Dark matter search results from DAMIC at SNOLAB

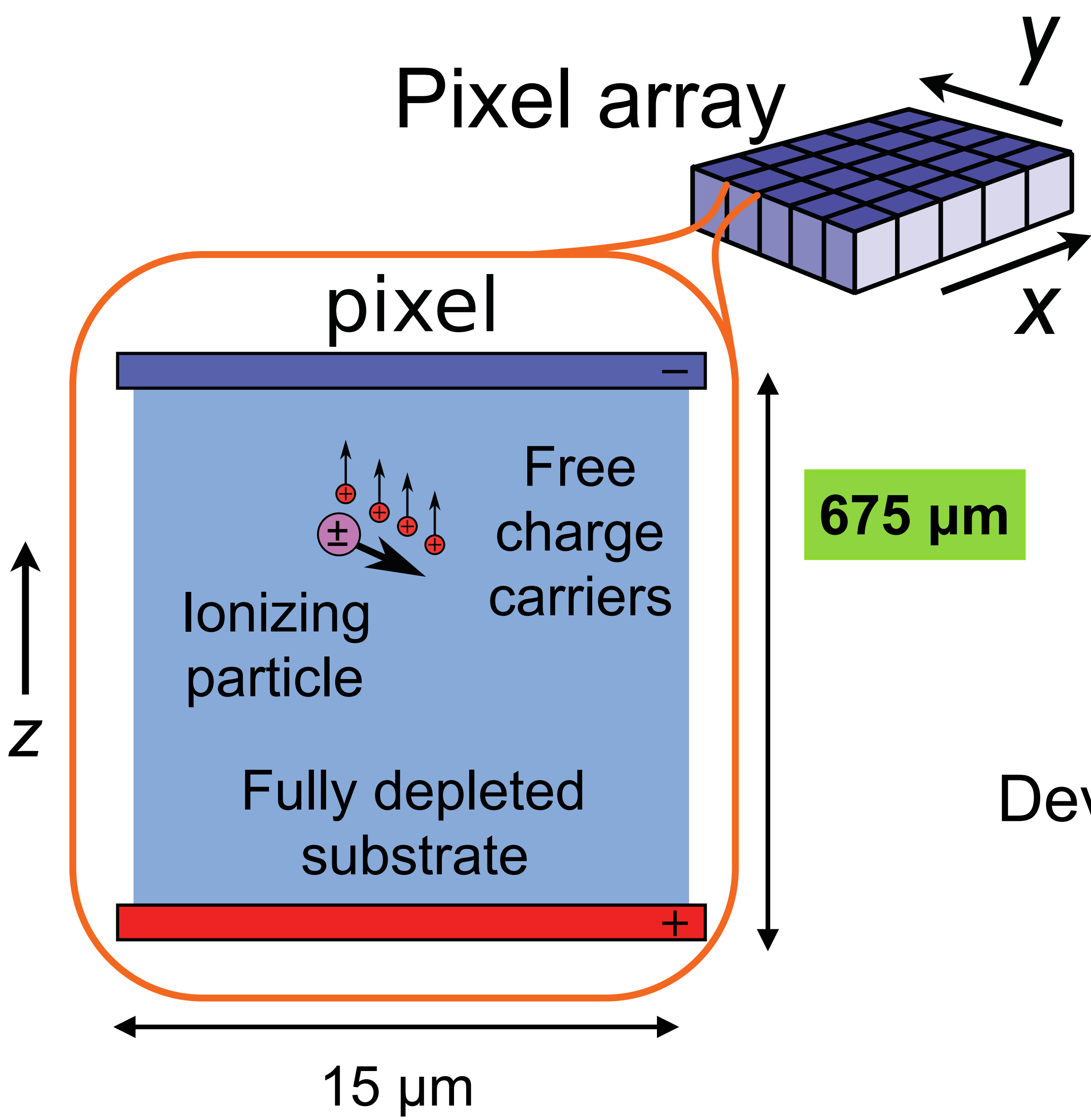
Alvaro E. Chavarria
University of Washington

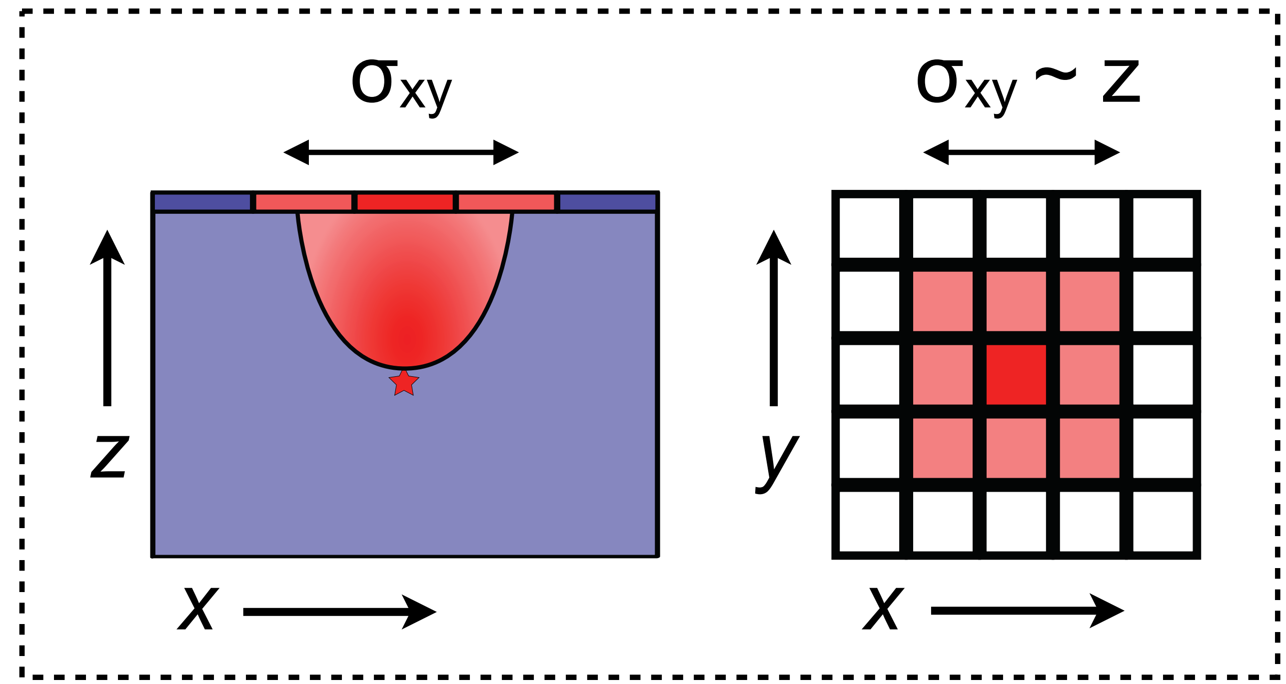
CENPA
Center for Experimental Nuclear Physics and Astrophysics
UNIVERSITY of WASHINGTON

Outline

- Charge-coupled devices to search for dark matter.
- Response of DAMIC CCDs to signal and backgrounds.
- DAMIC at SNOLAB.
- DM-e scattering search (**results**).
- WIMP search (**status**).

Charge coupled device



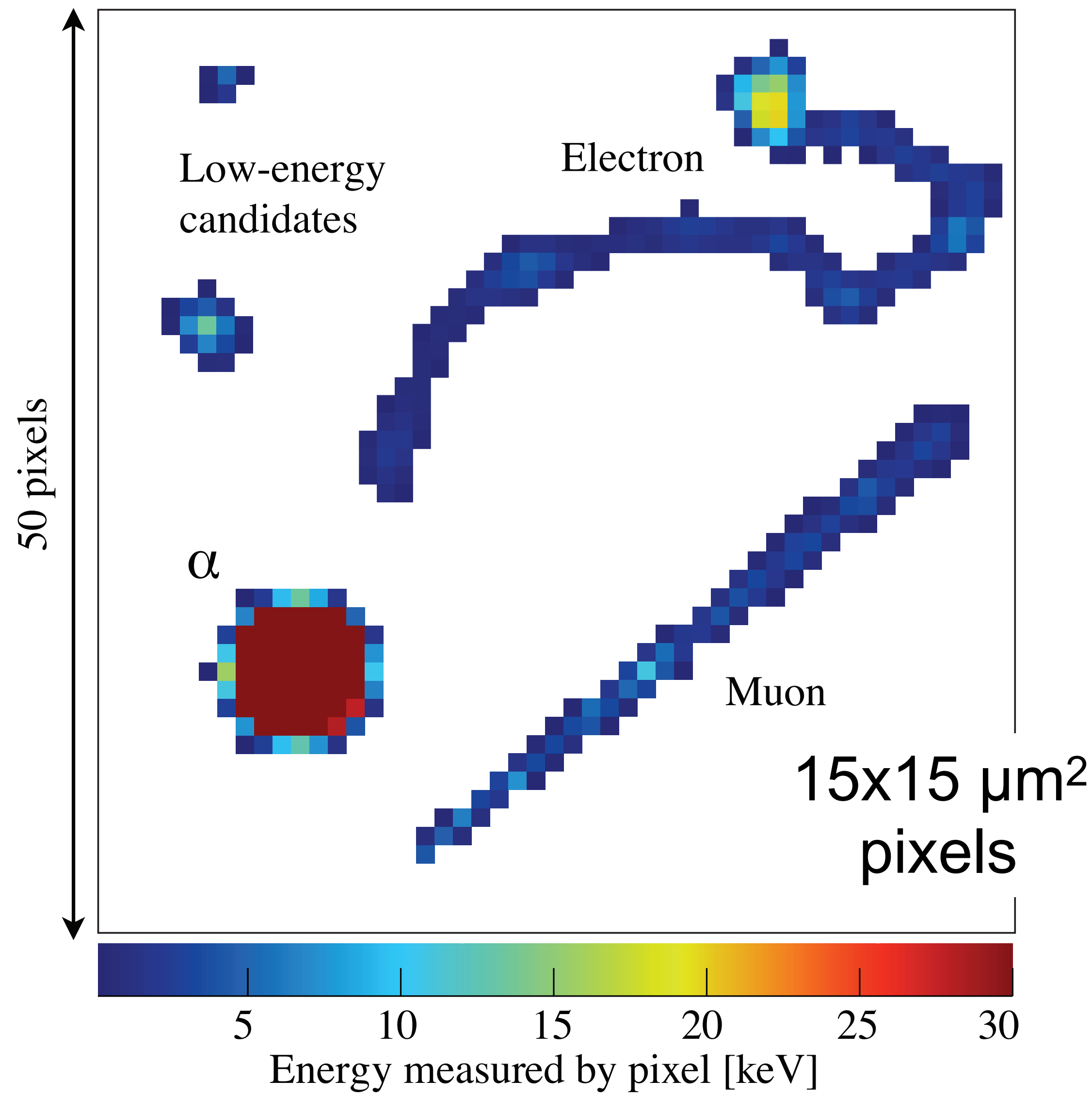


Device is “exposed,” collecting charge until user commands readout

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

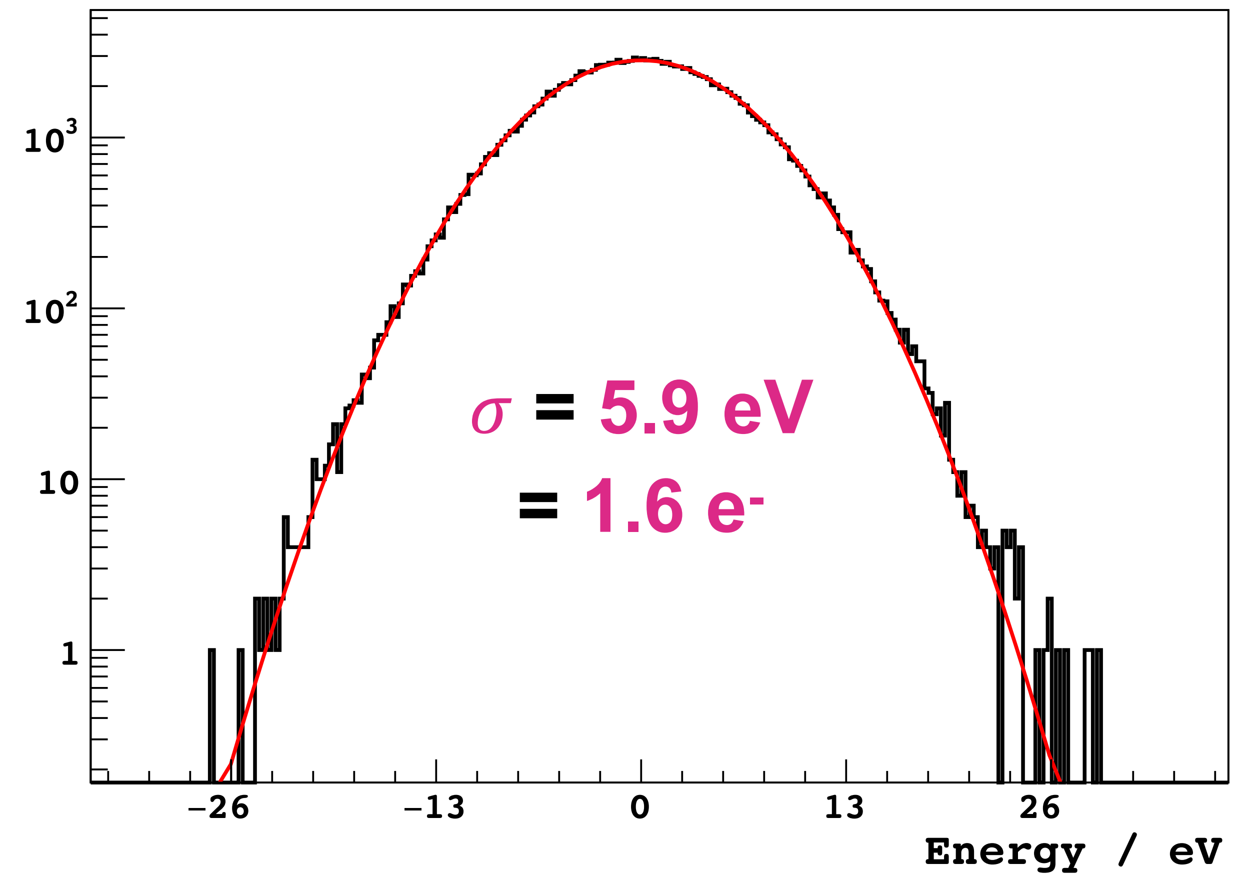
Standard fabrication in semiconductor industry and easy cryogenics (~100 K)

Perfomance



particle identification and background characterization

Pixel charge distribution

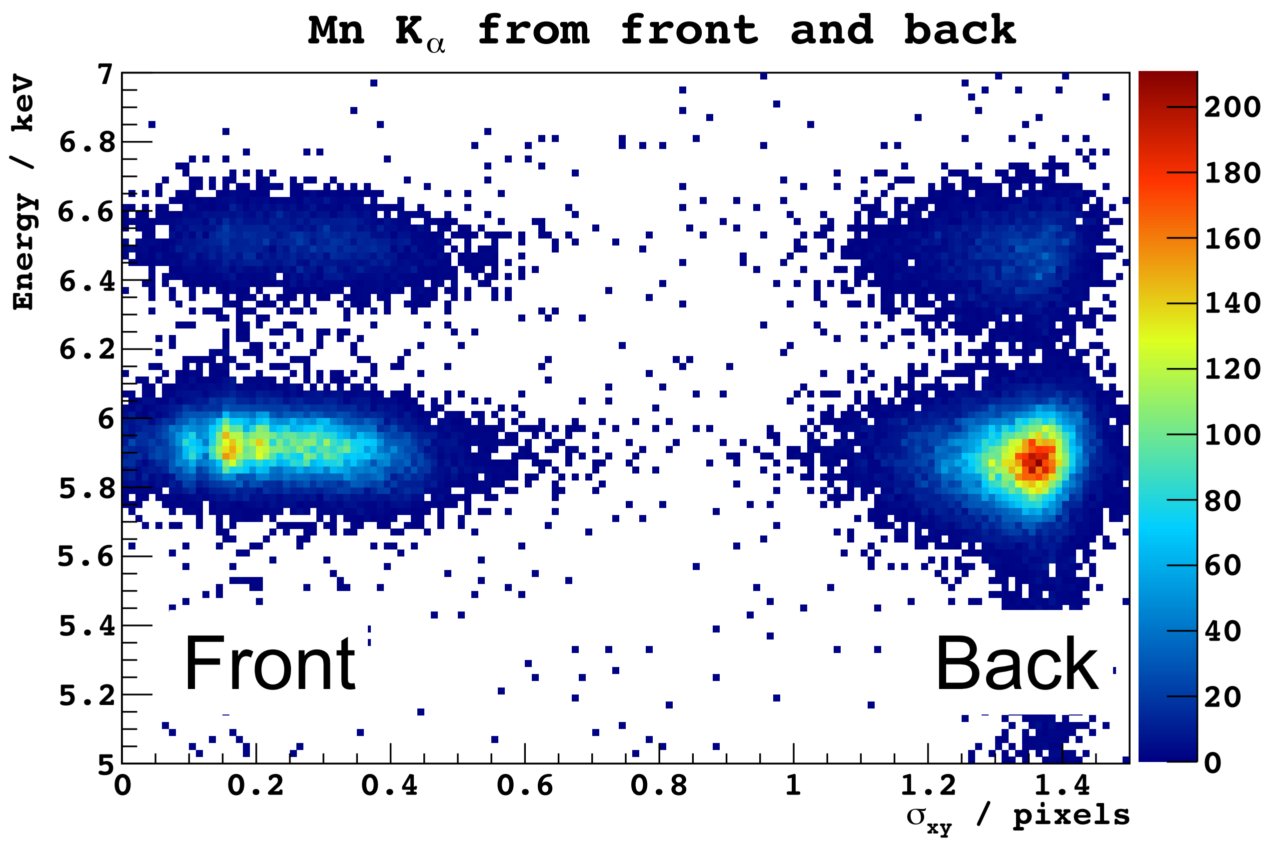


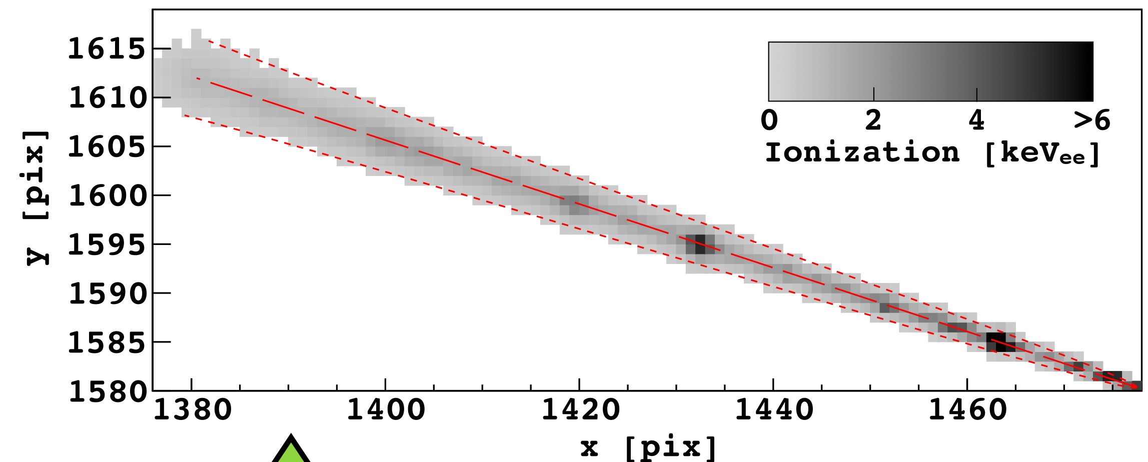
Very low noise and dark current

lowest dark current ever measured in a silicon detector:

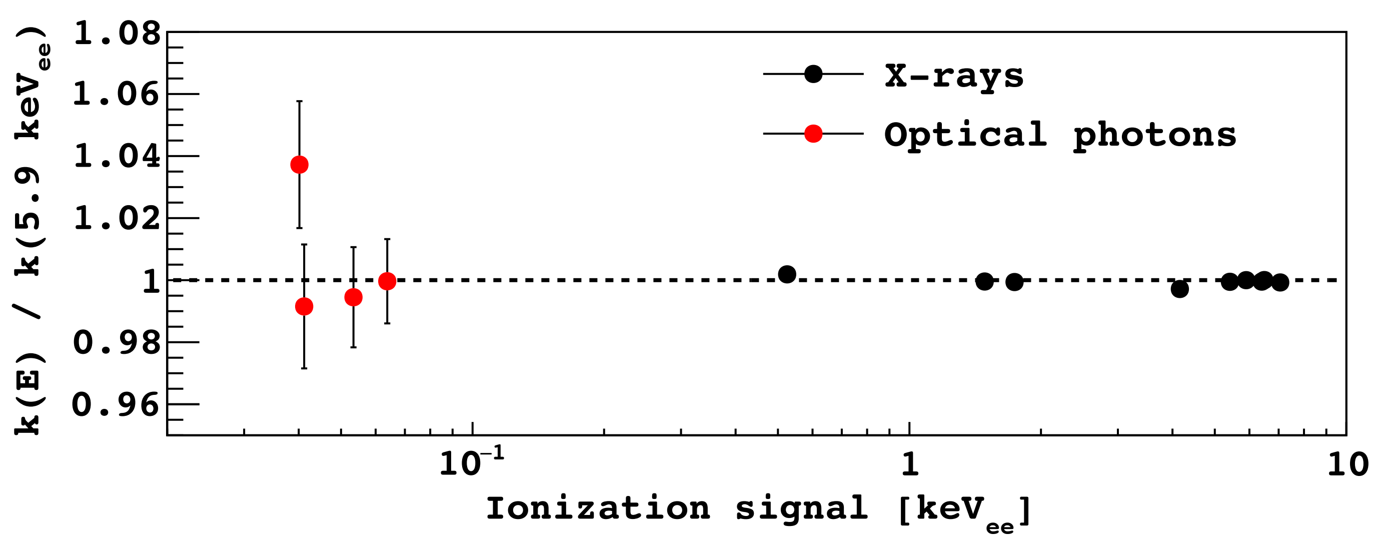
5×10^{-22} A/cm^2 (at 140 K)

Detector response





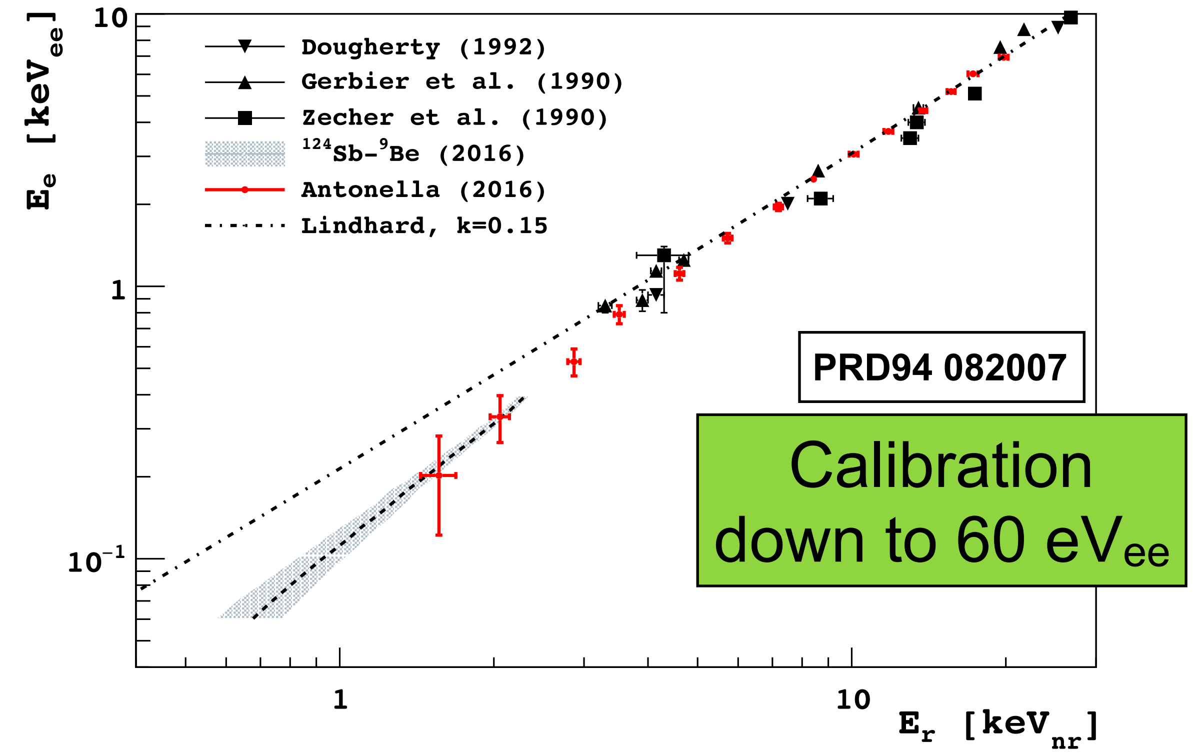
z reconstruction with X rays and cosmic rays

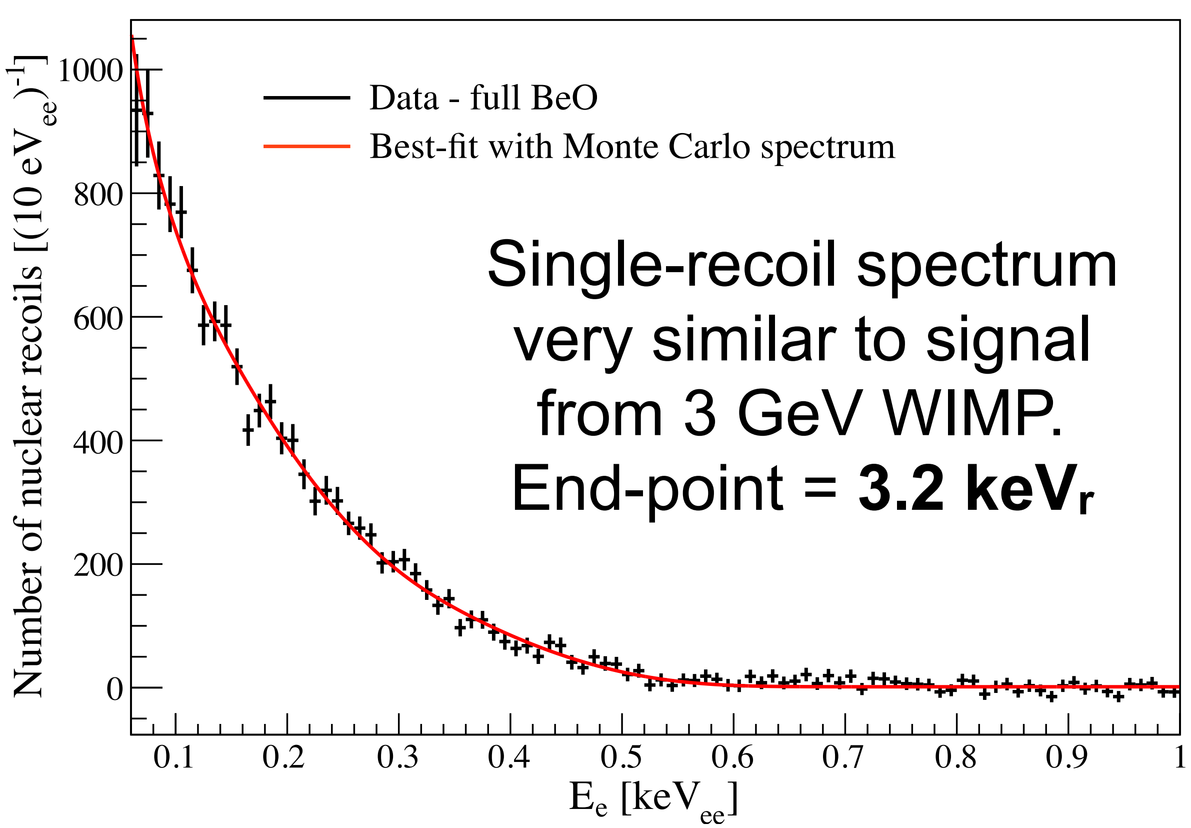


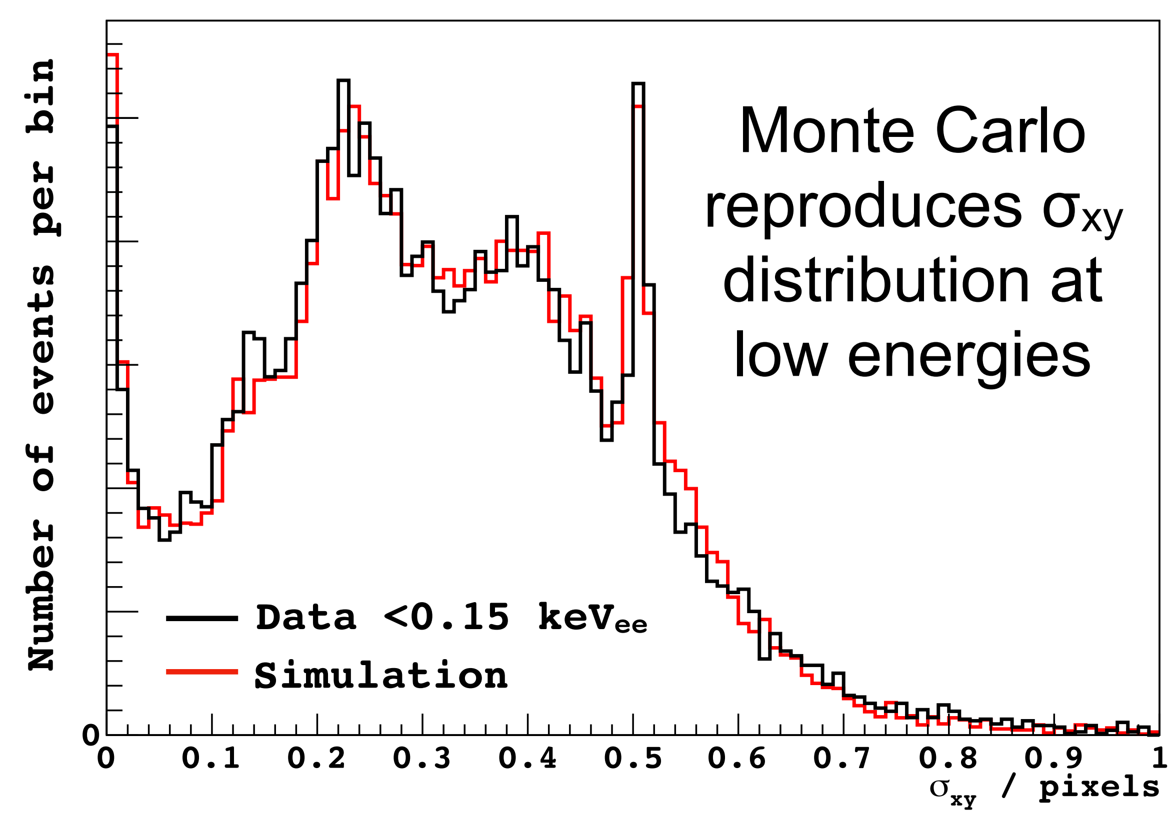
CCD linearity down to 40 eV$_{ee}$ with optical photons

Nuclear recoil response

- Detector response calibrated with 24 keV neutrons from $^9Be(\gamma,n)$ reaction.
- By comparing data and Monte Carlo spectra, ionization efficiency was measured to be lower than predicted by Lindhard model.
- Also validates diffusion model at low energies.



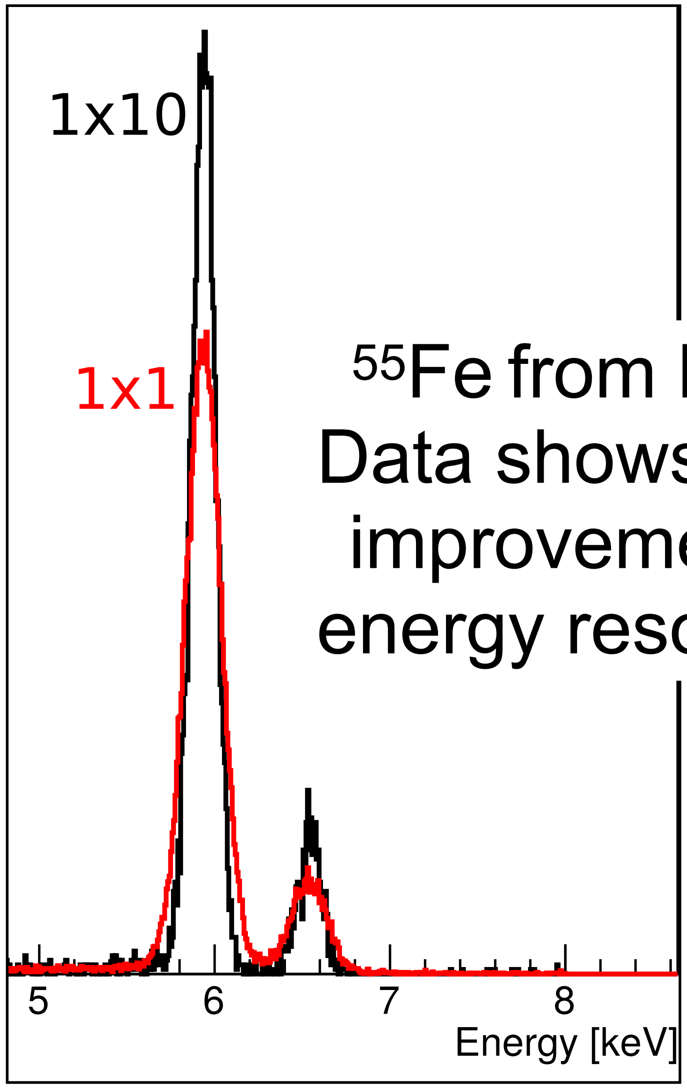




Flexibility in readout

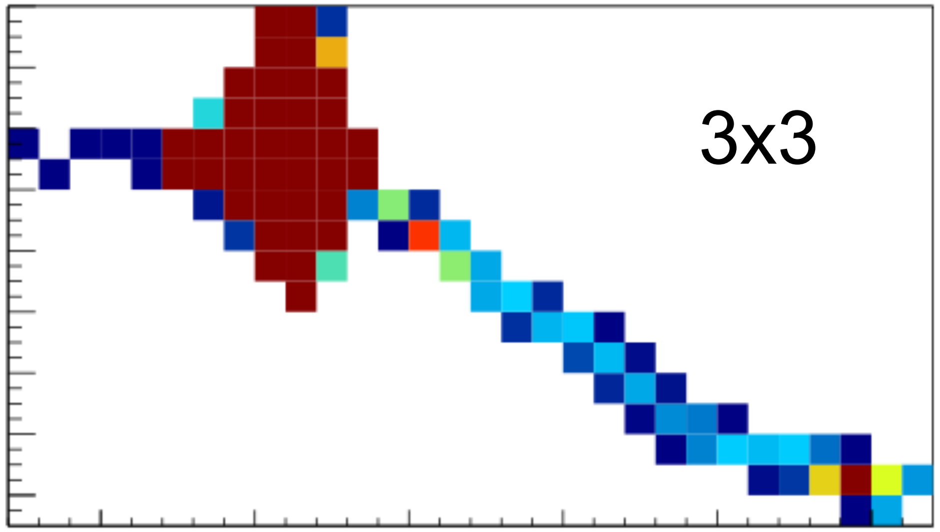
Pixels can be readout in "groups" and the total charge estimated in a single measurement.

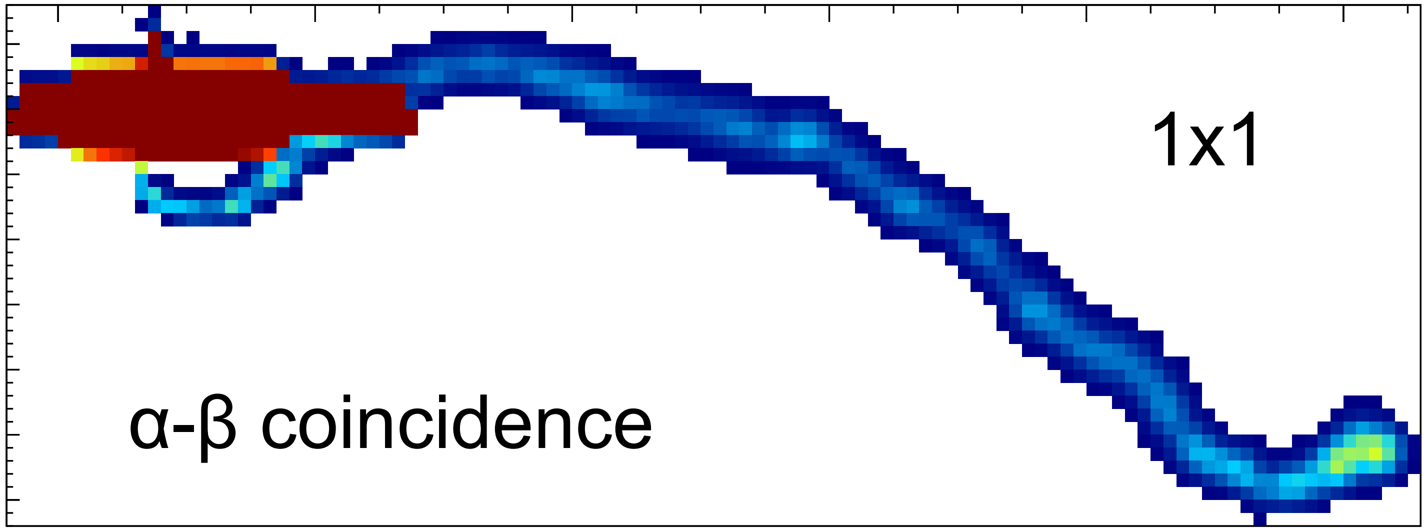
Less pixels but same noise *per* pixel!



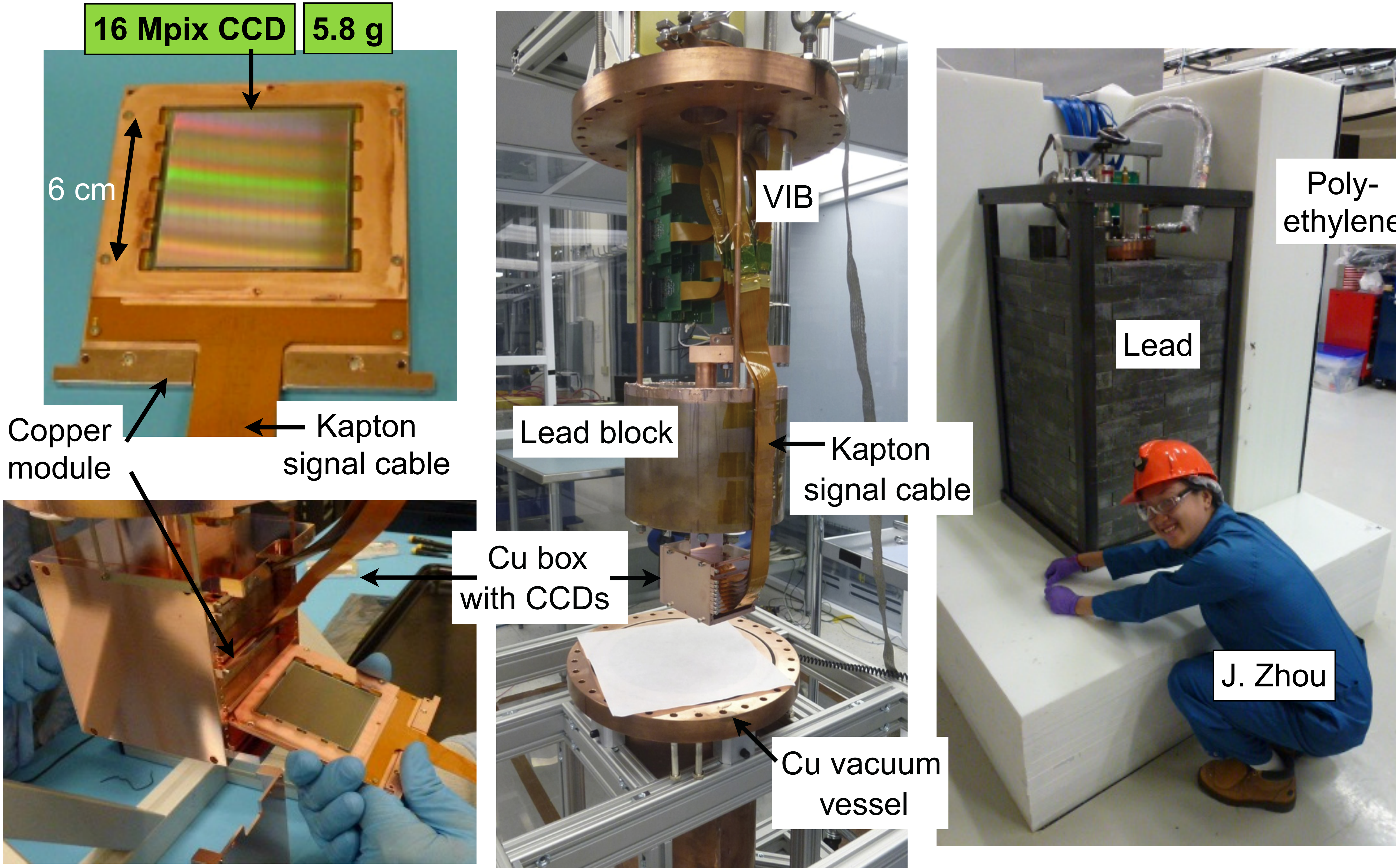
^{55}Fe from back: Data shows clear improvement in energy resolution

Loss of x, y and z information



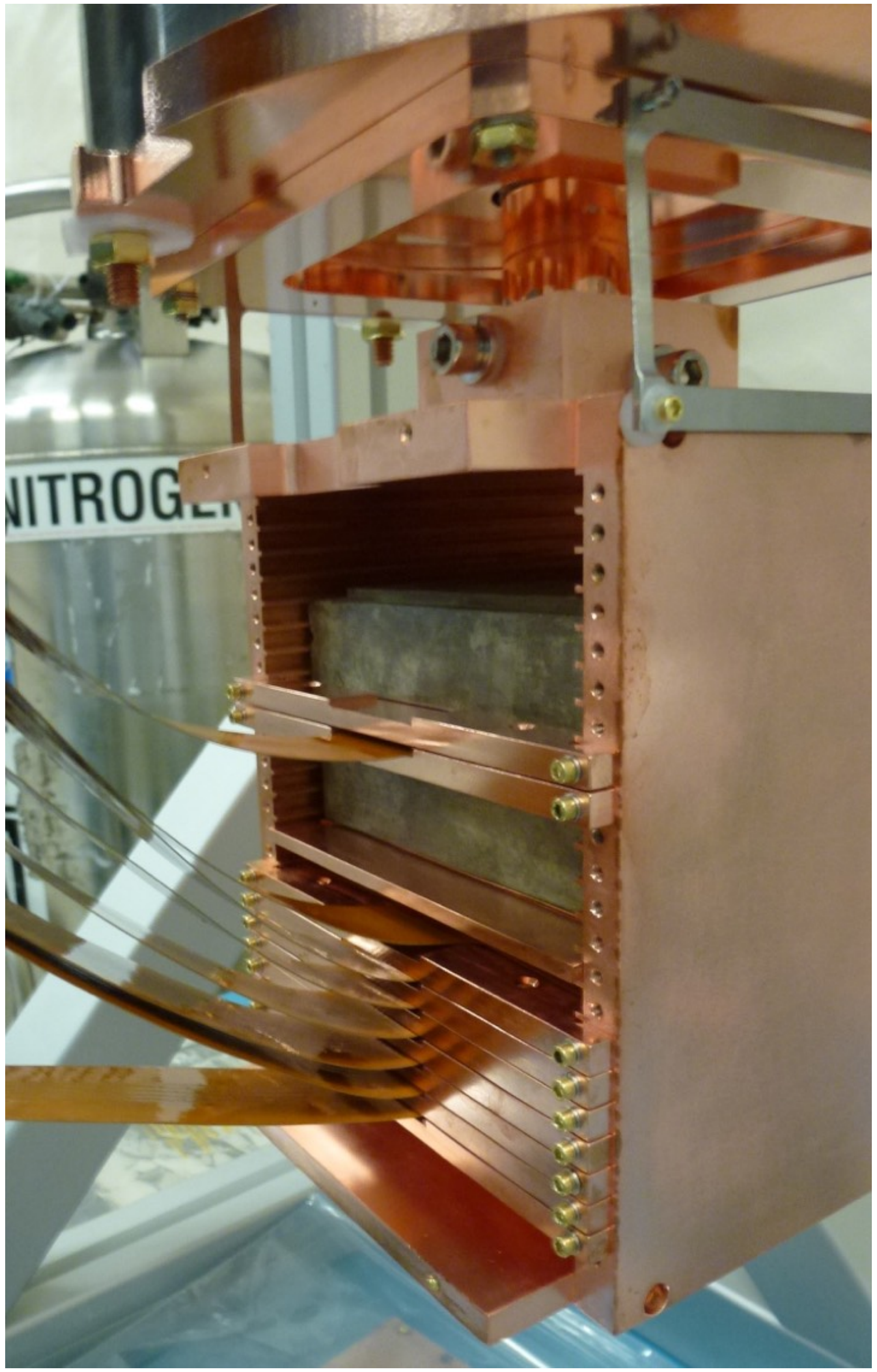


SNOLAB Installation

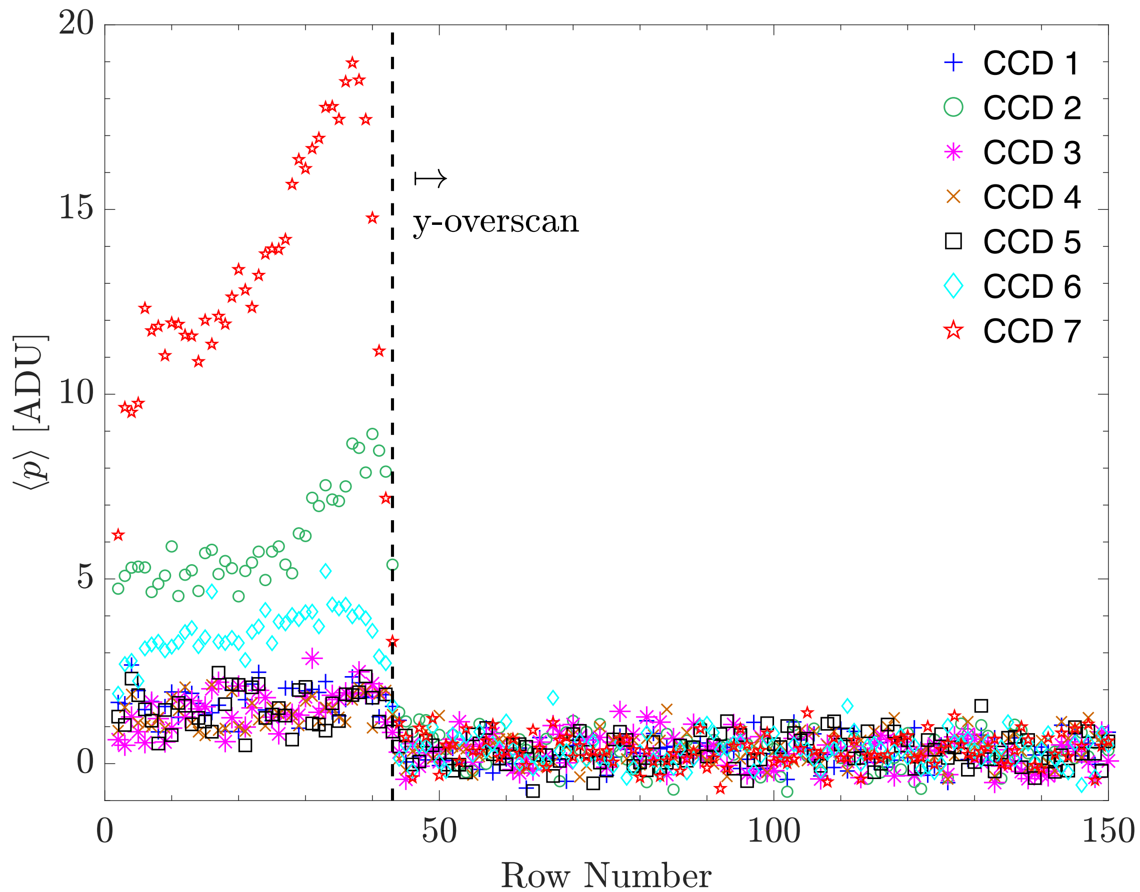


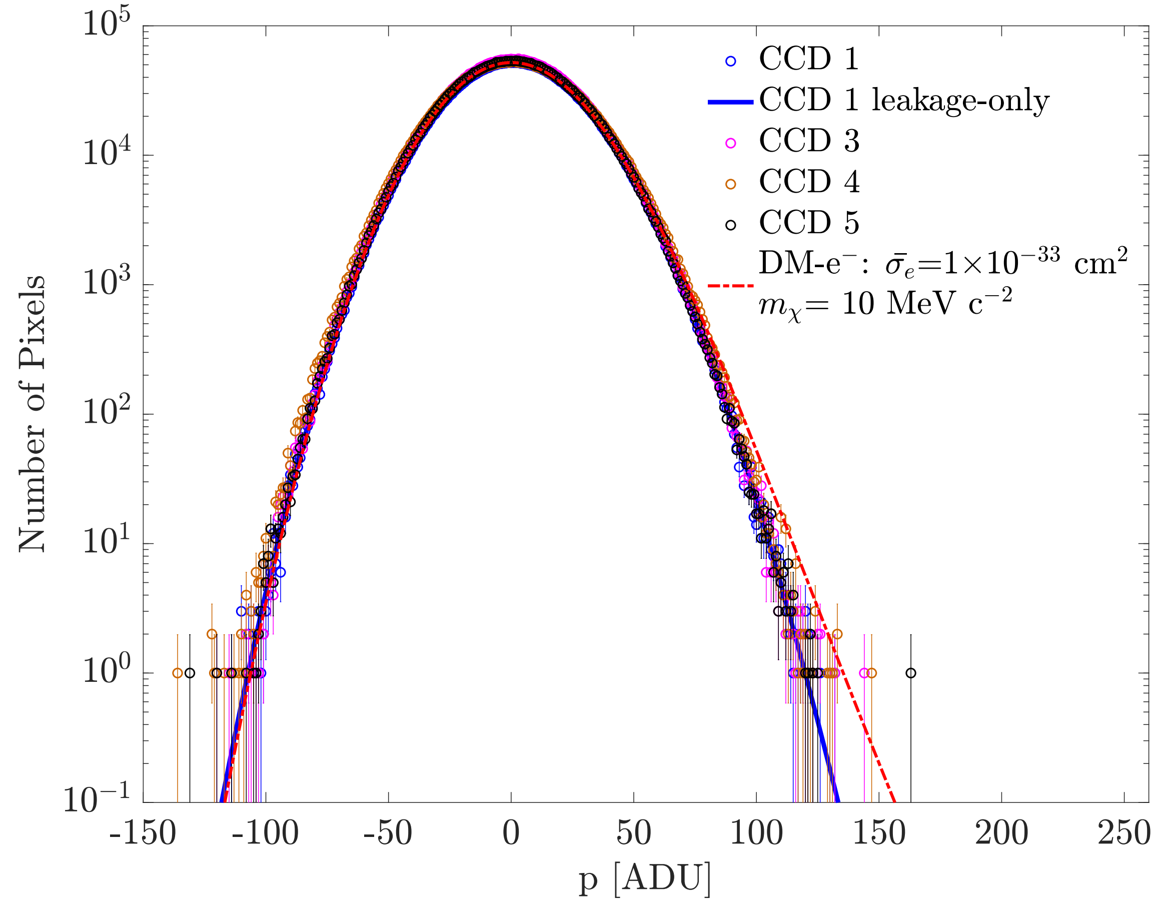
Current status

- **7 CCDs** in stable data taking since 2017 (1 CCD sandwiched in ancient lead).
- **40 g** target mass.
- Operating temperature of **~140K.**
- **Exposure for image: 8h and 24h** (each image acquisition is followed by a "blank" exposure).
- **7.6 kg-day** of data for **background** characterization in 1x1 format.
- **13 kg-day** of data collected for **DM search** in **1x100** format.
- Since Jan 2019, resumed background run and detector studies (e.g., **125 K** operation for lower leakage current) in preparation for **DAMIC-M**.



Leakage current analysis





- Select CCDs with constant leakage current.
- Compare pixel distribution to leakage-only hypothesis + signal from DM-e interactions.

Pixel distribution of **200 g-d** of data in 100 ks exposures

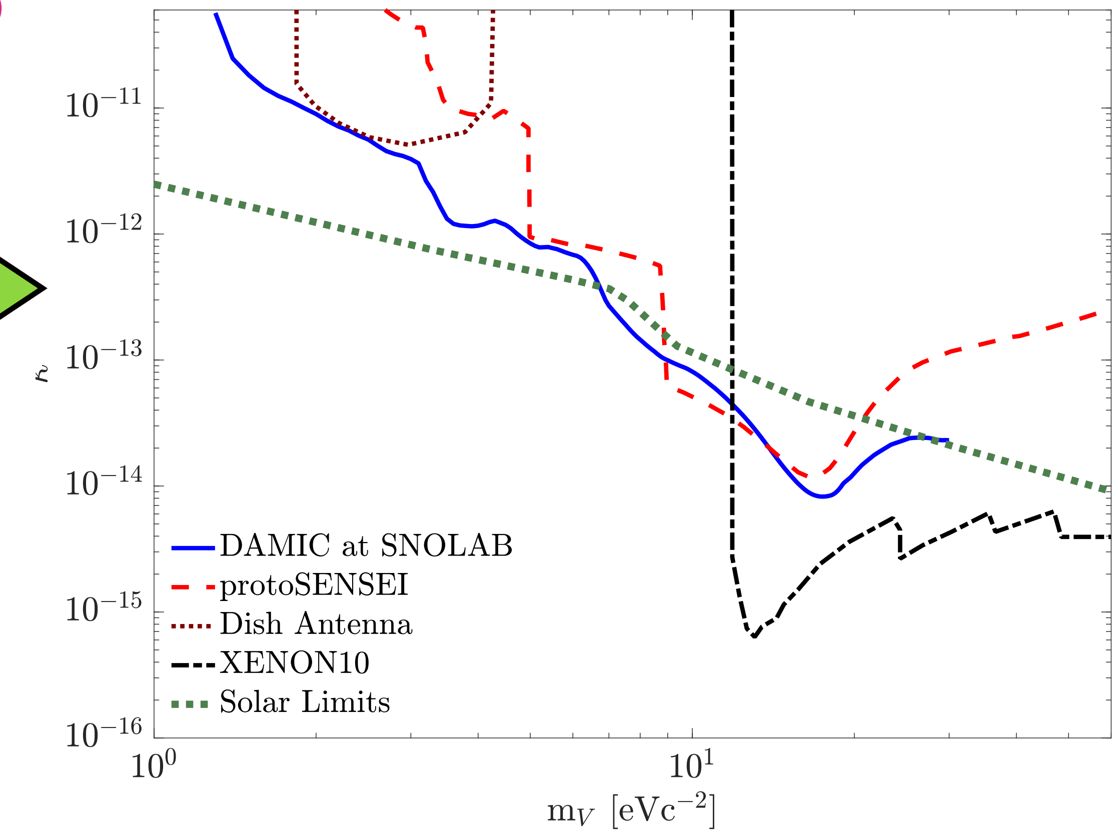
Bulk leakage current at the level of **2 e$^-$ mm^{-2} d^{-1}** at **~140 K**

(Before **4 e$^-$ mm^{-2} d^{-1}** at 105 K)

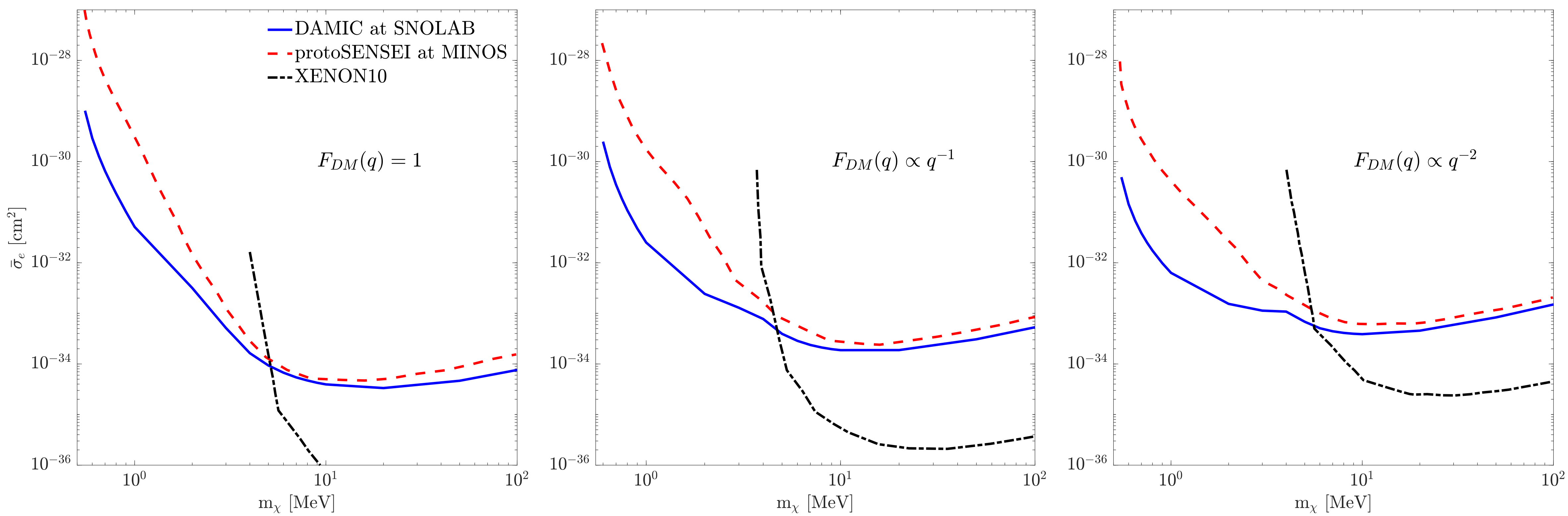
DM-e results

arXiv:1907.12628

Best exclusion limit for the absorption of hidden photons with masses 1-10 eV/c^2

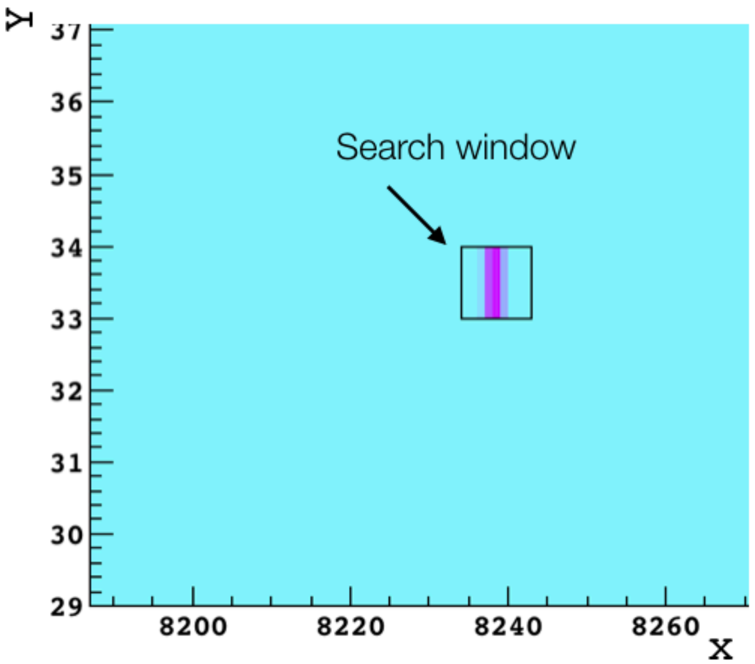


Best exclusion limits for the scattering of dark matter particles with masses <5 MeV/c^2



WIMP Search

- Remove pedestal and subtract correlated noise.
- Mask defects: repeating patterns in images.
- Select images with expected noise profile.
- Perform a log-likelihood fit for a signal in a moving window across the image.



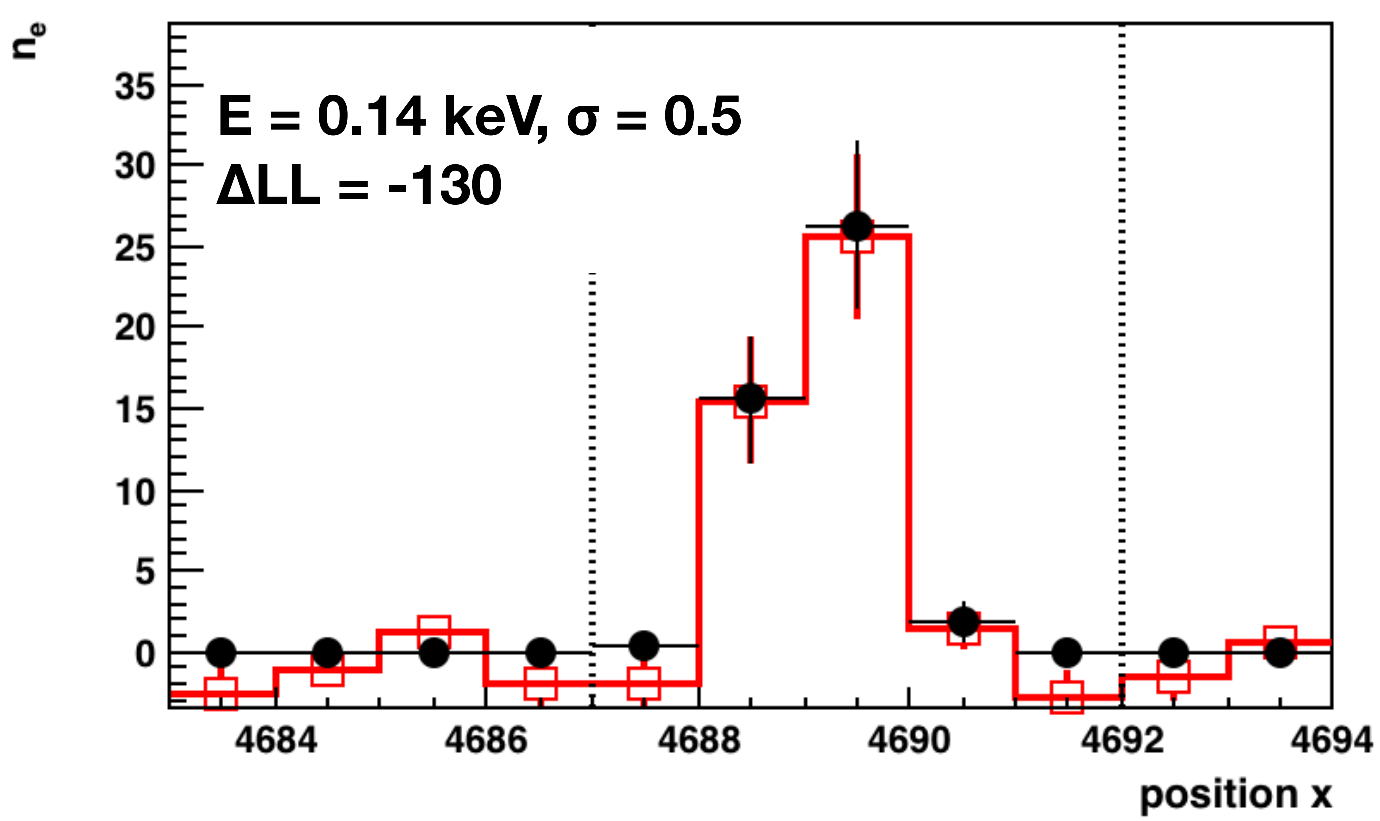
$$\Delta LL = \mathscr{L}_n - \mathscr{L}_s$$

flat noise

Gauss signal + flat noise

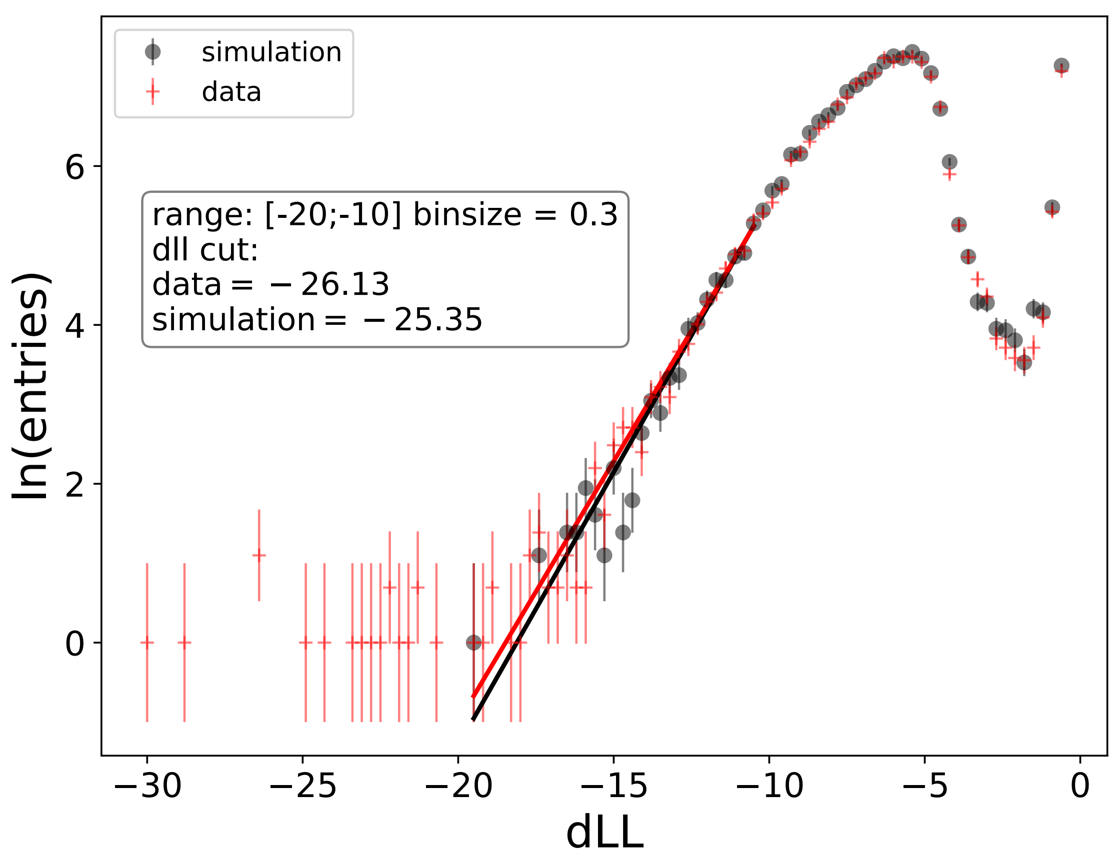
For every event we have its statistical significance *ΔLL* above noise, its amplitude (*E*, energy) and its spread (σ_x proportional to *z*)

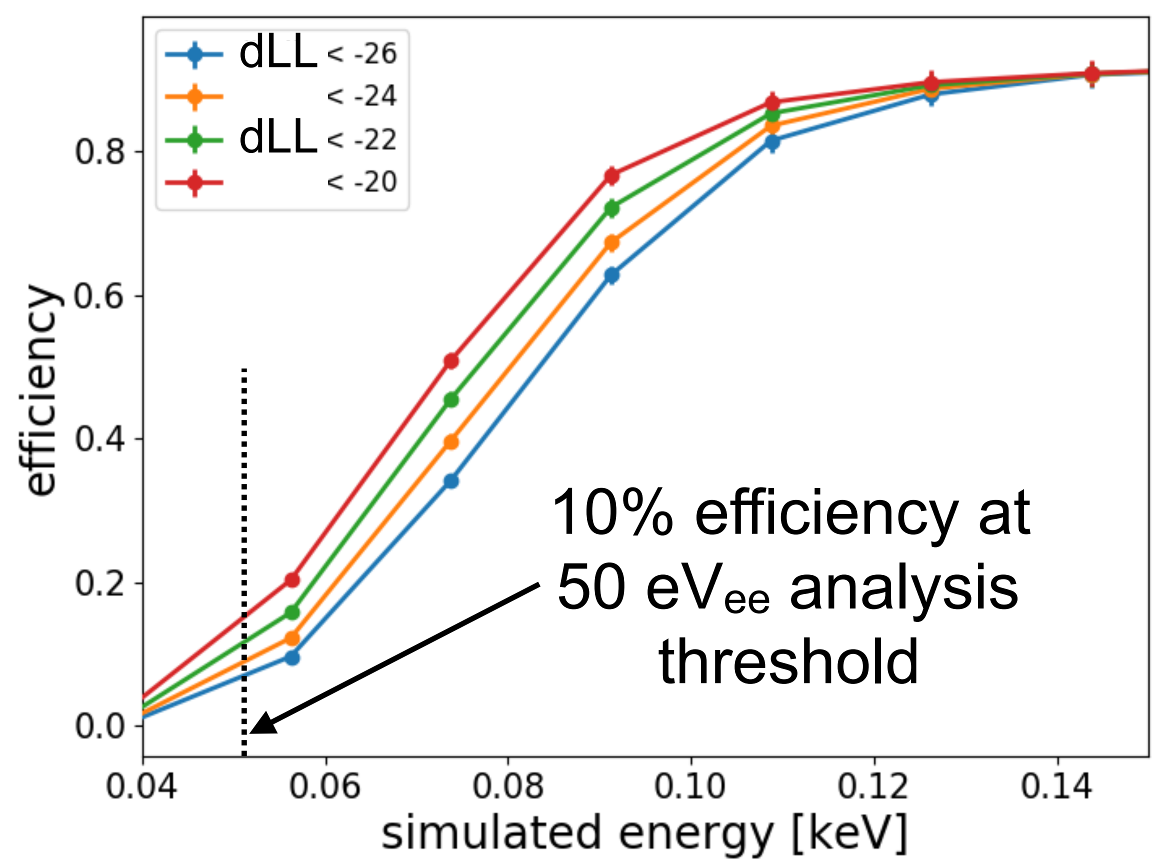
Example of one event



Noise rejection

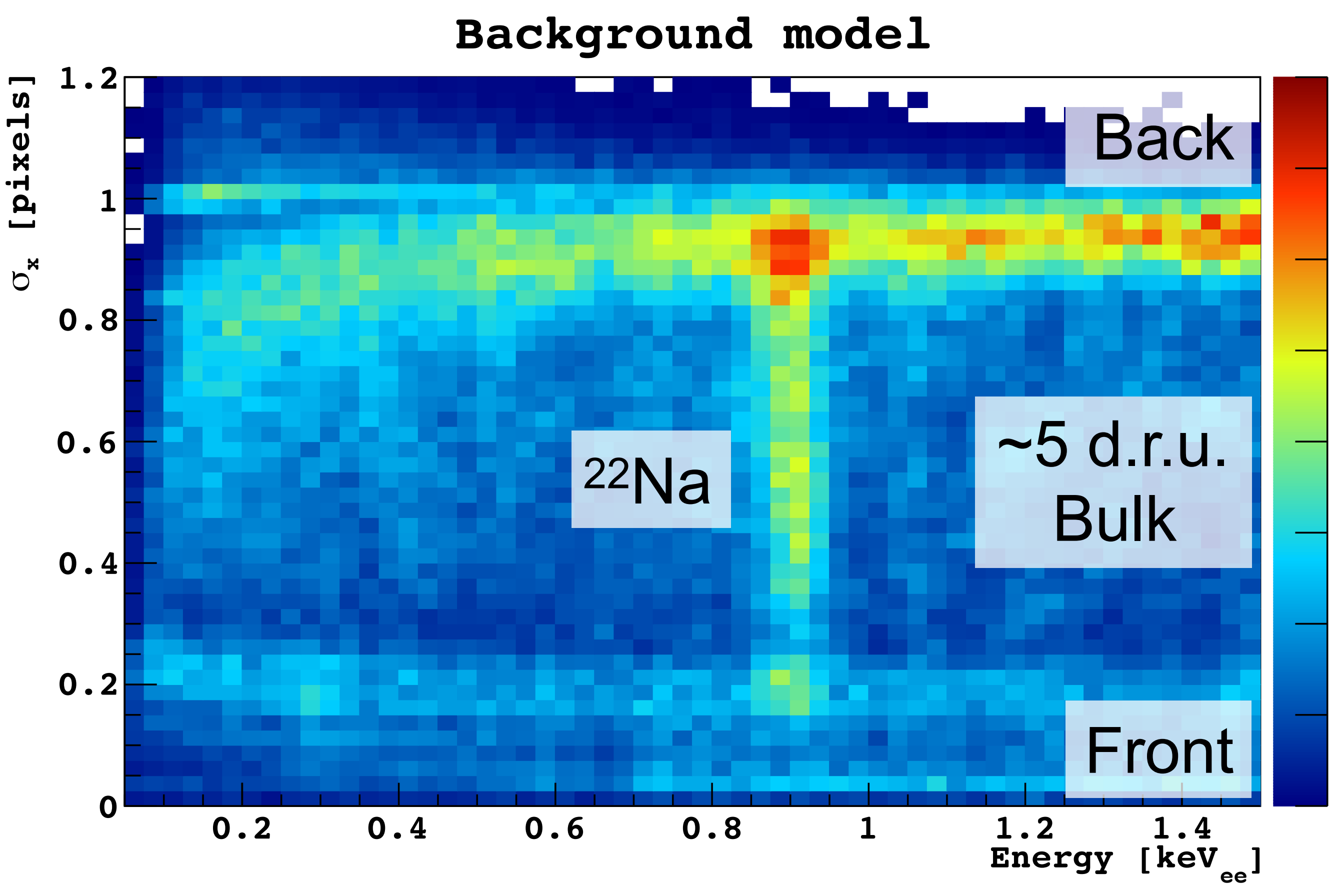
- We introduce leakage current on the blank (zero-exposure) images using a simple Poisson model.
- We run the full cluster extraction to obtain the *ΔLL* profile for “noise” clusters.
- Select a *ΔLL* value that removes all noise and calculate the event selection efficiency.

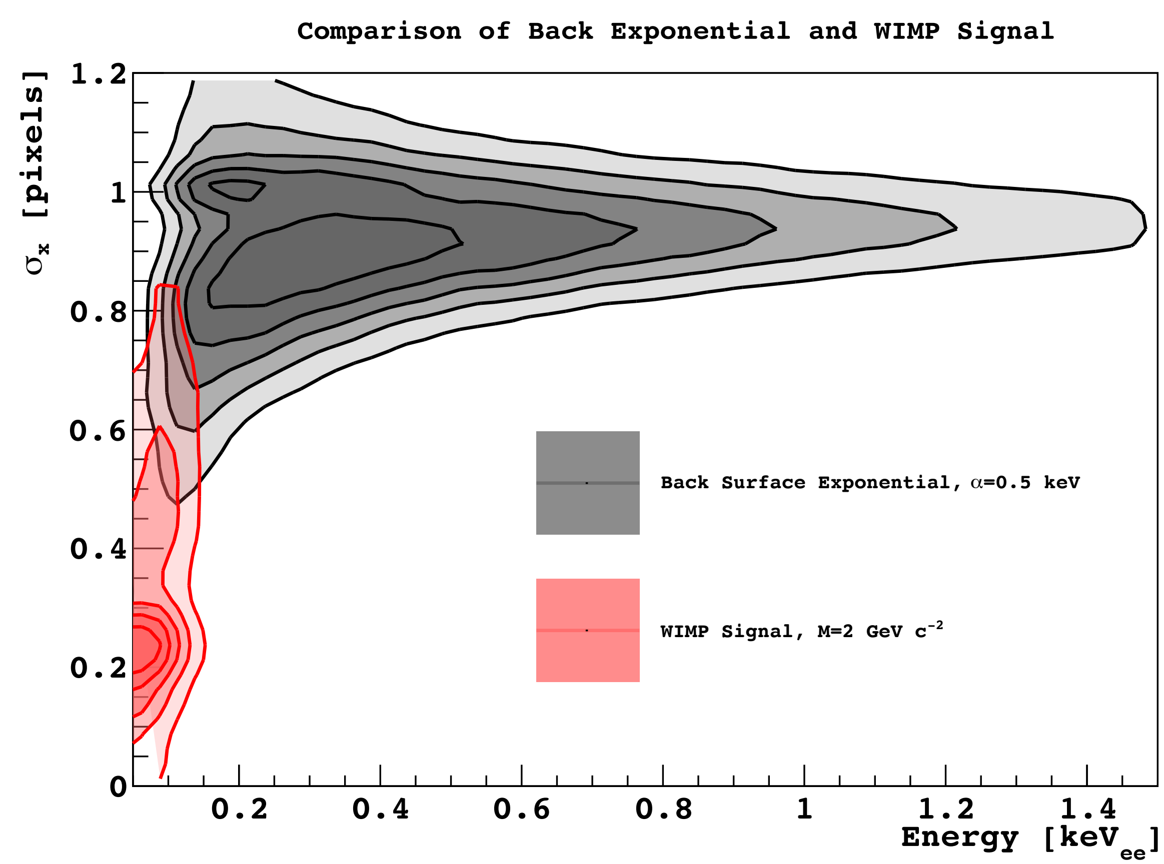




Background model

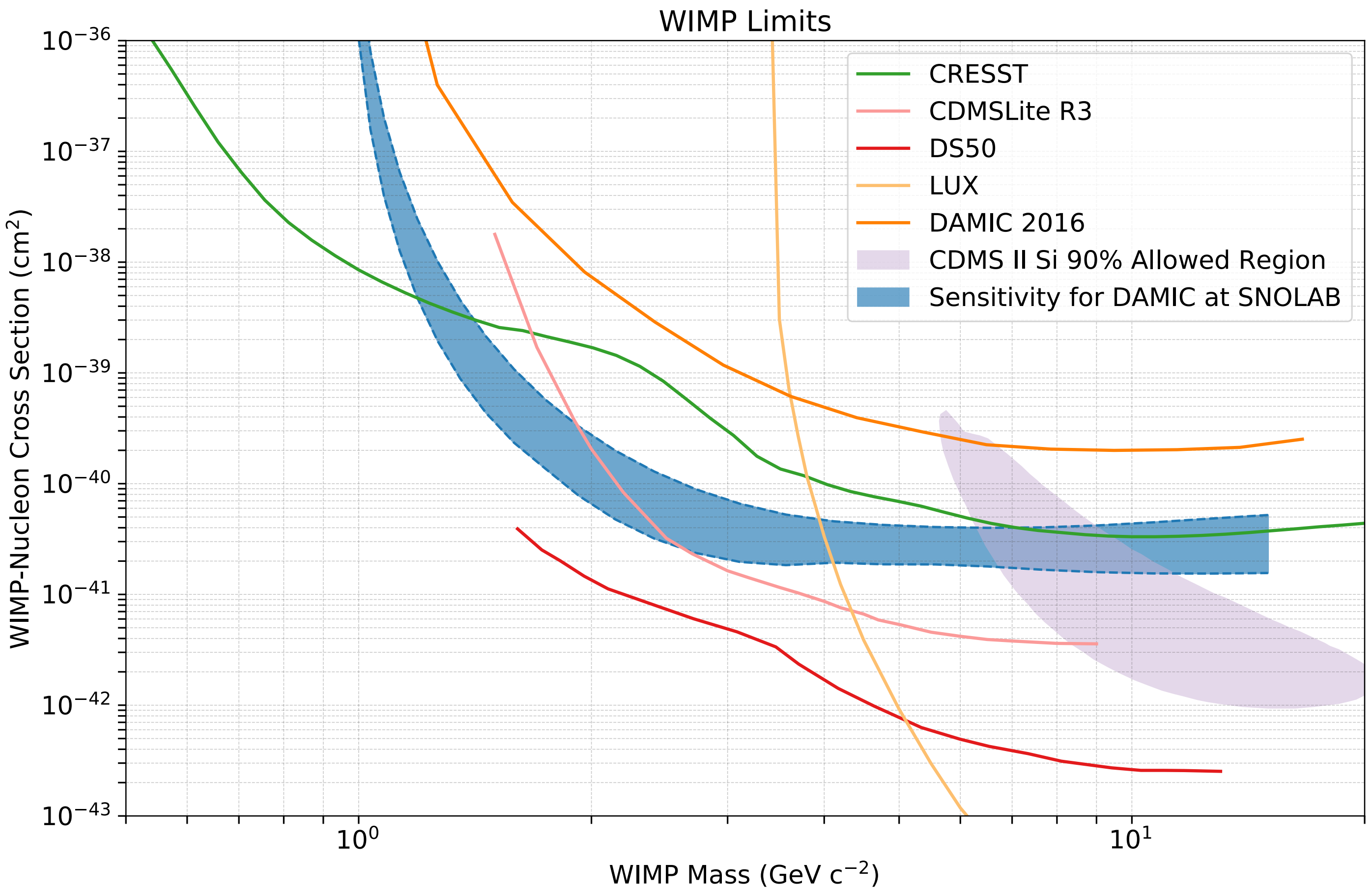
- Background model constructed from full particle tracking + detector response Monte Carlo. Two-D (E, σ_x) fit to data above 6 keV_{ee} with constraints from known radioactive contaminants. **D. Baxter**'s presentation from yesterday!
- Dominant systematic uncertainty are radioactive contaminants on the back of the active region, e.g., implanted ^{210}Pb or ^{3}H migration. Reconstructed depth allows to distinguish from WIMP signal.





Expected sensitivity

- Independent 2D unbinned likelihood fit with background model + WIMP signal to search for dark matter.
- Free parameters included in background model to account for systematic uncertainties.
- Analysis in its final stages. Results soon!
- We use latest background model and full analysis to generate expected sensitivity.
- Potential for discovery of WIMPs with masses 1–2 GeV/c^2.
- Result can exclude a significant fraction of CDMS II-Si.



Conclusions

- DAMIC at SNOLAB has demonstrated CCDs as an excellent technology for dark matter direct detection.
- Extensive understanding of CCD response and backgrounds for an experiment with potential for discovery.
- Best results for DM scattering with masses <5 MeV/c^2.
- WIMP search data campaign complete. Exposure of 13 kg-d under analysis. Expect results soon.
- Particularly good sensitivity for WIMPs with 1-2 GeV/c^2.
- Next step in the program: **DAMIC-M.** See **P. Privitera** talk later today.

DAMIC Collaboration

Thank you!