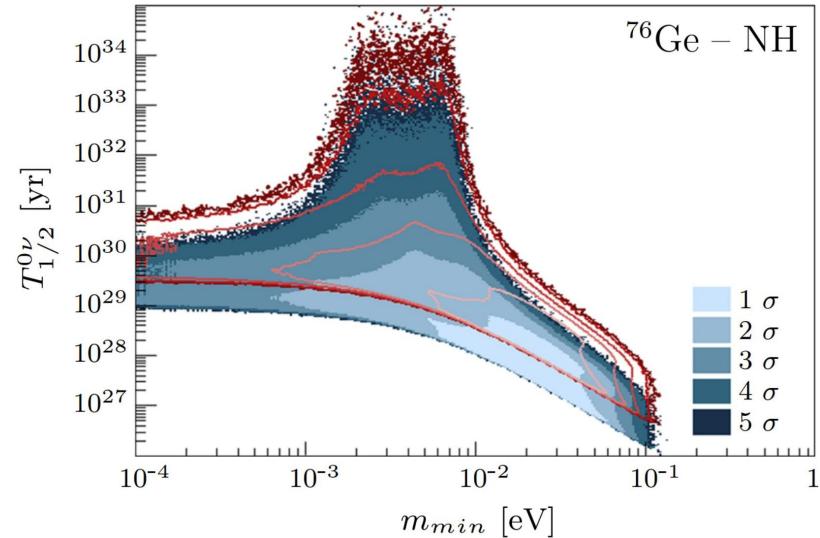
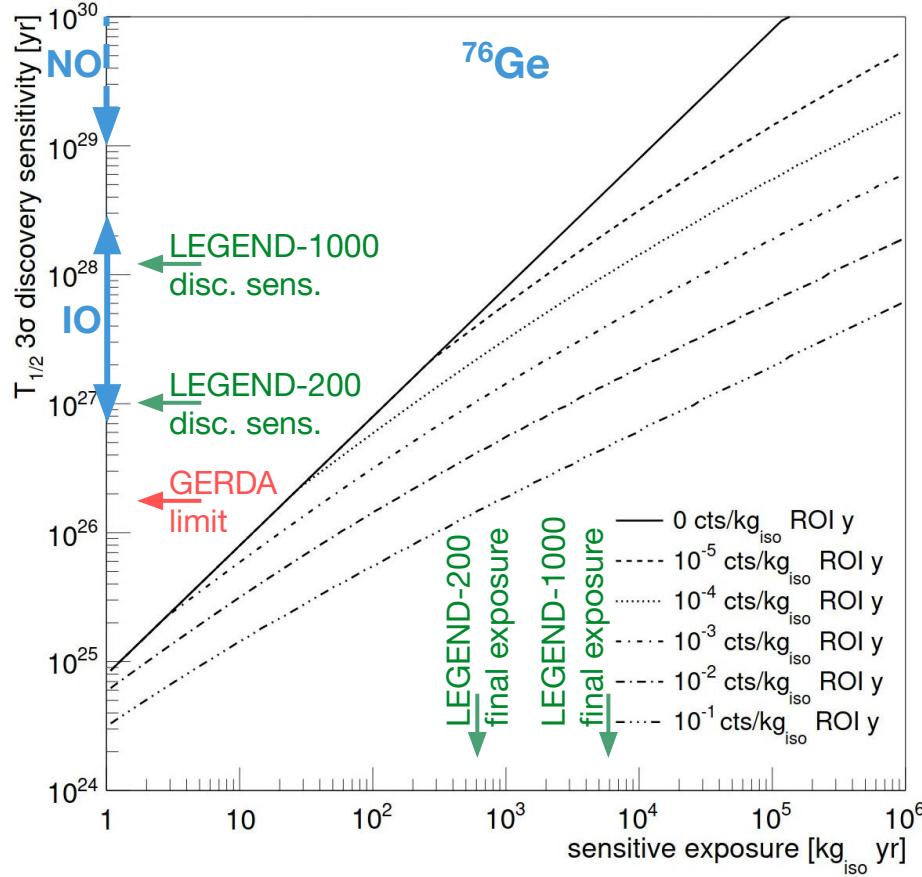


Currently negligible, future worrisome backgrounds for $0\nu\beta\beta$ decay experiments

Giovanni Benato

SnowMass workshop: $0\nu\beta\beta$ decay beyond the tonne-scale, Dec. 9-11, 2020

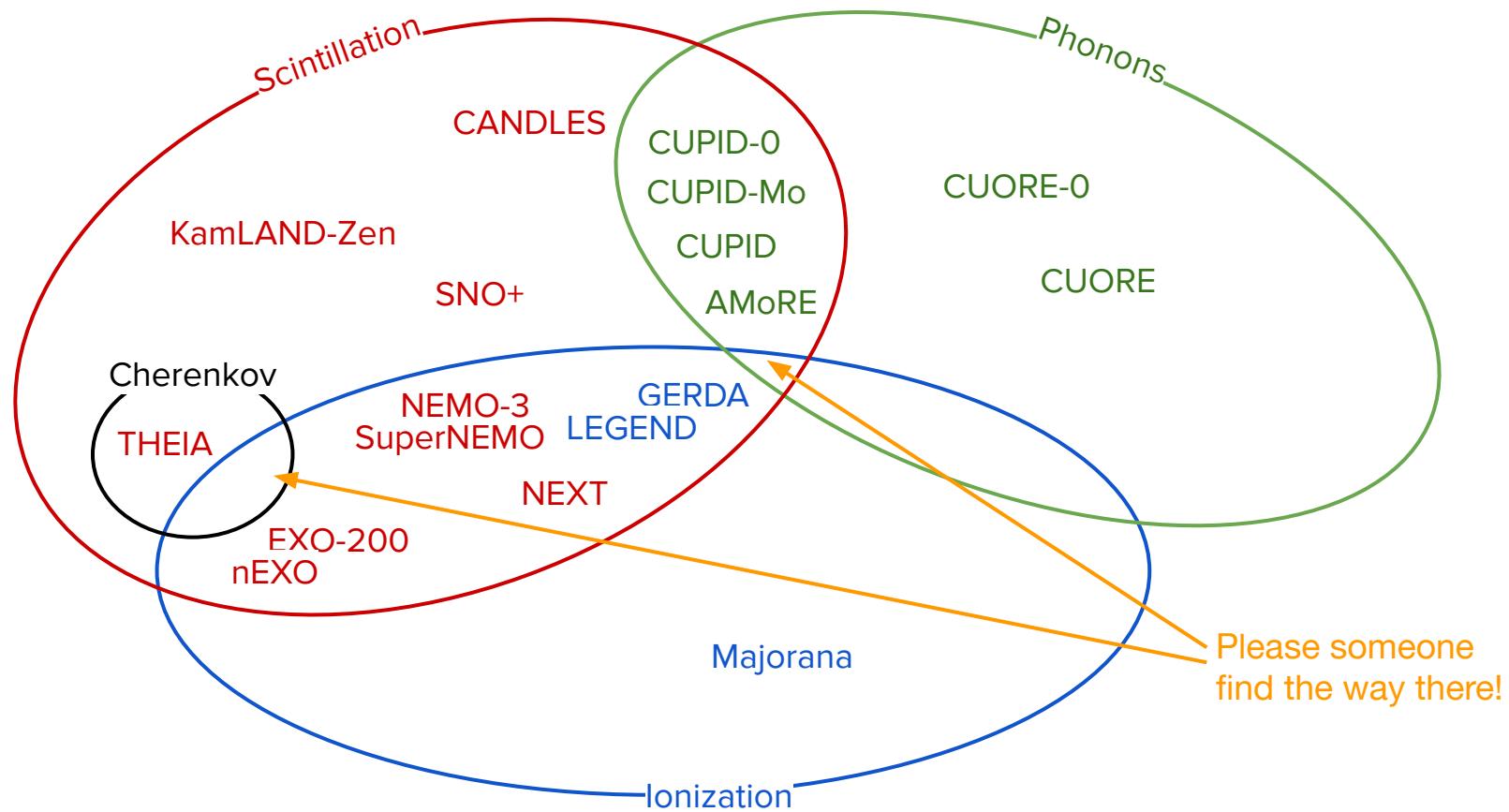
Requirements for beyond the tonne-scale



Minimum requirements (for ${}^{76}\text{Ge}$):

- Sensitive exposure $> 10^5 \text{ kg}_{\text{iso}} \cdot \text{yr}$
→ 10 tons × 10 yr
- Sensitive background $< 10^{-6} \text{ counts/kg}_{\text{iso}} / \text{yr}$
→ factor 60 better than GERDA

Readout channels: more is better than 1!



Natural and man-made radioactivity

Natural radioactivity

- U and Th chains will always be present, with all the related problems we know very well
 - The radiopurity requirements are going to be more and more stringent!
 - Screening measurements more tricky!

Possible active suppression techniques

- α vs β/γ discrimination
 - Many techniques available
- β vs γ discrimination
 - Many techniques available
- Single β vs $\beta\beta$ discrimination
 - Tracking or Cherenkov
- Delayed coincidences
 - May introduce significant dead time
- Energy+Time background modeling
 - Non-trivial + CPU expensive

Man-made radioactivity

Isotope	$T_{1/2}$	Q_β [keV]
^{110m}Ag	250 d	3008
^{134}Cs	2 yr	2059
$^{90}\text{Sr}-^{90}\text{Y}$	29 yr	2279

Possible active suppression techniques

- Single β vs $\beta\beta$ discrimination
 - Tracking or Cherenkov

Neutrons

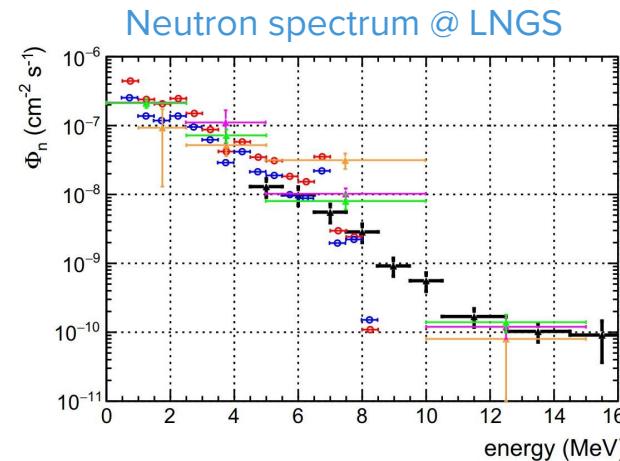
- Neutrons can induce (n,γ) reactions, neutron captures that activate some isotope, ...
- Actual background depends (mostly) on active materials

External neutrons

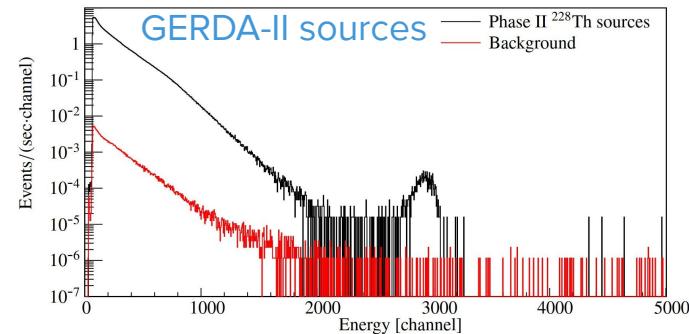
- Cosmic ray spallation in the rocks
- Fission in the rocks

Internal neutrons

- In-situ spallation
- (α,n) reactions in calibration sources and materials inside neutron shield
 - Parasitic neutron activity: 10^{-6} - 10^{-5} $\text{Bq}_n/\text{Bq}_\gamma$
 - Deploy e.g. ^3He or ^6Li in sensitive volume?



[G. Bruno and B. Fulgione, EPJ C79 \(2019\) 747](#)
[L. Baudis et al., JINST 10 \(2015\) 12, P12005](#)



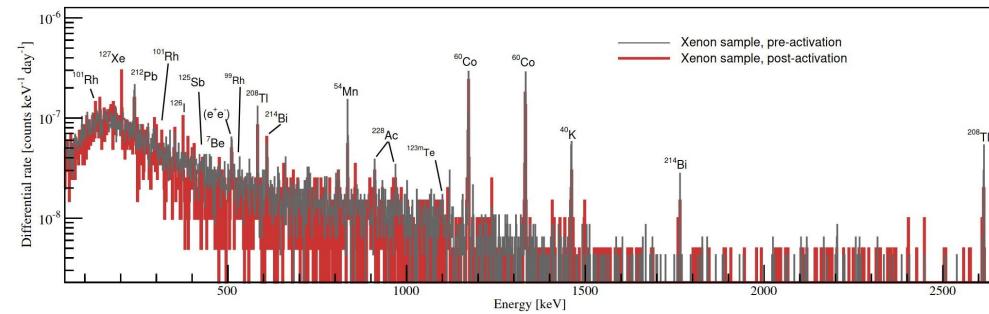
Cosmogenics

Cosmogenic activation above ground

- Affects all materials inside the shielding(s)
- Minimize the exposure
- Production underground
- Underground storage

In-situ cosmogenic activation

- Site-dependent
→ Deeper is better
- Actual background depends on specific case



[V. Lozza and J. Petzoldt, Astropart.Phys. 61 \(2015\) 62-71](#)

[L. Baudis et al., Eur.Phys.J.C 75 \(2015\) 10, 485](#)

[D. W. Bardayan et al., Phys.Rev.C 55 \(1997\) 820-827](#)

[B. S. Wang et al., Phys.Rev.C 92 \(2015\) 2, 024620](#)

[A. F. Barghouty et al., Nucl.Instrum.Meth.B 295 \(2013\) 16-21
EXO-200, JCAP 04 \(2016\) 029](#)

[C. Wiesinger et al., Eur.Phys.J.C 78 \(2018\) 7, 597](#)

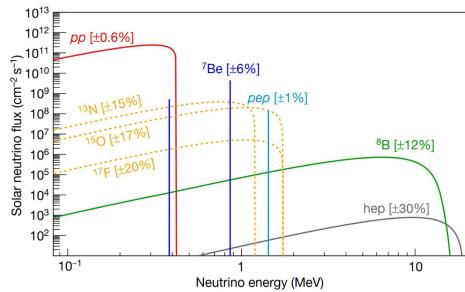
plus many more!

Solar neutrinos

Neutrino-electron elastic scattering

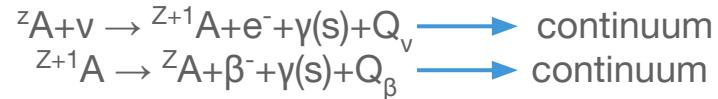


- Mostly a problem for experiments with liquid scintillator + dissolved isotope
- Rejection via discrimination of single e^- vs $\beta\beta$, and looking at e^- direction
→ Tracking or Cherenkov



THEIA, Eur.Phys.J.C
80 (2020) 5, 416

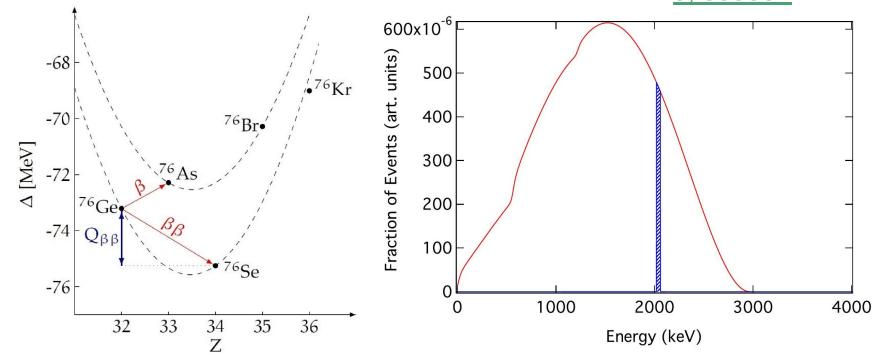
CC reactions



Possible discriminations:

- Delayed coincidence between the 2 processes
→ Depends on zA halflife
- Coincidence between e/β and $\gamma(s)$
- Single e/β vs $\beta\beta$ via event topology
→ Tracking or Cherenkov

H. Ejiri and S. Elliott,
[Phys.Rev.C 89 \(2014\)
5, 055501](#)
H. Ejiri and S. Elliott,
[Phys.Rev.C 95 \(2017\)
5, 055501](#)



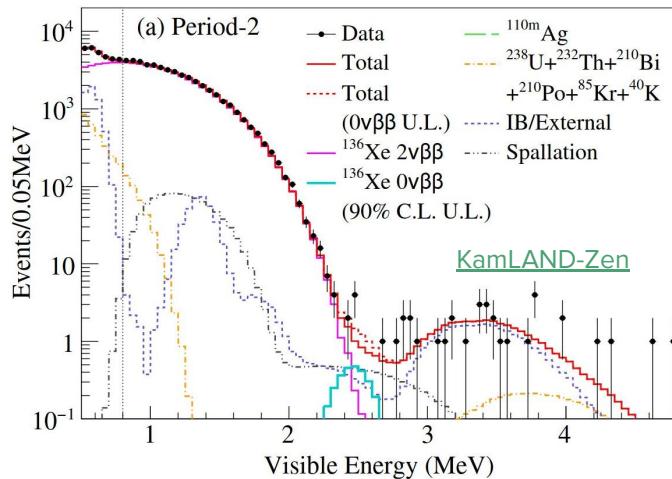
Diffuse Supernova Neutrino Background

- We expect O(0.1) events/kton/yr spread on a continuum spectrum

$2\nu\beta\beta$ and $2\nu\beta\beta$ pileup

$2\nu\beta\beta$

- It seems obvious, but energy resolution is going to be crucial
- 1% FWHM might not be enough anymore
- Irreducible by any mean.



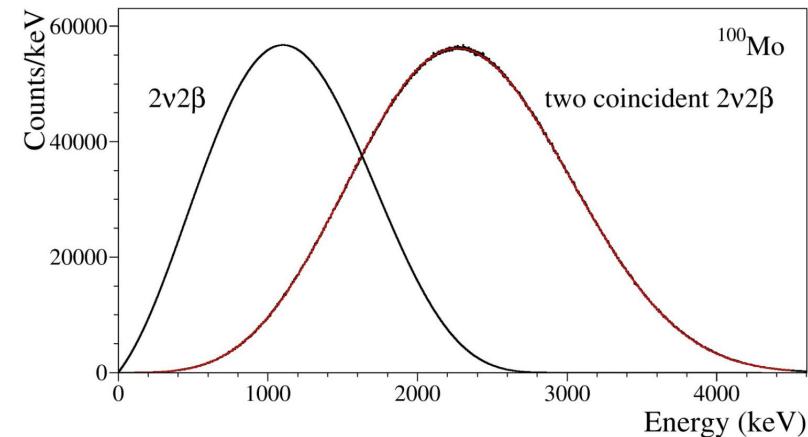
$2\nu\beta\beta$ pileup

$$B \sim \Delta t \cdot \Delta E \cdot (T_{1/2}^{2\nu\beta\beta})^{-2} \cdot V^2 \cdot f_{iso}$$

where:

- Δt = time resolution → Relevant for bolometers
- ΔE = energy resolution
- V = detector volume / volume resolution
- f_{iso} = isotopic fraction

[D. M. Chernyak et al.,](#)
[Eur.Phys.J.C 72 \(2012\) 1989](#)



Daughter tagging

Idea

- Locate interesting events (β or $\beta\beta$ near $Q_{\beta\beta}$) in real time
- Extract daughter with high efficiency

Advantages

- Potentially suppress (almost) every background

Limitations

- So far only works for Xe-Ba
→ We have enough time to improve the technology and expand it to other isotopes
- Does not reject intrinsic $2\nu\beta\beta$ background
- Does not reject CC events

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Article | Published: 22 June 2020

Fluorescent bicolour sensor for low-background neutrinoless double β decay experiments

Iván Rivilla, Borja Aparicio, Juan M. Bueno, David Casanova, Claire Tonnellé, Zoraida Freixa, Pablo Herrero, Celia Rogero, José I. Miranda, Rosa M. Martínez-Ojeda, Francesc Monrabal, Beñat Olave, Thomas Schäfer, Pablo Artal, David Nygren, Fernando P. Cossío✉ & Juan J. Gómez-Cadenas✉

Nature 583, 48–54(2020) | Cite this article

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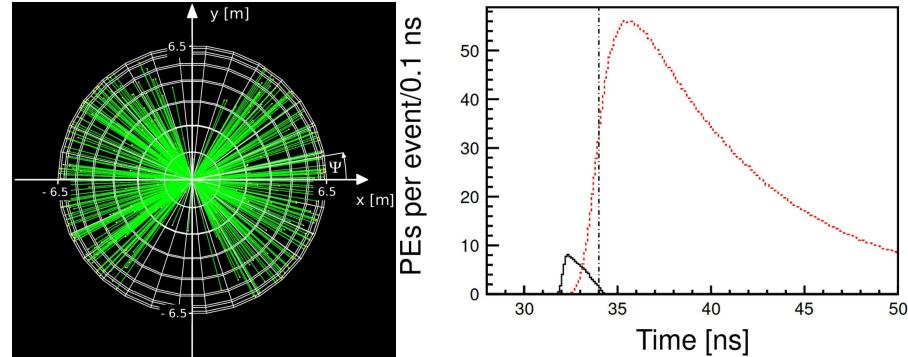
Cherenkov

Main features

- Low light yield
→ no energy measurement
- 1 MeV β emits Cherenkov light, α doesn't
→ α vs β/γ discrimination
- Cherenkov light is directional
→ 2β vs β and 2β vs γ discrimination

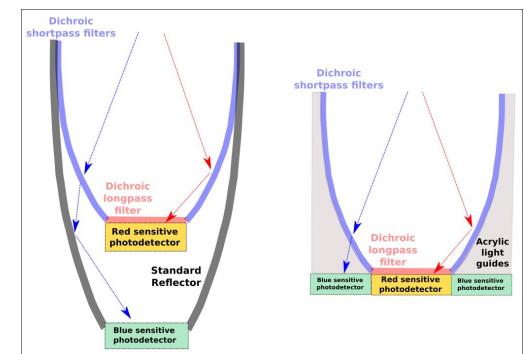
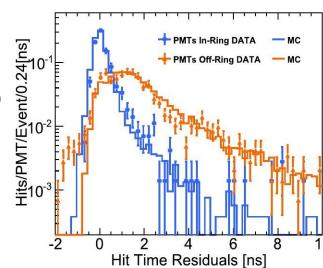
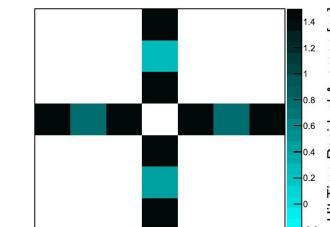
Cherenkov vs scintillation light

- Cherenkov light is prompt(er)
→ Need very fast light detectors (≤ 0.1 ns res.)
- Cherenkov light has a low LY
→ Need high detection efficiency (coverage)
- Cherenkov light has longer wavelength
→ Slow down scintillation? Wavelength shifter?
→ Need detectors sensitive to long wavelengths
→ Need filters with zero light loss



C. Aberle et al., JINST 9 (2014) P06012
J. Caravaca et al., Eur.Phys.J.C 80 (2020) 9, 867
T. Kapanoglu et al., Phys.Rev.D 101 (2020) 7, 072002

Plus many more



THANK YOU!