Latest Results from DAMIC at SNOLAB

Daniel Baxter

…on behalf of the DAMIC Collaboration

2021 SNOLAB User Meeting

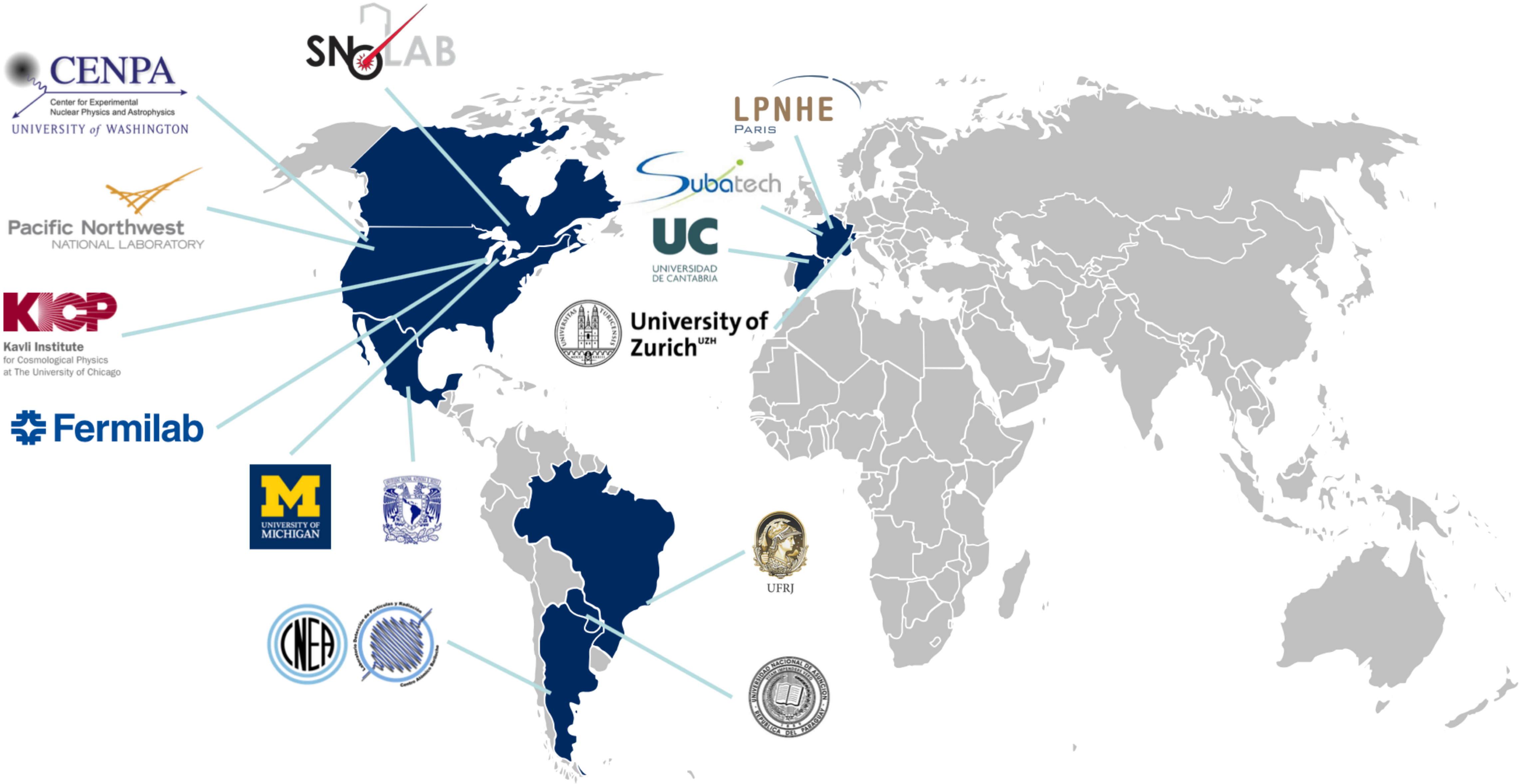
August 12, 2021

A little about me…

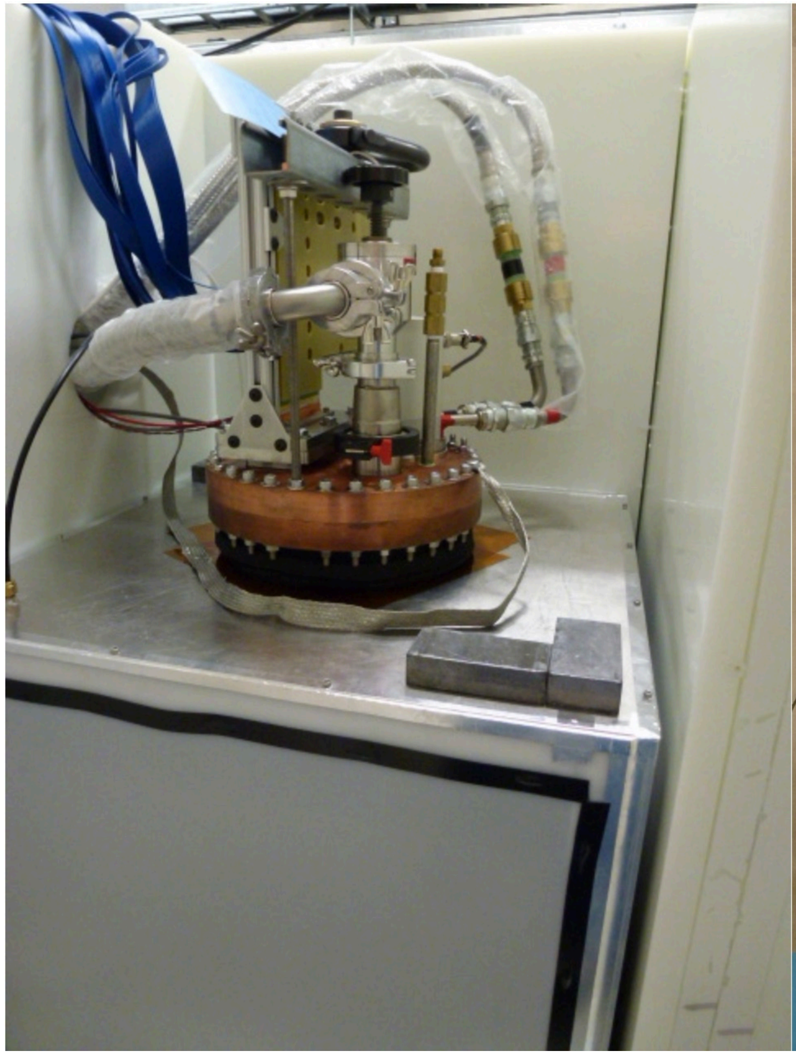
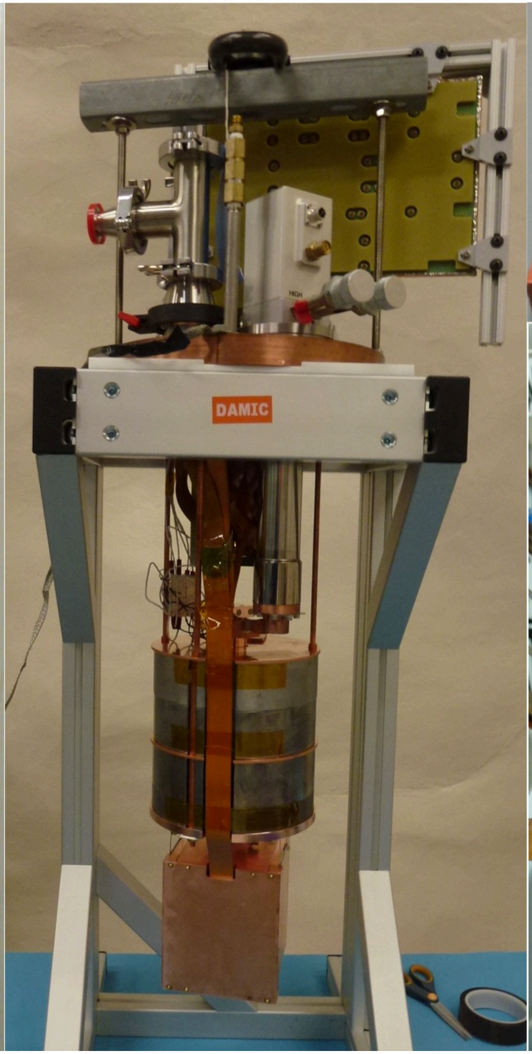
- **Northwestern University (2013-2018)**
  - PhD with Eric Dahl on PICO
- **University of Chicago (2018-2021)**
  - KICP Postdoctoral Fellow on DAMIC
- **Fermilab (2021-present)**
  - Associate Scientist working on quantum science and OSCURA

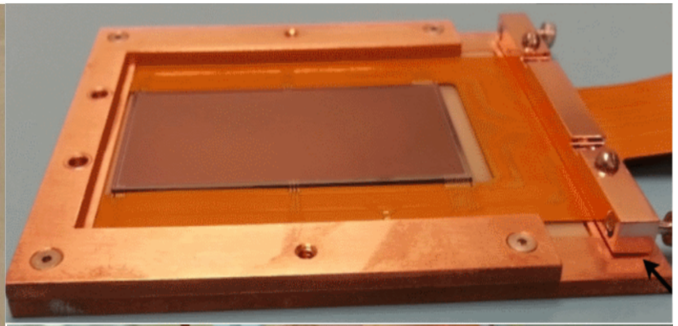
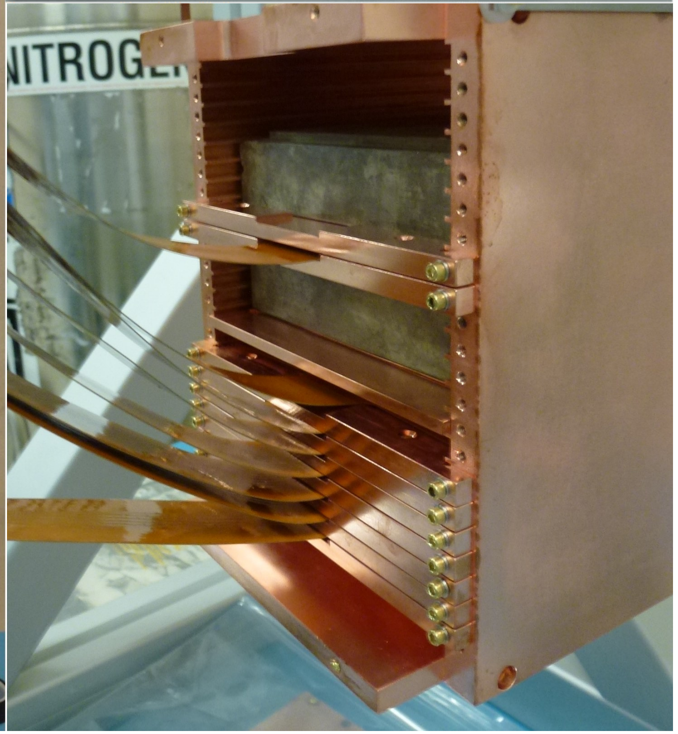
- **<u>Fun Fact</u>**: Among my many nerdy past-times, I am a *huge* musical theater fan

DAMIC Collaboration



DAMIC at SNOLAB

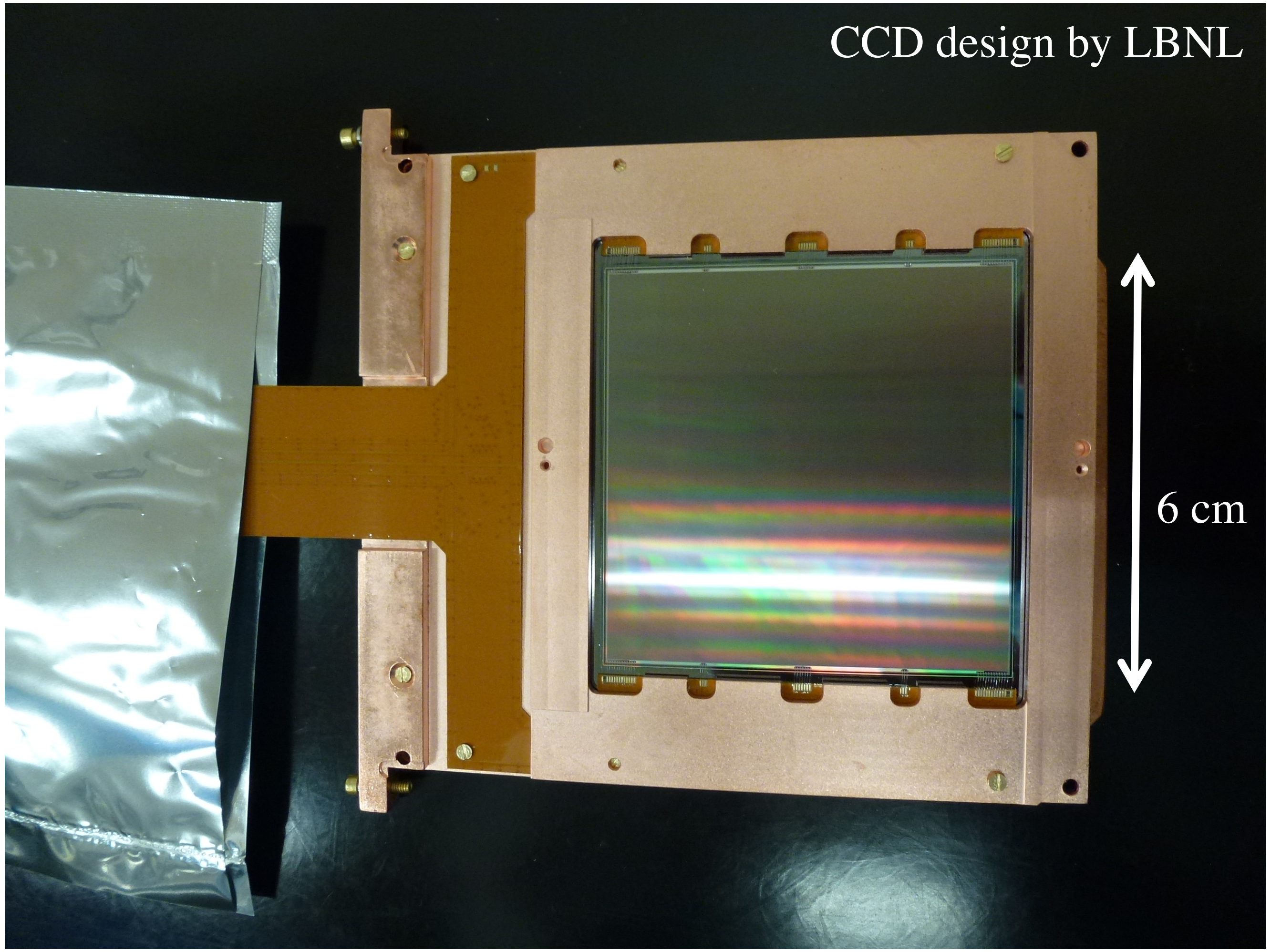



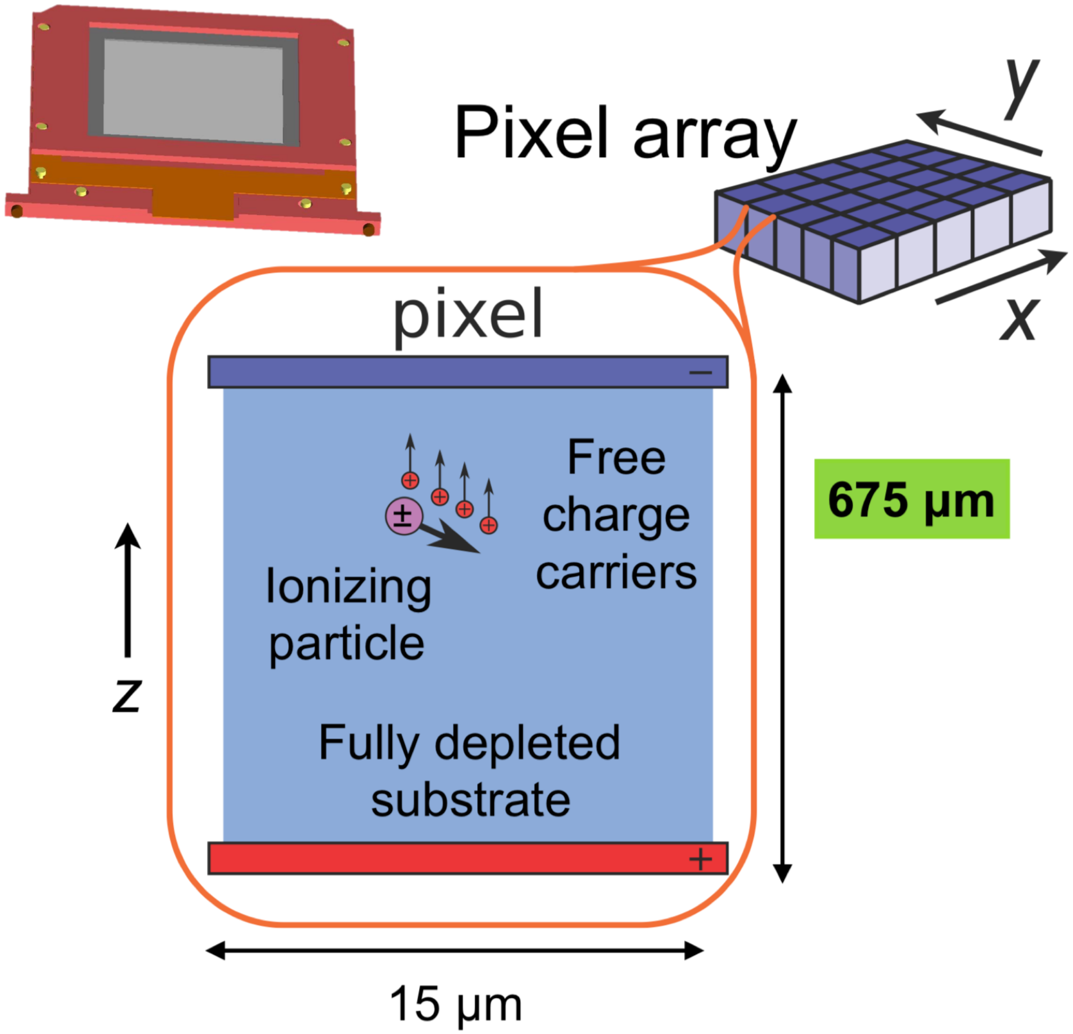
DAMIC at SNOLAB CCDs

- 4000x4000 pixels (6x6 cm^2)
- Pixel size 15x15 microns^2
- Depth ~675 microns
- Cooled to 140 K
- One Kapton cable per CCD

- Dominant intrinsic background expected to be tritium production from direct activation of the silicon wafers prior to production

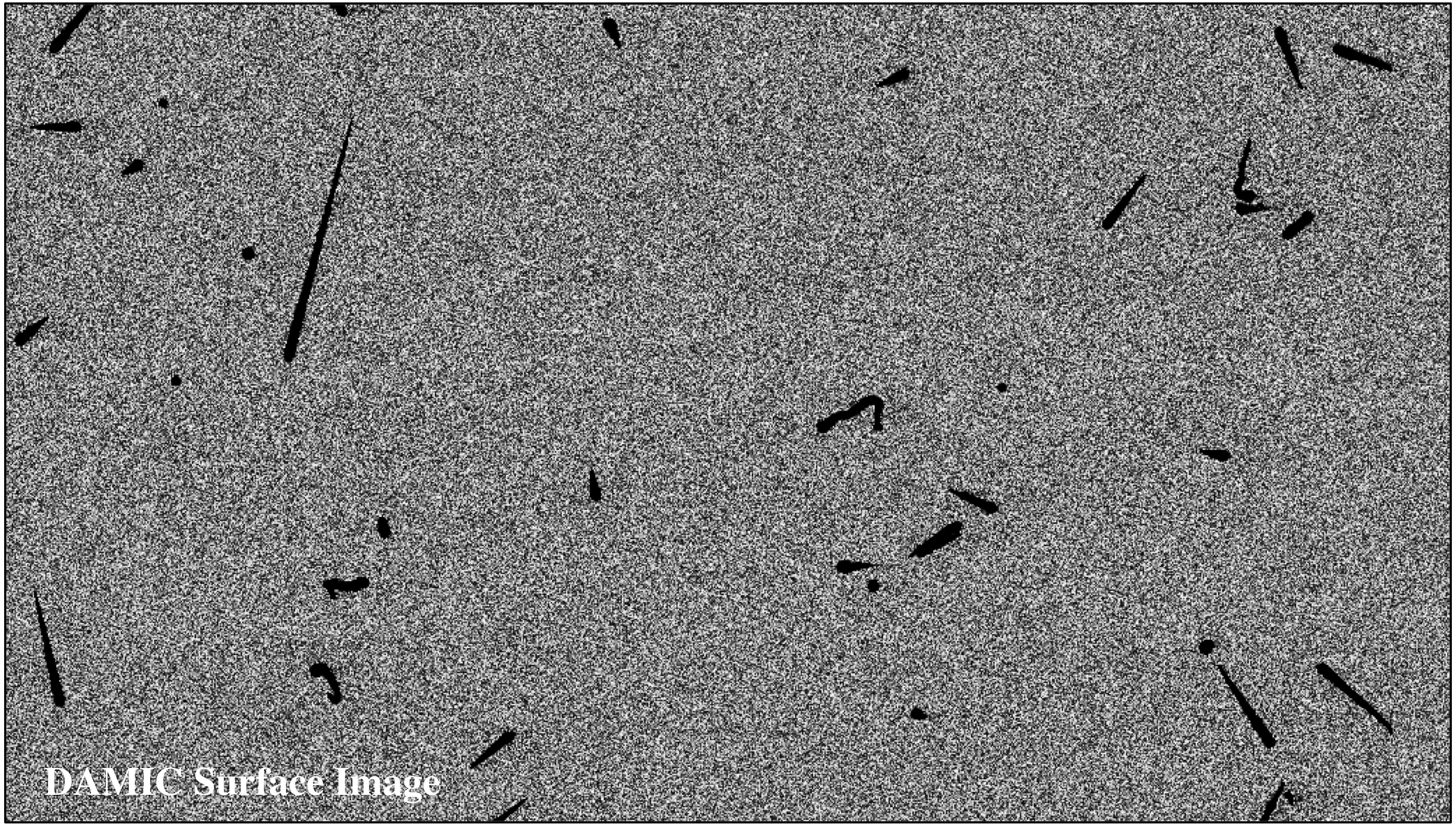


Charge Coupled Devices



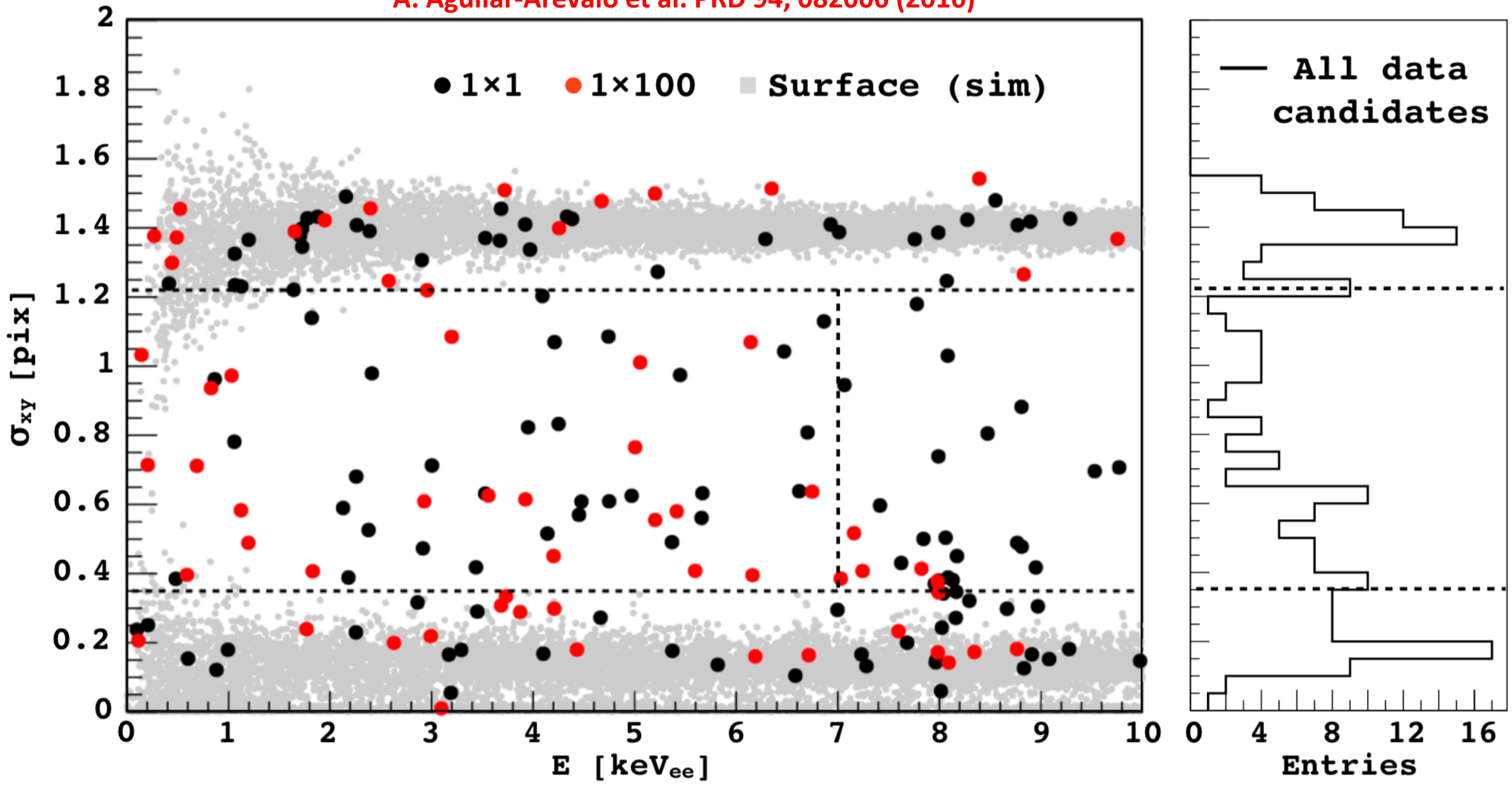
- Interaction with silicon produces free charge carriers…
  - …which are drifted across fully-depleted region… → *No loss of charge*
  - …and collected in 15 micron square pixels… → *exceptional position resolution*
  - …to be stored until a user-defined readout time after many hours. → *large exposures*

Charge Coupled Devices

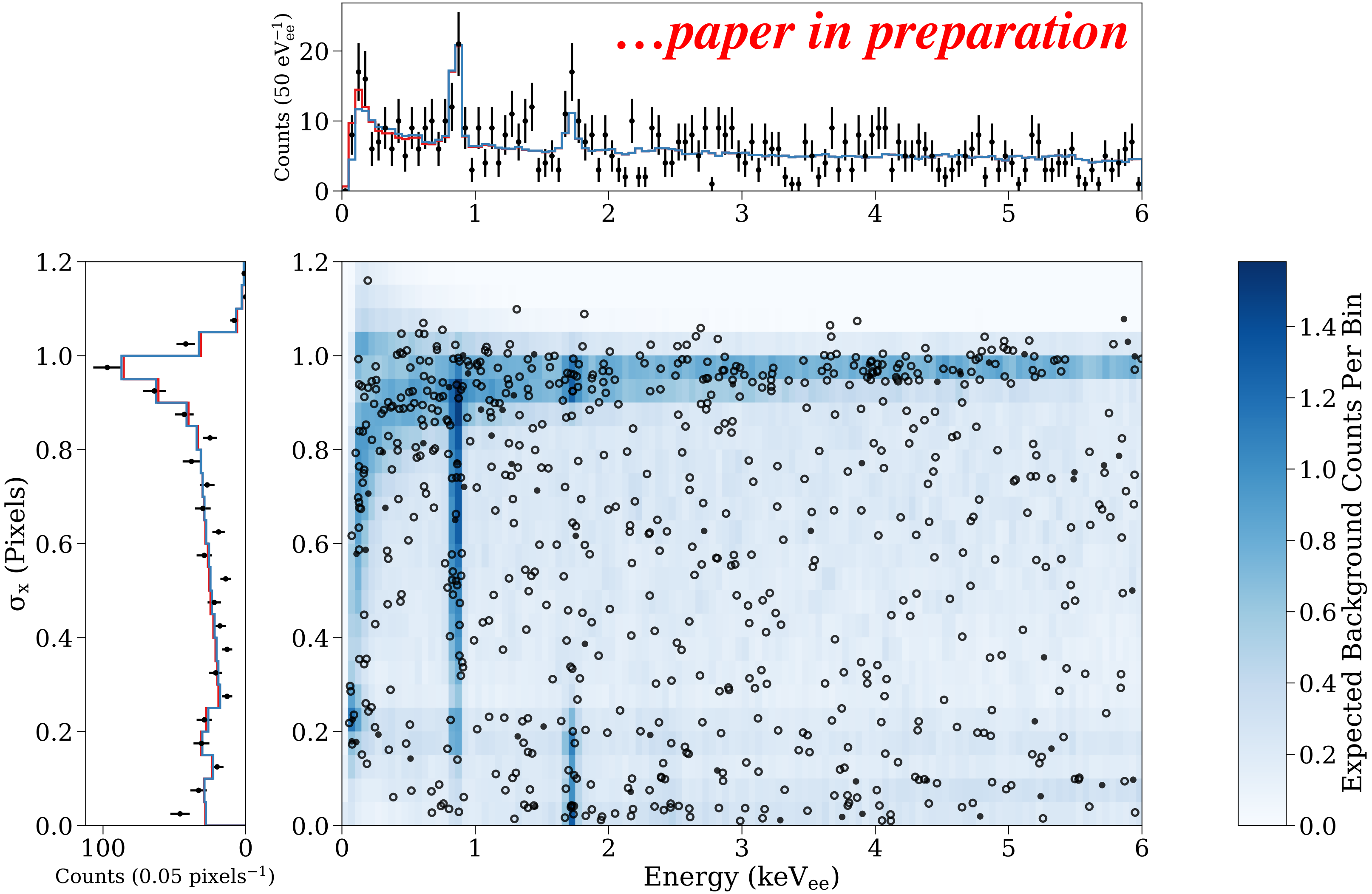


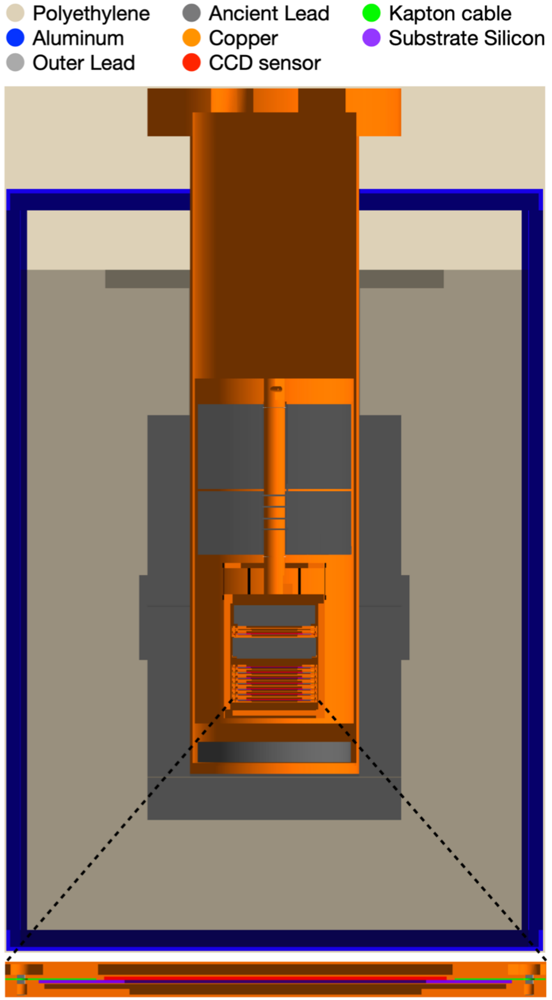
DAMIC Background Model (2016)

A. Aguilar-Arevalo et al. PRD 94, 082006 (2016)

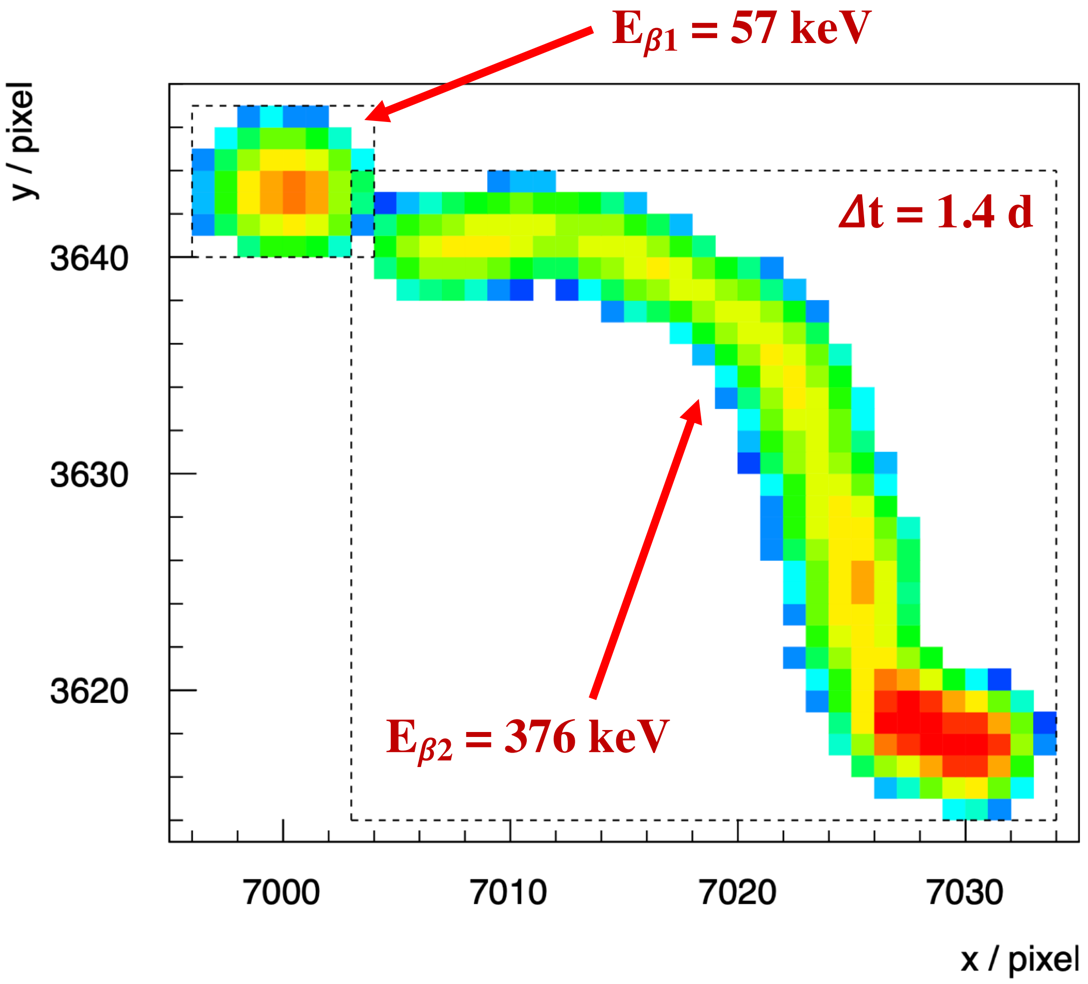


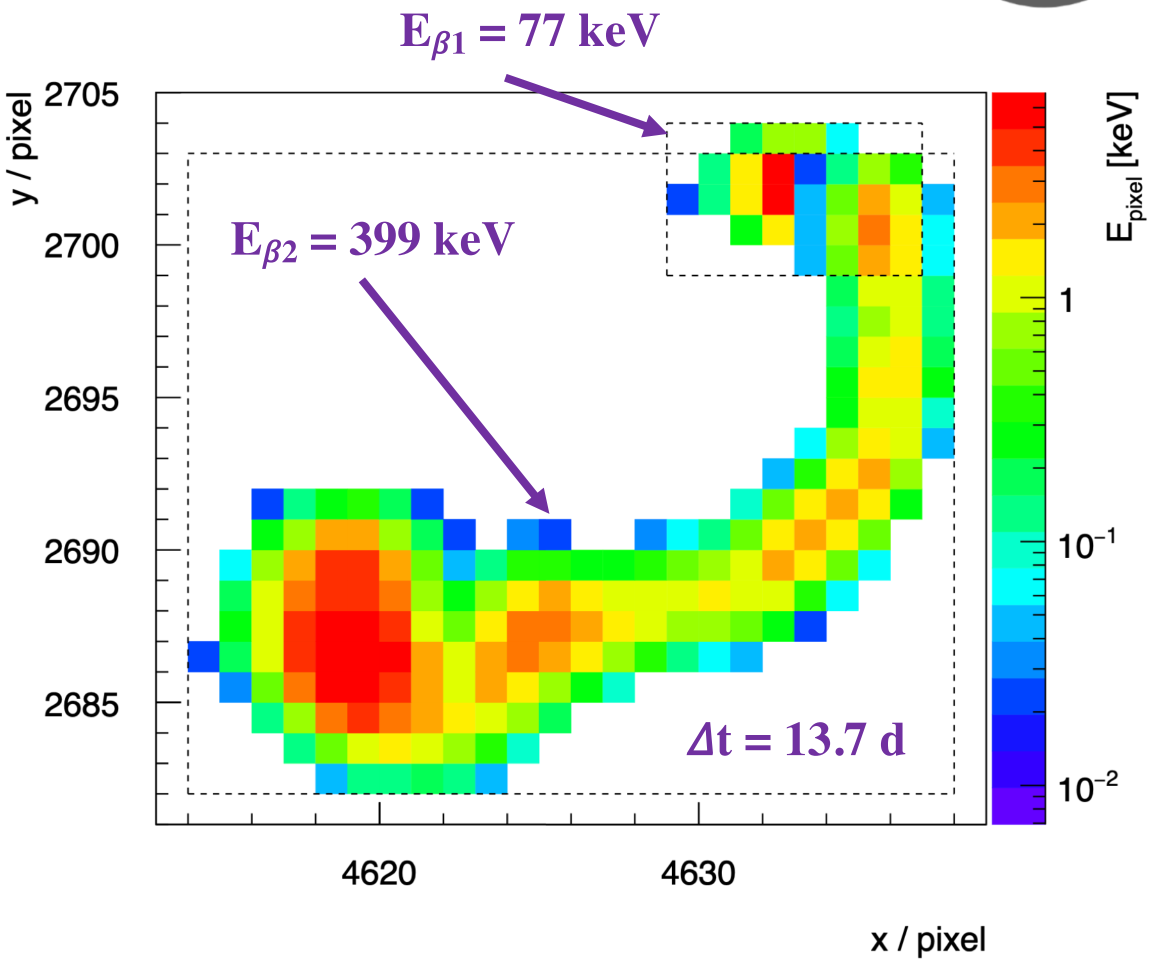
DAMIC Background Model (2020)





Background Coincidence Analysis

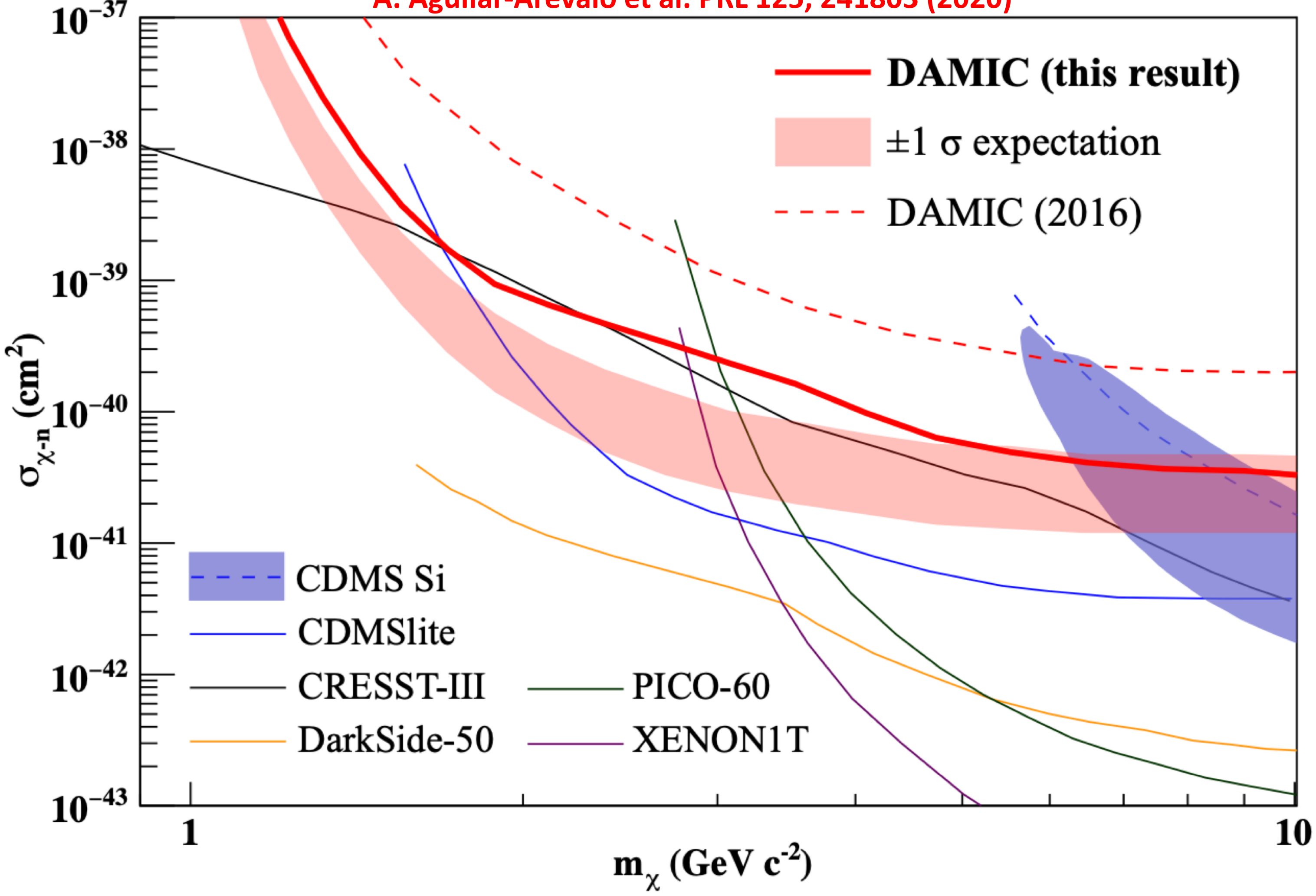




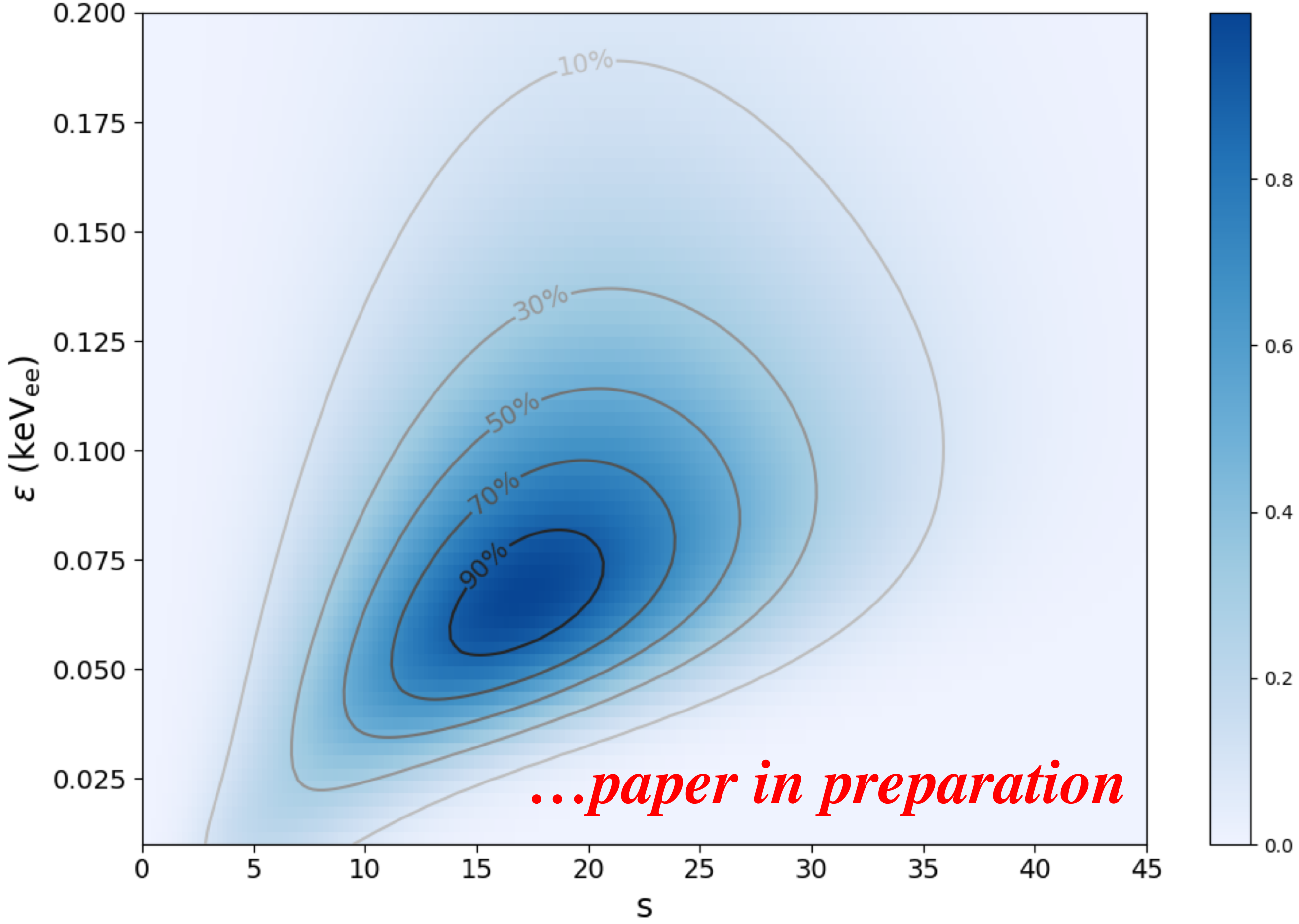
A. Aguilar-Arevalo et al. JINST 16, P06019 (2021)

DAMIC WIMP Results (2020)

A. Aguilar-Arevalo et al. PRL 125, 241803 (2020)



DAMIC WIMP Results (2020)

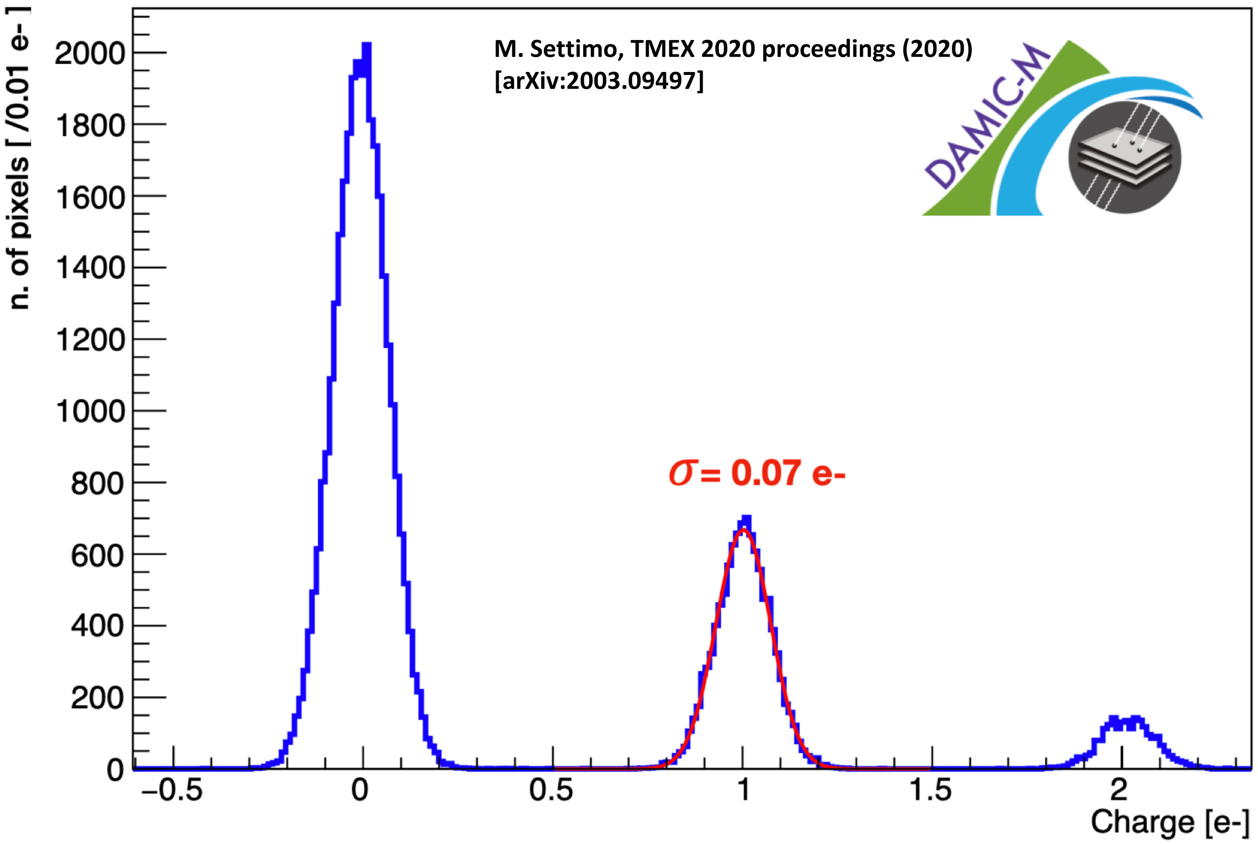


…paper in preparation

- Clear excess rate over background model below 200 eV
- Consistent with uniform (bulk) spectrum
- We choose not to report this as a potential WIMP signal, as further background model validation is required

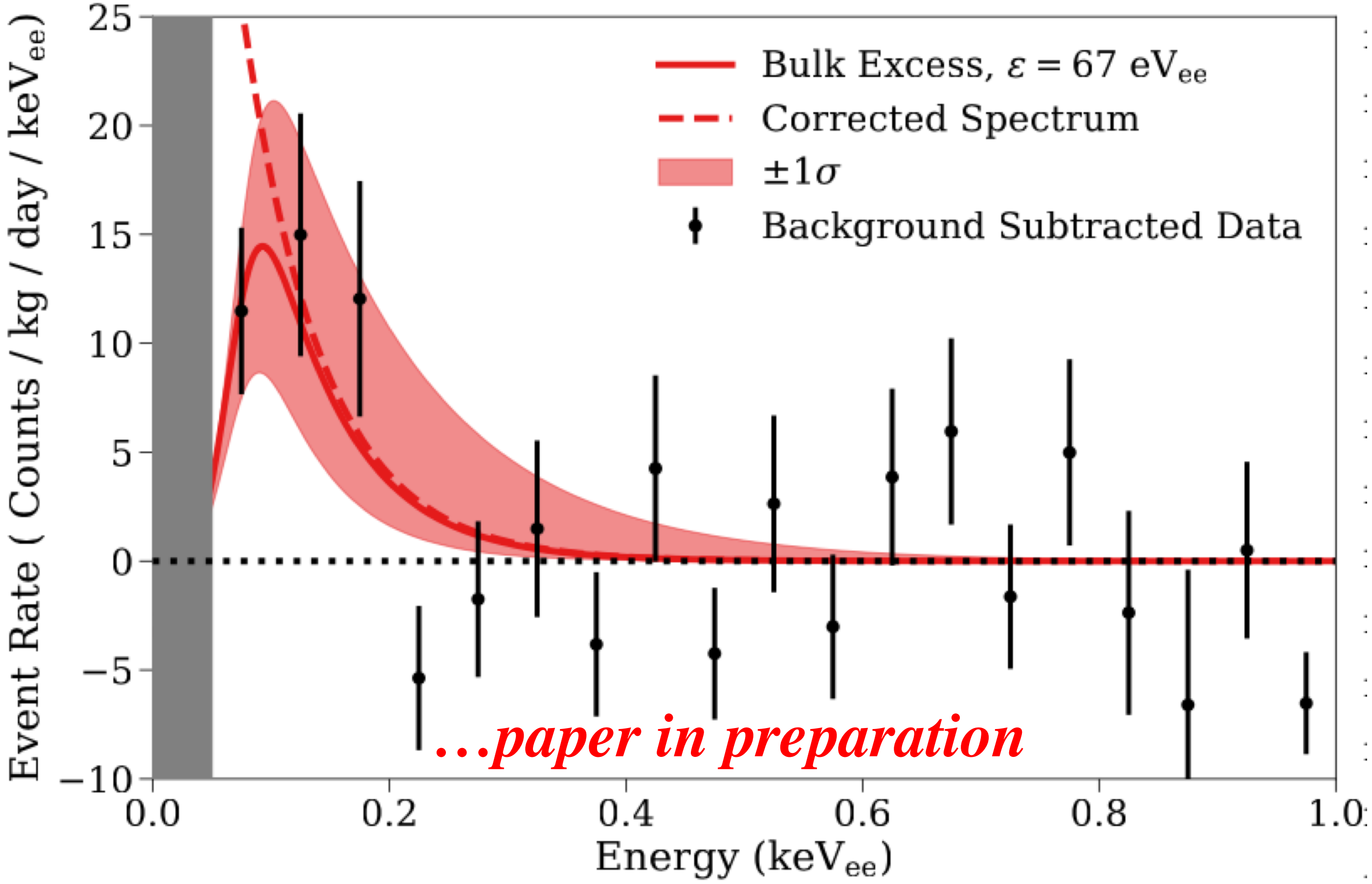
DAMIC Phase 1 Complete!

- DAMIC at SNOLAB is the first CCD dark matter array
- We have improved the limits by a factor of ~10 and excluded a significant fraction of the CDMS-II Si allowed region
- Inevitably, we were going to have a few surprises along the way
- … and we learned a lot about how low background CCDs work!
- Skipper CCDs are the future



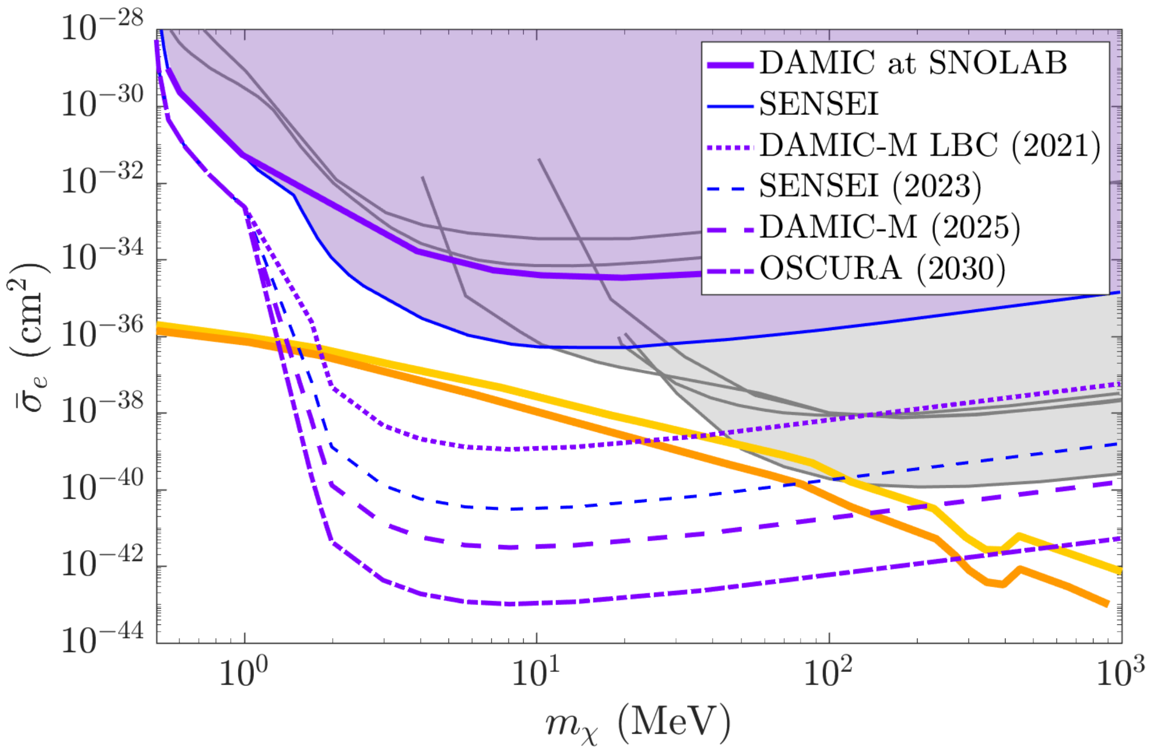
Next Steps: Verify

- Ongoing upgrade to the SNOLAB detector will install Skipper CCDs
  - Collaboration between SENSEI and DAMIC-M towards OSCURA
- …another measurement with lower threshold in the same background environment
  - If this is a threshold effect, it should go away
  - If it is a missing component in the background model, we will have many more events to study



Conclusions – the CCD Program

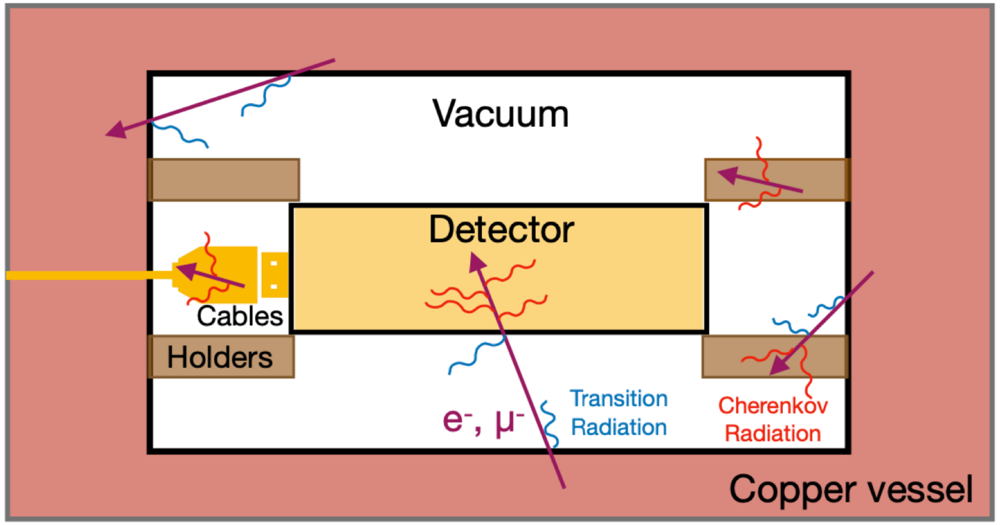
- DAMIC at SNOLAB continues to produce new, interesting results:
  - **NR Limits:** *PRL 125, 241803 (2020) [arXiv:2007.15622]*
  - **ER Limits:** *PRL 123, 181802 (2019) [arXiv:1907.12628]*
- SENSEI has advanced the CCD technology with single-electron resolution Skipper amplifiers
  - And will continue to improve limits with larger exposures with lower background rates
- DAMIC-M will improve on this with lower backgrounds, single electron resolution, and much larger exposure
  - Low background chamber (2021)
  - Full detector (installation 2023)
- OSCURA will push the limits of the CCD technology to 10 kg of silicon, single-electron threshold, 0.01 dru detector
  - DoE BRN funded R&D experiment merging the efforts of DAMIC at SNOLAB, DAMIC-M, and SENSEI
  - Cleared Gateway 0 for SNOLAB



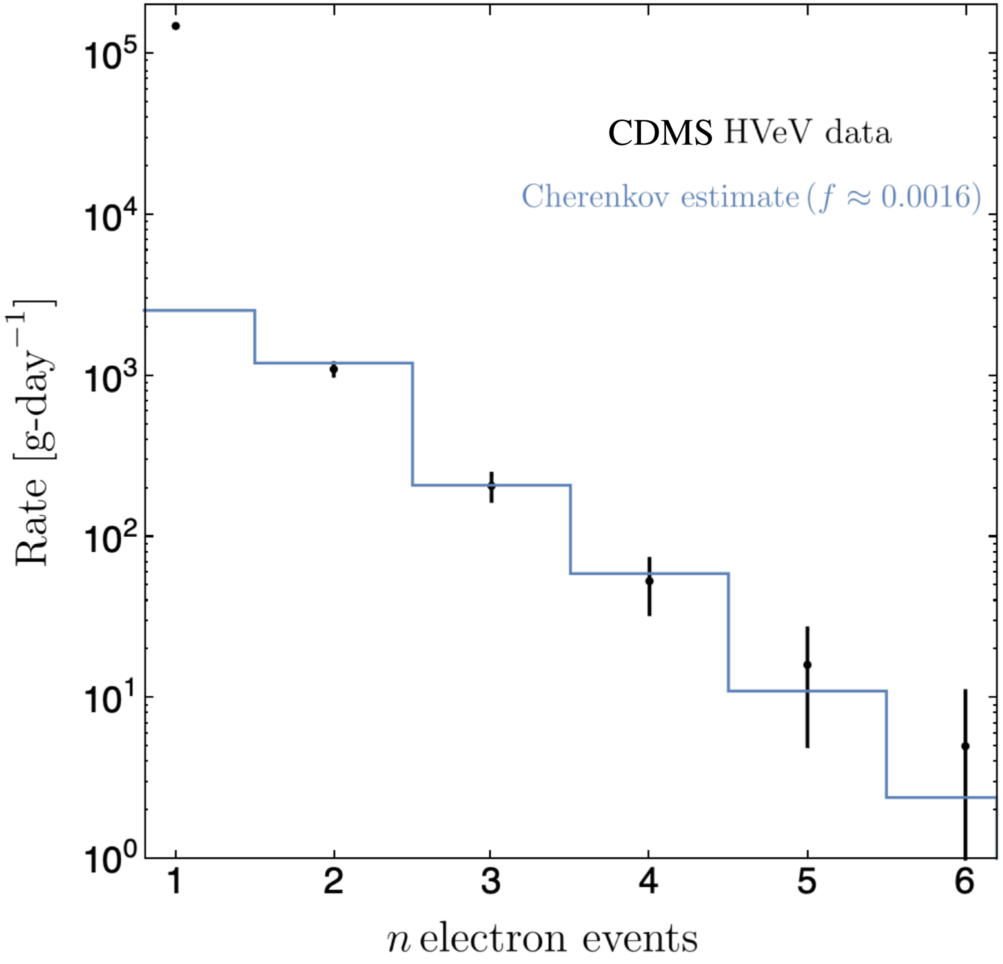
Extra Slides

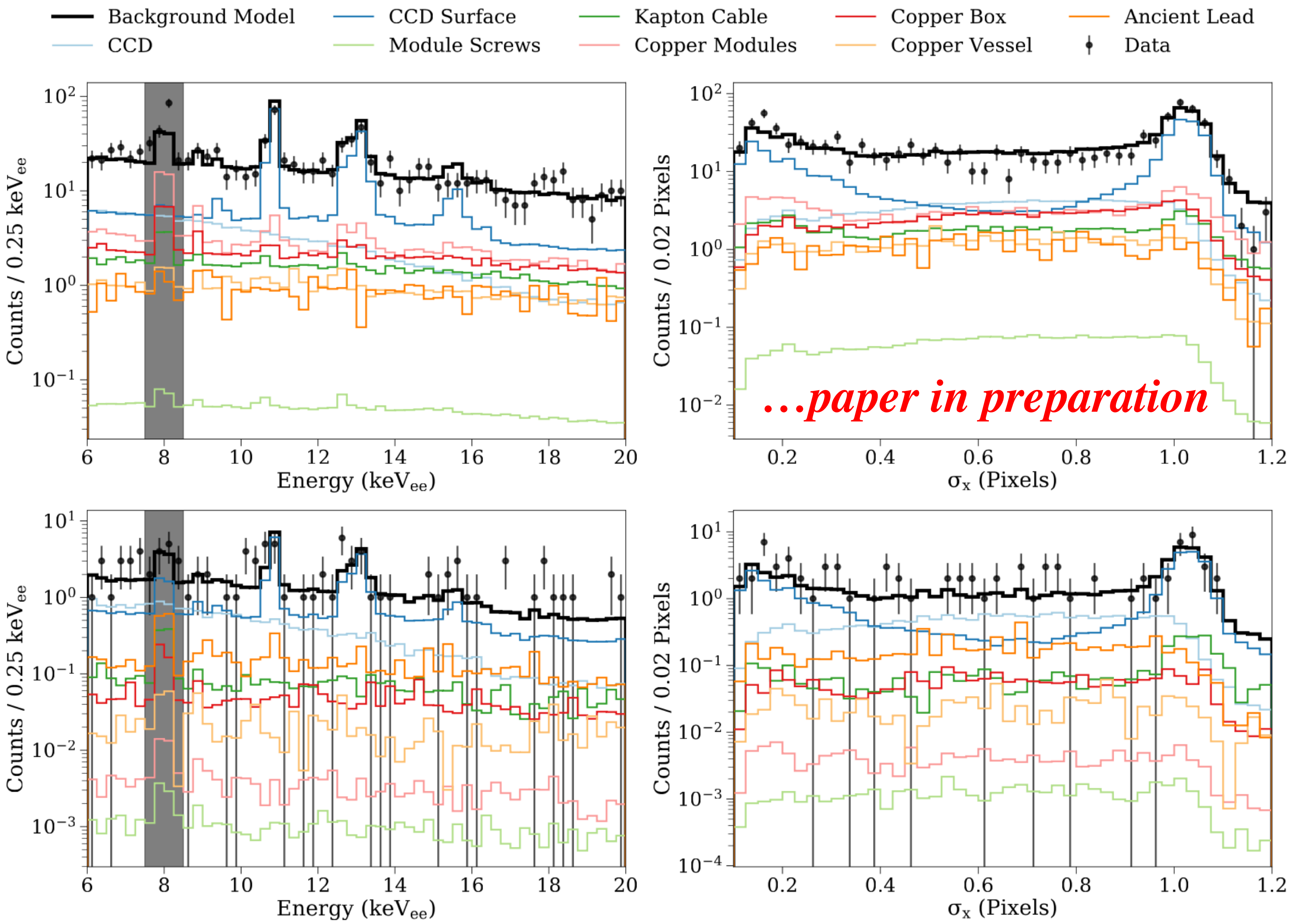
Non-radiogenic Backgrounds

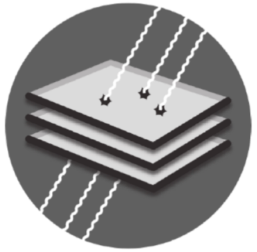
- Studies of dark rate sources are very active
- DAMIC at SNOLAB measures a dark rate of ~600 [g-day^{-1}]



P. Du et al. (2020) [arXiv:2011.13939]




Background Model
CCD Surface
Kapton Cable
Copper Box
Ancient Lead
CCD
Module Screws
Copper Modules
Copper Vessel
Data
Counts / 0.25 keV$_{ee}$
Energy (keV$_{ee}$)
Counts / 0.02 Pixels
σ_x (Pixels)
…paper in preparation

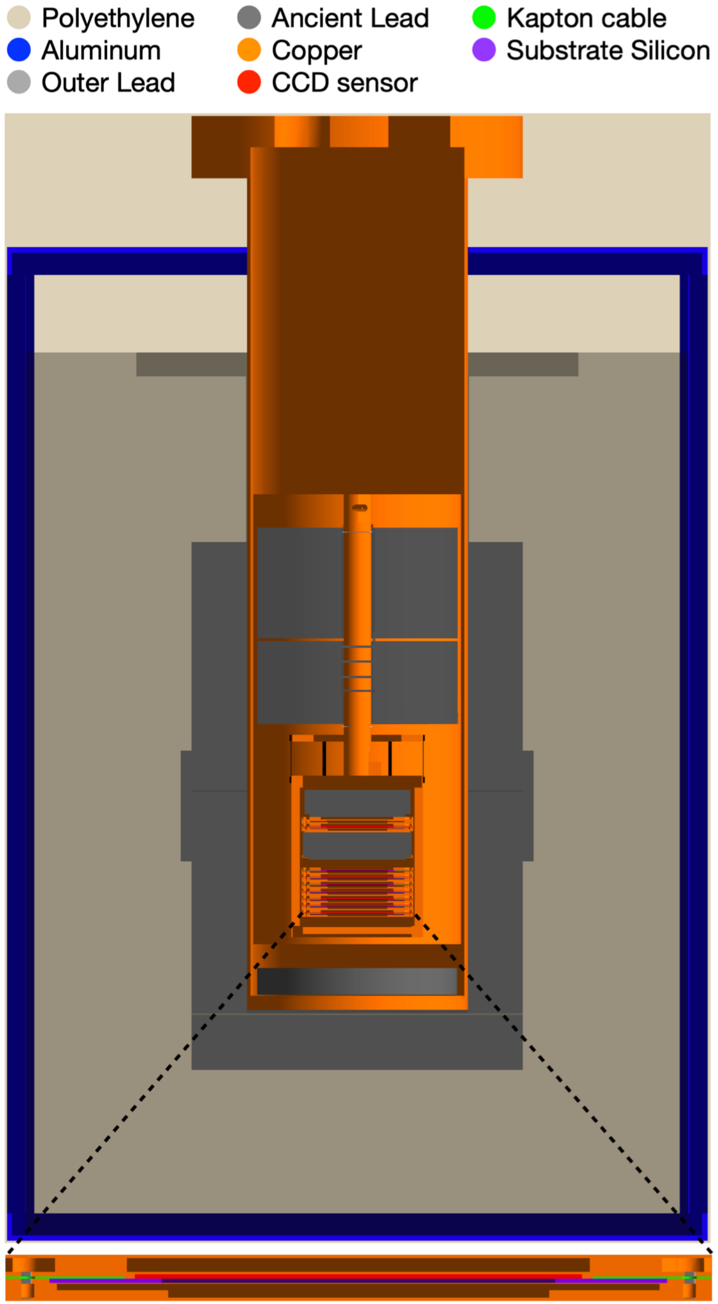


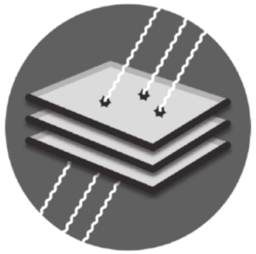
CCDs 2-7

CCD 1

Simulated Geometry

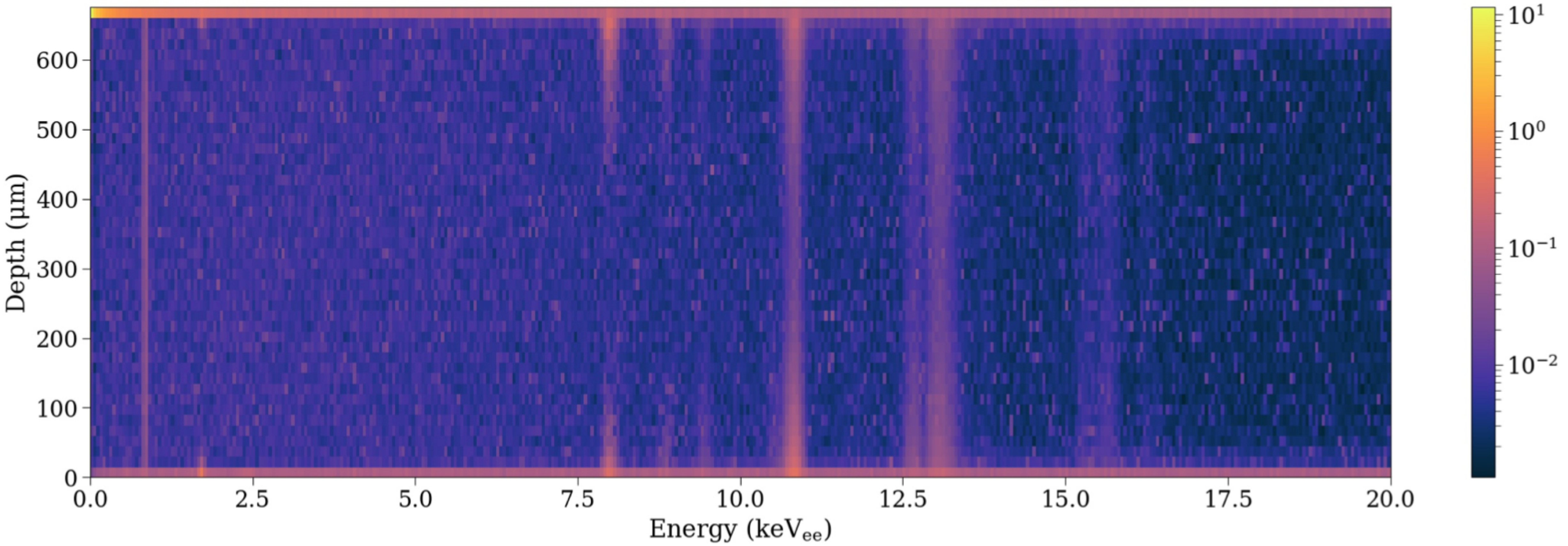
Parent Chain	Isoptope	Q value
^{238}U	^{234}Th	274 keV
	^{234m}Pa	2.27 MeV
^{226}Ra	^{214}Pb	1.02 MeV
	^{214}Bi	3.27 MeV
^{210}Pb	^{210}Pb	63.5 keV
	^{210}Bi	1.16 MeV
^{232}Th	^{228}Ra	45.5 keV
	^{228}Ac	2.12 MeV
	^{212}Pb	569 keV
	^{212}Bi	2.25 MeV
	^{208}Tl	5.00 MeV
^{40}K	^{40}K	1.31 MeV
Copper Activation	^{60}Co	2.82 MeV
	^{59}Fe	1.56 MeV
	^{58}Co	2.31 MeV
	^{57}Co	836 keV
	^{56}Co	4.57 MeV
	^{54}Mn	1.38 MeV
	^{46}Sc	2.37 MeV
^{32}Si	^{32}Si	227 keV
	^{32}P	1.71 MeV
Silicon Activation	^{22}Na	2.84 MeV
	^{3}H	18.6 keV





Simulated Background Model

…paper in preparation



Detector Response

- We use "fast" reconstruction method to group simulations above 6 keV for fit
- Paste events sampled from the resulting model on "blank" images
- Run "likelihood" clustering method on fake images