DAMIC

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DAMIC status and prospects for a kg mass experiment

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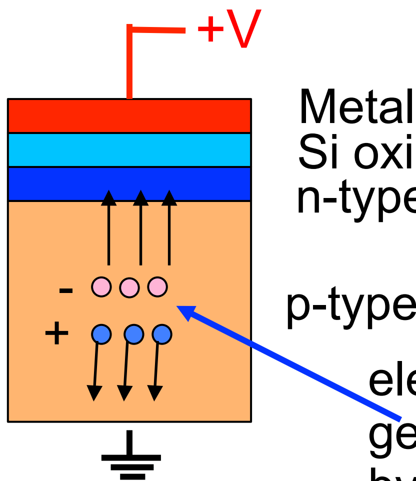
(Photo image: particle tracks in a DAMIC CCD)

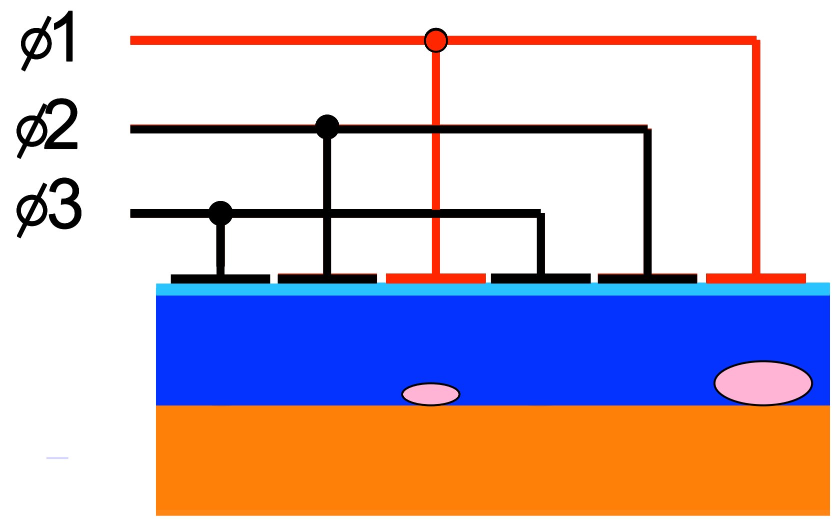
CCD principle

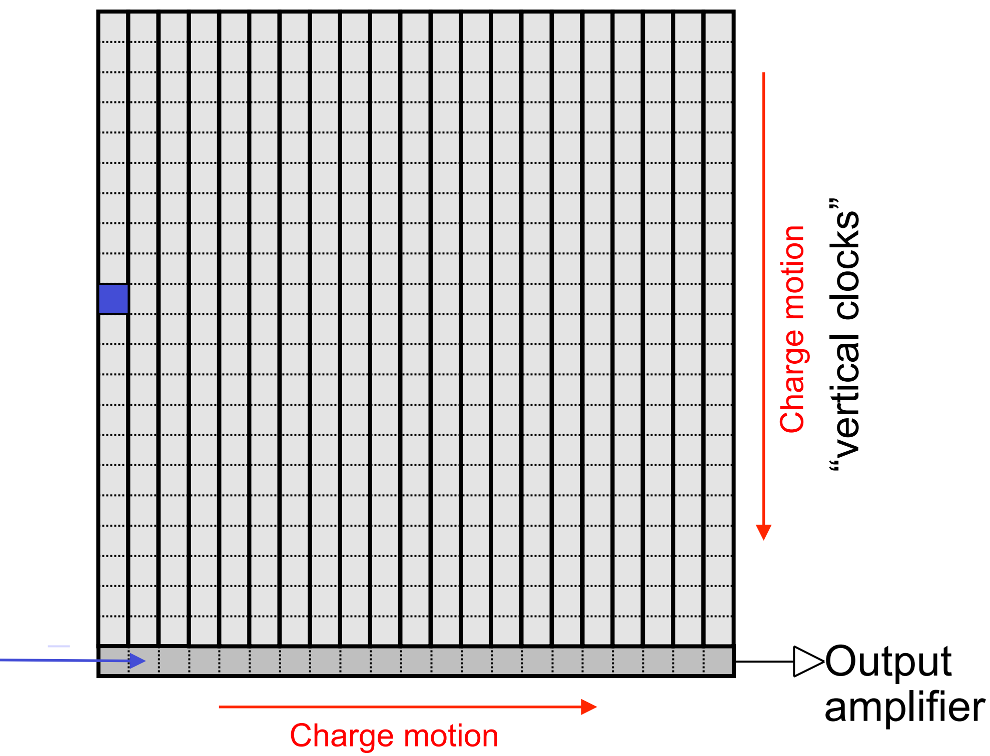
Metal-Oxide-Semiconductor capacitor



electron-hole pairs generated by a photon or ionizing particle

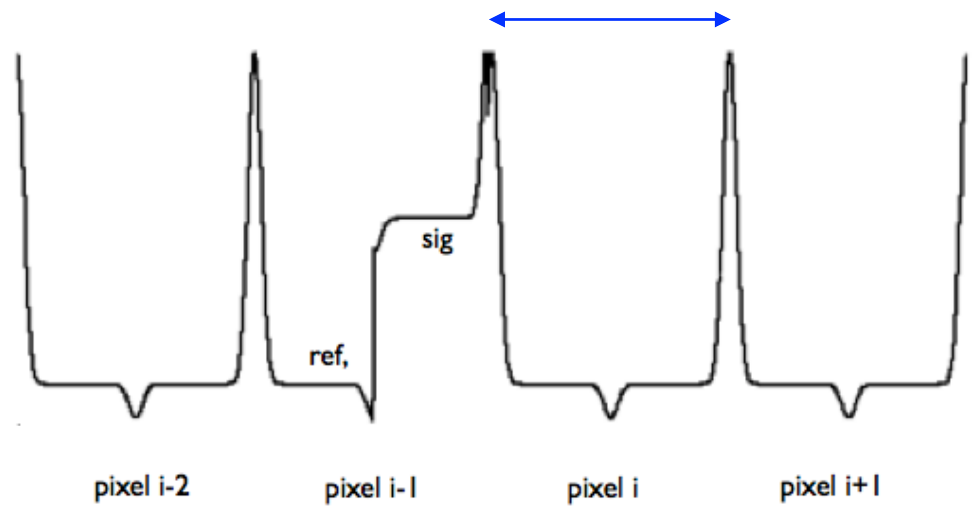
Moving charge from pixel to pixel





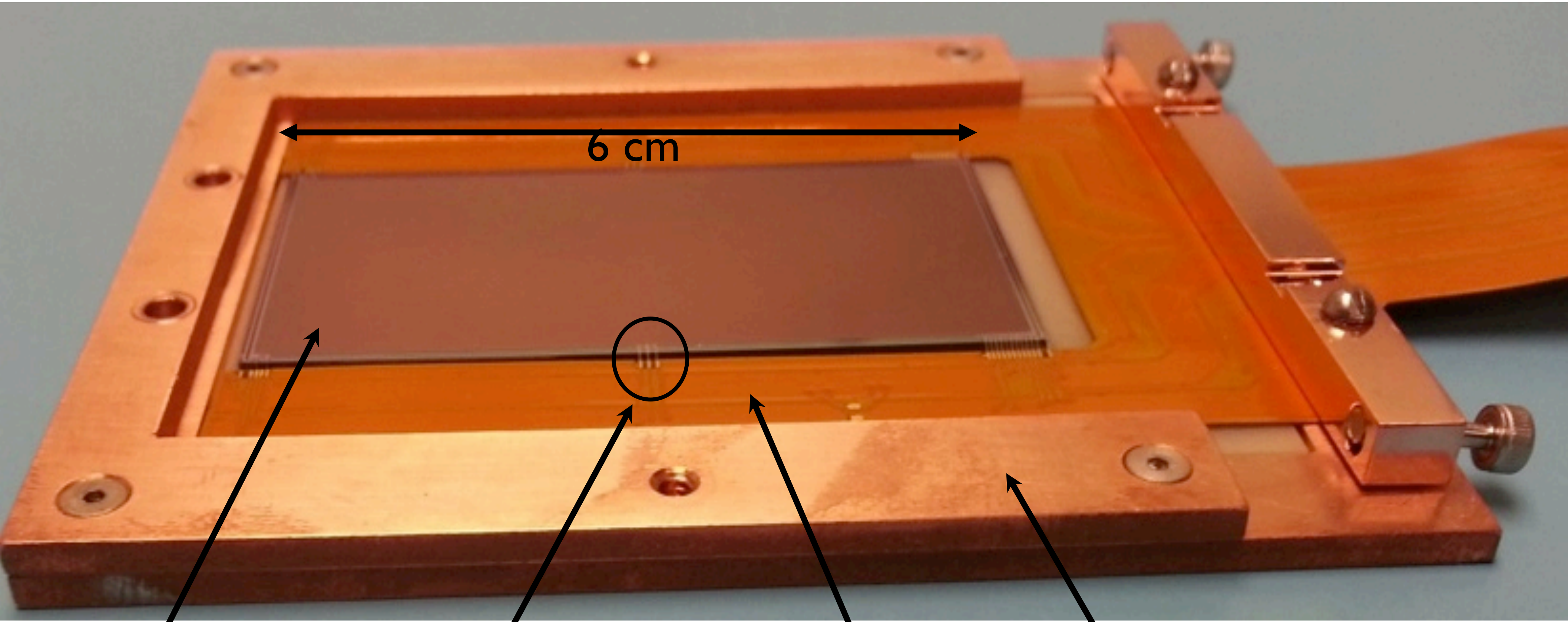
“horizontal clocks” (faster)

readout time



Correlated Double Sampling

DArk Matter In CCDs



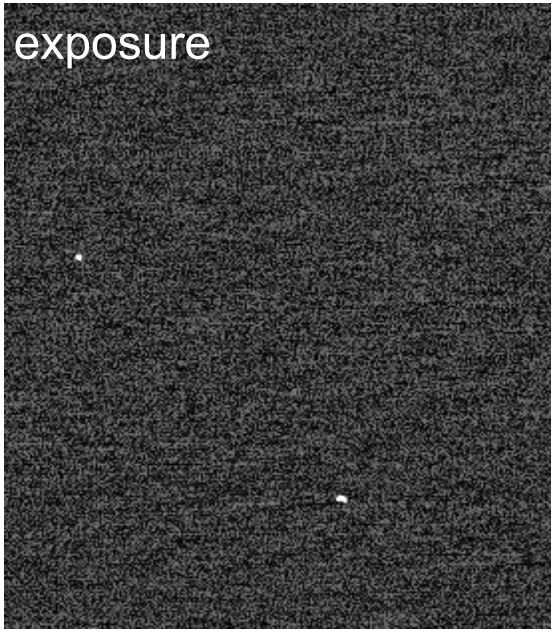
1) Sizable mass (high resistivity, thick CCDs designed by LBNL)

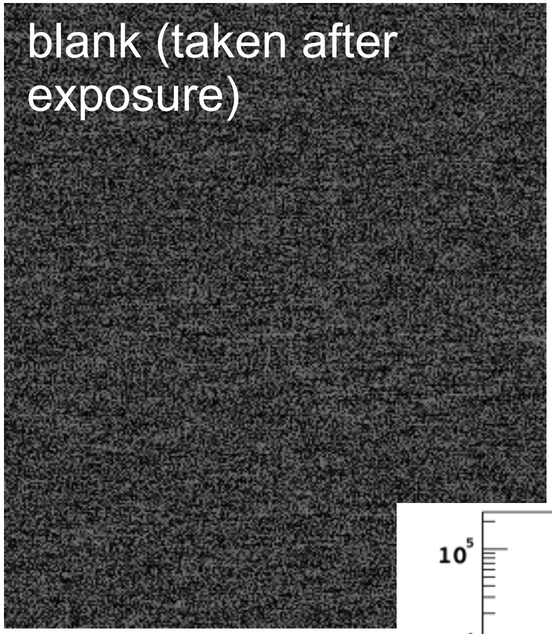
A DAMIC CCD has an active area of 6 cm x 6 cm, 16 Mpixel (each 15 μm x 15 μm) and a record thickness of 675 μm for a total of 5.9 g mass

DAMIC100 currently taking data at the SNOLAB underground laboratory

2) Unprecedented low energy threshold

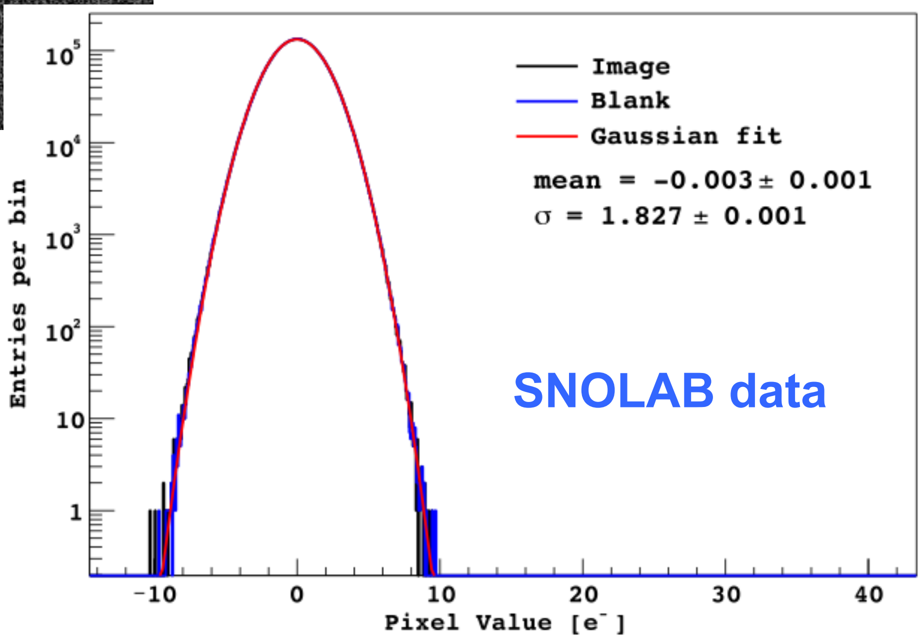
- Negligible noise contribution from dark current fluctuations (dark current < 0.001 e-/pixel/day with CCD cooled at 120 K). Readout noise dominant contribution.





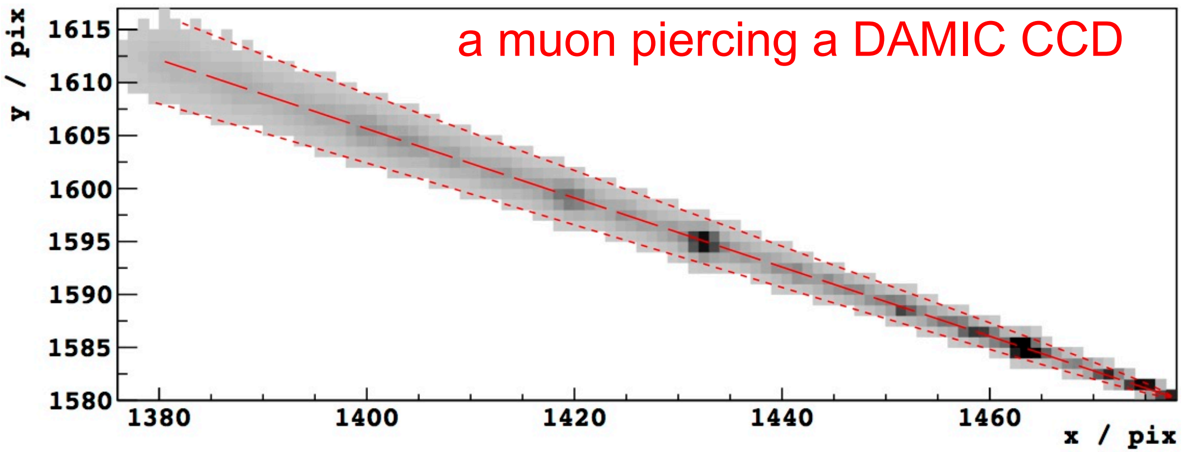
- A readout noise of ≈ 2 e- is achieved by slow CCD readout (≈ 10 min / 16 Mpix image).

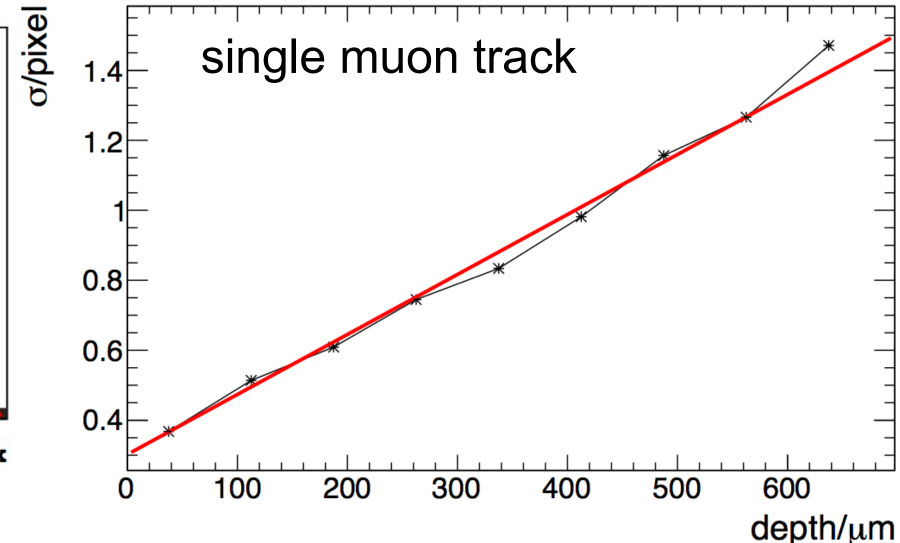
3.6 eV to produce 1 e-hole pair



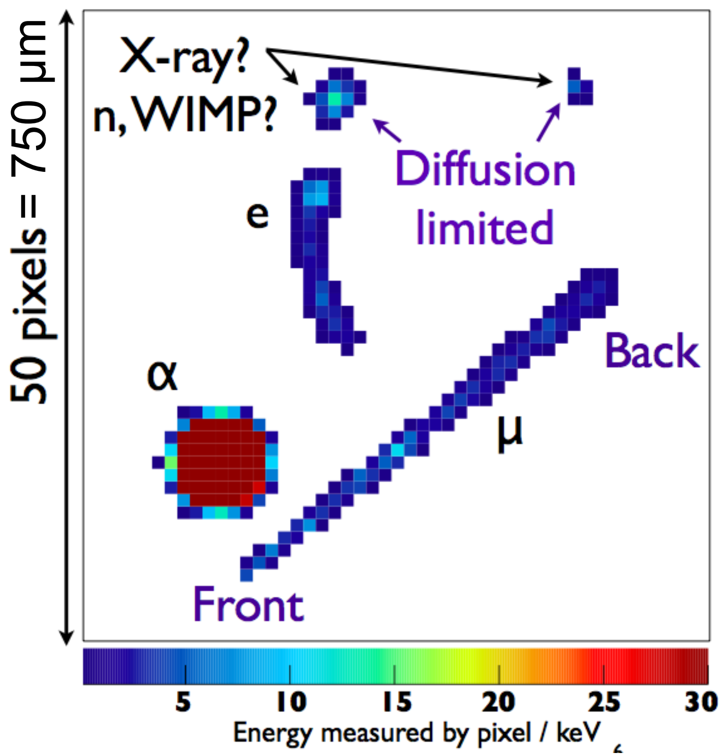
- Very long exposures (8 hours!) to minimize the n. of noise pixels above the energy threshold

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





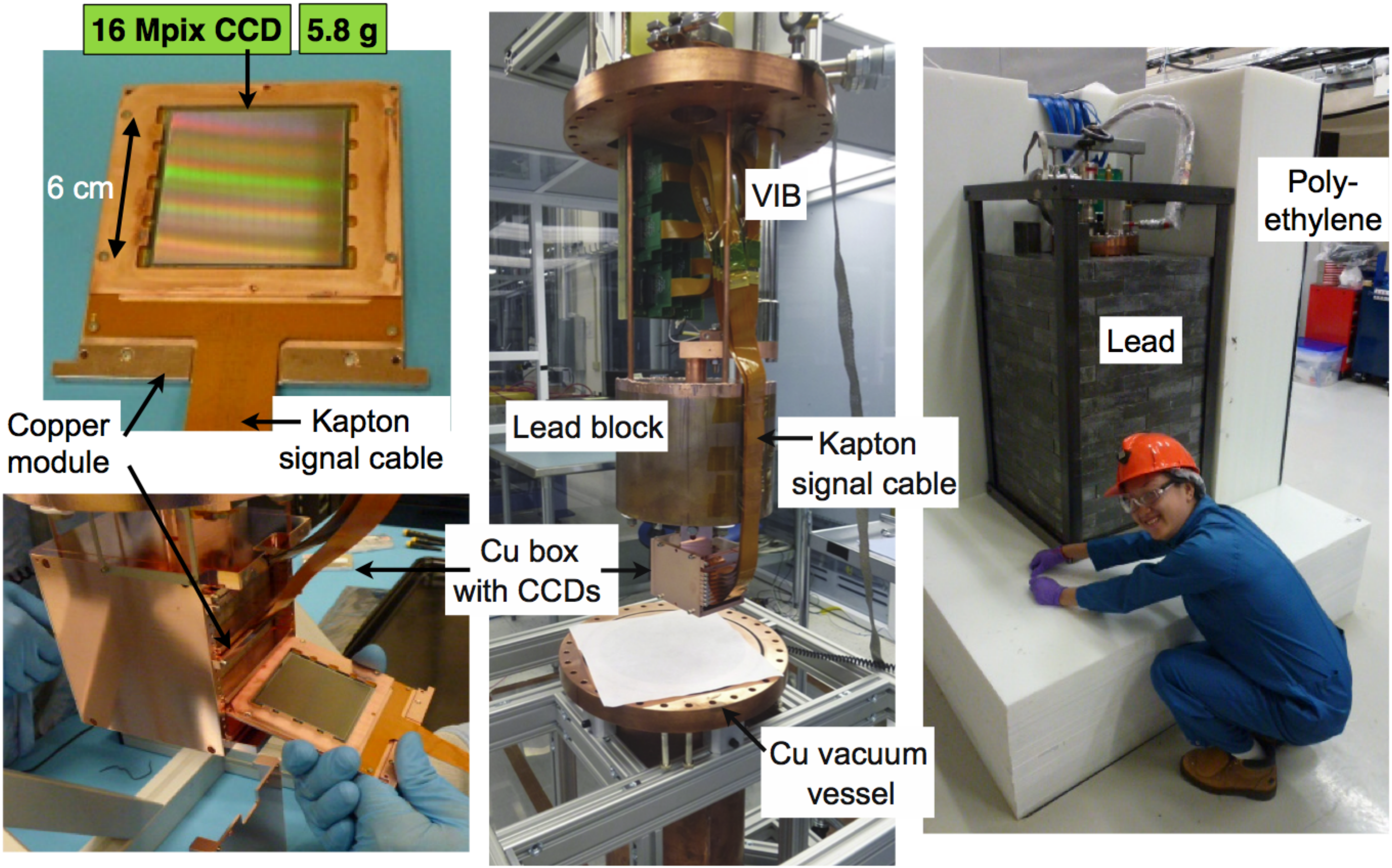
$\sigma_{xy} \approx Z$: fiducial volume definition and surface event rejection



- "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)*

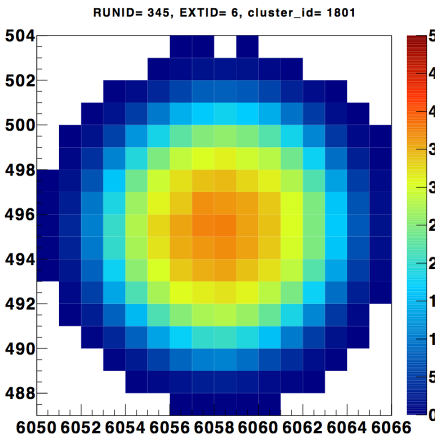
First direct detection constraints on eV-scale hidden-photon dark matter with DAMIC at SNOLAB *Phys. Rev. Lett. 118, 141803 (2017)*

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

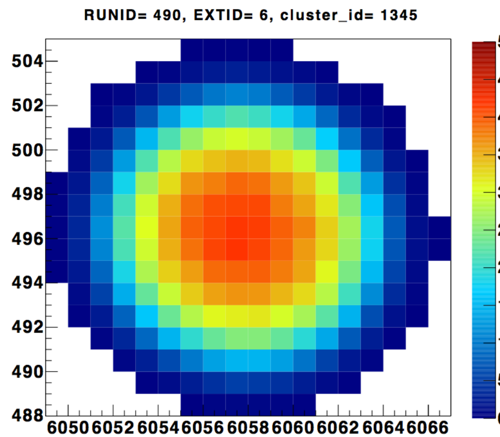
Antonella: A nuclear-recoil ionization-efficiency measurement in silicon at low energies *arXiv:1702.00873*

Radiogenic backgrounds

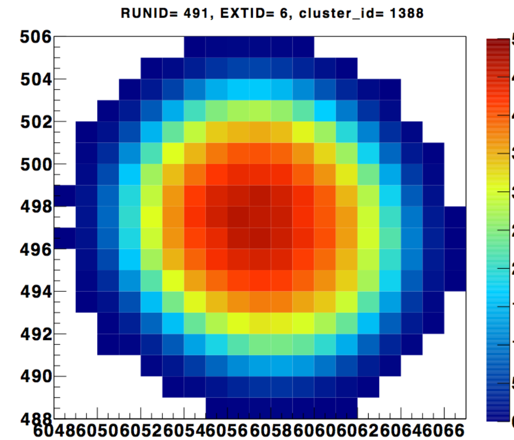
E = 5.4 MeV



E = 6.8 MeV

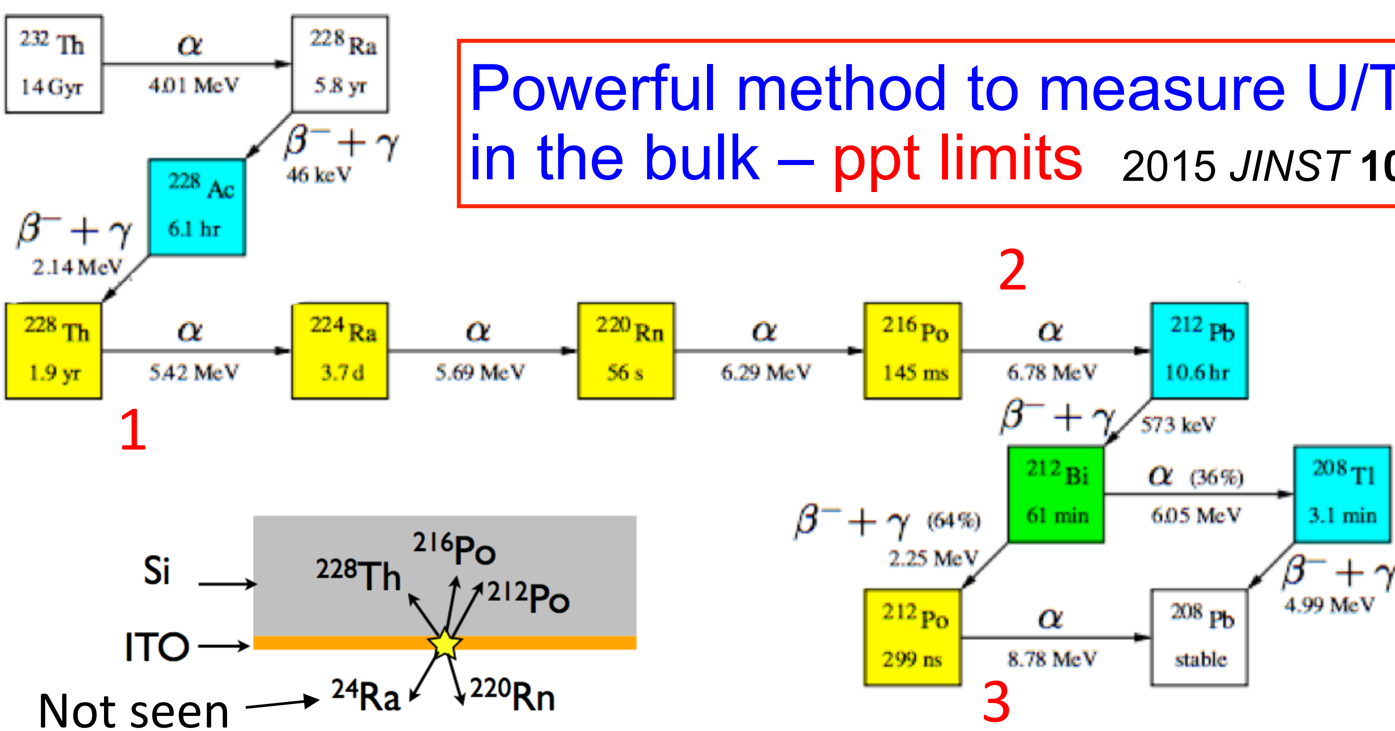


E = 8.8 MeV



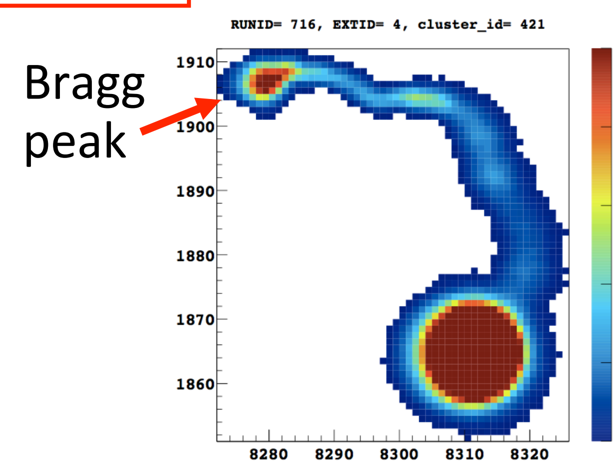
1 Δt = 17.8 d 2 Δt = 5.5 h 3

three α at the same location!

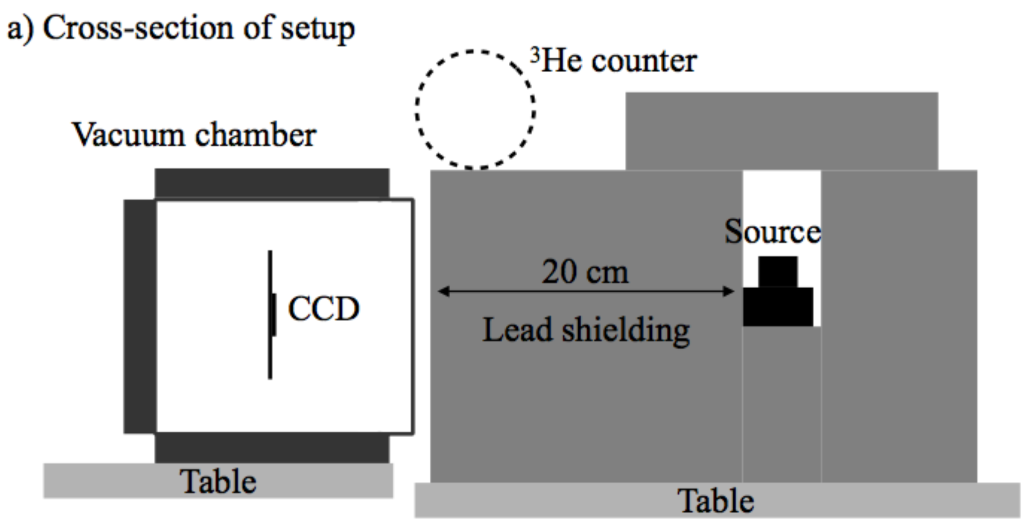


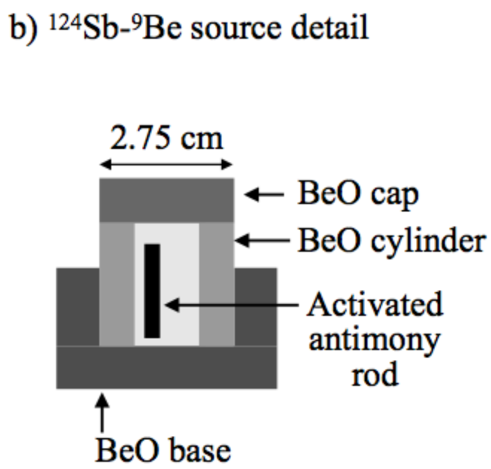
Powerful method to measure U/Th bkg in the bulk – ppt limits 2015 *JINST* **10** P08014

Example of α + β

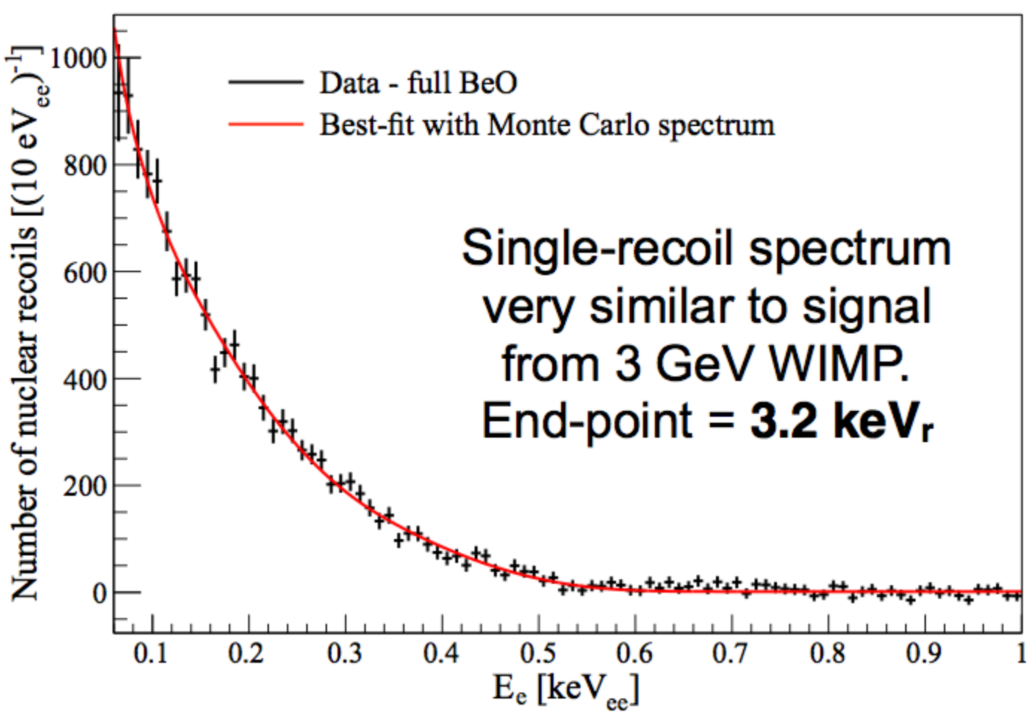


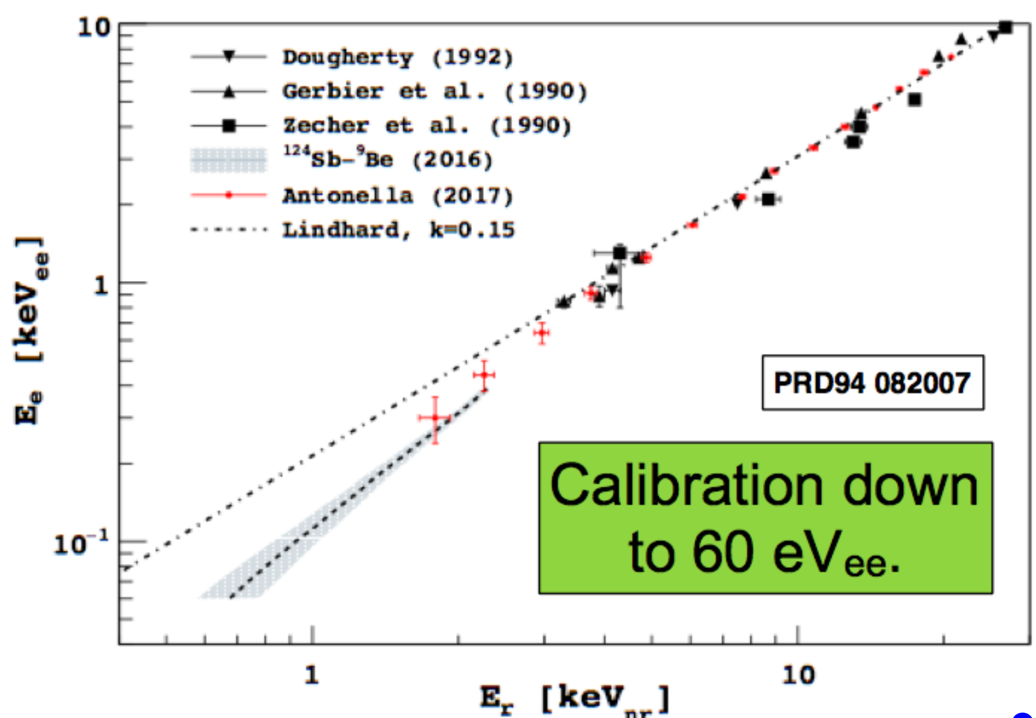
Nuclear recoil calibration



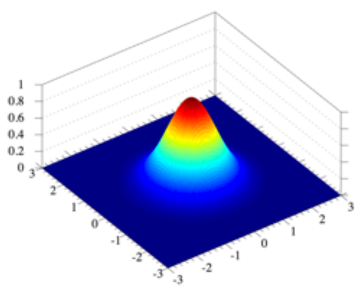


24 keV neutrons from ^{9}Be(γ,n) reaction



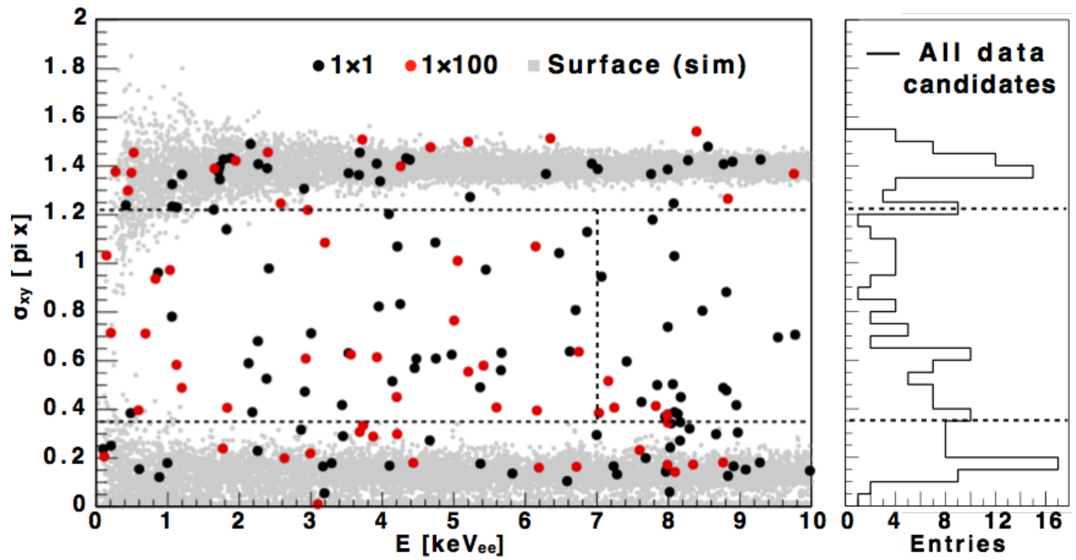


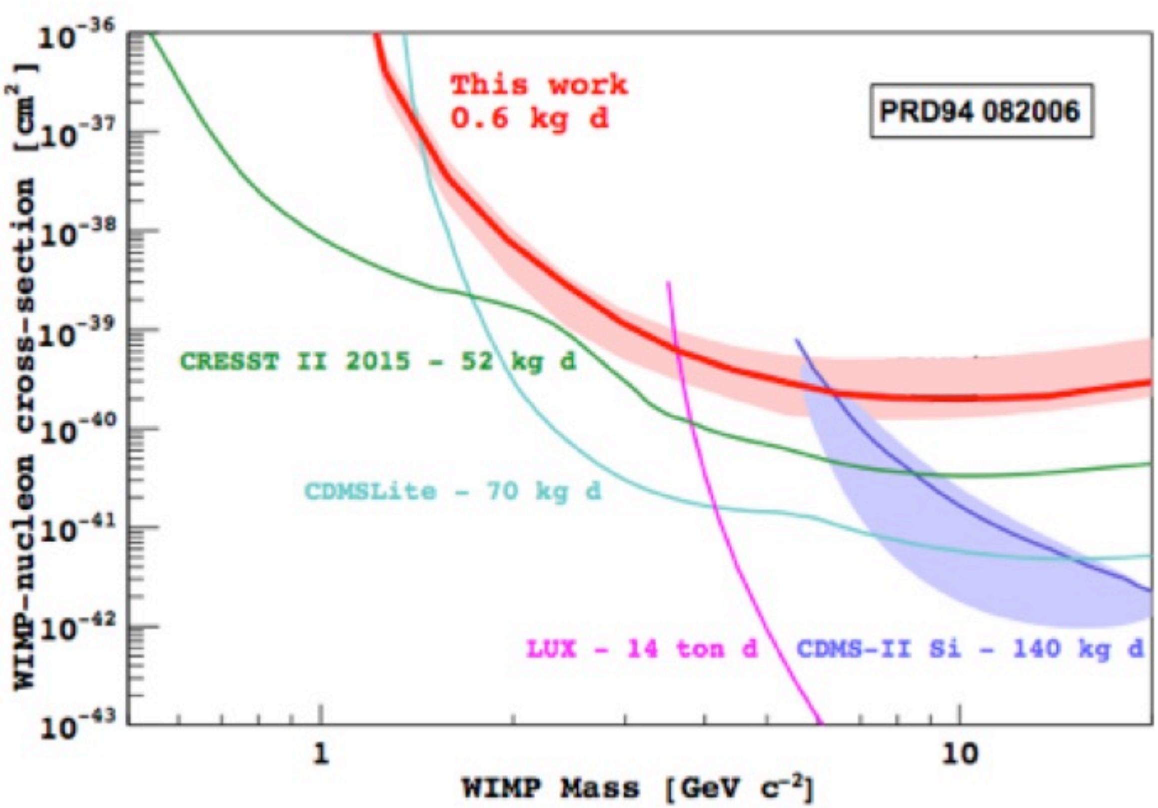
WIMPs search



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

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





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

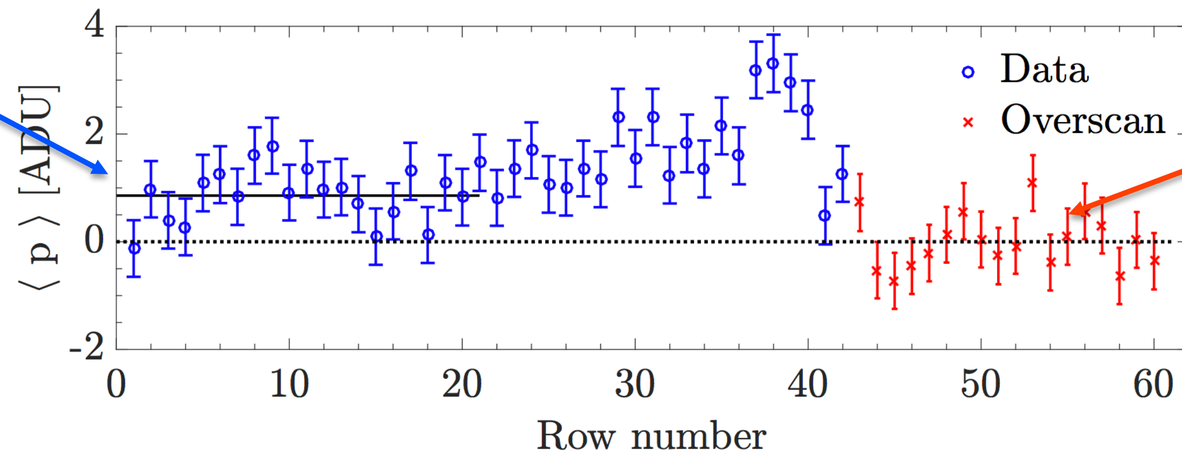
demonstration of DAMIC sensitivity to low-mass Dark Matter

NOTE: current bkg. ≈ 5 dru

Hidden photon DM search

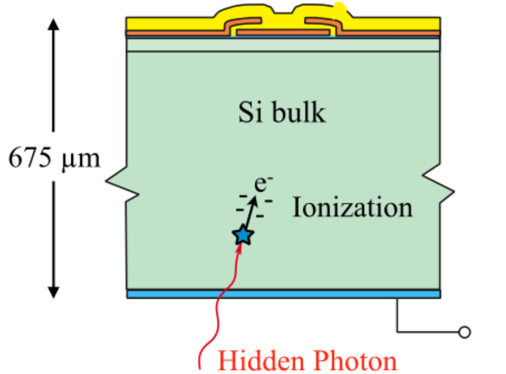
readout noise + leakage current + Hidden Photon

NOTE: 1x100 binning

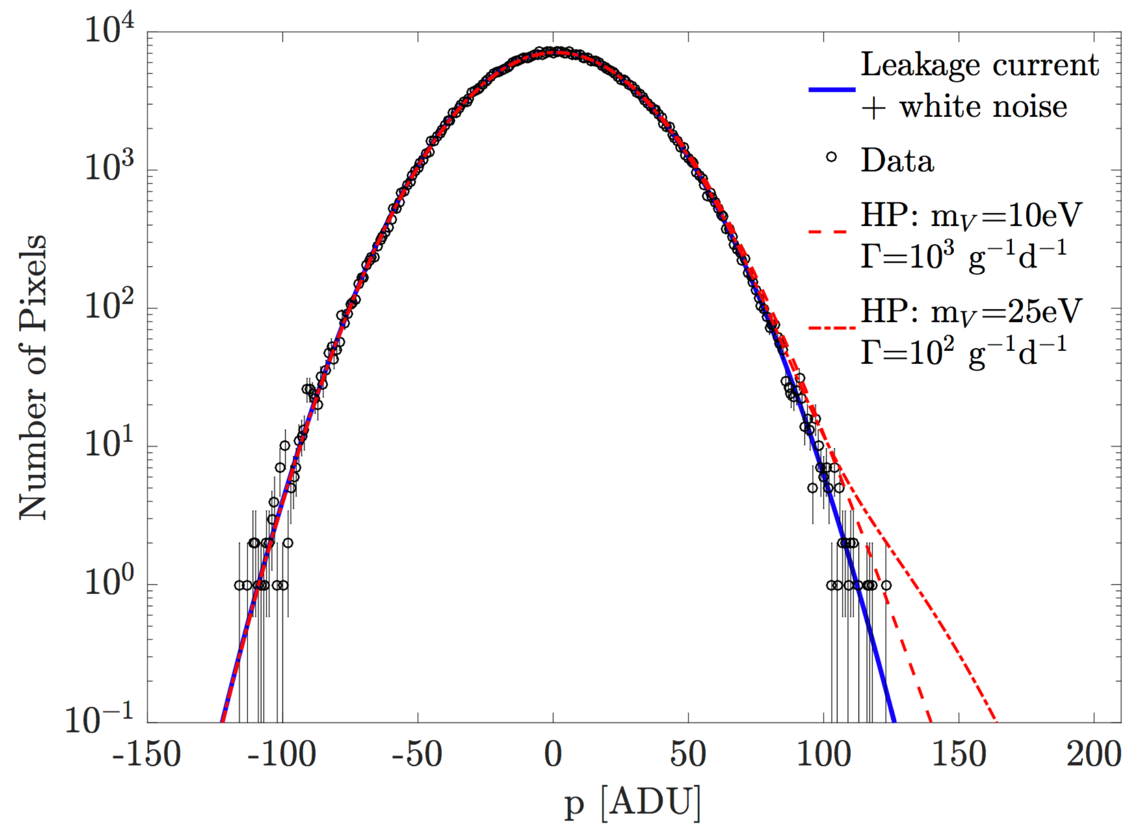


only readout noise in the overscan rows

Absorption of hidden-photon dark matter.

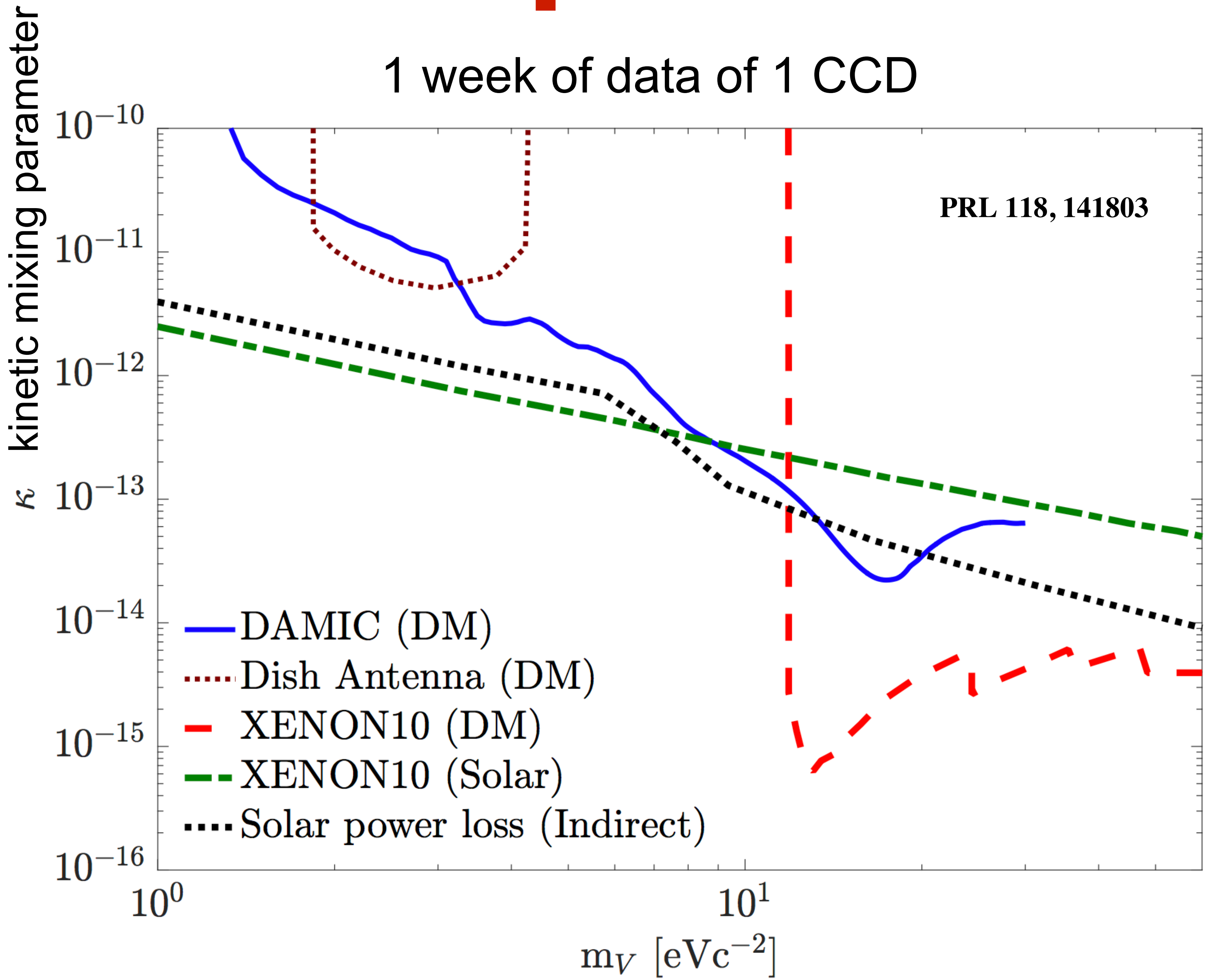


m_V



hidden photon absorption would produce m_V / 3.6 eV charge carriers in silicon:
HP sensitivity in the charge distribution

Hidden photon limit



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

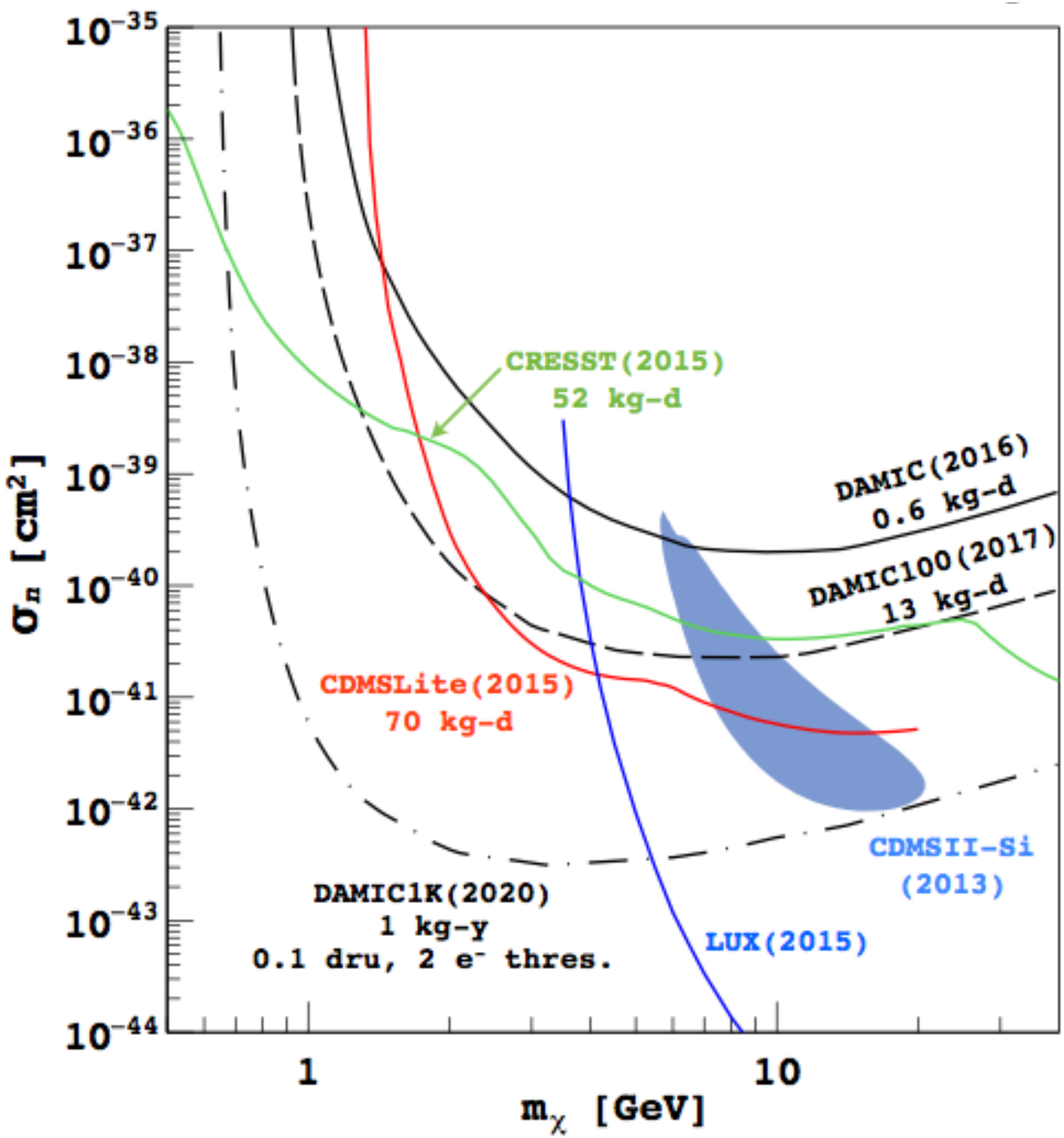
DAMIC now

- 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.

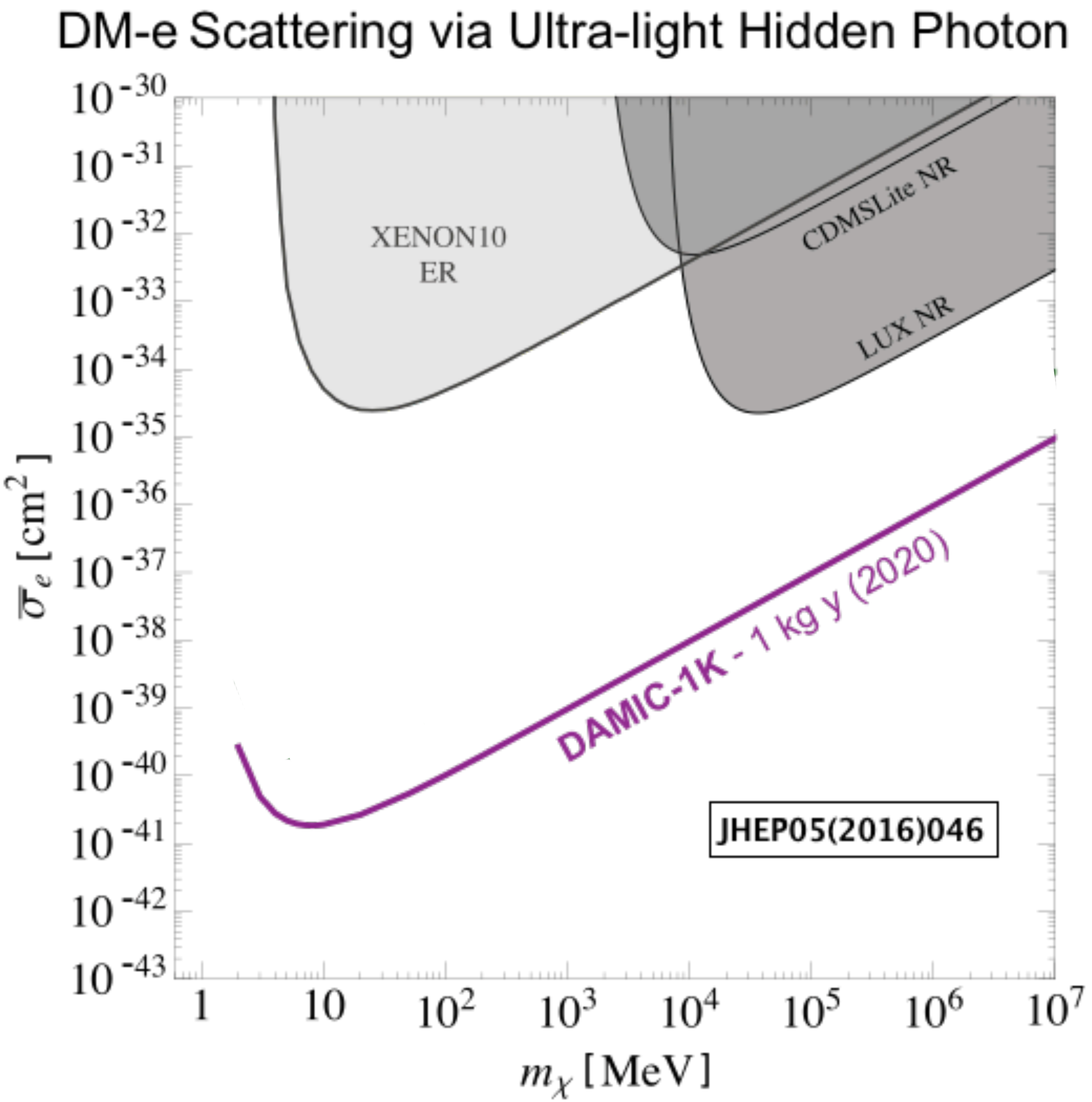
DAMIC-1K

- 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

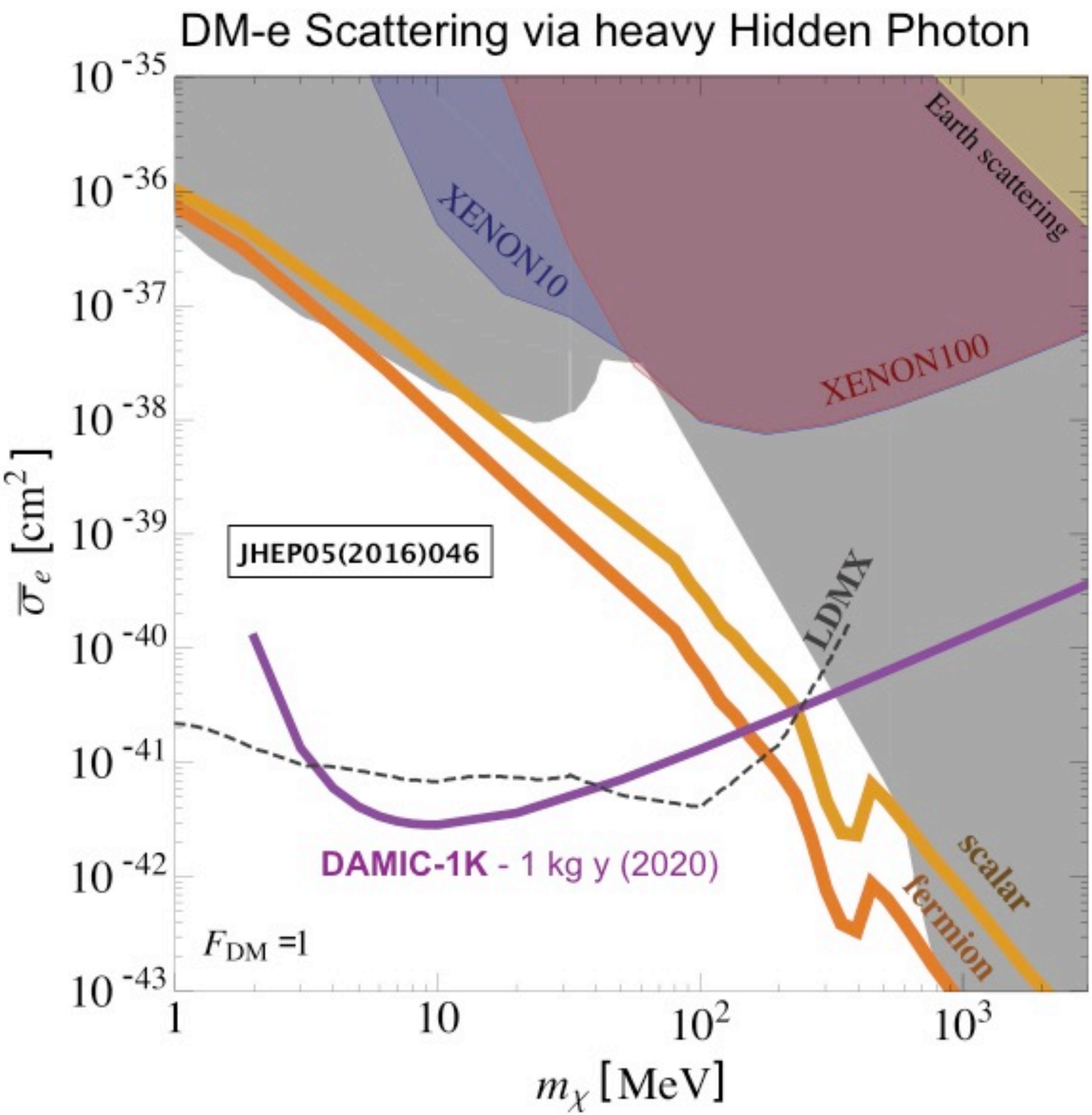
DAMIC-1K and WIMPs

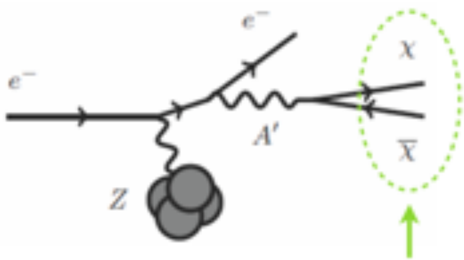


DAMIC-1K and dark sector



DAMIC-1K and dark sector





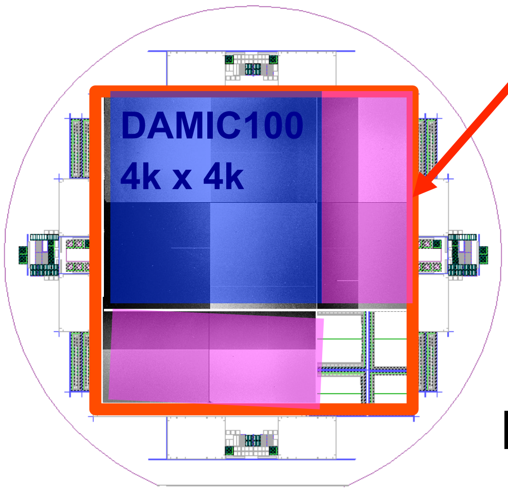
Complementary to accelerator searches!

(see T. Nelson talk)

DAMIC-1K technical challenges

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

Silicon wafer



6k x 6k pixels, 1 mm thick

≈ 20 g / CCD

≈ 50 CCDs / 1 Kg

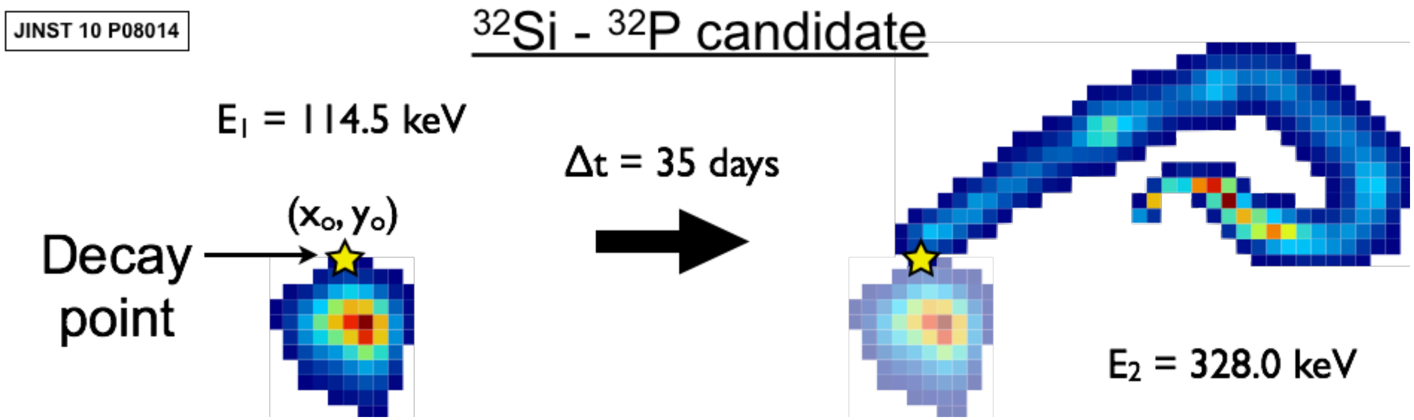
DALSA has confirmed the feasibility fabrication of these larger and thicker CCDs

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

- 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

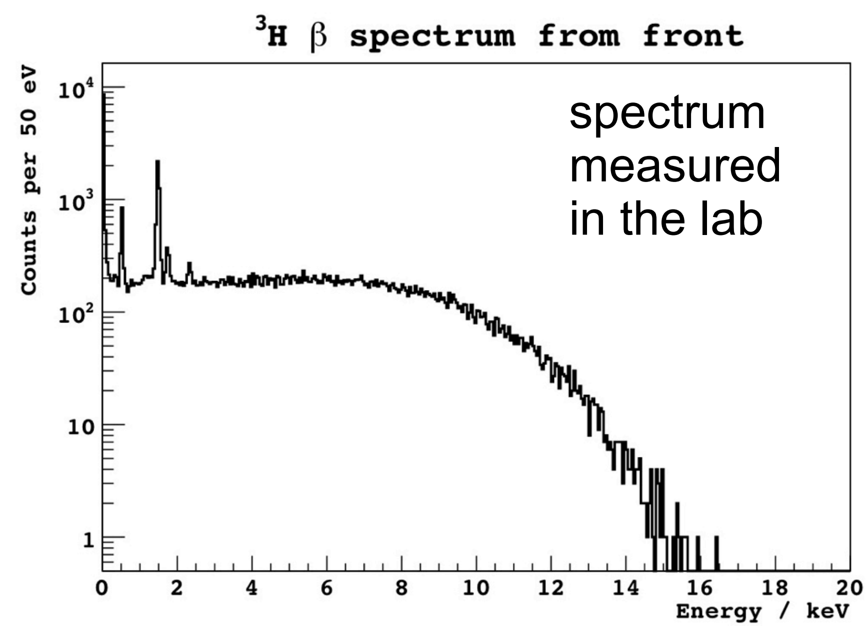
- Cosmogenic ^{32}Si rate will be accurately measured by the current detector at SNOLAB



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

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

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

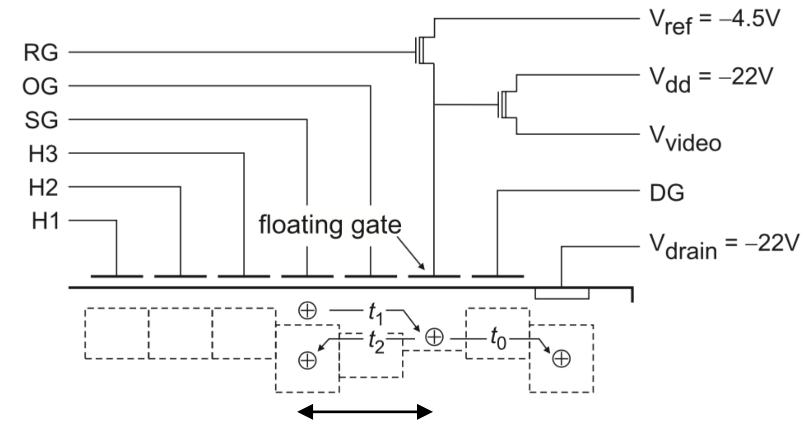


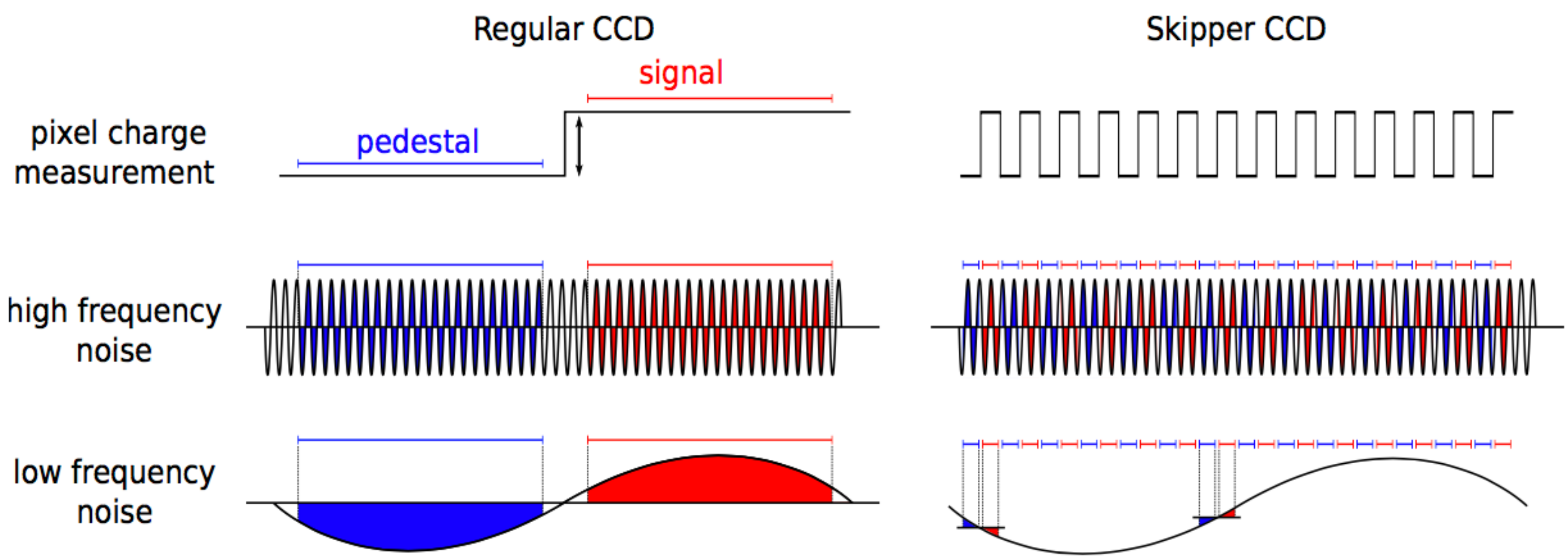
DAMIC-1K sub-e⁻ noise

- Skipper readout

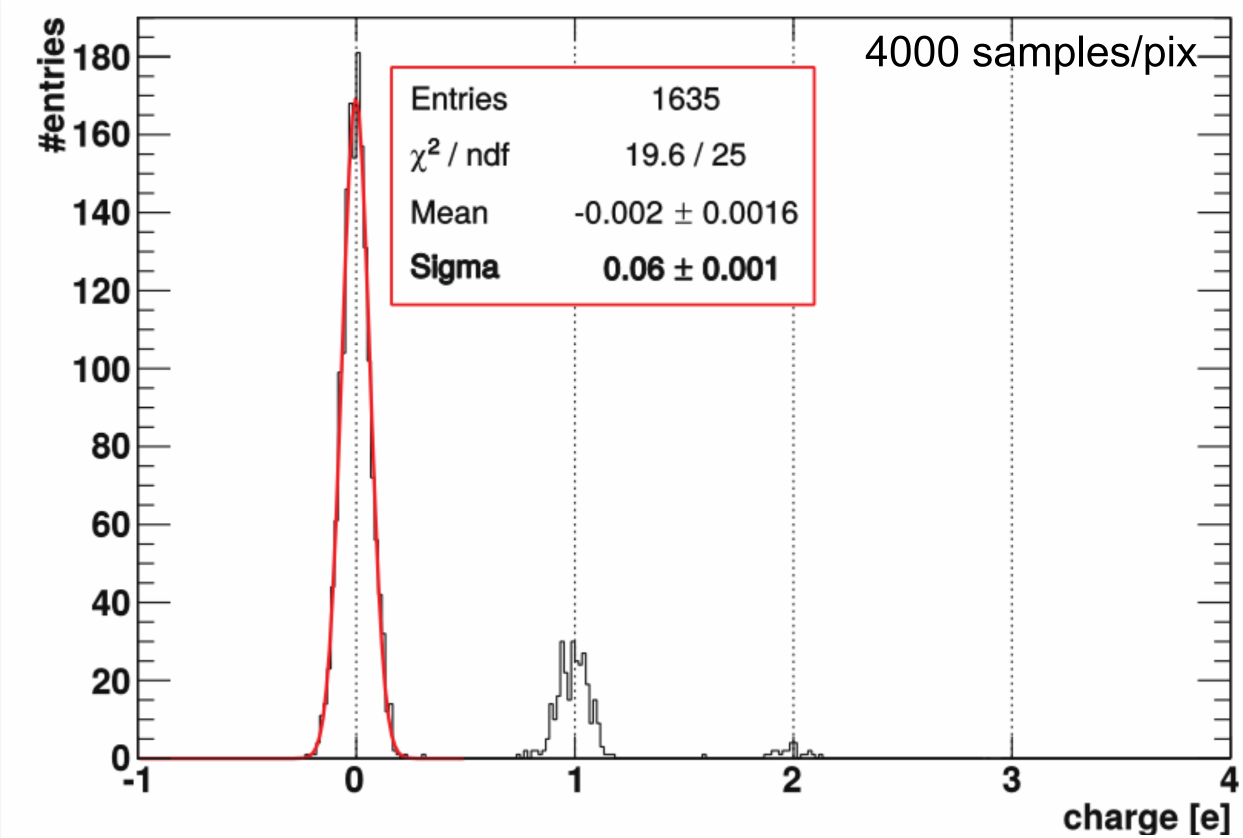
Non-destructive measurement of the charge!

Measure the charge fast (kill 1/f noise) and N times (noise ≈ 1/√N)

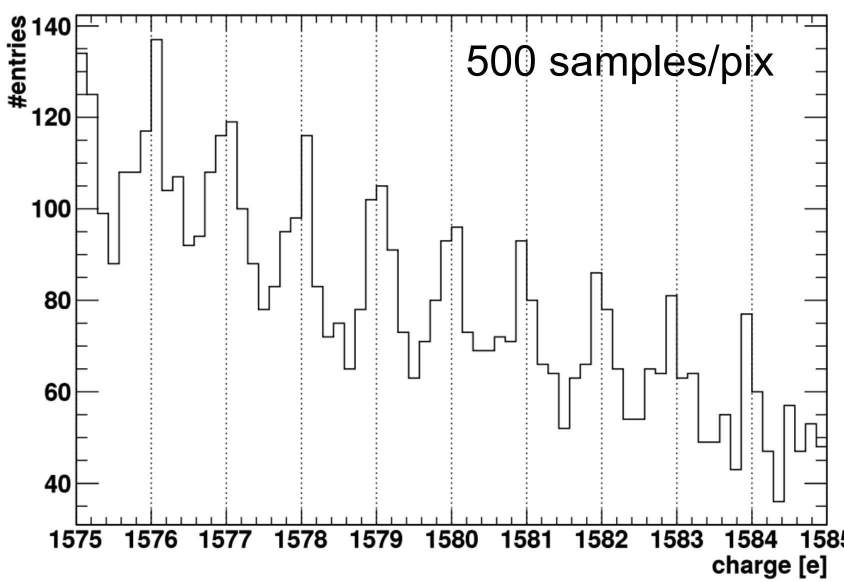


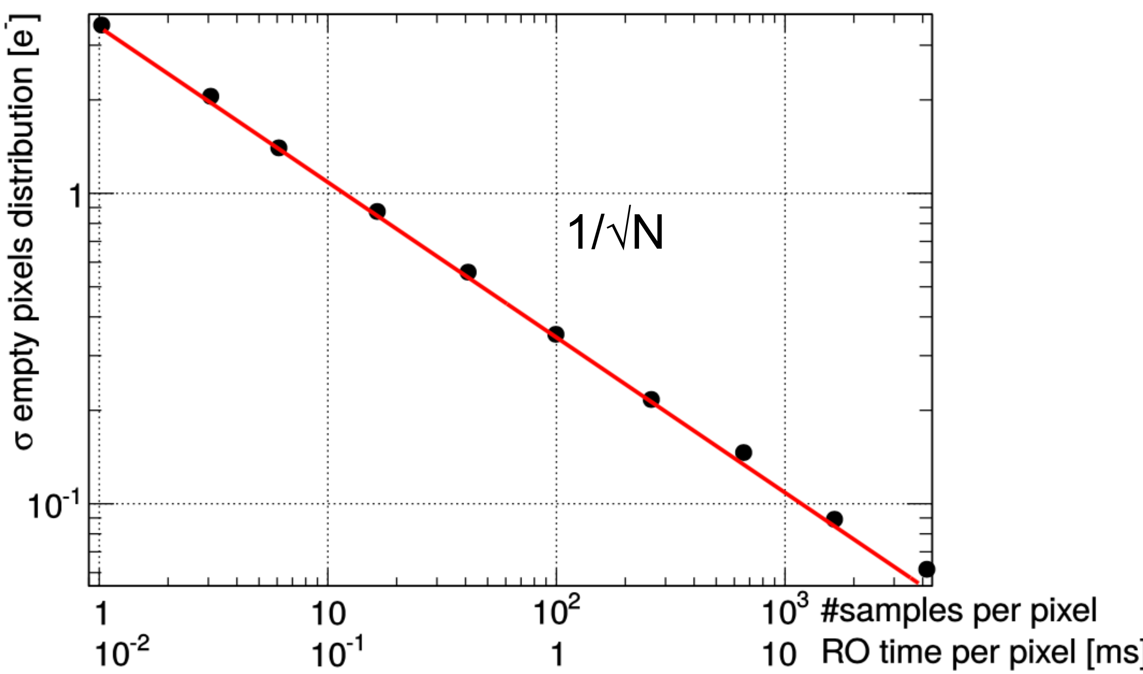


DAMIC-1K sub-e$^-$ noise



Skipper <u>unprecedented</u> 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 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 paradigma, 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.