DAMIC

U.S. Cosmic Visions: New Ideas in Dark Matter

University of Maryland March, 23rd 2017

DAMIC and a kg-size CCD experiment

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for the DAMIC Collaboration

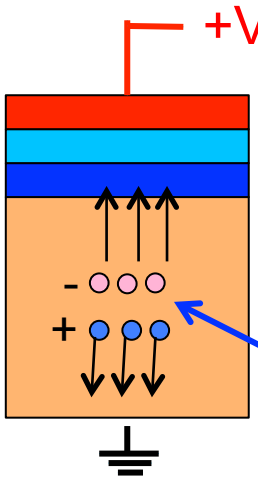
THE UNIVERSITY OF CHICAGO
PHYSICAL SCIENCES

KICP

(Photo image: particle tracks in a DAMIC CCD)

CCD principle

Metal-Oxide-Semiconductor capacitor

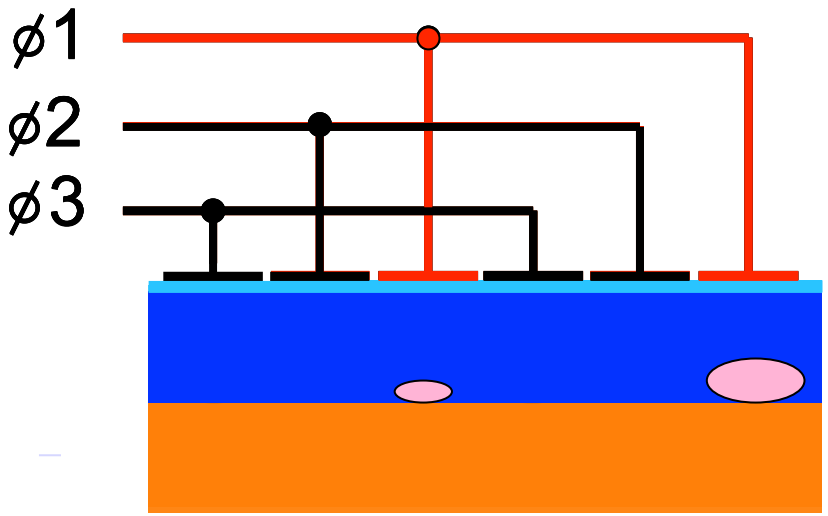


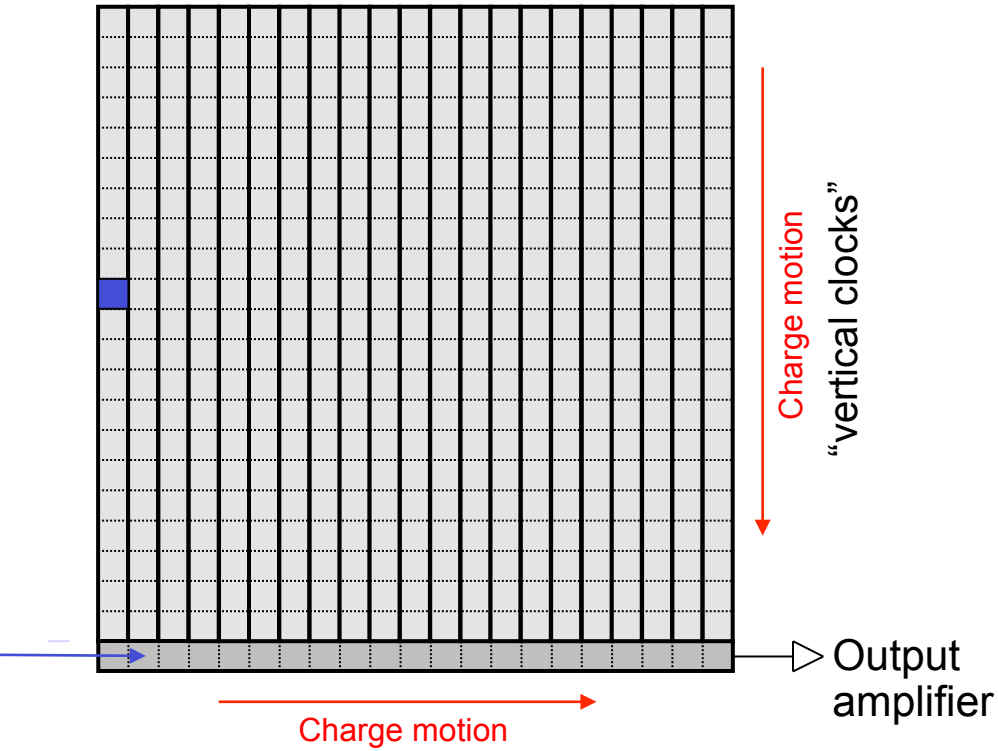
Metal gate
Si oxide (insulator)
n-type Si (buried channel)

p-type Si

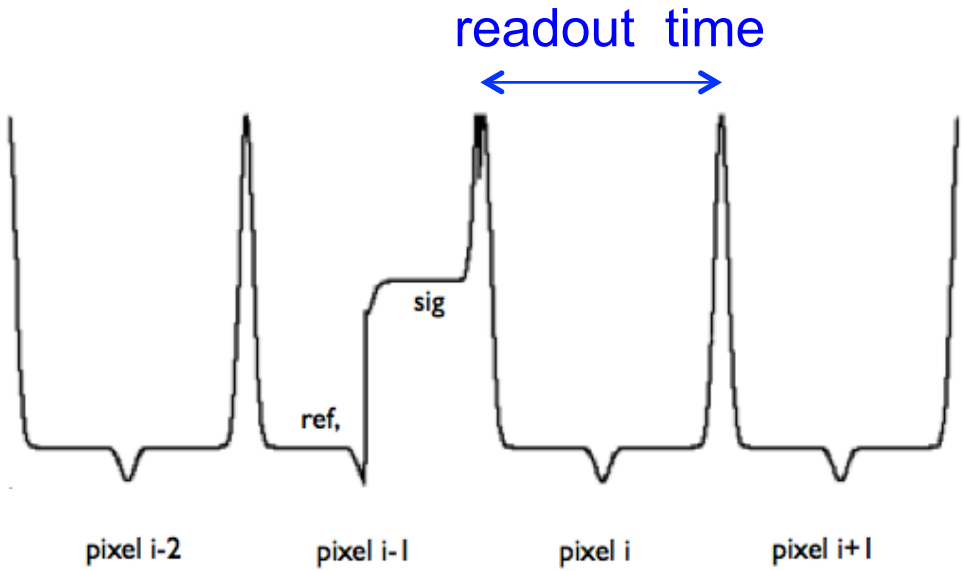
electron-hole pairs generated by a photon or ionizing particle

Moving charge from pixel to pixel

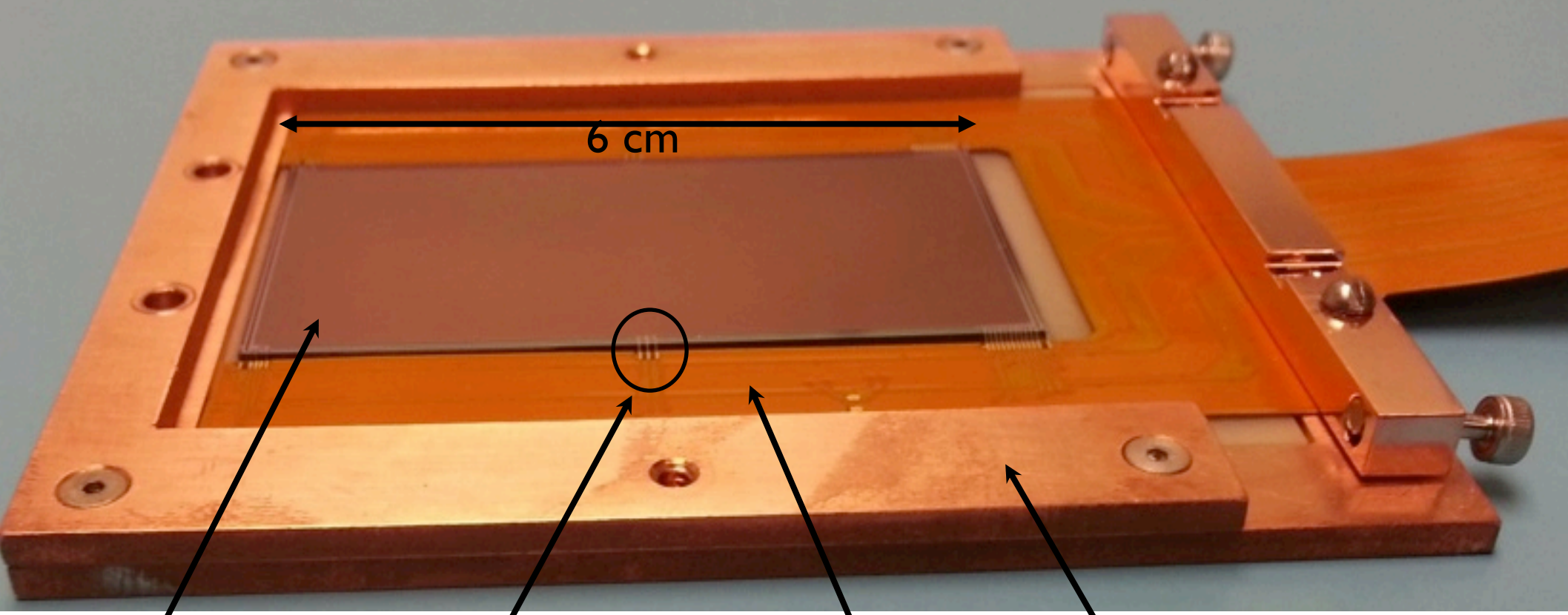




"horizontal clocks" (faster)



Correlated Double Sampling



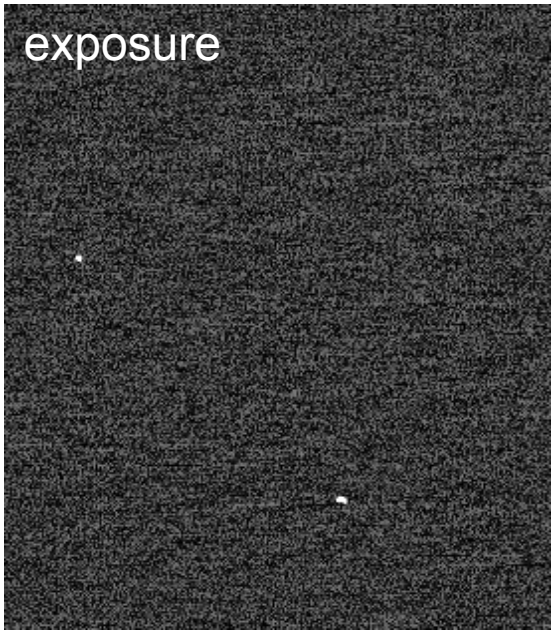
1) Sizable mass (high resistivity, thick CCDs designed by LBNL)

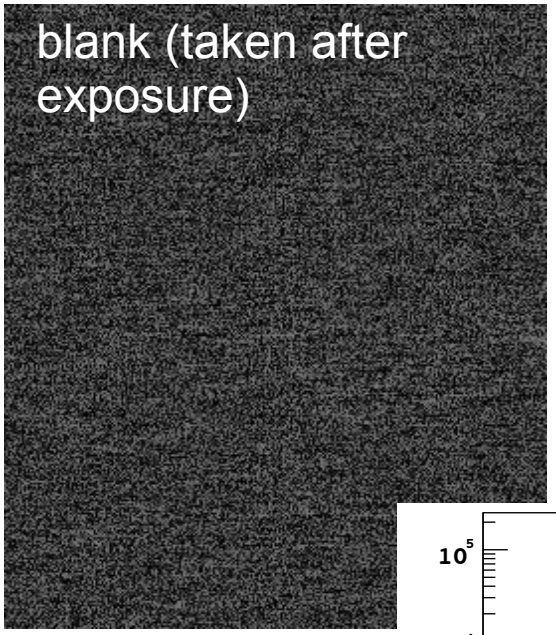
A DAMIC CCD has an active area of 6 cm x 6 cm, 16 Mpixel (each 15 μm x 15 μm) and a record thickness of 675 μm for a total of 5.9 g mass

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 e/pixel/day with CCD cooled at 120 K). Readout noise dominant contribution.

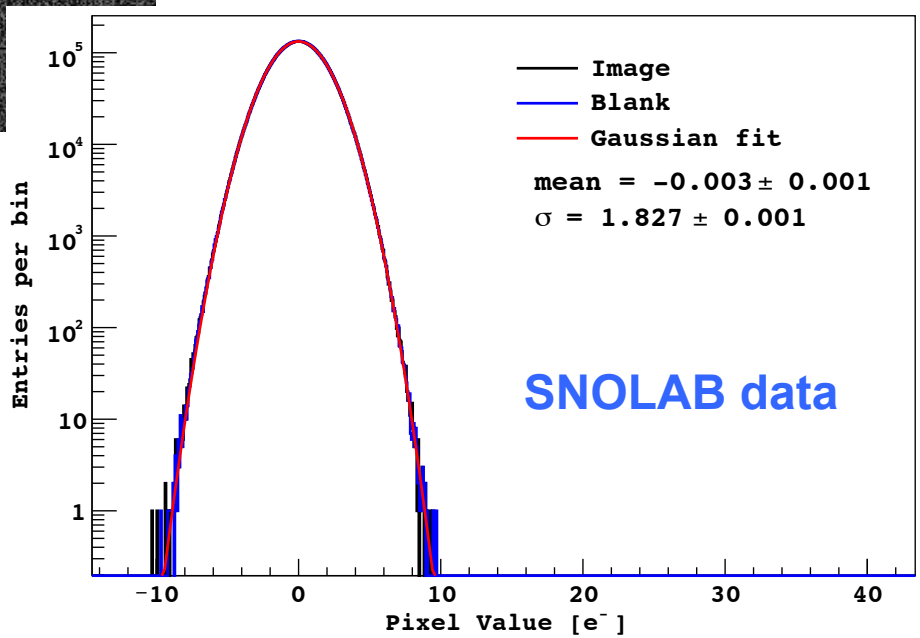




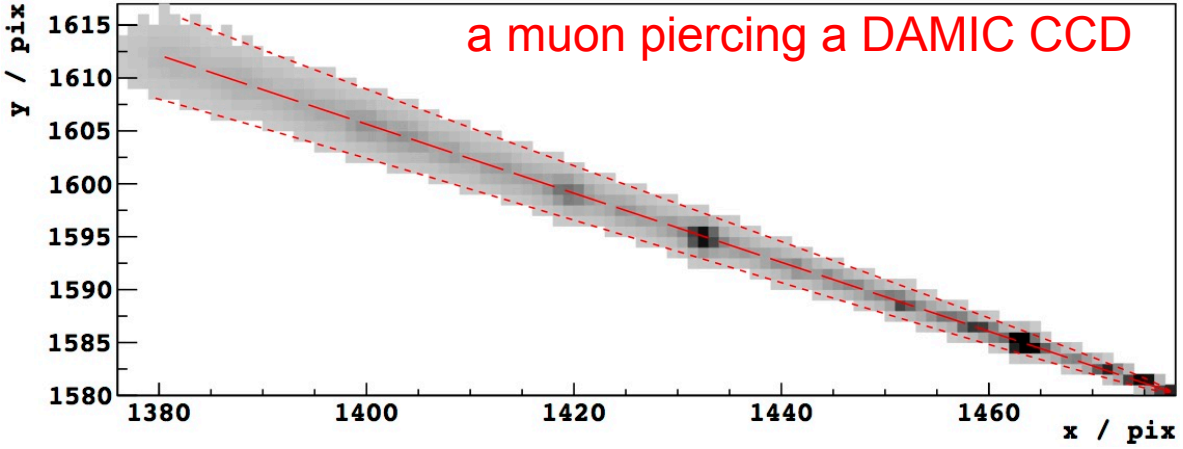
- A readout noise of ≈ 2 e- is achieved by slow CCD readout (≈ 10 min / 16 Mpix image).

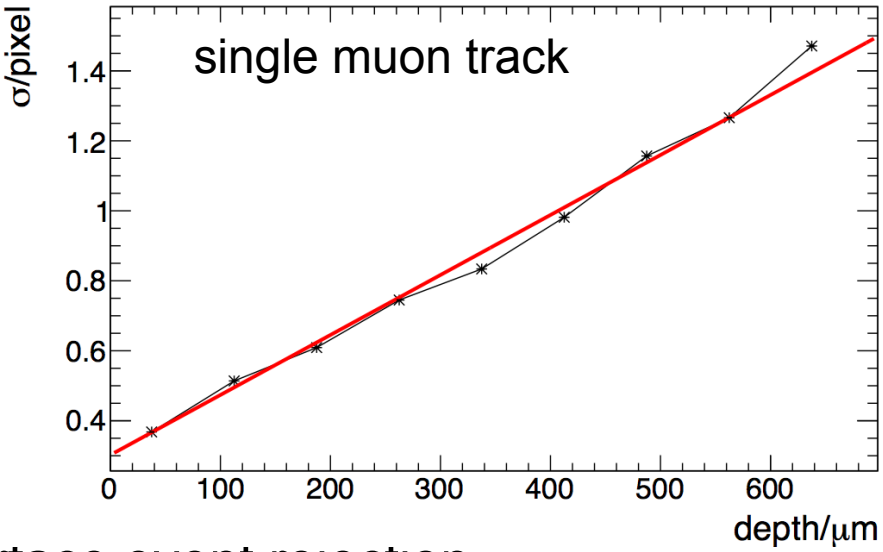
  3.6 eV to produce 1 e-hole pair

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

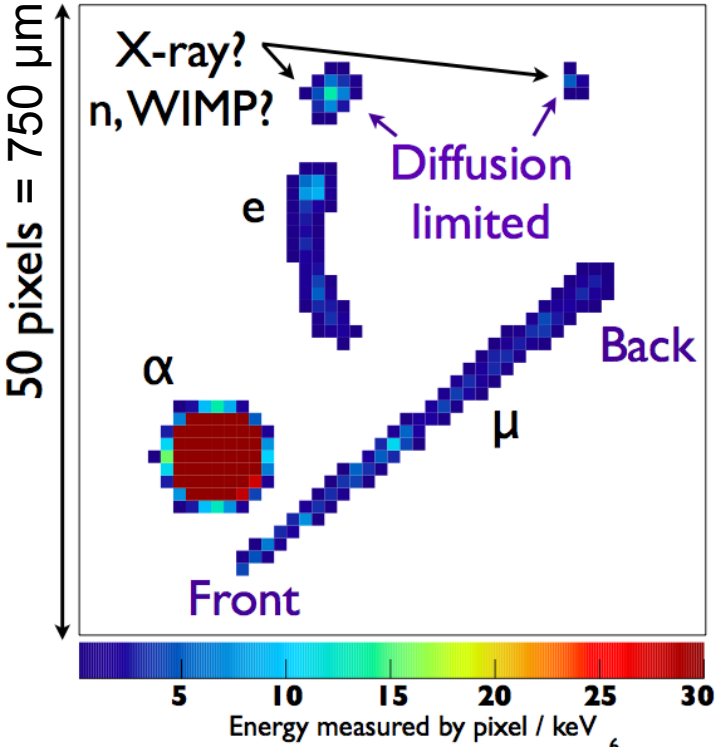


4) Unique spatial resolution: 3D position reconstruction and particle ID





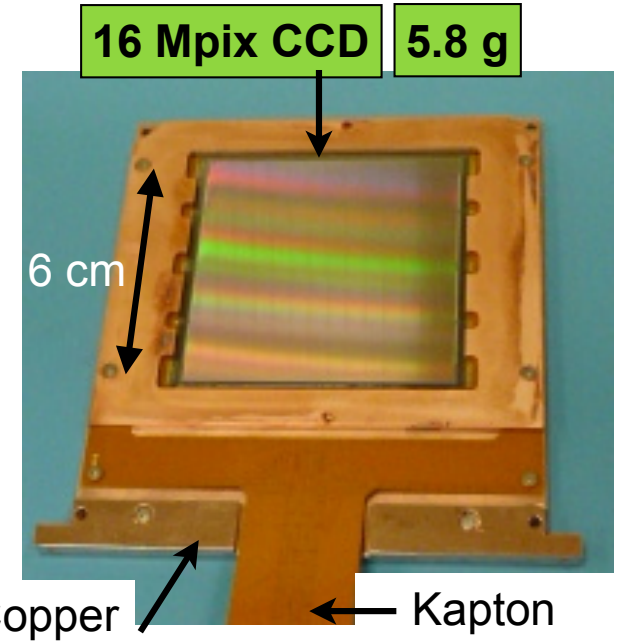
$\sigma_{xy} \approx Z$: fiducial volume definition and surface event rejection

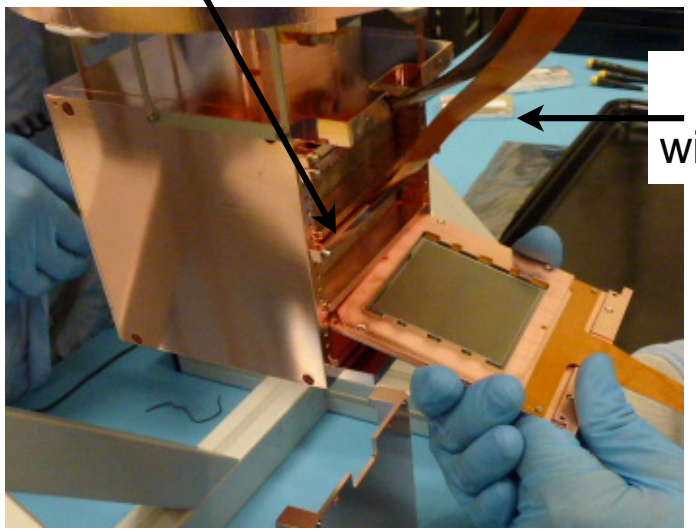


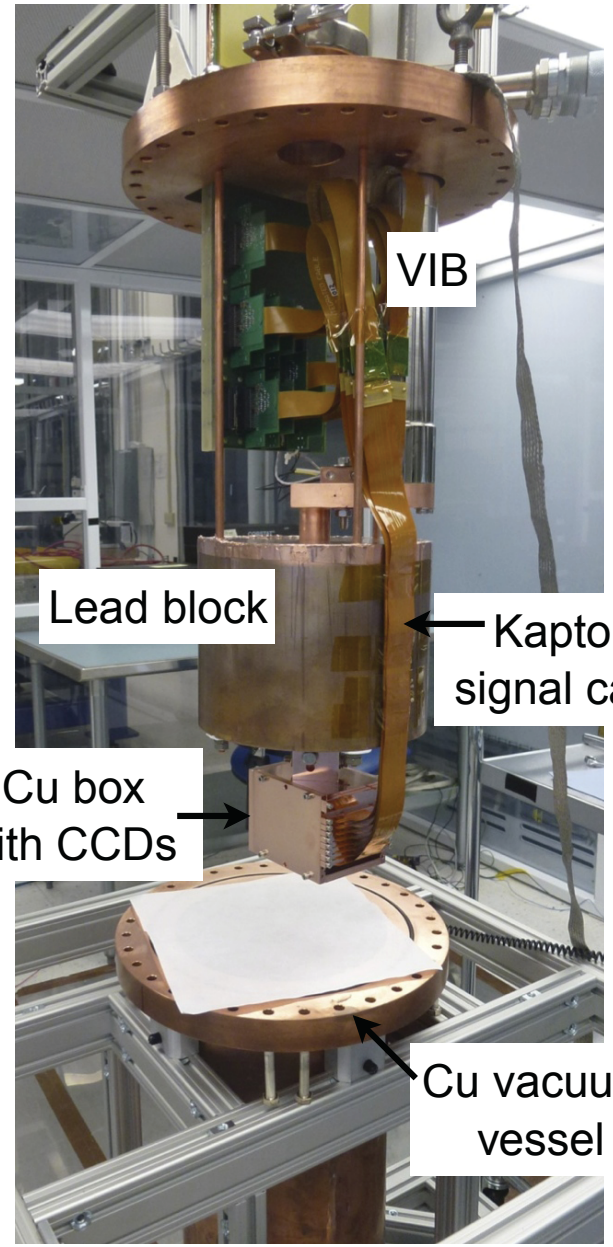
- "Worms": straggling electrons
- Straight tracks: minimum ionizing particles
- MeV charge blobs: alphas
- Diffusion-limited clusters: low-energy X-rays, nuclear recoils

- CCD spatial resolution provides a unique handle to the understanding of the background

DAMIC @ SNOLAB







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 *Phys. Rev. D 94, 082006 (2016)*

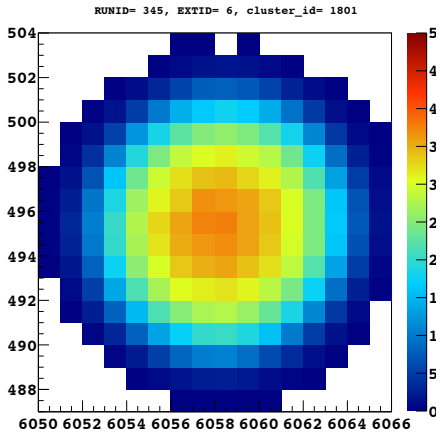
First direct detection constraints on eV-scale hidden-photon dark matter with DAMIC at SNOLAB *arXiv:1611.03066 accepted by Phys. Rev. Lett.*

Measurement of the ionization produced by sub-keV silicon nuclear recoils in a CCD dark matter detector *Phys. Rev. D 94, 082007 (2016)*

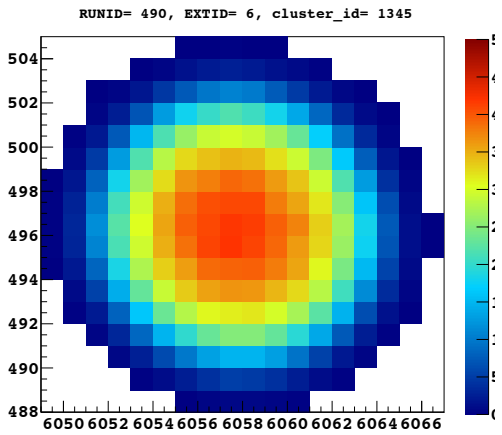
Antonella: A nuclear-recoil ionization-efficiency measurement in silicon at low energies *arXiv:1702.00873*

Radiogenic backgrounds

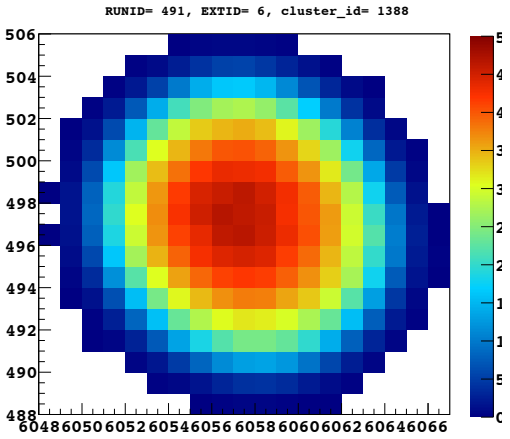
E = 5.4 MeV



E = 6.8 MeV

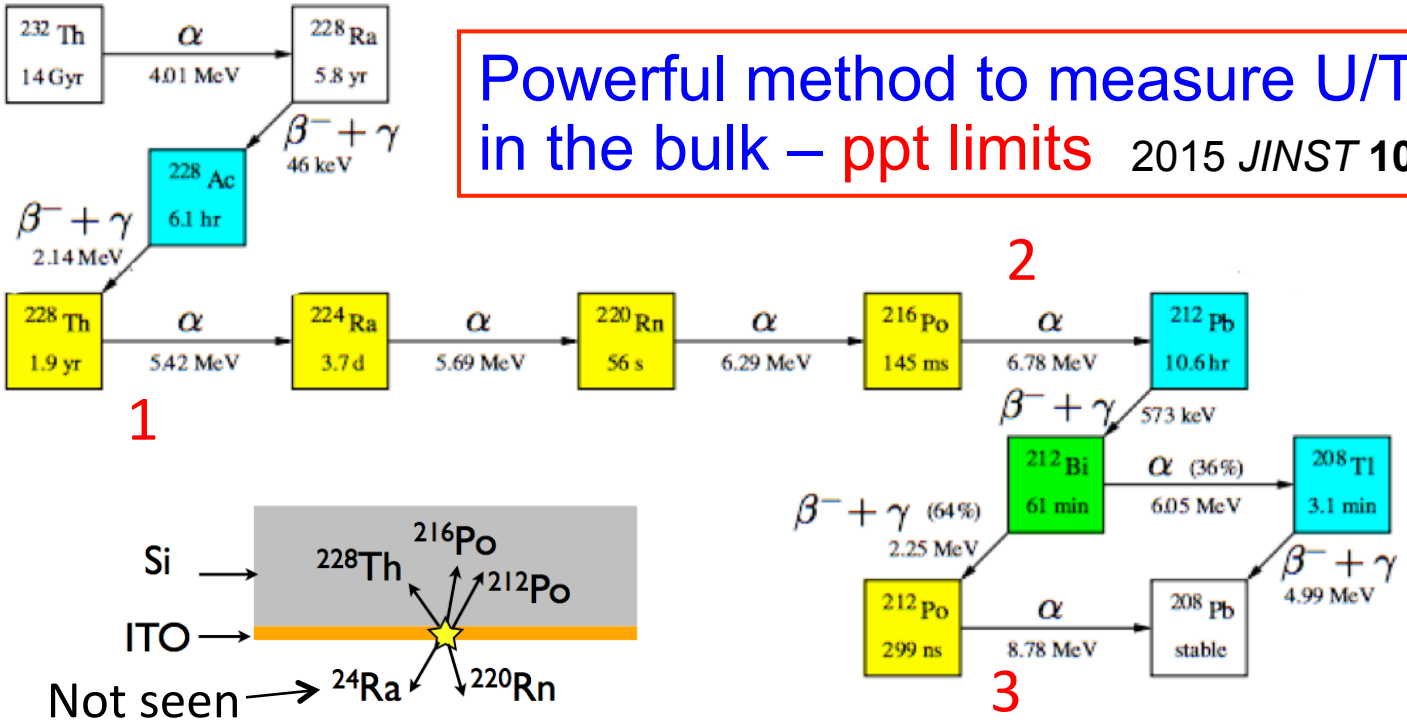


E = 8.8 MeV



1 Δt = 17.8 d 2 Δt = 5.5 h 3

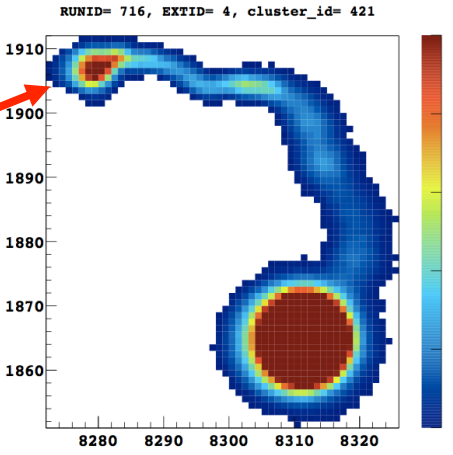
three α at the same location!



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

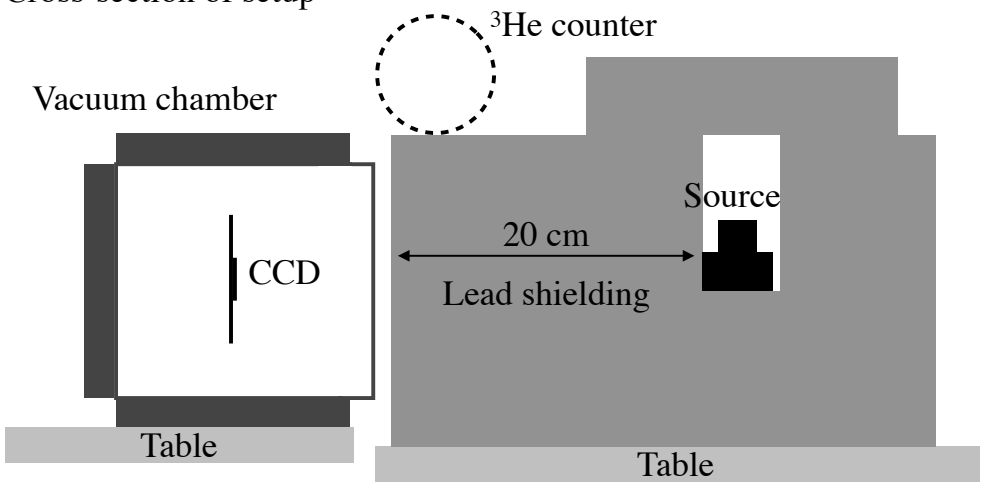
Example of α + β

Bragg peak

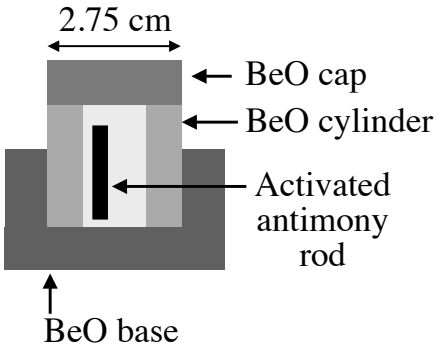


Nuclear recoil calibration

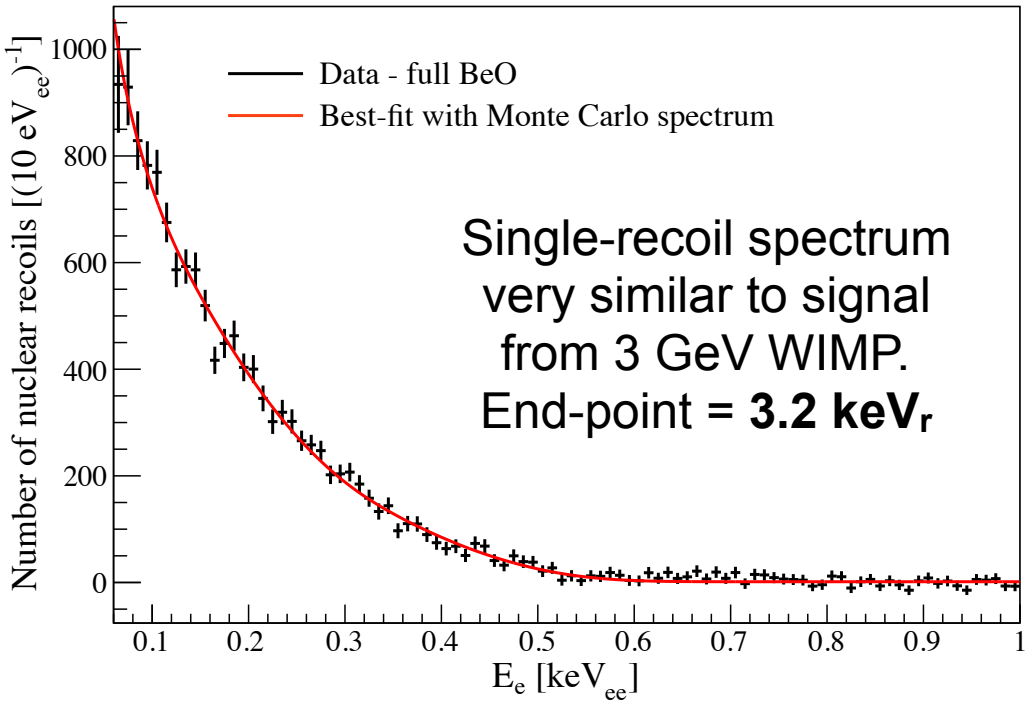
a) Cross-section of setup

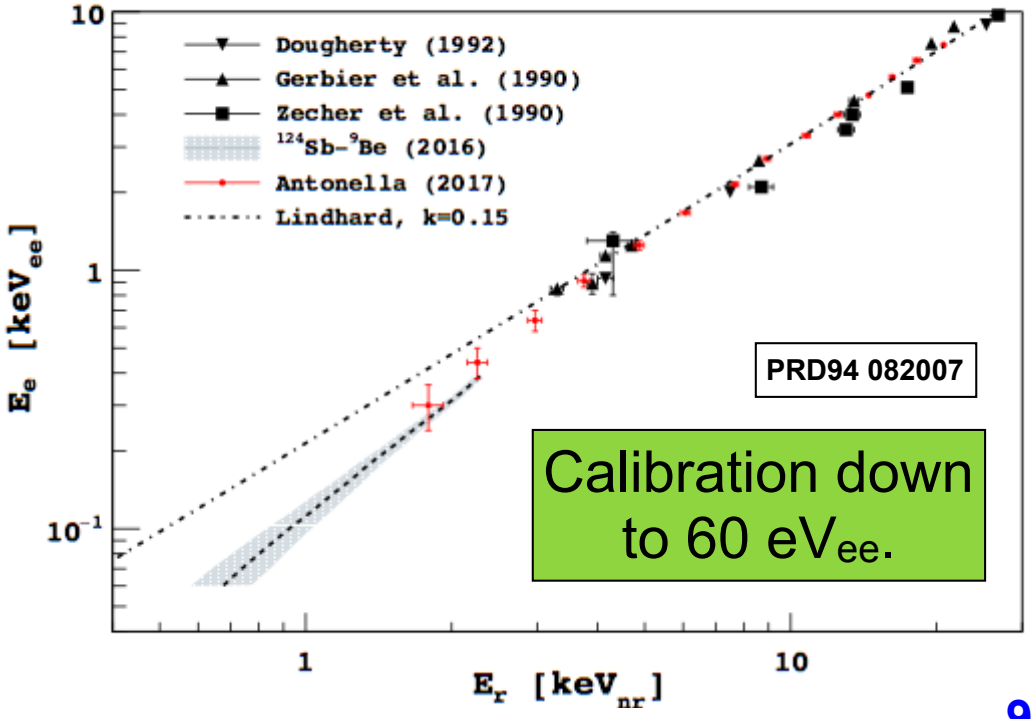


b) ^{124}Sb-^{9}Be source detail

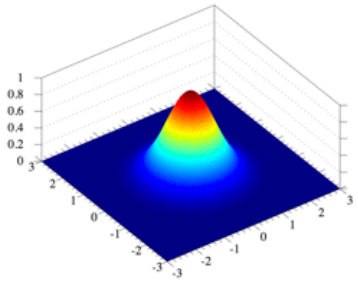


24 keV neutrons from ^{9}Be(γ,n) reaction



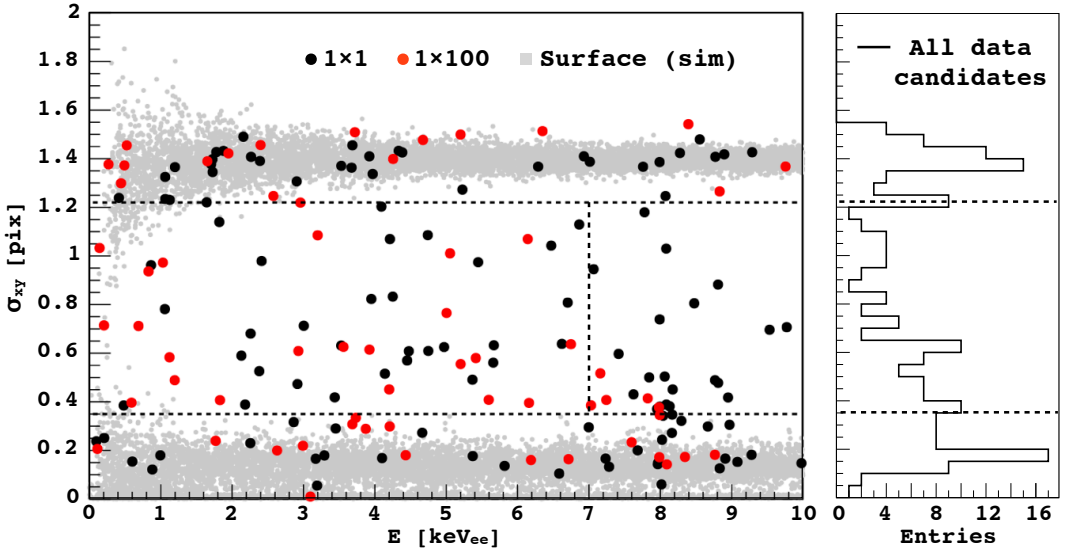


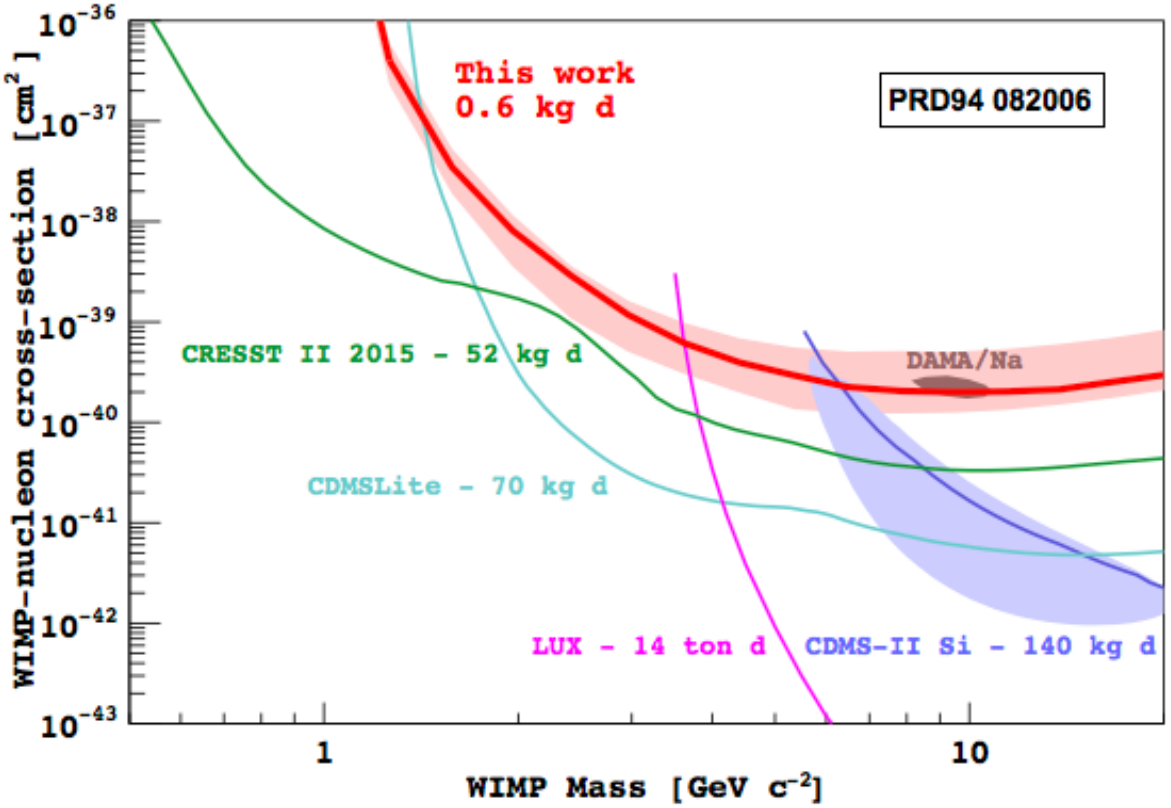
WIMPs search



Measure **E** and σ_{xy} for every cluster event.

σ_{xy} ≈ proportional to depth of interaction in the bulk silicon





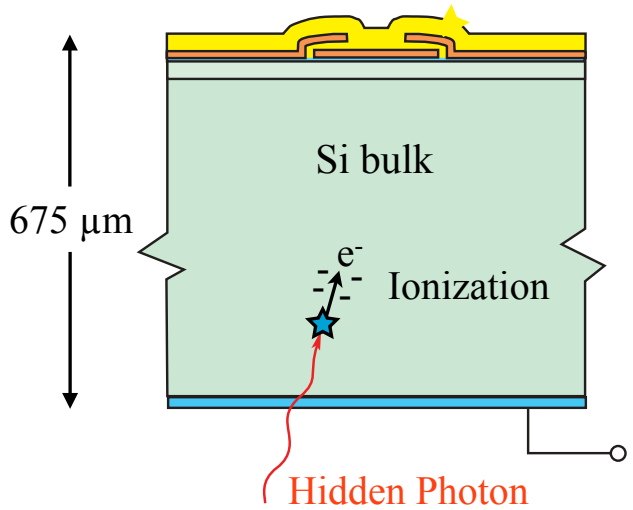
limited exposure taken during R&D phase (bkg. ≈ 30 dru)

demonstration of DAMIC sensitivity to low-mass Dark Matter

NOTE: current bkg. ≈ 5 dru

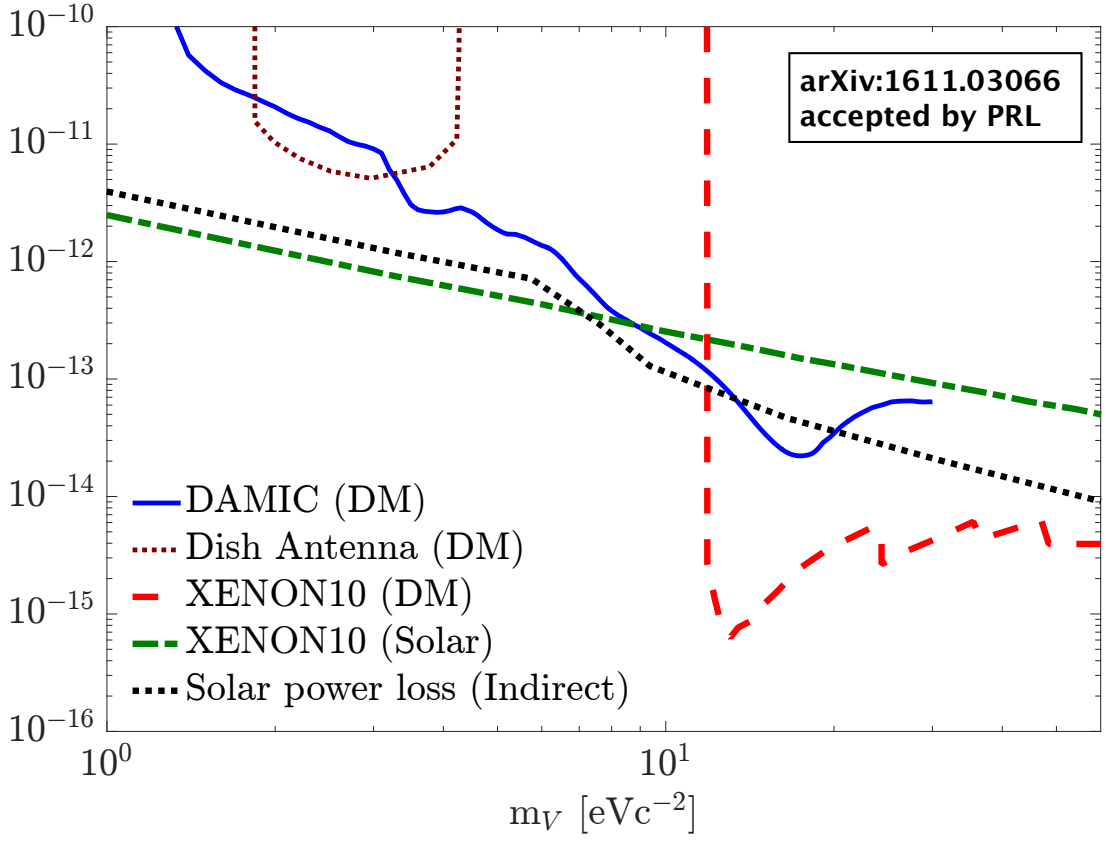
Hidden photon search

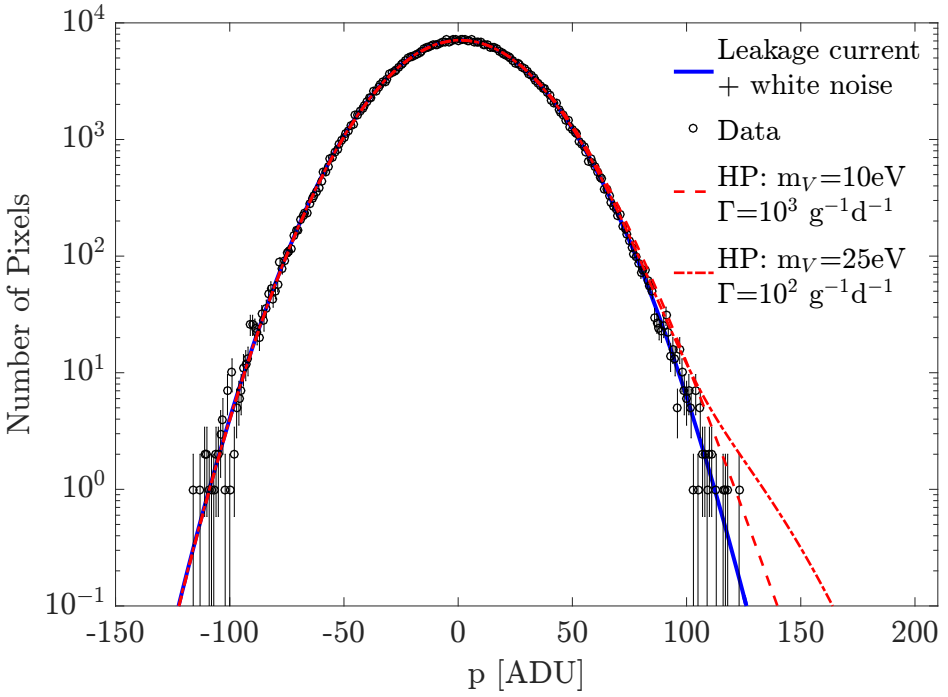
Absorption of hidden-photon dark matter.



~1 week of data with 1 CCD.

Leakage current **4 e⁻ mm⁻² d⁻¹**.





Pixel distribution consistent with white noise + uniform leakage current.

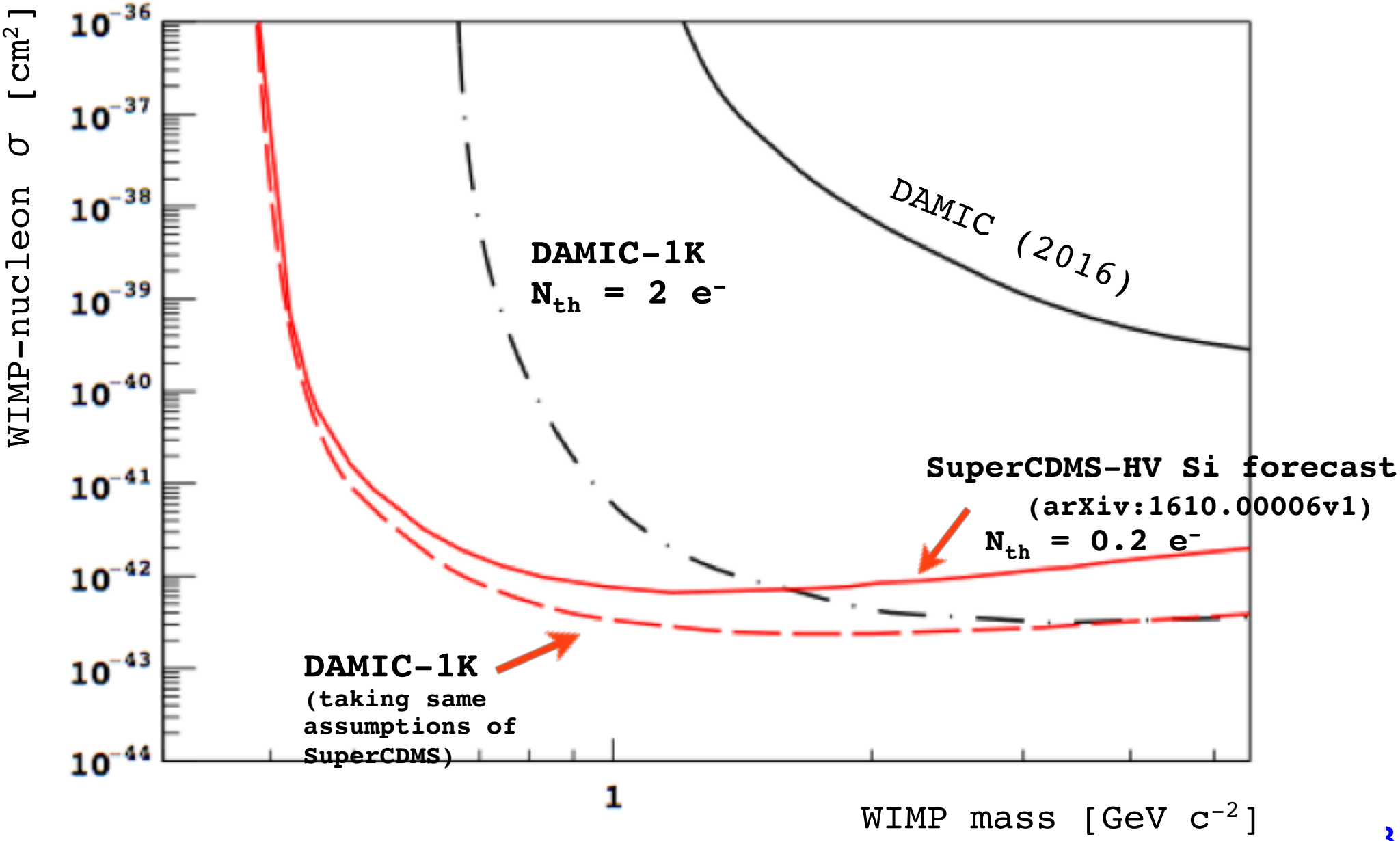
DAMIC now

- Already achieved radioactive background (**5 dru**) and low-noise (**<2 e-**) performance 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.
- Ongoing R&D for thicker, larger-area CCDs for a lower-noise, lower-background kg-size detector.

DAMIC-1K

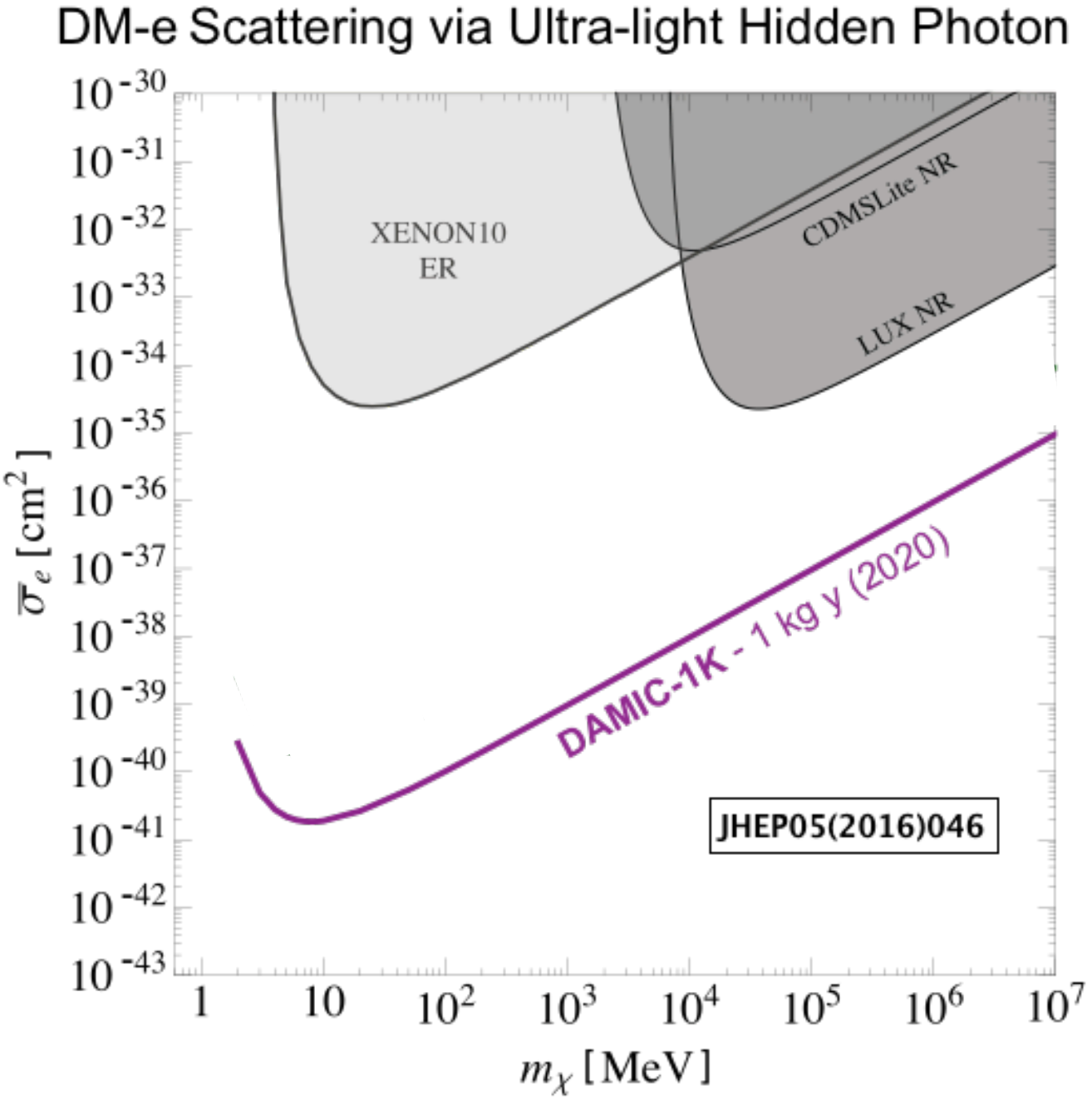
- A kg-size experiment with **0.1 dru** background and **≤ 2e-** threshold
- To lead the exploration of WIMPs and dark sector candidates in the low-mass DM parameter space

DAMIC-1K and WIMPs

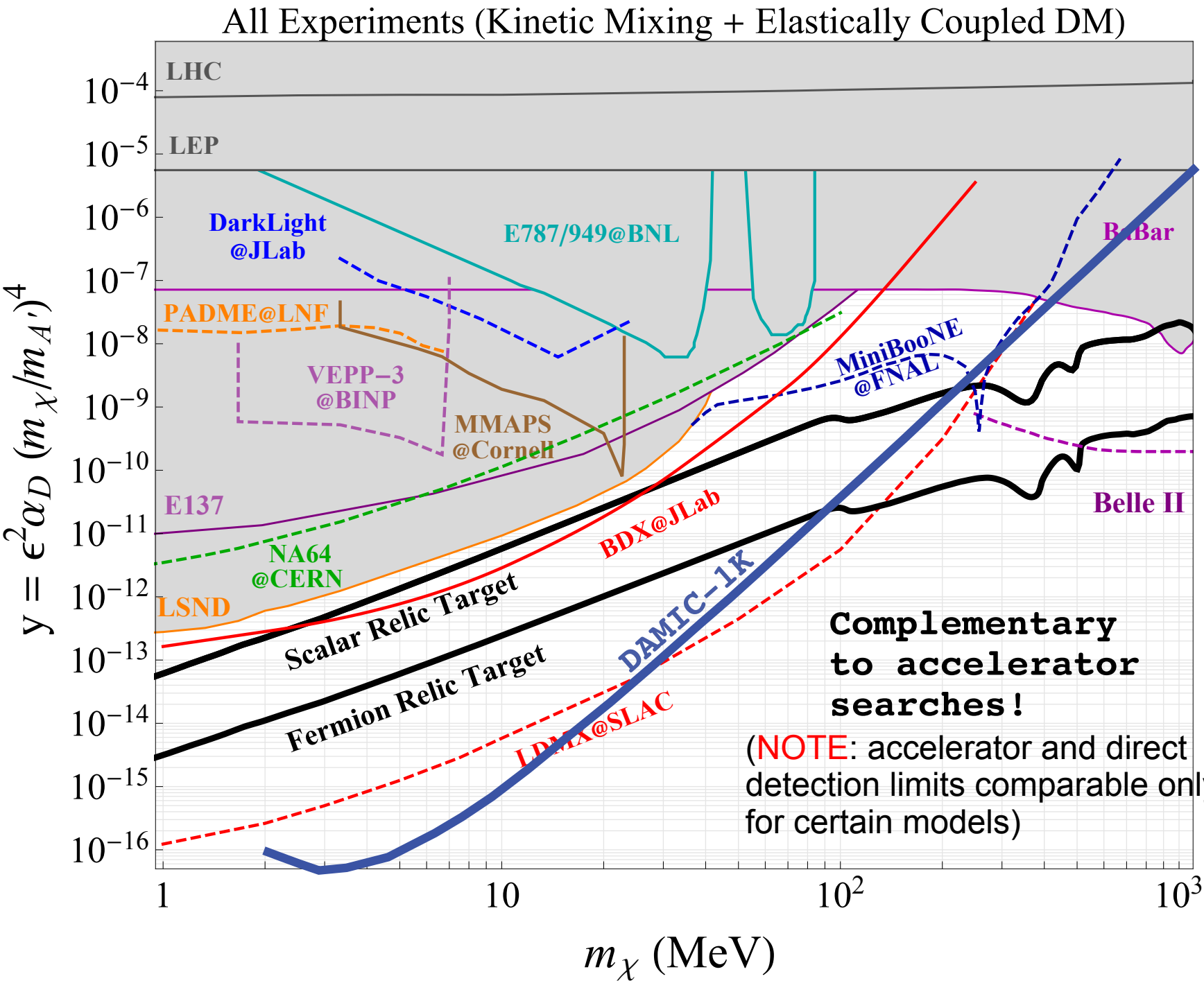


DAMIC-1K not limited by ^{32}Si bkg.

DAMIC-1K and dark sector

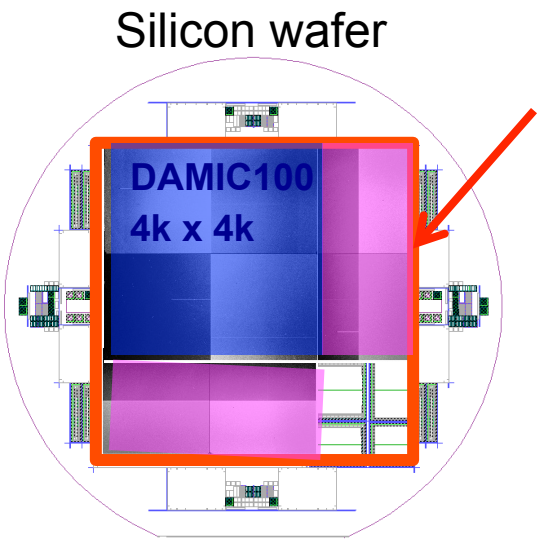


DAMIC-1K and dark sector



DAMIC-1K technical challenges

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



6k x 6k pixels, 1 mm thick

≈ 20 g / CCD

≈ 50 CCDs / 1 Kg

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

- Background

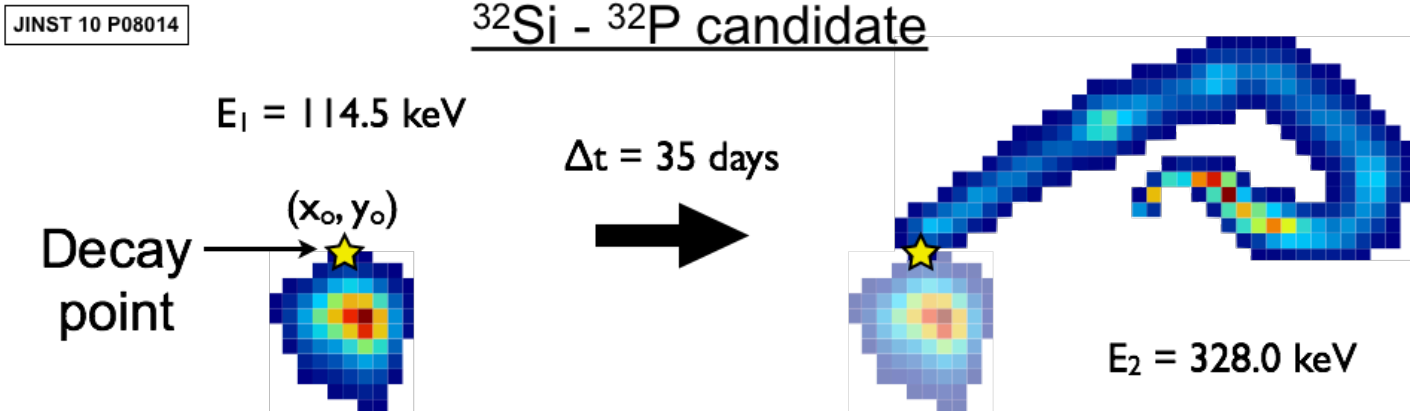
from a few dru to a fraction of dru.

external bkg.: improved design, materials (e.g. electroformed copper), strict procedures (silicon storage underground, radon, surface contamination)

internal bkg.: cosmogenic ^{32}Si and tritium

DAMIC-1K background

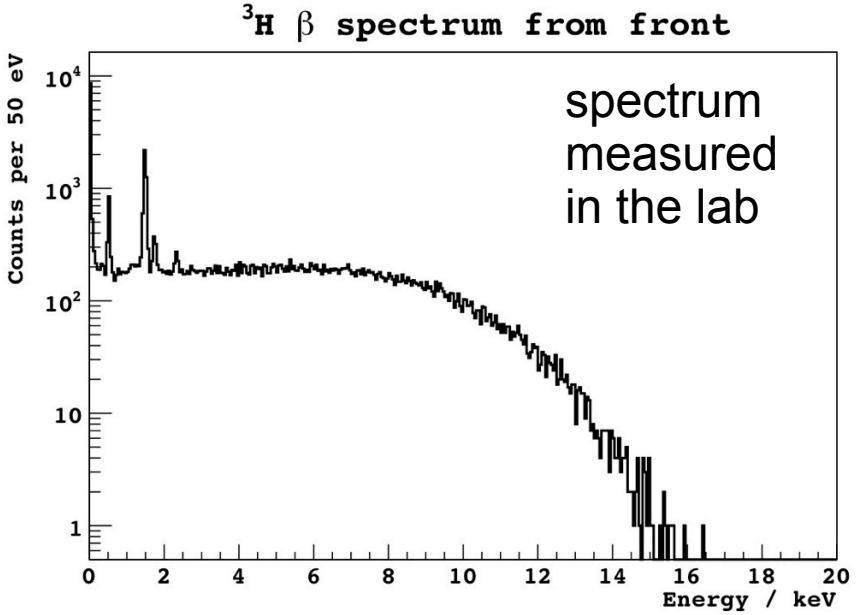
- Cosmogenic ^{32}Si rate will be accurately measured by the current detector at SNOLAB



≈ 1 dru (dominant bkg. in SuperCDMS); rejected in DAMIC-1K by spatial correlations

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

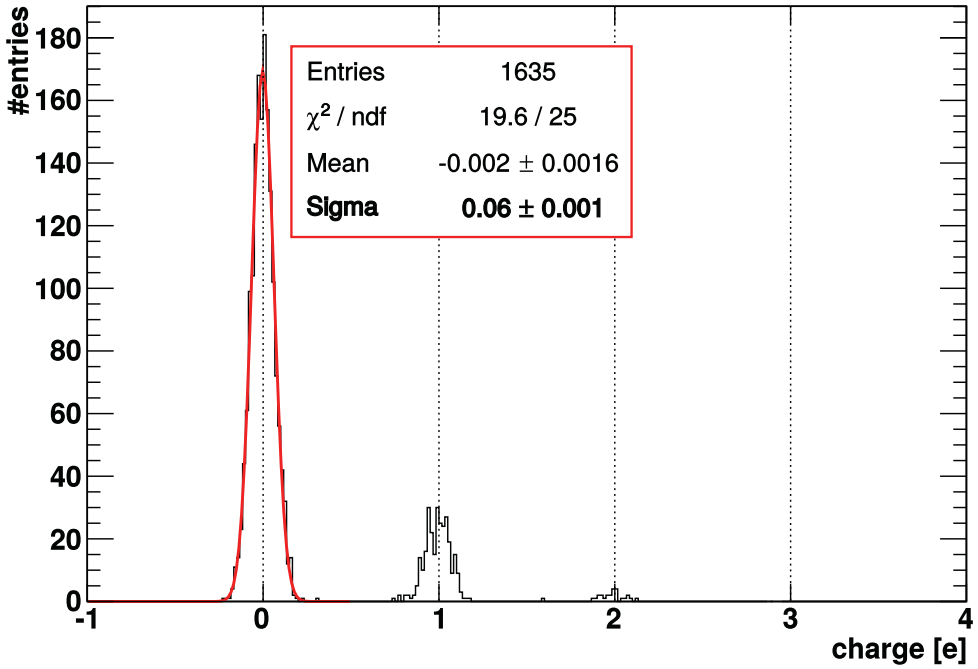
A measurement of its rate may be within reach of the current DAMIC detector at SNOLAB (so far only estimates are used for forecasts)



DAMIC-1K sub-e^- noise

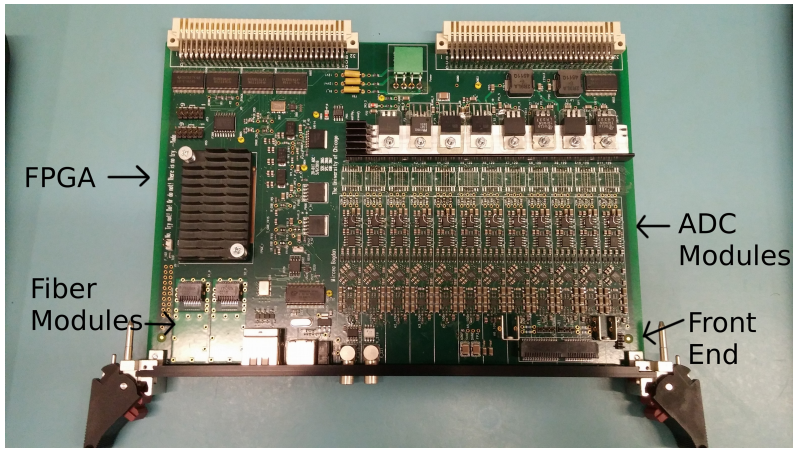
- Skipper readout

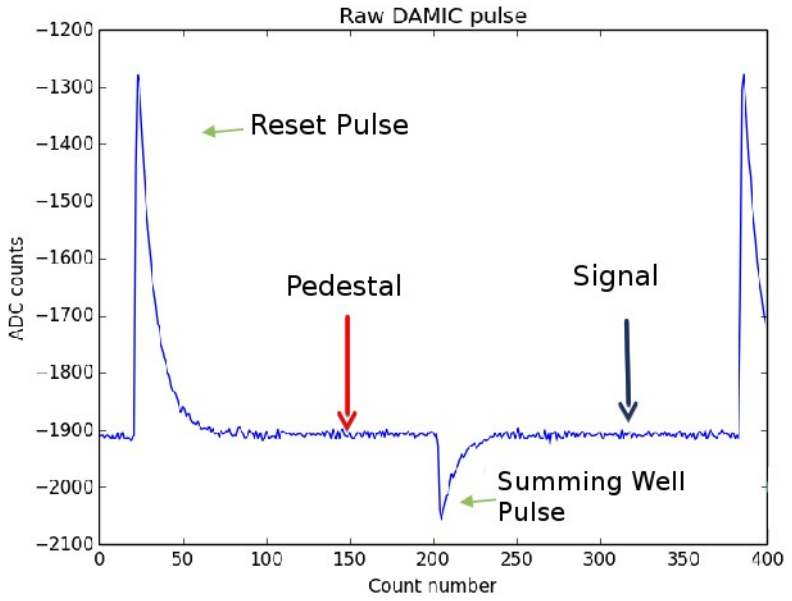
Already achieved on a small size CCD (LBNL design; LDRD at Fermilab)
See J. Tiffenberg SENSEI talk



- Digital filtered CDS

does not require a new CCD design, could already significantly improve sensitivity of DAMIC100





The DAMIC-1K experiment

- DAMIC Collaboration

CAB, Fermilab, LPNHE, SNOLAB, U Chicago, U Michigan, UNA, UNAM, UFRJ, U Zürich

Several new groups interested in joining DAMIC-1K
(PNNL, Denmark, France, Germany, Spain)

- Timing

2017-2018 R&D for sub-e^- noise/background measurements;
DAMIC100 results; finalize detector design
2018-2019 components validation (test at SNOLAB)
2019-2020 Construction

- Budget

≤ 3 M$ (construction)

Conclusions

- In the last two years DAMIC has established the CCD technology as a competitive technique for the search of low-mass Dark Matter particles
- DAMIC-1K, a kg-size CCD detector with low background and sub-electron noise, will explore a new large parameter space, scrutinizing the WIMPs paradigma, as well as dark sector candidates with sensitivity comparable to accelerator searches (for certain classes of models)
- The DAMIC-1K detector is an incremental step of proven technologies (larger size CCD, sub-electron noise). It will work as specified.
- There are strong synergies between DAMIC-1K and SuperCDMS Si: measurement of the quenching factor down to the ionization threshold; ^{32}Si “depleted” silicon: DAMIC spatial coincidence technique unique tool to measure residual background.