

A look at Xe discovery reach and comparison to Ge detectors

Brian Lenardo
SLAC National Accelerator Lab

Second Workshop on 0vbb search in Xe - Next Generation Experiment
Sept 15, 2026

Goal

Expanding on the Bayesian approaches in the literature¹ to estimate “likelihood of discovery” for a given half-life. In particular:

- What new parameter space do future 0vbb experiments probe, when compared to e.g. cosmological probes of neutrino mass?
- Comparing a discovery in Xe to a discovery in Ge; given one, how “likely” is the other?

I want to try to put numbers behind some possible critiques:

- “It looks like the hierarchy is normal, therefore ‘ton-scale’ 0vbb experiments have no chance of making a discovery”
- “Cosmological neutrino mass measurements already rule out the space that ‘ton-scale’ experiments are sensitive to”
- “Xe experiments need to reach 10^{28} -yr sensitivities to be competitive with ‘ton-scale’ Ge experiments like LEGEND-1000”

1. Agostini, Benato, & Detwiler, *Phys. Rev. D* **96**, 053001 (2017)

Generating a probability distribution for $\langle m_{\square\square} \rangle$

Assuming that $0\nu\beta\beta$ is mediated by the exchange of the known light neutrino states, the effective Majorana mass is given by:

$$|m_{\beta\beta}| = | |U_{e1}|^2 m_1 + |U_{e2}|^2 m_2 e^{i\alpha_1} + |U_{e3}|^2 m_3 e^{i\alpha_2} |$$

Where the U_{ei} are the elements of the PMNS matrix and α_1 and α_2 are come from the “Majorana phases” and the Dirac phase:

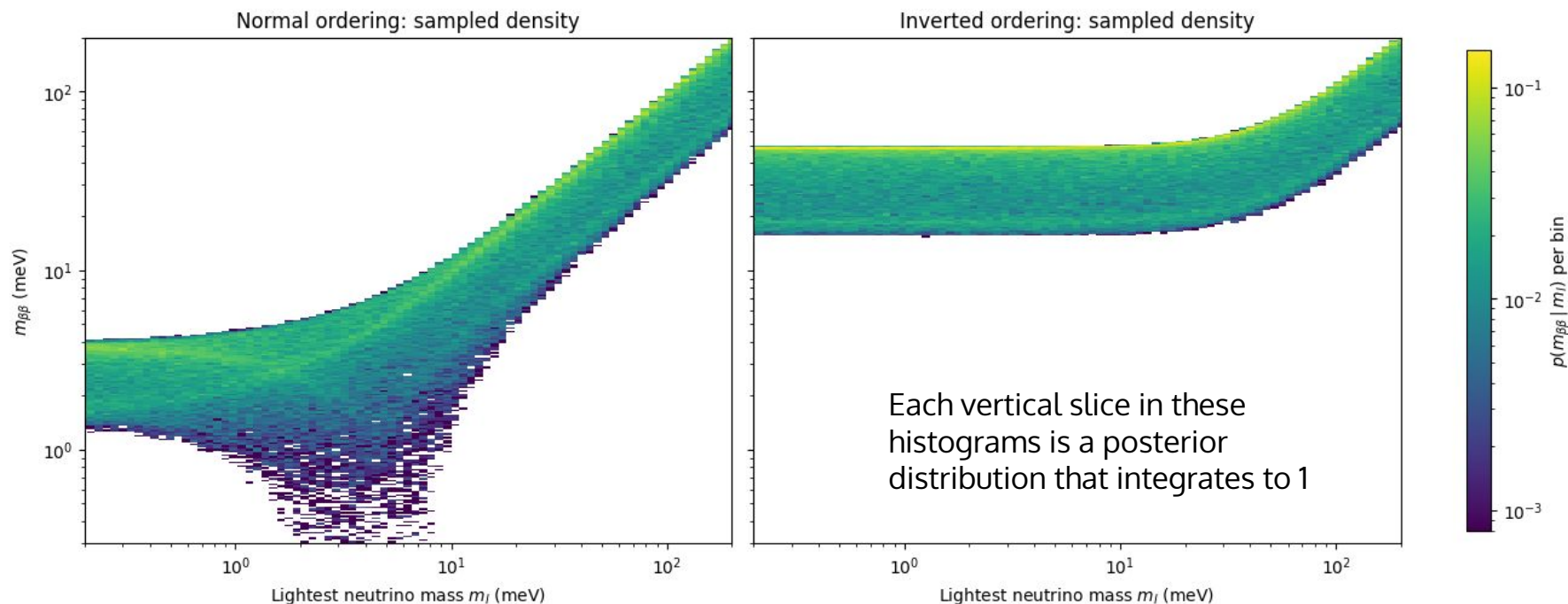
$$U_{\text{PMNS}}^{\text{Majorana}} = U \cdot P, \quad P = \text{diag}(1, e^{i\alpha_1/2}, e^{i\alpha_2/2}) \quad U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

Then we can choose priors for all of these parameters, and by sampling from those priors produce a posterior probability distribution for $m_{\square\square}$

- Gaussian priors on each of the mixing angles using the experimental uncertainties (from <https://globalfit.astroparticles.es/>)
- Uniform priors on the unknown Majorana phases

Posterior distributions

Since we still don't know the absolute mass scale for neutrinos, scan across possible values for the lightest neutrino mass state m_{lightest} . Also, consider normal and inverted orderings separately



Input parameters for experimental sensitivities

$$(T_{1/2}^{0\nu})^{-1} = g_A^4 G^{0\nu} |M^{0\nu}|^2 \frac{\langle m_{\beta\beta} \rangle^2}{m_e^2}$$

Assume **uniform priors**
on NMEs within the
ranges given below

[Kotila & Iachello, *Phys. Rev. C* **85** \(2012\)](#)

TABLE III. Phase-space factors $G_{0\nu}^{(0)}$ and $G_{0\nu}^{(1)}$ obtained using screened exact finite-size Coulomb wave functions.

Nucleus	$G_{0\nu}^{(0)}$ (10^{-15} yr^{-1})	$G_{0\nu}^{(1)}$ (10^{-15} yr^{-1})	$Q_{\beta\beta}$ (MeV)
⁴⁸ Ca	24.81	-23.09	4.27226(404)
⁷⁶ Ge	2.363	-1.954	2.03904(16)
⁸² Se	10.16	-9.074	2.99512(201)
⁹⁶ Zr	20.58	-18.67	3.35037(289)
¹⁰⁰ Mo	15.92	-14.25	3.03440(17)
¹¹⁰ Pd	4.815	-4.017	2.01785(64)
¹¹⁶ Cd	16.70	-14.83	2.81350(13)
¹²⁴ Sn	9.040	-7.765	2.28697(153)
¹²⁸ Te	0.5878	-0.3910	0.86587(131)
¹³⁰ Te	14.22	-12.45	2.52697(23)
¹³⁶ Xe	14.58	-12.73	2.45783(37)
¹⁴⁸ Nd	10.10	-8.506	1.92875(192)
¹⁵⁰ Nd	63.03	-57.76	3.37138(20)
¹⁵⁴ Sm	3.015	-2.295	1.21503(125)
¹⁶⁰ Gd	9.559	-7.932	1.72969(126)
¹⁹⁸ Pt	7.556	-5.868	1.04717(311)
²³² Th	13.93	-10.95	0.84215(246)
²³⁸ U	33.61	-28.13	1.14498(125)

[Shickele et al., *Phys. Rev. D* **114** \(2026\)](#)

TABLE I. Range of NMEs utilized in the study. Phenomenological NMEs are taken from IBM [40], pnQRPA [33], NSM [33], MR-CDFT [46] and GCF [57] calculations. Ab initio NMEs are from VS-IMSRG calculations in Refs. [50, 55, 86], with a full uncertainty quantification for ⁷⁶Ge [56] denoted IMSRG(UQ). All NMEs include the short-range contribution $M_S^{0\nu}$, except for the MR-CDFT values (see text).

	⁷⁶ Ge	¹⁰⁰ Mo	¹³⁰ Te	¹³⁶ Xe
IBM	6.89–8.49	5.77–7.61	4.59–5.82	3.72–4.68
pnQRPA	6.21–9.02	5.06–8.21	4.64–6.94	3.29–4.75
NSM	3.86–5.03	—	3.83–5.12	3.07–4.10
MR-CDFT	2.37–6.34	6.01–9.40	2.89–6.02	2.27–5.06
GCF	2.43–3.79	—	2.51–3.73	1.98–2.91
VS-IMSRG	2.09–3.09	1.80–3.96	1.52–2.40	1.08–1.90
IMSRG (UQ)	2.76 ^{+1.26} _{-1.44}	—	—	—

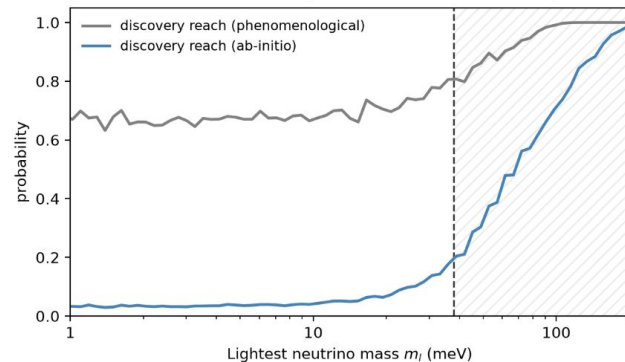
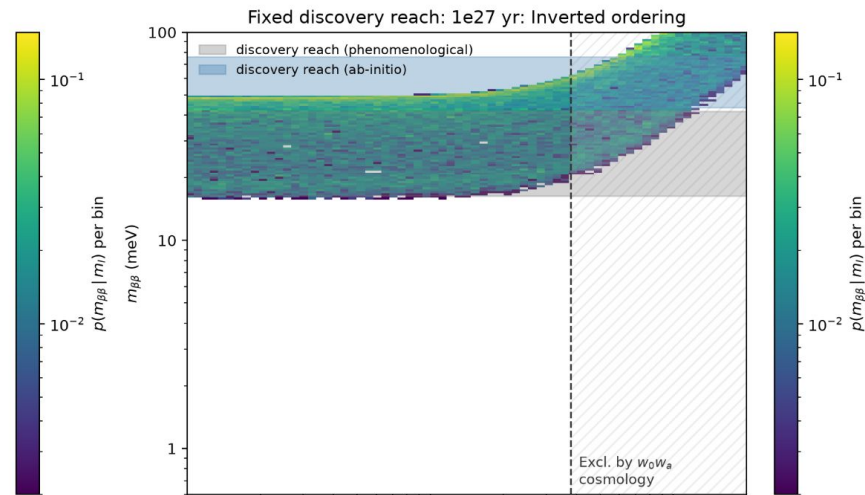
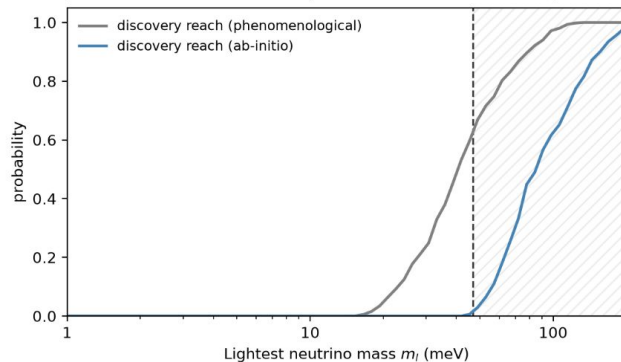
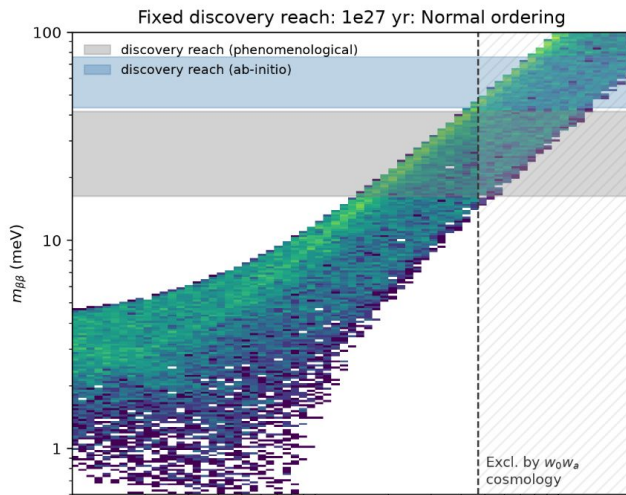
} pheno
← ab-initio

Discovery “probability” for Xe experiments

Assume a Xe experiment can discover a signal at a fixed half-life. What is probability of detecting a signal, as a function of m_{lightest} ?

Shown:

$$T_{1/2} = 1 \times 10^{27} \text{ yrs}$$

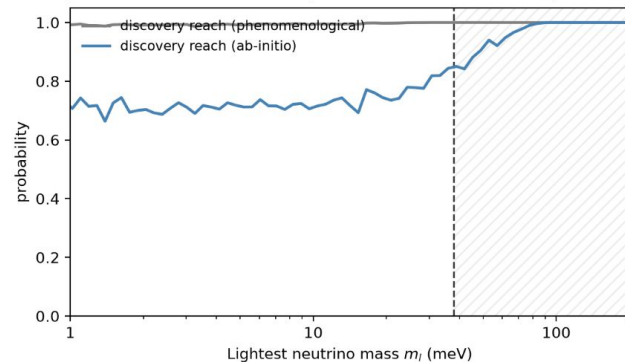
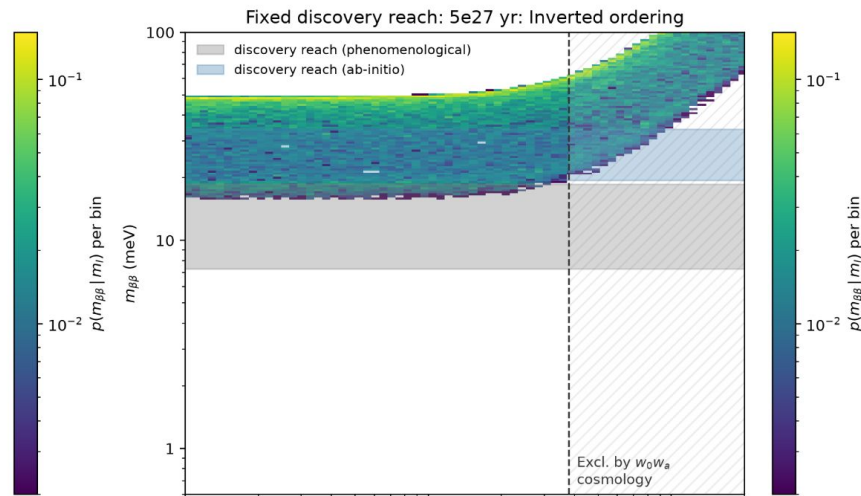
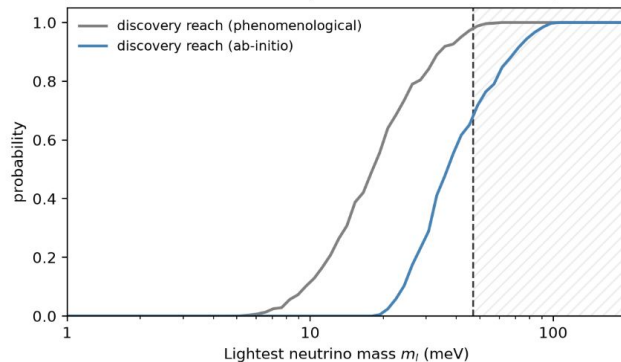
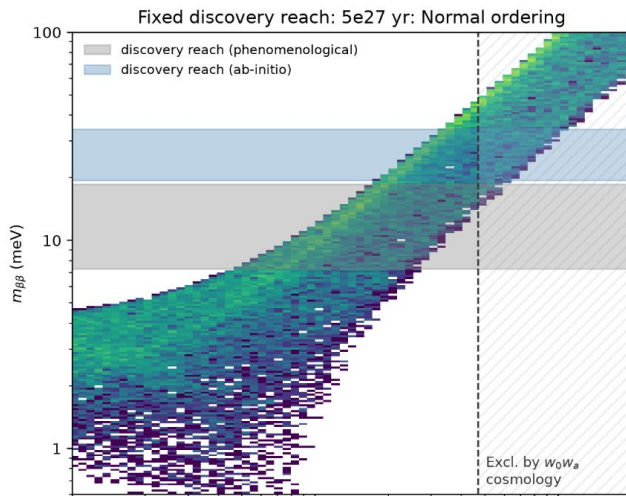


Discovery “probability” for Xe experiments

Assume a Xe experiment can discover a signal at a fixed half-life. What is probability of detecting a signal, as a function of m_{lightest} ?

Shown:

$$T_{1/2} = 5 \times 10^{27} \text{ yrs}$$

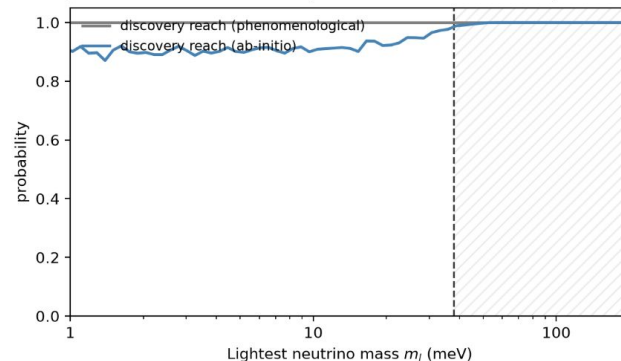
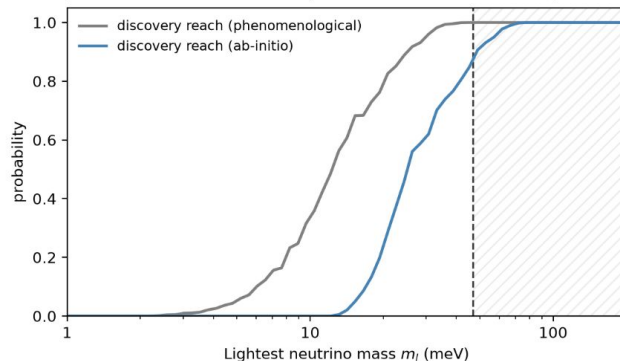
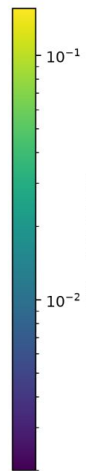
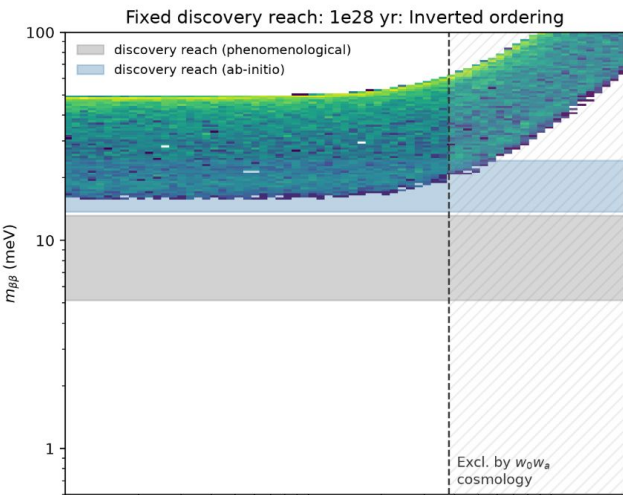
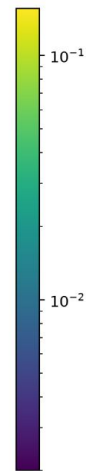
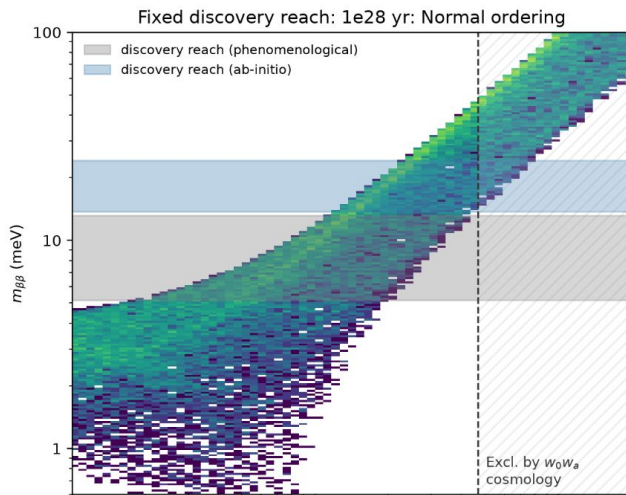


Discovery “probability” for Xe experiments

Assume a Xe experiment can discover a signal at a fixed half-life. What is probability of detecting a signal, as a function of m_{lightest} ?

Shown:

$$T_{1/2} = 1 \times 10^{28} \text{ yrs}$$

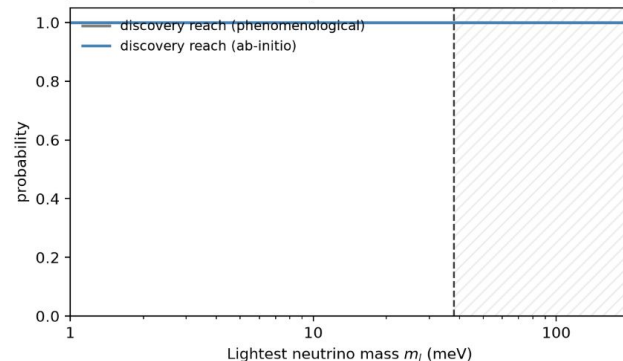
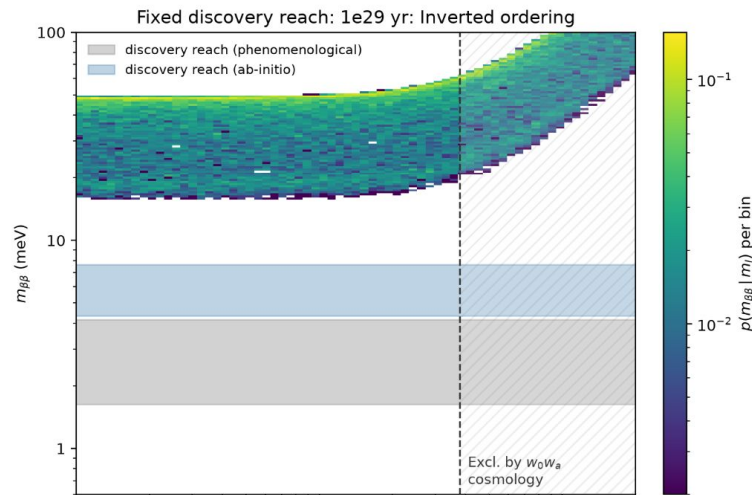
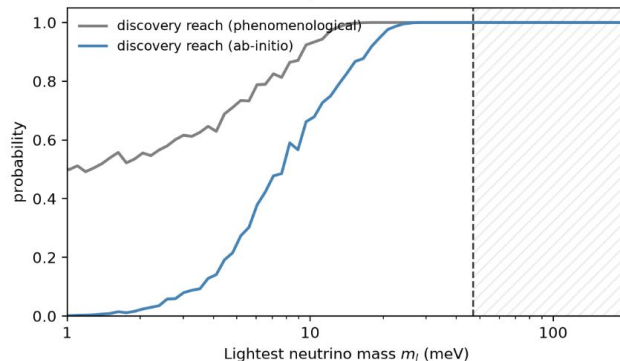
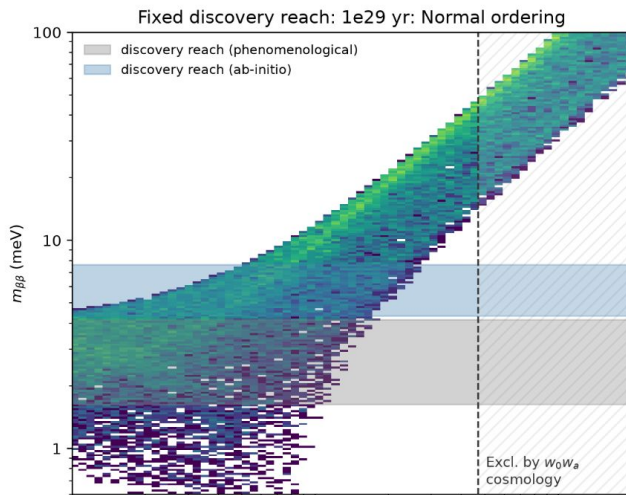


Discovery “probability” for Xe experiments

Assume a Xe experiment can discover a signal at a fixed half-life. What is probability of detecting a signal, as a function of m_{lightest} ?

Shown:

$$T_{1/2} = 1 \times 10^{29} \text{ yrs}$$

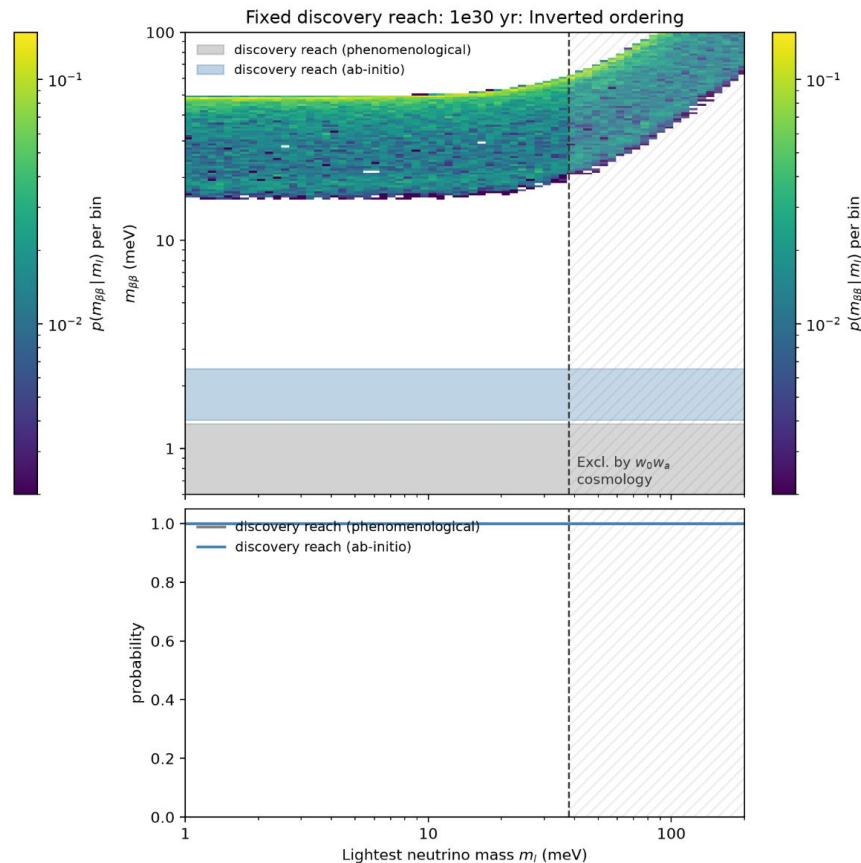
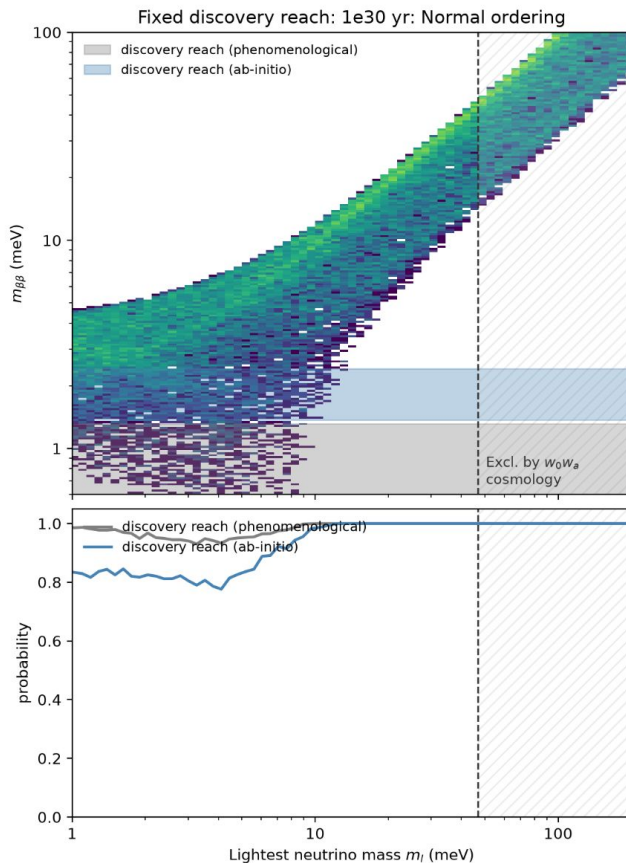


Discovery “probability” for Xe experiments

Assume a Xe experiment can discover a signal at a fixed half-life. What is probability of detecting a signal, as a function of m_{lightest} ?

Shown:

$$T_{1/2} = 1 \times 10^{30} \text{ yrs}$$



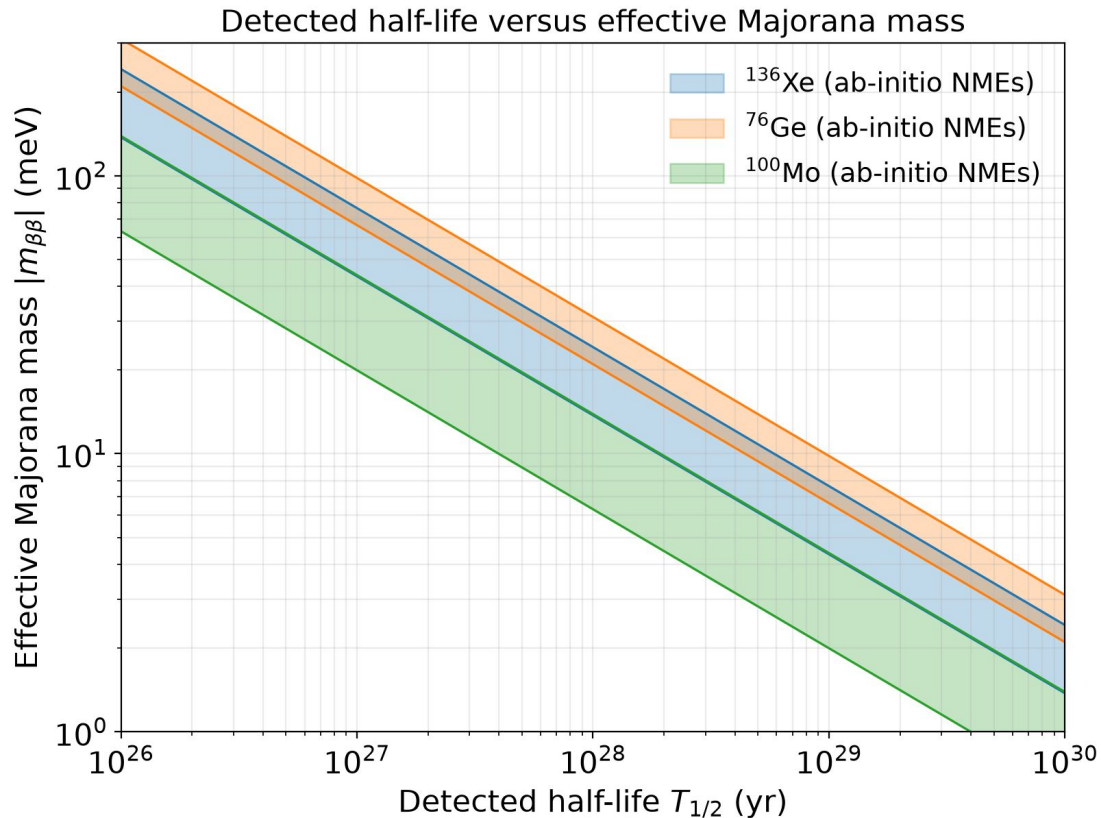
Comparing across isotopes

Can also look at different isotopes, and ask the questions:

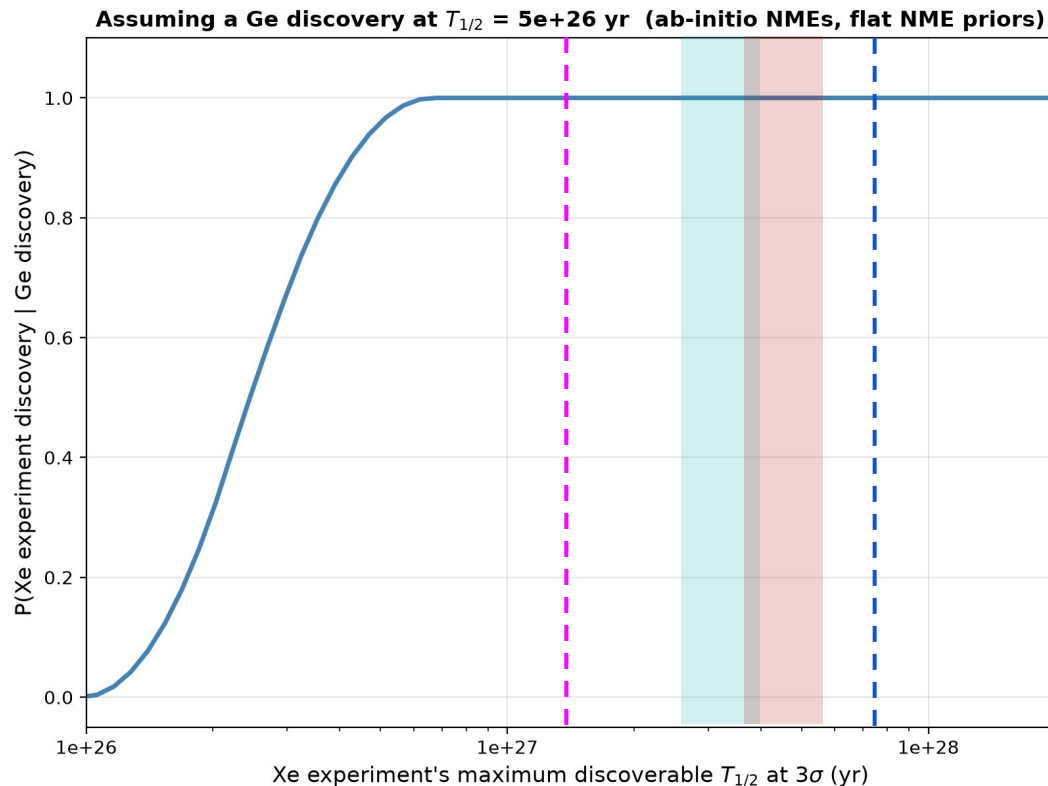
- What half-life sensitivities are needed for different isotopes to reach same discovery potential?
- Given a discovery in one experiment (e.g. Ge), what is probability of a discovery in another (e.g. Xe)?

Two simplifications here:

1. Ignoring statistical uncertainties/fluctuations
2. Only using [Shickele et al. ab-initio NMEs](#) with uniform priors, and assume no correlations between isotopes



Assuming a Ge discovery, will Xe see it?



$$T_{1/2} \text{ in Ge} = 5 \times 10^{26} \text{ yrs}$$

Xe expts' 3σ discovery potential:

NEXT-HD (1t)¹

XLZD 60t²

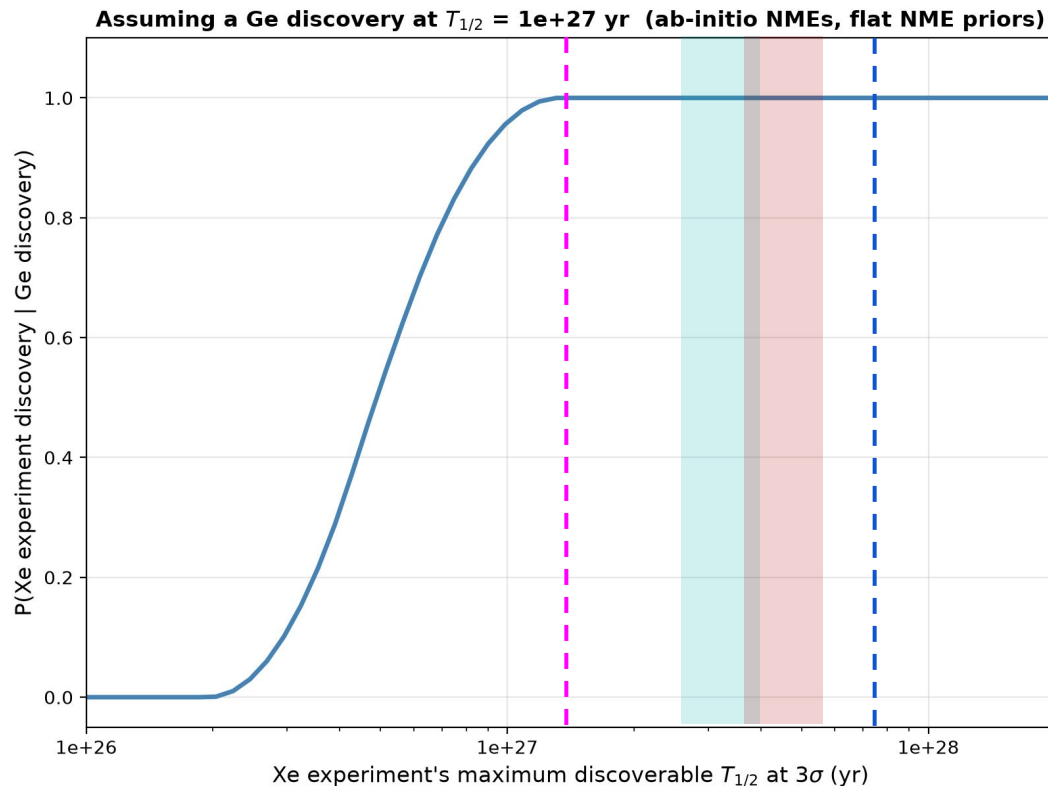
XLZD 80t²

nEXO³

(Note: PandaX-xT and K2Z are missing because I could not find 3σ discovery projections, apologies)

1. [Adams et al \(NEXT\), *JHEP* 2021 \(2021\) 08, 164](#)
2. [Aalbers et al. \(XLZD\), *J.Phys.G* 52 \(2025\) 4, 045102](#)
3. [Adhikari et al. \(nEXO\), *J.Phys.G* 49 \(2022\) 1, 015104](#)

Assuming a Ge discovery, will Xe see it?



$$T_{1/2} \text{ in Ge} = 1 \times 10^{27} \text{ yrs}$$

Xe expts' 3σ discovery potential:

NEXT-HD (1t)¹

XLZD 60t²

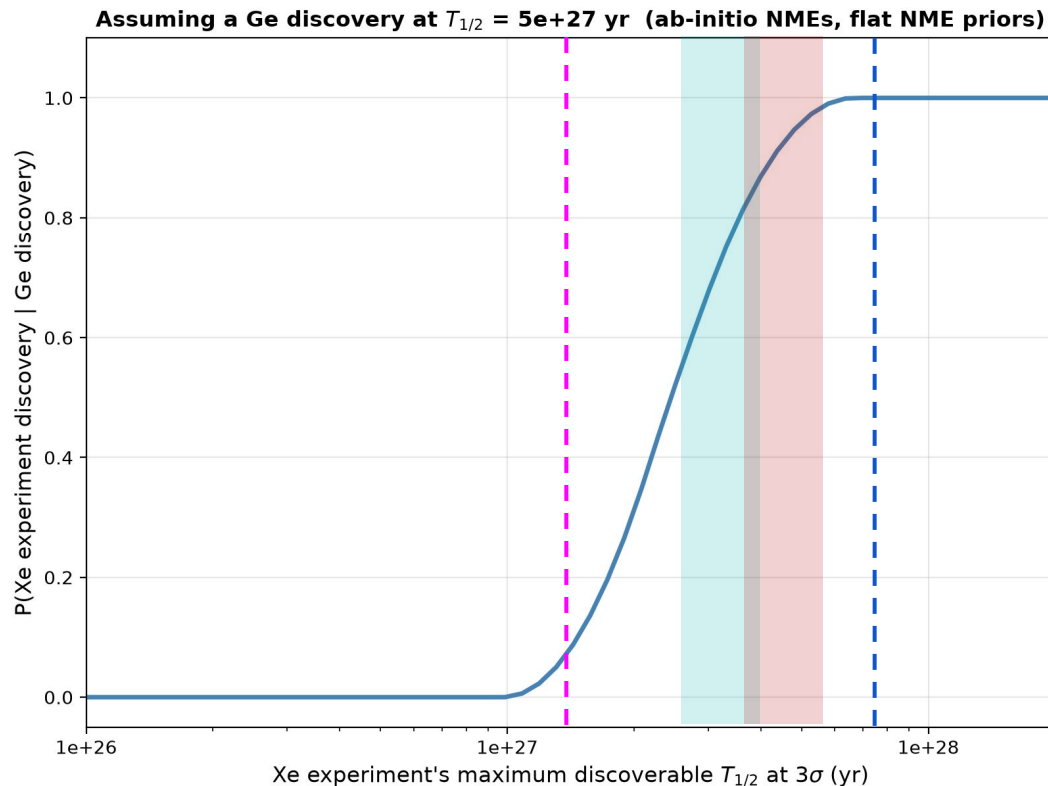
XLZD 80t²

nEXO³

(Note: PandaX-xT and K2Z are missing because I could not find 3σ discovery projections, apologies)

1. [Adams et al \(NEXT\), *JHEP* 2021 \(2021\) 08, 164](#)
2. [Aalbers et al. \(XLZD\), *J.Phys.G* 52 \(2025\) 4, 045102](#)
3. [Adhikari et al. \(nEXO\), *J.Phys.G* 49 \(2022\) 1, 015104](#)

Assuming a Ge discovery, will Xe see it?



$$T_{1/2} \text{ in Ge} = 5 \times 10^{27} \text{ yrs}$$

Xe expts' 3σ discovery potential:

NEXT-HD (1t)¹

XLZD 60t²

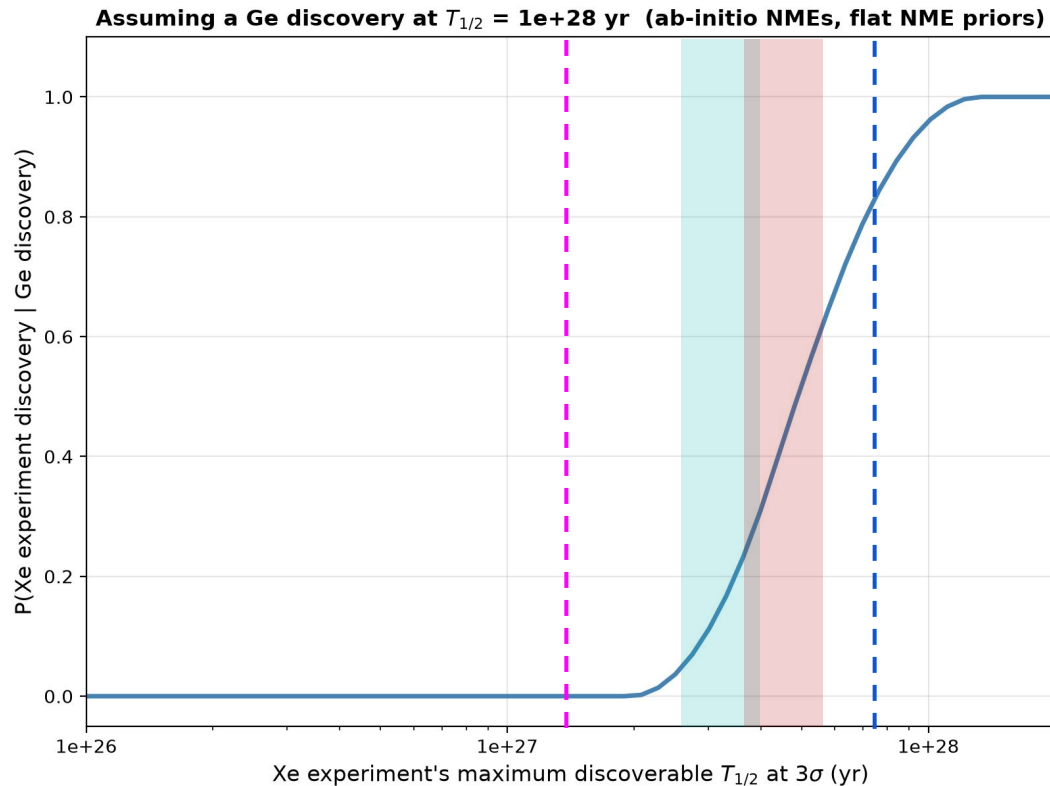
XLZD 80t²

nEXO³

(Note: PandaX-xT and K2Z are missing because I could not find 3σ discovery projections, apologies)

1. [Adams et al \(NEXT\), *JHEP* 2021 \(2021\) 08, 164](#)
2. [Aalbers et al. \(XLZD\), *J.Phys.G* 52 \(2025\) 4, 045102](#)
3. [Adhikari et al. \(nEXO\), *J.Phys.G* 49 \(2022\) 1, 015104](#)

Assuming a Ge discovery, will Xe see it?



$$T_{1/2} \text{ in Ge} = 1 \times 10^{28} \text{ yrs}$$

Xe expts' 3σ discovery potential:

NEXT-HD (1t)¹

XLZD 60t²

XLZD 80t²

nEXO³

(Note: PandaX-xT and K2Z are missing because I could not find 3σ discovery projections, apologies)

1. [Adams et al \(NEXT\), *JHEP* 2021 \(2021\) 08, 164](#)
2. [Aalbers et al. \(XLZD\), *J.Phys.G* 52 \(2025\) 4, 045102](#)
3. [Adhikari et al. \(nEXO\), *J.Phys.G* 49 \(2022\) 1, 015104](#)

An aside: work towards NME recommendations

Chart a path towards “recommended” ranges for NMEs, blessed by theory community

- Establish criteria for NME calculations
 - Near-term, very loose criteria for maximum reach
 - In 3 years, reconvene and establish strict criteria for more consistent comparisons
- Whitepaper in preparation ([see Jason's slides from recent community meeting](#))
- Aiming to circulate in ~Spring, and finalize at MEDEX next summer
 - Plan to seek endorsements from experimental collaborations

[Recent workshop at UW Institute for Nuclear Theory:](#)

Recommended Values for Neutrinoless Double-Beta Decay Nuclear Matrix Elements

June 29, 2026 - July 24, 2026

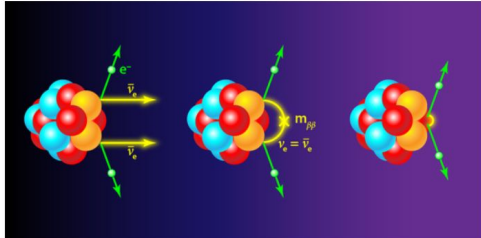
ORGANIZERS

Jason Detwiler
University of Washington
jasondet@uw.edu

Jason Holt
TRIUMF
jholt@triumf.ca

Brian Lenardo
SLAC National Accelerator Laboratory
blenardo@slac.stanford.edu

Javier Menendez
University of Barcelona
menendez@fqa.ub.edu



APS / Alan Stonebraker

[VIEW SCHEDULE](#)

[PARTICIPANT LIST](#)

The priority application deadline for this program has passed

Thank you