# Searching for Dark Matter with the CDMS Detector

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# Outline

Dark Matter and WIMPs

The Cryogenic Dark Matter Search (CDMS) Experimental Layout

Backgrounds and their Interaction with the Detector

Results, Conclusions, and the Future

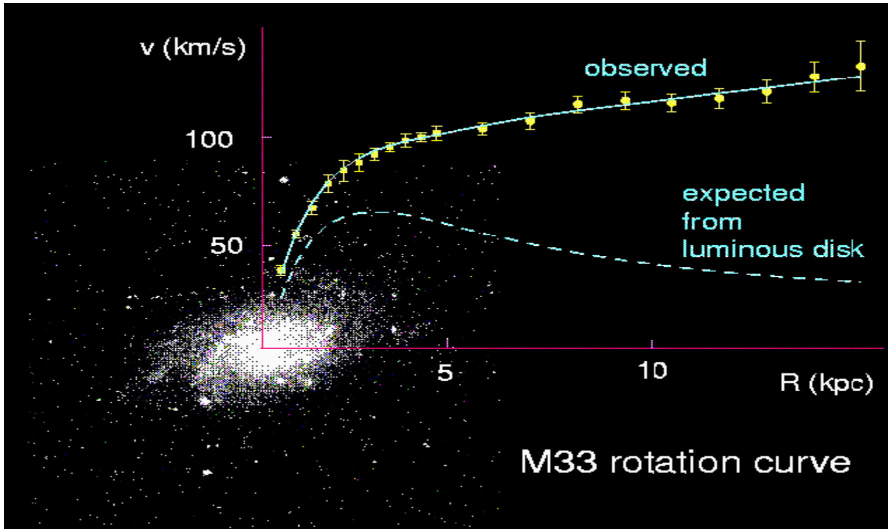
# Dark Matter and WIMPs

# Cosmology + Particle Physics

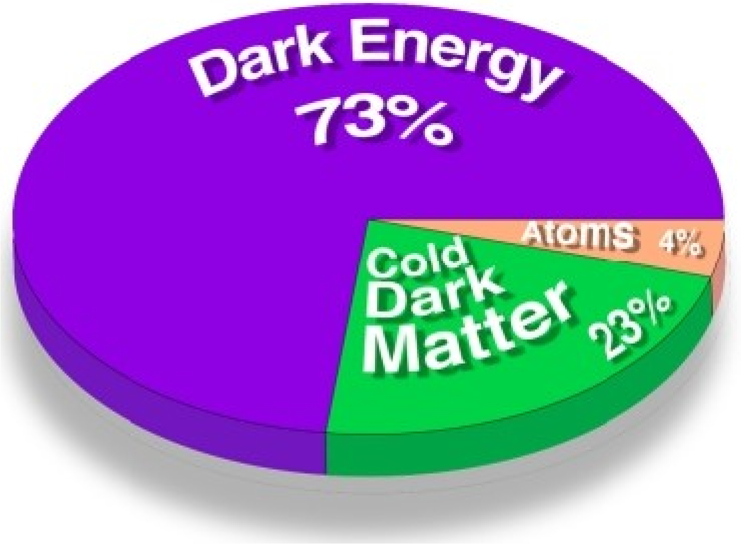
- Questions about the early universe require knowledge about its smallest inhabitants
- Likewise, understanding the universe gives us knowledge about fundamental particles

# Dark Matter

There is a large amount of evidence supporting the existence of dark matter



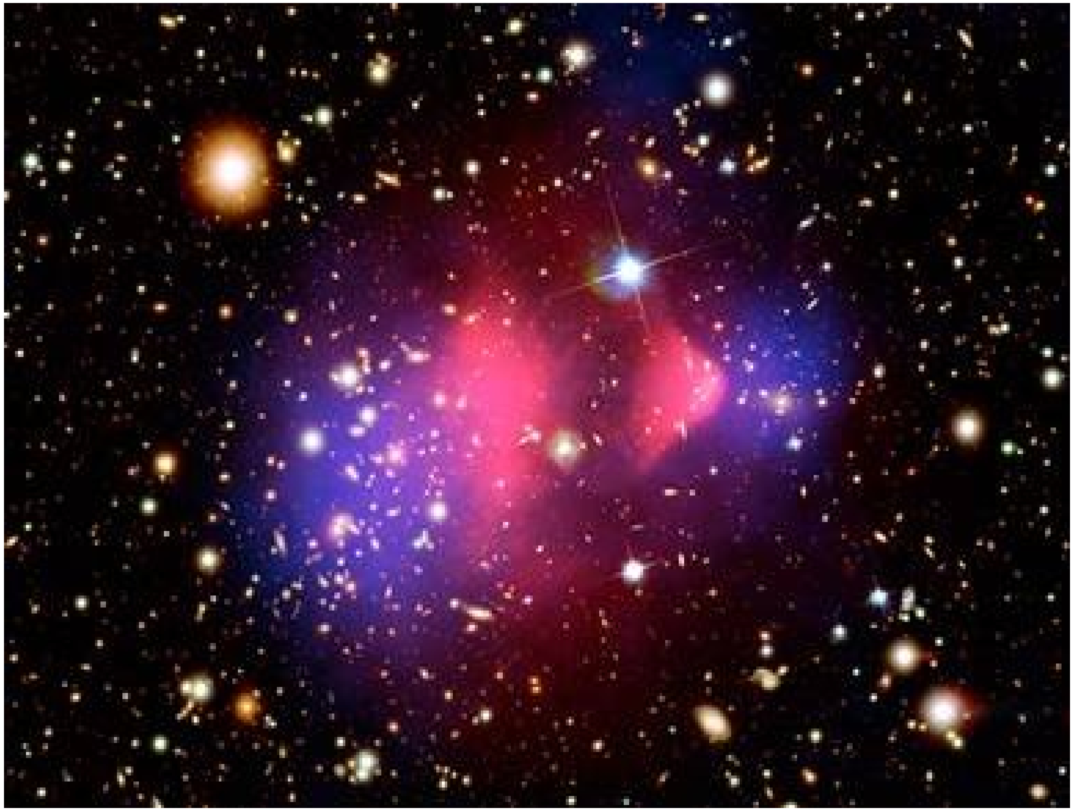
Dark matter is found throughout the universe and is about ¼ of the mass energy of the universe



# Dark Matter as a Particle?

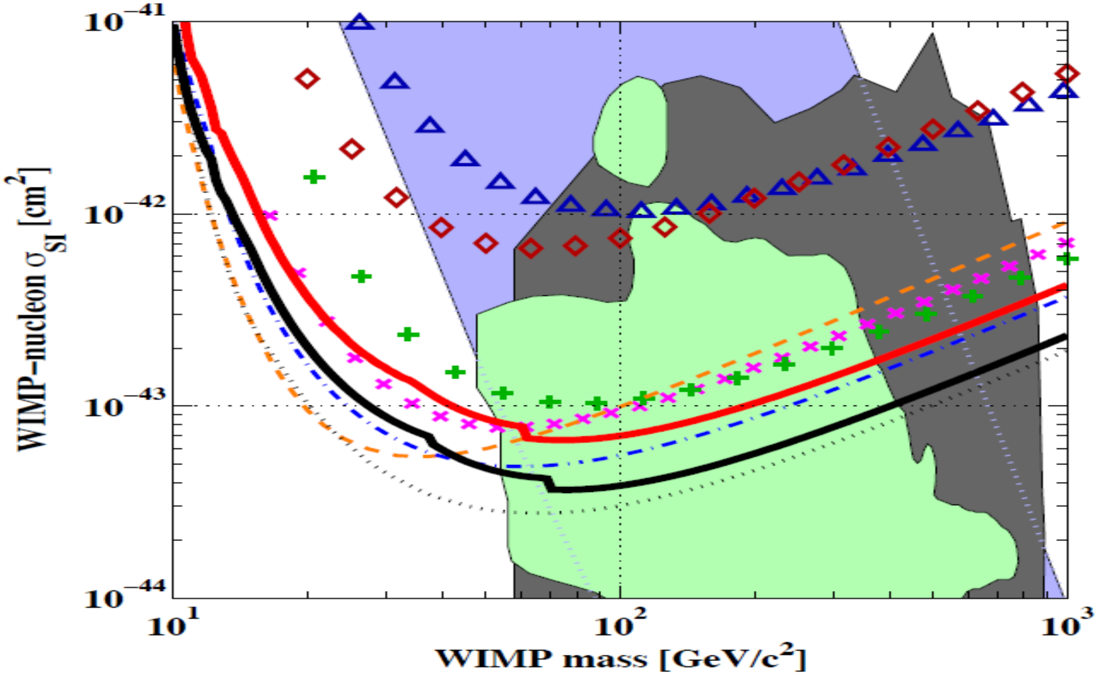
The Bullet Cluster suggests that dark matter may be particle in nature

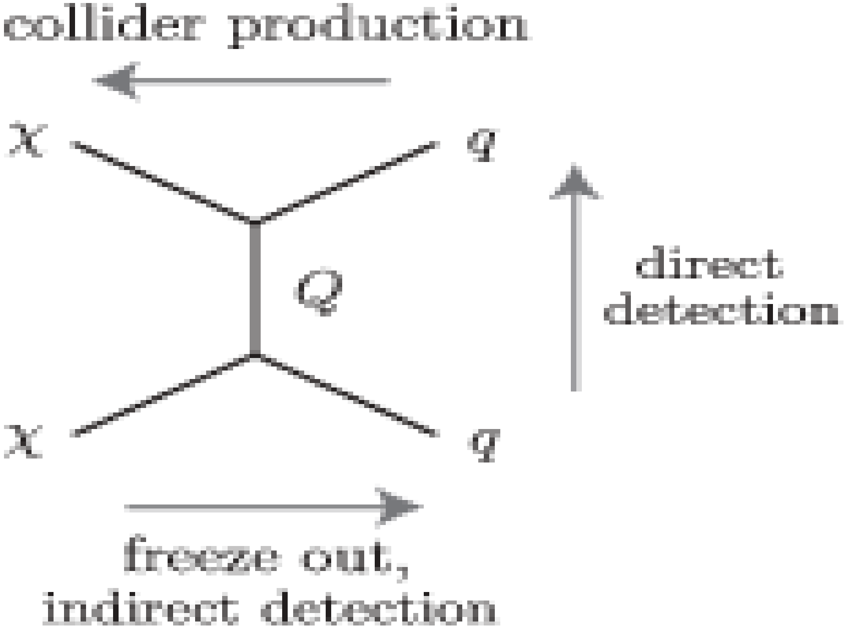
If dark matter is made of particles, we know some properties, but have to guess others



# Weakly Interacting Massive Particles

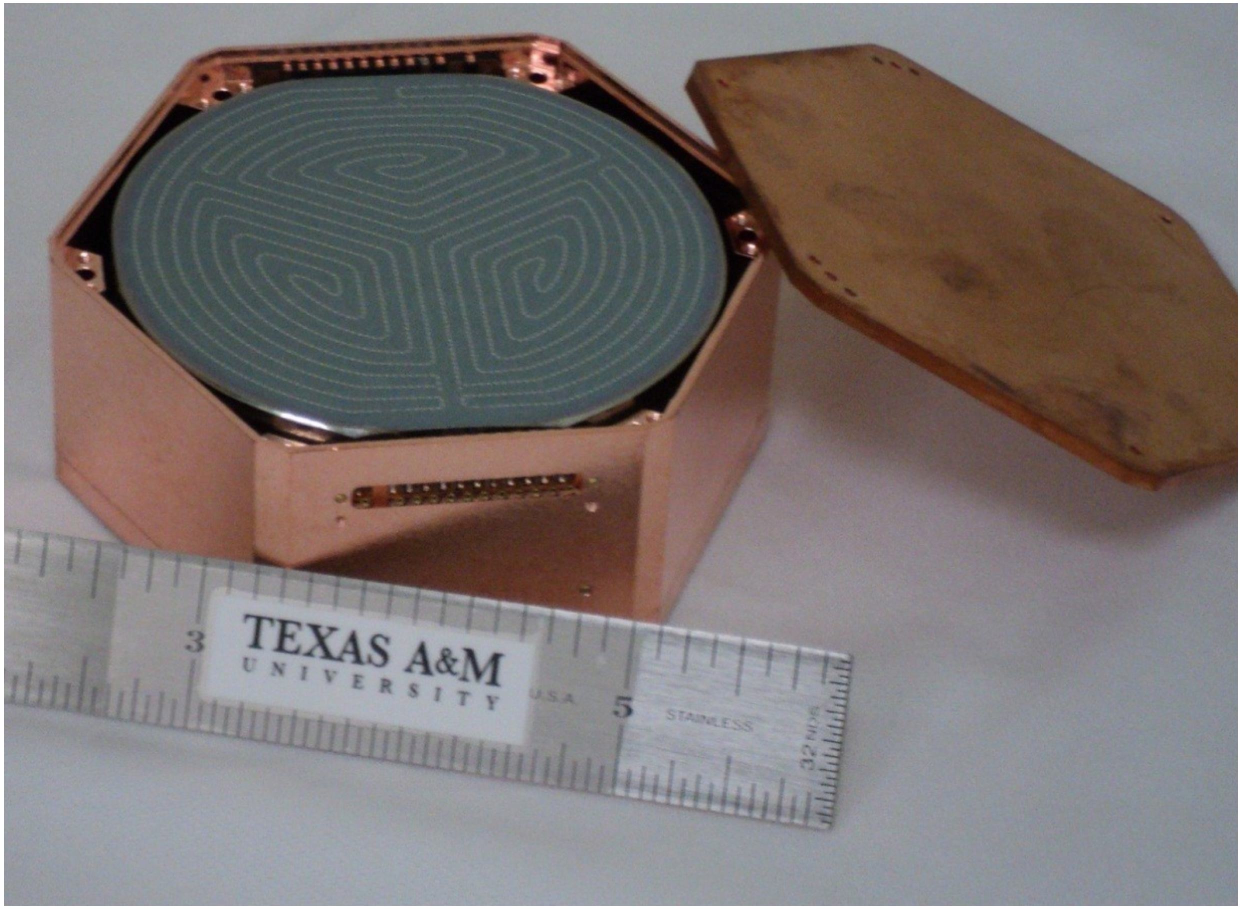
- Experiments put an upper limit on interaction cross section that is comparable to that of the weak force
- There are many different methods of looking for WIMPs
- CDMS uses the direct detection method of a WIMP interacting with a nucleus





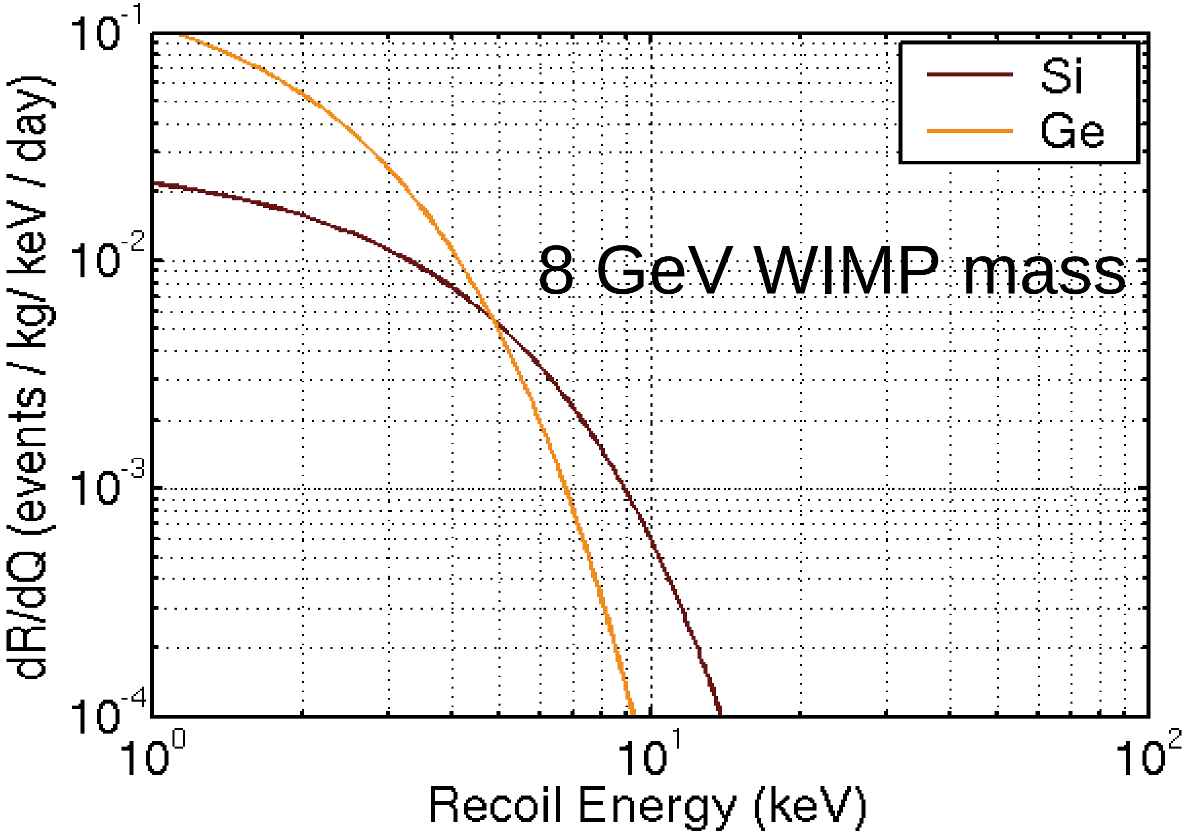
# The CDMS Experimental Layout

# Detector Basics



- Use 3” detectors
- Each detector features a superconducting crystal lattice of heavy nuclei
- Some are Si, some are Ge
- They provide extremely precise timing and energy resolution for low energy interactions

# Why Si and Ge?



When a particle interacts with a nucleus in the detector, it imparts a small amount of energy

The amount deposited depends on the mass of the nucleus and the mass of the particle

Since most interactions deposit a only small amount of energy, we use as low an energy threshold as possible

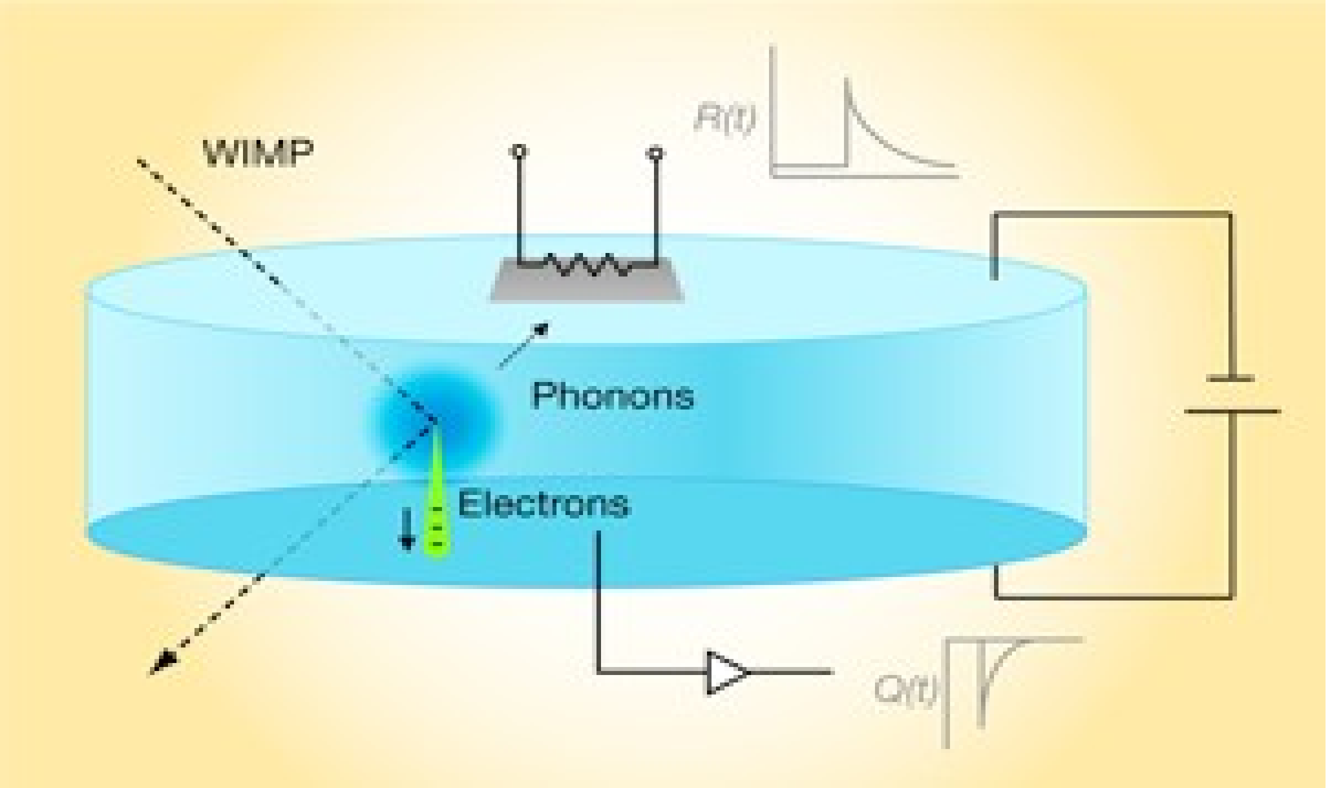
# Particle Interactions

Particle interactions can deposit energy in two ways:

1) The direct ionization of electrons

2) The creation of lattice vibrations, or phonons

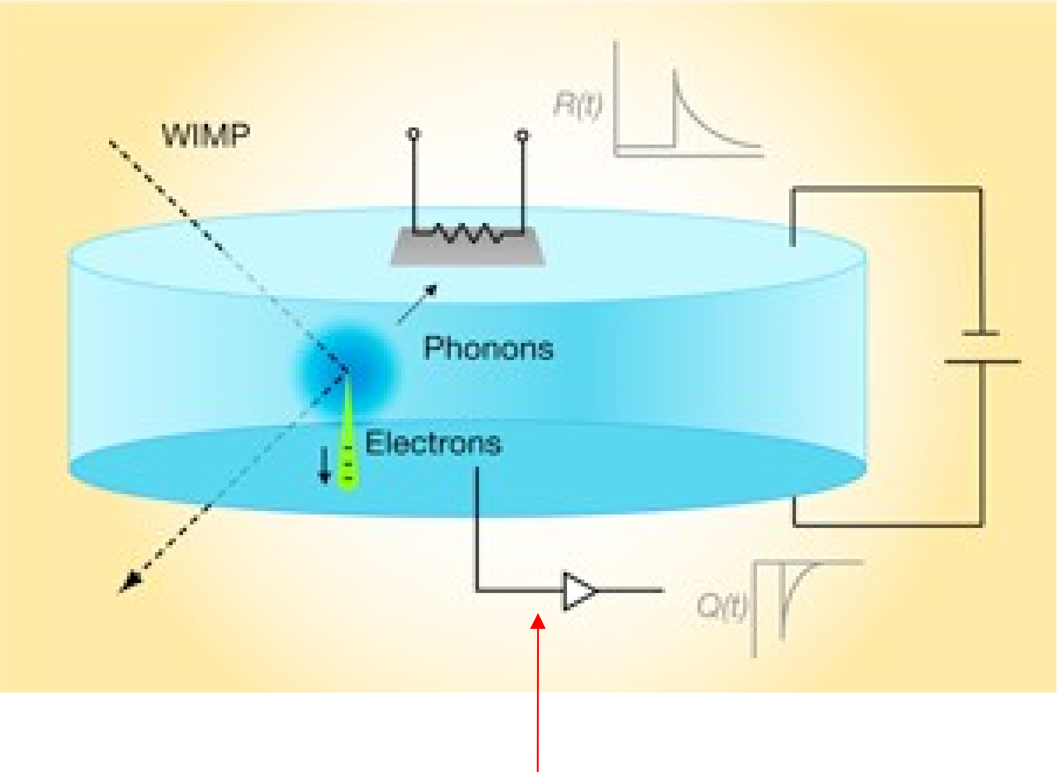
The detector is designed to measure both to determine what type of particle deposited energy



# Ionization Channel

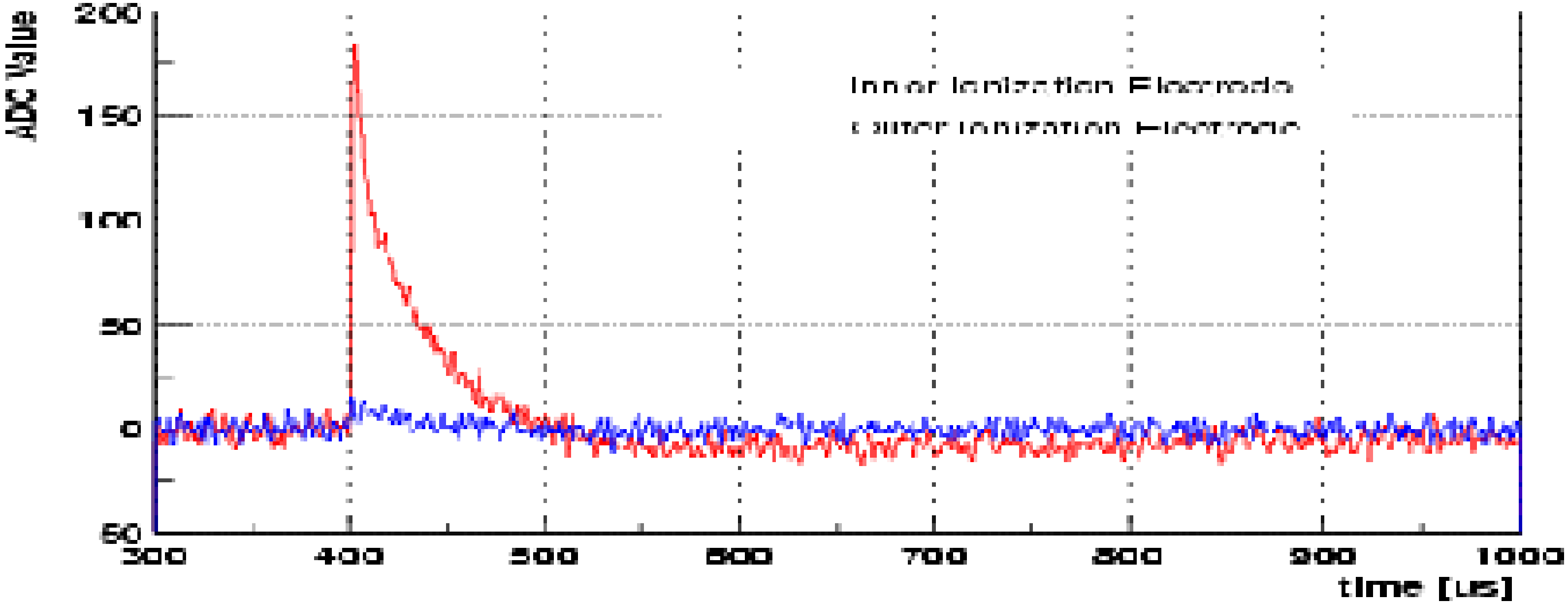
A voltage is applied to the crystal

Any charge carriers produced in the interaction move towards the edges where they are collected



Collector

# Ionization Channel Continued



We can plot the amount of collected charge vs. time

Notice steep rise time, use this to identify when pulse starts

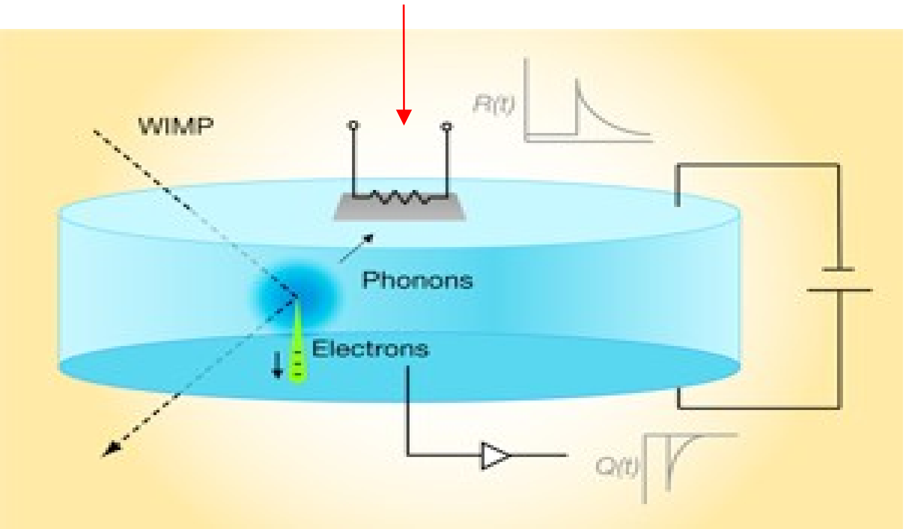
Use the peak to measure the recoil electron's energy which we will later use to identify the particle – call this ionization energy

# Phonon Channel

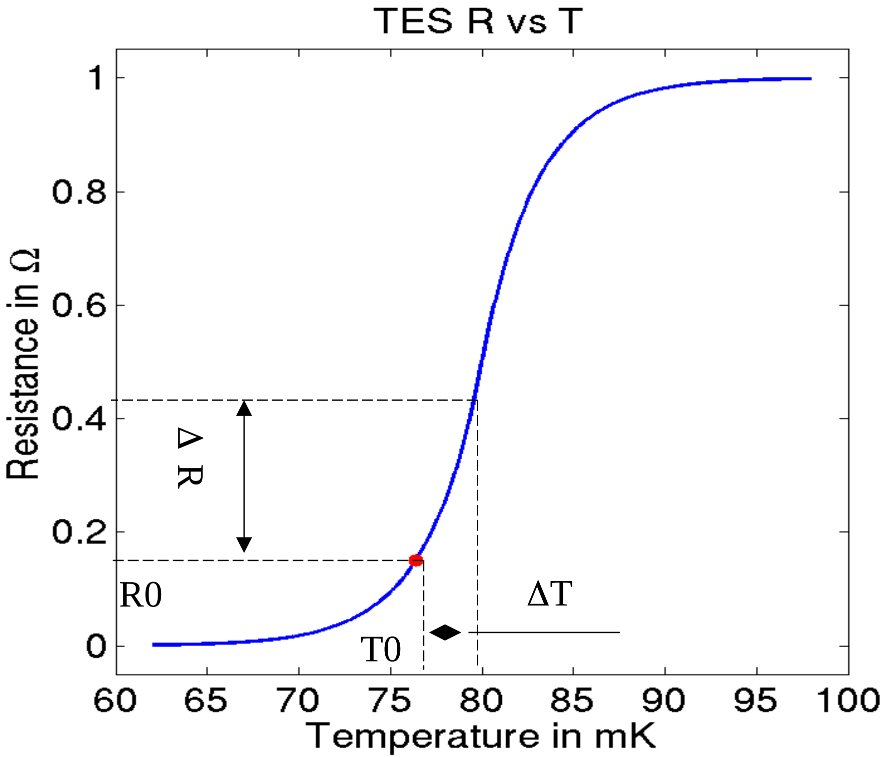
The detector is held at ~mK, in the superconducting temperature range

Any phonons produced will cause a small increase in temperature which causes a large increase in resistance

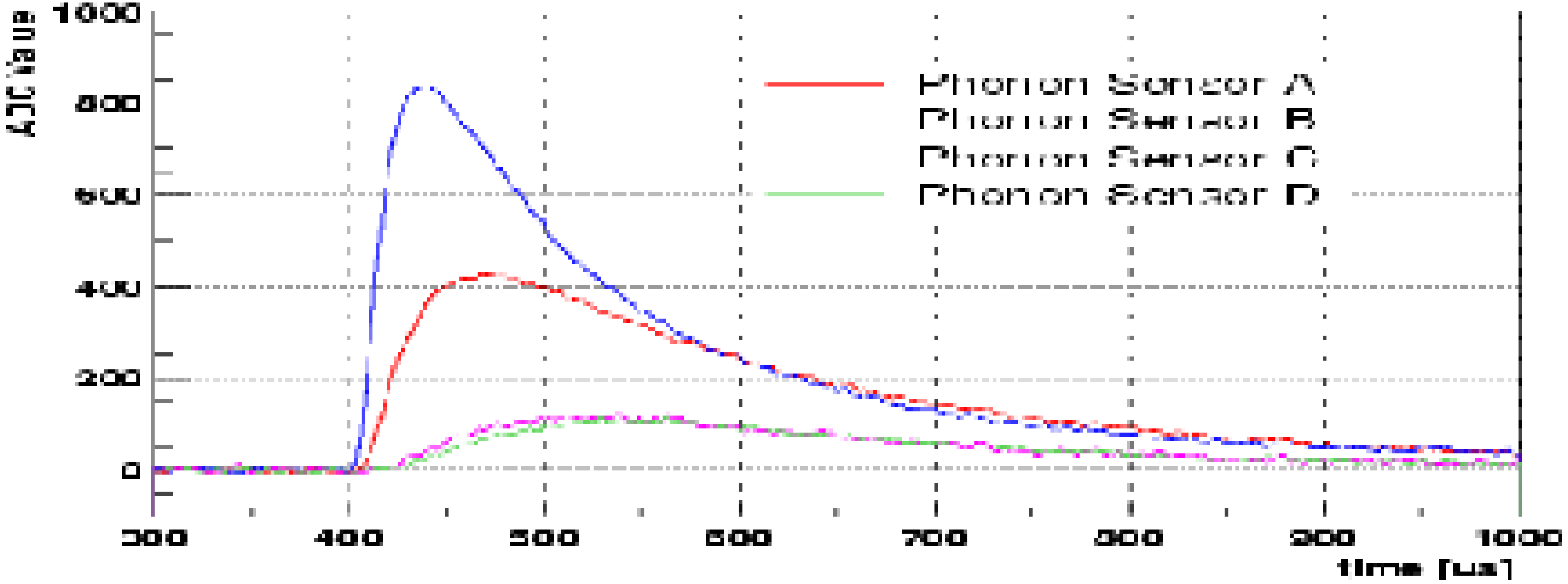
We measure this with Transition Edge Sensors (TES's) and Superconducting Quantum Interface Devices (SQUIDs)



Phonon Collection



# Phonon Channel Continued



The output of the SQUID is a measurement of current vs. time

The area under the curves gives a measure of the total energy that converted to phonons

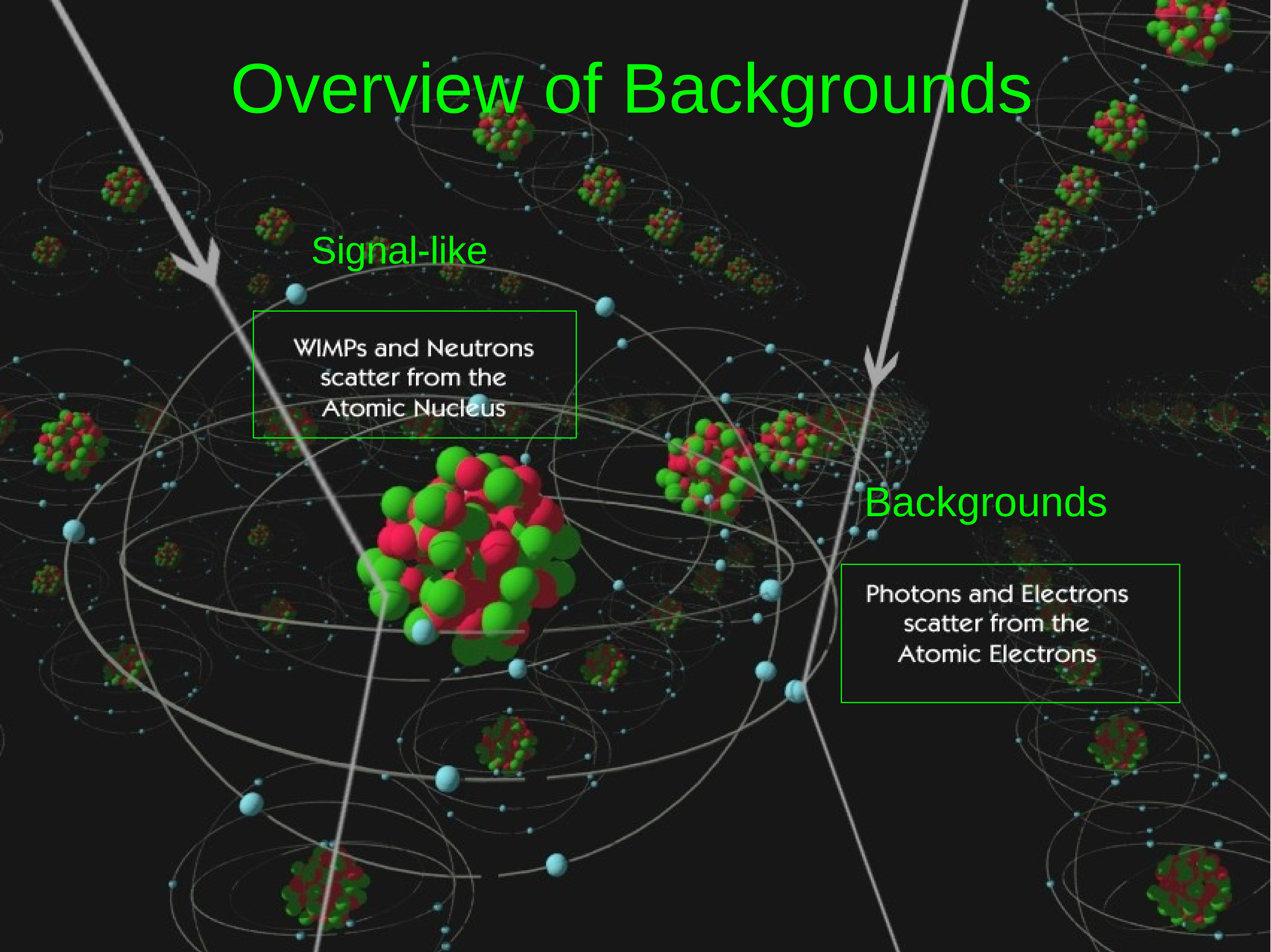
The initial slope, or rise time, will play a role later

# Signals and Backgrounds

- Will describe what a WIMP signal looks like in the detector after describing how different SM particles will interact with the detector

# Backgrounds and their Interaction with the Detector

# Overview of Backgrounds



Signal-like

WIMPs and Neutrons
scatter from the
Atomic Nucleus

Backgrounds

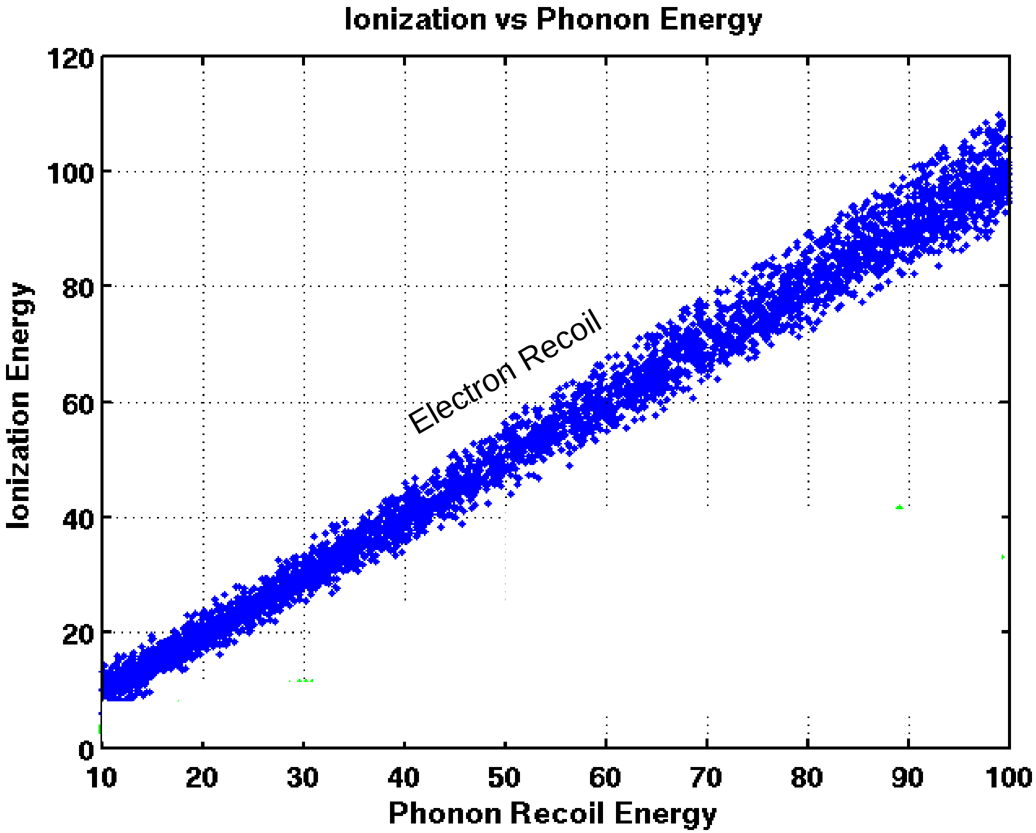
Photons and Electrons
scatter from the
Atomic Electrons

# Electrons and Photons

When electron or photon interacts with the detector, it deposits energy in the recoil electron which is ionized

Take measurements from ionization and phonon channels, plot them

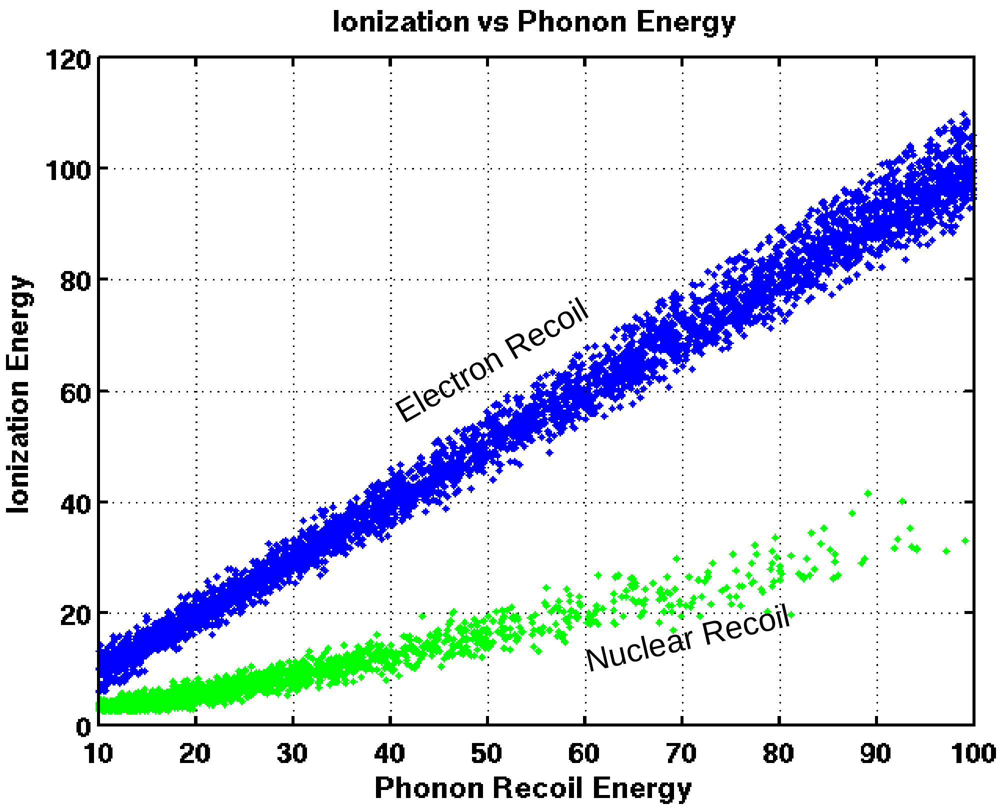
Calibrate for electron recoil with gamma radiation from $^{133}$Ba



# Neutrons

- When a neutron (or a WIMP) interacts with the detector, it excites a nucleus

- The excited nucleus has several ways to lose its energy – ionizing electrons is one of them



- For the same phonon measurement, we only observe about 1/3 as much ionization energy

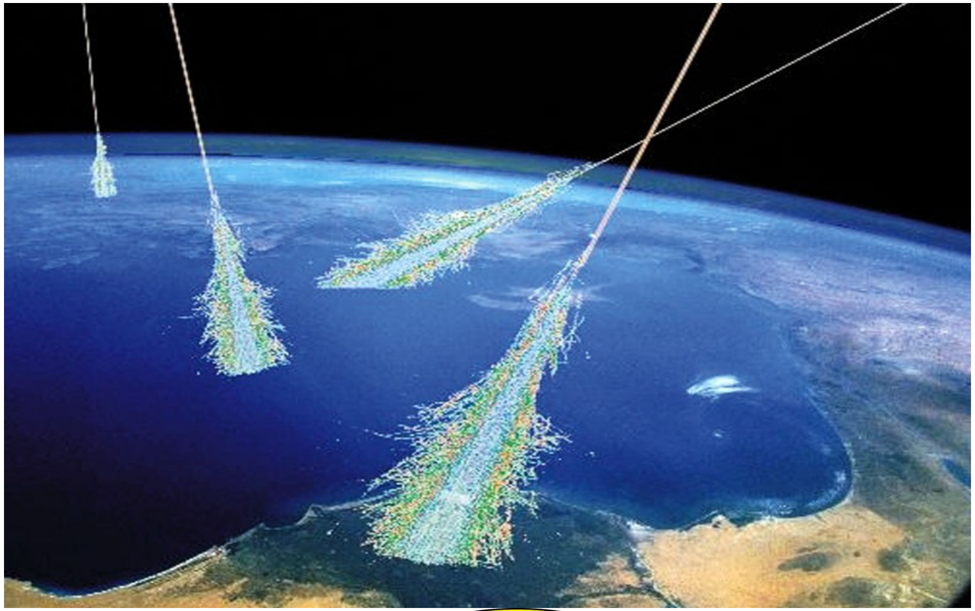
- We can use this to separate nuclear recoils from electron recoils

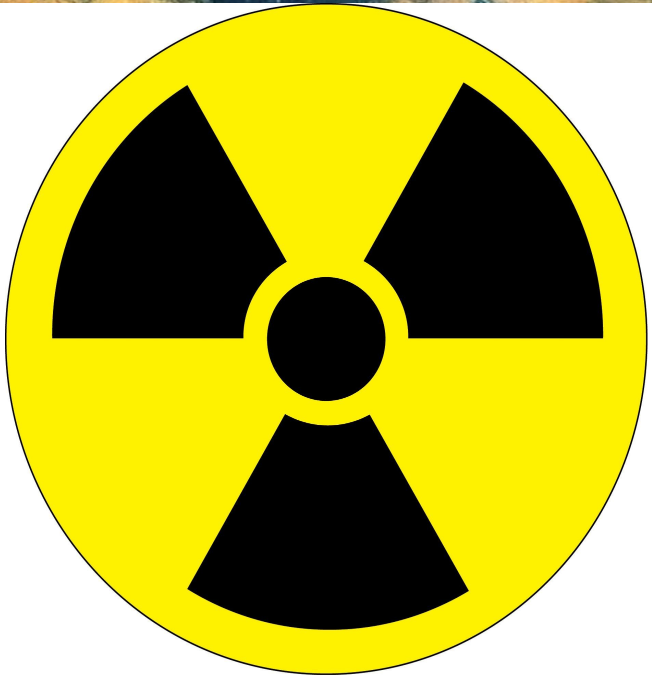
- Calibrate for neutron recoil with $^{252}$Cf

# Background Sources

1) Cosmogenic particles which are products of cosmic rays

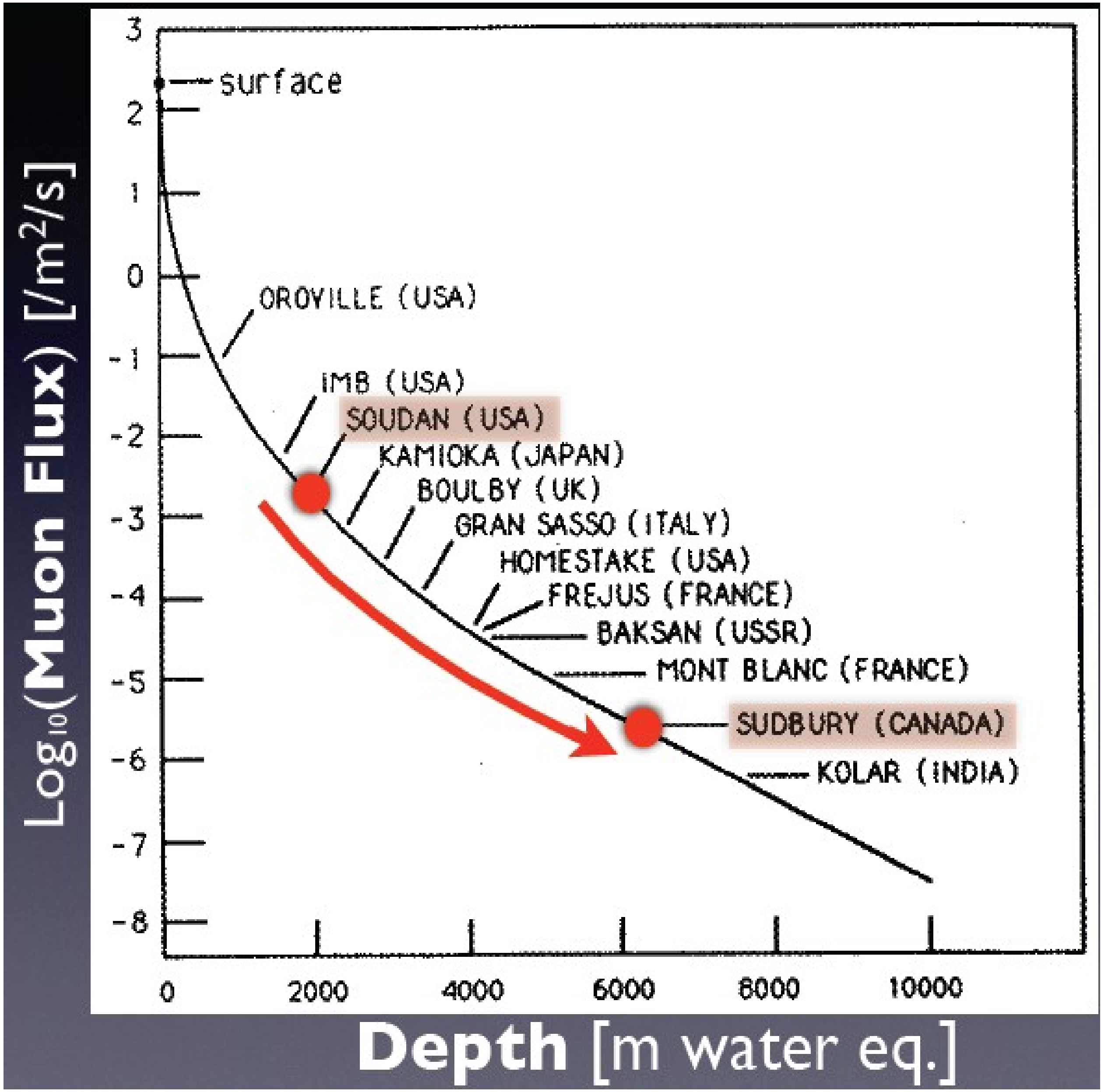
2) Radiogenic particles which are the result of the radioactive decays near the detector





# Cosmogenic Backgrounds

- Put experiment deep underground and identify via coincidence with cosmic muons
- Muons themselves are easy to identify, interact on the MeV scale



# Radiogenic Backgrounds

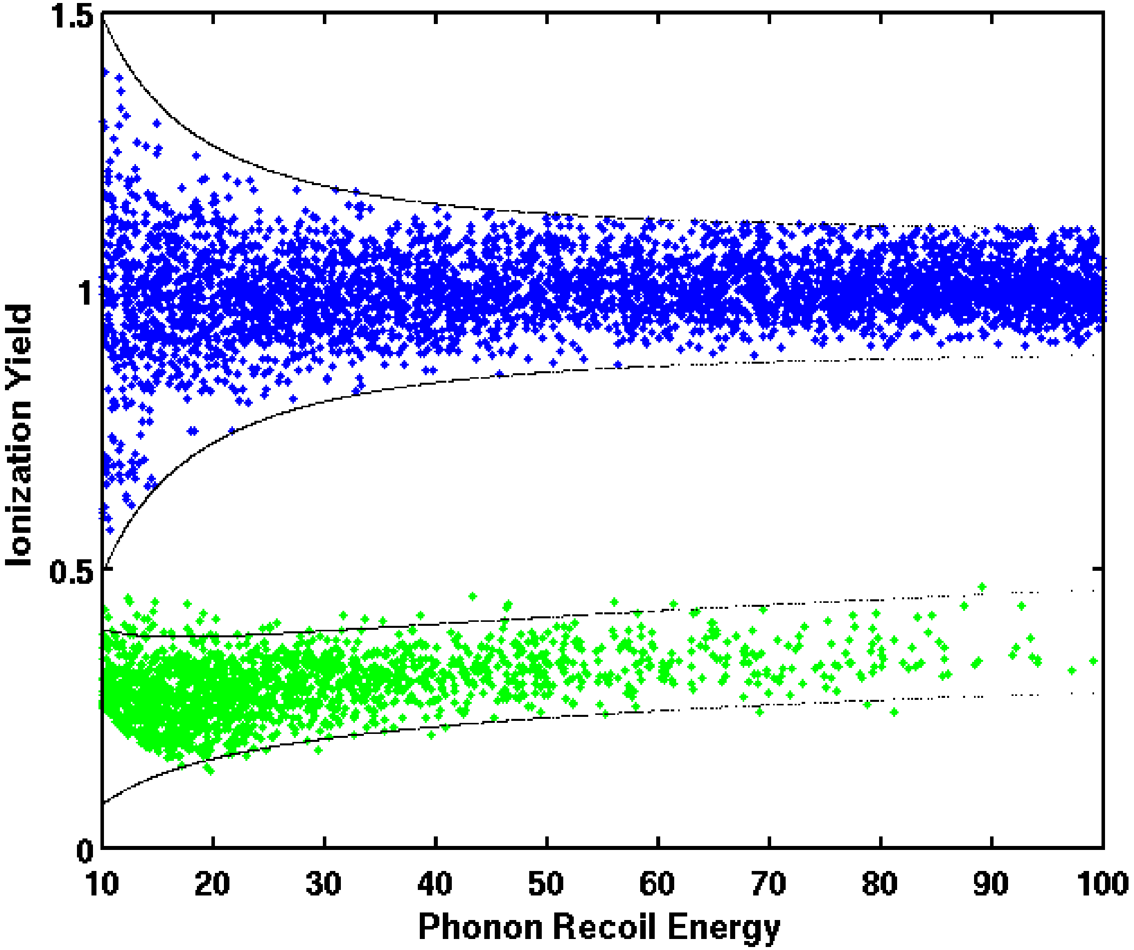
Use polyethylene shielding to reduce radiogenic neutrons

Surround detector with lead to minimize radiogenic gamma penetration

# Switching to Yield for Biggest Background

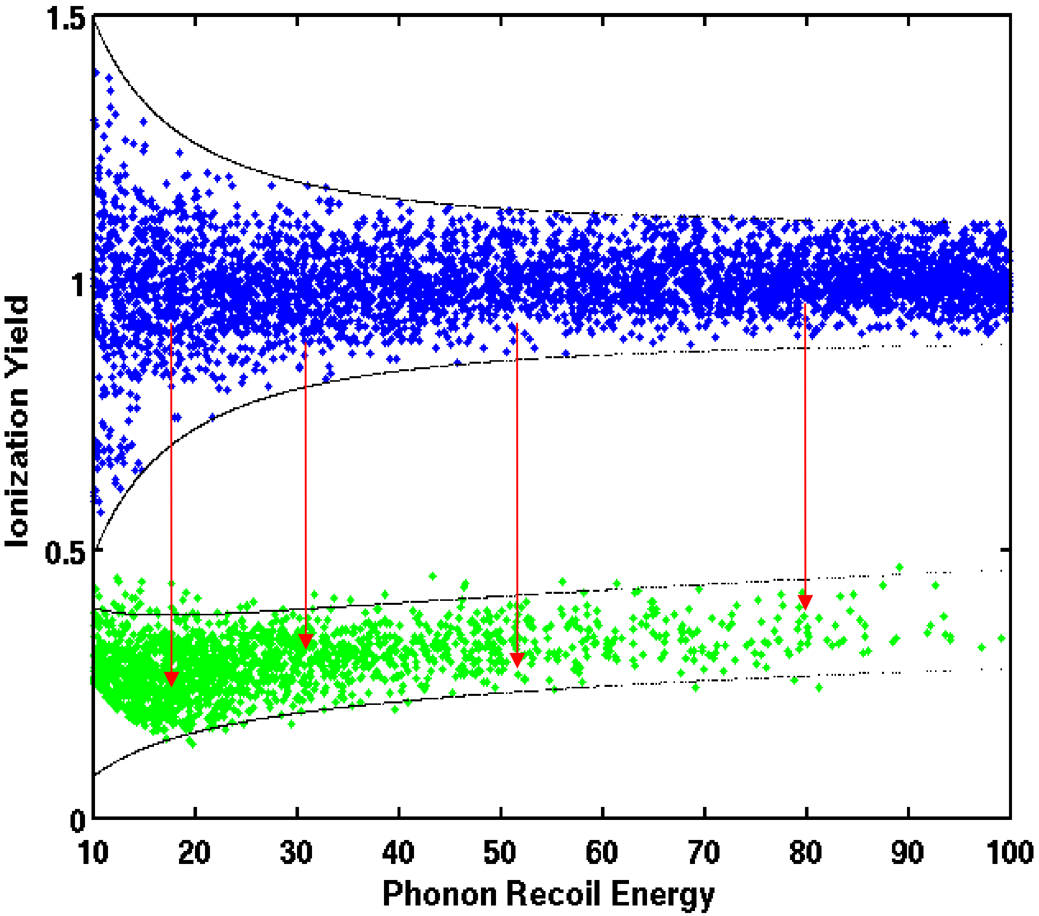
Yield = $E_{ion}$ / $E_{phonon}$

Can be used to more easily distinguish electron recoils from nuclear recoils



# The Dominant Background: Electron Recoil Surface Events

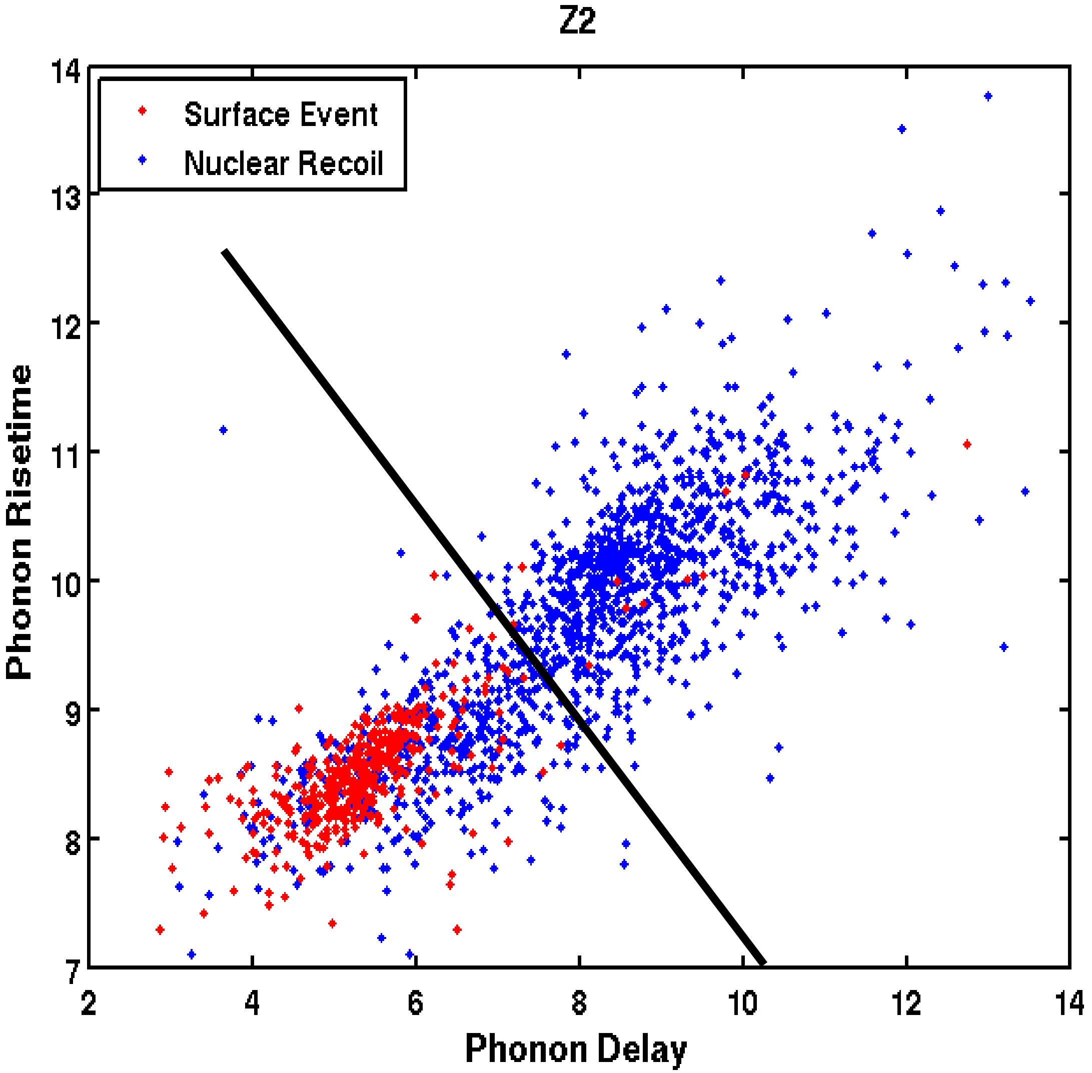
Near the surface of the detector the ionization energy is measured as smaller than it actually is



This results in surface events faking nuclear recoil events since they show up in the nuclear recoil band

Use timing to identify surface events, since they arrive at sensors faster

# Solution: Timing



- Property of phonons: they multiply at surface transitions
- This means that phonons from surface events will get noticed by the detector sooner and have a smaller risetime
- Can use this to reject surface events

# Blind Analysis

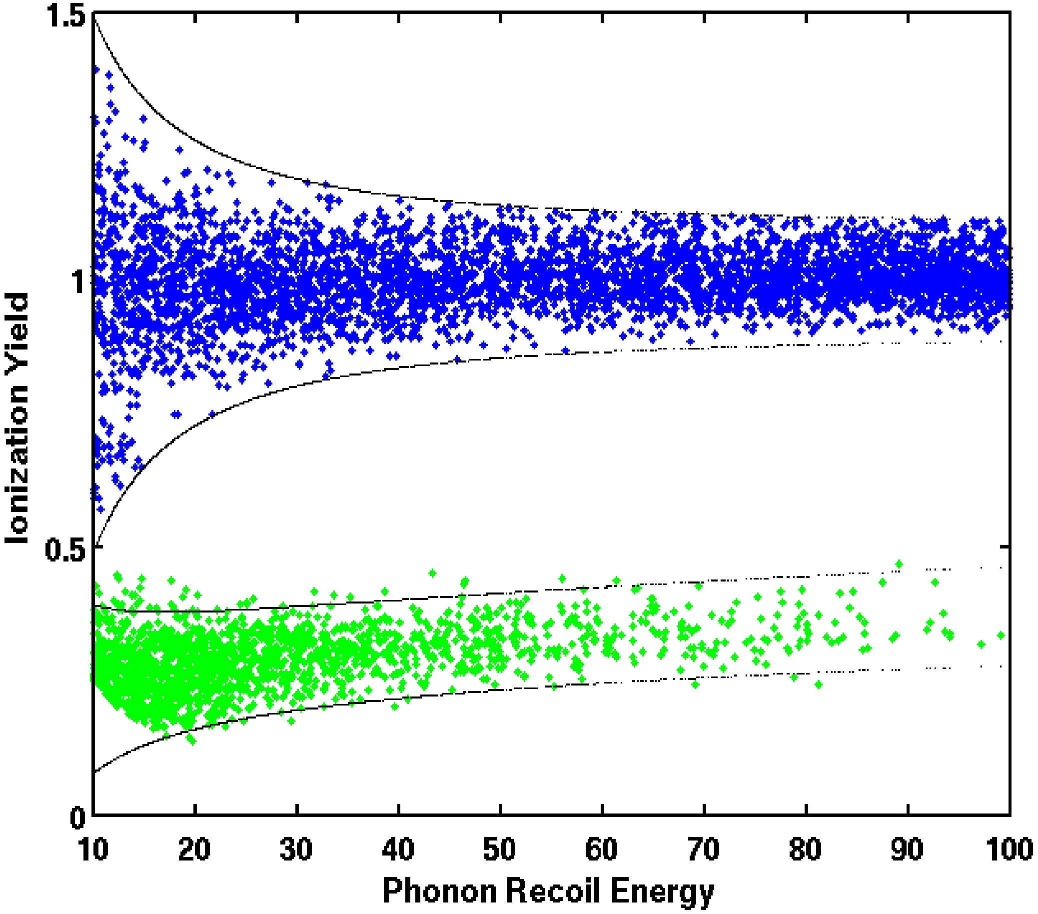
- Develop cuts before even looking at data
- Use calibrations to predict background as precisely as possible
- Minimizes bias in analysis

# Cuts and Background Estimation

1) Is a nuclear recoil (in green band)

2) Not a surface event

Use Geant4 and Monte Carlo simulations to predict number of all neutron recoil sources and surface electron recoil events

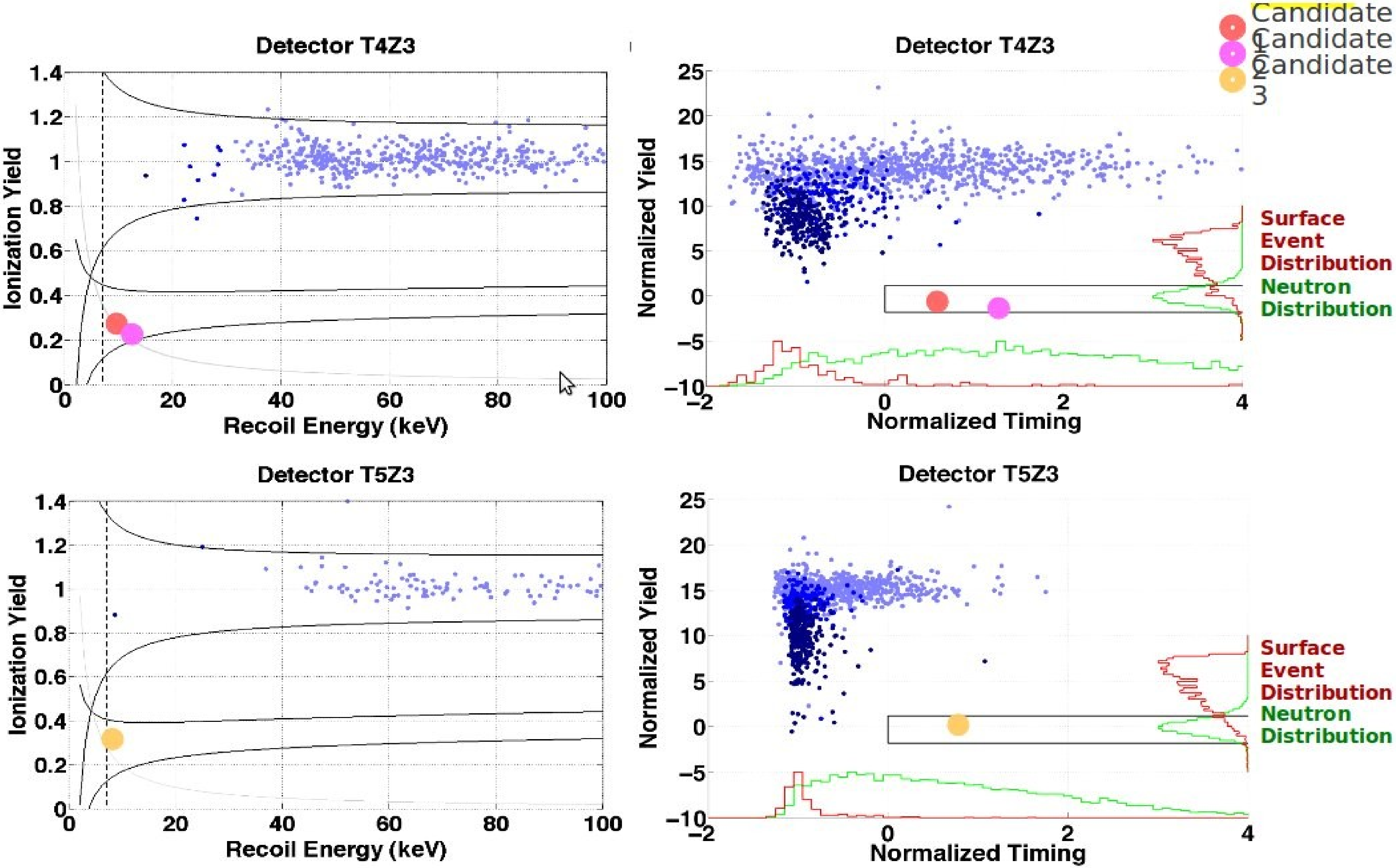


# Expected Background for Silicon

| | |
|---|---|
| Radiogenic Neutrons | 0.04 + 0.00 / -0.02 |
| Cosmogenic Neutrons | 0.04 + 0.04 / -0.02 |
| Surface Electron Recoils | 0.82 + 0.12 / -0.10 |
| | |
| Total | 0.9 ± 0.2 |

# Results, Conclusions, and the Future

# Three Candidate Events



# More on the Three Events

All three are near our energy threshold

Monte Carlo simulations suggest a 5.4% chance of the background producing 3 or more events

The WIMP + background hypothesis is favored in a likelihood test over the background only hypothesis by 99.8%

Best fit WIMP mass is 8 GeV

The Ge detectors saw 2 events, but this was consistent with the expected background of 0.6 events

# The Future

Lower our energy threshold to see if we can get more WIMP events.

Re-optimize our cuts with a focus on surface events

Upgraded to new Ge and Si detectors with better surface rejection (Super CDMS) and are taking data now

New results to be announced in two weeks

In a few years, moving to SNOlab, which will kill cosmogenic backgrounds with even better detectors

# Conclusions

So far the three potential WIMP events are very suggestive

They hint at low mass WIMPs, since an excess was found in Si but not Ge

More data is currently being taken

Next step is to re-optimize the cuts and employ them in the improved detectors at Super CDMS at SnoLAB

The future is very bright for the search for dark matter at CDMS!

Questions?

# Back Up Slides

# Back Up – CDMS vs. LUX

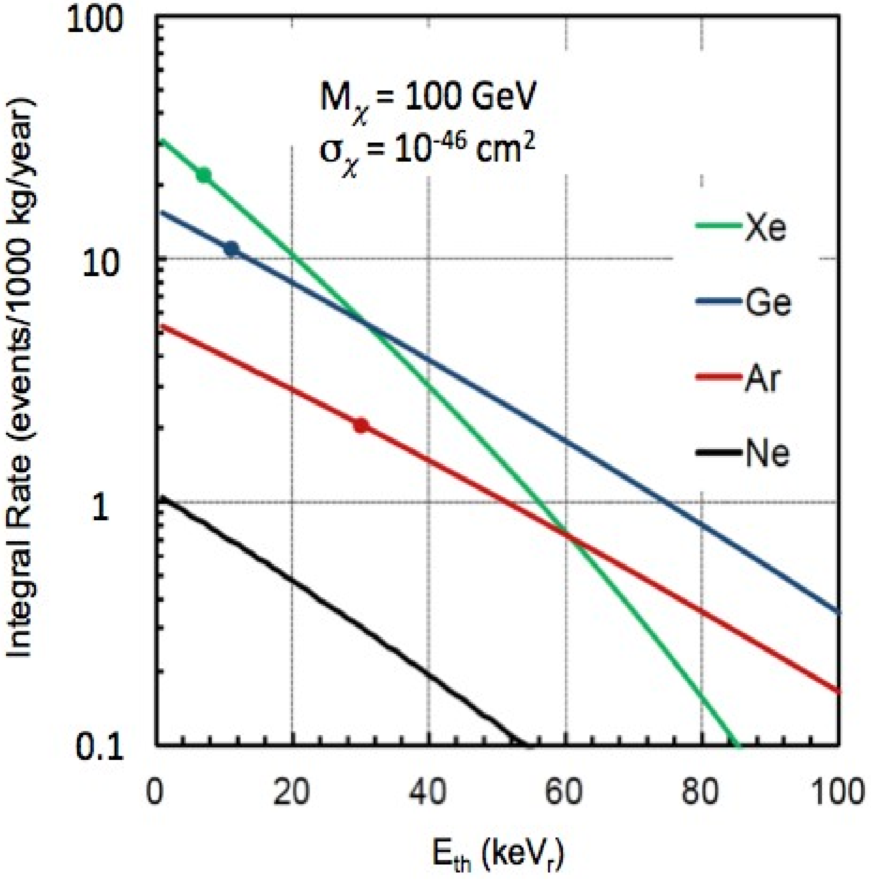
At a very low threshold Xe is better than Ge

LUX claims a threshold of 3 keV

“More realistically 5.5 keV” -Rupak

Current CDMS threshold is 7 keV

New thresholds: 2 keV for Ge and 3 keV for Si



Also new CDMS results are in 2 weeks

# Back Up - Upper Limits vs. Theory

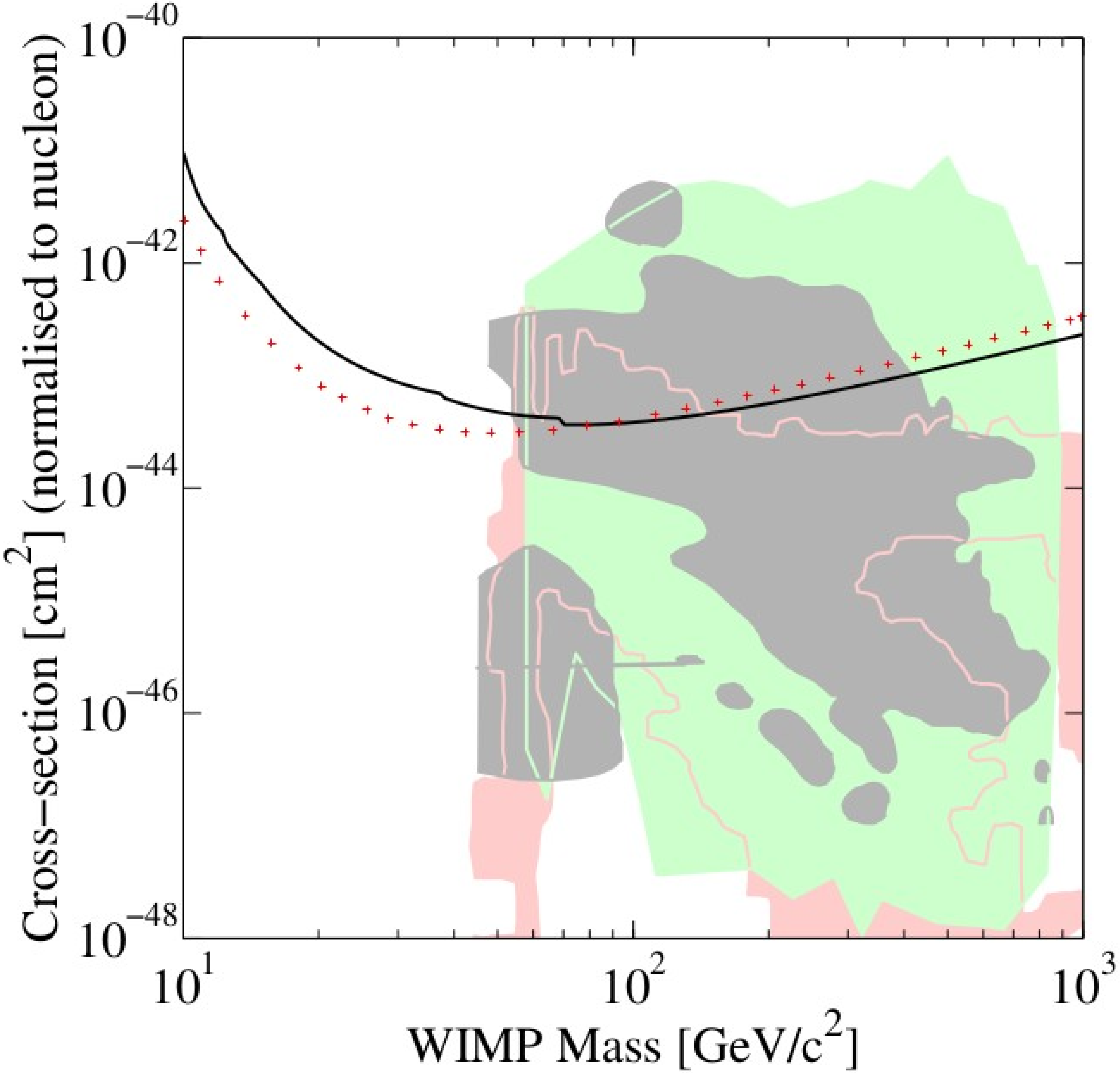
Black line:
CDMS

Red dots:
XENON100

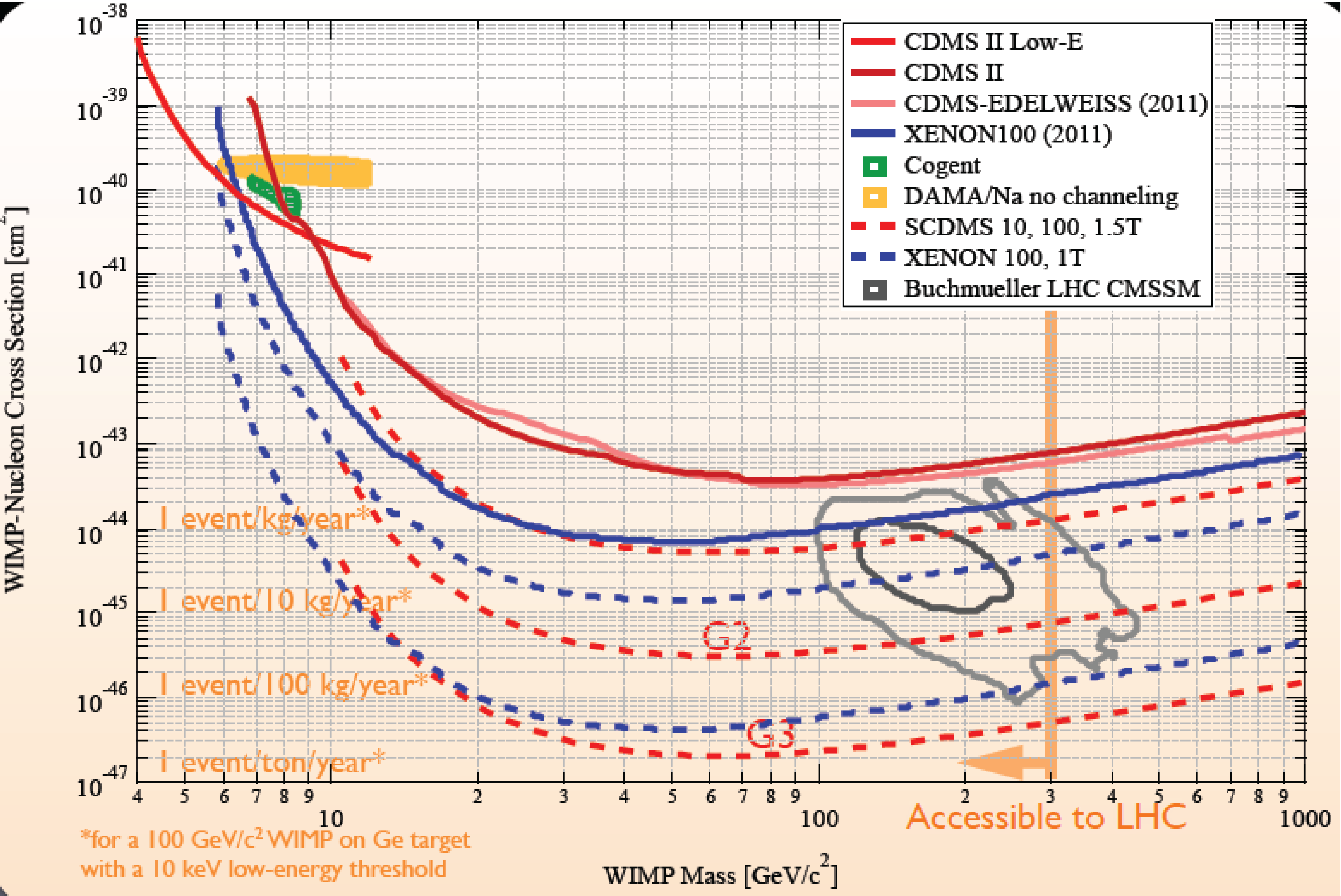
Grey: MSSM

Green: LEEST

Pink: mSUGRA



# Back Up - Comparison to LHC



*for a 100 GeV/c$^2$ WIMP on Ge target
with a 10 keV low-energy threshold

# Back Up -Three Event Details

| | Detector | Recoil Energy | Yield | Charge Signal to Noise | Date |
|---|---|---|---|---|---|
| Event 1 | T4Z3 | 9.51 keV | 0.27 | 4.87 σ | July 1, 2008 |
| Event 2 | T4Z3 | 12.29 keV | 0.23 | 5.11 σ | Sep 6, 2008 |
| Event 3 | T5Z3 | 8.20 keV | 0.32 | 6.66 σ | March 14, 2008 |