DAMIC status and prospects for a kg mass experiment

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(Photo image: particle tracks in a DAMIC CCD)
CCD principle

Metal-Oxide-Semiconductor capacitor

Metal gate
Si oxide (insulator)
n-type Si (buried channel)

p-type Si
electron-hole pairs generated by a photon or ionizing particle

Moving charge from pixel to pixel

Output amplifier

Charge motion
“vertical clocks”

“horizontal clocks” (faster)

Correlated Double Sampling
1) Sizable mass (high resistivity, thick CCDs designed by LBNL)

A DAMIC CCD has an active area of $6 \, \text{cm} \times 6 \, \text{cm}$, 16 Mpixel (each $15 \, \mu\text{m} \times 15 \, \mu\text{m}$) and a record thickness of $675 \, \mu\text{m}$ for a total of $5.9 \, \text{g}$ mass.

DAMIC100 currently taking data at the SNOLAB underground laboratory.
2) Unprecedented low energy threshold

- Negligible noise contribution from dark current fluctuations (dark current \(< 0.001 \text{ e-/pixel/day}\) with CCD cooled at 120 K). Readout noise dominant contribution.

- A readout noise of \(\approx 2 \text{ e-}\) is achieved by slow CCD readout (\(\approx 10 \text{ min} / 16 \text{ Mpix image}\)).

3.6 eV to produce 1 e-hole pair

- Very long exposures (8 hours!) to minimize the n. of noise pixels above the energy threshold

### SNOLAB data

- Image
- Blank
- Gaussian fit

\[\text{mean} = -0.003 \pm 0.001\]
\[\sigma = 1.827 \pm 0.001\]
4) Unique spatial resolution: 3D position reconstruction and particle ID

\[ \sigma_{xy} \approx Z : \text{fiducial volume definition and surface event rejection} \]

- "Worms": straggling electrons
- Straight tracks: minimum ionizing particles
- MeV charge blobs: alphas
- Diffusion-limited clusters: low-energy X-rays, nuclear recoils
- CCD spatial resolution provides a unique handle to the understanding of the background
DAMIC results

Measurement of radioactive contamination in the high-resistivity silicon CCDs of the DAMIC experiment  
*JINST 10* (2015) *P08014*

Search for low-mass WIMPs in a 0.6 kg day exposure of the DAMIC experiment at SNOLAB  

First direct detection constraints on eV-scale hidden-photon dark matter with DAMIC at SNOLAB  

Measurement of the ionization produced by sub-keV silicon nuclear recoils in a CCD dark matter detector  

Antonella: A nuclear-recoil ionization-efficiency measurement in silicon at low energies  
*arXiv:1702.00873*
Radiogenic backgrounds

E = 5.4 MeV
Δt = 17.8 d

E = 6.8 MeV
Δt = 5.5 h

E = 8.8 MeV

three α at the same location!

Powerful method to measure U/Th bkg in the bulk – ppt limits

Example of α + β

Not seen

2015 JINST 10 P08014
Nuclear recoil calibration

a) Cross-section of setup

Vacuum chamber

\[ \text{CCD} \]

3He counter

20 cm

Lead shielding

Source

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

2.75 cm

BeO cap

BeO cylinder

Activated antimony rod

BeO base

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

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Single-recoil spectrum very similar to signal from 3 GeV WIMP. End-point = \(3.2 \text{ keV}_r\)

Number of nuclear recoils \([10^{10} \text{ eV}_r^{-1}]\)

Data - full BeO

Best-fit with Monte Carlo spectrum

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Calibration down to 60 eV\(_{ee}\).
WIMPs search

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

$\sigma_{xy} \approx$ proportional to depth of interaction in the bulk silicon

limited exposure taken during R&D phase (bkg. $\approx$ 30 dru)

demonstration of DAMIC sensitivity to low-mass Dark Matter

NOTE: current bkg. $\approx$ 5 dru
Hidden photon DM search

hidden photon absorption would produce $m_V/3.6\text{ eV}$ charge carriers in silicon:
HP sensitivity in the charge distribution

NOTE: 1x100 binning

only readout noise in the overscan rows

Absorption of hidden-photon dark matter.

$m_V$
Hidden photon limit

1 week of data of 1 CCD

Lowest leakage current ever achieved in a Si detector $10^{-21}$ A/cm$^2$!
DAMIC now

• Already achieved low radioactive background (5 dru) and low-noise (<10 e-) threshold for a larger detector.

• Stack of 16 Mpix CCDs: DAMIC100 in current SNOLAB vacuum vessel and shielding.

• Installation took place in January, results with ≈ 10 kg day of data expected in 2017/2018.

• Ongoing R&D for thicker, larger-area CCDs for a lower-noise, lower-background kg-size detector.

DAMIC-1K

• A kg-size experiment with 0.1 dru background and ≤ 2e- threshold

• To lead the exploration of WIMPs and dark sector candidates in the low-mass DM parameter space
DAMIC-1K and WIMPs
DAMIC-1K and dark sector
DAMIC-1K and dark sector

DM-e Scattering via heavy Hidden Photon

Complementary to accelerator searches!

(see T. Nelson talk)
DAMIC-1K technical challenges

- A kg-size DAMIC can be built with the existing technology

- Background
  from a few dru to a fraction of dru.
  **external bkg.**: improved design, materials (e.g. electroformed copper), strict procedures (silicon storage underground, radon, surface contamination)
  **internal bkg.**: cosmogenic $^{32}$Si and tritium

DALSA has confirmed the feasibility fabrication of these larger and thicker CCDs

R&D for > 1mm-thick CCDs started at UChicago Pritzker Nanofab
DAMIC-1K background

- Cosmogenic $^{32}$Si rate will be accurately measured by the current detector at SNOLAB.

  $$E_1 = 114.5 \text{ keV}$$

  Decay point $(x_0, y_0)$

  $\Delta t = 35 \text{ days}$

  $$E_2 = 328.0 \text{ keV}$$

  $^{32}$Si - $^{32}$P candidate

  $\approx 1 \text{ dru (dominant bkg. in SuperCDMS); rejected in DAMIC-1K by spatial correlations}$

- Tritium expected to be the dominant bkg. for DAMIC-1K.

A measurement of its rate may be within reach of the current DAMIC detector at SNOLAB (so far only estimates are used for forecasts).

$^{3}_H \beta$ spectrum from front
DAMIC-1K sub-e\(^{-}\) noise

- Skipper readout

**Non-destructive** measurement of the charge!

Measure the charge fast (kill 1/f noise) and N times (noise \(\approx 1/\sqrt{N}\))
Skipper unprecedented sensitivity demonstrated on a small size DAMIC CCD (Fermilab, J. Tiffenberg)
Conclusions

• In the last three years DAMIC has established the CCD technology as a competitive technique for the search of low-mass Dark Matter particles. Unique amongst dark matter experiments for its spatial resolution and single-electron resolution and extremely low dark current.
• DAMIC100 currently taking data at SNOLAB. Main results expected: precise measurements of backgrounds ($^{32}$Si and tritium) and DM limits with $O(10 \text{ kg day})$ exposure.
• Preparing for DAMIC-1K, a kg-size CCD detector with low background and sub-electron noise, which will explore a new large parameter space, scrutinizing the WIMPs paradigm, as well as dark sector candidates with sensitivity comparable to accelerator searches.
• The DAMIC-1K detector is an incremental step of proven technologies (larger size CCD, sub-electron noise). It will work as specified.