Dark Matter Search with CDMS and SuperCDMS

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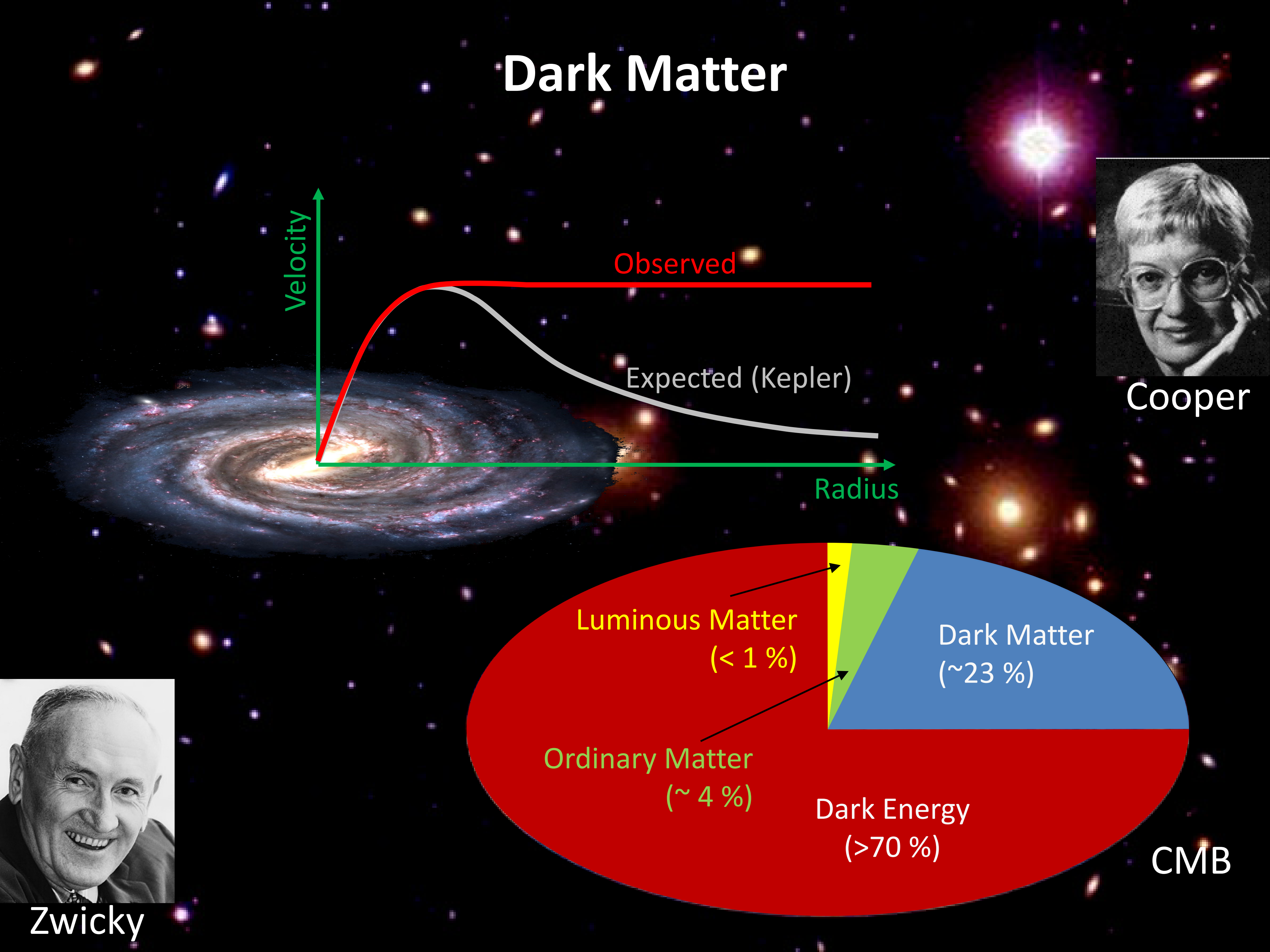
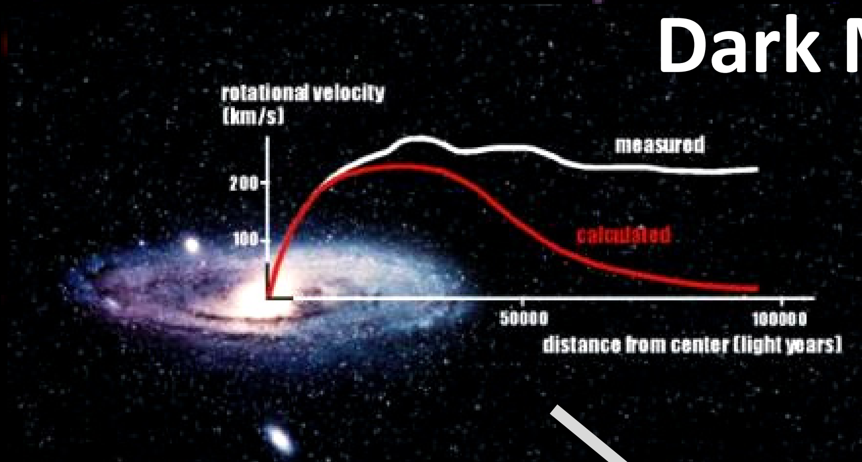
For the SuperCDMS Collaboration



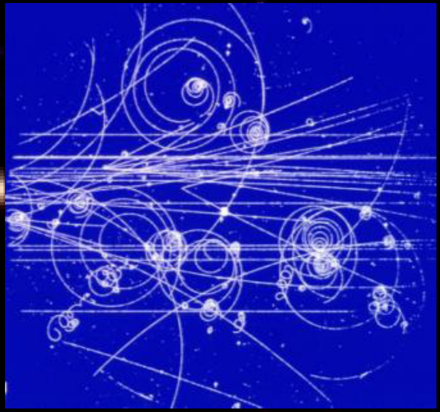
Dark Matter
Velocity
Observed
Expected (Kepler)
Radius
Cooper
Luminous Matter
(< 1 %)
Dark Matter
(~23 %)
Ordinary Matter
(~ 4 %)
Dark Energy
(>70 %)
CMB
Zwicky

Dark Matter



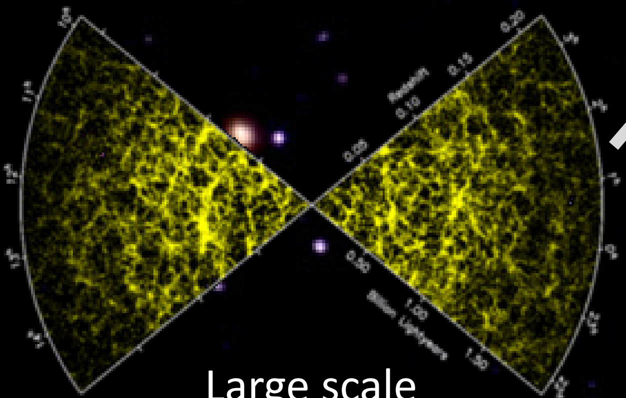
Here, but not yet observed in nature:
Weakly interacting

Not observed in accelerator experiments:
Massive



WIMP

(Weakly Interacting Massive Particle)



Large scale structure of the Universe:
Slowly moving ('cold')

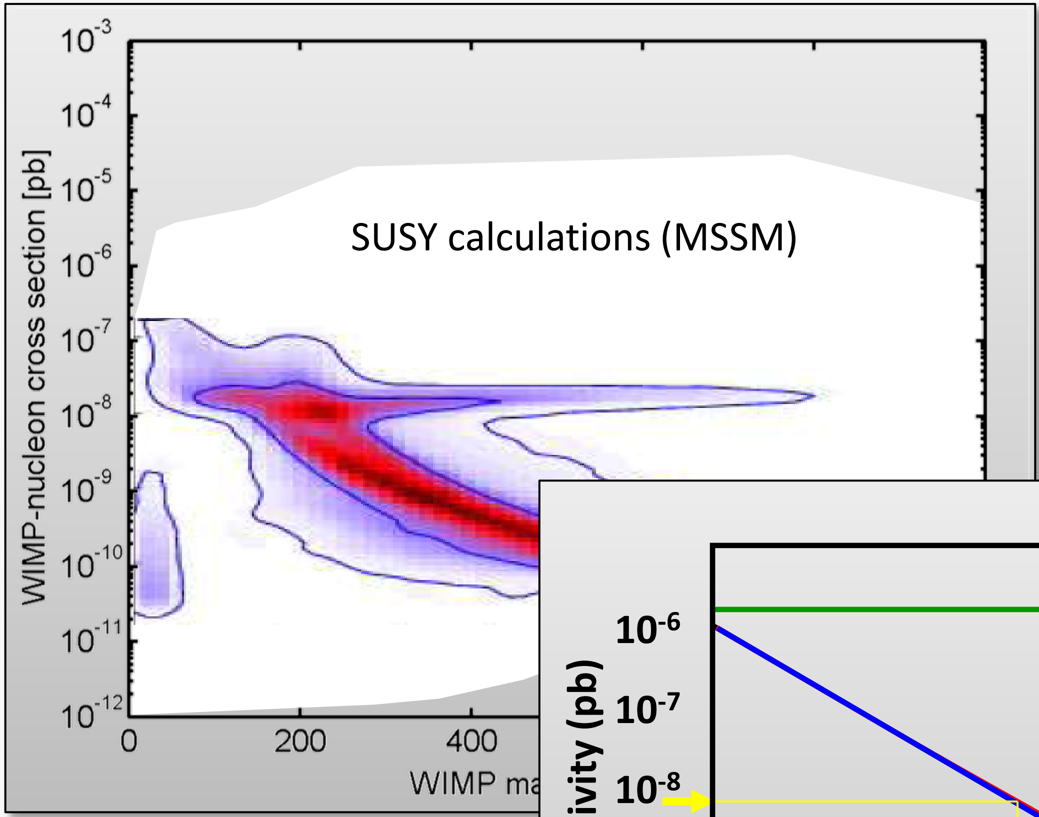
Predicted by SUSY:
Neutralino
Universal extra dimensions:
Kaluza-Klein particles

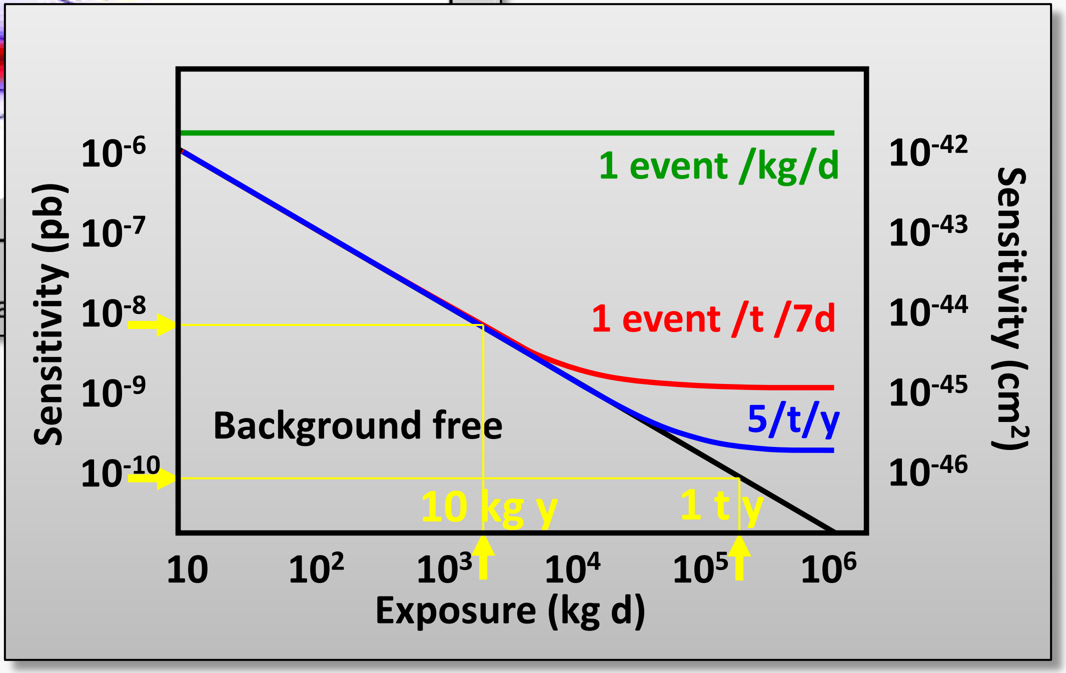
Overview

- Dark Matter Detection
- CDMS Technology
- SuperCDMS
- Analysis
- Conclusions

Dark Matter Detection

Landscape and Background





CDMS/SuperCDMS Collaboration

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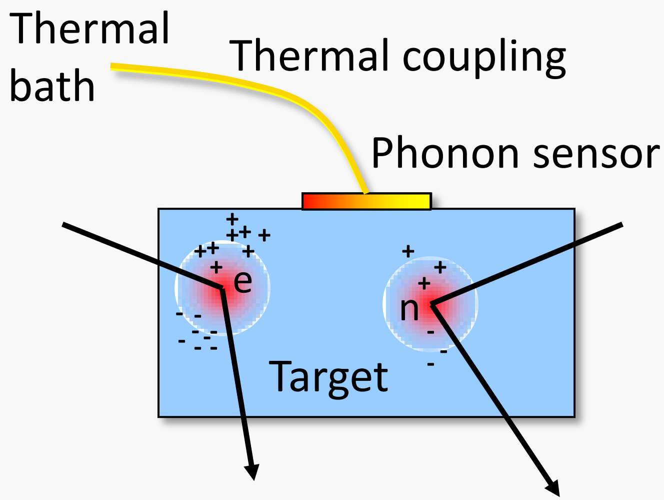
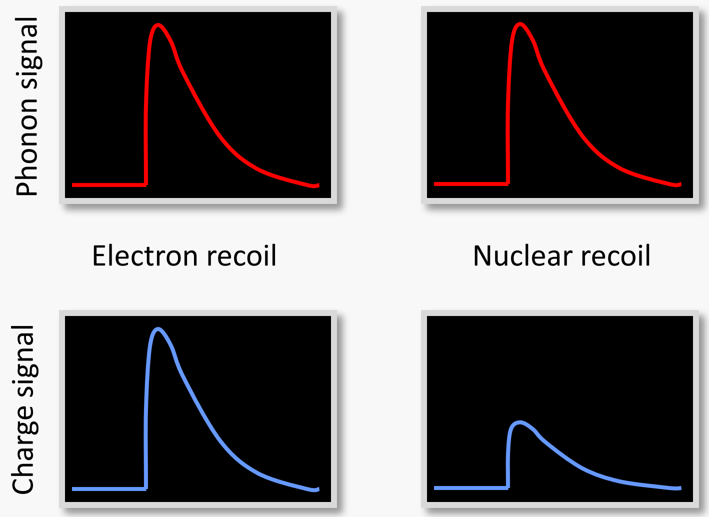
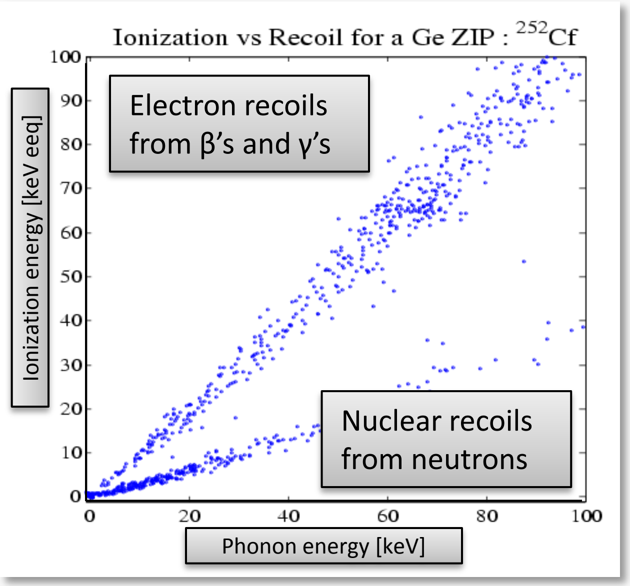
CDMS Technology

Operating Principle





- Phonon signal: measures energy deposition
- Ionization signal: quenched for nuclear recoils (lower signal efficiency)
- Allows us to distinguish potential signal from background

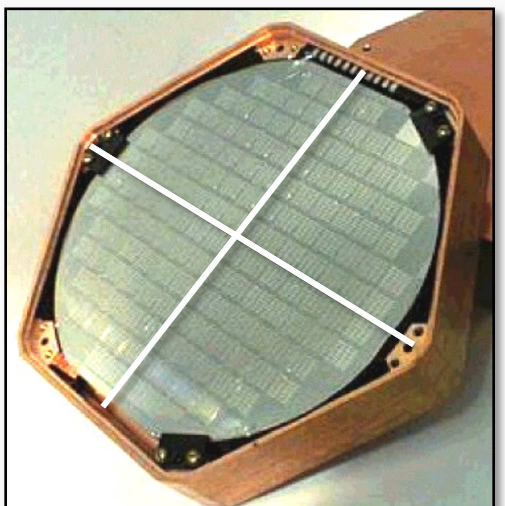


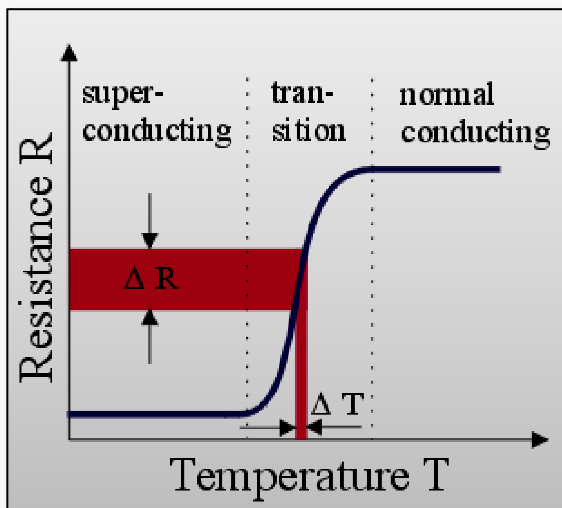
CDMS Technology

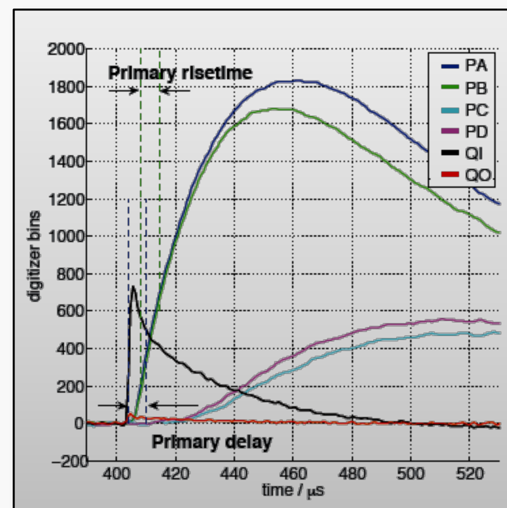
Detectors

Cryogenic ionization detectors, Ge (Si)

- ∅ = 7 cm, h = 1 cm, m = 250 g (100 g)
- Thermal readout: superconducting phase transition sensor (TES)
- Transition temperature: 50 – 100 mK
- 4 sensors/detector, fast signal (< ms)
- Charge readout: Al electrode, divided
- Low bias voltage (3 V, to minimize Luke effect)

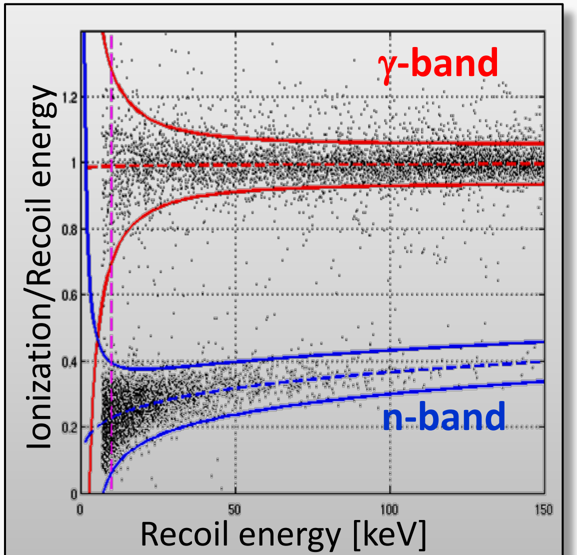


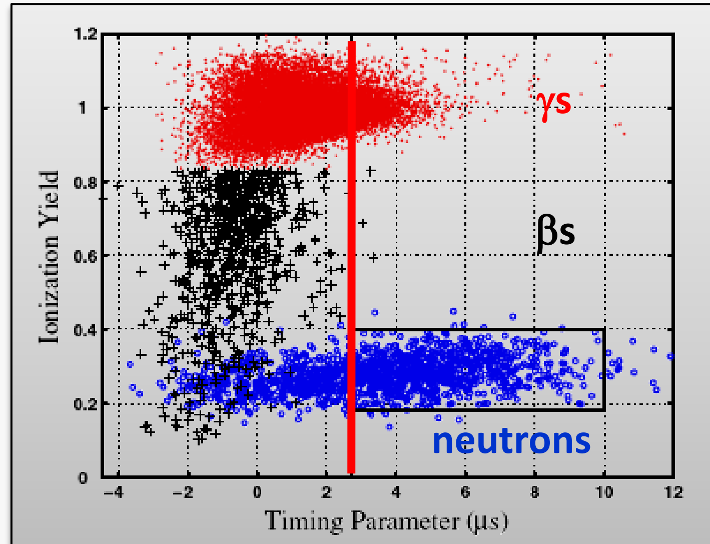


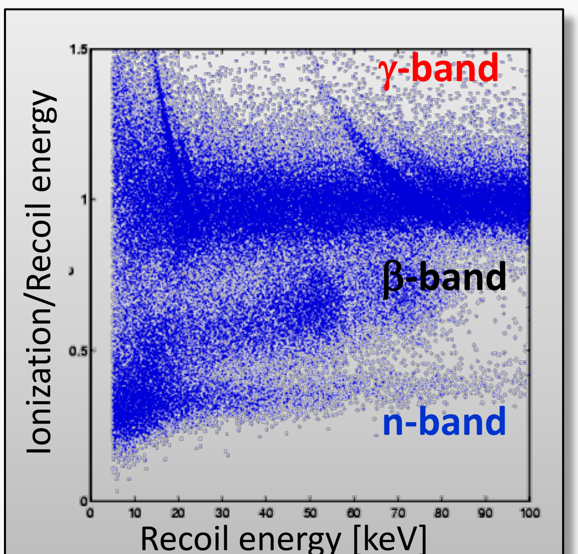


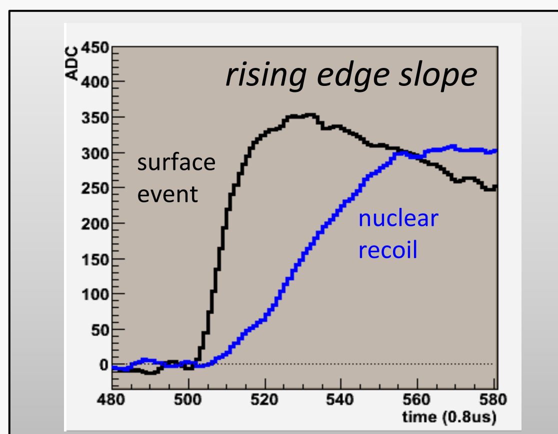
CDMS Technology

Detector Performance









Z -sensitive
I onization and
P honon
detectors

The CDMS Family

1998 - 2002

SUF, 10 mwe

CDMS I
6 detectors
1 kg Ge (30 kgd)
$\sigma < 3.5\text{e-}42\ \text{cm}^2$

2003 - 2009

CDMS II
30 detectors
~4 kg Ge (400 kgd)
$\sigma < 3.5\text{e-}44\ \text{cm}^2$

2009 - 2013

Soudan, 2100 mwe

SuperCDMS @ Soudan
15 detectors
~9 kg Ge (~2500 kgd)
$\sigma < 5\text{e-}45\ \text{cm}^2$

SuperCDMS @ SNOLAB
$\mathcal{O}$ (100) detectors
200 kg Ge (~t y)
$\sigma \approx \text{e-}46\ \text{cm}^2$

2014 - 2017

SNOLAB, 6000 mwe

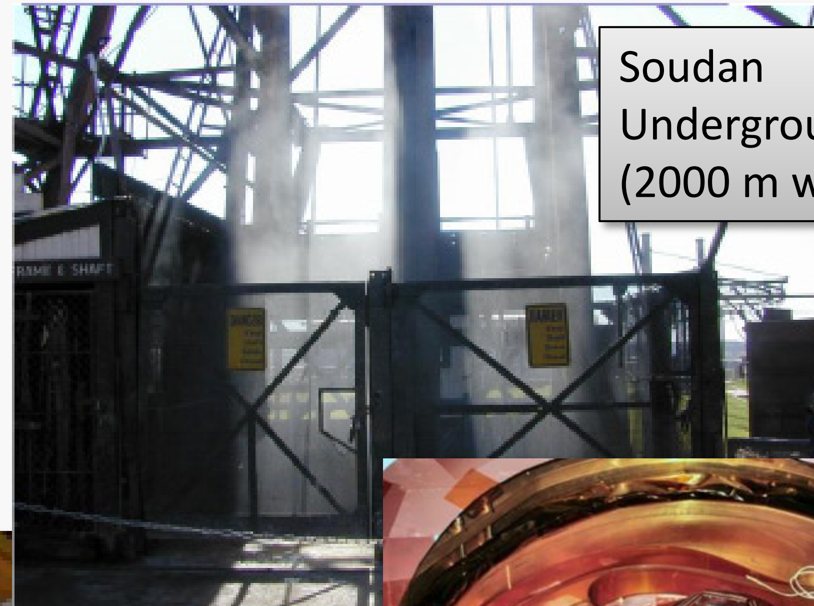
SuperCDMS test facility
@ SNOLAB

exposures are
after all cuts!

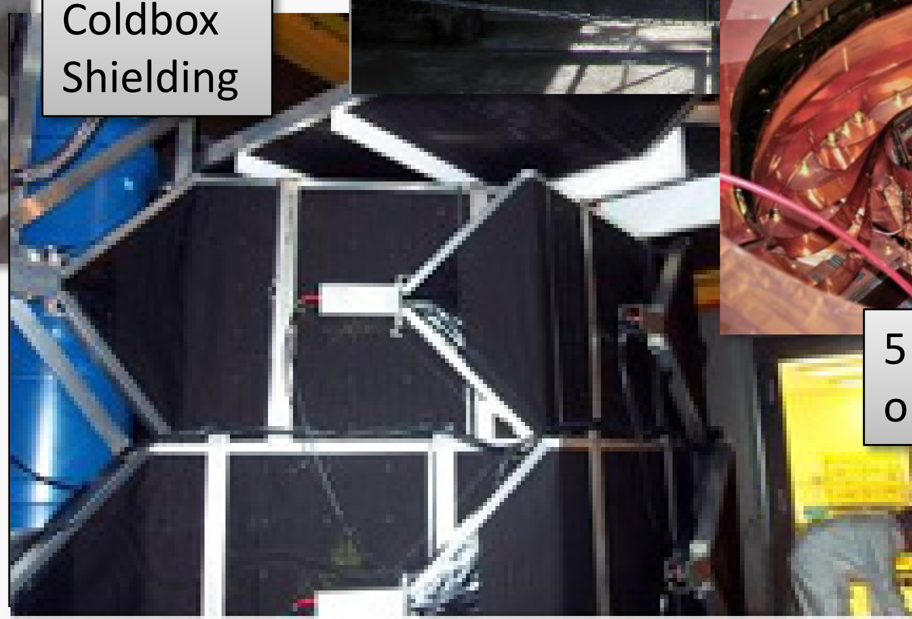
CDMS at Soudan

Experimental Setup

„Tower“
(6 Detectors)



Soudan
Underground lab
(2000 m w.e.)

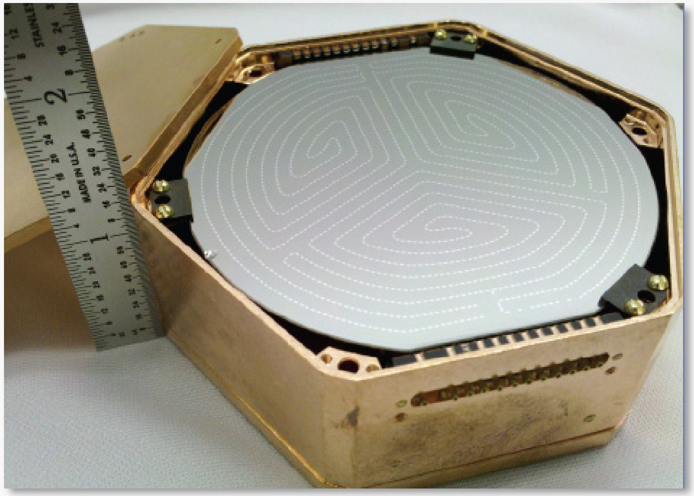


Cryostat,
Coldbox
Shielding

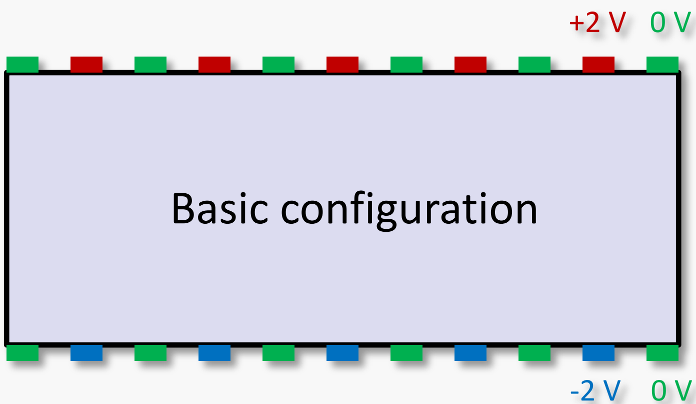
5 Towers (~ 5 kg Ge)
operated 2006 – 2008

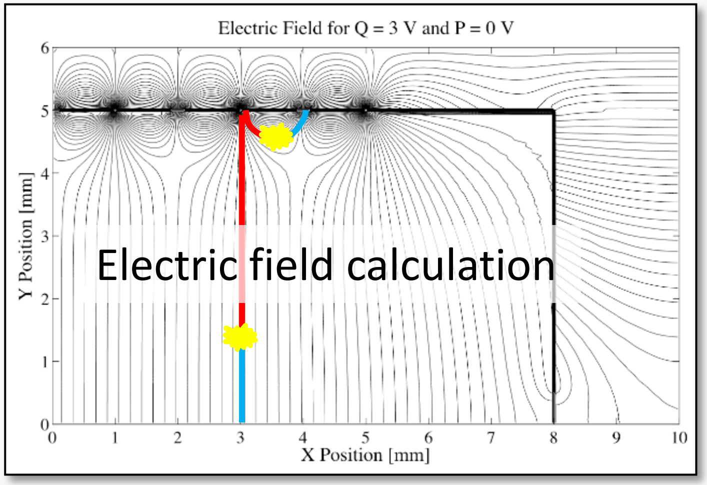
SuperCDMS

Soudan



- Larger mass per module:
  ~240 g → ~600 g
- Increased thickness
  → improved bulk/surface ratio
- Improved sensor design for better event reconstruction / surface event rejection

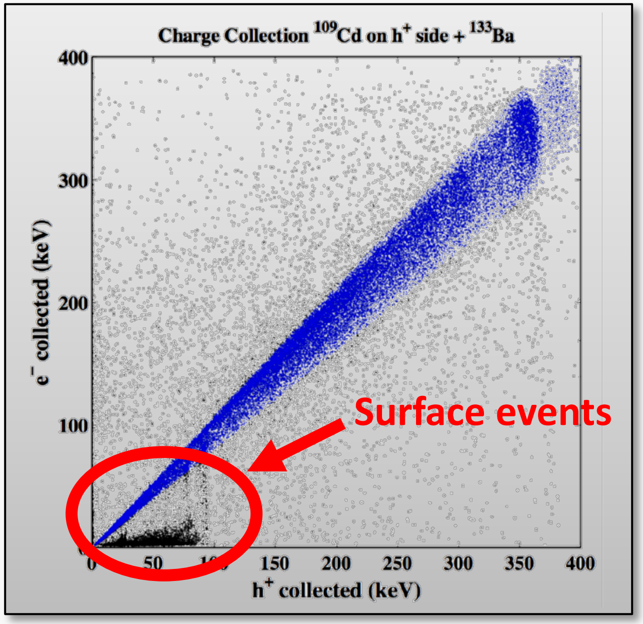




ZIP with interleaved electrodes: iZIP

SuperCDMS

Soudan



- Larger mass per module: ~240 g → ~600 g
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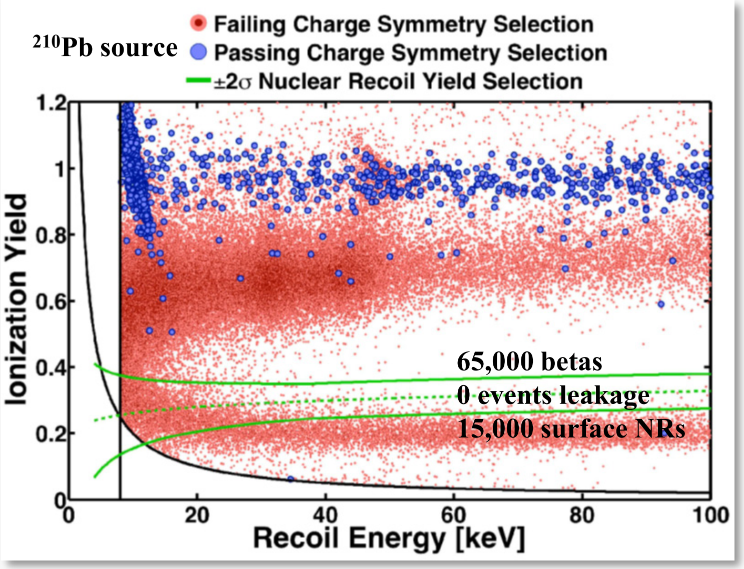


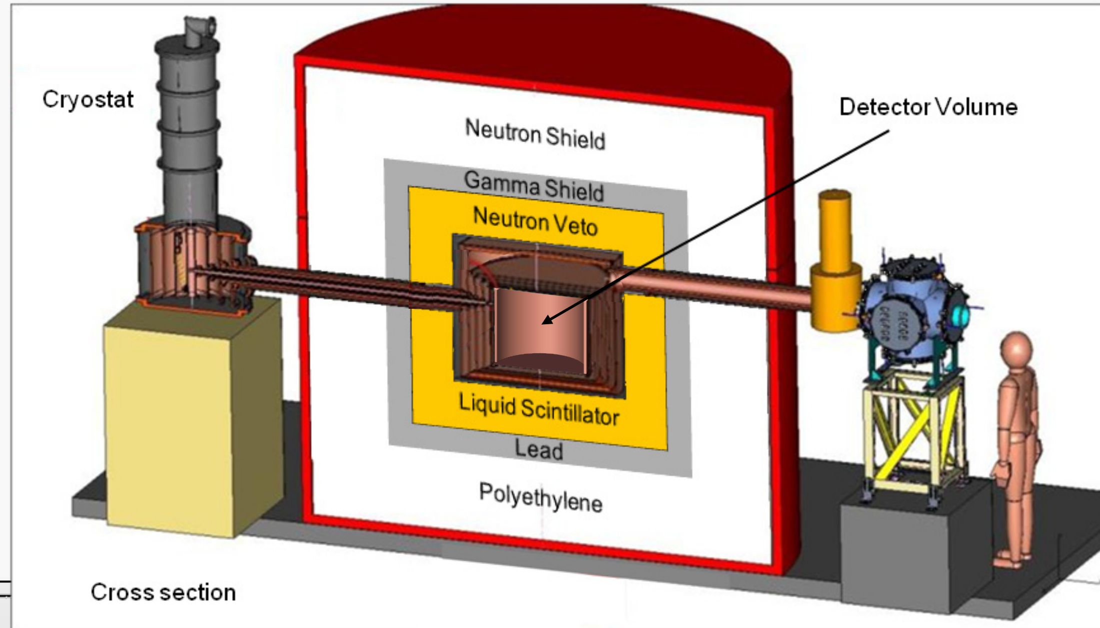
- 15 new detectors installed (~9 kg)
- DAQ adjusted to new requirements
- Detectors cold since November 2011
- Collecting DM data since March 2012
- Demonstrated surface event rejection
- Improve sensitivity by ~ x5-8
- Expect limitation from cosmogenic background after 2-3 years of operation

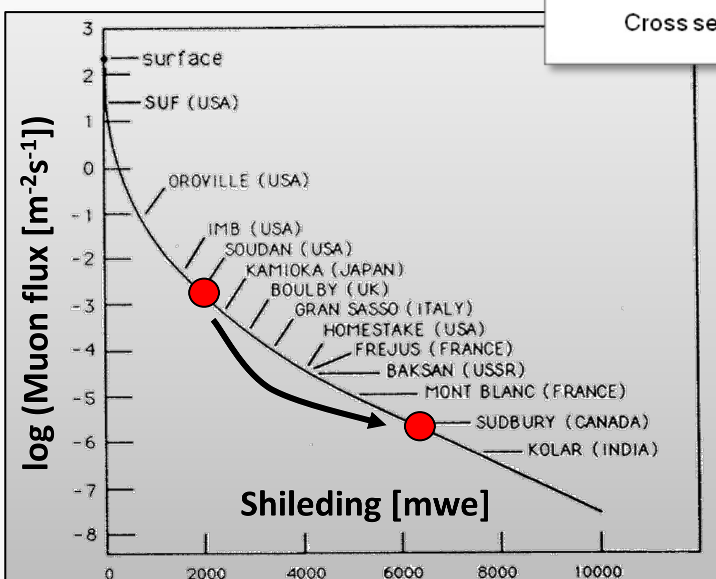
SuperCDMS

SNOLAB - Setup

Move to SNOLAB

- Less Cosmic radiation
- Cleaner environment
- Good Lab infrastructure
- CFI proposal for setup funded (cond. of US)
- Decision in US (DOE, NSF) early 2014

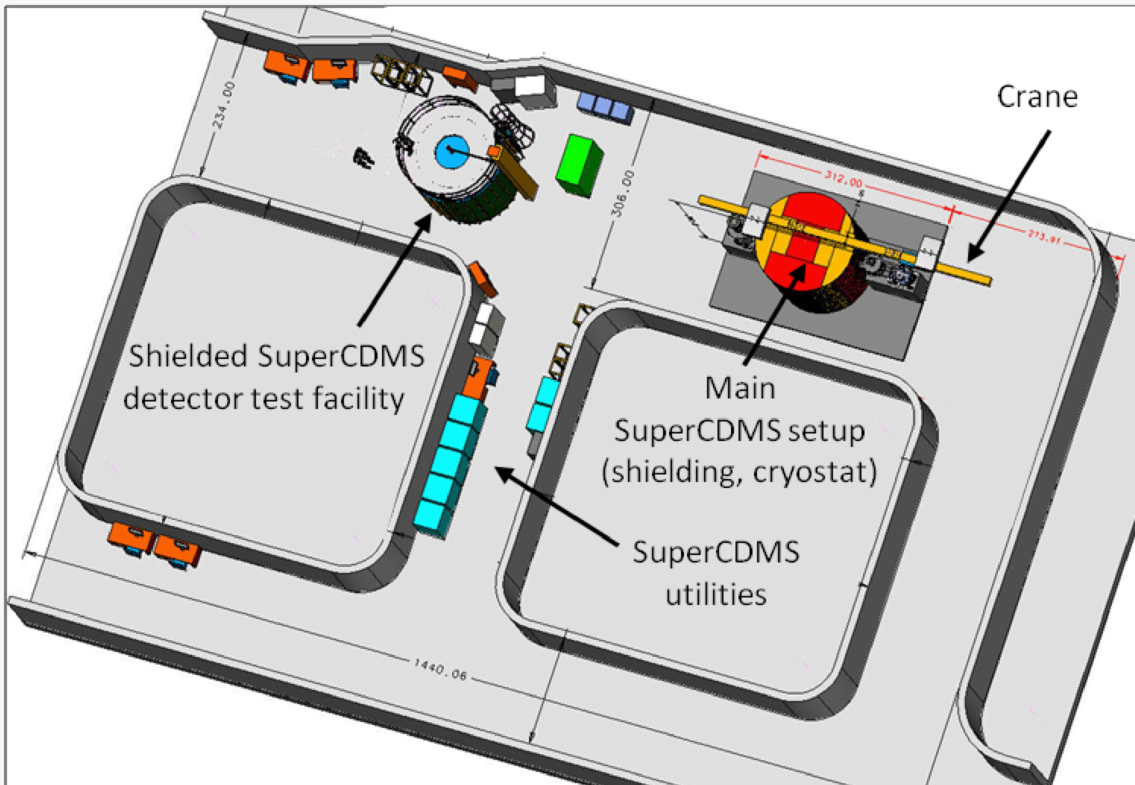




SuperCDMS Setup at SNOLAB

- Detector volume holds ~ 400 kg of active target (first phase install only 200 kg)
- Pb/Cu shielding against external radiation
- PE shielding against neutrons
- Neutron detector (monitor internal n flux, veto neutrons interacting in Ge detectors)
- Larger detectors (~1.2 kg, iZIP, 12 ph sens)

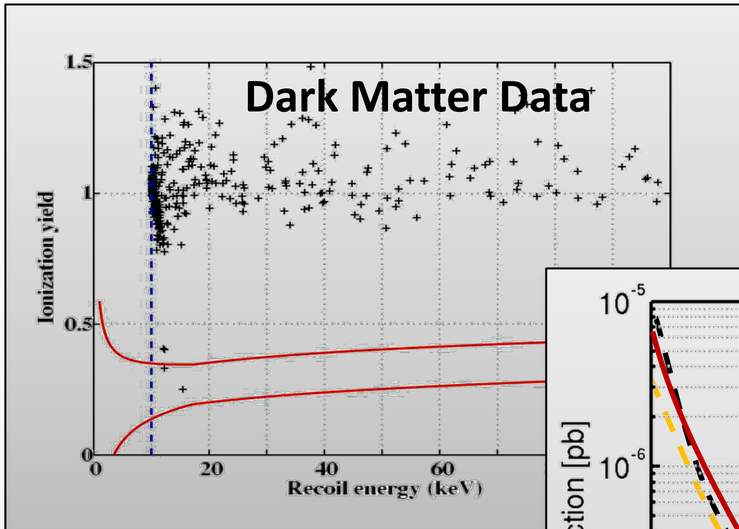
SuperCDMS at SNOLAB

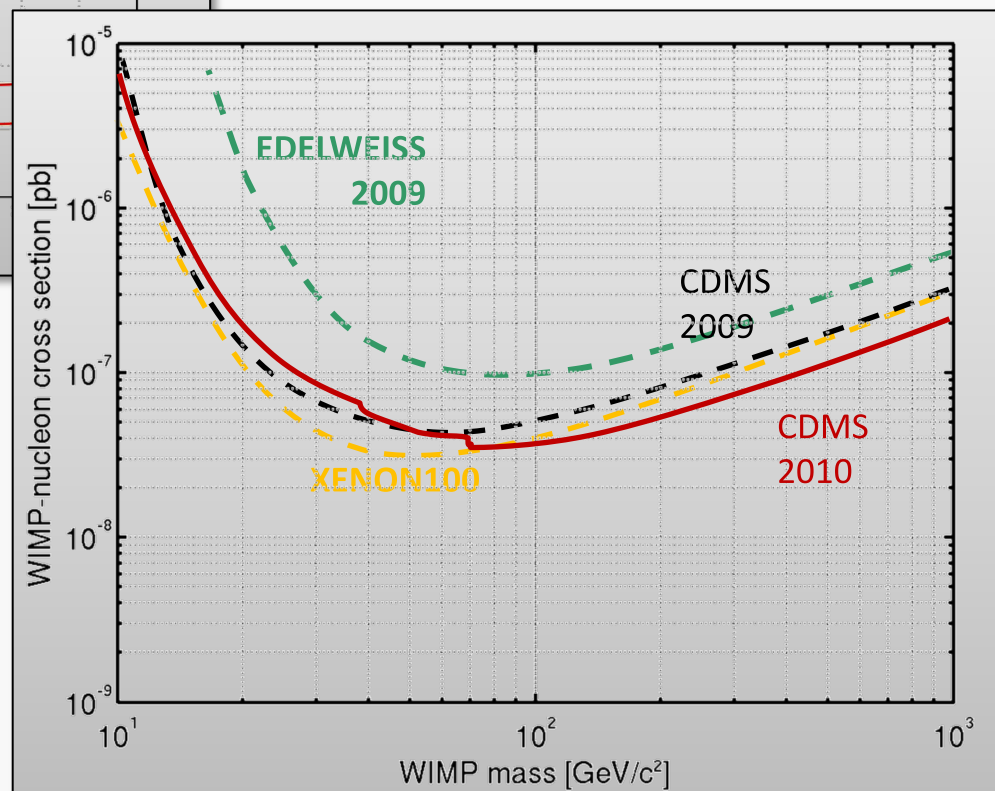


Ladder Lab – Tentative Layout

Standard WIMP Analysis

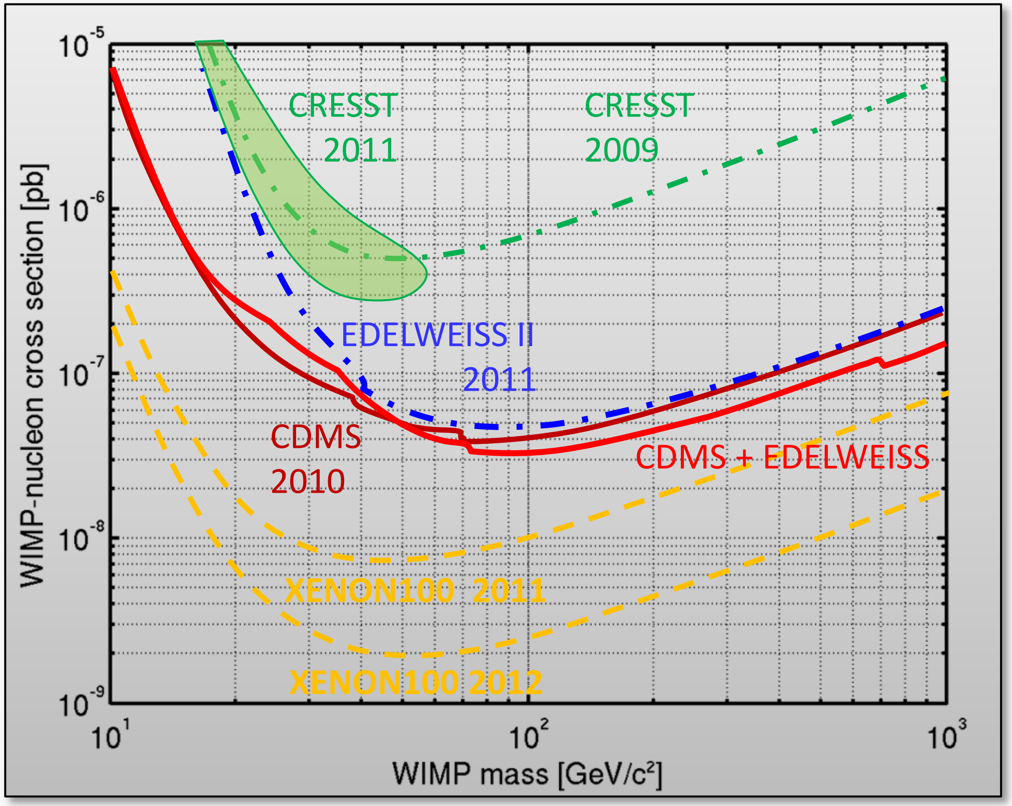
Spin independent interaction





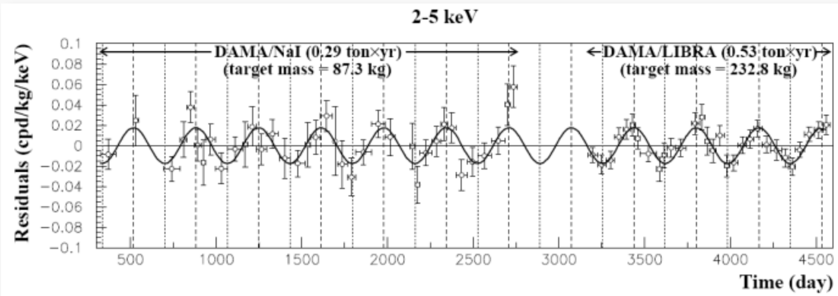
Standard WIMP Analysis

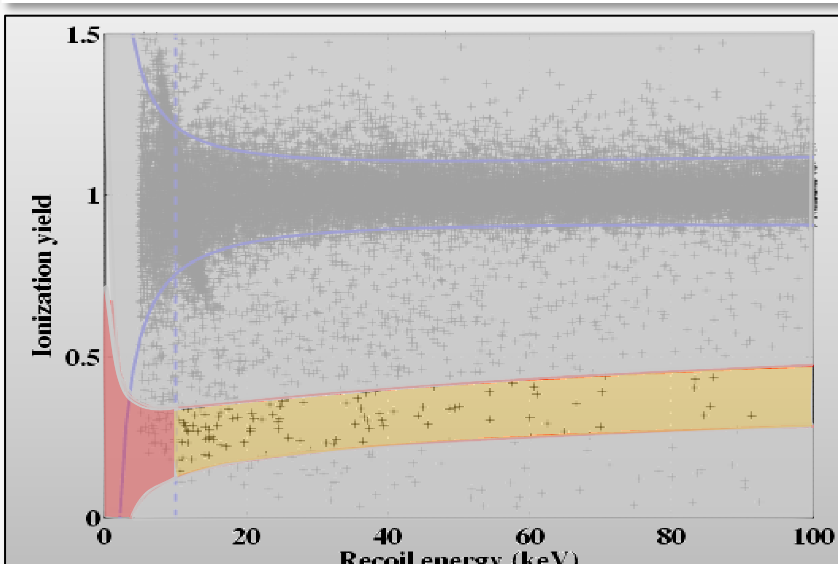
Spin independent interaction



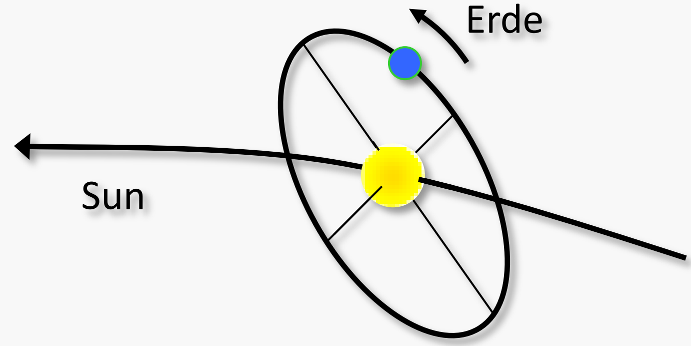
DAMA/CoGeNT – Low Mass WIMPs?

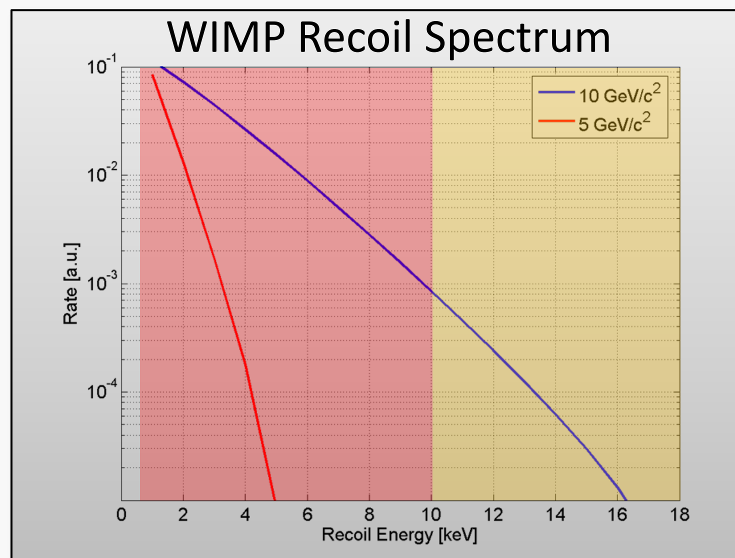
Evidence:
- DAMA: annual oscillation signal
- CoGeNT: exponential rate increase at low energy
- Both have an interpretation as low mass WIMP (< 10 GeV) signal





What can we (CDMS) do?
- Lower Threshold
- Background increases
- BUT: expected WIMP rate shoots up dramatically

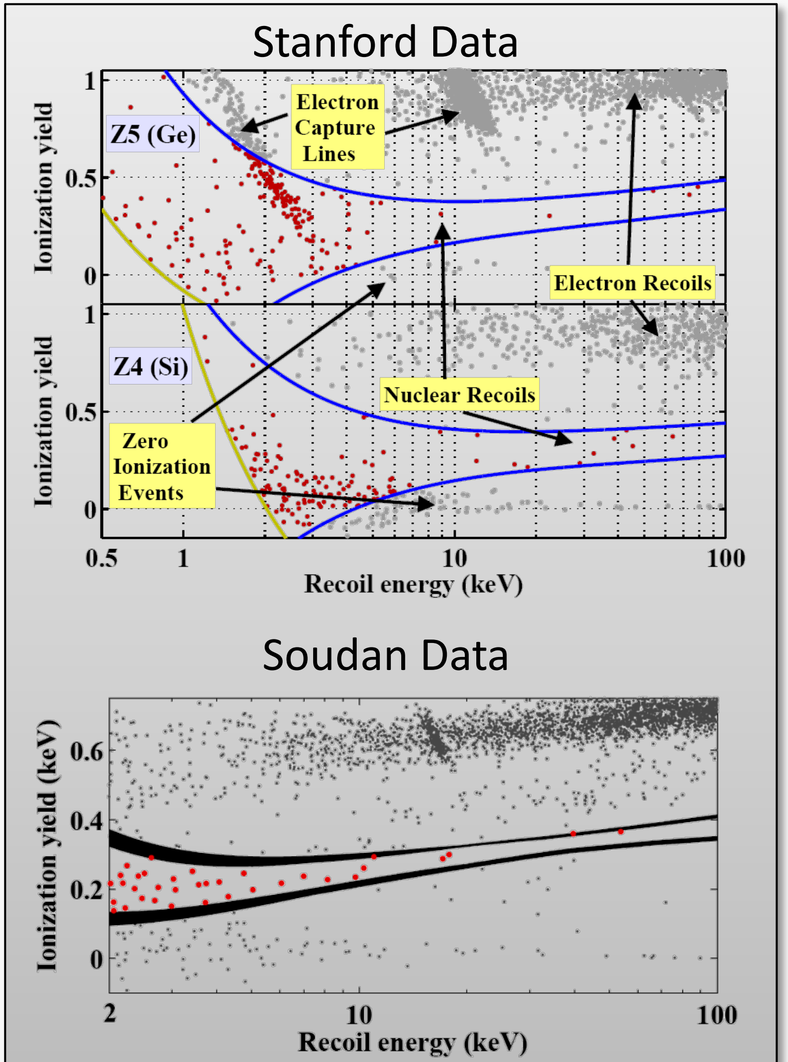




Dark Matter
CDMS
Super CDMS
Analysis
Conclusion

CDMS – Low Threshold Analysis

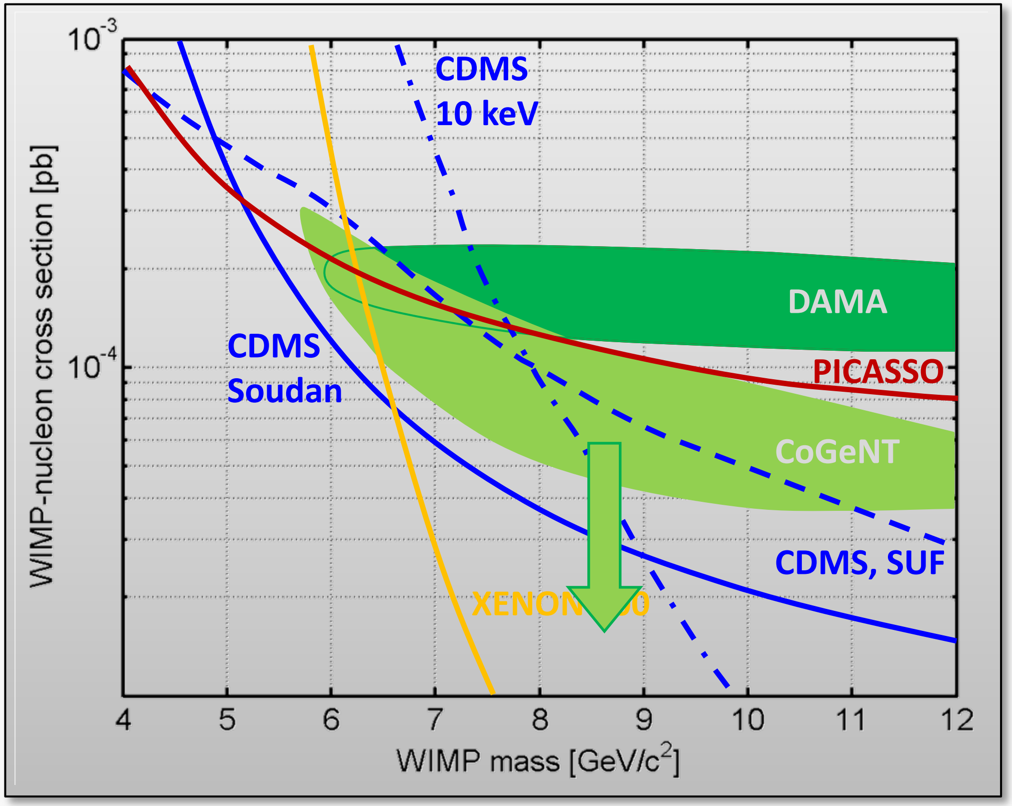
SUF and Soudan



- Low mass WIMPs deposit little energy
- Study data below full discrimination threshold (still partial discr.)
- Significant background: understood, but not subtracted
- Competitive sensitivity
- Stanford Underground Facility: early run (2001/02): very low noise, low trigger threshold (sub keV)
- Soudan: lower background, but slightly higher threshold (2 keV)
- New method of finding limit for multiple detectors with different background performance (Yellin)

Results

Low mass WIMPs



CDMSlite – Low Mass WIMPs (SuperCDMS)

Phonon signal:
recoil energy + charge carrier drift:

$E_{tot} = E_R + n_{eh} * q_e * V$

$n_{eh} = E_R * 1/\varepsilon * QF$

$\varepsilon = 3$ eV (average E / eh pair)

ER: QF = 1

NR: $QF(E_R) \approx 0.2\text{-}0.3$

$\Rightarrow E_{tot} = E_R * (1 + QF * q_e V/\varepsilon)$

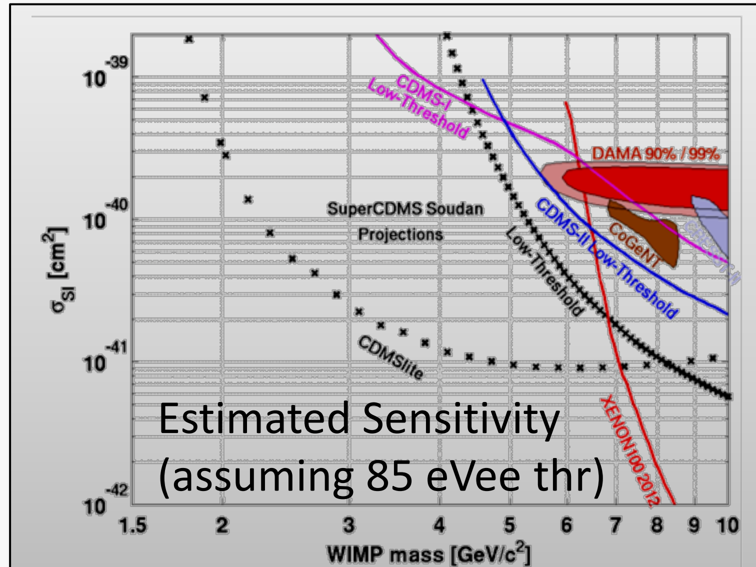
$= E_R * G_L$

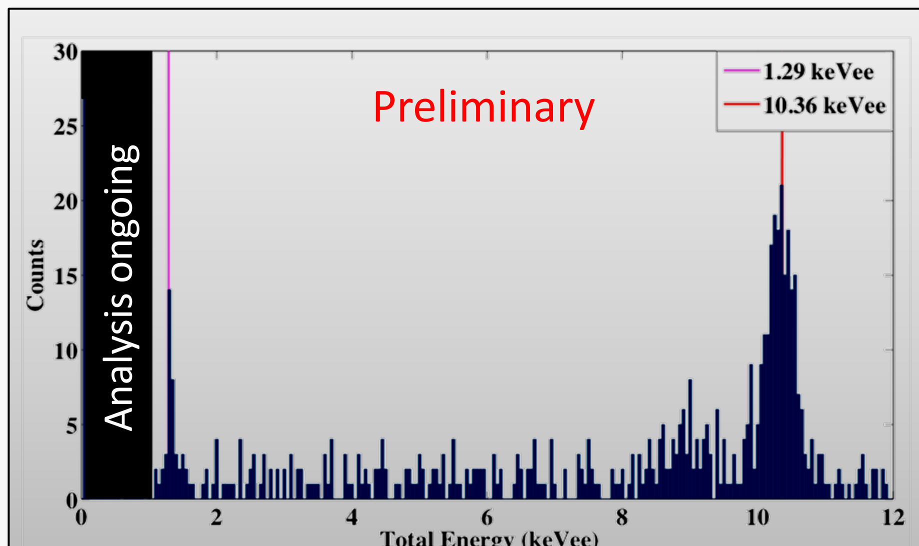
Operate at 69 V:

$G_L(ER) = 24$

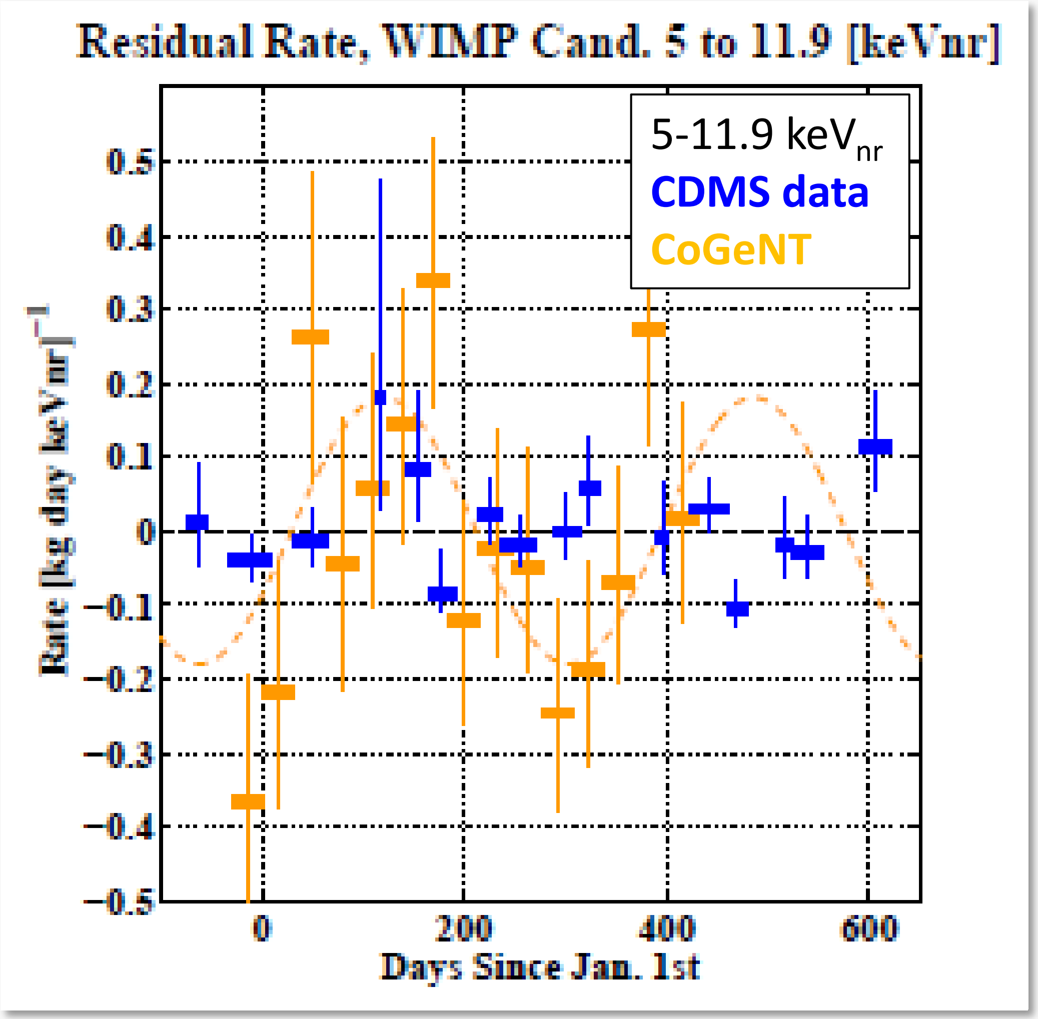
$G_L(NR) \approx 6$

$\Rightarrow$ Reduce threshold
AND dilute ER background
(no Q-signal, so no discr.)



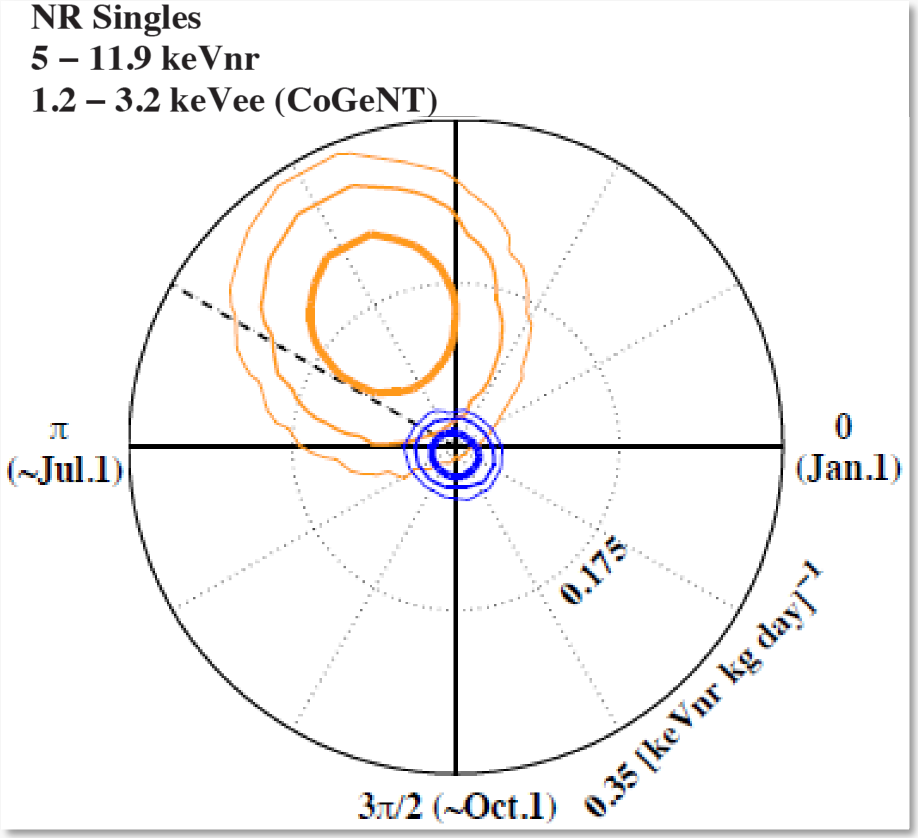


CDMS – Annual Modulation Analysis



- Test hypothesis that CoGeNT modulation is caused by nuclear recoils from a setup-independent source (such as dark matter)
- Need to convert energy scale (CoGeNT measures ionization only; CDMS uses phonon signal to determine energy)

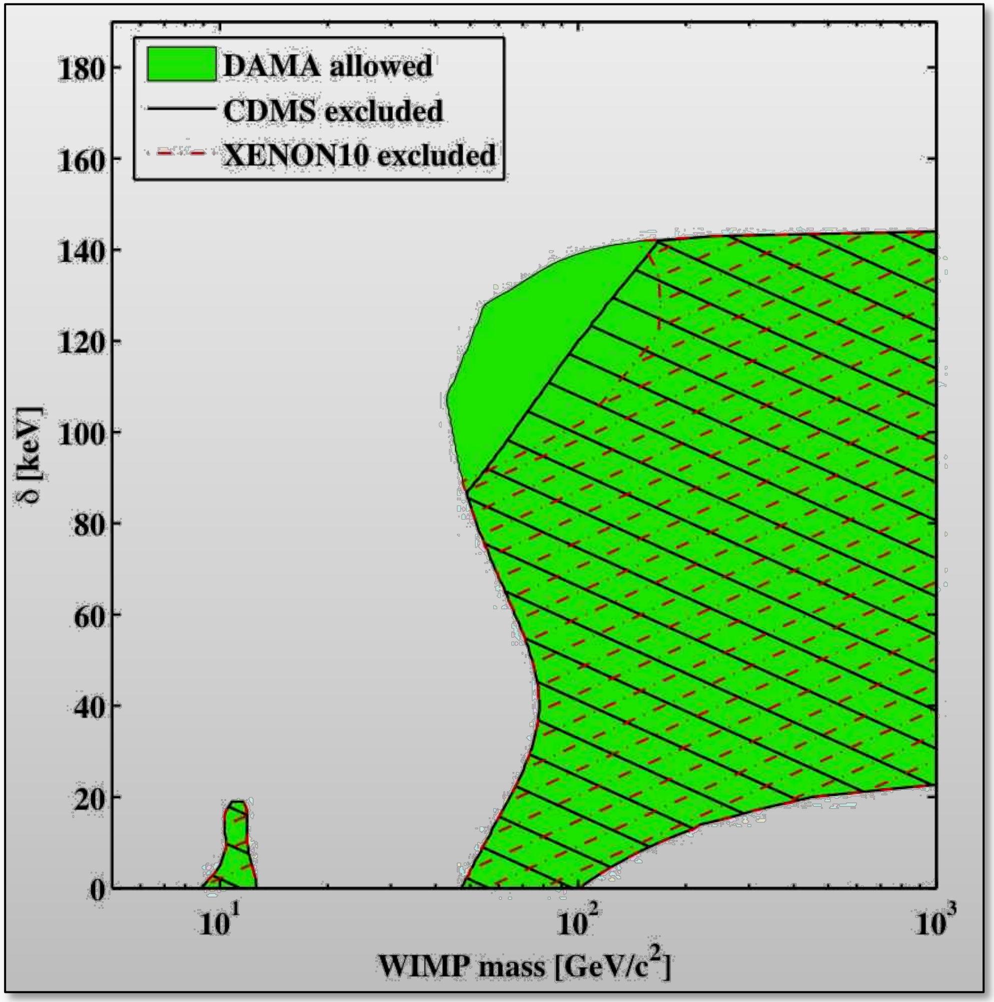
CDMS – Annual Modulation Analysis



- Nuclear Recoil Hypothesis inconsistent with CDMS data
- What if it is Electron Recoils?

  → Would need to go to lower energy (work in progress; checking down to 2 keV is conceivable)

Inelastic Dark Matter



- Proposed by Wiener et al. could explain DAMA/LIBRA
- Scattering includes transition of WIMP to excited state ($\Delta E = \delta$)
- DAMA allowed: marginalized over cross section
- Hashed: excluded at 90 % C.L.
- CRESST and XENON100: all DAMA allowed region excluded

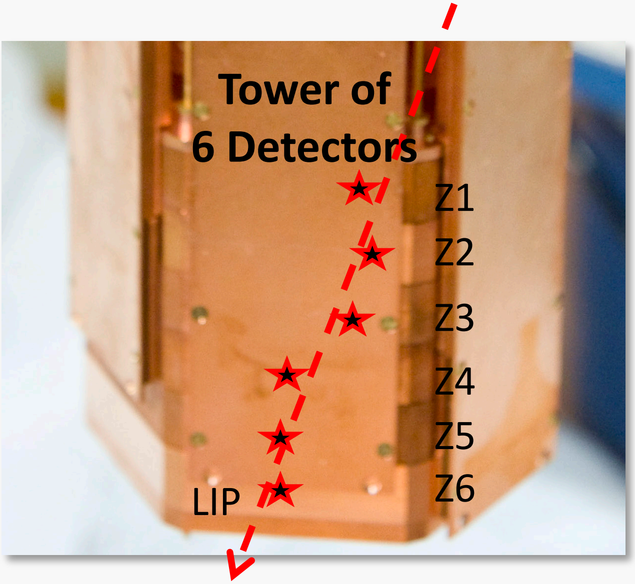
Lightly Ionizing Particles (LIPs)

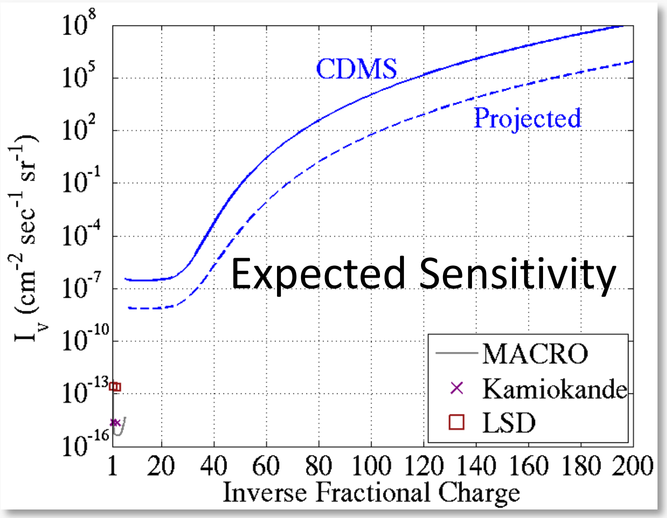
LIPs are relativistic particles with fractional charge
Would behave like muons,
but deposit less energy per length

Requirements:
- Hit all 6 detectors in a tower, no other hit (→ very small background)
- Straight line through whole tower
- Energy deposition the same in every detector (correct for electron density for Ge/Si)

CDMS is ideal to search for LIPs with fractional charges as low as e/200

(only 2 towers have 6 fully functional detectors)





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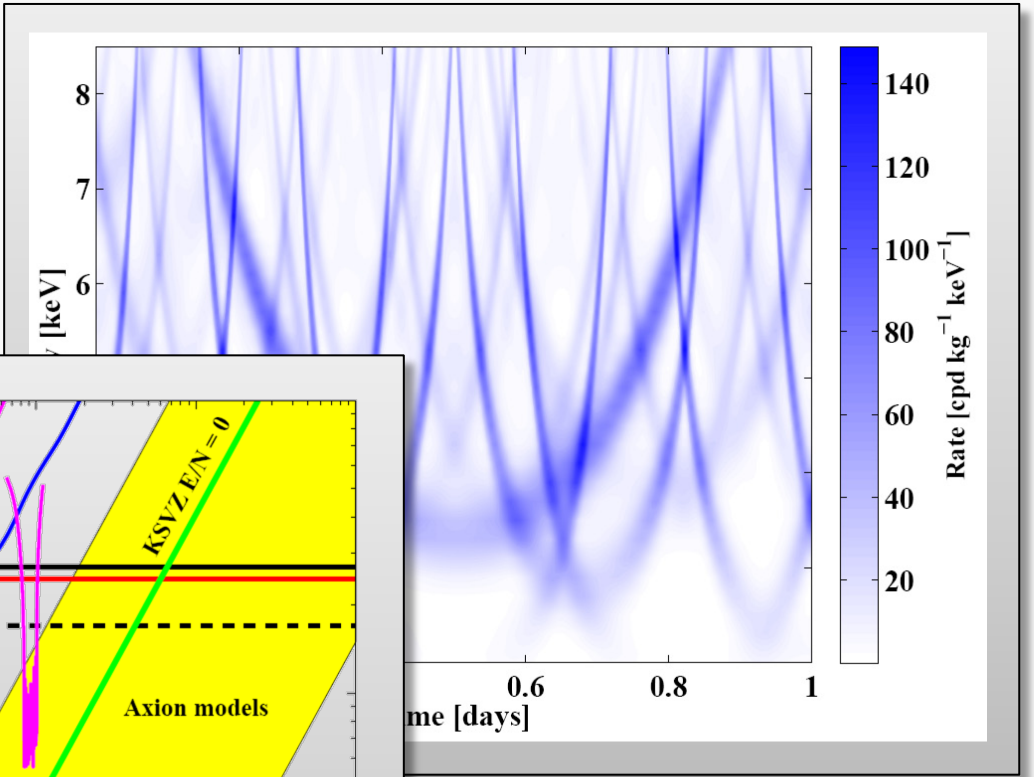
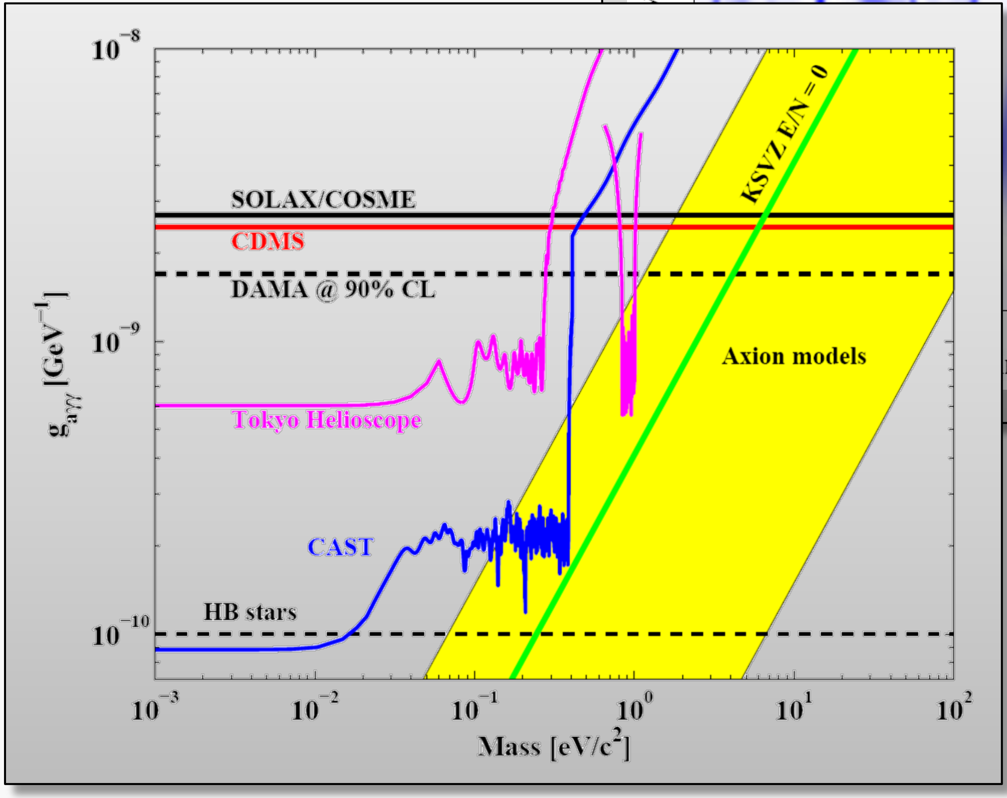
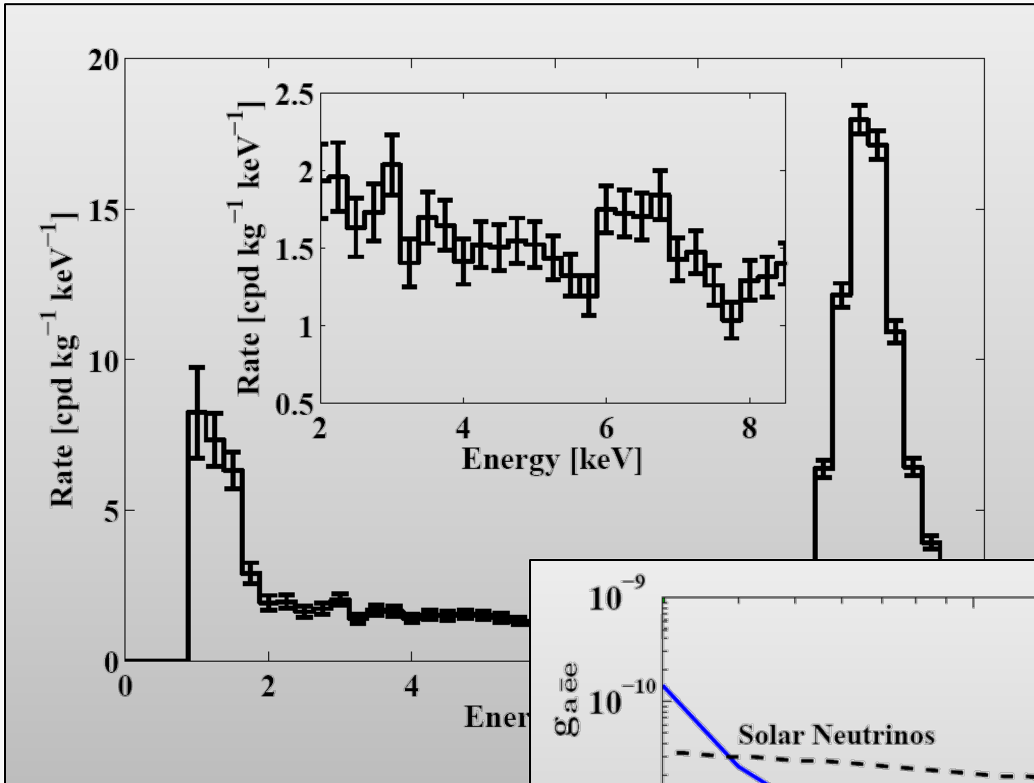
Axions

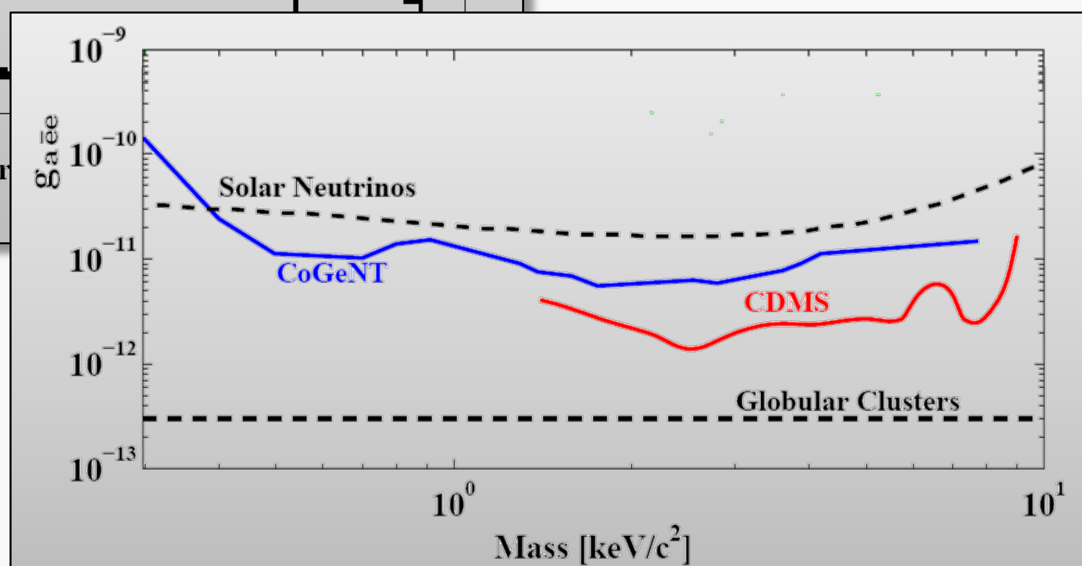
- Solar Axions
- Convert in nuclear electric field to $\gamma\gamma$
- "Bragg" condition enhances x-section





Low Energy Electron Recoils





No excess above background!

Interpretation with respect to relic axions:

- Signal: peak at axion mass
- No preferred direction
- Consider all electron recoil events

Conclusion

- Strong observational evidence for the existence of dark matter
- WIMPs are probably the best motivated candidates
- CDMS uses cryogenic semiconductor detector to search for WIMP interactions
- CDMS has provided best sensitivities for most of the past decade and continues to be among the top players
- SuperCDMS at Soudan (~9 kg, iZIP detectors) operational
- Will be limited by cosmogenic background after 2-3 years
- Planning new setup for SNOLAB ($\mathcal{O}$ (hundreds of kgs))
- So far no evidence for WIMPs has been confirmed
- Low Threshold Analysis in tension with low-mass WIMP interpretation of DAMA and CoGeNT; no evidence for annual modulation in CDMS data
- Non-WIMP analyses (Axions, axion-like relics, LIPs) have competitive or unique sensitivity