XLZD OUTER DETECTOR | NEUTRON VETO EFFICIENCY

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MOTIVATION

- **XLZD Outer Detector** (OD) serves to **attenuate external backgrounds** from **cavern gammas** and **neutrons**, and **veto gammas** and **neutrons** originating from **detector components**.
- Design must satisfy specific requirements to achieve the targeted sensitivities for Weakly Interacting Massive Particles (**WIMPs**) and neutrinoless double beta decay (**0νββ**) searches.
- Assuming **10 years continuous operation**, during which neutron-induced background events must remain subdominant relative to the "neutrino fog".
  - **< 1 single scatter neutron event** passing the veto cuts over full **10-year period** mandates a **neutron veto efficiency** of **≥ 95%.**

OD SIMULATION

Simulated neutrons originating from **four** key background components:

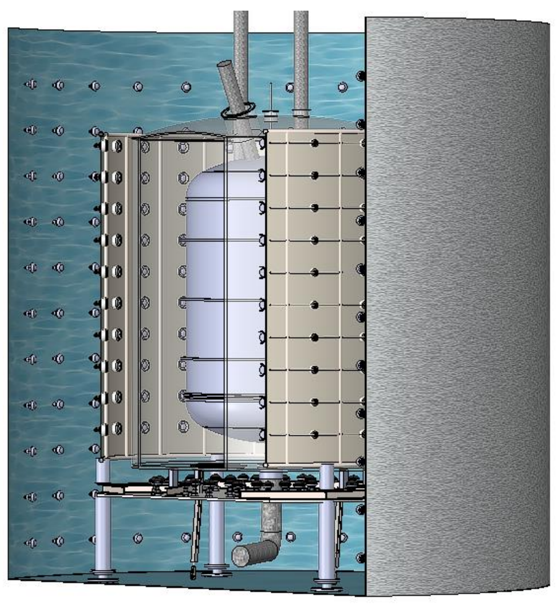
- Cryostat vessels
- TPC PMTs
- PTFE reflectors
- TPC field cage resistors

Kinetic energies sampled from distributions generated by **SOURCES4A**: calculates neutron energy distributions based on alpha particle energies and the target isotopes involved. Full **optical simulations** were run with **scintillation** and **Cherenkov** photons.

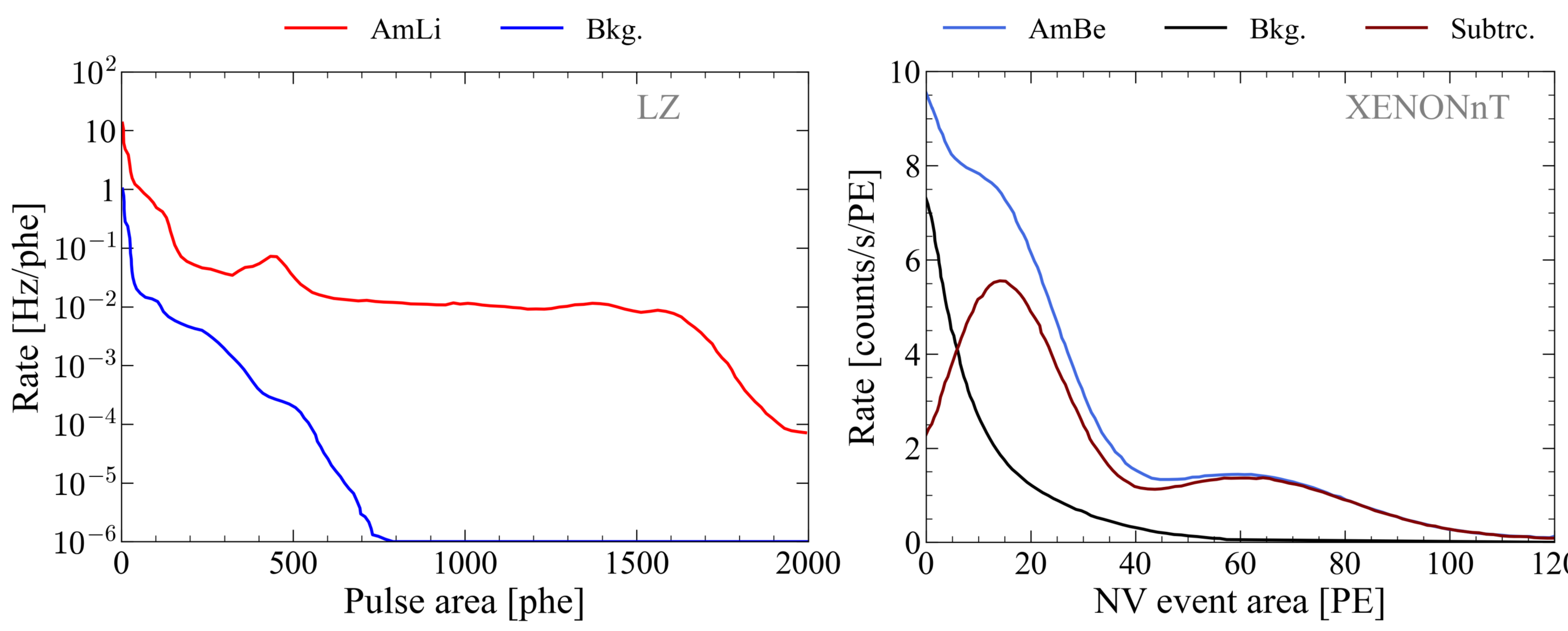
Detector Configurations

- Gd-LS with acrylic vessel (LZ)
- Gd-WbLS (BNL & LBL)
- Gd-Water (XENONnT)

0.1% Gd concentration enhances neutron capture efficiency and shortens the required veto window. **Neutron captures** produce either **4–5 γ-rays** with a **total energy** of up to **8.5 MeV** (**gadolinium**) or a single **2.2 MeV γ-ray** (**hydrogen).**



Optical simulations validated against LZ, XENONnT and WbLS test systems. Example pulse area spectra shown from the two extremes in light yield, **LZ's Gd-LS** and **XENONnT's Gd-water:**



SELECTION & CUTS

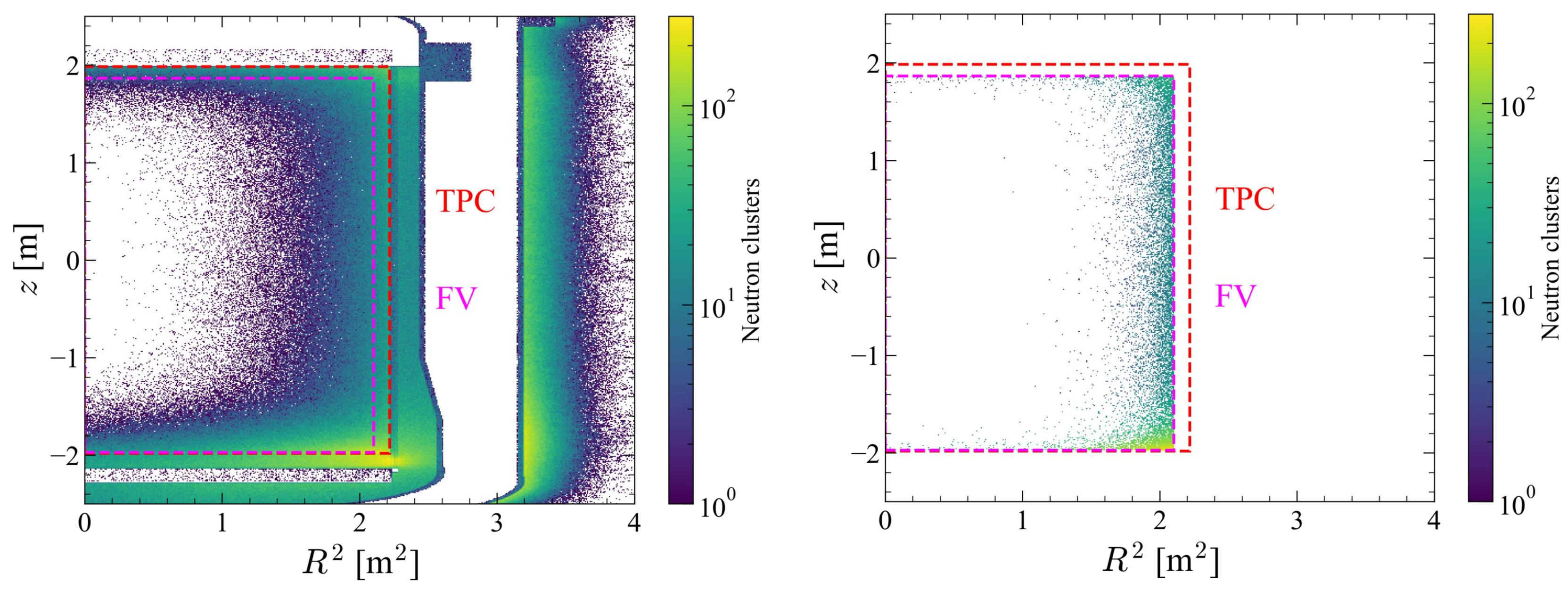
Neutron energy deposits clustered according to LZ resolution parameters:

- ΔR < 30 mm
- ΔZ < 2 mm
- Δt < 100 ns

Number of selection cuts applied to the dataset to define the **denominator** neutron events for efficiency studies:

- **Single scatter** (SS): Only one cluster within the event window
- **Region of Interest** (ROI): 6 – 30 keV$_{nr}$
- **Fiducial volume** (FV): Cylindrical volume bound 1 cm above the cathode, 12 cm below the gate, and 4 cm radially inward from TPC wall

All neutron clusters | **Clusters after all cuts**



Veto efficiency: ratio of the number of events that pass the WIMP-like selections and are vetoed by the OD or Skin veto cuts, to the total number of events that pass only the WIMP-like selections:

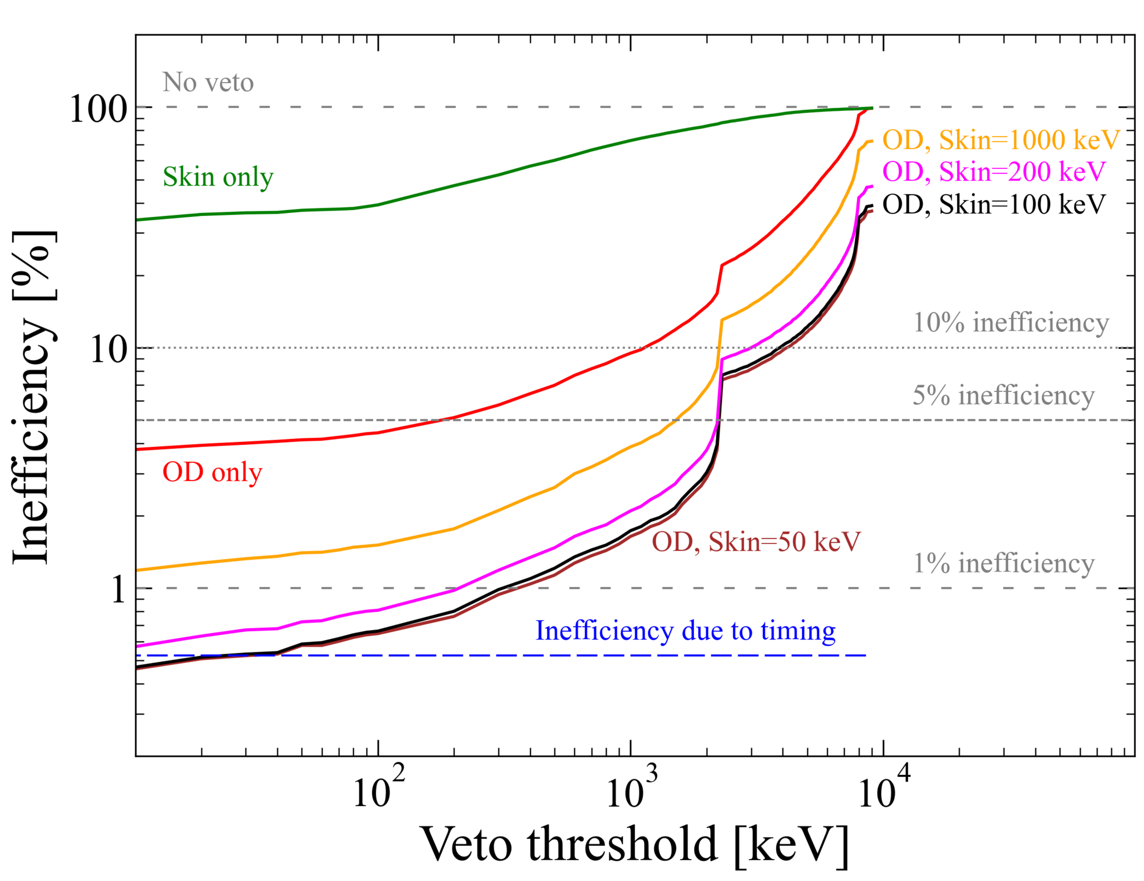
$$\epsilon = \frac{ROI+SS+FV+(OD(E_{\mathrm{Th,\,OD}},\Delta T)\parallel Skin(E_{\mathrm{Th,\,Skin}},\Delta T))}{ROI+SS+FV}$$

ΔT: veto time window (time difference between signals in TPC and OD/Skin)

OD/Skin cut: Energy deposited in the veto detector, above threshold and within ΔT

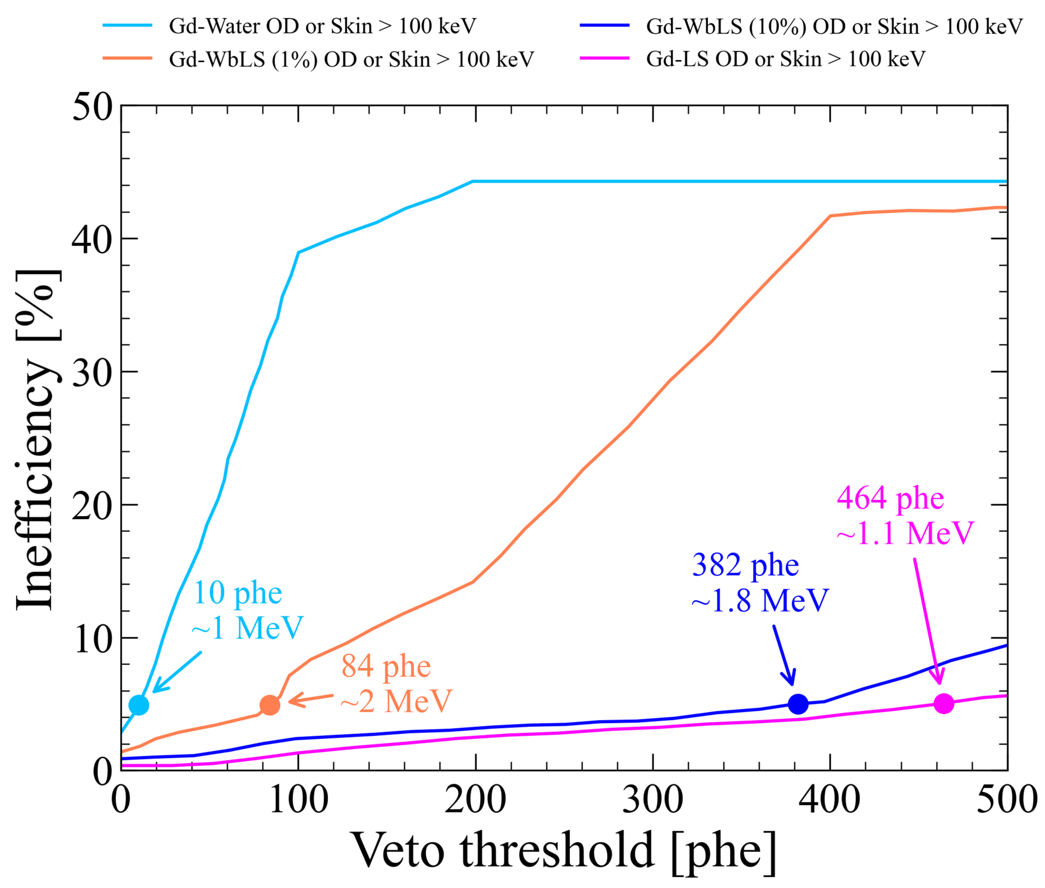
RESULTS

Energy deposited (Gd-LS Medium)



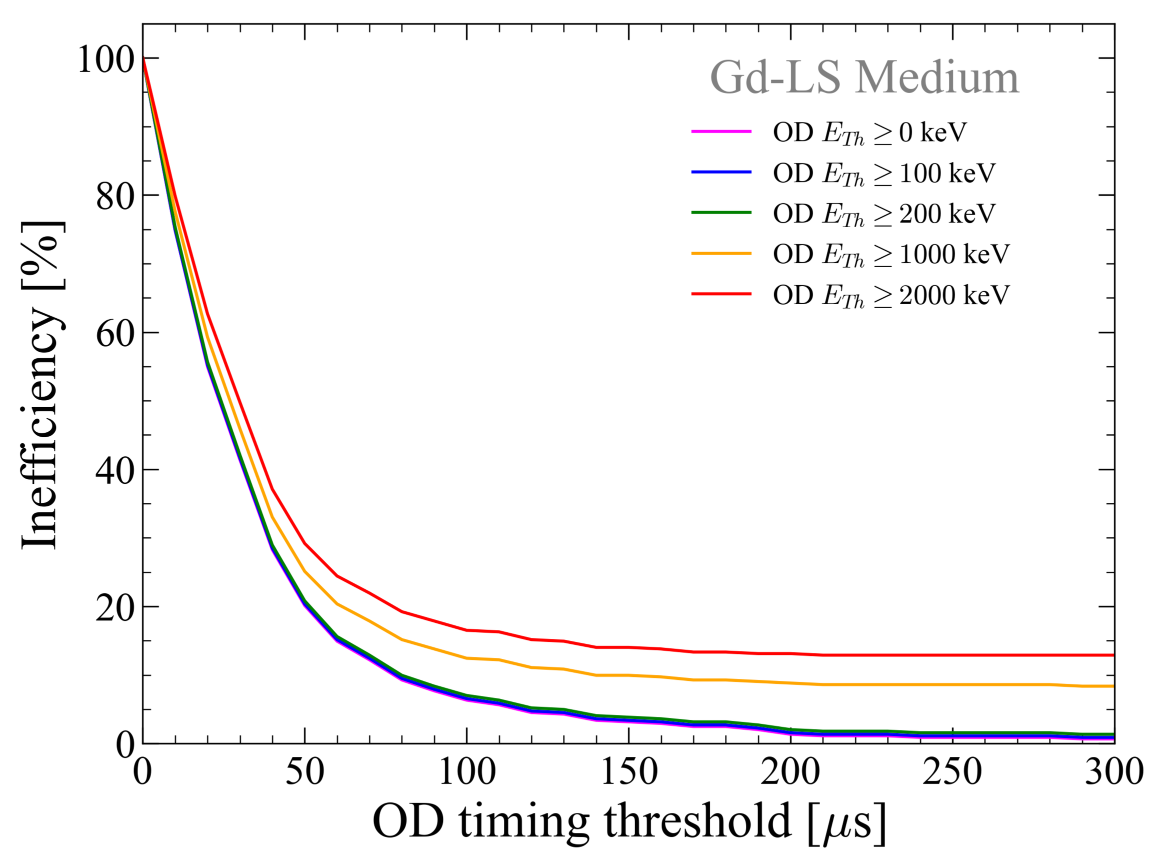
Neutron veto inefficiency as a function of veto energy threshold, which can be attributed to the Skin (Skin only) or OD (OD only or OD with fixed Skin thresholds). Figure made using the Gd-LS acrylic tank design.

Photons detected (various media)



Neutron veto inefficiency as a function of veto threshold in photoelectrons, for four different OD scintillating media. Highlighted data points show approximate conversion between energy in MeV and number of photoelectrons measured by OD PMTs.

Timing (Gd-LS Medium)



Neutron veto inefficiency as a function of OD timing threshold in microseconds, for a range of OD energy thresholds. Figure made using the Gd-LS acrylic tank design.

CONCLUSIONS

- The **highest possible efficiency** is achieved with the **Gd-LS scintillator design**, due to its enhanced **light yield**.
- The performance of **10% Gd-WbLS** is **very similar** to that of **Gd-LS**, as the lower light yield is offset by **reduced light absorption** in the medium.
- For **Gd-water**, achieving a **100** or **200 keV threshold** is **not feasible**, and it remains **extremely challenging** for **1% Gd-WbLS**. Still validating WbLS optical parameters as these are yet to be measured for Gd-loaded WbLS.
- The **lower light yield** of **1% Gd-WbLS**, as measured by the 1-tonne BNL demonstrator, results in a **reduced background rate**, bringing it closer to acceptable levels if the **PMTs** are placed **within the medium**. Although achieving the required neutron tagging efficiency becomes more challenging, the advantage of eliminating the need for a containment vessel is significant.