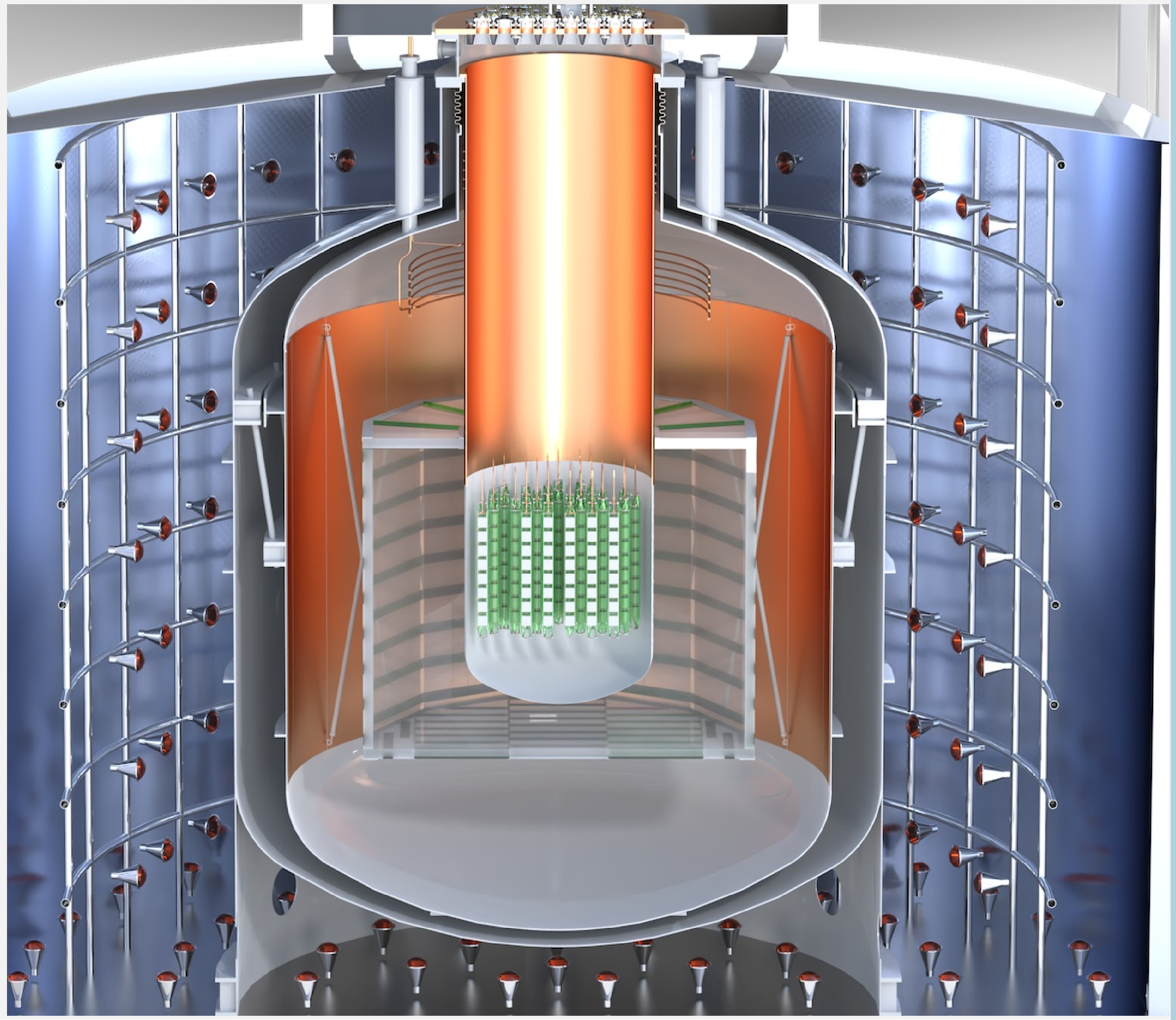
LEGEND-1000 Forschungsinfrastruktur

Large Enriched Germanium Experiment for Neutrinoless ββ Decay



Bernhard Schwingenheuer
Max Planck Institute for Nuclear Physics, Heidelberg

KAT strategy meeting, Karlsruhe
16-19 October, 2024

Why looking for neutrinoless double beta decay?

- I consider it a safe bet that neutrinos are Majorana particles
  → best way to test conjecture is to search for neutrinoless double beta decay, $\Delta L=2$

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  - neutrino has no charge that allows to discriminate particle from antiparticle

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LEGEND

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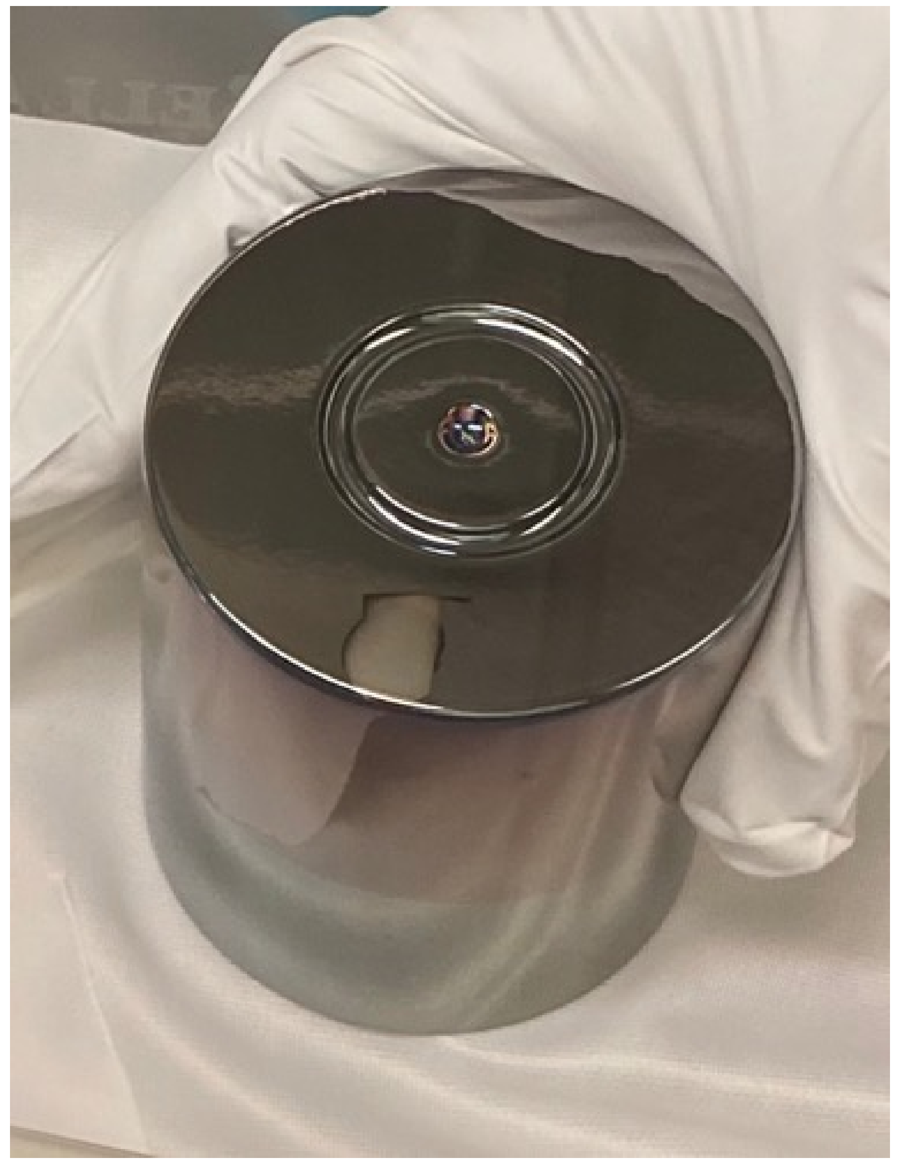
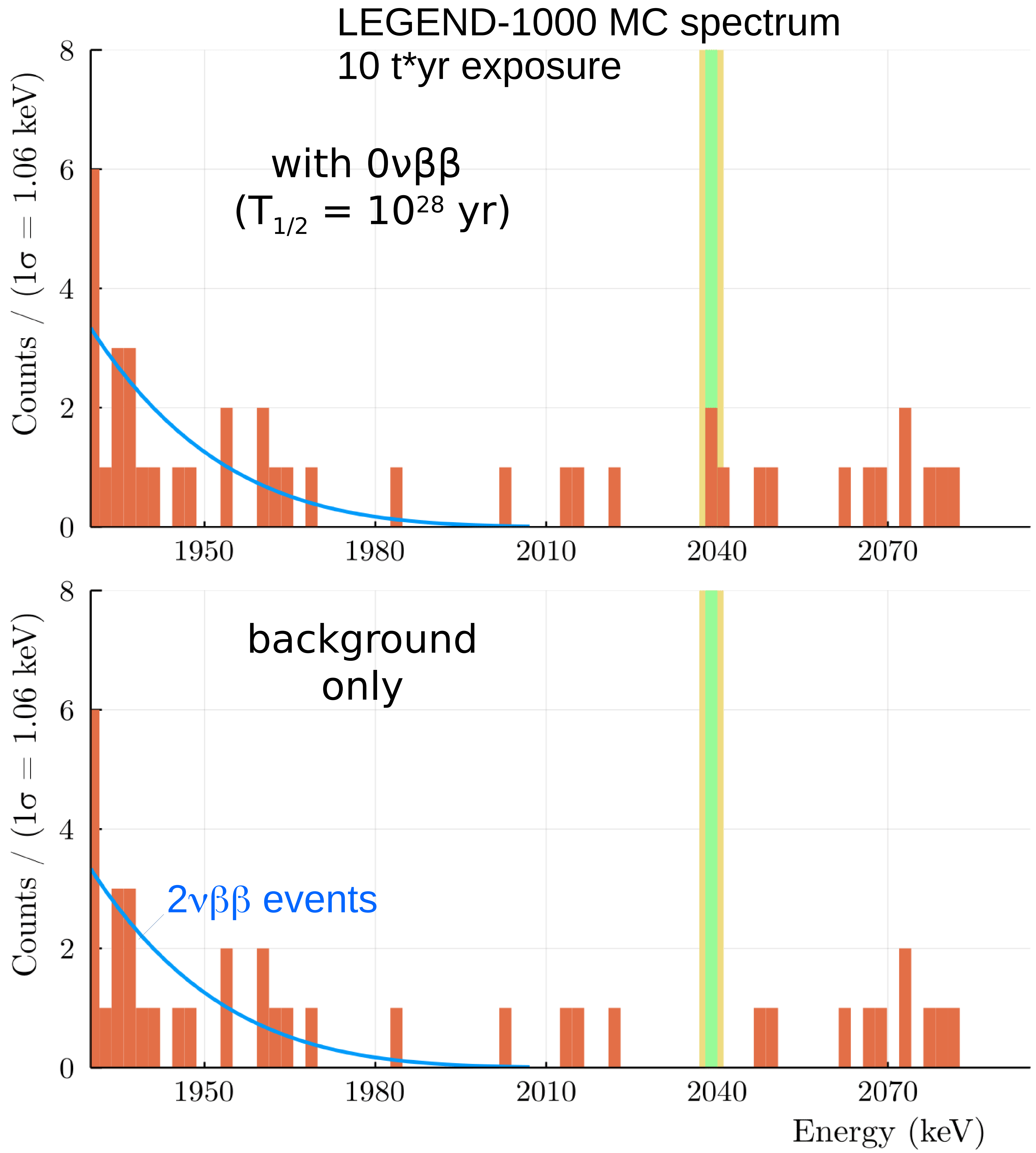
  - "most" extensions of Standard Model predict Majorana
  - neutrino mass tiny, dim 5 operator & seesaw mechanism explain the light mass

Why germanium-76?

- $^{Z}A \rightarrow {}^{Z+2}A + 2e$ → sum of electron energies = Q value of decay
  → Ge detectors have best E resolution





- sensitivity ~ Mass * time if "background-free"
  LEGEND-1000 is background-free (like GERDA) beyond 10 t*yr exposure
- concept "germanium detectors in liquid argon" pioneered by GERDA (idea of Gerd Heusser)

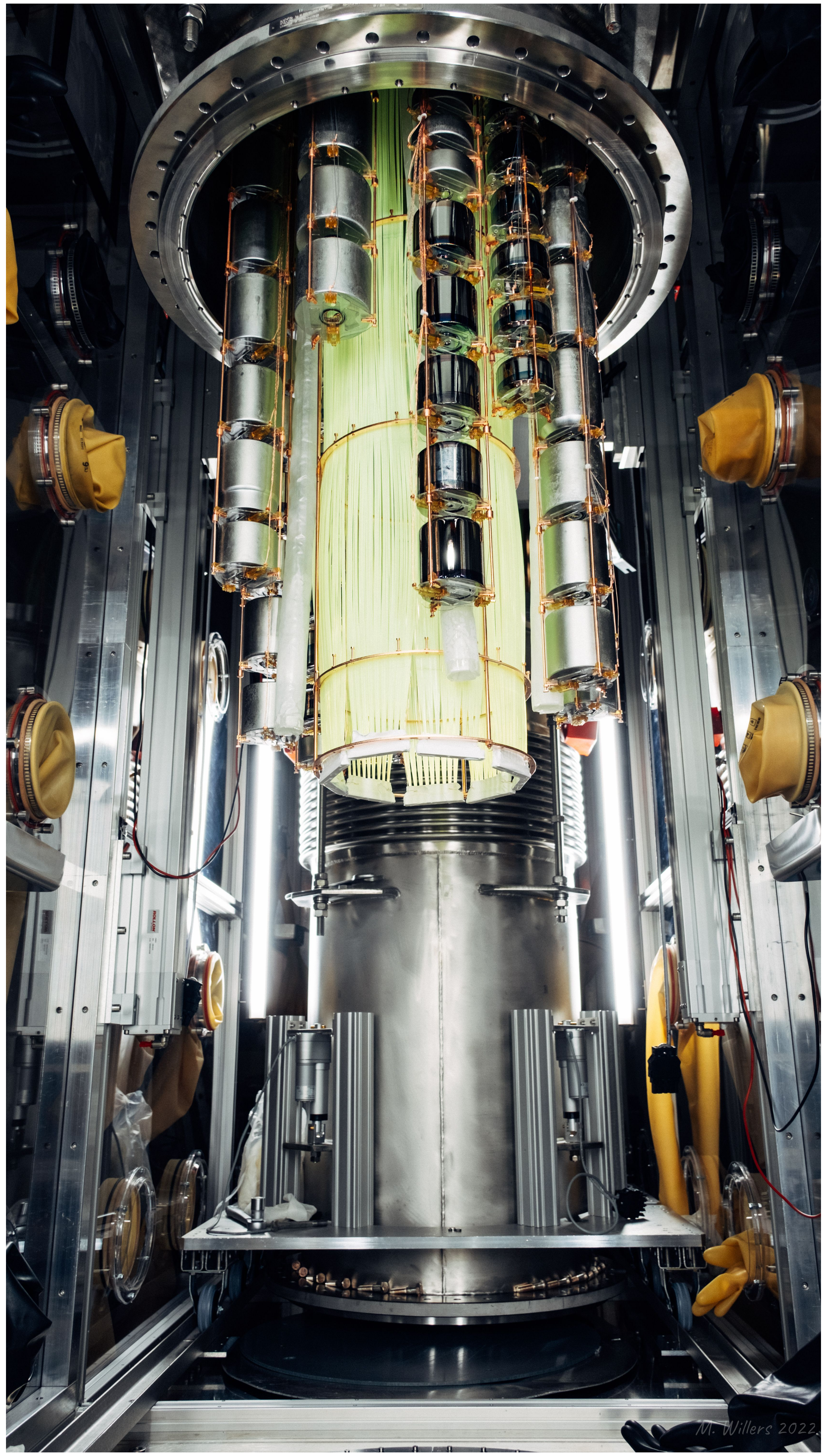
LEGEND collaboration

formed in 2016 by merger of GERDA + Majorana Demonstrator + others, 280 members

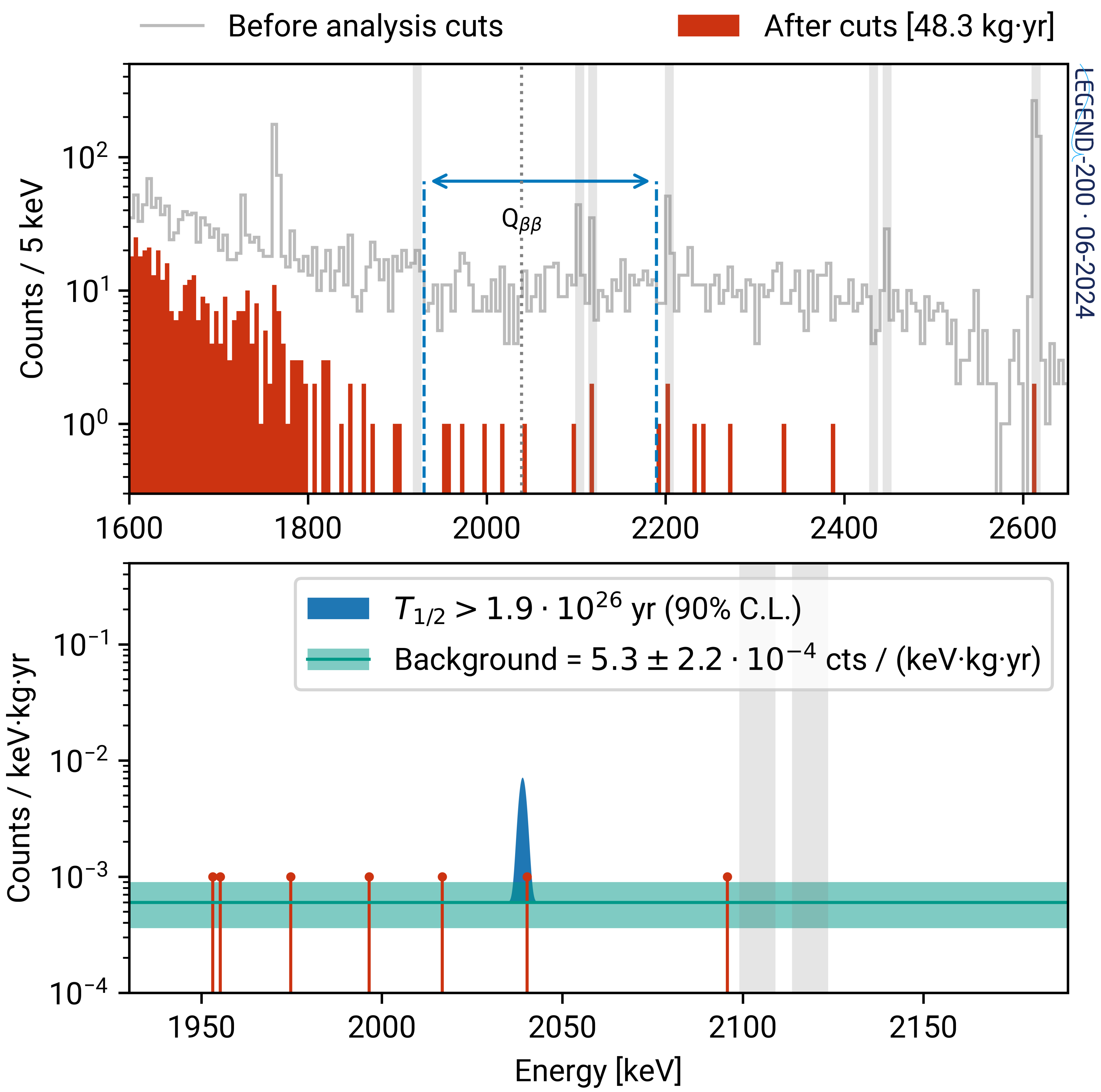
Comenius Univ.
Czech Tech. Univ. Prague and IEAP
Daresbury Lab.
Duke Univ. and TUNL
Gran Sasso Science Inst.
Indiana Univ. Bloomington
Inst. for Nucl. Res. Rus. Acad. Sci.
Jagiellonian Univ.
Joint Inst. for Nucl. Res.
Joint Res. Centre Geel
Lab. Naz. Gran Sasso
Lancaster Univ.
Leibniz Inst. for Crystal Growth
Leibniz Inst. for Polymer Research
Los Alamos Natl. Lab.
Max Planck Inst. for Nucl. Phy.
Max Planck Inst. for Physics
Natl. Res. Center Kurchatov Inst.
Natl. Res. Nucl. Univ. MEPhI
North Carolina State Univ.
Oak Ridge Natl. Lab.
Polytech. Univ. of Milan
Queen's Univ.
Roma Tre Univ. and INFN
Simon Fraser Univ.
SNOLAB
South Dakota Mines
Tech. Univ. Dresden
Tech. Univ. Munich
Tennessee Tech. Univ.
Univ. of California and LBNL
Univ. College London
Univ. of L'Aquila and INFN
Univ. of Liverpool
Univ. of Milan and INFN
Univ. of Milano Bicocca and INFN
Univ. of New Mexico
Univ. of North Carolina at Chapel Hill
Univ. of Padova and INFN
Univ. of Regina
Univ. of South Carolina
Univ. of South Dakota
Univ. of Tennessee Knoxville
Univ. of Texas at Austin
Univ. of Tuebingen
Univ. of Warwick
Univ. of Washington and CENPA
Univ. of Zuerich
Williams College

cooperation Hochschule Karlsruhe
more on LEGEND-1000

LEGEND-200



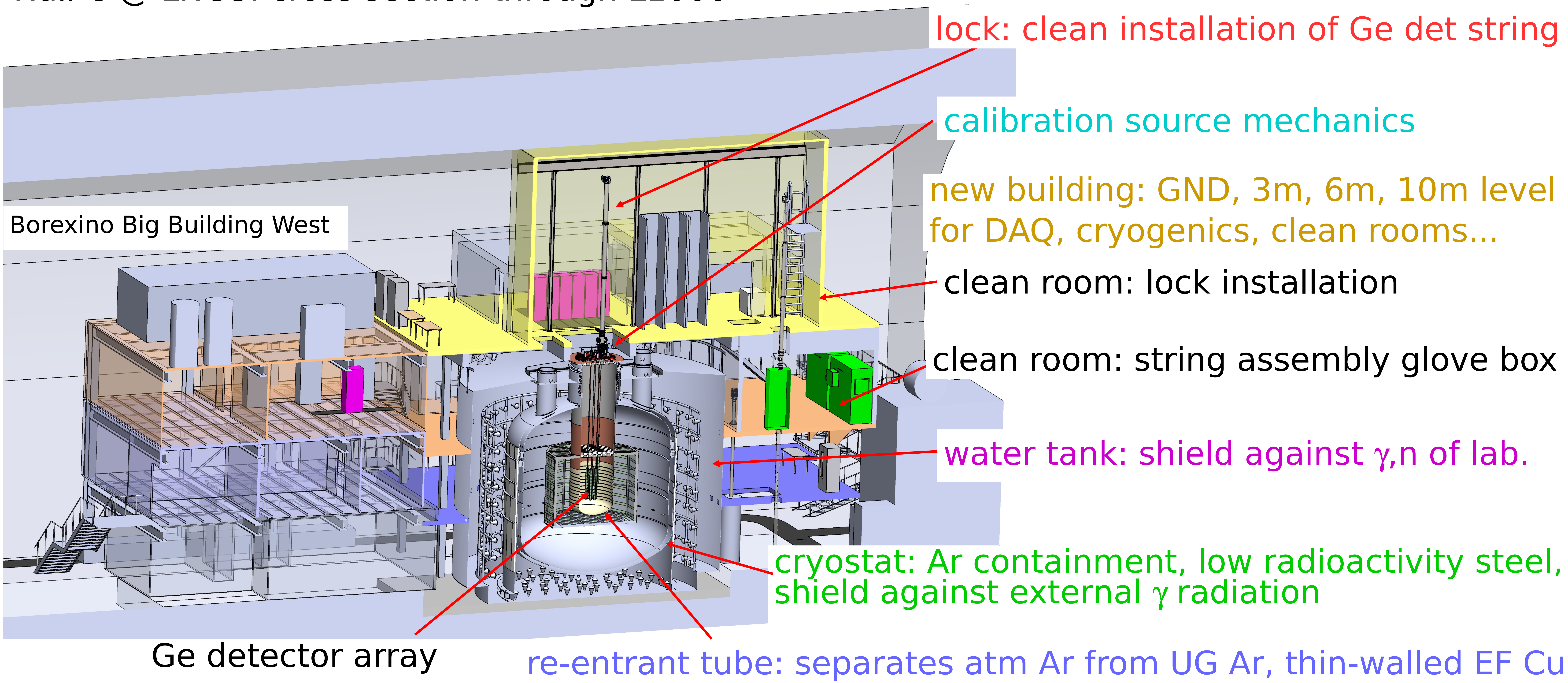
- took over GERDA infrastructure in 2020
- new + larger ^{76}Ge detectors
- new argon instrumentation
- new electronics, …
- start data taking end 2022 with 140 kg
- first unblinding for Neutrino’24
- detector production ongoing eventually ~200 kg
- $T_{1/2}$ sensitivity goal 10^{27} yr



LEGEND-1000 in Hall C @ LNGS

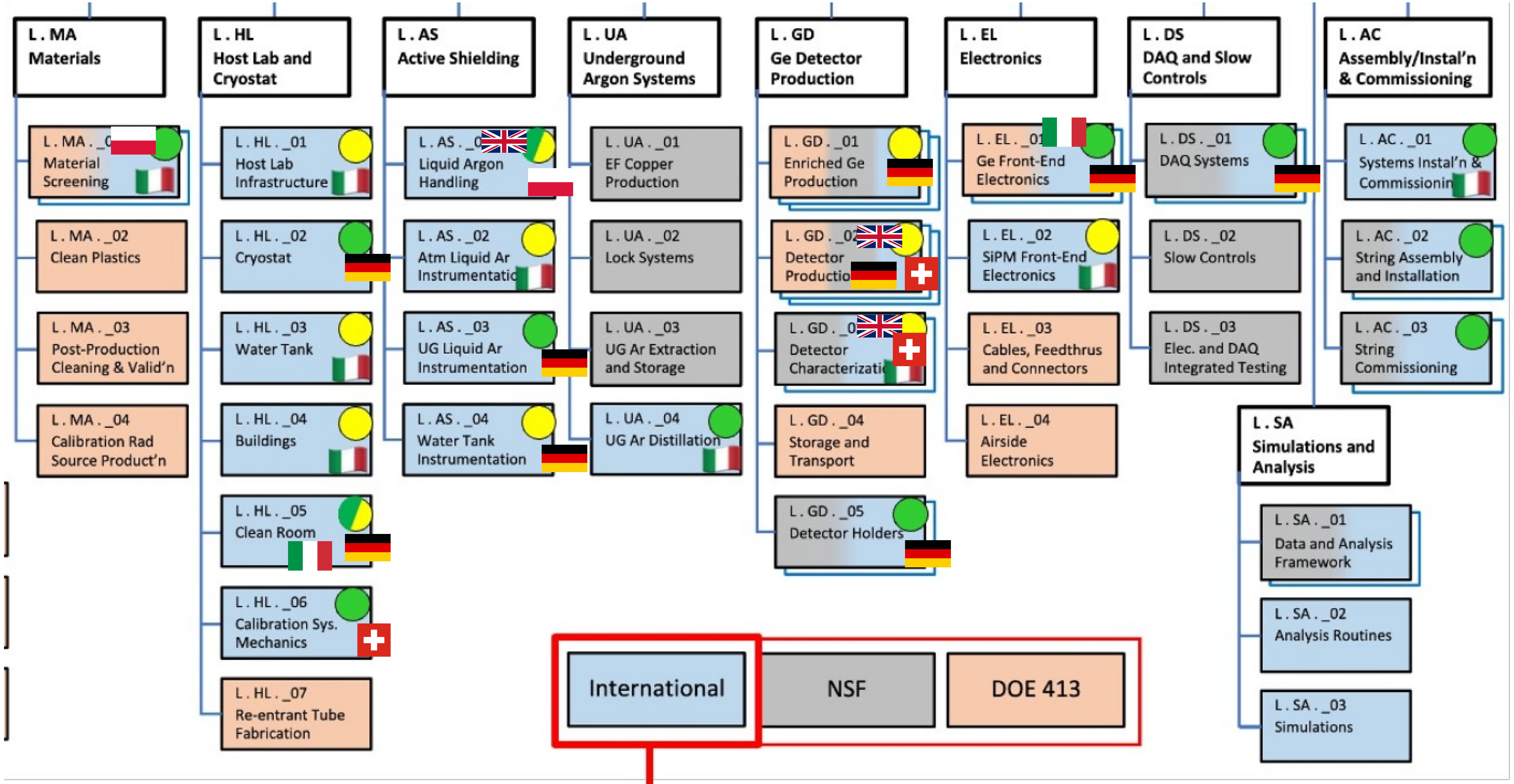
infrastructure design largely informed by GERDA

Hall C @ LNGS: cross section through L1000



LEGEND-1000 Work Breakdown Structure

left out: simulation + analysis and management



Ge enrich. + detectors > 50% of investment

first infrastructure items funded → can start now

procurement of steel for cryostat started

= SNF

= INFN

= NSC + MNSW

= funding (largely) secured

= funding request pending

= MPG + BMBF + DFG + EU

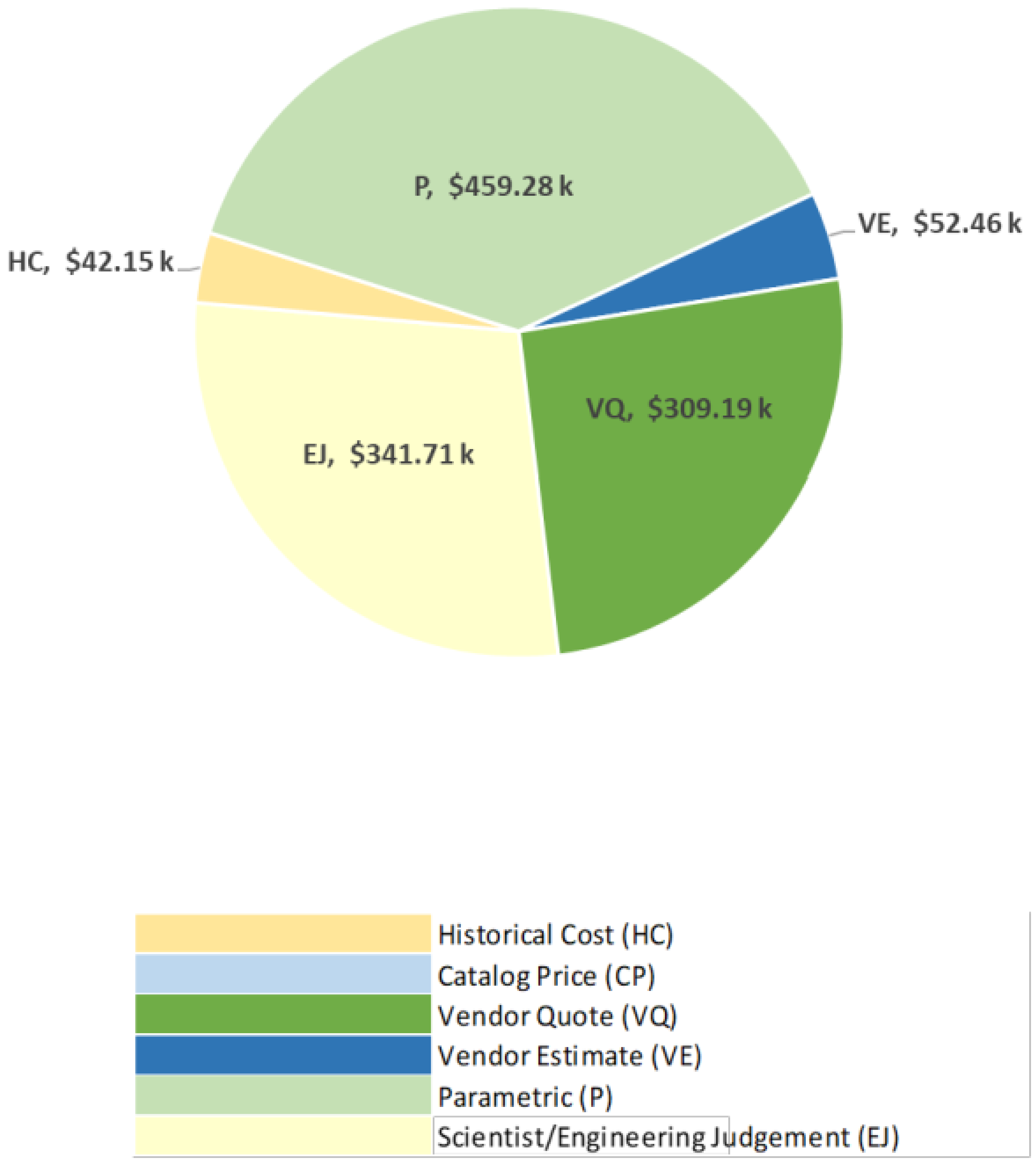
= STFC

LEGEND-1000 cost estimate

Cost basis

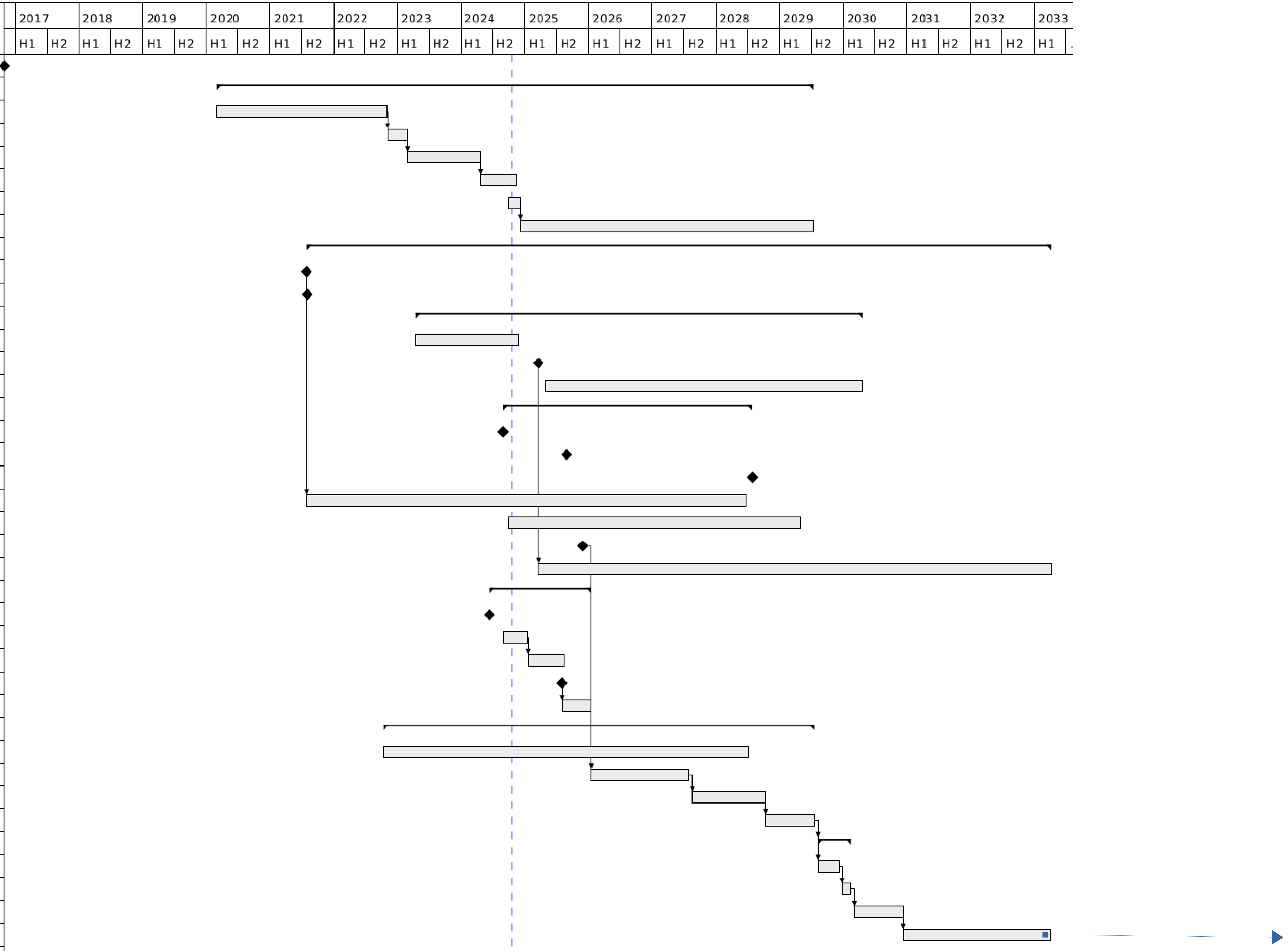
- bottom up cost estimate + schedule by Level 3 task manager
- started in 2021, regularly being updated
- cost uncertainties for vendor quote, ...
- biggest cost items germanium enrichment & detector production relatively well know from LEGEND-200
- in total ~3400 tasks in project management tool P6: schedule + invest + labor

example: L.UA.N02 Lock Systems



LEGEND-1000 technical schedule

Name	Work
LEGEND collaboration formed	
LEGEND-200	**2480d**
Construction	700d
commissioning	80d
first data taking	300d
screening campaign	150d
detector assembly	50d
continue data taking	1200d
LEGEND-1000	**10520d**
pre-conceptual design report	
DOE portfolio review	
NSF project	**1720d**
proposal	420d
NSF funding decision	
execution	1300d
DOE project	
status review	
CD-1 and CD-3a	
CD-2 / 3	
R&D for electronics, clean pastics, crystal pulling	1800d
enginering of LAr instr, water tank instr, ...	1200d
Borexino site ready for installation	
Ge detector production	2100d
LNGS approval	**370d**
approval Scientific Committee	
preliminary risk analysis	100d
environmental authorization VINCA	150d
Technical Design Report	
approval by LNGS director	120d
construction	**2400d**
R&D for ASIC, cables	1500d
cryostat constr at LNGS	400d
water tank, building, clean room constr.	300d
cryogenic infrastr, DAQ, glove boxes, LAr instr, water instr	200d
commissioning	**130d**
cryostat + water tank filling	90d
first Ge detect deployment, testing	40d
first data taking with subset of Ge det	200d
data taking	600d



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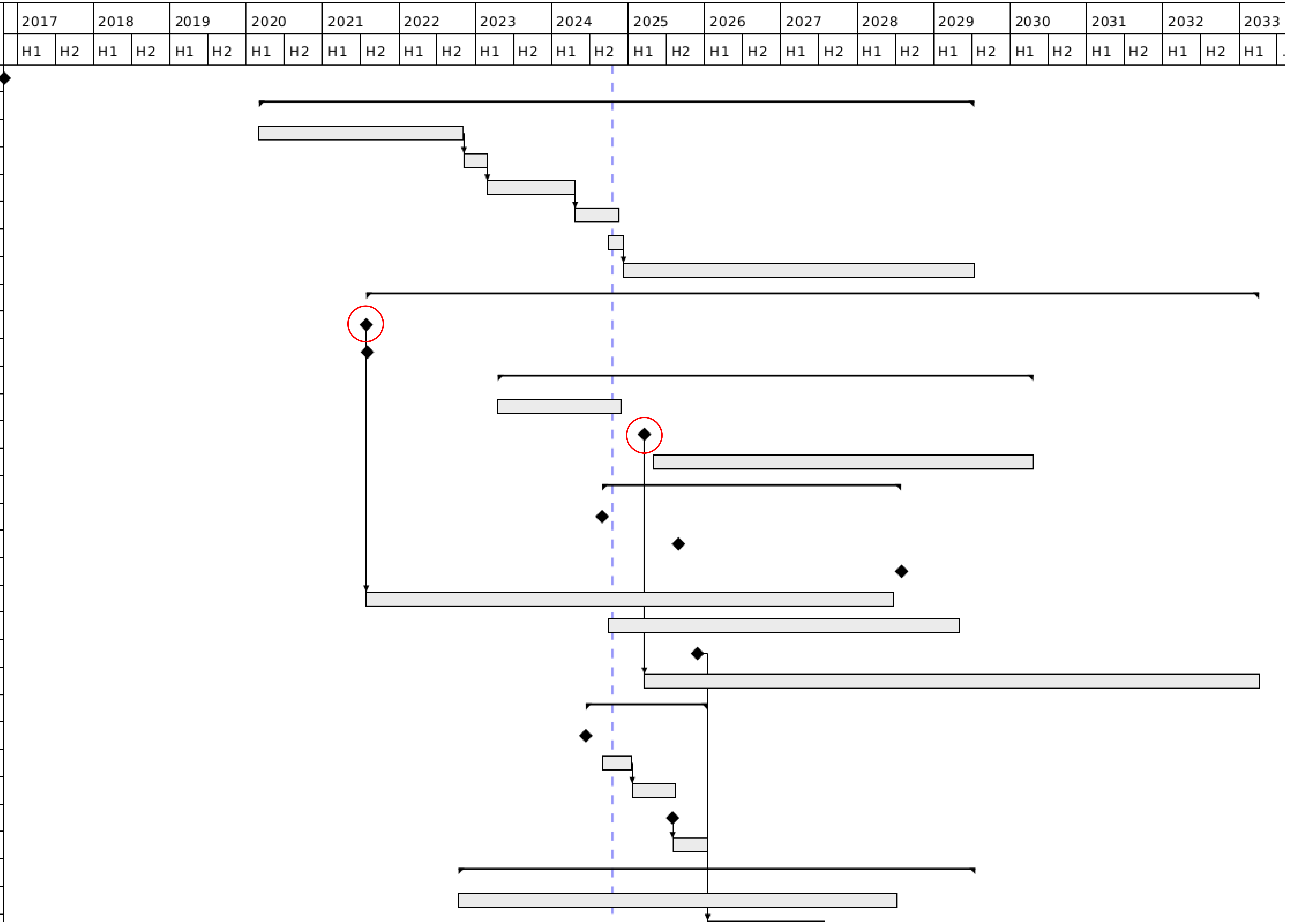
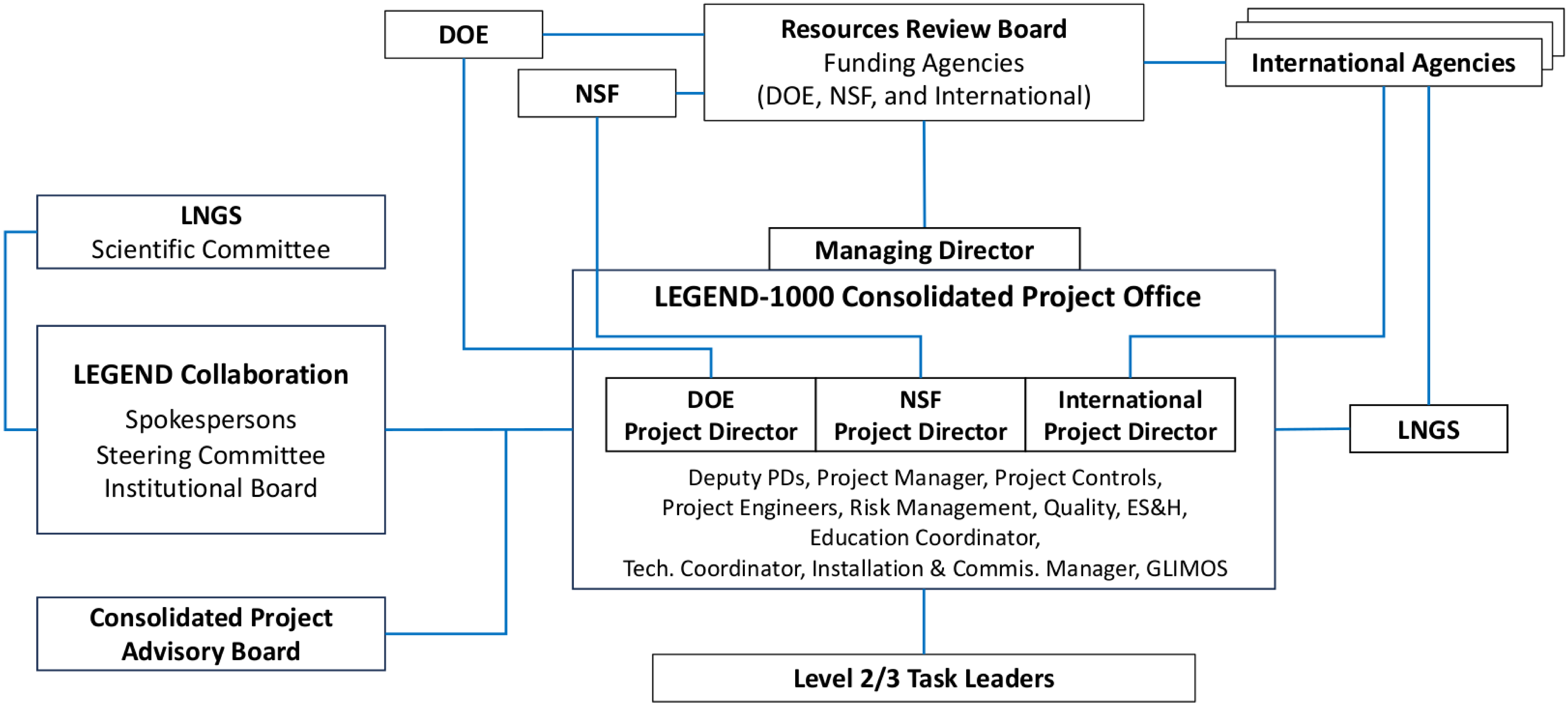


LEGEND-1000 consolidated project office



LEGEND-1000 consolidated risk management

Post-Mitigation Rating Summary	
Critical	0
High	12
Medium	22
Low	70
Very Low	34
Retired	0
Total Threats	138
Total Opportunities	5
Total Entries	143

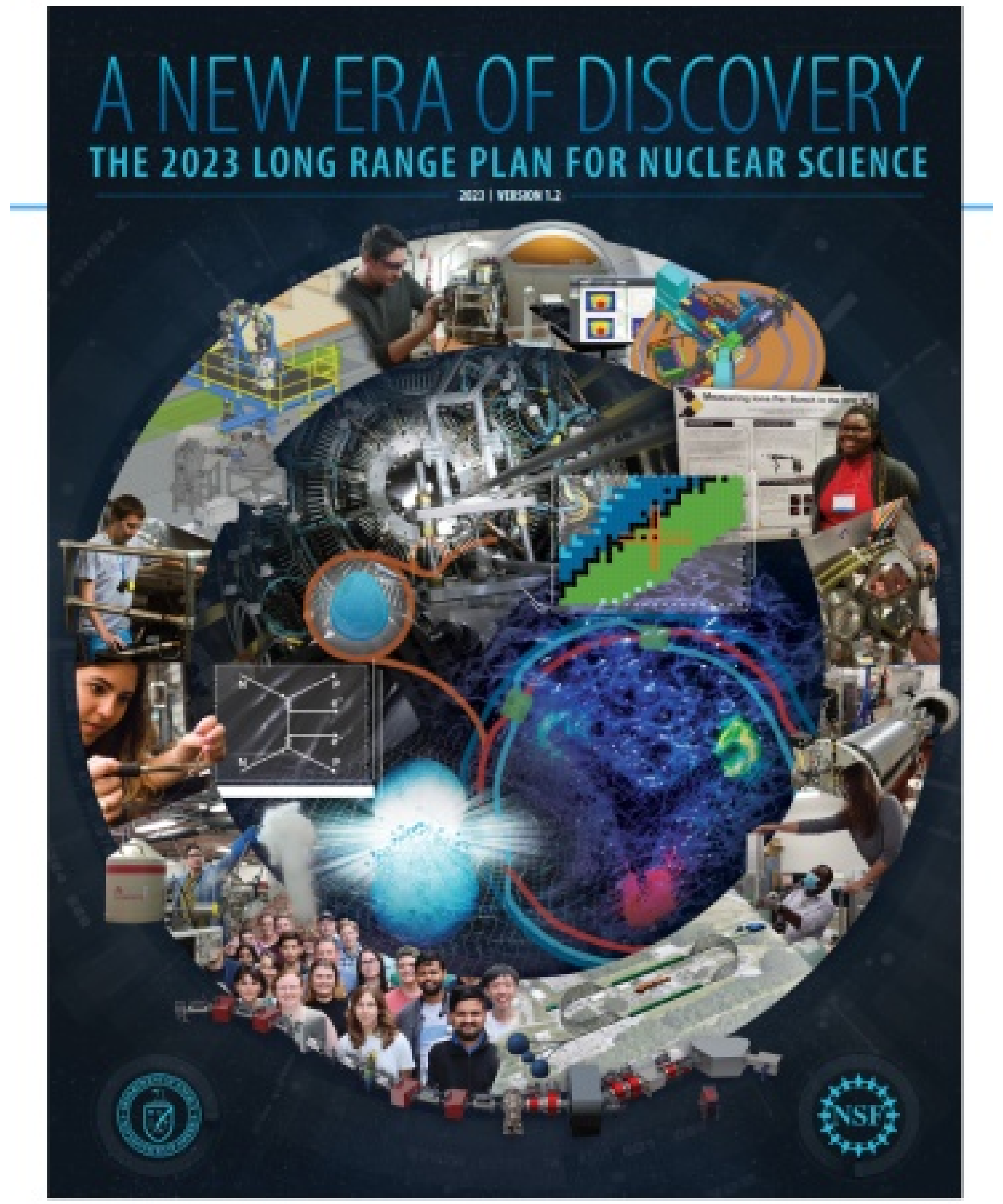
Post-Mitigation Matrix Summary (DOE and NSF)					
Probability	Consequence				
	Very Low	Low	Medium	High	Very High
>80%	0	0	0	0	0
>50% - 80%	0	0	0	0	0
>25% - 50%	0	4	5	3	2
>10% - 25%	1	17	8	11	7
10%	6	27	29	12	6

Risk Methodology

- ~170 threats
- Risks will be tracked in a Consolidated Risk Register
  - Currently DOE and NSF risks have been fully evaluated and reviewed.
  - International risks have been identified, but not yet fully evaluated.
- Developed from bottom-up through workshops, focused discussions, and management reviews
- Consolidated Risks will be managed according to the LEGEND-1000 DOE Risk Management Plan.

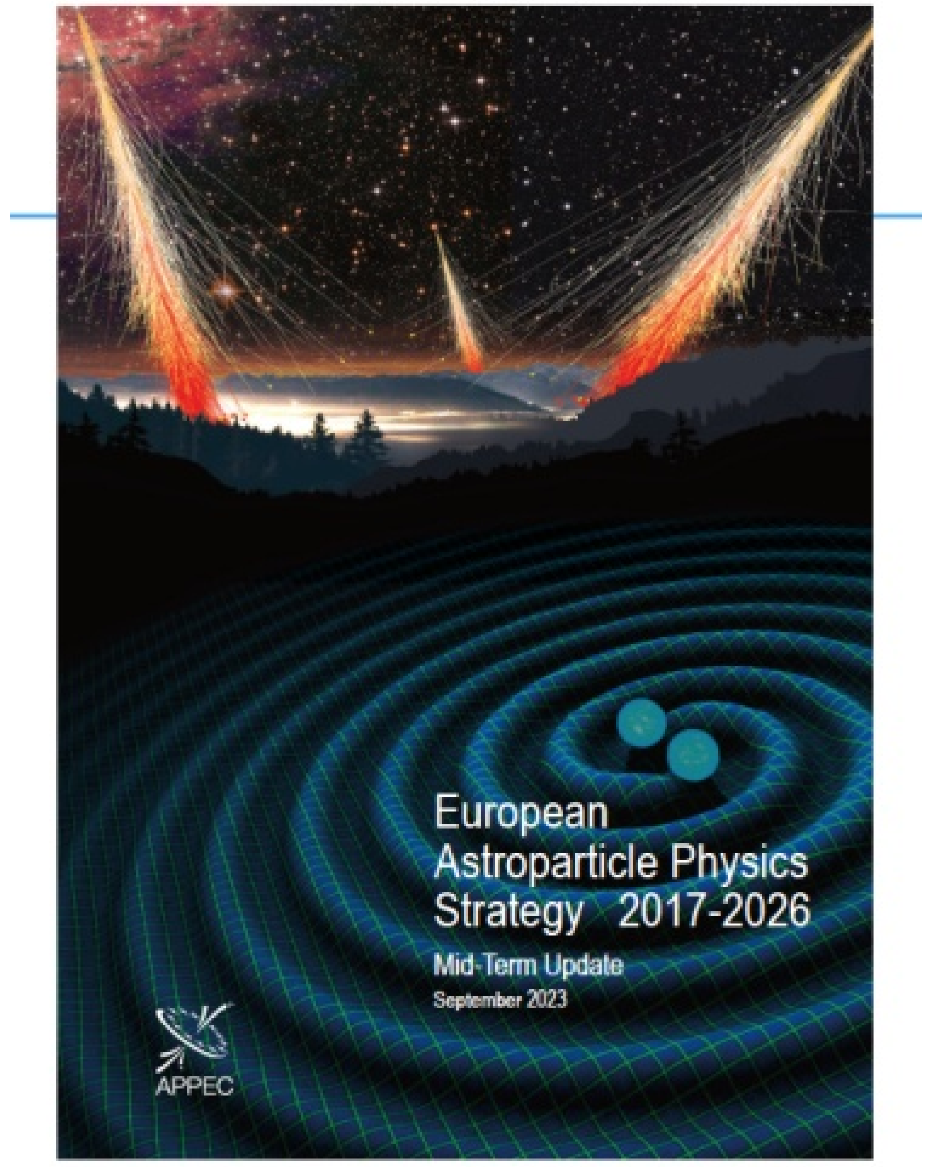
NSAC and APPEC statements

2023 NSAC long range plan



As the highest priority for new experiment construction, we recommend that the United States lead an international consortium that will undertake a neutrinoless double beta decay campaign, featuring the expeditious construction of ton-scale experiments, using different isotopes and complementary techniques.

2023 APPEC mid-term update



APPEC strongly supports the CUPID and LEGEND 1000 double-beta decay experiments selected in the US-European process and endorses the development of NEXT. APPEC strongly supports fully exploiting the potential of the KATRIN direct neutrino mass measurement and the development of a new generation of experiments beyond KATRIN.

Status of funding

NSF: mid-scale proposal submitted (90 M USD, incl. contingency & escalation)
NSF + Europe → can build LEGEND-1000 with >30% of Ge

DOE: CD-1 scheduled for November, shifted by DOE
now Office of Science conducts prioritization of projects (before end of year)
hope to schedule CD-1 for spring 2025, CD-3a for Ge procurement in Sept 2025
LEGEND-1000 ranked highest in 2021 portfolio review

Italy: INFN is strongly supporting LEGEND-1000 at LNGS with a global investment that exceeds 20 MEuro in the construction phase and several MEuro/year during operations (Marco Pallavicini)

Germany: Max Planck Society funding secured (cryostat, part of clean room, DAQ, …)
Verbundforschung not sufficient → BMBF Forschungsinfrastruktur
ERC grant of TUM: allowed to establish 2nd crystal supplier (→ cost + schedule risk)
excellence cluster TUM: support of people

Switzerland: expect constant funding profile

Poland: grant in 2022 from ministry, periodic funding from National Science Center

UK: STFC started prioritization process, submit proposal in 2025 if selected

Summary

o “Neutrinoless double beta decay ($0\nu\beta\beta$) is one of the most compelling outstanding issues in nuclear / particle physics, and as yet unmeasured.”

“Reviewers and panelists all agree that this is the best chance for the community to win a Nobel Prize.” (NSF review report)

LEGEND-1000 ranked highest in DOE portfolio review in 2021 (compared to nEXO and CUPID)

o best scenario: LEGEND and XLZD find $0\nu\beta\beta$ for ^{76}Ge and ^{136}Xe (and dark matter)

o If NSF proposal accepted (decision April 25) construction of LEGEND-1000 will start

o some R&D still ongoing: ASIC for Ge readout, pure plastics, …
(have fall back options in case of delay)

o LEGEND builds on the idea of Gerd Heusser and the realization by GERDA
German groups should play a major role → FIS funding needed
co-spokesperson = Stefan Schönert, international project director = Bernhard Schwingenheuer