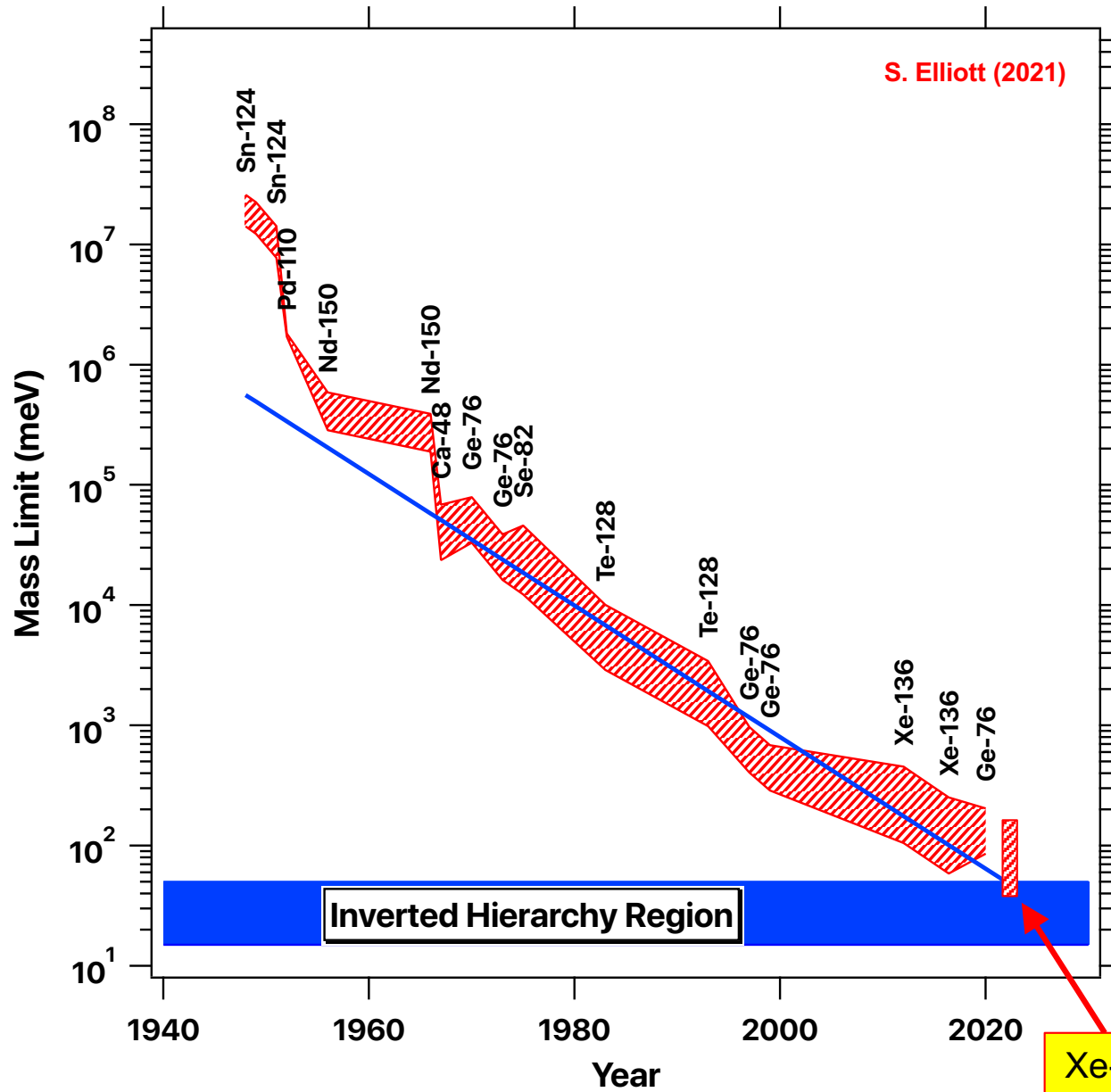
- Matter creation.
- Lepton number violation.



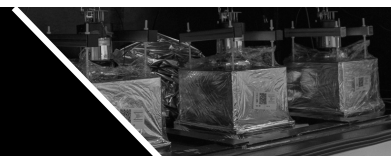
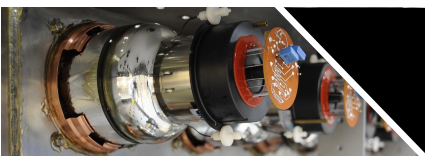
Basic Experimental Signature



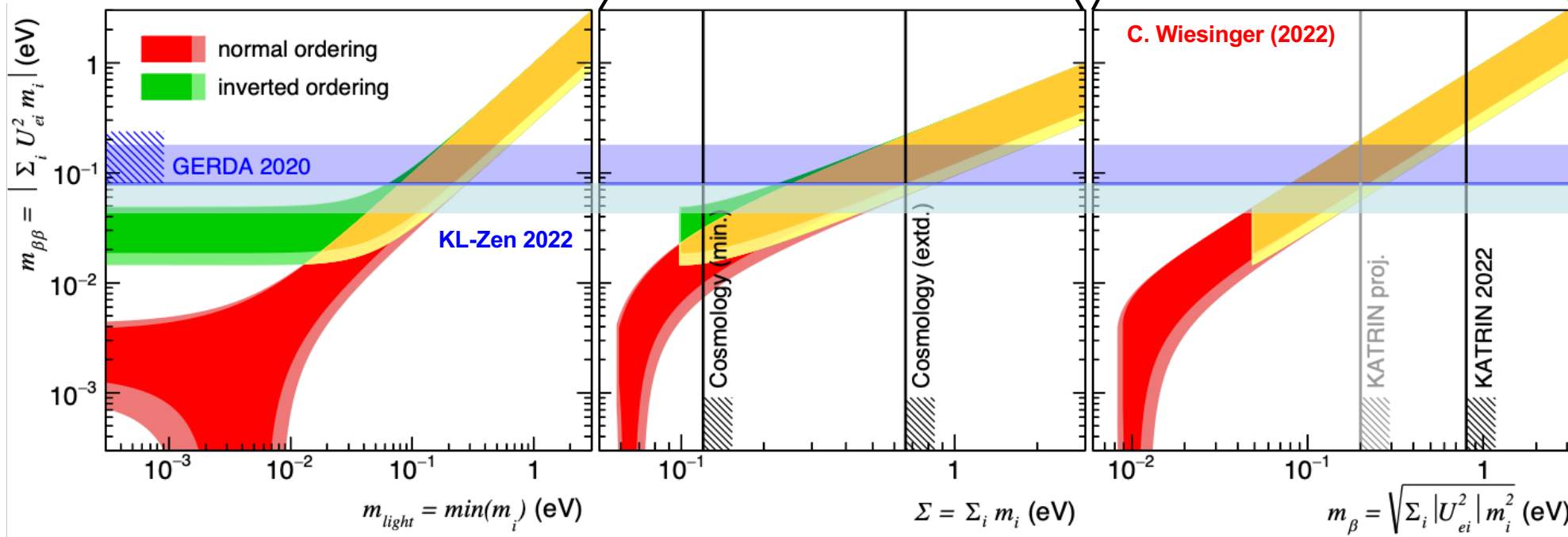
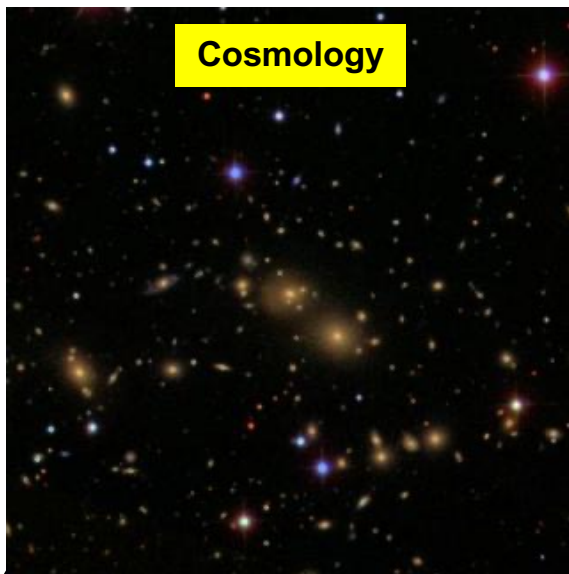
The Historical Record



What neutrino mass ?

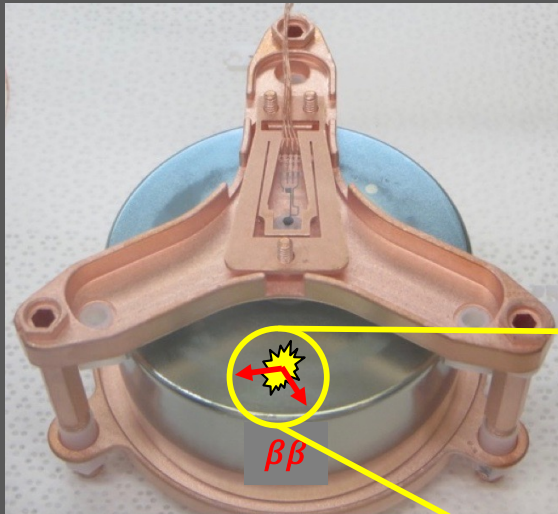


effective neutrino mass



Contrasting Techniques

Germanium



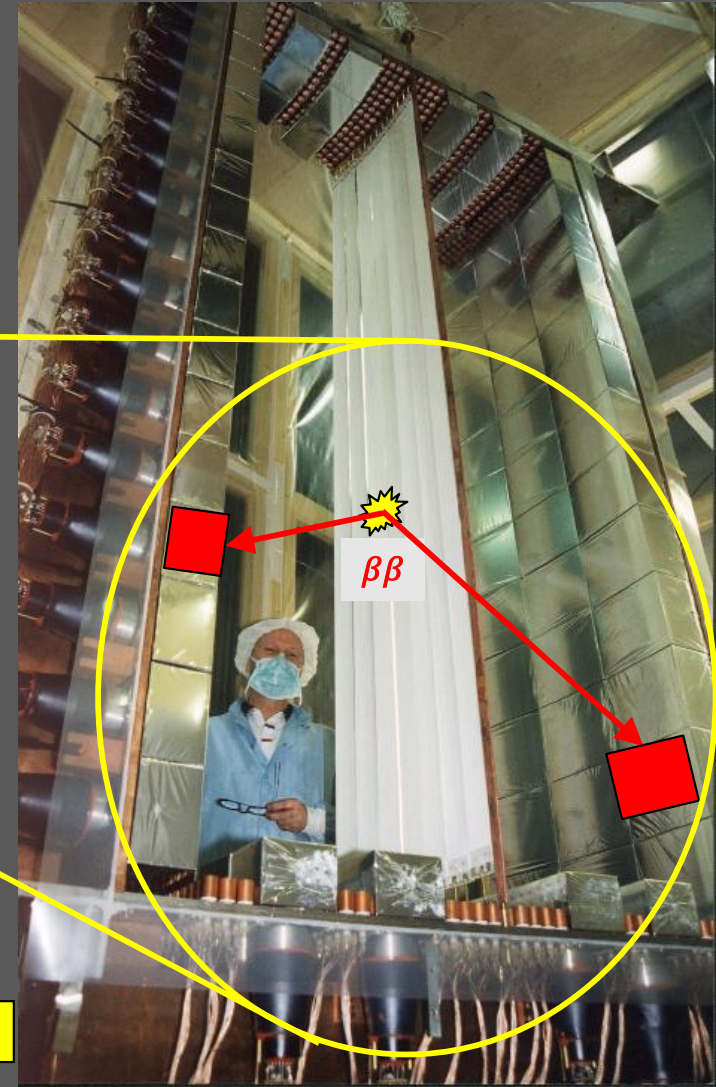
2 mm

- Best energy resolution (<0.1%)
- Lowest background index
- Powerful PSD
- Source = detector \rightarrow high efficiency

\rightarrow **Discovery instrument**

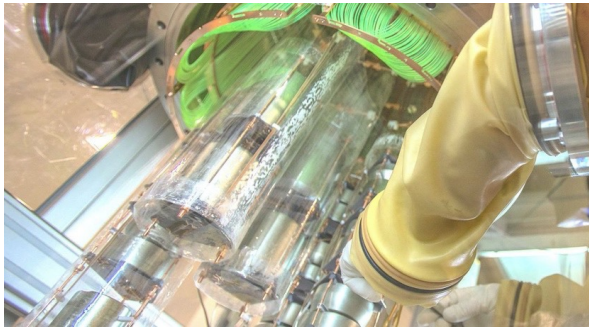
- Decay kinematics
 - Mechanism of decay
- \rightarrow **Discovery follow-up**

Imaging



2 m

Germanium $0\nu\beta\beta$ Experiments



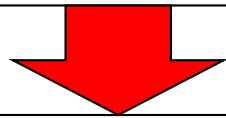
GERDA

- Bare HPGe detectors in liquid-argon.
- World leading limits.



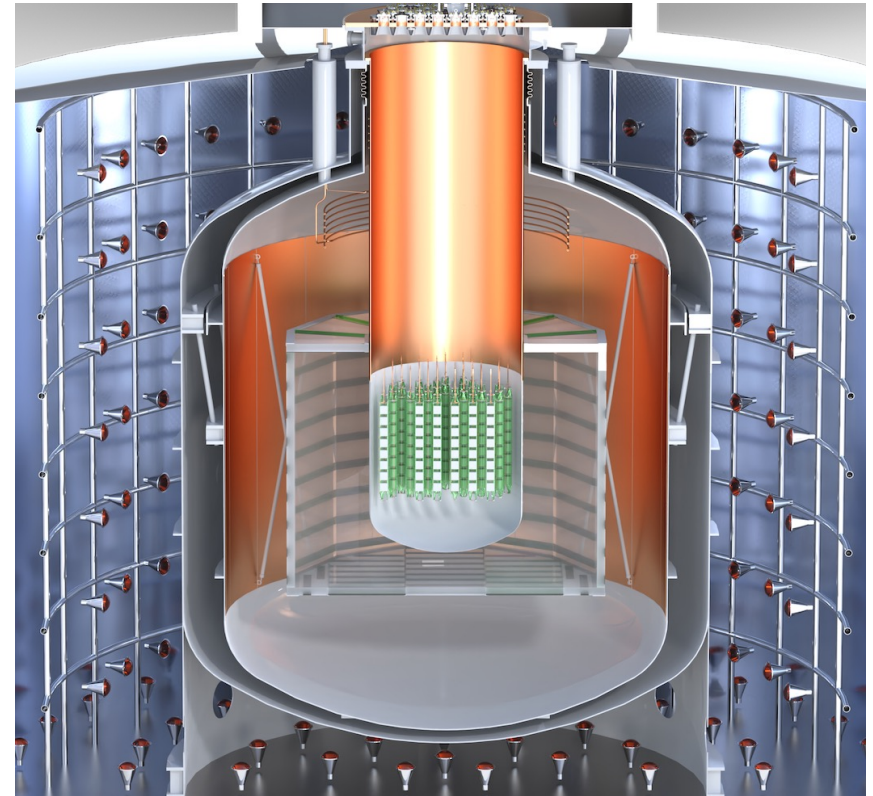
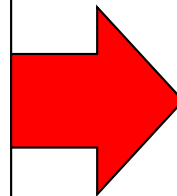
Majorana Demonstrator

- Point-contact detectors with advanced PSD.
- Radiopurity innovations.



LEGEND-200

- Operating now.
- George's Talk.

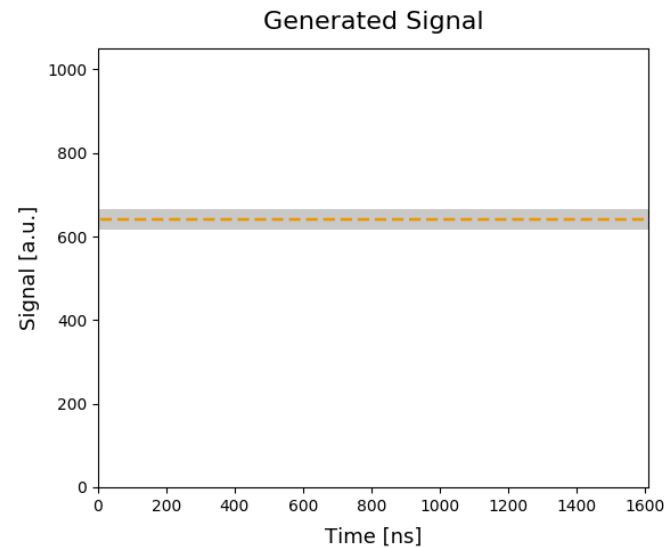
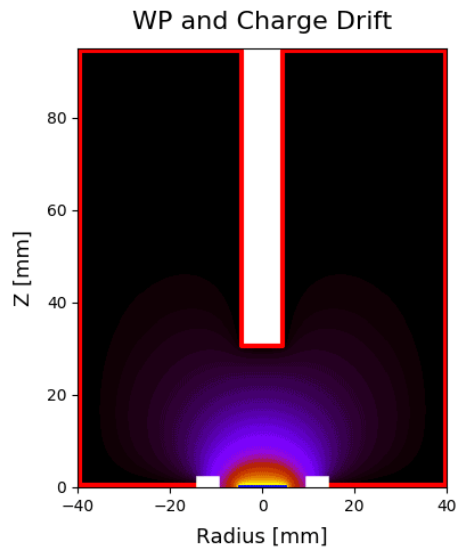
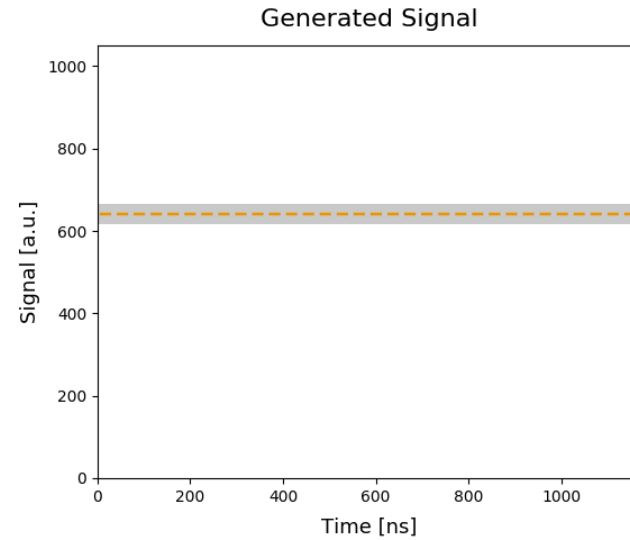
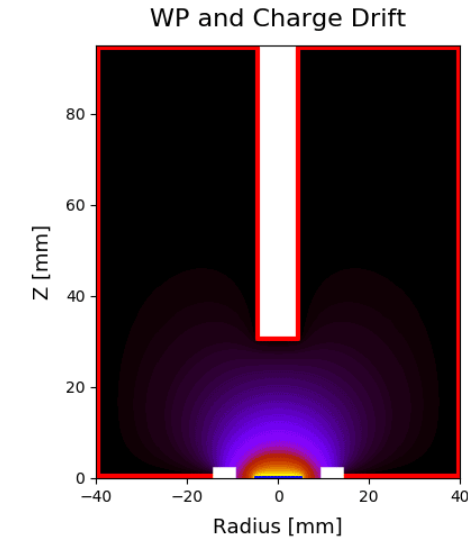


LEGEND-1000

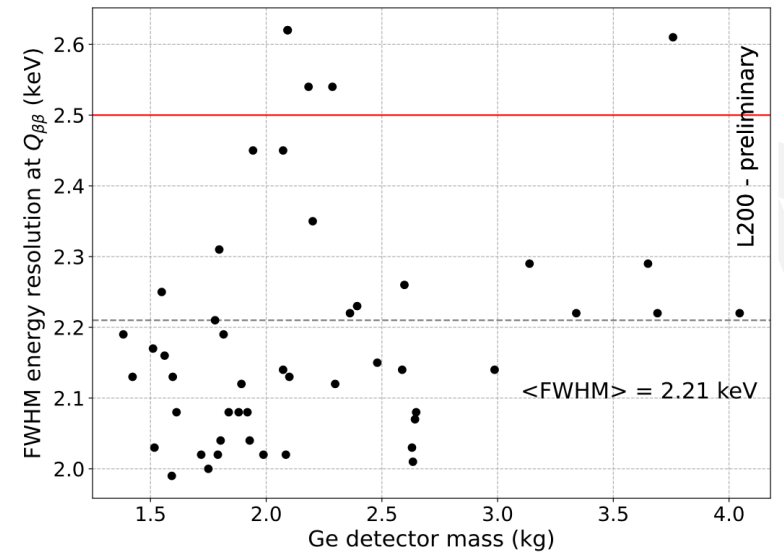
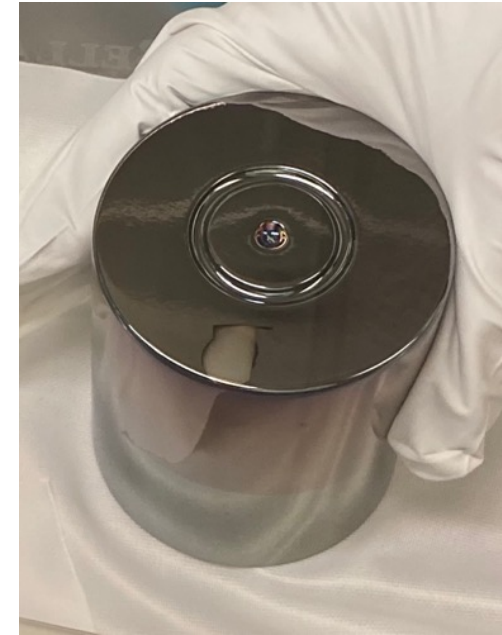
- Meets the DOE requirements for a next-generation $0\nu\beta\beta$ experiment.
- Uses technologies demonstrated in GERDA, MJD and LEGEND-200.
- Realistic performance improvements over LEGEND-200.

Germanium Detector Technology

“Solid-State TPCs”

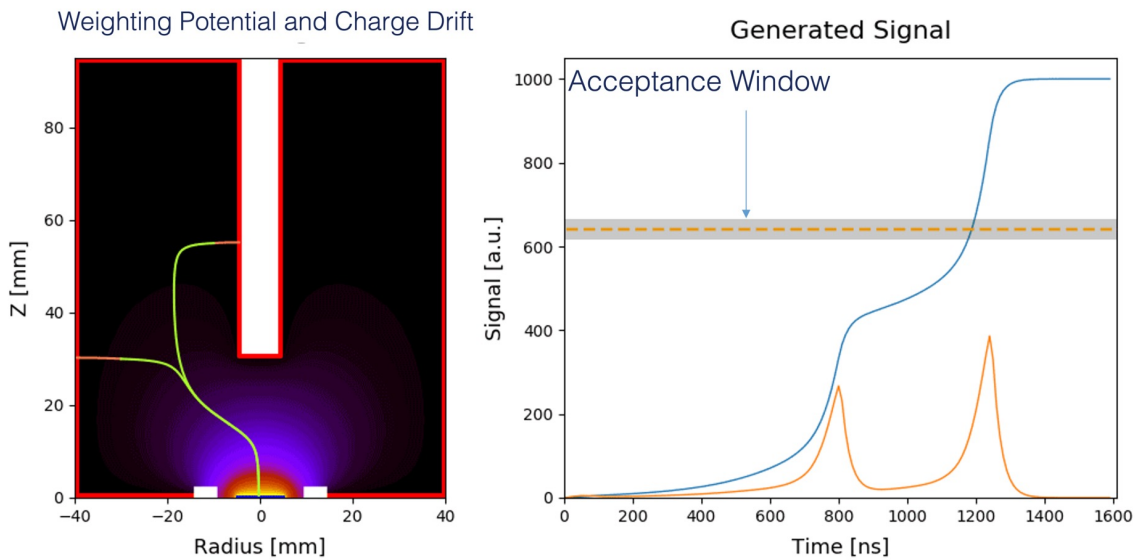
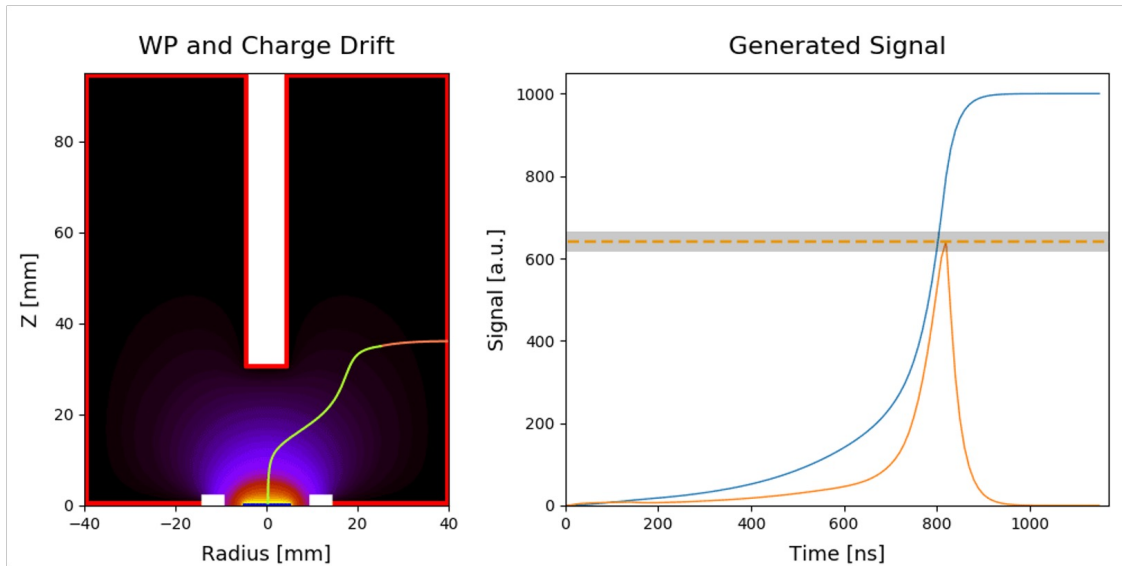


Performance of High Mass Detectors

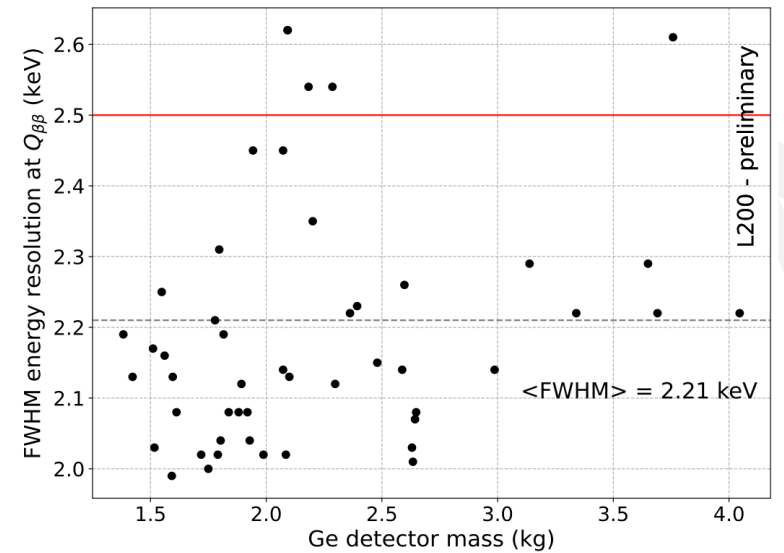
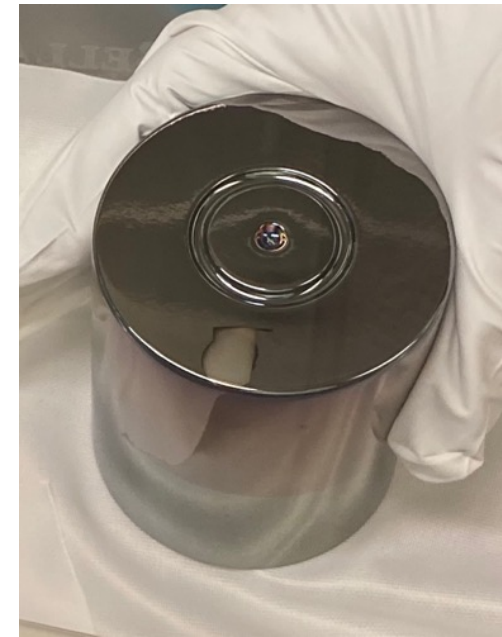


Germanium Detector Technology

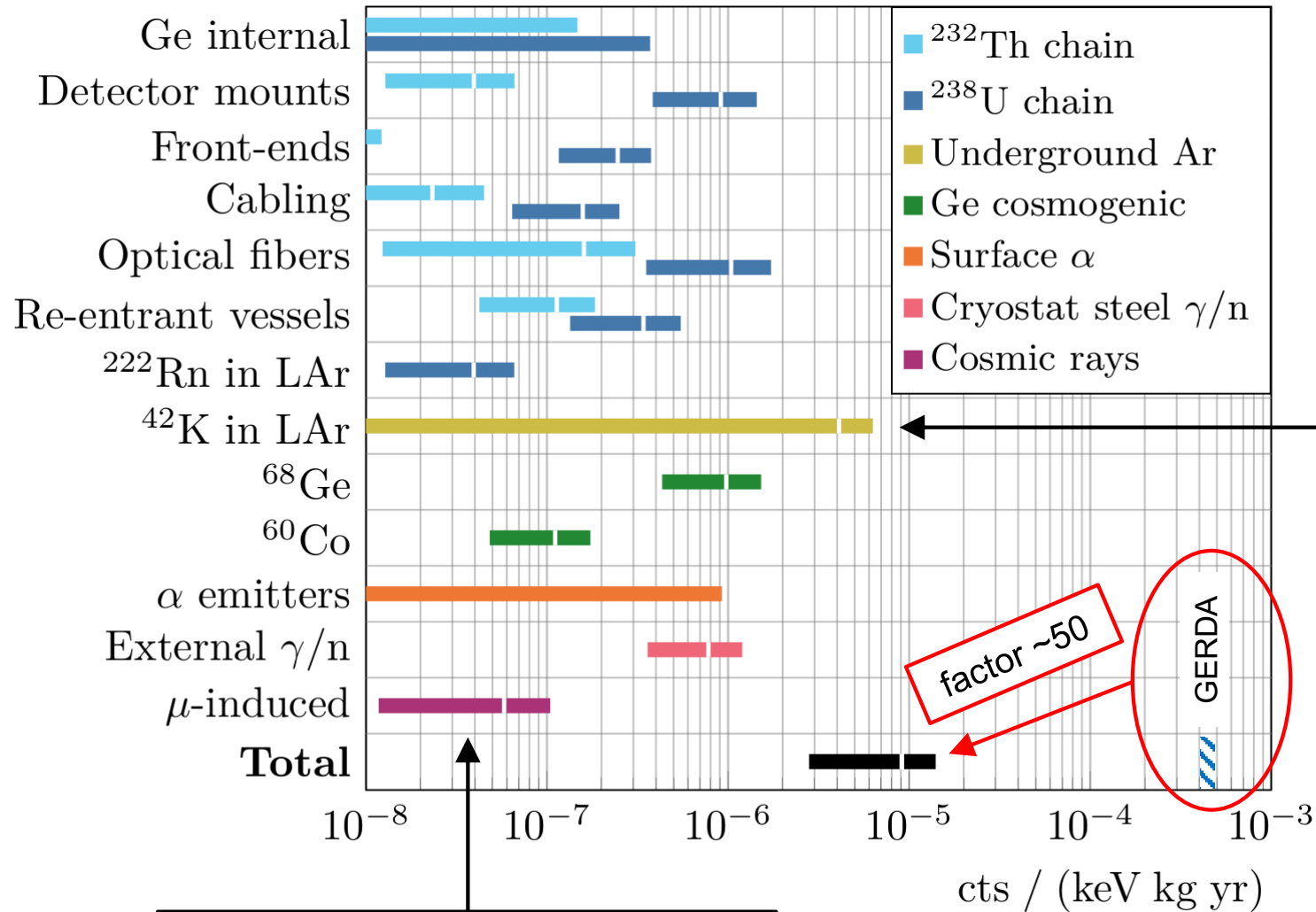
“Solid-State TPCs”



Performance of High
Mass Detectors



Background Requirements



Use of underground argon

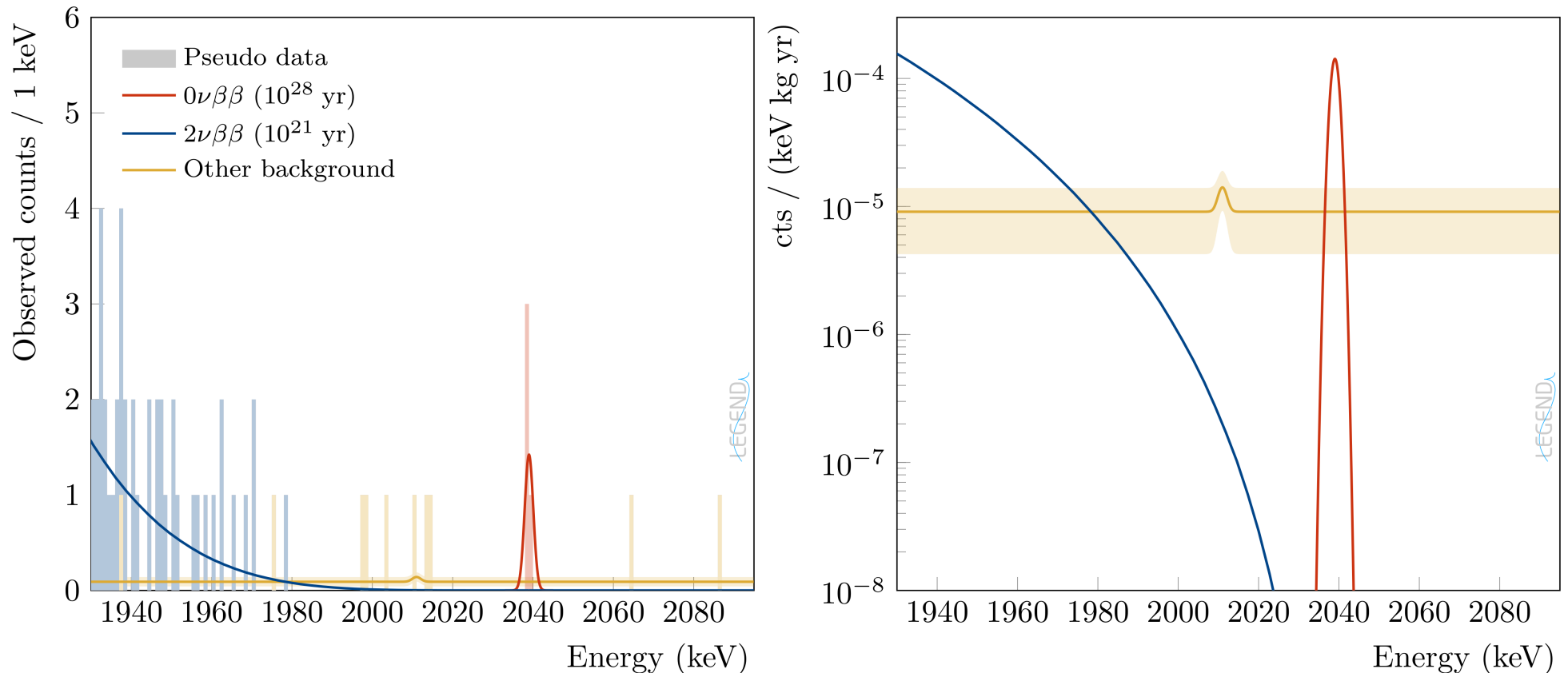
factor ~50

LNGS "virtual depth" is sufficient with smart topology-based cosmic veto.

What Does a Discovery Look Like?

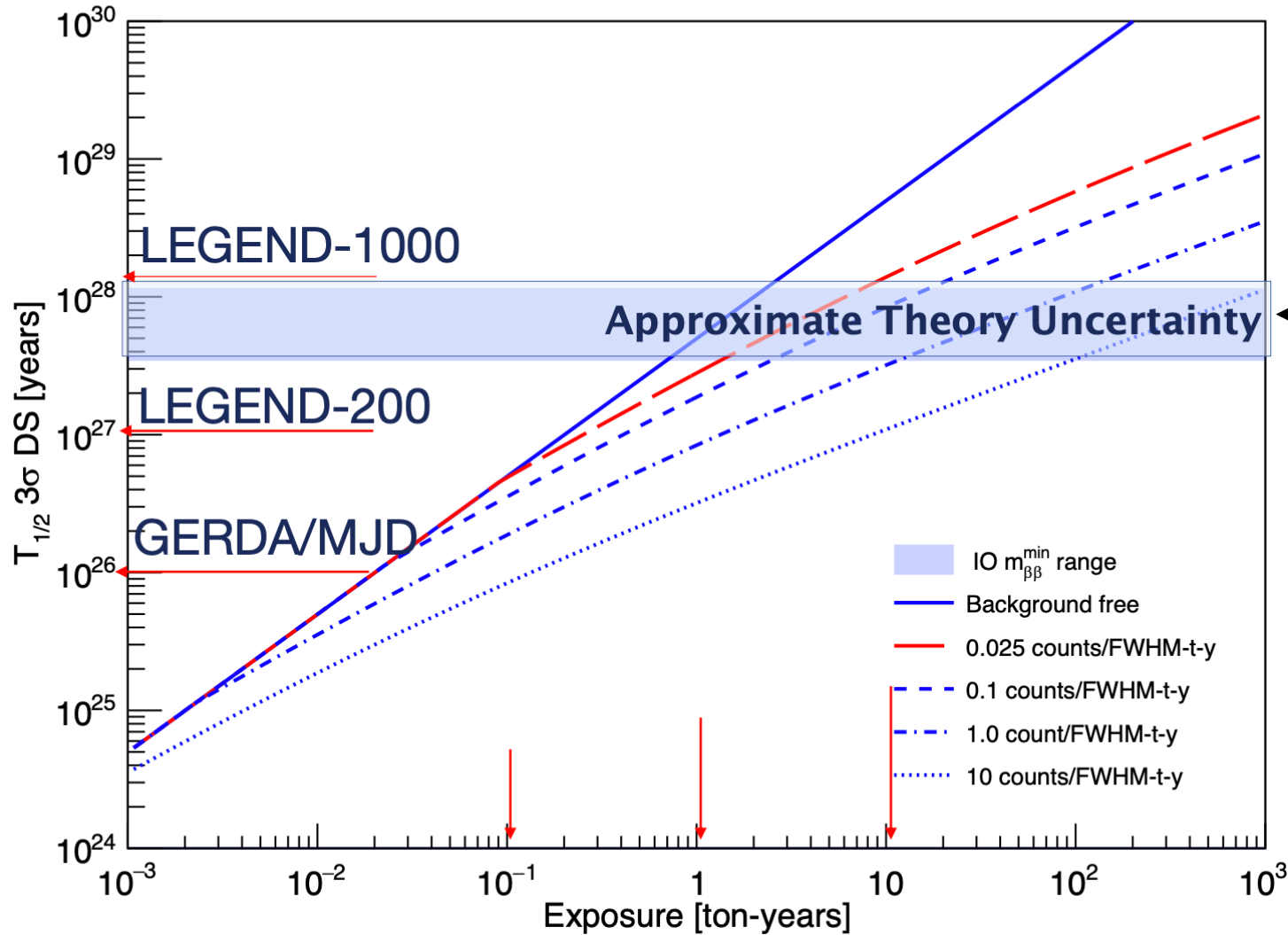
- Our resolution requirements (achieved) and background requirements (projected) will give a clear signal at the limit of our discovery sensitivity.
- For full LEGEND-1000 exposure (10 ton years):

$$\langle N_{0\nu\beta\beta} \rangle = 3.6 \quad \text{for } T_{1/2} = 10^{28} \text{ yr}$$



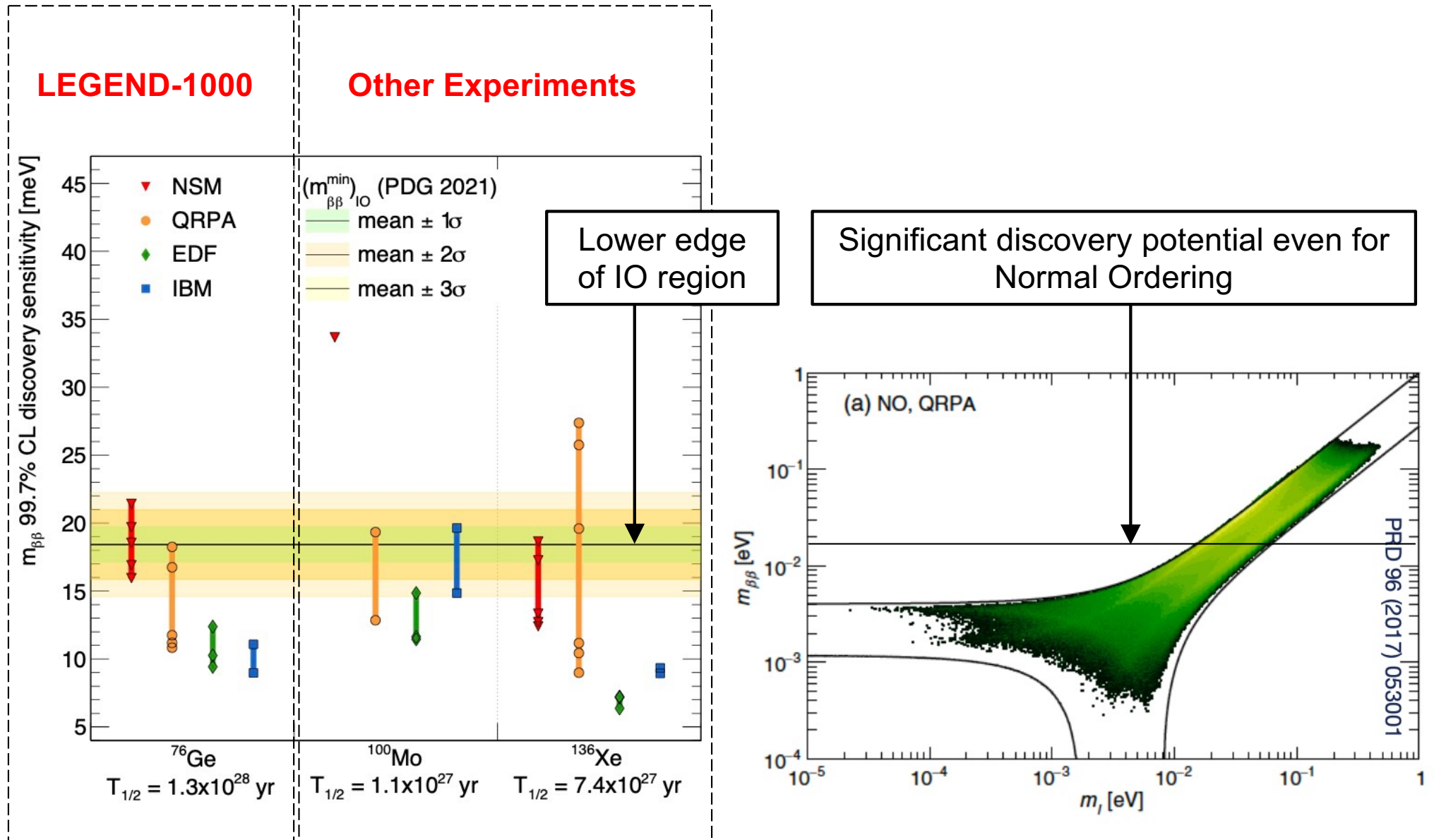
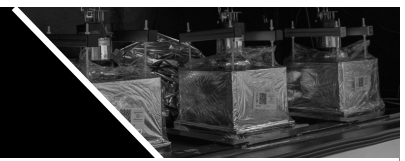
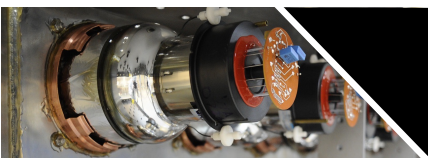
Sensitivity Projections

^{76}Ge (92% enr.)



Almost all NMEs at the bottom of the IO regime

Sensitivity Projections



LEGEND Collaboration



STFC Daresbury
Lab, Lancaster,
Liverpool, UCL,
Warwick

Leadership
includes IB Chairs,
Analysis Lead,
L2/3 Project
Leads.

Development/Construction of LEGEND-200
and Preparation of LEGEND-1000 pCDR

2021

- DoE $0\nu\beta\beta$ Portfolio Review
- North-America/Europe Workshop on $0\nu\beta\beta$.

2022-

- LEGEND-200
commissioning
and operations

2020

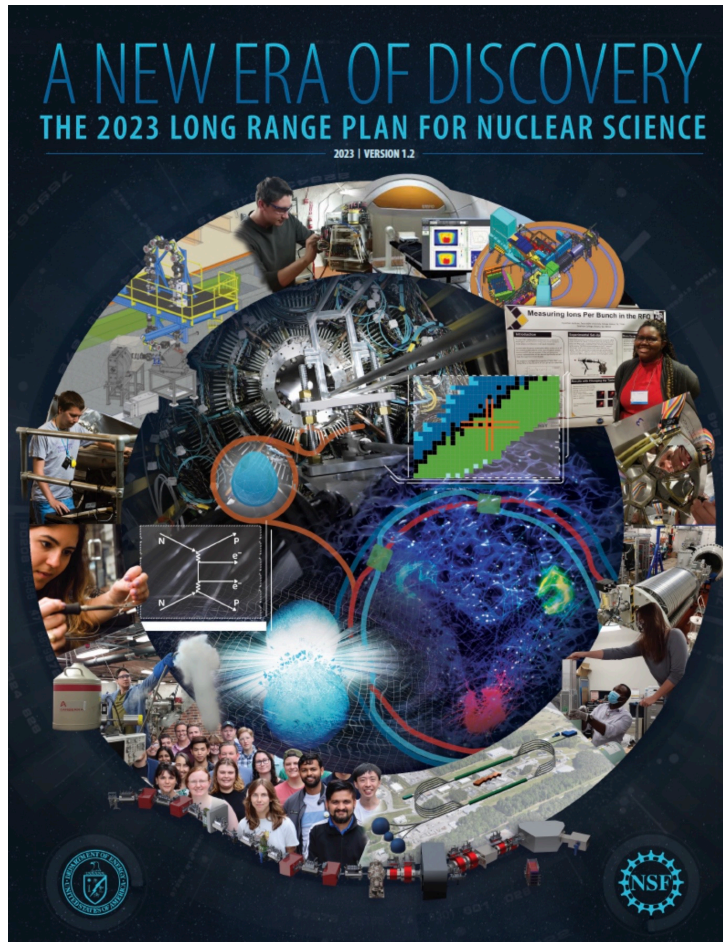
- STFC Opportunities Funding
- UK LEGEND Workshop in
March 2022.



2016

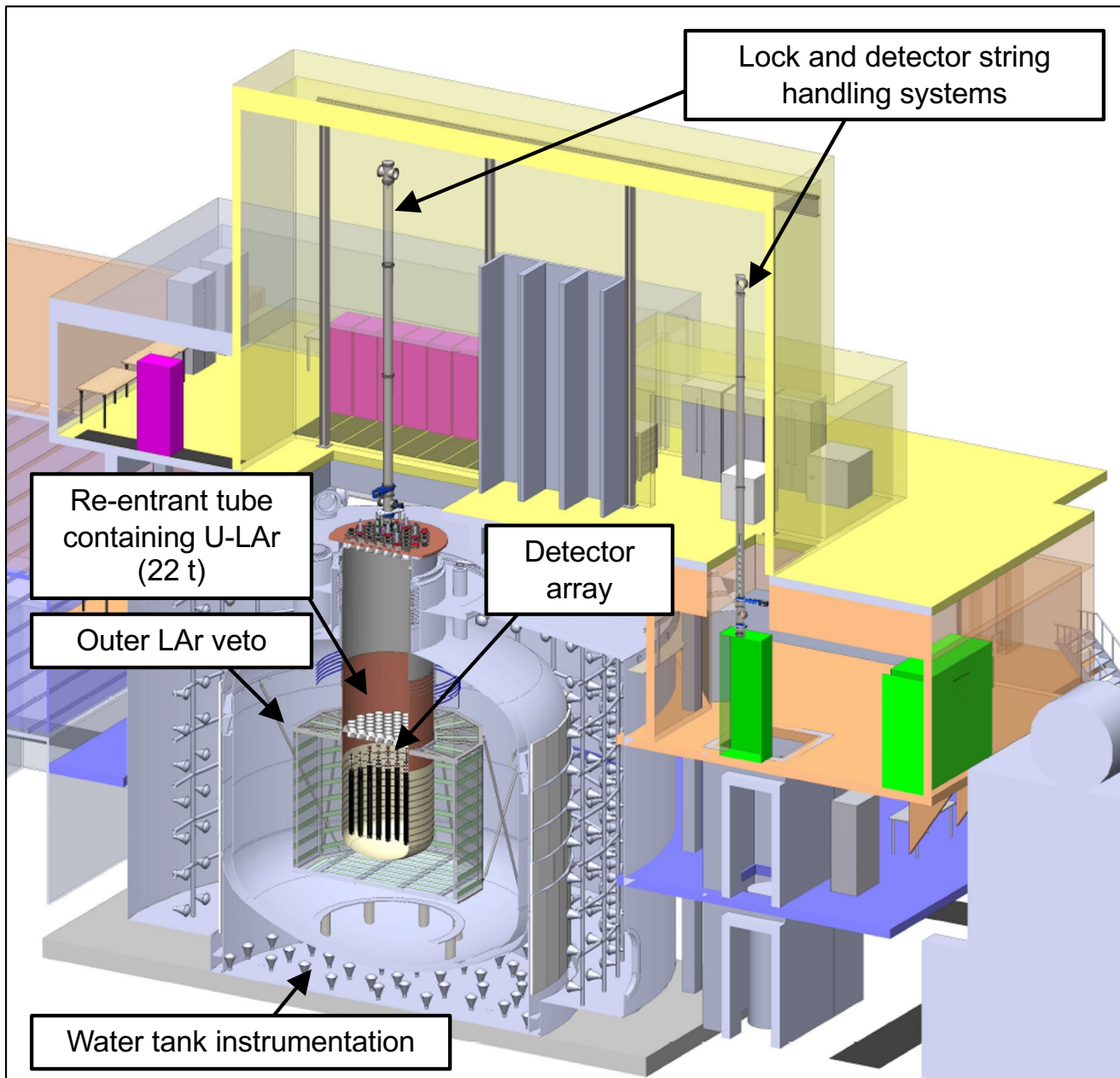
- LEGEND collaboration forms.
- UK groups are amongst the founding members.

LEGEND Collaboration



- Next-generation (“tonne-scale”) $0\nu\beta\beta$ experiments, and specifically LEGEND, are highlighted as top priorities for investment in the US and Europe.
- LEGEND-1000 emerged from the US portfolio review as the leading $0\nu\beta\beta$ experiment for funding agency support.

Site and Conceptual Design



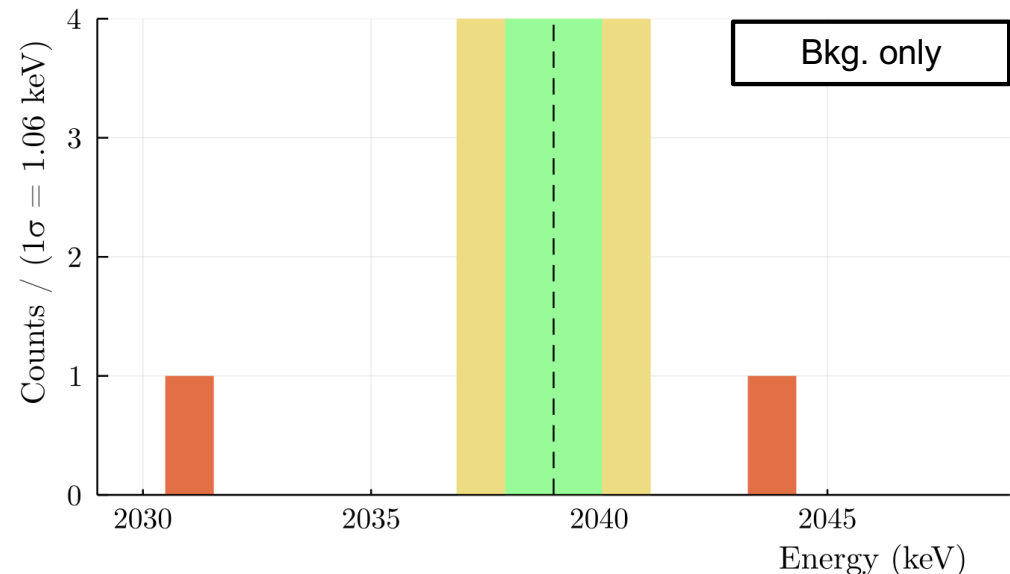
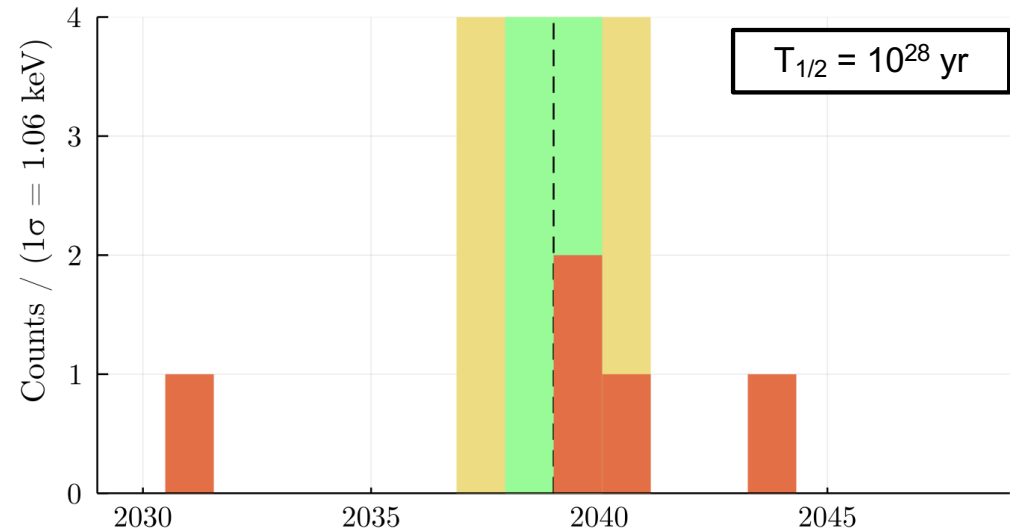
- LNGS, SNOLab, SURF and Boulby were all considered during the site selection process.
- LNGS (Hall-C) is the baseline site. Conceptual designs are well advanced.
- NSF MRI-2 and DOE CD-1 processes this year.
- Strong UK contributions include:
 - HPGe detector development and characterization.
 - Software & analysis.
 - Radiopurity & novel materials.
 - LAr handling systems design (STFC Daresbury)

Summary

- A $0\nu\beta\beta$ experiment sensitive to **10-20 meV** Majorana neutrinos is scientifically compelling.
- **HP⁷⁶Ge** detectors – designed and used for nuclear spectroscopy – are almost ideal for this purpose.
- We are **ready to build** LEGEND-1000 and it is the leading tonne-scale project in the US and Europe.
- The UK plays a key role and LEGEND-1000 is the community agreed **highest-priority $0\nu\beta\beta$ construction project**.



A discovery class instrument :



PSD and LAr Veto Complementarity

