DARK MATTER SEARCH WITH CDMS EXPERIMENT

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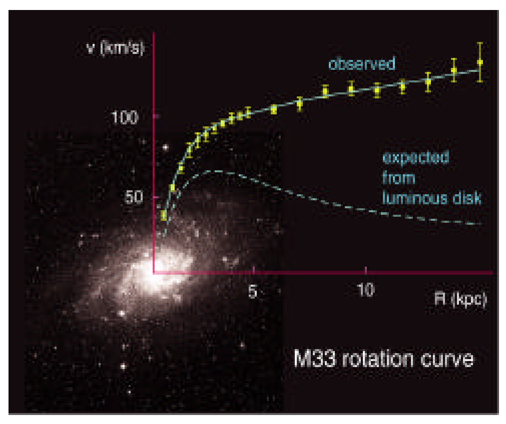
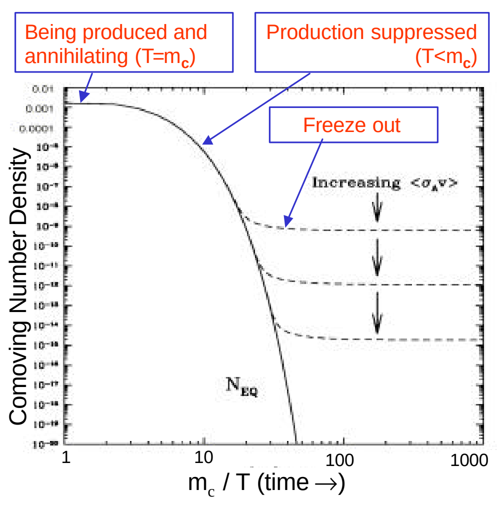
WIMPs as Non-Baryonic Cold Dark Matter

There is evidence in both astronomical observations and modern cosmology that most matter in the universe is dark and non-baryonic.

- Flat galactic rotation curves
  $W_m = 0.1$
- Cosmic Microwave Background
  $W_L + W_m \sim 1$
- WMAP (astro-ph/0302209)
  $W_m \sim 0.29 \pm 0.07$
- Big Bang Nucleosynthesis (astro-ph/0001318)
  $W_b = 0.040 \pm 0.005$
- Cosmic Microwave Background (astro-ph/0302209)
  $W_b = 0.047 \pm 0.006$





Weakly Interactive Massive Particles (WIMPs) as cold dark matter candidates arise naturally from supersymmetry. WIMPs refer to a more general class of particles, including neutralinos, that are relics left over from the Big Bang. Annihilation stops ($T \sim m_c/20$) when number density drops to the point that

$H > G_A \sim n_c \langle s_A v \rangle$

i.e., annihilation too slow to keep up with Hubble expansion ("freeze out")

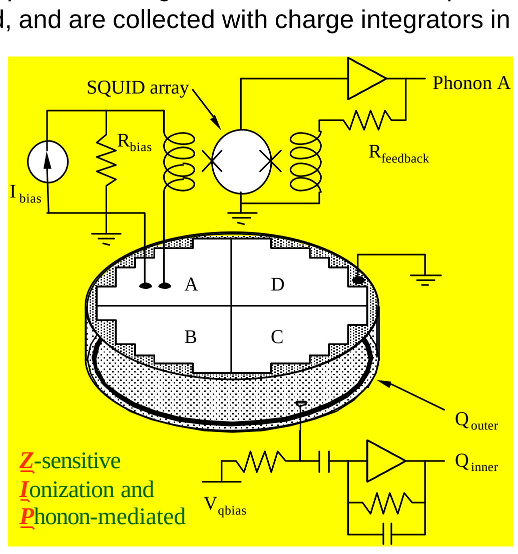
Leaves a relic abundance:

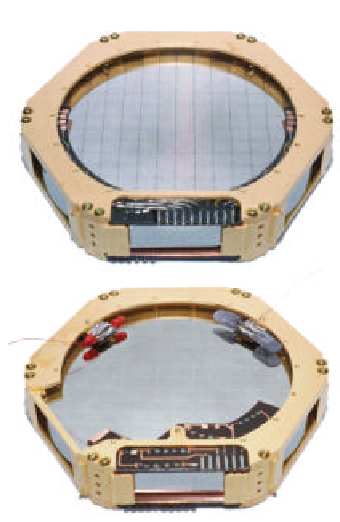
$W_c h^2 = 3\times10^{-27}\ cm^3\ s^{-1} / \langle s_A v \rangle_{fr}$

Cold Dark Matter Search (CDMS) experiment looks for WIMPs, which deposit few to few tens of keV energy when they elastically recoil off Ge or Si nuclei at 20mK at the rate < 1 event/kg/d. Underground experimental environment, active scintillation muon veto, shields of lead, polyethylene and copper provide the required low background conditions. And more important, CDMS detectors themselves have event by event background rejection capability.

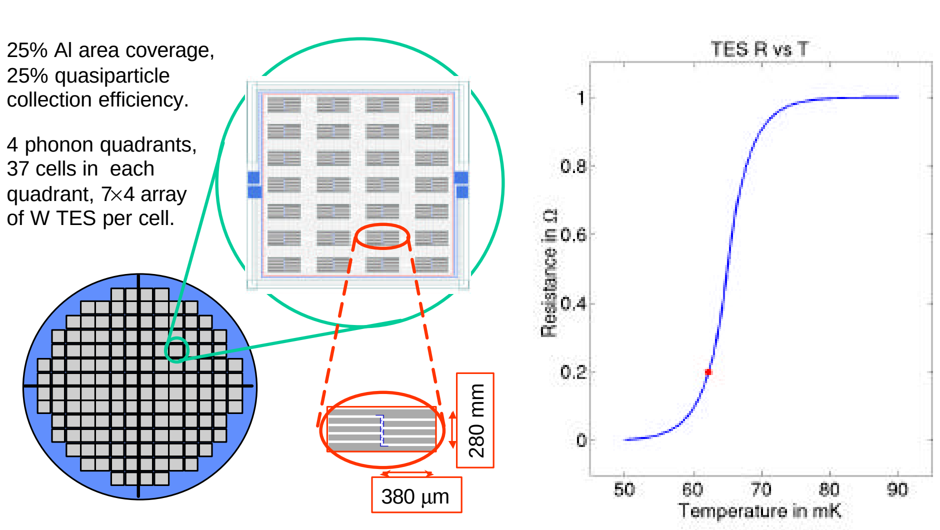
CDMS ZIP Detectors

CDMS ZIP detector is 250g (100g) germanium (silicon) 'puck', which has two charge collection channels and four ballistic phonon collection channels. When particles recoil off an electron or nucleus in the target material (Ge or Si), electron-hole pairs and phonons are generated. Electron-hole pairs are separated under external electric field, and are collected with charge integrators in inner and/or outer electrodes.

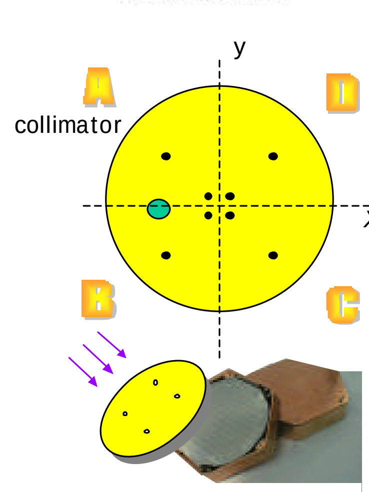




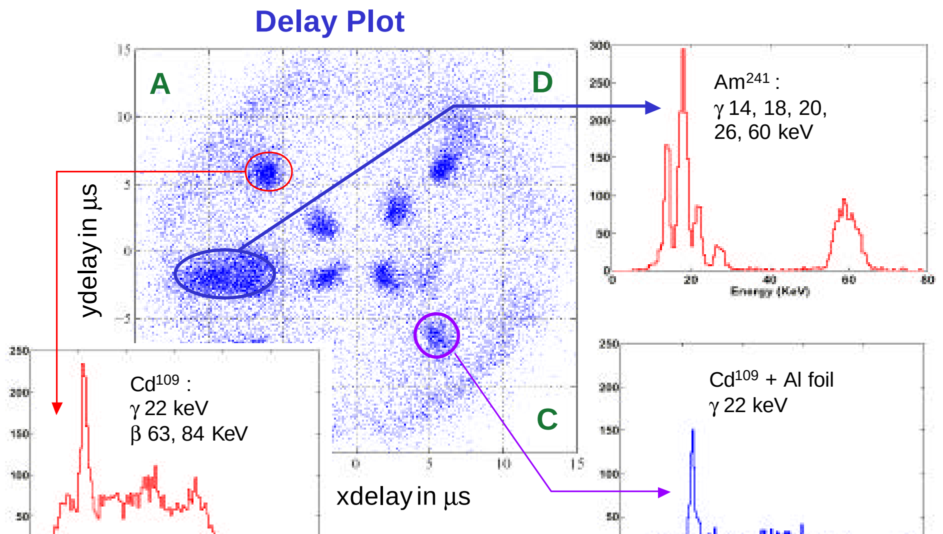
Phonon sensors are Al ballistic phonon trapping fins and W transition-edge sensors (TES). Quasiparticles created by phonons captured in Al fins diffuse into W TES. The resistance change in TES gives a current change (signal) in electrothermal feedback circuit (shown above). And the signal is read out with SQUID system.



- Four phonon channels A, B, C, D
- Phonons travel across the detector in quasi-ballistic mode, average phonon speed in Si (Ge) crystal of 0.25 (0.12) cm/µs results in measurable delays between the pulses of the measured 4 phonon channels
- x, y coordinates of interaction location can be reconstructed with four phonon channel's pulse start time
- Z-coordinate reconstruction is in progress
- Frequency down conversion of phonons depends on depth of interaction and this is the risetime handle of the phonon pulses



Delay Plot



CDMS Collaboration

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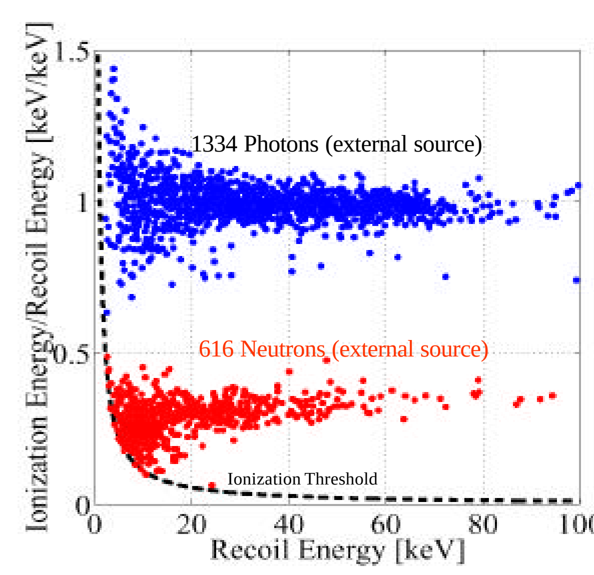
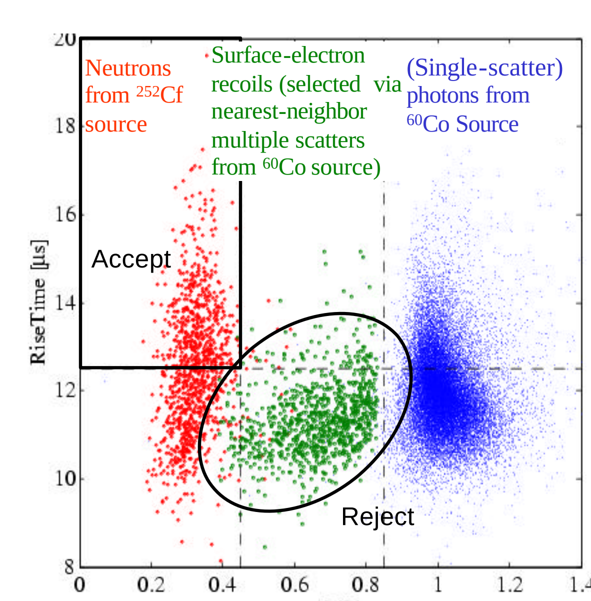
Cryogenic
Dark
Matter
Search

CDMS Background Discrimination

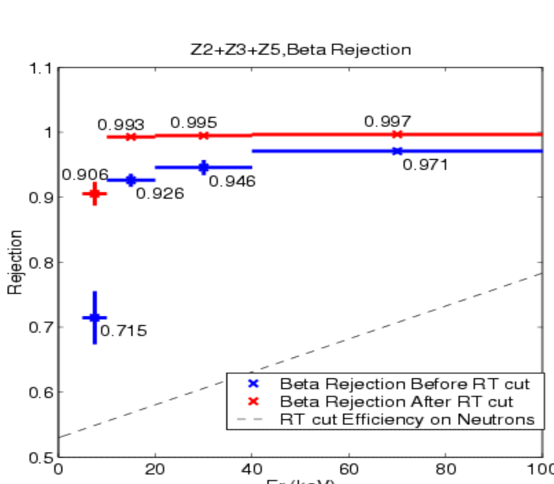
- Underground experimental environment reduces muon flux by orders of magnitude
- Active scintillation paddles veto muon-induced events
- Lead, polyethylene and pure copper shields suppress radioactive background
- Nitrogen gas purge keeps Radon away during detector storage and handling
- Cutting off events in outer charge channel rejects part of photon background
- Neutron background is estimated by looking at multiple scattering events and relative event rates in Ge nuclei and Si nuclei
- Detectors provide near-perfect event-by-event discrimination against otherwise dominant electron-recoil backgrounds

- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
- Most background sources (photons, electrons, alphas) produce electron recoils
- WIMPs (and neutrons) produce nuclear recoils
- Phonons from interaction are optical phonons, these phonons decay into high energy acoustic phonons
- Phonon propagation velocity is a strong function of phonon frequency.
- Surface impurities in Si or Ge have a soft electronic structure with low excited energy levels. Scattering rate of phonons with these impurities is several orders higher compared to the bulk closed-shell impurities
- Surface events produce lower-frequency phonons in much shorter time
- Faster phonons result in a shorter risetime of the phonon pulse
- Risetime helps eliminate the otherwise troublesome background surface events
- Nuclear recoil is identified with both yield and risetime



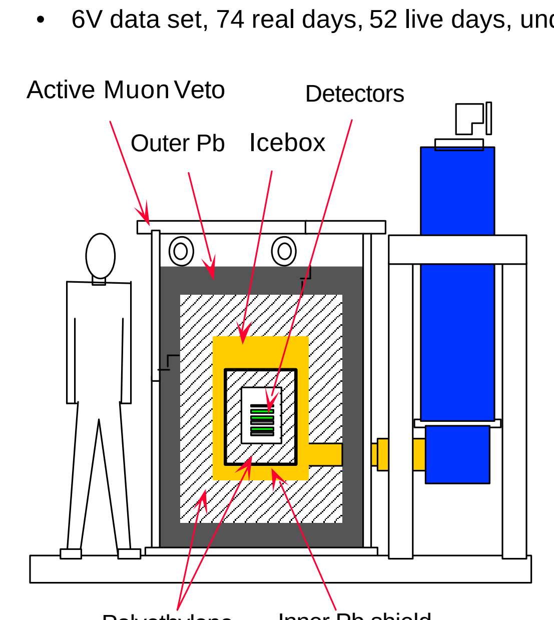


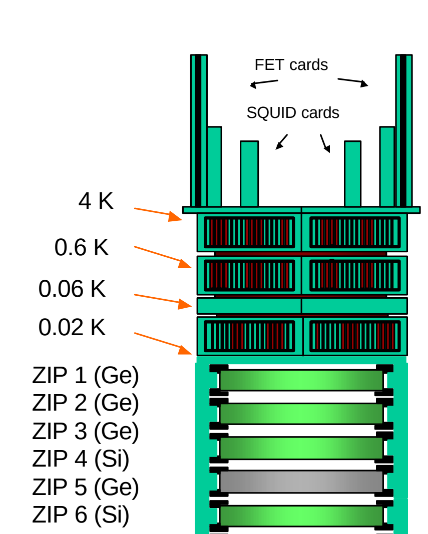
- Rejection of surface electrons based on ionization yield alone is >90% above 10 keV
- Rejection of electrons based on risetime of phonon pulses is >90% while keeping >55% of the neutrons
- Actual overall rejection of electrons is >99%, twice as good as in CDMS II proposal



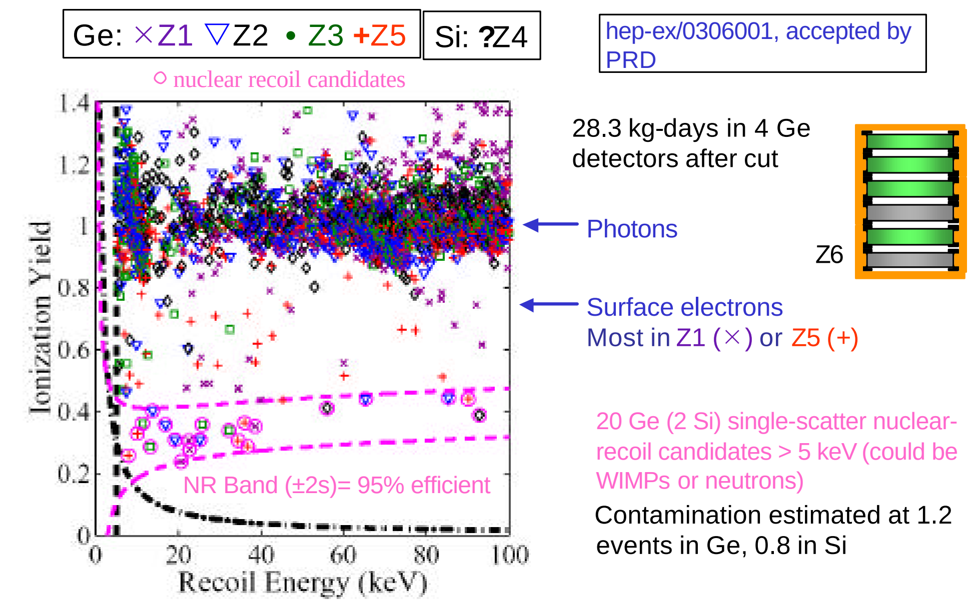
CDMS II SUF RUN

- Stanford Underground Facility (SUF) at 17 mwe of rock
- Active scintillator + gamma and neutron shielding + radio-pure inner volume
- Event-by-event nuclear recoil discrimination by using 6 ZIP detectors
- 4 Ge (250g each) and 2 Si (100g each) detectors
- 3V data set, 93 real days, 67 live days, and a total of 4.7 million events
- 6V data set, 74 real days, 52 live days, under analysis

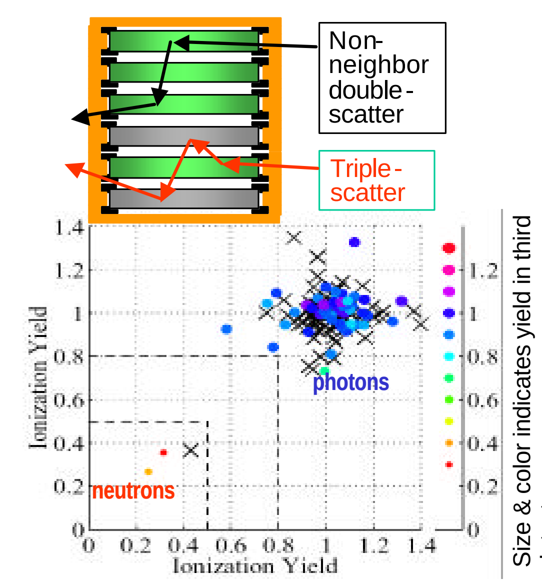




SUF Run Muon-Anticoincident Data



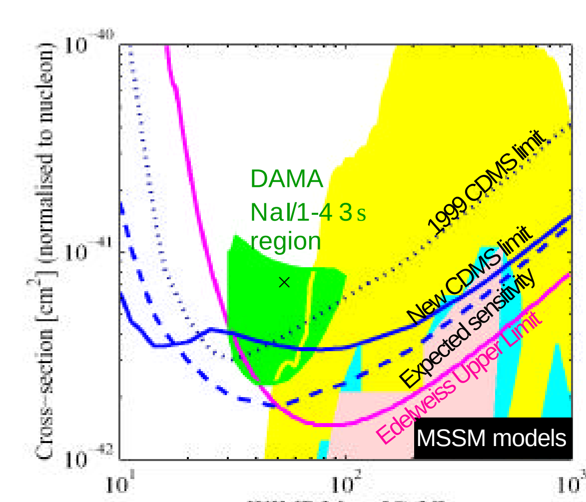
Neutron Multiple Scatters



- 2 triple-scatter (filled circles) and 1 non-nearest-neighbor double-scatter (×) NR candidates 5-100 keV
  - Ignore nearest-neighbor doubles because possible contamination by surface electrons
- Expect ~16 single-scatter neutrons per 3 multiple scatters
  - Implies many (or all) of 20 single-scatter WIMP candidates are neutrons

Resulting Experimental Upper Limits

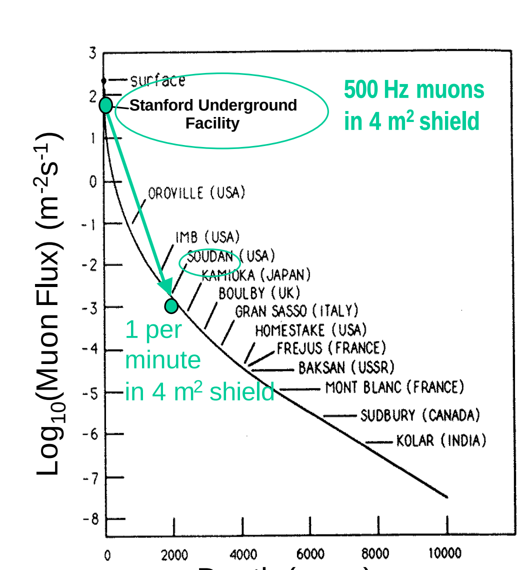
90% CL upper limits assuming standard halo, A^2 scaling

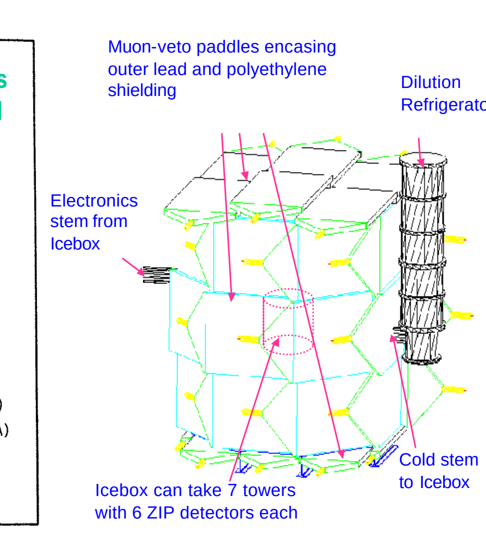


- Calculate allowed region using extension of "Feldman Cousins" method
  - Constrain neutron background based on 3 "gold-plated" neutron multiples, 2 Si neutron singles (considering possibility of background)
- Limits slightly worse than expected sensitivity (dashes)
- Exclude new parameter space for WIMP masses below 20 GeV
- Exclude a few interesting supersymmetry models
- Exclude DAMA most likely point (x) at 99.8% CL

CDMS II at Soudan

- Go to deep site: Soudan mine, Minnesota, 713 m (2090 mwe) under surface
- Muon flux reduced by > factor 30,000
- Neutron background reduced from ~1 / kg / day to ~1 / kg / year
- With current rejection and radioactive background rates, will improve sensitivity x100
  - Expected sensitivity ~ 0.07 evt/kg/day within two months
  - Final expected sensitivity ~ 0.01 evt/kg/day
- 12 detectors in 2 towers of 6, 1.5 kg of Ge, 0.6 kg of Si
- 18 more detectors in fabrication, 4 kg of Ge, 1.5 kg of Si
- Assembled entire shield and veto
- System test of DAQ and warm electronics performed at Soudan
- Detectors are at 40mK, low-background run commissioning is in progress





Experimental apparatus

(CDMS II Shield) µ-metal (with copper inside) (Two Towers in Icebox)