Low threshold DM search using Charge Coupled Devices. DAMIC

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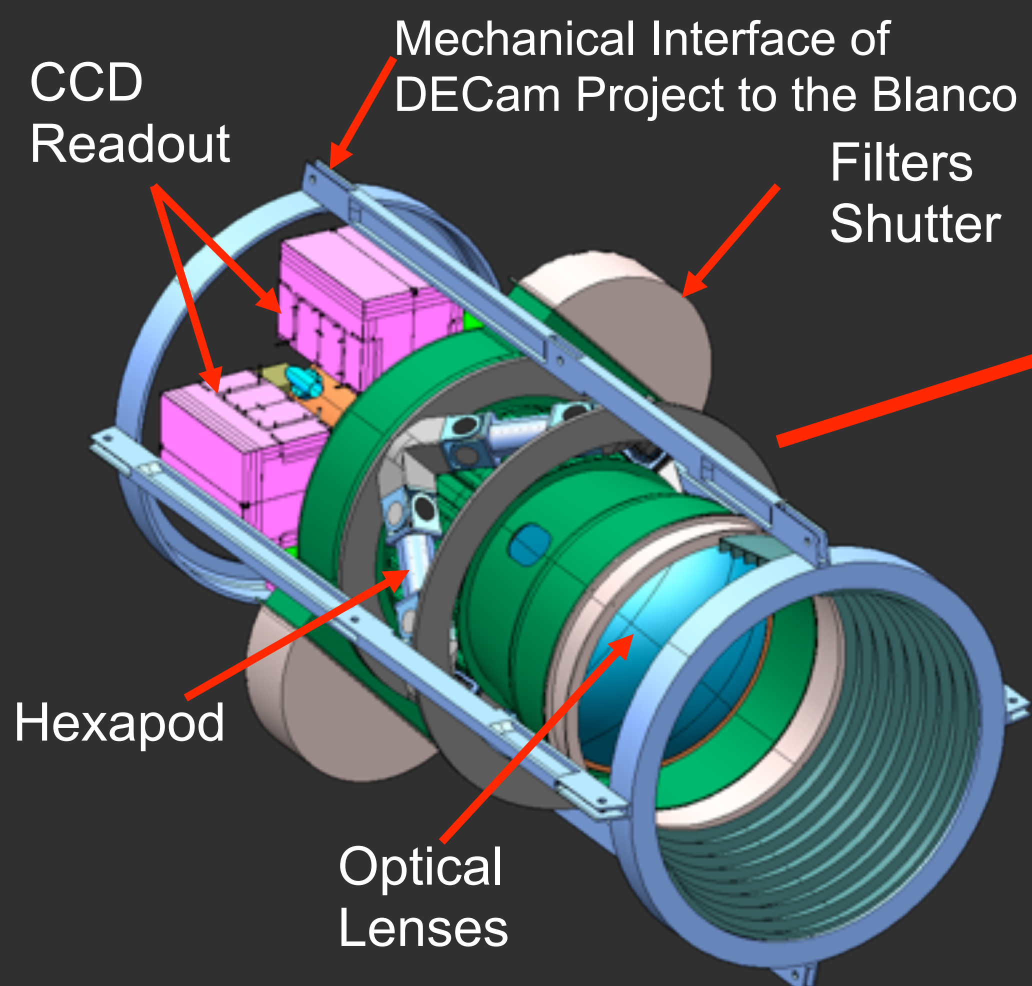
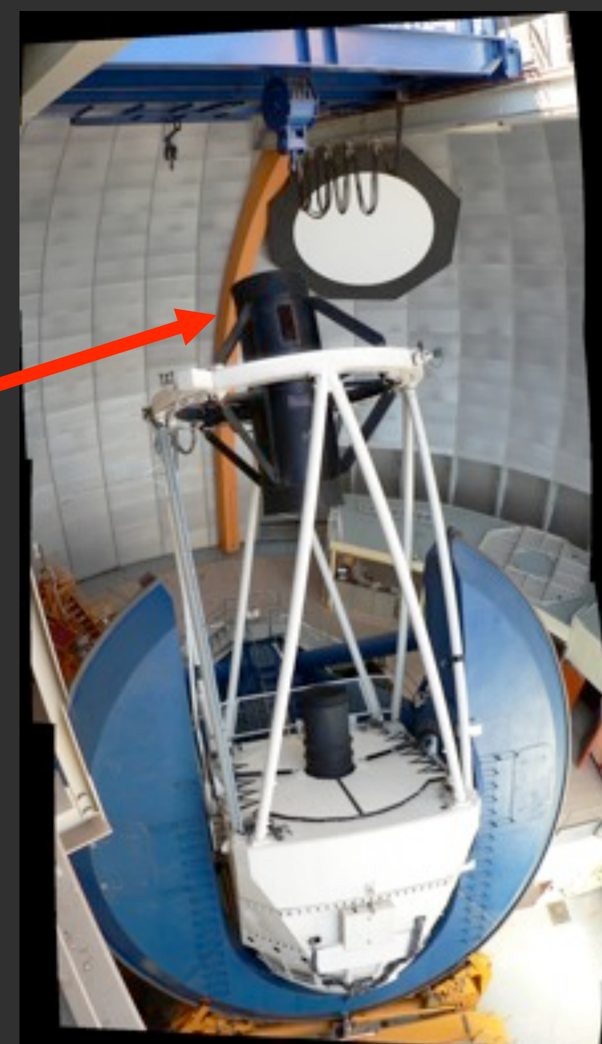
Fermilab

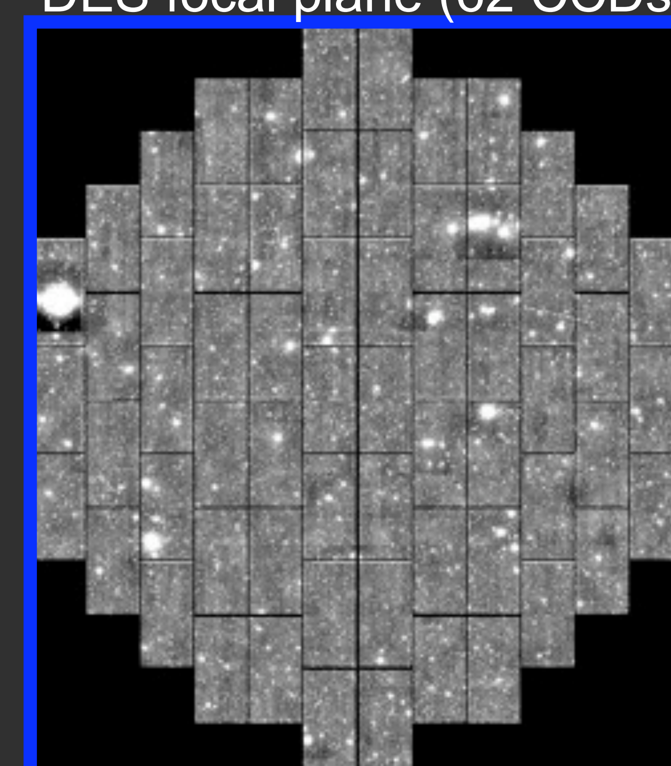
Dark Energy Camera (DECam)

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)



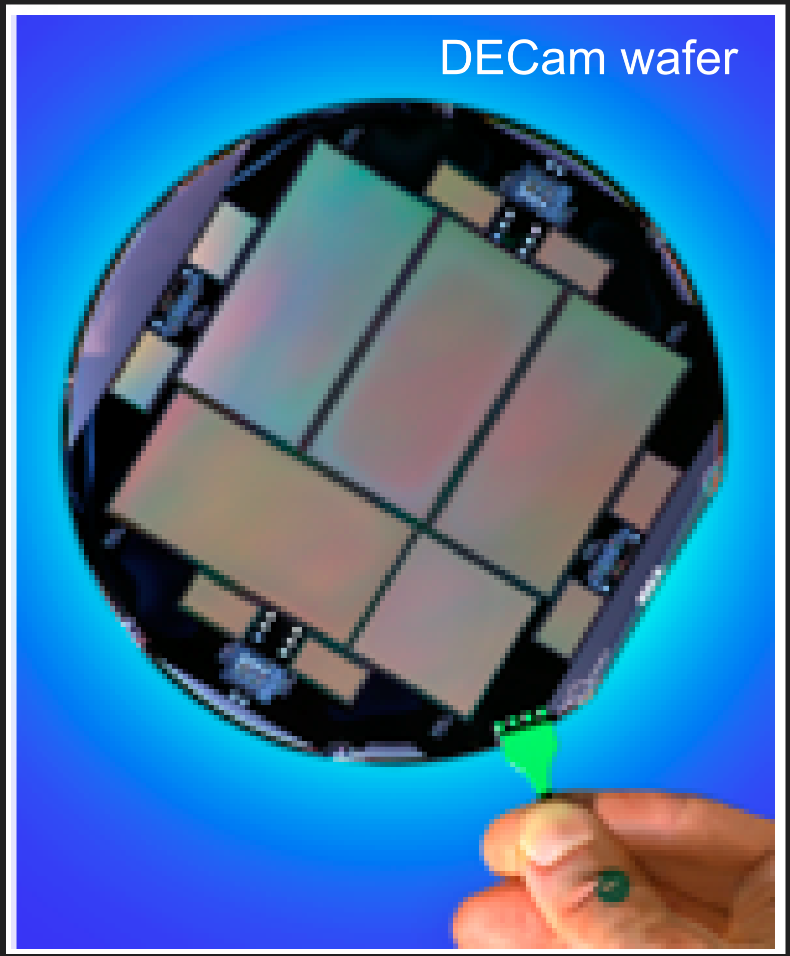
DECam focal plane detectors

Science goal requires DES to reach z~1

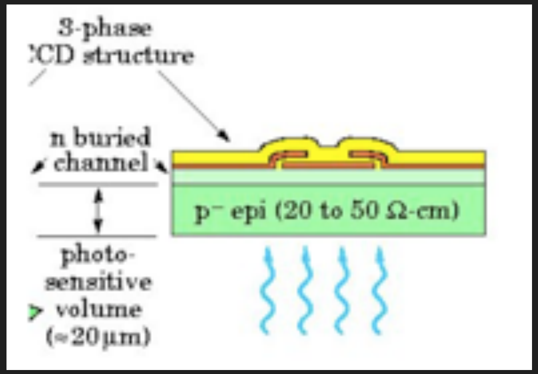
for DES we want to spend ~50% of time in z-filter (825-1100nm)
Astronomical CCDs are usually thinned to 30-40 microns (depletion):
Good 400nm response
Poor 900nm response

LBNL full depletion CCD are the choice for DECam:

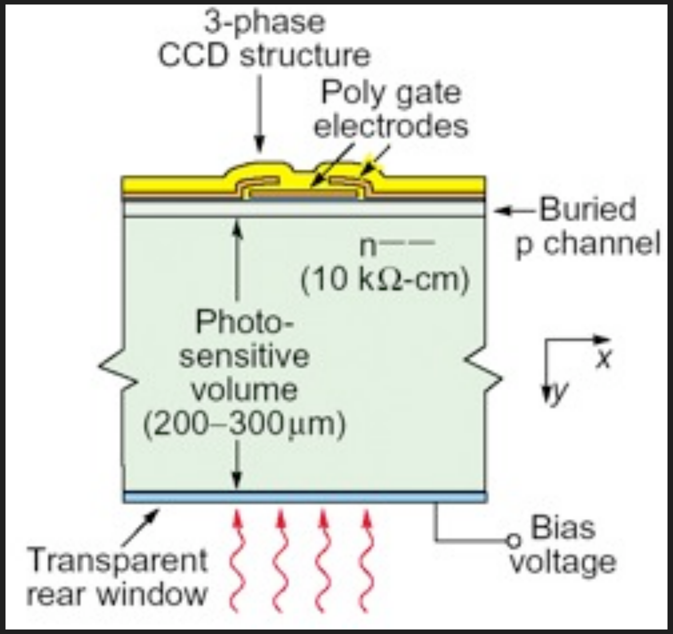
- 250 microns thick
- high resistivity silicon
- QE> 50% at 1000 nm



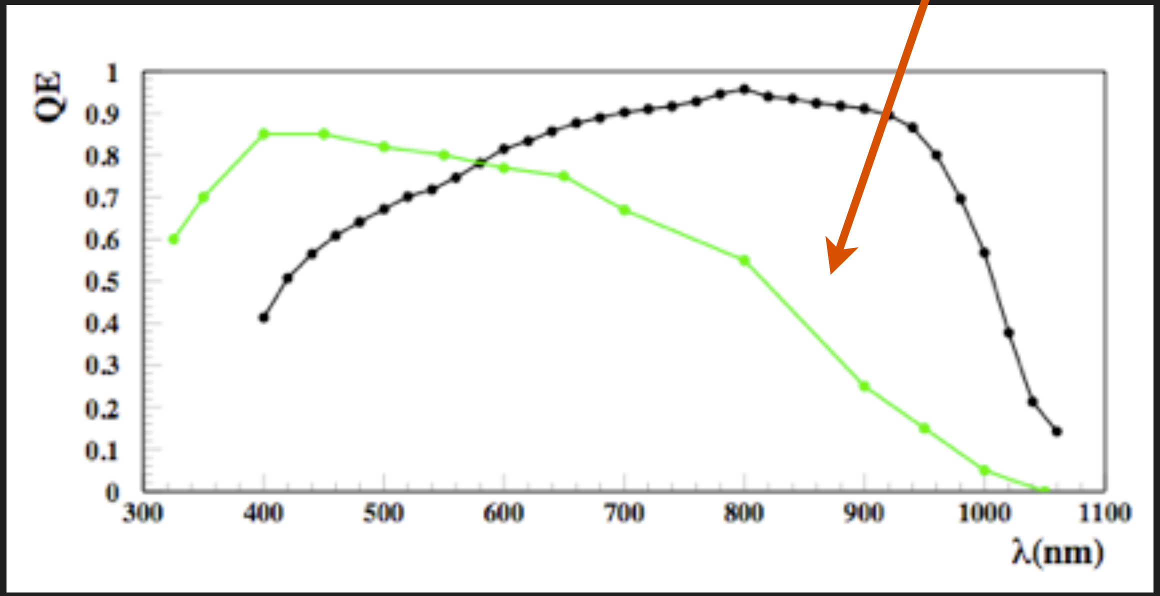
typical CCDs



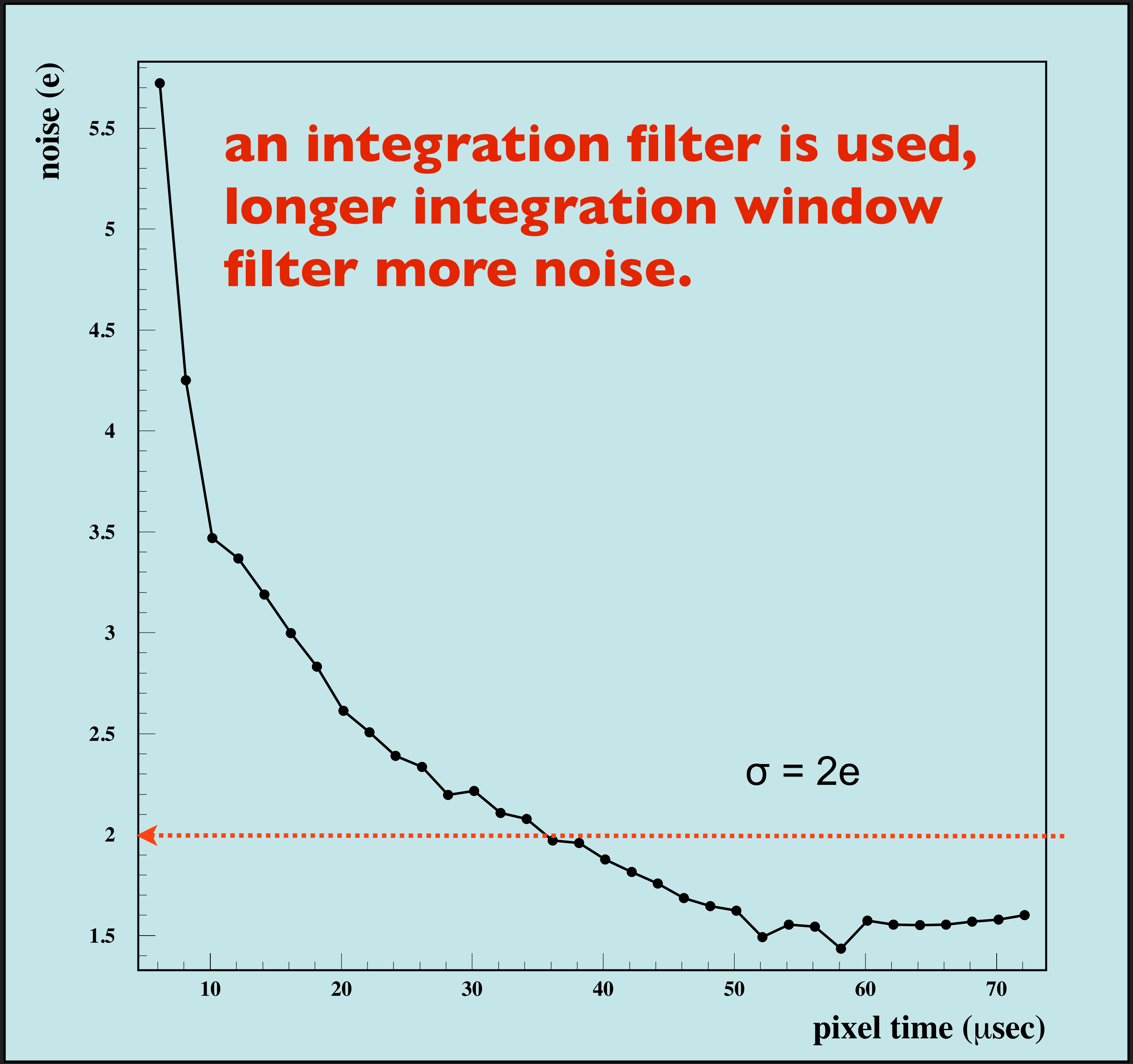
new thick CCDs



higher efficiency for hi-z objects.



New opportunities with these CCDs



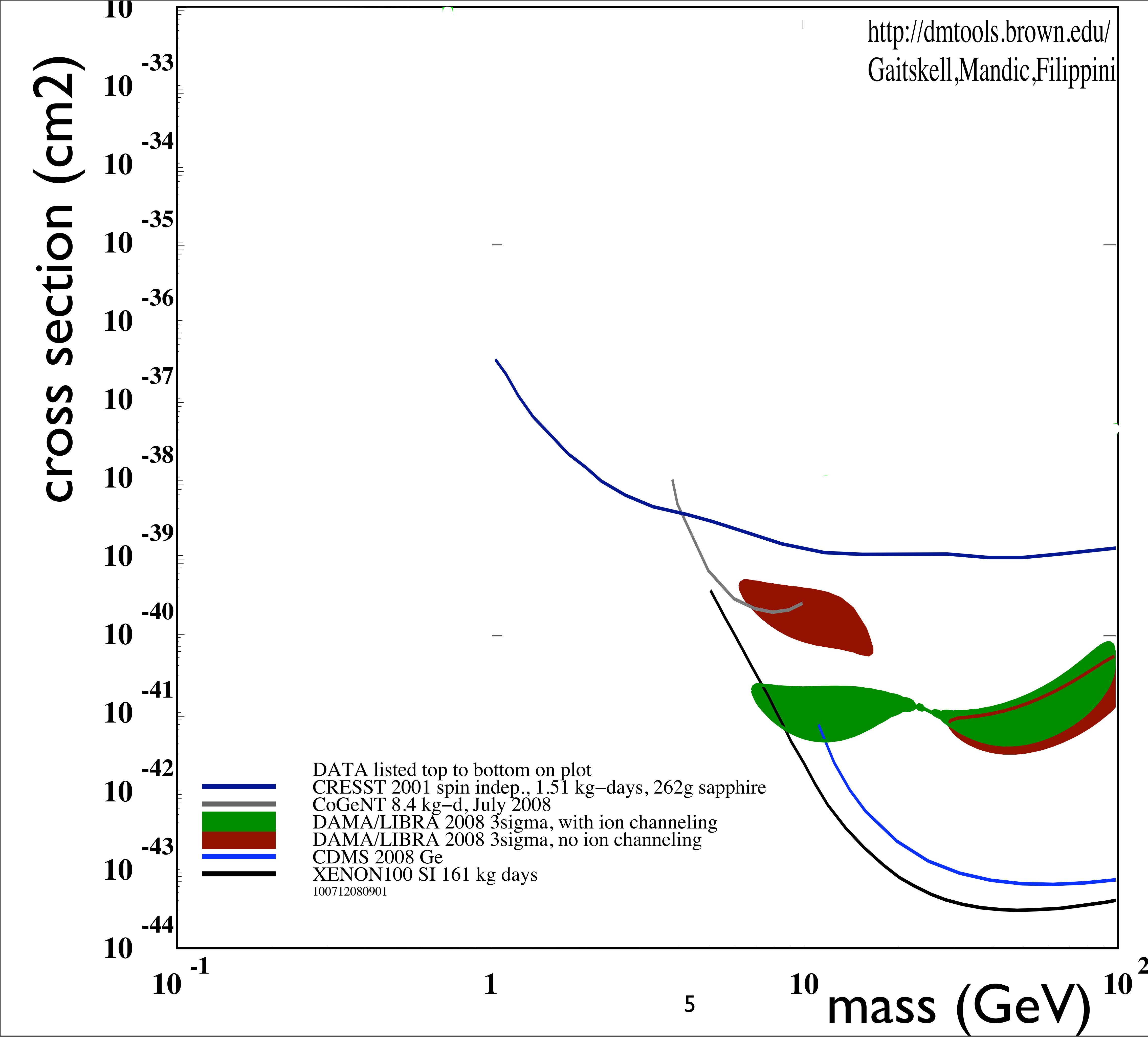
Two features:

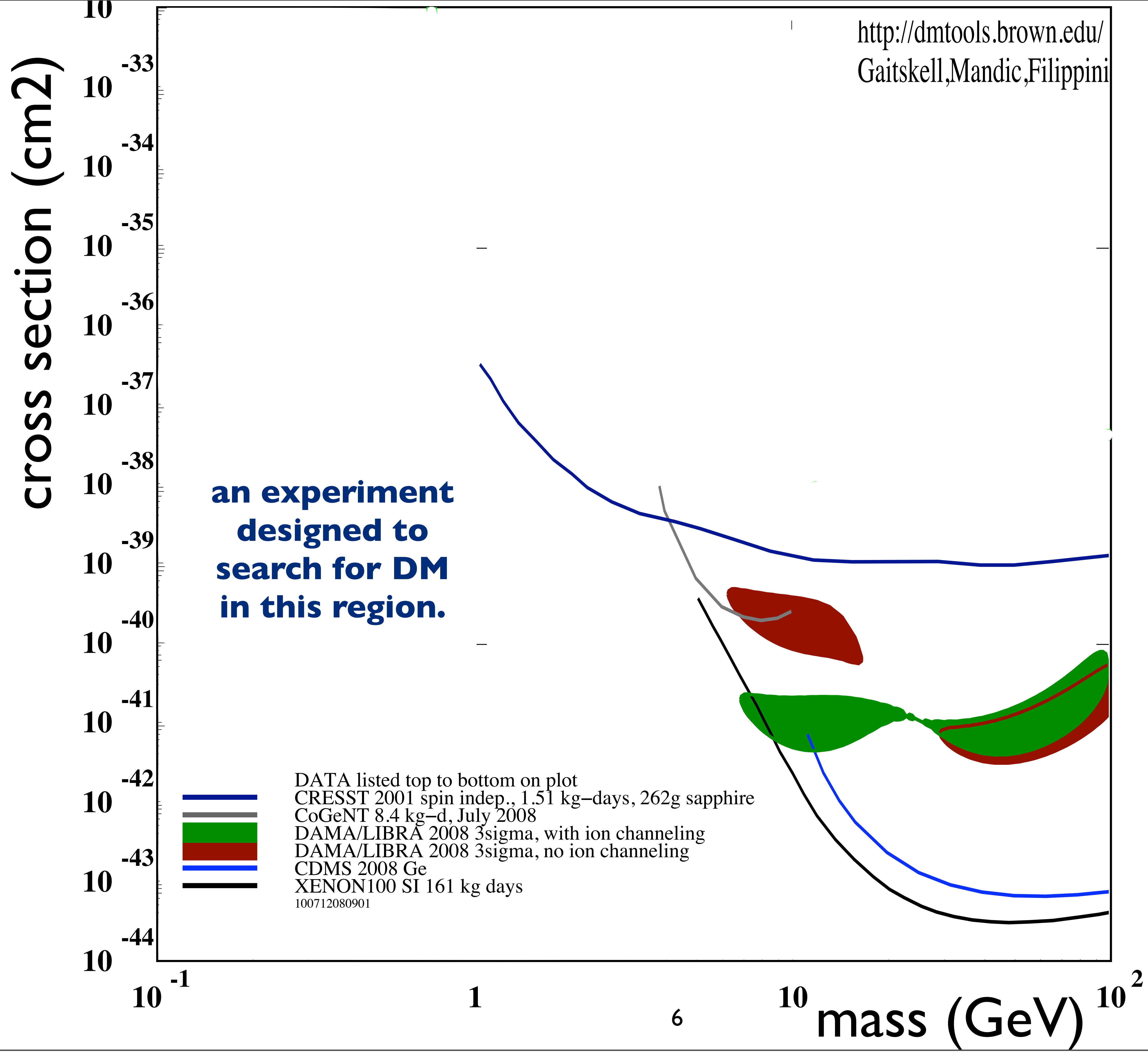
CCDs are readout serially (2 outputs for 8 million pixels). When readout slow, these detectors have a noise below 2e- (RMS). This means an **RMS noise of 7.2 eV in ionization energy!**

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

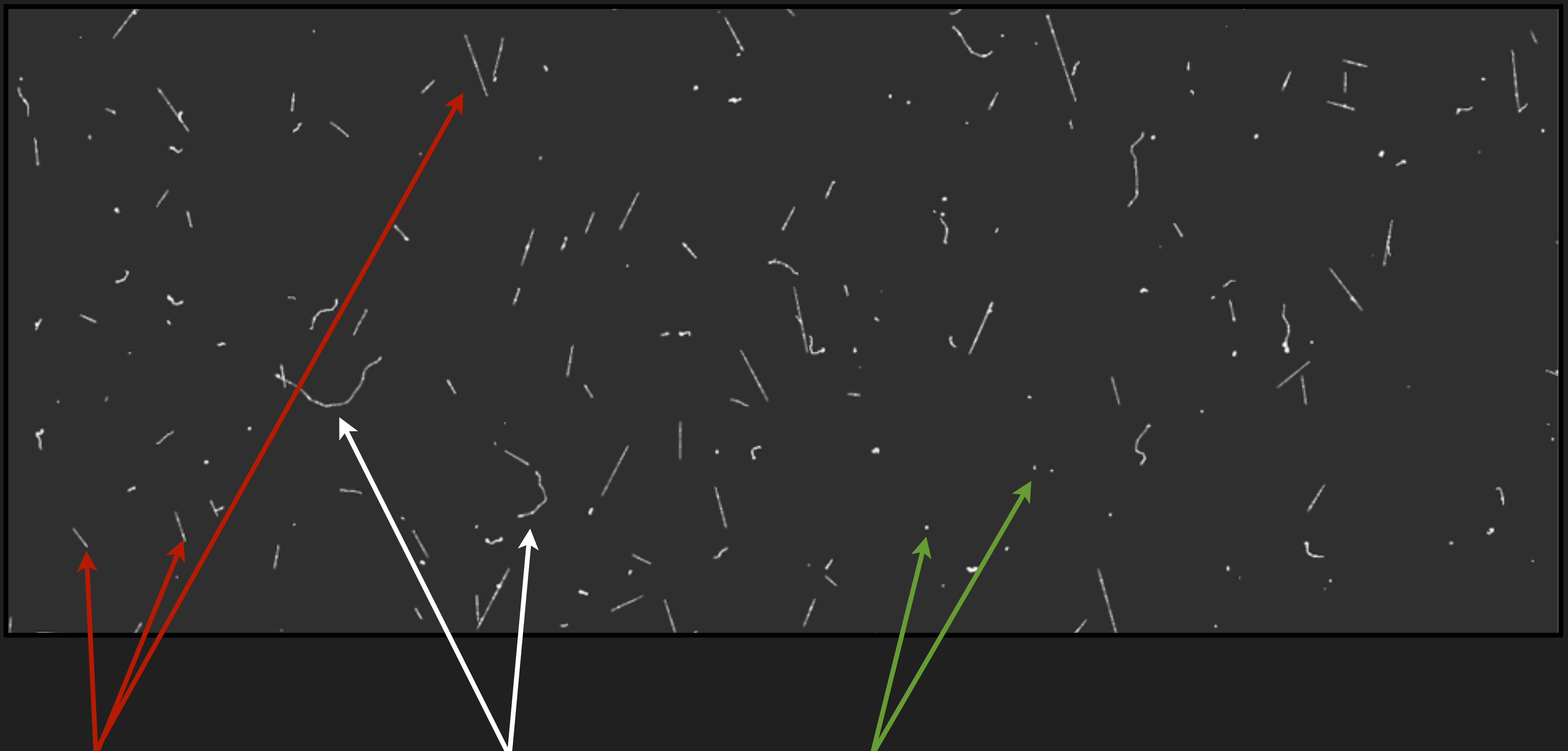
Interesting for a low threshold DM search.

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


http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
cross section (cm2)
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
5
10
10^{2}
mass (GeV)
DATA listed top to bottom on plot
CRESST 2001 spin indep., 1.51 kg−days, 262g sapphire
CoGeNT 8.4 kg−d, July 2008
DAMA/LIBRA 2008 3sigma, with ion channeling
DAMA/LIBRA 2008 3sigma, no ion channeling
CDMS 2008 Ge
XENON100 SI 161 kg days
100712080901


http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
cross section (cm2)
mass (GeV)
an experiment designed to search for DM in this region.
DATA listed top to bottom on plot
CRESST 2001 spin indep., 1.51 kg−days, 262g sapphire
CoGeNT 8.4 kg−d, July 2008
DAMA/LIBRA 2008 3sigma, with ion channeling
DAMA/LIBRA 2008 3sigma, no ion channeling
CDMS 2008 Ge
XENON100 SI 161 kg days
100712080901

Radiation in CCDs



muons, electrons and diffusion limited hits.

nuclear recoils will produce diffusion limited hits

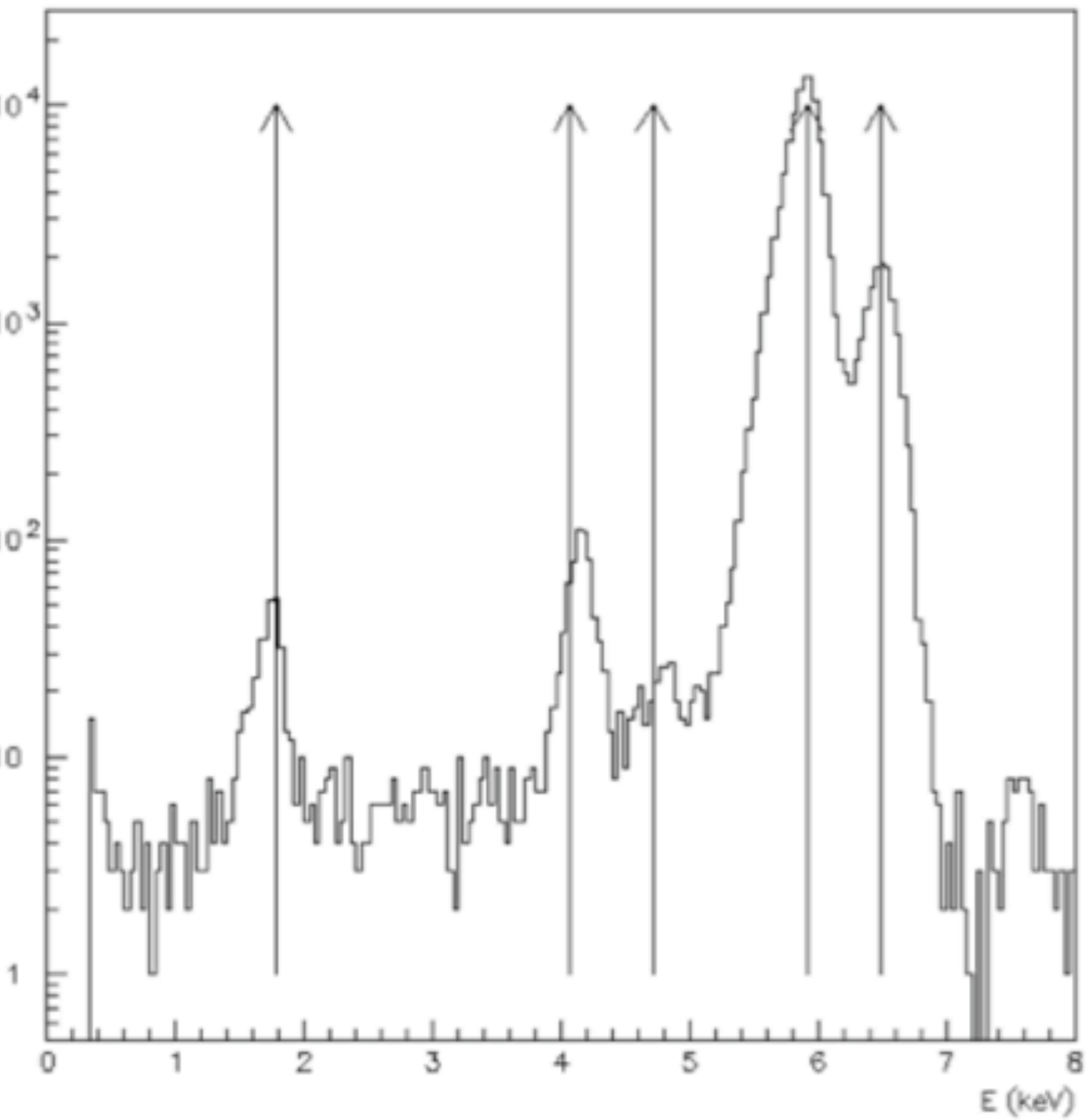
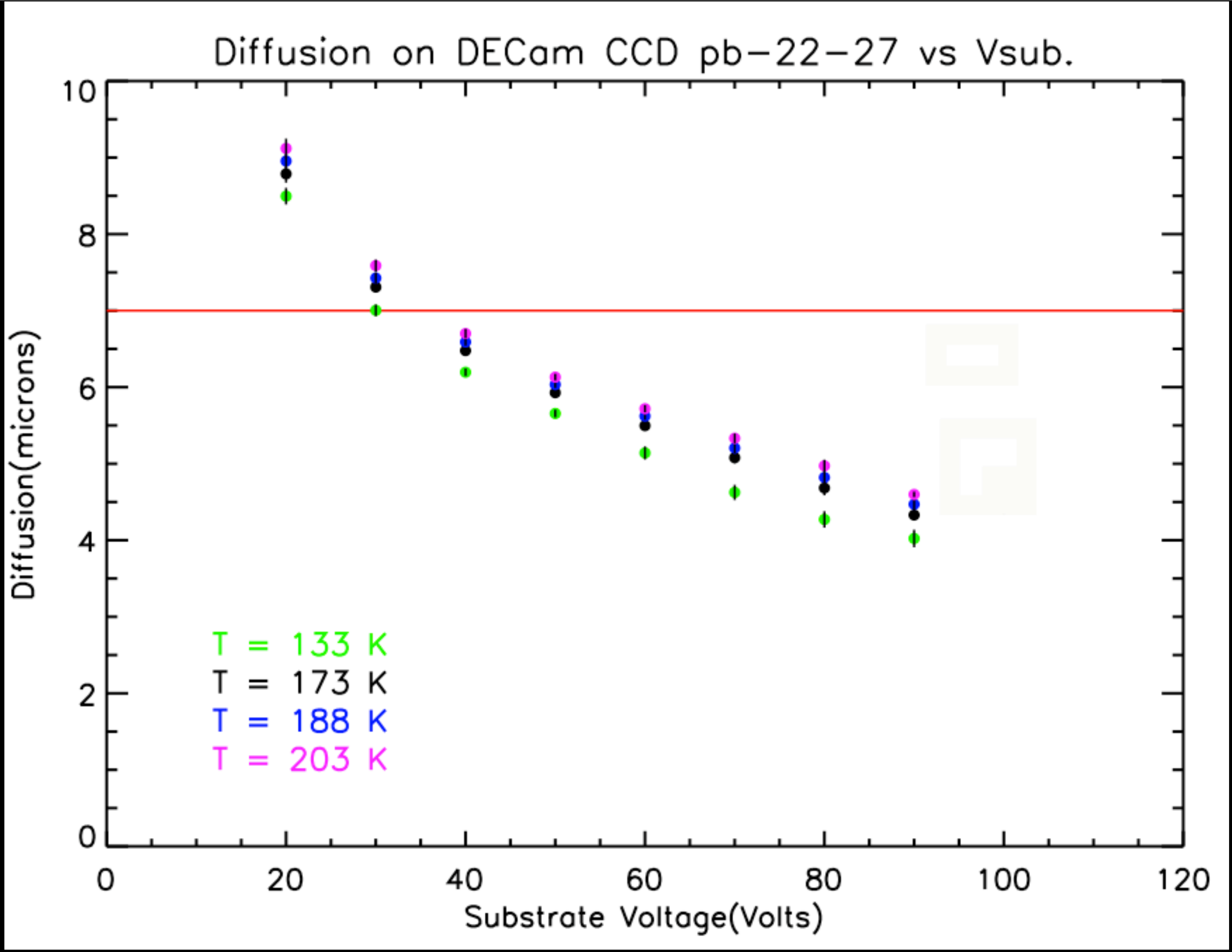


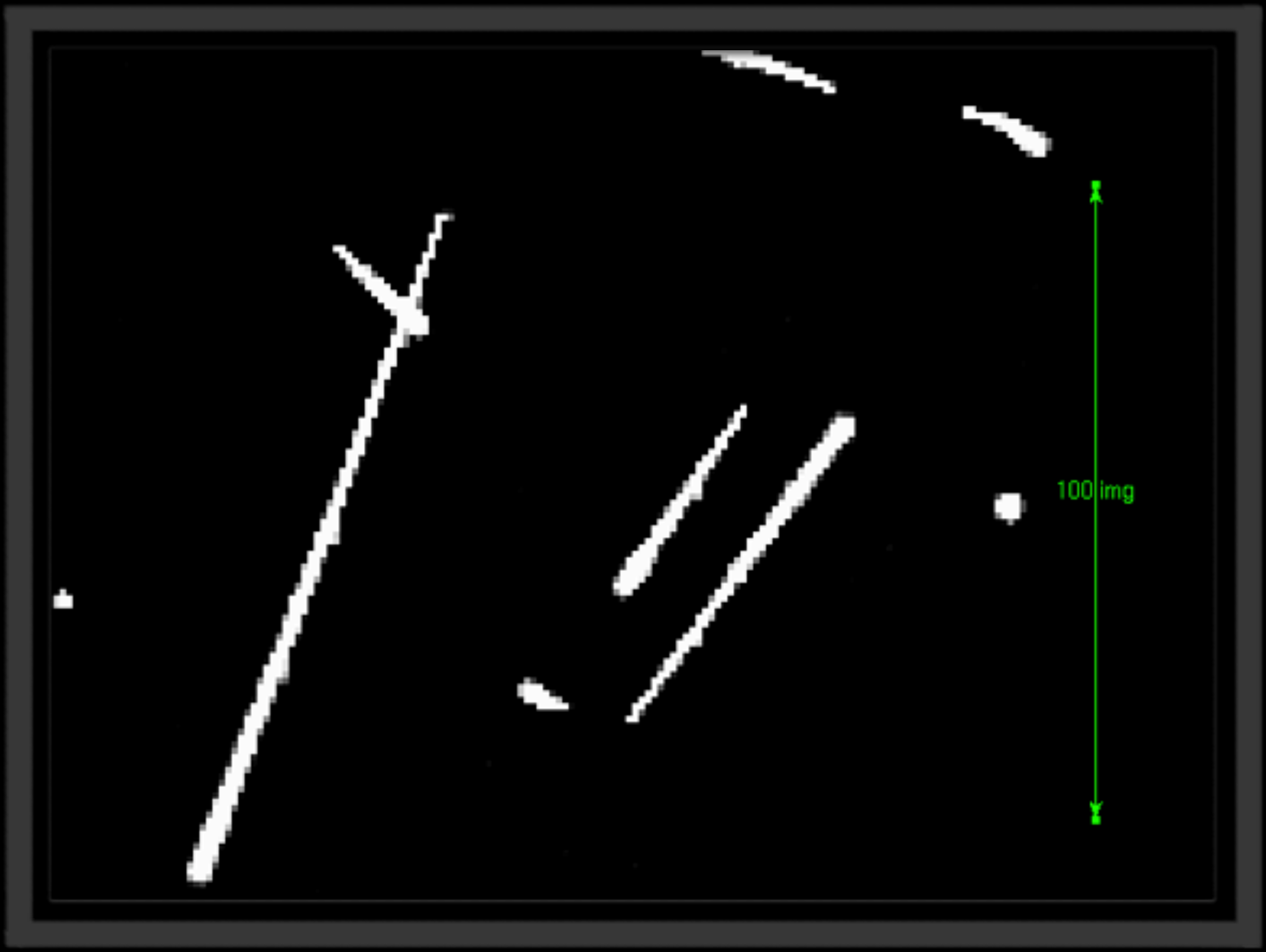
Figure 8. Spectrum obtained for the reconstructed X-ray hits in an ^{55}Fe exposure of a DECam CCD. The arrows are marking the direct X-rays from the source K_α=5.9 keV and K_α=6.5 keV. K_α and K_β escape lines at 4.2 and 4.8 keV, and the Si X-ray at 1.7 keV. The factor of 3.64 eV/e^- is used to covert from charge to ionization energy.

X-rays are a good way to calibrate the energy scale... and also measure diffusion.

diffusion limited hits ➢



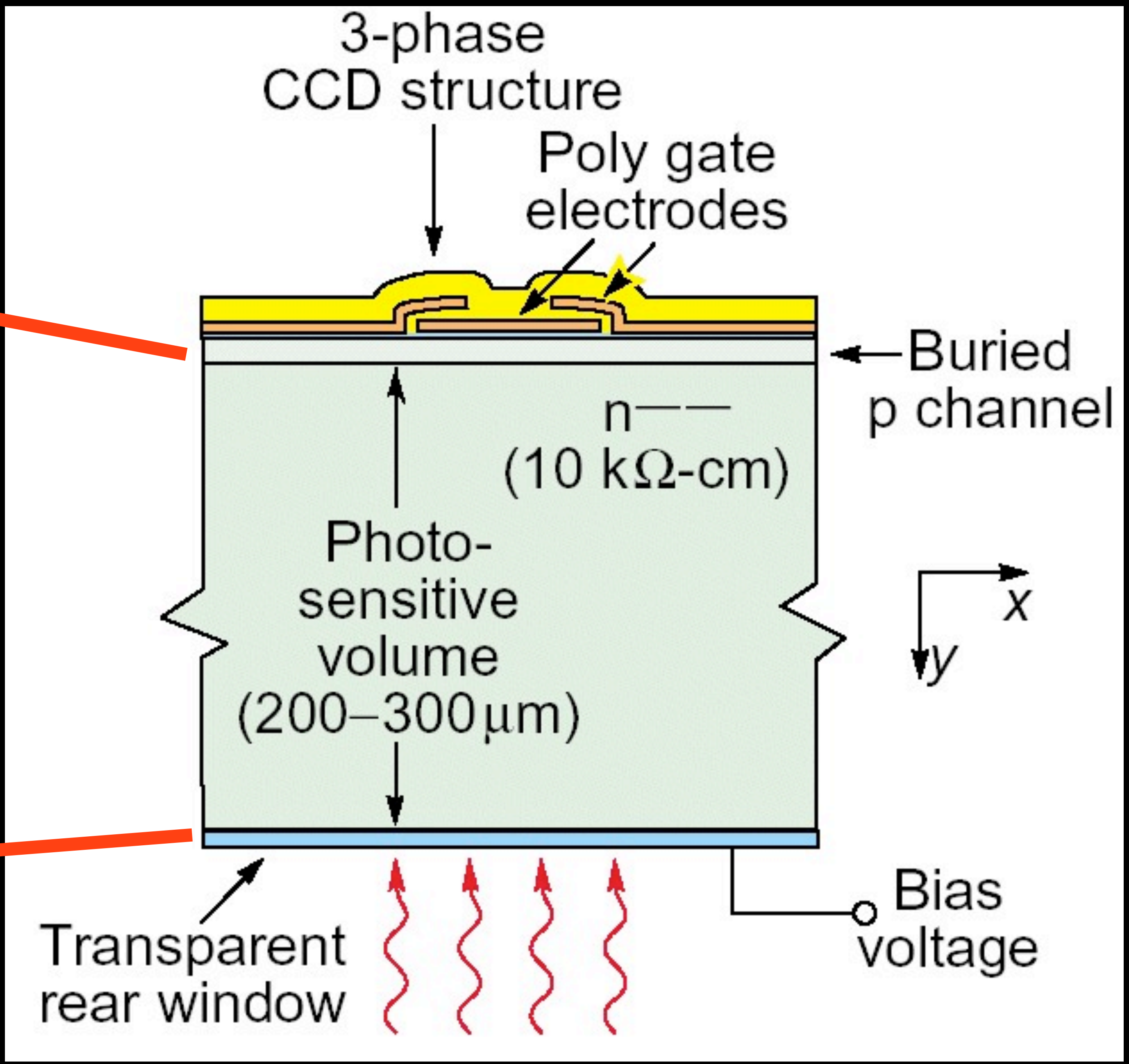
diffusion measurement using x-rays. One could simply select nuclear recoils by using the size... but there is a bit more of information.



the straight tracks are muons

...these tracks show the diffusion inside the CCDs no diffusion close to the gates

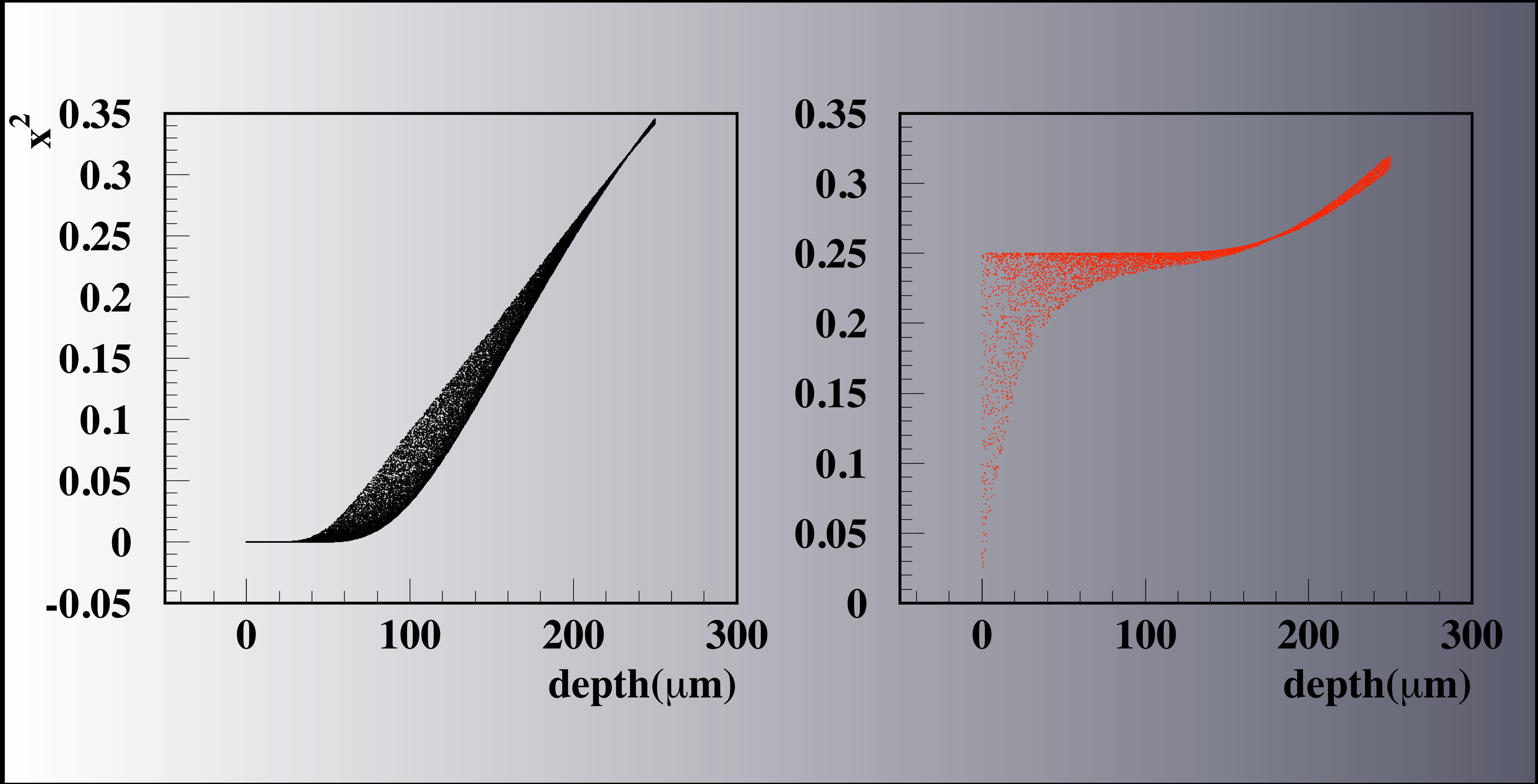
7 um diffusion at the back side

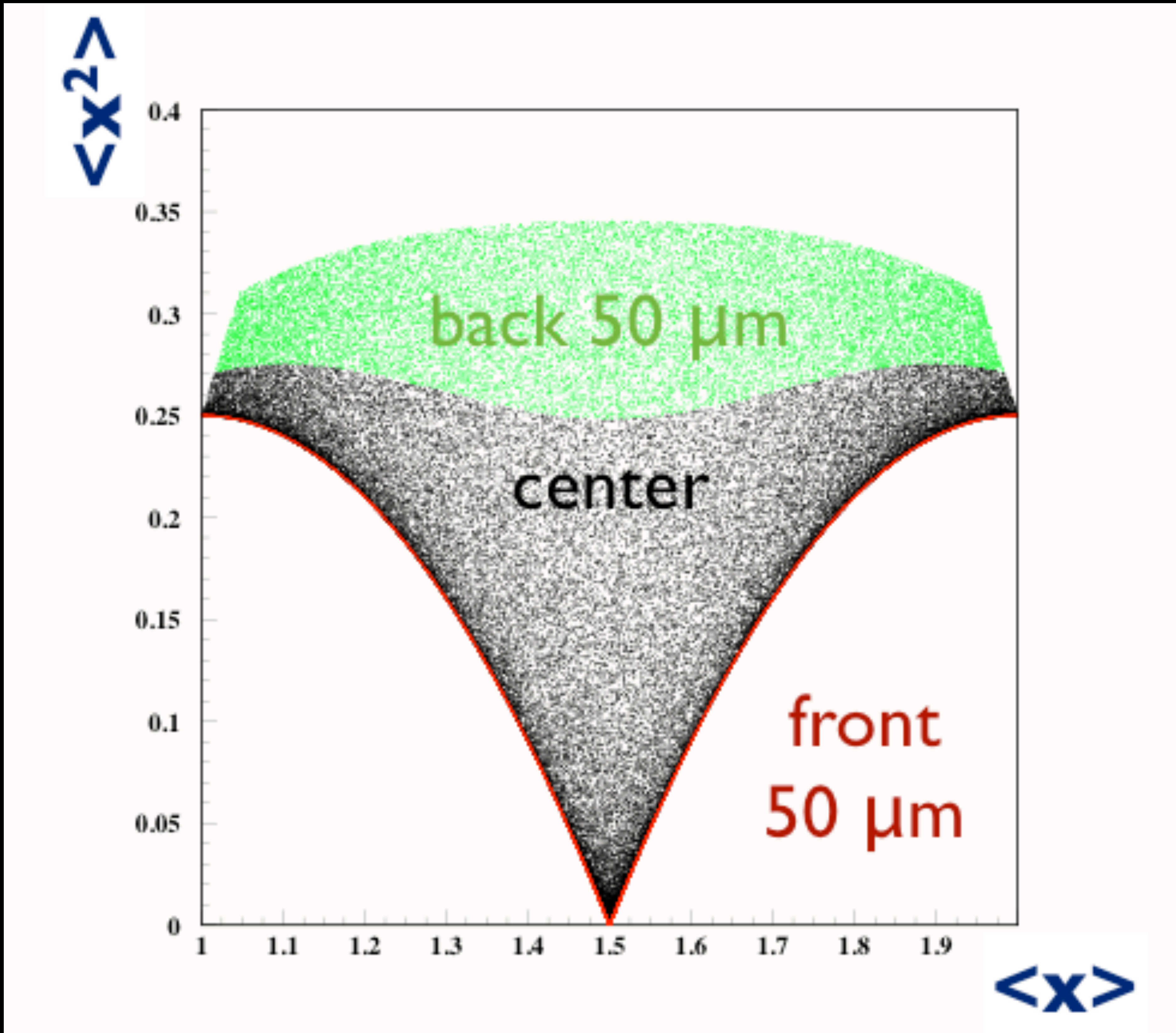


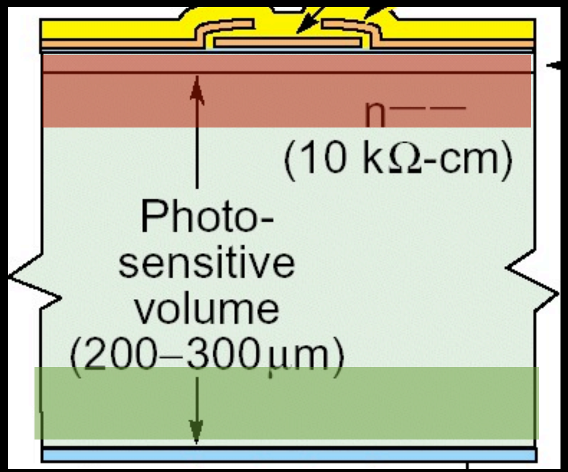
size of diffusion limited hits (simulation)

center

edge

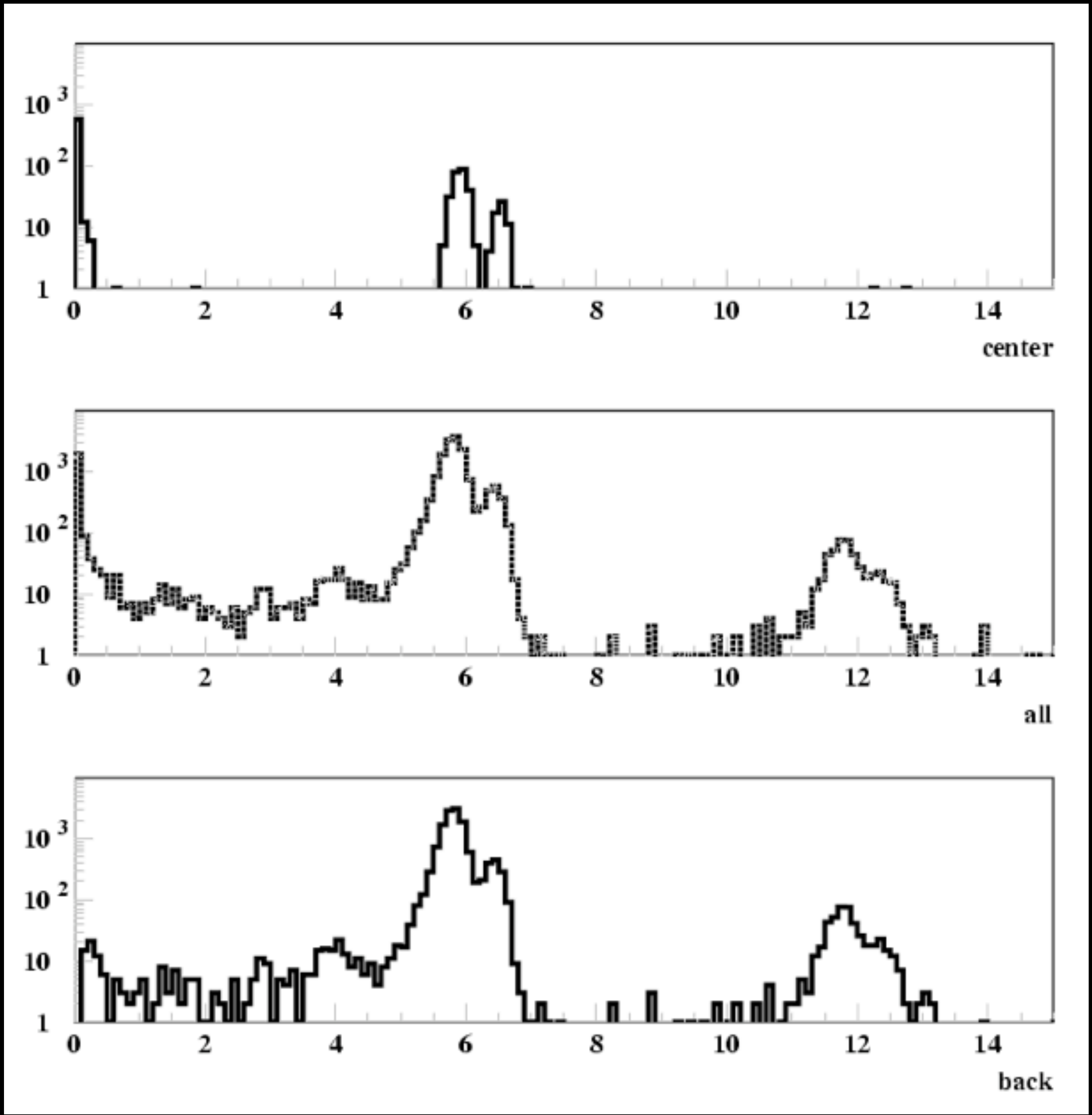


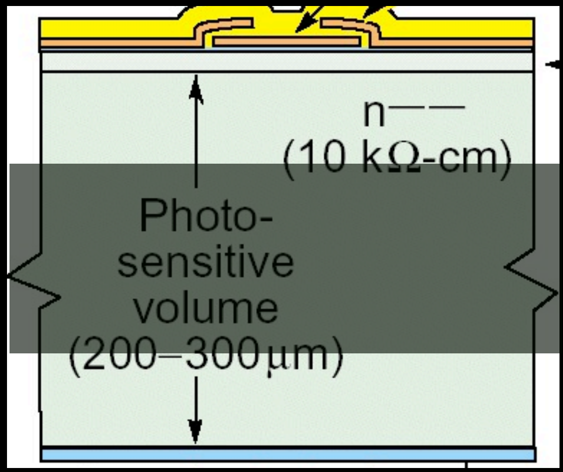


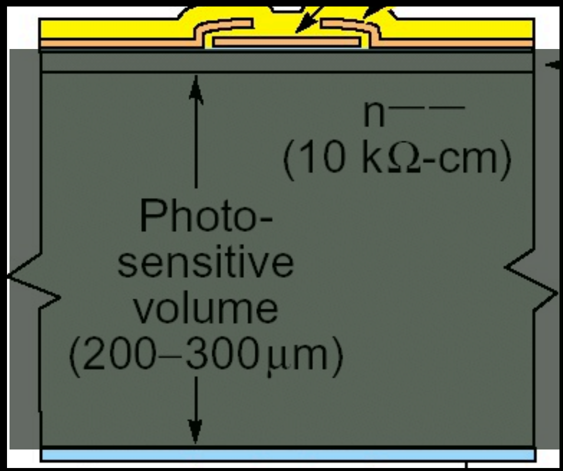


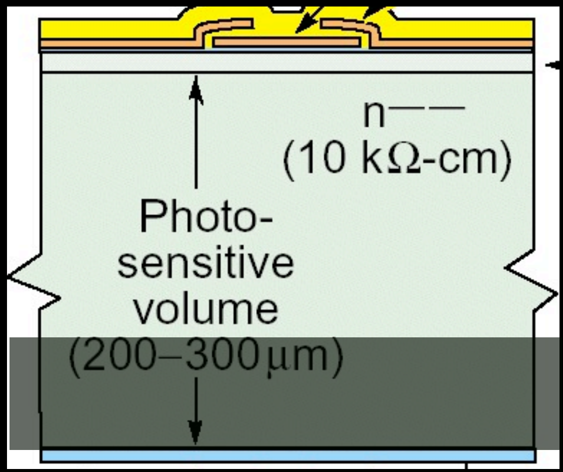
it is possible to select nuclear recoil on the bulk of the detector(cutting low energy photons on surface).

back illumination with x-rays

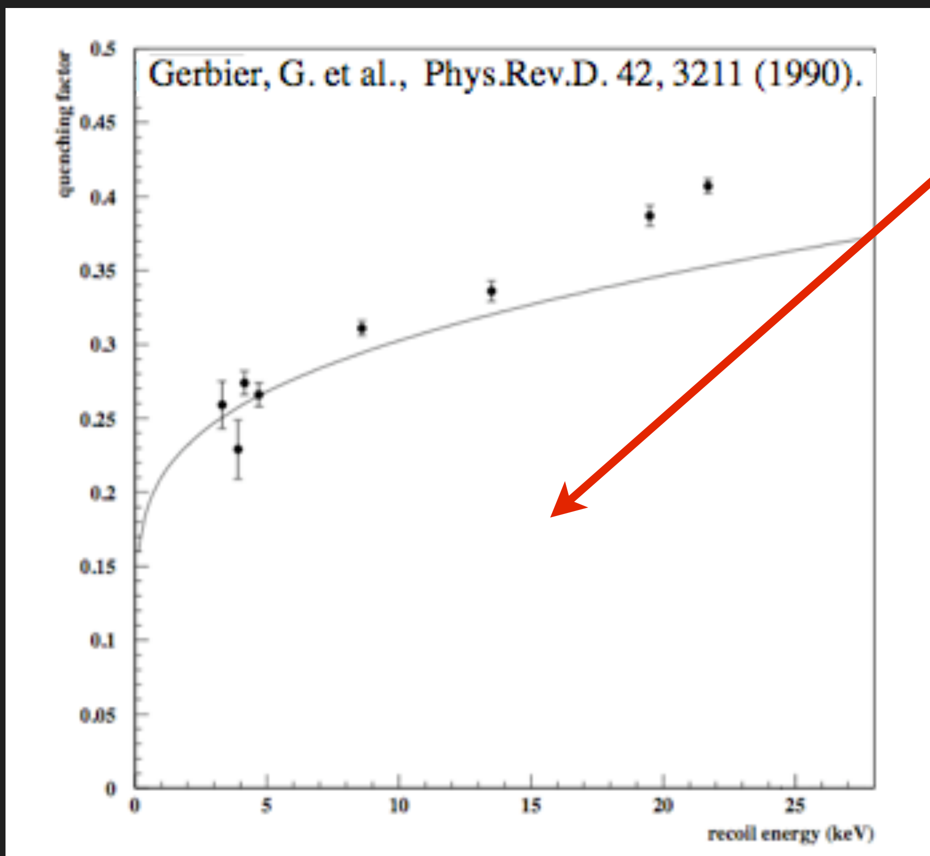




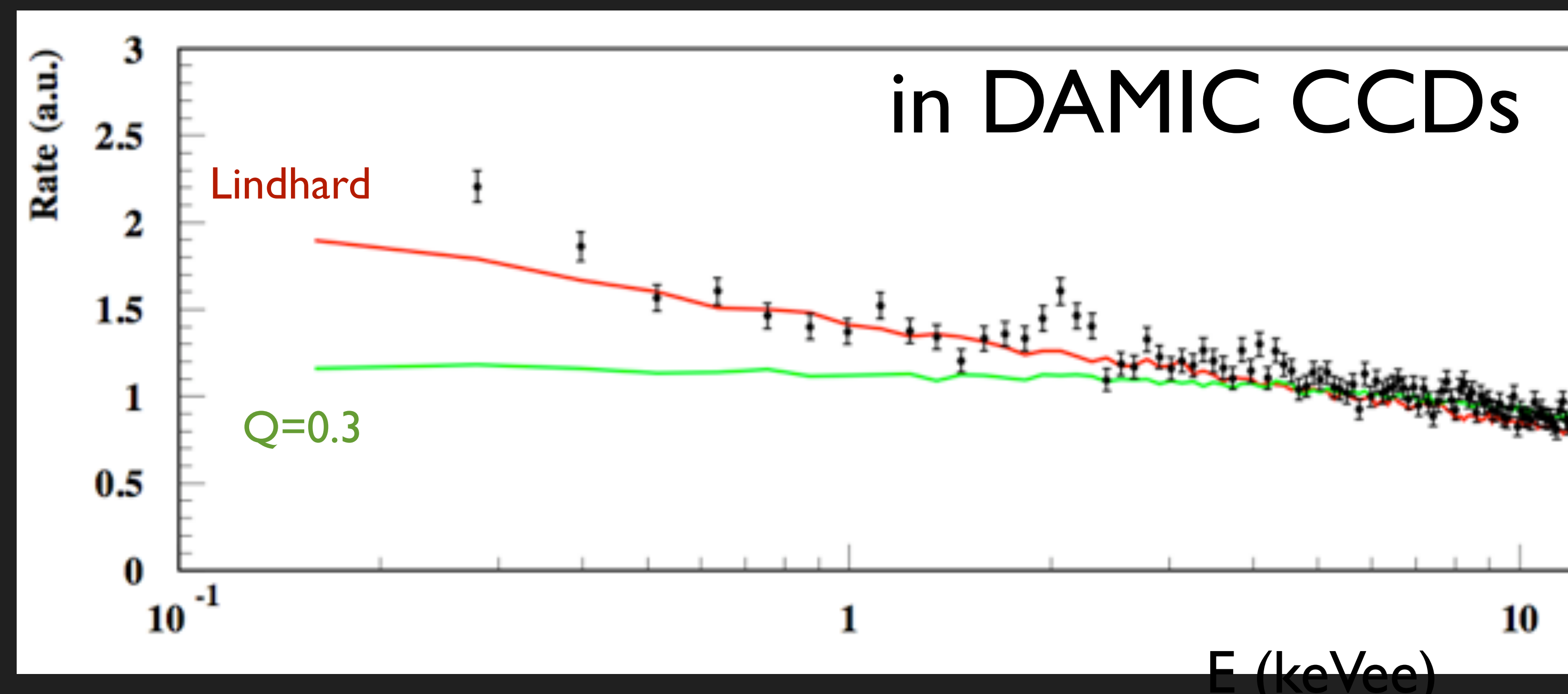




Calibration for nuclear recoils using ^{252}Cf

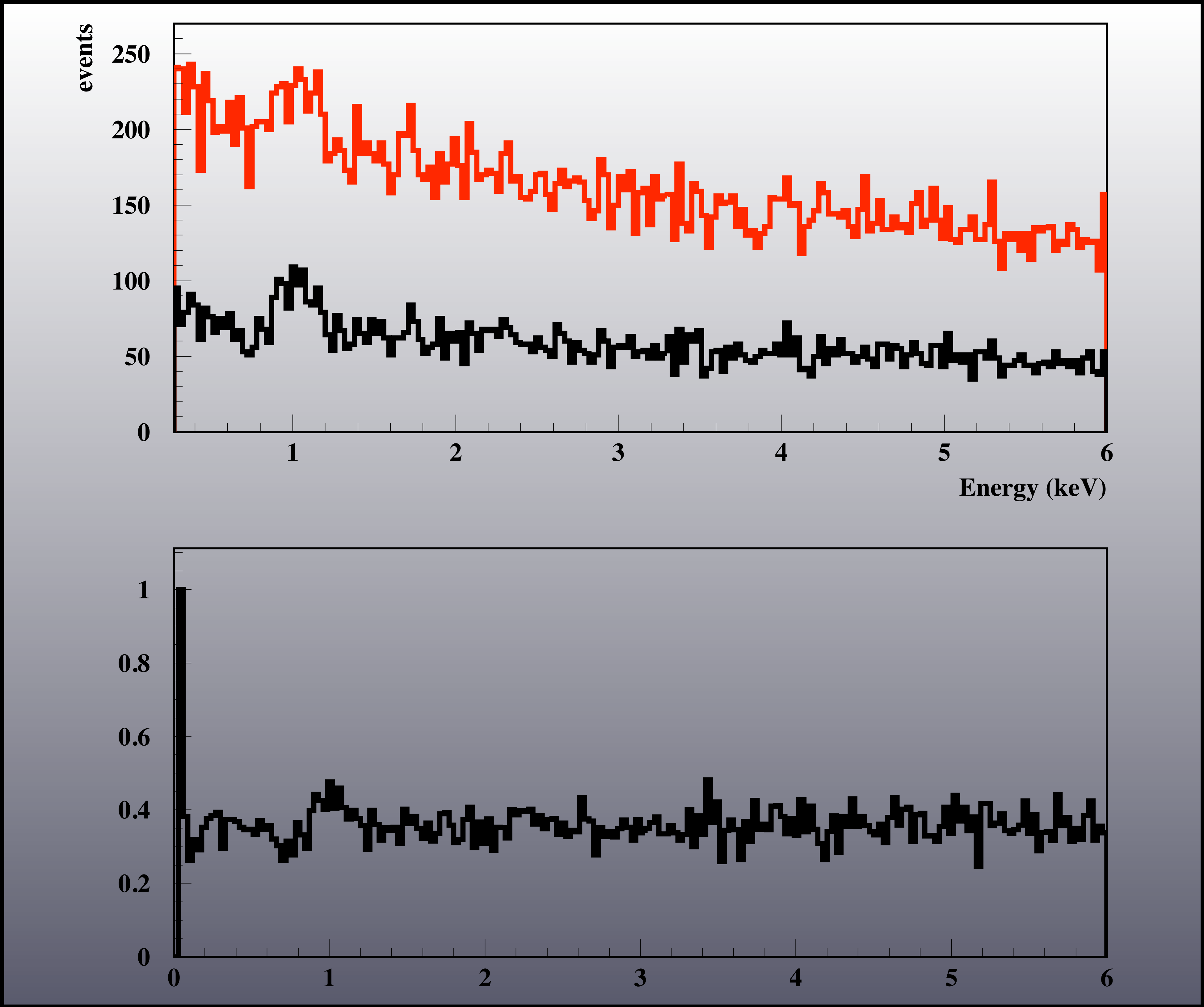


energy dependence measured above E_r=4 keV (Lindhard model)



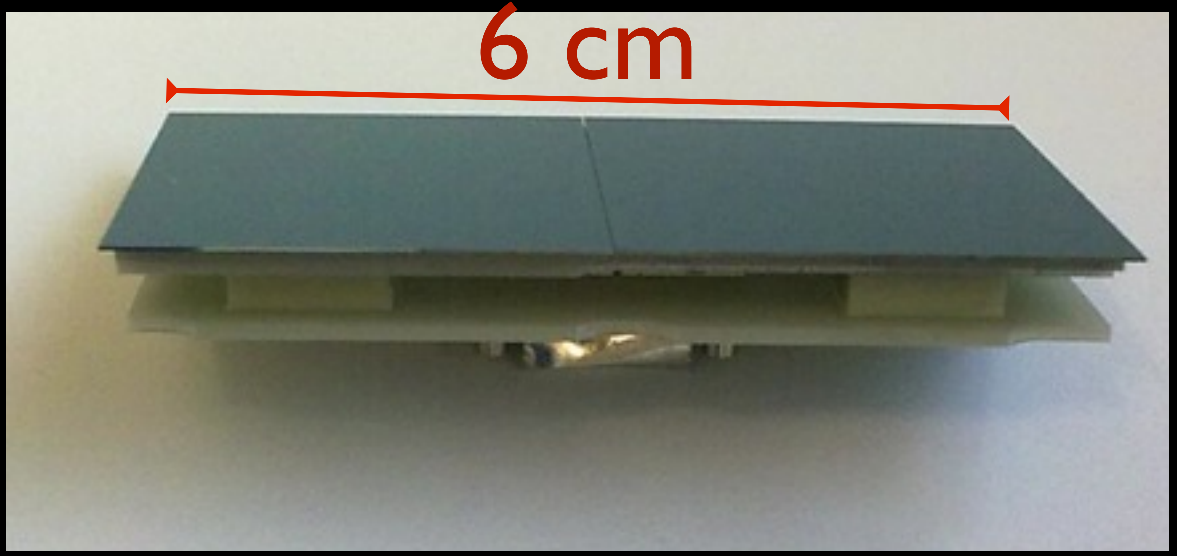
The ^{252}Cf source gives a “flat” spectrum of recoils at low energy. The shape of the measured spectrum in keVee gives the energy dependent quenching. Still some features to understand.

efficiency measurement using the neutrons from ^{252}Cf.



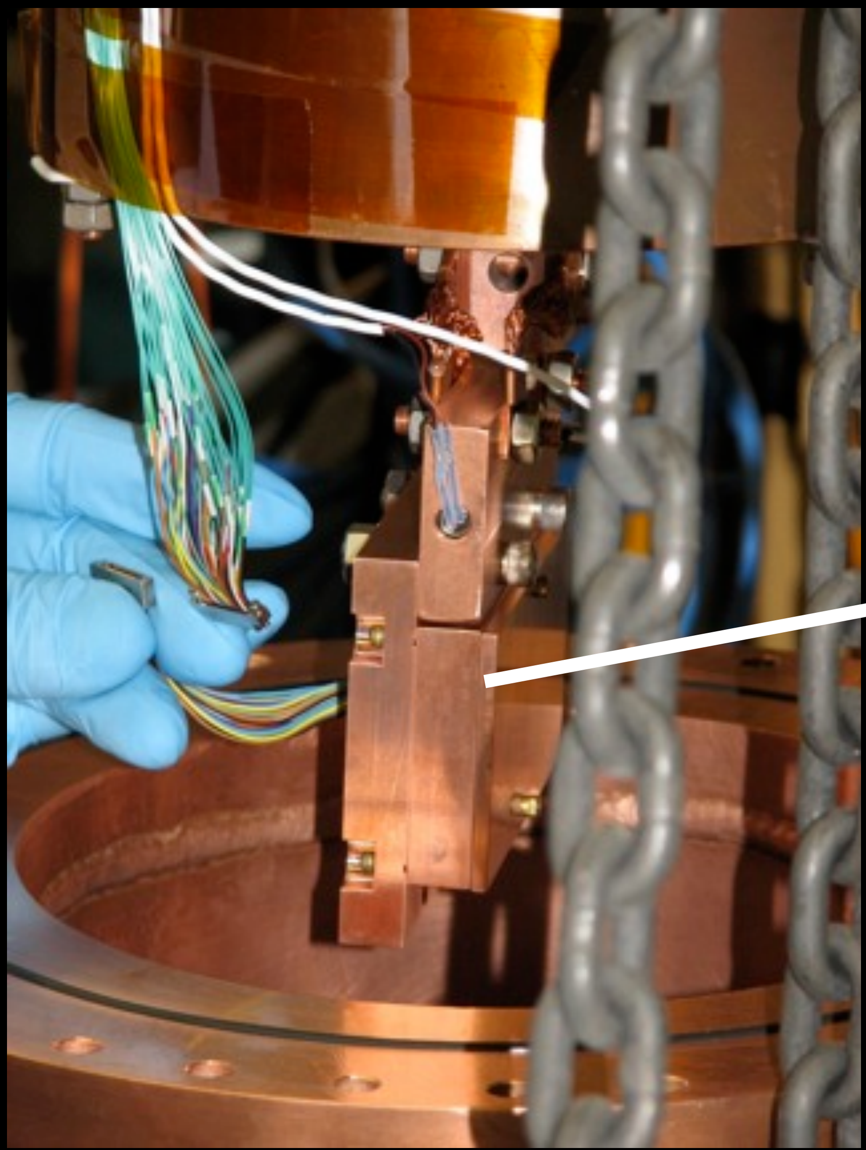
the experiment

new CCD package using only AlN. The AlN was measured to be low background at during 2009.

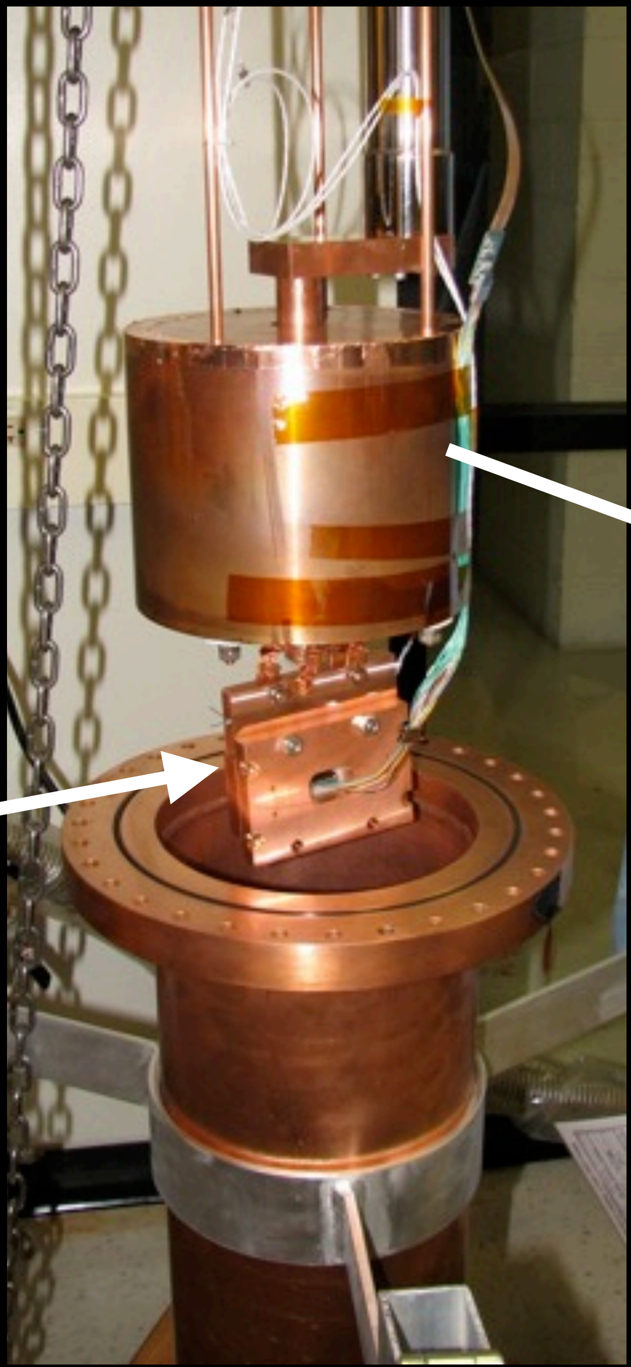


1 gram of Si

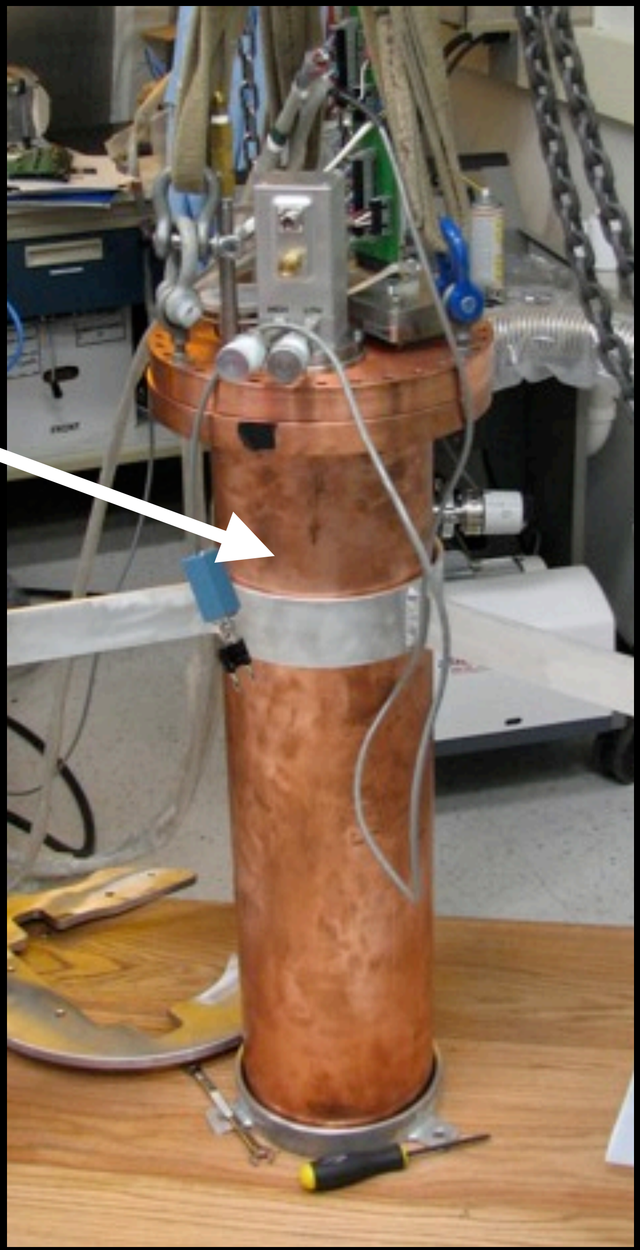
CCD wire-bonded to an AlN board. Some AlN blanks complete the package. Connector soldered to the back of the AlN board (connector radio purity unknown).



CCD inside a cold copper box. (IR shield)



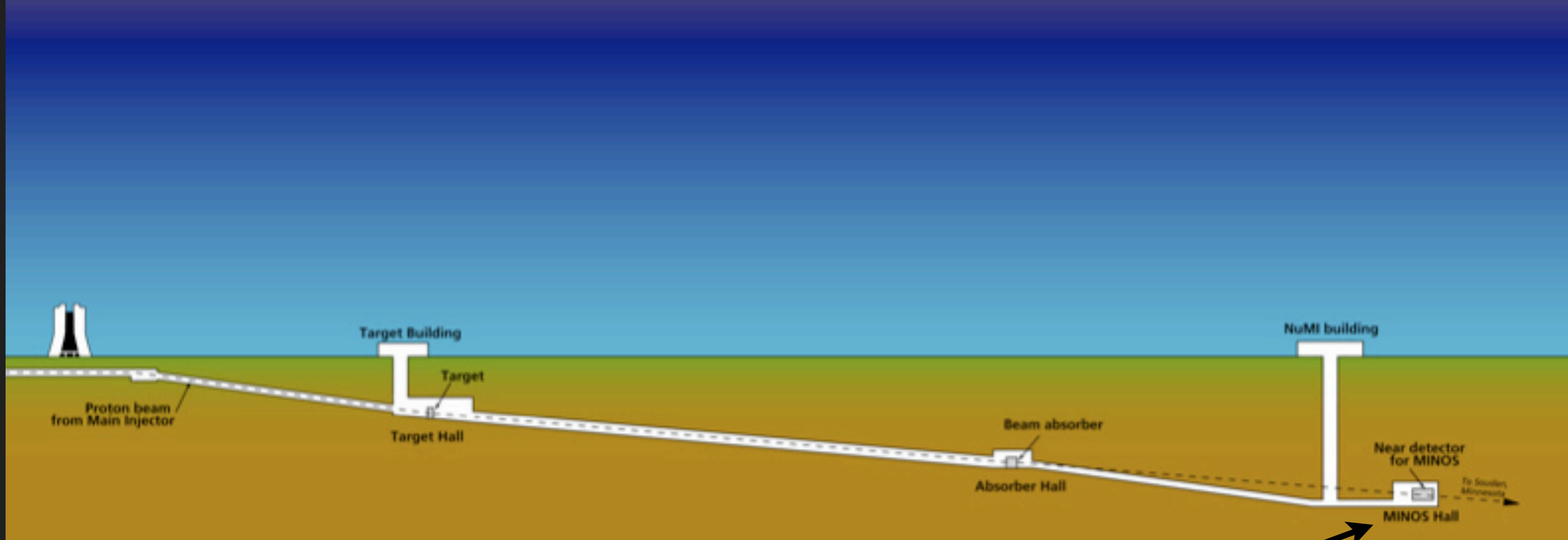
6" lead bucket inside vaccum



cylindrical copper dewar

DAMIC (FNAL T987)

Underground test of CCDs for DM



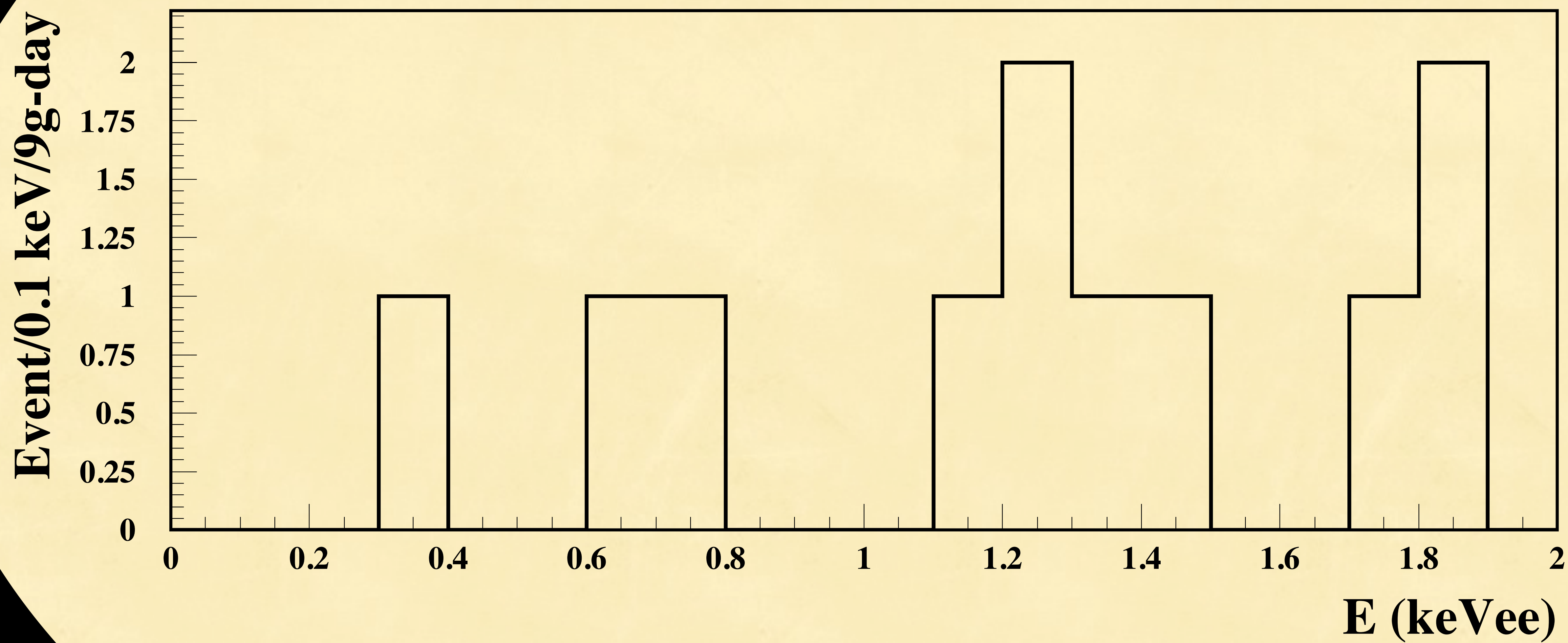
1 CCD

Installed on June 2010 350' underground at FNAL. This is the second version of DAMIC.

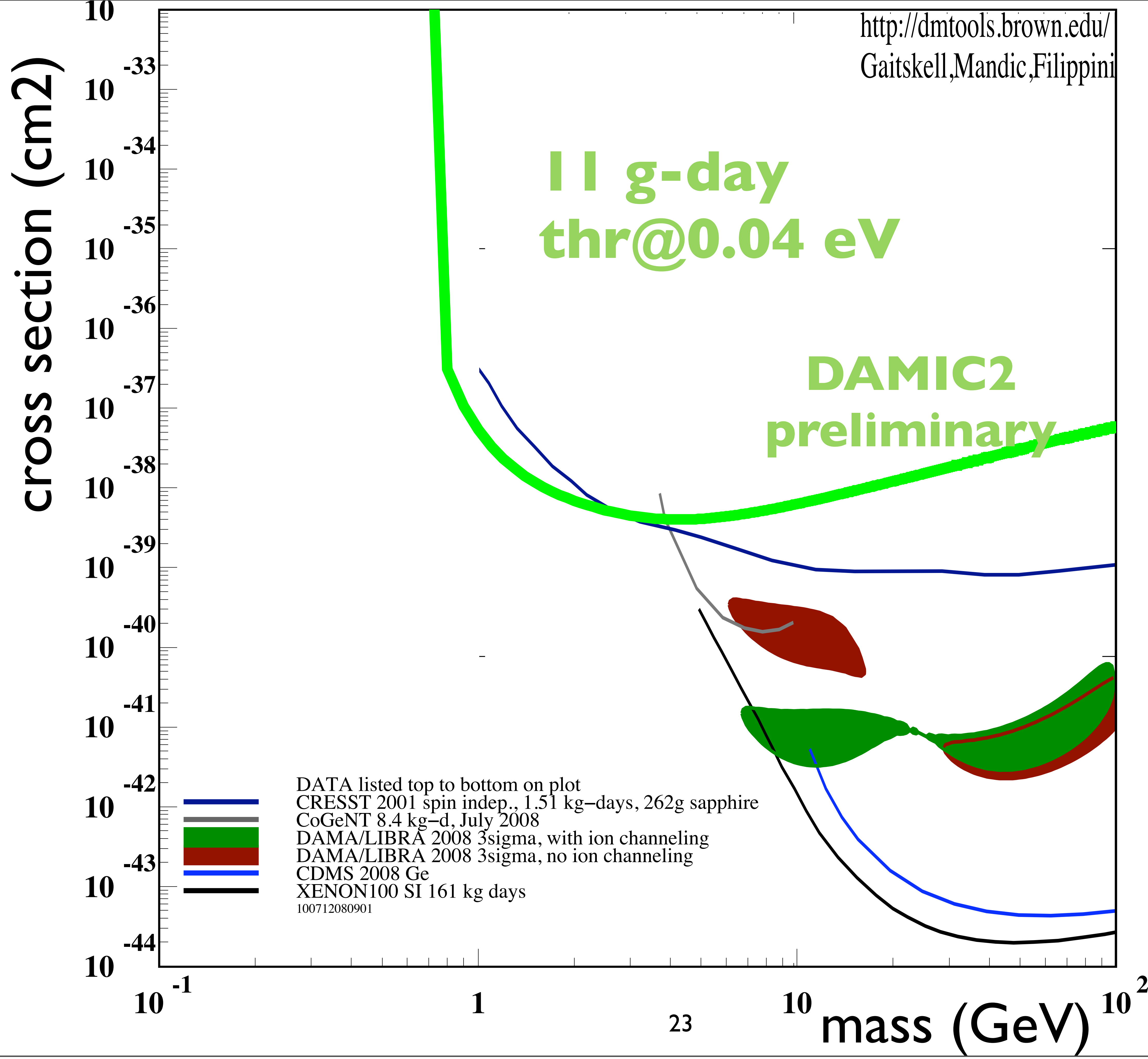
Premilinary

... just started running

Premilinary



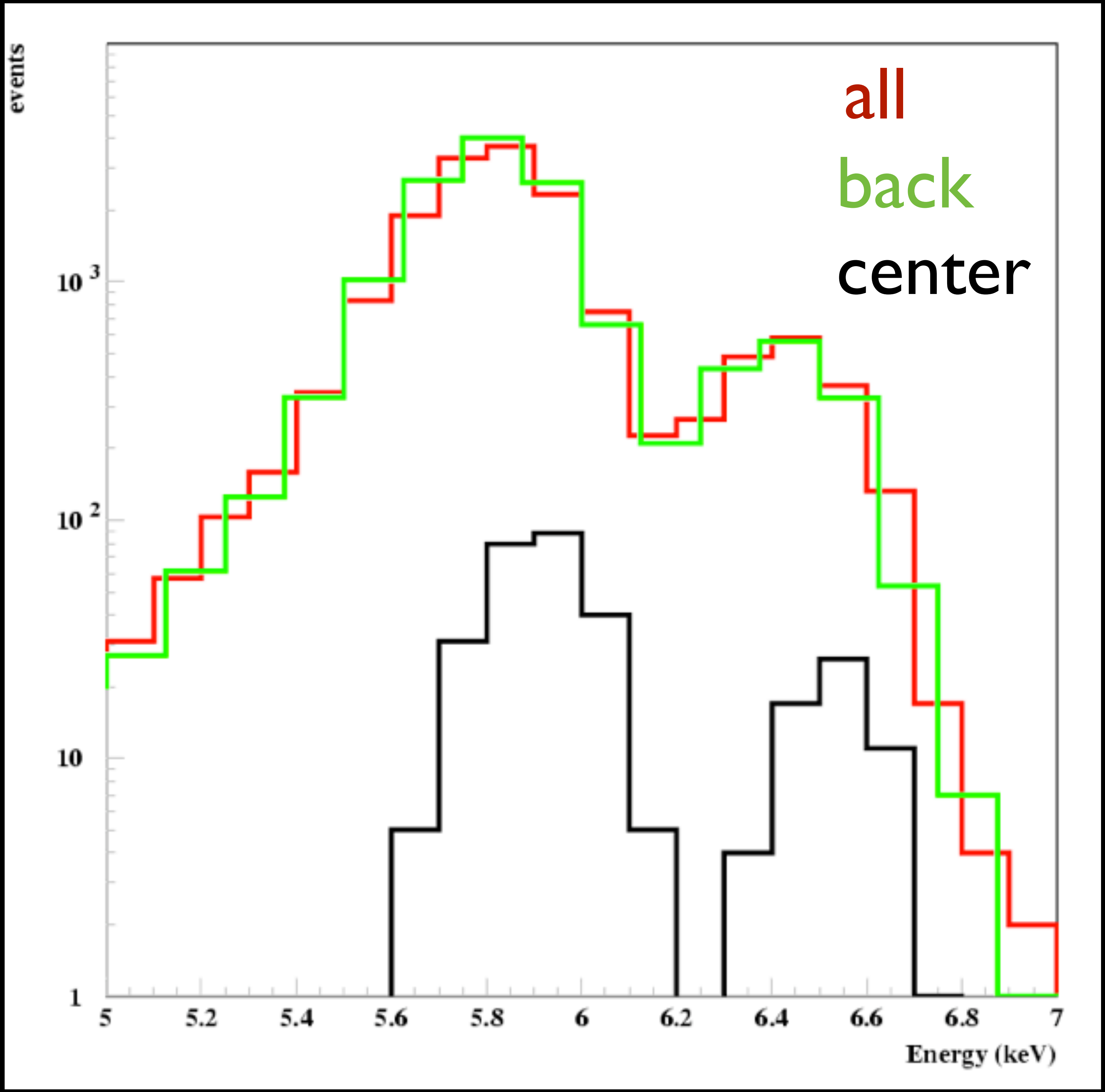
This is only after a couple of weeks running. Need to wait a bit longer to really measure the background spectrum. The expected limitation will be neutrons produced by muons in our shield. No muon veto!


http://dmtools.brown.edu/
Gaitskell,Mandic,Filippini
11 g-day
thr@0.04 eV
DAMIC2
preliminary
cross section (cm2)
mass (GeV)
DATA listed top to bottom on plot
CRESST 2001 spin indep., 1.51 kg−days, 262g sapphire
CoGeNT 8.4 kg−d, July 2008
DAMA/LIBRA 2008 3sigma, with ion channeling
DAMA/LIBRA 2008 3sigma, no ion channeling
CDMS 2008 Ge
XENON100 SI 161 kg days
100712080901

Conclusion

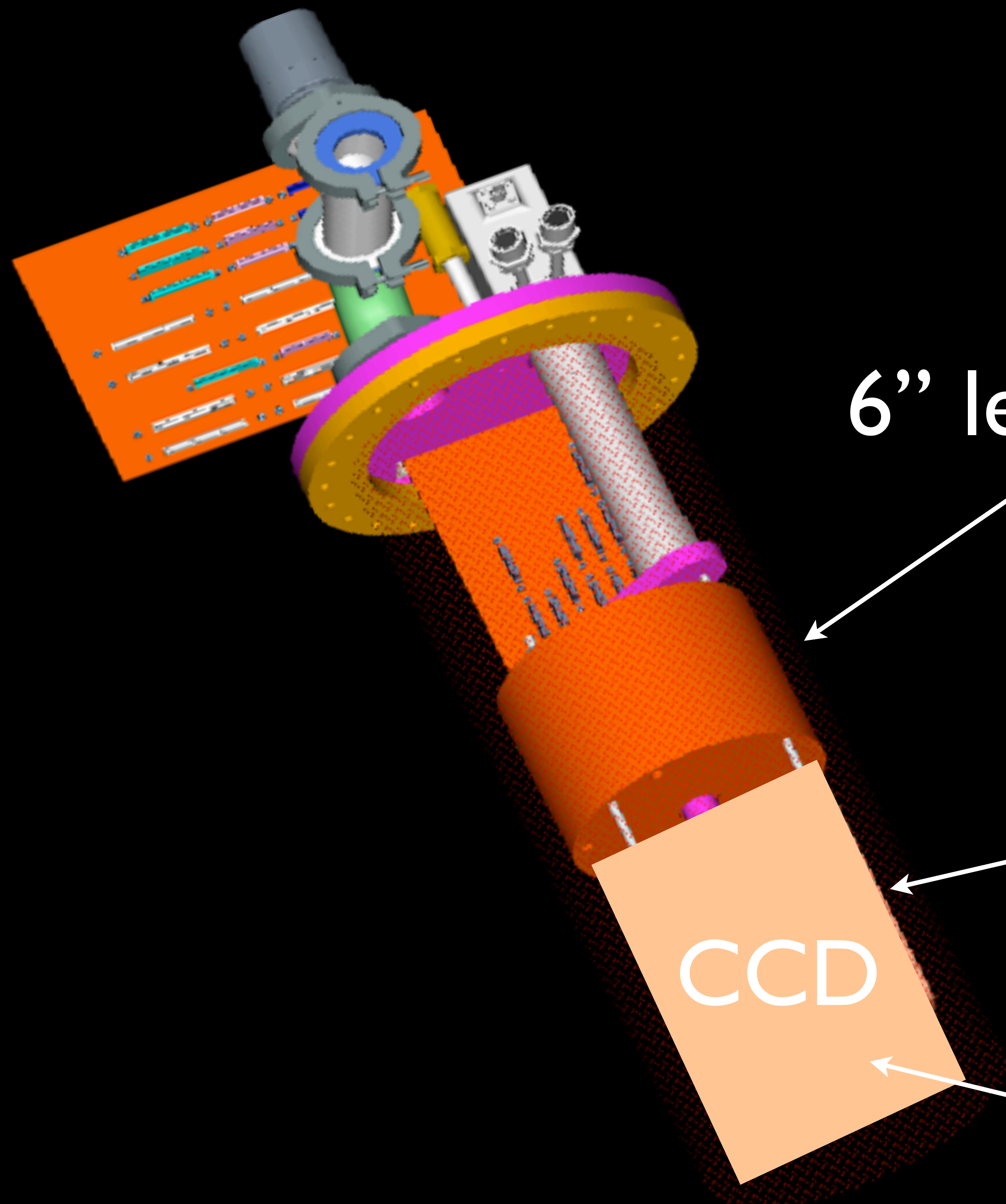
- DAMIC is now competitive searching for DM particles with masses ~ 1 GeV.
- Low threshold of 0.040 keV makes this possible.
- Future is promising :
  - new readout system to reduce noise by x2
  - 10g detector possible during 2010
  - go deeper to reduce muons 2011
- Stay tuned for exciting DAMIC results

back illumination with x-rays



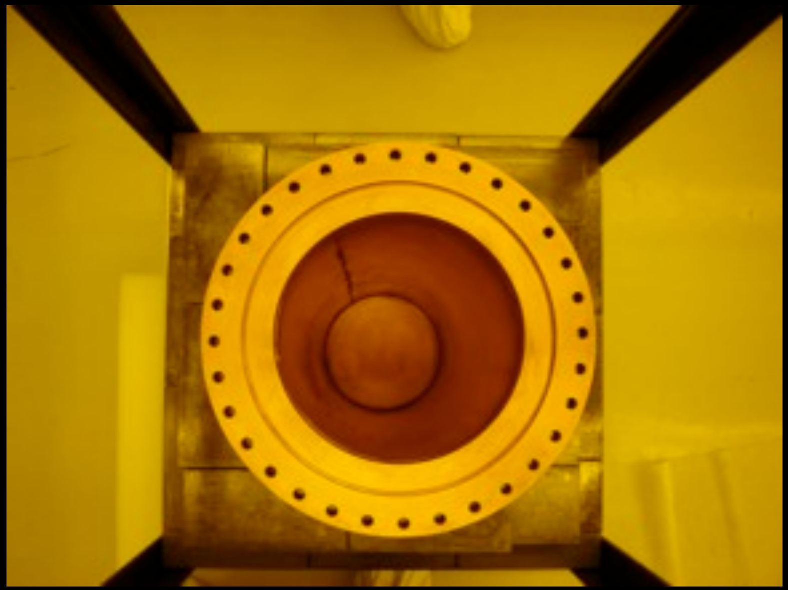
selection cut gives a factor 20 rejection for X-rays.

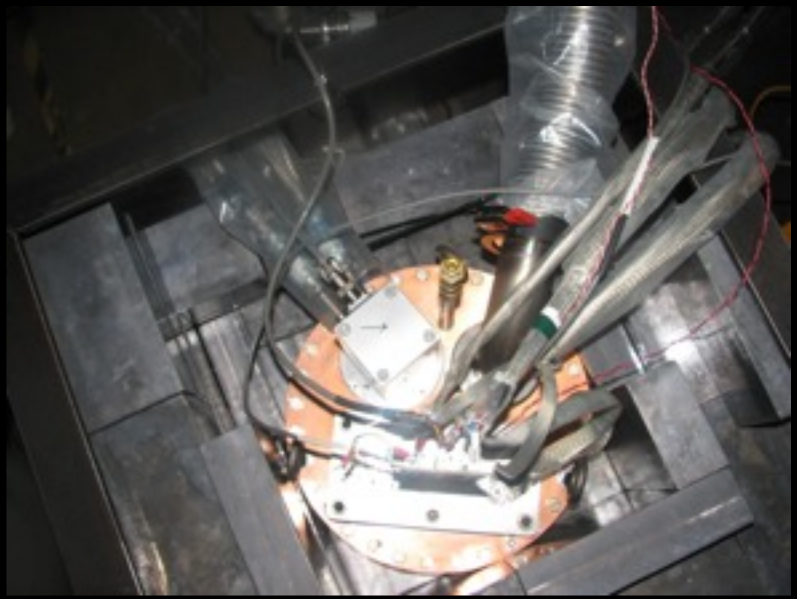
2010


6” lead shield inside vacuum
Cu box kept at -150C
(NIR shield)
CCD
CCD inside NIR shield

test fit

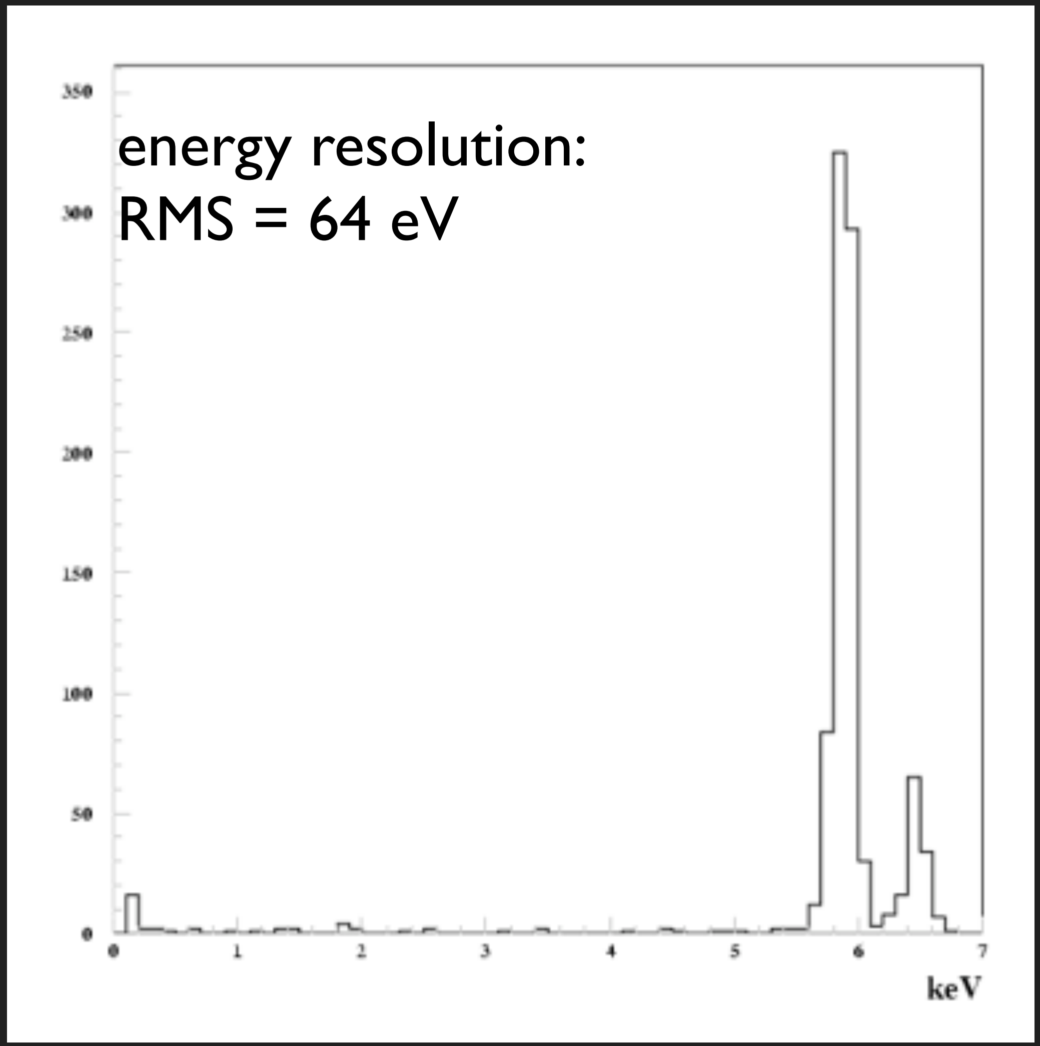
underground installation

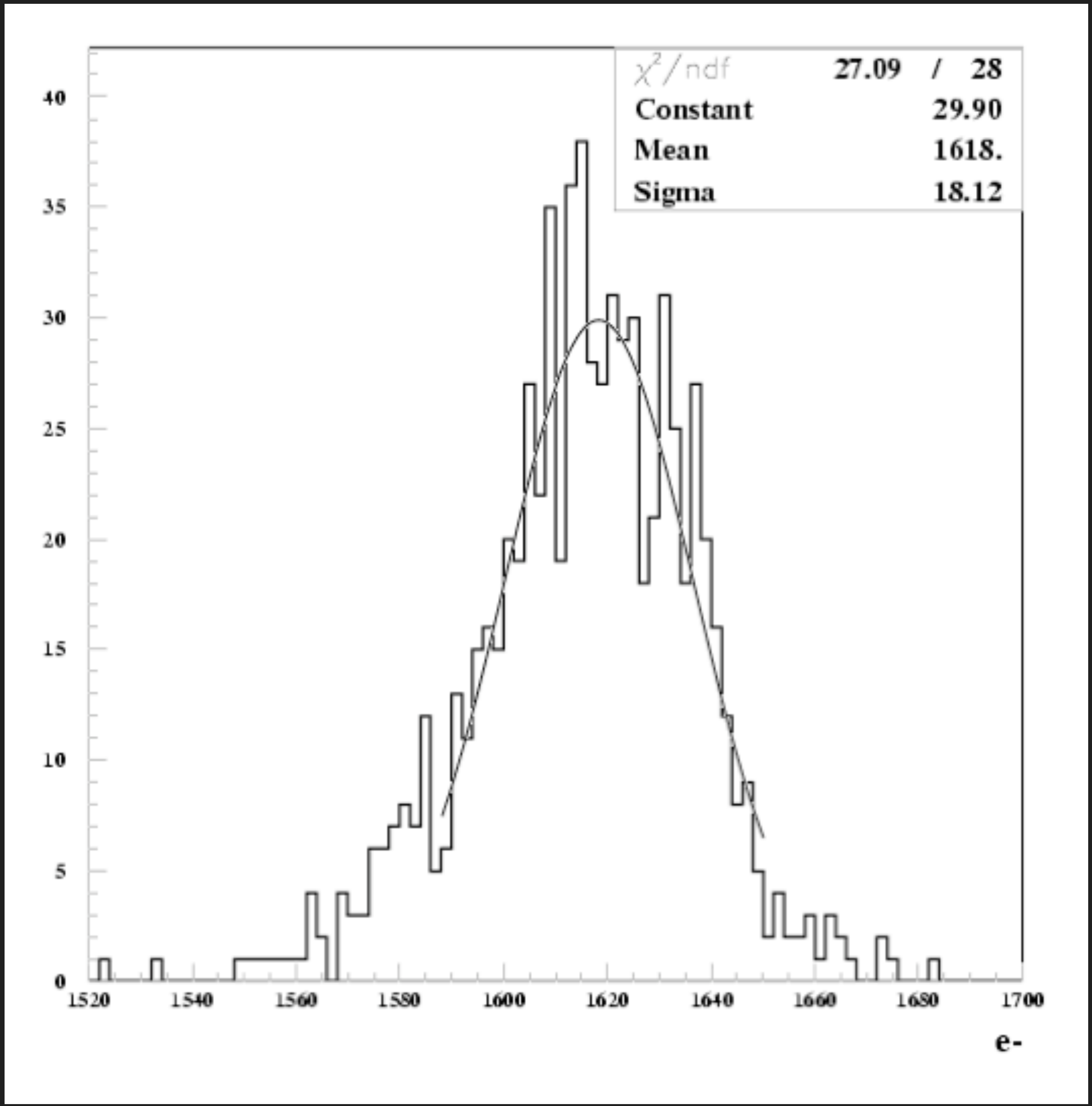




vacuum vessel inside a 6” lead shield

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

DAMIC (FNAL T987)

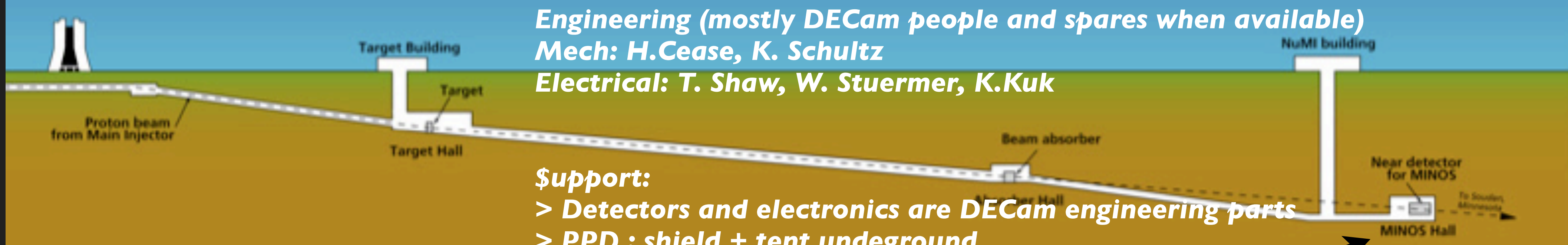
Underground test of CCDs for DM

2009

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)

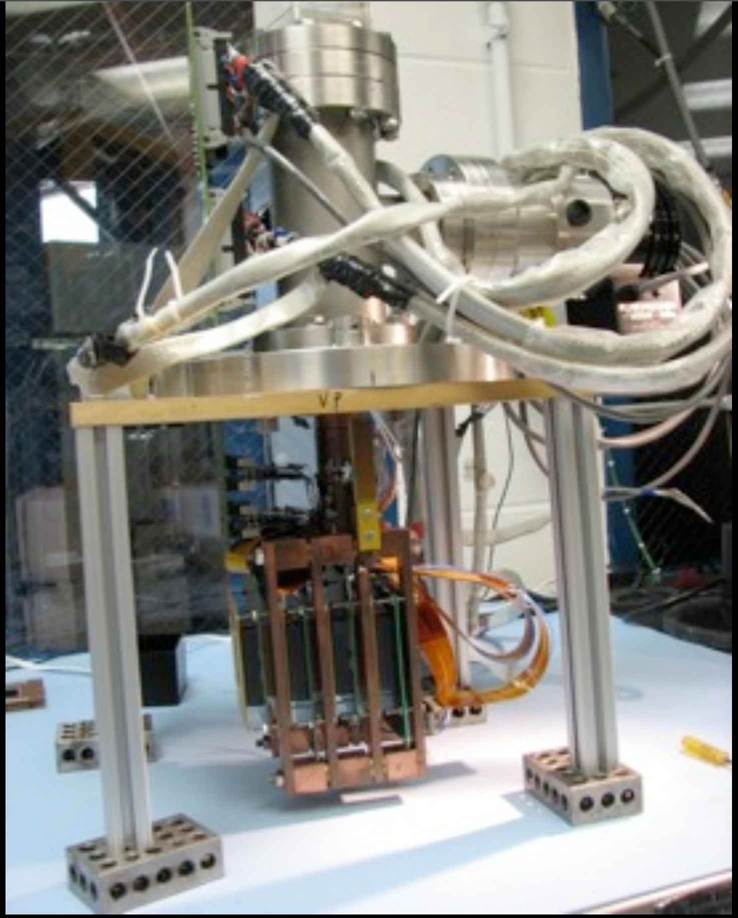
Engineering (mostly DECam people and spares when available)
Mech: H.Cease, K. Schultz
Electrical: T. Shaw, W. Stuermer, K.Kuk



$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

2009

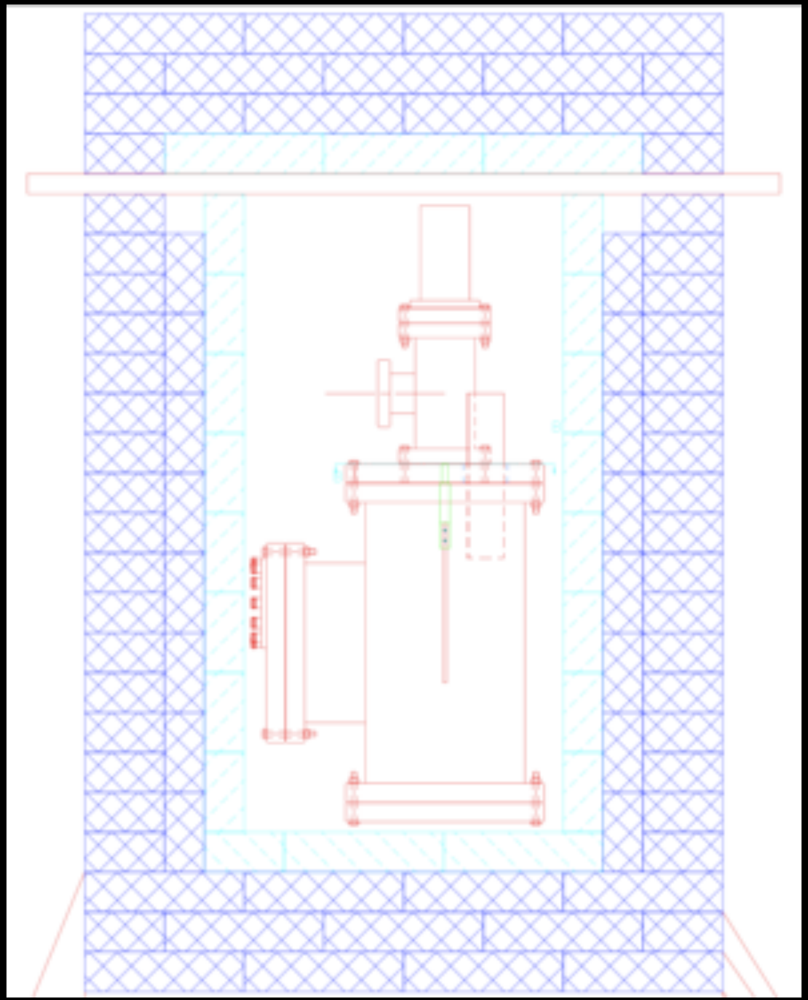


- 4 CCDs in picture frame packages (detector testing package with electronics very close to it)
- cryocooler + pump port + ion gauge inside the lead shield.
- stainless steel dewar

results:

~3000 cpd/keV

IR radiation from dewar wall dominating low energy background.



why 10^3 cpd/kg/day at 1 keV:

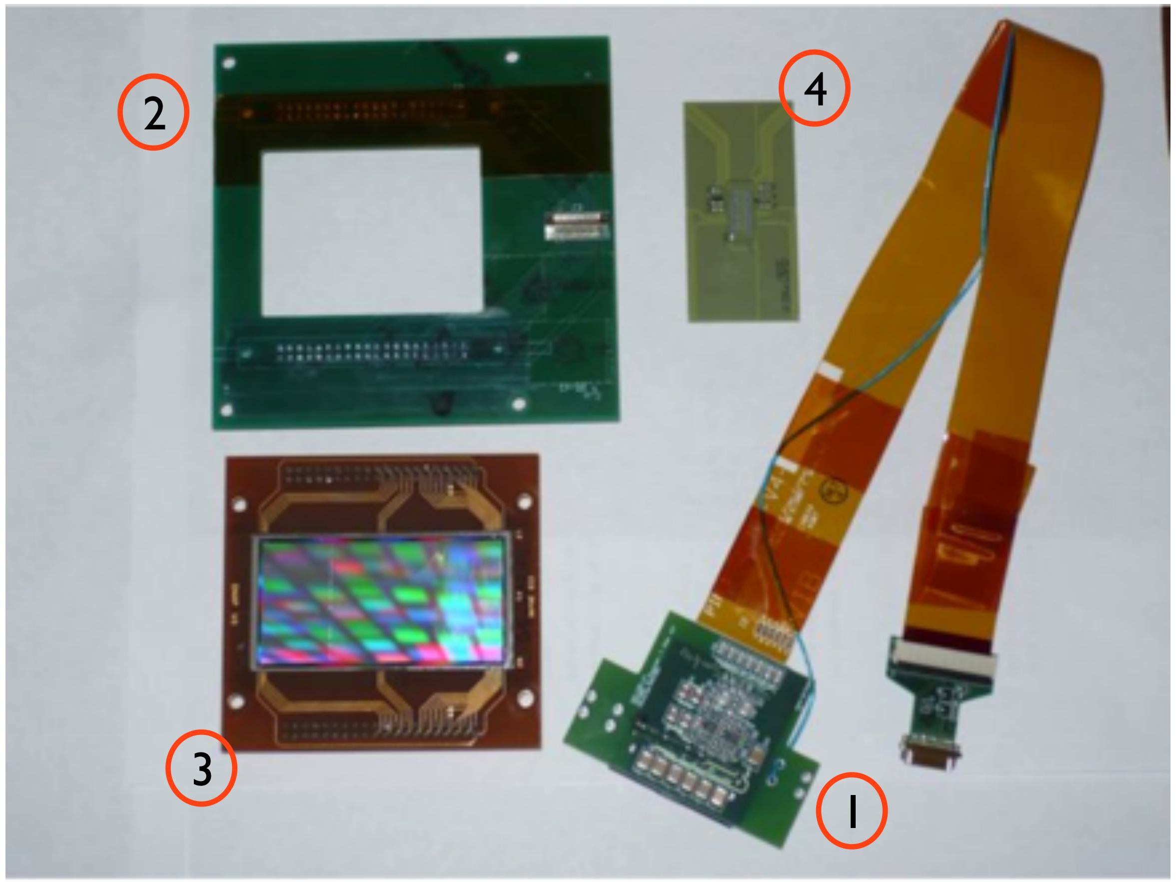


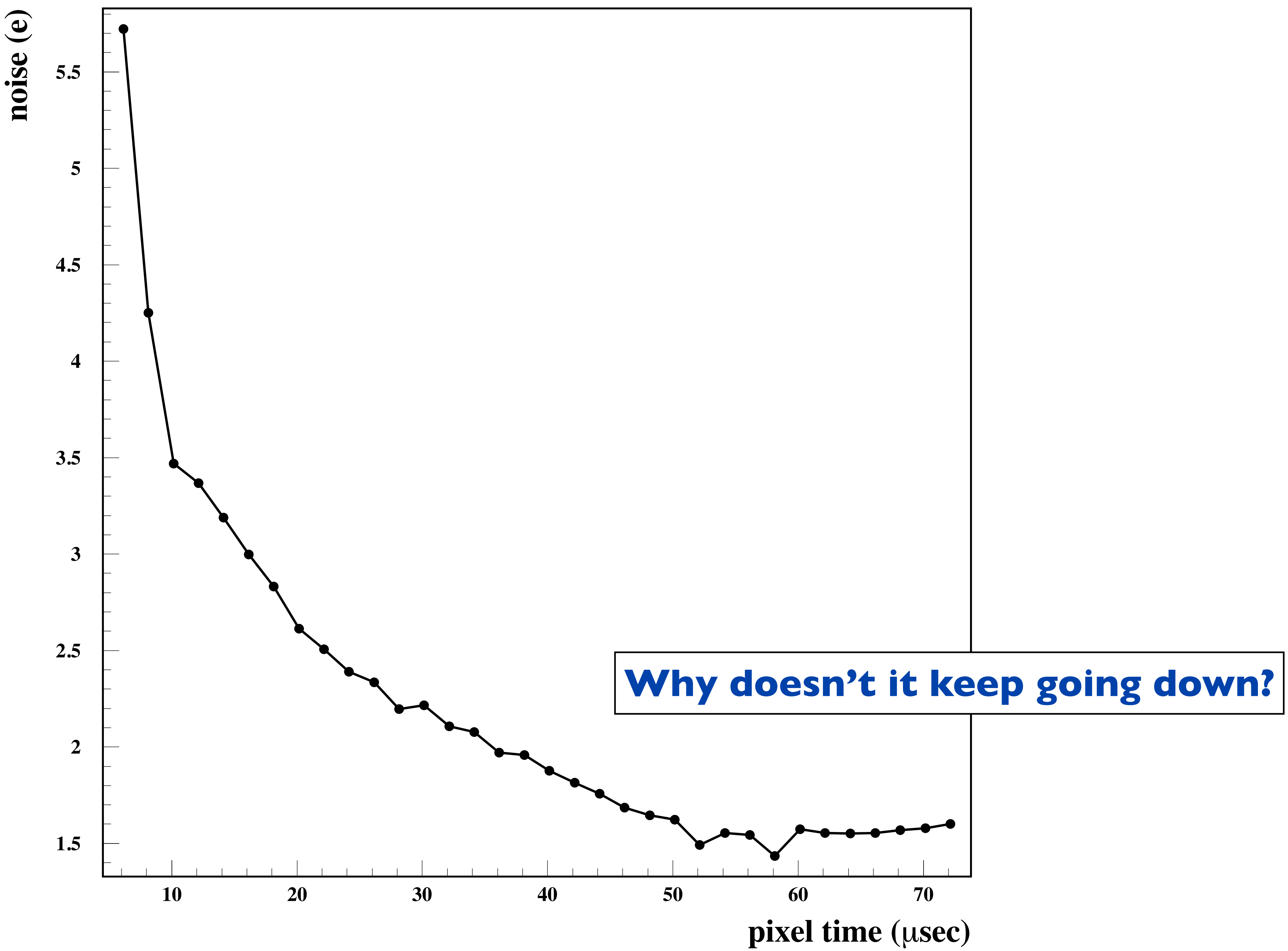
TABLE I: Radioactive decay measurement

	Detector part	Sample mass	Material	Activity
1	Kapton cables 9 pieces	218 gr	^{238}U	0.88 ppm
			^{232}Th	1.70 ppm
			^{40}K	0.012 pct
2	Picture frame adapters 15 pieces	476 gr	^{238}U	0.99 ppm
			^{232}Th	3.76 ppm
			^{40}K	0.027 pct
3	Picture frame 16 pieces	256 gr	^{238}U	1.18 ppm
			^{232}Th	5.59 ppm
			^{40}K	0.031 pct
4	Aluminum nitride 10 pieces	105.6 gr	all	< 1 ppm

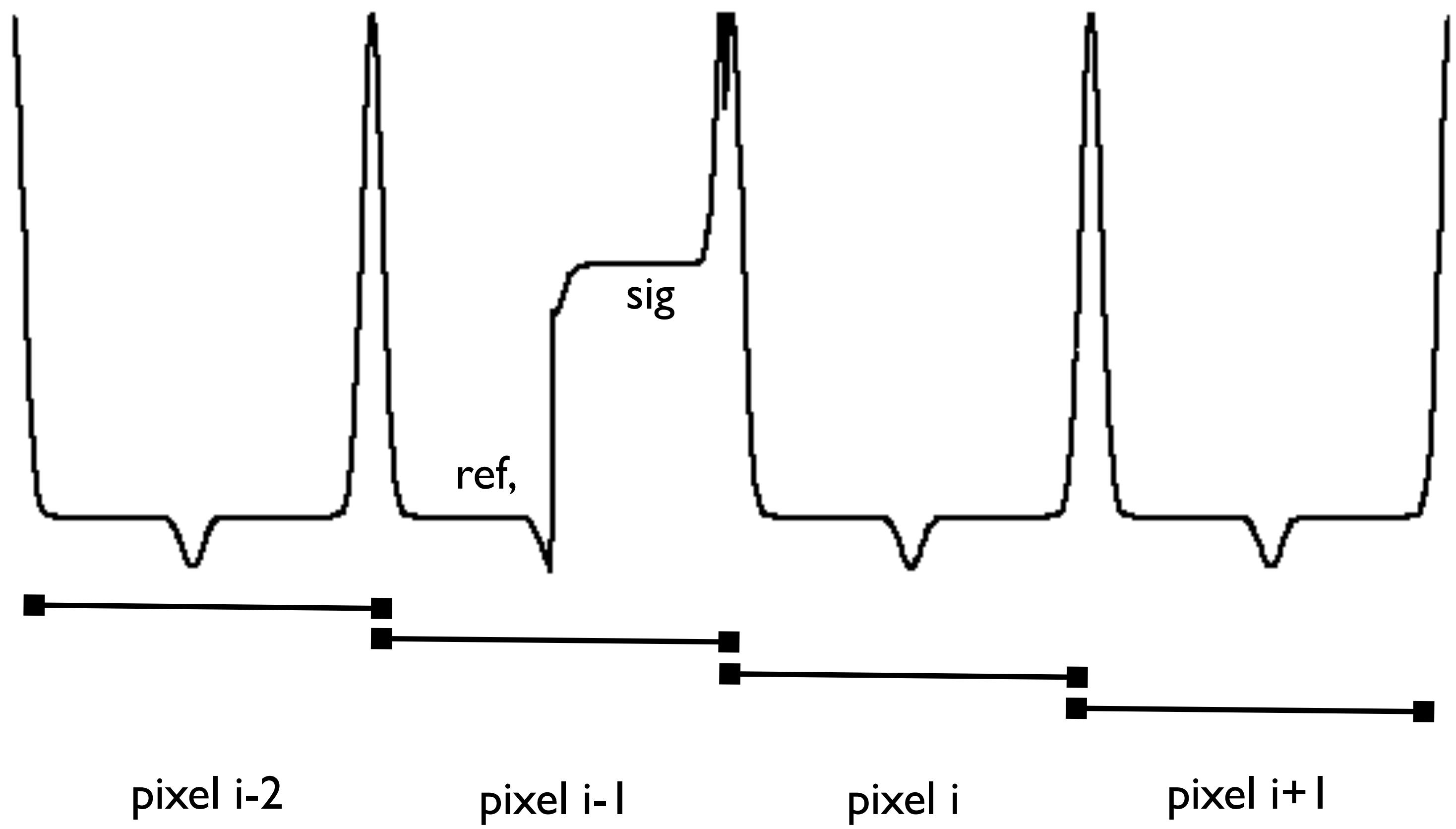
measurements done at LBNL.

we need a new packaging and electronics. We are eliminating kapton cable in the next version.

Plan to reduce the readout noise

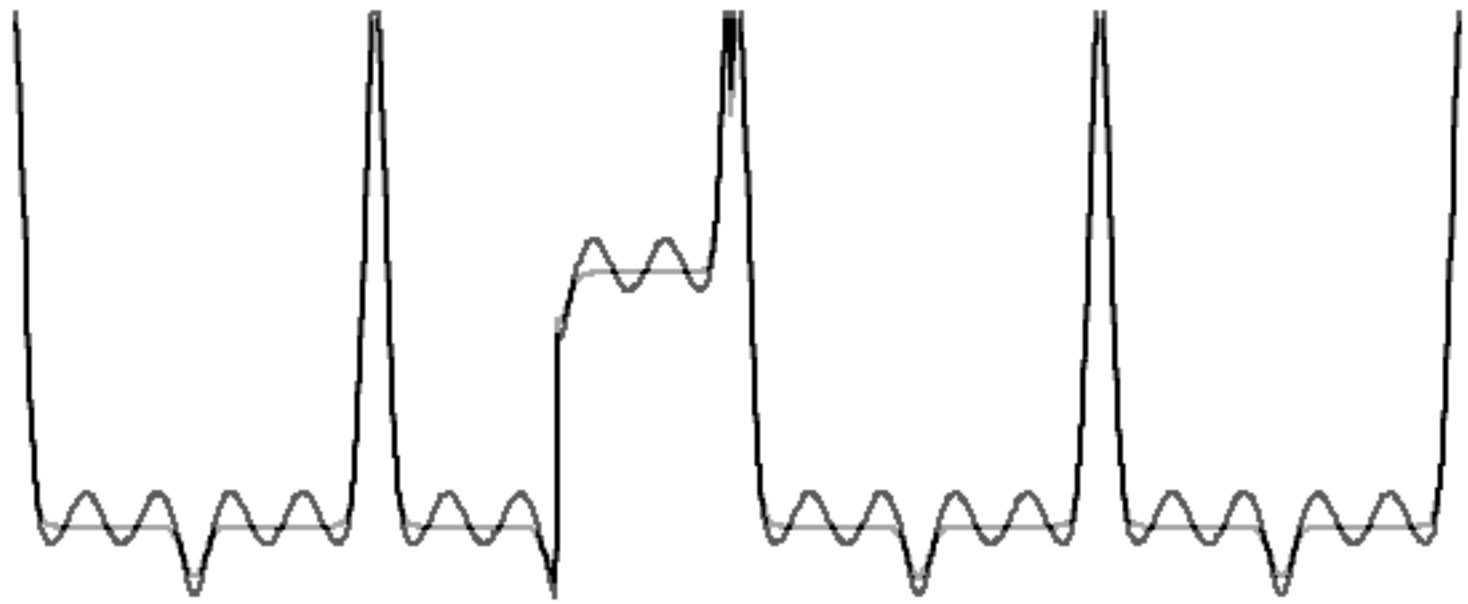


Correlated Double Sampling readout (CDS)

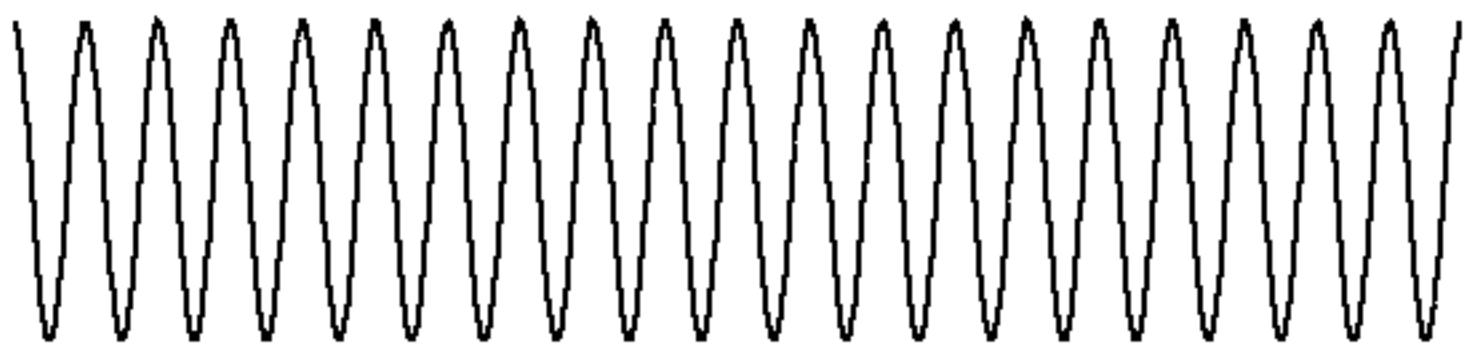


$$s_j^{cds} = \int_{t_j+\epsilon}^{t_j+\delta+\epsilon} [n(t) + \hat{s}_j] \mathrm{d}t - \int_{t_j}^{t_j+\delta} n(t) \mathrm{d}t.$$

filtering of high frequencies is responsible for reduction with integration time

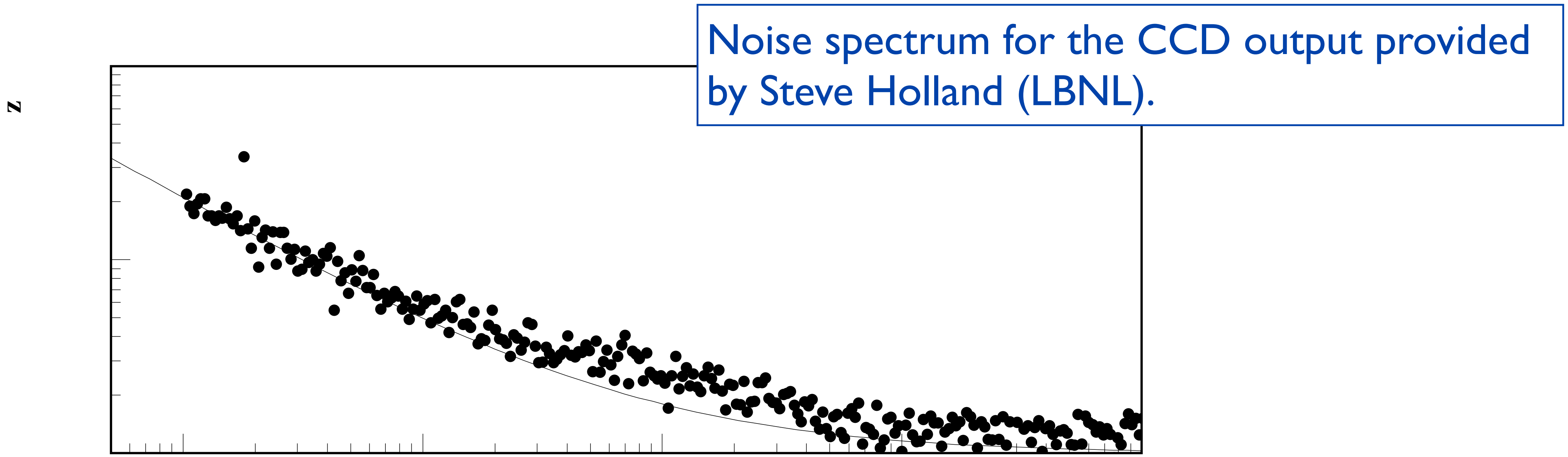


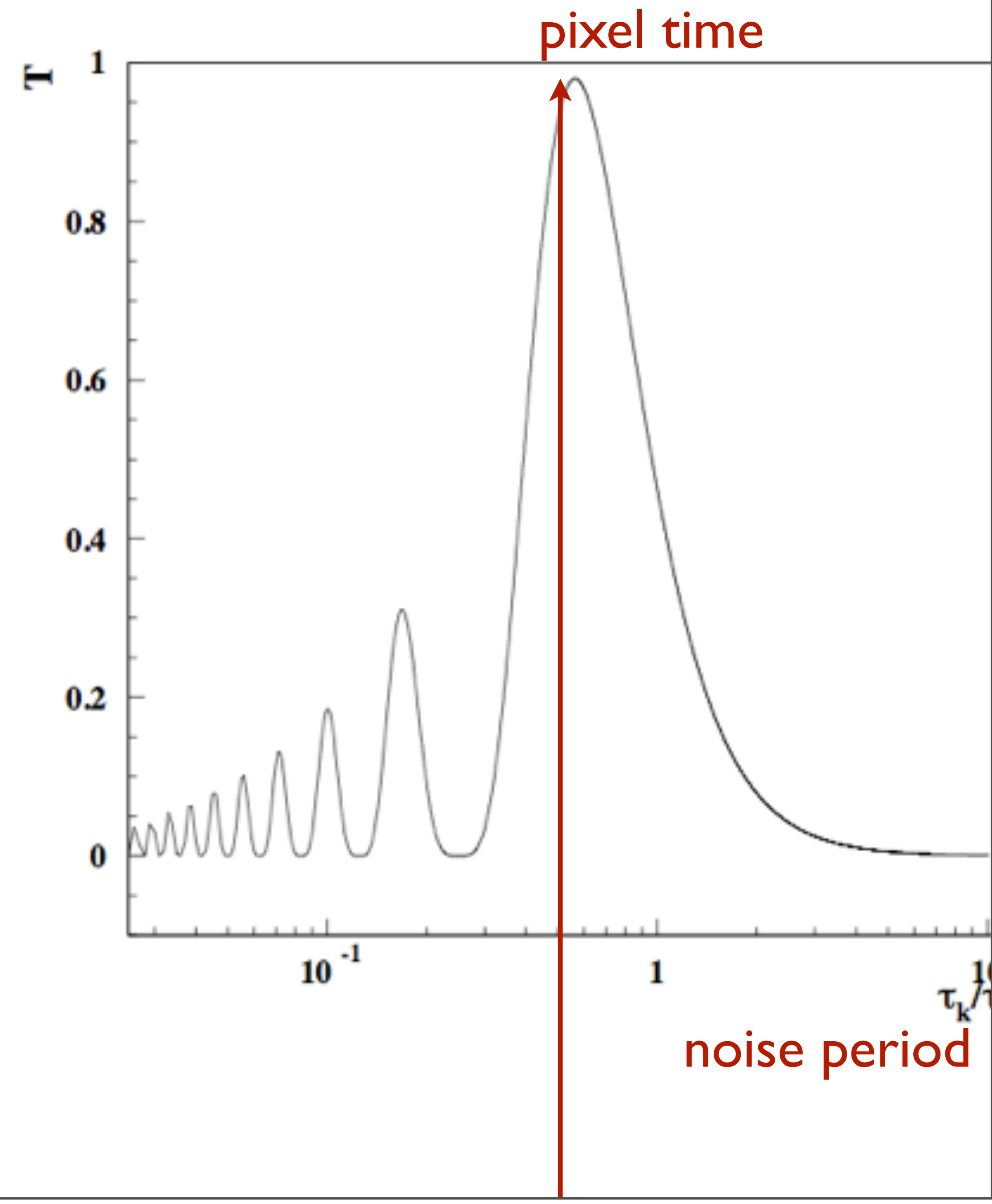
this “high frequency” noise is efficiently suppressed by the integrations for each window in the correlated double sampling.



noise at pixel frequency is not suppressed by CDS

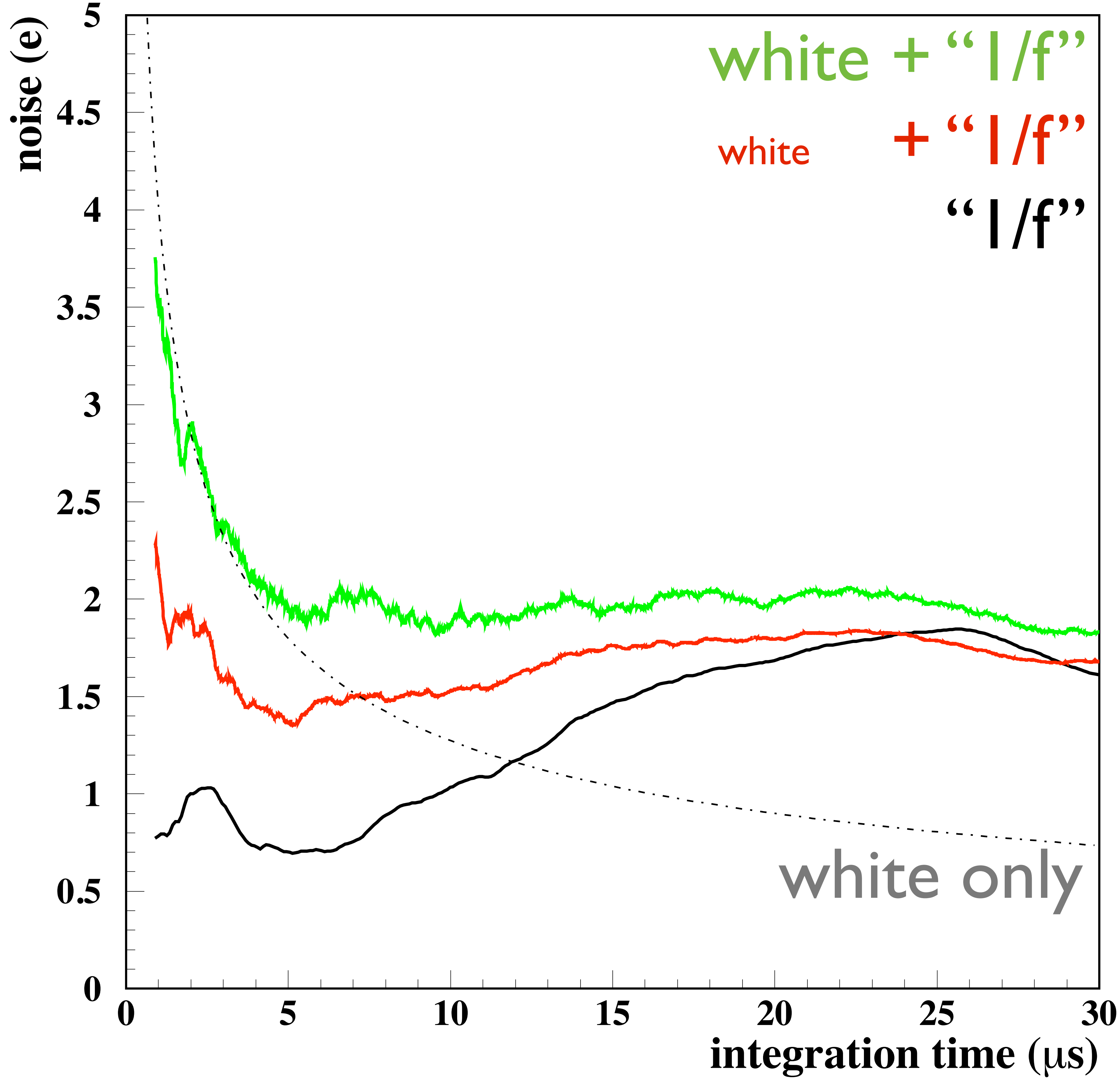
the noise with frequency of the order of the pixel is not filtered by the CDS. The only way to measure this contribution well is to look for the coherence of the noise over many pixels.





For long pixel times, CDS becomes susceptible to lower frequencies. Since there is a "1/f" aspect of to the noise, the CDS noise goes up when you make the pixel longer.

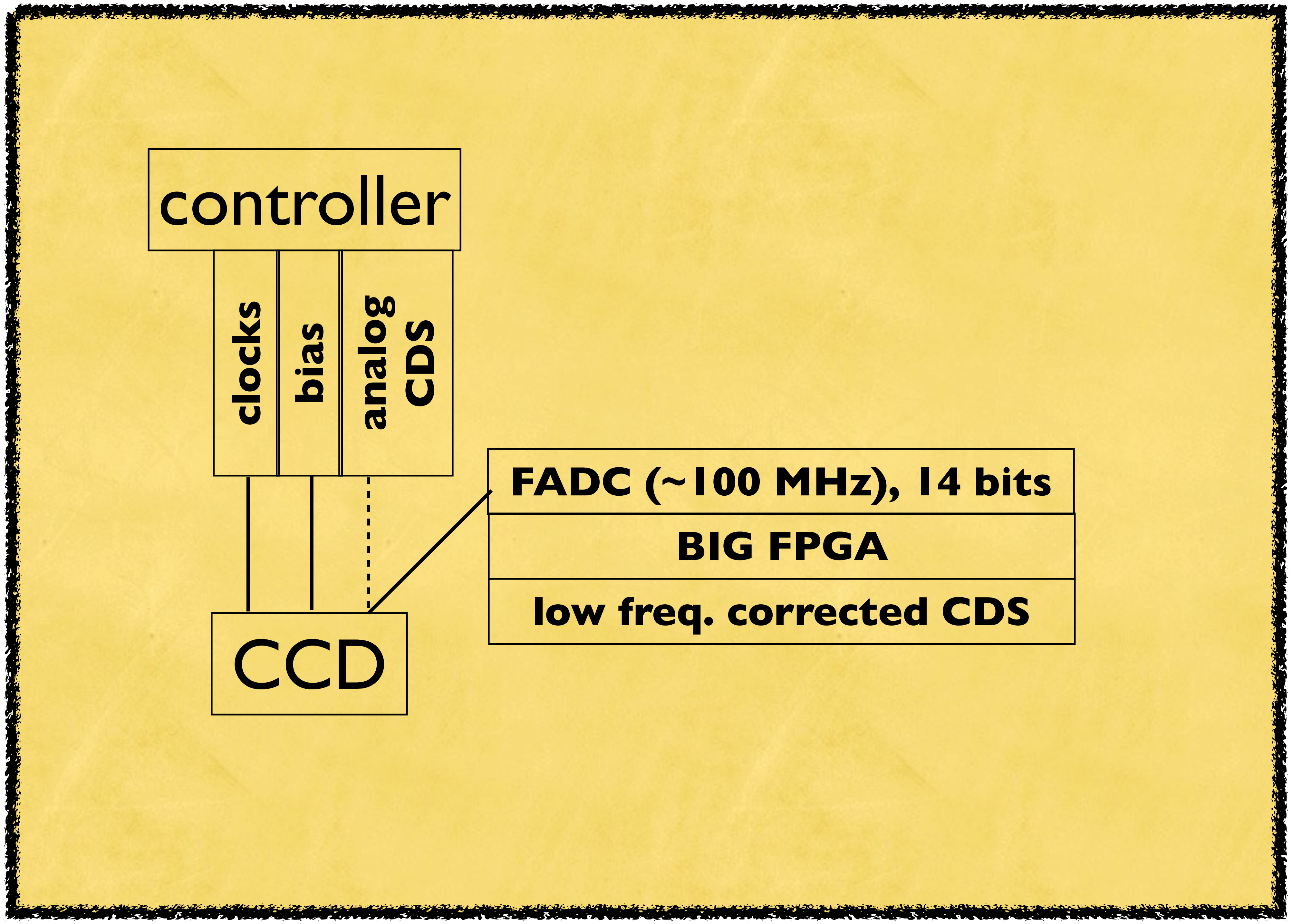
CDS noise in CCD simulation



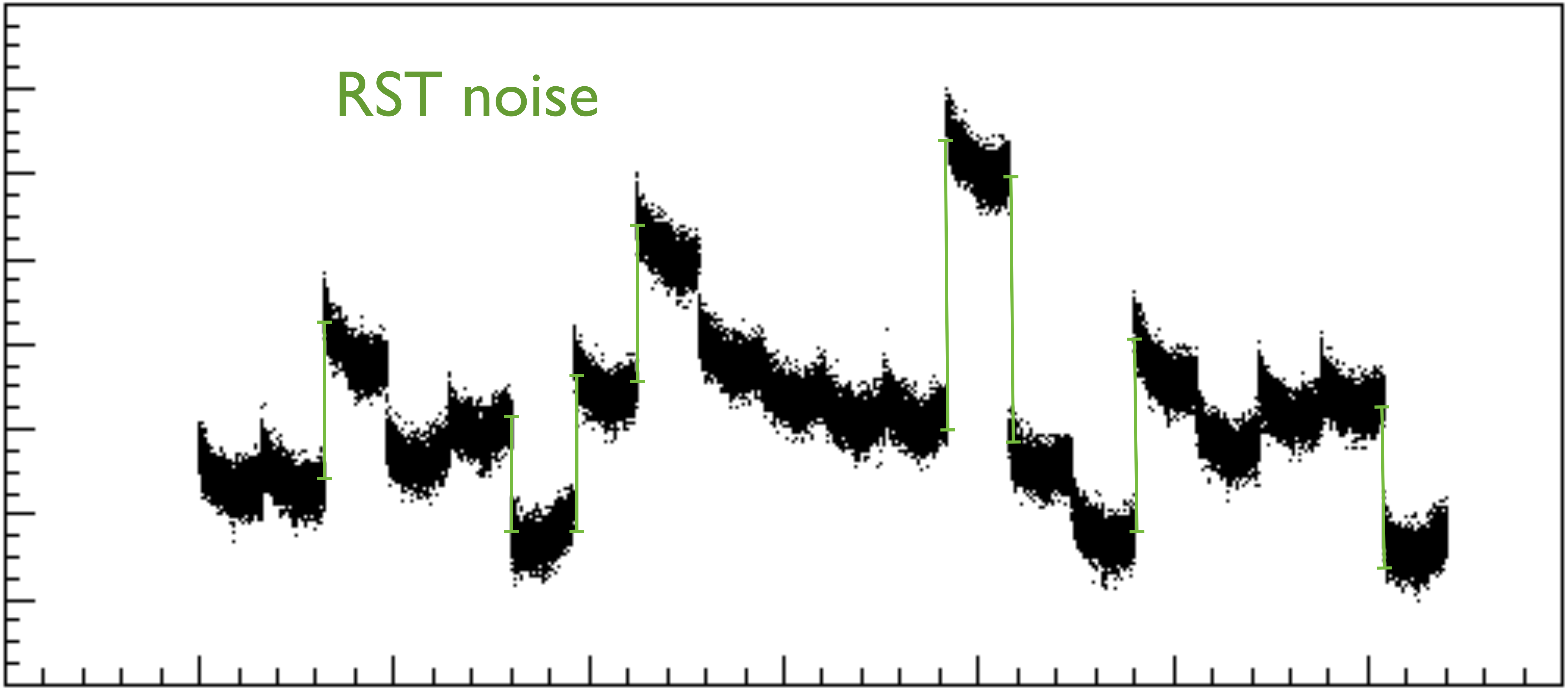
our strategy

sample the video signal of the CCD over many pixels with a fast ADC, then fit low low frequency components and subtract then before doing the CDS. This should suppress the low frequency noise contribution to CDS.

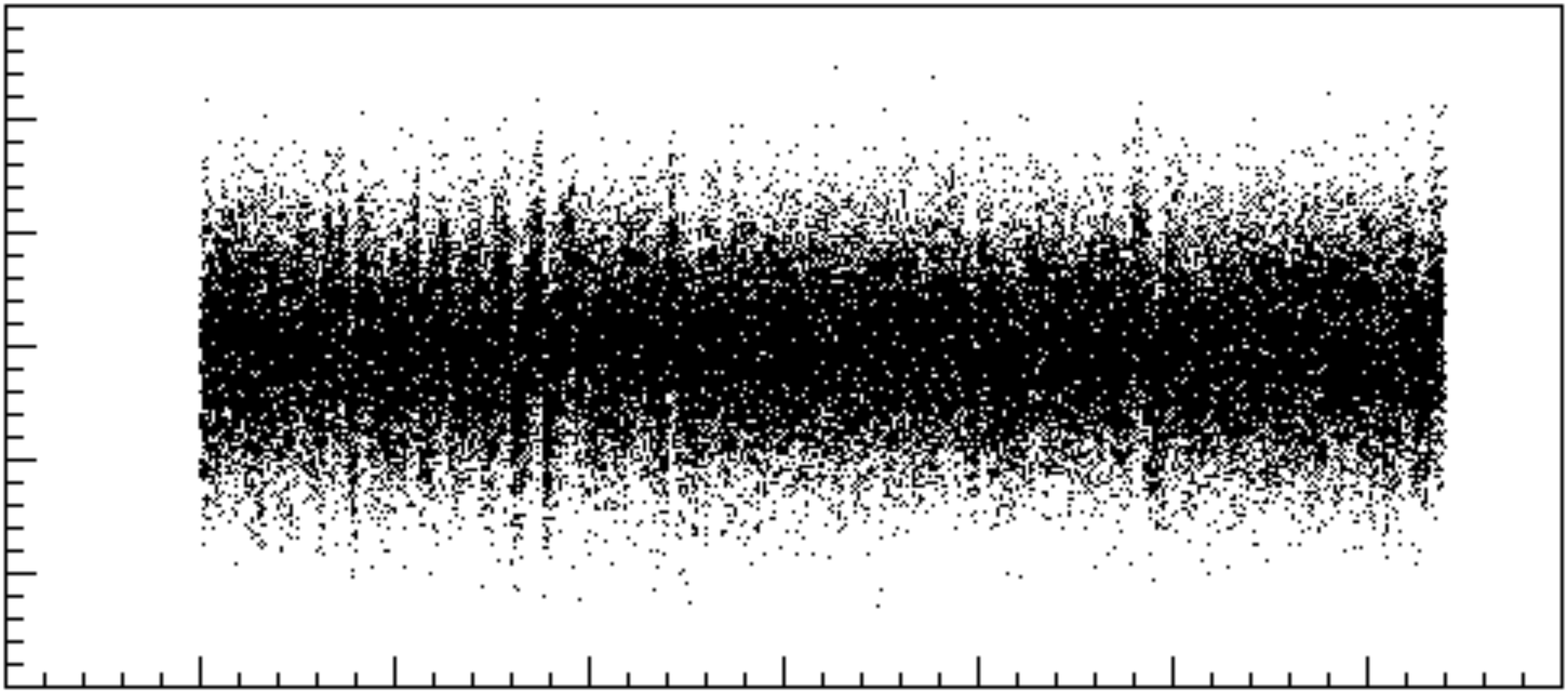
our strategy



Step 1: Digitize the signal

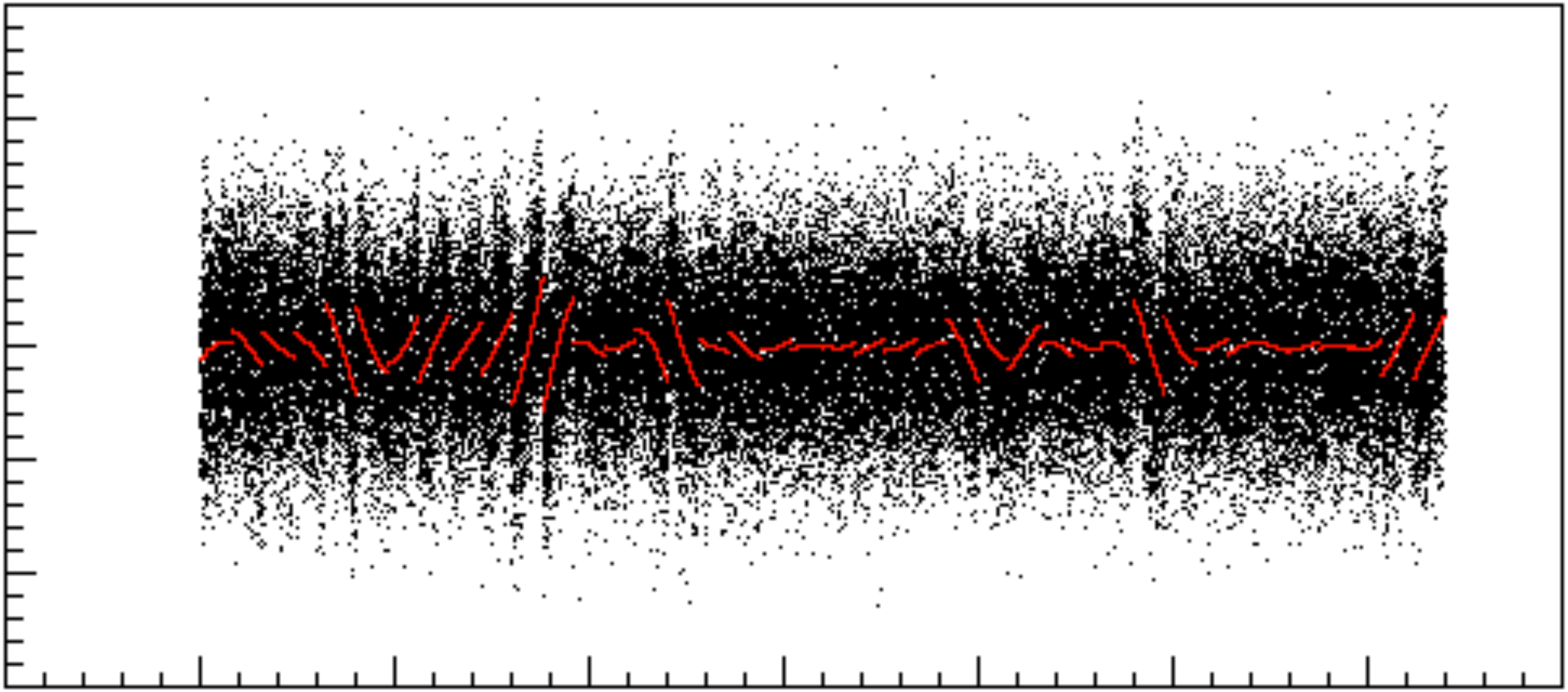


Step 2: remove features
(RST noise, signal level, clocks, pixel average shape)

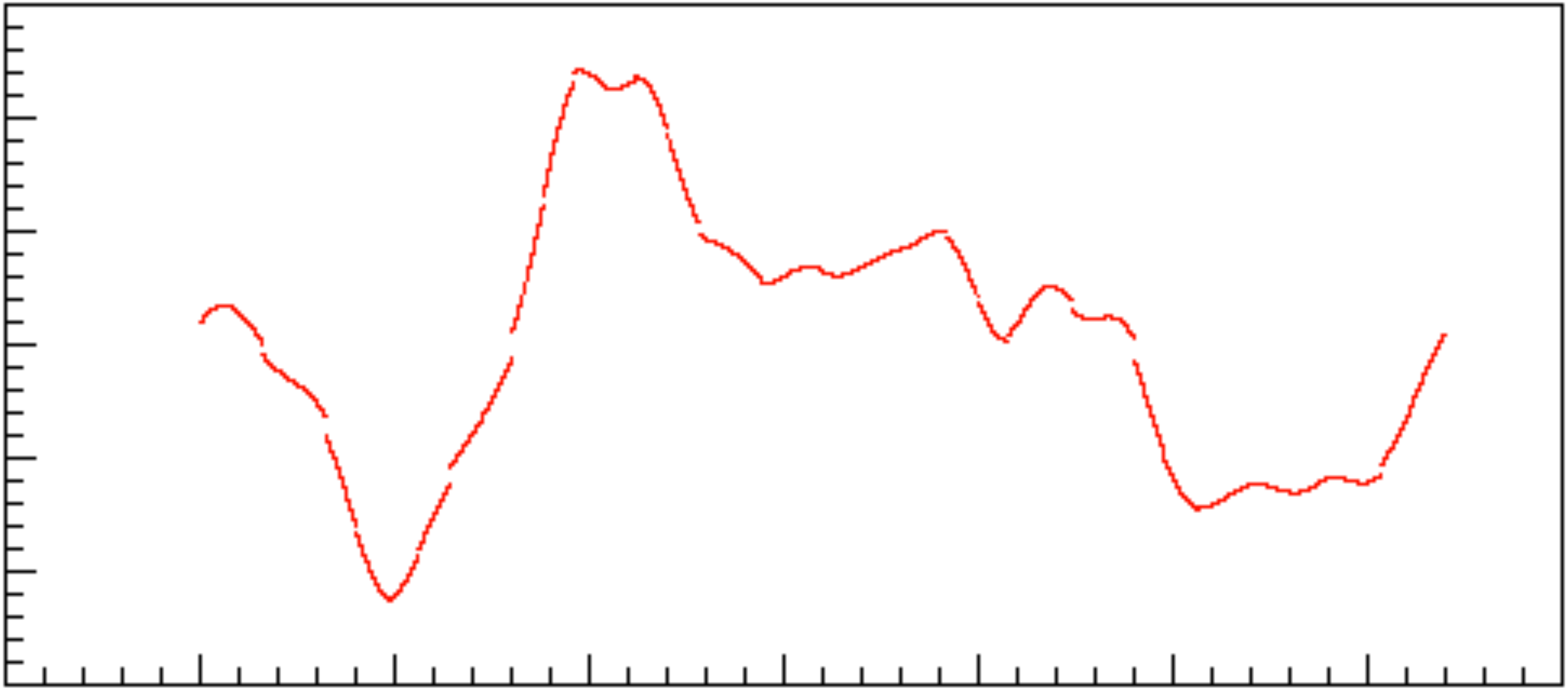


can you see the low frequency coherent components?

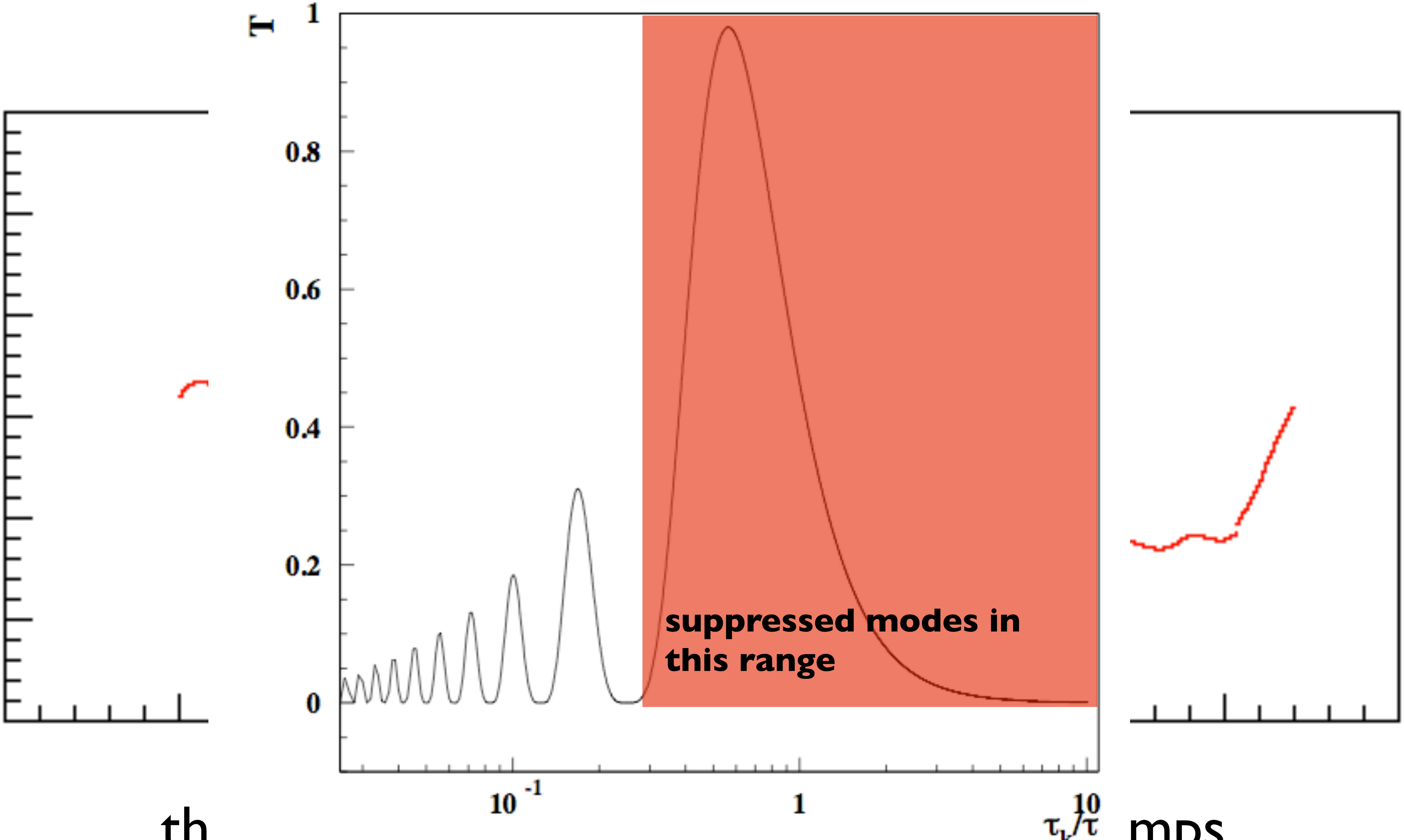
Step 3: Fit the low frequency noise (allow for jumps!)



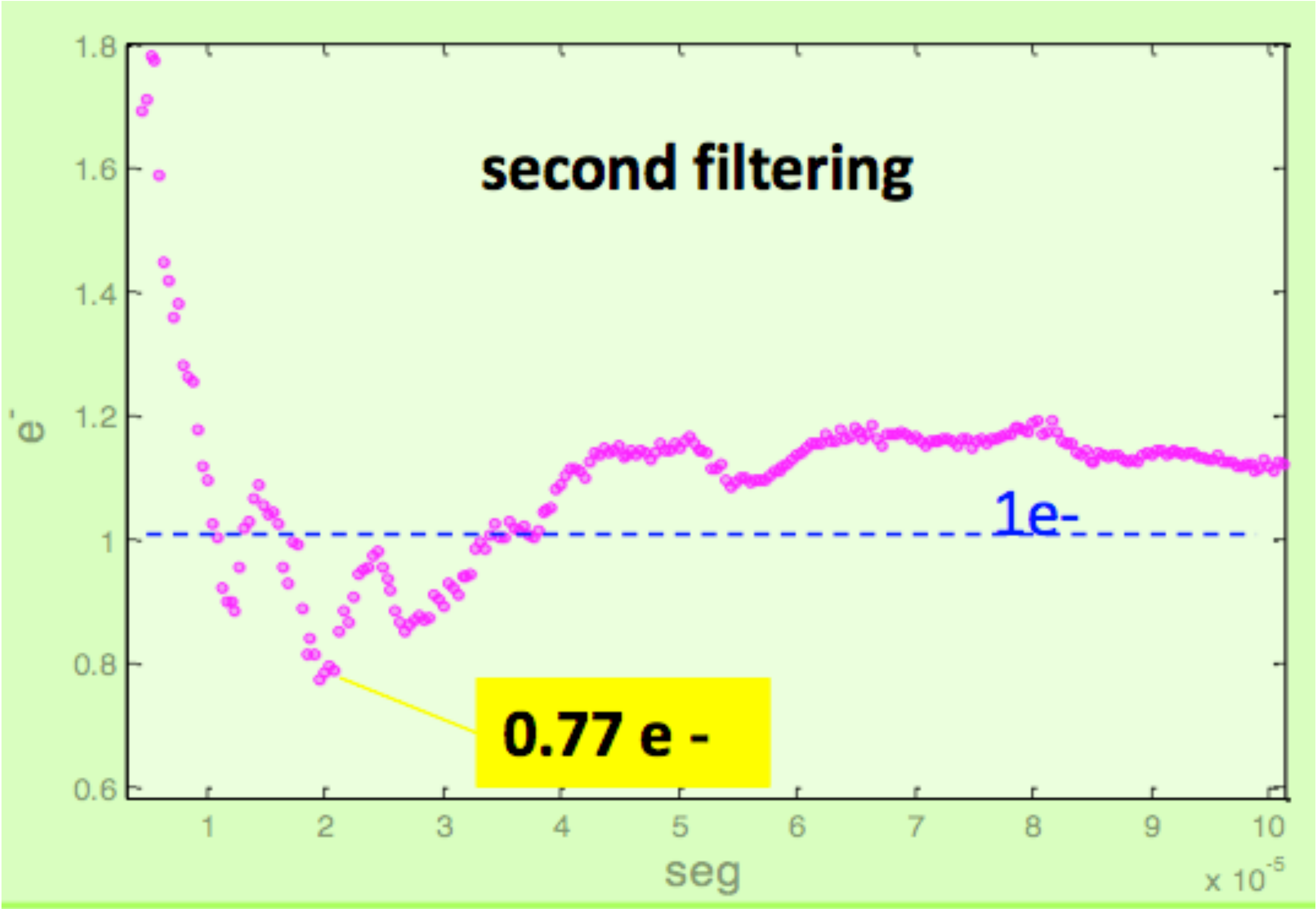
this is the difficult part... solve a very large chi2 problem



this is the low frequency stuff without jumps.


T
1
0.8
0.6
0.4
0.2
0
10^{-1}
1
10
τ_k/τ
suppressed modes in
this range

th mps.



we can now reduce the noise to 0.77e-, we need to implement this on DAMIC (G. Cancelo + international fellow student)