Backgrounds in the LZ Experiment

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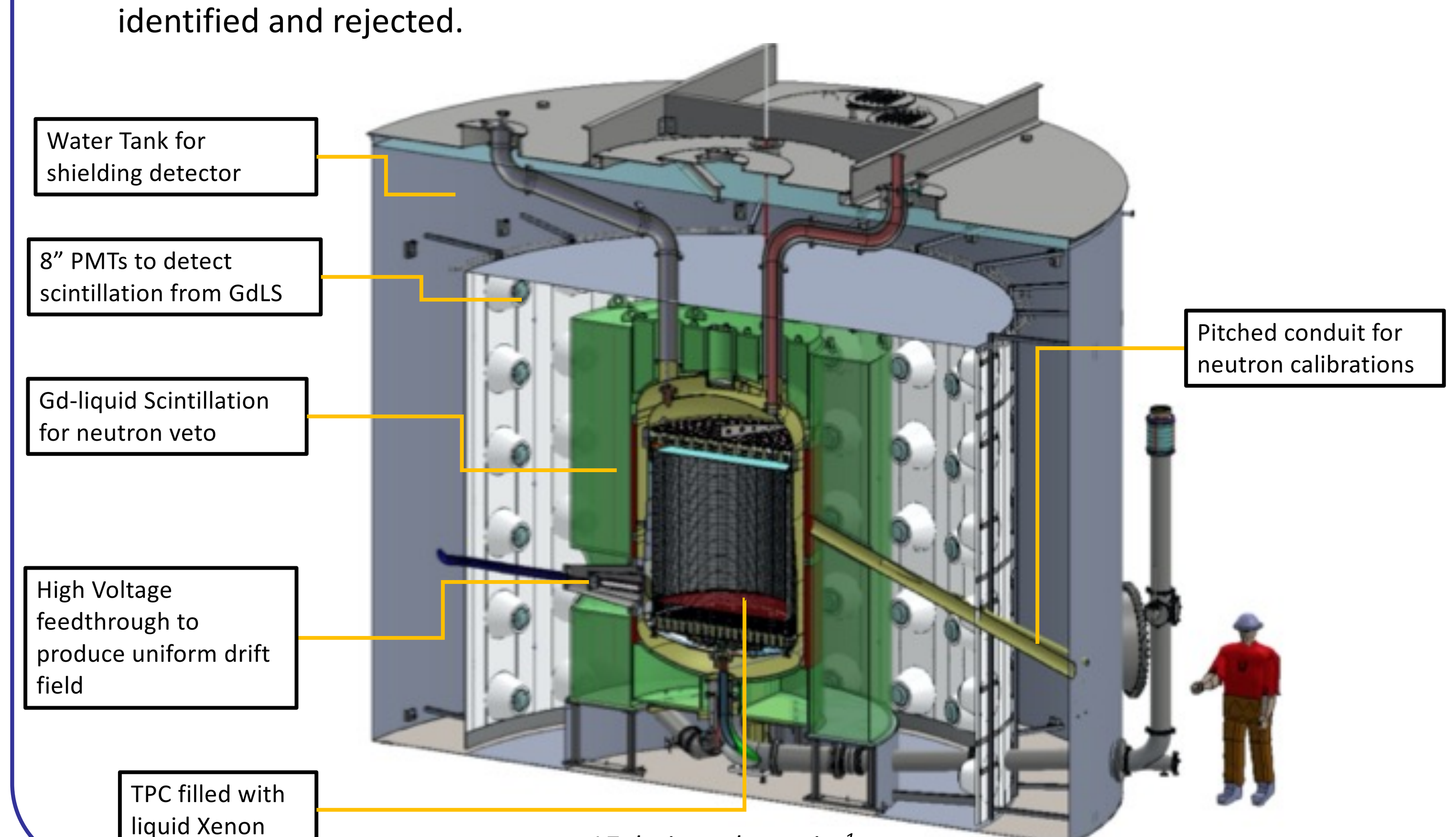
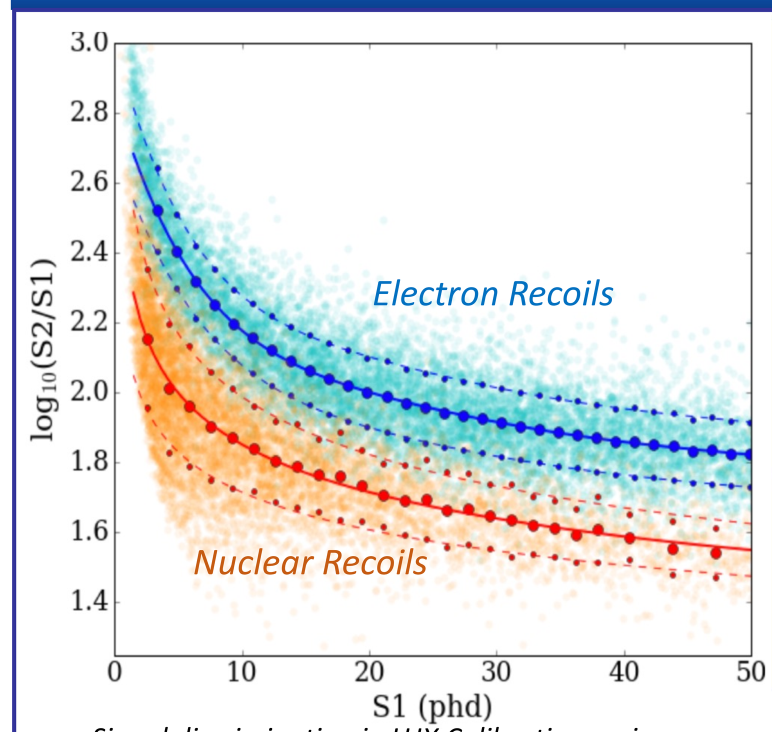
The LUX-ZEPLIN Detector

- The LUX-ZEPLIN project (LZ) is a direct detection experiment employing a liquid xenon (LXe) time projection chamber (TPC), located 1 mile underground in the Sanford Underground Research Facility (SURF), in South Dakota. LZ is currently being commissioned, and we expect first physics data in 2021.
- LZ is optimized for the detection of WIMP-induced, keV-scale nuclear recoils, and benefits from low background rates due to both radiopure detector materials, high purity LXe, and the self-shielding of LXe.
- The detector includes an integrated veto system, consisting of a liquid scintillator outer detector, a xenon skin, and a water tank, which allows for non-WIMP interactions to be identified and rejected.

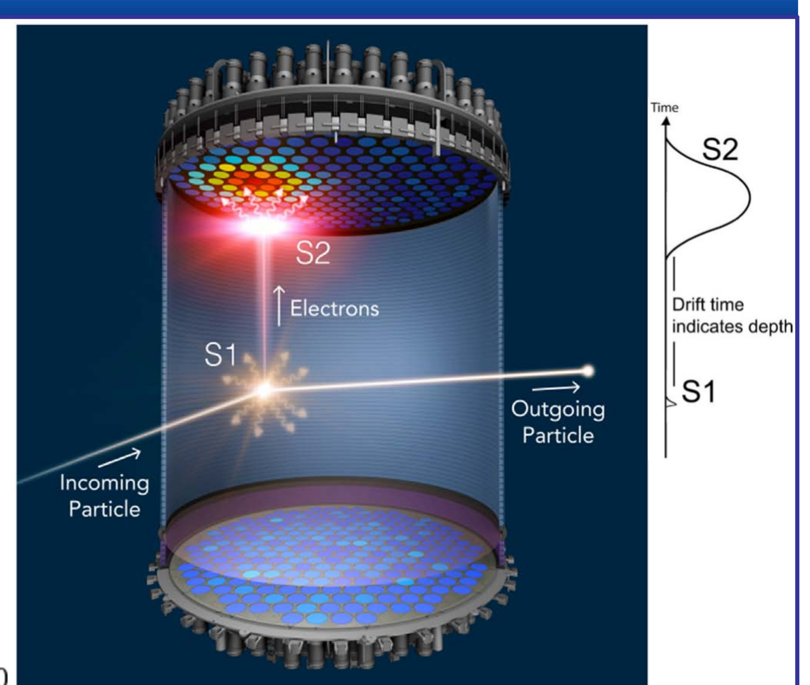


LZ design schematic. [1]

Signals In The TPC



Signal discrimination in LUX Calibrations using a neutron nuclear recoil (NR) source and diffused tritium electron recoil (ER) source. [2]



Time projection chamber (TPC) where interactions in xenon produce scintillation (S1) and ionization (S2) signals. [3]

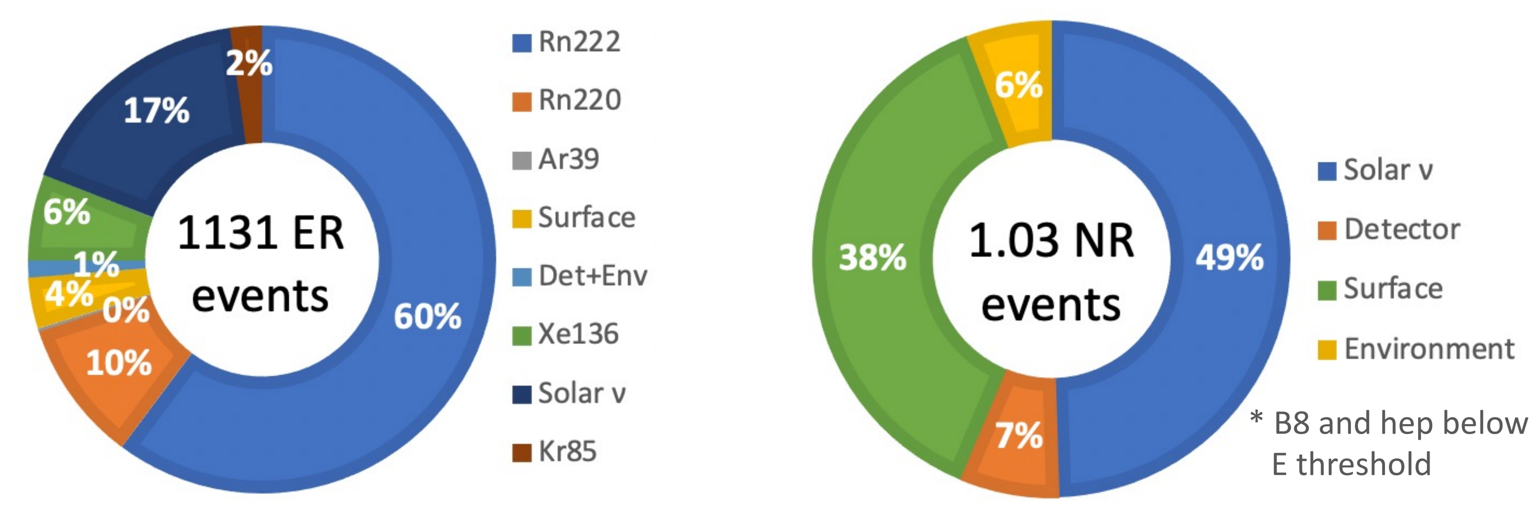
- The heart of the detector is a TPC which contains a 7 tonne active volume of LXe where particle interactions produce prompt scintillation (S1) and ionization electrons. Electrons drift under electric field to gas region where they electroluminesce and produce secondary photons (S2).
- TPCs also have accurate 3D position reconstruction. X-Y position is reconstructed using the S2 light pattern on the top PMT array, and Z position is reconstructed using the drift time of ionization electrons, i.e. time between S1 and S2 signal.
- Nuclear and electronic recoils in xenon produce different charge-light yields, thus producing two distinct bands in S1-S2 space and providing recoil type discrimination.

References

(1) Akerib, D.S. et al., "The LUX-ZEPLIN (LZ) Experiment", Nucl.Instrum.Meth.A 953 163047 (2020). arXiv:1910.09124
(2) Akerib, D.S. et al., "Signal yields, energy resolution, and recombination fluctuations in liquid xenon", Phys. Rev. D **95**, 012008 (2017). arXiv:1610.02076
(3) Mount, B. J. et al. "LUX-ZEPLIN (LZ) Technical Design Report", arXiv:1703.09144 (2017).
(4) Akerib, D.S. et al. "Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment", Phys. Rev. D 101, 052002 (2020) arXiv:1802.06039v1.
(5) Akerib, D.S. et al, "Projected sensitivities of the LUX-ZEPLIN (LZ) experiment to new physics via low-energy electron recoils", (2021). arXiv:2102.11740v1
(6) Lenardo, B. et al. "A Global Analysis of Light and Charge Yields in Liquid Xenon," in *IEEE Transactions on Nuclear Science*, vol. 62, no. 6, pp. 3387-3396 (Dec. 2015), arXiv:1412.4417

Backgrounds

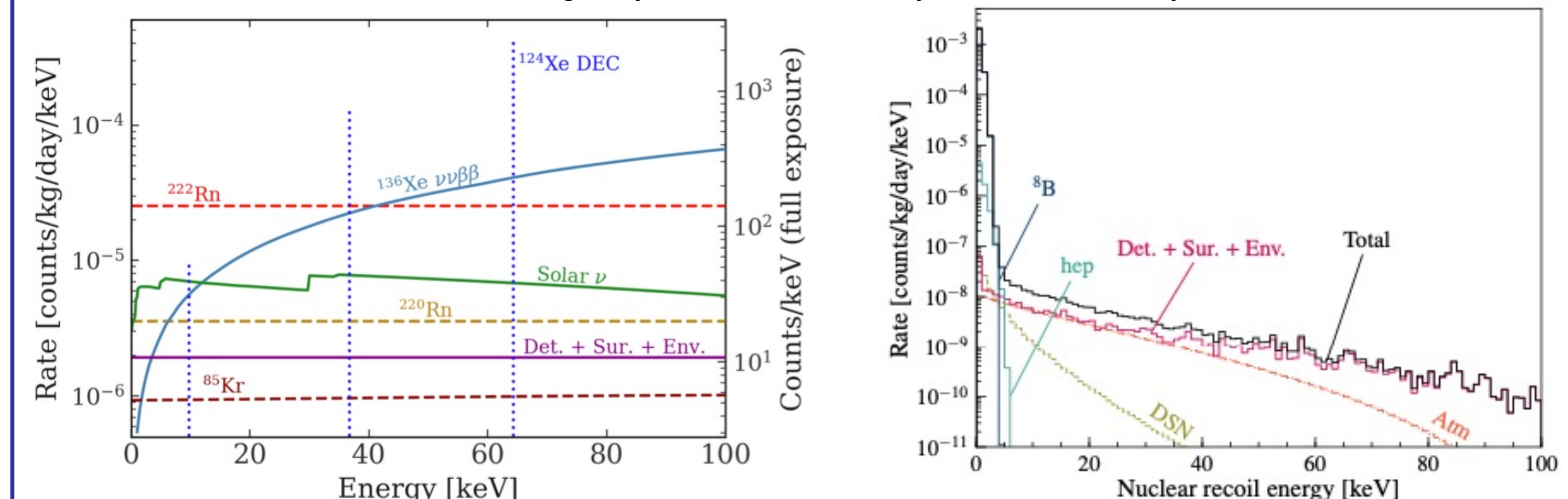
- The dominant backgrounds in LZ are from internal xenon contaminants: Rn222 and Rn220 and their daughters; Kr85; and Xe136. Contributions from radioactive detector materials/surroundings and solar/atmospheric neutrinos are extremely subdominant.
- Kr85 is intrinsic to the Xenon, and its concentration can be greatly reduced, but not eliminated, via charcoal chromatography. Radon emanates from detector materials and dust and produces backgrounds from the naked beta decays of Pb214 and Pb212.



≈ 5.66 events after 99.5% ER discrimination

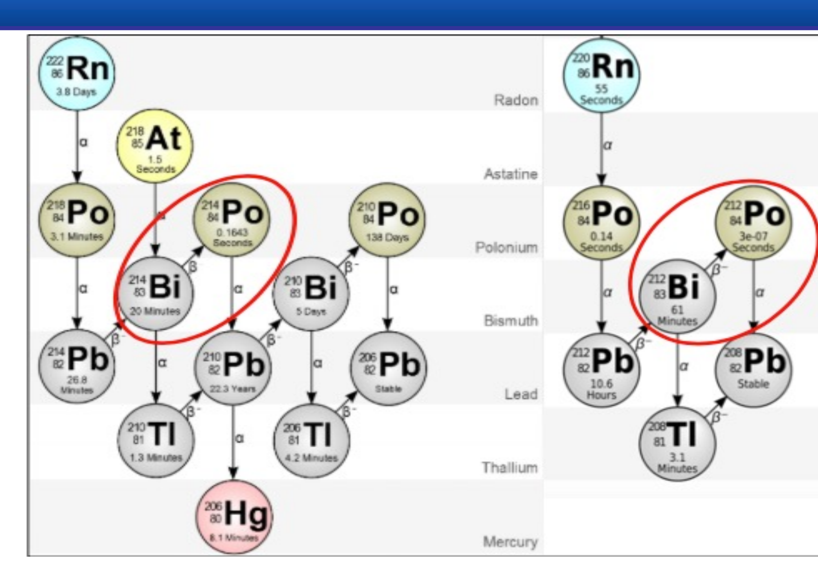
≈ 0.52 events after 50% NR acceptance

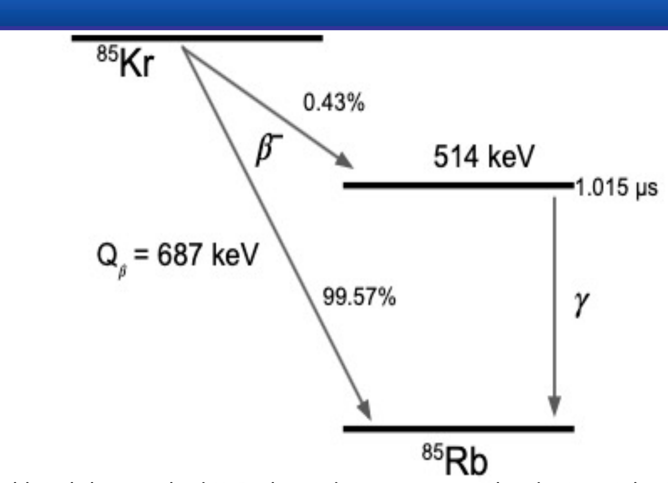
Total ER and NR backgrounds for a 40 GeV WIMP, after all cuts have been applied for a 1000-day search and 5.6 tonne fiducial volume. WIMP Region of interest is 1.5-6.5 keV for ERs and 6-30 keV for NRs.



Wimp Search backgrounds assuming 5.6 tonne fiducial volume prior to any outer detector veto. [4,5]

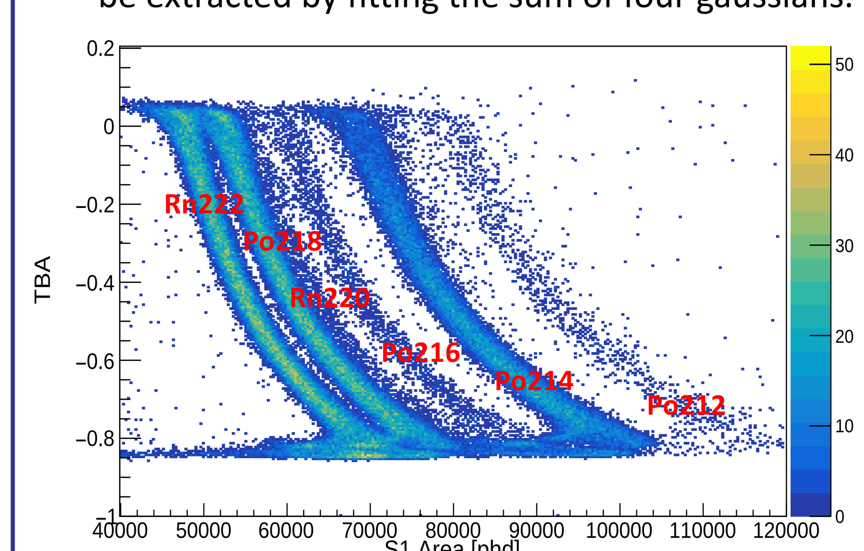
Radon and Krypton



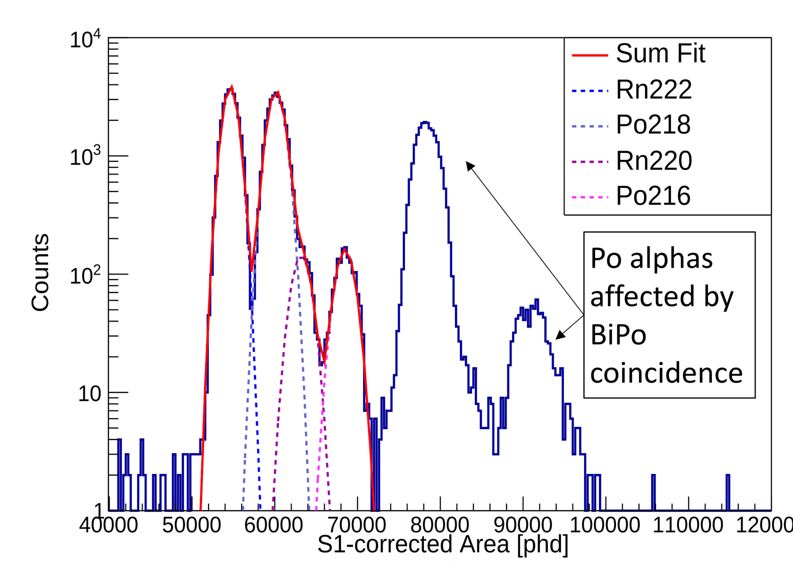


Unlike alphas, naked Kr85 beta decays can not be distinguished in data from other backgrounds leaving the beta-gamma coincidence as the only means of identification.

- Radon and its daughters, in both chains, can be readily tagged by identifying the alpha decays. Alphas are densely ionizing in LXe and thus produce extremely large S1 signals which are easily distinguishable in S1-TBA (top-bottom asymmetry of light collection) space. TBA is an effective proxy of depth in the detector. Light collection efficiency varies as a function of depth, thus leading alphas to form bands in a plot of S1 versus TBA.
- After correcting for light collection efficiency, alphas form clear S1 peaks such that the activity can be extracted by fitting the sum of four gaussians.



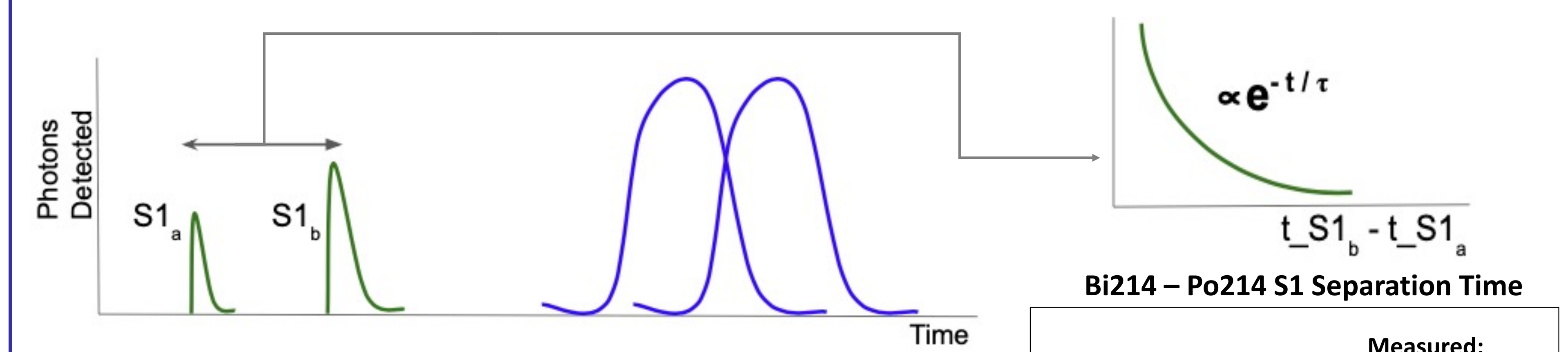
Using GEANT4 based simulation of the LZ detector and NEST[6] (Noble Element Simulation Technique) for generating xenon S1,S2 response, it can be seen that alpha decays form distinct bands in S1-TBA space.



Alpha spectra in S1 space after making a TBA based correction e.g. correcting for light collection efficiency as a function of depth.

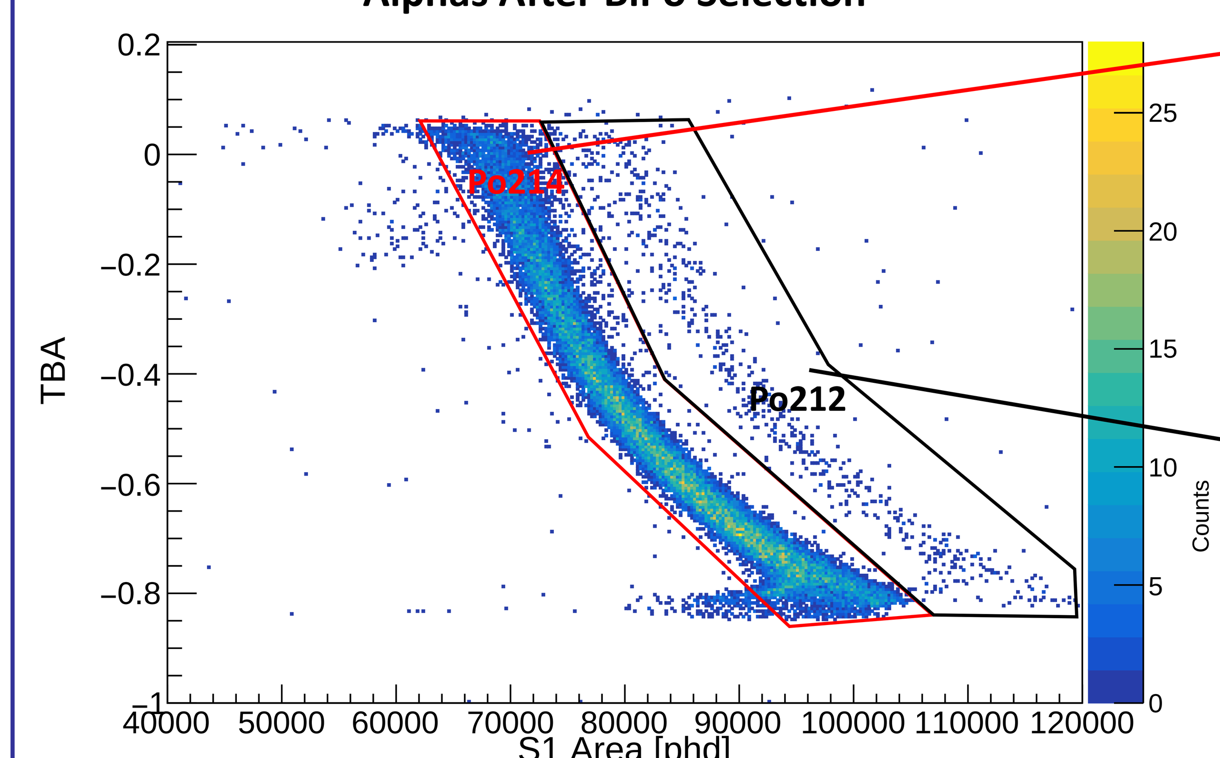
Tagging Radon and Krypton

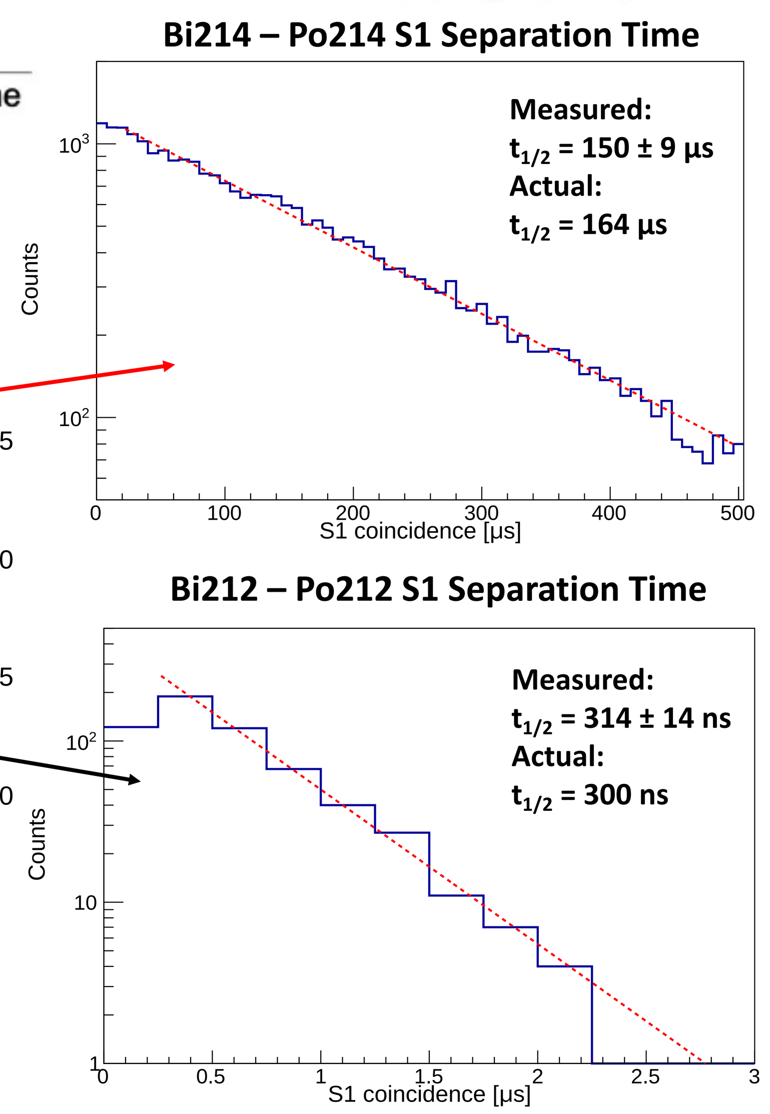
- Both Radon chains contain a Bismuth-Polonium (BiPo) coincidence where the Bi beta decays and is followed by a short-lived Po - 164us for Rn222 chain and 300 ns for Rn220 chain – which decays via emission of an alpha.
- Kr85 naked beta decays to Rb85 99.57% of the time, but 0.43% of the time it beta decays to Rb85m with a half-life of 1.015 us, which in turn decays to Rb-85 via 514 keV gamma.
- The identifying feature of these events is the decay coincidence: beta-gamma for Kr85 and beta-alpha for Rn, corresponding to a coincidence of two S1s.
- S2s are quite large O(1-2 µs) width, and will often merge, thus making it difficult to identify an S2 coincidence.



Cartoon of how coincident decays will look in an LZ event window. S1s are in green and S2s are in blue. S1 time separation is described by an exponential corresponding the lifetime of the second decay

Alphas After BiPo Selection





- For both BiPo and Kr85 coincidences there is a loss of events when either, for separations < 150 ns, the two S1s will merge or when the S1 separation time exceeds the drift time of the first decay. In the latter case, an S2 signal will occur before the second S1, causing event classification to fail.
- In the Kr85 case, we use a 10 µs window and require that the smaller and larger S1s have an area matching a Q = 173 keV beta and a 514 keV gamma, respectively. One can similarly restrict the S2 area based on the estimated beta and gamma S2 areas.

Constraining Rates and LZ Projected Sensitivity

LZ projected sensitivity to SI WIMP-nucleon elastic scattering for 1000 live days and a 5.6 tonne fiducial mass. [4]

- WIMP sensitivity depends on how well Radon and Krypton rates are constrained: the better their rates are constrained, the easier it is to distinguish an over fluctuation of background from an actual WIMP signal as ER events will leak into the NR region.
- For novel physics signals which produce low energy ER signals such as solar axions, hidden photons, dark matter – electron scattering, etc, these constraints become even more critical[5].