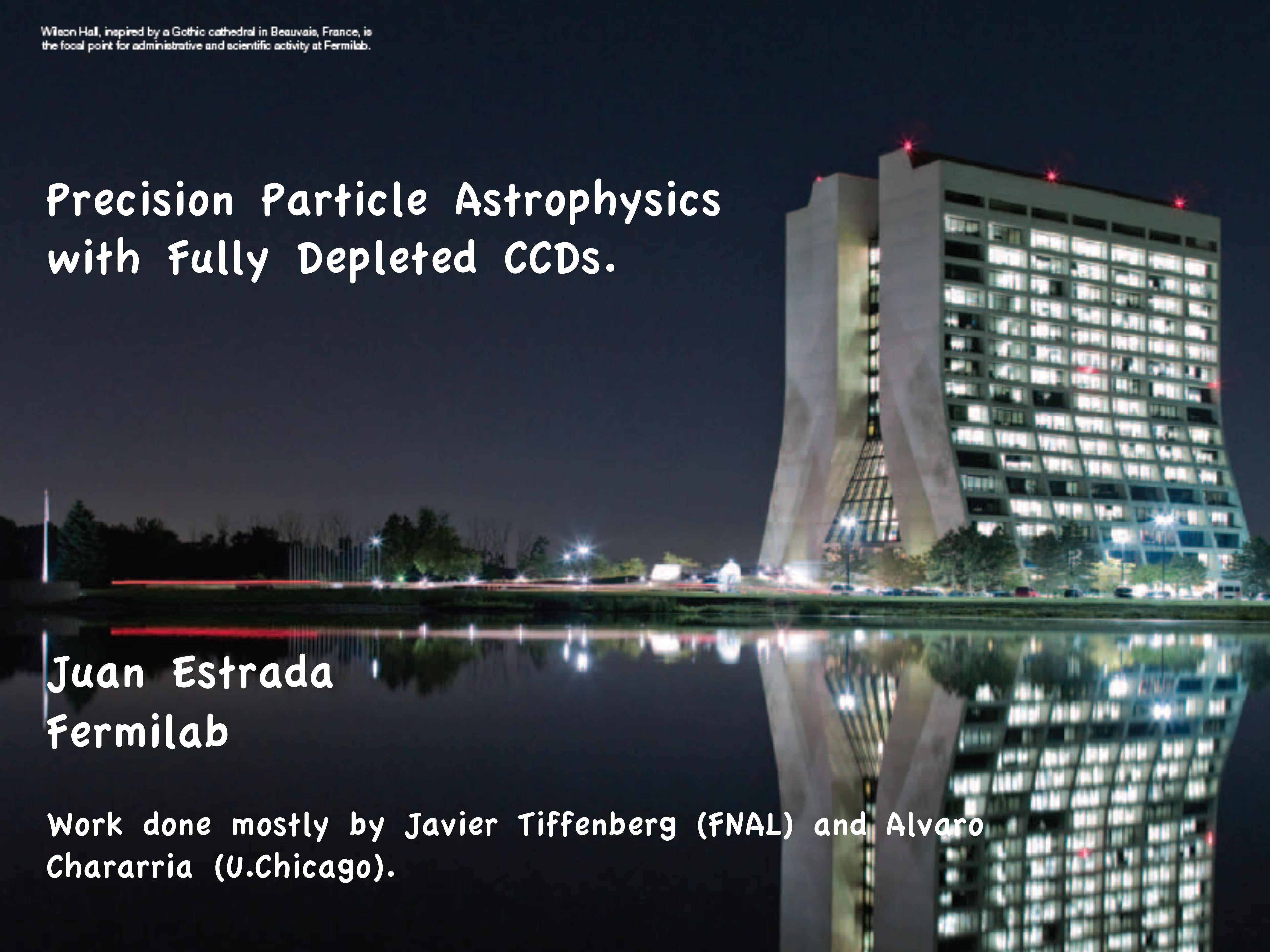


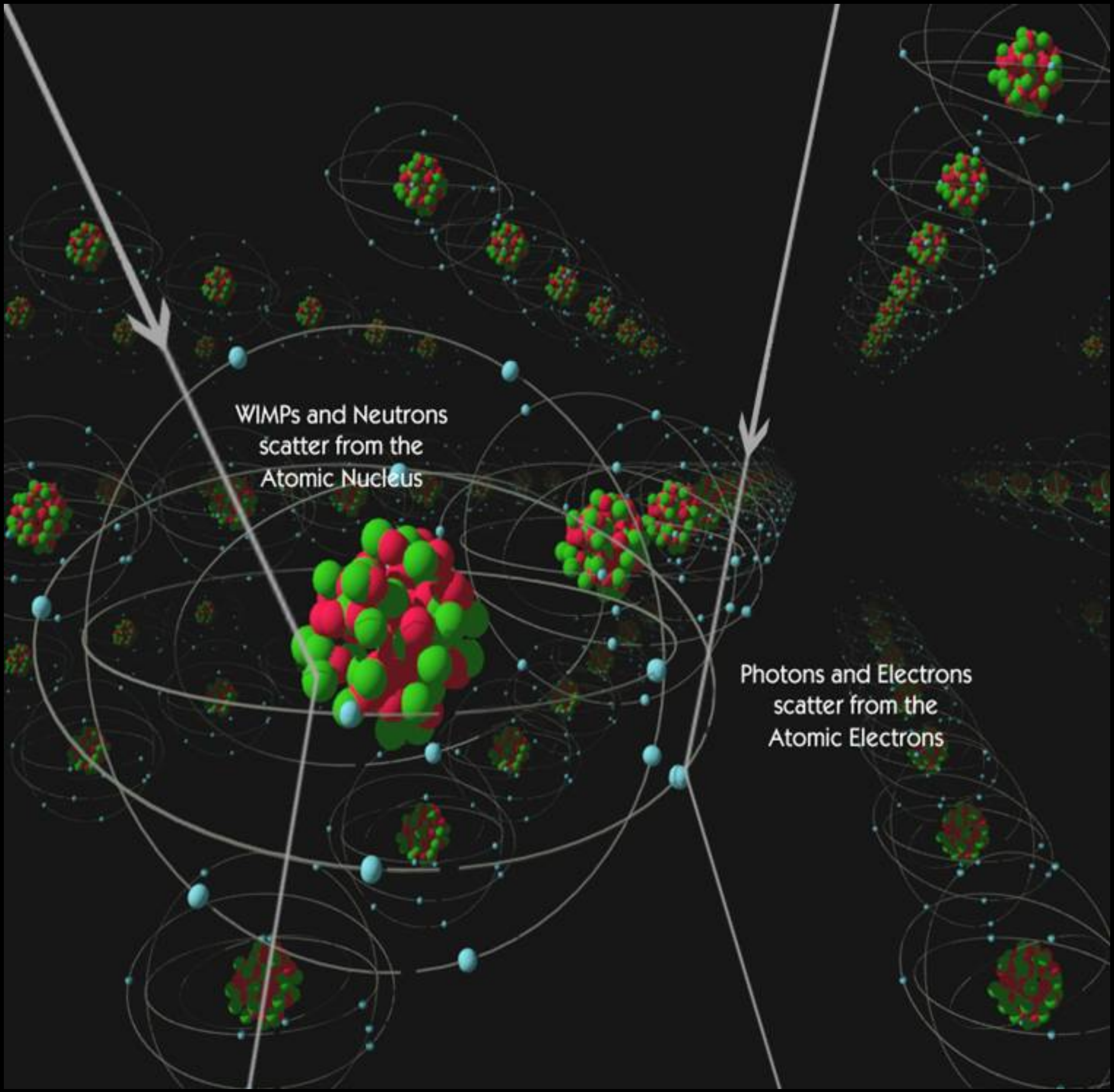
Wilson Hall, inspired by a Gothic cathedral in Beauvais, France, is the focal point for administrative and scientific activity at Fermilab.

Precision Particle Astrophysics with Fully Depleted CCDs.

Juan Estrada
Fermilab

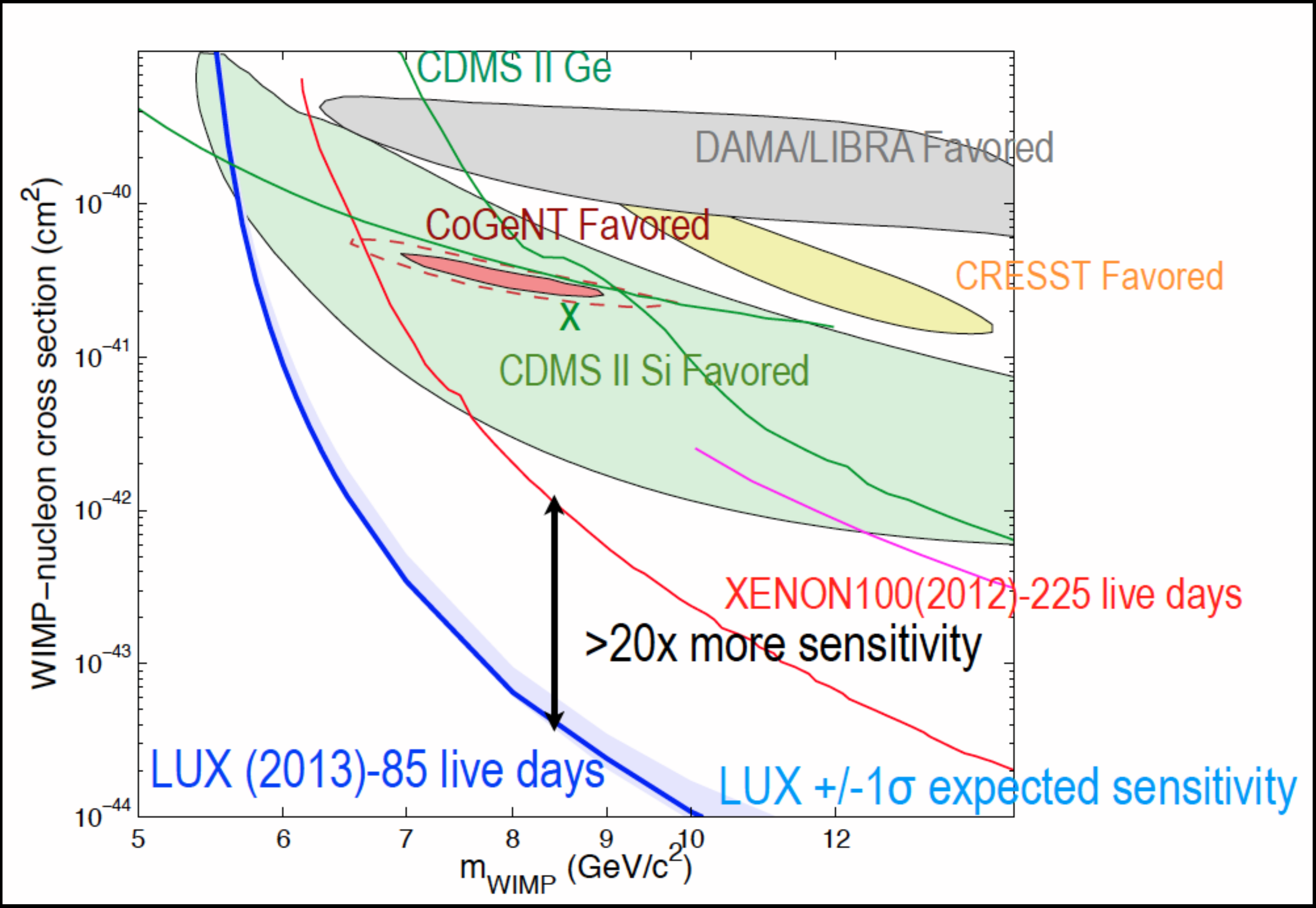
Work done mostly by Javier Tiffenberg (FNAL) and Alvaro Chararria (U.Chicago).

The problem is that the beautiful images of the sky obtained with CCDs show only 15% of the matter in the universe. We are going for the not so shinny 85%.



DM properties:
Small cross section for interaction with standard matter. Electrically neutral.

Recipe:
1) Choose a detector that can see neutral particles
2) Install it in a location where you will see small background from non DM particles
3) Wait for a DM particle to hit your detector

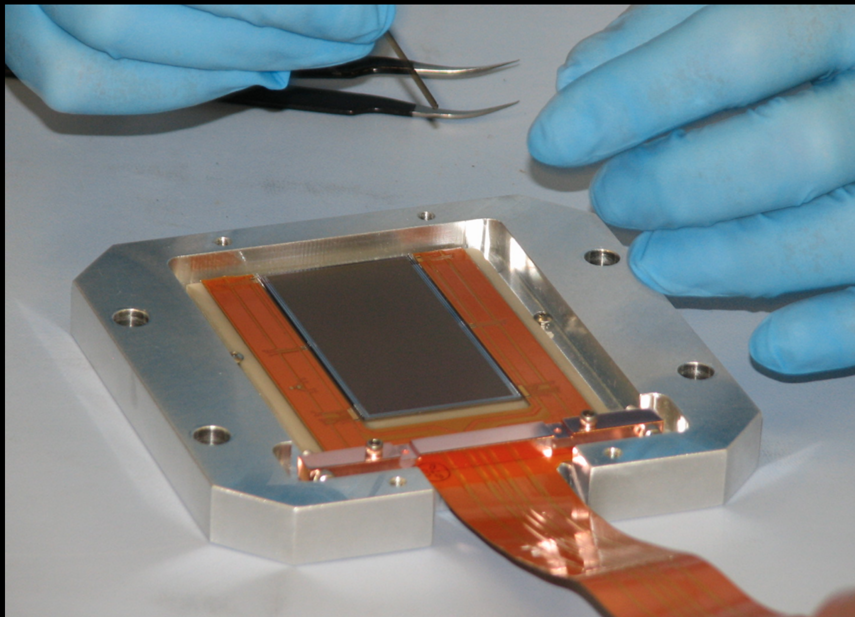


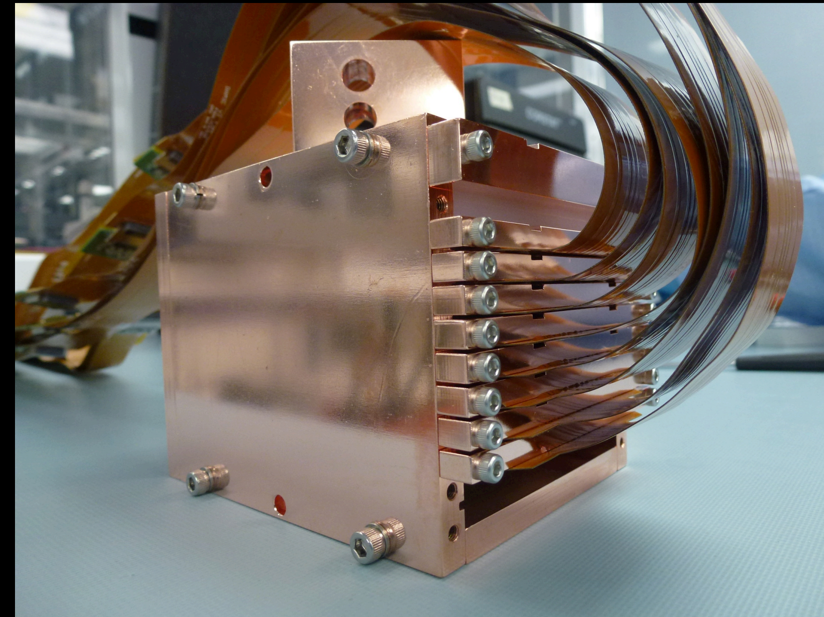
Lot's of activity in the low mass dark matter region.
Thick CCDs have role here because they have very low readout noise (x50 lower than other radiation detectors with a similar mass).

DAMIC Collaboration

First Collaboration meeting in Mexico, May 2013

Fermi National Accelerator Laboratory, Universidad Autonoma de Mexico, Universidad Nacional de Asuncion, University of Chicago, University of Michigan, University of Zurich
10 faculty, 2 postdocs, 5 graduate students, undergraduate students






Ruger


DANGER
HOT WORK PROHIBITED IN THIS AREA

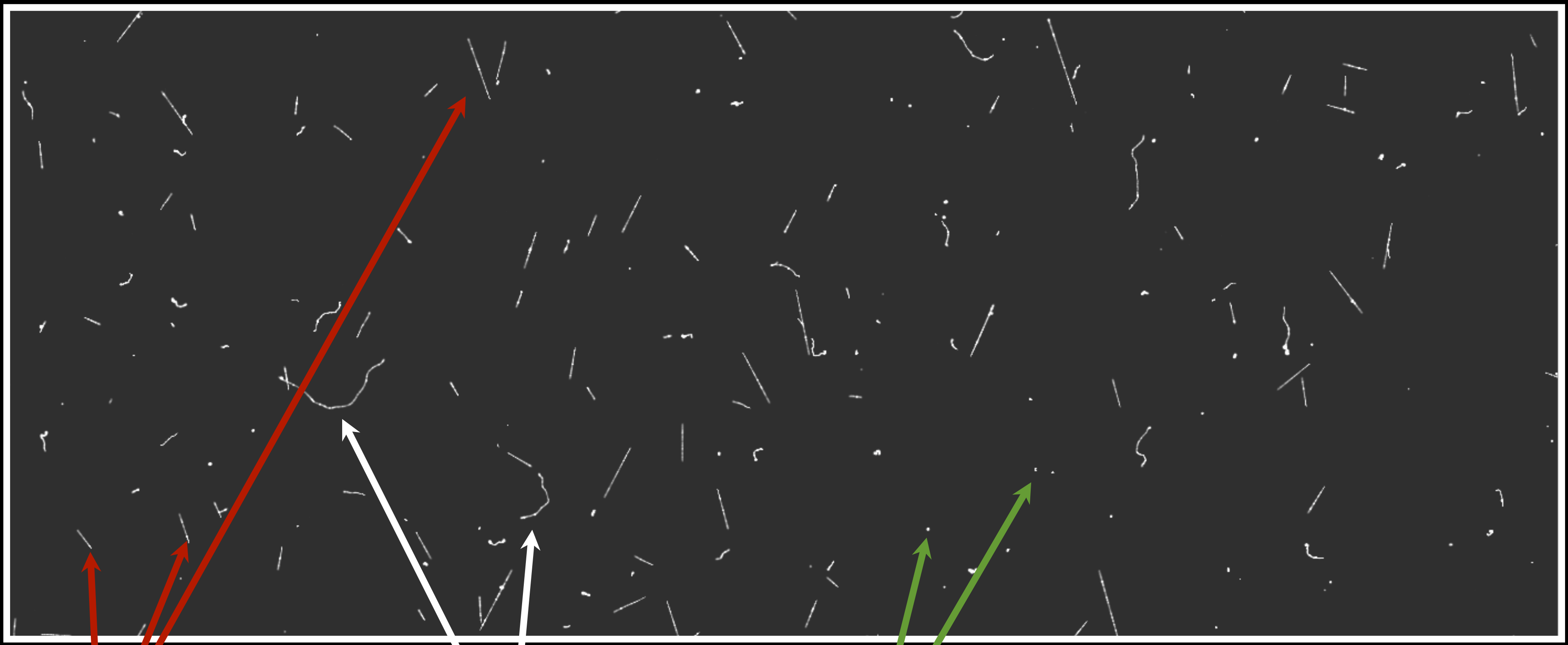

DANGER
HOT WORK PROHIBITED IN THIS AREA

Cerro Tololo Observatory
2200 m above see level

SNOLAB Underground Laboratory
2000 m underground.

Good detectors go to heaven, others go everywhere and have more fun...

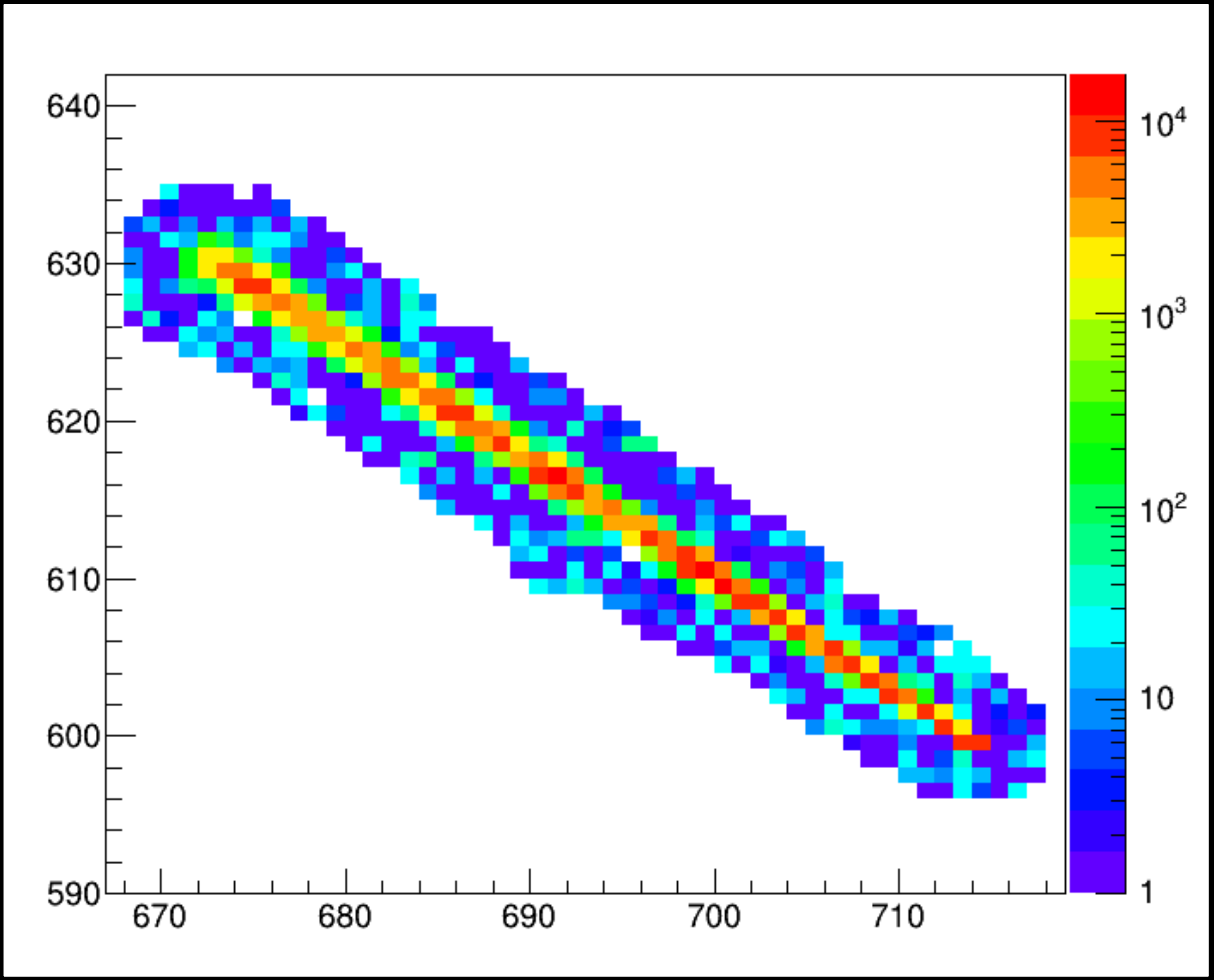
For the purpose of this conference, this is a study of ionizing radiation in the CCDs. How it could be used to improve our understanding of the detectors?



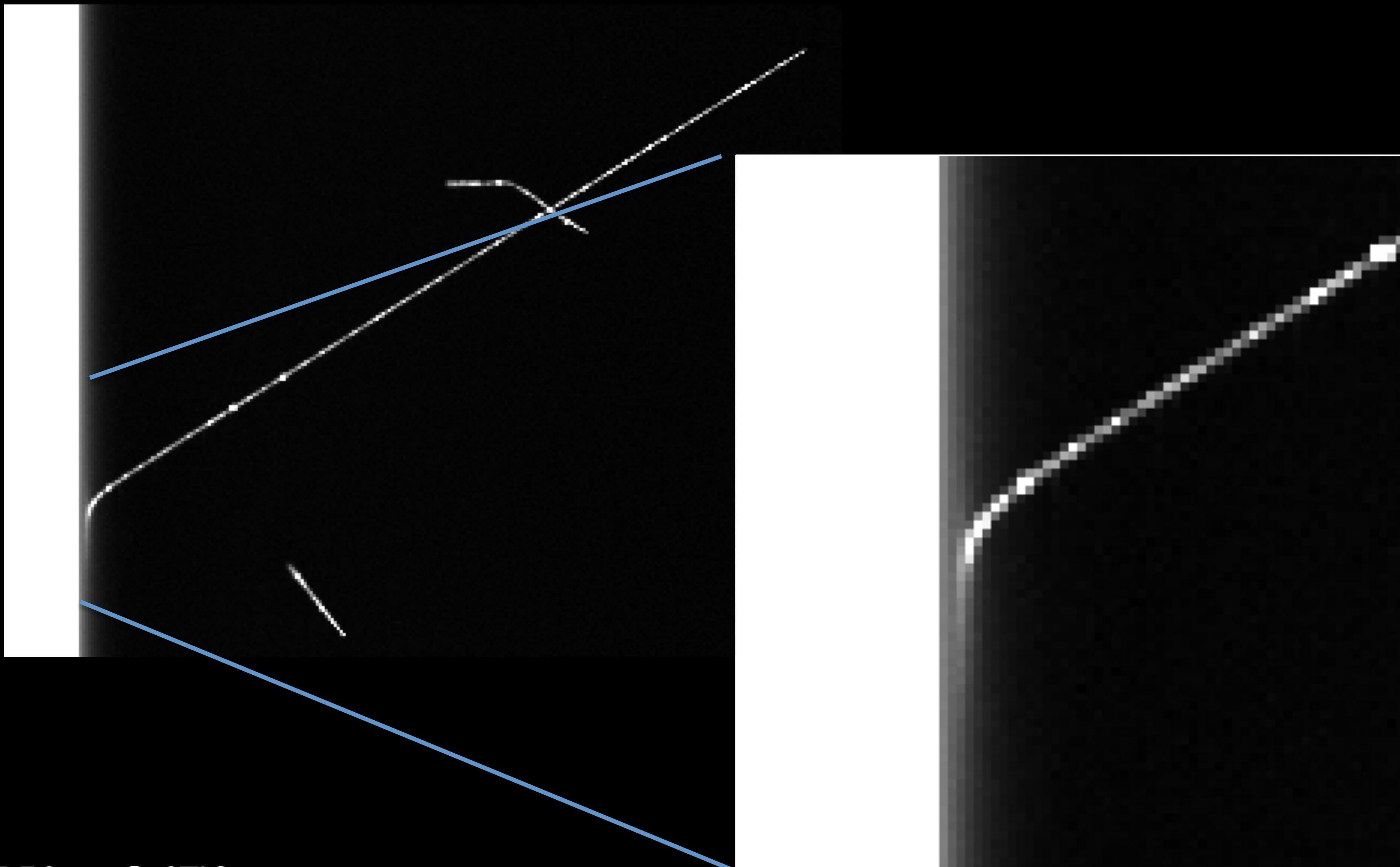
muons, electrons and diffusion limited hits.

nuclear recoils will produce diffusion limited hits
Dark Matter is expected to produce nuclear recoils

Let's start with muons

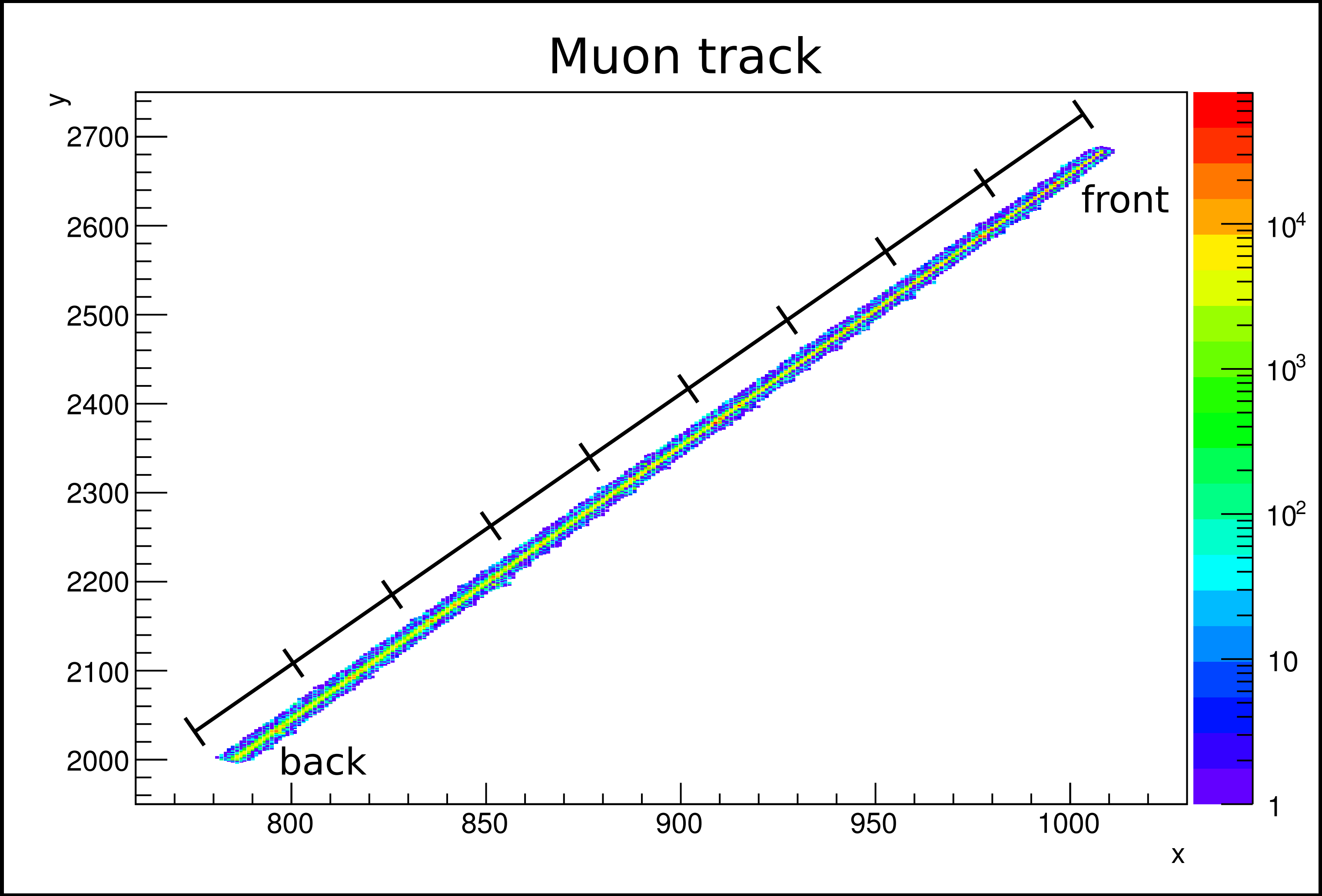


GeV particles go through the sensors in a straight line producing a track. Minimum Ionizing Particle.

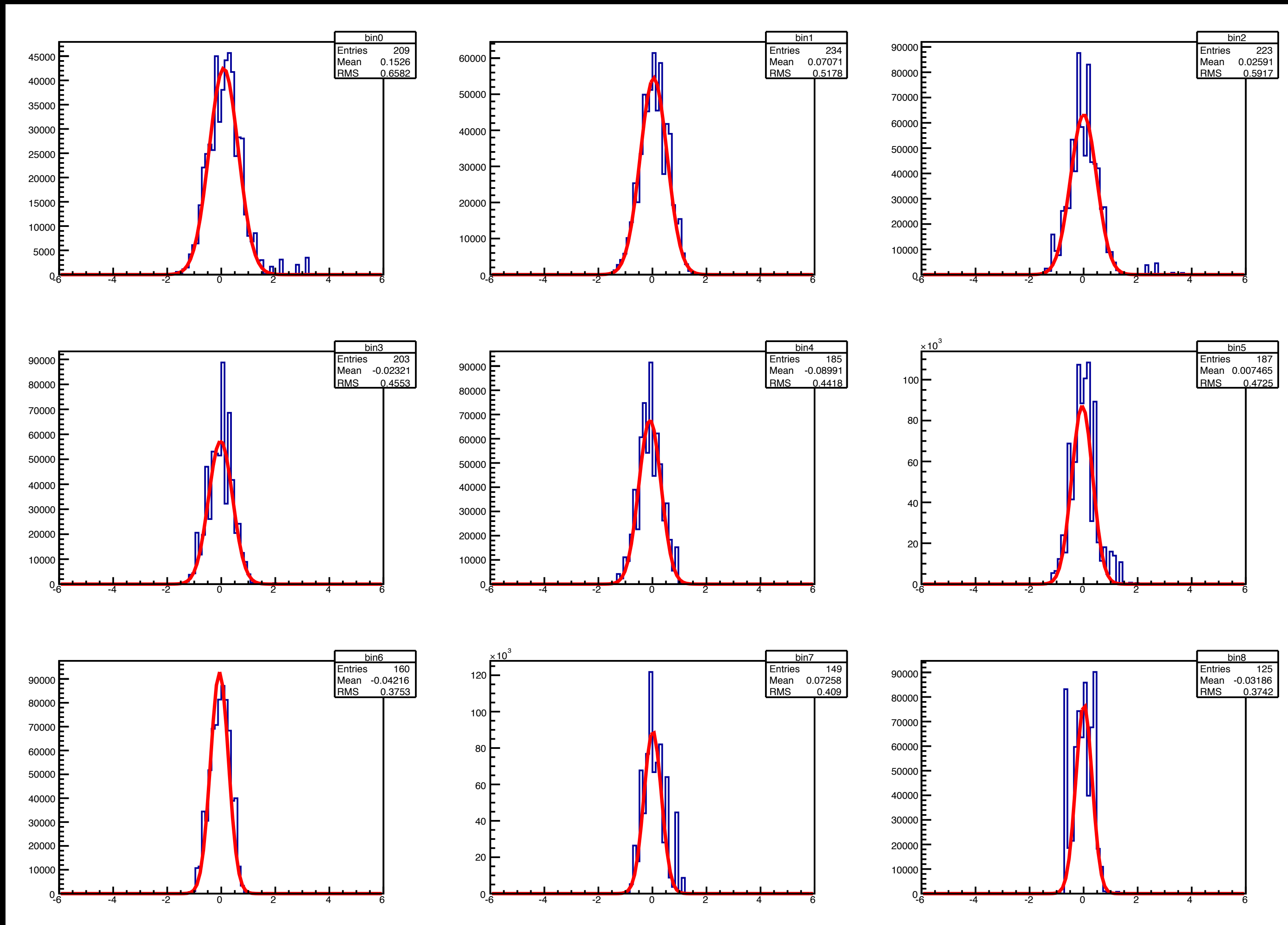


DECam @ CTIO
Muons do not bend!

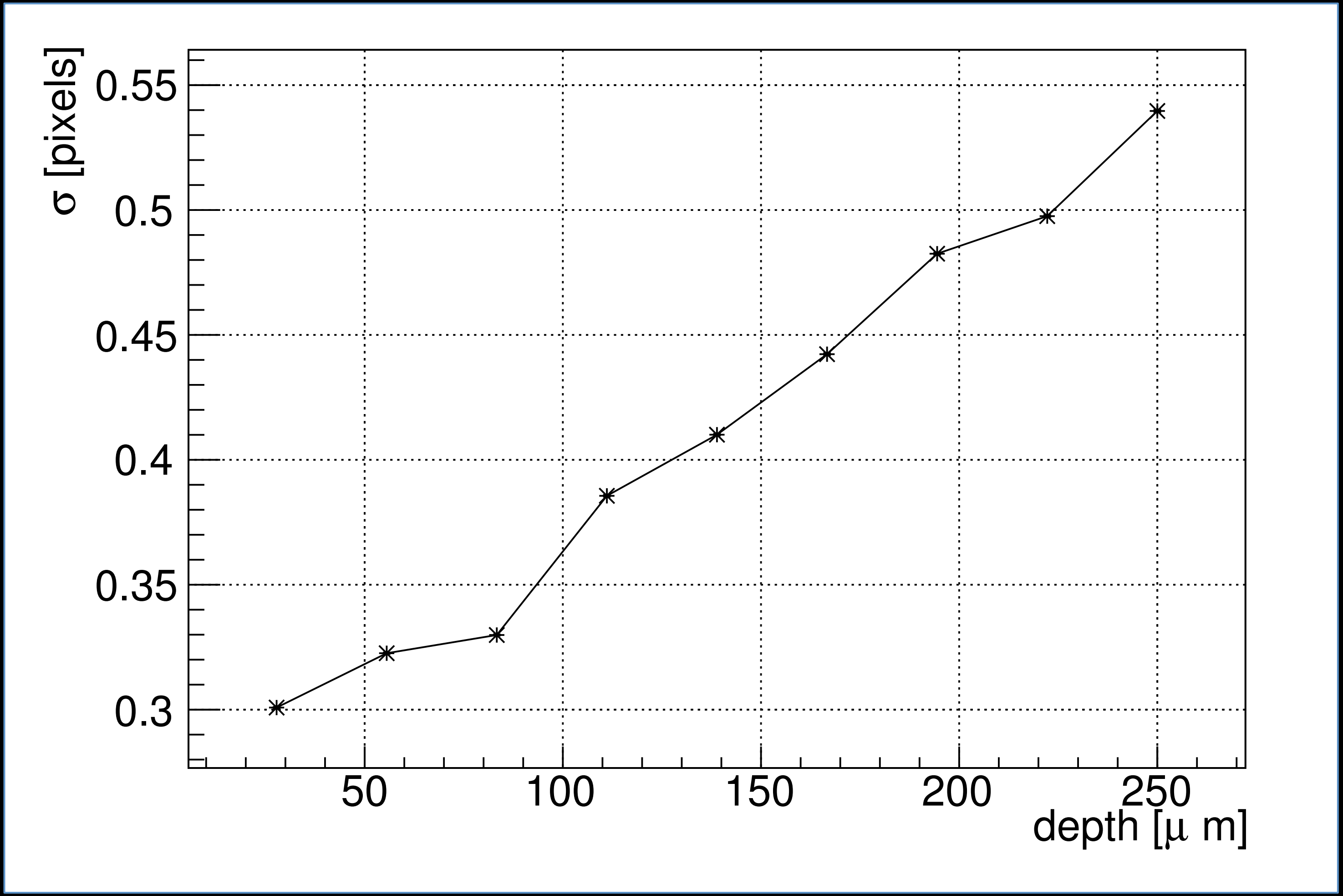
Have a lot of muons in DECam. They could teach us image deformation.
You could measure the deformation inside the silicon, instead of the 2D projection.



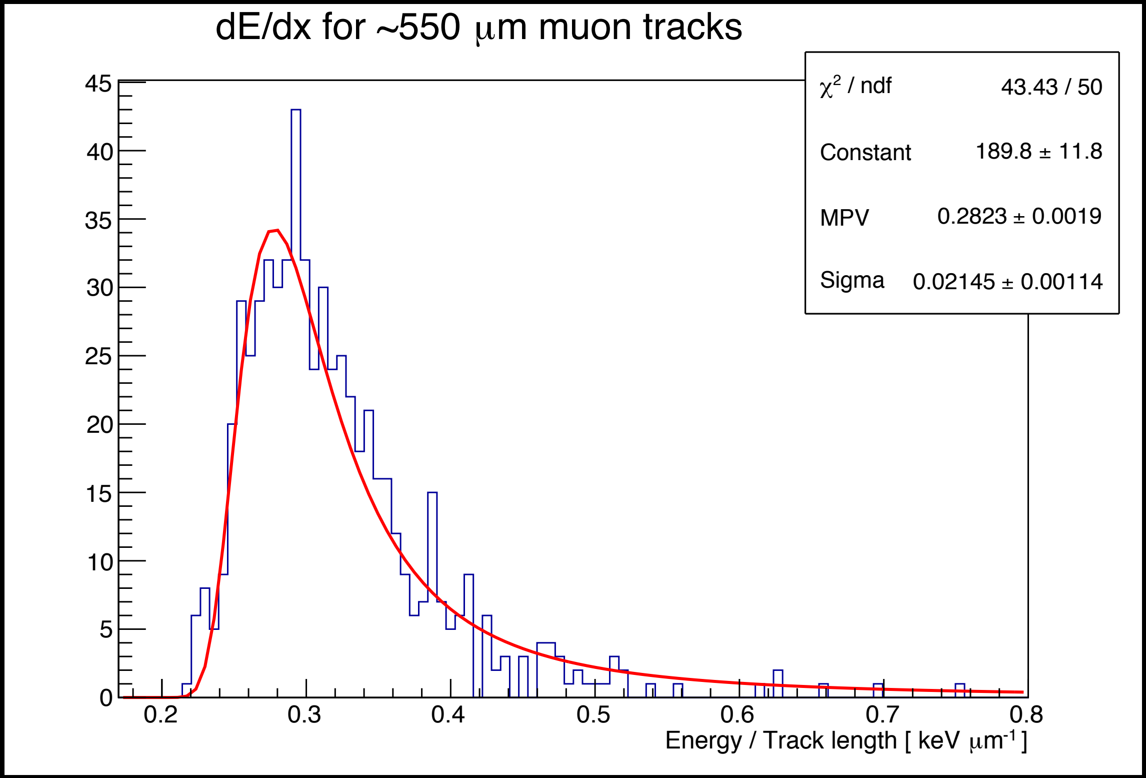
Measurement of diffusion at each section of the track.



Measurement of diffusion at each section of the track.



Each muon track gives you a map of the field inside the detector. Each muon gives you a series of diffusion measurements for each track position.

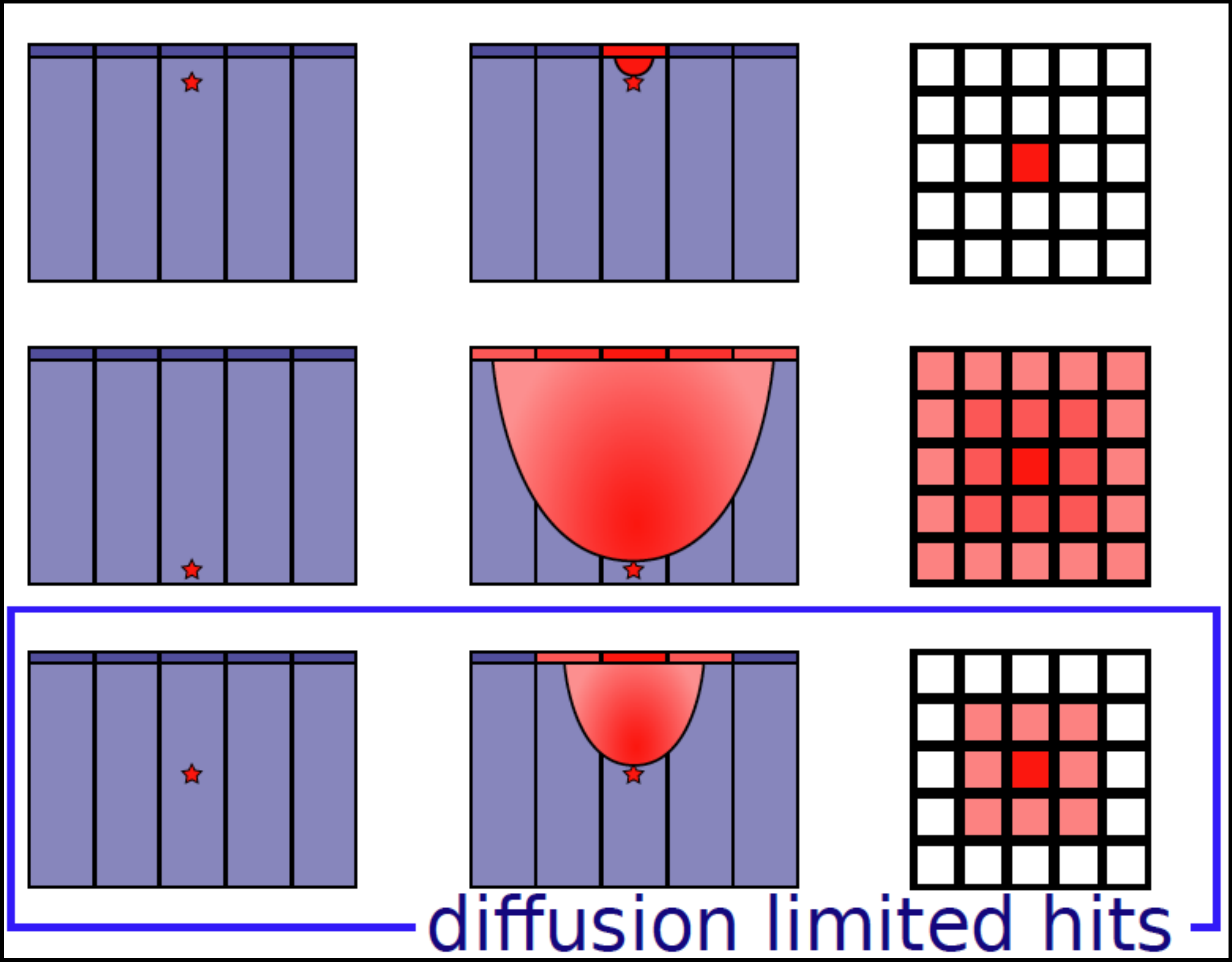


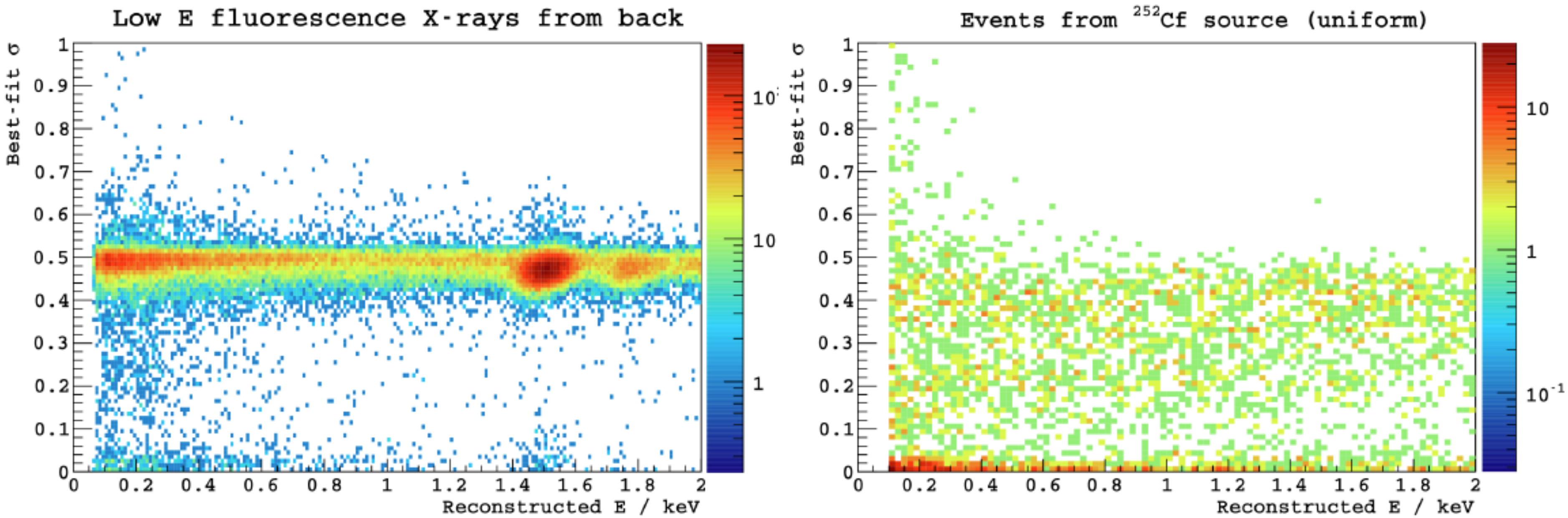
The charge deposited per unit length of the track inside the silicon is a Landau distribution with the most probable value of 0.287 keV/um.

This means that we could monitor the muons and have a running measurement of the gain in our sensors.

We could use the muons to build a full 3D map of the fields inside the CCD. We could also use them to constantly monitor the gain of the system.

Diffusion gives us 3D hit reconstruction



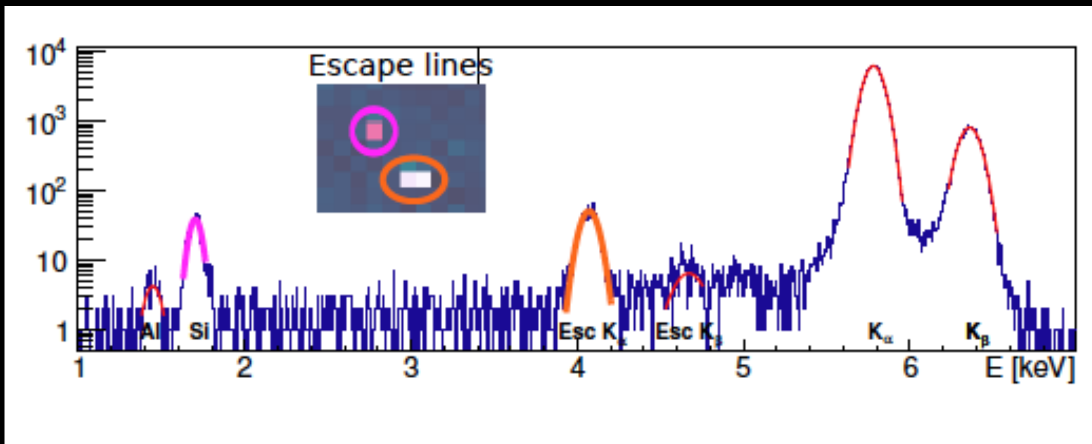


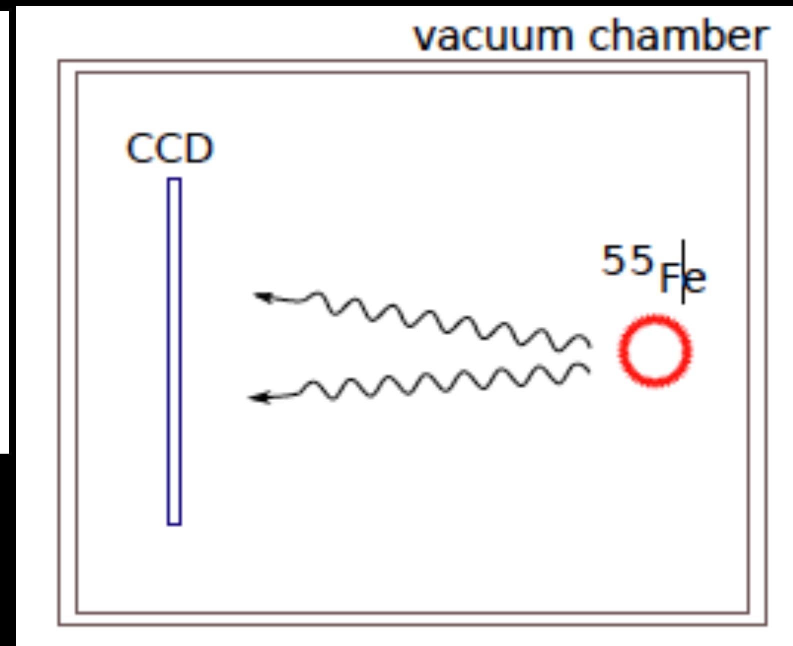
X-ray penetrate few um into the silicon.
Neutrons interact everywhere in the bulk.

The density of hits for neutrons should be constant (only depend on the mass of each pixel). This is a nice way to measure the 3D volume of each pixel.

What is even nicer… you can simply put the source outside your camera. Should we start doing neutron flat fields in addition to dome flats, and sky flats?

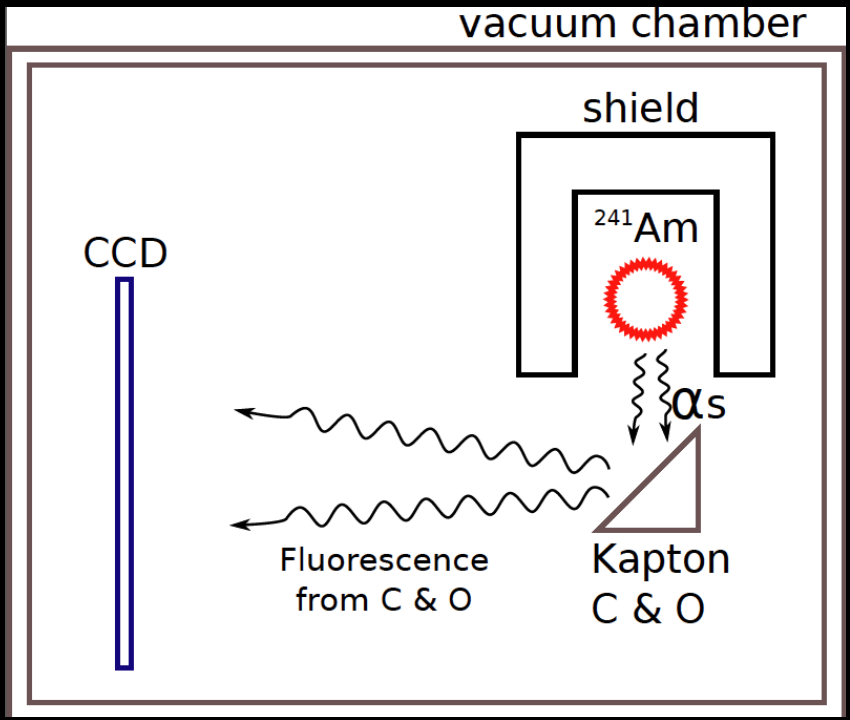
X-rays

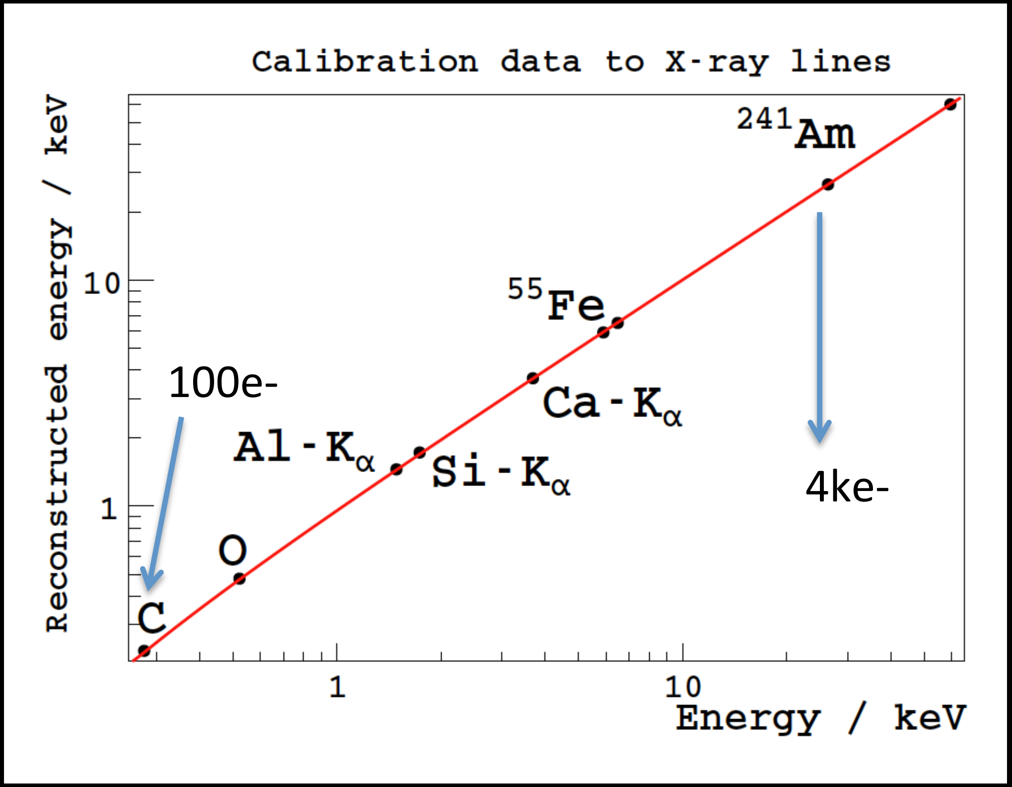




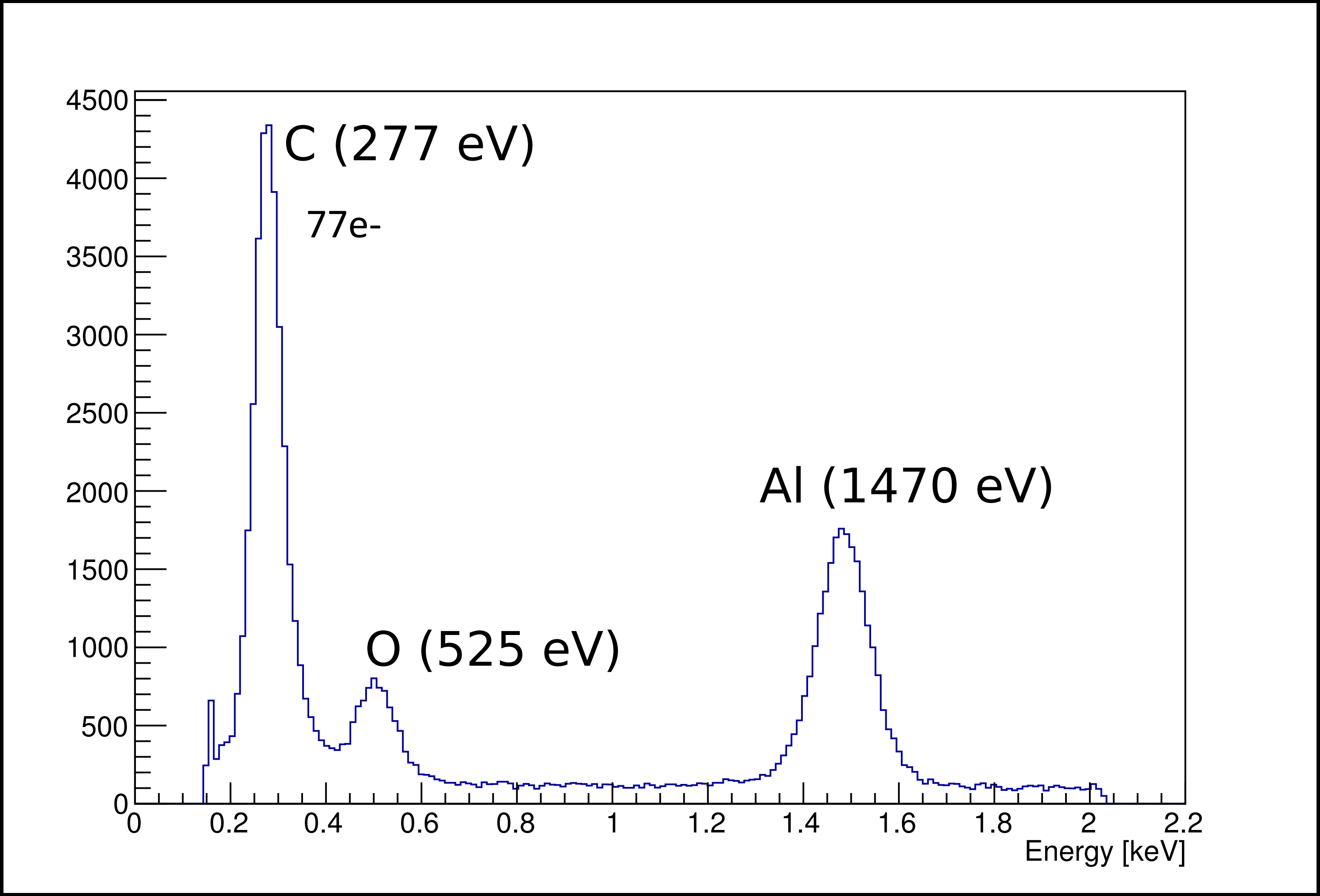
This is a very standard technique, see poster outside.

X-rays – fluorescence from alpha source

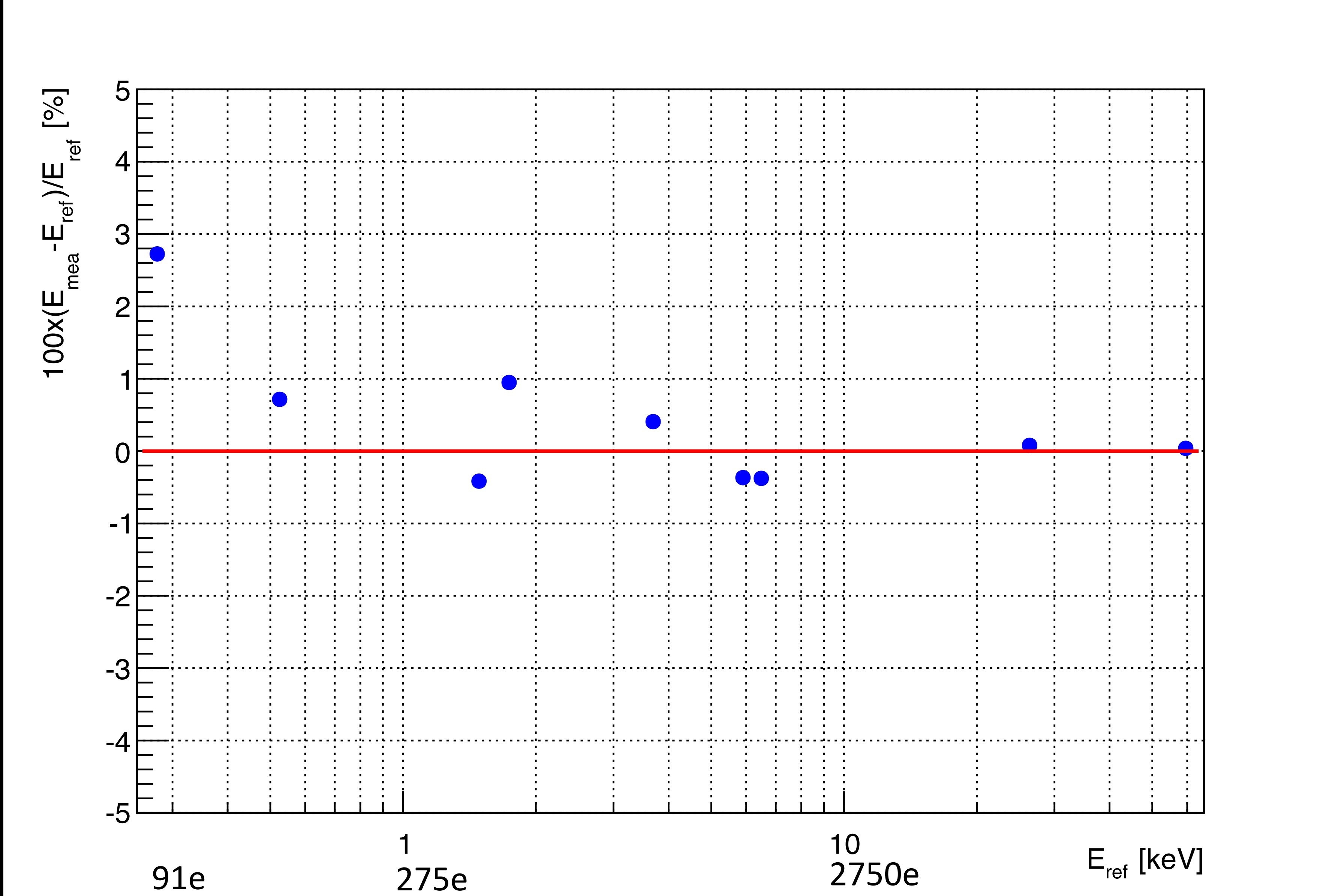




Am-241 source one can get a nice set of calibration points at low signal levels.

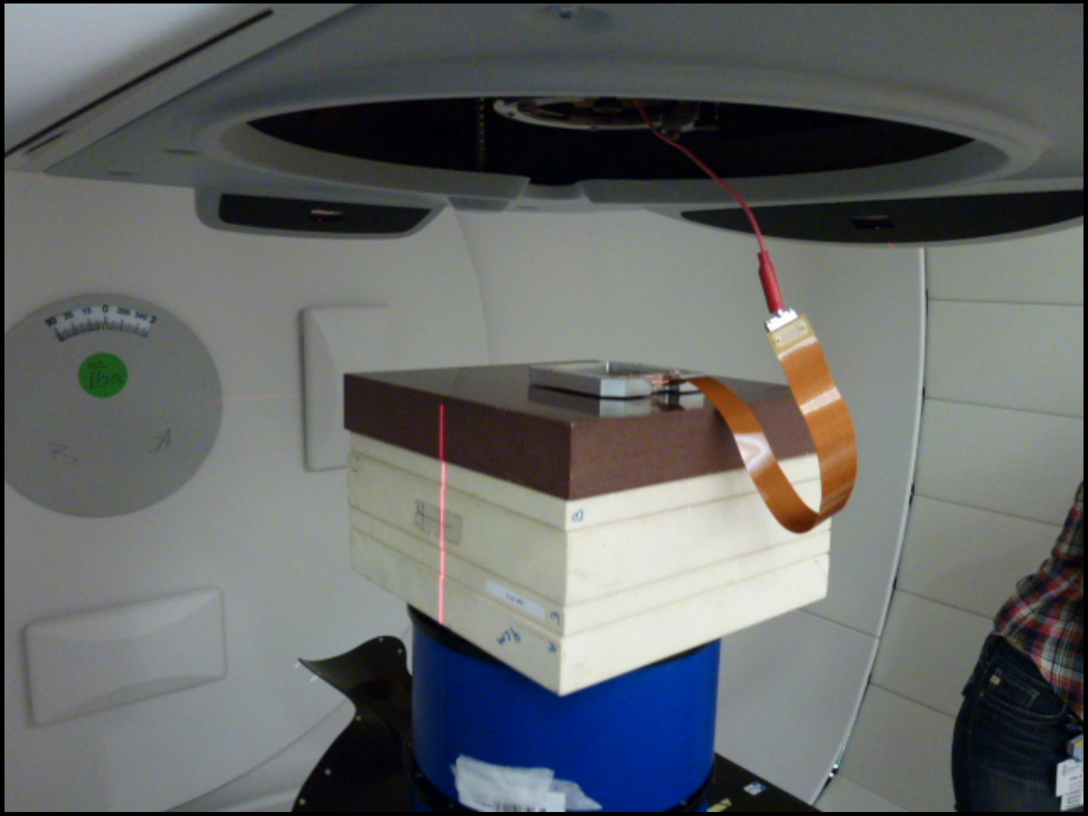


Clear peaks for the low signal calibration of the detector.



We see a 2.5% non-linearity at ~80e-
0.06 keV offset in the fit → 16e- offset

One more calibration at very low energies

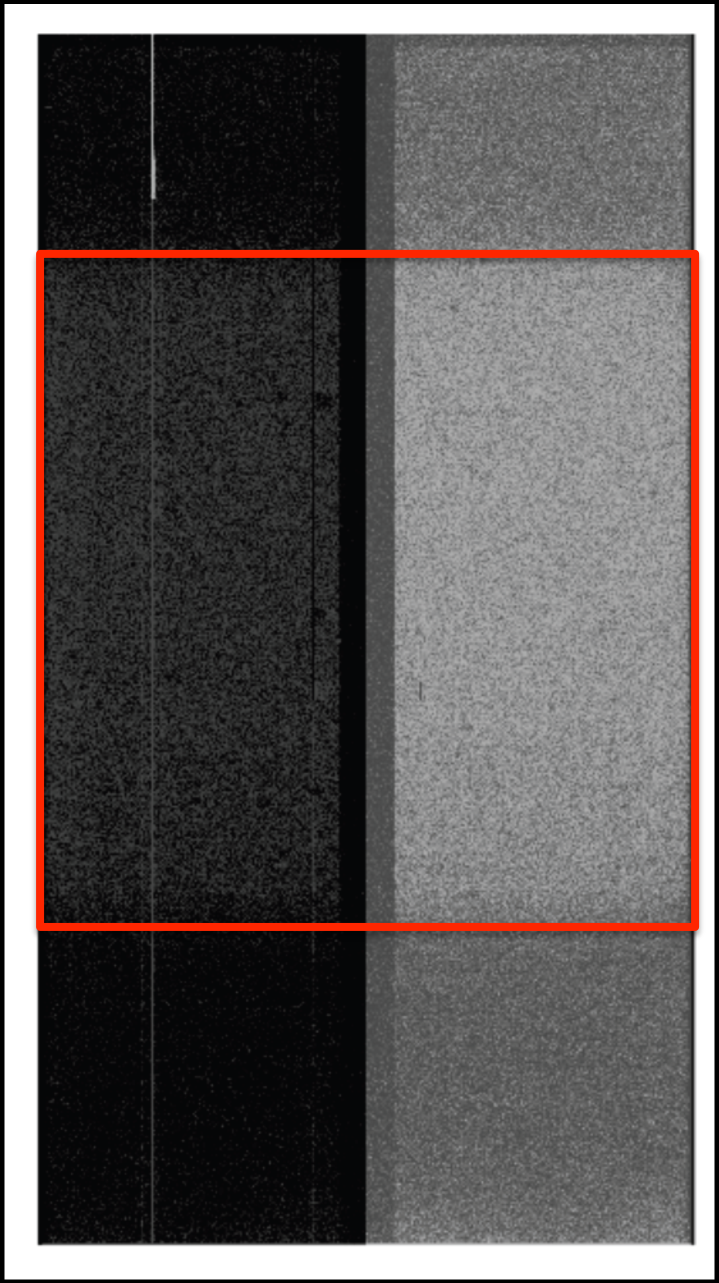


We produced ^{22}Na in our detector ~0.6 Bq (with 2E10 p/cm2)

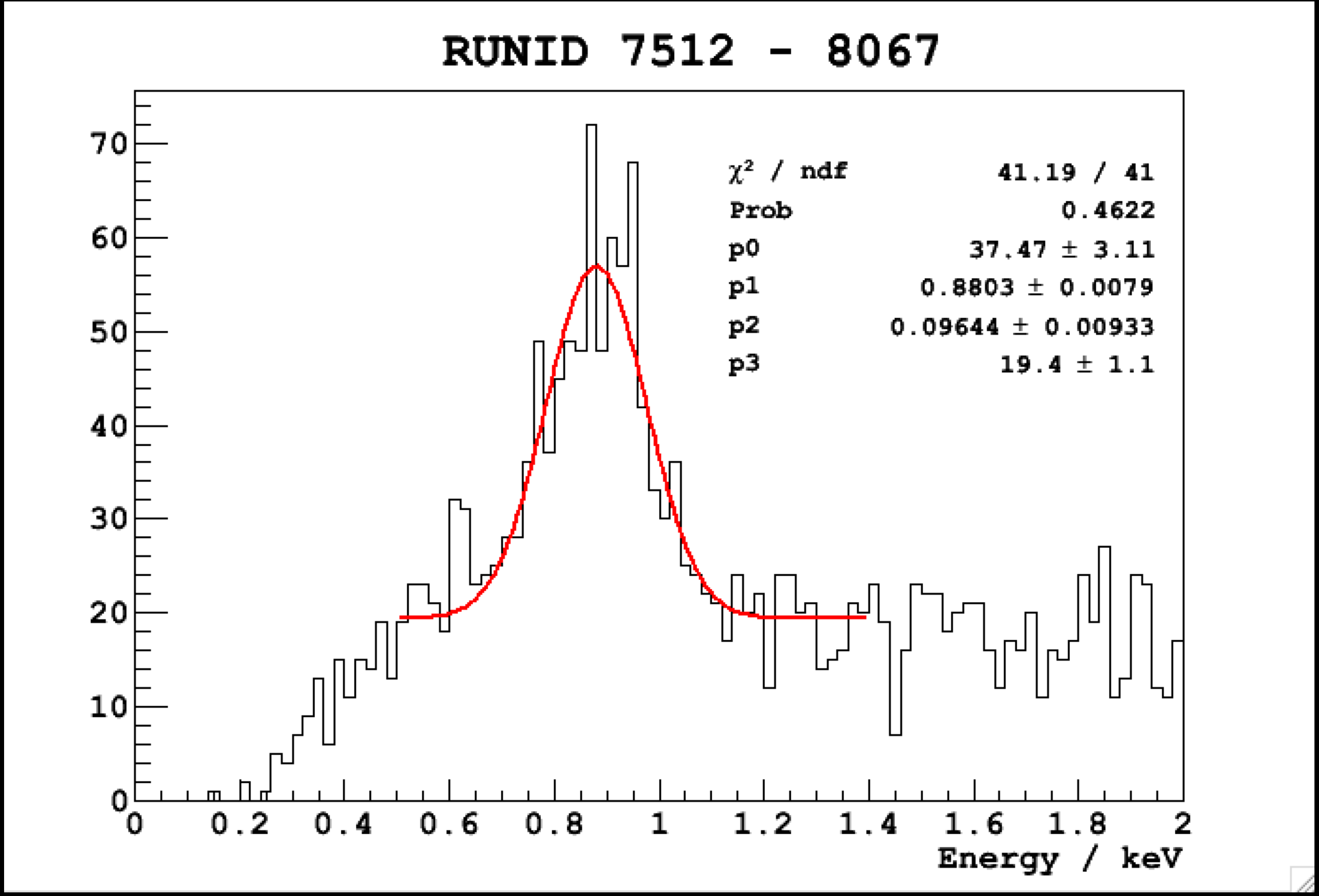
Electron Capture decay:

$$^{22}\mathrm{Na} + e^- \longrightarrow {}^{22}\mathrm{Ne} + \nu_e + \gamma$$

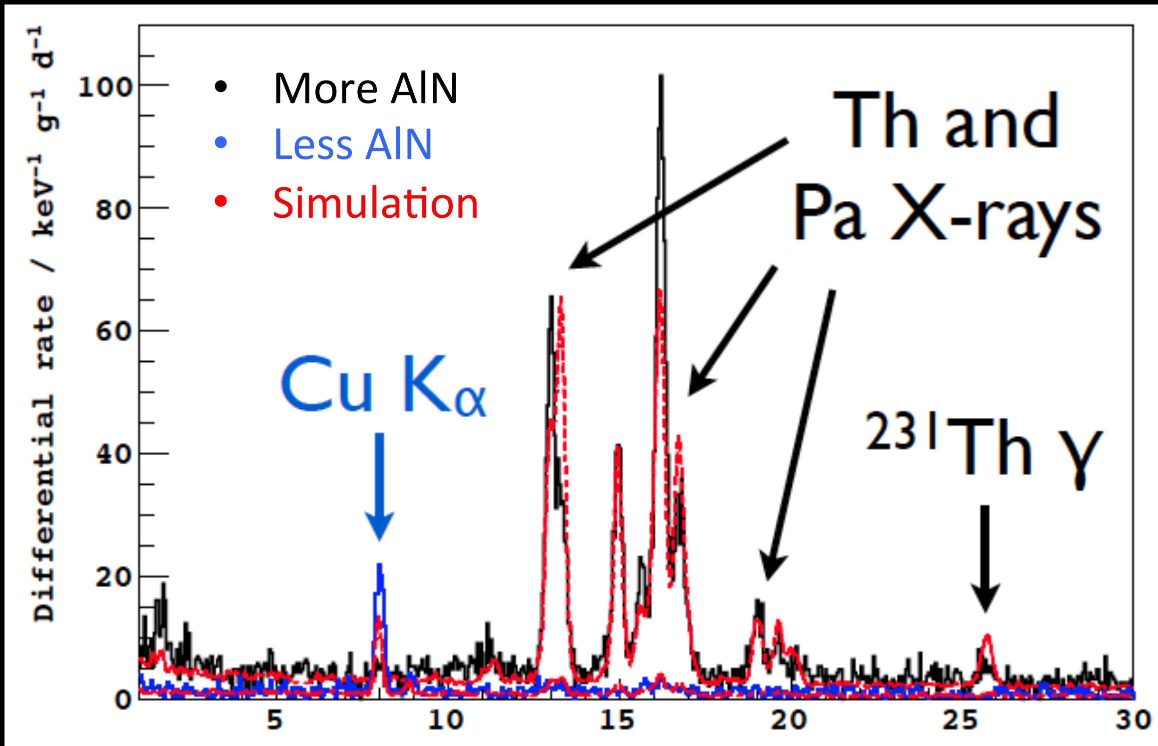
The emission of neutrino and gamma produces a nuclear recoil followed by an X-ray at about 1 keV. This is produced inside the detector!



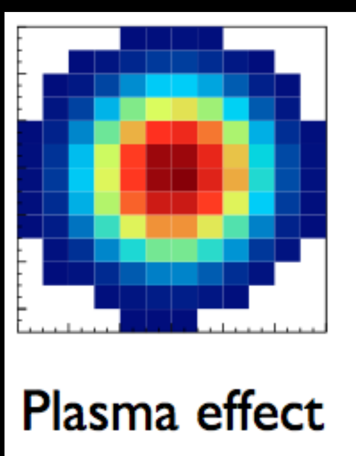
The irradiated area of the detector has higher dark current, as expected.



The 880 eV, which corresponds to a 244e- object.
Probably about 150e- in the brightest spot, 2e- of error in this calibration!
Nice tool for low signal studies (important for DM)

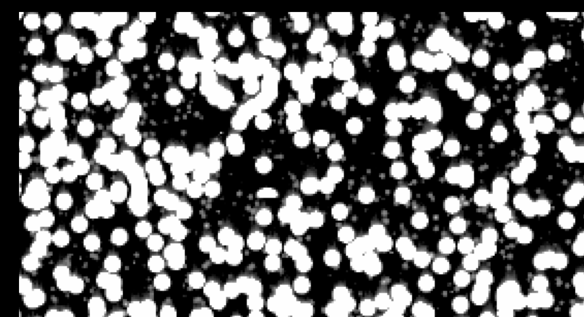


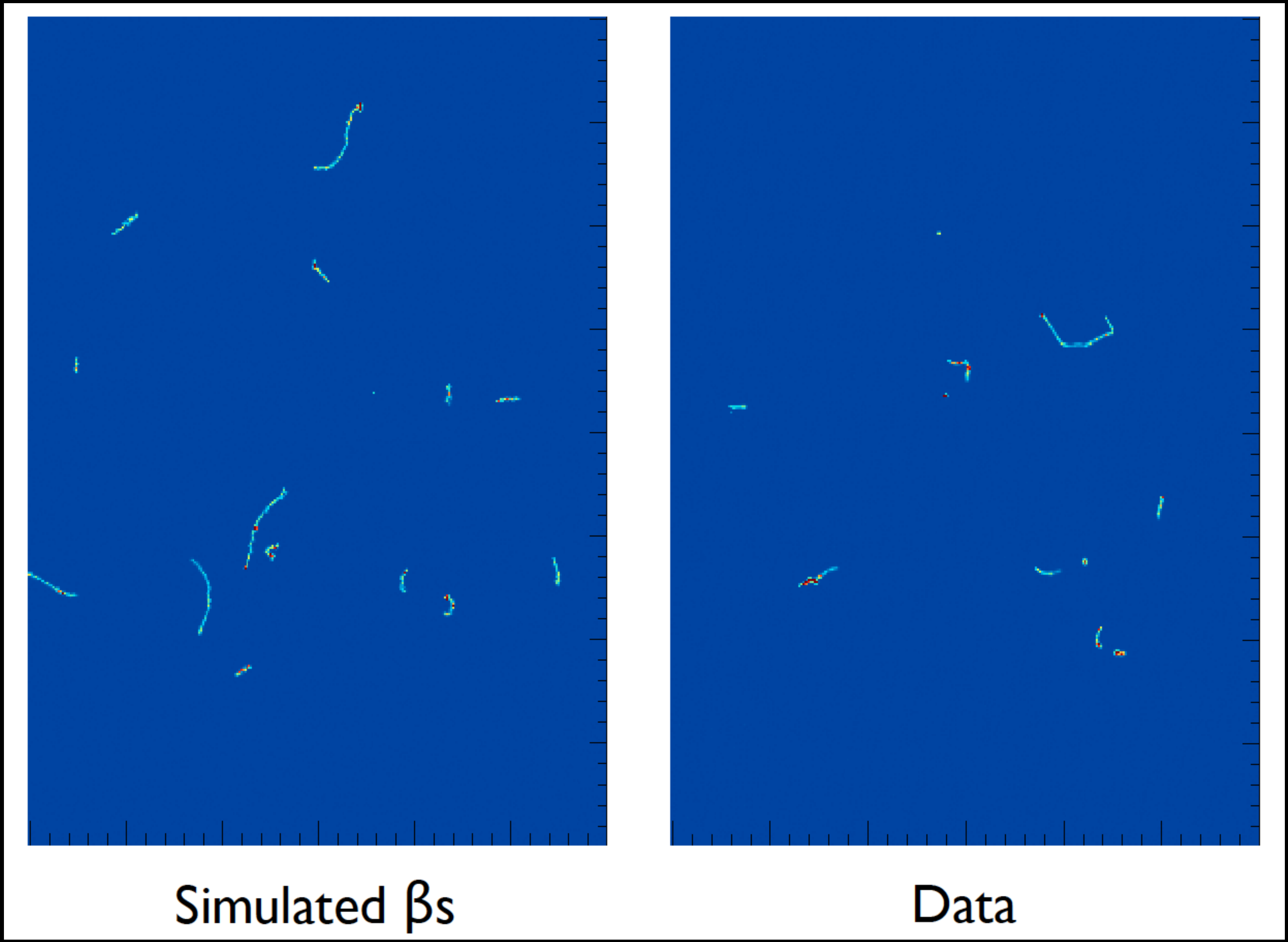
We are also starting to get a very good idea about which parts of the package are radioactive. The electronics next to the CCD is the largest offender, the AlN comes next.



Alpha particles produce plasma effect in silicon, and the signature is very easy to identify in the images.

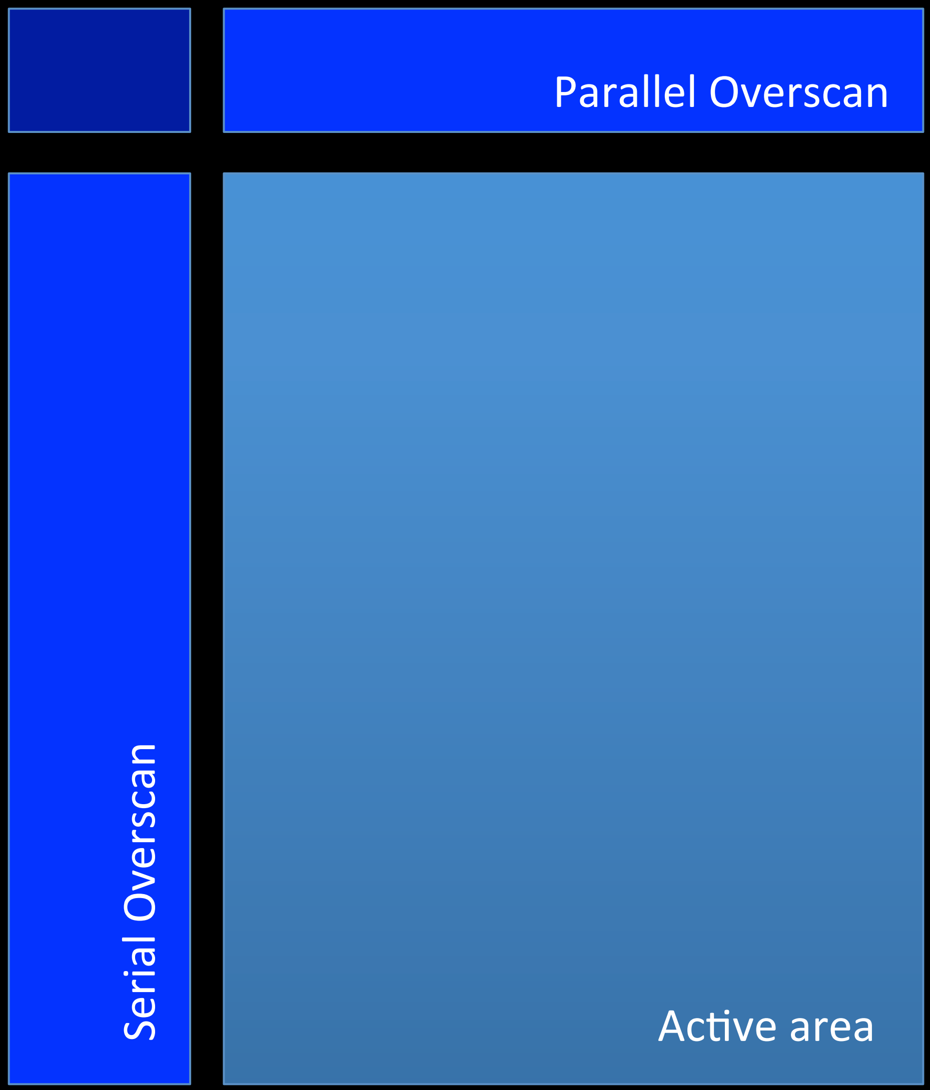
U and Th contamination in the Silicon would produce these, and they will not escape detection. Short range. We get **<10-4 Bq/kg of U + Th. Nice!**





As for any particle detector we simulate the data, in this case what people in this meeting would call "cosmic rays". These tools already exists MCNPX.

Mystery 1



What we expect for darks:

As you reduce the exposure time, will have lower signal level in the active area until you reach the level close to your overscan.

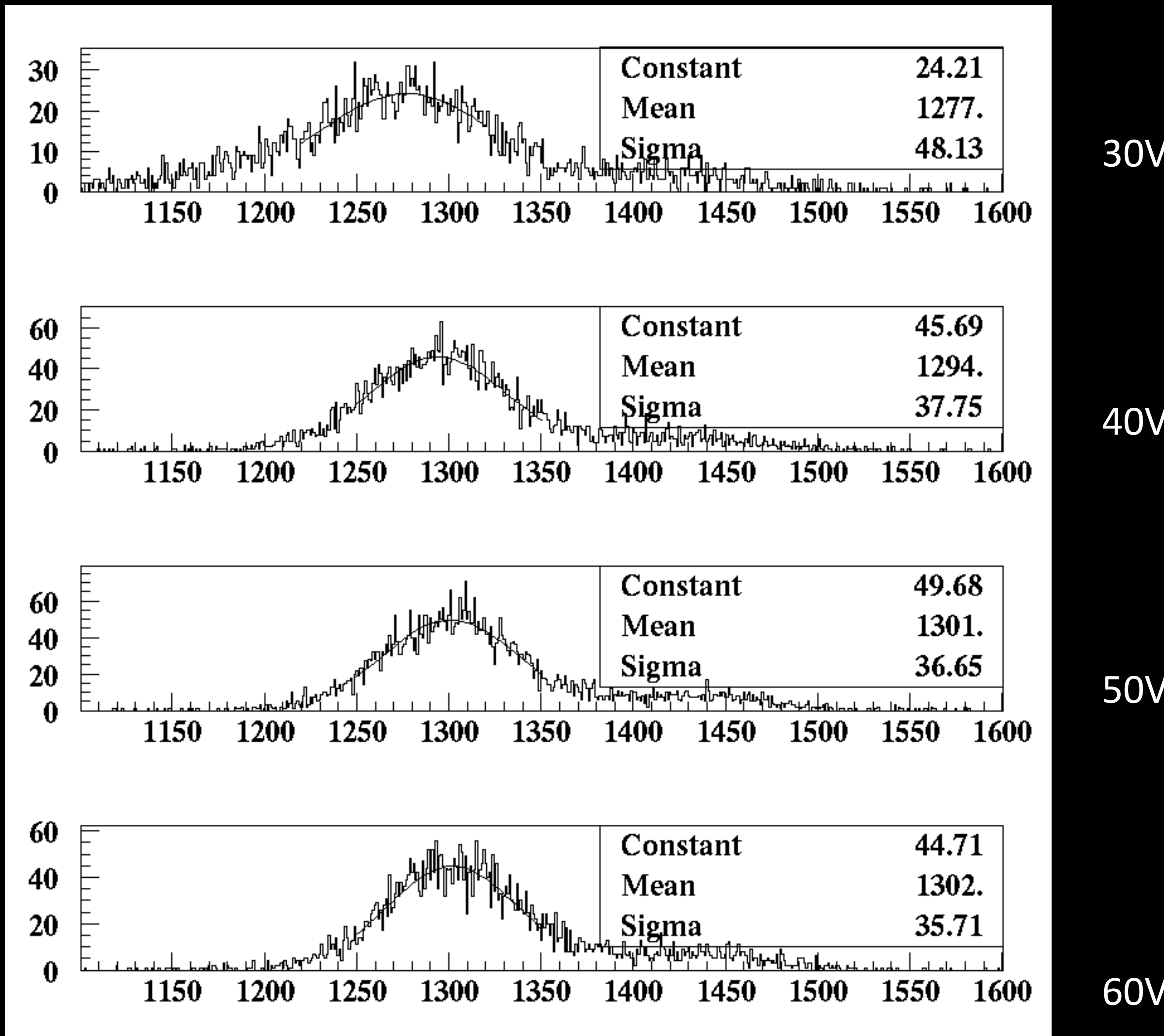
What we get:

Seems like we have a constant offset with respect to the overscan. Like if the TG transition injected a fixed amount of charge into the serial register.

This shows up as an offset in a linearity measurement. Also as extra noise in active area with respect to overscan.

Still under investigation.
What can we do with TG to improve this?

Mystery 2 :

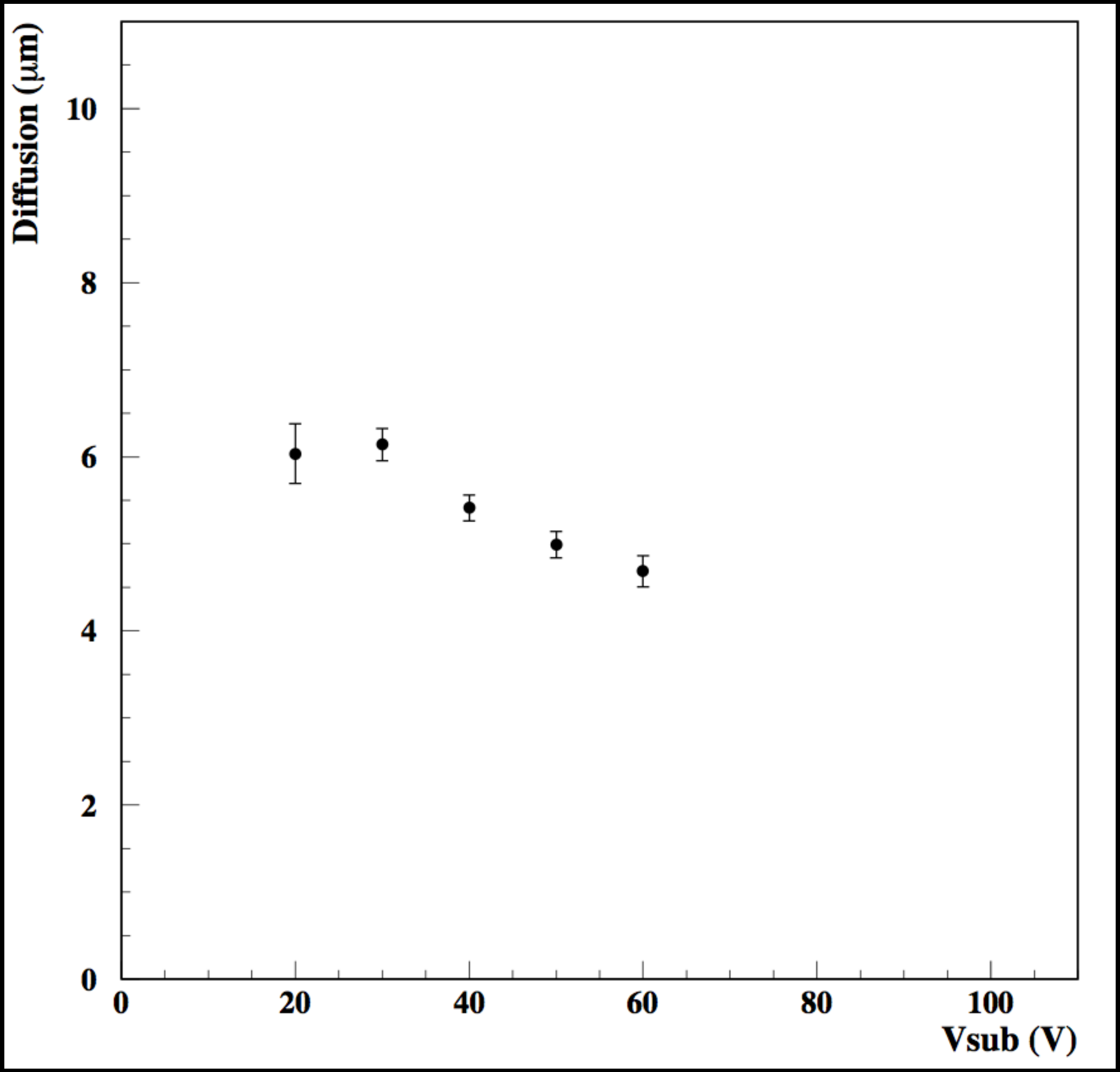


When we change the substrate voltage during the exposure, we see a shift in the X-ray peak. The shift is small.

Between 40 and 60V in the substrate, we see and increase in signal by 0.6%.

This is not a lot, but why?

Is there any charge recombination inside the silicon that gets suppressed with the higher voltage?



Diffusion measurement with the same data.

Opposite to the fatter thinner mentioned several times these days.

Conclusion

The CCDs are particle detectors, and particles call teach us about what goes on inside silicon.

Muons, X-ray, alphas and neutrons could be useful tools to learn more about these sensors for astronomy.