

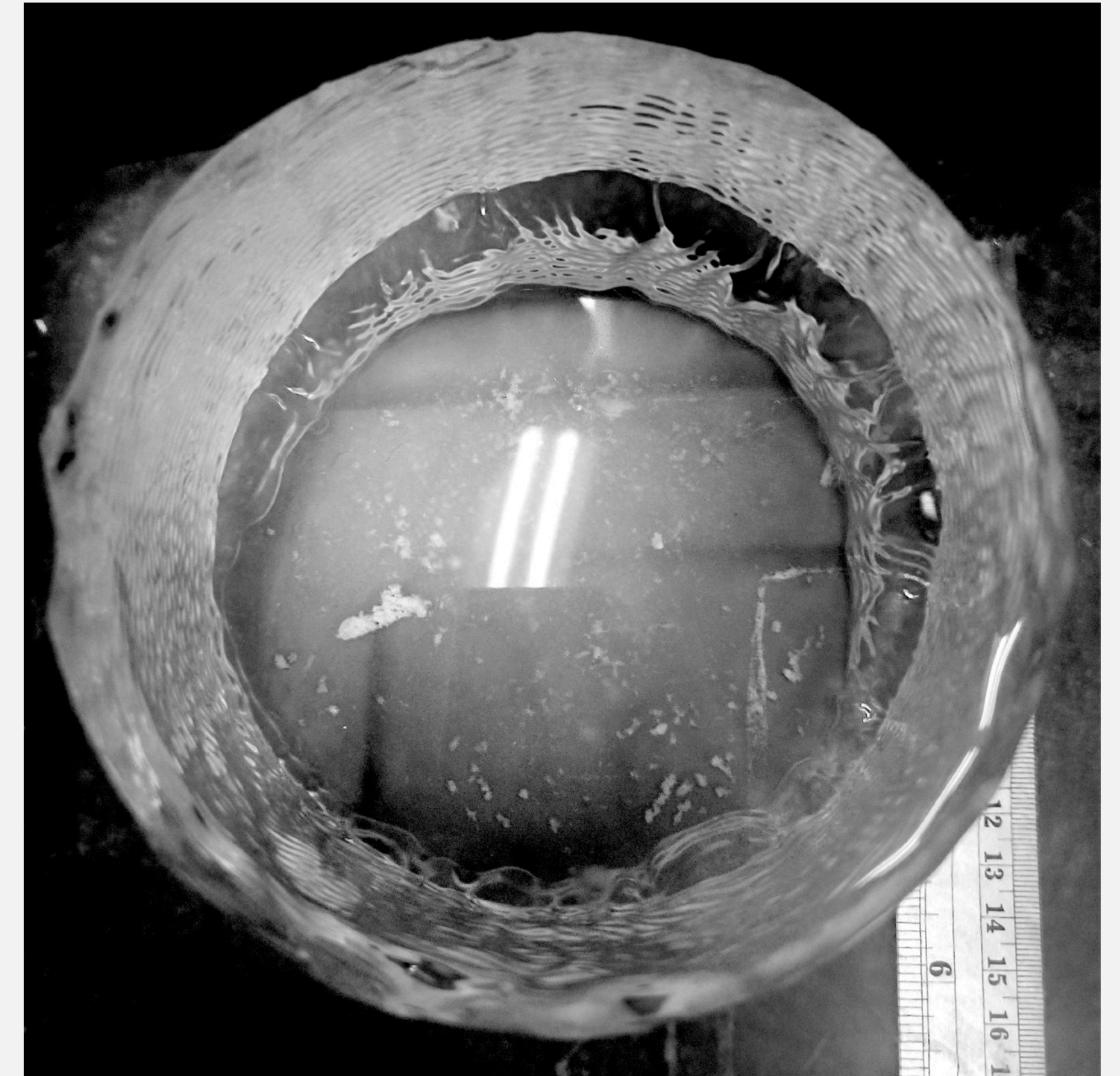
Study of scintillation properties of solid argon

Claudio Savarese

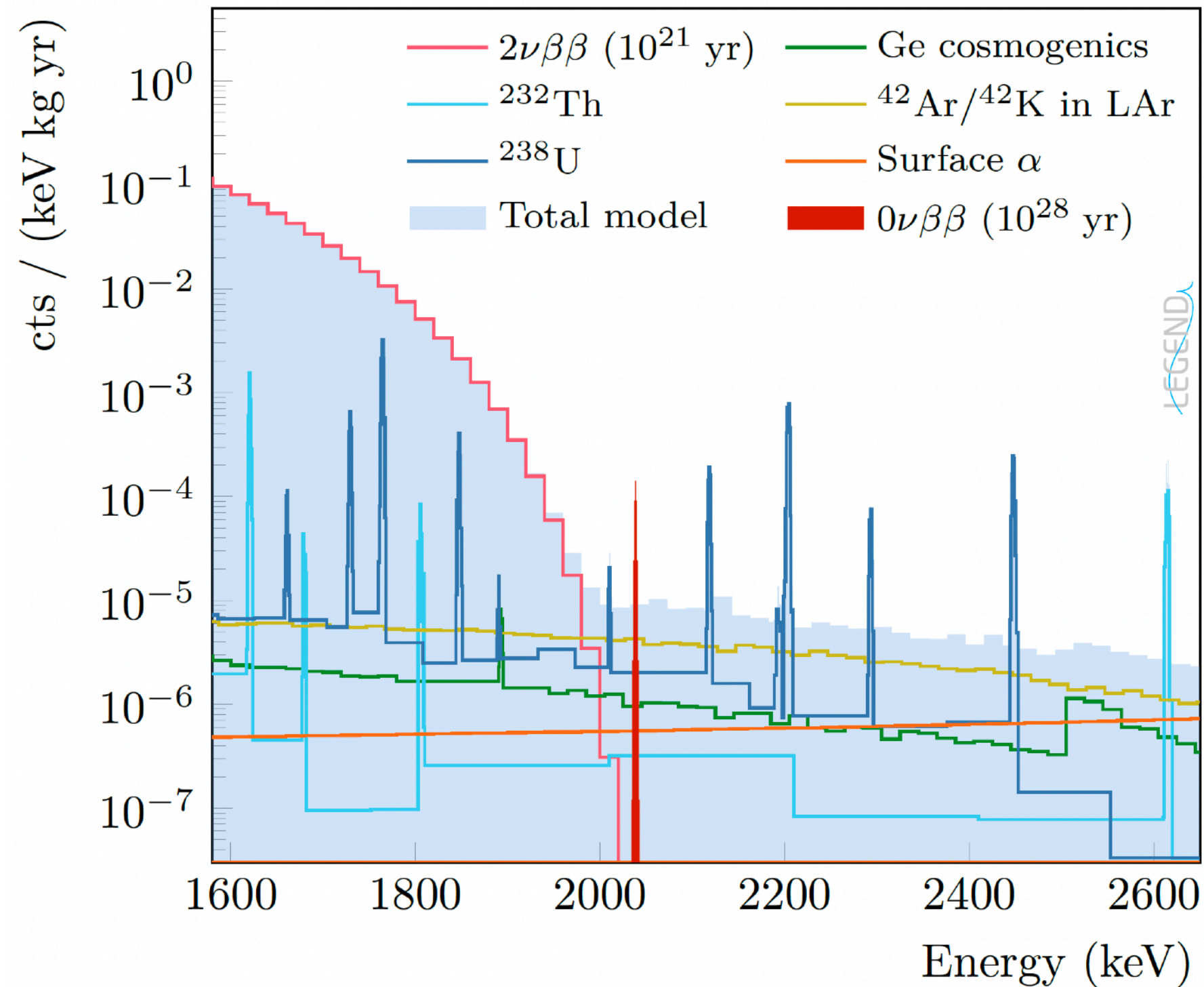
Center for Experimental Nuclear Physics and
Astrophysics (CENPA), University of Washington

CPAD 2026, Seattle

October 20th, 2026

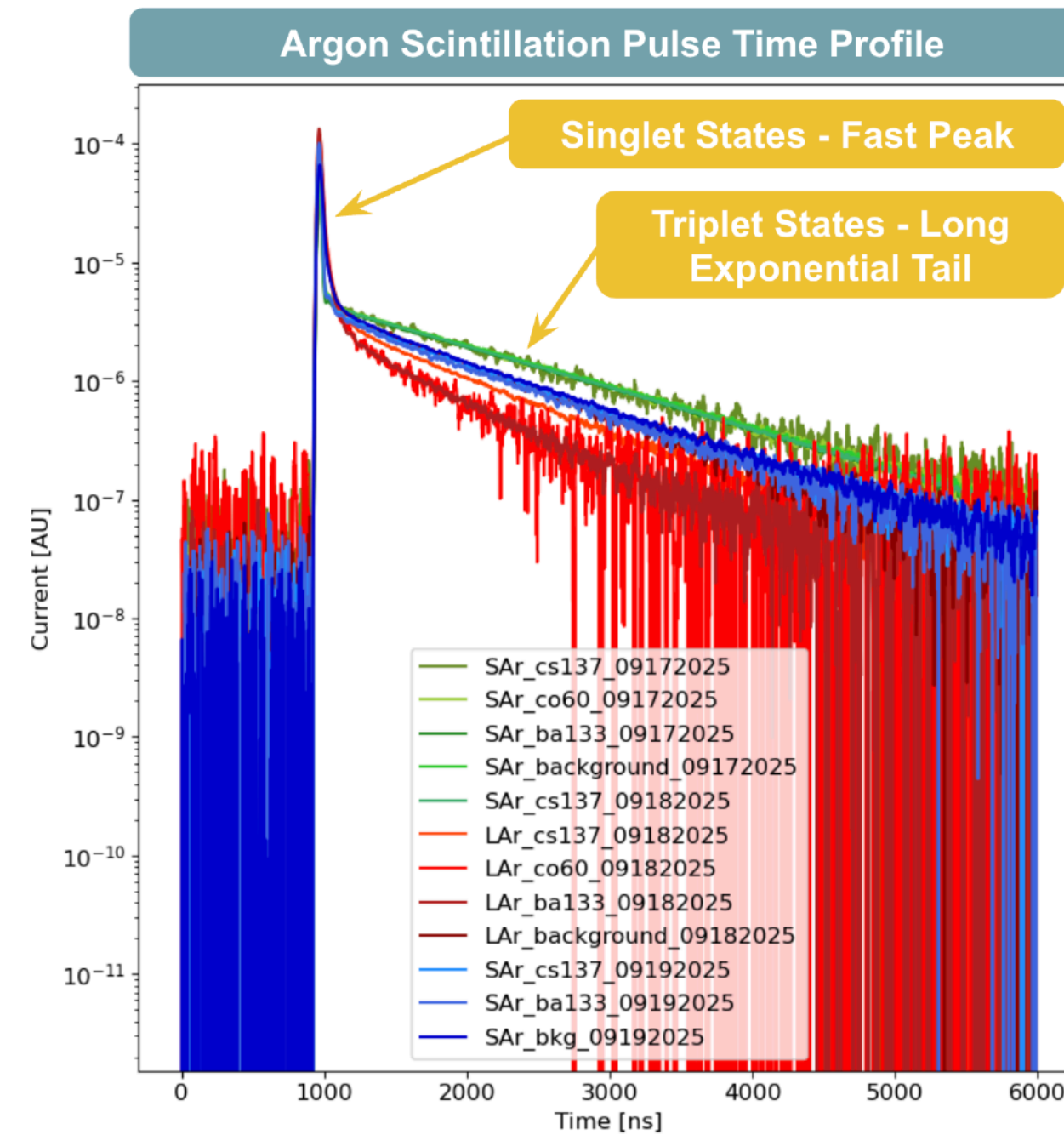


Motivation



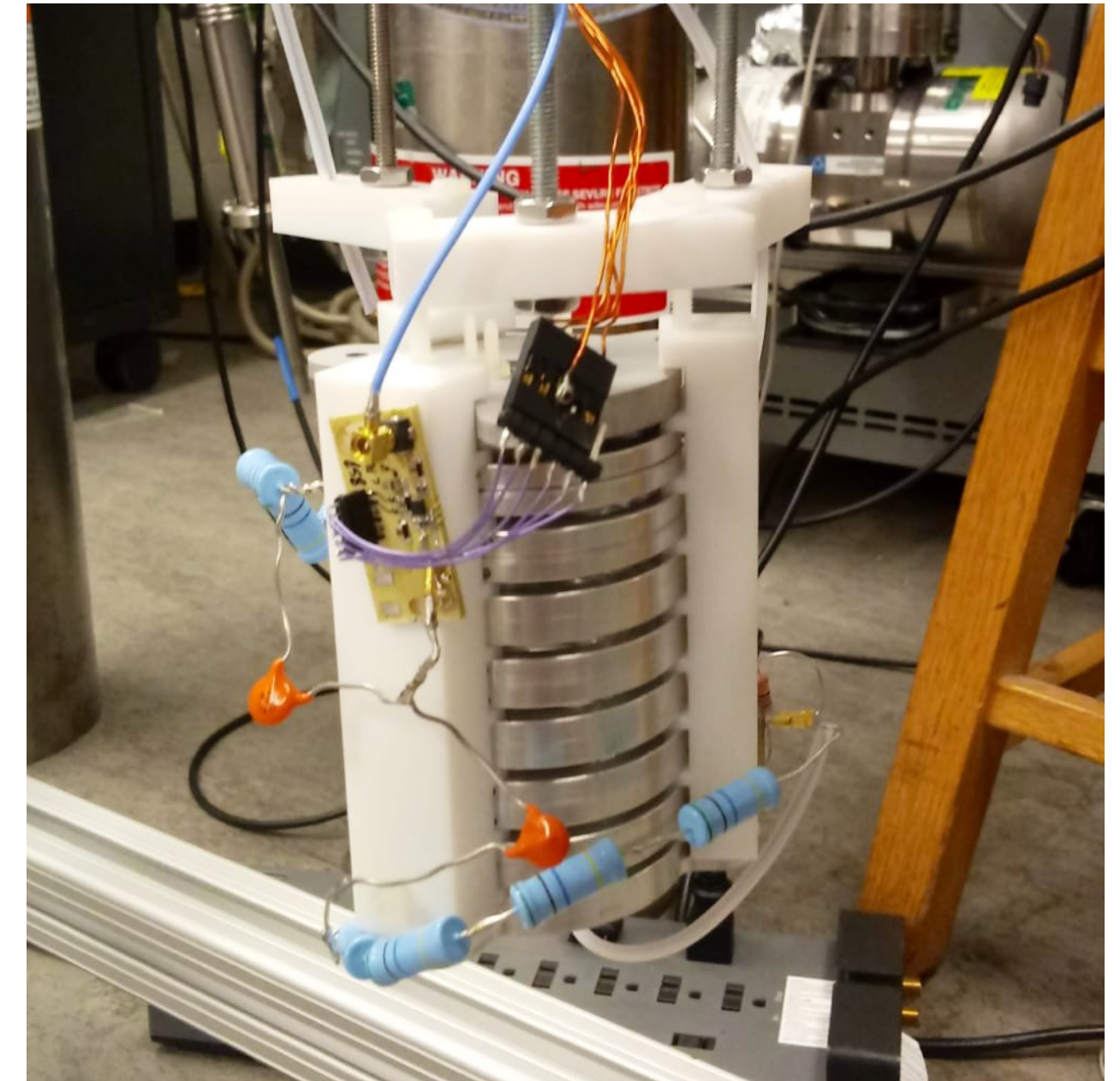
- ^{42}K background in LEGEND
- MC Simulations

Current Studies



- Freezing argon
- SiPM in SAr
- Analysis pipeline
- Preliminary results

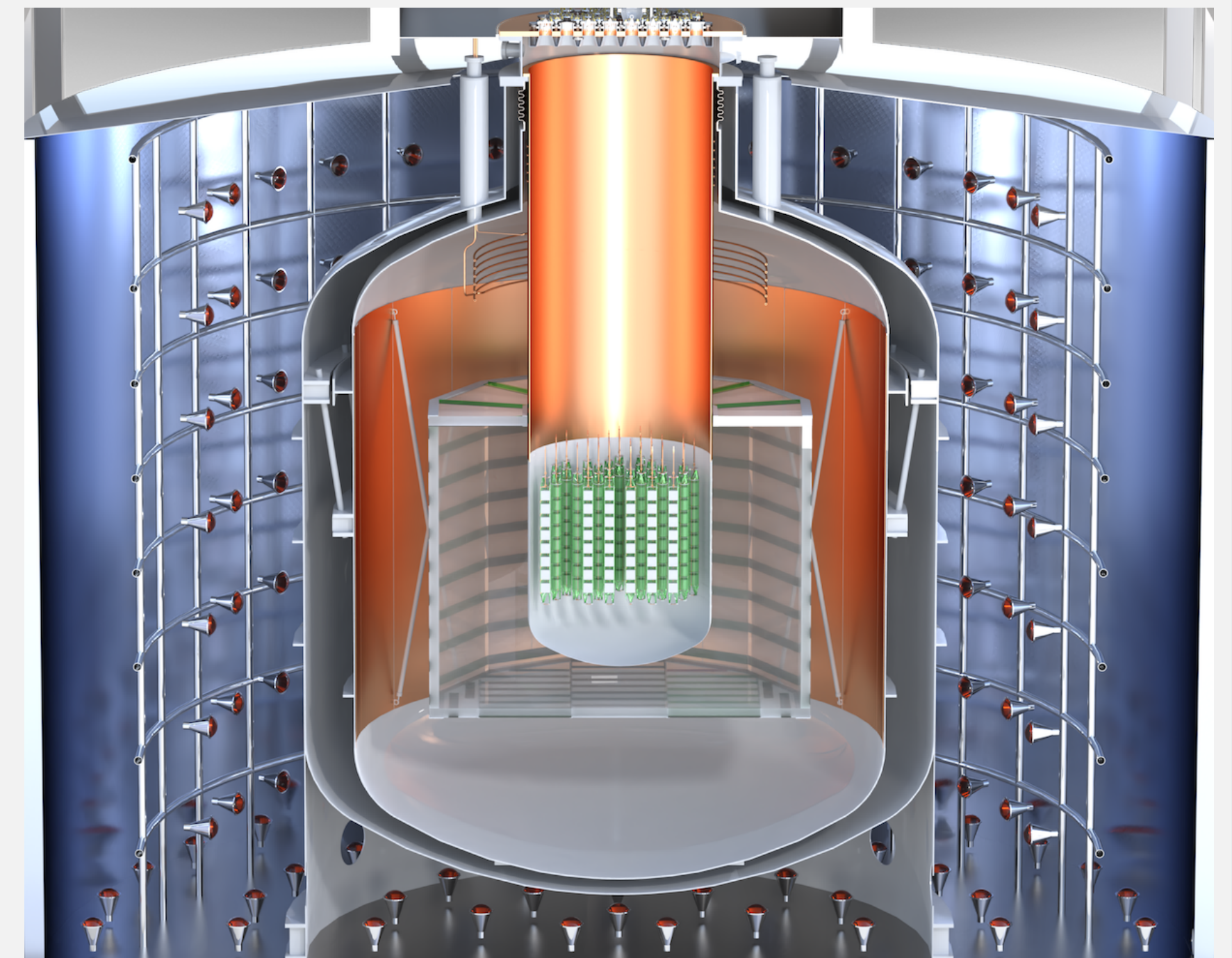
The future

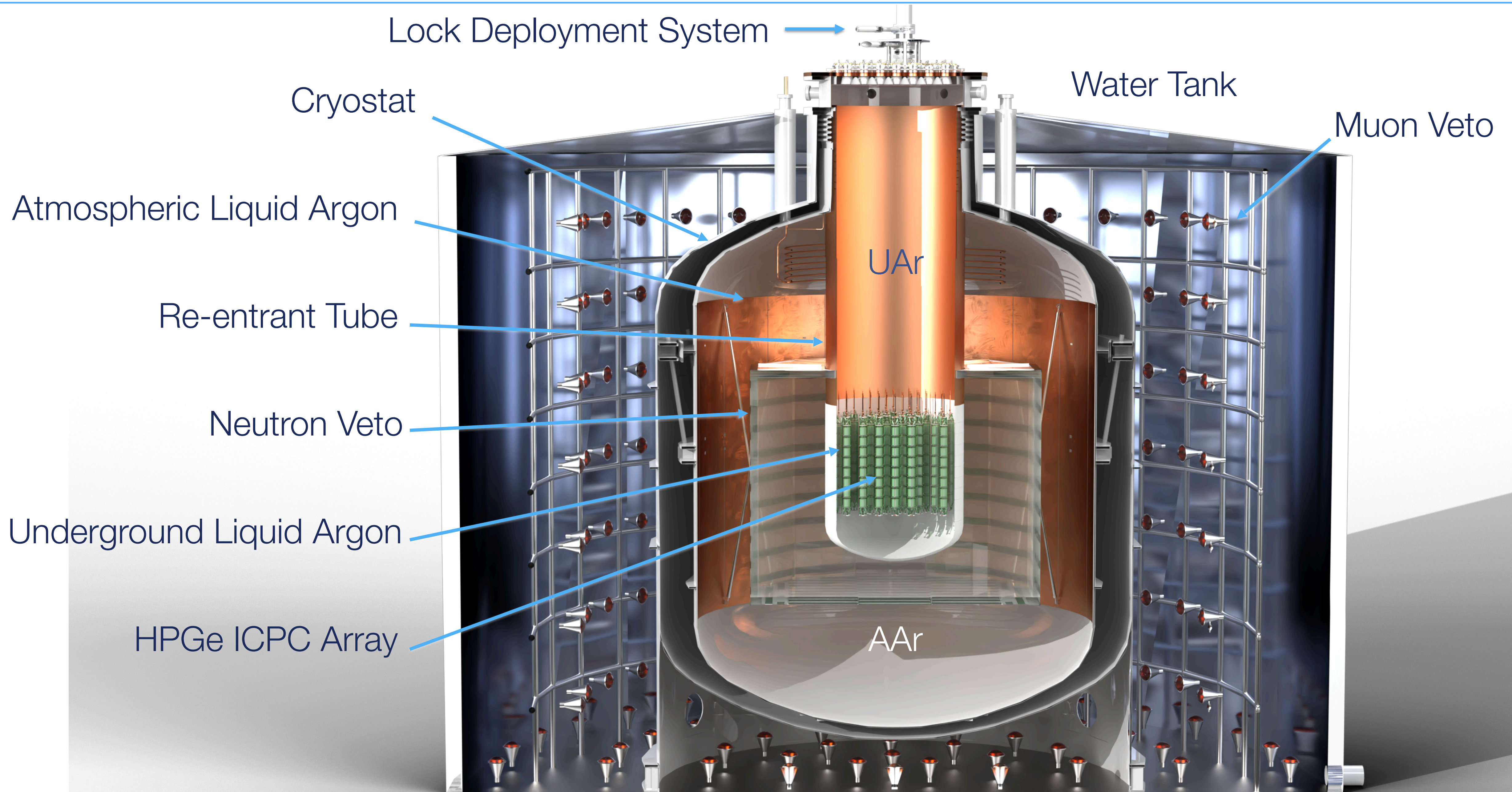


- Pulse Shape Discrimination
- Electron transport

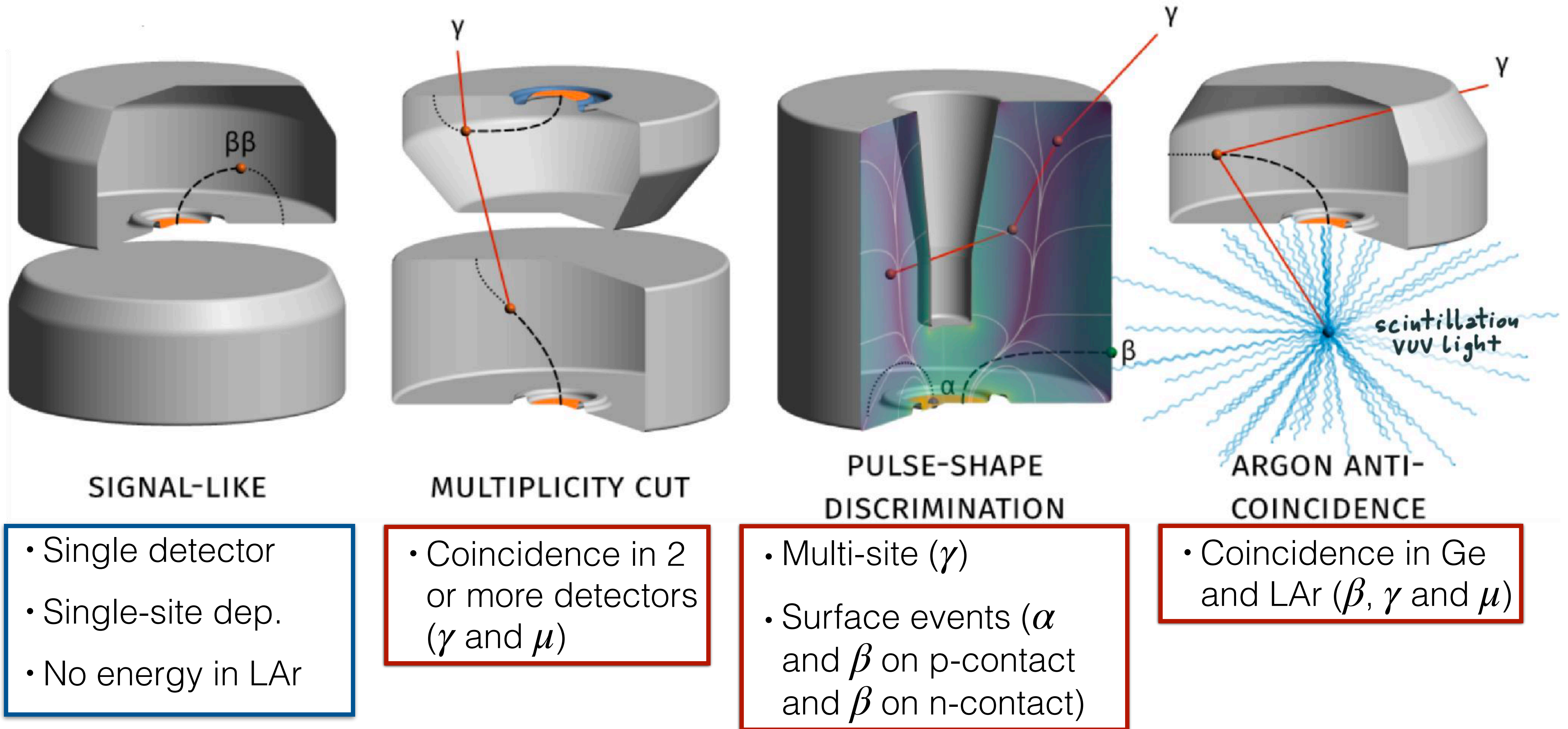
^{42}Ar background in LEGEND

LEGEND Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay



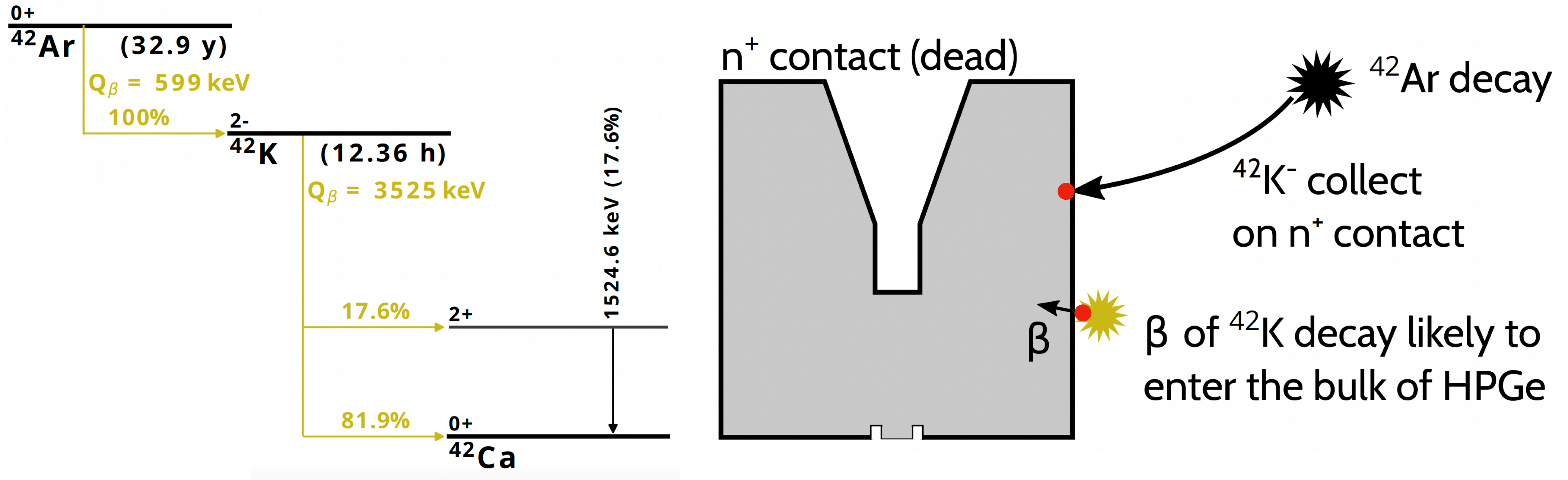


Background suppression in LEGEND



Hear more from Aparajita Mazumdar! Oct 20th, 2:00 pm- RDC 7 (Low-Background Detectors)

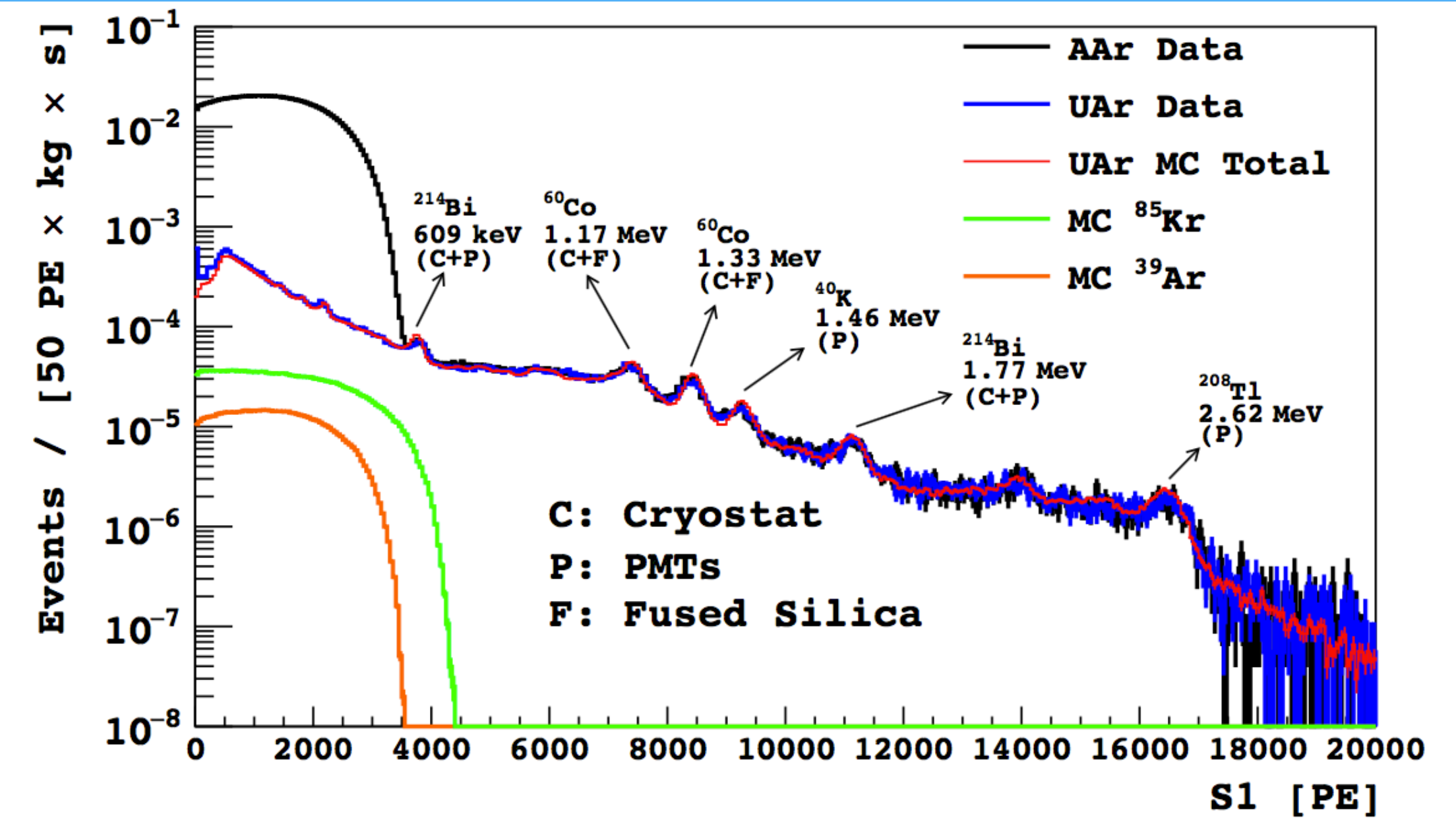
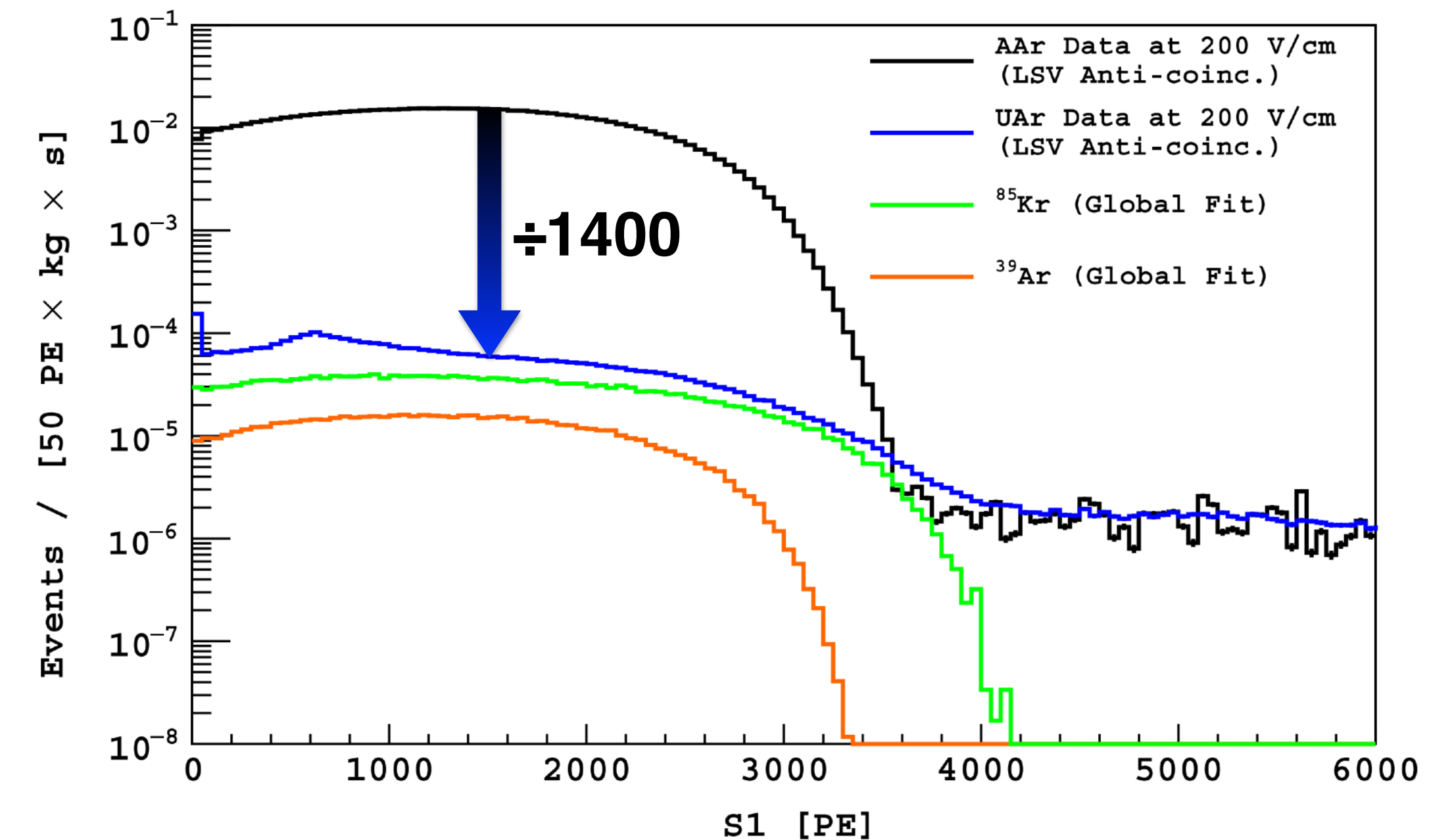
^{42}K induced background



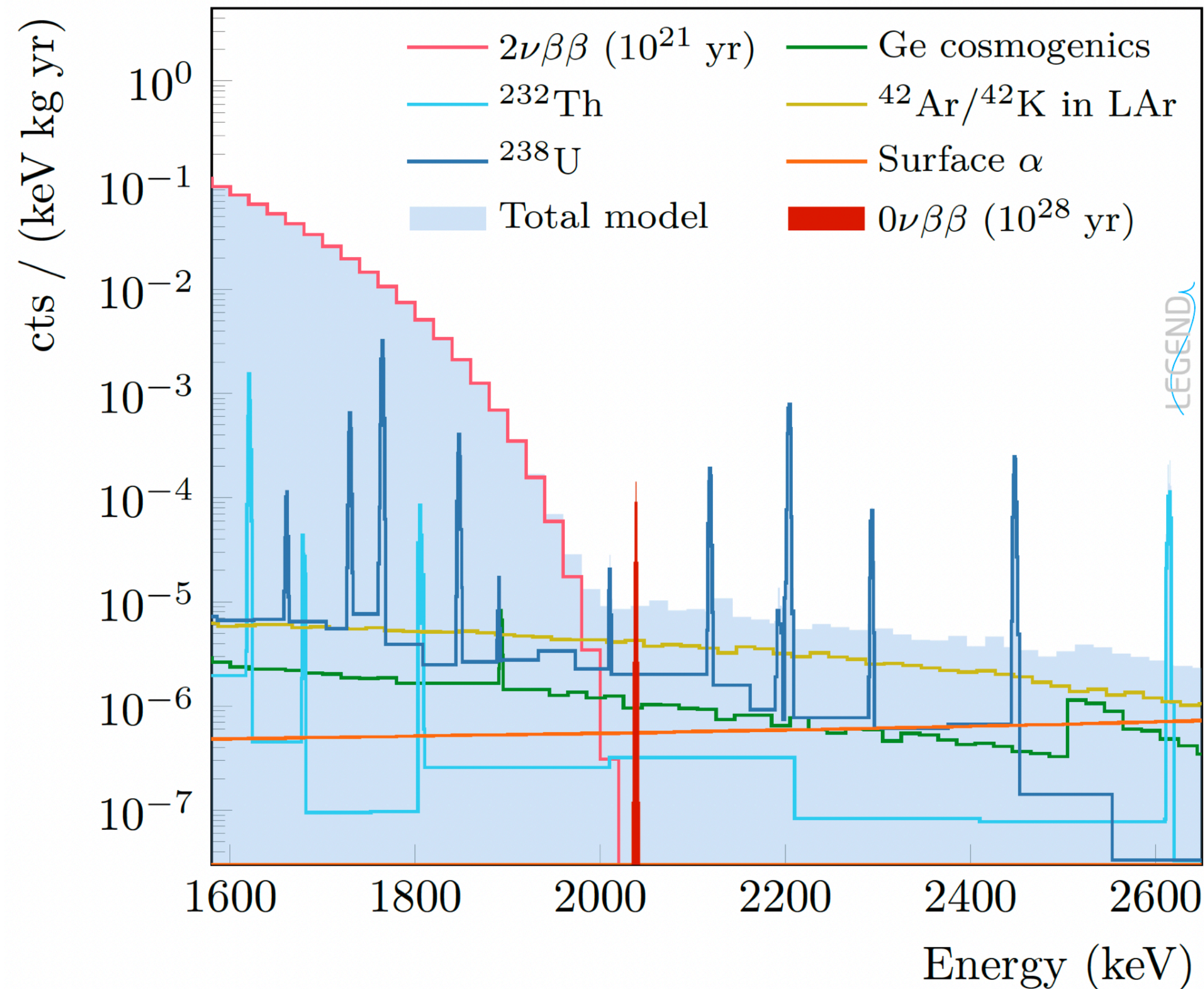
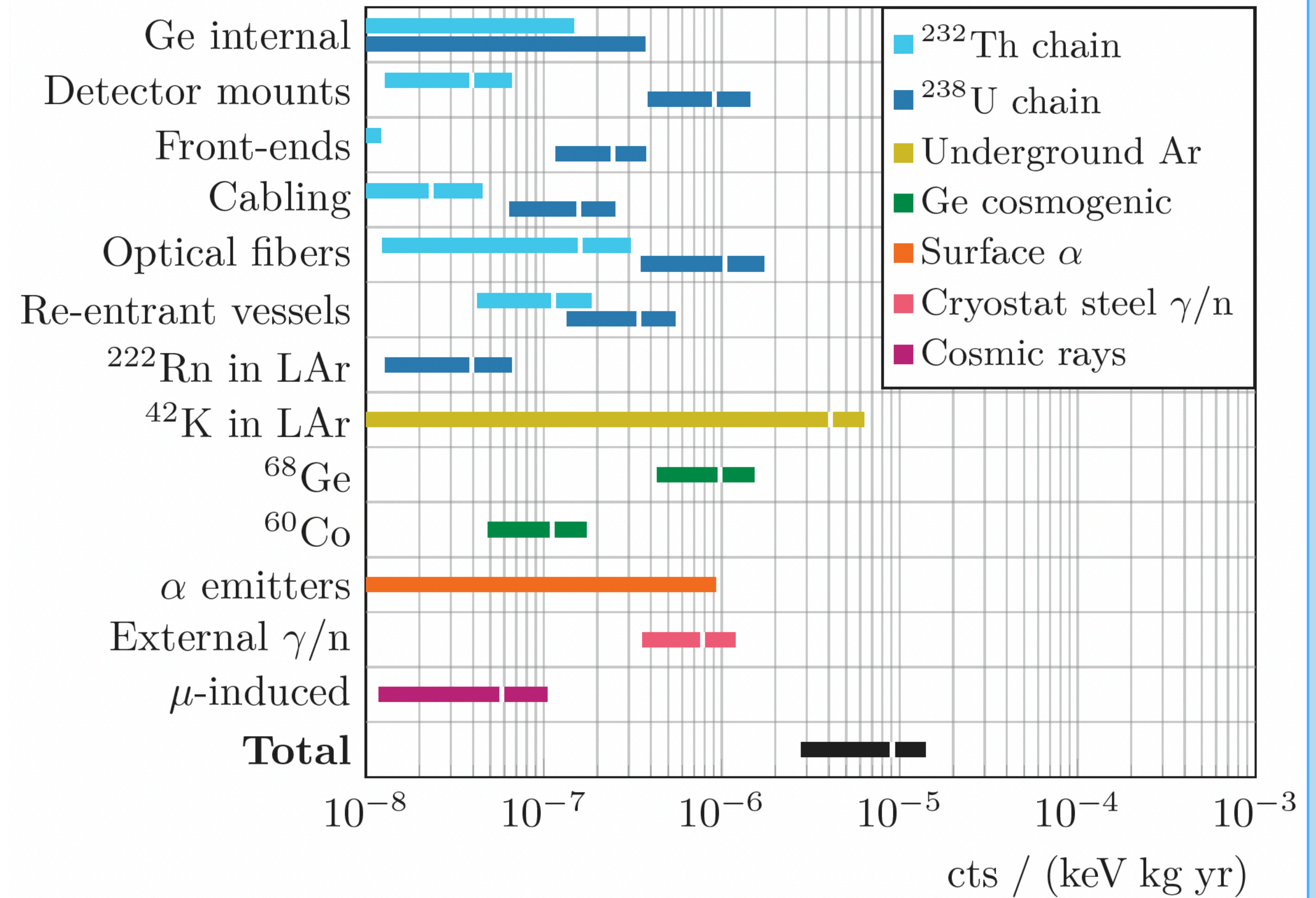
- Cosmogenic ^{42}Ar ($T_{1/2} \sim 33 \text{ yr}$) is present (in traces) in argon sourced from the atmosphere.
- ^{42}Ar β -decays to ^{42}K , which β -decays to ^{42}Ca with $Q_{\beta\beta} \sim 3.5 \text{ MeV}$.
- ^{42}K drifts and collects onto the Ge detectors before decaying.
- Energy loss in Ge surface dead-layer - Continuum bkg in $0\nu\beta\beta$ ROI (2039 keV)

Argon from underground for L-1000

- Both ^{39}Ar and ^{42}Ar are cosmogenic
- ^{39}Ar has more production channels and lower reaction thresholds.
- If UAr has a ^{39}Ar depletion factor of 1,400, then the ^{42}Ar suppression should be higher.
- All background projections for LEGEND-1000 are done assuming 1,400 (conservative).
- ~20 tonnes of UAr needed + SiPM photo-sensing technology



L-1000 Background model



Background goal x20 lower than LEGEND-200

^{42}K from the decay of ^{42}Ar is by far the strongest expected background

A wild idea

Preventing the ^{42}K drift

LEGEND Large Enriched
Germanium Experiment
for Neutrinoless $\beta\beta$ Decay

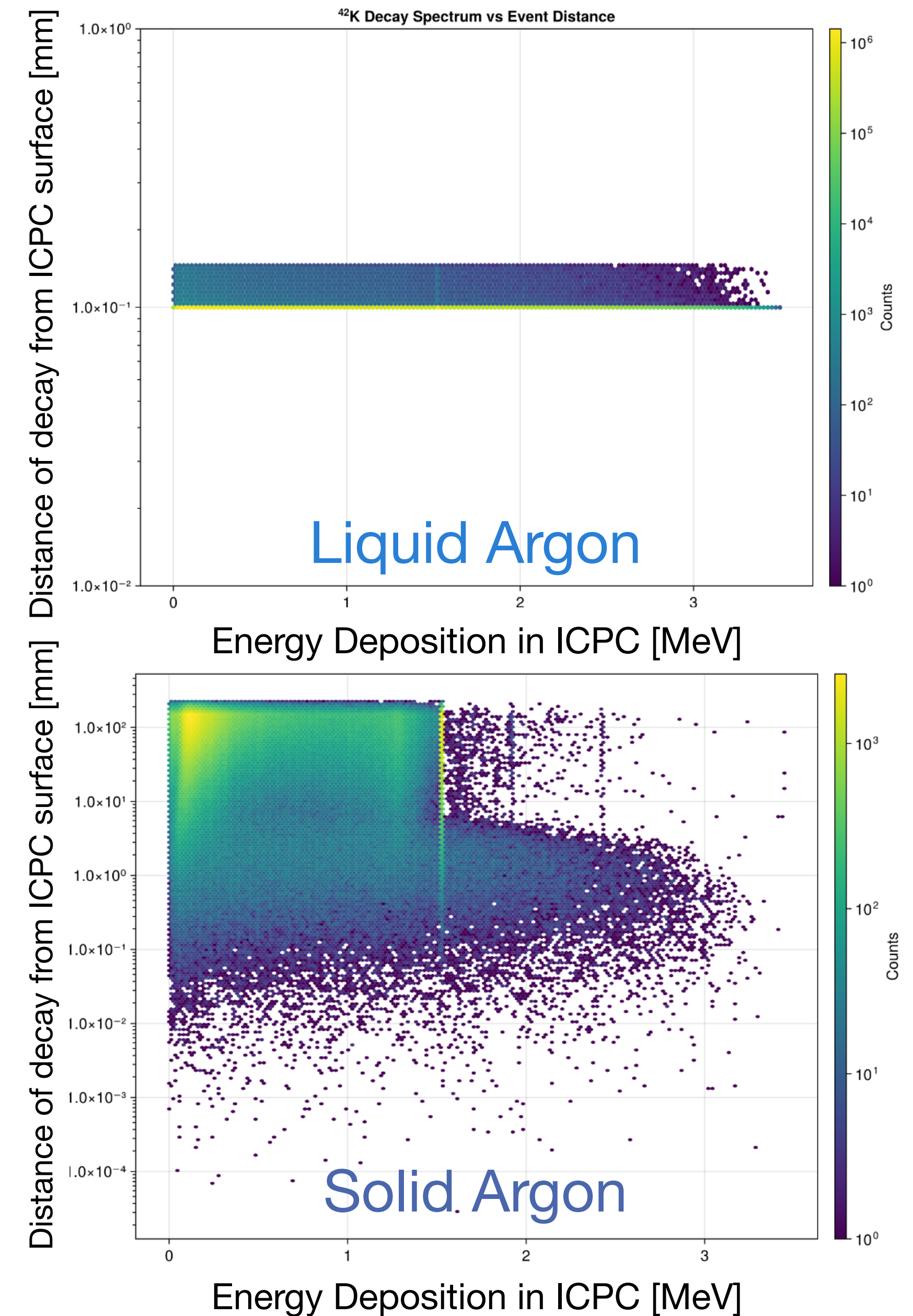


MC Simulations - by REU J. Buetov

Geant-4 MC simulations to compare expected rate of ^{42}K β -decays events in $0\nu\beta\beta$ ROI.

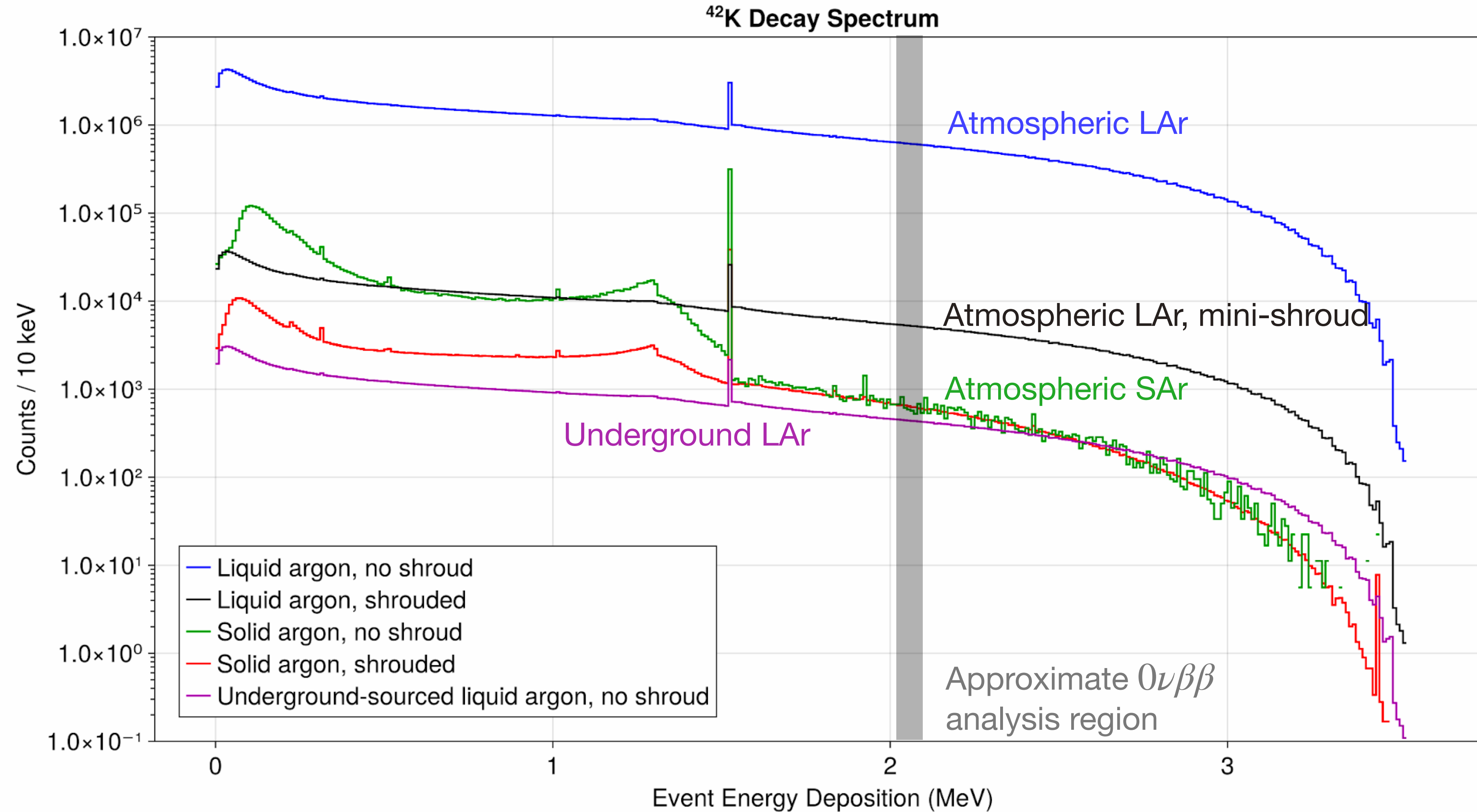
Assumptions:

- in LAr ^{42}K drifts (100% efficiency) to the surface of Ge detectors.
- In SAr ^{42}K does not move from its origin point.
- The Ge dead layer was not implemented in this work.
- Simple setup with 2 similar geometries:
 1. ICPC immersed in **liquid argon** bath
 - All ^{42}K β -decays concentrated on the ICPC surface.
 2. ICPC enclosed in **solid argon** block
 - ^{42}K β -decays uniform distribution in SAr volume.



Geometric effect

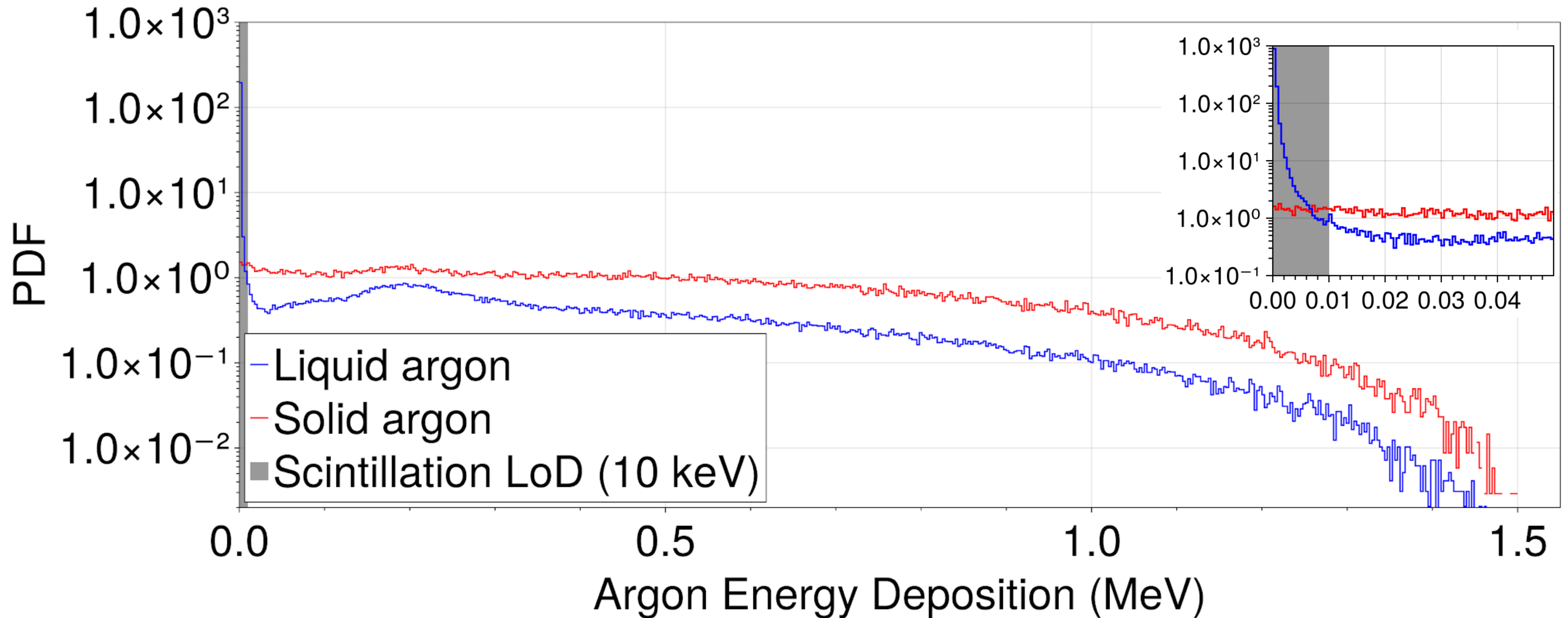
^{42}K beta decay spectra with activity normalized to 10 years of ^{42}Ar activity in L1000



All activities normalized to CDR numbers.

UAr delivers best bkg suppression, atmospheric solid argon about x2 higher

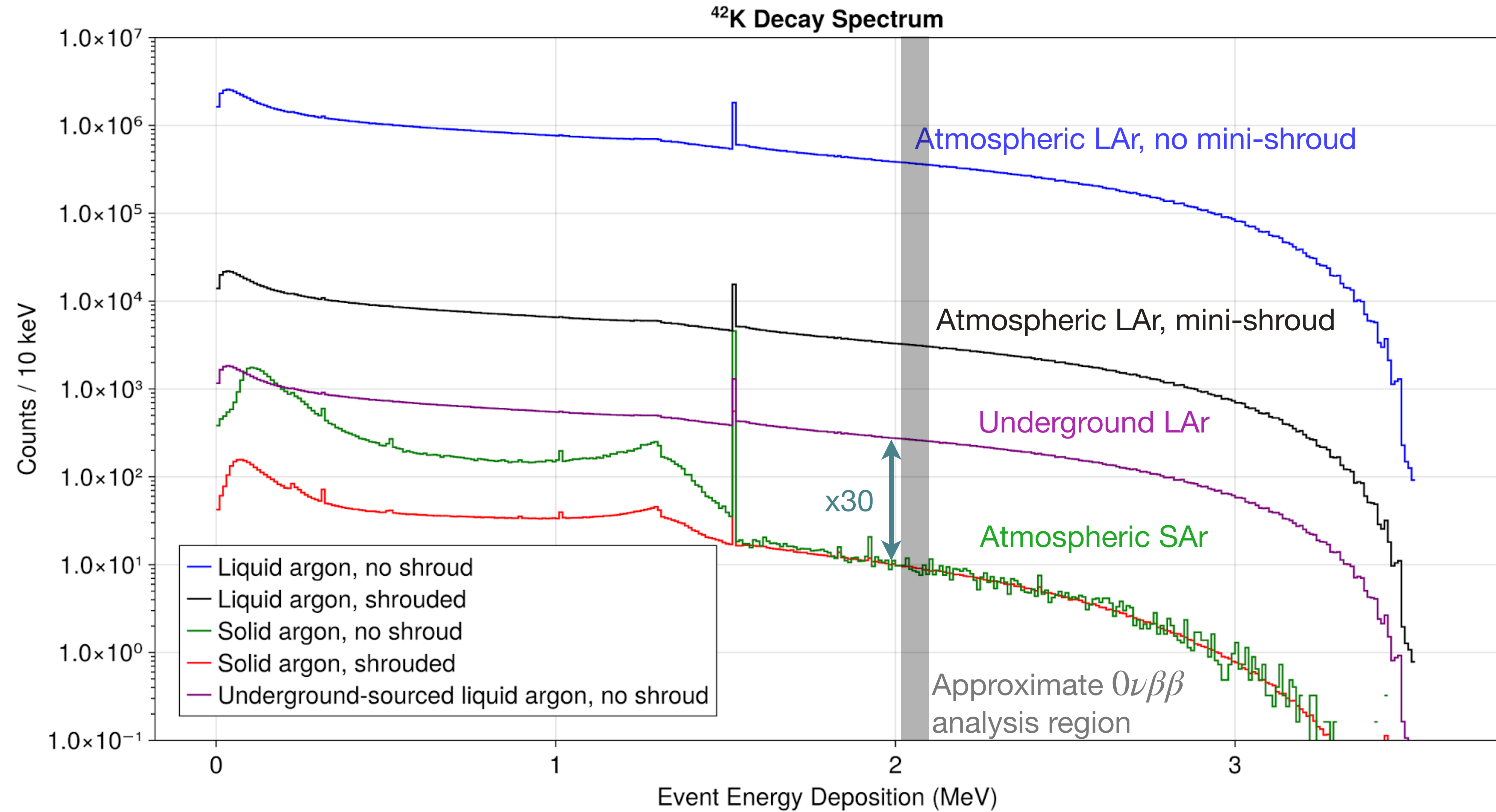
Use argon for anti-coincidence cuts



Hypothetical light detection threshold in argon: ~ 10 keV (~ 400 photons)

- For LAr, $\sim 60\%$ of events depositing energy in the Ge crystals deposits < 10 keV in argon.
- For SAr, $\sim 1.5\%$ of events deposits < 10 keV of energy in SAr.

Post-AC cut spectra



Solid argon could potentially deliver much lower background levels than UAr!

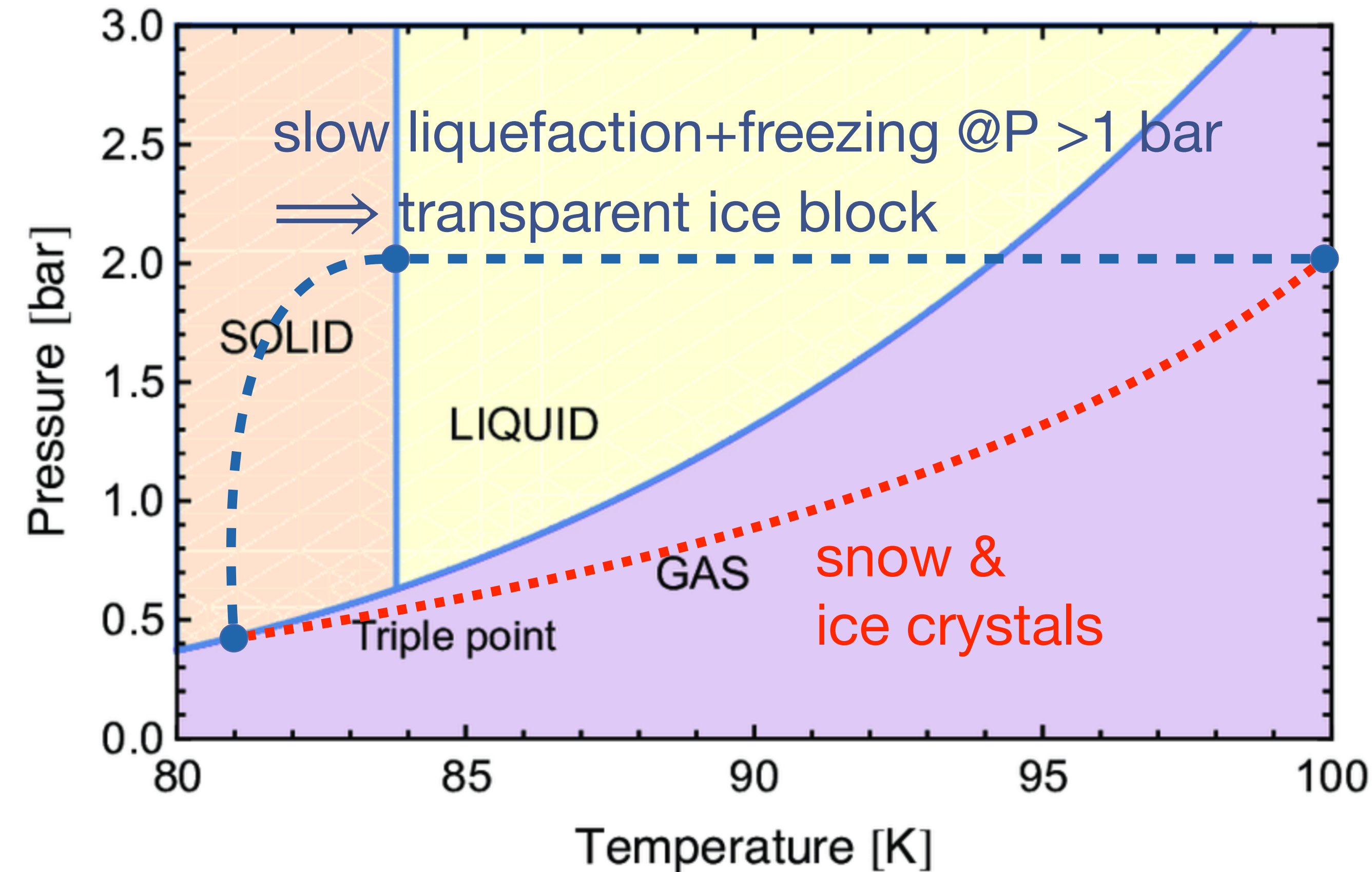
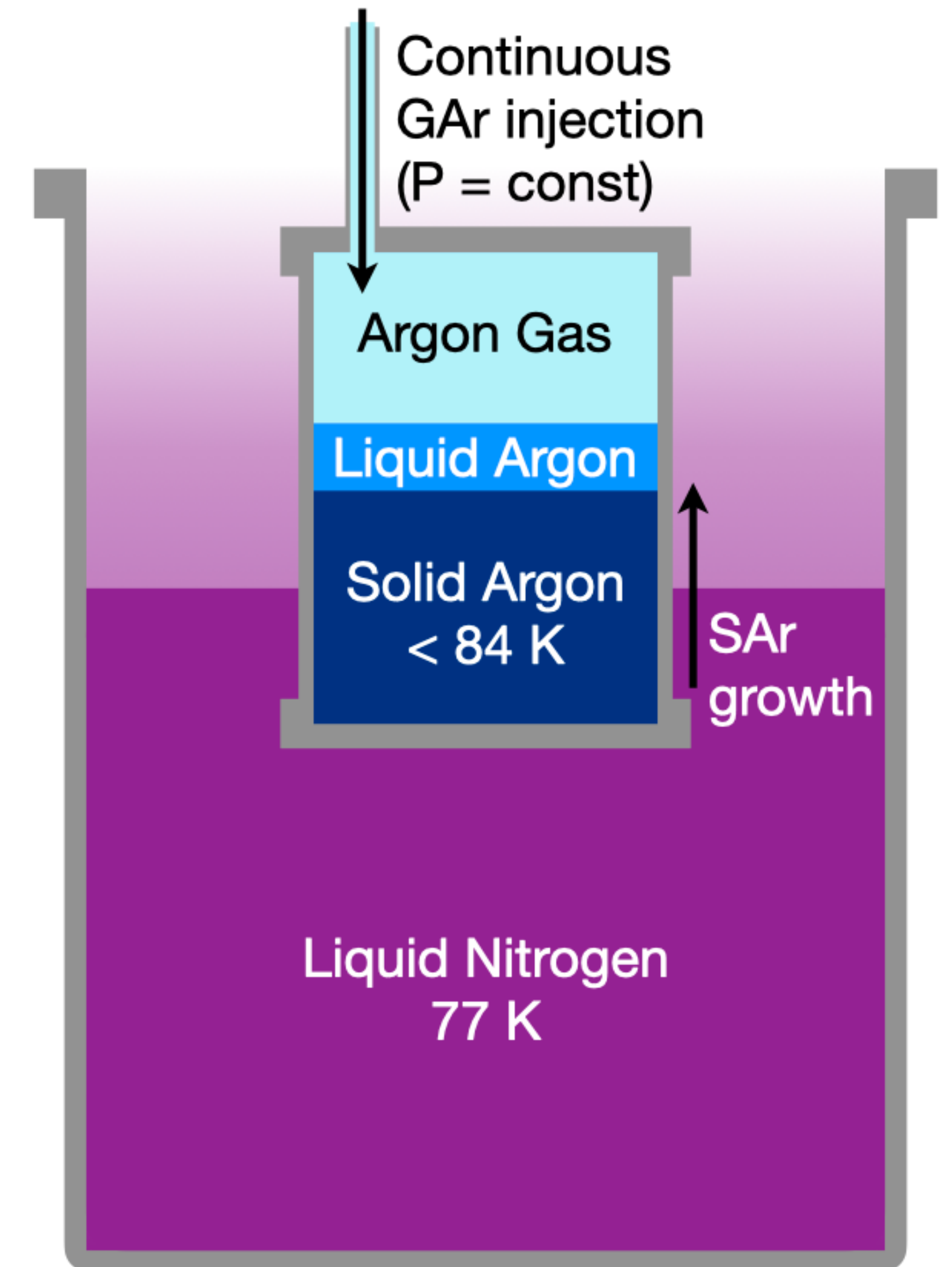
Freezing technique

LEGEND Large Enriched
Germanium Experiment
for Neutrinoless $\beta\beta$ Decay



Strategy and Setup

Adapted from: <https://doi.org/10.3390/cryst12101416>



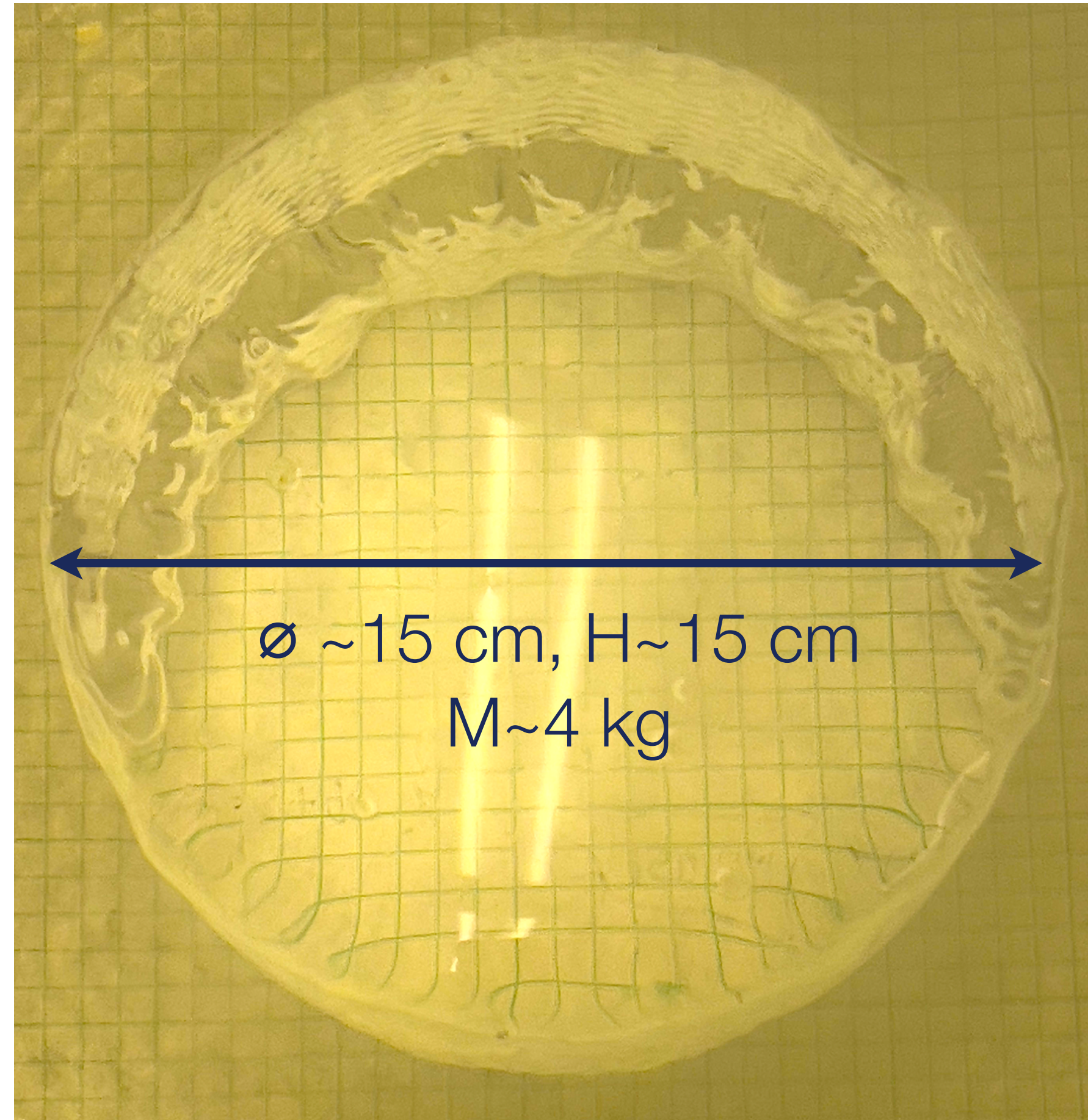
If pressure drops below triple point, snow and multiple crystals.

Strategy:

- keep const pressure by feeding new gas through a regulator;
- establish a temp gradient from bottom (77 K) to top (~ 270 K).

Results

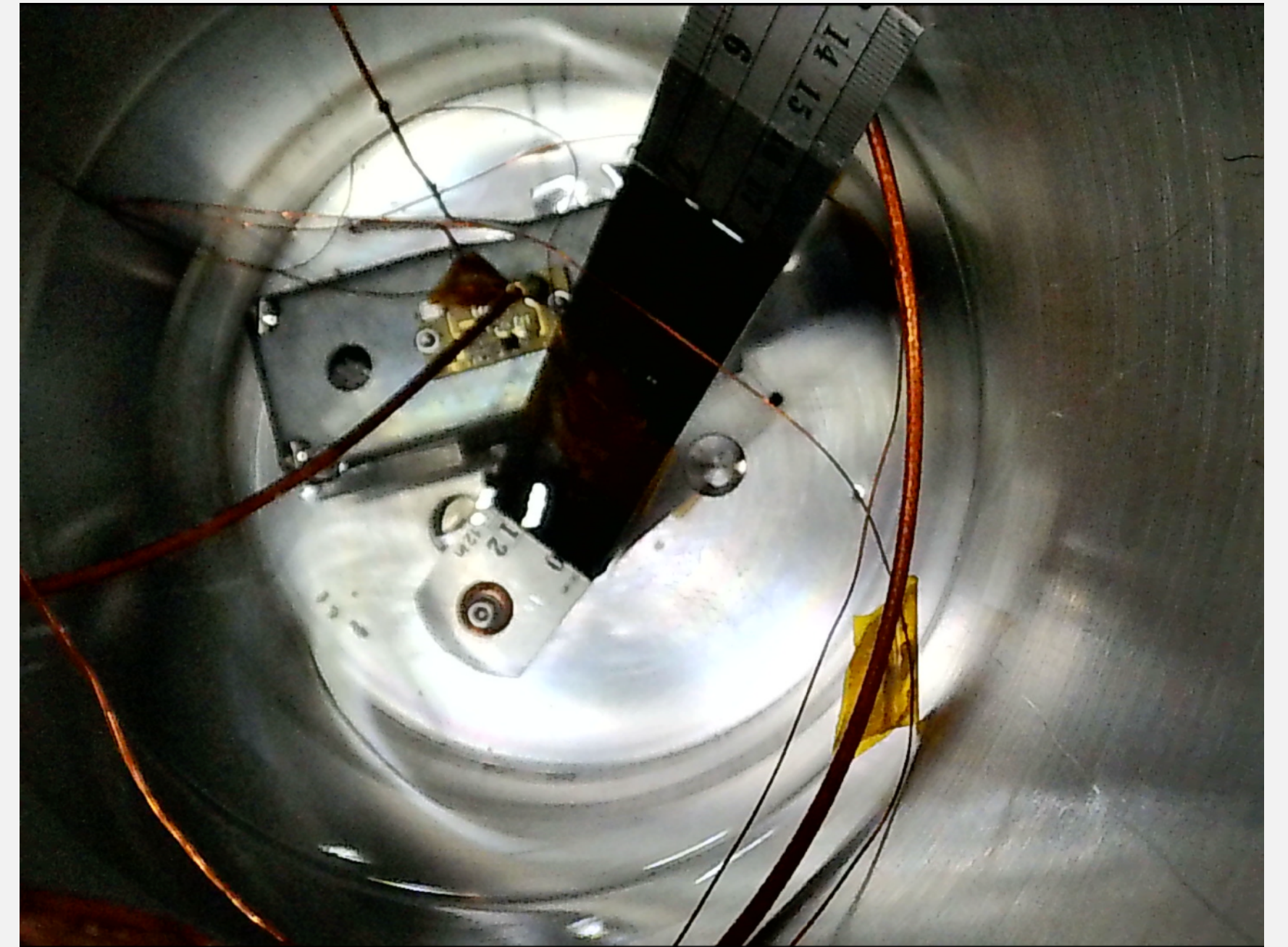
- ~15 cycles since last year, reliable production of transparent ice with no visible optical defects.
- Multiple cycles with the same argon ($\text{LAr} \rightarrow \text{SAr} \rightarrow \text{LAr} \rightarrow \text{SAr}$)
- Freezing duration optimized, reduced from ~24h down to ~3h for ~4kg blocks.



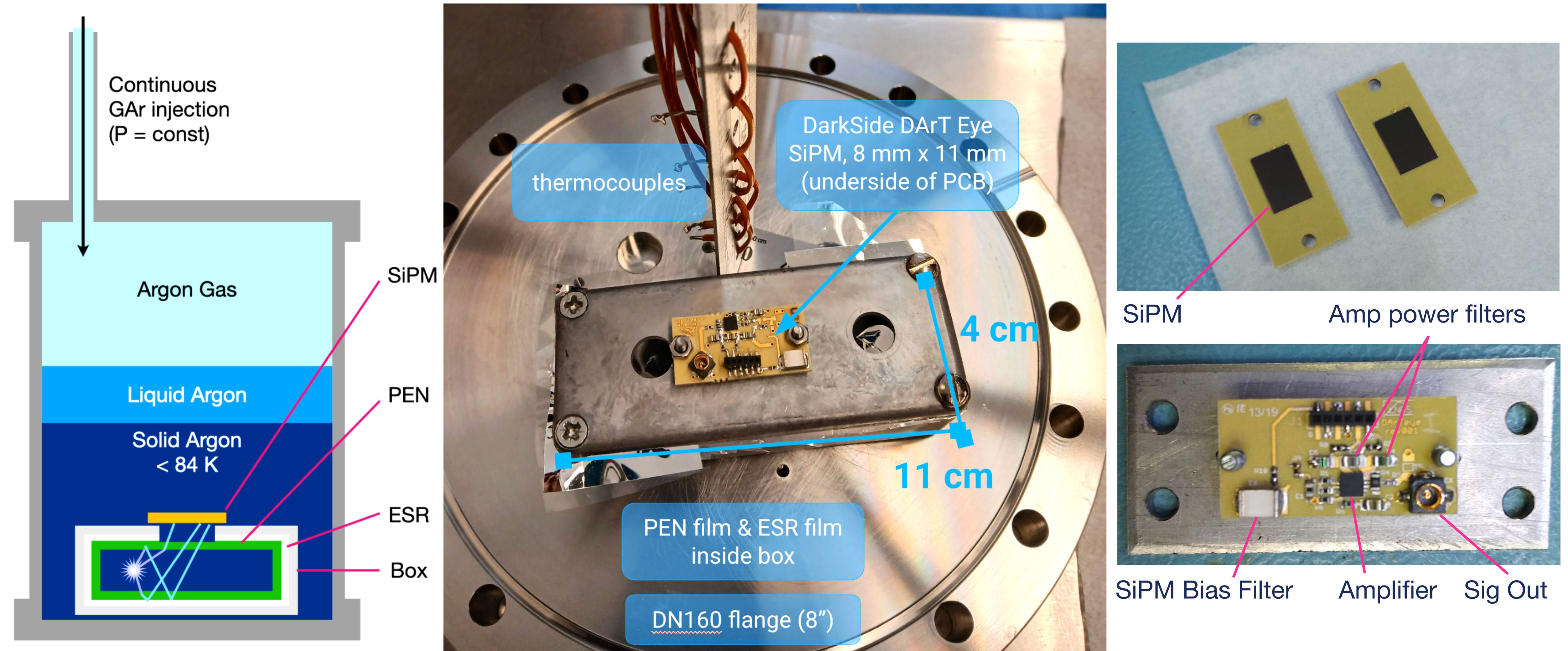
- Does solid argon even scintillate?
- How does solid argon scintillation compare to liquid argon's?

Photo-detection in SAr

LEGEND Large Enriched
Germanium Experiment
for Neutrinoless $\beta\beta$ Decay



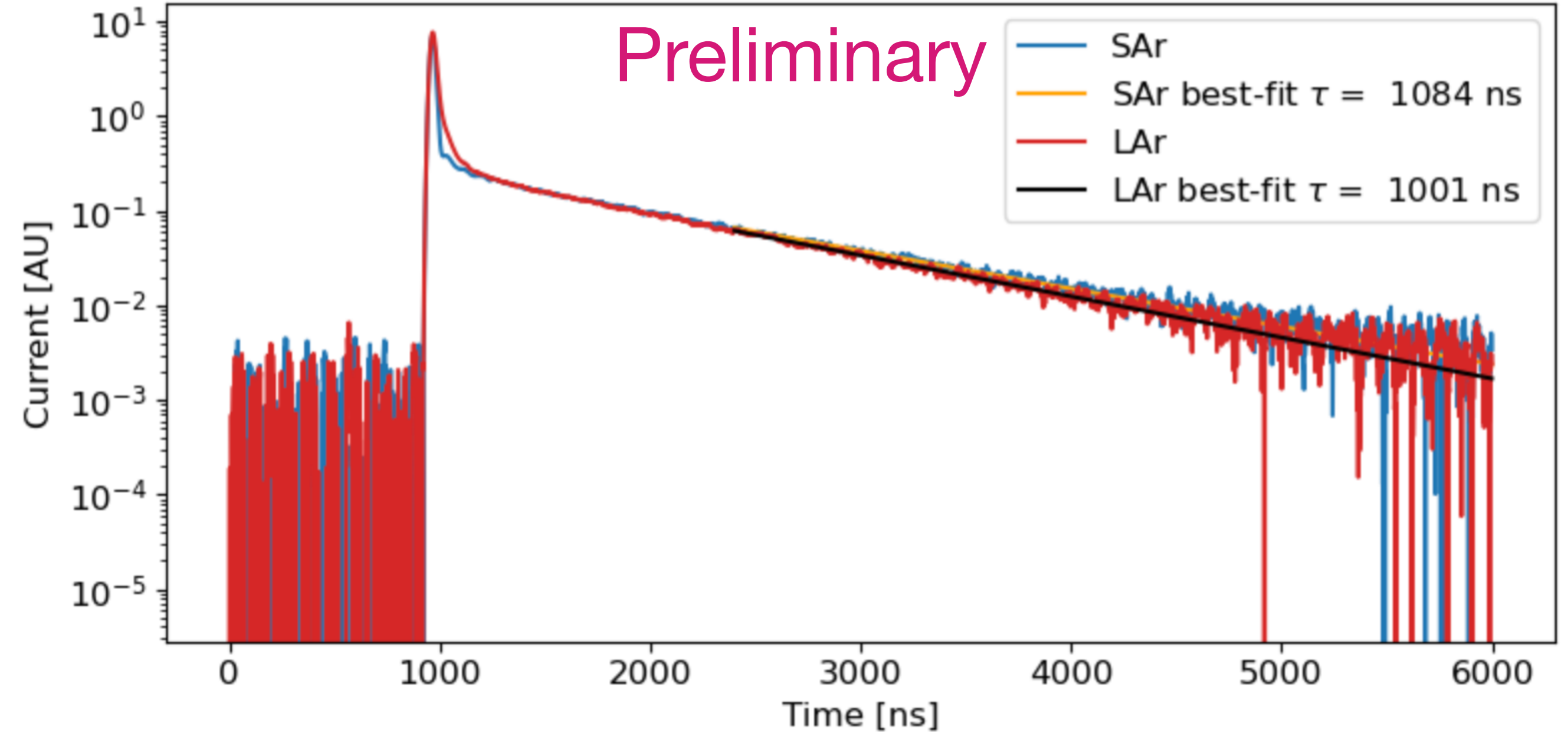
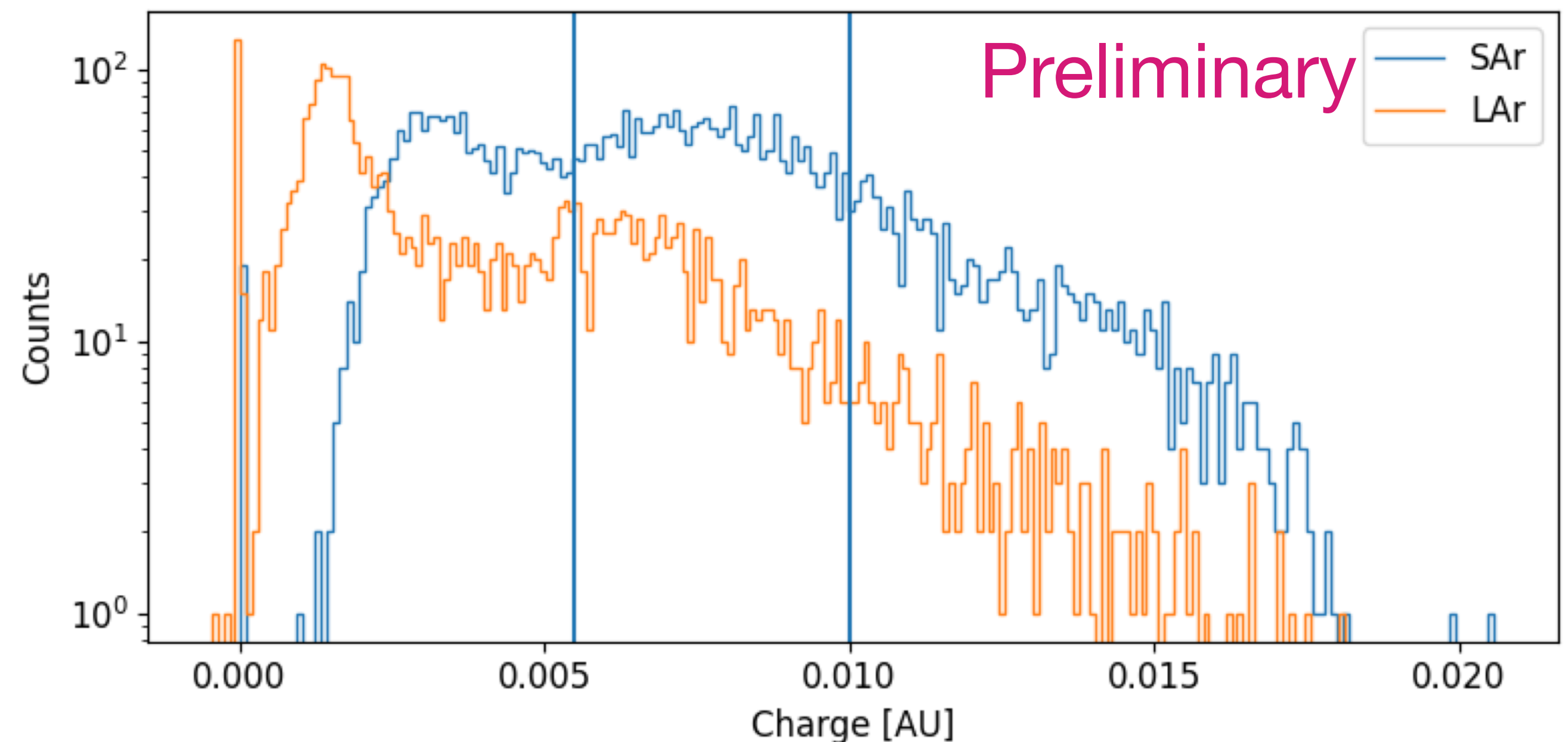
Setup



Idea: line the inner walls of a small box with reflector (ESR) and a wavelength shifter (25 μm Teonex Q51). The box is equipped with a $\sim 1 \text{ cm}^2$ SiPM with cryogenic amplifier (DArT Eye).

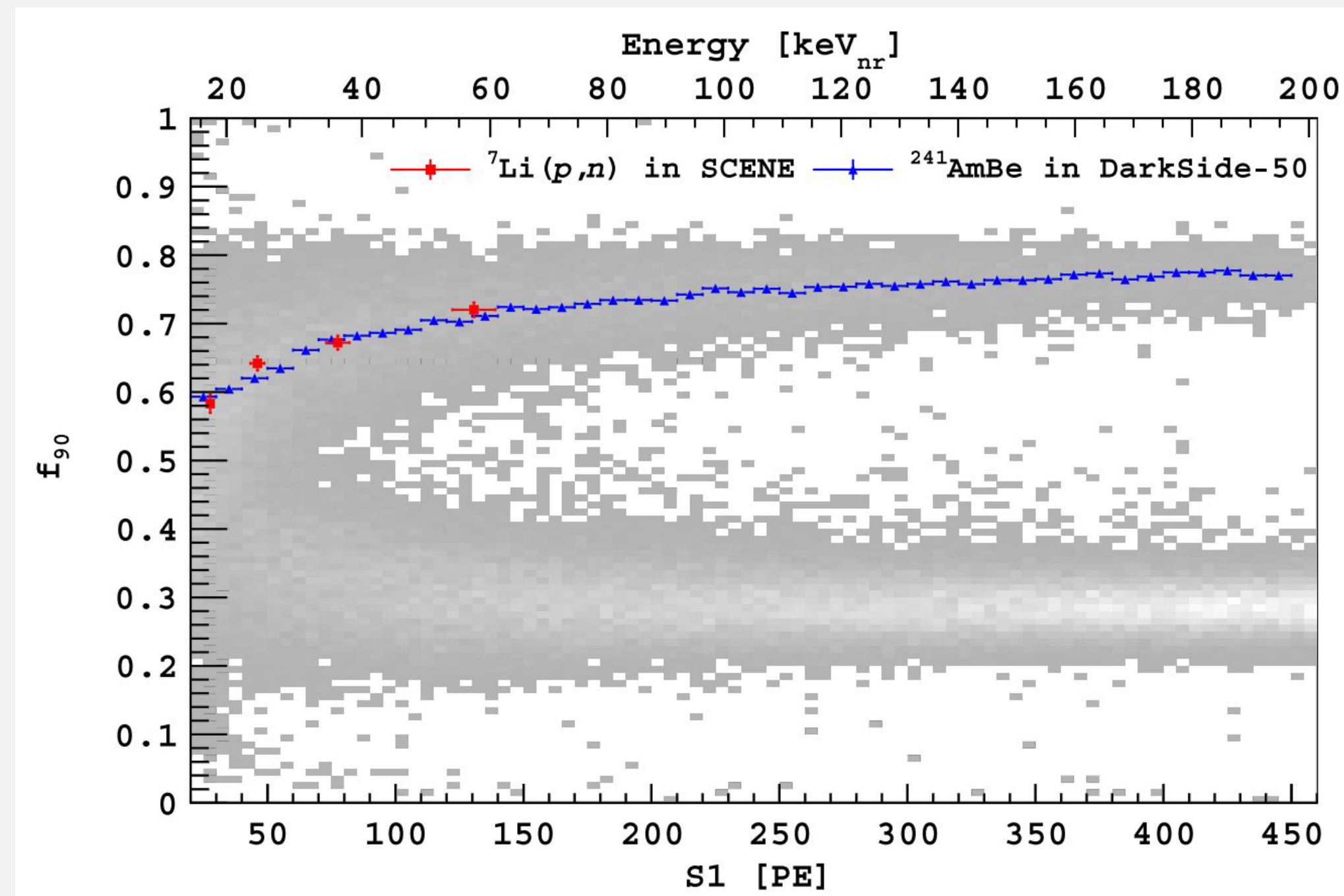
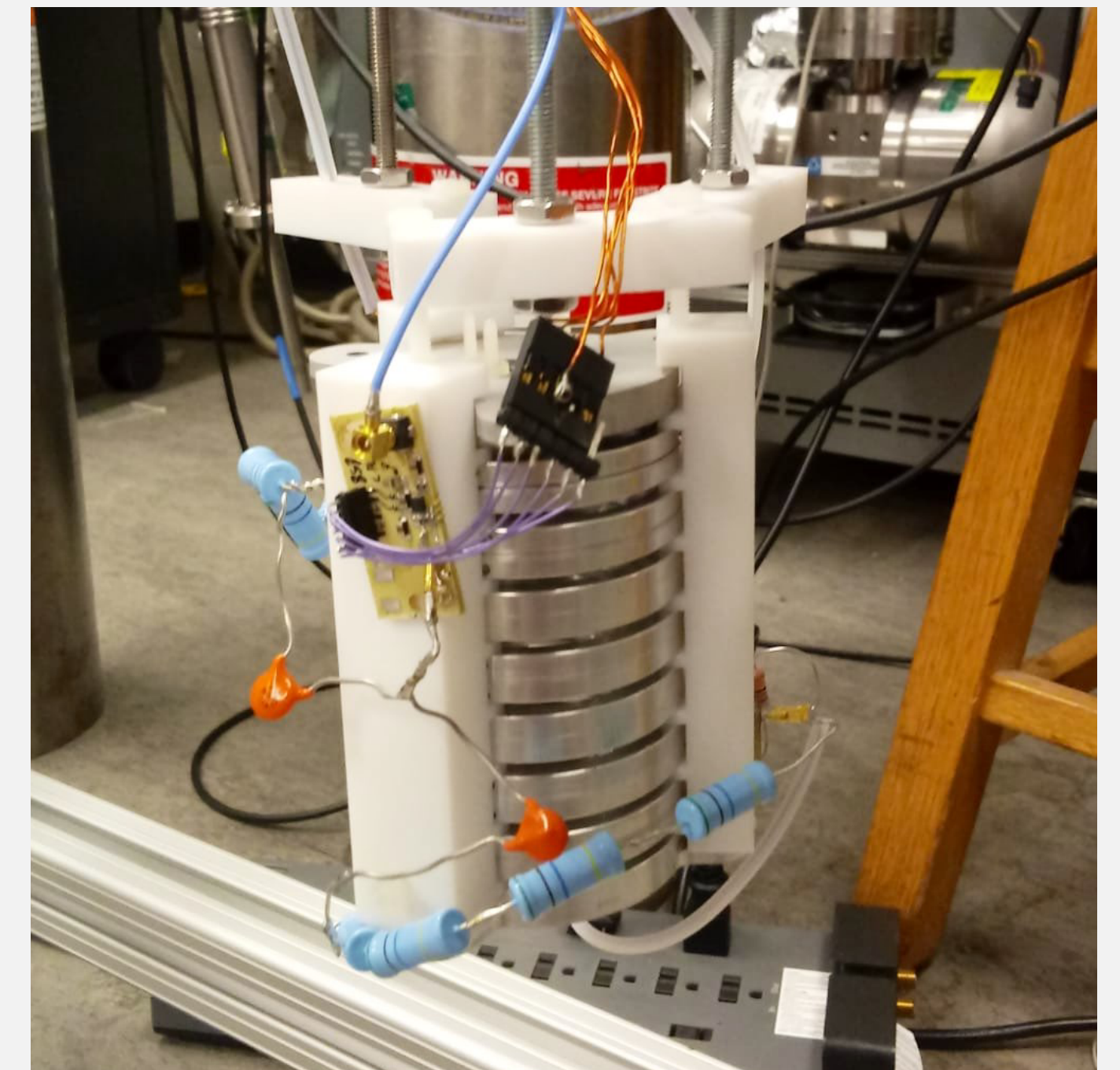
Early data from our setup

- Does solid argon even scintillate?
 - YES! Plenty of light even after freezing
- How does solid argon scintillation compare to liquid argon's?
 - Very similar time profile!
 - Triplet lifetime a bit longer
 - Light Yield a bit higher?
- Two possible explanations:
 - Impurities locked in place $\Rightarrow$ less collisions with excimers
 - Less impurities in argon due to different solubility while cooling?



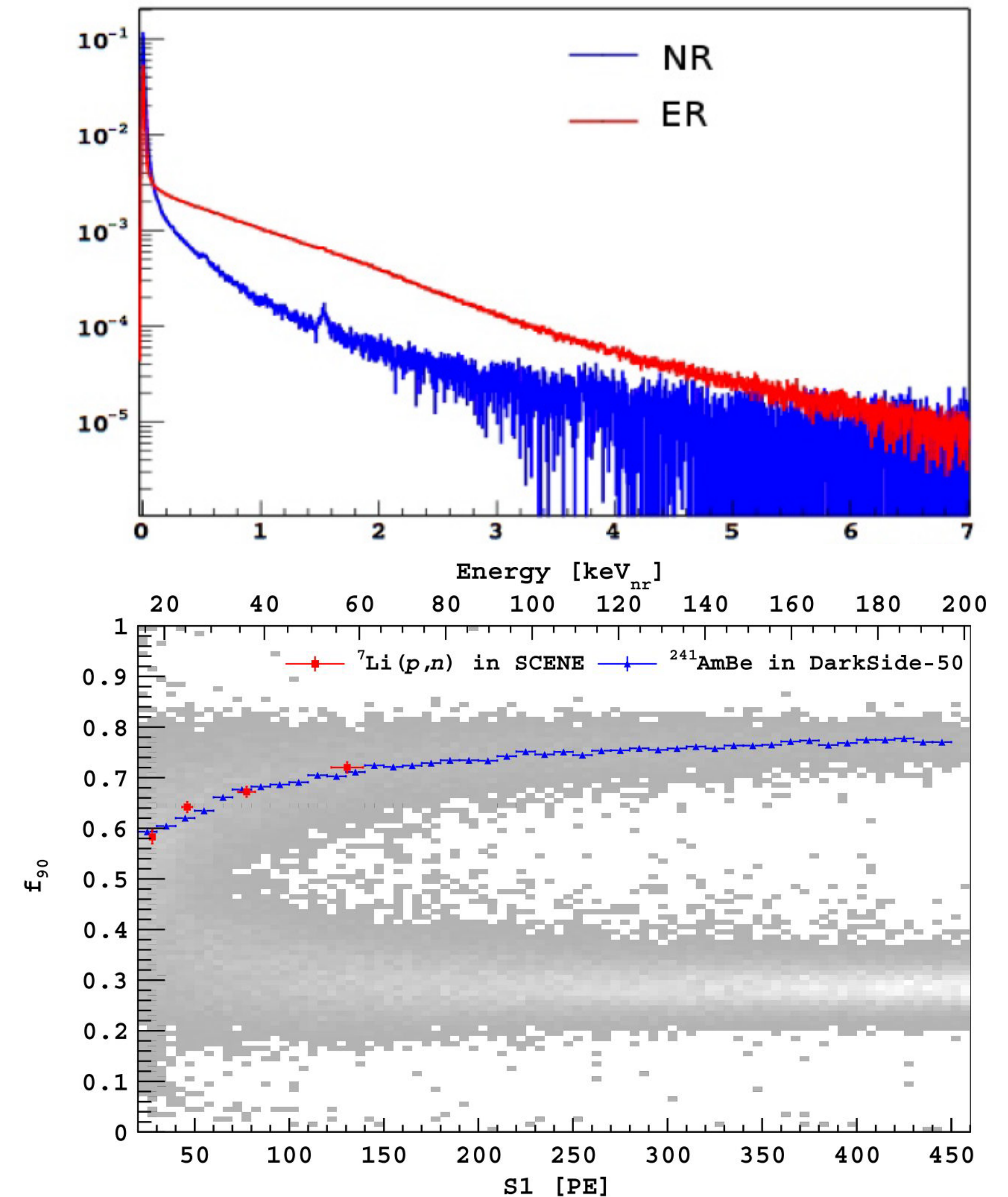
Future Studies

LEGEND Large Enriched
Germanium Experiment
for Neutrinoless $\beta\beta$ Decay



Neutron vs γ/β discrimination via pulse shape

- Nuclear recoils and electron recoils generate different ratios of singlet/triplet excimers (ionization density)
- Pulse shape dramatically different $\Rightarrow$ Discrimination
- Prompt-to-total light is an easy figure of merit
- Does Solid Argon preserve PSD capabilities?
- Plan:
 - Make a new “test volume” with more SiPMs (higher LY)
 - Use AmBe source to collect NR and ER
 - Develop a suitable PSD cut, if possible
- Not useful to LEGEND now, but could be in the future if we improve veto LY

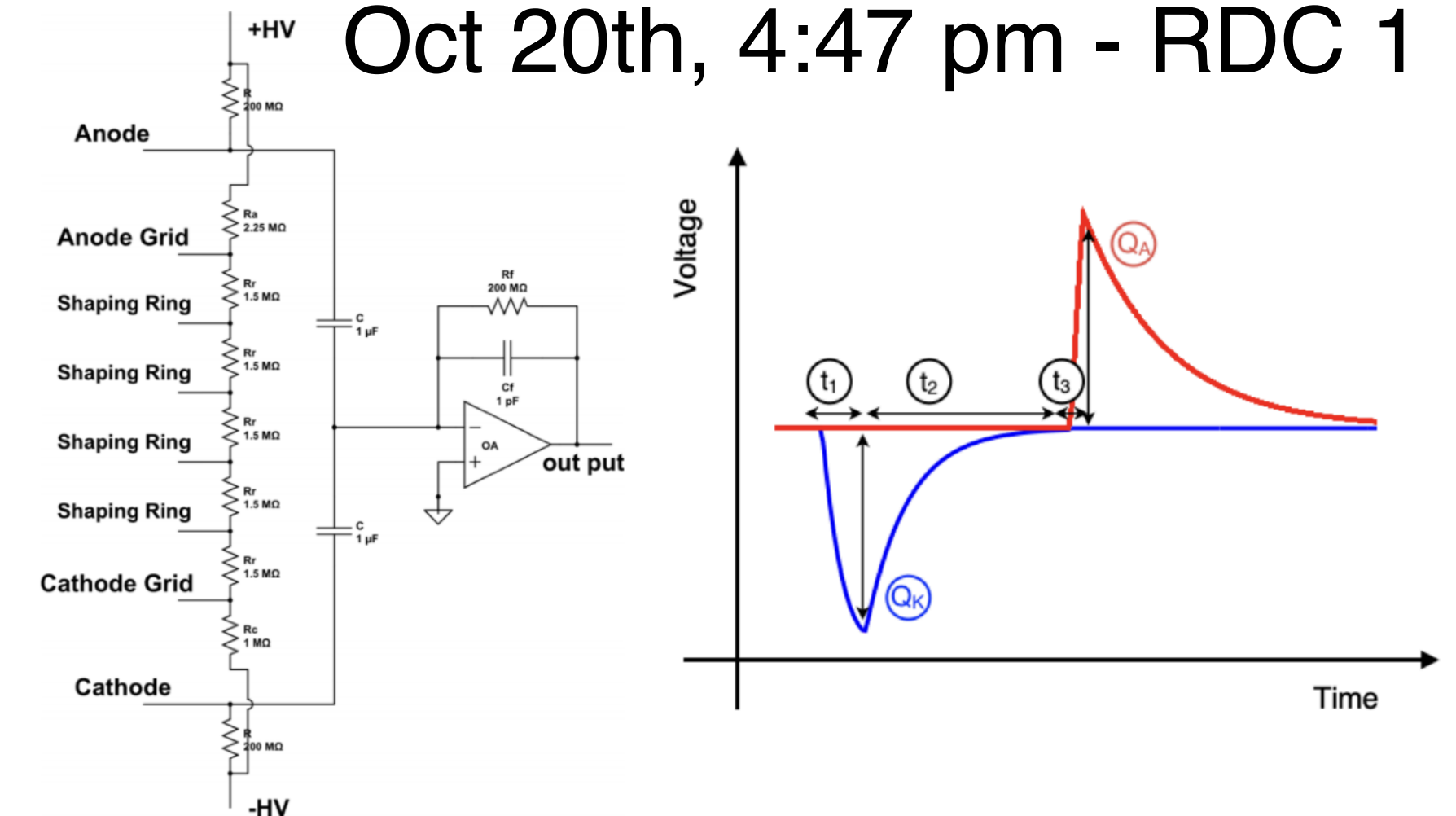
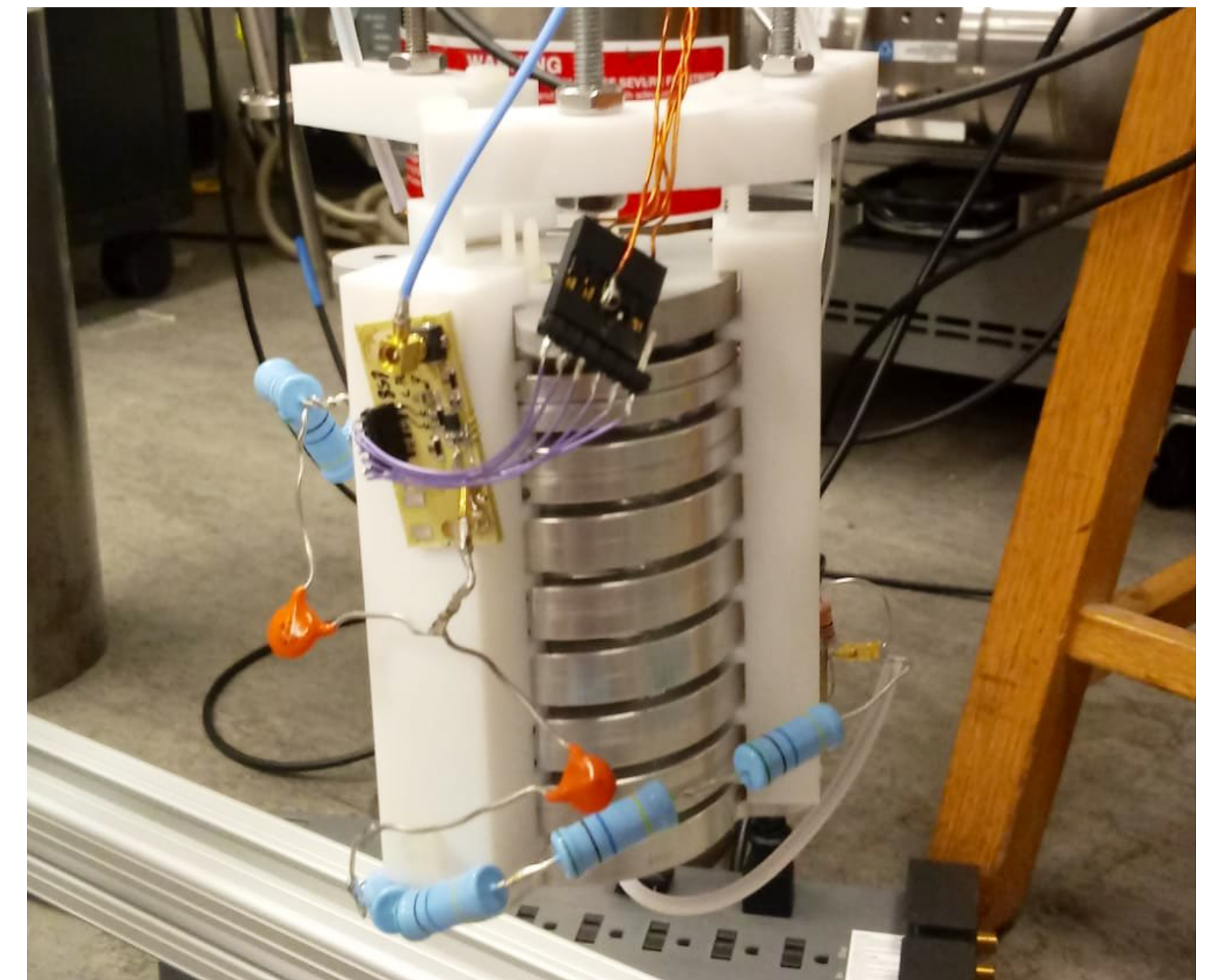


Electron transport in SAr

- LAr allows the drifting and collection of ionization electrons $\implies$ Working principle of LAr TPC for neutrino experiments and DM searches.
- Can SAr also transport electrons over macroscopic distances?
- Designing a small single-phase TPC:
 - Anode, Cathode: Gold-coated FS
 - Field shaping rings: Copper
 - Mechanical Supports: PEEK (UHV compatible)
 - Electron source: alpha source OR photoelectric emission from gold cathode.

Hear more from Sam Bellman!

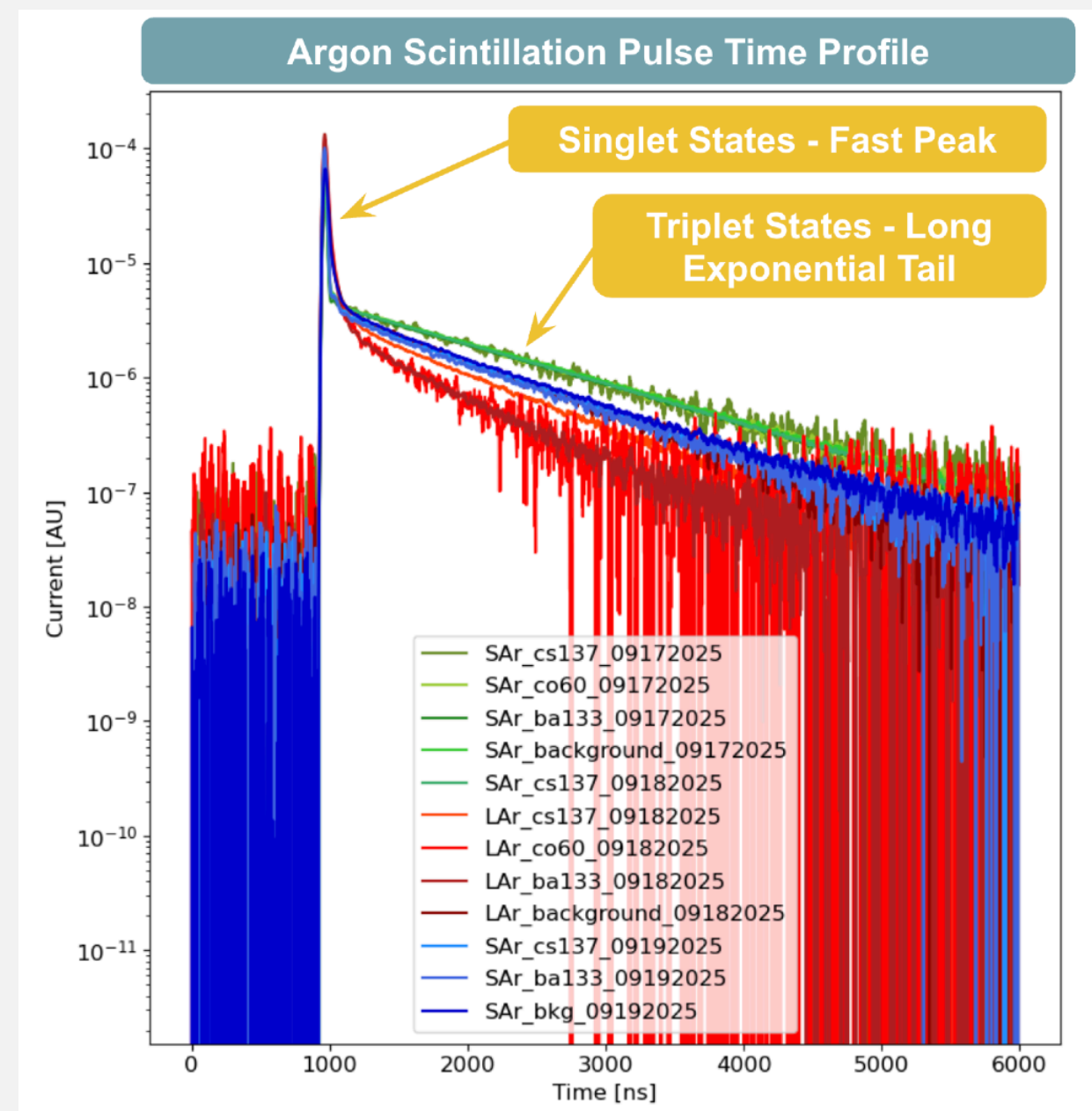
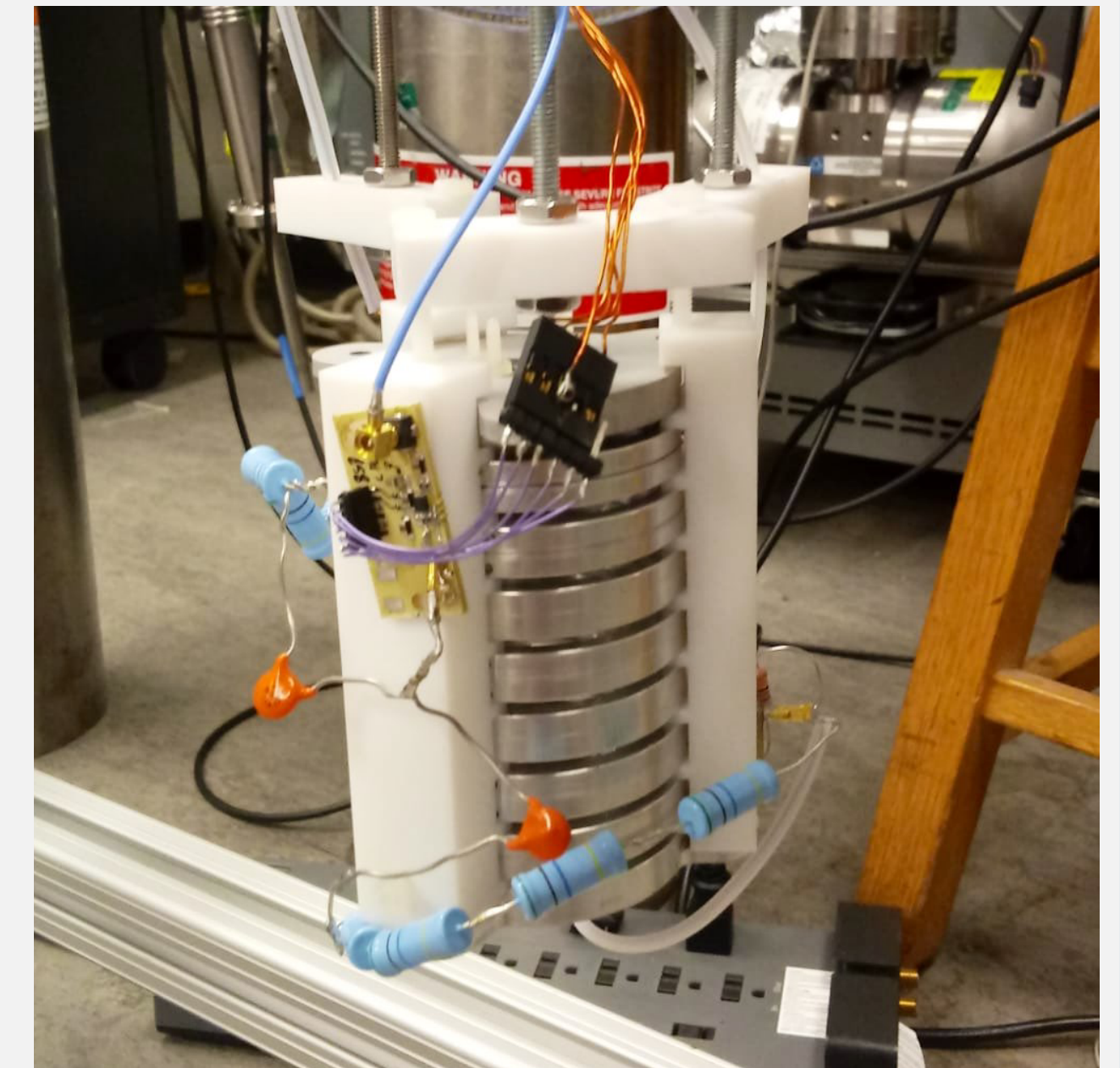
Oct 20th, 4:47 pm - RDC 1



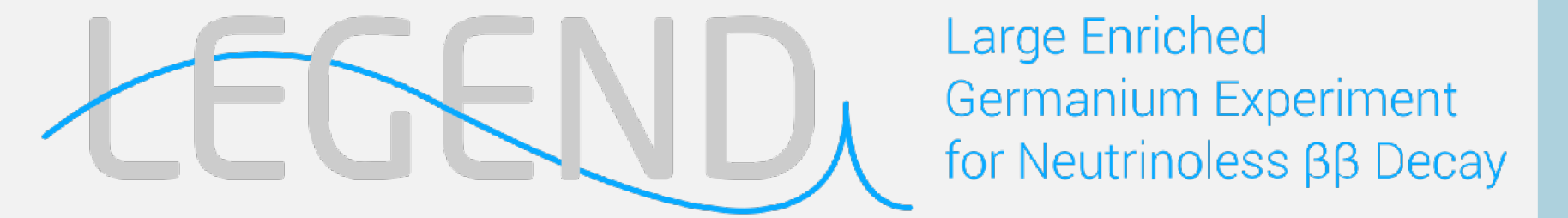
- A Solid Argon active veto might afford powerful suppression of the K-42 background in next generation LEGEND-like experiments.
- We developed a reliable and quick freezing procedure to obtain transparent solid argon
- SAr scintillates, and its scintillation is similar to LAr
- Future: test if PSD capabilities are retained
- Future: test electron transport

Thank you!

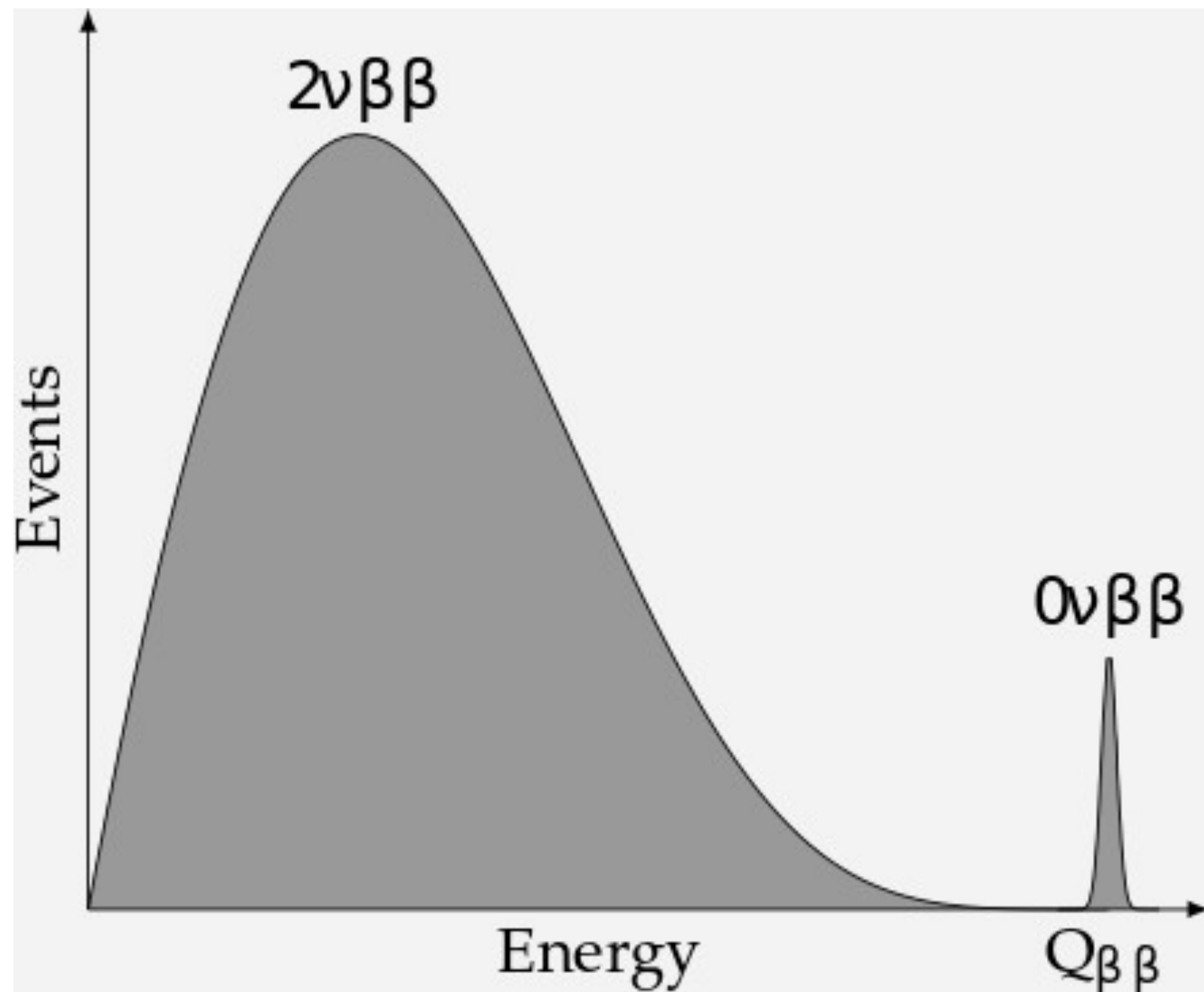
LEGEND Large Enriched
Germanium Experiment
for Neutrinoless $\beta\beta$ Decay



Back up content

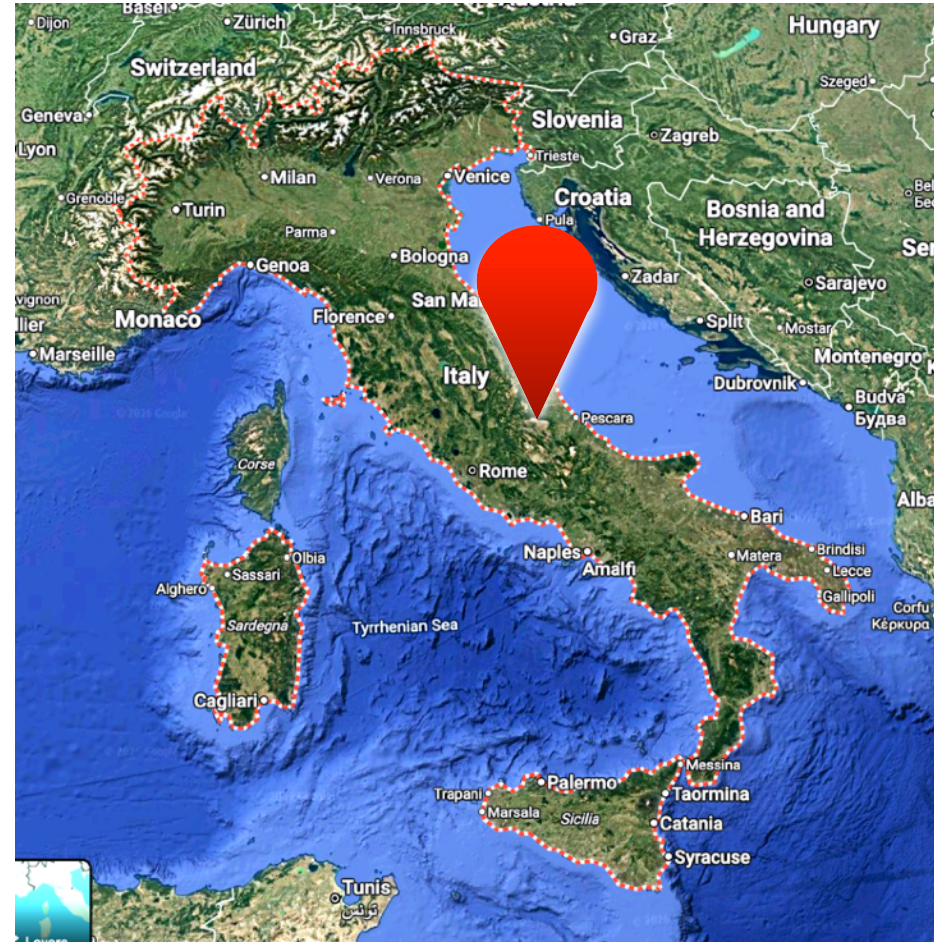
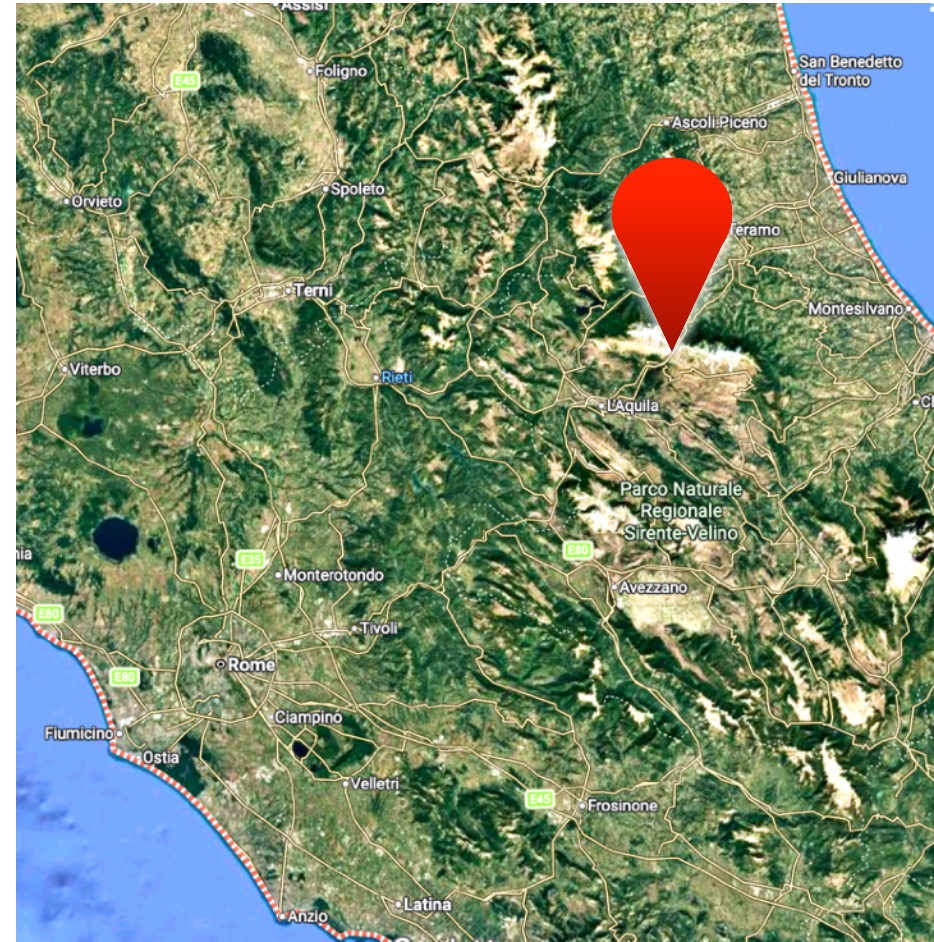
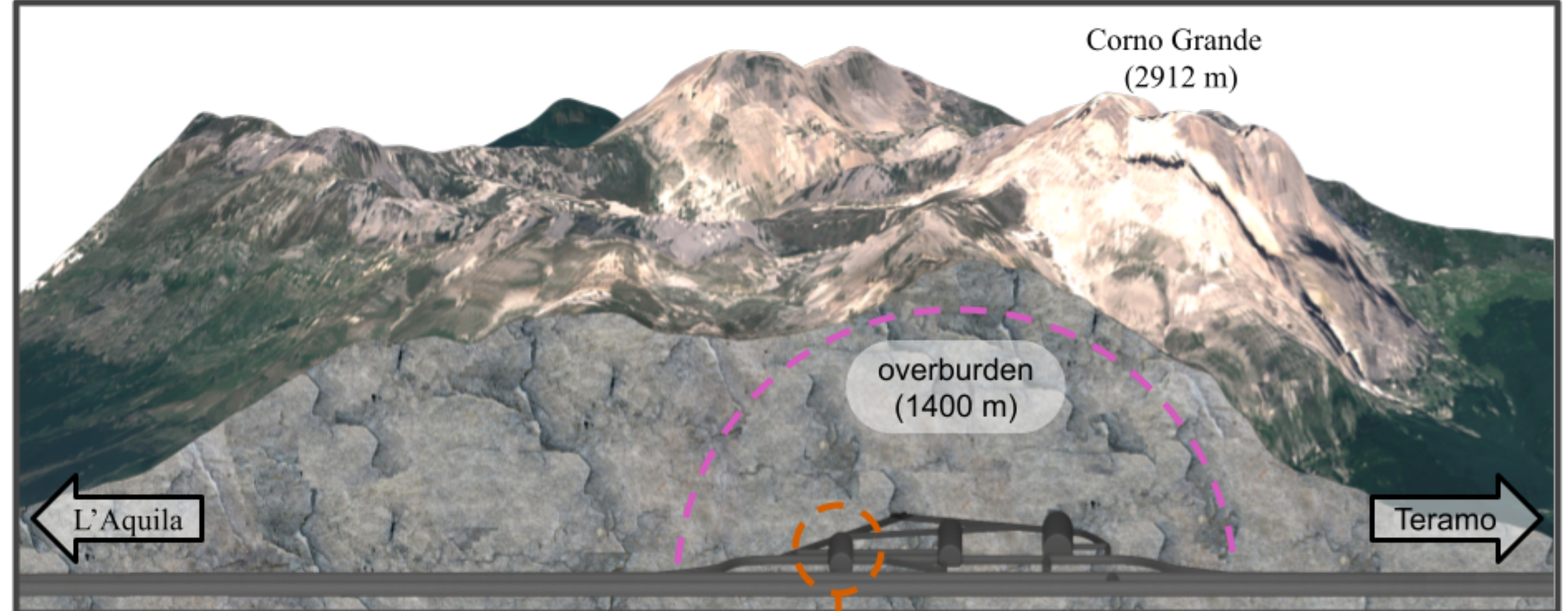
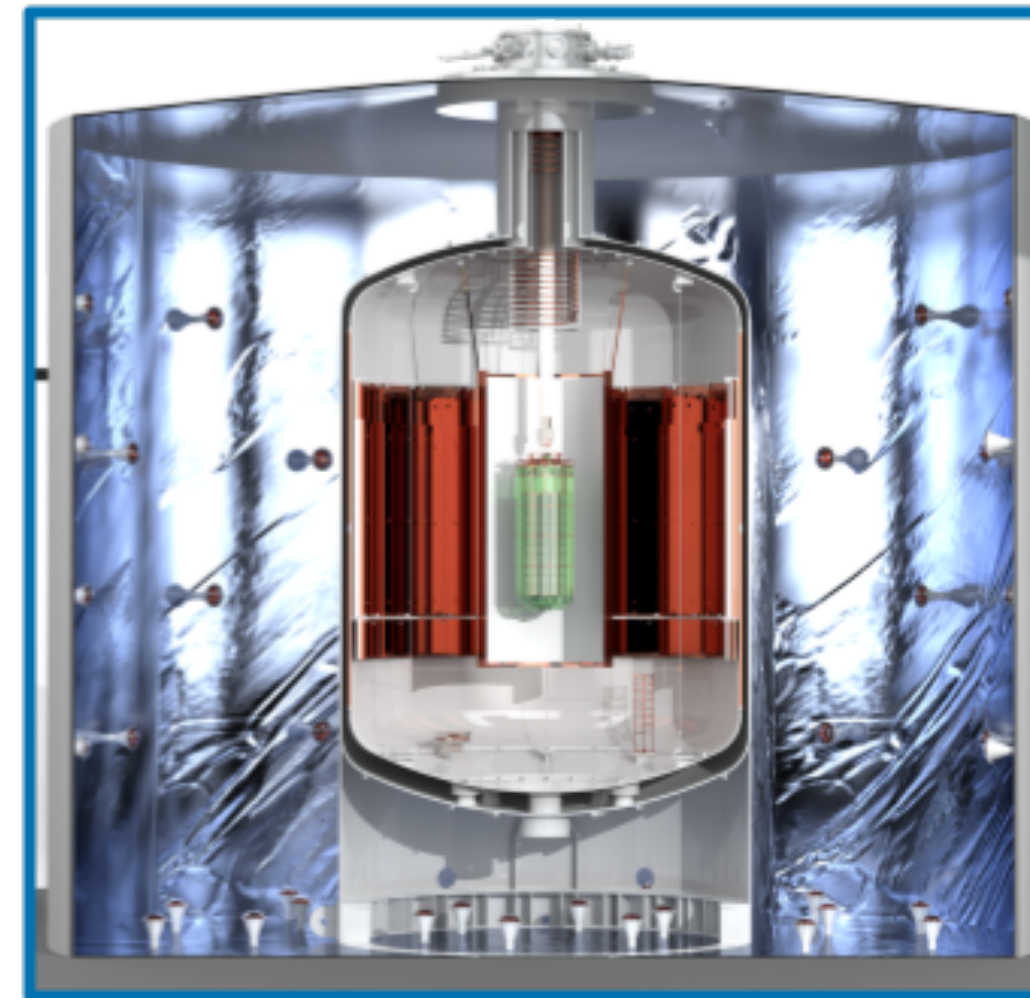
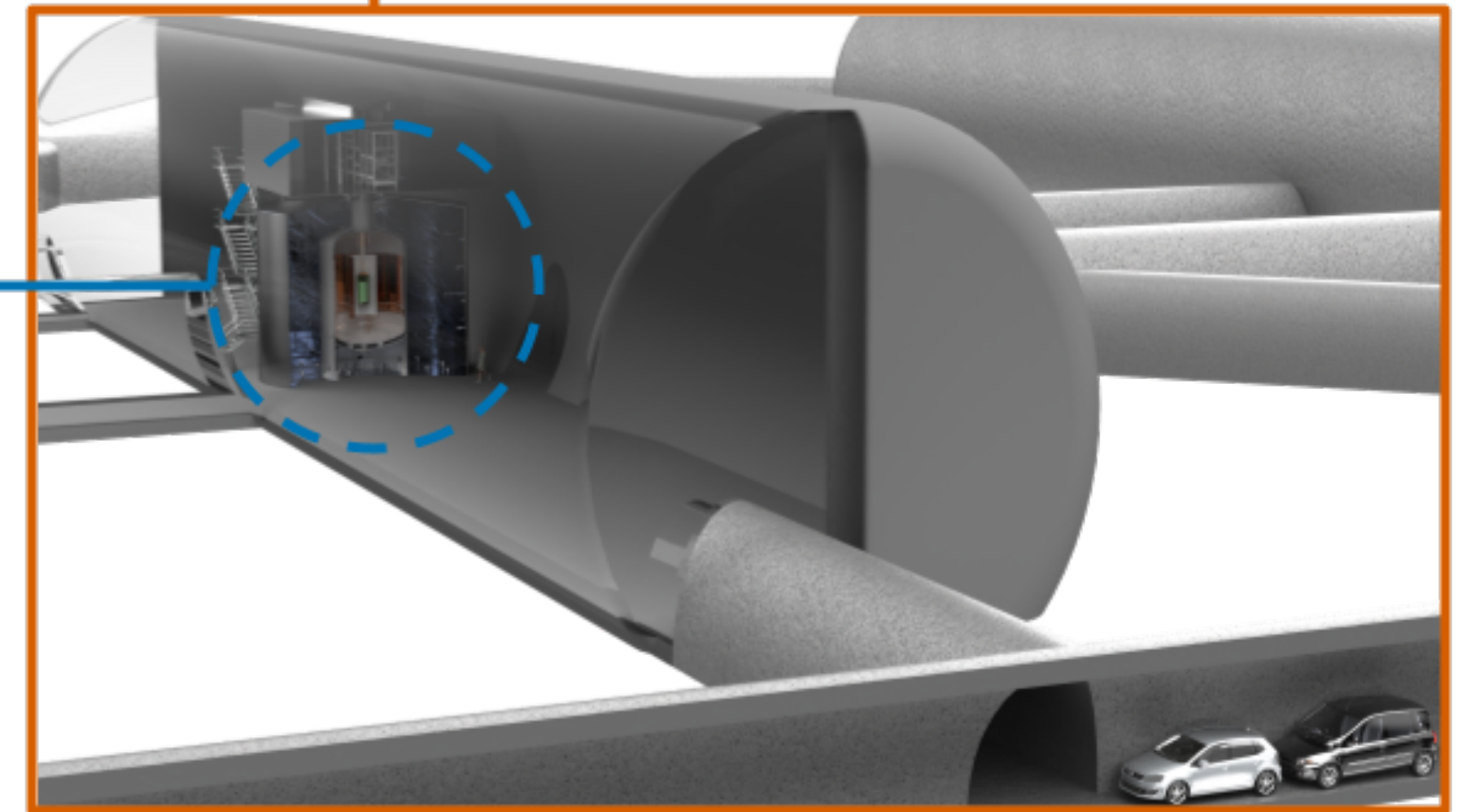


$0\nu\beta\beta$ decay - broad experimental considerations

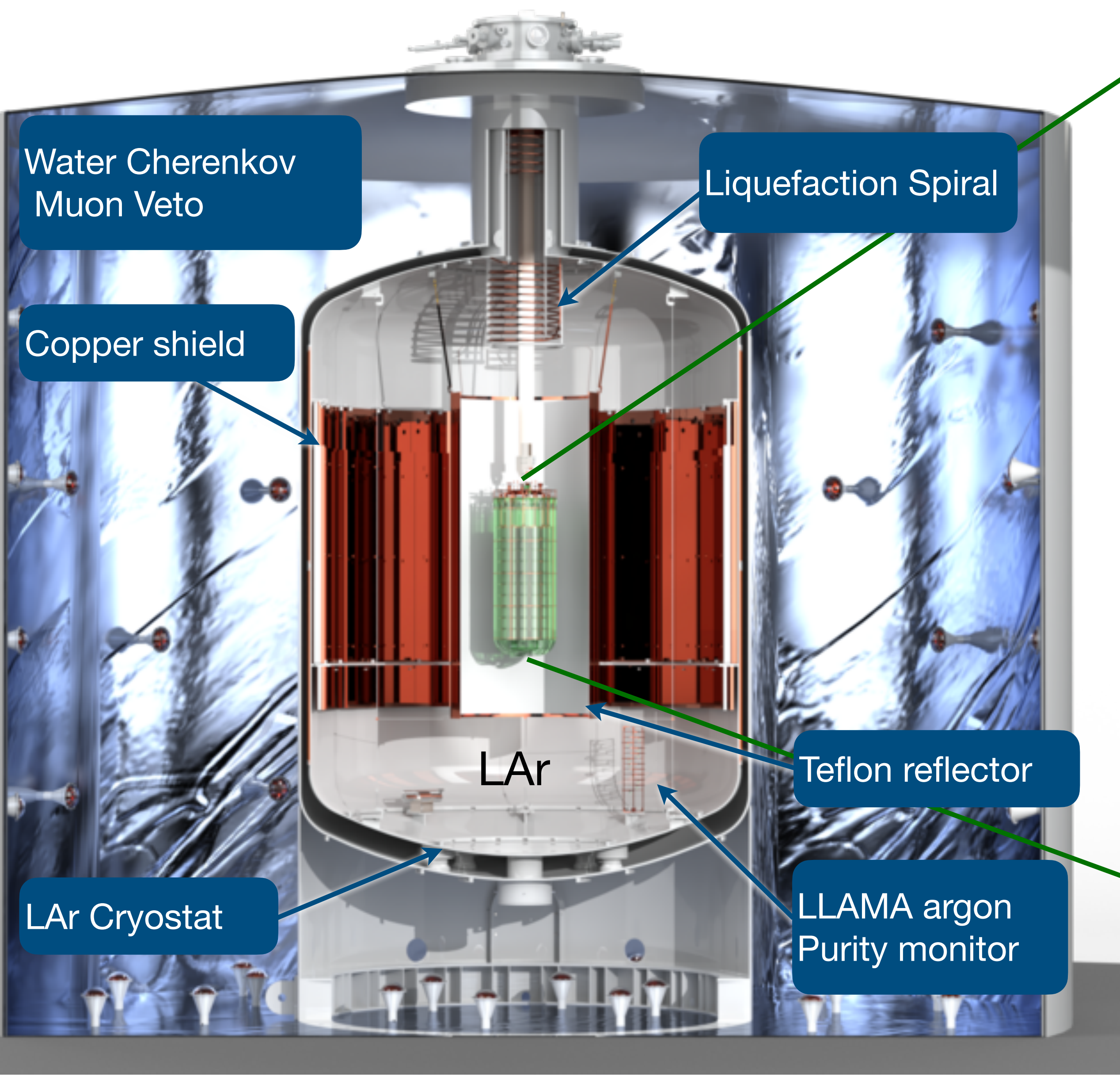
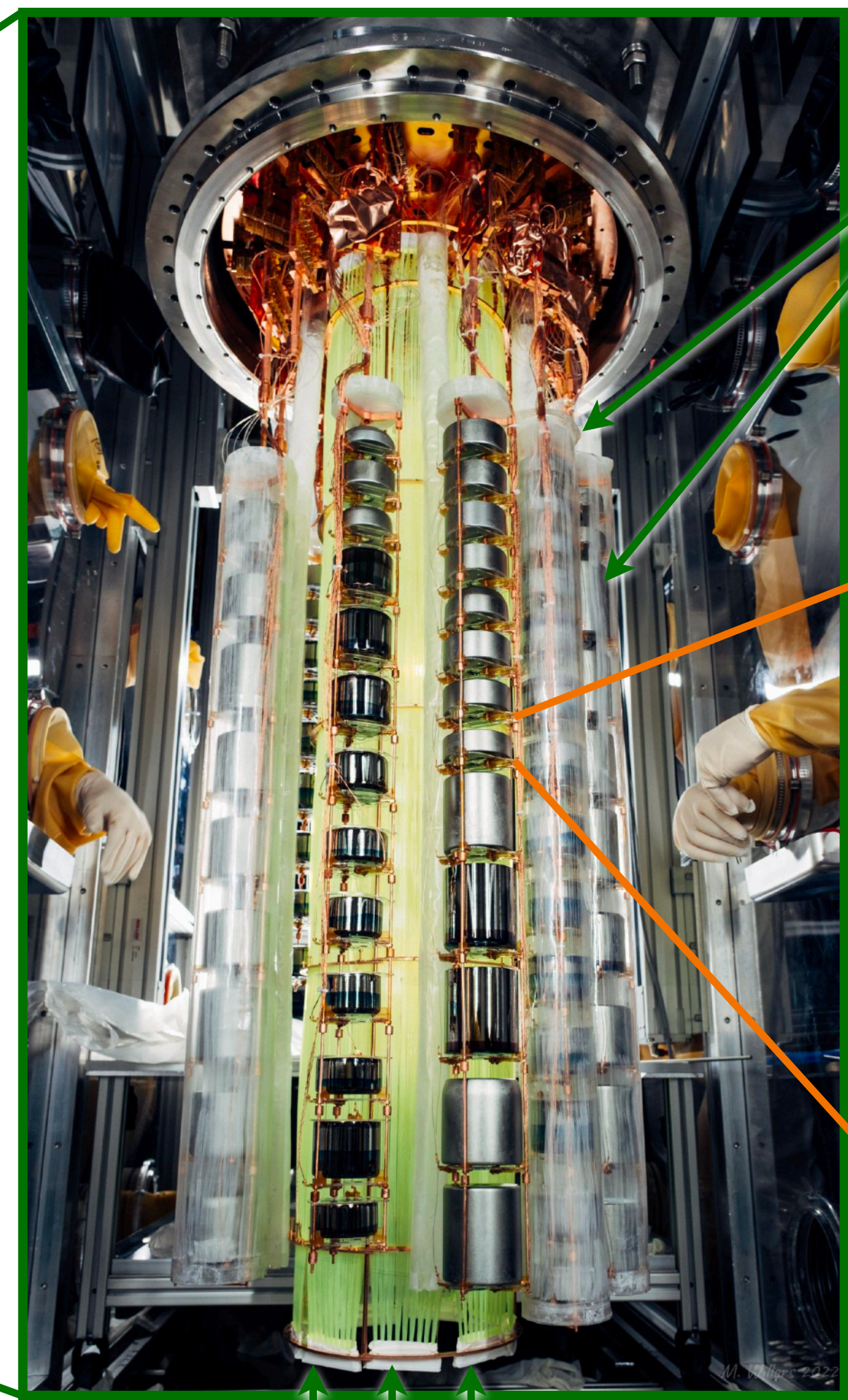
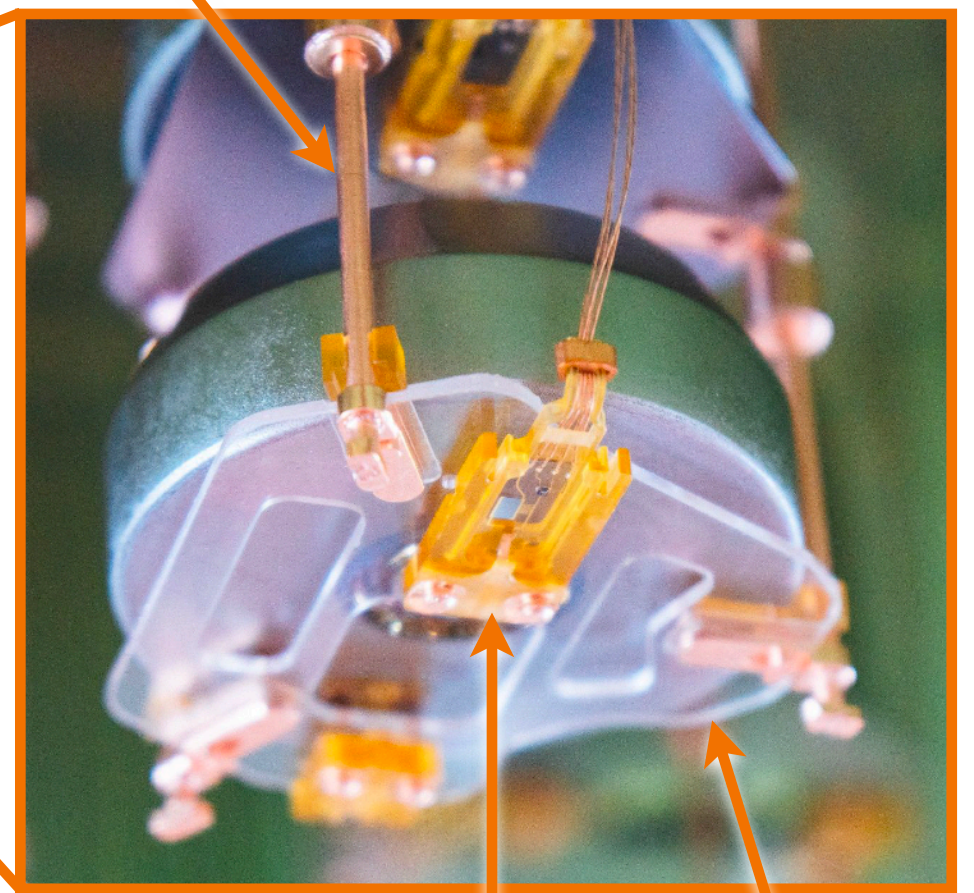


- Electrons KE = Q-value
- Experimental signature: **mono-energetic peak** at the end of the $2\nu2\beta$ energy spectrum
- Strategy: accumulate many of such nuclei and reconstruct the energy of all decays
- **Source = Detector**

Host laboratories: LNGS

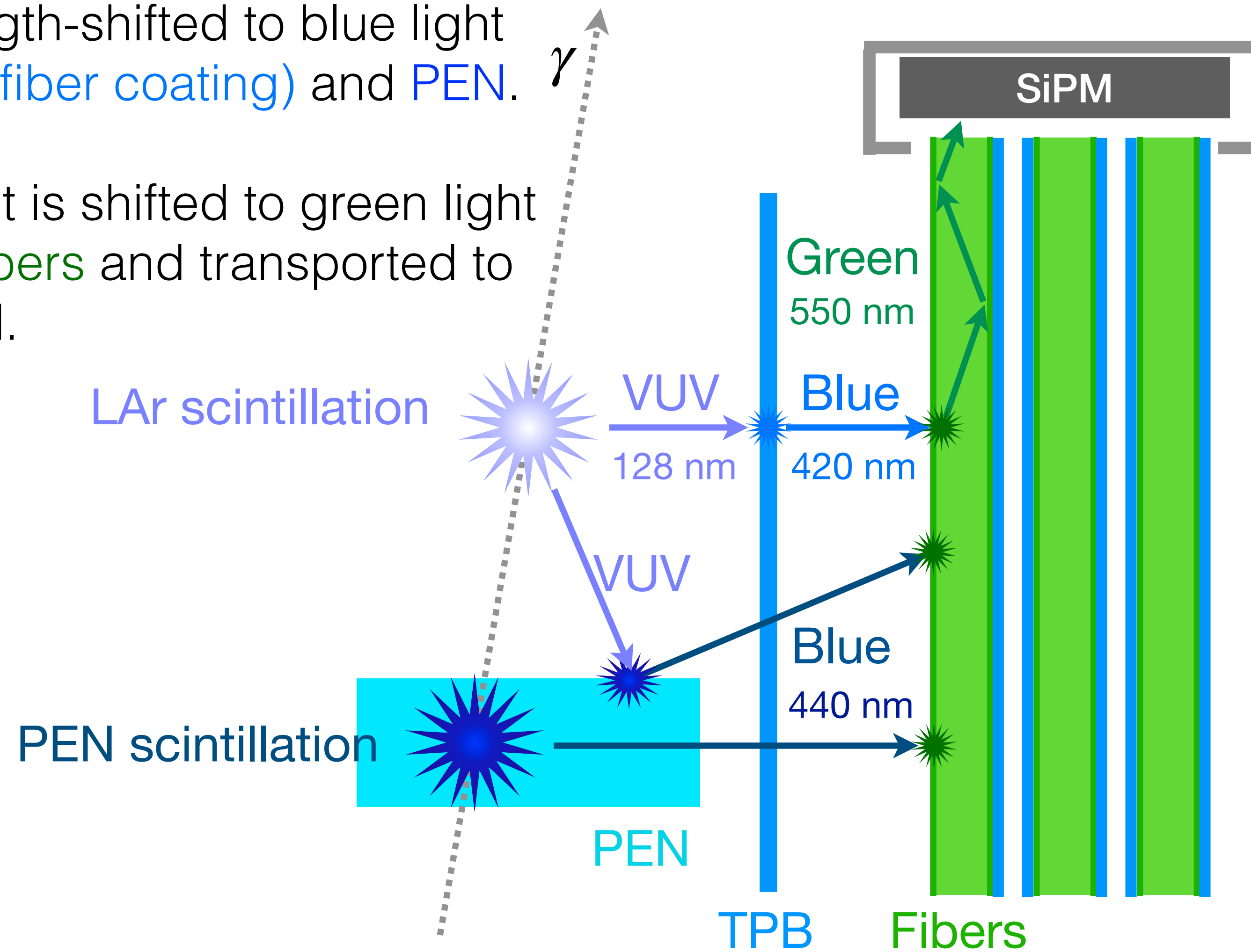
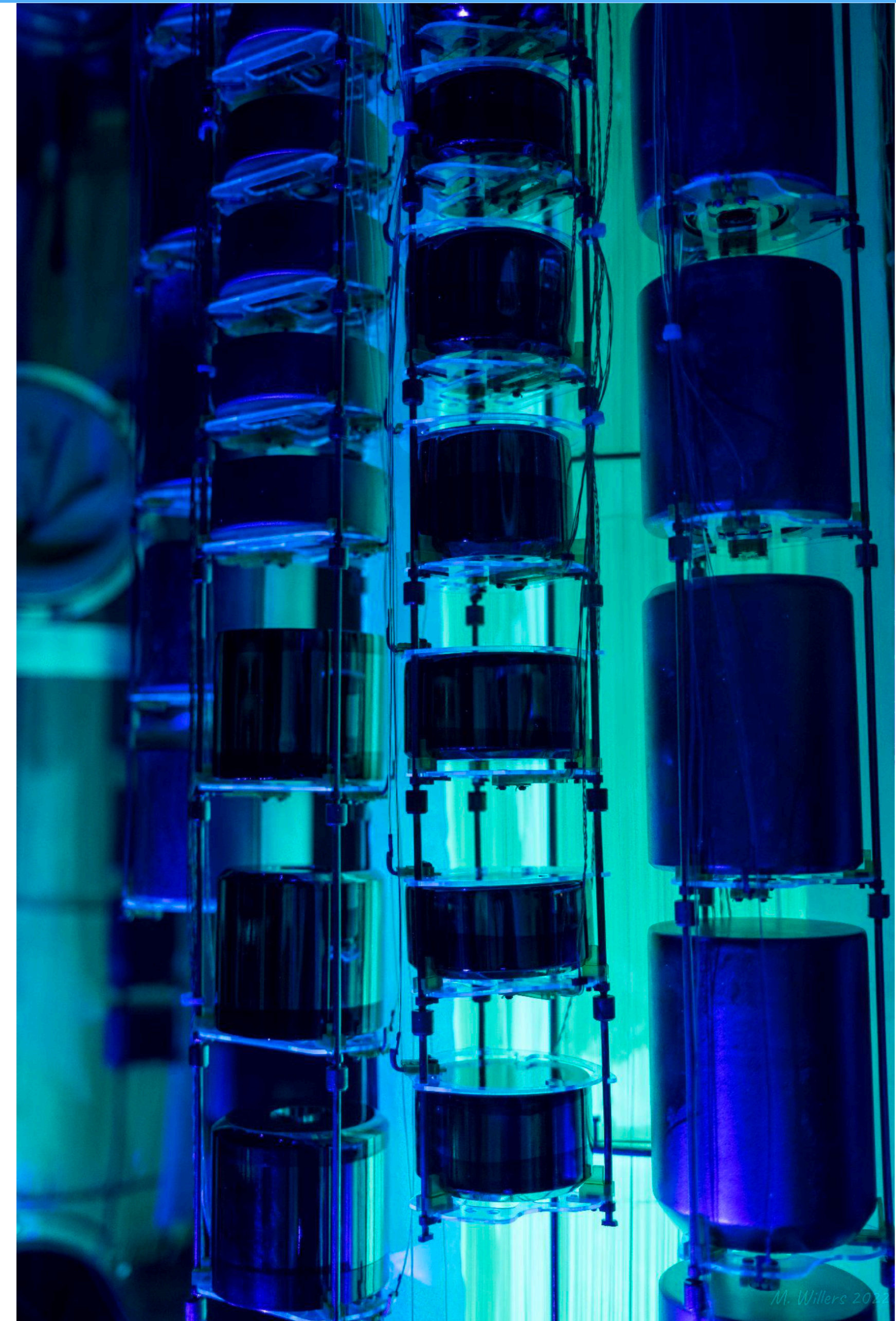


- NE of Rome, IT - Gran Sasso
- Highway access to experimental halls
- 1400 m rock overburden $\implies$ Muon flux reduction factor $\sim 10^6$



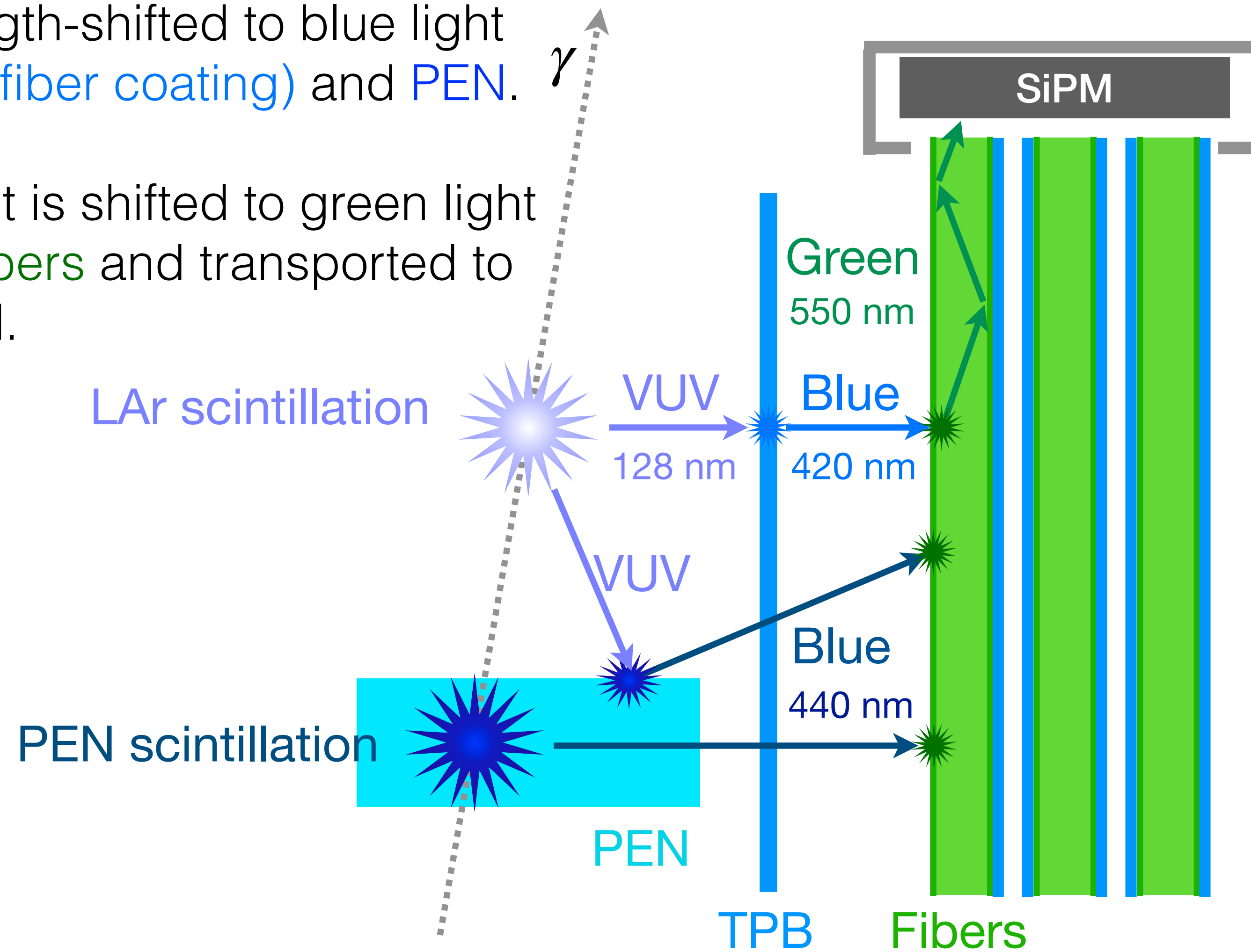
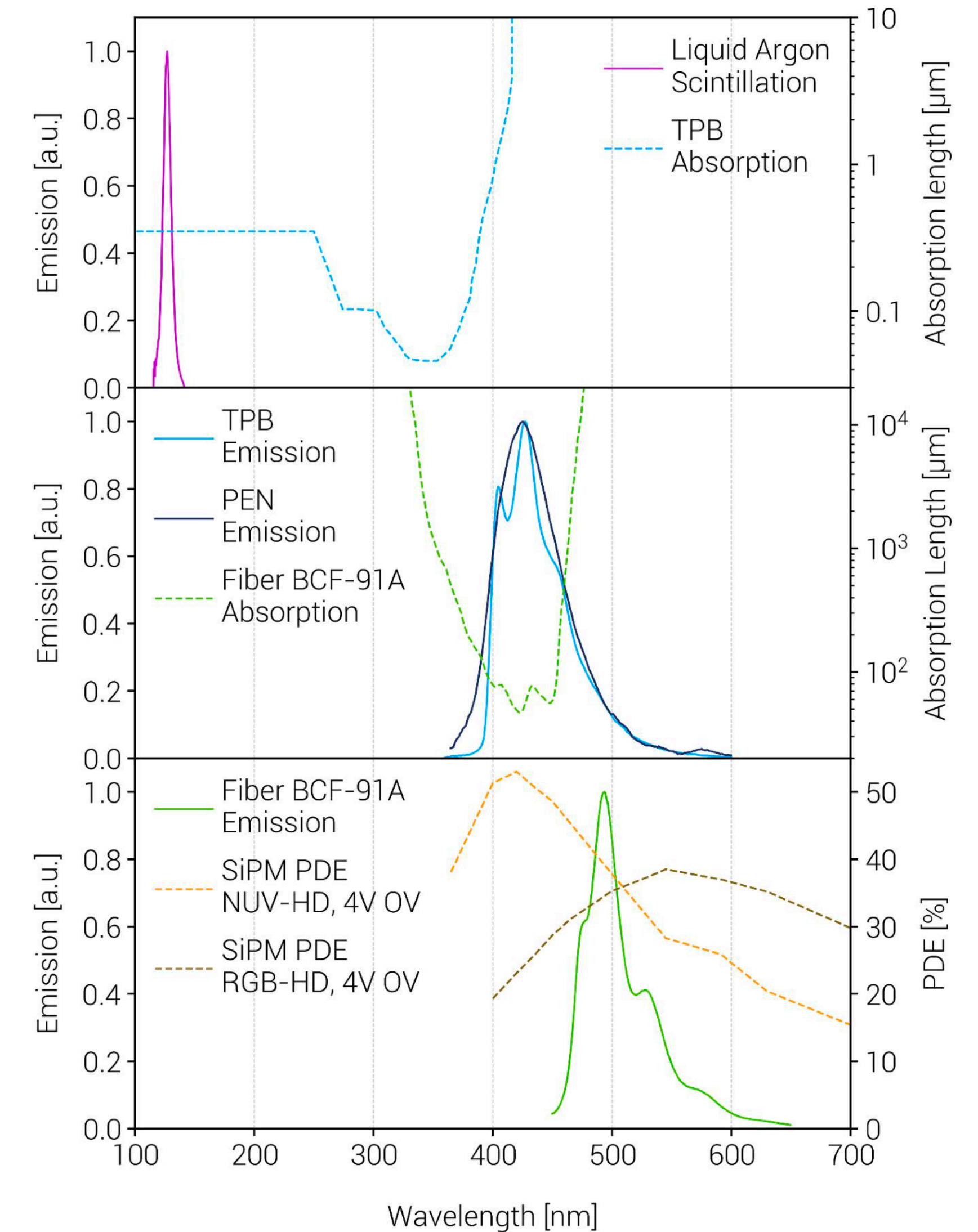
Active liquid argon veto

- LAr VUV scintillation light is wavelength-shifted to blue light by TPB (fiber coating) and PEN.
- Blue light is shifted to green light by the fibers and transported to the SiPM.



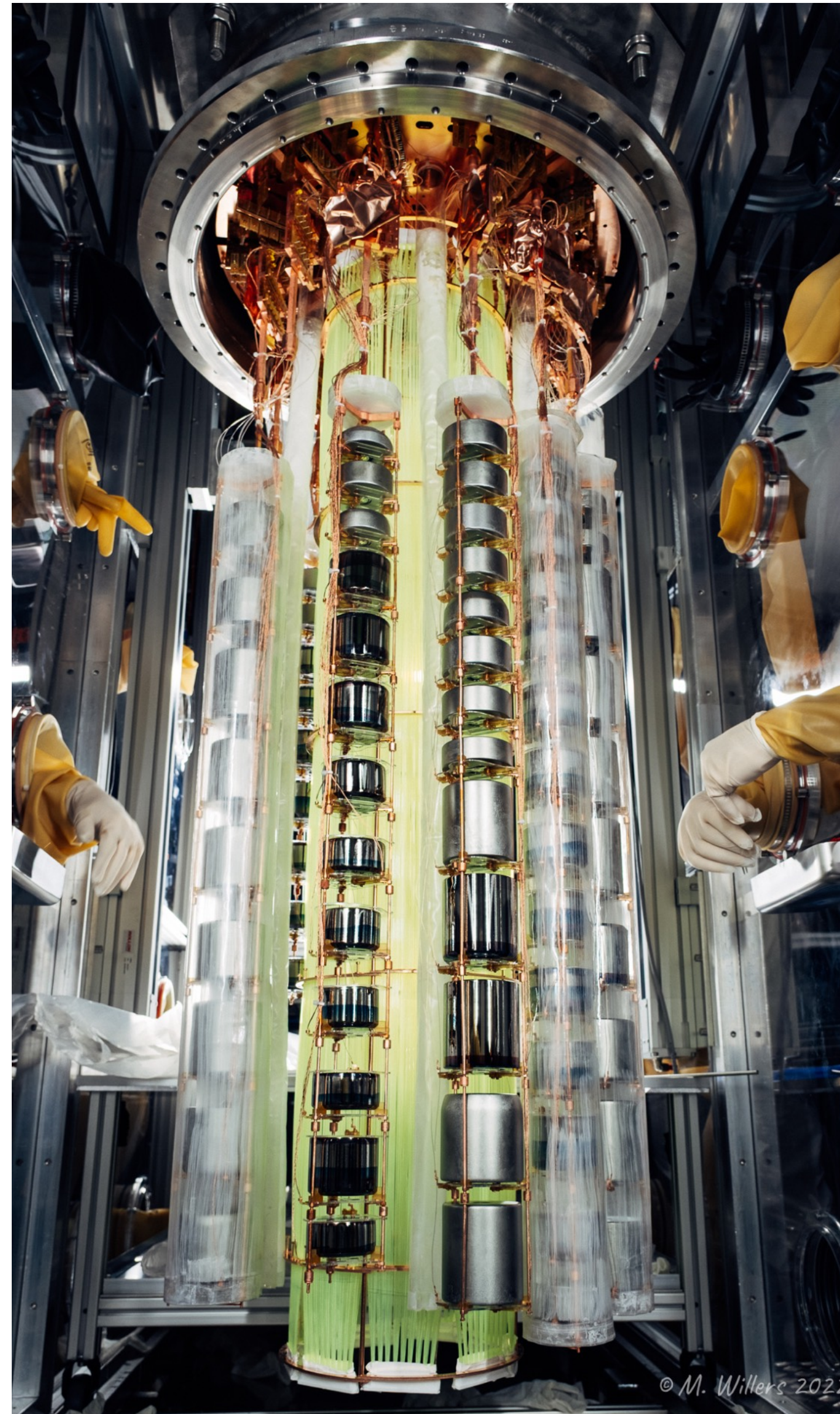
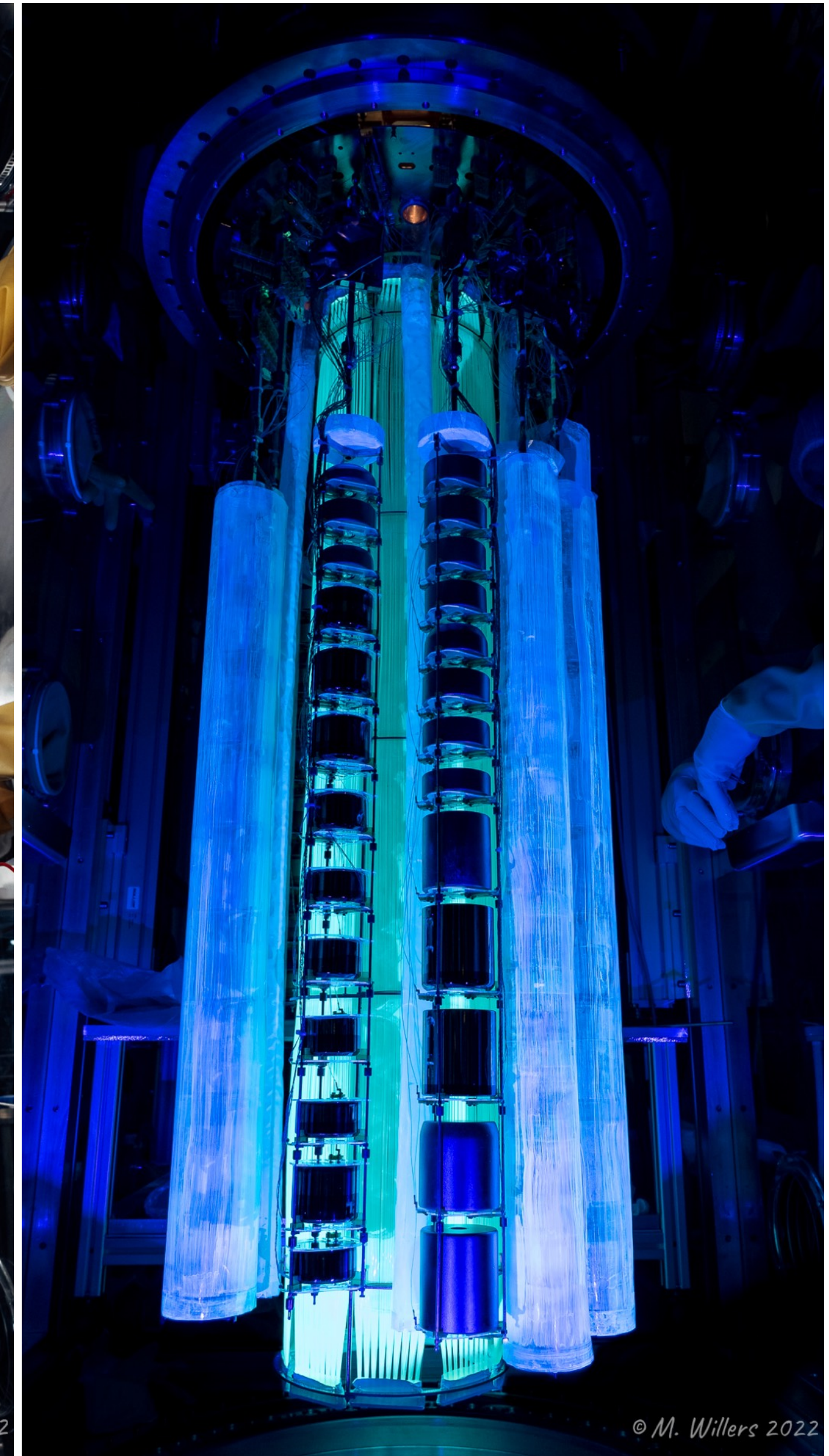
Active liquid argon veto

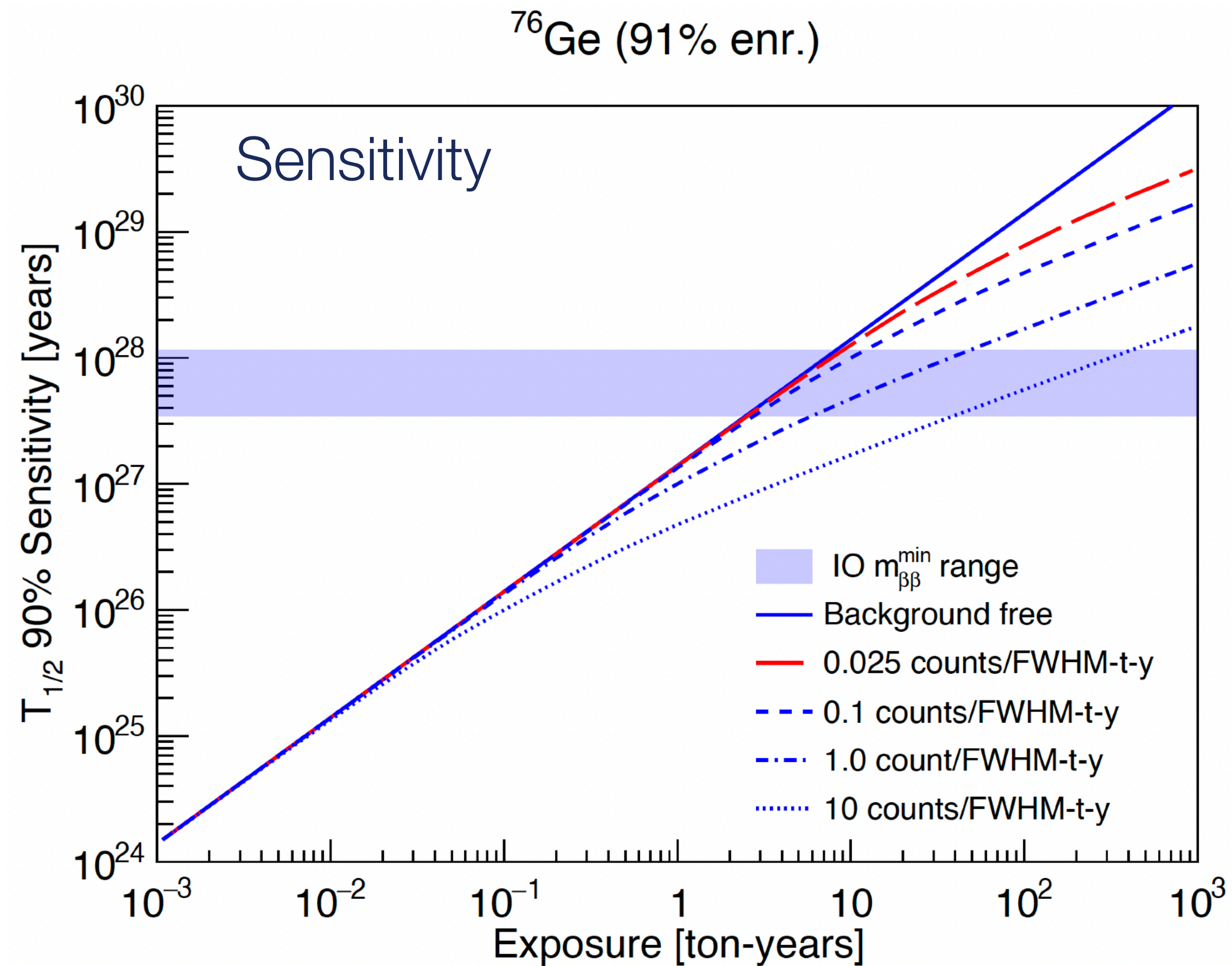
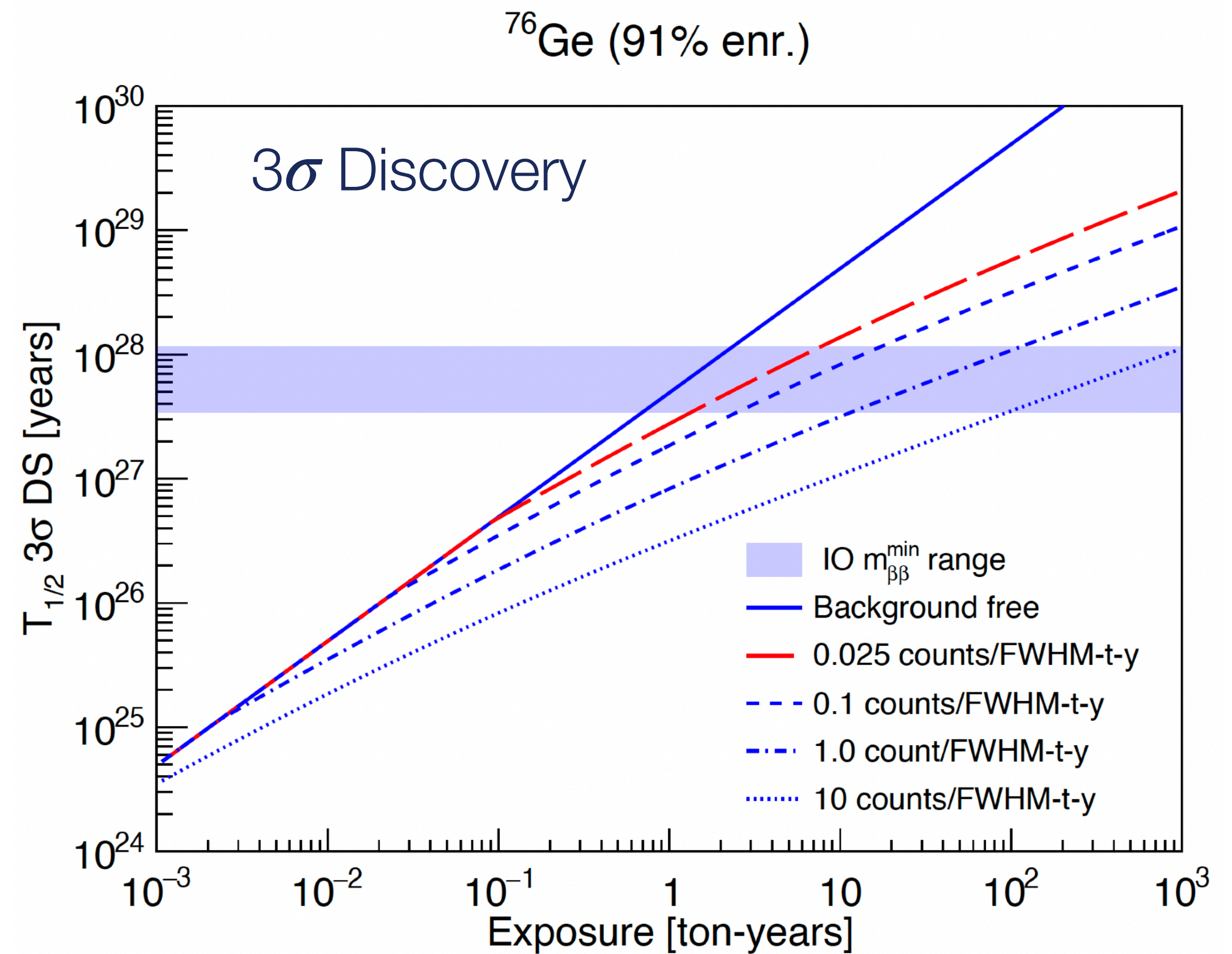
- LAr VUV scintillation light is wavelength-shifted to blue light by TPB (fiber coating) and PEN.
- Blue light is shifted to green light by the fibers and transported to the SiPM.



LEGEND-200 Solution

- TPB-coated PEN Minishrouds
- Physical barrier to K ion drift
- Demonstrated suppression of ^{42}K
- Enough for L-200, but not at the level needed for L-1000

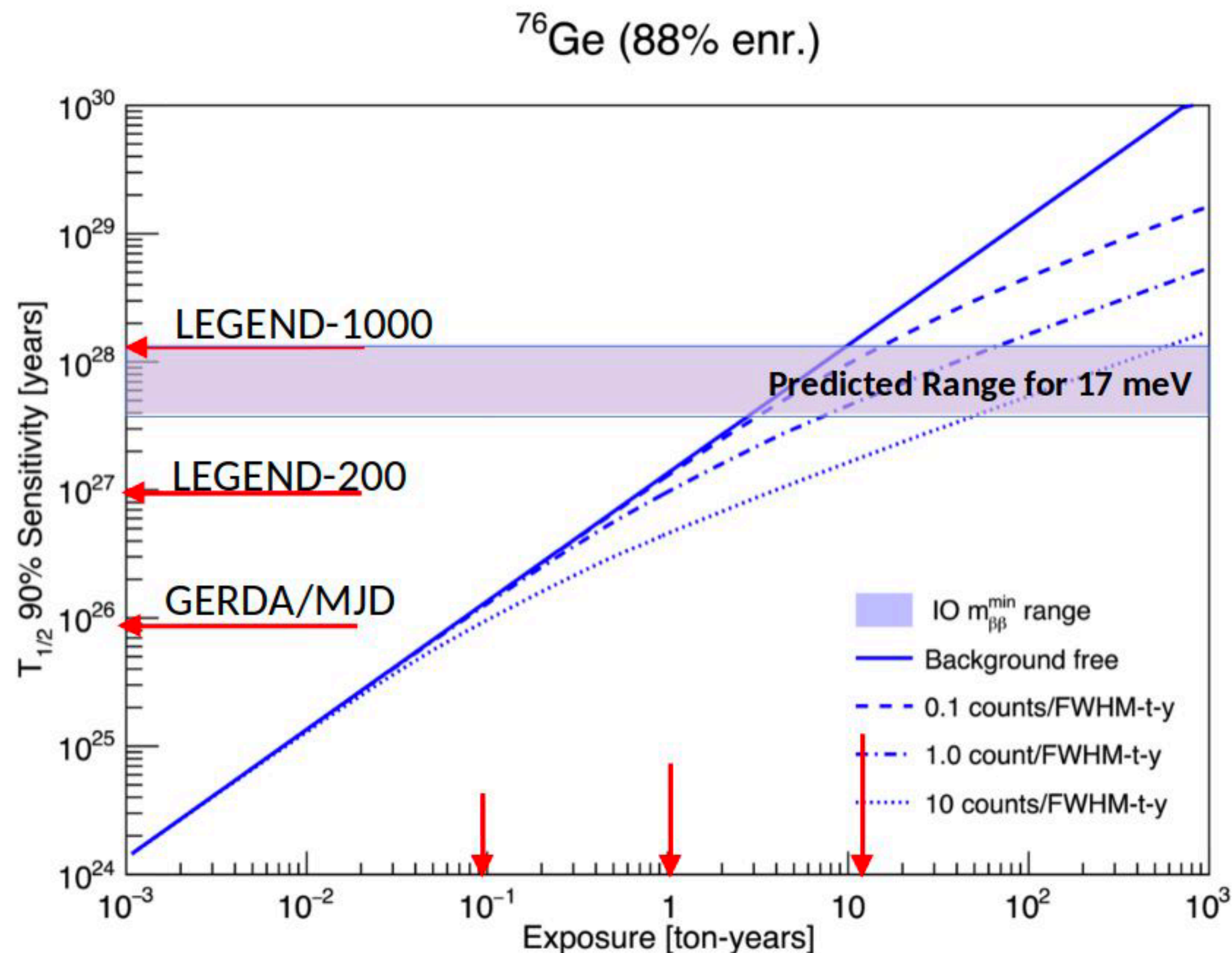




Expected background: $<10^{-5}$ cts/(keV kg yr) $\Rightarrow$ 3σ discovery: $T_{1/2} \sim 1.2 \times 10^{28}$ yr @ ~ 10 t yr

$m_{\beta\beta}$ upper limit in [10 - 20] meV $\Rightarrow$ Sweep full IO and a significant fraction of NO parameter space.

Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay



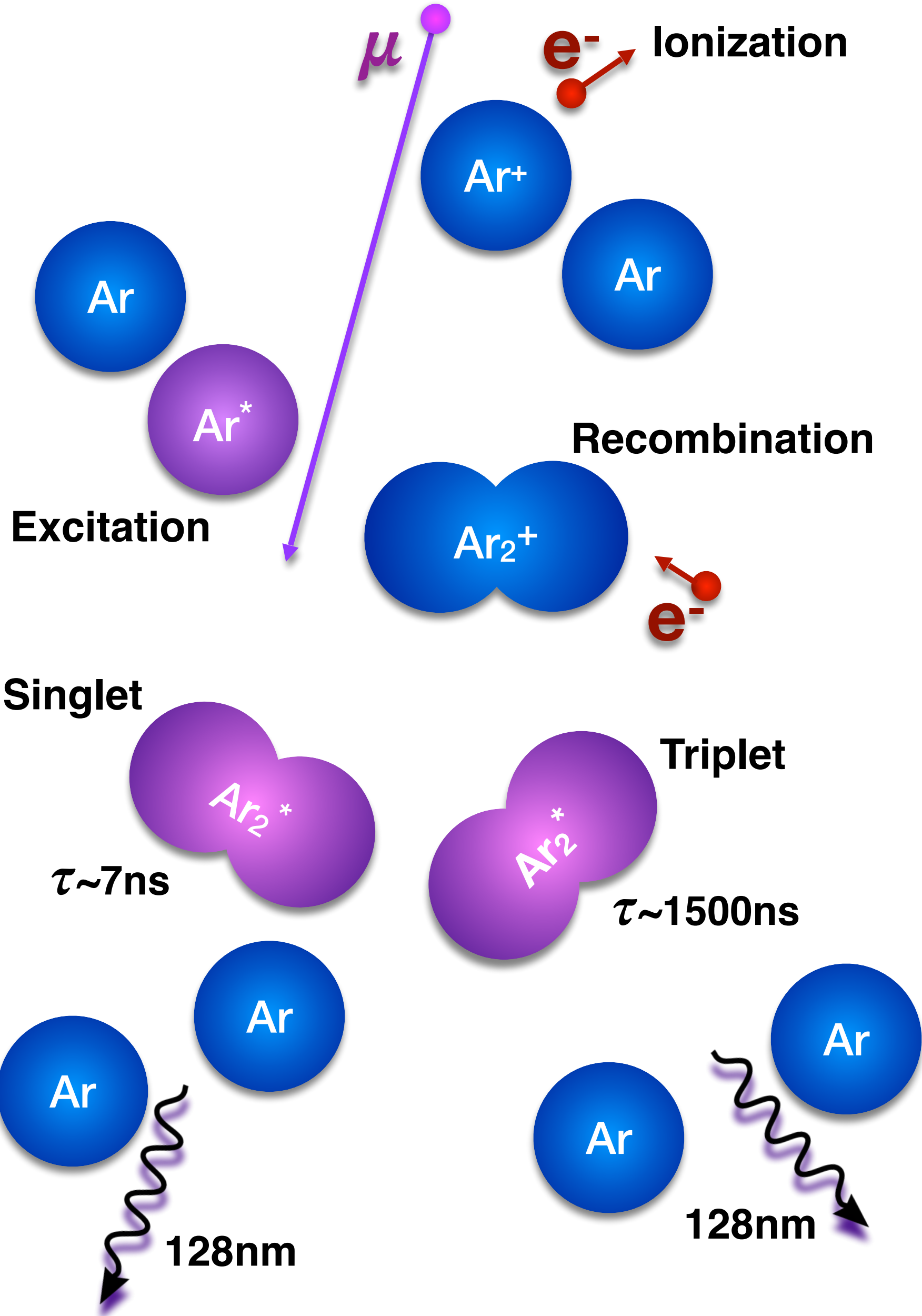
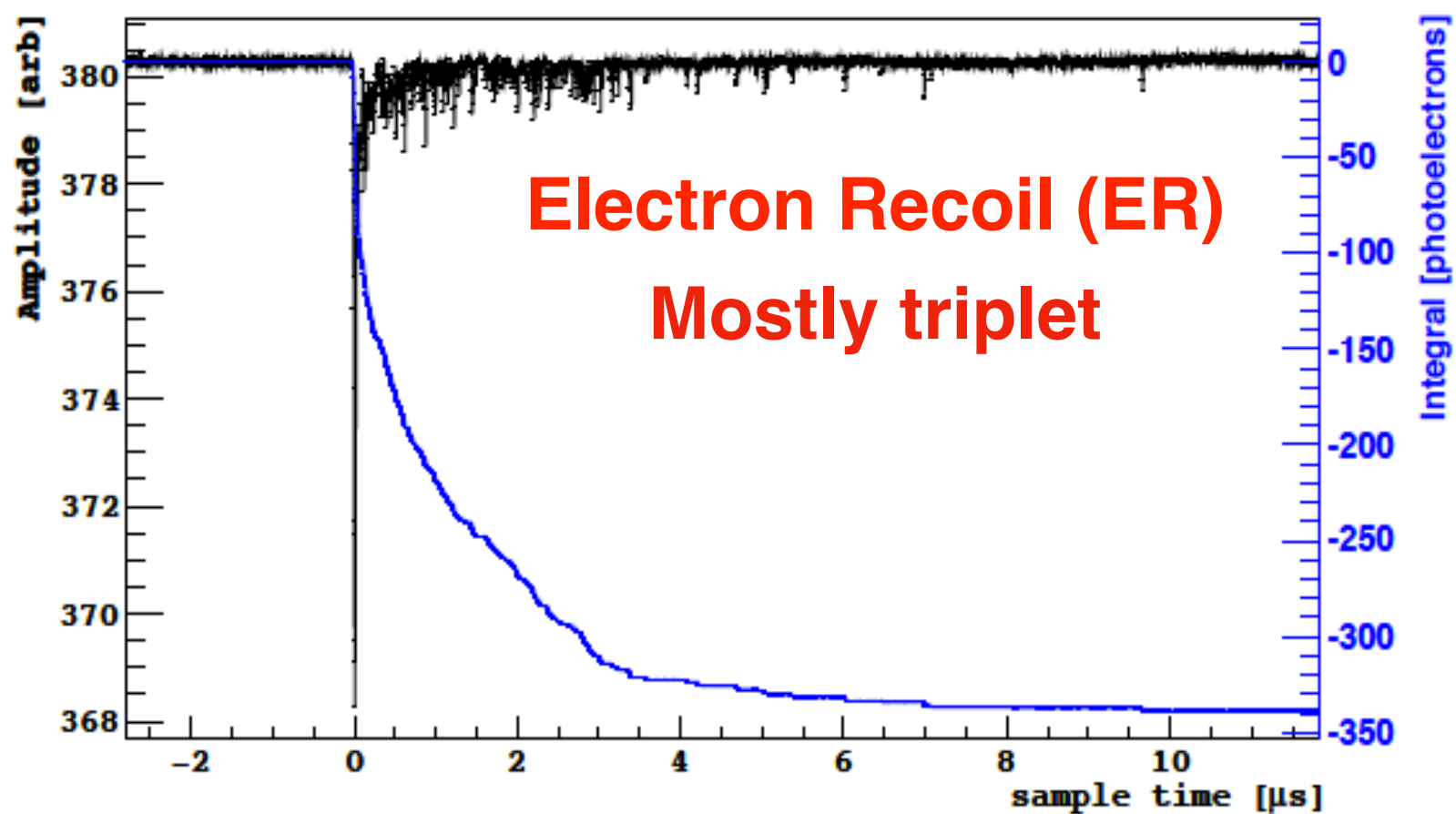
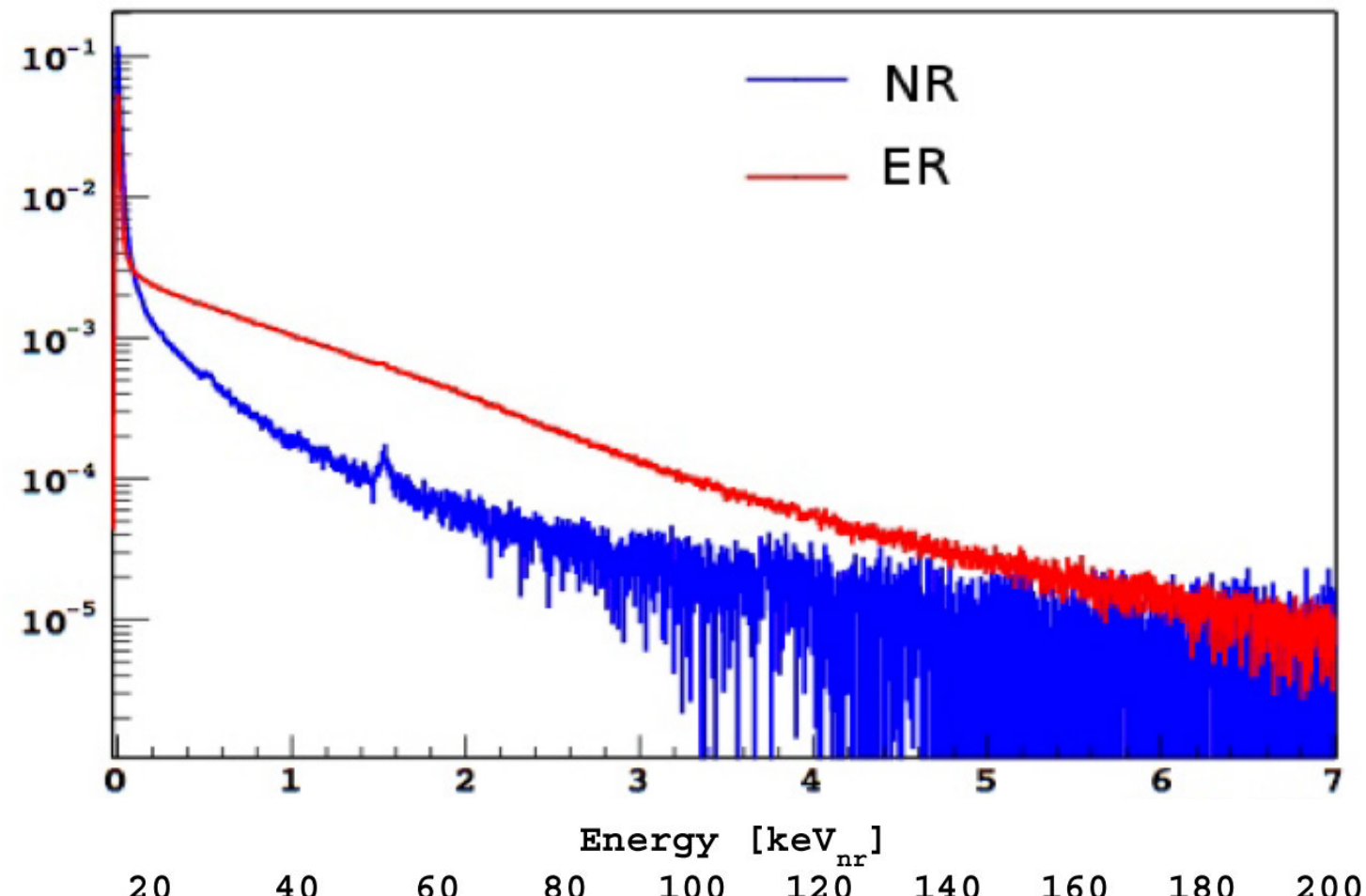
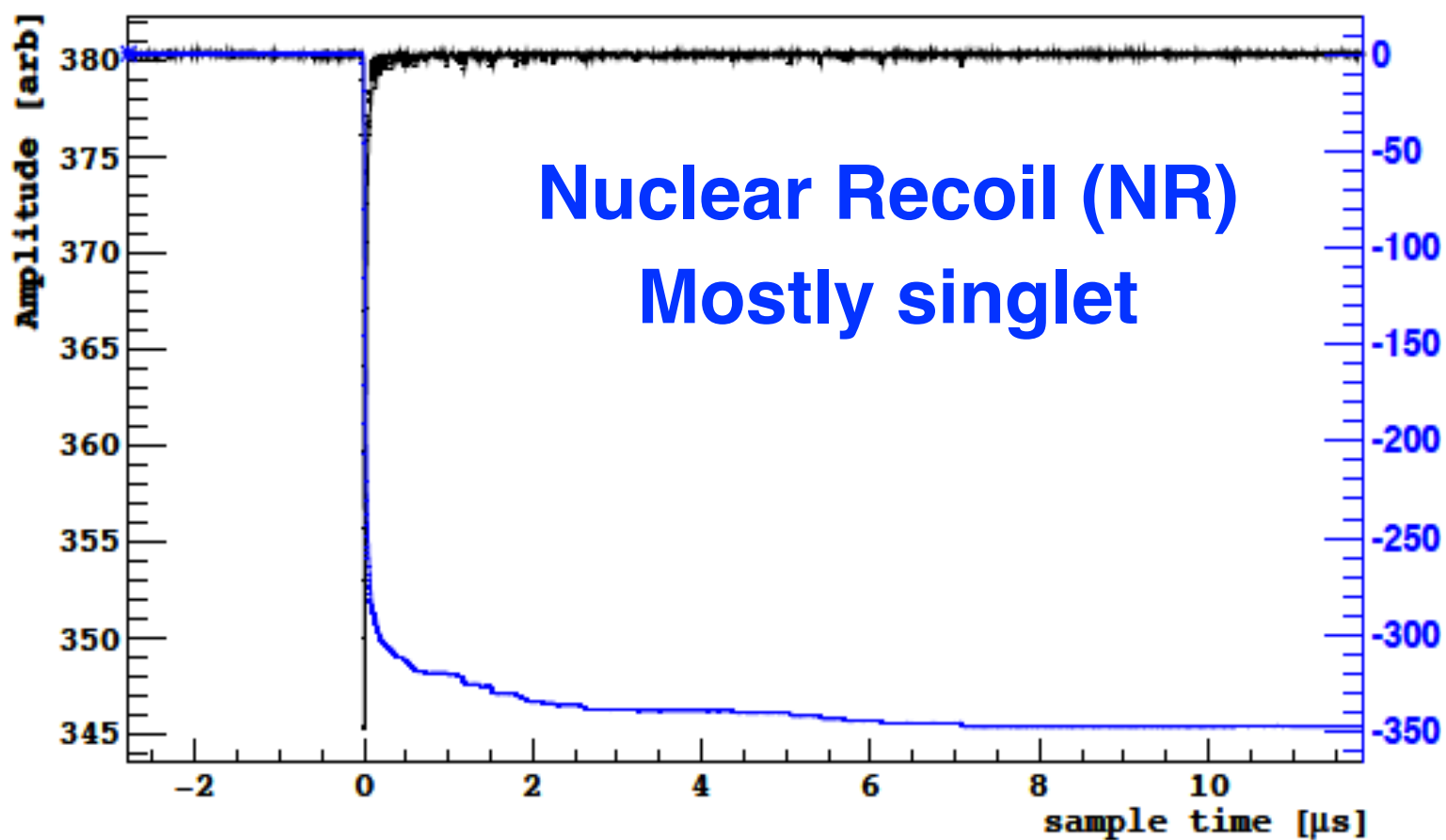
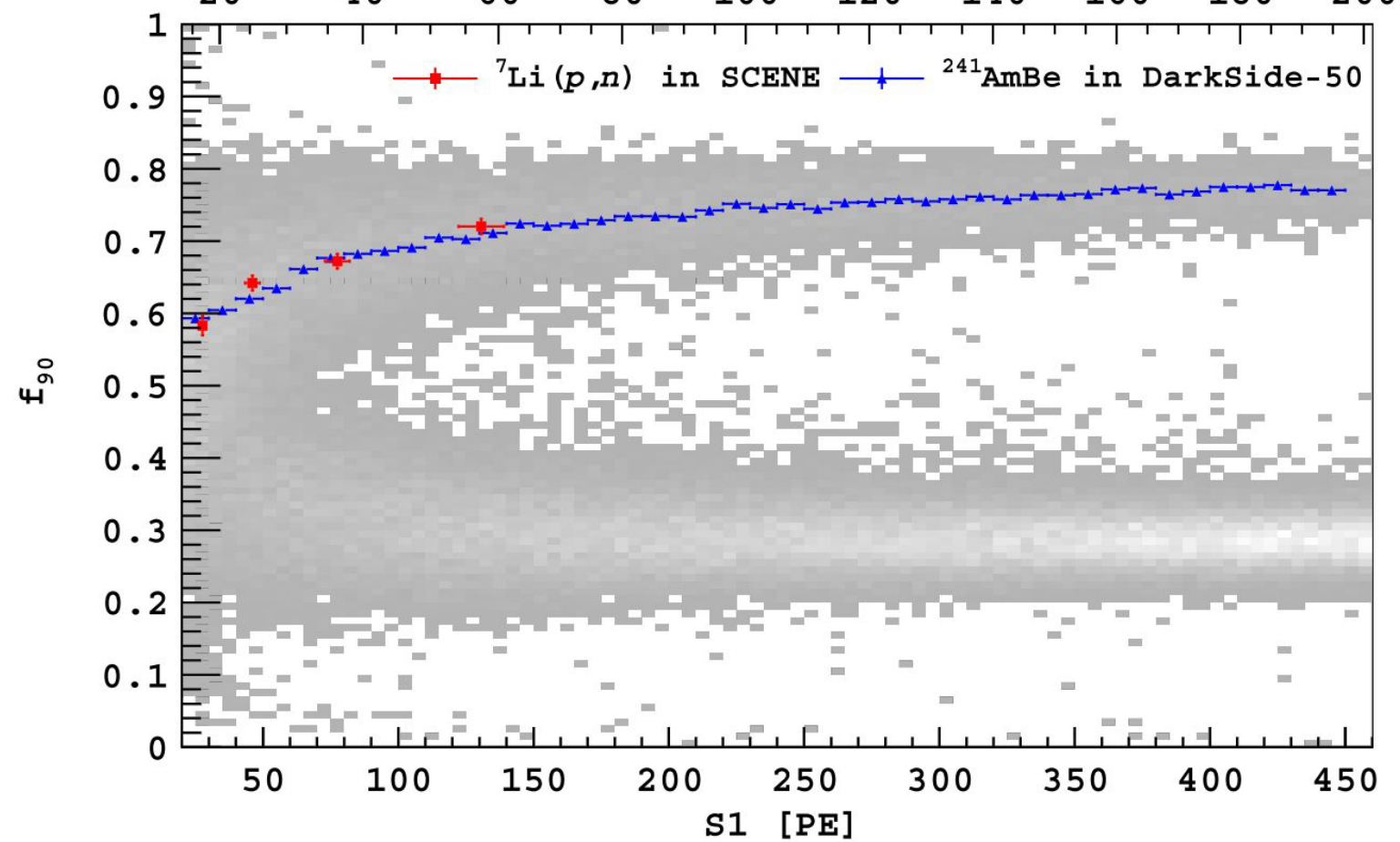
LEGEND-200

- LEGEND searches for $0\nu\beta\beta$ of ^{76}Ge
- Combination of **Majorana** and **GERDA**
- Uses Ge crystals as source and detectors.
- The detectors are enriched at 88% of ^{76}Ge .
- Staged deployment to increase active mass over time

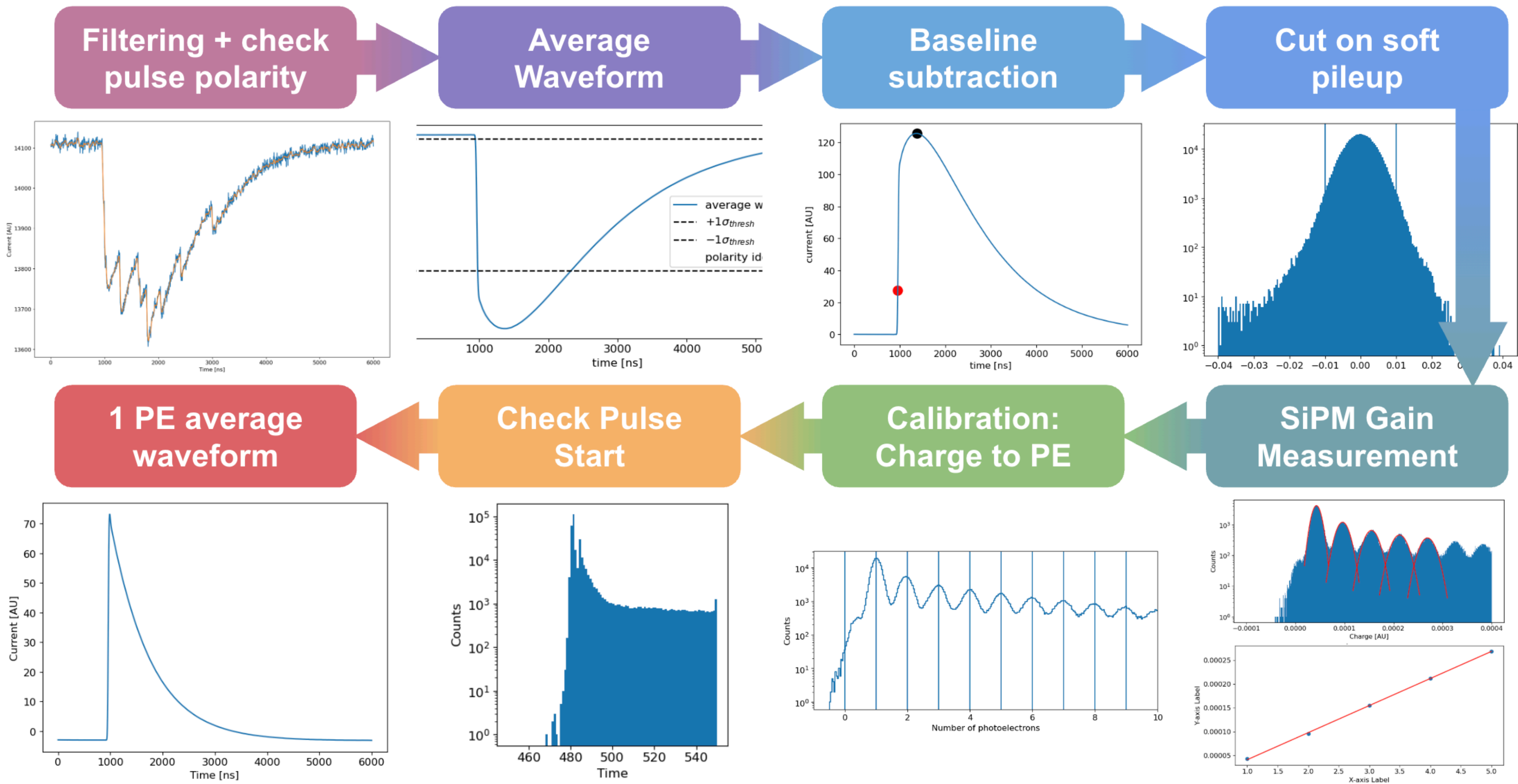
Goals:

- Energy resolution: $\sim 0.1\%$ FWHM @ $Q_{\beta\beta}$
- Background: 2×10^{-4} cts/(keV·kg·yr)

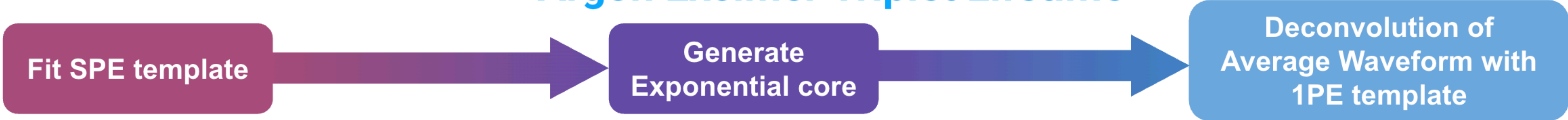
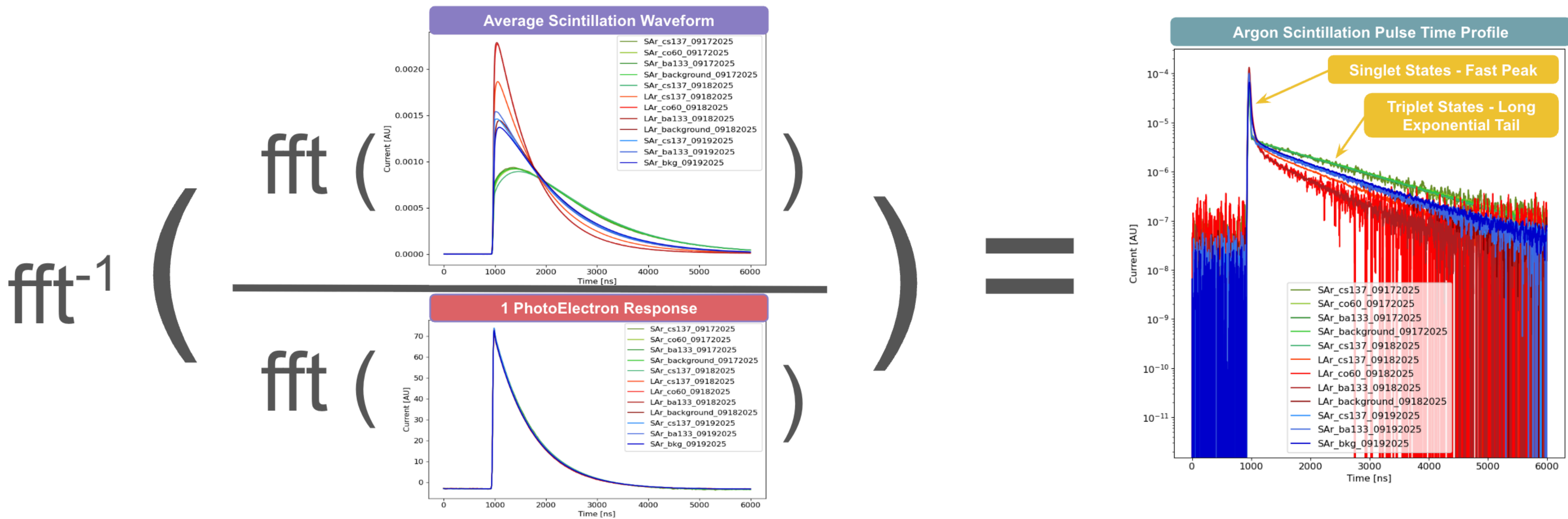
Scintillation mechanism of argon



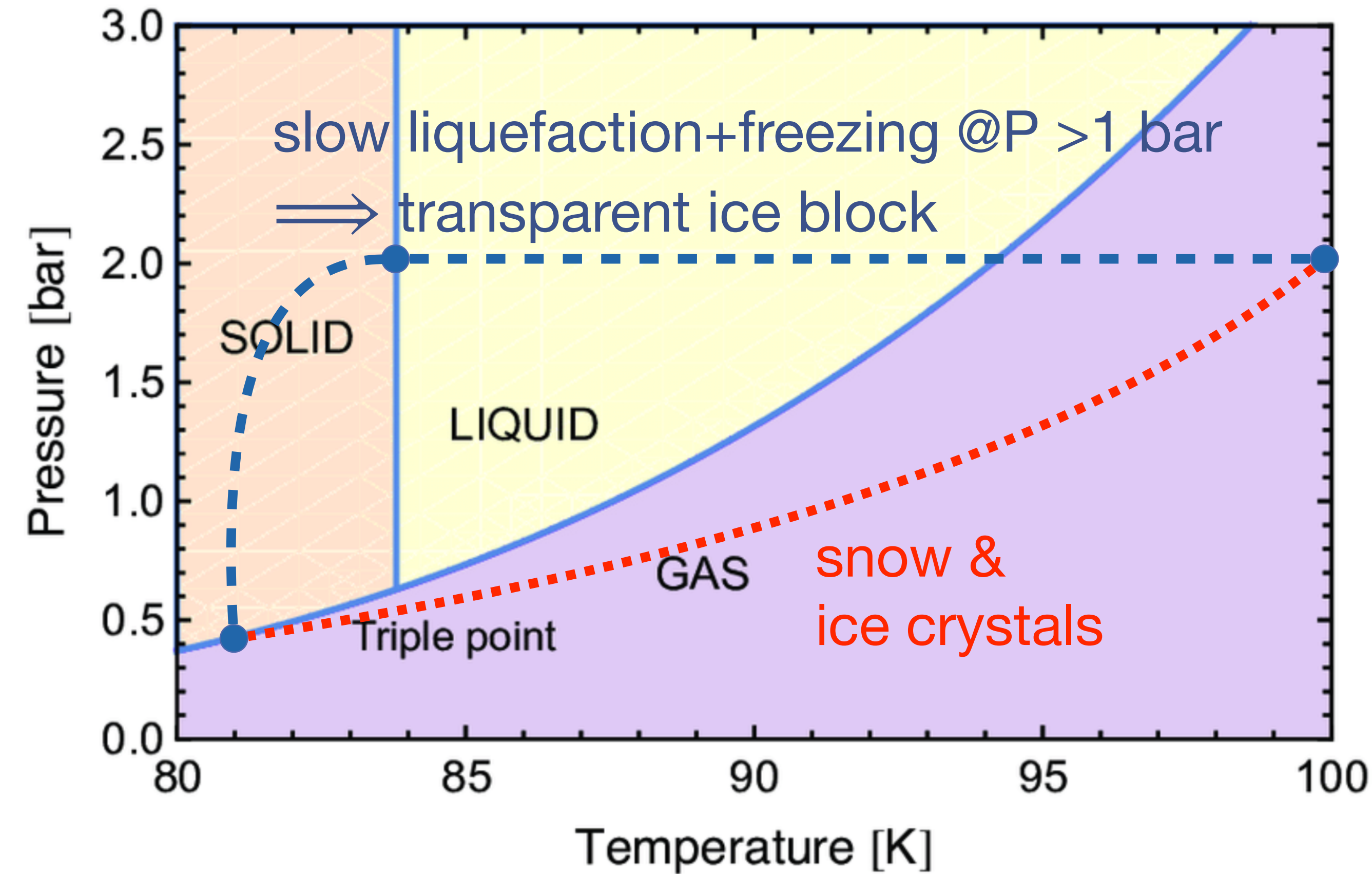
Low level analysis



Argon Excimer Triplet Lifetime



Strategy and Setup



Adapted from: <https://doi.org/10.3390/cryst12101416>

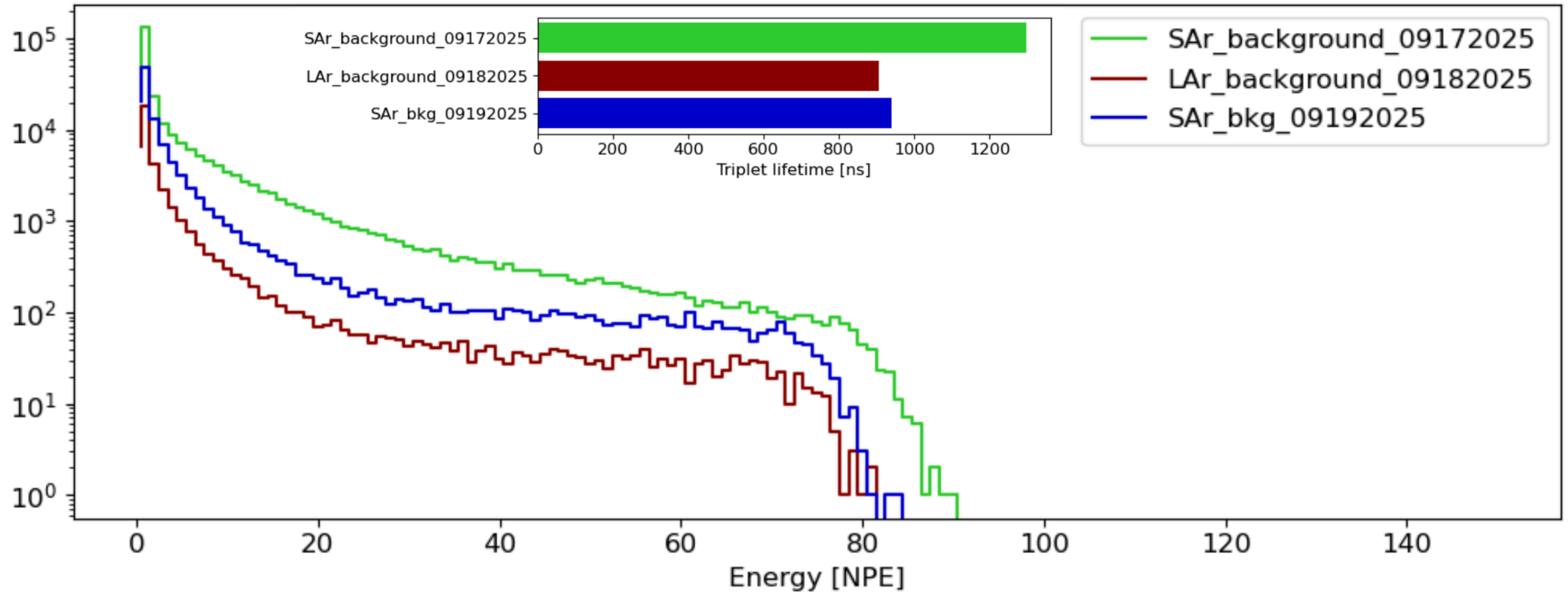


If pressure drops below triple point, snow and multiple crystals.

Strategy:

- keep const pressure by feeding new gas through a regulator;
- establish a temp gradient from bottom (77 K) to top (~ 270 K).

Following runs



- First dataset when frozen → Melted (and relief valve opened) → Frozen again
- First dataset with highest triplet lifetime and LY $\implies$ Impurities flowed through open relief valve?
- Still marginal improvement in scintillation parameters from liquid to solid argon