Solar neutrino backgrounds for double beta decay

Los Alamos
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$\beta\beta$ Background Requirement
Solar νs as a $\beta\beta$ Background
Calculation Description
Discussion of Specific Cases

In collaboration with Hiro Ejiri
PRC 89, 055501 (2014)
PRC 95, 055501 (2017)

Signal Rates
Background is the key R&D challenge for ββ

Half life (years)	~Signal (cnts/ton-year)	~Neutrino mass scale (meV)	
10^{25}	530	400	Degenerate
5×10^{26}	10	100	
5×10^{27}		40	Inverted Ordering
$>10^{29}$	<0.05	<10	Normal Ordering

To reach IO scale need BG on order 1/t-y or better.

Discovery, Background and Exposure

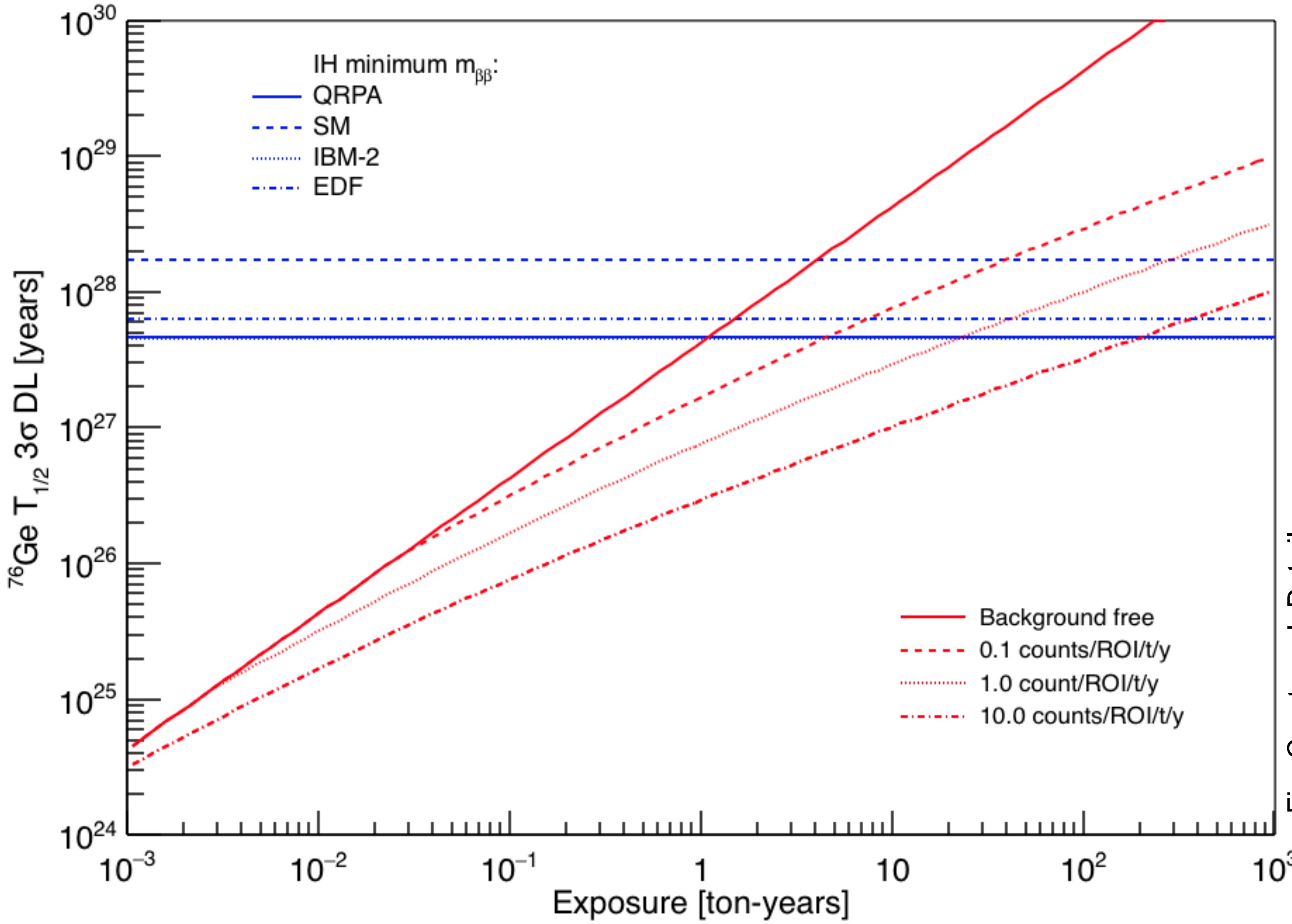


Fig: Courtesy J. Detwiler

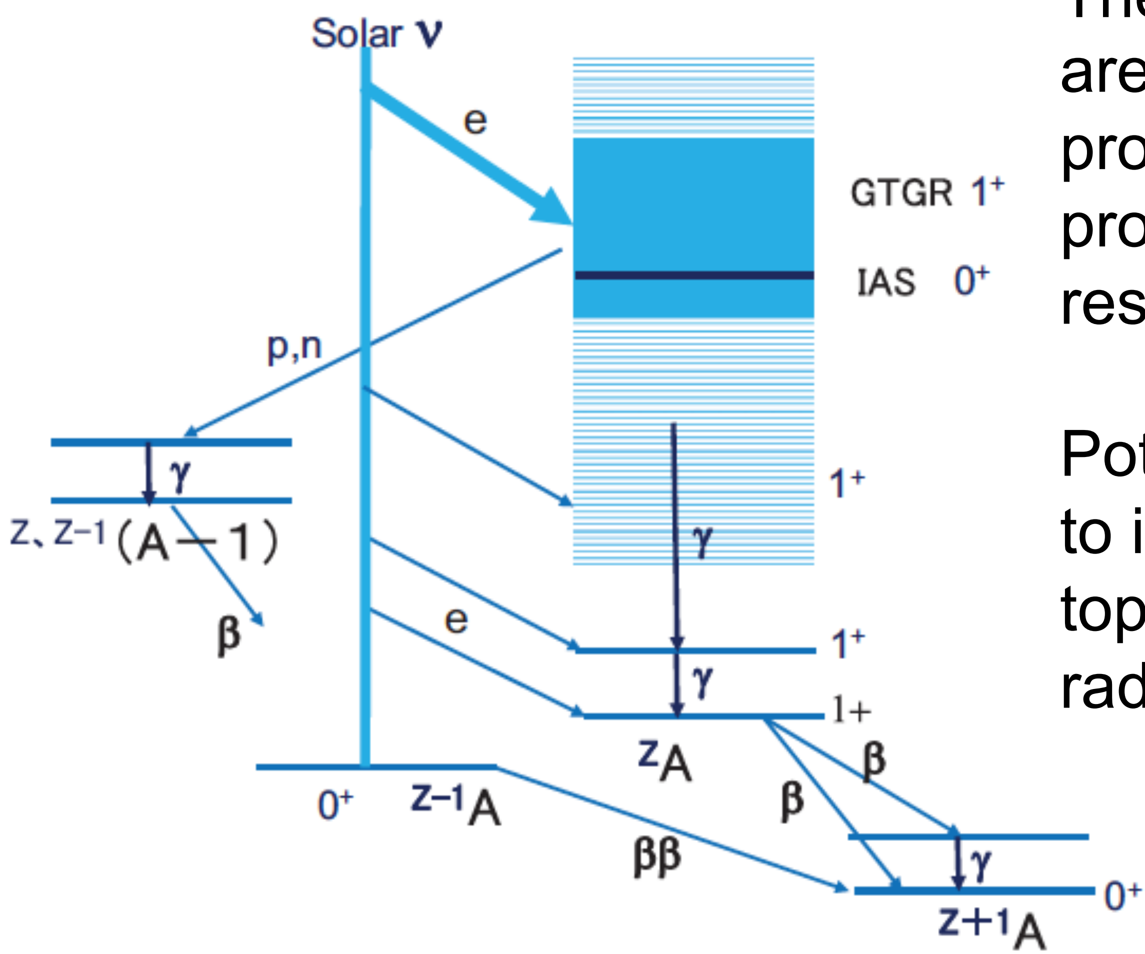
Need Unprecedented Background Level

- For pessimistic values of the matrix elements, a background near 0.1 count/(ROI t y) is required.
- For optimistic values, background approaching 1 count/(ROI t y) is OK.
- For both, plan for about 10 t-y exposure to reach 15 meV target.

Minor Background Component

- If we need a background < 0.1 counts/ ROI t y, then any single component needs be less than 0.01 counts/ROI t y.
- Charge-current interactions with solar neutrinos will contribute at these levels.
- CC populates the intermediate nucleus. When it decays, the decay energy is greater than the $\beta\beta$ Q Value.

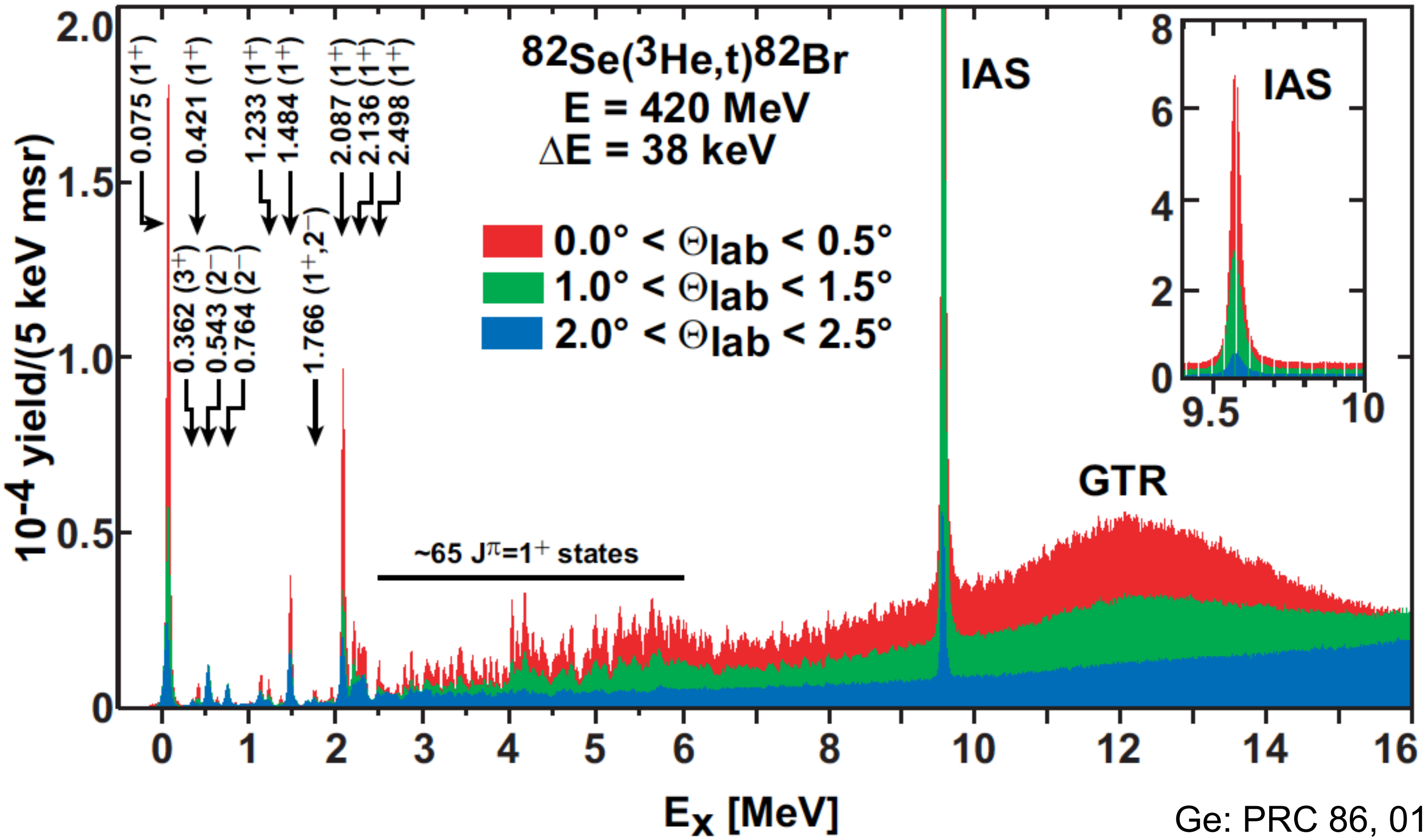
Solar Neutrino Backgrounds



The β, and γ sum spectra are continuous and can produce background in proportion to the resolution.

Potential for rejection due to initial CC event or the topology of the summed radiations.

Recent BGT Measurements



Ge: PRC 86, 014304 (2012)
Se: PRC 94, 014614 (2016)
Mo: PRC86, 044309 (2012)
Te: PRC 86, 044603 (2012)
Xe: PRC 84, 051305(R) (2011)
Nd: PRC 83, 064318 (2011)

Cross Section and Rate Calculations

$$\sigma_k = \frac{G_F^2 \cos^2\theta_c}{\pi} p_e E_e F(Z,E_e)\left[B(F)_k + \left(\frac{g_A}{g_V}\right)^2 B(GT)_k\right]$$

$$= (1.597 \times 10^{-44}\ \mathrm{cm}^2) p_e E_e F(Z,E_e)$$

$$\times\left[B(F)_k + \left(\frac{g_A}{g_V}\right)^2 B(GT)_k\right],$$

$$R = \sum_k \int \sigma_k \frac{d\phi_\nu}{dE_\nu} dE_\nu$$

About 10% accuracy

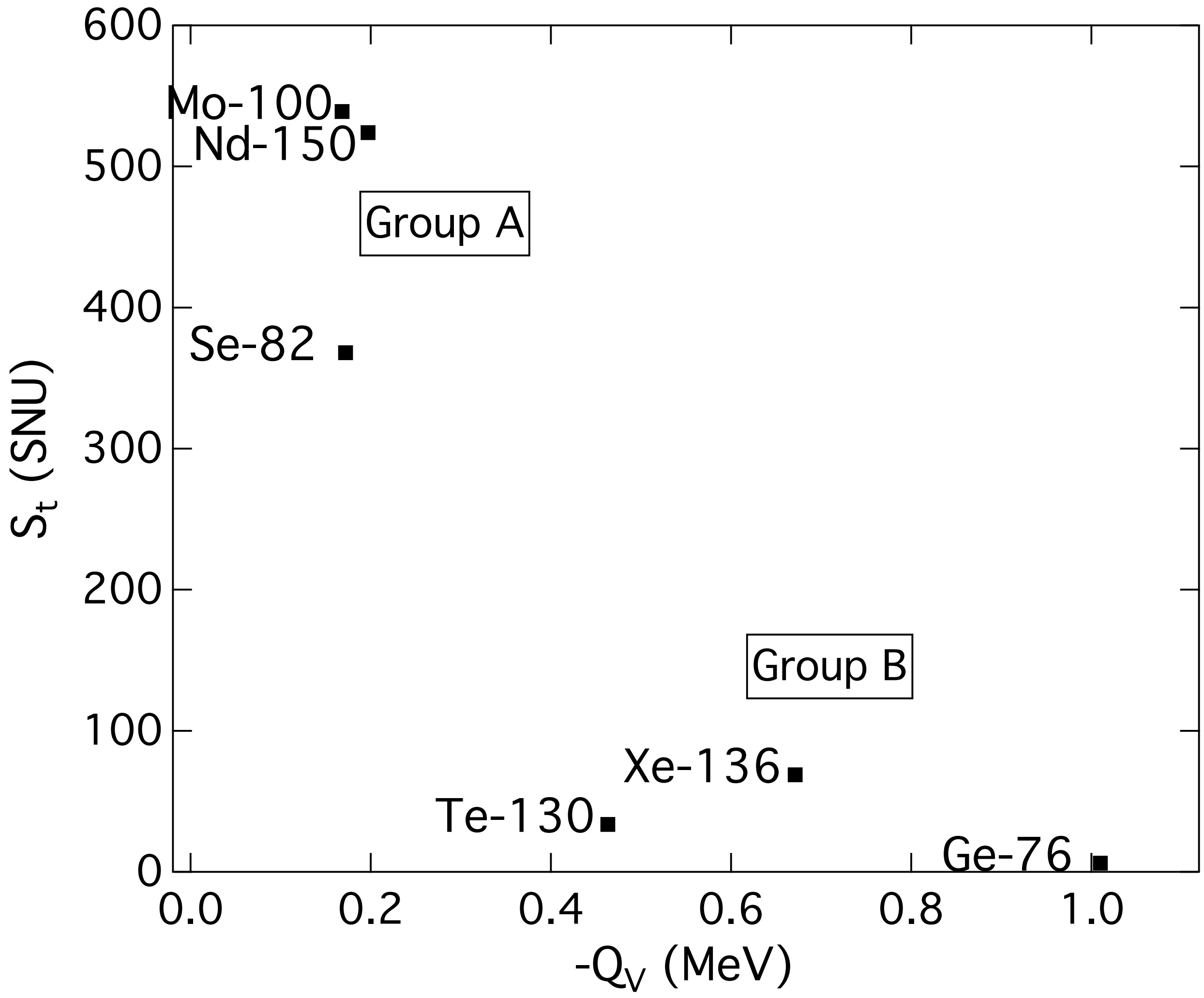
Use BP05(OP) fluxes with oscillation.

Astrophys. J. Lett 621,L85 (2005)

Fermi function from tables

Behrens & Jänecke

Solar ν and ββ Isotopes



Group A: low Q and hence significant pp response.

Group B: high Q and low solar response.

Solar Neutrino Rates

Isotope	$\beta\beta(2\nu)\ \tau_{1/2}$ years	$Q_{\beta\beta}$ MeV	Q_{ν} MeV	Q_{β} MeV	S_{pp} (SNU)	S_{B} (SNU)	S_t no osc. (SNU)	S_t (SNU)
^{82}Se	9.2×10^{19} [17]	2.992	−0.172	3.093	257	10.0	672	368
^{100}Mo	7.1×10^{18} [17]	3.034	−0.168	3.202	391	6.0	975	539
^{150}Nd	8.2×10^{18} [17]	3.368	−0.197	3.454	352	15.5	961	524
^{76}Ge	1.93×10^{21} [18]	2.039	−1.010	2.962	0	5.0	15.7	6.3
^{130}Te	6.9×10^{20} [17]	2.528	−0.463	2.949	0	6.1	67.7	33.7
^{136}Xe	2.19×10^{21} [17]	2.468	−0.671	2.548	0	9.8	136	68.8

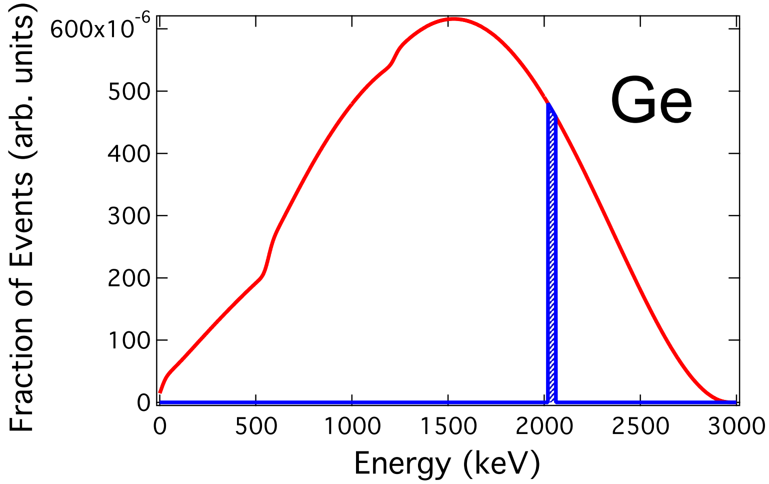
Some of these isotopes might make good solar neutrino detectors.

Beta decay effects and calculations

$$\frac{dN}{dE} \sim (E_0 - E_e)^2 E_e p_e F(Z, E_e),$$

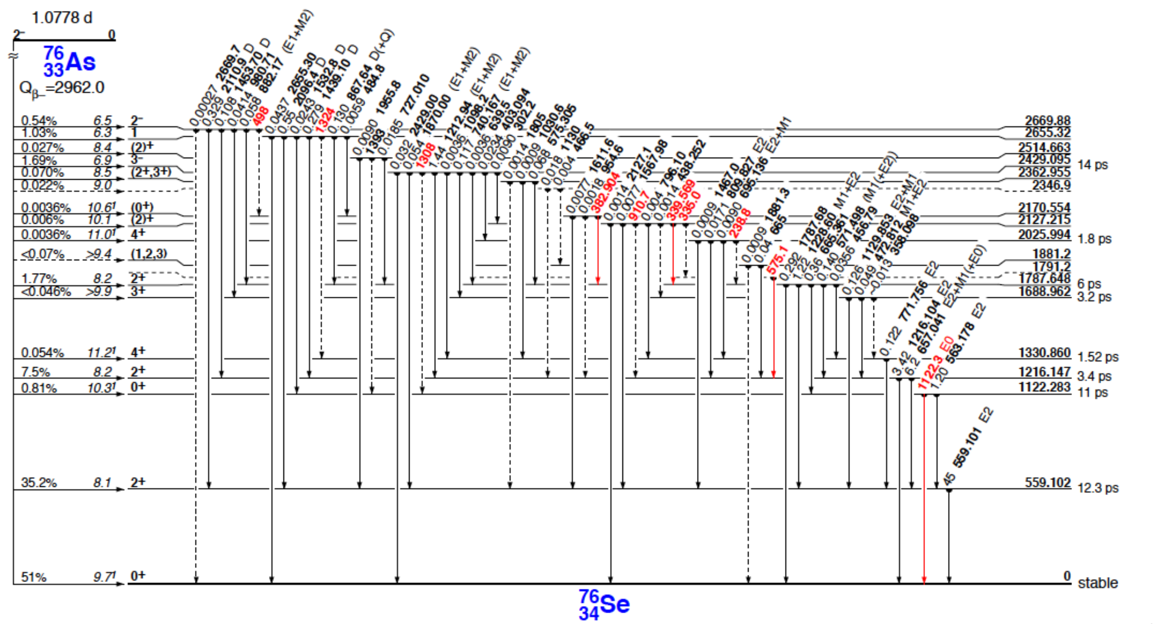
- We consider most of the β strength.
  - ~95% or more of the total branching ratio.
- Calculate the β spectrum and its sum with any γs.
- Estimate the fraction of the spectrum that falls at the ROI for a given resolution. We did this as a function of resolution.

Ge-76

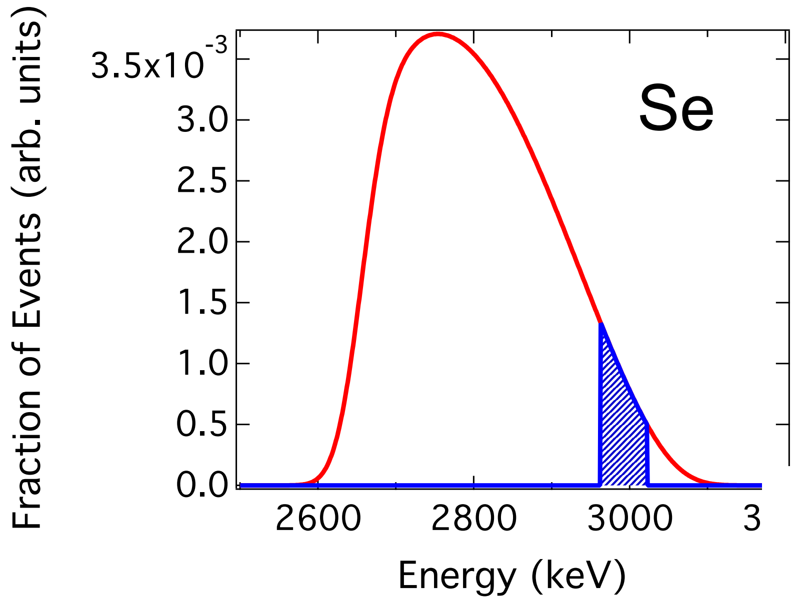


6 SNU
3 primary decays (93.7%) to various states.
β plus γ sum.
Results in a large overlap with ROI.
For 2% resol.: 0.03 counts/t y

^{76}As has 1 d $\tau_{1/2}$
No CC tag.
Ground state trans.
About half MSE decay
HPGE good resol.
Very low rate.

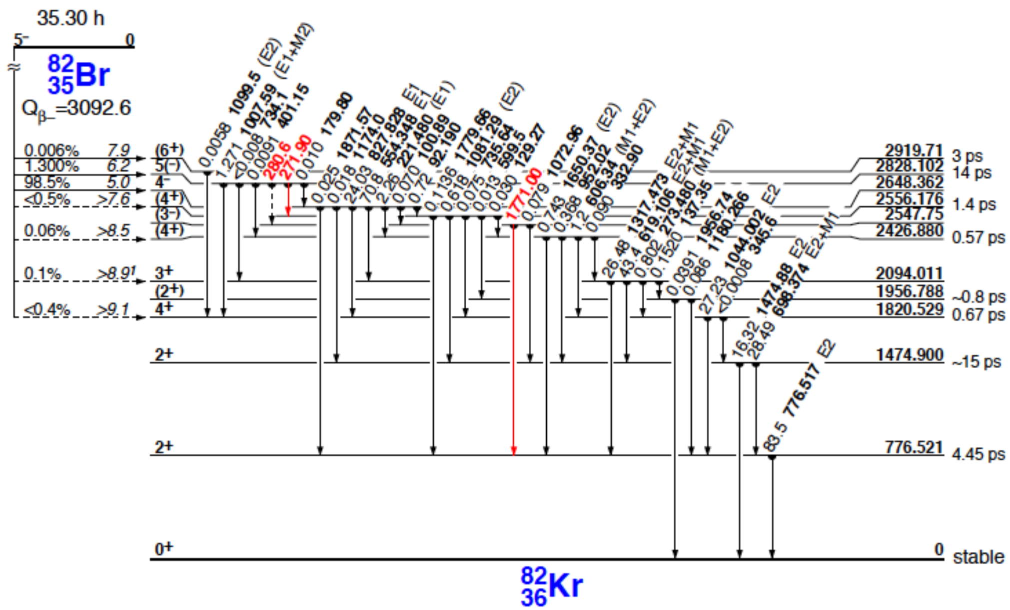


Se-82



370 SNU
98.5% decay to a lone state.
Low energy β plus a γ.
Results in a large overlap with ROI.
For 2% resol.: 4.4 counts/t y

^{82}Br has 35 h $\tau_{1/2}$
No CC tag.
Excited state trans.
Permits MSE cut
Very high rate.



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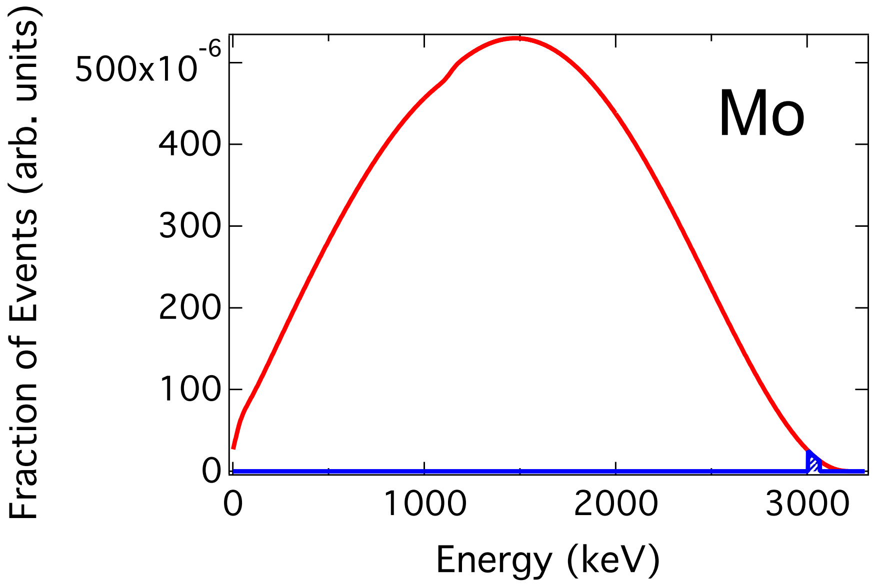
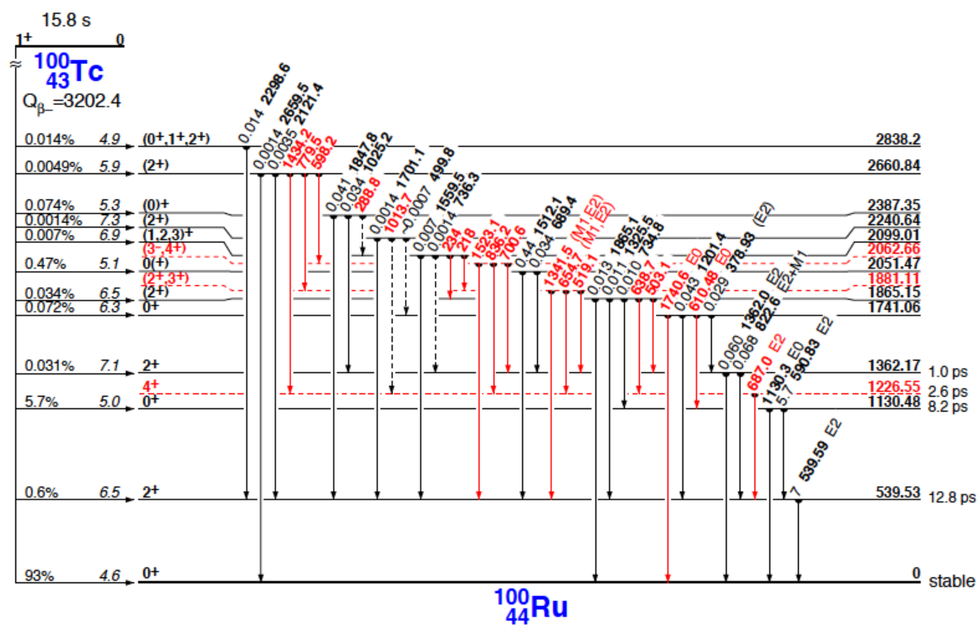
Mo-100

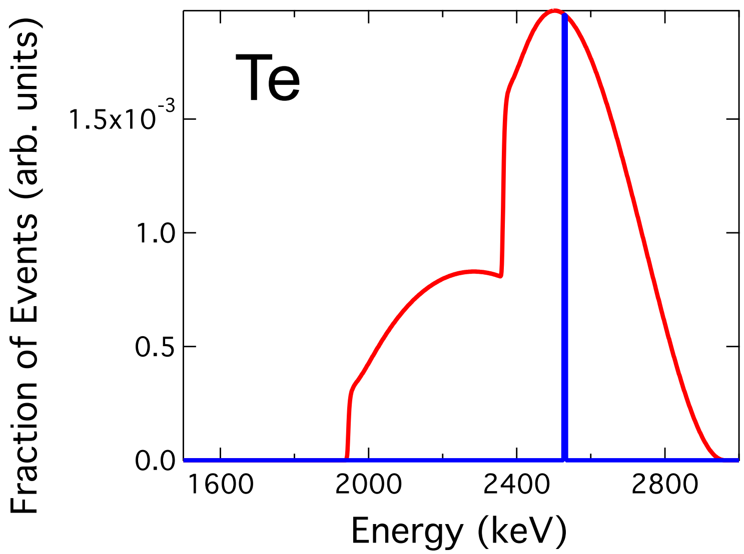


540 SNU
93% decay to ground state.
Results in a small overlap with ROI.
For 2% resol.: 0.1 counts/t y

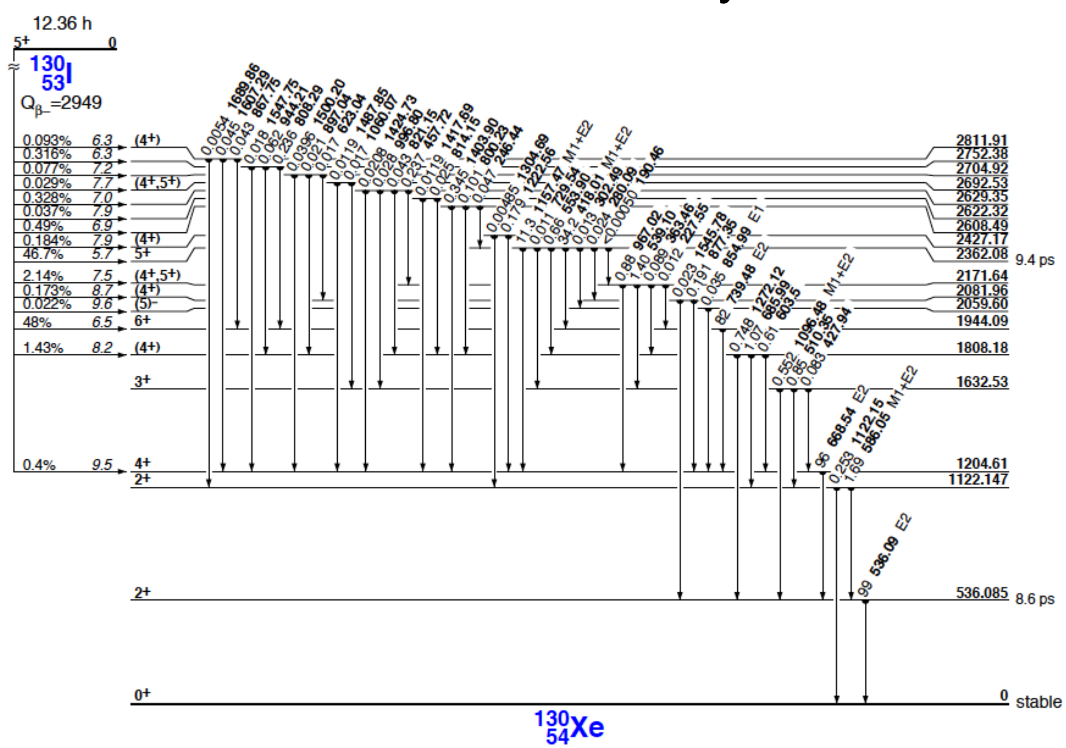
^{100}Tc has 16 s $\tau_{1/2}$
CC tag possible
Ground state trans.
Makes MSE hard
Very high rate.



Te-130

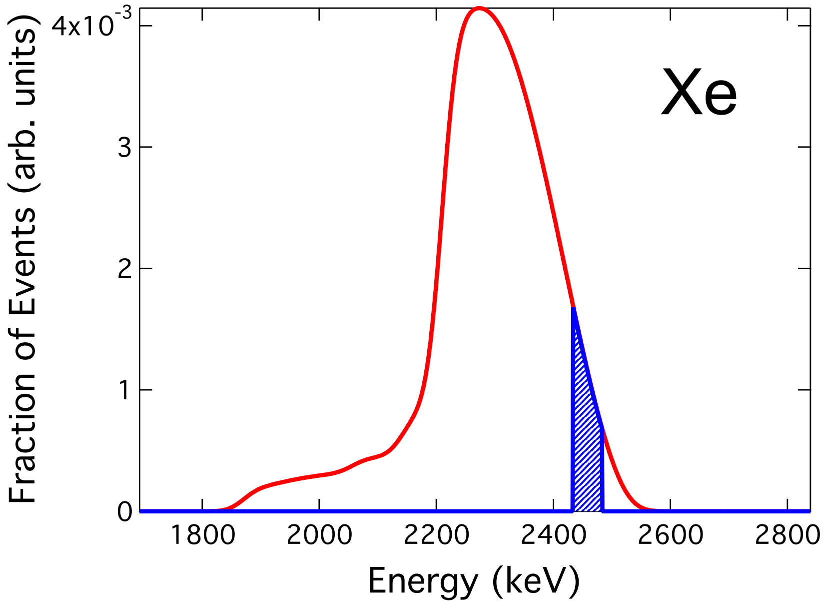


34 SNU
94.7% decay to two states.
Low energy β plus a γ.
Results in a very large overlap with ROI.
For 2% resol: 0.5 counts/t y



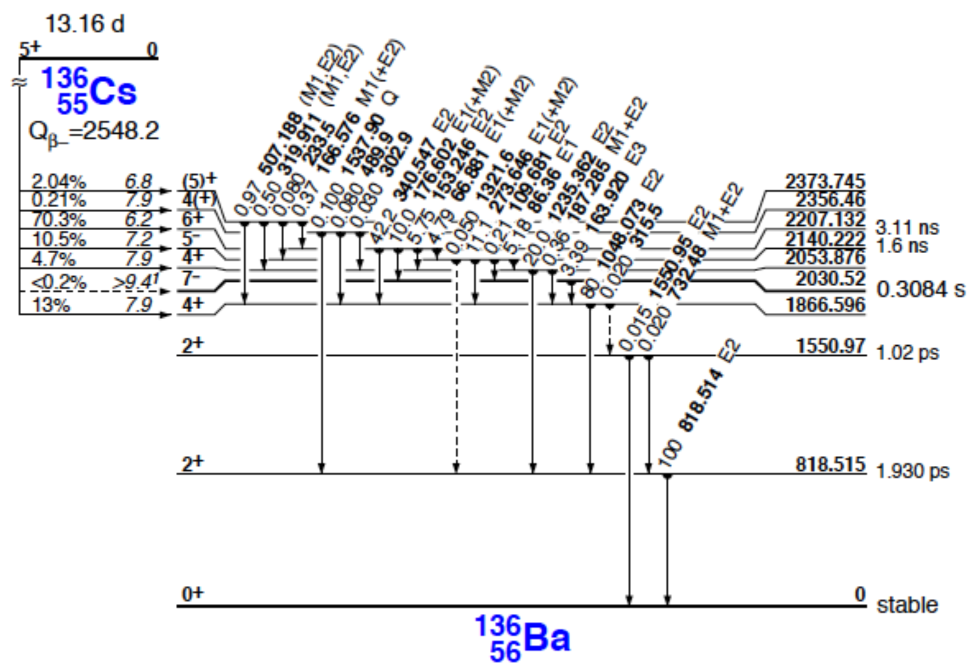
^{130}I has 12 h $\tau_{1/2}$
No CC tag
Excited state trans.
Good MSE rejection
Bolometer good resol.
Low rate.

Xe-136



69 SNU
98.5% decay to various states.
70.3% to a lone state
Low energy β plus γ.
Results in a large overlap with ROI.
For 2% resol.: 0.6 counts/ t y

^{136}Xe has 13 d $\tau_{1/2}$
No CC tag.
Excited state trans.
Good MSE rejection
Modest rate.



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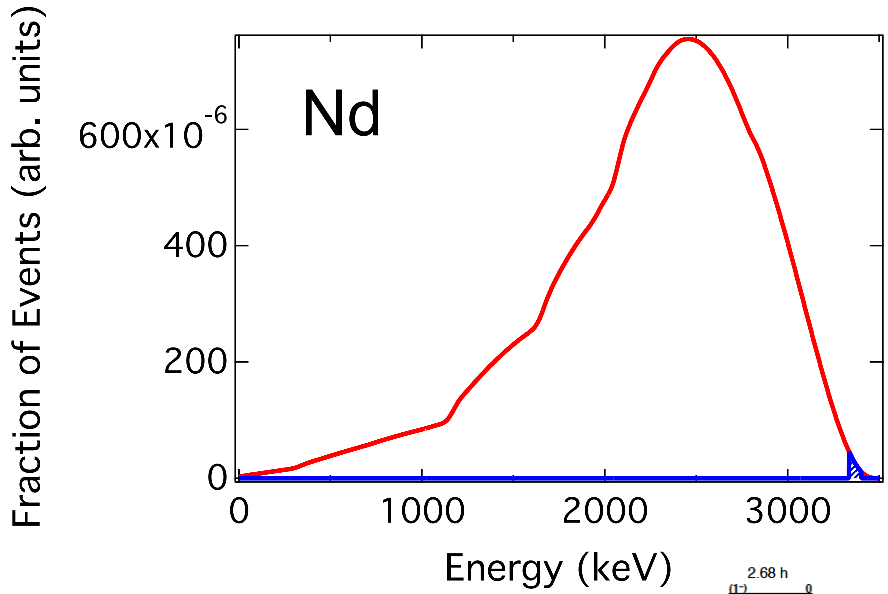
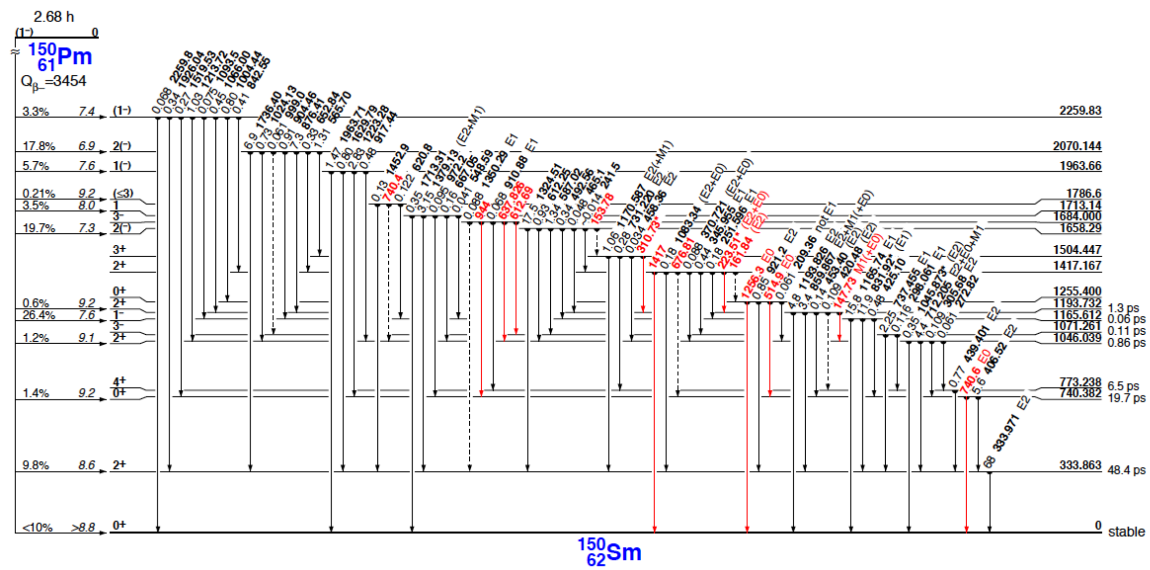
Nd-150



524 SNU
Numerous states with significant BR.
Low energy β plus a γ.
Results in a small overlap with ROI.
For 2% resol.: 0.1 counts/t y

^{150}Pm has 3 h $\tau_{1/2}$
No CC tag.
Ground & Excited state trans., Good MSE rej.
Very High rate.



Relative Rates- Energy Selection Only

2% resol.

Isotope	$\beta\beta(2\nu)$ $\tau_{1/2}$ years	$Q_{\beta\beta}$ MeV	Q_{ν} MeV	Q_{β} MeV	B_{SB} events/t y	$B_{2\nu}$ events/t y
^{82}Se	9.2×10^{19} [17]	2.992	−0.172	3.093	4.42	0.15
^{100}Mo	7.1×10^{18} [17]	3.034	−0.168	3.202	0.11	1.56
^{150}Nd	8.2×10^{18} [17]	3.368	−0.197	3.454	0.12	1.00
^{76}Ge	1.93×10^{21} [18]	2.039	−1.010	2.962	0.03	0.005
^{130}Te	6.9×10^{20} [17]	2.528	−0.463	2.949	0.48	0.01
^{136}Xe	2.19×10^{21} [17]	2.468	−0.671	2.548	0.55	0.003

$$R_{\beta\beta} = \frac{1}{M}\frac{dN}{dt} = \frac{\lambda N}{M} \approx \frac{420}{W}\left(\frac{10^{27}}{T^{0\nu}_{1/2}}\right)/(\text{ton yr}),$$

Ge 10^{28} y: 0.6 counts/ t y
Xe 10^{28} y: 0.3 counts/ t y

Overall discussion of background

- If we required <0.01 counts/t y from this channel, energy cuts alone won't suffice for all isotopes.
  - Will required additional topology cuts, like Multi-site energy deposit (MSE)

Isotope	CC rate	CC Tag	Resol.	MSE
Ge-76	Very low	No	Yes	Some
Se-82	Very high	No		Yes
Mo-100	Very high	Yes		No
Te-130	Low	No	Yes	Yes
Xe-136	Low	No	Some	Yes
Nd-160	Very High	No		Yes

Note on Elastic Scattering

$$R_8 = (F_8 \frac{\Delta\sigma}{\Delta E} N_A)\left(\Delta E \frac{1}{MW_t(g)} N_e\right)$$
$$\approx (8 \times 10^{-4}/(\text{keV y t}))\left(\Delta E \frac{M}{MW_t(g)} N_e\right)$$

F_8 ^{8}B flux
N_e e- per molecule

Will become an issue for loaded scintillator for $\tau_{1/2} > 10^{27}$ y.
Tags are much harder for this channel. Just energy resolution.

J. Phys. G30 (2004), R183
J. Phys. G43 (2016),

Summary

- Solar neutrinos will create signals in ββ targets at a level near future goals.
- Use of the CC tag or MSE cuts will be necessary to reduce this background in most nuclei.
- Elastic scattering is a concern for ββ targets where the ββ isotope is a small fraction of the total detector mass.