Next Generation Double Beta Decay Experiments and their Sensitivity projections

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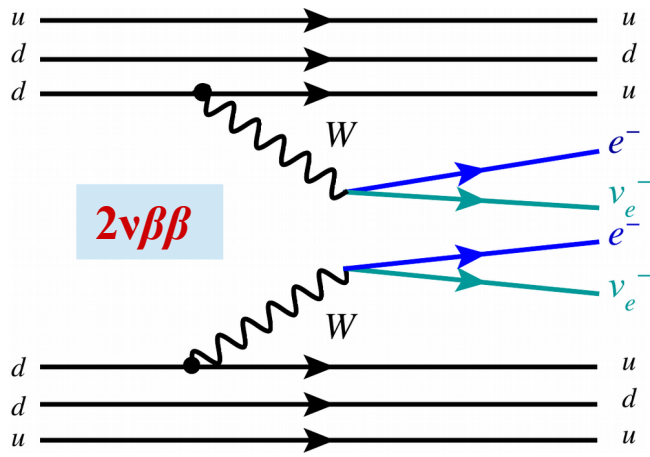
Contents

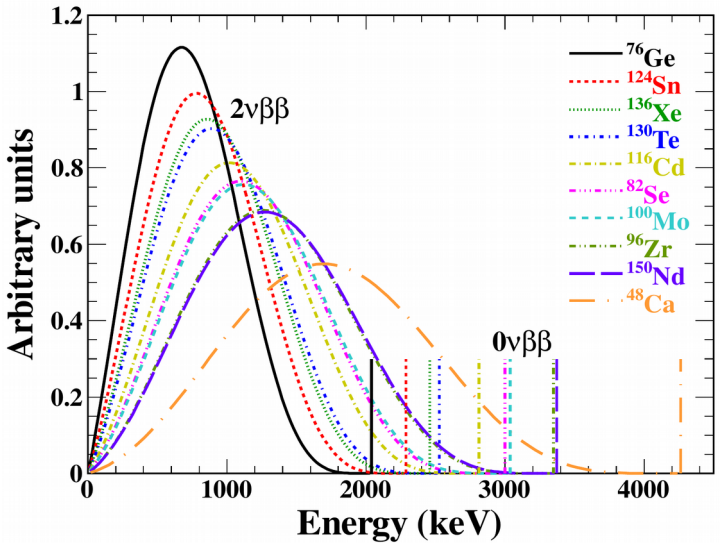
- Double Beta Decay
- Status & Projection of Double Beta Decay Experiments
- LEGEND: L200
- LEGEND: L1000
- Our Contribution for L1000
- Sensitivity Projection

Double Beta Decay

- A second-order weak process
- Detectable: If First order β-decay energetically forbidden
- In SM for even(N)-even(Z) nuclei:

$2\nu\beta\beta$: ${}^{N}_{Z}A_{\beta\beta} \rightarrow {}^{N-2}_{Z+2}A + 2e^- + 2\bar{\nu}_e$ [Goeppert-Mayer, 1935]

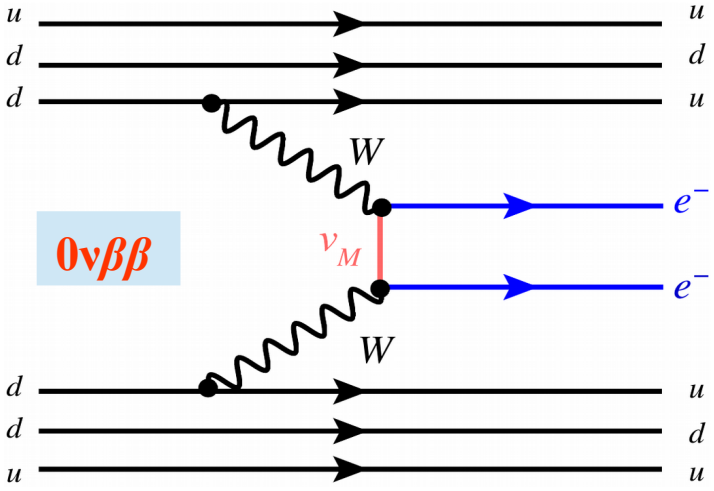




- Neutrinoless double beta decay

  $0\nu\beta\beta$: ${}^{N}_{Z}A_{\beta\beta} \rightarrow {}^{N-2}_{Z+2}A + 2e^-$ [Furry, 1939]

  - Forbidden in the Standard Model
  - Very Rare
  - Never been observed
  - BSM Process
- Lepton number violation (2 Units)
- Majorana Neutrino Mass $\langle m_{\beta\beta} \rangle \neq 0$
- Signal: Mono-energetic peak at $Q_{\beta\beta}$-value of decay

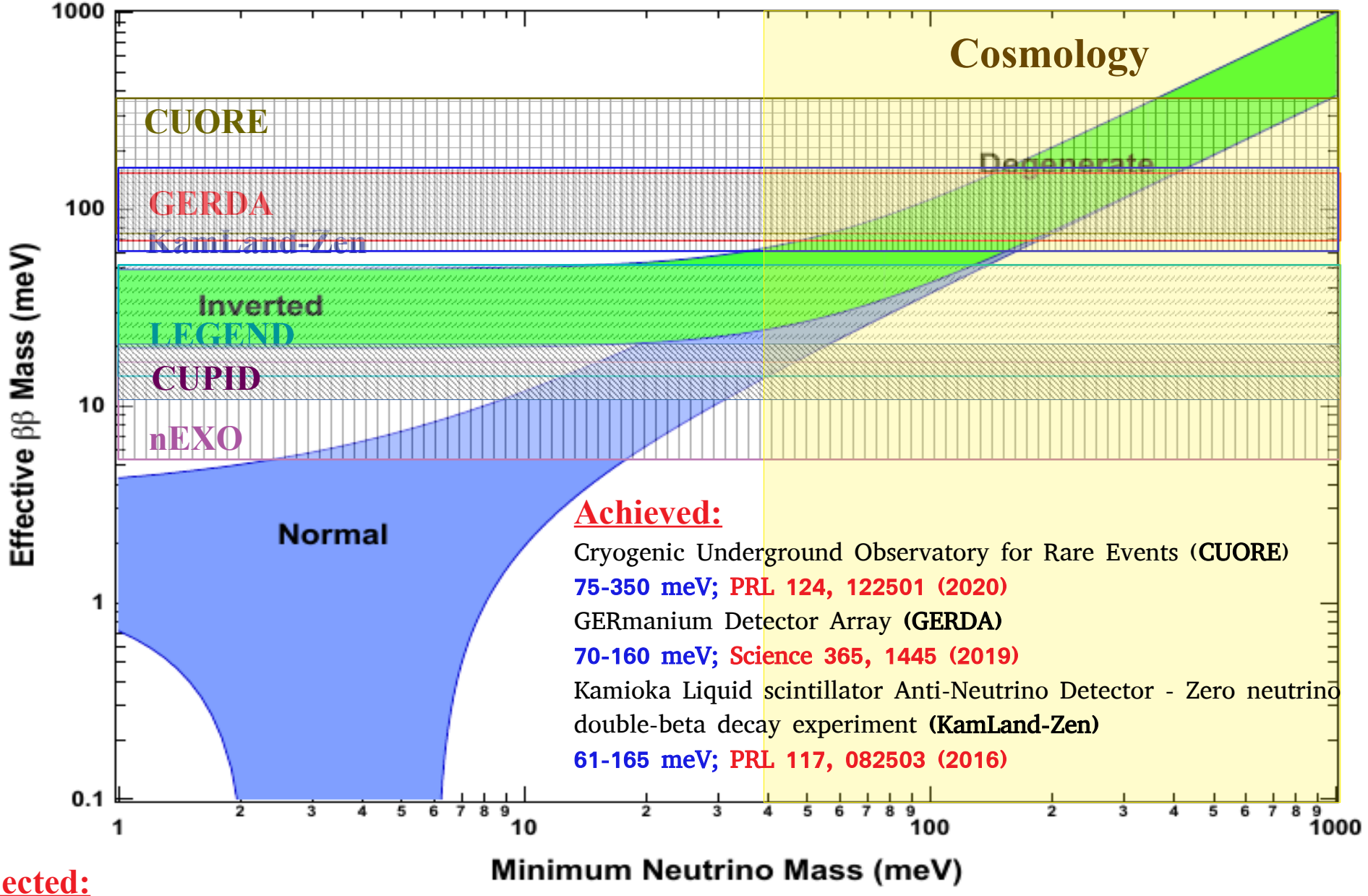


$$T^{0\nu}_{1/2} = \ln 2 \cdot N(A_{\beta\beta}) \cdot t_{\mathrm{DAQ}} \cdot \left[\frac{\varepsilon_{RoI}}{N^{0\nu}_{obs}}\right] = \ln 2 \cdot \left[\frac{N_A}{M(A_{\beta\beta})}\right] \cdot \sum \cdot \left[\frac{\varepsilon_{RoI}}{N^{0\nu}_{obs}}\right]$$

$$\left[\frac{1}{T^{0\nu}_{1/2}}\right] = G^{0\nu} g_A^4 \left|M^{0\nu}\right|^2 \left|\frac{\langle m_{\beta\beta}\rangle}{m_e}\right|^2$$

$$\langle m_{\beta\beta}\rangle = |U^2_{e1}|m_1 + |U^2_{e2}|m_2 e^{i\alpha} + |U^2_{e3}|m_3 e^{i\beta}|$$

Status & Projection of Double Beta Decay Experiment



Achieved:

Cryogenic Underground Observatory for Rare Events (**CUORE**)
75-350 meV; PRL 124, 122501 (2020)

GERmanium Detector Array (**GERDA**)
70-160 meV; Science 365, 1445 (2019)

Kamioka Liquid scintillator Anti-Neutrino Detector - Zero neutrino double-beta decay experiment (**KamLand-Zen**)
61-165 meV; PRL 117, 082503 (2016)

First Goal: Completely Cover Inverted Hierarchy

Projected:

Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay (**LEGEND**)
15-50 meV; AIP Conference Proceedings 1894, 020027 (2017)

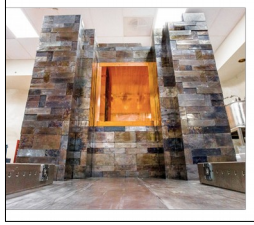
CUORE Upgrade with Particle Identification (**CUPID**)
12-20 meV; arXiv:1907.09376v1

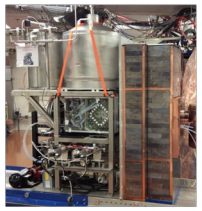
next Enriched Xenon Observatory (**nEXO**)
5.7-17.7 meV; PRC 97, 065503 (2018)

LEGEND L200

Based on Two Current Large O(10 kg) Ge-0$\nu\beta\beta$ Experiments

GERDA
Bare ^{enr}Ge detectors immersed in instrumented LAr shield

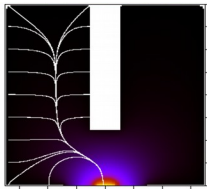




MAJORANA DEMONSTRATOR
^{enr}Ge detectors operated in vacuum cryostats in a passive graded shield with ultra-clean copper

Design Criteria

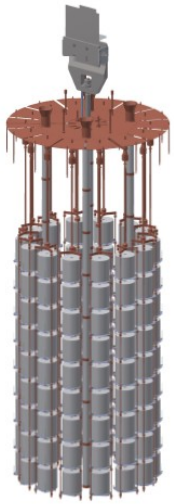
- Phased Approach
  - 200-500-1000 kg steps, for example
  - Allows operation of previously installed detectors
  - Use existing infrastructure for early phase to obtain near-term physics results
- Background goals
  - 200 kg: 0.6 c/(FWHM t y)
    - Required reduction only x5 better than MAJORANA/GERDA
    - Goal is similar to the best of the GERDA detectors
  - 1000 kg: <0.1 c/(FWHM t y)
- ~900 kg of additional enriched ^{76}Ge for 1000 kg
- 1000 kg of p-type, point-contact Ge detectors (2-3 kg/300-500 detectors)
- Resolution ~2.5 keV FWHM@2039 keV



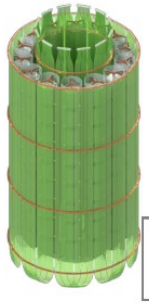
Inverted Coaxial Point-Contact Detector : > 2 kg

Mechanics following closely GERDA

130–140 kg of new ICPC detectors + 70 kg of detectors from GERDA & MAJORANA

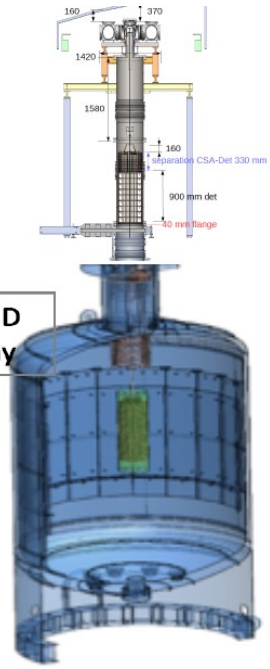


New String layout, PEN det. plates, front end electronics, & DAQ



New LAr veto, SiPM coupled fibers

COVID Delay



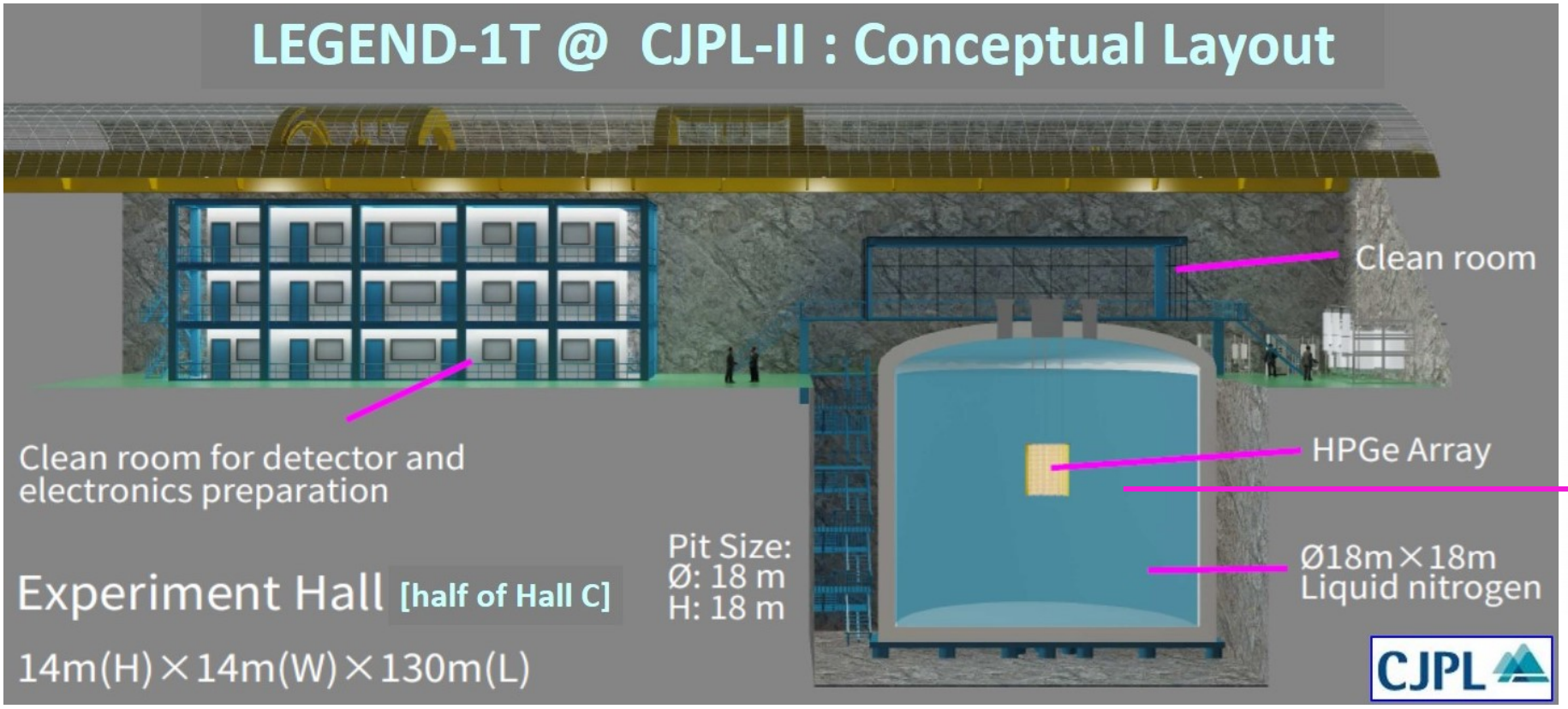
Upgrade GERDA cryostat: new lock, cabling detector suspension

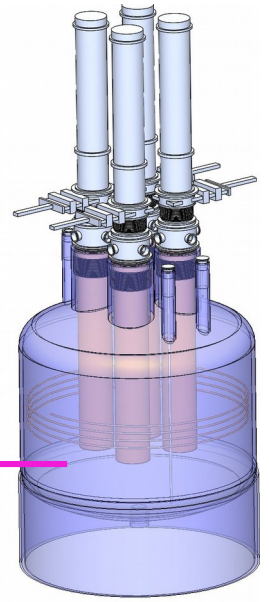
LNGS Hall A
GERDA water tank, modified cleanroom

1st stage

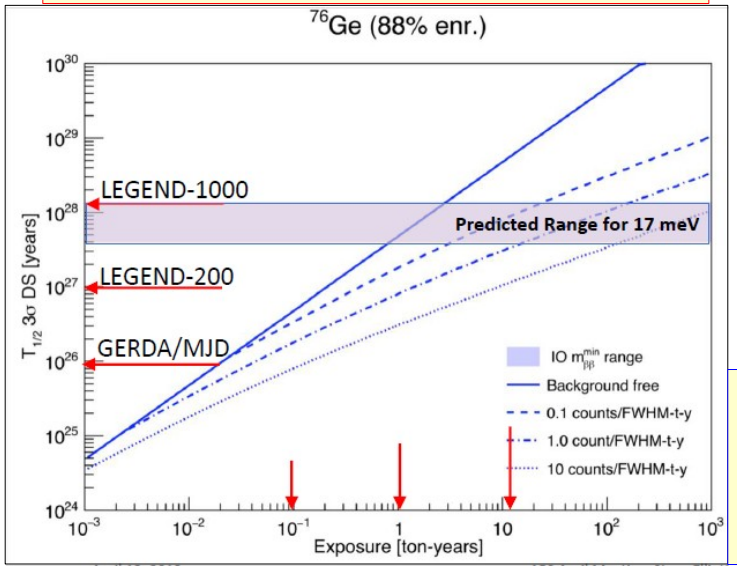
- (up to) 200kg in upgrade of Existing infrastructure @ LNGS
- Data start ~ End of This Year 2021

L1000





Sensitivity for 3σ signal discovery



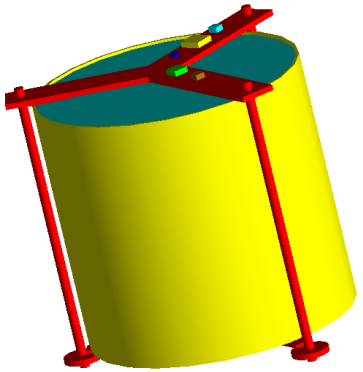
Subsequent Stages

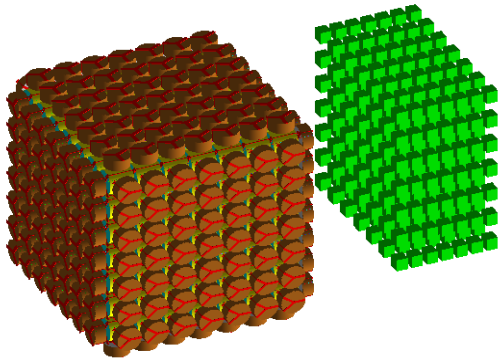
- 1000 kg, staged via individual payloads
- Timeline connected to review process
- Location not yet determined
- BKG Goal: < 0.1 counts/FWHM-ton-year
- Required depth (Ge-77m) under investigation

CDEX groups – exploring scenarios of hosting this experiment at CJPL-II

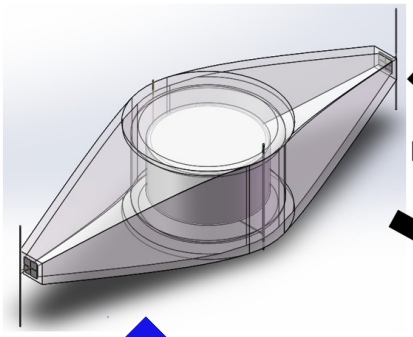
Our Contribution for LEGEND

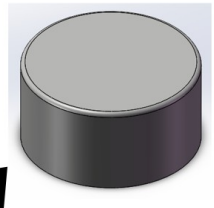
Geometry



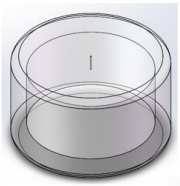


HPGe-PEN Unit

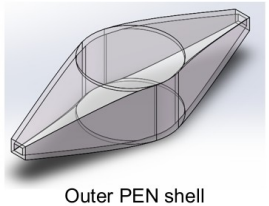




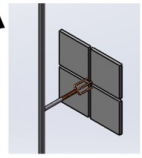
HPGe detector



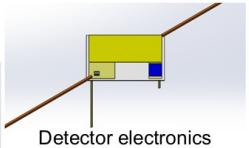
Inner PEN shell



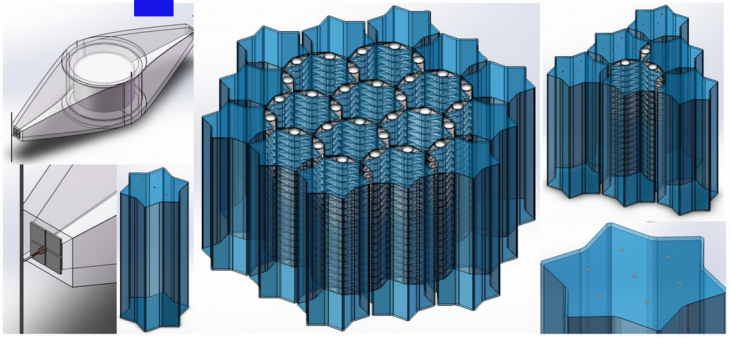
Outer PEN shell



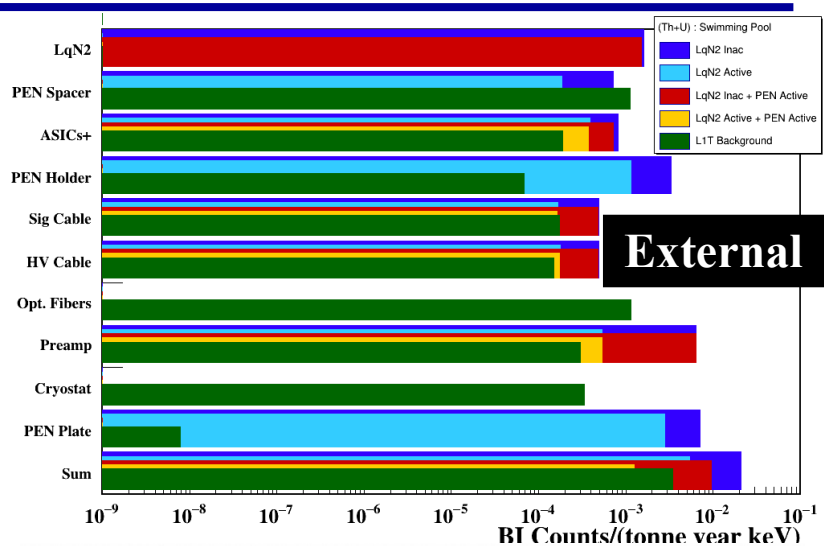
SiPM Readout array

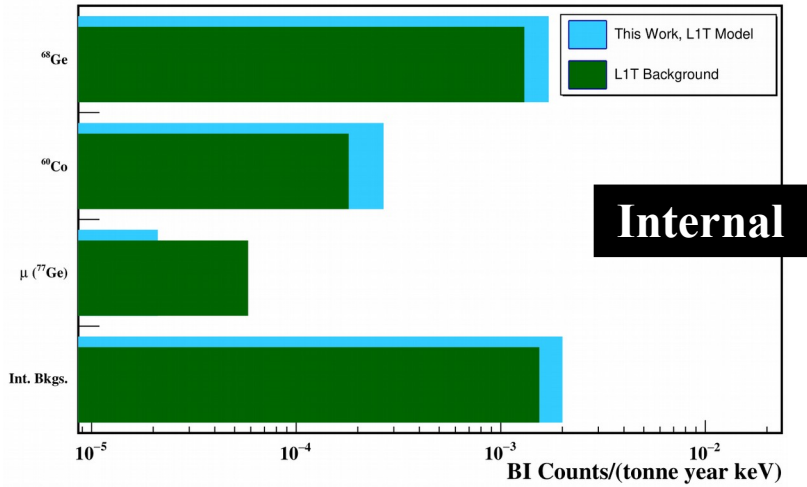


Detector electronics



Background Budget



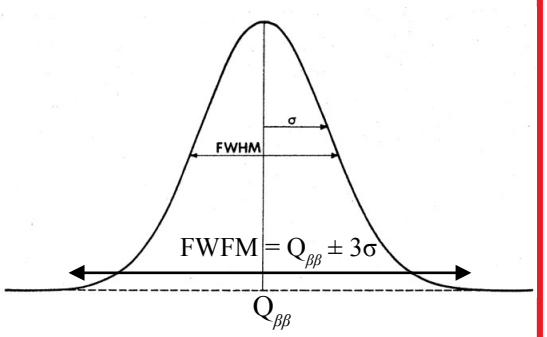


CDEX: Mastering Key Technologies towards Ge-1T

- ☑ Ge purification and crystal growth;
- ☑ HPGe detector fabrication;
- ☑ Ultra-low background VFE and FADC;
- ☑ Ultra-pure Cu for structure and cables;
- ☑ Large-volume cooling tank “cryostat”

Sensitivity Projection

- Background Index (BI) defined as: $BI = B_0(RoI)/\Sigma$
- Universally applicable



PRD 101, 013006 (2020)

Next-generation: 10 ton-year to cover IH

Resolution

$\Delta \leq (0.3\text{-}0.9)\%$ $\langle m_{\beta\beta} \rangle$ IH

$\Delta \leq (0.1\text{-}0.3)\%$ $\langle m_{\beta\beta} \rangle$ NH

Future Projects

Best Achieved Background-GERDA

RoI = $Q_{\beta\beta} \pm 3\sigma$

RoI = $w_{1/2}$(FWHM)

Benchmark [1 count/($w_{1/2}$-Σ)]

NH

IH

Preferred hardware specification space

$\langle m_{\beta\beta} \rangle^{NH}_{-}$

$\langle m_{\beta\beta} \rangle^{NH}_{95\%}$

$\langle m_{\beta\beta} \rangle^{IH}_{-}$

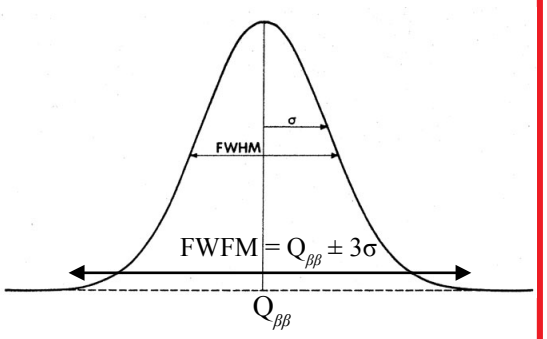
$\langle m_{\beta\beta} \rangle^{IH}_{95\%}$

Σ (ton-yr)

BI [counts/($w_{1/2}$-ton-yr)]

Sensitivity Projection

- Background Index (BI) defined as: $BI = B_0(RoI)/\Sigma$
- Universally applicable



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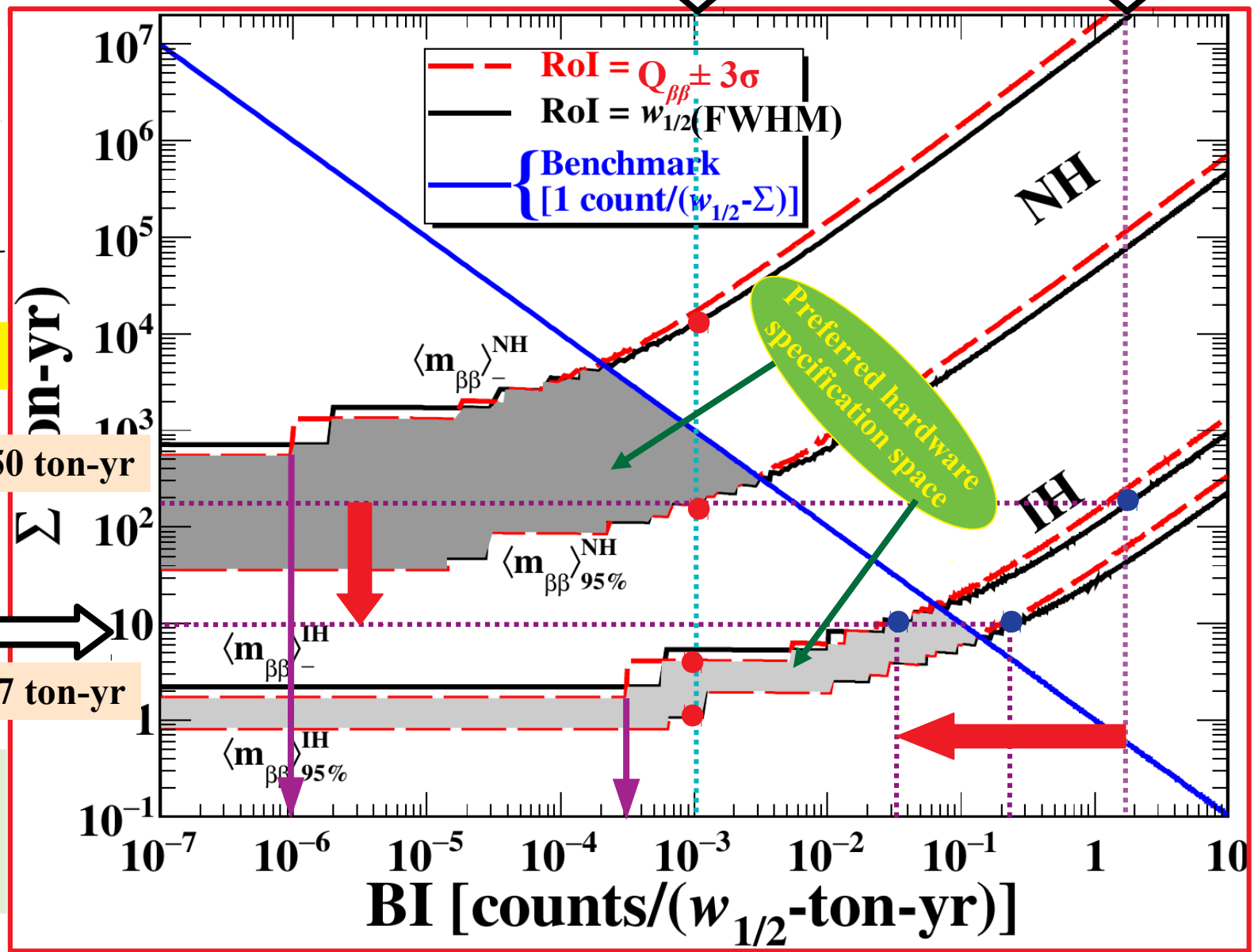

Thank You !