UCLA Dark Matter 2018, February, 23rd

First data from the full CCD array of DAMIC at SNOLAB

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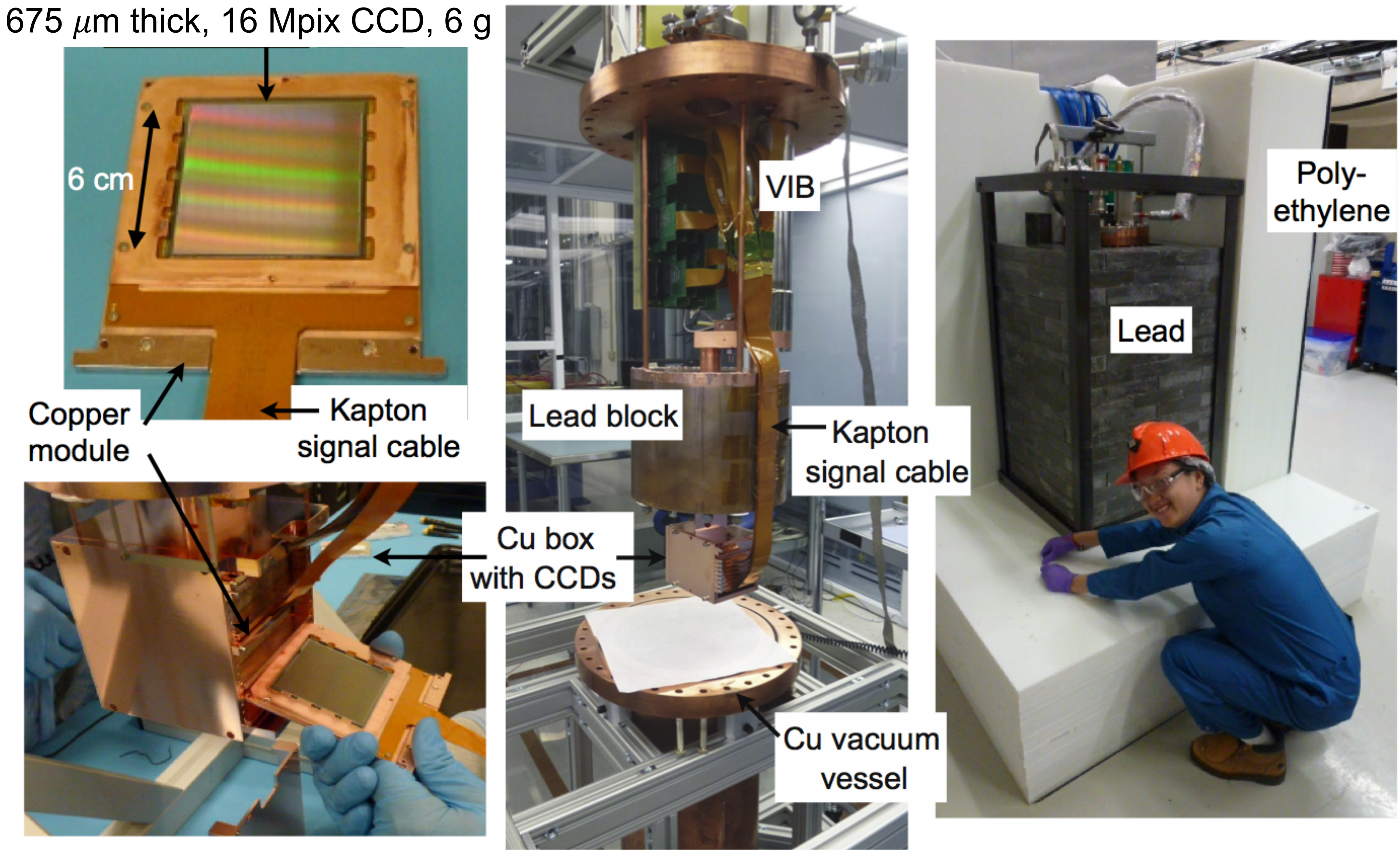
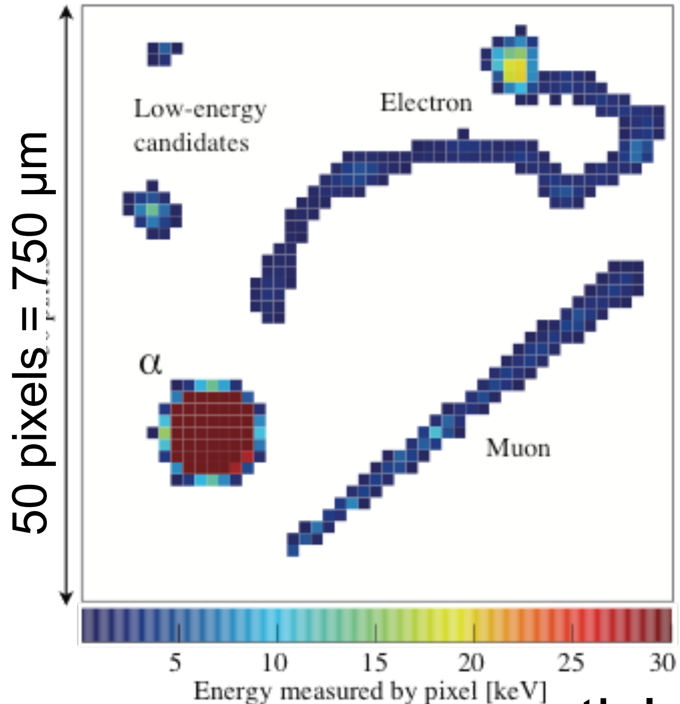
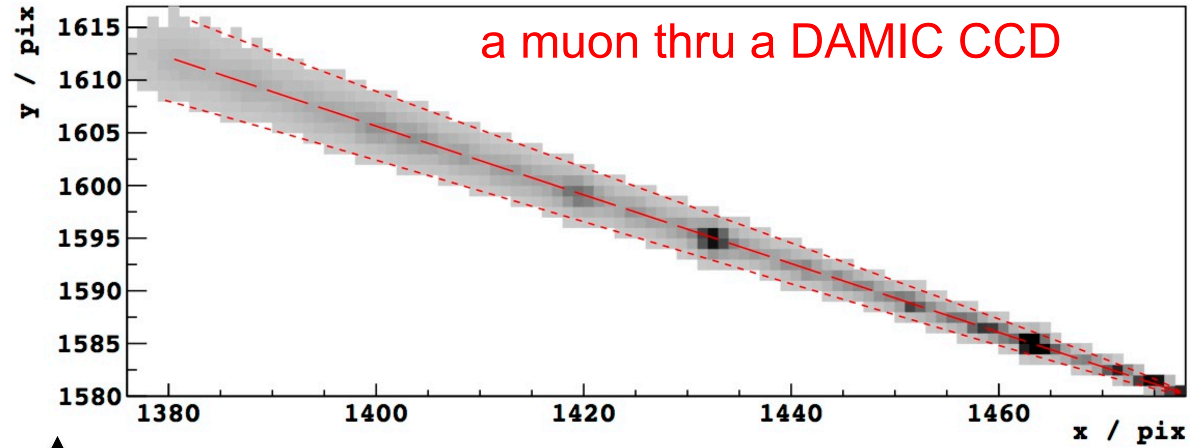
(Photo image: particle tracks in a DAMIC CCD)

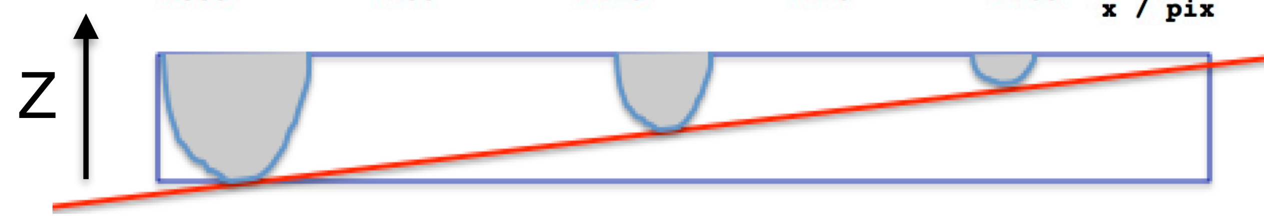
DAMIC @ SNOLAB



exquisite spatial resolution

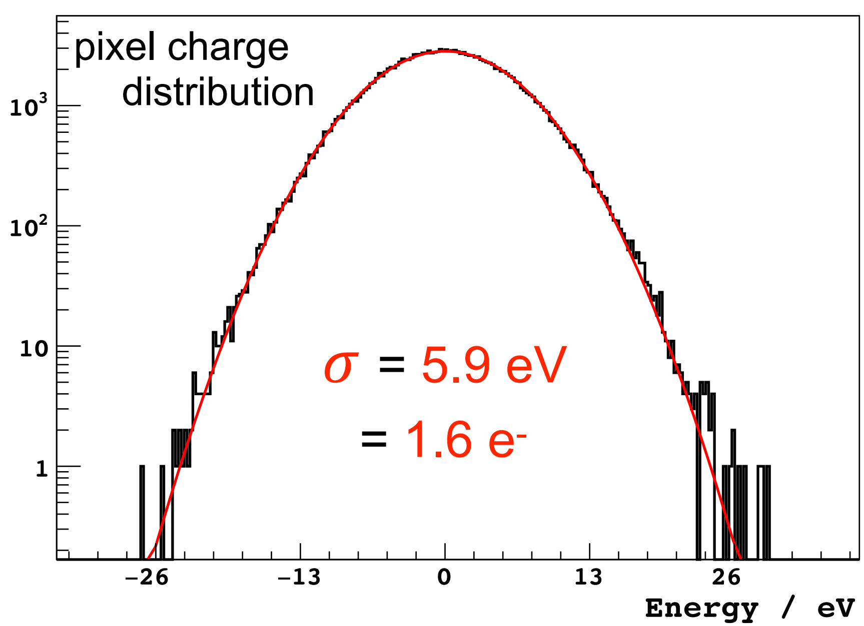






$\sigma_{xy} \approx Z$: fiducial volume definition

particle identification and background characterization



extremely low noise and dark current

lowest dark current ever measured in a silicon detector:

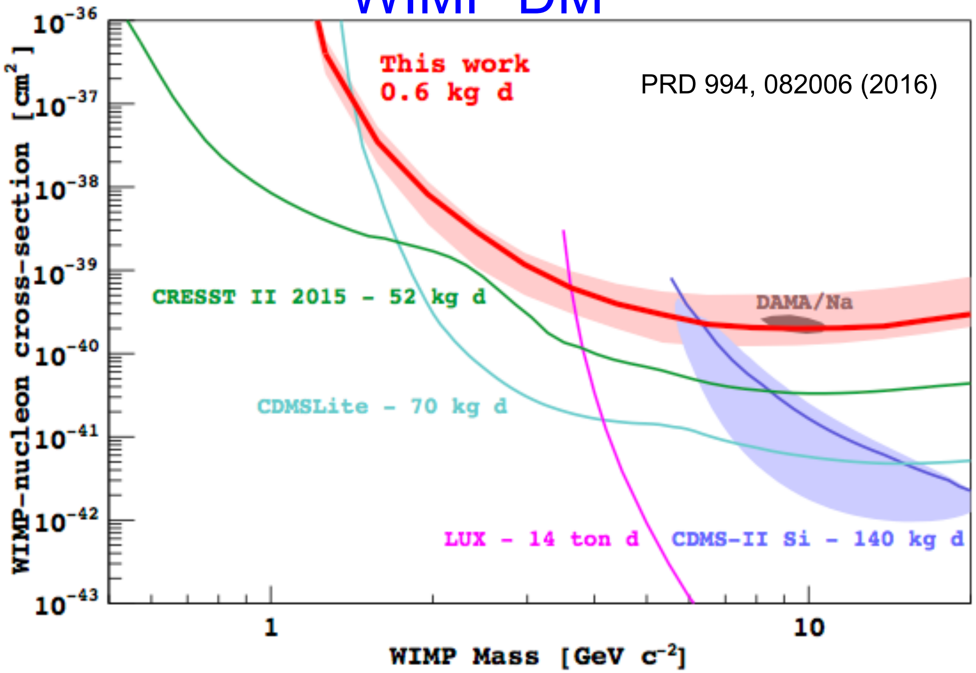
5×10^{-22} A/cm² (at 140 K)

(improved wrt R&D phase where σ = 2 e^- and current = 10^{-21} A/cm² at 100 K)

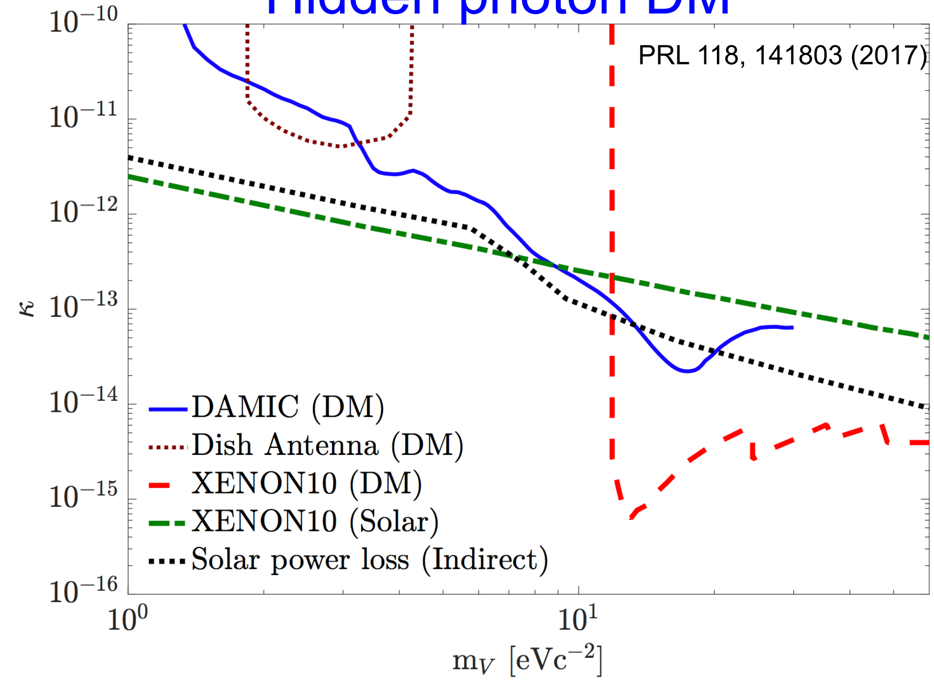
DAMIC CCDs

Selected results

WIMP DM

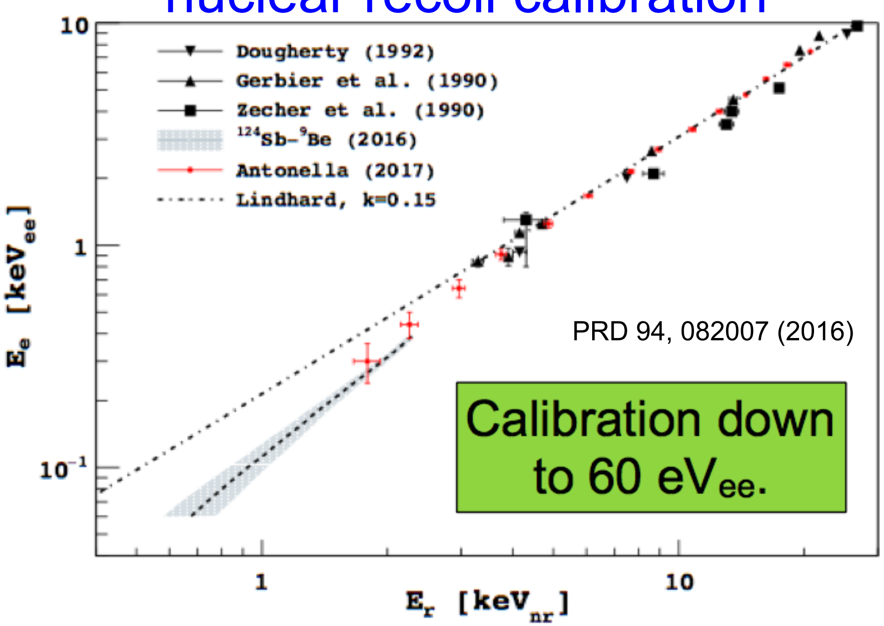


Hidden photon DM



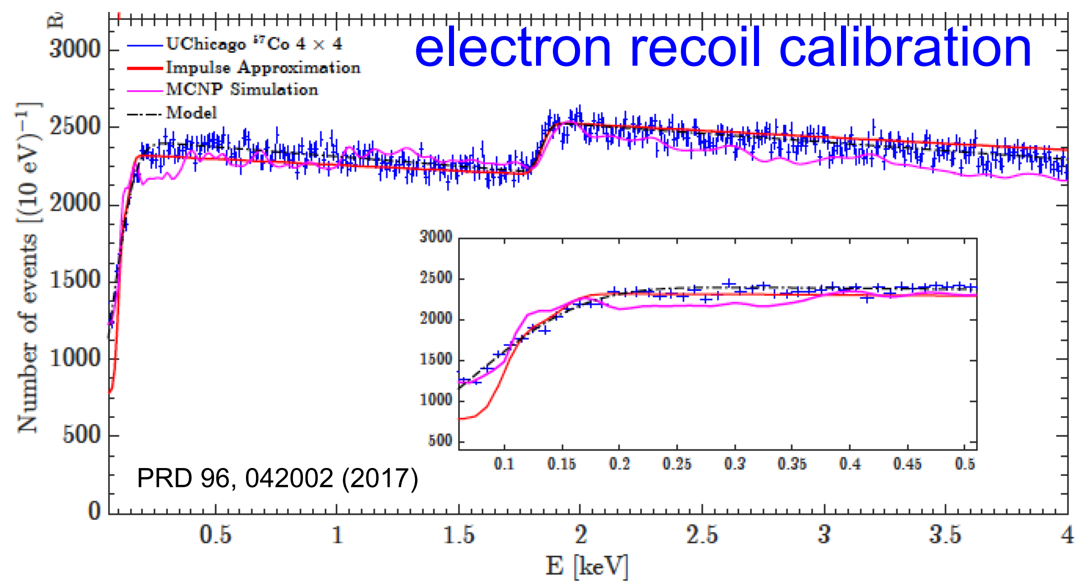
radioactive bkg in the silicon bulk
2015 *JINST* **10** P08014

nuclear recoil calibration



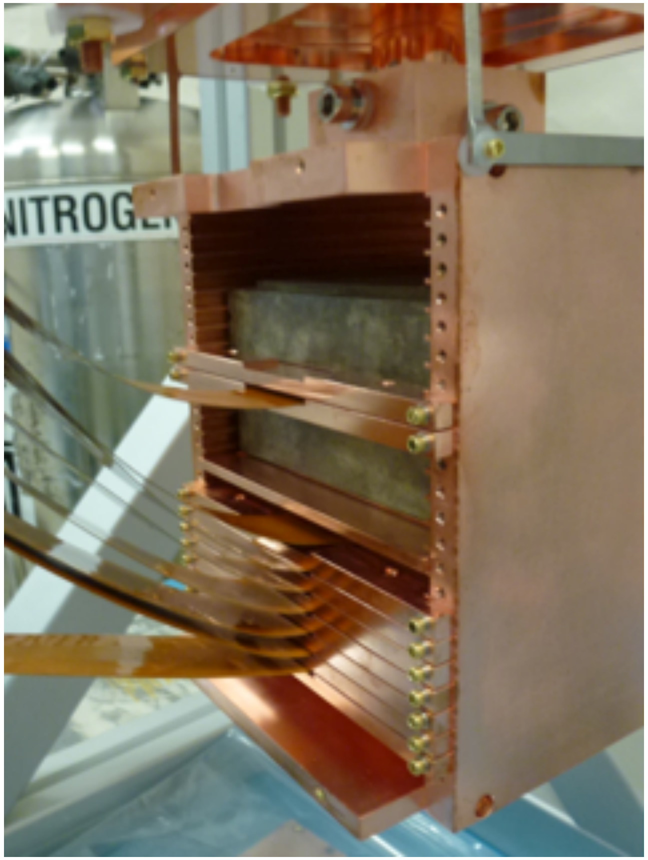
Calibration down to 60 eV$_{ee}$.

electron recoil calibration

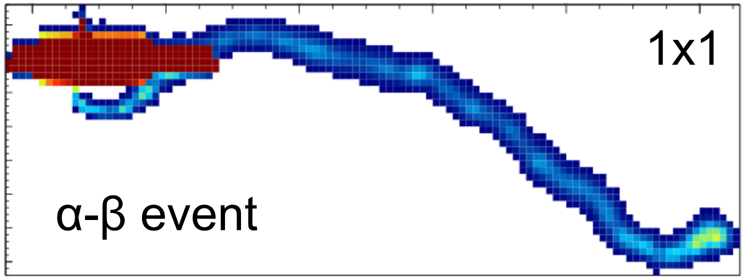


Current status

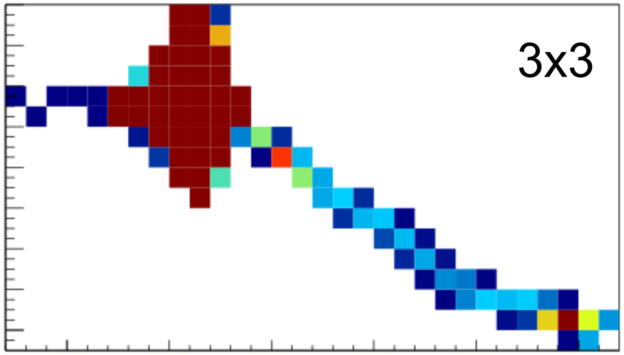
- Seven CCDs in stable data taking; 40 g detector
  One CCD sandwiched in ancient lead
- A data set (7.6 kg day) collected with full spatial resolution (1x1 binning), optimized for background characterization and measurement (^{32}Si, ^{210}Pb)
- A second data set being collected (so far 4.7 kg day) with best energy threshold (1x100 binning)



binning: charge of several pixels are added before readout

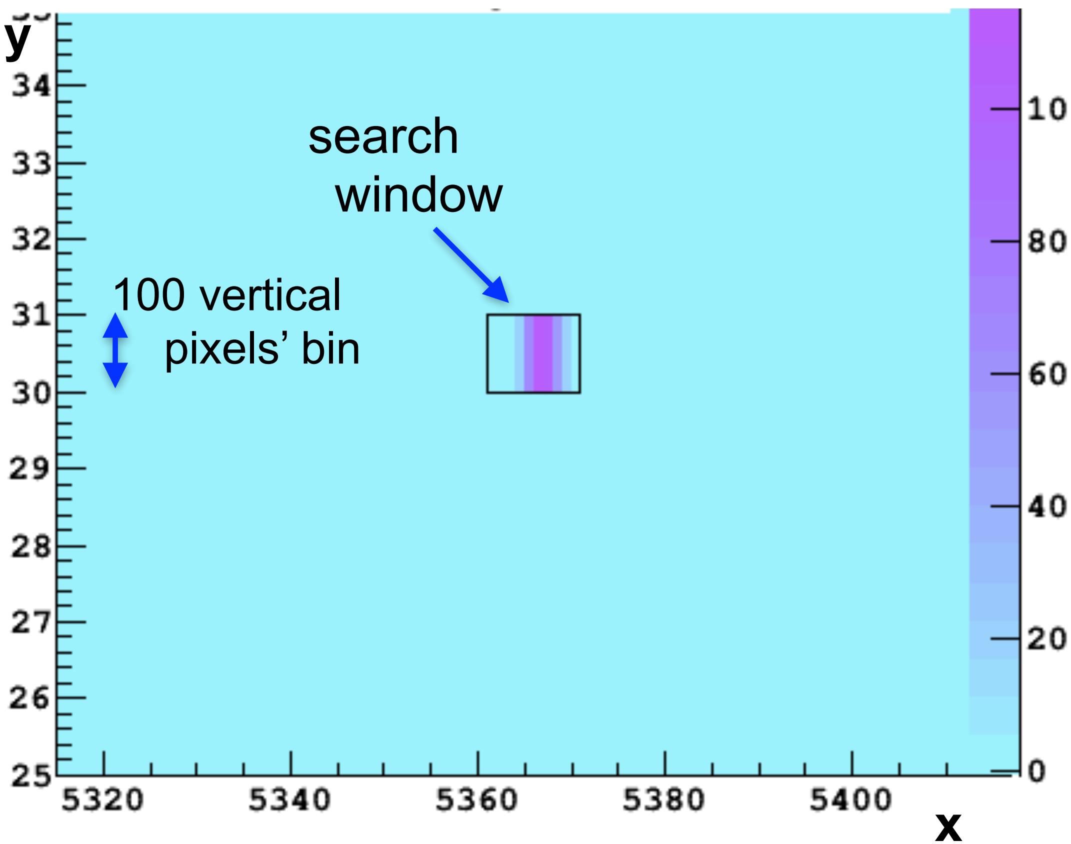


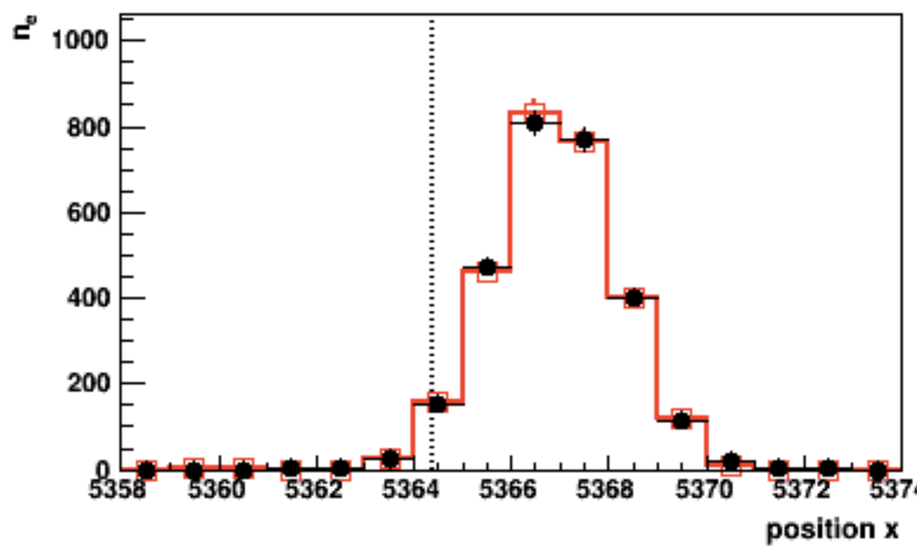
some loss of spatial resolution but improved signal to noise (same readout noise but more charge in a binned pixel)



Event selection

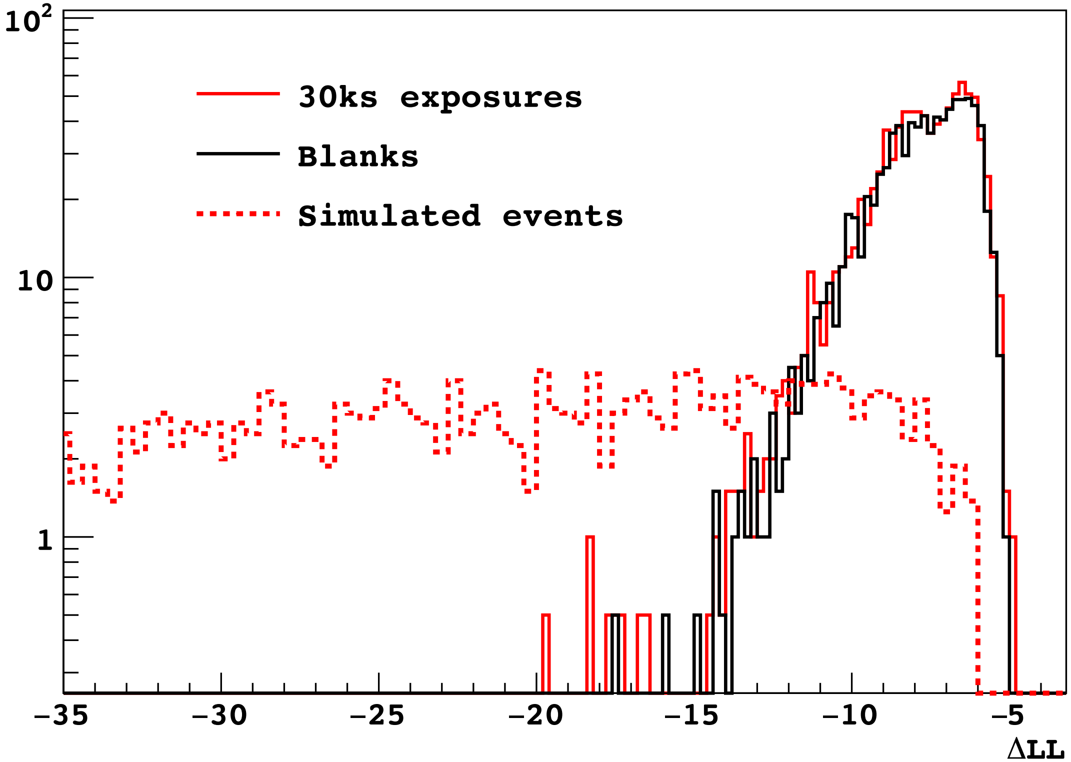
- A search window is moved across the CCD array
- A ML fit is performed to a gaussian signal plus noise hypothesis: fit provides event position, energy, spatial **σ** and L_S value
- A ML fit is performed to only noise hypothesis, fit provides L_N
- The likelihood difference is calculated, $\Delta LL = L_N - L_S$, which is used to select candidate events



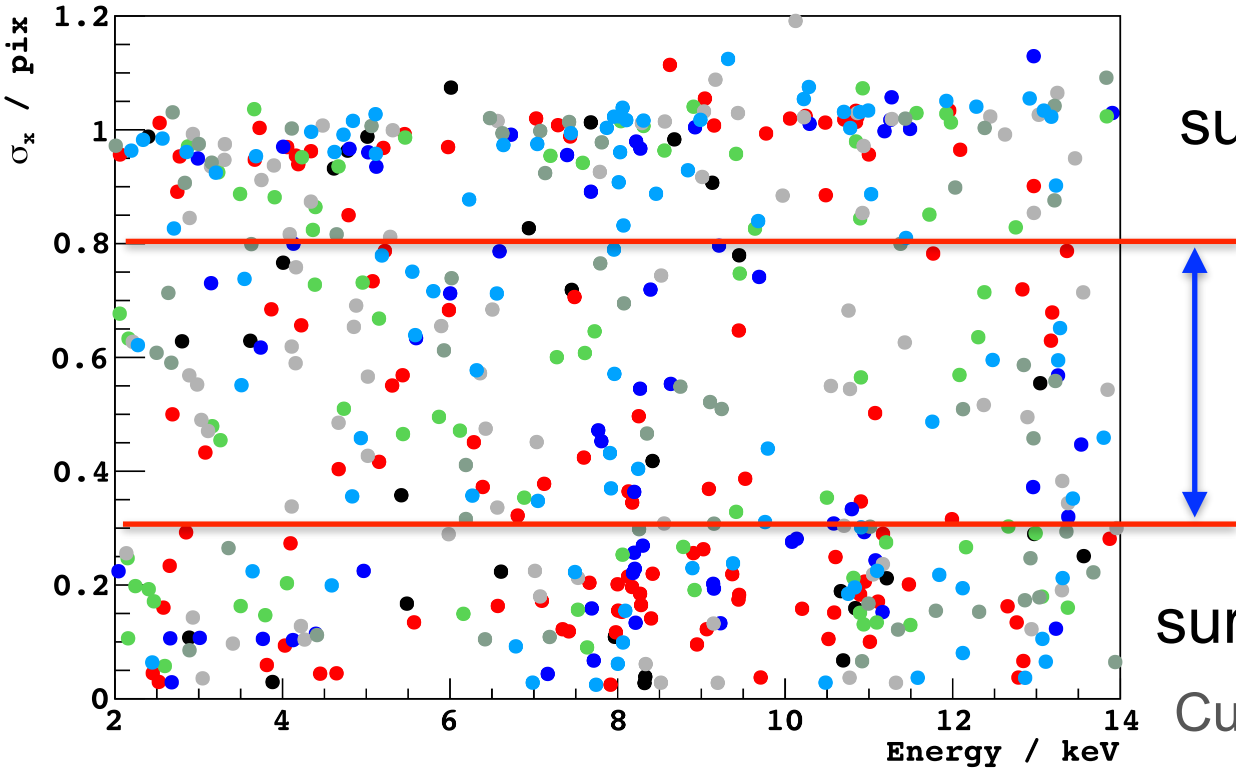


E = 10 keV **σ** = 1.0 pix

ΔLL = -184000



- ΔLL < -25 required (from distribution of "blanks", images with zero exposure which only have noise)
- Rejection of surface events by requirements on spatial **σ**



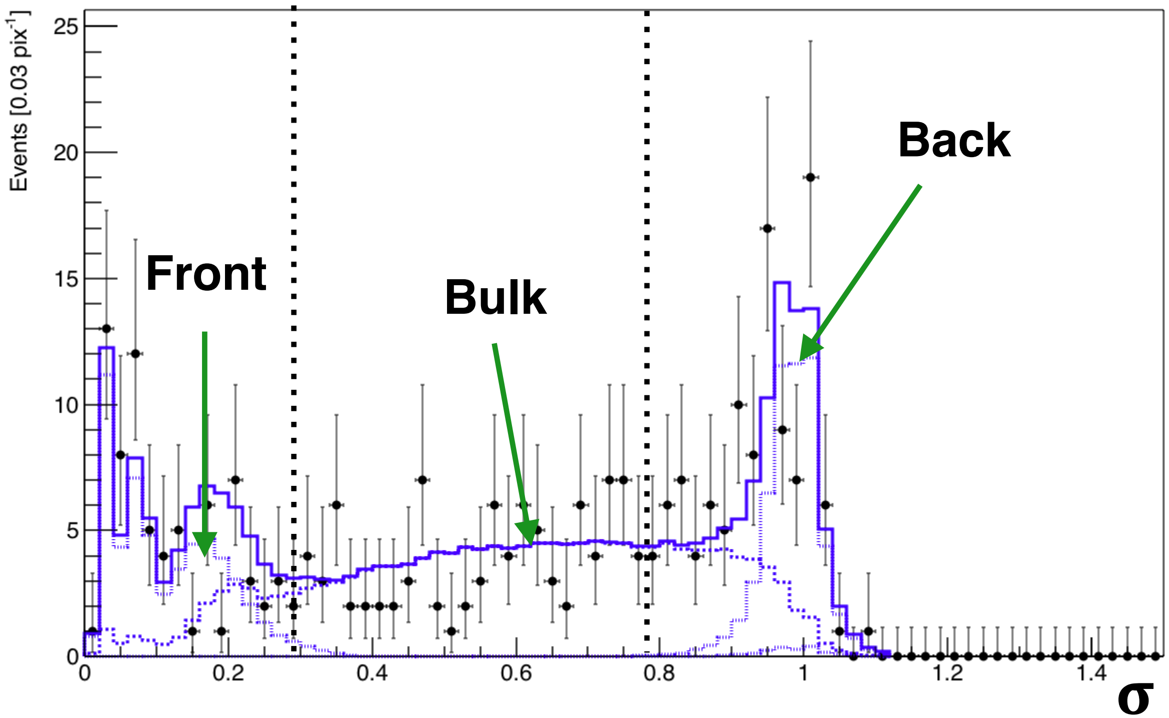
surface background

fiducial region for bulk events

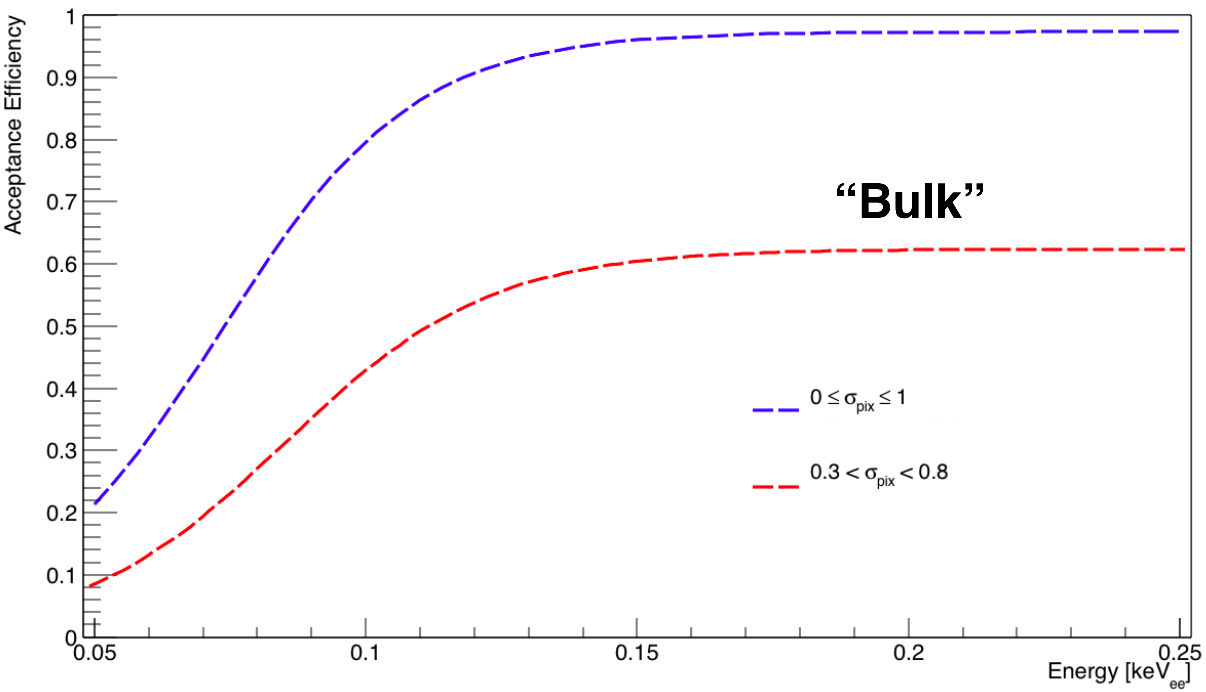
$0.3 < \sigma < 0.8$

surface background

Cu fluorescence and Pb x rays visible

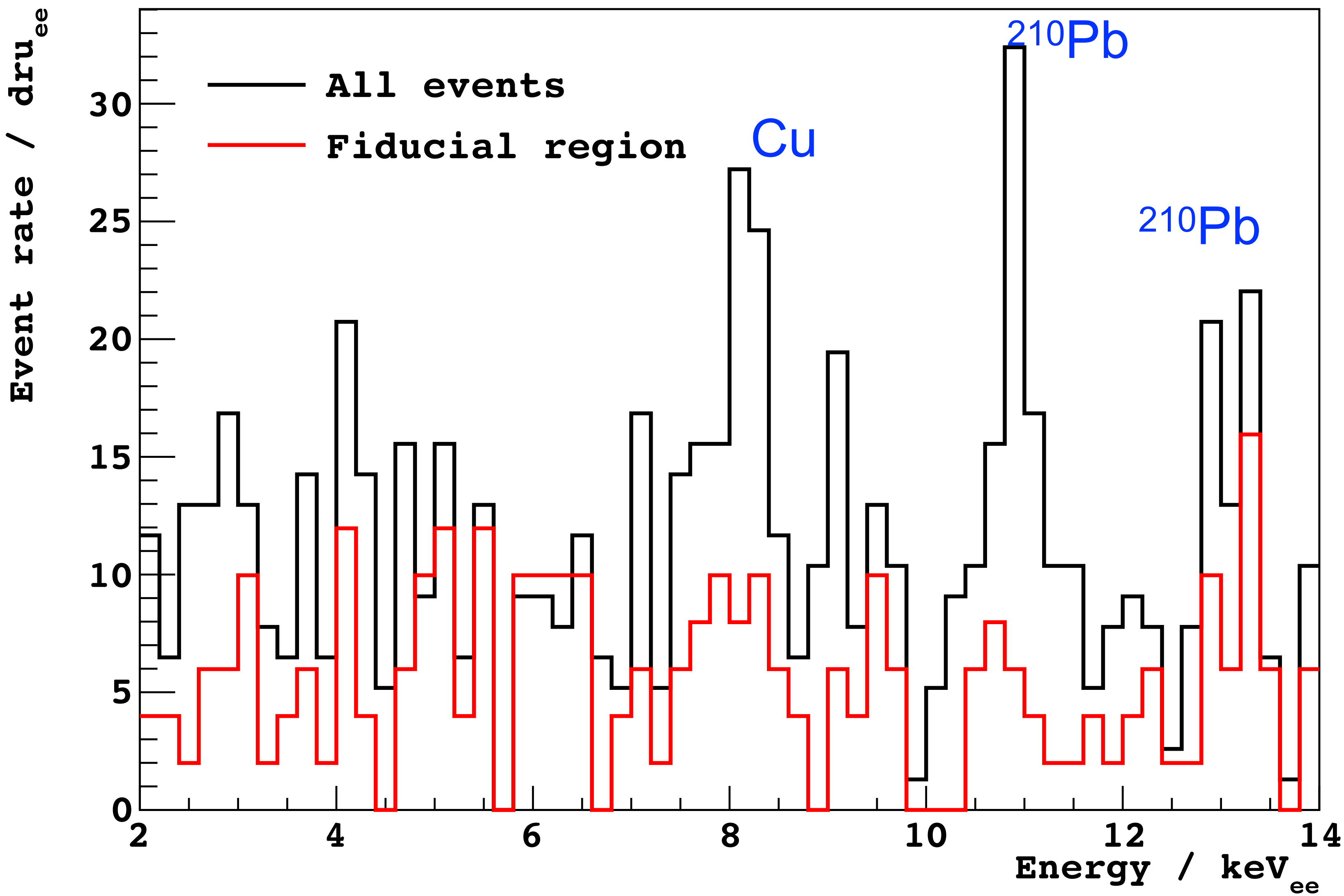


- Backgrounds: on front and back surfaces of CCDs, in the bulk
- Data compared with background model 50/25/25 bulk/front/back (estimated from high energy data)



- Acceptance for energy deposit in the bulk estimated from MC simulations; threshold at 50 eV_{ee}

Energy spectrum above 2 keV



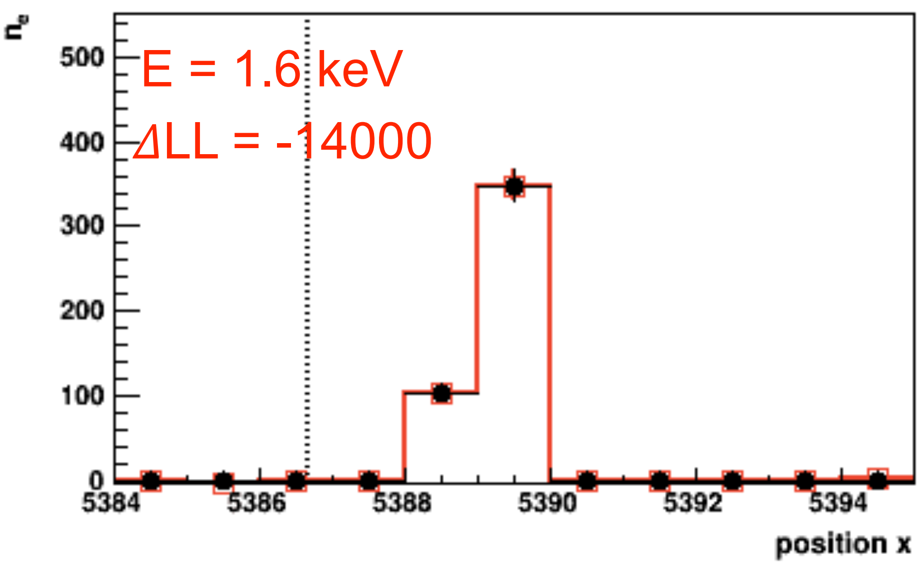
≃ 5 dru in fiducial region, consistent between CCDs

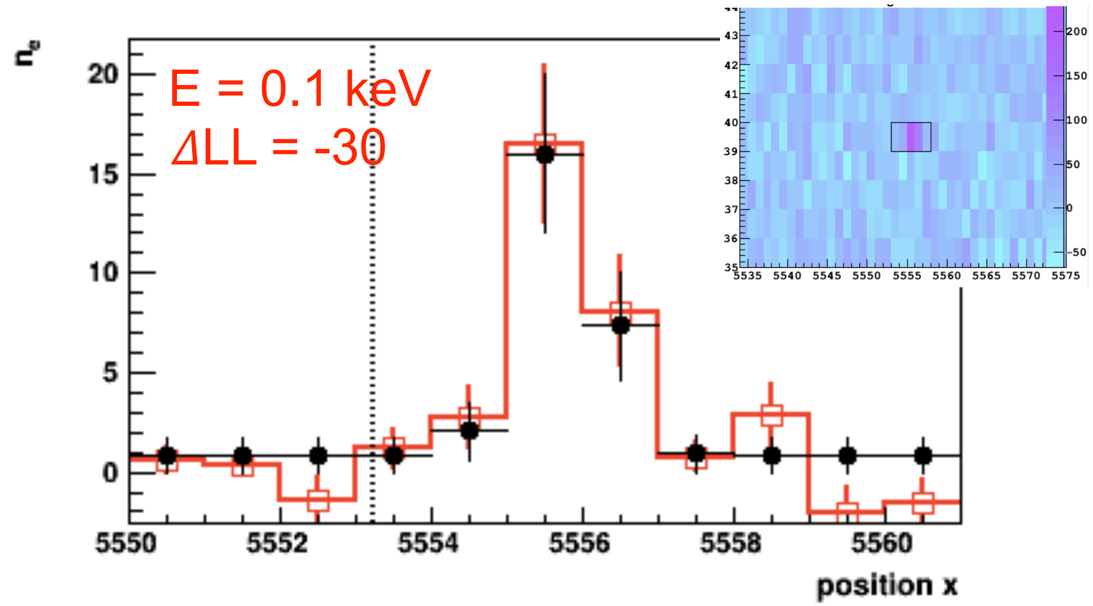
a factor of ≃ 3-4 lower than our previous background level

≃ 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.





- <u>NOTE</u>: CDMS II silicon potential signal obtained with a 7 keV_{nr} threshold (≈ 2 keV_{ee})

We are exploring for the first time the silicon target with a much lower threshold of 0.6 keV_{nr} (≈ 0.05 keV_{ee})

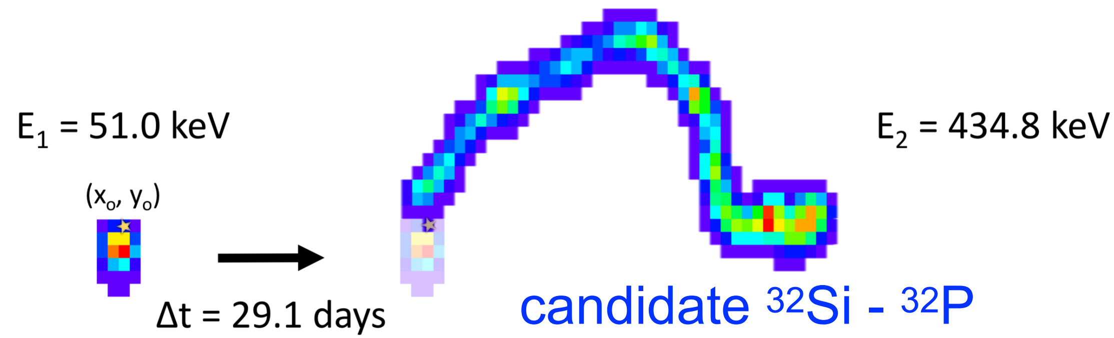
Our results will be relevant for SuperCDMS Si and DAMIC-1K

On-going background measurements

- Cosmogenic ^{32}Si

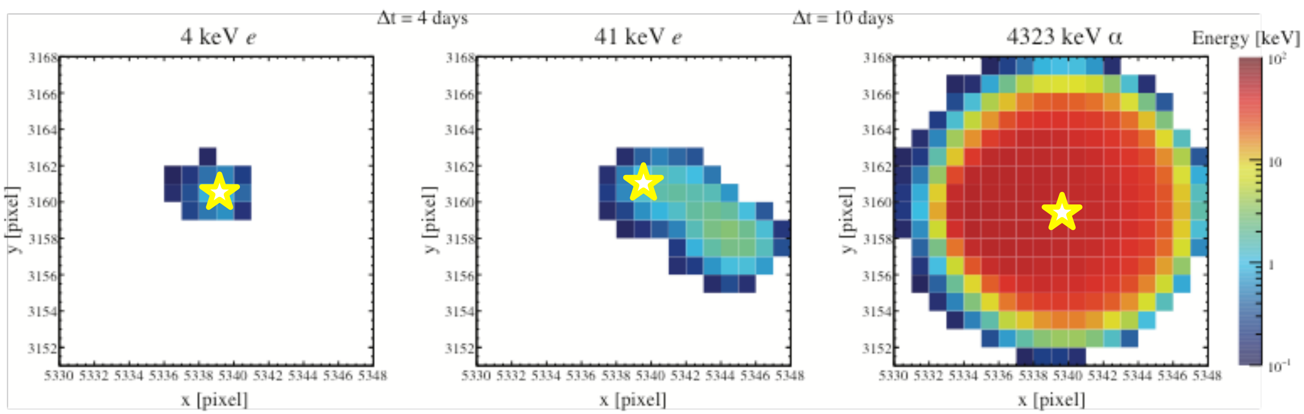
^{32}Si ($T_{1/2}$= 150 y, β) ➔ ^{32}P ($T_{1/2}$= 14 days, β)

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



candidate ^{32}Si - ^{32}P in the new data set

- Bulk and surface radiogenic backgrounds



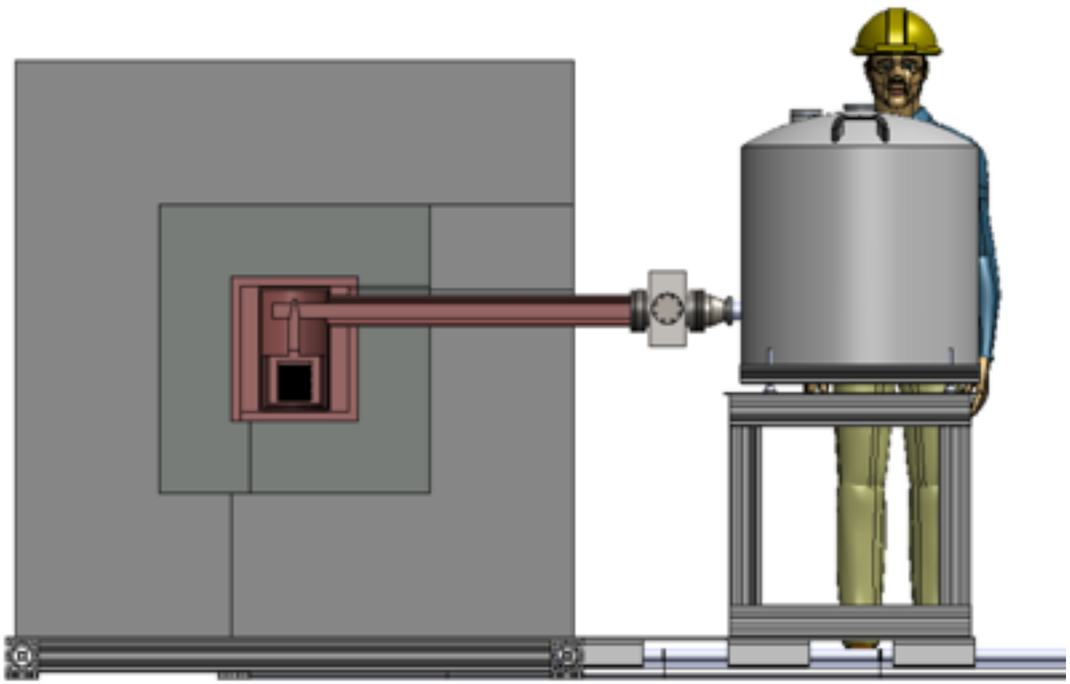
ppt levels sensitivity to bulk contamination

^{210}Pb ($T_{1/2}$= 22.3 y, β) ➔ ^{210}Bi ($T_{1/2}$=5.0 days, β) ➔ ^{210}Po ($T_{1/2}$= 138 days, α)

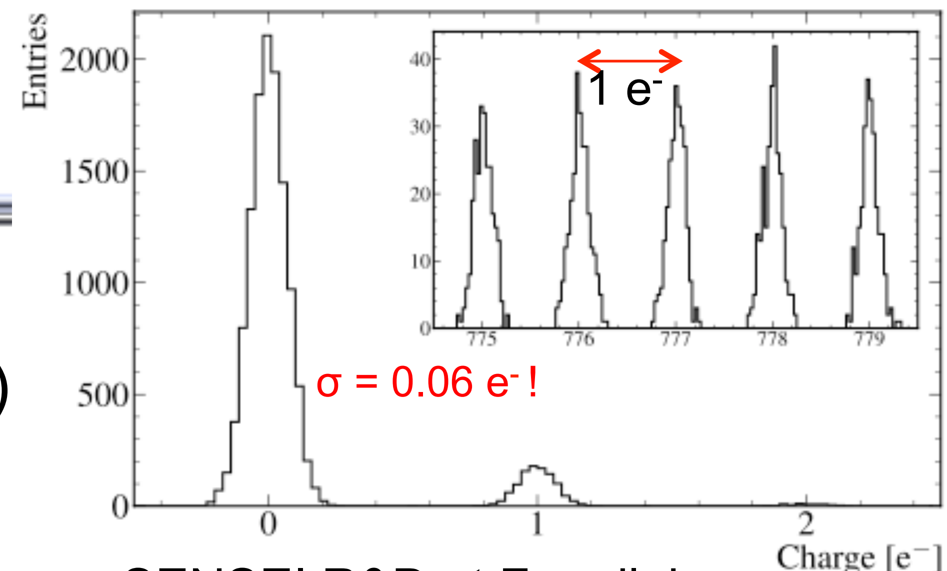
- Cosmogenic tritium sensitivity

Sensitivity to activation rate down to few tens of tritium atoms/kg/day

DAMIC-1K at the LSM



- Proposals submitted for a kg-size detector at the *Laboratoire Souterrain de Modane*
- CCDs with skipper readout for <u>sub-electron noise</u>



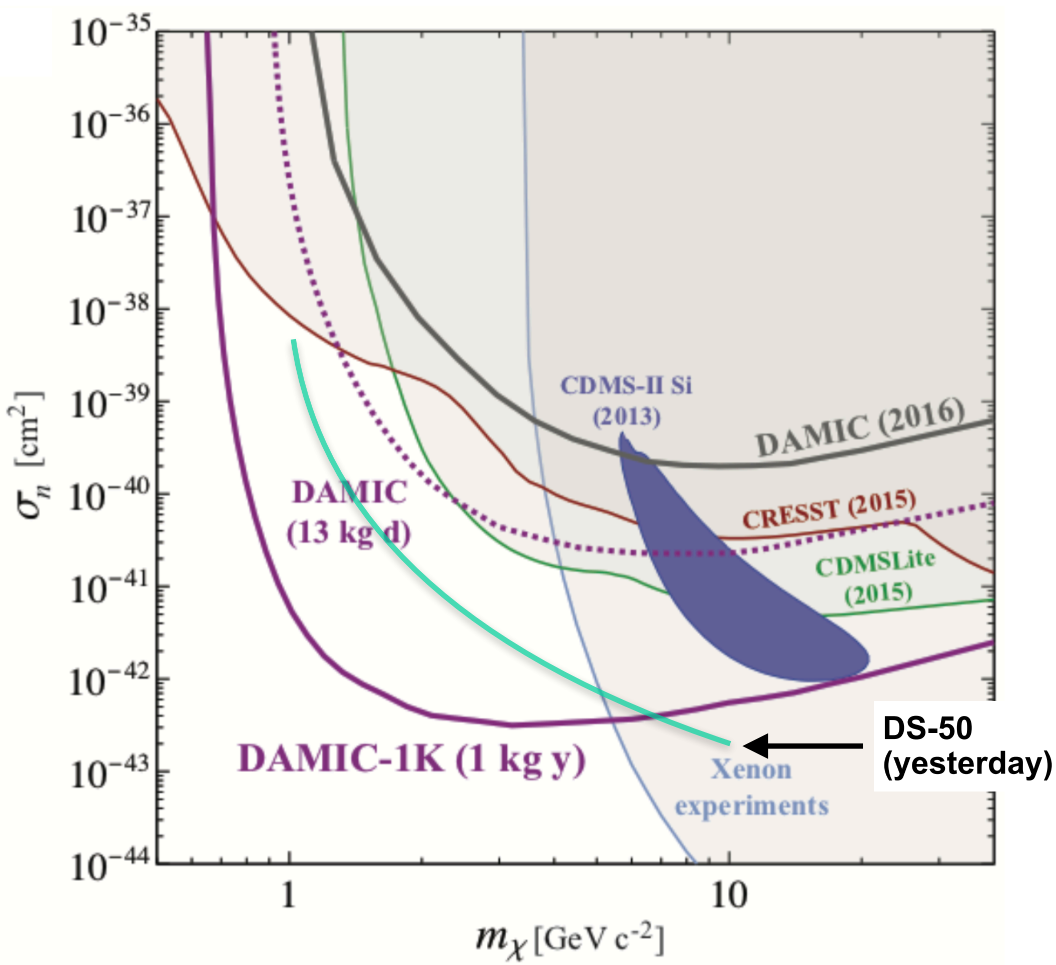
SENSEI R&D at Fermilab

- Large size Skipper CCDs (6k x 4k) for DAMIC-1K development will arrive at **UW in May/June 2018**.

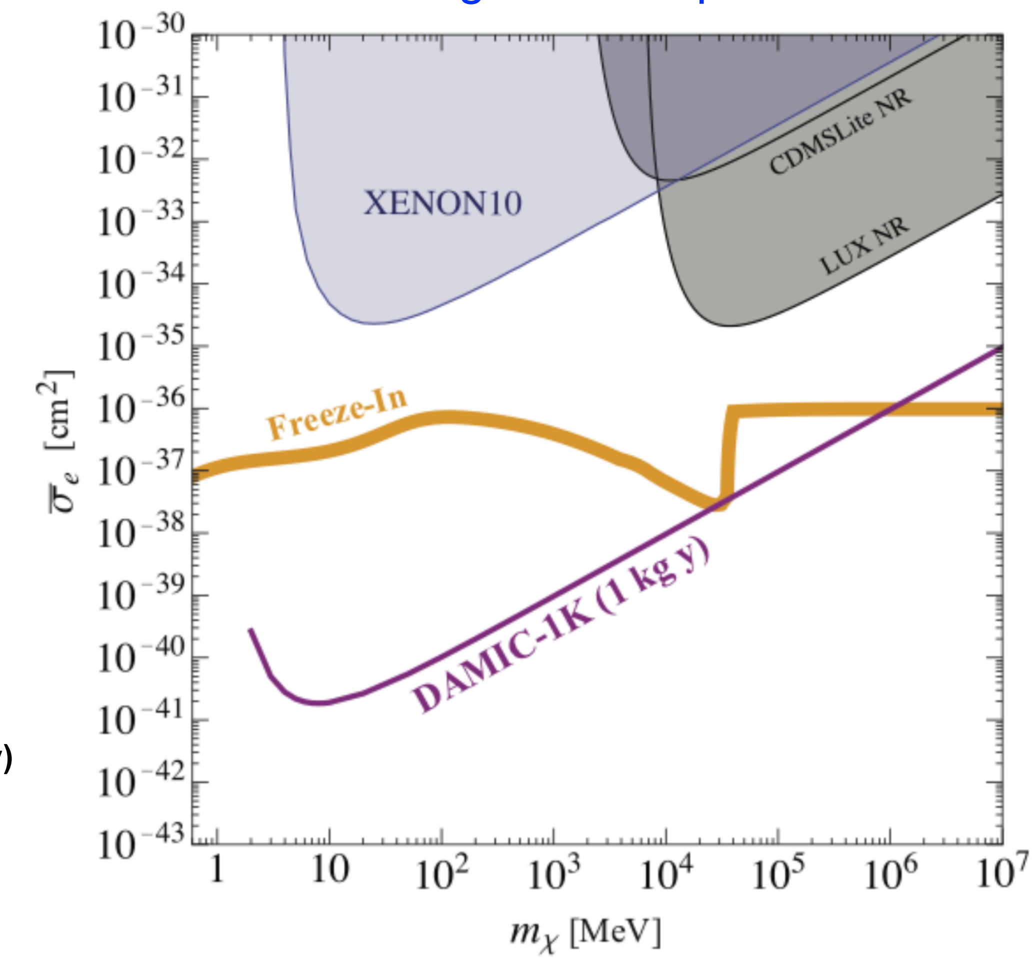
University of Chicago, University of Washington, Pacific Northwest National Laboratory, SNOLAB, Laboratoire de Physique Nucléaire et de Hautes Energies (LPNHE), the Laboratoire de l'Accélérateur Linéaire (LAL) and the Laboratoire Souterrain de Modane/Grenoble (LSM), University of Zurich, Niels Bohr Institute, the University of Southern Denmark, University of Santander, Universidad Federal do Rio de Janeiro, Centro Atomico Bariloche

DAMIC-1K sensitivity

WIMP DM



DM-electron scattering via
ultra-light hidden photon



Outlook

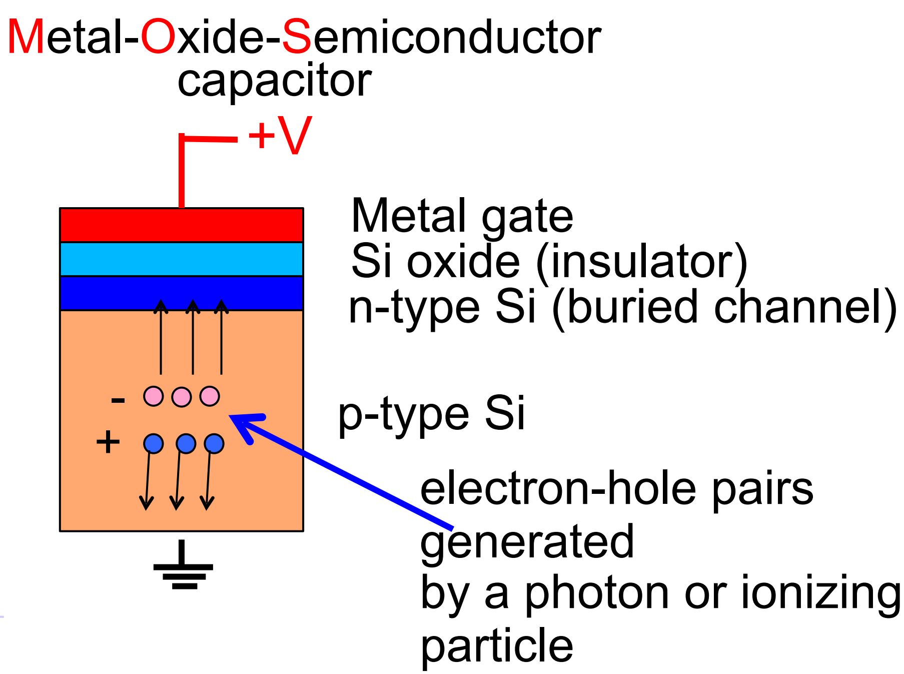
- DAMIC is collecting high quality data - few dru background and 50 eV threshold - with a 40 g CCD detector at SNOLAB. We will reach ≈ 15 kg day in 2018.

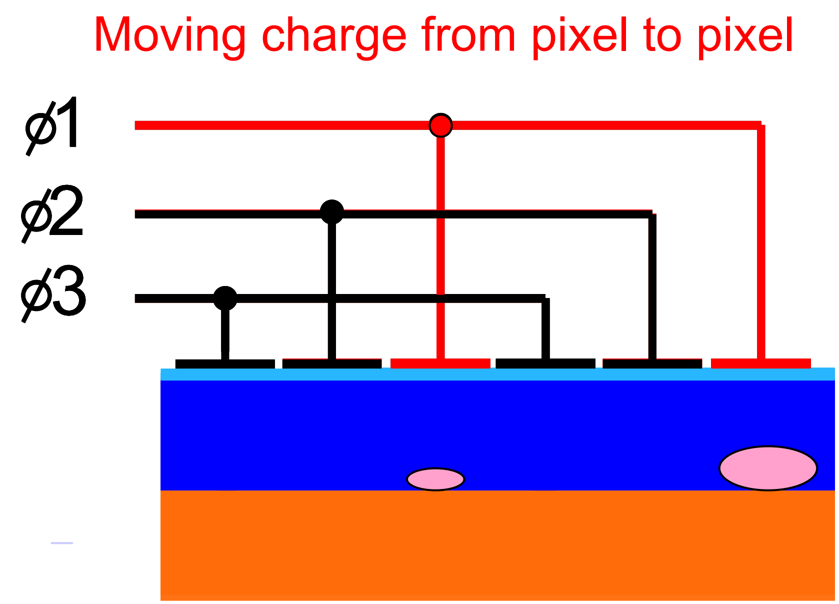
- These data will provide essential information for the next generation of silicon detectors (DAMIC-1K, SuperCDMS):
  - explore spectrum below 2 keV_{ee} in silicon
  - measure cosmogenic and radiogenic backgrounds in silicon
  - measure CCD dark current at the lowest temperatures

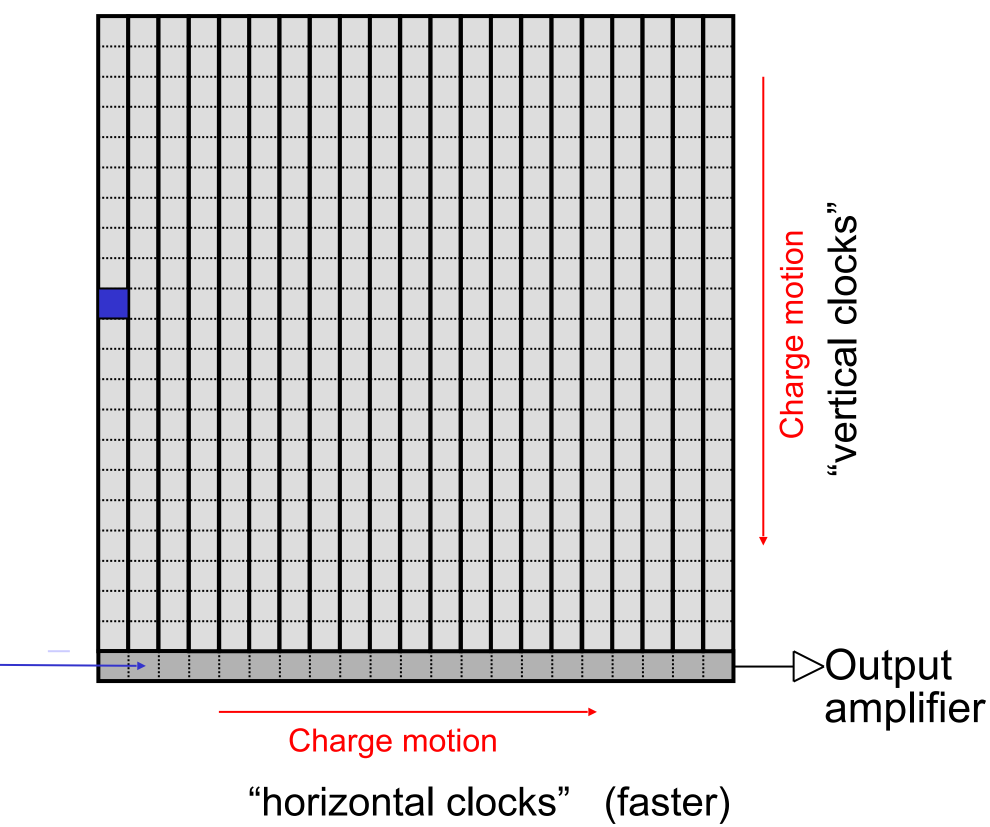
- Next stage is a kg-size DAMIC detector to be installed at the LSM in France. Large-size skipper CCDs will be characterized this year. We will continue to profit from the current setup at SNOLAB in this development stage

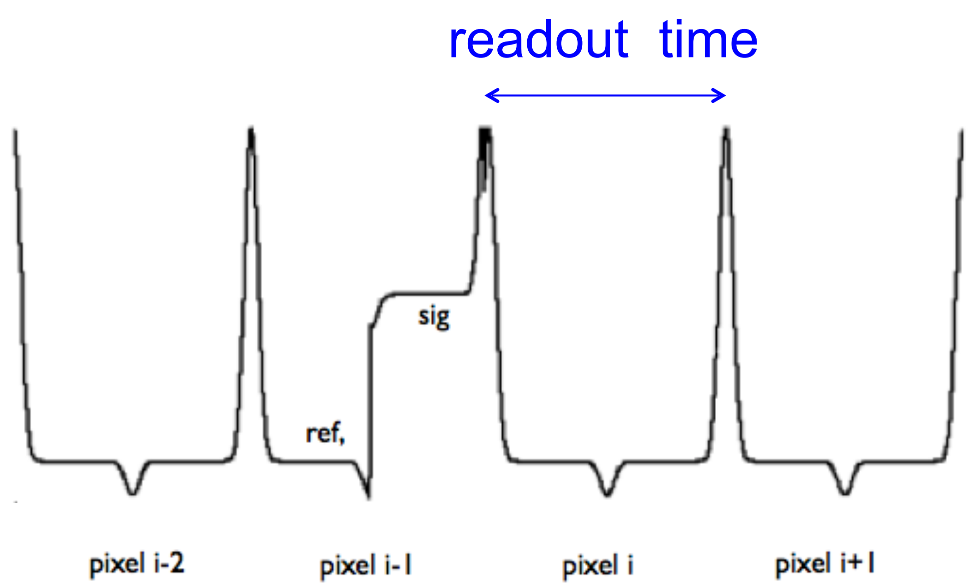
Backup

CCD principle







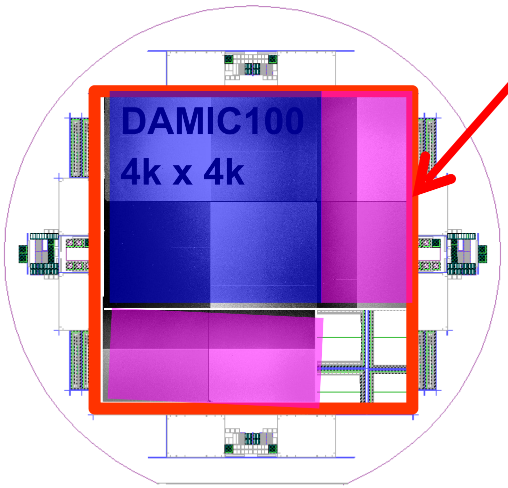


Correlated Double Sampling

DAMIC-1K features

- A kg-size DAMIC built with the existing technology

Silicon wafer



6k x 6k pixels, 1 mm thick

≈ 20 g / CCD

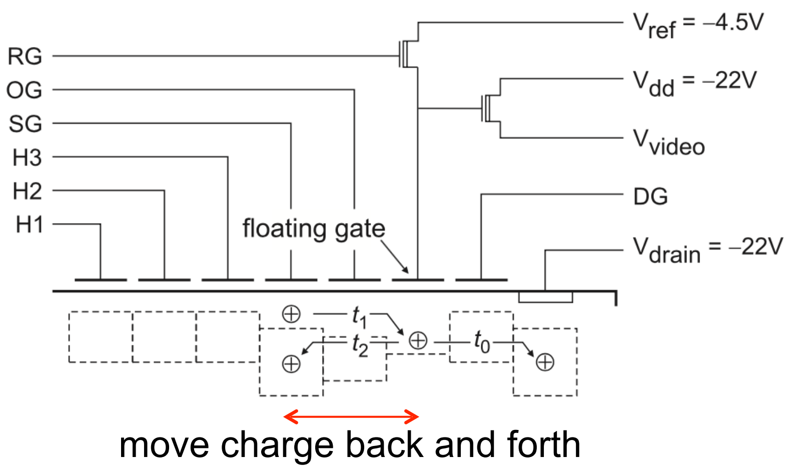
≈ 50 CCDs / 1 Kg

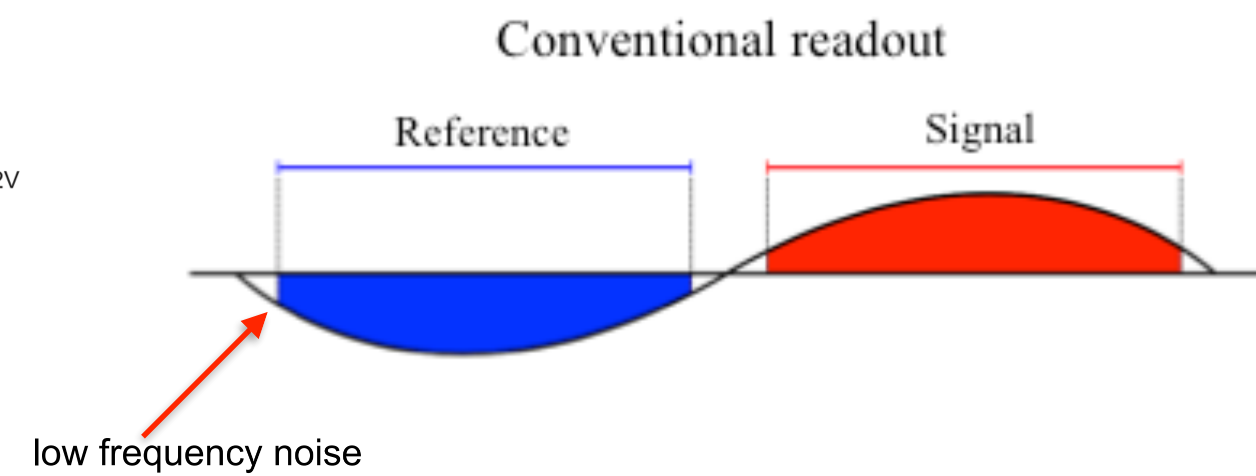
DALSA has confirmed the feasibility to fabricate these larger and thicker CCDs

- 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 sub-e^{-} noise

- Skipper readout — a novel charge readout approach which results in *single electron resolution*





Non-destructive measurement of the charge!

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