# Cosmogenic Backgrounds for EXO-200 and nEXO


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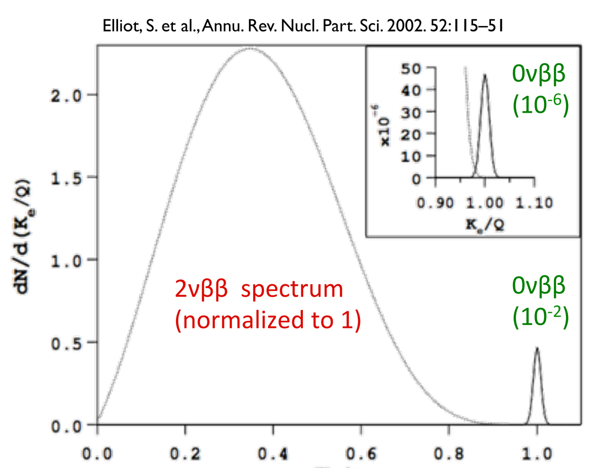
## Neutrino-less Double Beta Decay (0νββ)

**Best chance to probe the nature of the neutrino**

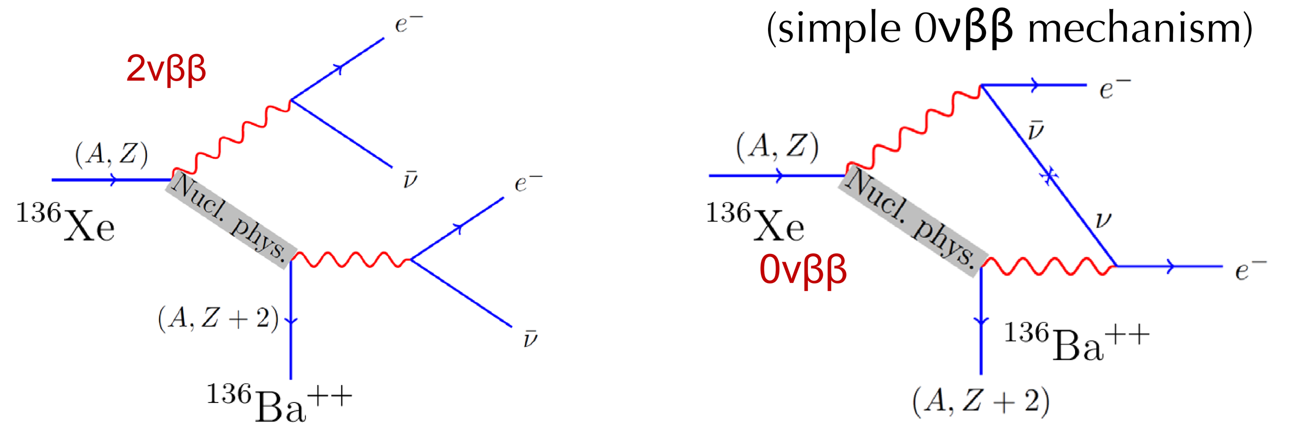
Observation of 0νββ would:

- Determine the Dirac/Majorana nature of the neutrino
  - $\nu = \overline{\nu}$?
- Demonstrate non-conservation of lepton number (beyond SM)
  - $\Delta L \neq 0$?
- Reveal the absolute ν mass
  - $\langle m_\nu \rangle^2 \propto \left(T_{1/2}^{0\nu\beta\beta}\right)^{-1}$




Signal of 0νββ is a beta-like mono-energetic peak at the Q-value (2458 keV for $^{136}$Xe).

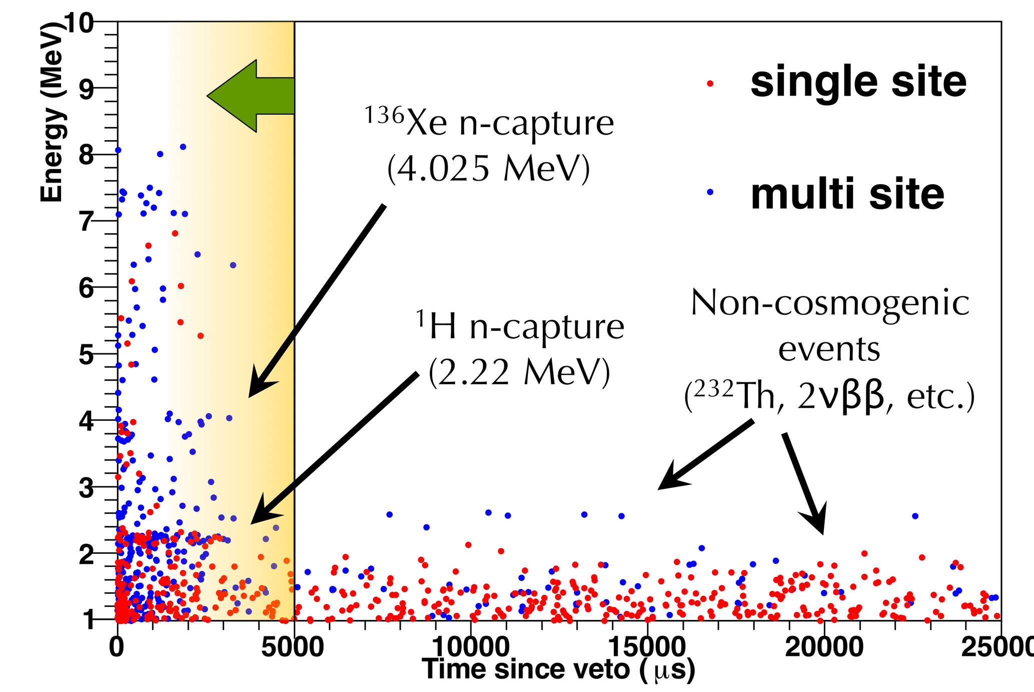
Non-observation can be used to set limits on Majorana neutrino mass.




## Muon Veto-tagged Dataset

**Neutron-enriched dataset in coincidence with muon veto panels**

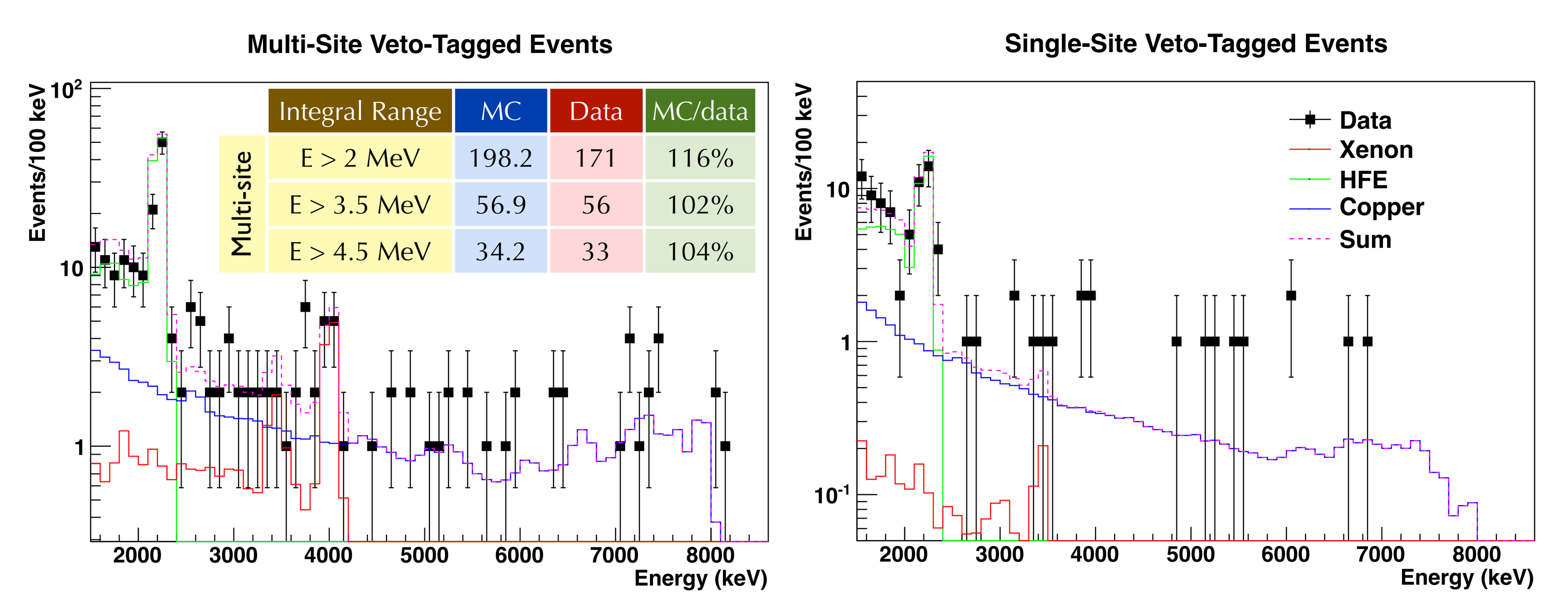
- Look in muon veto rejected data.
- Select data with:
  
  10 μs < $t_{\text{after veto}}$ < 5 ms.
- Event sample is highly "neutron-enriched".
- Neutron capture γ lines visible.
- Use this data to validate understanding of neutron captures and cosmogenic backgrounds.
- 4990 μs per veto, corresponds to ~0.14% of runtime.




## Comparing Veto-tagged Data and MC

**Good shape/rate agreement based only on model and measured muon rate!**

Comparing the veto-tagged data and MC spectra, we see remarkably good agreement. The MC PDFs are based on neutron capture PDFs, and normalized to the neutron capture predictions from our FLUKA simulation. The MC is normalized to the data livetime and measured muon flux at WIPP. No fitting was used in this comparison. The shape and rate agreement validates our MC model and demonstrates that EXO-200 can perform as a neutron detector.

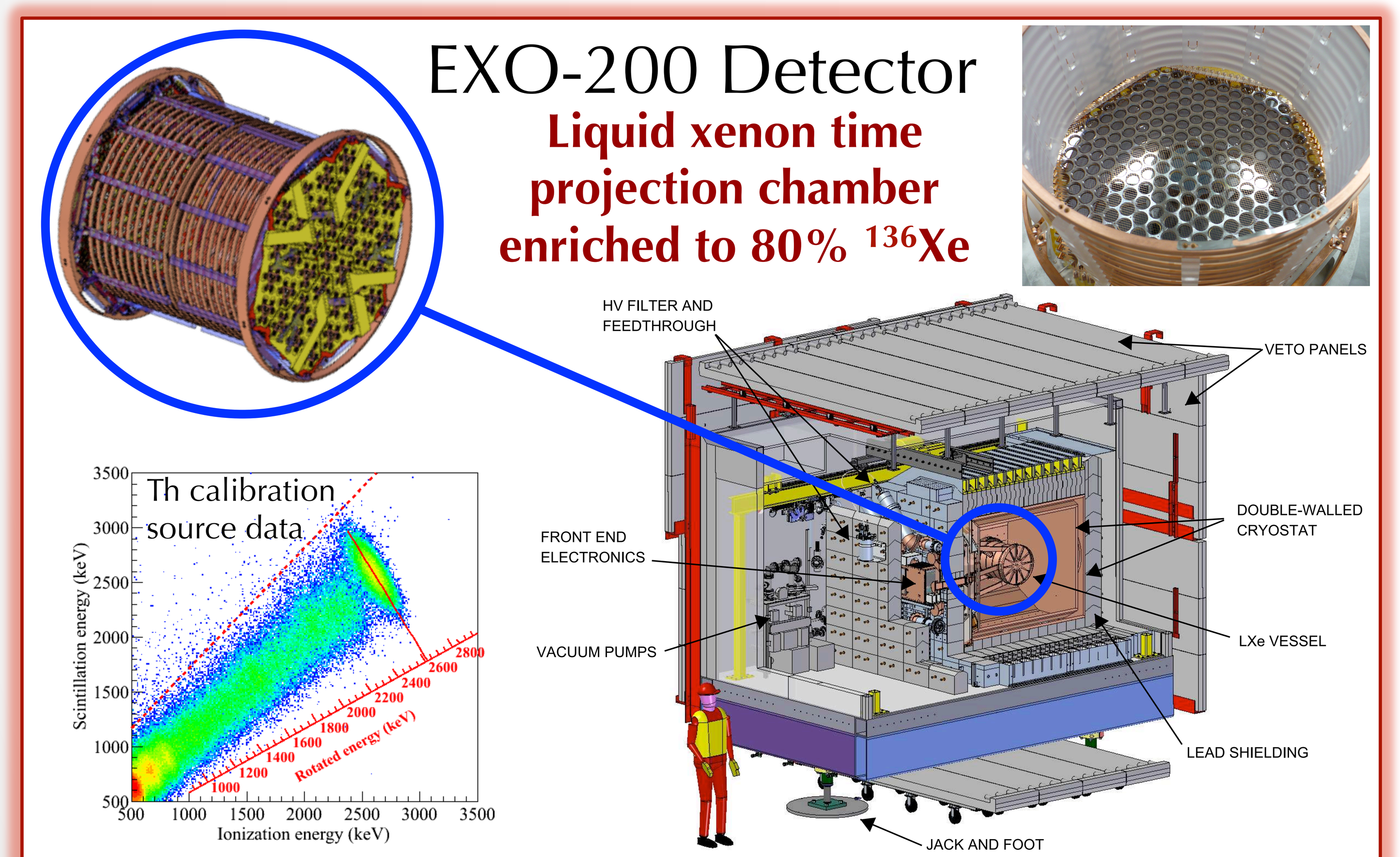



| | Integral Range | MC | Data | MC/data |
|---|---|---|---|---|
| Multi-site | E > 2 MeV | 198.2 | 171 | 116% |
| | E > 3.5 MeV | 56.9 | 56 | 102% |
| | E > 4.5 MeV | 34.2 | 33 | 104% |

- Analytic μ energy and angle distributions [3]
- Muon rate from TPC muon measurement (unpublished so far)
- FLUKA MC package for neutron production, transport, & capture
- Geant4 for capture gammas and detector response

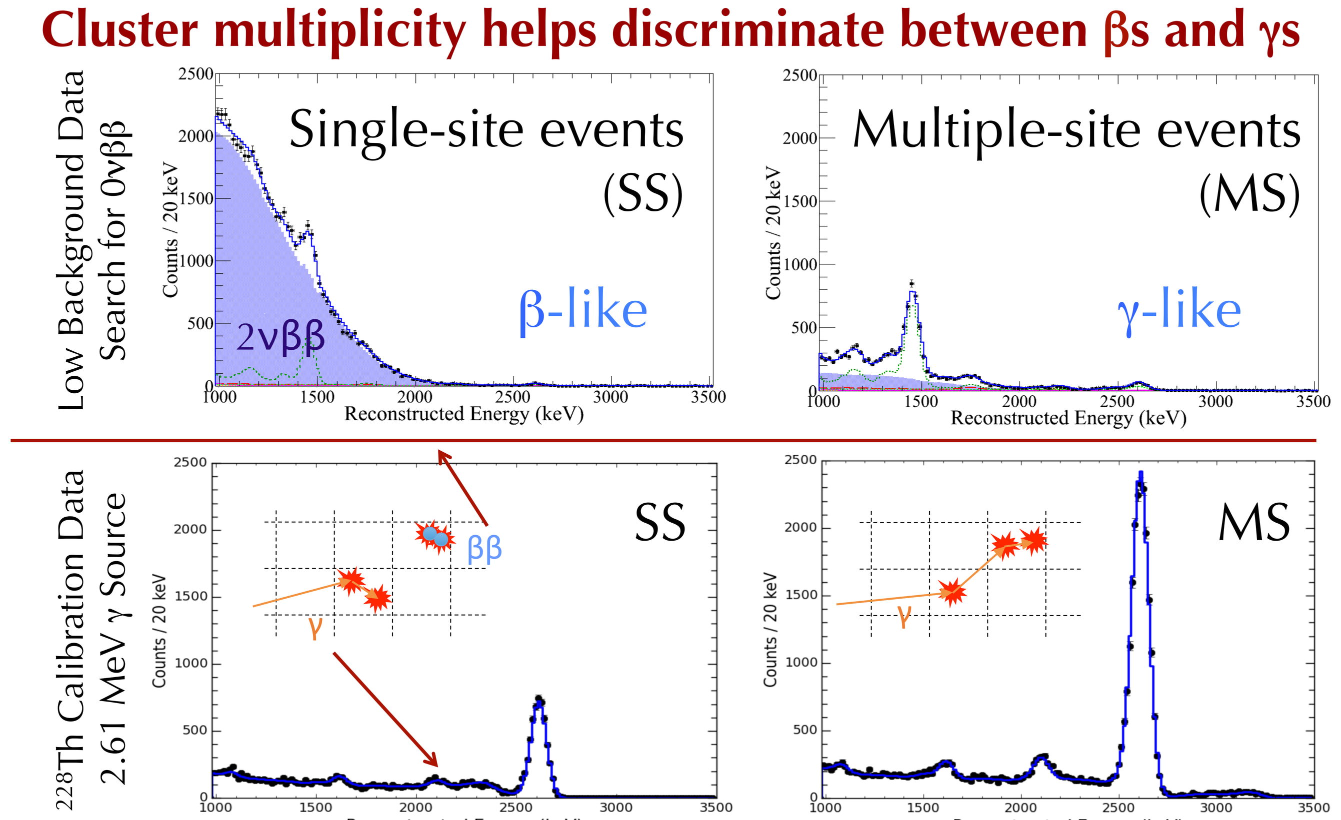
## EXO-200 Detector

**Liquid xenon time projection chamber enriched to 80% $^{136}$Xe**




## EXO-200 Signals and Backgrounds

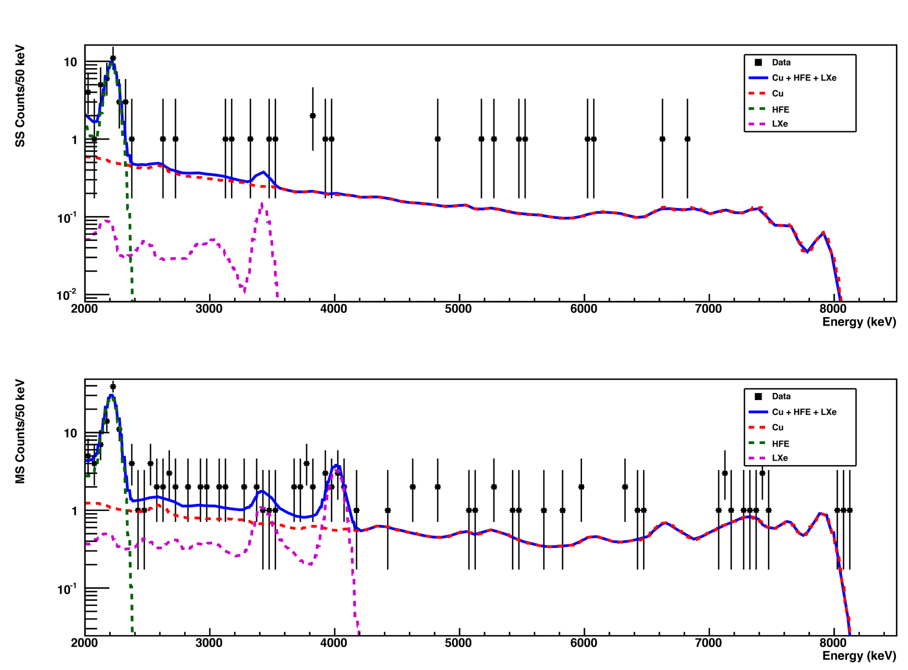
**Cluster multiplicity helps discriminate between βs and γs**



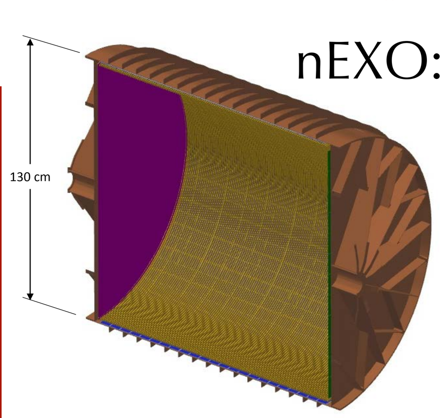

## Utilizing this technique in EXO-200 and beyond

**Independent $^{137}$Xe measurement, veto future cosmogenic backgrounds**

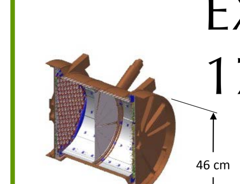
- Veto-tagged data fits to 0.46 ± 0.15 $^{136}$Xe captures/day/FV after efficiency and livetime corrections.
- Corresponds to 6.5 ± 2.1 $^{137}$Xe events in 2-σ SS ROI. Consistent with low background fit of 7.0 events.




nEXO: ~5 ton LXe, next-gen R&D + design phase




EXO-200: 175 kg LXe

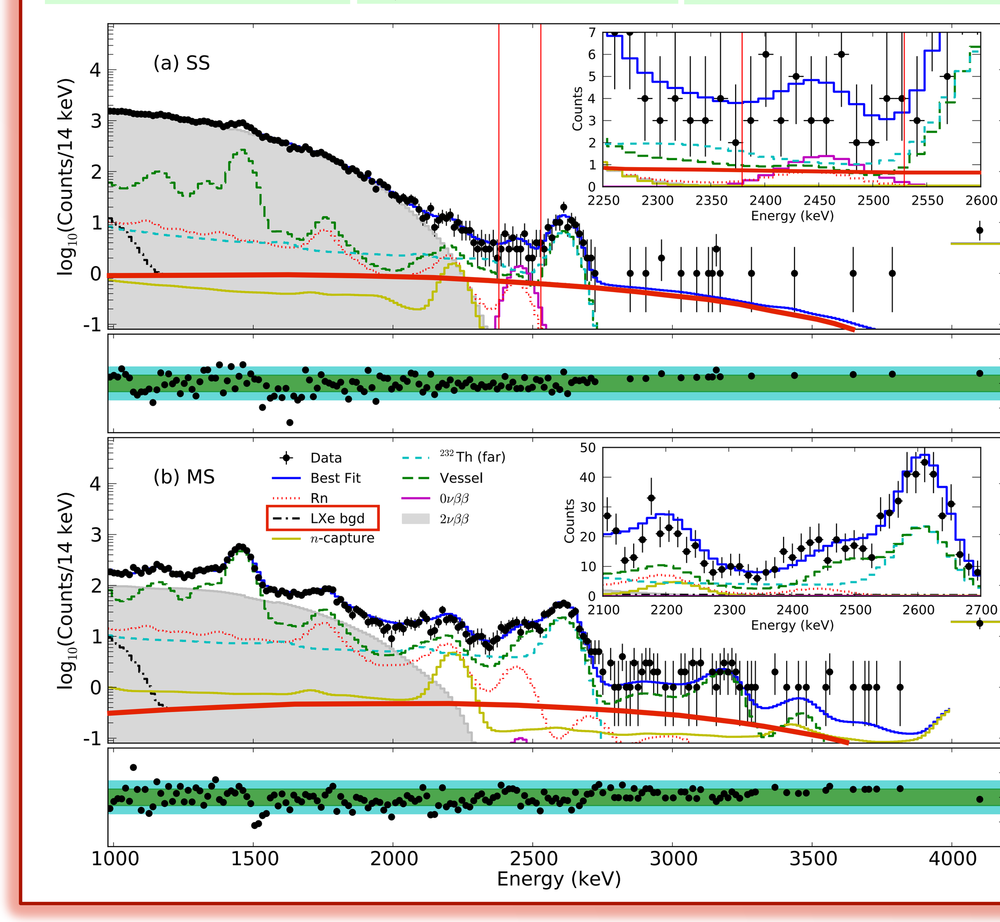



- Coincidence of muon veto and $^{136}$Xe n-capture signal can be used to start a long (~20 min.) veto to reject $^{137}$Xe decay.
- Requires good understanding of capture signal to reduce livetime loss.
- Applicable for both EXO-200 and nEXO.
- Important for nEXO depth requirements.
- Passive xenon self-shielding in nEXO greatly improves γ rejection for inner volume, but more penetrating neutrons require this active technique.

## Latest 0νββ Results

**Fit signal and background PDFs simultaneously in standoff distance and SS/MS energy to set limits on 0νββ**

| 90% sensitivity | 90% limit from ML fit | Majorana mass limit |
|---|---|---|
| $t_{1/2}^{0\nu\beta\beta} > 1.9\cdot10^{25}$yr | $t_{1/2}^{0\nu\beta\beta} > 1.1\cdot10^{25}$yr | $\langle m\rangle_{\beta\beta} < 190-450$ meV |




| Background series | Best fit counts in 2-σ SS ROI |
|---|---|
| $^{232}$Th | 16.0 |
| $^{238}$U | 8.1 |
| $^{137}$Xe | 7.0 |

- Maximum likelihood fit to 99.8 kg-yr $^{136}$Xe exposure.
- $^{137}$Xe background (highlighted in dark red) fits to ~22.5% of total background in 2-σ SS region of interest.

see Nature or arXiv [1]

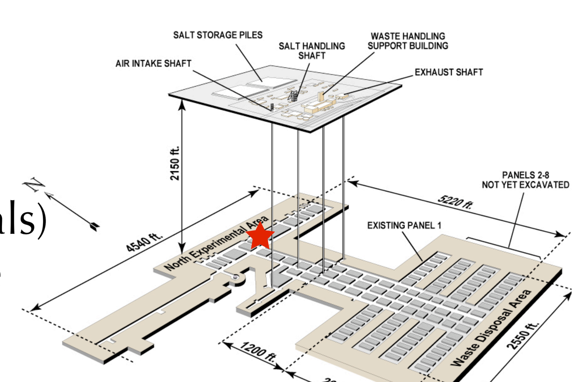
## Cosmogenic Backgrounds

**Prompt and delayed signals from muons**

Reduce cosmic ray backgrounds with:

- Depth (1585 m.w.e. at WIPP)
- Passive shielding (stop e⁻, p, γ)
- Active muon veto (reject prompt signals)

Muon-induced neutrons can still capture and produce long-lived radioisotopes.



$^{136}Xe + n \rightarrow {}^{137}Xe \rightarrow {}^{137}Cs + e^- + \overline{\nu}_e$

$t_{1/2}$ = 3.8 min    $Q_\beta$ = 4.2 MeV

Beta decay with $Q_\beta > Q_{0\nu\beta\beta}$ : critical background!

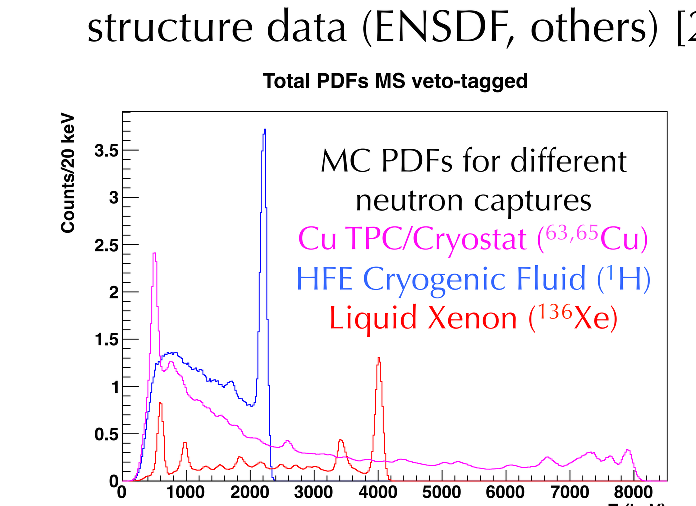
## Neutron Capture Gammas

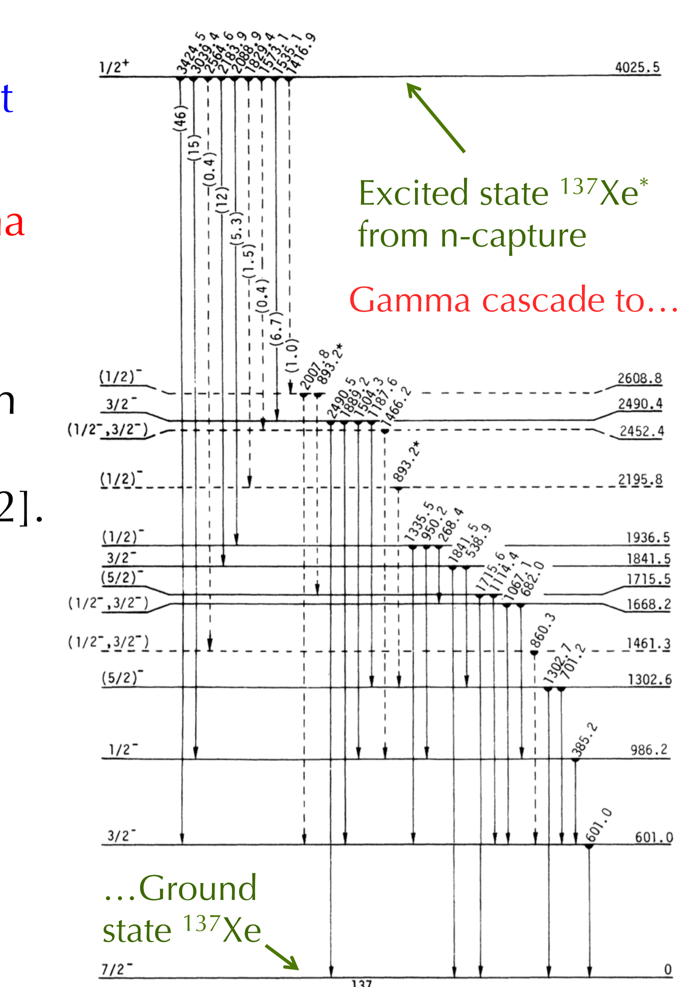
**Modeling and Identifying Prompt Capture Signals**

One chance to tag this background: identify the prompt capture signal!

Nuclear de-excitation by gamma emission from excited capture state to ground state.

Developed custom generators in Geant4 based on nuclear structure data (ENSDF, others) [2].




## References


[1] J.B. Albert, et al, The EXO-200 Collaboration. Search for Majorana neutrinos with the first two years of EXO-200 data. doi:10.1038/nature13432, also arXiv:1402.6956 [nucl-ex]

[2] Stanley G. Prussin, et al. Gamma rays from thermal neutron capture in Xe-136. Phys.Rev., C16:1001–1009, 1977.

$^{63}$Cu and $^{65}$Cu data extracted from the ENSDF database, http://www.nndc.bnl.gov.

[3] S. Miyake. Rapporteur Paper On Muons And Neutrinos. 1973. 13th International Cosmic Ray Conference, Denver, CO, vol. 5, 1973, p. 3638.

J. Beringer et al. Review of Particle Physics (RPP). Phys.Rev., D86:010001, 2012.