DAMIC at SNOLAB Excess

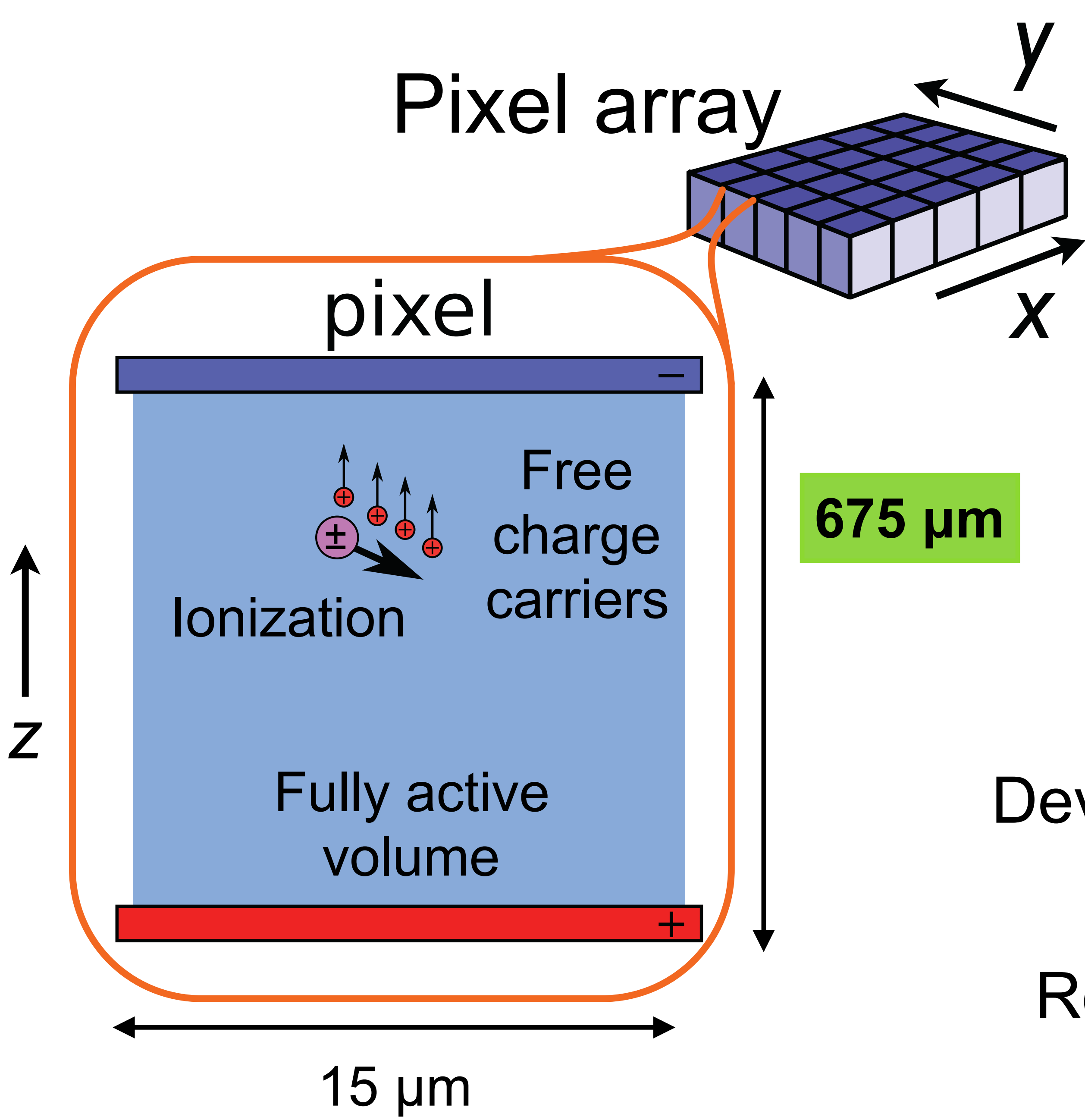
Alvaro E. Chavarria
University of Washington

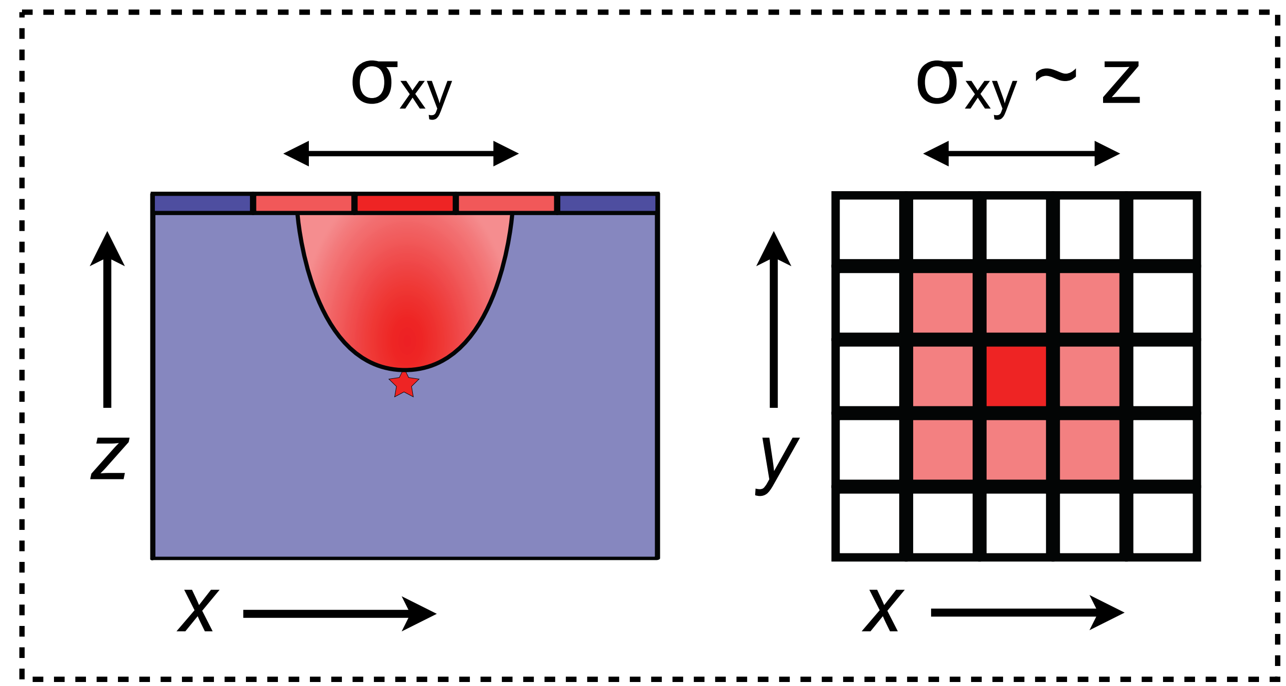
CENPA
Center for Experimental
Nuclear Physics and Astrophysics
UNIVERSITY *of* WASHINGTON

Outline

- Charge-coupled devices (CCDs).
- CCD detector response.
- DAMIC at SNOLAB.
- Dark Matter (DM) / WIMP Search.
- The Event **Excess**.
- Upgrade DAMIC at SNOLAB to investigate.

Charge coupled device





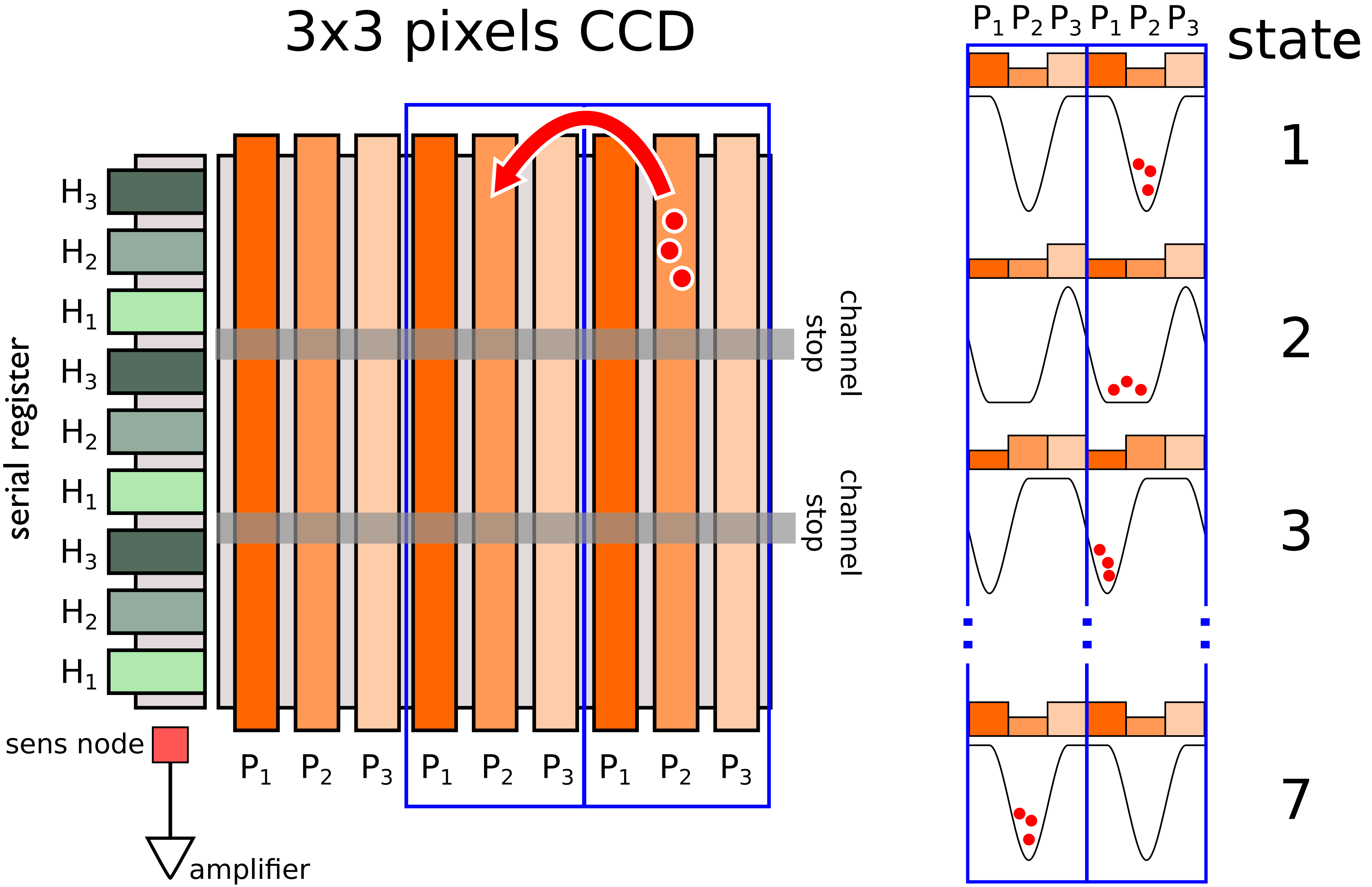
Standard fabrication in semiconductor industry and easy cryogenics (~100 K).

Device is "exposed," collecting charge until user commands readout

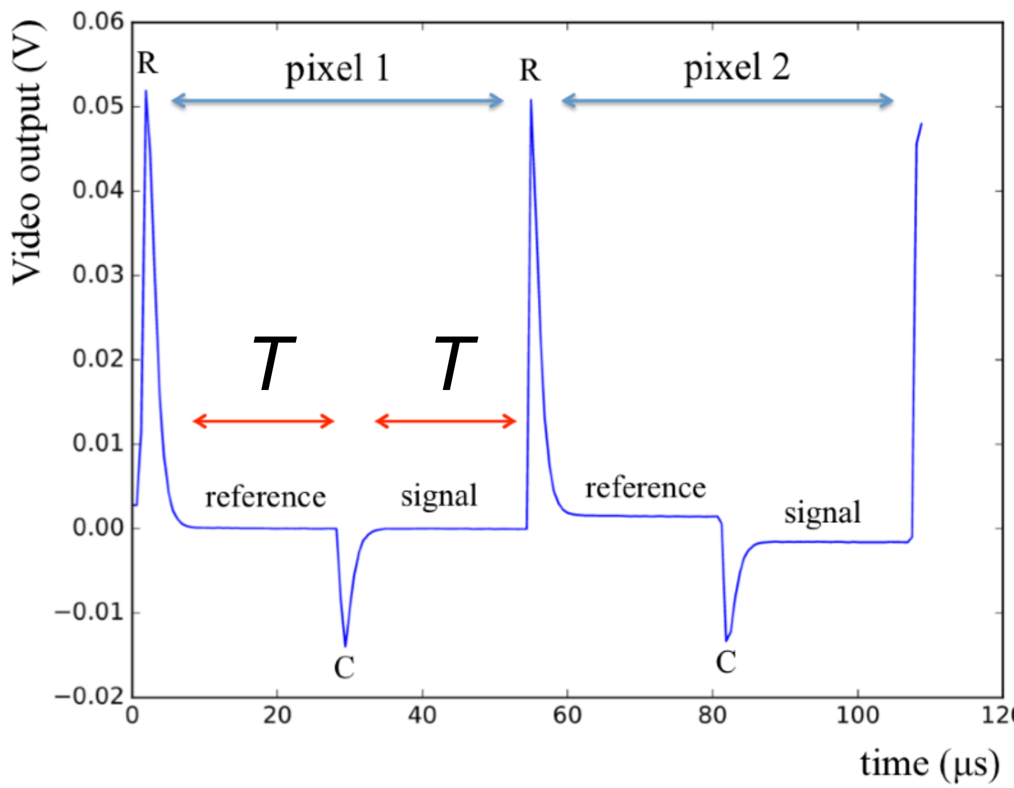
Readout can be slow / non-destructive :
low noise (few e^-)

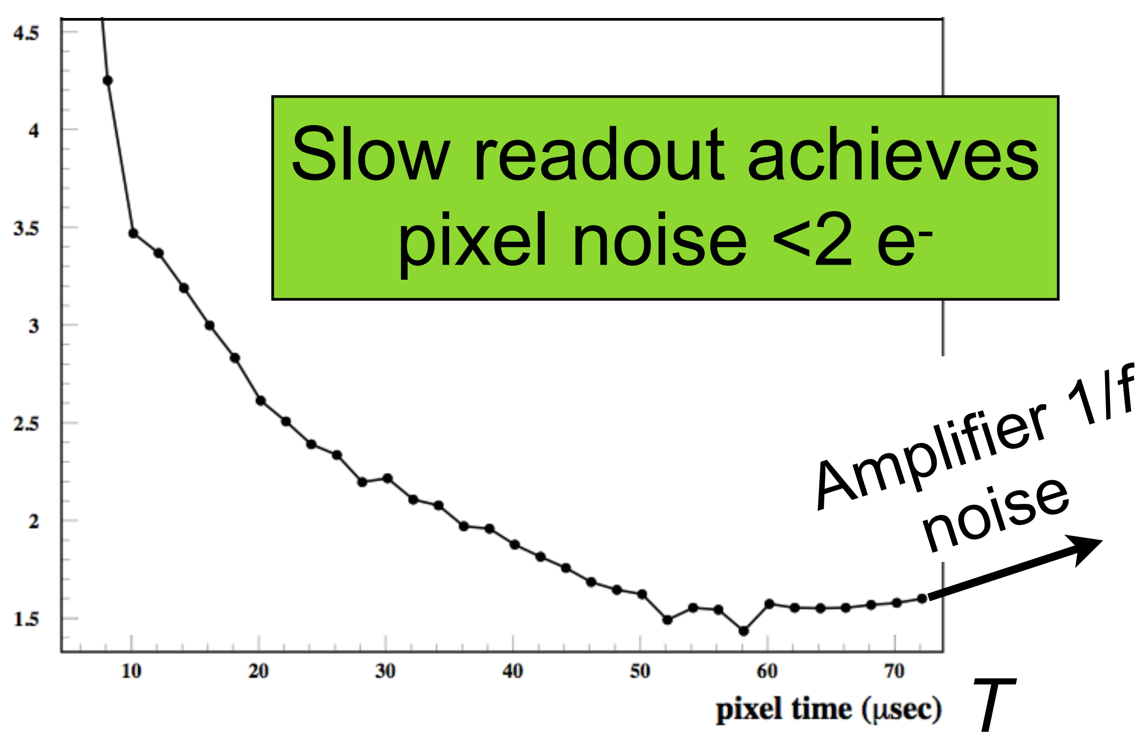
Silicon band-gap: 1.2 eV
Mean energy for 1 e-h pair: 3.8 eV

CCD readout


3x3 pixels CCD
serial register
H3
H2
H1
H3
H2
H1
H3
H2
H1
sens node
amplifier
P1 P2 P3 P1 P2 P3 P1 P2 P3
channel stop
channel stop
P1 P2 P3 P1 P2 P3
state
1
2
3
7

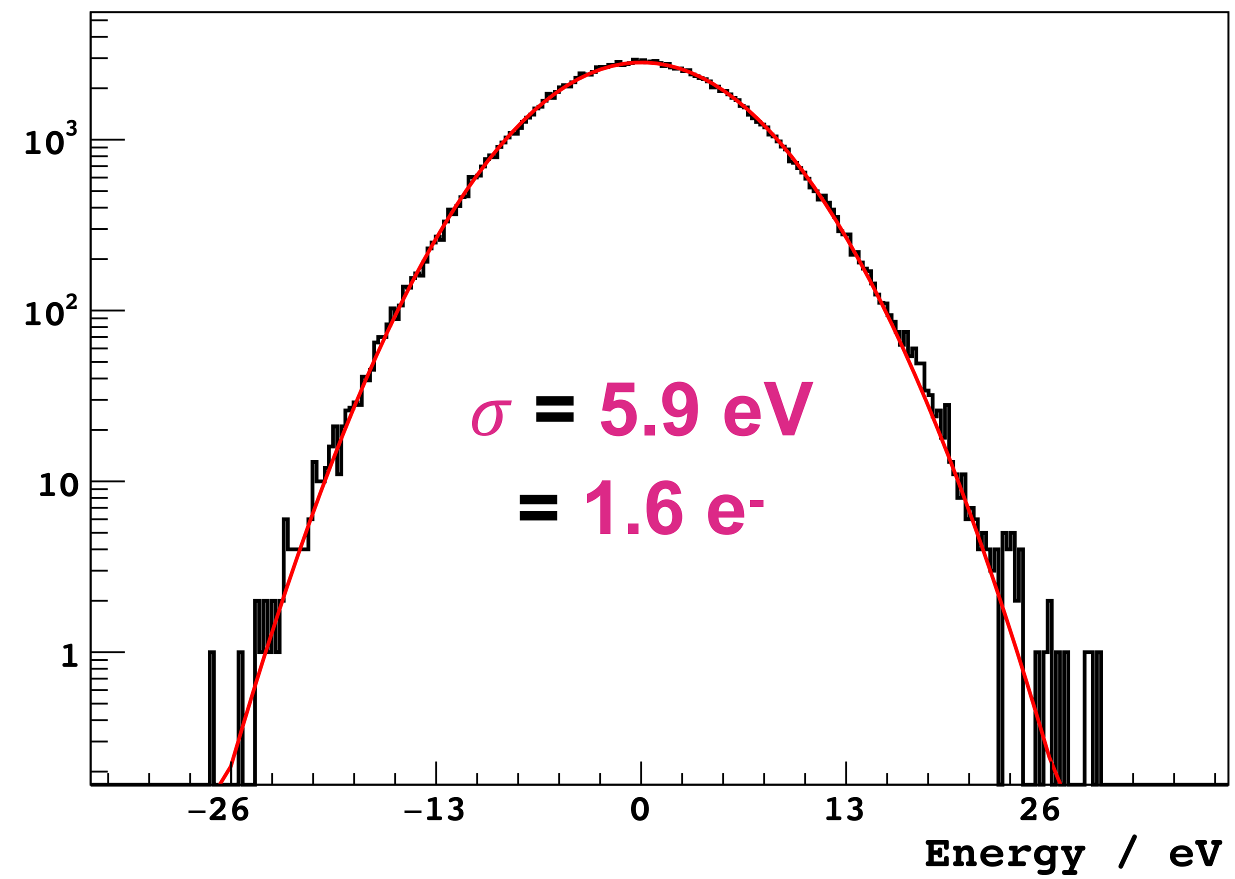
Charge measurement





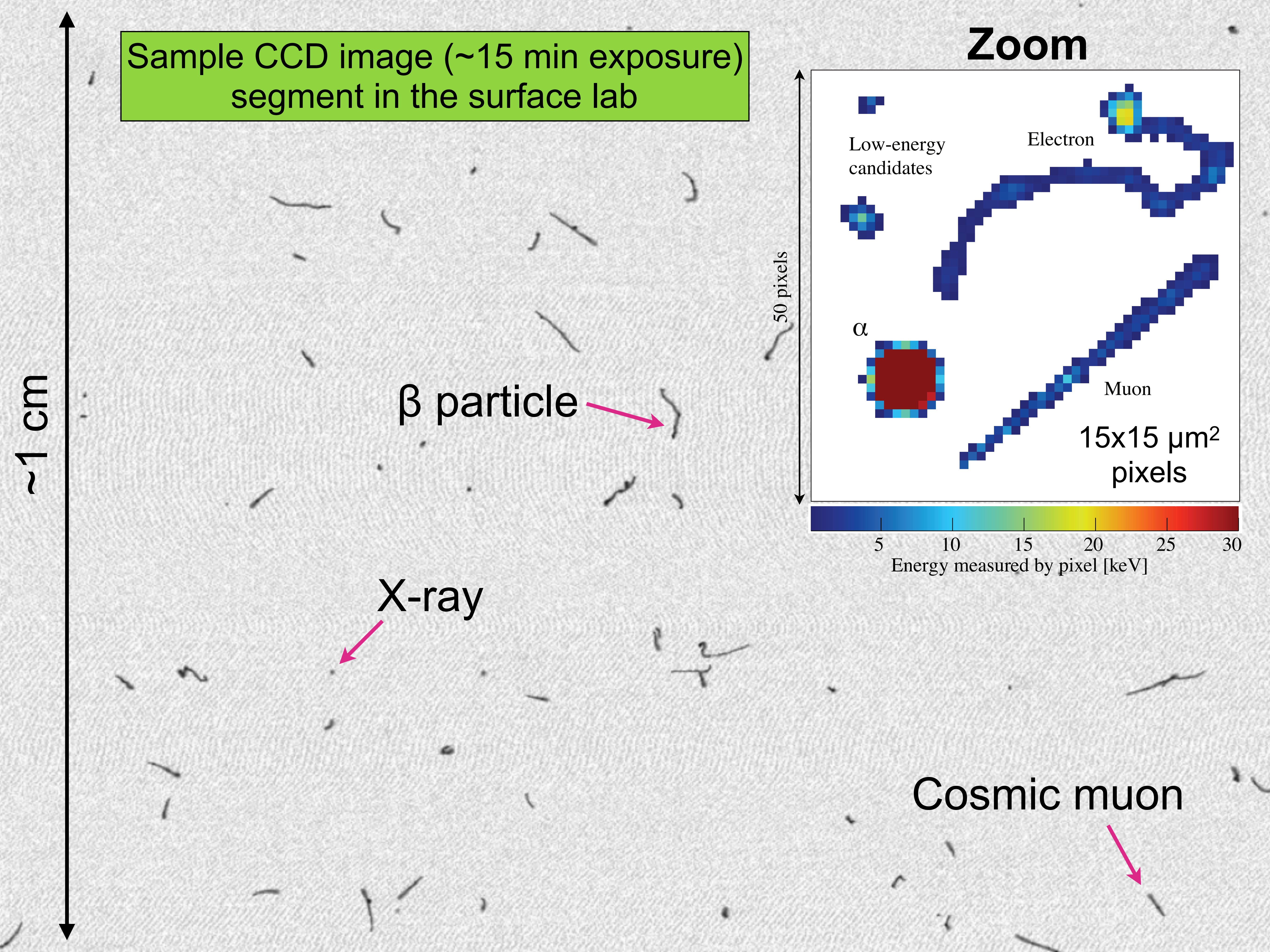
Slow readout achieves pixel noise <2 e^-

Pixel charge distribution

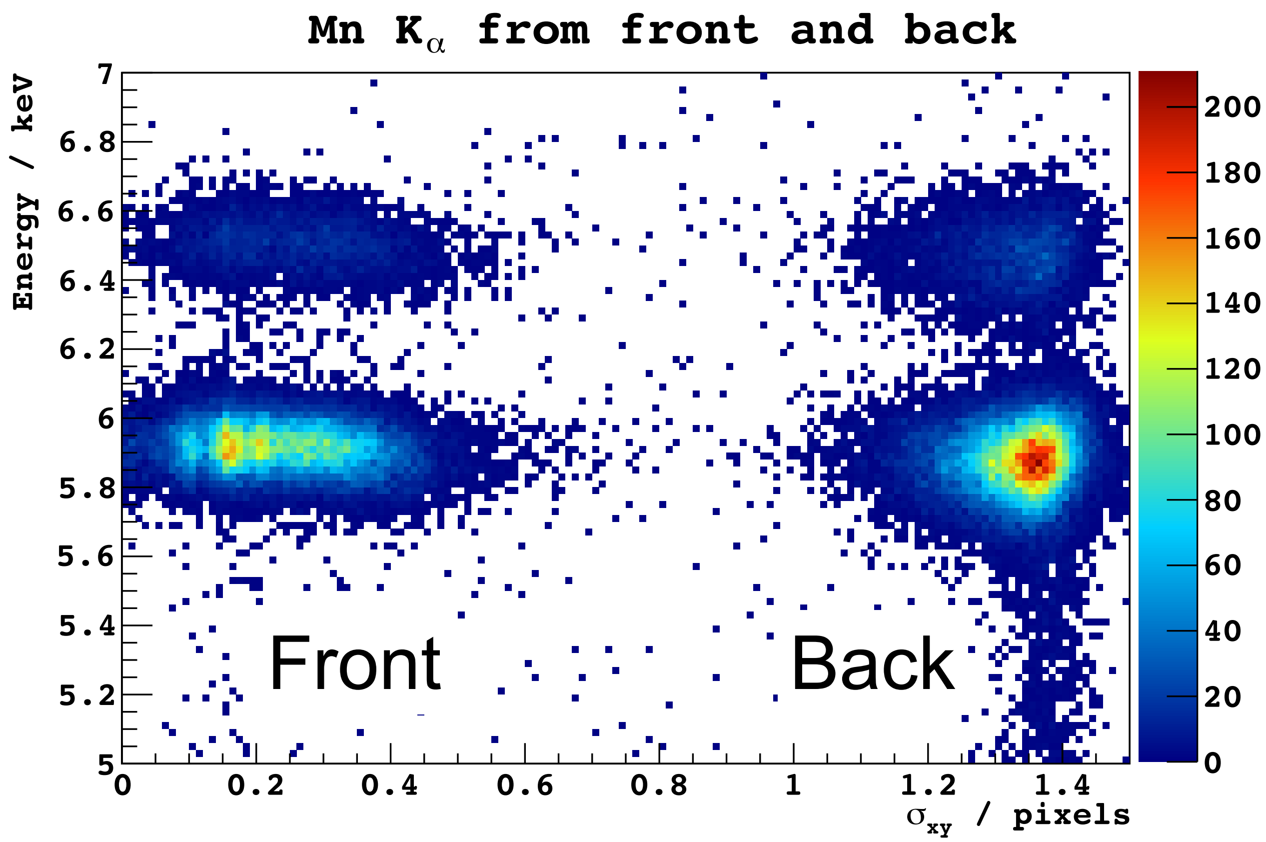


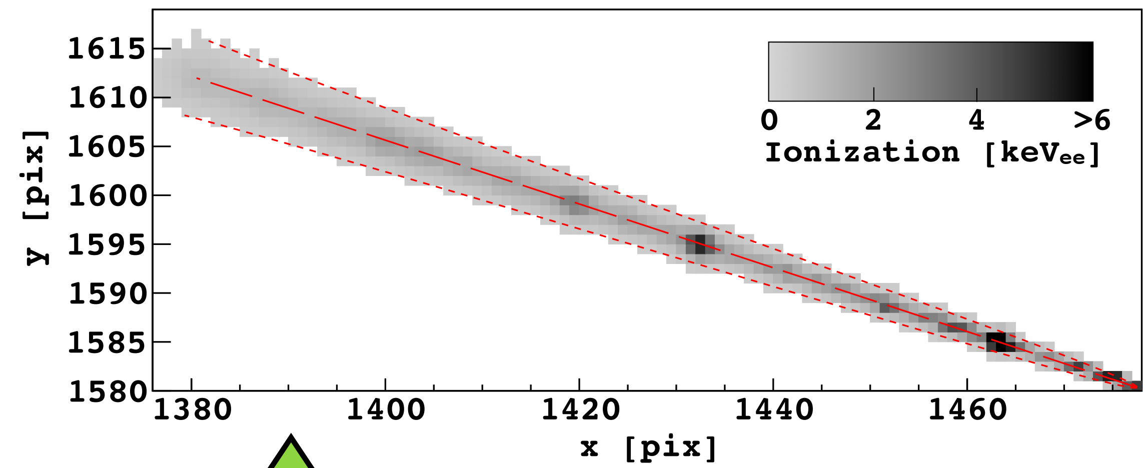
Very low noise and dark current

Ultra low leakage / dark current:
5×10^{-22} A/cm^2 (at 140 K)

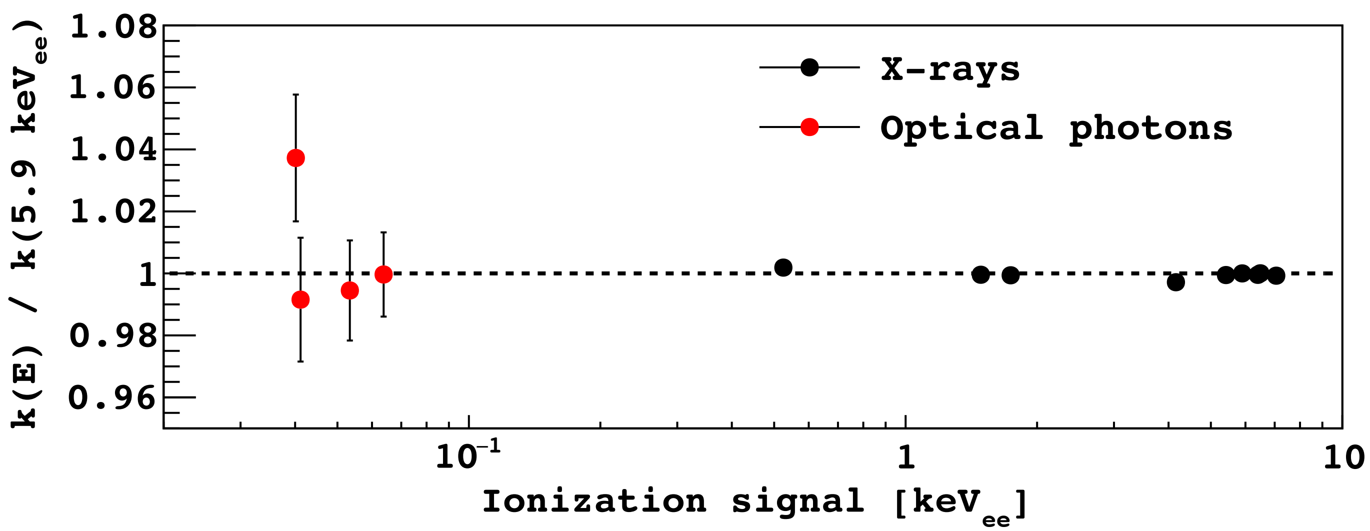

Sample CCD image (~15 min exposure)
segment in the surface lab
~1 cm
β particle
X-ray
Cosmic muon
Zoom
Low-energy
candidates
Electron
α
Muon
50 pixels
15x15 μm2
pixels
5 10 15 20 25 30
Energy measured by pixel [keV]

Detector response





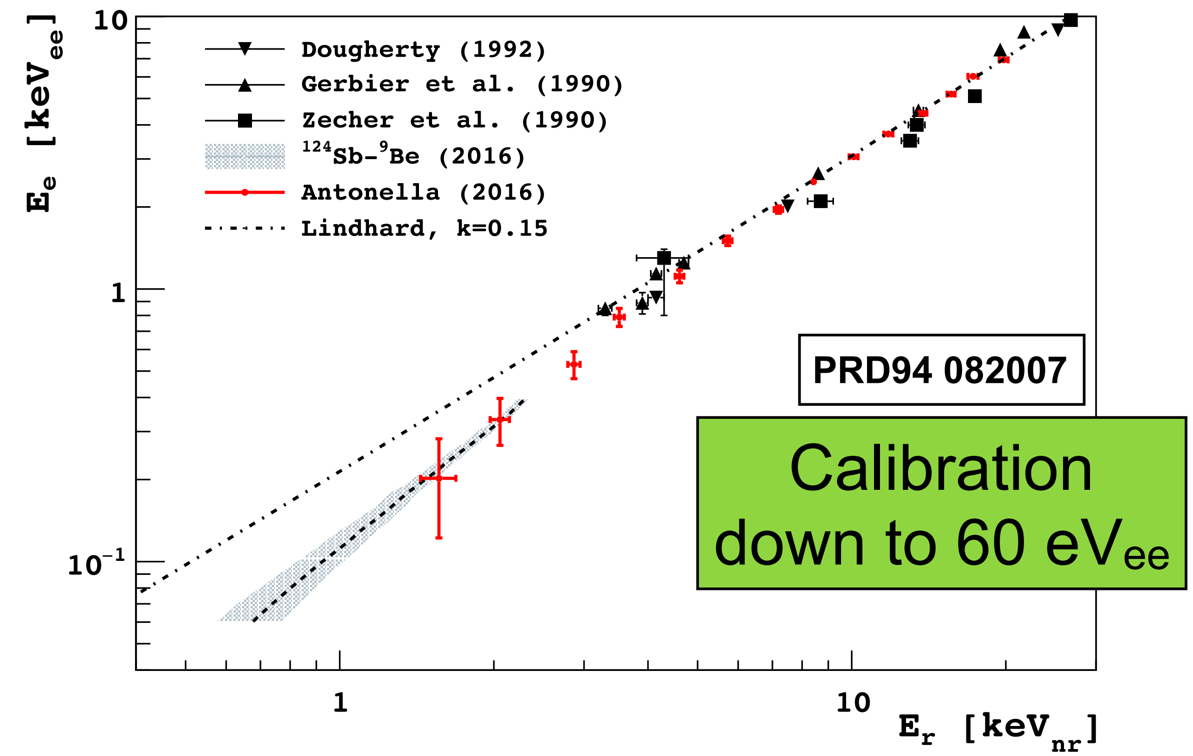
z reconstruction with X rays and cosmic rays

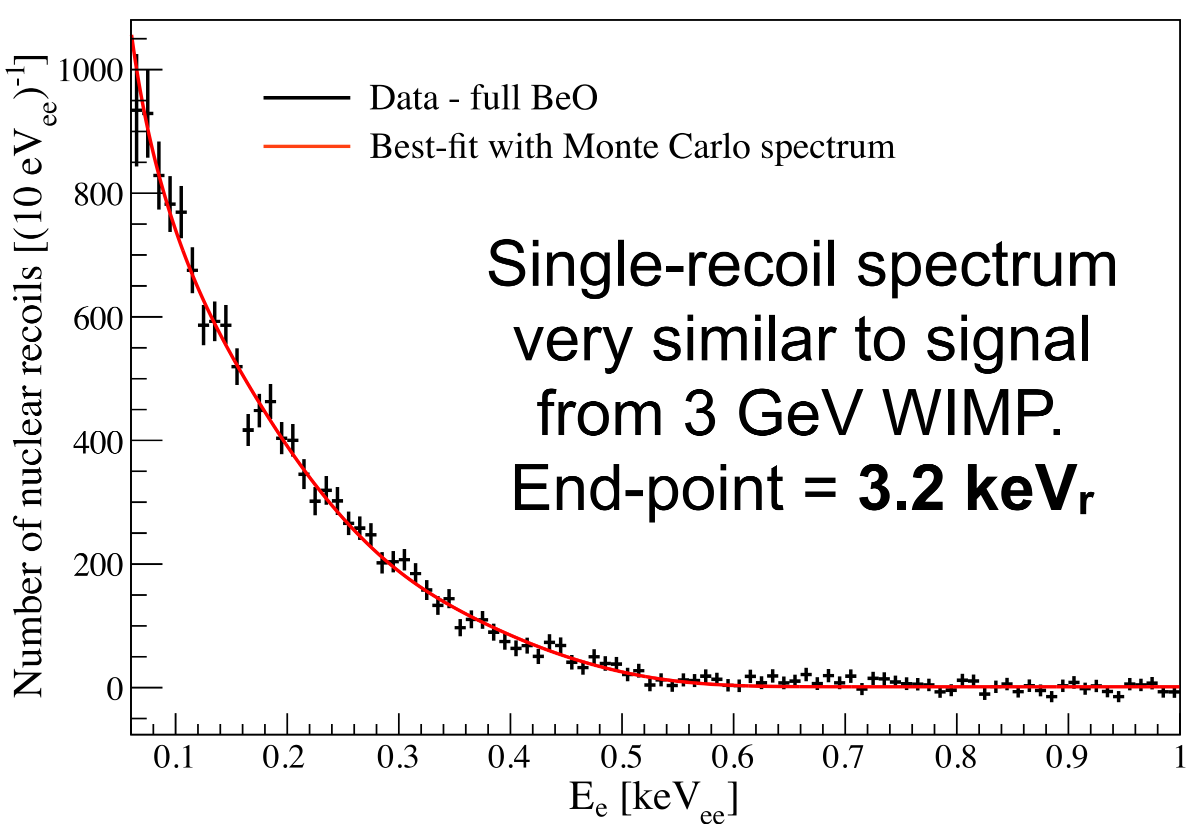


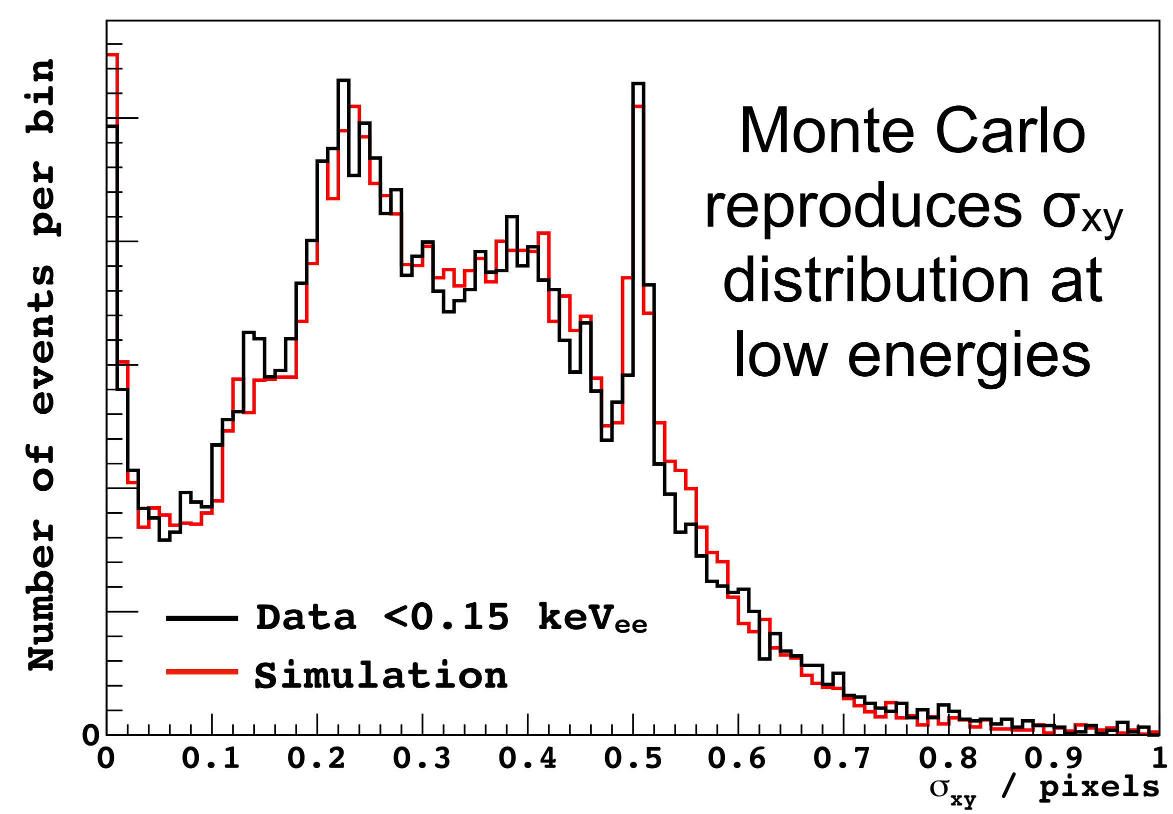
CCD linearity down to 40 eV_{ee} with optical photons

Nuclear recoil response

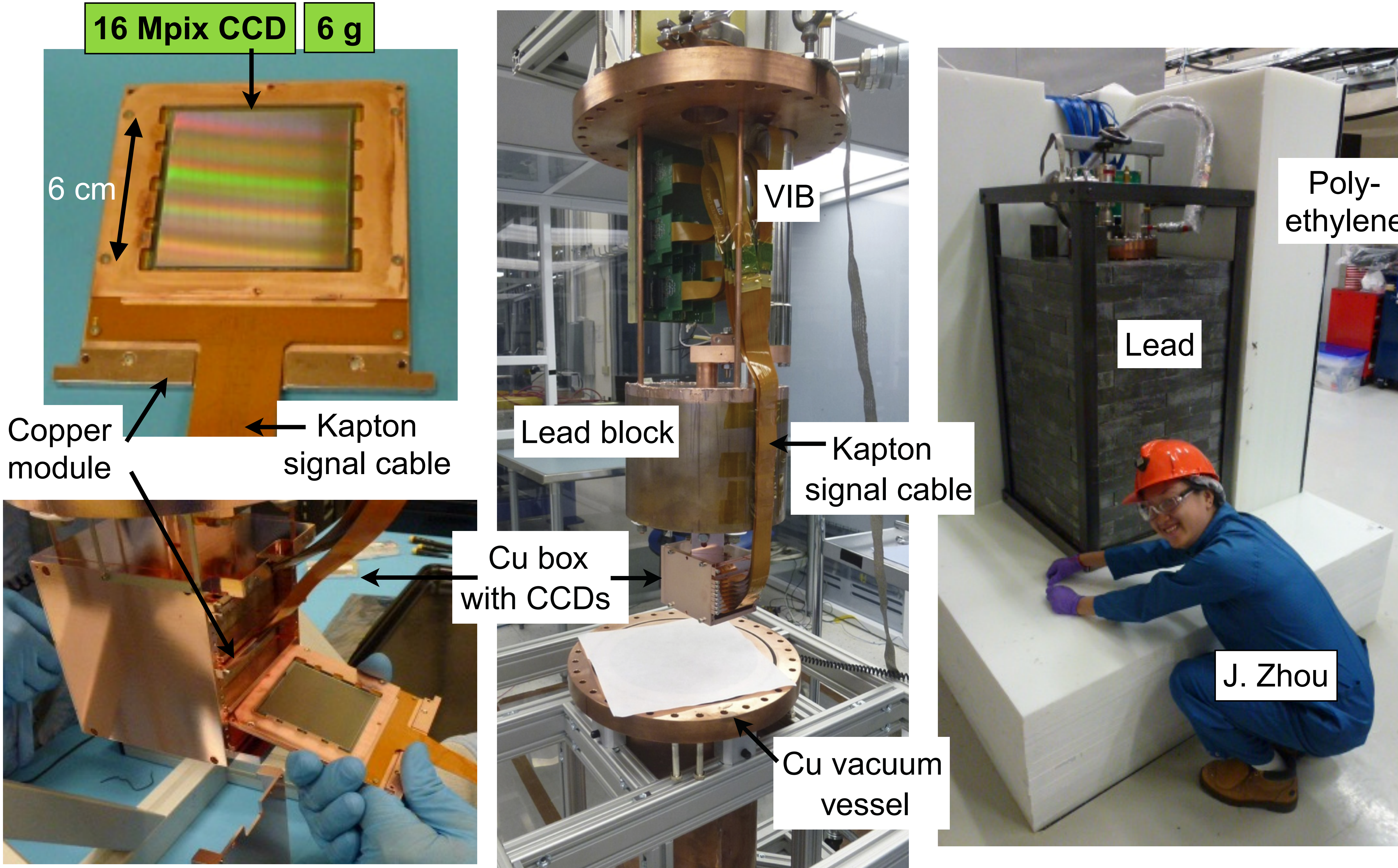
- Detector response calibrated with 24 keV neutrons from $^{9}Be(\gamma,n)$ reaction.
- By comparing data and Monte Carlo spectra, ionization efficiency was measured to be lower than predicted by Lindhard model.
- Also validates diffusion model at low energies.





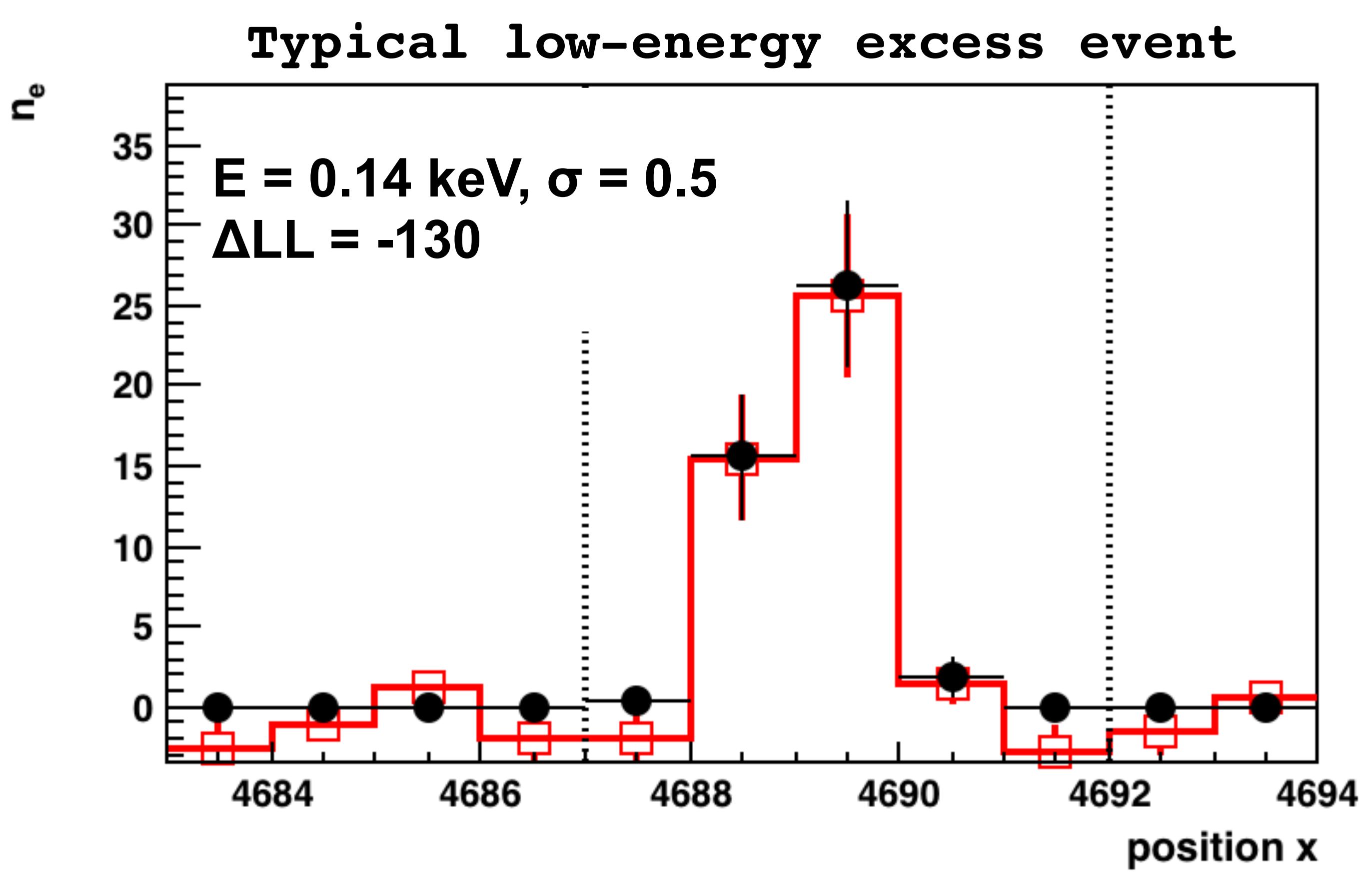


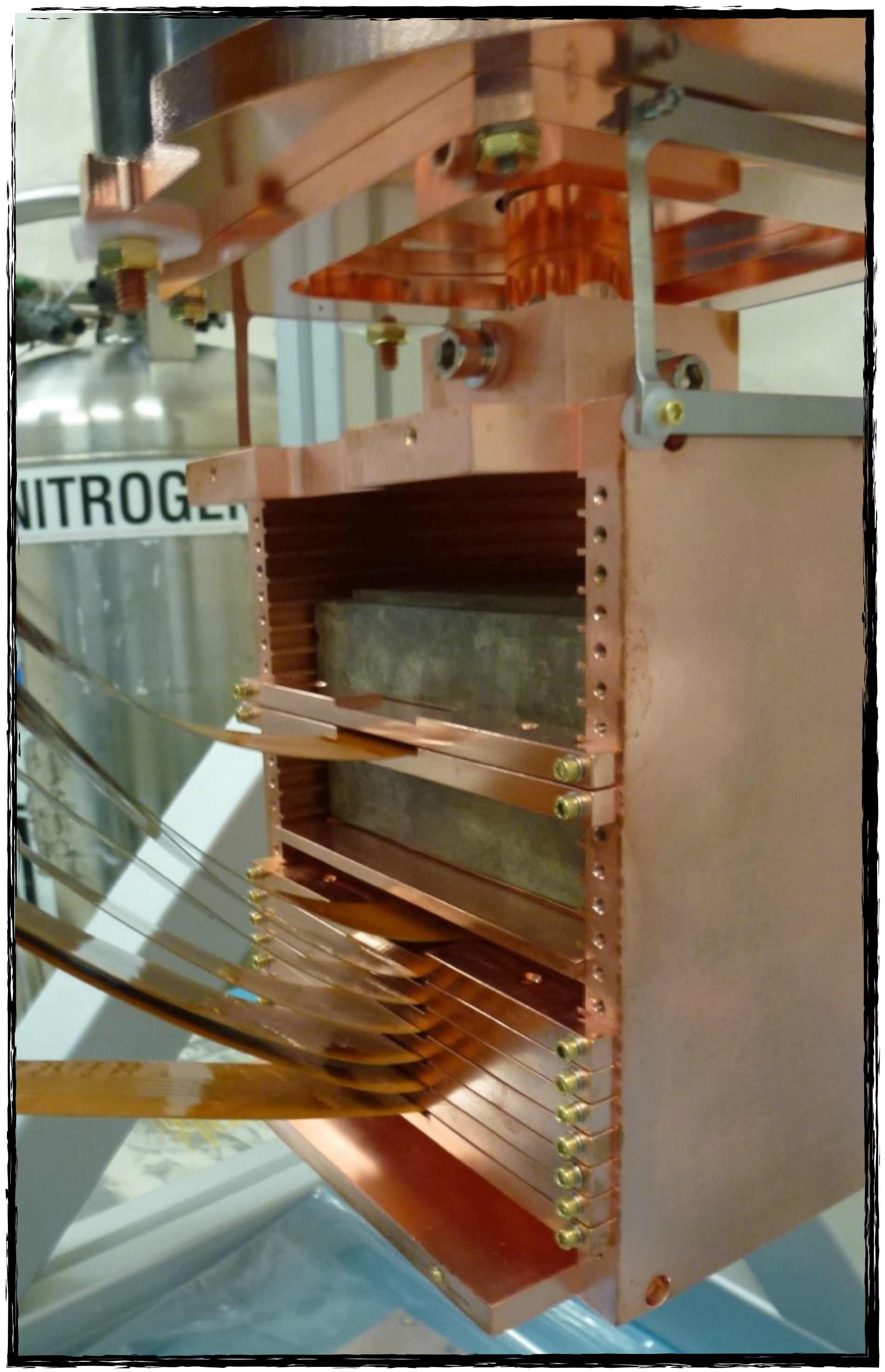
SNOLAB Installation



Dark Matter Search

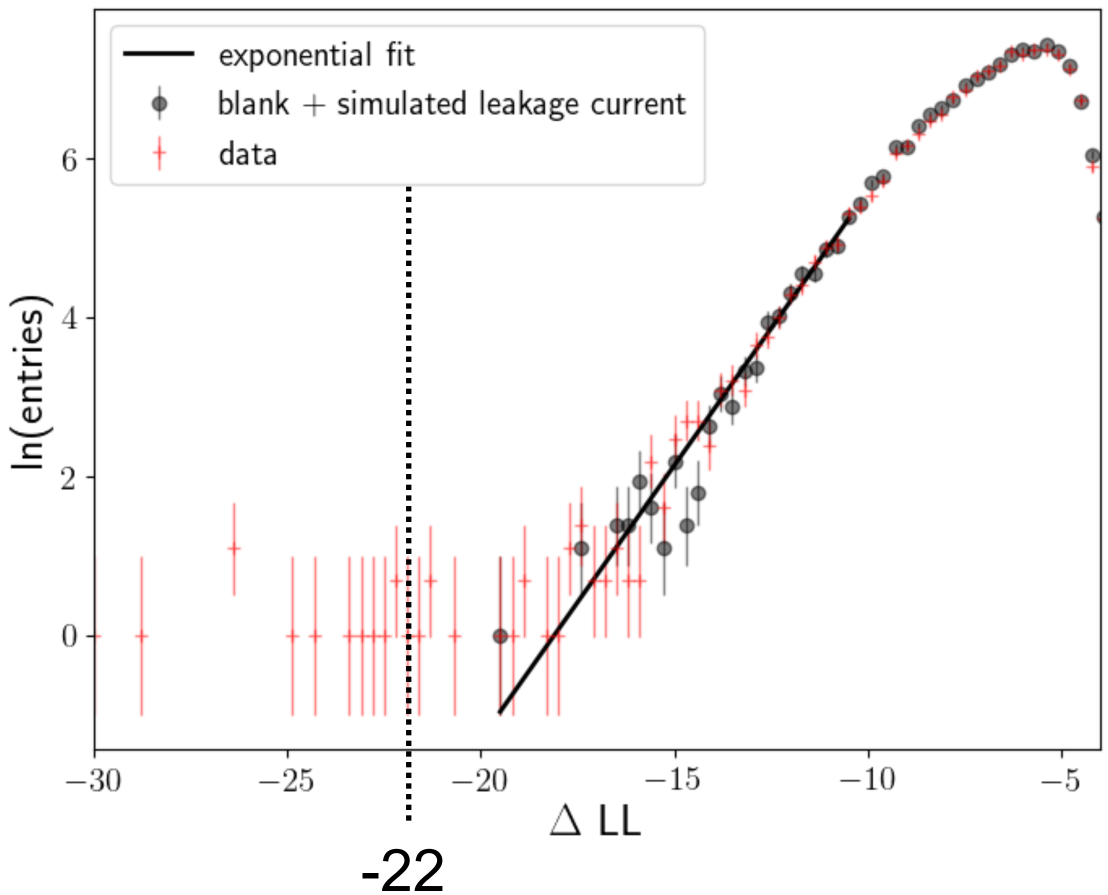
- **7 CCDs** (40 g target mass) collected **11 kg-day** of data over >1 year.
- We compare the observed spectrum of events with a model for our background.
- We measure an excess of 17.1 ± 7.6 events above background model.

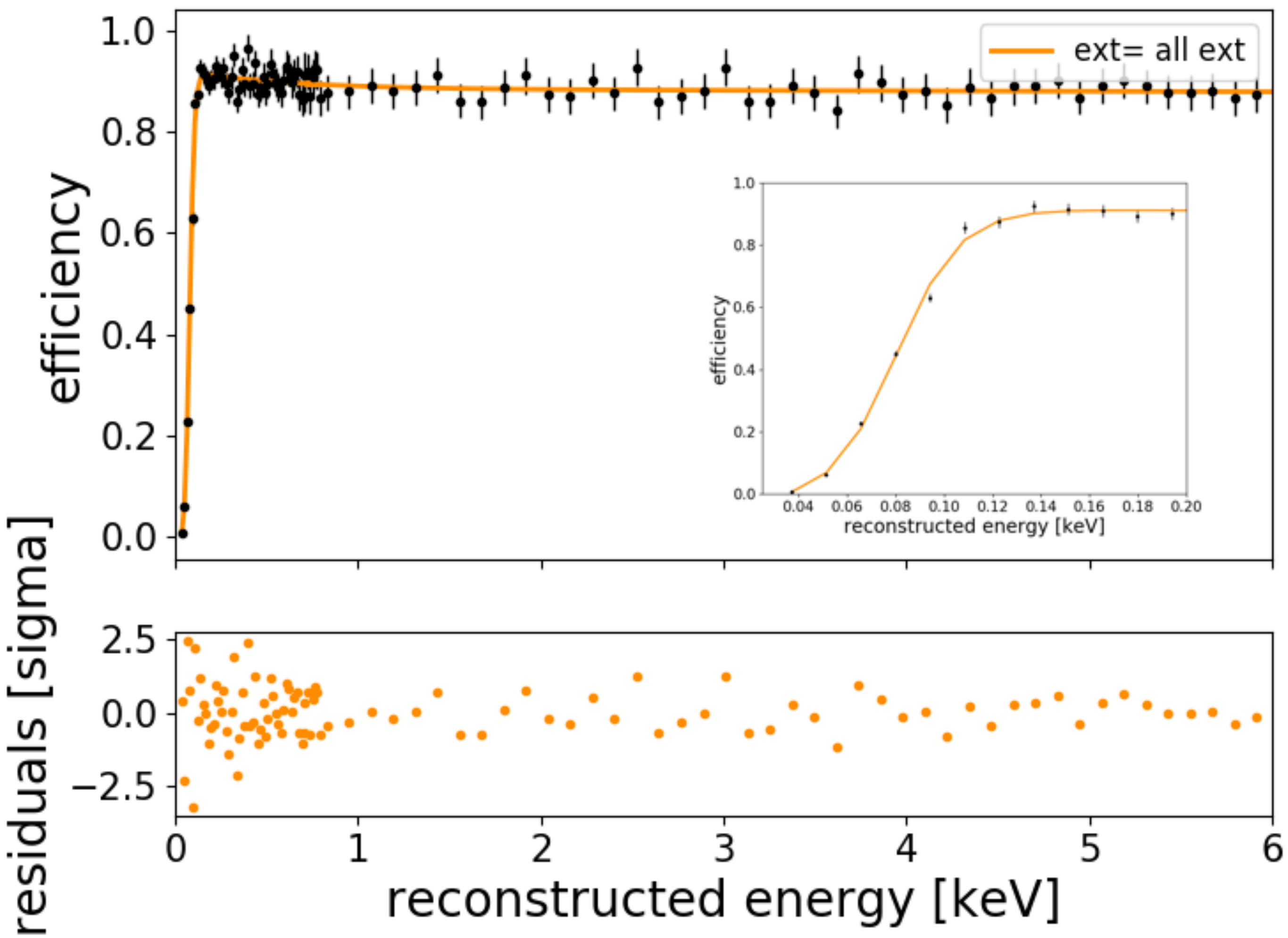




Event selection

- No clustering in *masked* regions.
- For every candidate cluster, we perform a likelihood ratio test between the white-noise only and white-noise + Gaussian hypothesis. The resulting test statistic *ΔLL* is used to reject noise.

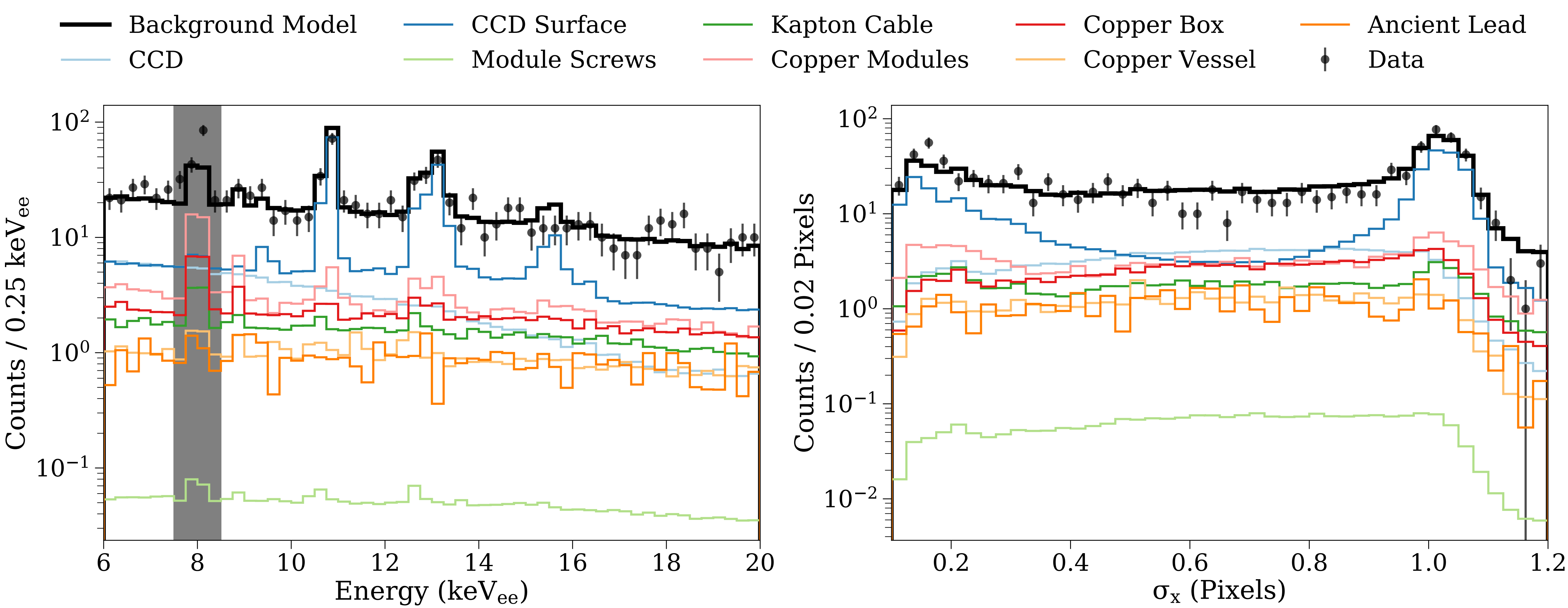




<0.1 noise events in exposure with *ΔLL* ≤ -22

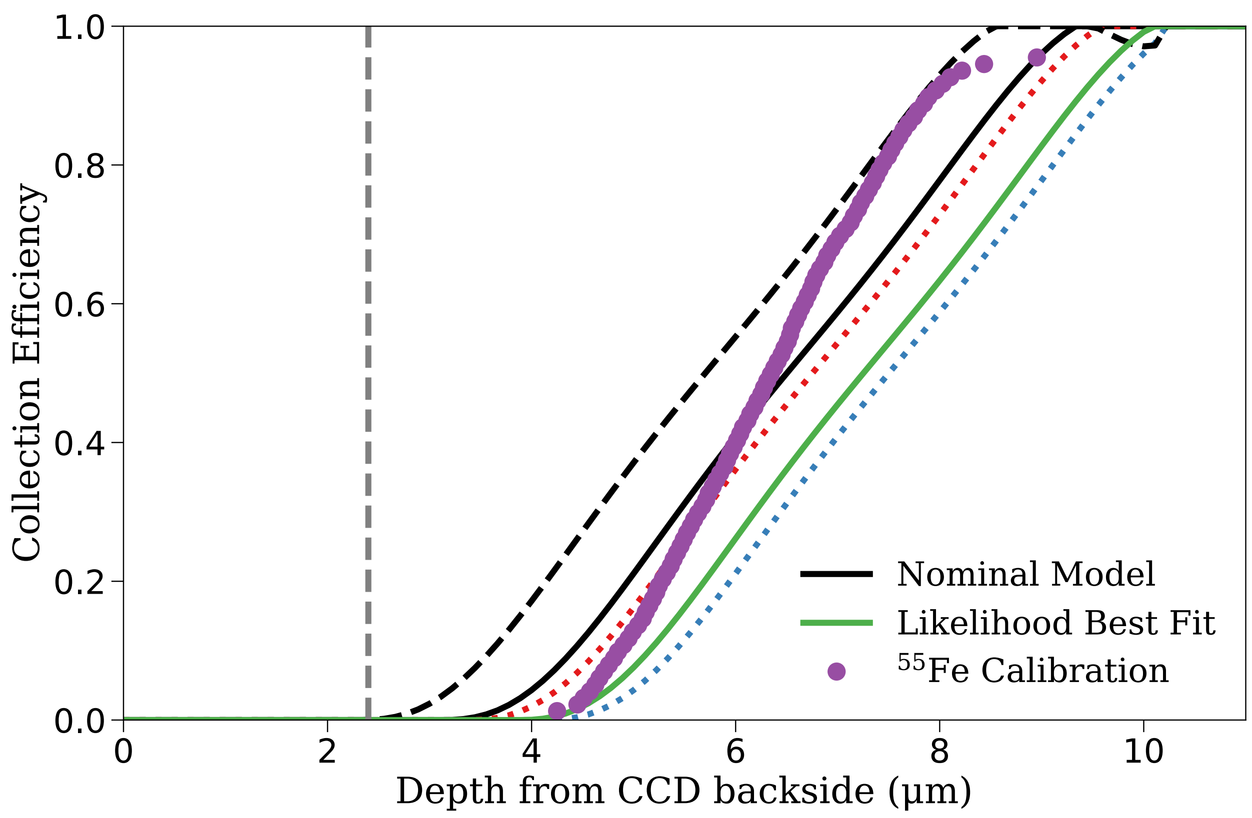
Background model

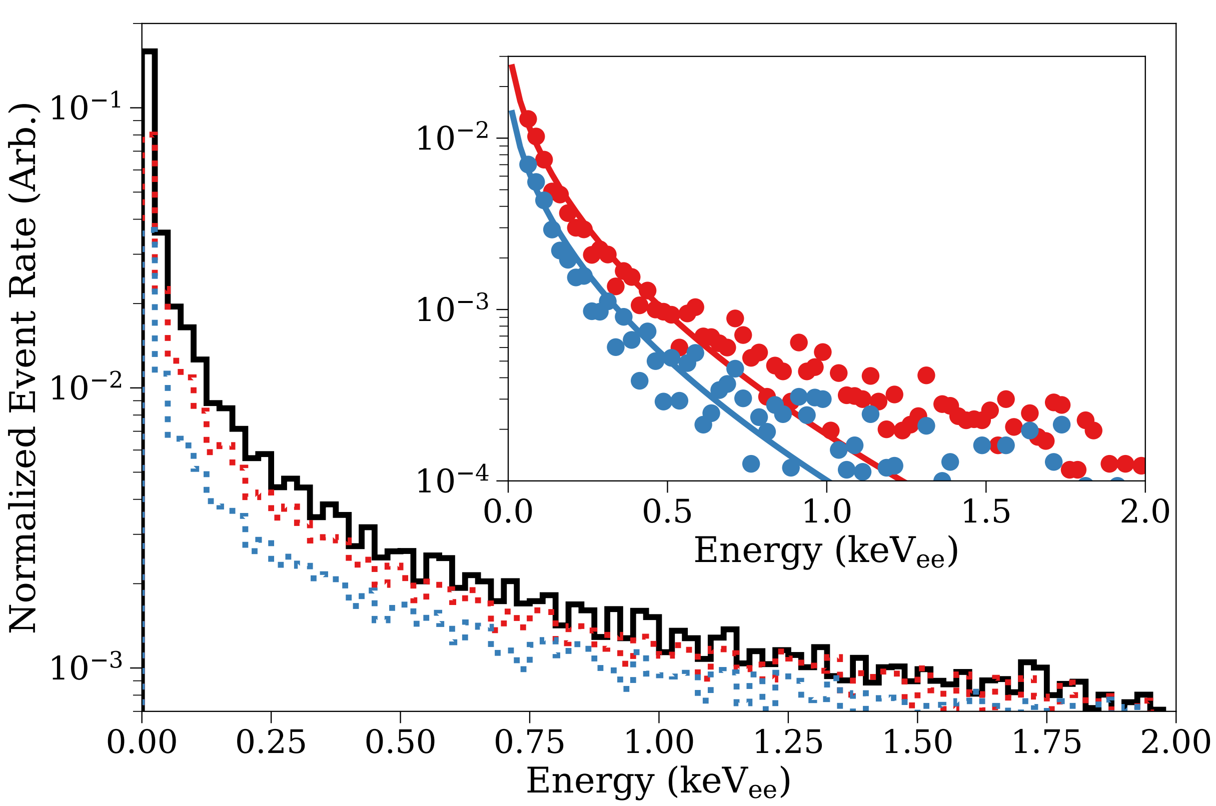
- Consider E and σ_x for final events >6 keV_{ee} (no DM signal).
- Generate Monte Carlo templates: start from radioactive decays in detector components + apply detector response.
- Fit CCD data with templates constrained by measured contamination.



Partial charge collection

- CCD backside contact in highly-doped in-situ doped polysilicon (ISDP).
- Phosphorous (P) in ISDP layer diffuses a microns into the CCD bulk.
- At intermediate P concentrations some of the ionization charge recombines ➔ partial charge collection.
- Causes spectral distortion for decays on CCD backside, esp. ^{210}Pb.
- We parametrize spectral distortion from simulation and include it as "free" component in our fit to the DM search region.

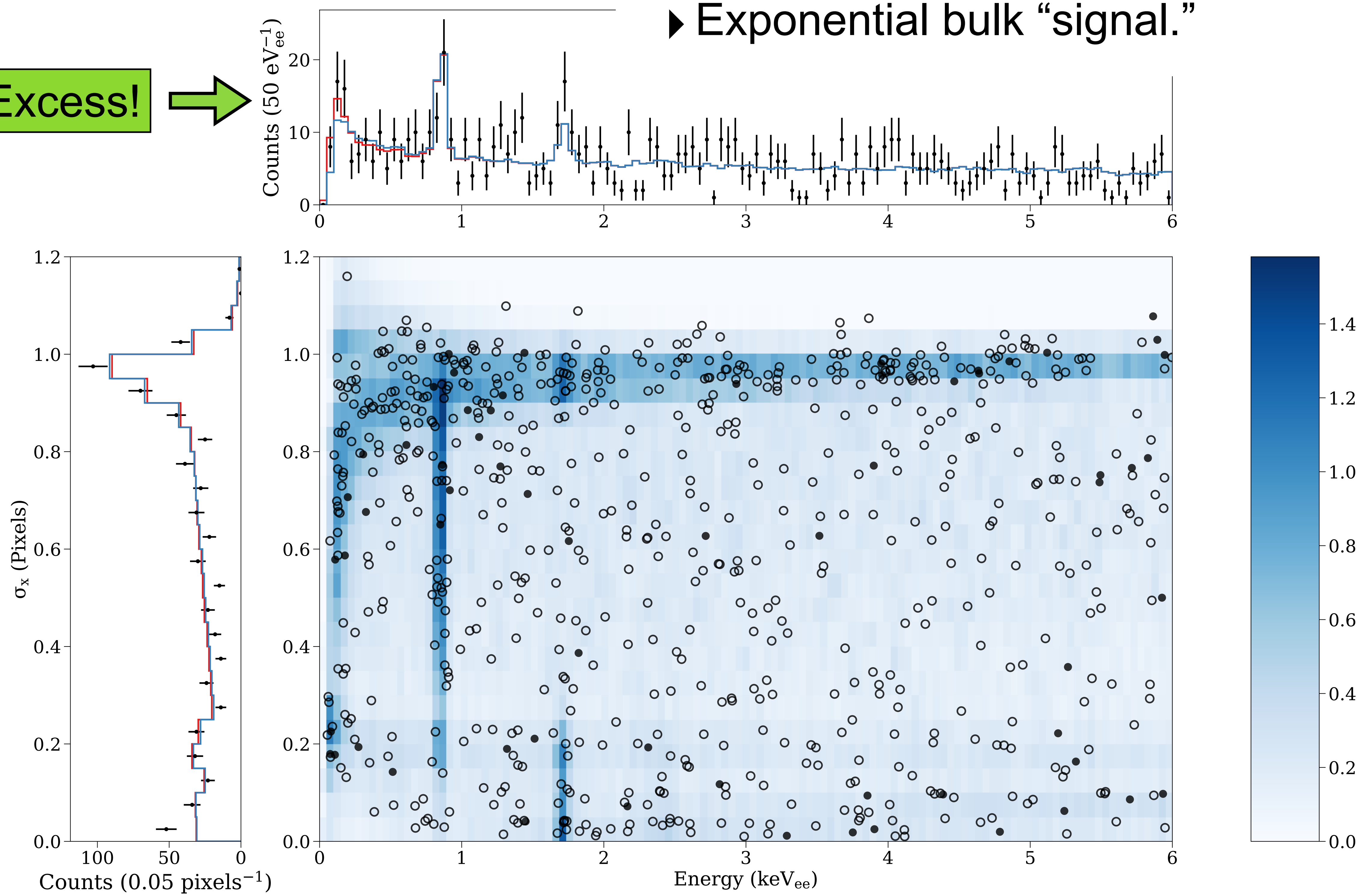




Final fit:

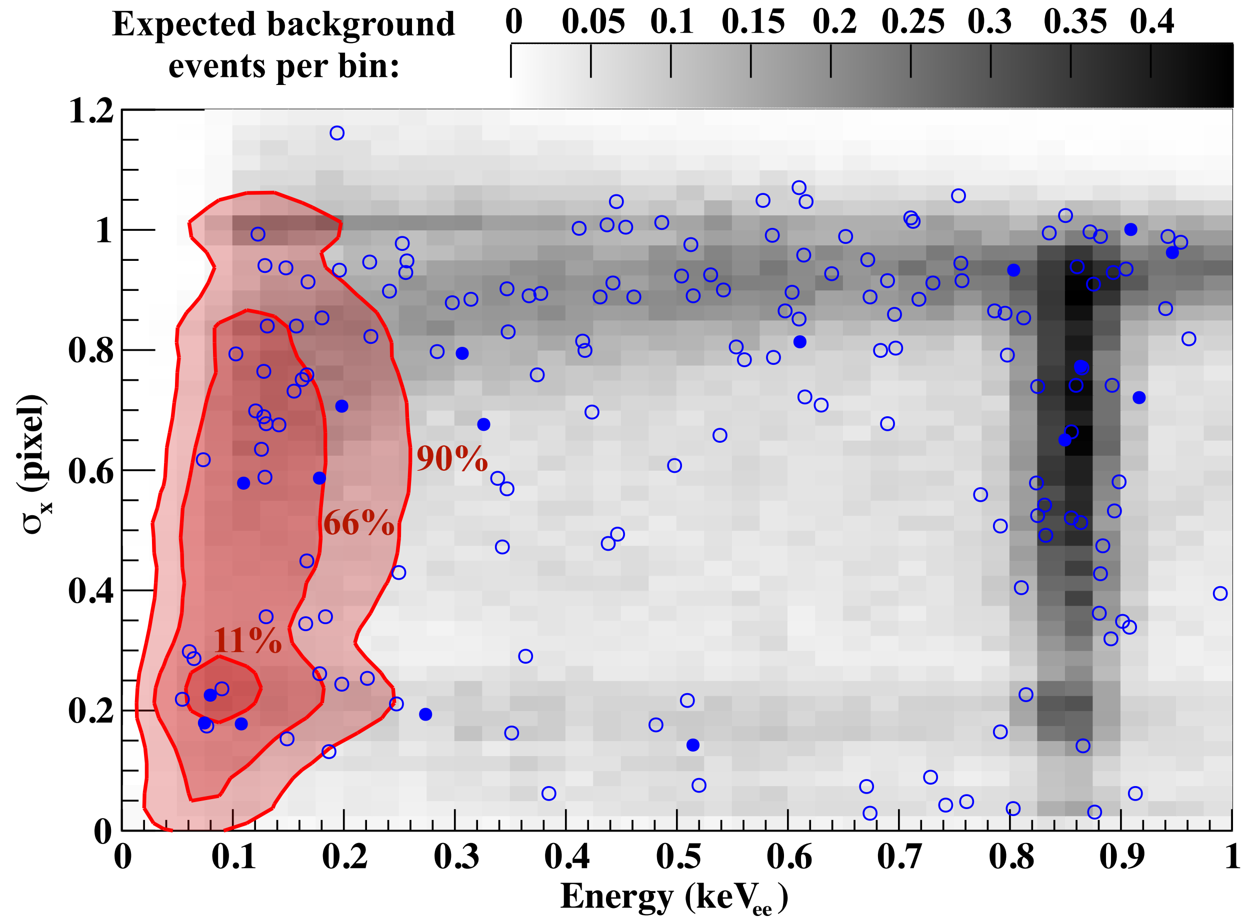
- Best background model.
- Backside PCC spectral correction.
- Exponential bulk "signal."

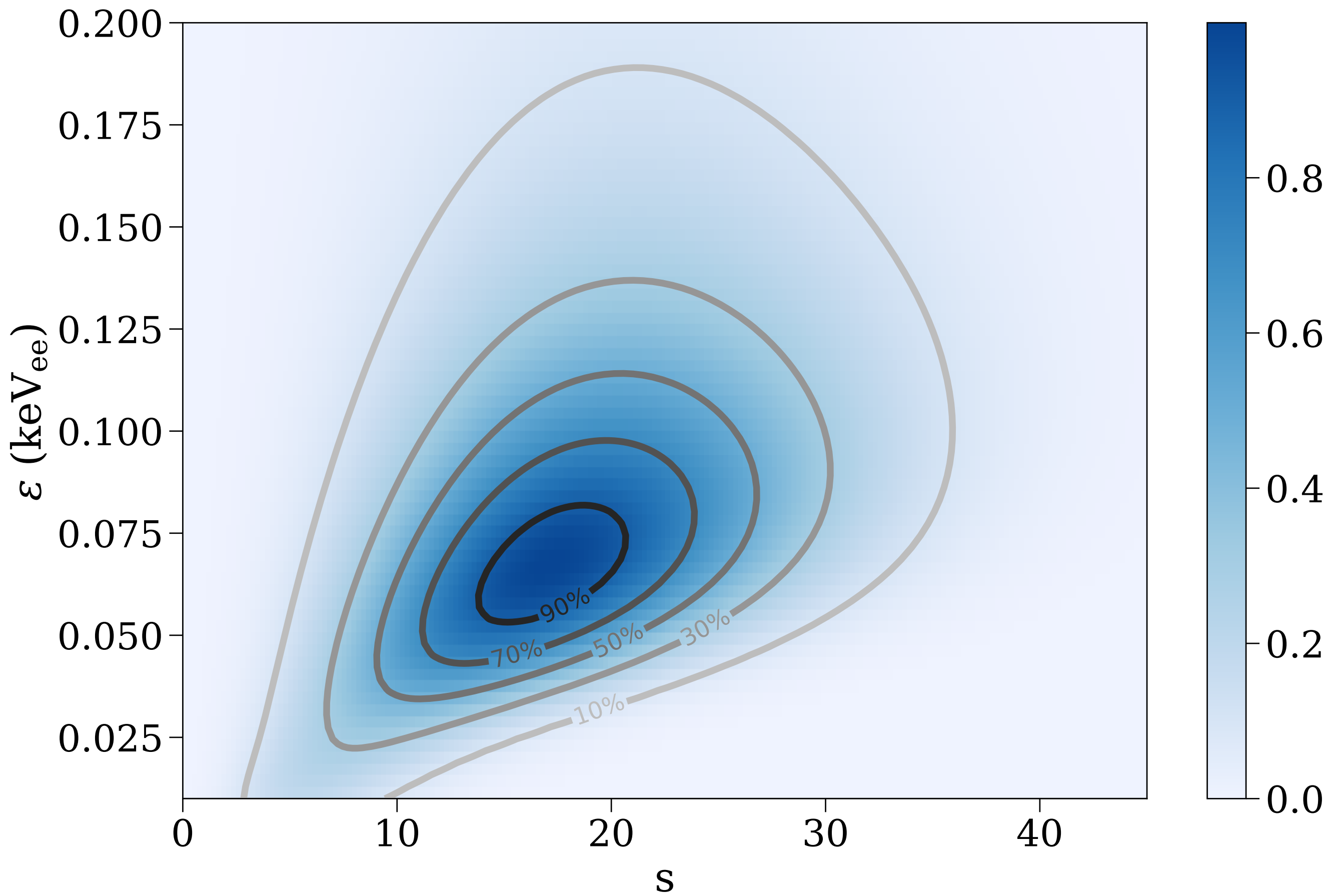
Excess!

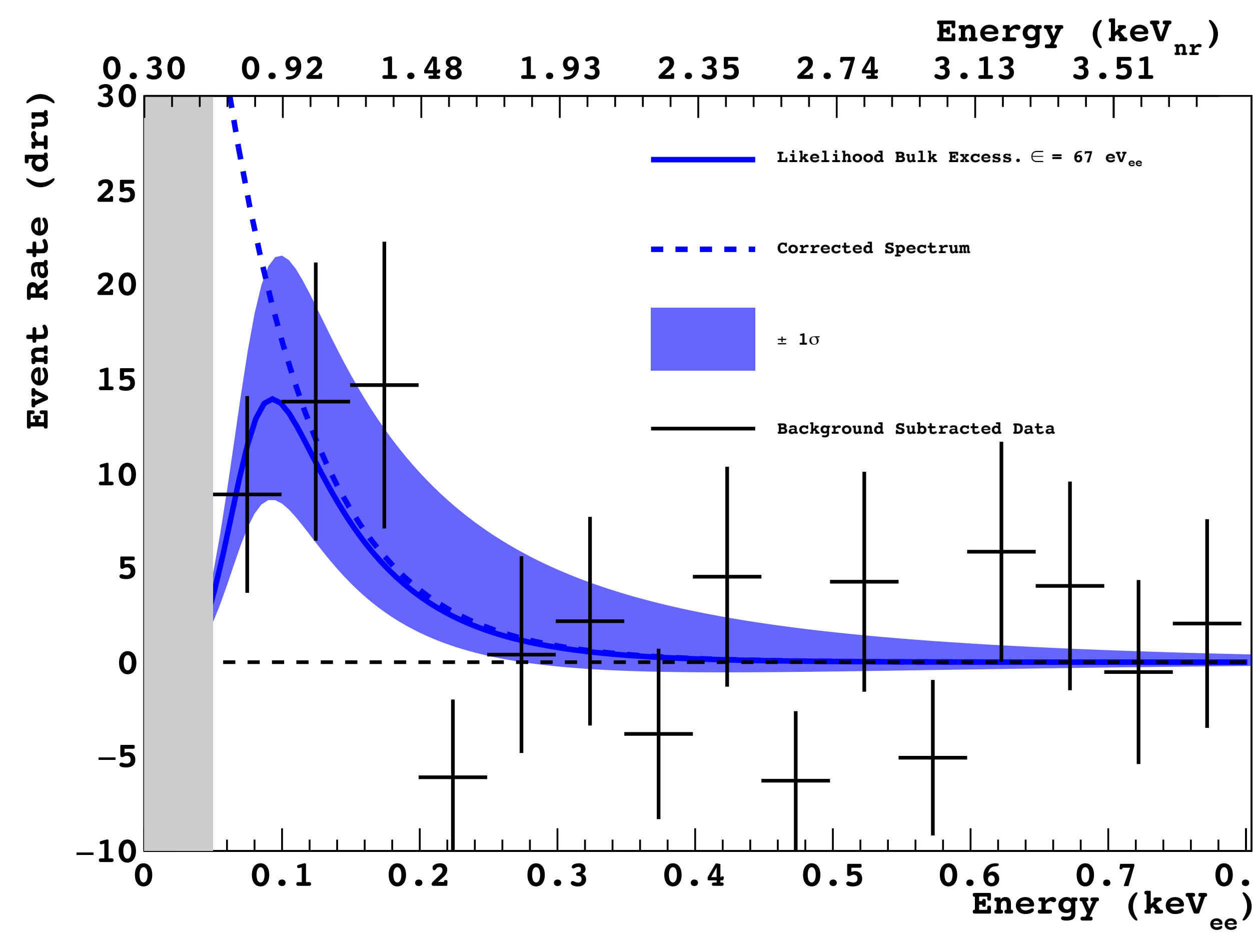


Excess

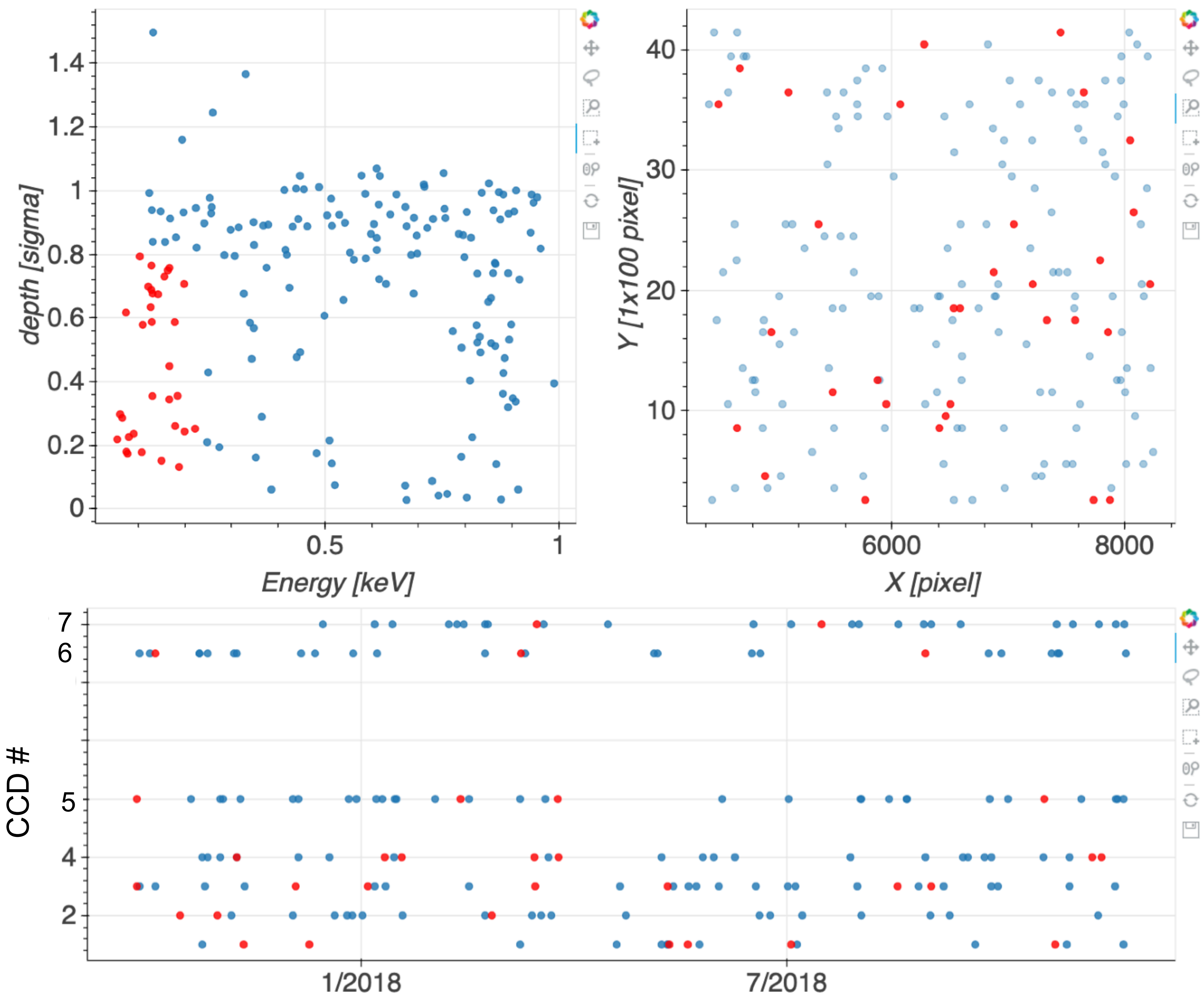
- Excess of 17.1 ± 7.6 events.
- Exponential decay spectrum with ε = 67 ± 37 eV_{ee}.
- Fit prefers signal + background over background-only with ***p* value** 2.2 x 10^{-4}.





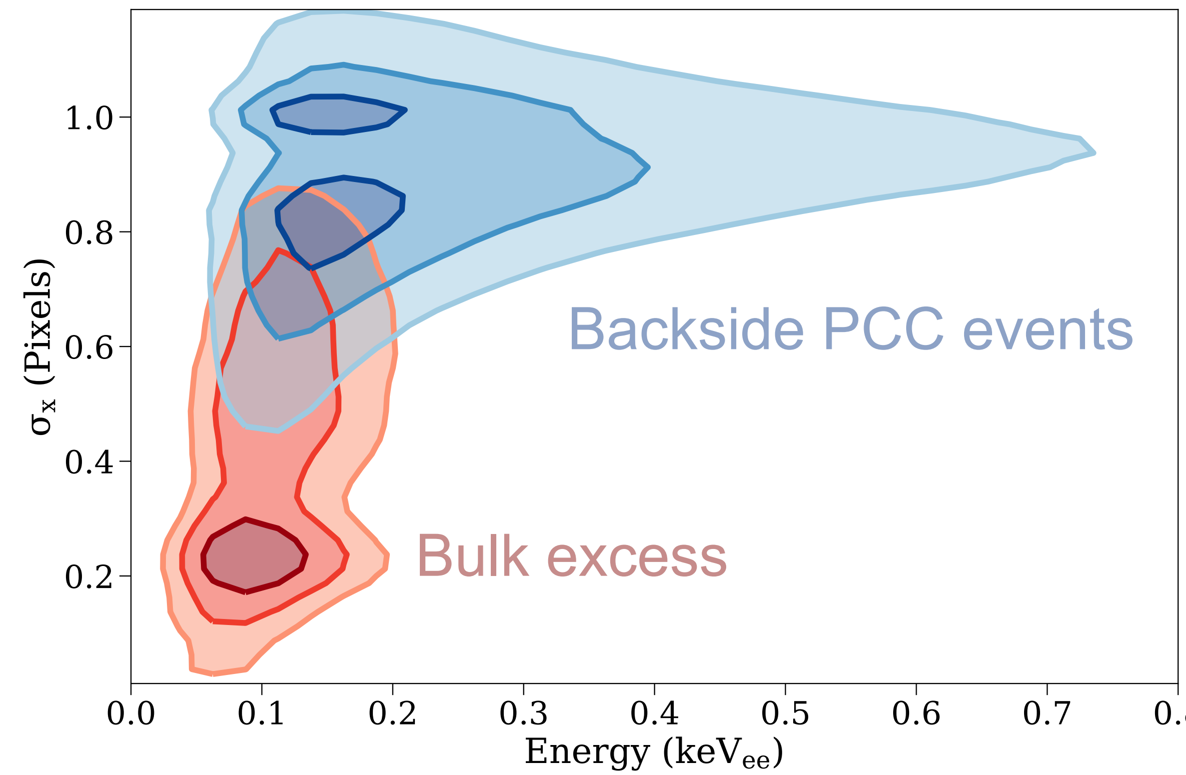


Event distributions



Systematics

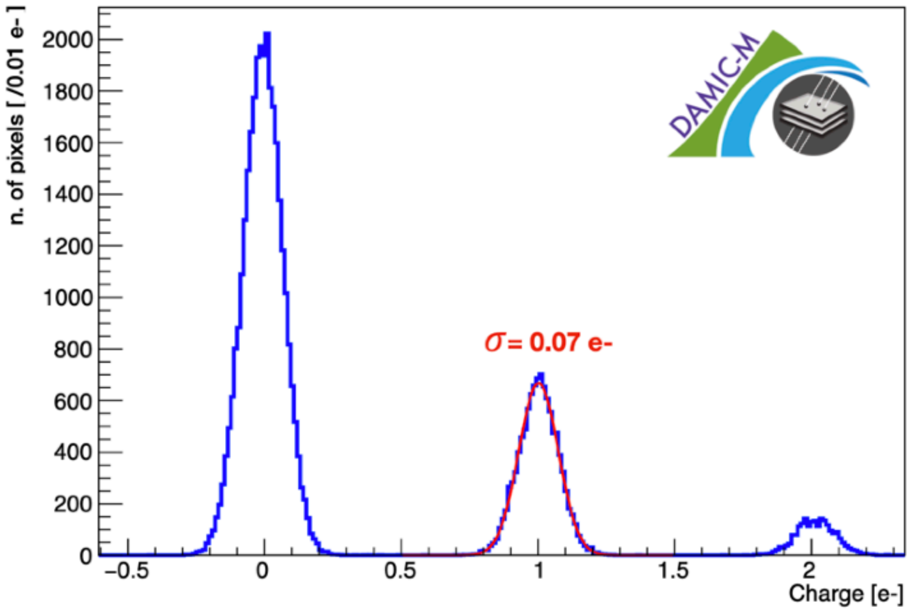
- Events really look like they are in the bulk:
- 1) Compare backside and bulk signal distributions.
- 2) Perform signal extraction after removing single-pixel events (preferentially from the front surface): Consistent exponential excess with ***p* value** 2.6 x 10^{-3}.
- Statistically, data is well-behaved: no statistically significant features in the spectrum besides the low energy excess.

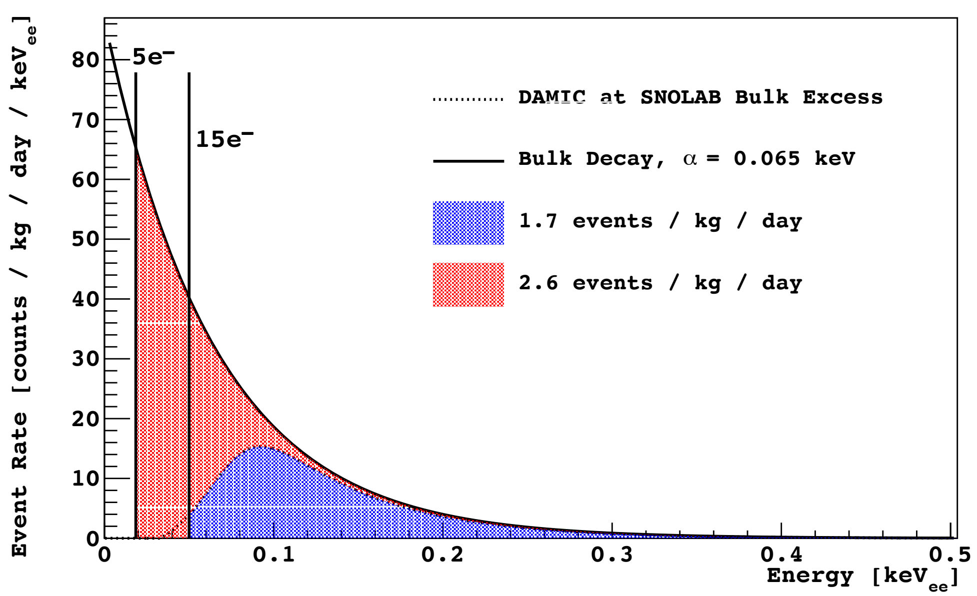


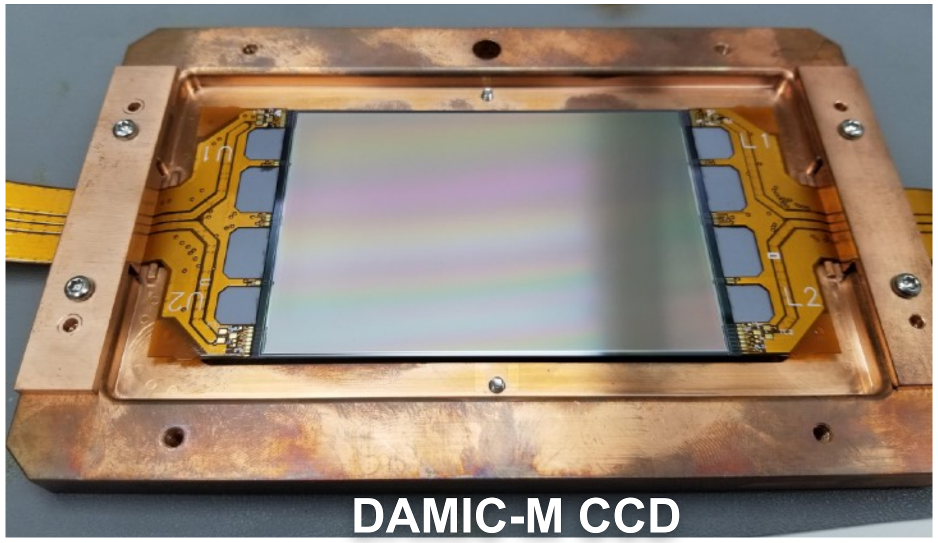
- No *known* background or detector response hypothesis to explain the excess.
- Known unknowns: unidentified noise source? imperfect surface background response model?

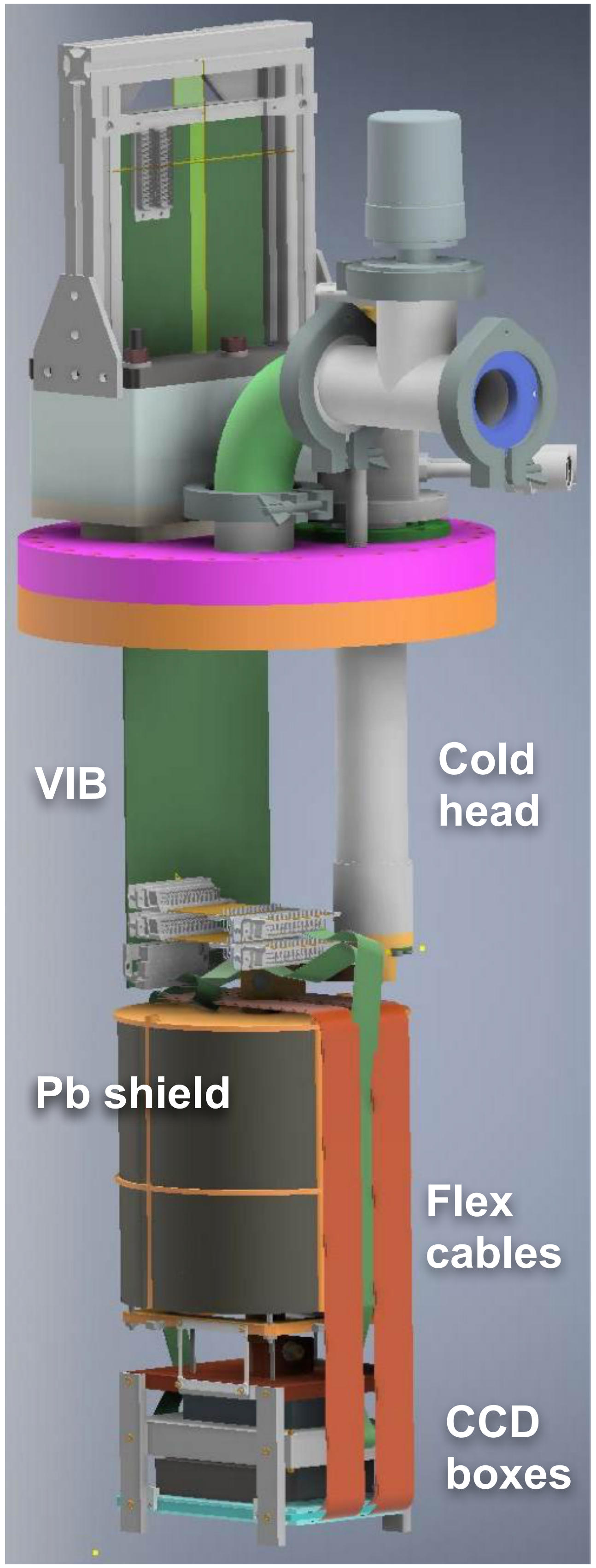
DAMIC Upgrade

- Install DAMIC-M and SENSEI skipper CCDs in DAMIC cryostat.
- Two 6kx4k CCDs and four 1kx6k CCDs (27 grams).
- *Same* background environment, *much better* energy and depth reconstruction.
- Does the excess persist?









Thank you!