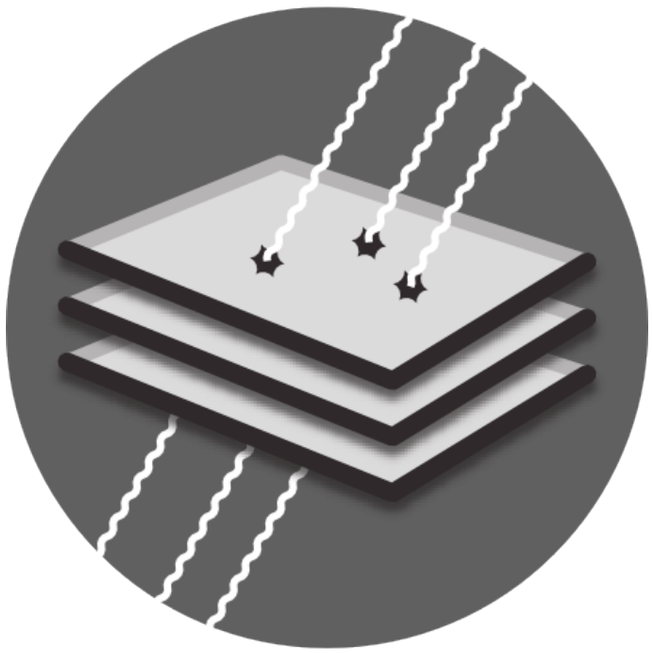
DAMIC at SNOLAB



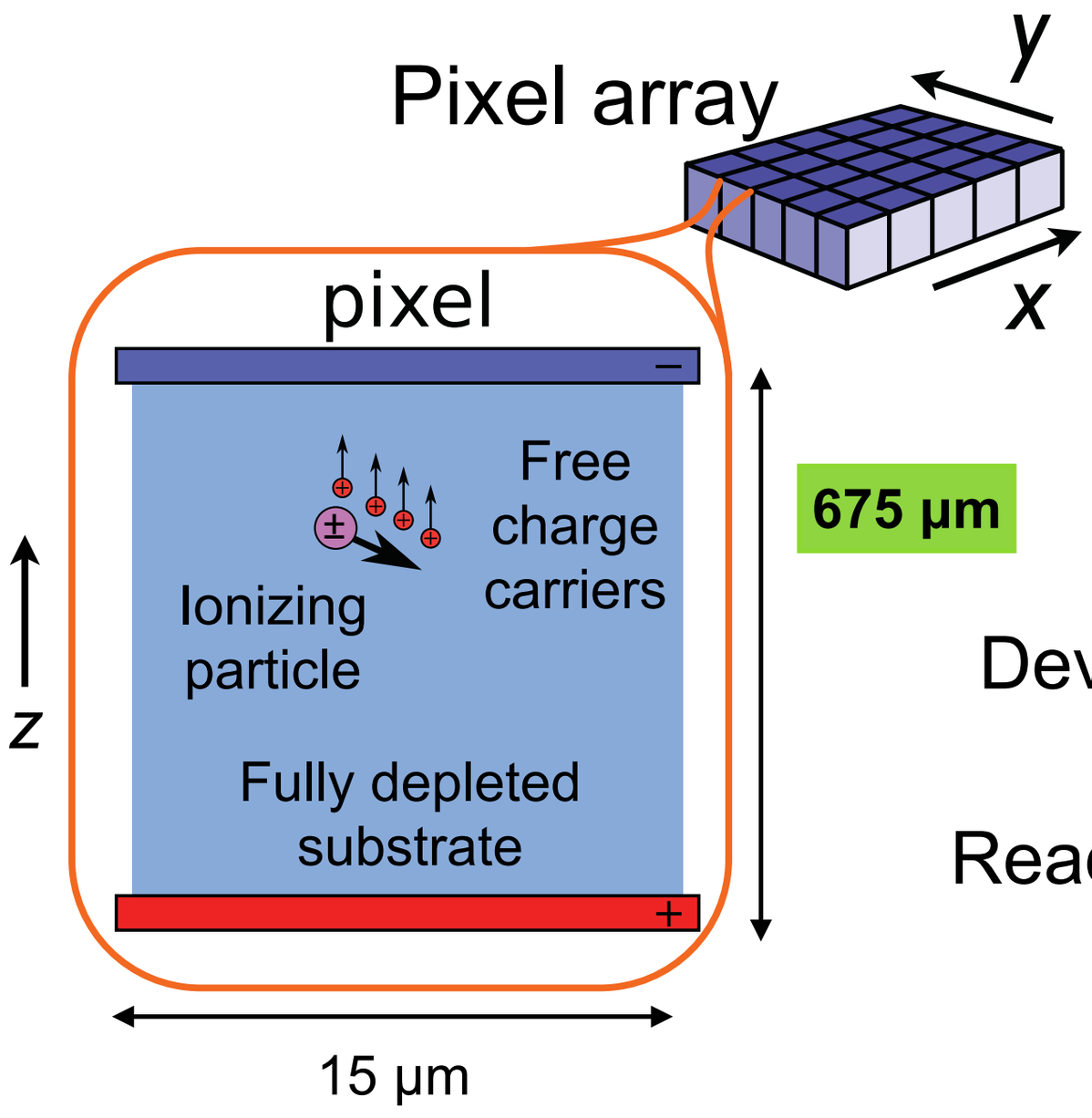
Alvaro E Chavarria
University of Chicago

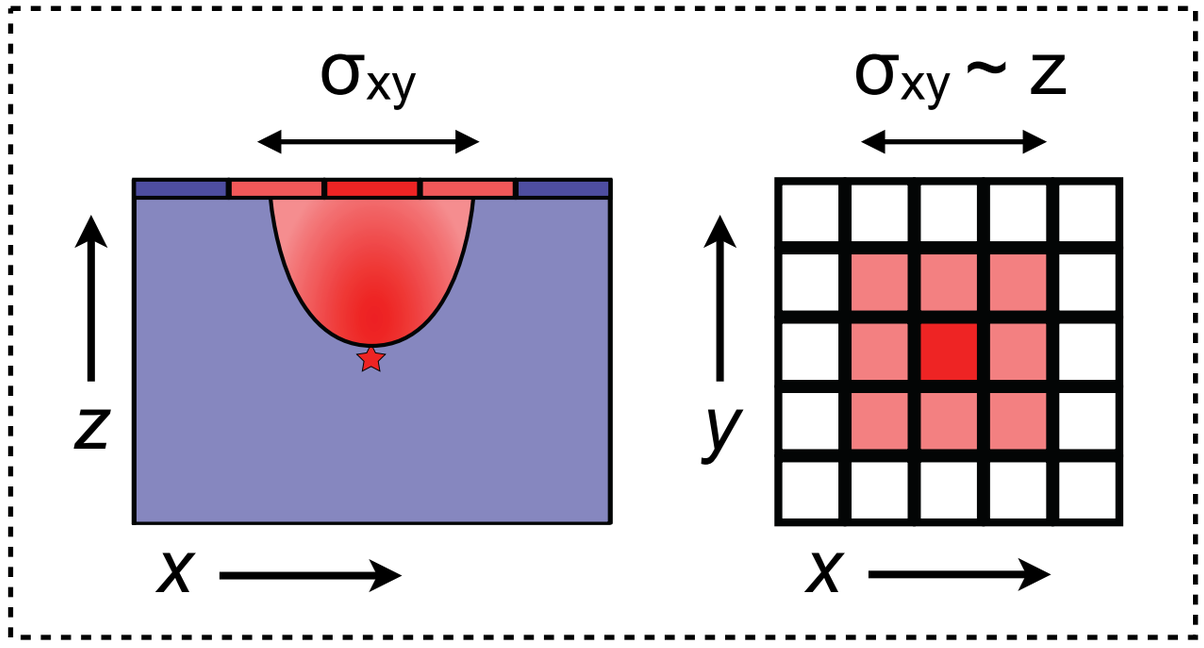
for the **DAMIC Collaboration**

Outline

- Charge coupled devices (CCDs) as detectors for low-energy particles.
- Characterization of the DAMIC devices.
- DAMIC installation at SNOLAB.
- **Low-mass** dark matter search results.
- Background suppression techniques.
- Future of the DAMIC program.

Charge coupled device



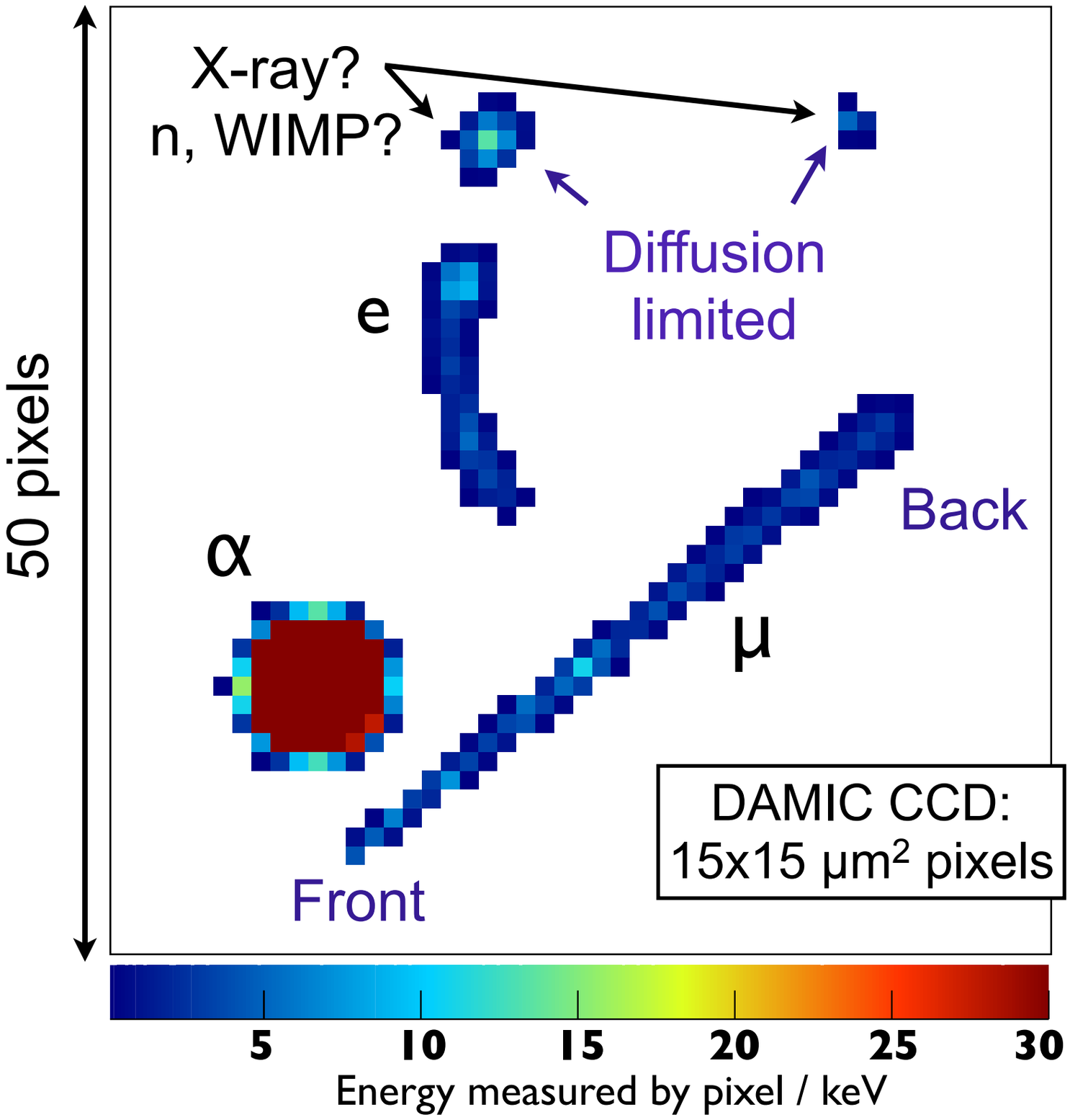


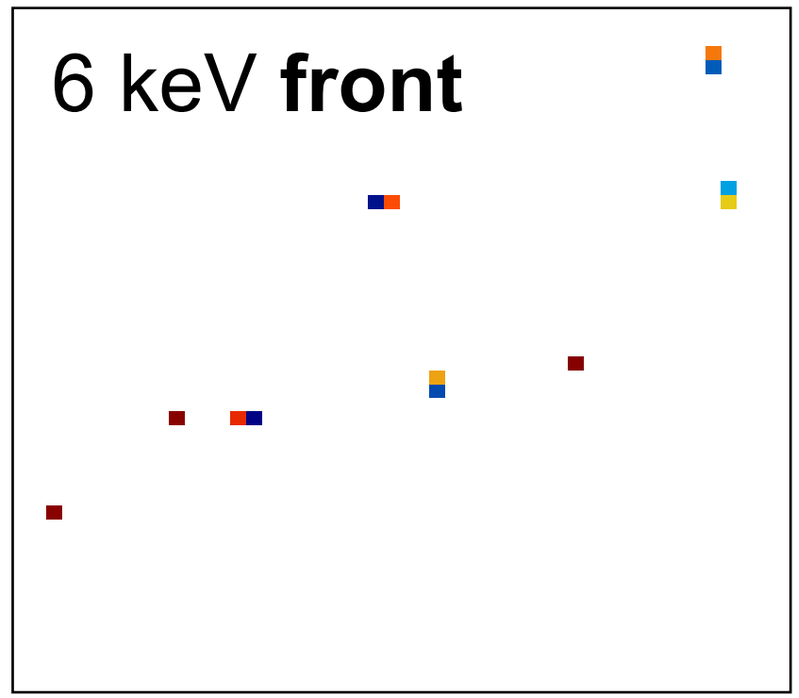
Device is “exposed,” collecting charge until user commands readout.

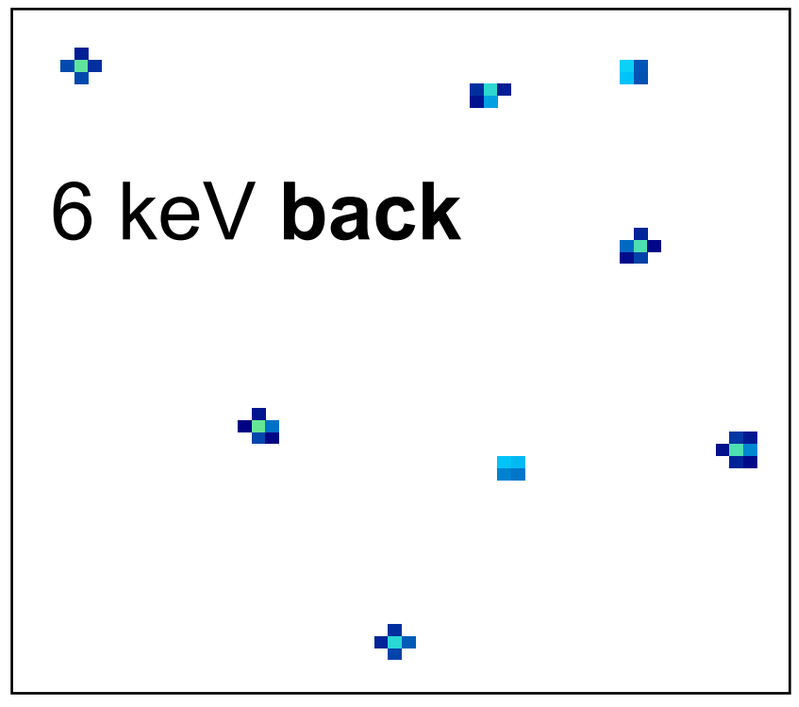
Readout can be slow / non-destructive : **very low noise (few e^-).**

Silicon band-gap: 1.2 eV.
Mean energy for 1 e-h pair: 3.8 eV.

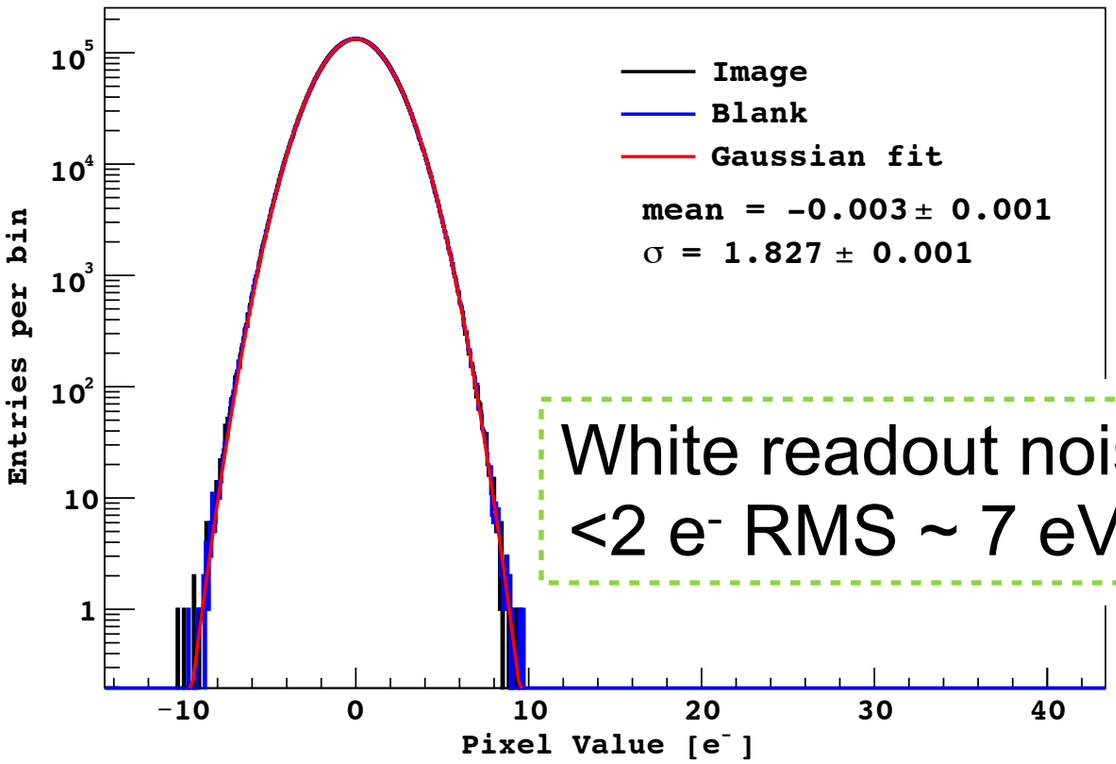
Particle tracks





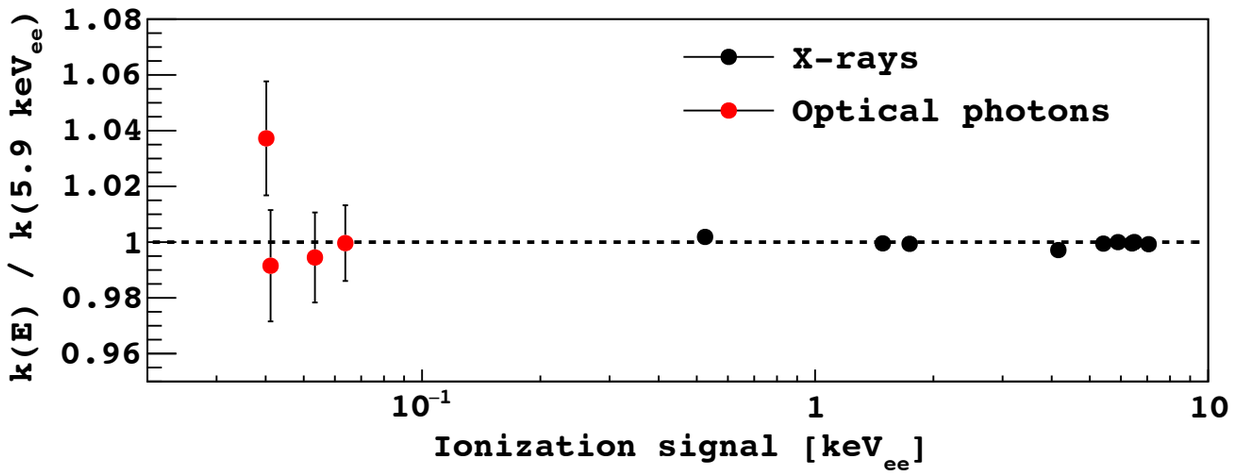


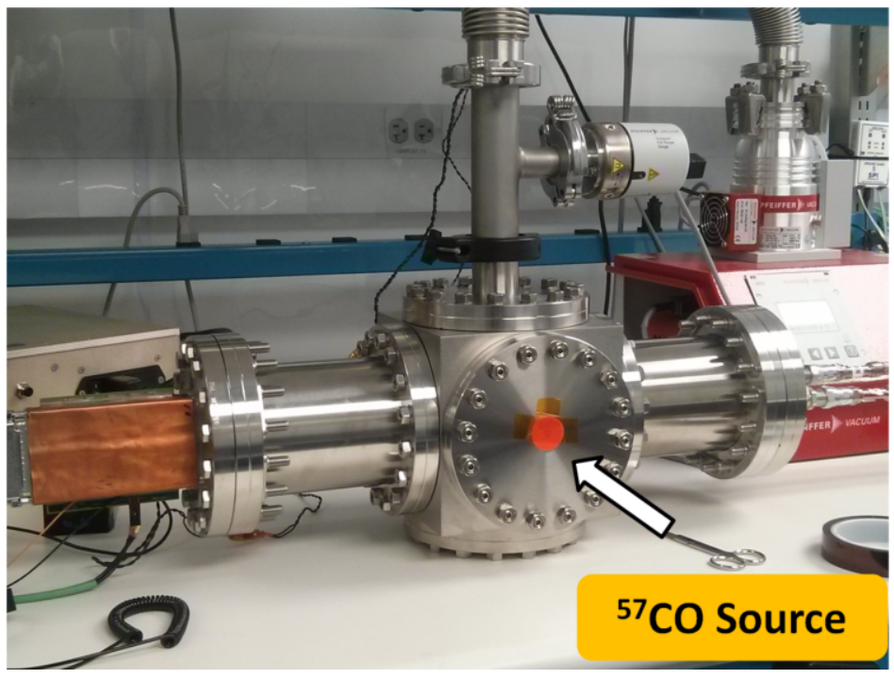
Device performance



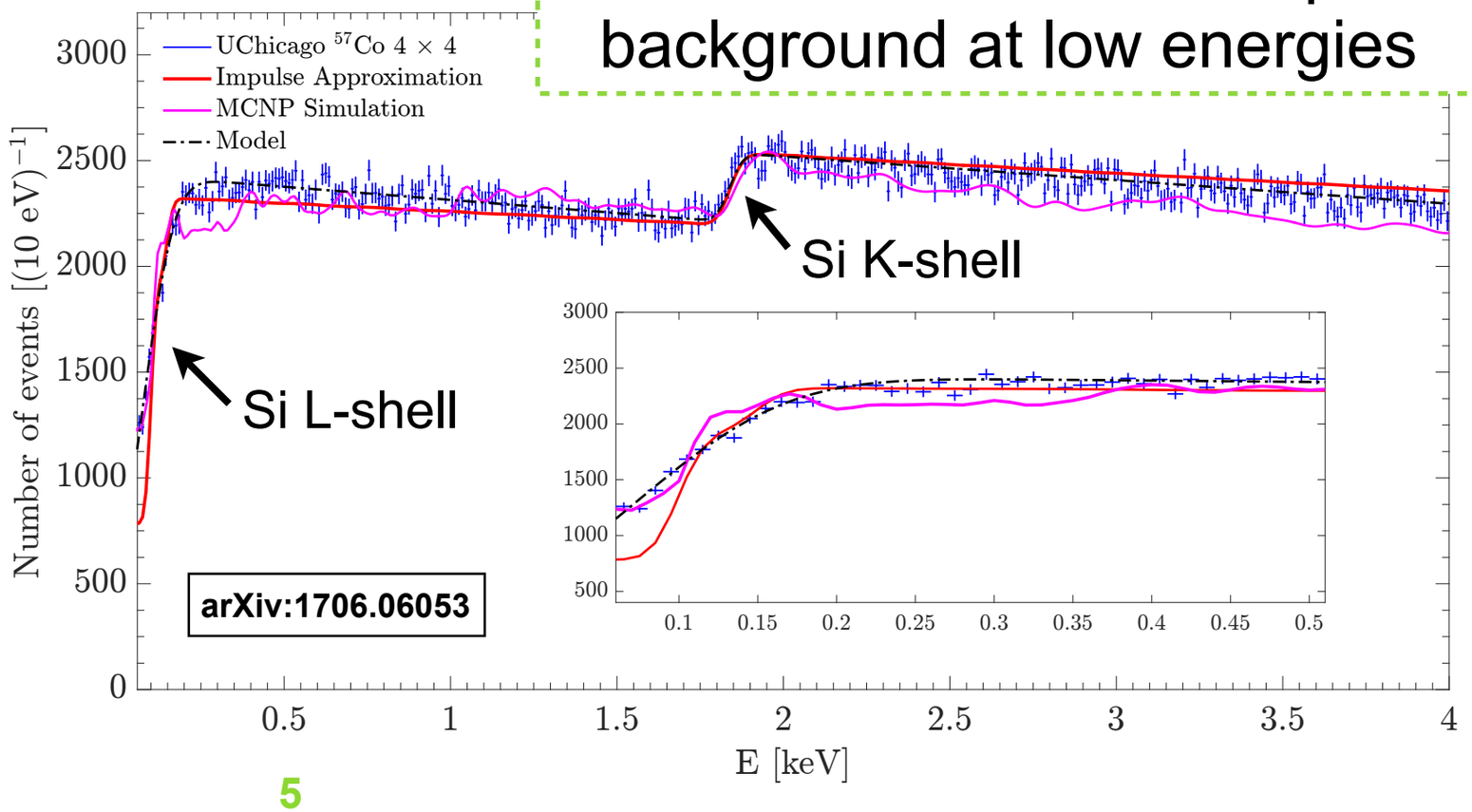
White readout noise
<2 e^- RMS ~ 7 eV_{ee}

Linearity demonstrated for signals <10 e^-.



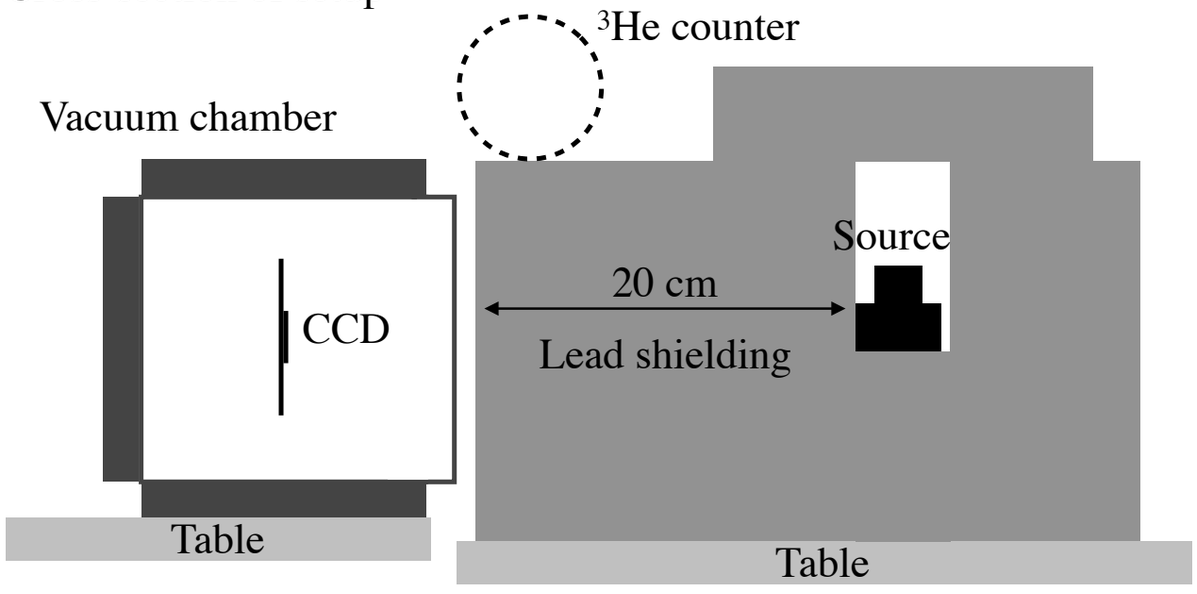


Characterization of Compton background at low energies

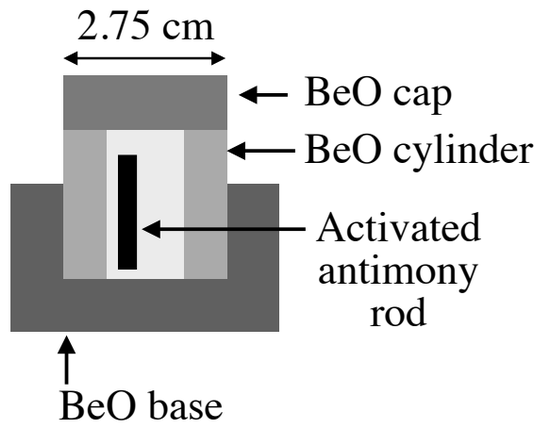


Nuclear recoil response

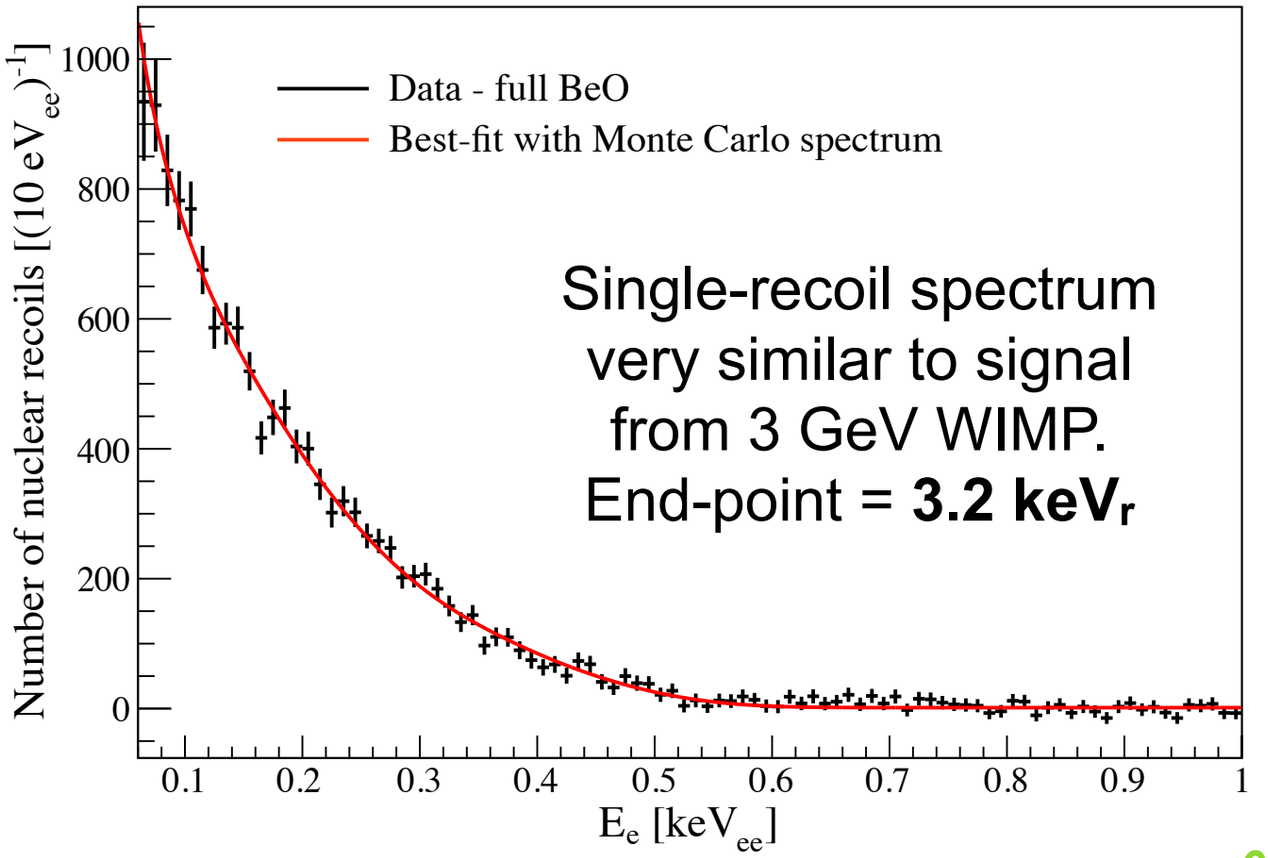
a) Cross-section of setup



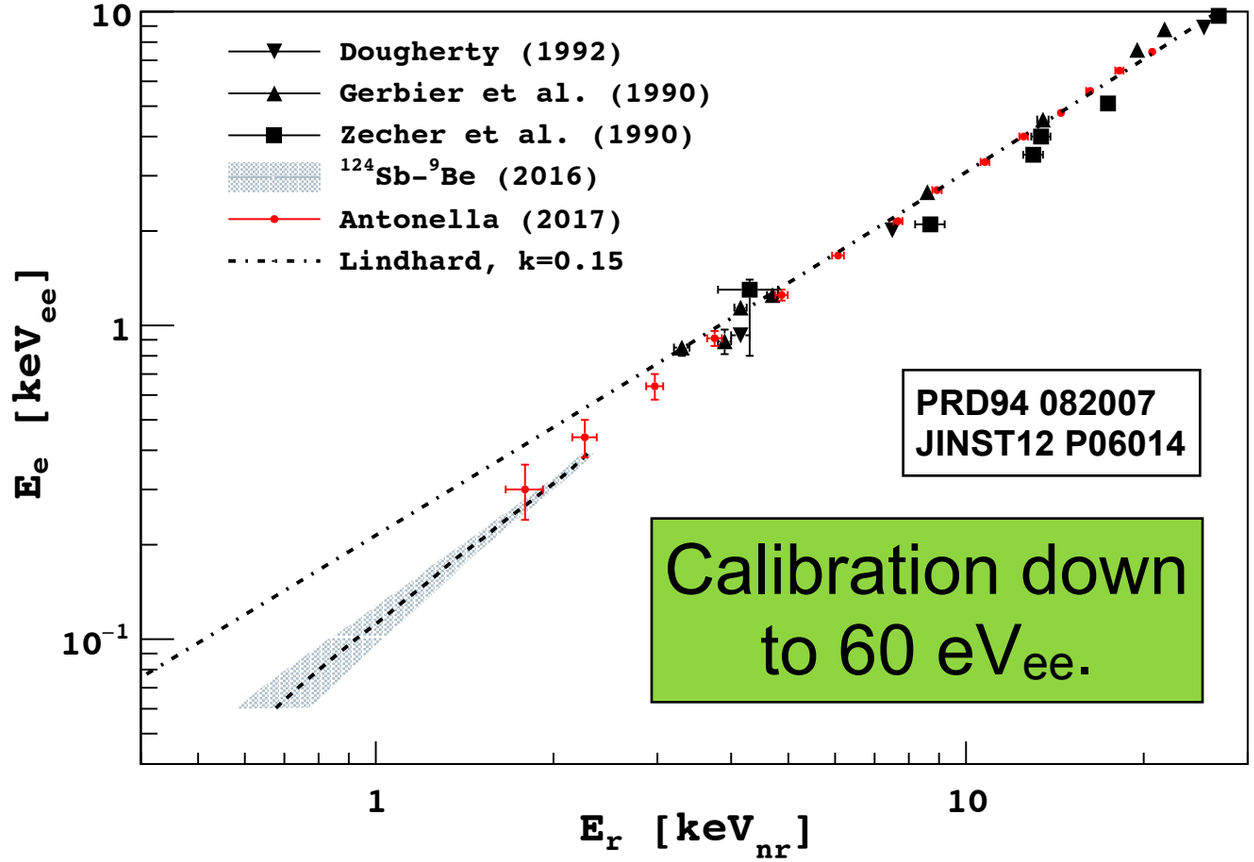
b) ^{124}Sb-^{9}Be source detail



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

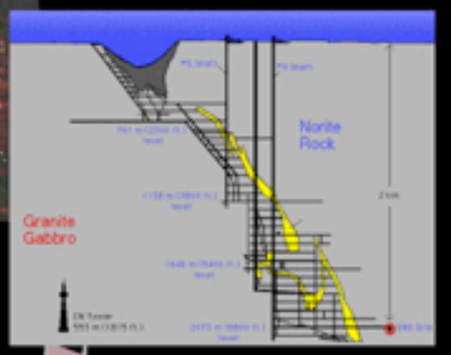


Single-recoil spectrum very similar to signal from 3 GeV WIMP. End-point = **3.2 keV$_r$**



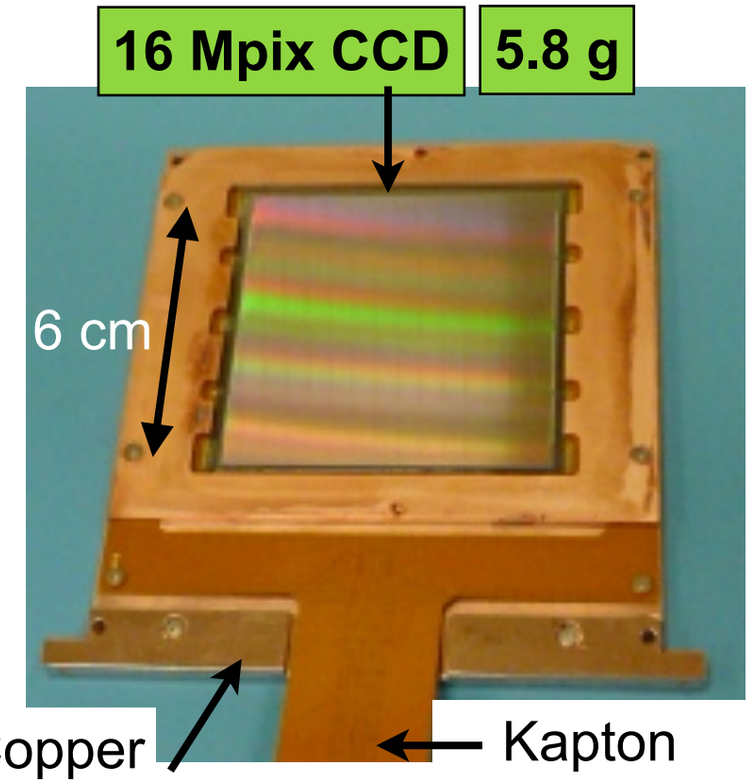
Calibration down to 60 eV$_{ee}$.

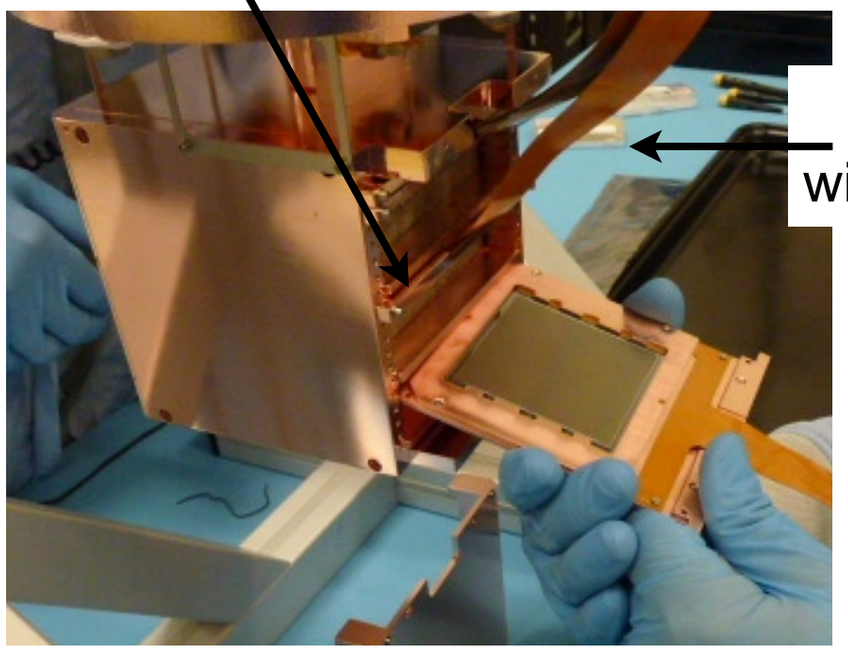
2 km underground

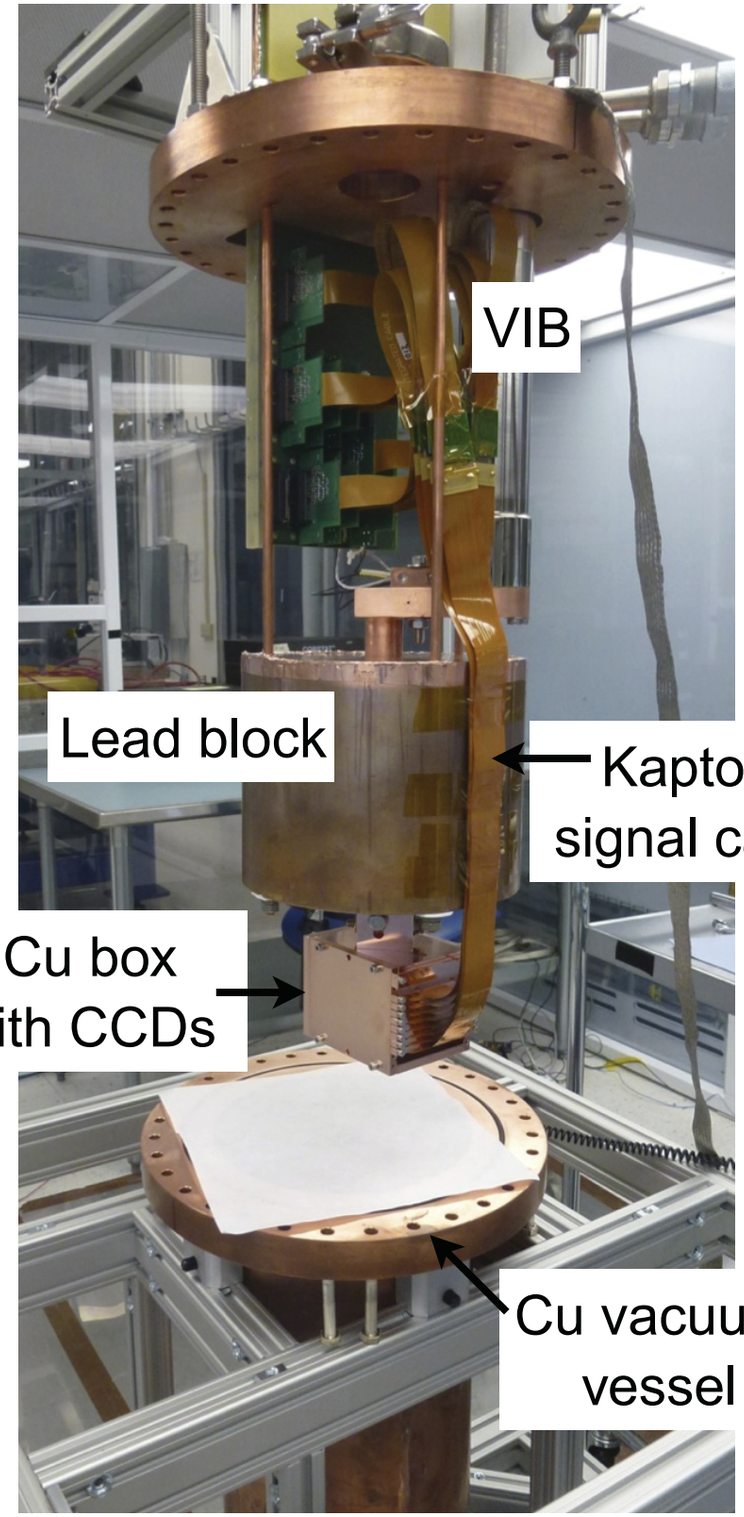


SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

SNOLAB Installation

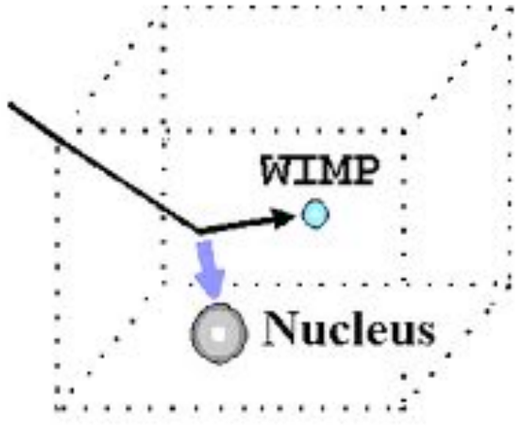




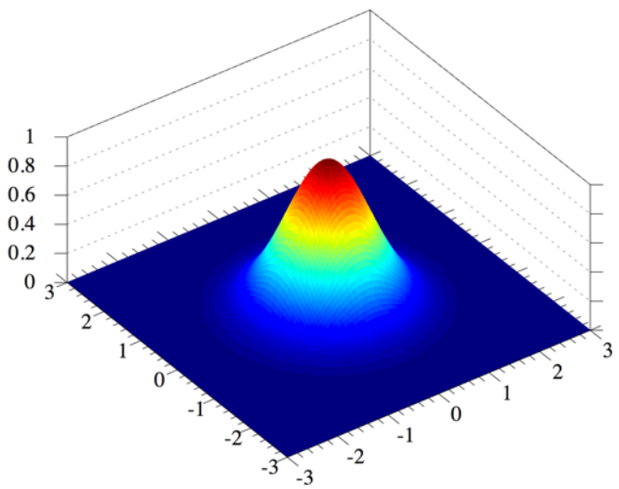


WIMP search

Elastic scattering of WIMPs with silicon nuclei.

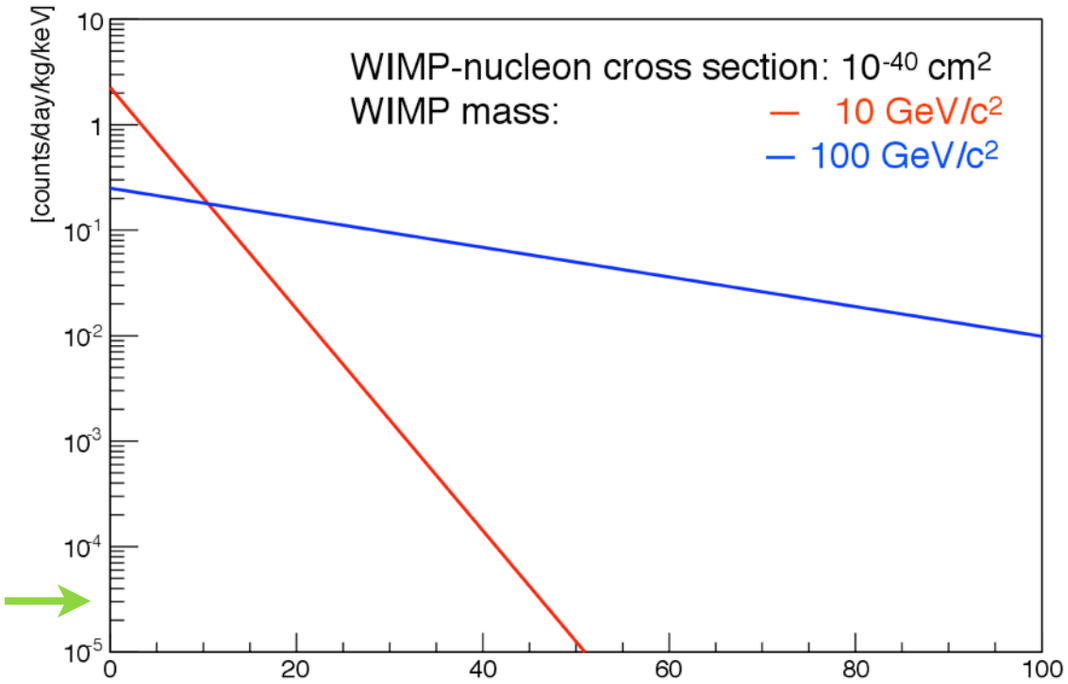


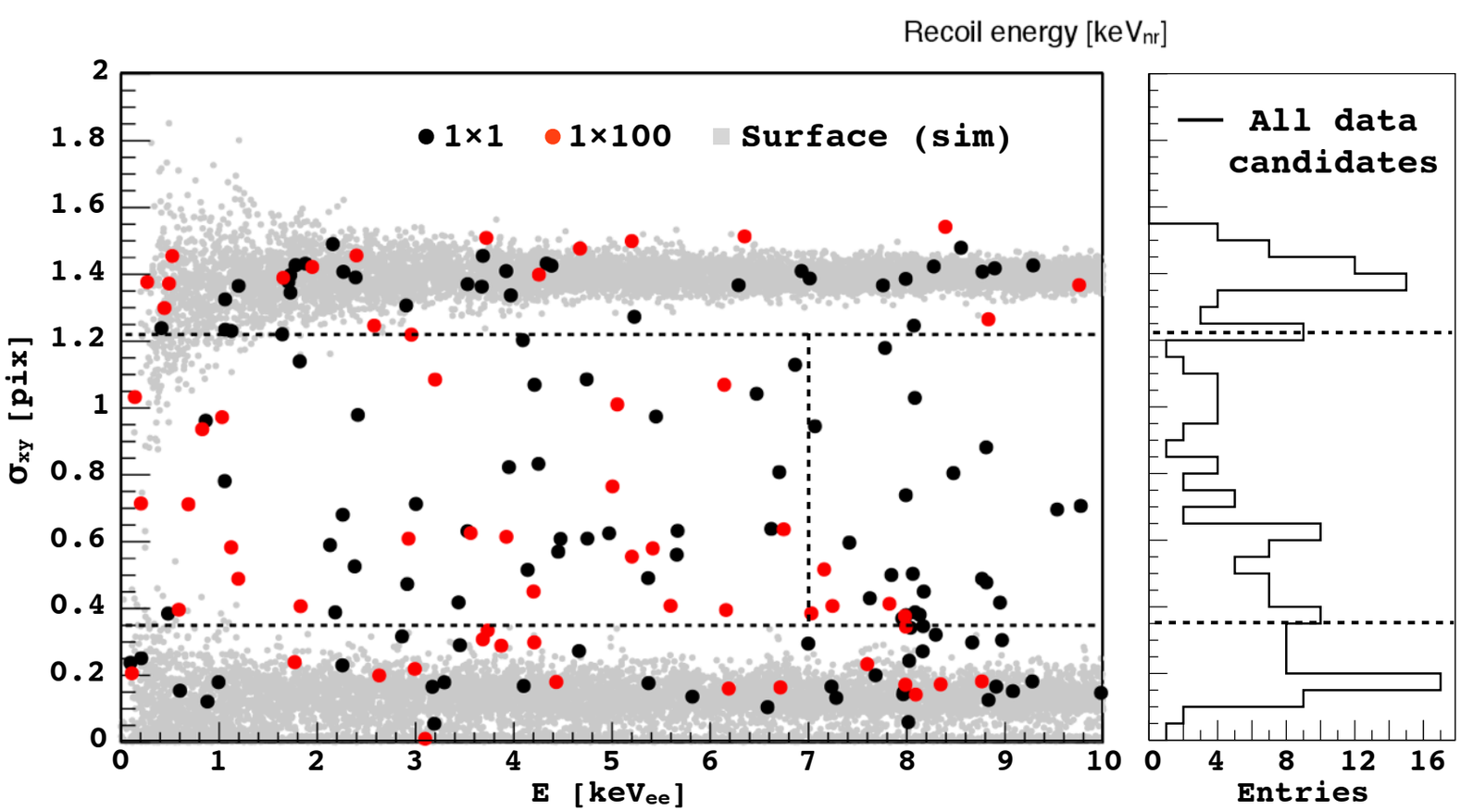
2D Gaussian distribution of free charge on pixel array.



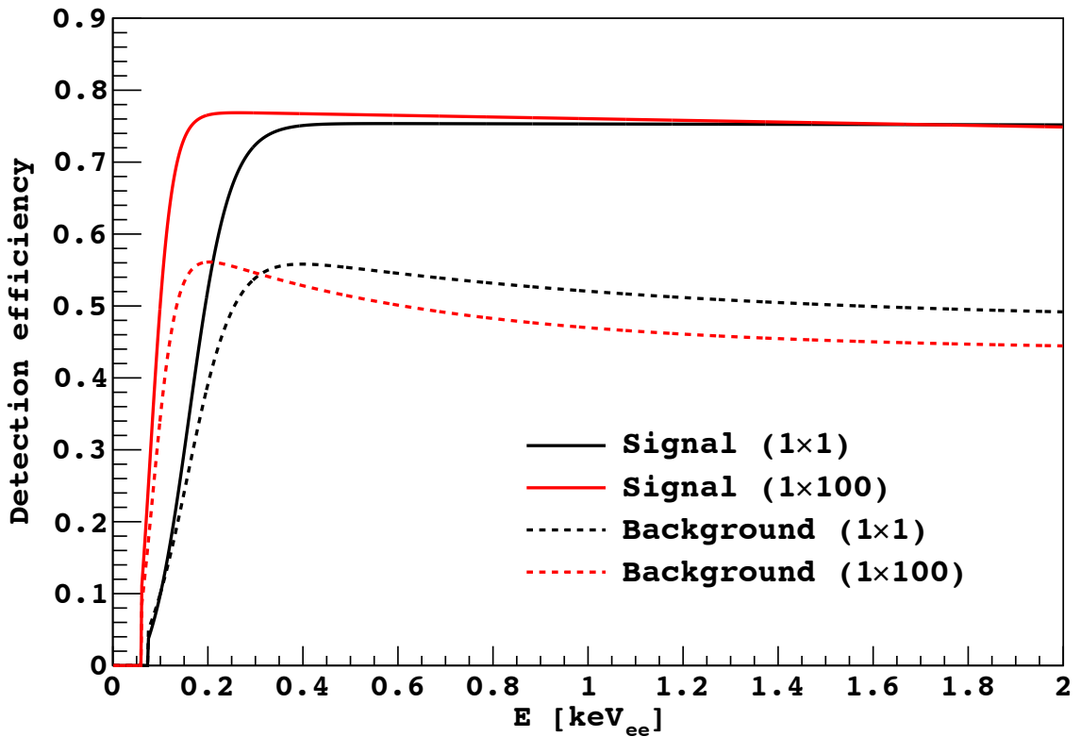
Measure **E** and σ_{xy} for every event.

Recoil spectrum in Si target

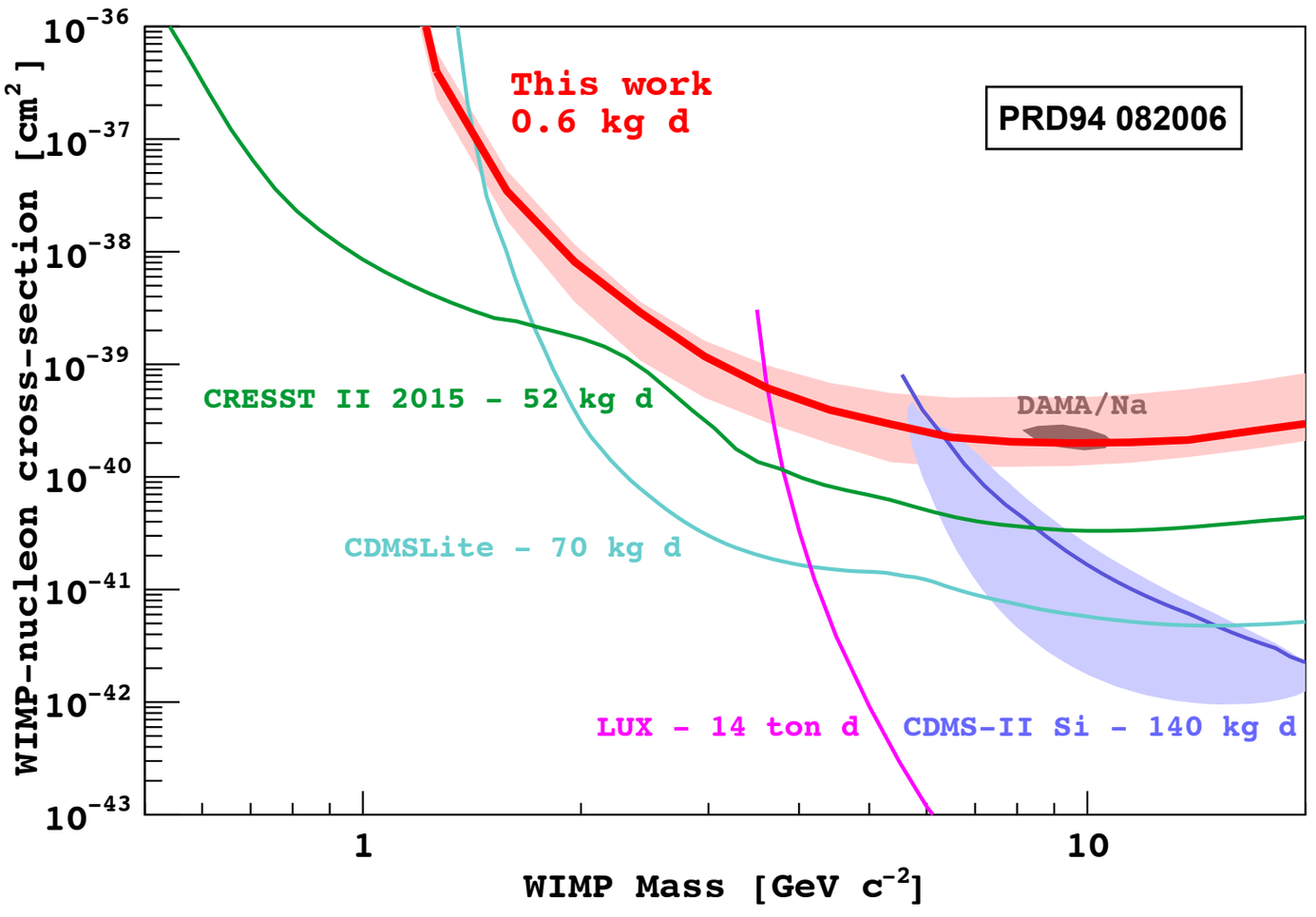




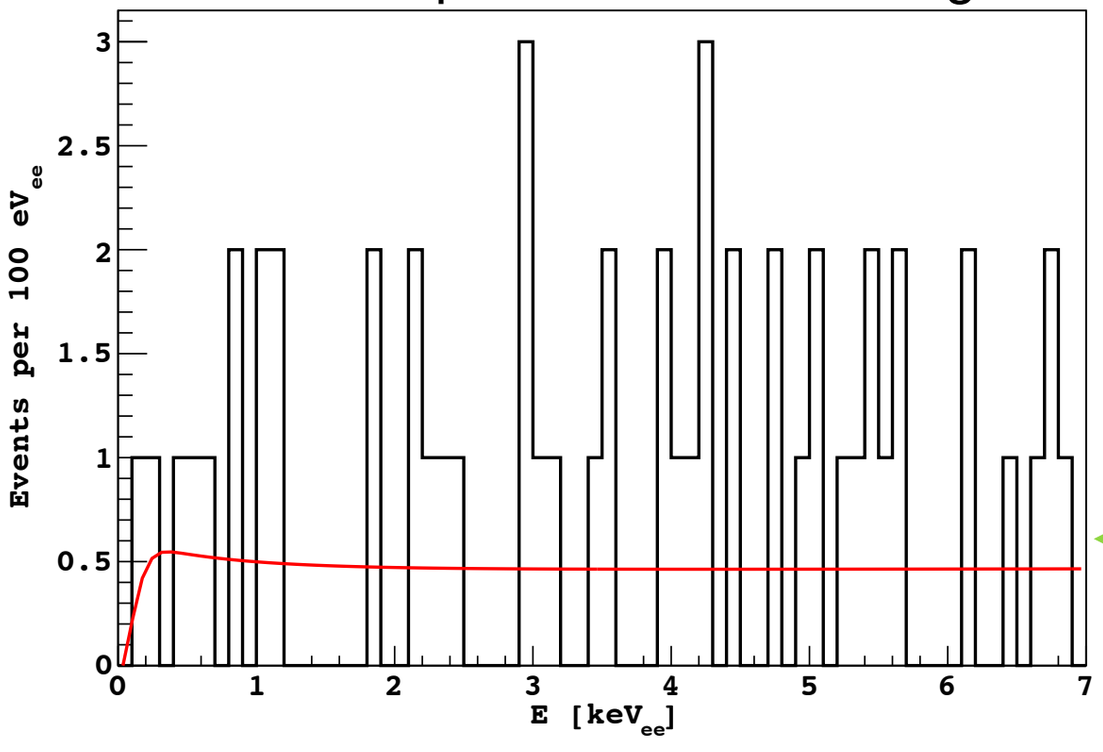
WIMP search



0.6 kg days of data with test devices at SNOLAB.
~30 dru total background.



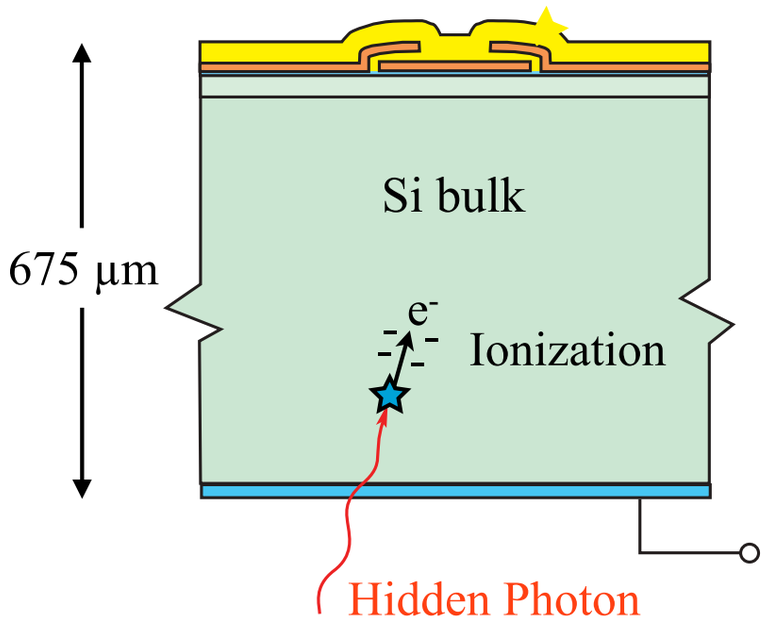
Observed spectrum in fiducial region



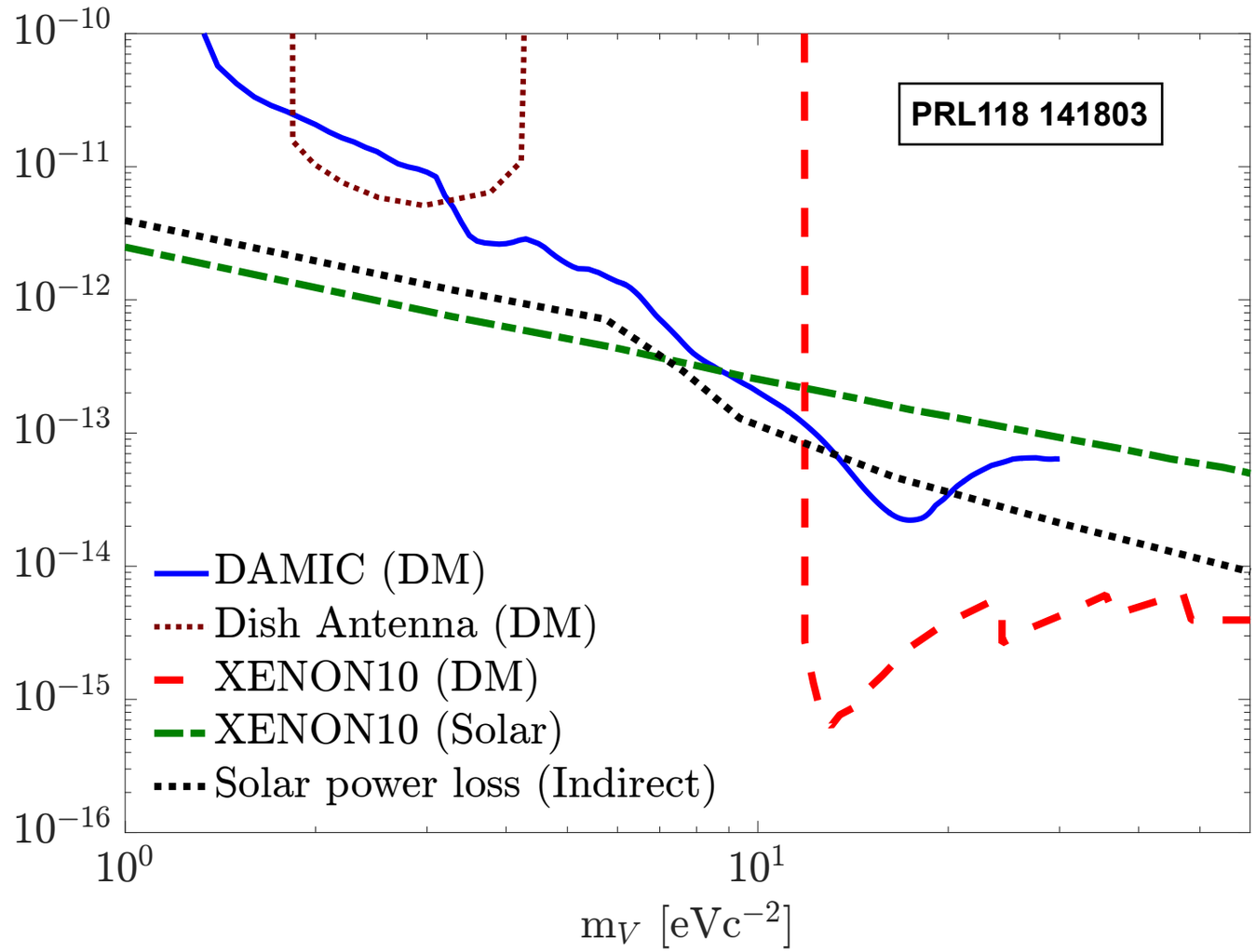
Spectrum consistent with Compton scattered electrons in fiducial region:
No WIMP signal.

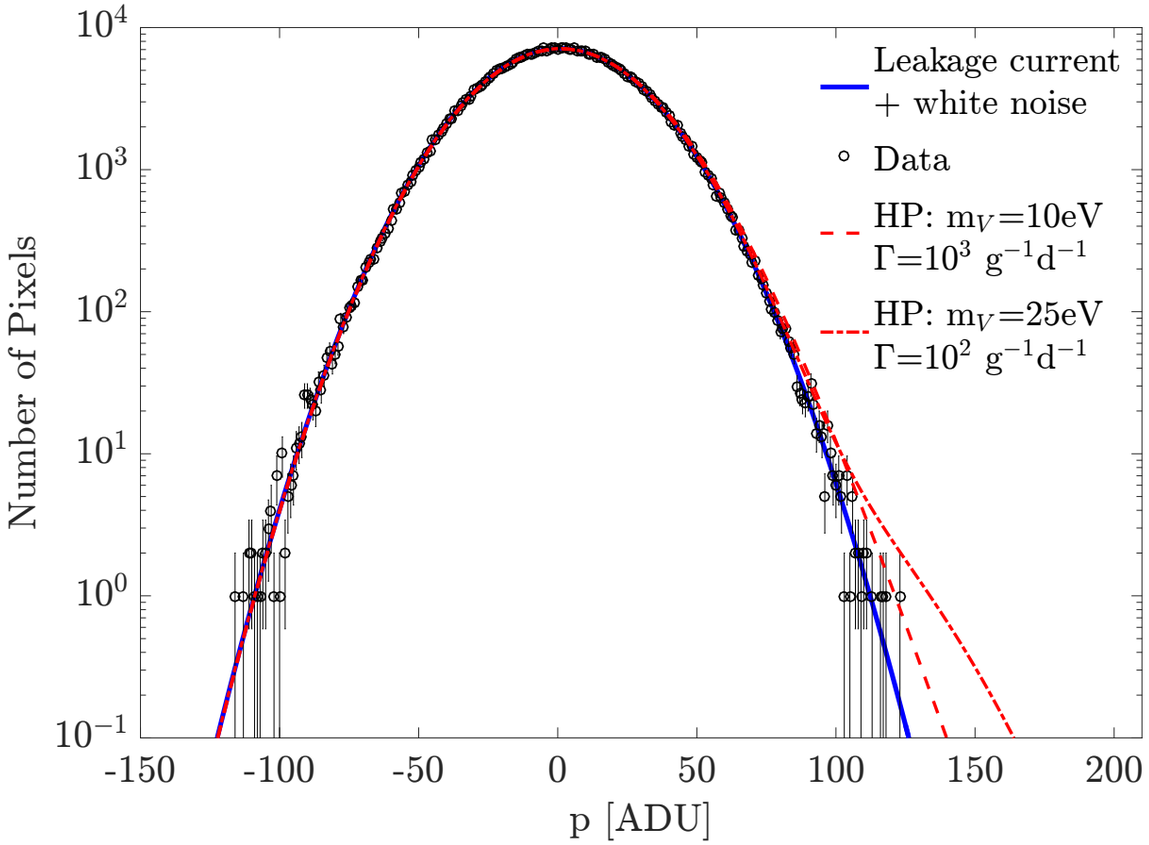
Hidden photon search

Absorption of hidden-photon dark matter.



~1 week of data with 1 CCD.
Leakage current **4 e^- mm^{-2} d^{-1}**
7×10^{-22} A cm^{-2}





Pixel distribution consistent with white noise + uniform leakage current.

ββ coincidences

64 keV 1.2 MeV

$^{210}Pb \longrightarrow ^{210}Bi \longrightarrow ^{210}Po$

$\tau_{1/2} = 5$ d

0.22 MeV 1.7 MeV

$^{32}Si \longrightarrow ^{32}P \longrightarrow ^{32}S$

$\tau_{1/2} = 14$ 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.)

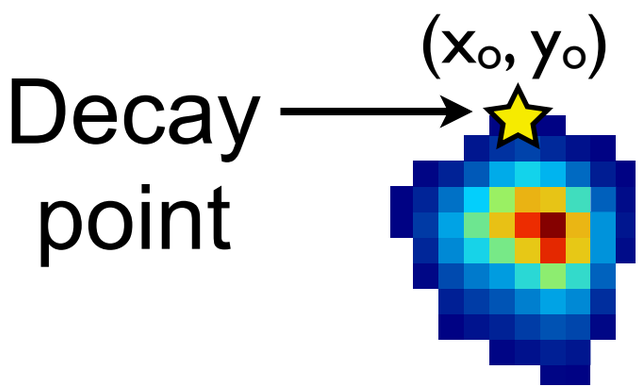
JINST 10 P08014

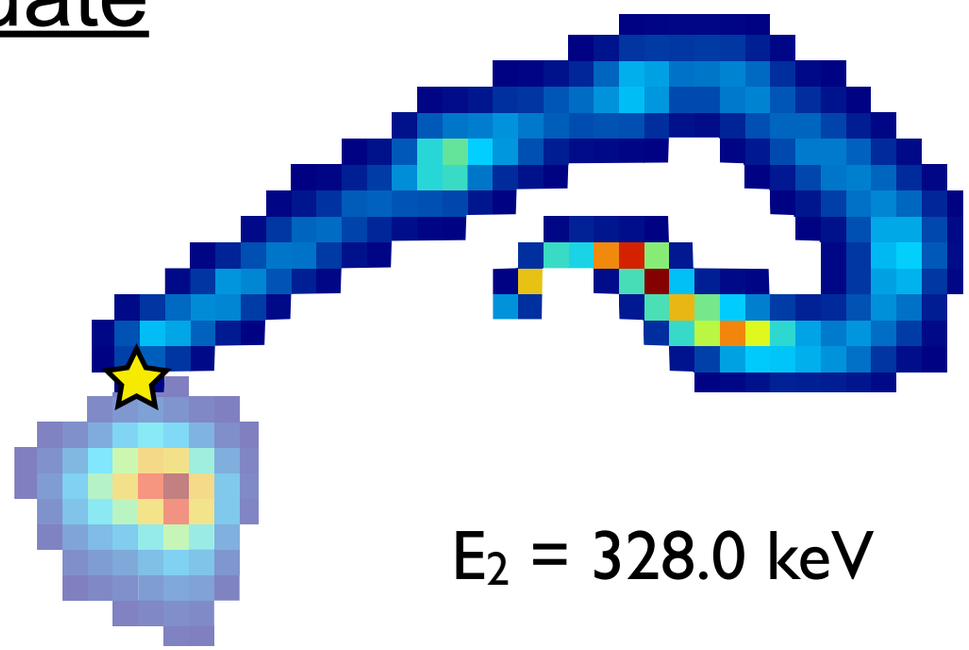
^{32}Si - ^{32}P candidate

$E_1 = 114.5$ keV

$\Delta t = 35$ days

$E_2 = 328.0$ keV





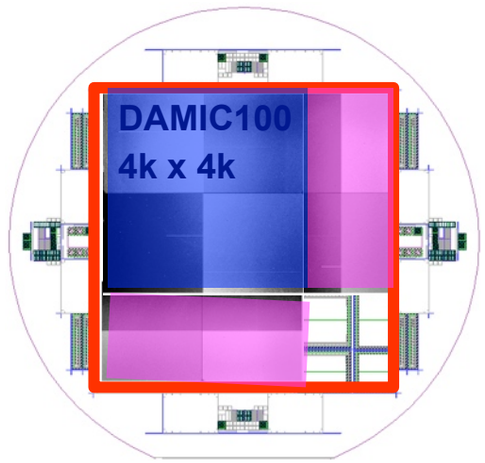
DAMIC100

- Seven CCDs (~40 g) running at SNOLAB since **Jan 2017**.
- Already have ~6 kg-day of data with 5-15 dru *total* background rate. Analysis ongoing.

DAMIC-1K

6k x 6k pixels, 1 mm thick
≈ 20 g / CCD
≈ 50 CCDs / 1 Kg

- A 1 kg detector built with *existing* technology.
- Sub-e^- resolution, 2 e^- threshold.
- Background improvement to 0.1 dru:
  -Improved design for background suppression.
  -Strict handling and packaging procedures.
  -^{3}H mitigation: silicon transport in shielded container and removal by baking wafers (R&D).

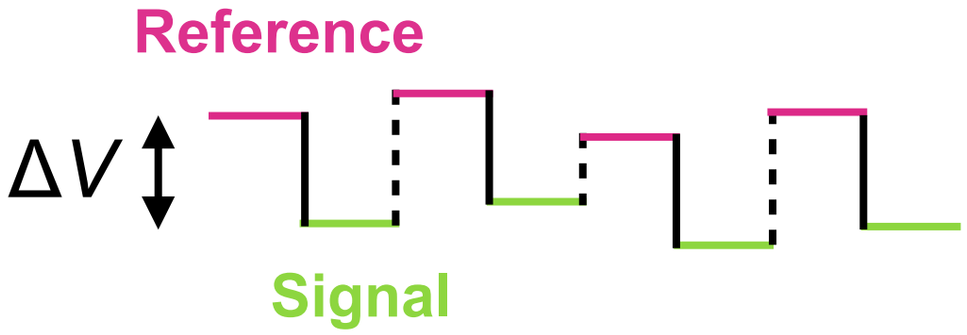


Silicon wafer

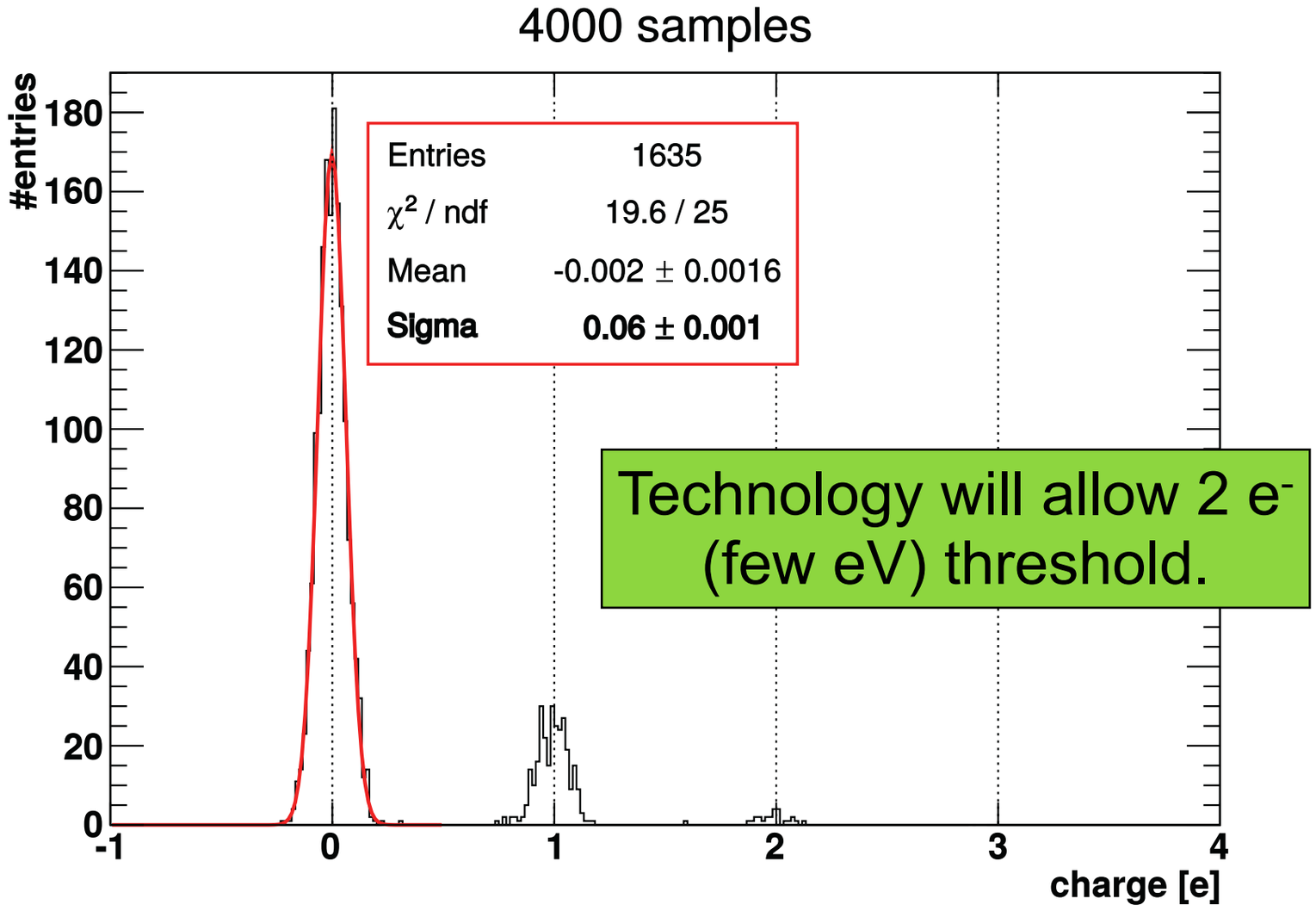
SENSEI

LDRD at Fermilab (PI Tiffenberg): Skipper CCDs (LBNL design) successfully tested with sub e^- noise. X-ray spectroscopy demonstrated. arXiv:1706.00028

Non destructive "skipper" readout: Perform *N* uncorrelated measurements of the same pixel. Noise decreases by ~$1/\sqrt{N}$.

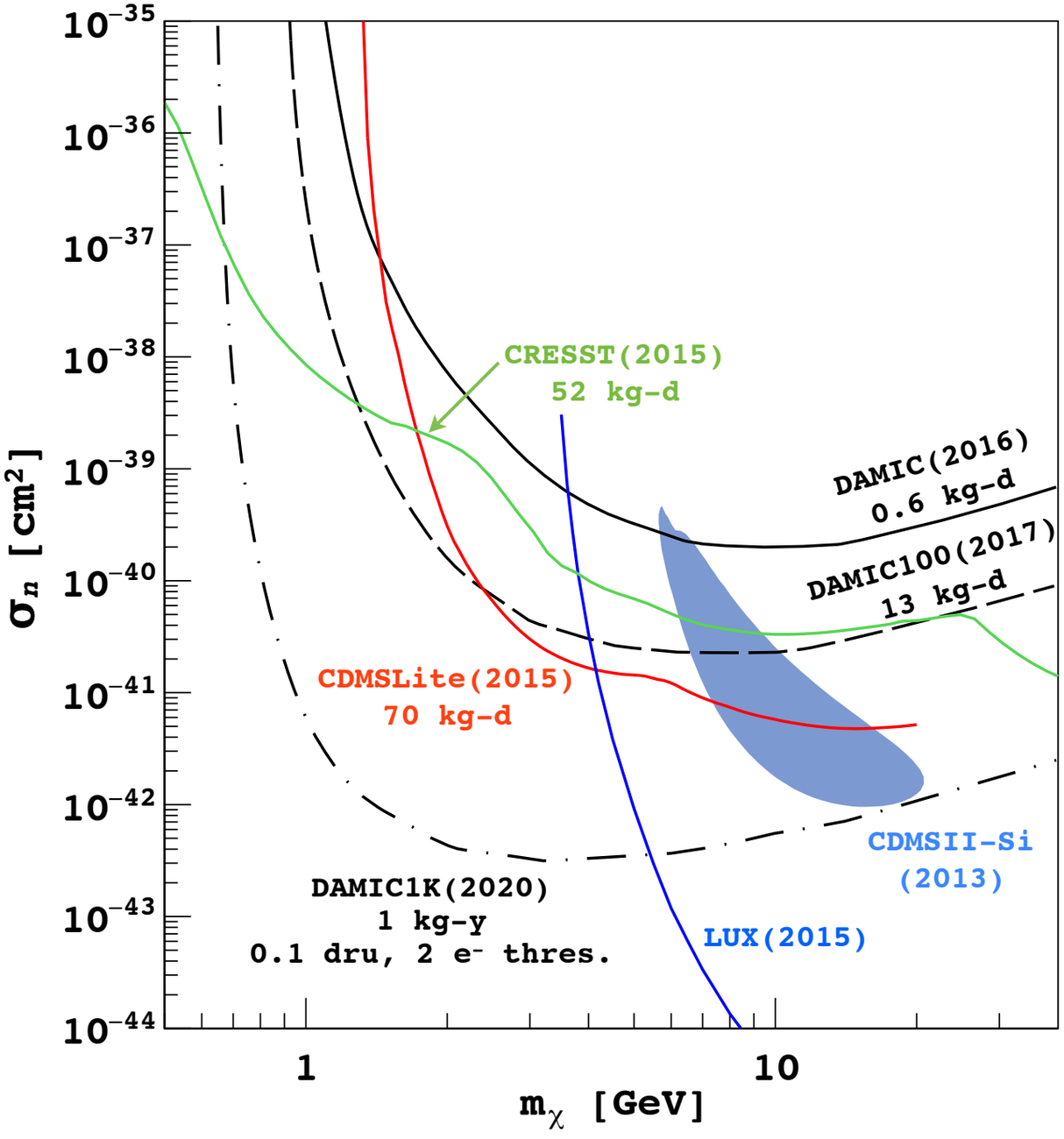


Measure Δ*V* *N* times.

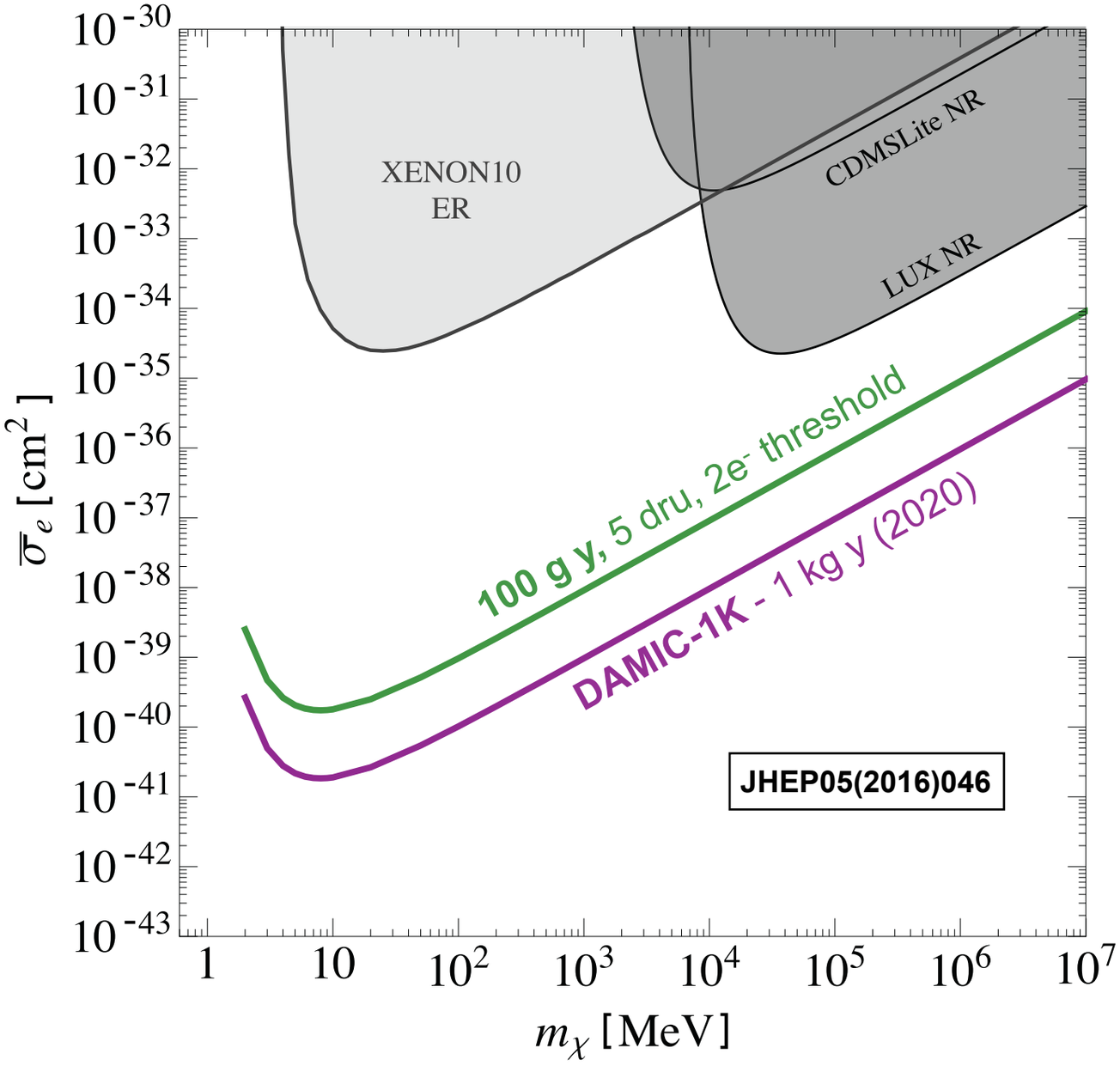


DAMIC Program

DM-nucleus SI coherent scattering



DM-e Scattering via Ultra-light Hidden Photon

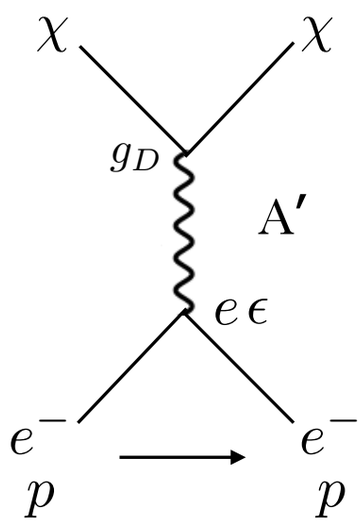


Also best limits for absorption of hidden photon dark matter.

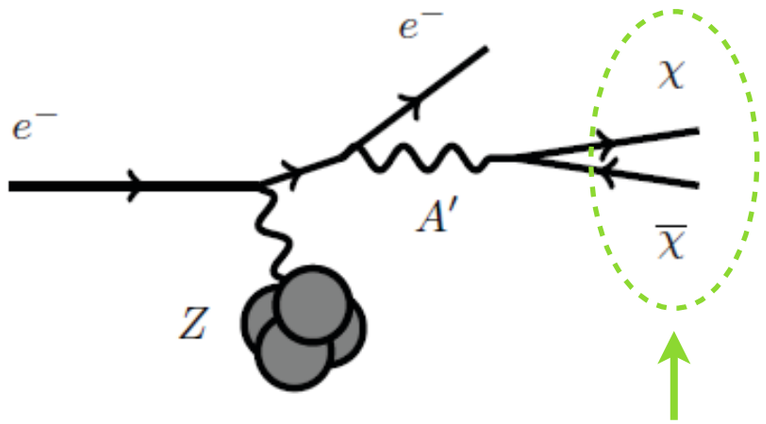
DAMIC Program

Direct search:

Ionization produced by dark matter - electron / nucleus scattering.

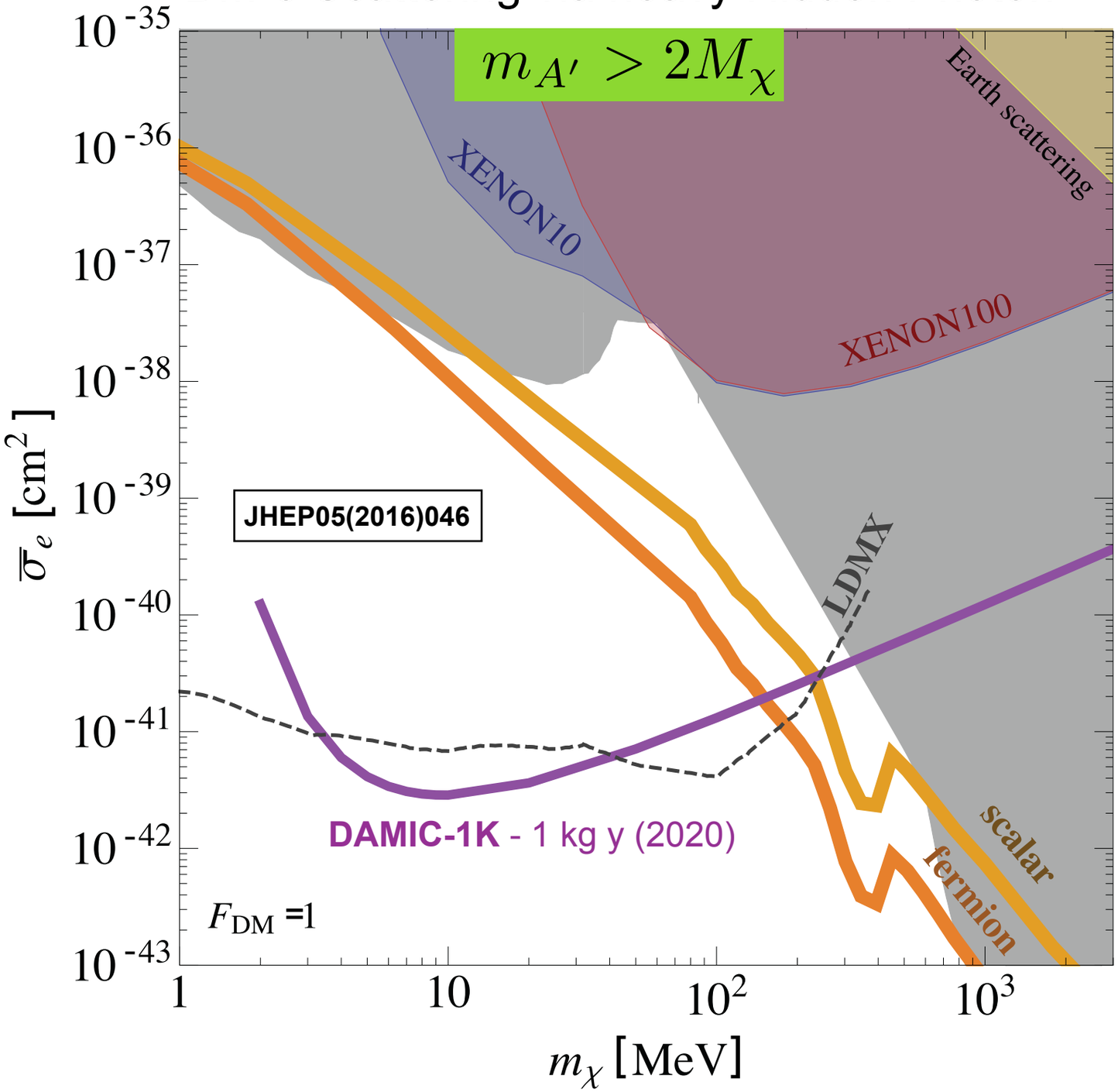


Accelerators:



Look for electron's missing momentum (**LDMX**) or χ interacting directly (**BDX**).

DM-e Scattering via heavy Hidden Photon



Conclusion

- CCDs are low-radioactivity, low-noise particle detectors whose *response to ionizing radiation has been thoroughly characterized*.
- **DAMIC** has placed competitive dark matter search results (WIMPs + hidden photons) with early R&D data.
- Established discrimination techniques to measure and suppress backgrounds (esp. dominant ^{32}Si).
- Ongoing R&D efforts for a **DAMIC-1K**: 50 skipper CCDs for a 1 kg detector with 2 e^- threshold to search for low-mass dark matter by DM-nucleon and DM-electron scattering.

Thank you!