Status of DAMIC at SNOLAB

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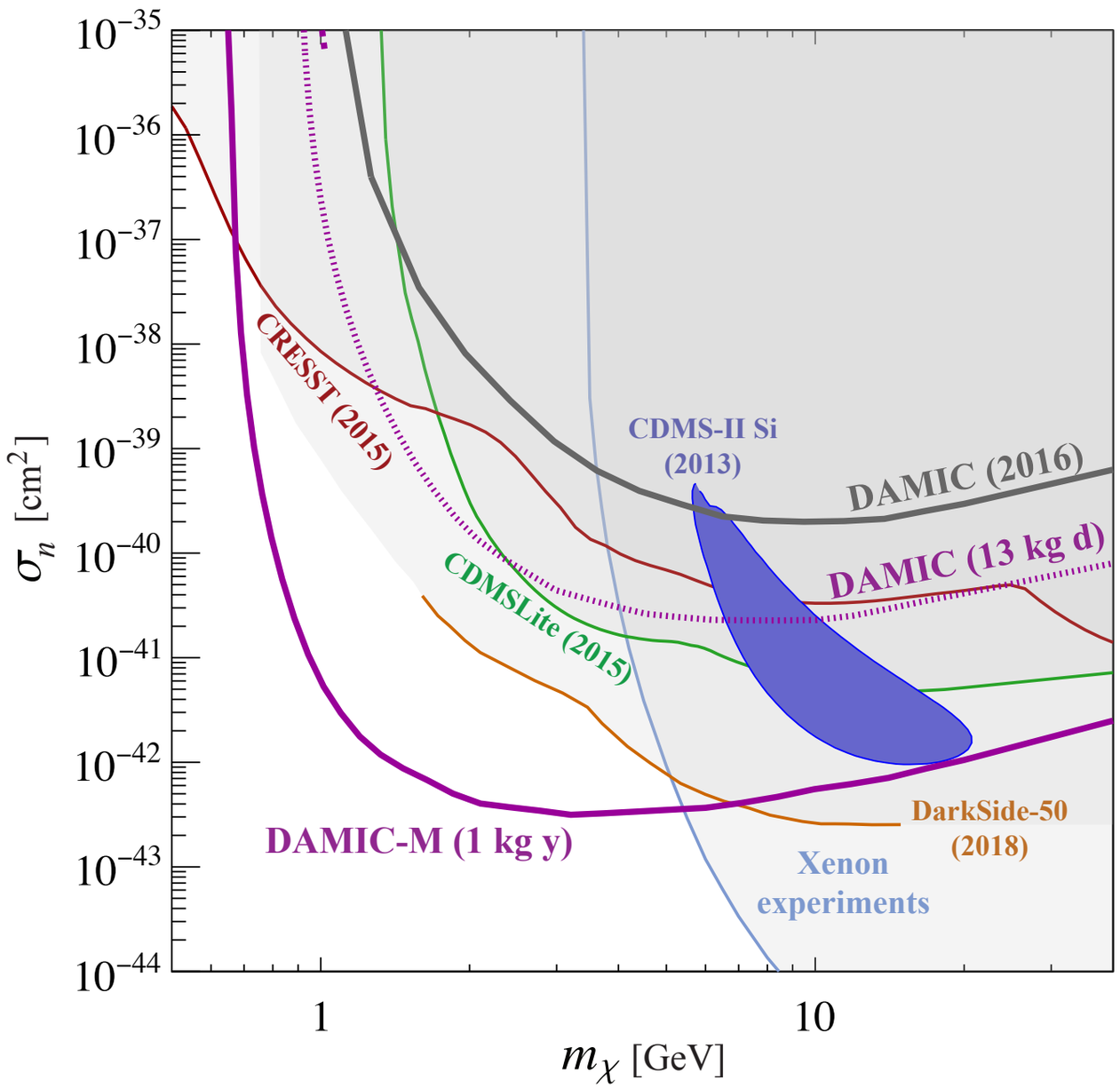
Sensitivity

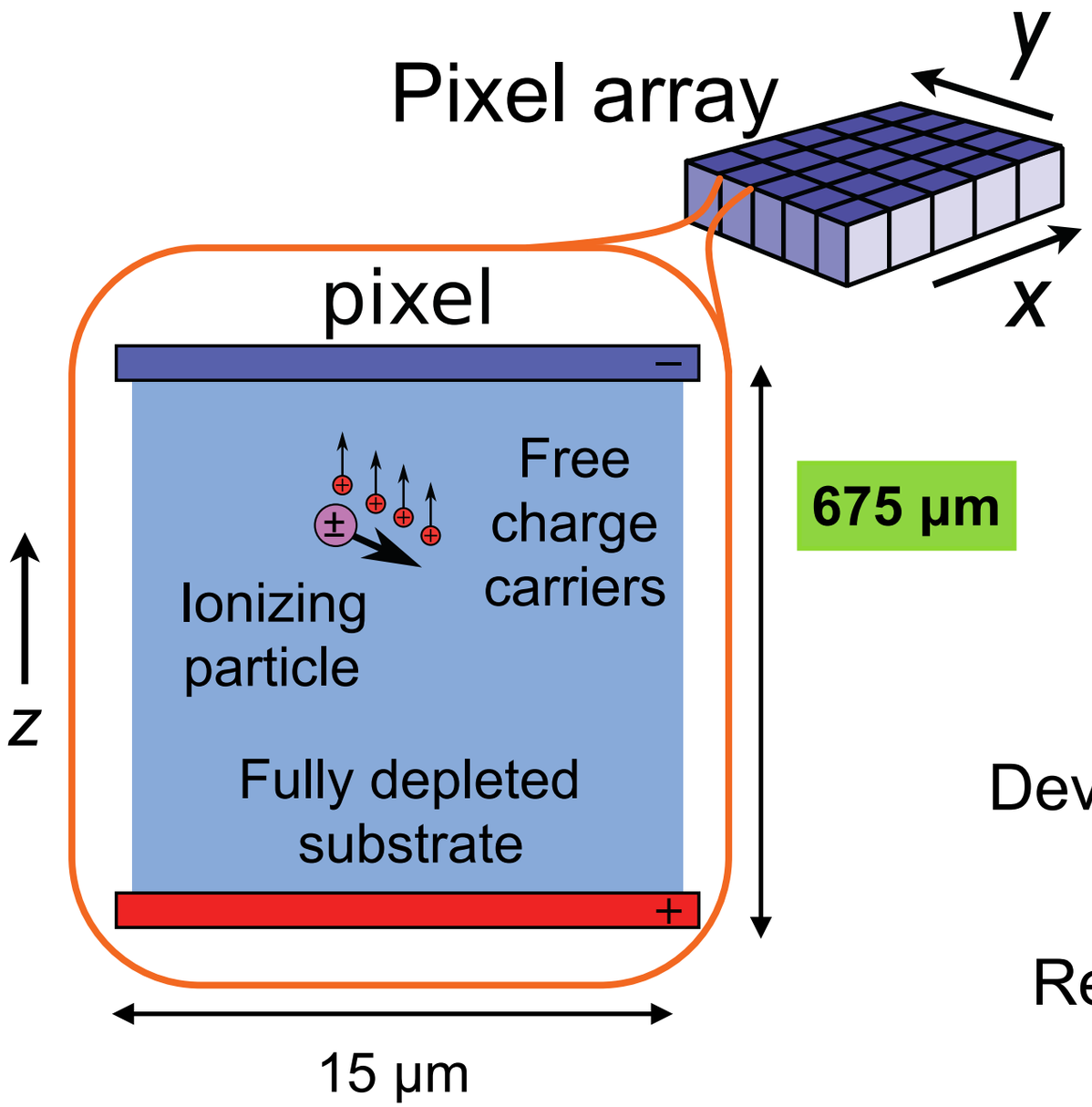


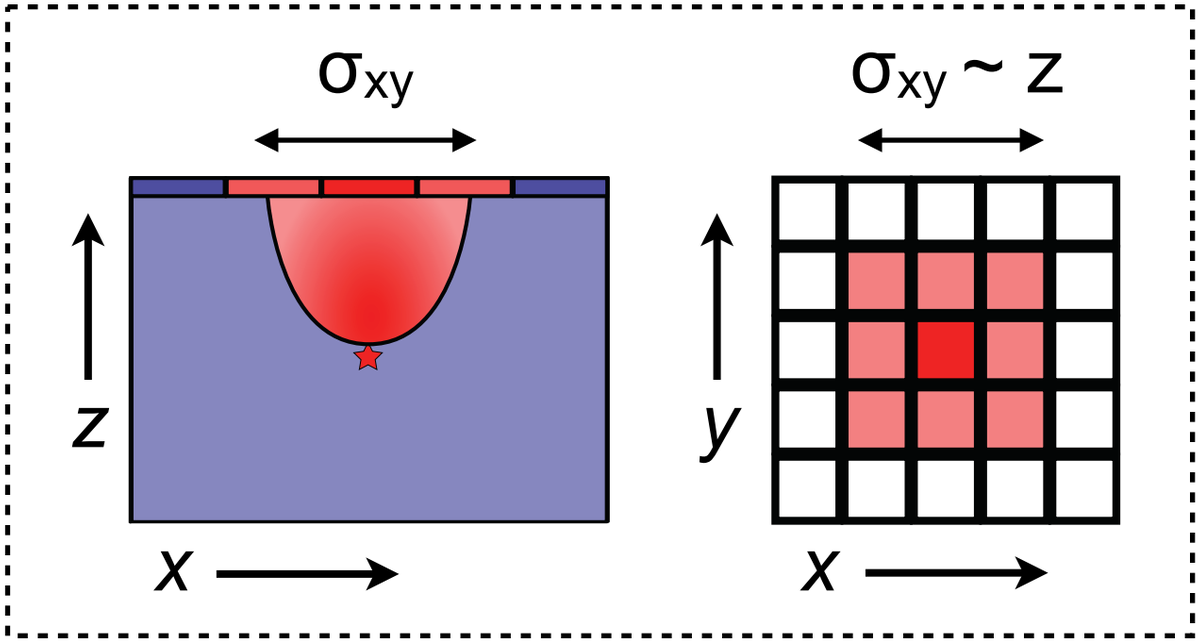
Sensitivity by **end 2018** with measured background and detector performance.

Three excess events in **CDMS-II Si**
0.19% probability for background-only hypothesis

PRL111 251301

Charge coupled device





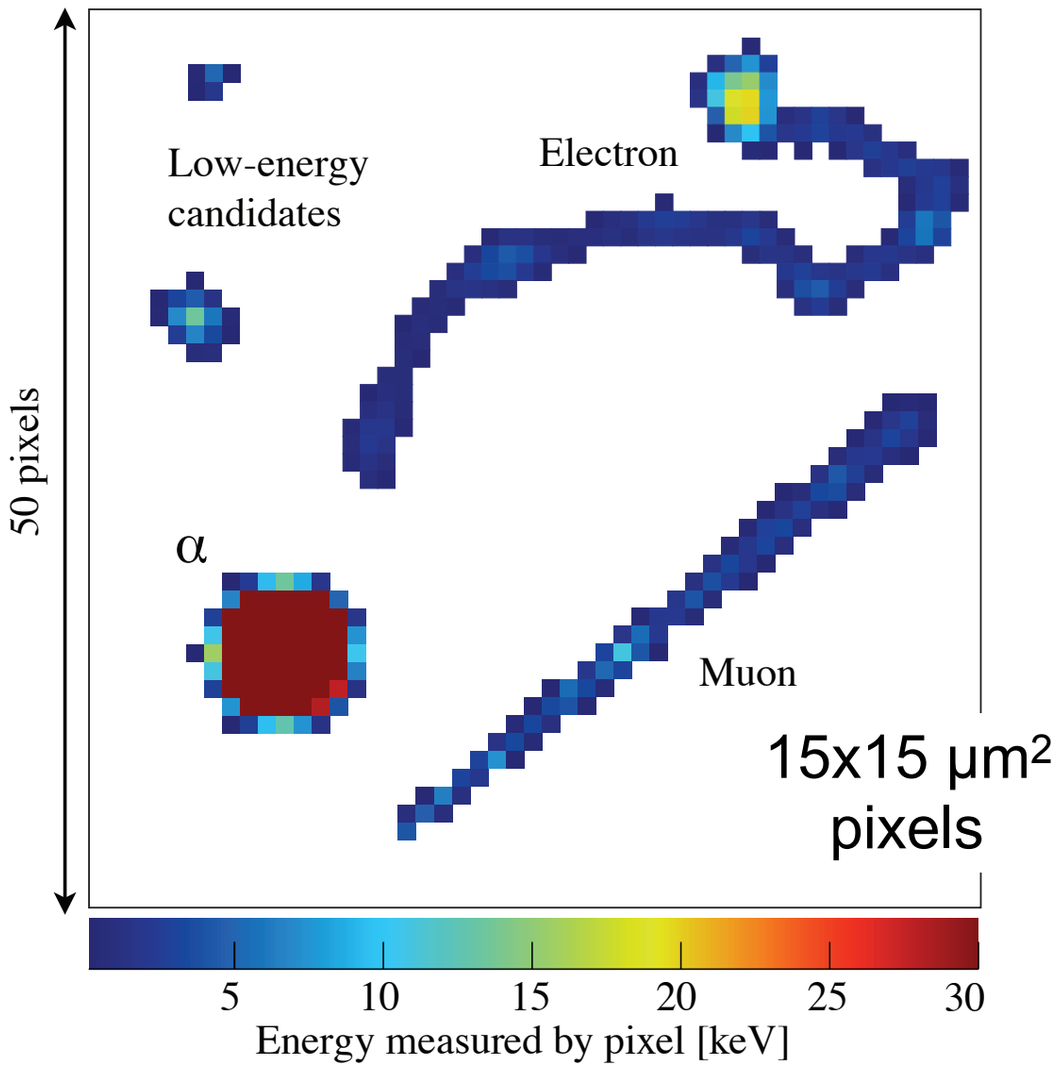
Standard fabrication in semiconductor industry and easy cryogenics (~100 K).

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

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

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

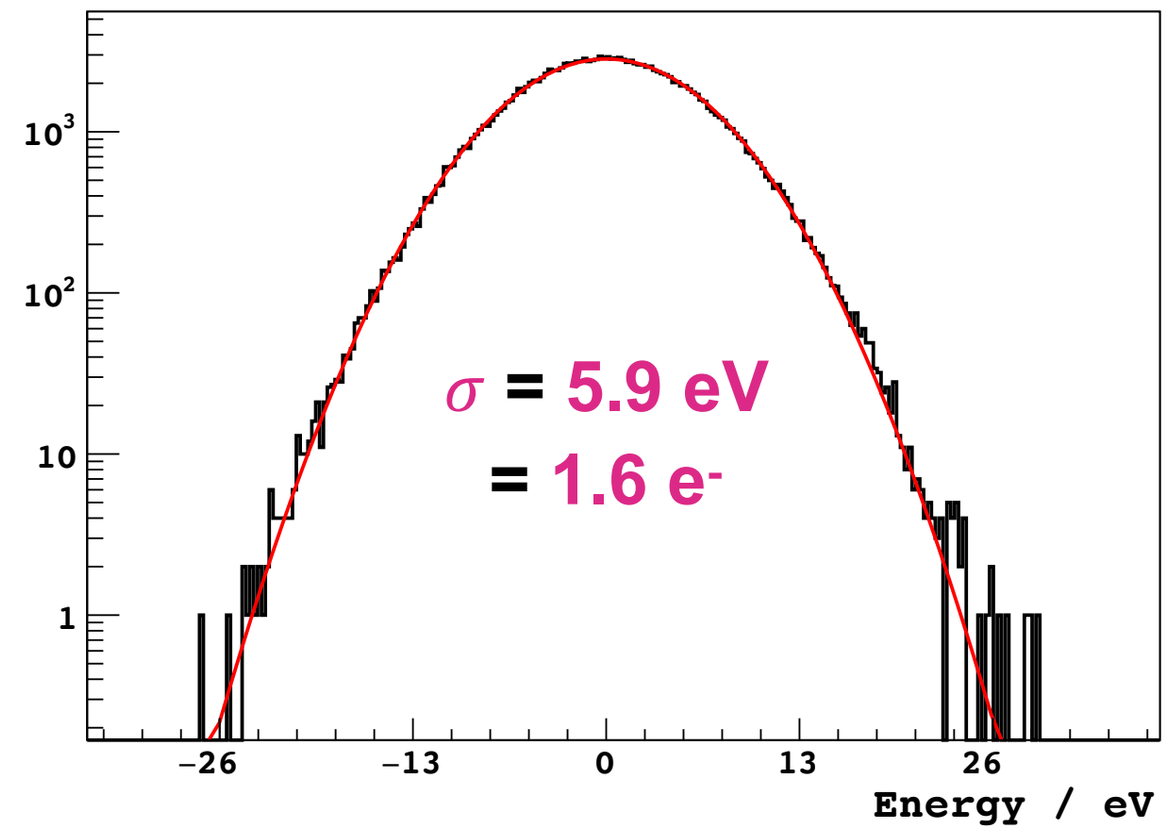
Perfomance



particle identification and background characterization

$\sigma_{xy} \approx z$: fiducial volume definition

Pixel charge distribution

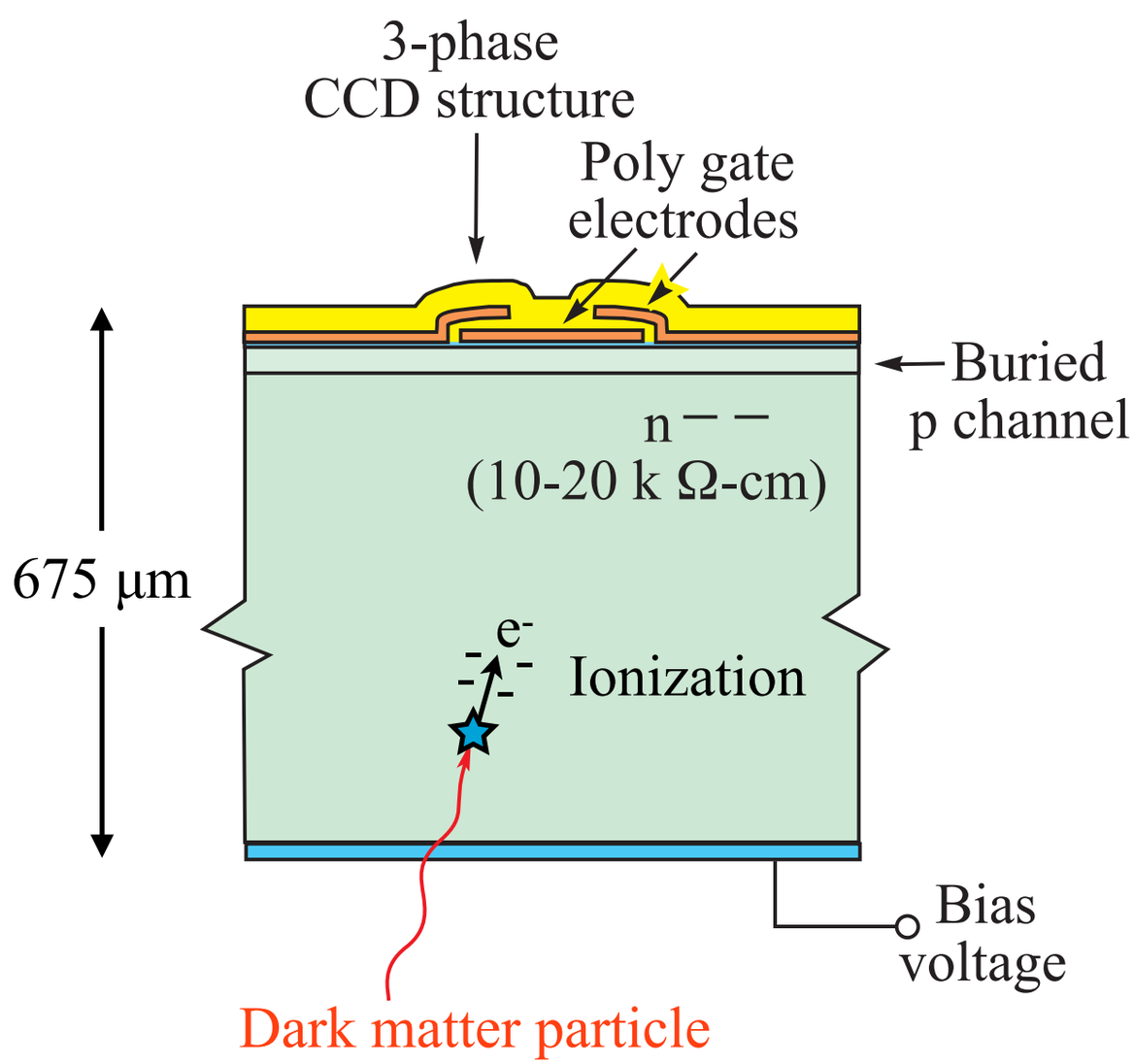


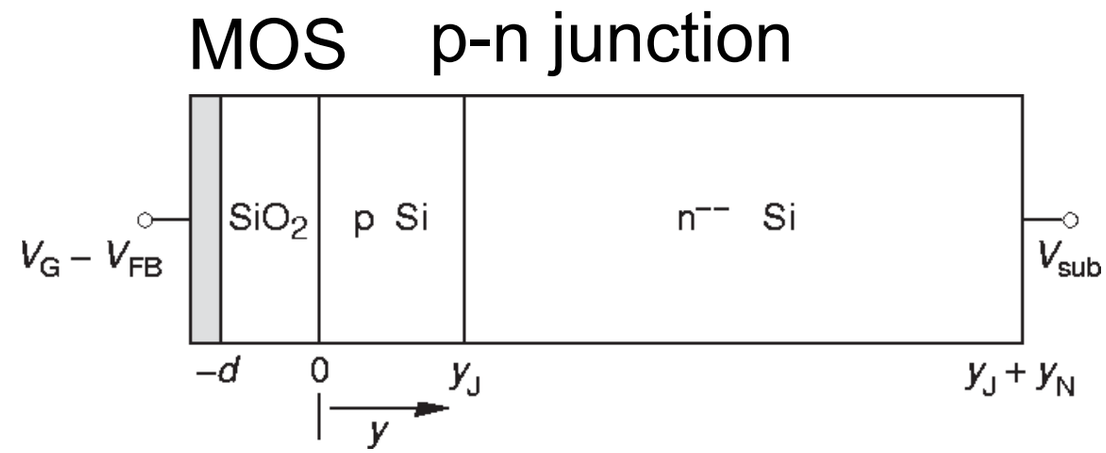
Very low noise and dark current

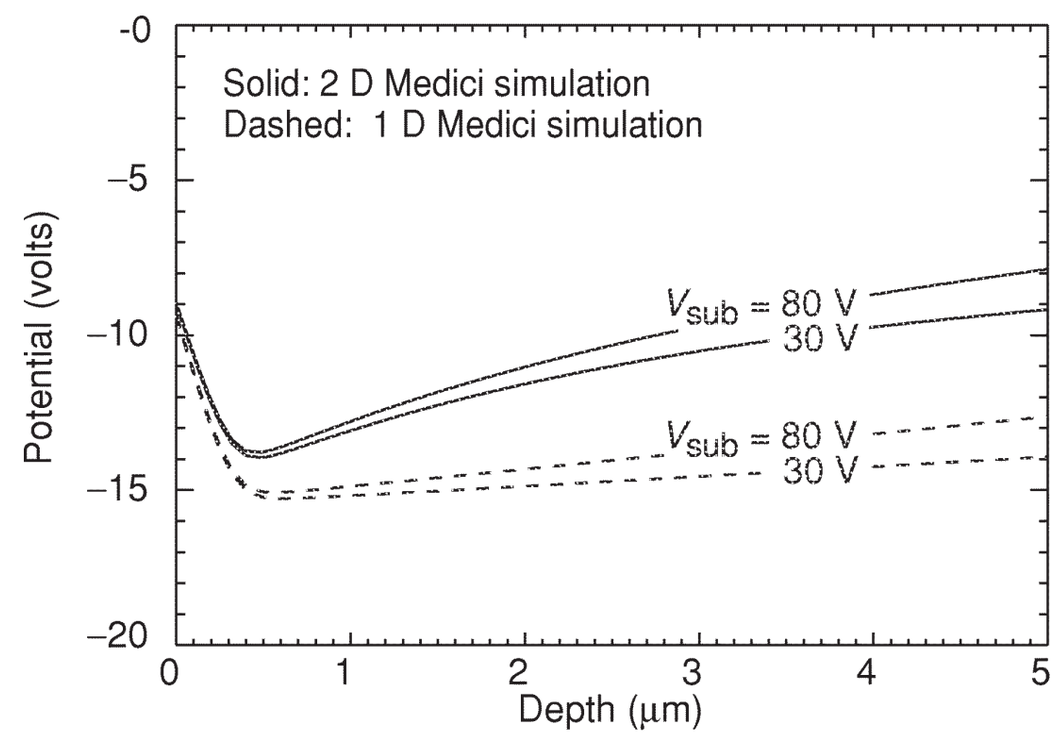
lowest dark current ever measured in a silicon detector:

5×10^{-22} A/cm² (at 140 K)

DAMIC CCD

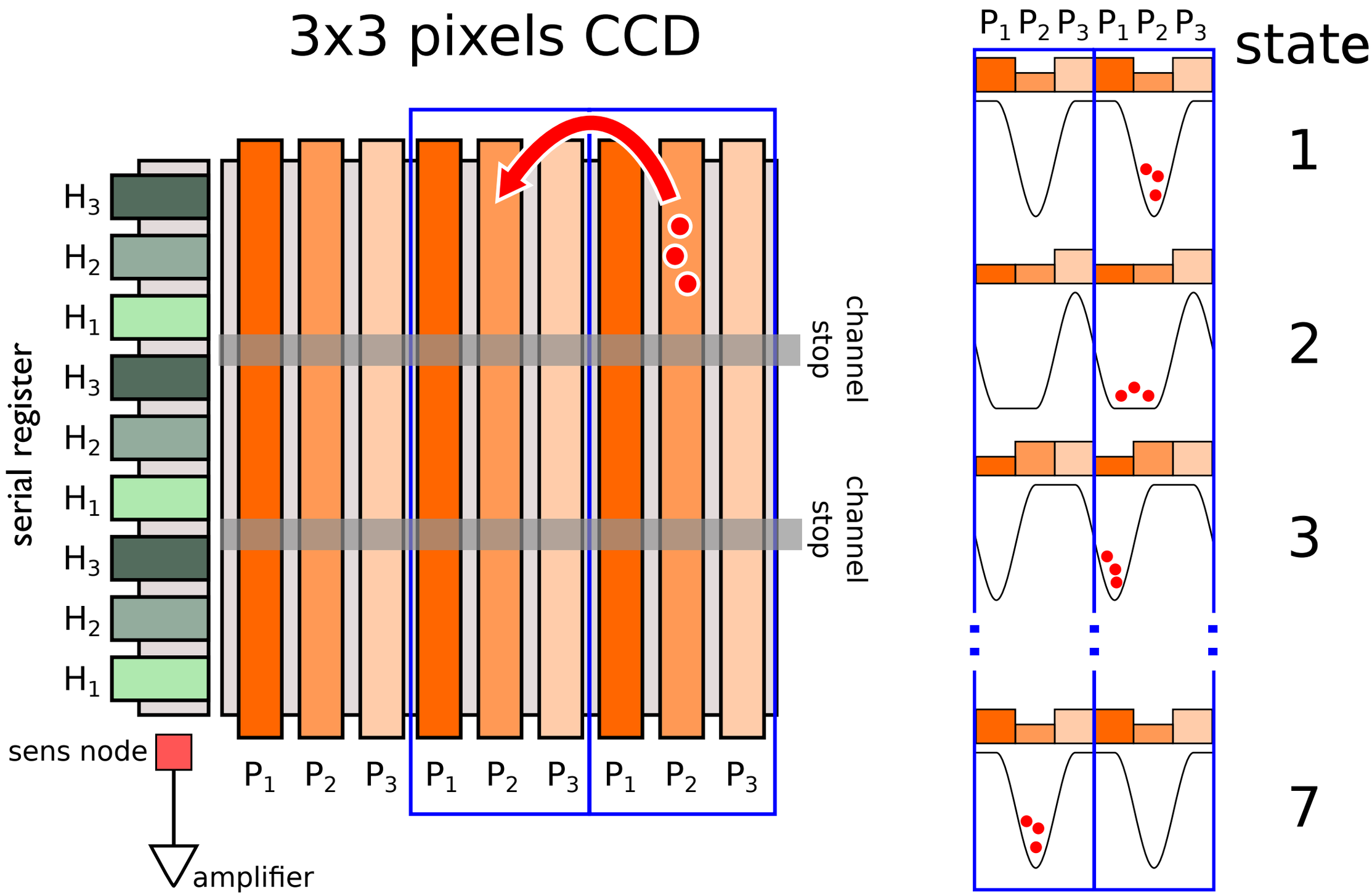




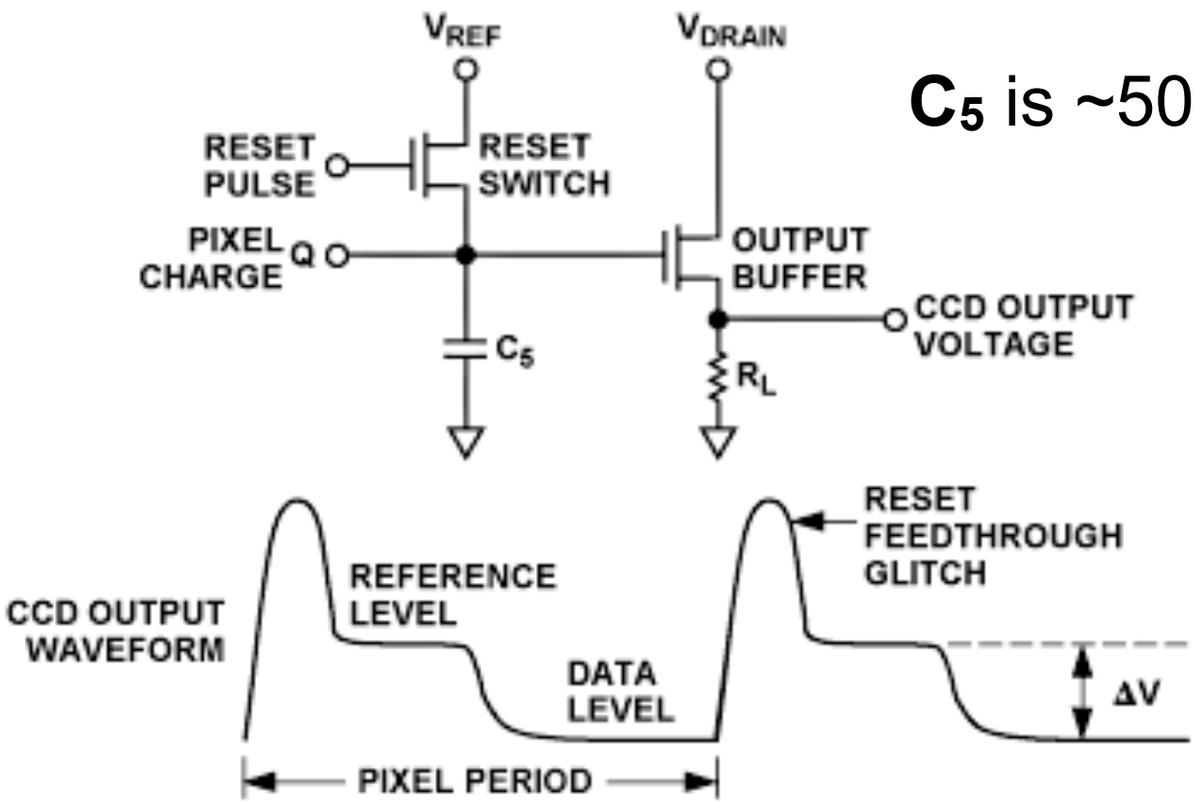


LBNL design

CCD readout


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

CDS readout

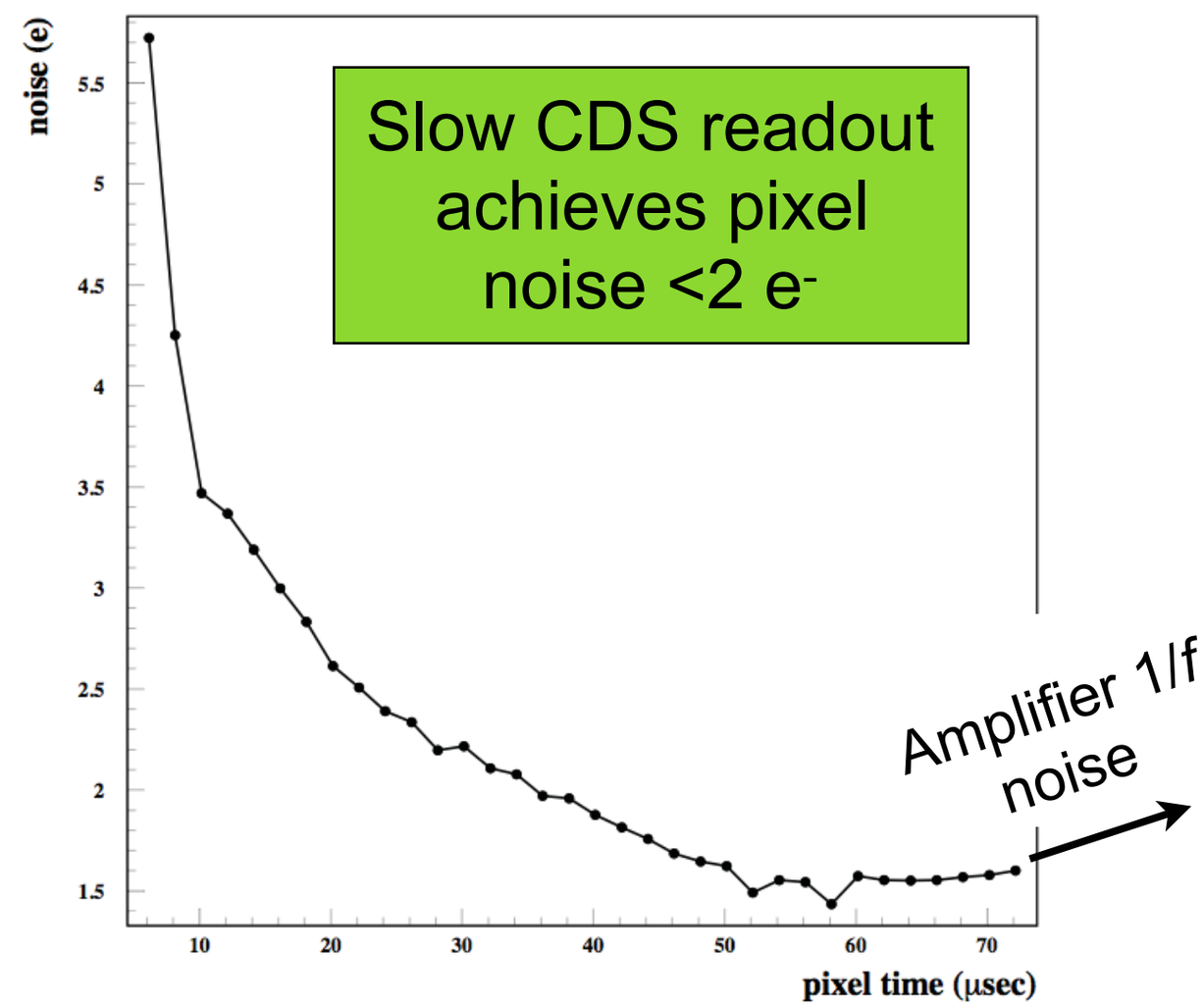


C_5 is ~50 fF

ΔV is ~3 μV per e-

"Skipper" readout can improve noise further

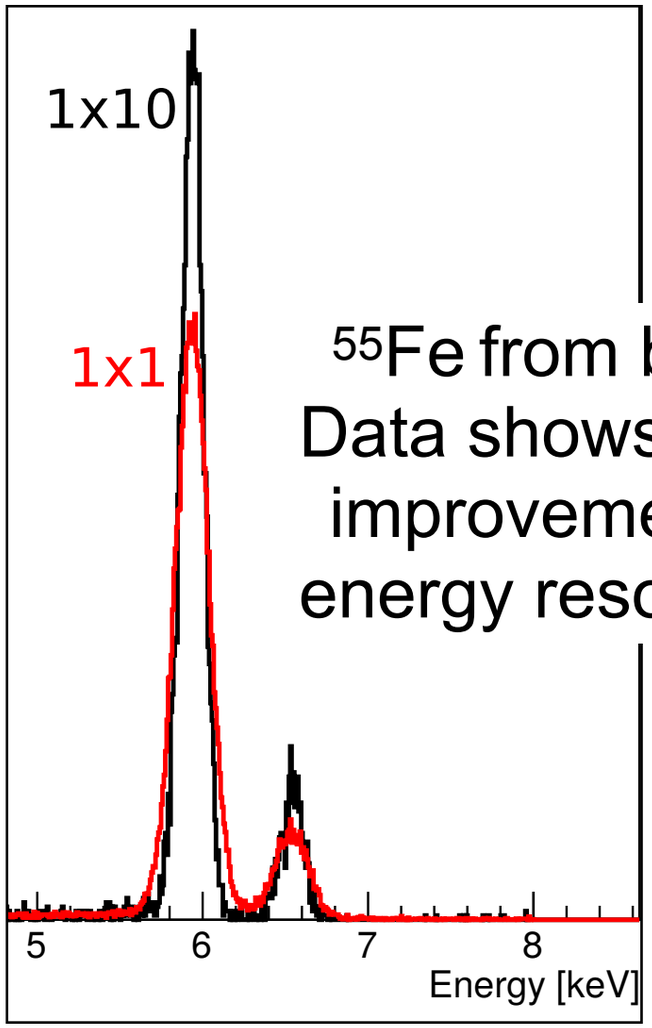
CDS: "Correlated double sampling"



Flexibility in readout

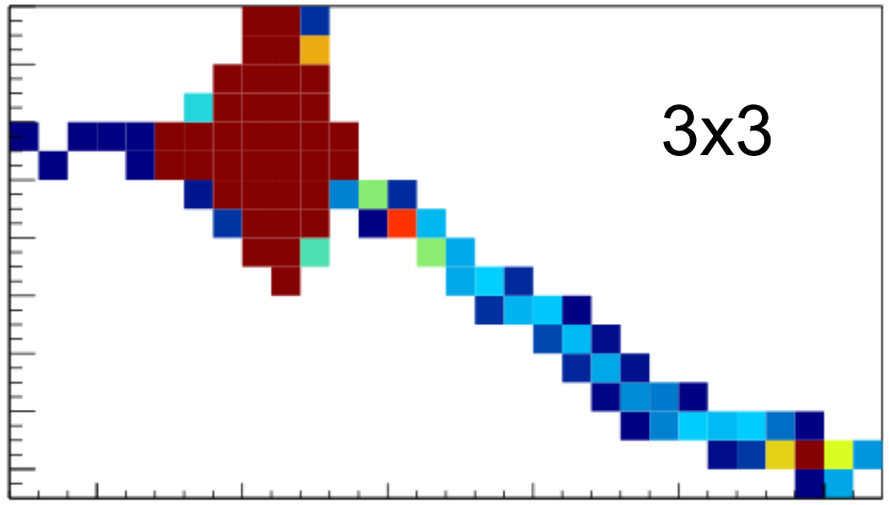
Pixels can be readout in “groups” and the total charge estimated in a single measurement.

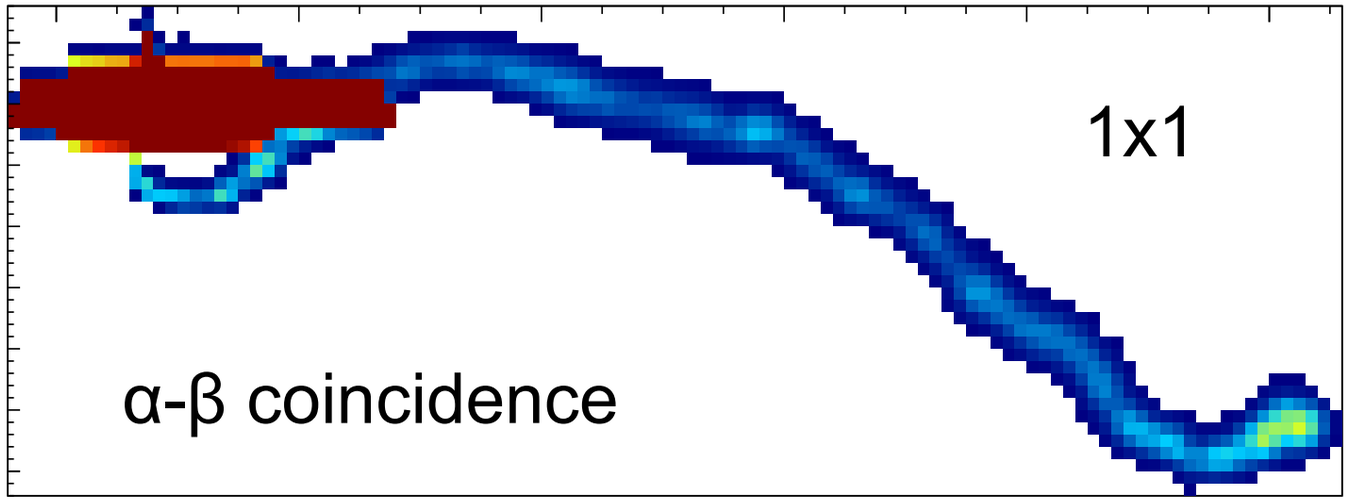
Less pixels but same noise *per* pixel!



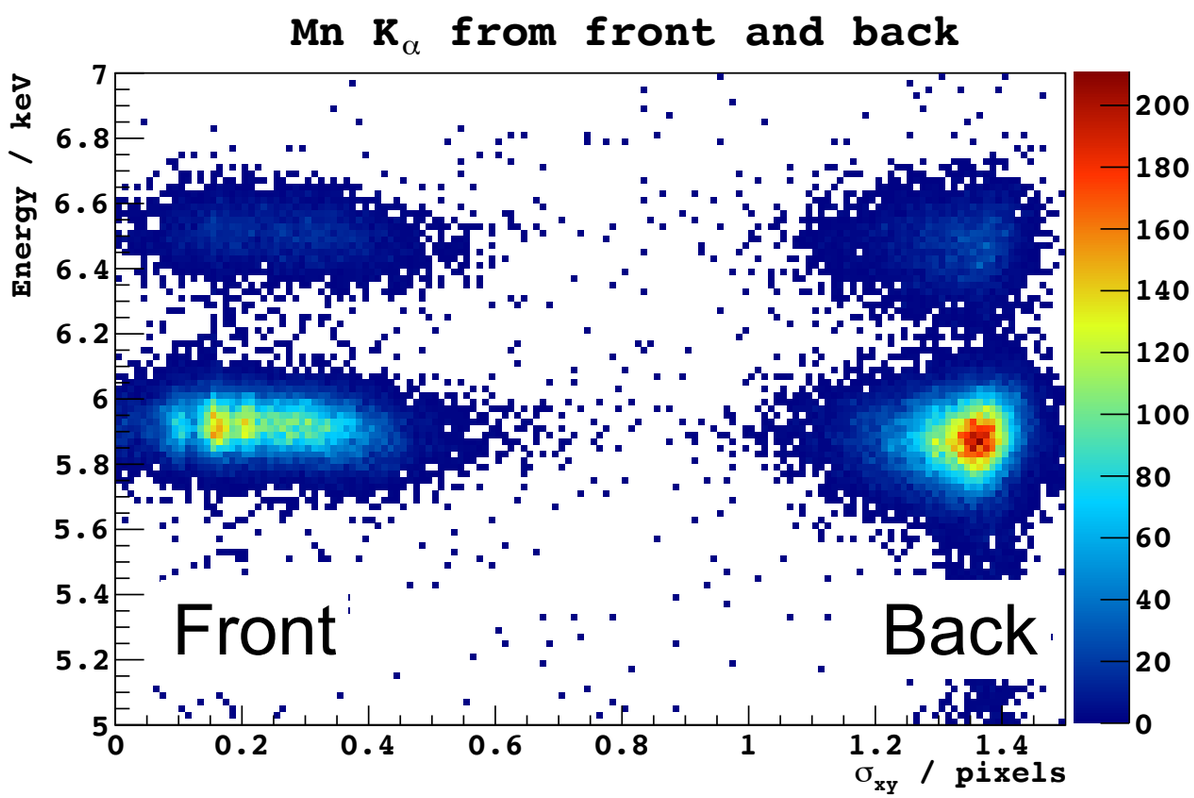
^{55}Fe from back: Data shows clear improvement in energy resolution

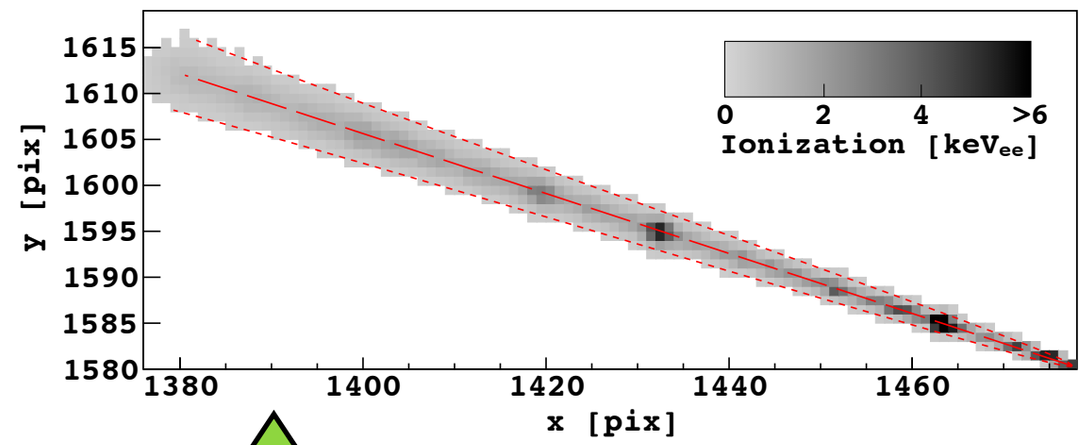
Loss of x, y and z information



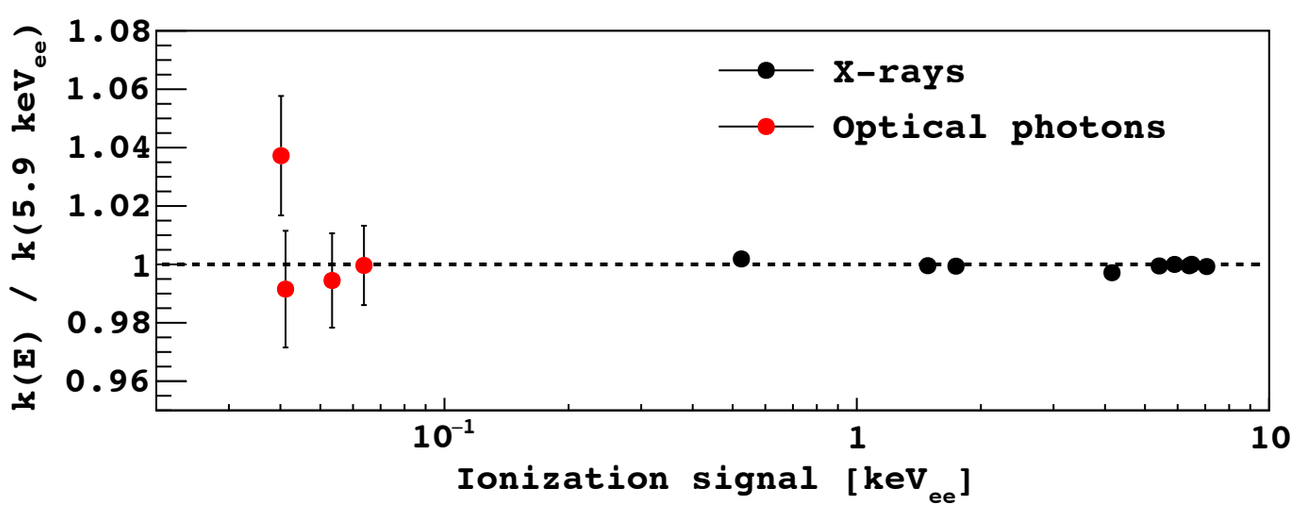


CCD characterization





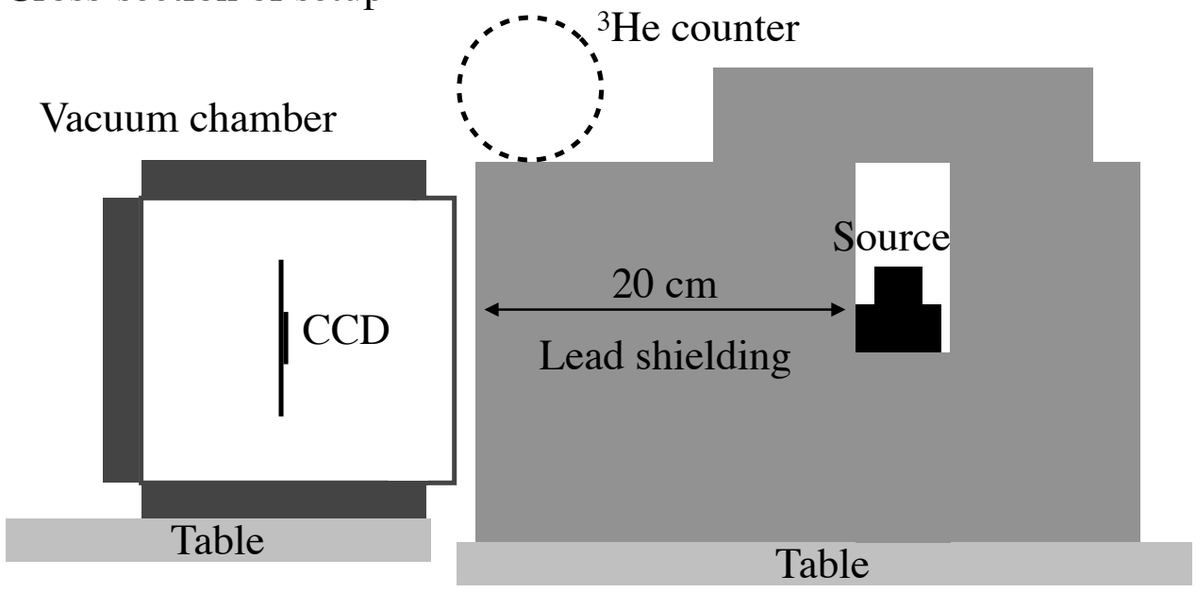
z reconstruction with X rays and cosmic rays



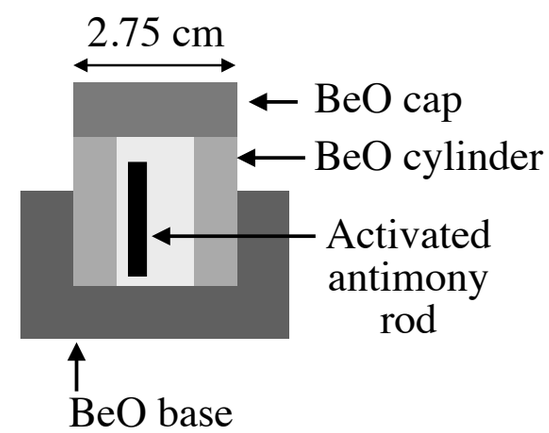
CCD linearity down to 40 eV_{ee} with optical photons

NR signal response

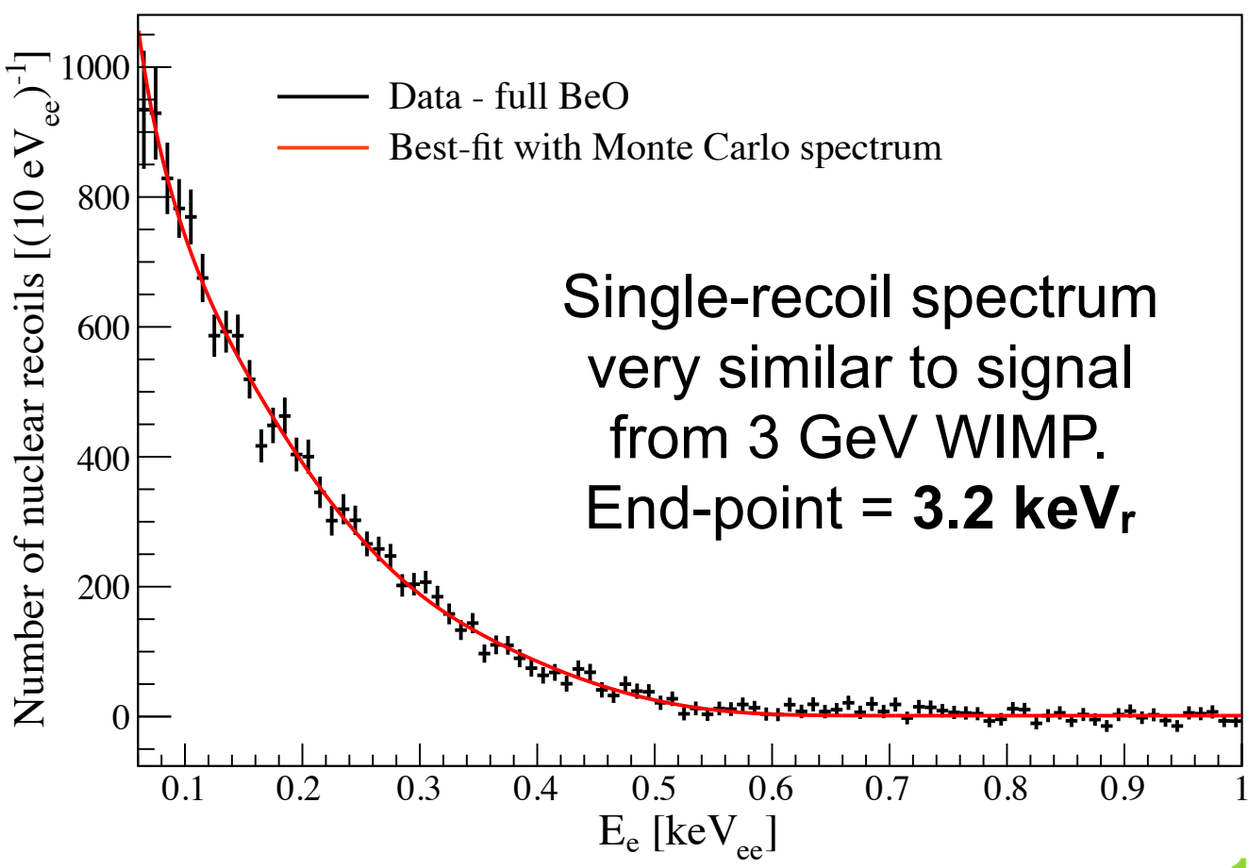
a) Cross-section of setup



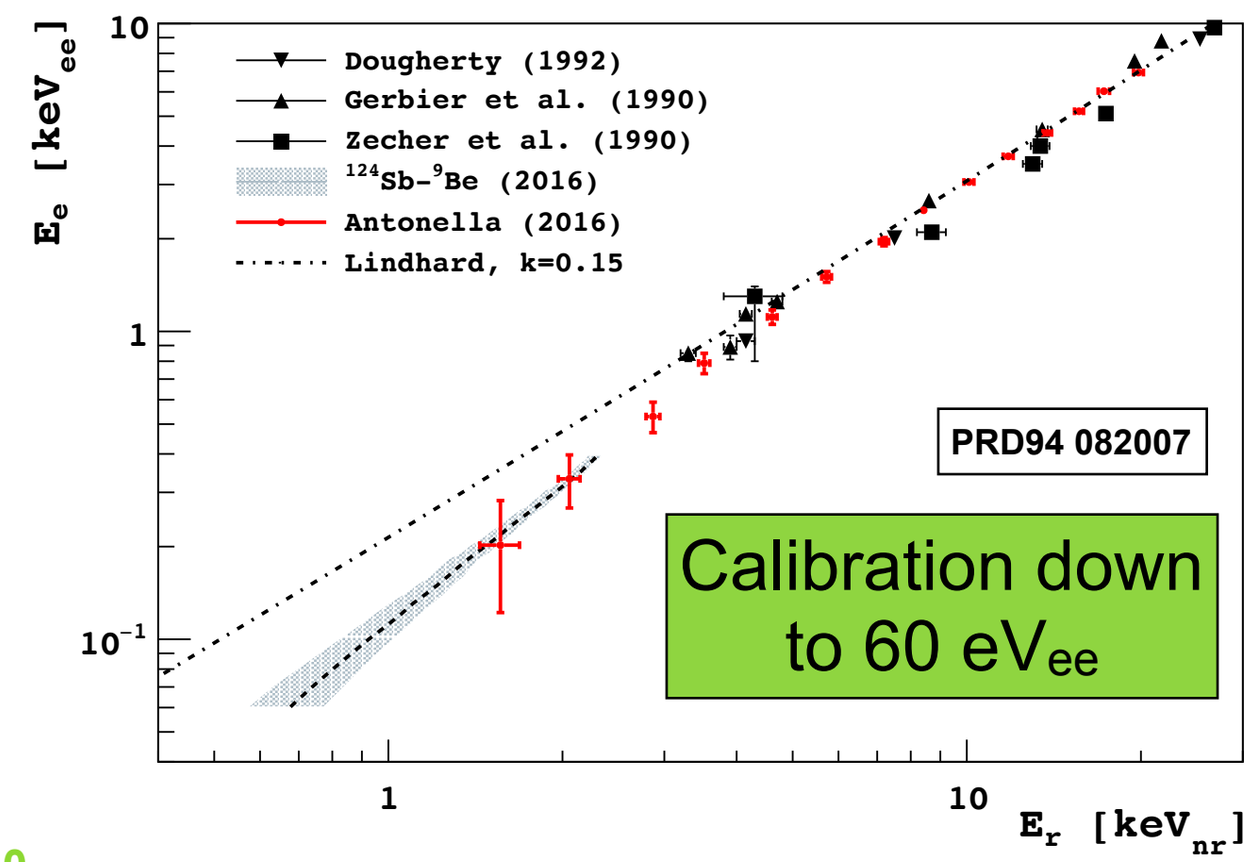
b) ^{124}Sb-^{9}Be source detail



24 keV neutrons from ^{9}Be(γ,n) reaction



Single-recoil spectrum very similar to signal from 3 GeV WIMP. End-point = **3.2 keV$_r$**



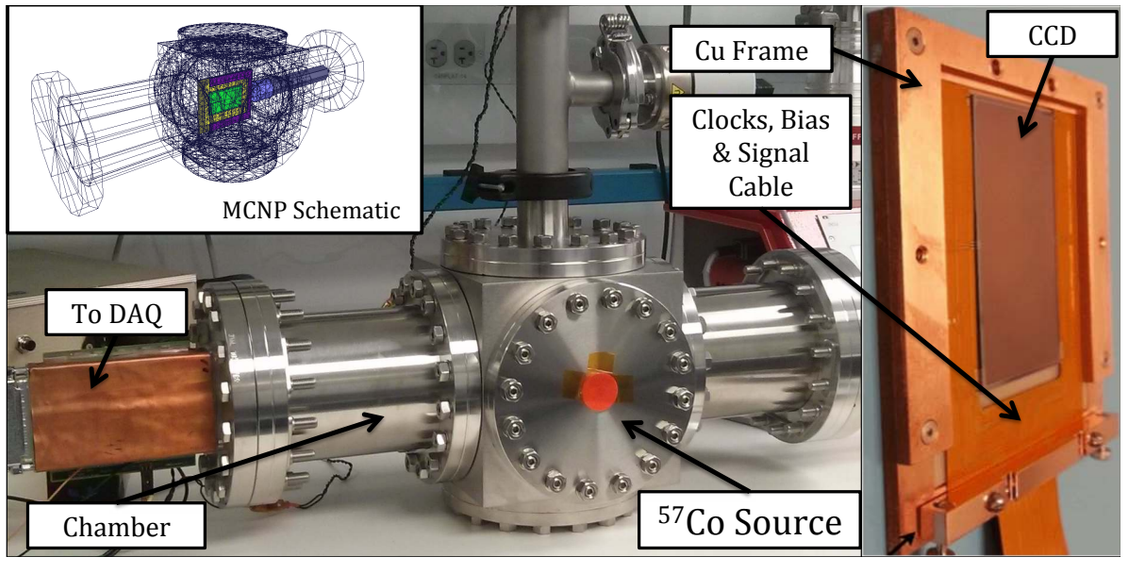
Calibration down to 60 eV$_{ee}$

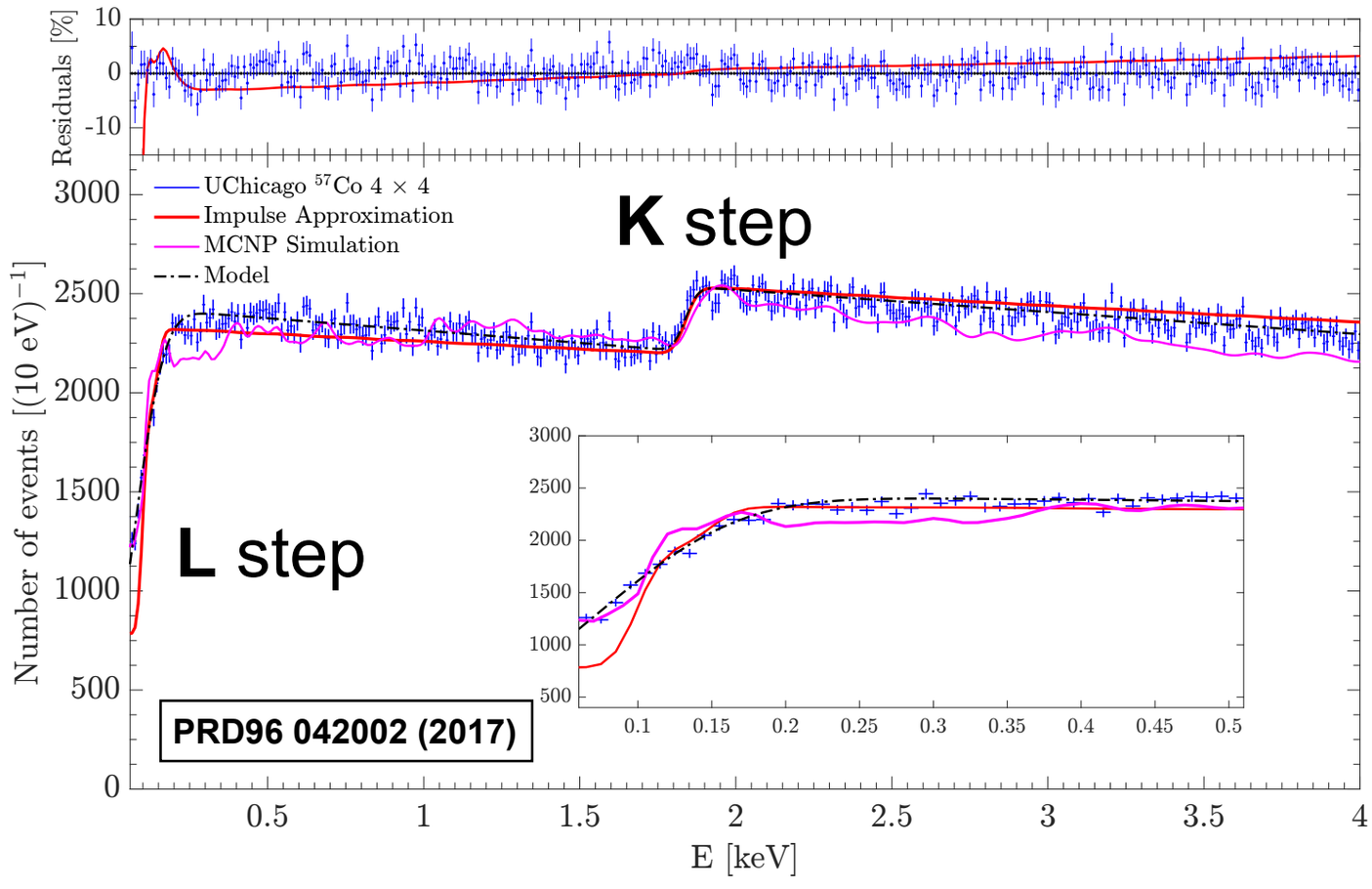
γ-ray response

Electron recoils in the bulk of the CCD from small-angle Compton scattering of **γ rays** are dominant background for DAMIC.

Linear spectrum, with slope dependent on the energy of the incident photons, with characteristic steps at the atomic binding energies.

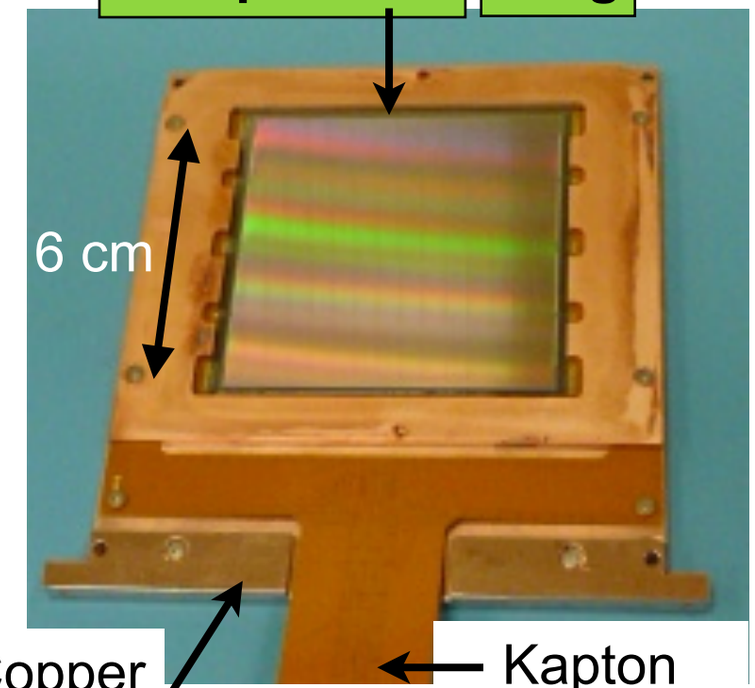
Calibrated the parameters of a generic γ-ray model with ^{241}Am and ^{57}Co sources.

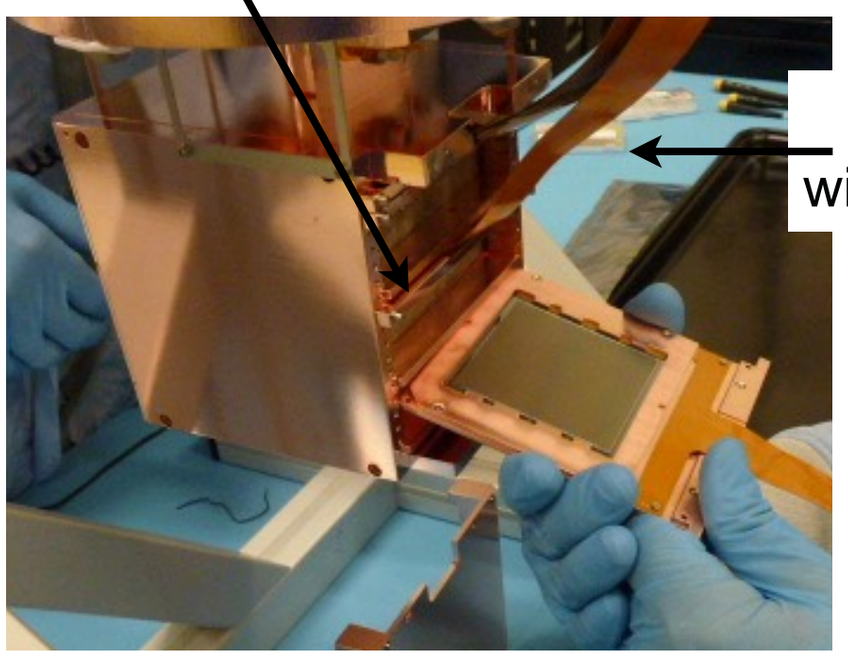


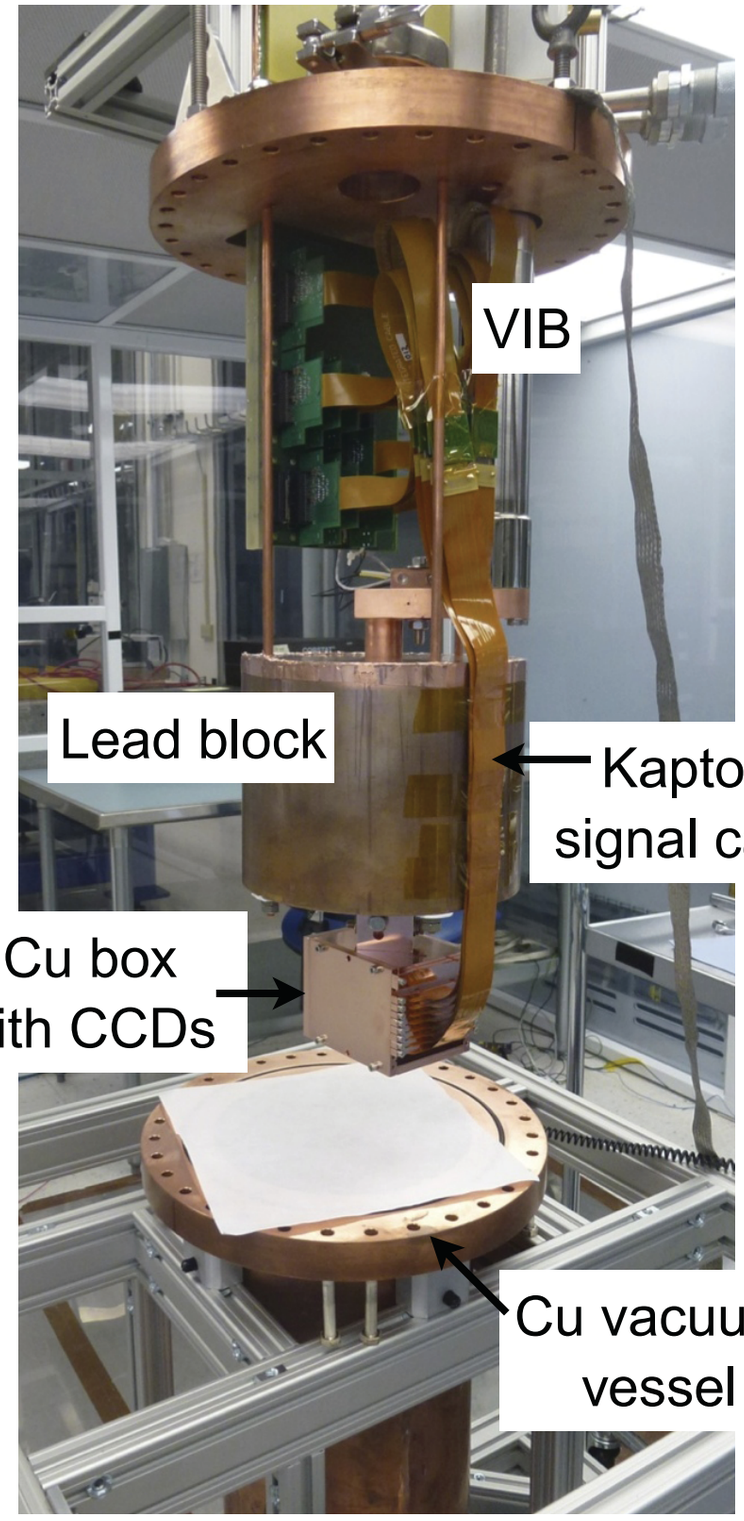


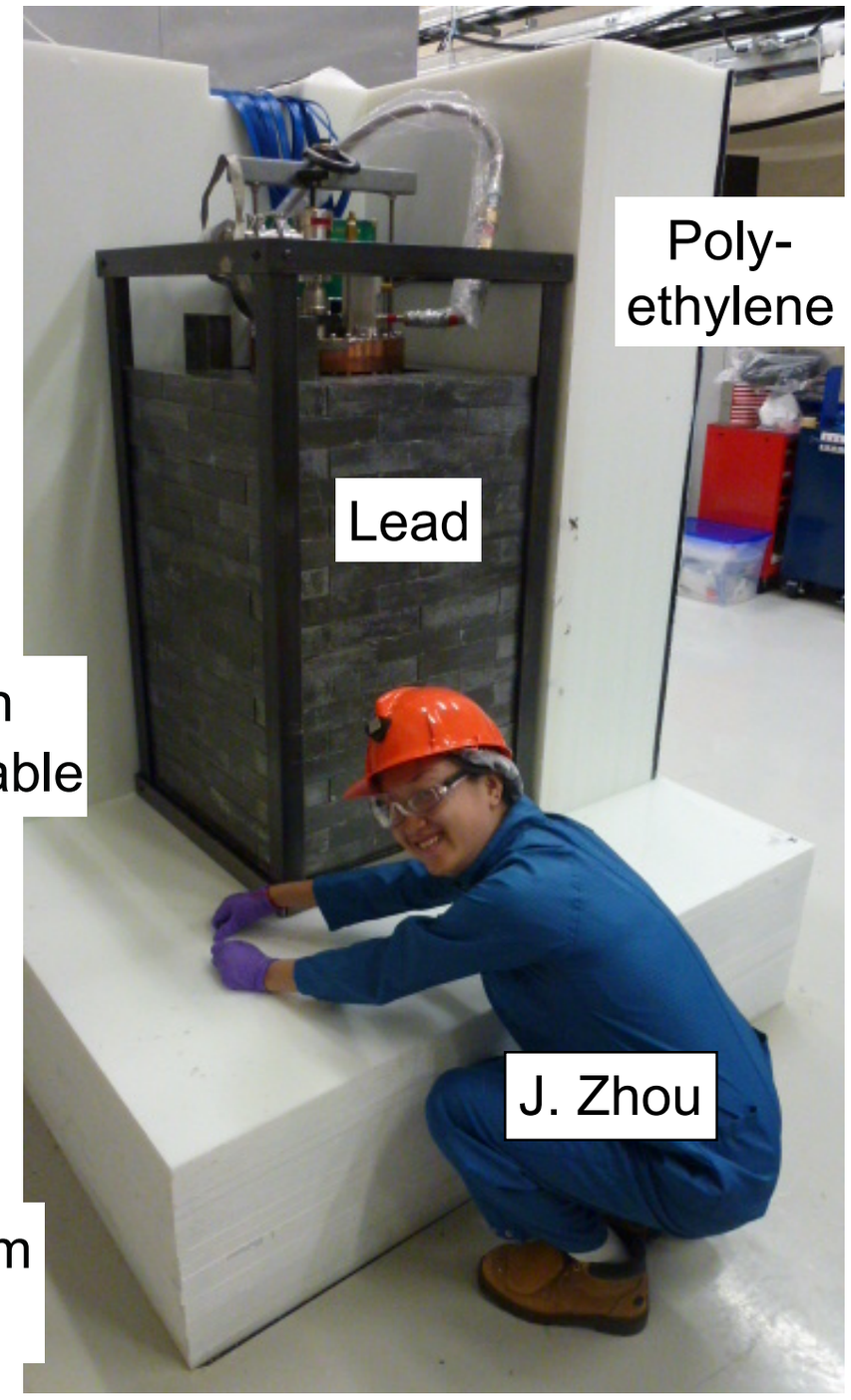
2 km underground

SNOLAB Installation



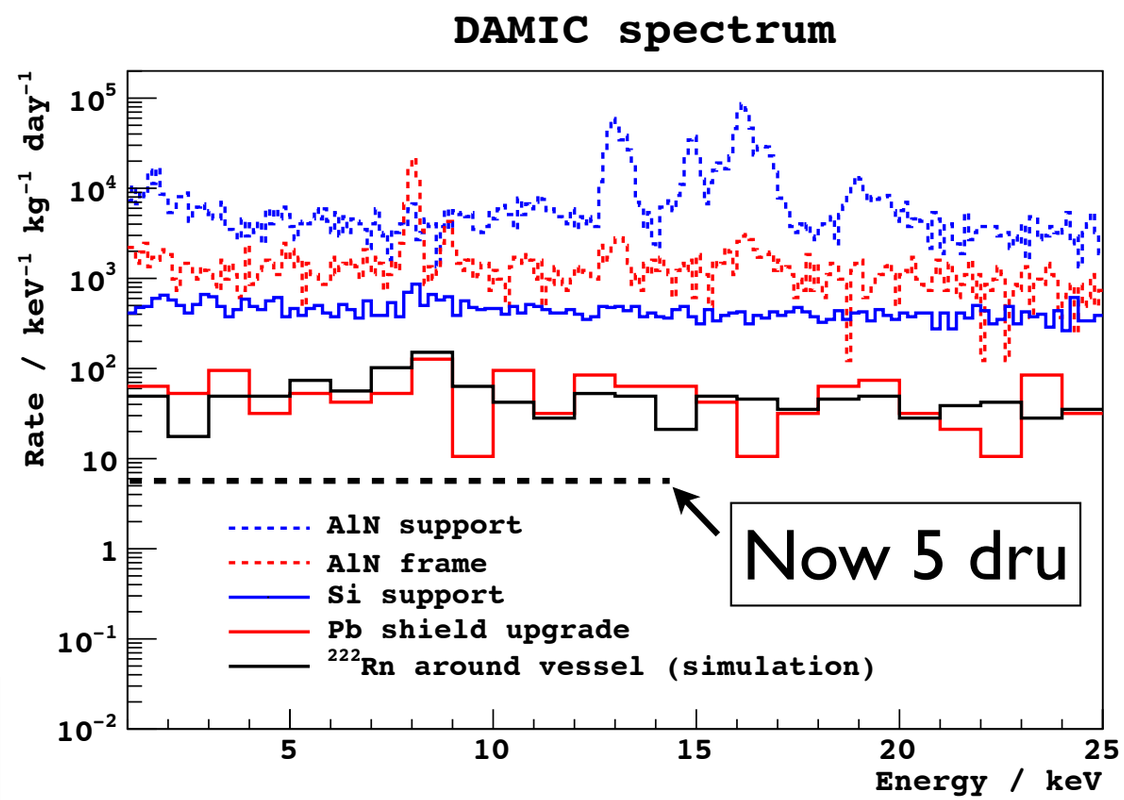


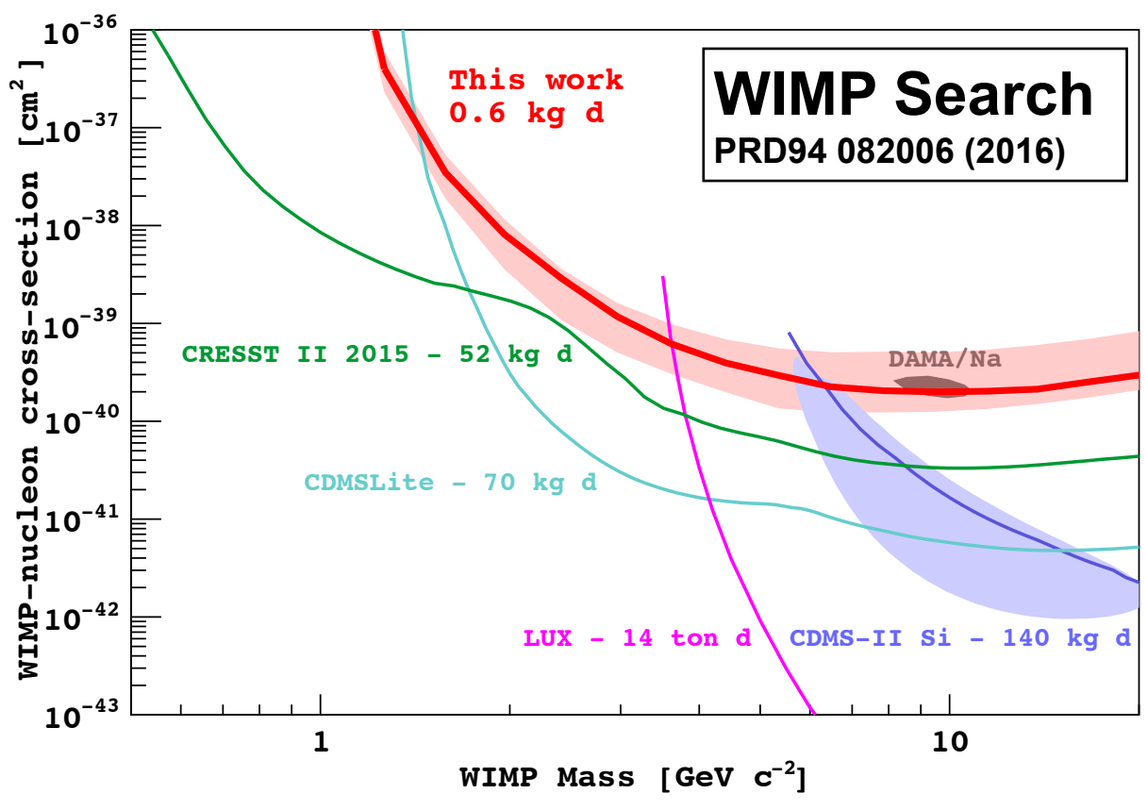




Timeline

- First CCDs installed at SNOLAB in December 2012.
- Three years 2013-2015 to achieve low radioactive background.
- WIMP and HP results with R&D data.

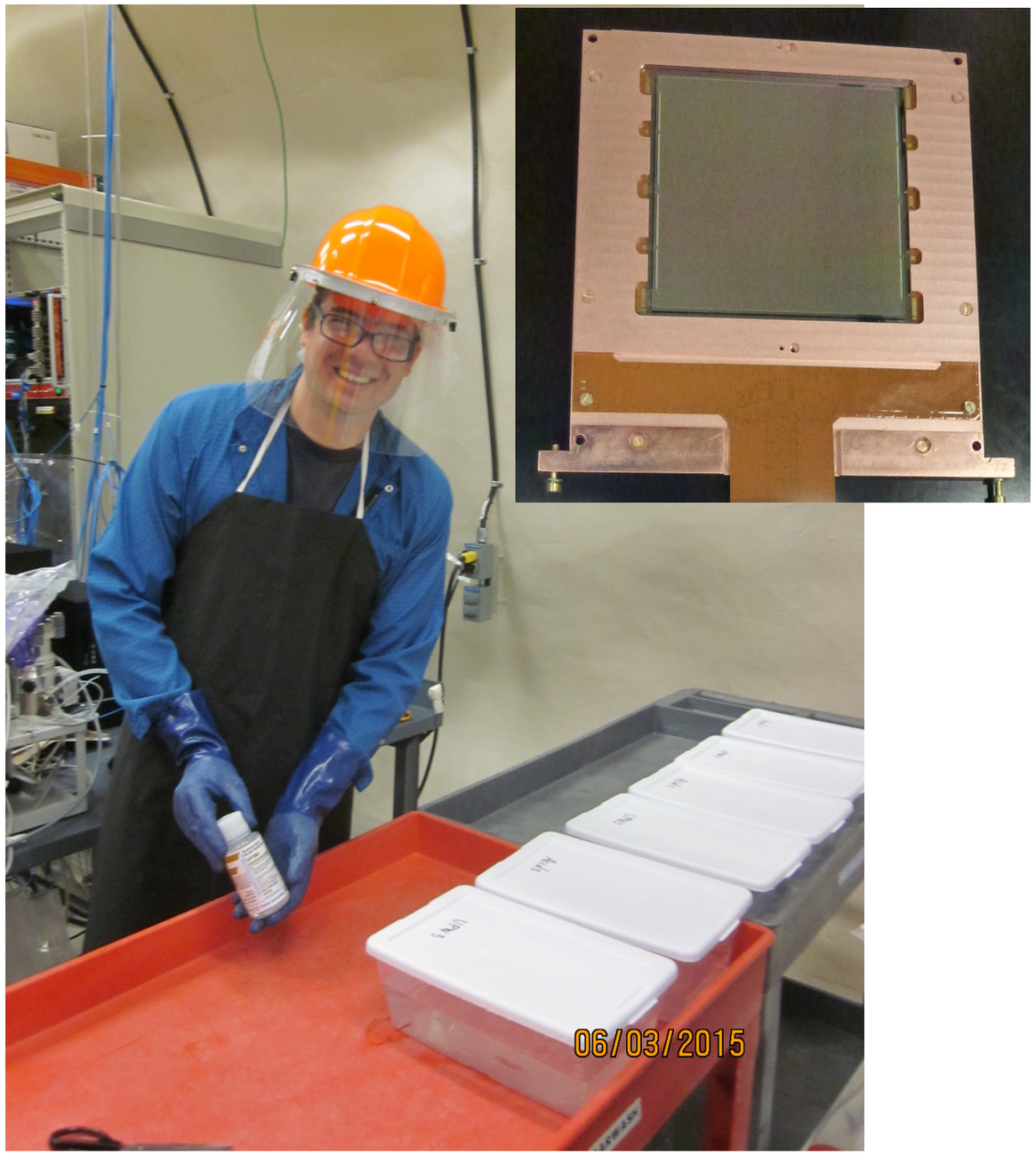


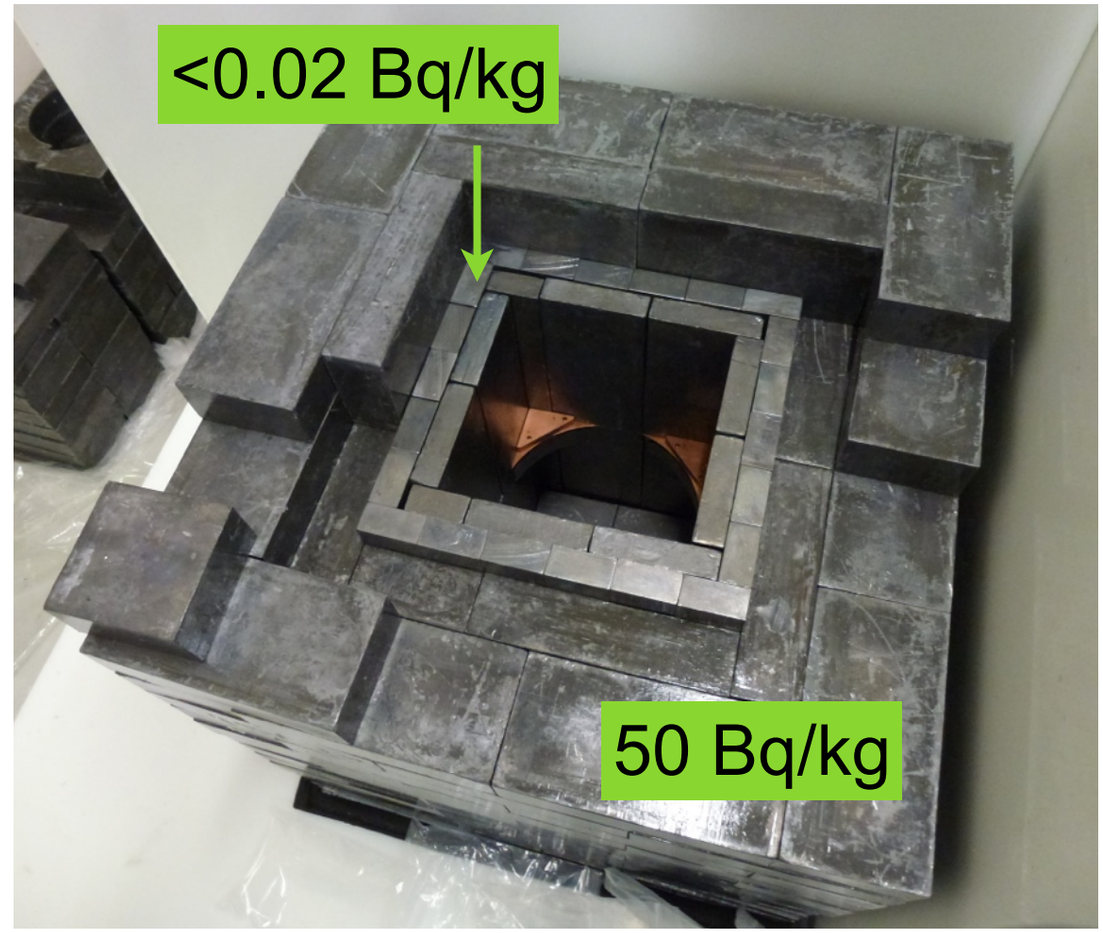


- First deployment early 2016: problems with mechanics of CCD package.
- Second deployment early 2017.
- Taking data since.

Background at SNOLAB

Extensive selection of copper, special machining and chemical cleaning.





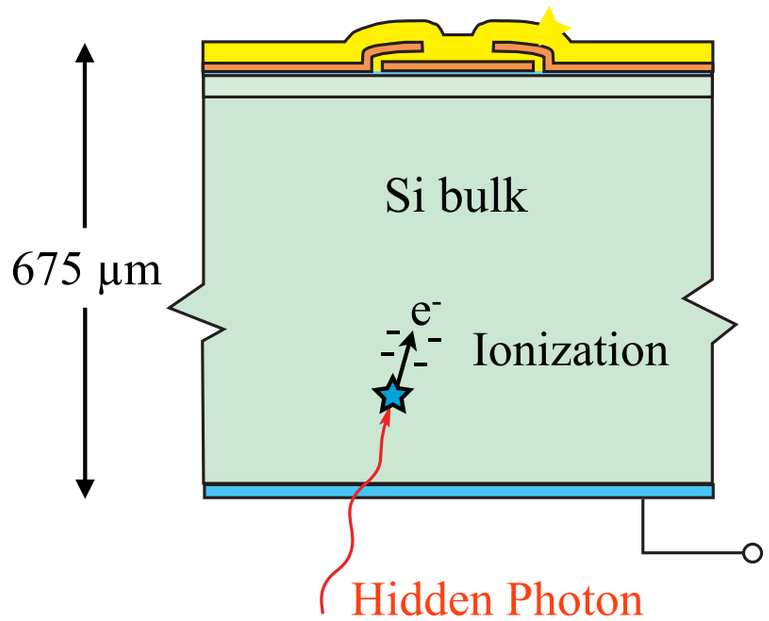
Lead shielding to stop external γs: Inner 2” of lead is ancient to stop bremsstrahlung from ^{210}Bi decay.

Nitrogen purge around lead to suppress radon «1 Bq/m^3.

Current event rate **5 /keV$_{ee}$/kg/d**.

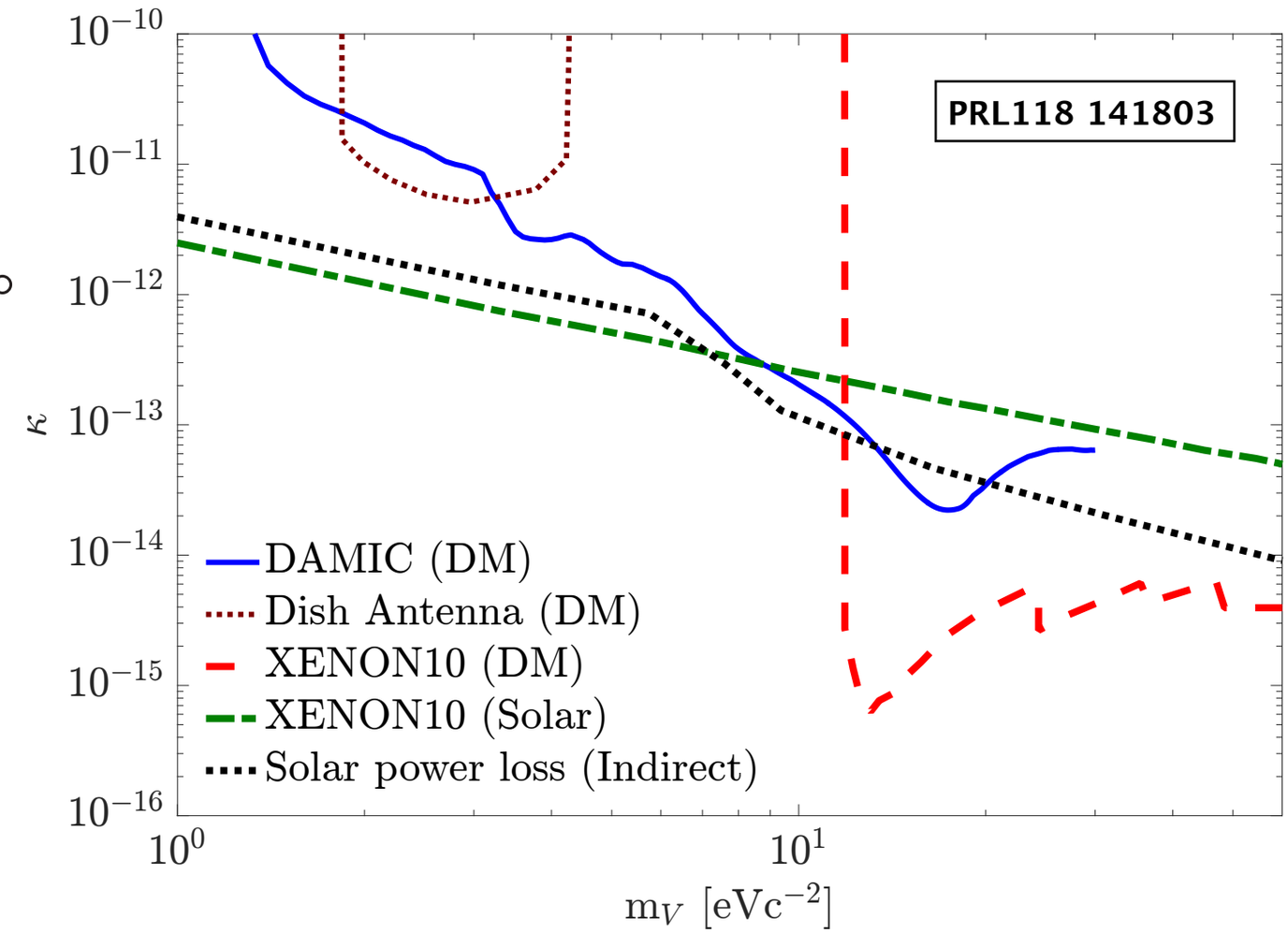
Hidden photon search

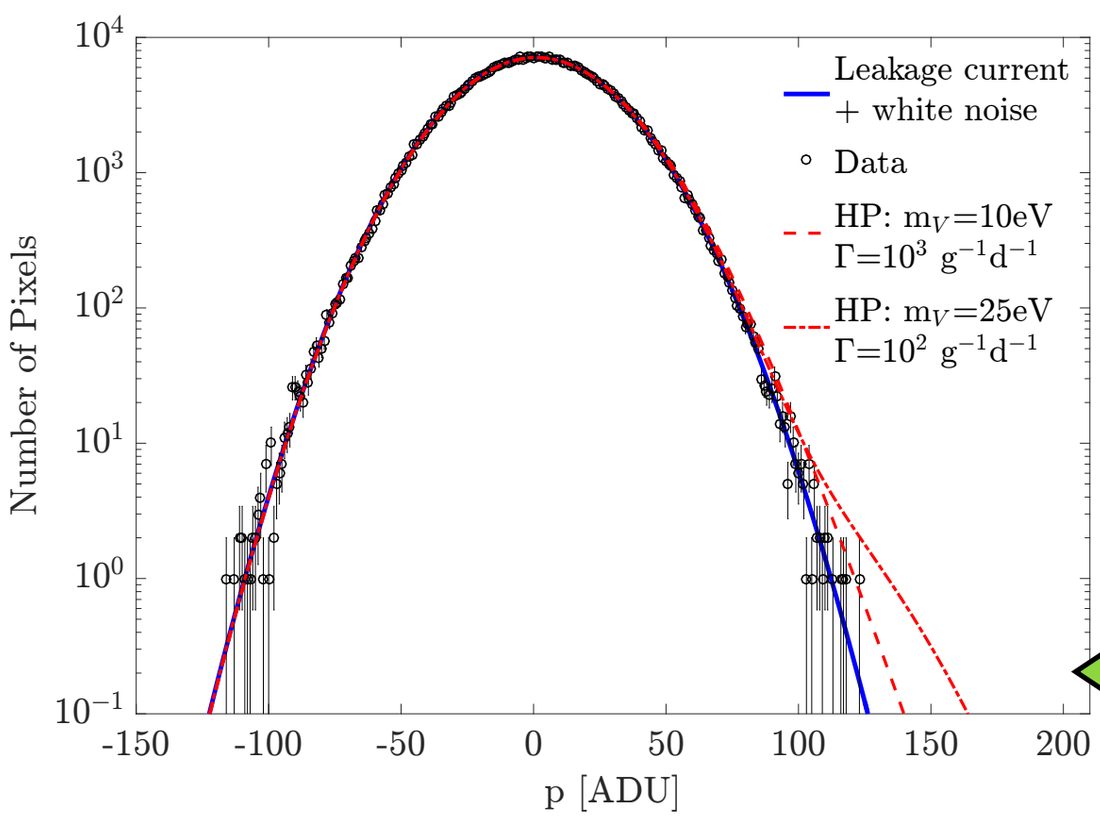
Absorption of hidden-photon dark matter.



~1 week of data with 1 CCD.

Leakage current **4 e⁻ mm⁻² d⁻¹**.

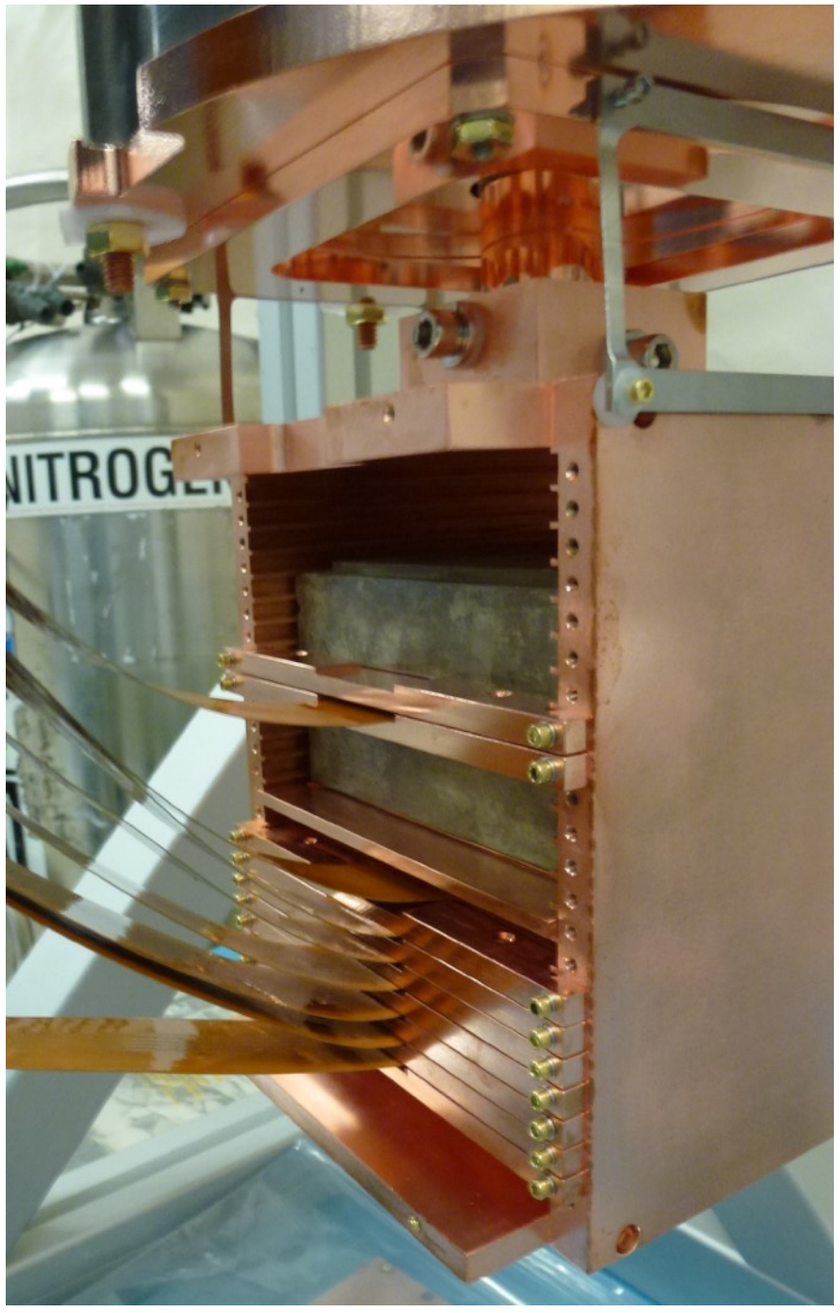




Pixel distribution consistent with white noise + uniform leakage current

Current status

- **7 CCDs** in stable data taking since 2017 (1 CCD sandwiched in ancient lead).
- **1 CCD** dead.
- **40 g** target mass.
- Operating temperature of **140K** and **most recently at 135 K.**
- **Exposure for image: 8h and 24h** (each image acquisition is followed by a “blank” exposure).
- Data acquired in **1x1** or **1x100** formats.

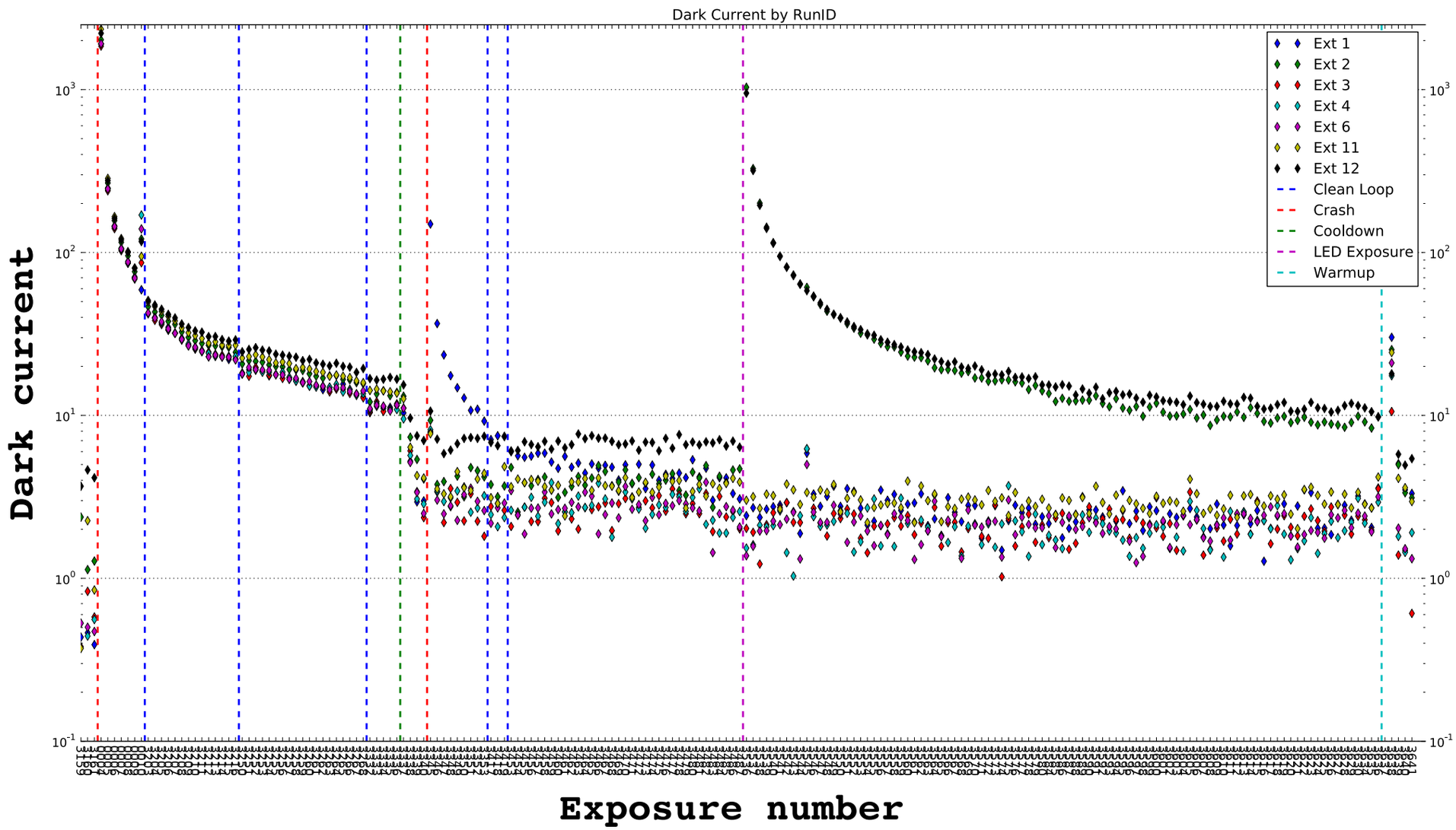


Data timeline

- We deployed in Feb 2017 but detector was not fully commissioned until Sep 2017.
- The response of the CCDs in the first **7.6 kg-day** in 1x1 format is not well understood: data is useful for some background studies + millicharge cosmic particle search.
- Commissioning (tuning of CCD clocks / biases) with the LED started in May 2017 (on and off) until we had acceptable performance in 1x100 data.
- We had a few temperature cycles from power outages at SNOLAB throughout second half 2017 and a “scare” in late Nov 2017 from the failure of a safety vent valve.
- Acquired data stably in 1x100 format (~1.6 e^- noise, <10^{-3} e^-/pix/day) from Sep 2017 until March 2017: **4.6 kg-day** of data. A “teaser” presented at Moriond and Aspen conferences.

Data timeline

- After Moriond (since ~1 April), acquired **2.2 kg-day** of additional data doing some tests on the dark current because of some DAQ hick-ups.
- We are back to nominal operating conditions as of last week.



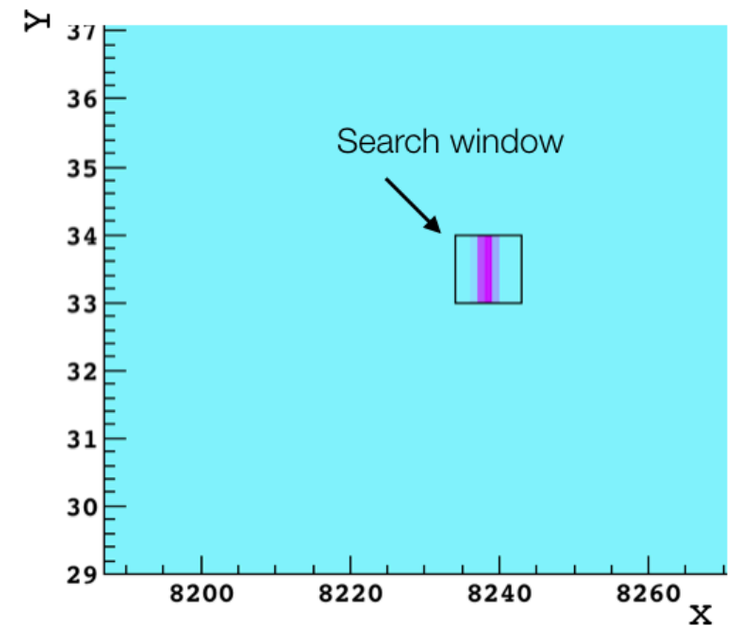
Event selection

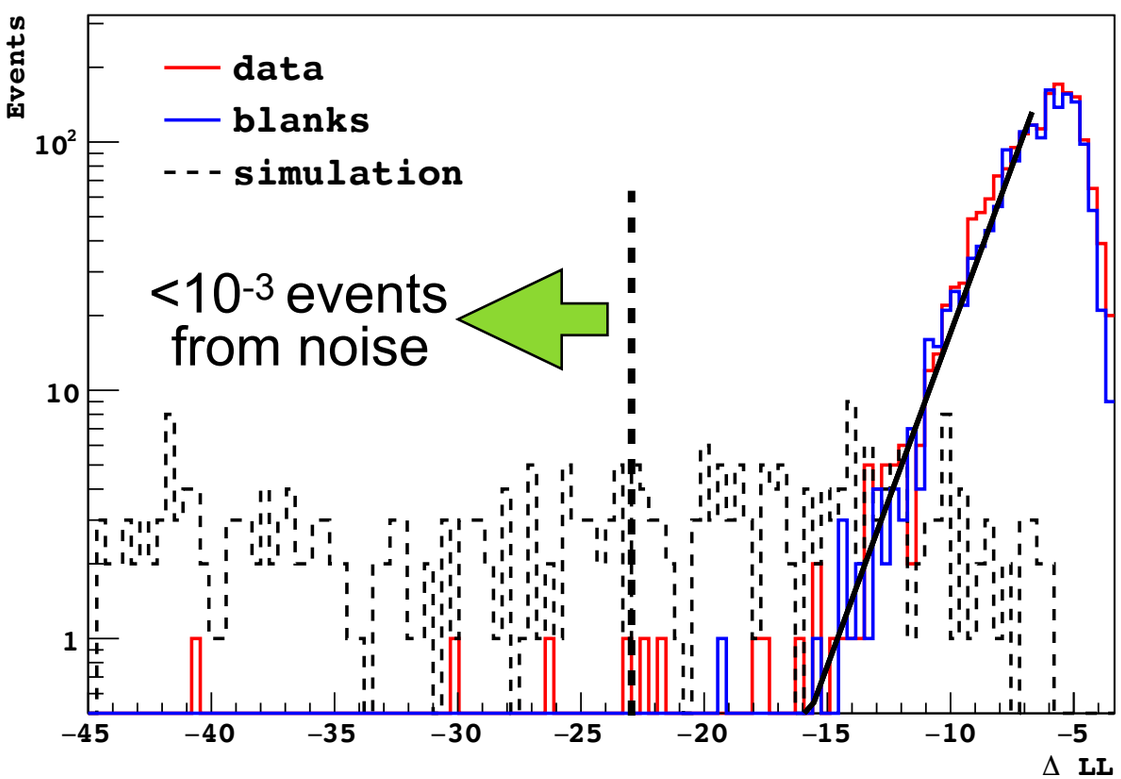
- Pedestal and correlated noise subtraction (hot pixels among several images masked)
- LL fit of the signal in a moving window across the image

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

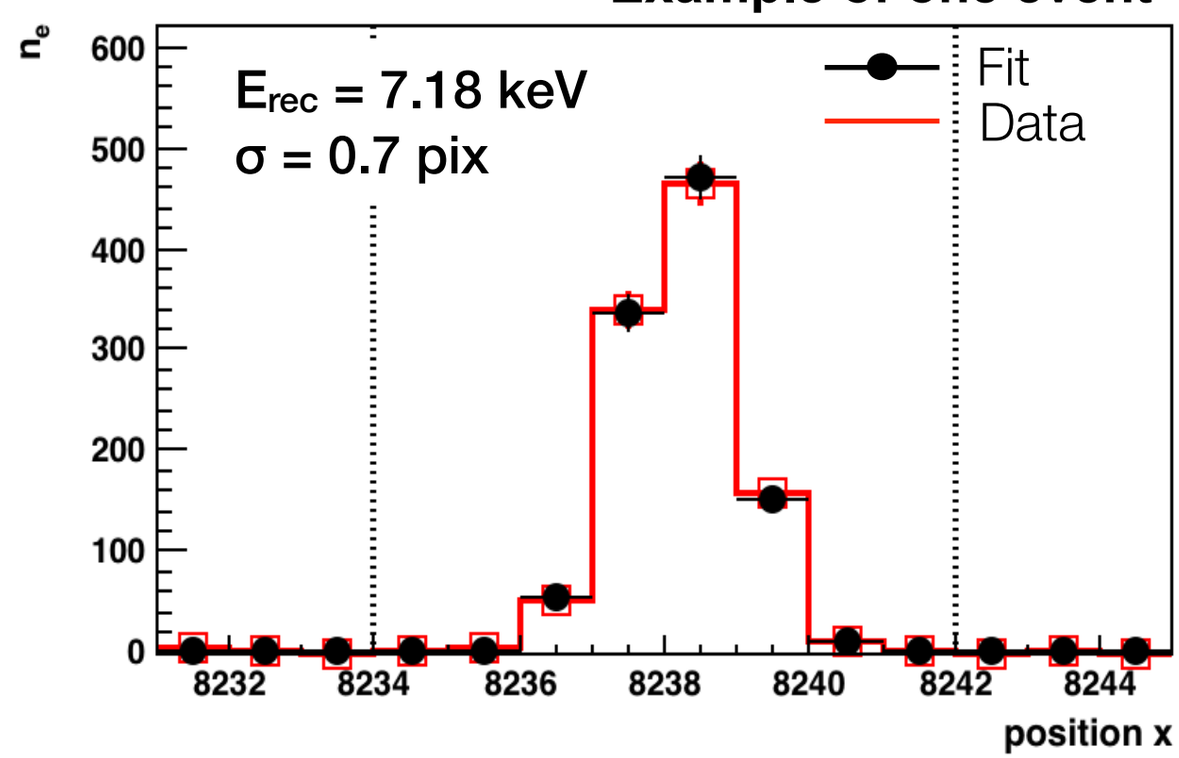
flat noise

Gauss signal + flat noise

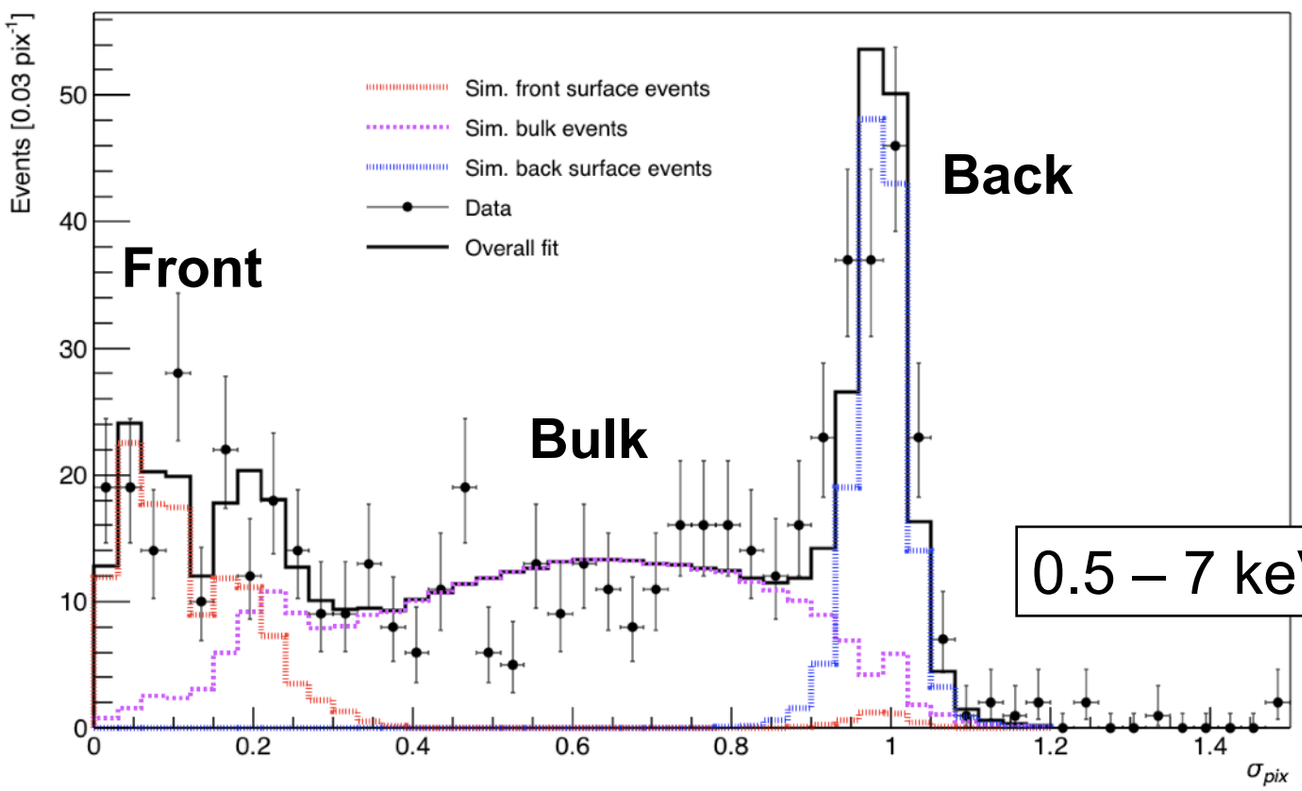




Example of one event

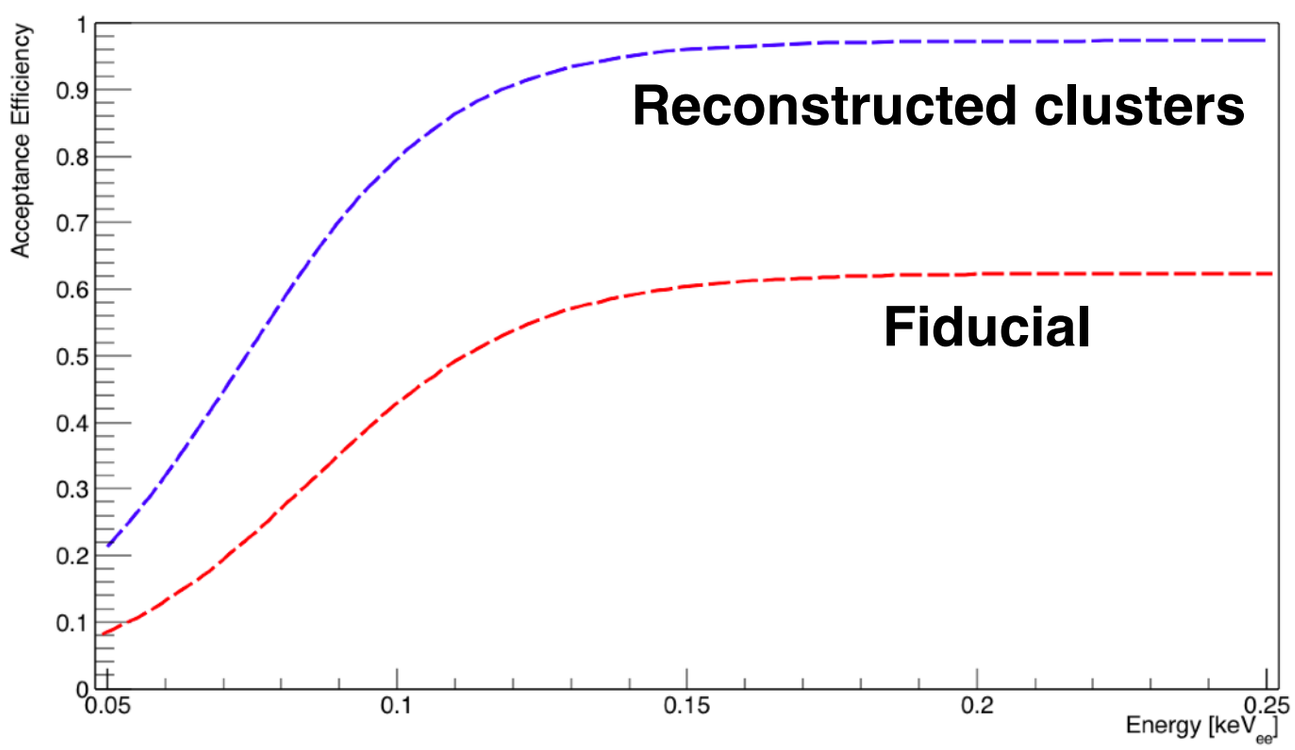


Acceptance



Background + signal model from simulations

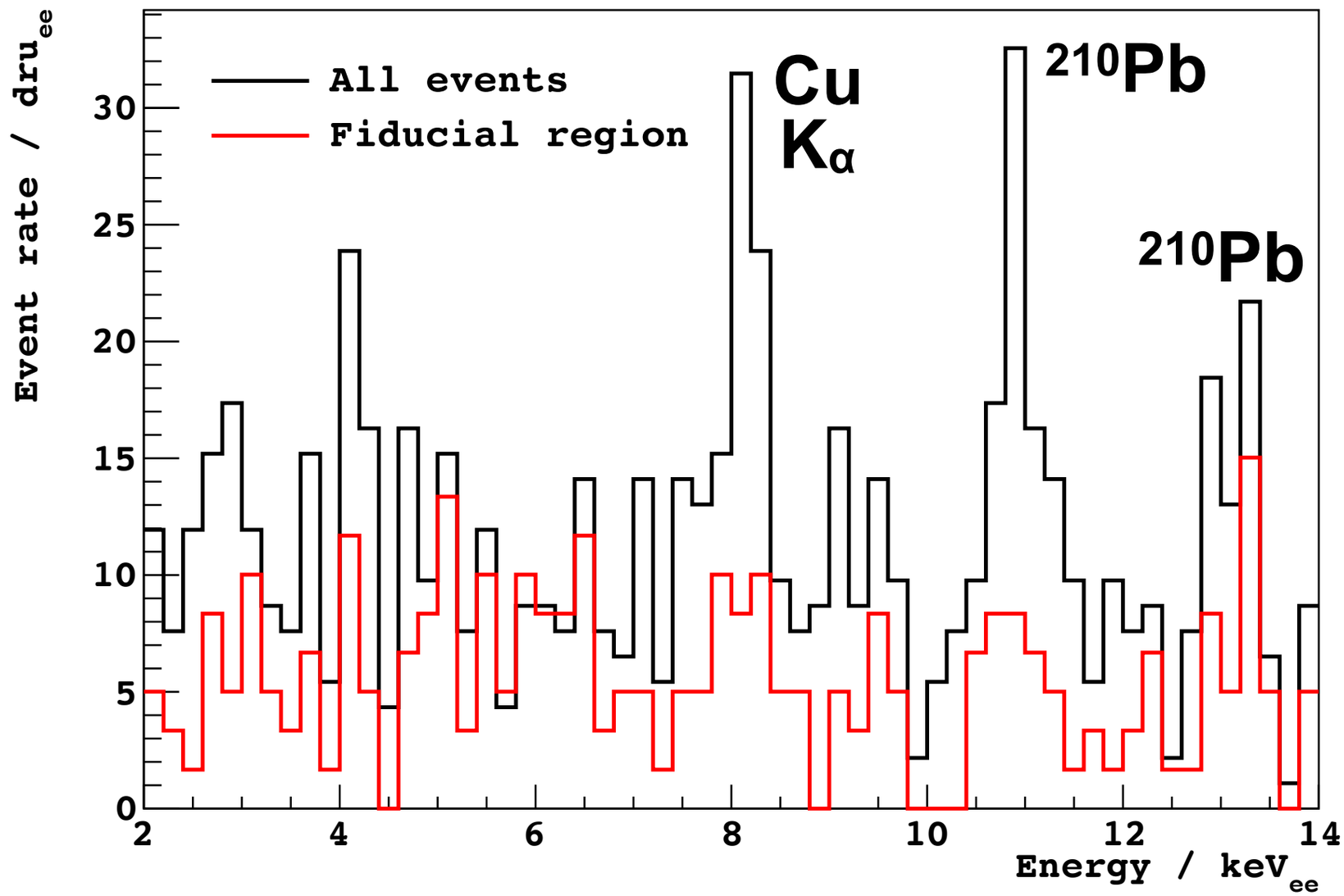
0.5 – 7 keV_{ee}



Acceptance for bulk events

Software energy threshold: **50 eV_{ee}**

Energy spectrum



≃**5 dru** in fiducial region, consistent between CCDs

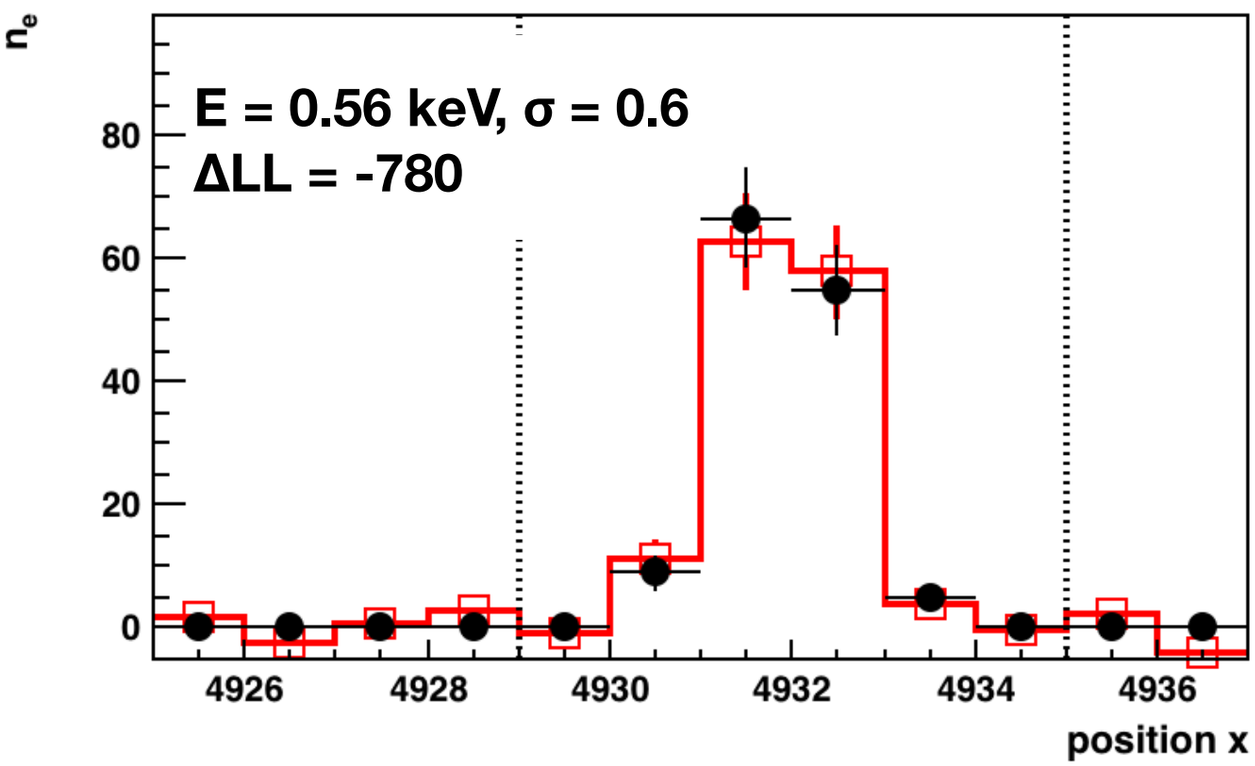
a factor of ≃ 3-4 lower than our previous background level

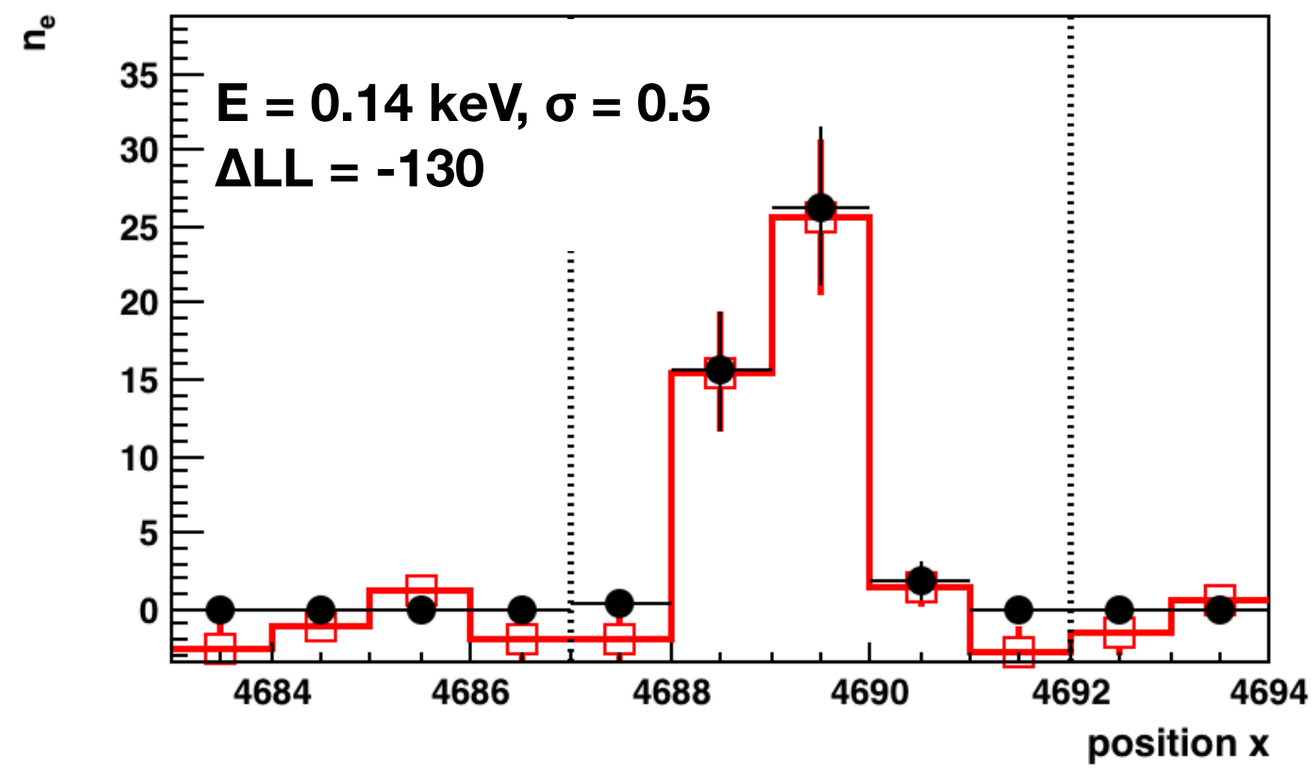
≃**2 dru** for lead sandwiched CCD

Low energy data

We are analyzing the data from **50 eV to 2 keV**, which provide most sensitivity to low mass WIMPs. Some examples of candidates:

Two example events (data + fit)



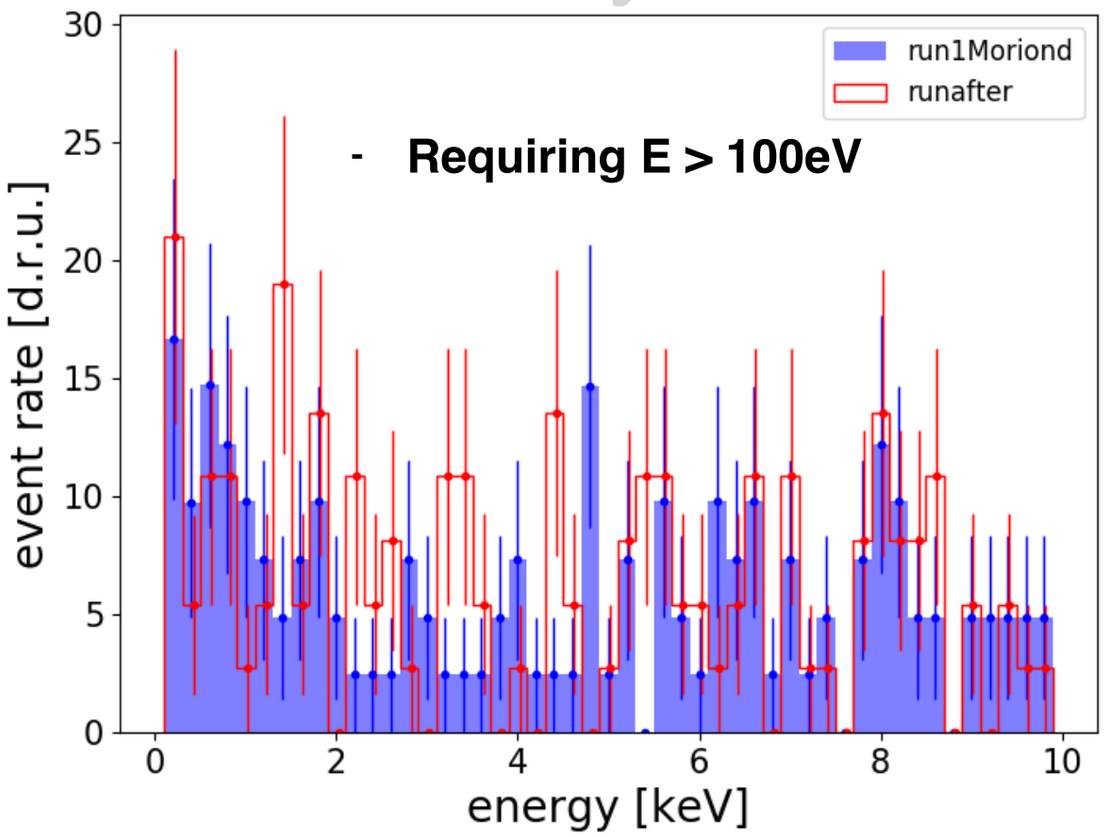


Note: CDMS II silicon potential signal obtained with a 7 keV_{nr} threshold (≈2 keV_{ee}). We are exploring for the first time the silicon target with a much lower threshold of 0.6 keV_{nr} (≈ 0.05 keV_{ee}).

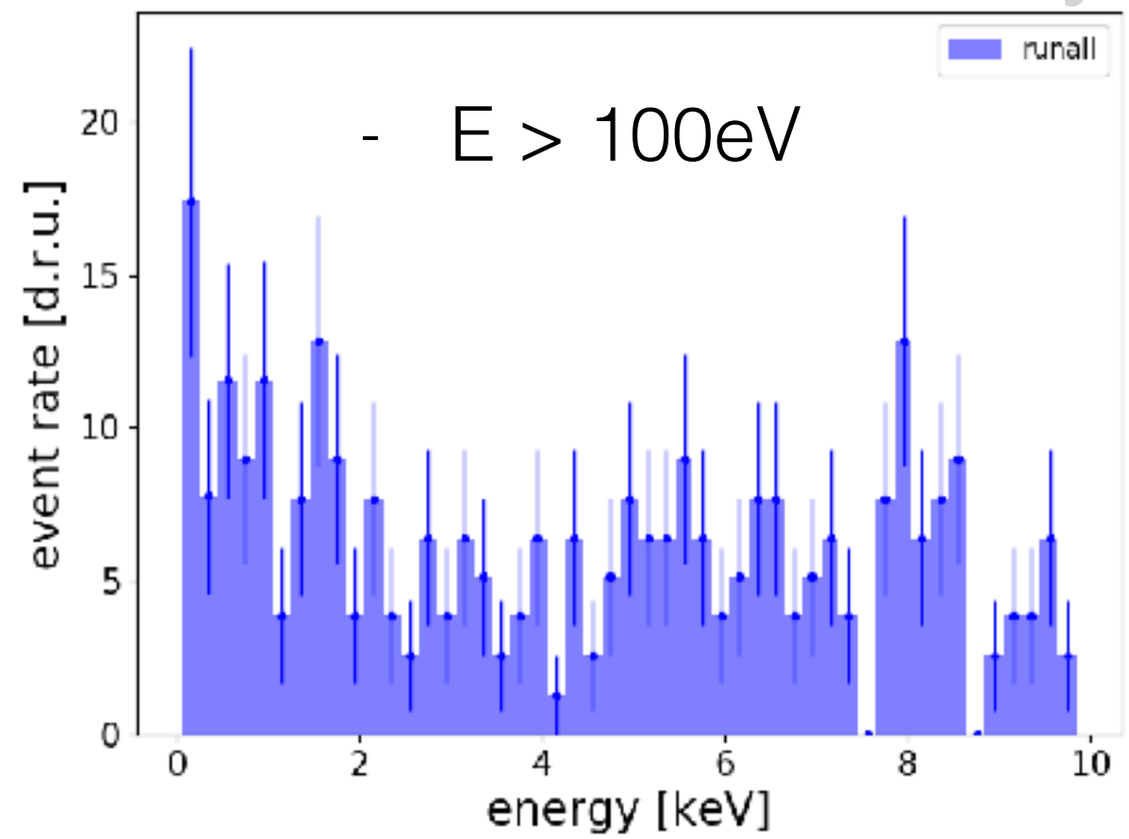
Latest results

Spectra in fiducial region

Preliminary



Preliminary



Since Moriond data set we have noted a slight excess of events at low energies. Under investigation since then. Many eyes on the data (Romain, Mariangela, Karthik, Alvaro, Paolo, Grayson…)
Mostly focused to see if it is an instrumental artifact. Need a good radioactive background model.

Background studies

- **Cosmogenic ^{32}Si**

  Search for spatially correlated beta decays. Sensitivity with current data is few Bq/kg.

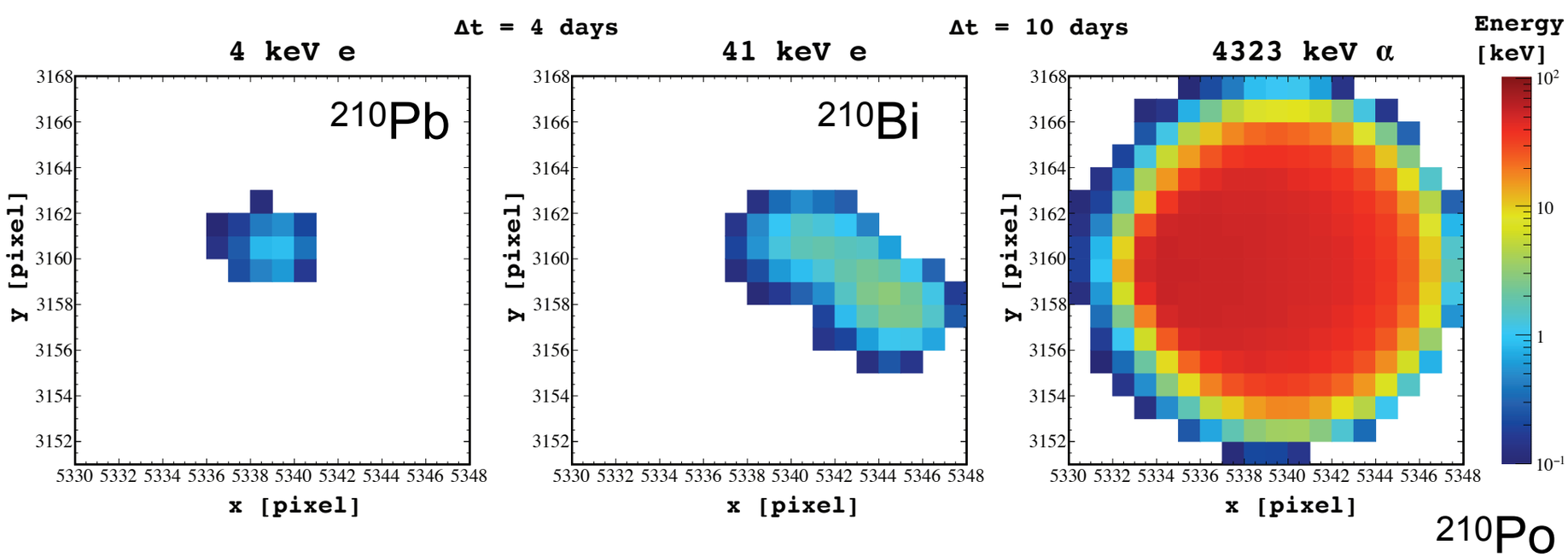
  Previous results: **JINST 10 P08014 (2015)**

^{32}Si ($T_{1/2}$= 150 y, β) ➔ ^{32}P ($T_{1/2}$= 14 days, β)

candidate ^{32}Si – ^{32}P in new data

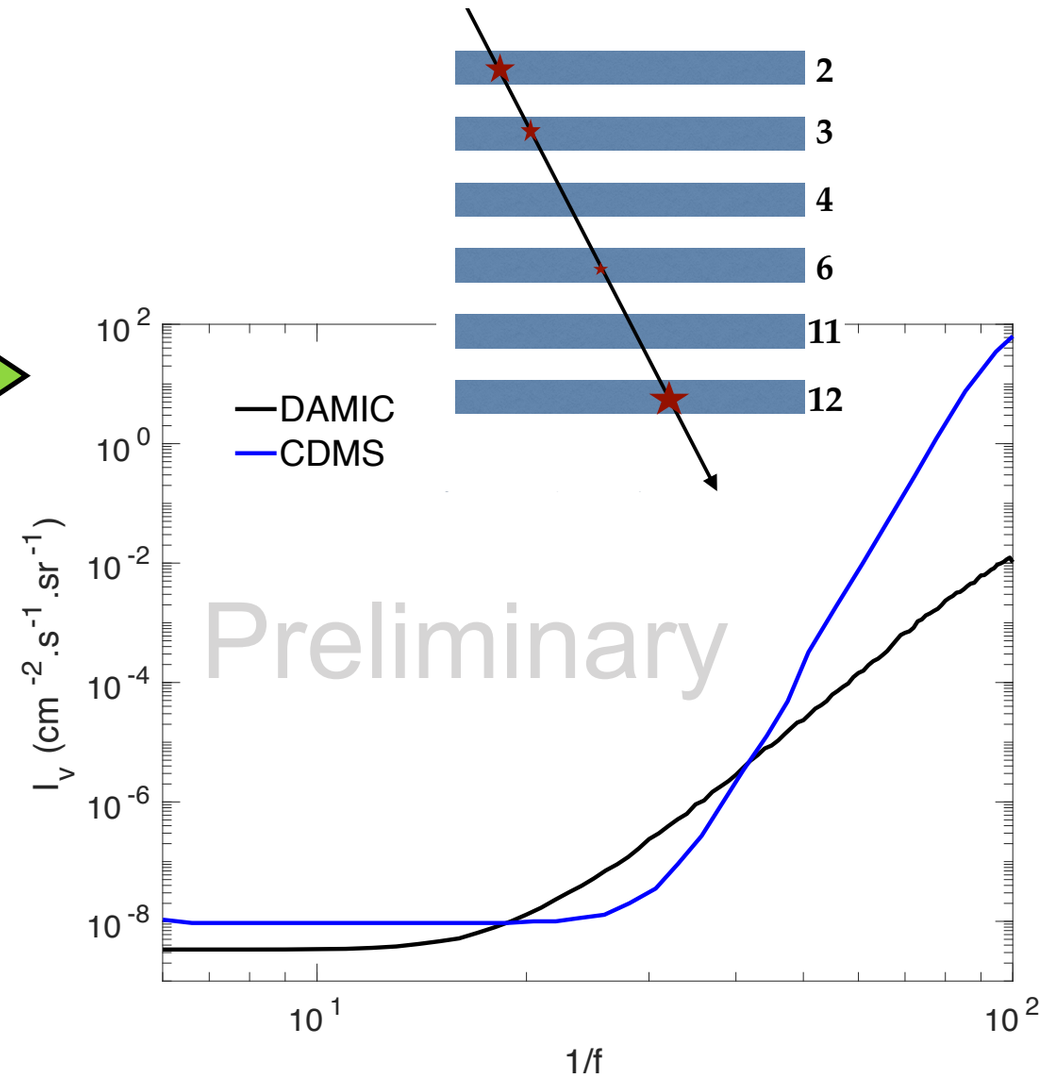
- **Bulk and surface background**

  ppt levels sensitivity to U+Th bulk contamination. Will demonstrate that the devices themselves are radiopure for kg-year exposures.



Ongoing activities

- **WIMP search**: Romain, Mariangela, Alvaro, Karthik, Grayson.
- **Millicharge cosmic particle:** Diego, Victor + UFRJ.
- **Background studies:** Grayson, Ariel, Paolo + UC.
- **Data quality:** Rocio, Ryan, Xiaohao, Victor.
- **Simulations:** Joao, Ryan.



We have very active working groups and expect more publications soon!

Contributions

Know-how, not necessarily in funding!

- CCD package design: **Fermilab**.
- CCD packaging + testing: **Fermilab**.
- Detector box + vacuum vessel design: **Fermilab**.
- Detector installation: Fermilab + UC.
- Slow control: **Fermilab.**
- Radiation shielding: **UC** + Zurich + Fermilab.
- Electronics + DAQ: adopted from DECam.
- Low-background: **UC**.
- Detector operations: UC + Fermilab.
- Calibrations: **UC**.
- Data analysis: **UC** + **LPNHE** + UFRJ + Fermilab.
- Data quality: UC + UFRJ + IFCA.
- Simulations: LPNHE + UC.

For simplicity, I take contributions from people now at Nantes and UW as LPNHE and UC, respectively.