The LZ Photoneutron Calibration Source

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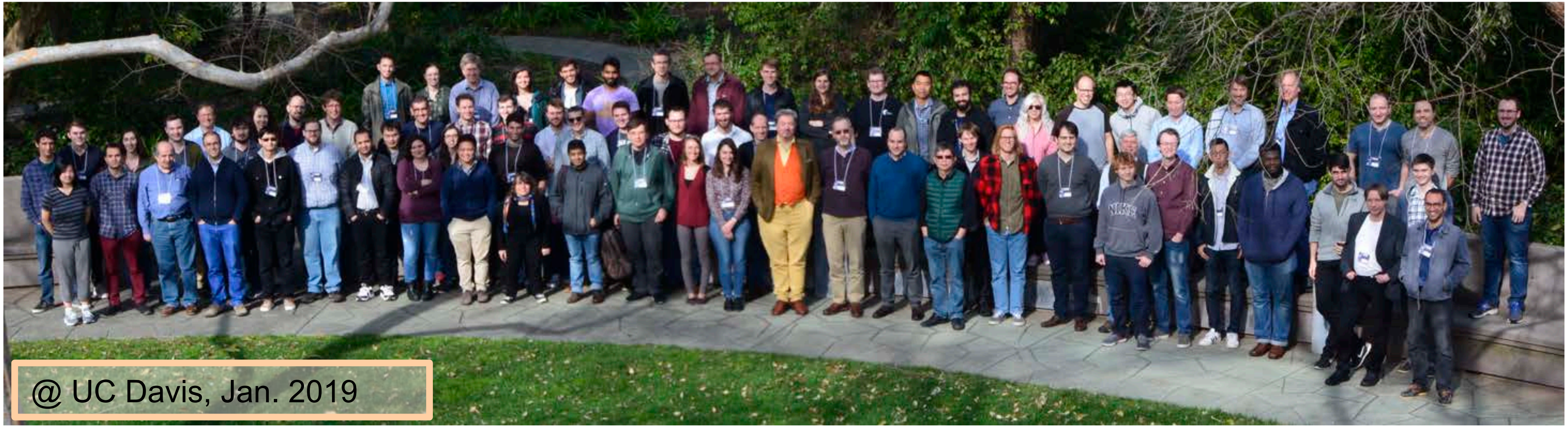
UC Berkeley
APS April Meeting
April 15, 2019

on behalf of the LZ Collaboration

The LZ Collaboration

37 institutions; 250 scientists, engineers, and technicians



The LZ detector is being built at SURF in Lead, SD

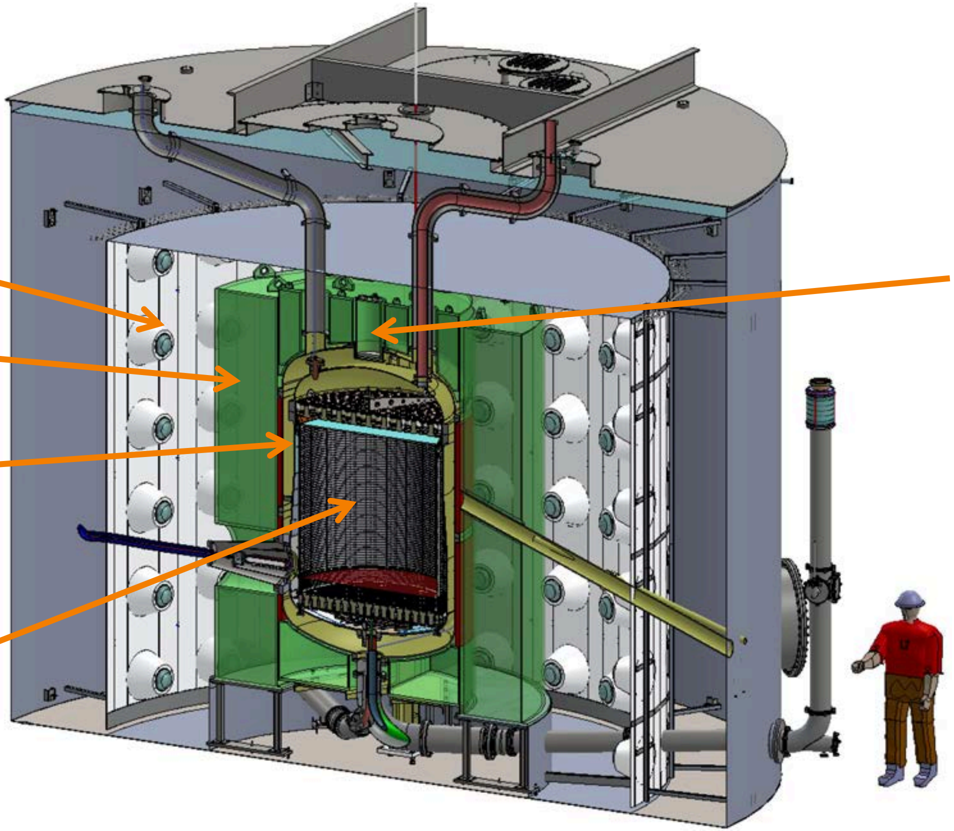
The LZ Detector

Veto system

High purity water

Gd-loaded liquid scintillator

Instrumented Xe skin region

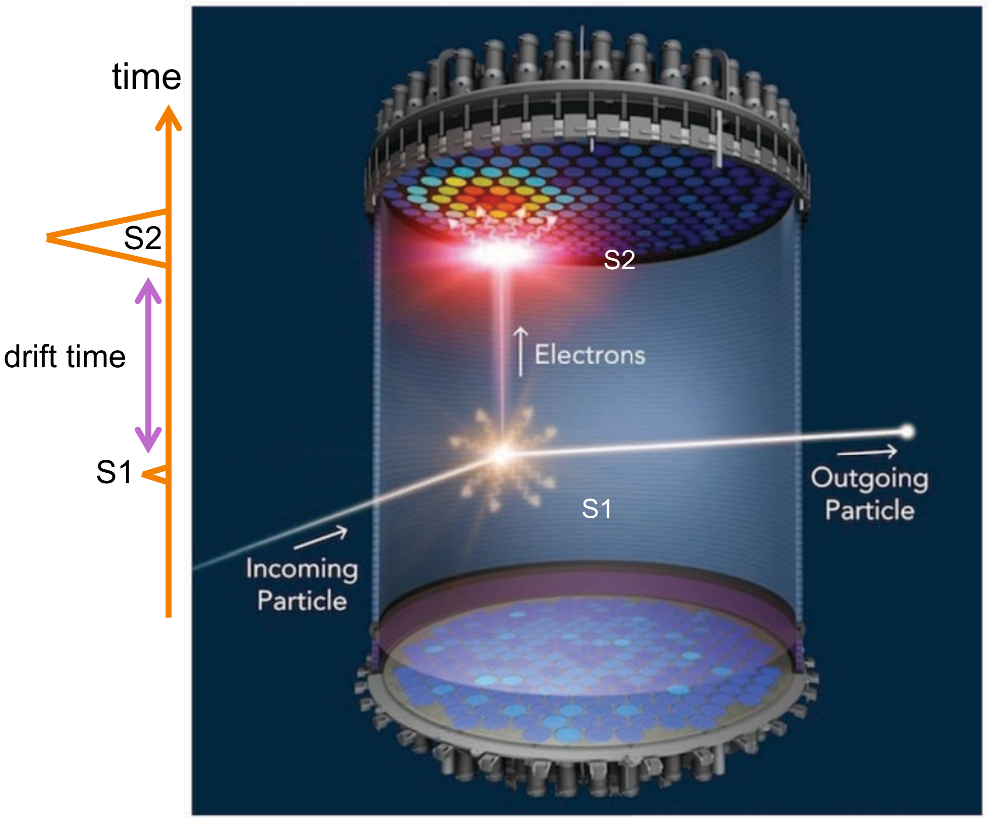


Liquid scintillator filled plug

LXe Time Projection Chamber
7 tons active Xe
5.6 ton fiducial volume

LZ TDR:
arXiv:1703.09144

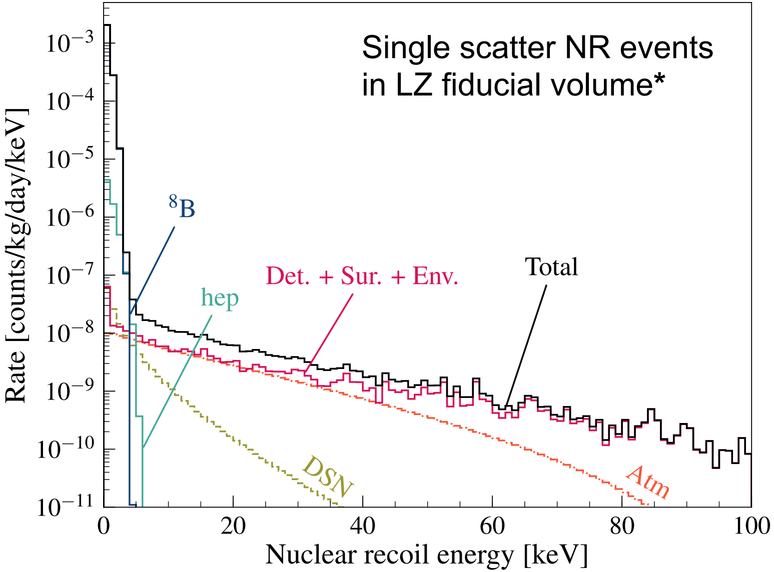
How LZ Works



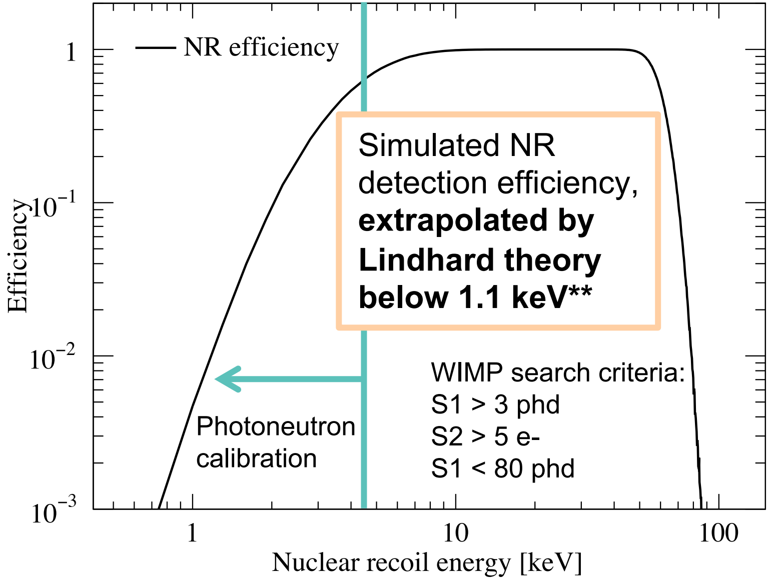
- Energy deposited by particle interactions
  - S1 light: prompt scintillation
  - S2 light: electroluminescence from drifted electrons
- 3D position reconstruction
- Discrimination between electron recoils (ERs) and nuclear recoils (NRs)
- Possibility of low energy S2 only analysis
  - complicated by lack of discrimination

Low Energy Nuclear Recoil Backgrounds

LZ sensitivity paper: arXiv:1802.06039



* after outer detector and skin vetoes applied, before efficiency and S1 selection cuts



** multiple low-energy NR calibrations planned; see TDR

Photoneutrons

- Match gamma energy to Q for low energy neutrons
- First order: monoenergetic neutrons from monoenergetic gammas
- Process has fairly small cross section

$$^{9}\mathrm{Be} + \gamma \rightarrow {}^{8}\mathrm{Be} + n \quad (Q = -1.667\ \mathrm{MeV})$$

$$E_n \propto E_\gamma + Q$$

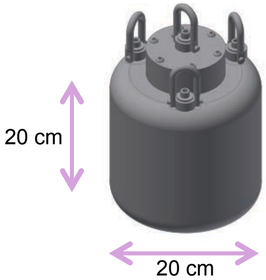
$$N_\gamma : N_n \sim 10^4 : 1$$

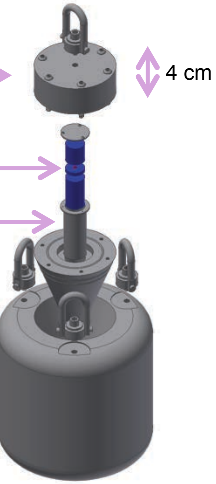
Gamma Source	Neutron Energy [keV]	Xenon Recoil Endpoint [keV]	
^{88}Y	153	4.6	This talk
^{205}Bi	88.5	2.7	
^{206}Bi	47.5	1.4	Future work
^{124}Sb	22.5	0.7	

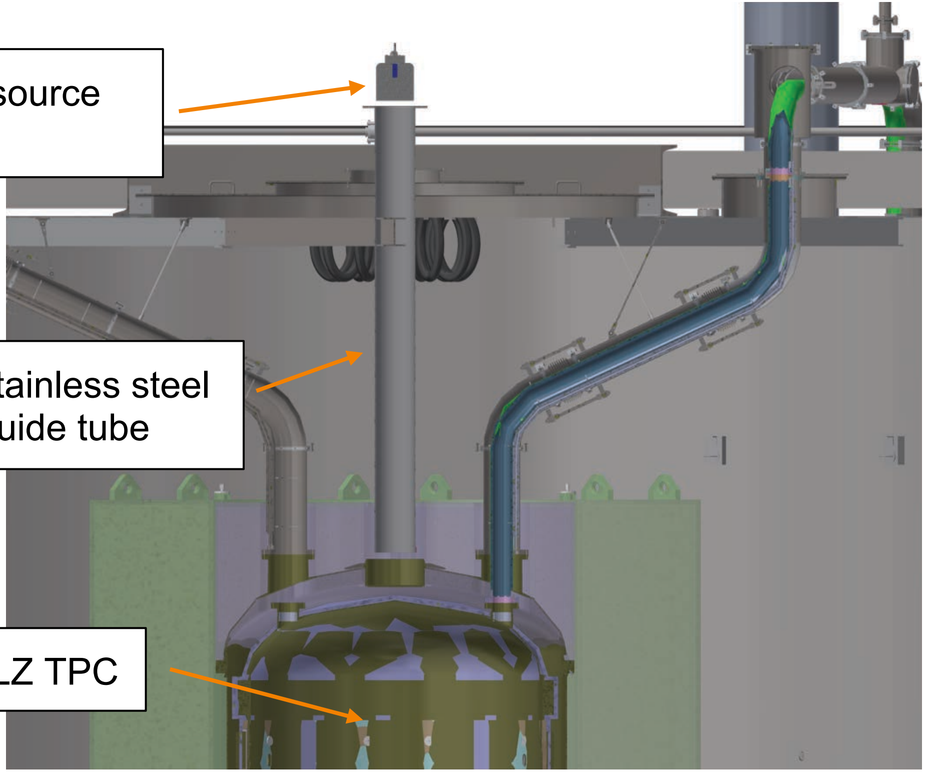
Overview: G. F. Knoll. *Radiation Detection and Measurement*. (2000).

Proposed as DM calibration: J. I. Collar. *PRL*, 110(21), 2013.

A Photoneutron Calibration Source







What Could Go Wrong?

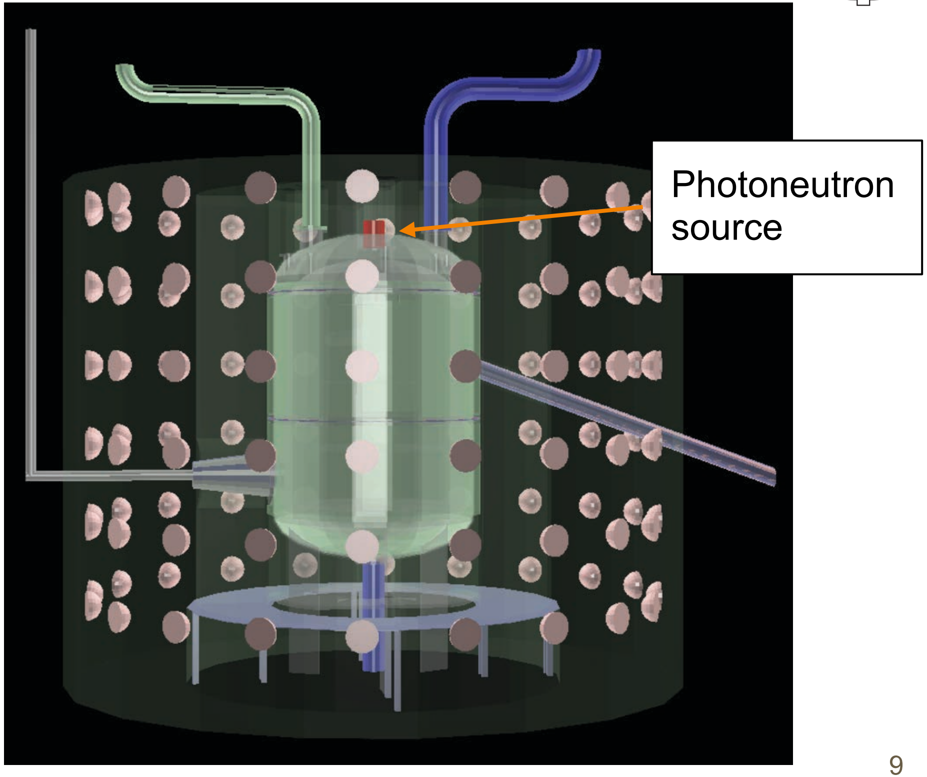
- Radiation from YBe source:
  1. 3.7 MBq ^{88}Y MeV-scale gammas
  2. 270 neutrons per second
  3. MeV-scale gammas from neutron capture

- Key questions about **event pileup**:
  - Will the total event rate overwhelm matching of S1s and S2s from photoneutron events?
  - Will there be a well-defined endpoint in the photoneutron single scattering spectrum?
  - Will we be able to distinguish signals from backgrounds such as delayed electron noise?

e.g. P. Sorensen and K. Kamdin. *JINST*, 13 P02032, 2018.

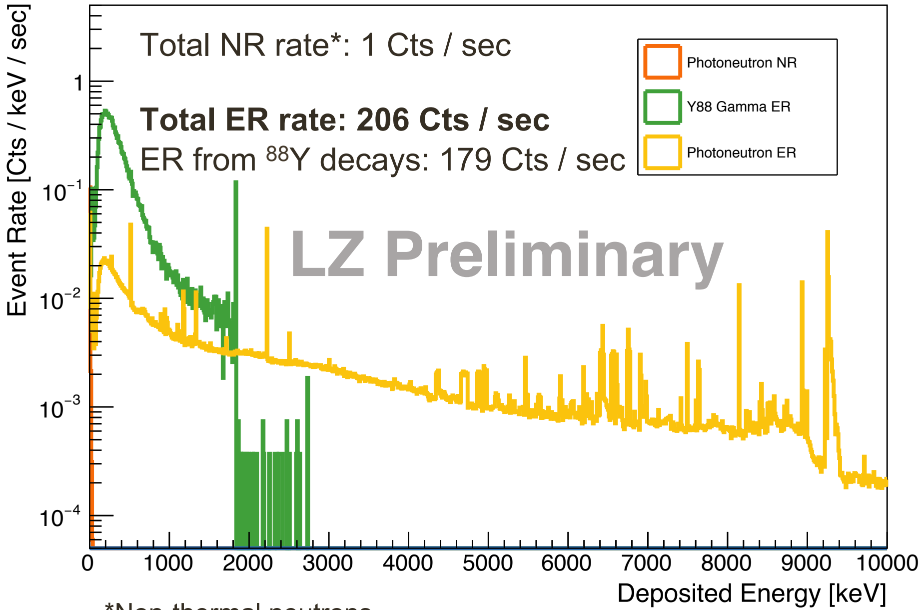
Current Simulation Approach

- Full model of LZ in a GEANT4-based simulation
    - ^{88}Y gammas directly from decay in GEANT4
    - Photoneutrons from virtual gamma vectors
        - Sample locations and momentum-energy relation more accurately
    - First-order approximation from photoneutron cross section to scale datasets together



The Total Event Rate

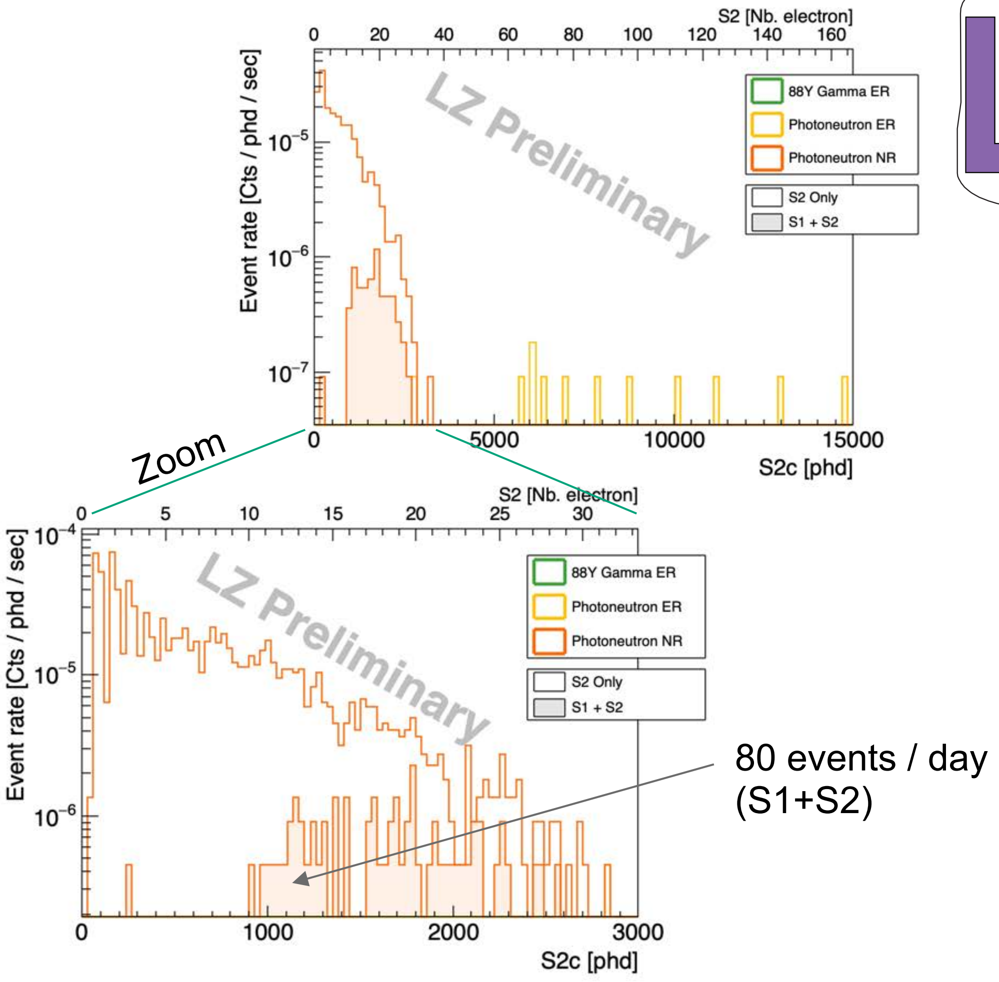
- No cuts on events after post-processing
- 3.7 MBq ^{88}Y decay gammas main source of event rate
- Gamma rate from neutron capture coupled to photoneutron rate (1^{st} bin)
- Source events towards top of TPC, so less time between S1 and S2
    - Define small fiducial region towards the top of the detector as signal region



*Non-thermal neutrons

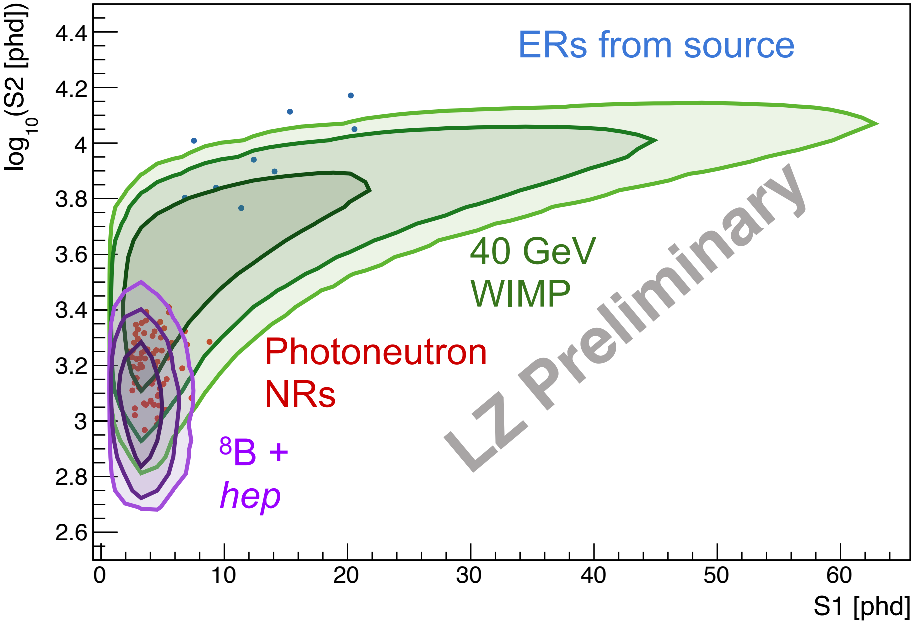
The Signal Region

- Signal region looks great!
- S2 only (no S1 detected) events shown, but not the focus of this talk



Calibrating Expected Signals

- What 24 hours of calibration data could look like
- Radiogenic detector backgrounds negligible in fiducial region (<< 1 Cts / day)
- Nice overlap with coherent neutrino scattering signal region, mainly from ^{8}B solar neutrinos



Summary

- Incorporate full optical response, electronics response, and analysis framework into simulation analysis
    - e.g. “LZ Mock Data Challenge 3” happening soon

- Incorporate more sophisticated event overlap and delayed electron noise in simulations

- Consider physics simulation accuracy
  e.g. A. E. Robinson. PRC, 89(3), March 2014.

- We will have a physical source later this year

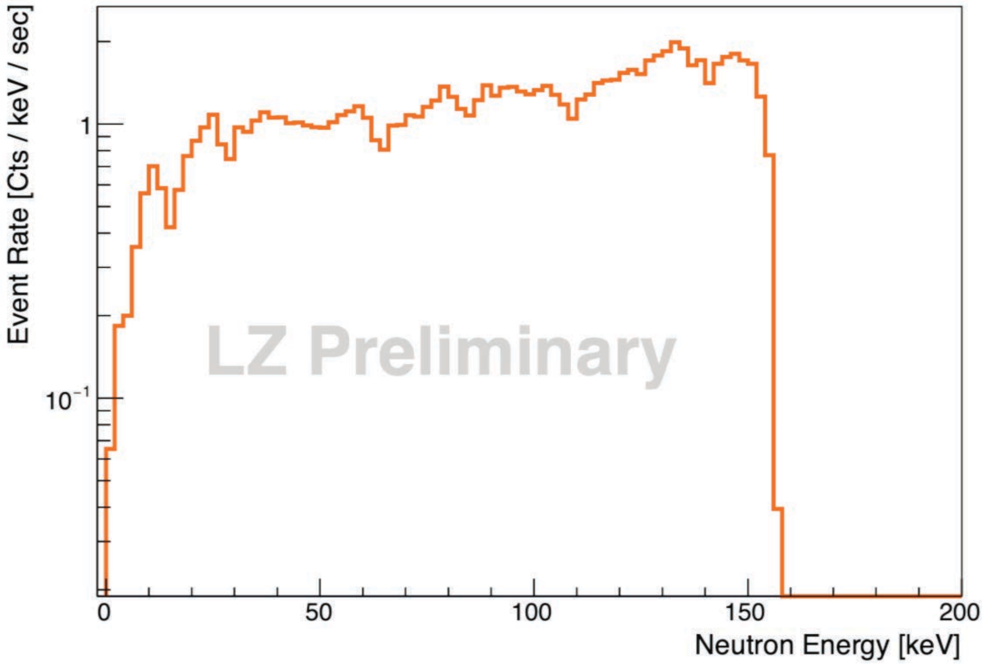
Special Thanks

- Lawrence Berkeley National Lab
- LZ Collaboration
    - Specifically: Junsong Lin, Quentin Riffard, Peter Sorensen, Rick Gaitskell, Dan McKinsey
- NSF GRFP Program for support

Backup Slides

Outgoing Neutron Spectrum

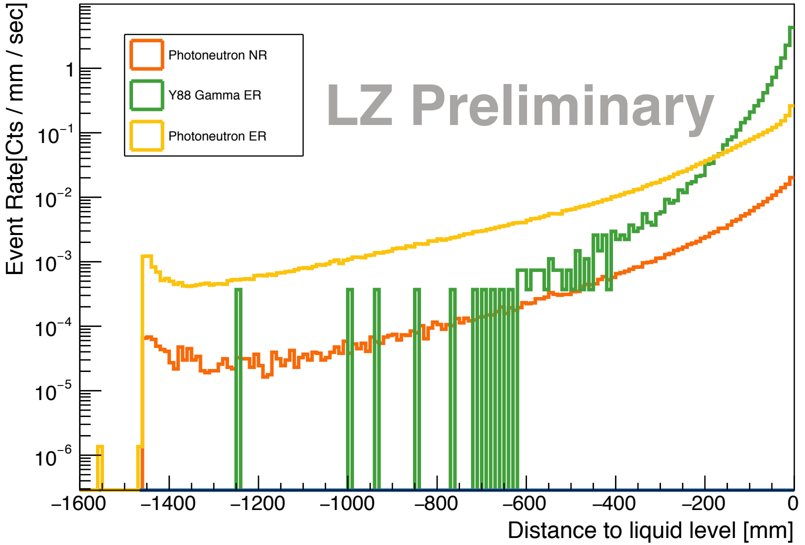
- 180 photoneutrons per second leave the tungsten shield block



Mean z of Events

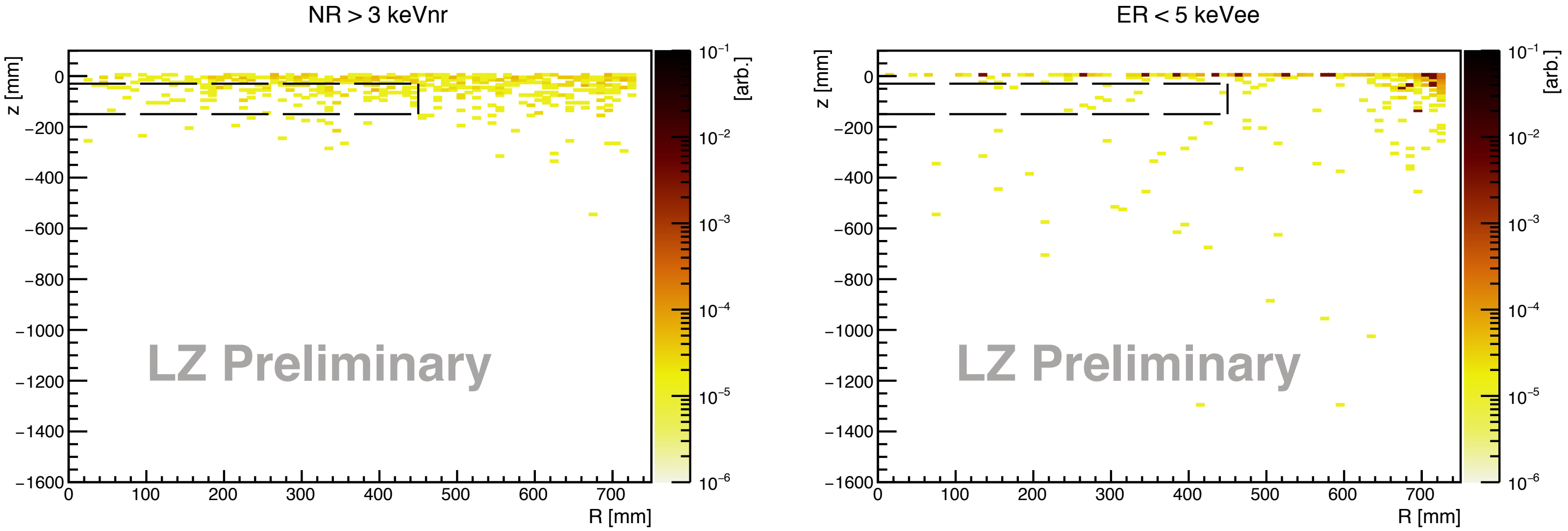
- Largest z-position of each event (single and multiple scatters)
- Use mean z for back of the envelope Poisson calculation of event overlap fraction

- Mean z: -160 mm
- Mean drift time 94 μs (assuming uniform drift field)



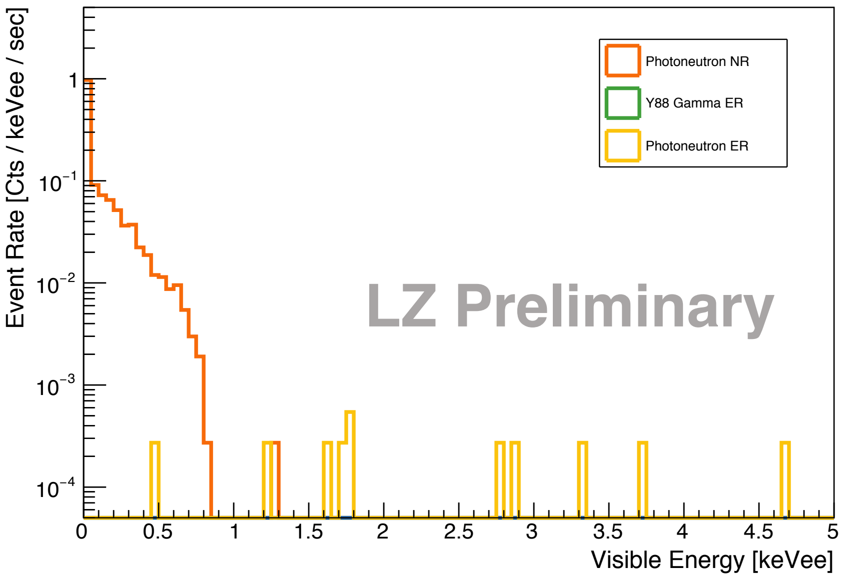
Fiducial Volume

- Single scattering events in signal region
- Consider NRs near endpoint (4.6 keVnr)



Signal Energy Spectrum in LXe

- MC events from slide 11 and 12 before detector response effects applied



Pushing to Lower Energies

- S1+S2 events are mostly > 10 e-
  - Confusion with delayed electron events less likely (at toy MC level)
- S2 only spectrum needs more detailed simulation to understand delayed electron effect

- S2 only (no S1 detected) events shown, but not the focus of this talk