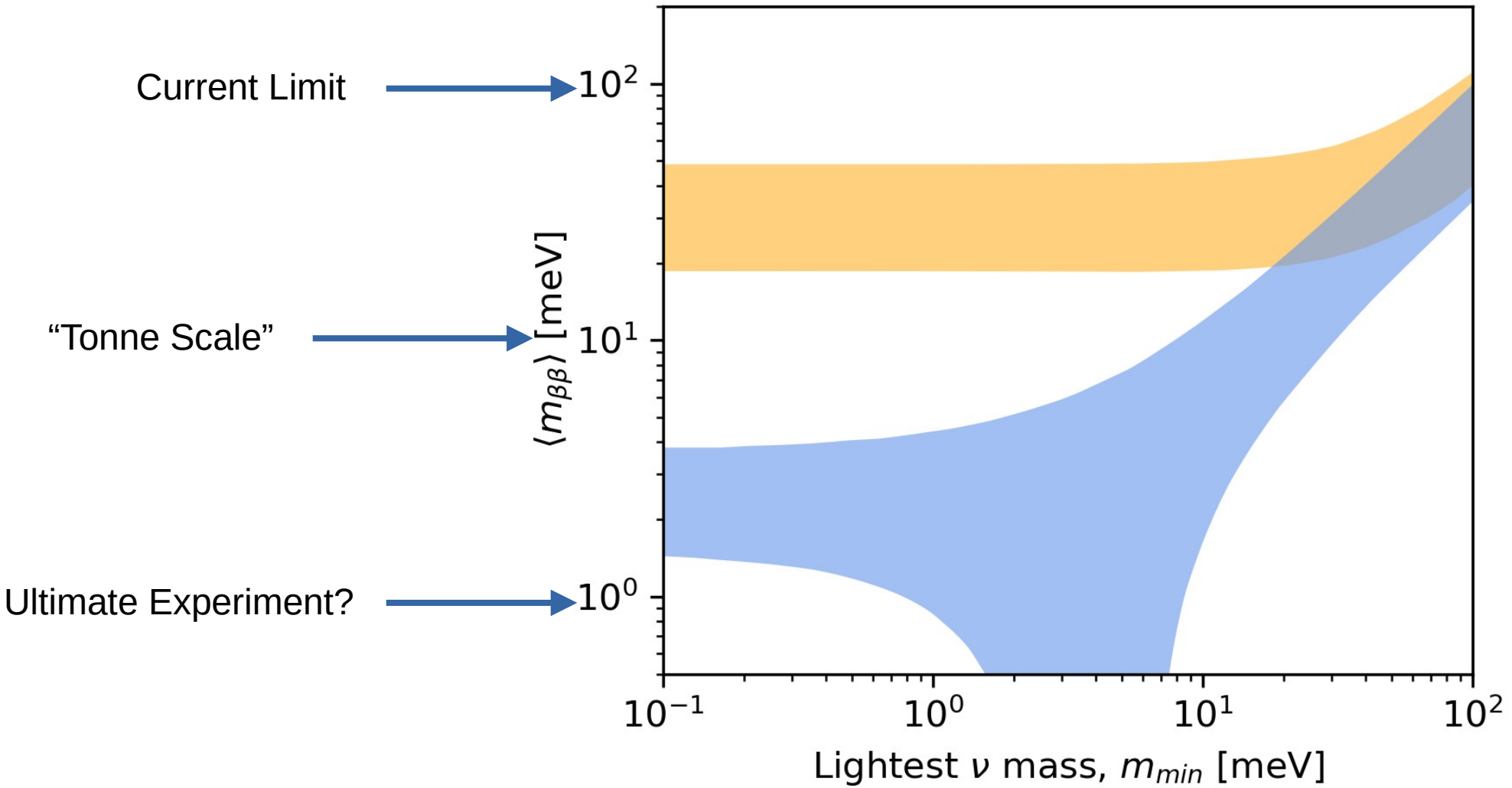
ORIGIN-X:
A 0ν2β experiment with $T_{1/2}$ sensitivity of 10^{30} years.

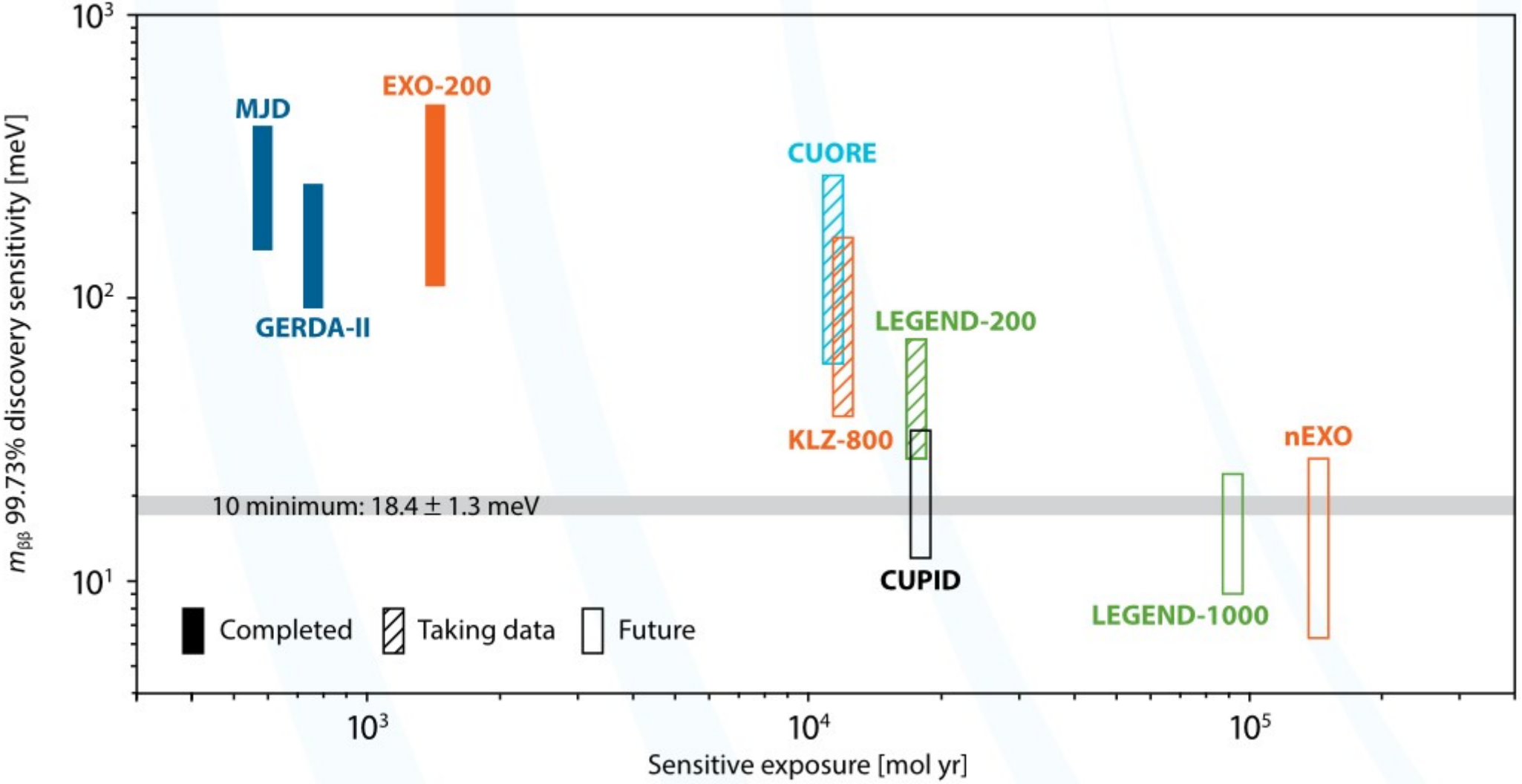
Mike Heffner
Lawrence Livermore National Lab

ktonne TPC Workshop SLAC 2023

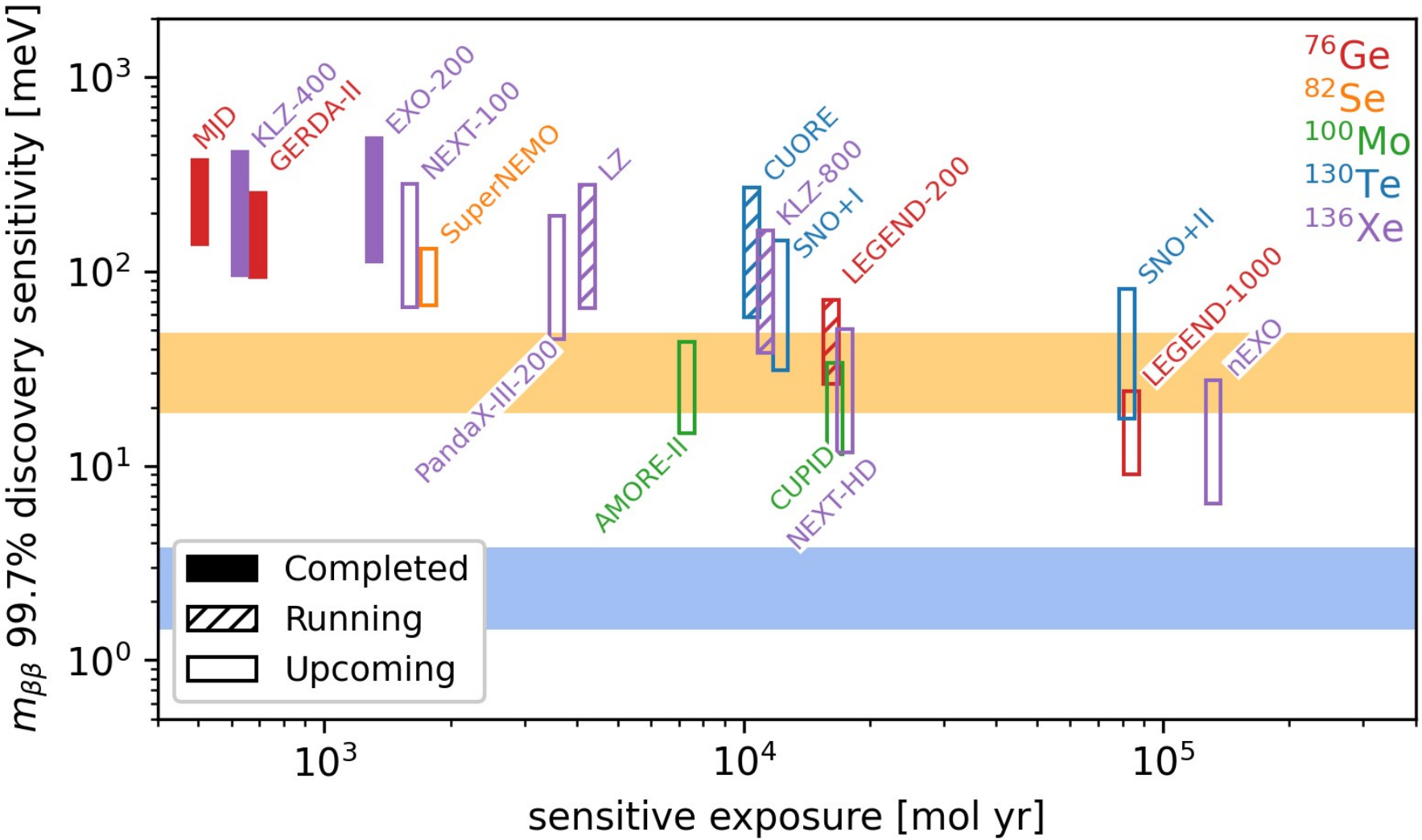
Avasthi et al., arXiv: 2110.01537 (2021)

What is the largest 0ν2β experiment that should/could be built?


Current Limit
“Tonne Scale”
Ultimate Experiment?
10^2
10^1
10^0
$\langle m_{\beta\beta} \rangle$ [meV]
10^{-1}
10^0
10^1
10^2
Lightest ν mass, m_{min} [meV]

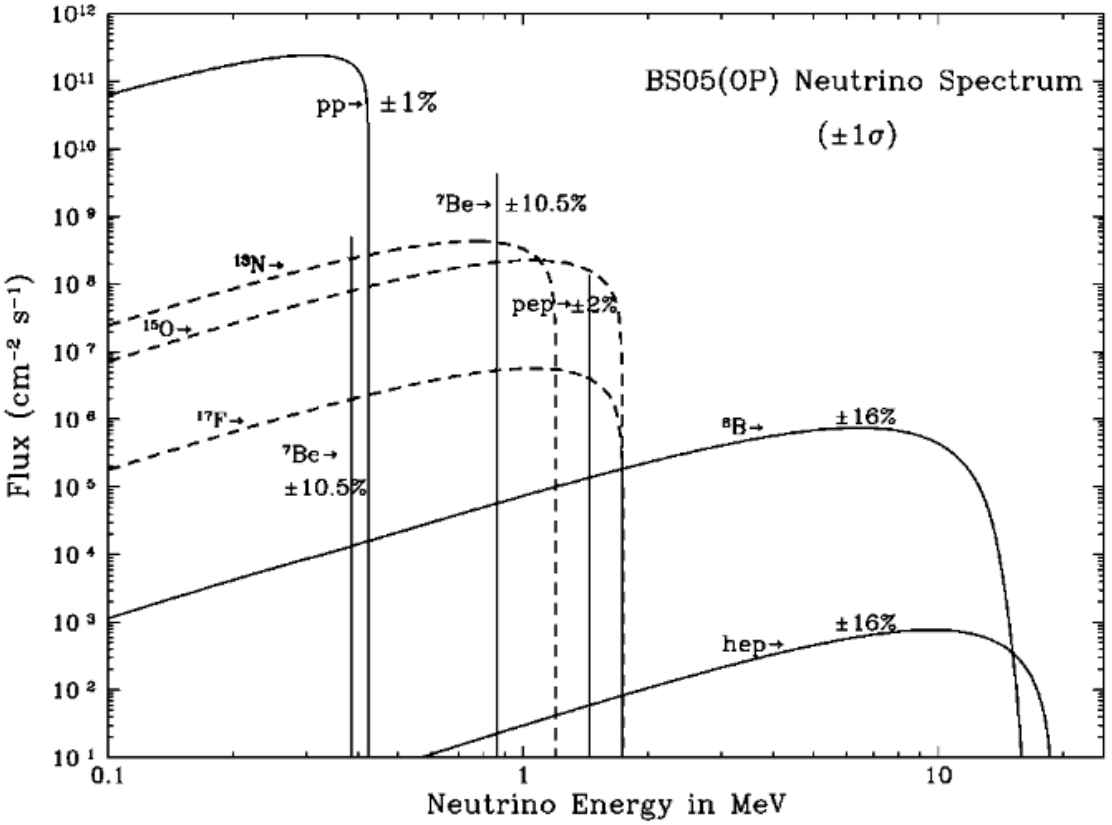


Long Range Plan for Nuclear Science 2023

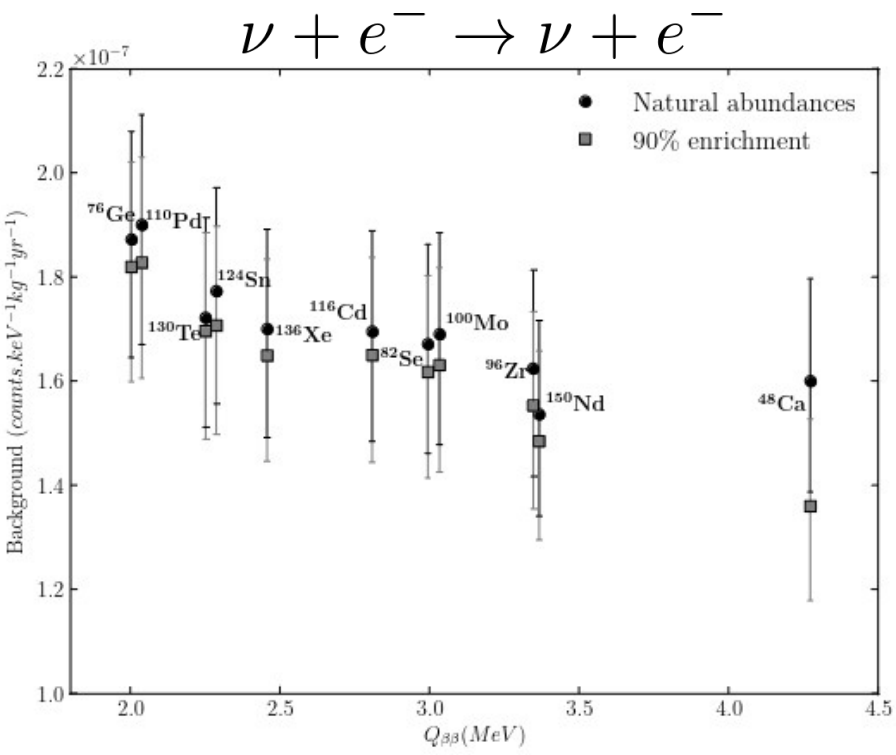

$m_{\beta\beta}$ 99.7% discovery sensitivity [meV]
10^3
10^2
10^1
10^0
10^3
10^4
10^5
sensitive exposure [mol yr]
MJD
KLZ-400
GERDA-II
EXO-200
NEXT-100
SuperNEMO
LZ
PandaX-III-200
AMORE-II
CUORE
KLZ-800
SNO+I
CUPID
NEXT-HD
LEGEND-200
SNO+II
LEGEND-1000
nEXO
^{76}Ge
^{82}Se
^{100}Mo
^{130}Te
^{136}Xe
Completed
Running
Upcoming

The limits: solar neutrinos

5 (2) evts/(FWHM kTonne yr) @ 0.5% (0.2%)

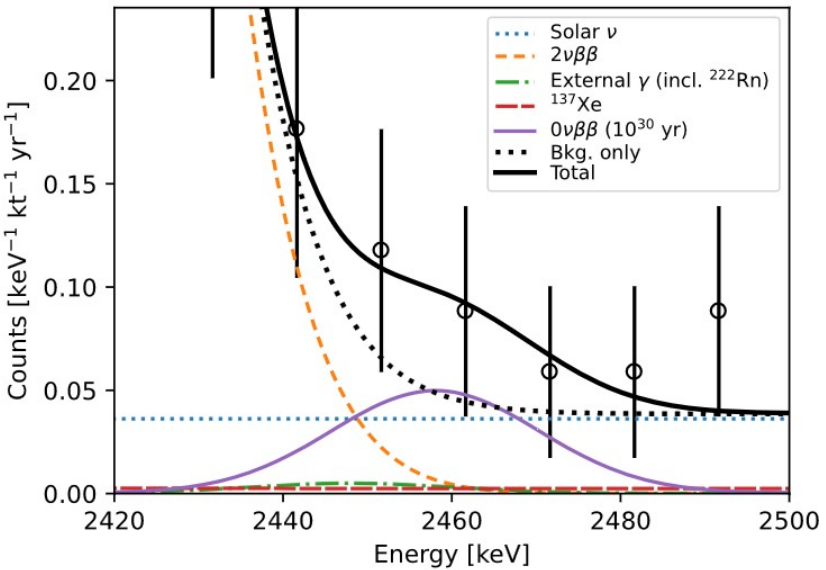


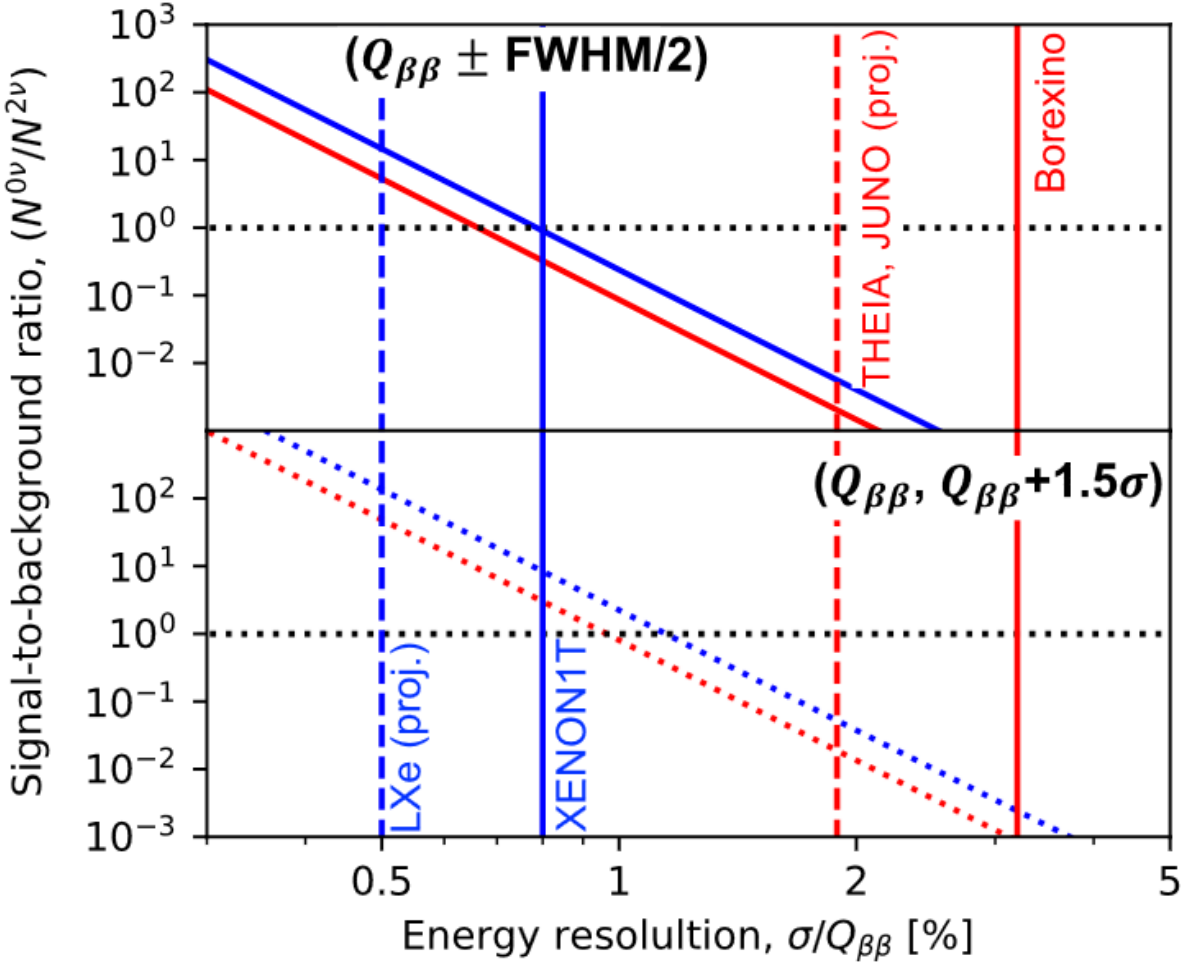
J. Bahcal, et al, The Astrophysical Journal, 621:L85–L88, 2005 March 1



NF deBarros et al, J. Phys. G: Nucl. Part. Phys. 38 (2011) 105201

The limits: 2v2B





Assume we can perfectly reject backgroud, how much mass do we need?

Radioactive Decay

$$\frac{dN}{dt} = \frac{ln(2)}{T_{1/2}} N$$

Half life(yr)	Events/tonne/yr*
10^{26}	30
10^{27}	3
10^{28}	0.3
10^{29}	0.03
10^{30}	0.003

*for xenon

Amount of Xenon that Could be Collected

5.2×10^{21} g Handbook of Chemistry and Physics

NASA Photo of Earth Atmosphere

~2 GTonne of Xenon in Atmosphere

1kTonne is only ~10^{-6} of the total abundance

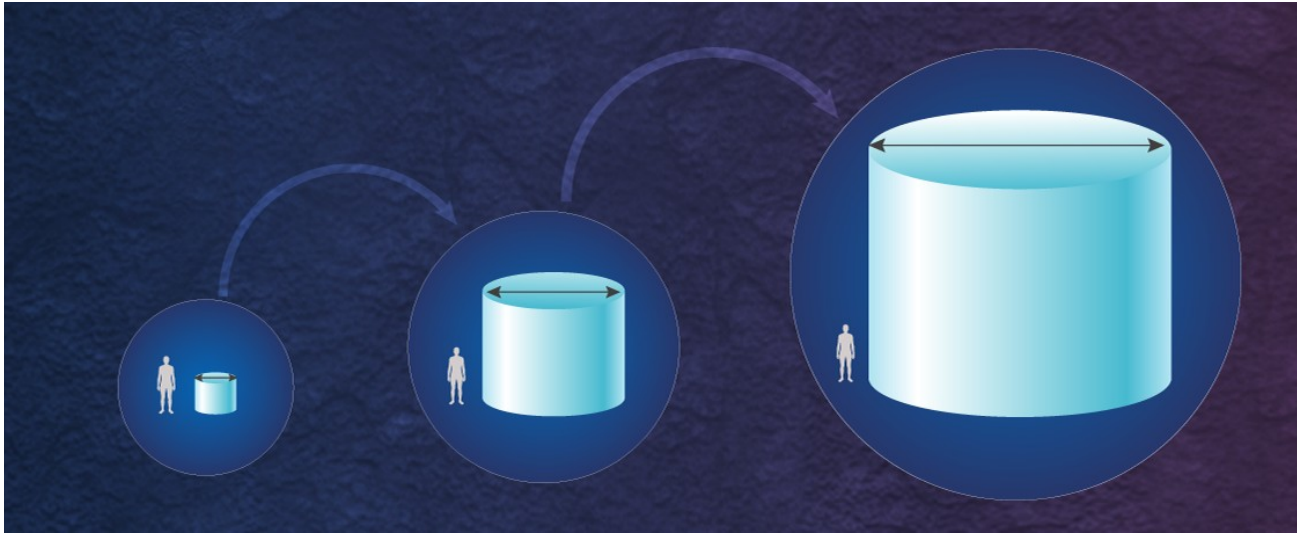
87 nL/L Xenon concentration

Assume ideal gas
29 g/mol for air
136 g/mol for xenon

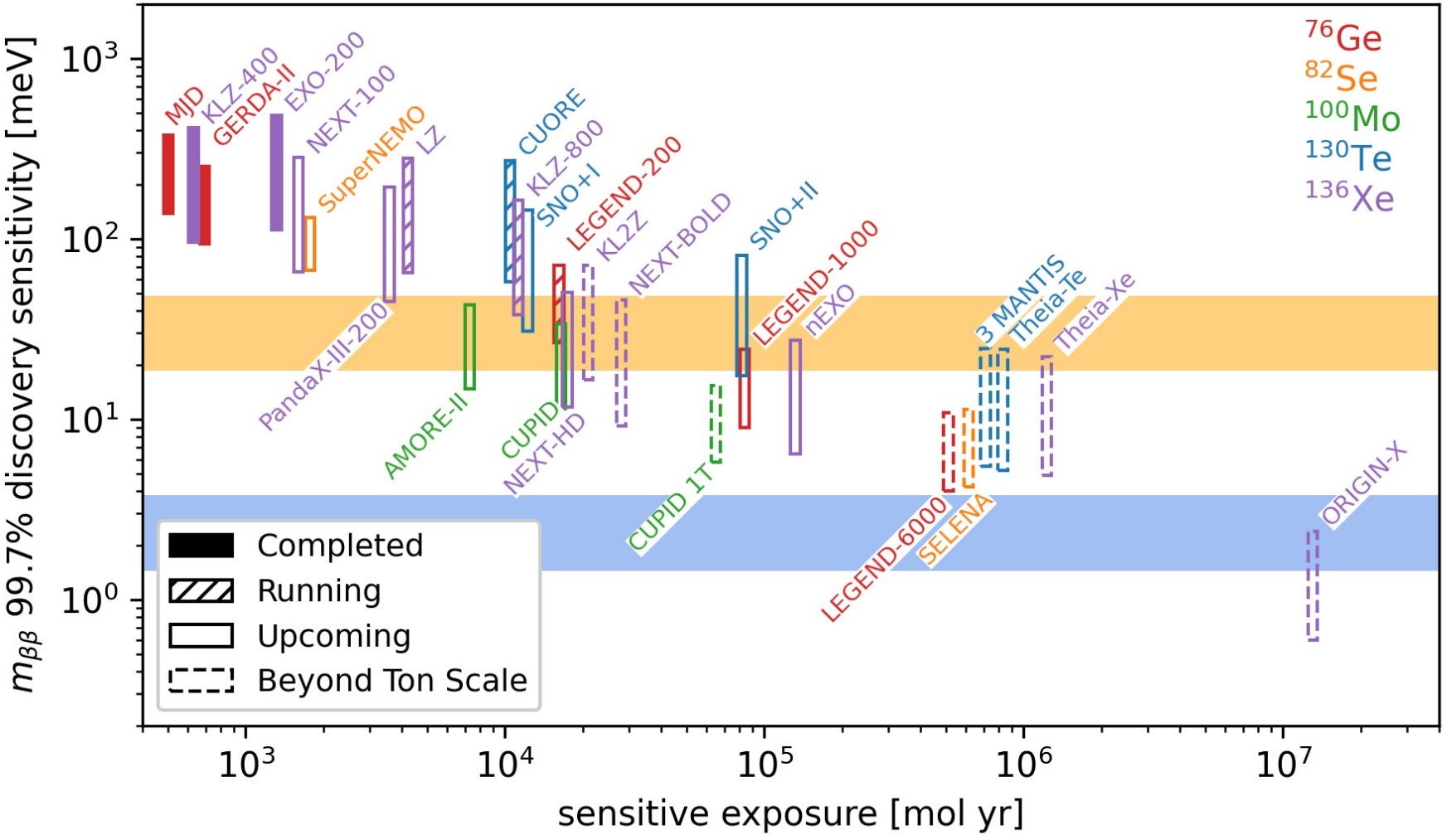
$$5.2\times10^{21}\,g\times\frac{mol}{29\,g}\times\frac{22.4\,L}{mol}\times87\times10^{-9}\frac{L}{L}\times\frac{mol}{22.4\,L}\times\frac{136\,g}{mol}=2122\times10^{12}\,g$$

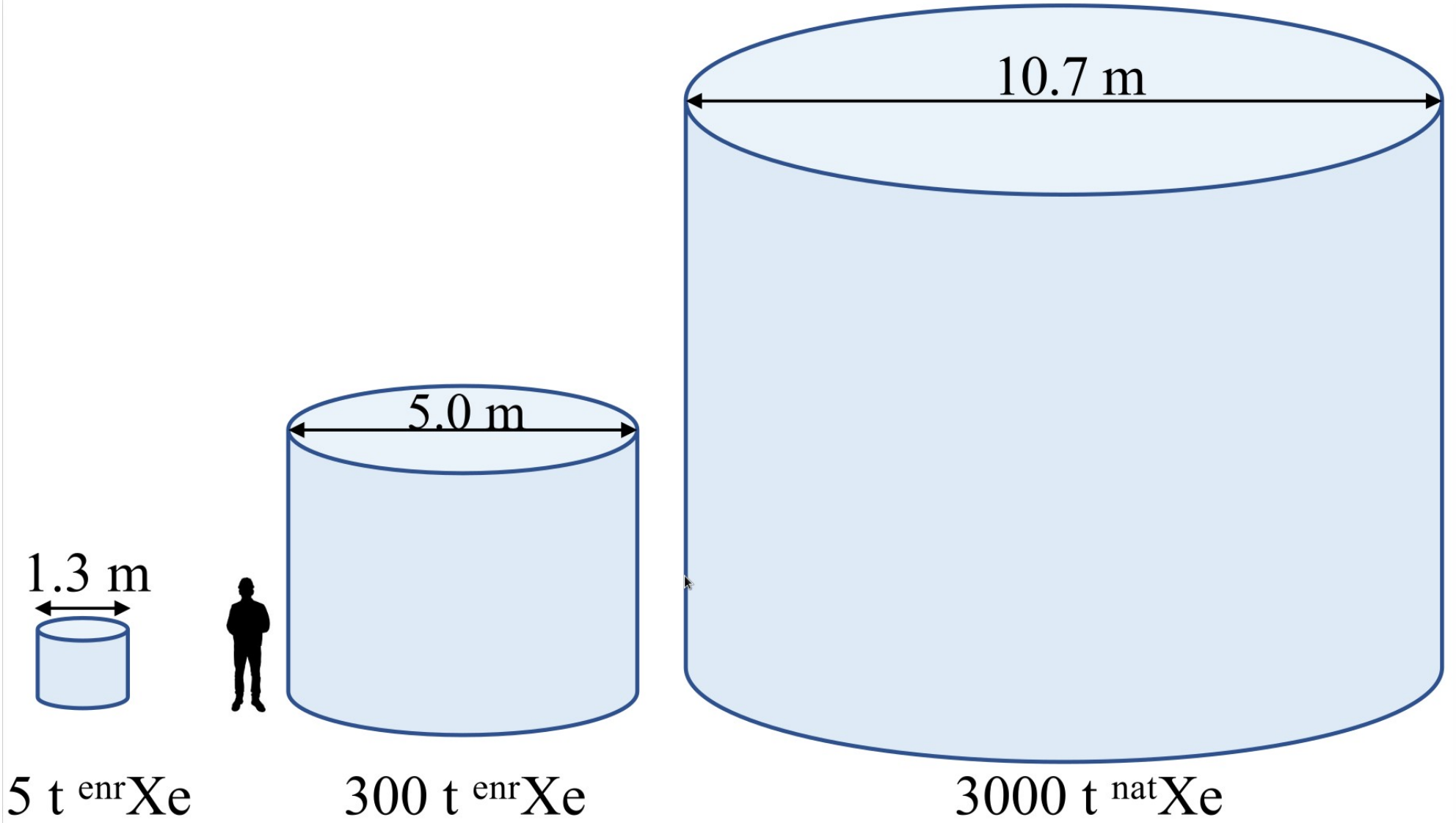
ORIGIN-X

Observing Rare Interactions with a GIaNt Xenon experiment

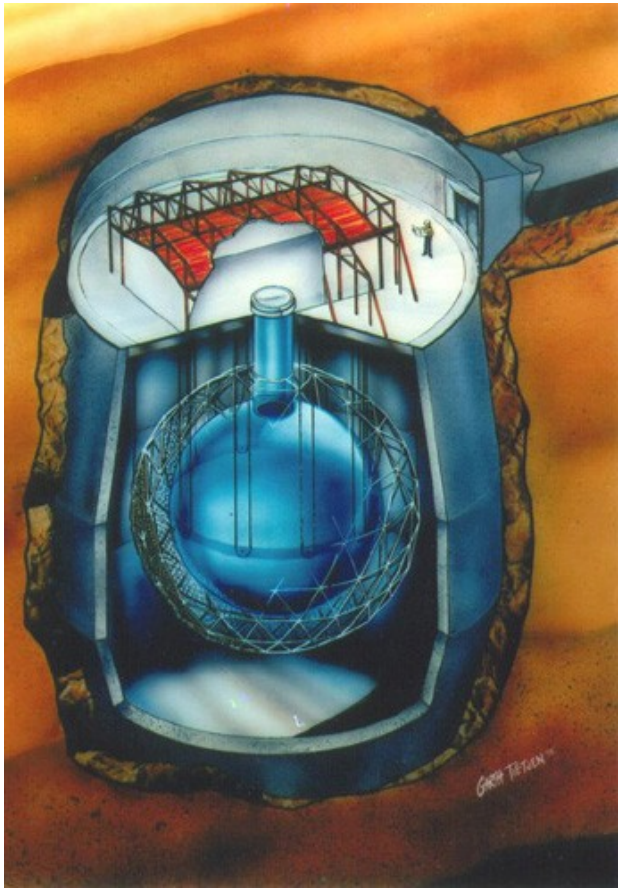


https://origin-x.llnl.gov/


$m_{\beta\beta}$ 99.7% discovery sensitivity [meV]
10^3
10^2
10^1
10^0
10^3
10^4
10^5
10^6
10^7
sensitive exposure [mol yr]
^{76}Ge
^{82}Se
^{100}Mo
^{130}Te
^{136}Xe
MJD
KLZ-400
GERDA-II
EXO-200
NEXT-100
SuperNEMO
LZ
PandaX-III-200
AMORE-II
CUORE
KLZ-800
SNO+I
CUPID
NEXT-HD
LEGEND-200
KL2Z
NEXT-BOLD
CUPID 1T
SNO+II
LEGEND-1000
nEXO
LEGEND-6000
SELENA
3 MANTIS
Theia-Te
Theia-Xe
ORIGIN-X
Completed
Running
Upcoming
Beyond Ton Scale


10.7 m
5.0 m
1.3 m
5 t enrXe
300 t enrXe
3000 t natXe

Cavern size has been demonstrated

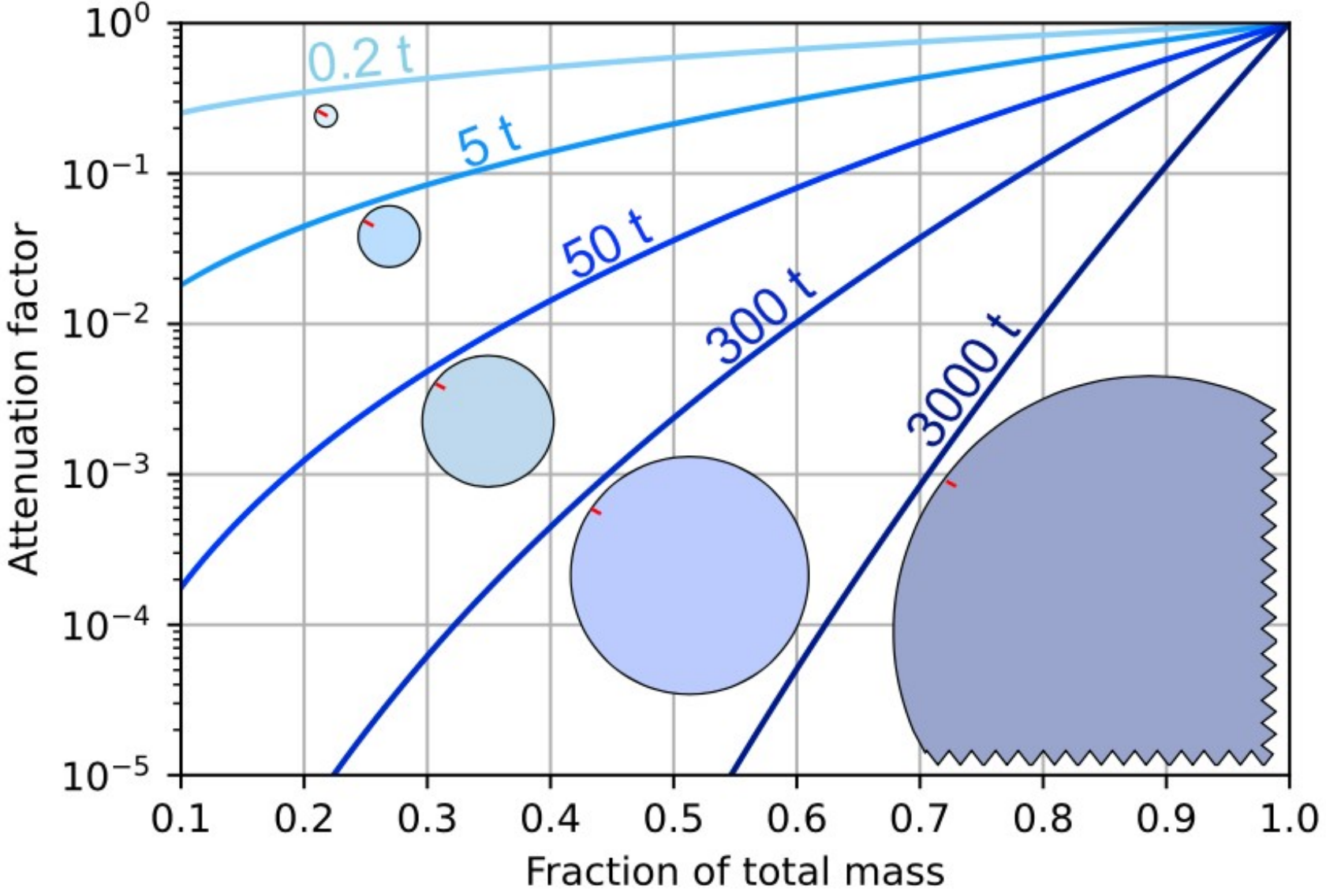


“The detector cavity, 22 metres in diameter and 30 metres high, is the largest cavity at that depth anywhere in the world.” – R. Brewer

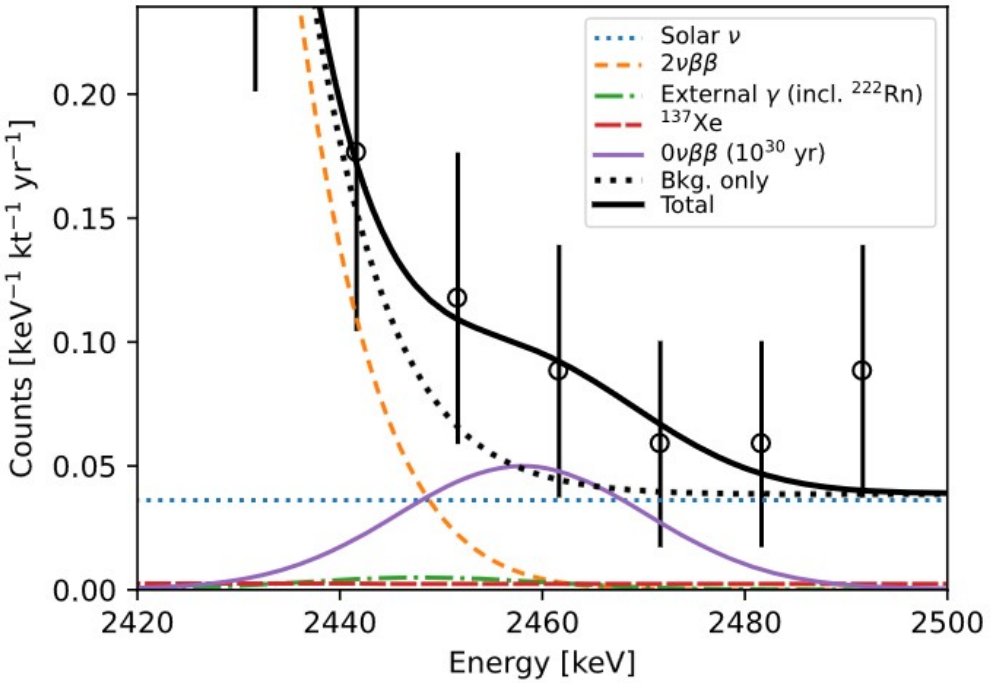
15m dia. 20m tall

SNOLAB Cryopit

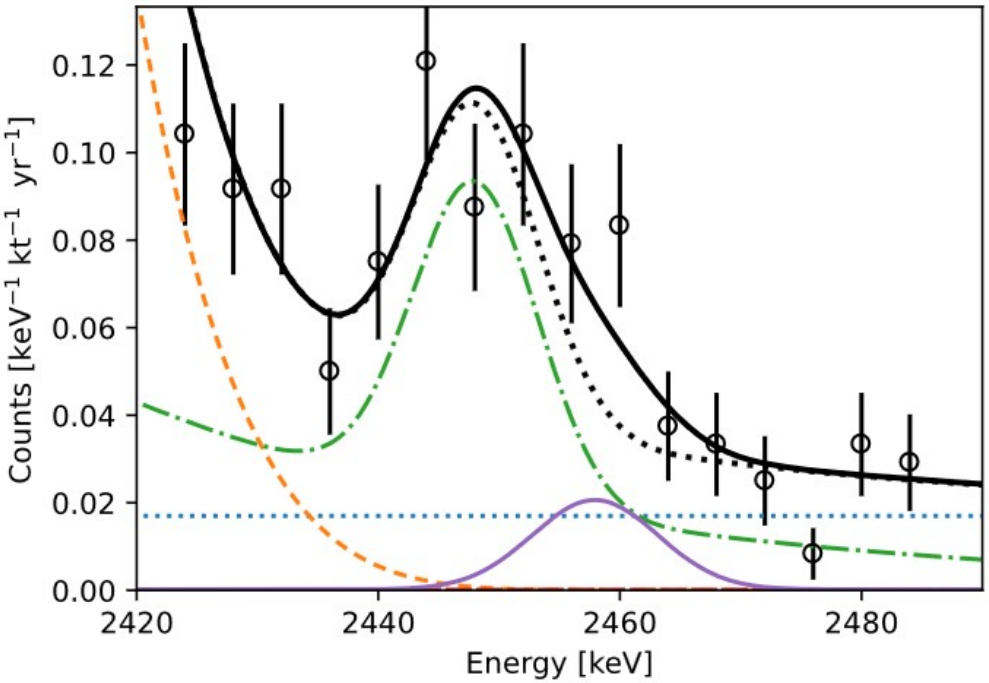
SNO Cavern

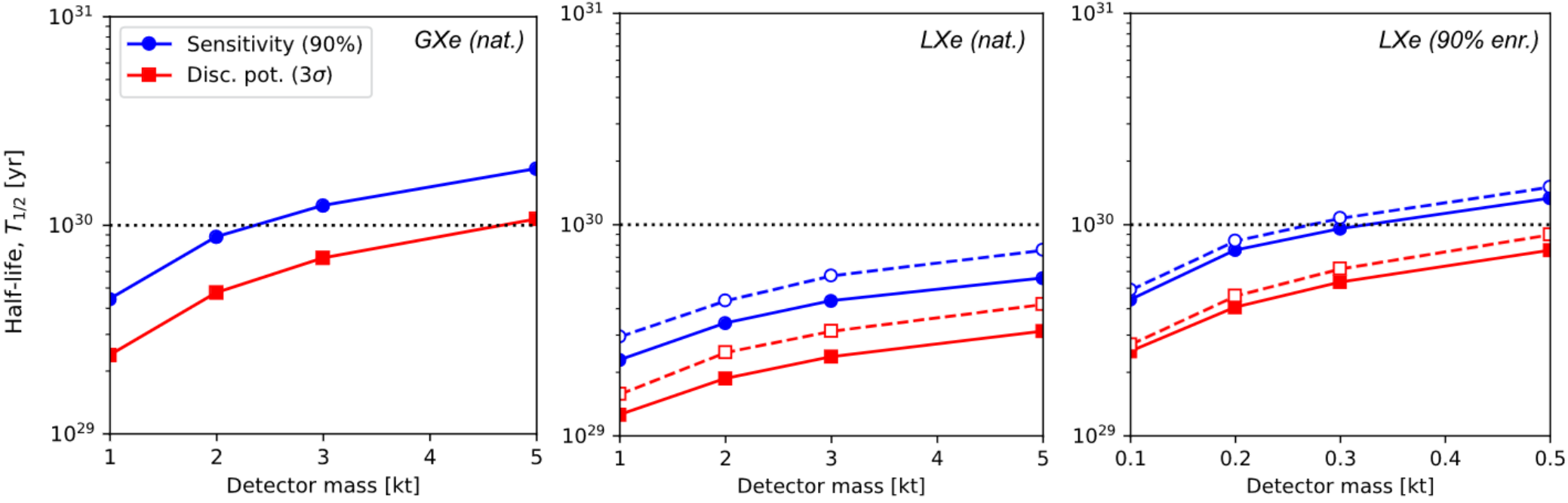

0.2 t
5 t
50 t
300 t
3000 t
Attenuation factor
Fraction of total mass
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

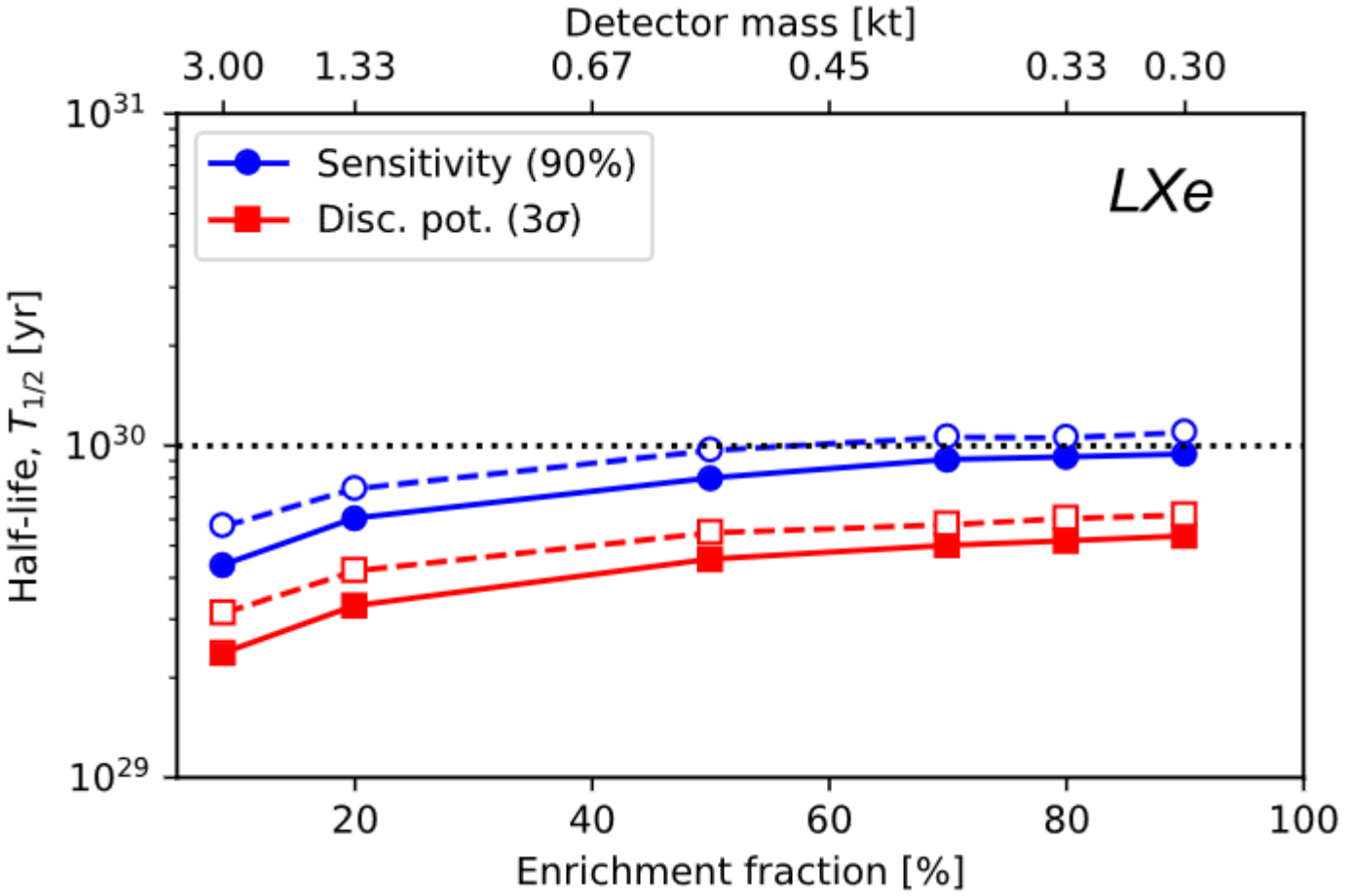
300T enriched Liquid Xenon



3kT natural Gas Xenon




Sensitivity (90%)
Disc. pot. (3σ)
GXe (nat.)
LXe (nat.)
LXe (90% enr.)
Half-life, $T_{1/2}$ [yr]
10^{31}
10^{30}
10^{29}
1
2
3
4
5
0.1
0.2
0.3
0.4
0.5
Detector mass [kt]


Detector mass [kt]
3.00
1.33
0.67
0.45
0.33
0.30
10^{31}
10^{30}
10^{29}
Sensitivity (90%)
Disc. pot. (3σ)
LXe
Half-life, $T_{1/2}$ [yr]
20
40
60
80
100
Enrichment fraction [%]

Detector technology			Isotope acquisition	External backgrounds	Internal backgrounds	Energy resolution ($2\nu\beta\beta$)	Isotope mass fraction (solar ν)	Detector technology maturity (kton scale)
Segmented detectors								
	HPGe		?	✗	?	✓	✓/?	✗
	Bolometers		✓/?	✗	?	✓	✓/?	✗
	Tracking/CCDs	Se based	✓	?/✗	?	✓	✓	✗
Monolithic detectors								
	Liquid scintillator	Te doped	✓	✓	?	✗	✗	✓
		Xe doped	✗	✓	✓	✗	✗	✓
	TPCs	Gas Xe	✗	✓	✓	✓	✓	✓/?
		Liquid Xe	✗	✓	✓	✓	✓/?	✓
		Xe doped Ar	✗	✓	✗/?	✗/?	✗	✓
		SeF_6 (ion drift)	✓	✓	?	?	✓/?	✗

Continuing the story in the next talks

Material science R&D
for xenon capture

Extracting xenon from the atmosphere
at low cost and high volume.

Summary

- It is plausible to build a ~ktonne 0vBB detector
- Xenon acquisition is the key challenge
- Adsorption development is likely a breakthrough R&D path (TSA+MOF+structured bed)
- More details in arXiv paper: http://arxiv.org/abs/2110.01537

END