The DAMIC Experiment at SNOLAB

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For the DAMIC Collaboration

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Outline

- Charge Coupled Devices (CCDs) as particle detectors.
- DAMIC at SNOLAB.
- Background discrimination.
- Low mass dark matter search results.
- Future of the DAMIC program.
CCD Principles

- Particle produces ionization which drifts to surface of CCD
- Drift of electrons \( \sigma_{xy} \) to depth
- Pixels are “exposed” for long periods of time and then shifted pixel-by-pixel to amplifier for readout

Pixel array

- Ionizing particle
- Free charge carriers
- Fully depleted substrate
- 15 µm
CCD Performance

- Negligible (<0.001 e/pixel/day) dark current @ 120 K

*Image* Blank Gaussian fit
mean = -0.003 0.001 = 1.827 0.001

Readout noise <2e\(^-\) RMS ~7 e\(_{ee}\)

- “Worms”: electrons
- Straight tracks: minimum ionizing particles
- MeV blobs: alphas
- Point-like clusters: low-energy X-rays, Compton scatters, nuclear recoils
Nuclear Recoil Calibration

a) Cross-section of setup

Vacuum chamber

\[ ^3 \text{He counter} \]

\[ \text{20 cm} \]

\[ \text{Lead shielding} \]

Table

CCD

b) \(^{124}\text{Sb} - ^{9}\text{Be} \) source detail

\[ \text{2.75 cm} \]

\[ \text{BeO cap} \]

\[ \text{BeO cylinder} \]

\[ \text{Activated antimony rod} \]

\[ \text{BeO base} \]

24 keV neutrons from \(^{9}\text{Be}(\gamma,n)\) reaction

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

Calibration down to 60 eV\(_{ee}\).
Background Suppression

E=5.4 MeV

Δt=17.8d

Δt < 5.5h

Three α at the same location!

Powerful method to measure U/Th bkg in the bulk – ppt limits 2015 JINST 10 P08014
DAMIC at SNOLAB

16 Mpix CCD  5.8 g

Copper module
Kapton signal cable

Lead block
Kapton signal cable

Cu box with CCDs

Cu vacuum vessel

VIB

Poly-ethylene

Lead
WIMP Search

2D Gaussian distribution of free charge in pixel array.

Measure $E$ and $\sigma_{xy}$ for every event

0.6 kg days of data with test devices at SNOLAB ~30 dru of background
Hidden Photon Search

Absorption of hidden-photon dark matter.

~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.
DAMIC100

- Seven CCDs (~40 g) running at SNOLAB since Jan 2017.
- Currently ~6 kg-day of data with 5-15 dru total background.

DAMIC-1K

- A 1kg detector built with the existing technology.
- Sub-e- resolution, 2 e- (~7 eV\textsubscript{ee}) threshold.
- Background improvement to 0.1 dru:
  - Improved design
  - Strict handling
  - Baking to remove $^{3}$H
SENSEI

LDRD at Fermilab (PI Tiffenberg): Skipper CCDs (LBNL design) successfully tested with sub e- noise.

Non destructive “skipper” readout:
Perform N uncorrelated measurements of the same pixel for ~1/√N noise reduction.

Technology will allow 2 e- (few eV) threshold.

![Graph showing signal and noise distributions with reference and signal peaks.](image-url)
DAMIC Program

DM-nucleus SI coherent scattering

DM-e Scattering via Ultra-light Hidden Photon

$\sigma_n [cm^2]$ vs $m_\chi [GeV]$

$\sigma_\ell [cm^2]$ vs $m_\chi [MeV]$

- DAMIC (2016) 0.6 kg-d
- DAMIC 100 (2017) 13 kg-d
- DAMIC 1K (2020) 1 kg-y 0.1 dru, 2 e- threshold
- CDMS Lite (2015) 70 kg-d
- CDMS Lite (2015) 52 kg-d
- CRESST (2015)
- LUX (2015)
- XENON10 ER
- CDMS Lite NR
- LUX NR

100 g.y., 5 dru, 2e- threshold

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Conclusion

• CCDs offer low-noise, low-background detectors with high-resolution position reconstruction.
• DAMIC has already placed competitive dark matter search results (WIMP & hidden photon) with early development detectors.
• Developed discrimination techniques to measure and suppress backgrounds.
• Can build kg scale detector with 2 e$^-$ (7 eV$_{ee}$) threshold.