SuperCDMS Searches for New Physics

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The Hunt for Dark Matter

Production in Colliders

Annihilation in Cosmos

Direct Detection

FERMI, Pamela, ATTIC

HESS, VERITAS, Magic

AMS-02

LHC

LUX

SuperCDMS

IceCube
Direct Detection

\[ \chi_0 \rightarrow Ge \]

\[ \frac{v}{c} = \beta \approx 0.7 \times 10^{-3} \]

Rate = \( N \phi \sigma \)

WIMP Scattering Rate for \( \sigma = 10^{-41} \text{cm}^2 \)

- Small signal and huge Radioactive background
- Reduction and Rejection strategy
- Threshold must match expected WIMP search

Background
At 1 keV – Million phonon quanta vs 0 light quanta. Huge statistics.
The SuperCDMS Collaboration (21 Universities)
CDMS Principle

- Ge/Si crystals (~kg) cooled to 40 mK
- Measure recoil energy via phonons
- Measure the Ionization. E-field: ~3V/cm
- Near surface events
  - Electron recoil but poor charge collection
  - Near geometrical boundaries

-3V Hot charge carriers (3eV/pair)

Quasi-diffusive THz phonons
Ballistic Neganov-Luke phonons
Ballistic low-frequency phonons

New interleaved Ionization Phonon Detector (iZIP)
designed to reject surface events with high surface field
iZIP: A new detector design

- Interleaved electrodes (1 mm pitch) on both sides
- Alternating +V & ground (i.e. phonon sensors) on one side -V & ground on the other side.
- Bulk events see the average Voltage on each side: Uniform Field in the bulk.
- In contrast the problematic Near-surface events sense the big transverse field at the surface.
Collect and Concentrate Phonon Energy into W TES
$1 \times 10^4$ surface discrimination from ionization signal!
SuperCDMS Soudan

5 Super Towers of Ge iZIPs (9 kg total)
   Fully operational since early 2012

WIMP-search strategies

CDMSlite (No discrimination)
   Special bias configuration & readout
   Light WIMP masses: < 10 GeV/c^2

Low-threshold (LT) analysis (with discrimination)
   Subset of array w/ best trigger thresholds
   Light WIMP masses: < 20 GeV/c^2

High-threshold Near-zero background analysis
   Full detector array & exposure
   Higher thresholds to prevent background from resolution effects
   Heavier WIMP masses: > 10 GeV/c^2
The most significant sources in the background model were $^{210}\text{Pb}$, $^{68,71}\text{Ge}$ 1.3 keV L-capture, and gamma rays from K, U, Th contamination in the detector construction.
Voltage Assisted Ionization Detection

- Detectors operated for two weeks at 30 V/cm
- World leading limits below 5 GeV
- In principle, increase bias to reach Poisson limit
- In practice, breakdown in Ge limited the bias V
- Huge progress in detector R&D (Berkeley + TAMU) shows promising resolution to few eV!

A signal gain of 24 was demonstrated using SuperCDMS iZIPs with alternative electronics. This allowed a lower threshold of 160 eVee.

High Voltage athermal phonon readout: contact free biasing

- One face of the detector processed similar to a CDMS II detector:
  - fully covered by Four W based athermal phonon readouts.
- The other face of the detector left free
- Bias the detector through a gap ~ 0.5 mm
Results from Texas A&M G37 detector

- Observed No break down for positive polarity bias.

σ < 8 eV Base line resolution
Noise of Texas A&M G23R Low Tc Detector @ 0V

- $T_c = 52-53$ mK
- iZIP-IV TES Geometry

Estimated Noise: TFN + Johnson Noise
Low Threshold Detectors Open up Many Frontiers, while Searching for WIMPs
Assuming LIPs are massive and minimum ionizing.

Lightly Ionizing Particles (LIPs)

- Quarks, but confined in hadrons
- Large Number of searches
  - Search limited by threshold due to $f^2$ penalty in $\sigma$
- Unique opportunity for us!
  - Low threshold and tracking
  - Anything not explicitly forbidden is required. Gell-Mann
  - SM + extra U(1) gauge symmetry, as in String Theory, feature dark photon with small kinetic mixing with SM photon can give very small charge in Hidden Sector

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Particles with fractional charge?
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Z1 Z2 Z3 Z4 Z5 Z6
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“Tower” of 6 Detectors
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1cm
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```
LIP
```

```
Assuming LIPs are massive and minimum ionizing.
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10^{-12}
```

```
10^{-13}
```

```
10^{-14}
```

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LIP flux limit (cm^{-2} s^{-1} sr^{-1})
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MACRO 2004
```

```
MACRO 2000
```

```
Kamiokande
```

```
LSD
```

```
INVERSE Fractional Charge: e/q
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```
6.0
```

```
5.0
```

```
4.0
```

```
3.0
```

```
2.0
```

```
1.0
```
Electromagnetic background events tend to interact in a few detectors…

…a LIP is expected to interact in all detectors in a tower

Expected background before energy consistency and tracking cuts

Difference primarily due to live time
Energy Consistency

Hits should have energy consistent with a LIP hypothesis

- 99% LIP acceptance
- 90% background rejection

Illustrative sample distribution more consistent with $f=1/15^{th}$ than $f=1/6^{th}$ or $f=1/60^{th}$. 
CDMS Probes Unexplored milli-charge Parameter Space

- LIP would leave similar energy in each of 6 detectors in a tower and have a 3-D linear track
- $<0.05$ expected background from entire dataset!
- 14 orders of magnitude improvement at $e/200$ and reach micro-electron charge sensitivity! “DM”?
Coherent Neutrino-Nucleus Elastic Scattering

Flavor-blind Standard Model process

\[ \sigma_{\nu N \to \nu N} \simeq \frac{G_F^2}{4\pi} N^2 E_{\nu}^2 \]

| \( \sigma_{\bar{\nu} N \to \bar{\nu} N} \) | \( E_{\nu} = 3\text{MeV} \) |
| Ge | \( 6.0 \times 10^{-41}\text{cm}^2 \) |
| Ar | \( 1.8 \times 10^{-41}\text{cm}^2 \) |
| Si | \( 7.4 \times 10^{-42}\text{cm}^2 \) |

Can be utilized to probe non-SM interactions and sterile neutrinos. Oscillations would indicate mixing solely to non-active neutrinos.

Major plans at TAMU Nuclear Reactor with MW->GW Pulsed mode. 10 eV \( E_{\text{th}} \)
Detector few inches from the core!

Never been measured, due to lack of ultralow threshold (10-50 eV) detectors.
Approved Projects – SuperCDMS and LZ
Going Deeper: Less Muons

100x reduction in muon flux at SNOLAB compared to Soudan

3/27/2014

N. Mirabolfathi - Texas A&M Physics
Cryostat designed for 400 kg of Ge detectors, with initial 50kg payload (6 Ge iZIP, 1 Si iZIP, 1 Ge+Si HV Towers of 6 detectors each). Many upgrade paths, including other detector material and technology!
SuperCDMS SNOLAB – Many Experiments in One

- Ge and Si in iZIP and HV mode for WIMP/LIP Search
- First experiment to hit the neutrino floor
- Modular detector means possibly significantly more advanced detectors designed to address changing field
  - Ultra-low threshold
  - Lower background
  - Different det. material to target specific interactions
  - Confirming a Xenon detector signal (must scale up quickly)

![Exclusion limits for isoscalar EFT operator $O_3$](image1)

![Exclusion limits for isoscalar EFT operator $O_5$](image2)

![Event rate comparison for 300 GeV WIMP, isoscalar interactions](image3)
Major Detector Fabrication Improvements for SNOLAB
Photolithographically Patterned Ge Detector

- Multi-step process repeatable for high quality detectors
- Photo Coat
- Circuit Mask Exposure
- Chemical Etch
- XRD
- Inspect and Package
- Deposition
- Polish
Major Equipment Upgrades at Stanford and Texas A&M

TAMU SEG1 system (load lock, 8 substrate carrier). Demonstrated W T_c down to 54 mK.

Stanford AJA system (load lock, 4 substrate carrier). In-situ substrate flip capability)

Load locked system keeps deposition chamber under high quality vacuum for ~year, monitored by RGA for excellent repeatable Tc, within and across batches
Tc Uniformity – Reduced Testing, Cost and Failure

Tc demonstrated to be uniform to +/- 2 mK within detector and predictable to within +/- 5 mK among batches.

Completely eliminates need for ion-implantation, thus reducing cost and risks.

Tc stability within a batch of detectors is crucial to reduce testing costs.
- Test one detector per batch
- More similar detector responses will reduce analysis time and cost

Detector cost brought down from ~$475,000/kg in CDMS to $50,000 in SuperCDMS SNOLAB
SuperCDMS-SNOLAB G2 Low Mass Search

- Dramatic increase in sensitivity, especially for WIMPs <10 GeV
- Two main technology advances
  - X10 better energy resolution
    - Better electronics
    - Lower temperatures
  - X200 lower backgrounds
    - Material selection
    - Better cleaning/handling
    - Minimize cosmic-ray exposure
Beyond Early G2 SuperCDMS@SNOLAB

- Large inner can to host up to 400 kg of Ge detectors. Initial payload ~ 50 kg
- Exploring collaborations with EURECA for possible payload similar to EDELWEISS and CRESST detectors. Key is base temp – EURECA requires 15 mK. We are trying hard, but may not reach that base temp.
- Exploring funding from other sources, such as private foundation funding and international funding for additional payload.
- R&D in full fledge to achieve very low resolution (<8eV achieved so far)
100 years to understand 4%

How long to understand 23%?

Gravity √
Weak  ?
Electromagnetic X/?
Strong  X
Conclusions

• Current Generation 1 technologies (~15-30kg $10^{-44}$cm$^2$ sensitivity)
  • SuperCDMS, LUX, Xenon100 probing some SUSY space

• SuperCDMS (Low M) and LZ (High M) have been approved for G2

• Complimentary target and technology important for discovery
  • Exact interaction is anything but known for sure

• There will be pleasant and unpleasant surprises and we may discover something different from what we set out to find!

• When will we detect Dark Matter? “The two most powerful warriors are patience and time” – Leo Tolstoy
Backup Slides
Athermal Phonon Sensors

Collect and Concentrate Phonon Energy into W TES (Transition Edge Sensor)
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1 eV resolution possible – working hard on new ideas for High Voltage detectors

Ultra-low threshold detector key to understand may new BSM physics processes
Chasing WIMPs Down to \( \nu \) Floor

![Graphs showing event rates and recoil energy distributions for WIMPs.](image)