Dark Matter Search with CCDs

J. Estrada
4/18/2009

DECam focal detectors

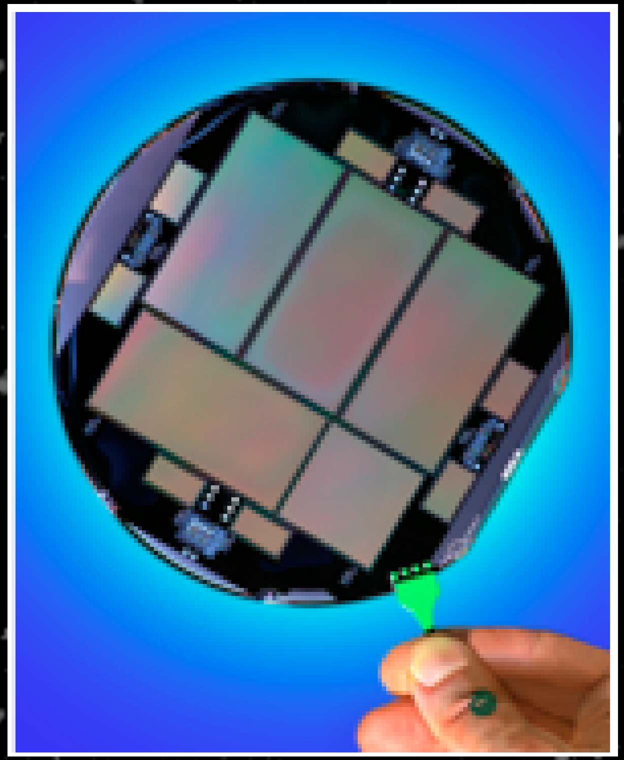
Science goal requires DES to reach z~1

we want to spend ~50% of time in z-filter (825-1100nm)
Astronomical CCDs are usually thinned to 30-40 microns (depletion):
Good 400nm response
Poor 900nm response

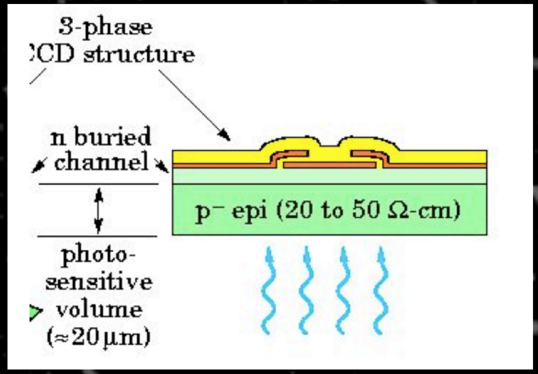
LBNL full depletion CCD are the choice for DECam:

–250 microns thick
–high resistivity silicon
–QE> 50% at 1000 nm

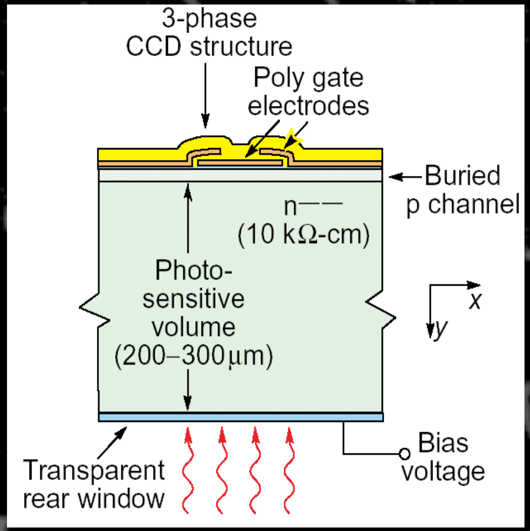
DECam wafer



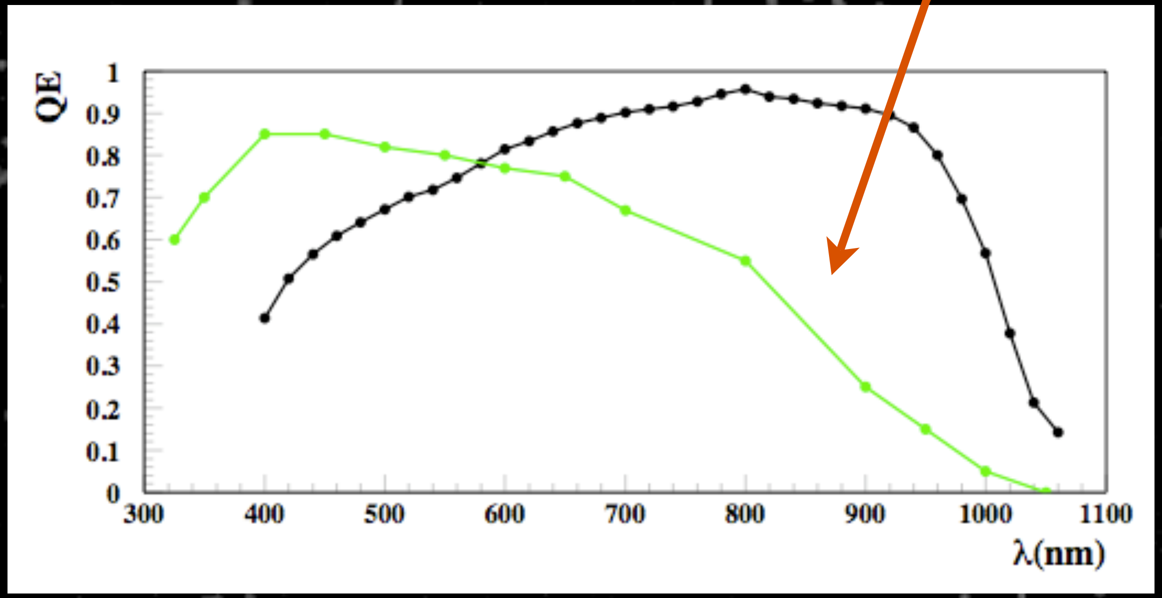
typical CCDs



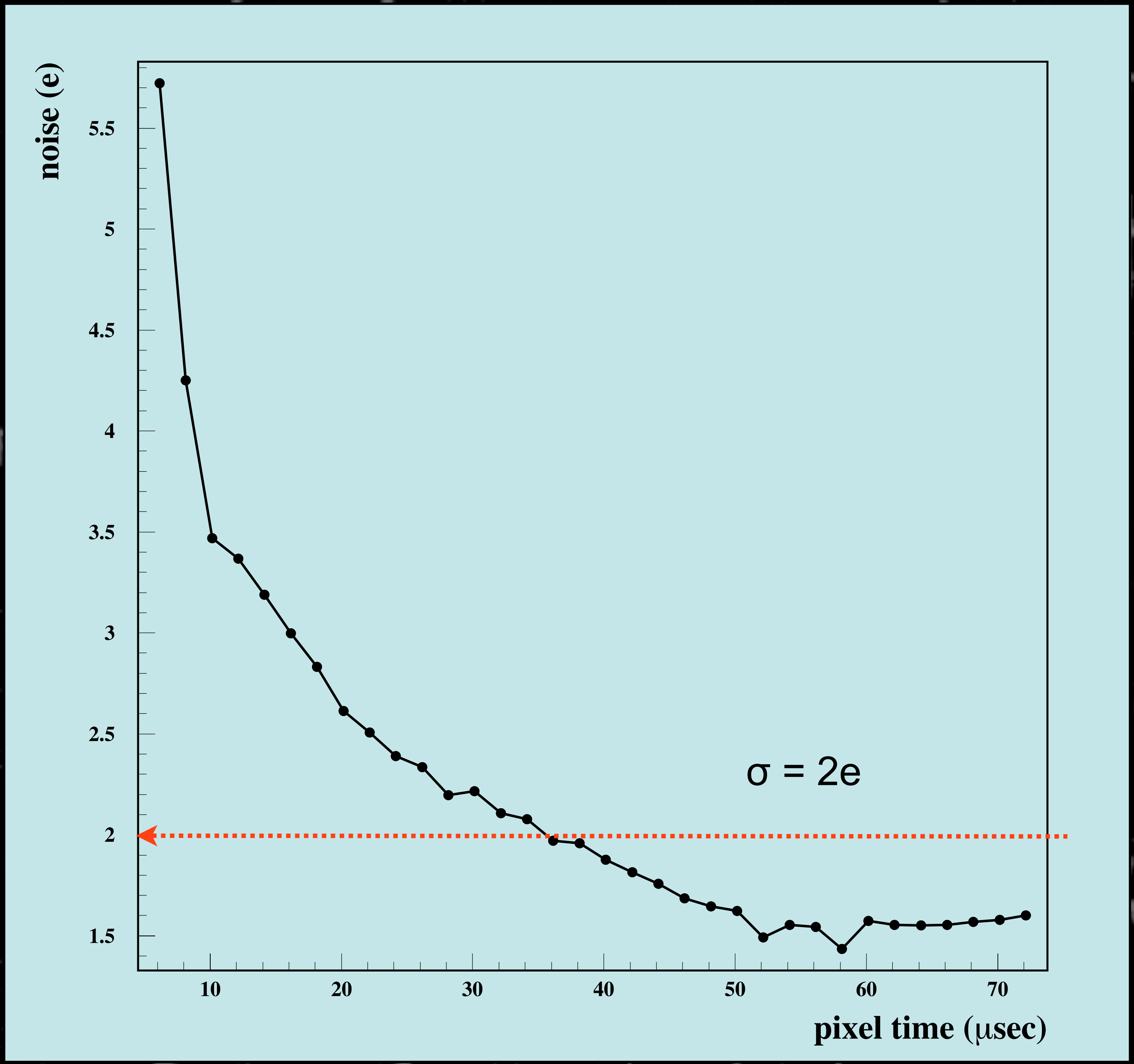
new thick CCDs



higher efficiency for hi-z objects.



New opportunities with these CCDs



Two features:

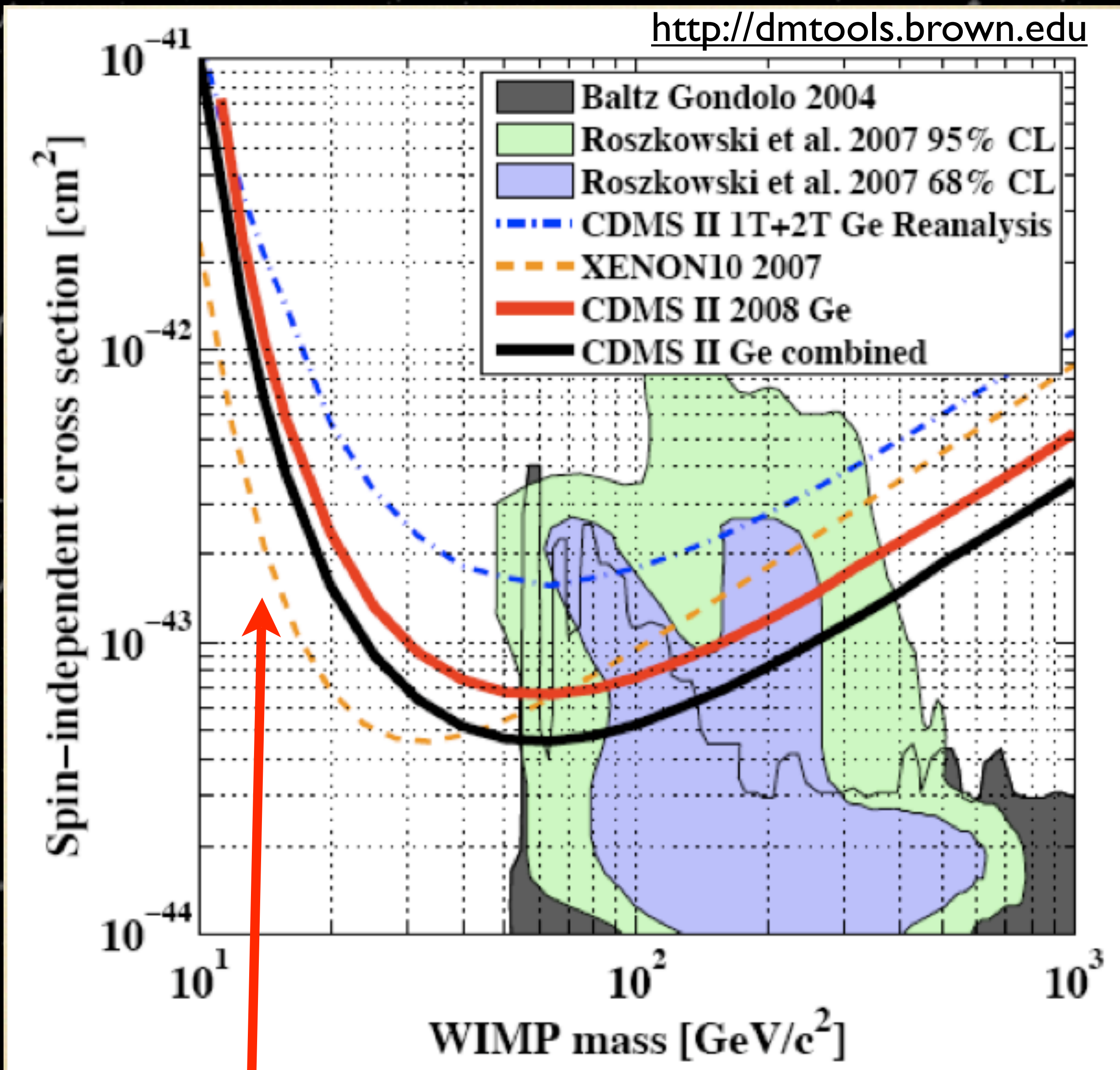
CCDs are readout serially (2 outputs for 8 million pixels). When readout slow, these detectors have a noise below 2e- (RMS). This means an **RMS noise of 7.2 eV in ionization energy!**

The devices are "massive", 1 gram per CCD. Which means you could easily build ~10 g detector. DECam would be a 70 g detector.

Interesting for a low threshold DM search.

- 7.2 eV noise ⇨ low threshod (~0.036 keVee)
- 250 µm thick ⇨ reasonable mass (a few gram detector)

DM search results



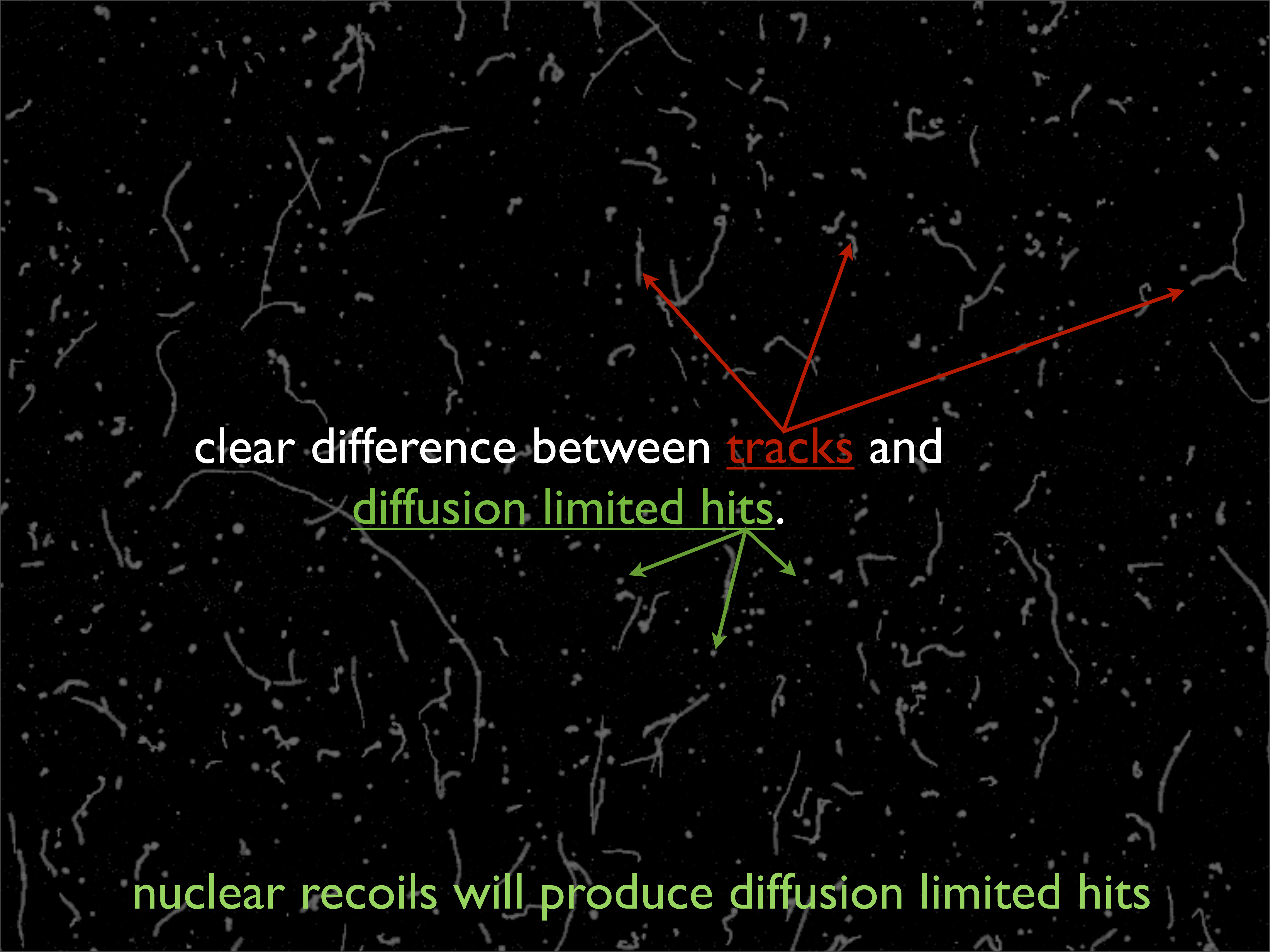
minimal SUSY likes heavy WIMPs, and most experiments are trying to cover that area.

from Petriello & Zurek 0806.3989

Experiment	Target	Exposure (kg-d)	Threshold	Ref
CDMS-SUF	Ge	65.8	5 keV	[2]
	Si	6.58	5 keV	
CDMS-II	Ge	121.3	10 keV	[3]
	Si	12.1	7 keV	[4]
XENON10	Xe	131	4.5 keV	[5]
CRESST-I	Al_2O_3	1.51	0.6 keV	[16]
DAMIC	**Si**	**~1**	**0.1 keV**	

limited by detector threshold, typically a few keV. This limitation comes in part from the readout noise.

given our low noise, we can set a much lower threshold and scan the low energy region.


clear difference between tracks and
diffusion limited hits.
nuclear recoils will produce diffusion limited hits

5.9 keV X-ray from Fe55 gives 1620e-

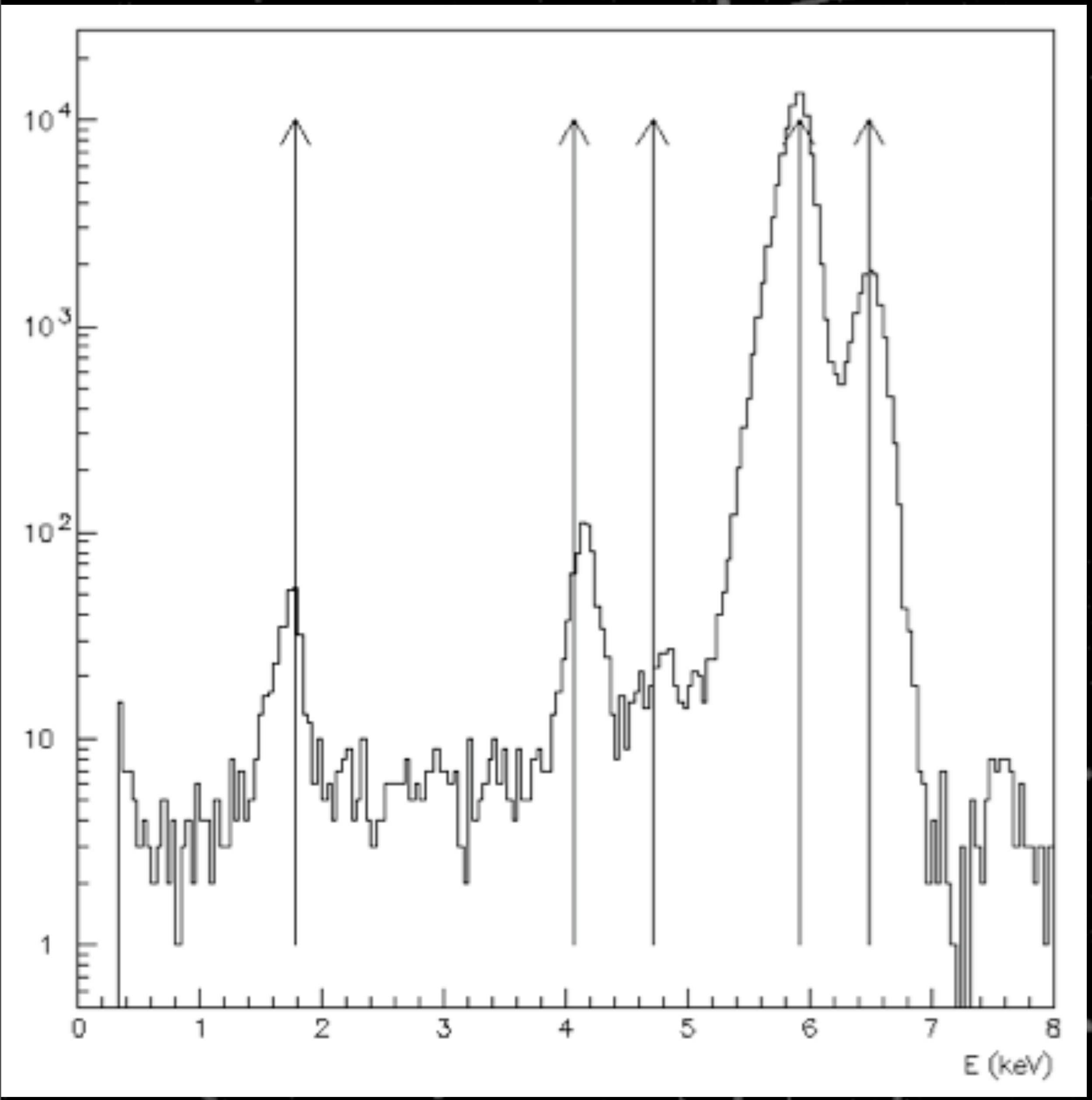
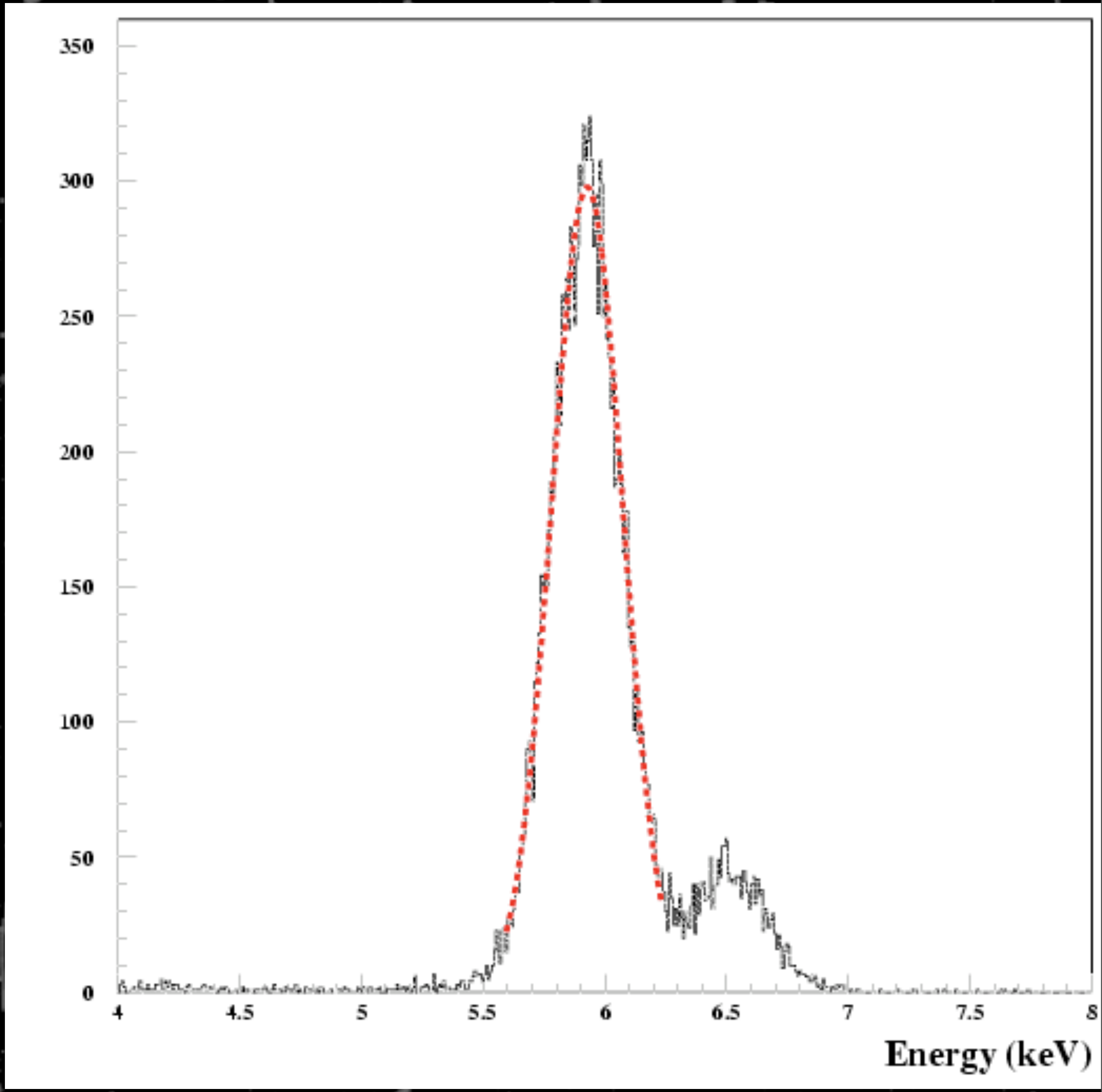


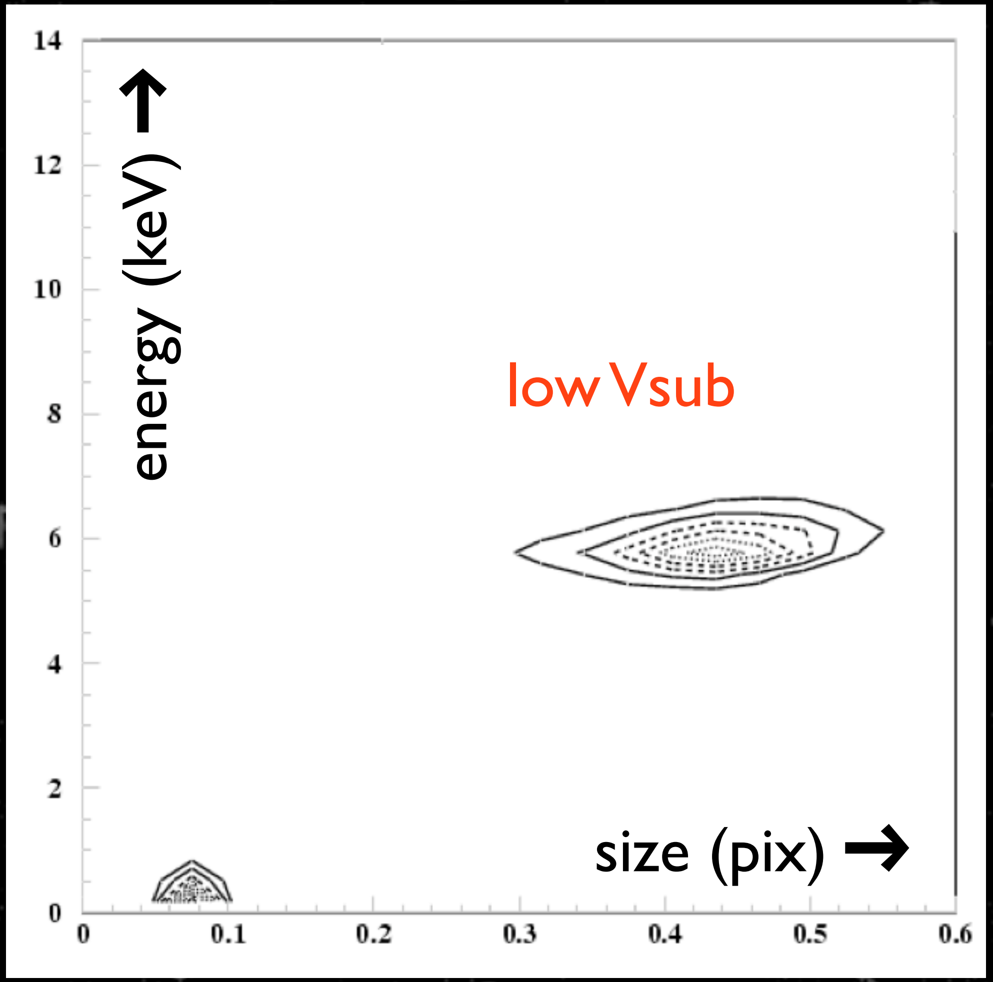
FIG. 4: Spectrum obtained for the reconstructed X-ray hits in an ^{55}Fe exposure of a DECam CCD. The arrows mark the direct X-rays from the source Kα=5.9 keV and Kα=6.5 keV, the Kα and Kβ escape lines at 4.2 and 4.8 keV, and the Si X-ray at 1.7 keV. The factor 3.64 eV/e is used to convert from charge to ionization energy.

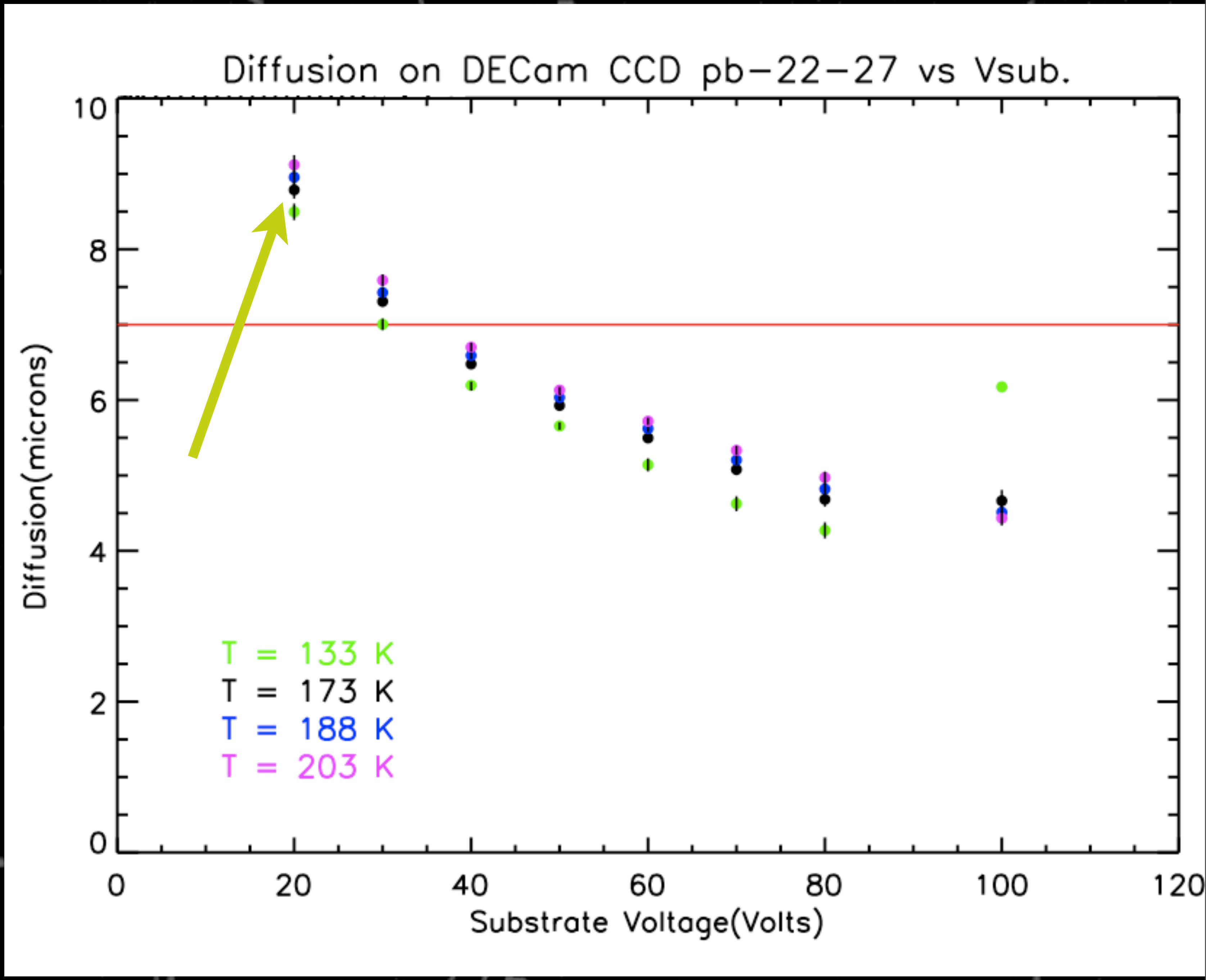
Energy resolution

0.15 keV = 41 e- = sqrt (1620e-)

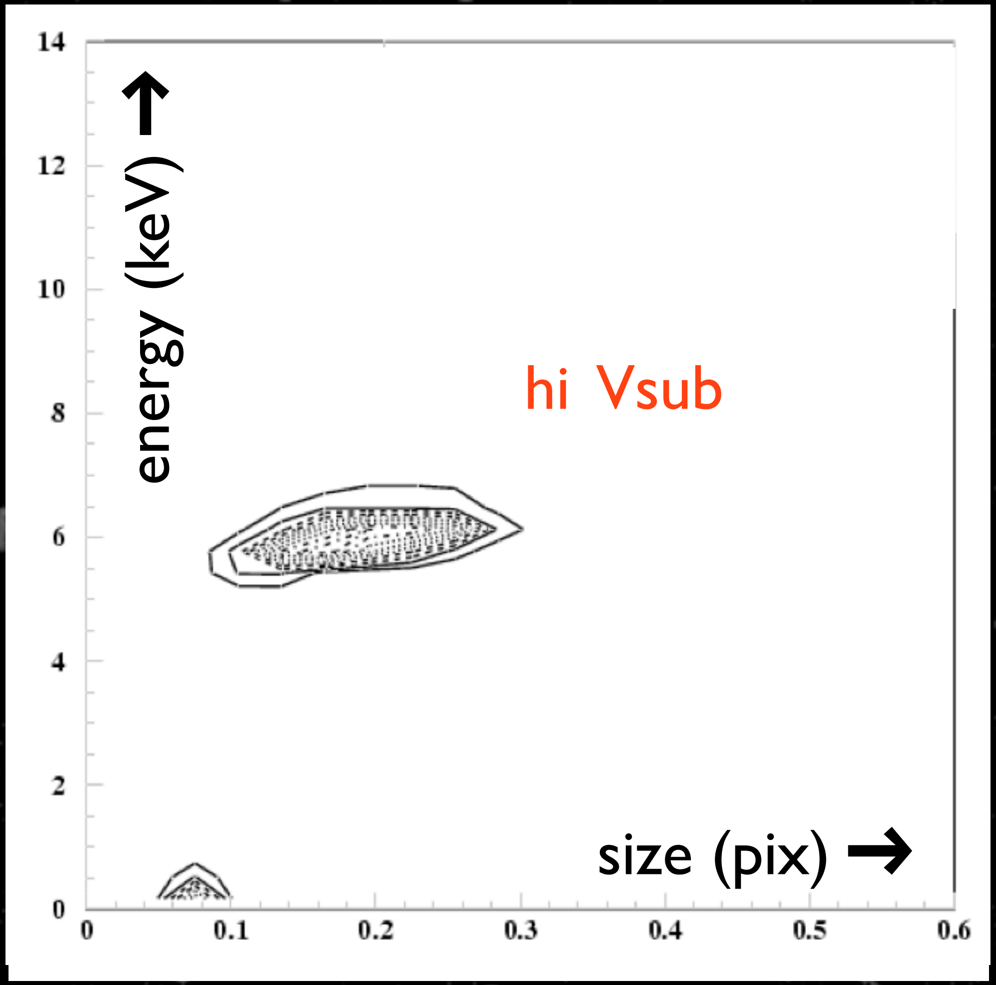


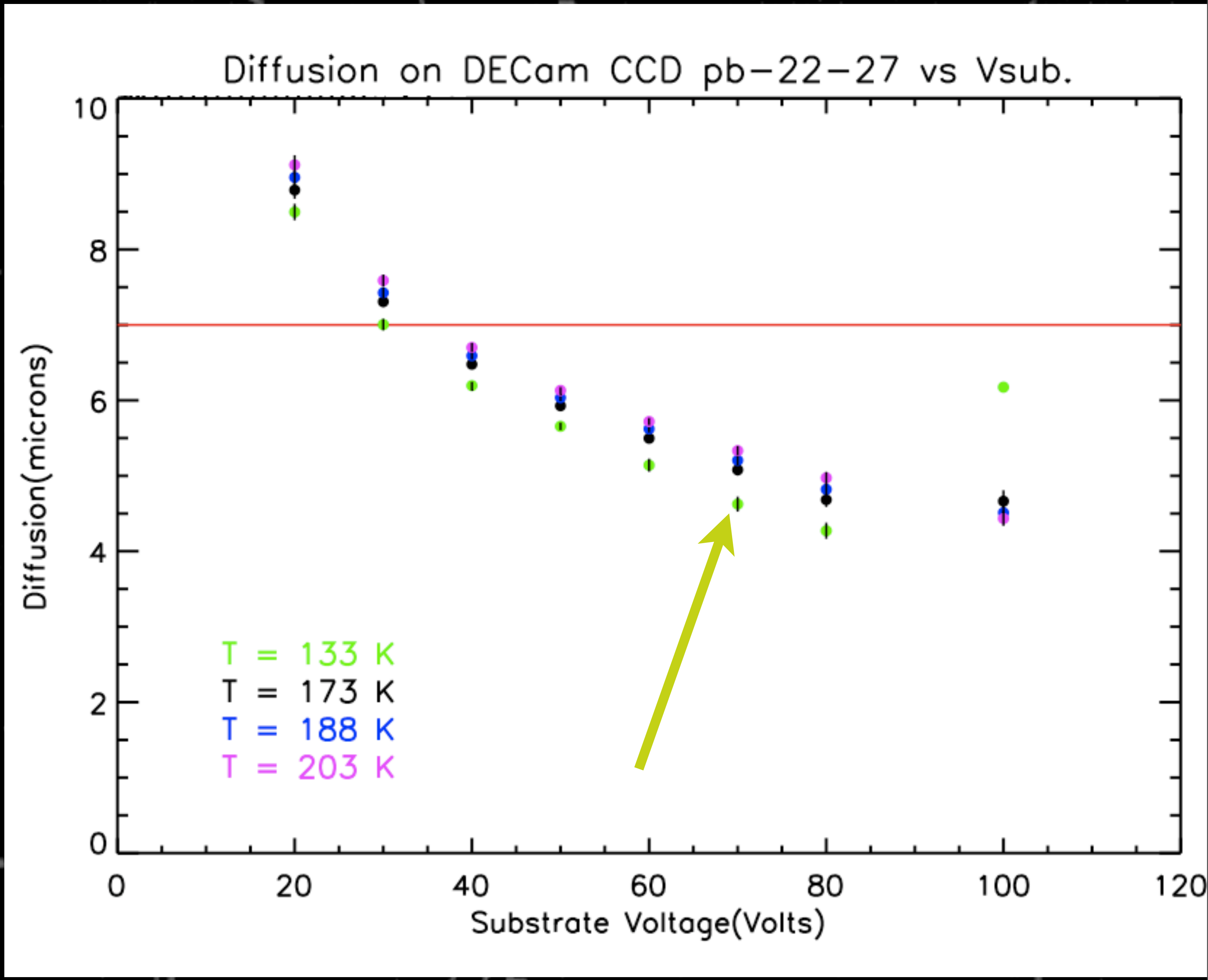
Charge diffusion with X-rays



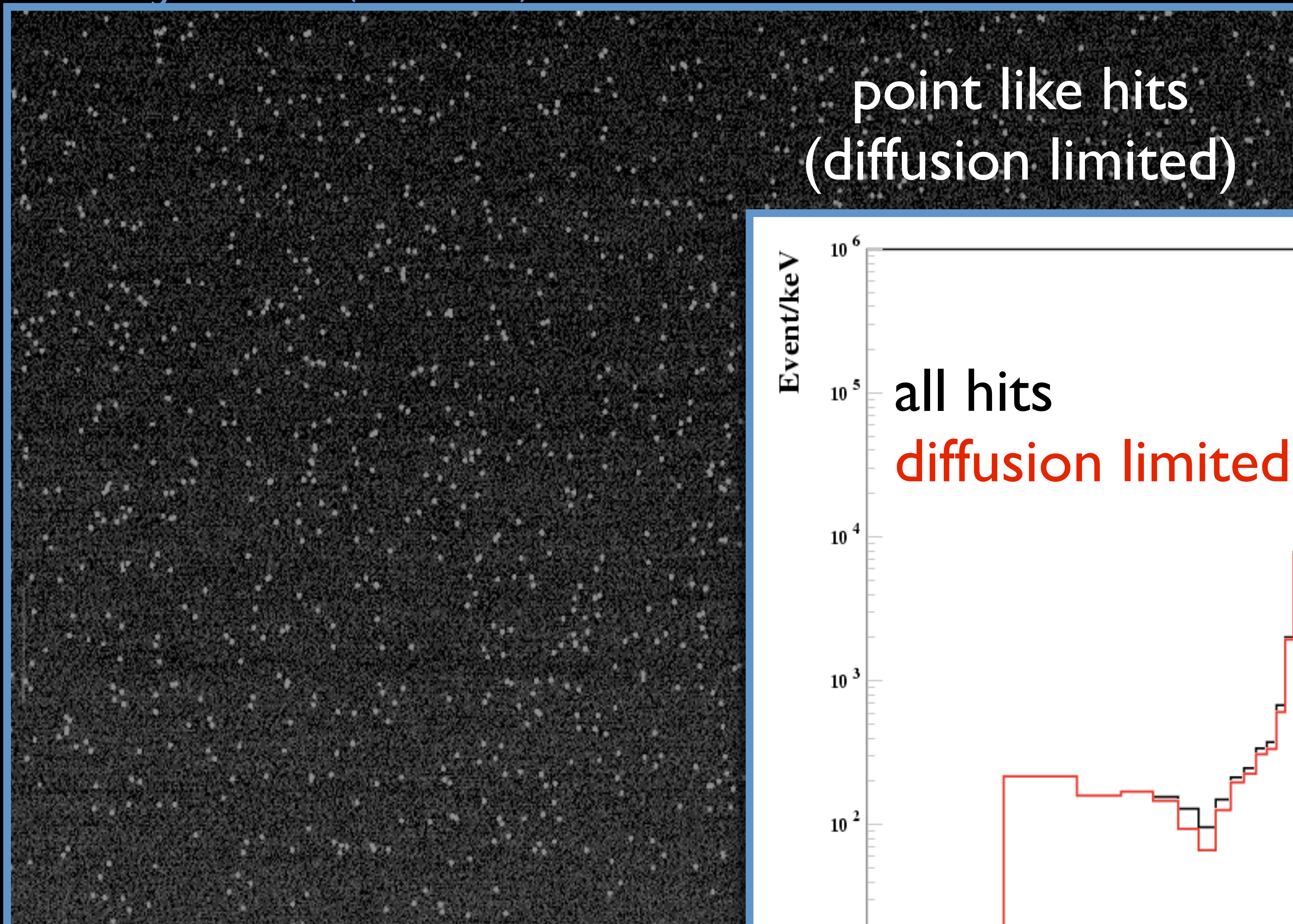


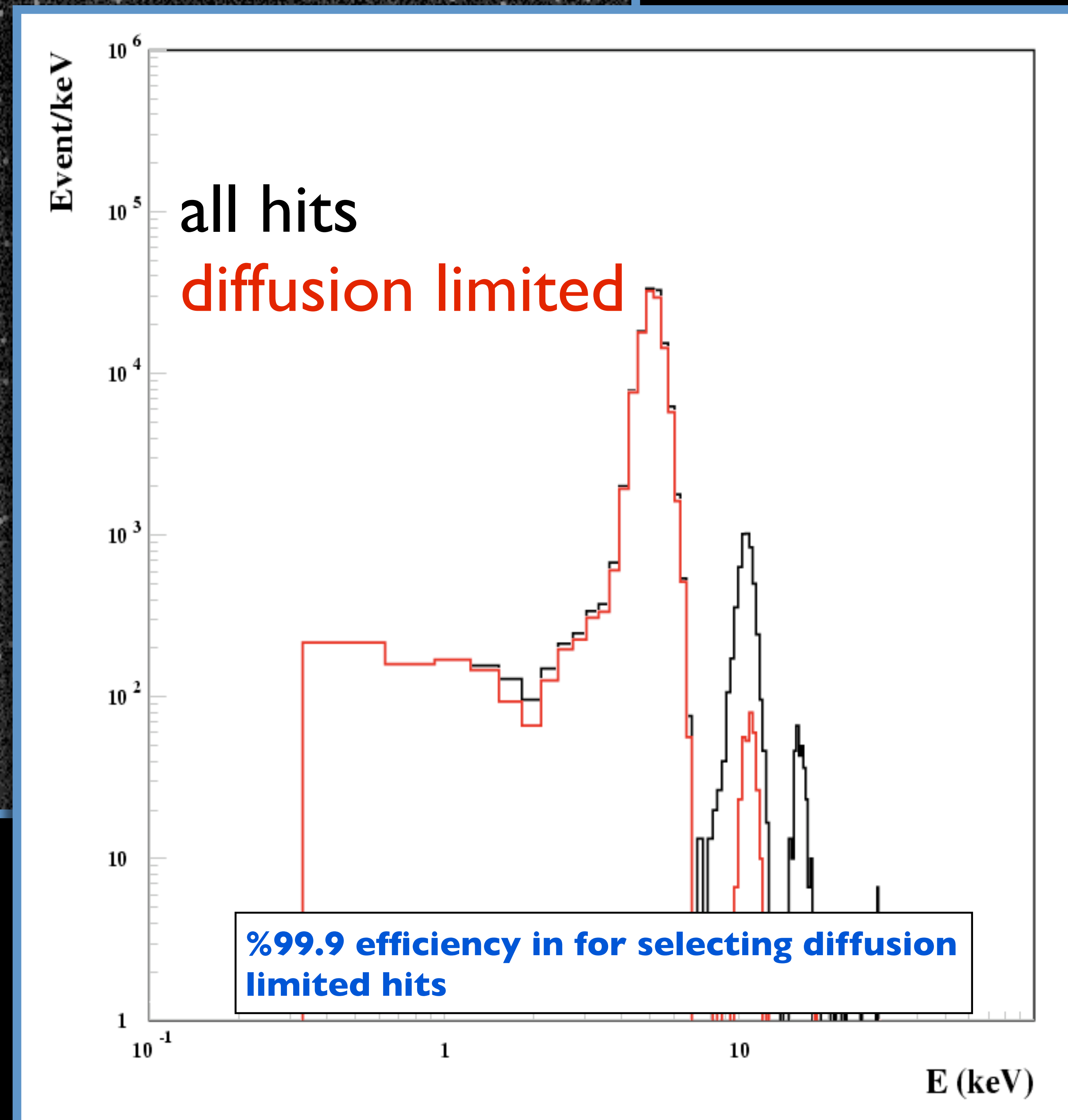
Charge diffusion with X-rays





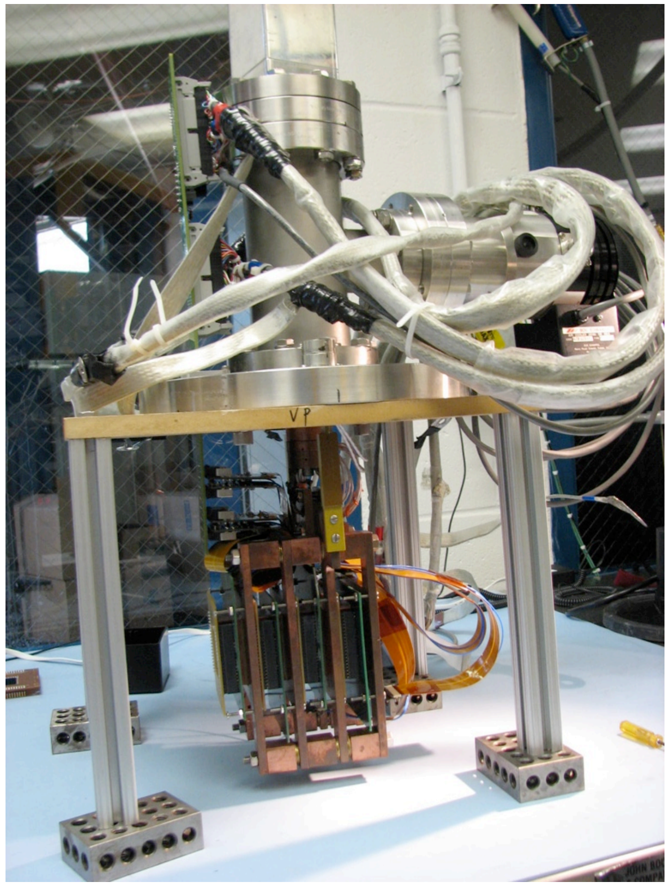
X-ray ^{55}Fe (5.9 keV)

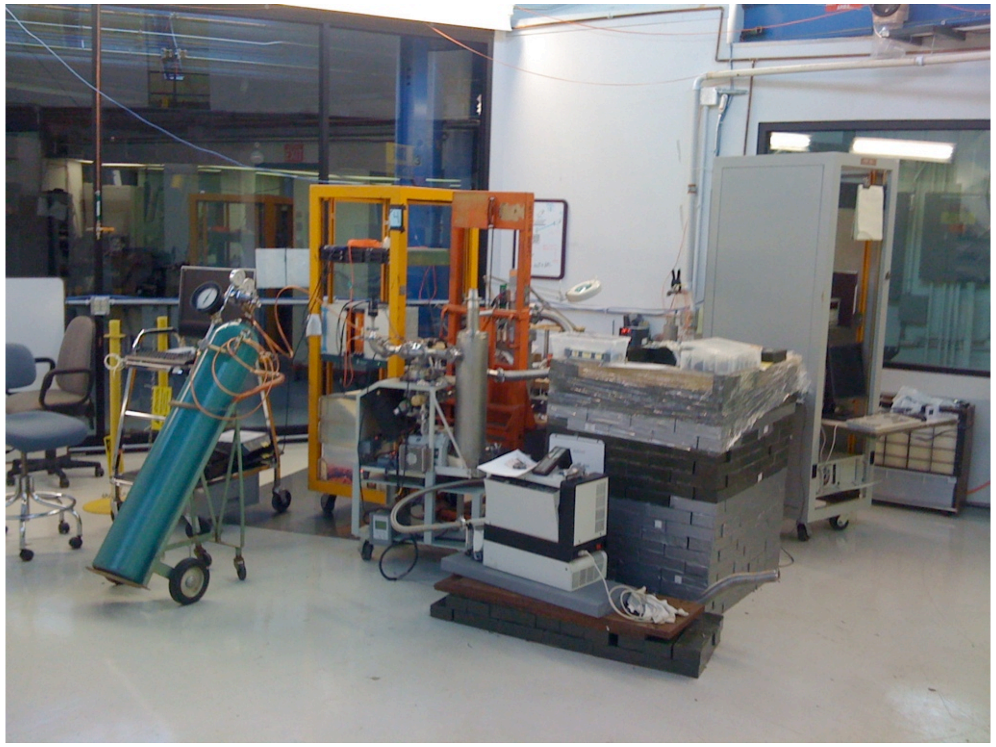




DAMIC started at SiDet

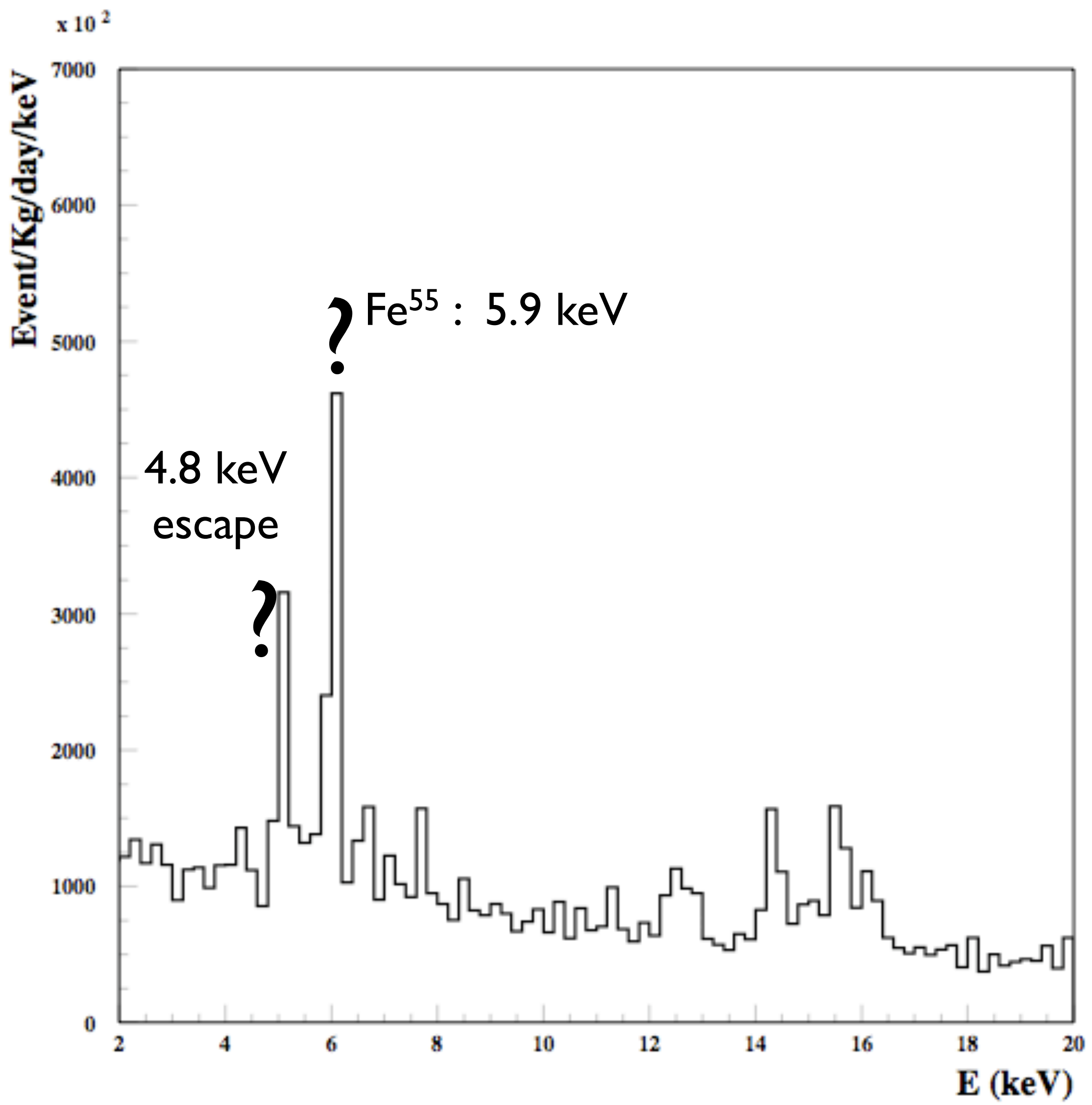
BTev/SNAP dewar adapted for DECam CCDs. 4CCD array pin compatible with DECam prototype.

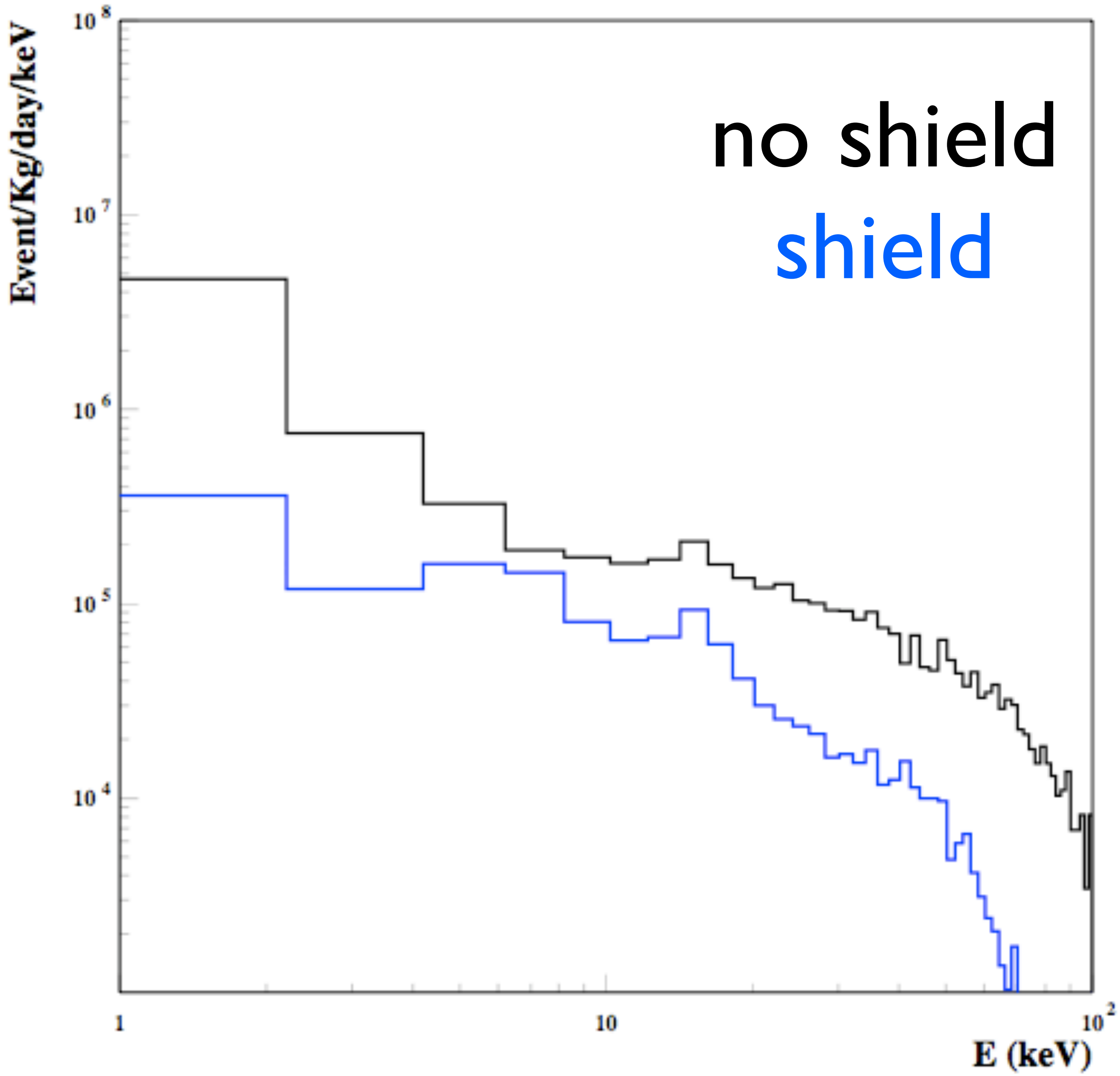




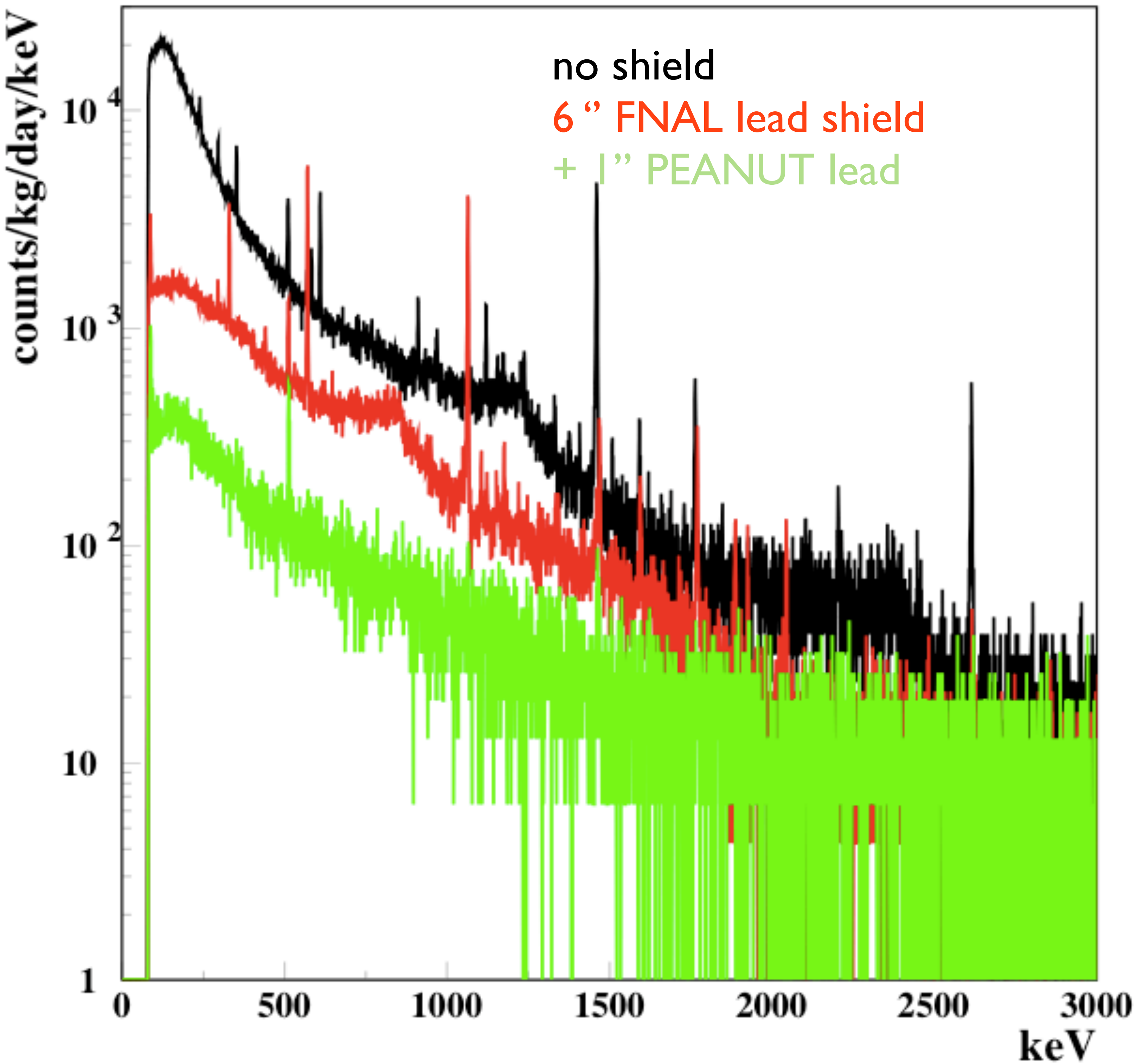
DECam prototype electronics used

runs at Lab-A gave 10^6 cpd/keV... too high!





Shield studies:Ge detector at LAB-A

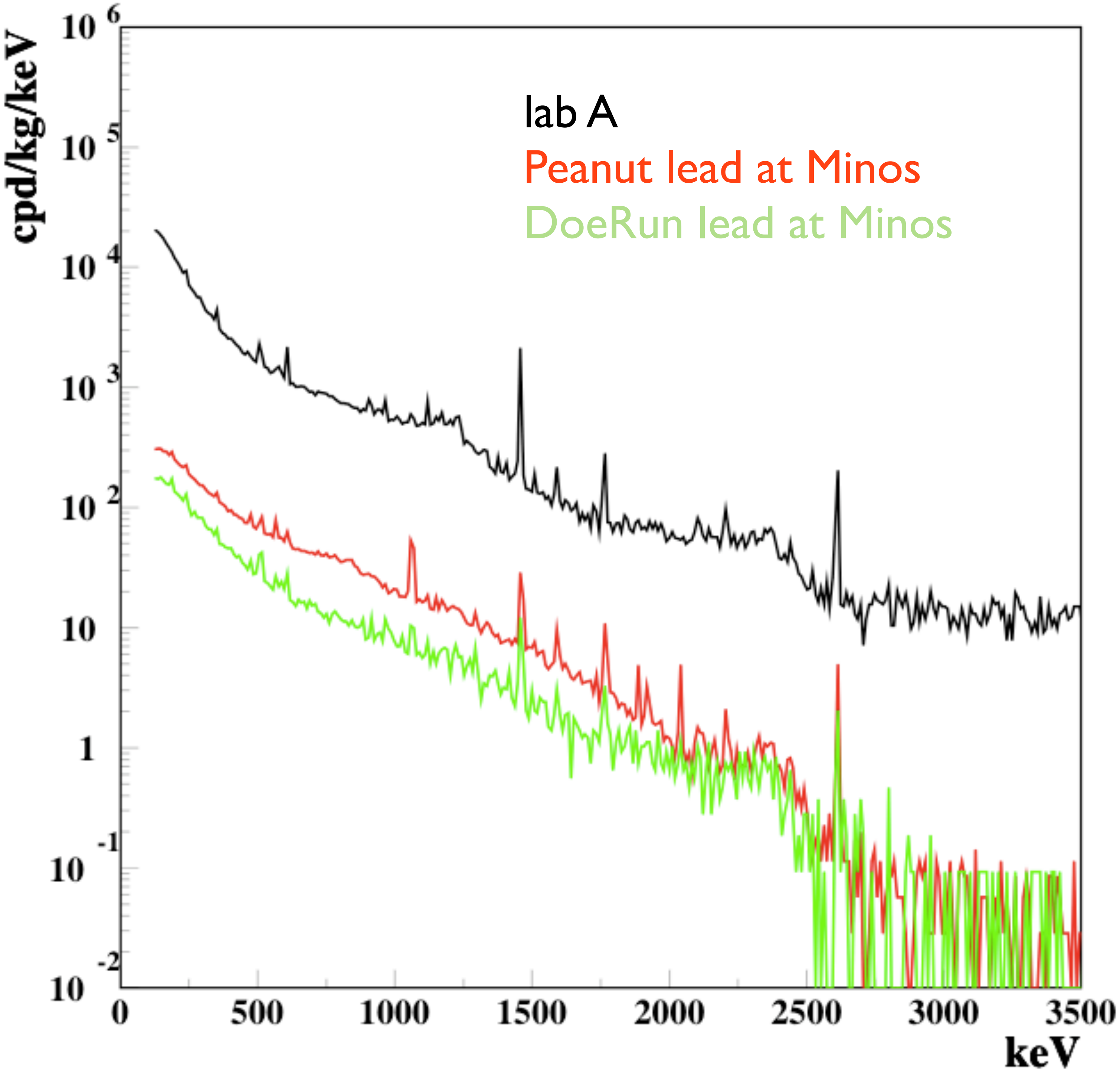


FNAL lead is bad, it had Bi-207 from exposure to beam.

Peanut lead was available at FNAL for these test, but not enough for the experiment.

Ge detector from surplus!

Shield studies:Ge detector at Minos



Purchased new lead before the price went down... and made a shield at Minos for the Ge detector.

Test indicated we could get about 2 orders of magnitudes.

Moved CCDs to Minos in January

built a tent in the near detector hall and installed our detectors inside

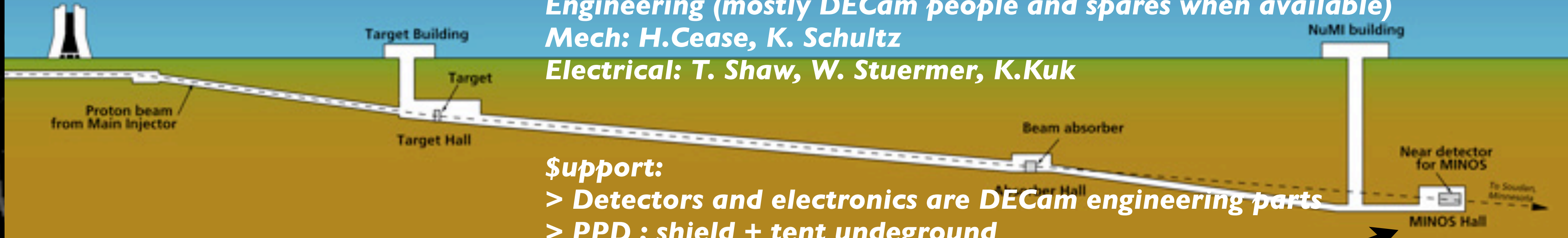
DAMIC (FNAL MOU T987)

Underground test of CCDs for DM

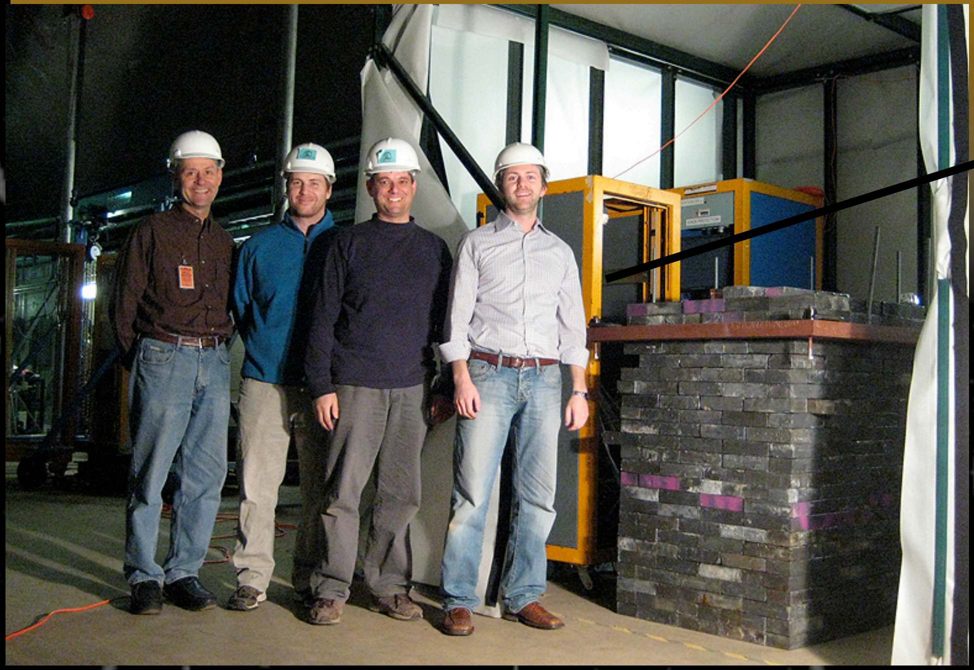
CPA people:
DES: *T. Diehl, J. Estrada, B. Flaugher, , D. Kubik, V. Scarpine*
COUPP: *E. Ramberg, A. Sonnenschein*
CDF: *Ben Kilminster*

Visitors:
J. Molina (CIEMAT), J. Jones (Purdue)

Engineering (mostly DECam people and spares when available)
Mech: H.Cease, K. Schultz
Electrical: T. Shaw, W. Stuermer, K.Kuk



$upport:
> Detectors and electronics are DECam engineering parts
> PPD : shield + tent undeground
> CPA : some electronics boards (VIB)

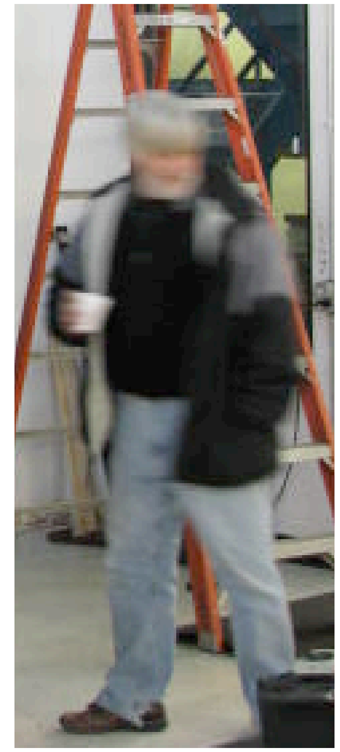


setting up a 4CCD array here. ~350 foot depth

... thanks!

T. Nebel (inside)

J. Tweed

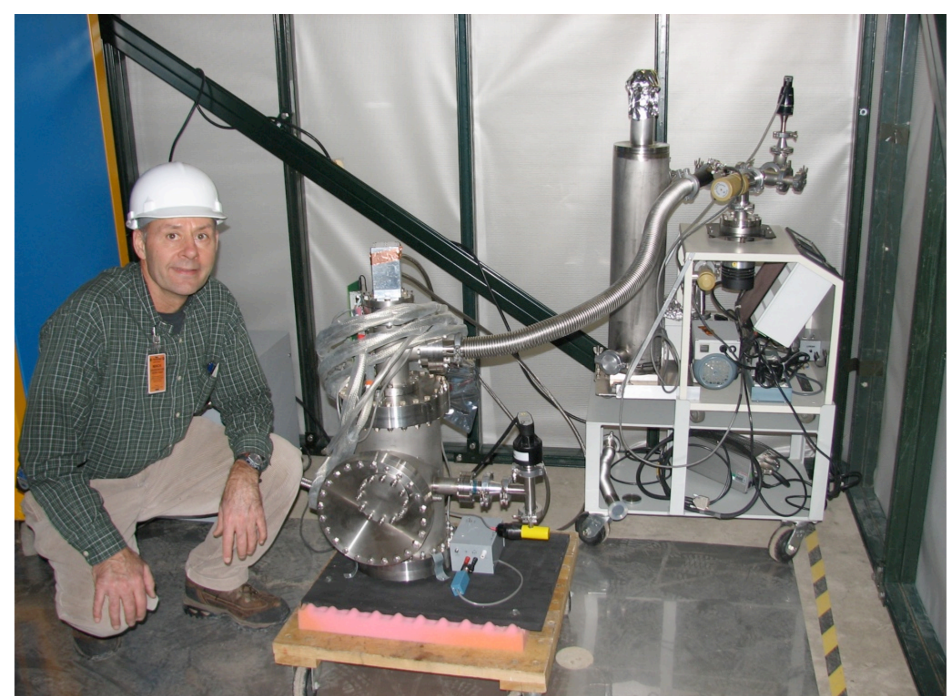


S. Jakubowski

K. Schultz

J. Voirin

J. Delao (and lead workers)



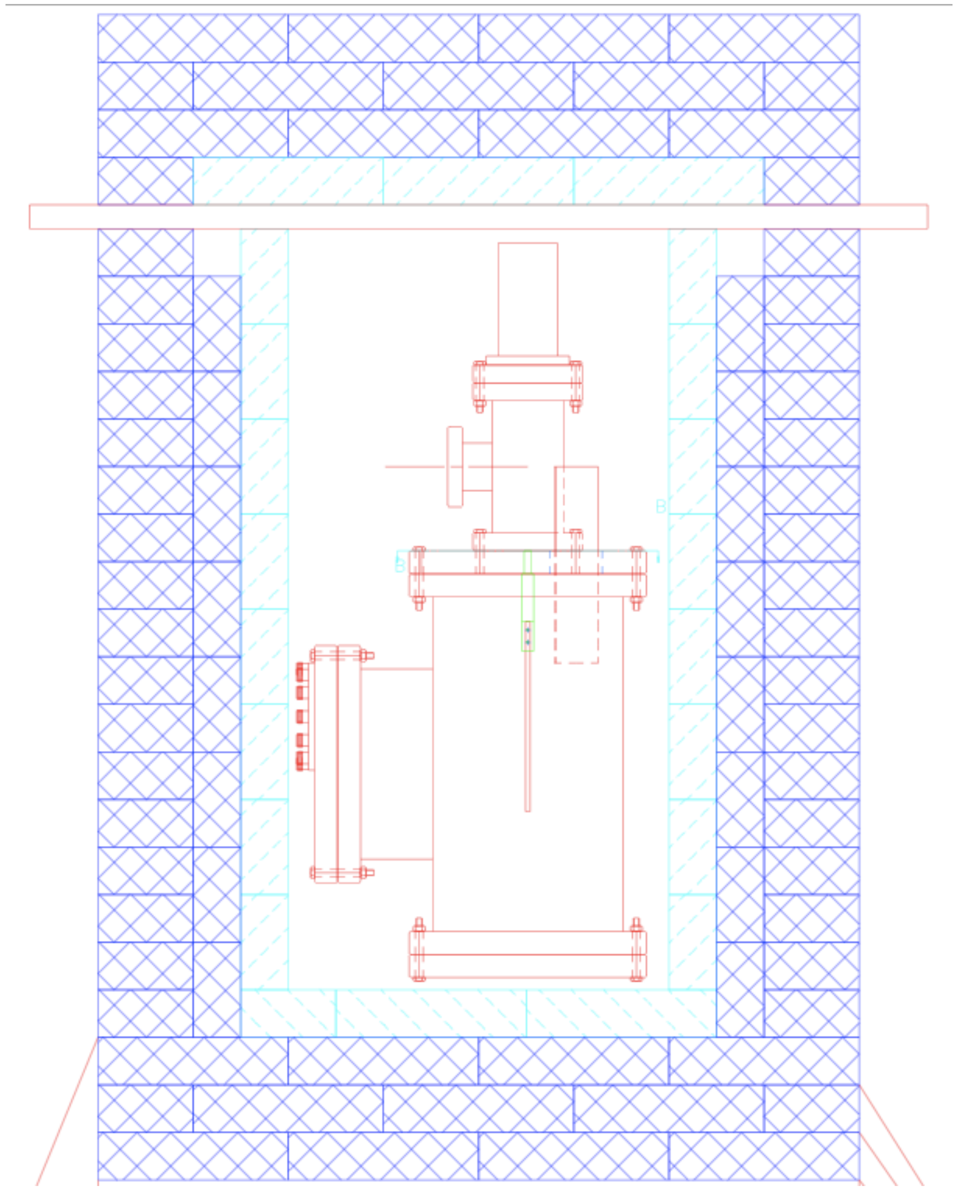
K. Kuk

M. Watson

Finished shield with new lead in March

2" of DoeRun lead and 6" of FNAL lead. Tight fit.

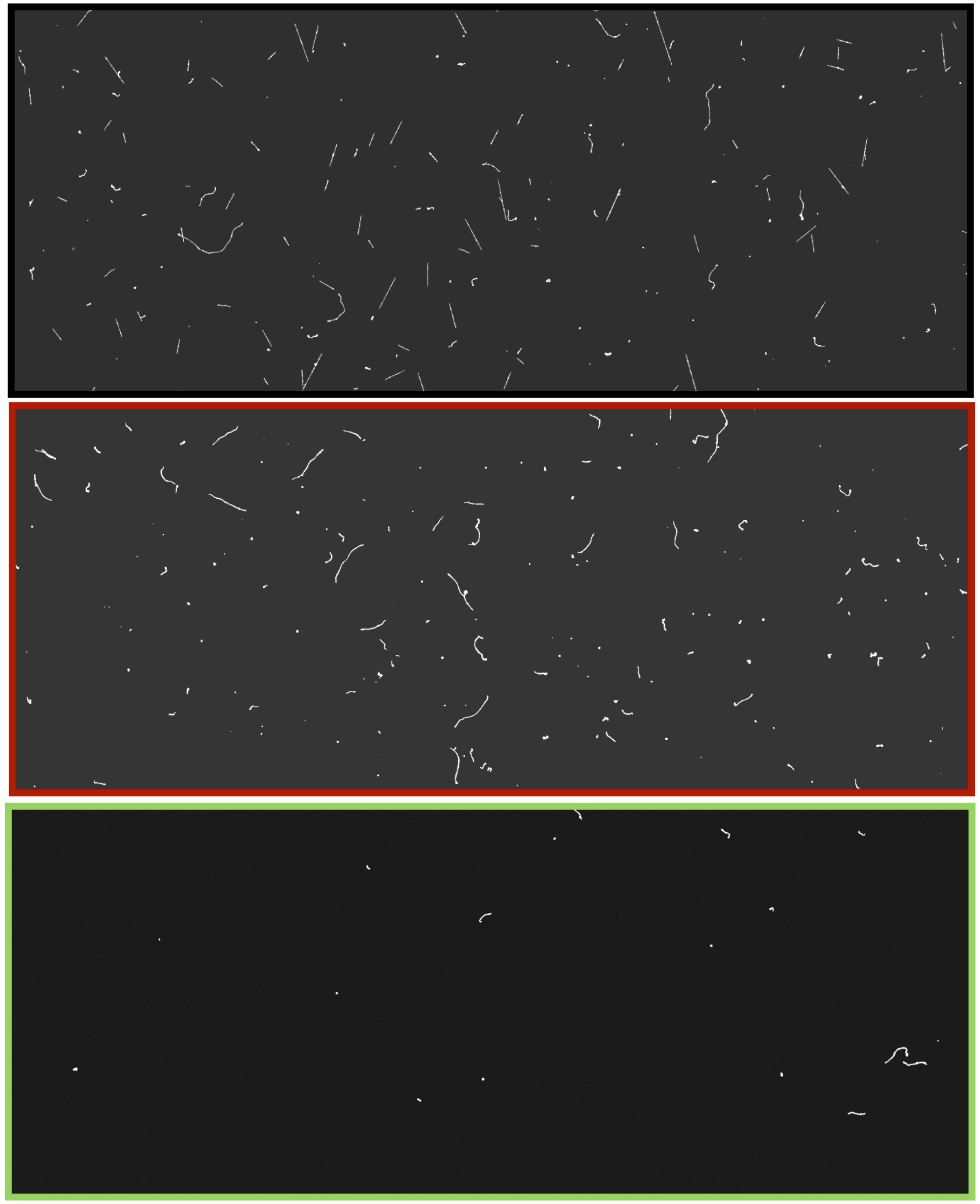
"clean tent"

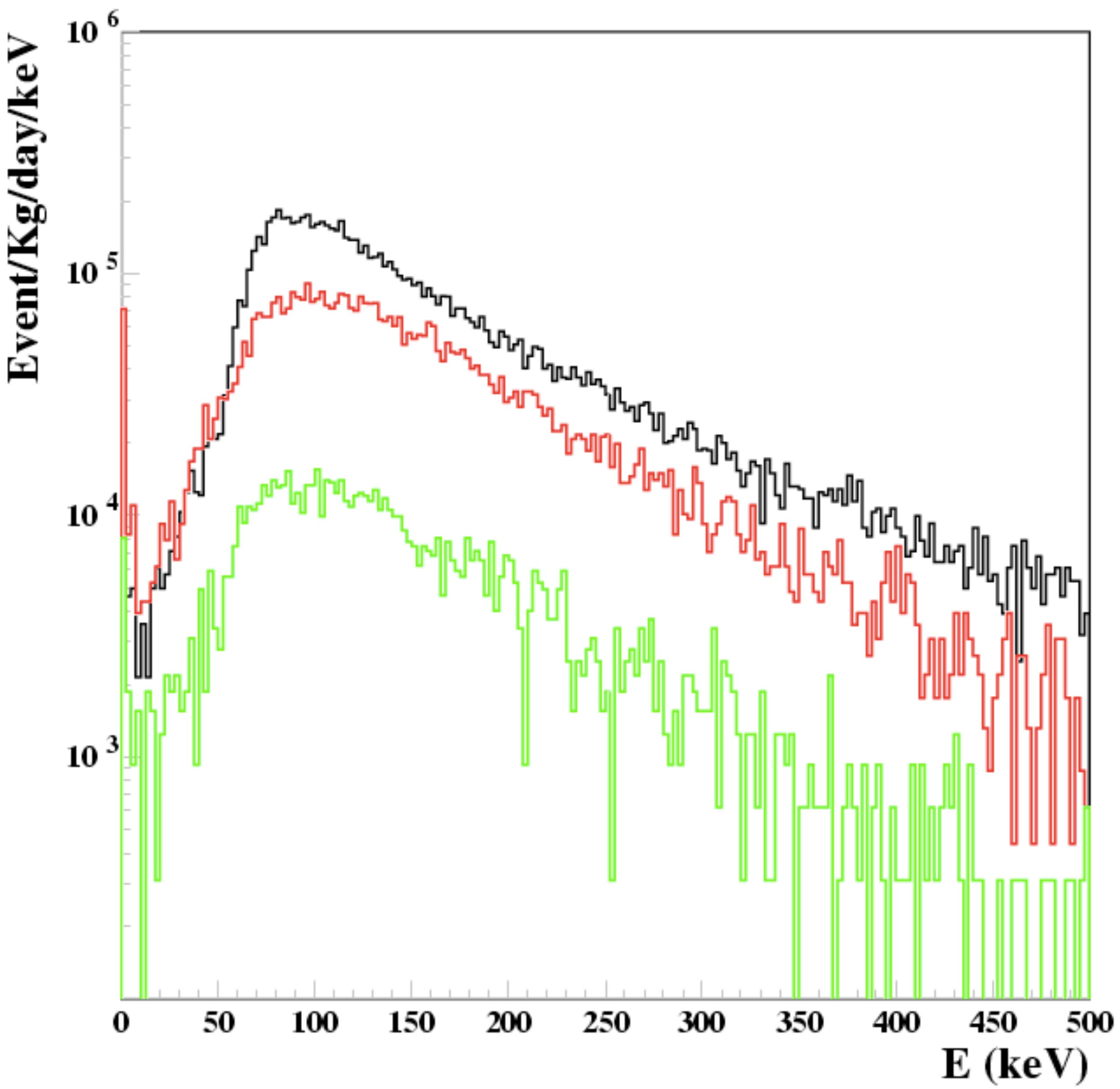


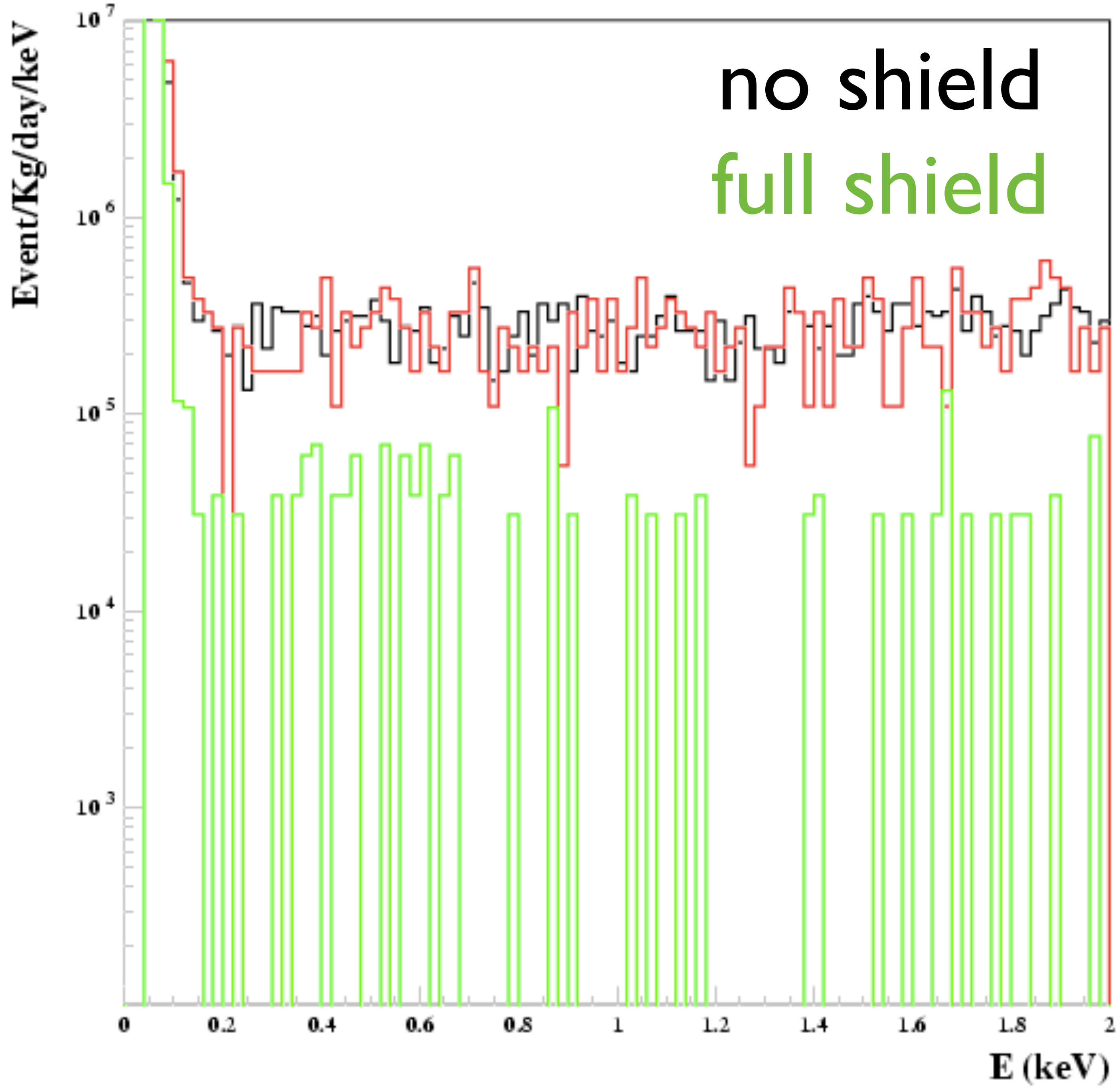
no more tape... FNAL lead painted with "german sport car" clear coat. New lead naked.

tracks:

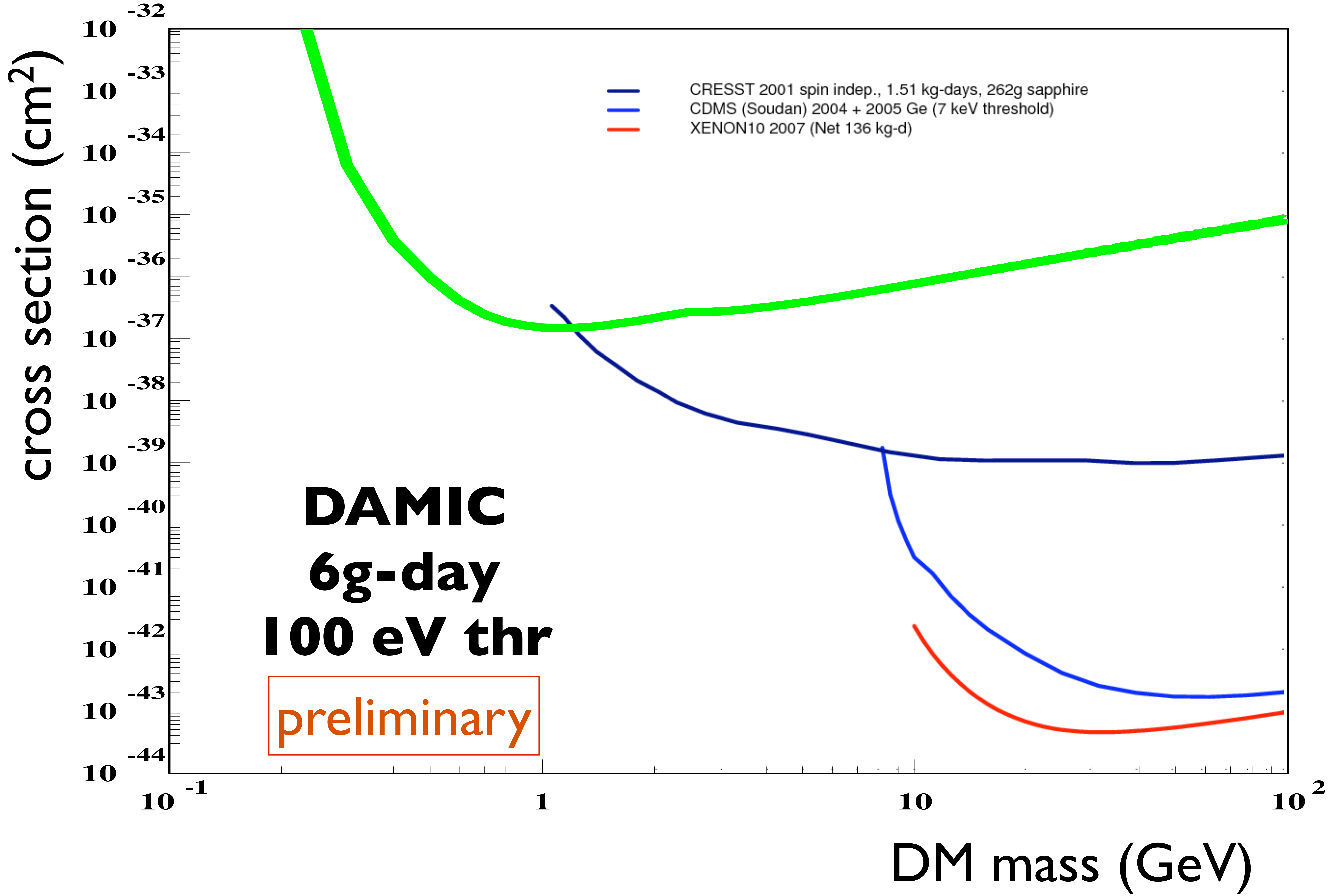
- Lab-A
- Minos
- Minos + lead shield



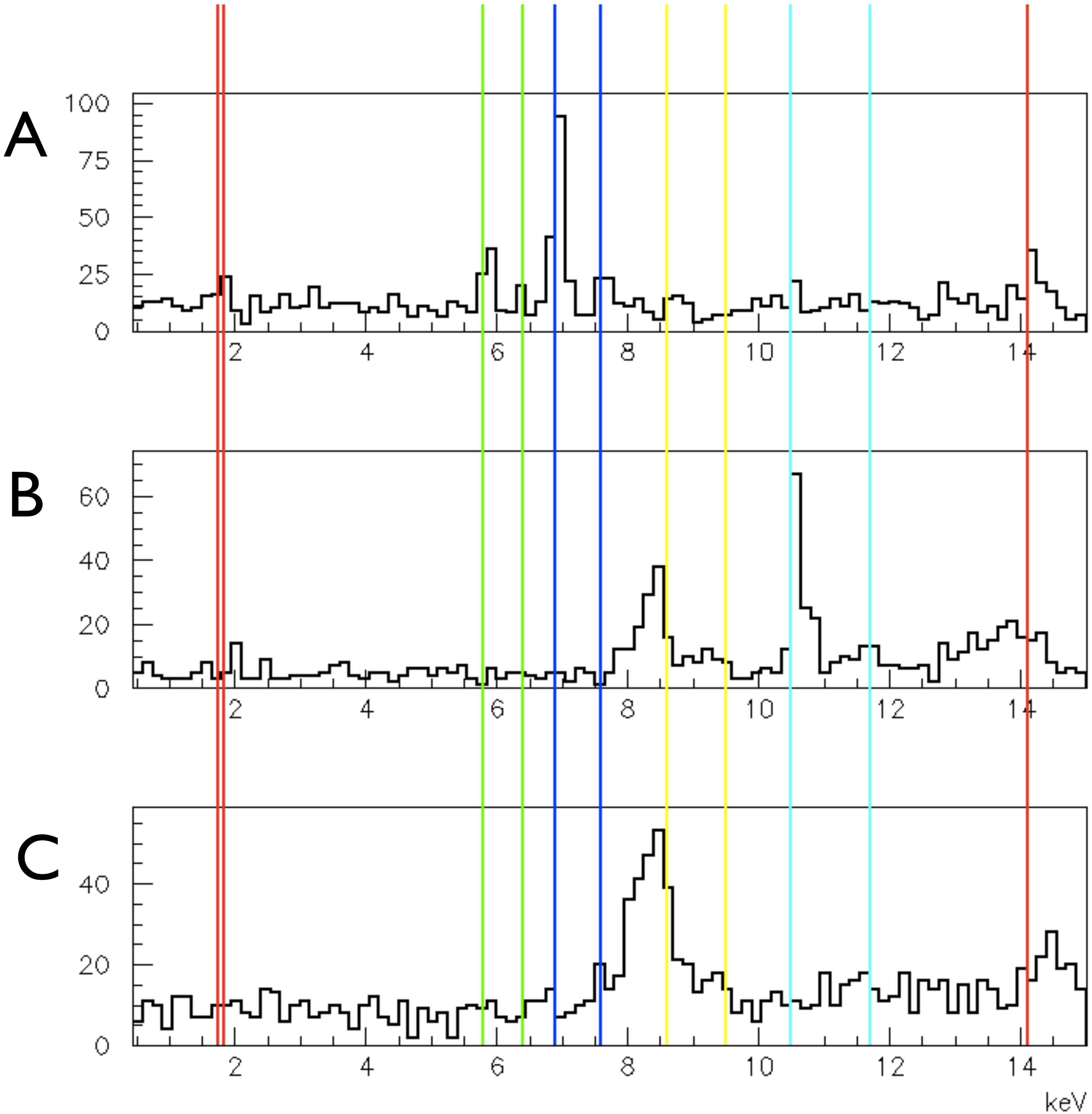




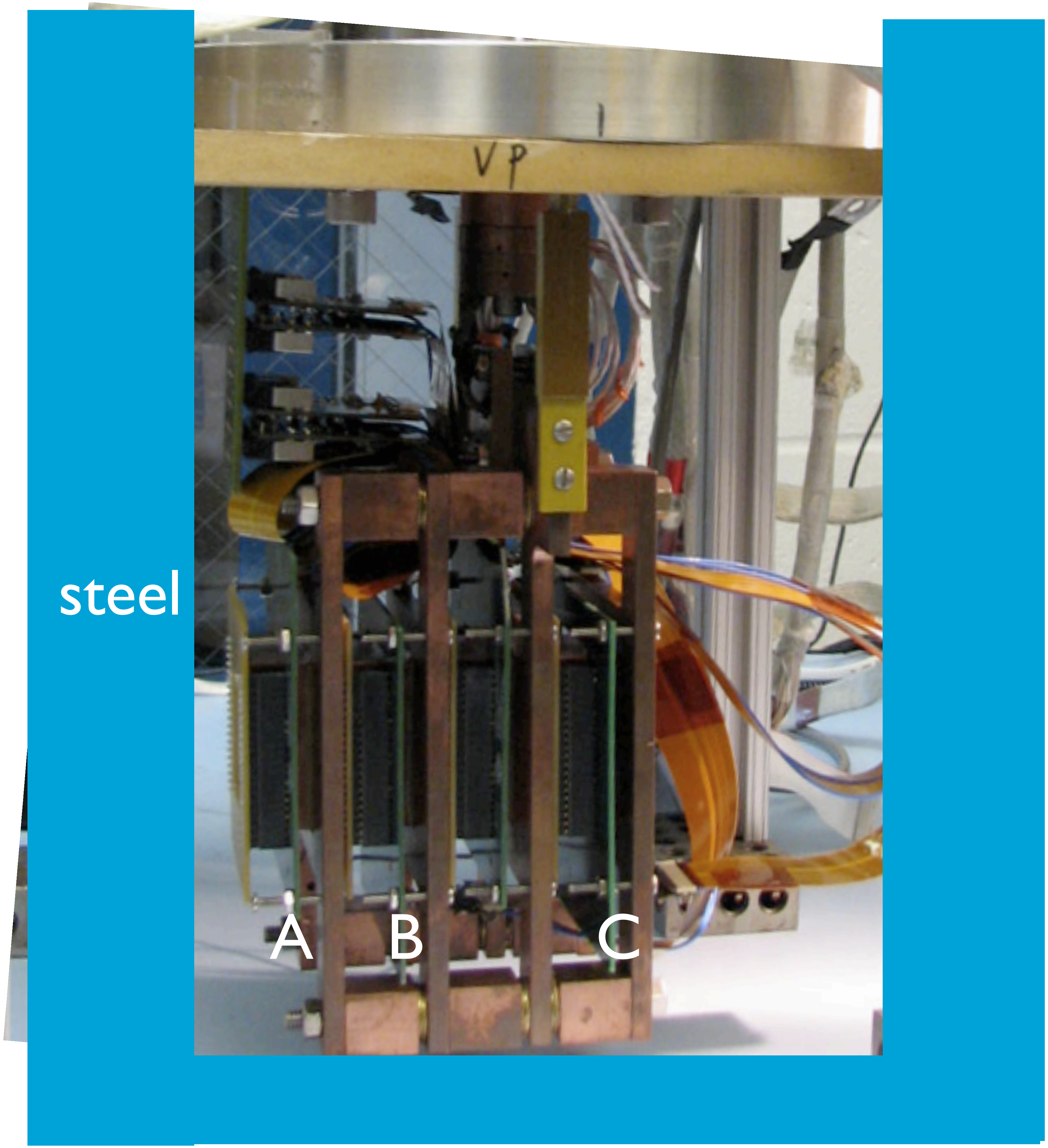
no shield
full shield
Event/Kg/day/keV
E (keV)
10^7
10^6
10^5
10^4
10^3
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



cross section (cm^2)
DM mass (GeV)
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-1}
1
10
10^{2}
CRESST 2001 spin indep., 1.51 kg-days, 262g sapphire
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
XENON10 2007 (Net 136 kg-d)
DAMIC
6g-day
100 eV thr
preliminary



Each detector in our setup sees a different spectrum.



Each detector in our setup sees a different spectrum.

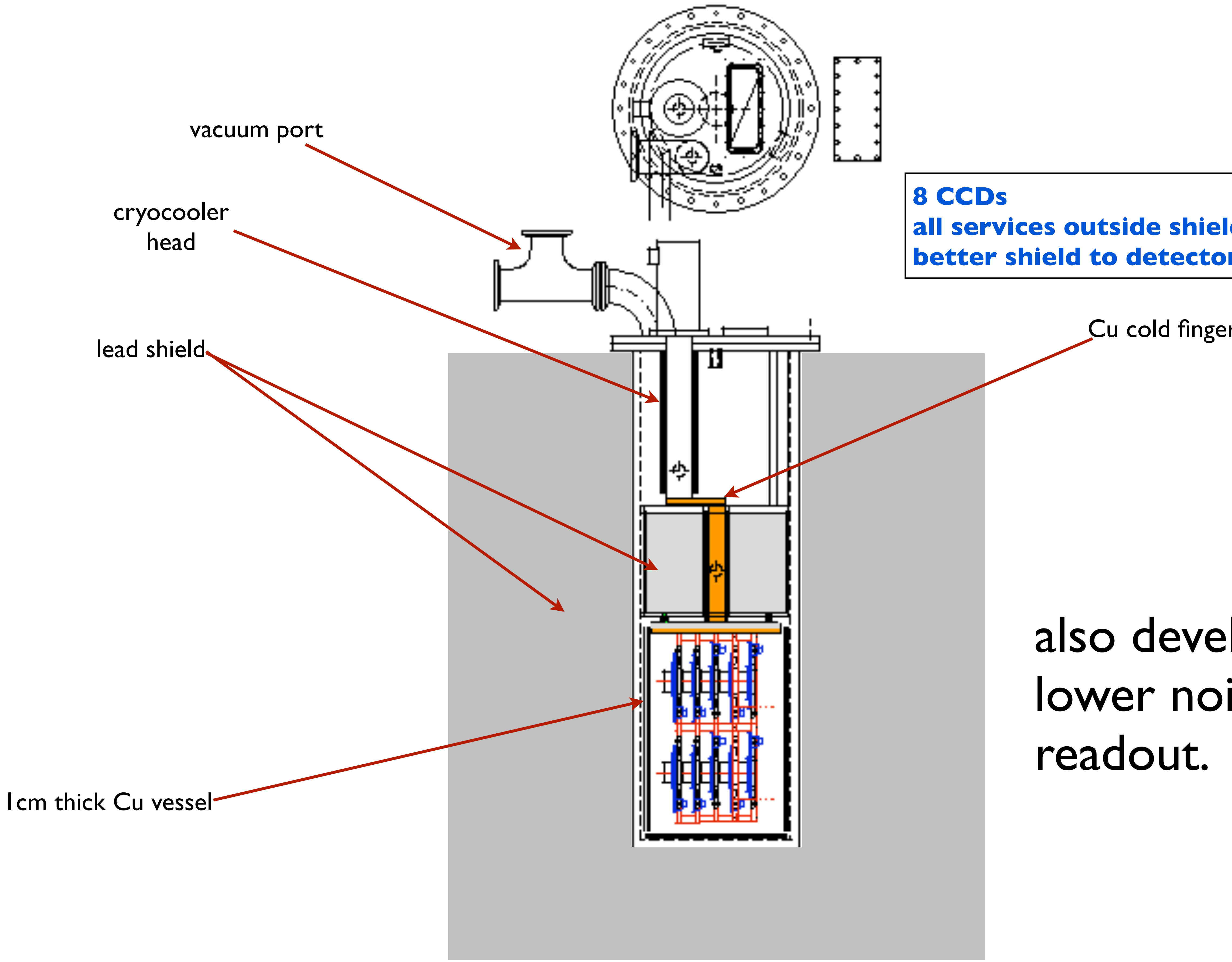
A sees a lot of steel:
Mn (Manganese)
Co (Cobalt)

B sees a lot of electronics:
As (Arsenic) - transistors
Zn (Zinc) - flex circuits

C sees a lot of cables:
Zn (Zinc) - flex circuits

Sr (Strotium) in A?

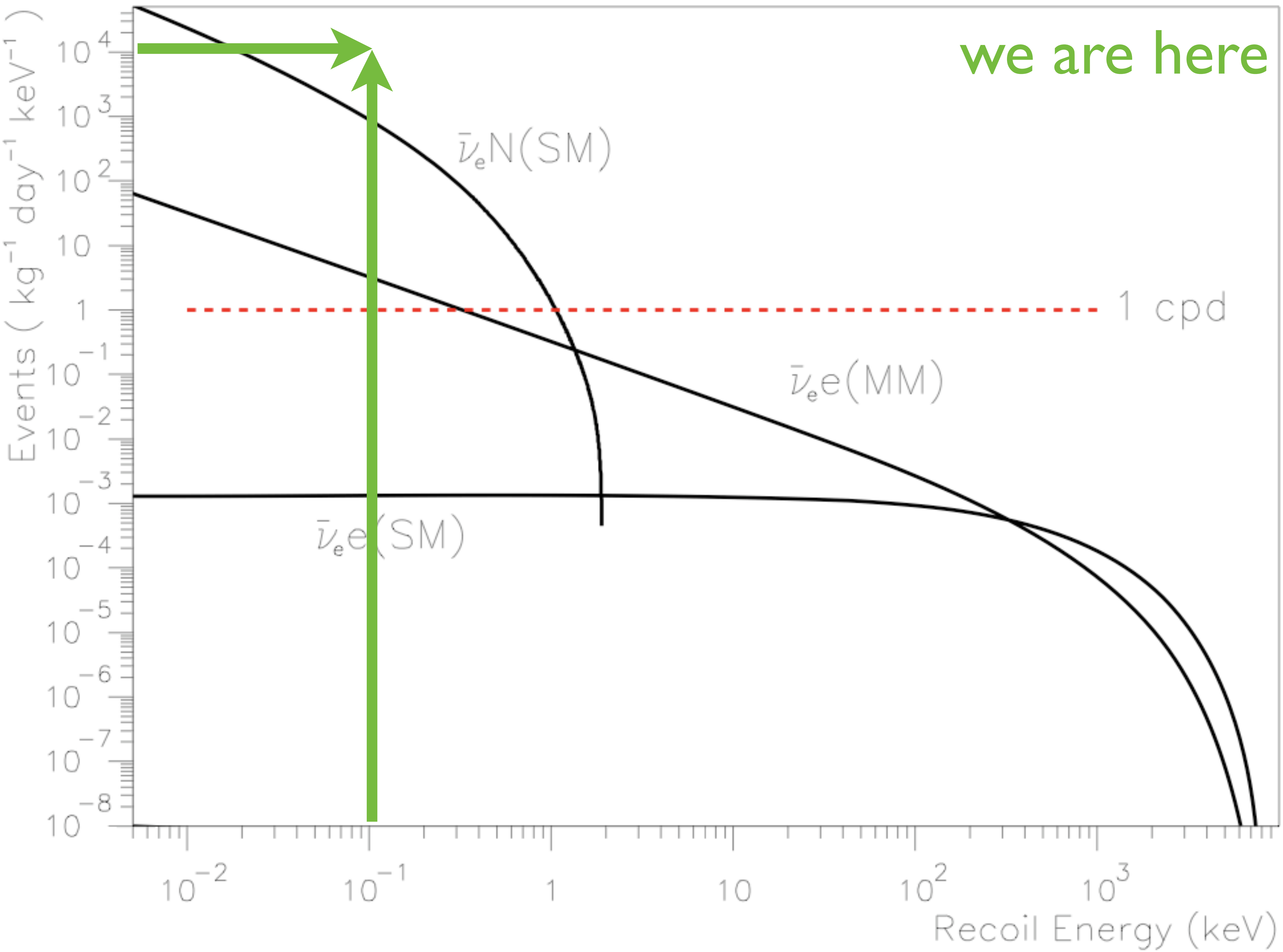
Next: New dewar!



8 CCDs
all services outside shield
better shield to detector mass ratio

also developing lower noise readout.

neutrino coherent scattering spectrum at 28m of a 3GW reactor (Texono Collaboration)



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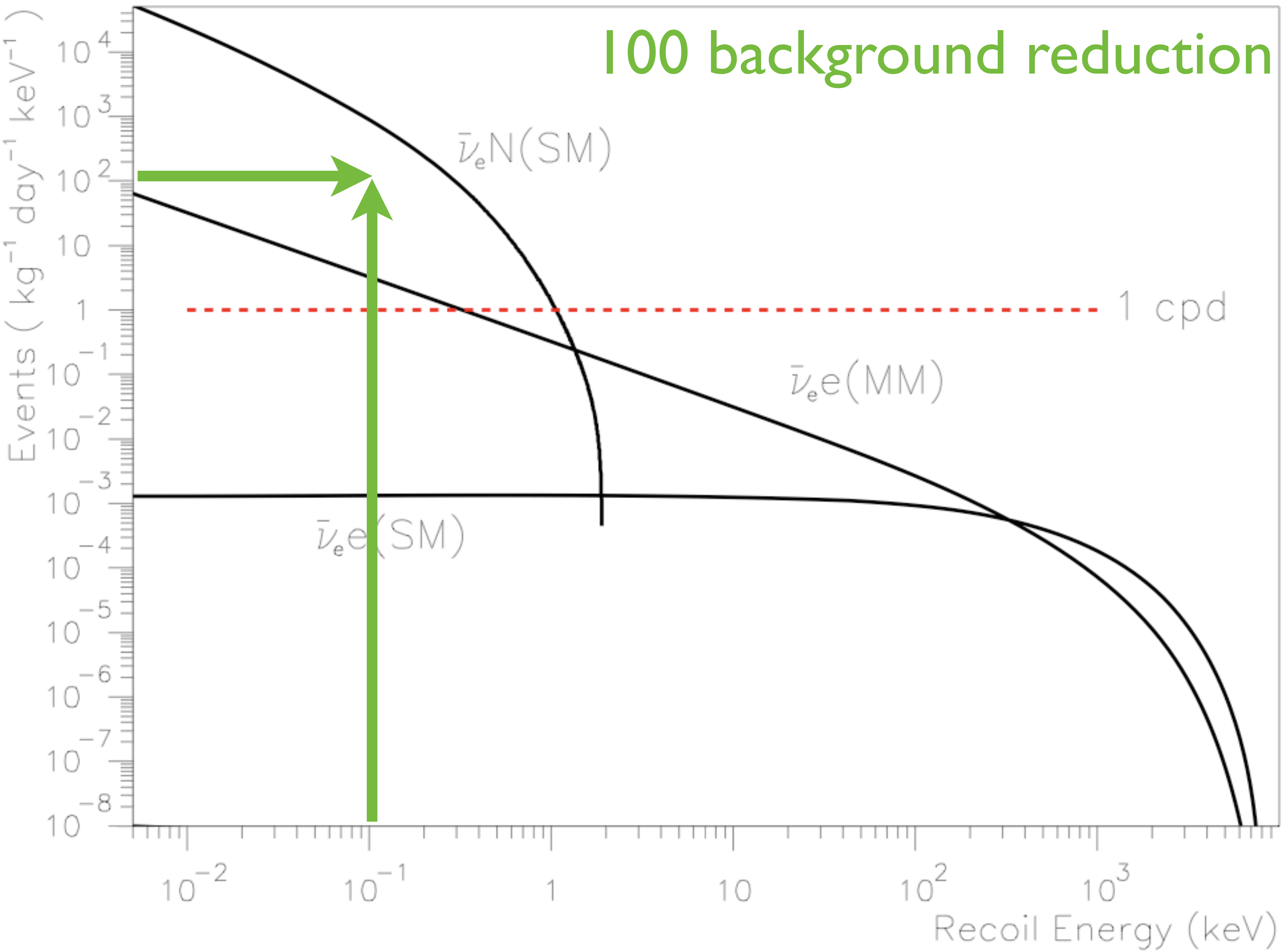

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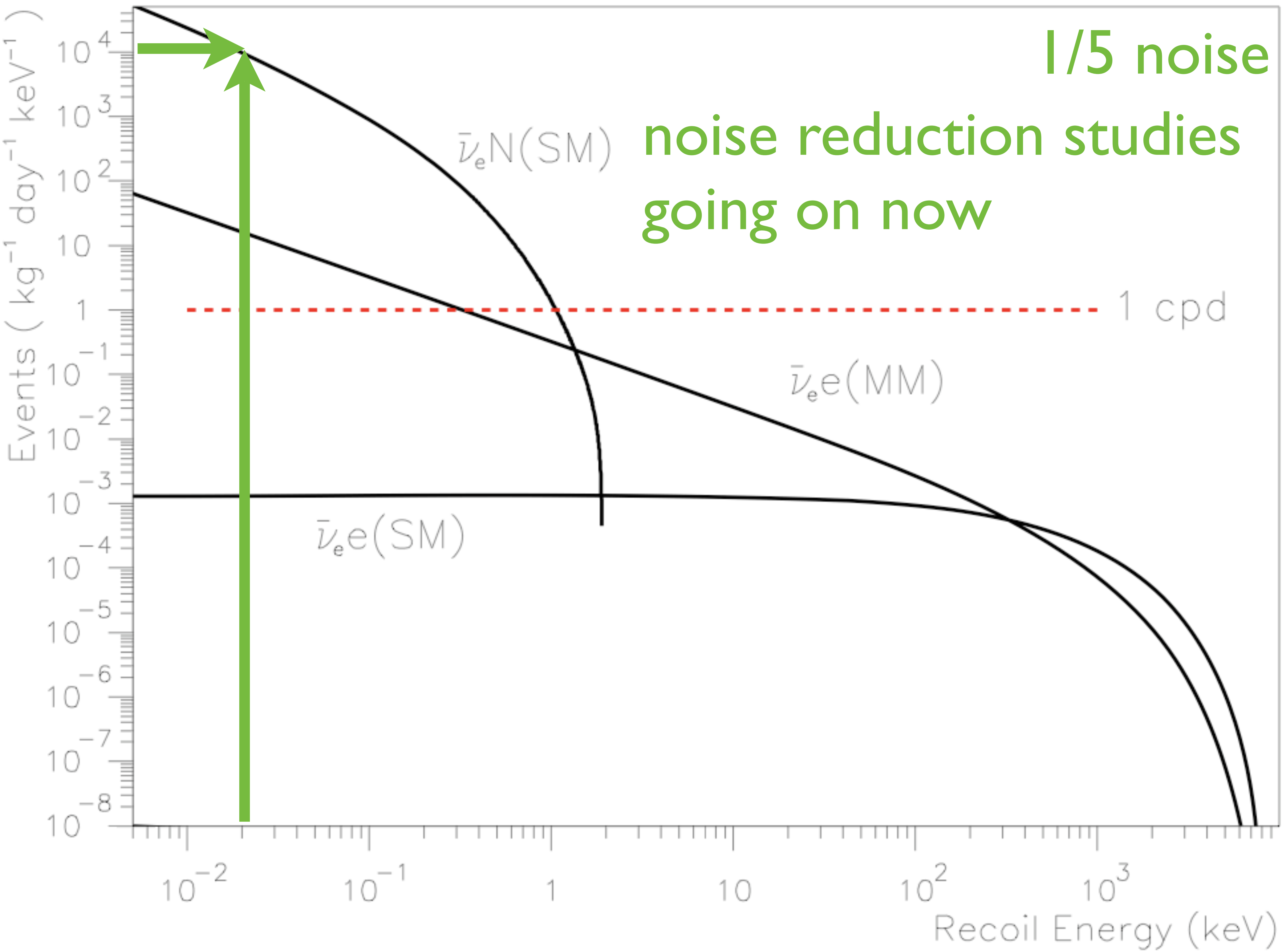


conclusion

- DM search with low noise CCDs starting to look interesting at FNAL.
- First results encouraging.
- Should be able to reduce x100 the background with standard methods, and that will make this technique much more powerful (new dewar)
- possible application for neutrino detection
- keep tuned for results on development of "zero" noise readout system.

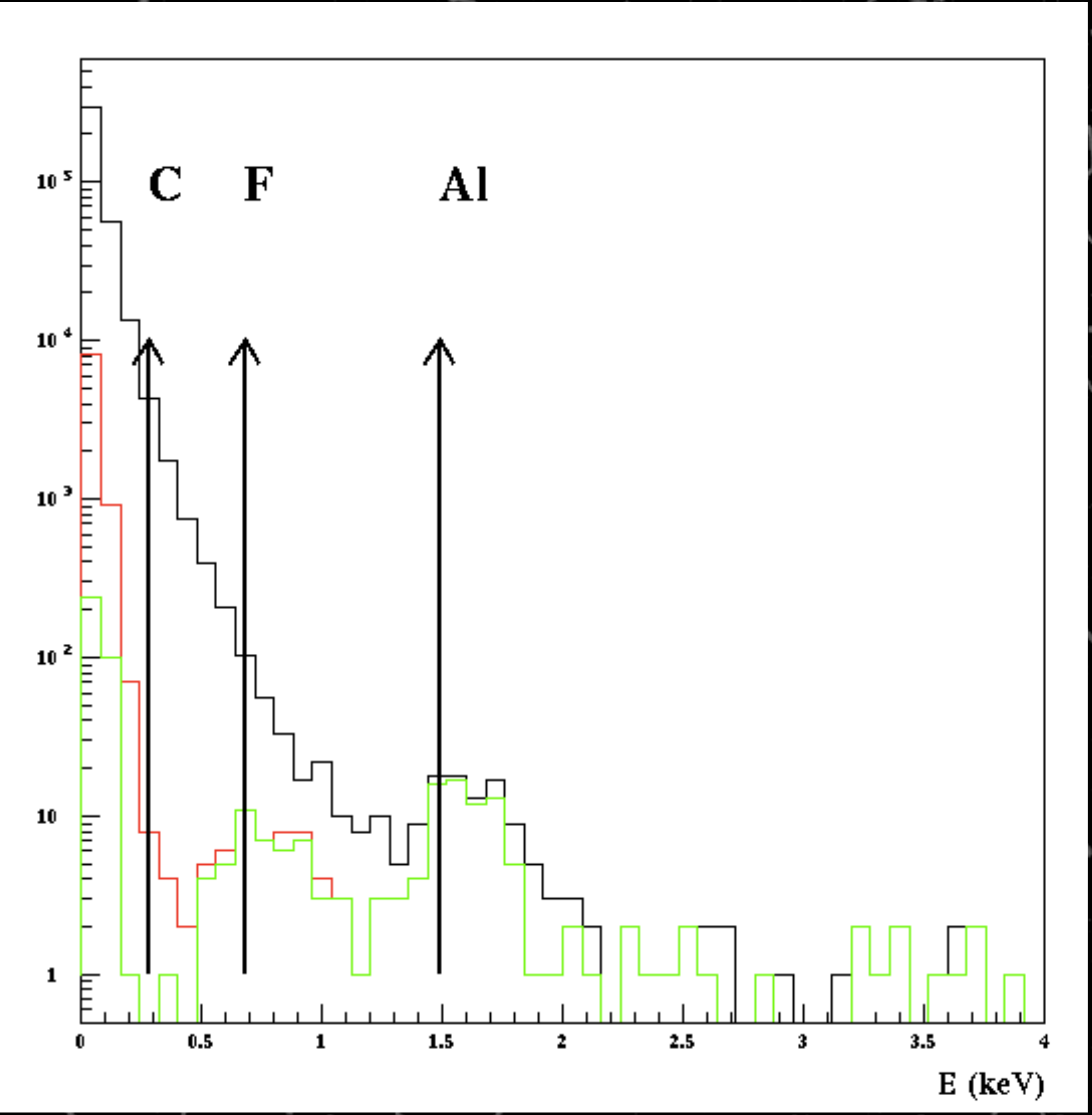
backup

lower energy more X-rays

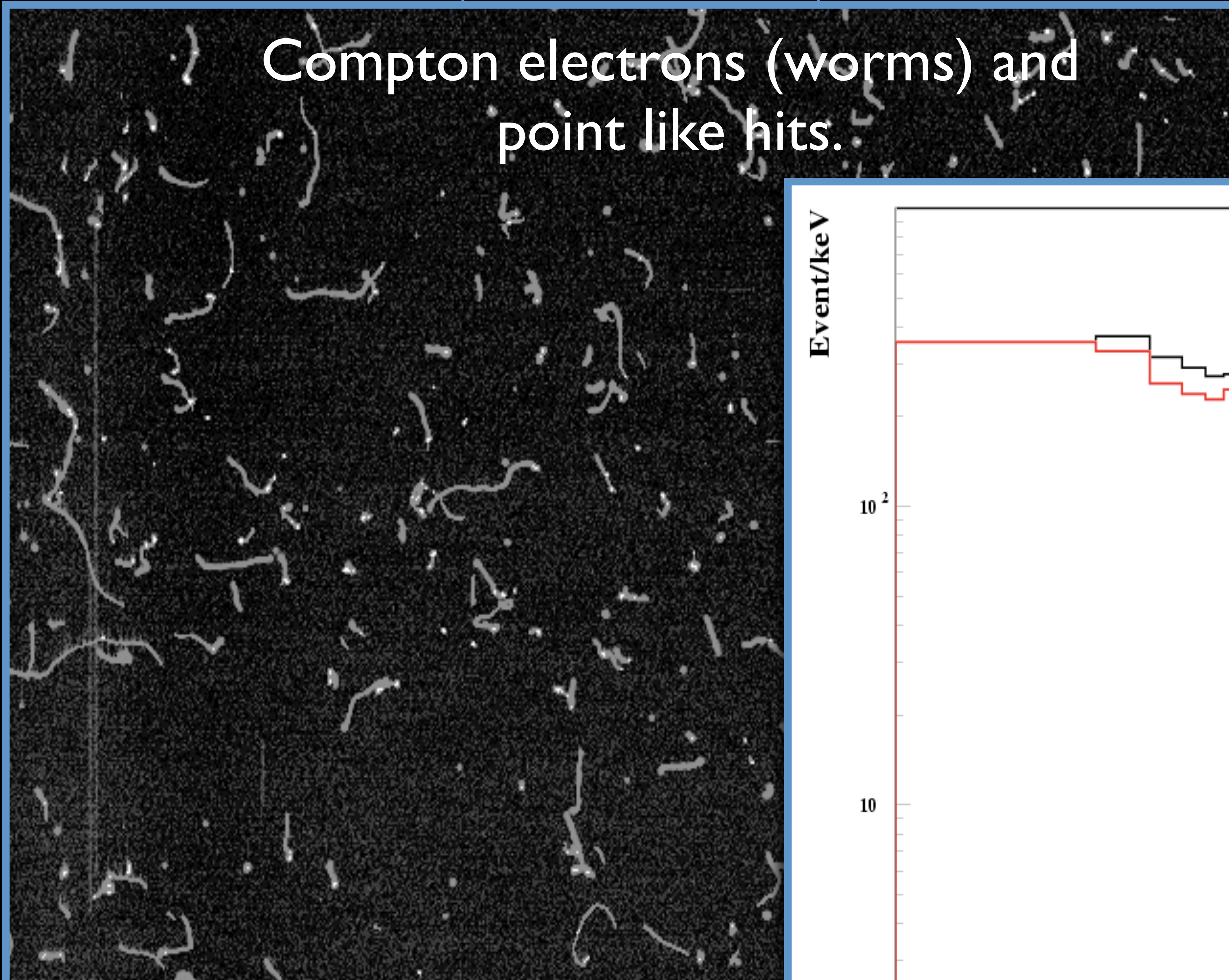
With the Fe55 X-rays hit a teflon or Al and produce lower energy X-rays for study of the diffusion in the first few microns on the back side (important for UV image quality)

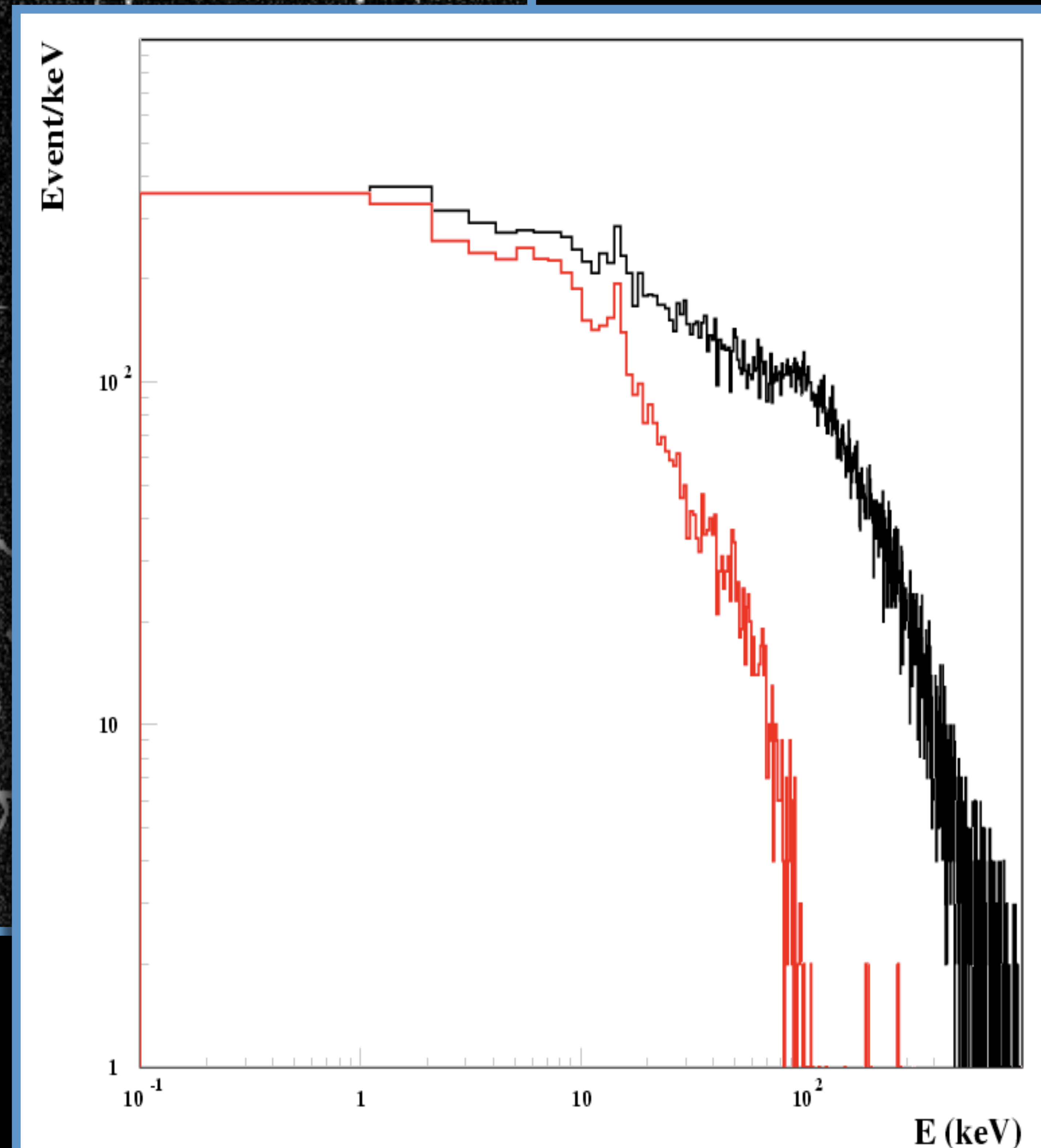
expected lines:

C =0.28 keV (not seen)
F =0.68 keV
Al =1.49 keV

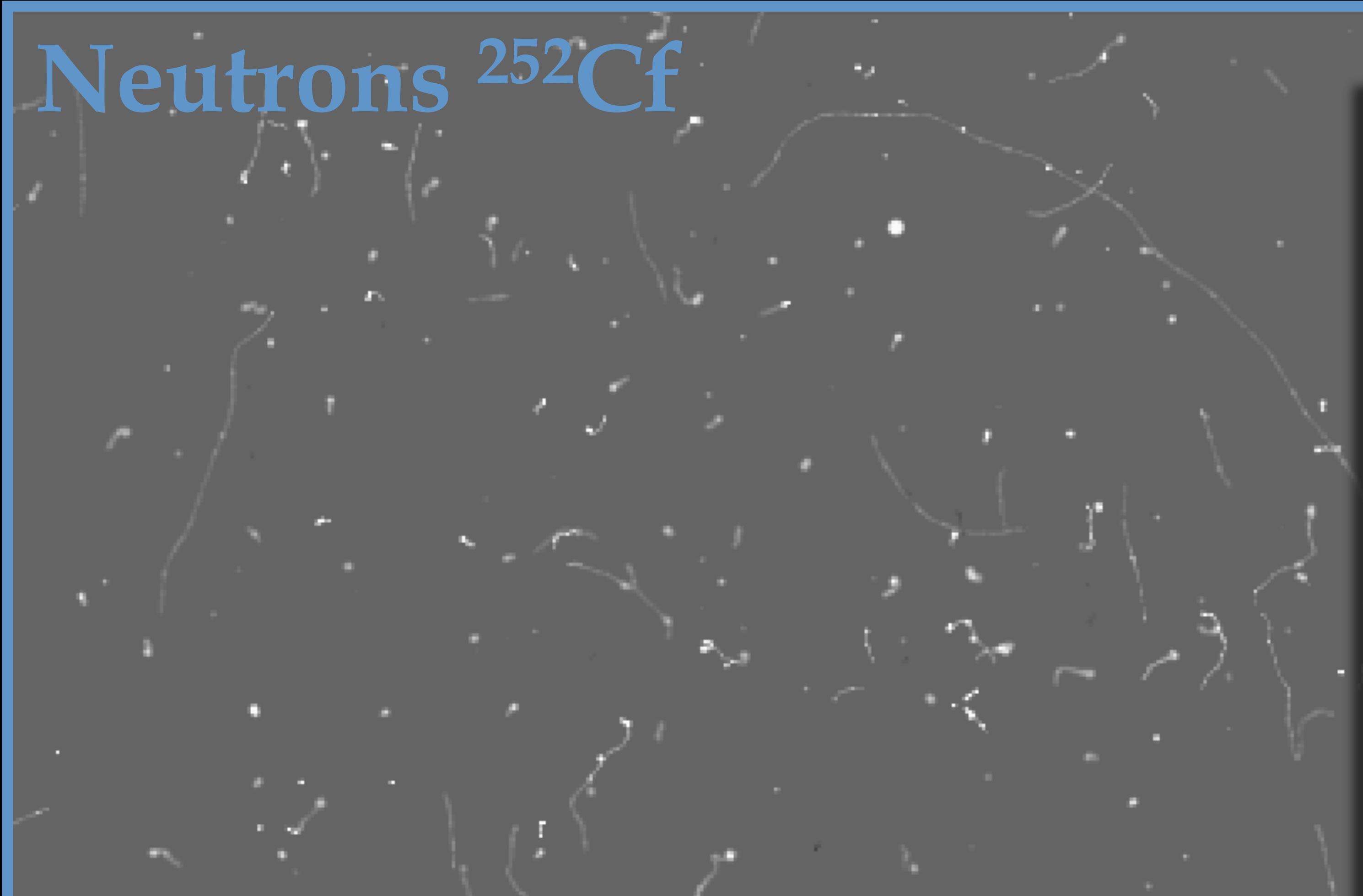


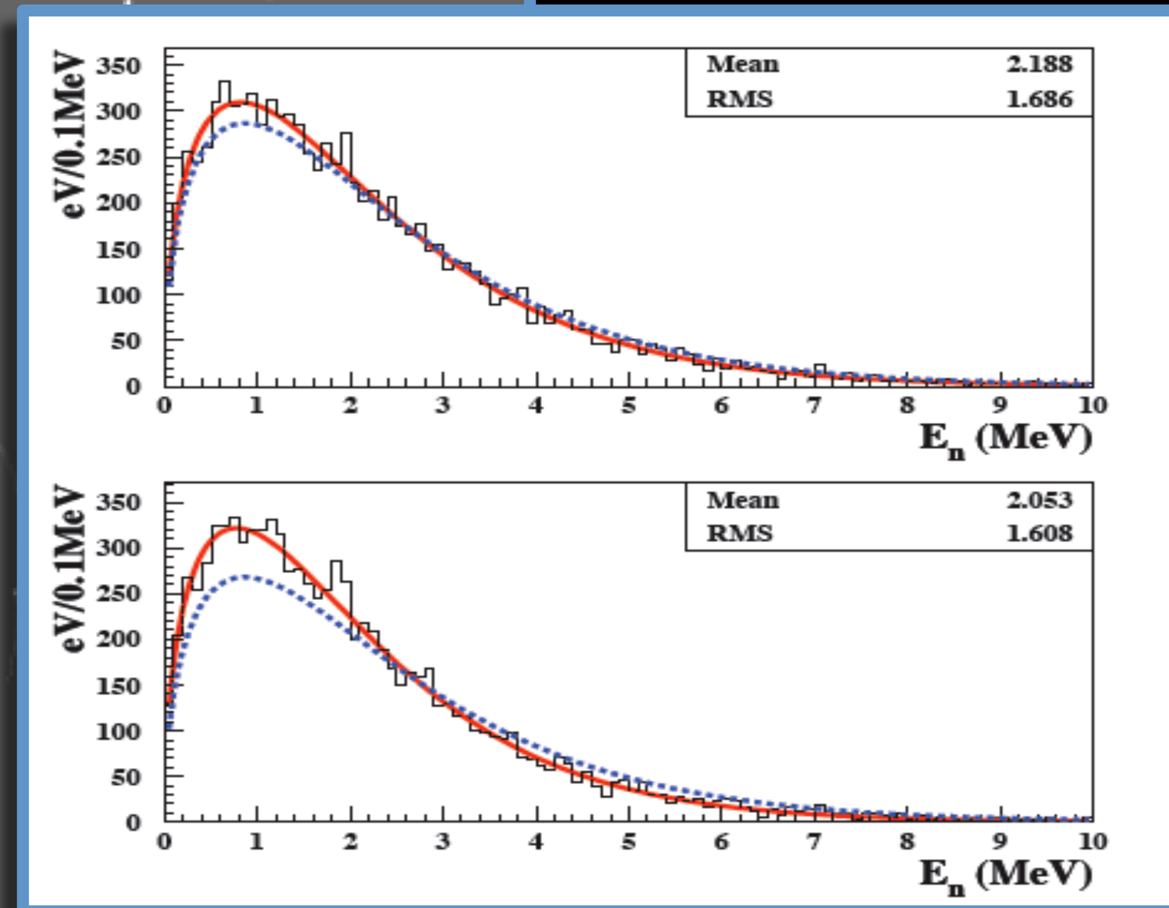
Gammas ^{60}Co (1.33 & 1.77 MeV)

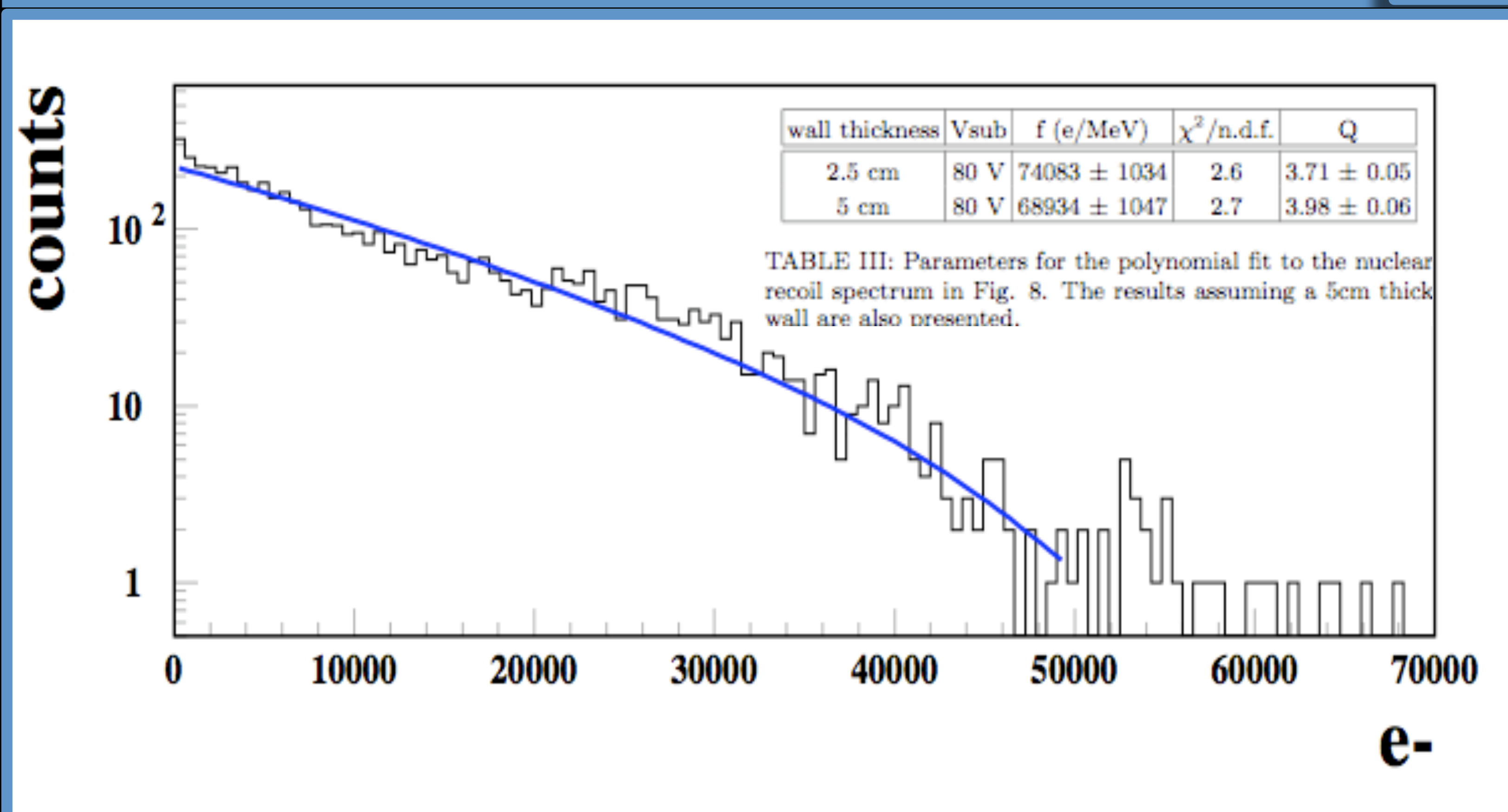




"Calibration" with Neutrons (quenching)

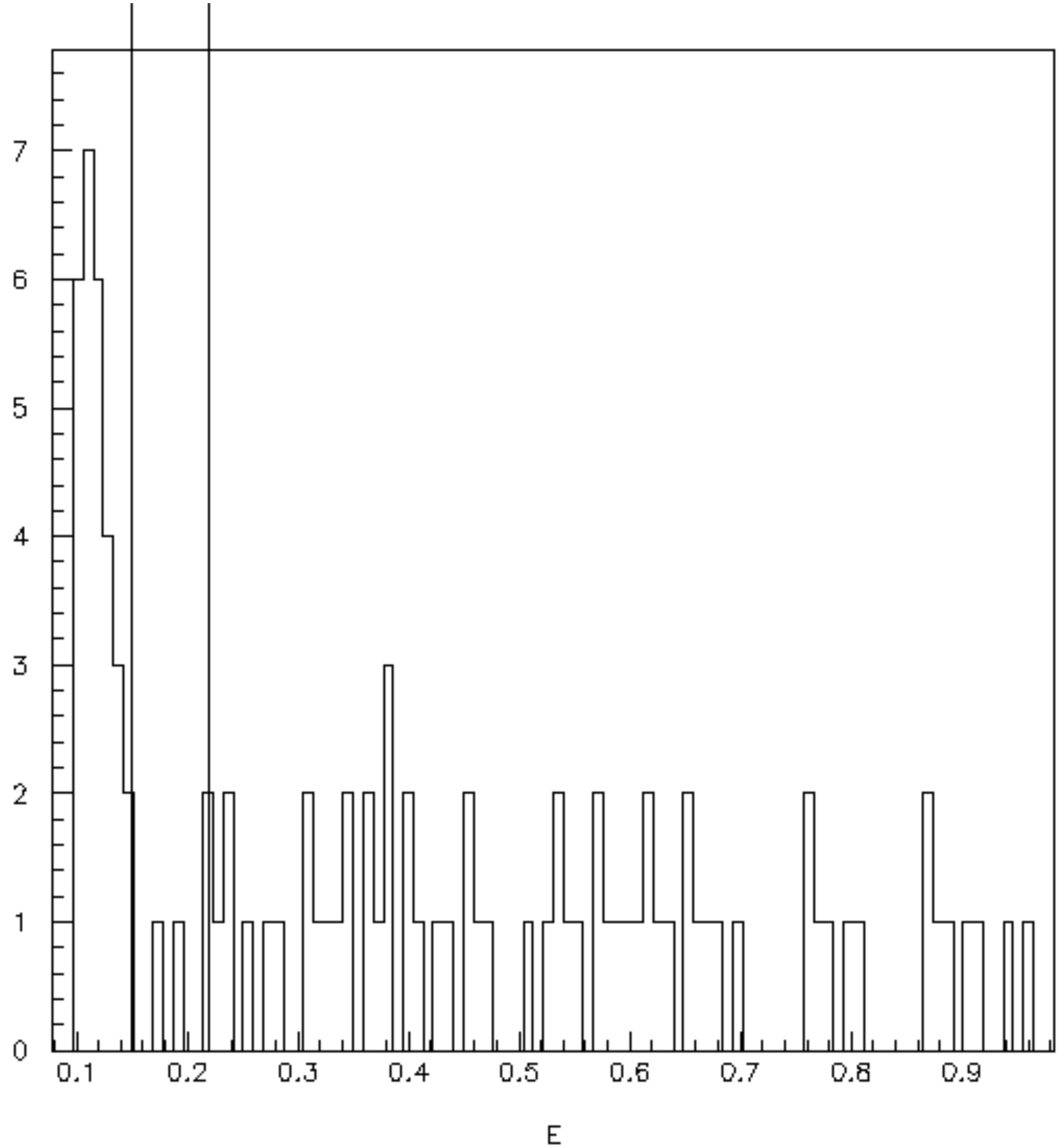






Nuclear recoils have different charge yield than photons. New calibration required.

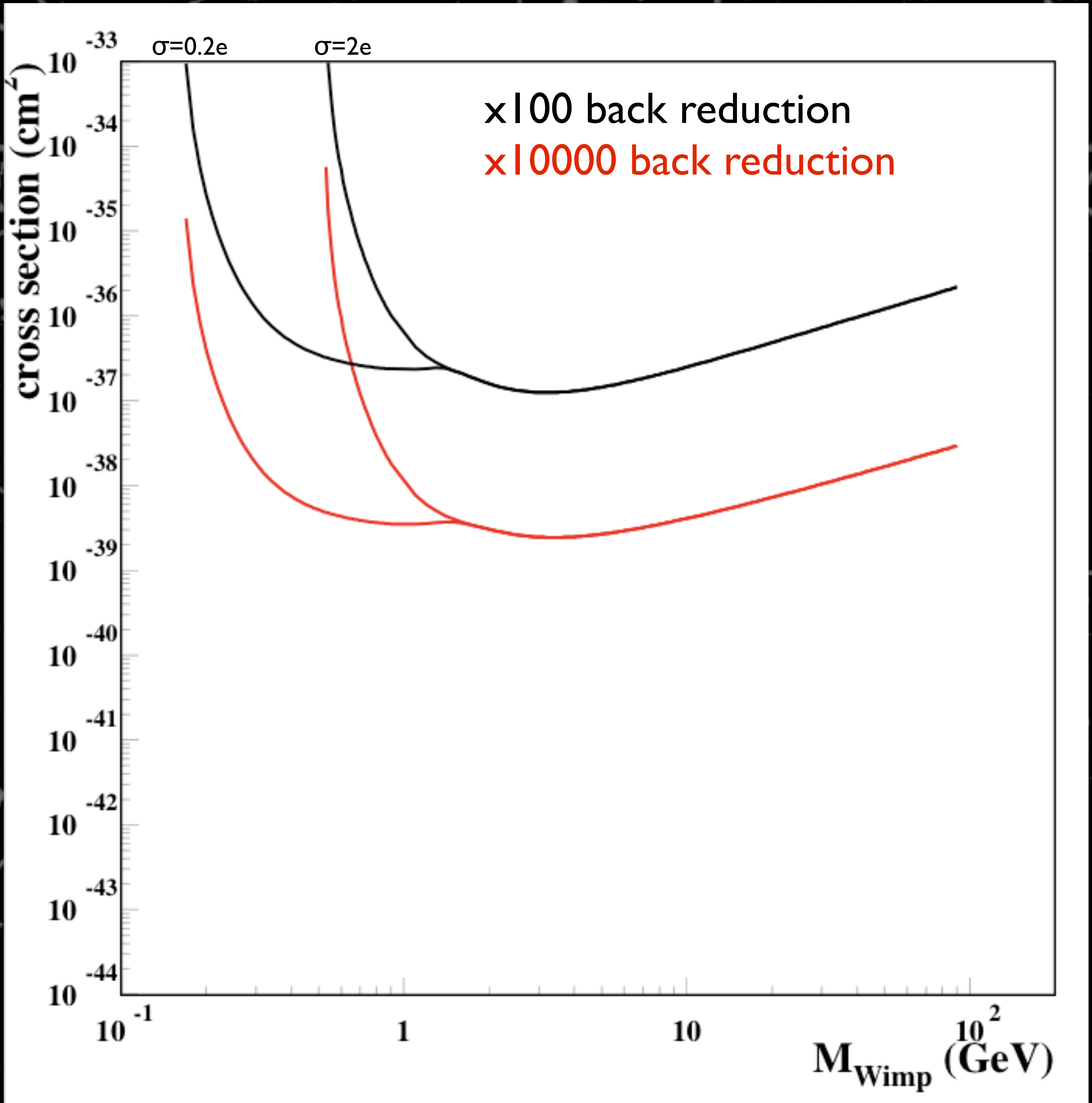
We measured nuclear recoils from a neutron source and fitted an ionization yield of ~13.9 eV/e- . This is not a real calibration because we can not fit the energy dependence of this yield, but the result is consistent with previous work.



optimal interval:

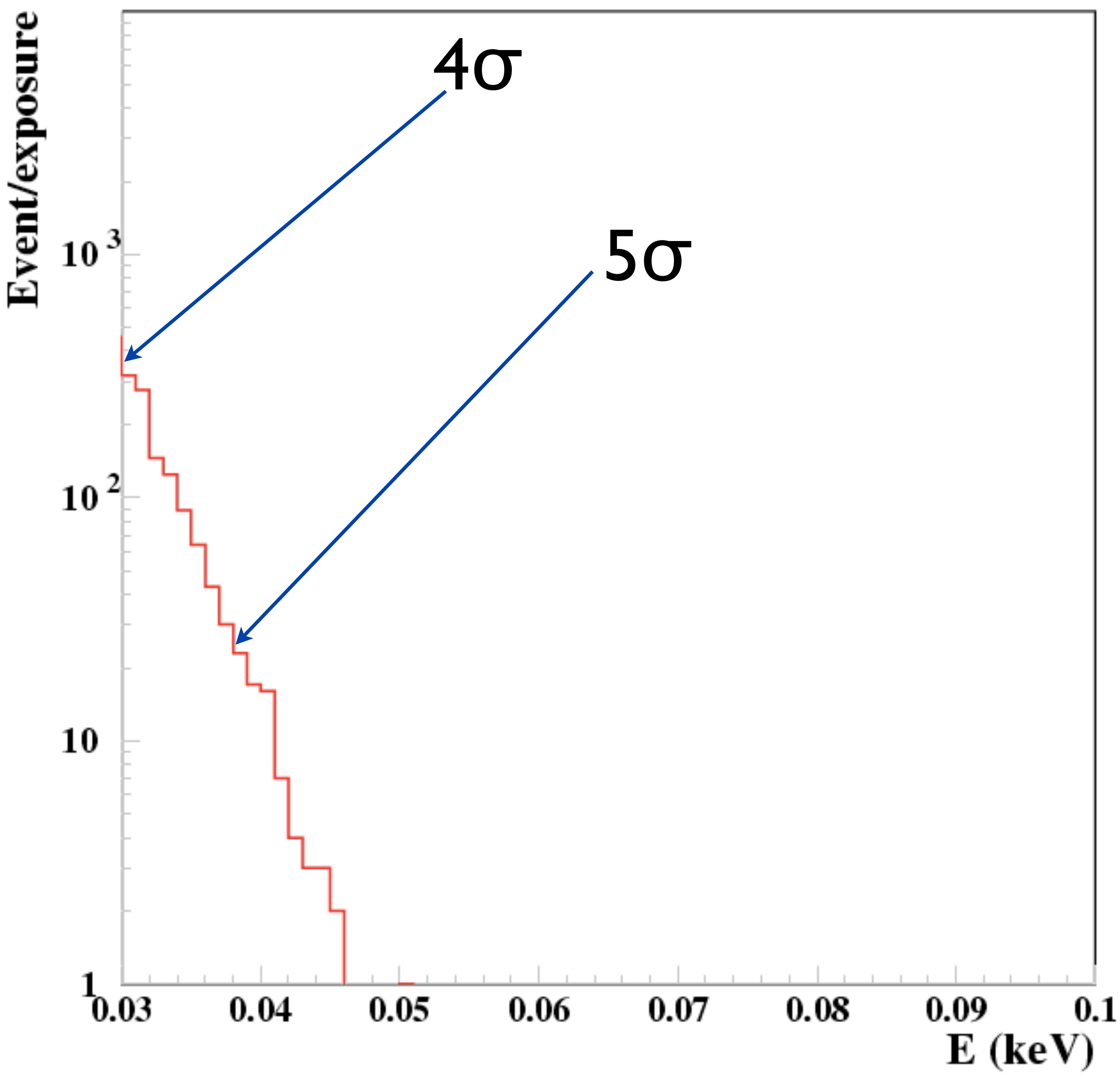
In the plot I am showing you the interval that gives the maximum ratio for 1 GeV mass. The 90% C.L. limit for the mean number of events in this interval is 5.3. For a wimp sigma=1e-39 cm2 you expect 0.035 events in this interval, and that is why the limit is about 1E-37 cm2.

Prospects



σ=0.2e
σ=2e
x100 back reduction
x10000 back reduction
cross section (cm²)
M_Wimp (GeV)

noise per exposure



$\sigma \sim 7.2$ eV
1 image has
4Mpix

Prob(x > 4σ) = 3.2E-5
in one image we expect
4E6 x 3.2E-5 = 128 4σ hits
4E6 x 3.8E-7 = 1.5 5σ hits

some evidence of non-gaussian tails.

each exposure is 0.05 g-day for a 4000sec exposure

(noise rate is multiplied by ~2E4/kg-day)

a few hundred exposures to accumulate some mass.