Sensitivity

Sensitivity by end 2018 with measured background and detector performance.

Three excess events in CDMS-II Si
0.19% probability for background-only hypothesis

PRL111 251301
Charge coupled device

Device is “exposed,” collecting charge until user commands readout

Readout can be slow / non-destructive: very low noise (few e-)

Silicon band-gap: 1.2 eV
Mean energy for 1 e-h pair: 3.8 eV

Standard fabrication in semiconductor industry and easy cryogenics (~100 K).
Performance

Particle identification and background characterization

\[ \sigma_{xy} \approx z \] : fiducial volume definition

Very low noise and dark current

Lowest dark current ever measured in a silicon detector:

\[ 5 \times 10^{-22} \text{ A/cm}^2 \] (at 140 K)
DAMIC CCD

3-phase CCD structure
Poly gate electrodes
Buried p channel
(10-20 k \(\Omega\)-cm)

Bias voltage
Dark matter particle

MOS p-n junction

675 \(\mu\)m

Solid: 2 D Medici simulation
Dashed: 1 D Medici simulation

LBNL design
CCD readout

3x3 pixels CCD

serial register
sens node
amplifier

P_1 P_2 P_3 P_1 P_2 P_3

channel
stop

state
1
2
3
7

Capacitance of the system is set by the SN: 

\[ C = 0.05 \ \text{pF} \]

10 / 52
CDS readout

\[ \Delta V \text{ is } \sim 3 \mu \text{V per e}^- \]

CDS: “Correlated double sampling”

Amplifier 1/f noise

Slow CDS readout achieves pixel noise <2 e-

“Skipper” readout can improve noise further

\[ C_5 \text{ is } \sim 50 \text{ fF} \]
Flexibility in readout

Pixels can be readout in “groups” and the total charge estimated in a single measurement.

Less pixels but same noise per pixel!

$^{55}$Fe from back: Data shows clear improvement in energy resolution

Loss of x, y and z information

α-β coincidence
CCD characterization

Mn K_{\alpha} from front and back

Front
Back

z reconstruction with X rays and cosmic rays

CCD linearity down to 40 eV_{ee} with optical photons
NR signal response

a) Cross-section of setup

b) $^{124}$Sb-$^9$Be source detail

24 keV neutrons from $^9$Be($\gamma$,n) reaction

Single-recoil spectrum very similar to signal from 3 GeV WIMP. End-point = 3.2 keV$_r$

Number of nuclear recoils ([(10 eV)$^{-1}$])

Data - full BeO
Best-fit with Monte Carlo spectrum

Calibration down to 60 eV$_{ee}$
Electron recoils in the bulk of the CCD from small-angle Compton scattering of \( \gamma \) rays are dominant background for DAMIC.

Linear spectrum, with slope dependent on the energy of the incident photons, with characteristic steps at the atomic binding energies.

Calibrated the parameters of a generic \( \gamma \)-ray model with \(^{241}\text{Am}\) and \(^{57}\text{Co}\) sources.
2 km underground
SNOLAB Installation

- 16 Mpix CCD
- 5.8 g
- 6 cm

Copper module
Kapton signal cable

Lead block
Kapton signal cable

Cu box with CCDs

VIB

Cu vacuum vessel

Polyethylene
Lead

J. Zhou
Timeline

- First CCDS installed at SNOLAB in December 2012.
- Three years 2013-2015 to achieve low radioactive background.
- WIMP and HP results with R&D data.

Timeline

- First deployment early 2016: problems with mechanics of CCD package.
- Taking data since.

WIMP Search

CDMS-II Si - 140 kg d
CDMSLite - 70 kg d
DAMA/Na
LUX - 14 ton d
CRESST II 2015 - 52 kg d
0.6 kg d

Since 2013 we have decreased the background by >10^3.
About order of magnitude improvement per year.
Not easy!

In the last year:
- Seven interventions at SNOLAB.
- Nitrogen purge installation.
- Improvements in treatment of copper surfaces.
- Suppression of background from thermal neutron captures in copper.
- Mitigation of background from condensation e.g. 3H.

WIMP Search

PRD94 082006 (2016)

DAMIC spectrum

DAMIC spectrum

Now 5 dru

First deployment early 2016:
problems with mechanics of CCD package.
Taking data since.
Background at SNOLAB

Extensive selection of copper, special machining and chemical cleaning.

Lead shielding to stop external γs: Inner 2” of lead is ancient to stop bremsstrahlung from $^{210}$Bi decay.

Nitrogen purge around lead to suppress radon ≪1 Bq/m$^3$.

Current event rate $5 /$keV$^{ee}$/kg/d.
Absorption of hidden-photon dark matter.

Si bulk

e⁻

Ionization

Hidden Photon

~1 week of data with 1 CCD.

Leakage current $4 \text{ e}^- \text{ mm}^{-2} \text{ d}^{-1}$.

Pixel distribution consistent with white noise + uniform leakage current
Current status

- **7 CCDs** in stable data taking since 2017 (1 CCD sandwiched in ancient lead).
- **1 CCD** dead.
- **40 g** target mass.
- Operating temperature of **140K** and most recently at **135 K**.
- Exposure for image: 8h and 24h (each image acquisition is followed by a “blank” exposure).
- Data acquired in **1x1** or **1x100** formats.
Data timeline

- We deployed in Feb 2017 but detector was not fully commissioned until Sep 2017.
- The response of the CCDs in the first **7.6 kg-day** in 1x1 format is not well understood: data is useful for some background studies + millicharge cosmic particle search.
- Commissioning (tuning of CCD clocks / biases) with the LED started in May 2017 (on and off) until we had acceptable performance in 1x100 data.
- We had a few temperature cycles from power outages at SNOLAB throughout second half 2017 and a “scare” in late Nov 2017 from the failure of a safety vent valve.
- Acquired data stably in 1x100 format (~1.6 e⁻ noise, <10⁻³ e⁻/pix/day) from Sep 2017 until March 2017: **4.6 kg-day** of data. A “teaser” presented at Moriond and Aspen conferences.
Data timeline

- After Moriond (since ~1 April), acquired **2.2 kg-day** of additional data doing some tests on the dark current because of some DAQ hick-ups.
- We are back to nominal operating conditions as of last week.
Event selection

- Pedestal and correlated noise subtraction (hot pixels among several images masked)
- LL fit of the signal in a moving window across the image

\[ \Delta LL = L_n - L_S \]

- Flat noise
- Gauss signal + flat noise

Example of one event

- \( E_{rec} = 7.18 \) keV
- \( \sigma = 0.7 \) pix

<10^{-3} events from noise
Acceptance

Background + signal model from simulations

Acceptance for bulk events

Software energy threshold: 50 eV_{ee}
≈5 dru in fiducial region, consistent between CCDs

a factor of ≈ 3-4 lower than our previous background level

≈2 dru for lead sandwiched CCD
Low energy data

We are analyzing the data from **50 eV to 2 keV**, which provide most sensitivity to low mass WIMPs. Some examples of candidates:

**Two example events (data + fit)**

- **E = 0.56 keV, σ = 0.6
  ΔLL = -780**

- **E = 0.14 keV, σ = 0.5
  ΔLL = -130**

**Note:** CDMS II silicon potential signal obtained with a 7 keV<sub>nr</sub> threshold (≈2 keV<sub>ee</sub>). We are exploring for the first time the silicon target with a much lower threshold of 0.6 keV<sub>nr</sub> (≈ 0.05 keV<sub>ee</sub>).
Since Moriond data set we have noted a slight excess of events at low energies. Under investigation since then. Many eyes on the data (Romain, Mariangela, Karthik, Alvaro, Paolo, Grayson…) Mostly focused to see if it is an instrumental artifact. Need a good radioactive background model.
Background studies

- **Cosmogenic $^{32}$Si**

Search for spatially correlated beta decays. Sensitivity with current data is few Bq/kg.

Previous results: [JINST 10 P08014 (2015)]

- **Bulk and surface background**

  ppt levels sensitivity to U+Th bulk contamination. Will demonstrate that the devices themselves are radiopure for kg-year exposures.

$^{32}$Si ($T_{1/2} = 150$ y, $\beta$) $\rightarrow ^{32}$P ($T_{1/2} = 14$ days, $\beta$)

$E_1 = 51.0$ keV

$E_2 = 434.8$ keV

$(x_o, y_o)$

$\Delta t = 29.1$ days

candidate $^{32}$Si – $^{32}$P in new data

$^{210}$Pb

$^{210}$Bi

$^{210}$Po
Ongoing activities

- **WIMP search**: Romain, Mariangela, Alvaro, Karthik, Grayson.

- **Millicharge cosmic particle**: Diego, Victor + UFRJ.

- **Background studies**: Grayson, Ariel, Paolo + UC.

- **Data quality**: Rocio, Ryan, Xiaohao, Victor.

- **Simulations**: Joao, Ryan.

We have very active working groups and expect more publications soon!
Contributions

Know-how, not necessarily in funding!

- CCD package design: Fermilab.
- CCD packaging + testing: Fermilab.
- Detector box + vacuum vessel design: Fermilab.
- Detector installation: Fermilab + UC.
- Slow control: Fermilab.
- Radiation shielding: UC + Zurich + Fermilab.
- Electronics + DAQ: adopted from DECam.
- Low-background: UC.
- Detector operations: UC + Fermilab.
- Calibrations: UC.
- Data analysis: UC + LPNHE + UFRJ + Fermilab.
- Data quality: UC + UFRJ + IFCA.
- Simulations: LPNHE + UC.

For simplicity, I take contributions from people now at Nantes and UW as LPNHE and UC, respectively.