Active background reduction methods in low background experiments

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Why reduce background

$$T^{0\nu}_{1/2} \propto \sqrt{\frac{m \cdot t}{BI \cdot \Delta E}} \text{ with } \begin{cases} m \cdot t & , \quad \text{exposure} \\ BI & , \quad \text{background index} \\ \Delta E & , \quad \text{energy resolution} \end{cases}$$

$$\begin{aligned} \Delta E &\rightarrow \text{is limited by the detectors} \\ m \cdot t &\rightarrow \text{is limited by funding} \\ BI &\rightarrow \text{can be improved!} \end{aligned}$$

Two ways to reduce: make things clean, active reduction

Active background reduction

- Active reduction: add methods to veto background from signal
- Provide tagging for particles from outside
  - Muon veto panels
  - Water tank tags neutrons
- Can also remove background from within: scintillators

Detector Overview

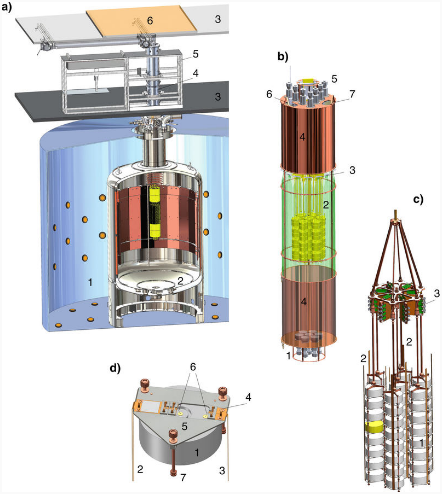


Figure: Detector layout of GERDA. A) Dectector overview. B)LAr Veto System. C) Detector Array. D) Detector holding structure

Scintillators: What are they?

- Materials that emit light when exposed to ionising radiation
- Organic (plastics):
  - Short emission time (ns)
  - Light yield around 10,000 photons / MeV
  - Potentially strong material properties
- Inorganic (liquid noble gas)
  - Emission time on order μs
  - Potential for light yield around 30,000 / MeV
  - Cryogenic liquid: cool the inner detectors

Scintillation Mechanism

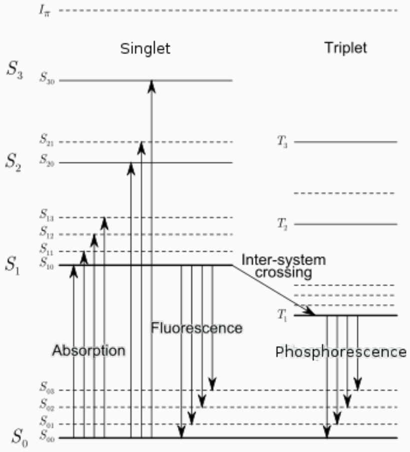


Figure: Energy level diagram of a scintillator.

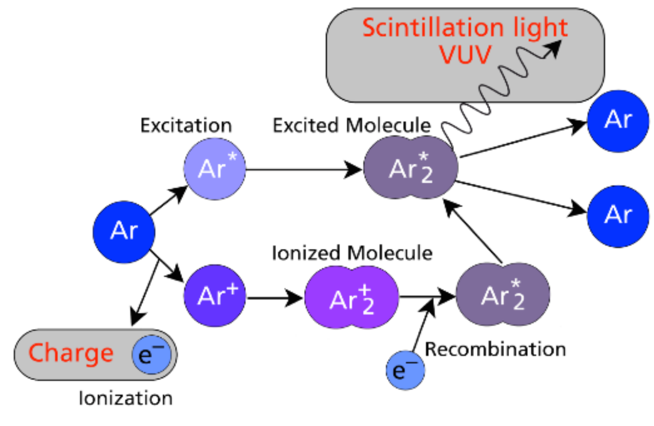


Figure: Scintillation mechanism in liquid argon, from http://darkmatter.ethz.ch/

Before liquid argon cuts

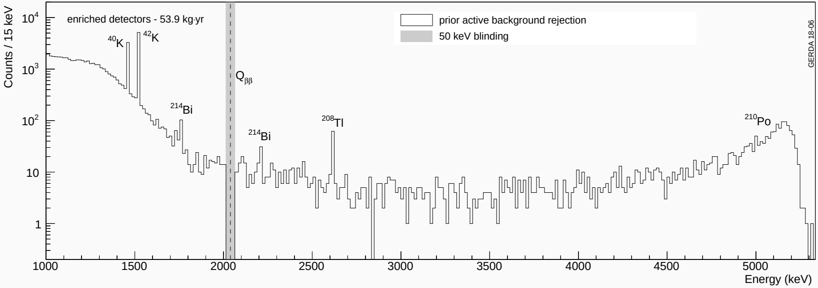


Figure: Background spectrum before liquid argon anti-coincidence cut

After liquid argon cuts

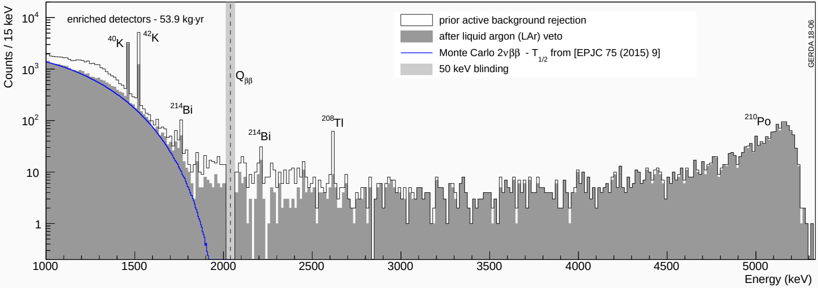


Figure: Background spectrum after liquid argon anti-coincidence cut

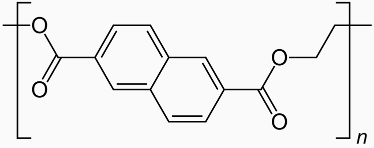
Limitations of current design

- Liquid argon peak emission is VUV, hard to find matching photosensors
- Requires wavelength shifting, more materials, more contamination
- Wavelength shifting shroud efficiency around 30%
- Lots of opaque material near detectors, reducing efficiency

Solution: replace parts of the holding structure with transparent material, ideally scintillating.

Enter: PEN

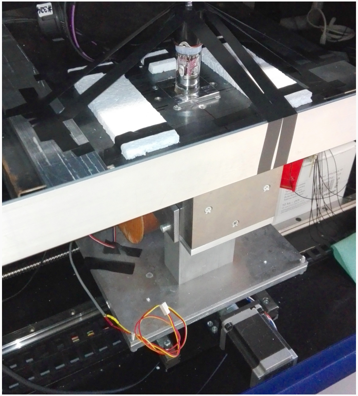
What is PEN?



Top: Structural formula of PEN.
Bottom: Custom molded PEN capsule parts

- Commercially available
- Brandnames: Teonex
- Relatively cheap
- Experience in manufacturing
- Transparent plastic
- Known to scintillate [arXiv:1903.10736]
    - Self-veto?
- PEN as low background material?

Light Yield Measurements



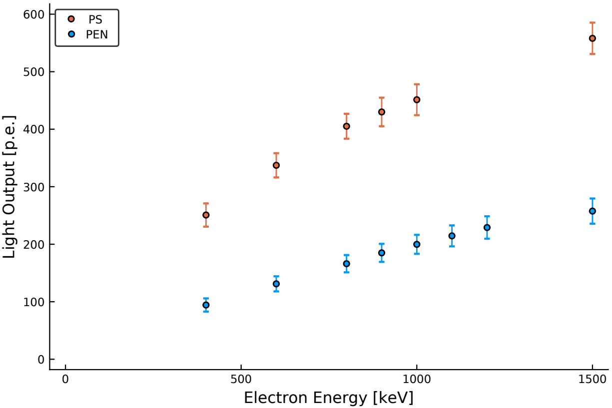
Set up used for light yield measurements

- Scintillation yield measured in electron spectrometer

  [doi:10.1088/1748-0221/10/09/P09008]

- Electron energies between 0.4 - 1.6 MeV used
- Compared to a PS, SuperNEMO

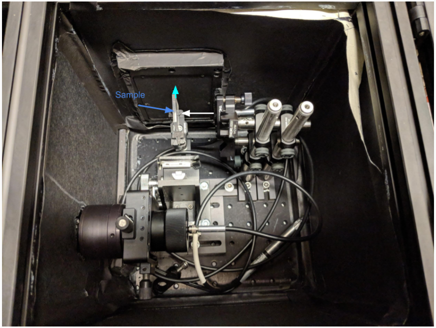
Light Yield Results



PS and PEN light output when excited with mono-energetic electrons (FWHM = 1.0 ± 0.2 % at 1 MeV)

- Light yield for PEN around 2/3s of PS
- Lower yield then literature, self produced tiles
- Trade off: cleanliness vs light yield

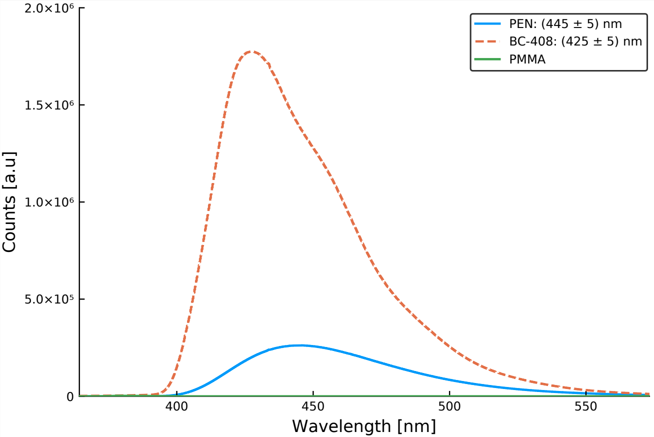
Emission Spectra



Set up for emission spectrum

- PEN emits blue light,
  no extra fluors
- Good match to commercial PMTs and SiPMs
- Emission spectrum measured with spectrograph
- BC-408 and PS similar yields, use BC-408 as reference
- Excited by monochromatic 380 nm light
- Drawback:
  limited absorption length

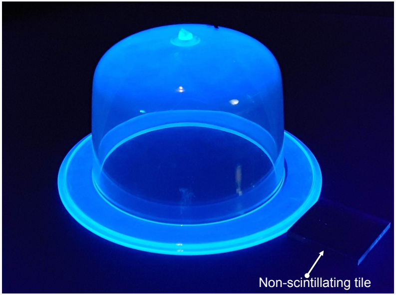
Emission Spectra Results



Emission Spectra of PEN, BC-408 and PMMA tiles (30 x 30 x 3 mm^3)

- Blue emission from PEN
- Lower yield than BC-408

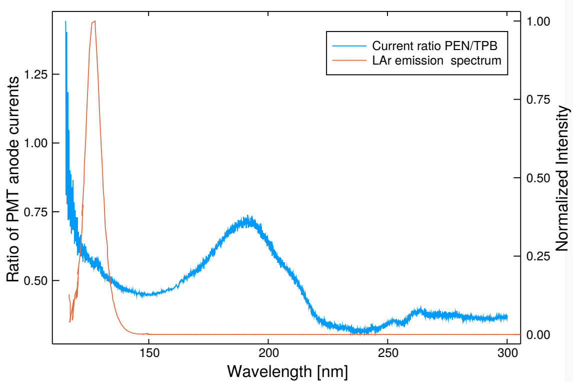
Wavelength Shifting



PEN exposed to UV

- Measured emission spectrum from wavelength shifting, not scintillation
- Can PEN shift VUV?
- 126 nm light from LAr source
- Compare efficiency of tile coated with TPB and PEN

Wavelength Shifting Results



Left: Ratio of PMT anode currents (blue line) PEN/TPB Right: VUV/UV emission spectrum of liquid argon [arXiv:1511.07718]

- Efficiency of wavelength shift around 50% of TPB at 126 nm
- Optically active without scintillation
- Enhanced efficiency of liquid argon vetoes
- Consistent with DEAP: arXiv:1806.04020

Radiopurity Screening

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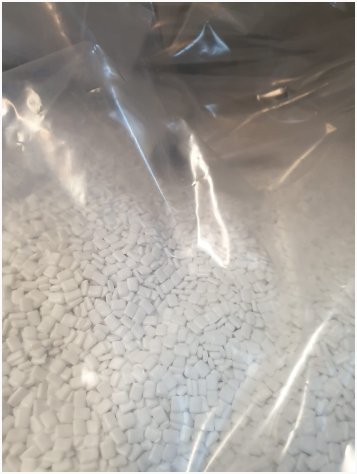

Raw PEN Granulate

- Low-background experiments need low-background material
- Commercially available PEN granulate gamma screened at LNGS
- Two types: TN8050, TN8065
- Reference measurement: GERDA HV-capacitor [arXiv:1903.10736]

Radiopurity Results

	TN-8065S	TN-8050SC	Teonex Q51 [Eur. Phys. J. C (2013) 73:2445]
		[mBq/kg]	
Ra-228	< 0.15	< 0.15	
Th-228	(0.23 ± 0.05)	< 0.13	< 1.4
Ra-226	(0.25 ± 0.05)	< 0.11	< 2.0
Th-234	< 11	< 15	
Pa-234m	< 3.4	<3.0	
U-235	< 0.066	< 0.054	
K-40:	1600 ± 400	1000 ± 400	< 3.6
Cs-137	< 0.057	< 0.064	

Measurement by M. Laubenstein (68 % C.L.)

- Commercially available pellets have comparable counts to materials in use
- Surface contamination
- Reduce levels in PEN by synthesis

Summary

- GERDA currently employs active background rejection to improve signal to noise ratio
- Multi-phase approach, muon veto, water Cherenkov tagging and liquid argon
- Efficiency for current argon veto is not very high
- PEN is a commercially available plastic, relatively radiopure
- Both scintillates and wavelength shifts
- Emission peak suitable for many photo-detectors
- Scintillation yield lower than other plastics,
  attenuation limits part size
- Demonstrated to wavelength shift liquid argon peak emission to blue