Shielding/Water Tank

November 13, 2025
Hugh Lippincott
(borrowing liberally from Sally Shaw, Brian Lenardo, Scott Haselschwardt, Gabriel Orebi Gann, among many others)

Also see Teena John on cosmic veto from yesterday

UCSB

Why Shielding/Water Tank

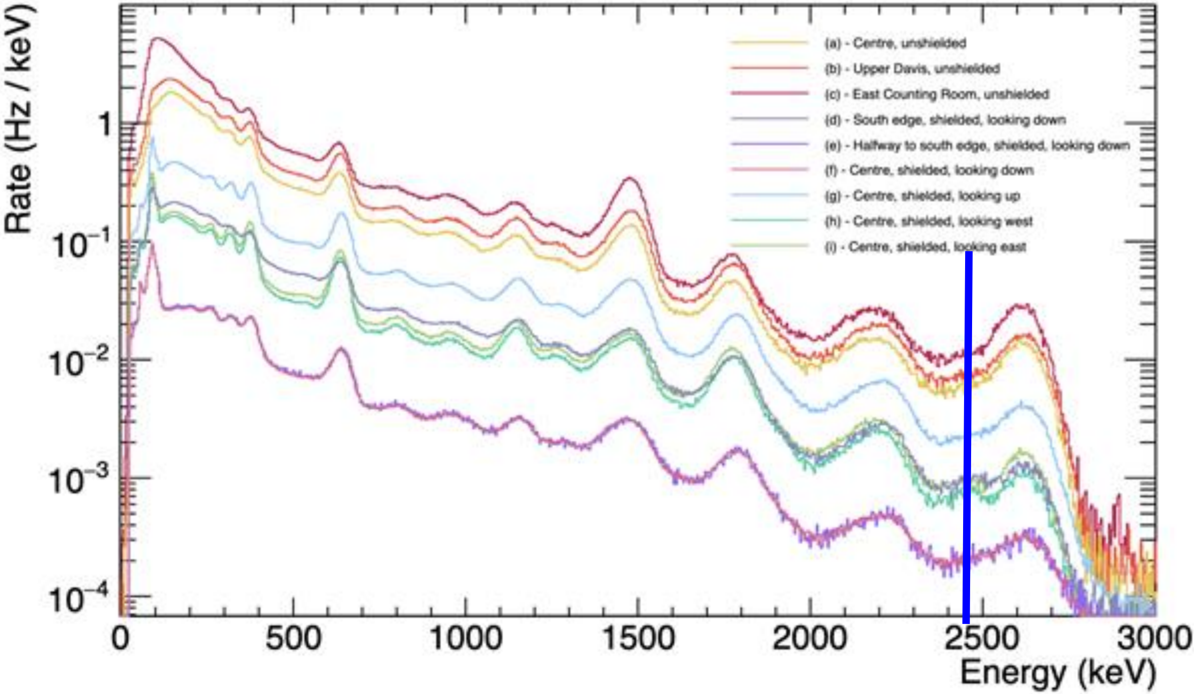
- Background Mitigation

Why Shielding/Water Tank

- Background Mitigation
    a. Shielding - mainly from the lab environment
        - Both gammas and neutrons

Gamma mitigation

- E.g. Gamma ray backgrounds in Davis Cavern at SURF (measured with 1.6 kg NaI)
- Top line is unshielded
- Bottom line is with 8” of lead shielding
- Radon in air present throughout



- To reach nEXO sensitivity, need something like ~1e10 reduction at Q value

From 1904.02112

Neutron mitigation

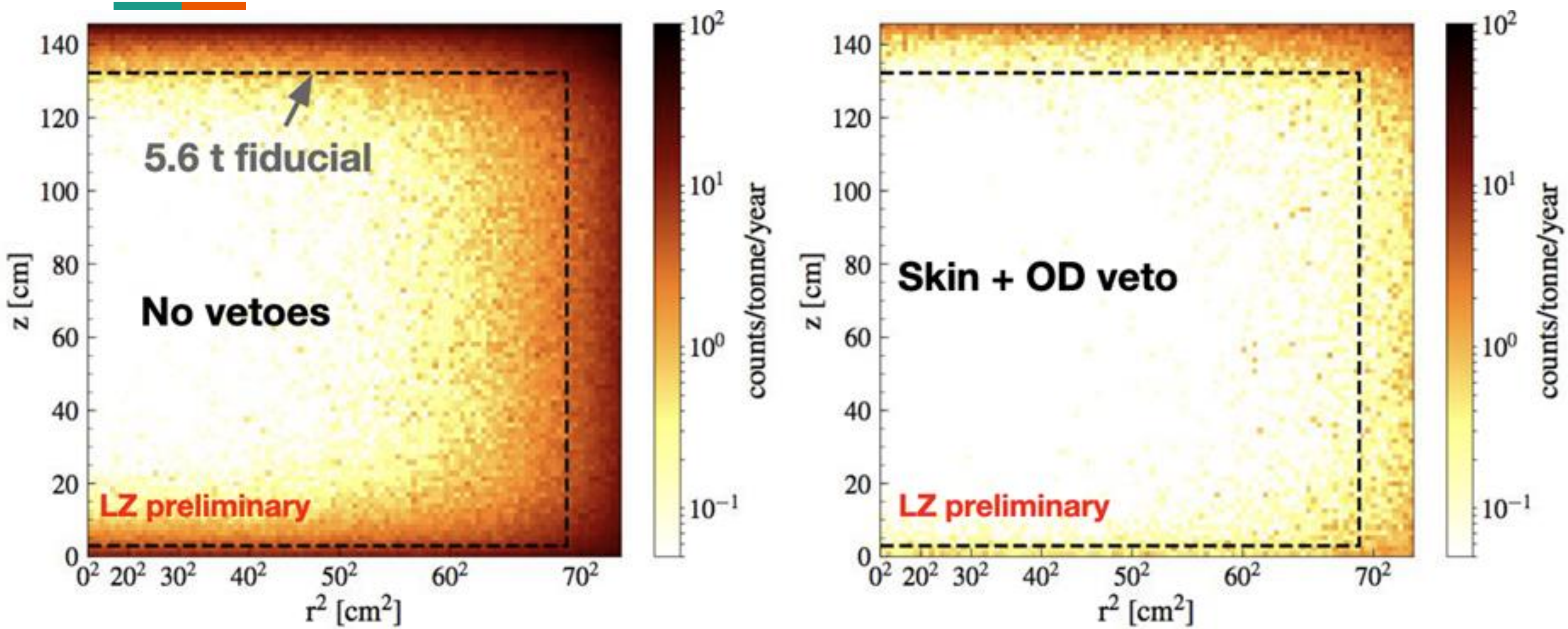
- E.g. Neutron flux in SNOLAB is ~4000 fast and 4000 thermal neutrons/m^2/d*
  - (This is just a lot of neutrons, although 1000 times less than surface)
- For DM experiments, goal is <1 neutron interaction per exposure.
  - E.g. XENONnT has a surface area of 10 m^2
  - ~1e10 neutrons traversing the detector per year (if it were in SNOLAB)
- Thermal neutrons lead to capture induced gammas
  - E.g. ^{16}O(n, gamma)^{17}O with 3.2 MeV gamma
  - E.g. ^{16}O(n, p)^{16}N with 6.17 gamma
  - Iron, nickel, chromium (and Gd) have capture lines in 7-9 MeV range

*SNOLAB Technical Reference Manual

Why Shielding/Water Tank

- Background Mitigation
  a. Shielding - mainly from the lab environment
     - Both gammas and neutrons
  b. Active veto
     - Tag events that scatter in the central detector

Active Veto

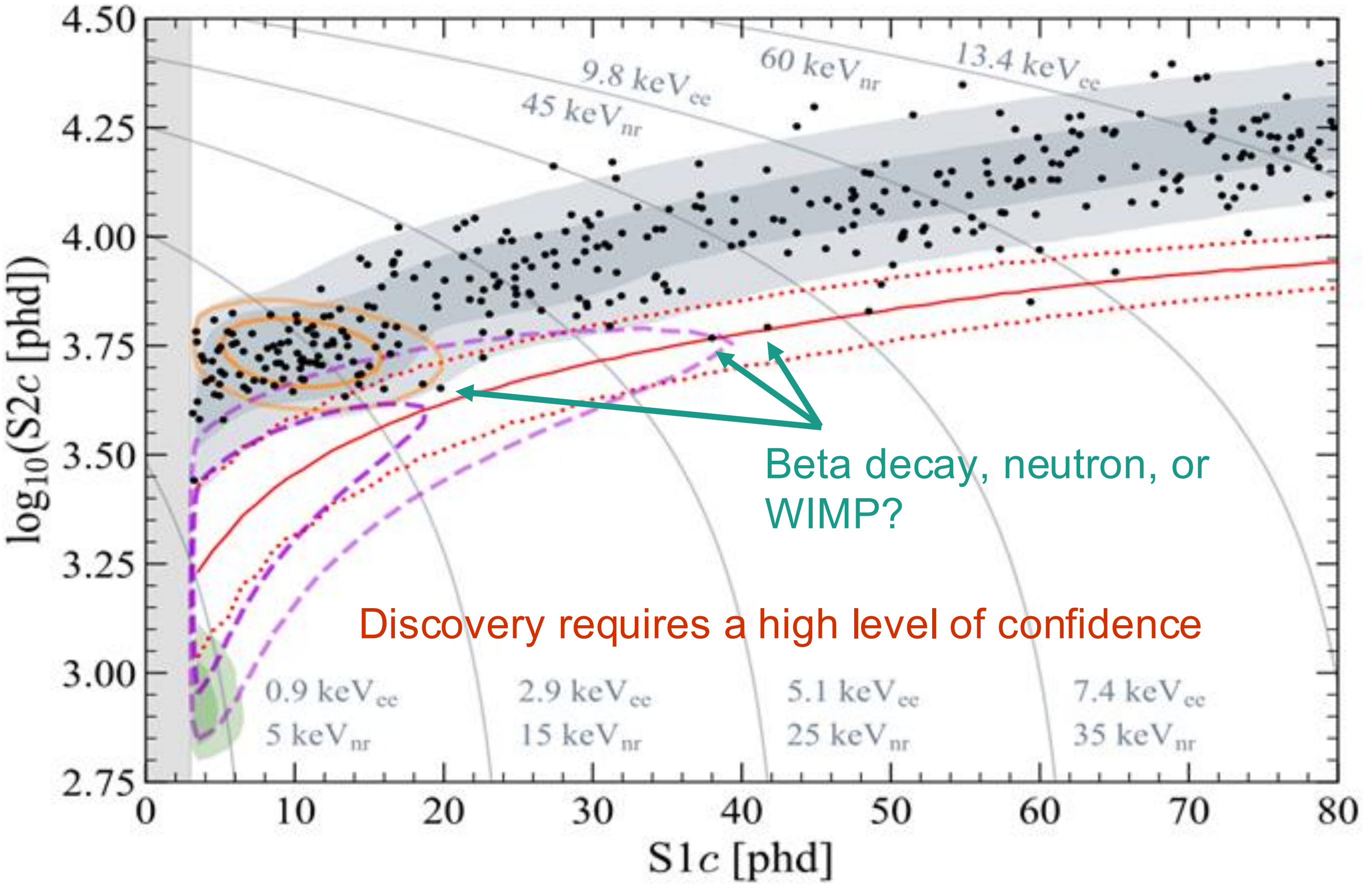


- Example: LZ expands fiducial volume by 2.3 tonnes (out of 5.5) with active veto of gamma rays and particularly neutrons

Why Shielding/Water Tank

- Background Mitigation
  a. Shielding - mainly from the lab environment
     - Both gammas and neutrons
  b. Active veto
     - Tag events that scatter in the central detector
  c. Vibes...

Vibes...



Beta decay, neutron, or WIMP?

Discovery requires a high level of confidence

Elements of Shielding/Water Tank

- Passive shielding - e.g. Super CDMS (Jack Nelson, DPF 2021)

Design of Shield

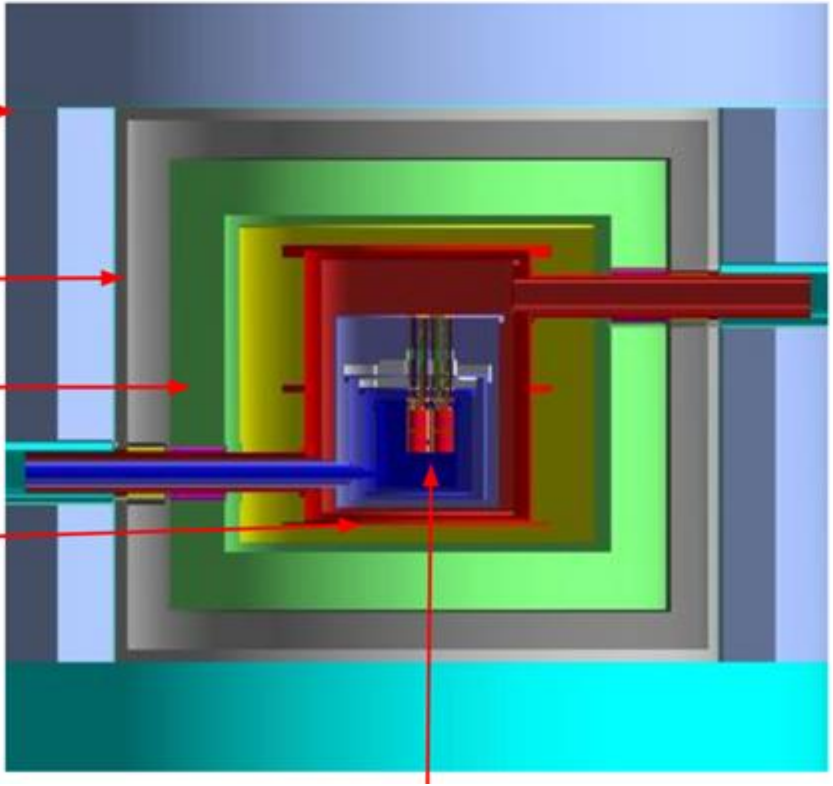
Outer neutron shield
- 60 cm of water in stainless steel tanks + high density polyethylene base
- Reduces MeV neutrons from cavern wall by 10^6

Gamma shield
- 23 cm lead. Inner layer is cleaner
- Reduces MeV gammas from cavern wall by 10^5

Inner neutron shield
- 40 cm high density polyethylene
- Reduces GeV neutrons induced by muons in cavern or shield by 100

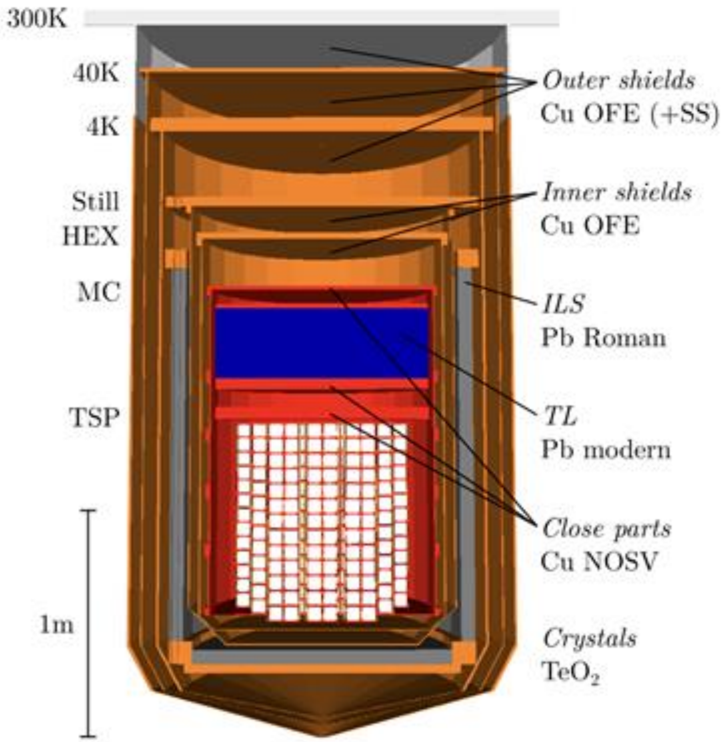
Cryostat
- Shielding is secondary function, but few cm Cu provides modest gamma reduction

Layered design provides complimentary shielding from environmental neutrons and gammas



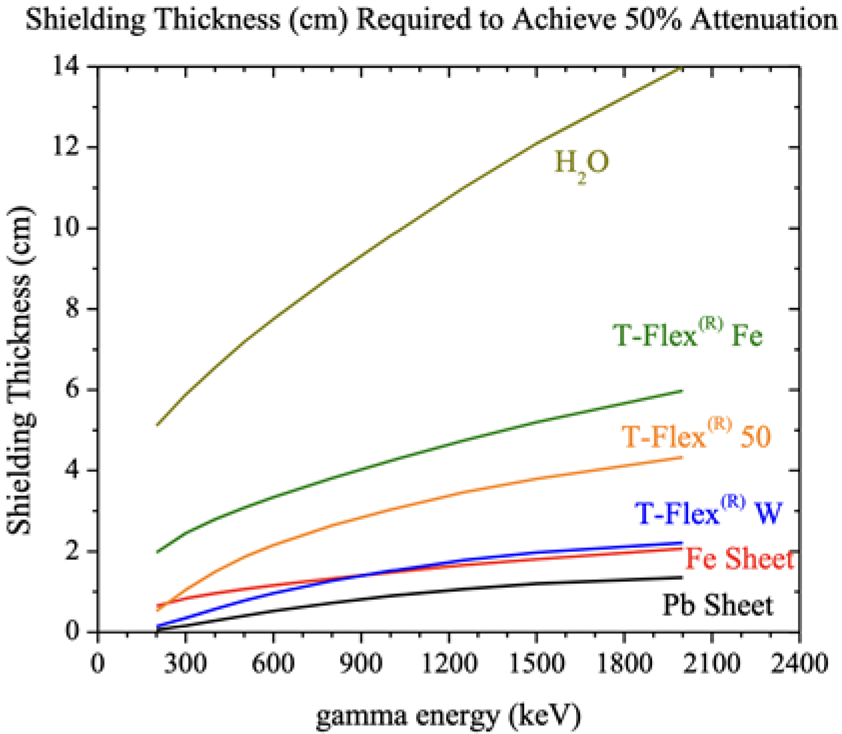
Elements of Shielding/Water Tank

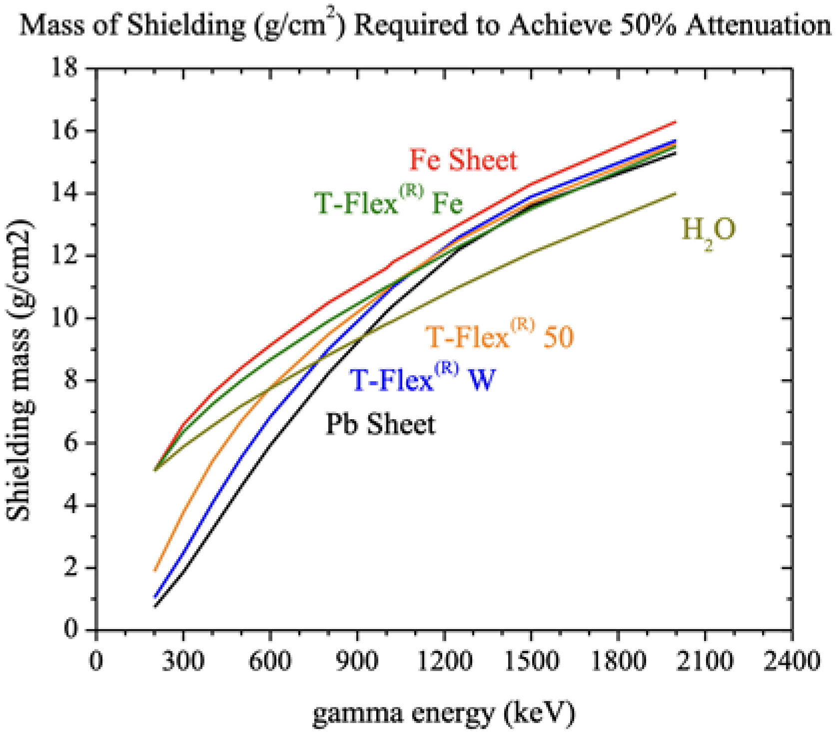
- Passive shielding - e.g. CUORE (PRD 110, 052003)
  - External lead shield and poly+boric acid
  - Copper
  - Lead (modern and ancient
  - Copper again (also for thermal shielding)



Elements of Shielding/Water Tank

- Passive shielding - why not just water?

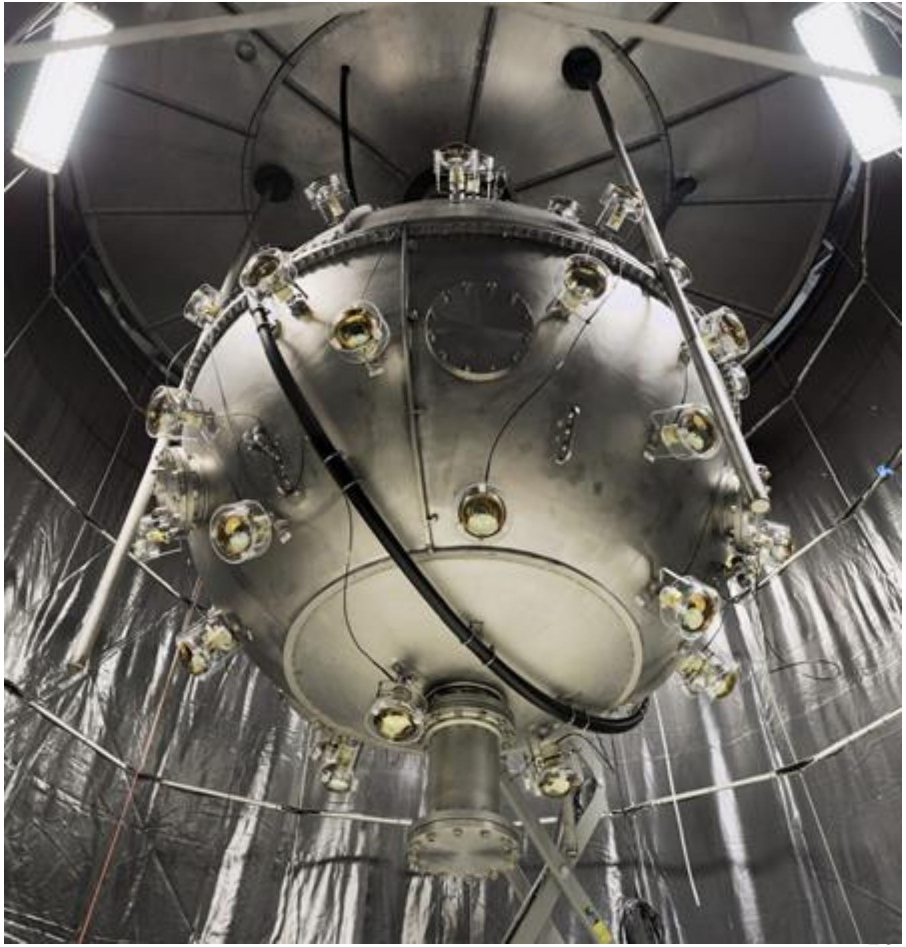




McAlister Tech note

Elements of Shielding/Water Tank

- If using water, why not instrument it? -> Active shielding
  - E.g. DEAP-3600 in its water tank
  - Note the outward facing PMTs



Elements of an Active Veto

- Detection medium
    a. Water (e.g. many)
    b. Water with Gd for thermal neutron capture (e.g. XnT)
    c. Water based liquid scintillator
    d. Liquid scintillator or LS
    e. Gd-LS (e.g. LZ)
    f. Liquid xenon (“skin”)
    g. Liquid argon (e.g. LEGEND, DarkSide)
    h. …

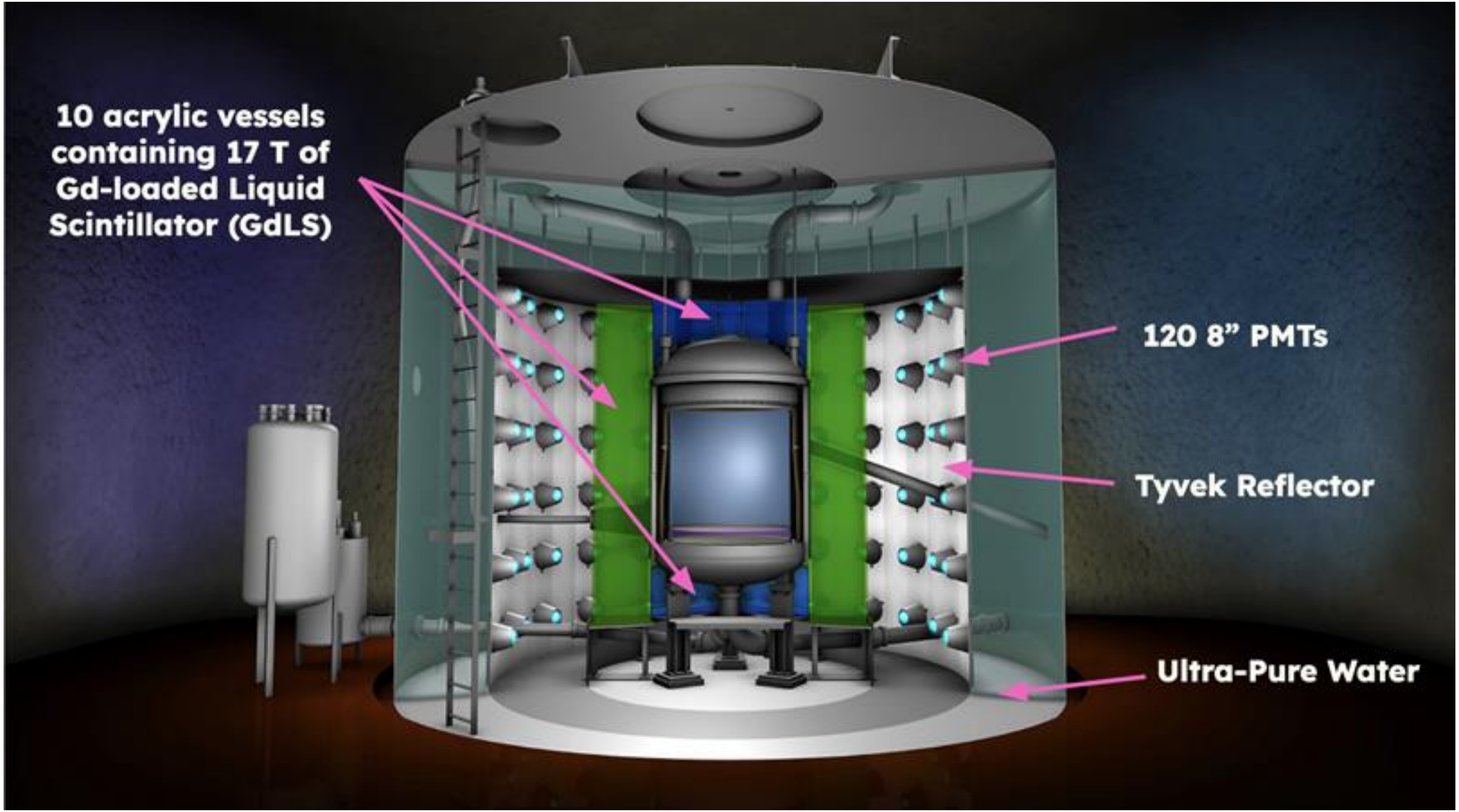
Elements of an Active Veto

- Containment
    a. Steel
    b. Steel with tyvek or other reflector
    c. Acrylic (for LS)
    d. ...
- Light collection
    a. PMTs most common
    b. SiPMs (e.g. DS-20k)
    c. Wavelength shifting fibers to SiPMs (e.g. LAr in LEGEND)
    d. ...

Considerations

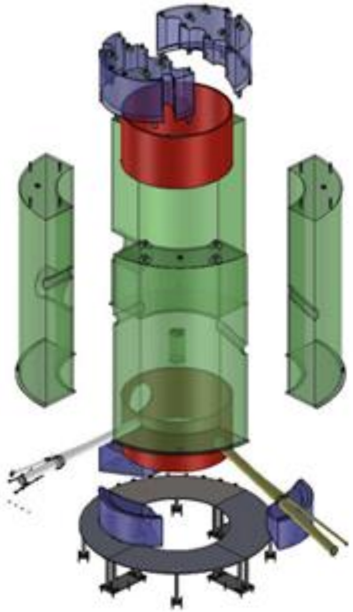
- Size
  a. Factor 1e10 reduction in ~2.5 MeV gammas takes ~5 meters of water in all directions
  b. Immediately drives a ~12x12 m water tank (need space for the actual detector)
- Ease of fabrication
  a. Big steel tanks are relatively straightforward
  b. Acrylic tanks less so (especially if they are sealed)
- Medium vs light collection
  a. Trade light yield (e.g. LS vs. water) for additional light sensors
  b. How much to instrument?
  c. Reflector?

Some designs - LZ



Some designs - LZ

- LZ water tank is a bit small (7.6 m x 5.9 m with 238 tonnes of water)
- 10 acrylic vessels that fit together around the detector
    a. Driven by cost considerations

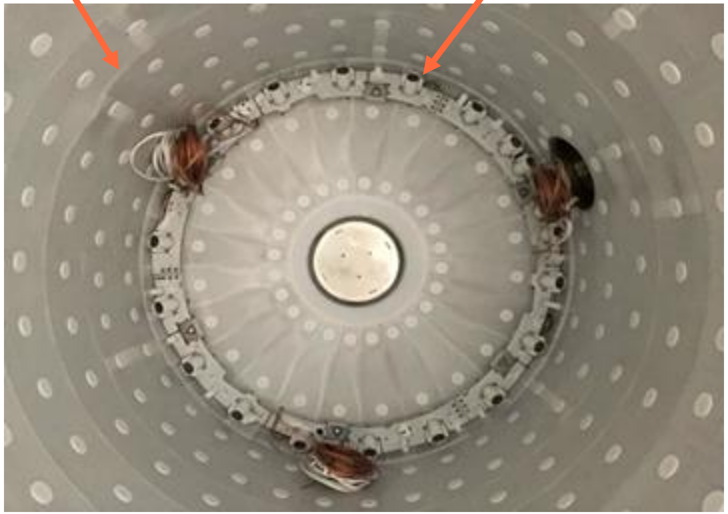


Some designs - LZ

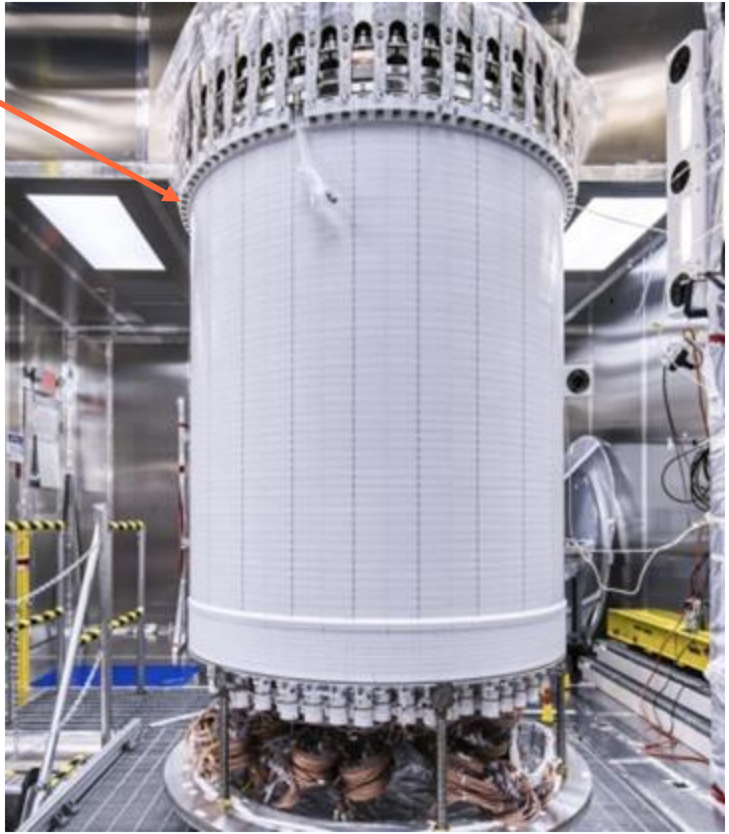
- 2 tonnes LXe skin

PTFE reflector

38 2” PMTs



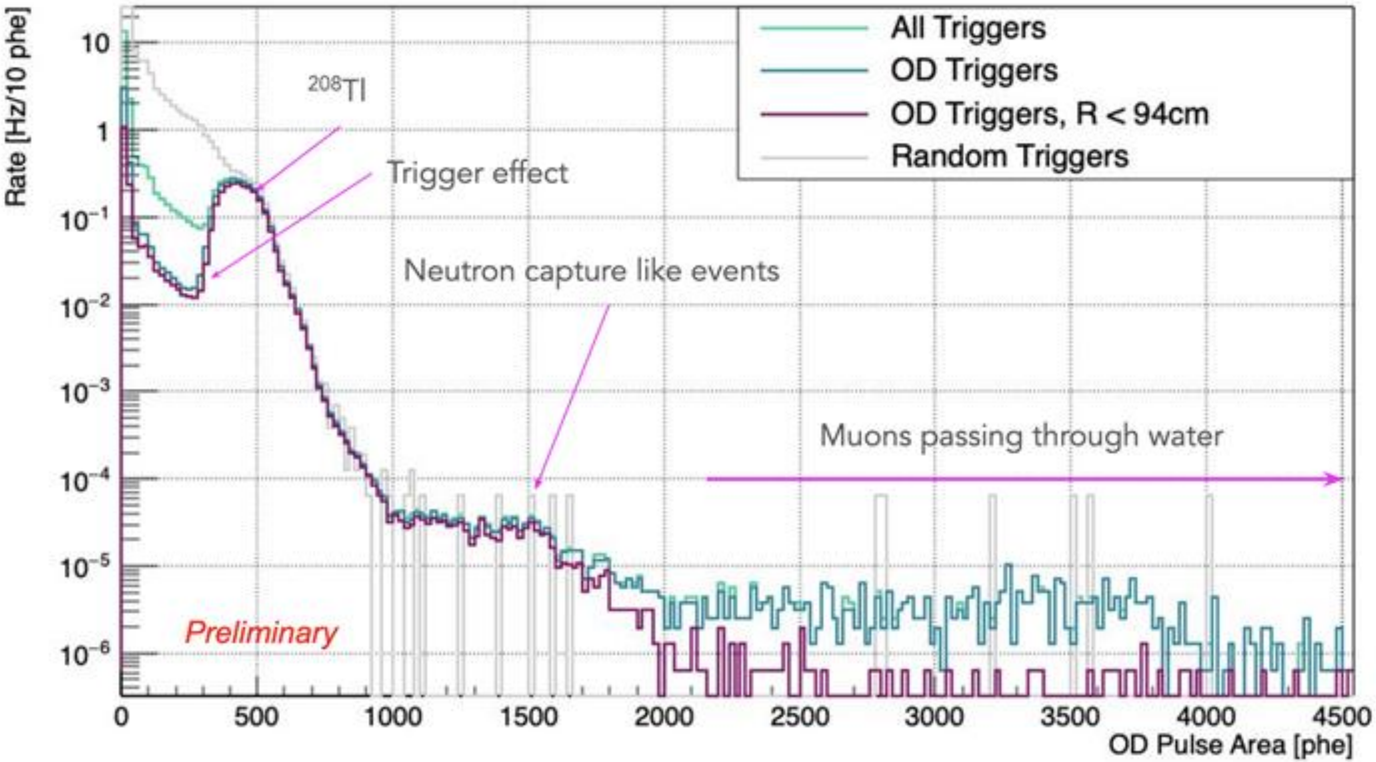
93 1” PMTs



Some designs - LZ

- Low veto threshold required (~150-200 keV in OD, 100 keV in skin)
  - Maximize veto efficiency - the vessels are too thin to contain 2.2 MeV gammas let alone 8.5 MeV endpoint of Gd capture
  - In turn requires high light yield (>80 pe/MeV)
- Minimize OD background rate (<100 Hz) to minimize livetime loss in WIMP search
  - Accidental veto in OD from backgrounds is deadtime
  - Drives standoff from steel tank to Tyvek curtain
  - Drives GdLS radiopurity requirement
  - Drives PMT/support structure radiopurity requirement

Some designs - LZ



Higher than expected (x100) n capture rate

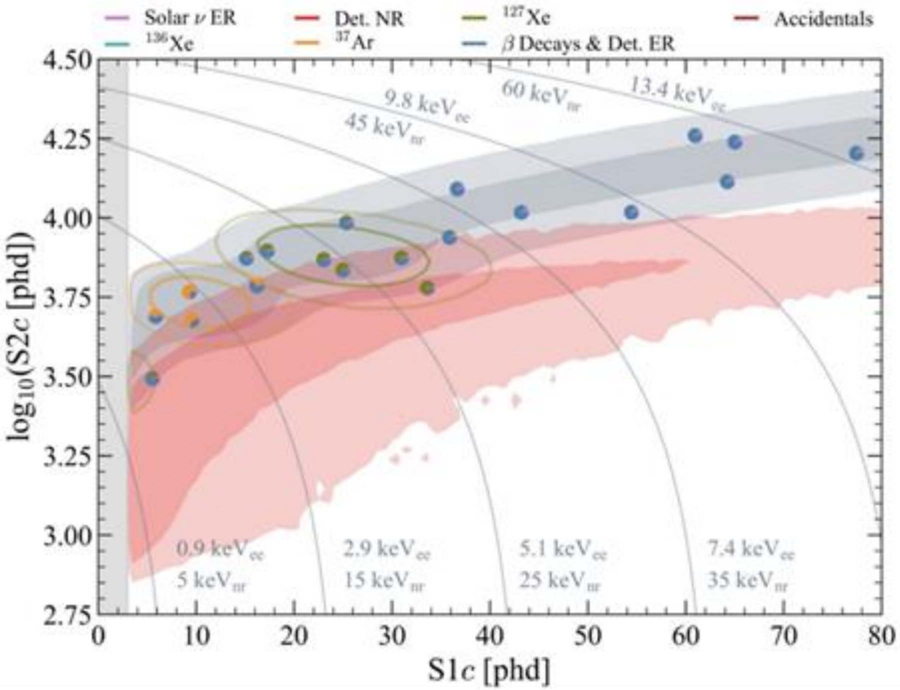
Partly (at least 50%) due to cavern neutrons capturing on water tank walls

Some designs - LZ

- OD+skin used to directly constrain neutron rate as a sideband in WIMP search
- Measured ~92% neutron tagging efficiency with 3% dead time

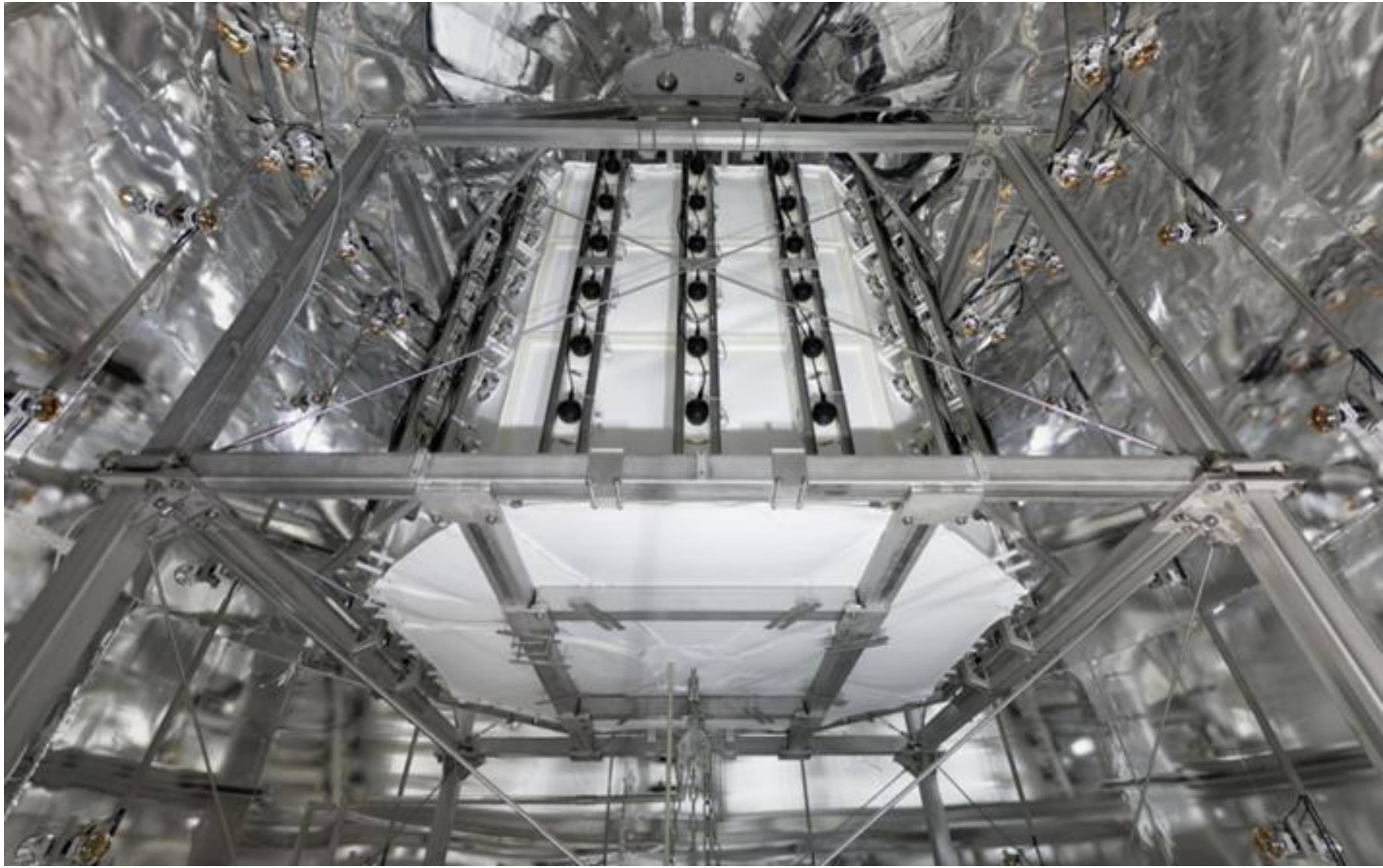
Source	Pre-fit Expectation	Fit Result
^{214}Pb βs	743 ± 88	733 ± 34
^{85}Kr + ^{39}Ar βs + det. γs	162 ± 22	161 ± 21
Solar ν ER	102 ± 6	102 ± 6
^{212}Pb + ^{218}Po βs	62.7 ± 7.5	63.7 ± 7.4
Tritium+ ^{14}C βs	58.3 ± 3.3	59.7 ± 3.3
^{136}Xe $2\nu\beta\beta$	55.6 ± 8.3	55.9 ± 8.2
^{124}Xe DEC	19.4 ± 2.5	20.4 ± 2.4
^{127}Xe + ^{125}Xe EC	3.2 ± 0.6	2.7 ± 0.6
Accidental coincidences	2.8 ± 0.6	2.6 ± 0.6
Atm. ν NR	0.12 ± 0.02	0.12 ± 0.02
^{8}B+hep ν NR	0.06 ± 0.01	0.06 ± 0.01
Detector neutrons	[a] $0.0^{+0.2}$	$0.0^{+0.2}$
40 GeV/c^2 WIMP	–	$0.0^{+0.6}$
Total	1210 ± 91	1202 ± 41

[a] The expected number of neutron events results from a fit to the sample of veto detector-tagged events. This expectation is not explicitly used in the final combined fit as this sample is included directly in the likelihood, as described in the text.



Some designs - XENONnT

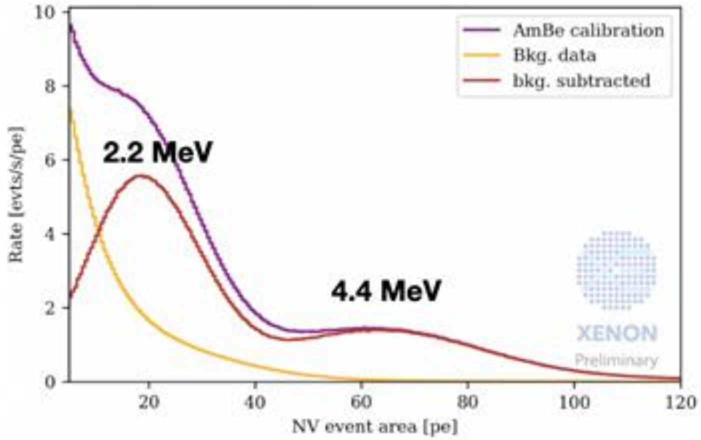
- 9.6 x 10.2 m (700 tonnes total)
- 33 tonne inner water region around cryostat separated by PTFE
- Now loaded with Gd

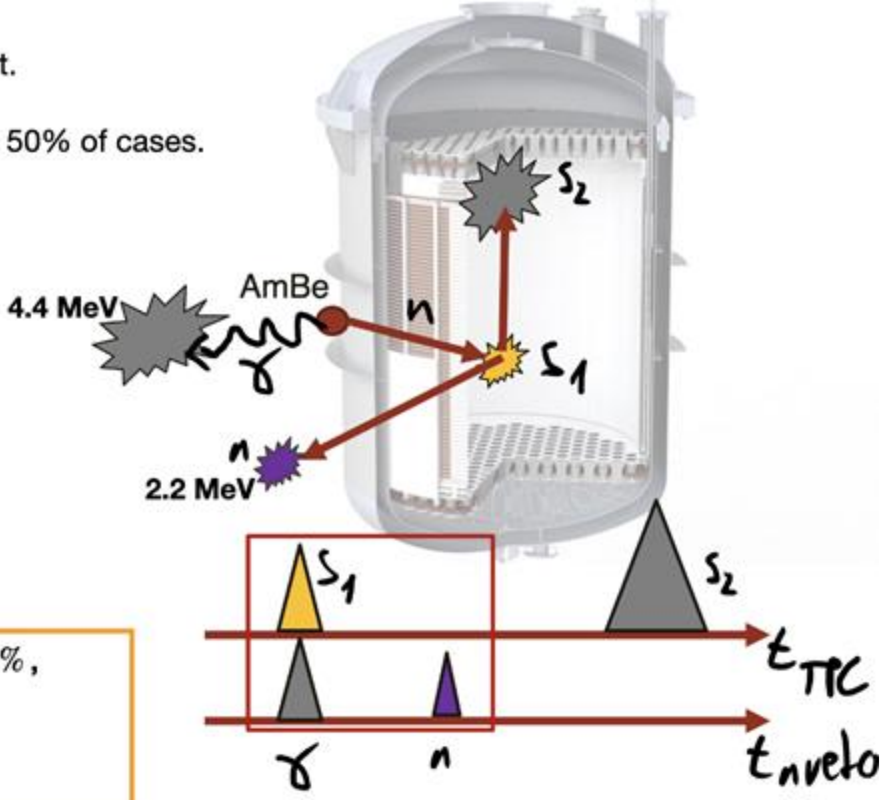


Some designs - XENONnT

- Neutron calibration with AmBe source placed close to the cryostat.

- AmBe emits a 4.4 MeV gamma together with the neutron in about 50% of cases.



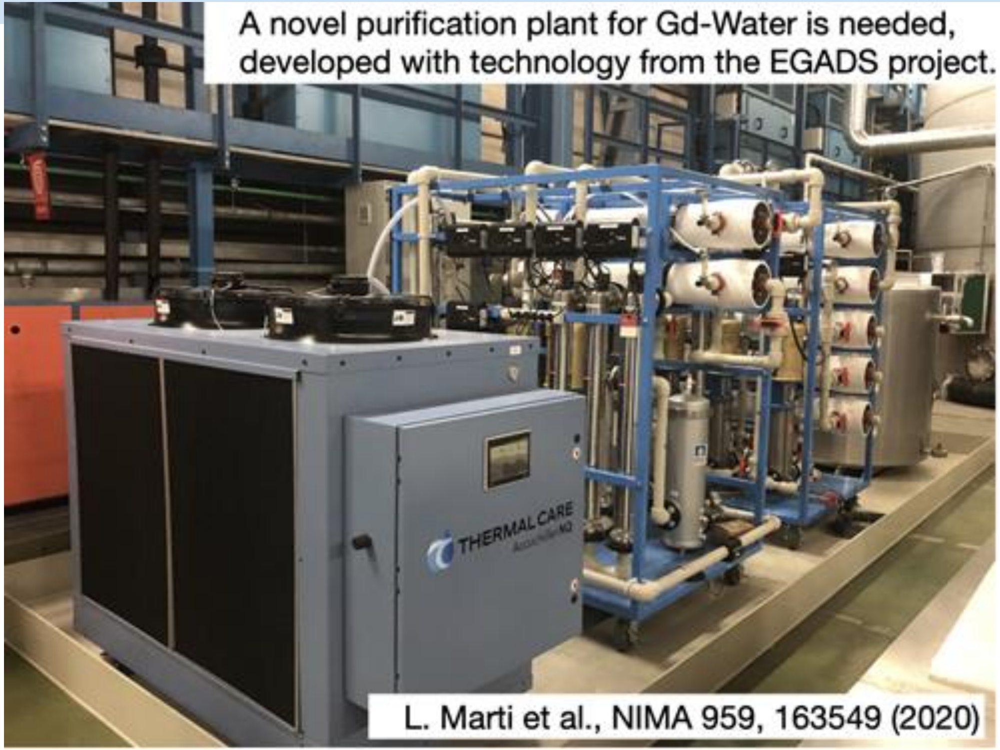


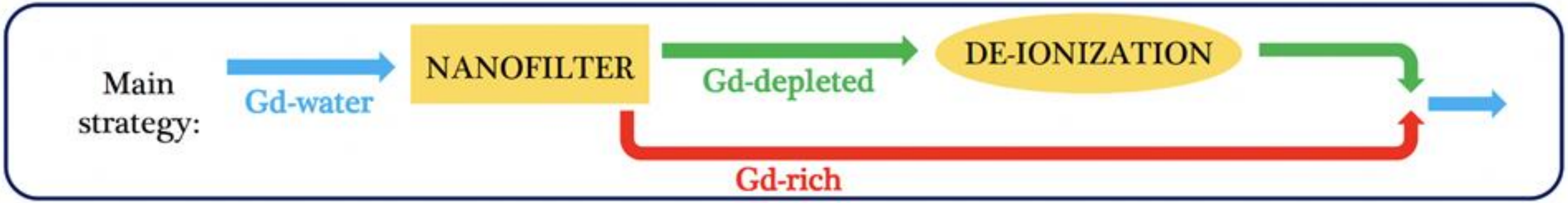
The neutron tagging efficiency in a 250 us window is $(53 \pm 3)\,\%$**,**
with a live-time loss is 1.6%
(the best ever obtained in a water Cherenkov detector)

Paper submitted to EPJ-C, https://arxiv.org/abs/2412.0526

Some designs - XENONnT

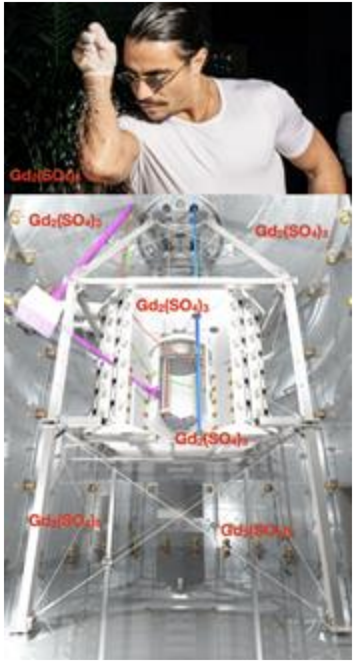
- Add Gd-Sulphate-Octahydrate salt at 0.02% Gd concentration
- Improve neutron tag by factor of 2
- See M. Selvi, DRD2 meeting

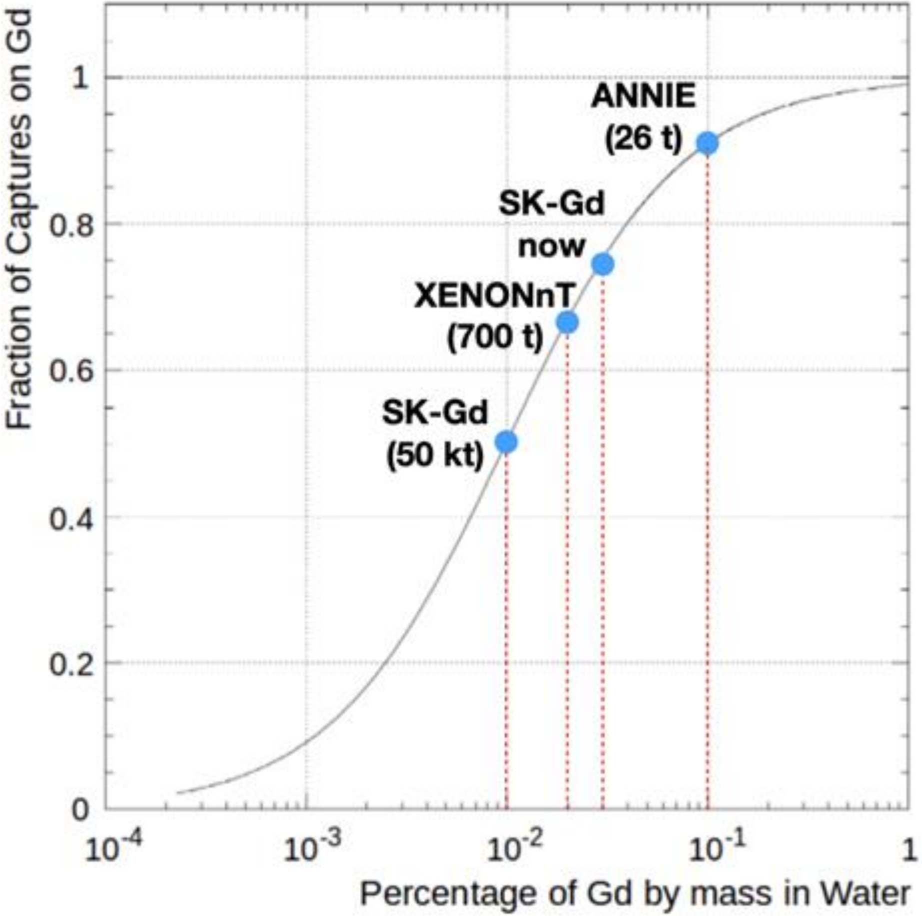




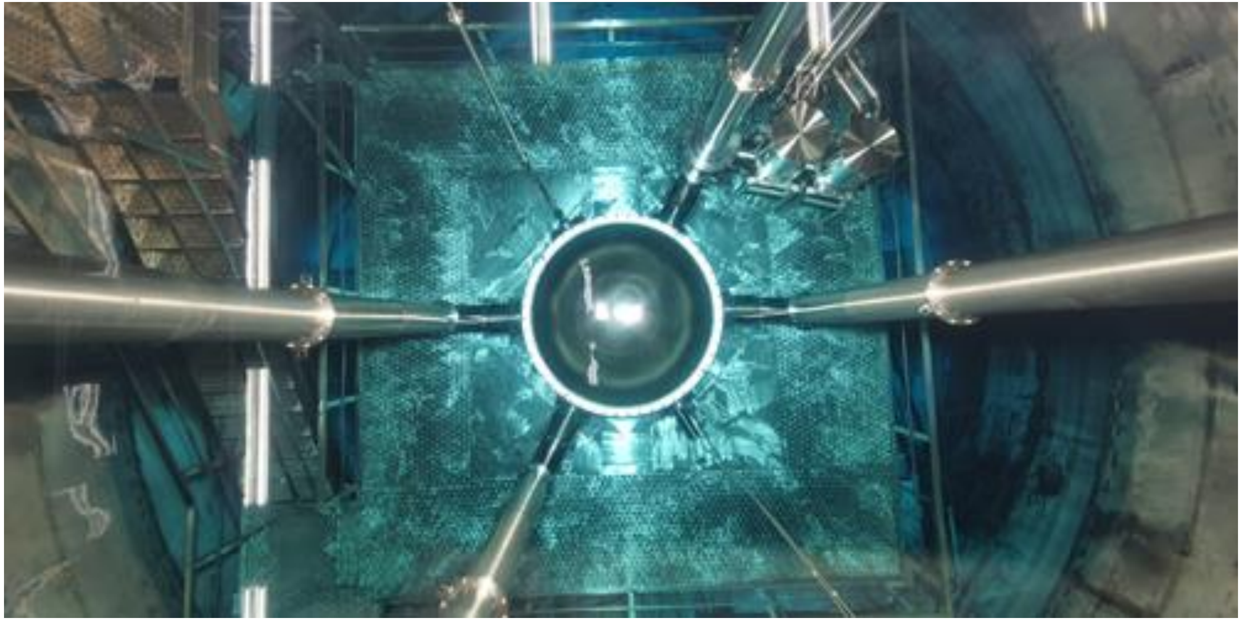
Some designs - XENONnT

- Goal to increase Gd concentration
- Plans for recovery at end of run





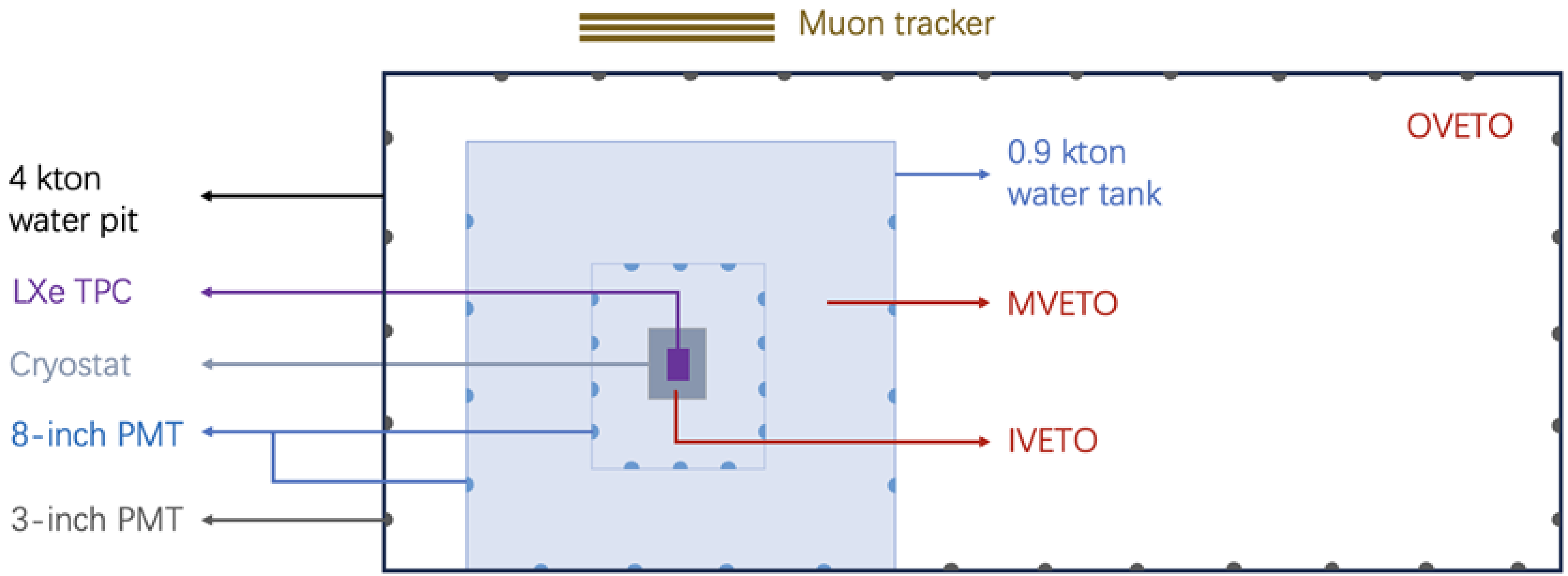
Some designs - PandaX



- In PandaX-4T, just a very big tank - 10m x 13m with 900 tonnes of water

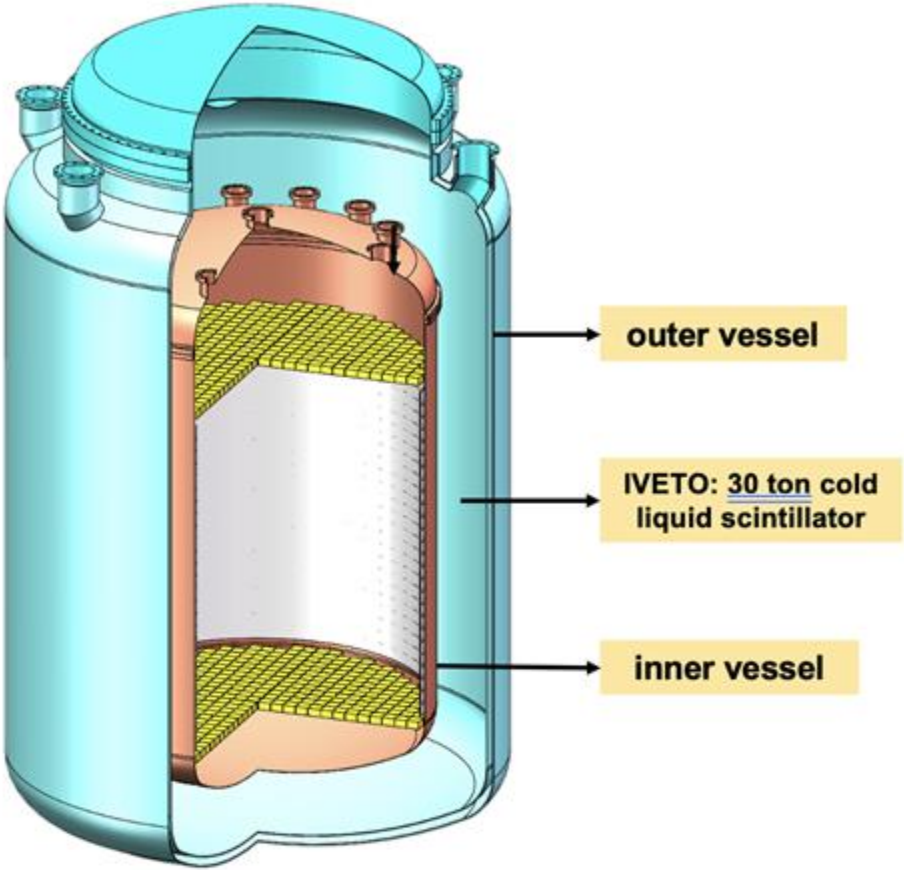
Some designs - PandaX-xT

- MVETO: 0.9 kton water Cherenkov detector (currently running)
- OVETO: 4 kton water Cherenkov detector (under development)
- IVETO: cold liquid scintillator (R&D in progress)



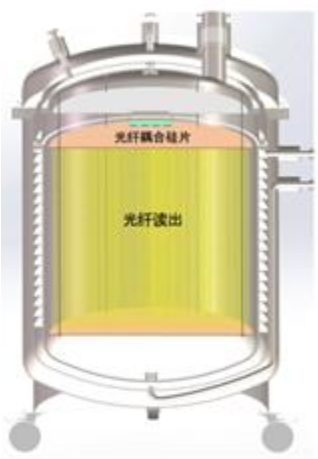
Some designs - PandaX-xT

- Cold liquid scintillator between a steel outer vessel and a copper shell
    a. Similar to nEXO HFE design in terms of cryo and pressure
- Fibers + SiPM for light detection in the cold LS
- Under R&D



Some designs - PandaX-xT

- Light yield drops cold
  - Working on 1 m^3 prototype
- See J. Huang talk at PandaX Open meeting for more - link



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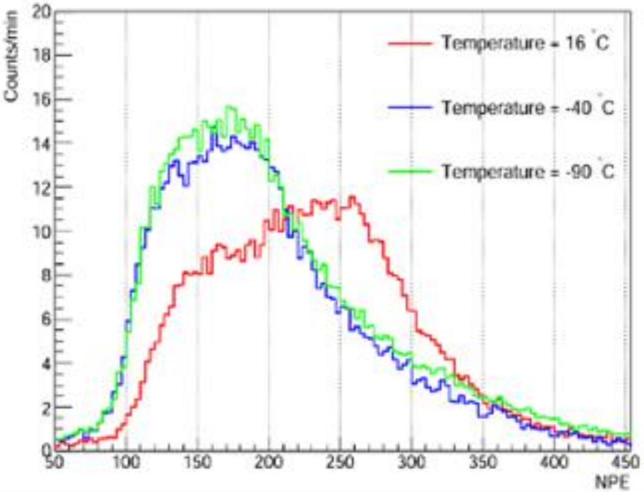
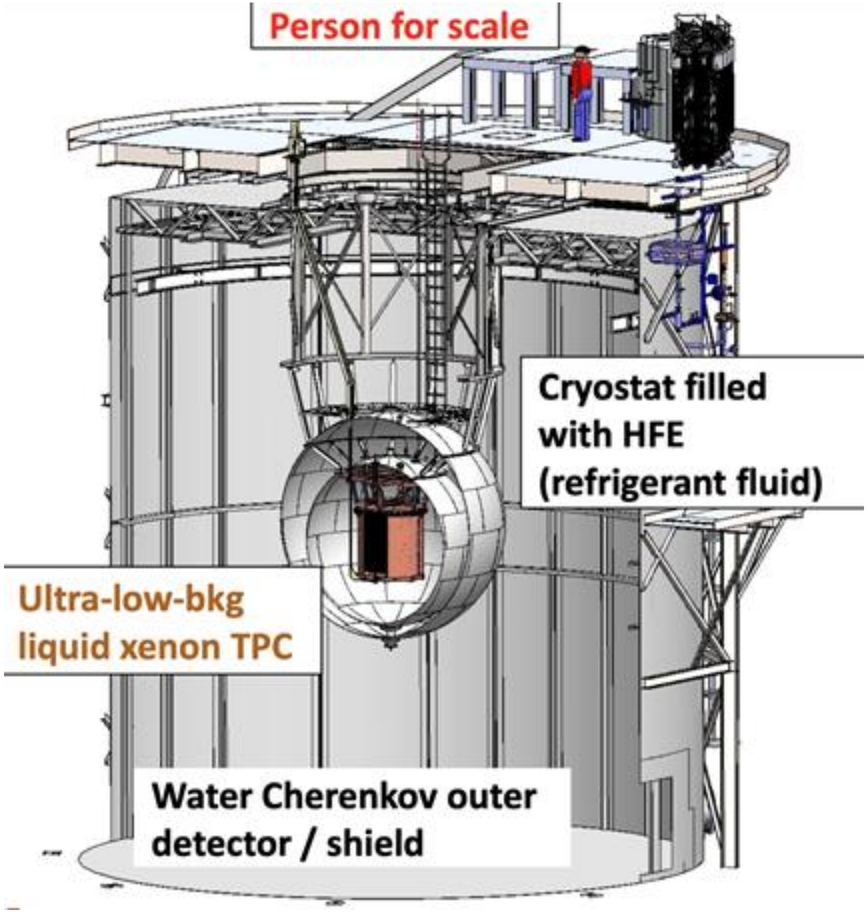


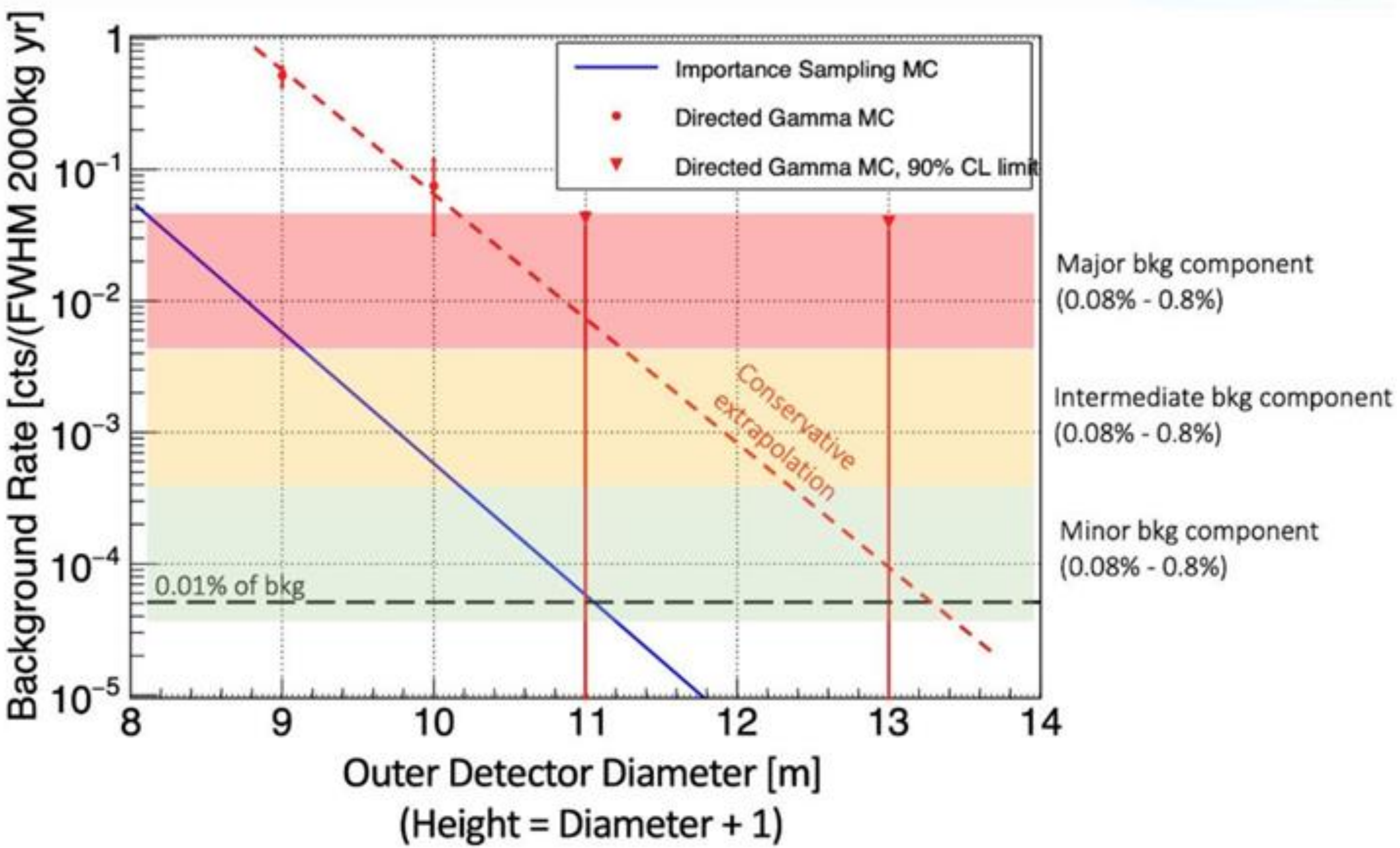
Th232

Some designs - nEXO

- 12x12.8 m water tank
- Passive shielding (from gammas)
  - Reduces cavern gammas to subdominant contribution
- Active for muons
- Tyvek on outside

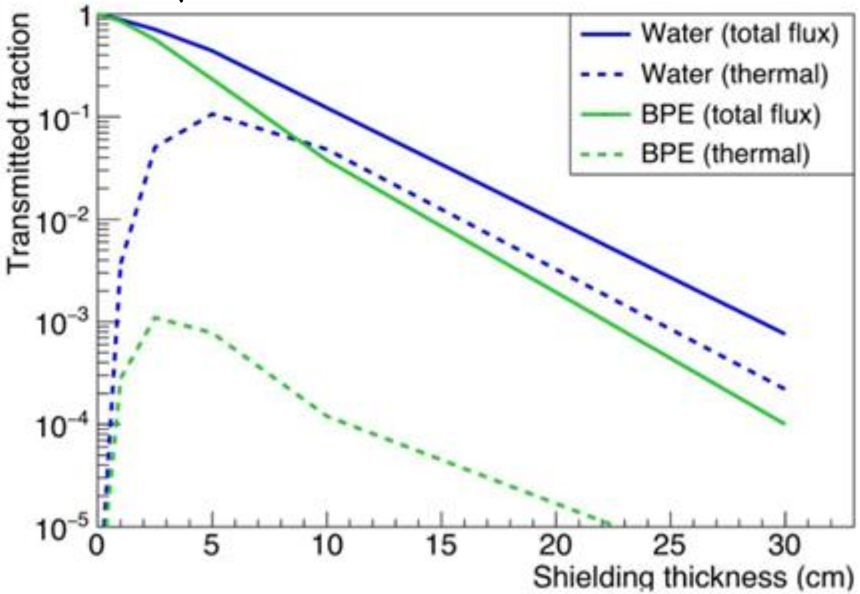


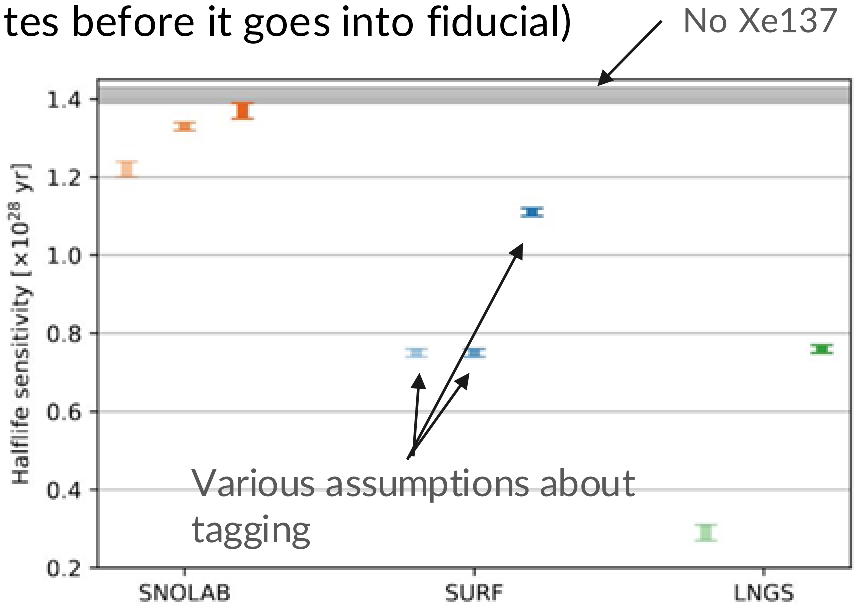
Some designs - nEXO



Some designs - nEXO

- Neutrons absorbed in water tank
- Neutron capture on 136Xe outside tank (site dependent)
  - Shielding required for external Xe in purification system
  - (Or hold xenon in water tank for 30 minutes before it goes into fiducial)





Some designs - nEXO

- Also includes a skin as part of an optically open TPC design
  - Reduces gamma and radon backgrounds by tagging

(https://arxiv.org/abs/2009.10231)

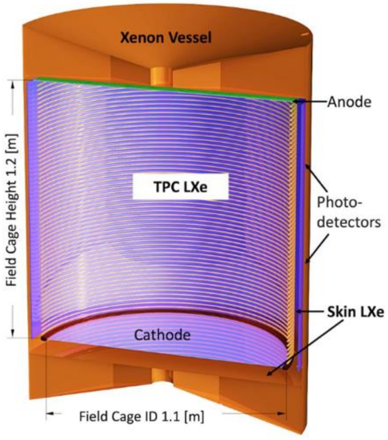


Figure 1: Cross-section of the proposed TPC for nEXO.

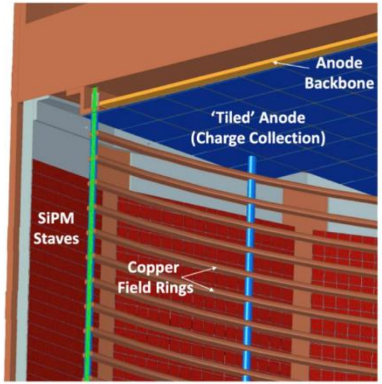
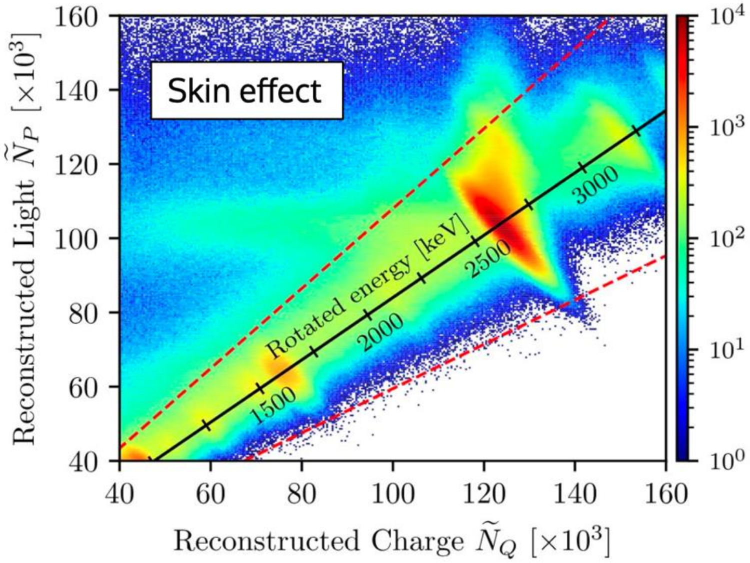


Figure 2: Cutaway sketch of the anode section of the TPC. The configuration of the charge collection tiles is shown below a cutaway of the anode backbone. [4]



Some designs - NEXT

- Standard water tank with potential neutron absorption doping (like Gd)
- Inner copper shielding (2005.06467)

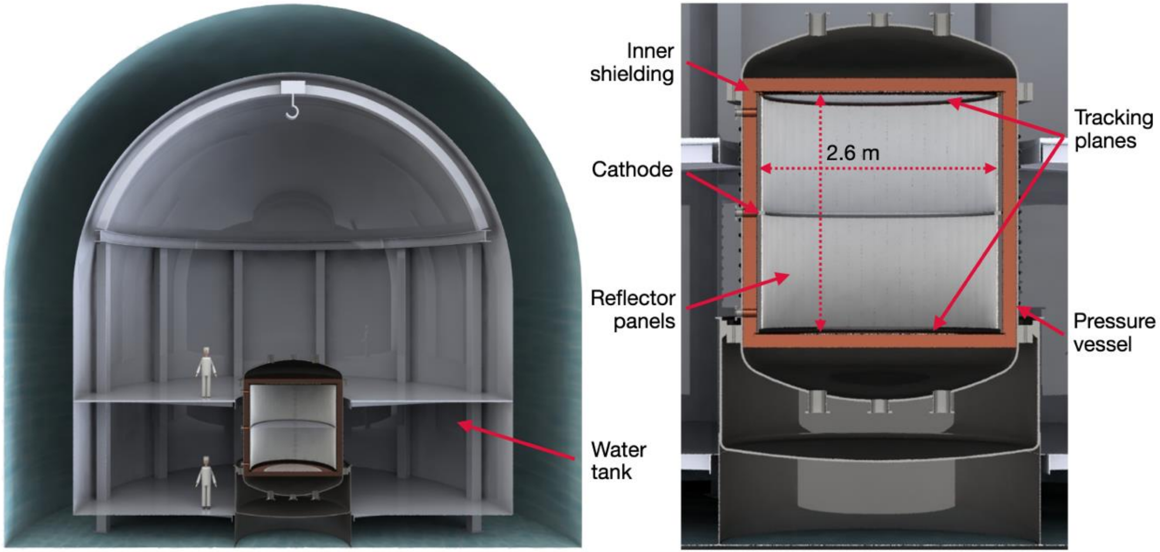
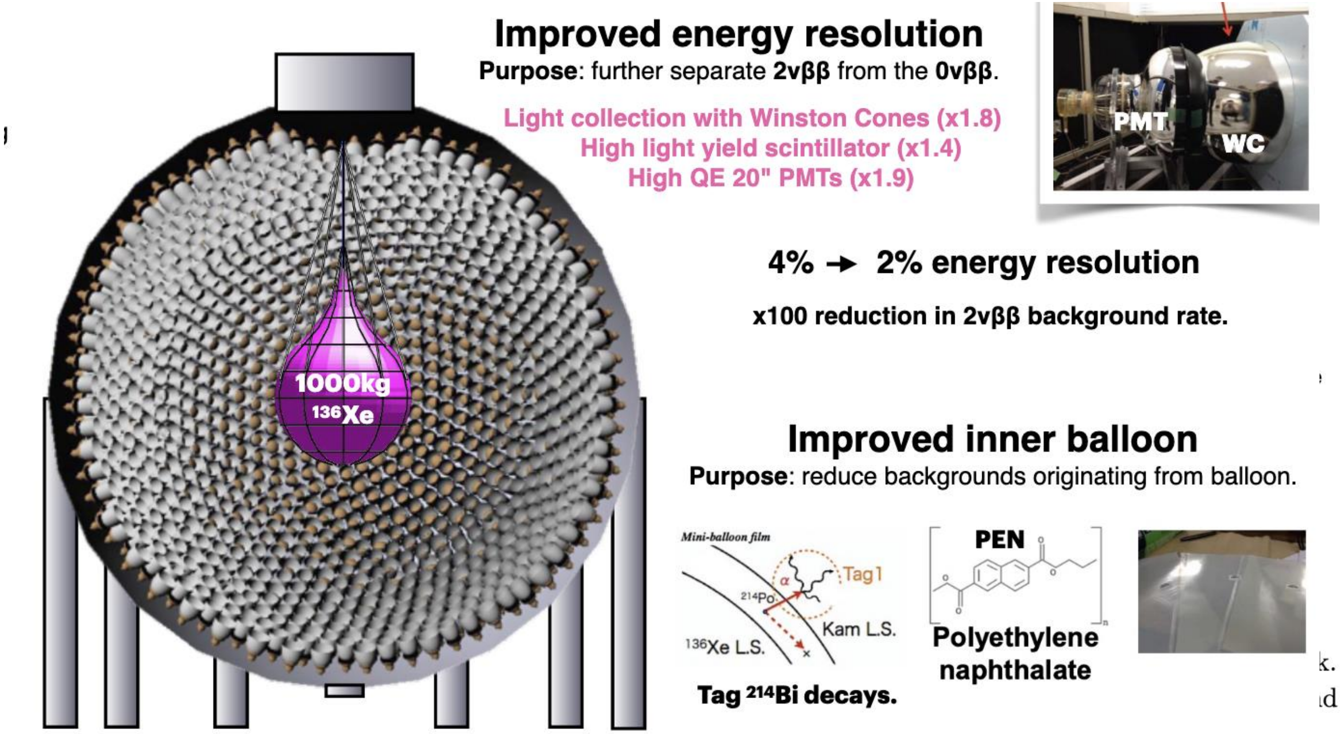


Figure 2. Left: conceptual design of a tonne-scale NEXT detector installed inside a water tank. Right: detail of the internal structures of the detector. The active volume, 2.6 m in diameter and height, would hold a mass of ^{136}Xe of approximately 1109 kg at 15 bar.

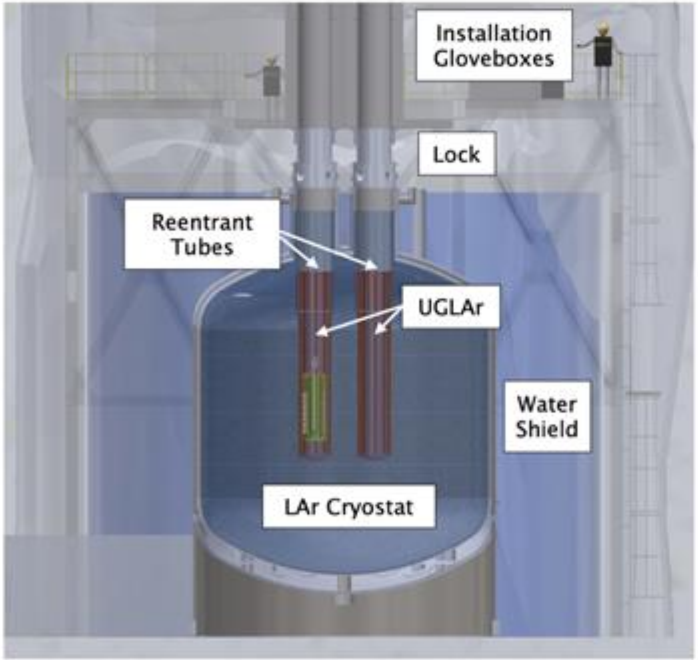
Some designs – KAMLAND-Zen2

- From Spencer Axani yesterday
- Existing LS veto with addition of PEN balloon



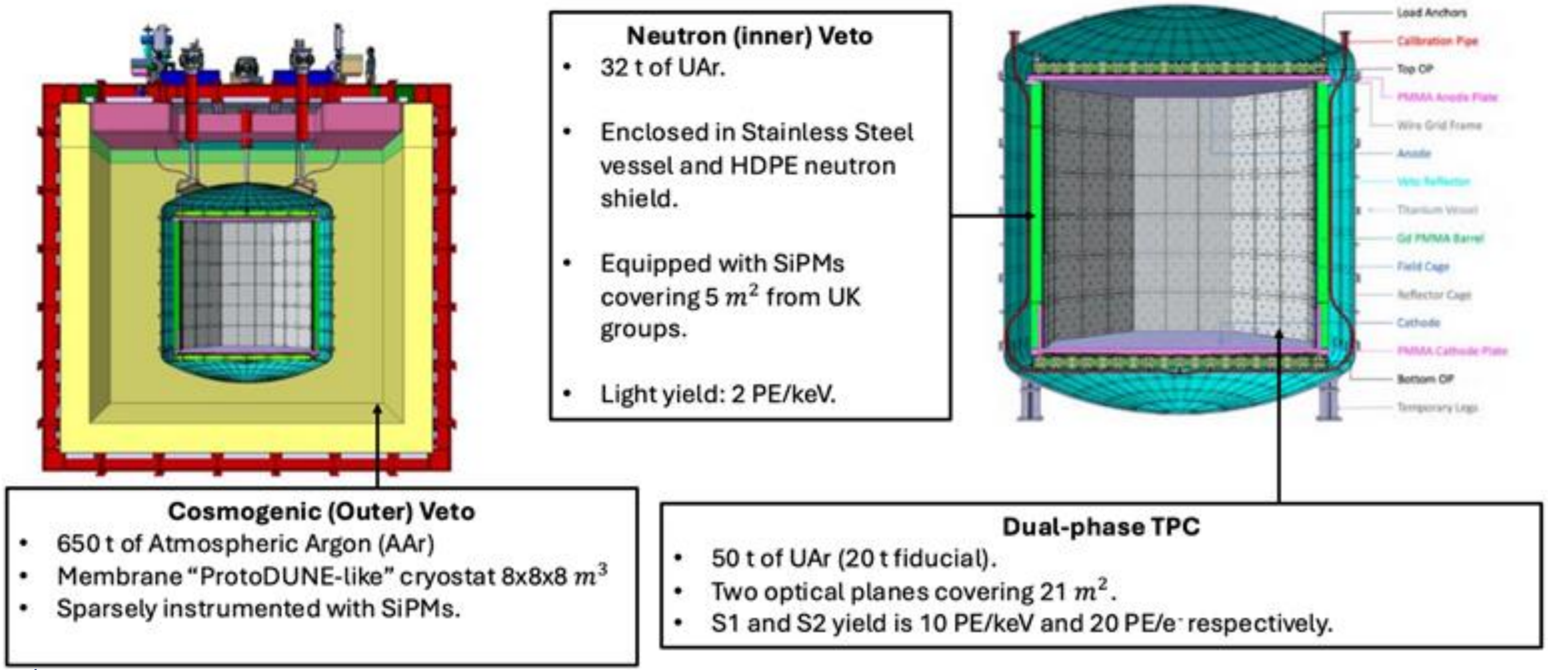
Some designs - GERDA/LEGEND

- Liquid argon active veto, also providing cooling to the Ge detectors
- 7 m diameter cryostat, 332 tonnes of LAr
- Inner reentrant tubes with 0.95 m diameter to hold the detectors with underground LAr
    - ^{42}Ar decays to ^{42}K which famously can attach to surfaces and beta decay at 3525 keV
    - UAr eliminates need for nylon shrouds used in GERDA
- Light detection through WLS polystyrene fibers coupled to SiPMs (coated with TPB)



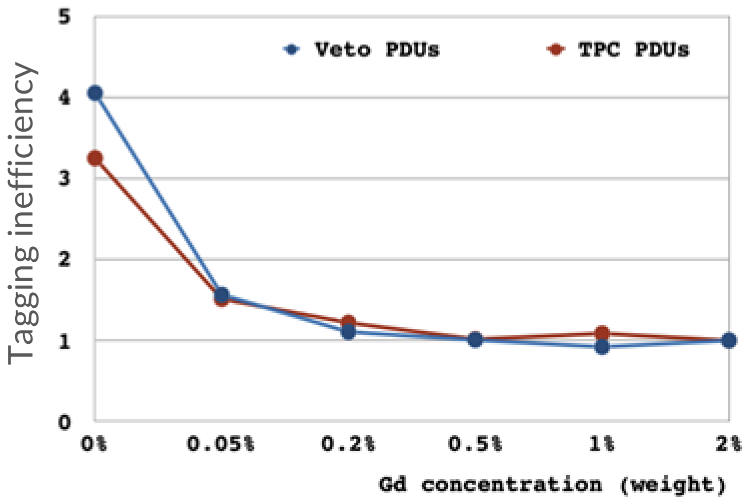
Some designs - DarkSide-20k

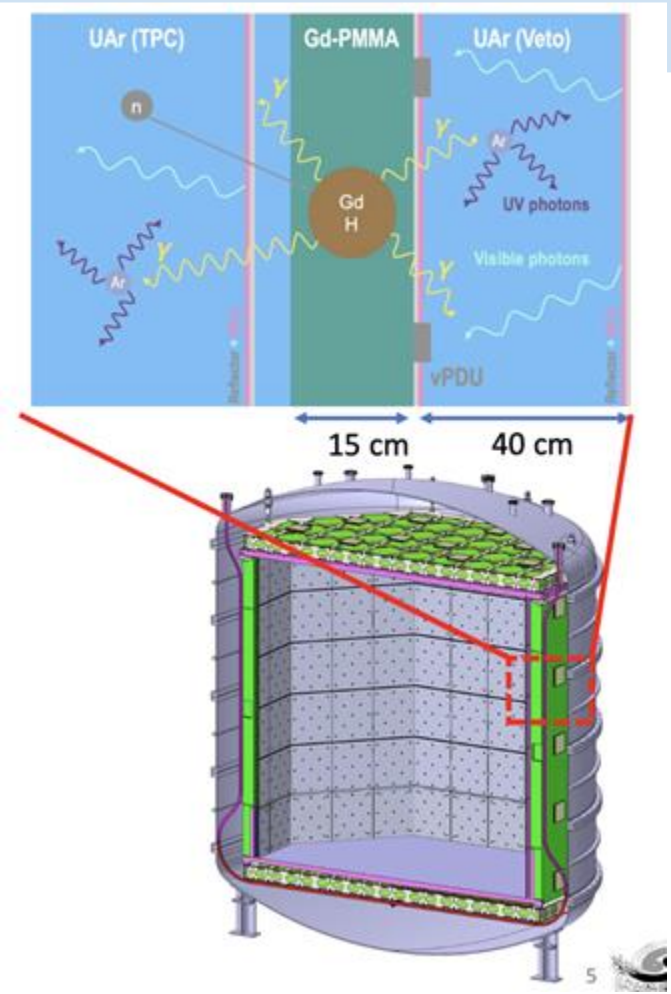
- Outer veto for muons of atmospheric argon
- Neutron inner veto (skin) of UAr



Some designs - DarkSide-20k

- Outer veto for muons of atmospheric argon
- Neutron inner veto (skin) of UAr
    - Key is 15 cm Gd-loaded PMMA (acrylic)
    - Capture gammas interact in the argon volume





[Yi Wang, LIDINE2024]

Some comments - Requirements

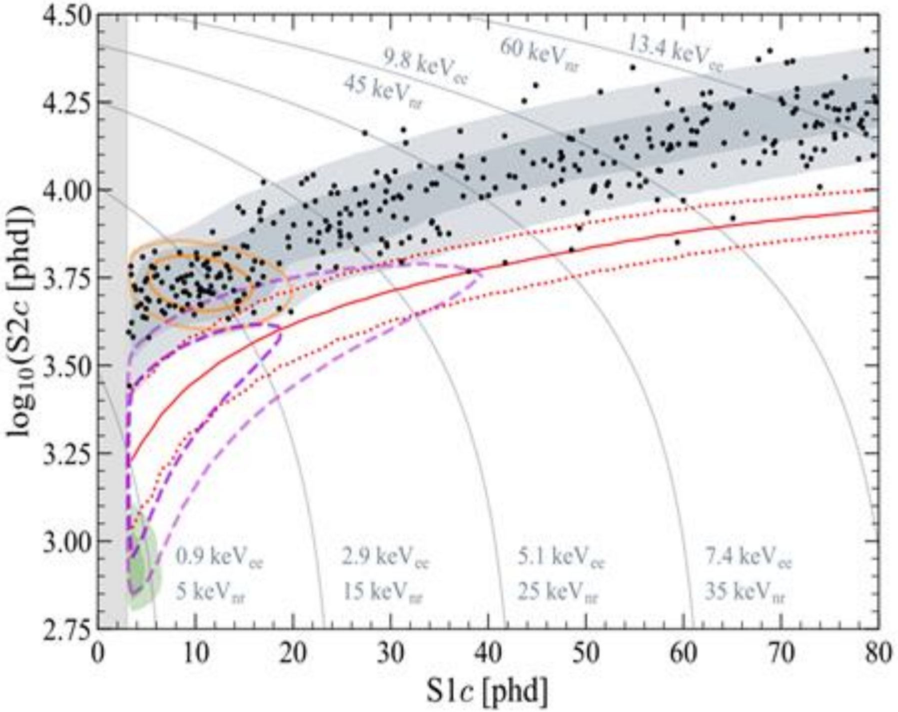
	✔	✘
Passive shield	Cost effective Labor saving (short term)	Limited capability No input to bkg model Extremely costly to add post facto
Simple veto	Known behaviour Simple modeling Balance between cost and complexity / capability	Balance between cost and complexity / capability
~~More~~ Most capable outer detector (MCOD)	PID, fiducial., coincidence logic Save by spending	Enables physics Risk mitigation Future proofing

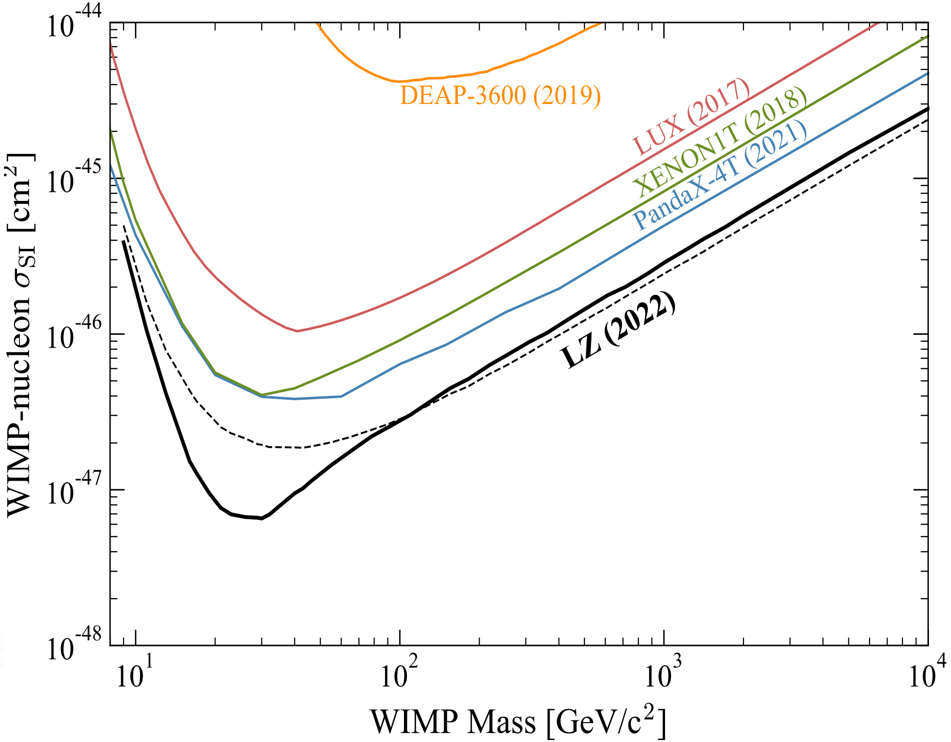
G. Orebi Gann

Some comments - Requirements

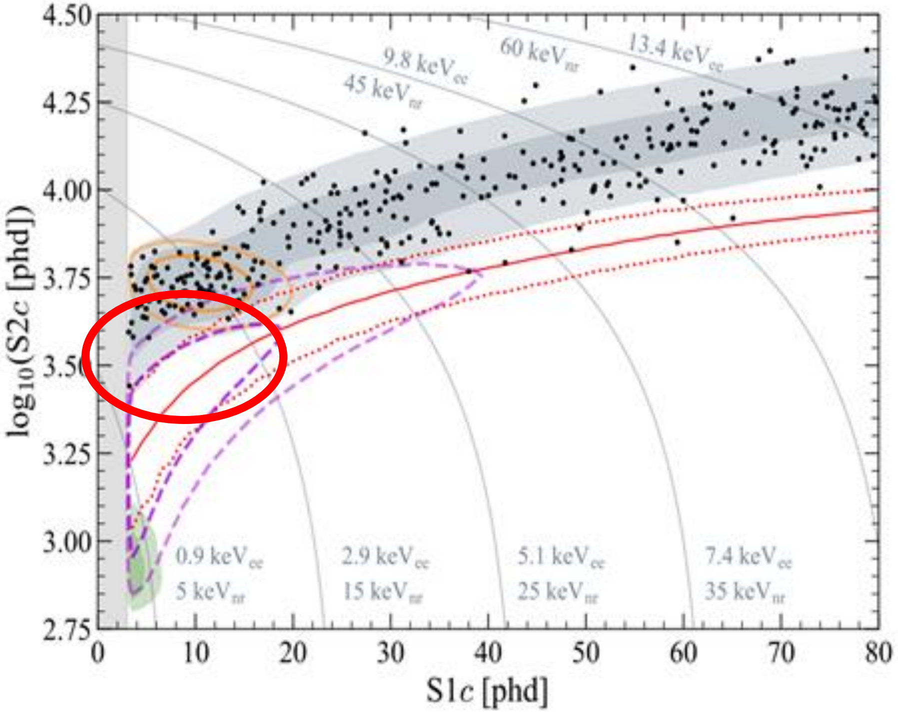
- Is the active veto *required*?
  - In LZ, OD cost was ~9% of the total project cost
  - Extra complication to build and fill
  - How does that scale with increased size?
- In large liquid xenon detector, for double beta decay, the skin is potentially the most important veto, knocking down internal 208Tl by order of magnitude
- Dark matter drives the neutron and high performance (low threshold) requirements
  - For such a large detector, it's not so obvious (to me) what that requirement needs to be (how much rejection is provided by MS in the TPC itself?)
- Back to vibes - hard to put a cost on having that extra handle when the difference between a signal and a fluctuation is a couple of counts

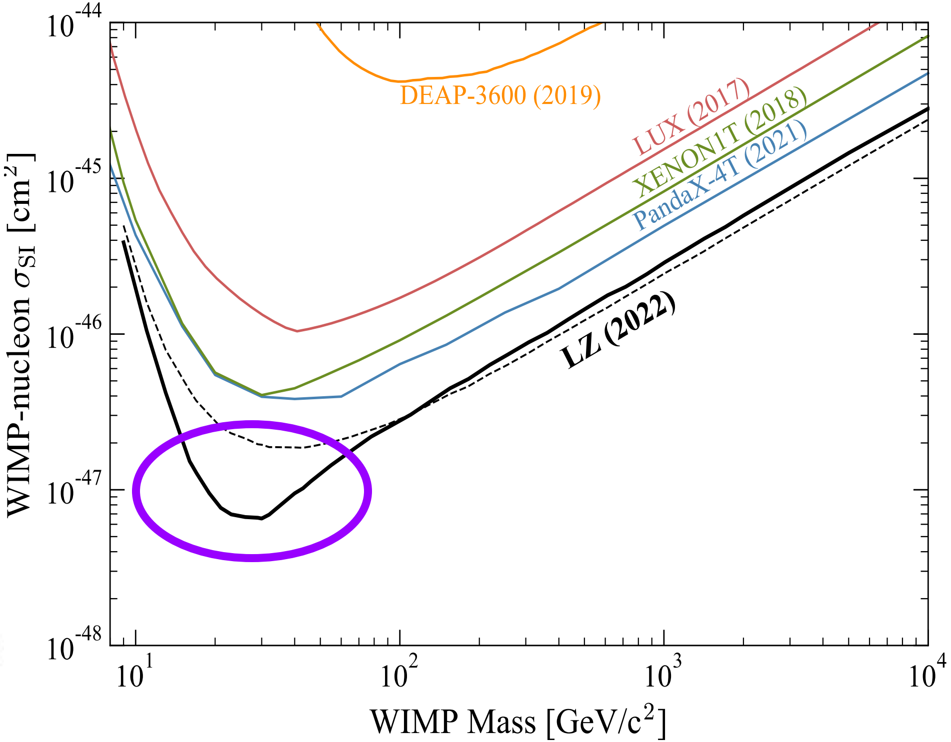
Case study – LZ WS2022





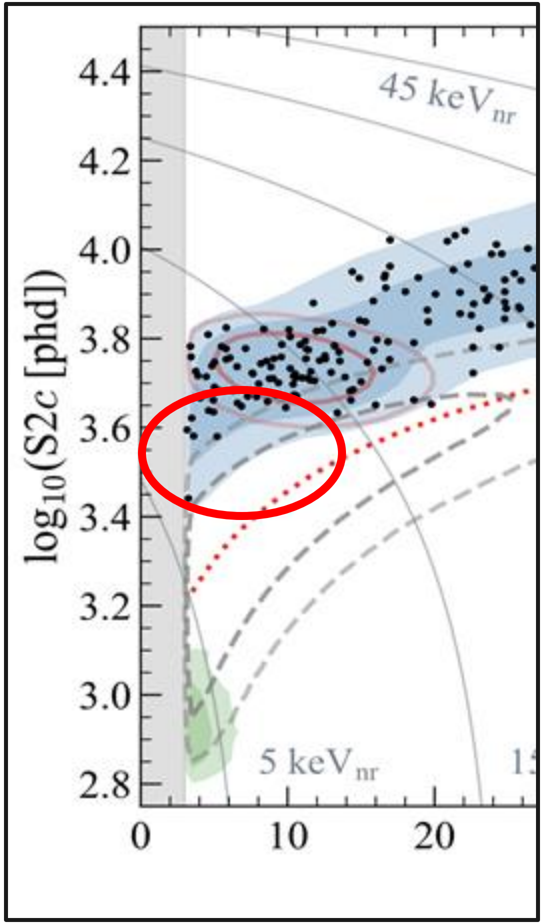
Case study – LZ WS2022

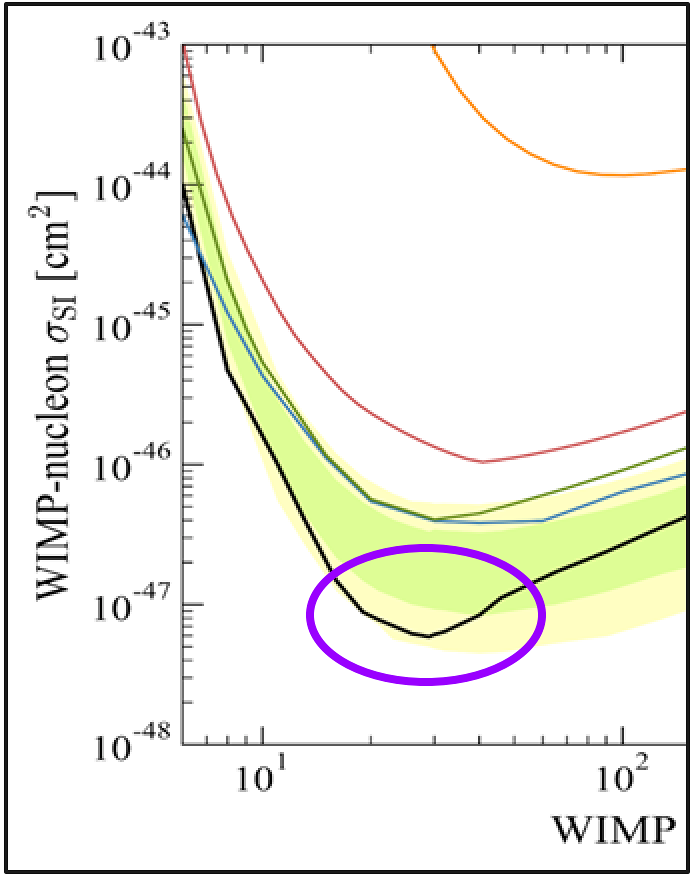




Case study

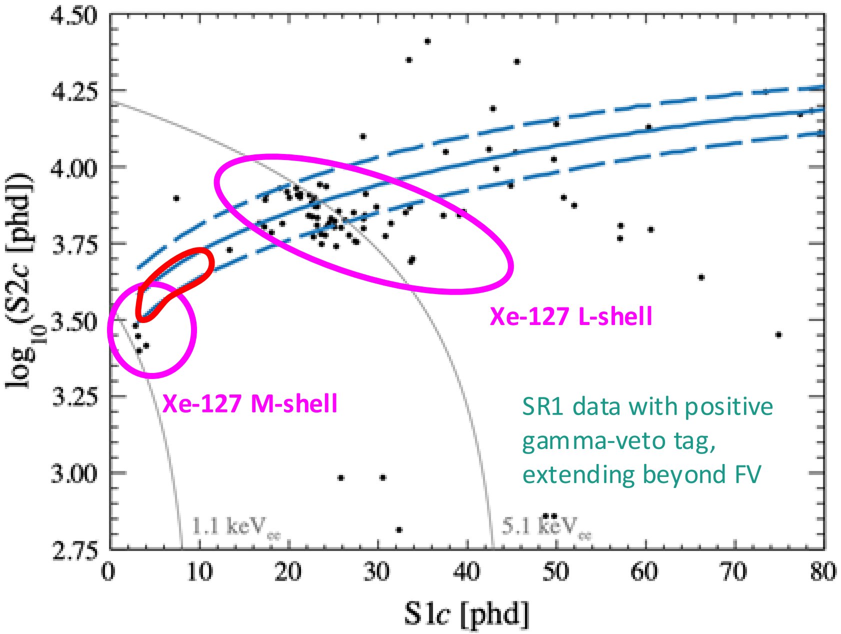
- LZ WS2022 had a downward fluctuation in the observed upper limit (purple ellipse)
- Attributed to deficiency of events under the Ar-37 population (red ellipse).
- Alternative is problem with signal efficiency that changed over the run

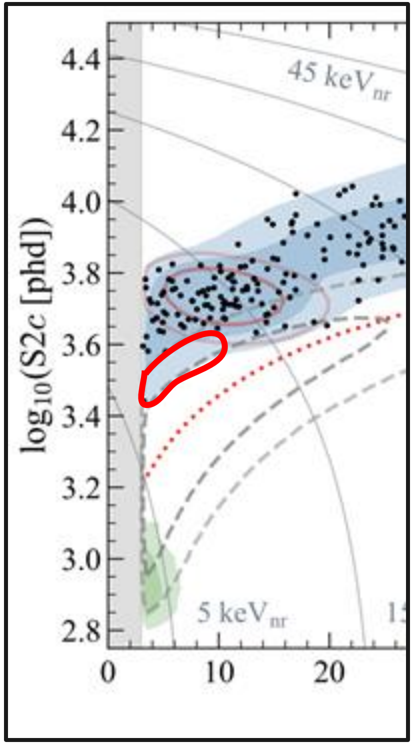




Case study

- The skin detector can tag gammas from Xe-127 electron capture decays
- The Xe-127 M-shell population is exactly in the deficient region
- Served as a cross check - 4 events are distributed throughout run consistent with the expected number of events.





Conclusion

- Surprising variety of design choices for what started as ”shielding/water tank”
- Each detector/collaboration needs to think about its own requirements carefully
- Critical component of a complete background model