Status of the DAMIC-SNOLAB Dark Matter Experiment

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for the DAMIC Collaboration

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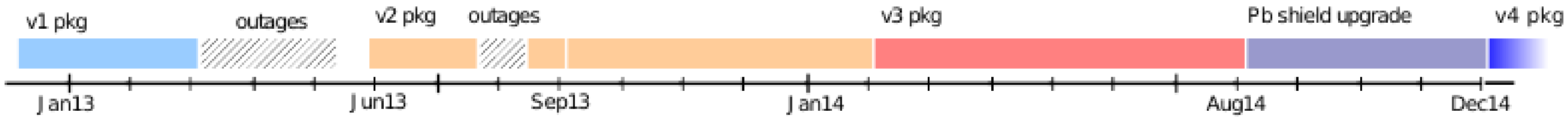
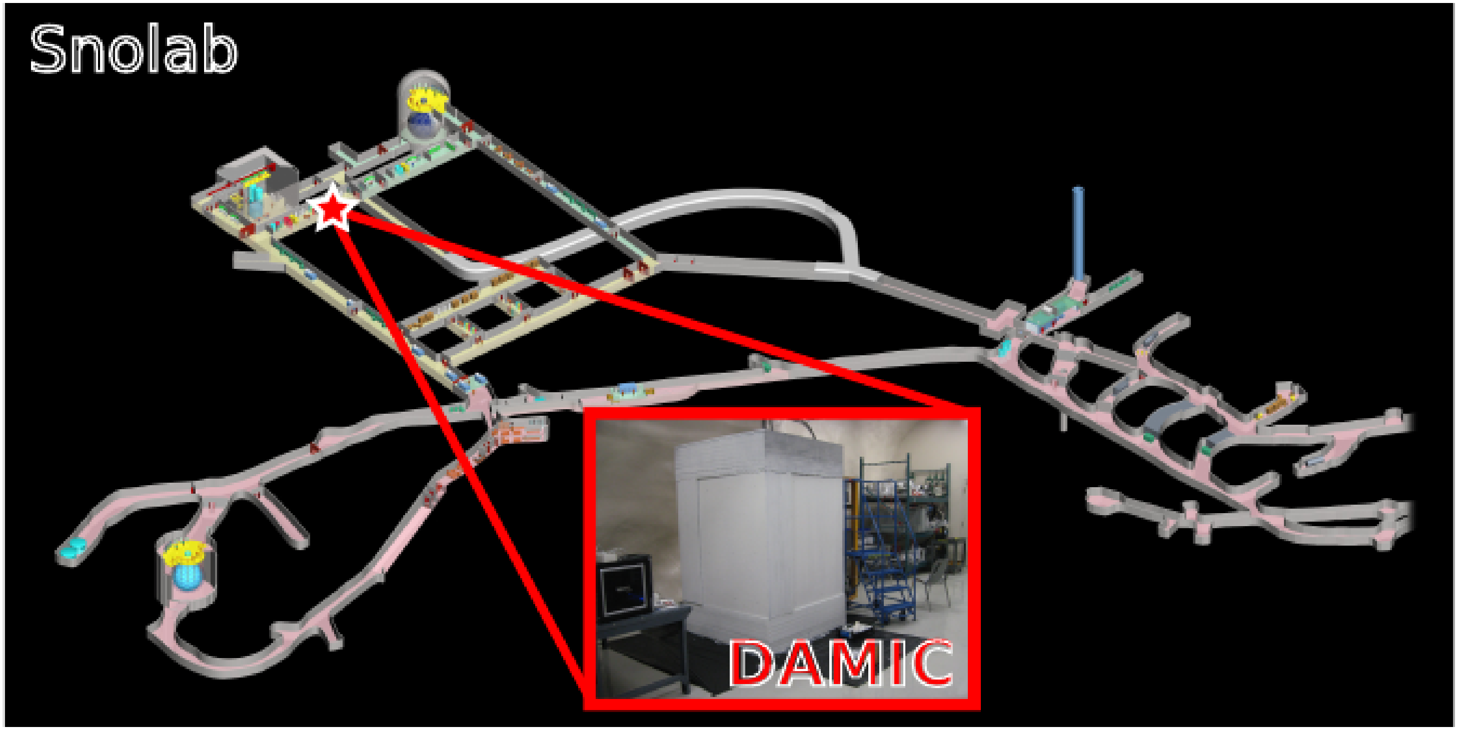
June 14, 2018

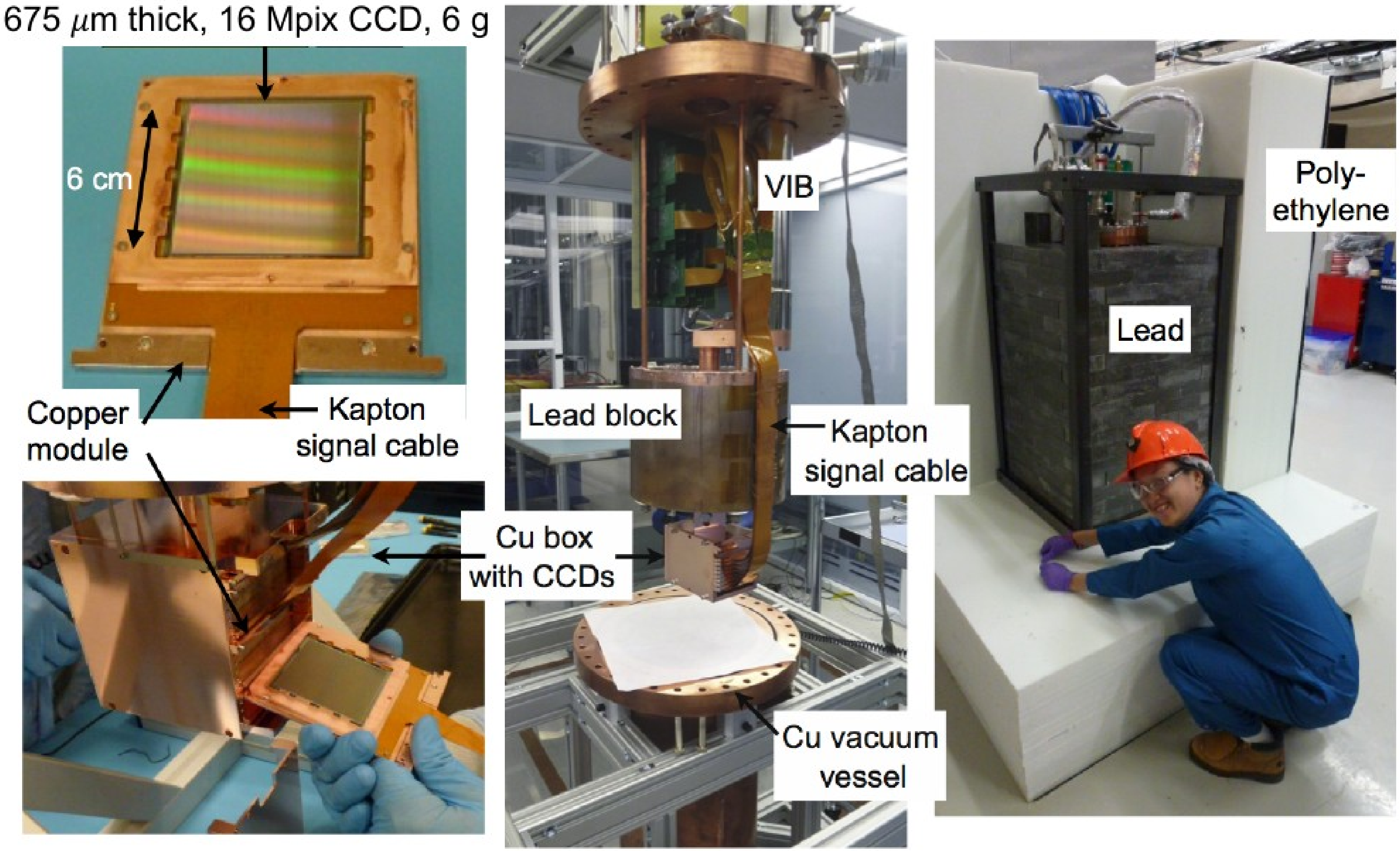
DAMIC-SNOLAB



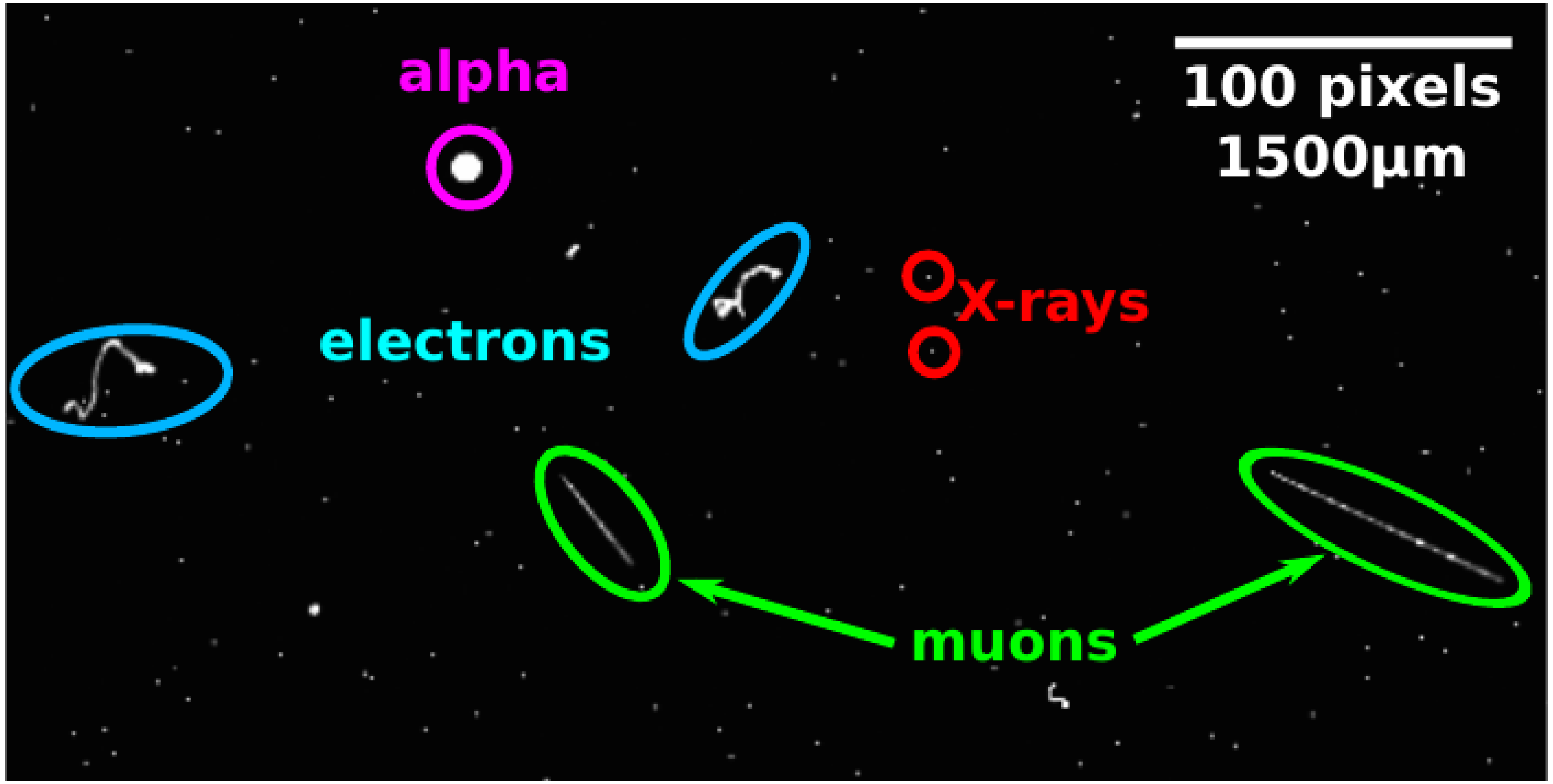


Installed at Snolab: 2km of norite overburden → 6000m water equivalent

DAMIC-SNOLAB



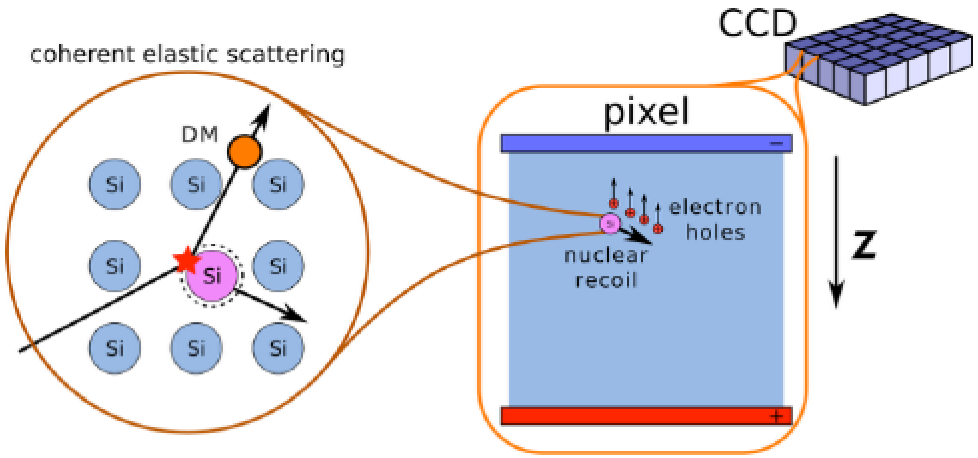
Particle Identification



Data taken at Fermilab (sea level, no radiation shielding)

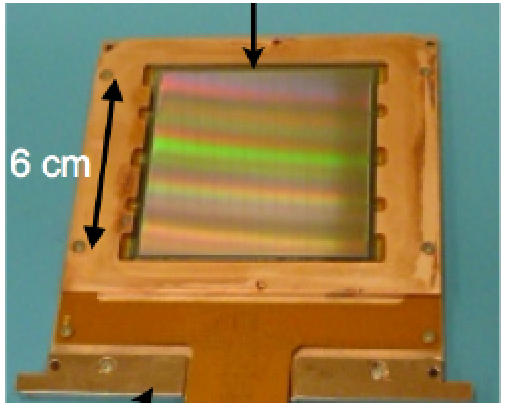
DAMIC-SNOLAB

Detection of point-like energy deposit from nuclear recoils induced by WIMPS interactions in the bulk of CCDs.

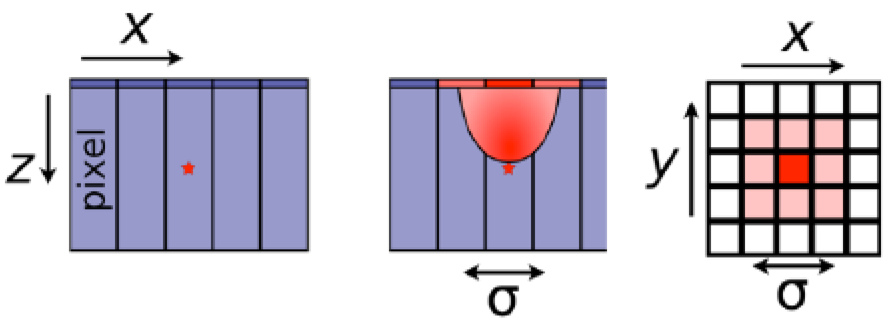


3.7 eV to create e-h pair

Charge-Coupled Device (CCD)



16 Mpix, 15 μm x15 μm, 675 μm thick, 5.9 g mass



3D reconstruction (x, y, z) and unique spatial resolution

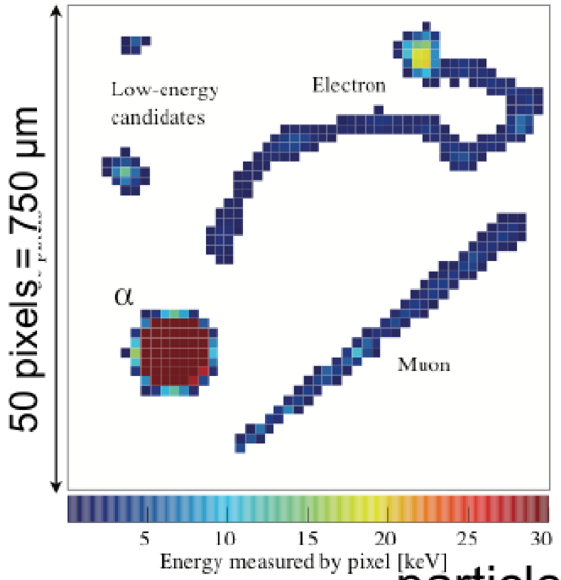
Sensitivity to DM masses
< 10 GeV (nuclear recoil)
~ eV (electron recoil)

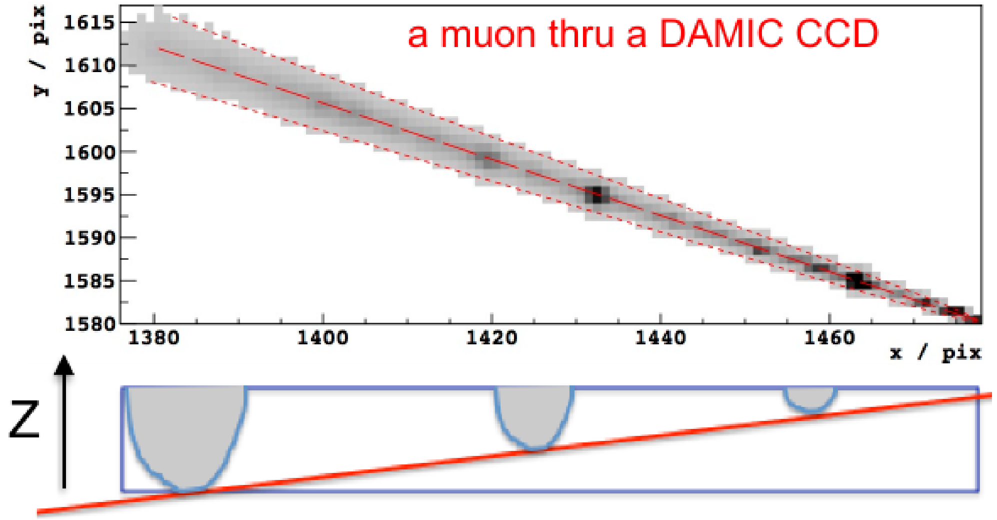
R&D program (2013-2015)

40g detector commissioned in 2017

DAMIC CCDs

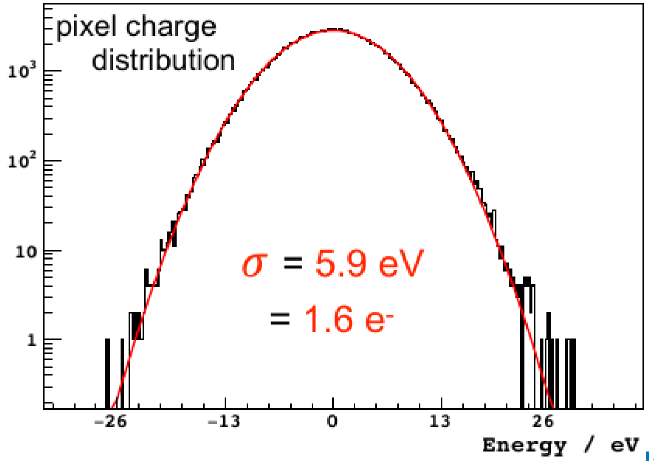
exquisite spatial resolution





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

particle identification and background characterization



extremely low noise and dark current

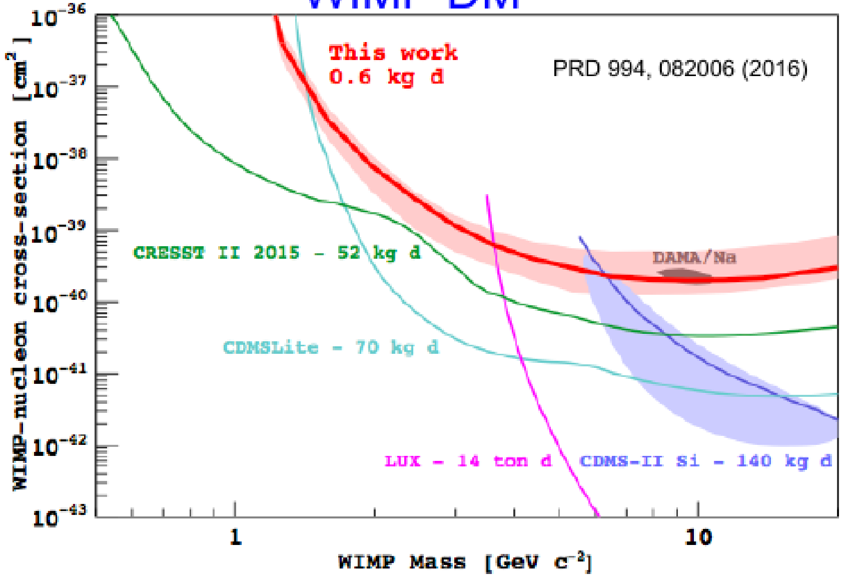
lowest dark current ever measured in a silicon detector:

5×10^{-22} A/cm² (at 140 K)

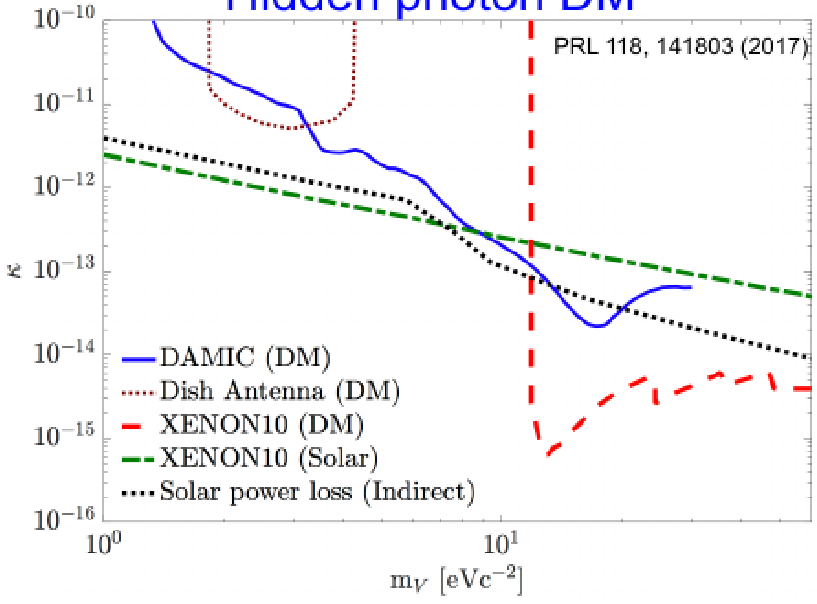
(improved wrt R&D phase where σ = 2 e^- and current = 10^{-21} A/cm² at 100 K)

Selected Results

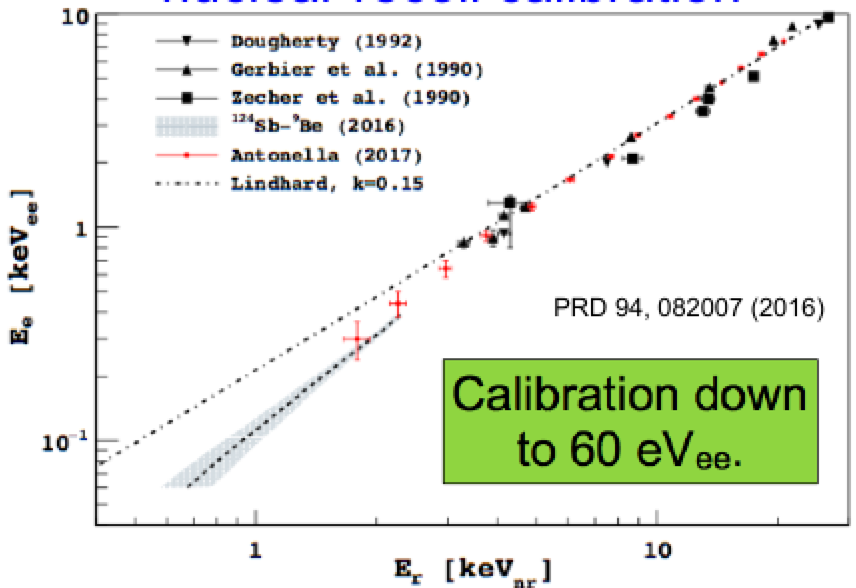
WIMP DM



Hidden photon DM



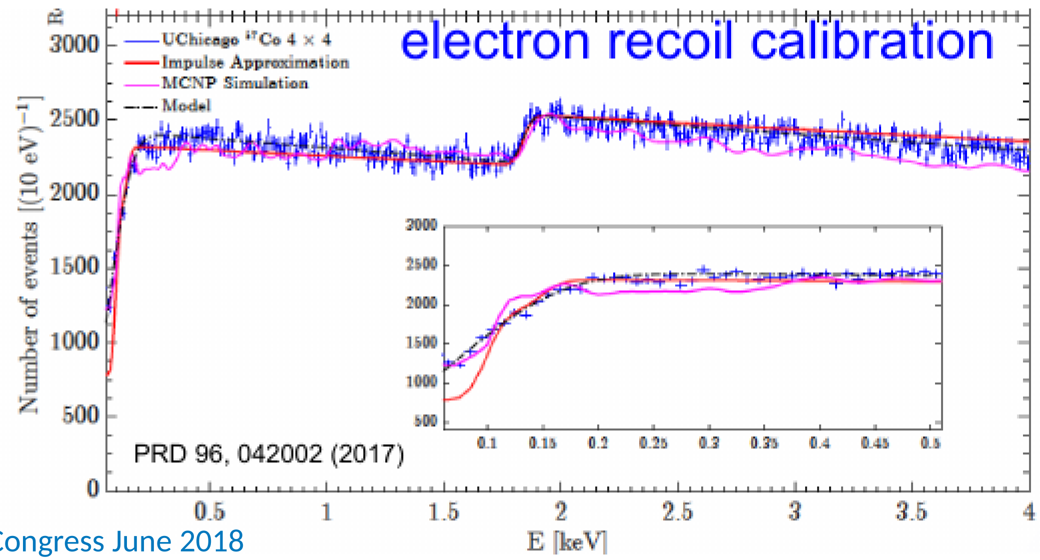
nuclear recoil calibration



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

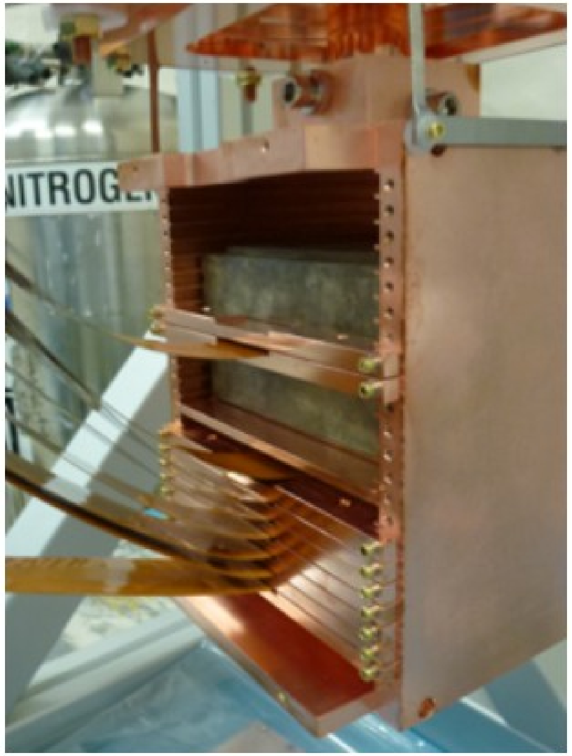
radioactive bkg in the silicon bulk
2015 *JINST* **10** P08014

electron recoil calibration

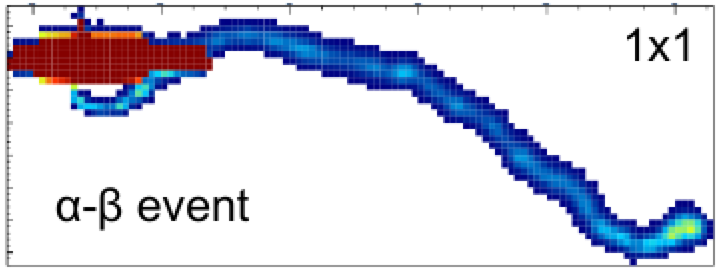


Current Status

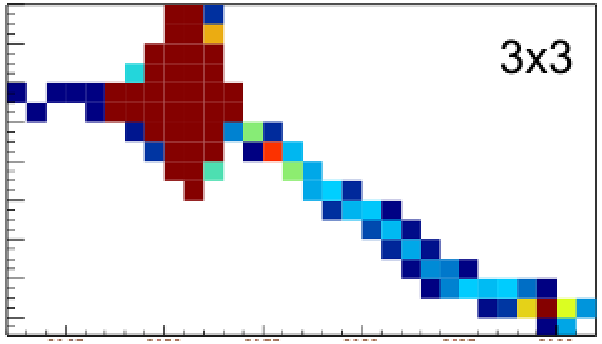
- Seven CCDs in stable data taking;
  40 g detector
  One CCD sandwiched in ancient lead
- A data set (7.6 kg day) collected with full spatial resolution (1x1 binning), optimized for background characterization and measurement (^{32}Si, ^{210}Pb)
- A second data set being collected (so far 4.7 kg day)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

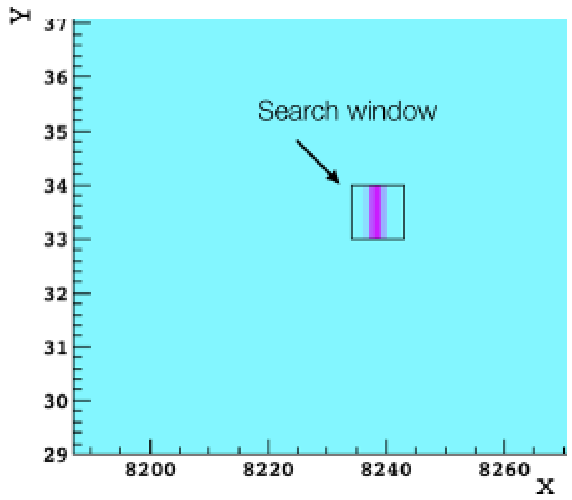


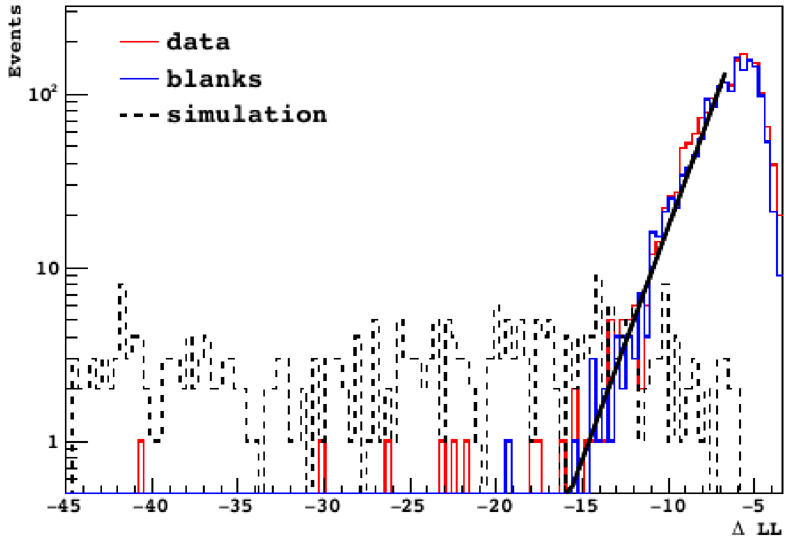
Event Selection

- Pedestal and correlated noise subtraction (hot pixels among several images masked)
- LL fit of the signal in a moving window across the image

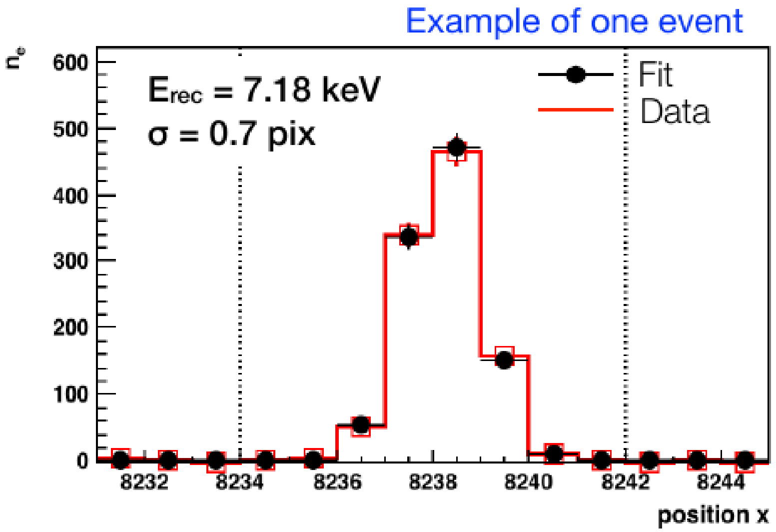
$$\Delta LL = \mathscr{L}_n - \mathscr{L}_s$$

flat noise ($\mathscr{L}_n$) — Gaus signal + flat noise ($\mathscr{L}_s$)

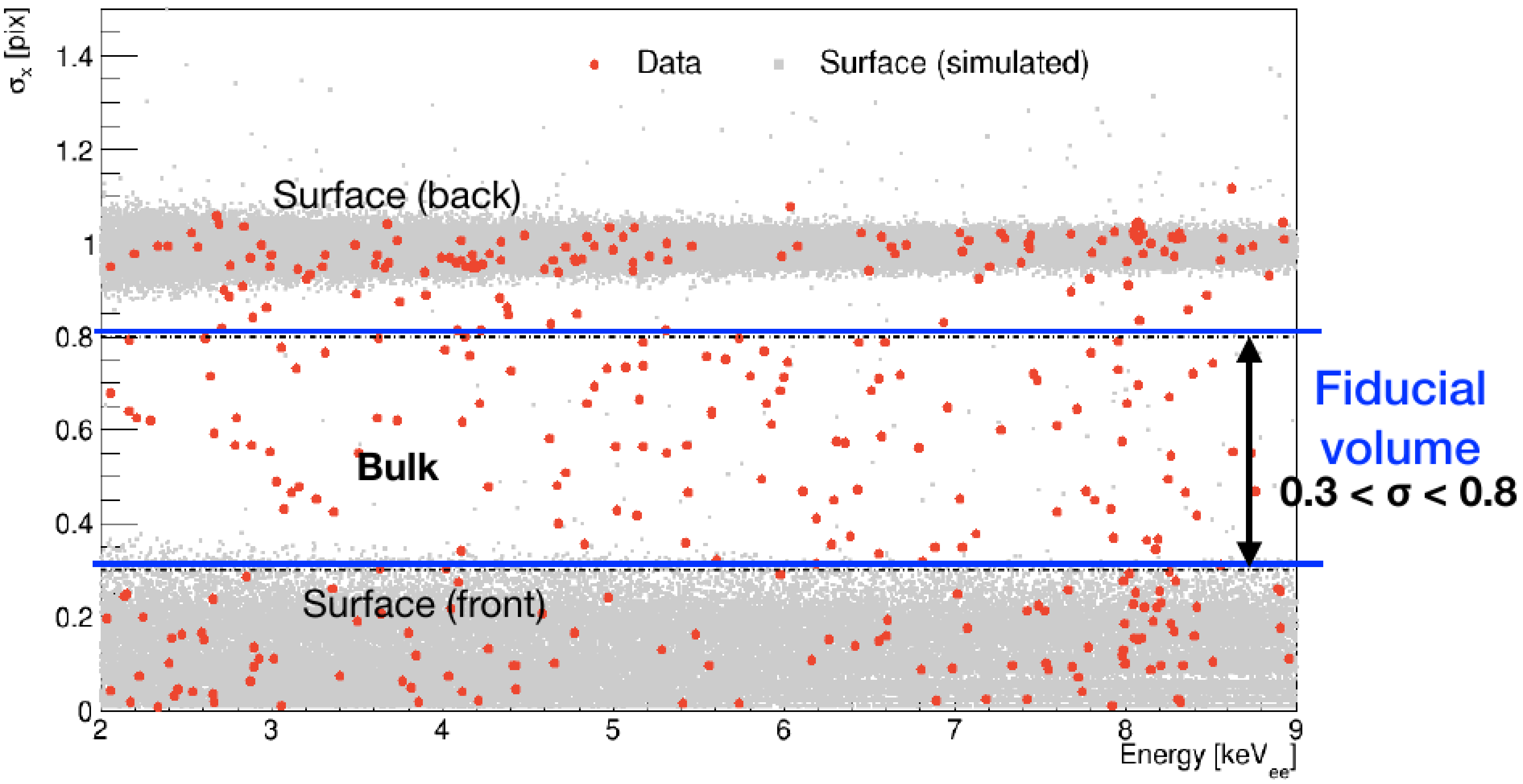




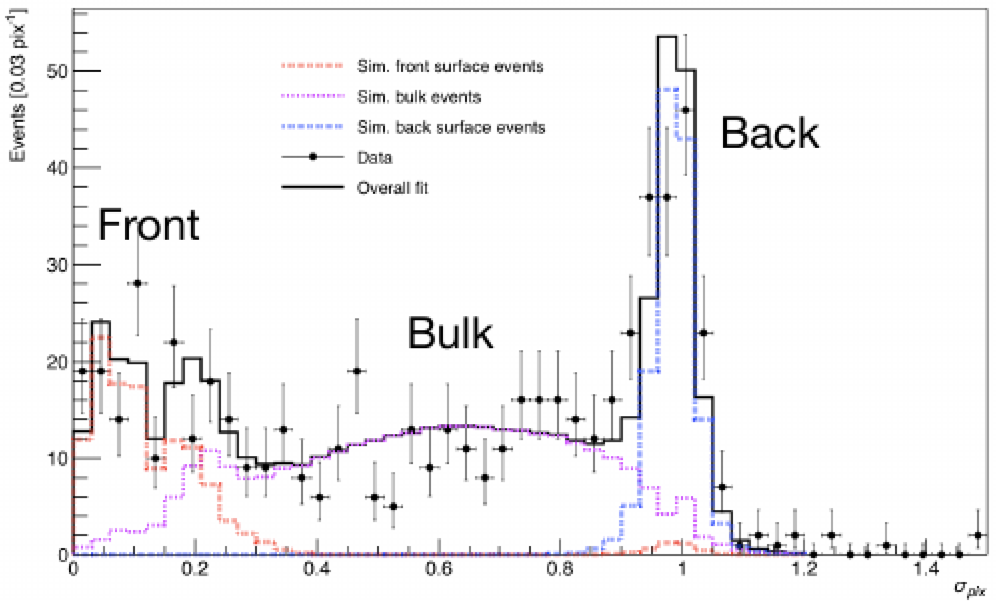
DLL cut : < 0.001 bkg events from exponential fit of the "blanks" distrib

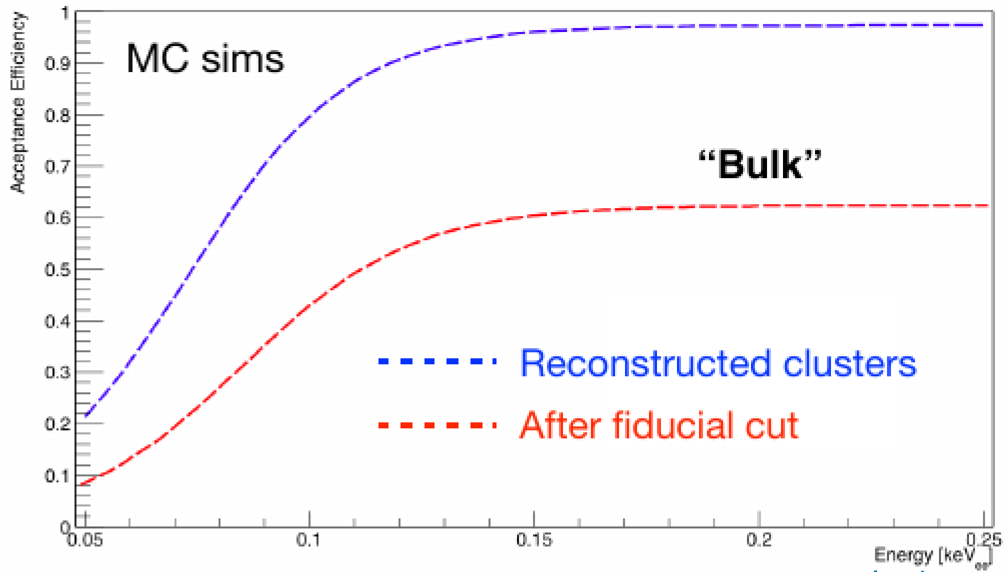


Surface Background Rejection



Backgrounds





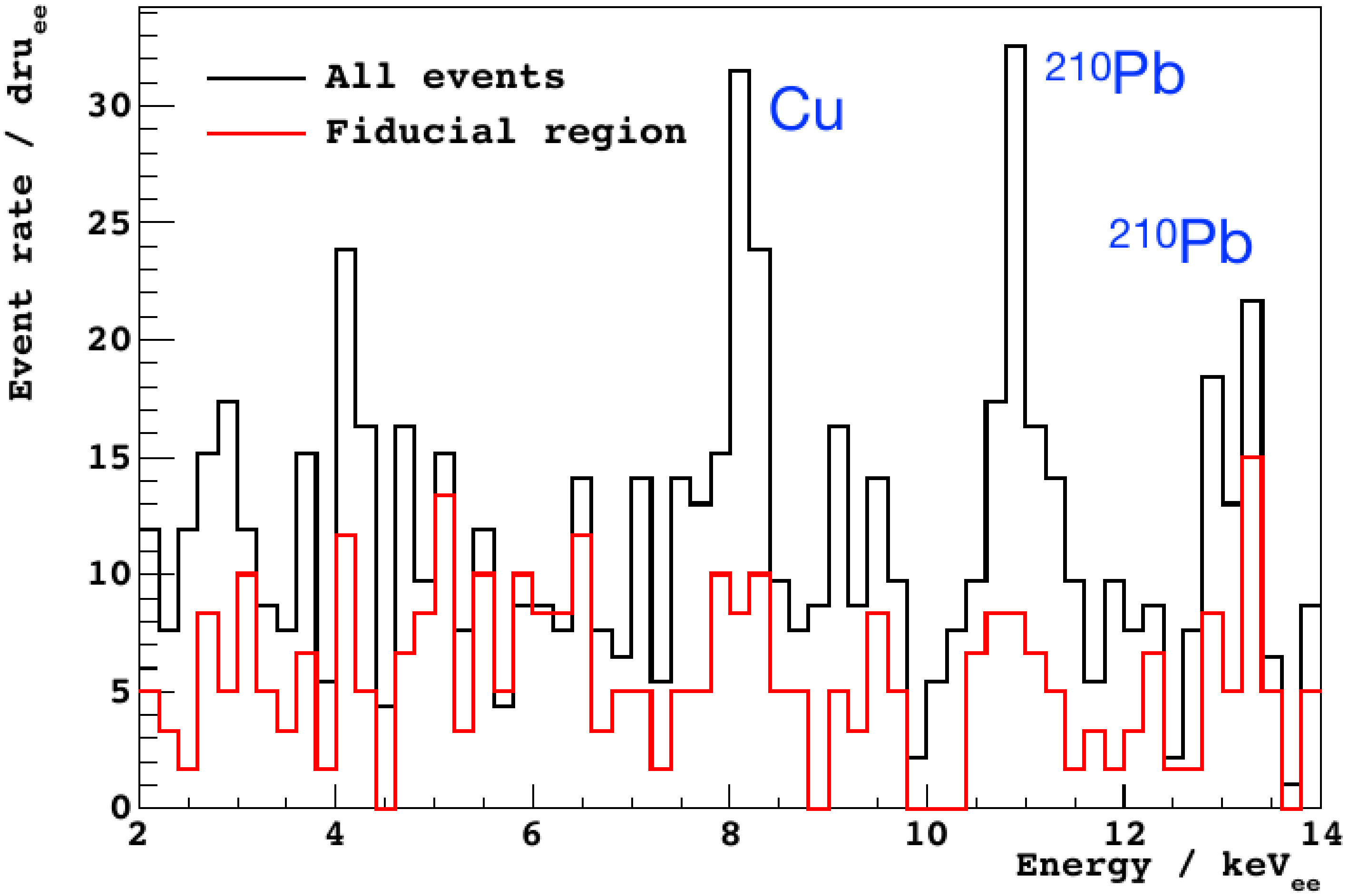
Background on front/back surfaces of the CCD

Bkg model compared to data
(50/25/25 of bulk/front/back)

Acceptance for bulk events (from MC simulations)

Energy threshold : 50 eV$_{ee}$

Energy Spectrum Above 2 keV



≃ 5 dru in fiducial region, consistent between CCDs

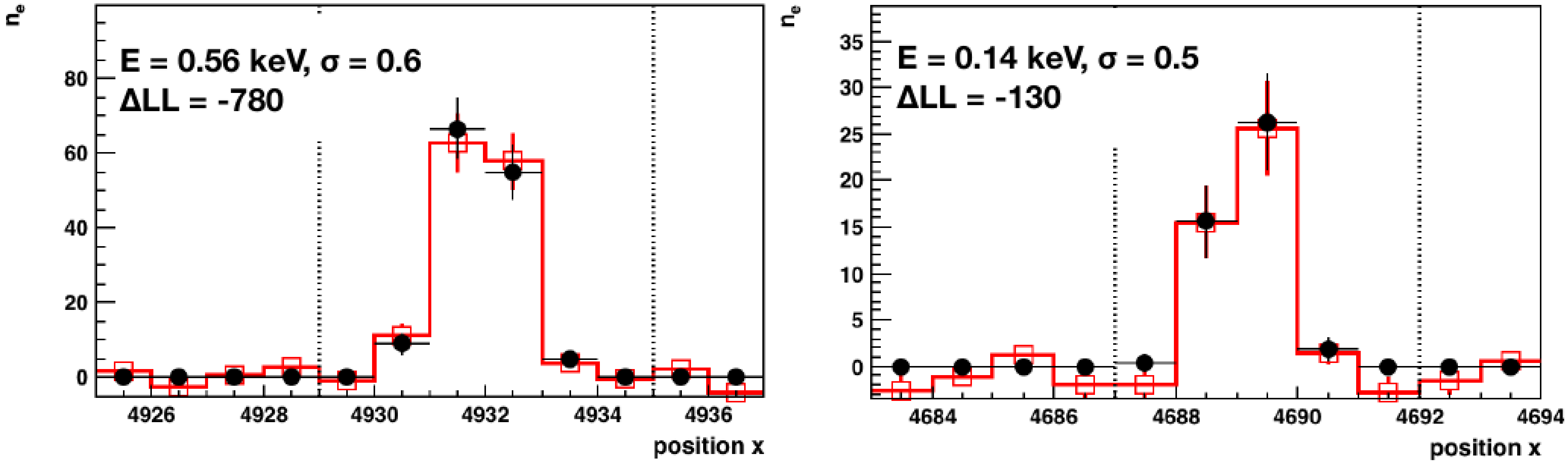
a factor of ≃ 3-4 lower than our previous background level

≃ 2 dru for lead sandwiched CCD

Differential rate unit (dru) = 1 event /keV/kg/day

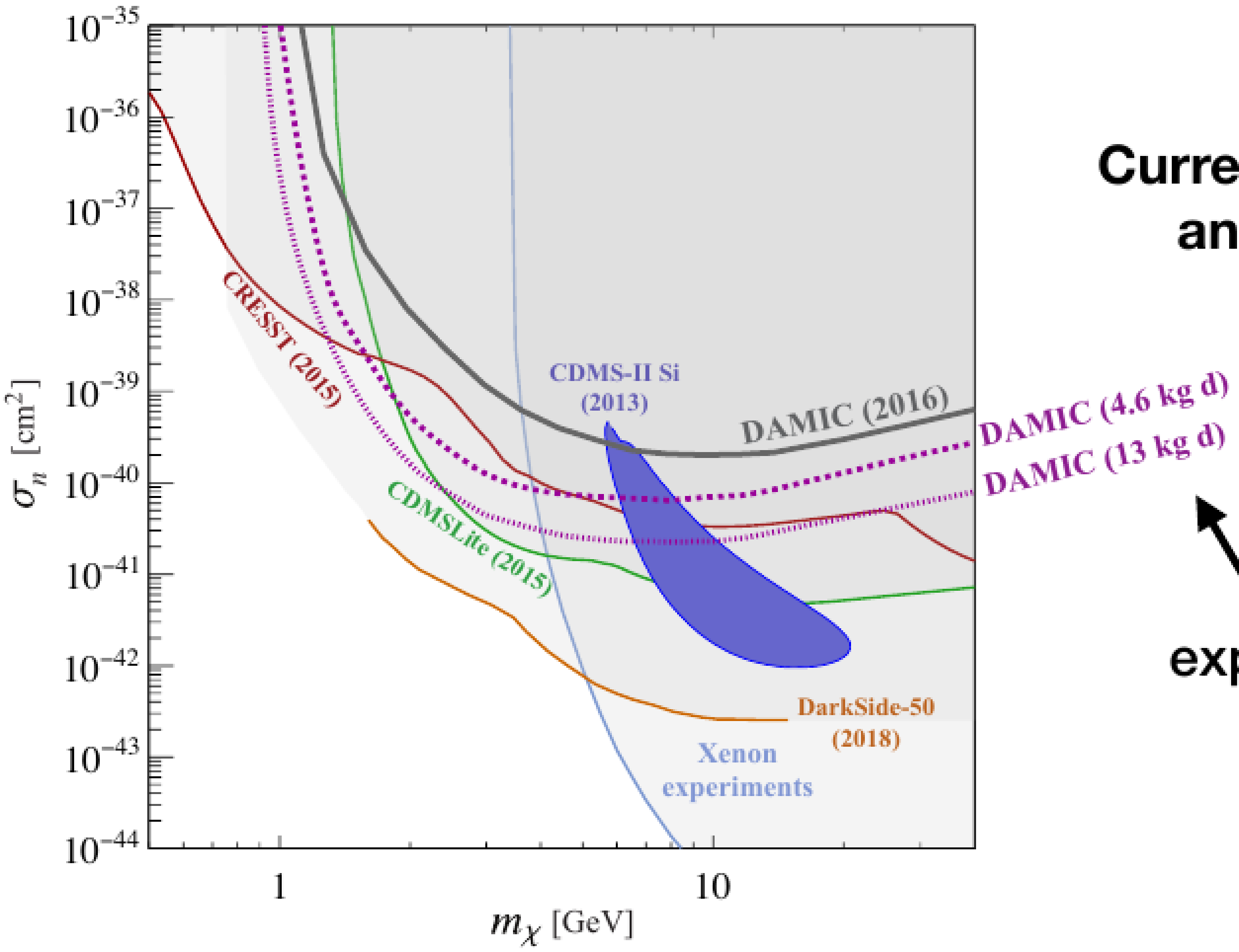
Low Energy Data 0.05 - 2 keV

Two example events (data + fit)



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

Expected Sensitivity

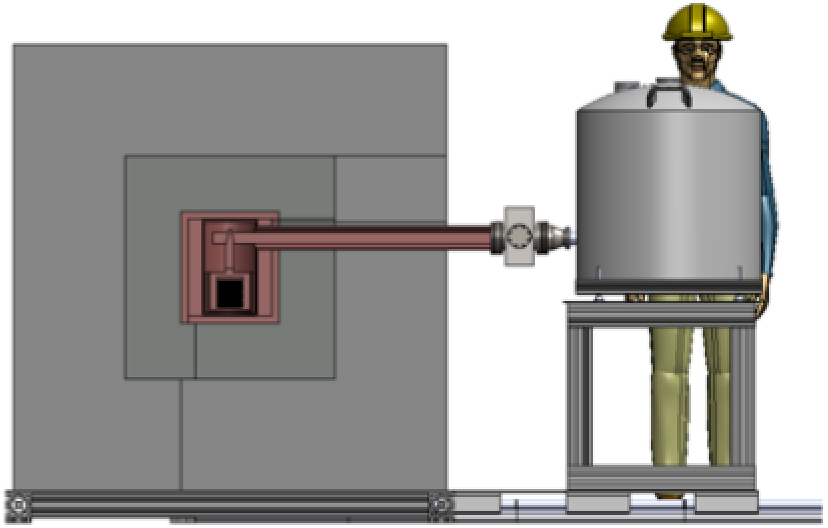


Current exposure (03/2018) and bkg (5 keV/kg/d)

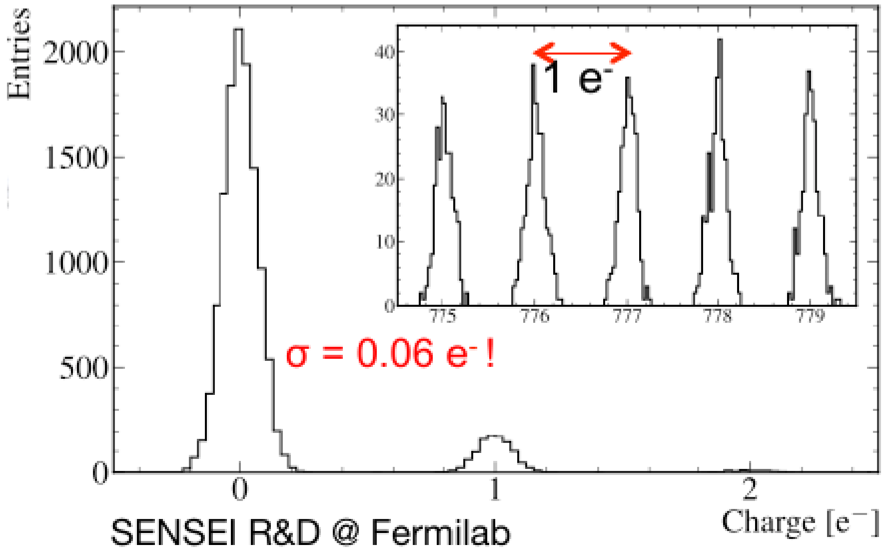
exposure by end 2018

Exploring for the 1st time the CDMS signal with the silicon target and a much lower energy threshold (0.6 keV_{nr} ~ 0.05 keV_{ee})

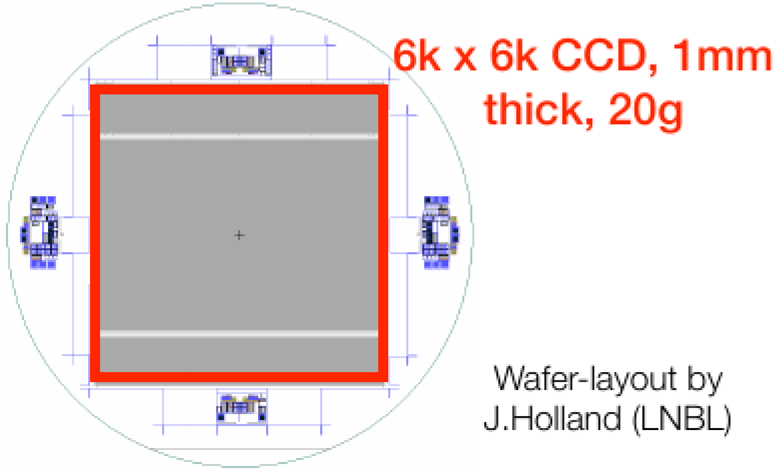
DAMIC-M at Laboratoire Souterrain de Modane



- Largest CCD ever built
  (6k x 6k x 1mm, mass 20 g)
- Skipper readout for sub-eV noise
- Bkg reduction to a fraction of dru
  (improved design, materials, procedures)



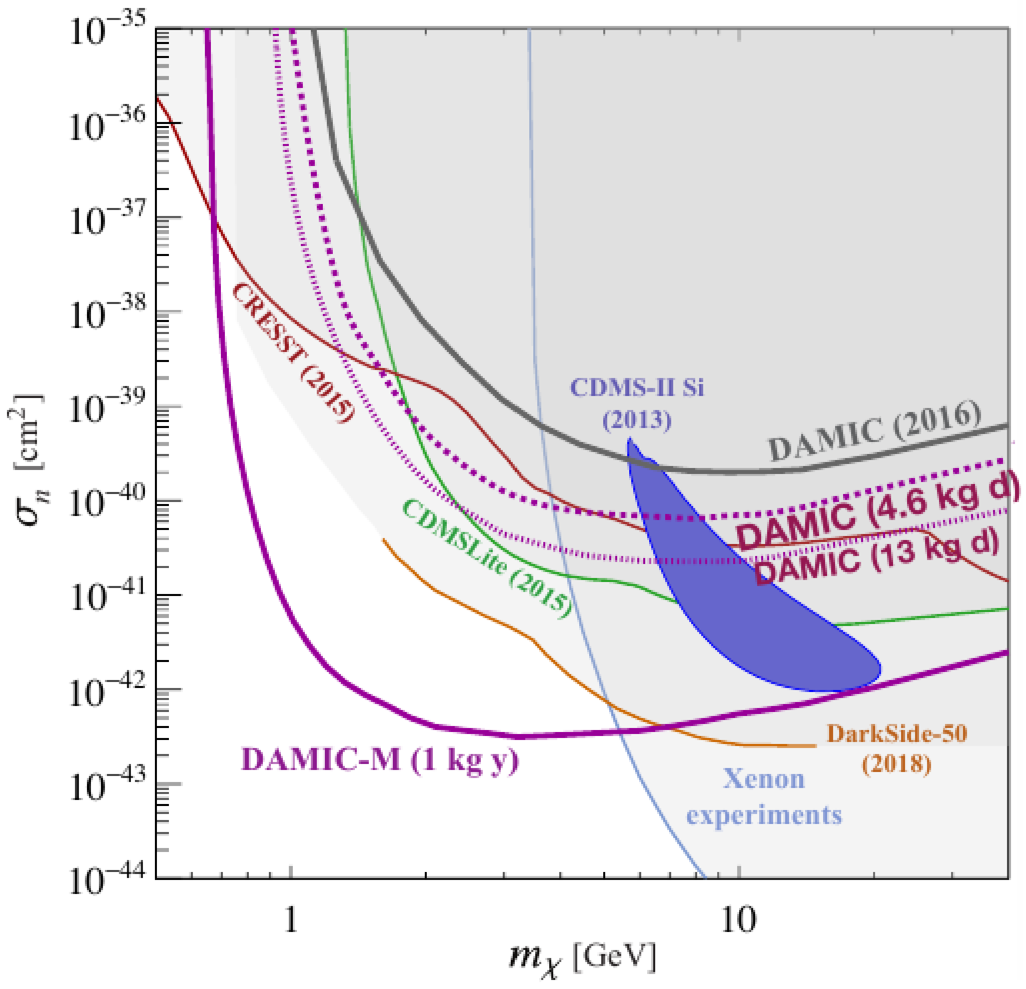
SENSEI R&D @ Fermilab



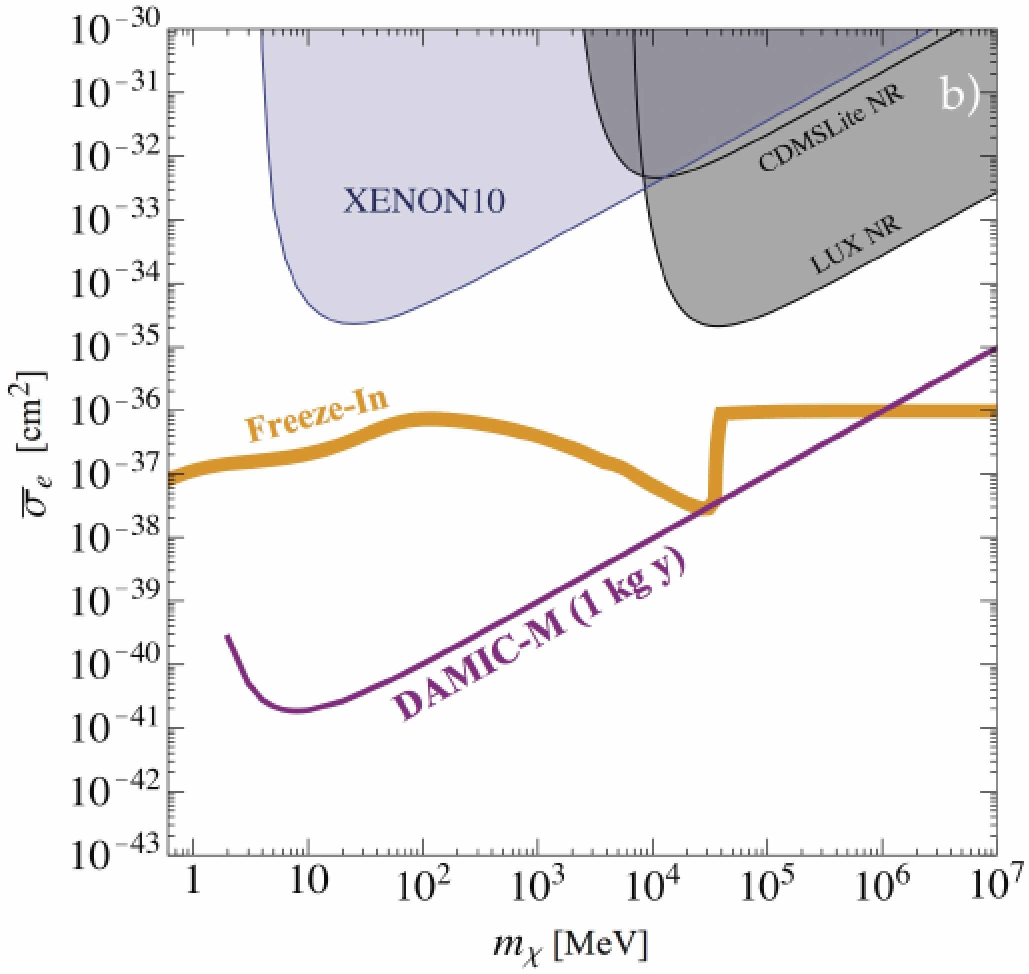
1st skipper CCDs (10g) at UW in summer for testing

Expected DAMIC-M Sensitivity to Dark Matter

WIMP search



DM-electron scattering via ultra-light hidden photon



Summary and Outlook

DAMIC operating with 40 g detector since 2017.

- Collect exposure: ~ 4.6 kg-d so far,
  expect to have ~ 13 kg-d by end of 2018

High quality data:

- 50 eV threshold
- Low noise (dominated by readout)
- Few dru background

These data will provide essential information for the next generation of silicon detectors.

- Spectrum below 2 keV
- Cosmogenic and radiogenic backgrounds in silicon
- CCD dark current at lowest temperature

Next phase: a kg size DAMIC detector at LSM, France

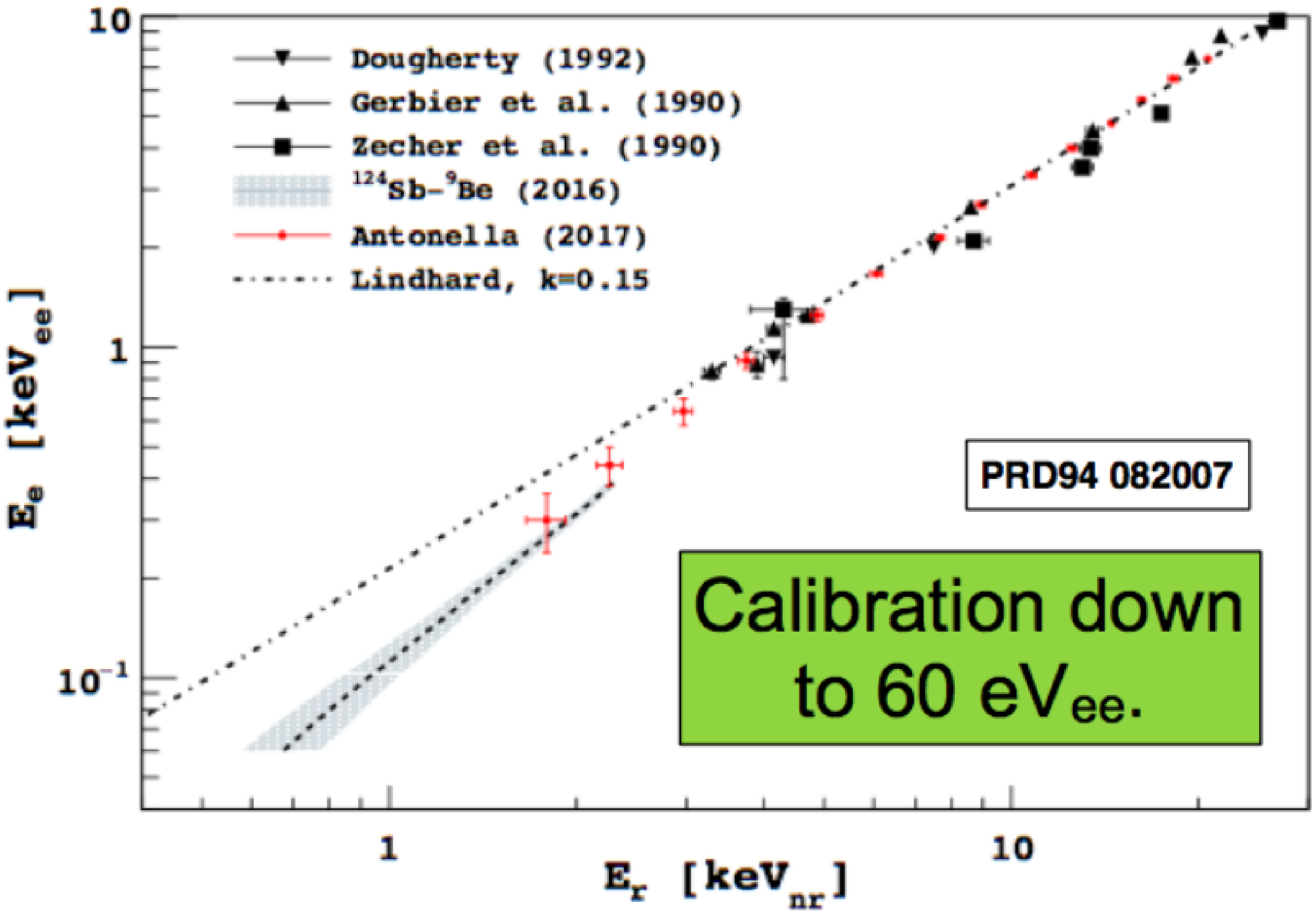
- A larger skipper CCD will be characterized in early 2019 in the SNOLAB-DAMIC experiment
- DAMIC-SNOLAB will continue to run while DAMIC-M is designed and built

DAMIC Collaboration

Argentina:	Centro Atómico Bariloche
Brazil:	Universidade Federal do Rio de Janeiro
Canada:	SNOLAB
Columbia:	University of Santander
France:	LPNHE Paris, Laboratoire de l'Accélérateur Linéaire (LAL), Laboratoire Souterrain de Modane/Grenoble (LSM)
Denmark:	Niels Bohr Institute, University of Southern Denmark
Mexico:	Universidad Nacional Autónoma de México
Paraguay:	Universidad Nacional de Asuncion
Switzerland:	Universität Zürich (UZH)
United States:	Fermilab, U. Chicago, U. Michigan, U. Washington, PNNL

Backup Slides

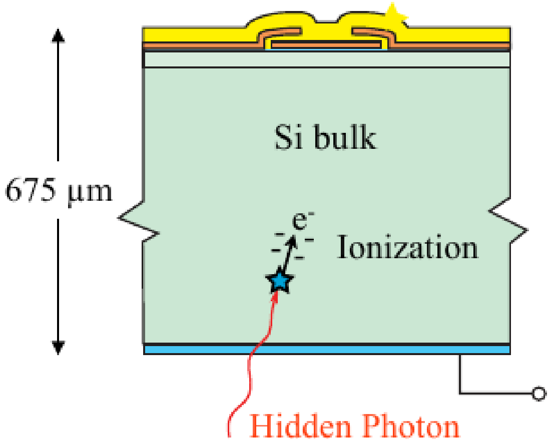
Nuclear-recoil Ionization Efficiency in Silicon

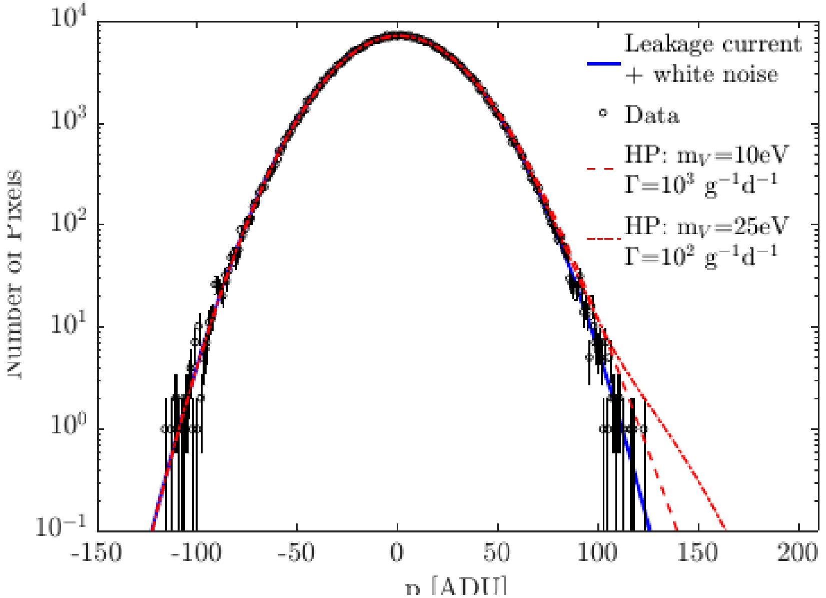


deviation from Lindhard theory observed – crucial for low-mass WIMP searches with silicon detectors

Hidden Photon Search

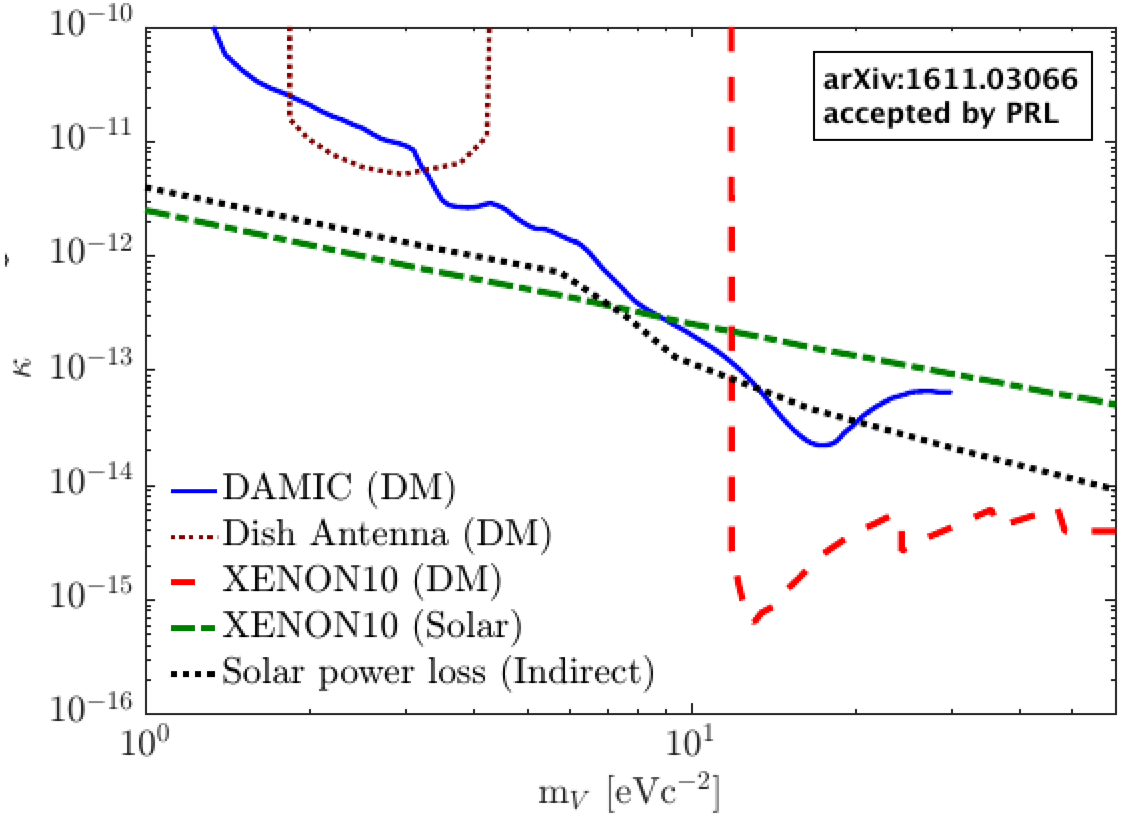
Absorption of hidden-photon dark matter.





~1 week of data with 1 CCD.

Leakage current **4 e^- mm^{-2} d^{-1}**.



← Pixel distribution consistent with white noise + uniform leakage current.

ββ Coincidences

$^{210}Pb \xrightarrow{64\ keV} {}^{210}Bi \xrightarrow{1.2\ MeV} {}^{210}Po$

$T_{1/2} = 5$ d

$^{32}Si \xrightarrow{0.22\ MeV} {}^{32}P \xrightarrow{1.7\ MeV} {}^{32}S$

$T_{1/2} = 14$ d

57 days of data in 1 CCD:

^{210}**Pb** < 37 kg^{-1}d^{-1}
(95% C.L.)

^{32}**Si** = 80^{+110}_{-65} kg^{-1}d^{-1}
(95% C.L.)

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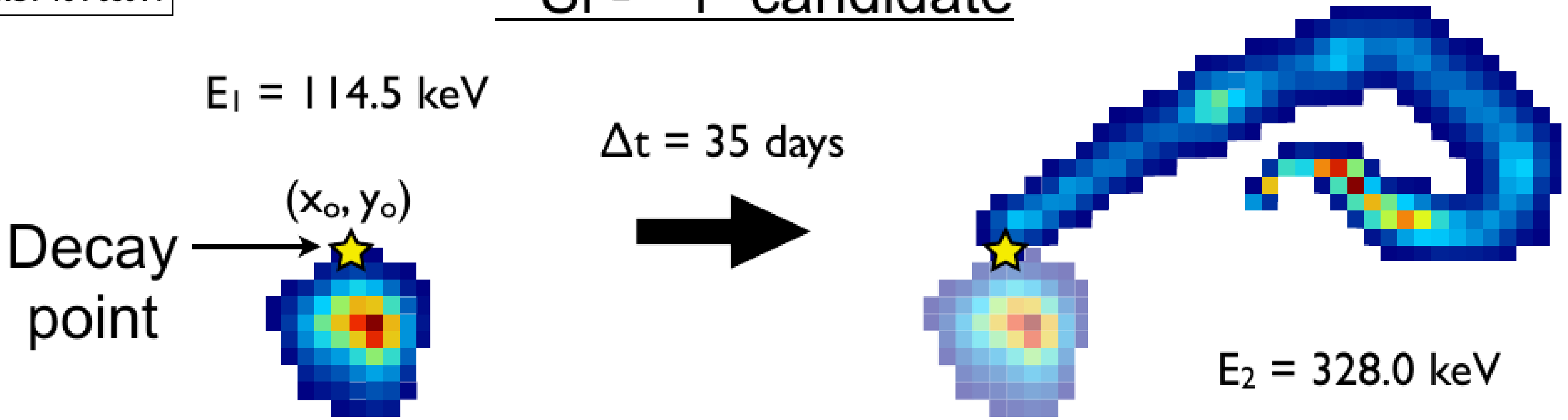
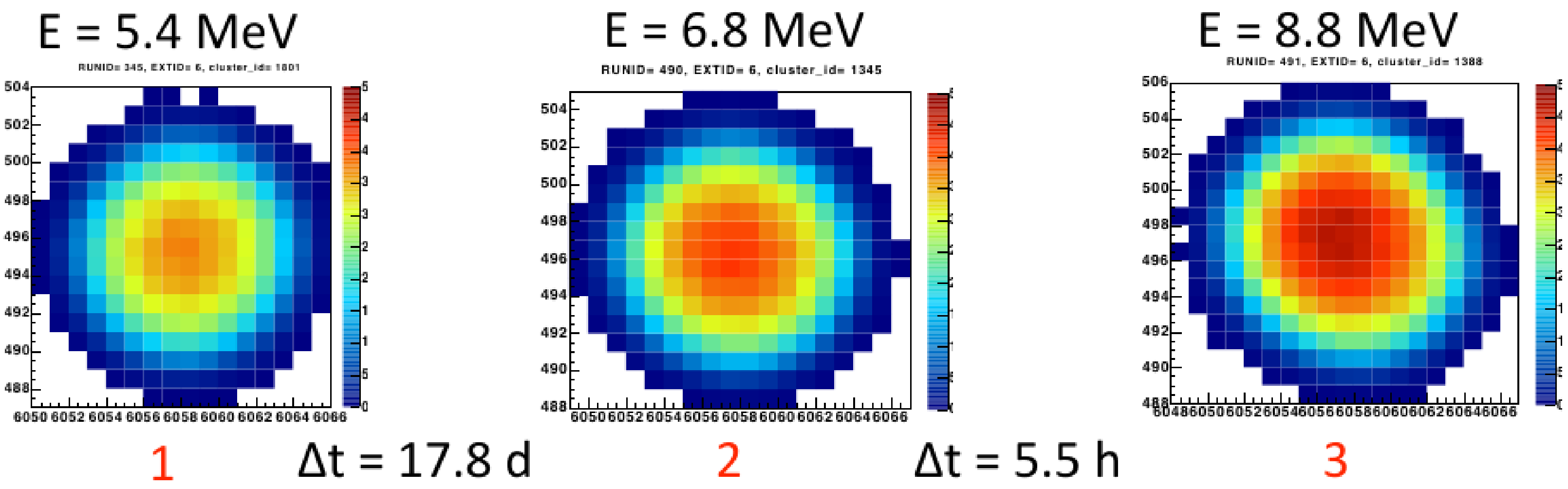
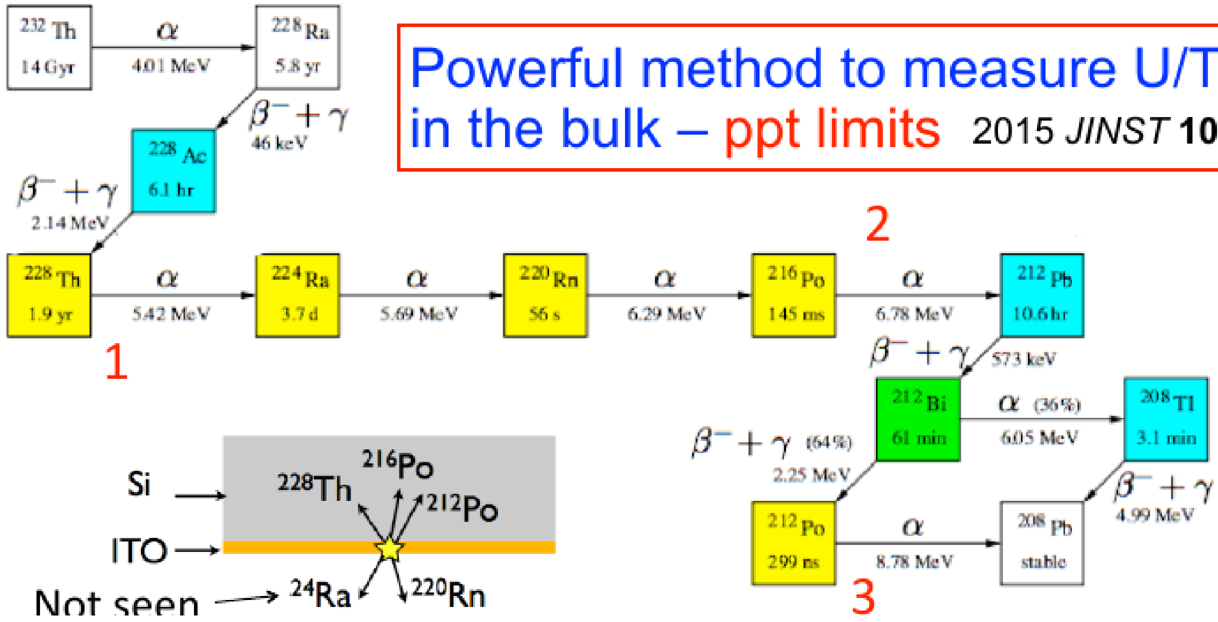
^{32}Si - ^{32}P candidate



DAMIC Background Characterization

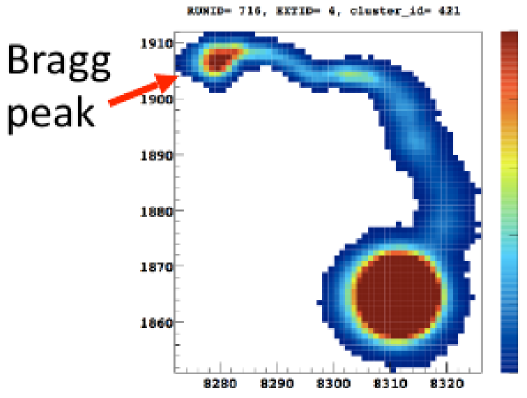


Three α at the same location!



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

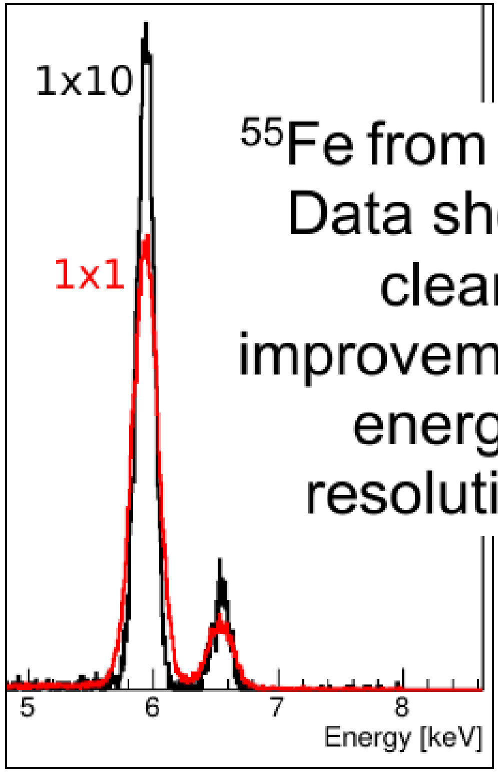
Example of α + β



Readout Flexibility

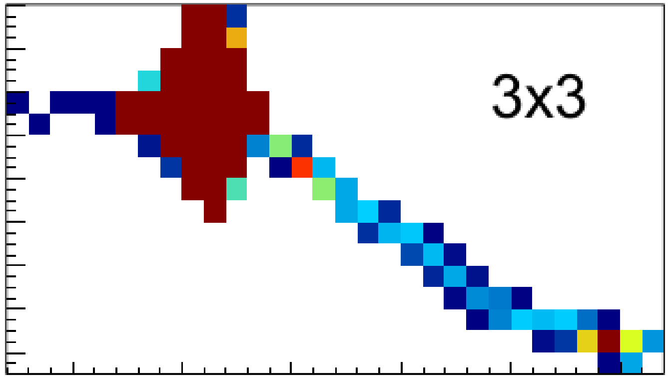
Pixels can be readout in “groups” and the total charge estimated in a single measurement.

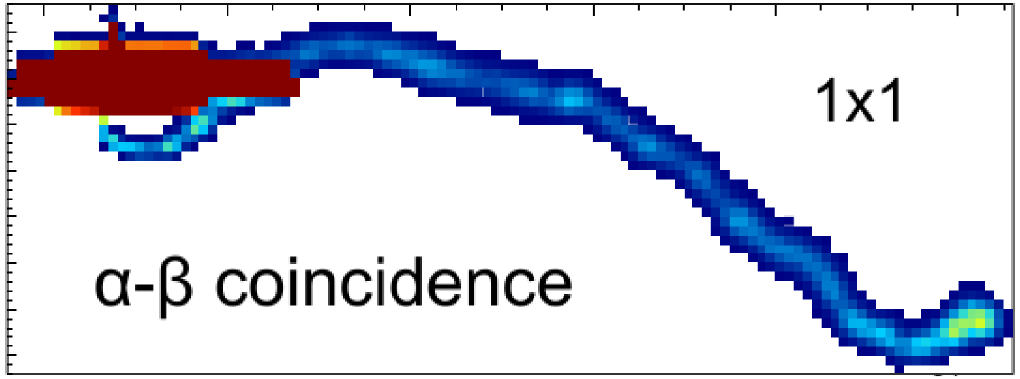
Less pixels but same noise *per* pixel!



^{55}Fe from back: Data shows clear improvement in energy resolution.

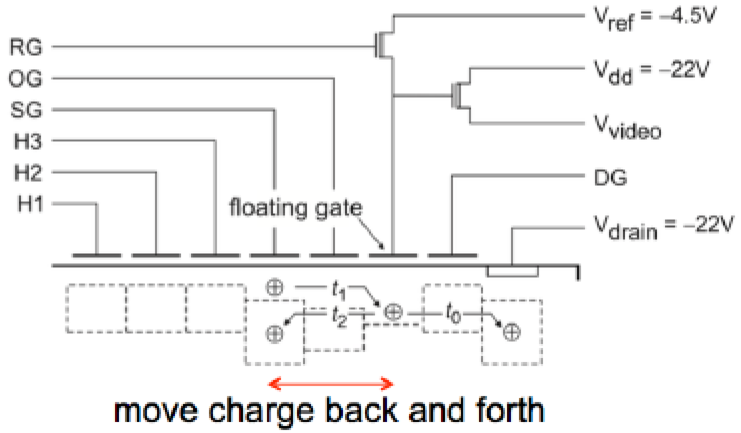
Loss of x, y and z information

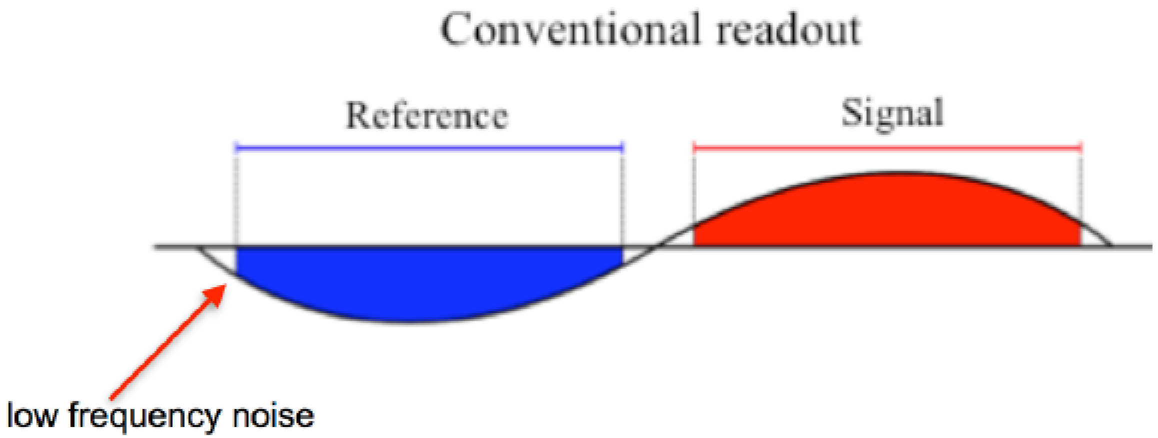




DAMIC-1K Sub-e⁻ Noise

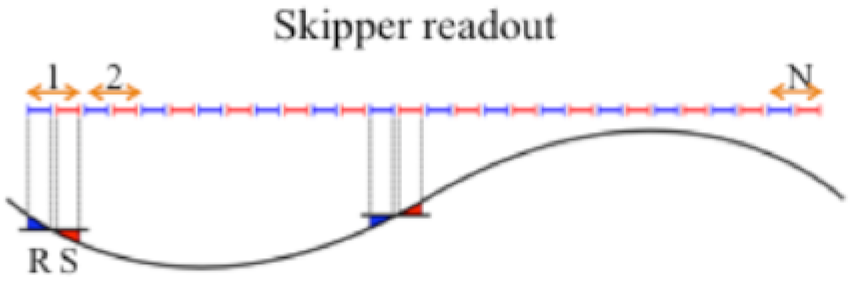
- Skipper readout — a novel charge readout approach which results in *single electron resolution*





Non-destructive measurement of the charge!

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



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