LEGEND

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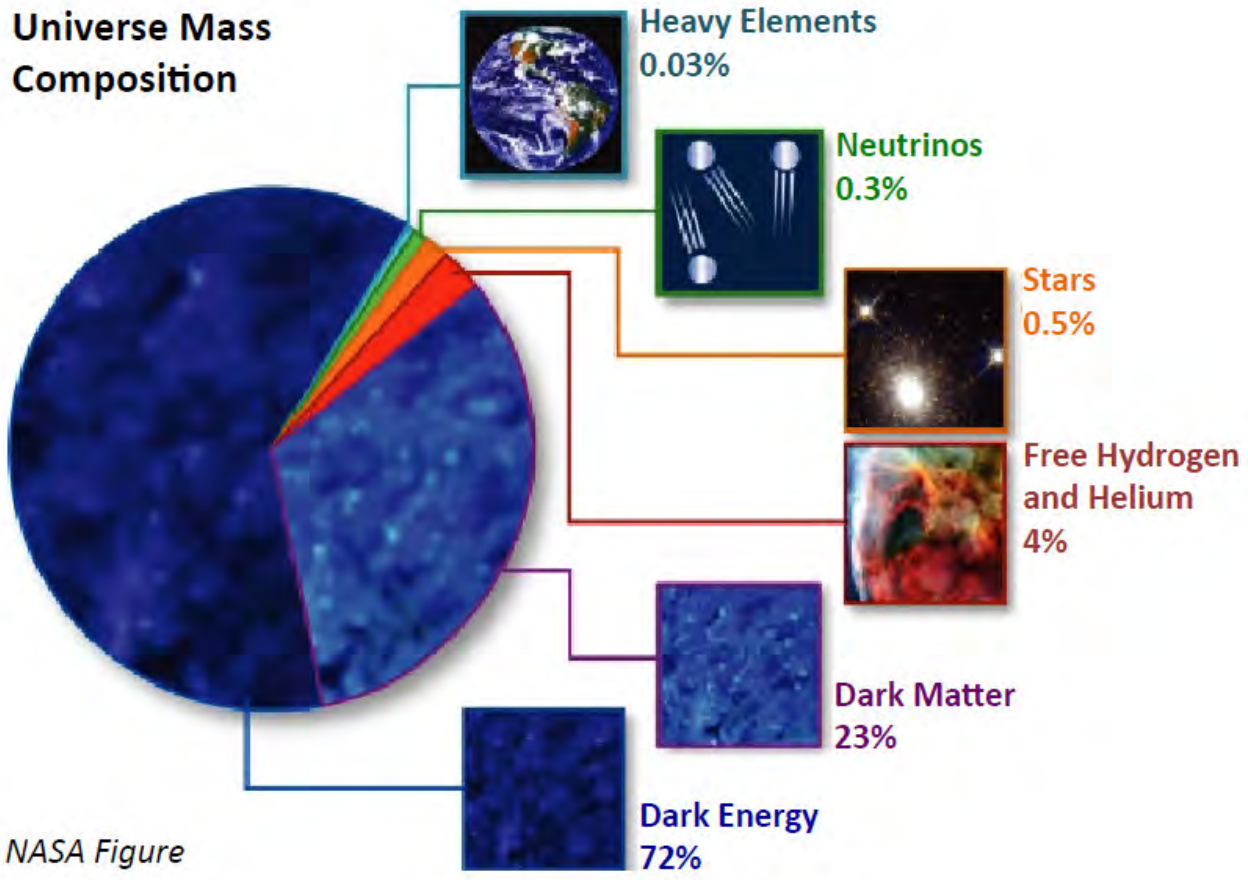
Our Universe



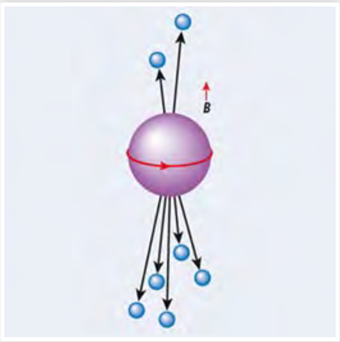
- Only ~5% of the energy-mass density in the universe is composed of baryonic matter
- The dark sector is completely unknown
- Matter-antimatter symmetry violated; known mechanisms for matter-antimatter symmetry violation cannot explain observed asymmetry

Broken symmetries

When a symmetry is broken, there are often deep implications for fundamental interactions

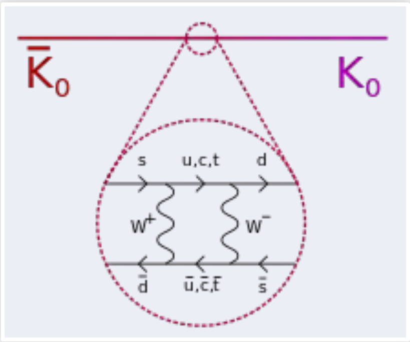
Parity violation

- Formalism of parity violation in weak decays, established by experiments by C. S. Wu
- 1957 Nobel Prize in Physics: T. D. Lee and C. N. Yang



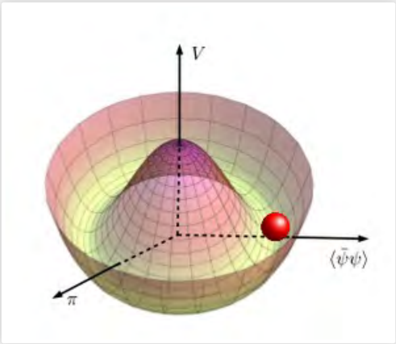
CP violation

- Observation of CP violation in the light quark sector (kaons)
- 1980 Nobel Prize in Physics: V. Fitch and J. Cronin



Spontaneous

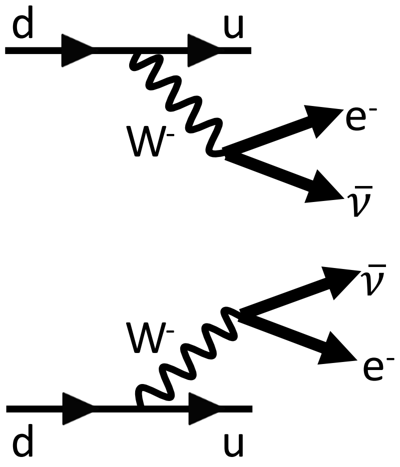
- Discovery of mechanism and origin of spontaneous broken symmetries
- 2008 Nobel Prize in Physics: Y. Nambu, M. Kobayashi, T. Maskawa

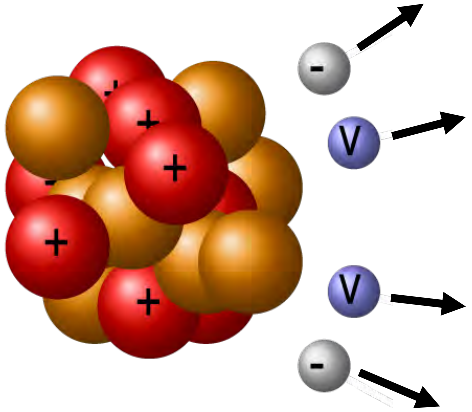


Gauge symmetry breaking

- Spontaneous breaking of the gauge symmetry in fundamental interactions
- Predicted the Higgs boson and provided for a mechanism of the origin of mass
- 2013 Nobel Prize in Physics: F. Englert and P. Higgs

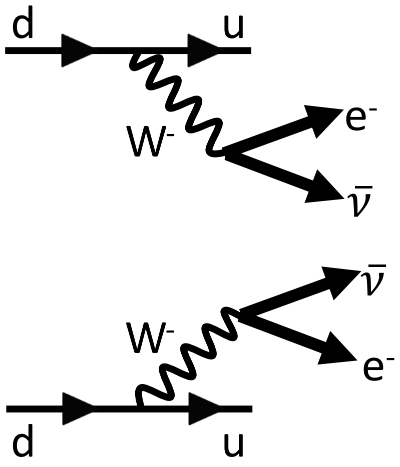
Nature of the neutrino

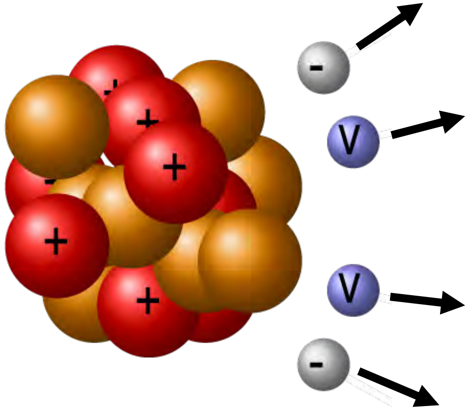


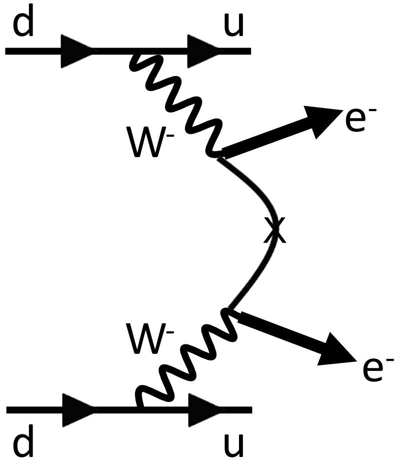


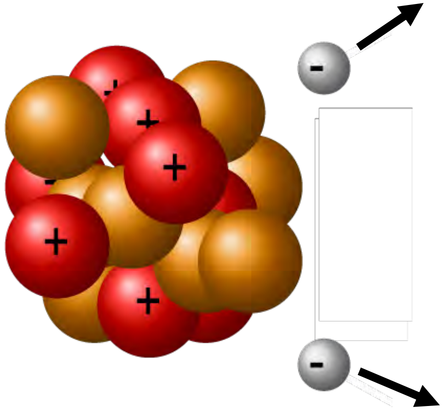
- **Double beta decay**
  - Predicted by Maria Goeppert-Mayer in 1935
  - First observation in 1987 in ^{82}Se

Nature of the neutrino



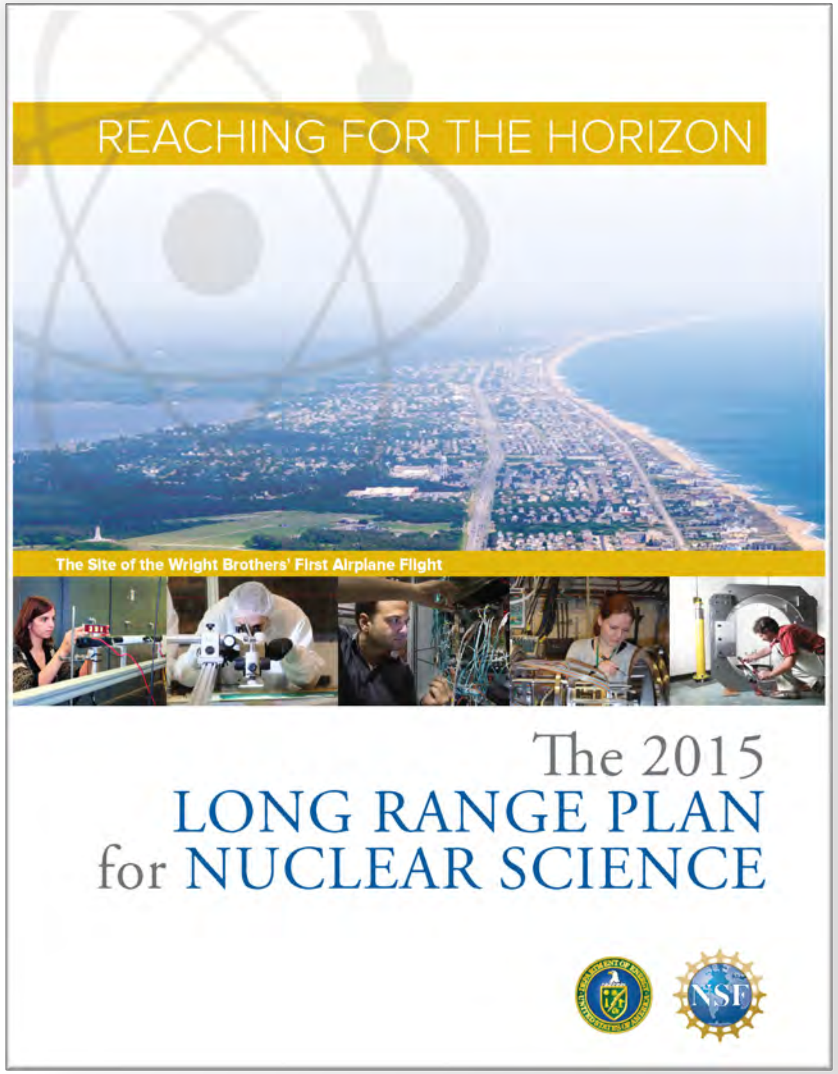






- **Double beta decay**
  - Predicted by Maria Goeppert-Mayer in 1935
  - First observation in 1987 in ^{82}Se
- **Neutrinoless double-beta decay**
  - Violates lepton number conservation
  - Demonstrates that a neutrino is its own antiparticle (Majorana particle)
  - Provides potential mechanism for the very light masses of neutrinos
  - Gives a model-dependent measurement of the absolute neutrino mass

NSAC Long-Range Plan, 2015



"

The excess of matter over antimatter in the universe is one of the most compelling mysteries in all of science

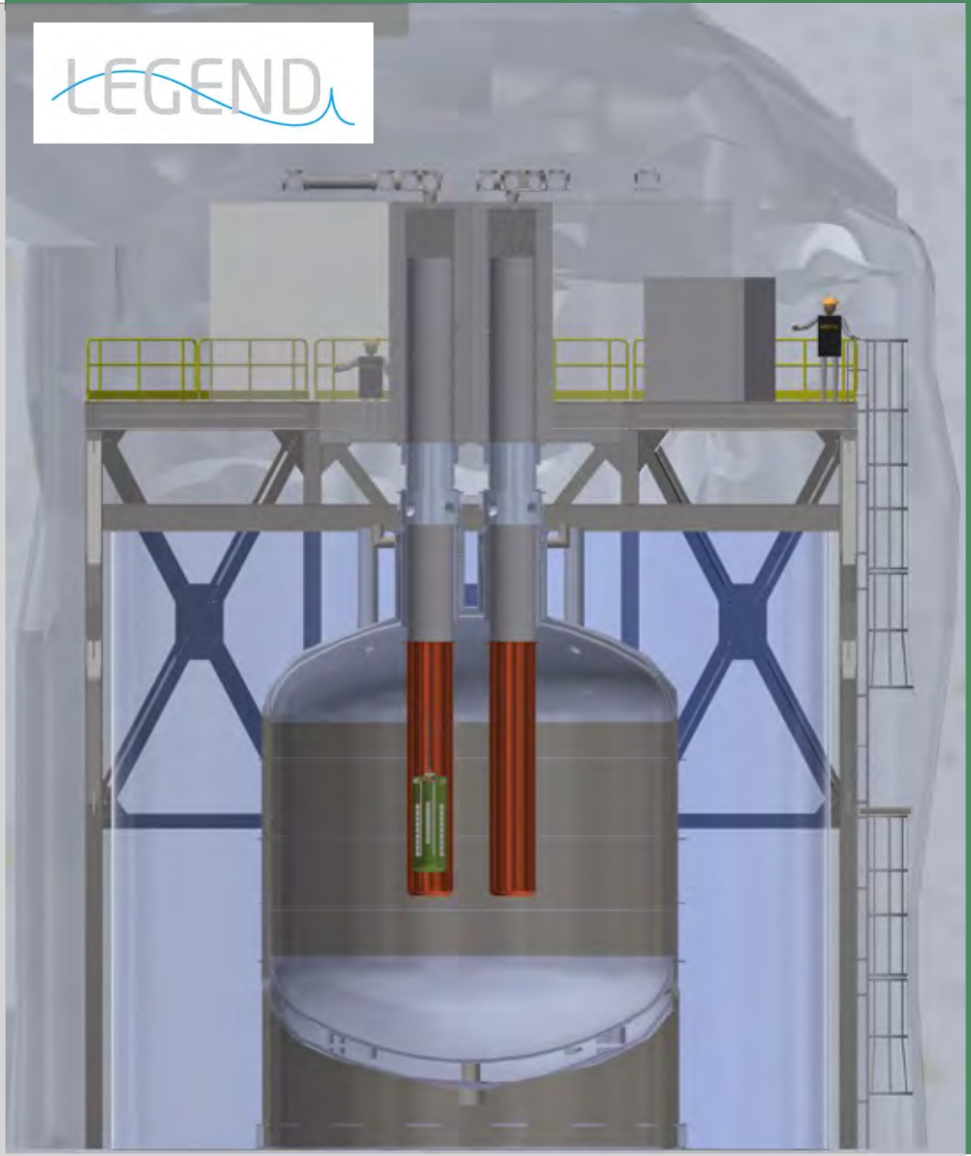
The observation of neutrinoless double beta decay in nuclei would immediately demonstrate that neutrinos are their own antiparticles and would have profound implications for our understanding of the matter-antimatter mystery

We recommend the timely development and deployment of a US-led ton-scale neutrinoless double beta decay experiment

"

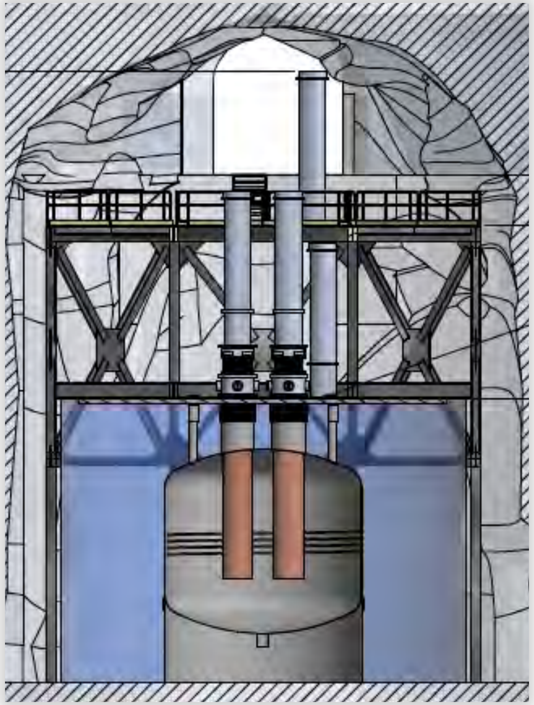
LEGEND

- LEGEND: Large Enriched Germanium Experiment for Neutrinoless ββ Decay
  - 1000 kg of highly enriched ^{76}Ge
  - Located in a deep underground laboratory to mitigate cosmic ray backgrounds
  - Germanium-76 is source and detector
- Experimental signature:
  Total energy of 2 electrons at E = 2039 keV
- Challenges:
  - Unprecedented low background and ultra-pure materials



LEGEND approach

- Merger of the Germanium Detector Array (GERDA) and Majorana Demonstrator (MJD) experiments
- Adopts best techniques and technologies based on the combined experience
  - GERDA, at Laboratori Nazionali del Gran Sasso (LGNS), has best background rejection
  - MJD at Sanford Underground Research Facility has best energy resolution; ORNL is lead laboratory for the MJD experiment



LEGEND-200 at LNGS	LEGEND-1000
200 kg ^{76}Ge in upgrade of existing infrastructure	1000 kg, staged via individual payloads
Background goal < 0.6 counts/(FWHM t-year)	Background goal < 0.03 counts/(FWHM t-year)
Discovery sensitivity at a half-life of 10^{27} years	Discovery sensitivity beyond a half-life of 10^{28} years
Start data by ~2021	Location: TBD

OAK RIDGE National Laboratory

^{76}Ge for 0νββ-Decay

- Best energy resolution (FWHM = 0.12%)
- Best background rejection:
  goal 0.03 counts/(FWHM t-y)
  - No prominent background g lines near Qbb.
  - 2νββ background negligible
- Detector is a solid crystal; experiment scalable
- Stable long-term operation
- Large, reliable global supply of raw material
  - ECP (Russia), URENCO (Netherlands)
- Germanium detectors invented at ORNL
- Germanium crystals will all be grown
  in Oak Ridge (Mirion, ORTEC)

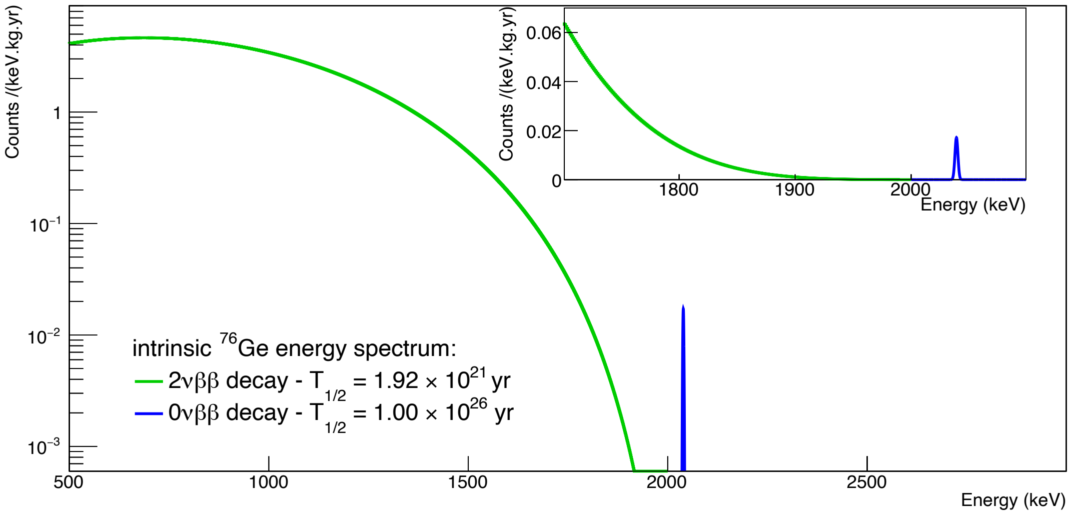
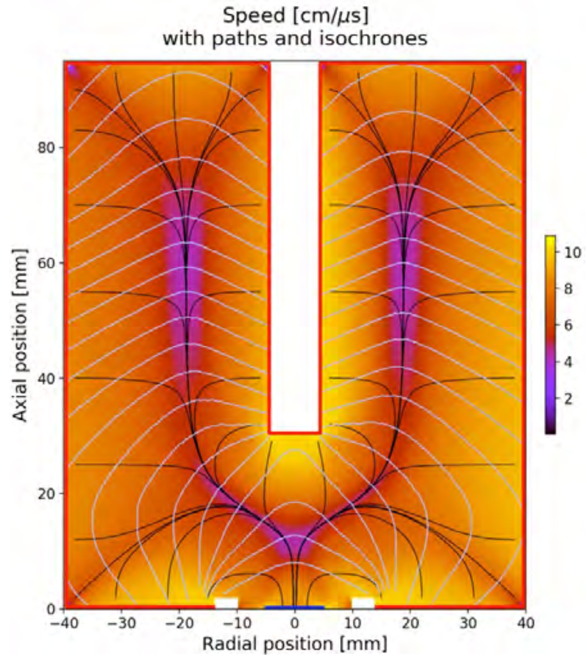
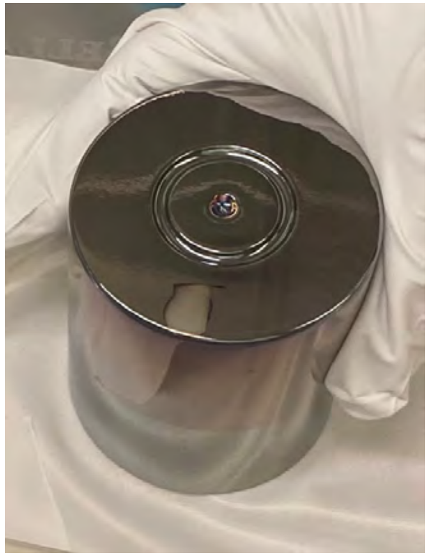
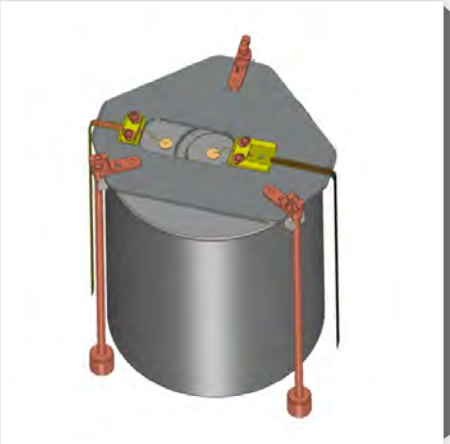


Fig. Kermaïdic, Neutrino 2020



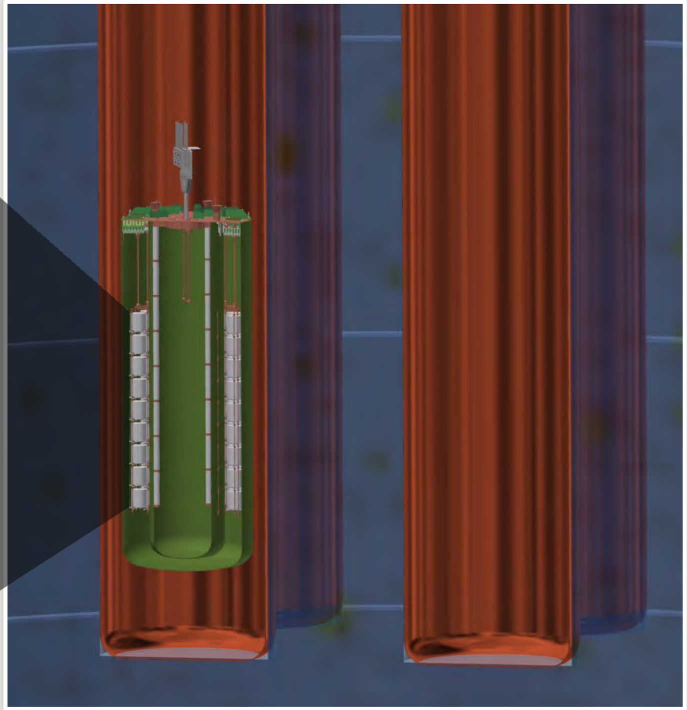


LEGEND baseline experiment



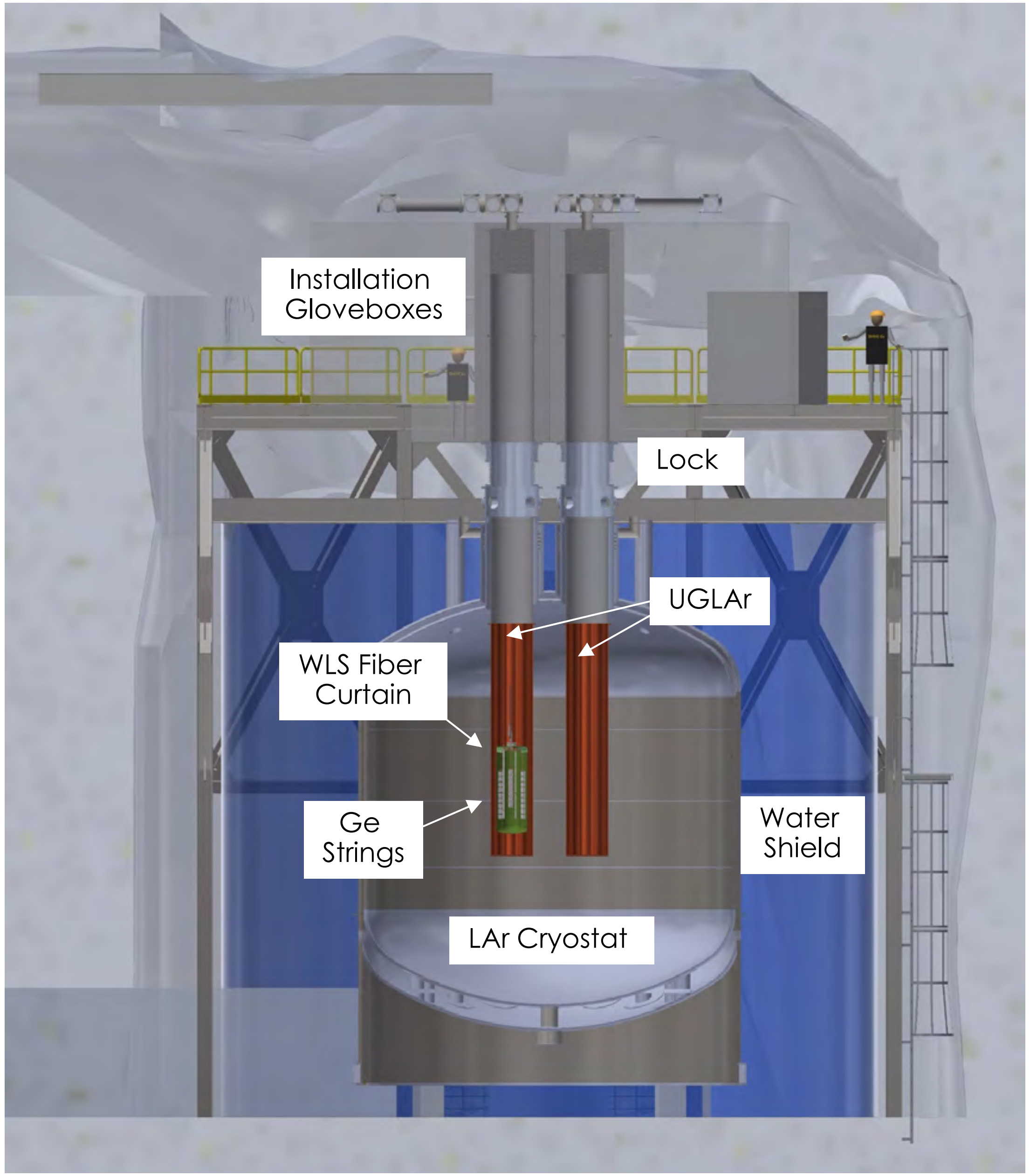
Inverted coaxial point contact Ge detector

300–400 detectors at ~3 kg each



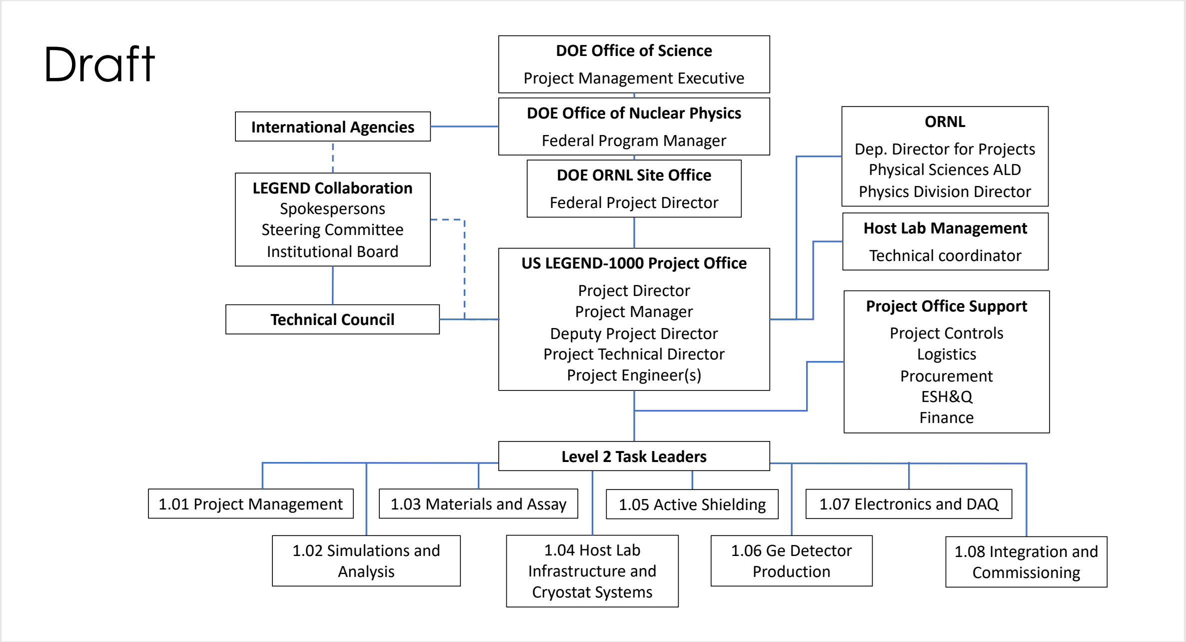
4 modules of Ge strings of ~100 detectors each

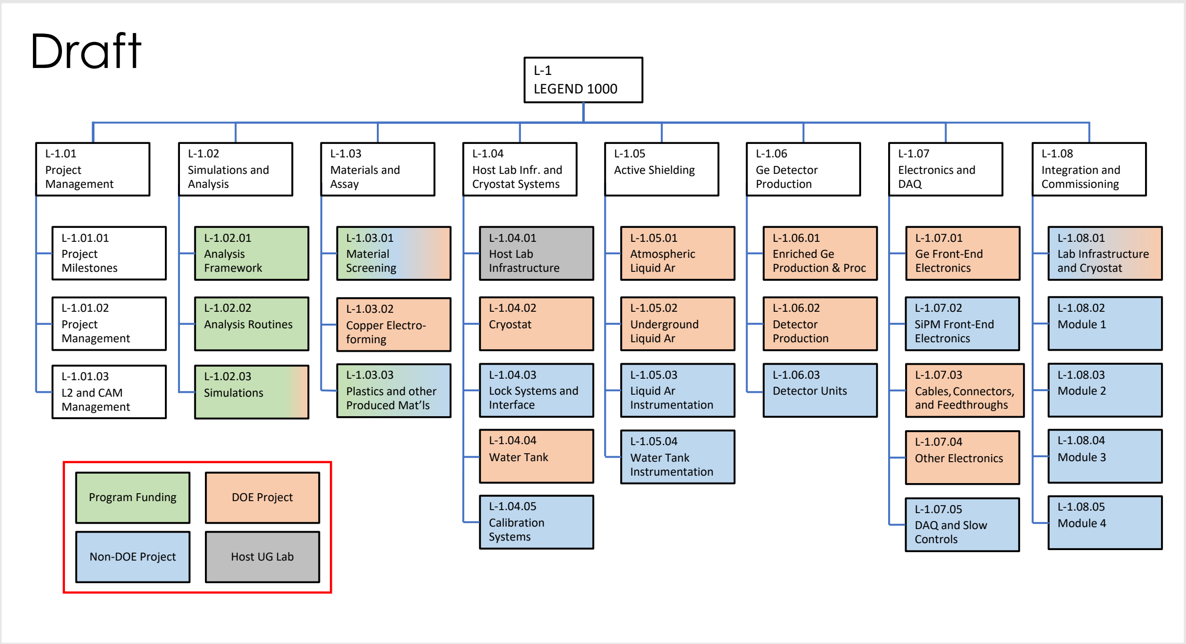
Immersed in19 tons underground LAr (depleted in ^{42}Ar)



LEGEND project

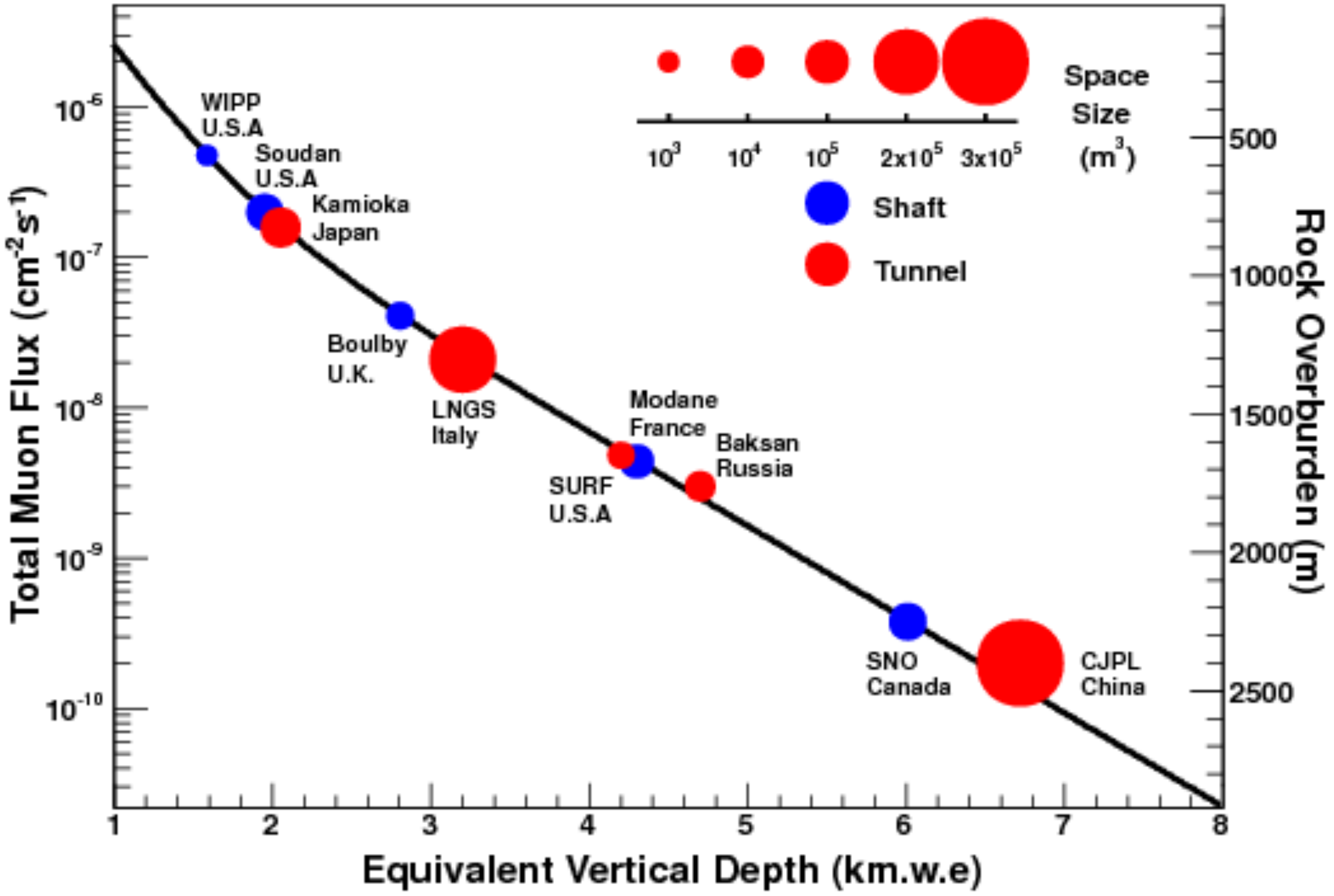
- ORNL selected as US lead lab by LEGEND Science Advisory Committee
- LEGEND project team is being formed with discussions about US and international scope
  - LEGEND comprises 50 institutions world-wide, with 250 collaborators
- Internal review conducted last month to refine technical, US and International scope
- 7-year construction project
  - Estimated total project cost ~$450M
  - Expected US scope ~70%





Underground Laboratory to Host

- 2 preferred sites:
  - Gran Sasso underground laboratory in Italy
  - SNOLAB in Sudbury, Canada
  - (SURF: Conflicts with LBNF/DUNE)
- SNOLAB preferable for a US-led experiment.
- Limited international negotiations to date.
- 2 key issues:
  - Technology downselect
  - Site selection



International context

- In Europe, $0\nu\beta\beta$ decay falls under APPEC, the AstroParticle Physics European Consortium (https://www.appec.org)
- The APPEC roadmap for 2017–2026 states:
  - A multi-isotope program exploiting different technologies at the highest level of sensitivity should be supported in Europe
  - The projects will study three different isotopes (^{76}Ge, ^{136}Xe, ^{100}Mo) using different technological approaches, offering a strong complementarity
- APPEC plans to partner with DOE in the technology downselect process and site selection
  - Discussions so far between DOE and APPEC chair
  - An "international summit" is being discussed
- It is critical to align international process timelines and discuss site selection in a timely manner.

Summary

- The search for neutrinoless double beta decay is an ambitious, high-priority project: Evidence would overturn our understanding of fundamental interactions
- Germanium-based search is well established and has the best discovery potential
  - The staged approach mitigates risks
- ORNL leads the Majorana Demonstrator project and the US-LEGEND project
  - Developed germanium detectors through ARRA and LDRD funding
  - Crystals grown in Oak Ridge
- Timely international negotiations are key.

Discussion