DAMIC results on WIMP search with 11 kg day

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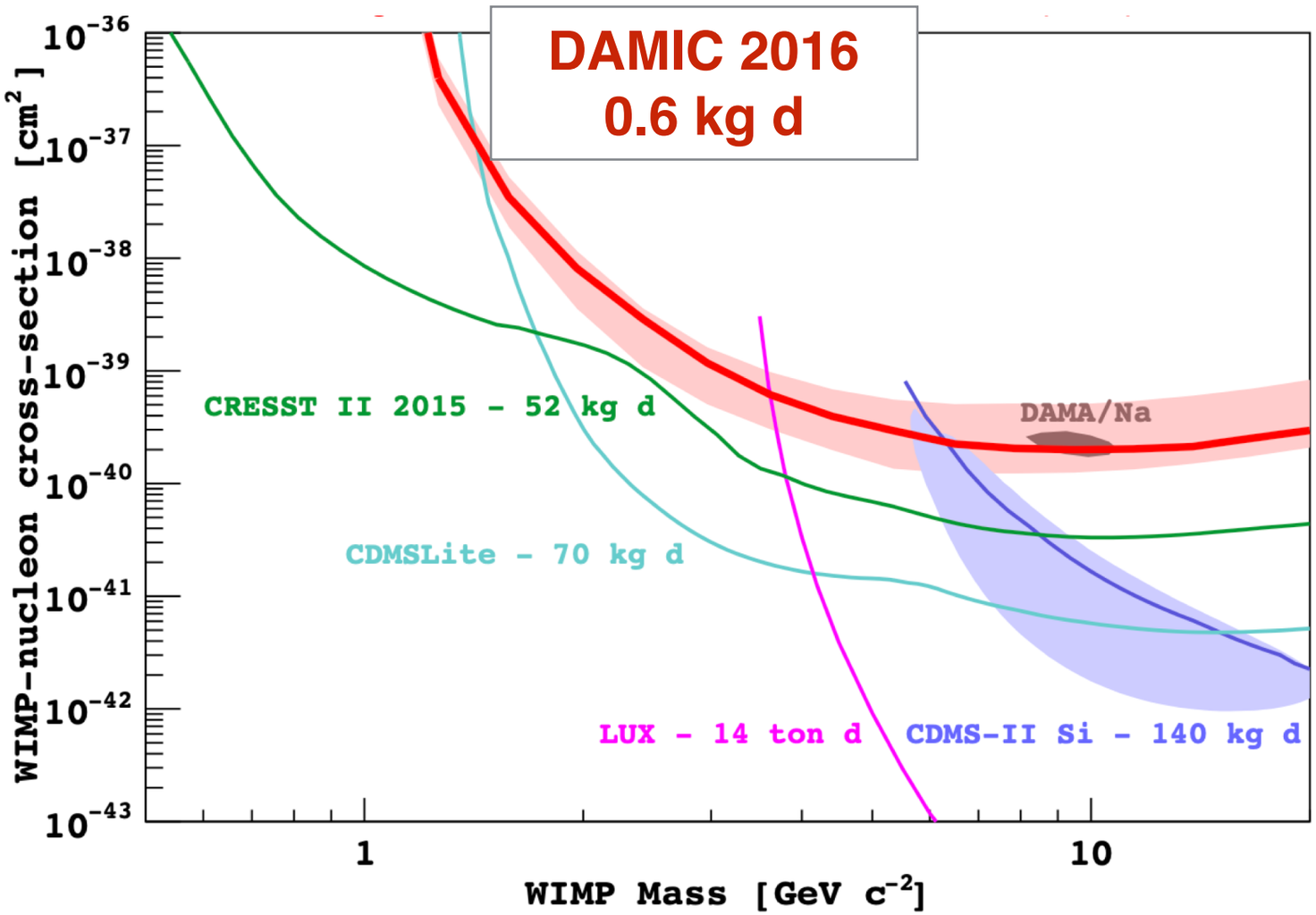
CONTEXT – MOTIVATION

- Dark Matter: astrophysical / cosmological probes (rotation curves, CMB, BBN)
  —> ~25% of the Energy Matter content of the universe

  Dark Matter: The evidence from astronomy, astrophysics and cosmology,M. ROOS arXiv:1001.031,

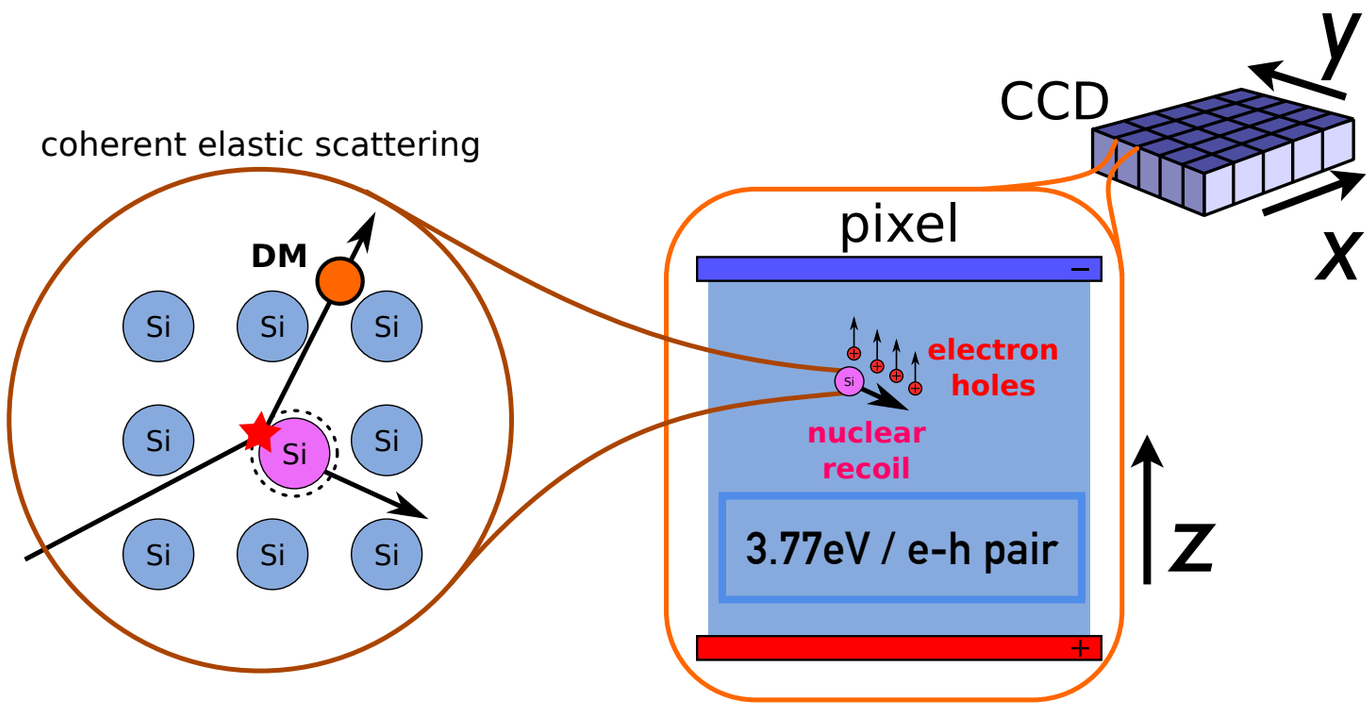
  An Introduction to Particle Dark Matter. Profumo et al arXiv:1910.05610

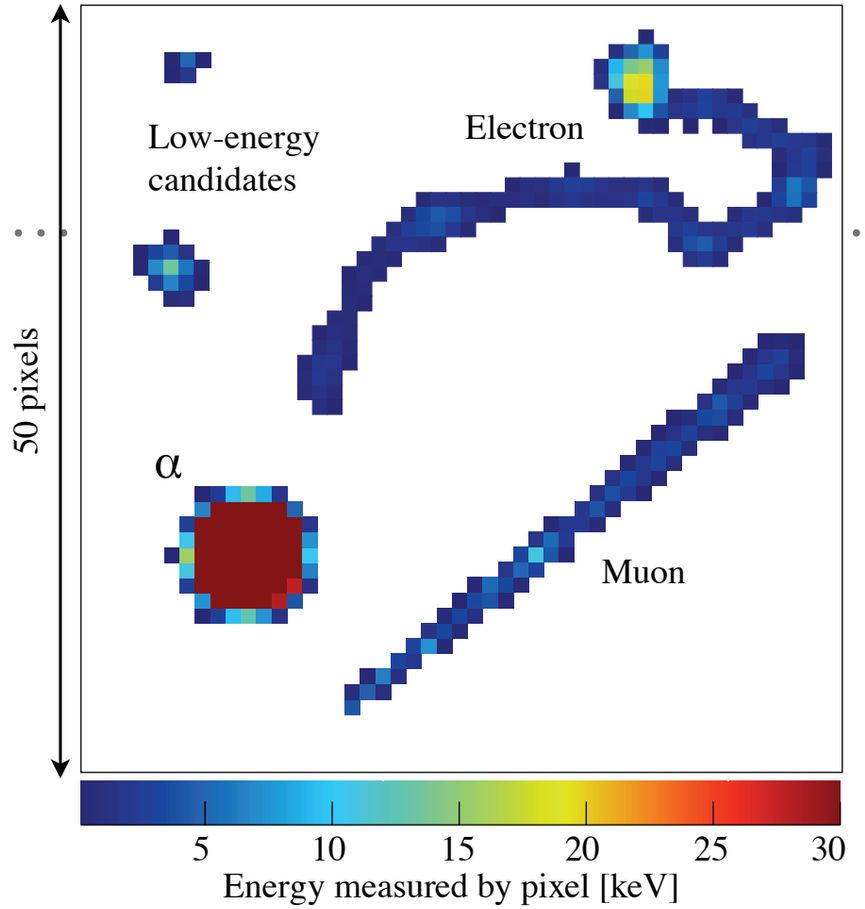
- WIMP (Weakly Interacting Massive Particle): considered as the favourite candidate
  —> nominal model m ~ 100GeV

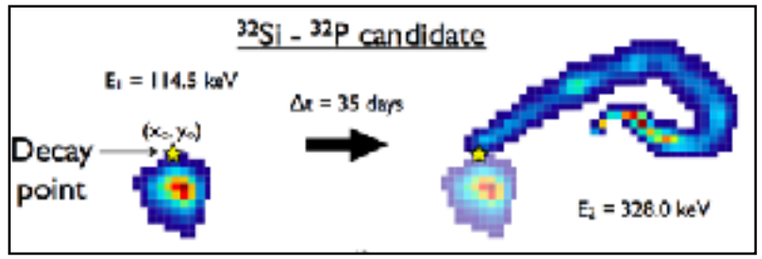


- Light WIMPs
- CDMS **Si** excess
  CDMS collab, arXiv:1304.4279

DARK MATTER IN CCD (DAMIC)





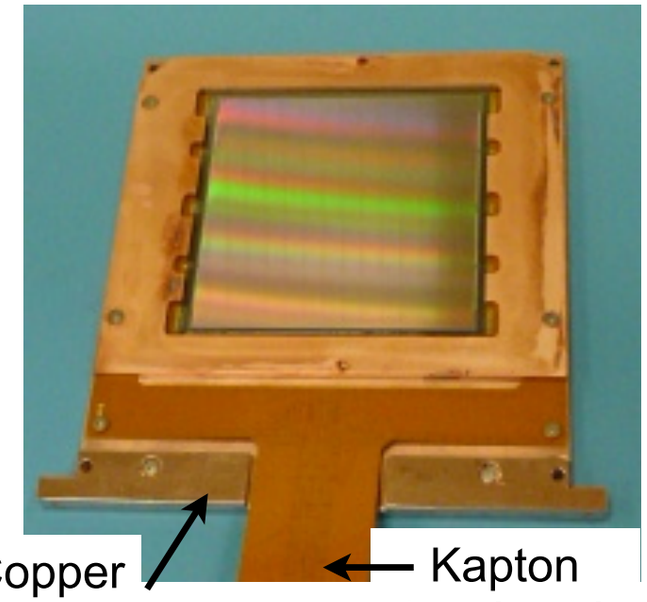


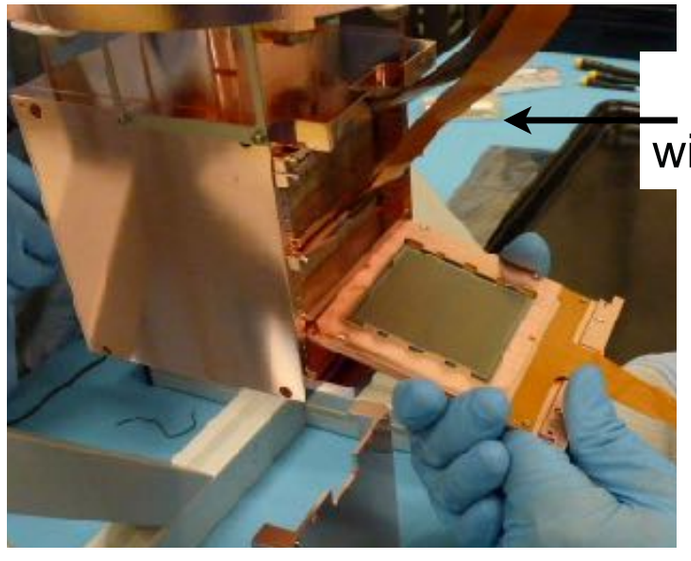
- Ionisation threshold ~3.7 eV
- low readout noise ~1.6 e- ($E_{threshold}$ = 50-60 eVee)

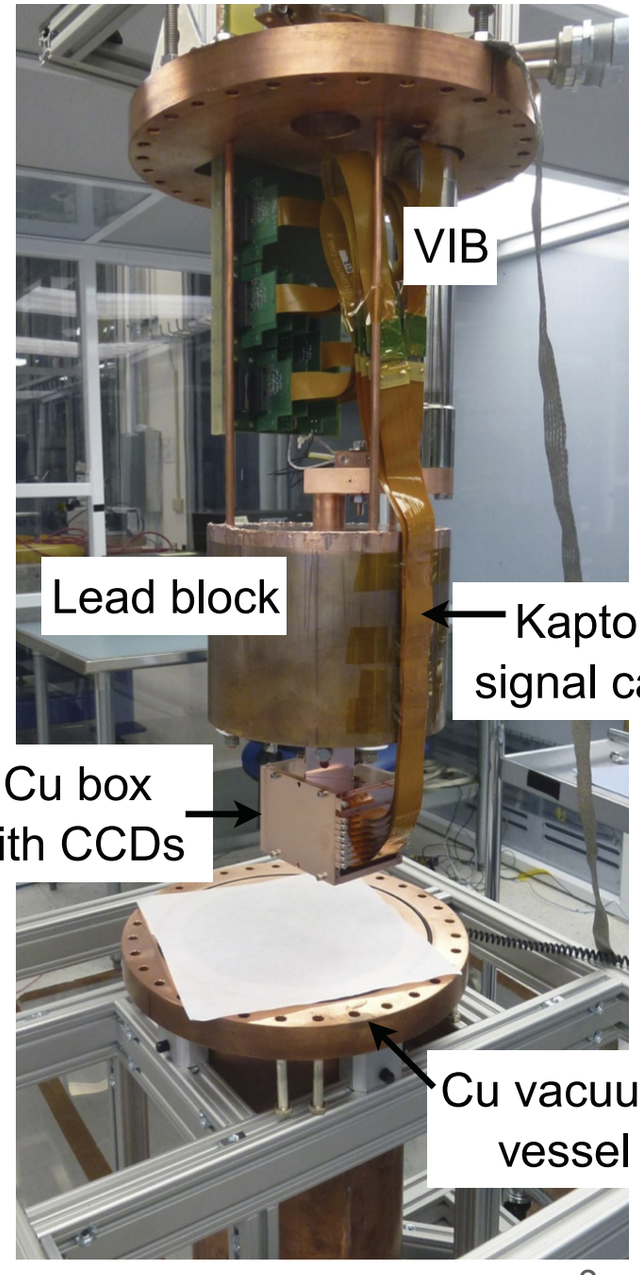
- High granularity (15μm)
  - PID —> Bkg discrimination
  - Depth information (diffusion)
- Thick fully depleted CCD (675μm)

IEEE Transactions On Electron Devices, VOL. 50, No. 1, 225-338, Jan.. 2003

DAMIC AT SNOLAB







- SNOLAB (Canada): 2km deep in a mine (0.3 muon / m^2 / day !)
- Physics goal: WIMP search (this presentation: **arXiv:2007.15622**)
  Dark sector (*Phys. Rev. Lett.* ***123****, 181802*)
  Silicon radioactive contamination (*arXiv:1506.02562, JINST 10 (2016) no.08 P08014*)

WIMP SEARCH METHODOLOGY

1

Acquire and select data

2

Build a background model

3

Compare data / simulation —> Signal or limit (or both…)

Results on low-mass weakly interacting massive particles from a 11 kg d target exposure of DAMIC at SNOLAB

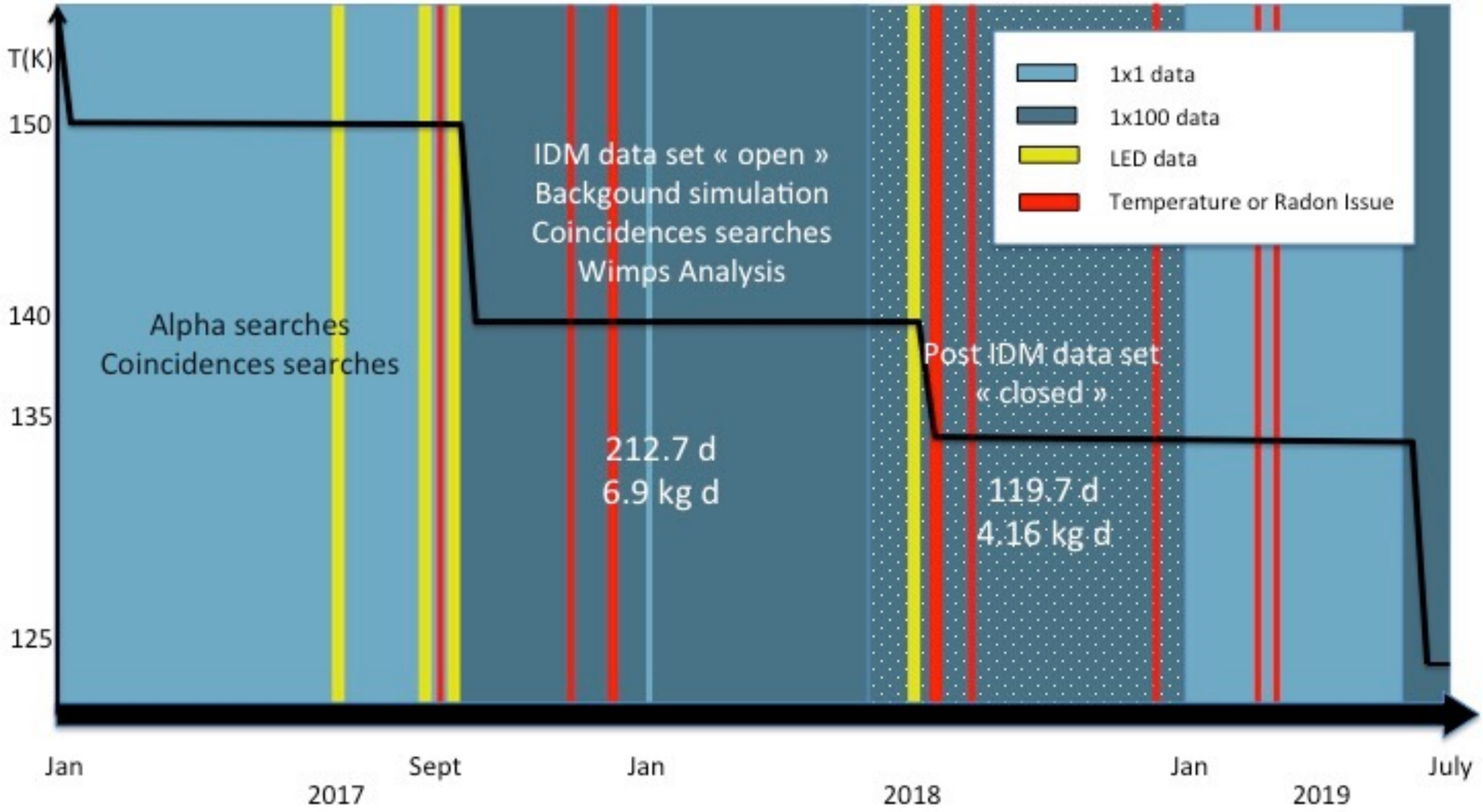
A. Aguilar-Arevalo,[1] D. Amidei,[2] D. Baxter,[3] G. Cancelo,[4] B.A. Cervantes Vergara,[1] A.E. Chavarria,[5] J.C. D'Olivo,[1] J. Estrada,[4] F. Favela-Perez,[1] R. Gaïor,[6] Y. Guardincerri,[4,*] E.W. Hoppe,[7] T.W. Hossbach,[7] B. Kilminster,[8] I. Lawson,[9] S.J. Lee,[8] A. Letessier-Selvon,[6] A. Matalon,[3,6] P. Mitra,[5] C.T. Overman,[7] A. Piers,[5] P. Privitera,[3,6] K. Ramanathan,[3] J. Da Rocha,[6] Y. Sarkis,[1] M. Settimo,[10] R. Smida,[3] R. Thomas,[3] J. Tiffenberg,[4] M. Traina,[6] R. Vilar,[11] and A.L. Virto[11]
(DAMIC Collaboration)

arXiv:2007.15622

1

Acquire and select data

DATA ACQUISITION

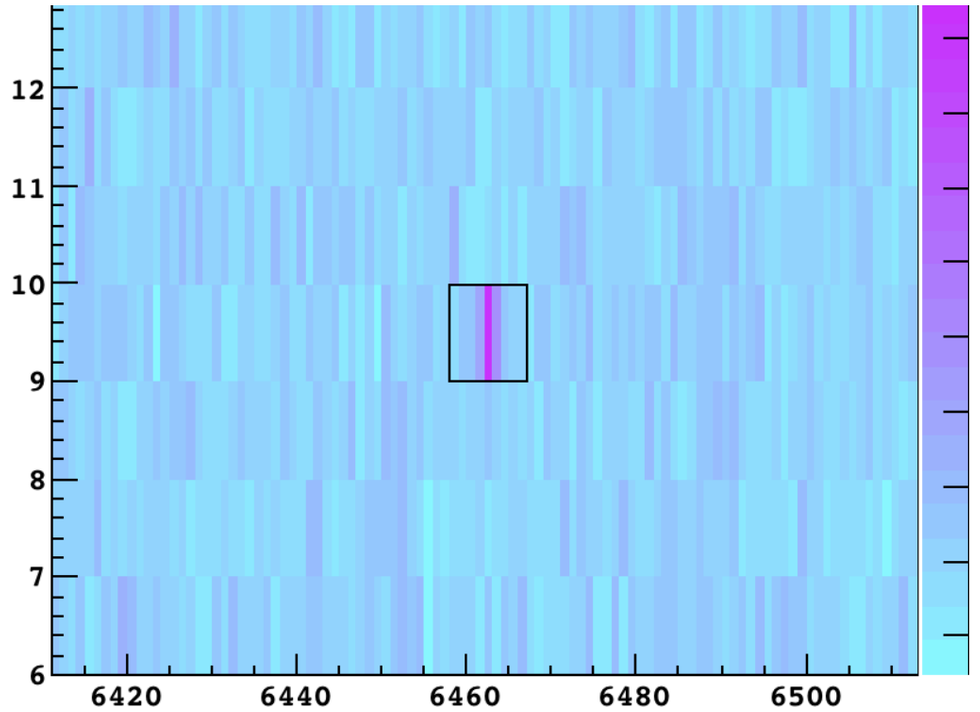


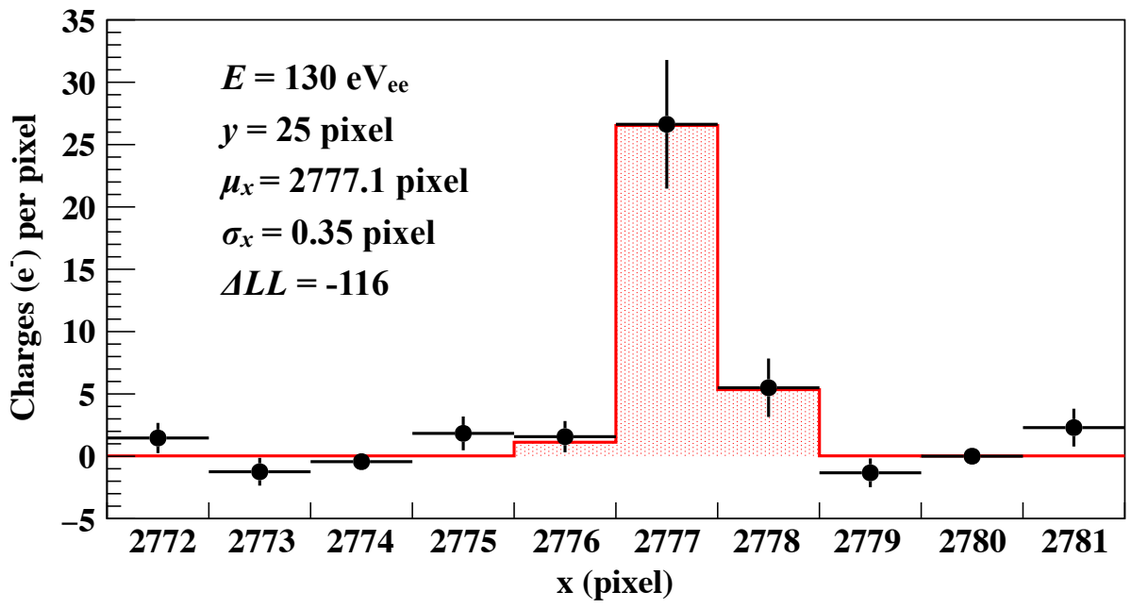
DATA SELECTION

- 1x100 images
  better energy resolution
- stringent masking
  ~7% of data removed
- leakage current
  exposure duration and image selection

➡ *11 kg day of exposure*

- cluster search
  Gaussian vs constant likelihood
- selection on ΔLL
- efficiency
  50% at ~80 eV



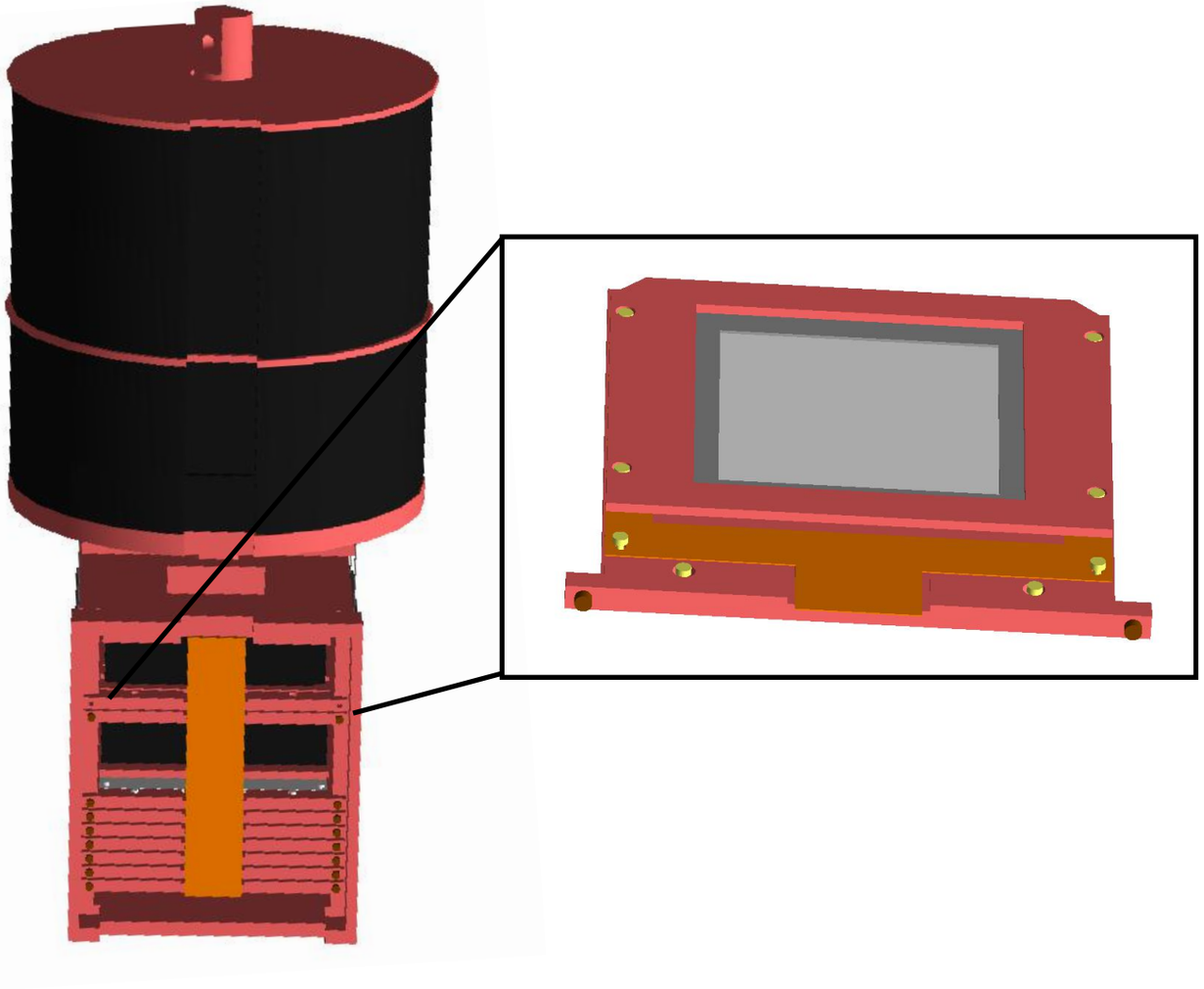


⟶ Map of clusters in Energy vs σ (~depth) plane

2

Build a background model

GEANT4 SIMULATION



Simulations features

- CCD structure
- Bulk and surface simulation
- G4 Livermore physics list

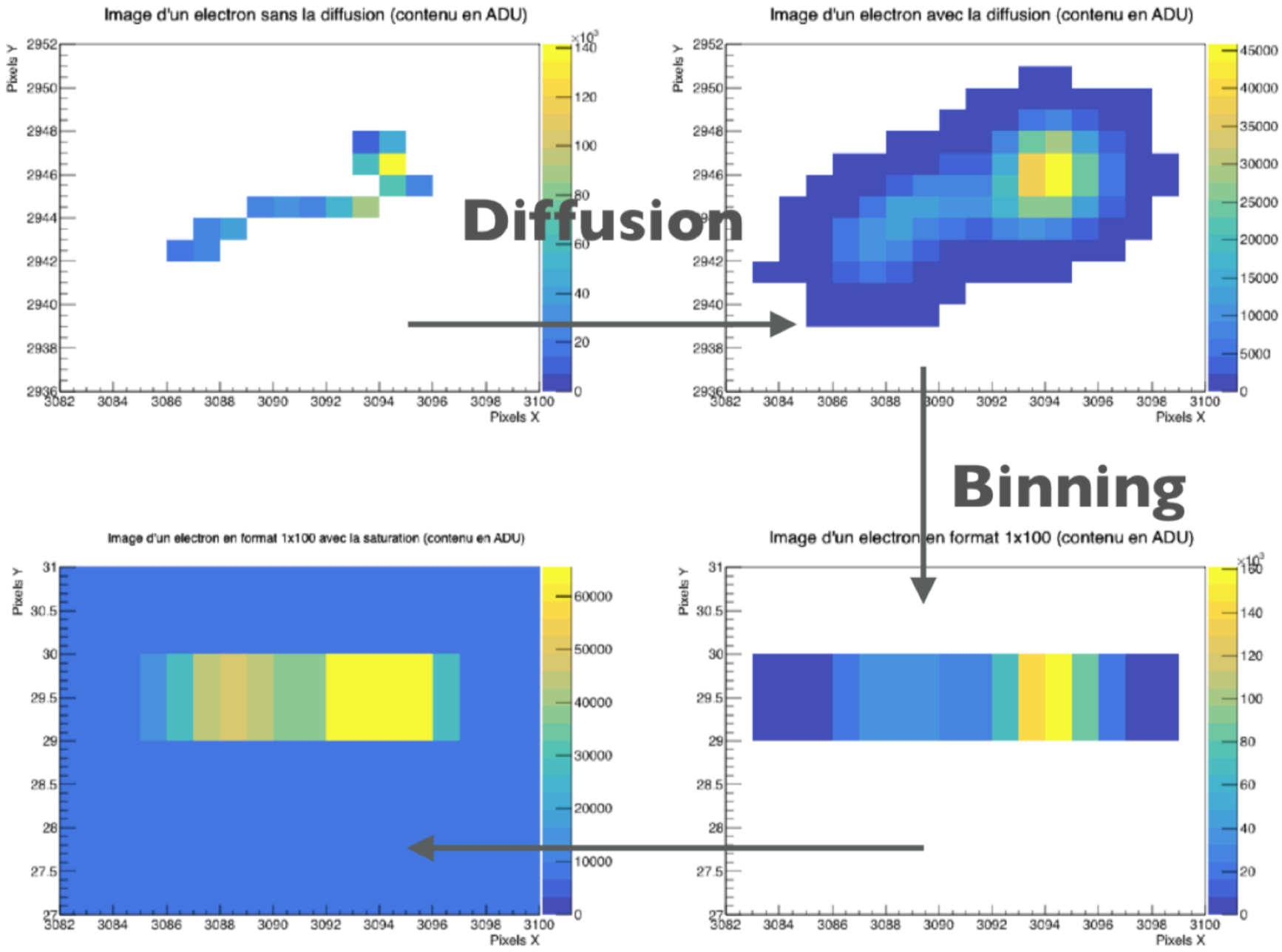
Expected contributions:

- low energy gamma
- low energy beta
- neutron —> negligible

Main Contaminant

- Primordial nuclide ^{238}U, ^{232}Th —> **^{210}Pb**
- Copper activation
- CCD specific contributions ^{32}Si, ^{32}P, ^{22}Na, **^{3}H**

DETECTOR RESPONSE SIMULATION + STANDARD ANALYSIS



Saturation + noise

→ Templates of clusters in Energy Depth plane

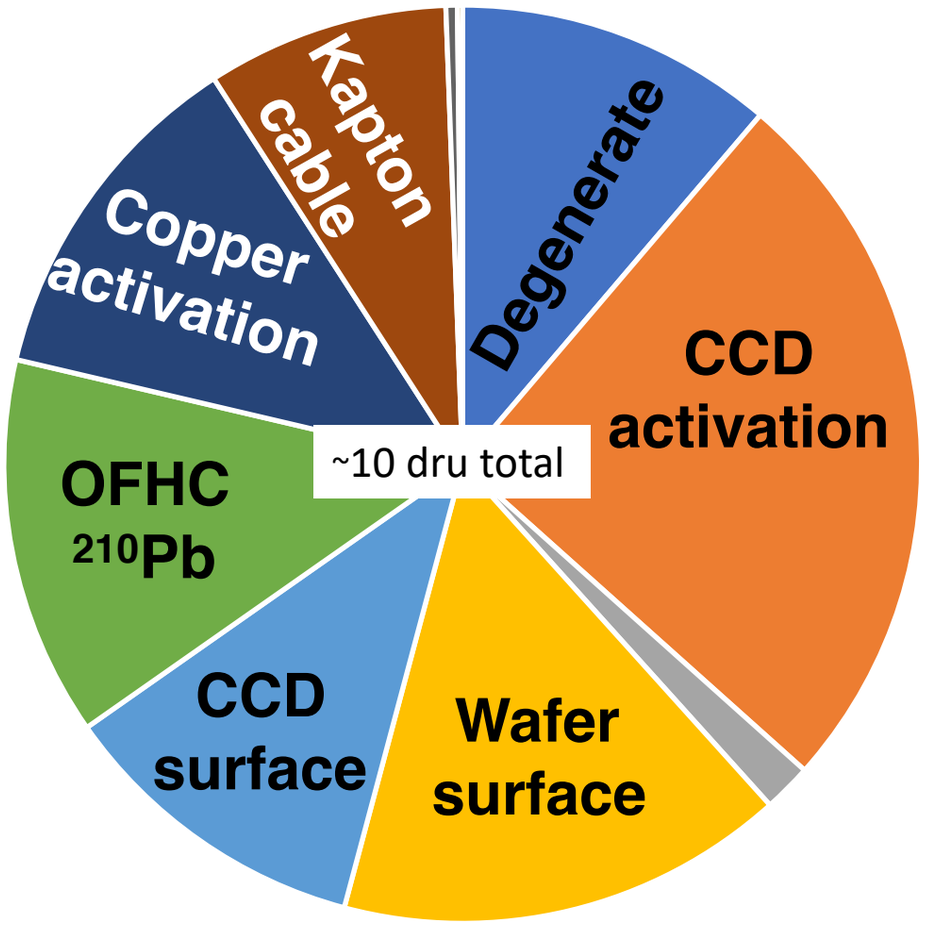
BACKGROUND ESTIMATION FROM DATA

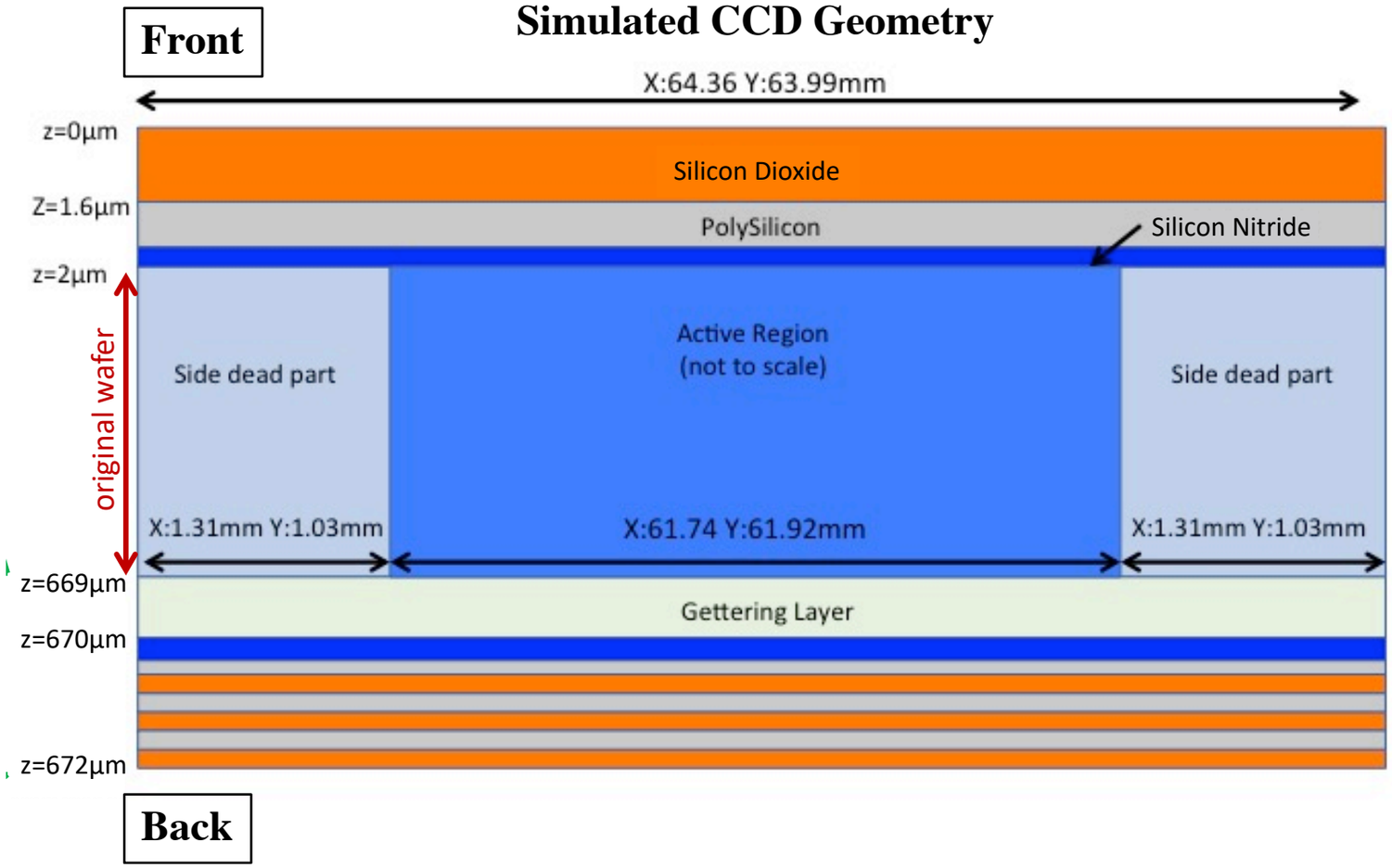
- Set the Energy range: [6 - 20] keV
- Collect the G4 simulated template for volume / contaminant
- Adjust with a 2D [E vs Depth] binned likelihood template fit between data and simulation
  - constrained by assays and coincidence analysis

measurement / upper limits on actvities

Part	U-238	Ra-226	Pb-210	Th-232	K-40
CCD	<0.53	<0.43	<33*	<0.4	<0.04
Kapton cable	5000 ± 420	420 ± 490	420*	280 ± 40	2480 ± 170
Copper	<10.7	<11.2	2350 ± 720	<3.5	<2.7
Module Screws	1400 ± 3800	<138	2350 ± 720†	200 ± 140	2400 ± 1300
Ancient lead shield	<2.0	<22.5	2850‡	0.2‡	<0.5
Outer lead shield	<1.1	<17.6	1560000 ± 430000	<0.4	<19

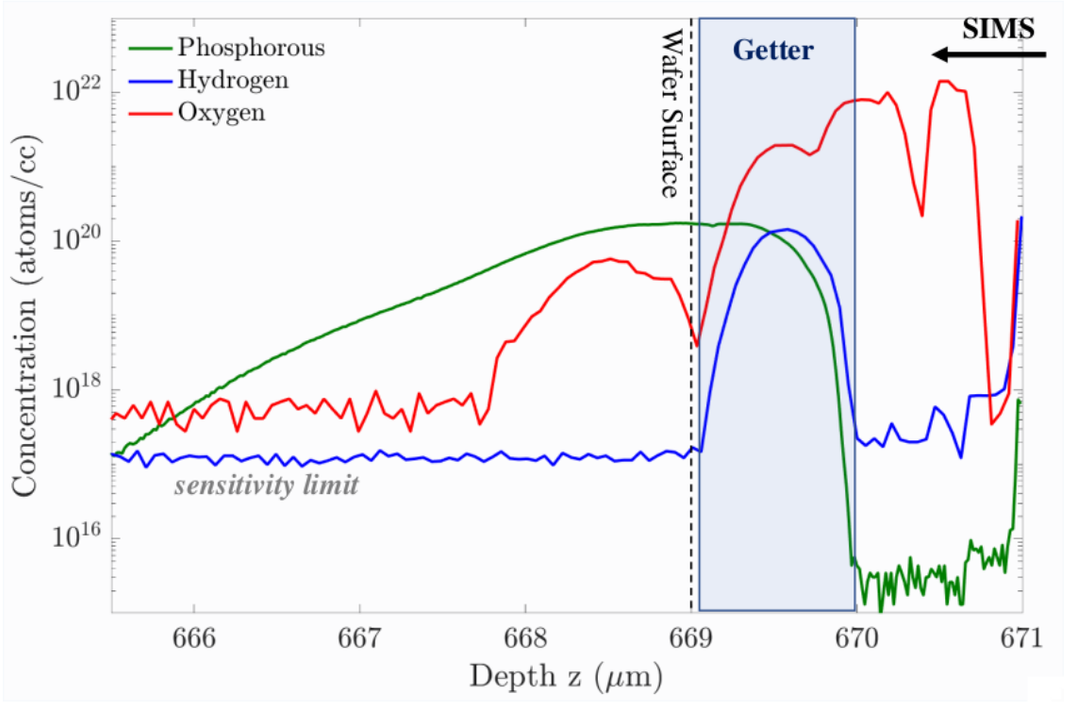
BACKGROUND STUDY RESULTS

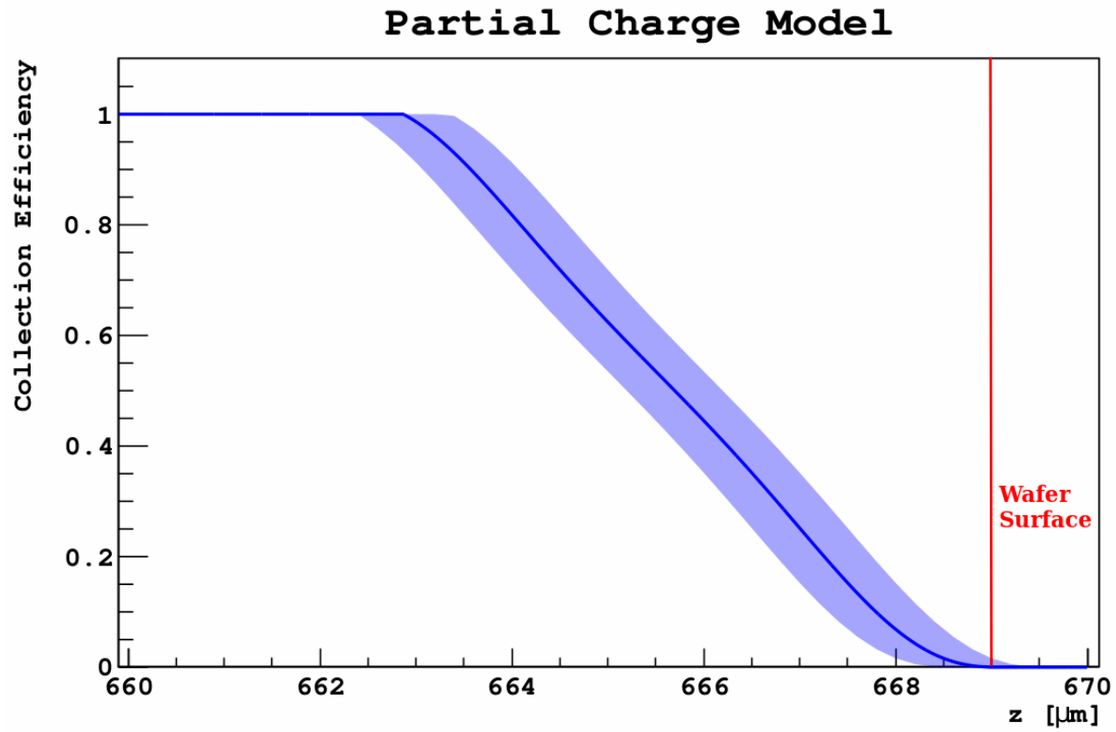




- Sensitive to structure of the CCD
- Important guide for next generation CCD based experiment

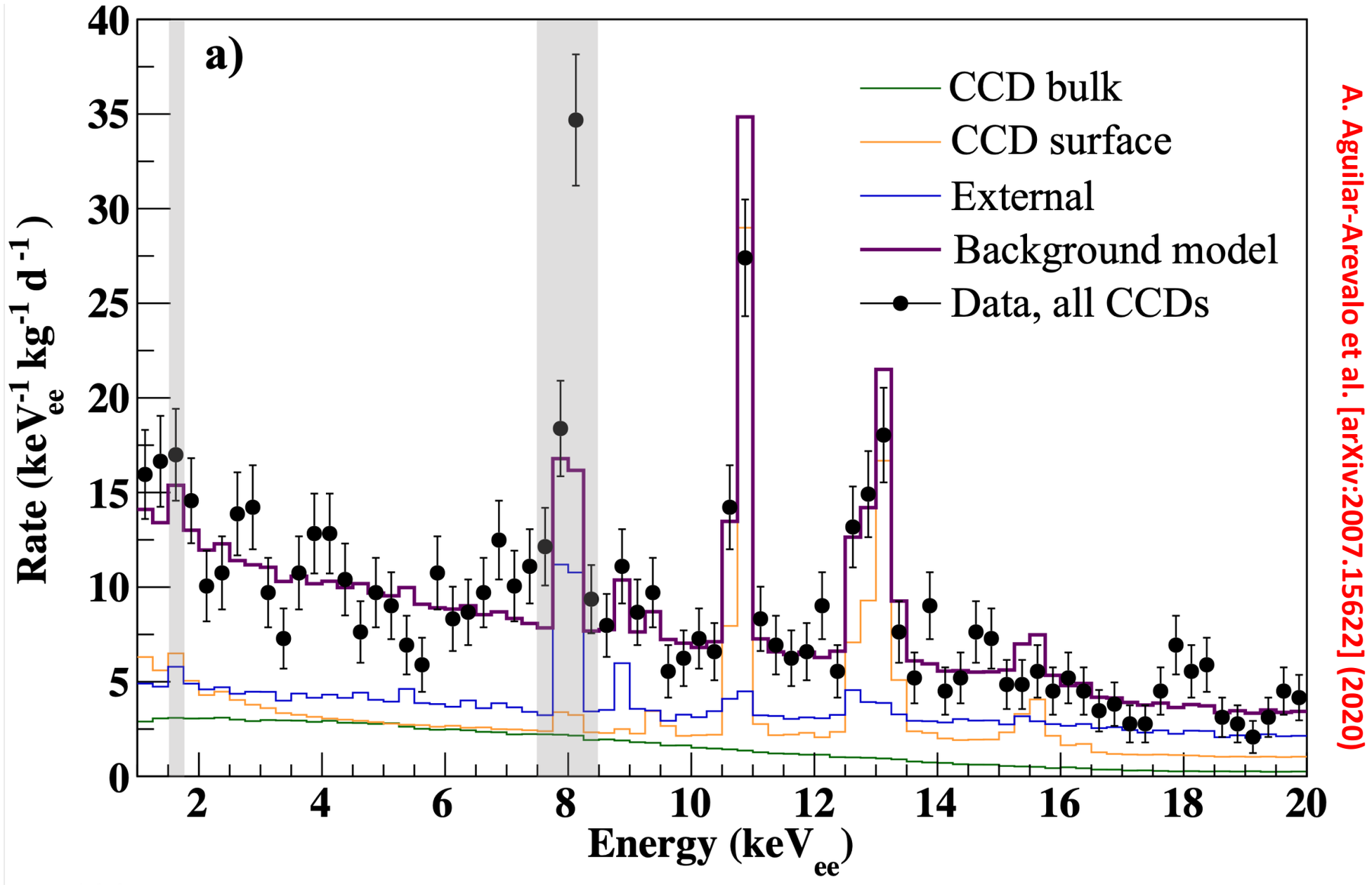
PARTIAL CHARGE COLLECTION





- SIMS measurement of the CCD show a diffusion of P donor on a few microns in the bulk region
- Leads to effects at low energies
- Performed systematic studies on this effect (shift, temperature)

ENERGY PROJECTION

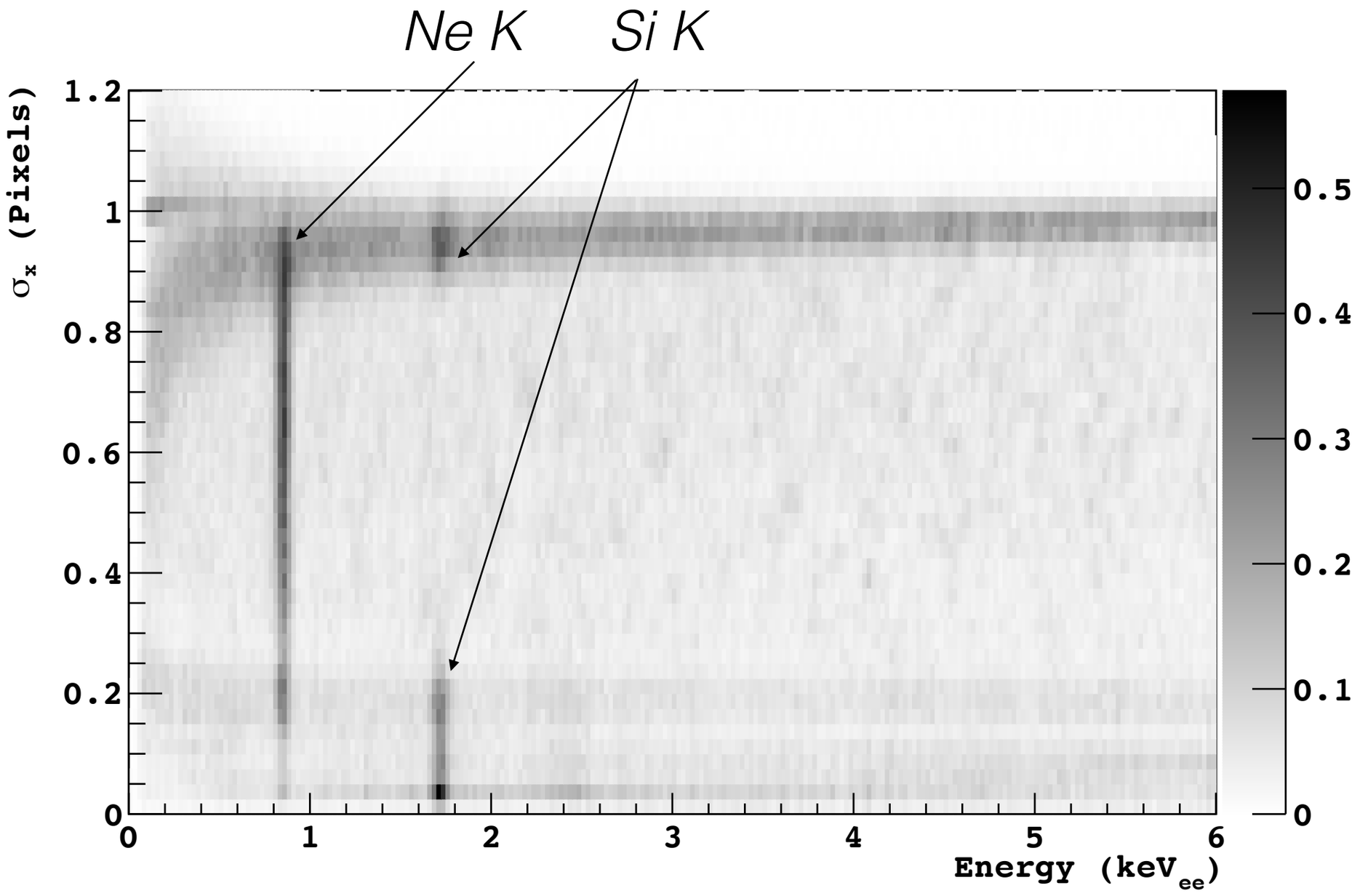


A. Aguilar-Arevalo et al. [arXiv:2007.15622] (2020)

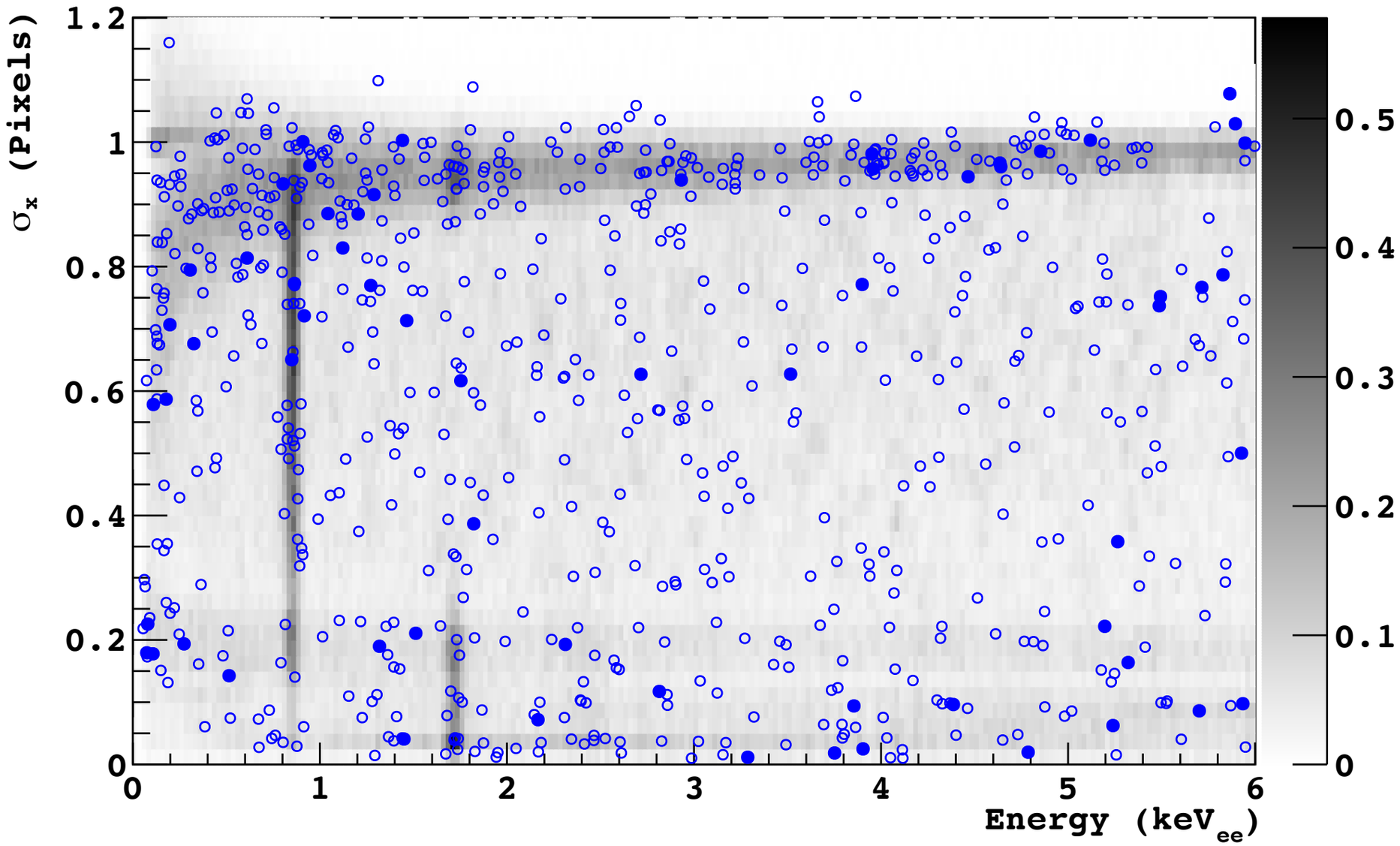
3

Compare data / background model

BACKGROUND MODEL



BACKGROUND MODEL + DATA



BACKGROUND MODEL + DATA

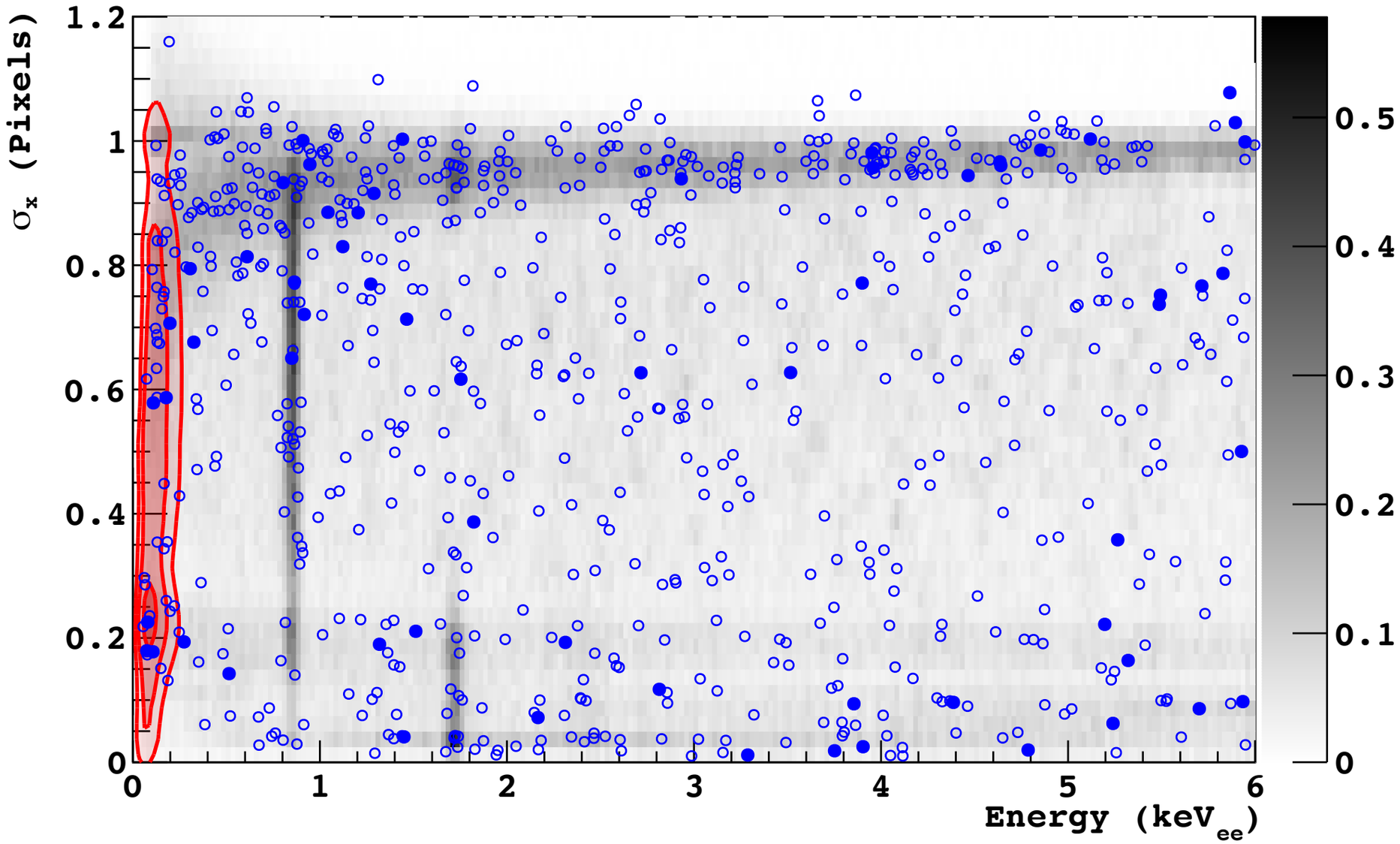
Extended likelihood function for WIMP spectrum

$$\ln \mathcal{L}(s, b_{sys}, M, c_{pcc}, \alpha_{pcc}) = -(s + b_{sys}) + \sum_{i=1}^{N} \ln \left(s f_s(E_i, \sigma_{xi}|M) + b_{sys} f_{b_{sys}}(E_i, \sigma_{xi}|c_{pcc}, \alpha_{pcc}) \right)$$

We actually do it for a generic bulk excess…

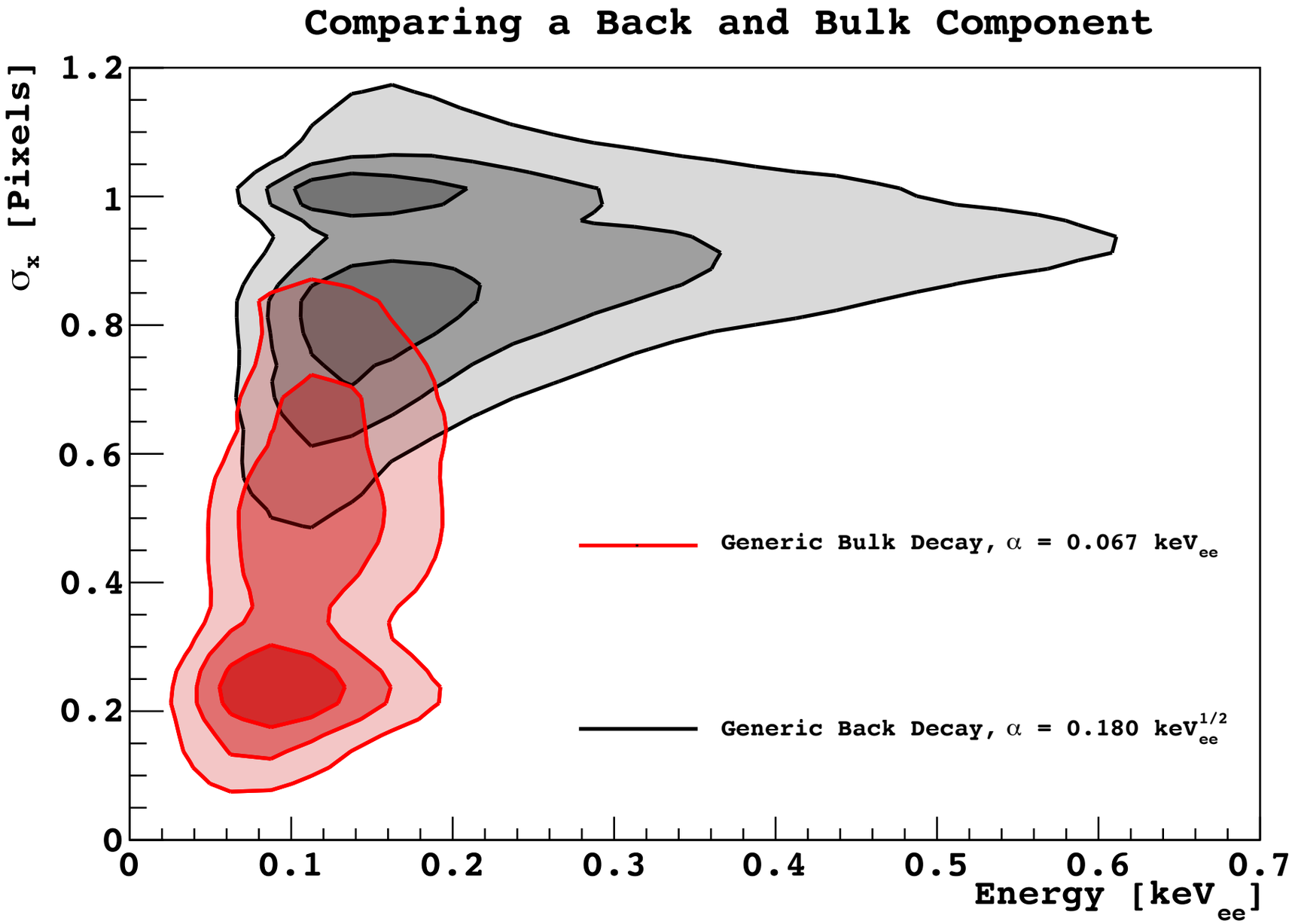
$f_s \longrightarrow$ $$f_b(E|\alpha_s, \sigma) = \frac{N}{\alpha_s} \exp(-E/\alpha_s) \exp(\sigma^2/2\alpha_s^2) \operatorname{erfc}\left(\frac{\sigma/\alpha_s - E}{\sqrt{2}\sigma} \right)$$

BACKGROUND MODEL + DATA + EXCESS



- We report an excess — not interpreted as DM
- Additional checks are needed

EXCESS

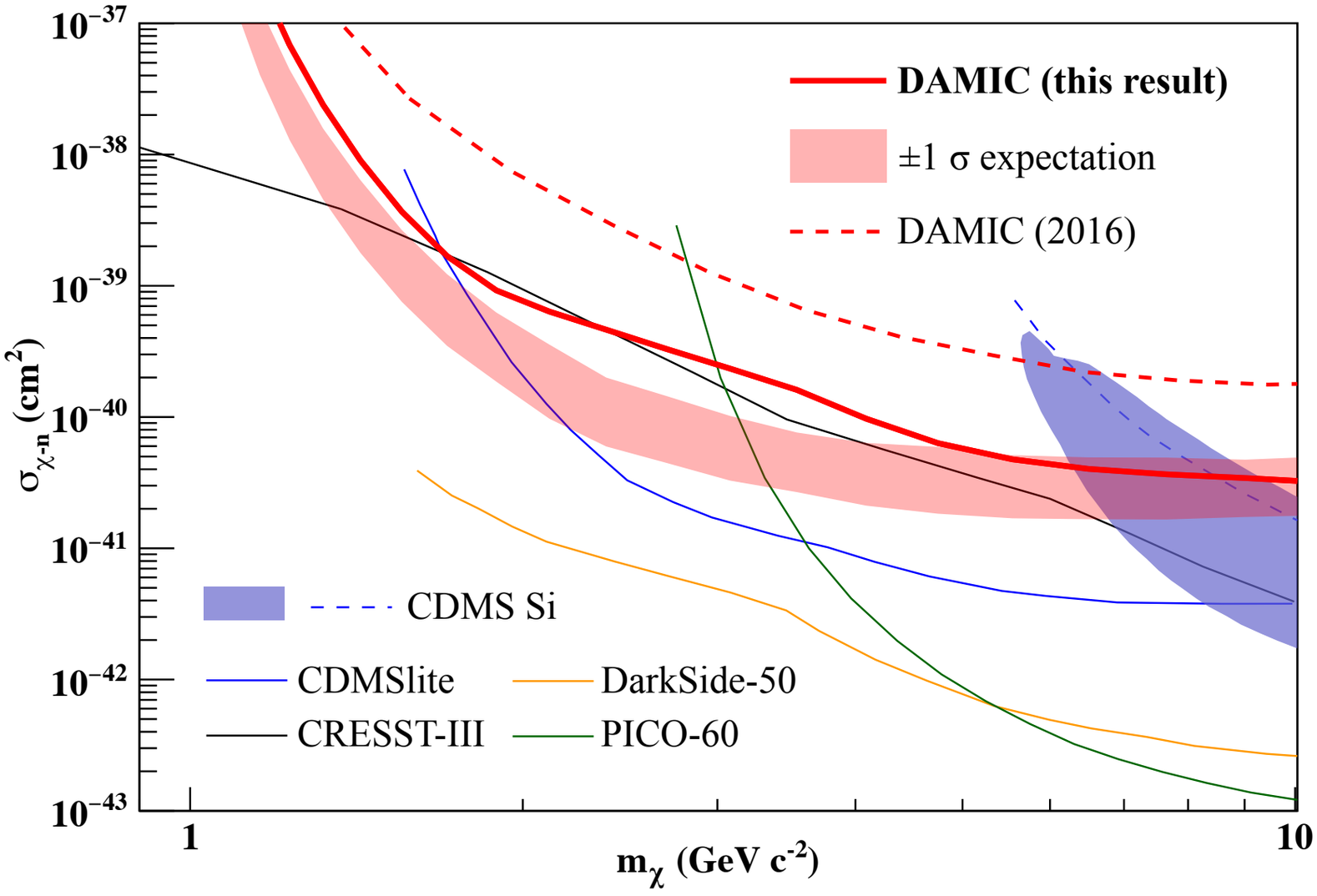


- best fit finds ~17 events in excess with an expo. decay of 67eV
- back and bulk excess are not degenerate

SO WHAT IS IT THEN ???

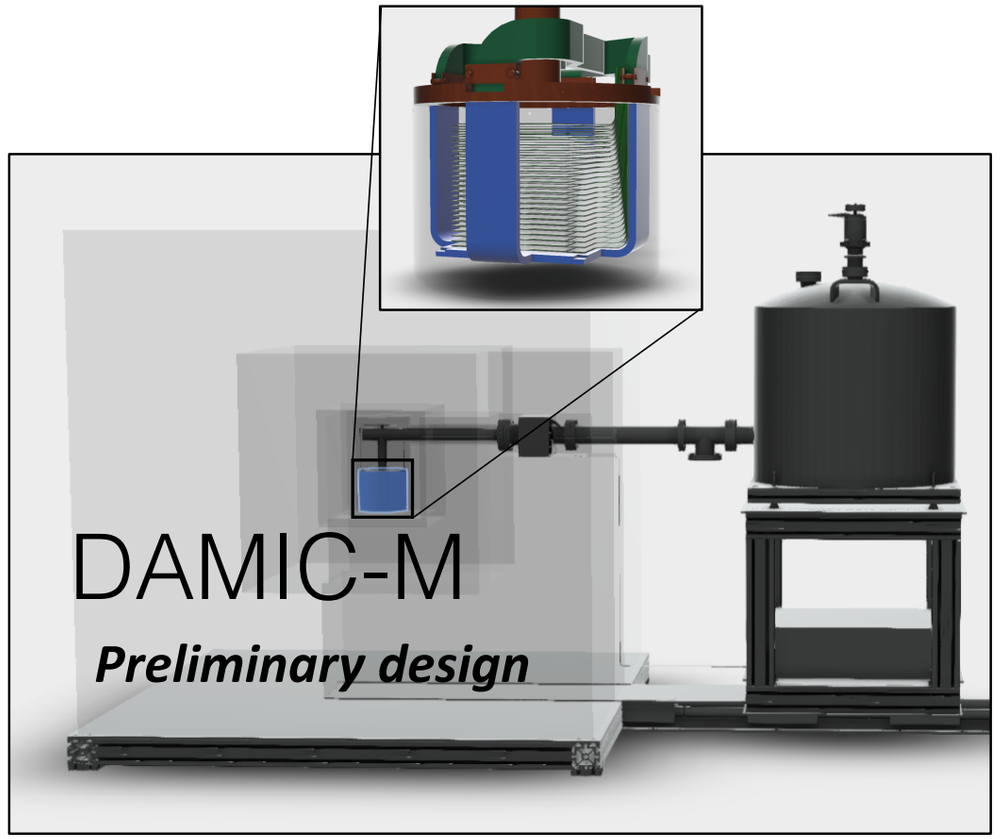
- missing component in the background model
- detector effect on the front side of the CCD
- Silicon new physics
- Dark Matter interaction
- …

WIMP LIMITS



- We report a limit on WIMP - nucleon SI interaction
- Significant fraction of the CDMS Si excluded

FUTURE

- **DAMIC at SNOLAB continues…**
  - a few Skipper CCDs (sub e- resolution) will be installed
    —> lower threshold
  - threshold effect or new bkg component or new physics…

- **DAMIC-M**
  - 1kg scale detector at Modane is being developed
    - First demonstrator with science results ~2021
    - Full experiment ~ 2022/2023
  - see Ben Kilminster (tuesday 11h25 room 3)