Dark Matter Seach with CCDs - DAMIC

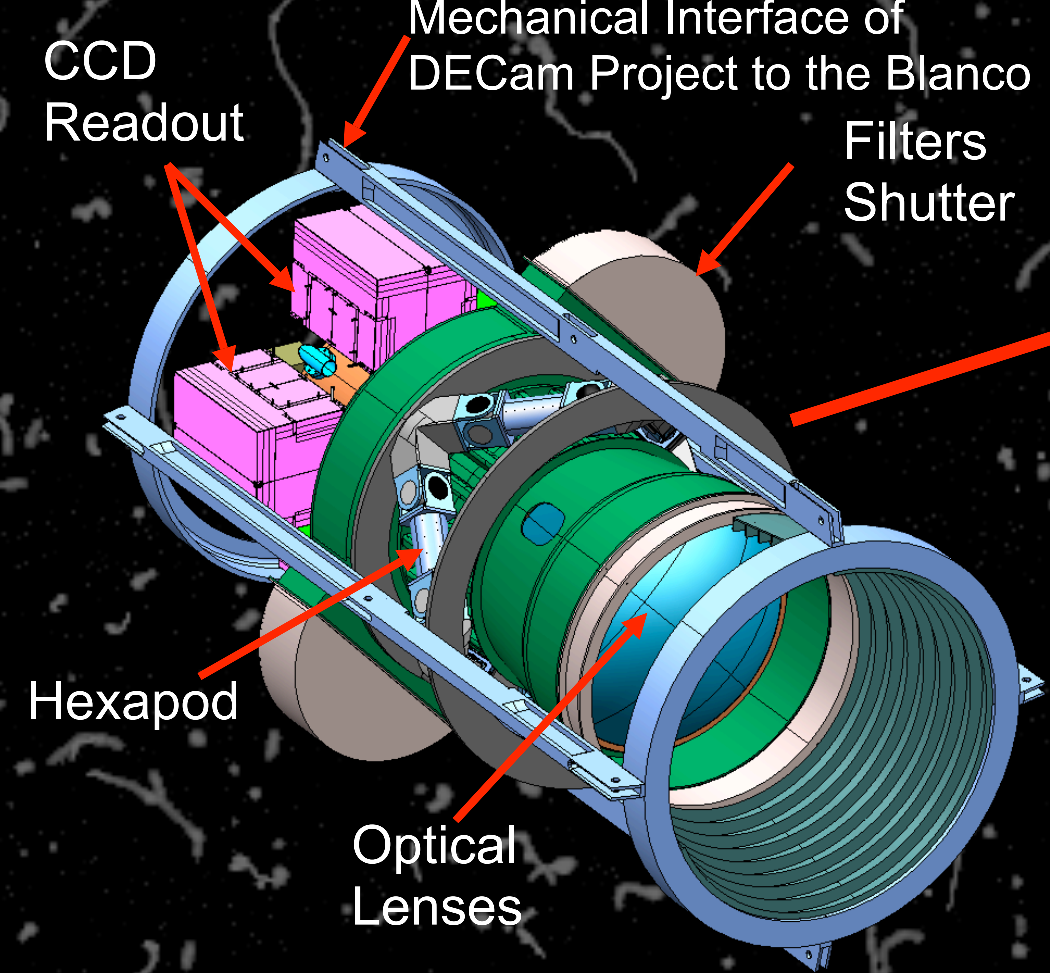
Juan Cruz Estrada - Fermilab

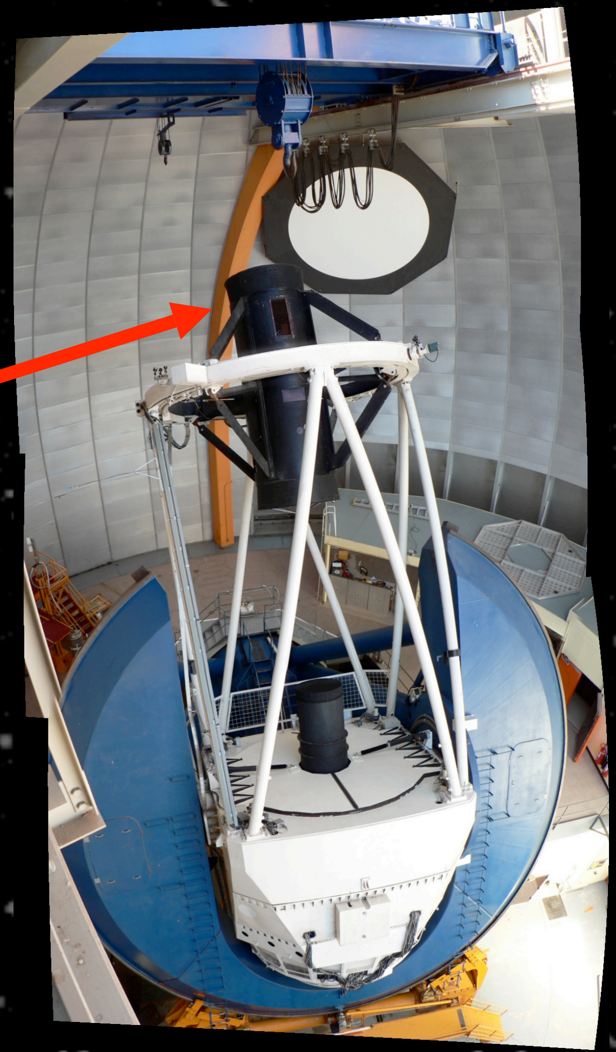
TAUP, July 2009

Rome, Italy

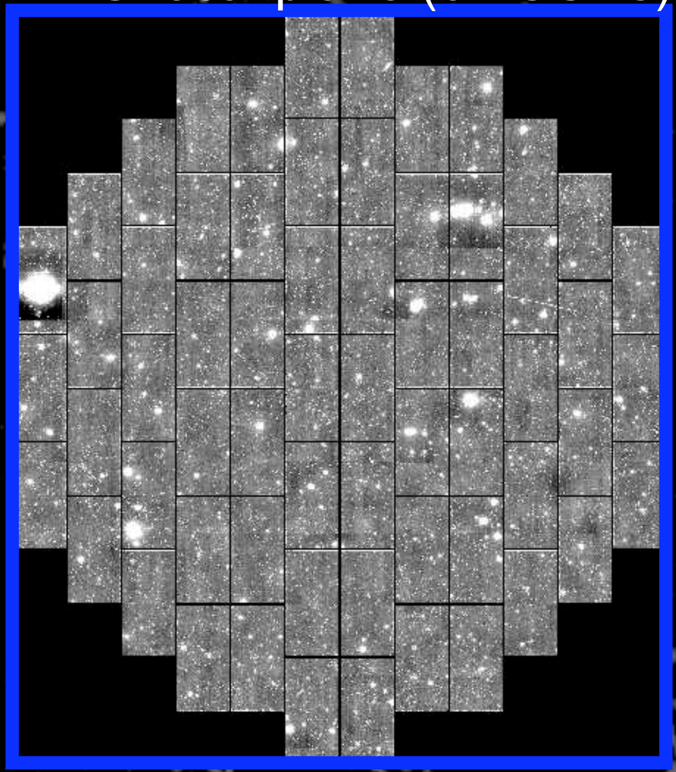
Dark Energy Camera (DECam)

New wide field imager (3 sq-deg) for the Blanco 4m telescope to be delivered in 2010 in exchange for 30% of the telescope time during 5 years. Being built at FNAL.





DES focal plane (62 CCDs)



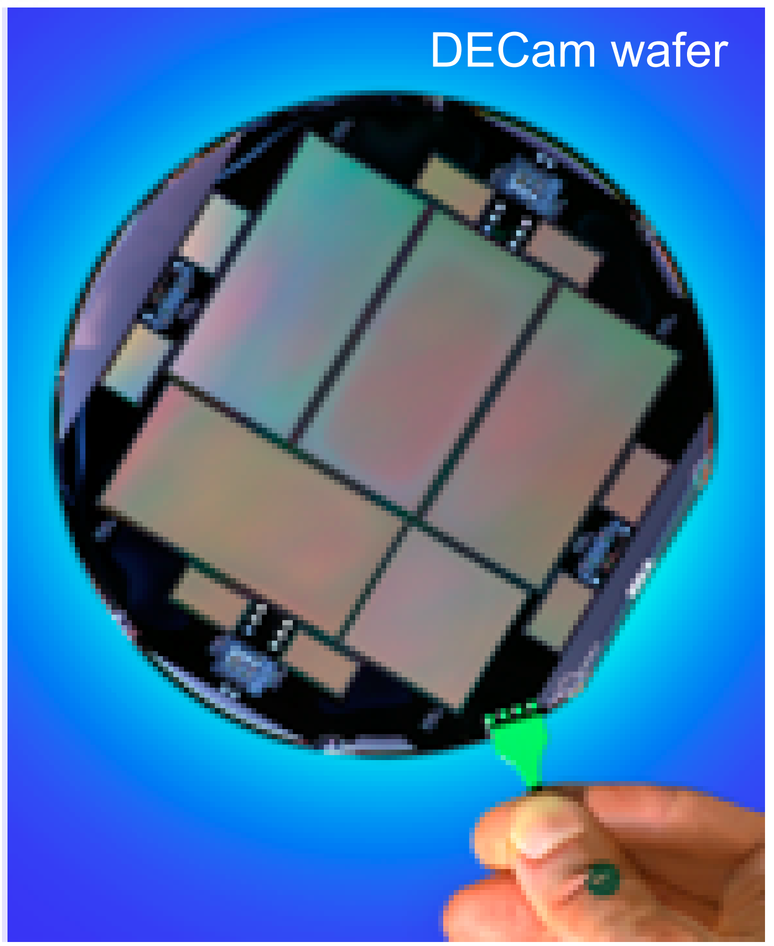
DECam focal detectors

Science goal requires DES to reach z~1

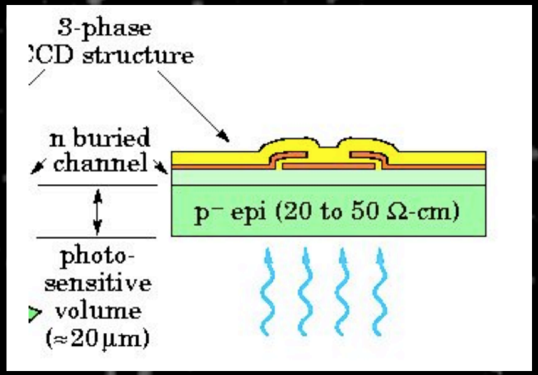
we want to spend ~50% of time in z-filter (825-1100nm)
Astronomical CCDs are usually thinned to 30-40 microns (depletion):
Good 400nm response
Poor 900nm response

LBNL full depletion CCD are the choice for DECam:

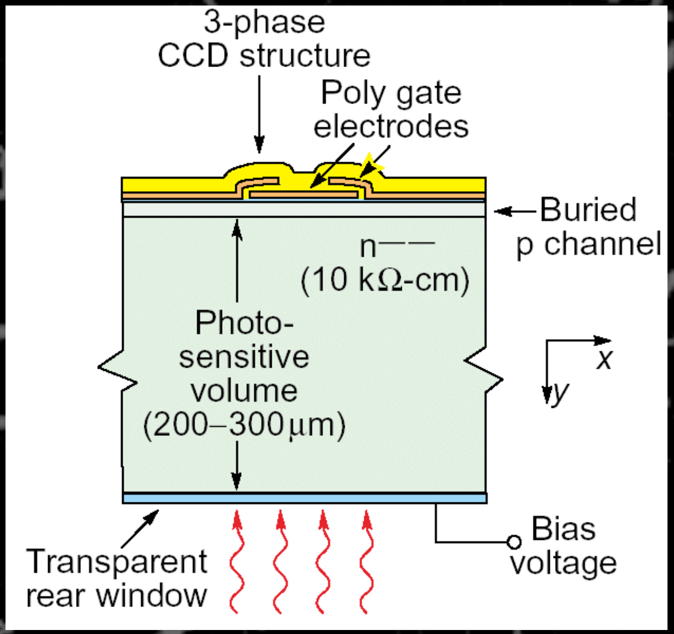
- –250 microns thick
- –high resistivity silicon
- –QE> 50% at 1000 nm



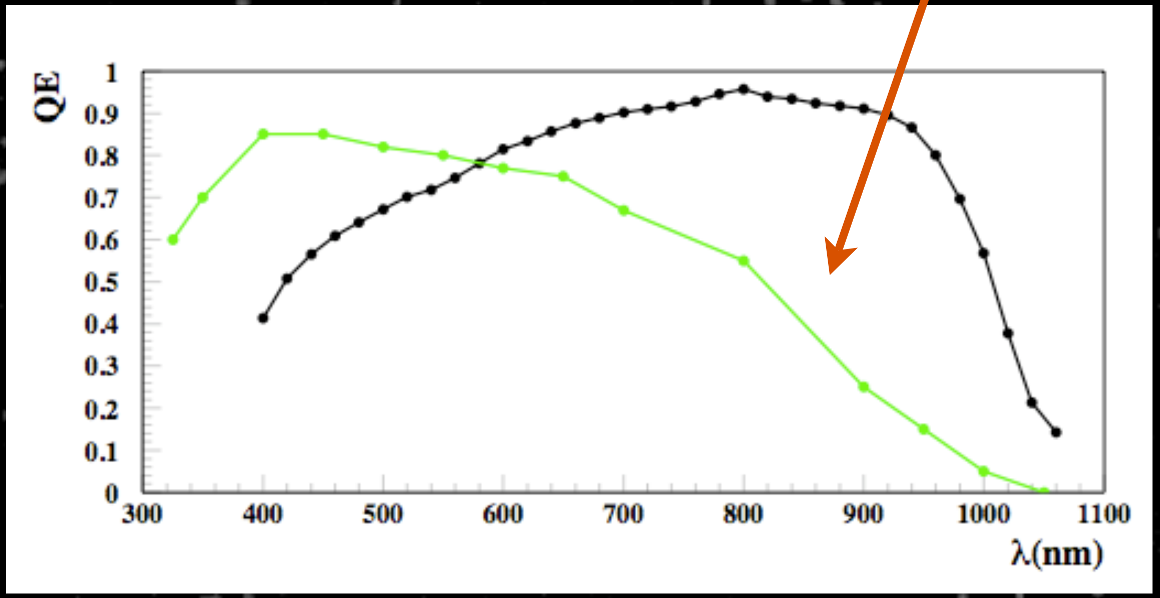
typical CCDs



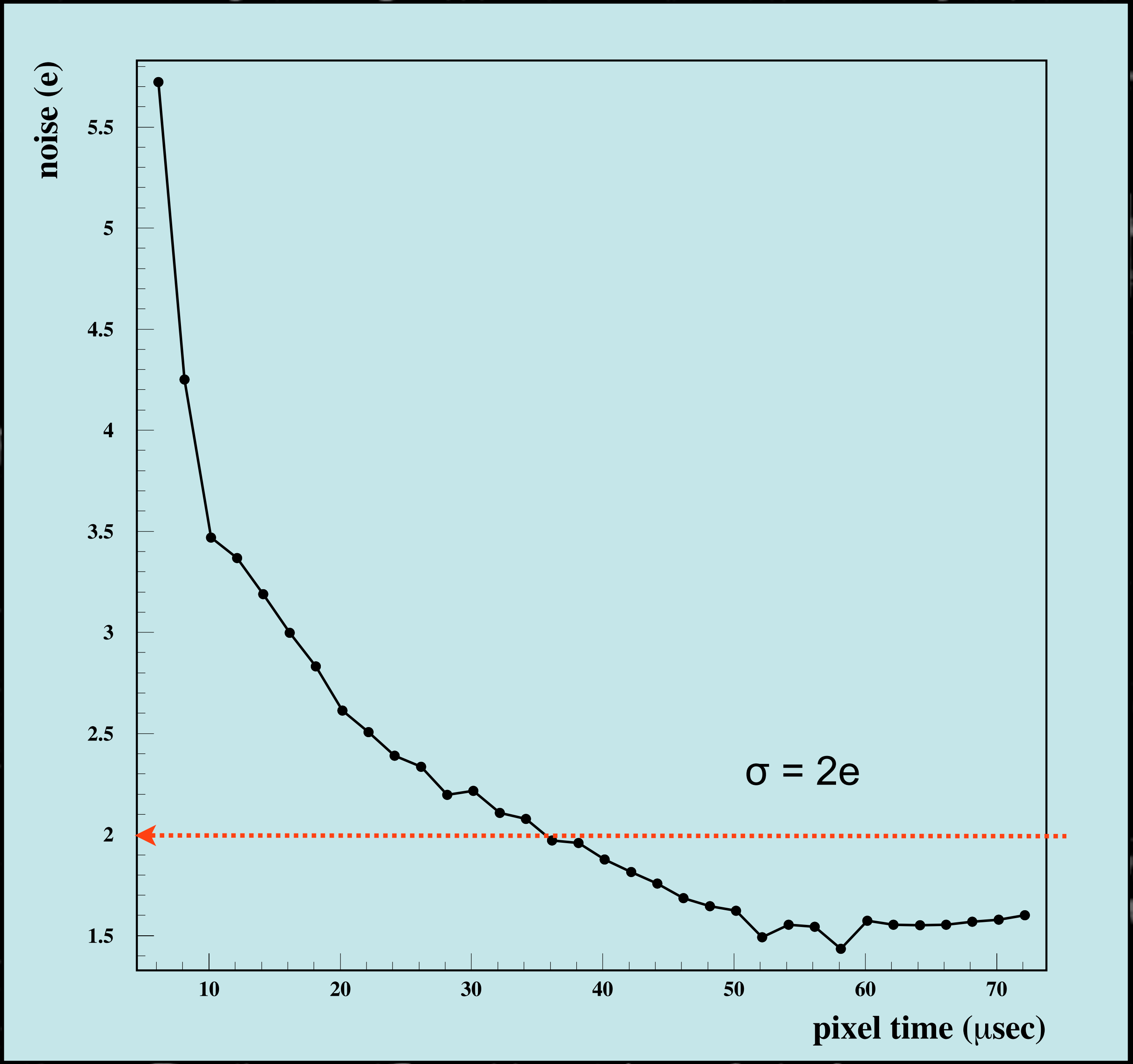
new thick CCDs



higher efficiency for hi-z objects.



New opportunities with these CCDs



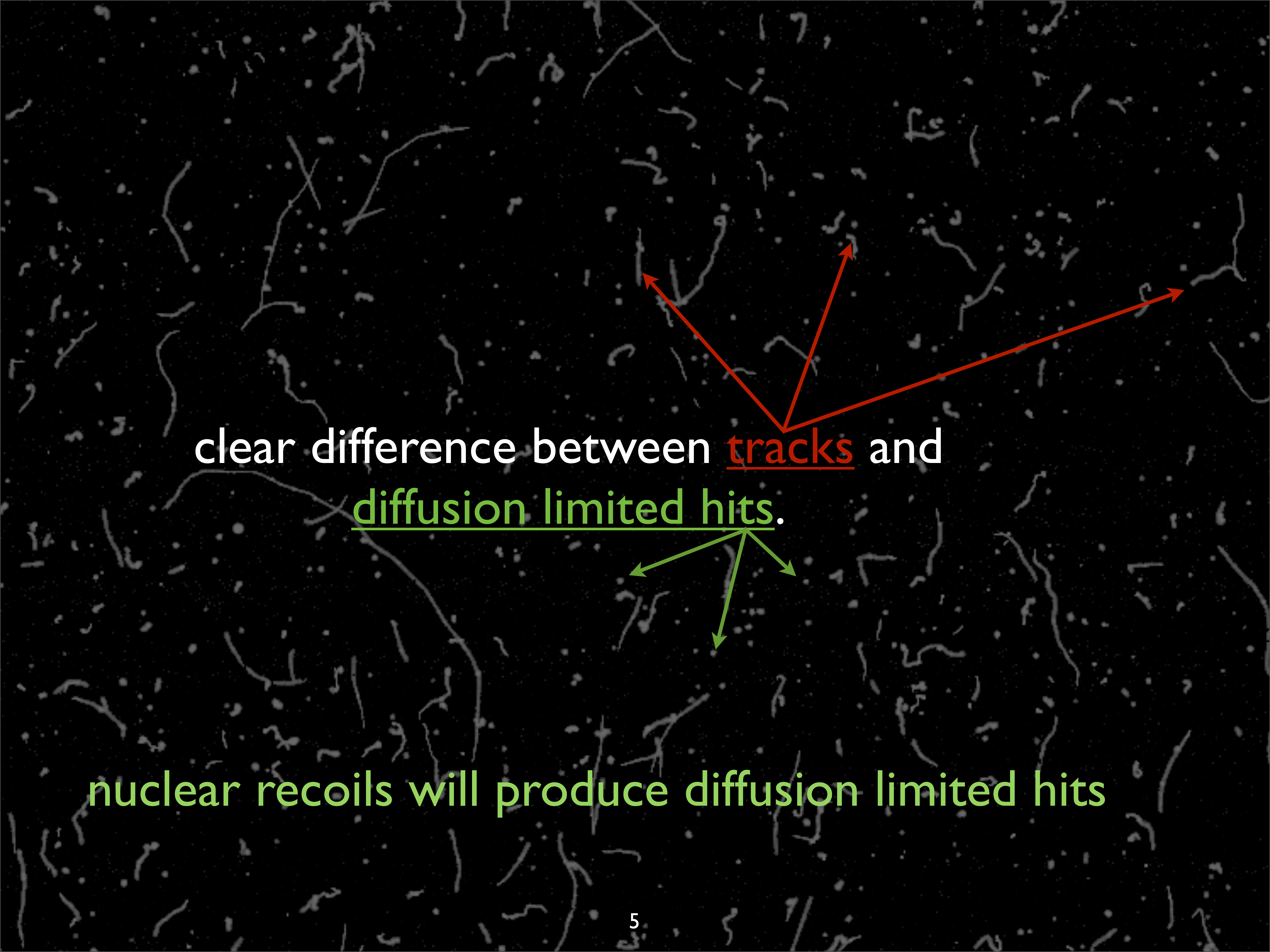
Two features:

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)



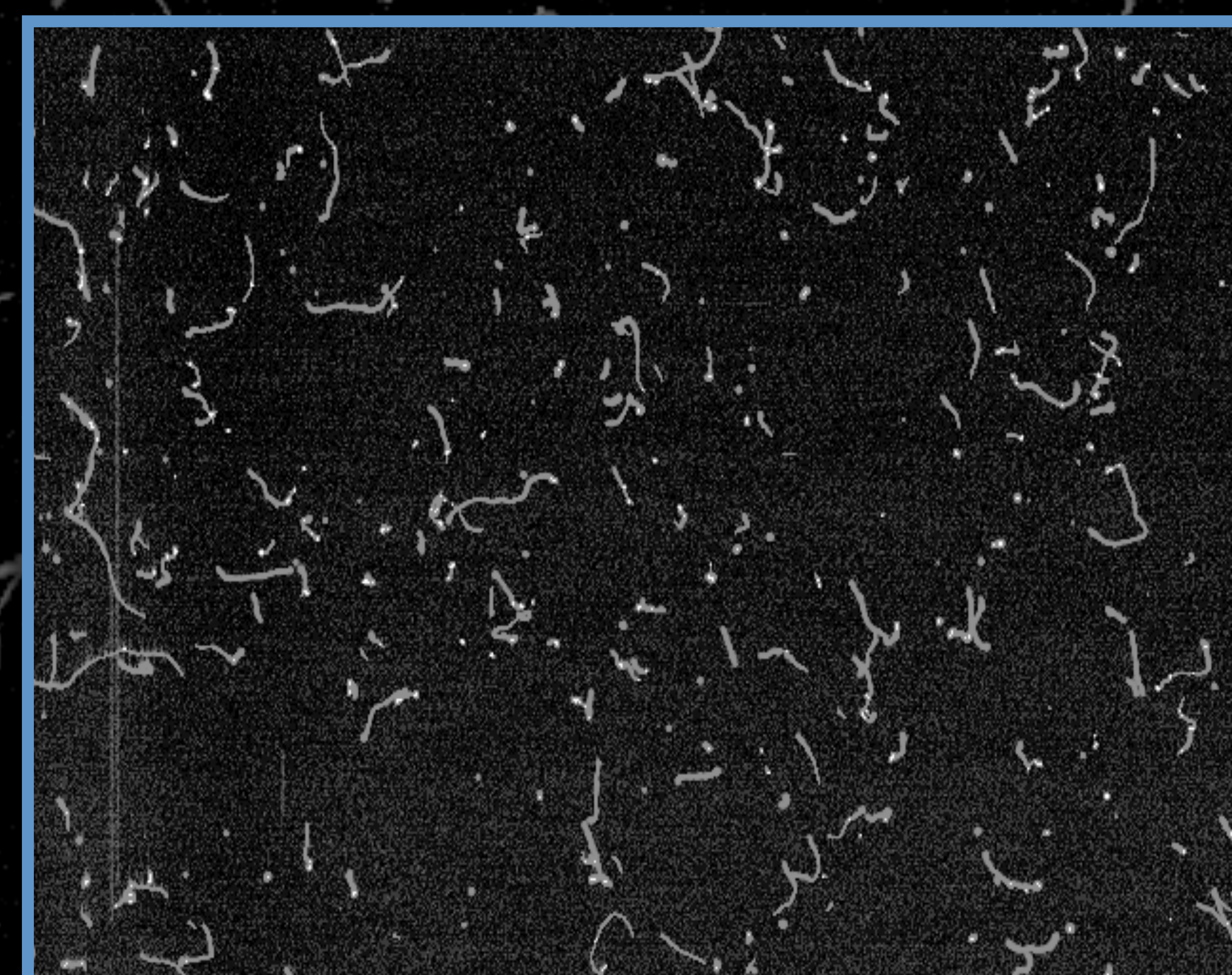
clear difference between tracks and diffusion limited hits.

nuclear recoils will produce diffusion limited hits

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

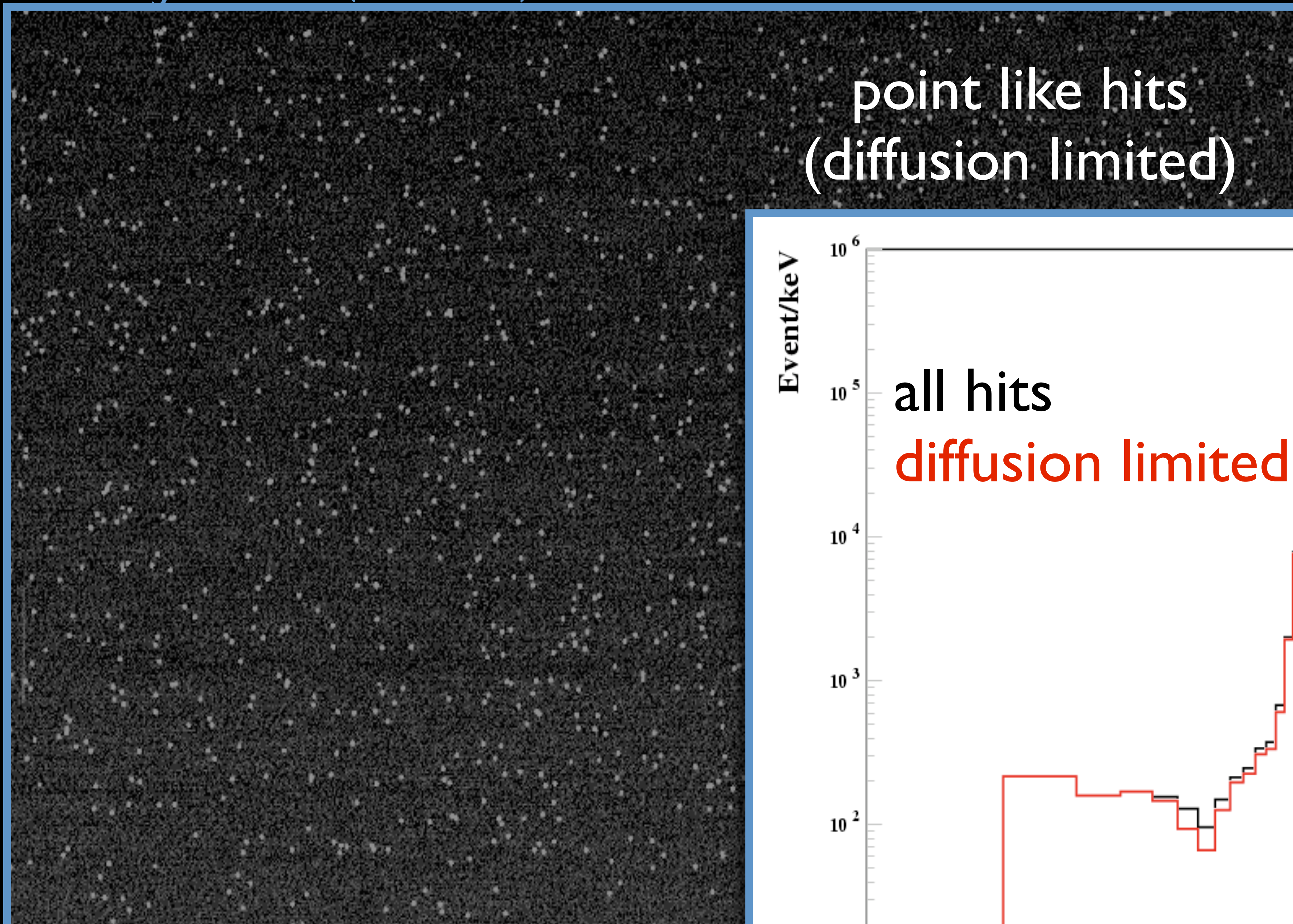
Point like hits
(diffusion limited)

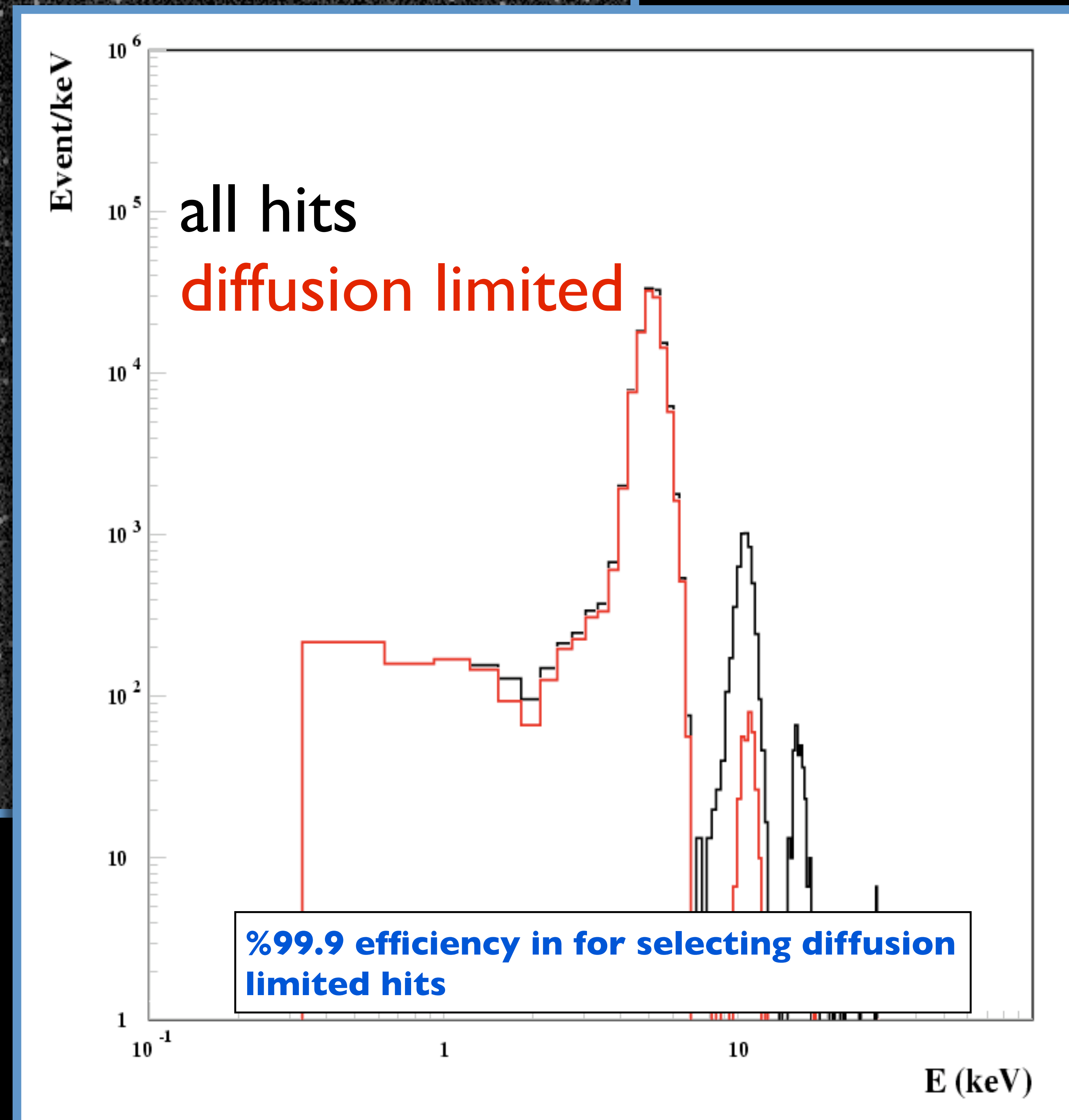
Gammas ^{60}Co (1.33 & 1.77 MeV)



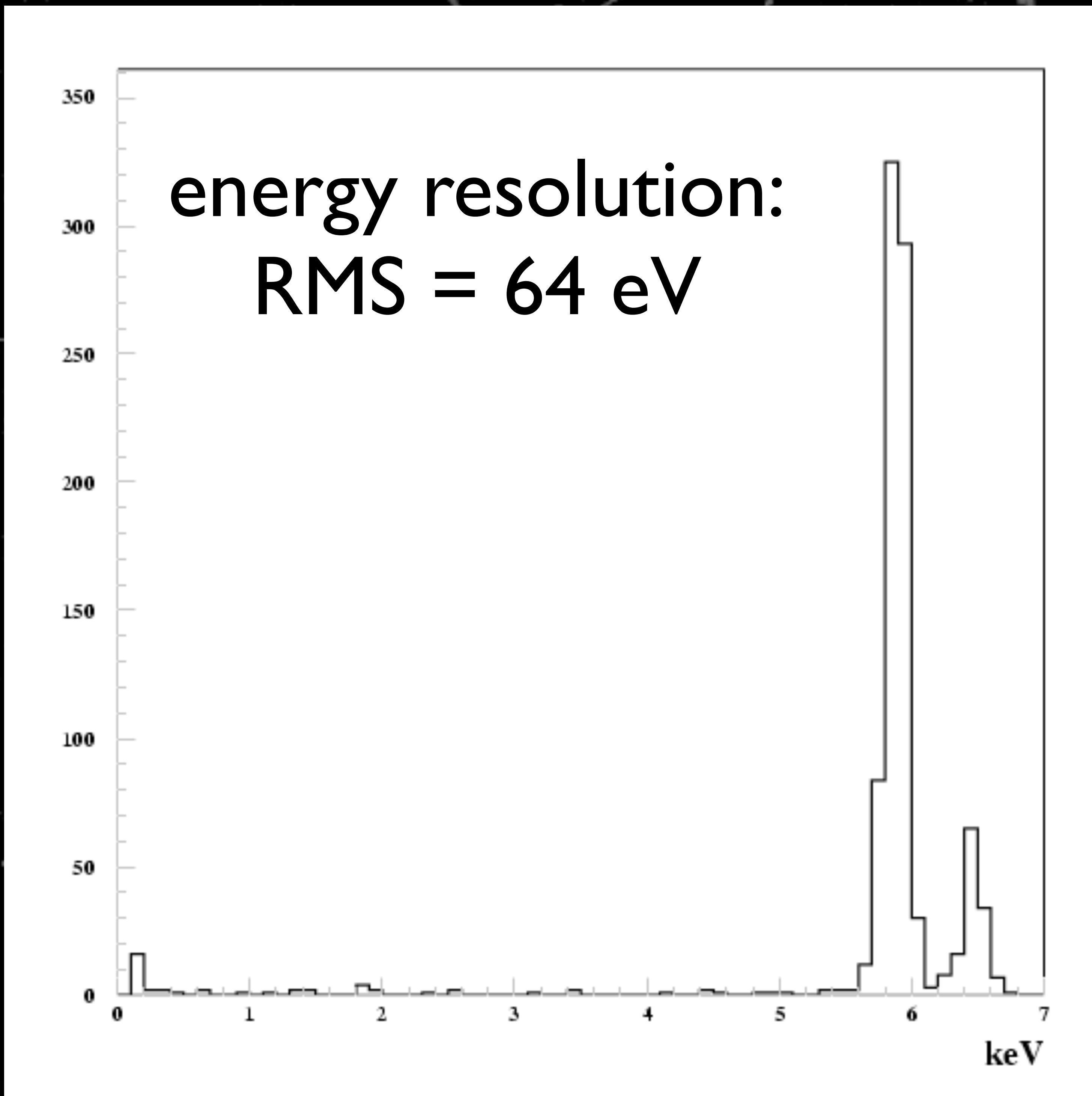
Compton
electrons
(worms) and
point like hits.

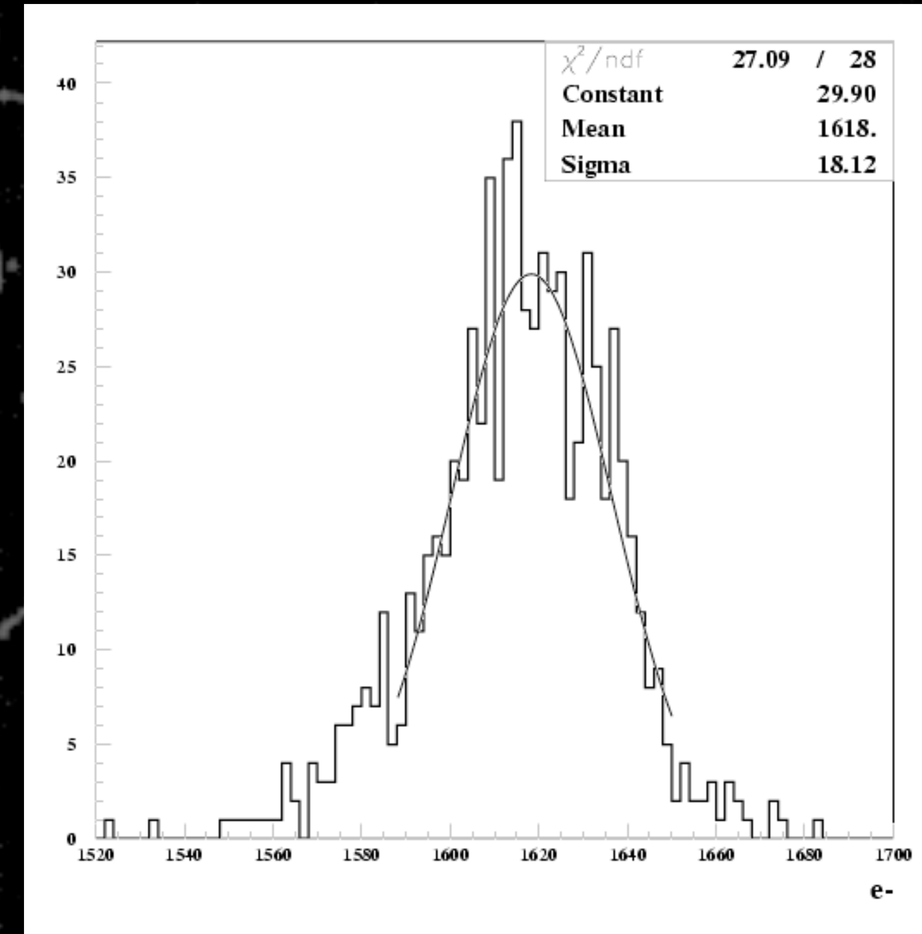
X-ray ^{55}Fe (5.9 keV)





low noise readout for Fe55





effective fano factor:

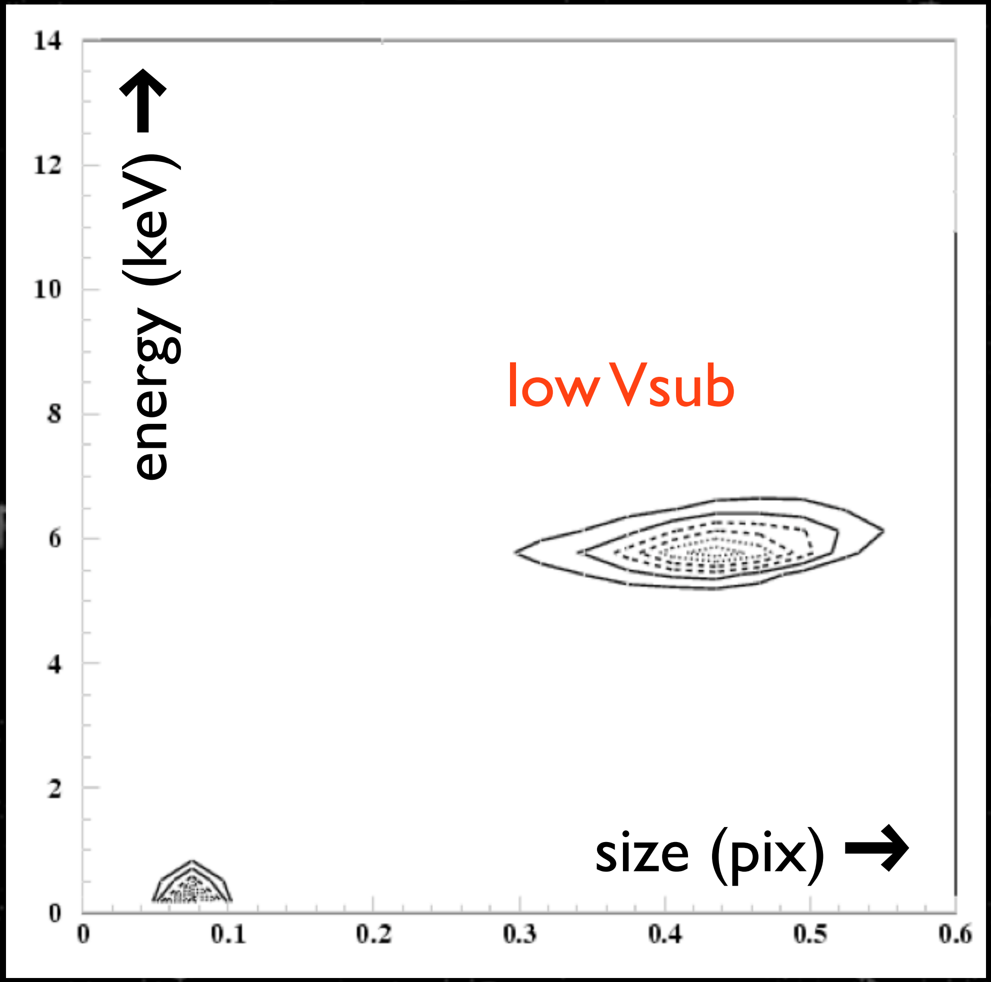
$F^{eff} = (18^2 - 2^2)/1620.$

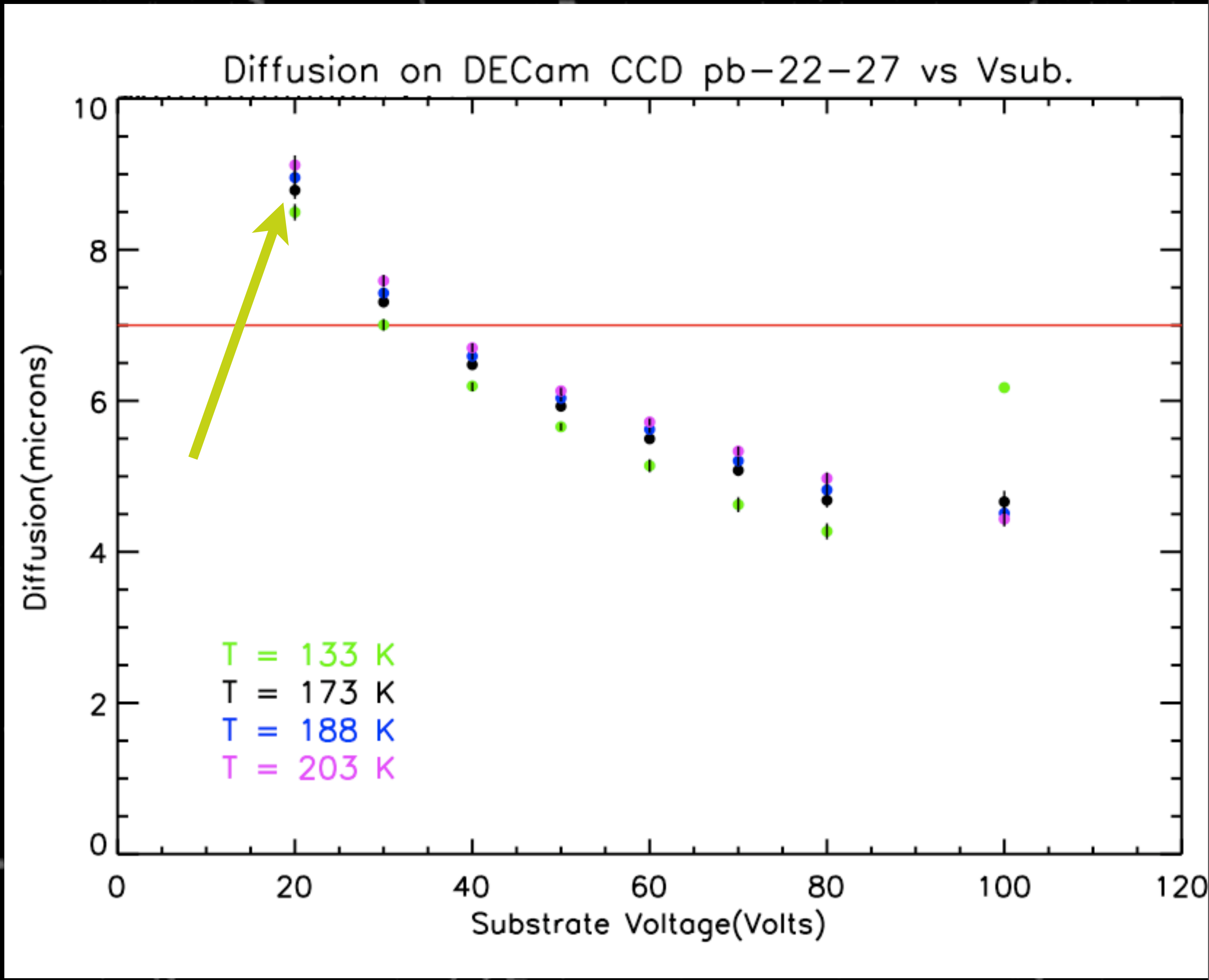
$F^{eff} = 0.17$

this typical for CCDs (CTI, clustering)

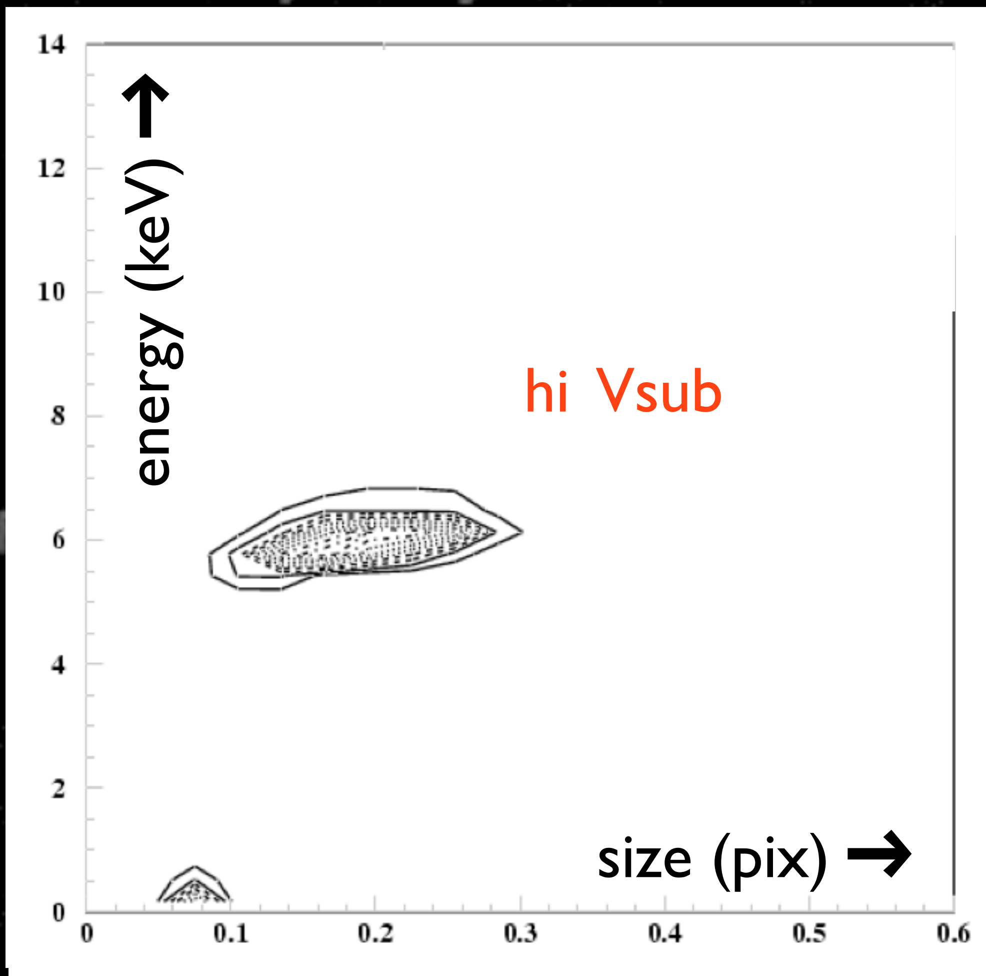
in silicon: 0.10

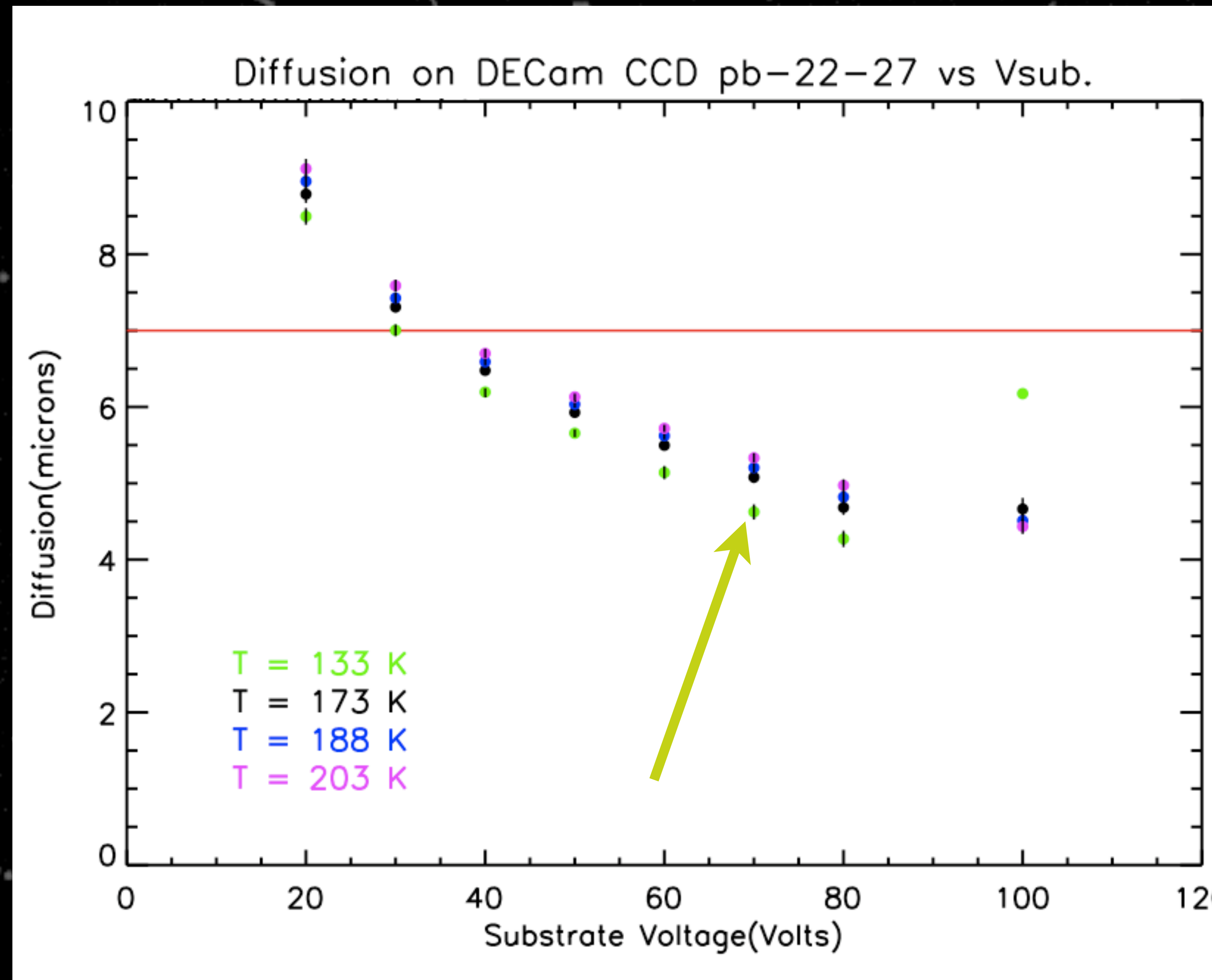
Charge diffusion with X-rays





Charge diffusion with X-rays

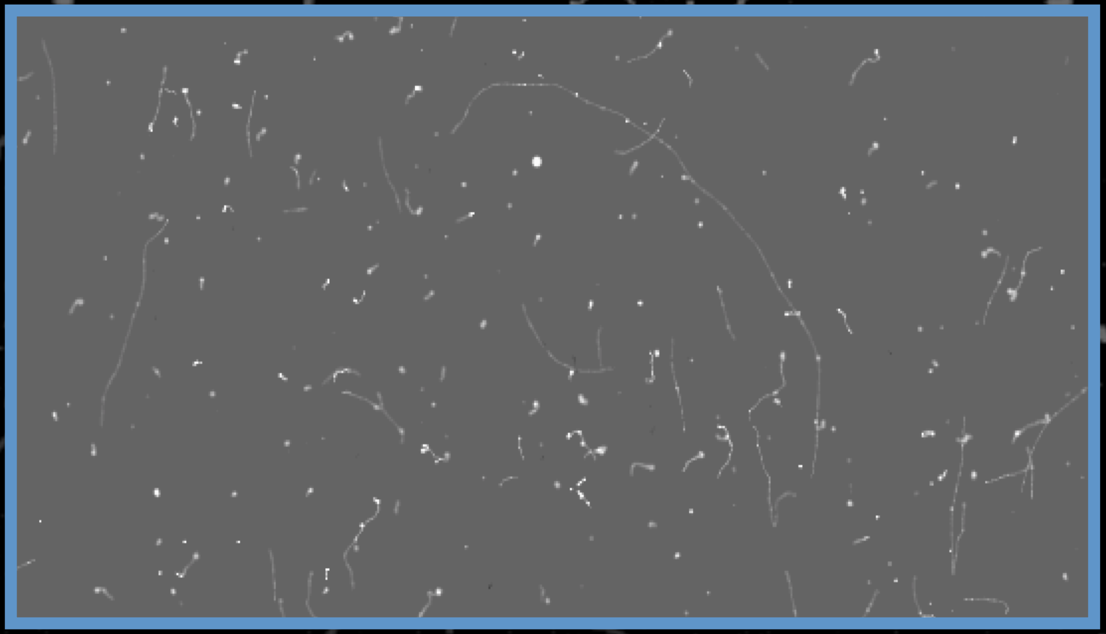


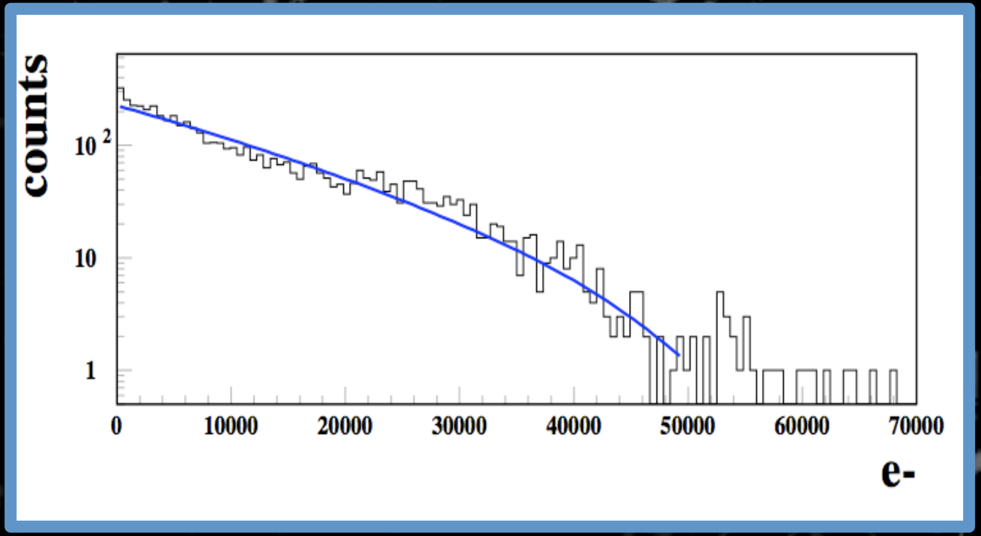


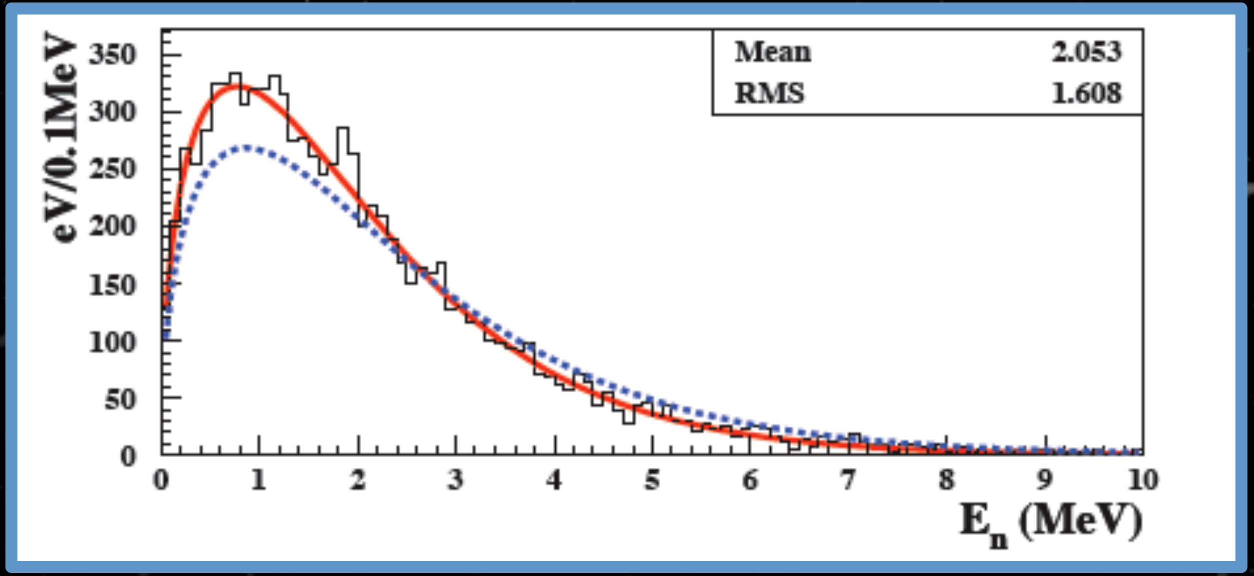
we operate them at 40V for the moment.

Nuclear Recoils in CCDs

Neutrons ^{252}Cf







We have measured nuclear recoils from a neutron source and fitted an ionization yield of ~13.9 eV/e- ("Q=3.8"). **<u>This is not a real calibration, just first check for the response to nuclear recoils.</u>** We did not fit the energy dependence of this yield. Now setting up for collecting more data to attempt a real calibration.

DAMIC (FNAL MOU T987)

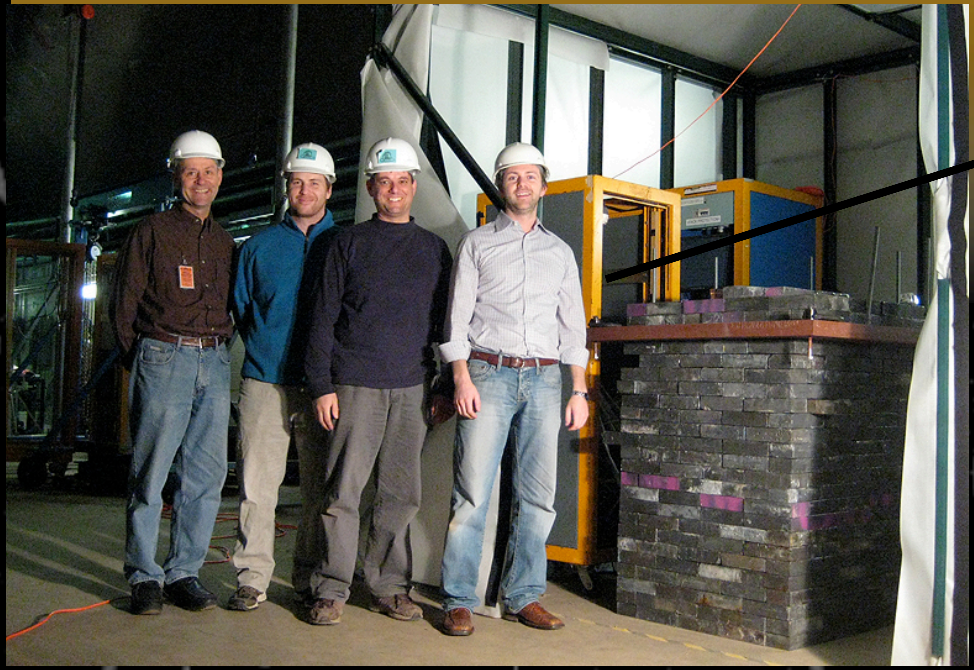
Underground test of CCDs for DM

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

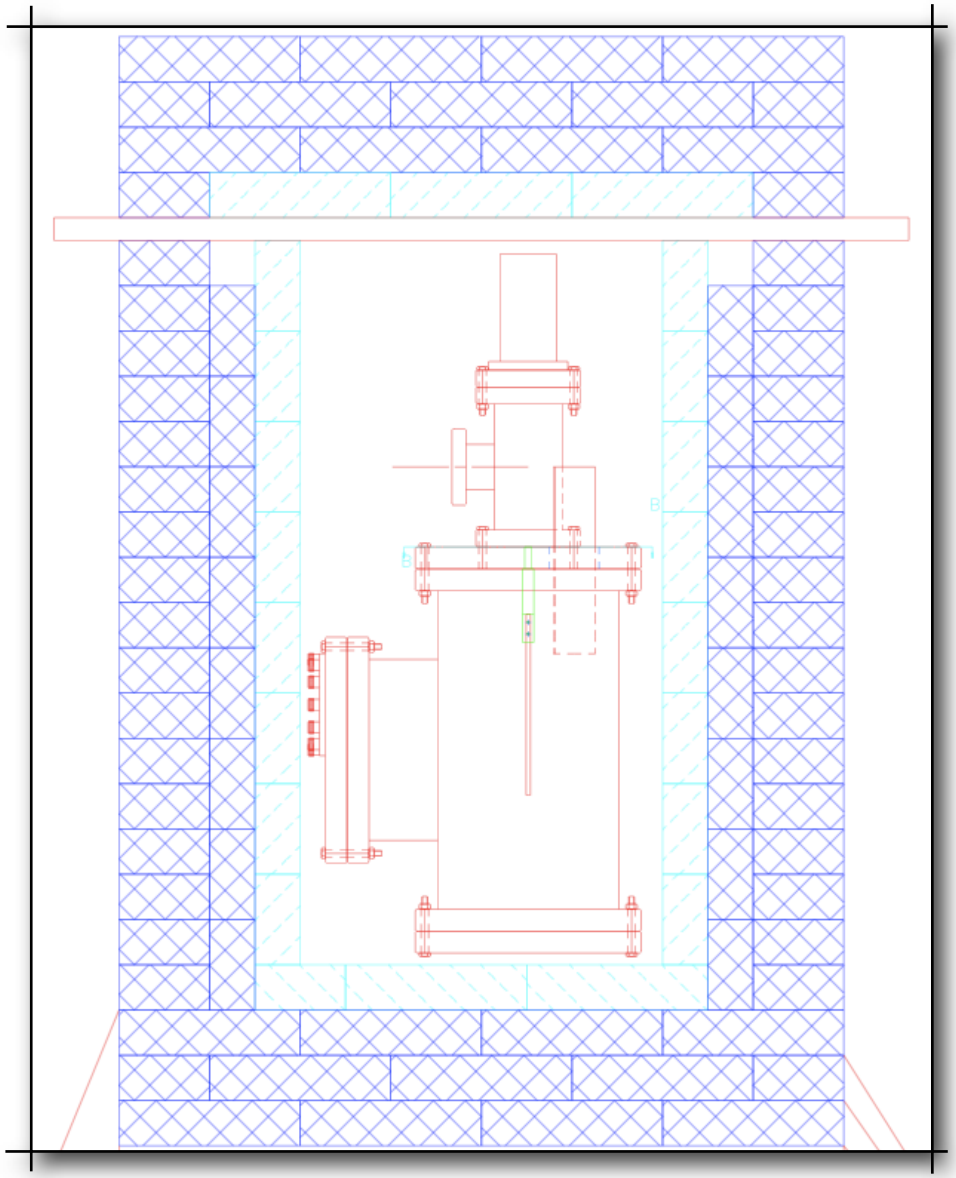
$upport:
> Detectors and electronics are DECam engineering parts
> PPD : shield + tent undeground
> CPA : some electronics boards (VIB)



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

Moved CCDs to Minos in January

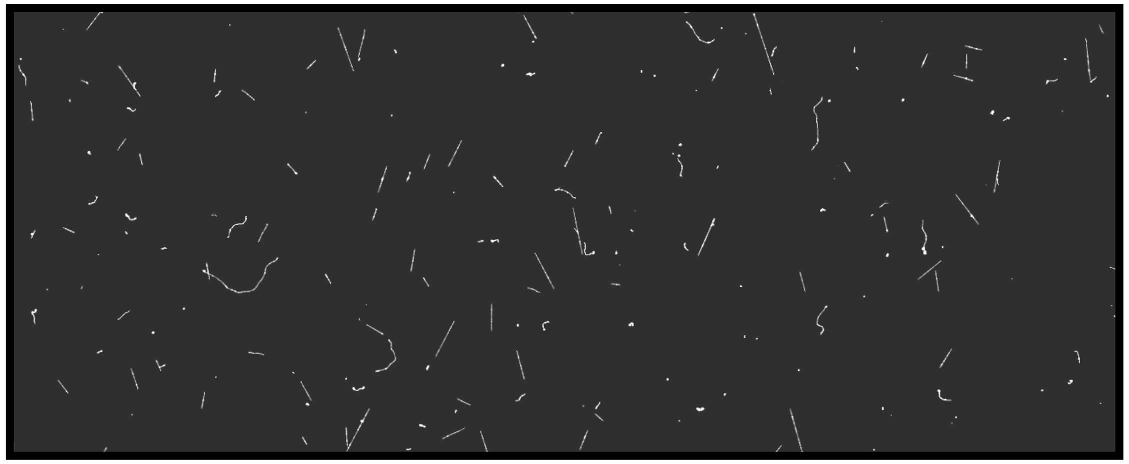
built a tent in the near detector hall and installed our detectors inside

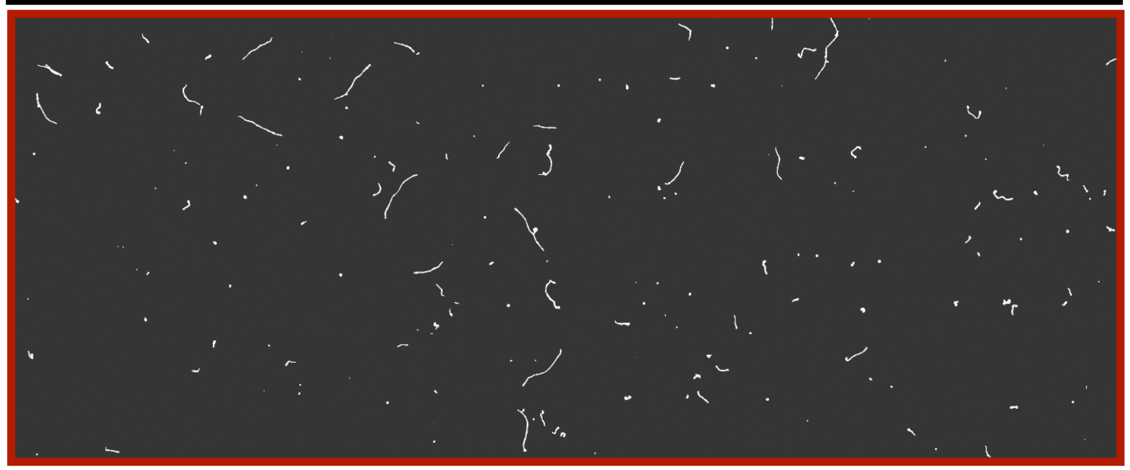


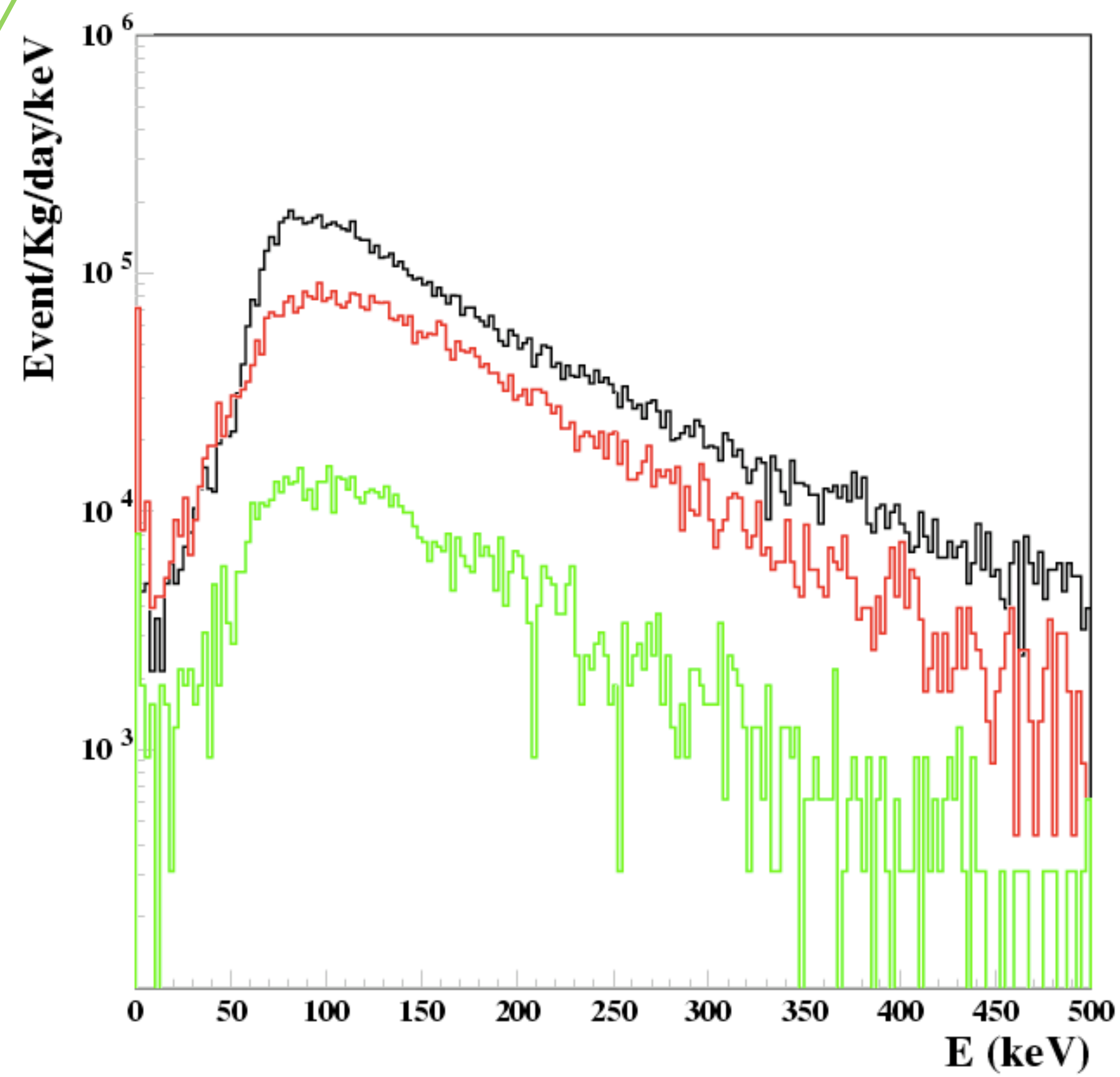
all parts used were spares from other FNAL projects... not designed for low background.

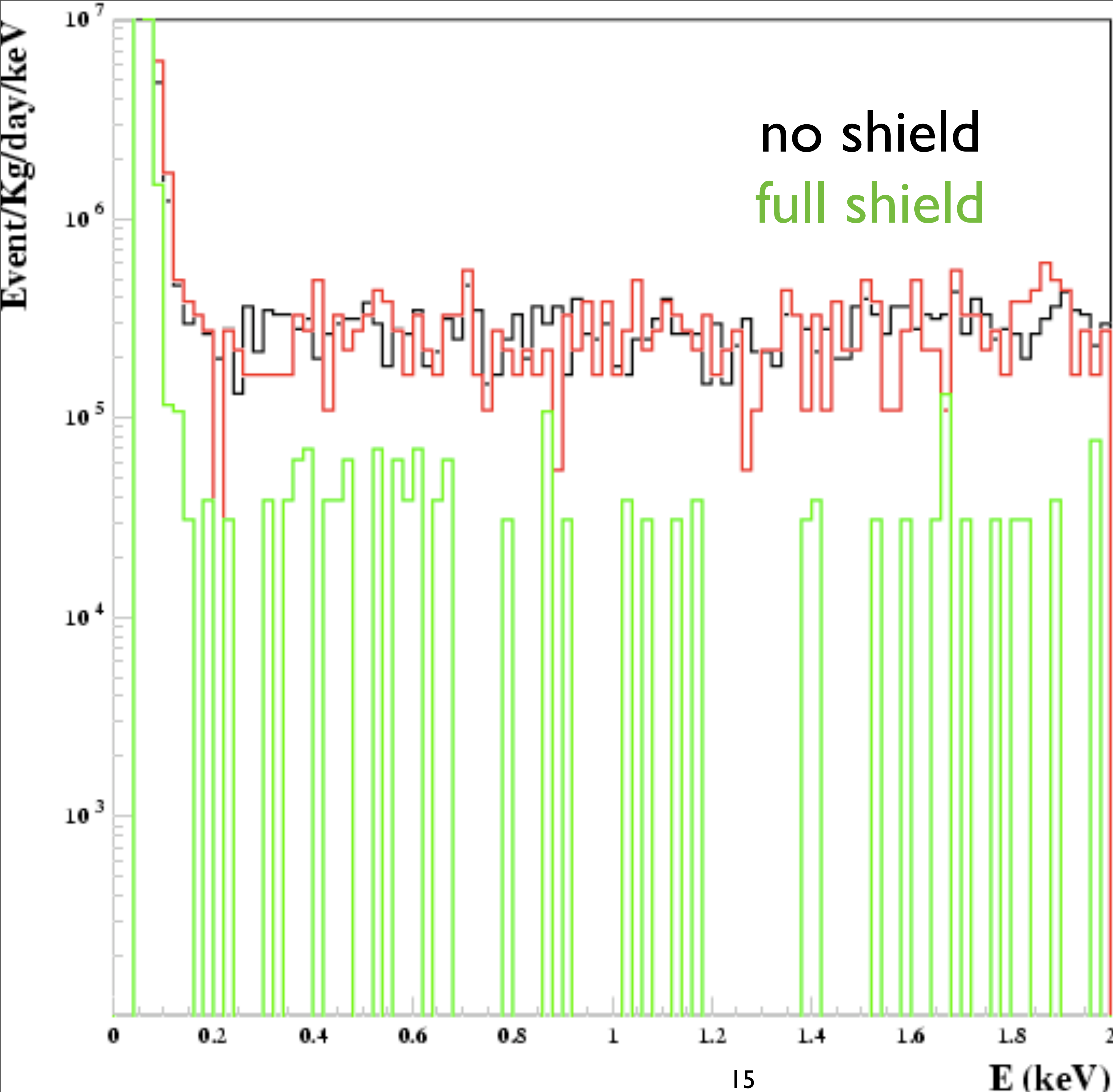
tracks:

- surface
- Minos (350’ underg.)
- Minos + 8”lead shield



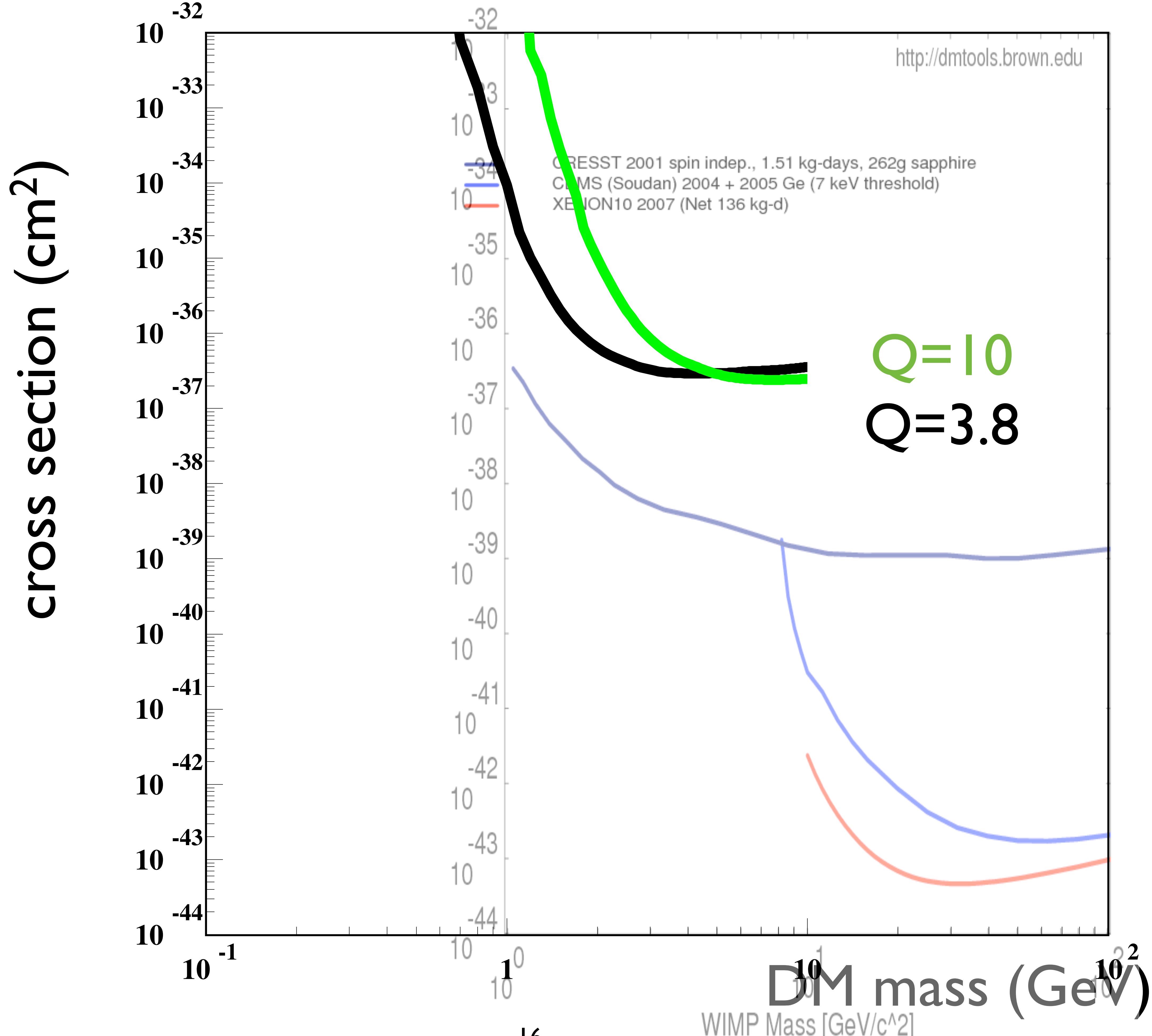






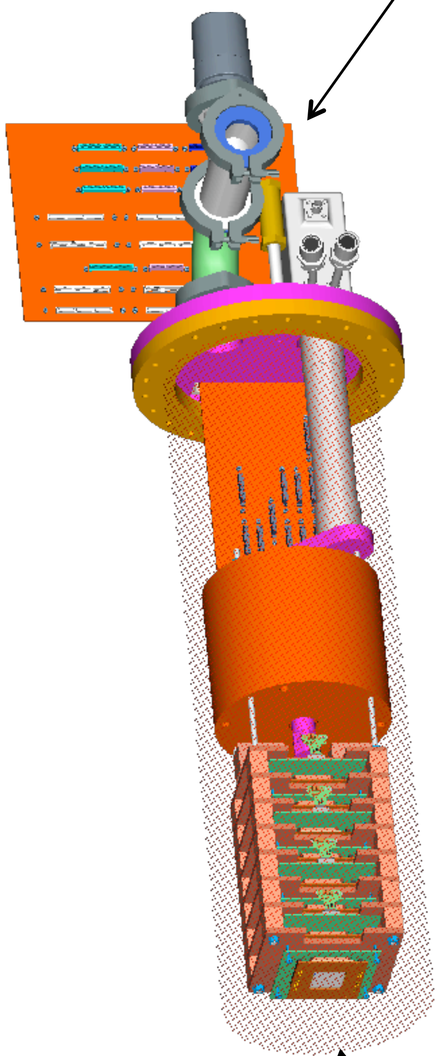
I apologize for showing this result in a conference where everybody shows low backgrounds..

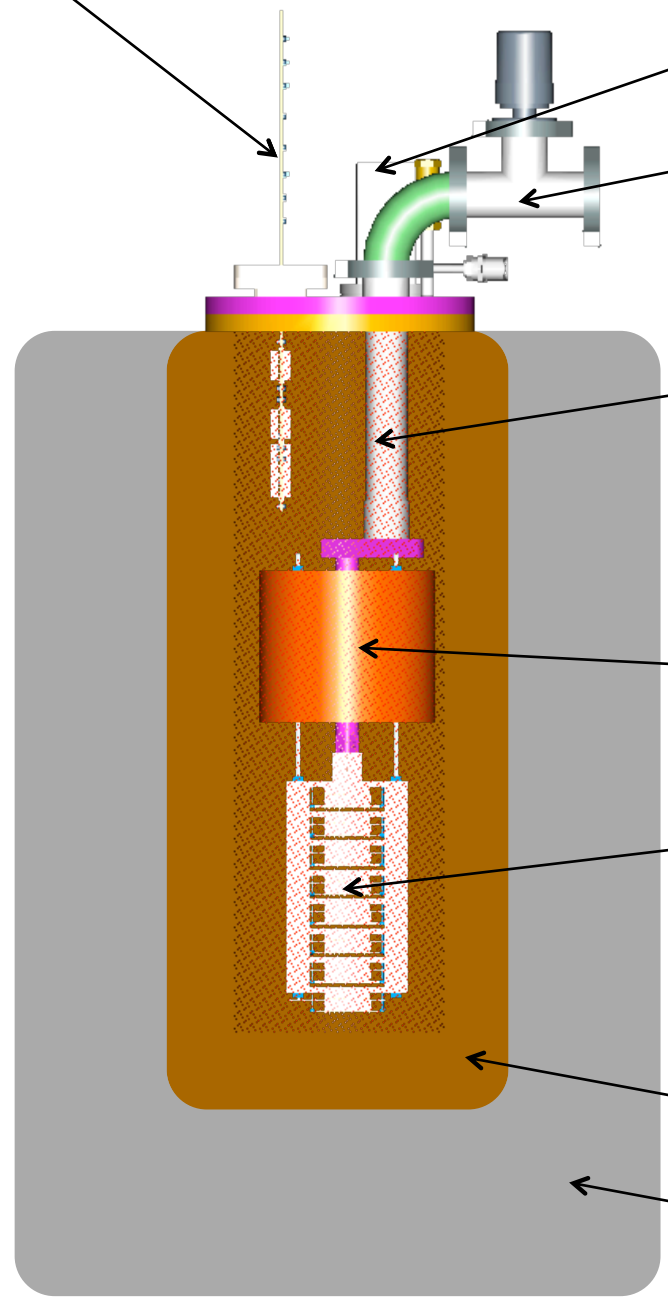
to become competitive we need to reduce another 2 orders of magnitude.



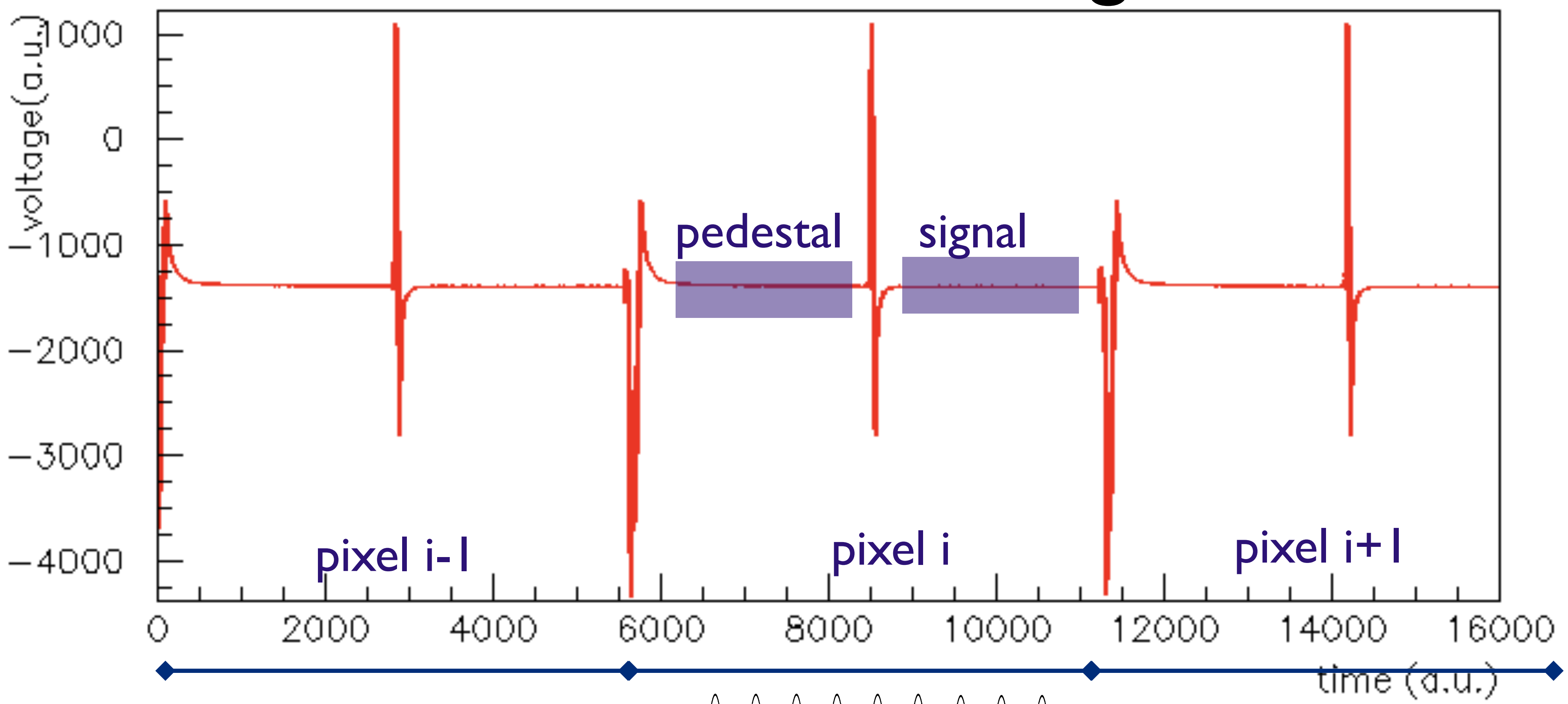
http://dmtools.brown.edu
CRESST 2001 spin indep., 1.51 kg-days, 262g sapphire
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
XENON10 2007 (Net 136 kg-d)
Q=10
Q=3.8
cross section (cm^2)
DM mass (GeV)
WIMP Mass [GeV/c^2]

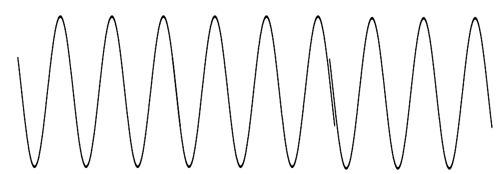
To reduce background we are building this new dewar for a 21 gr detector. We still have to do a better job selecting the cold electronics.



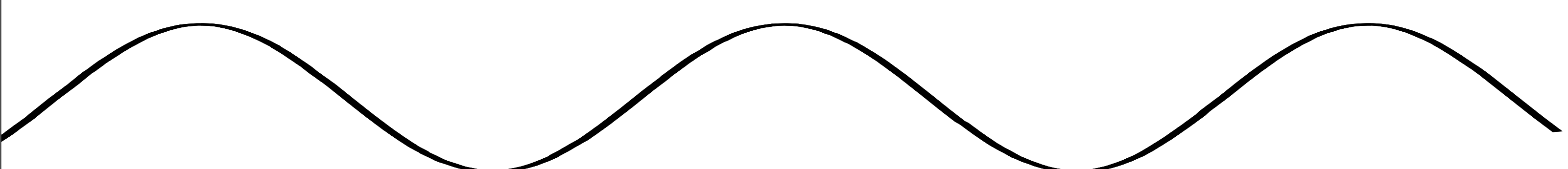


CCD readout : lowering noise



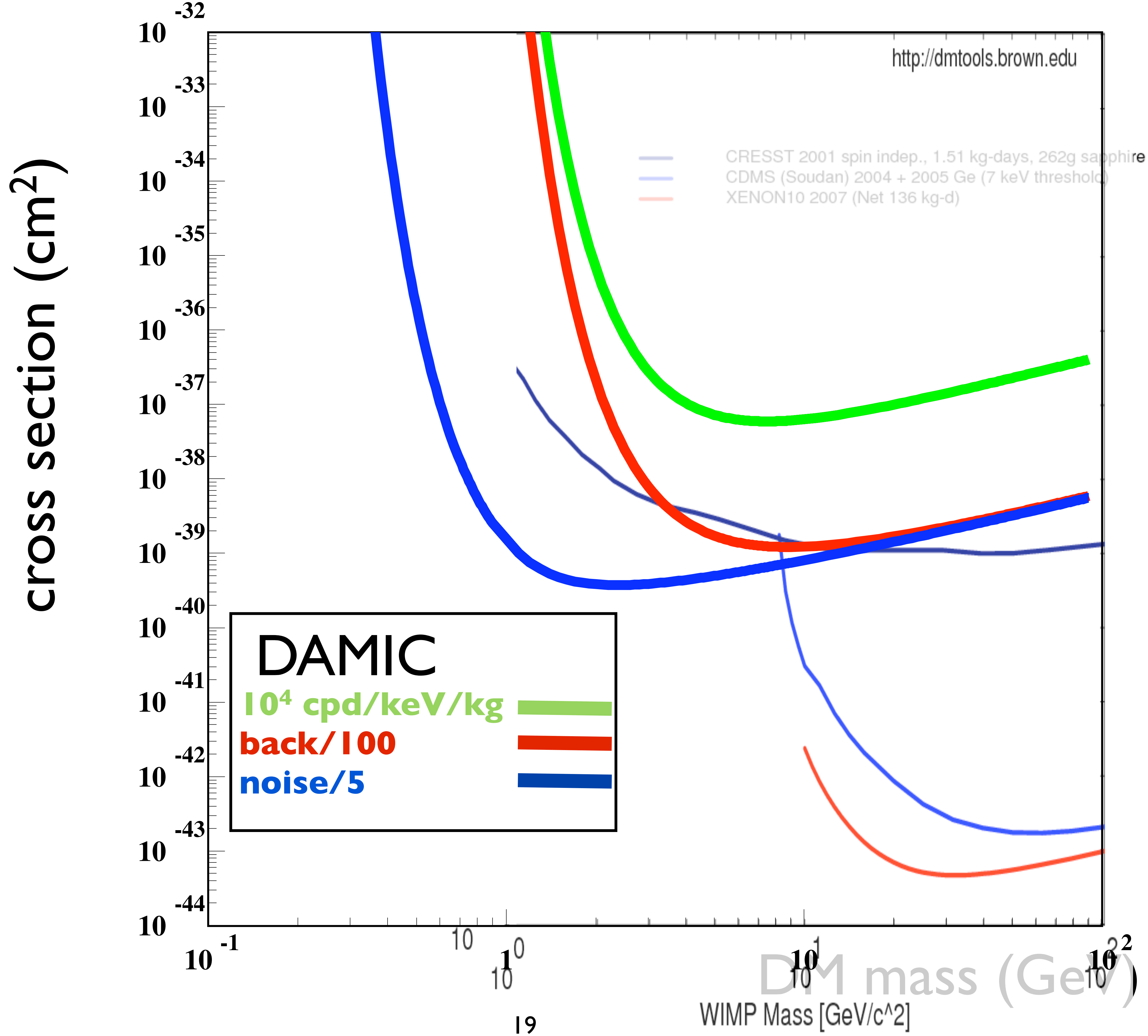


well filtered by integration in CDS



not filtered by the CDS
could be filtered by looking at many pixels

CDS: the amount of charge on each pixel is given by the difference between signal and pedestal levels inside an integration window. **High frequencies as suppressed by the integration window, low frequencies are suppressed by the double sampling.** working on digital filtering of the intermediate frequencies by looking at the signal over many pixels...



cross section (cm^2)
DM mass (GeV)
WIMP Mass [GeV/c^2]
http://dmtools.brown.edu
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
10^4 cpd/keV/kg
back/100
noise/5

Conclusions

- We started an R&D program to investigate **CCDs as candidates for direct DM searches at low threshold**.

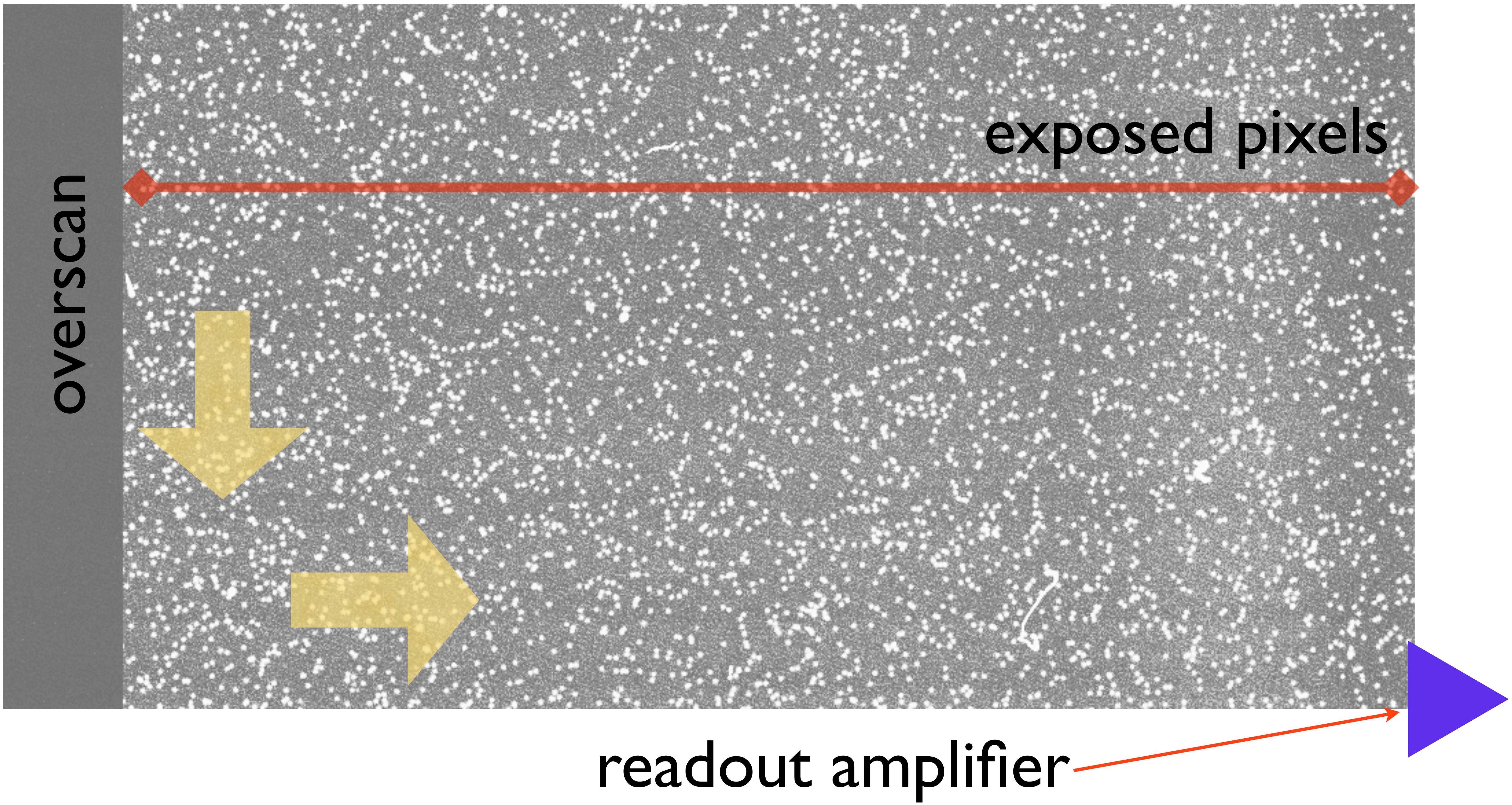
- First test (without low background design) indicates that **we need x100 background reduction to become competitive**.

- Next:
  - Built a **low background setup** (new design almost done).
  - A **new readout system** to filter the low frequency noise remaining after CDS.
  - Real calibration **nuclear recoils.**

- There are other efforts to get low threshold in DM searches. If this works it has potential extremely low threshold. **With 0.5e of noise a 5 sigma threshold on 10 eVee is possible**. Right now have no reason to believe that this is impossible, so we will try it.

END

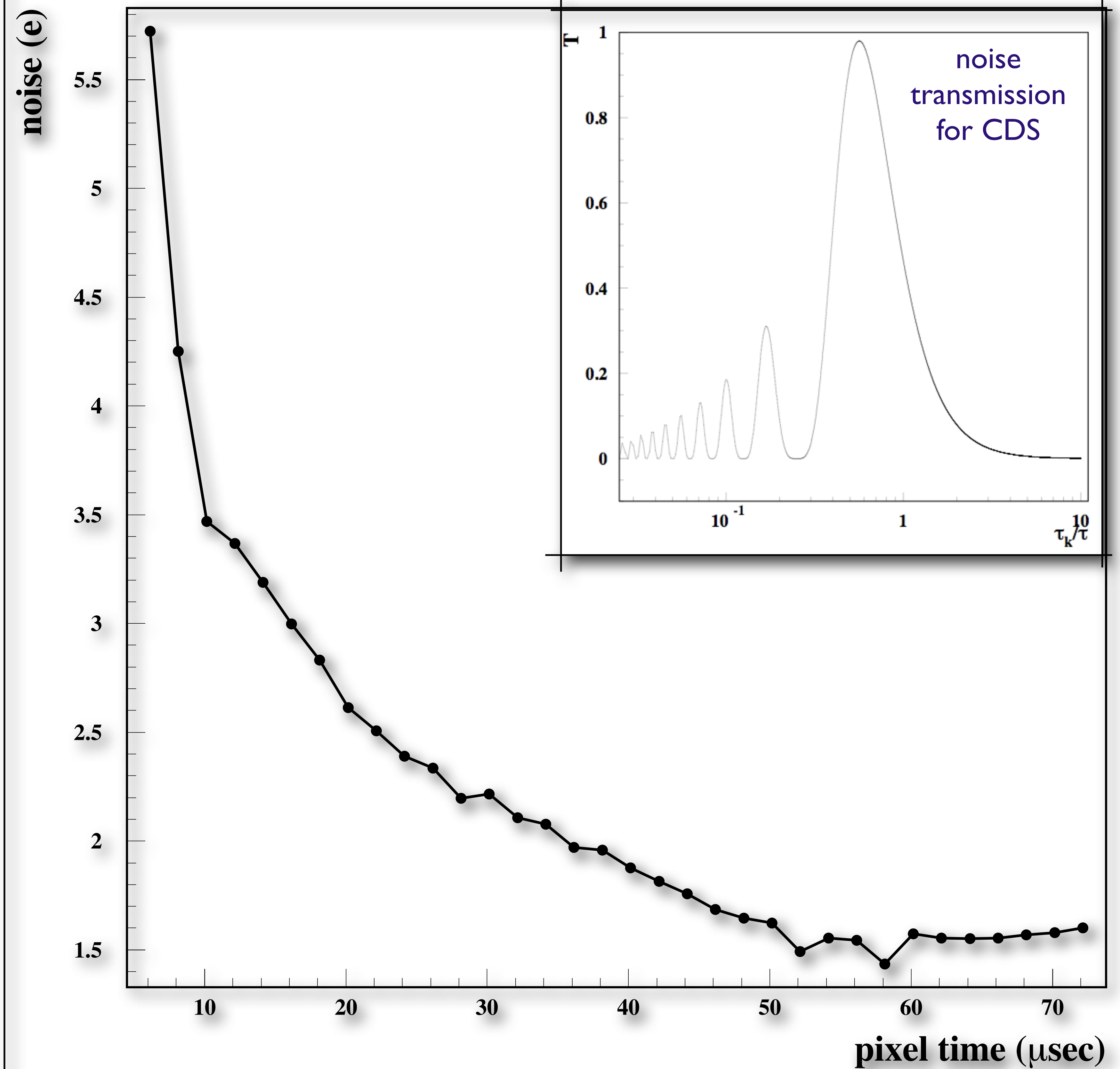
CCD readout



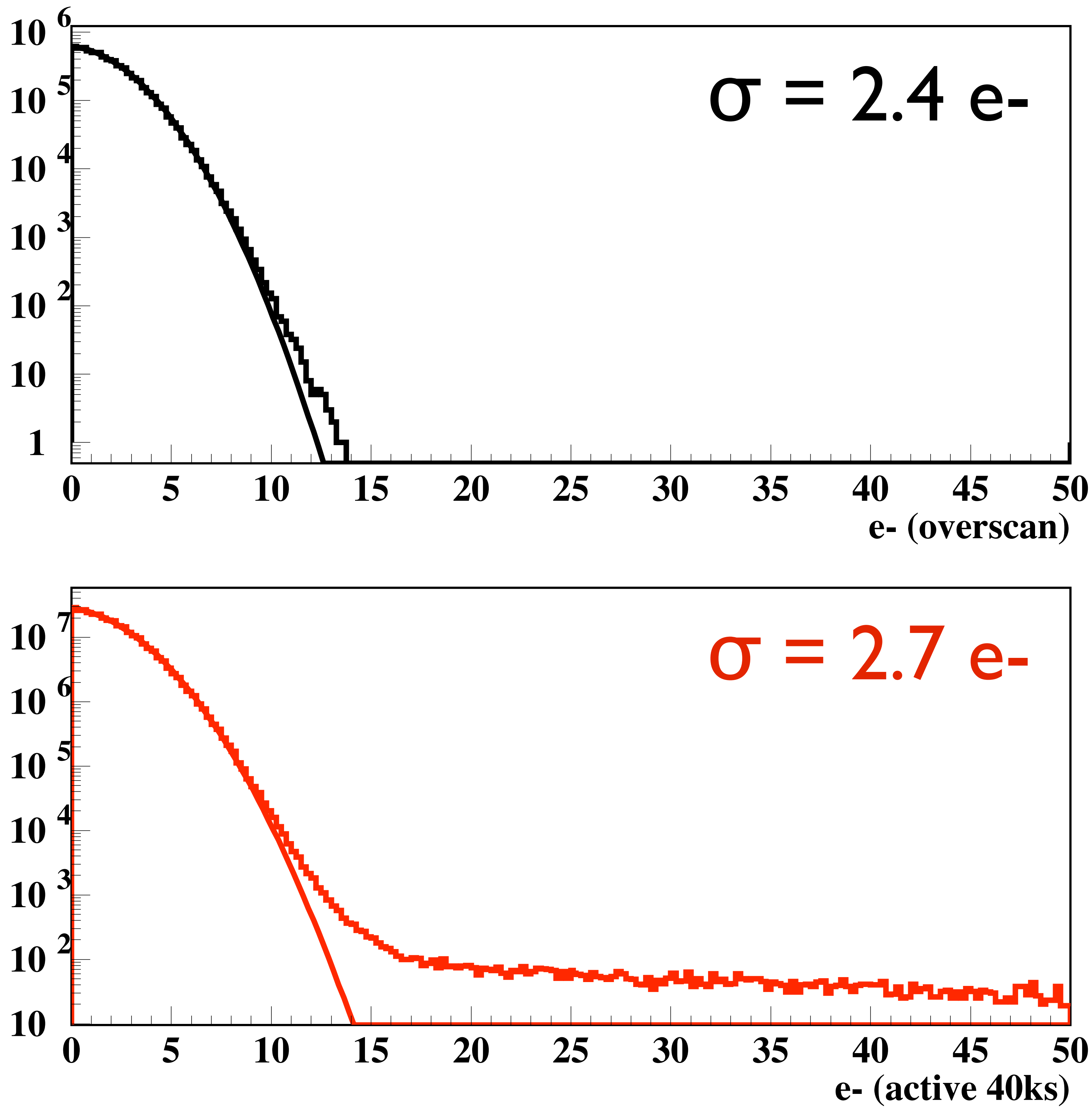
charge is clocked to a serial register (SR) and the shifted to the readout node. you can continue shifting the SR after you are done reading out physical pixels and this produces the overscan region.

the 1/f noise component produces increase the noise of the CDS result when the pixel time becomes too slow.

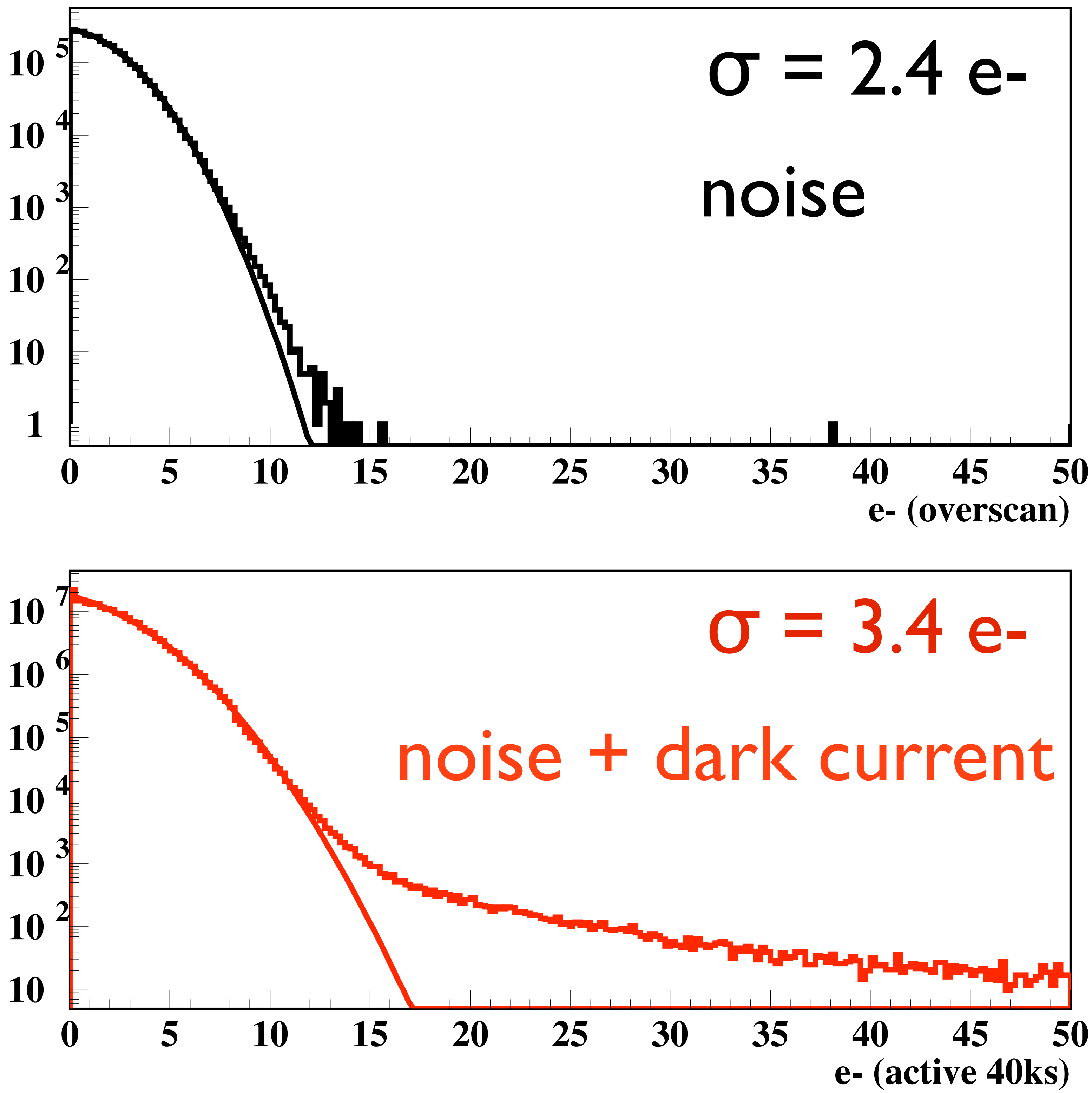
We are working on a digital filtering algorithm to improve the low frequency filtering... maybe this will allow us to go below 1e- of noise.



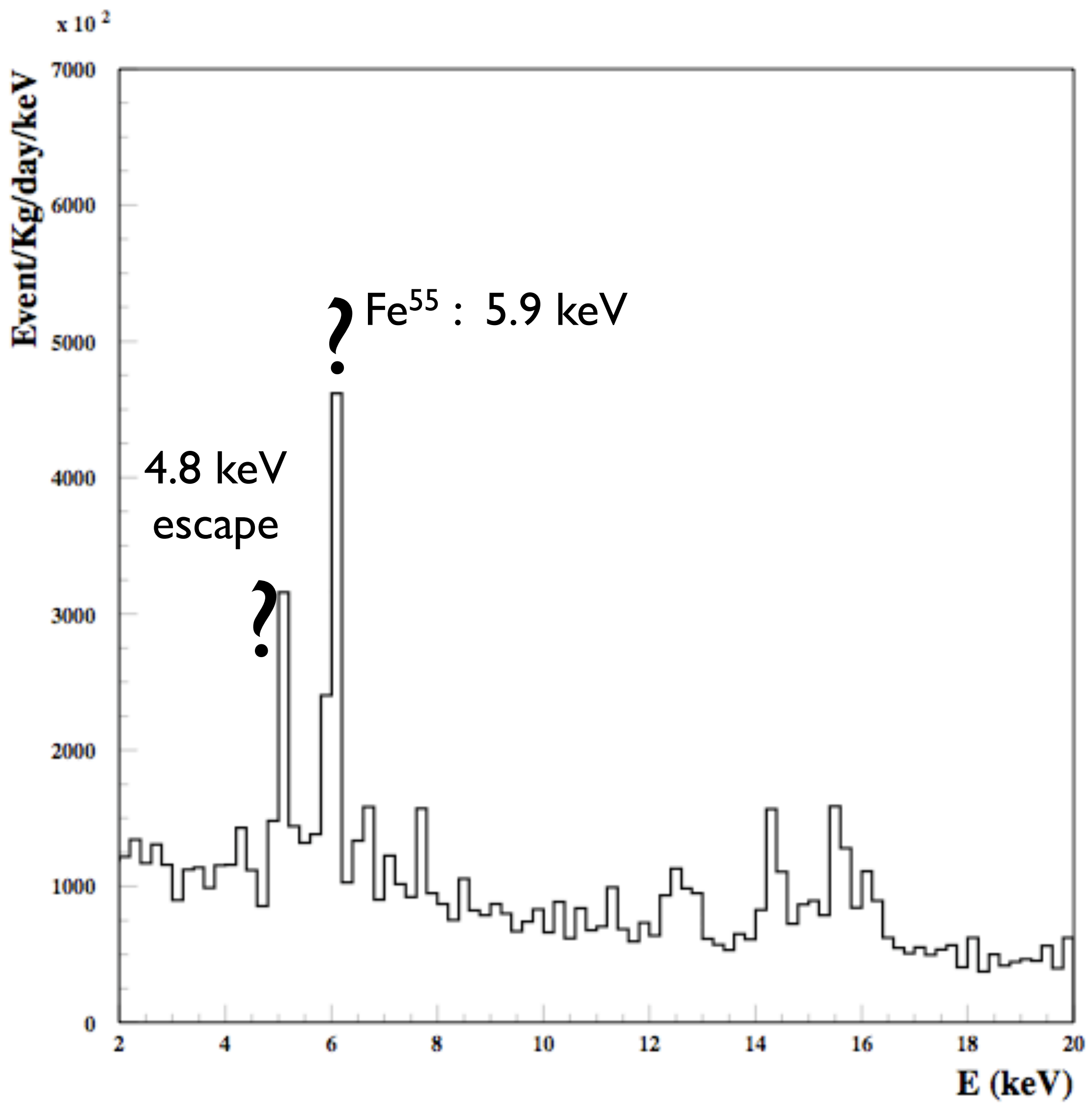
4000 sec exposures

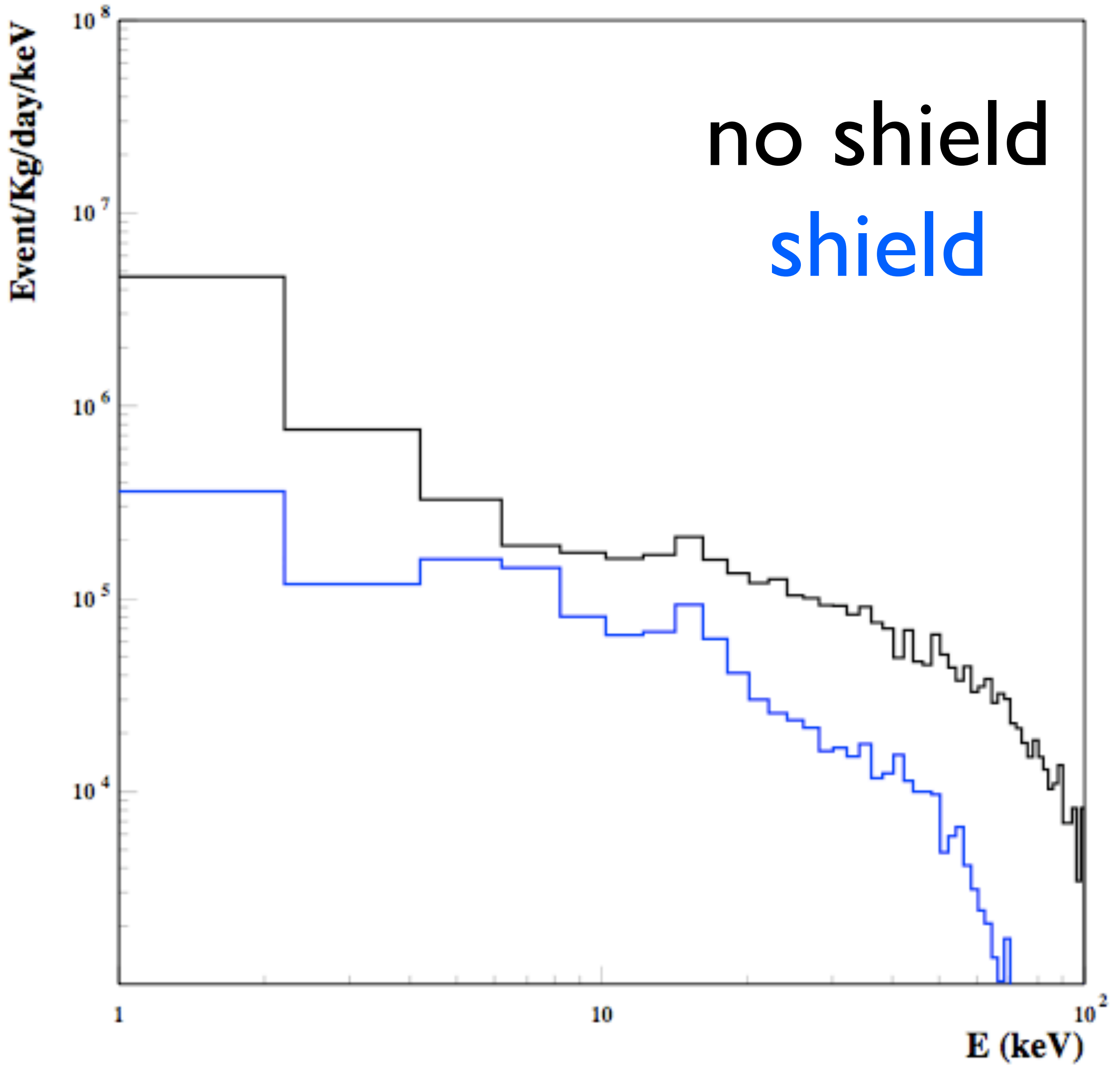


40000 sec exposures

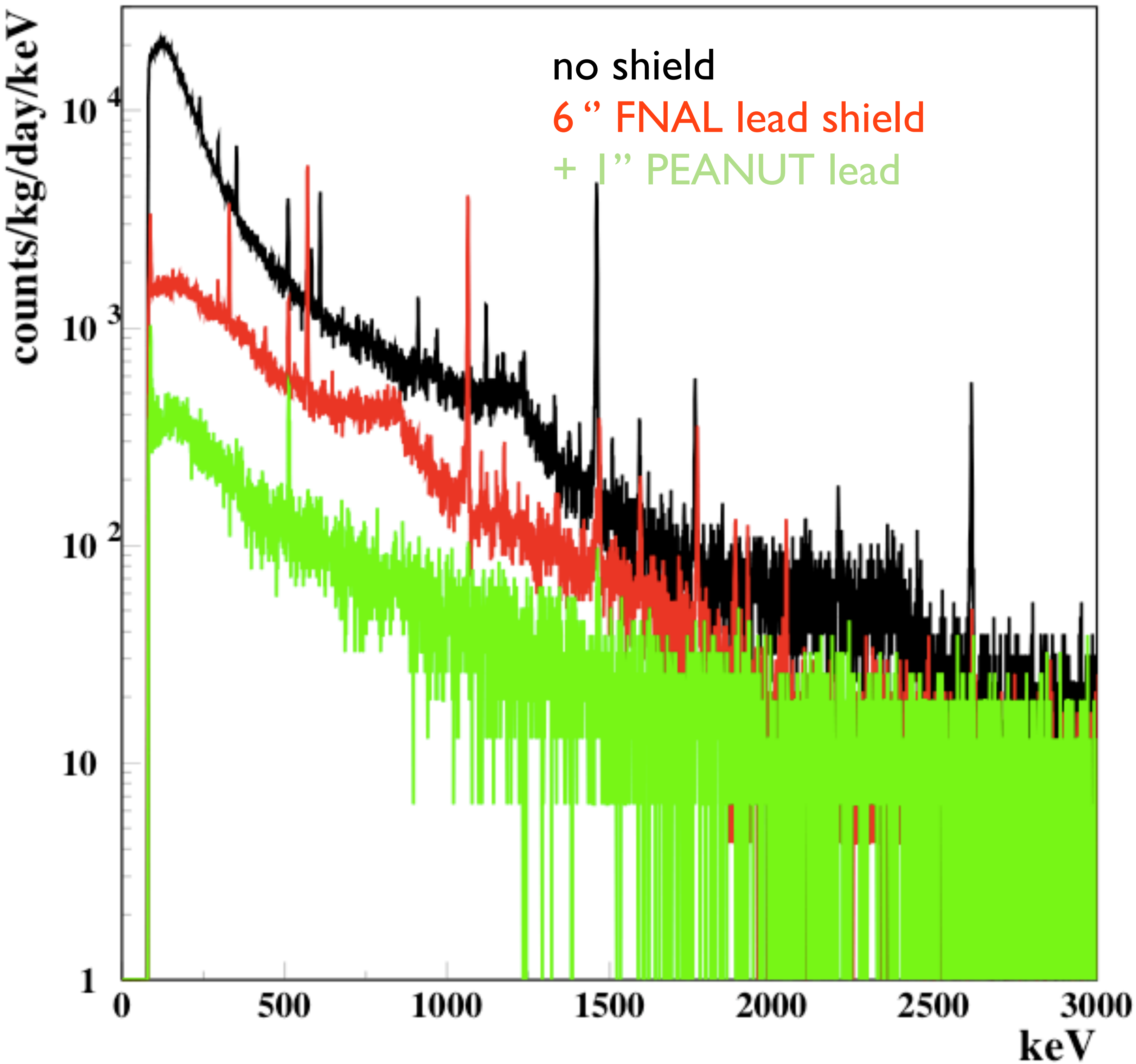


runs at Lab-A gave 10^6 cpd/keV... too high!





Shield studies:Ge detector at LAB-A

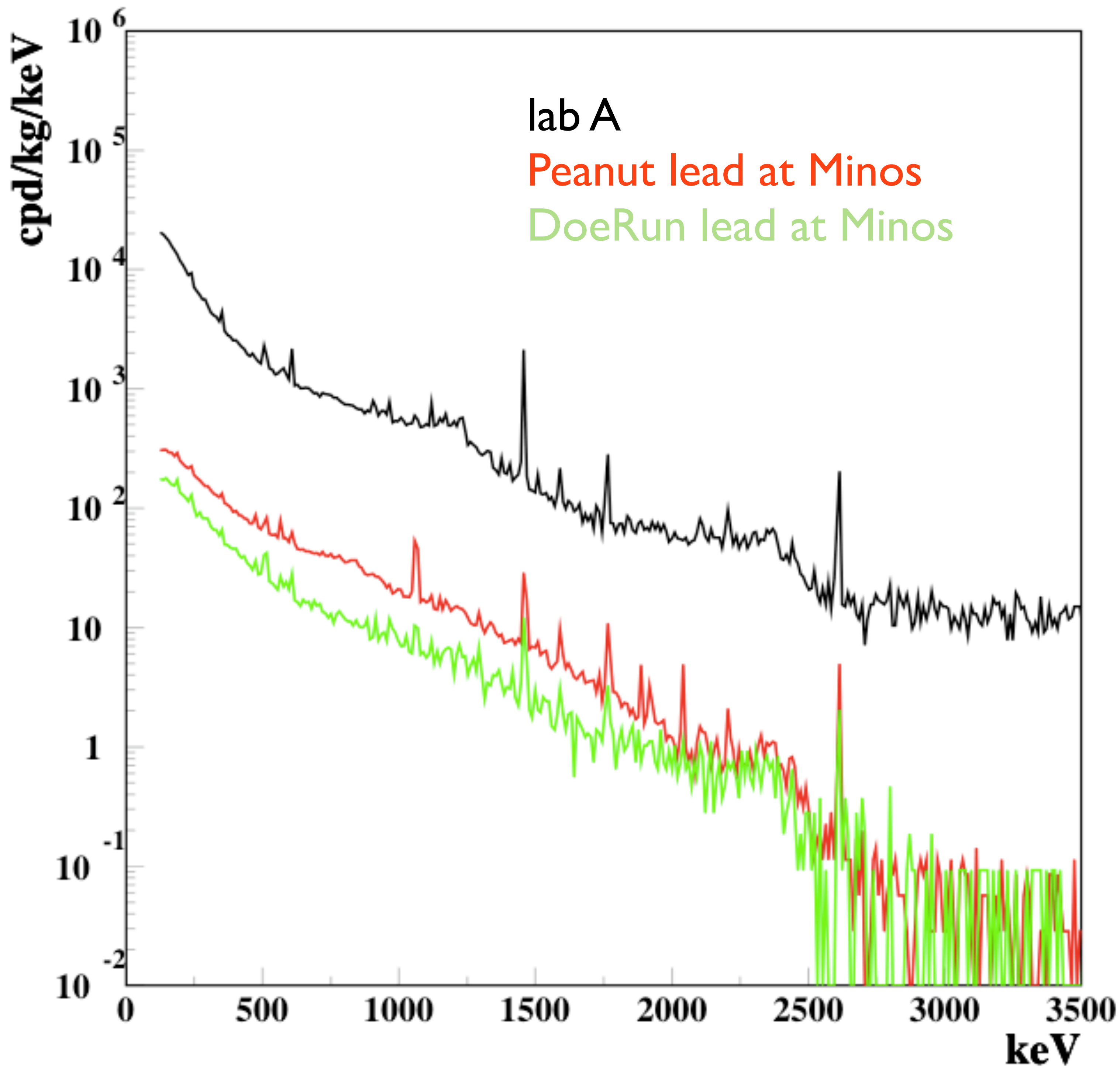


FNAL lead is bad, it had Bi-207 from exposure to beam.

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



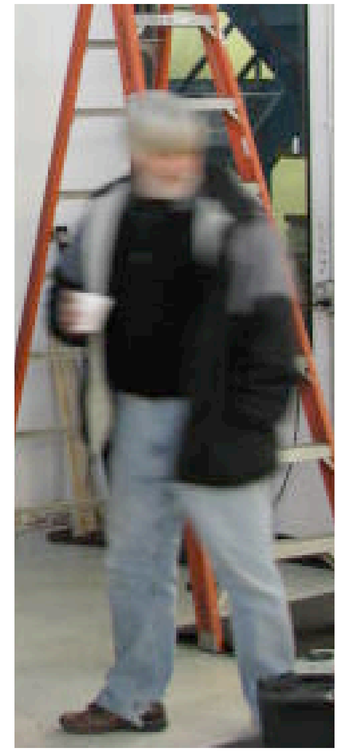
Purchased new lead before the price went down... and made a shield at Minos for the Ge detector.

Test indicated we could get about 2 orders of magnitudes.

... thanks!

T. Nebel (inside)

J. Tweed

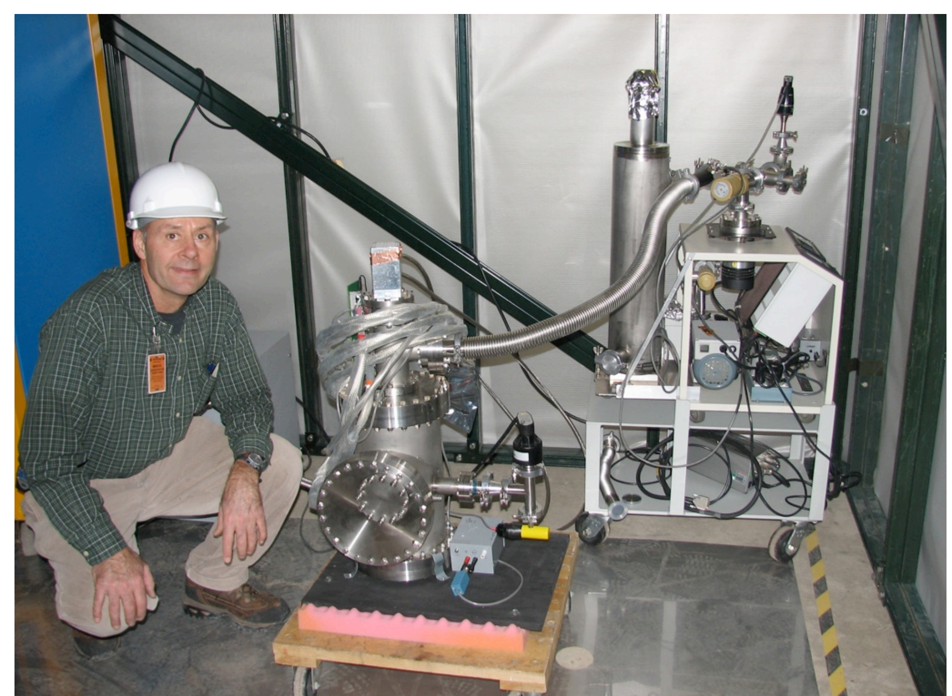


S. Jakubowski

K. Schultz

J. Voirin

J. Delao (and lead workers)



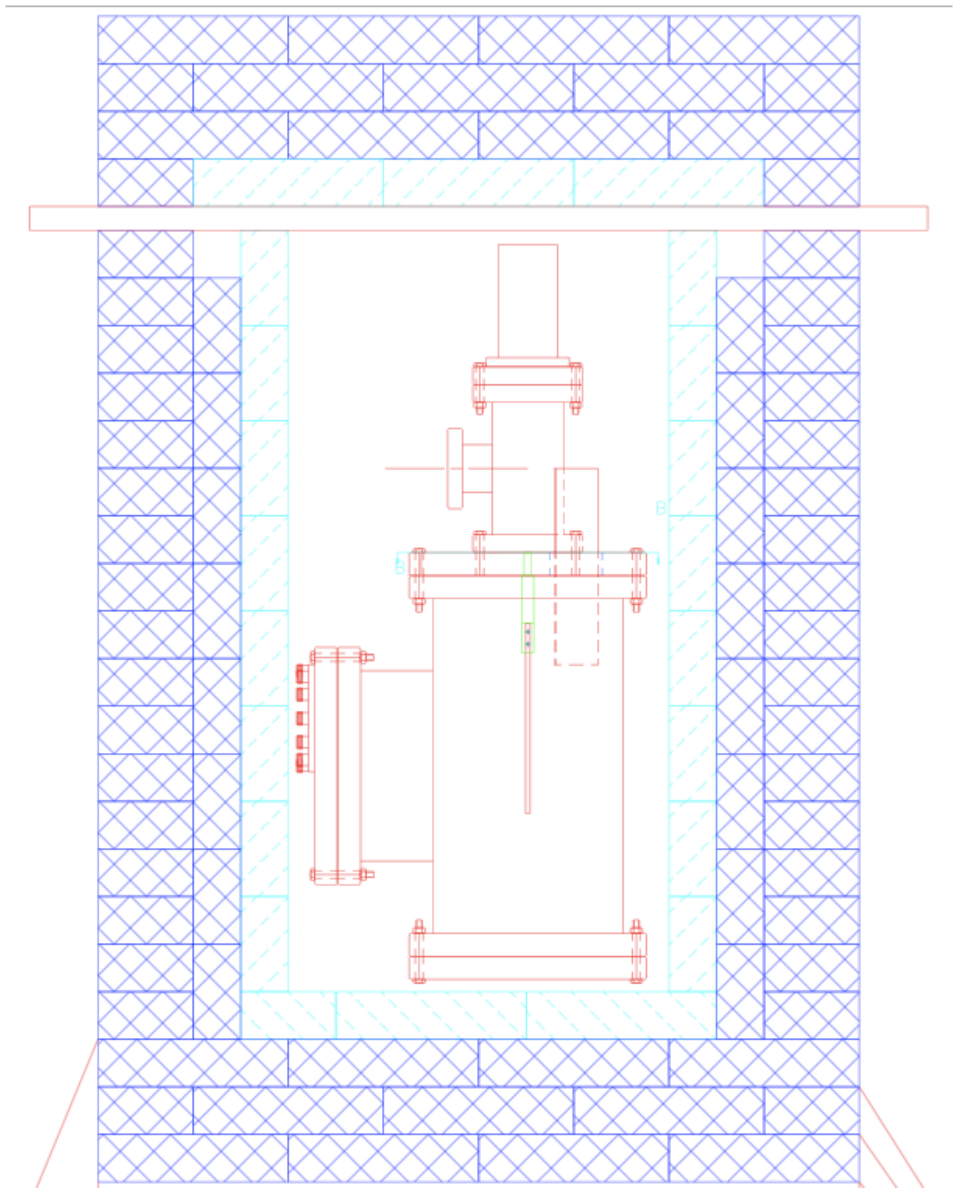
K. Kuk

M. Watson

Finished shield with new lead in March

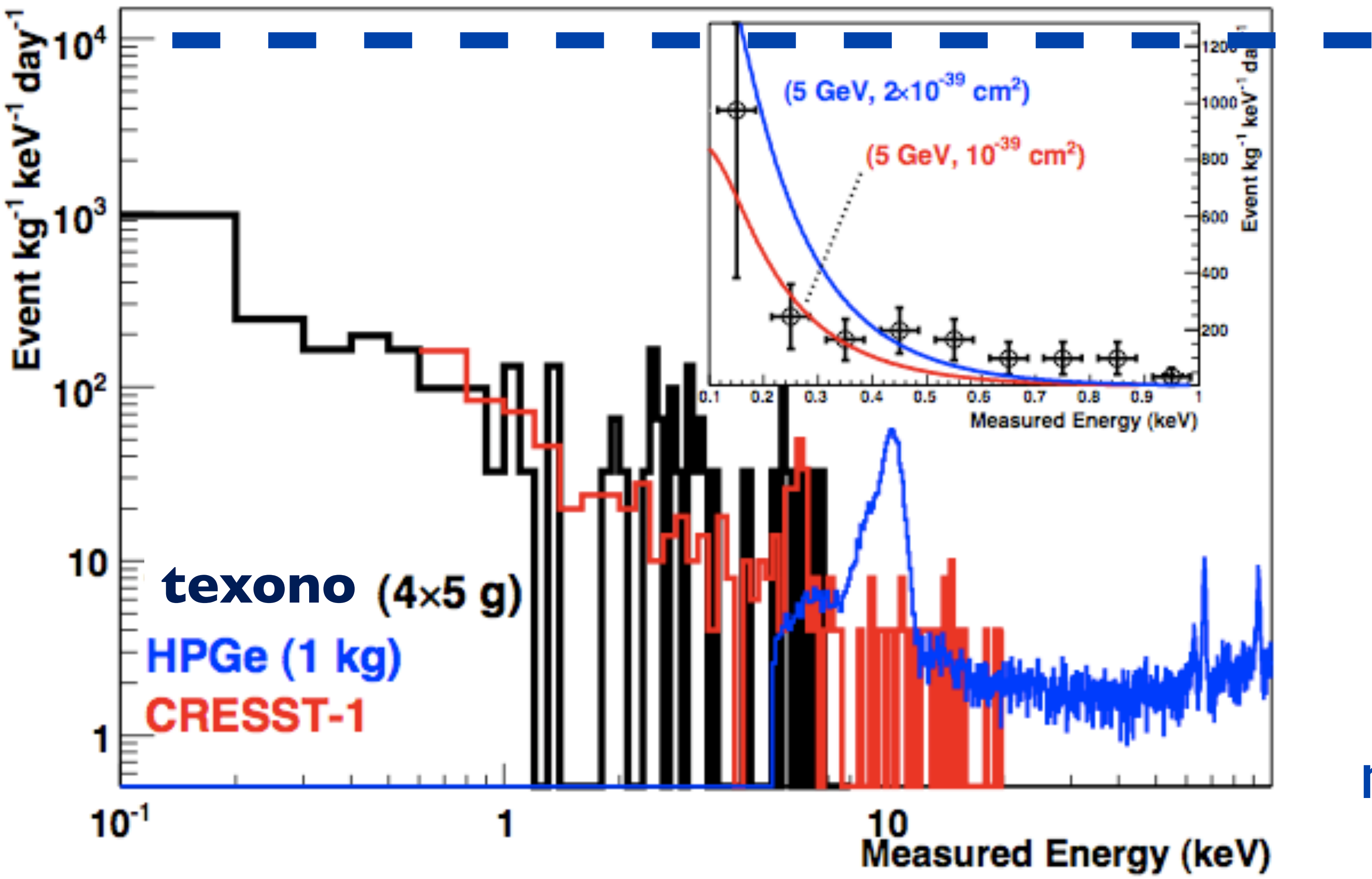
2" of DoeRun lead and 6" of FNAL lead. Tight fit.

"clean tent"



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

how low could we go?

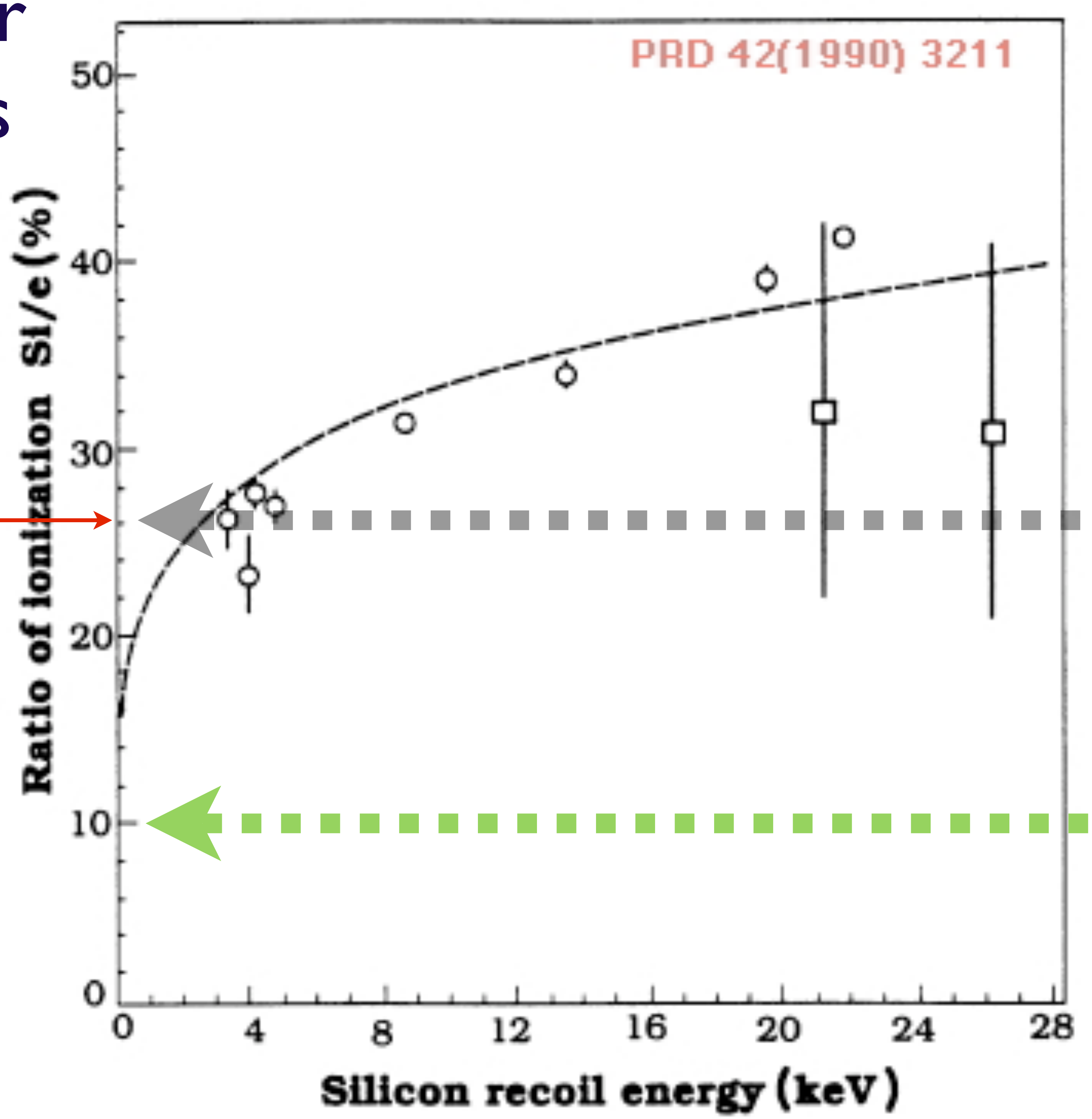


DAMIC

FIG. 4: The measured spectrum of ULEGe with 0.338 kg-day of data, after CRV, ACV and PSD selections. Background spectra of the CRESST-I experiment [9] and the HPGe [13] are overlaid for comparison. The expected nuclear recoil spectra for two cases of $(m_\chi, \sigma^{SI}_{\chi N})$ are superimposed onto the spectrum shown in linear scales in the inset.

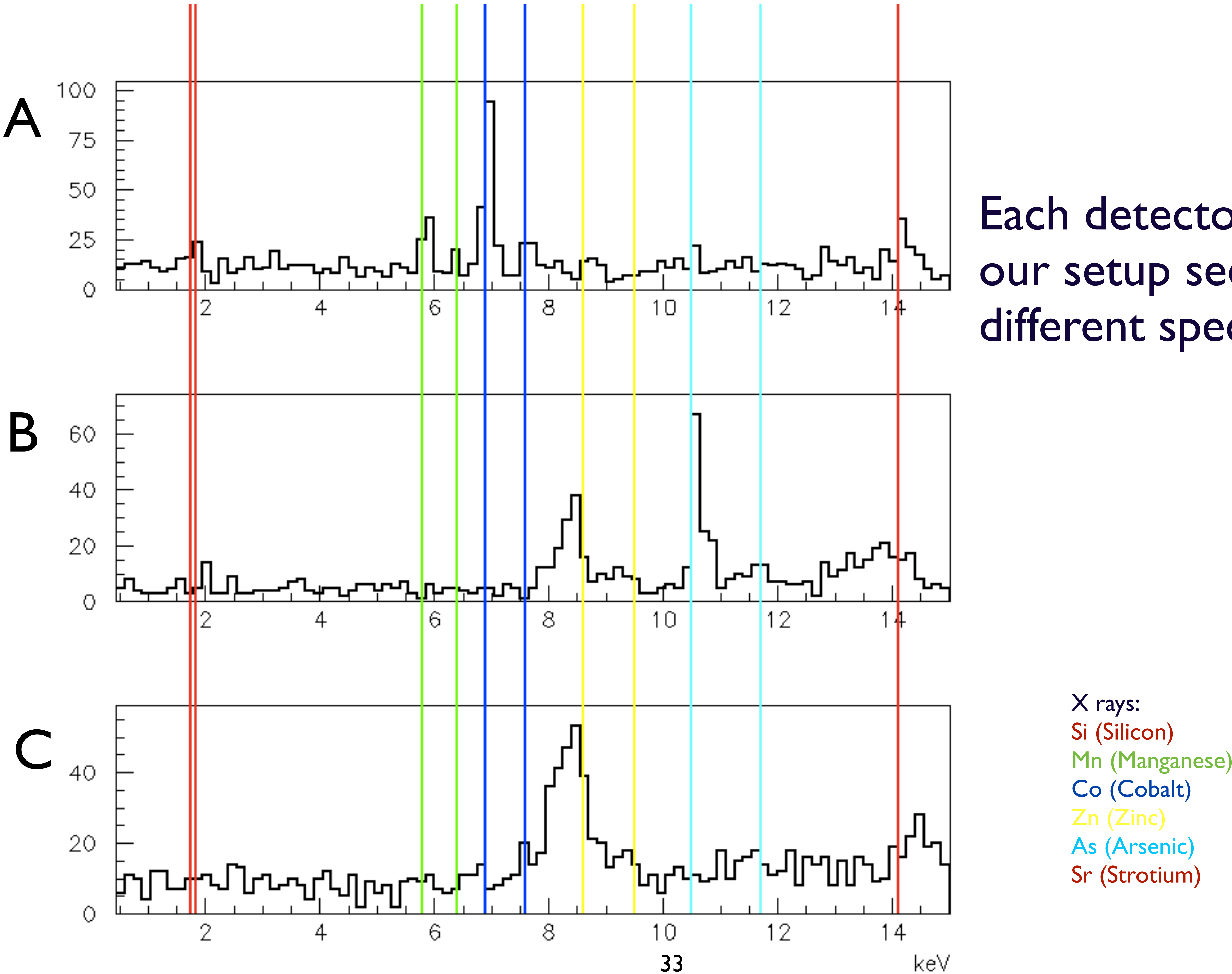
Current DAMIC background levels

Two to four orders of magnitude reduction seem possible based on other experiments result from our fit to neutrons

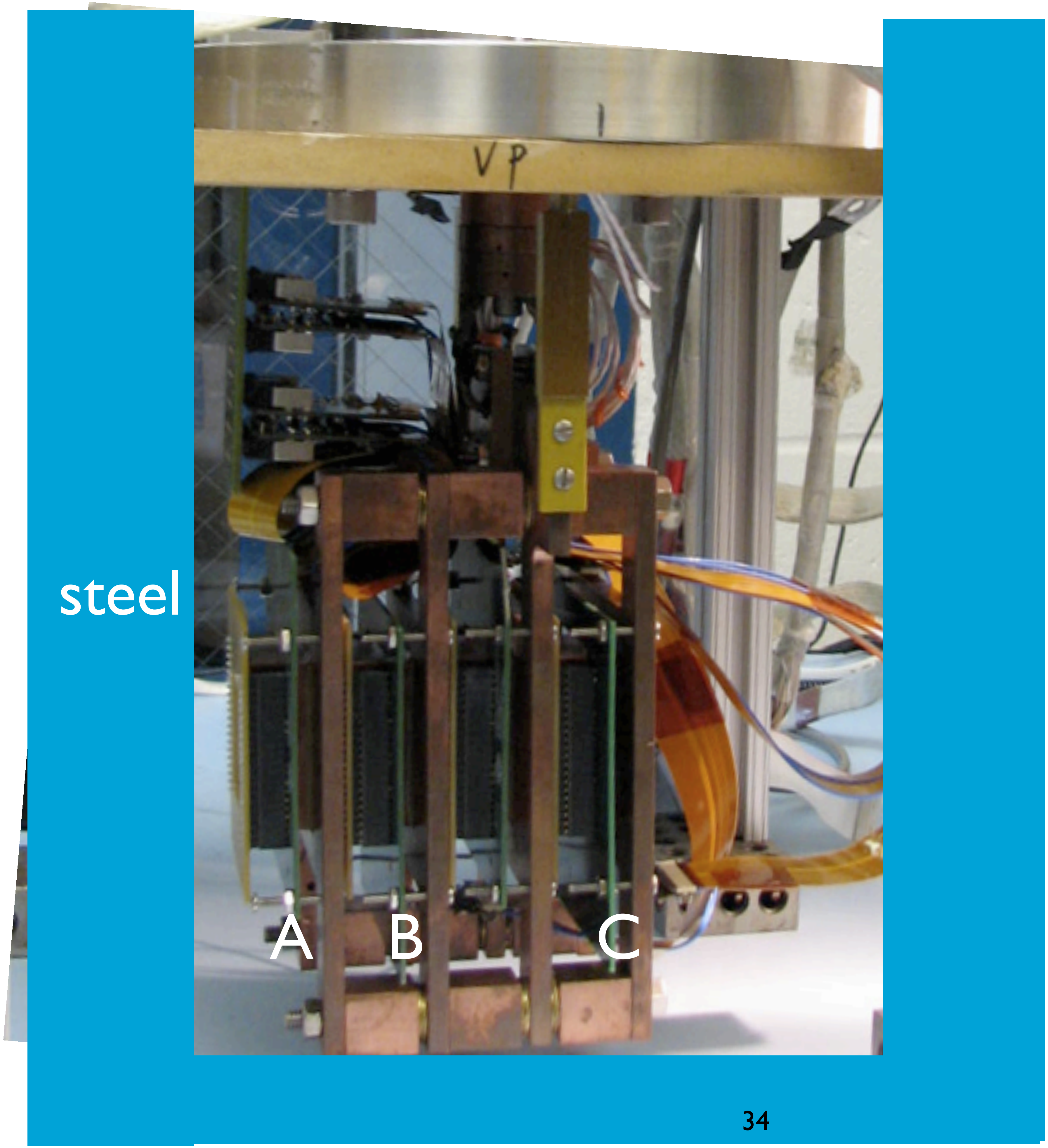


case1

case2



Each detector in our setup sees a different spectrum.



Each detector in our setup sees a different spectrum.

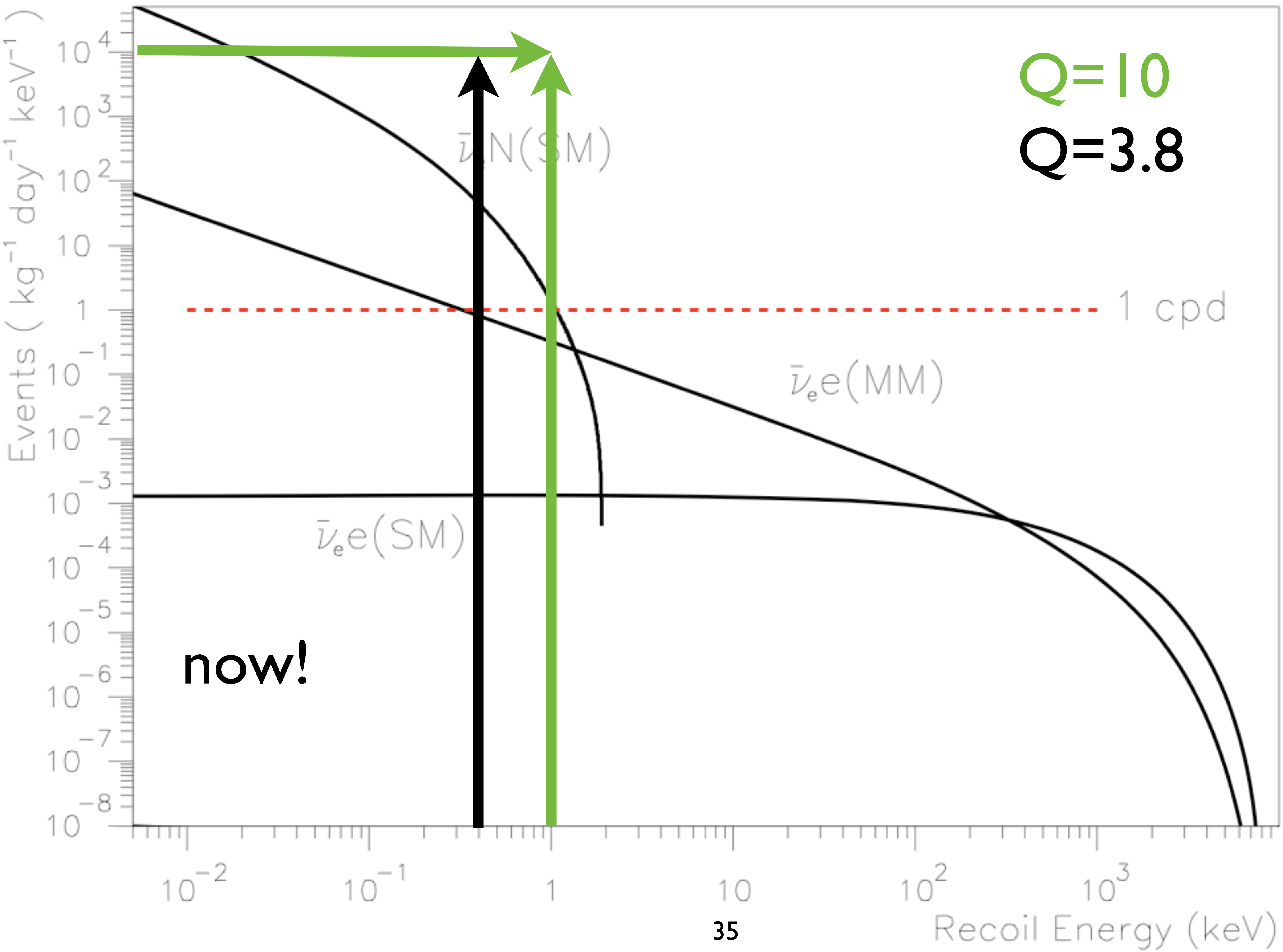
A sees a lot of steel:
Mn (Manganese)
Co (Cobalt)

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

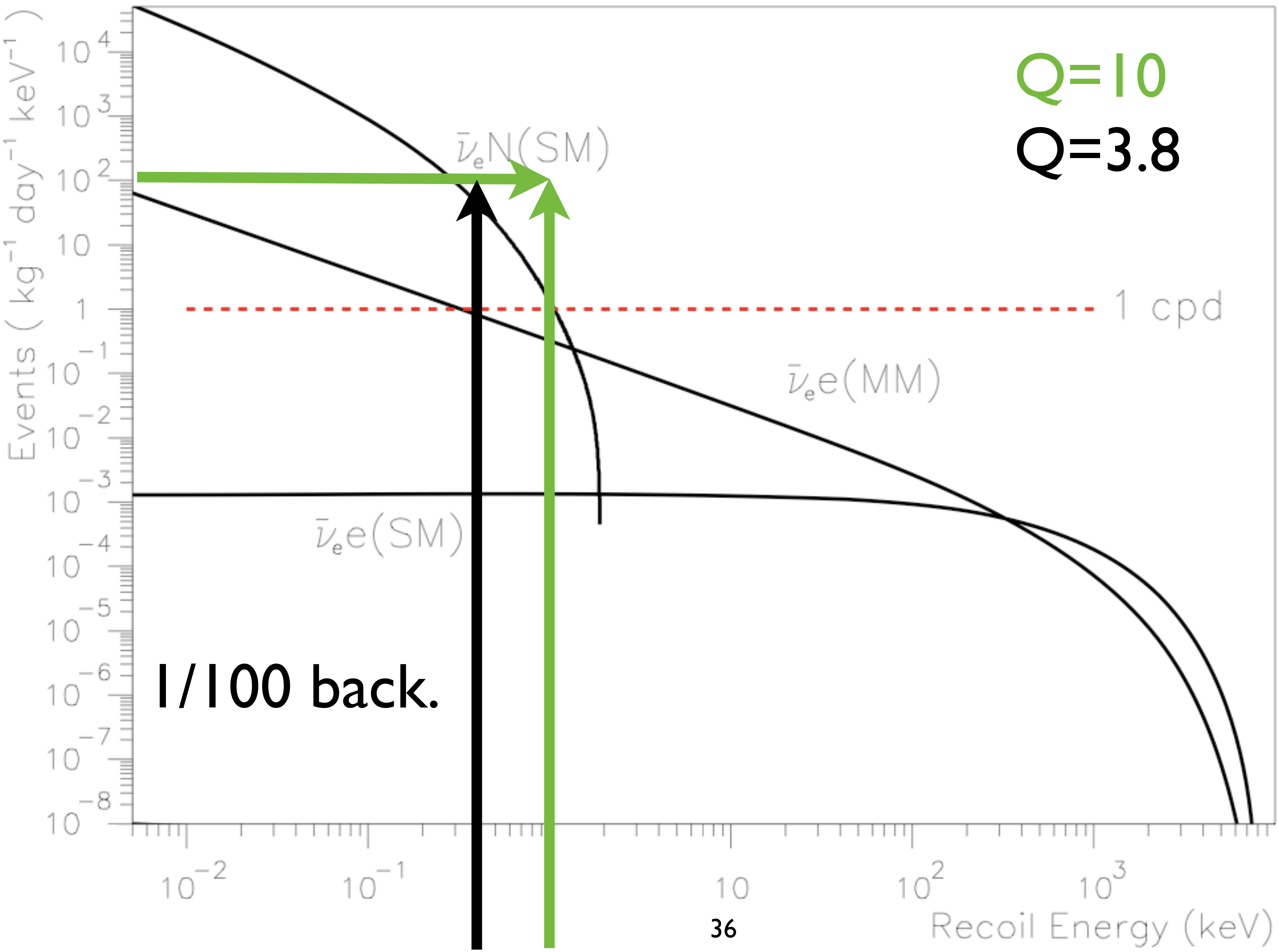
C sees a lot of cables:
Zn (Zinc) - flex circuits

Sr (Strotium) in A?

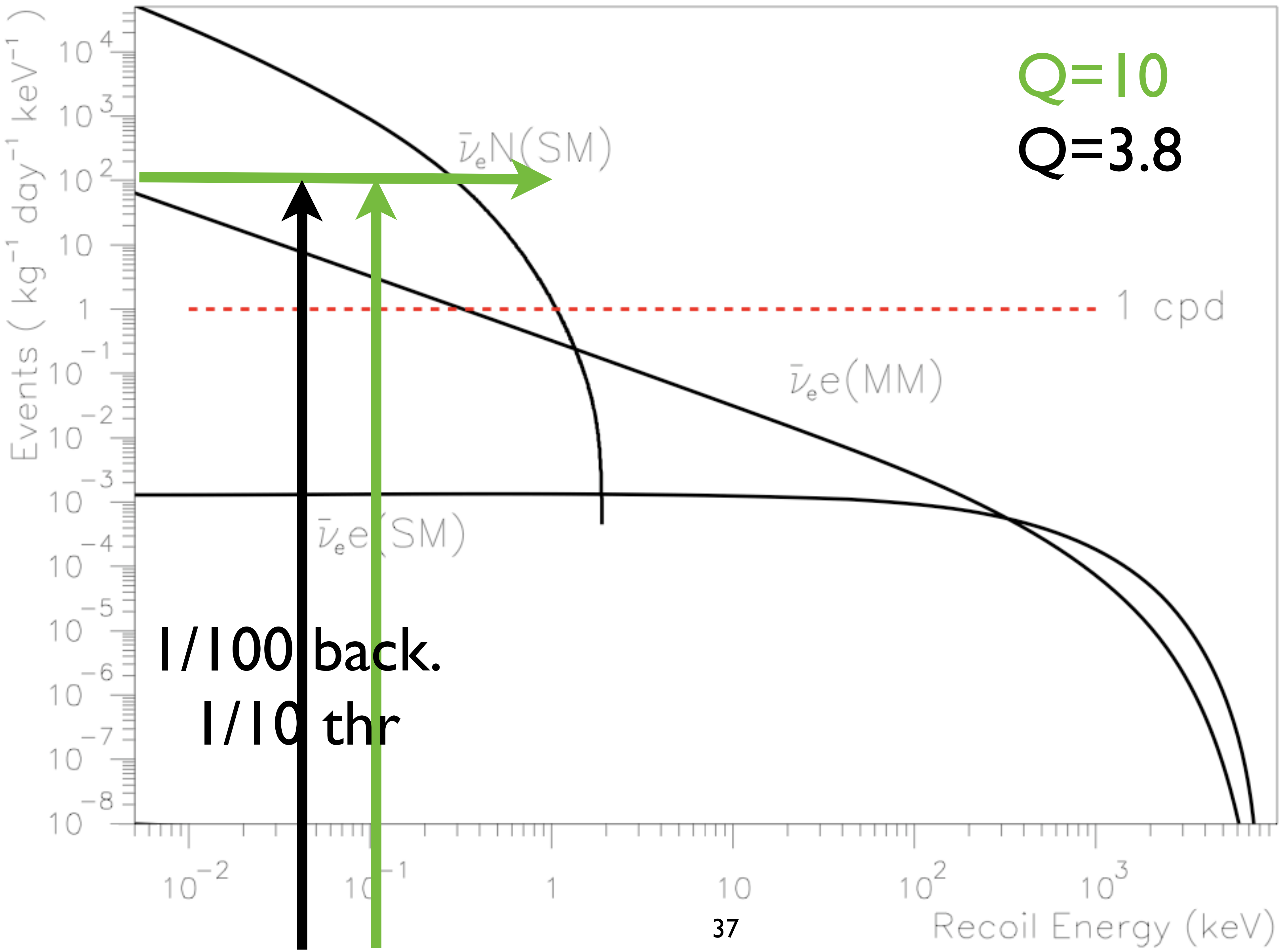
neutrino coherent scattering spectrum at 28m of a 3GW reactor (Texono Collaboration)



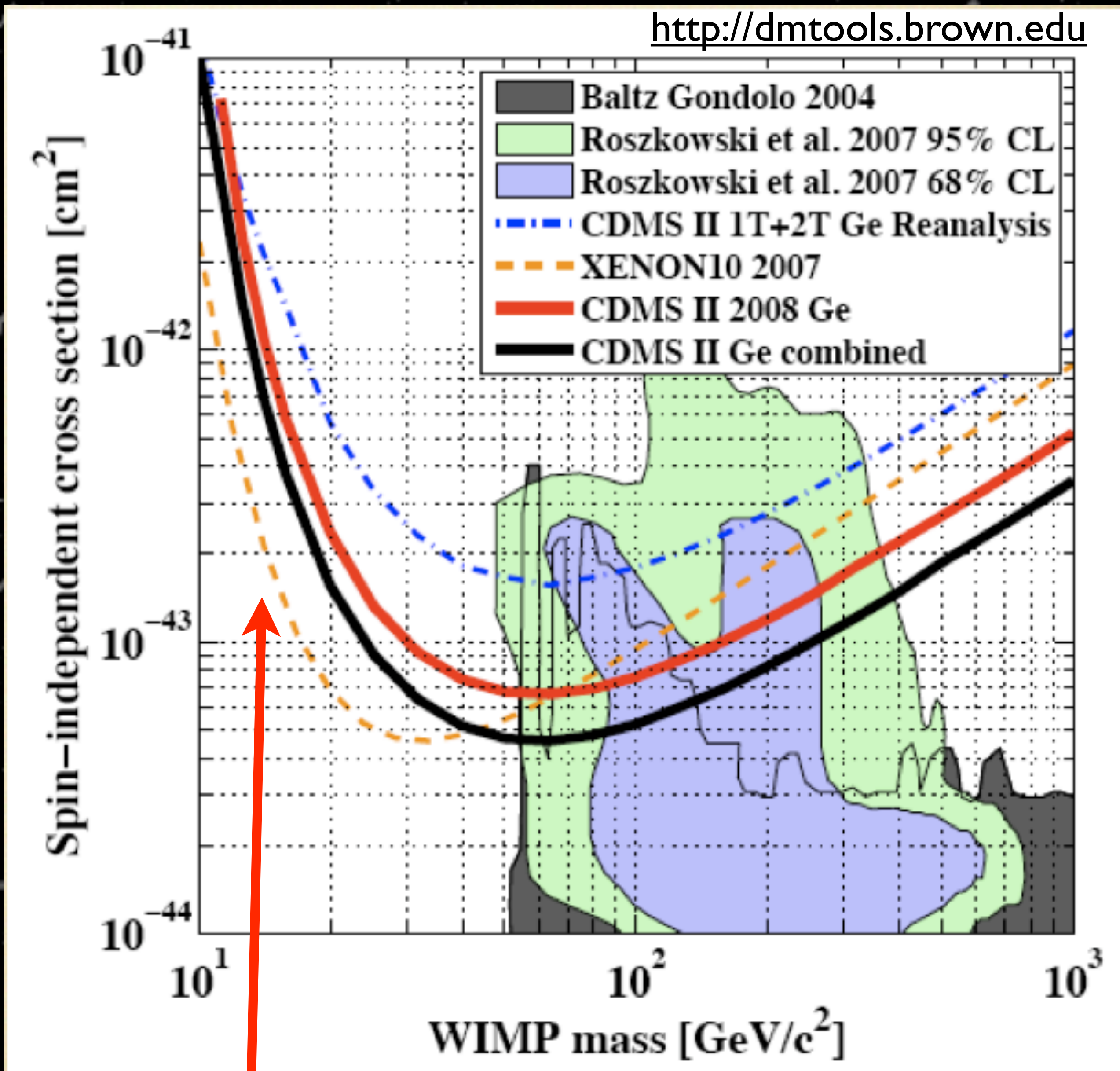
neutrino coherent scattering spectrum at 28m of a 3GW reactor (Texono Collaboration)



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



DM search results



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

from Petriello & Zurek 0806.3989

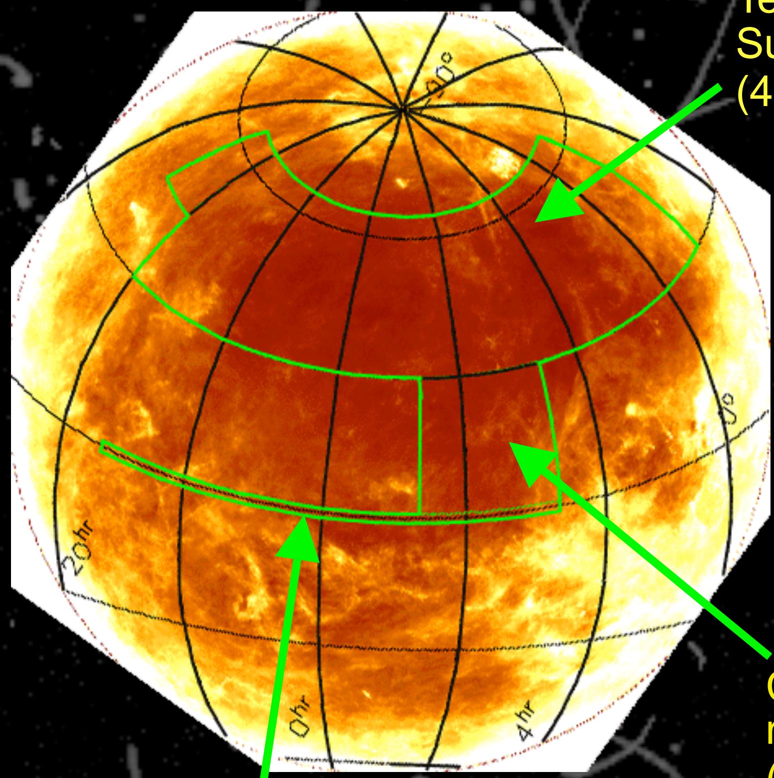
Experiment	Target	Exposure (kg-d)	Threshold	Ref
CDMS-SUF	Ge	65.8	5 keV	[2]
	Si	6.58	5 keV	
CDMS-II	Ge	121.3	10 keV	[3]
	Si	12.1	7 keV	[4]
XENON10	Xe	131	4.5 keV	[5]
CRESST-I	Al_2O_3	1.51	0.6 keV	[16]
DAMIC	**Si**	**~1**	**0.1 keV**	

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

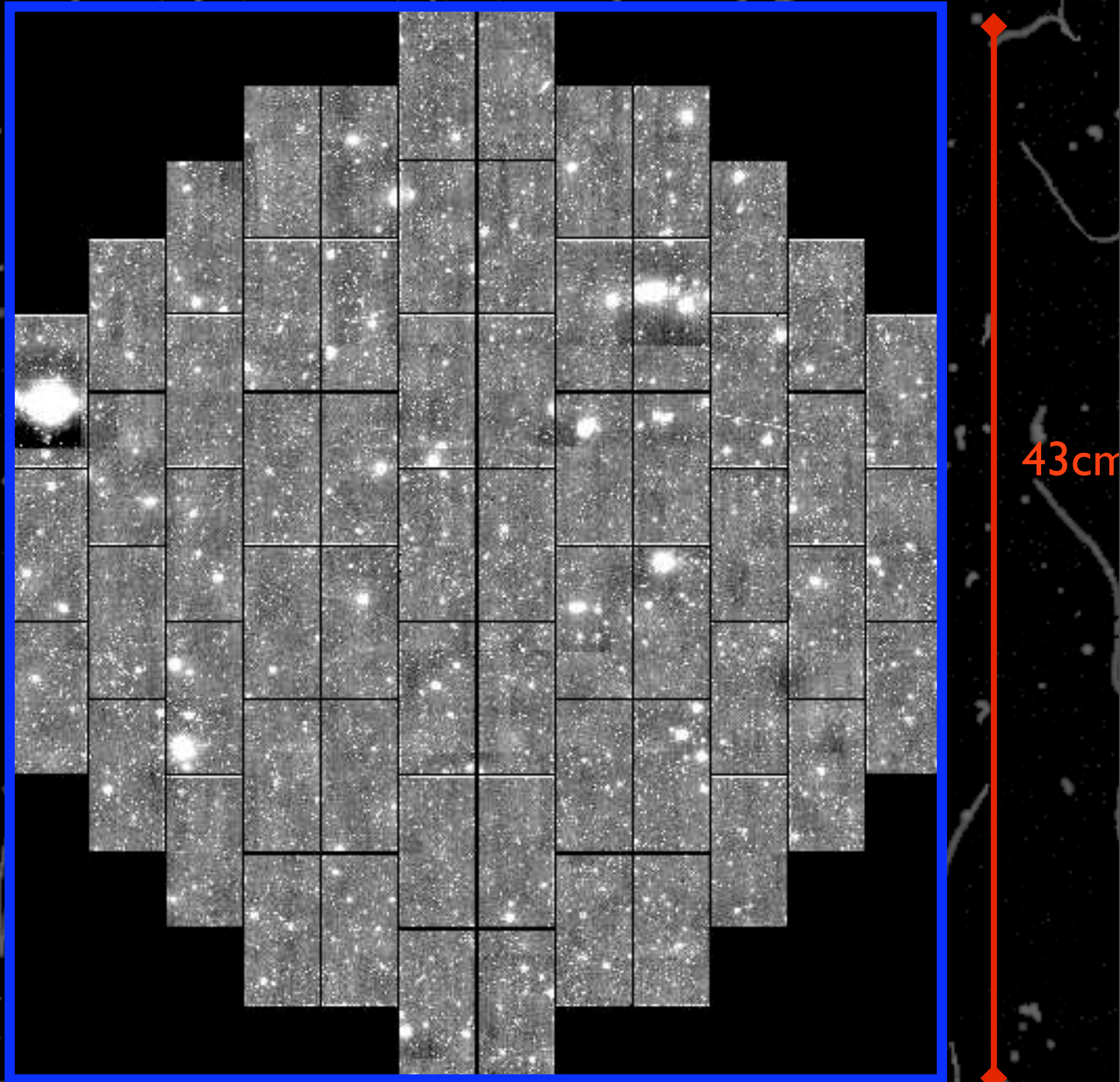
limited by detector threshold, typically a few keV. This limitation comes in part from the readout noise.

Dark Energy Survey

Survey Area



optimized to measure the equation of state parameter w for Dark Energy. Relation between pressure and density.



Galaxy Cluster counting

(collaboration with SPT, see next slides)
20,000 clusters to z=1 with $M>2x10^{14}M_{sun}$

Spatial clustering of galaxies (BAO)

300 million galaxies to z ~ 1

Weak lensing

300 million galaxies with shape measurements over 5000 sq deg

Supernovae type Ia (secondary survey)

~1100 SNe Ia, to z = 1

5.9 keV X-ray from Fe55 gives 1620e-

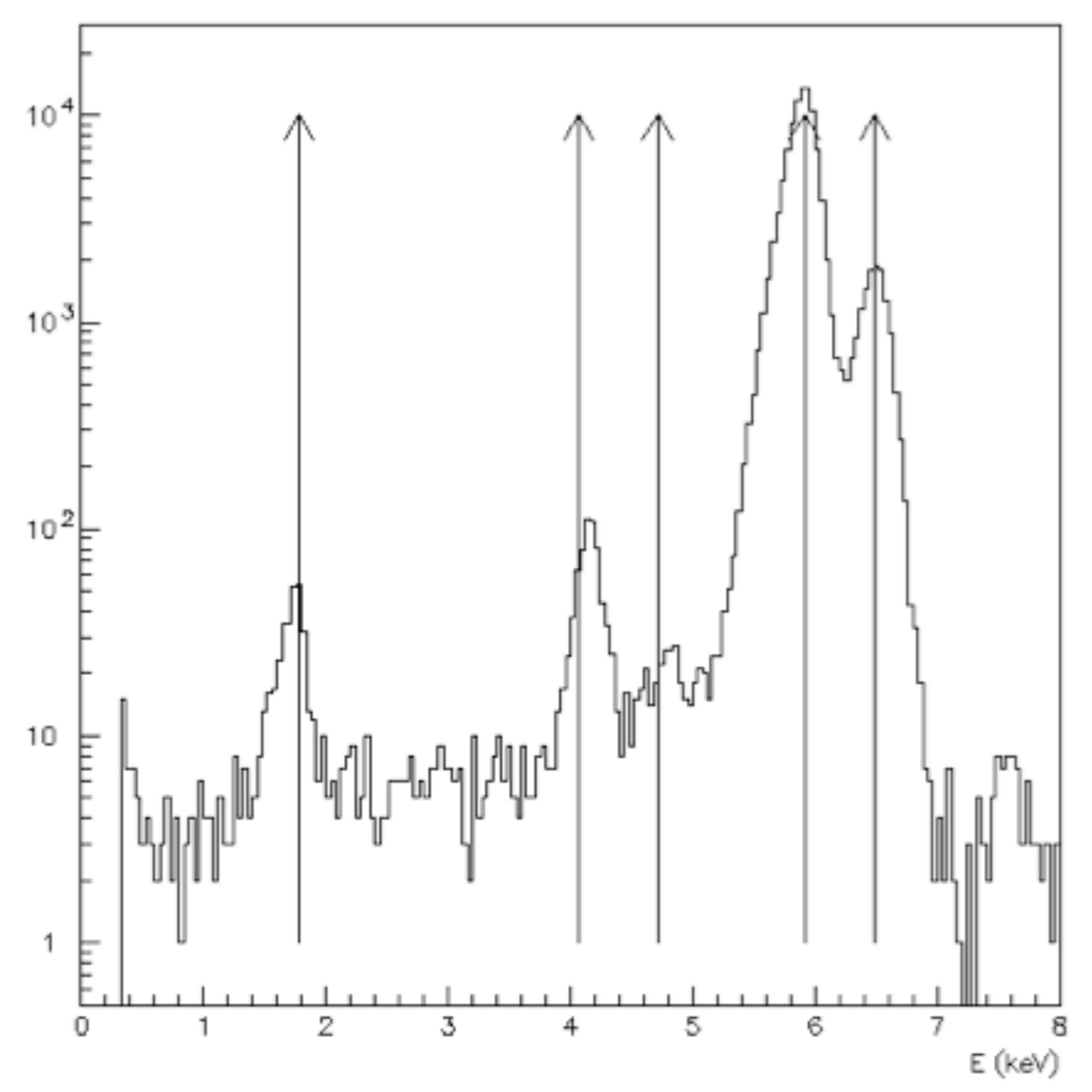
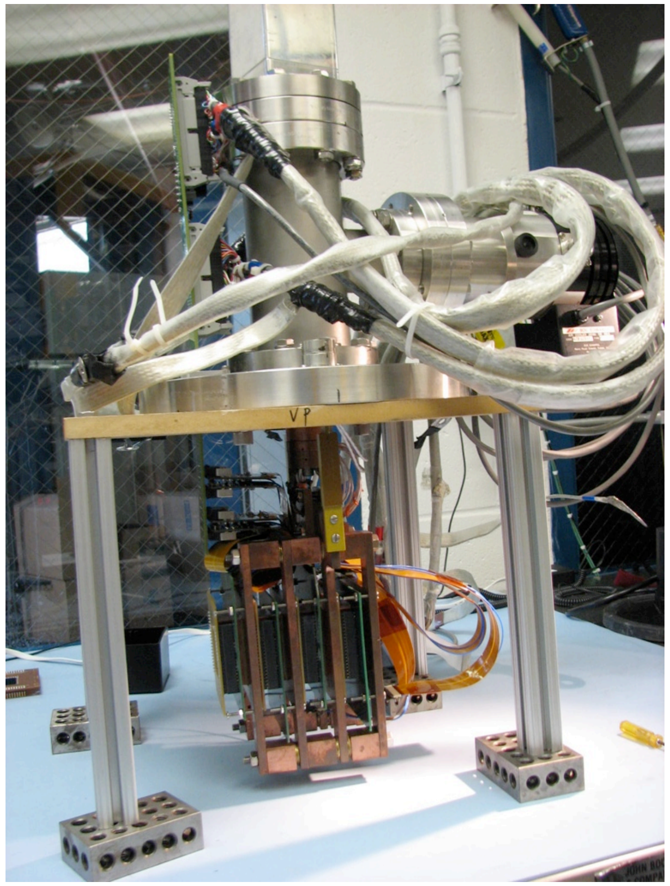
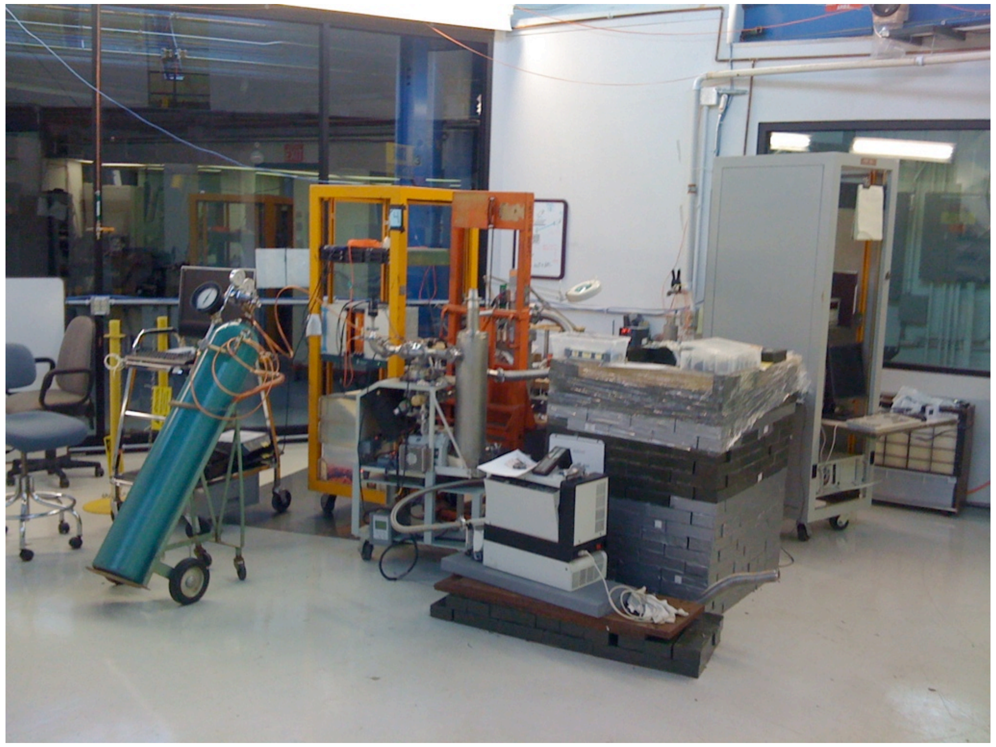


FIG. 4: Spectrum obtained for the reconstructed X-ray hits in an ^{55}Fe exposure of a DECam CCD. The arrows mark the direct X-rays from the source $K\alpha$=5.9 keV and $K\alpha$=6.5 keV, the $K\alpha$ and $K\beta$ escape lines at 4.2 and 4.8 keV, and the Si X-ray at 1.7 keV. The factor 3.64 eV/e is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

DAMIC started at SiDet

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





DECam prototype electronics used