# Background Control in the LUX-ZEPLIN Dark Matter Experiment

Black Hills State University

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## Dark Matter Matters

✧Galaxies in our universe are rotating at a seemingly impossible speed. With the observed mass of these galaxies, they should have been torn apart long ago. Observed galactic clusters follow this same trend; there must be something more to explain this motion. This odd motion can be seen in fig. 1.

✧Dark matter is a proposed particle not yet included in the Standard Model of Particle Physics. This unknown matter doesn't interact electromagnetically with normal matter yet could account for the unknown mass holding galaxies together.

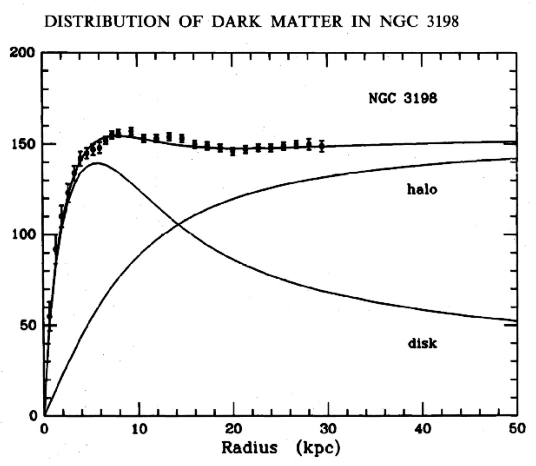


*Figure 1* - Galaxy Rotation Curve: Orbital speeds of visible stars and gas in a galaxy plotted against their radius in that galaxy. The disk curve shows the expected relation for observed matter whereas NGC 3196 shows the actual observation. The halo curve represents dark matter in that galaxy that accounts for the discrepancy between the two curves.

## Nerds searching for WIMPs

✧There are several possibilities for what dark matter is, a popular theory is that dark matter is made up of weakly interacting massive particles (WIMPs).

✧The motivation for WIMPs can be found in more than just the missing mass that explains galactic orbital rotation speeds. Models of Super Symmetry predict a particle consistent with a WIMP that could also be a solution to a fine tuning problem in electroweak force.

## The LUX-ZEPLIN Summary and Direct Detection

✧LUX-ZEPLIN (fig. 2) is an extension of previous experiments, designed with the goal of using a 7 tonne liquid xenon (LXe) target to reach world-leading sensitivity.

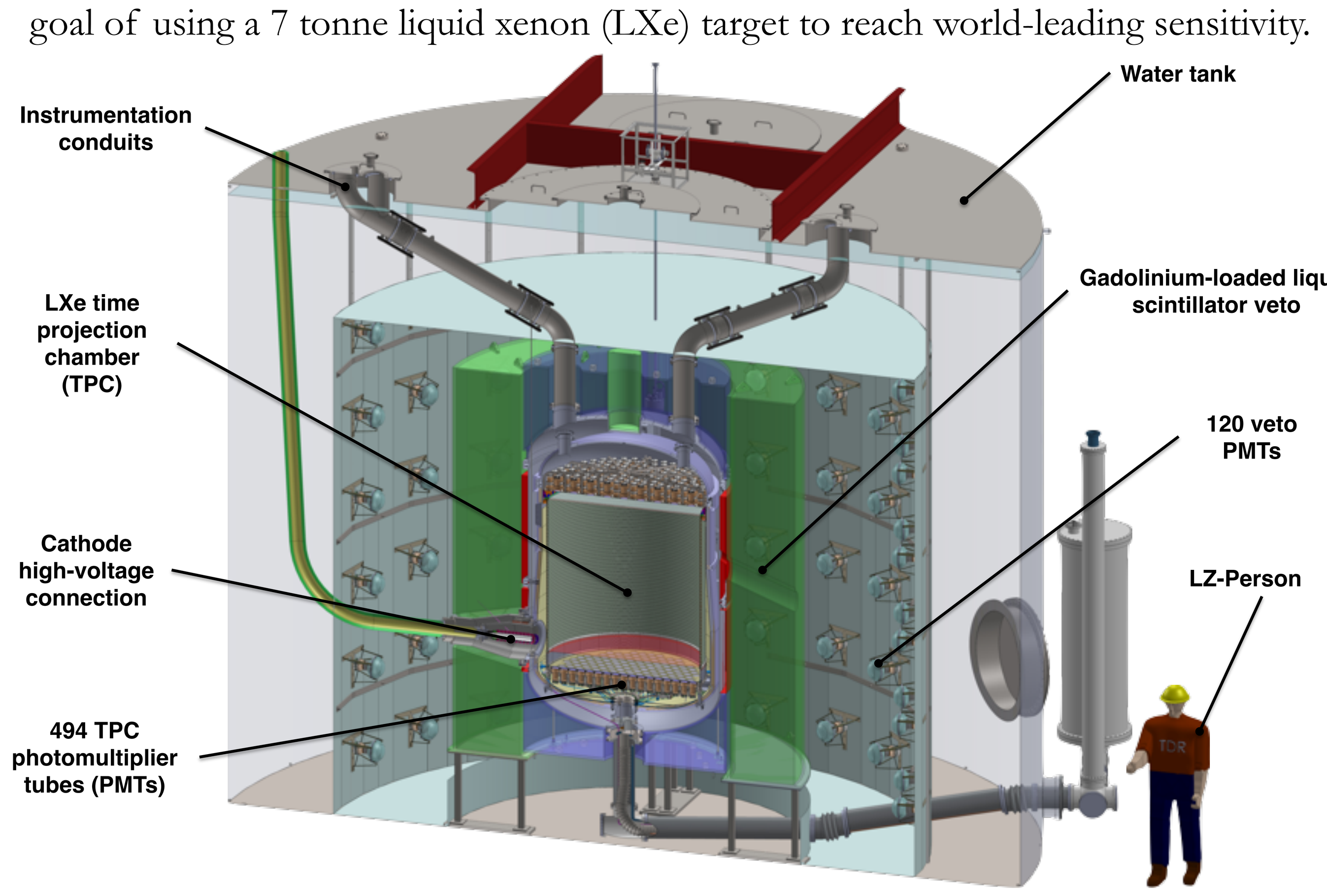


*Figure 2* - The LZ detector concept.

✧LZ uses the method of direct detection. Just like with other observed galaxies, our very own Milky Way has a dark matter cloud that the Earth passes through at approximately 140 miles per second. Some of the particles in that cloud may collide with the LXe nuclei. This will cause photon emission (scintillation) and electron removal from the nucleus (ionization). LZ's photomultiplier tubes detect this light.

✧A voltage will be applied across the TPC to direct the ionized electrons to the top of the TPC where they again produce light. The PMTs will amplify the signal from the scintillation and ionization and use the time difference between the two to find the depth of the nuclear recoil as shown in fig. 3.

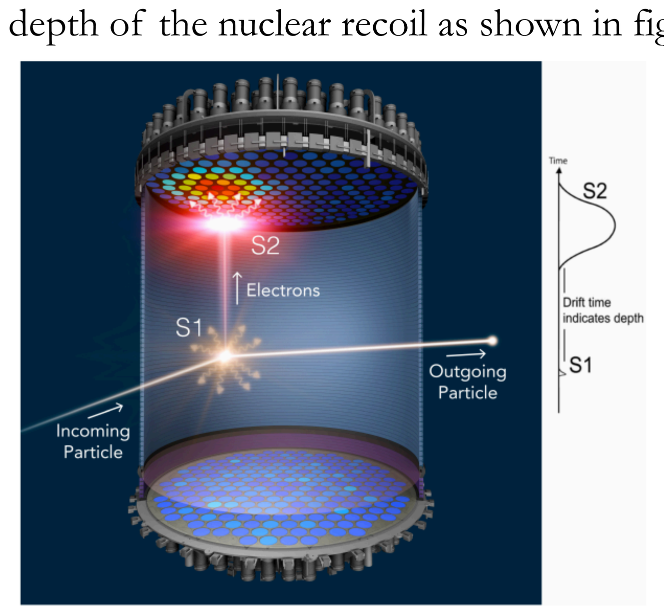


*Figure 3* - Each interaction in the TPC creates two signals. Scintillation, S1, occurs followed by delayed ionization, S2. From this, the precise location of events can be found in three dimensions.

## Limited by Background

✧Ultimately, the sensitivity of LUX-ZEPLIN is determined by the background of the experiment. Sources of background noise in LZ range all the way from solar neutrinos to a little bit too much dust.

| Item | ER cts | NR cts |
|---|---|---|
| Detector Components | 6.2 | 0.07 |
| Dispersed radionuclides (Rn, Kr, Ar) | 911 | - |
| Laboratory and cosmogenic | 4.3 | 0.06 |
| Fixed surface contamination | 0.19 | 0.37 |
| $^{136}$Xe 2νββ | 67 | - |
| Neutrinos (ν-e, ν-A) | 255 | 0.72 |
| Total | 1244 | 1.22 |
| Total (with 99.5% ER discrimination, 50% NR efficiency | 6.22 | 0.61 |
| Total ER+NR background events | 6.83 | |

*Figure 4* – LZ background summary: The expected number of counts for a 5.6-tonne fiducial mass in 1,000 live days ER is electron recoils and NR is nuclear recoils.

✧In order to protect from cosmic rays, after primary assembly, LZ will be moved to the 4850-foot level of the Sanford Underground Research Facility (SURF).

✧Along the same lines, materials for LZ are screened for radio-purity in high purity germanium (HPGe) detectors in a class 1000 clean room in the Black Hills Underground Campus also on the 4850 level. For clean rooms at SURF the rating of the clean room is determined by the number of 0.5 micron dust particle per foot cubed.

✧While LZ parts are assembled at the surface, they spend their time in the radon-reduced clean room (RCR) in the surface assembly lab (SAL). This is a radon mitigated clean room that one must use an airlock in order to enter. The goal of this room is to prevent radon daughters from plating out onto any exposed LZ surface.

✧Of particular importance to avoid is $^{222}$Rn which is found in the $^{238}$U decay chain. While most radioactive isotopes in this chain have a half-life anywhere from minutes to days, $^{210}$Pb has a half-life of 22.3 years as seen below.

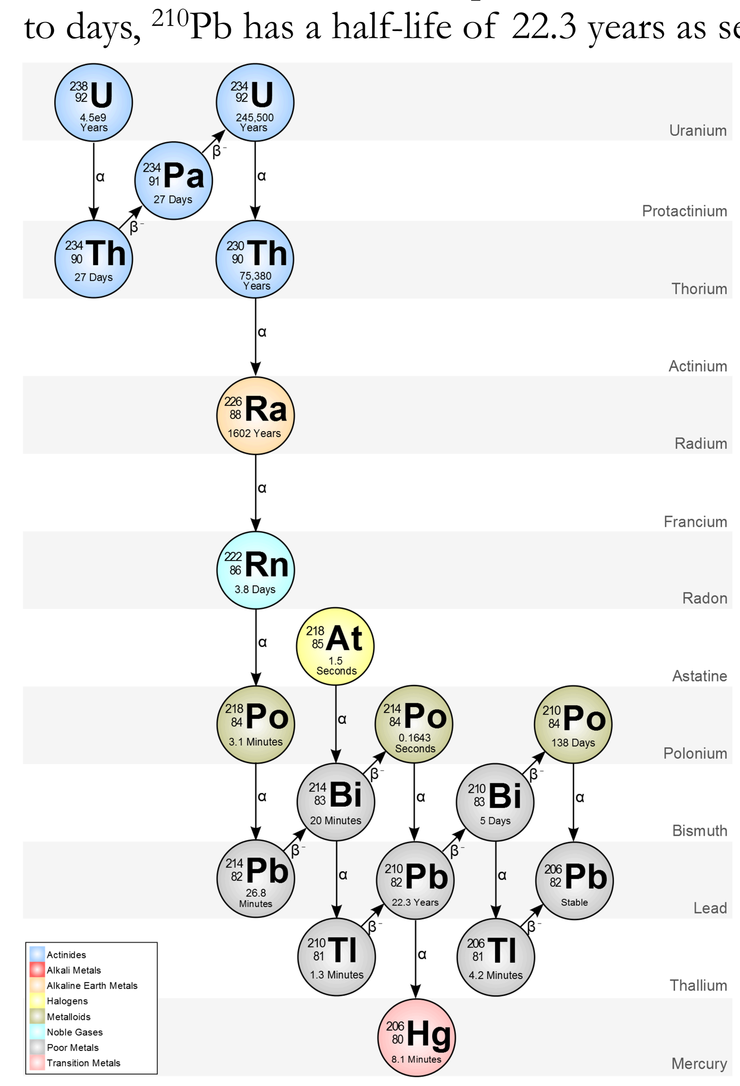


*Figure 5* – Uranium-238 Decay Chain: radon-222, seen in the middle of this decay chain, decays to various radioactive isotopes including lead-210 which has a half-life of 22.3 years.

✧While not in use in the RCR, large components of LZ such as the inner cryostat vessel are wrapped in specially constructed nylon bags made on site. This is to prevent radon daughter plate out should the radon mitigation system fail. Once removed from the RCR, components are hermetically sealed in two nylon bags then wrapped in a third layer to protect from bugs.

✧Radon levels and dust particle levels are monitored in the RCR at all times as well. Though the clean room is rated at Clean Room 1000 level, much lower levels of dust are recorded very frequently. Before any work is done on large components, radon levels in the RCR are determined.

## References

1. "Projected WIMP sensitivity of the LUX-ZEPLIN (LZ) dark matter experiment", LZ Collaboration, arXiv: 1802.06039.
2. "LUX-ZEPLIN (LZ) Technical Design Report", LZ Collaboration, arXiv:1703.09144.
3. "Nuclear Forensic Research Project", http://metadata.berkeley.edu/nuclear-forensics/Decay%20Chains.html

Sanford Underground Research Facility

## Dust Matters Too

✧An important aspect of our REU was dust analysis. Besides continuously monitoring dust levels in the air, various types of slides are placed in the RCR to find the dust plate out as well. Dust is important in two ways in that dust is radioactive enough to cause background in the experiment as well as can act as a source for radon. For this reason, LUX-ZEPLIN has the goal of having 1 gram of dust or less across the entire experiment.

✧Due to the supplies at the SAL, only glass slides are assayed on site. PTFE (Teflon) slides are transported to and from the South Dakota School of Mines and Technology where they are analyzed using fluorescence microscopy.

✧The following procedure is used to analyze dust at the surface lab:

1. Slides are chosen based on the quality of the surface. Slides with many scratches, especially near the center are not chosen as will this will affect the results.
2. Slides are then meticulously cleaned with isopropyl alcohol and held up against light to check for any visible particles on the glass. Once the surface is cleaned with confidence, a nitrogen blower is used to clean off any remaining particles.
3. Slides are then pre-assayed. This means 20 pictures of the surface of the slide are taken each 2mm apart at a 10x magnification.
4. These images are put through a program called ImageJ. The ImageJ macro filters the image, subtracting the background so that only particles appear black while the rest of the image is white. Then a threshold level is chosen, selecting all the dust that appears in the image.
5. Once this is done for all 20 images from a slide, the data files from ImageJ are analyzed using Matlab. During this process, a density map is created from a composite of all the images. Any particle that appears in about 4 or more slides is removed because this is likely a particle in the actual microscope or camera and not on the slide. Finally, a value for the mass of dust per area (ng/cm$^2$) is found.
6. Now pre-assayed, slides are placed out in various places in the RCR and standard clean room. They are left to accumulate dust for anywhere from 1-3 weeks. They are then carefully collected and go through the same process, called post-assay.
7. The pre-assay and post-assay results are then compared to find the dust deposition for the period of time that the slide was out. These values can be compared to the amount of dust measured in the air for that time. An eventual goal is to find the correlation between dust in air and dust deposition.

*Figure 6* – Dust image analysis from initial slide image to setting a threshold value to select the dust before running the data through Matlab.

✧Finally, when the difference in dust over a period of time is found in ng/cm$^2$, the amount of dust accumulated on certain components of LZ can be calculated using the amount of time they were exposed and their total surface area.

✧Many assumptions go into dust analysis, and many sources of error exist as well. The dust particles are assumed to be spherical and assumed to all have the same specific gravity. Though glass slides are used, many pieces of LZ are metal or plastic. As a remedy for this, School of Mines analyzes teflon and titanium witness plates are set out as well.

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