Searching for Dark Matter: Simulating Interactions in the CDMS Detectors

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Master's Defense
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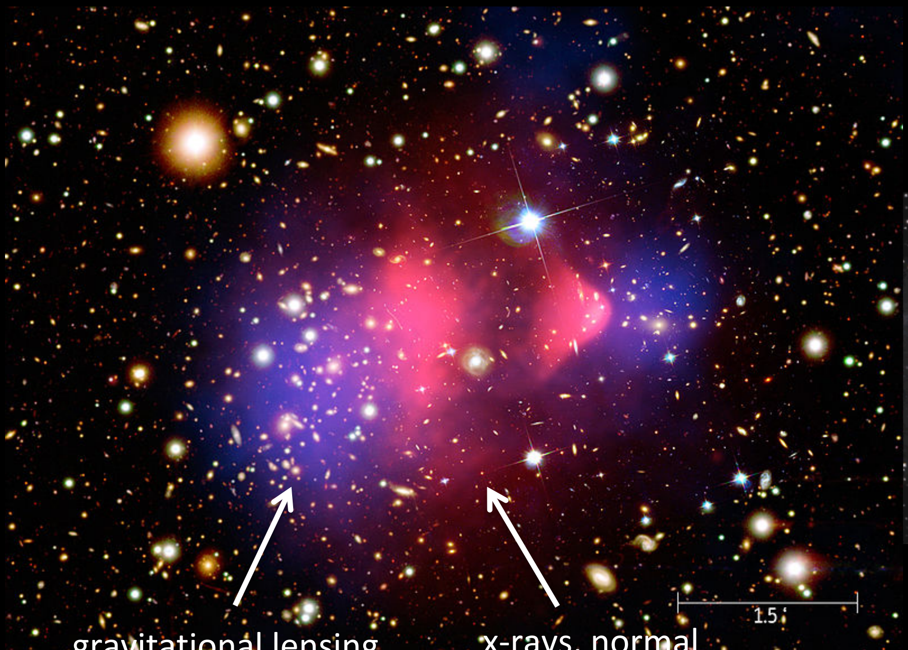
Outline

I. Physics goals: Dark Matter
II. The SuperCDMS experiment
III. Simulation overview
IV. Calibration source and contaminant simulations
V. Noise simulations
VI. Future Work
VII. Conclusion

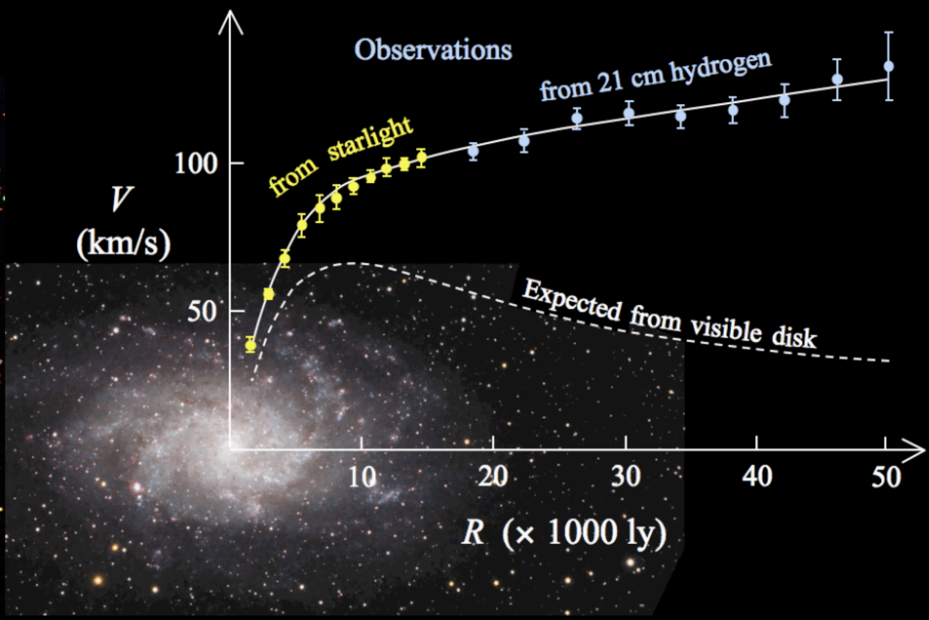
I. Physics Goals



gravitational lensing (blue)

x-rays, normal matter (pink)

Bullet cluster: baryonic centers of mass lagging behind overall center of mass?



Why do stars in the outer regions of galaxies orbit so quickly?

→ **Extra, unseen mass: Dark Matter?**

II. The SuperCDMS Experiment

Weakly Interacting Massive Particles (WIMPs) are major candidates for the composition of dark matter.

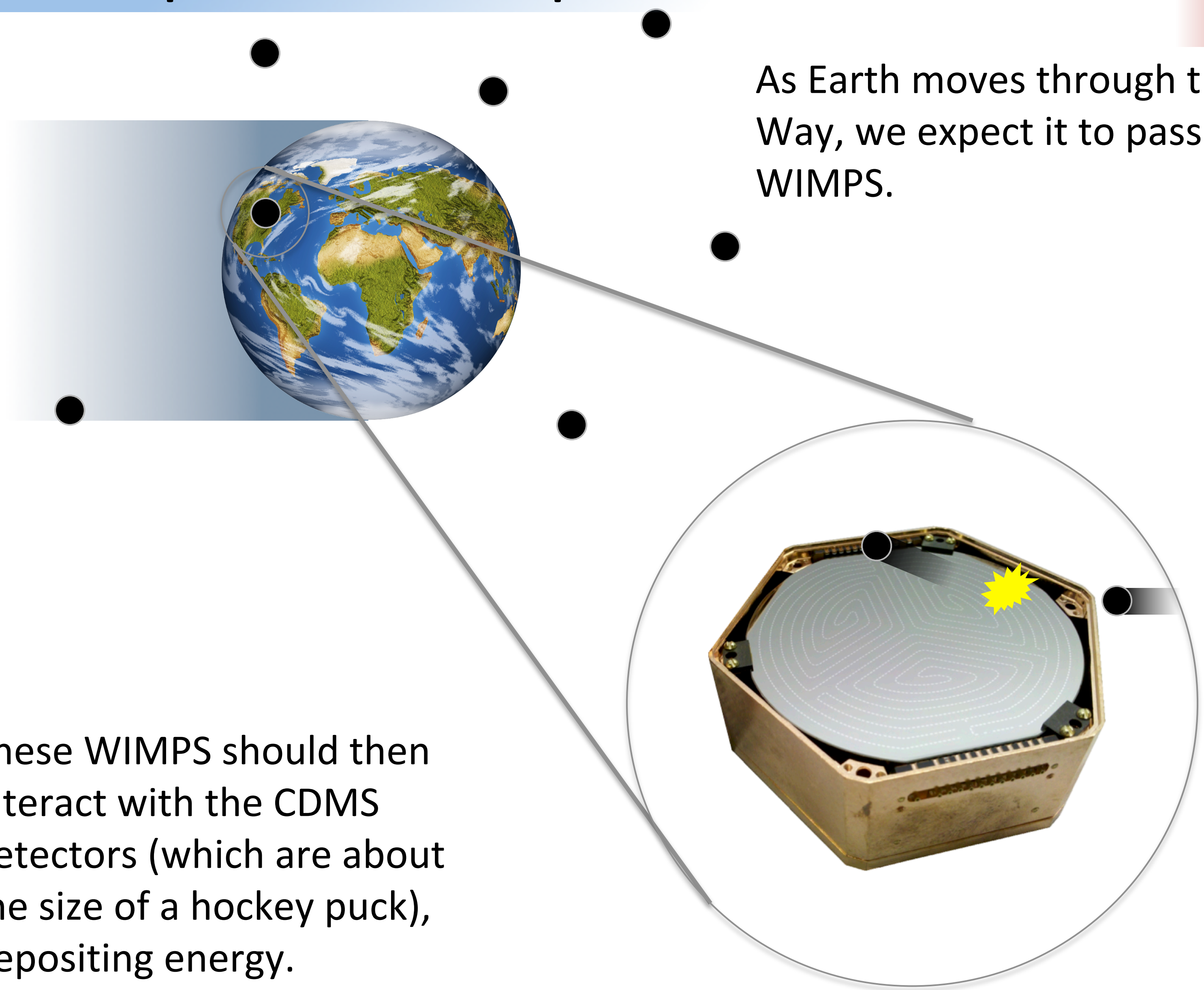
SuperCDMS is looking to detect such particles via nuclear collisions.

Our current work will be used for analysis of data from SCDMS's previous Soudan experiment and for preparation for the upcoming SNOLAB experiment.

II. The SuperCDMS Experiment

Details

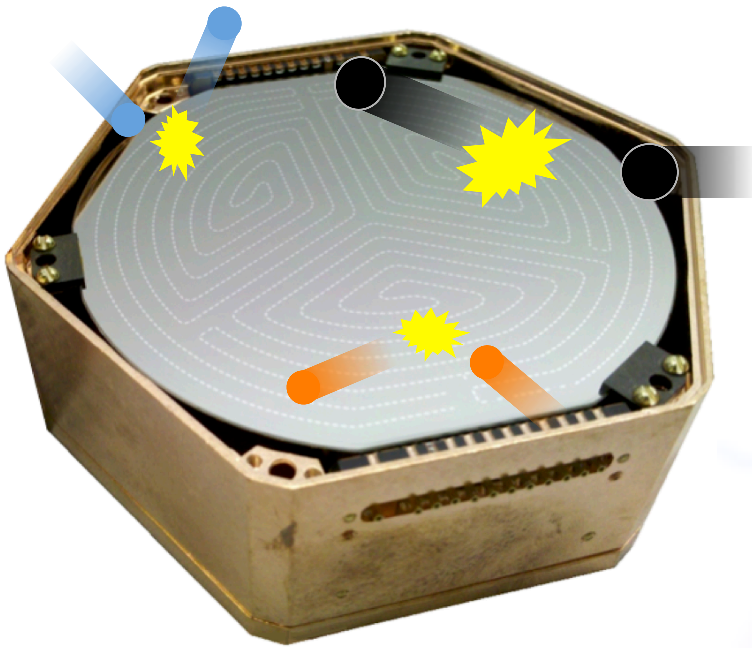
As Earth moves through the Milky Way, we expect it to pass through WIMPS.



These WIMPS should then interact with the CDMS detectors (which are about the size of a hockey puck), depositing energy.

II. The SuperCDMS Experiment

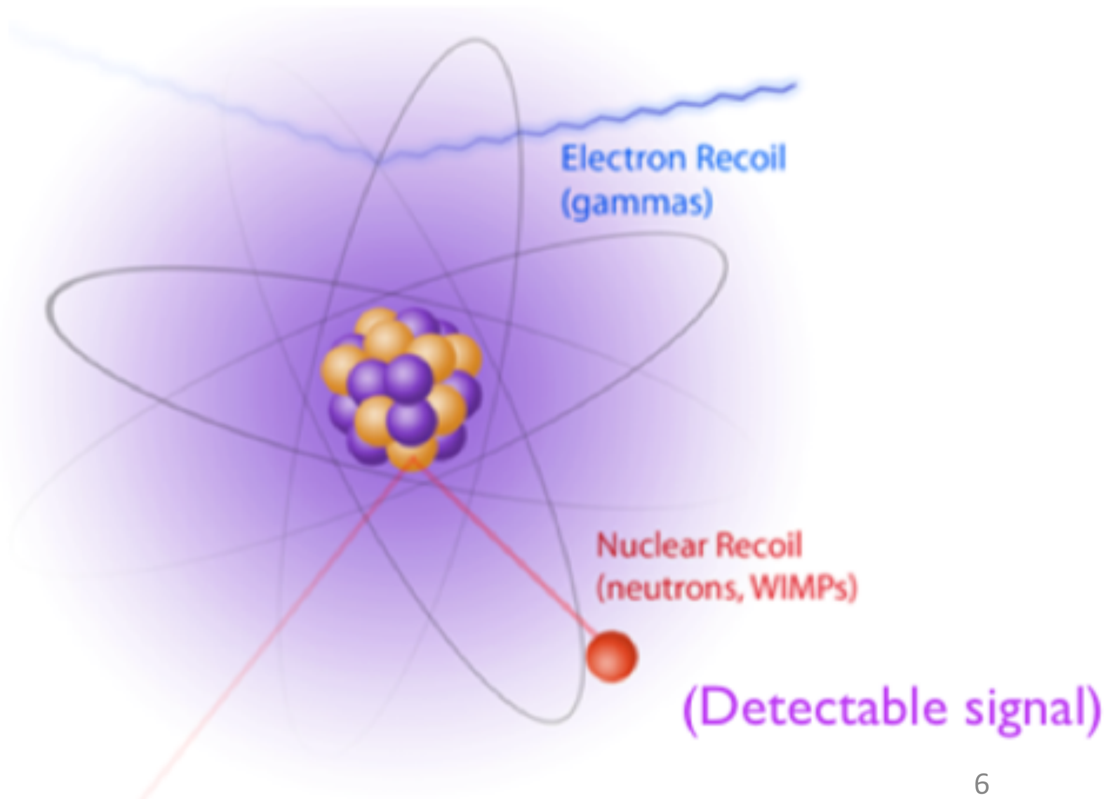
Details



The detectors are sensitive to energy depositions from more than just dark matter.

- Both WIMPS and neutrons can cause nuclear recoils (signals and signal-like backgrounds)

- Gammas and betas can cause electron recoils (backgrounds)

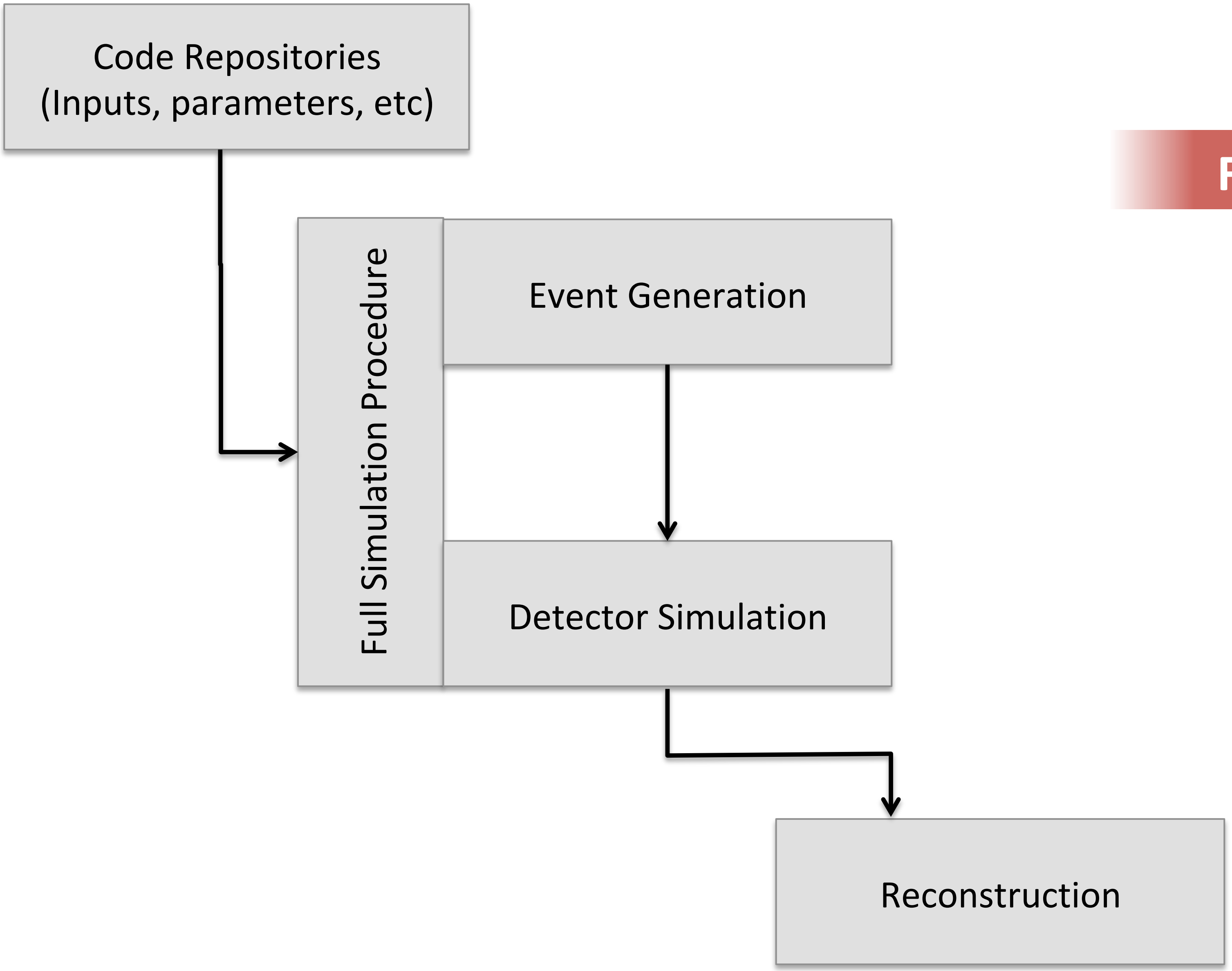


- To optimize the sensitivity of future searches, we want to be able to simulate all the interactions we expect in the real detectors

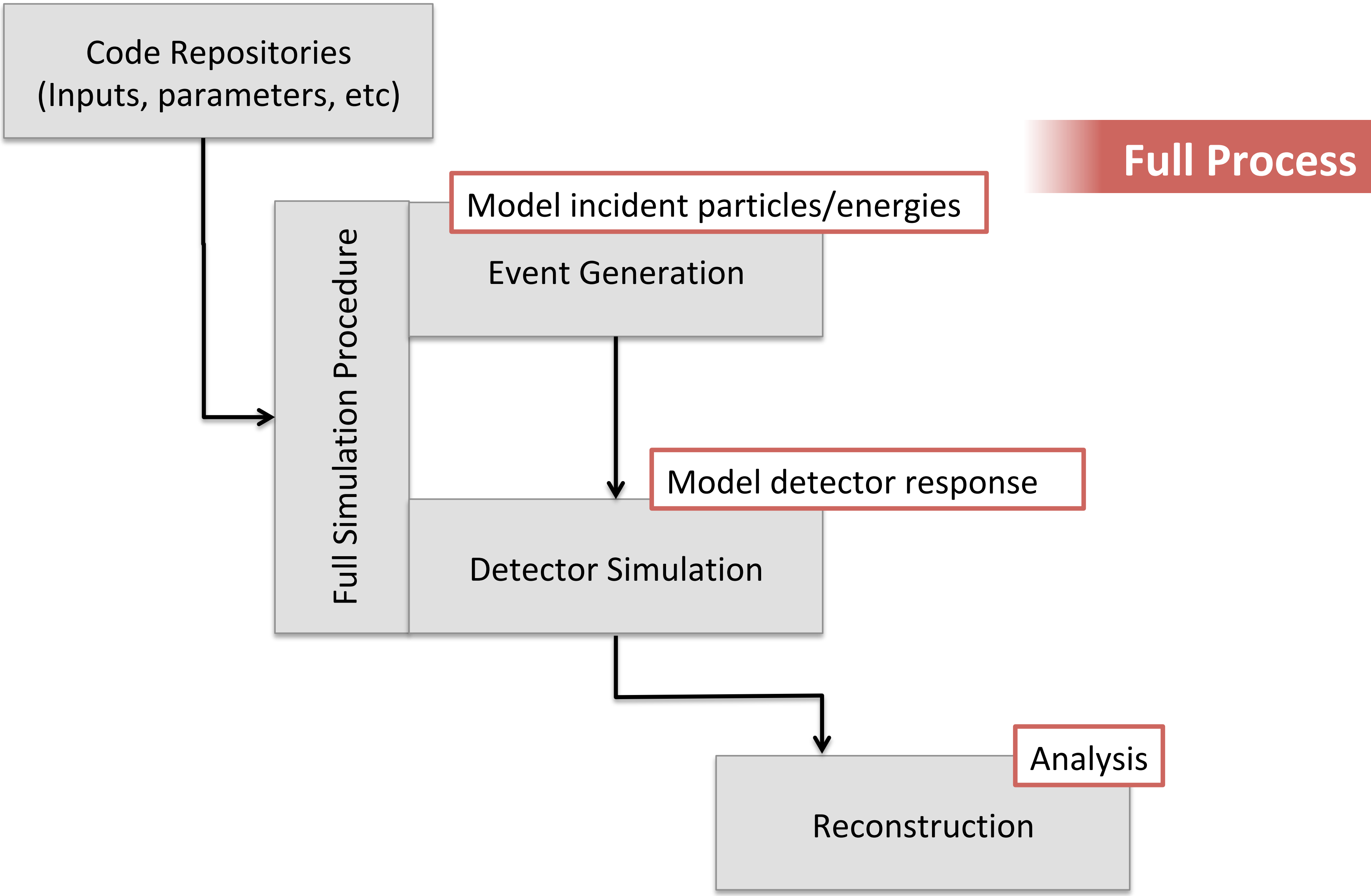
- I.e. we want to be able to recreate signals and backgrounds that were/will be seen in experimental data

III. Simulation Overview

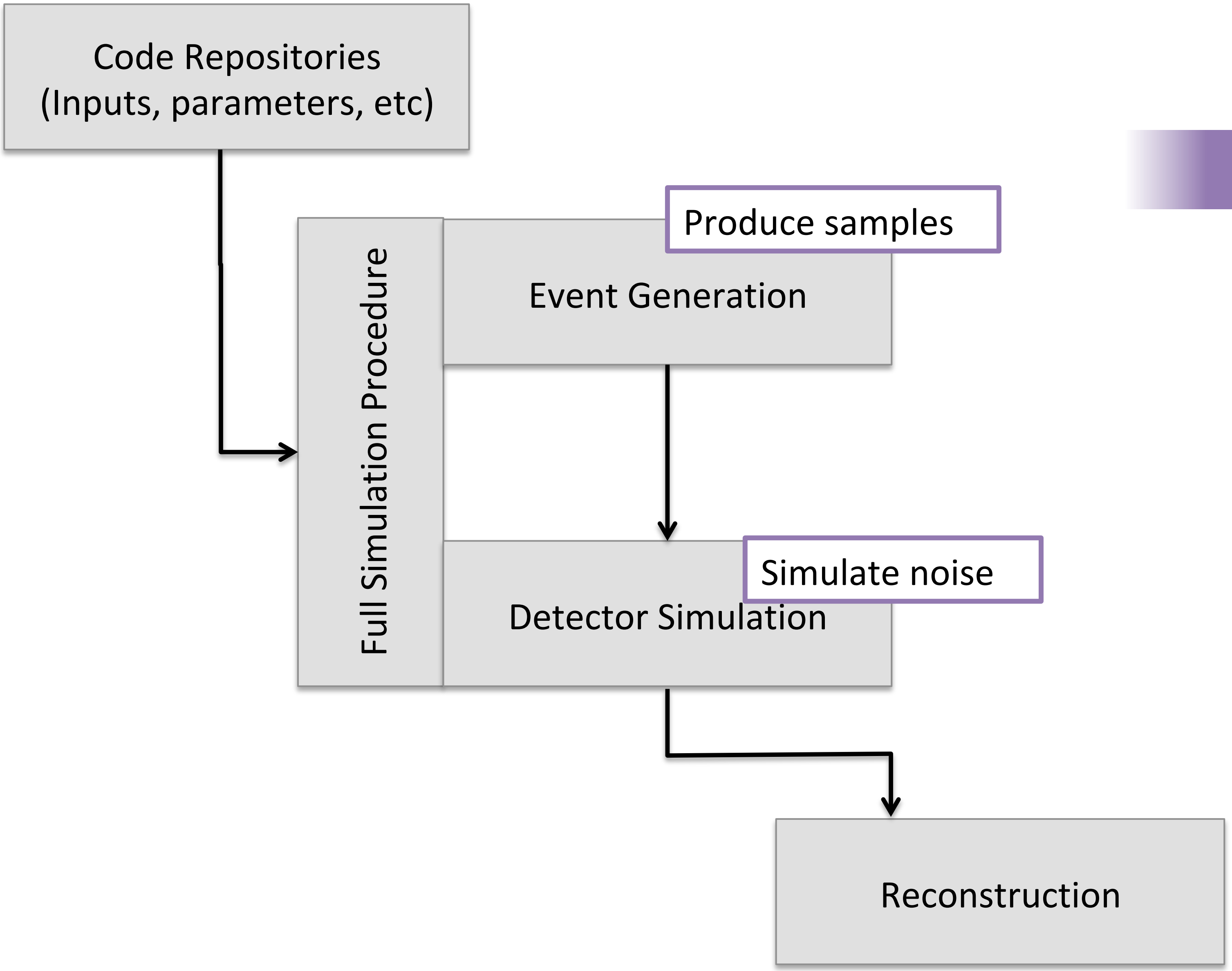
Full Process



III. Simulation Overview



III. Simulation Overview



My focus

IV. Calibration source and contaminant simulations

First stage of simulation: model particles and energies incident on the detectors

- Simulate photons, neutrons, etc. interacting with the detectors—i.e. given particles being created, traveling through a given volume, and depositing energy
- Also will be able to model WIMPS in the detectors

The elements that will be shown here have been simulated before; in addition to checking physical accuracy, then, I have had the goal of verifying that our simulations still work —through system updates and code revisions—such that all our results are reproducible.

IV. Calibration source and contaminant simulations

There are multiple types of particles that the detectors could pick up. To identify potential dark matter activity, we must know what interactions with more mundane matter would look like. I have mostly been studying these two examples:

- Barium -- Used for calibration
- Germanium -- Detector contaminant

IV. Calibration source and contaminant simulations

Particular elements show particular energy spectra; radioactive Ba-133 and Cf-252 sources were placed near the detectors in the SOUDAN experiment for calibration purposes: we know the particular energies they would let off as they decay, and by identifying those patterns in our data, we know what energies everything else has.

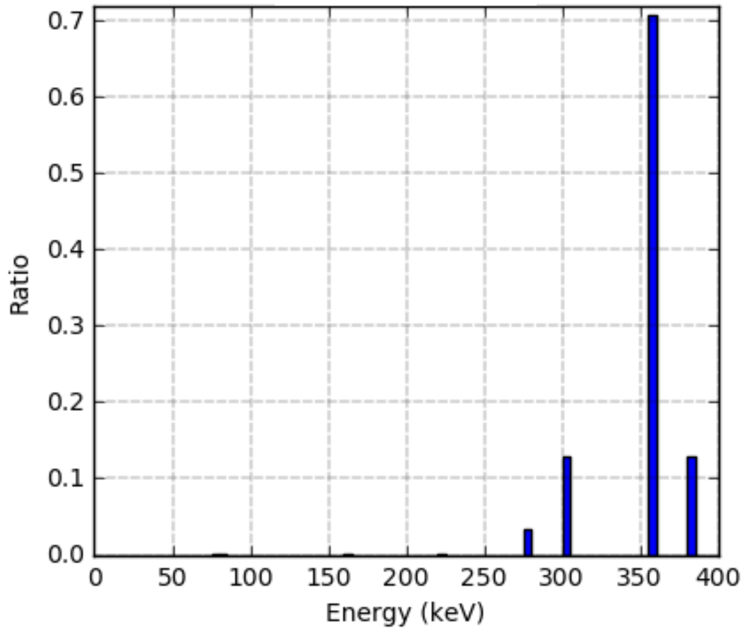
- Barium -- Used for calibration
- Germanium -- Detector contaminant

IV. Calibration source and contaminant simulations

Calibration

- We expect Barium-133 to emit photons with particular energies at particular rates: over 60% around 356 keV, or about 10% around a maximum energy of 383 keV, for example
- As shown in the plot below, the simulation appears to be meeting these expectations
- Lower energies than the ones seen in the plot are emitted as well, but these are generally absorbed before reaching the detector

Primaries

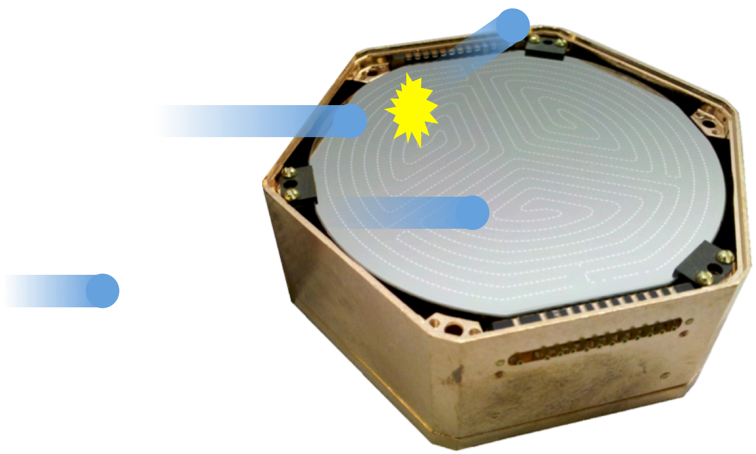


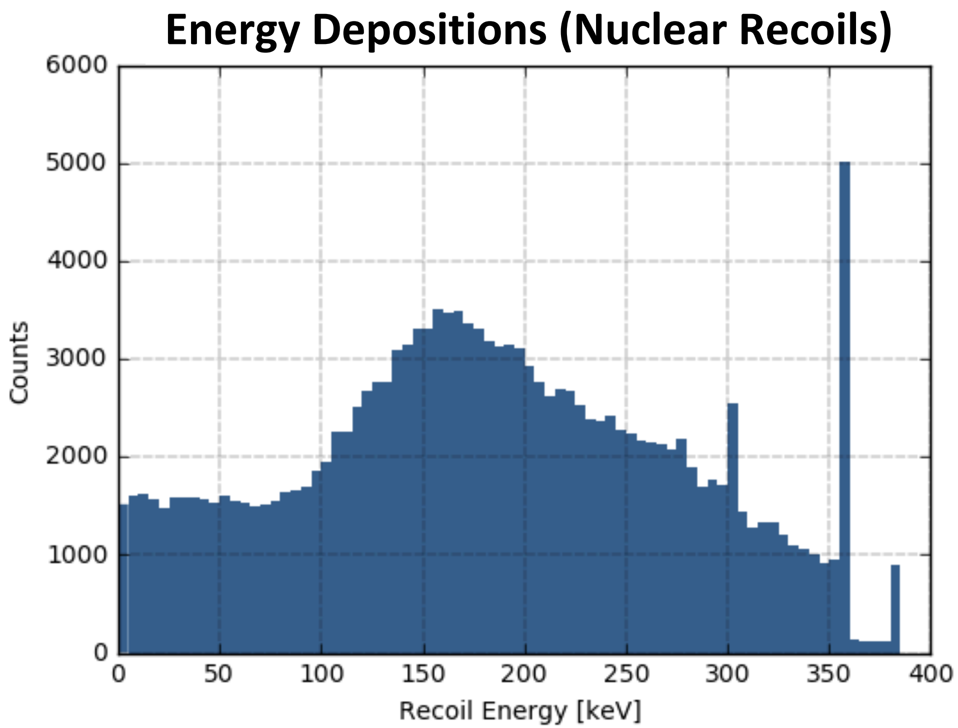
IV. Calibration source and contaminant simulations

Calibration

- Since the detectors have finite volume, particles may only glance off detector atoms and then leave without depositing all their energy (i.e. Compton scattering events)

- The final distribution of energy deposited in the detectors, then, will show a pattern similar to that seen in the primaries, but these recoil energies will also be spread out below the primary energies; this is in fact what we observe:





IV. Calibration source and contaminant simulations

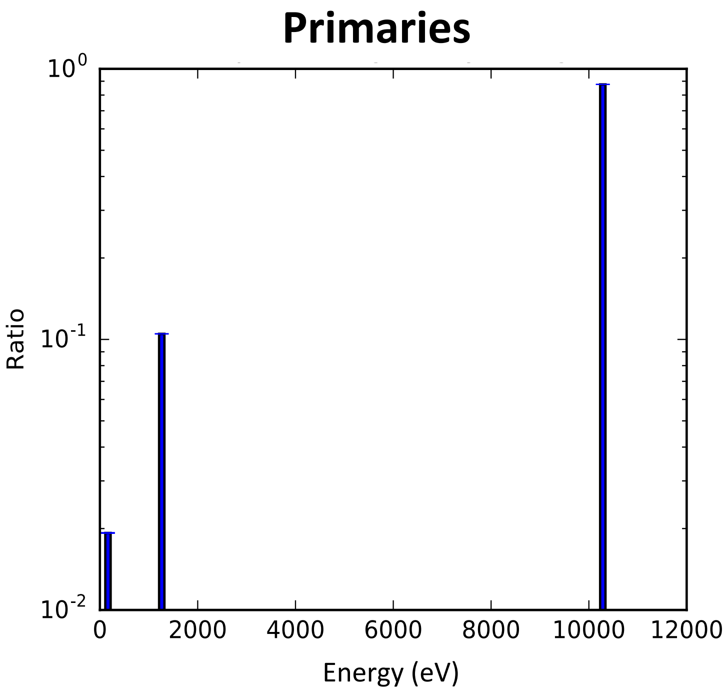
Though the detectors are shielded, there are some non-dark matter sources that can't be avoided, such as excited atoms in the detector:

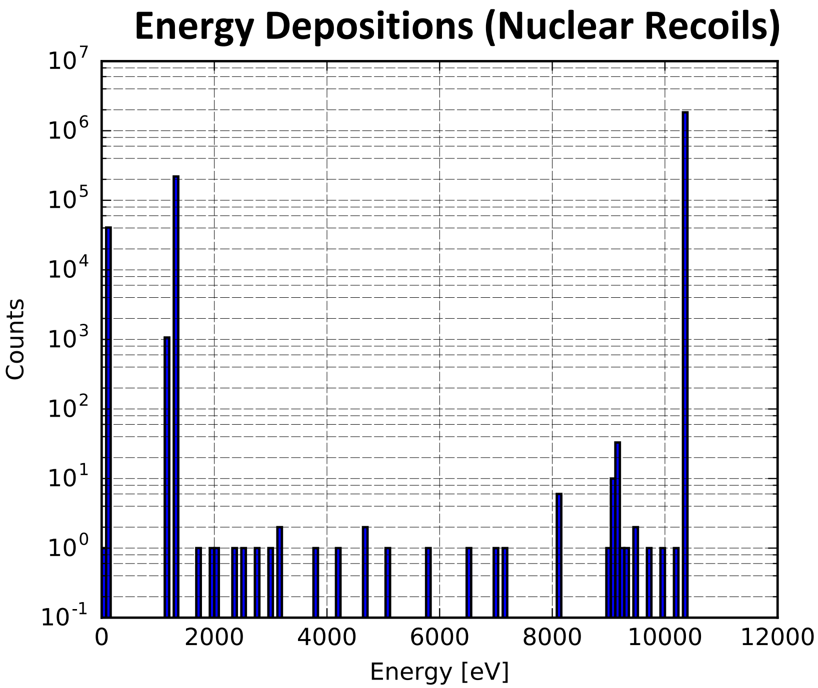
- Barium -- Used for calibration
- Germanium -- Detector contaminant

IV. Calibration source and contaminant simulations

Germanium

- As with the calibration sources, germanium, once it's excited and decays, emits particular energies at particular rates, which we were able to replicate in our simulations

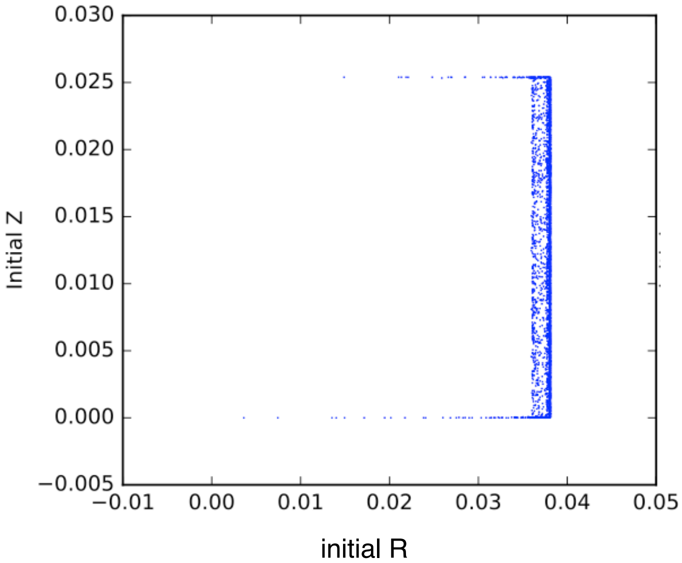


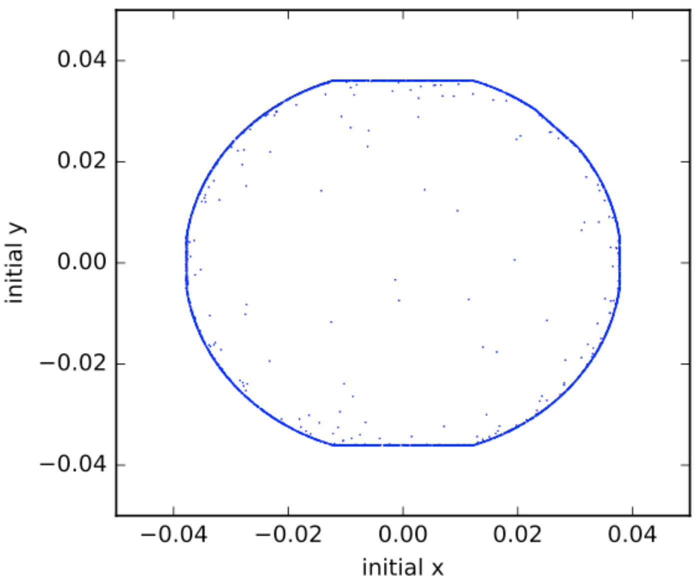


- The energy deposition plot again shows a distribution similar to that of the primary plot, but with other events between/below the primary energies

IV. Calibration source and contaminant simulations

Initial locations of events that lost energy

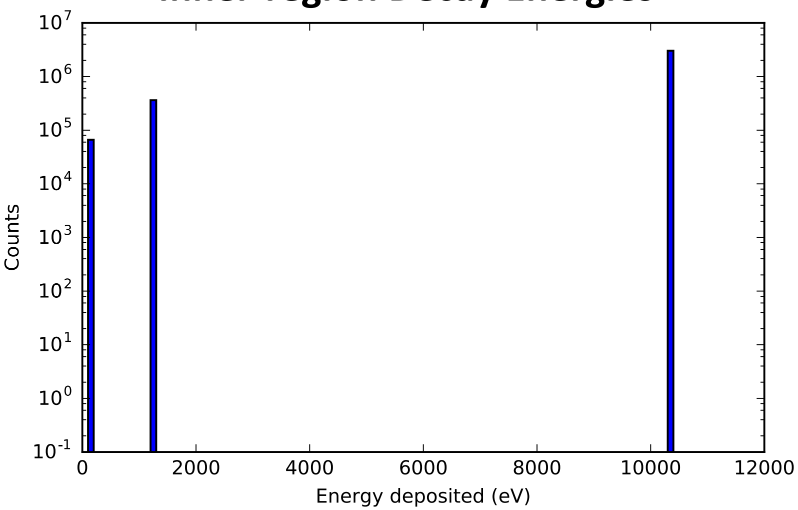




Germanium

- We checked the starting locations of all events that ultimately deposited non-primary energies—and found that such events all began on the detector edges, which is where energy-loss is most likely to happen
- We recovered an energy signature like the incoming primary energies by removing such edge events

Inner-region Decay Energies



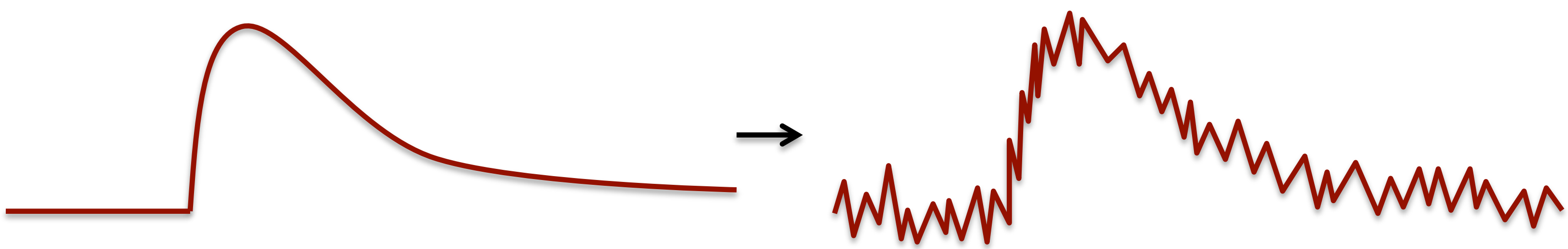
Second stage of simulation: model the detectors' reactions to the deposited energies

- In both the detector and the readout equipment, there is potential for noise to show up
- We must next simulate this noise and include it in the source and detector simulation chain

V. Noise simulations

V. Noise simulations

- There will always be some amount of noise in the detector's output; this must specifically be modeled



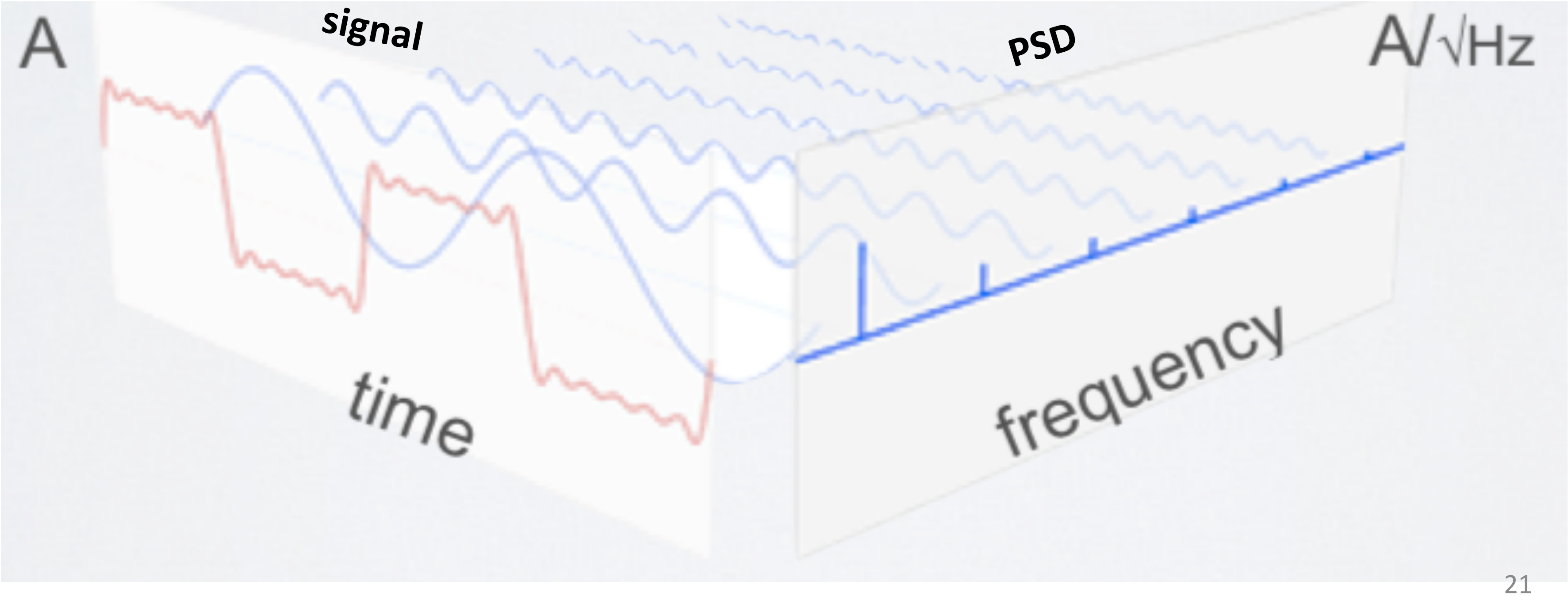
Simulated pulse *Simulated pulse + noise*

- Noise was previously modeled by randomly recording real data when no events were occurring and later adding these random 'events' to simulated pulses

V. Noise simulations

PSDs

- Now when we measure the noise, a Fourier transform is applied to find the power at each frequency and so produce a "Power Spectral Density" function
- I've written code in which this PSD can be used (by reversing the Fourier transform) to simulate further noise with a more generalized distribution

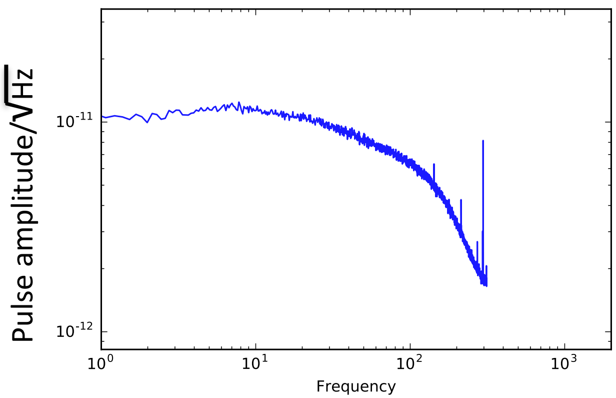


V. Noise simulations

PSDs

- For testing this new code, if we were to be given a PSD and use it to add noise to simulated *blank* pulses, we should be able to recreate the original PSD at the end of our simulation chain

Original PSD
Created from real data



?
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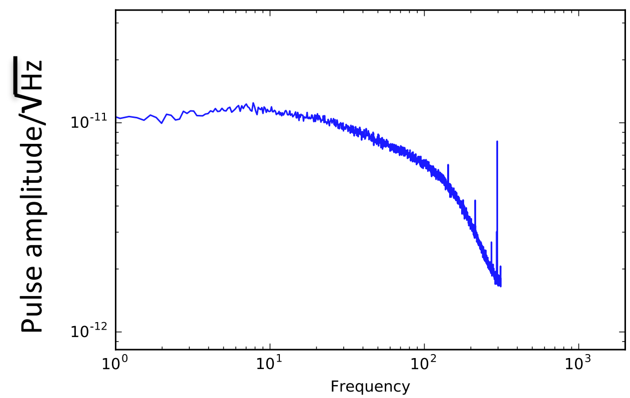
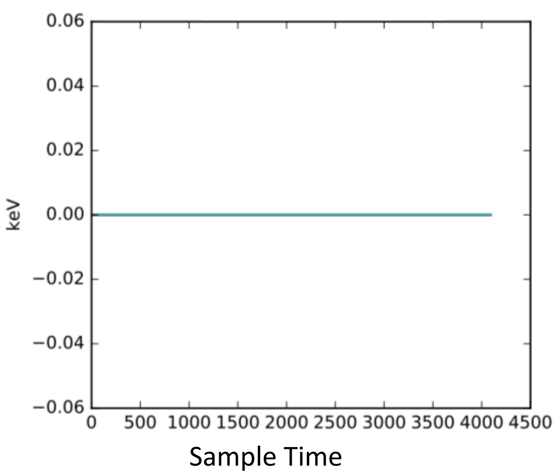
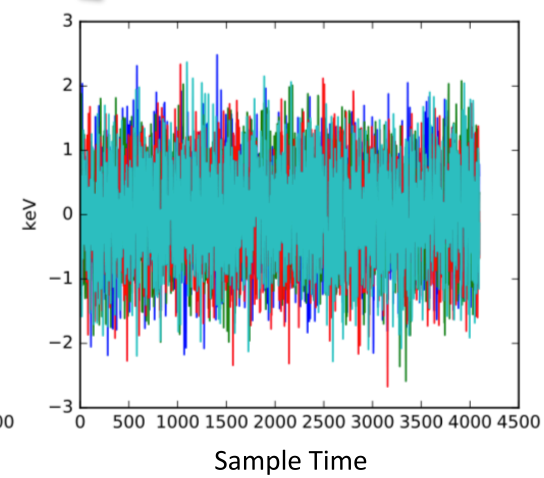
New PSD
Created from simulation



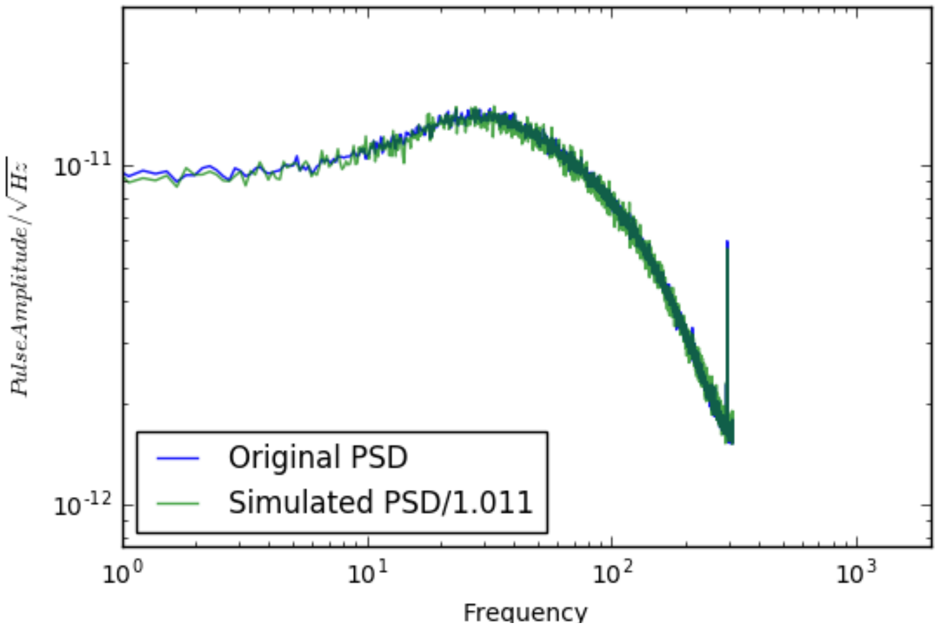
Empty Events





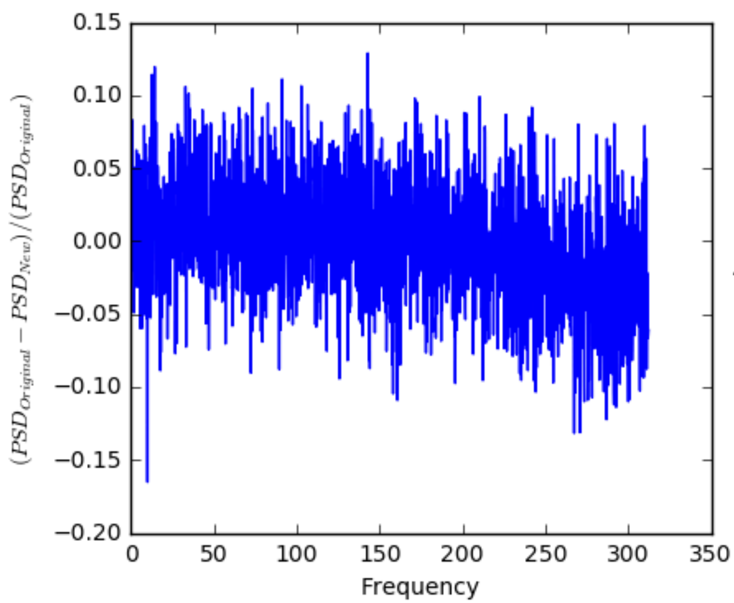
Empty Events
+noise

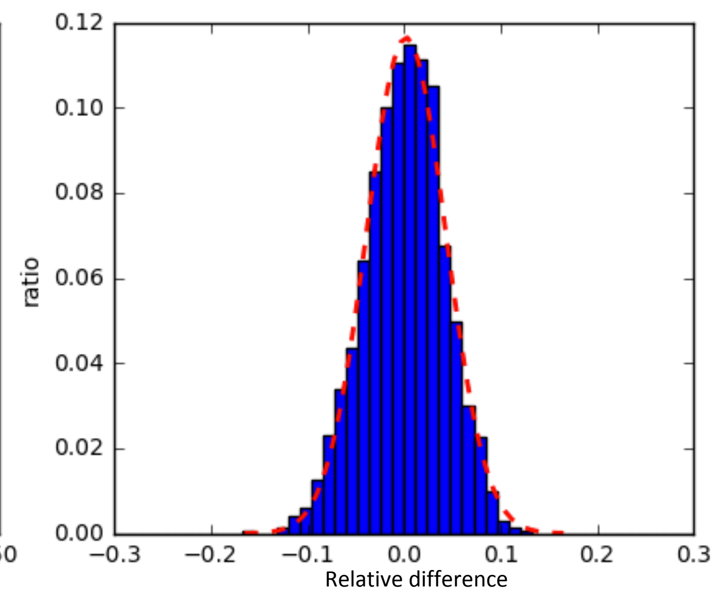
V. Noise simulations



Noise Addition

- We were able to recreate the original noise PSD after running it through all our simulation code; as shown below, the relative error is generally small
- The noise code, then, is not adding or removing noise unnecessarily, so it can now be used with real pulses





VI. Future Work

Looking ahead for this project, our simulations could include the following:

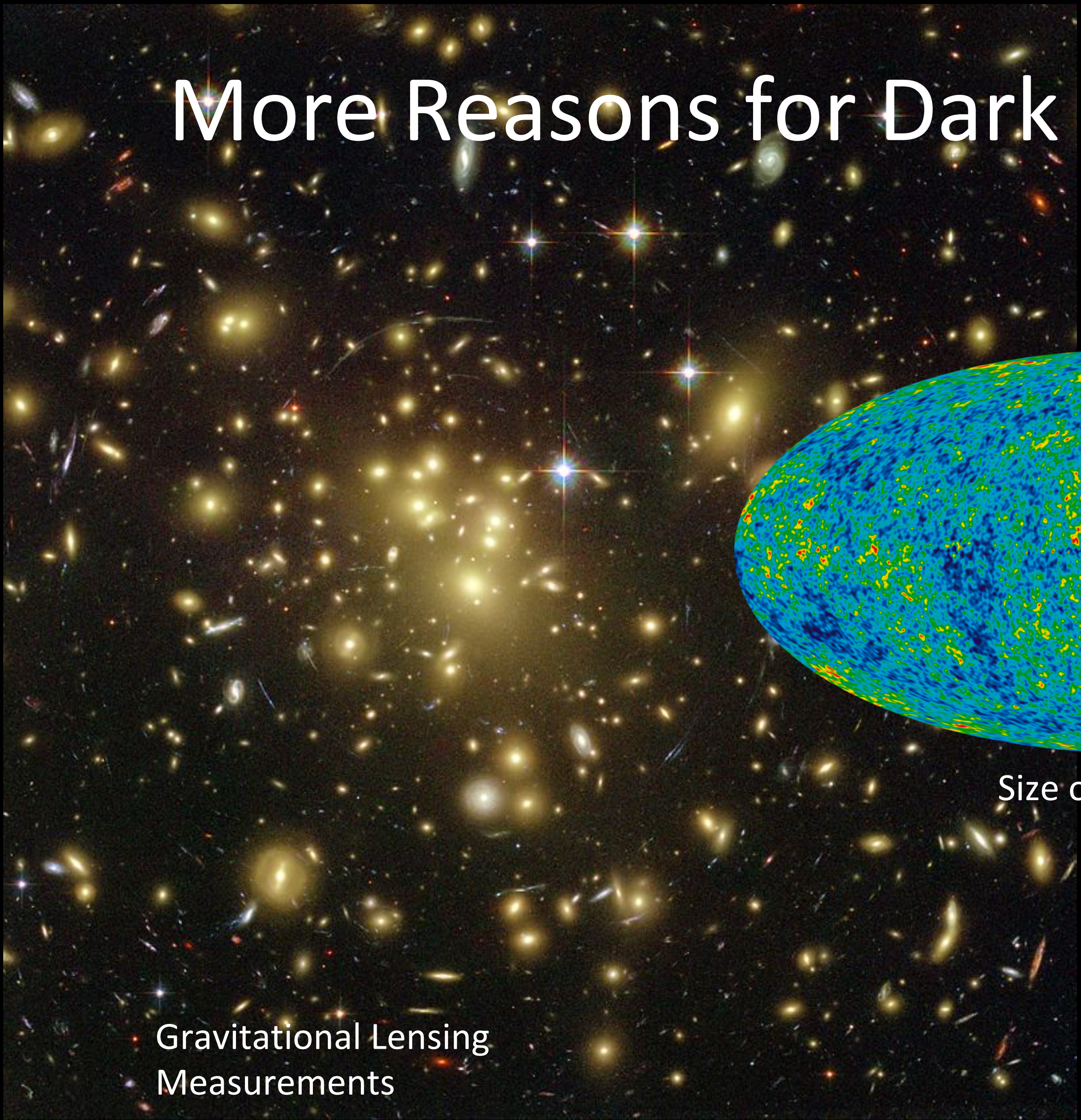
- Event Generation: studies for Pb (a shielding contaminant) and WIMPS themselves; automatic validation for version upgrades
- Detector Simulation: Scaling of noise for different detector channel calibrations

VII. Conclusion

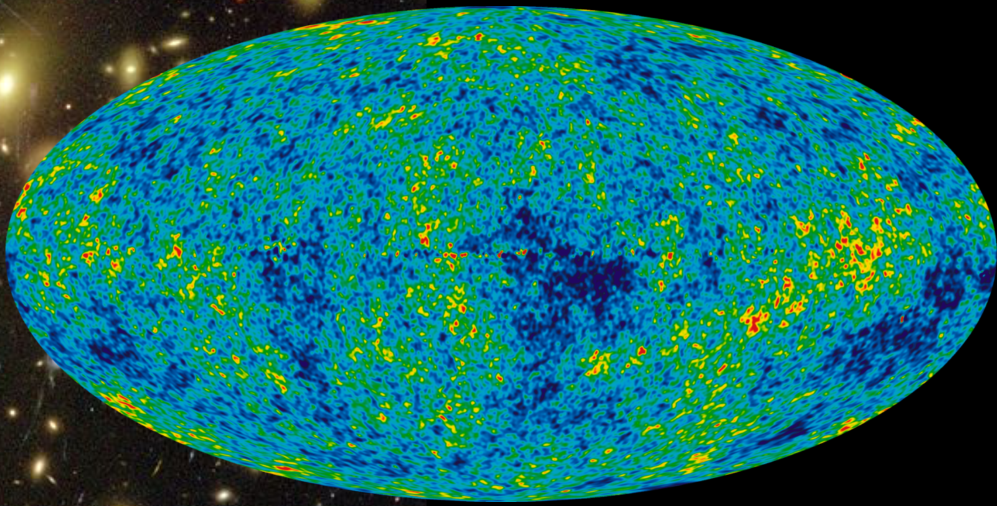
- We are searching for dark matter with the SuperCDMS experiment
- We are developing simulation tools to make our experimental setup more sensitive
- We have made significant progress on these tools and demonstrated that they work as expected
- We will use them to analyze data that has already been taken and will use them again when the current experiment has been upgraded

BACKUP SLIDES

More Reasons for Dark Matter

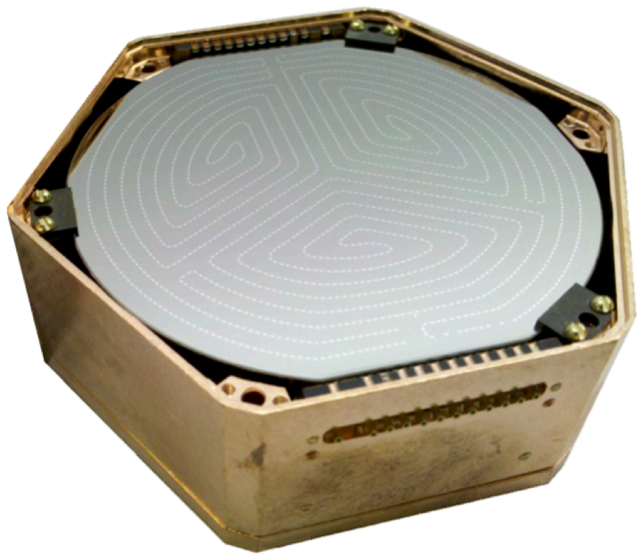


Gravitational Lensing
Measurements



Size of fluctuations in CMB

CDMS Detectors



Transition Edge Sensors: tungsten network with aluminum fins, kept just at the temperature where tungsten becomes superconducting

Nuclear recoils create phonons, which are absorbed by the fins, which heat up the tungsten, and so rapidly increase the resistance, which is detected in the current sent through