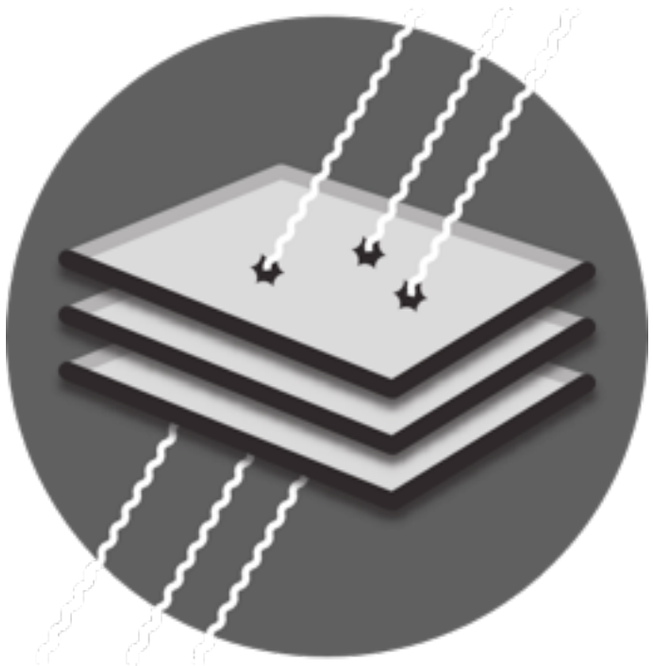
DAMIC at SNOLAB



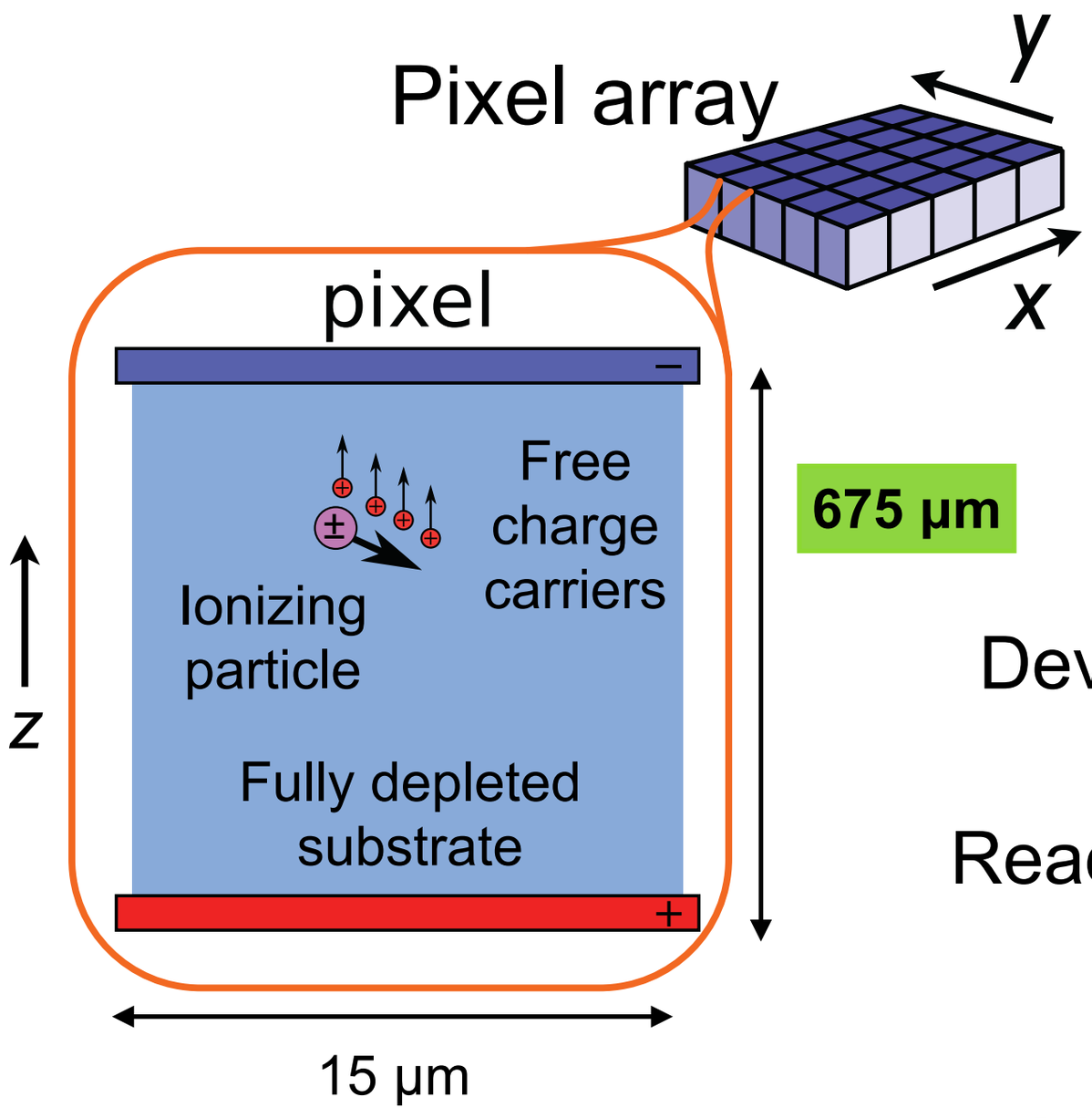
Alvaro E Chavarria
University of Chicago

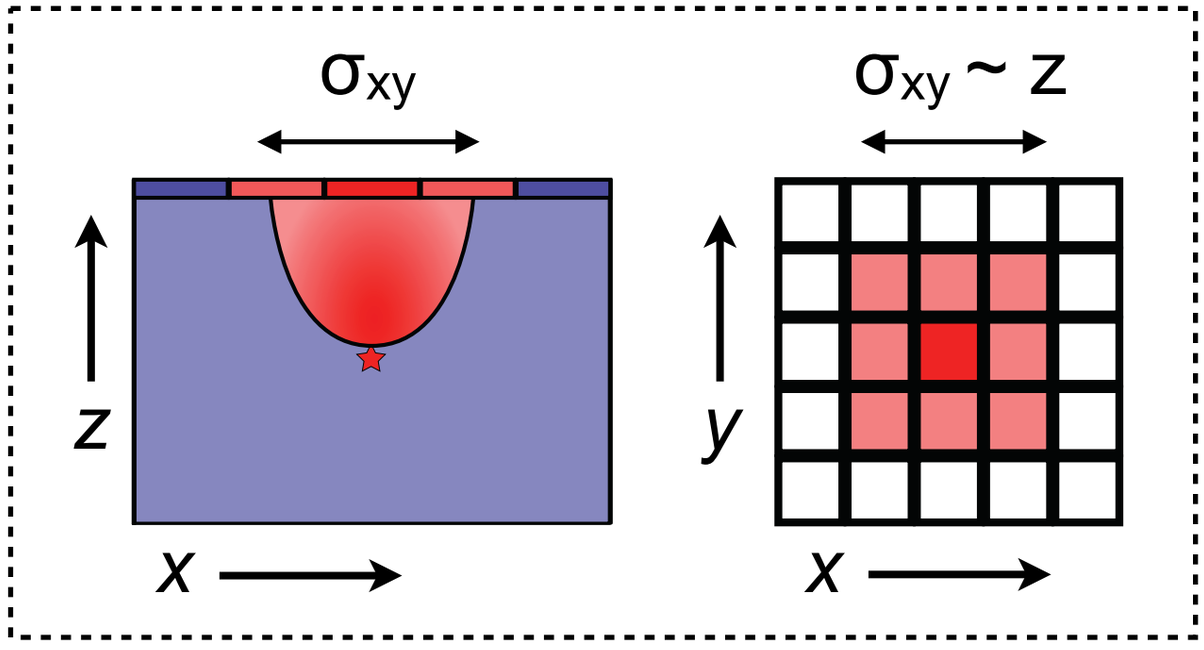
for the **DAMIC Collaboration**

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



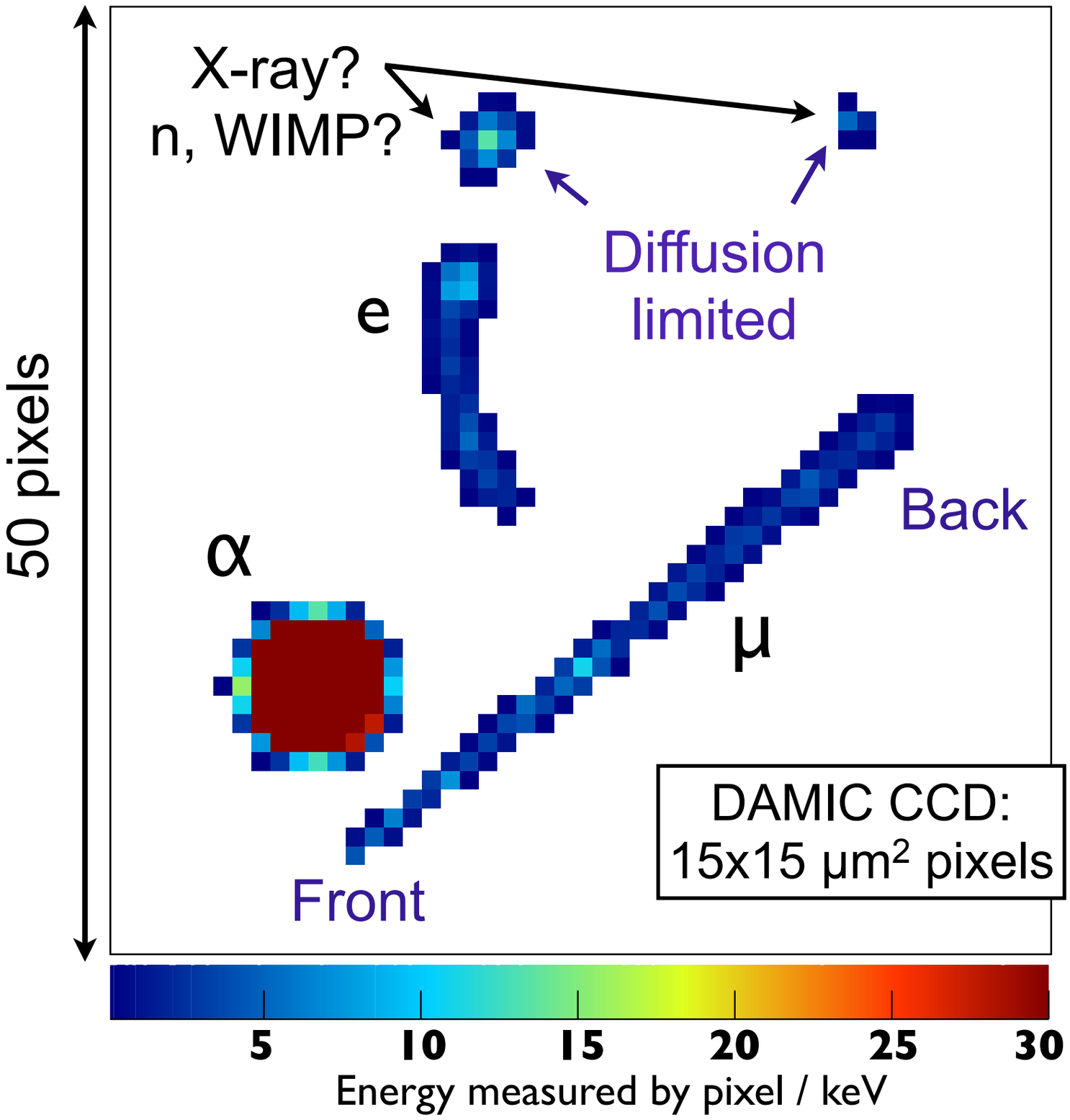


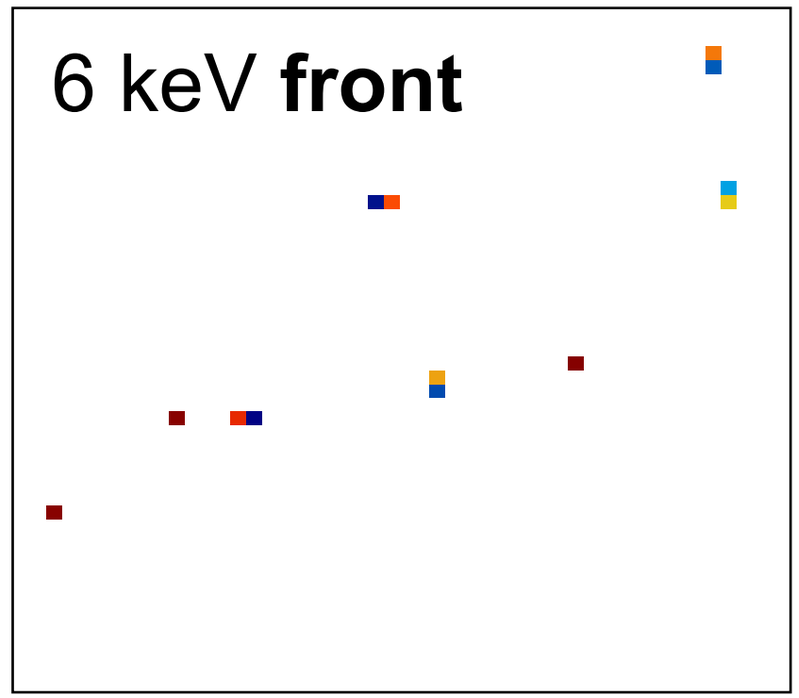
Device is “exposed,” collecting charge until user commands readout.

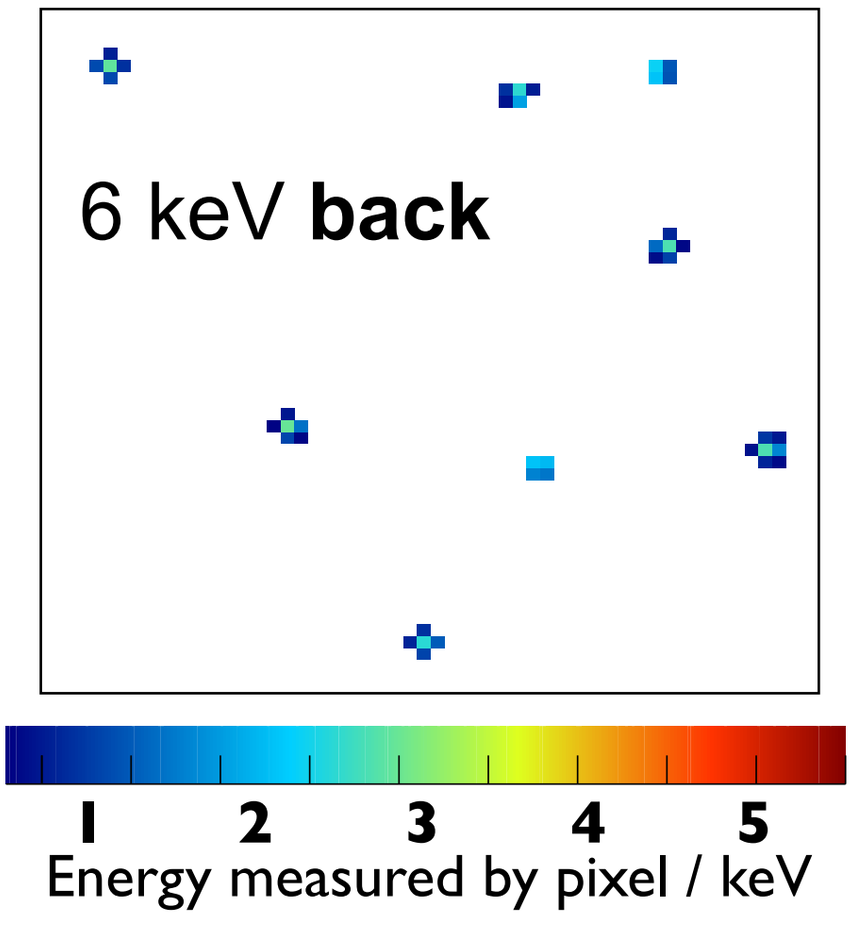
Readout can be slow / non-destructive : **very low noise (few e^-).**

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

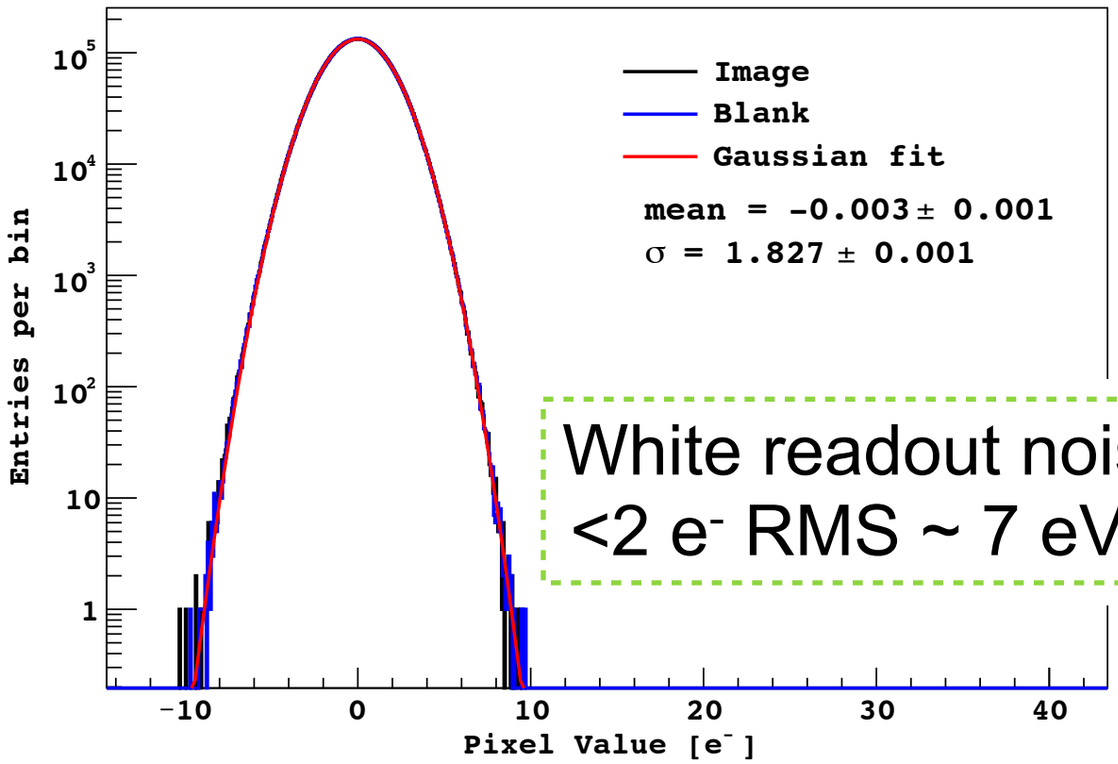
Particle tracks





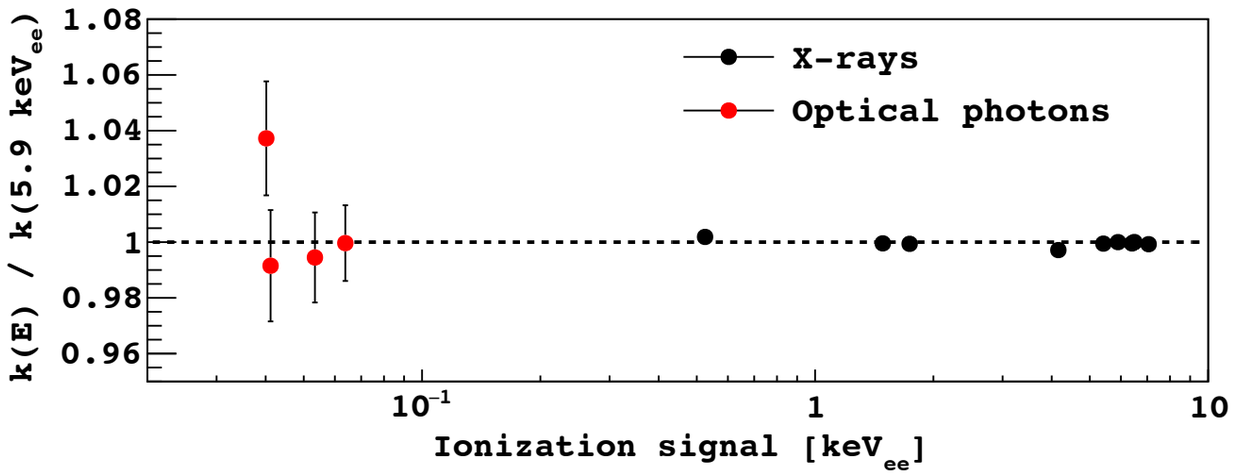


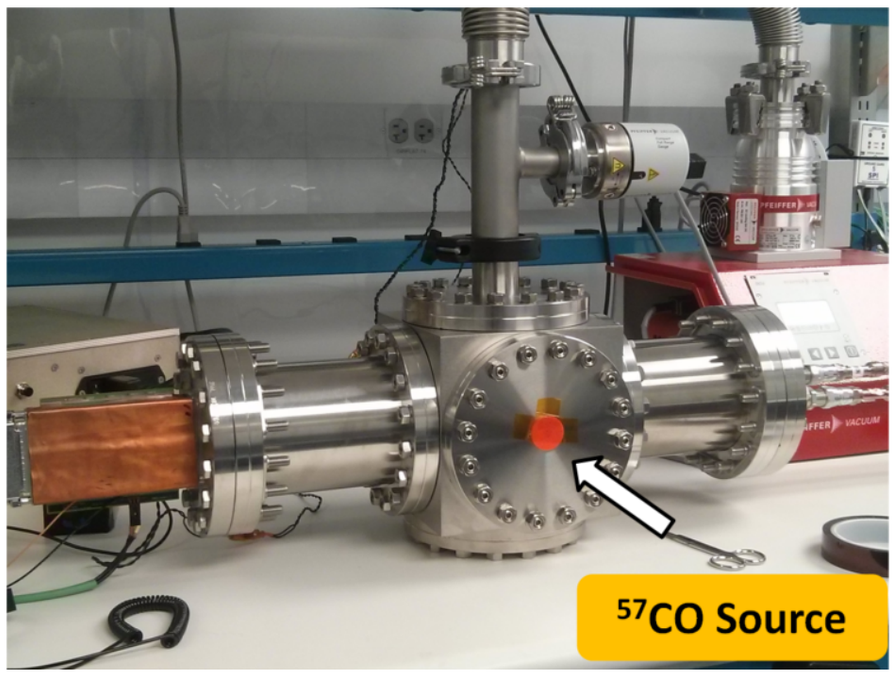
Device performance



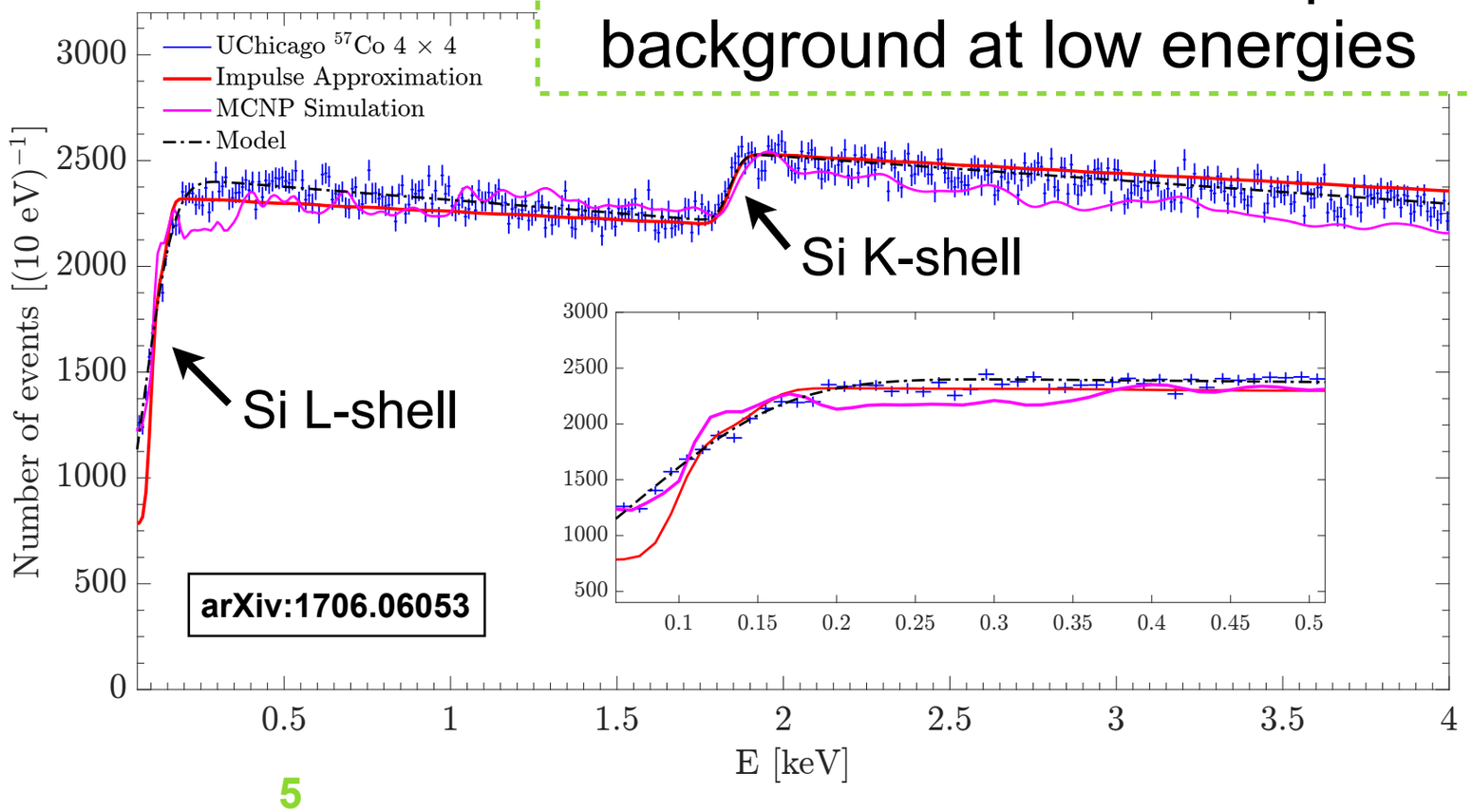
White readout noise
<2 e^- RMS ~ 7 eV_{ee}

Linearity demonstrated for signals <10 e^-.



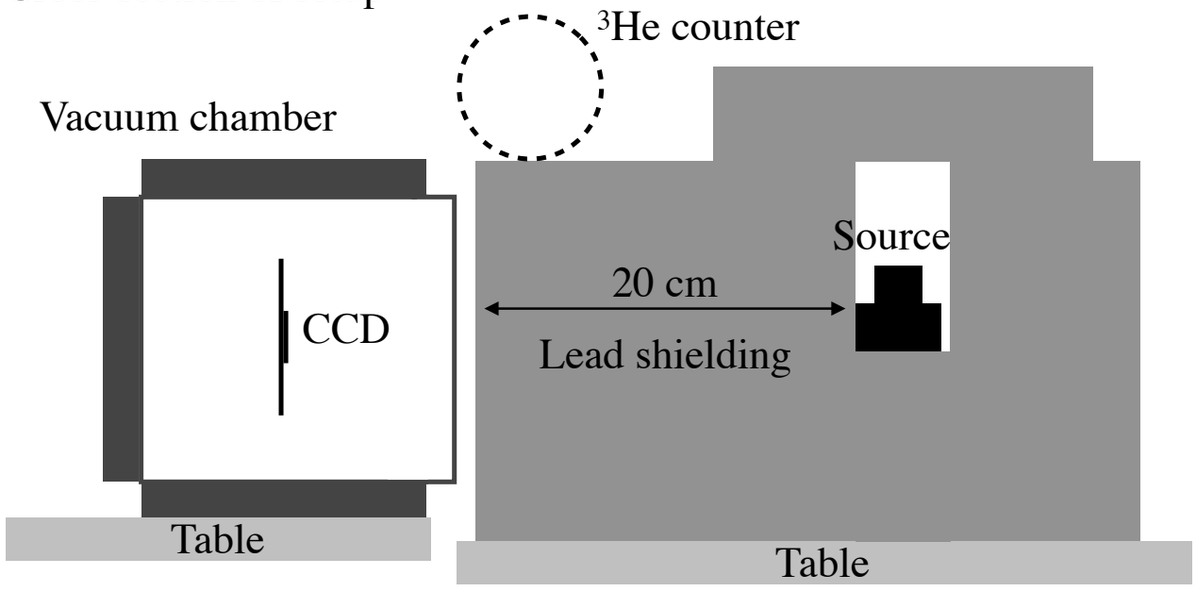


Characterization of Compton background at low energies

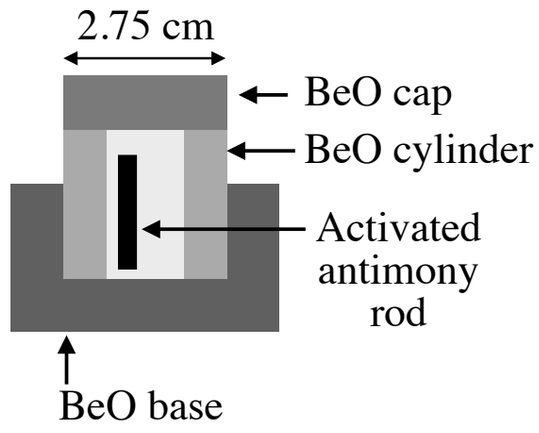


Nuclear recoil response

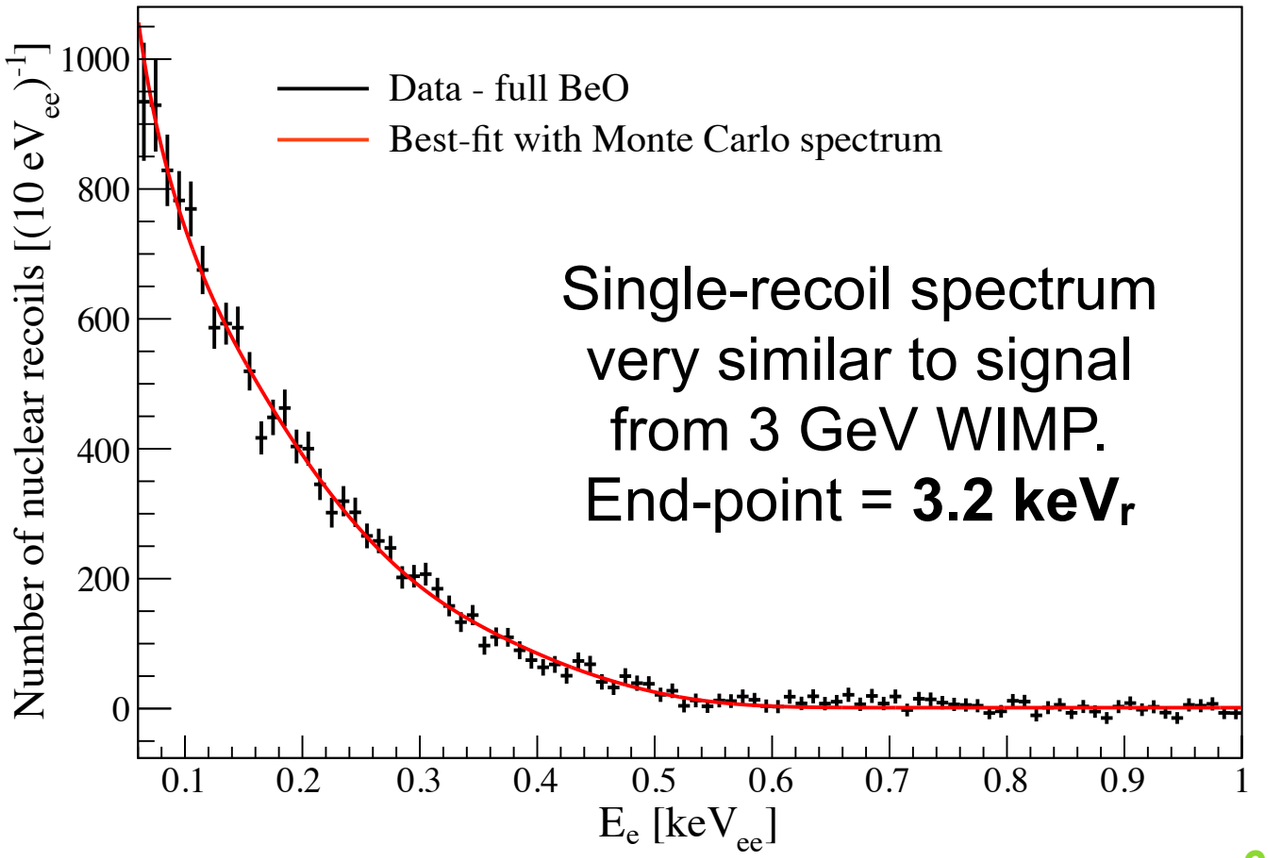
a) Cross-section of setup



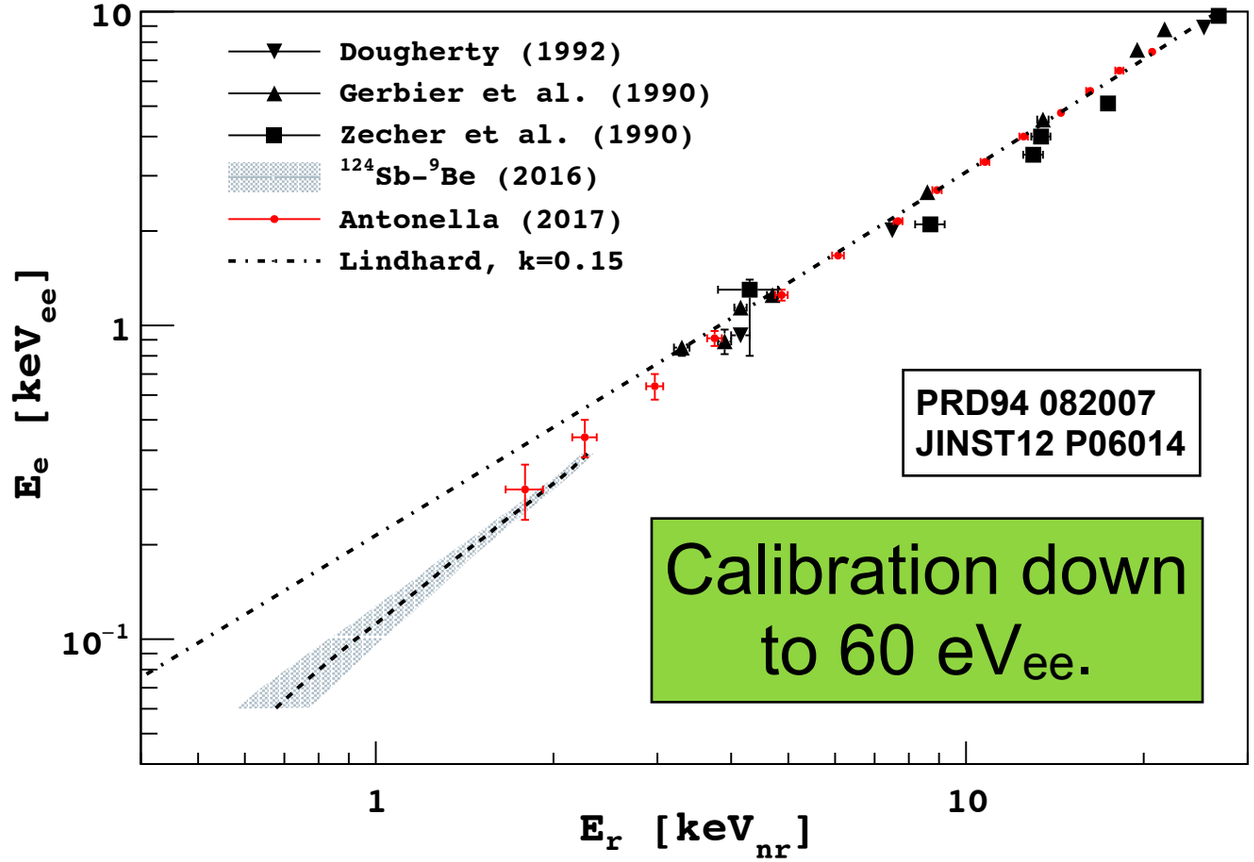
b) ^{124}Sb-^{9}Be source detail



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$_r$**

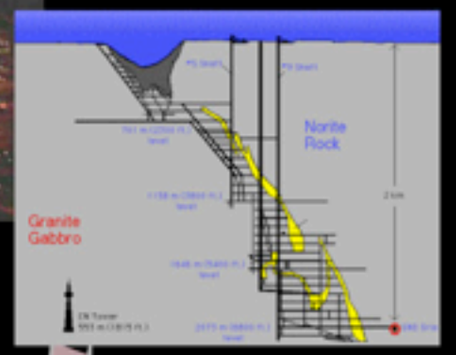


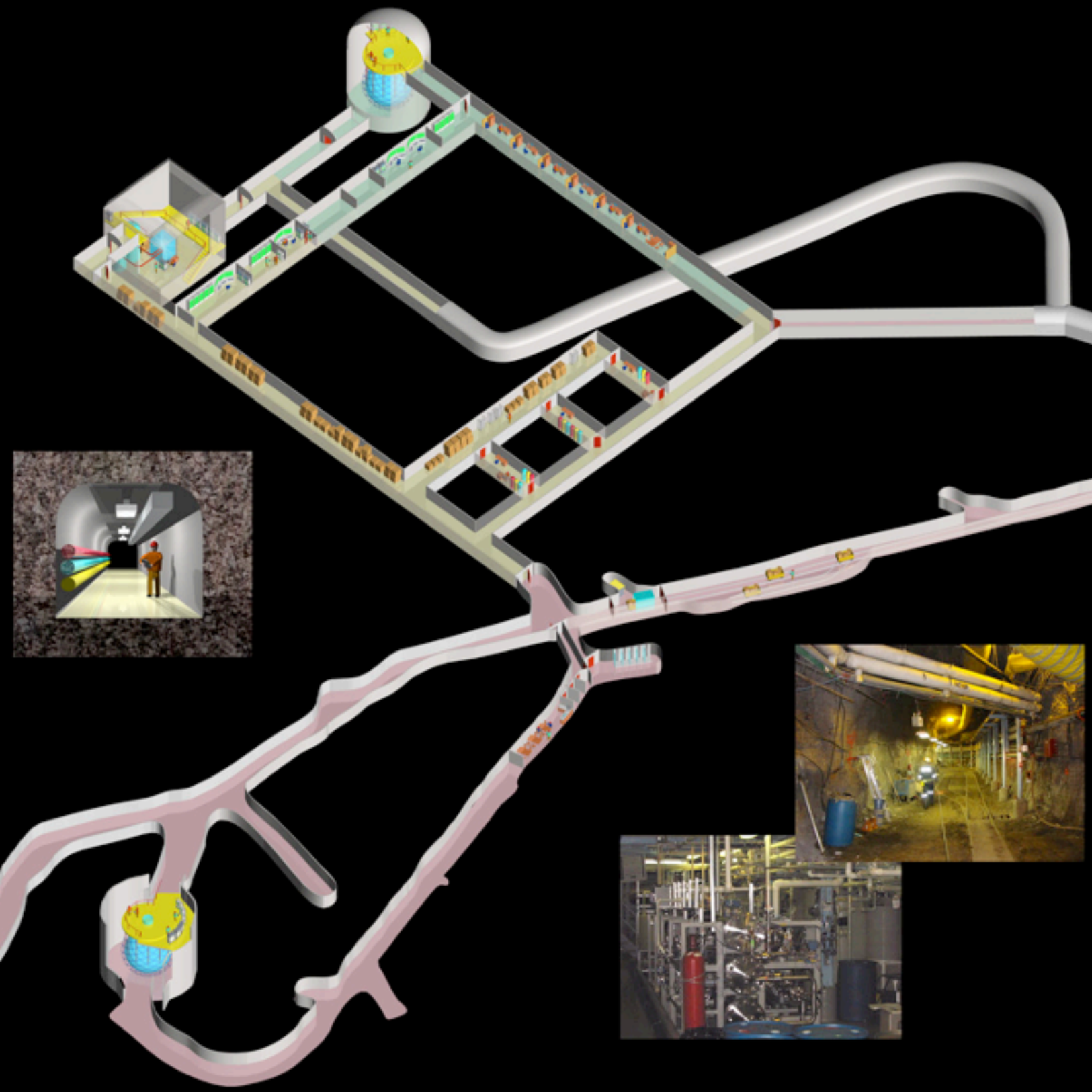
PRD94 082007
JINST12 P06014

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

2 km underground

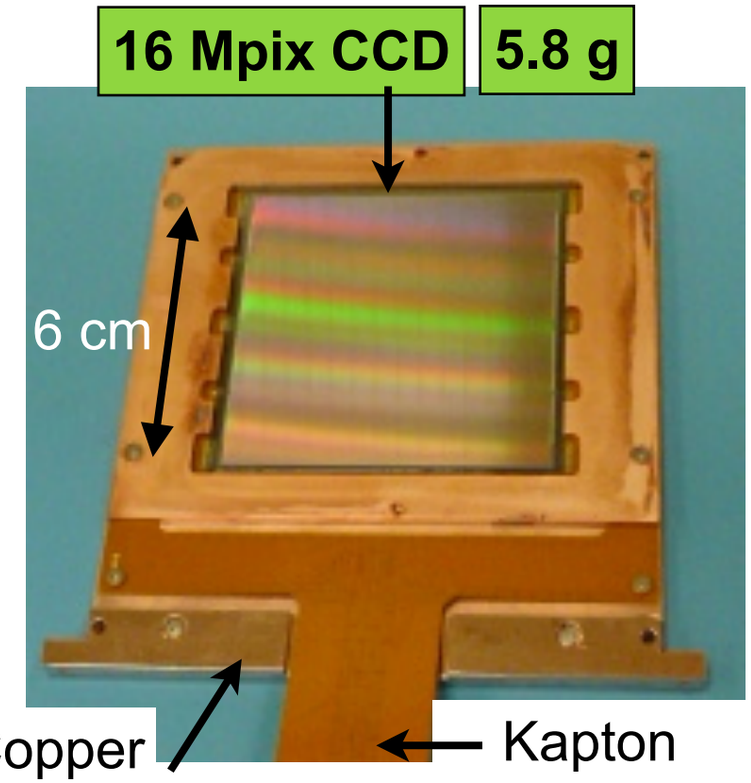
Inco Ltd.
Creighton No.9 Shaft

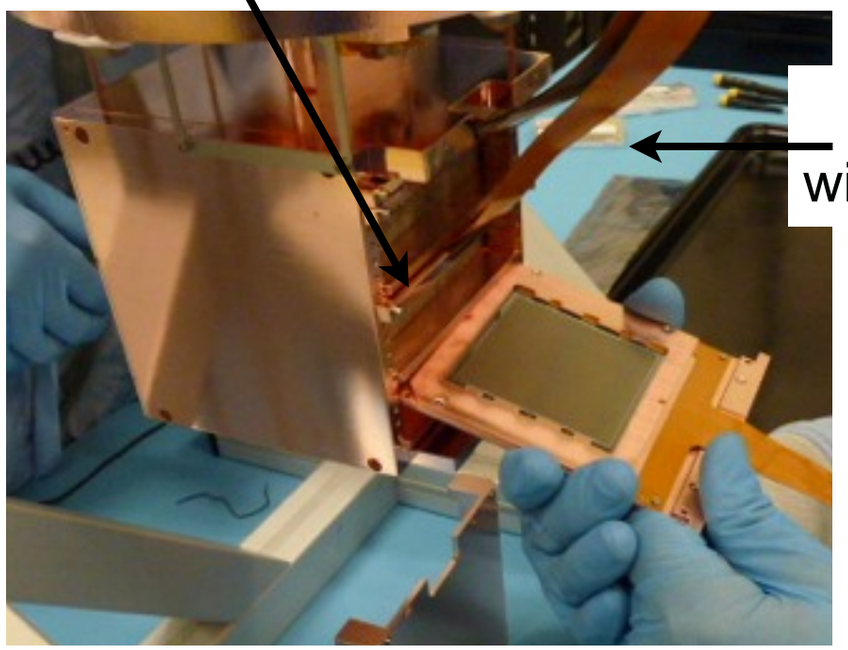


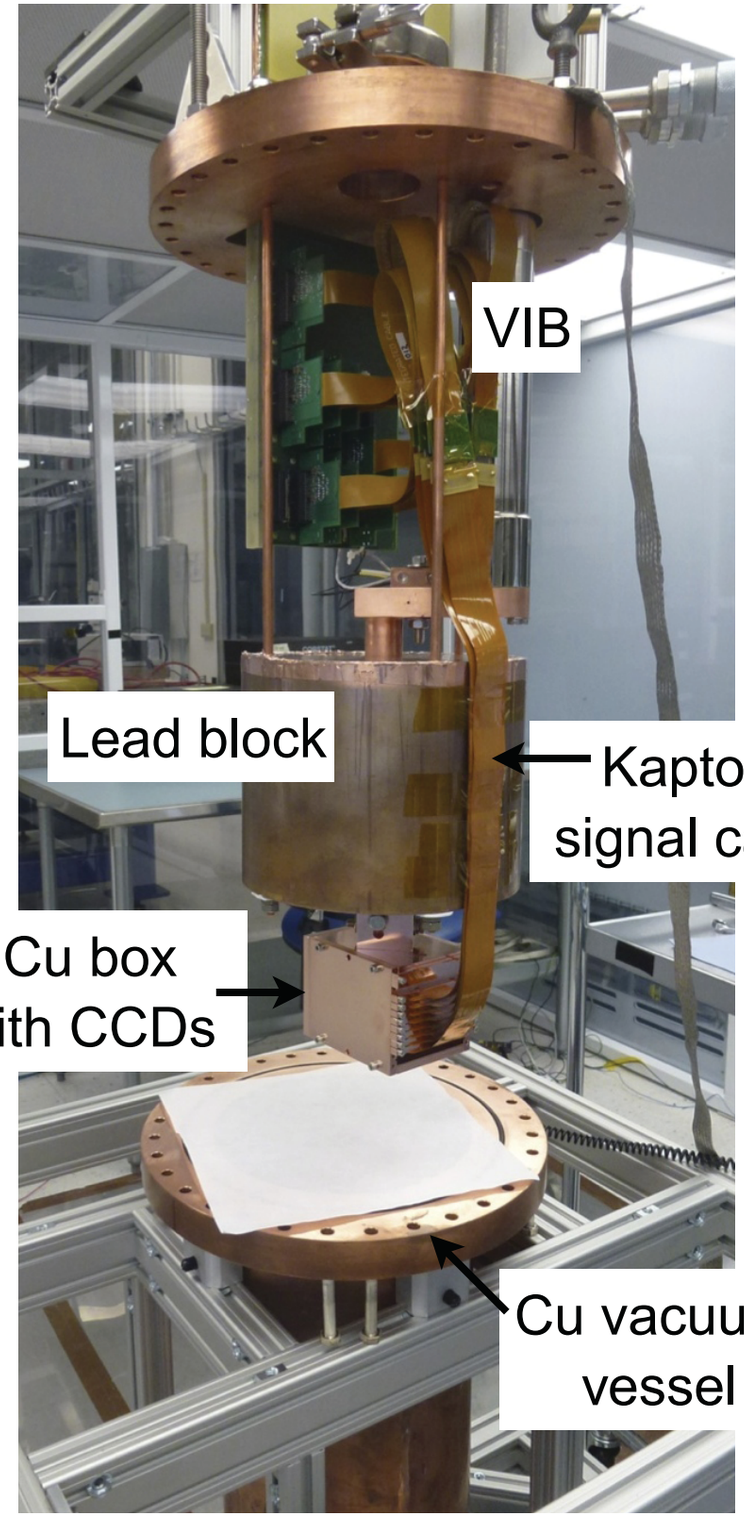


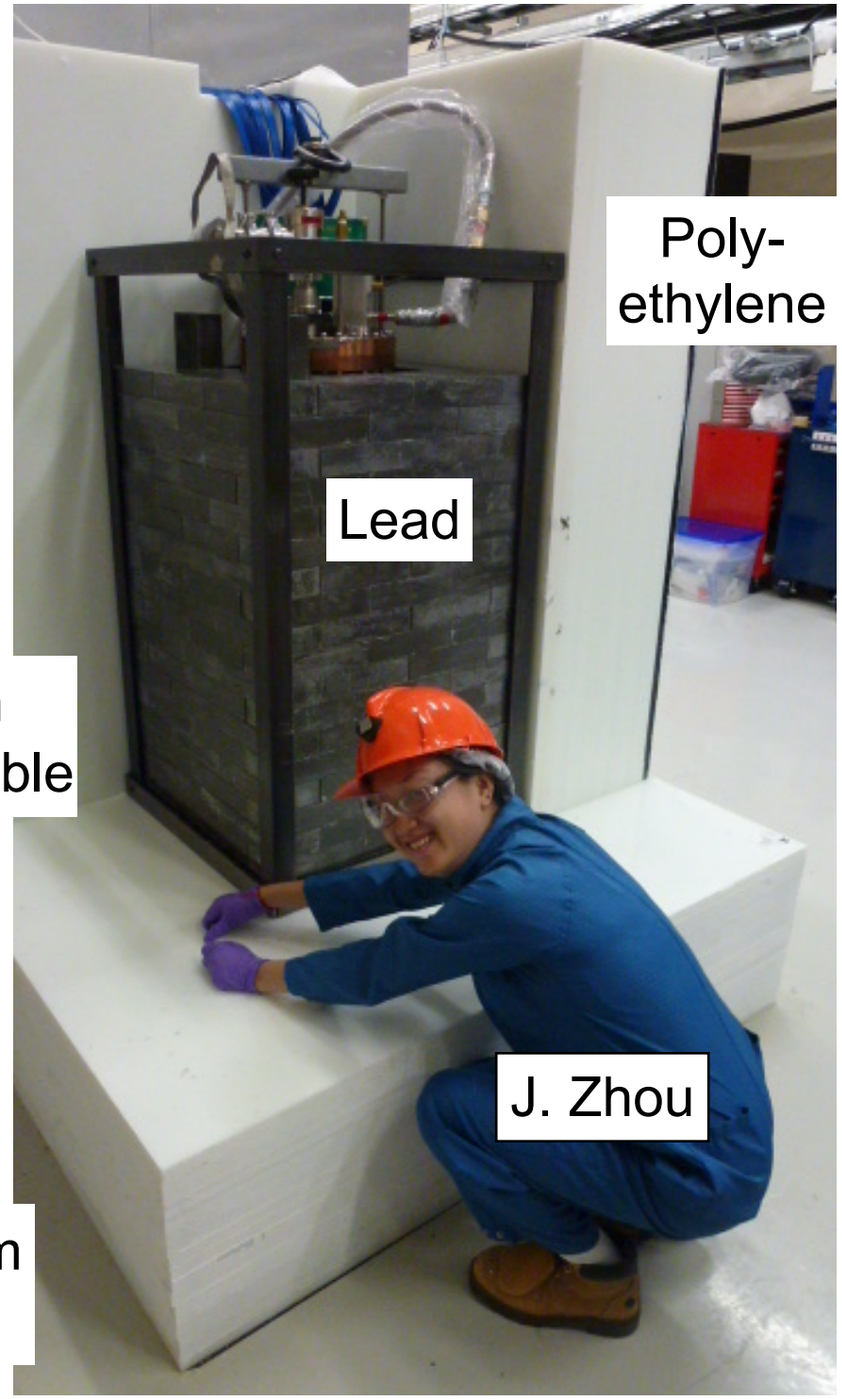
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

SNOLAB Installation



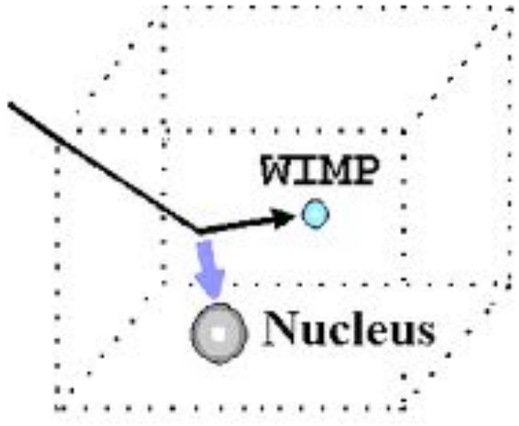




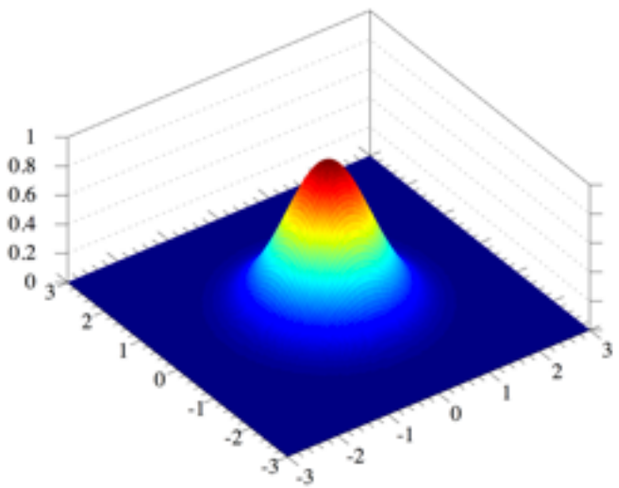


WIMP search

Elastic scattering of WIMPs with silicon nuclei.

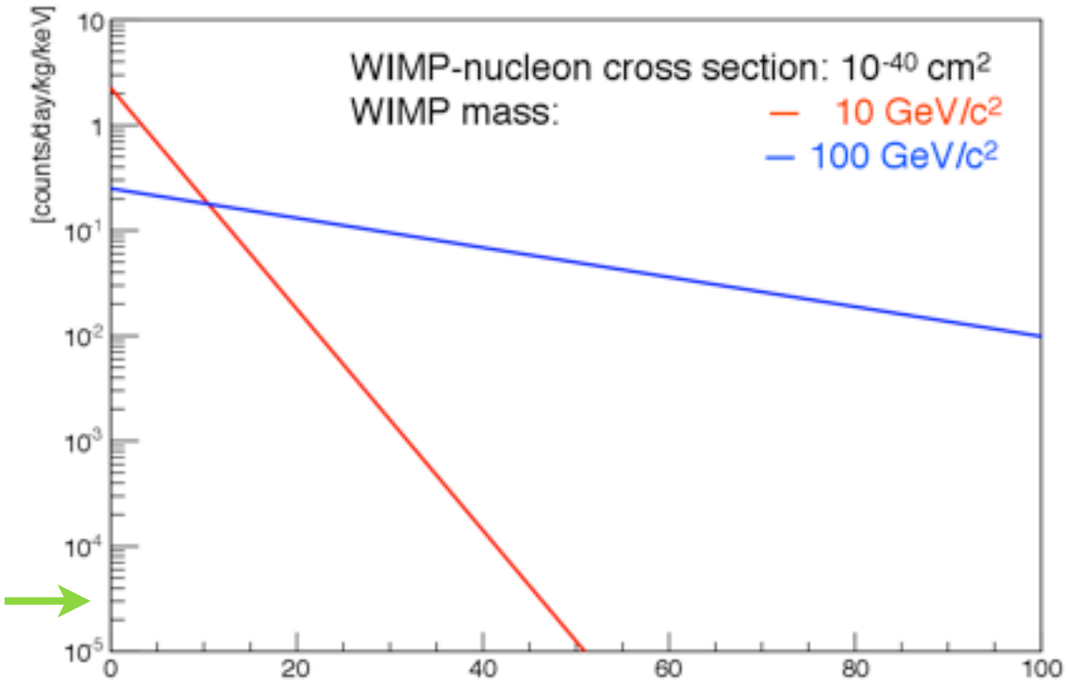


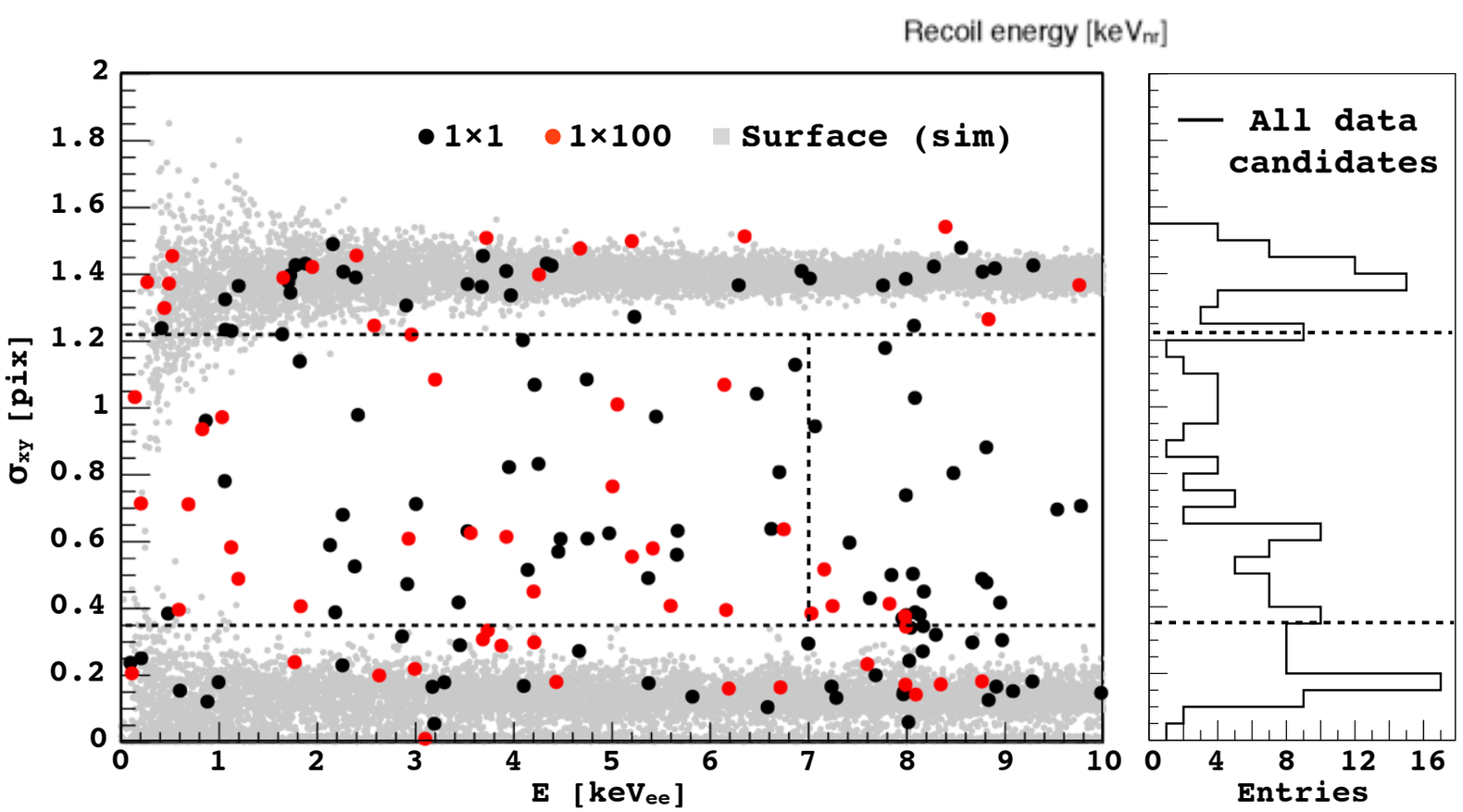
2D Gaussian distribution of free charge on pixel array.



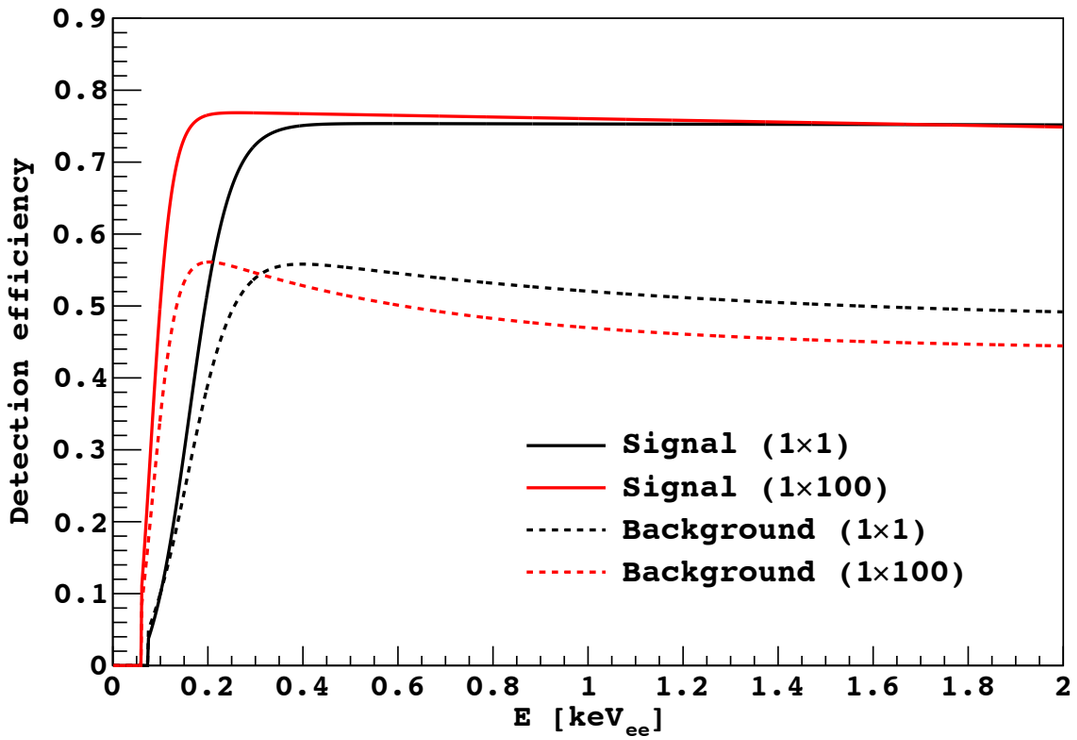
Measure **E** and σ_{xy} for every event.

Recoil spectrum in Si target

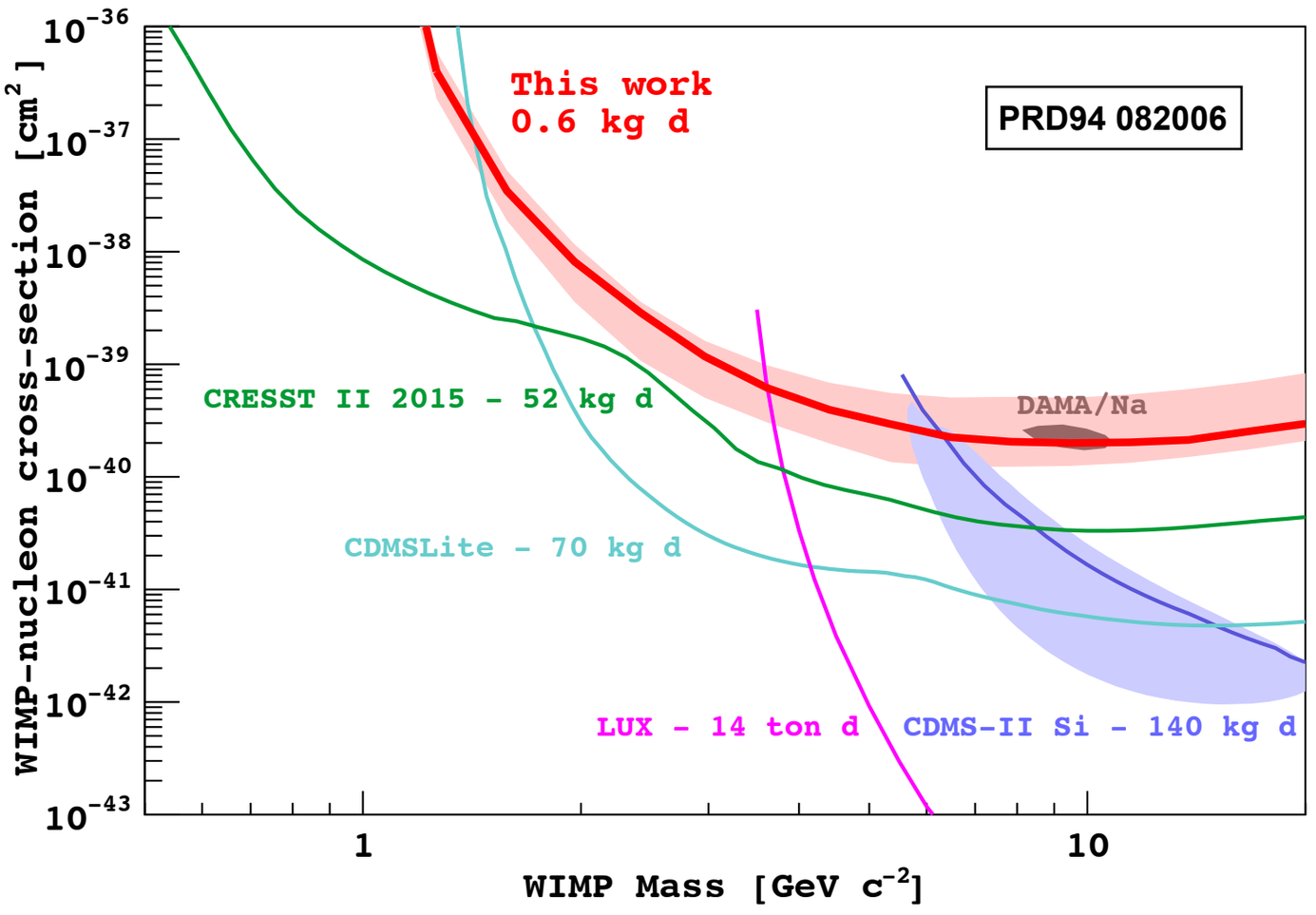




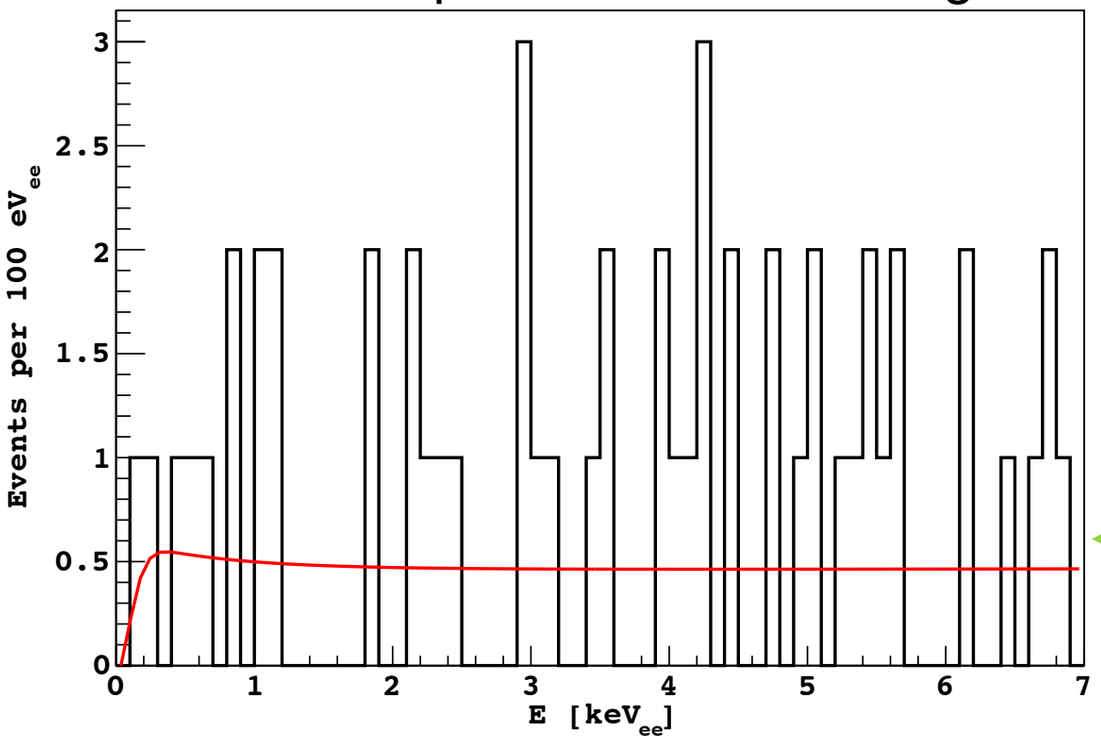
WIMP search



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



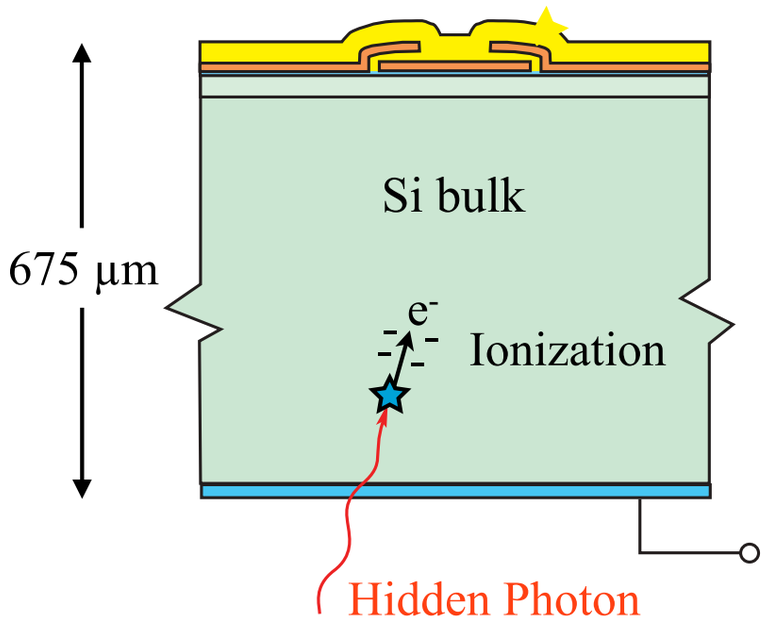
Observed spectrum in fiducial region



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

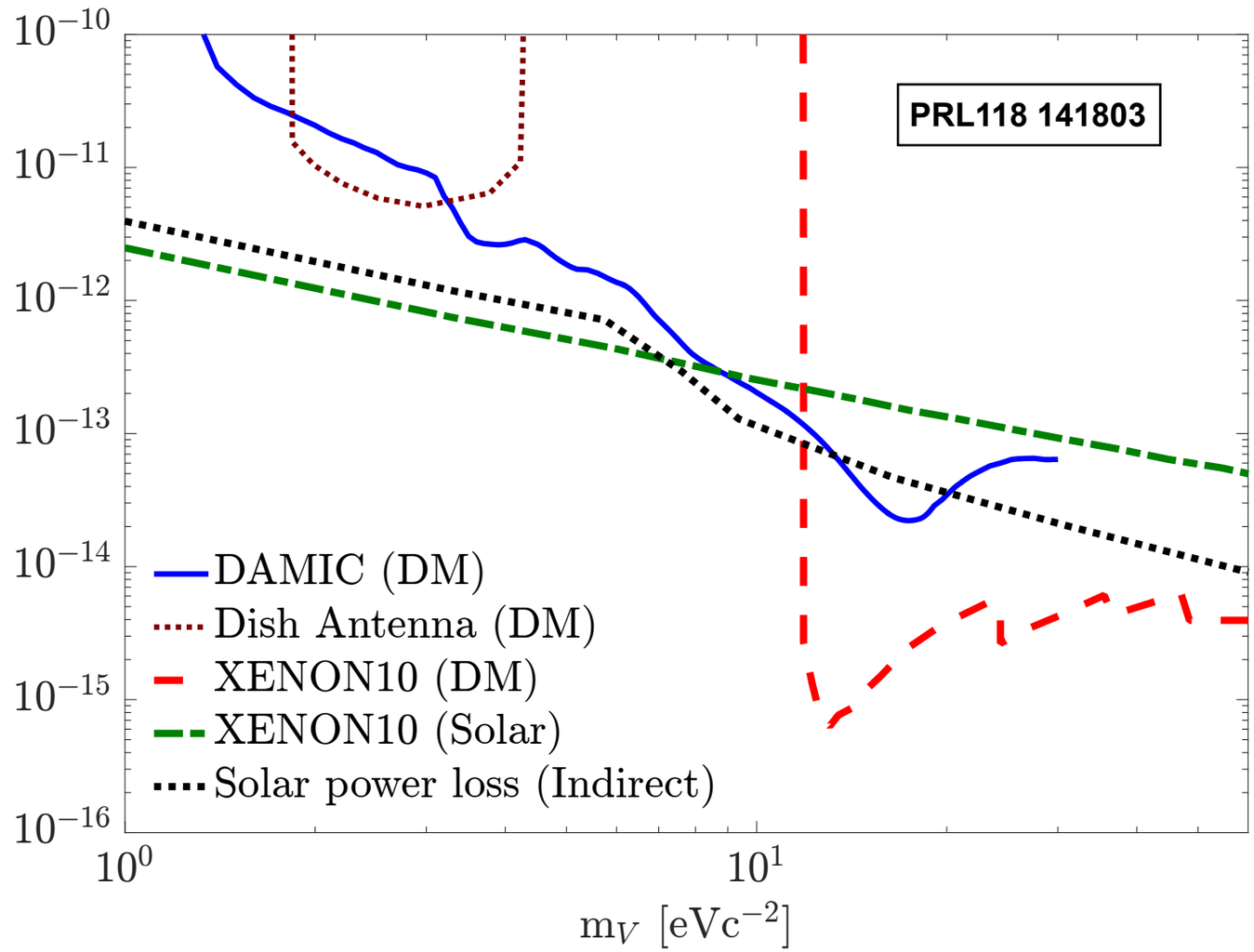
Hidden photon search

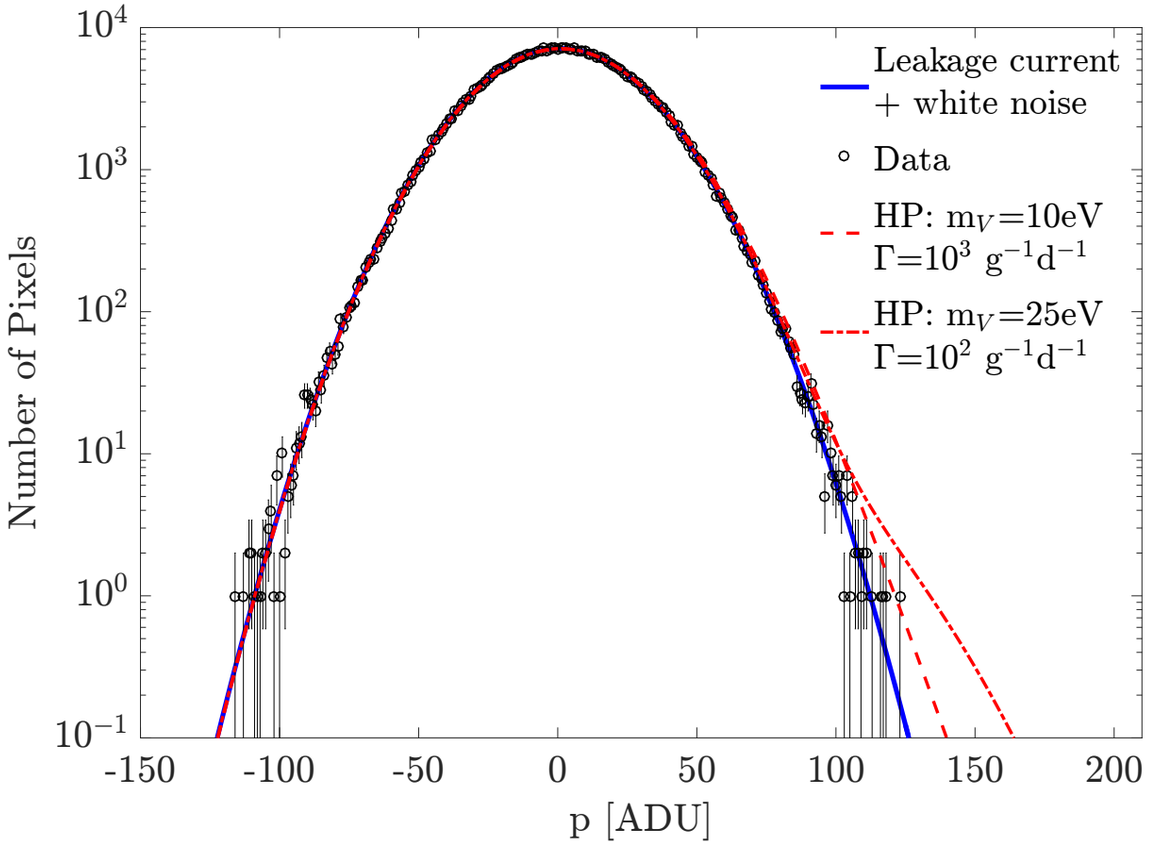
Absorption of hidden-photon dark matter.



~1 week of data with 1 CCD.

Leakage current **4 e⁻ mm⁻² d⁻¹**.





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.)

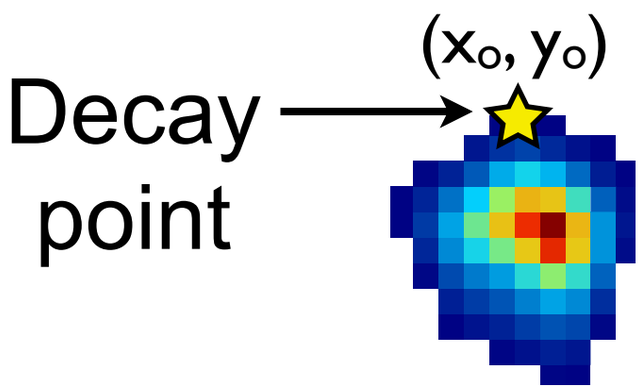
JINST 10 P08014

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

$E_1 = 114.5$ keV

$\Delta t = 35$ days

$E_2 = 328.0$ keV



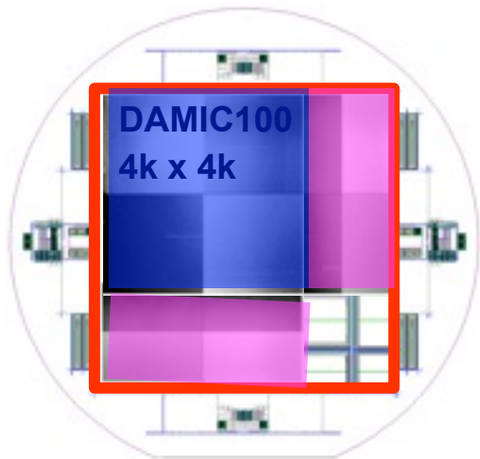
DAMIC100

- 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.
  -Baking of wafers during/after fabrication to remove ^3H.

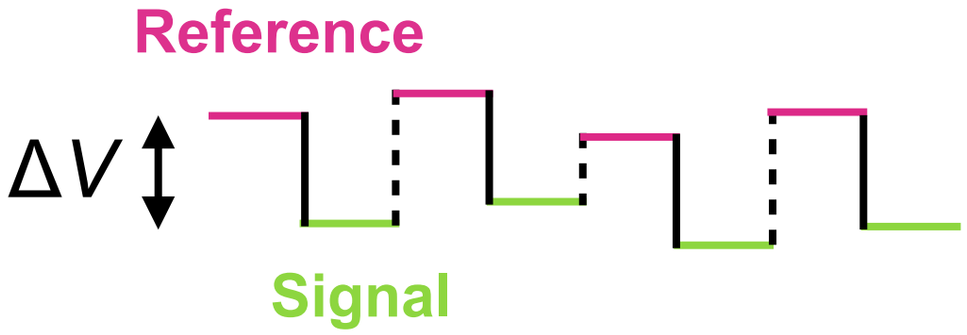


Silicon wafer

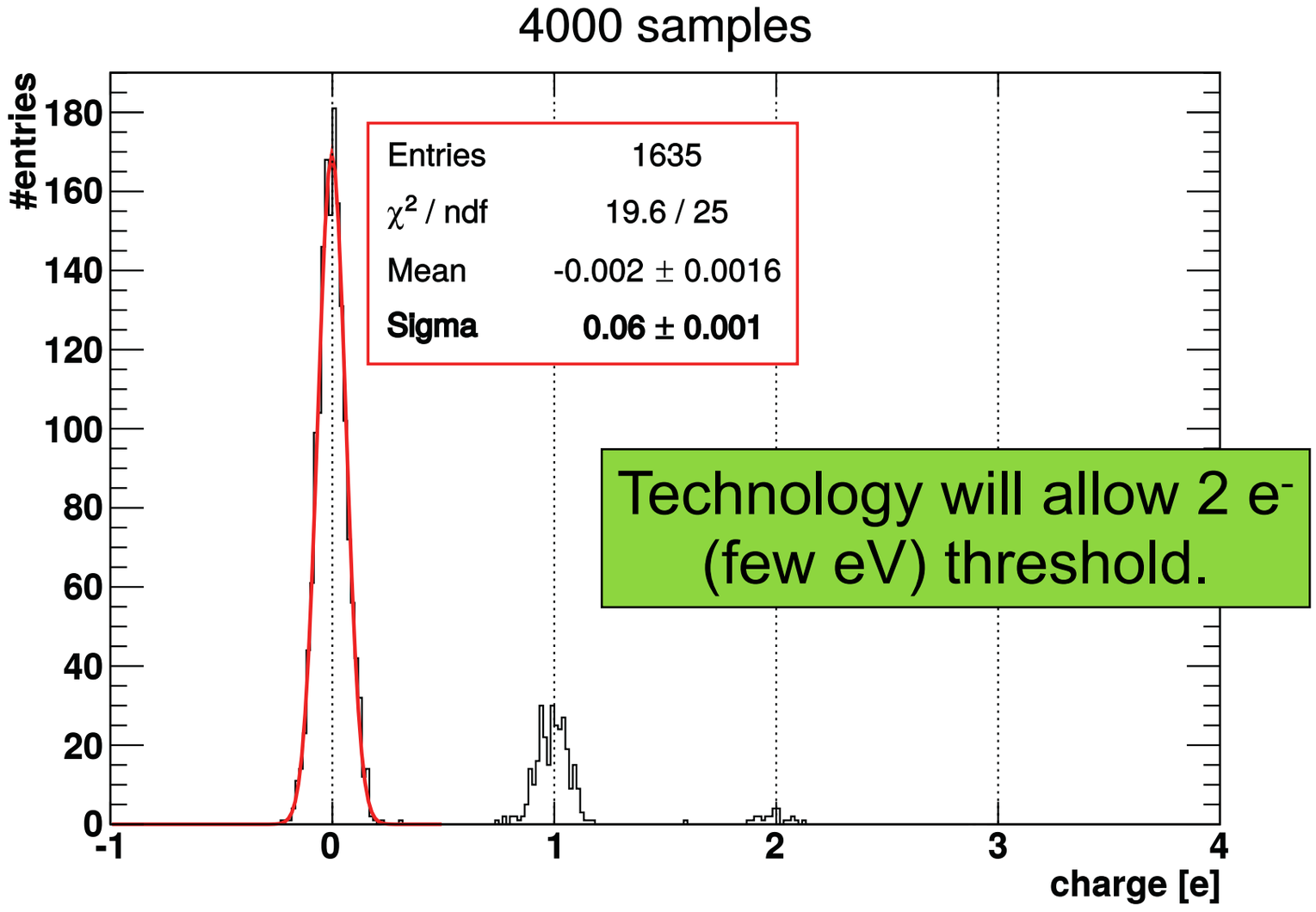
SENSEI

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 ~$1/\sqrt{N}$.

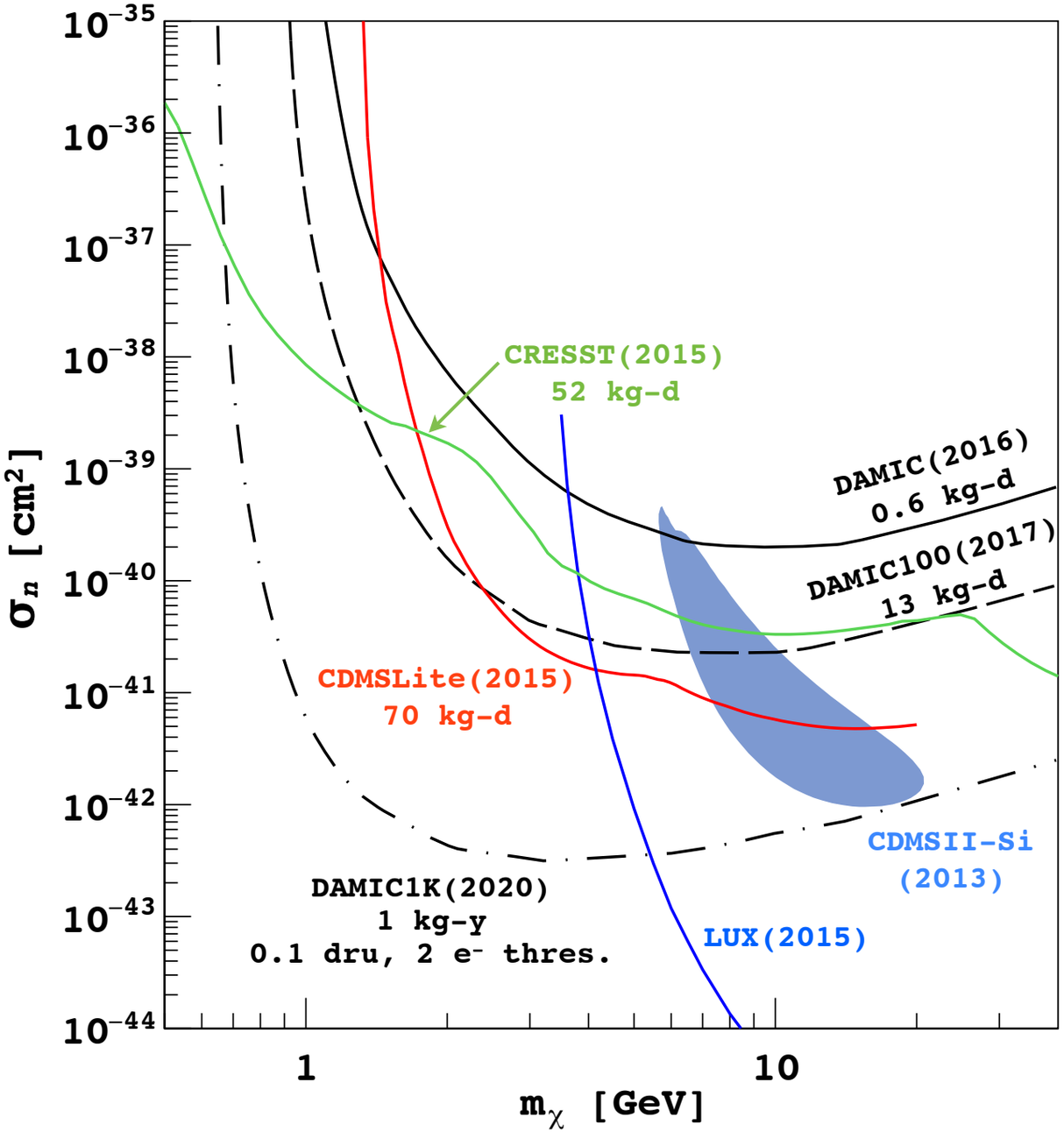


Measure Δ*V* *N* times.

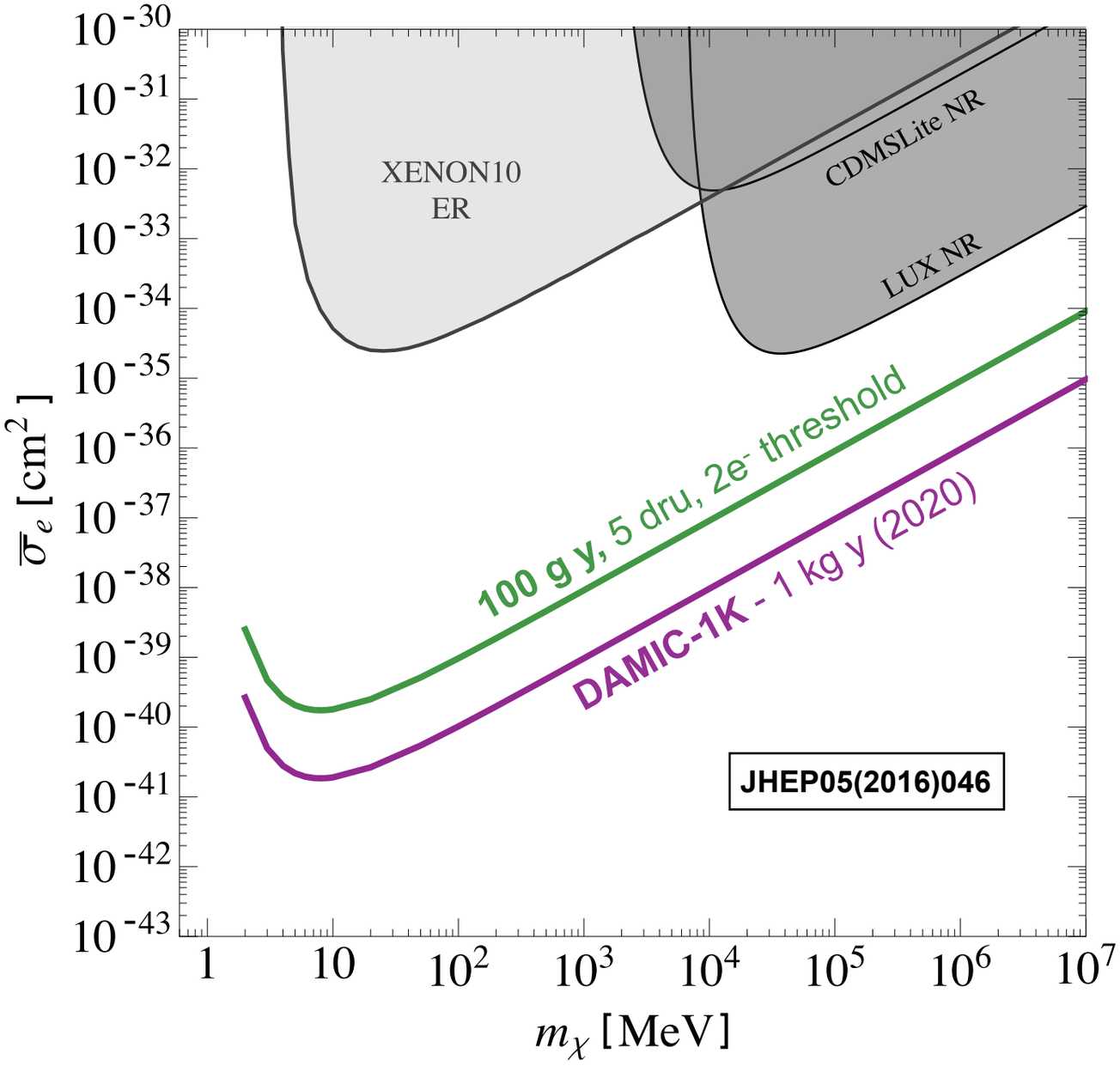


DAMIC Program

DM-nucleus SI coherent scattering



DM-e Scattering via Ultra-light Hidden Photon

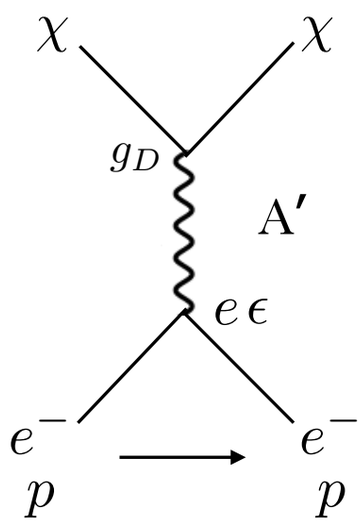


Also best limits for absorption of hidden photon dark matter.

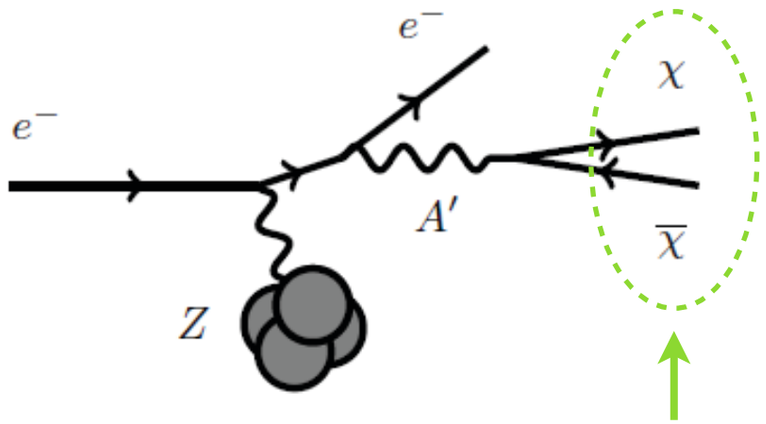
DAMIC Program

Direct search:

Ionization produced by dark matter - electron / nucleus scattering.

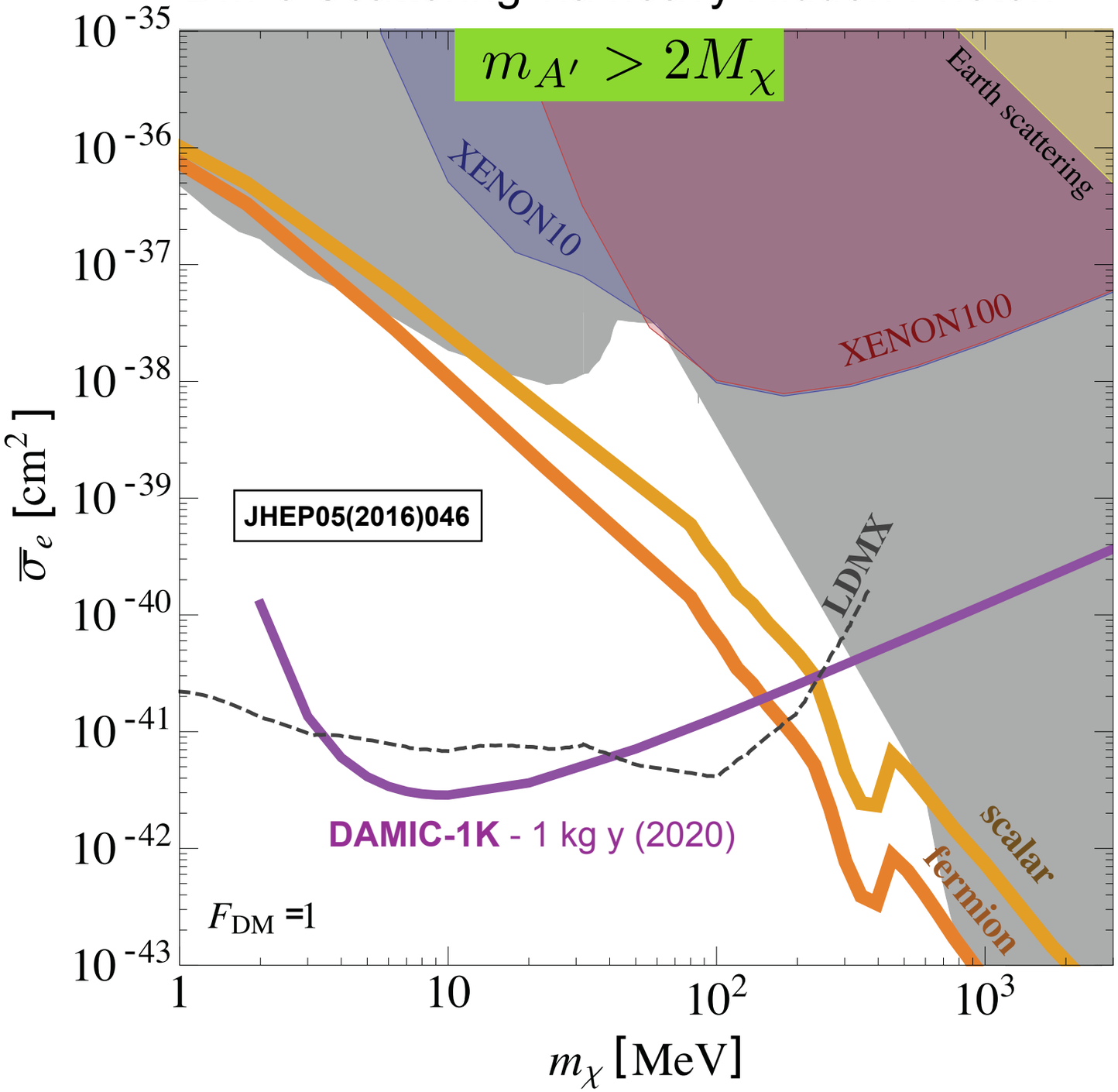


Accelerators:



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!