LZ’s Sensitivity to Supernova Neutrinos

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on behalf of the LUX-ZEPLIN (LZ) Collaboration

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Overview

This work is supported in the U.S. by its Department of Energy DoE (LZ) and by the National Science Foundation NSF (SNEWS 2.0). Many other funding agencies around the world support LZ as well (thanked at the end of this talk)

- Introduction to the LUX-ZEPLIN (LZ) experiment
  - Participation in the Supernova Neutrino Early Warning System 2.0 (SNEWS2.0) collaboration
- The neutrino signal originating from core-collapse supernovae (CCSN)
- LZ's neutrino detection mechanism: coherent elastic neutrino-nucleus scattering (CEvNS)
  - LZ's sensitivity to neutral-current (NC) neutrino interactions
- Modeling LZ's response to CCSN neutrinos: `νESPER` & `NEST`.
  - Developing the Neutrino Engine Simulating the Process of Energetic Recoils (`νESPER`) tool (python).
  - The Noble Element Simulation Technique (`NEST`) and the LZ simulation chain
- Results of LZ's sensitivity to neutrino signals from CCSNs.

v = nu = neutrino

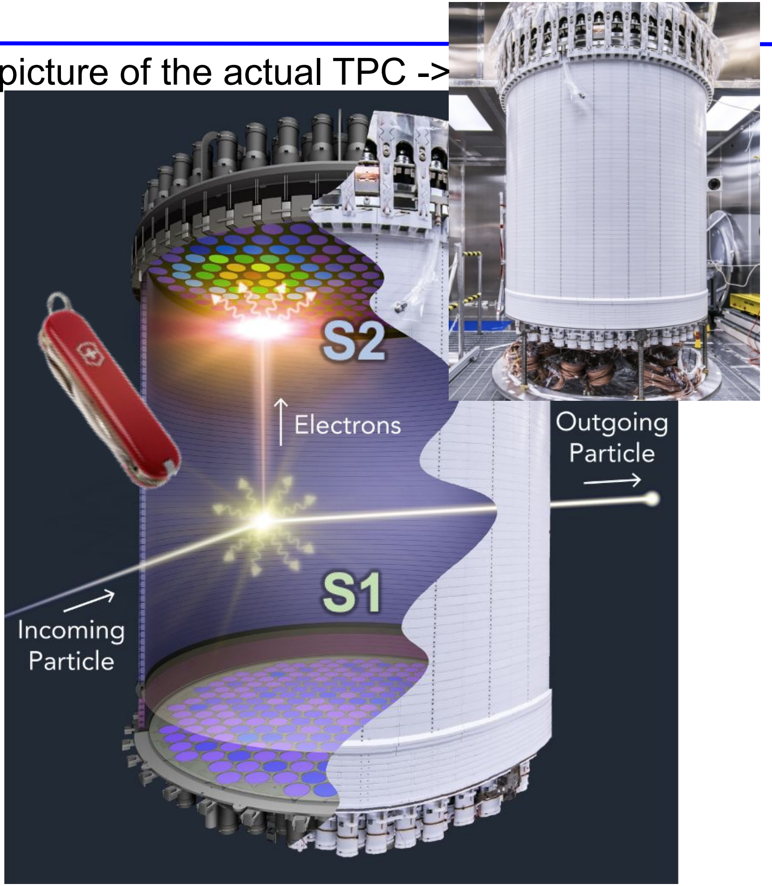
The LUX-ZEPLIN Experiment @SURF, South Dakota U.S.

- Primary focus: O(10-100 GeV) mass WIMP
  - Slow-moving, stable thermal relic, rarely interacting
  - No E&M interactions, but gravitational (plus.. ??)
- 2-phase Xe TPC: 5.5 tonne fiducial mass

mostly liquid

  - 7 tonnes "active," w/ PTFE for VUV light reflection
- Xenon: purifiable, dense, high Z, low 'W'
- Good position recon, and energy resolution
  - Z position from S2 - S1 timing (electron drift)
  - Radial position from S2 (top) light hit pattern
- Energy from sum of S1s and S2s together
- Signal v. BG discrimination from S2 v. S1
  - Nuclear recoils (NR: WIMPs, neutrons) versus electronic recoils (ER: betas, gammas, x-rays)
- Skin, GdLS OD for maximizing discovery potential: gammas, n's, and muons tagged
- BGs mitigated: detector material screening, Rn-reduced clean-room, purification UG

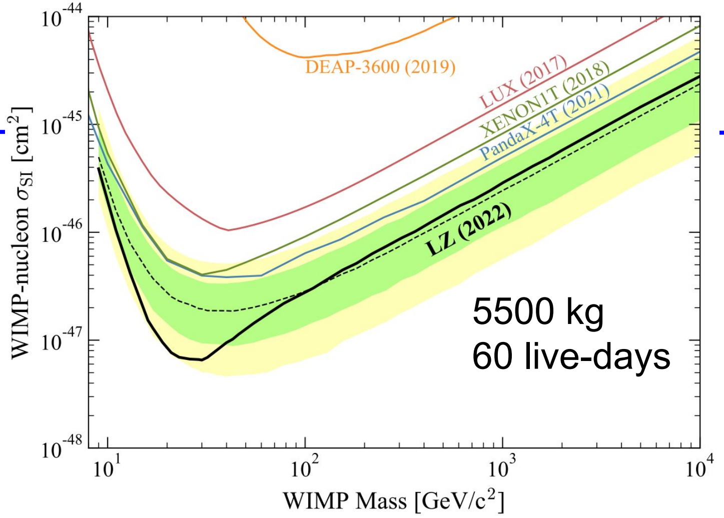
picture of the actual TPC ->

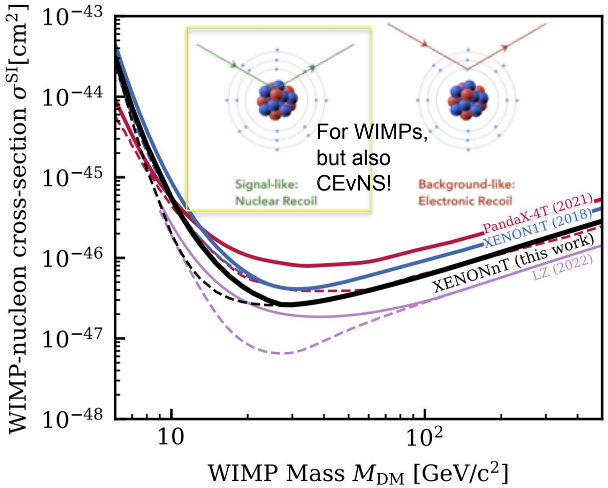


https://arxiv.org/abs/2207.03764

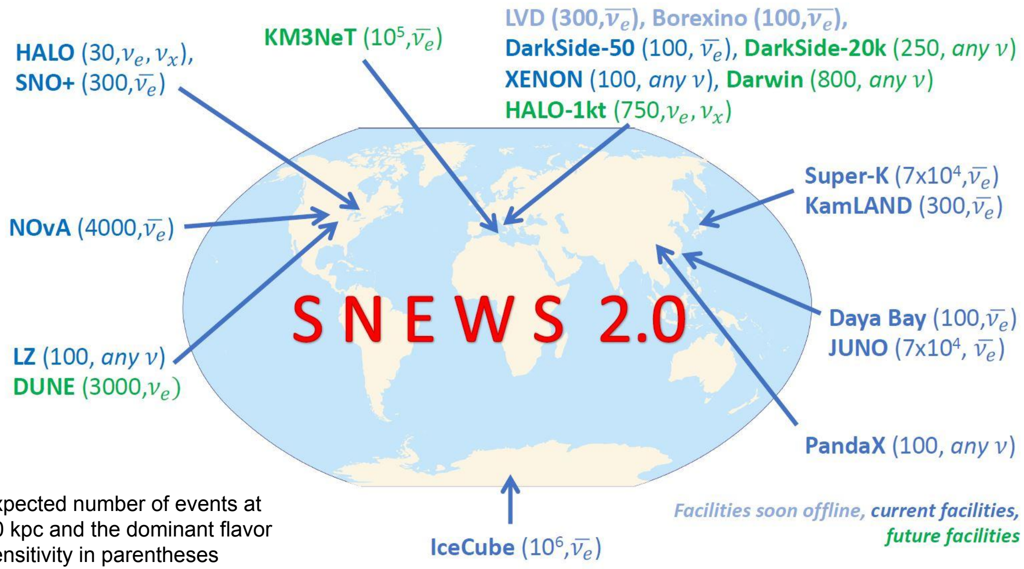
First Results: Strictest WIMP Limits

- A US Dept. of Energy flagship G2 experiment
- SR1 (Science Run 1) did not find dark matter but measured zero better than anyone else :-)
  - Over 4 orders of magnitude in possible WIMP mass
- Most stringent statistical limits in world placed on the WIMP-nucleon scattering cross-section
  - Spin-independent (pictured), spin-dependent (n & p)
- Sufficiently high electric field for excellent BG discrimination of remaining beta (Rn) events
  - ~99.9% discrimination (D-D) and 99.75% (FLAT NR)
- Bias mitigated: all cuts based on calibrations, side-band populations, vetoes (skin & OD).
  - This was only the first, short run. Next one “salted”
- But, this is not the reason we are here today. We’re here for supernovae, and their neutrinos





Detection of Neutrinos From CCSN: The Science Potential



expected number of events at 10 kpc and the dominant flavor sensitivity in parentheses

Elise McCarthy, a University of Rochester PhD graduate student in Prof. Frank Wolfs' group, is LZ's point of contact with SNEWS.

LZ is a member experiment of the Supernova Neutrino Early Warning System 2.0 (SNEWS2.0) collaboration.

Neutrinos from the neutronization & accretion phases are emitted prior to the explosion. They constitute the earliest-to-arrive signal originating from a galactic CCSN.

SNEWS2.0 is a consortium of many neutrino-sensitive experiments, aiming to pool info from a CCSN detection and generate a rapid alert to provide to the optical astronomy community.

Map of locations of experiments at left

SNEWS2.0 Collaboration: LZ’s Participation

The SNEWS2.0 network formulates an alert based on signals from participating experiments.

- When an alert is generated it is disseminated to the participating experiments and observational astrophysicists.
- SNEWS2.0 will play a leading role in coordinating the response to any CCSN observation.

LZ has implemented the ability to receive alerts from the SNEWS2.0 network.

- This network and communication protocol are still in the testing and development phase.
- In the near future, LZ will provide a heartbeat signal to SNEWS2.0.
- We are developing a CCSN neutrino trigger in LZ.
    - LZ will be able to provide this alert to the SNEWS2.0 network.
    - This trigger will not impact LZ’s primary science goals.

Motivations for Today's Talk. Neutrinos From CCSN

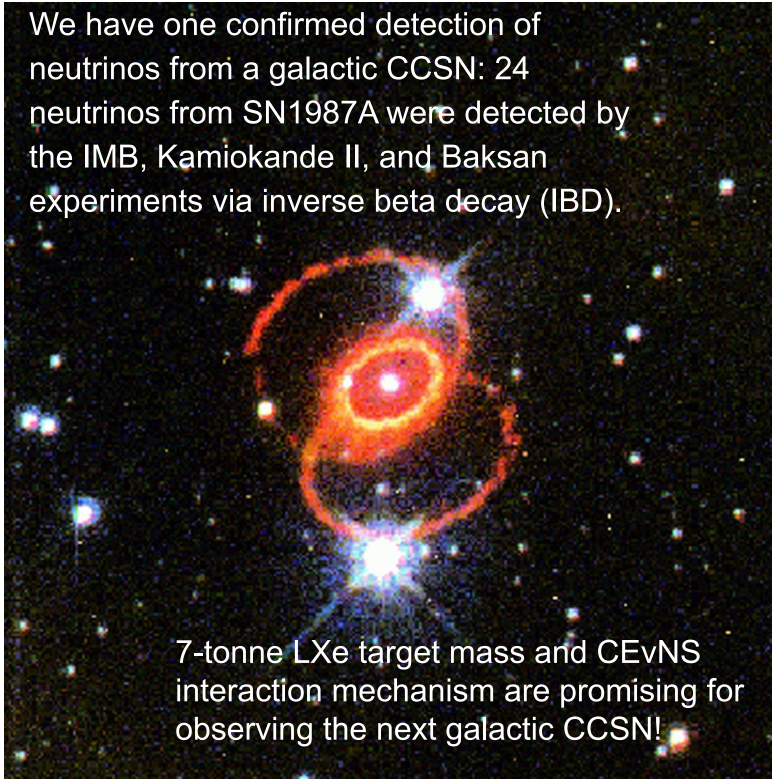


Image credit: ESA/Hubble, 9 June 1997

LZ will be sensitive to these neutrinos via coherent elastic neutrino-nucleus scattering (CEvNS)

- Studies by Aalbers et al. 2022 (arXiv:2203.02309) for XLZD and Dev Khaitan (Rochester) 2018 for LZ itself (arXiv:1801.05651)
- CC and non-CEvNS NC channels too but our dominant interaction mechanism will be CEvNS NC

In LZ, we have now studied:

- The average number of neutrino interactions
- The energy deposition spectrum
- The time profile of these interactions

The findings are being used to develop an LZ DAQ trigger for CCSN neutrino signals.

νESPER: Simulating LZ's response to Supernova Neutrinos

LZ has two simulation paths:

- A full-chain that employs tools like the `Geant4`-based `BACCARAT`.
  - Used to characterize and produce simulations to validate results. Has `NEST` underneath
- A fast-chain that employs tools like `NEST` (Noble Element Simulation Technique) more directly
  - Used to study sensitivity and make projections.
  - `NEST` is capable of accurately modeling LXe detector response.

For studying neutrino energy deposition in LZ's TPC, we developed a simulation package called `νESPER` (Neutrino Engine Simulating the Process of Energetic Recoils).

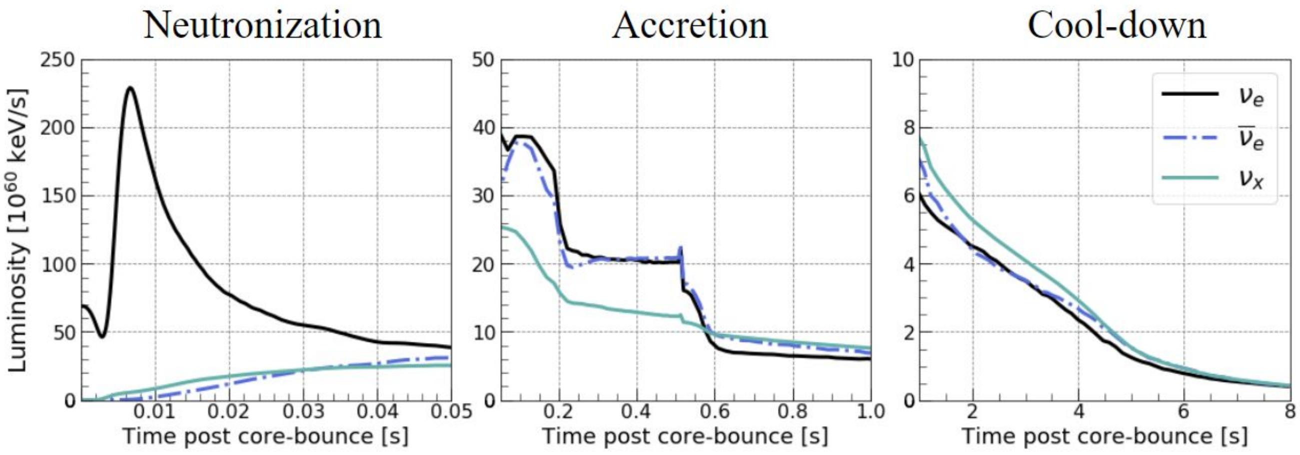
- This package bridges the gap between different neutrino emission models and the standard LZ detector response simulation tools.
- Neutrino emission models use different formats and require dedicated processing harnesses to be made compatible with LZ simulation tools.

Neutrinos From CCSN: Model Details

We have implemented 1D and 3D models from the simulations group at MPI Garching in νESPER.

- Today we present results from the LS220 27 and 11 solar mass models. https://arxiv.org/abs/1508.00785
  - These are spherically symmetrical 1D models simulated using the PROMETHEUS-VERTEX SN code.
  - These models treat the different flavours of neutrinos individually.
  - These models do not include neutrino oscillation.
    - This does not limit our studies as neutrino oscillation would not impact the number of CEνNS interactions in LZ.
  - These models are not self-exploding and are artificially exploded at ~0.5 s post core-bounce.
    - This explosion triggers the transition from the accretion phase to the cool-down phase.
  - These progenitors produce O(1) solar mass proto-neutron star remnants.
- We have made comparisons of neutrino emission profiles between 1D and 3D models.
  - Except for the black hole forming models, we find qualitative agreement in the time profile and neutrino energy spectrum of these emissions.
    - This includes models where the SASI (standing accretion shock instability) phenomenon is observed.

Neutrinos From CCSN: Emission Phases



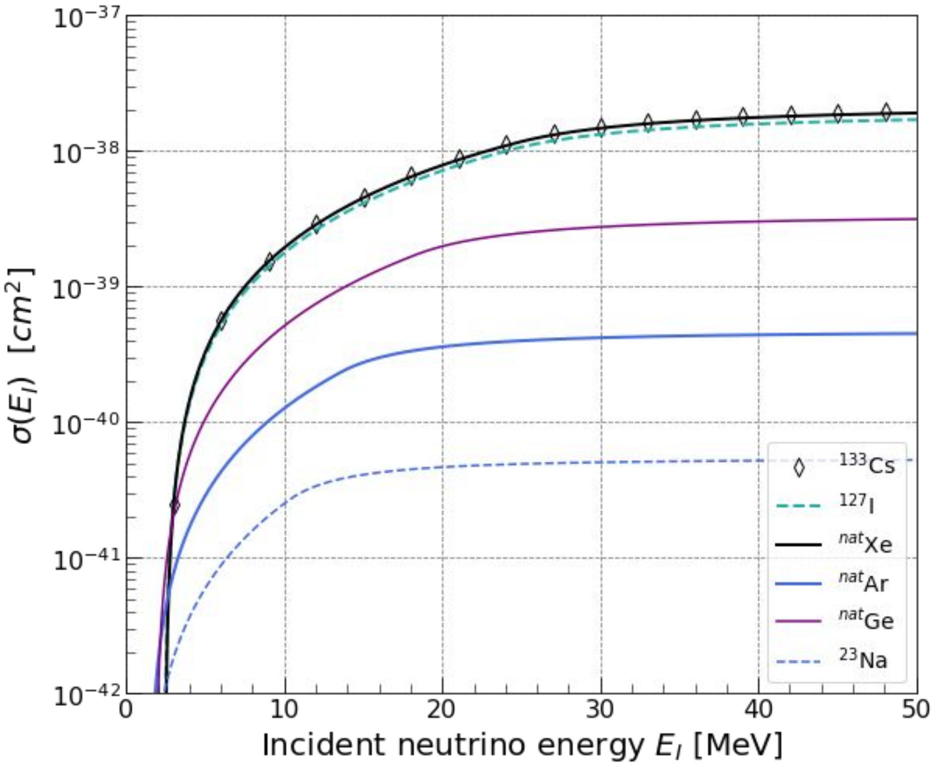
We have implemented 1D and 3D models from the [simulations group at MPI Garching] in νESPER.

- These models report binned neutrino luminosity, <E>, and <E^2> as a function of time.
  - The neutrino luminosity is divided by flavor.
- We use the luminosity and <E> to calculate the flux at LZ.
- We use the <E> and <E^2> to calculate the the neutrino spectrum. https://arxiv.org/pdf/1211.3920.pdf
- **Many thanks to the SNEWS 2.0 collaboration and the Garching group for providing access to these models!**

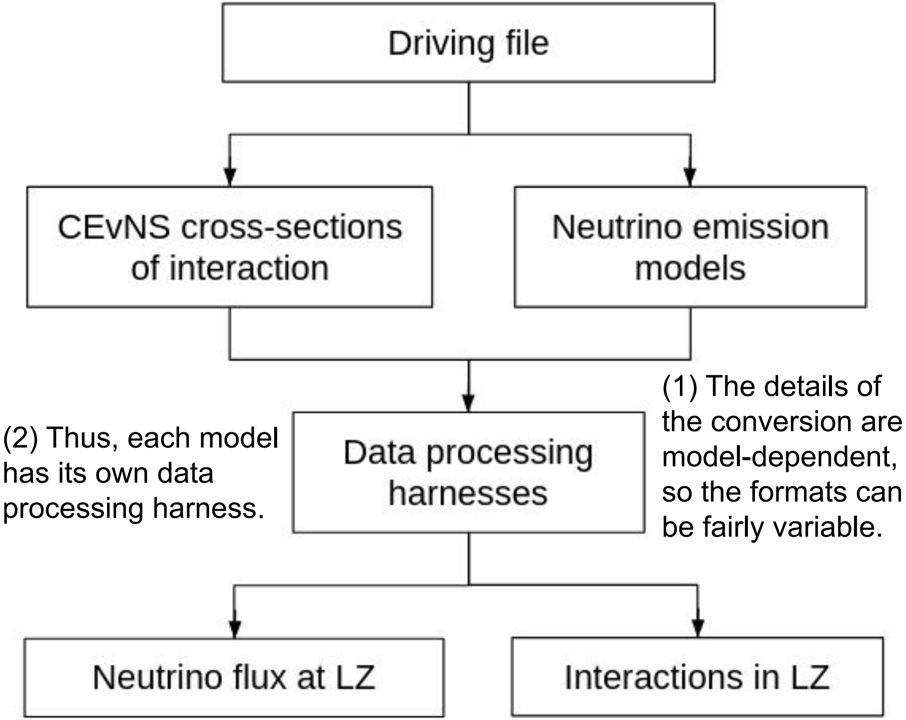
Above is an example of an 11 solar mass progenitor through the 3 stages of a CCSN.

Neutrino Detection Within LZ: CEvNS (NC)

- LZ will observe the neutrinos emitted by a galactic CCSN via CEvNS (it would be a first).
- CEvNS is a weak neutral-current interaction in which incident neutrinos of all flavors scatter elastically with a nucleus
  - First discovered (measured) only a few years ago (COHERENT, arXiv:1708.01294) in CsI, then LAr
  - In LXe, CEvNS events are *O*(1 keV) NR (recall: nuclear recoils).
- In `νESPER`, we have implemented a calculation for the cross-sections and energy deposition via CEvNS interactions.
  - We model the CEvNS as an elastic scatter between two hard spheres.



νESPER: Development and Architecture



(2) Thus, each model has its own data processing harness.

(1) The details of the conversion are model-dependent, so the formats can be fairly variable.

νESPER is a Python 3.6 simulation package we have developed.

- Able to handle different neutrino emission models

We have access to multiple different models through SNEWS.

- We used Garching models for development purposes.

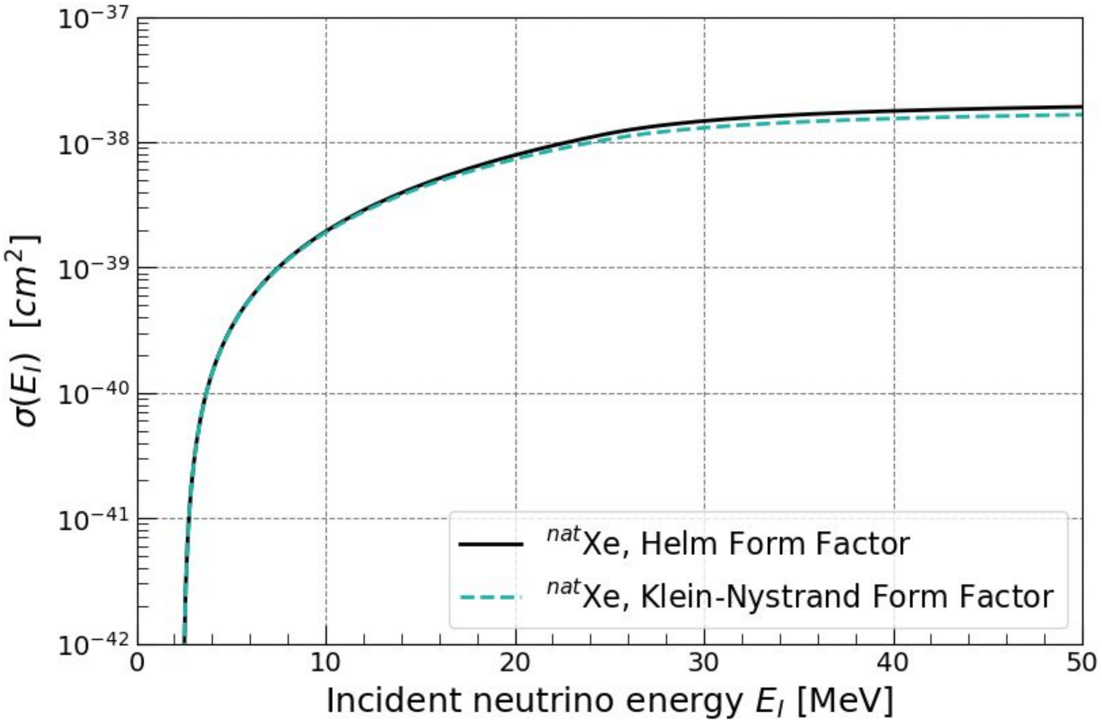
The processing harnesses are configurable.

- An end user will be able to select a great deal (next slide).

The Flexibility of νESPER's Processing and Design

A νESPER user is able to easily modify the simulation configuration. This includes:

- Distance from Earth to CCSN progenitor.
- Target material for CEvNS interaction.
- Relative abundances of target material isotopes.
- Nuclear form factors:
  - Default: Helm (standard for LXe dark matter detectors)
  - Klein-Nystrand (COHERENT's default form factor)
  - Hoferichter, Menéndez, Schwenk (future work)
- Detection threshold -- smallest recoil energy that should be considered as part of the calculations.



vESPER: Outputs

From the neutrino emission model, the processing harness calculates the interactions in LZ's TPC.

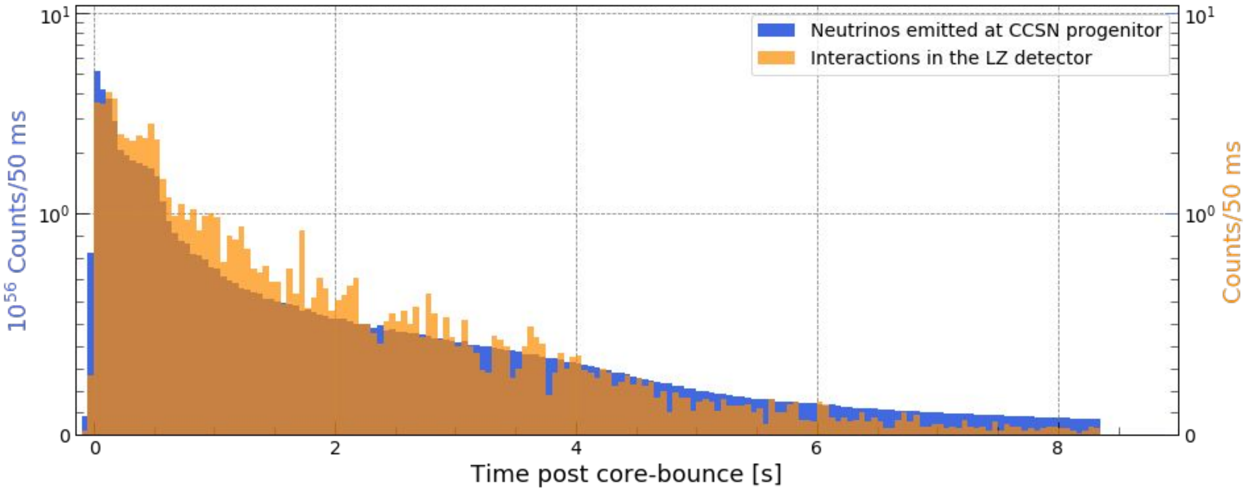
The neutrino emission data is binned in time. vESPER calculates, using the CEvNS cross section of interaction and the flux in that bin, the number of neutrinos that will interact.

- We assume the flux is flat within the binned neutrino emission, thus we assign a time t, sampled uniformly within that bin.
- From the flux in that time bin, vESPER constructs a probability distribution of incident neutrino energies E_I.
    - The selected value of E_I determines the maximum value of E_R (energy of Xe recoil)
- CEvNS interactions are modeled as elastic scatters between two hard spheres so all recoil energies, between 0 keV and the maximum value determined by E_I, are equally probable. vESPER selects E_R from a uniform distribution over this range.
    - The mass of the target nucleus is assumed to be the average of all stable isotope masses, weighted by relative abundance. We assume the natural abundance, here -- LZ is quite close to that

Results From νESPER

To produce preliminary results, we simulate a 27 solar mass progenitor 10 kpc from LZ.

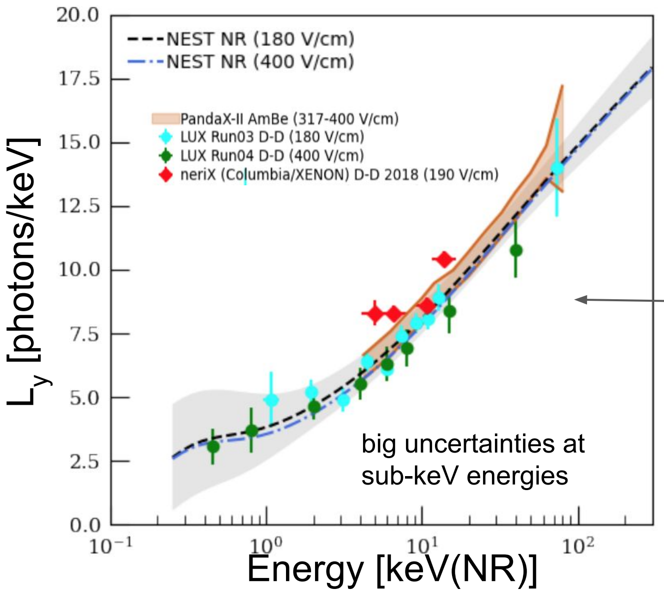
- Before applying any detector modeling - we assumed a 0.1 keV threshold (for NR).
    - This is 'interaction threshold'
    - We will explore different detector/analysis thresholds in a few slides using NEST.
- For an average of 100 simulations, we show the number of neutrinos emitted at the progenitor (blue) and the number of interactions in the LZ TPC (orange).



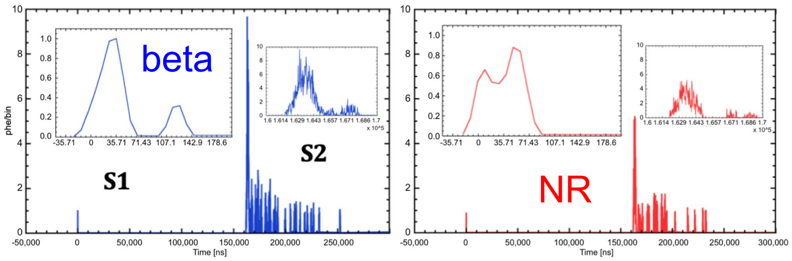
νESPER does not apply any time delay to the interactions in LZ. It is expected that the average interaction rate will be consistent with the emitted flux.

- The emitted flux is consistent with the average interaction rate from 100 simulations.
- The above figure is a semi-log-y plot. The y scales are linear between 0 and 1, then logarithmic between 1 and 10.

Next Steps: Studies With NEST and the Full LZ Sims Chain



[arXiv:2211.10726](https://arxiv.org/abs/2211.10726)



To explore the physics reach of a CCSN neutrino signal detection, we need to feed our simulation outputs into NEST and then the full LZ sims chain.

- ○ Working with the NEST collaboration & the LZ sims coordinator / group to tailor these simulations for our studies.

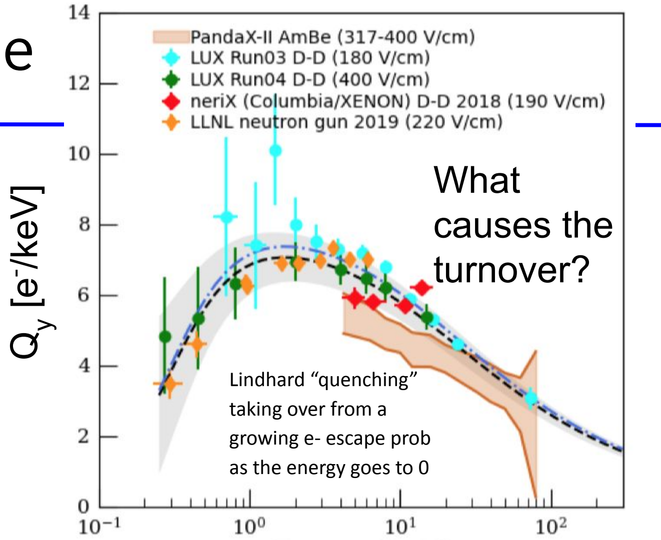
Questions we want to explore:

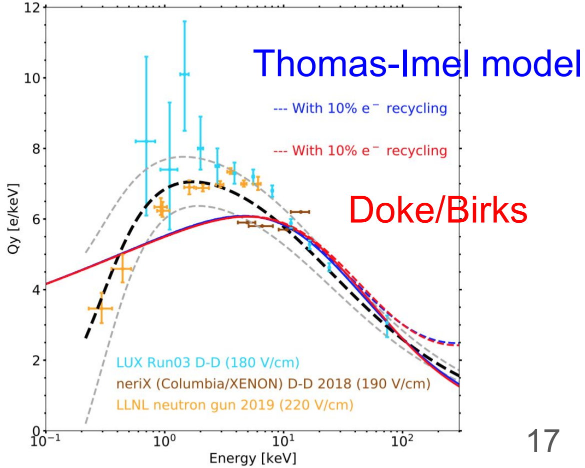
- What is the typical response of LZ to the Garching neutrino emission model in terms of the S1 and S2 signals? *initial results today*
- What is the largest distance at which a 27 solar mass CCSN is detectable? *initial results today*
- From the neutrino signal in LZ, can we calculate the total neutrino flux at LZ from a CCSN? *WiP*
- Can we calculate the neutronization burst time? *WiP*
- What is LZ's signal in other neutrino models? *WiP*

Future Work: CC interactions in the LXe, the water, and the GdLS.

NEST: The Noble Element Sim Technique

- To model LZ's response in terms of the S1 and S2 signals, vESPER's output will be used as input to the LZ sim chain
    - Which is based upon NEST at its lowest levels (the Ly and Qy)
- What is NEST? Open-source Monte Carlo software for Xe and Ar (liquid and gas). Detector-agnostic
    - Available in both python and C++ (also Garfield++ and ROOT)
    - https://github.com/NESTCollaboration/nest and https://github.com/NESTCollaboration/nestpy (GitHub)
- S2 (scintillation from ionization) only analysis will be more key due to the incredibly low energies involved
    - Good news: extremely well calibrated\modeled, even sub-keV
    - Bad news: there are S2-only backgrounds like single/few e-'s
- LZ's DAQ triggering with ~100% efficiency at 5e-
    - S2 of about 200 phd (g2 ~ 40 phd per ionization electron)
- nest.physics.ucdavis.edu/ (NEST started @UCDavis)





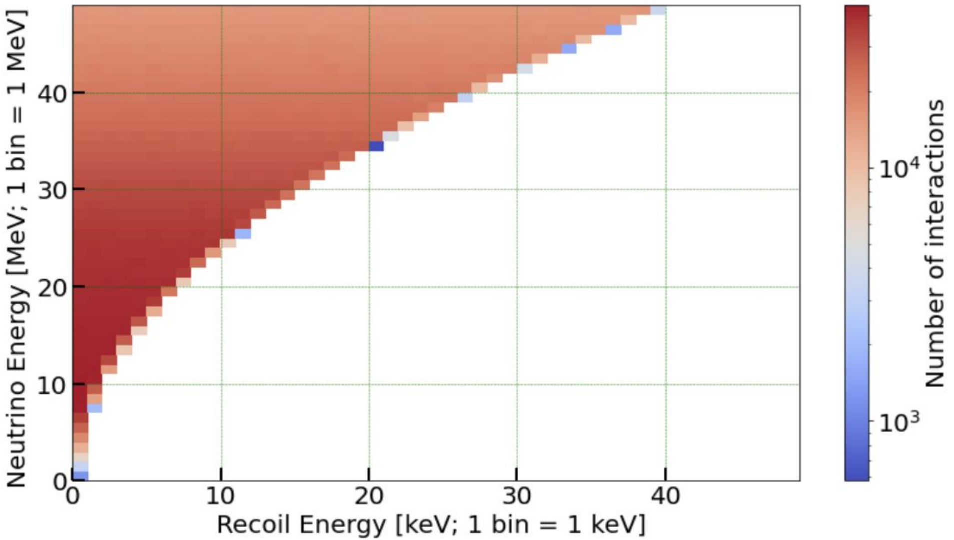
LZ’s Neutrino Sensitivity

To study LZ’s sensitivity to neutrinos we employ `νESPER` and `NEST` and start with a “flat” neutrino spectrum.

- In `νESPER`, we simulate 1e19 neutrinos at each energy between 1 and 50 MeV in steps of 1 MeV.
  - We chose 1E19 as it produced 1E3 entries for a 1 MeV incident neutrino.
- We record the number of interactions and their energies in LZ.
  - The elastic scatter means, for a given incident neutrino, all energy depositions up to the maximum are equally likely.
- No additional normalization.

We find that even for a 10 MeV neutrino, we have <2 keV of energy deposition in LZ’s TPC.

- We propagate these energies through NEST.
- We assume the detector settings used in LZ’s first science campaign.



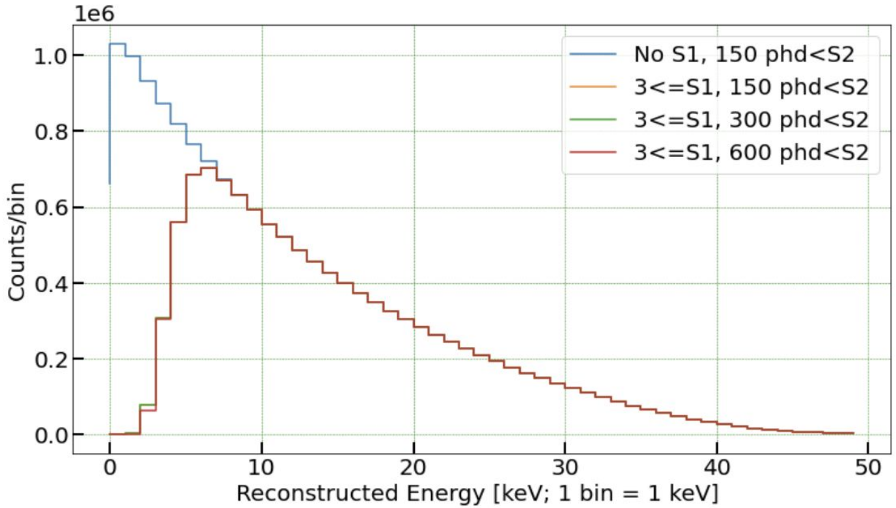
Reconstructed Energy Spectra

We used the 50 x 1E19 neutrinos from the vESPER / NEST simulations for studying LZ's sensitivity.

- Of these neutrinos, 17,305,038 would've interacted with the LXe of LZ.
- We applied different detector/analysis thresholds.
  - We apply a requirement on the S1 coincidence.
  - We apply a requirement on the S2 area.
- We present the detection efficiency for these different configurations.

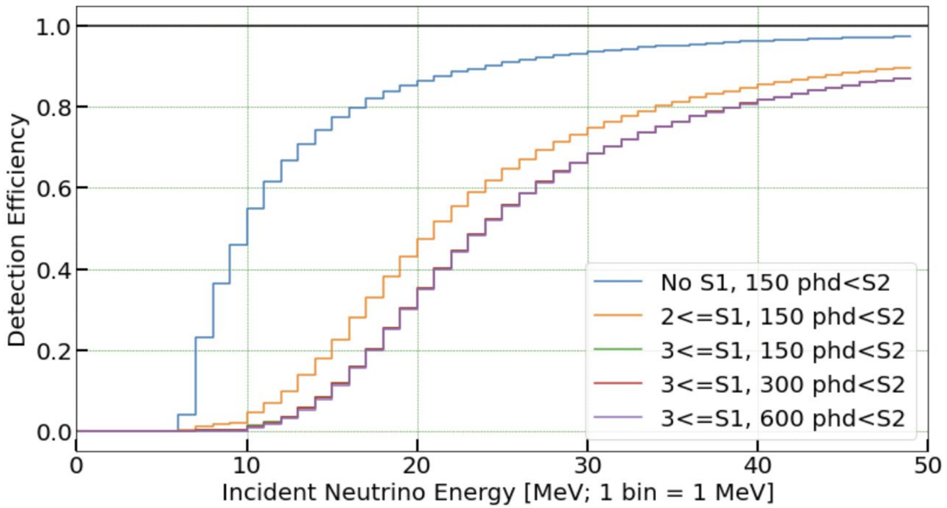
We find that the driving factor for sensitivity is the S1 requirement.

- There are only small losses due to different S2 thresholds.



Detection Efficiency for a flat neutrino spectrum between 1 and 50 MeV.			
	No S1 requirement	2 <= S1	3 <= S1
150 phd < S2	91.0%	71.1%	65.2%
300 phd < S2	89.6%	71.0%	65.2%
600 phd < S2	83.6%	70.6%	65.1%
Out of 50 x 1E19 neutrinos uniformly simulated between 0 and 50 MeV.			

LZ General Nu Sensitivity, as Function of Analysis Thresholds



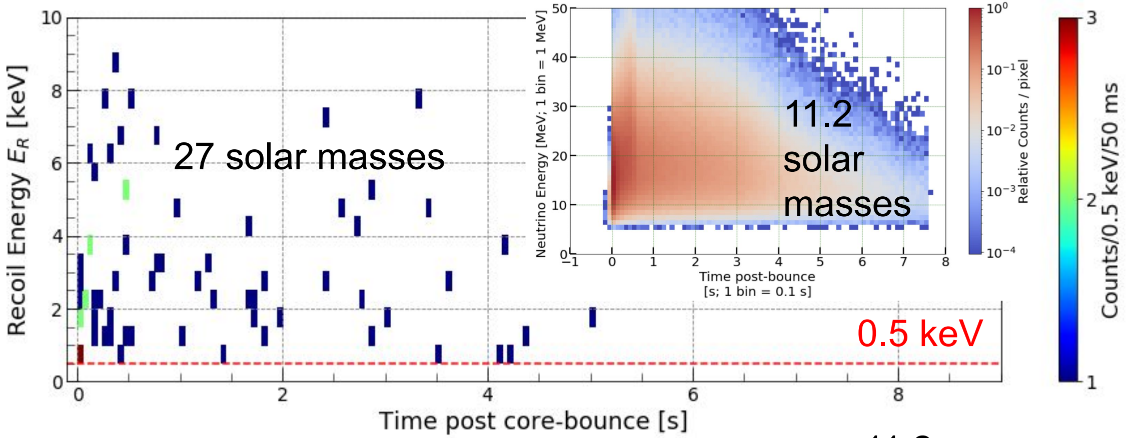
We find that the driving factor for sensitivity is the S1 requirement, of course

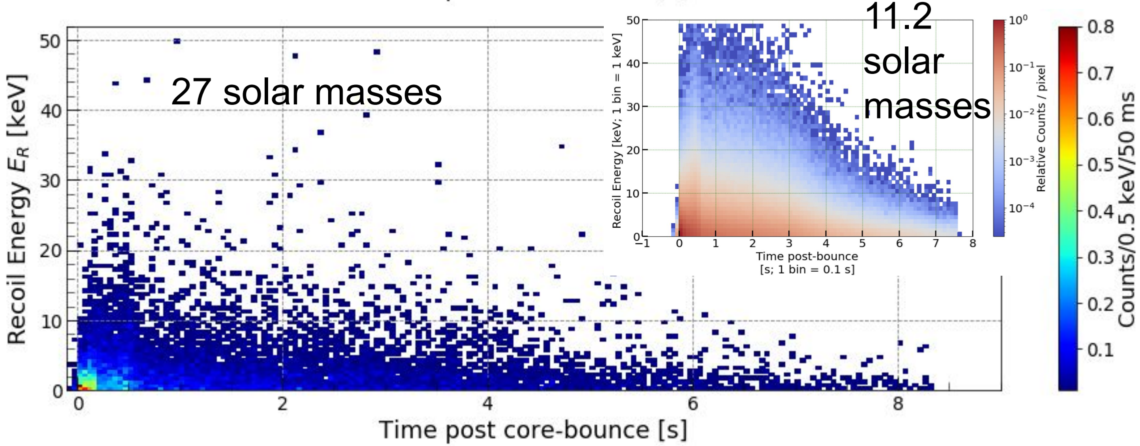
- There are only small losses due to a different S2 pulse area (phd, detected photons) threshold.
- This all certainly needs to be balanced with the background rejection power.

Using these simulations we can calculate our efficiency to detect neutrinos with different incident energies.

- If we remove the S1 requirement, we have >=50% detection efficiency for neutrinos of 10 MeV and higher energies
- If we implement the usual S1 requirement of 3-fold coincidence, we achieve 50% detection efficiency at 25 MeV neutrino energy.
- Even for 50 MeV neutrinos, we do not achieve 100% efficiency.
    - This is due to the flat energy deposition spectrum (per neutrino *E*) that can always produce responses below our thresholds.

Results From νESPER (Continued)





<u>LZ is sensitive to neutrinos emitted during all phases of a CCSN event</u>

Top Left: Heat map of observations from 1 CCSN (27 solar mass, 10 kpc)

Bottom Left: Average heat map of interactions from 100 such CCSNs.

Top Right: Neutrinos emitted from an 11 solar-mass CCSN have an average energy between 10 and 15 MeV.

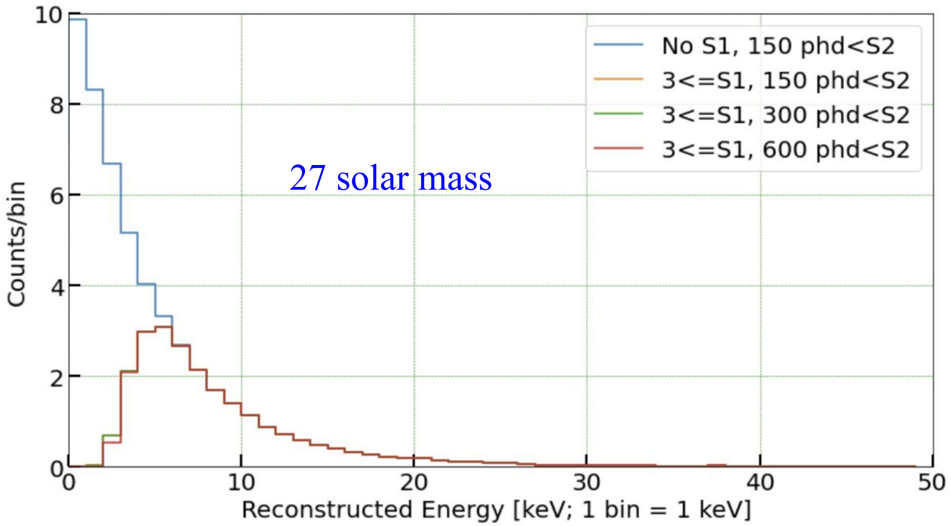
- But, have a broad distribution with neutrino energies as high as 100 MeV during the accretion phase.

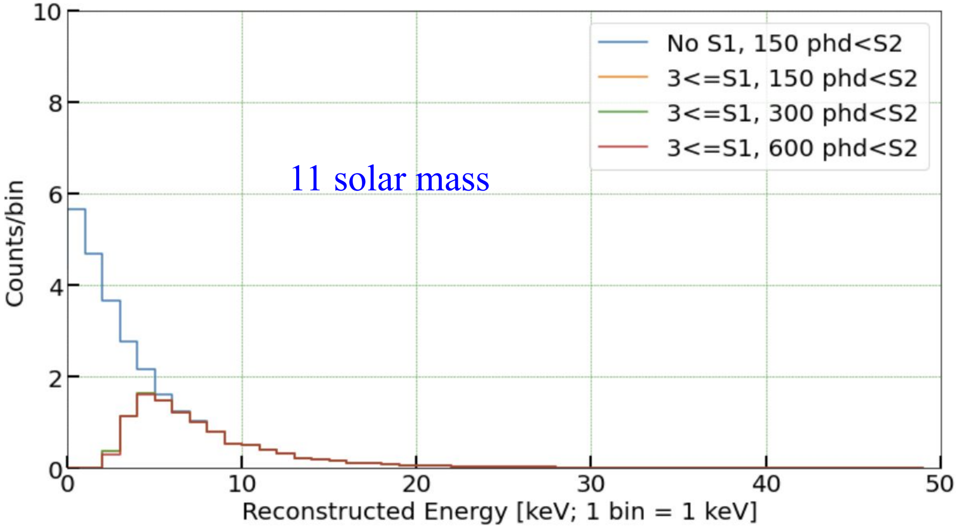
Bottom Right: Recoil *E* spectrum (Xe) (oversampled example) v. time. 0.05 kpc

Our max interaction rate (as expected) will coincide with the neutronization peak. Most recoil *E*s < 10 keV

νESPER allows us to study neutrino interactions in terms of the variables E_I, E_R, the two energies, and time t.

27 versus 11 solar masses: LZ Sensitivity to CCSN Neutrinos





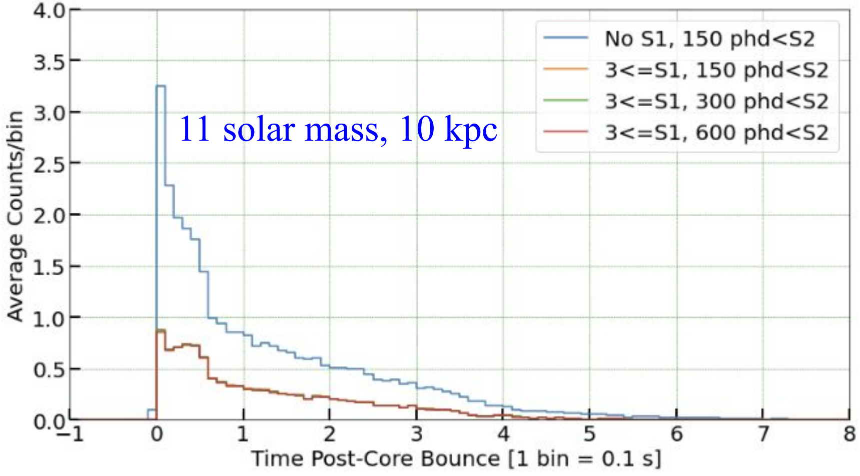
	No S1 requirement	2 <= S1	3 <= S1
150 phd < S2	58	29	23
300 phd < S2	54	29	23
600 phd < S2	46	28	22

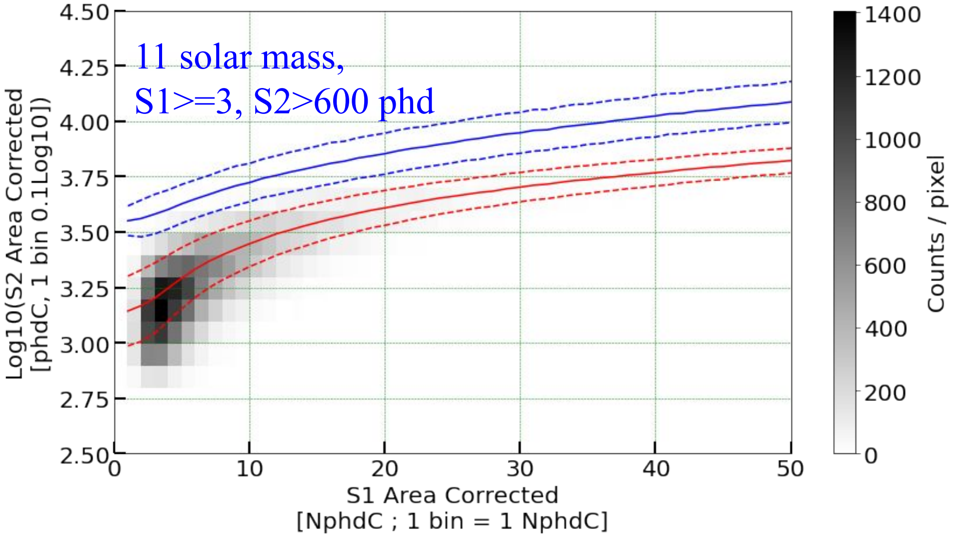
Average number of neutrinos detected from 1000 simulations of 27 solar mass CCSN at 10 kpc from LZ.

	No S1 requirement	2 <= S1	3 <= S1
150 phd < S2	31	14	10
300 phd < S2	28	14	10
600 phd < S2	23	13	10

Average number of neutrinos detected from 1000 simulations of 11 solar mass CCSN at 10 kpc from LZ.

The Neutrino Signal in LZ





The neutrino signal is lower than the standard NR band.

- Resembles a low-mass WIMP signal.

We see that implementing an S1 requirement reduces the number of interactions in LZ.

- This impacts the signal seen during all phases of CCSN neutrino emission.
  - Largest impact visible during the neutronization peak.
- Little-to-no visible impact by increasing the S2 threshold from 150 to 600 phd.

		27 Solar Mass @ 10 kpc		11 Solar Mass @ 10 kpc	
Phase	Duration of phase	No S1, 150 phd <S2	3<= S1, 150 phd <S2	No S1, 150 phd <S2	3<= S1, 150 phd <S2
Neutronization	0-0.05 s	2.5 events	0.5 events	2 events	0.5 events
Accretion	0.05-0.5 s	17 events	8 events	9 events	3 events
Cool-down	0.5-10 s	38 events	14 events	19 events	7 events

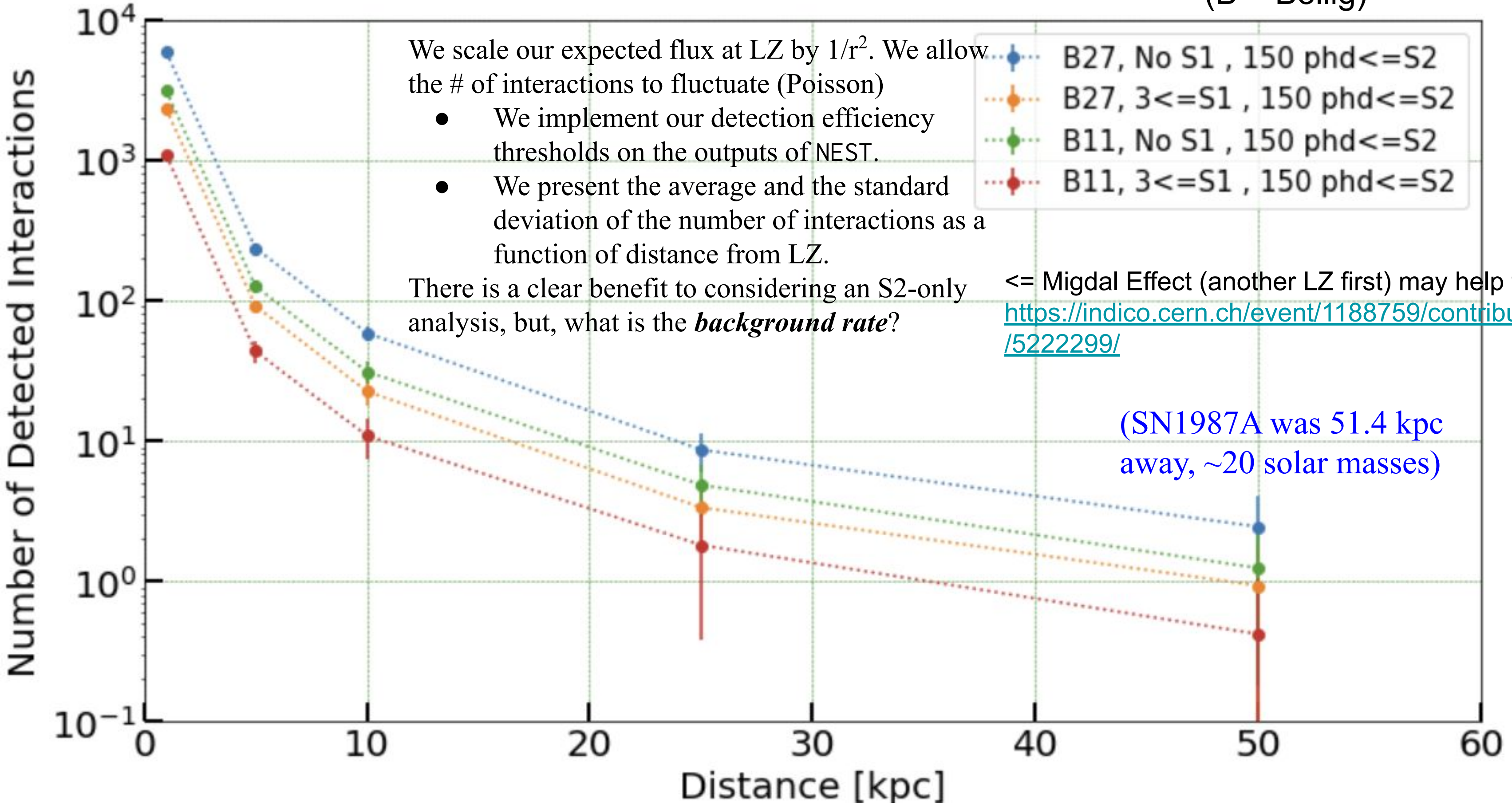
Same Masses, but Sensitivity Presented vs. Distance Now

(B = Bollig)

We scale our expected flux at LZ by $1/r^2$. We allow the # of interactions to fluctuate (Poisson)

- We implement our detection efficiency thresholds on the outputs of NEST.
- We present the average and the standard deviation of the number of interactions as a function of distance from LZ.

There is a clear benefit to considering an S2-only analysis, but, what is the ***background rate***?



<= Migdal Effect (another LZ first) may help too https://indico.cern.ch/event/1188759/contributions/5222299/

(SN1987A was 51.4 kpc away, ~20 solar masses)

Implementation of a CCSN Neutrino Trigger (Soon)

In the next year, we will implement an LZ CCSNv trigger.

- Within LZ, we are in complete control of the DAQ’s firmware development and implementation.
- This would be a first for SNEWS2.0 from its participating CEvNS-sensitive experiments.
- This would be a type of DAQ trigger which would not impact the underlying WIMP-search acquisition.
    - We will define the LZ follow-up for when such a trigger is generated in coordination with SNEWS2.0.

Regardless of this trigger, we can always go back to look at events captured during a CCSN given the default S2 trigger

Summary

- LZ is more than dark matter, more than WIMPs - may see CCSNv, in a distinct way (CEvNS) cf. DUNE / other, traditional (huge-scale, MeV-GeV) nu projects
- We have developed a simulation framework, `vESPER`, to study LZ’s response to neutrinos from a galactic CCSN. It feeds into `NEST`, which showed S1 hard
- We produced a sensitivity curve for a flat nu spectrum at different thresholds
- Sensitivity study repeated for 27 and 11 solar mass CCSN progenitors near the galactic center (10 kpc away) and elsewhere.
    - From first example progenitors LZ is capable of observing neutrinos from all phases of the CCSN event, from the neutronization peak to the cool-down, but has limited sensitivity outside of our own Milky Way galaxy.
- More work: additional models, BGs v. thresholds, exploration of physics reach of a CCSN neutrino detection in LZ with vE spec, CCSN trigger implementation

LZ (LUX-ZEPLIN) Collaboration: Its People

37 Institutions: 250 Scientists, Engineers, and technical staff

@lzdarkmatter

https://lz.lbl.gov/

- Black Hills State University
- Brookhaven National Laboratory
- Brown University
- Center for Underground Physics
- Edinburgh University
- Fermi National Accelerator Lab.
- Imperial College London
- King's College London
- Lawrence Berkeley National Lab.
- Lawrence Livermore National Lab.
- LIP Coimbra
- Northwestern University
- Pennsylvania State University
- Royal Holloway University of London
- SLAC National Accelerator Lab.
- South Dakota School of Mines & Tech
- South Dakota Science & Technology Authority
- STFC Rutherford Appleton Lab.
- Texas A&M University
- University at Albany, SUNY
- University of Alabama
- University of Bristol
- University College London
- University of California Berkeley
- University of California Davis
- University of California Los Angeles
- University of California Santa Barbara
- University of Liverpool
- University of Maryland
- University of Massachusetts, Amherst
- University of Michigan
- University of Oxford
- University of Rochester
- University of Sheffield
- University of Sydney
- University of Texas at Austin
- University of Wisconsin, Madison

US UK Portugal Korea Australia

LZ Collaboration Meeting
University Of Maryland
5th-7th January 2023 (most recent)

U.S. Department of Energy Office of Science

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THANK YOU to our sponsors and 37 participating institutions!

Thanks! Any Questions??

Supplementary Slides

$$
\begin{array}{l}
S\,N\,v \\
\quad\;\; v\;\; E\,S \quad\;\; P\,E\,R \\
\;\; N\quad E\,S\,T\,p \qquad\qquad y \\
\hline
S\,N\,v\,E\,S\,T\,p \qquad\qquad y
\end{array}
$$

CEvNS: Differential cross section of interaction

The differential cross section of interaction is given by

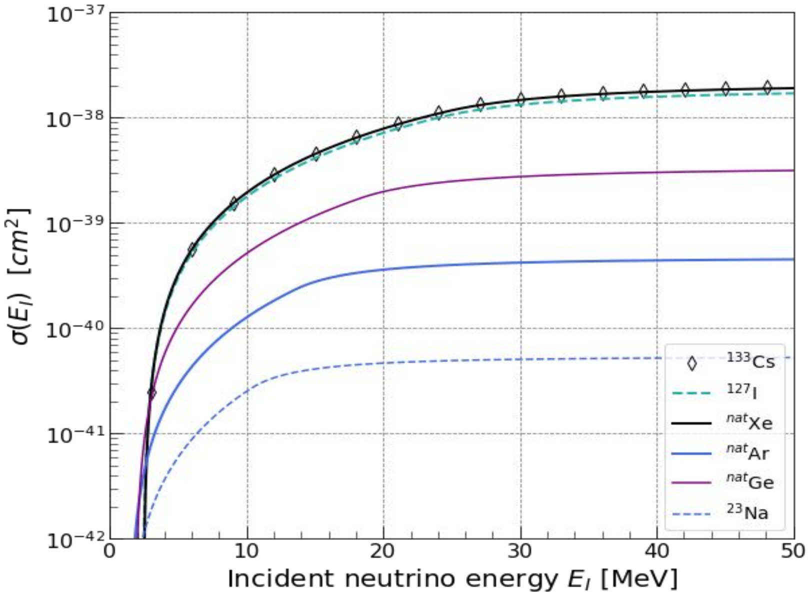
$$\frac{d\sigma}{dE_R} = \frac{G_F^2}{2\pi} M \left[2 - \frac{2E_R}{E_I} + \left(\frac{E_R}{E_I} \right)^2 - \frac{M E_R}{E_I^2} \right] \frac{Q_W^2}{4} F^2(Q^2)$$

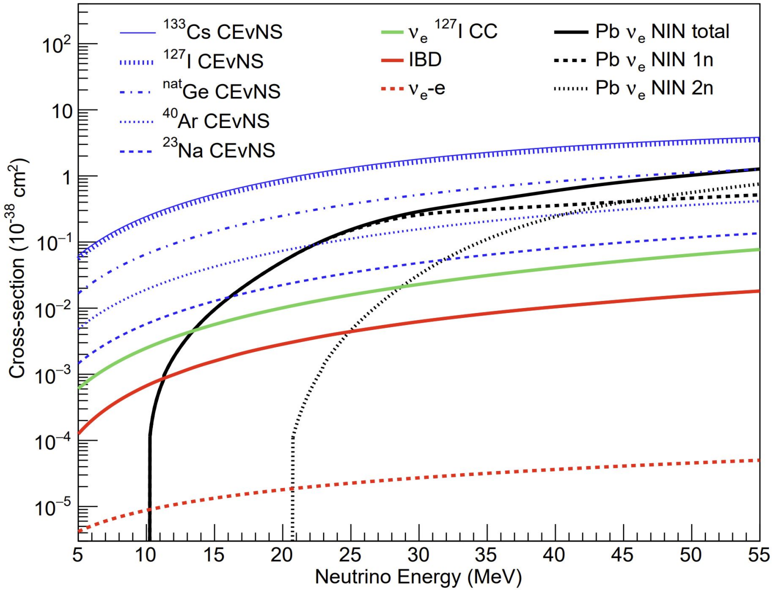
where

$$Q_W = N - [1 - 1 sin^2(\theta_W)] Z, \;\; sin^2(\theta_W) = 0.213$$

is the weak mixing term, and $F(Q^2)$ is the nuclear form factor as a function of the momentum transfer Q. `vESPER` utilizes the Helm form factor.

νESPER cross-check: total cross-section of interaction





Left: Total cross-section of interaction for many target materials, computed by νESPER.

Right: Total cross-sections of interaction obtained by Scholberg (2018).

νESPER computes the CEvNS cross-section of interaction internally. To verify the accuracy of this calculation, we compute cross-sections for ^{133}Cs and ^{127}I using νESPER and compare to the values obtained by Scholberg (2018).

This is an important cross-check, as νESPER uses the total cross-section to obtain the expected number of interactions.
Also, Xe cross-section is expected to follow Cs and I closely given a similar mean nucleon number of ~130 so we have faith in the Xe calculation.

Converting the Garching model to a flux at LZ

For this model, the data is provided to us as a time series of neutrino luminosity, <E>, and <E^2>.

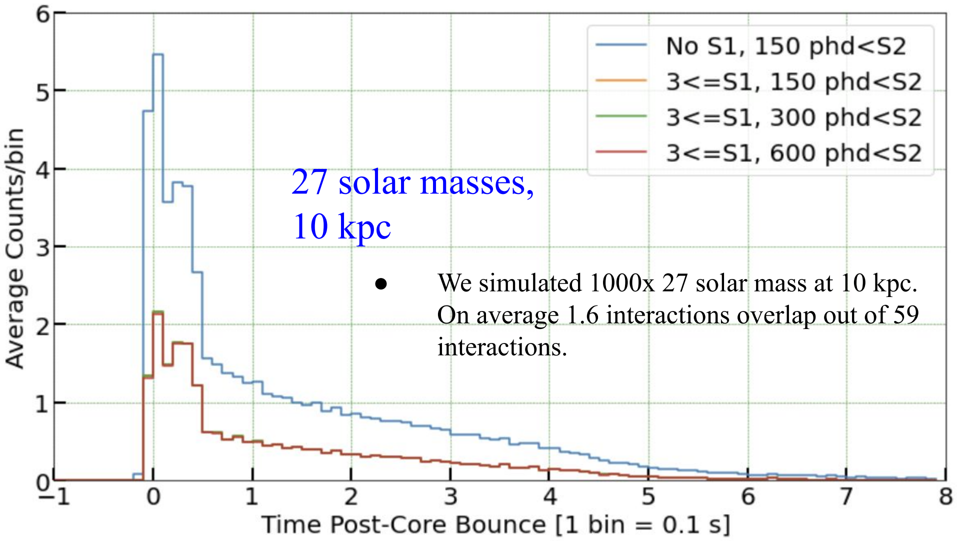
We reconstruct the neutrino flux as a function of neutrino energy and time using the equations at right. This approach is described in [Tamborra et al. (2012)](#).

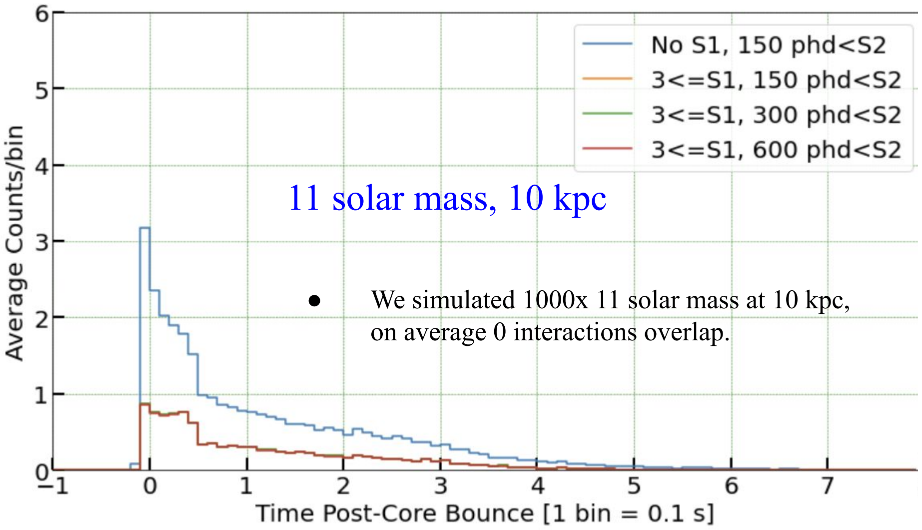
Alpha is a parameter describing the degree of spectral pinch - alpha = 2 is a Maxwell-Boltzmann spectrum, while alpha = 2.30 corresponds to the Fermi-Dirac distribution with 0 chemical potential.

$$f_\nu(E) \propto E^\alpha e^{\frac{-(\alpha-1)}{<E>}}$$

$$\frac{< E^2 >}{< E >^2} = \frac{2+\alpha}{1+\alpha}$$

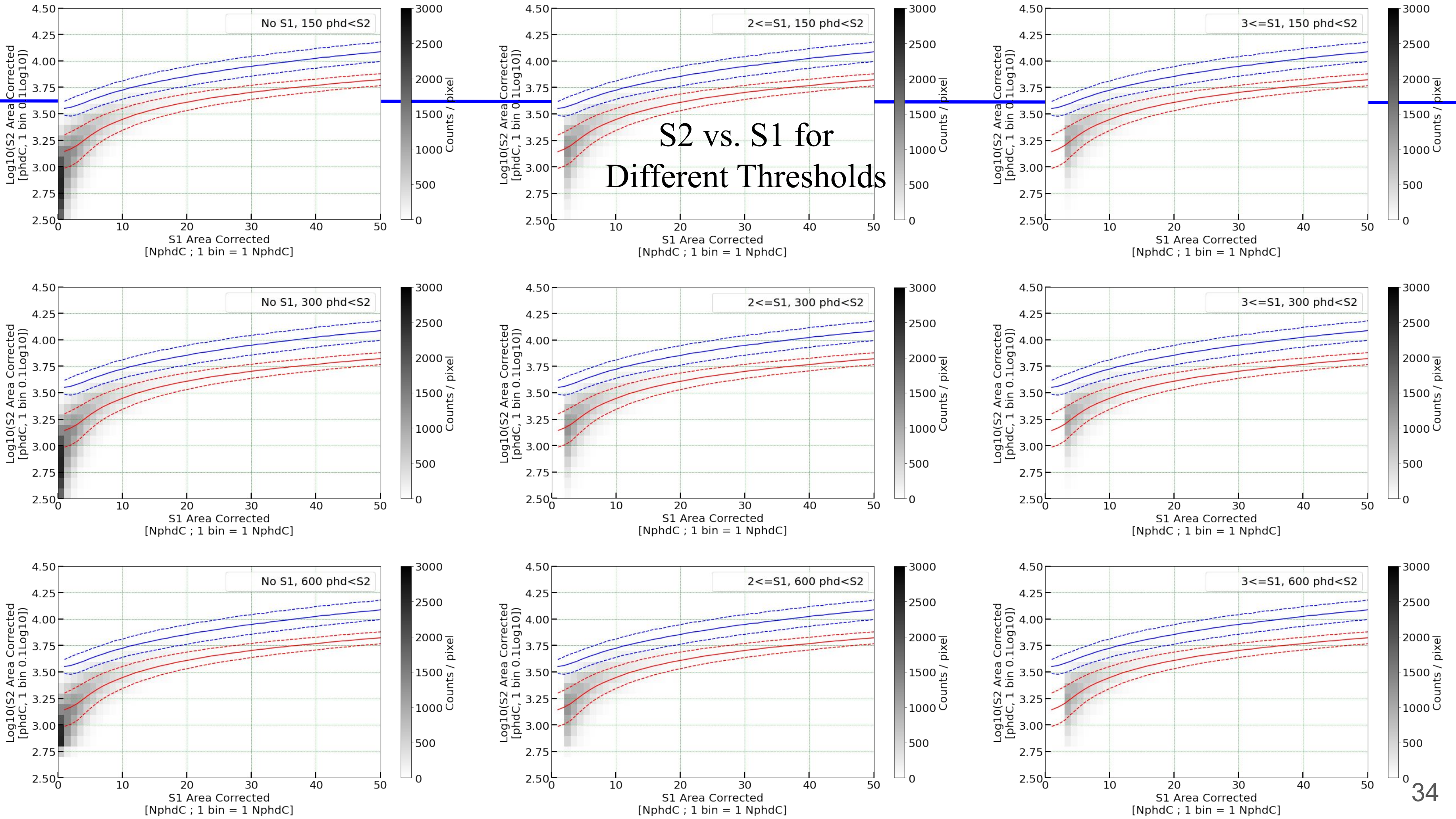
Interaction Overlap

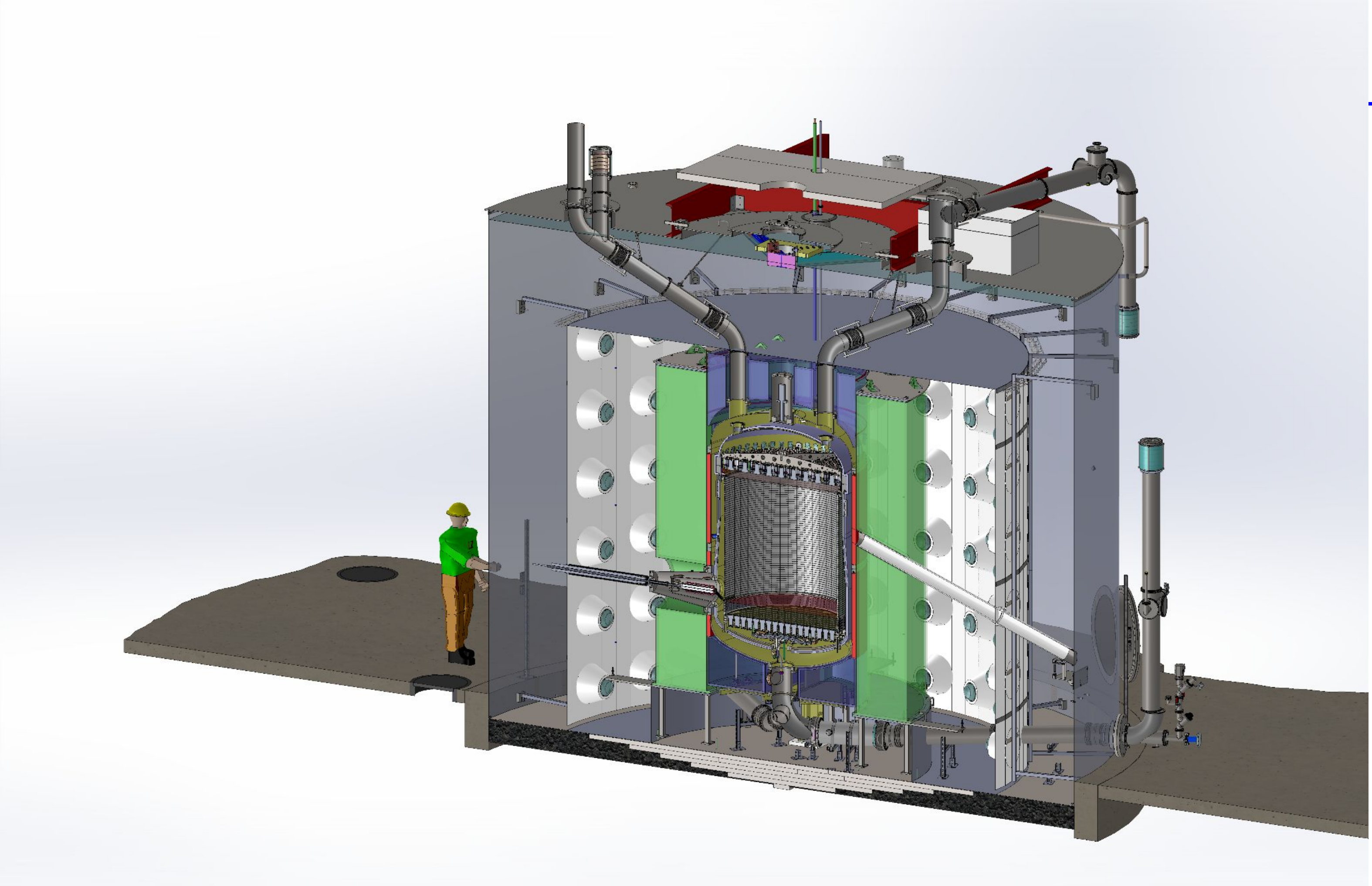




Using the NEST reported drift times, we can count the number of overlapping interactions. We used “S1 >= 3, S2 > 150 phd.”

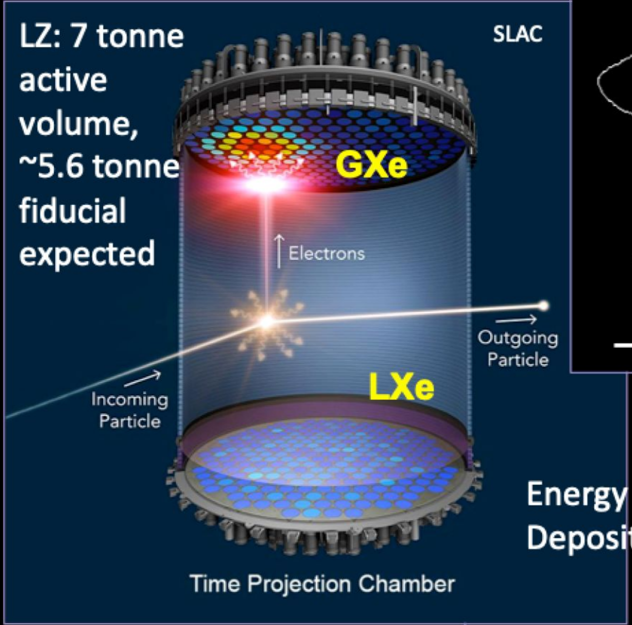
S2 vs. S1 for Different Thresholds

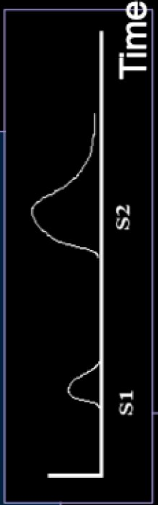




Two-Phase TPC at the Heart

LZ: 7 tonne active volume, ~5.6 tonne fiducial expected

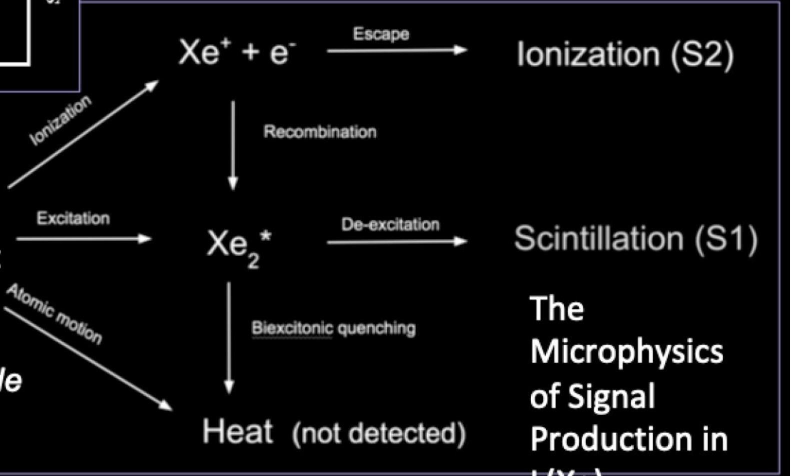




$$E = \frac{W}{L}(n_{ph} + n_e)$$

$$\langle \mathrm{S1c} \rangle = g_1 \langle n_{ph} \rangle \quad \langle \mathrm{S2c} \rangle = g_2 \langle n_e \rangle$$

We typically use "position-corrected" S1 and S2 signals (S1c and S2c), characterizing the "actual" yields to remove the detector-specific variations

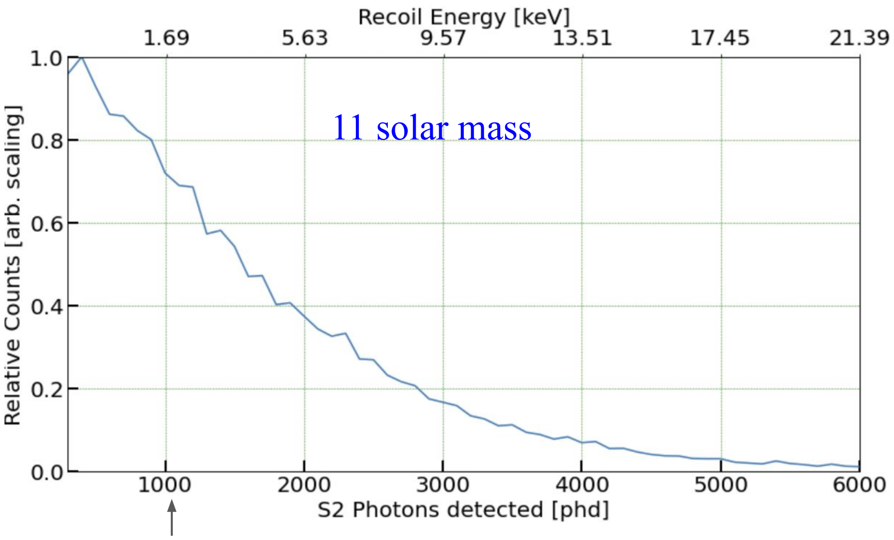


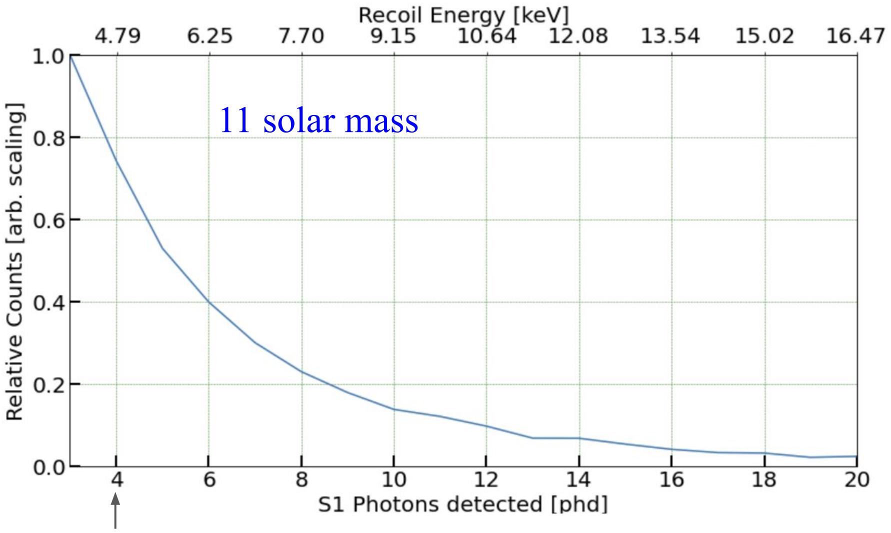
The Microphysics of Signal Production in L(Xe)

Particles that multiply scatter will only provide 1 S1, but 1 S2 for each vertex of scattering

3

Low-Energy NR Signals from `NEST(v2.3.12)`





(Ne- ~ 21) (127) (Nph = 35) (176)

- The S2/electroluminescence *(Left)* and S1/scintillation *(Right)* signal sizes, predicted by NEST (taking mean yields models at face value sans errors, fluctuations) for an incident nu spectrum from the 11 solar mass model.
    - The mirrored axes show the MC Truth recoil energy of the Xe nucleus.
- Just like in DUNE, right at threshold, but many orders of magnitude lower in *E* (a **unique** window on SNs)