New Results from DAMIC at SNOLAB

Dan Baxter

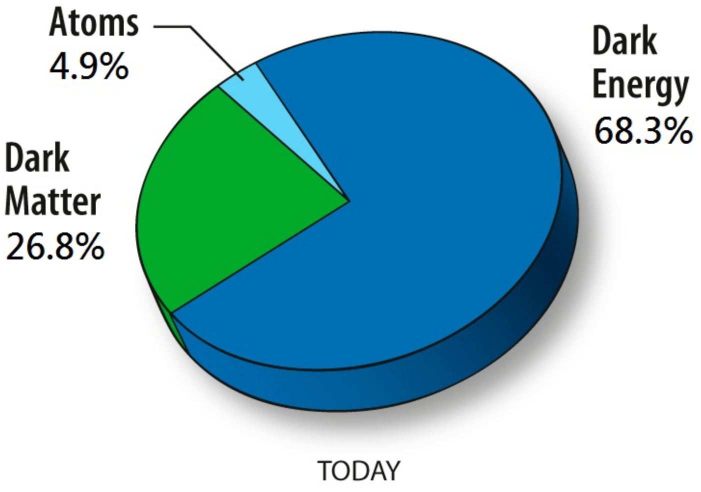
International Cosmic Ray Conference

July 29, 2019

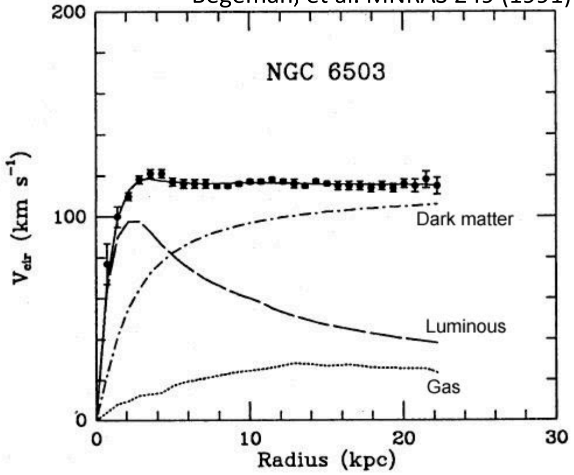
Dark Matter

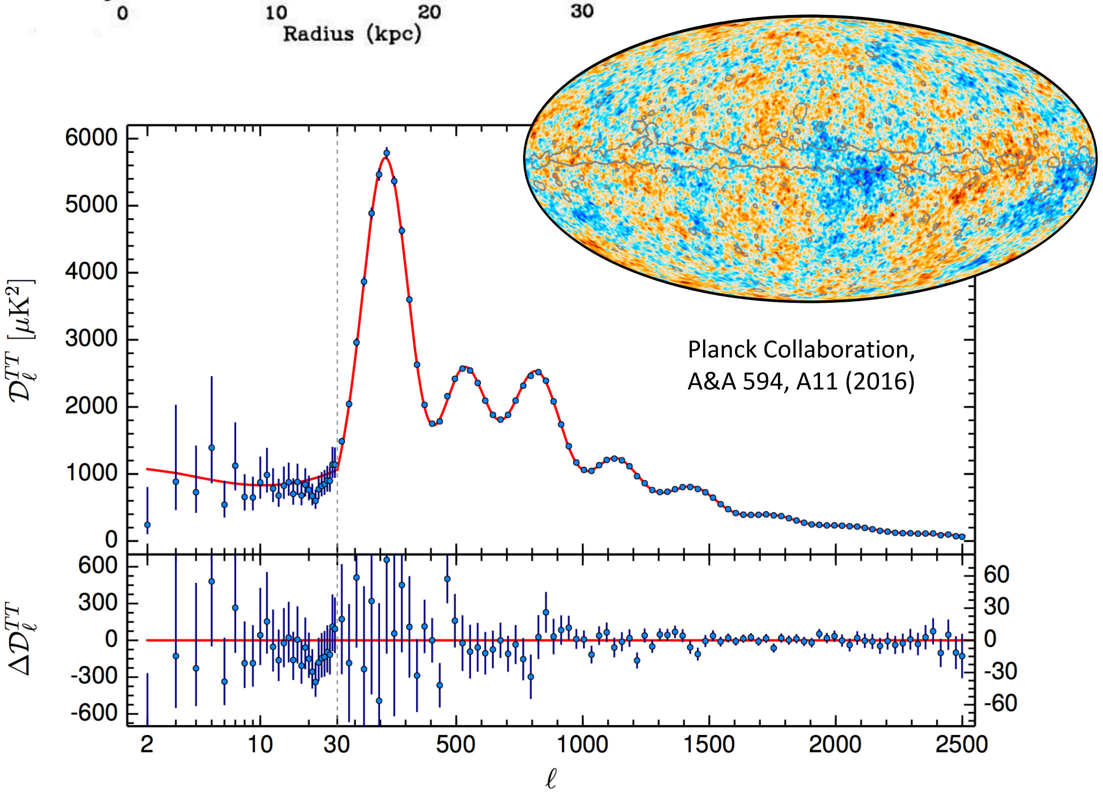
Evidence:

- **Galaxy Rotation**
- **CMB**
- Lensing
- ...and many more



Begeman, et al. MNRAS 249 (1991)



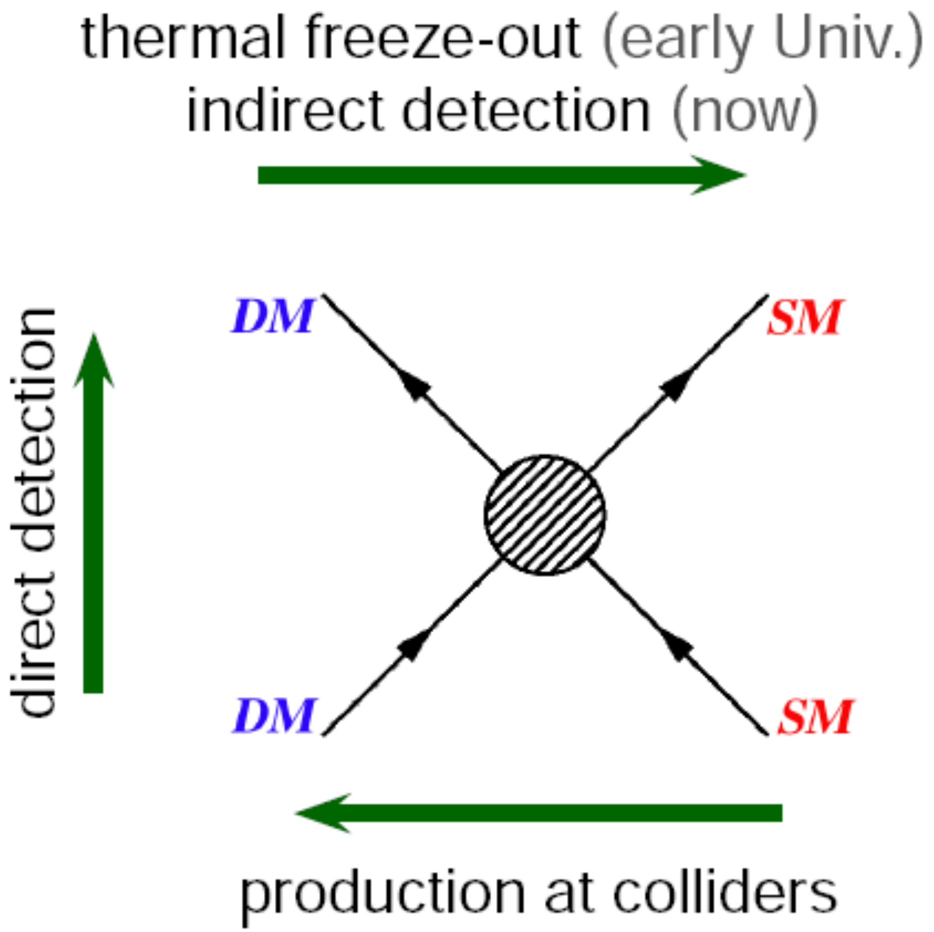


Interactions:

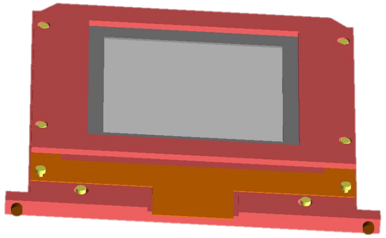
- Gravity: YES (*matter*)
- EM: NO (*dark*)
- other: maybe?
  - **Weakly Interacting Massive Particles**
  - **Dark Photon Mediator**
  - Axions

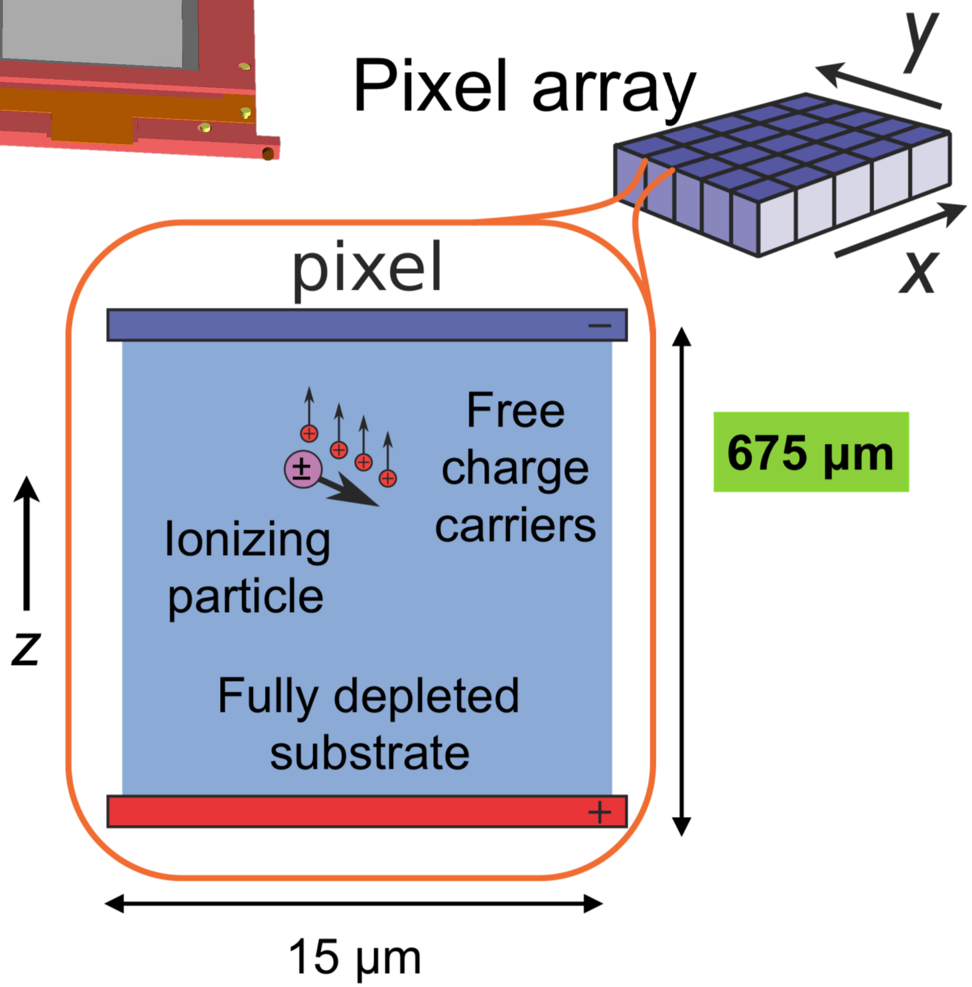
Direct Detection

- Build a detector to identify the small energy deposition of dark matter scattering off SM particles
- Scattering off nuclei (elastic):
  - The standard WIMP paradigm
  - 1-1000 GeV DM masses
  - 1-100 keV recoil energy
- Scattering off electrons (inelastic):
  - As in the case of a dark photon
  - 1-1000 MeV DM masses
  - 1-100 eV recoil energy



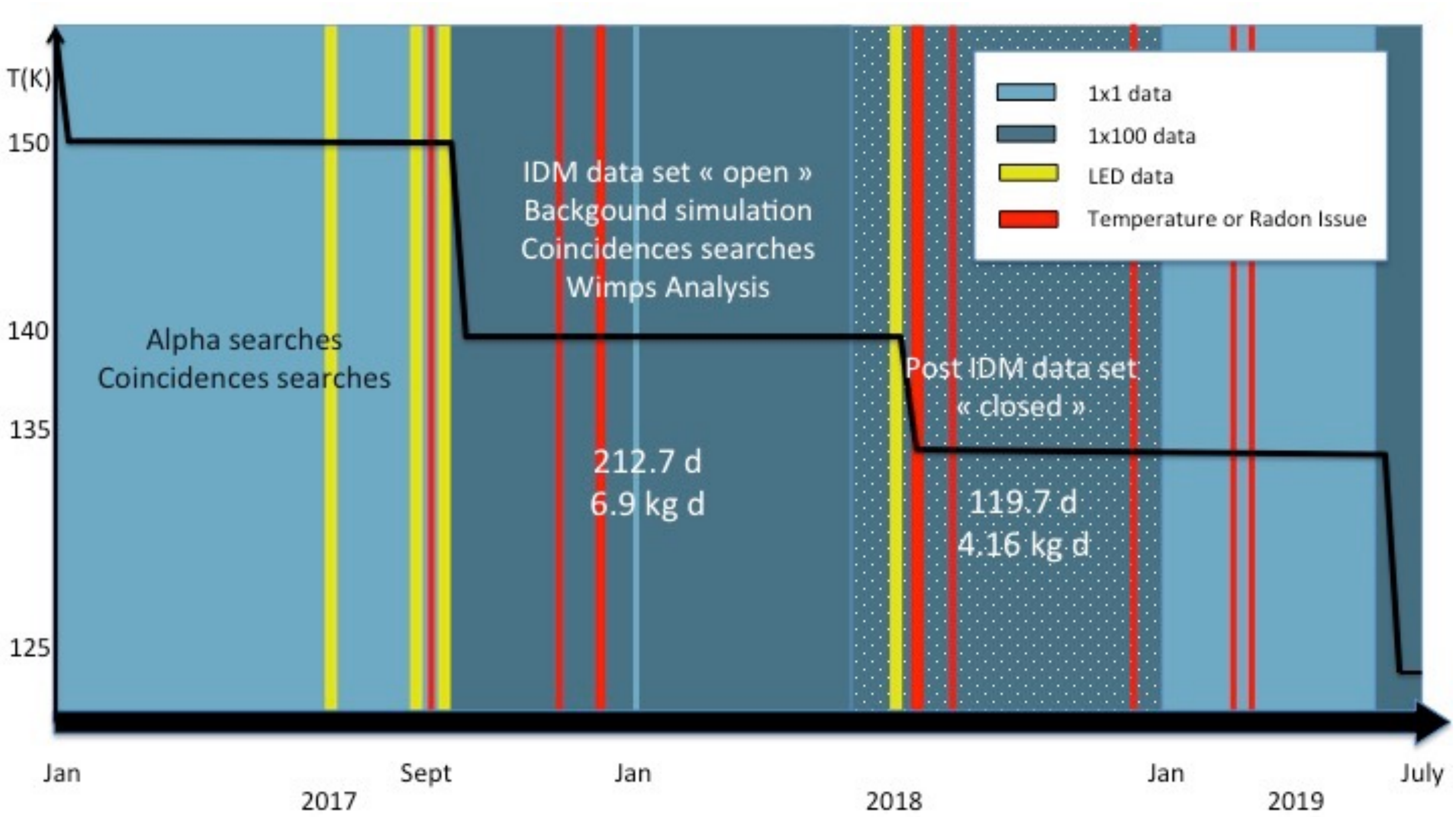
Charge Coupled Devices (CCDs)

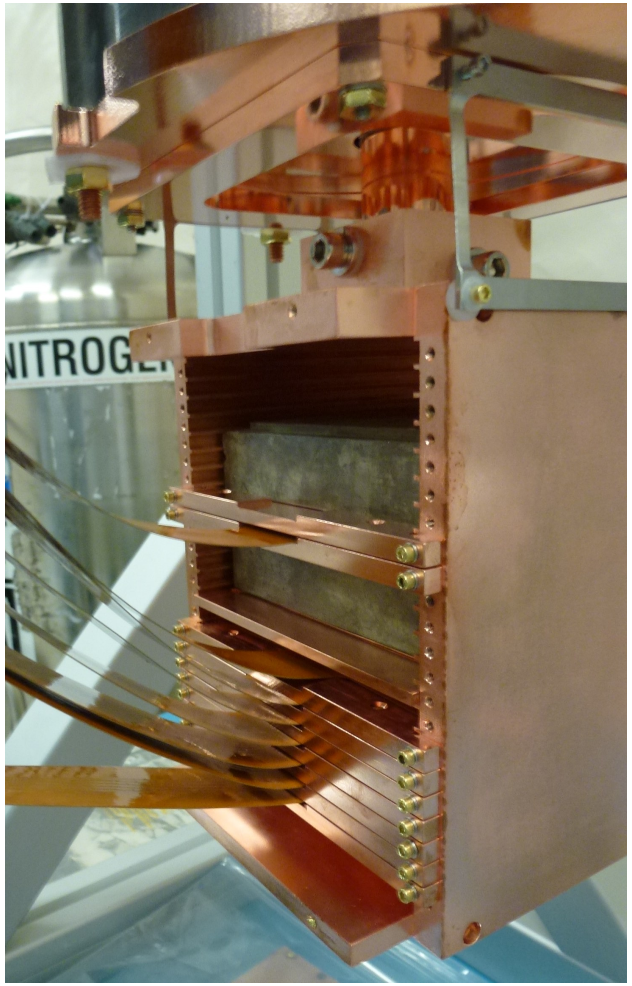




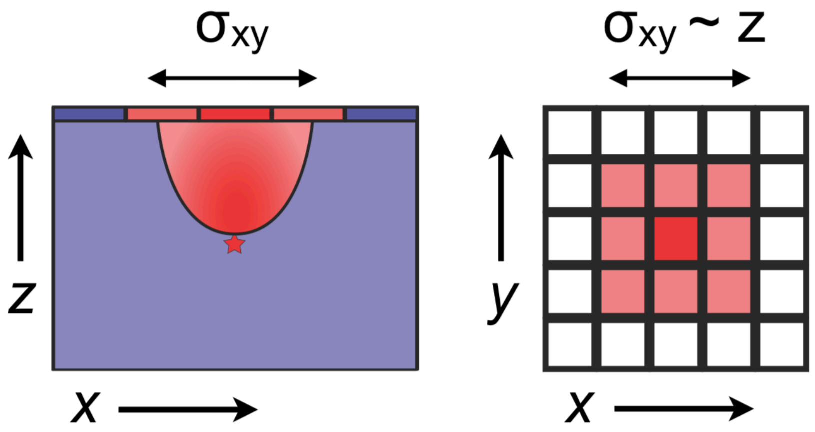
- Interaction with silicon produces free charge carriers…
  - …which are drifted across fully-depleted region… → *very little loss of charge*
  - …and collected in 15 micron square pixels… → *exceptional position resolution*
  - …to be stored until a user-defined readout time after many hours. → *large exposures*
- The method of read-out can be optimized to improve read-out noise at the cost of read-out time

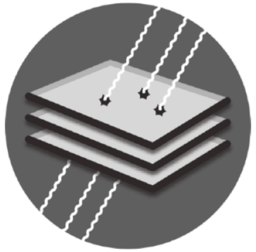
DAMIC at SNOLAB





Particle Identification

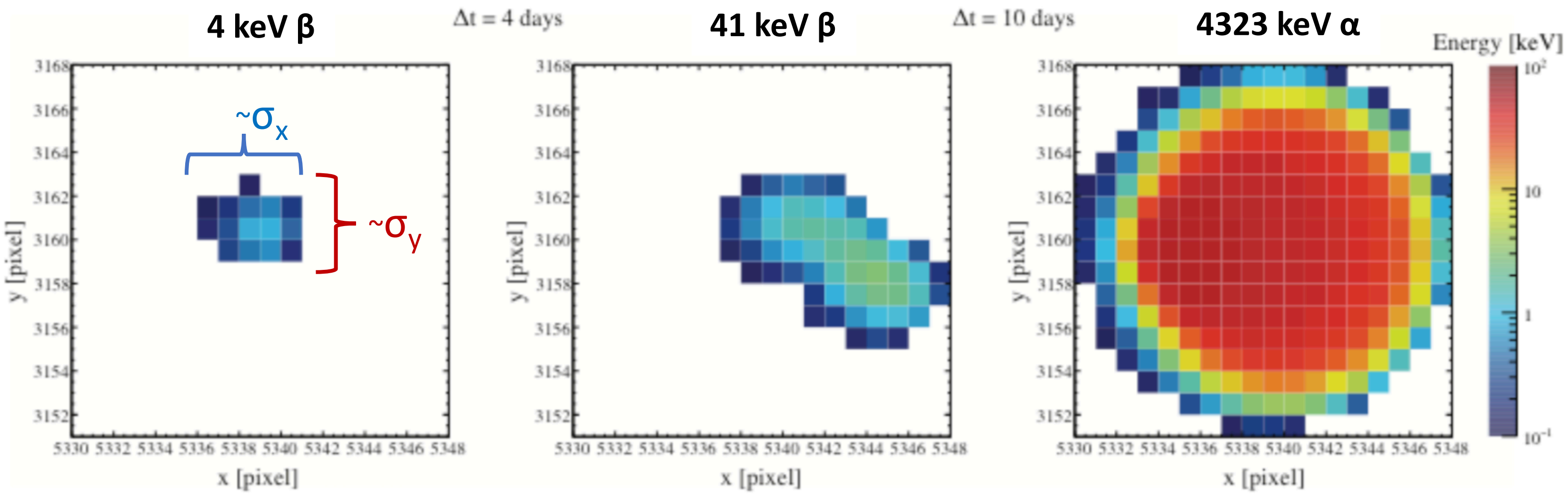




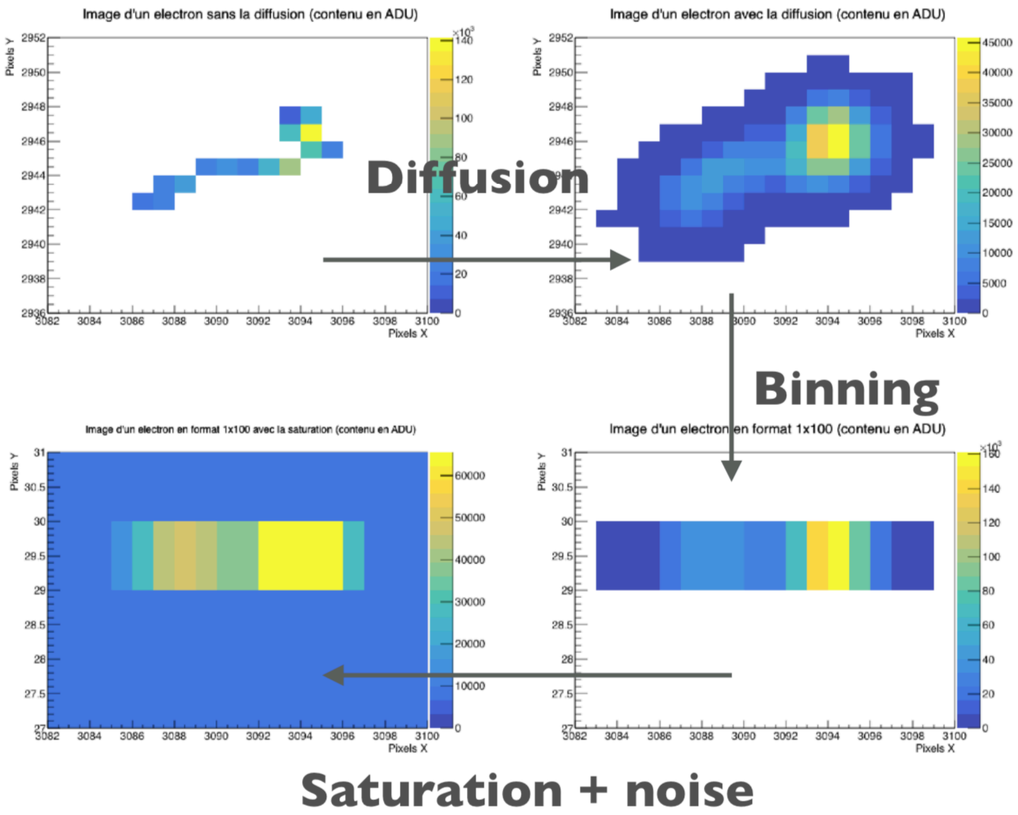
- Silicon band-gap: 1.2 eV
- Mean energy/e⁻: 3.8 eV

- As charges drift across the CCD, they experience lateral thermal motion (diffusion) proportional to vertical distance traveled (depth)
- Above 1 keV, the event profile can identify the progenitor…

1. **Tight deposition:**
   - **nuclear recoil**
   - **low-E electron recoil**
2. Elongated track:
   - high-E electron recoil
   - muon
3. Large blob:
   - alpha decay



Background Modeling

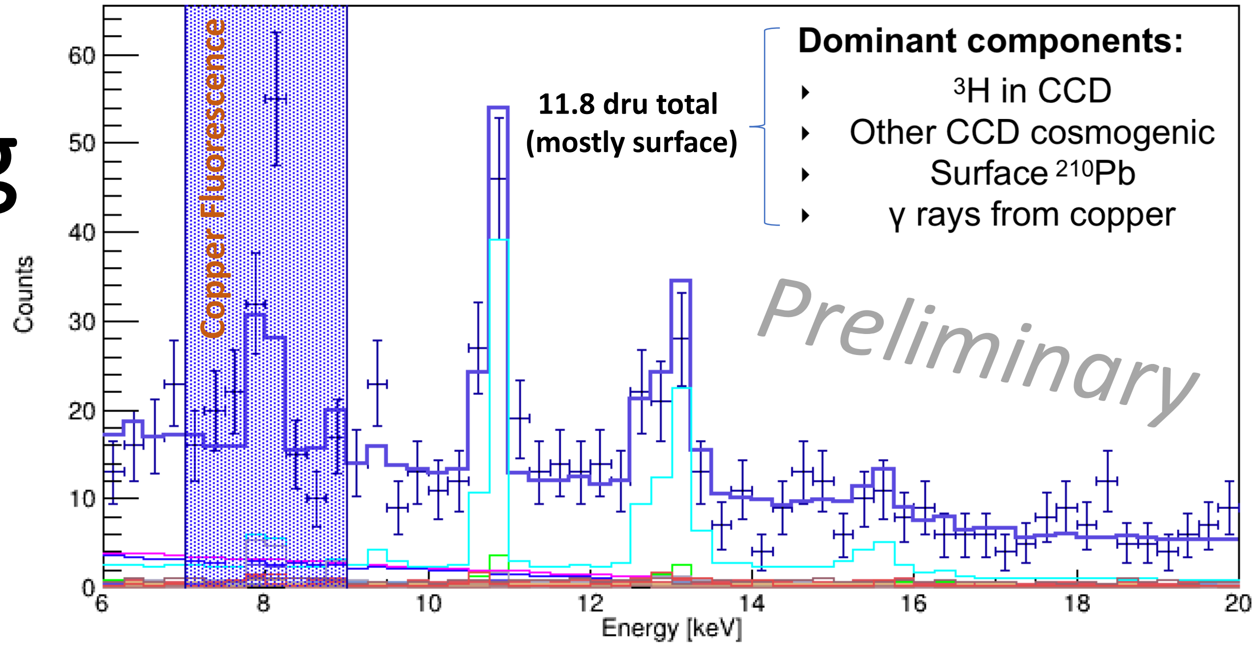


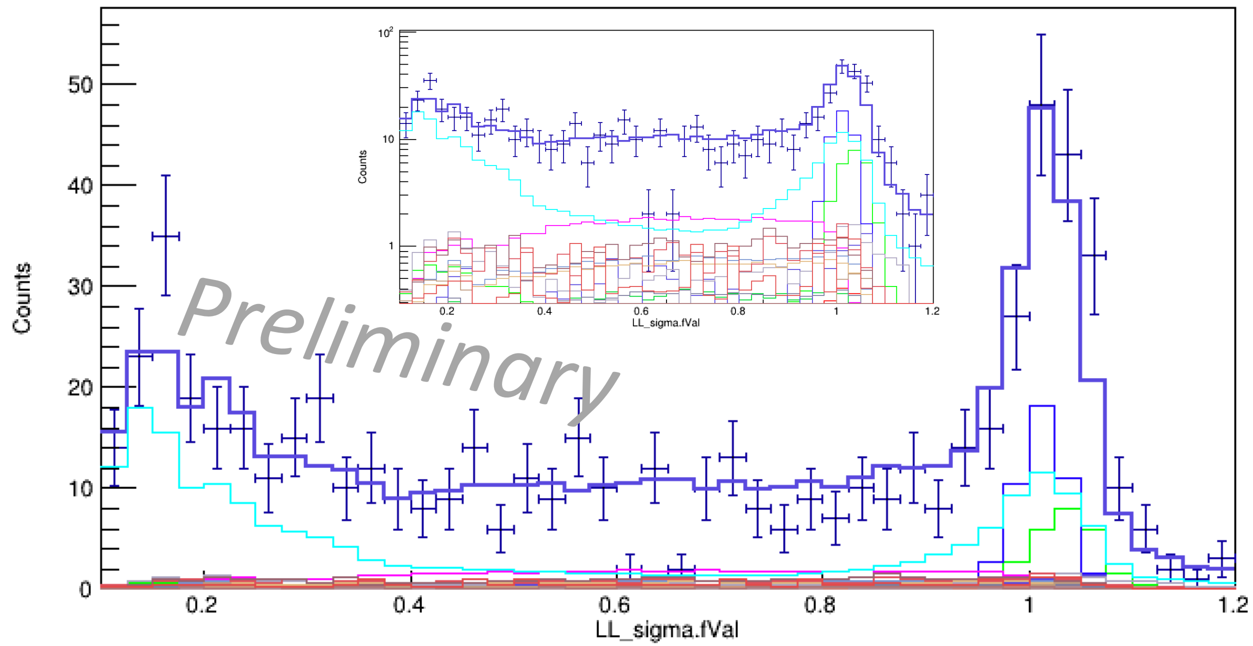
Part	U-238	Ra-226	Pb-210	Th-232	K-40
CCD	<0.53	<0.43	<33	<0.4	<0.04
Kapton cable	5013.8 ± 423.4	420 ± 490	420 ± 490*	276.5 ± 42.0	2475.4 ± 172.8
Copper	<10.7	<10.7*	2350 ± 720	<3.5	<2.7
Module Screws	1400 ± 3800	<138	2350 ± 720	200 ± 140	2400 ± 1300
Ancient lead shield	<10.7	<25.9	2850 ± 285*	<2.8	<0.5
Outer lead shield	<1.1	<13*	1560000 ± 430000	<0.4	<19
Surface	-	-	$7.2\pm1.0 \times10^{-5}$ /mm^2/day	-	-

- We assay each component to determine its activity in counts/kg/day (above)
- We simulate the various isotopes in our detector and group them by decay chain (using GEANT)
- We constrain the amount of each to assays of that component

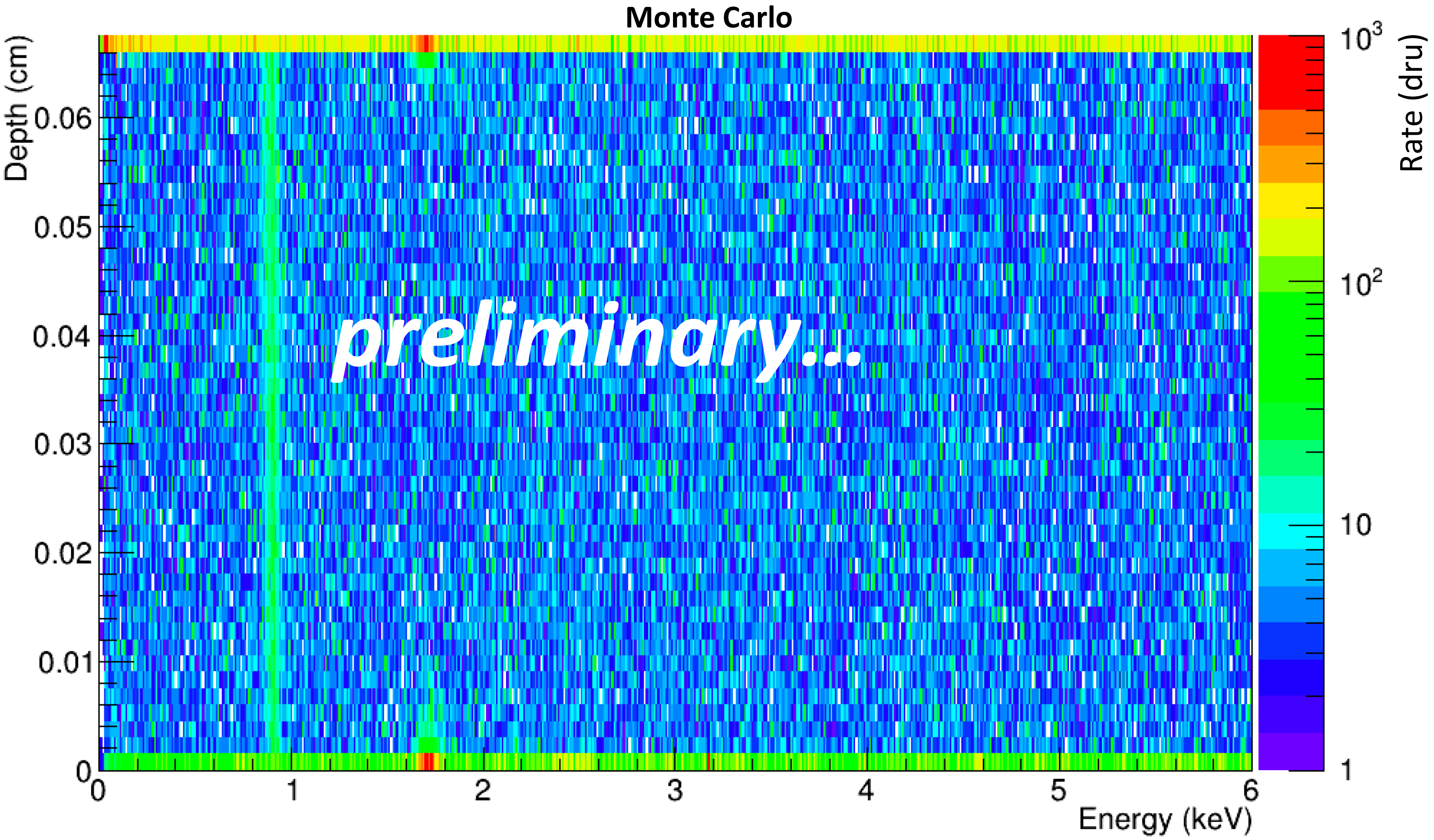
Background Modeling

- This gives us 50 templates in energy-sigma for each detector part + decay chain
- …which we fit against the data above 6 keV
  - This implicitly assumes that we have no DM signal above 6 keV (DM mass > 10 GeV)
  - Each component is allowed to float within the uncertainty of the respective assay
- We use the fit above 6 keV to give us a background model for our ROI (below 6 keV)…



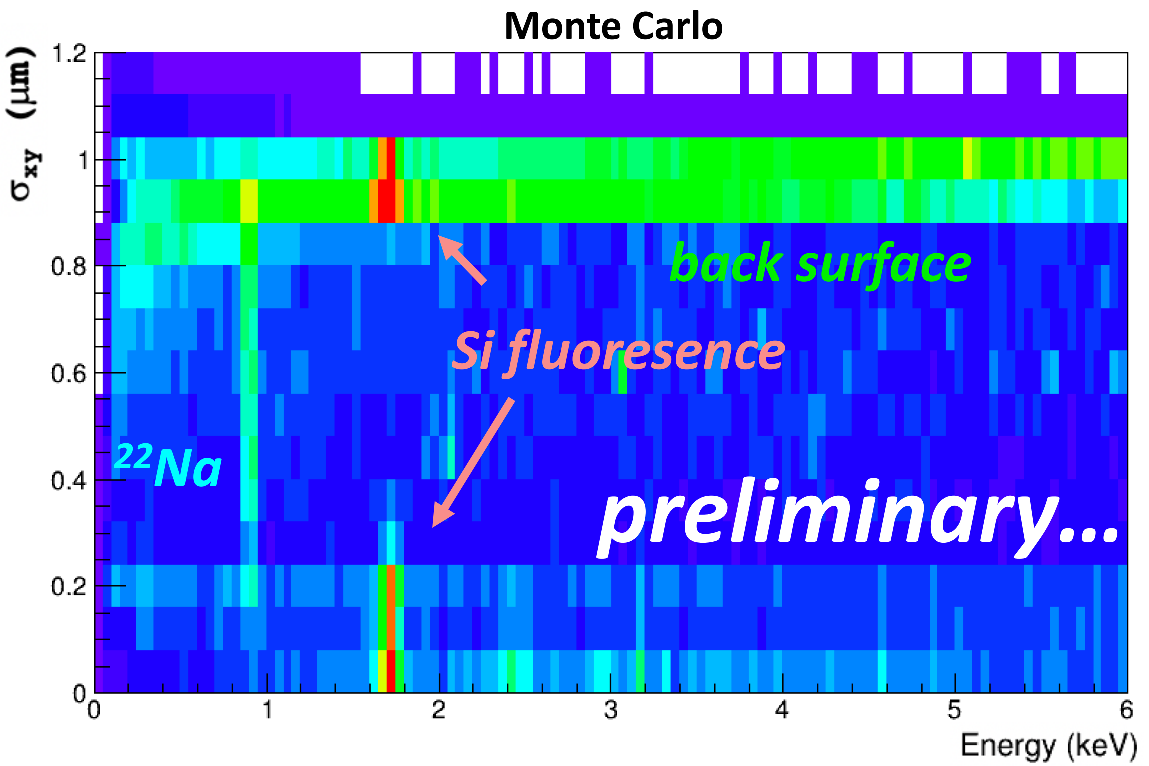


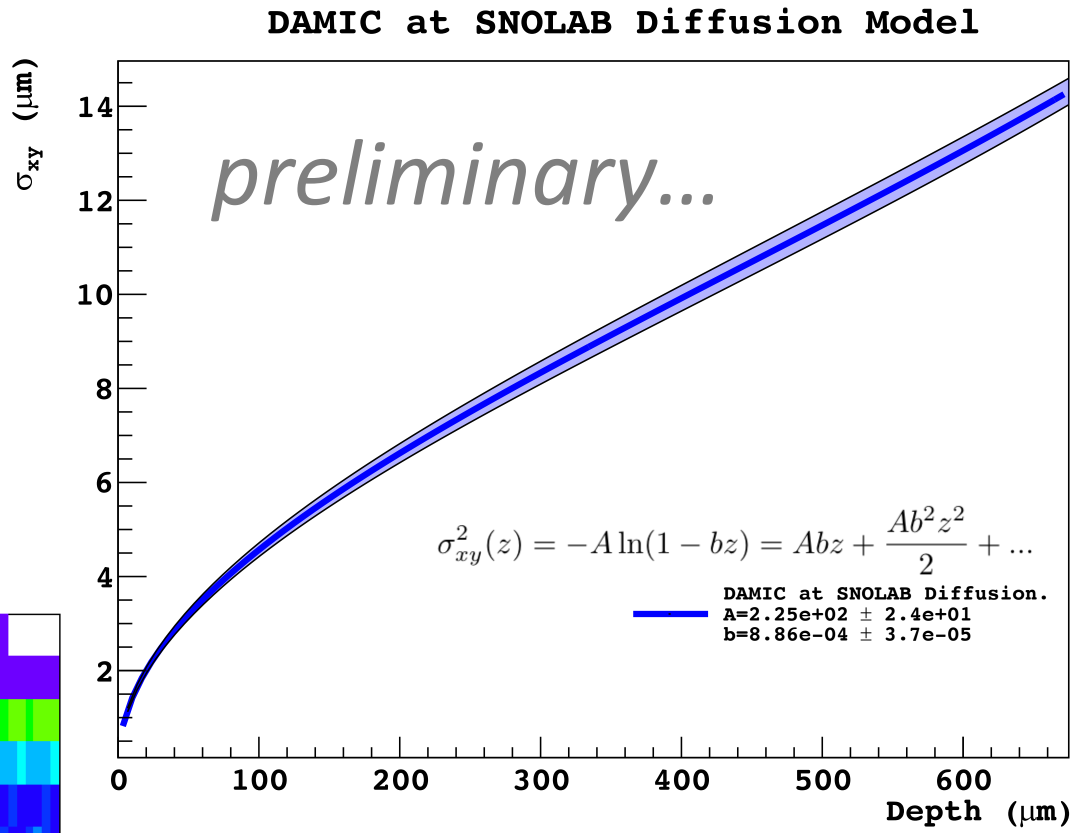
Background Modeling



Modeling Diffusion

- We calibrate depth (diffusion) using events at the back of the CCD and muons passing through

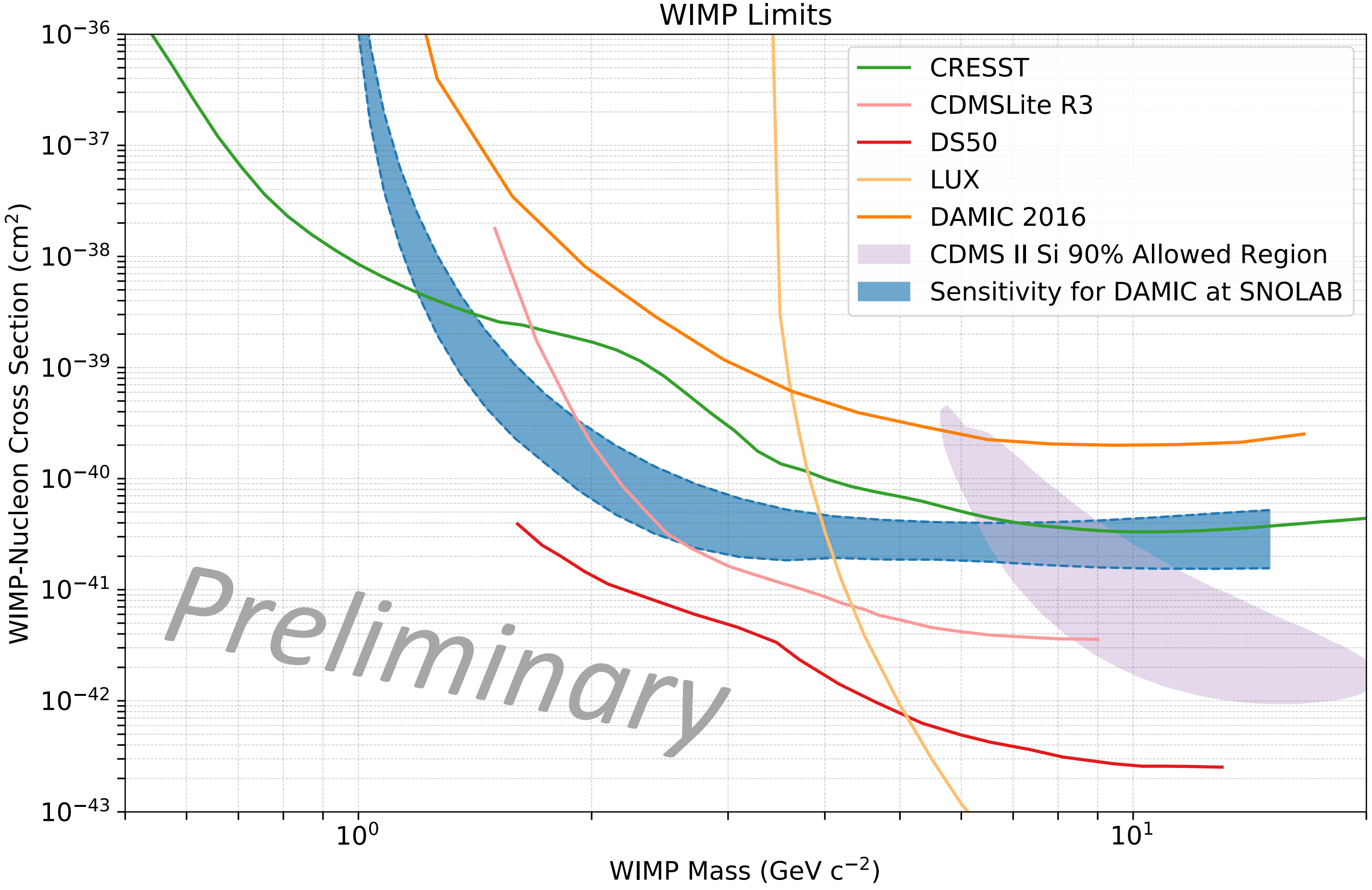




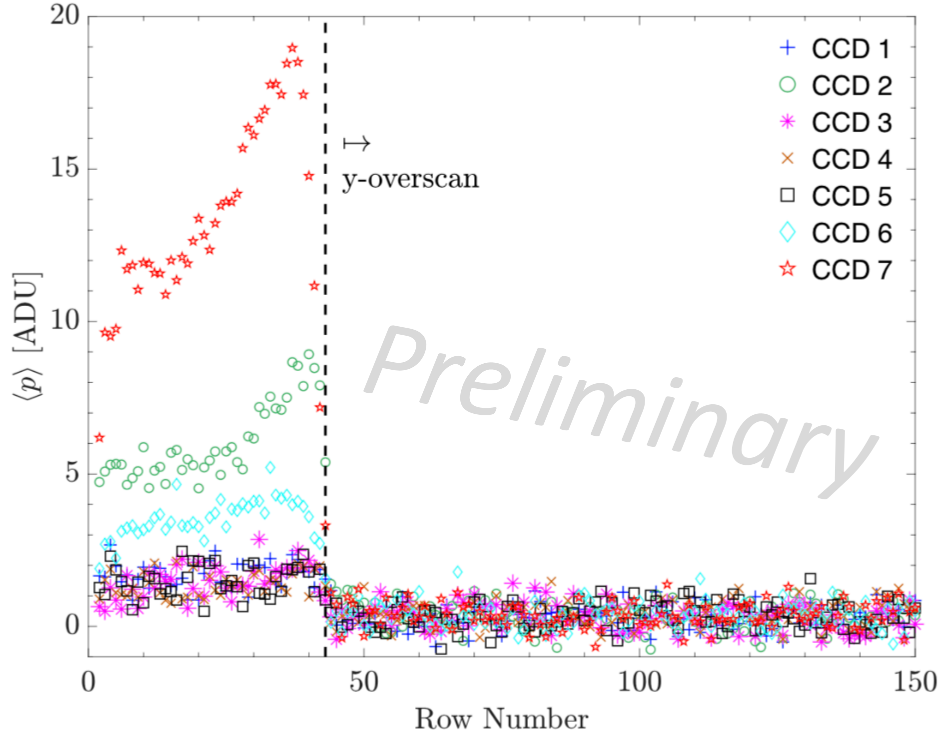
- We randomly sample our background model (in E-z)…
- …apply our diffusion model to fake events…
- …paste onto blank images to account for read-out noise…
- …and output a background model in observed variables energy-sigma

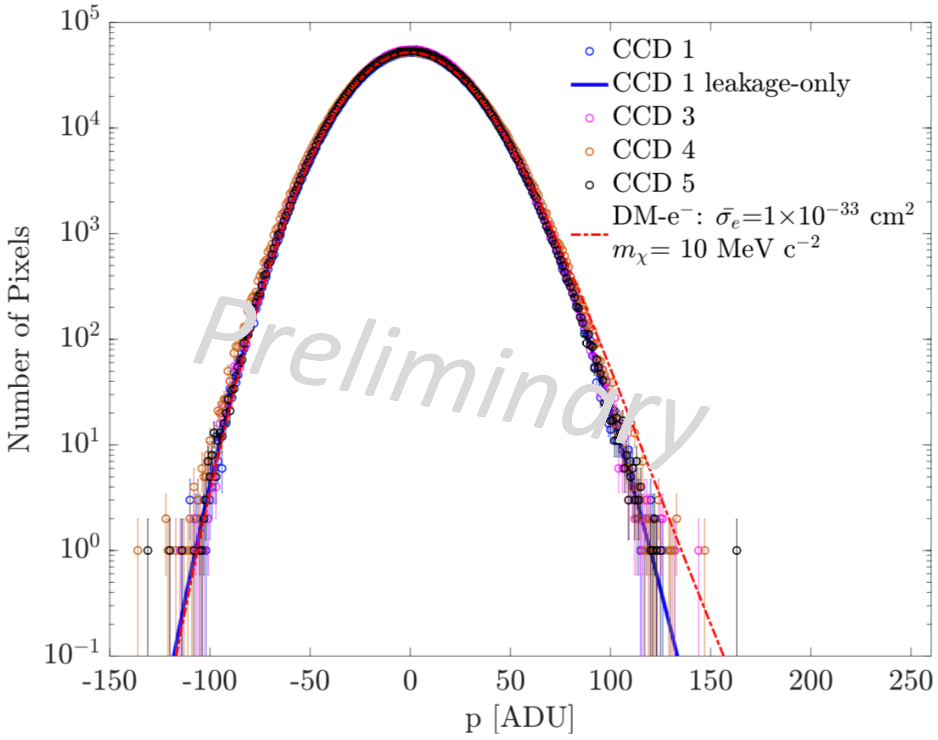
Projections for nucleon coupling

- We then randomly sample this background model many times
- and see what limit we would get with the fake data (containing no WIMP signal)
- to determine the expected sensitivity of DAMIC@SNOLAB



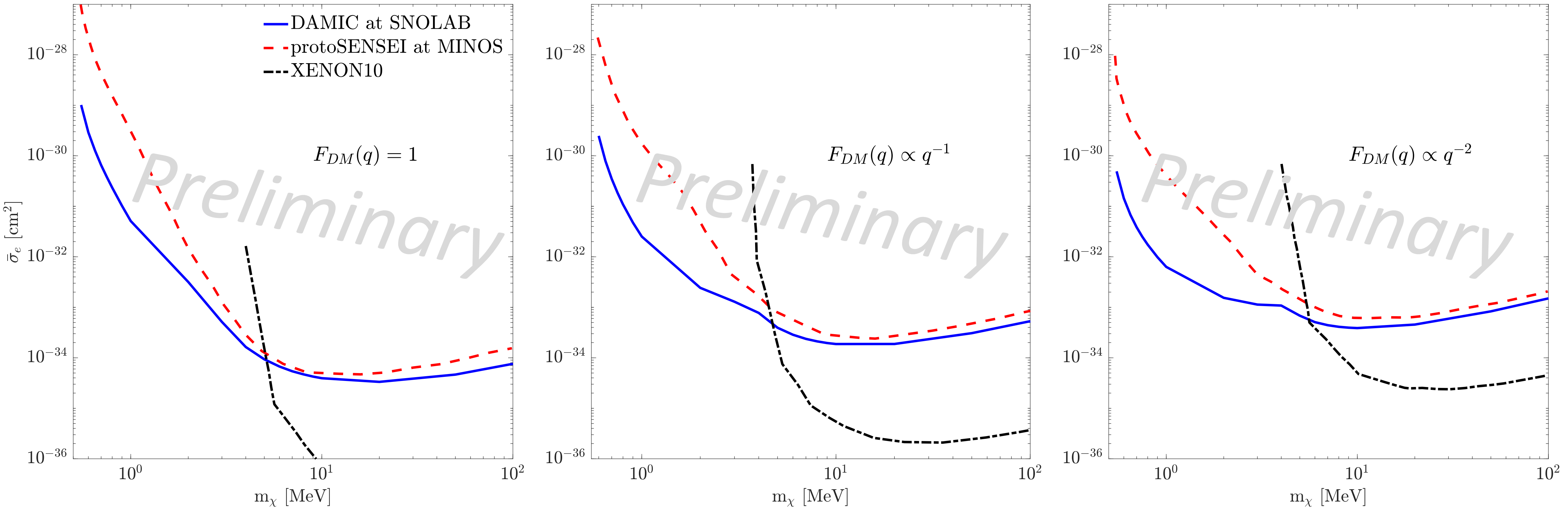
Noise Identification





- Measure leakage current for each CCD (2e$^-$/day /mm^2)
  - Note: this is the lowest leakage current ever measured in a silicon detector
- Look for deviation from this leakage current which could be attributed to dark matter electron scattering

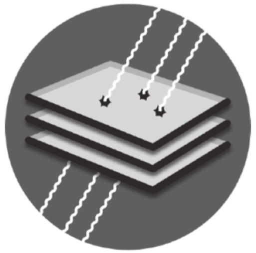
Limits on electron coupling

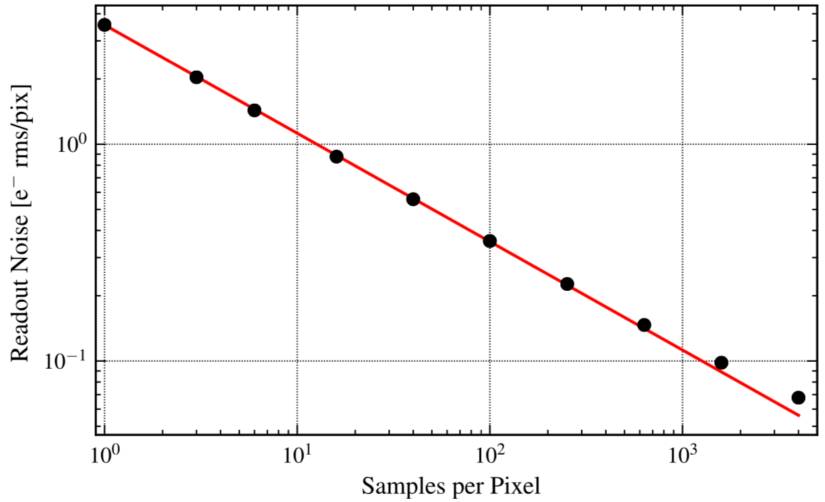


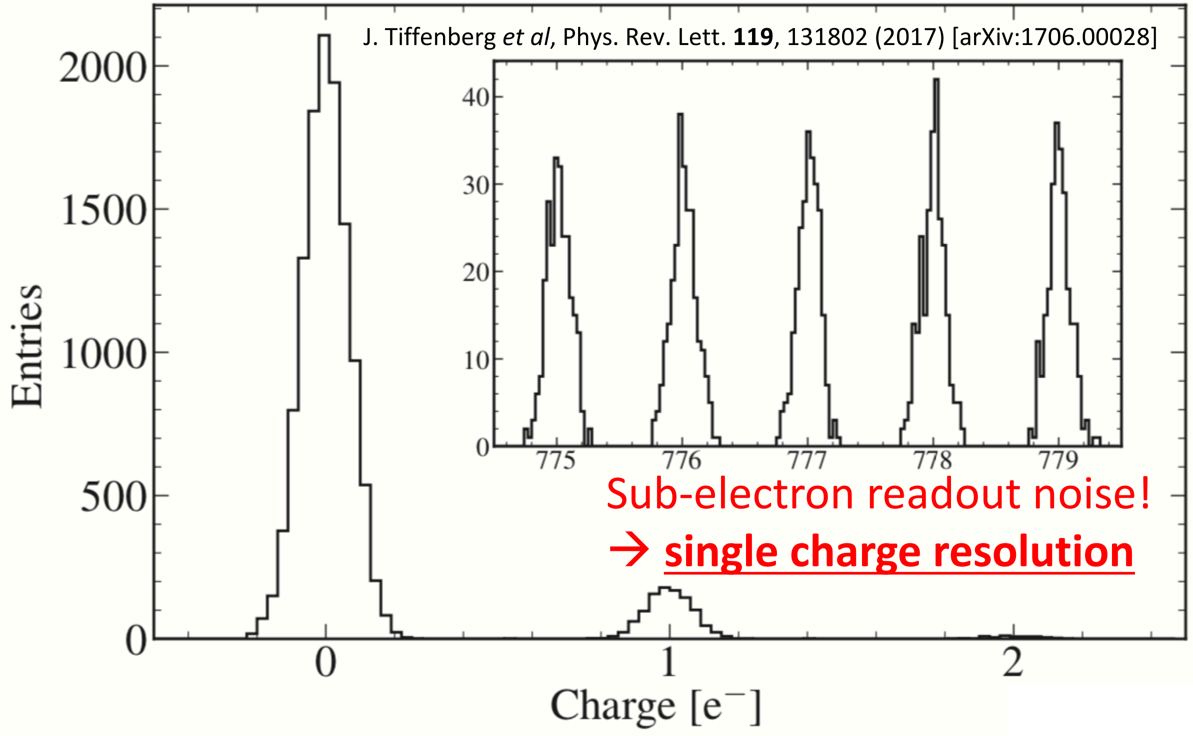
- Expect a paper on the arXiv **SOON** (in a matter of days/weeks)

Skipper CCDs

- New method of Skipper CCD readout has been developed by LBNL for the SENSEI detector…
  - …allowing consecutive non-destructive readout of a single pixel
  - …dramatically reducing read-out noise to a fraction of a single electron!
- DAMIC now has Skipper CCDs in hand, and will show more soon



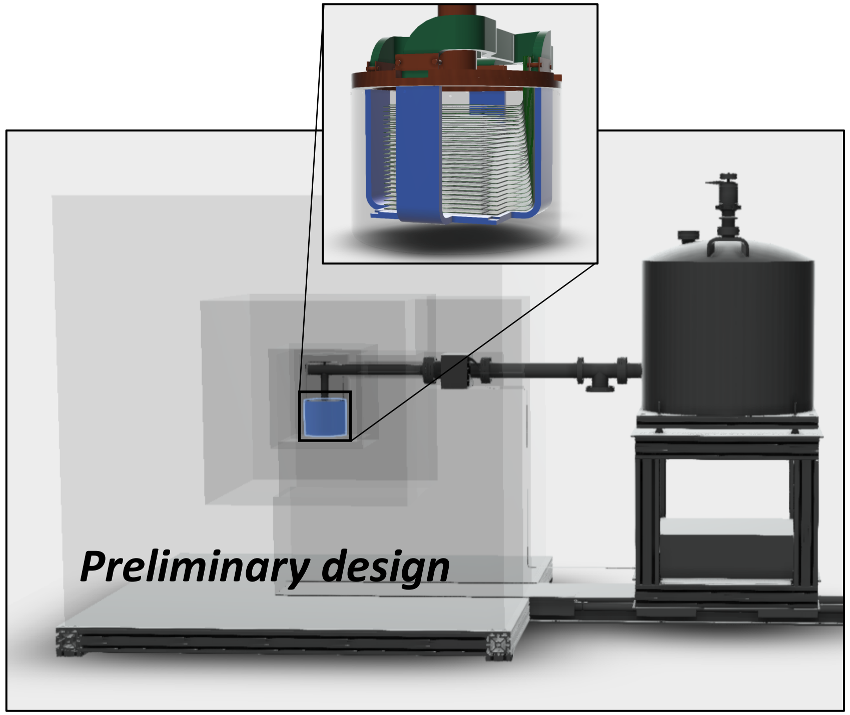


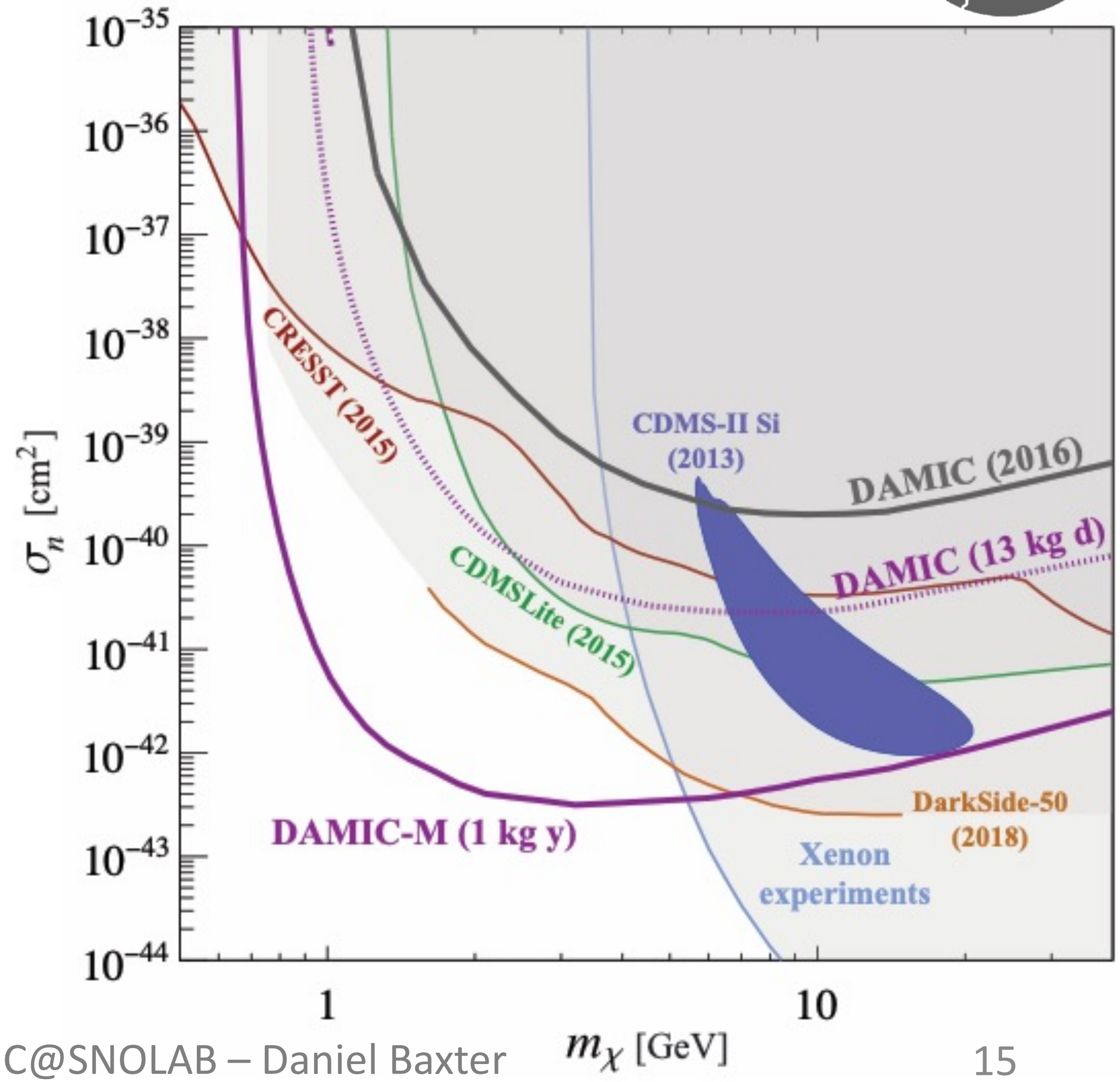


J. Tiffenberg *et al*, Phys. Rev. Lett. **119**, 131802 (2017) [arXiv:1706.00028]

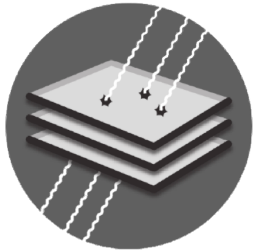
Projections for DAMIC-M

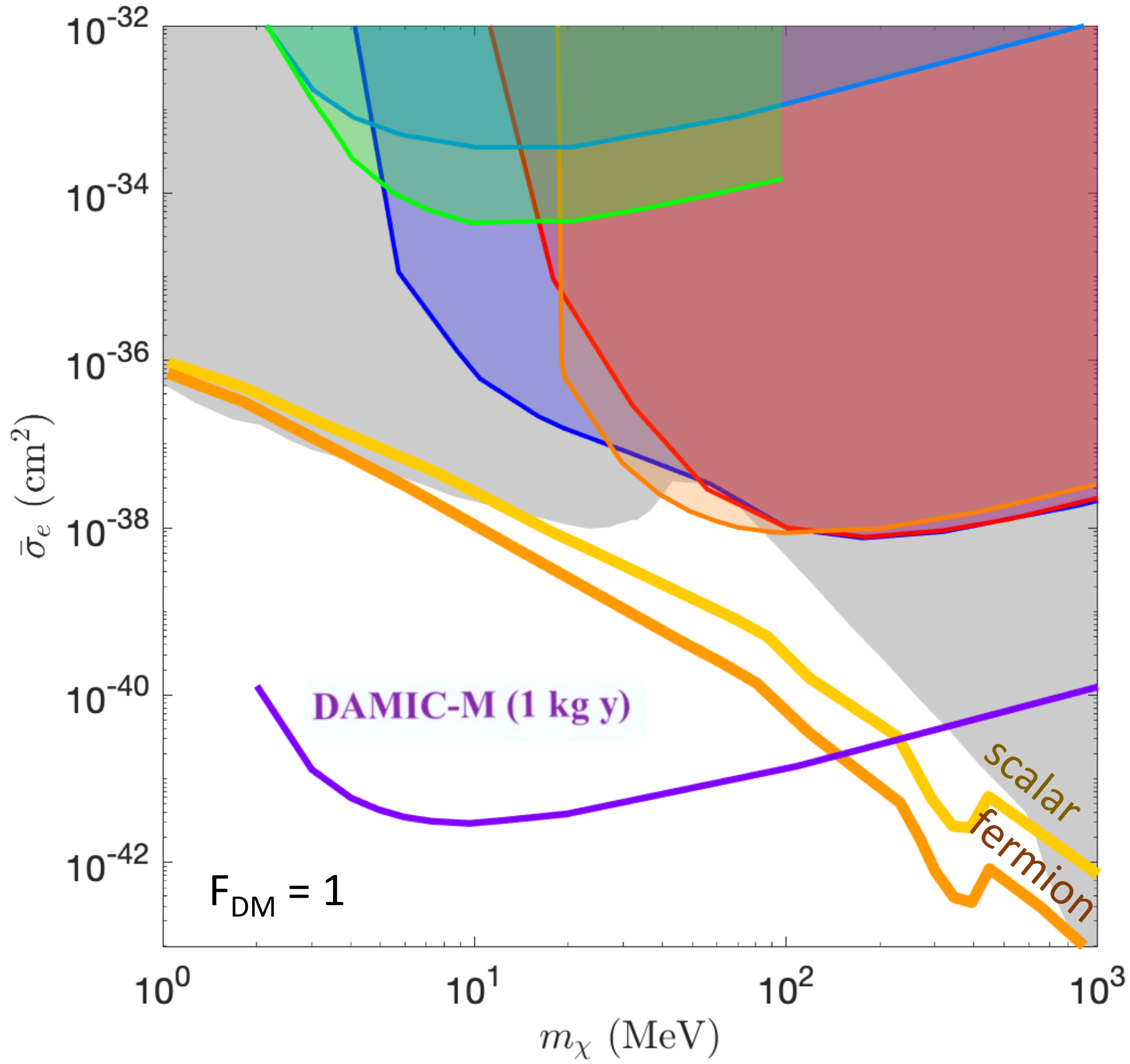
- The DAMIC-M detector (DAMIC at Modane) will achieve background-free exposure of 1 kg-year above a threshold of 2e⁻ using Skipper CCDs

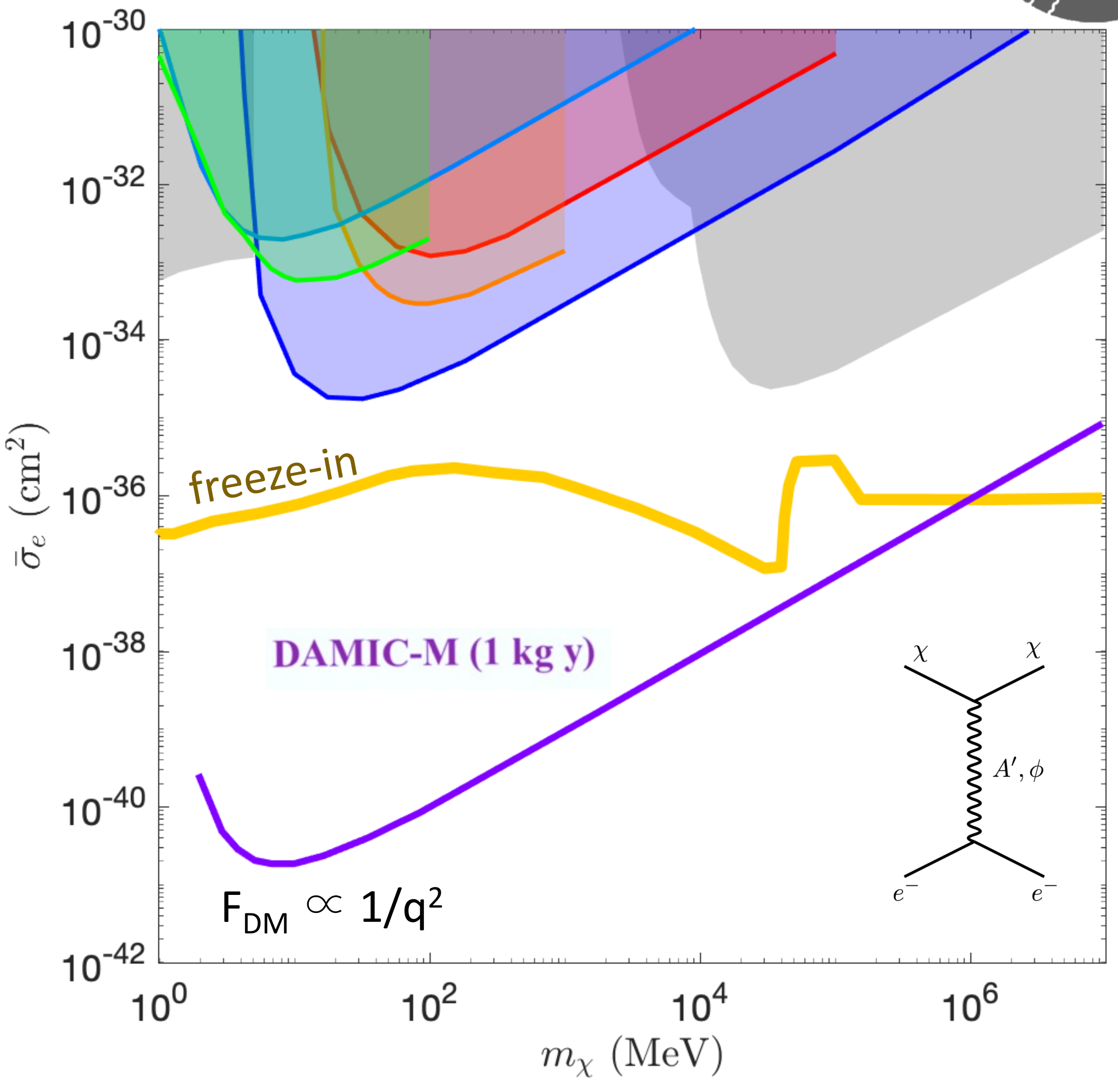




Projections for electron coupling

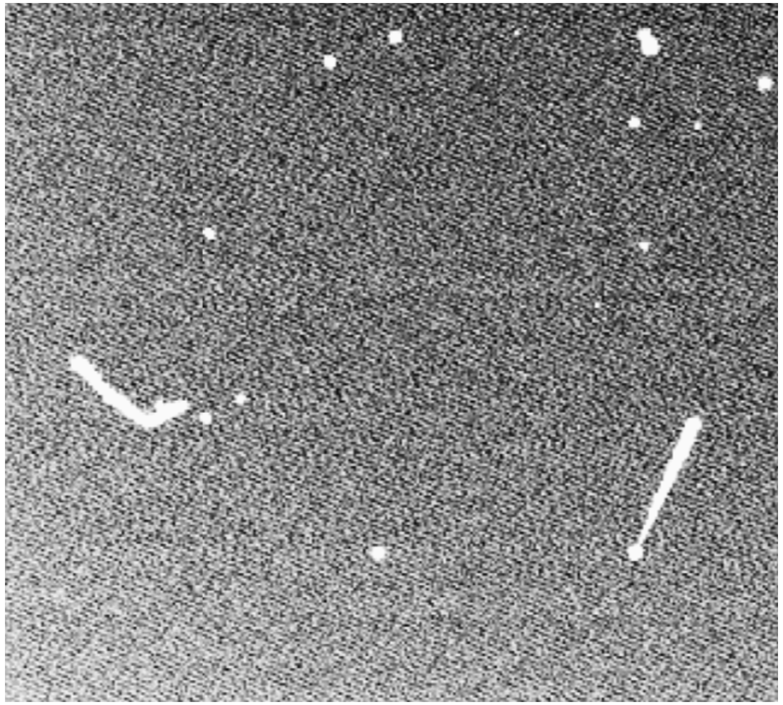






Conclusions

- DAMIC at SNOLAB continues to produce excellent physics
  - Expect a paper on sensitivity to dark matter electron coupling within a few weeks
  - Expect a paper on sensitivity to dark matter nucleon coupling within a few months
- DAMIC-M will improve on this by orders of magnitude due to lower backgrounds, single electron resolution, and much larger exposure



European Research Council
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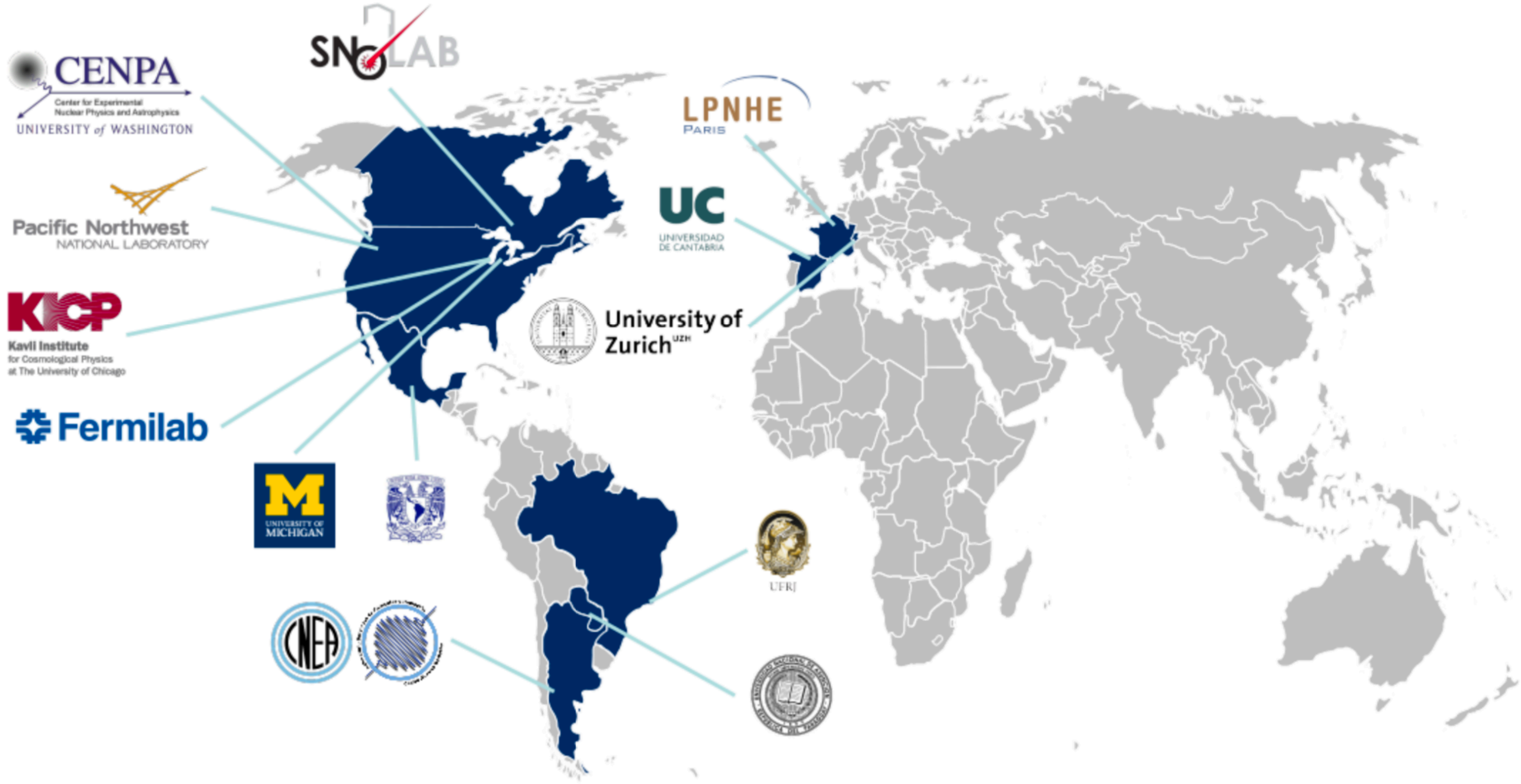
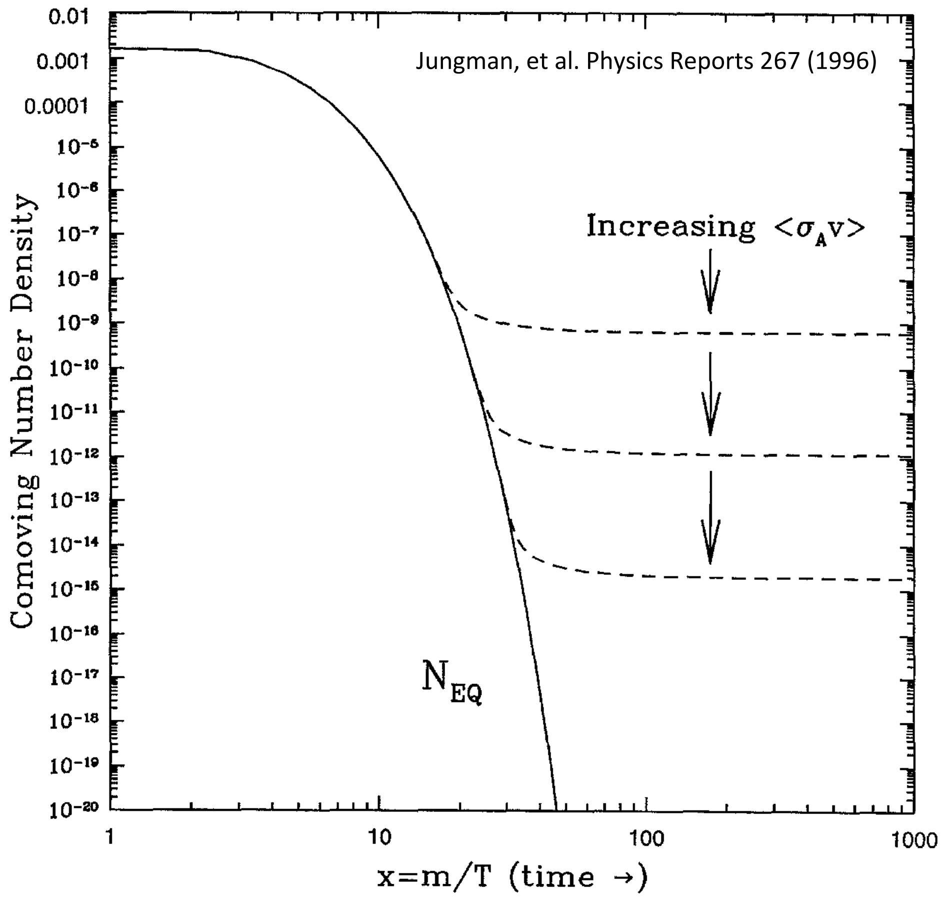
DAMIC at SNOLAB Collaboration



Extra Slides

Weakly Interacting Massive Particles

- Natural thermal production in the early universe
- Freeze-out with annihilation cross section of order weak-scale gives roughly the relic density
- Mass of order 1-1000 GeV
  - comparable to ordinary nuclei
- Weak-scale interaction would result in elastic scattering with ordinary nuclei (1-100 keV)
  - Note: for DAMIC, we are interested in the low end of this range

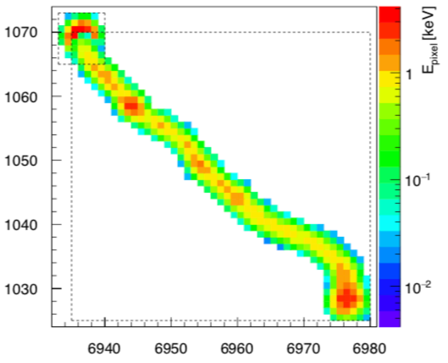


Coincidence Measurements

Bulk Contamination		
$^{32}Si \rightarrow {}^{32}P$	Q = 224.5 keV	$t_{1/2}$ = 150 y
$^{32}P \rightarrow {}^{32}S$	Q = 1710 keV	$t_{1/2}$ = 14.3 d

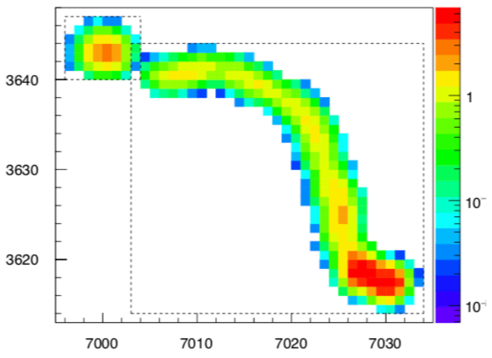
Surface Contamination		
$^{210}Pb \rightarrow {}^{210}Bi$	Q = 63.5 keV	$t_{1/2}$ = 22.3 y
$^{210}Bi \rightarrow {}^{210}Po$	Q = 1161 keV	$t_{1/2}$ = 5.01 d
$^{210}Po \rightarrow {}^{206}Po$	Q = 5407 keV	$t_{1/2}$ = 138 d

^{32}Si β_1-β_2



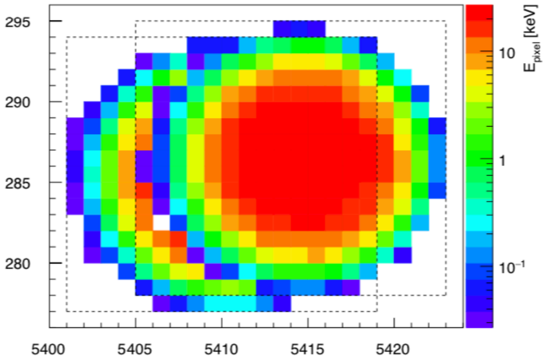
- $E_{\beta 1}$ = 110 keV
- $E_{\beta 2}$ = 361 keV
- Δt = 11.7 d

^{210}Pb β_1-β_2



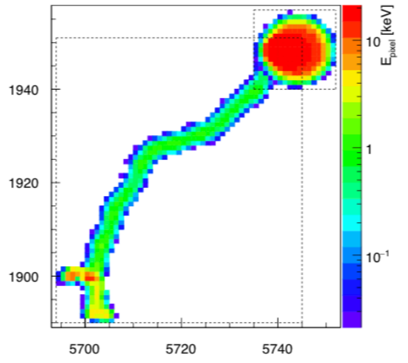
- $E_{\beta 1}$ = 57 keV
- $E_{\beta 2}$ = 376 keV
- Δt = 1.4 d

α-α



- $E_{\alpha 1}$ = 4.3 MeV
- $E_{\alpha 2}$ = 3.8 MeV
- Δt = 5.2 d

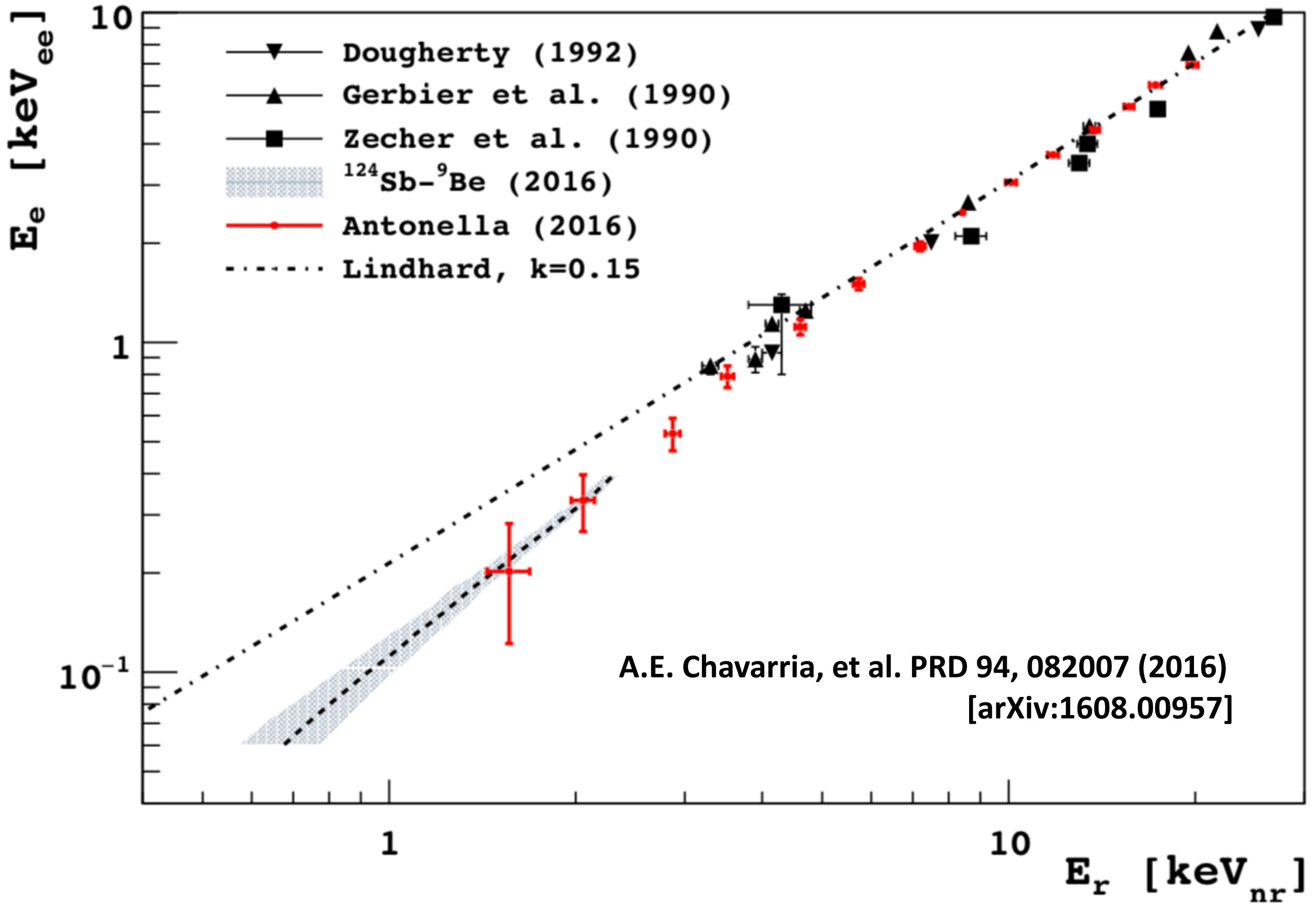
^{210}Pb β_1-α



- $E_{\beta 1}$ = 717 keV
- E_{α} = 3.62 MeV
- Δt = 32.3 d

see A. Matalon presentation at LRT 2019 or A. Aguilar-Arevalo et al, JINST 10 (2015) P08014 [arXiv:1506.02562] for details

Ionization Efficiency



- Calibration performed using SbBe source with very low energy neutrons (< 24 keV)
- Ionization efficiency calibrated down to 60 eV!!!