Title: What it takes for double beta decay experiments to reach few meV sensitivity (normal mass hierarchy)

Date: Jul 20, 2017 02:00 PM

URL: http://pirsa.org/17070009

Abstract:

Talk Outline

- very brief introduction to neutrinoless double beta decay
- pushing sensitivity down to few meV
- isotope considerations
- case study for normal hierarchy: tellurium-loaded liquid scintillator
  - “new” ideas for background rejection


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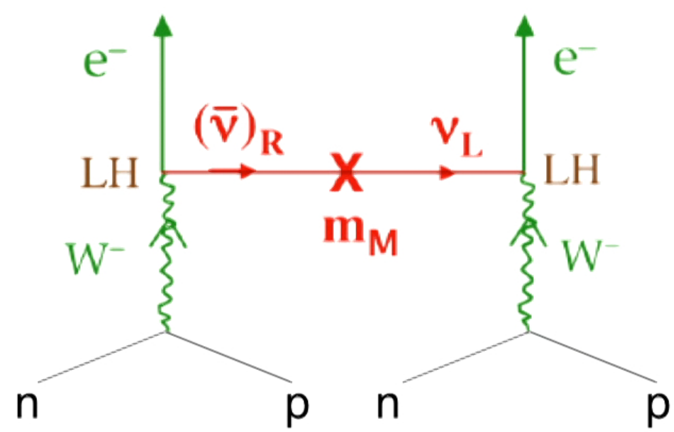
er QE

Majorana Neutrino Mass

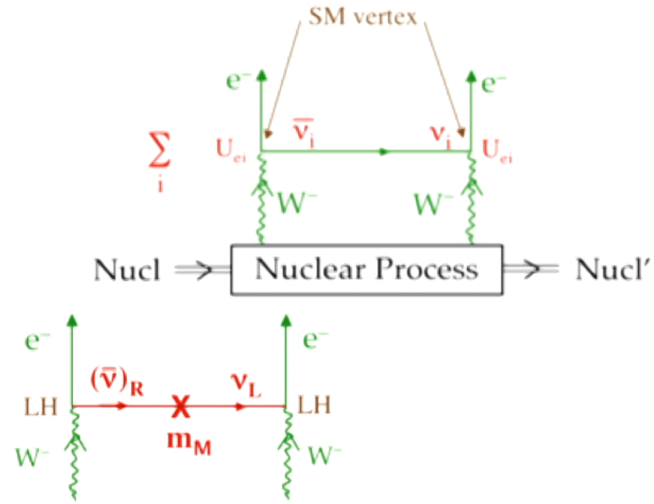
$$m\,\overline{\psi}_L^C \psi_L$$

is precisely the term in the Lagrangian
that's responsible for the process below



Neutrinoless Double Beta Decay Amplitude

- if and only if Majorana
  - antineutrino = neutrino
- chirality mismatch
  - antineutrino is dominantly right-handed with component m/E that is left-handed
- amplitude



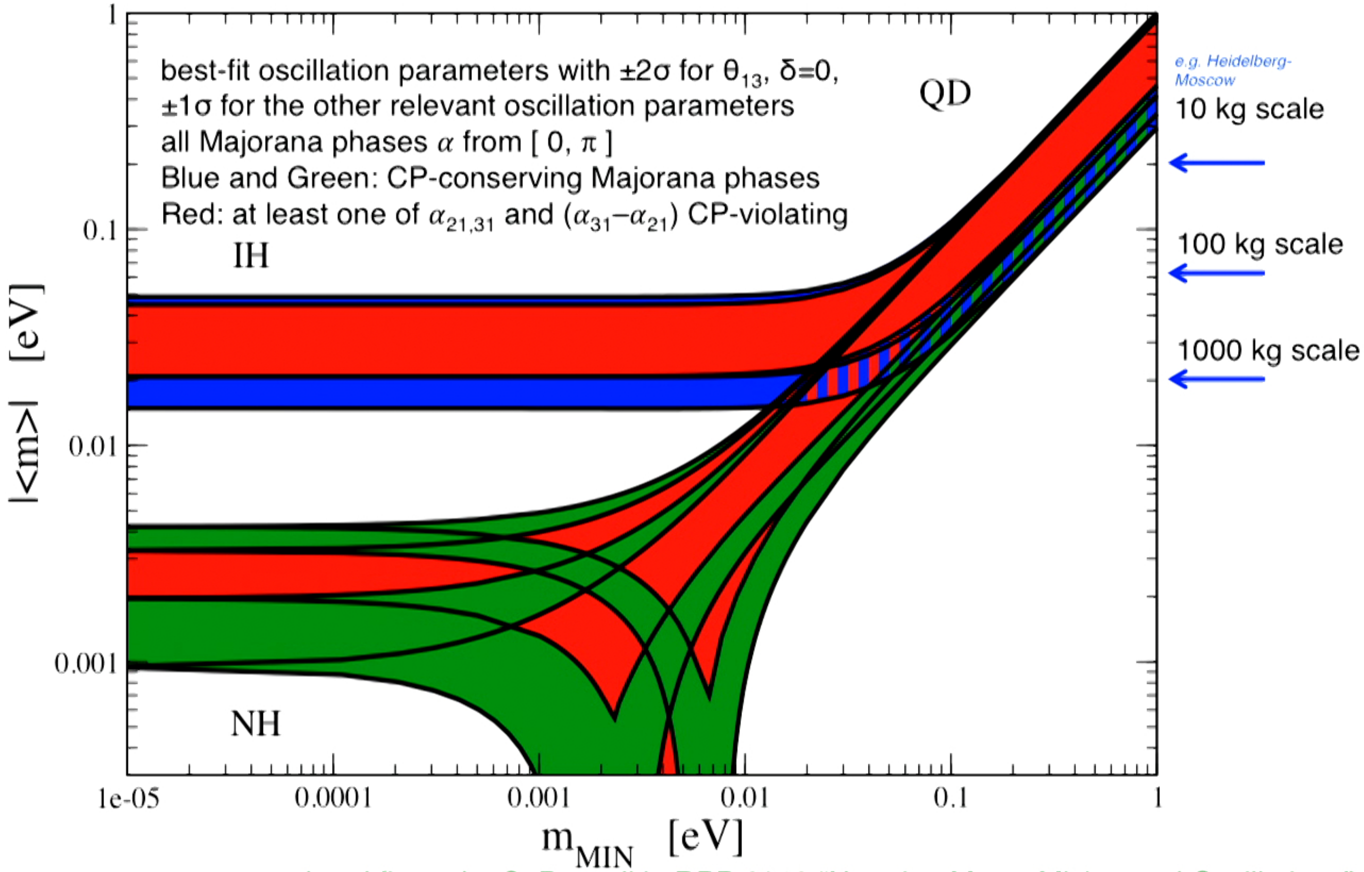
$$\left|\sum_i m_i U_{ei}^2\right| \equiv \langle m_{\beta\beta} \rangle$$

decay rate is amplitude squared, hence $\propto \langle m_{\beta\beta} \rangle^2$

take note: it's the sum of complex-valued U_{ei} with the "Majorana phases"

$$\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix} \times \mathrm{diag}(1, e^{i\alpha_1}, e^{i\alpha_2})$$

$\langle m_{\beta\beta} \rangle$ and the Neutrino Mass Hierarchy



updated figure by S. Pascoli in RPP 2013 "Neutrino Mass, Mixing and Oscillations", originally in S. Pascoli and S. Petcov, PRD 77, 113003 (2008)

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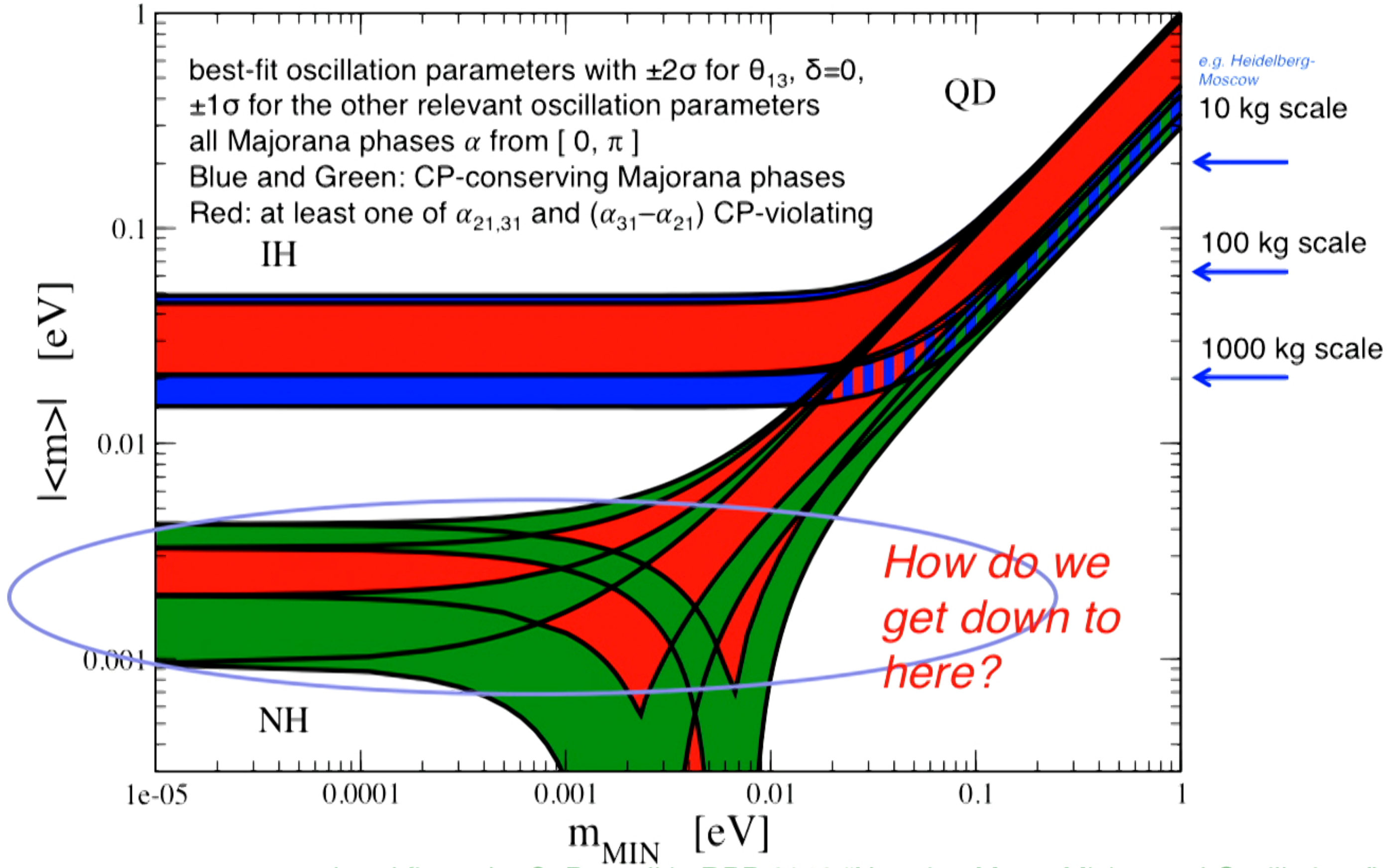

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For Ultimate $\langle m_{\beta\beta} \rangle$ Sensitivity?

Large mass (# of nuclei) of candidate DBD isotope

– efficiently deployed/instrumented

With extremely low backgrounds

That's it

We need both, and making progress on both fronts is required to get us there

How to Push Backgrounds Lower?

goal: a "normal hierarchy" $0\nu\beta\beta$ experiment

- improve energy resolution
- event topology for background rejection
  - e.g. $\beta\beta$ track identification, see next talk by Alvaro
  - also includes single site/multi-site, β/γ, β/α, etc.
- improve radiopurity and/or shielding
- implement decay daughter identification (tagging)

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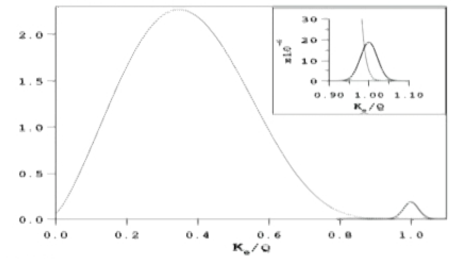

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Which Isotope?

- 35 naturally-occurring isotopes can double beta decay
  - double beta isotopes with Q > 2 MeV listed below

isotope	Q-value [MeV]	natural abundance	tons of isotope for $m_{\beta\beta}$ = 2.5 meV 1 event/year	equivalent natural tons and / approx cost
^{48}Ca	4.27	0.187%	31	16580 / $3M
^{150}Nd	3.37	5.6%	13	232 / $11M
^{96}Zr	3.35	2.8%	21	750 / $27M
^{100}Mo	3.03	9.8%	12	122 / $4M
^{82}Se	3.00	8.7%	21	241 / $39M
^{116}Cd	2.80	7.5%	22	293 / $2M
^{130}Te	2.53	34.1%	24	70 / $24M
^{136}Xe	2.48	8.86%	46	519 / $519M
^{124}Sn	2.29	5.8%	41	707 / $22M
^{76}Ge	2.04	7.73%	58	750 / $1221M
^{110}Pd	2.01	11.7%	26	222 / $5078M

amounts and costs (edited) from S.D. Biller, PRD **87** 071301 (2013)

Key Points: Enriched Isotope

- mass of isotope (enriched) required is, within a factor of a few, the same for all candidate
- enriching any isotope is costly, if the technology exists at all
  - perhaps future tech development should be in this direction?
- scale-up factor between current large deployments of enriched isotope and what's needed for normal hierarchy
  - Xe factor 135 over KamLAND-Zen (over nEXO, proposed, factor 10)
  - Ge factor 300 (over LEGEND, itself a scale-up, in production)
  - Se factor 200 (over SuperNEMO, itself a scale-up over current Demonstrator phase)

…and you have to make a detector out of the desired element

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Key Points: Natural Element

- can avoid limiting, costly enrichment by using natural element
  - however, potentially outlandish quantities and/or costs!
- what looks *potentially* feasible?
  - Te, Cd, Mo, Nd, Se, Zr, Sn

We've run the course looking at the amounts and prices; I'm not going to delve into the feasibility issues element by element, except to note...

- scale-up factor between current experiments with large mass of natural isotope and what's needed for normal hierarchy
  - Te factor 17(90): SNO+ will be deploying 3.9 tonnes of ^{nat}Te, with 0.77 tonnes in fiducial volume)

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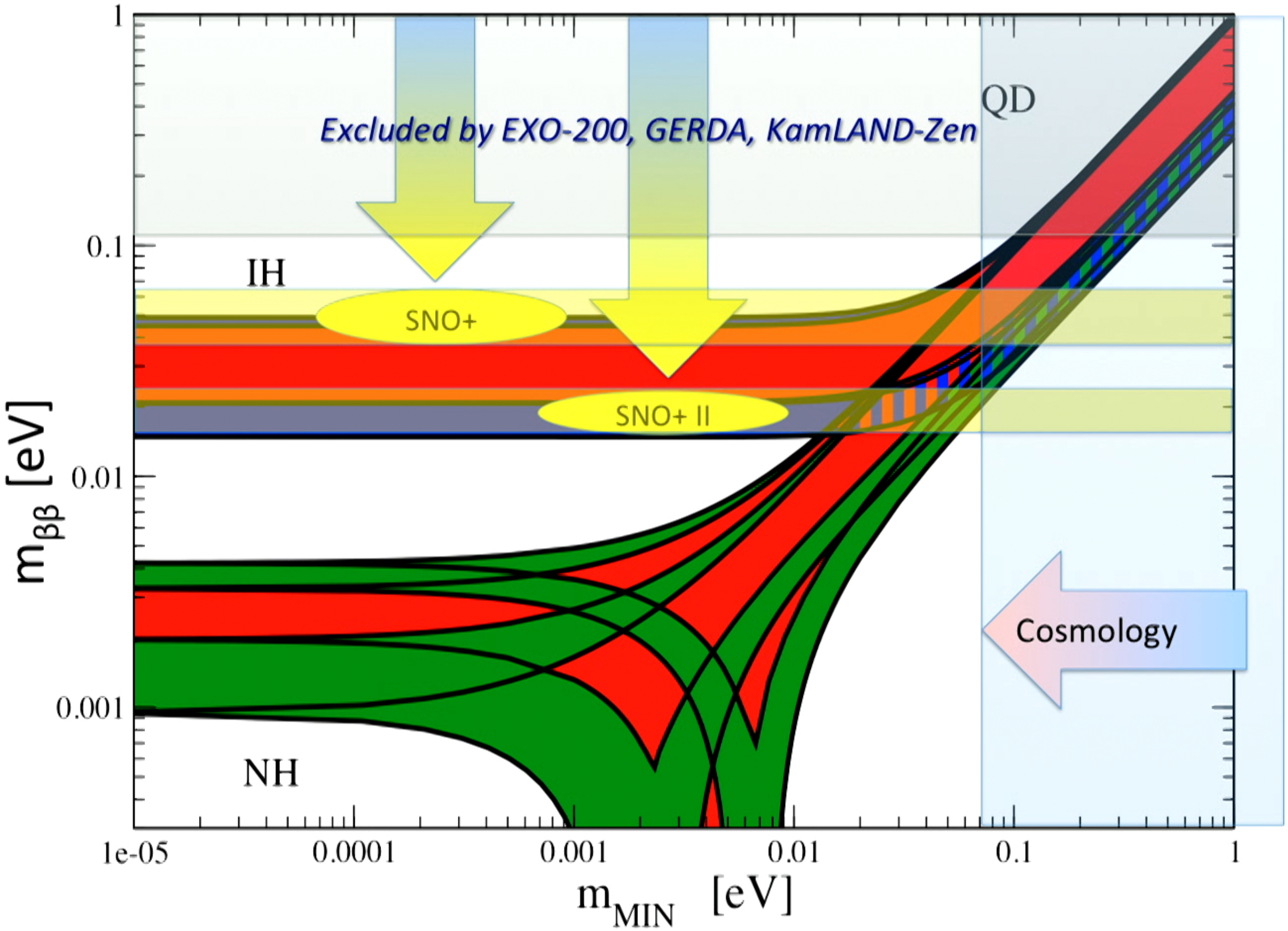

Excluded by EXO-200, GERDA, KamLAND-Zen
QD
IH
SNO+
SNO+ II
NH
Cosmology
$m_{\beta\beta}$ [eV]
1
0.1
0.01
0.001
1e-05
0.0001
0.001
0.01
0.1
1
m_{MIN} [eV]

Ideal NLDBD Experiment Capabilities

from NSAC Town Meeting in Chicago, September 2014
(with my commentary)

- very low backgrounds (internal and external)
- good energy resolution (and calibration)
- scalability (acceptable cost)
- tracking of betas to identify $\beta\beta$ event topology
- large Q-value (ROI above U and Th backgrounds, larger phase space)
- ability to remove or replace isotope (to demonstrate possible signal)

The Te-loaded liquid scintillator approach does the ones (in blue) very well

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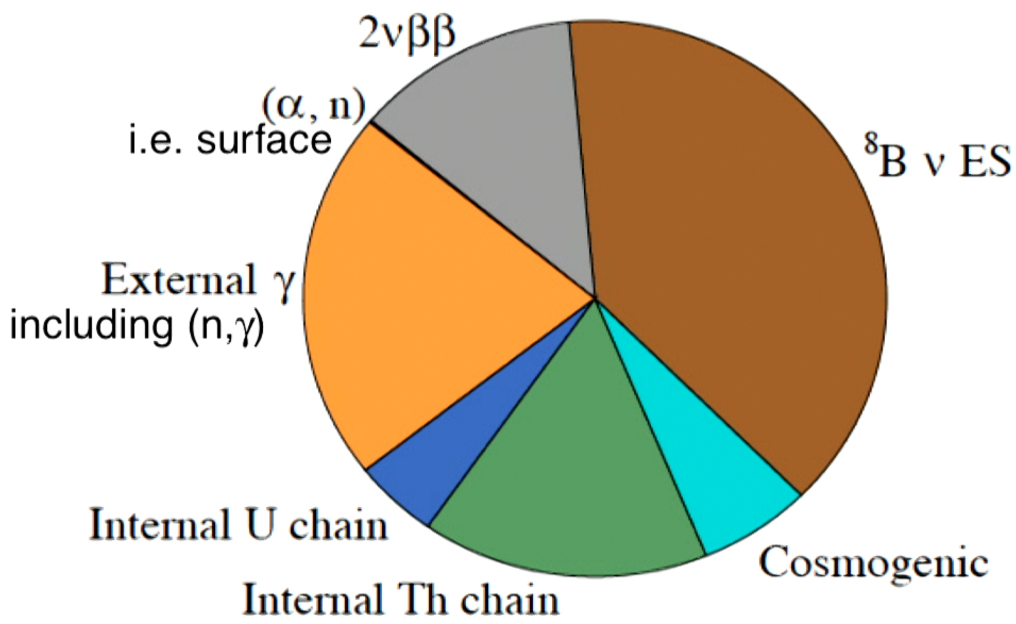
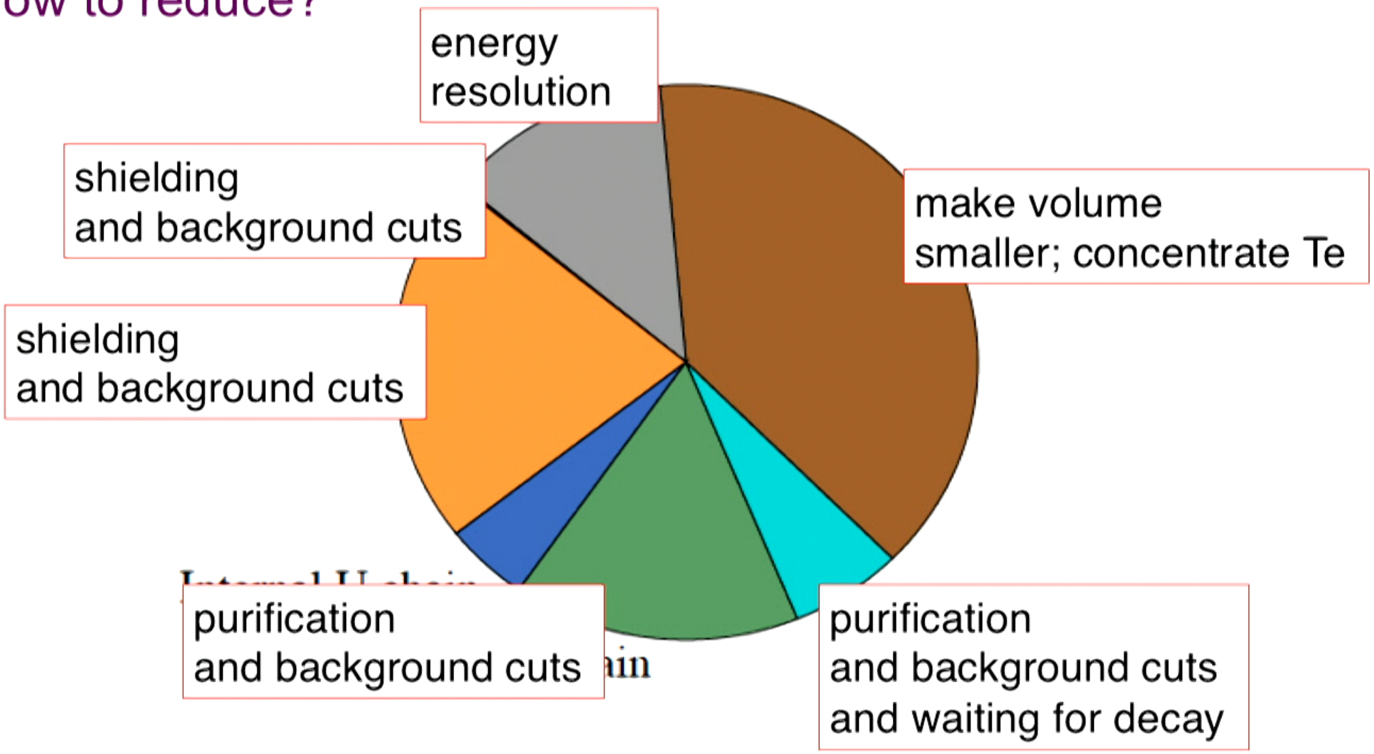
Background Pie Chart

SNO+ double beta decay backgrounds



Background Pie Chart

How to reduce?



New Ideas: Te Liquid Scintillator Background Rejection

Cherenkov-scintillation separation

- the only **other** way, perhaps, to reduce ^{8}B solar neutrino backgrounds might be to identify solar neutrinos by picking out the directional Cherenkov light signal amidst much more abundant isotropic scintillation light, and correlating to the direction of the Sun
- could possibly use for β/γ event discrimination too, based on the "Cherenkov-scintillation deficit"™

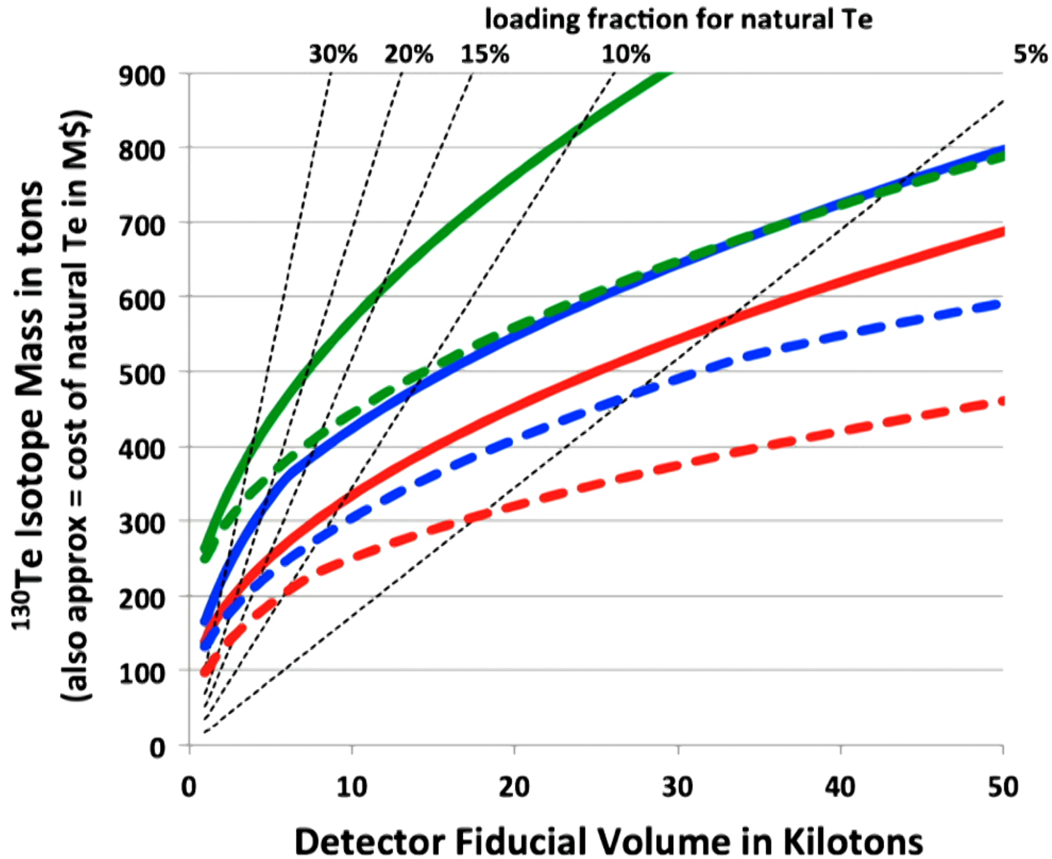
Experimentally: weak scintillation (bad idea); slow scintillation (good idea); improve light detection (higher QE and faster); increased pixelization of readout

S.D. Biller, PRD **87** 071301 (2013)

Biller "Normal Hierarchy" Paper

1000 pe/MeV
1500 pe/MeV
2000 pe/MeV

Dashed Curves: include ⁸B solar neutrino suppression using to-be-developed Cherenkov identification



Decay Daughter Tagging

- ^{136}Xe decays to Ba: EXO (and now NEXT) talk about barium tagging
  - using single atom techniques from the AMO field
  - challenge includes drifting and/or collecting the barium within a large liquid or gas xenon volume
- ^{130}Te decays to Xe
  - techniques for single atom Xe detection?
  - in Te-loaded liquid scintillator, drifting xenon – YES!

Summary

Q: Can we get to meV sensitivity for neutrinoless double beta decay (normal mass hierarchy)?

A: working on it…