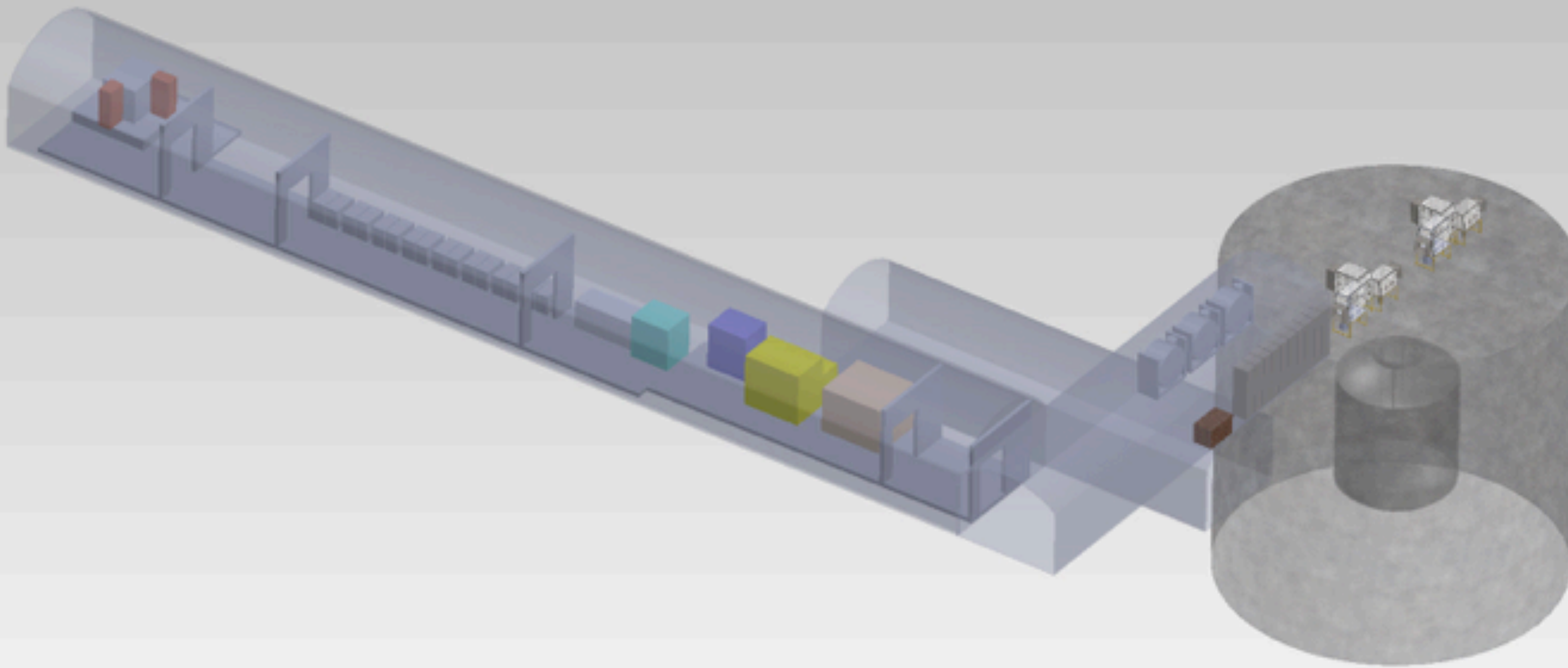
Conceptual Ton Scale ^{76}Ge $0\nu\beta\beta$



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TUNL

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Outline

- Justification for ton scale — sensitivity and backgrounds
- Signals and backgrounds.
- Conceptual Design and issues
- Summary

NLDBD NSAC - Next Generation Experiments

The Subcommittee recommends the following guidelines be used in the development and consideration of future proposals for the next generation experiments:

1.) **Discovery potential**: Favor approaches that have a credible path toward reaching 3σ sensitivity to the effective Majorana neutrino mass parameter $m_{\beta\beta}$=15 meV within 10 years of counting, assuming the lower matrix element values among viable nuclear structure model calculations.

2.) **Staging**: Given the risks and level of resources required, support for one or more intermediate stages along the maximum discovery potential path may be the optimal approach.

3.) **Standard of proof**: Each next-generation experiment worldwide must be capable of providing, on its own, compelling evidence of the validity of a possible non-null signal.

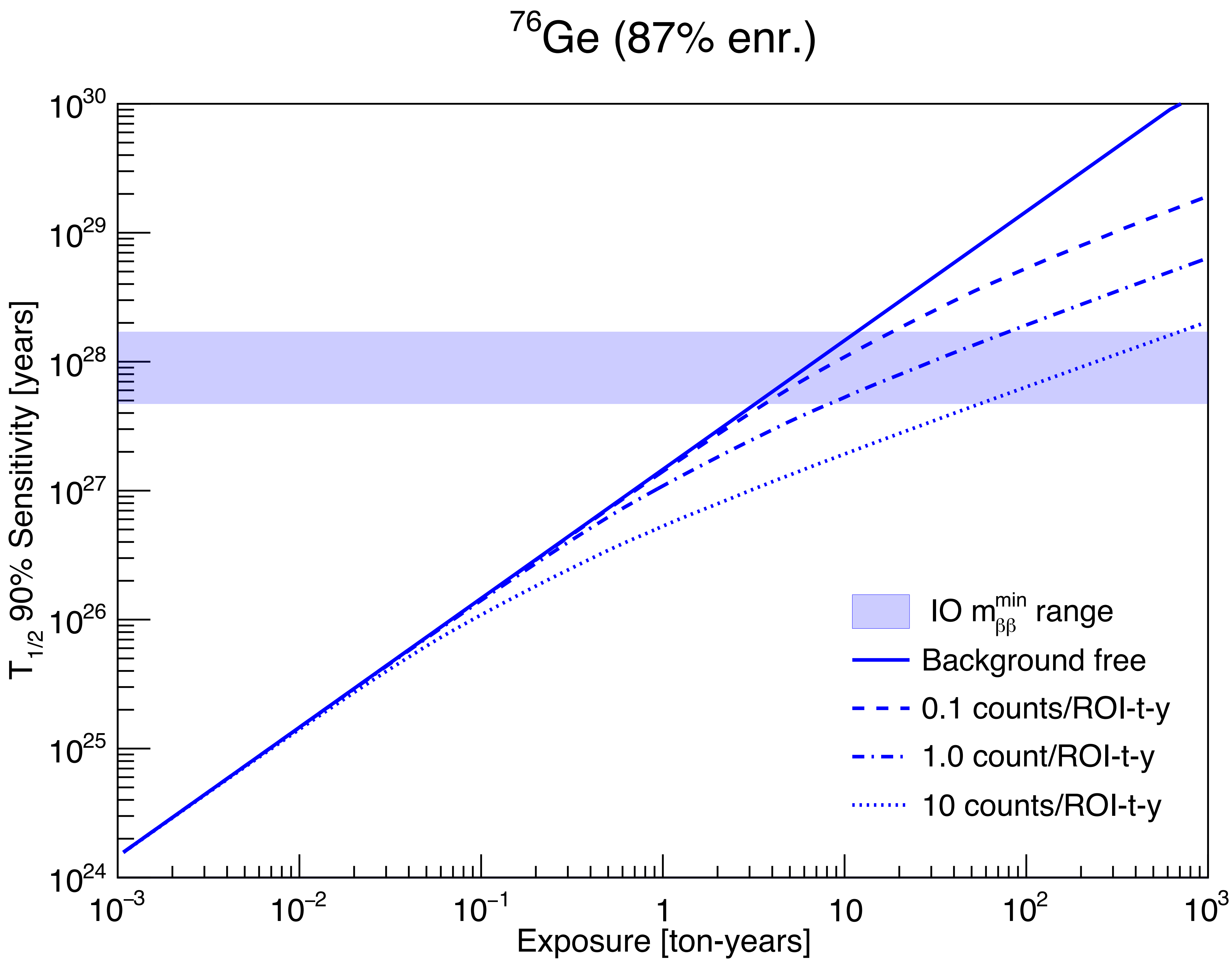
4.) **Continuing R&D**: The demands on background reduction are so stringent that modest scope demonstration projects for promising new approaches to background suppression or sensitivity enhancement should be pursued with high priority, in parallel with or in combination with ongoing NLDBD searches.

5.) **International Collaboration**: Given the desirability of establishing a signal in multiple isotopes and the likely cost of these experiments, it is important to coordinate with other countries and funding agencies to develop an international approach.

6.) **Timeliness**: It is desirable to push for results from at least the first stage of a next-generation effort on time scales competitive with other international double beta decay efforts and with independent experiments aiming to pin down the neutrino mass hierarchy.

Sensitivity vs. Exposure ^{76}Ge

J. Detwiler



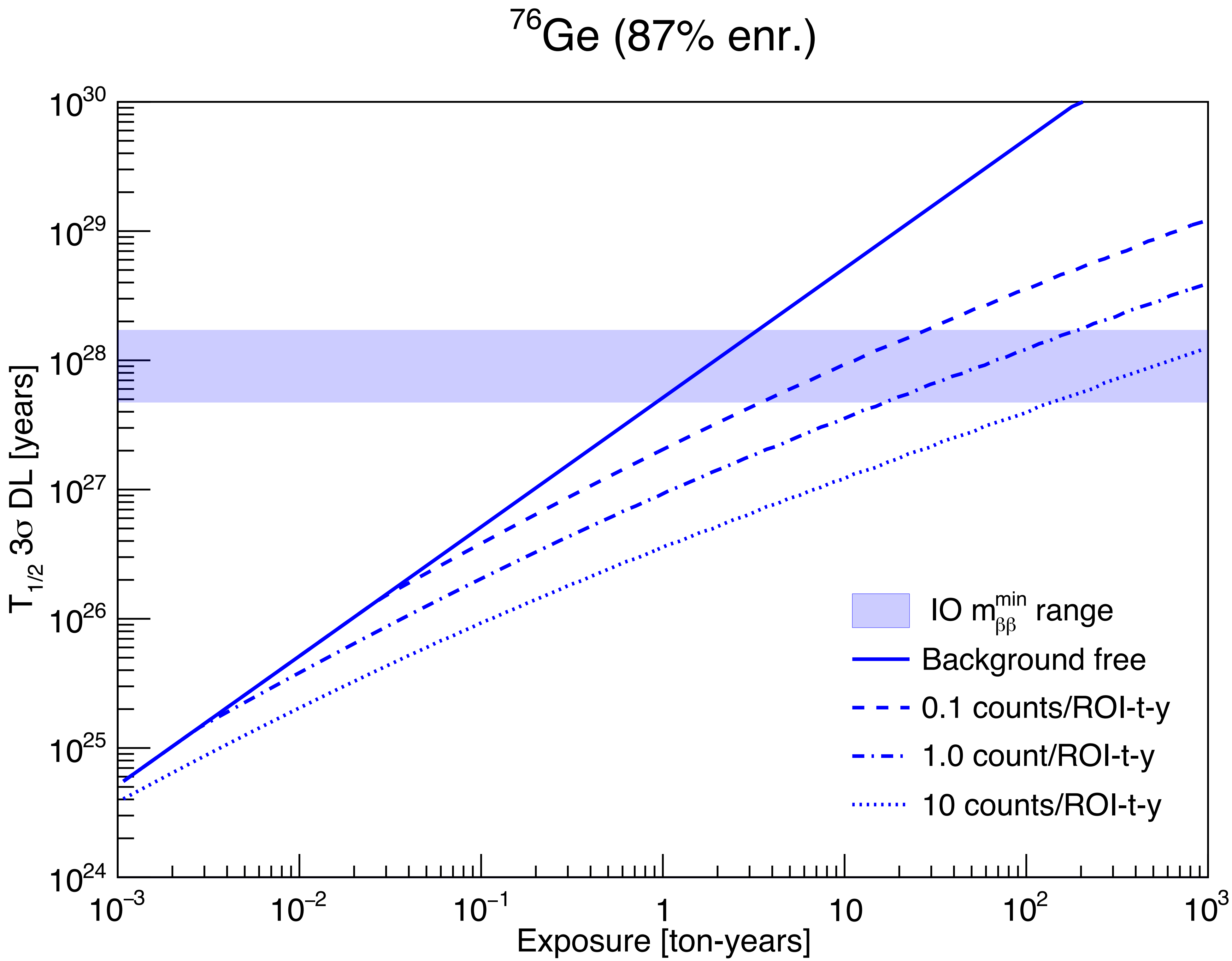
Inverted Ordering (IO)

Minimum IO $m_{\beta\beta}$=18.3 meV, taken from using the PDG2013 central values of the oscillation parameters, and the most pessimistic NME for the corresponding isotope among QRPA, SM, IBM, PHFB, and EDF

Assumes 75% efficiency based on GERDA Phase I. Enrichment level is accounted for in the exposure

3σ Discovery vs. Exposure for ^{76}Ge

J. Detwiler



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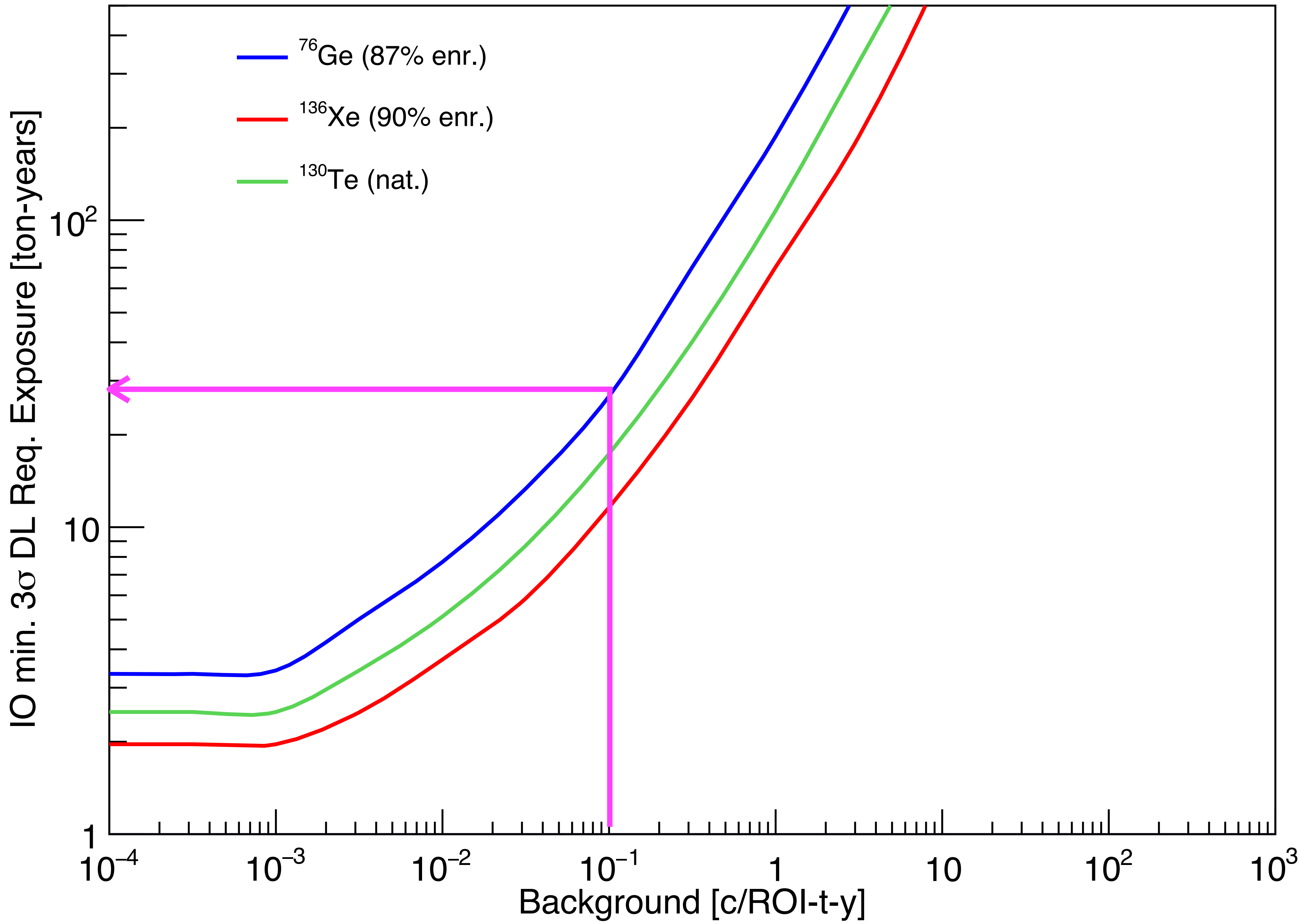
Required 3σ Exposure vs. Background

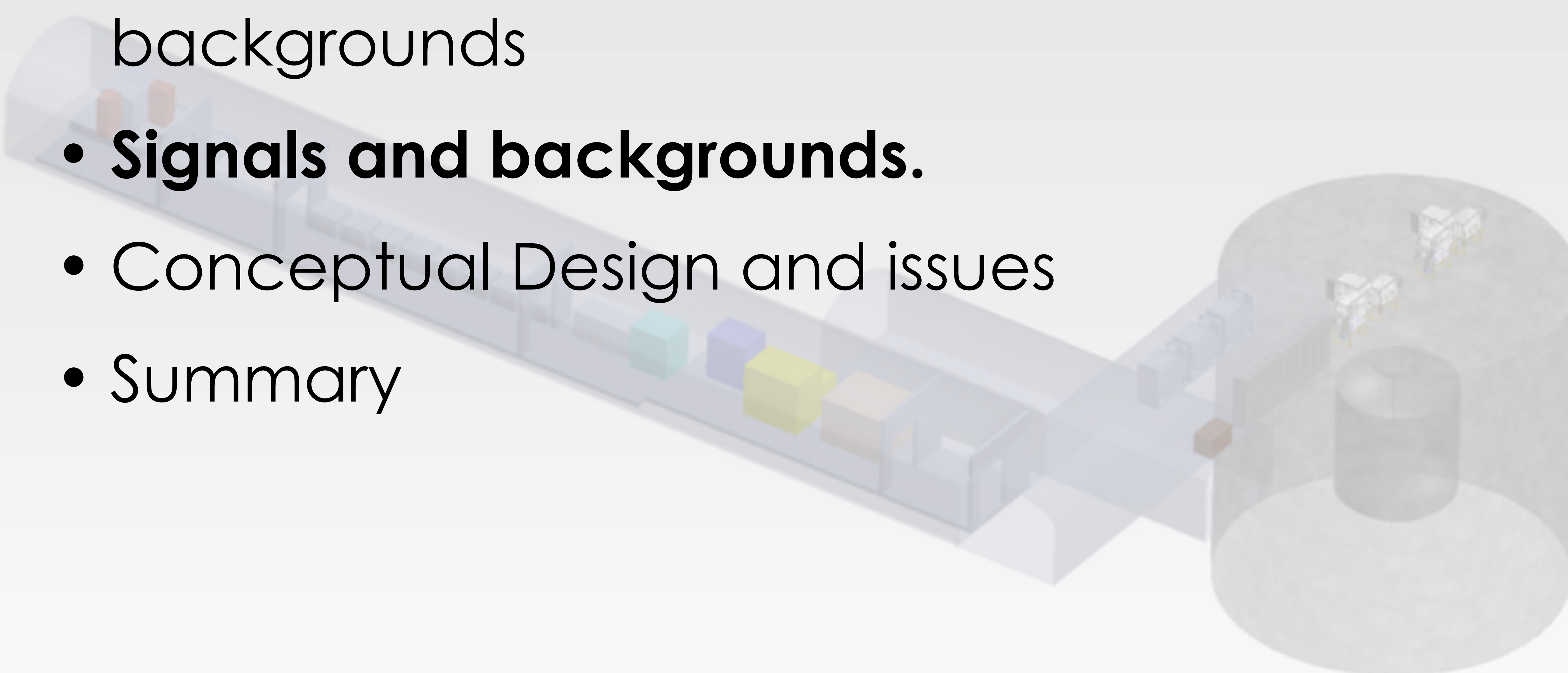
J. Detwiler



"Required" exposure assuming minimum IO $m_{\beta\beta}$=18.3 meV, taken from using the PDG2013 central values of the oscillation parameters, and the most pessimistic NME for the corresponding isotope among QRPA, SM, IBM, PHFB, and EDF

Outline

- Justification for ton scale — sensitivity and backgrounds
- **Signals and backgrounds.**
- Conceptual Design and issues
- Summary



0νββ signals & sensitivity

Half life (years)	~Signal (cnts/tonne-year)
10^{25}	500
5×10^{26}	10
5×10^{27}	1
5×10^{28}	0.1
$>10^{29}$	0.05

$$\left[T_{1/2}^{0\nu}\right] \propto \varepsilon ff \cdot I_{abundance} \cdot Source\ Mass \cdot Time$$

Background free

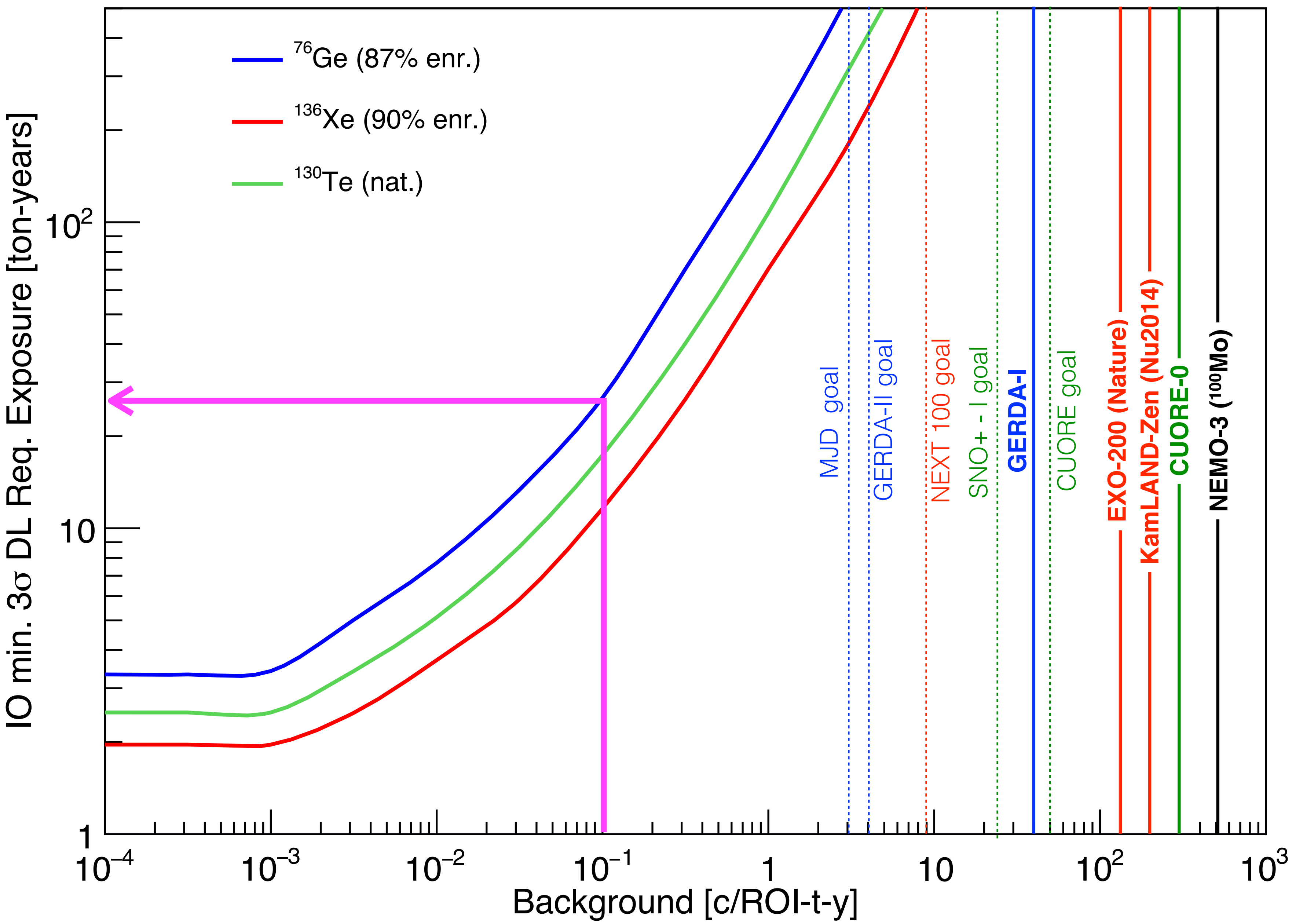
$$\left[T_{1/2}^{0\nu}\right] \propto \varepsilon ff \cdot I_{abundance} \cdot \sqrt{\frac{Source\ Mass \cdot Time}{Bkg \cdot \Delta E}}$$

Background limited

Note : Backgrounds do not always scale with active detector mass

3σ Discovery vs. Background

J. Detwiler



Take away:

Realistically, a next generation experiment should aim for backgrounds at or below 0.1 c/ROI-t-y

Outline

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- Signals and backgrounds.
- **Conceptual Design and issues**
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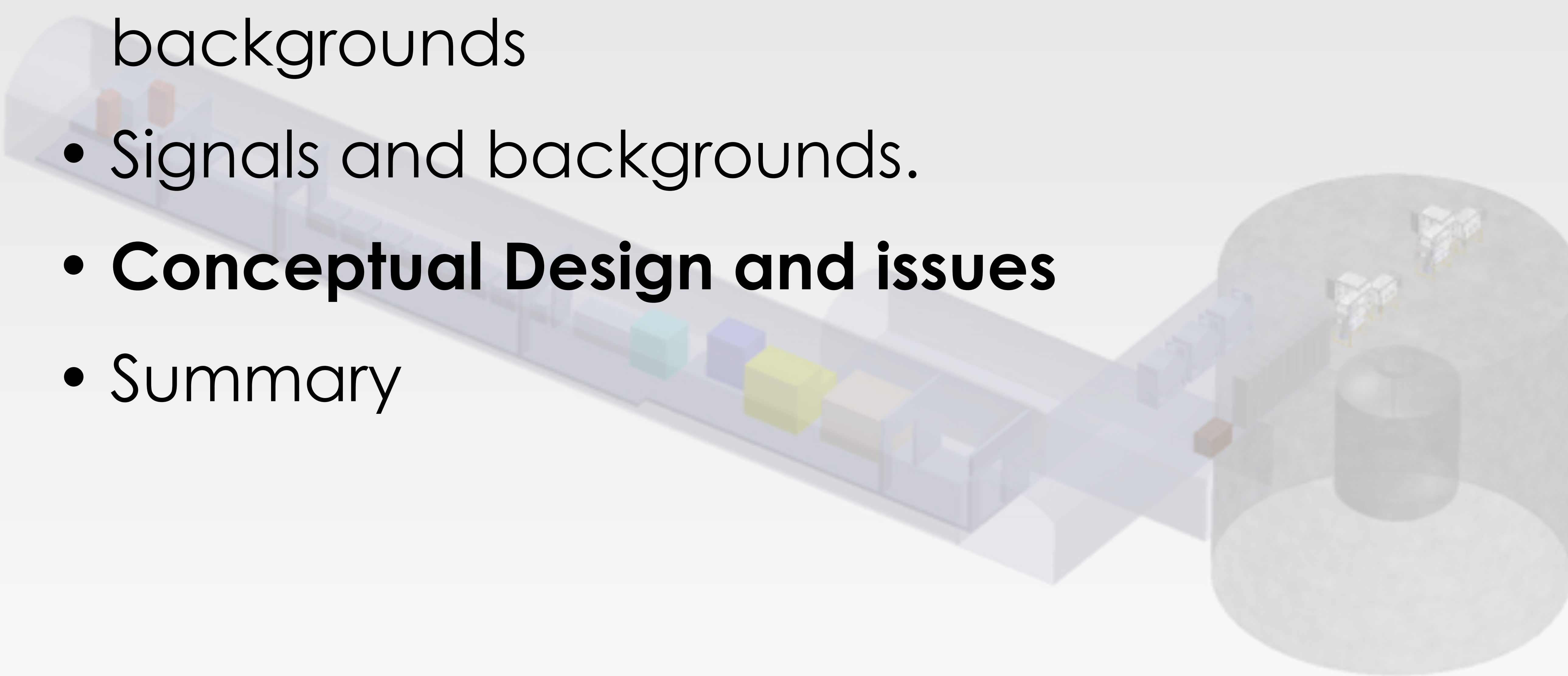
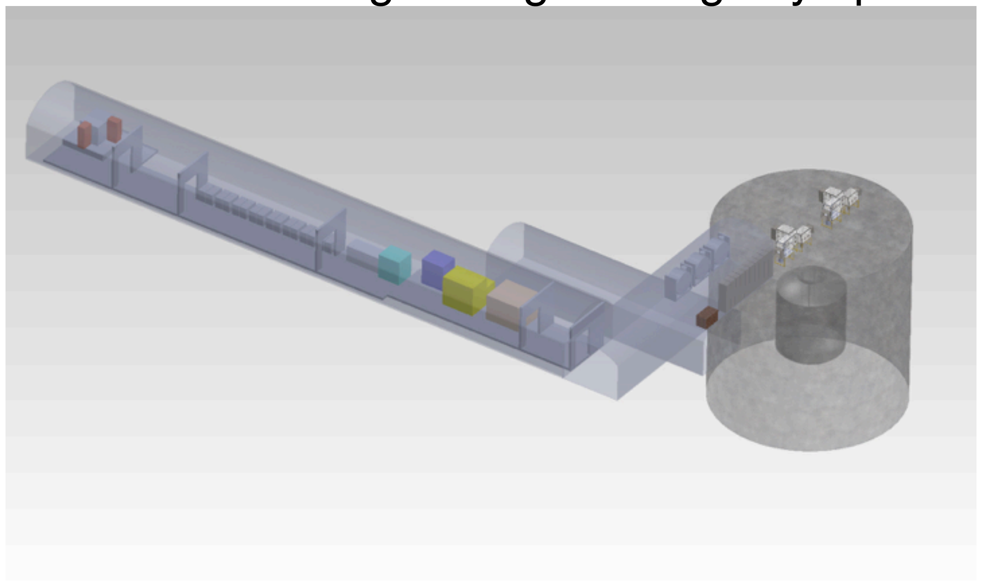


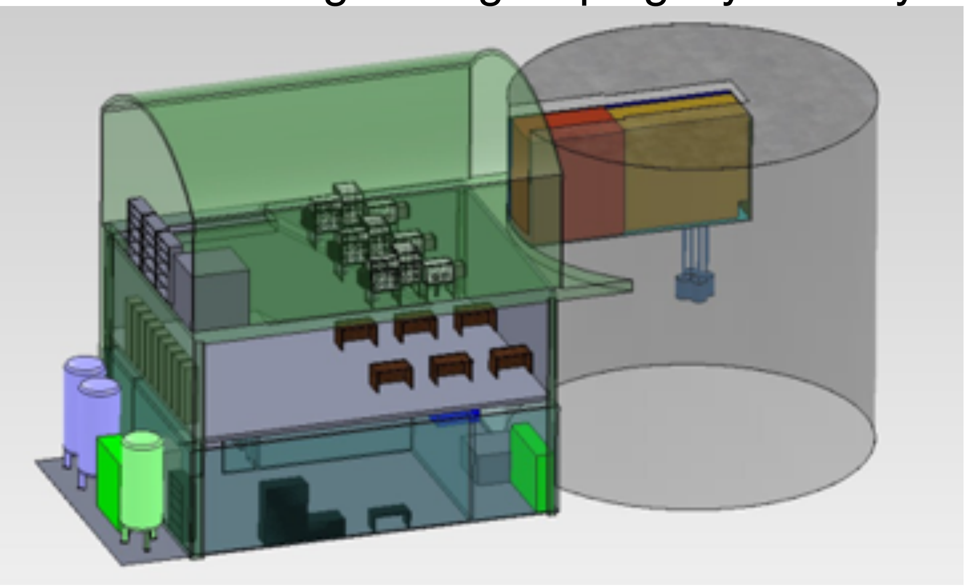
Next Generation ton scale ^{76}Ge $0\nu\beta\beta$

- Goal: background of 0.1 c / ROI-t-y
  5 yr 90% CL sensitivity: $T1/2 > 6.1 \cdot 10^{27}$ yr
  5 yr 3σ discovery: $T1/2 \sim 5.9 \cdot 10^{27}$ yr
- Moving forward predicated on ***demonstration*** of projected backgrounds by GERDA and/or MJD, with further reductions extrapolated to the ton scale.
- Envision a phased, stepwise implementation;
  e.g. 200 → 500 → 1000 kg
- Anticipate down-select of best technologies, based on what has been learned from GERDA and the MAJORANA DEMONSTRATOR, as well as contributions from other groups and experiments.

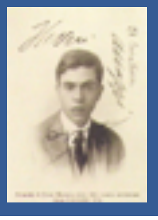
SNOLAB Design using existing Cryo pit.



Generic Design using Jinping style cavity



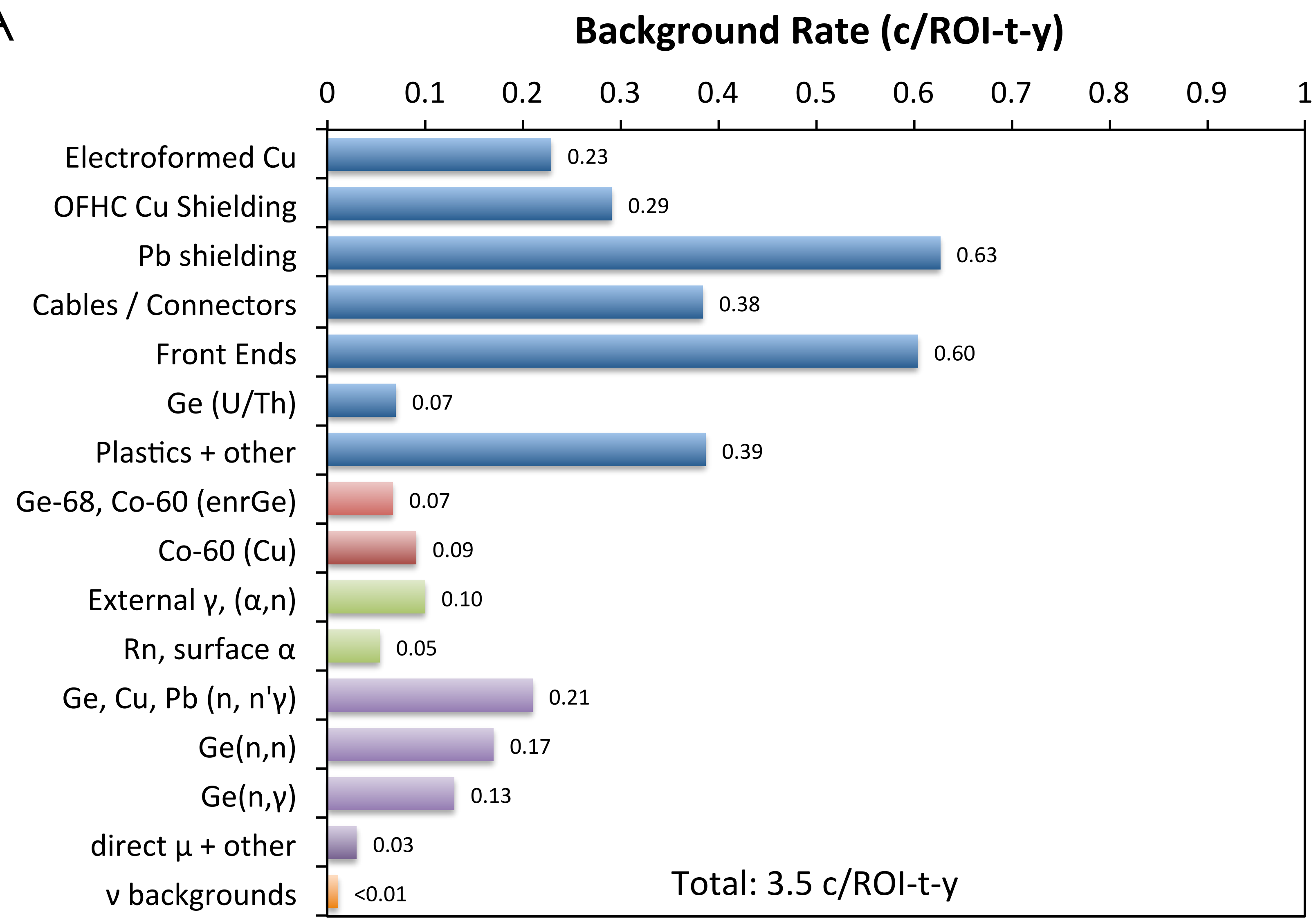
Next generation ^{76}Ge experiment



If MJD and GERDA Phase II reach their background goals of ~4 c/ROI-t-y, that would scale to 1 c/ROI-t-y for a large scale Ge experiment.

Based on both discovery level and sensitivity considerations, the aim is for a total background budget of ≤ 0.1 c/ROI-t-y.

Building on MJD and GERDA how does one get there?



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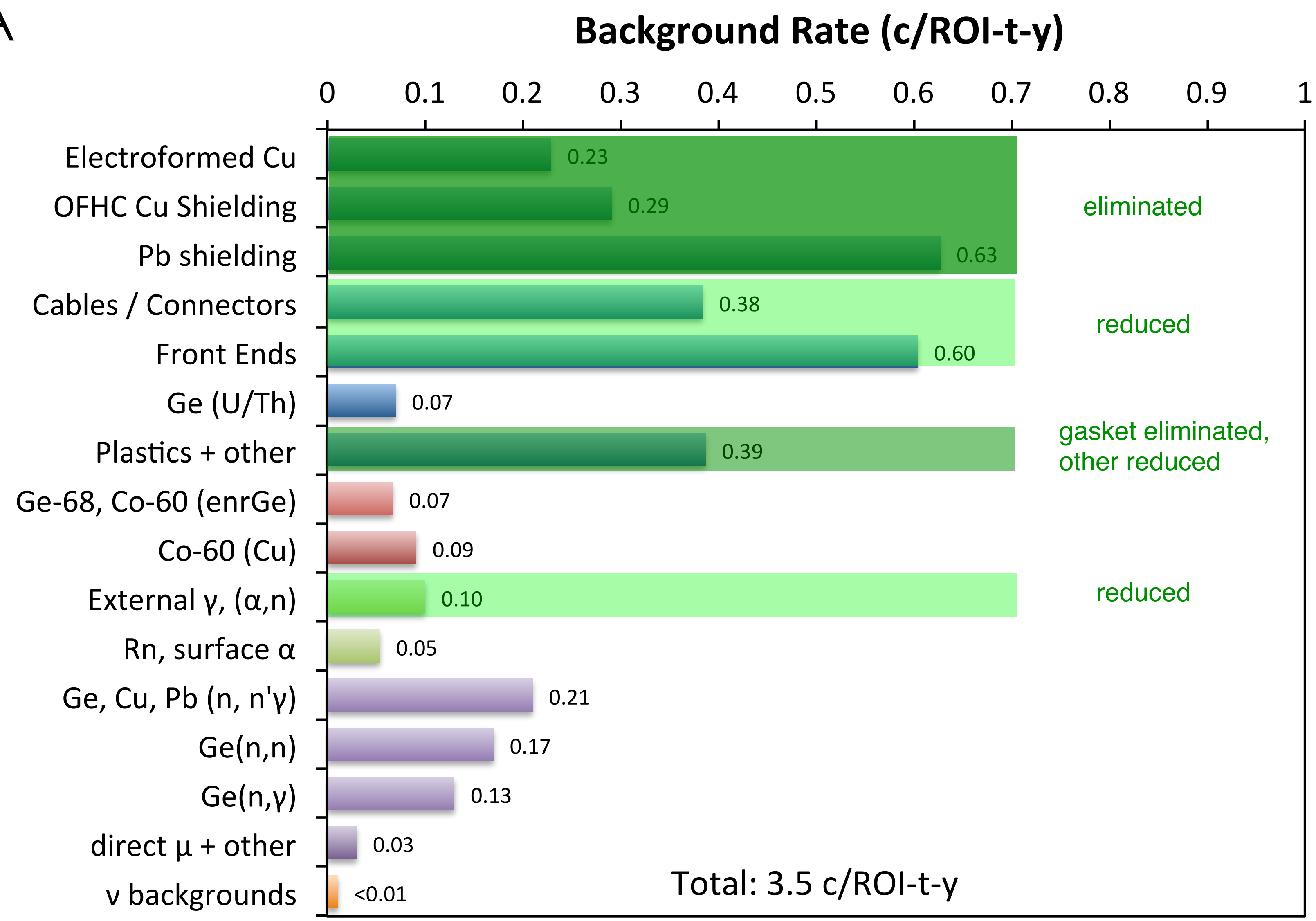
Building on MJD and GERDA how does one get there?

- clean, active shield



Next generation ^{76}Ge experiment

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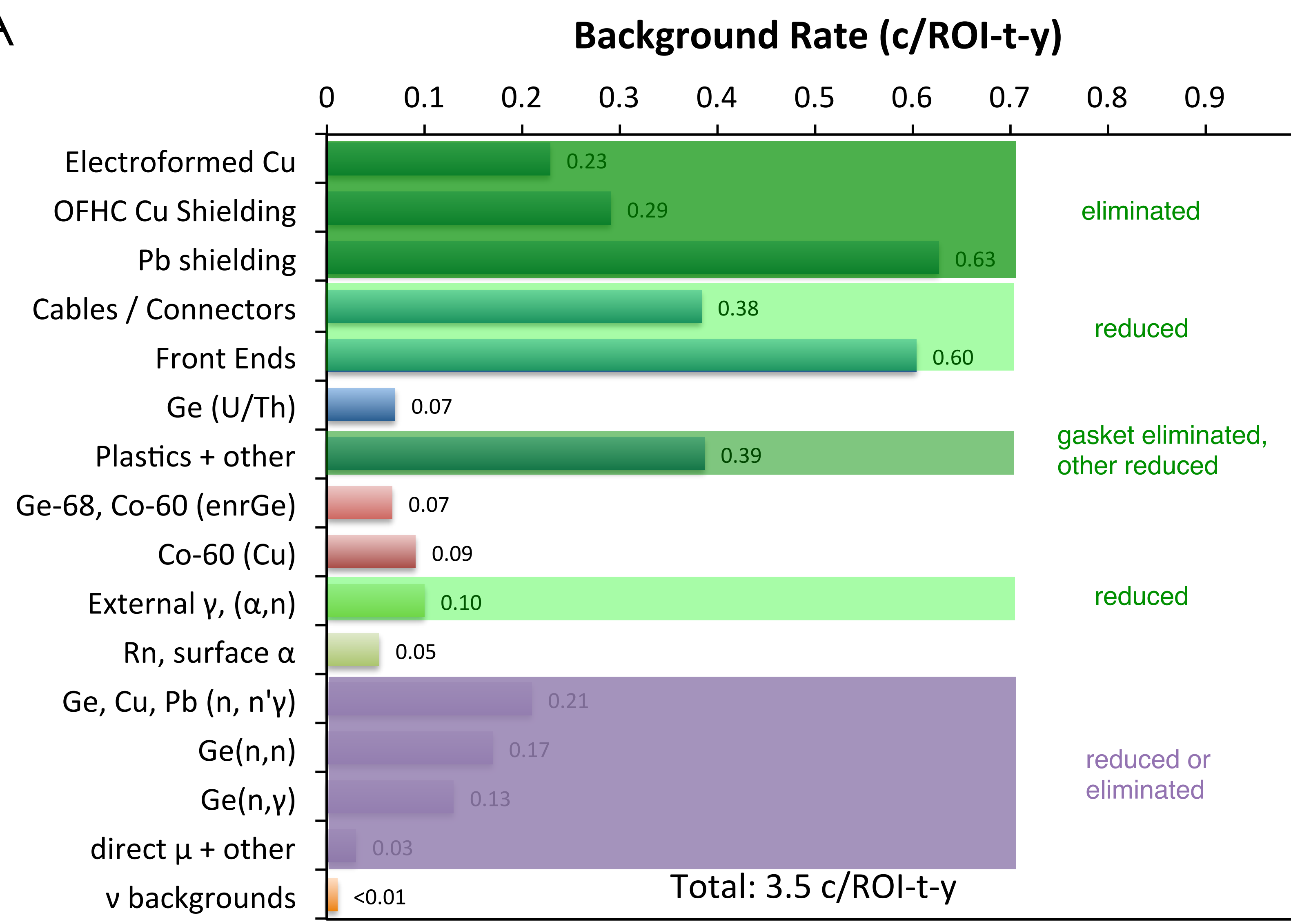
Building on MJD and GERDA how does one get there?

- clean, active shield
- deeper and/or active shield



Next generation ^{76}Ge experiment

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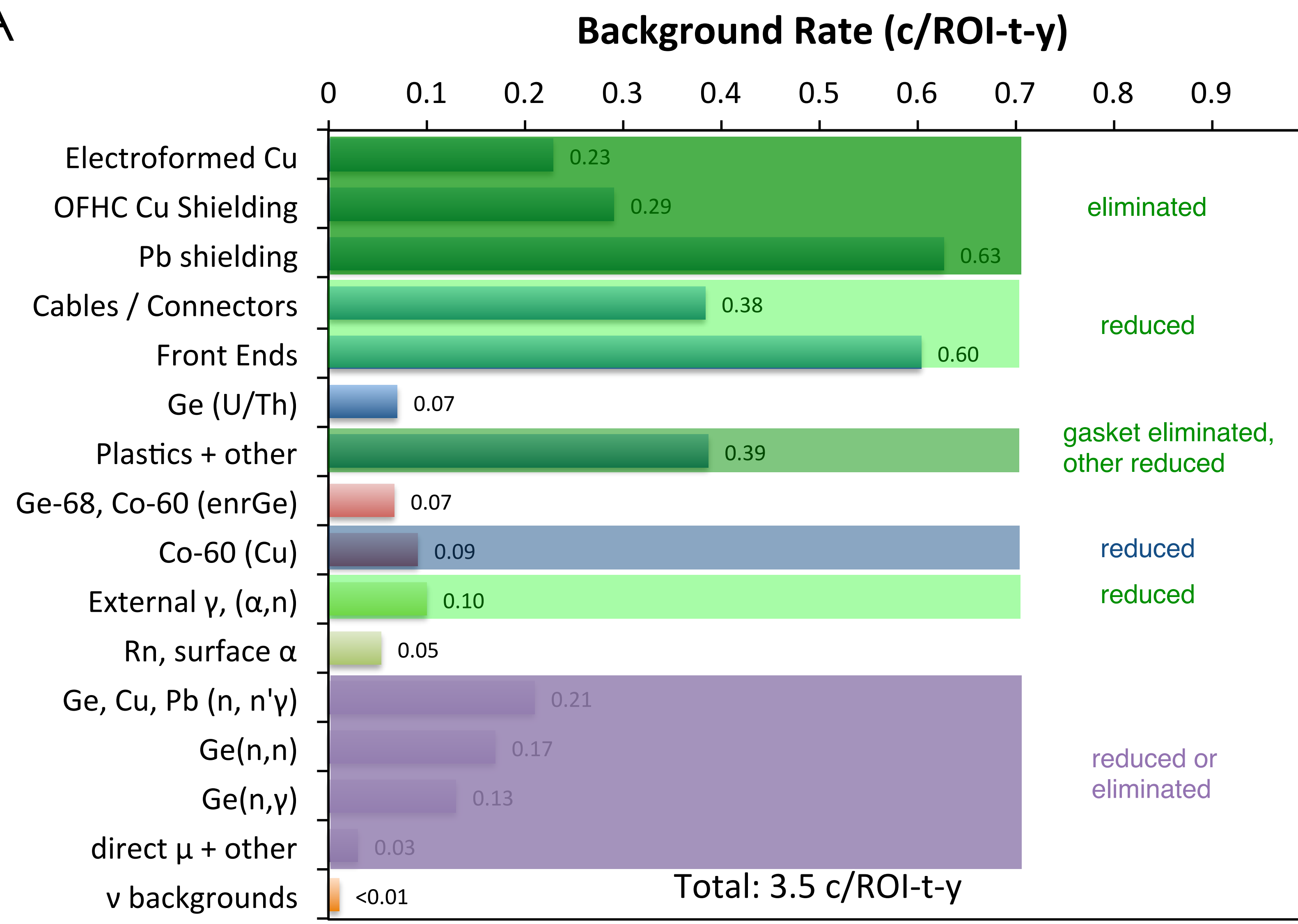
Building on MJD and GERDA how does one get there?

- clean, active shield
- deeper and/or active shield
- EF all Cu underground



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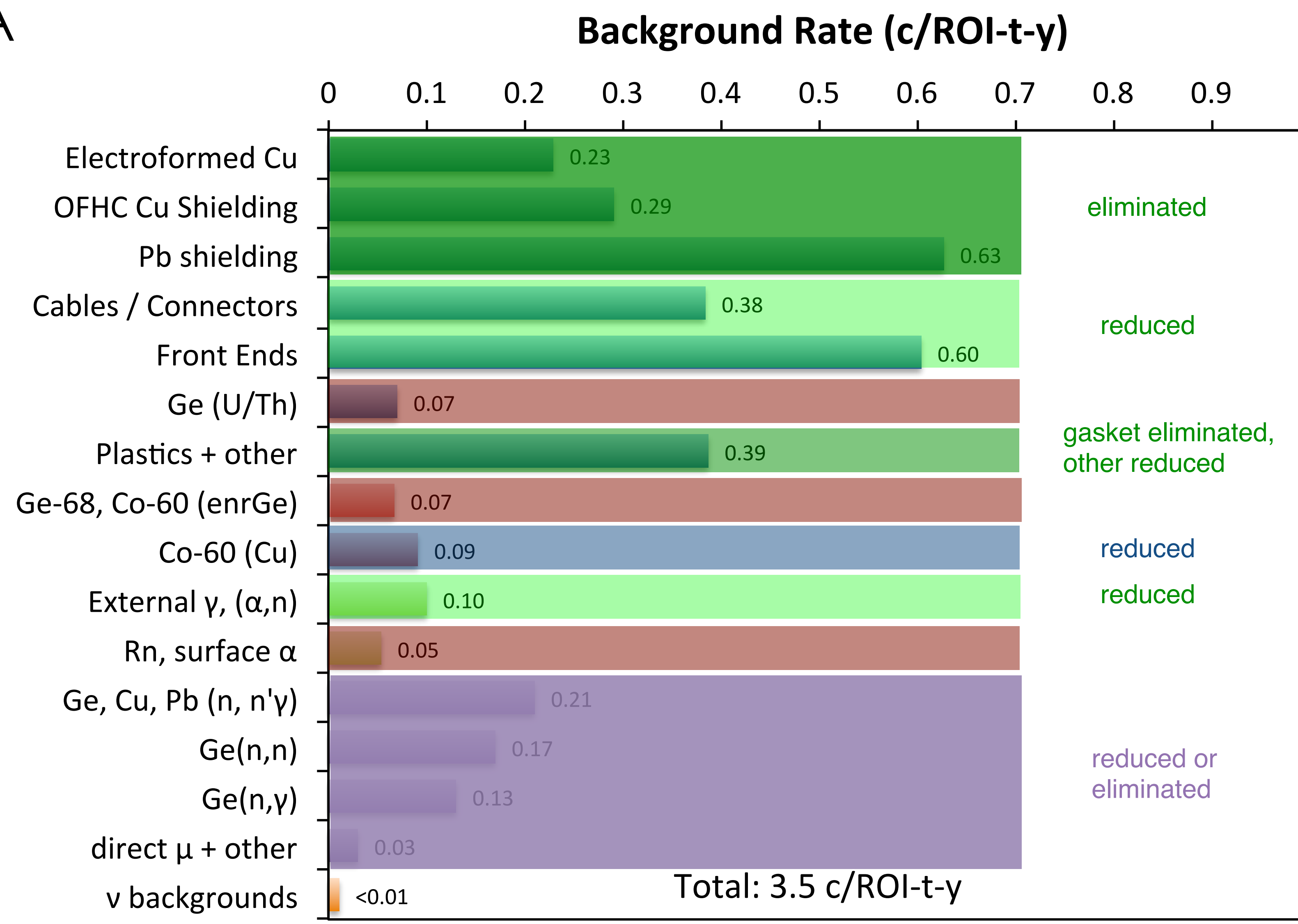
Building on MJD and GERDA how does one get there?

- clean, active shield
- deeper and/or active shield
- EF all Cu underground
- Learn from MJD & GERDA II (values are largely upper limits)



NG-Ge76 Conceptual Design

Based on GERDA and MAJORANA DEMONSTRATOR
(will focus on ton scale issues)

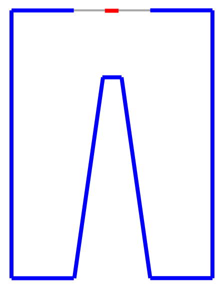
- Enriched material
- Detectors
- Ultra-clean materials and Assay
- Cables and connectors
- Clean, automated fabrication and assembly
- Active Shield
- Deep underground laboratory

NG-Ge76 Concept : Isotope

- Isotopic Enrichment from 7.8% to 87% ^{76}Ge.
- GERDA and MJD acquired enriched material from Zelenogorsk Electrochemical Plant Zelenogorsk, Russia.
  - Need 1200 kg (so ~12 tons of feed stock)
    - world production of germanium is 165 tons per year
- Refinement and recycling has been demonstrated.
- Issues
  - **Quantity and throughput** — requires annual enriched production rate of ~250 kg per year.
  - **Cost** — \$55 - \$100 per gram
  - Alternative enrichment methods and/or sources of enriched material could address both problems.

NG-Ge76 Concept : Detectors

- Point contact detectors, size of 600 -1000 g
- Multiple vendors available — Amtek, Canberra
- Issues
  - **Detector size** : would like to have detectors with 2-3 kg mass with good yield. Would result in 350 - 500 detectors.

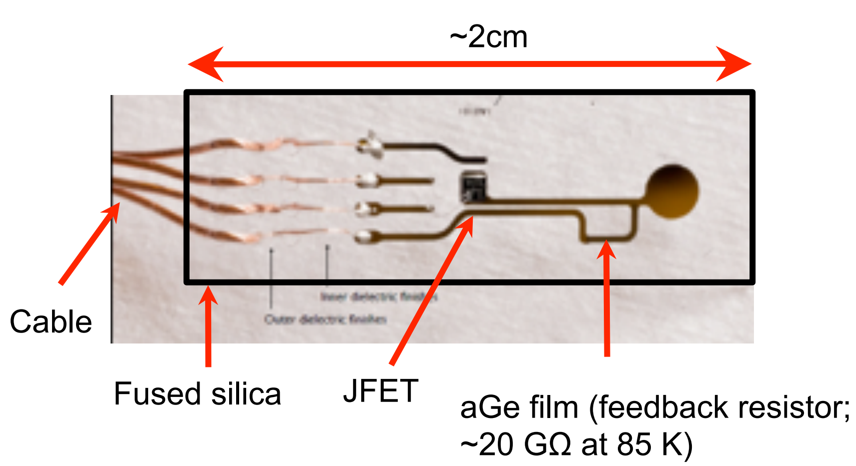


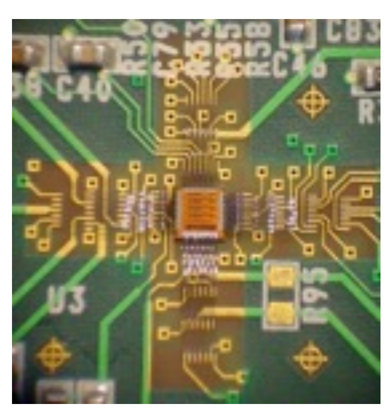
  - **Throughput** : requires producing 3-5 detectors per week (over 3-4 year period). Exceeds current vendor capabilities.
  - **Automation ?** : during production, characterization, …
  - **Backgrounds**
    - Need to reduce Rn exposure (alpha backgrounds)
    - May need to grow/fabricate underground
    - “Shielding” backgrounds — GERDA (^{42}K); MJ (EFCu)
  - **Cost** — $30k per detector (for kg size)

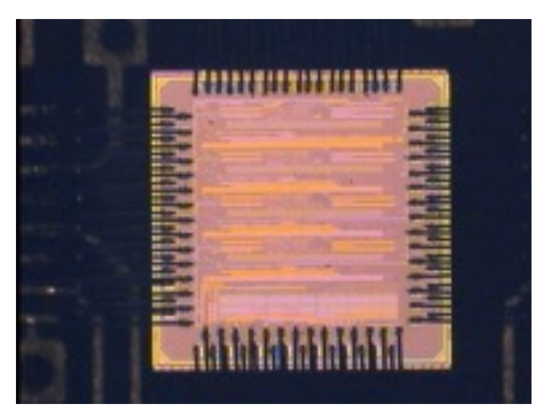
Detectors and readout R&D

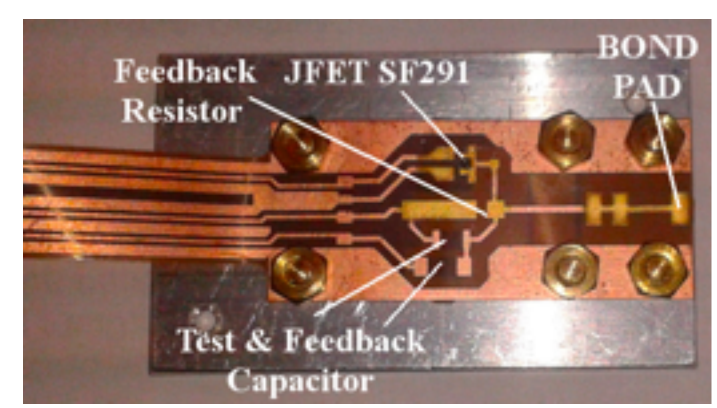
- **Alternative Detector Designs**
  - Larger detectors with thin contacts would use the valuable enriched Ge more efficiently.
  - Larger detectors improve the ratio of Ge mass to readout system mass, reducing backgrounds.
  - Explore alternatives to thick Li contacts, improved improved fiducial volume.

- **Detector Signal Readout**
  - In current MJD two stage approach, the readout design has reached its limit due to the maximum cable length
  - study feasibility of in-situ amplification with a custom ASIC and improvement to the front-end
  - investigate integrating much of the signal processing into a single ASIC, optimized for in-situ operation at cryogenic temperature.





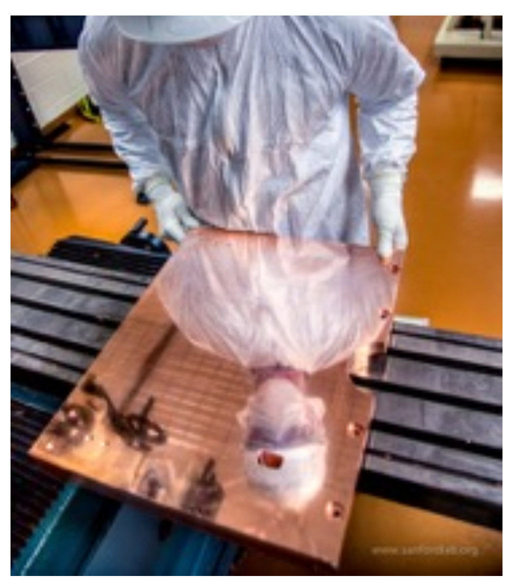




NG-Ge76 Concept : Materials & Assay

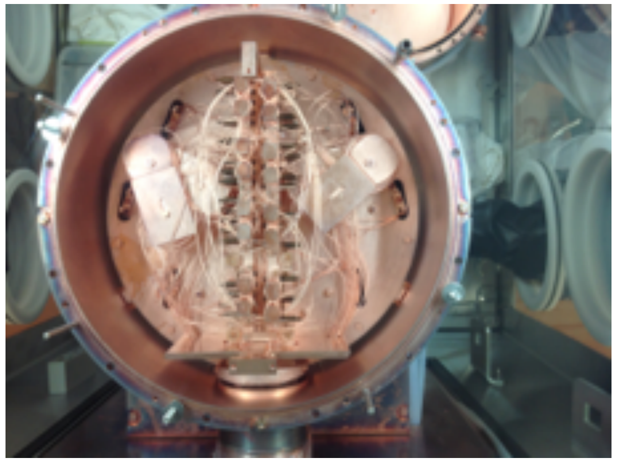
- Have developed a suite of ultra clean materials including capabilities to produce ultra-clean electroformed copper, machined underground.
- Also developed ultra-sensitive assays for next generation experiments.
- Issues
  - Surface and Rn contamination.
  - Investigate new advanced materials — electroforming : Cr, Cr-Cu alloys; plastics : polyethylene naphthalate (PEN), …
  - Cost and throughput of assays.

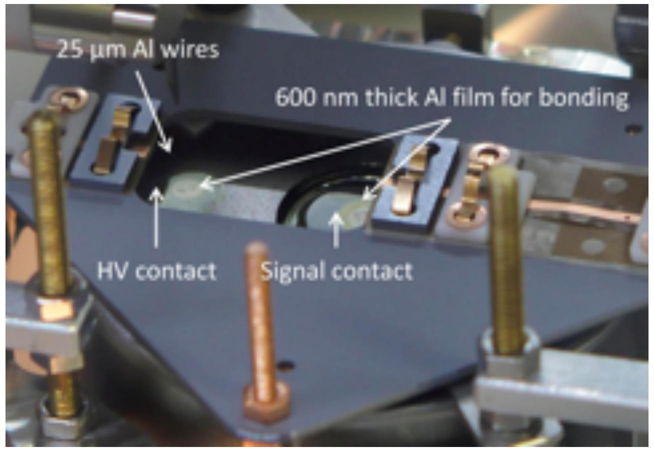
EF copper after turning on lathe



NG-Ge76 Concept : Cables & Connectors

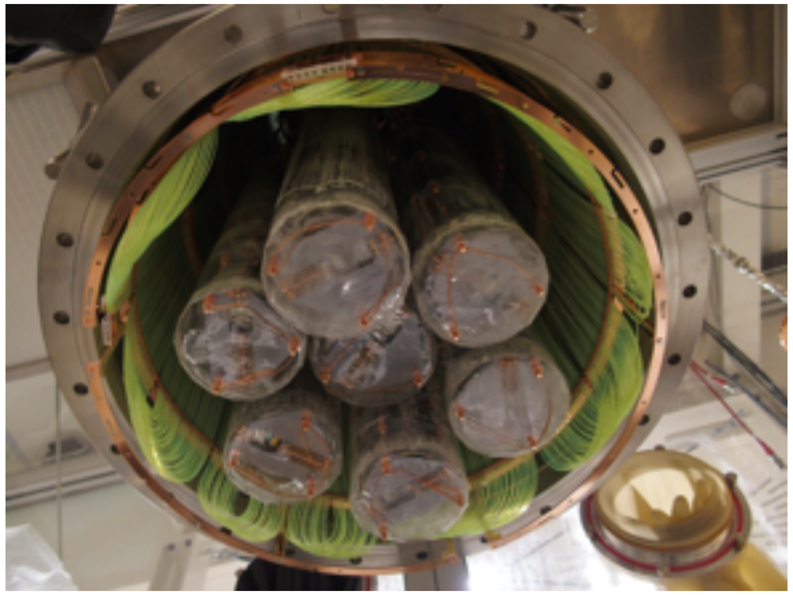
- Have produced some of the lowest activity cables and connectors currently in use.
- Tension between low-activity components and robust electrical connections (e.g. clean spring material). MJD and GERDA have encountered connection or connector issues.
- Issues
  - Reliable low-temperature connections. Automation of connections
  - Backgrounds - improve Cu wire radiopurity
  - High voltage contact
  - Designs that eliminate close-by connections.

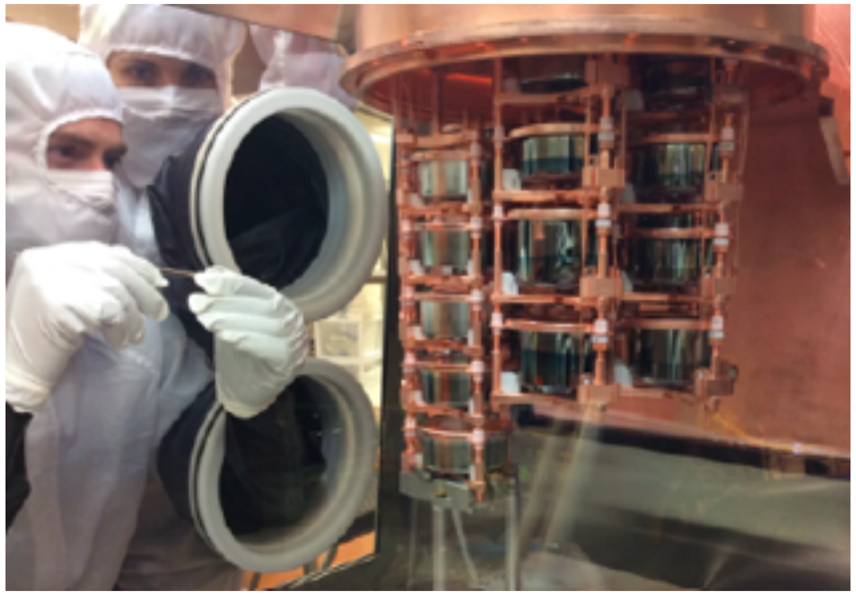




NG-Ge76 Concept : Clean, automated assembly

- Clean, underground machine shop.
- Rn mitigation via glove boxes.
- Clean assembly — class ~ 100 to 1000
- Issues
  - Improved radon mitigation.
  - Automation needed for assembly & connections.
  - Minimization of complexity





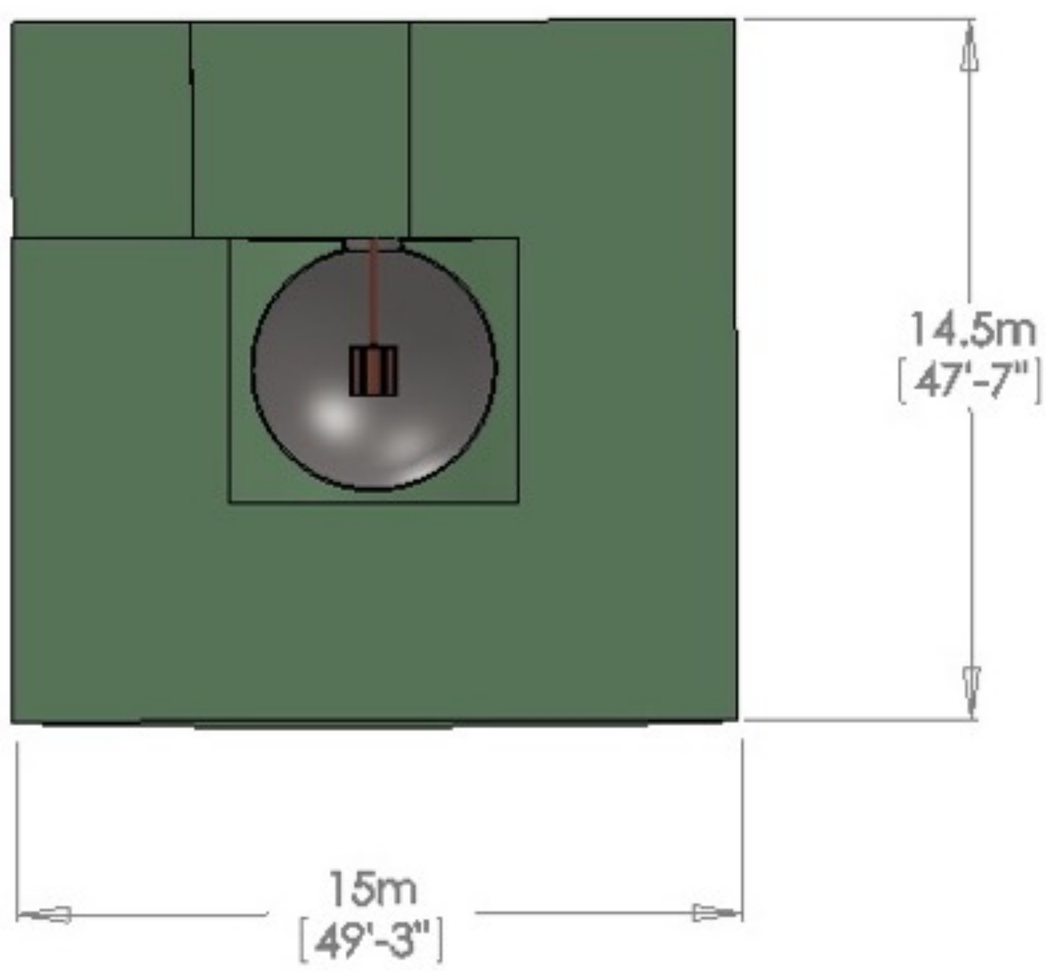
NG-Ge76 Concept: Preliminary shield ideas

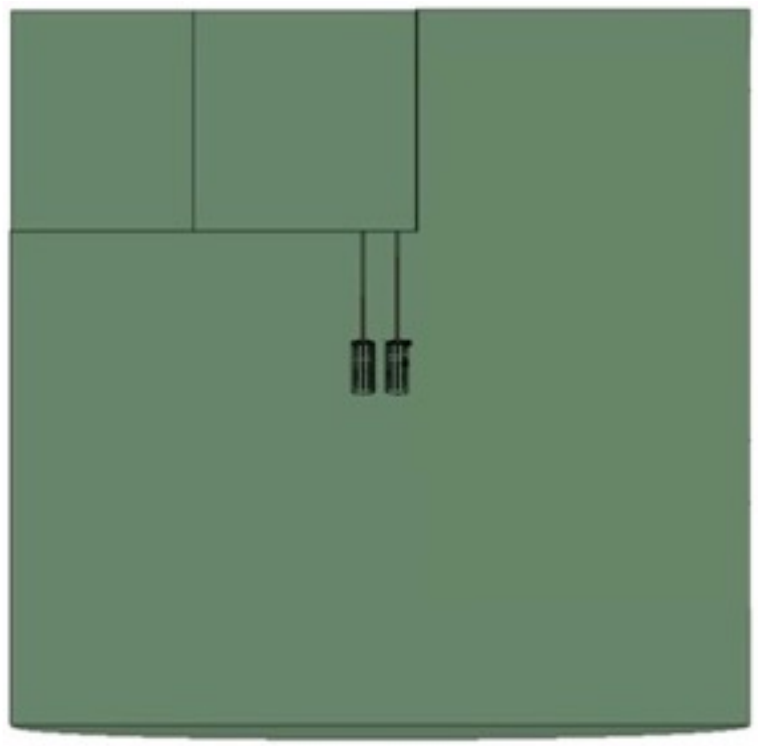
GERDA type LAr Shield

- ^{76}Ge array submersed in LAr
- Use LAr as Compton suppression and veto
- Water Cherenkov μ veto

Alternative Design

- vacuum cryostat with local active veto in water or liquid scintillator

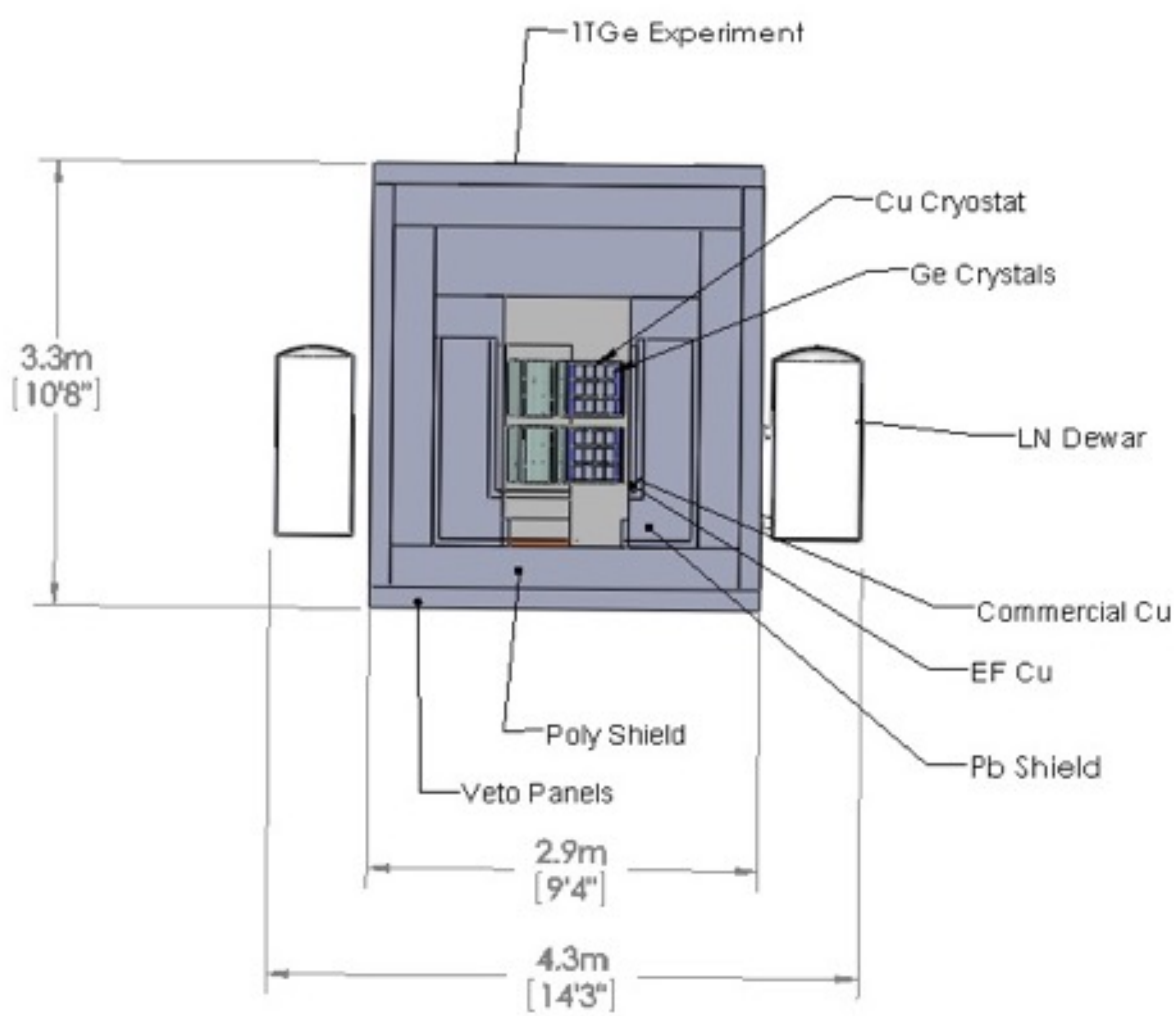




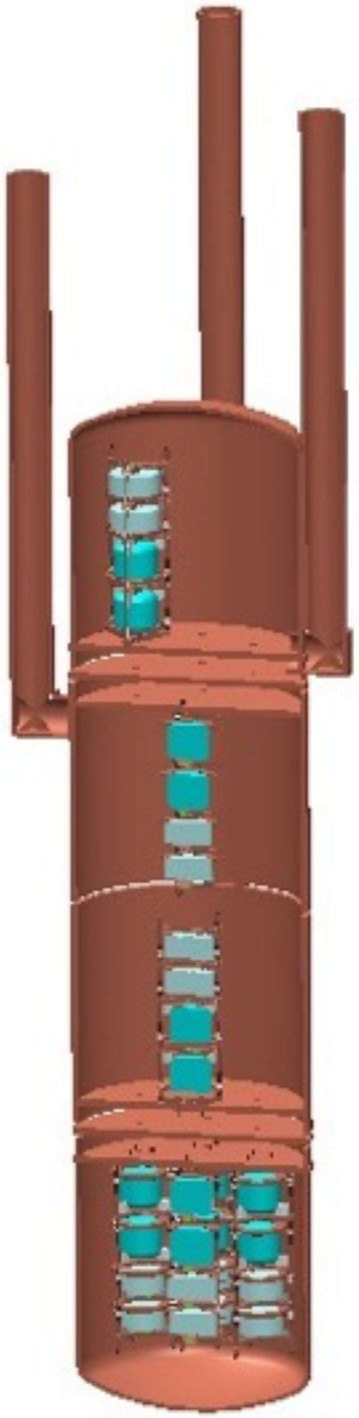
NG-Ge76 Concept: Preliminary shield ideas

MAJORANA DEMONSTRATOR type
Compact Shield

- ^{76}Ge modules in compact electroformed Cu cryostat, Cu / Pb passive shield
- 4π plastic scintillator μ veto



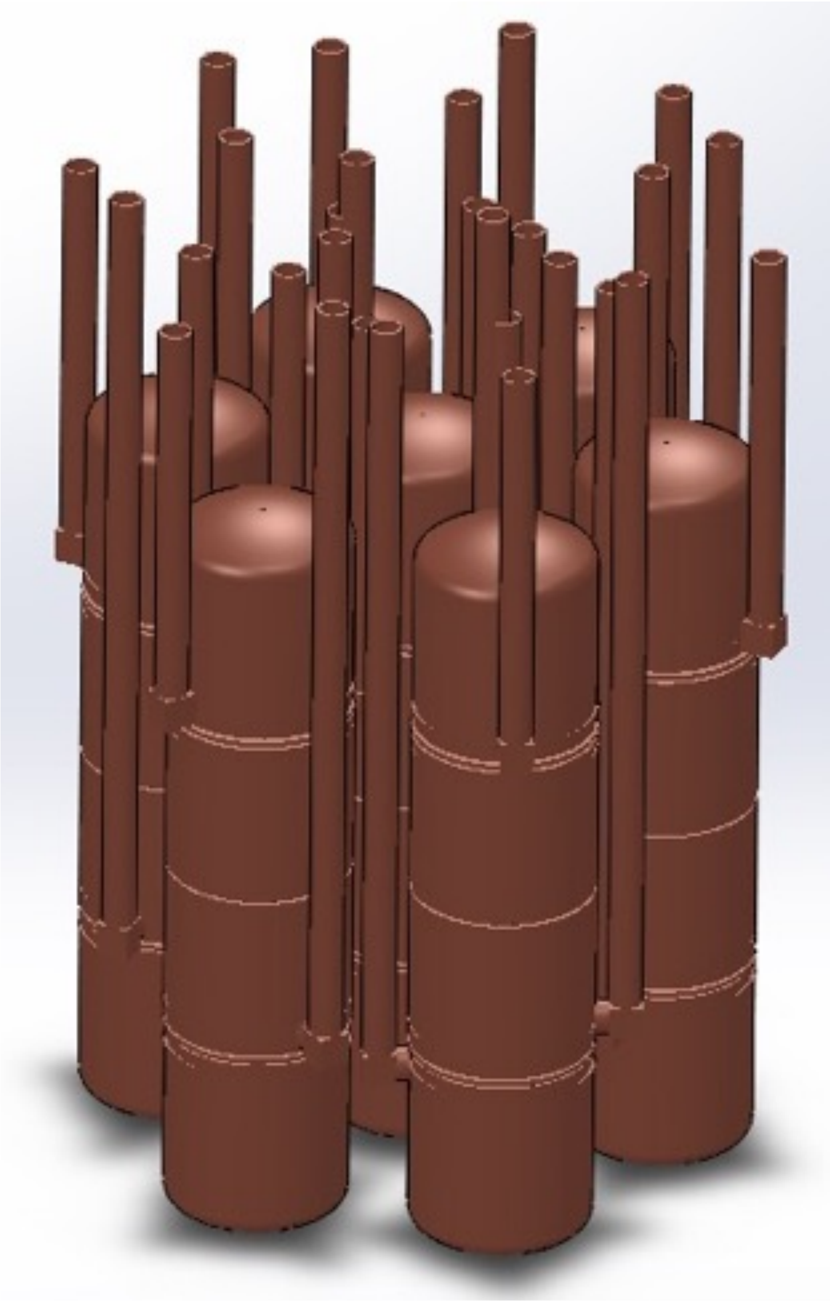
NG-Ge76 Concept : Liquid shield configuration



Hang from cable feed thru / pump ports for insertion into water or cryo shield. Turn port tubes horizontal for Copper shield.

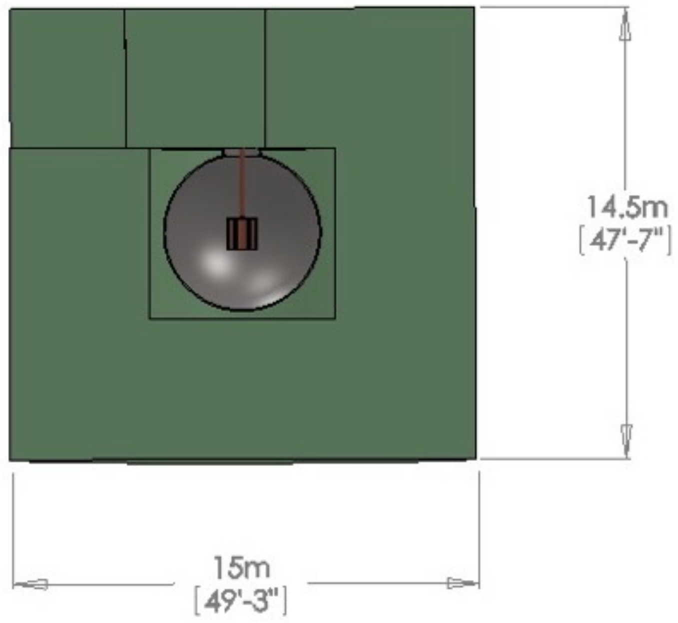
Demountable flange allows variable cryostat length for smaller module units if necessary (30-60-90-120 kg)

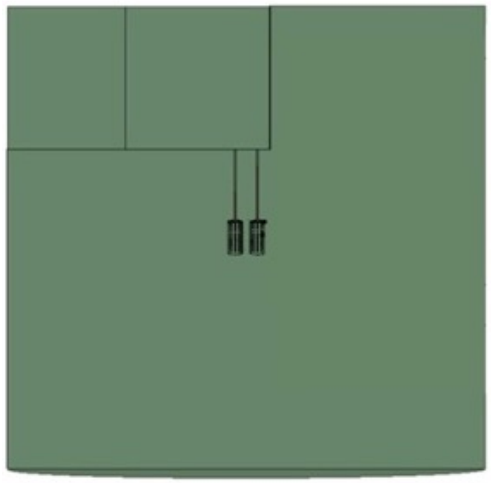
- 30kg x 4 x 7 = 840 kg nominal (each string can be extended to provide 1T+)
- Overall size is ~1.6m tall x 1.6m diameter



NG-Ge76 Concept : Shield

- To reach the 0.1 counts/ton-year background goal, an active shield seems to be required.
- Issues
  - Intrinsic backgrounds from LAr — ^{42}K, loss of low energy ^{68}Ge cut and other low energy physics.
  - Are there alternative methods to actively shield?
  - Cycle time to add/remove detectors.
  - Cavity constraints.

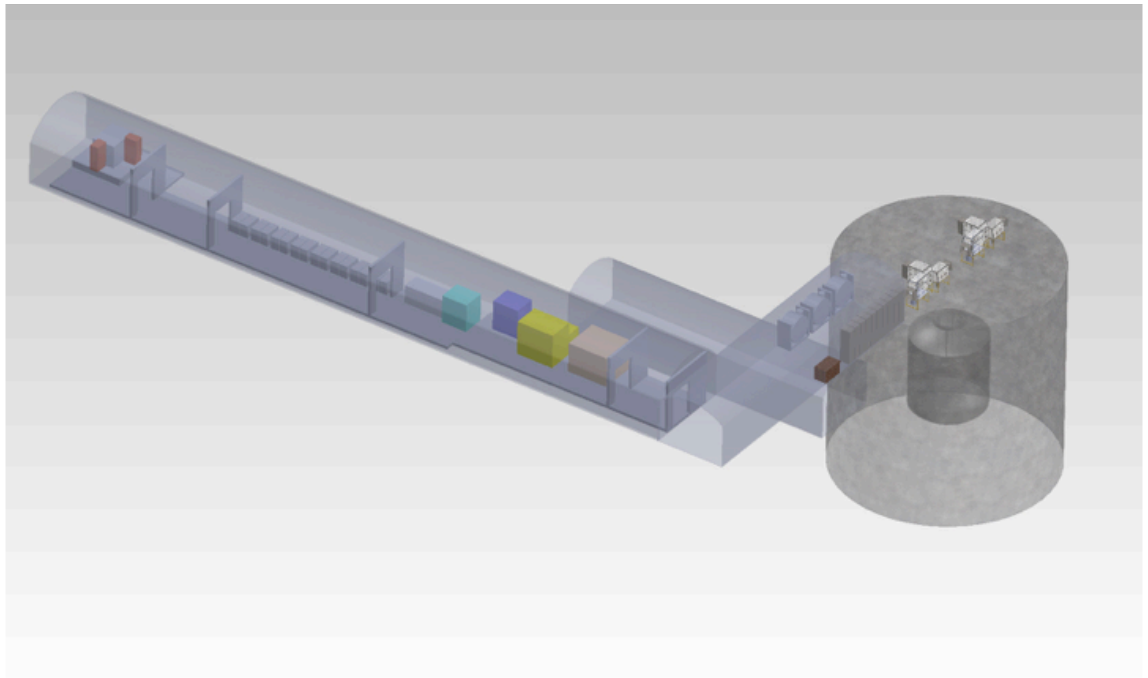




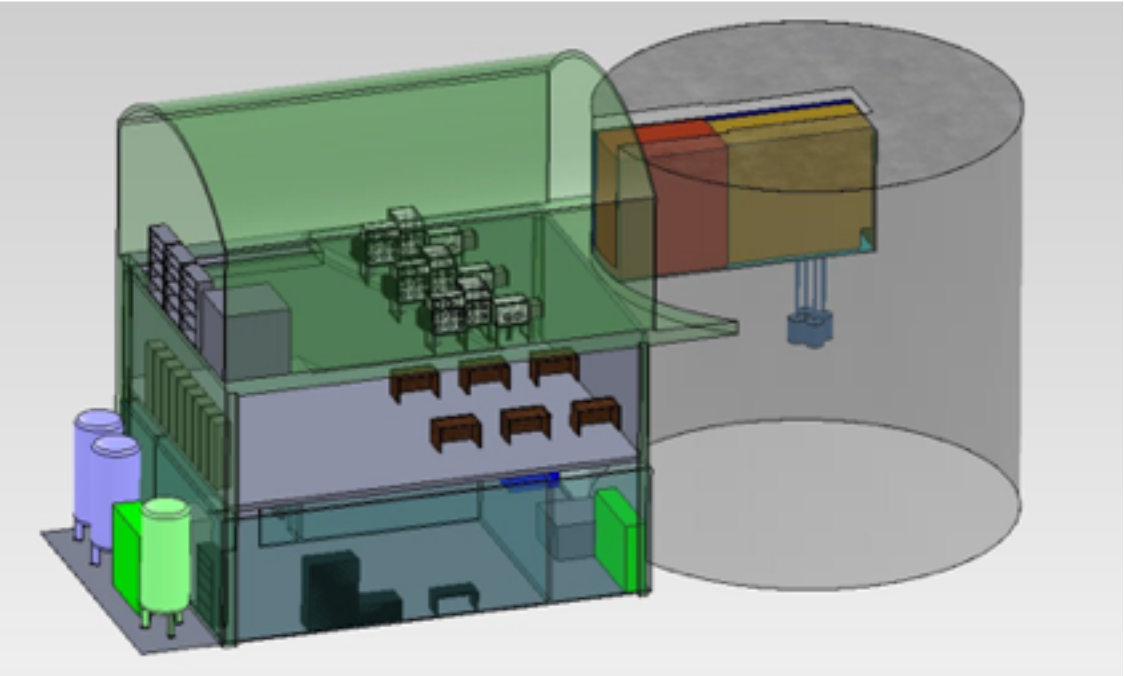
NG-Ge76 Concept : Underground Lab

- Two possible deep sites: SNOLAB, JinPing
- Moderate depth sites: SURF, Gran Sasso
- Issues
  - **Backgrounds:** Cosmogenic ^{77}Ge.
  - **Access** : getting equipment (cosmogenics) and people to the laboratory Underground transport constraints.
  - **Available cavities, infrastructure, & support.**

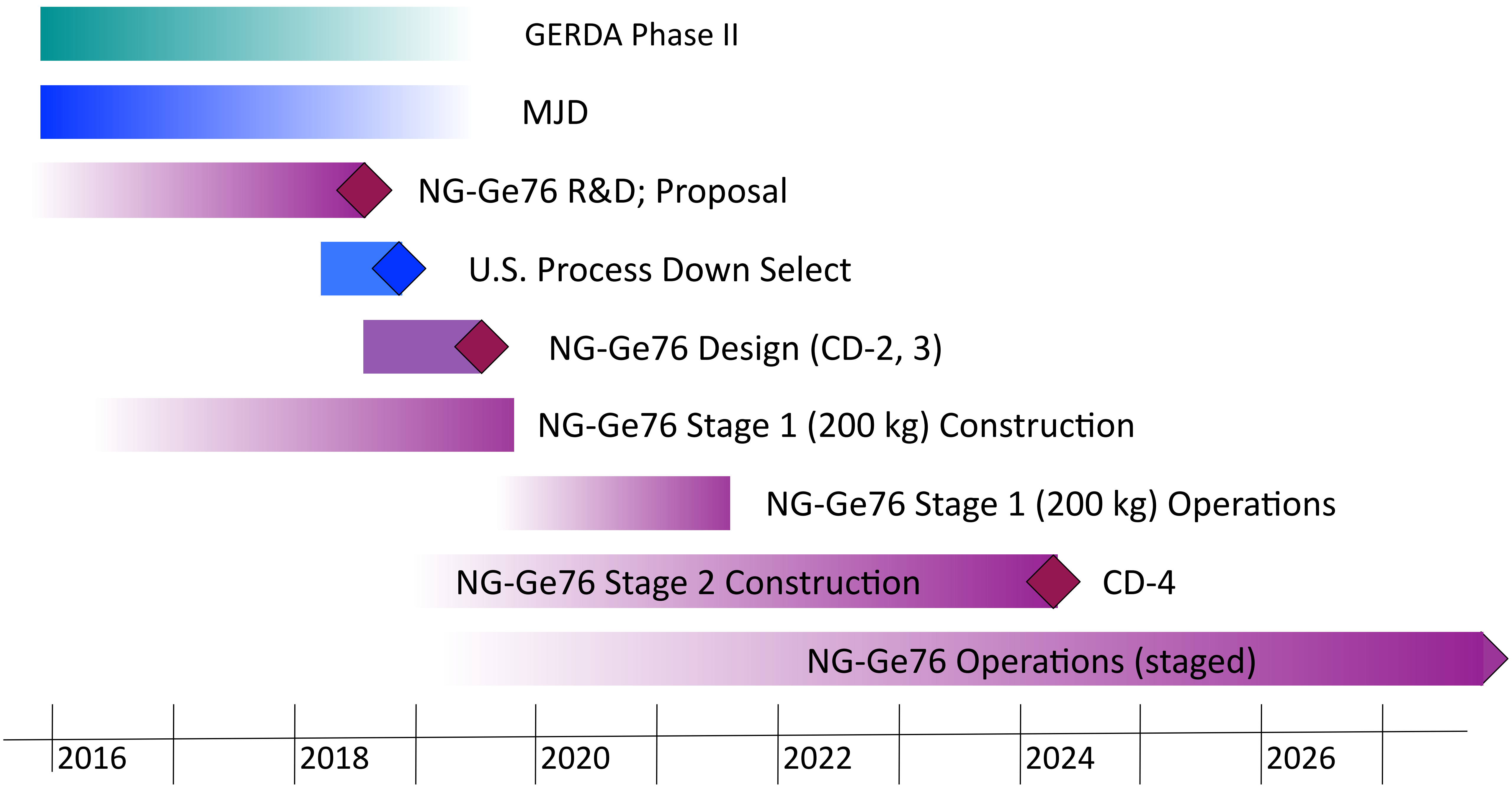
SNOLAB Design using existing Cryo pit.



Generic Design using Jinping style cavity



NG-Ge76 Conceptual Timeline



NG-Ge76 Conceptual Ton Scale Expt.

- ^{76}Ge combines the best detector resolution with the best backgrounds achieved to date.
- GERDA and the MAJORANA DEMONSTRATOR have established the feasibility of proceeding with a ton scale ^{76}Ge experiment.
- The first 200 kg phase (Schwingenheuer's talk) will provide an opportunity to resolve outstanding issues and show reduced backgrounds.
- Much work needs to be done to go from a conceptual design to a viable, competitive proposal.