Measurement of radioactive contamination with CCDs

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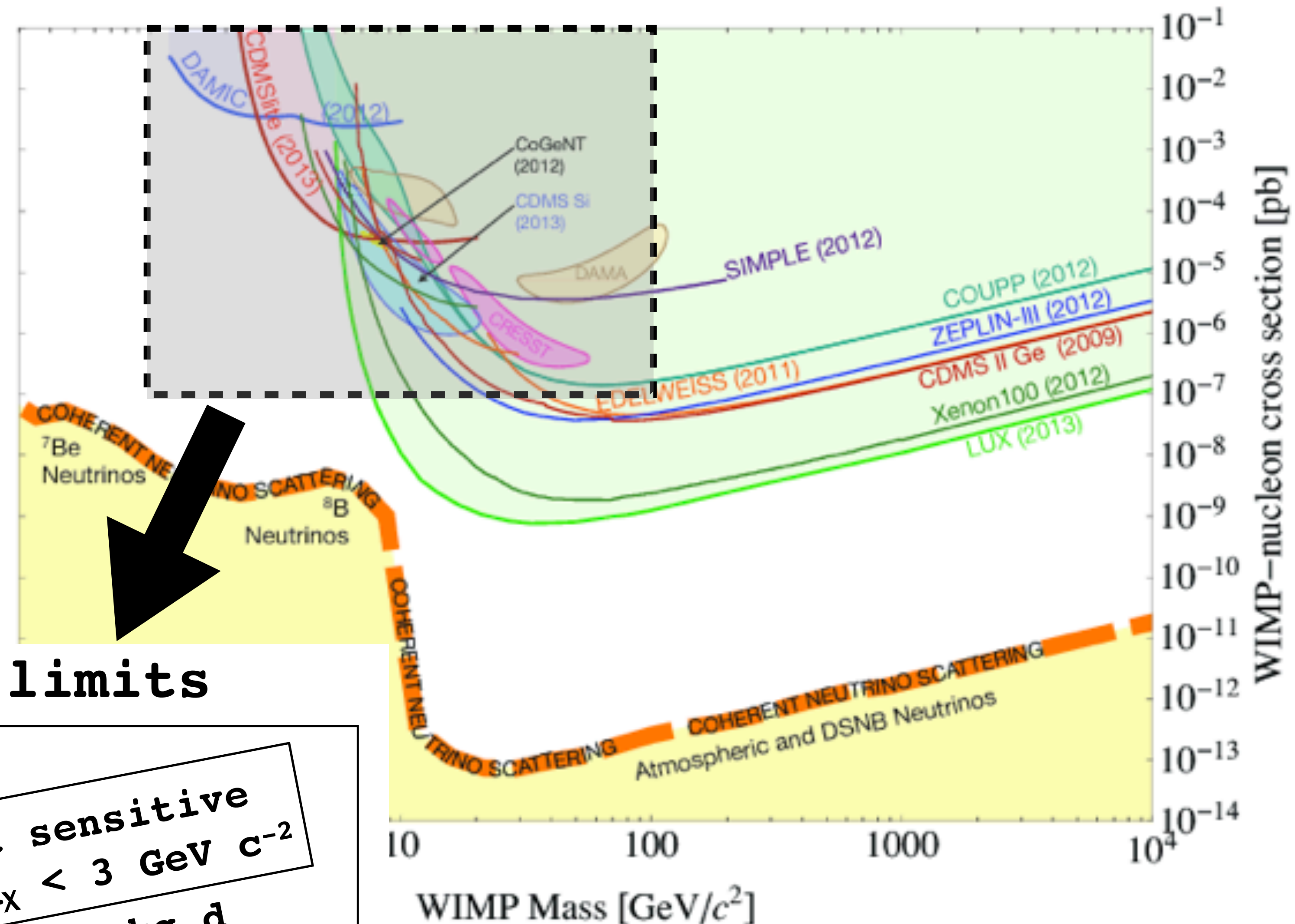
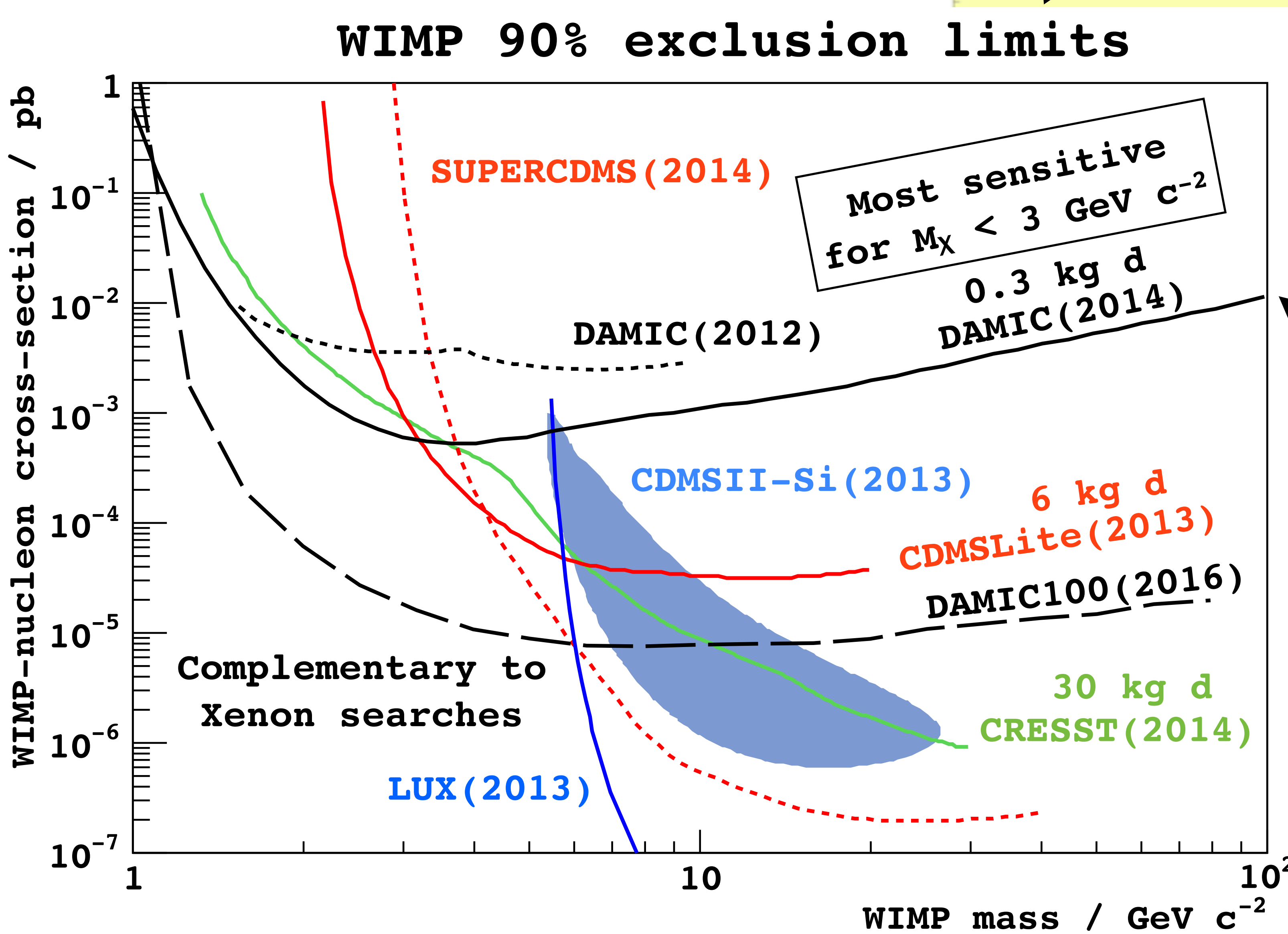
Outline

- The DAMIC experiment at SNOLAB.
- CCD operation and low-noise performance.
- CCD response to X-rays, γ-rays and α-particles.
- Spatial correlation of decay sequences (α-α, α-β and β-β).
- Radioactive contamination in CCD bulk Si.

DAMIC

Charge-coupled devices (CCDs) as low threshold, low background particle detectors.

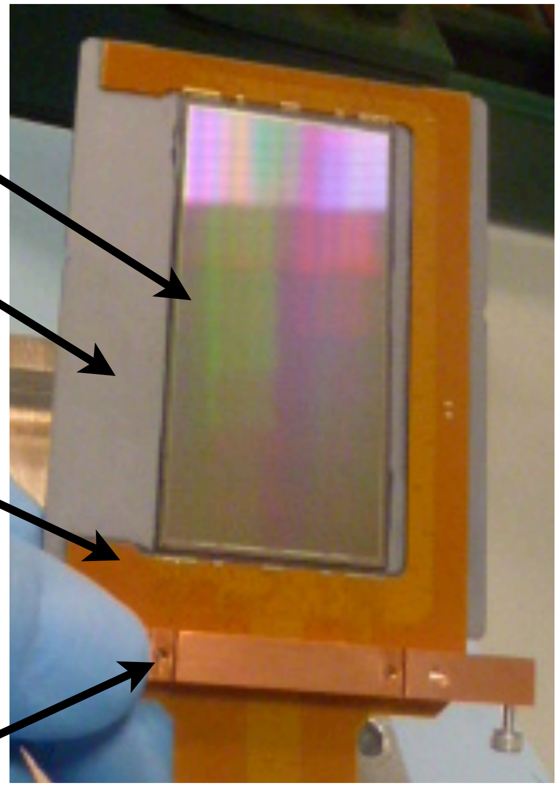


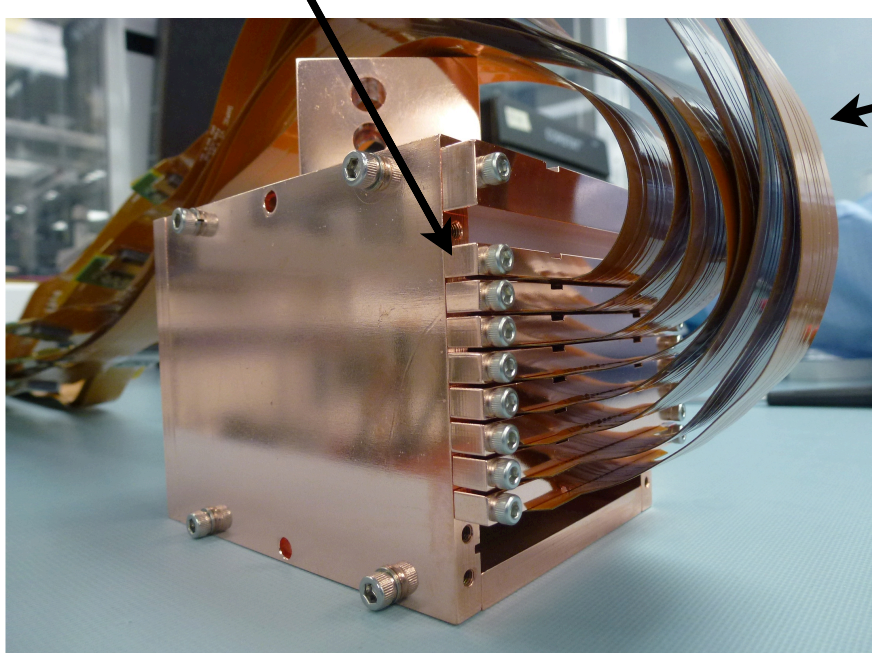


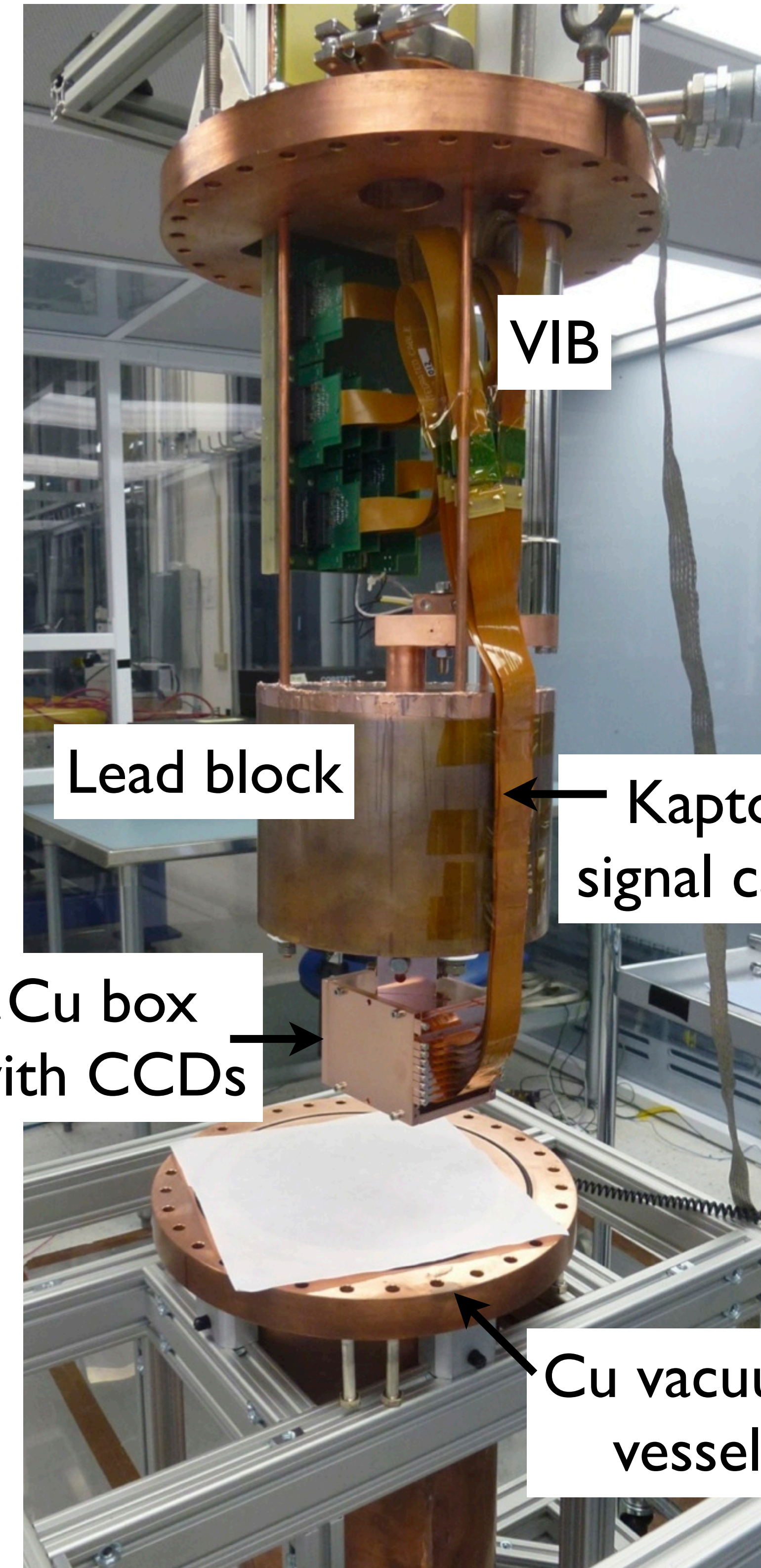
Test setup at SNOLAB already shows great potential.

Will directly probe the possible signal in CDMS II-Si.

SNOLAB installation

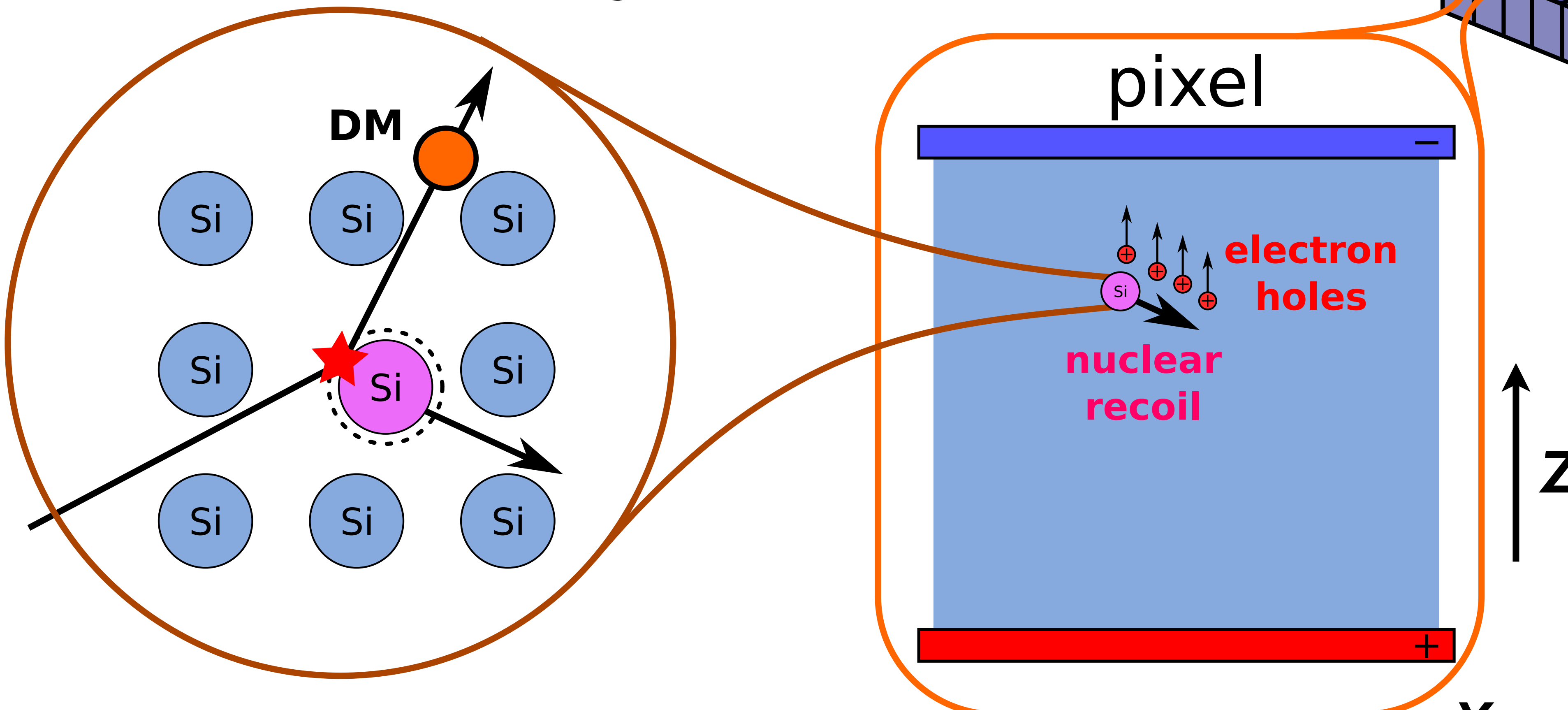


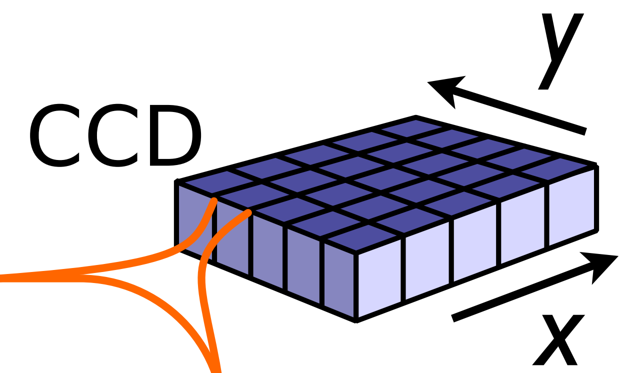




Detector

coherent elastic scattering

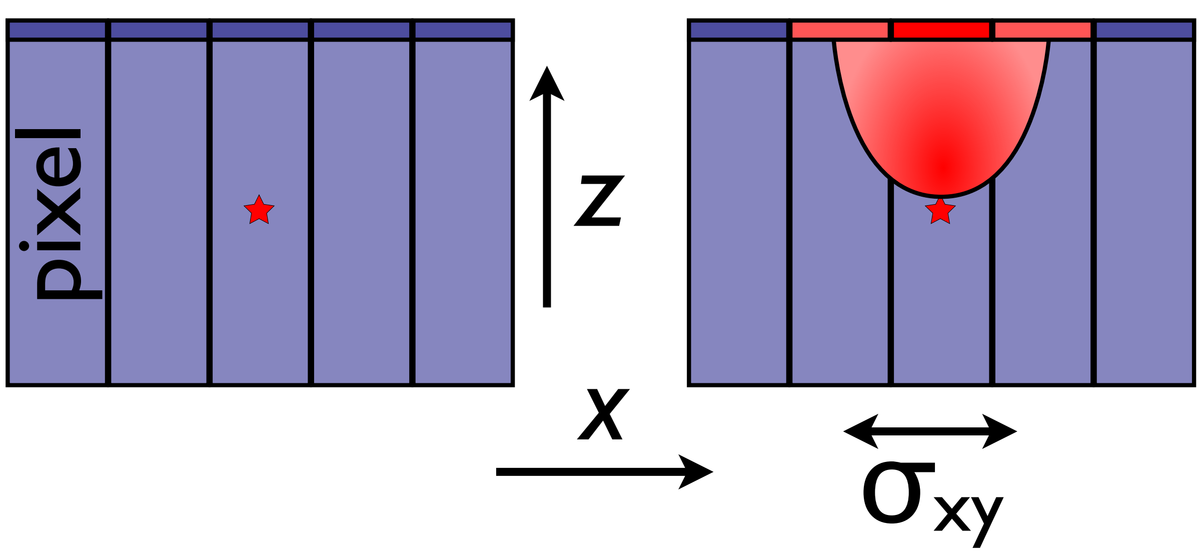


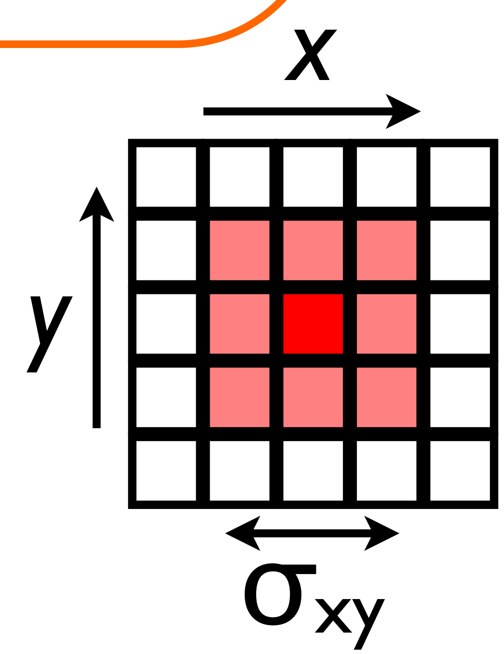


Charged particles produce ionization in CCD bulk.

3.62 eV for e-h pair.

Charge drifted up and held at gates.

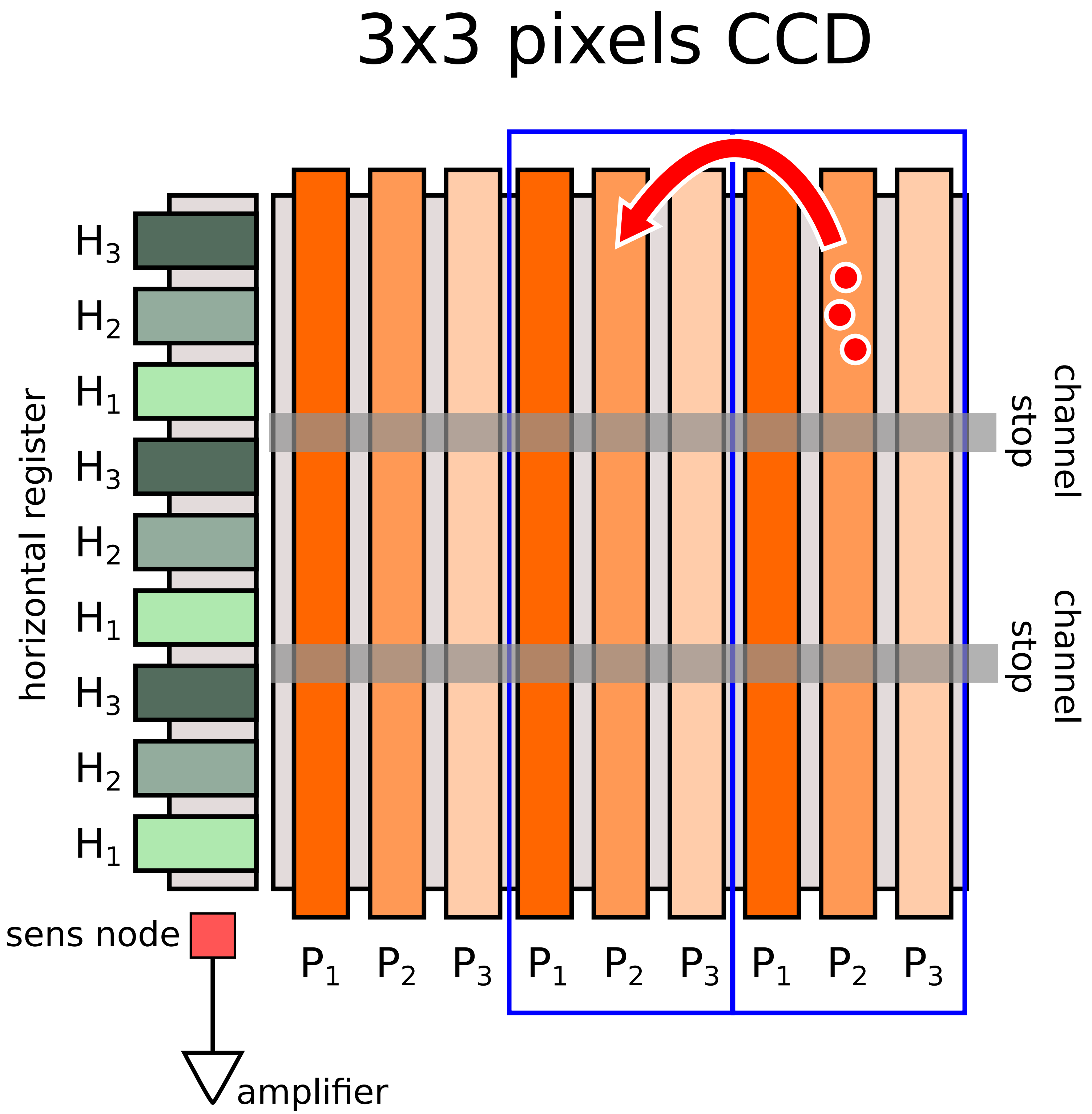


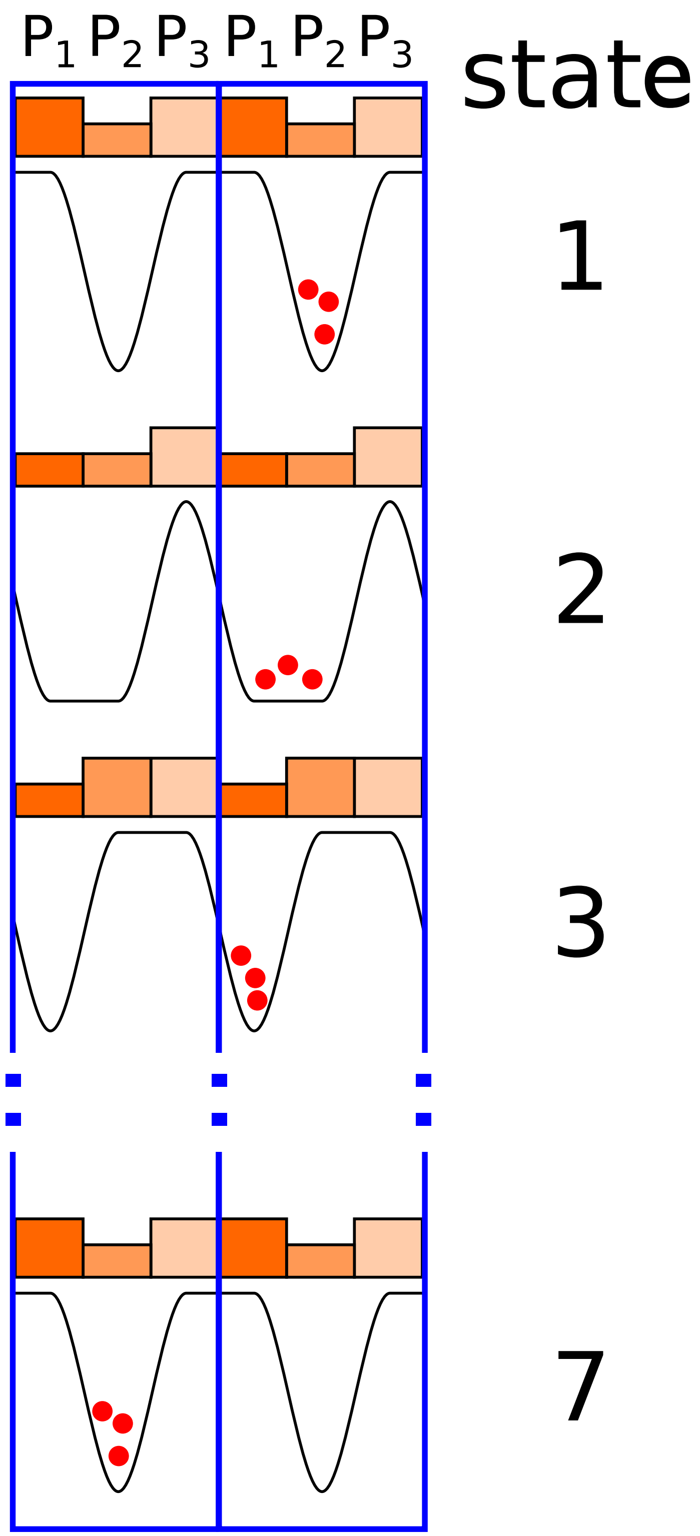


Charge collected by each pixel on CCD plane is read out.

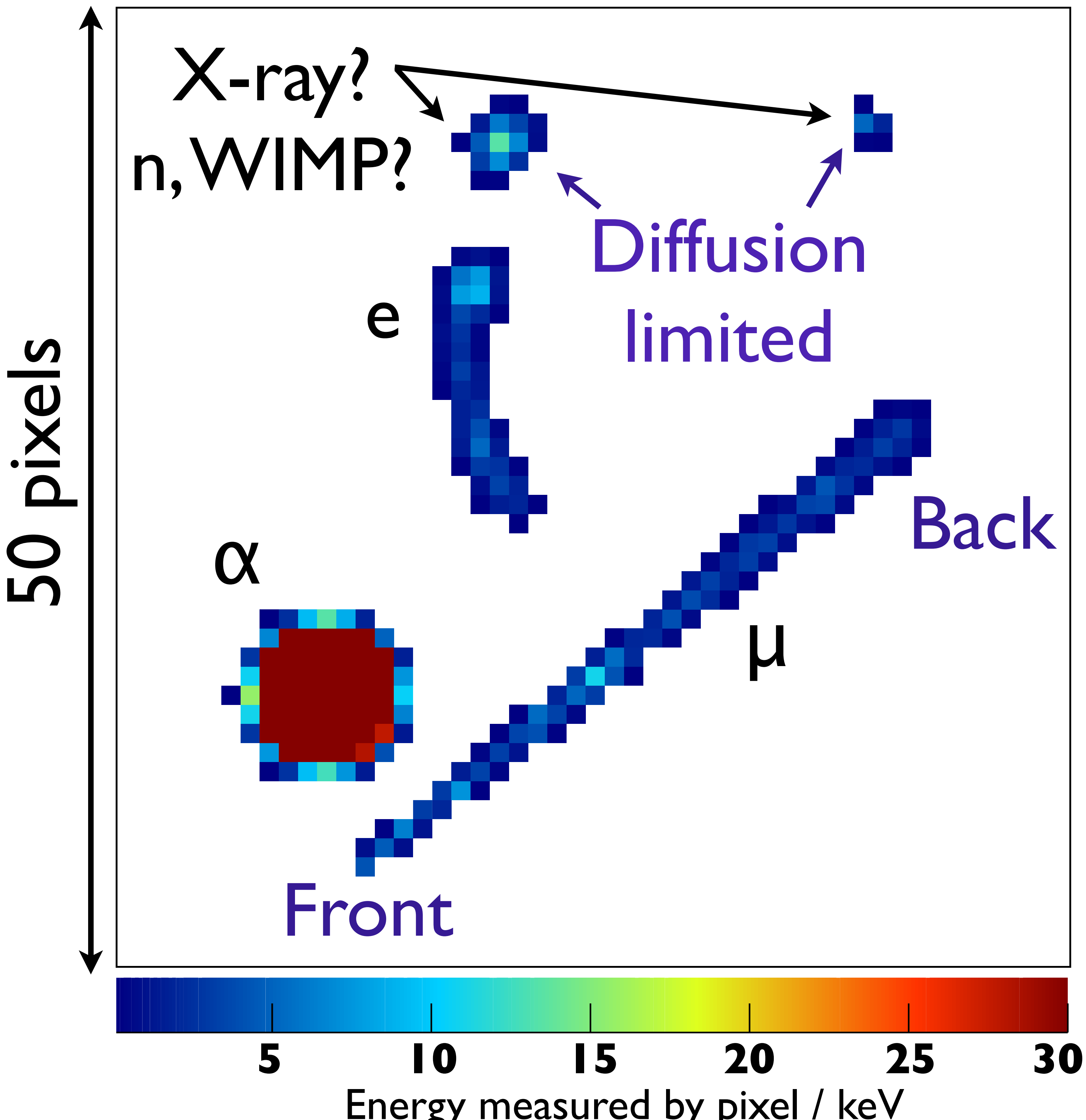
~2 e⁻ RMS read-out noise.

CCD readout

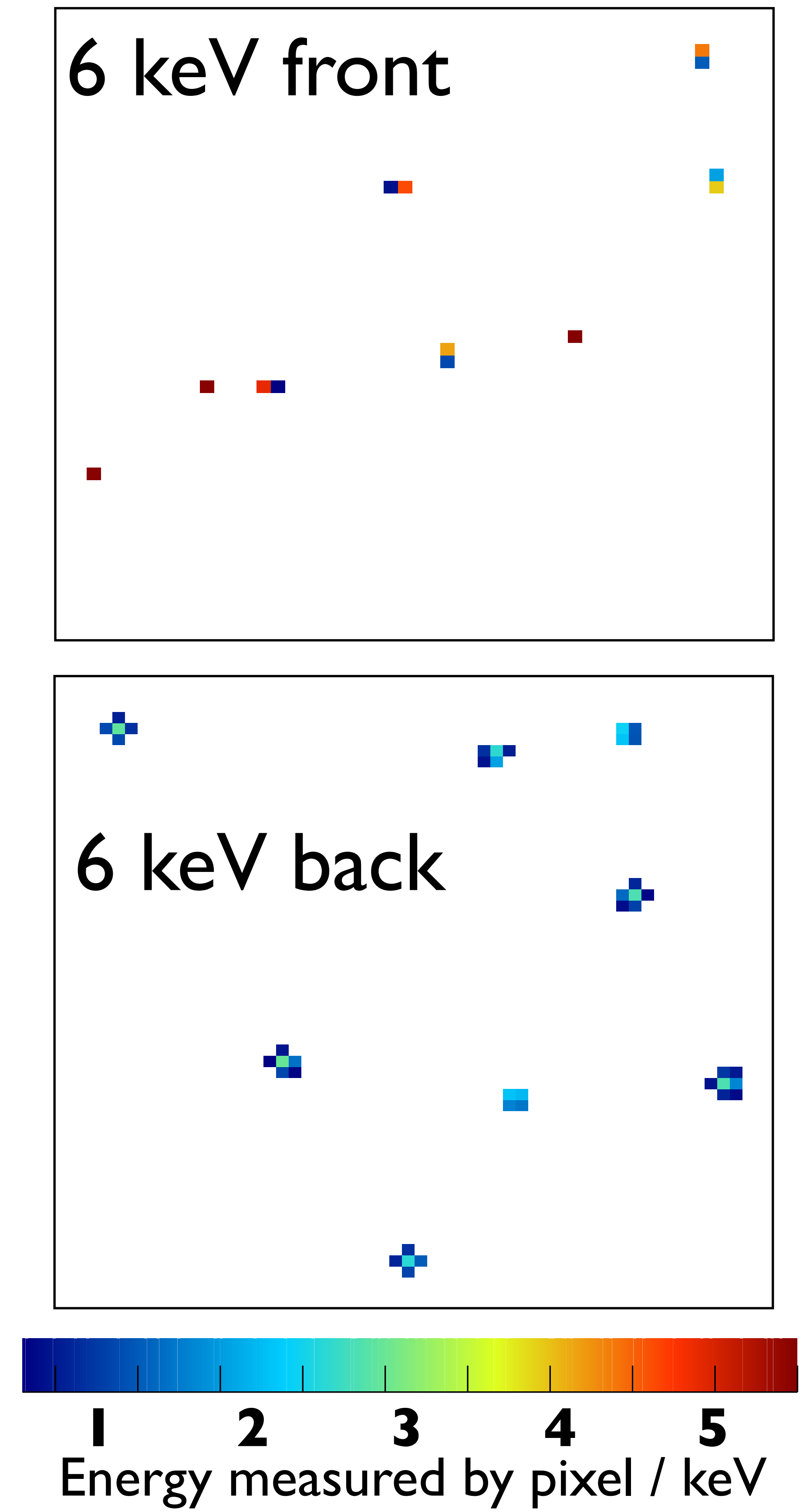

3x3 pixels CCD
horizontal register
H_3
H_2
H_1
H_3
H_2
H_1
H_3
H_2
H_1
channel stop
channel stop
sens node
amplifier
P_1 P_2 P_3 P_1 P_2 P_3 P_1 P_2 P_3


P_1 P_2 P_3 P_1 P_2 P_3
state
1
2
3
7

Particle tracks



Diffusion limited



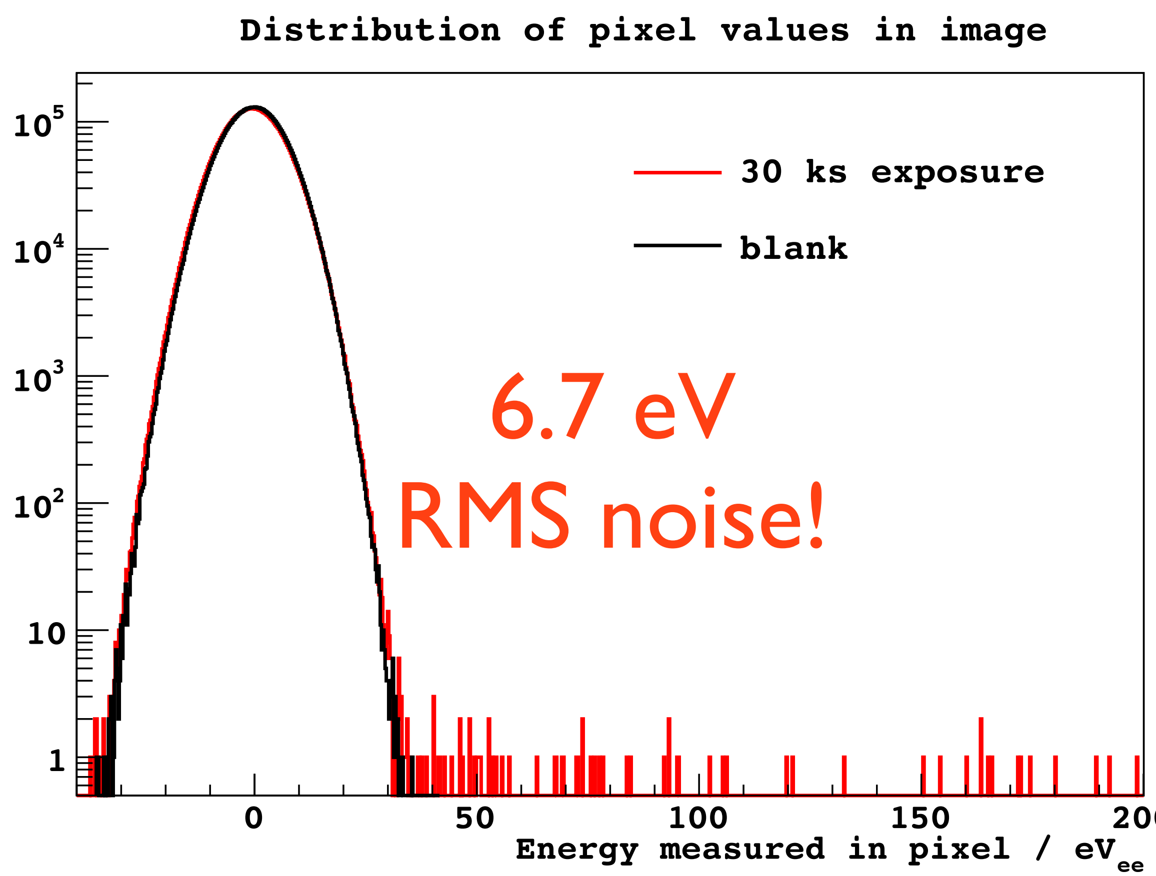
CCD Performance

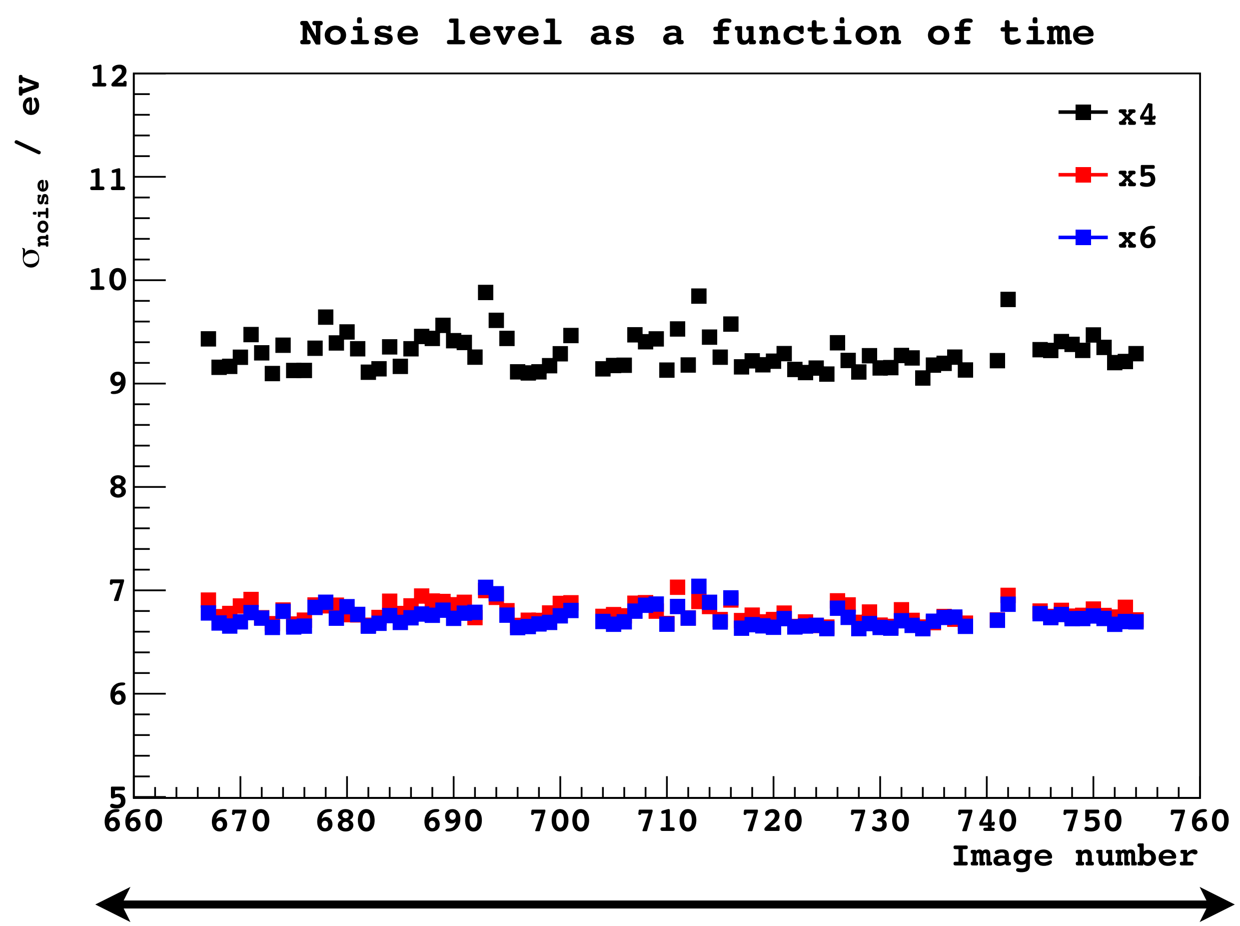
CCDs are manufactured with very high resistivity silicon:

Low radioactive backgrounds.

Low dark current (0.1 e^- / pix / day).

Very few (if any) defects in the silicon lattice.

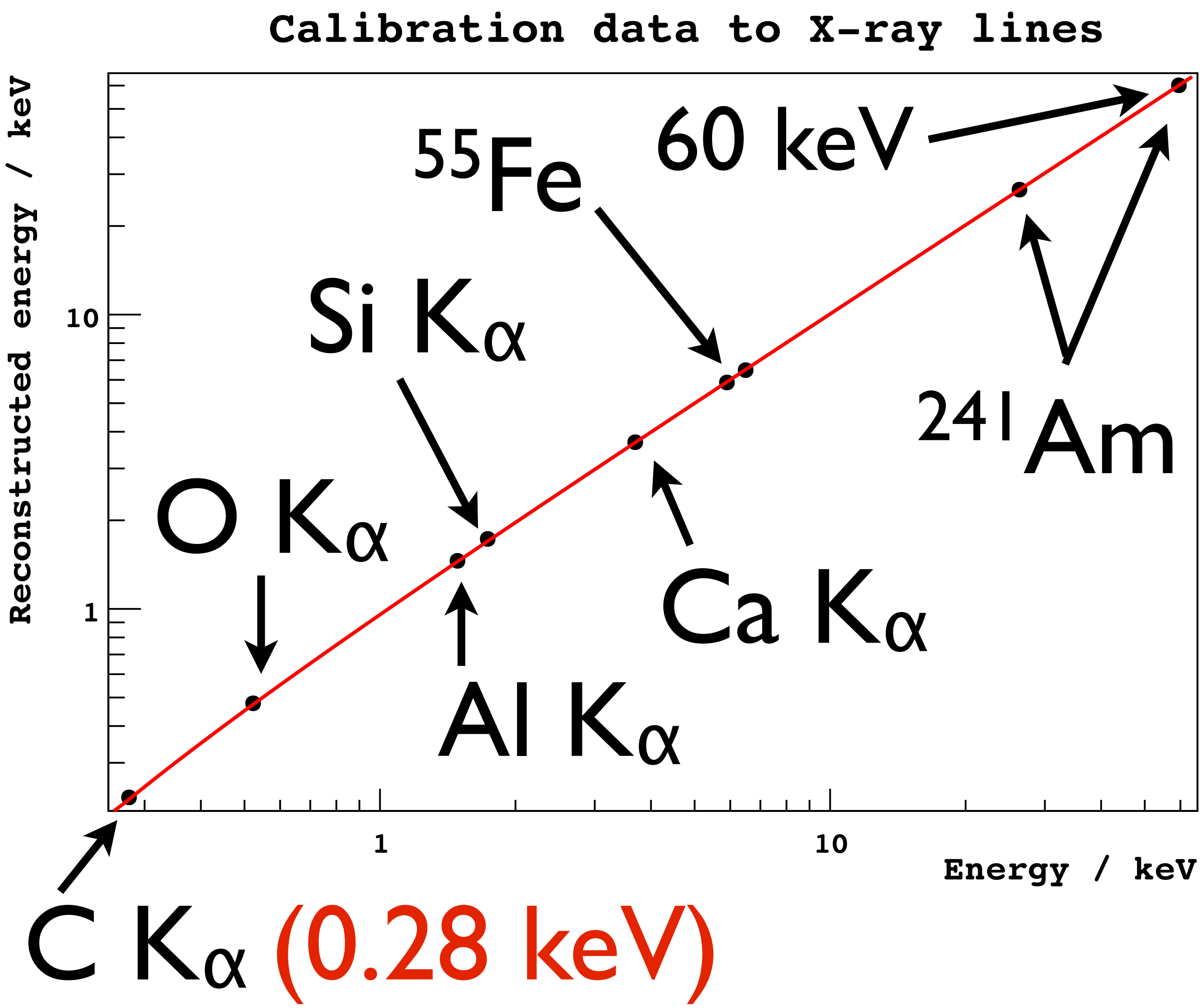


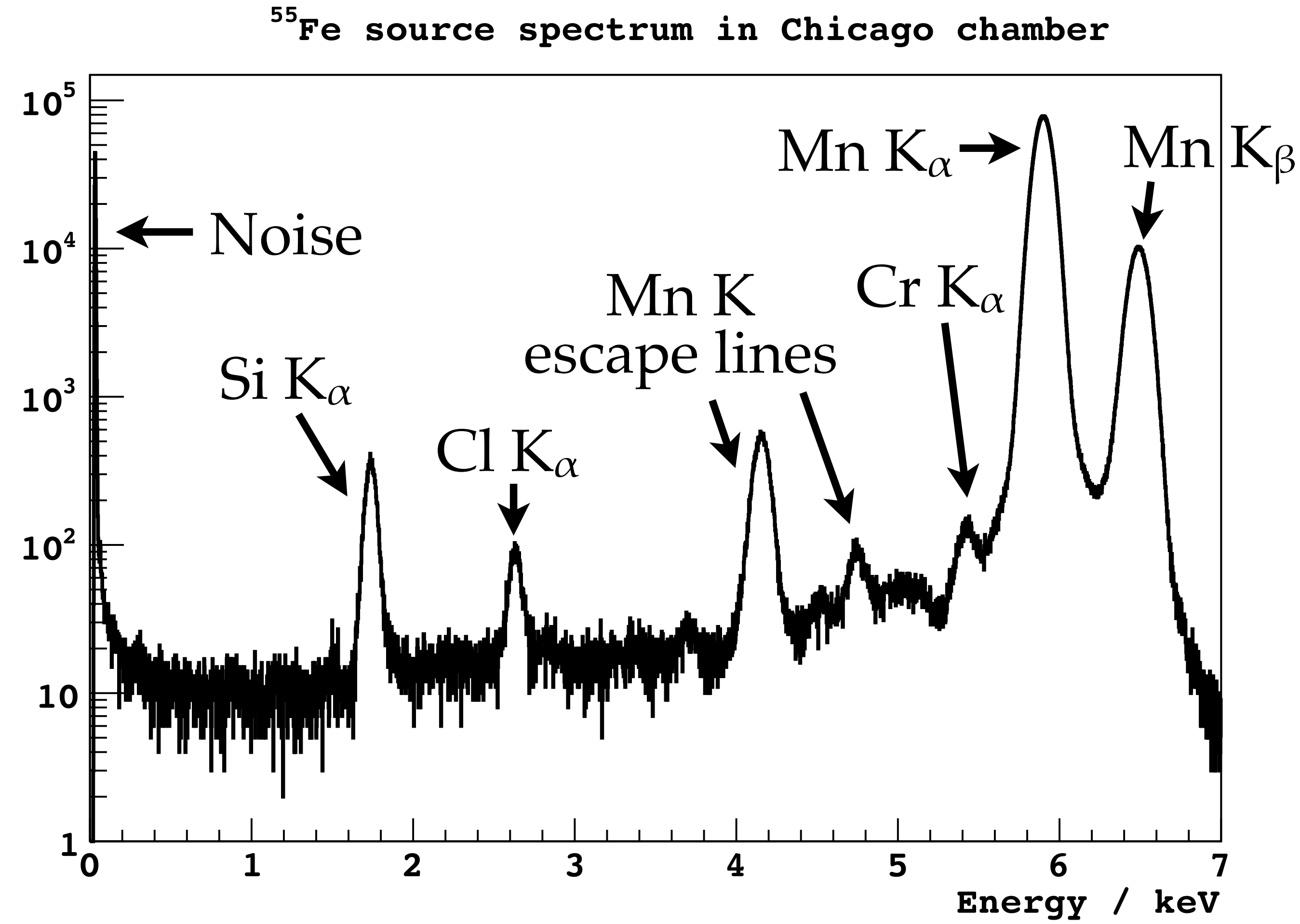


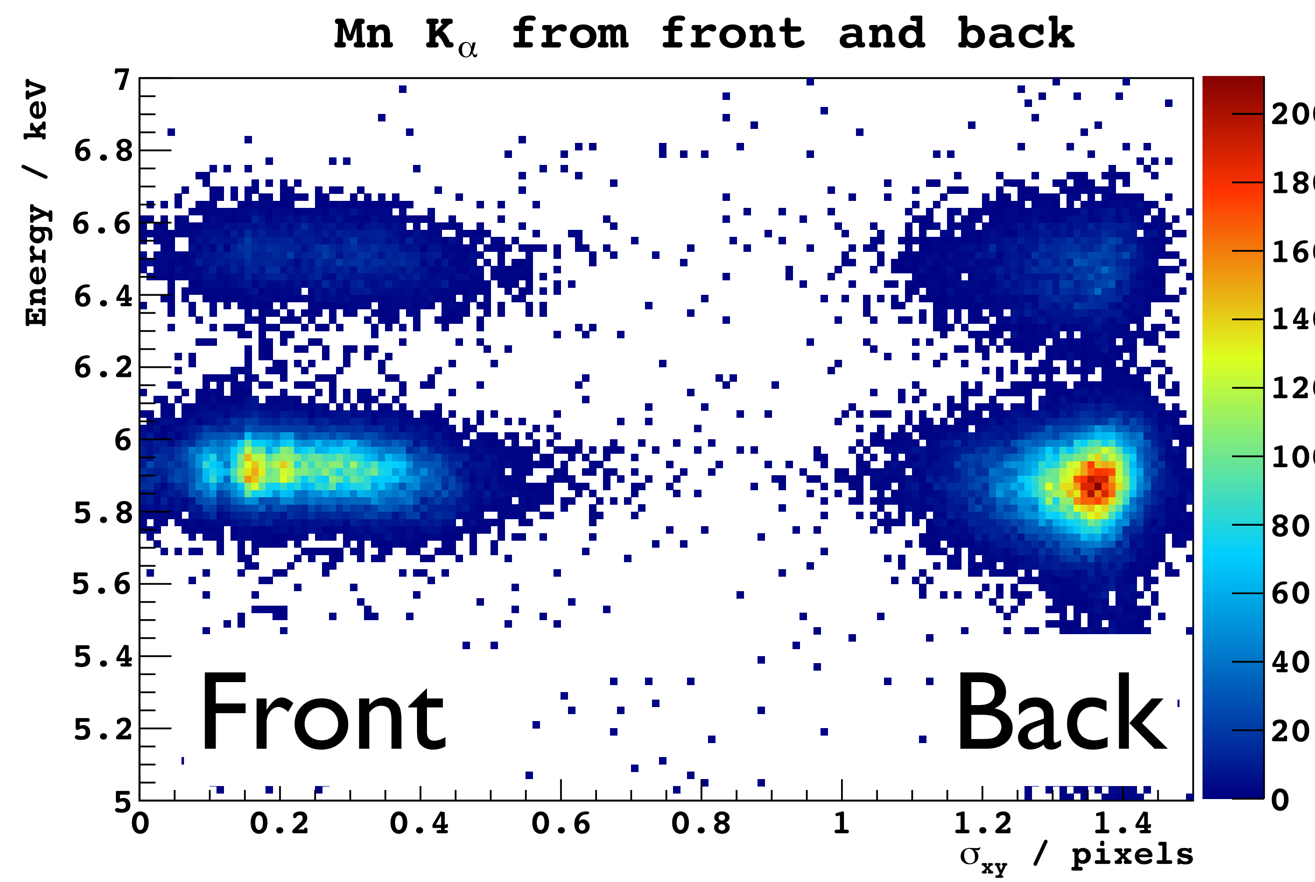
>95% of the image good quality.

30 days of data at SNOLAB. 96% duty cycle.

X-rays







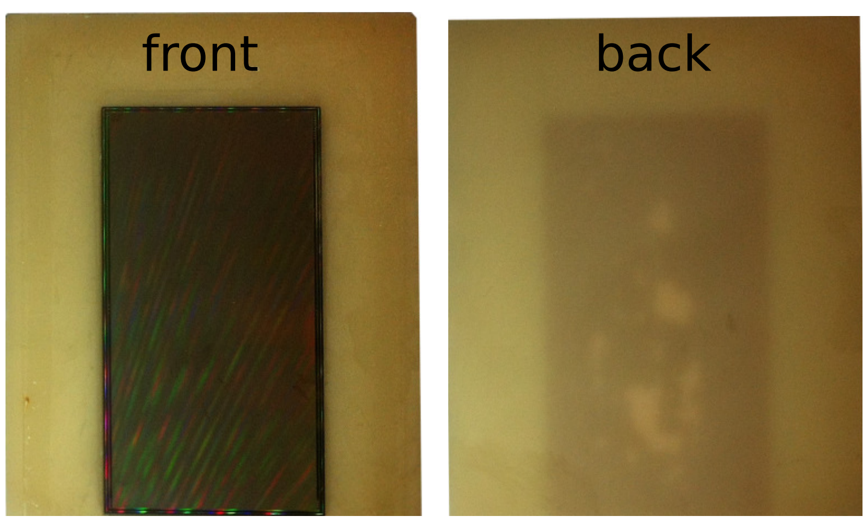
$\sigma_{xy} = 1.4 \longrightarrow z = 675\ \mu m$

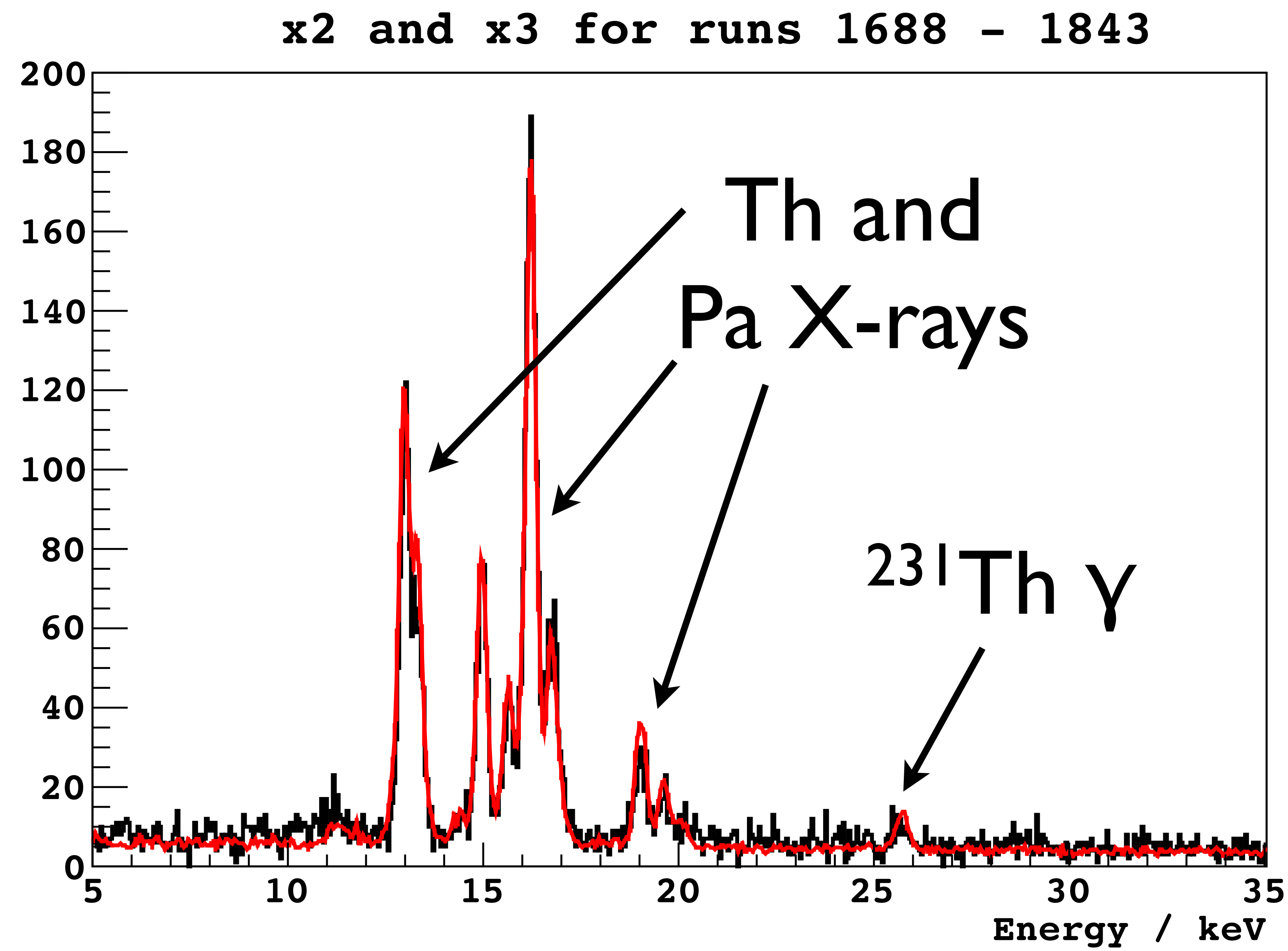
E resolution:
53 eV at 5.9 keV from front!
Fano = 0.13.

Depth reconstruction.

Uranium screening

CCD with radioactive AlN ceramic support





	mBq / kg
^{235}U	330 ± 30
^{238}U	4110 ± 530
^{226}Ra	42 ± 9
^{232}Th	32 ± 8

SNOLAB γ-ray measurement of AlN

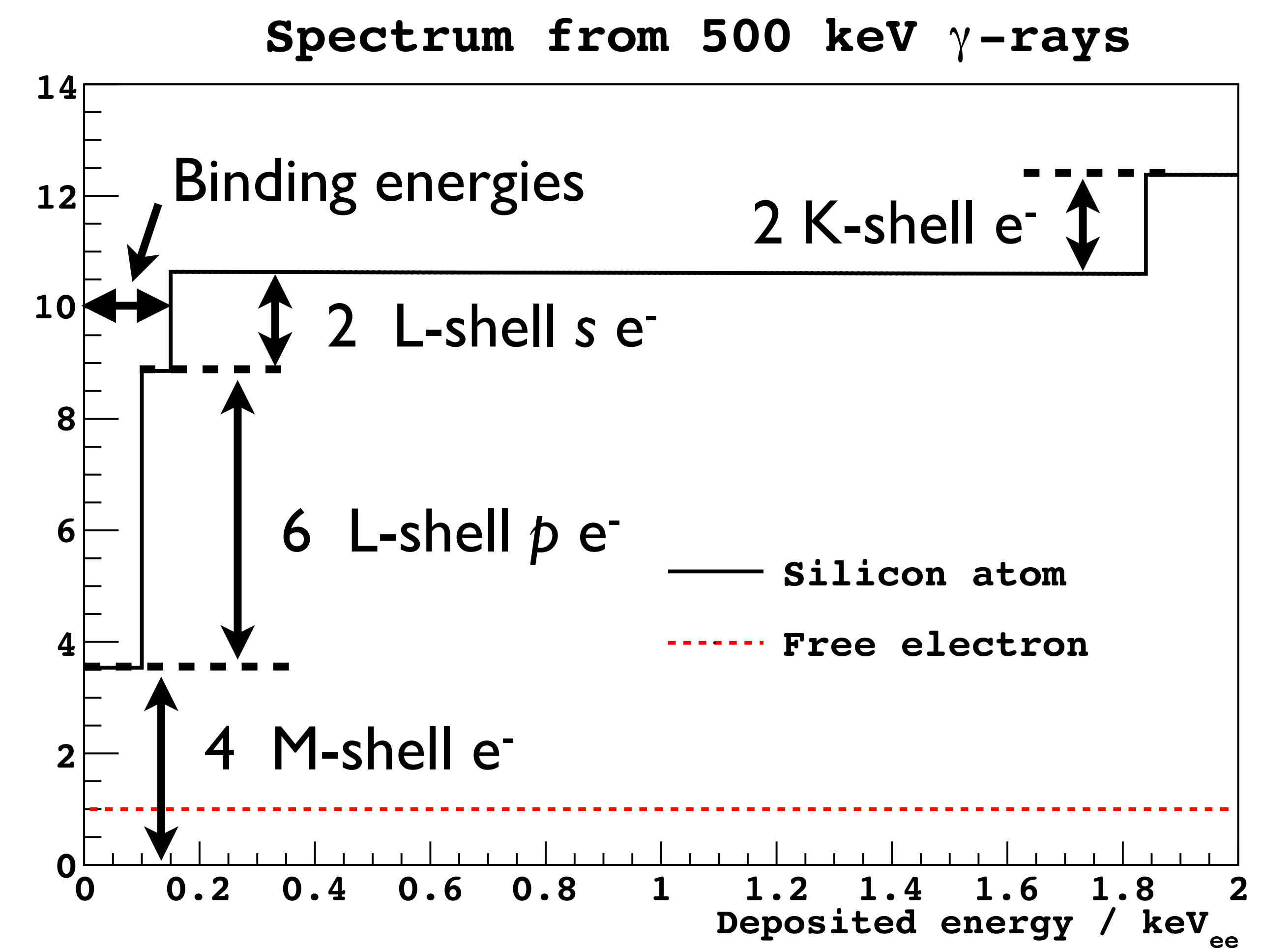
} ppb levels

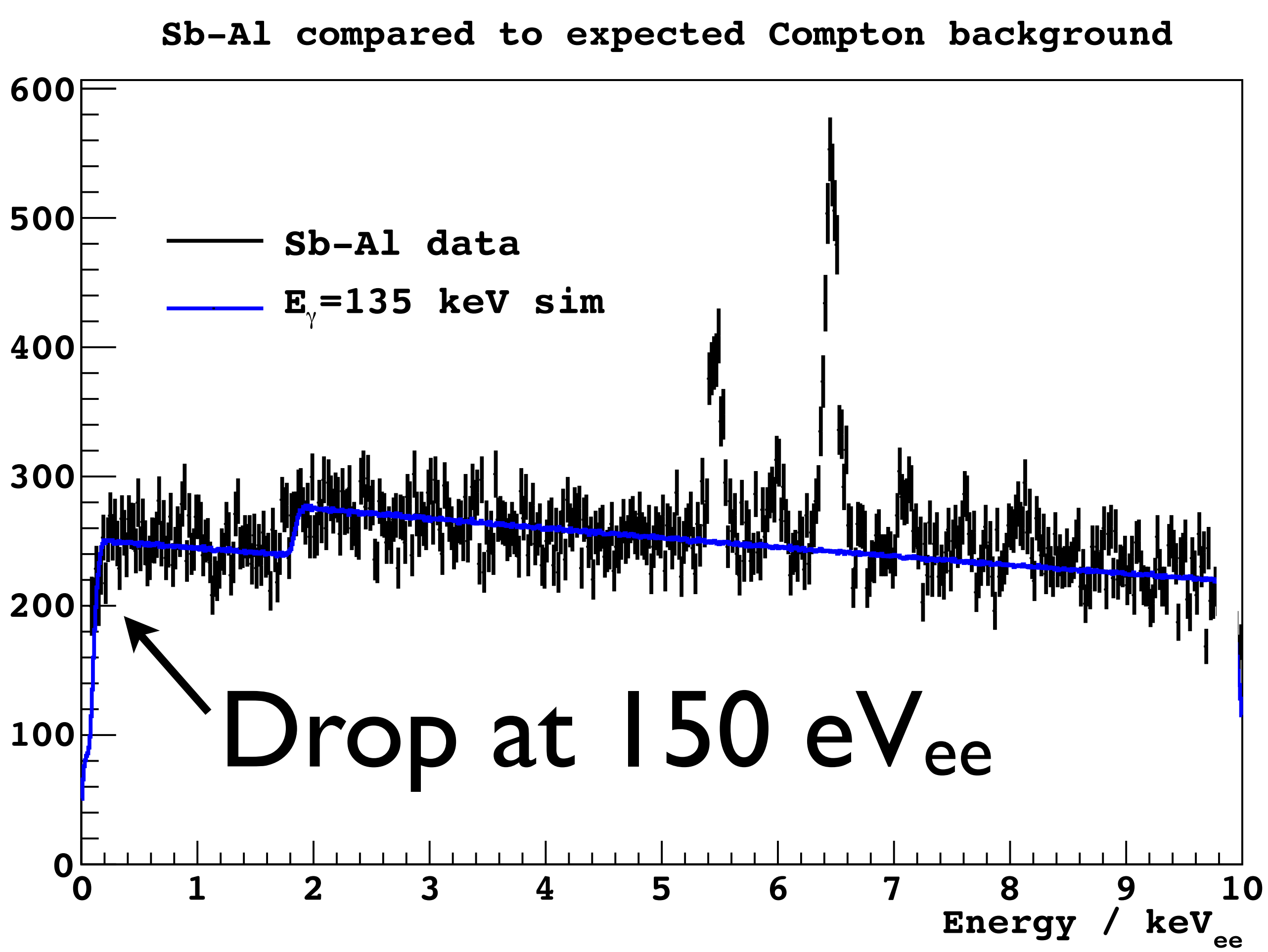
U is very dim in γ but very bright in X-rays.

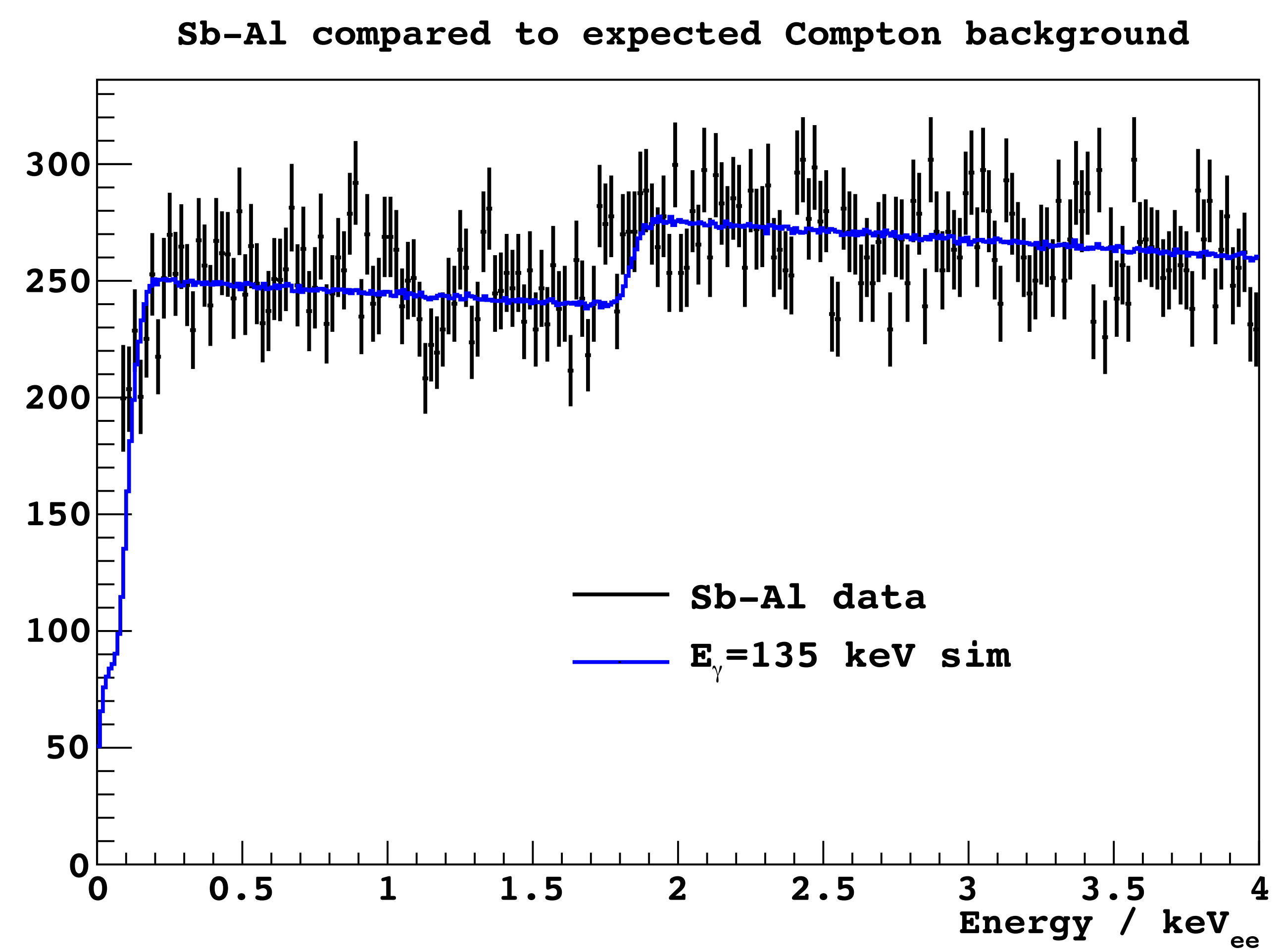
γ-rays

Observed Si atomic structure in single-scatter Compton spectrum.

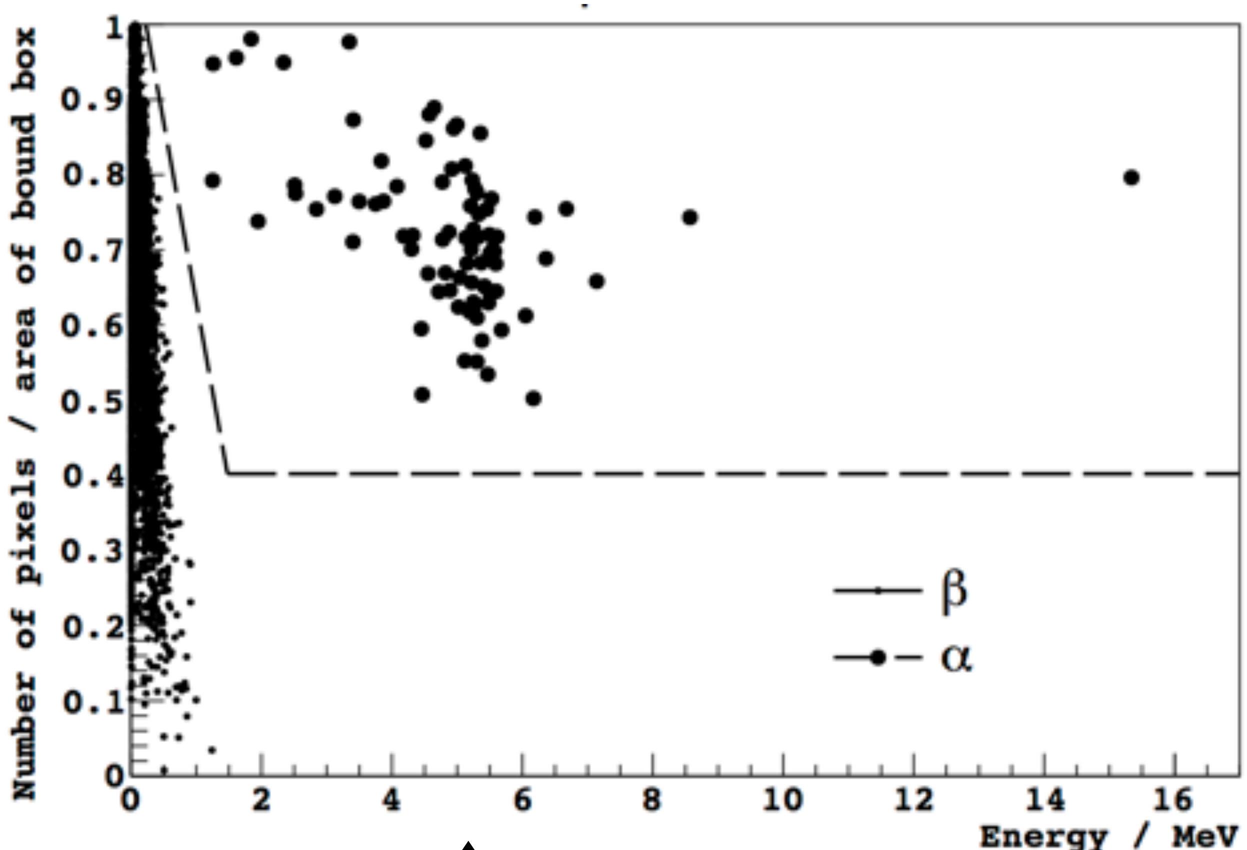
Can resolve spectral features near threshold.

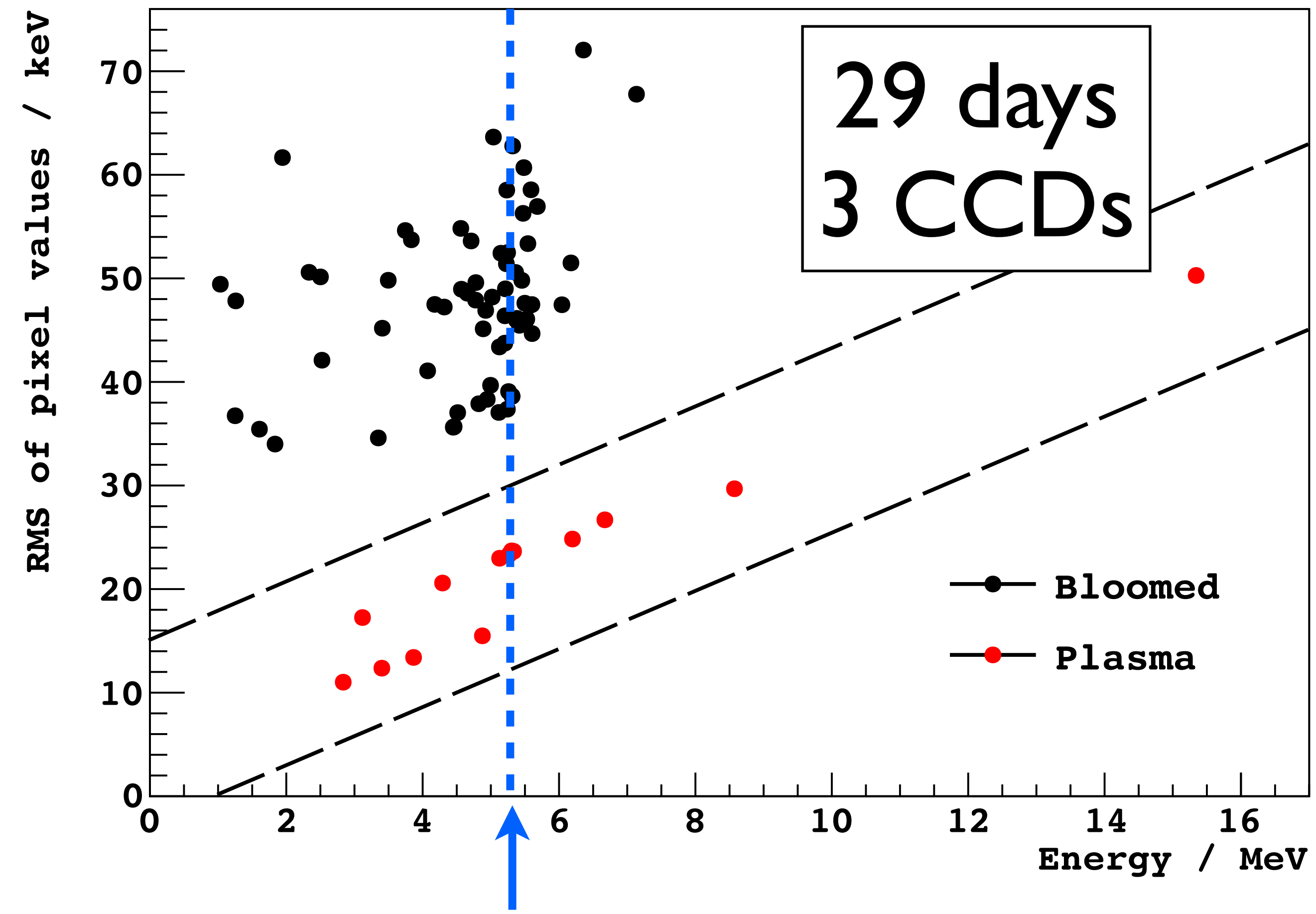






α particles





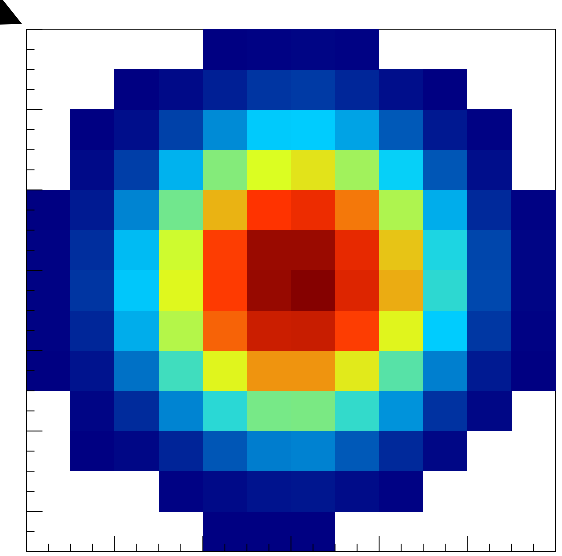
^{210}Po (surface)

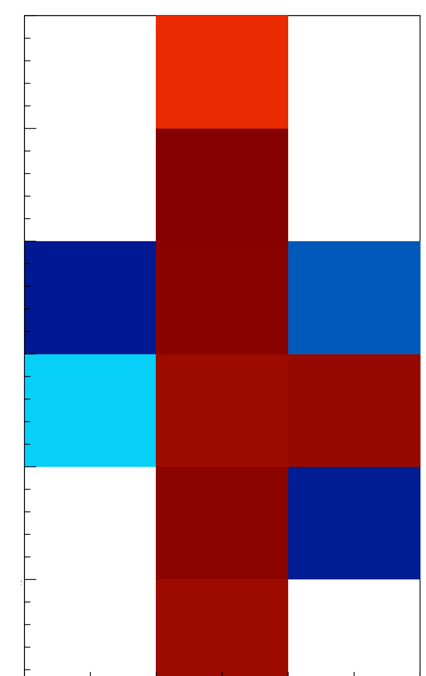
Bloomed (front)

α-β discrimination based on shape of track.

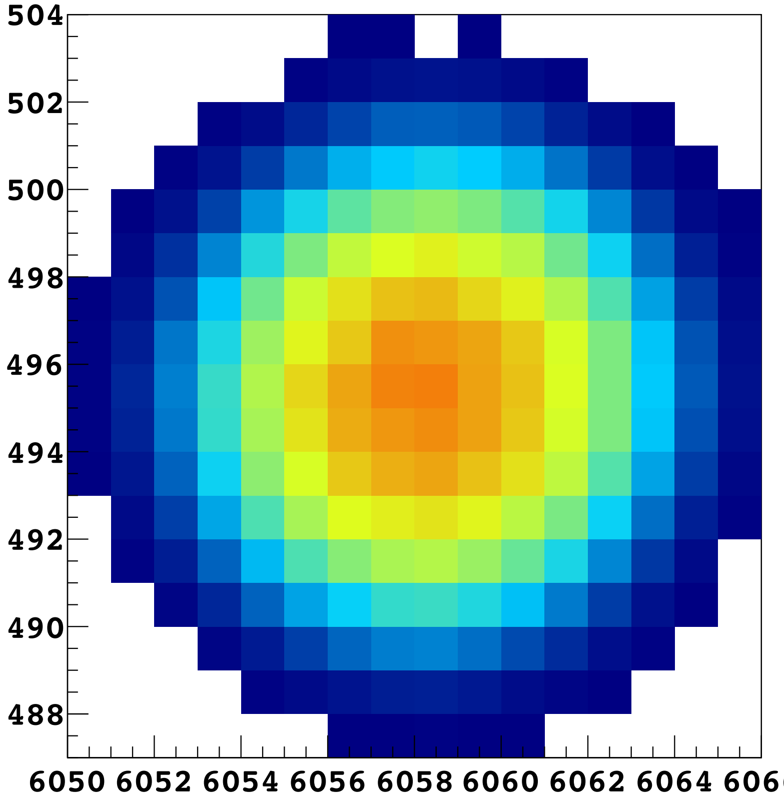
Bound box

Plasma (back or bulk)

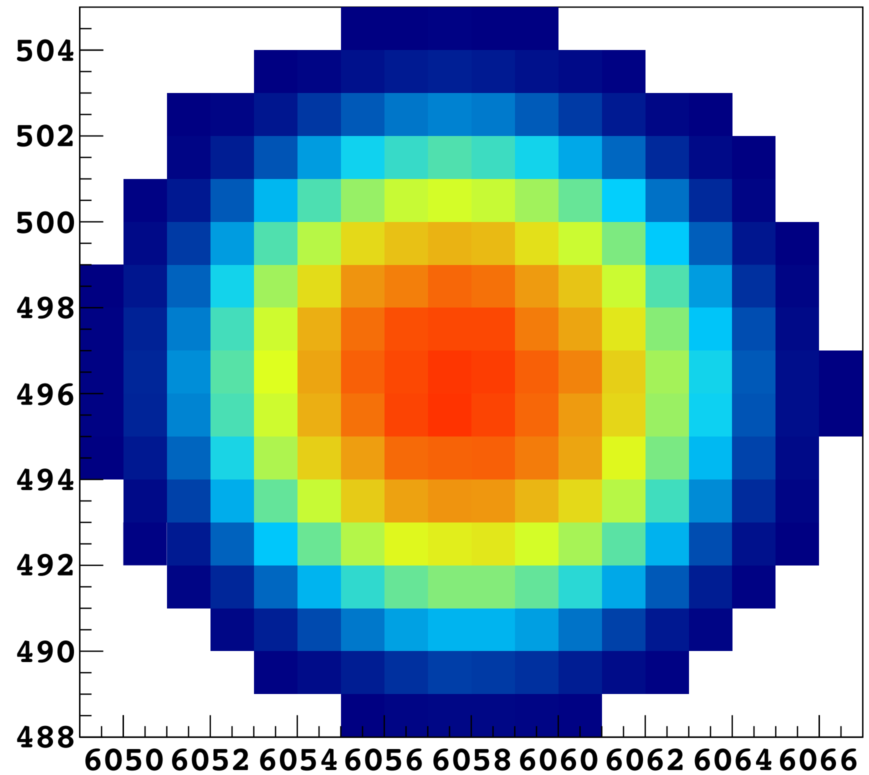




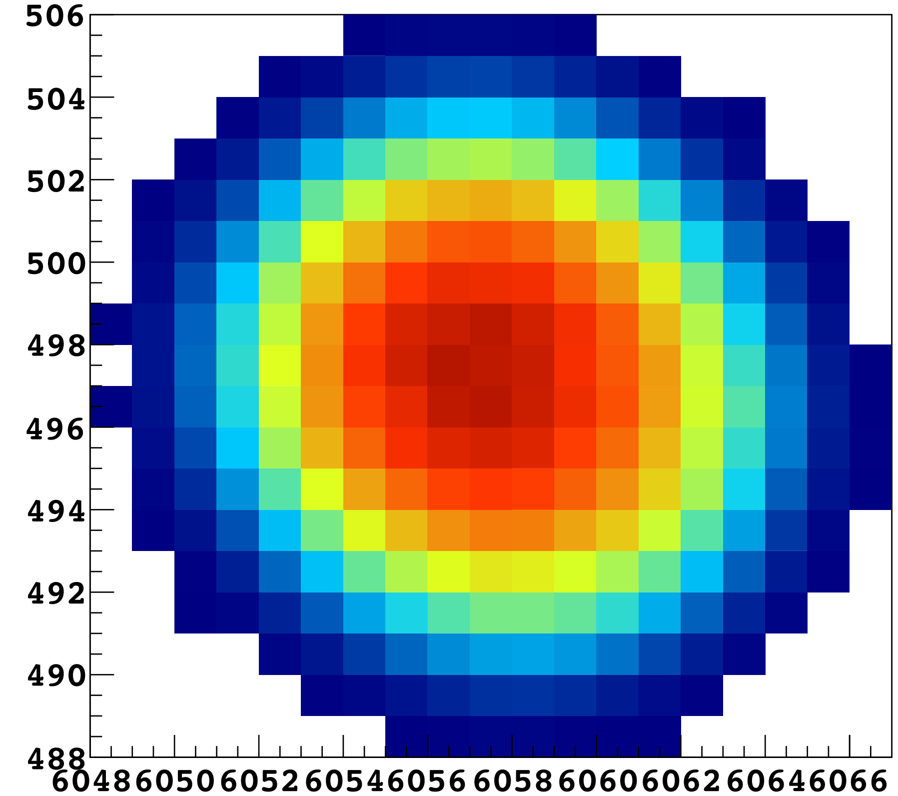
E = 5.39 MeV



E = 6.75 MeV



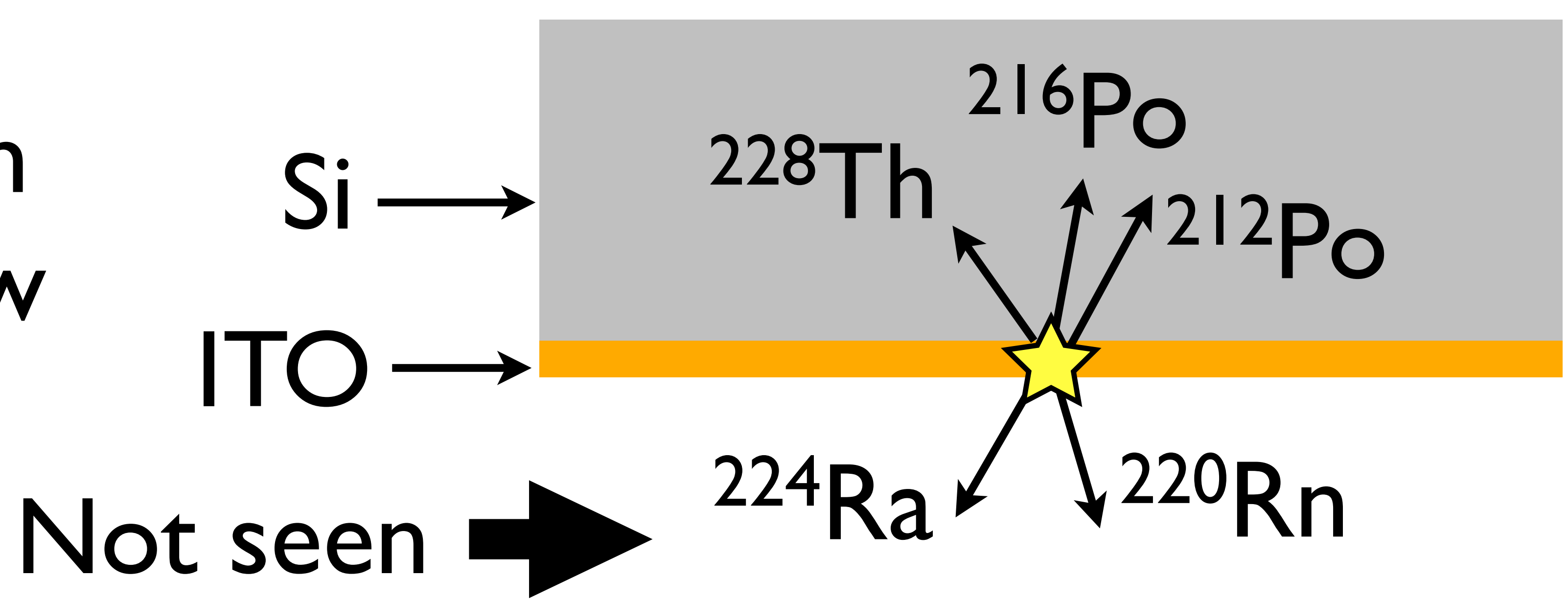
E = 8.66 MeV



$\Delta t = 17.8$ d $\qquad$ $\Delta t < 5.5$ h

^{228}Th $\qquad$ ^{216}Po $\qquad$ ^{212}Po

Identification of ^{228}Th decay sequence below CCD (ITO?).



Limits from αs

From α search in 4.5 - 5 MeV energy region

^{238}U uncorrelated daughters ^{234}U (4.77 MeV), ^{230}Th (4.69 MeV), ^{226}Ra (4.79 MeV) place limit

$< 8\ kg^{-1}\ day^{-1} = 0.08\ mBq\ kg^{-1} = 7$ ppt (95% C.L.)

From α search of 18.8 MeV pile-up α from fast sequence

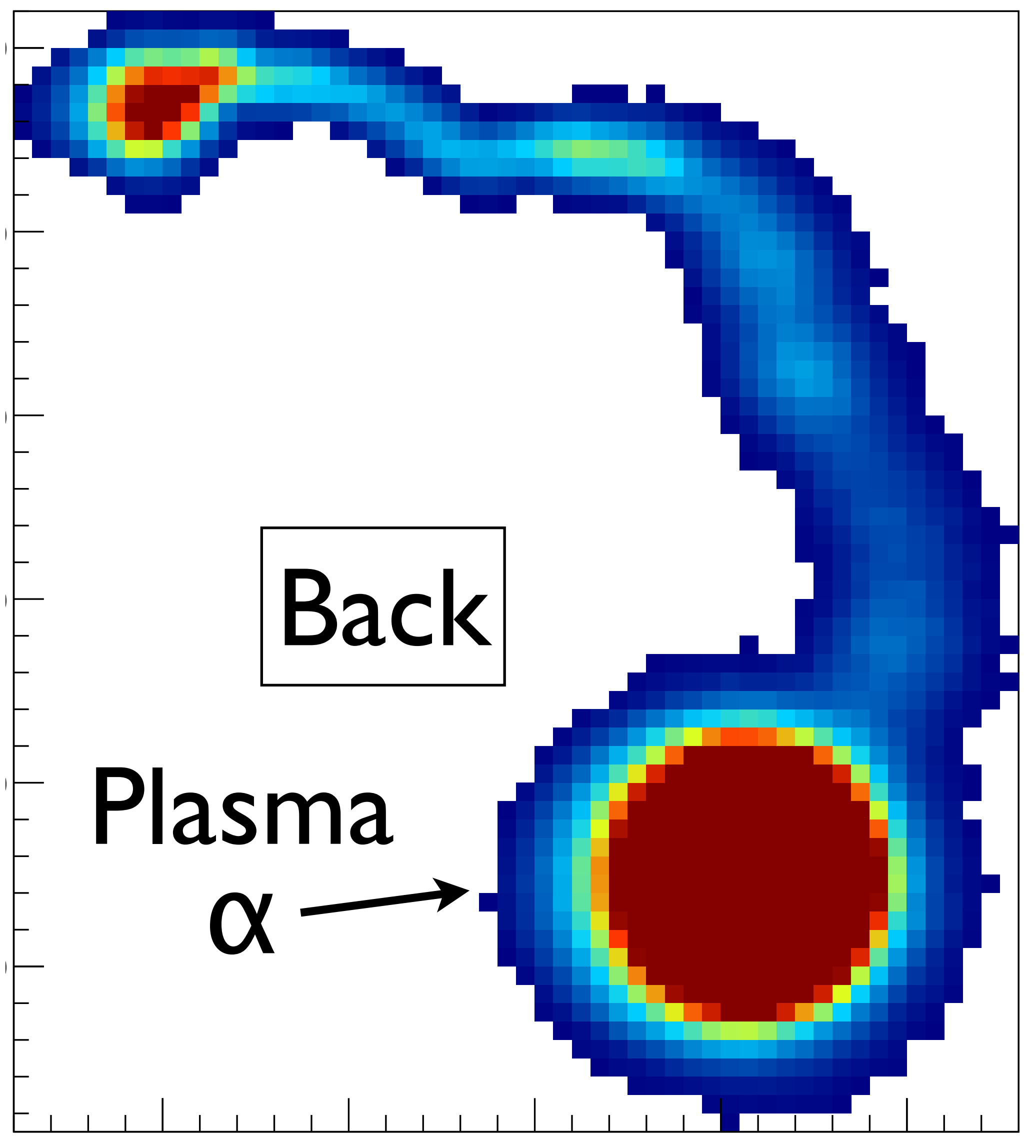
^{224}Ra (5.69 MeV) $\rightarrow$ ^{220}Rn (6.29 MeV) $\rightarrow$ ^{216}Po (6.78 MeV)

^{232}Th:

$< 15\ kg^{-1}\ d^{-1} = 0.17\ mBq\ kg^{-1} = 43$ ppt (95% C.L.)

α-β coincidences

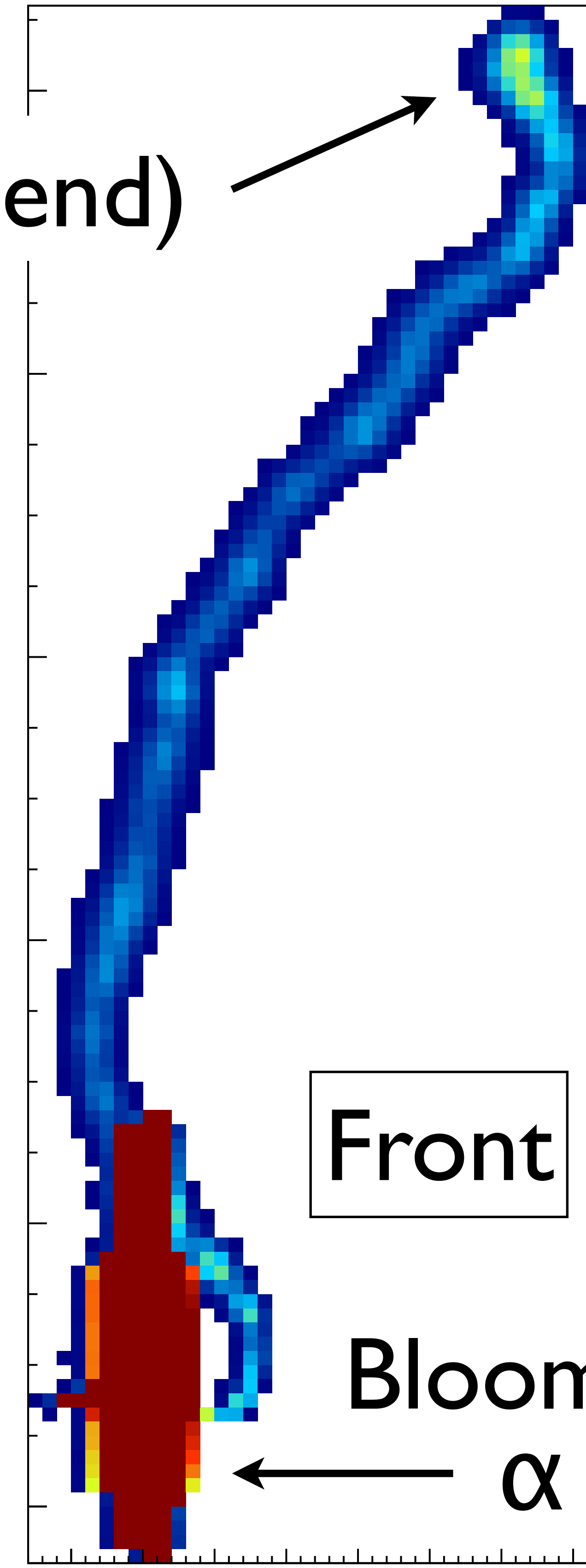
β Bragg peak (end)



Plasma
α

β Bragg peak (end)

β emerges
from decay
point under α.



Bloomed
α

β-β coincidences

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

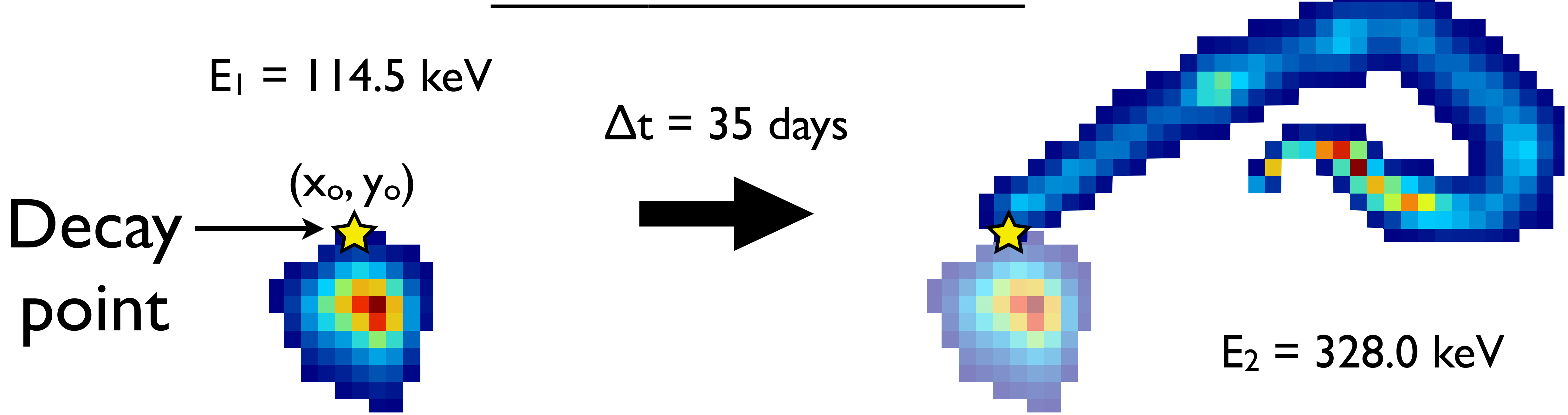
$$\tau_{1/2} = 5\ \mathrm{d}$$

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

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

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

^{32}Si - ^{32}P candidate

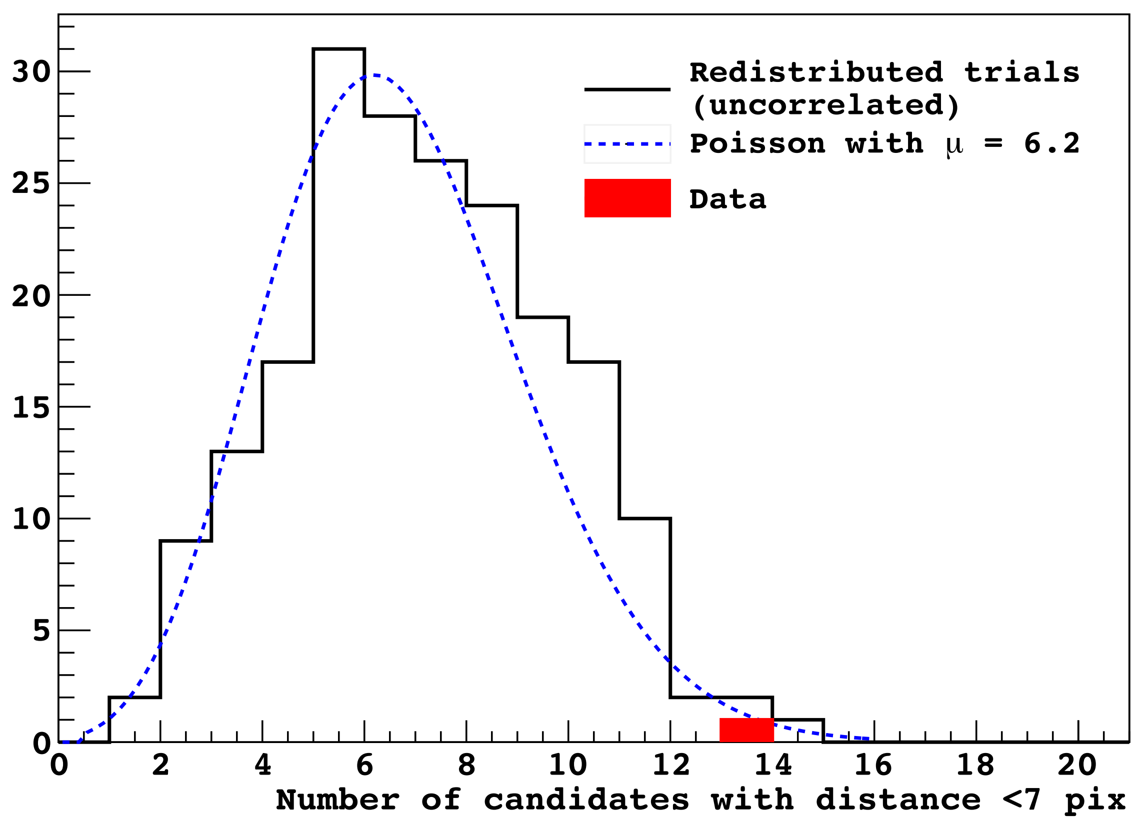


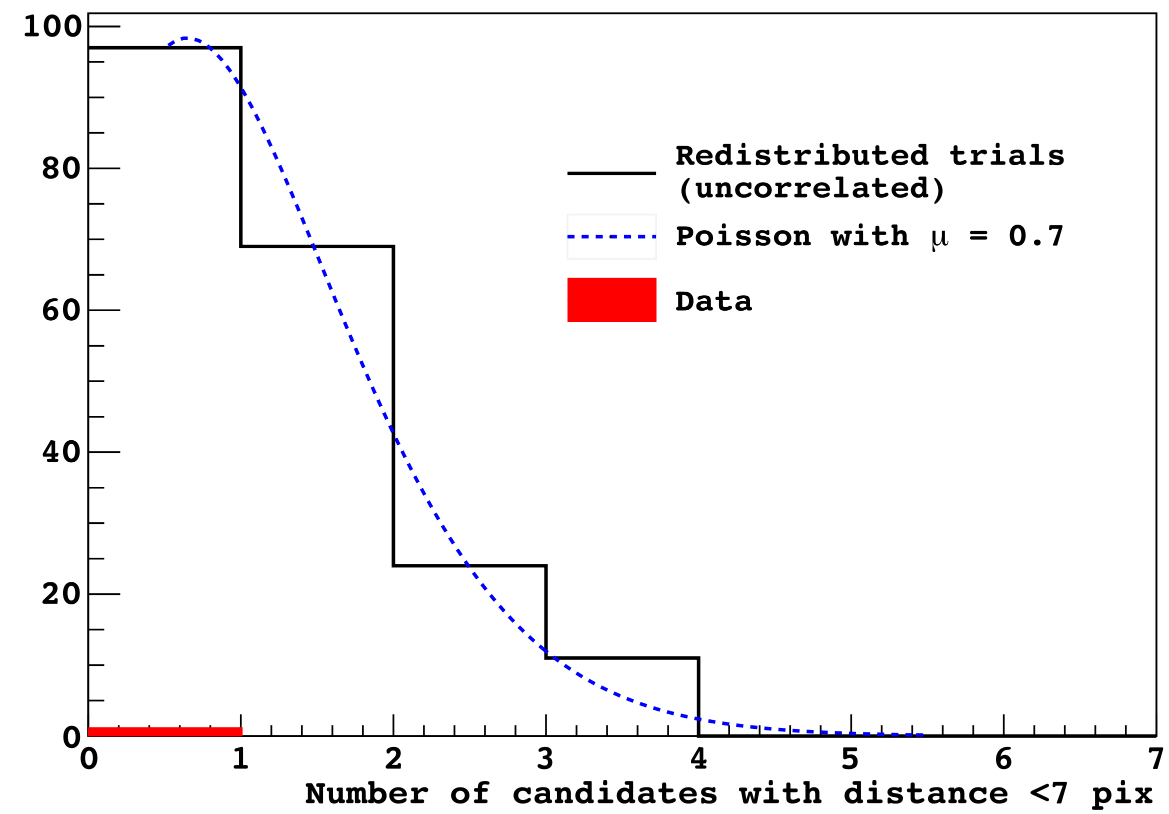
β-β coincidences

Search in 57 days of data in 1 CCD:

^{32}Si = 120^{+160}_{-90} kg^{-1}d^{-1} (95% C.L.)

^{210}Pb < 50 kg^{-1}d^{-1} (95% C.L.)





100 kg^{-1} d^{-1} of ^{32}Si ⟶ ~1 dru at low energies.

Spatial correlations will allow DAMIC to veto these decays.

(limitation for other silicon technologies?)

Conclusions

- CCDs perform well as particle detectors: superb energy threshold and spatial resolution.
- Modest DAMIC exposure (0.3 kg d) can already probe new regions of WIMP parameter space.
- CCDs are well suited to identify and suppress radioactive backgrounds. Possible applications beyond dark matter searches.
- Current data hints at the presence of ^{32}Si in the bulk silicon of the detector. Other background searches return null.