Current status of the DAMIC experiment

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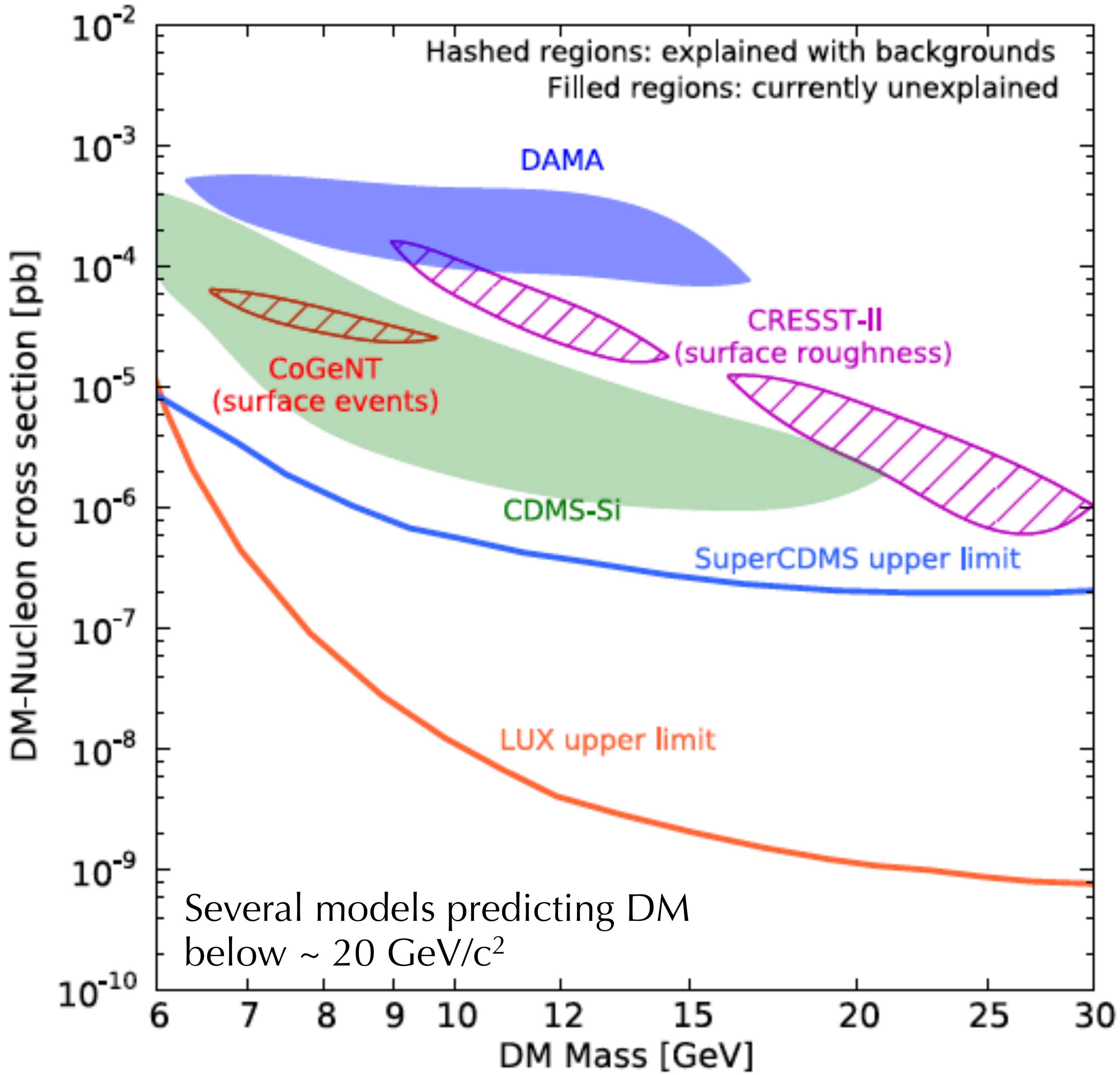
for the DAMIC collaboration

Fifth International Workshop
for the Design of the
ANDES Underground Laboratory

Buenos Aires, Argentina
29 - 30 June 2017

Current status

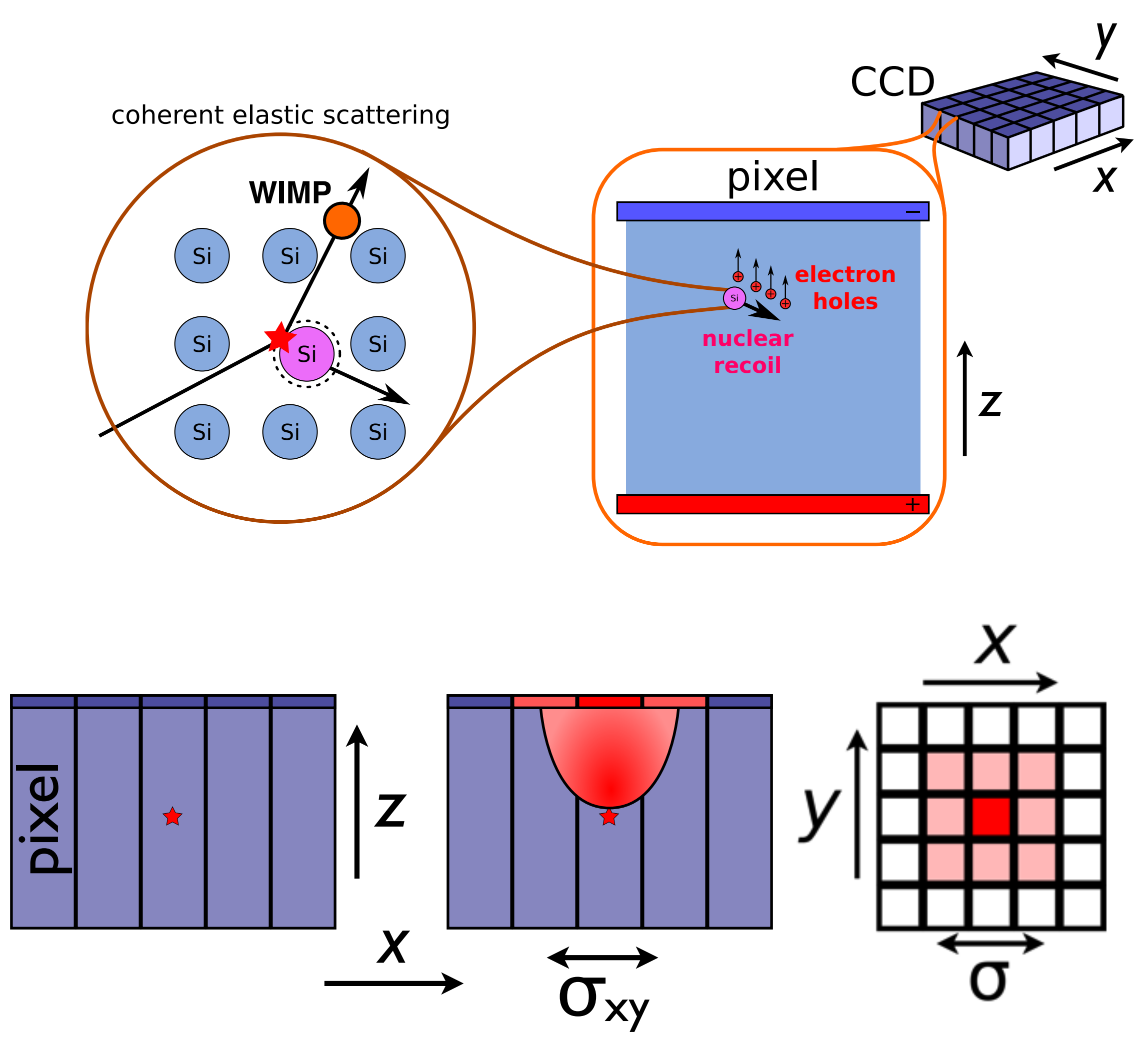


Constant need for different technologies to confirm/exclude incompatible scenarios

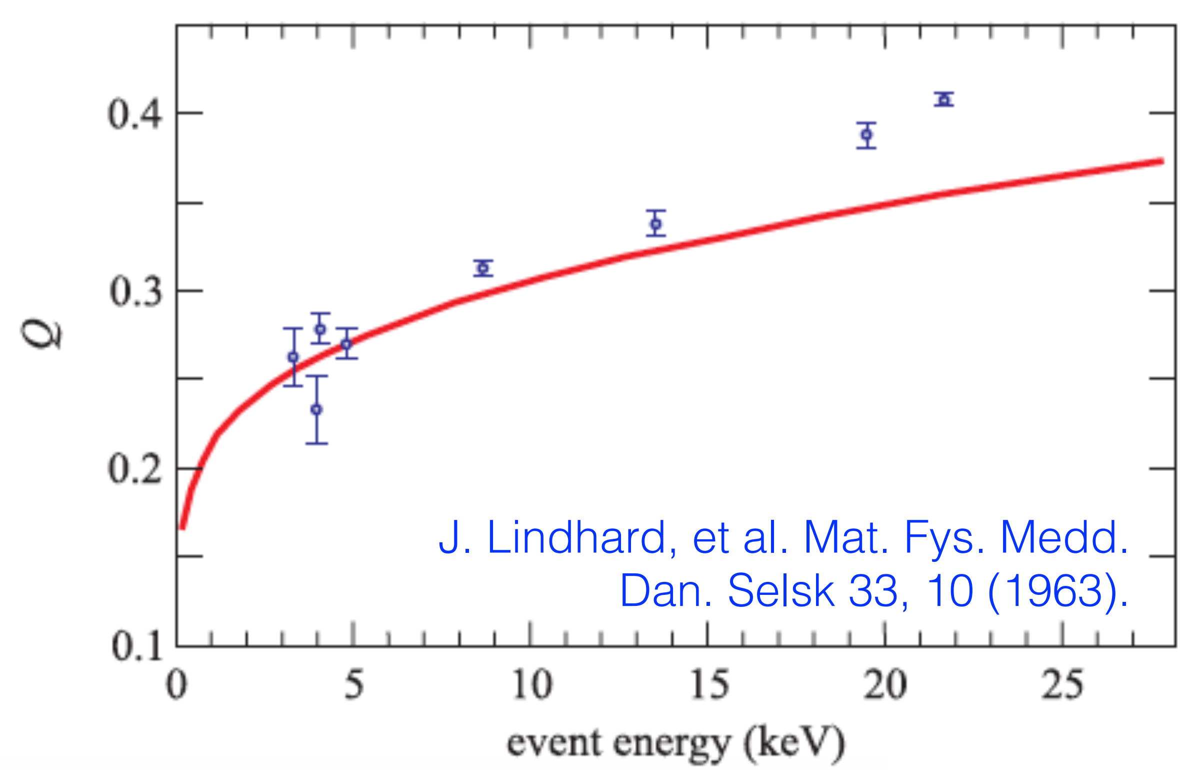
Charge Coupled Devices (CCDs)

Goal: lower the energy threshold in Si detectors

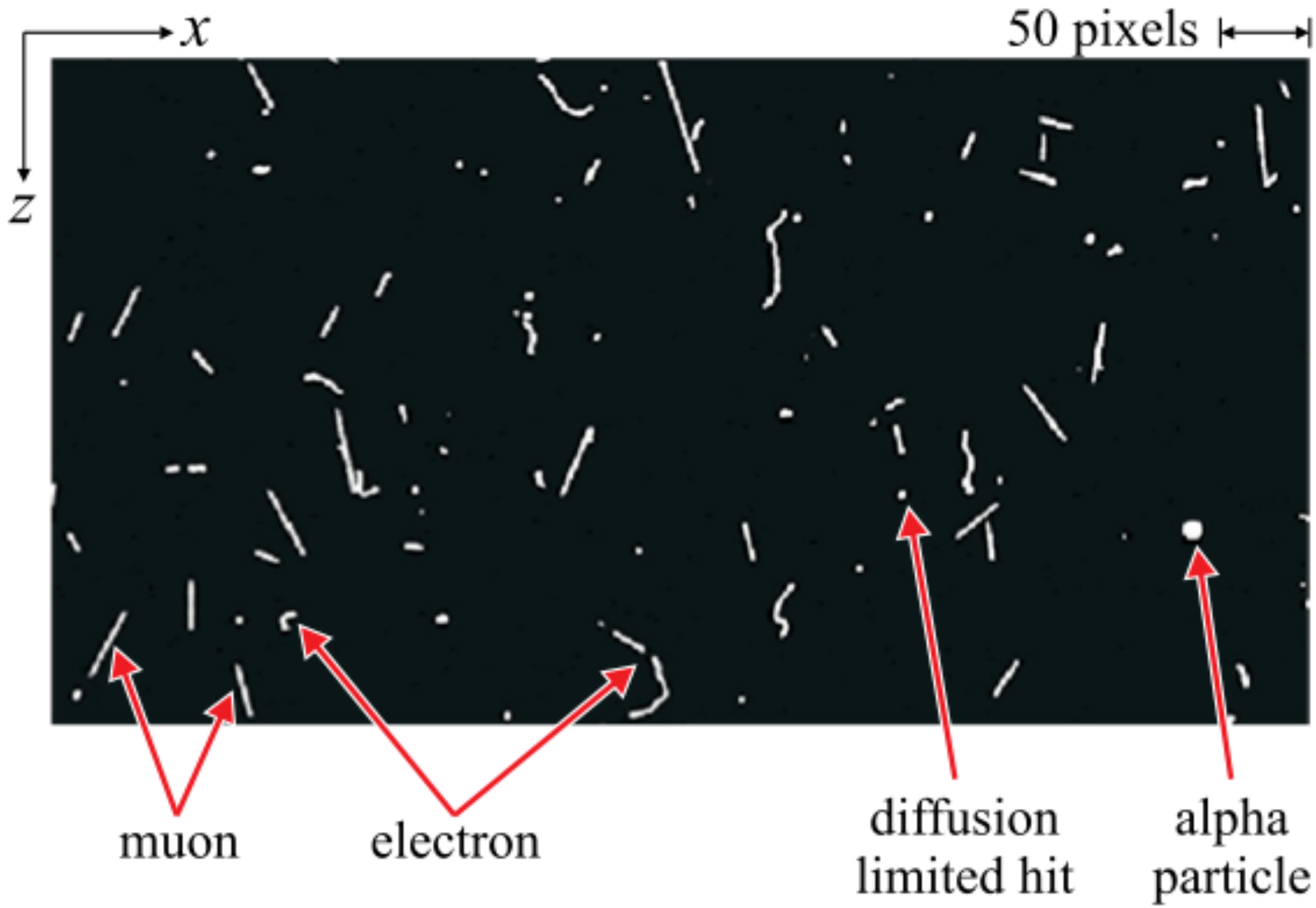
Idea: use CCDs as target and record the ionization produced in Si



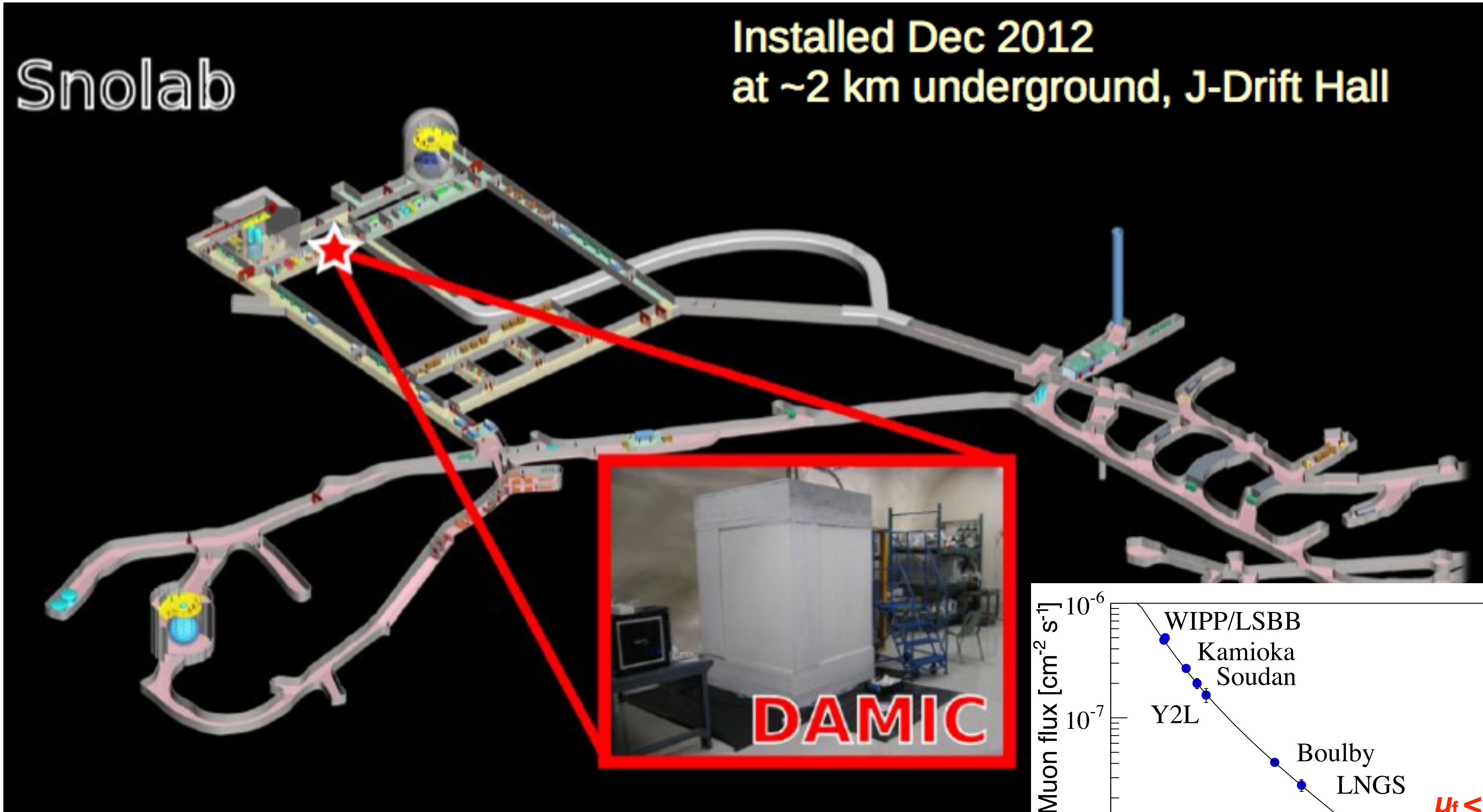
Ionization efficiency in silicon

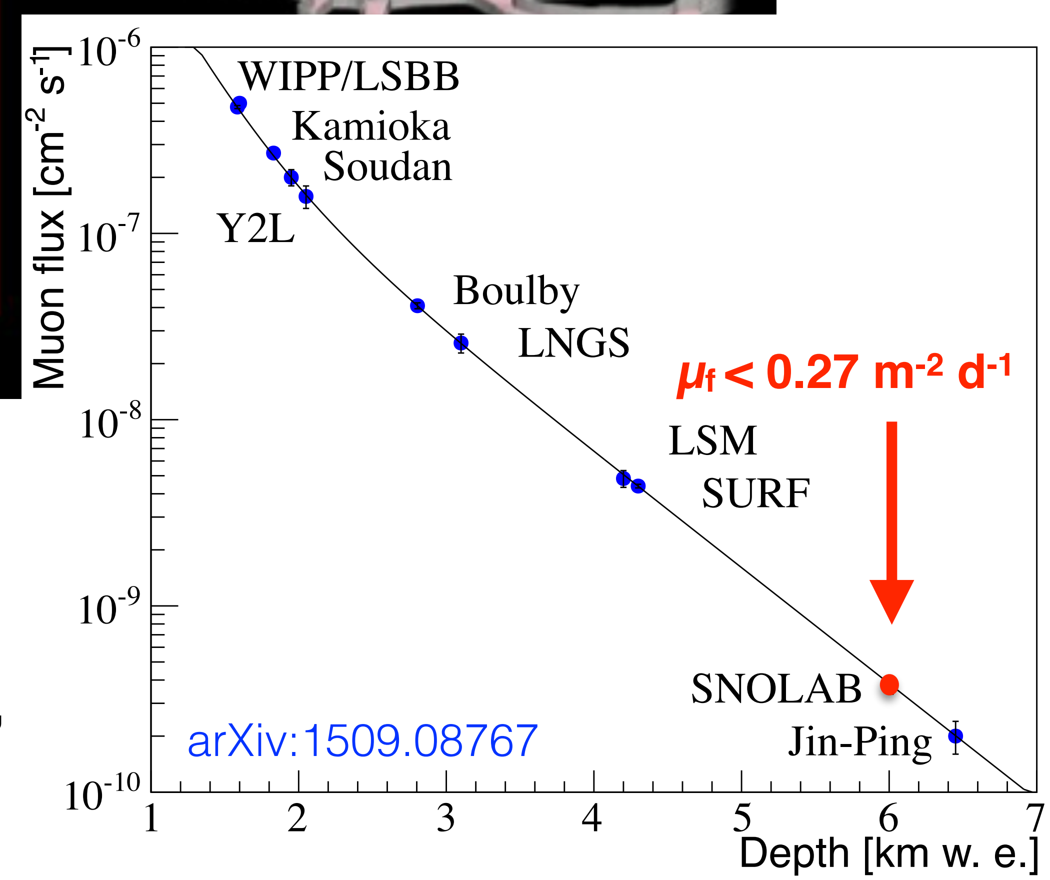


Charge Coupled Devices (CCDs)



The DAMIC experiment

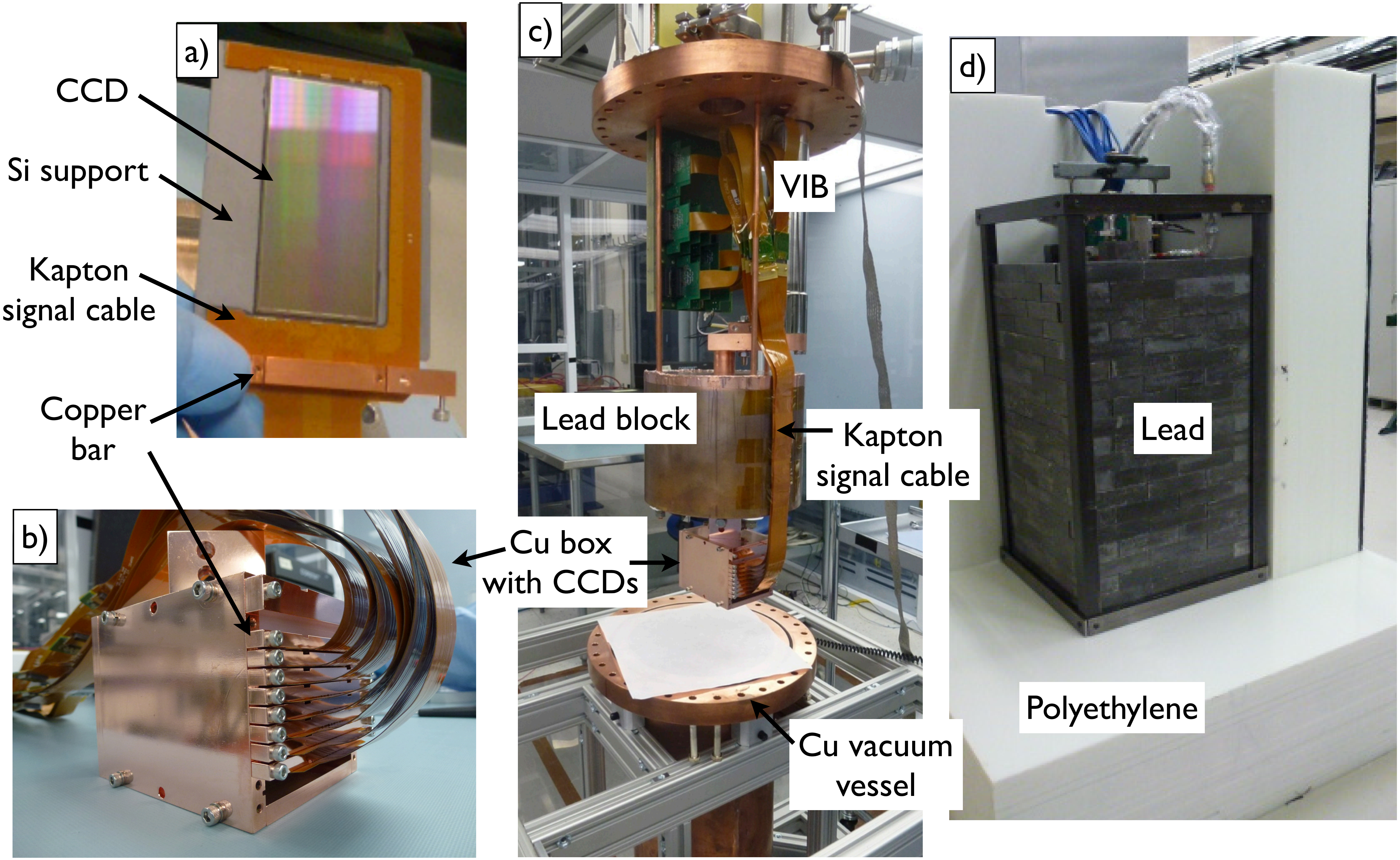




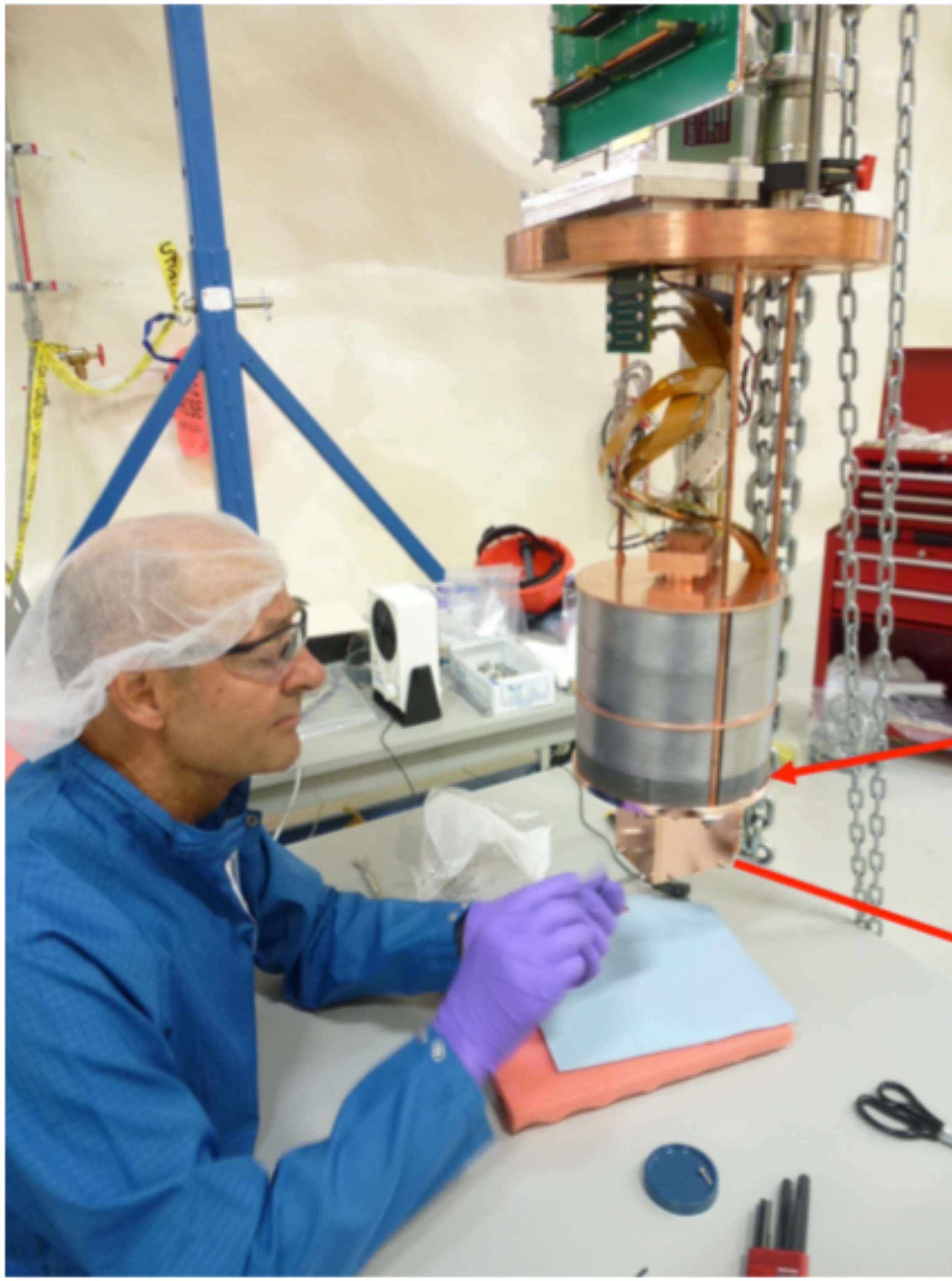
Sudbury, Canada

Fermilab, U. Chicago, U. Zurich, Snolab, U. Michigan,
UNAM, FIUNA, CAB, UFRJ, U. Paris VI & VII

The DAMIC experiment

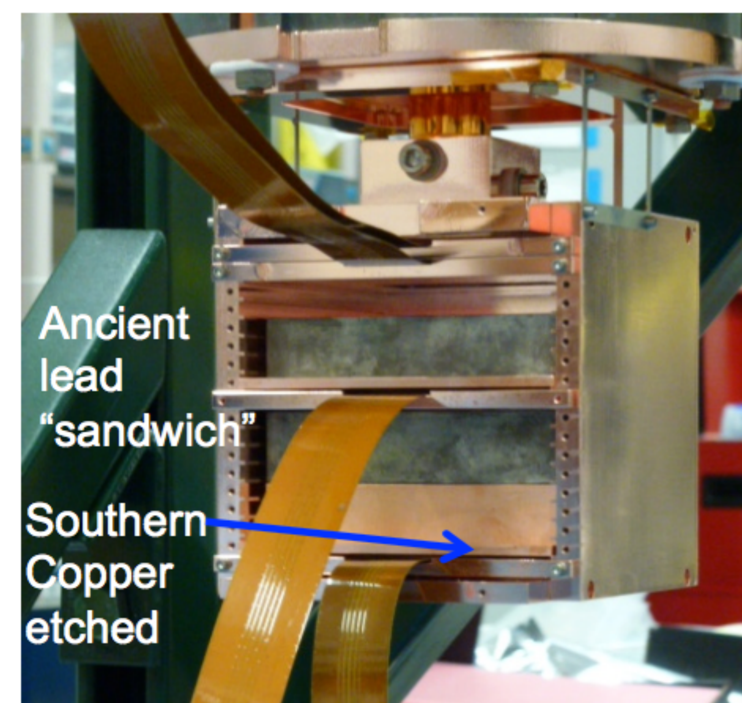


The DAMIC experiment

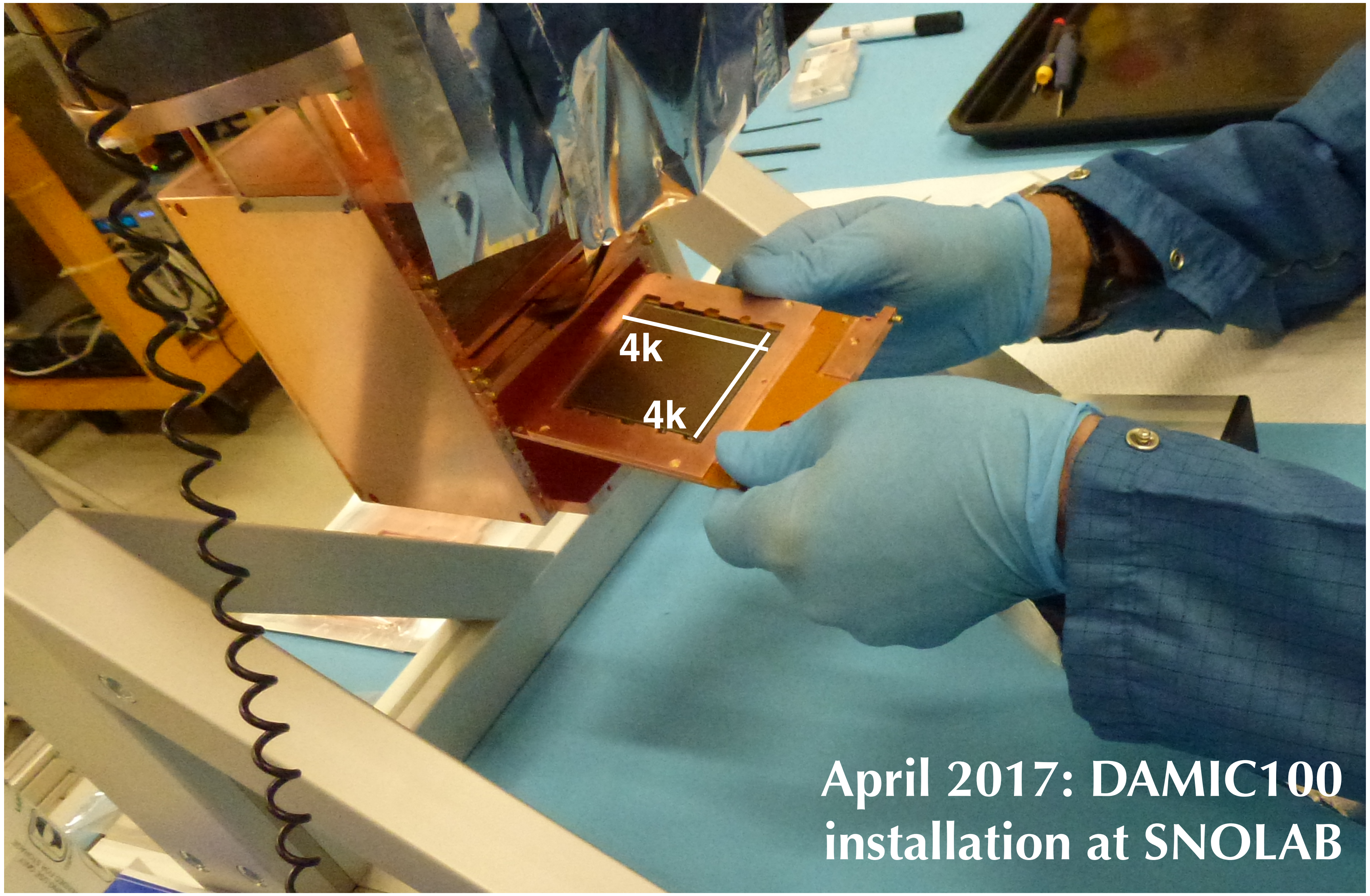


1 inch Spanish galleon lead

Cu box with CCDs

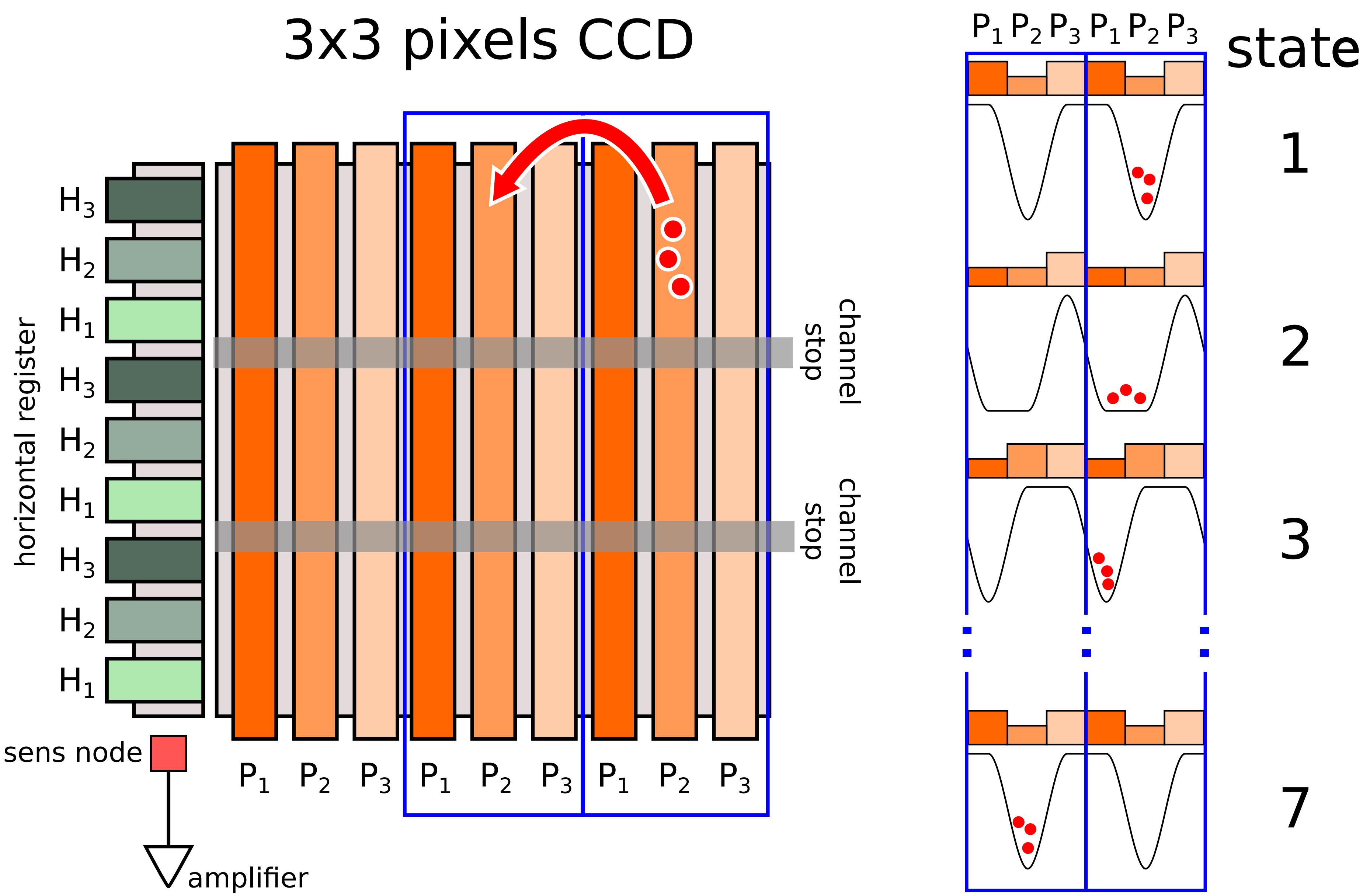


Charge Coupled Devices (CCDs)



- pixel size of 15 μm x 15 μm
- large mass compared to regular CCDs ~ 5.7 g/CCD (675 μm thick)

Readout of the CCDs

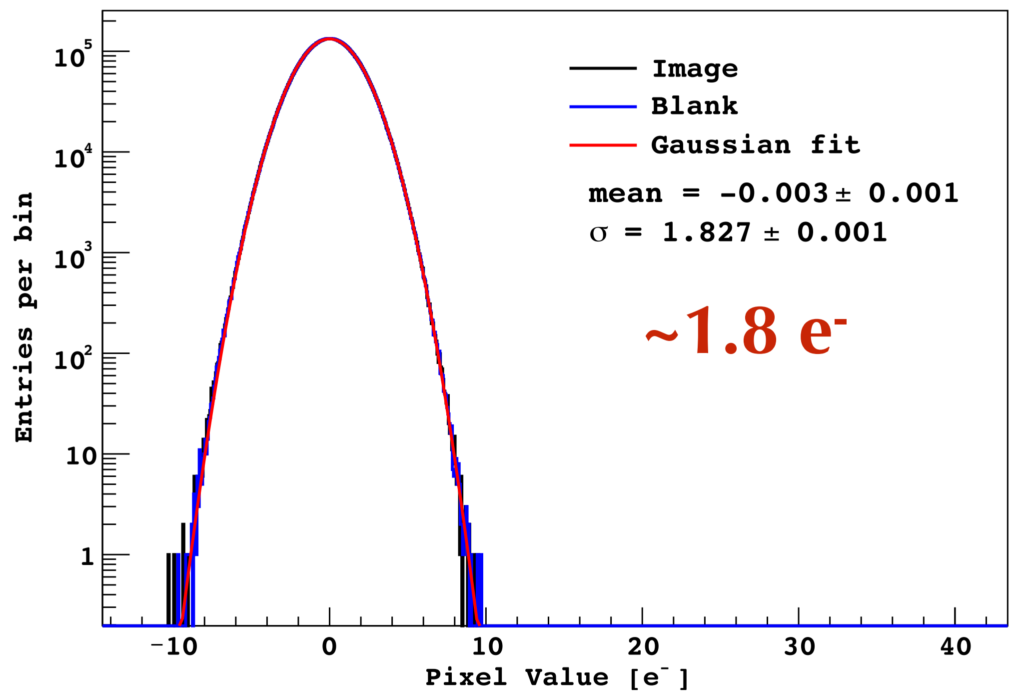


Each pixel readout introduces 7.2 eV (2e$^-$) noise

Dark current negligible —> total noise depending on the number of readouts

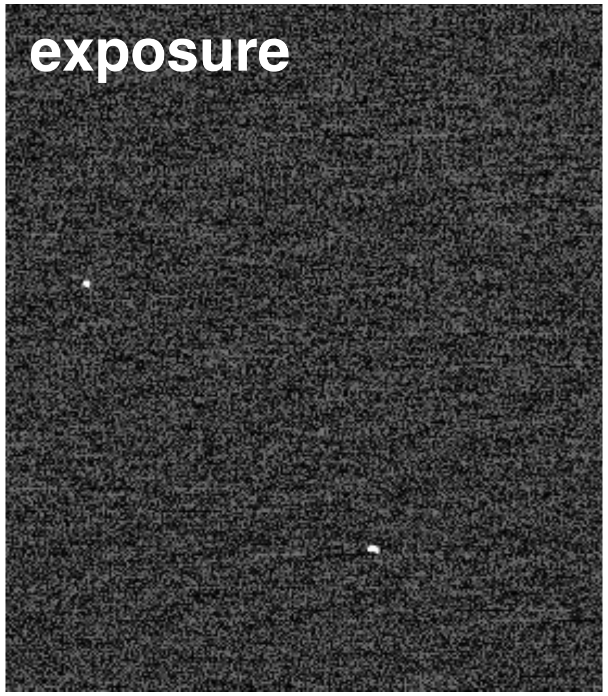
Performance

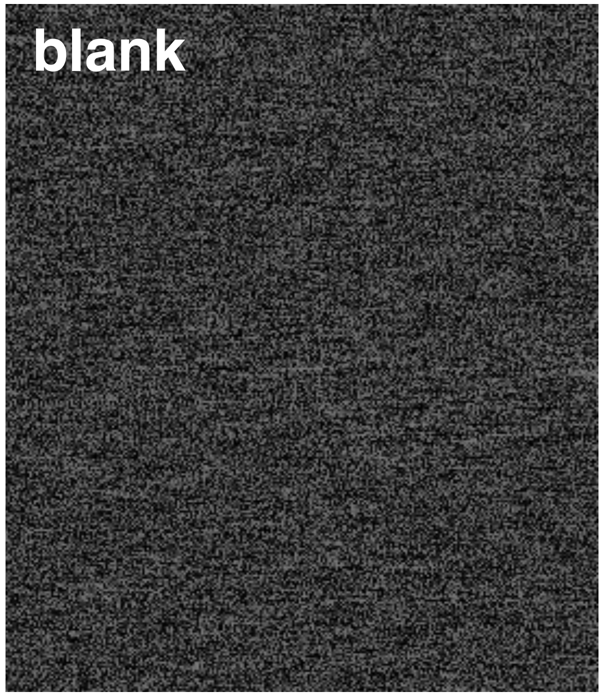
- Readout noise



- Noise limited by readout and improved with correlated double sampling
- Equivalent to ~ 7 eV of ionization energy
- This is what makes DAMIC unique: 40 eV threshold is possible

- Dark current

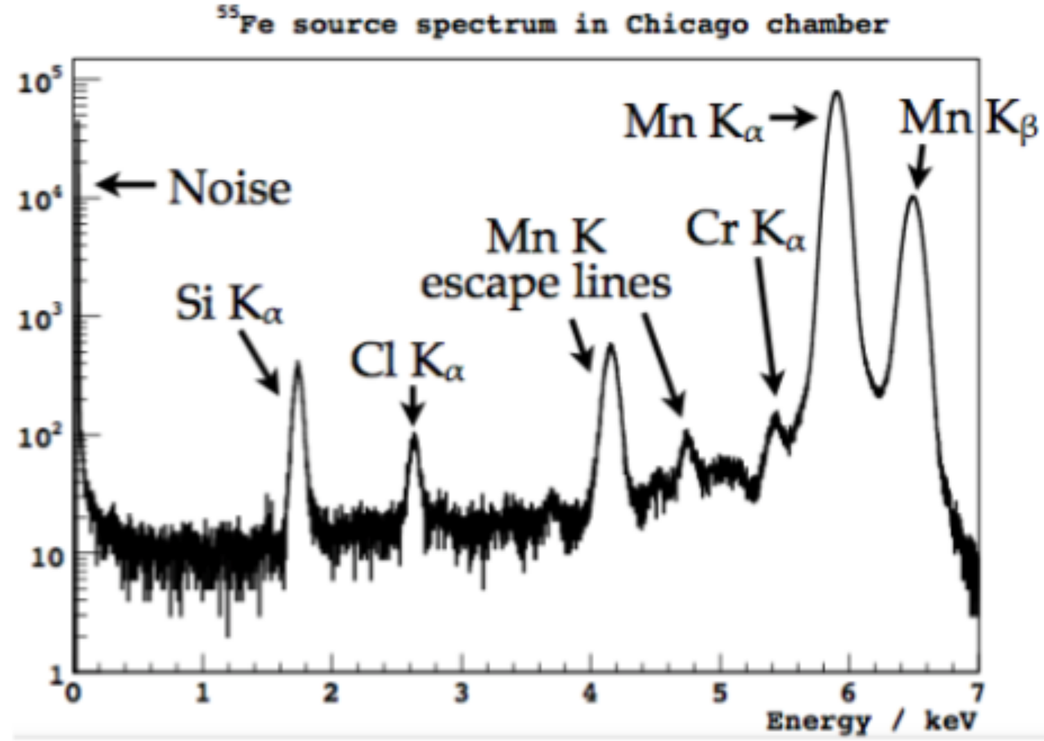




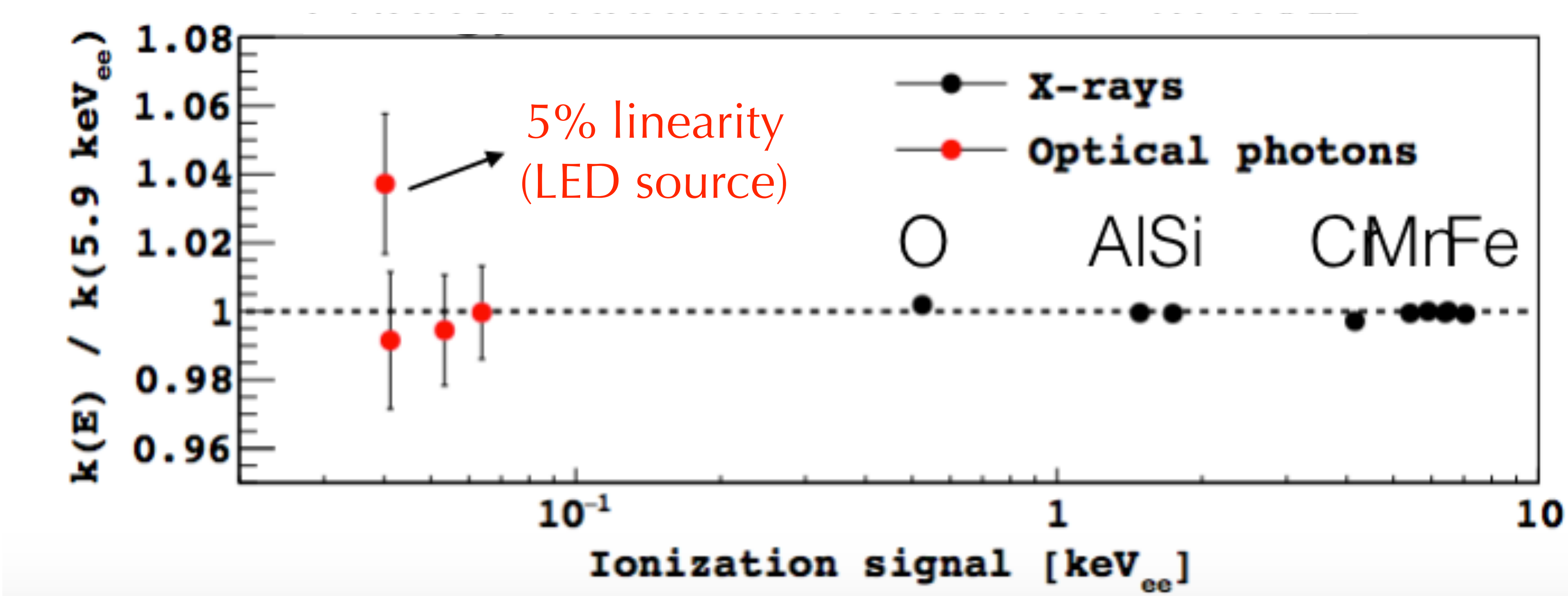
- Low dark current (0.001 e^-/pix/day) @ 120 K

Calibration and energy resolution

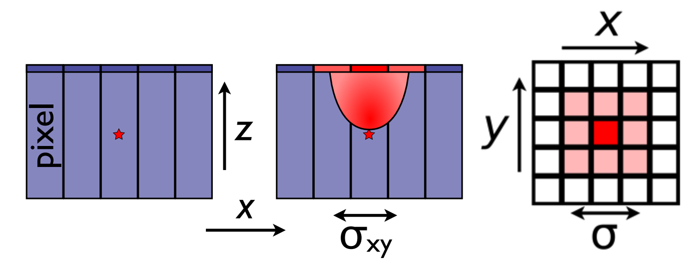
- Energy calibration using a ^{55}Fe source noise



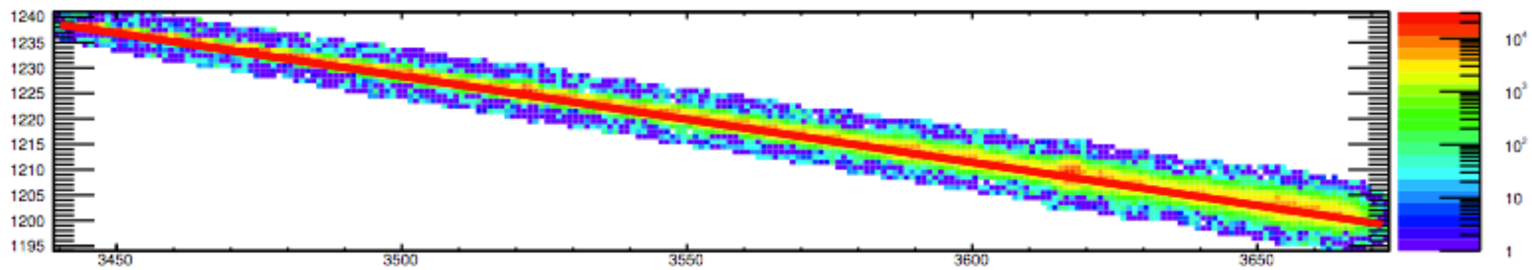
- Energy resolution down to 40 eV



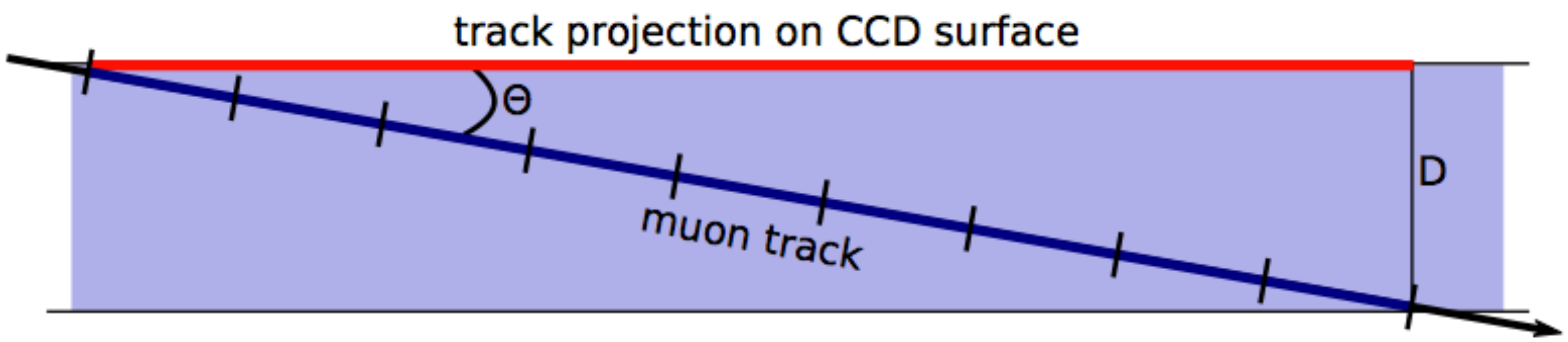
Depth reconstruction



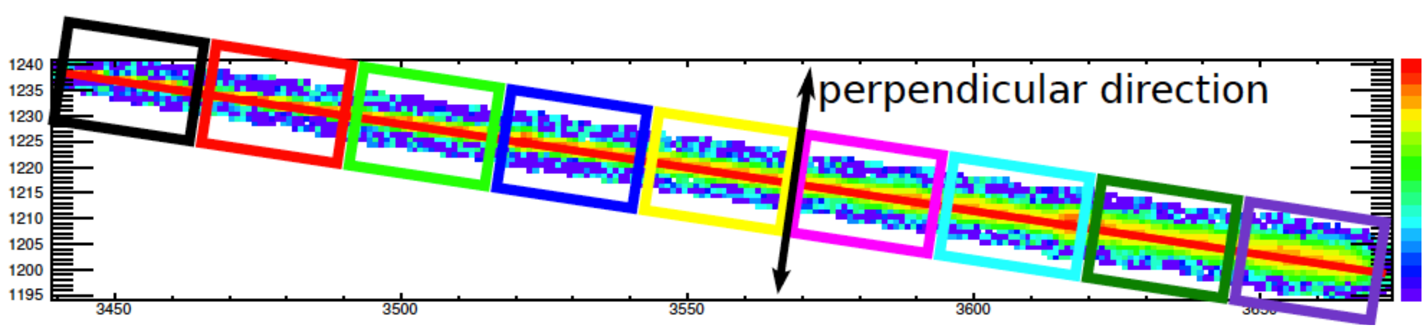
- Recorded track: CCD top view

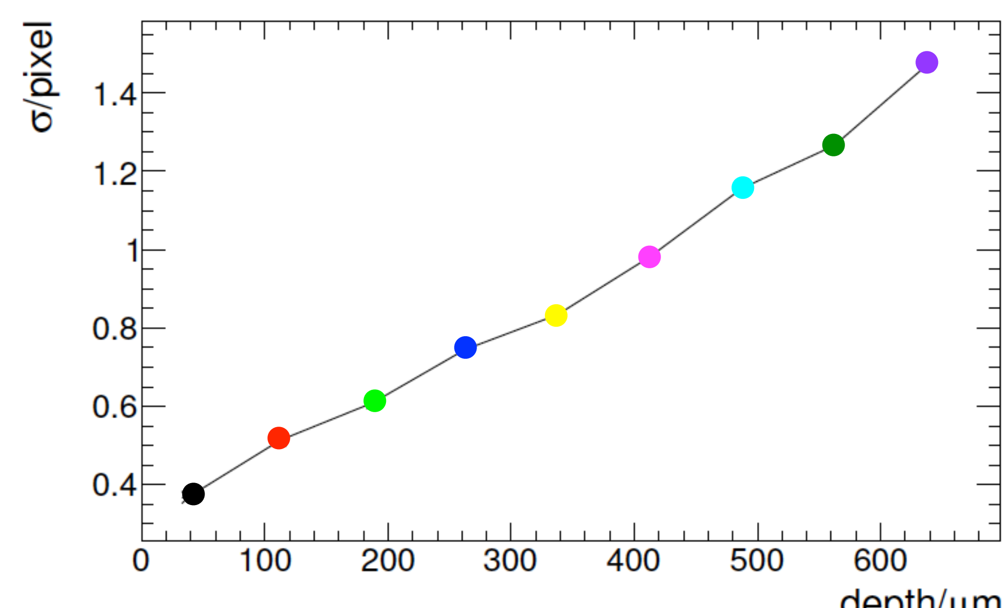


- CCD side view



- Diffusion can be measured as a function of the interaction depth. No need to rely on models.



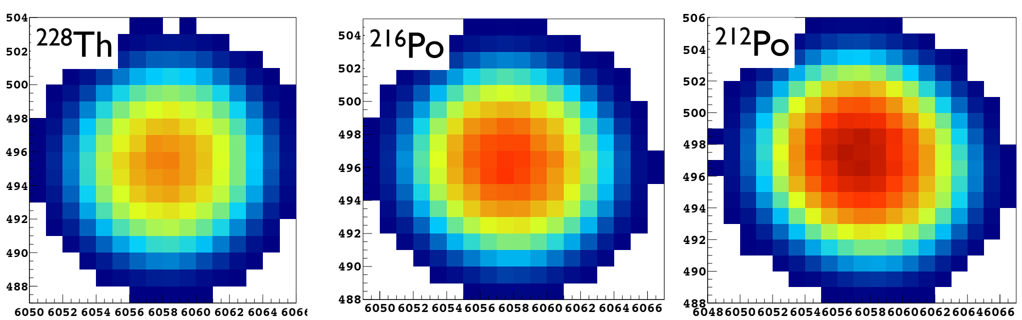


Radioactive contamination

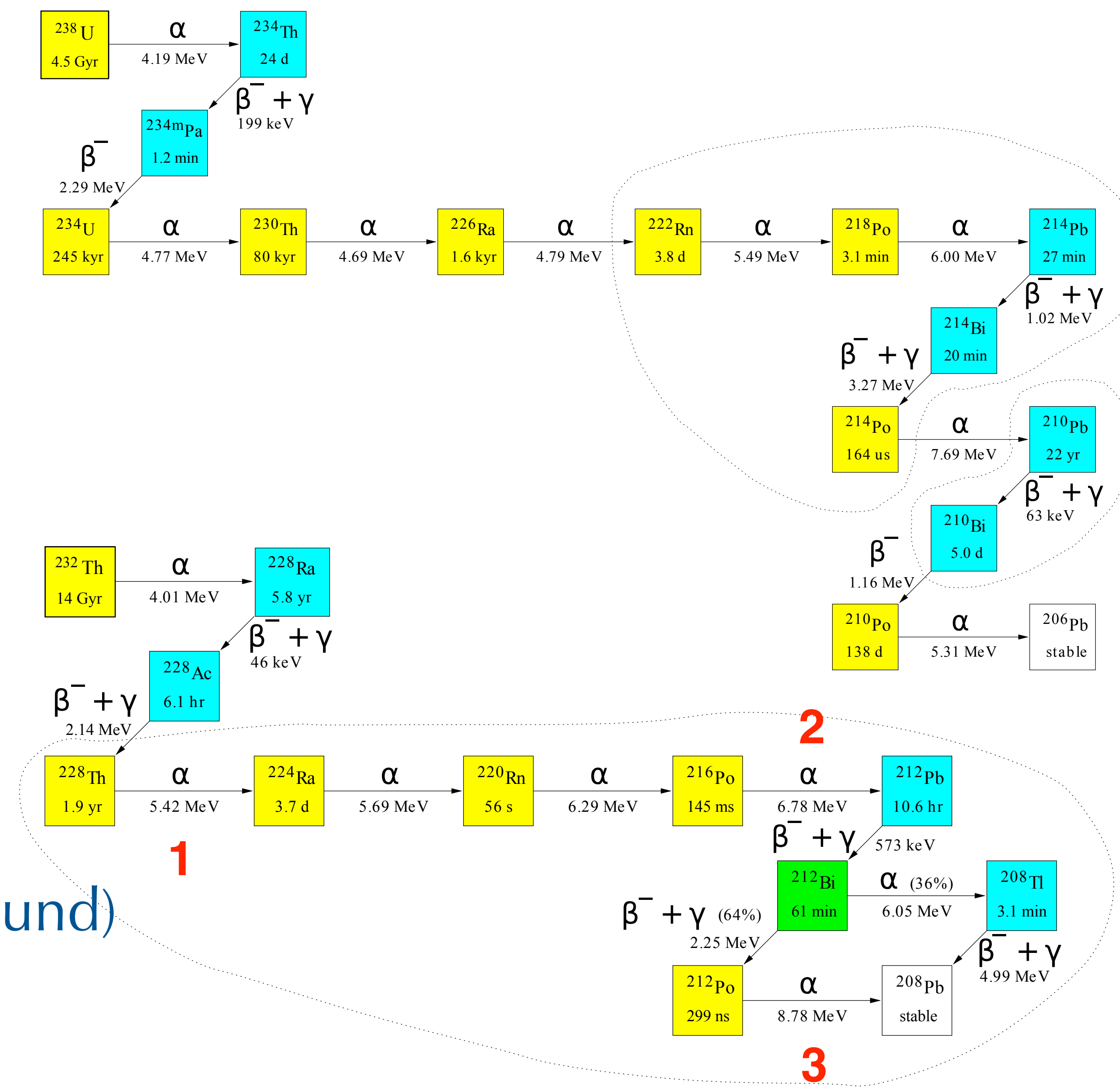
JINST 10 P08014 (2015)

Unique spatial resolution: alpha sequences
Three alphas at the same location!
—> Powerful method to measure U/Th background in the bulk

E = 5.39 MeV | E = 6.75 MeV | E = 8.66 MeV

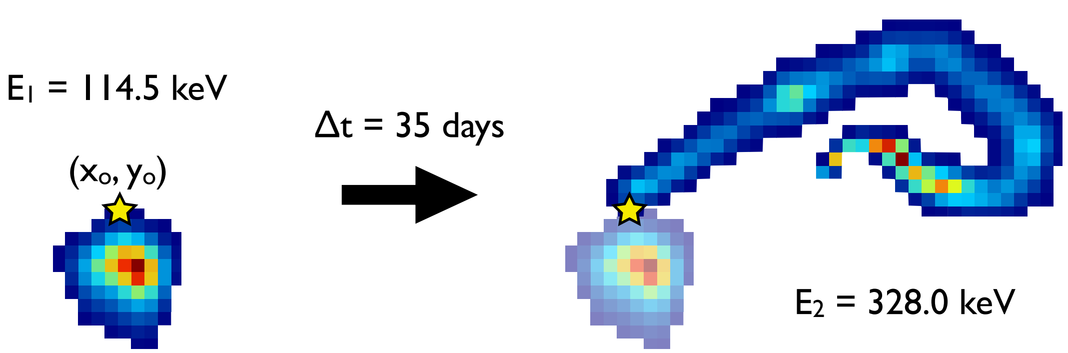


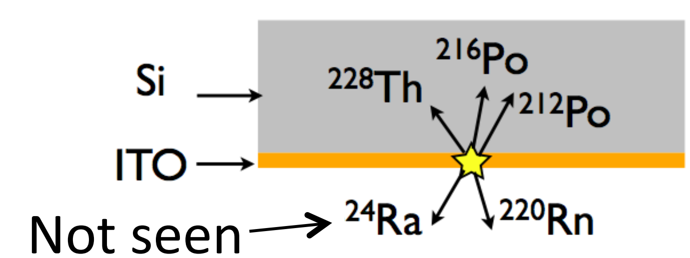
Δt = 17.8 d   Δt < 5.5 h



- Limits on ^{238}U and ^{232}Th concentration
- Limits on cosmogenic ^{32}Si (intrinsic background)

^{32}Si - ^{32}P candidate from data:



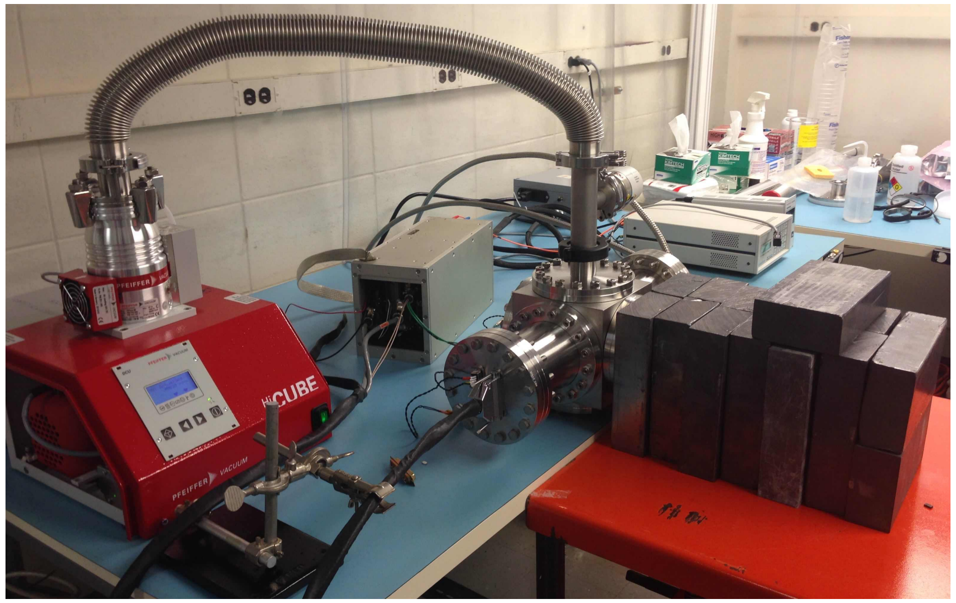


$$^{32}\mathrm{Si} = 80^{+110}_{-65}\ \mathrm{kg}^{-1}\mathrm{d}^{-1} \quad (95\%\ \mathrm{CL})$$

Nuclear recoil calibration

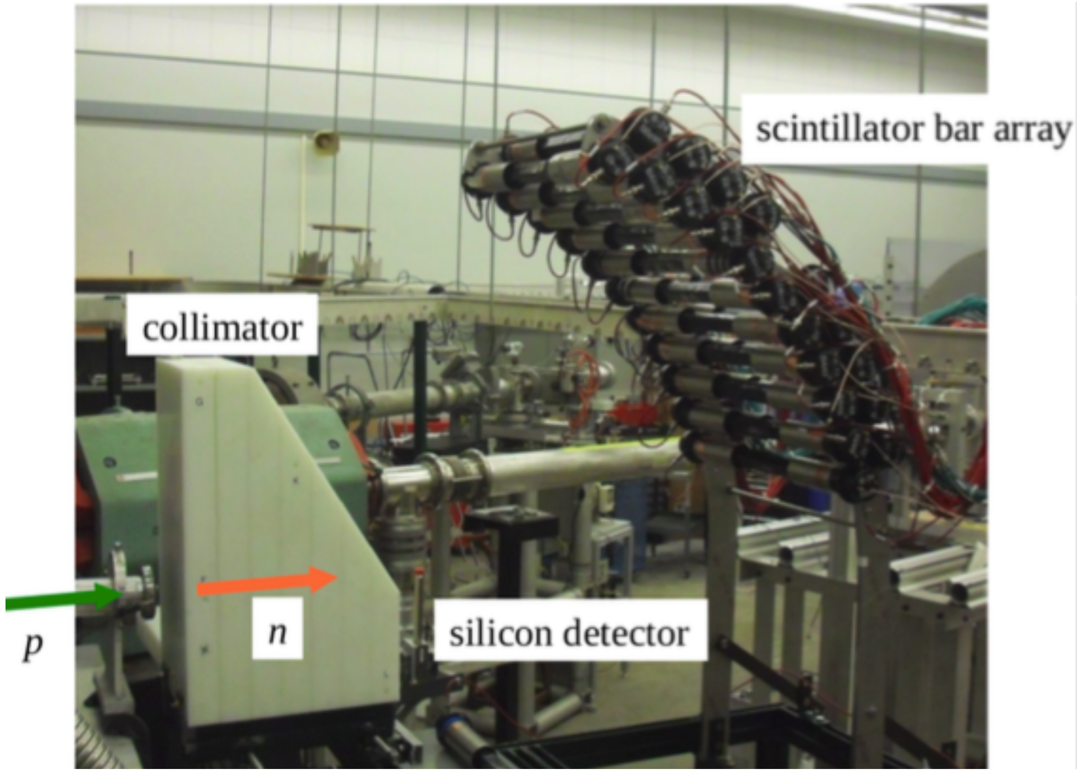
- Decreasing the energy threshold means we need to calibrate nuclear recoil ionization efficiency to low energies
- Challenging to get mono-energetic neutron beam Previously, Lindhard theory had been accepted
- Two calibrations using neutrons for calibrating silicon at low energies

$^{124}Sb \longrightarrow Te + \gamma$ (1690 keV +…)
$^{9}Be + \gamma \longrightarrow$ **n** $+ {}^{*8}Be \longrightarrow 2\alpha$



Phys. Rev. D, 94 (2016) 082007

Antonella



Journal of Instrumentation, 12 (2017)

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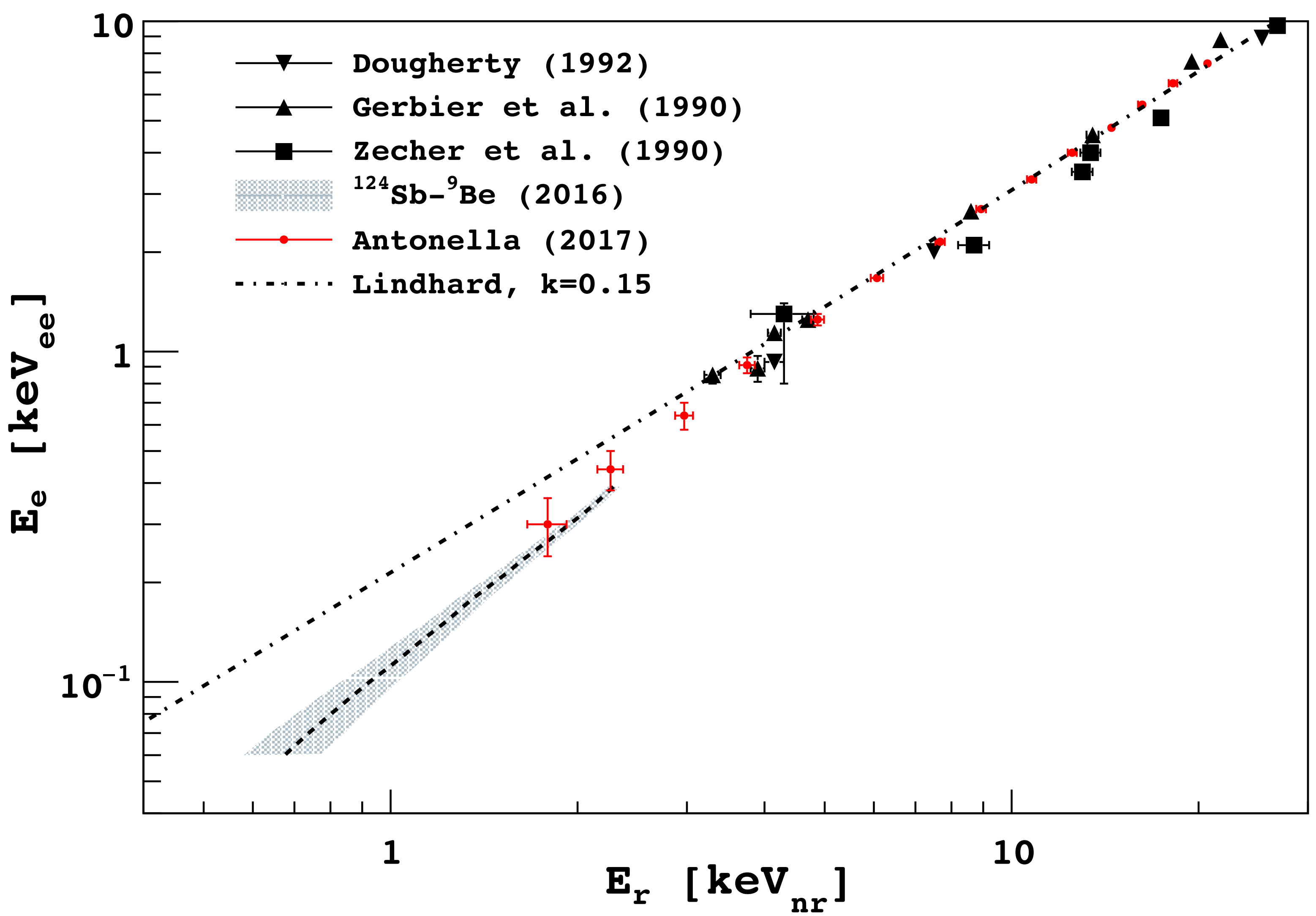
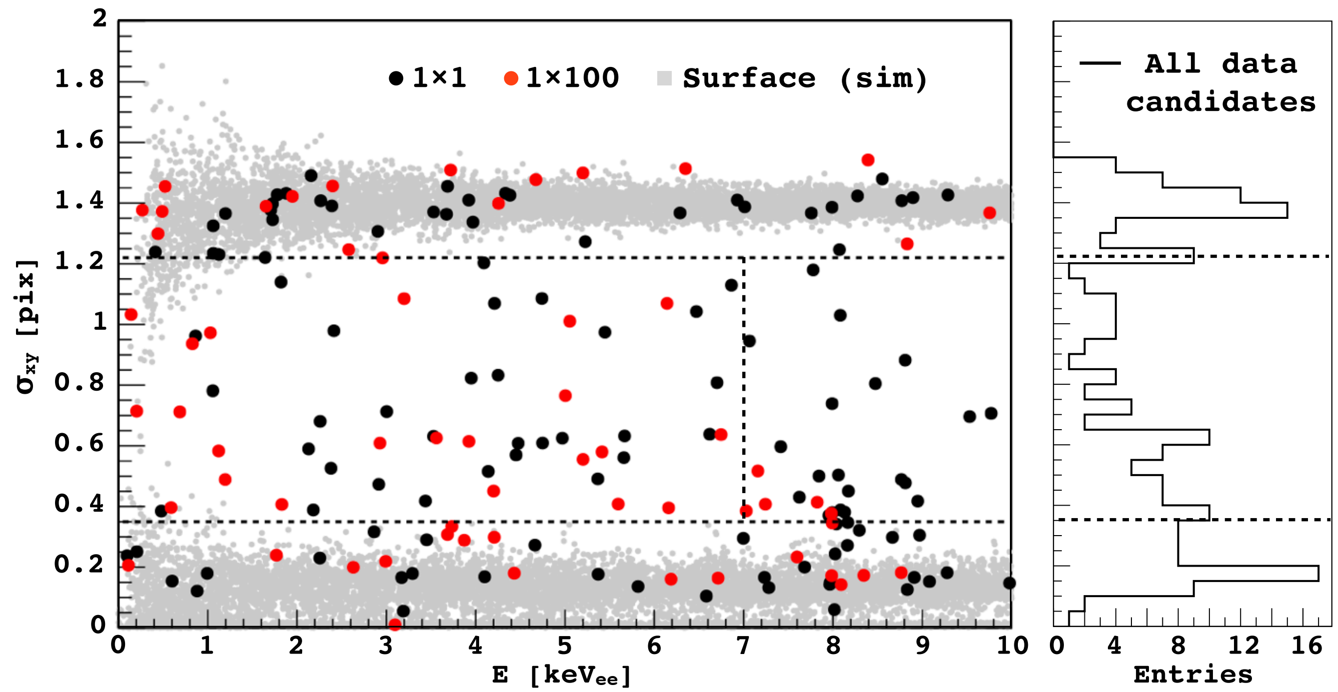


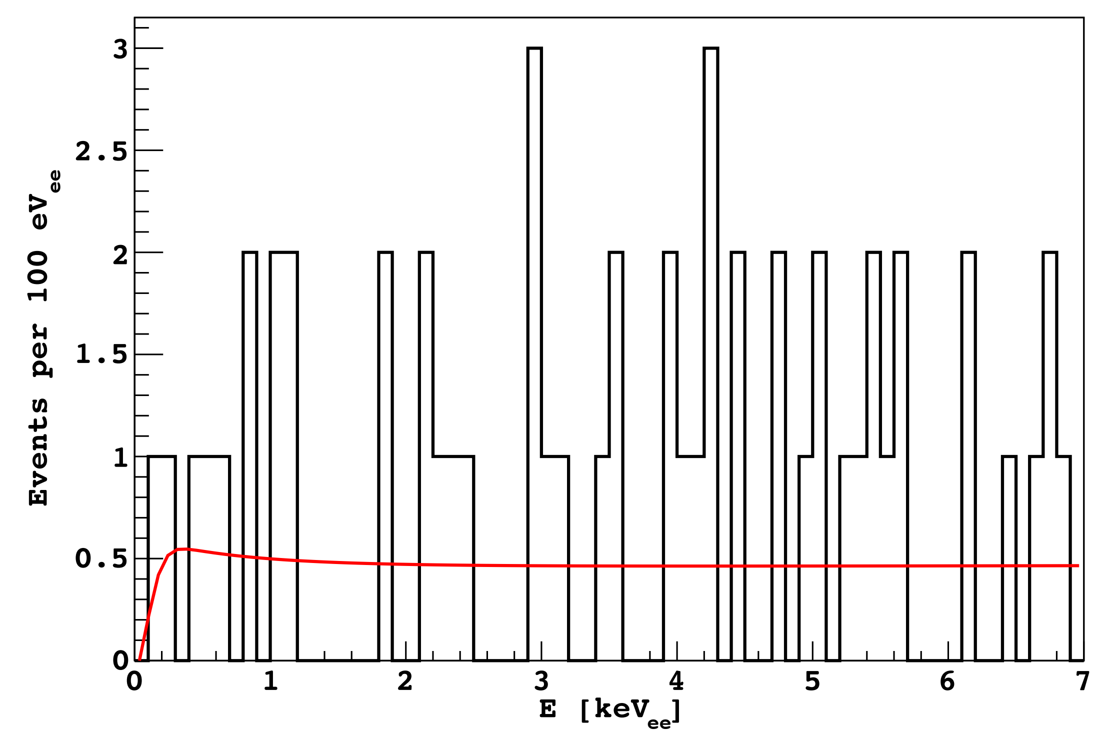
Phys. Rev. D, 94 (2016) 082006

Event selection

Selection of bulk events



Energy spectrum



Standard Likelihood analysis employed

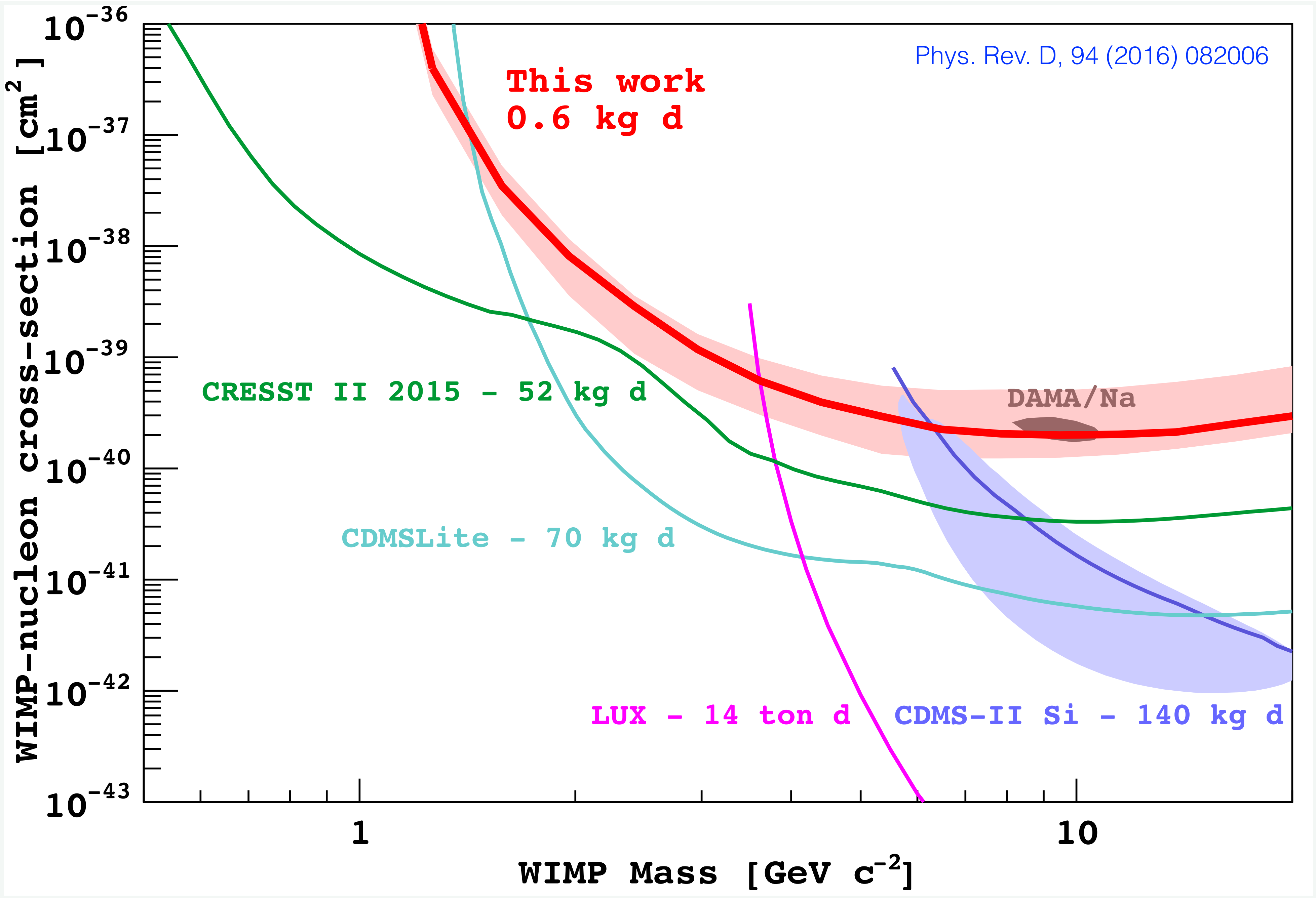
Spectrum consistent with background-only hypothesis

Competitive with a very low exposure taken during R&D phase

Background ~ 30 dru (now 5 dru)

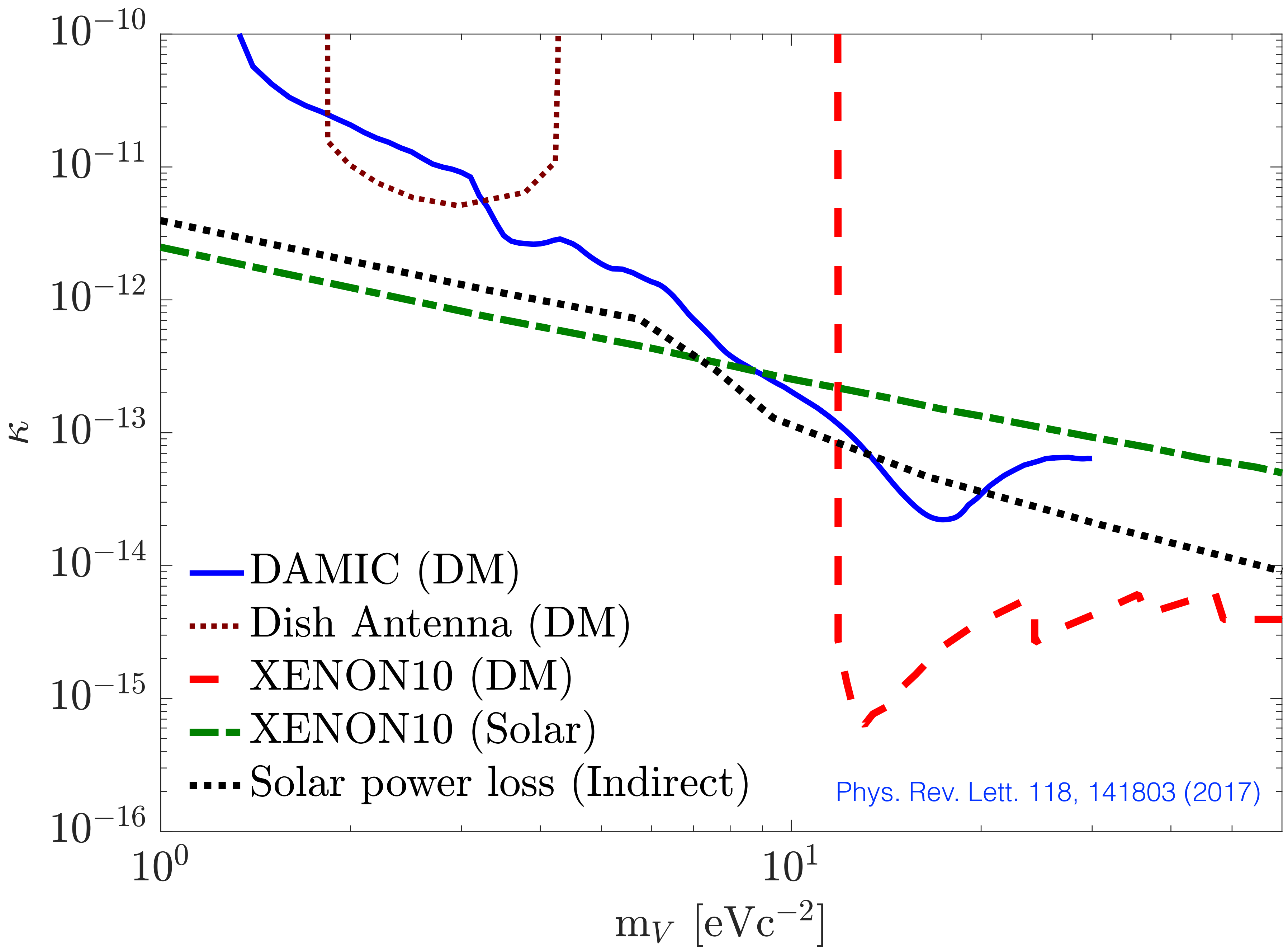
1 dru = 1 event keV^{-1} kg^{-1} day^{-1}

Event selection



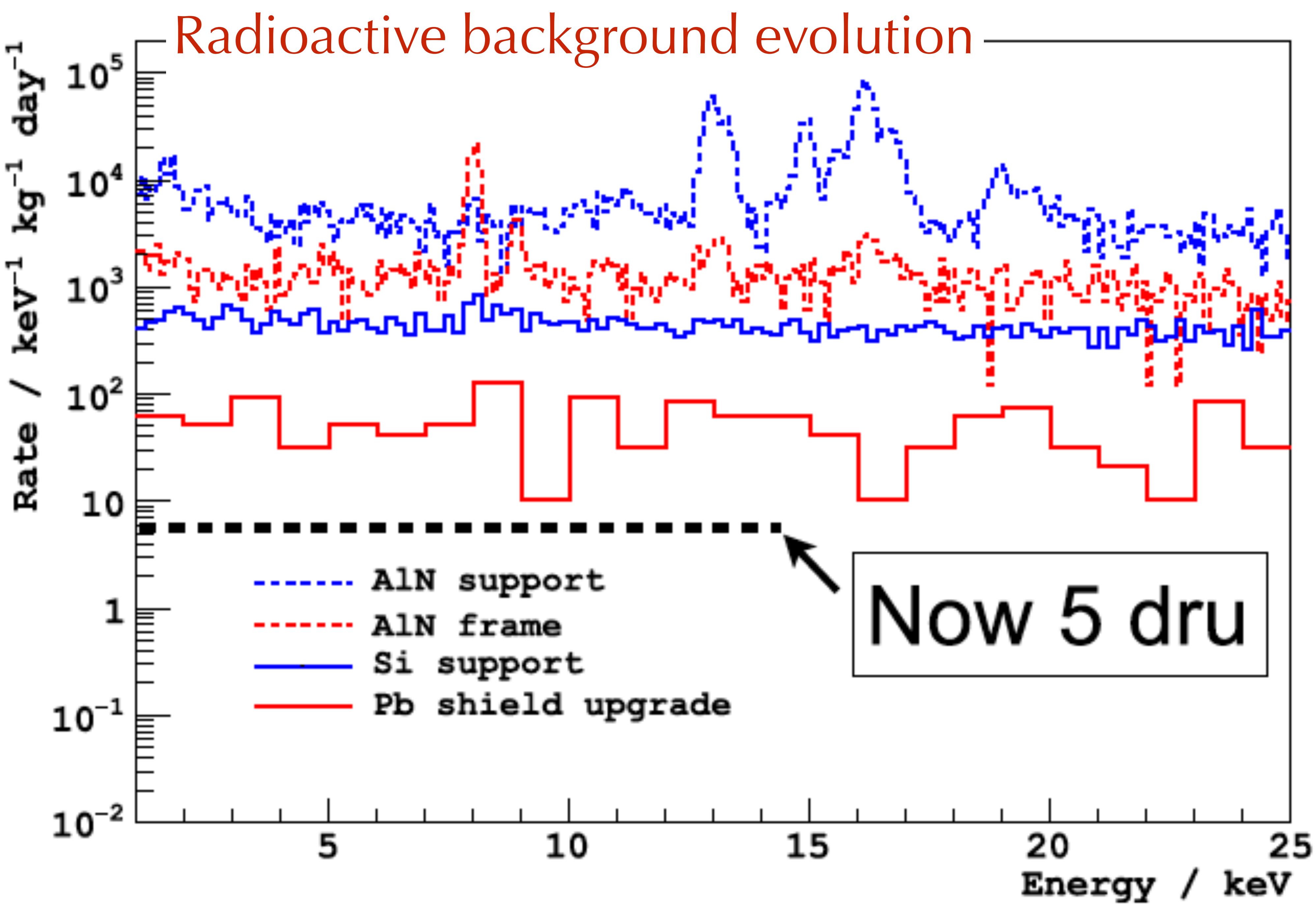
Hidden-photon dark matter with DAMIC

- DAMIC can detect small ionization signals from DM-electron interactions.
- DAMIC has published the most stringent direct detection constraints on hidden-photon dark matter with masses 3 - 12 eV.



Summary

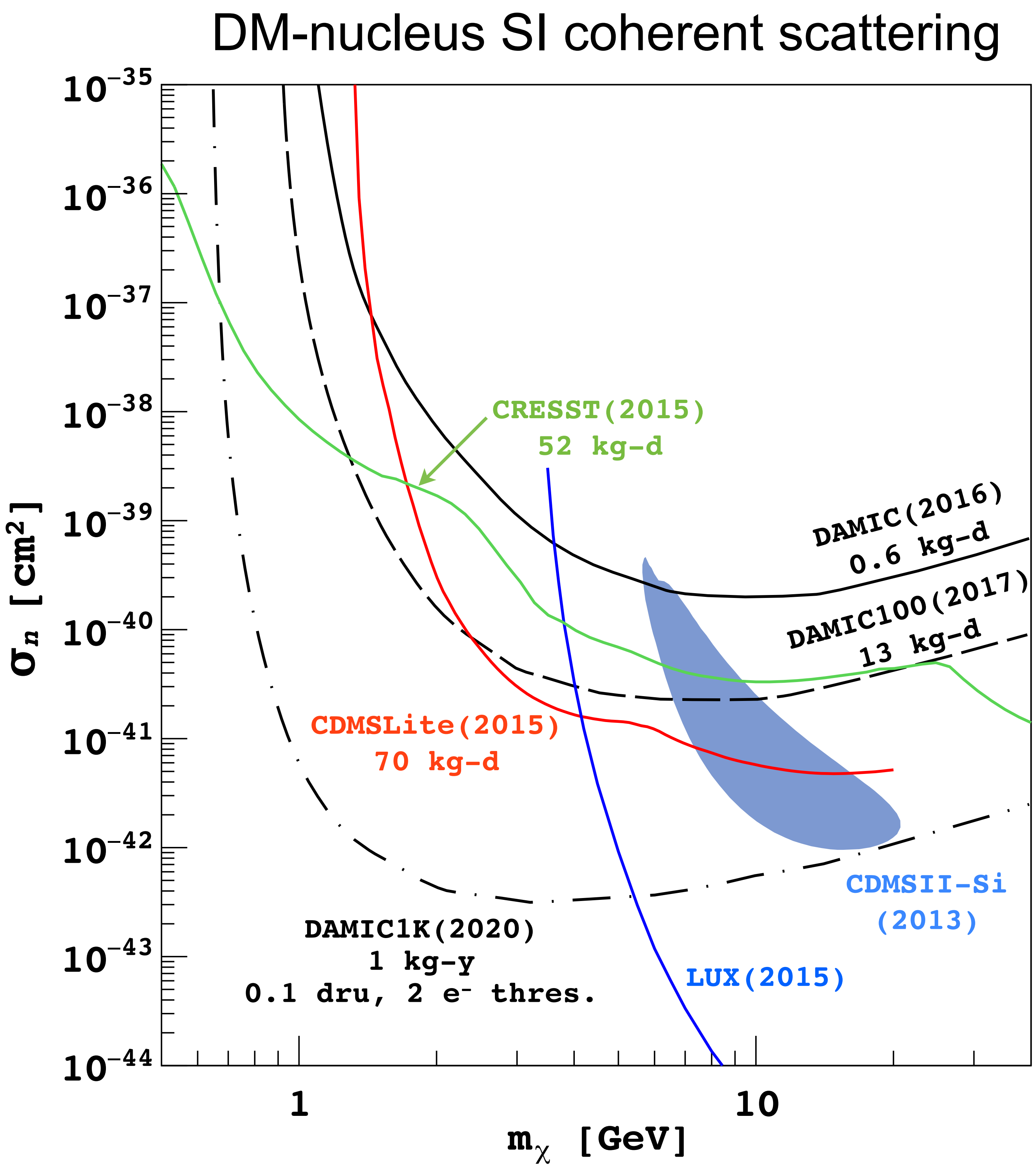
- 7 CCDs (16 Mpixel) installed and taking data currently
- 5 dru background and < 2e- noise achieved



Summary

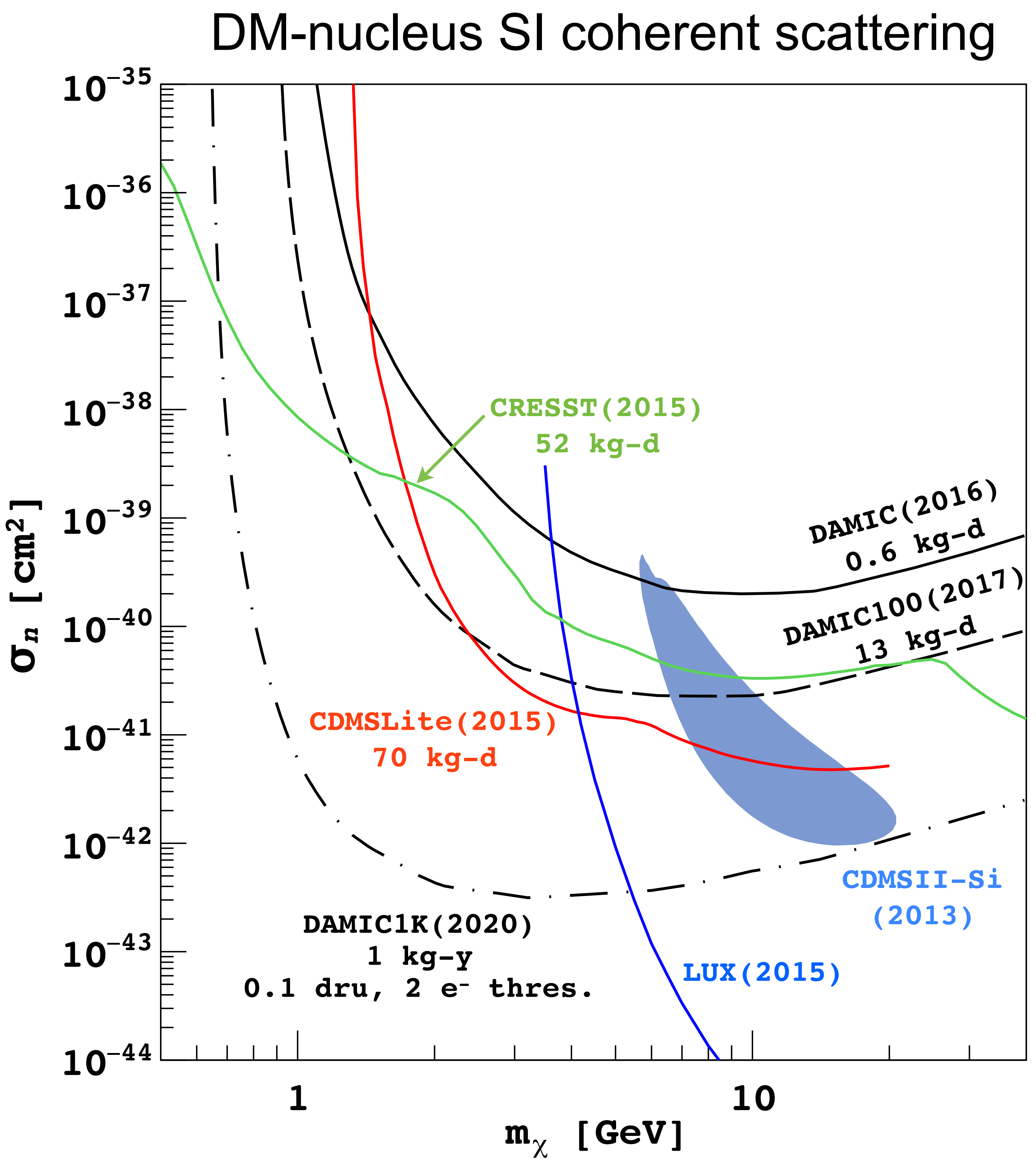
- 7 CCDs (16 Mpixel) installed and taking data currently
- 5 dru background and <2e- noise achieved
- DAMIC100 CCDs calibration planned
- R&D for thicker, larger-area, low-noise detector
- Improve external and internal backgrounds (< 0.1 dru)

DAMIC 1kg



DM-nucleus SI coherent scattering
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
σ_n [cm^2]
CRESST(2015)
52 kg-d
DAMIC(2016)
0.6 kg-d
DAMIC100(2017)
13 kg-d
CDMSLite(2015)
70 kg-d
CDMSII-Si
(2013)
DAMIC1K(2020)
1 kg-y
0.1 dru, 2 e⁻ thres.
LUX(2015)
1
10
m_χ [GeV]

DAMIC 1kg



Thank you !!

BACKUP

DAMIC scientific production

- Measurement of **radioactive contamination** in the high-resistivity silicon CCDs of the DAMIC experiment

  JINST 10 (2015) P080-14

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

  Phys. Rev. D, 94 (2016) 082006

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

  Phys. Rev. Lett, 118 (2017) 141803

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

  Phys. Rev. D, 94 (2016) 082007

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

  Journal of Instrumentation, 12 (2017)

Towards a kg-size experiment

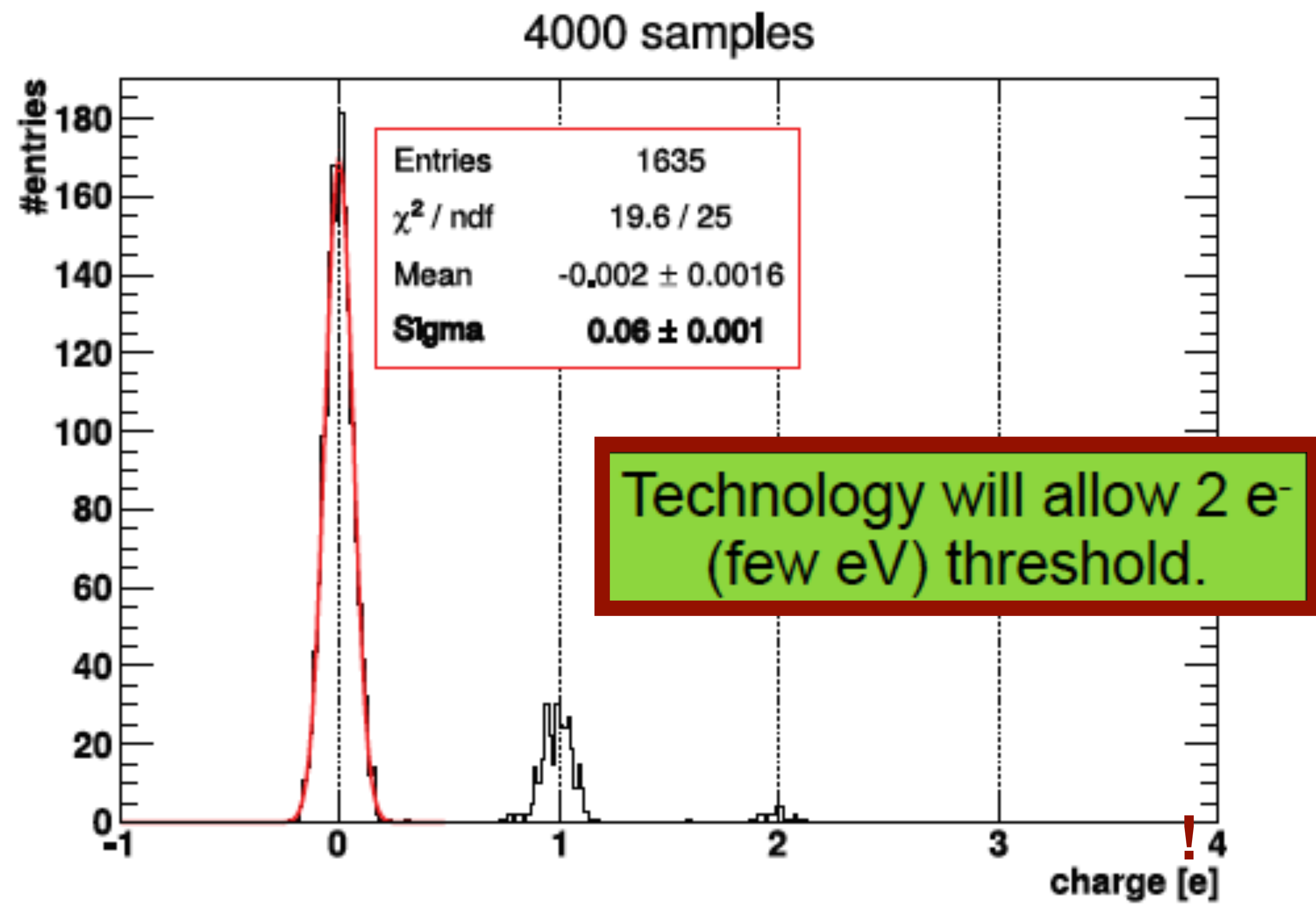
SENSEI project

Sub-Electron-Noise-SkipperCCD Experimental Instrument

Main difference: the Skipper CCD allows multiple sampling of the same pixel without corrupting the charge packet

↓

- Probe DM masses at 0.1 GeV through nuclear recoil
- Probe DM masses at MeV scale through electron recoil
- Probe axion/dark photon DM with masses down to 1 eV
- Coherent-nucleus interaction



A collaboration between **Fermilab, LBNL, Stony Brook, Tel Aviv U., CERN, Stanford U.**

From J. Tiffenberg's talk, Berkeley 2016

Event selection

1) Fit a 2D gaussian around a 7x7 pixels window
2) Compute the Log-Likelihood (LL) of the best fit
3) Subtract from background LL —> ΔLL

$$\Delta LL = -\ln\left[\frac{\max(\mathcal{L}_G)}{\mathcal{L}_n}\right]$$

$$N_e(E) \times \mathrm{Gaus}(x, y|\mu_x, \mu_y, \sigma(Z))$$

Lateral spread

Number of ionized electrons

Best estimator for mean of energy deposition