CCDs as low energy threshold detectors DAMIC@Snolab and CONNIE

Javier Tiffenberg† ⋆

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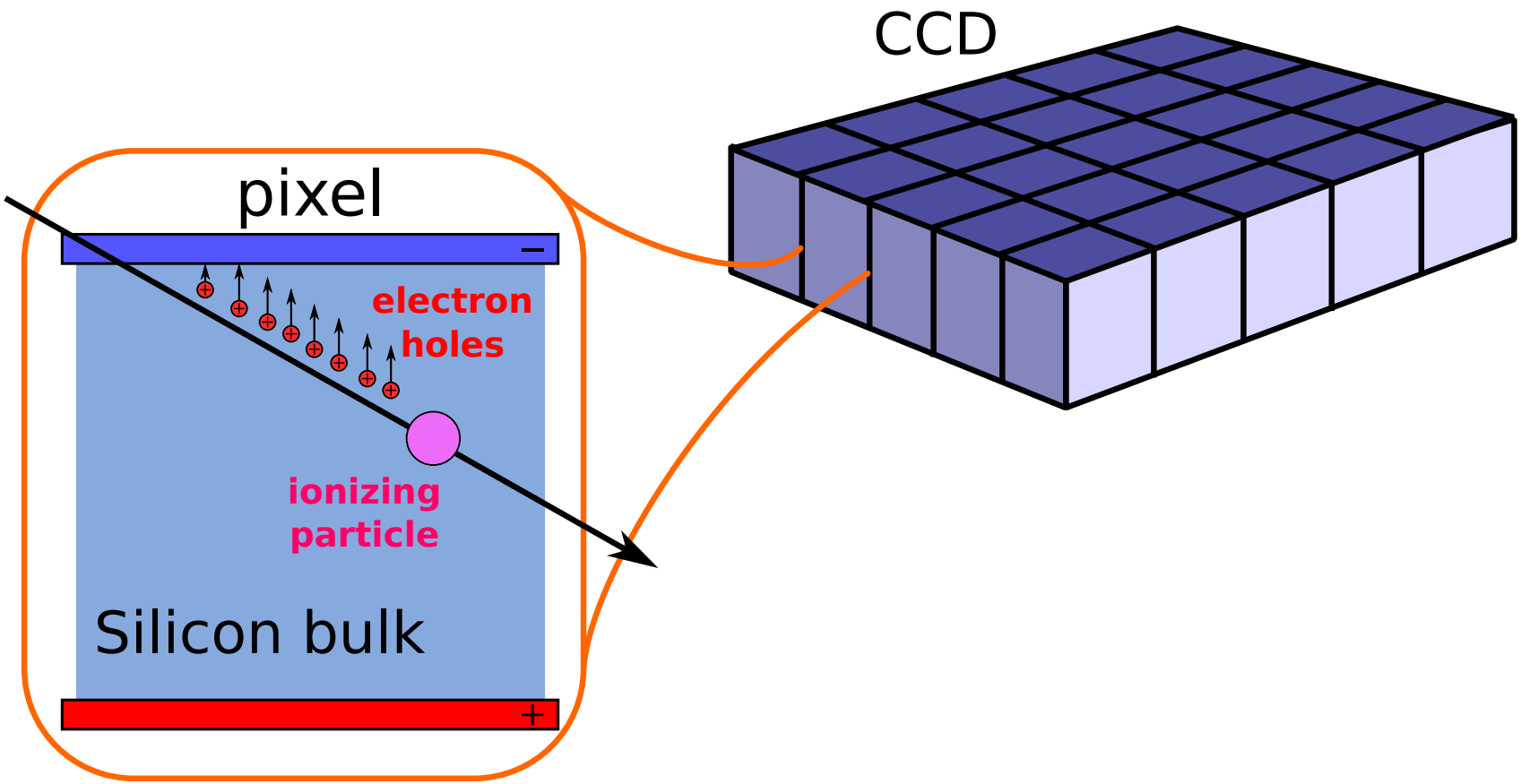
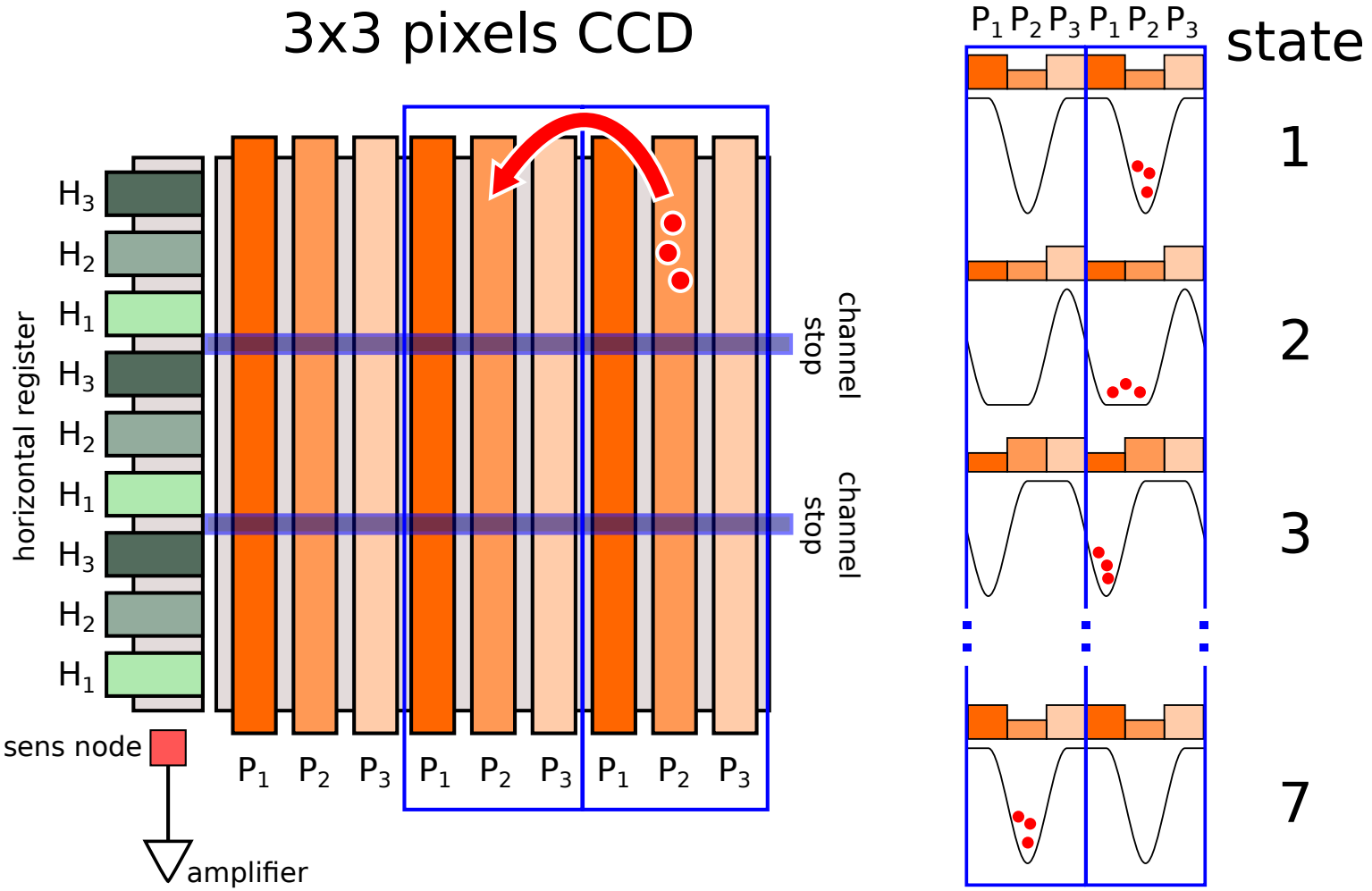
† Fermi National Laboratory

⋆DAMIC Collaboration: Fermilab, U Chicago, U Zurich, U Michigan, UNAM, FIUNA, CAB

CCD: charge generation



CCD: readout

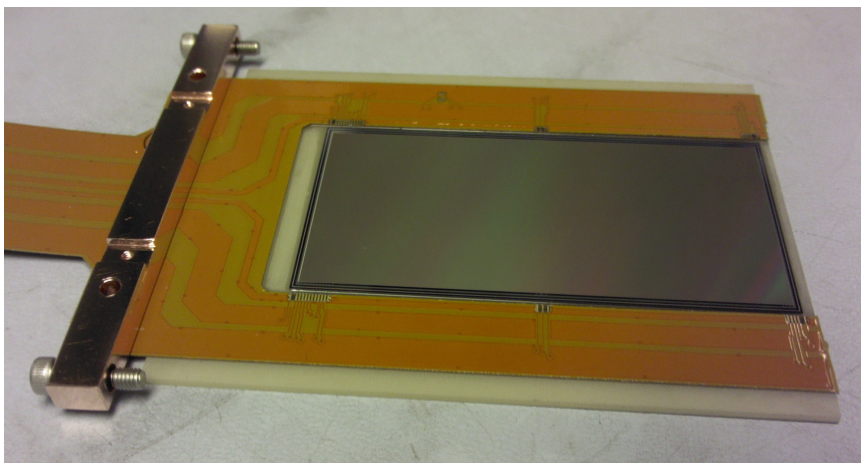
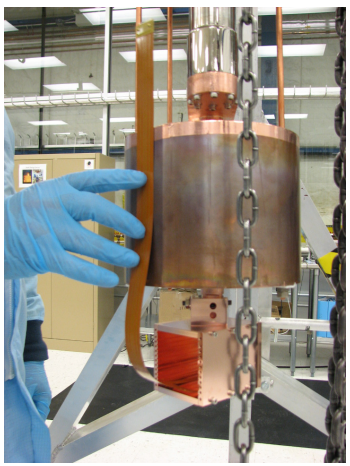


capacitance of the system is set by the SN: C=0.05pF$\rightarrow$ 3μV/e

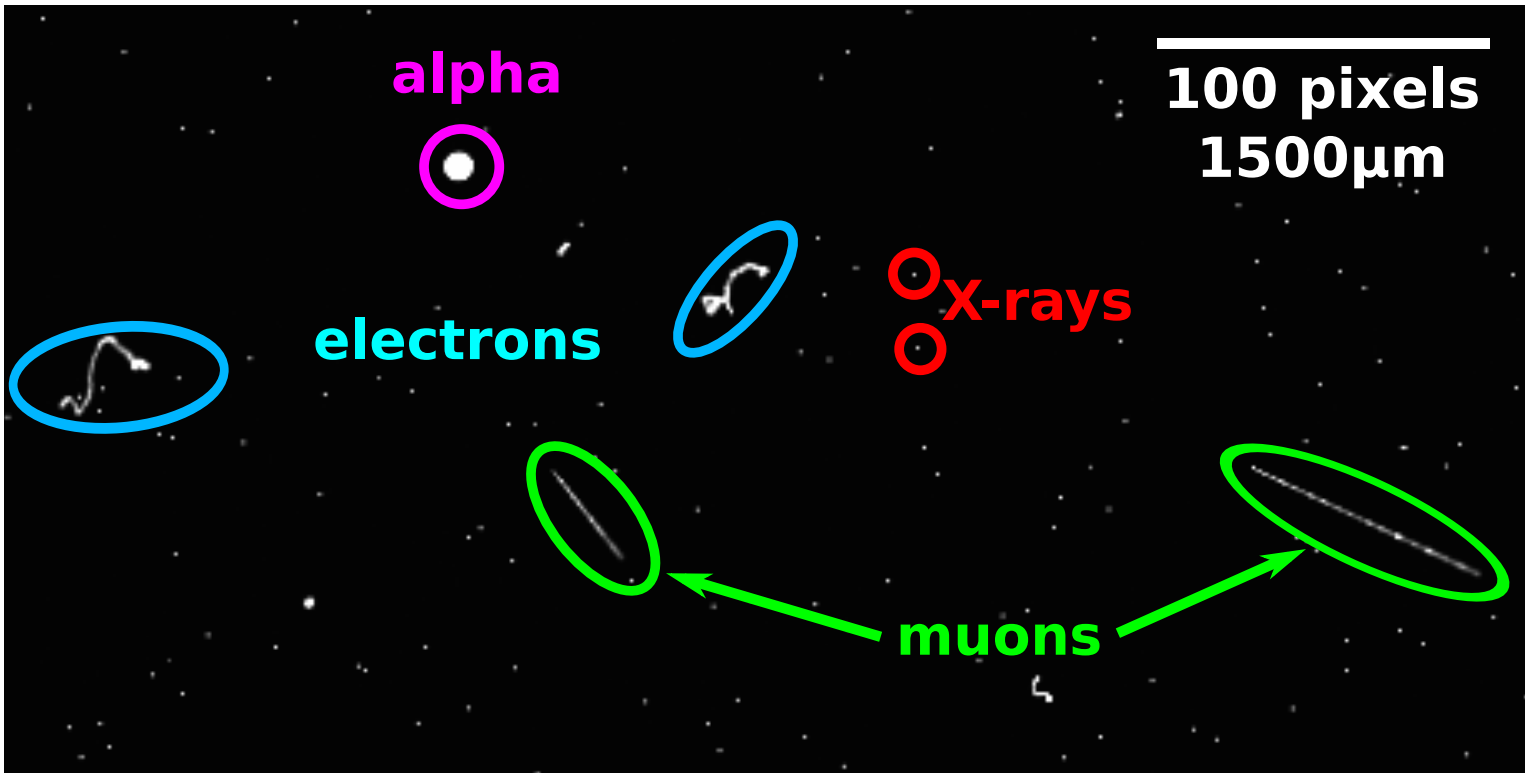
Detectors:

We use scientific CCDs developed by LBNL microdectors group

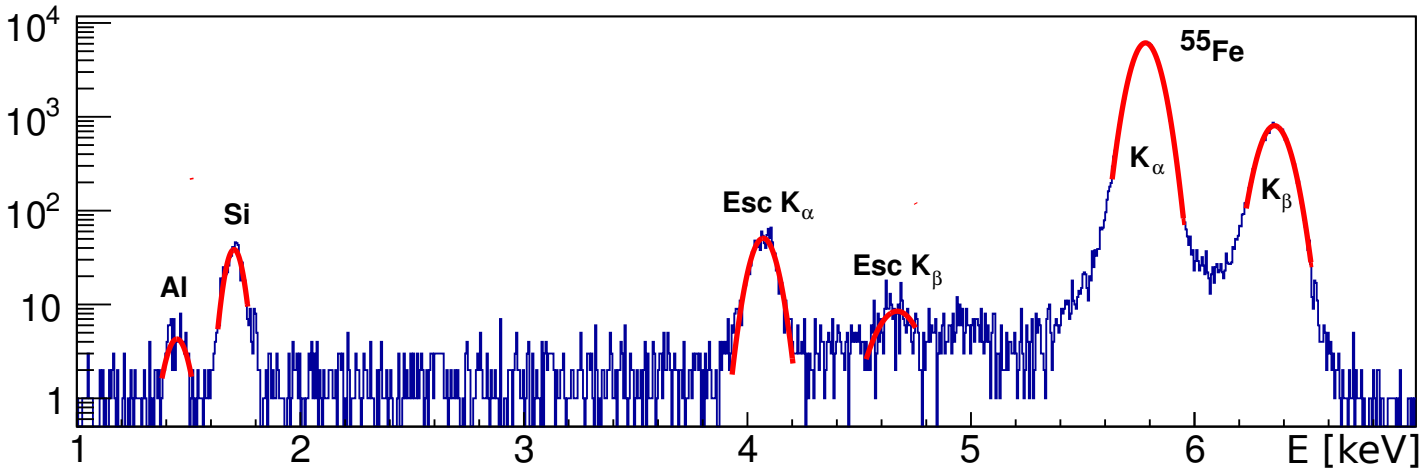
- pixel size of 15 μm
- 10x/27x thicker than most CCDs (250/675 μm)
  - up to 5.5 gr per CCD
  - diffusion $\rightarrow$ 3D rec $\rightarrow$ rejection of surface events
- CCDs cooled to 150 K to achieve readout noise RMS $\sim$ 2 e^-
- Energy threshold of $\sim$0.05 keVee

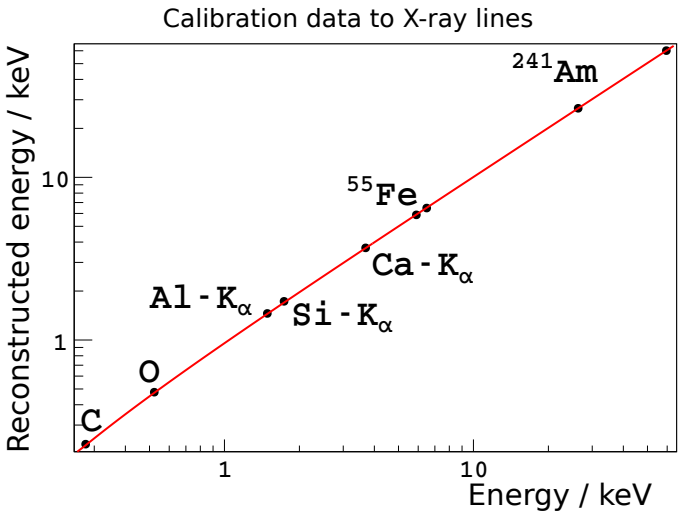



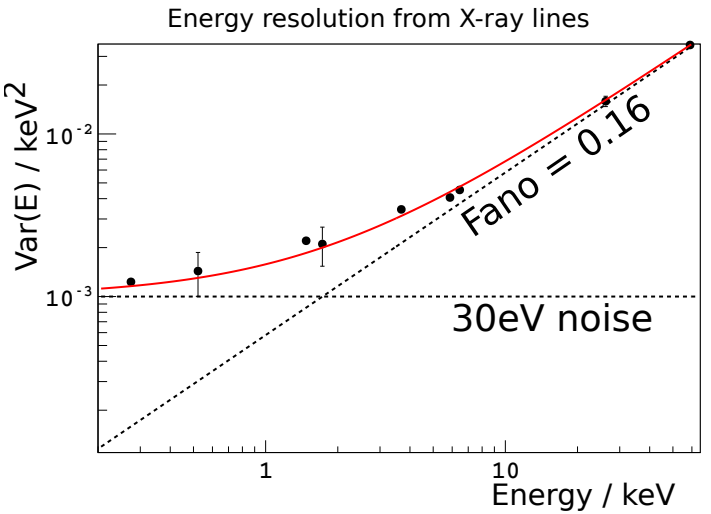
Particle ID



Energy calibration using X-rays

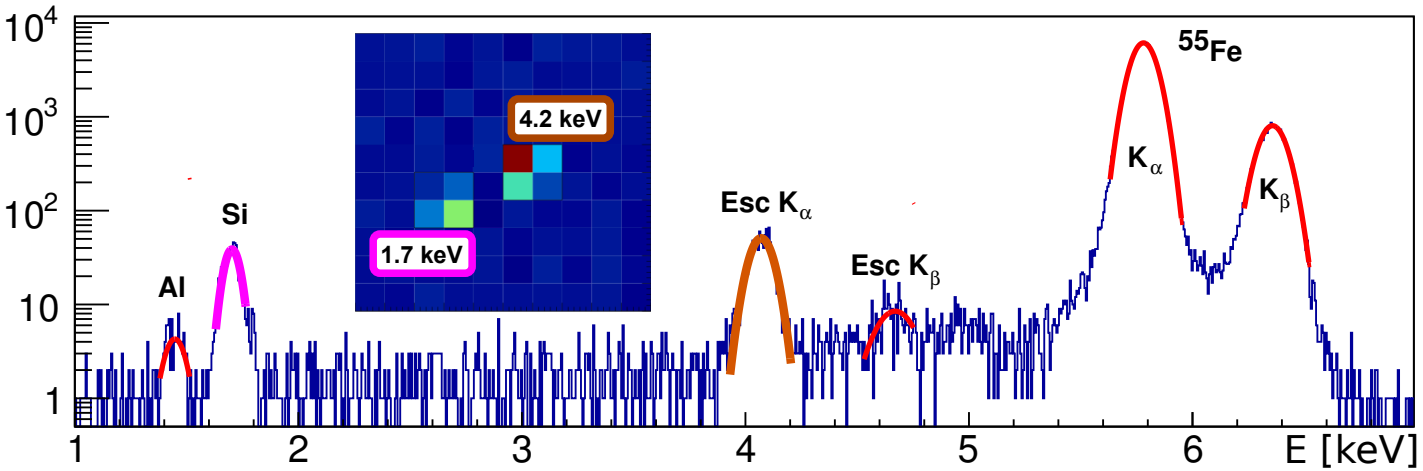


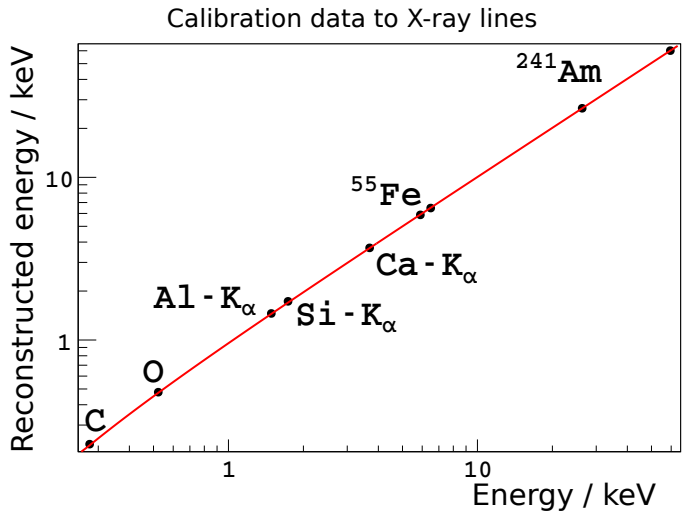


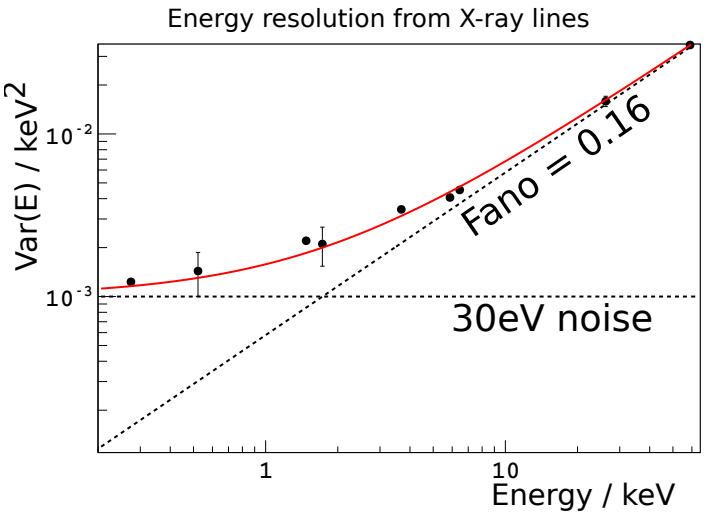


Electron energy scale calibrated down to 280eV, 63eV RMS @6keV

Energy calibration using X-rays

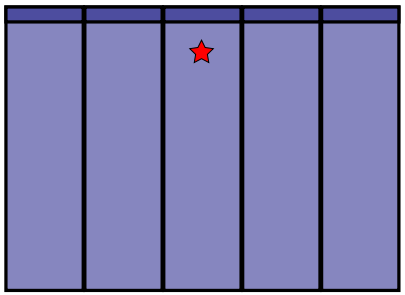


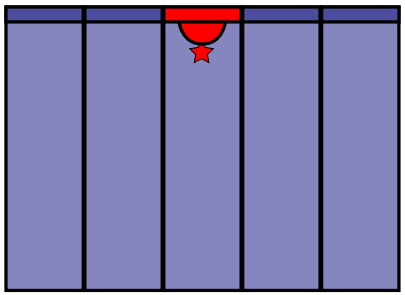


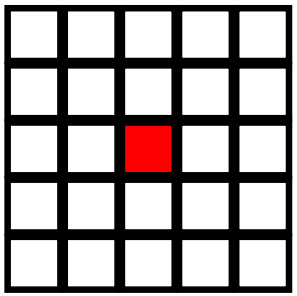


Electron energy scale calibrated down to 280eV, 63eV RMS @6keV

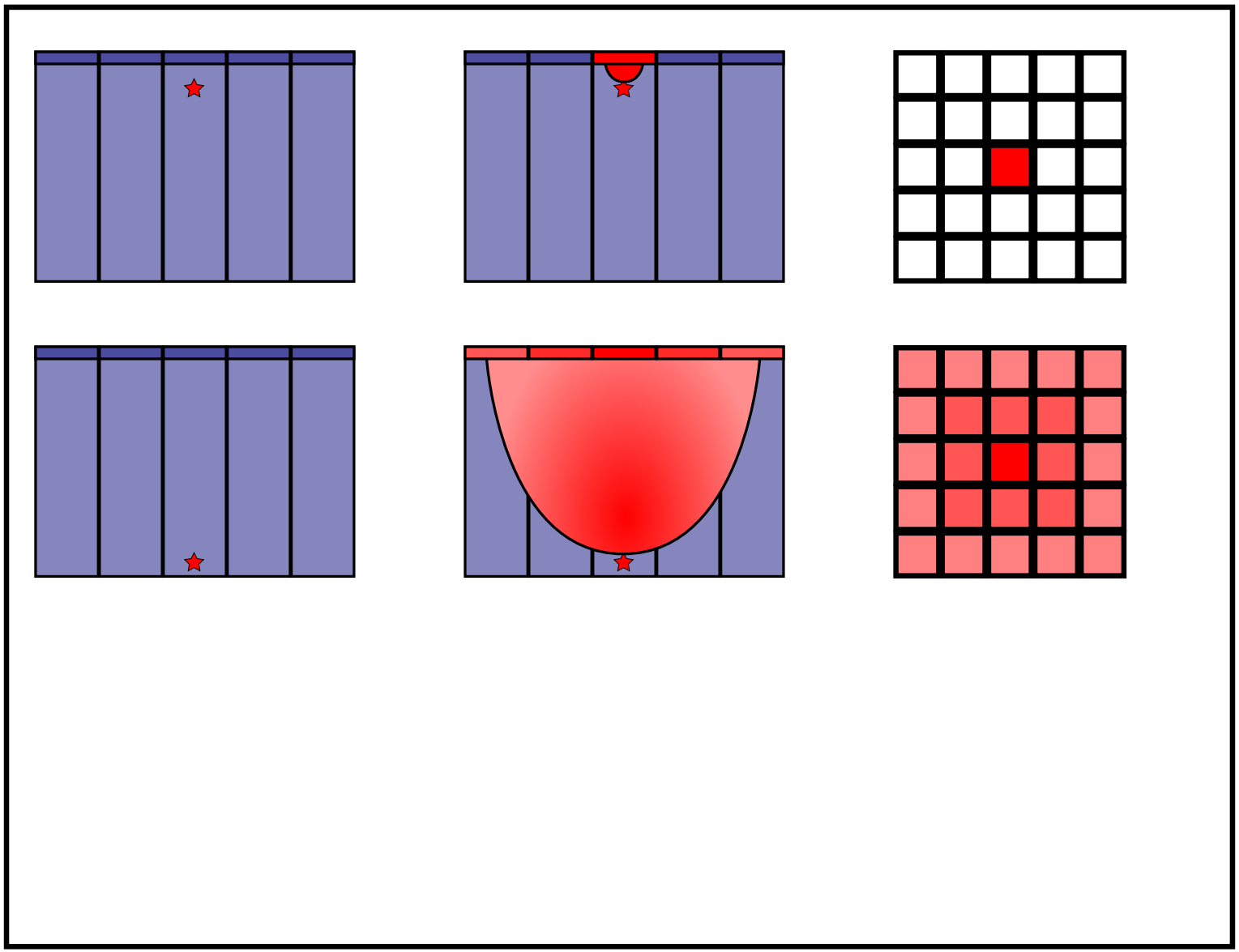
Diffusion



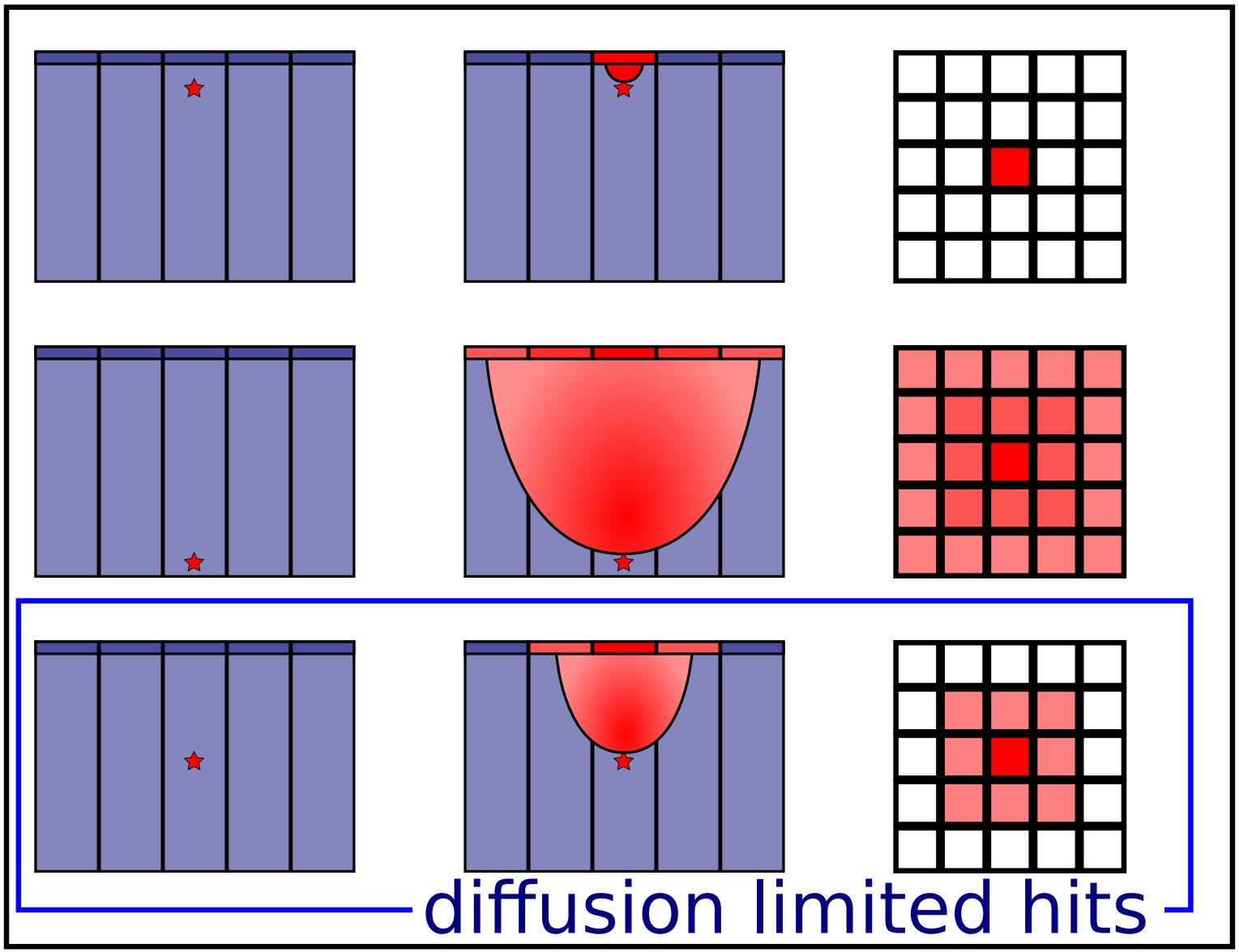




Diffusion

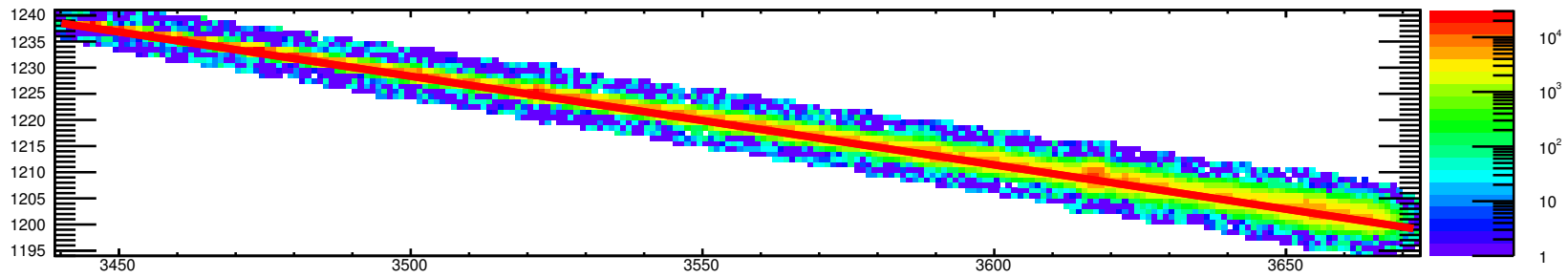


Diffusion

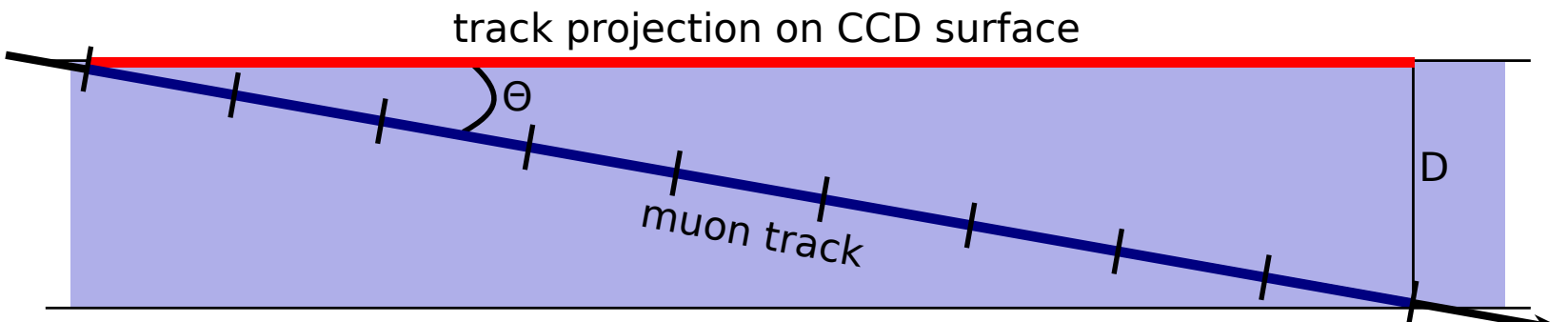


Measuring diffusion

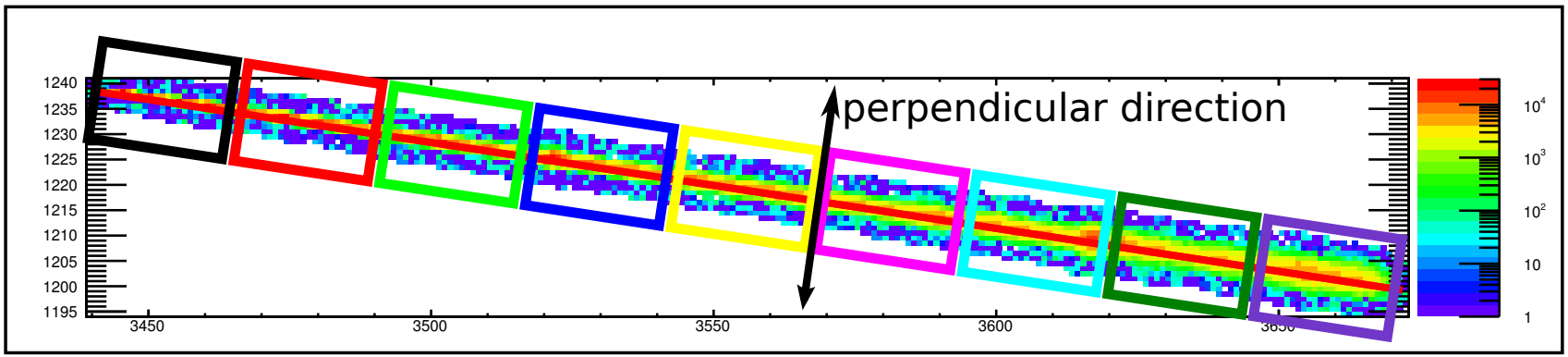
Recorded track: CCD top view

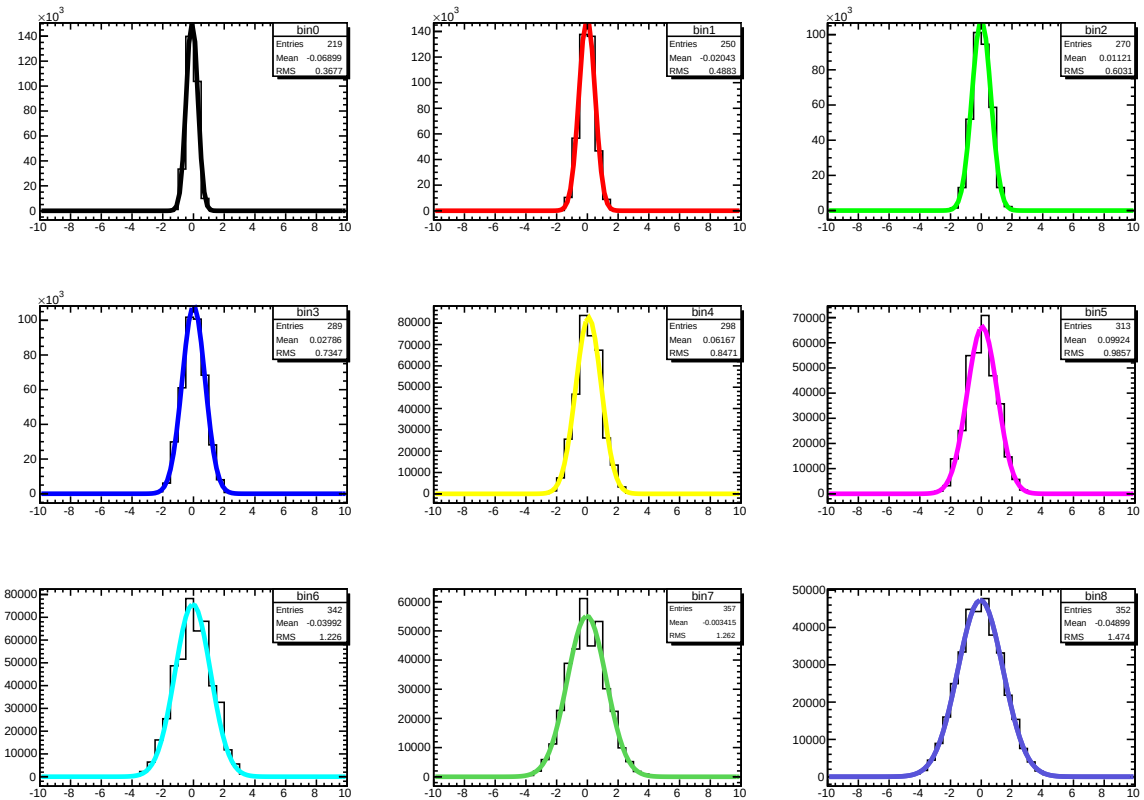


CCD side view

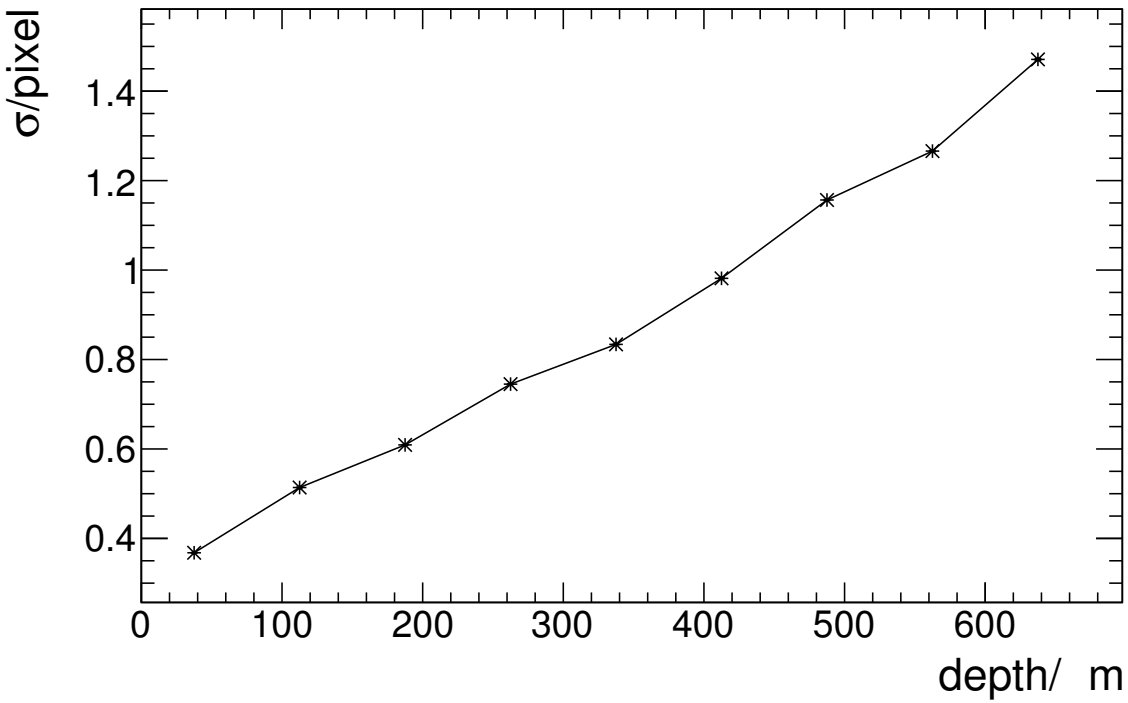


Measuring diffusion



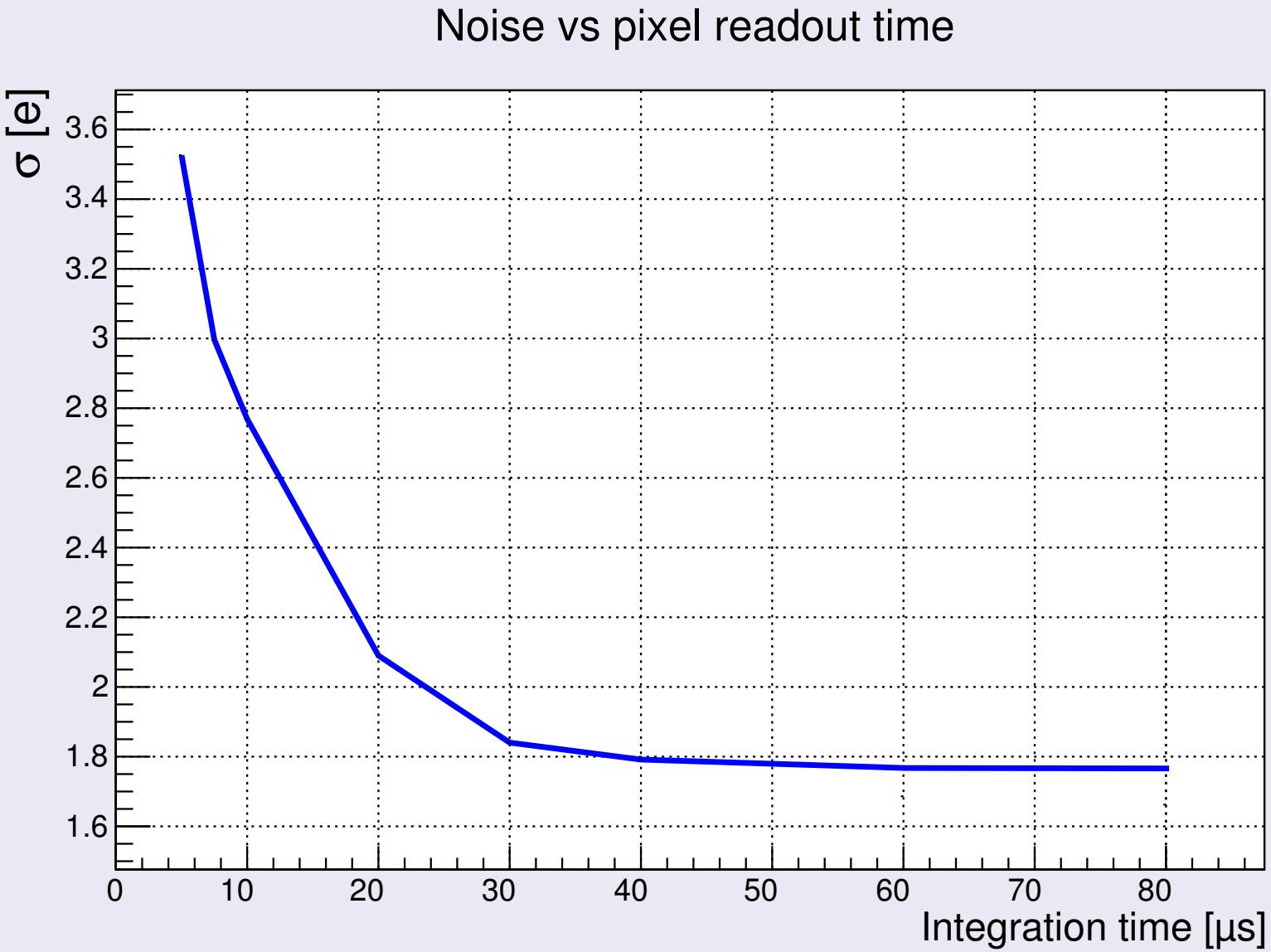


Measuring diffusion



Diffusion can be measured as a function of the interaction depth.
No need to rely on models.

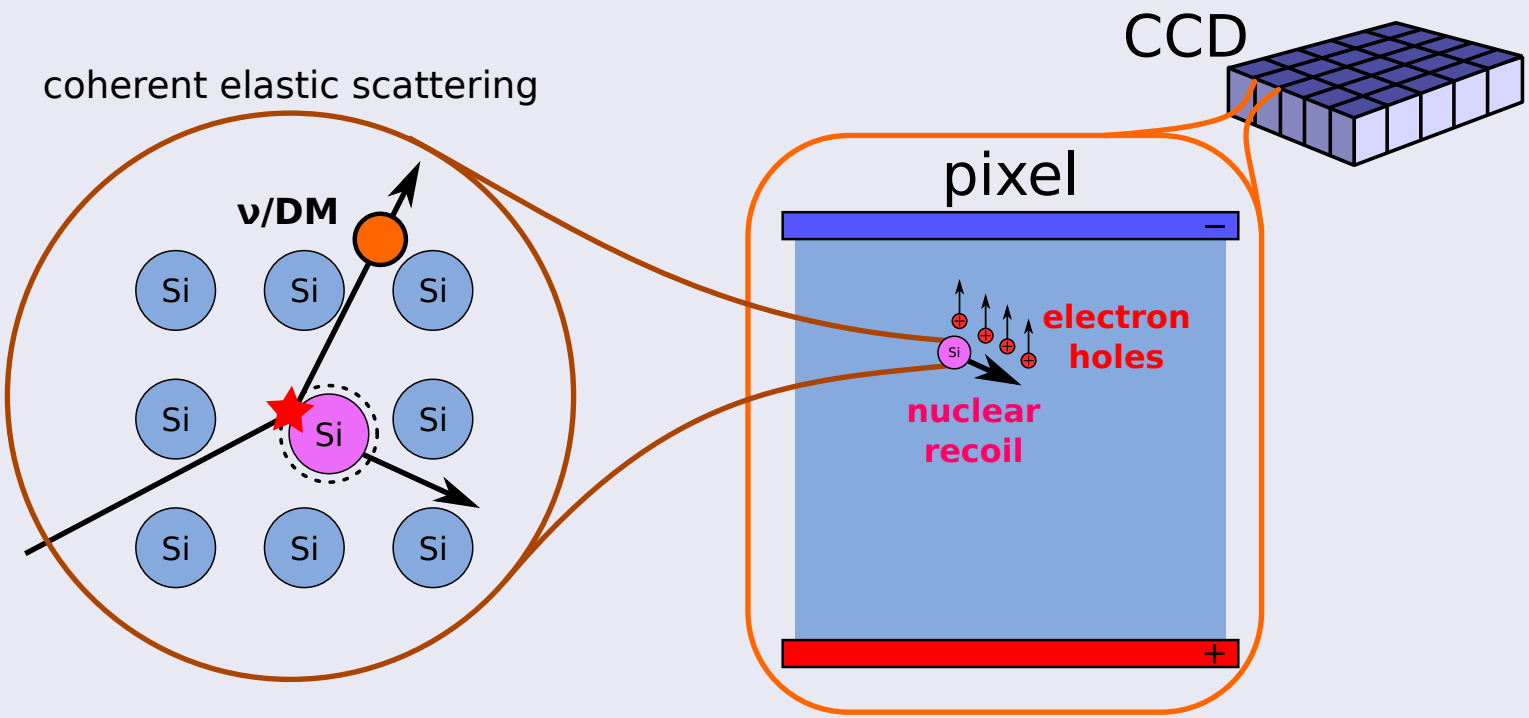
Low noise, ∼1.8 electrons!



Goal: lower the energy threshold in Si detectors

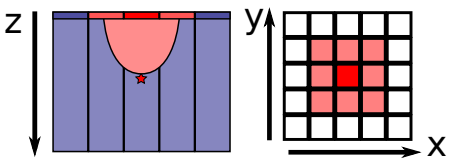
Detect coherent (DM/ν)-nucleus interactions by measuring the ionization produced by the nuclear recoils

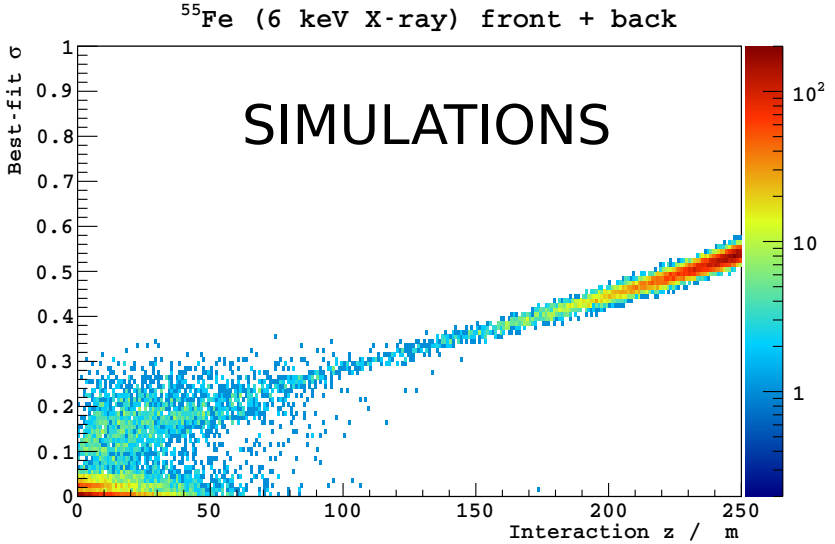
Idea: use CCDs as target and record the ionization produced

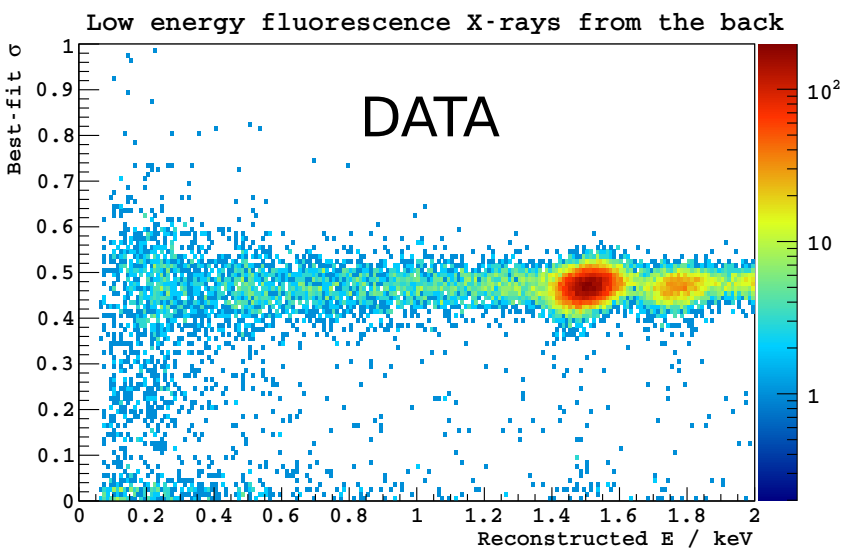


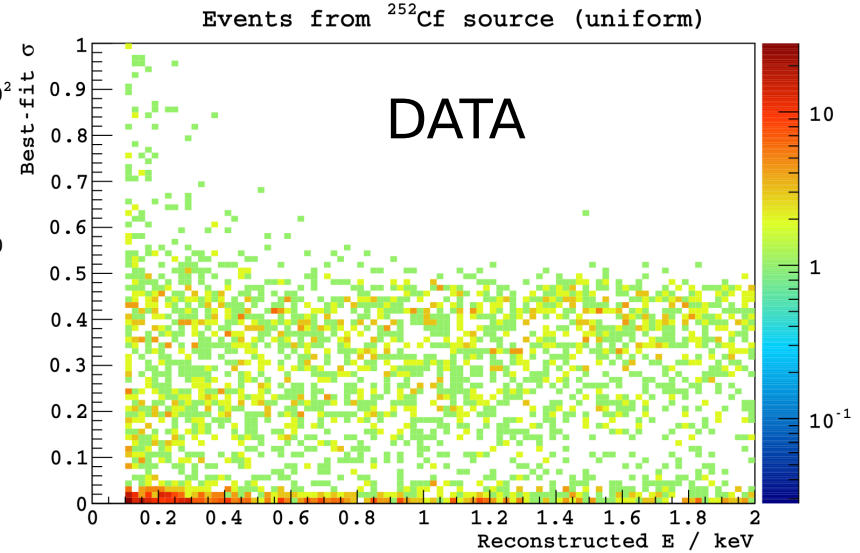
3D reconstruction of low energy (point like) like events

We fit to the radial spread of the cluster to estimate its position in z within the CCD bulk

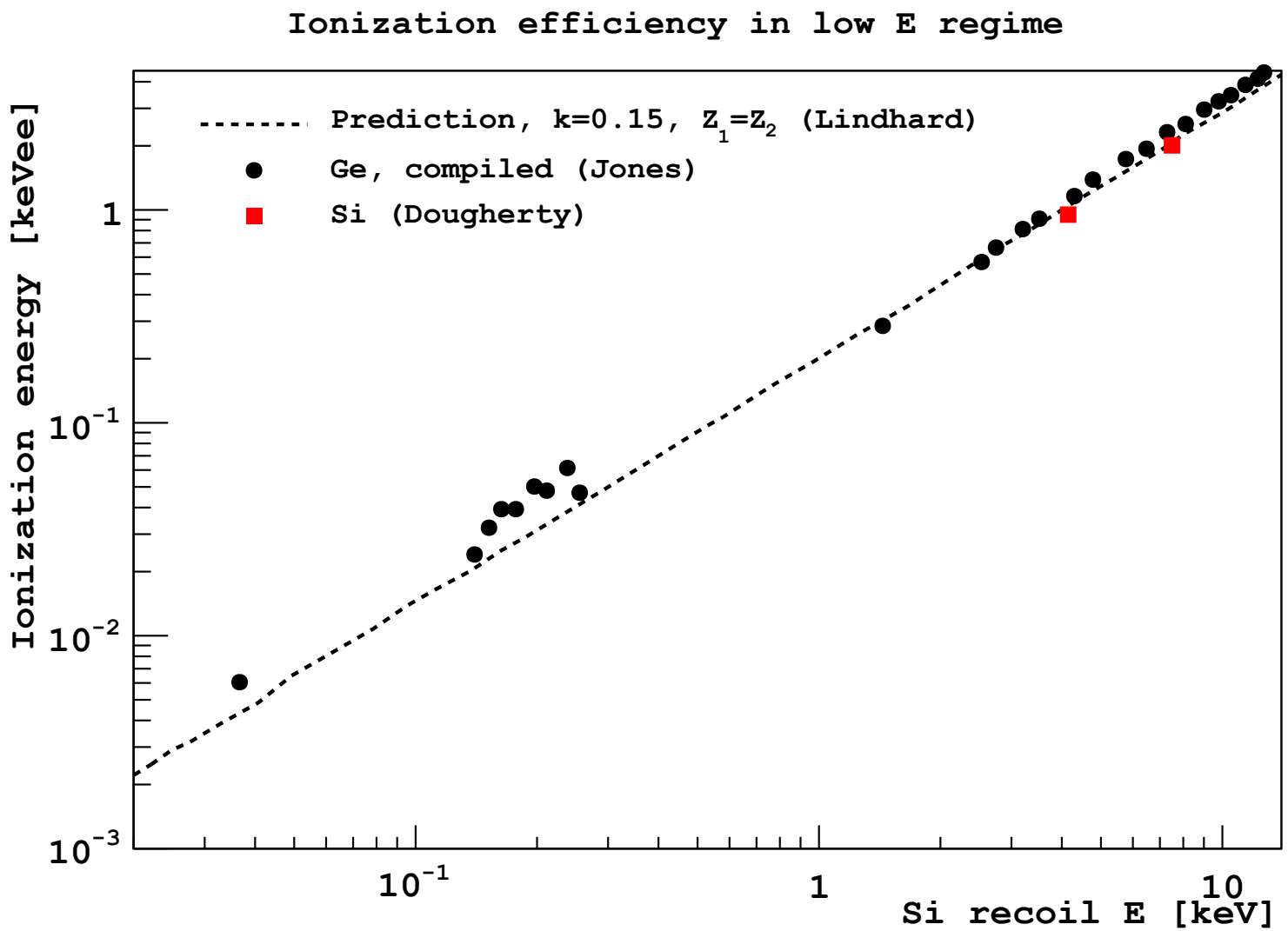








Quenching factor: nuclear recoil ionization efficiency

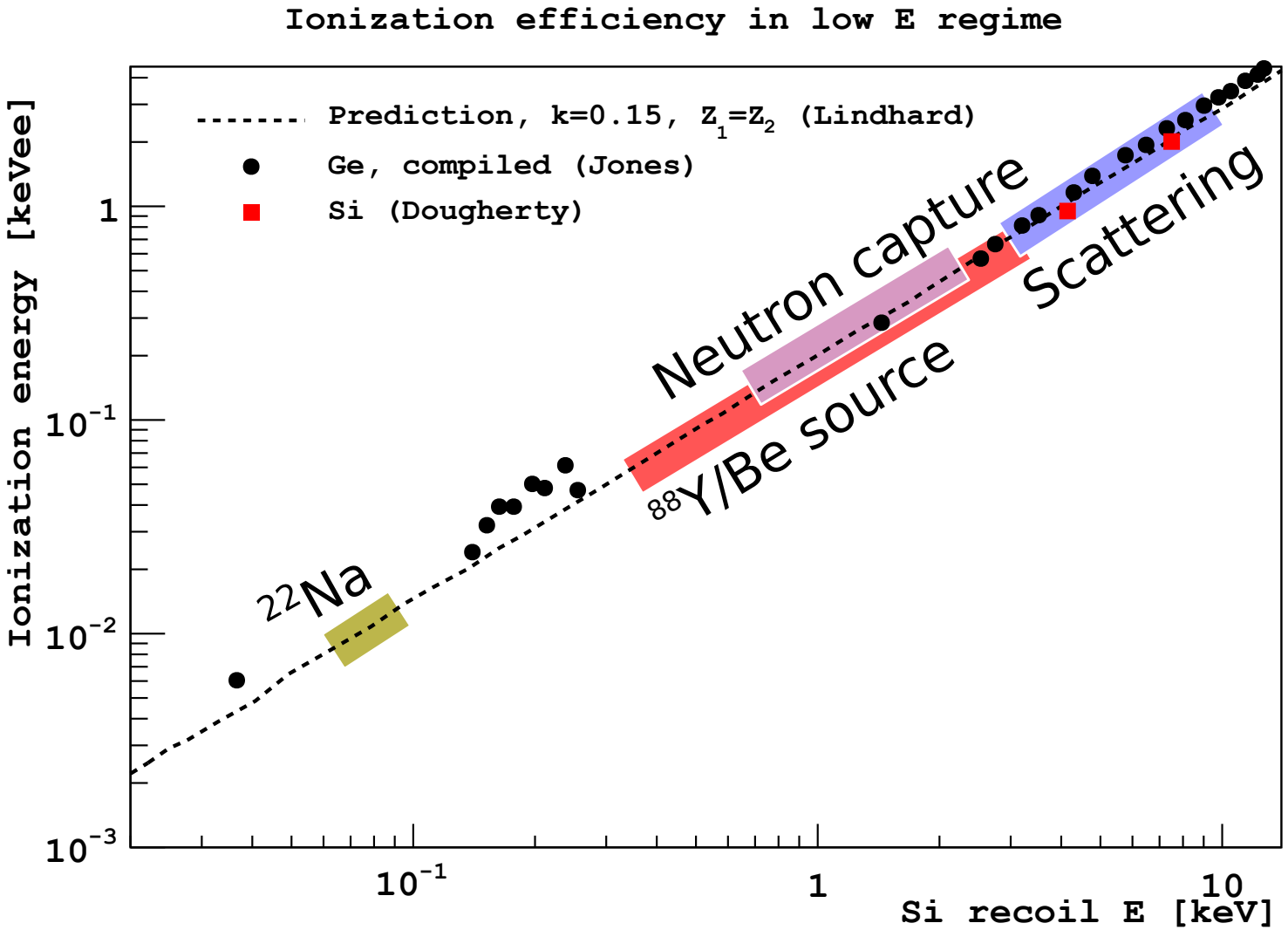


Measuring Q: ongoing efforts

- Scattering experiment at a neutron beam.
- Neutron capture: ^{28}Si+n $\rightarrow$ ^{29}Si+γ
  - Using a LAAPD + NaI detector in coincidence.
  - Using a CCD at a nuclear reactor.
- *Monochromatic* neutron exposure: ^{88}Y/Be source
- CCD activation at a proton beam:

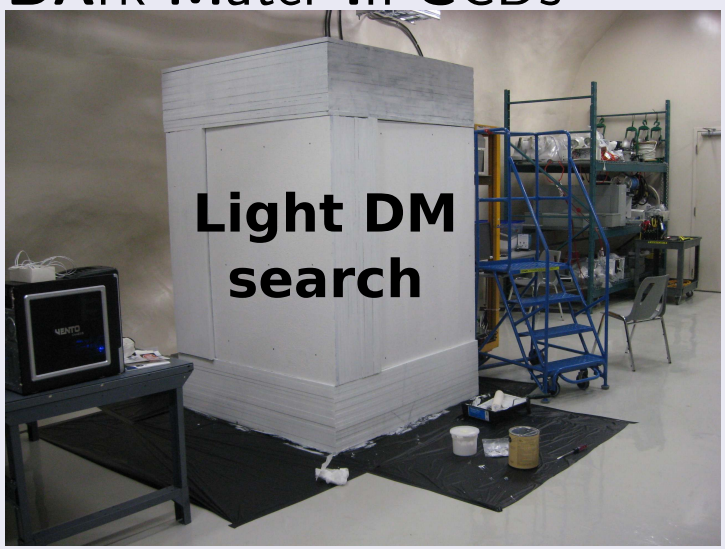
  measure nuclear recoils after EC of ^{22}Na.

Measuring Q: ongoing efforts



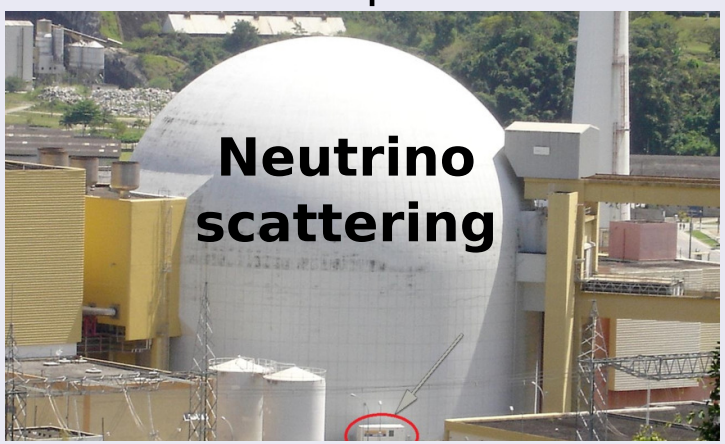
DAMIC:

DArk **M**ater **I**n **C**CDs



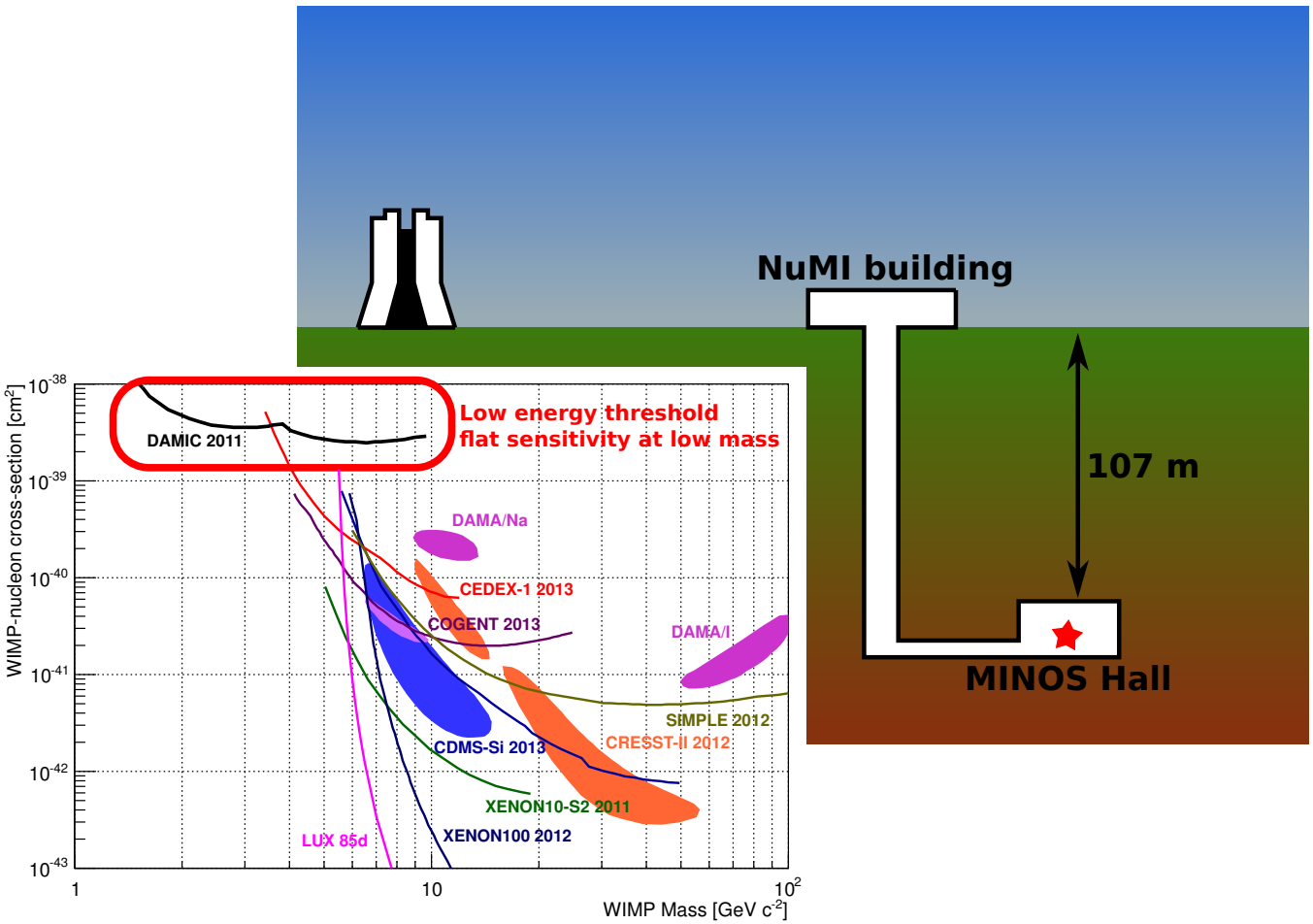
CONNIE:

COherent **N**eutrino-**N**ucleus **I**nteraction **E**xperiment

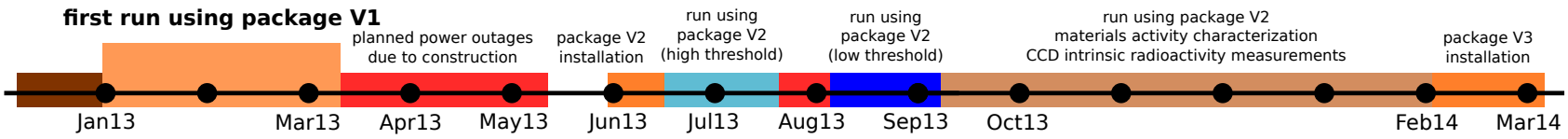


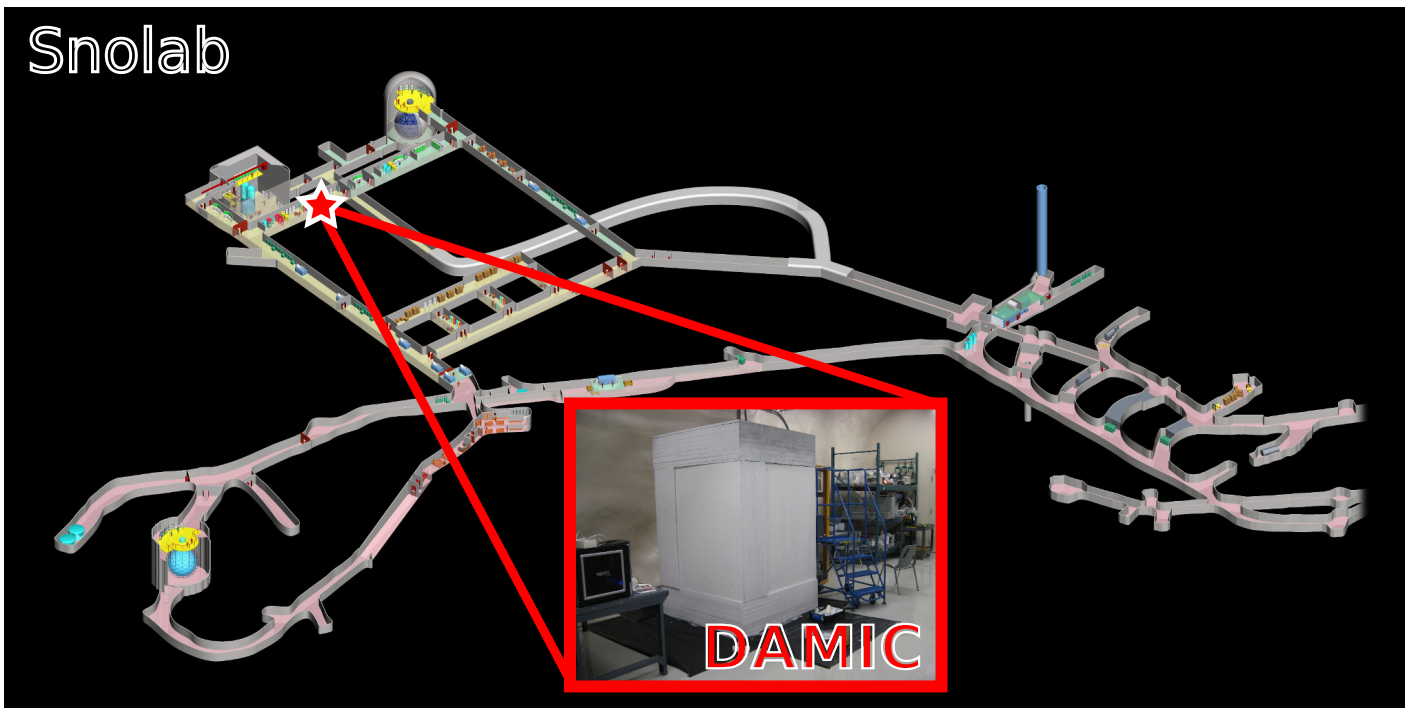
DAMIC: First run - technique demonstration @MINOS

Operated from June 2010 to May 2011. Exposure: 107 g days^{-1}.



DAMIC @Snolab (installed Dec12)





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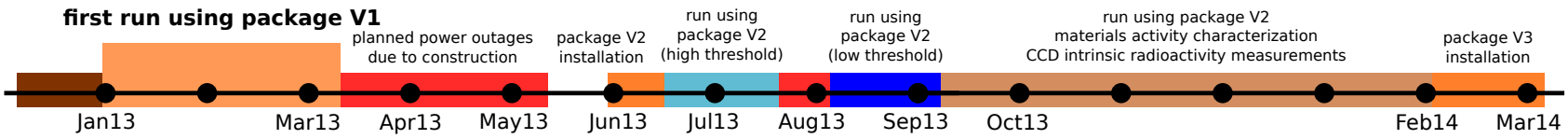

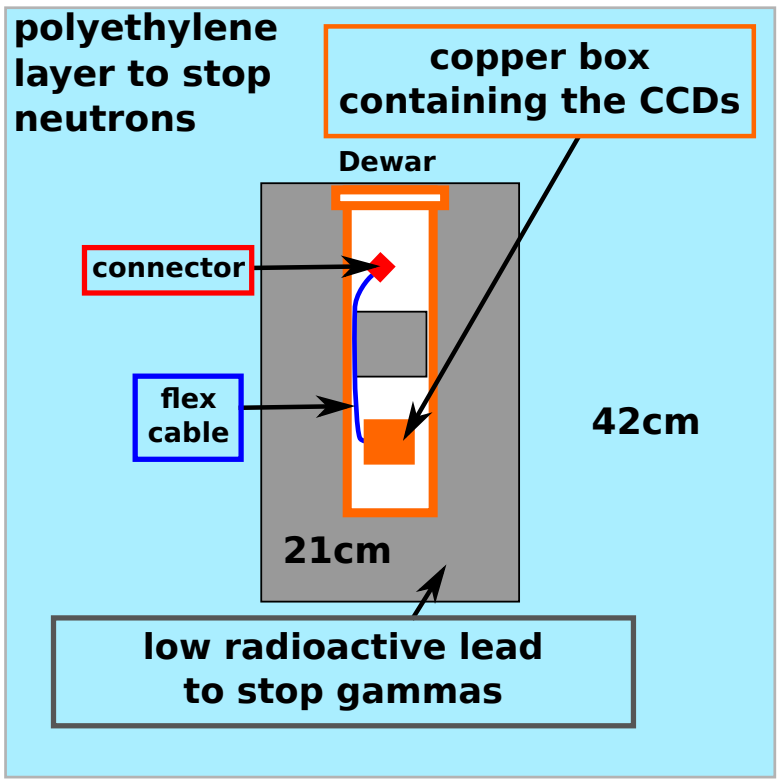

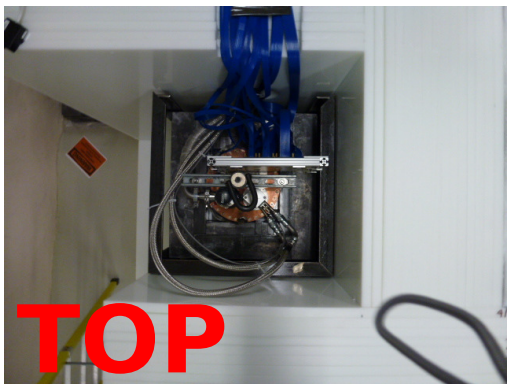

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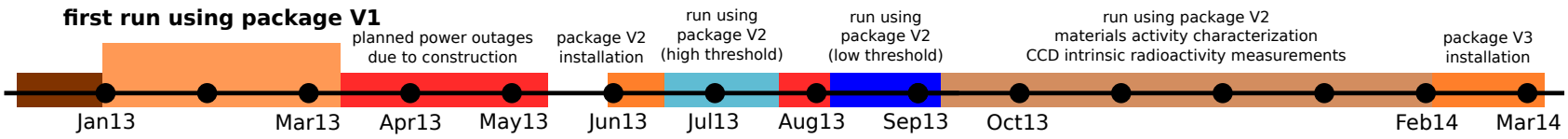

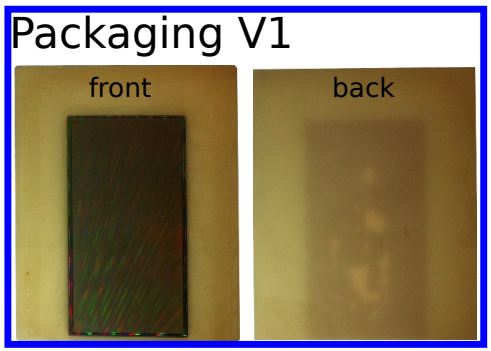

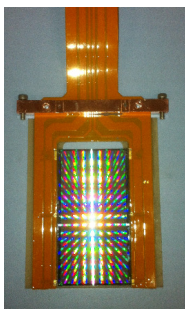

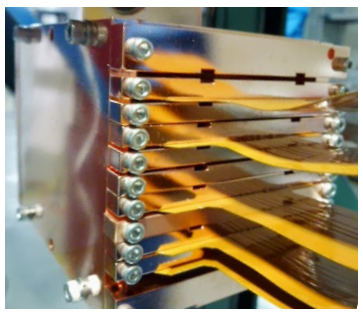

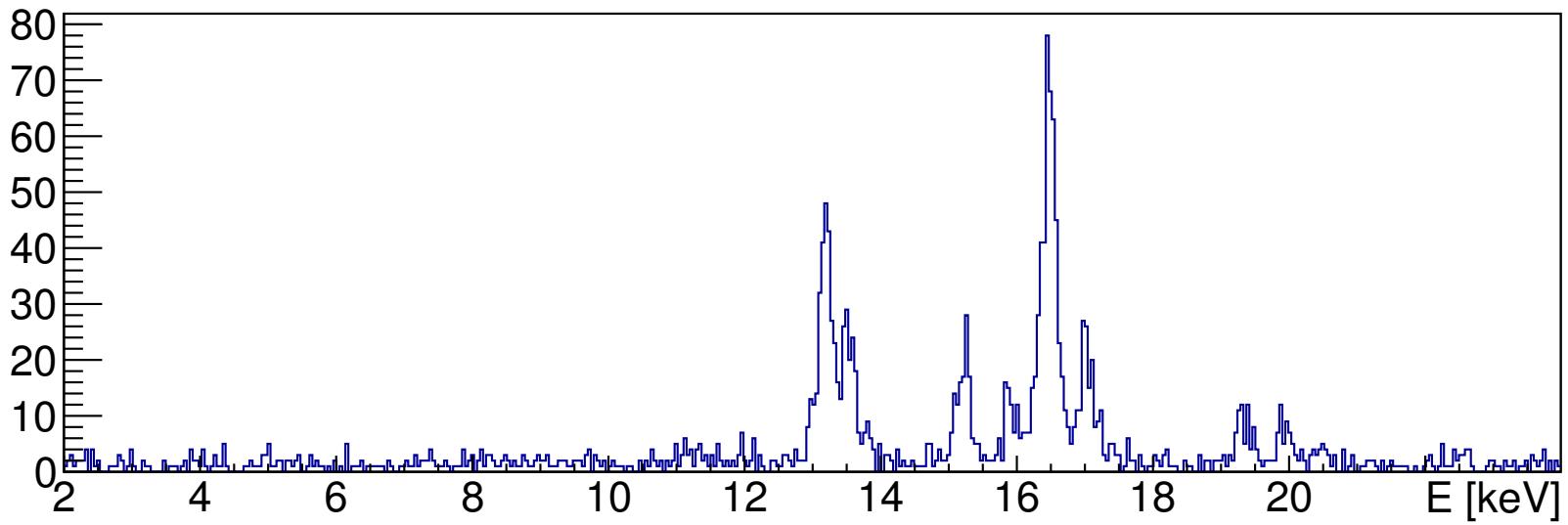

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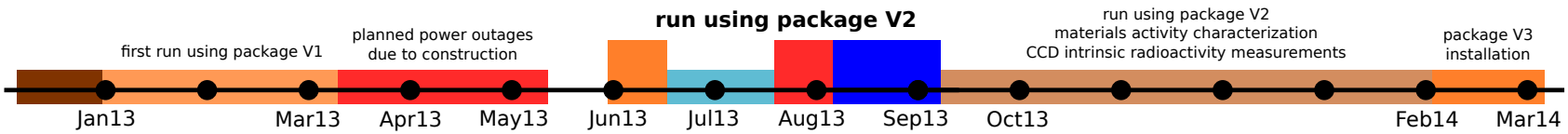

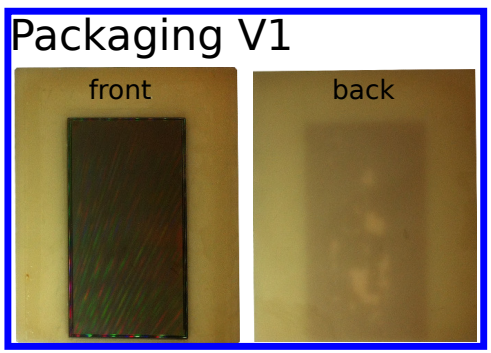

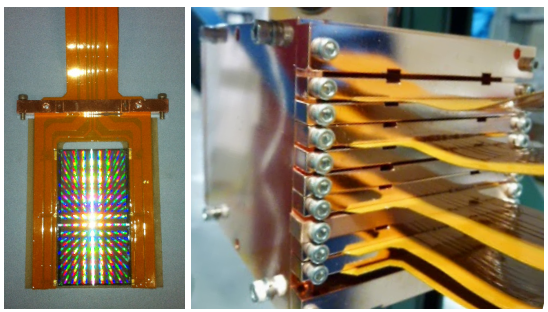

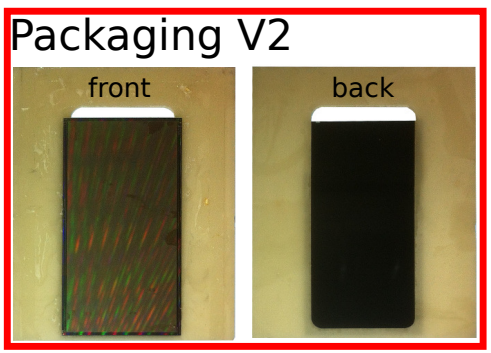

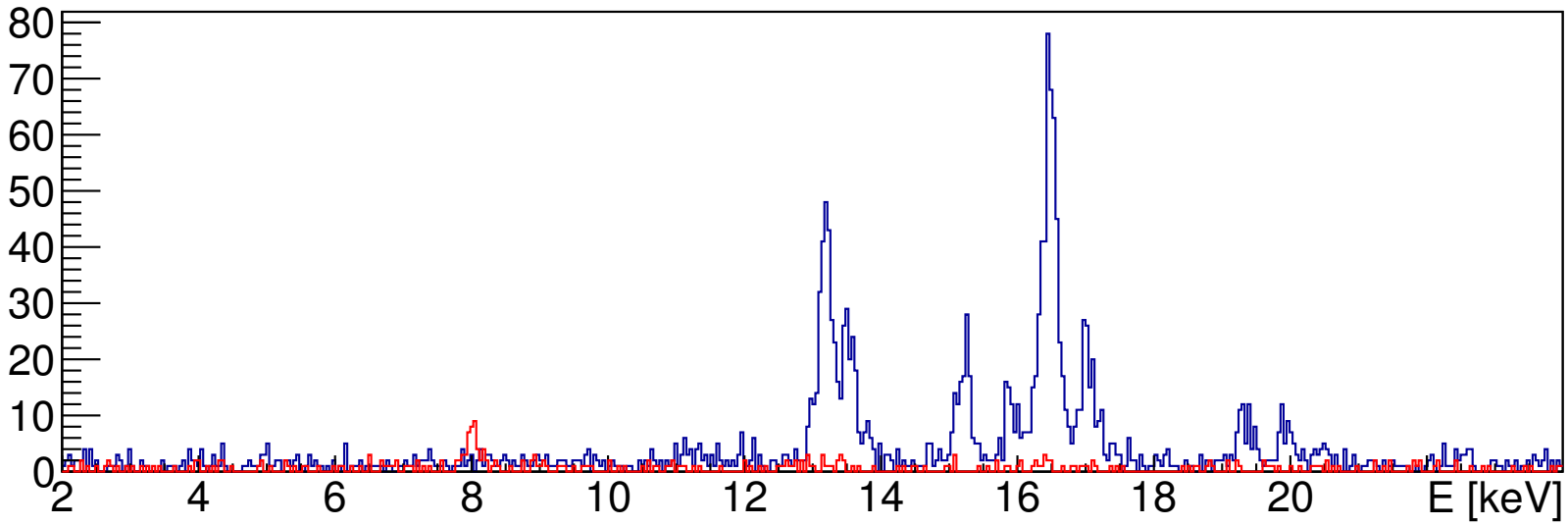

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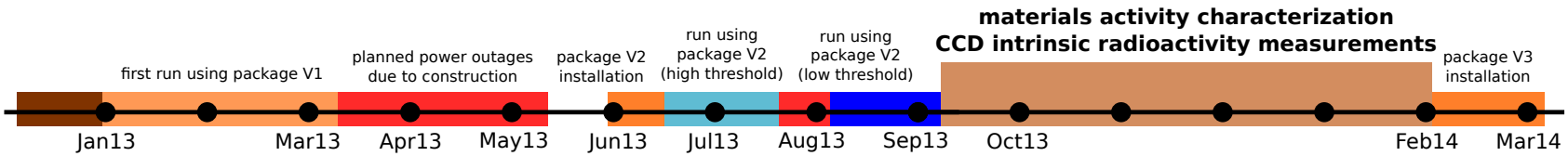
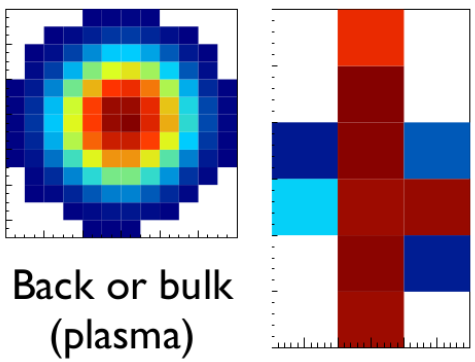


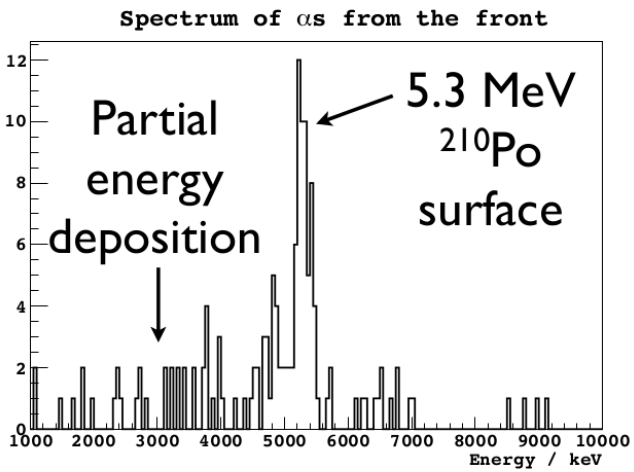
Alpha search



Back or bulk (plasma)

Front (bloomed)

^{232}Th:<0.08 mBq/kg
^{238}U: <0.06 mBq/kg



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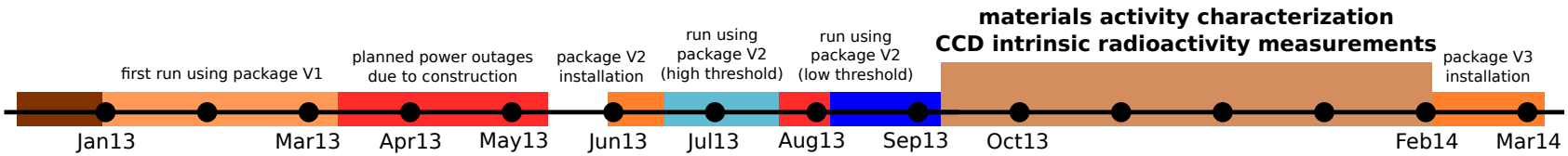
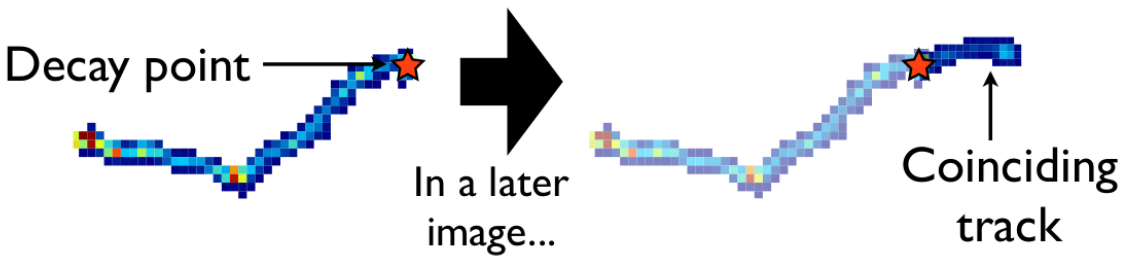


Spatial coincidences



$^{210}Pb \xrightarrow{64\ keV} {}^{210}Bi \xrightarrow{1.2\ MeV} {}^{210}Po$

$\tau_{1/2} = 5$ d

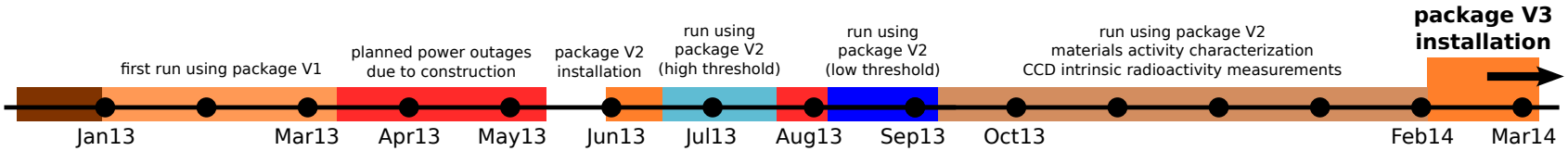
$^{32}Si \xrightarrow{0.22\ MeV} {}^{32}P \xrightarrow{1.7\ MeV} {}^{32}S$

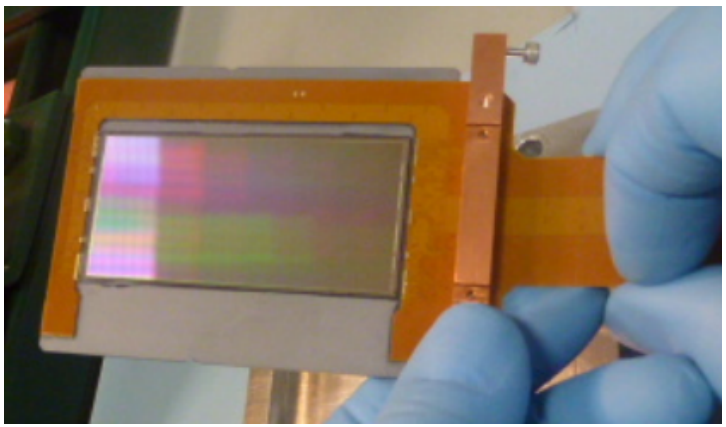
$\tau_{1/2} = 14$ d

Sequence of βs starting in the same pixel of the CCD in different images

^{32}Si: <2.6 mBq/kg
^{210}Pb: <0.6 mBq/kg

DAMIC @Snolab (installed Dec12)



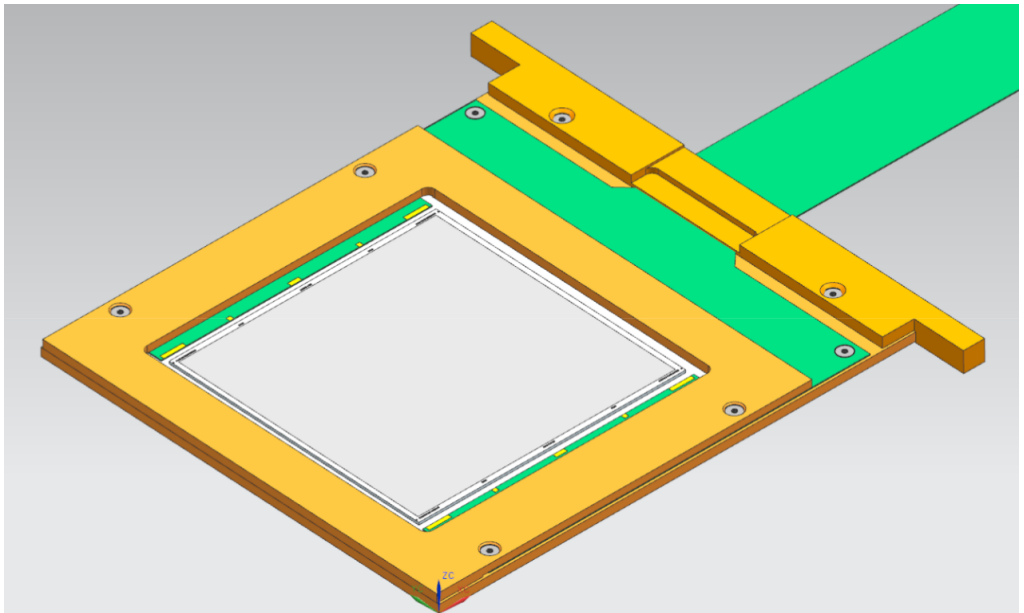


- **Two astronomy optimized CCDs: 500µm with ITO on silicon substrate**
- **One DM optimized CCD: 650µm CCD without ITO on**

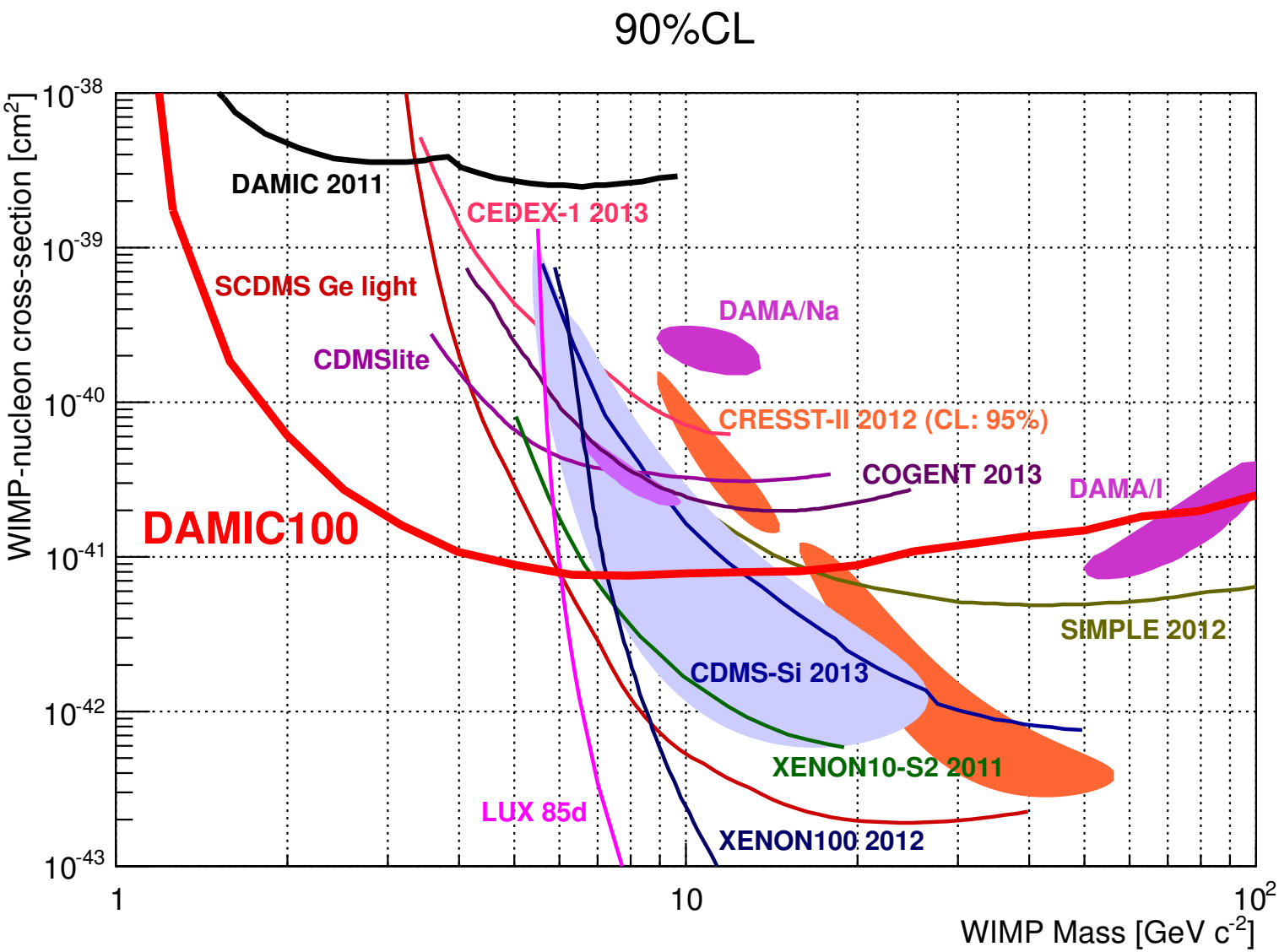
Near future: DAMIC100

Currently packaging and testing next generation CCDs optimized for dark matter experiment. Will deploy 100 g of active mass. Prototypes already installed and taking data. First batch of CCDs in final package to be installed at SNOLAB during 2014.

- Scalable and compact $\rightarrow$ we can install 24 CCDs in the dewar.
- We are focused on understanding the activity of the inner materials to get full advantage of the mass increase.

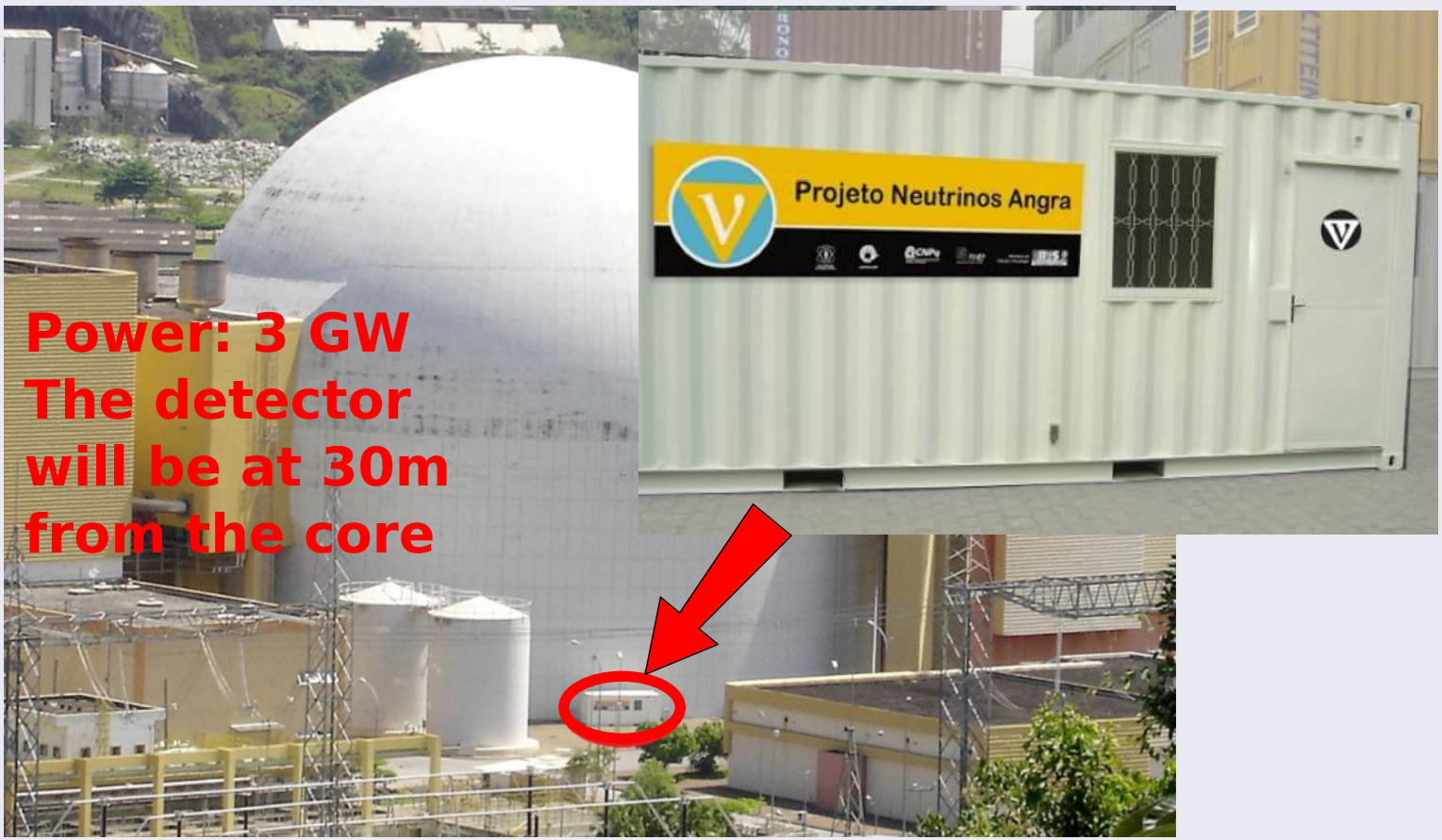


DAMIC100 @Snolab - expected sensitivity



CONNIE

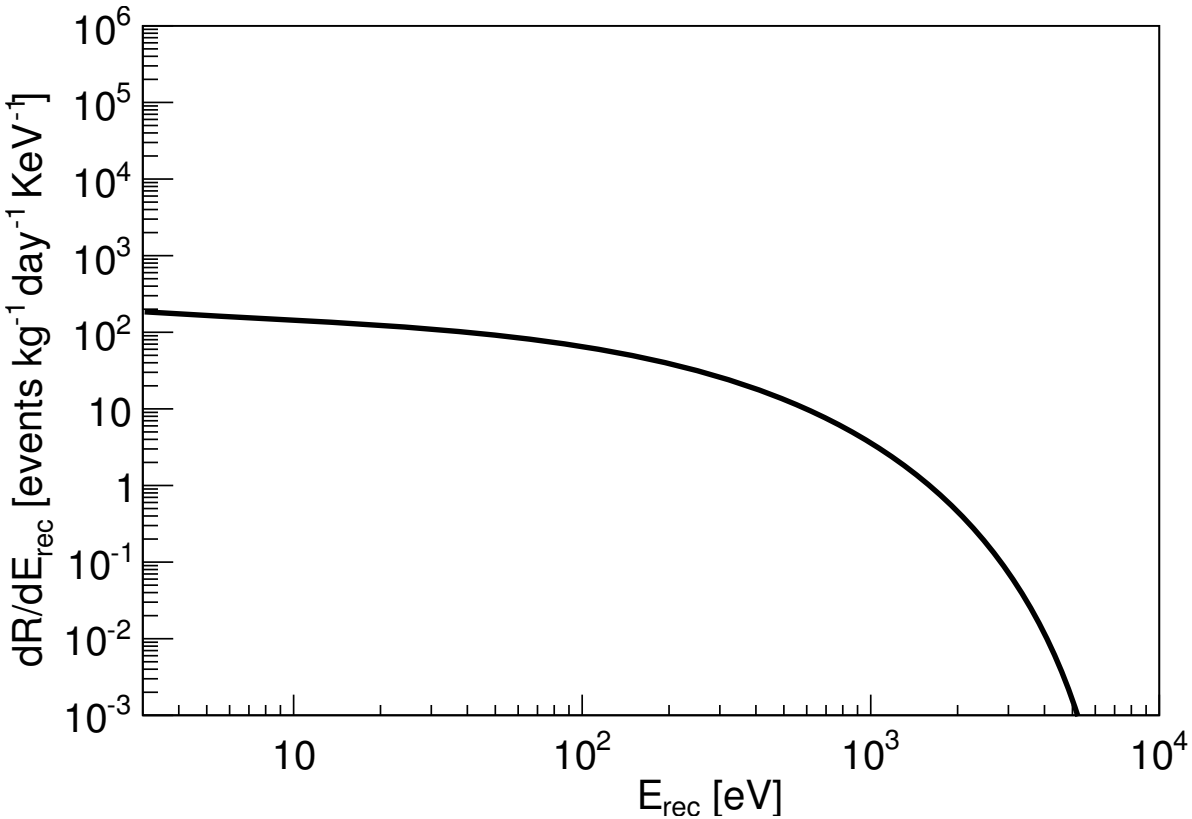
Location: Nuclear power plant in Angra, Brazil



CONNIE

Event rate

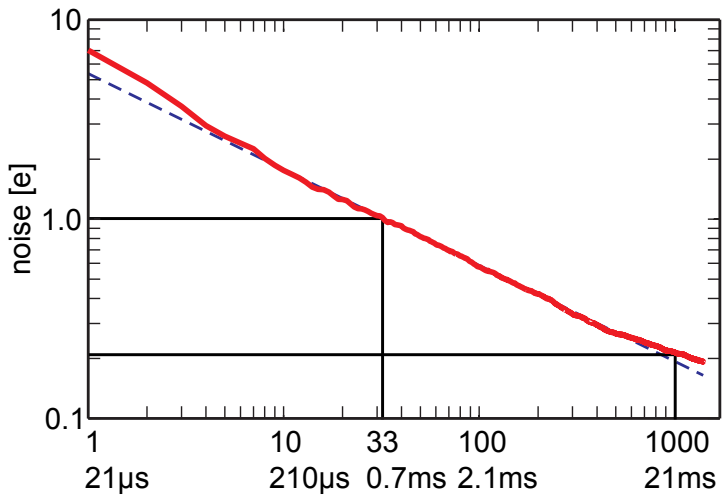
For 10 grams: $\sim$ 0.3 ν elastic scattering events per day



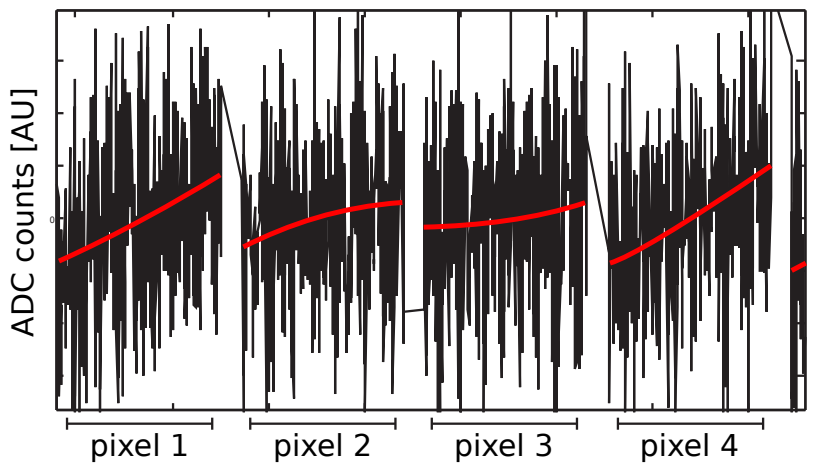
Lowering the noise, reaching the sub-electron level.

Two ongoing efforts

Skipper CCD

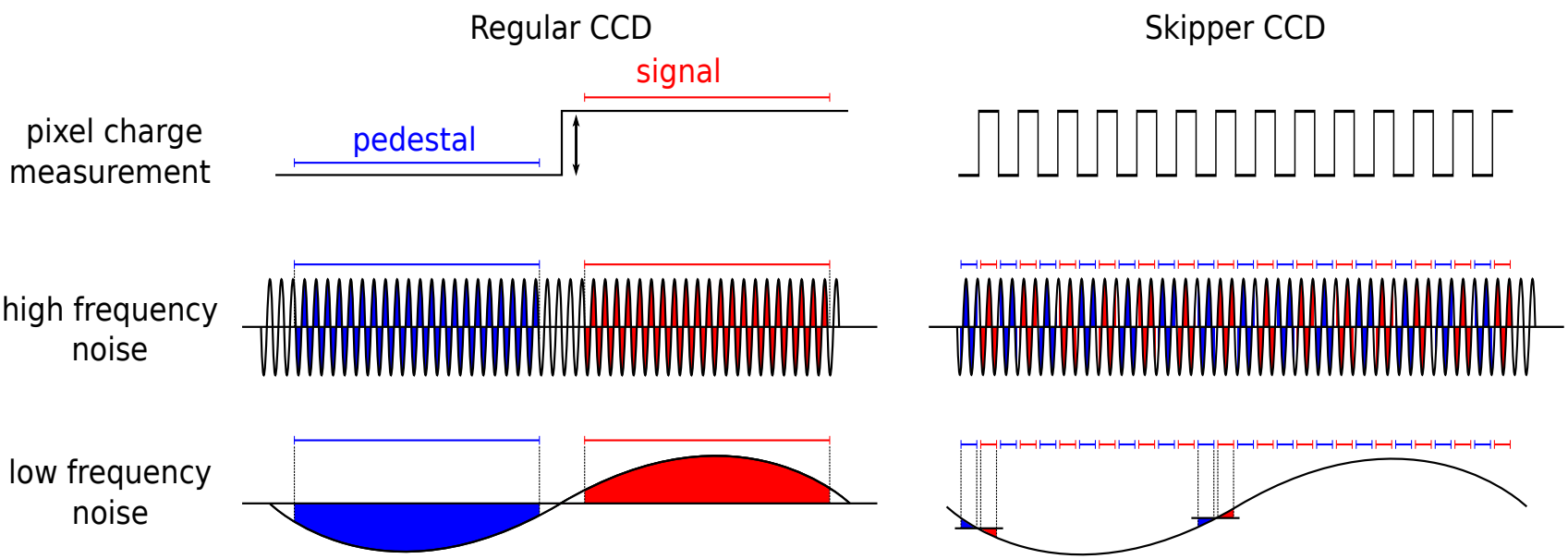


Low Frequency Noise Reduction

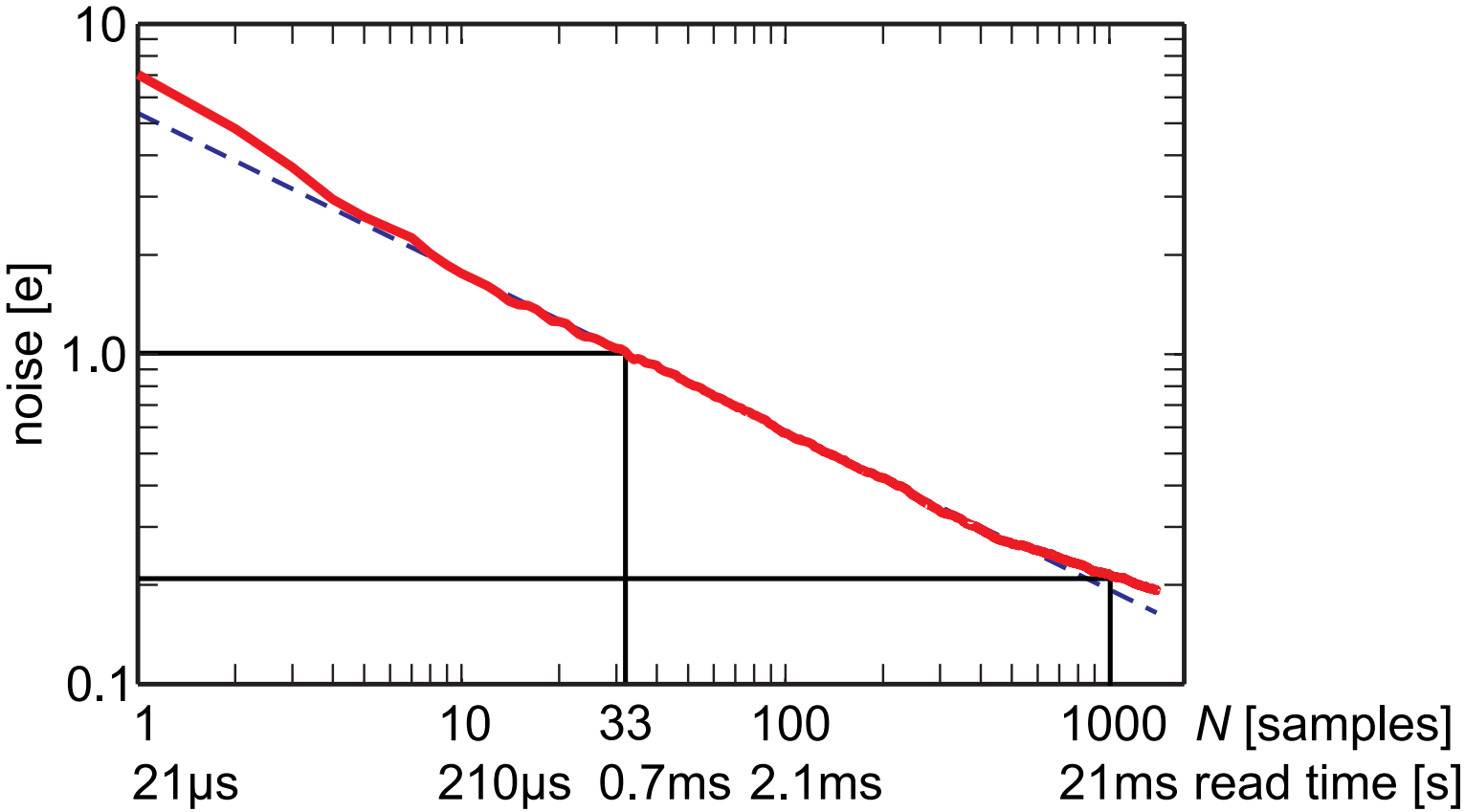


Lowering the noise: Skipper CCD

- Main difference: the CCD allows multiple sampling of the same pixel without corrupting the charge packet.
- The final pixel value is the average of the samples
  Pixel value $= \frac{1}{N}\Sigma_i^N$ **(pixel sample)**$_i$

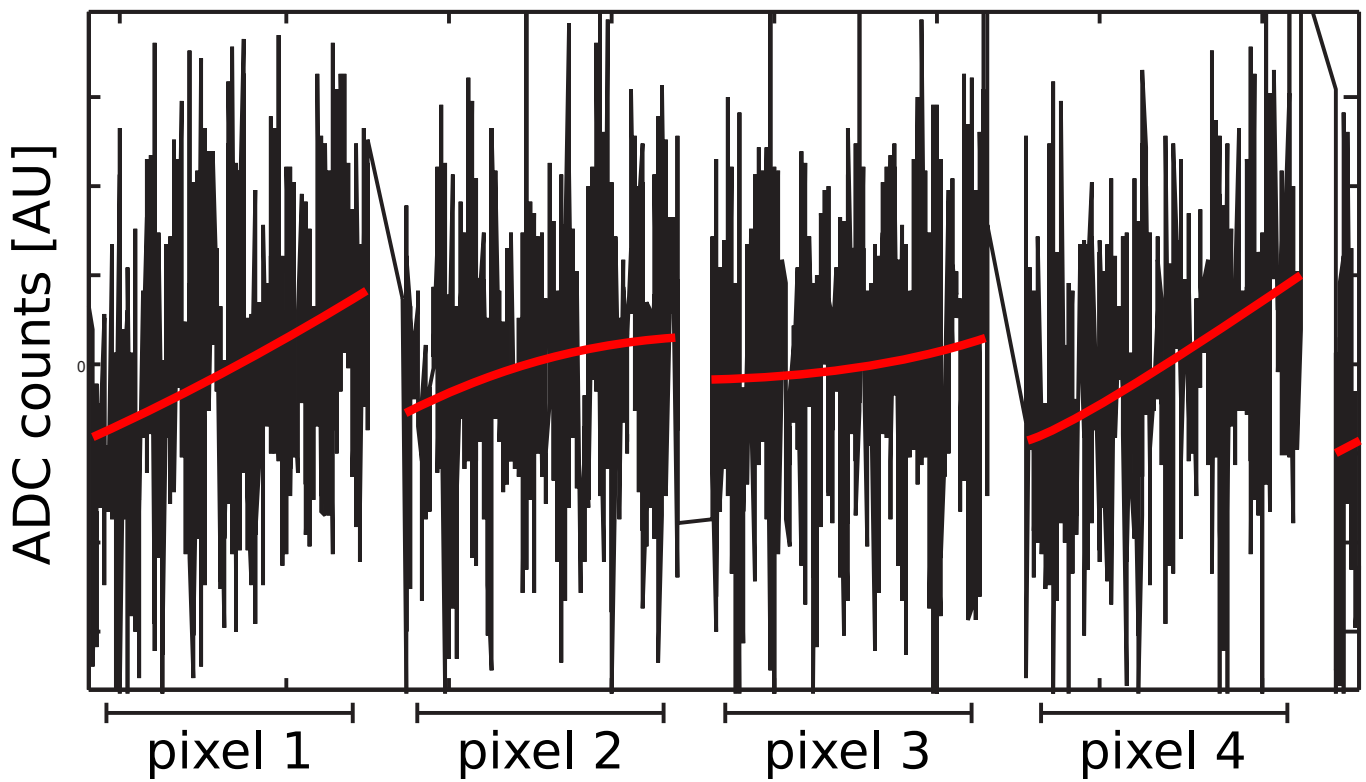


Lowering the noise: Skipper CCD

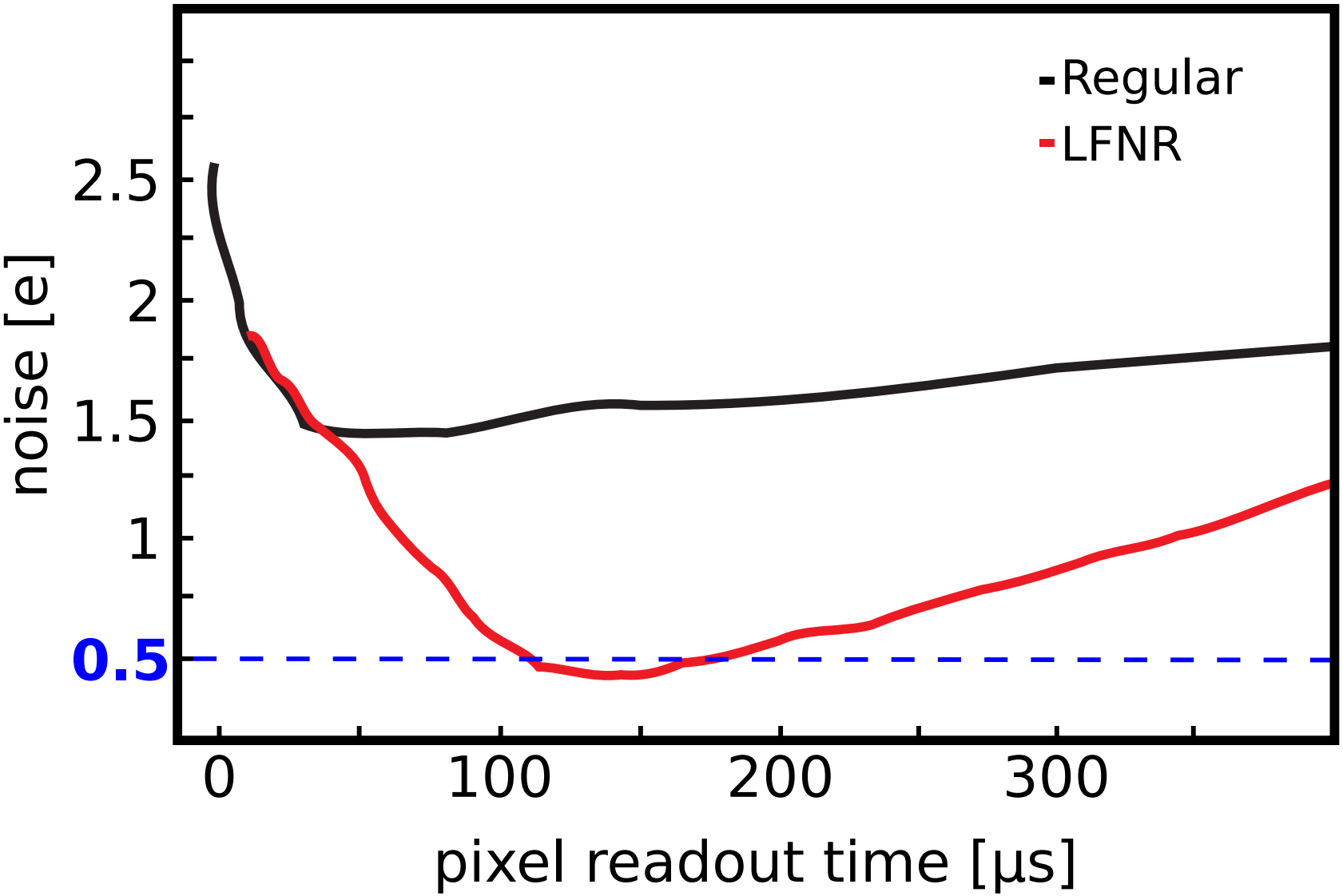


Lowering the noise: Low Frequency Noise Reduction

- There is some low frequency tendency which has a significant effect in the pixel error.
- This slow variation are estimated from each pixel using Least Square Fitting.



Lowering the noise: Low Frequency Noise Reduction

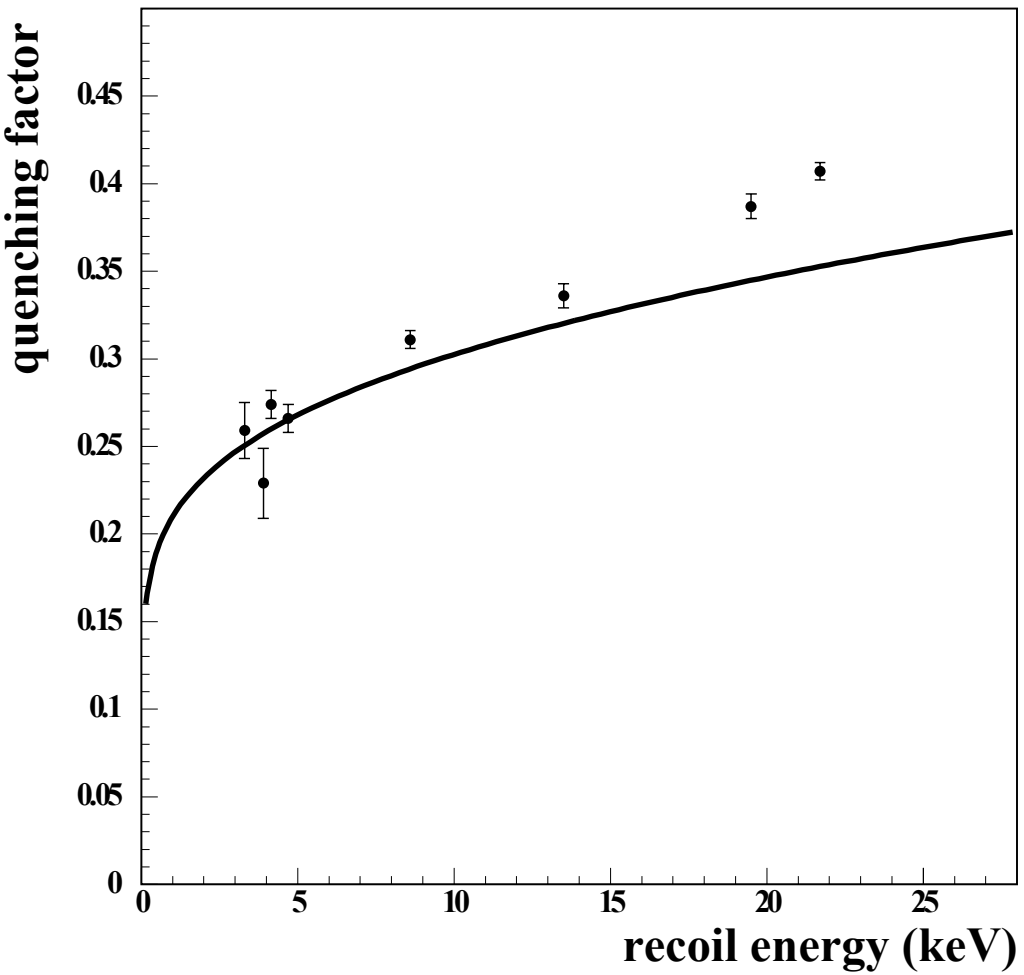


Summary

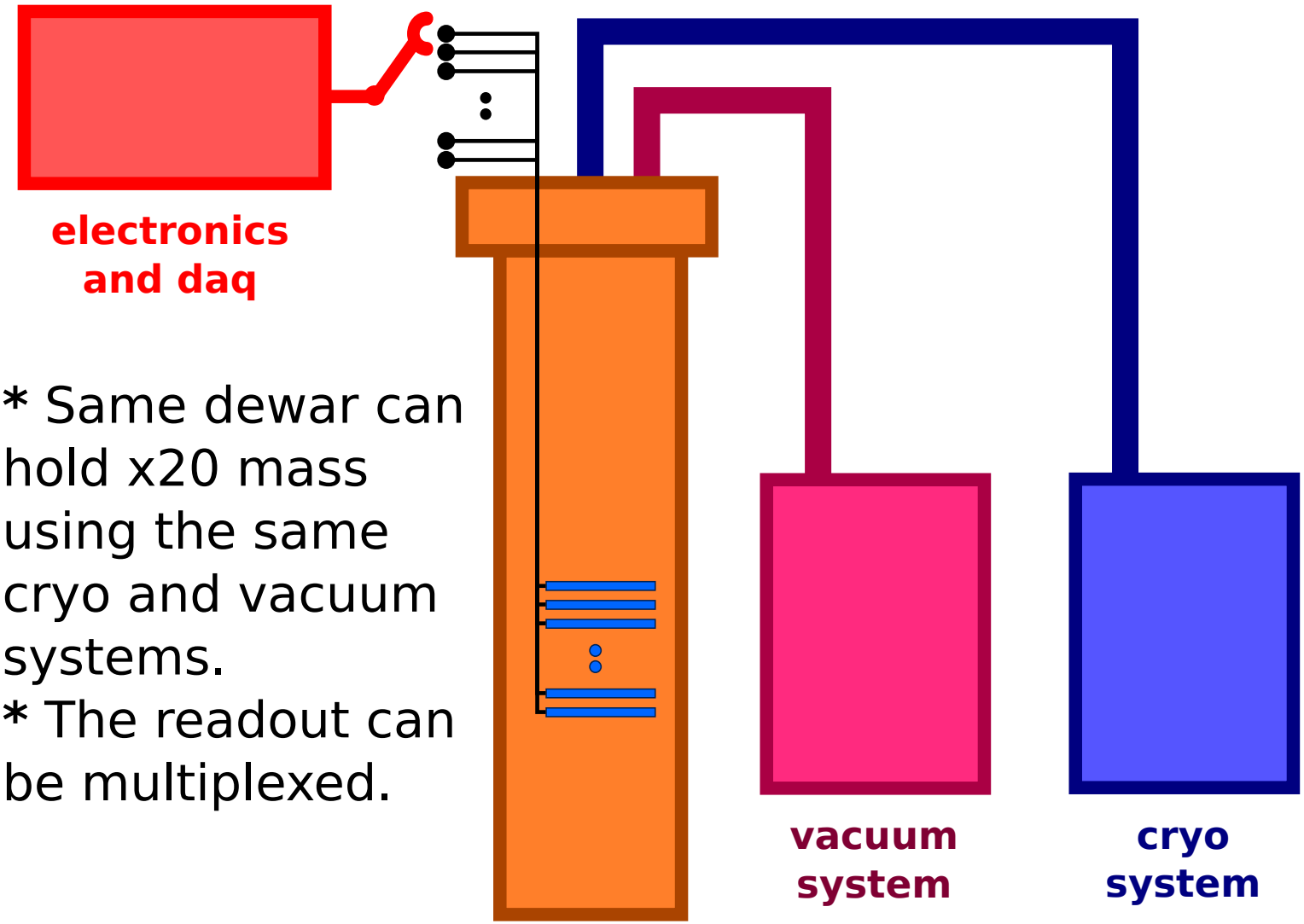
- CCDs are an excellent candidate for detecting low energy DM/ν events. The lack of mass is compensated by the low threshold.
- Response to electron interactions calibrated down to 0.28 keVee. 1% energy resolution at 6 keV. Detector is fully active.
- Radioactivity of CCDs demonstrated to be low enough for low background experiments.
- DAMIC installed at Snolab, running since Dec-2012.
- DAMIC-100 will be installed during 2014. It will have enough sensitivity to explore possible low mass signals from CDMS-Si and others.
- CONNIE shipped to Brazil. Will start taking data before the end of 2014.
- Several ongoing efforts to measure the quenching factor at low energies.

BACK UP SLIDES

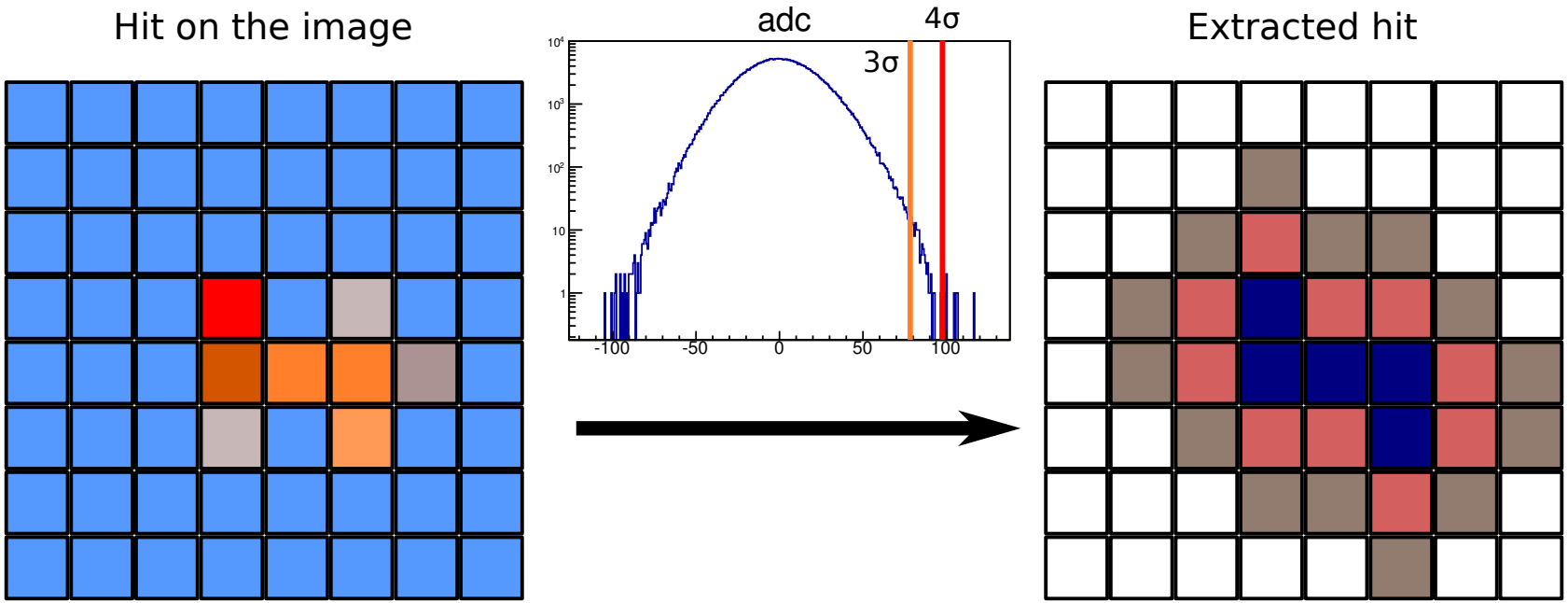
Quenching factor.



Scalability



* Same dewar can hold x20 mass using the same cryo and vacuum systems.
* The readout can be multiplexed.

simple & cheap to scale up

hit extraction