CONνIE

COHERENT NEUTRINO NUCLEUS
INTERACTION EXPERIMENT

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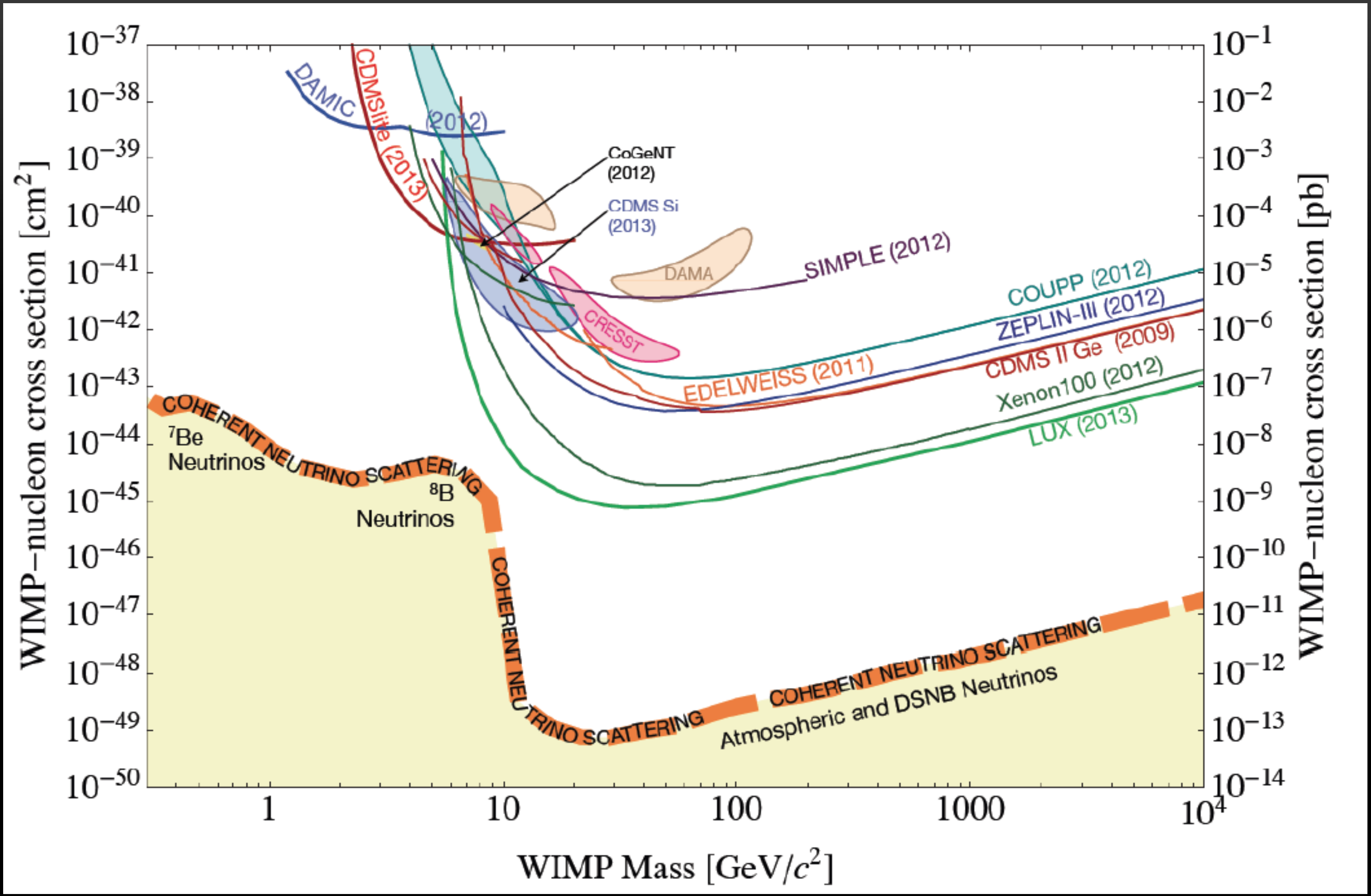
NEW PHYSICS IN THE LOW ENERGY NEUTRINO SECTOR



Coherent scattering is the limitation of the next generations of Dark Matter experiments.

GEMMA 09 (3GW reactor)

To realize this useful feature in our GEMMA spectrometer[14], we use a 1.5 kg HPGe detector with the energy threshold as low as 3.0 keV. To be sure that there is no efficiency cut at this energy, the "hard" trigger threshold was twice lower (1.5 keV).

Background is suppressed in several steps. First, the detector is placed inside a cup-like NaI crystal with 14 cm thick walls surrounded with 5 cm of electrolytic copper and 15 cm of lead. This active and passive shielding reduces external γ-background in the ROI to the level of ~ 2 counts/keV/kg/day. Being located just under reactor #2 of the KNPP (at a distance of 13.9 m from the reactor core, which corresponds to the antineutrino flux of $2.7\times10^{13}\ \bar{\nu}_e/\mathrm{cm}^2/\mathrm{s}$), detector is well shielded against the hadronic component of cosmic rays by the reactor body and technologic equipment (overburden$\simeq$70 m w.e.). The muon component is also reduced by a factor of $\sim$10 at $\pm20^\circ$ with respect to the vertical and $\sim$3 at $70^\circ - 80^\circ$, but a part of residual muons are captured in massive shielding and thus produce neutrons which scatter elastically in Ge and give rise to a low-energy background. To

$$\frac{d\sigma_W}{dT} = \frac{G_F^2 m_e}{2\pi}\left[\left(1-\frac{T}{E_\nu}\right)^2\left(1+2\sin^2\theta_W\right)^2 + 4\sin^2\theta_W - 2\left(1+2\sin^2\theta_W\right)\sin^2\theta_W\frac{m_e T}{E_\nu^2}\right], \quad (1)$$

$$\frac{d\sigma_{EM}}{dT} = \pi r_0^2\left(\frac{\mu_\nu}{\mu_B}\right)^2\left(\frac{1}{T}-\frac{1}{E_\nu}\right), \quad (2)$$

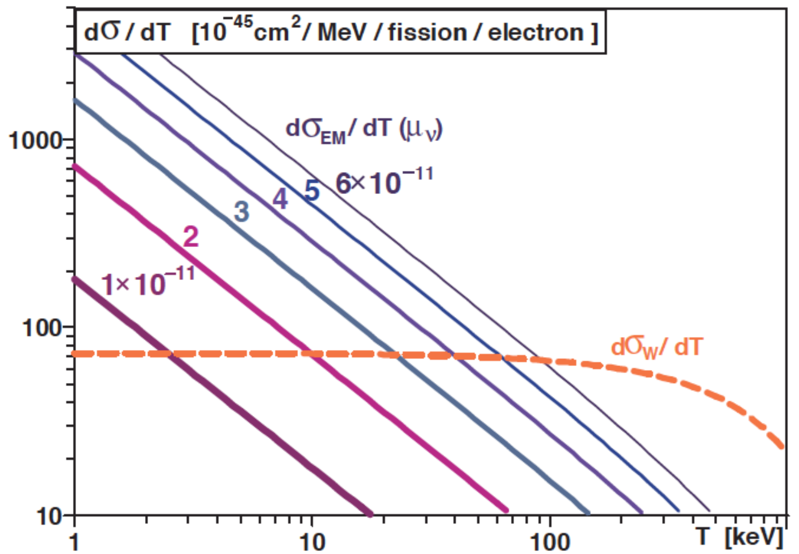
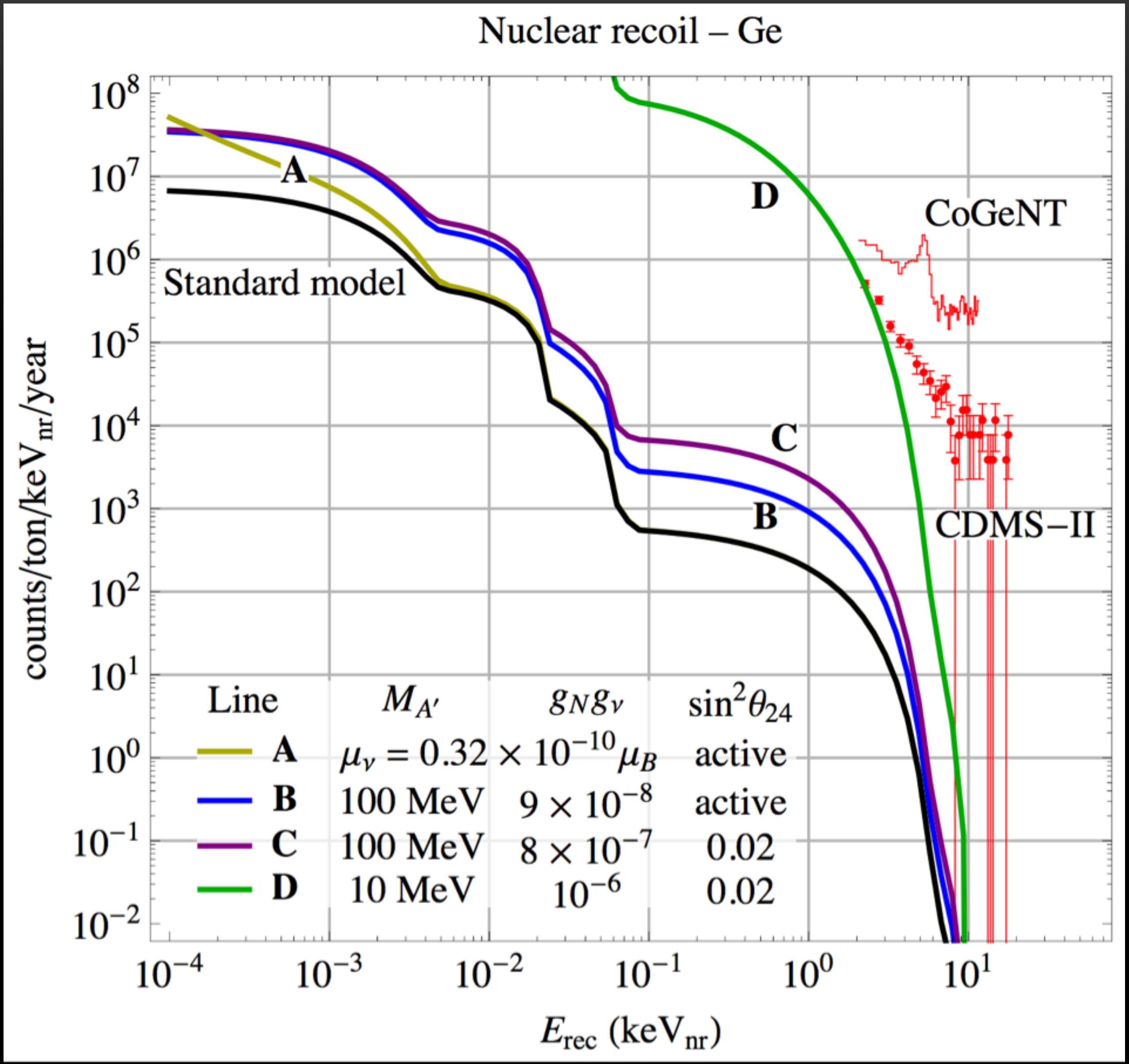


FIG. 1: Weak (W) and electromagnetic (EM) cross-sections calculated for several NMM values.

$$\mu_\nu^a < 2.9\times10^{-11}\mu_B.$$

Current best limit comes from GEMMA (using Ge detector at reactor) $3.2\mathrm{x}10^{-11}\ \mu_B\ m_\nu/\mathrm{eV}$



understanding the new physics also important for future dark matter searches…

Collaboration

CO.νNie

COHERENT NEUTRINO NUCLEUS INTERACTION EXPERIMENT

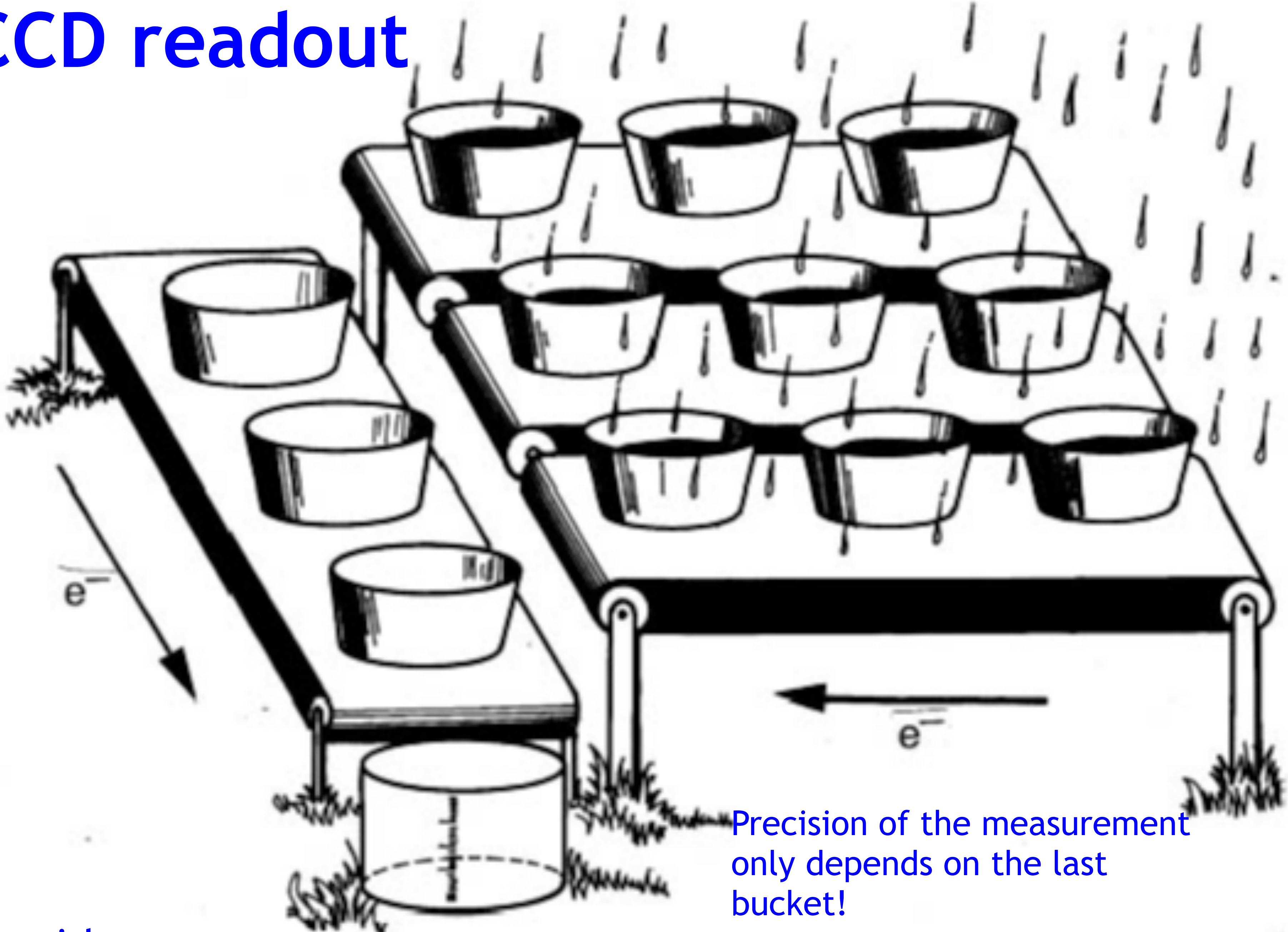
First Collaboration Meeting June 2014
Rio de Janeiro

~20 people

THE DETECTOR:

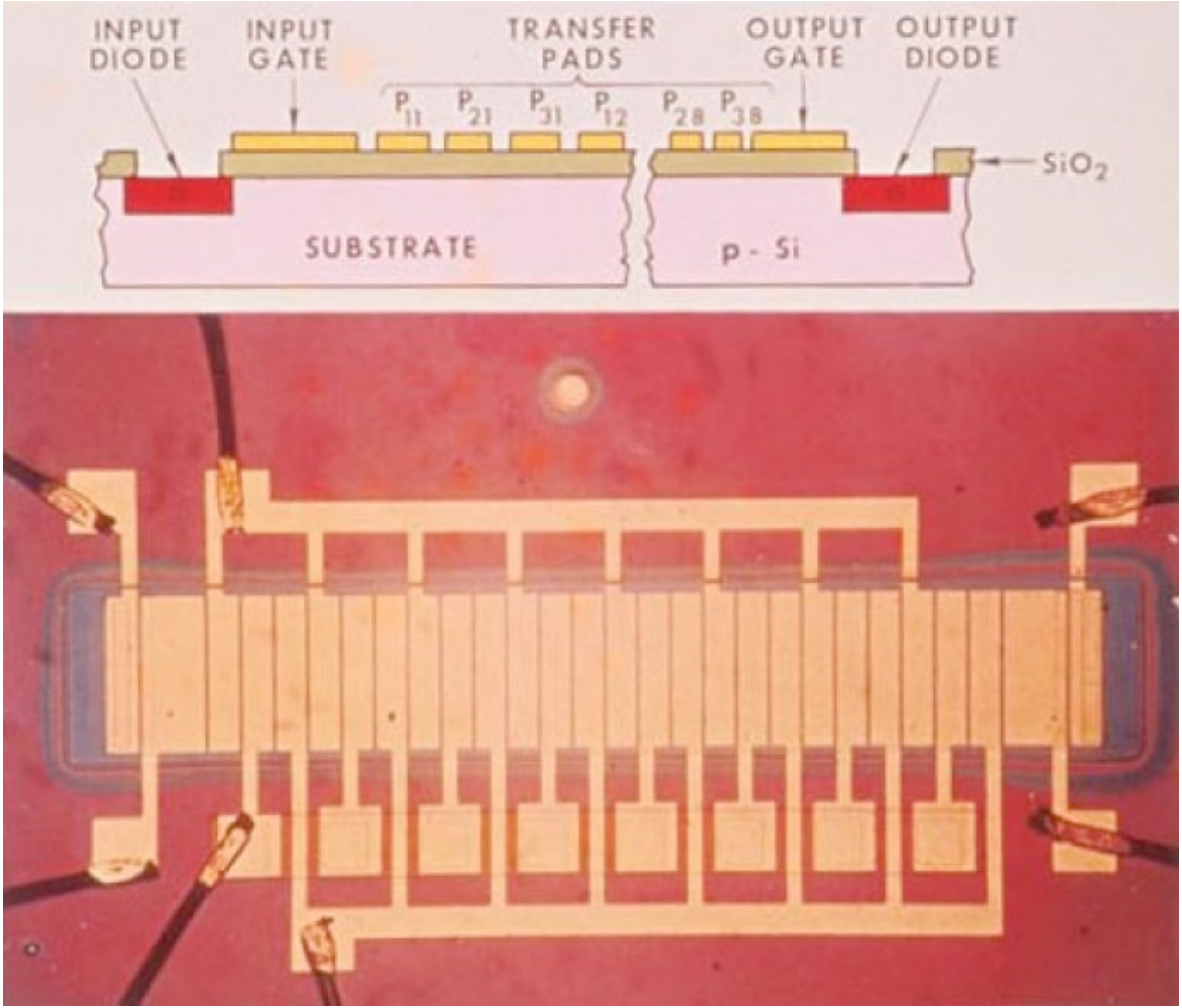
THICK CCD

CCD readout



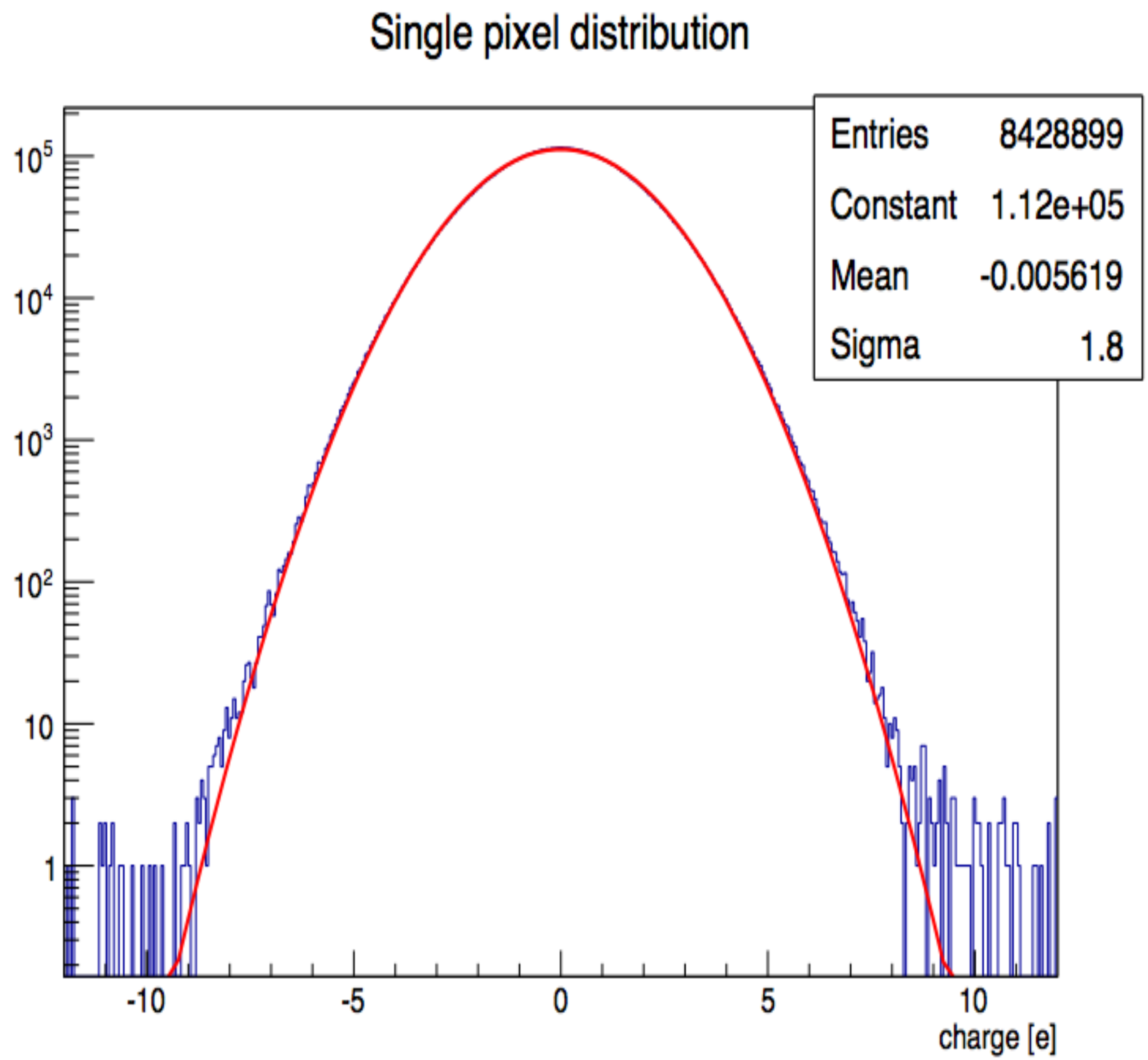
Precision of the measurement only depends on the last bucket!

Janesick

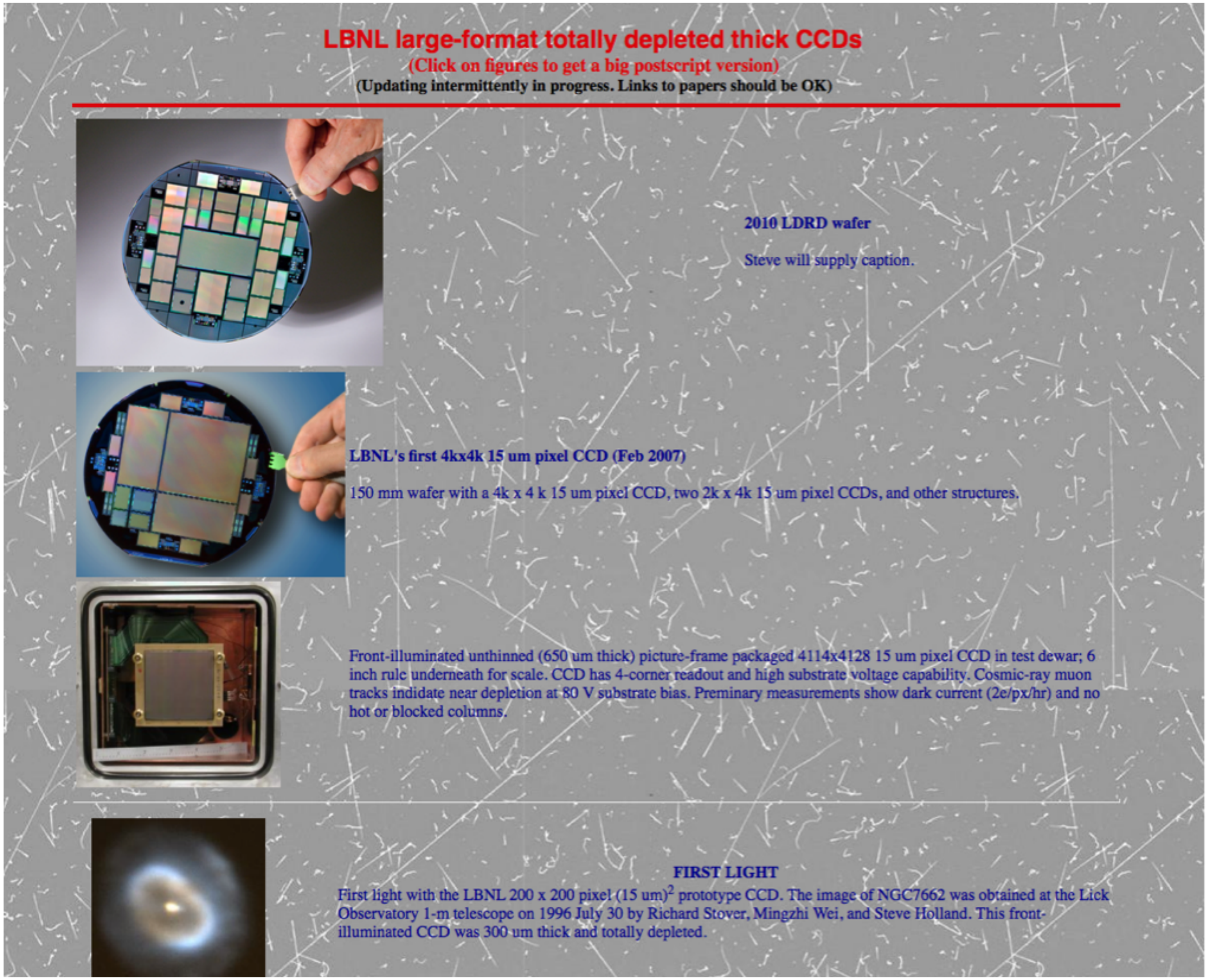


First CCD 1974 (2009 Nobel Prize)

1.8 e- RMS noise: this is what makes



1e ≈ 3.6eV → 40eV threshold is possible (x10 lower than closer competitor)


LBNL large-format totally depleted thick CCDs
(Click on figures to get a big postscript version)
(Updating intermittently in progress. Links to papers should be OK)

2010 LDRD wafer

Steve will supply caption.

LBNL's first 4kx4k 15 um pixel CCD (Feb 2007)

150 mm wafer with a 4k x 4 k 15 um pixel CCD, two 2k x 4k 15 um pixel CCDs, and other structures.

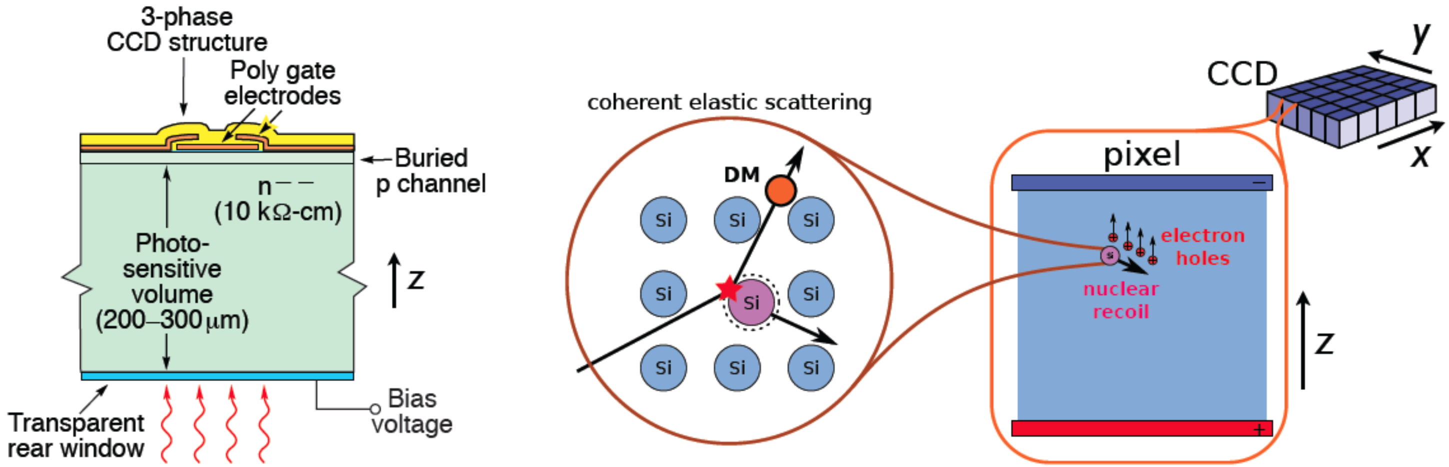
Front-illuminated unthinned (650 um thick) picture-frame packaged 4114x4128 15 um pixel CCD in test dewar; 6 inch rule underneath for scale. CCD has 4-corner readout and high substrate voltage capability. Cosmic-ray muon tracks indidate near depletion at 80 V substrate bias. Preminary measurements show dark current (2e/px/hr) and no hot or blocked columns.

FIRST LIGHT

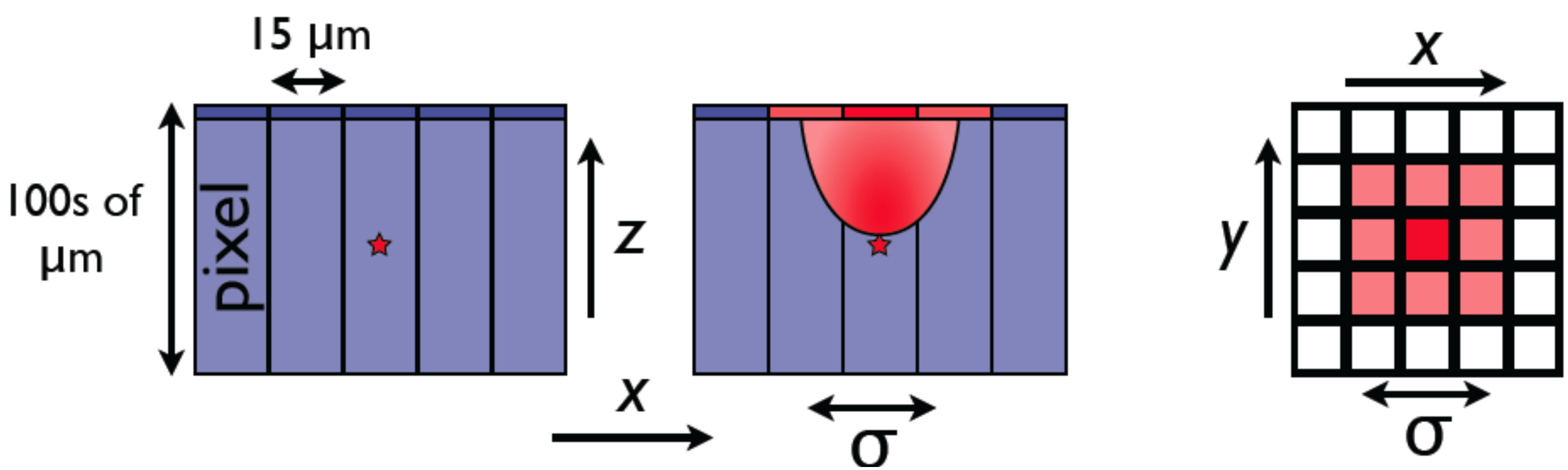
First light with the LBNL 200 x 200 pixel (15 um)^2 prototype CCD. The image of NGC7662 was obtained at the Lick Observatory 1-m telescope on 1996 July 30 by Richard Stover, Mingzhi Wei, and Steve Holland. This front-illuminated CCD was 300 um thick and totally depleted.

LBNL has developed thick CCDs… massive piece of silicon with 2e- readout noise!

Enabling Technology : thick CCD

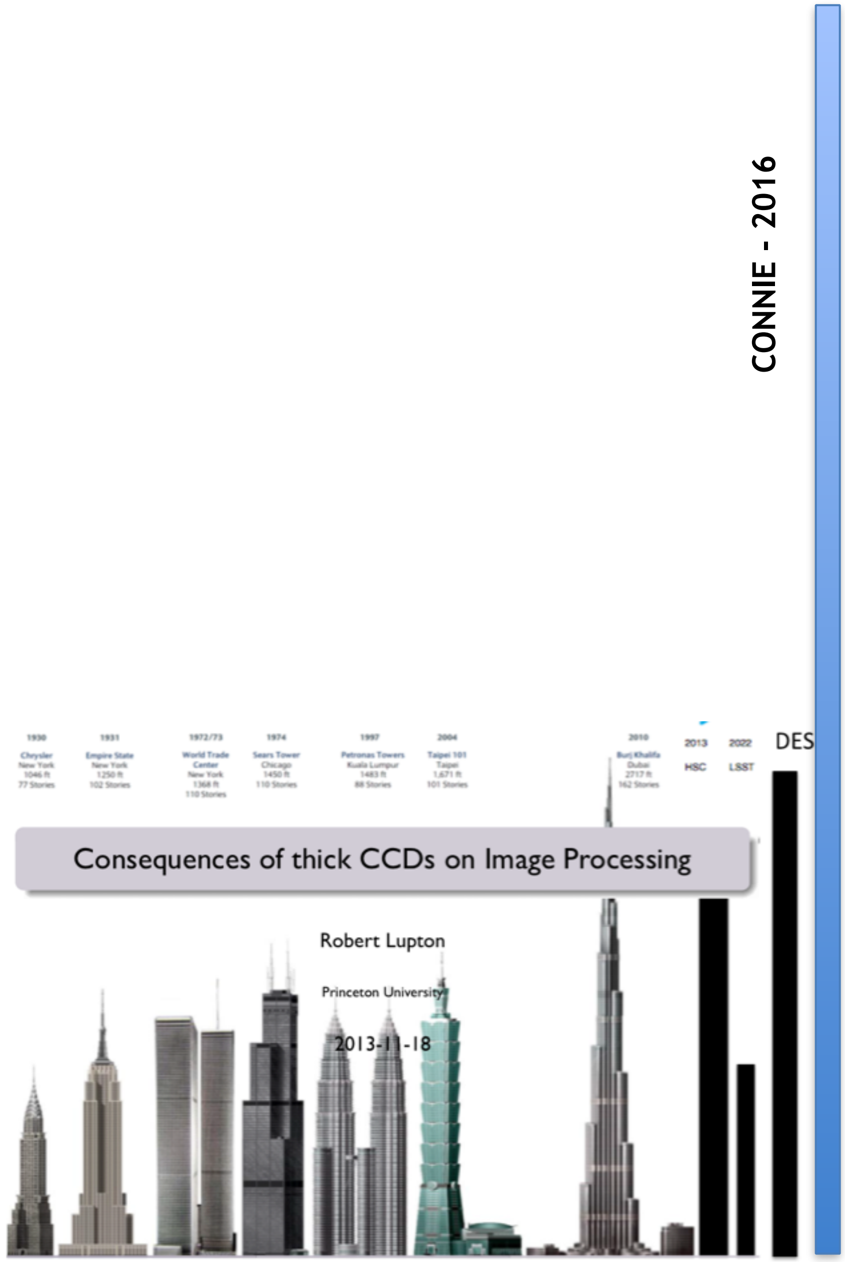


(a) A CCD pixel (b) WIMP detection principle

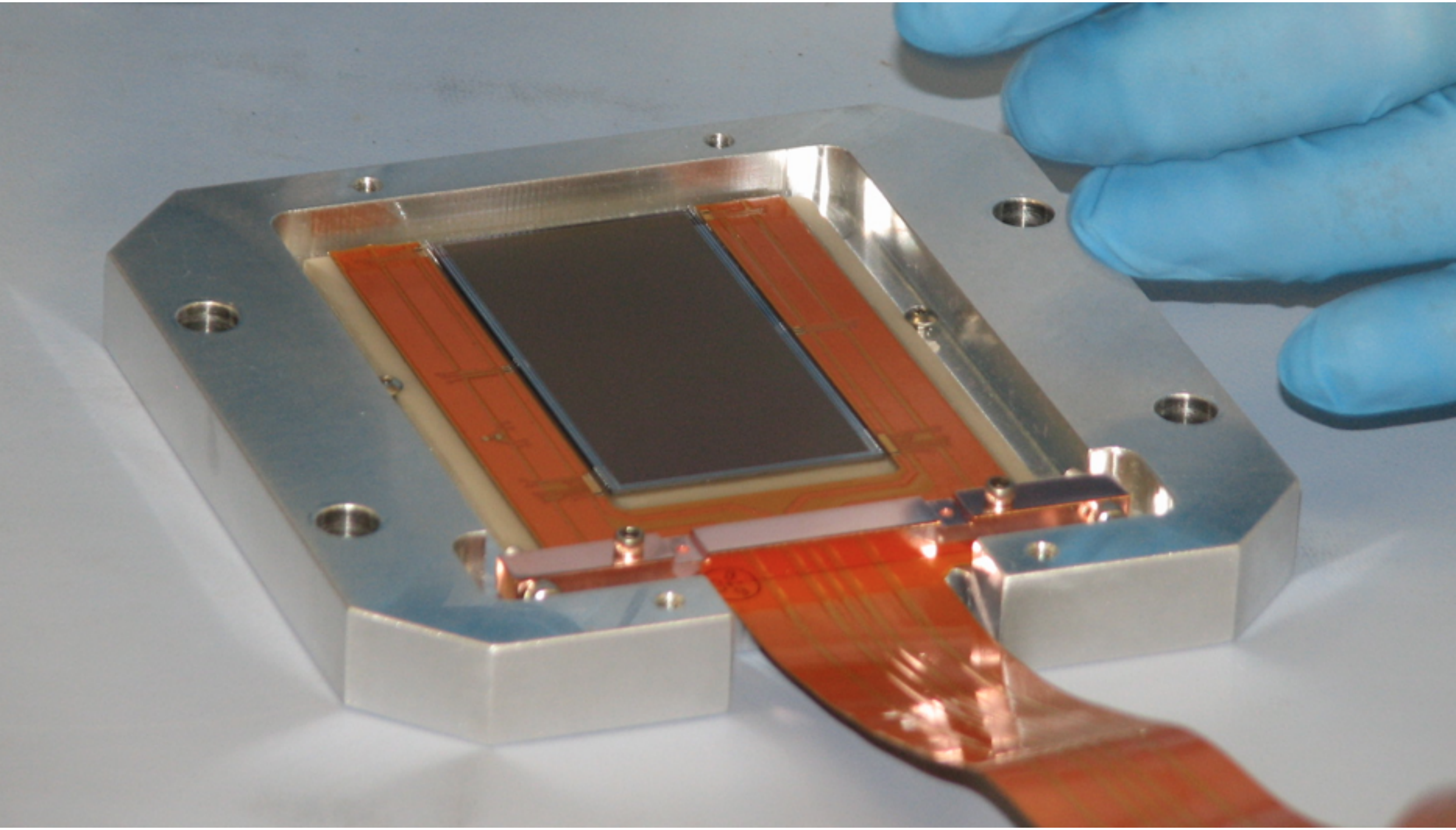


DECam detectors are 250um thick and 8 Mpix, 1g per CCD. DAMIC started with this. DAMIC-100 is now going to 675 um thick and 16 Mpix, 5.2g per CCD. In 2014 installed the first 675um detectors, provided by **LBNL** to test the concept.

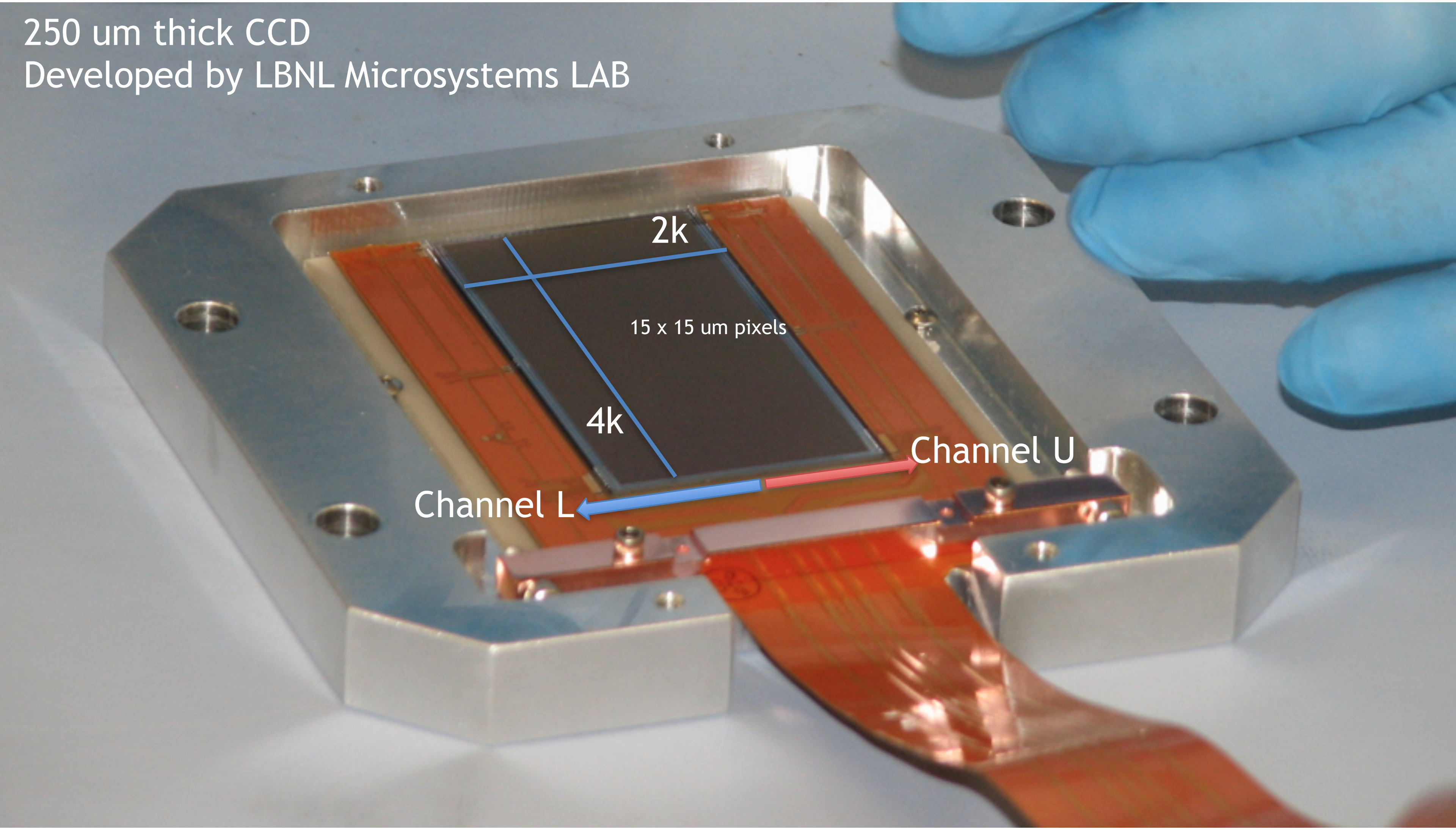
very thick CCDs!



CONNIE sensor:

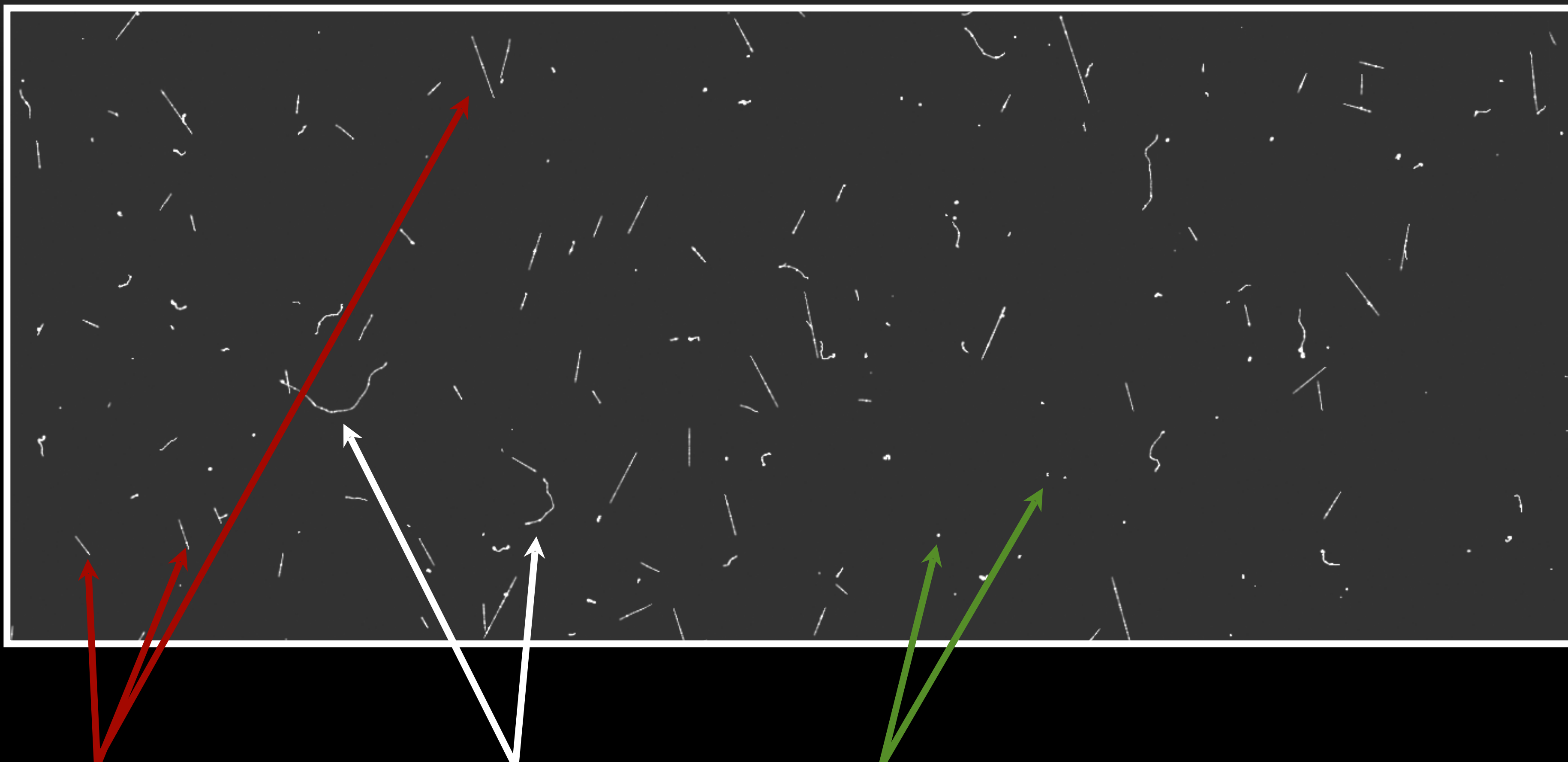


CONNIE sensor



The noise is determined by the capacitance of the output node.
The active pixels are decouples from the readout node!

Particle identification in a CCD image

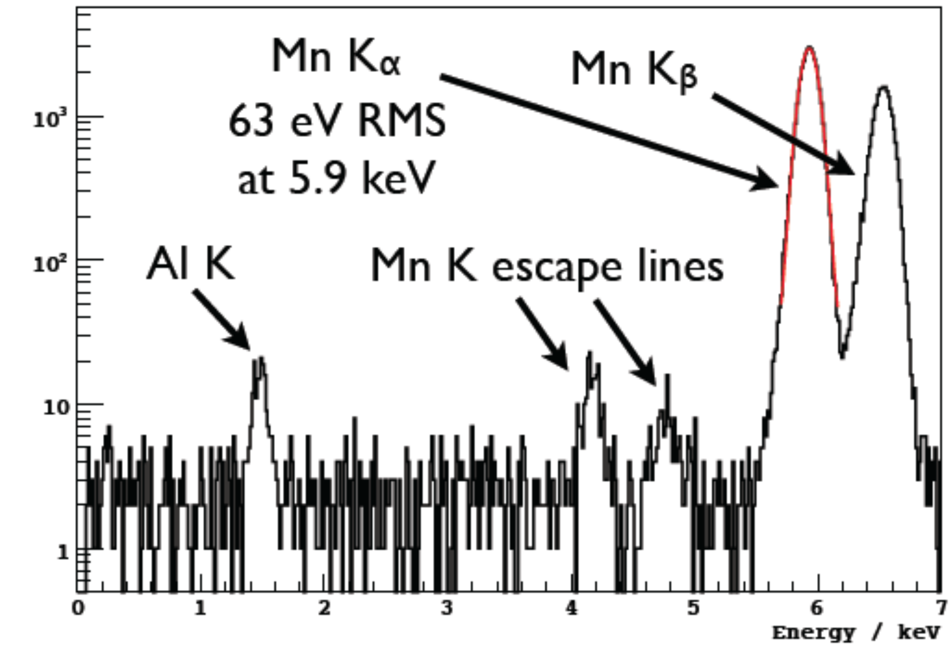


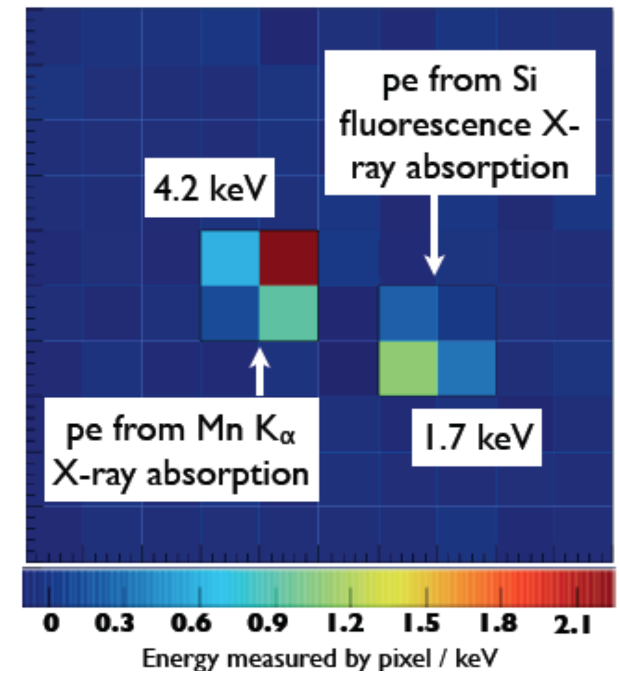
muons, electrons and diffusion limited hits.

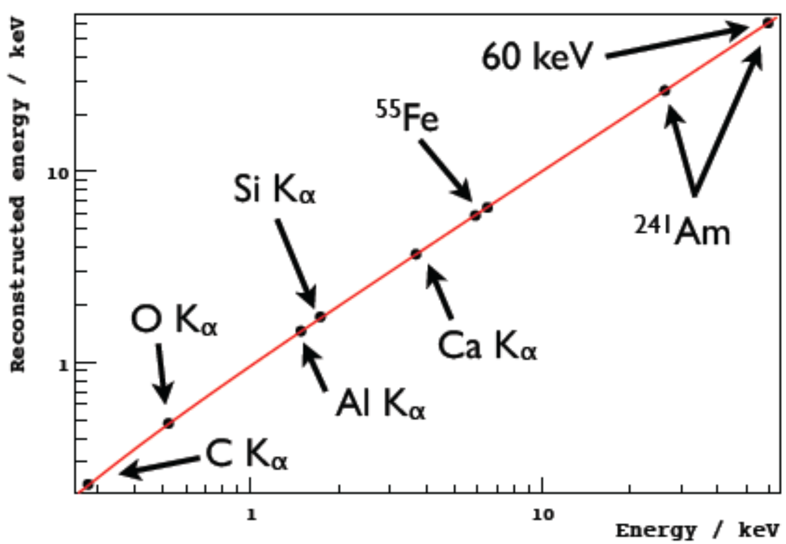
Nuclear recoils will produce diffusion limited hits. Neutrinos from reactor are expected to produce nuclear recoils at a rate of 10,000 per day for each kilogram of detector.

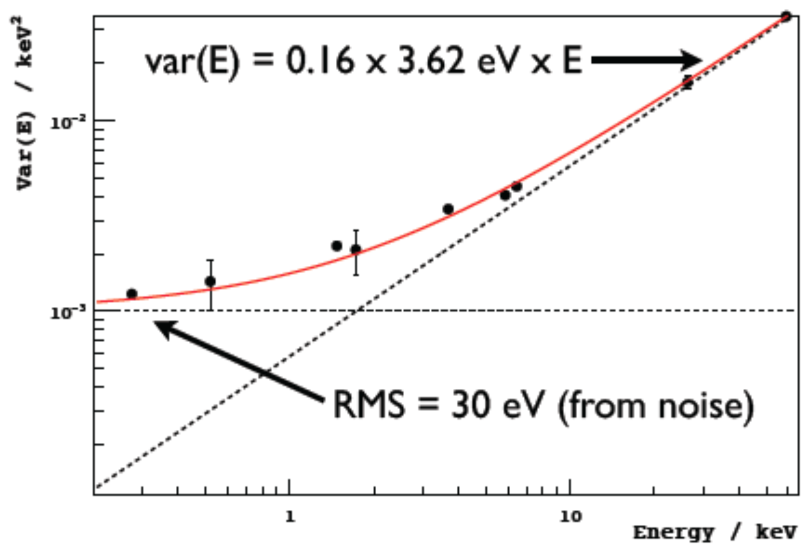
arXiv:1408.3263

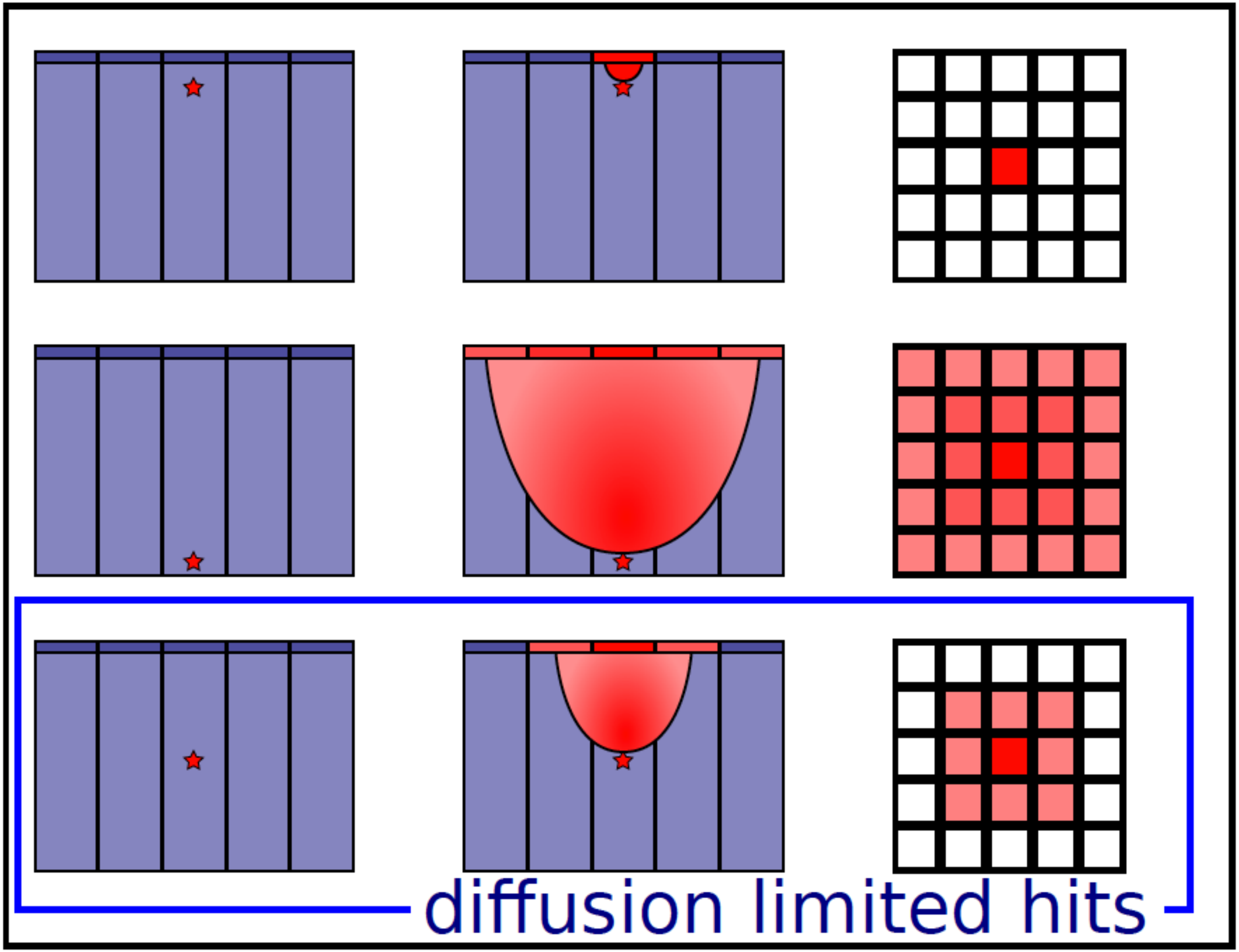
Calibration using X-rays

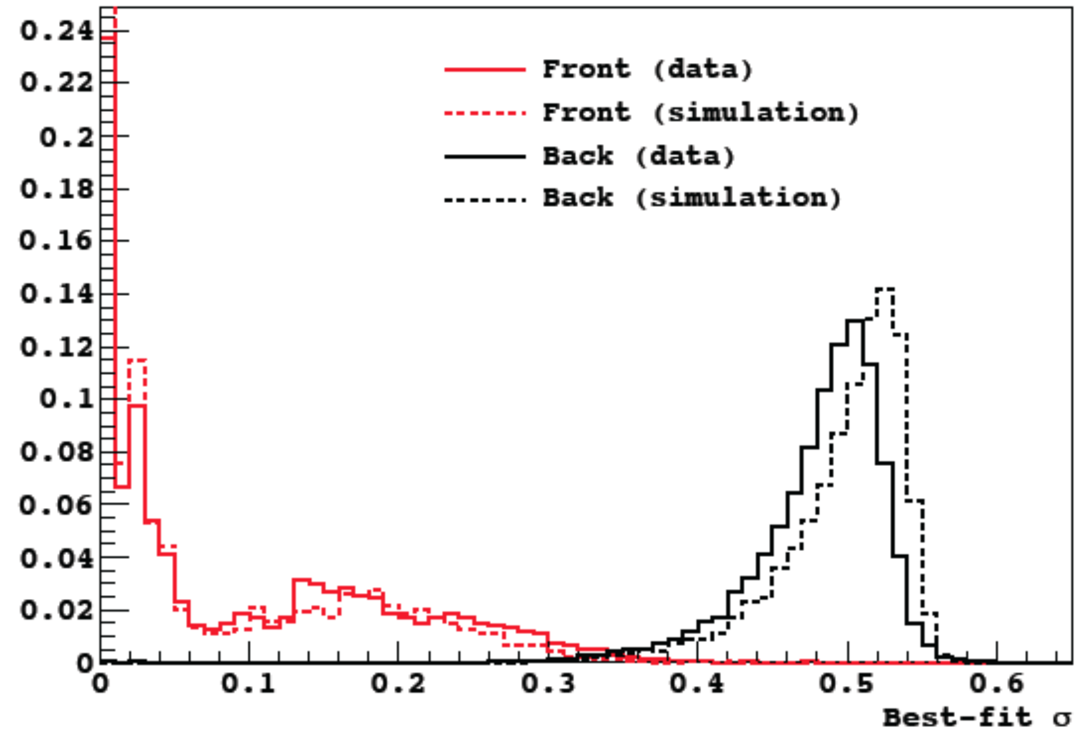






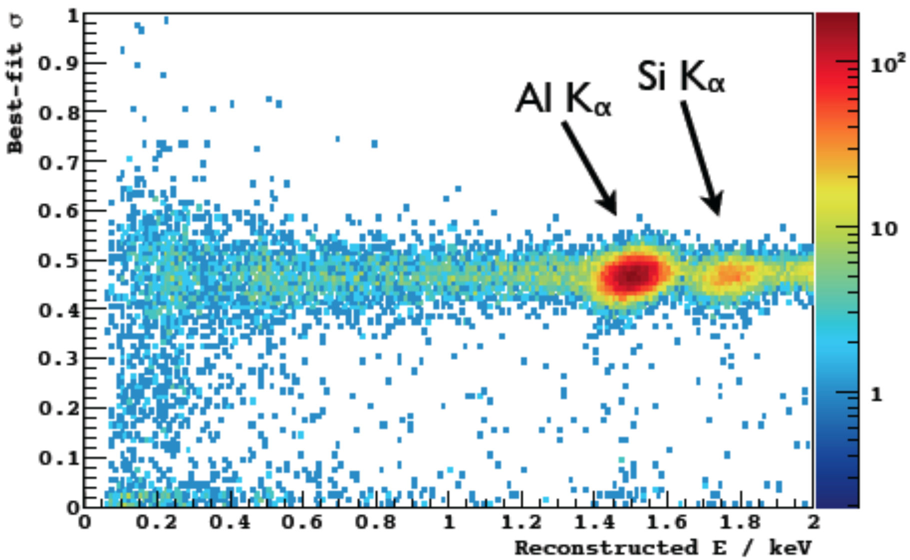


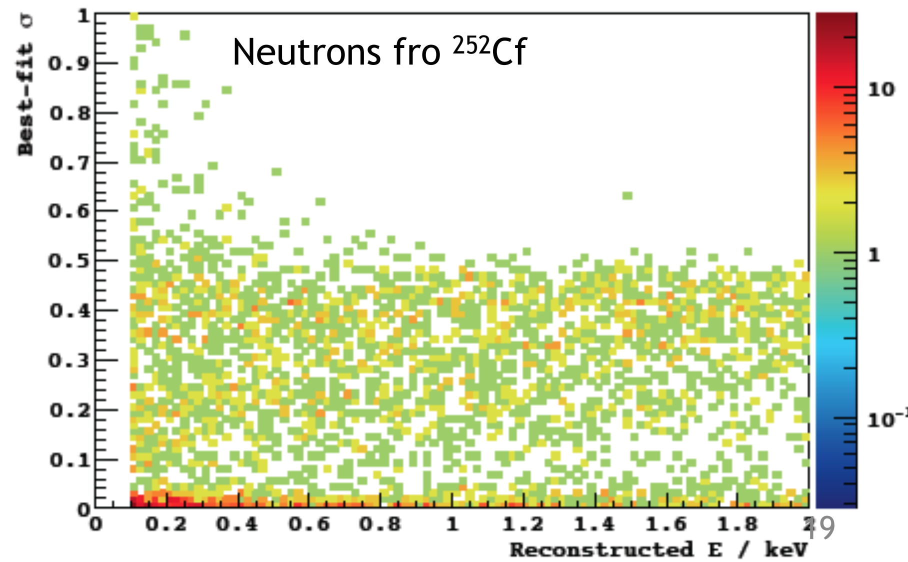

diffusion limited hits



Once diffusion is measured, we can simulate X-rays and neutrons on the CCD and compare with the data.

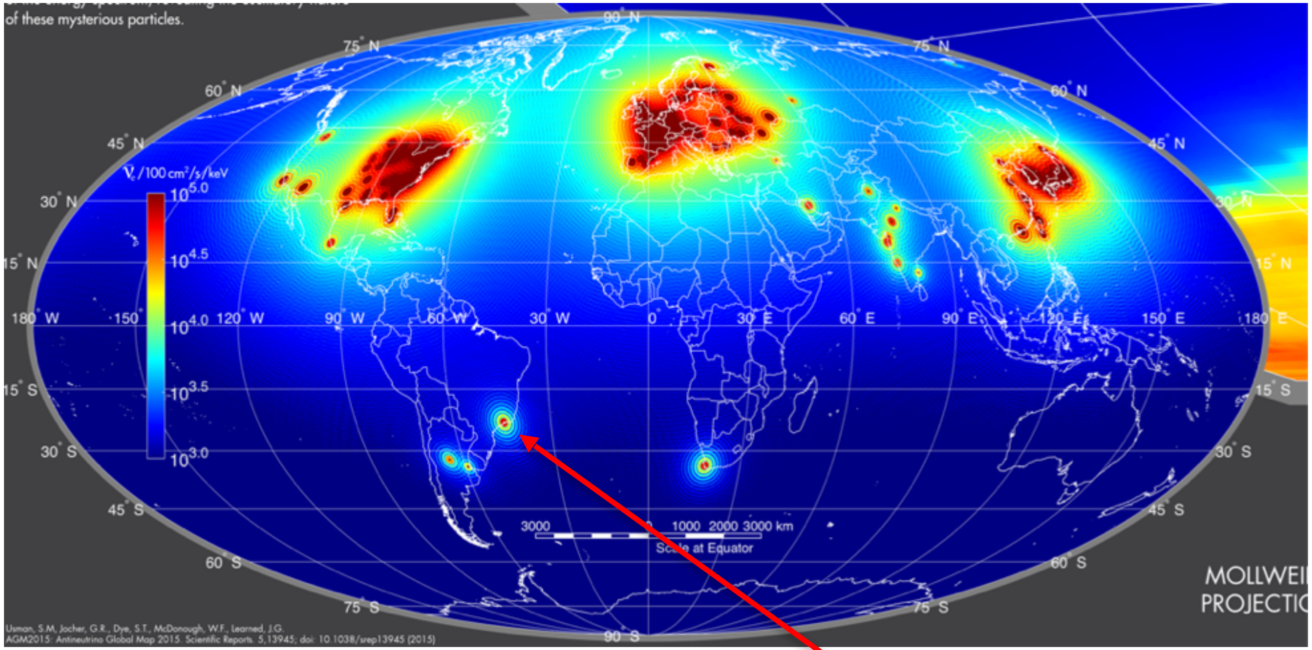
Self shielding to low energy X-rays!





THE SOURCE :

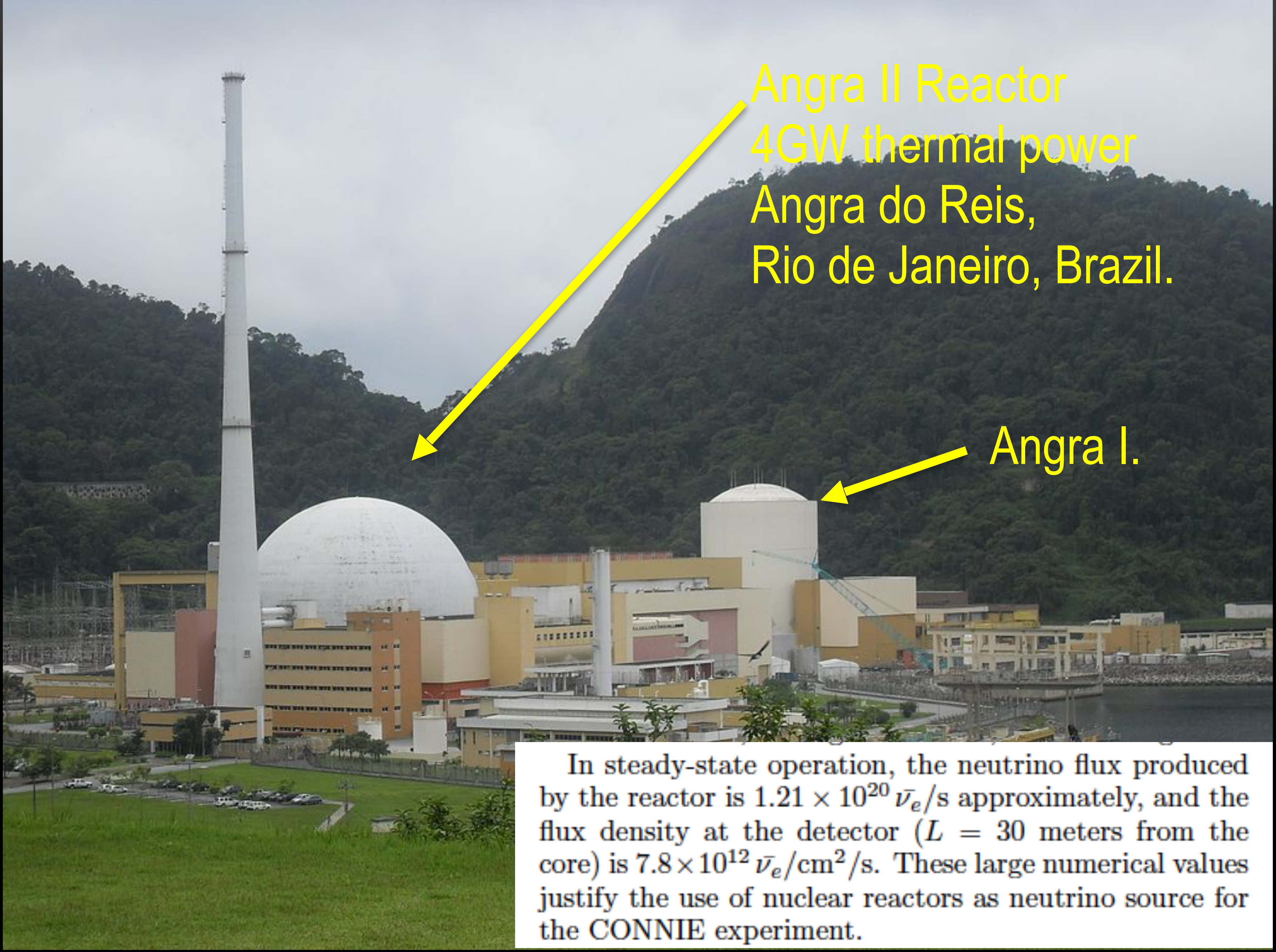
ANGRA-2 NUCLEAR POWER PLANT (4 GW)



Angra Nuclear Power plant.

Three reactors. Two operational and one under construction.

Centro Brasileiro de Pesquisas Fisicas (Rio de Janeiro) has a agreement with the reactor to perform neutrino experiments on site. CONNIE is one of two experiments planned.



In steady-state operation, the neutrino flux produced by the reactor is $1.21 \times 10^{20}\, \bar{\nu}_e/\mathrm{s}$ approximately, and the flux density at the detector ($L = 30$ meters from the core) is $7.8 \times 10^{12}\, \bar{\nu}_e/\mathrm{cm}^2/\mathrm{s}$. These large numerical values justify the use of nuclear reactors as neutrino source for the CONNIE experiment.

Our Collaborators in Brazil (CBPF and UFRJ) invited us to try this 30m from the core Angra-II power plant. Inside a conditioned shipping container.

EVENT RATE FOR CONNIE

assuming 52g detector array

Signal vents day (year)

E_{th}	$Q = 0.2$
$1\sigma_{RMS}$ (5.5eV)	1.46 (532)
$5\sigma_{RMS}$ (28eV)	0.94 (343)

Estimated
Bkg=8.5 ev/day

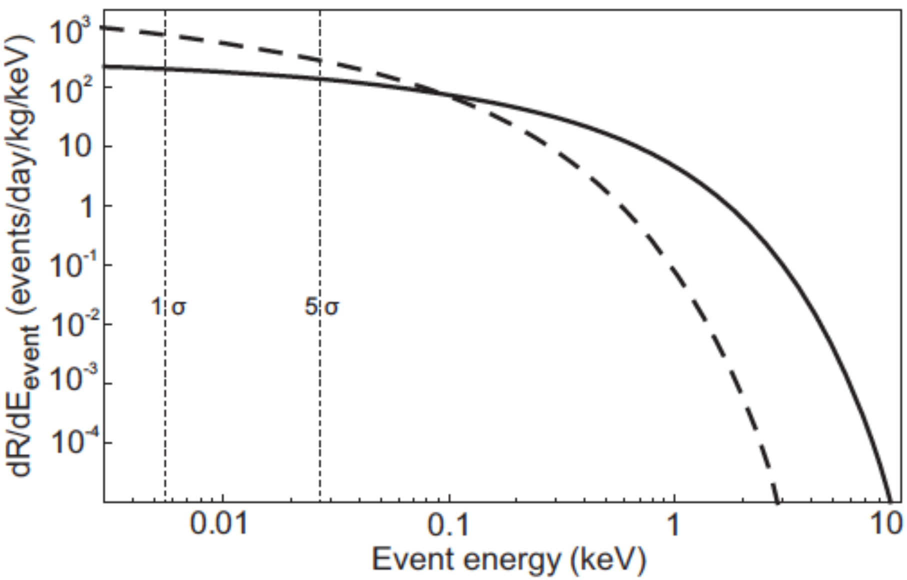


FIG. 8. Energy spectra for events expected in silicon detectors: the nuclear-recoil energy spectrum (—); the spectrum for detectable events (– –), using the quenching factor from Lindhand, *et al.* [28, 29].

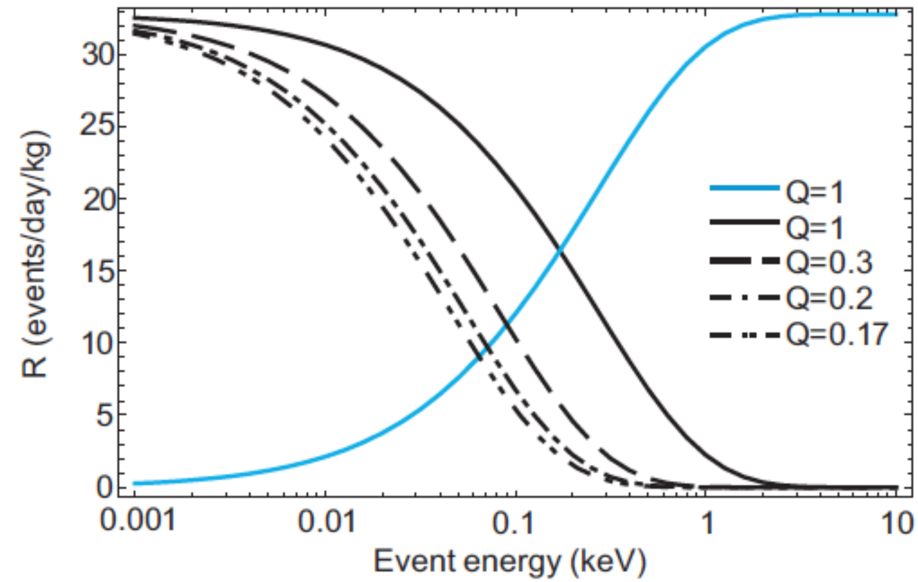


FIG. 9. Total number of events as a function of the threshold energy for different quenching factors: $Q = 1$, $Q = 0.3$, $Q = 0.2$ and $Q = 0.17$ (black curves). The light-blue curve shows the total number of events as a function of the maximum detectable recoil energy using $Q = 1$.

90 days of running => s/n = 0.92*90/sqrt(8.5*90) = 3

Moroni et al 2014 arXiv:1405.5761
Accepted in PRD 2015

TIMELINE

- Detector Shipping August-September 2014
- Detector installation and first data October-November 2014 (10 grams)
- Initial operations supported by experts from FNAL(LDRD) and UNAM(Mexico)
- Continuous operation now supported by local team (UFRJ + CBPF)
- Full shield assembly completed July 2015 (strike permitting)
- September 2015 – full month with reactor ON
- October 2015 – full month of full reactor OFF

Future:

- Mid 2016: upgrade to 100g

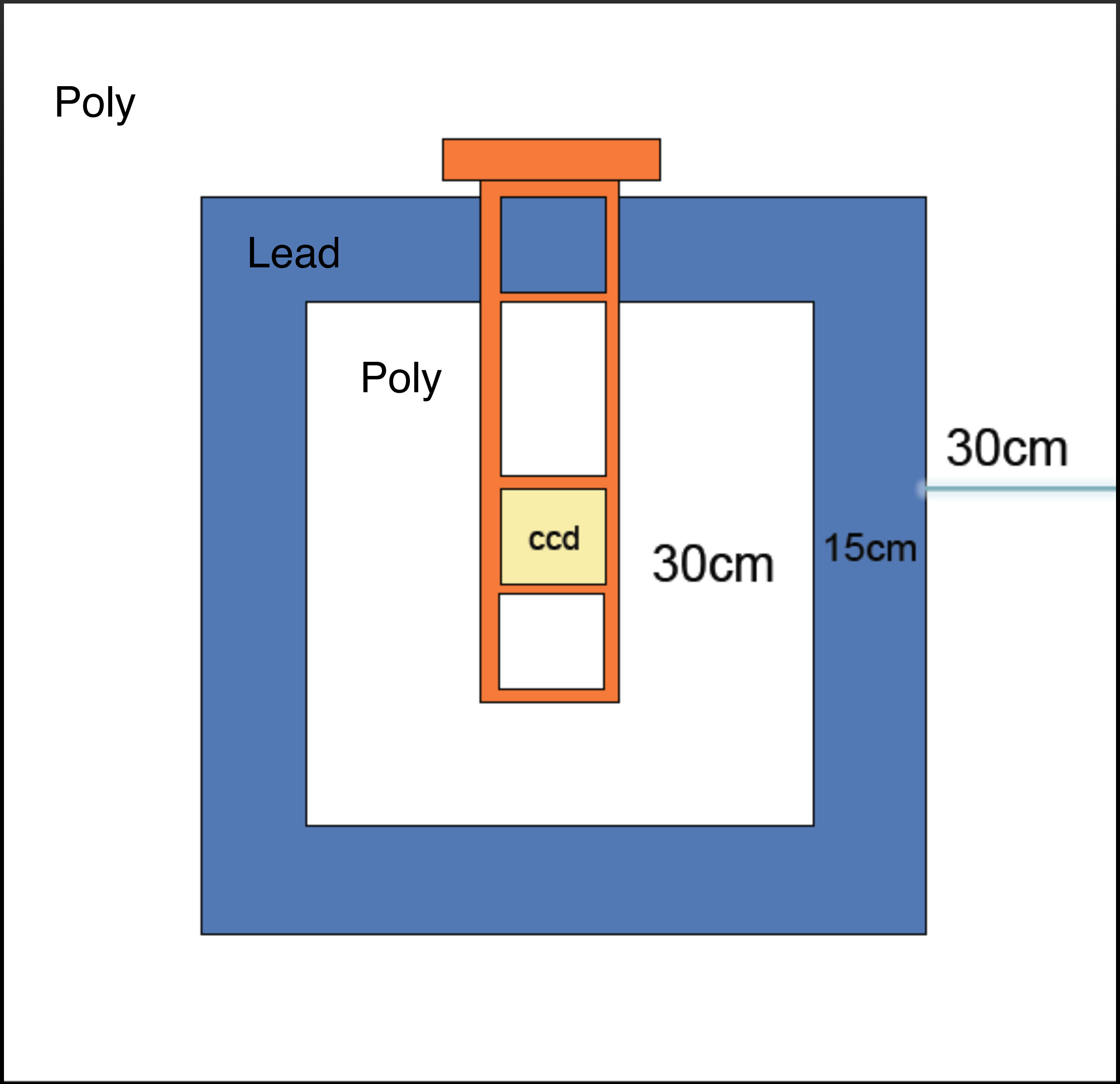
4GW reactor at Angra do Reis, Brazil

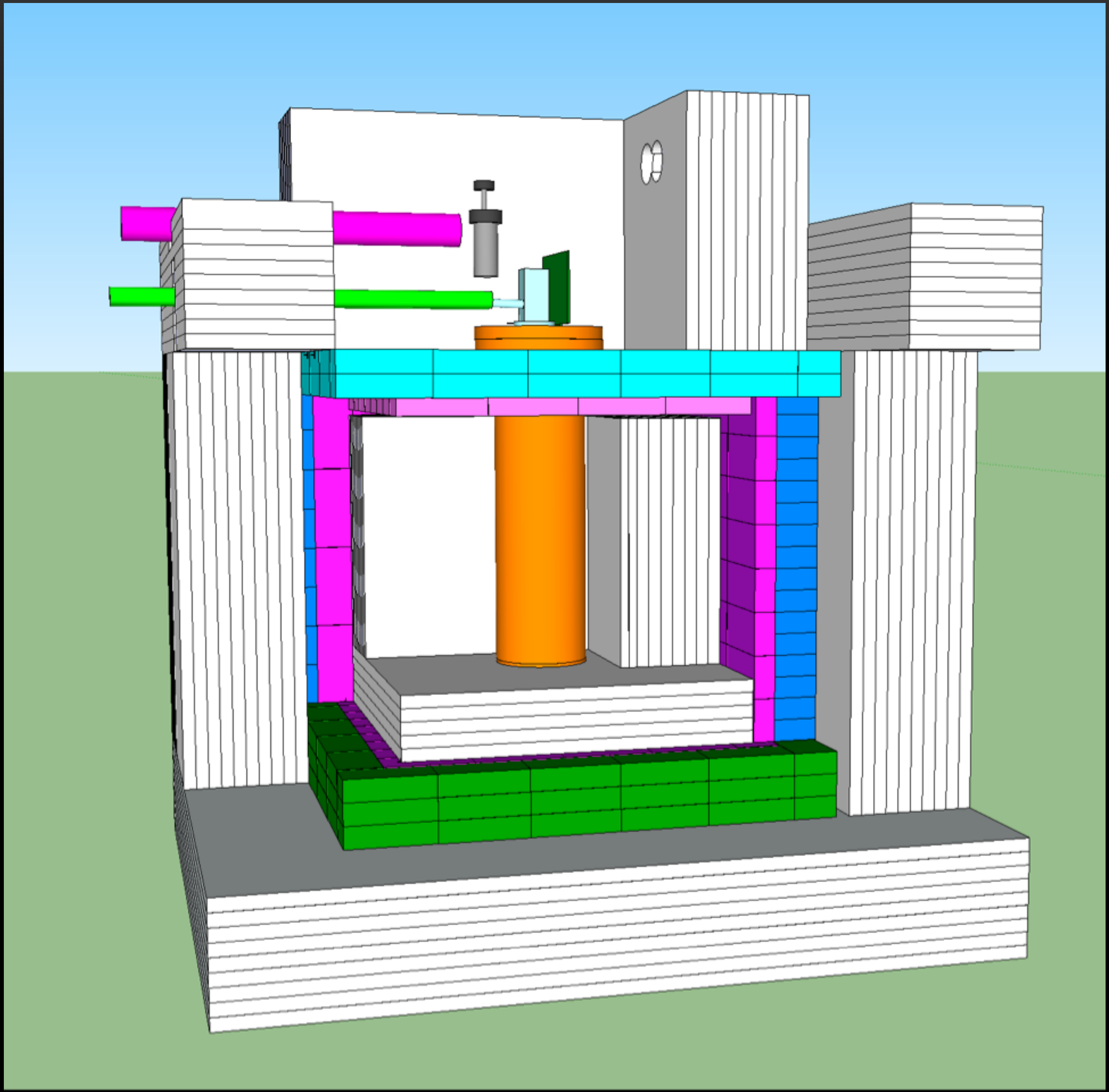
Equipment shipped from Fermilab to Angra do Reis in Sept-2014.

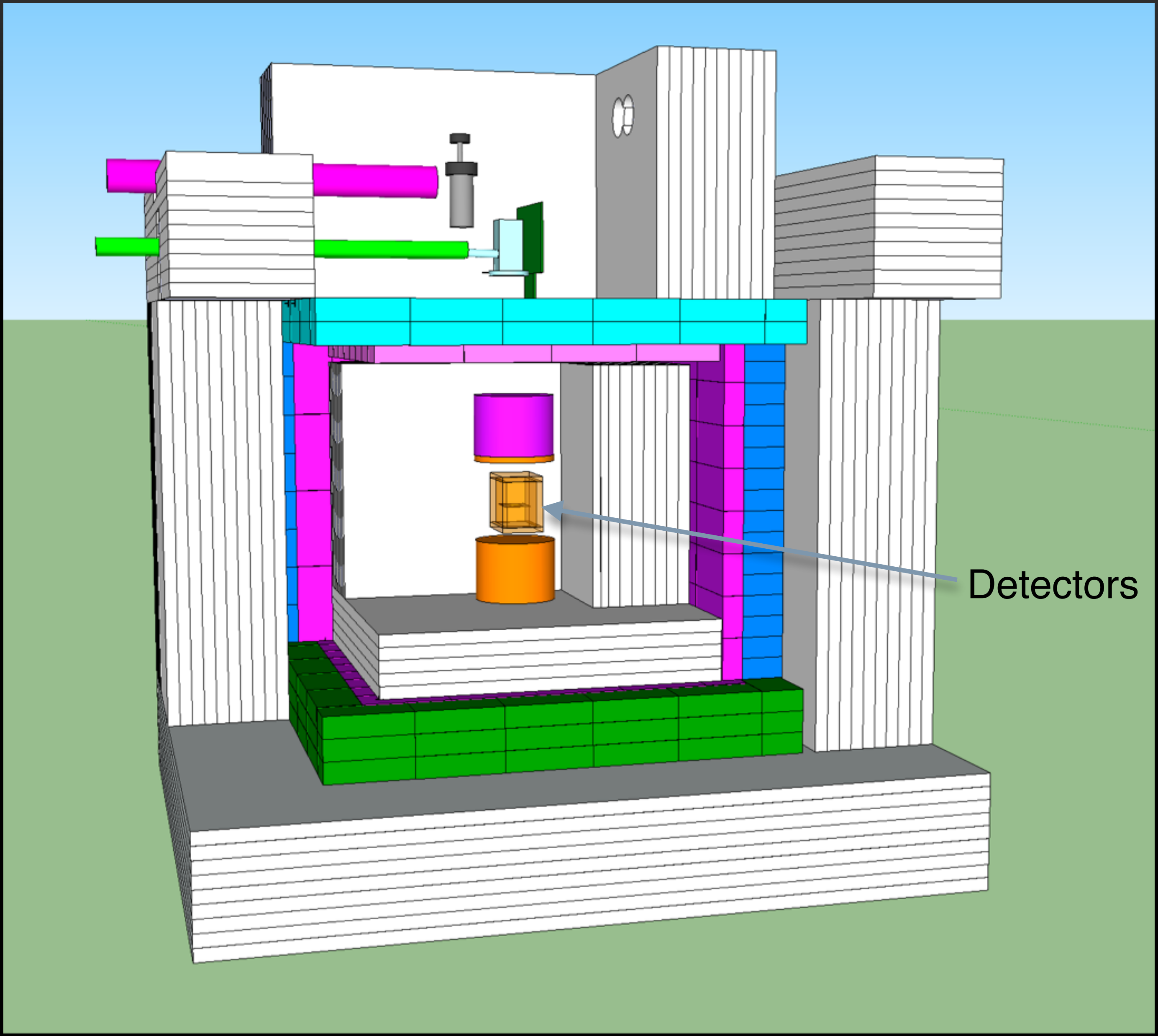
Shipping container conditioned for neutrino experiments, 30 meters from core.

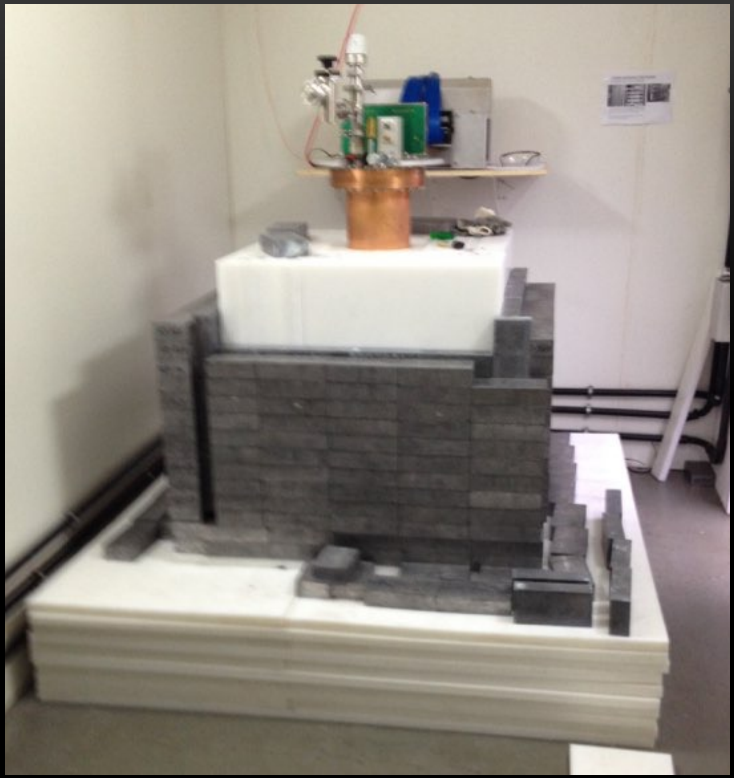
Poly + lead shield, cryogenics, vacuum and DAQ operating on site Oct-2014.

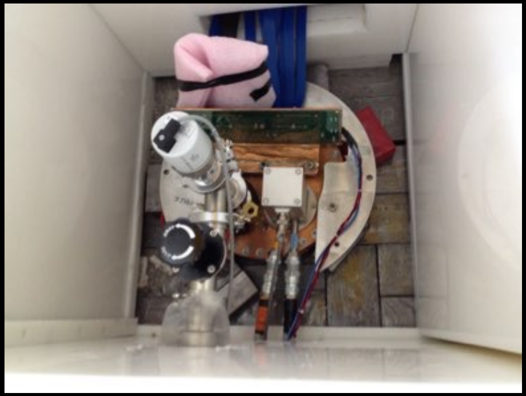
shield design



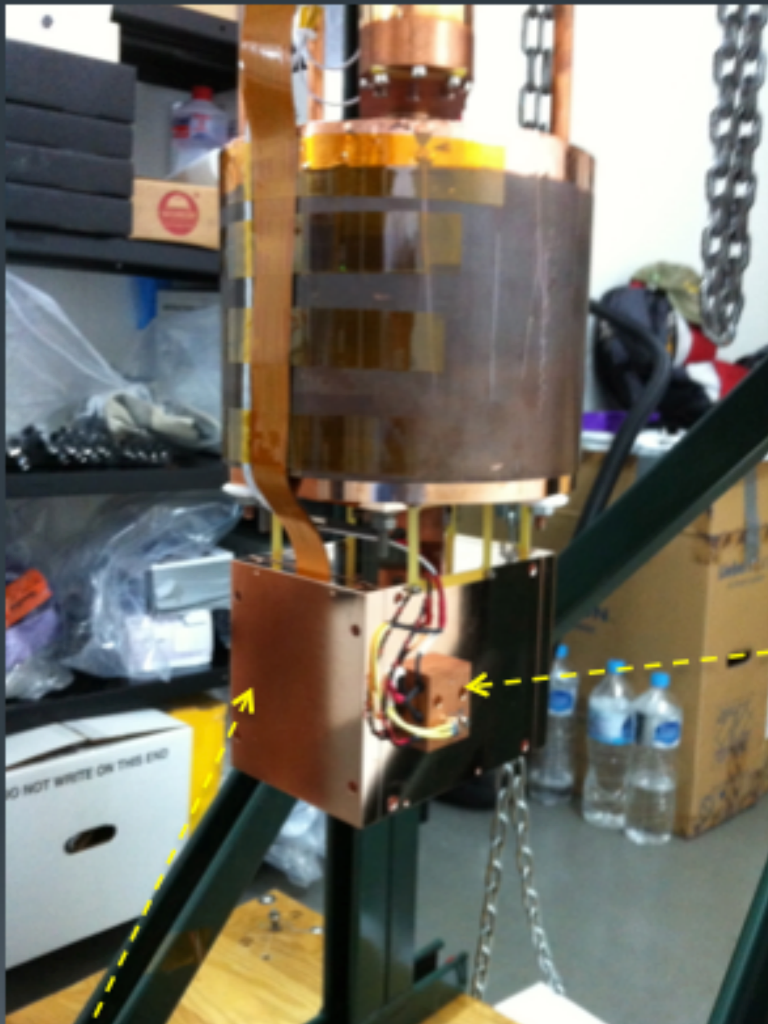



Detectors



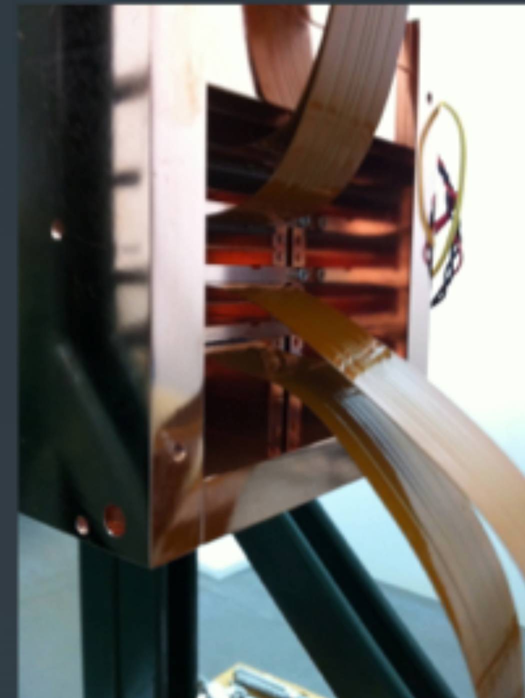


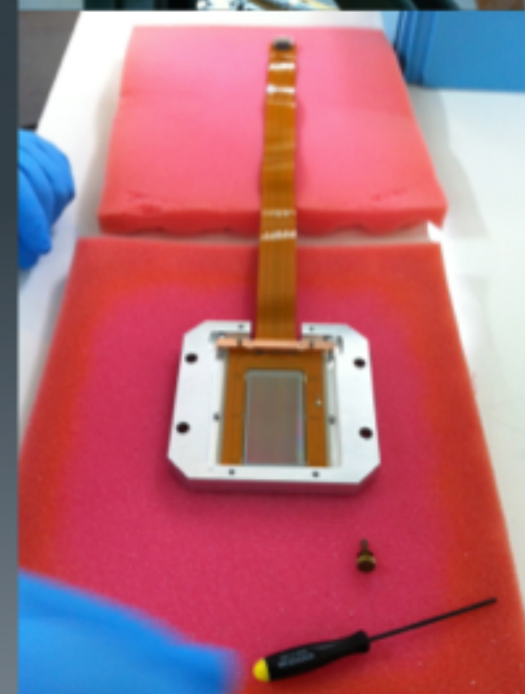
Detector configuration (November 9th, 2014)

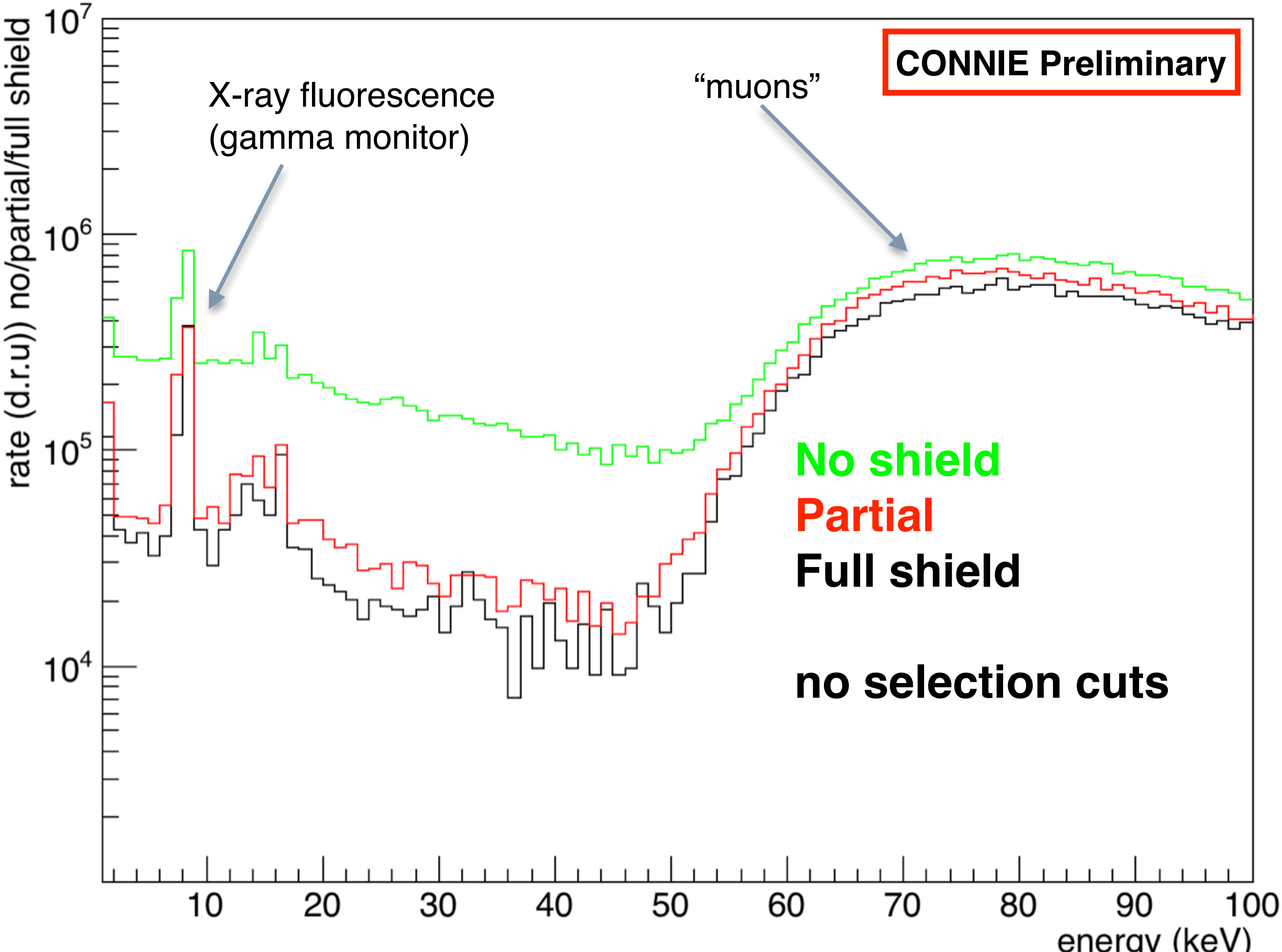


Heater
Temp. sensor

Front door of the Cu-Box (CCD installatioin)

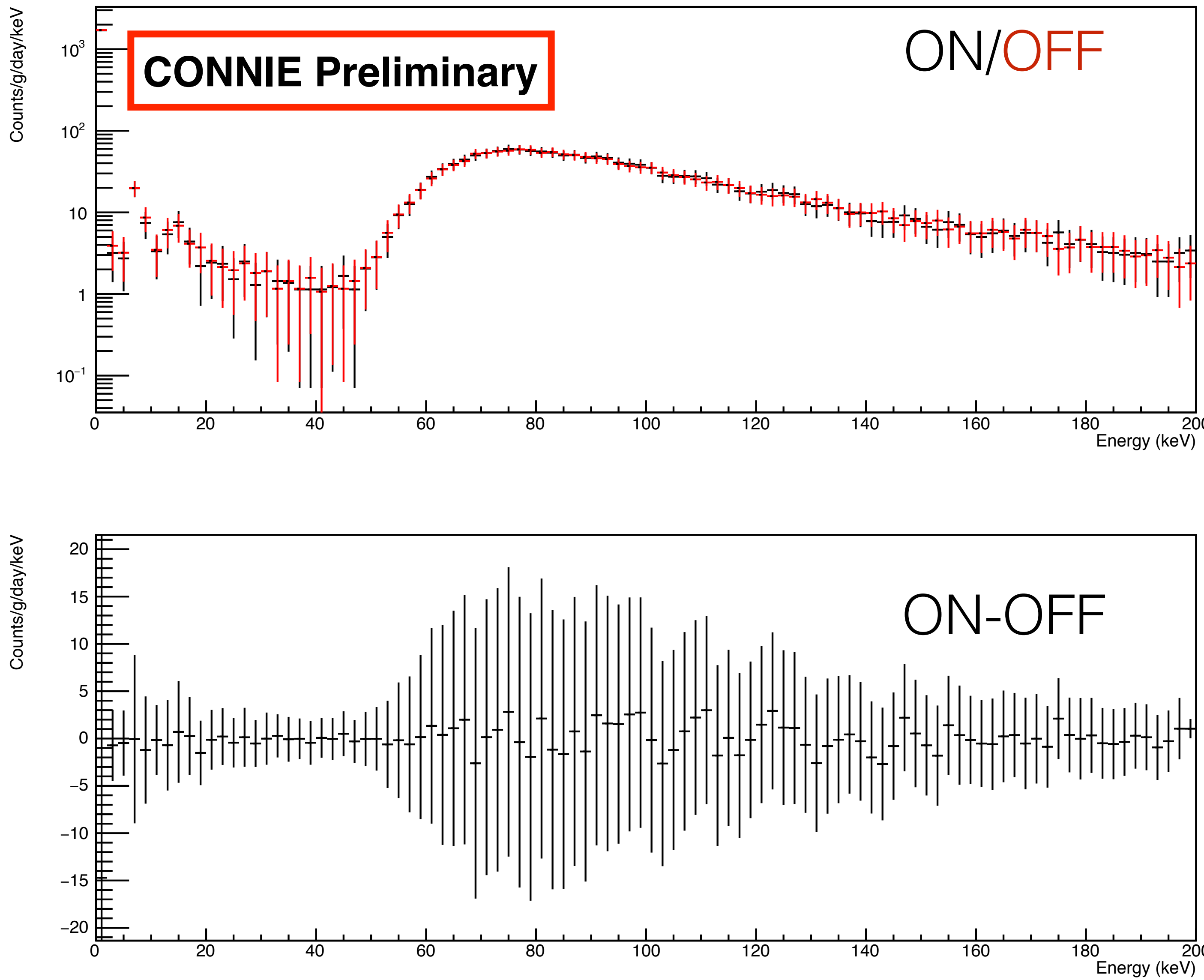




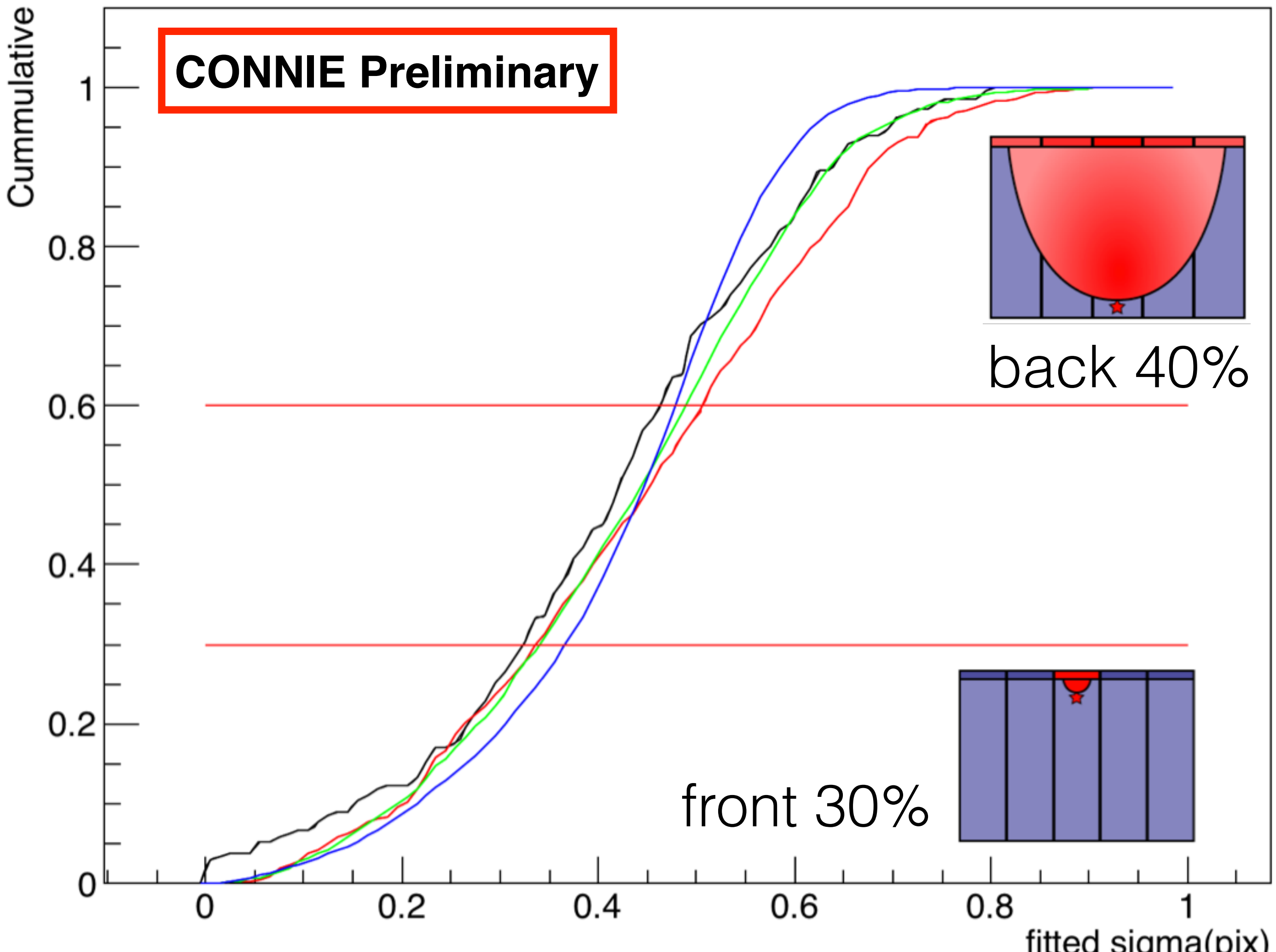


CONNIE Preliminary
X-ray fluorescence
(gamma monitor)
"muons"
No shield
Partial
Full shield
no selection cuts
rate (d.r.u)) no/partial/full shield
energy (keV)
10^7
10^6
10^5
10^4
10
20
30
40
50
60
70
80
90
100

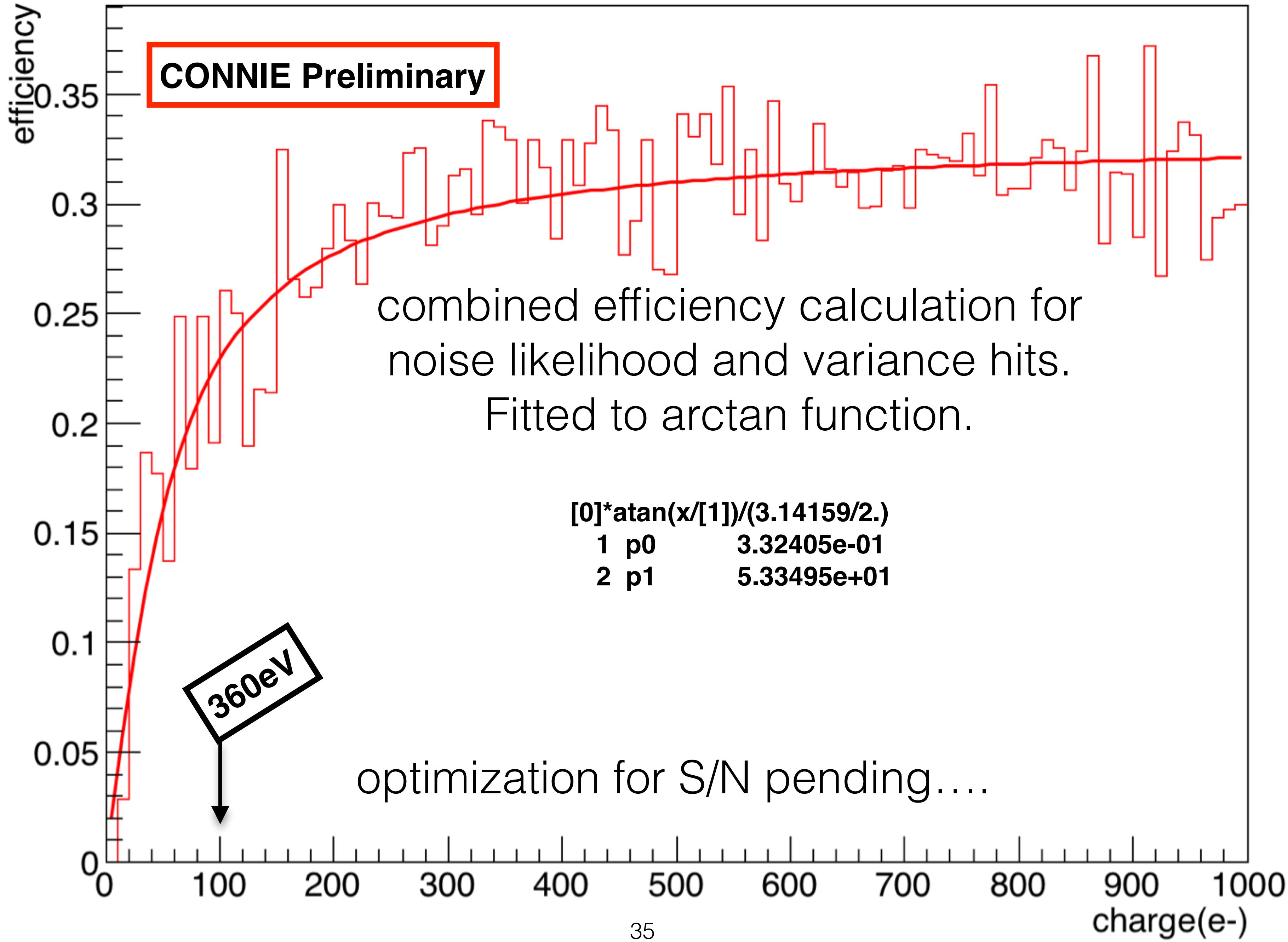
~10 days reactor ON/OFF comparison, 1g detector

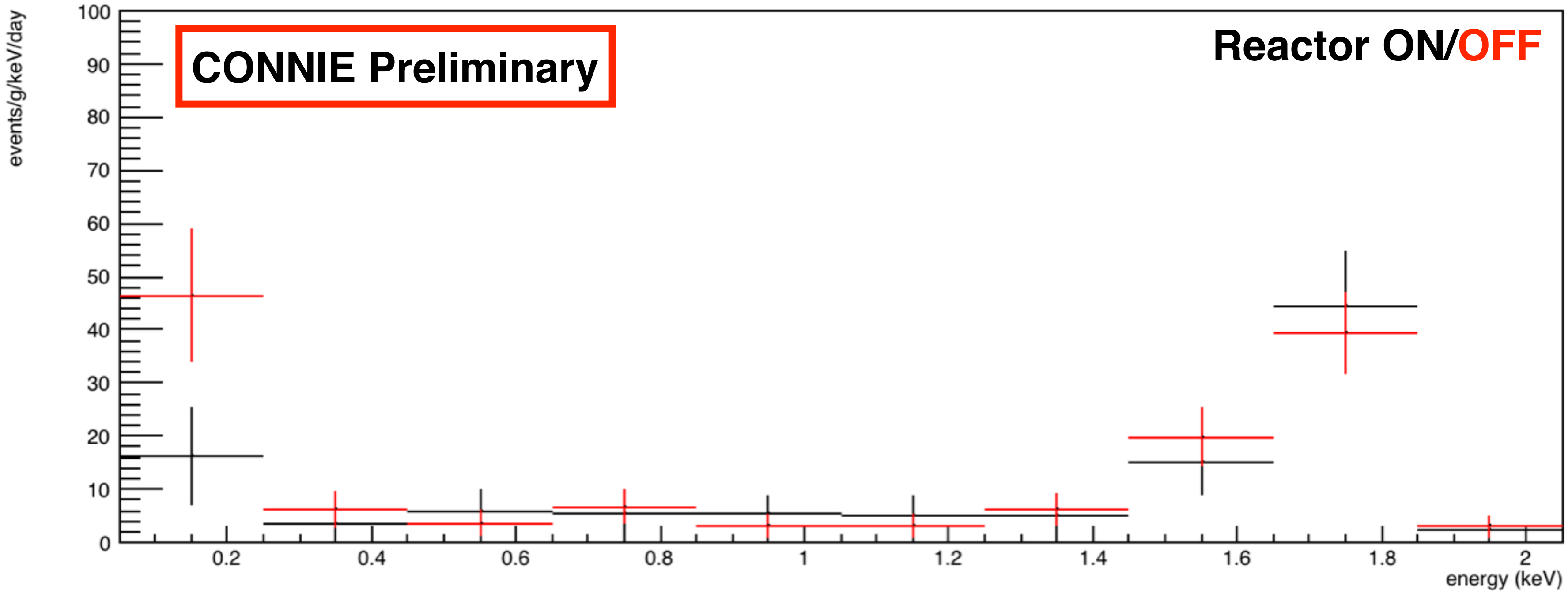


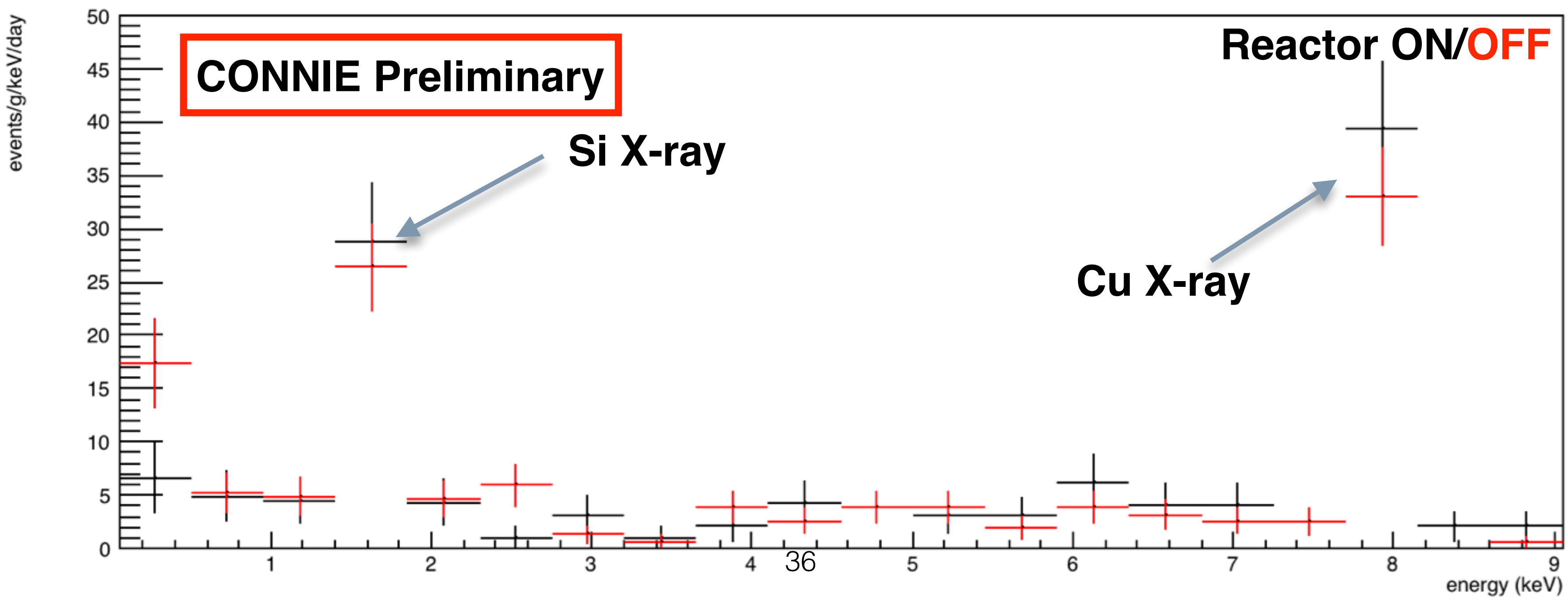
hit size used to select events in core of the CCD to remove low energy X-rays.

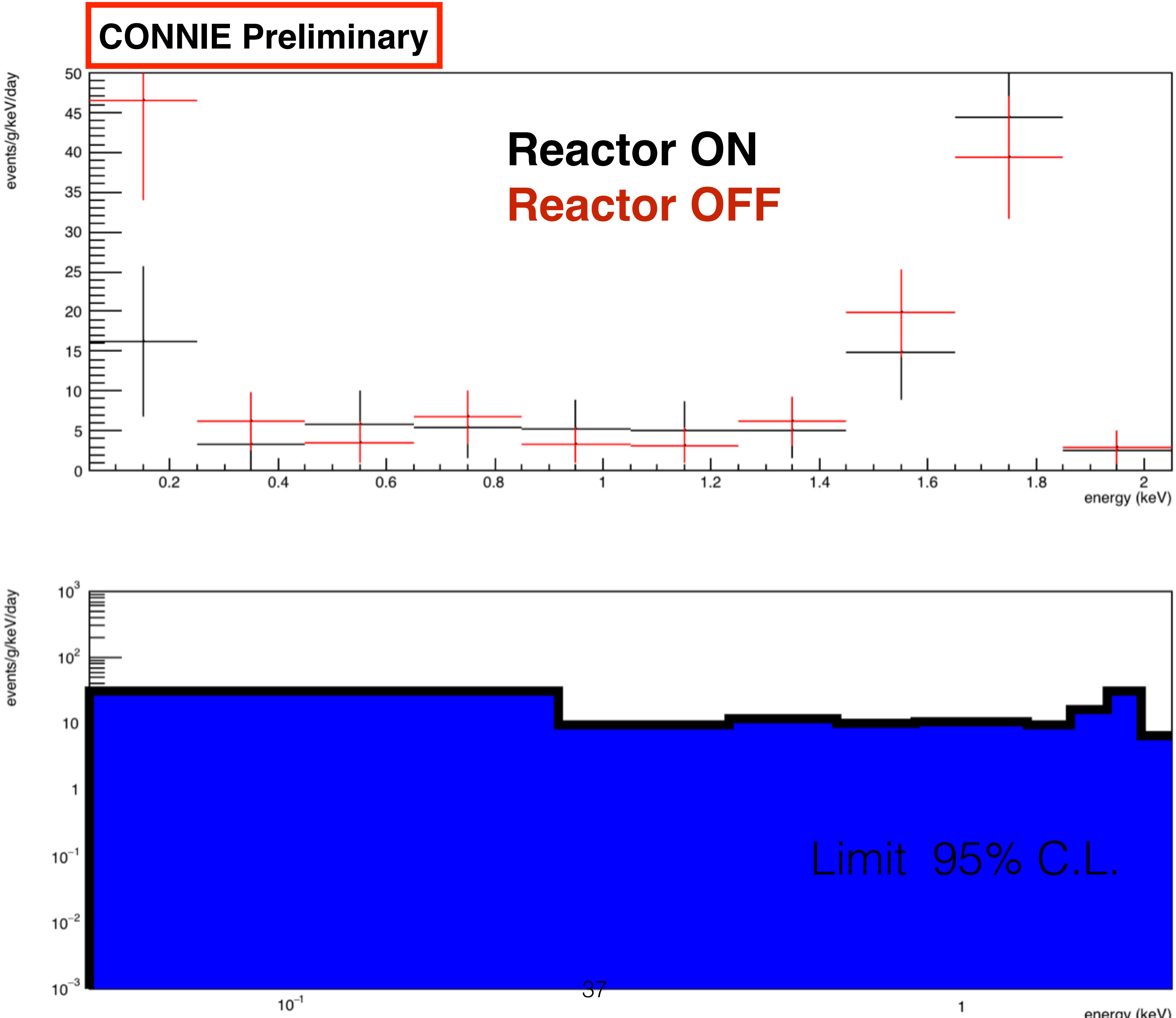


optimization for S/N pending….

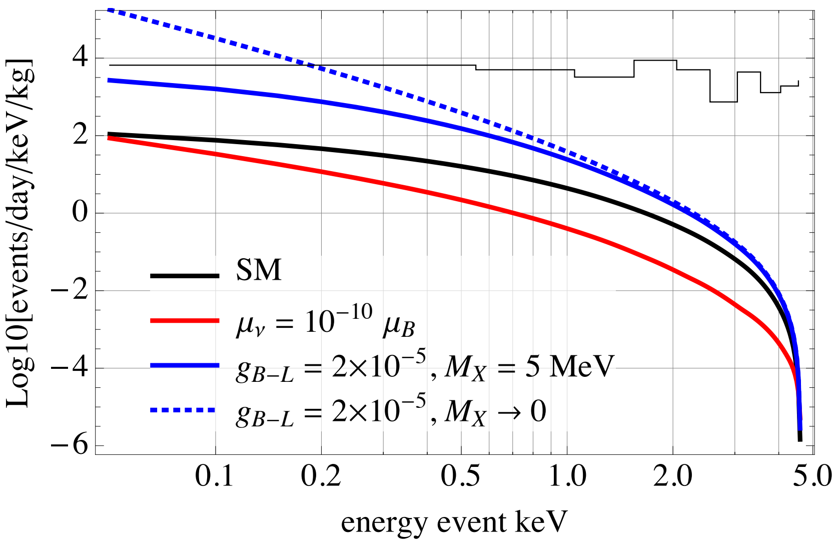

CONNIE Preliminary
combined efficiency calculation for noise likelihood and variance hits. Fitted to arctan function.
[0]*atan(x/[1])/(3.14159/2.)
1 p0 3.32405e-01
2 p1 5.33495e+01
360eV
optimization for S/N pending….
efficiency
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
100
200
300
400
500
600
700
800
900
1000
charge(e-)

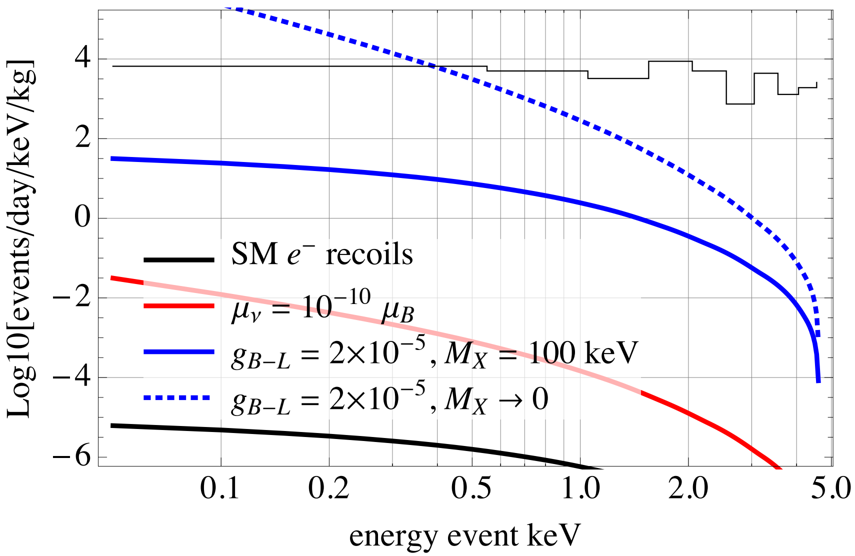

CONNIE Preliminary
Reactor ON/OFF
events/g/keV/day
energy (keV)
0
10
20
30
40
50
60
70
80
90
100
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2


CONNIE Preliminary
Reactor ON/OFF
Si X-ray
Cu X-ray
events/g/keV/day
energy (keV)
0
5
10
15
20
25
30
35
40
45
50
1
2
3
4
5
6
7
8
9

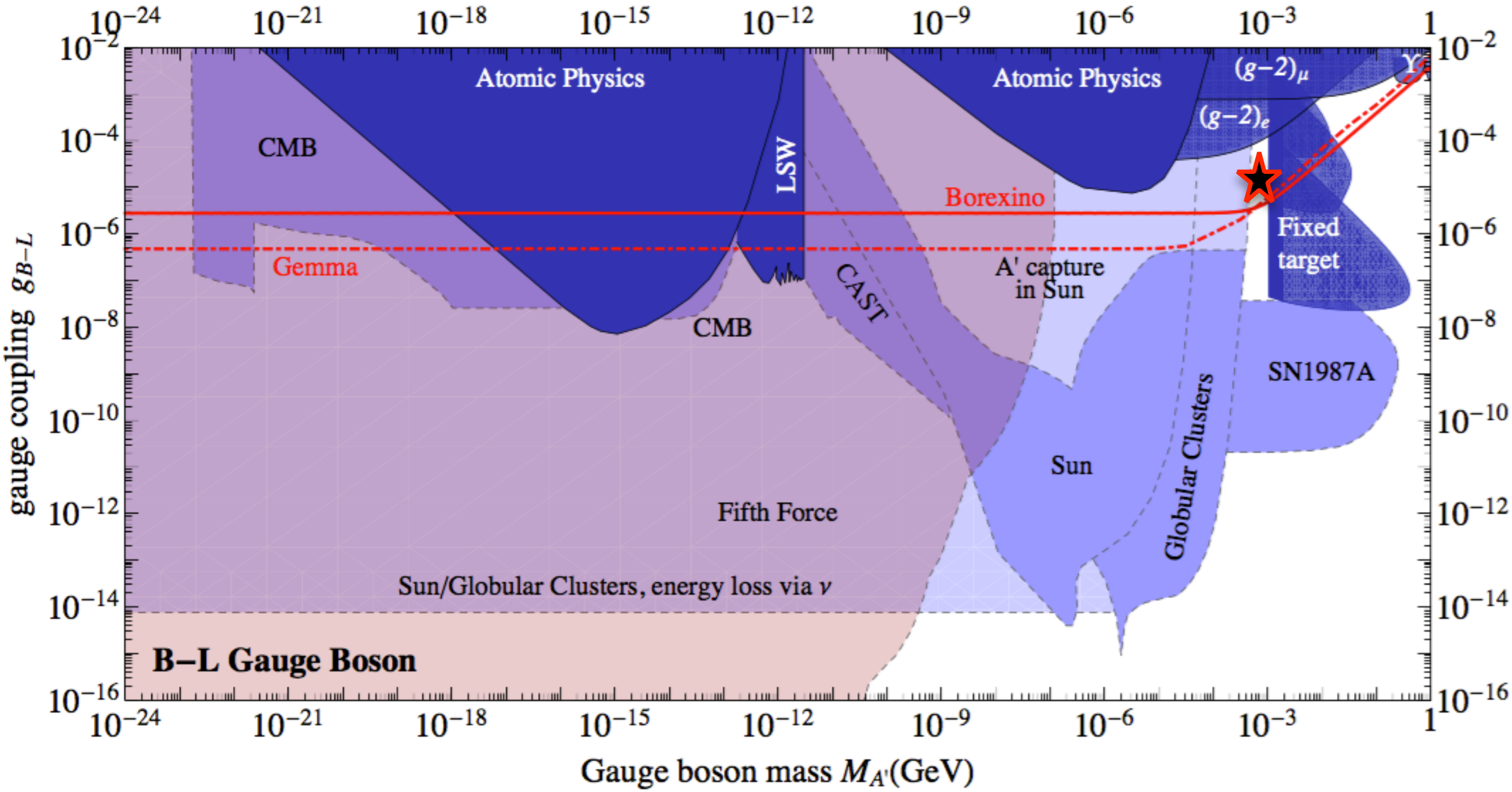


CONNIE Preliminary
Reactor ON
Reactor OFF
events/g/keV/day
50
45
40
35
30
25
20
15
10
5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
energy (keV)
events/g/keV/day
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
energy (keV)
Limit 95% C.L.





Some models of interest compared to events rates similar to preliminary constraints from CONNIE (from Pedro Machado).



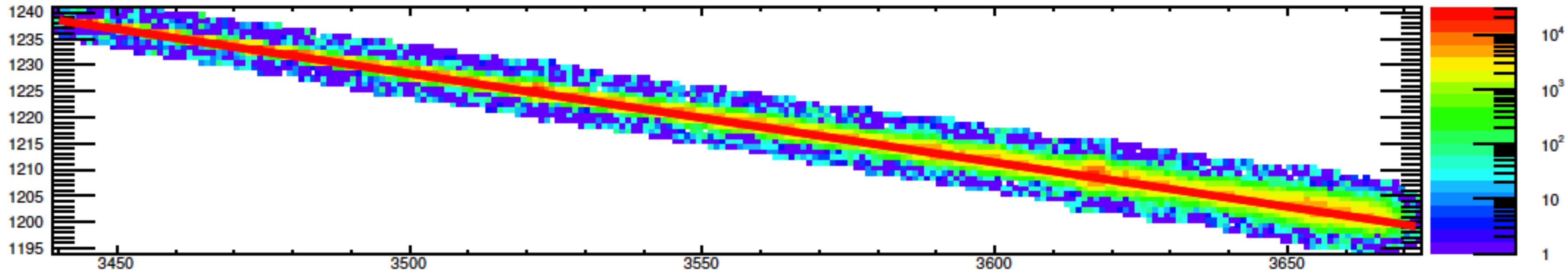
CONNIE is now starting to probe an interesting region of the parameters space for new physics in the low energy neutrino sector.

SUMMARY

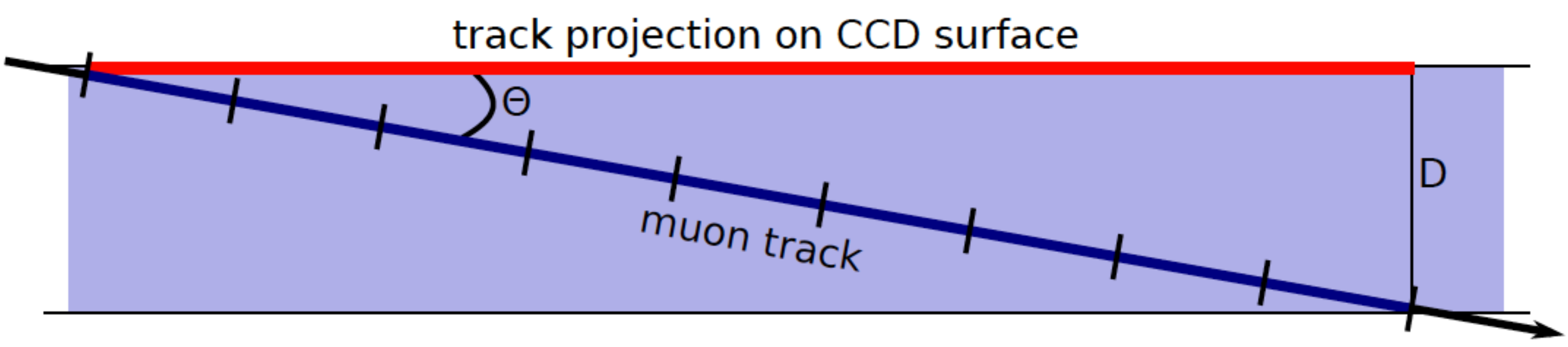
- CONNIE started operations at ANGRA in 2014 with a engineering prototype.
- CONNIE is science ready, starting to produce the first constraints of new physics in the low energy neutrino sector.
- Data shown here is for 1g, operated for about 10 days. More data in the disk to improve preliminary results.
- CONNIE is upgrading to 100g by mid 2016.

Diffusion measurement using a muon track.

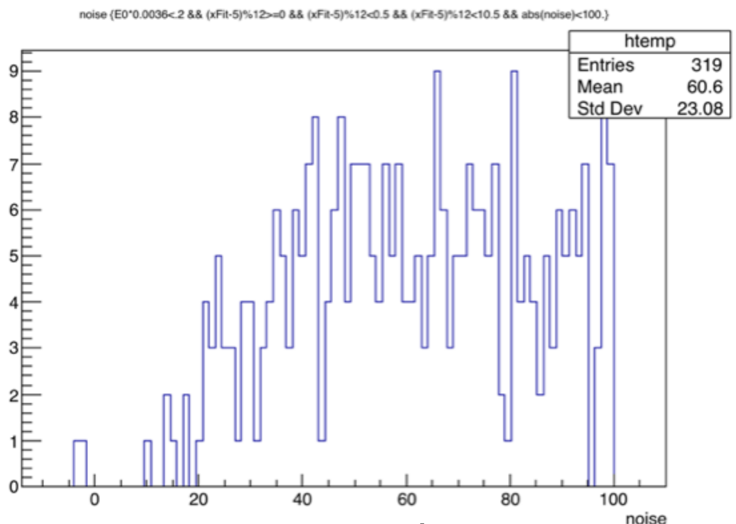
Recorded track: CCD top view



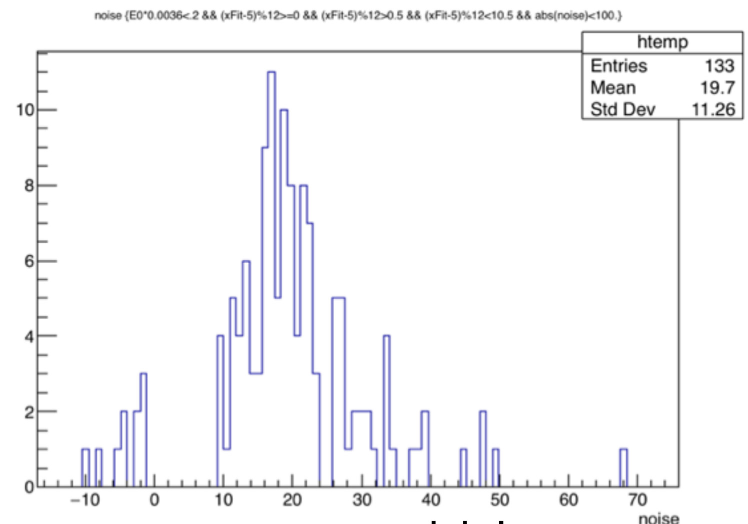
CCD side view



noise likehood in simulations, E<0.2keV



reconstructed hits from simulated hits



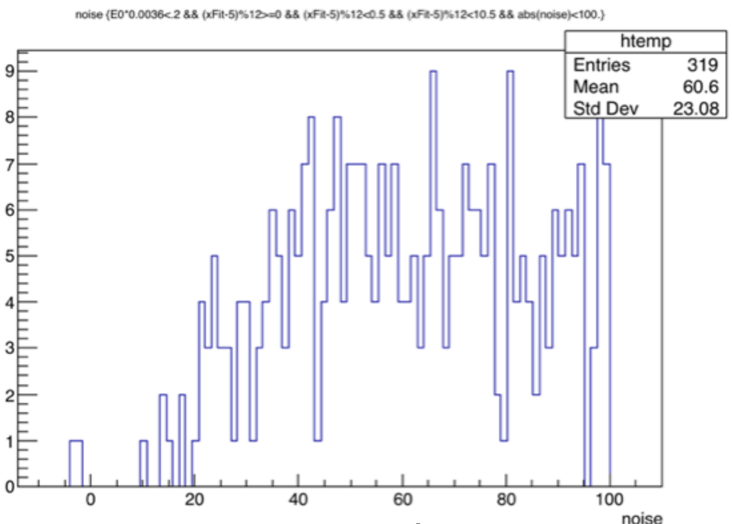
reconstructed hits from simulated noise

-> need a lot more lowE simulations (Guillermo)

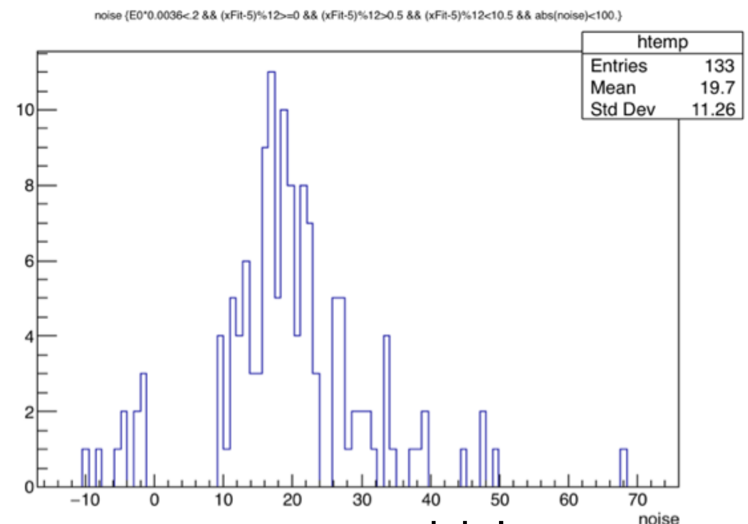
-> need a lot more noise simulations

however it is clear that cut in this likehood variable will do a lot of good.

noise likehood in simulations, E<0.2keV



reconstructed hits from simulated hits



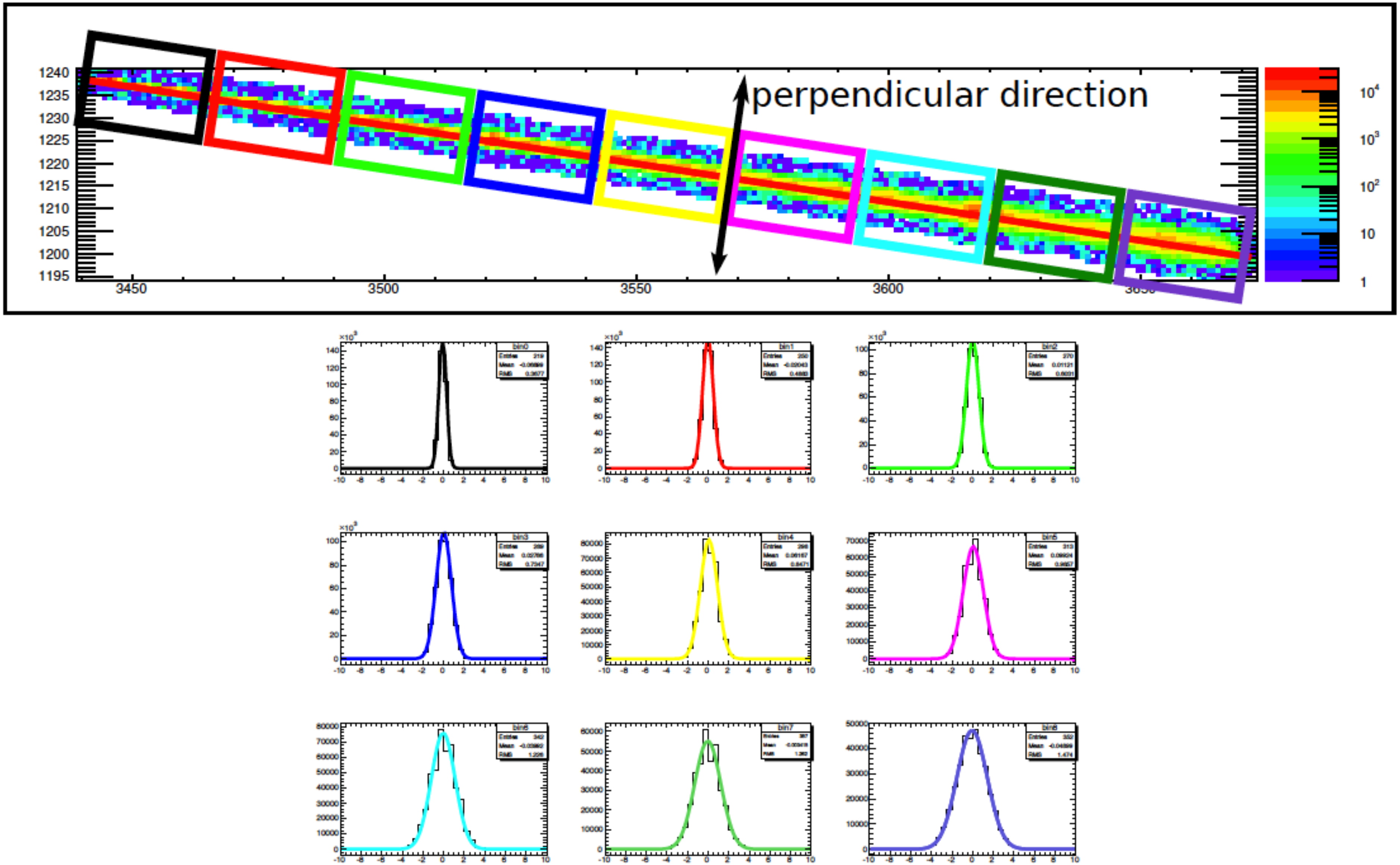
reconstructed hits from simulated noise

Noise>40

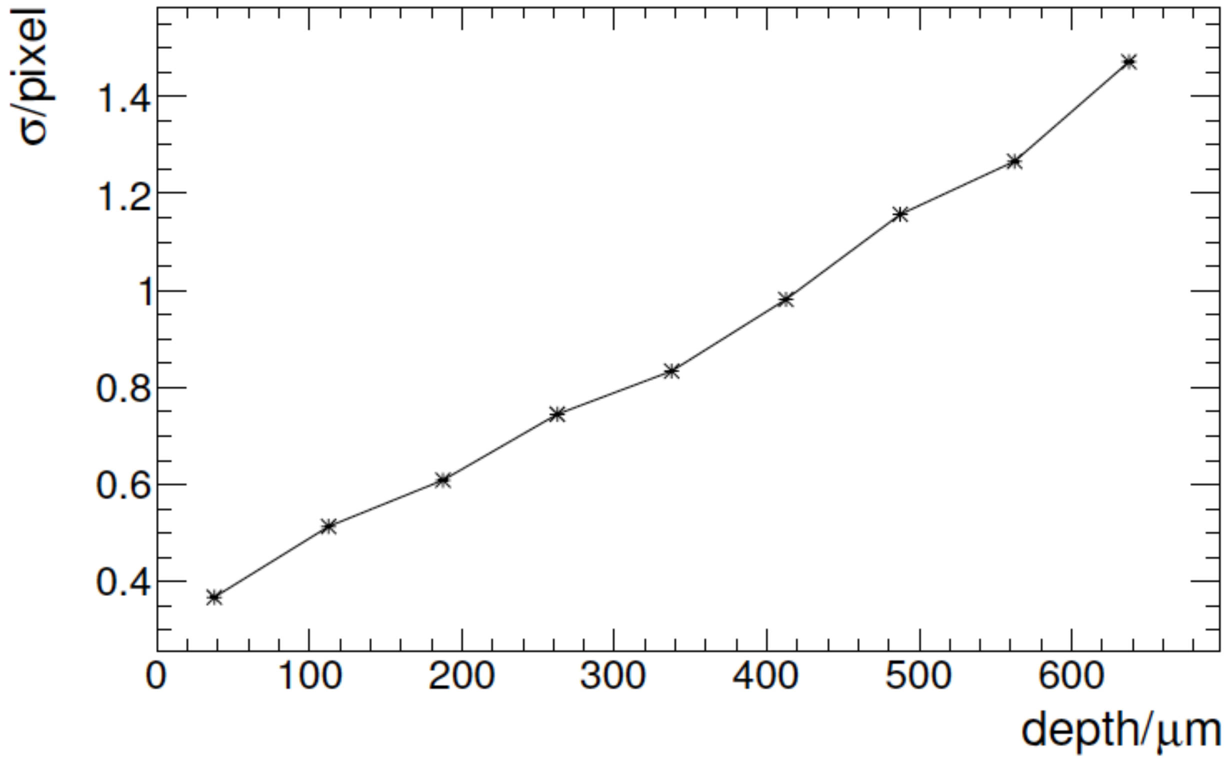
E0<0.2 keV
9/133 = 0.07 acceptance for noise
252/319 = 0.68 acceptance for real hits

E0<0.1 keV
4/132 =0.03 accept. for noise
98/163 = 0.60 accept. for real hits

Diffusion measurement using a muon track.

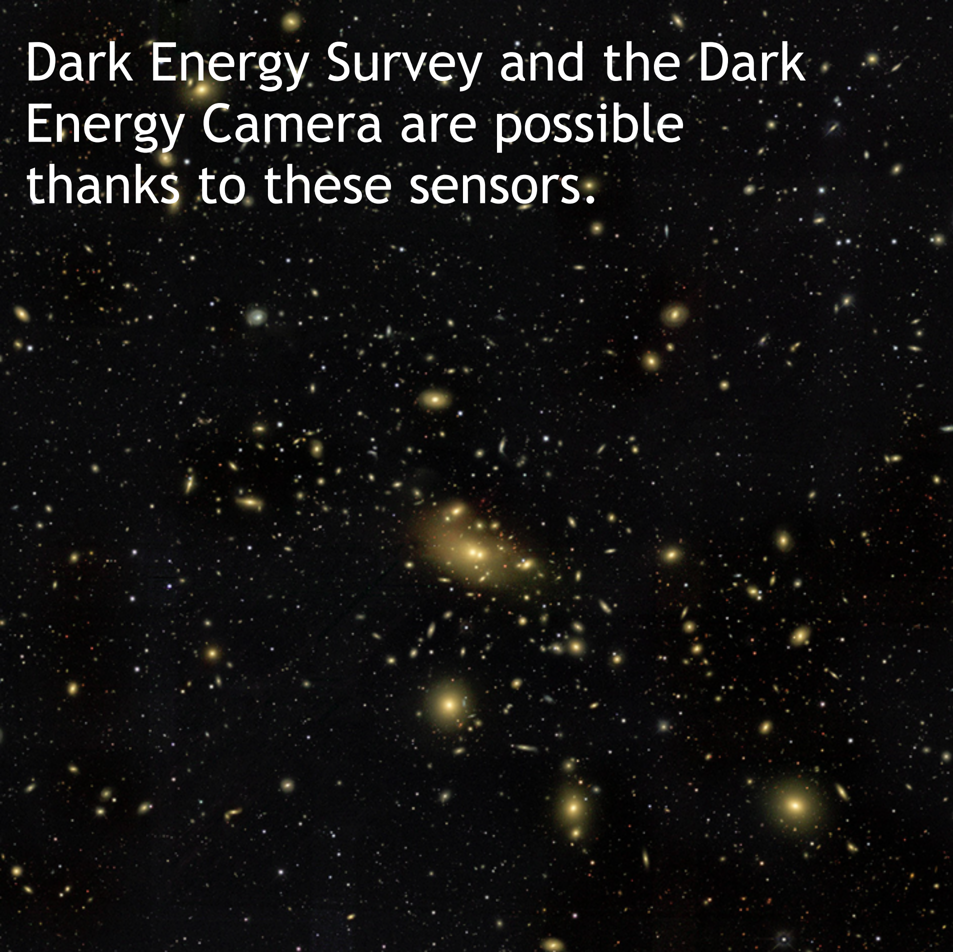


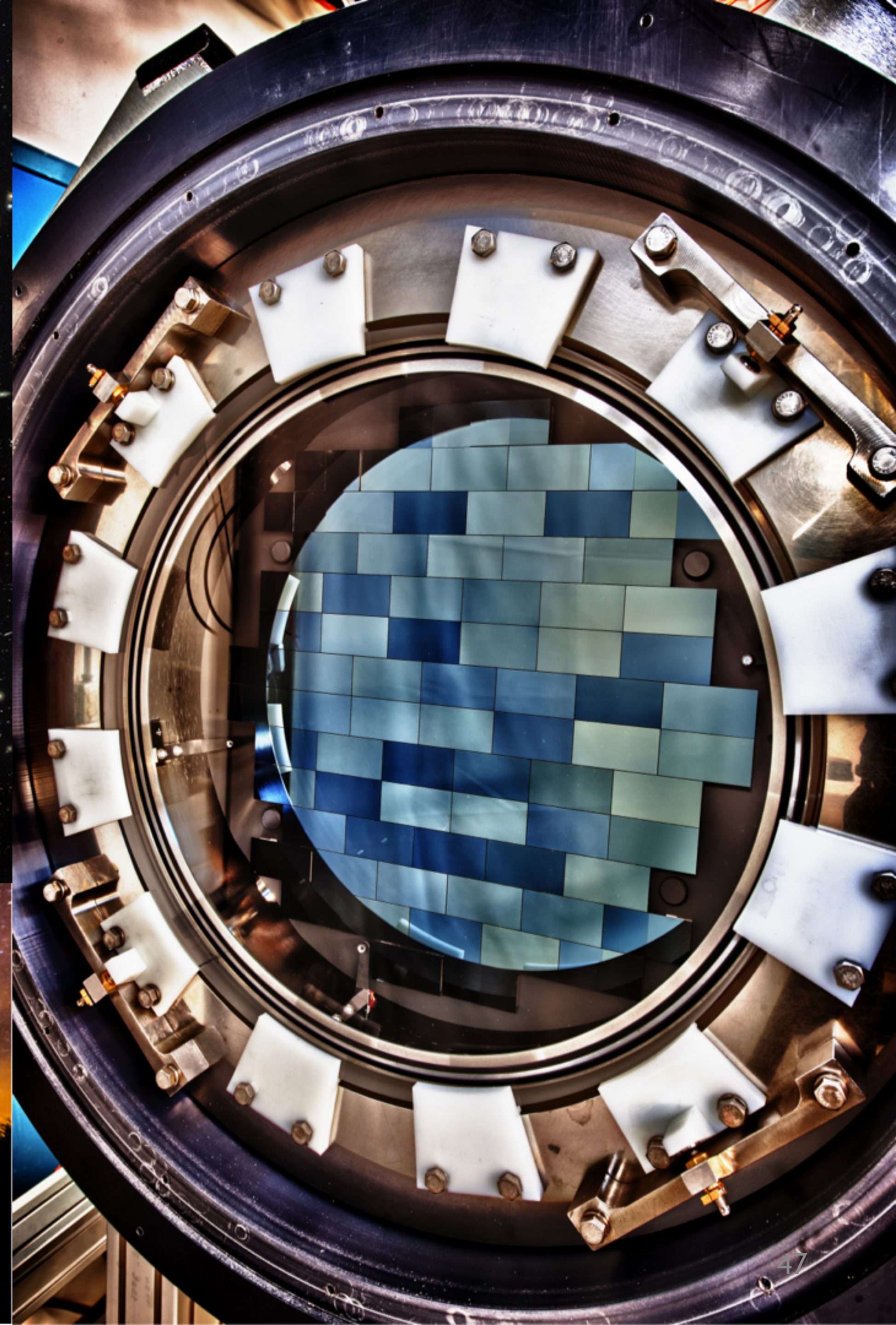
Diffusion measurement using a muon track.



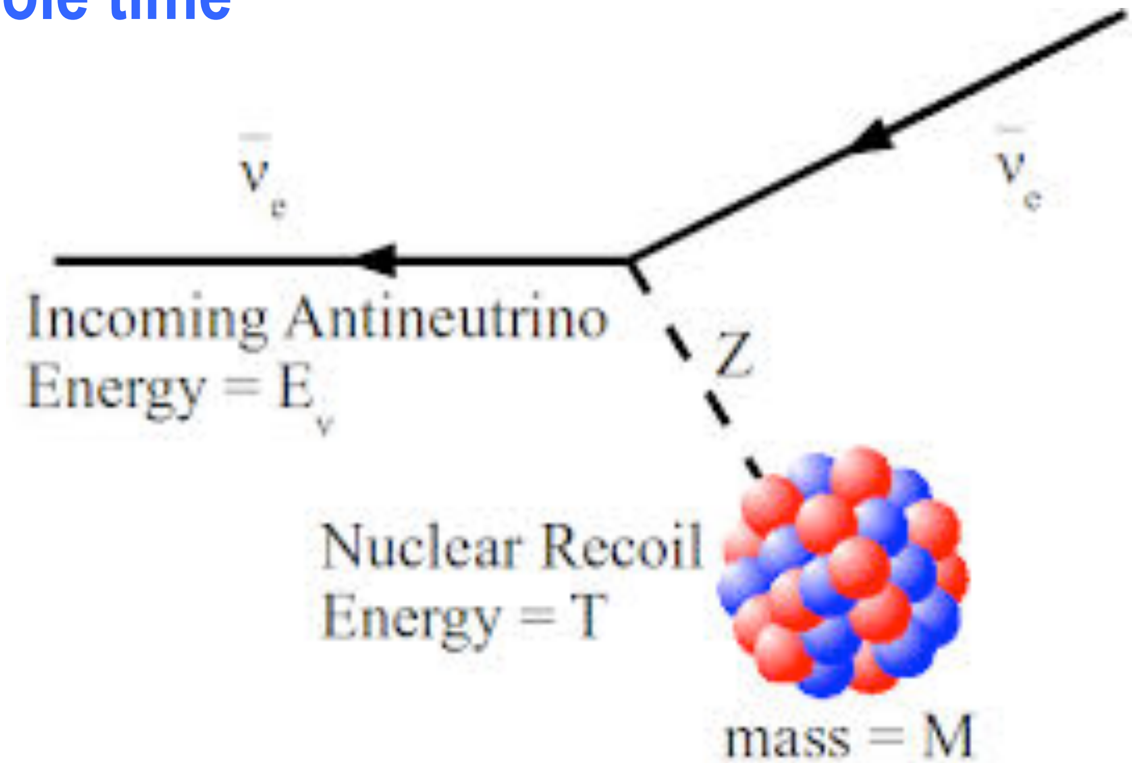
Diffusion can be measured as a function of the interaction depth.
No need to rely on models.

Dark Energy Survey and the Dark Energy Camera are possible thanks to these sensors.





at low energies the neutrino can not penetrate the nucleus… it sees the whole time



$$\frac{d\sigma}{dT_A} = \frac{G_F^2}{4\pi} m_A [Z(1-4\sin^2\theta_W) - N]^2 \left[1 - \frac{m_A T_A}{2E_\nu^2}\right]$$

Exploring ν signals in dark matter detectors

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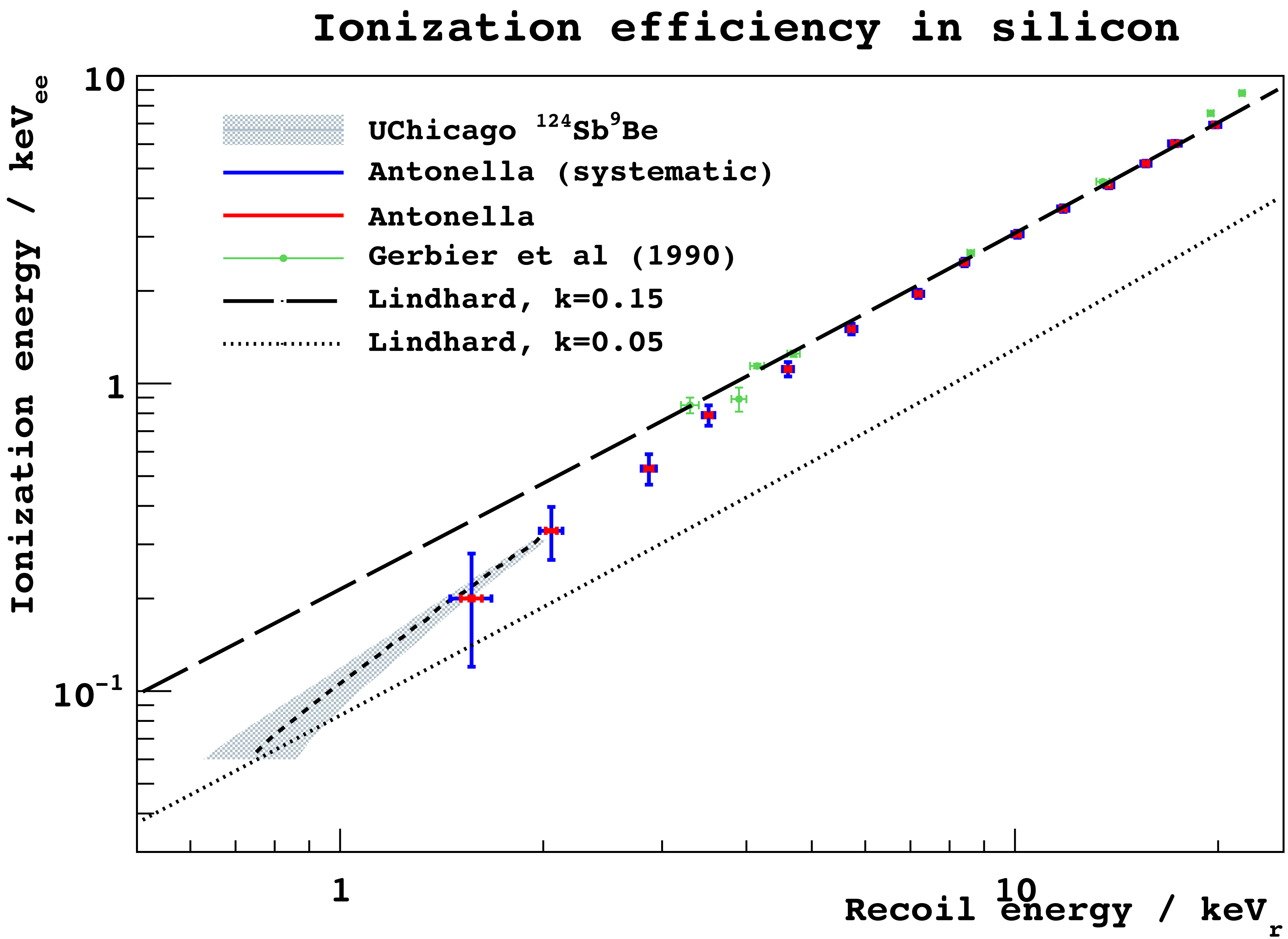
(Dated: February 27, 2011)

As we have seen in section 3.1, a magnetic moment contribution to the neutrino–electron and neutrino–nucleus scattering cross section falls proportional to E_r^{-1} at low recoil energy. We will now turn our attention to scattering processes for which the recoil energy spectrum falls even more steeply ($\propto E_r^{-2}$), and hence a larger enhancement of the neutrino scattering rate at low energies is possible without violating the Borexino constraint.

This can be achieved if there is a new neutrino–electron or neutrino–quark interaction mediated by a light particle whose couplings do not contain derivatives. Let us in particular consider a model with gauged $B-L$ (baryon number minus lepton number) symmetry, with the corresponding $U(1)_{B-L}$ gauge boson A' having a mass $M_{A'} \ll 1$ GeV:

$$\mathcal{L}_{B-L} \supset -g_{B-L}\,\bar{e}\gamma^\alpha A'_\alpha e + \frac{1}{3} g_{B-L}\,\bar{q}\gamma^\alpha A'_\alpha q - g_{B-L}\,\bar{\nu}\gamma^\alpha A'_\alpha \nu + \dots \,. \tag{10}$$

Here, g_{B-L} is the $U(1)_{B-L}$ coupling constant and q, e and ν are quark, charged lepton and neutrino fields, respectively. We will call A' a "dark photon" here and in the following.[5] Note that we neglect the possibility of kinetic mixing between the dark photon and the photon here. We will discuss models with kinetic mixing (but with couplings to $B-L$) in great detail below, and we will argue



Ionization efficiency in silicon
UChicago 124Sb9Be
Antonella (systematic)
Antonella
Gerbier et al (1990)
Lindhard, k=0.15
Lindhard, k=0.05
Ionization energy / keVee
Recoil energy / keVr
10
1
10−1
1
10