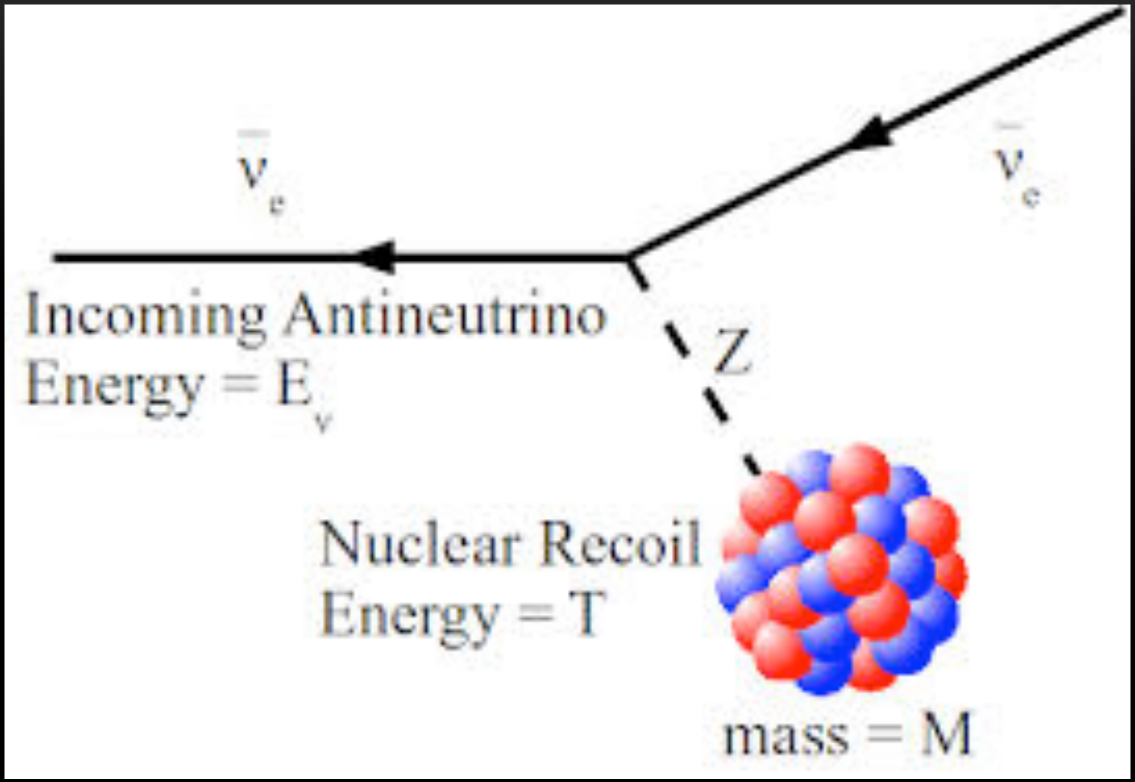
Results from the engineering run of the Coherent Neutrino Nucleus Interaction Experiment (CONNIE).

Juan Estrada
February 2016

Coherent Neutrino Nucleus Scattering:



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

At low recoil energies (T_A) the cross section is enhanced by ~N^2. This process has not been measured yet…

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

this seems to be the starting point… here in Batavia

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small ($10-10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

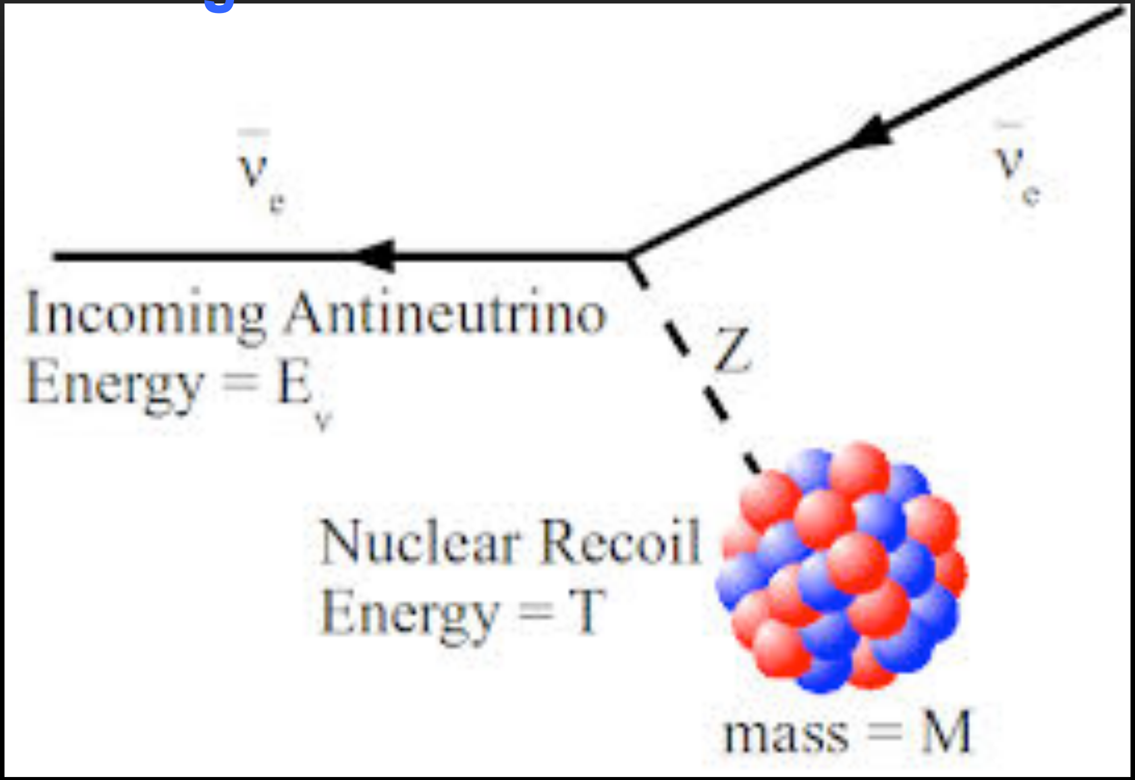
Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small $(10-10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.

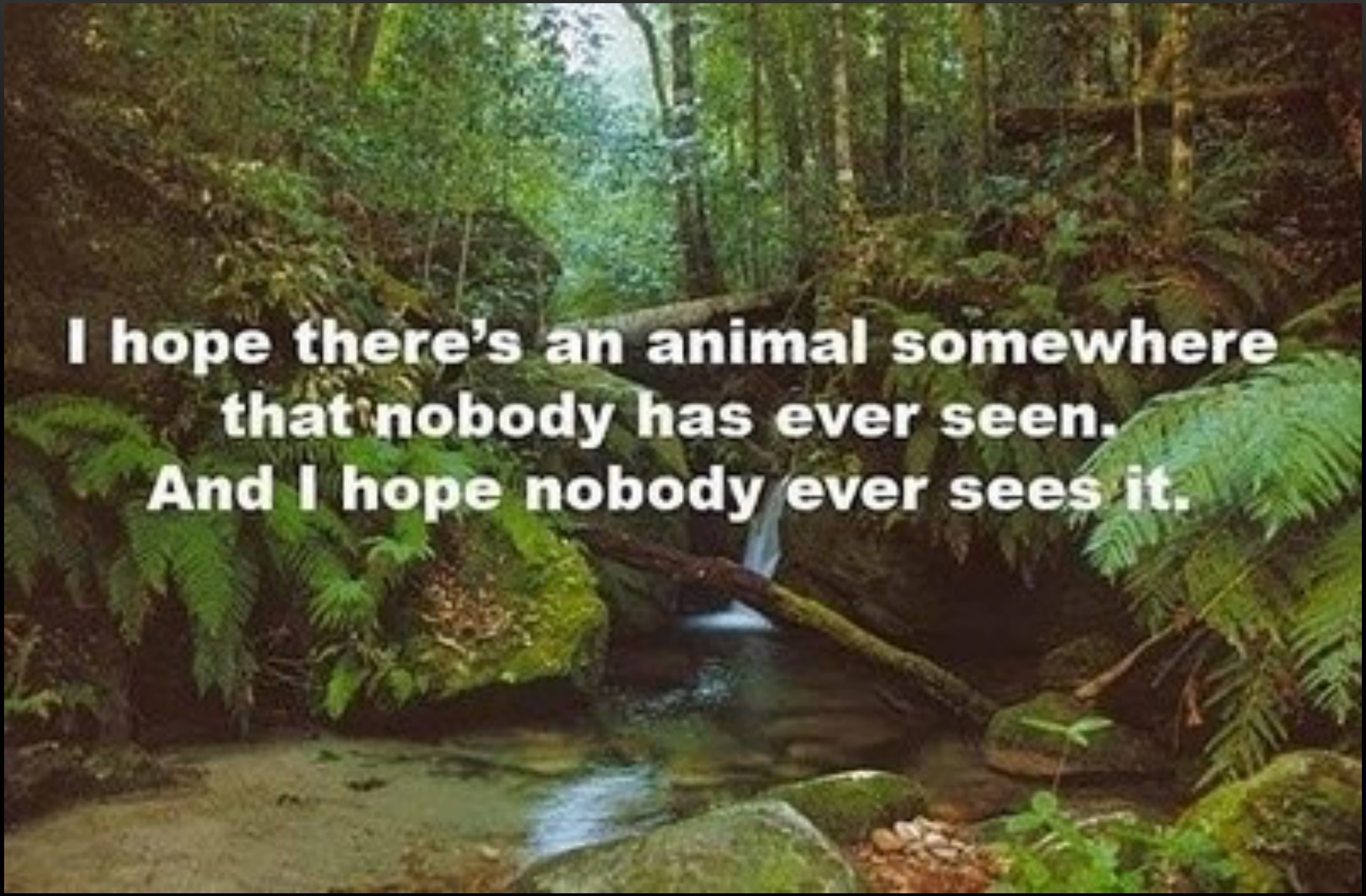
a couple of important things to remember…

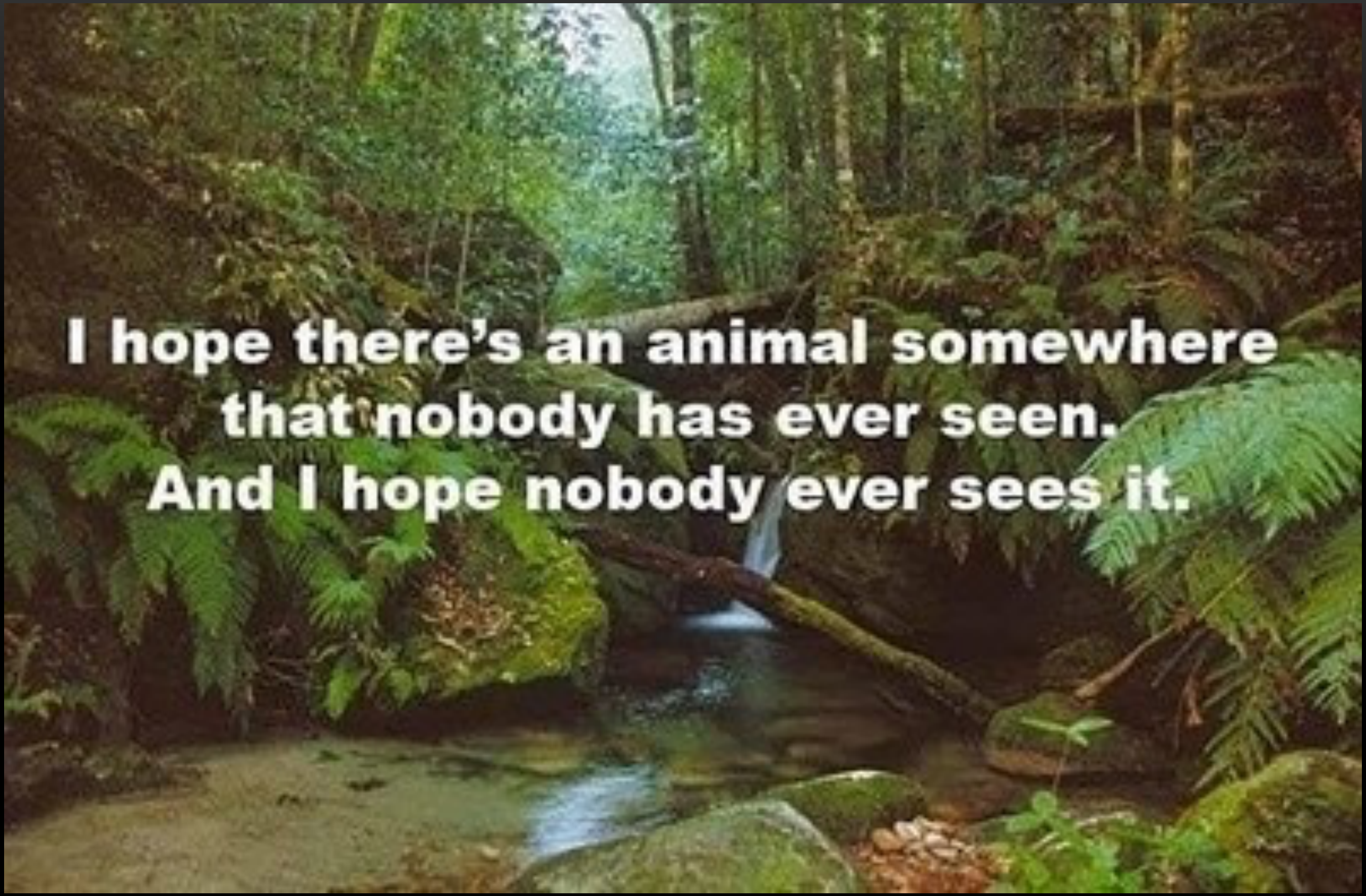
at low energies the neutrino can not penetrate the nucleus… it sees the whole thing



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

we have not seen it yet…


I hope there's an animal somewhere
that nobody has ever seen.
And I hope nobody ever sees it.

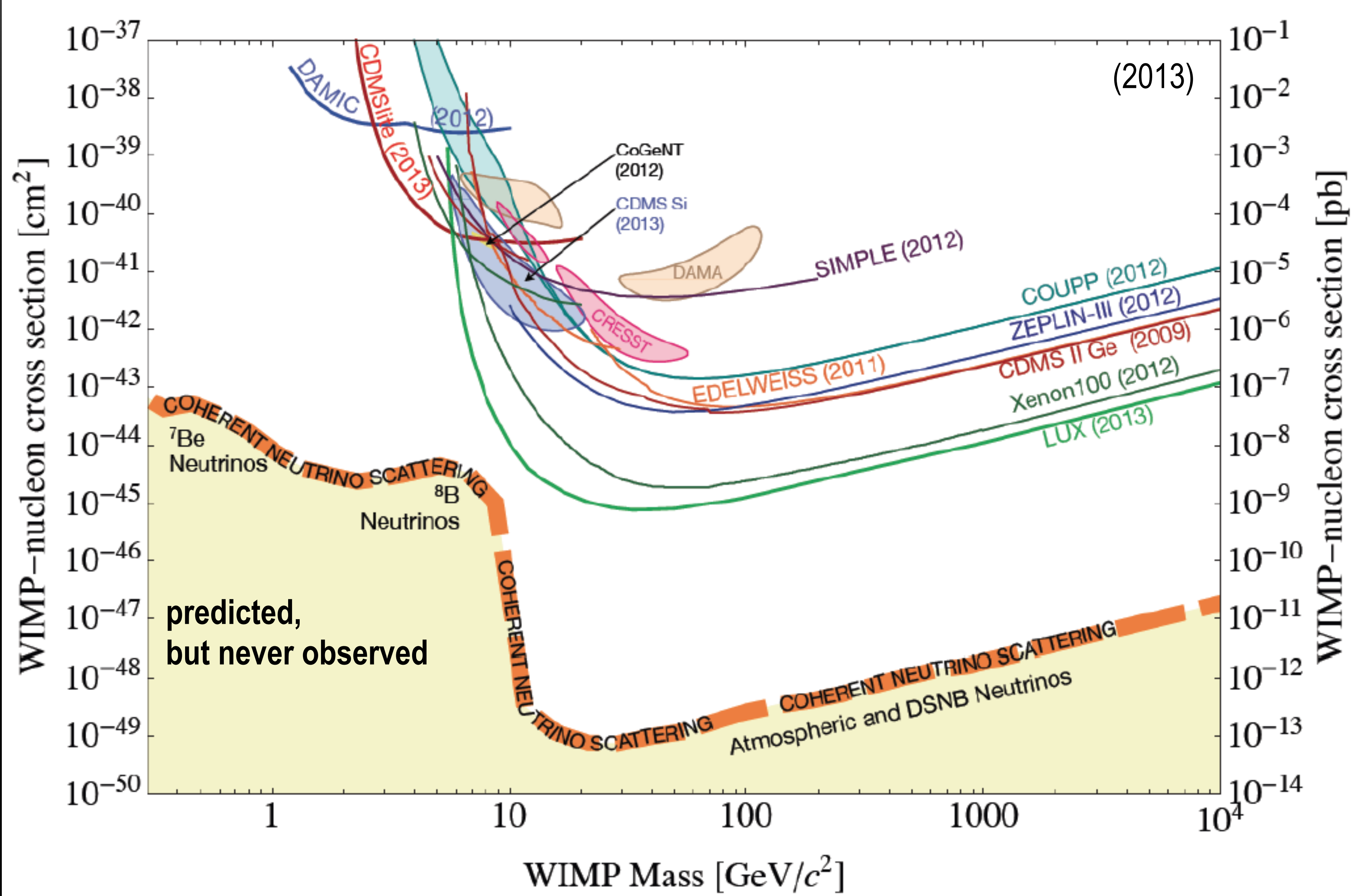


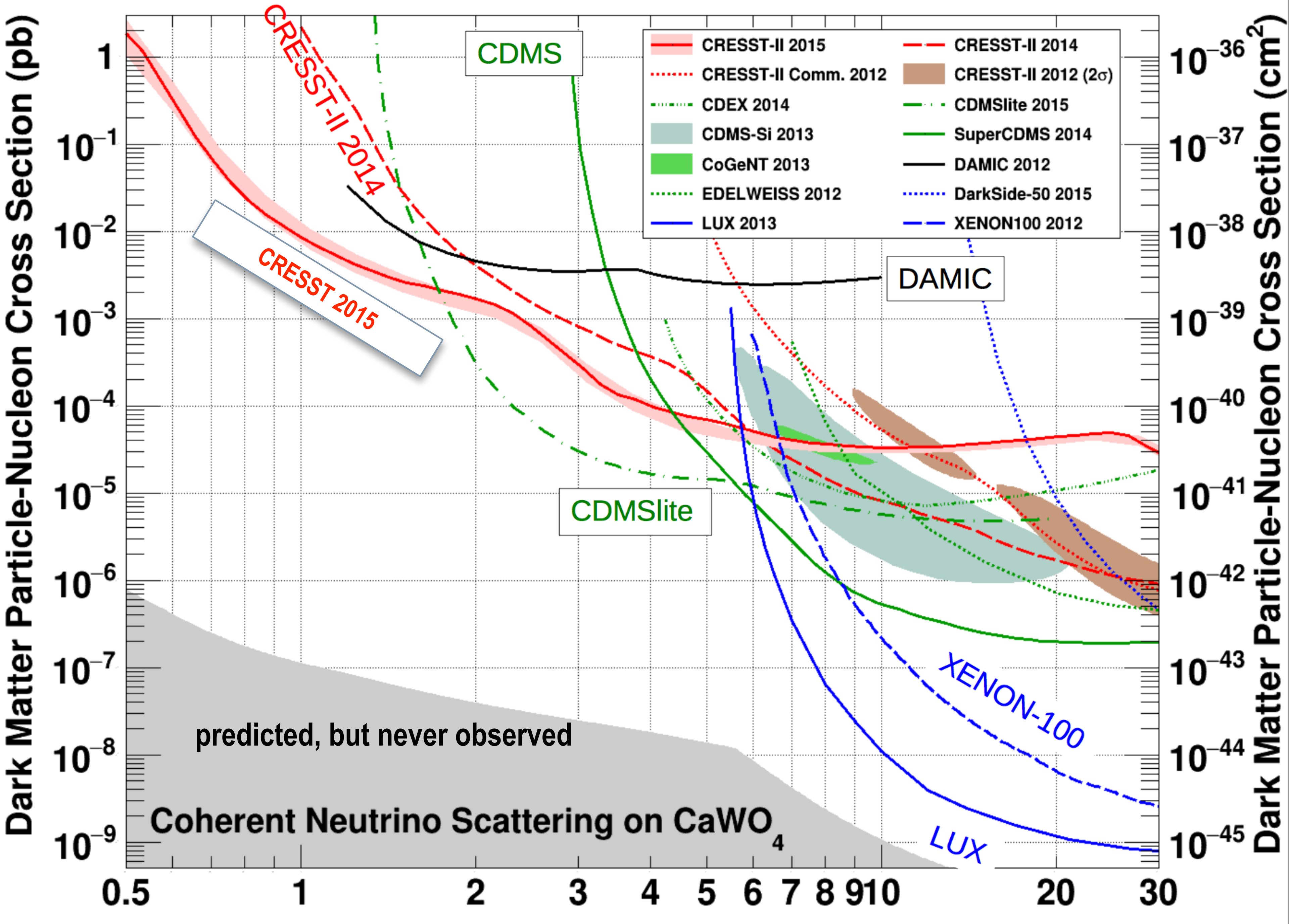
not the plan in this case

- Window for new physics:

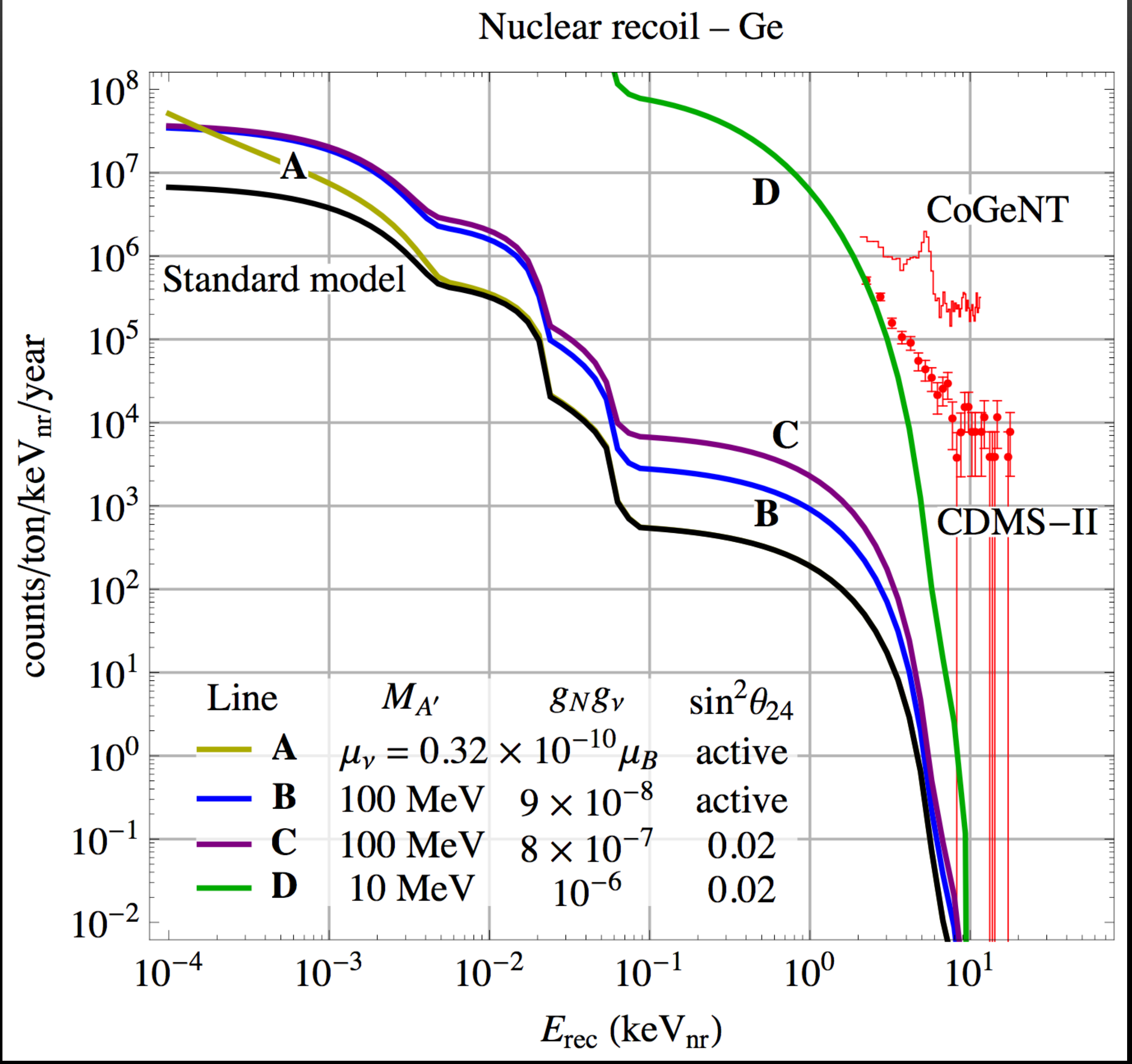
  - Very important for future Dark Matter searches
  - Non Standard interactions
  - Neutrino Anomalous Magnetic Moment
  - New tool for neutrino experiments (very short baseline oscillation experiments – low energy)

- Technological applications:
  - Neutrinos could be used to monitor reactors


(2013)
WIMP–nucleon cross section [cm²]
WIMP–nucleon cross section [pb]
WIMP Mass [GeV/c²]
DAMIC
(2012)
CDMSlite (2013)
CoGeNT
(2012)
CDMS Si
(2013)
DAMA
SIMPLE (2012)
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
EDELWEISS (2011)
Xenon100 (2012)
LUX (2013)
CRESST
COHERENT NEUTRINO SCATTERING
⁷Be
Neutrinos
⁸B
Neutrinos
Atmospheric and DSNB Neutrinos
predicted,
but never observed



adapted from F.Reindl 2-2016



understanding the new physics also important for future dark matter searches…
R. Harnik et al. (2012)

(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 $\sim$ 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 $\pm20°$ with respect to the vertical and $\sim$3 at $70° - 80°$, 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

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

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

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

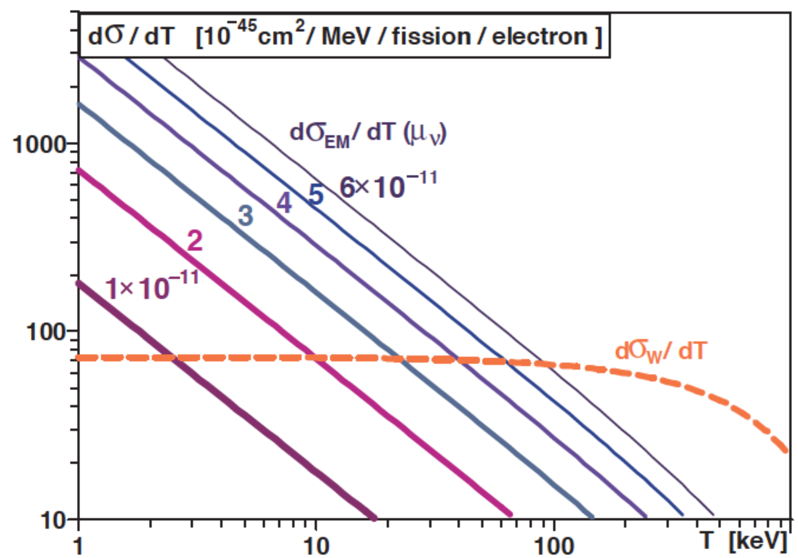
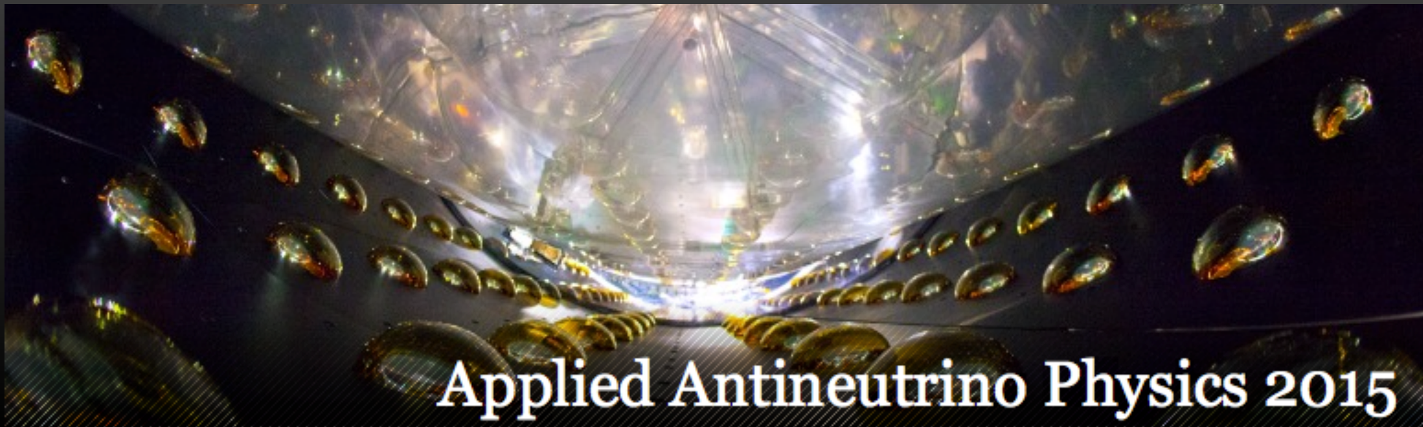
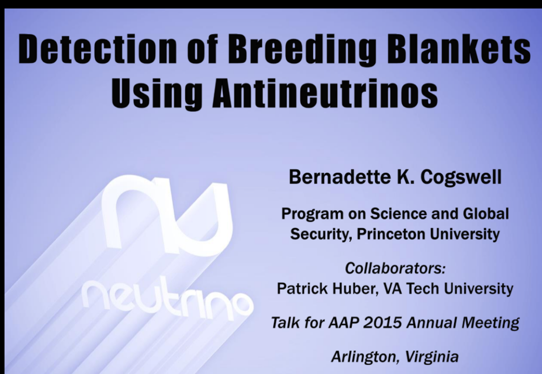
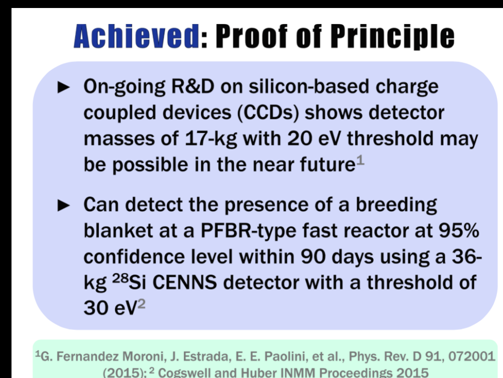


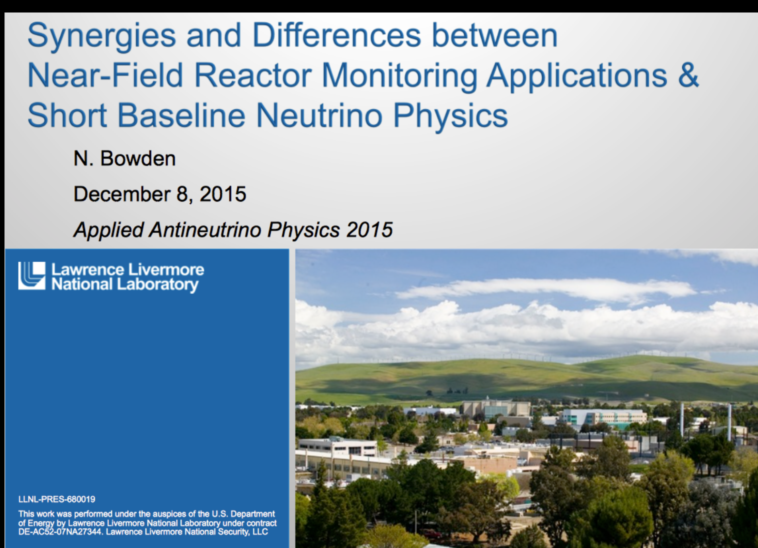
FIG. 1: Weak (W) and electromagnetic (EM) cross-sections calculated for several NMM values.

Current best limit comes from GEMMA (using Ge detector at reactor) $3.2\times10^{-11}\ \mu_B\ m_\nu/\mathrm{eV}$









people have been thinking about technological applications for a while, maybe we are getting close now.

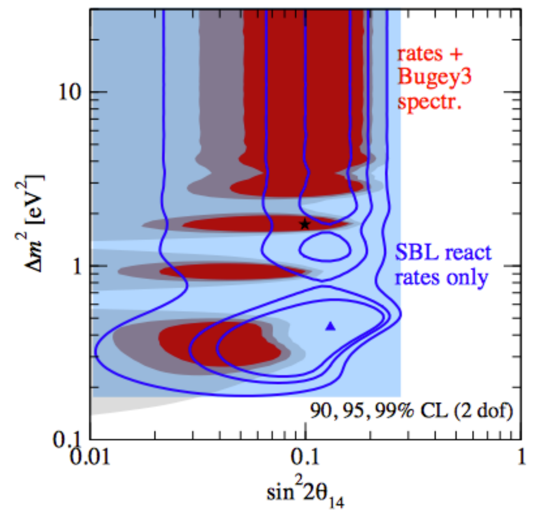
Sterile neutrino oscillations…

$$P(E,R) = 1-\sin^2\theta_{14}\sin^2\left(\Delta m_s^2 \frac{R}{E}\right)$$

for sterile neutrino mass

$$\Delta m_s^2 \sim 1.78\ \mathrm{eV}^2$$

for 1 MeV neutrinos oscillation scale in the order of 1m



Ricochet

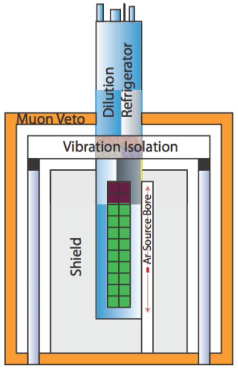


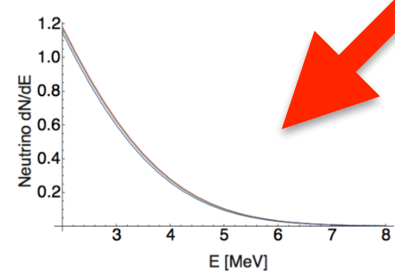
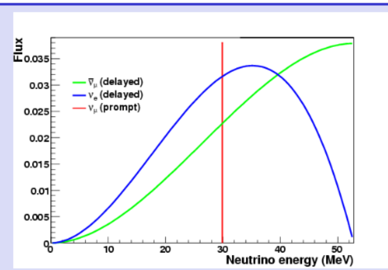
FIG. 5: Conceptual schematic of the experimental setup for a bolometric measurement of coherent scattering from a high-intensity ^{37}Ar neutrino source. An array of 10,000 Si bolometers is arranged in a column of dimensions 0.42 (dia.) × 2.0 (length) meters (shown in green) inside a dilution refrigerator suspended from a vibration isolation mount. Each Si bolometer has a mass of 50 g for a total active mass of 500 kg. Appropriate passive or active shielding surrounds the refrigerator. A cylindrical bore in the shield allows the ^{37}Ar source, mounted on a translation mechanism, to be moved to different positions along the side of the array. Periodic movement of the source throughout the measurement sequence allows each detector to sample multiple baselines, enables cross-calibration among detectors, and aids in background subtraction. The minimum distance from the source to a bolometer is assumed to be ∼10 cm.

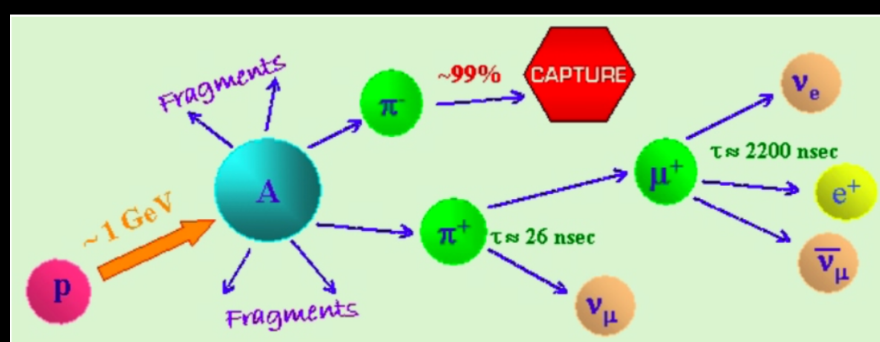
Very short baseline sterile neutrino oscillation experiment would become possible if we have a way to detect coherent scattering.

great…. but how do we do it?

Two ways to get high flux low energy neutrinos:

Will talk about this.

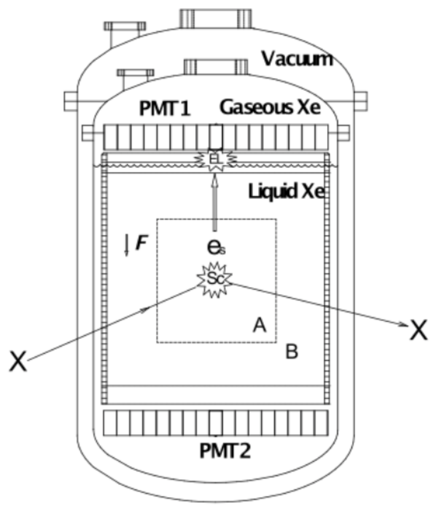
Reactors		Low energy, but very high fluxes possible; ~continuous source good bg rejection needed
Stopped pions (decay at rest)		High energy, pulsed beam possible for good background rejection; possible neutron backgrounds



COHERENT collaboration @ SNS

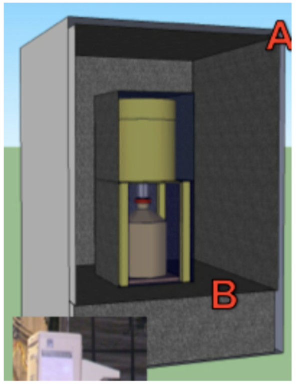
Three possible technologies under consideration

Two-phase LXe



arXiv:1310.0125

CsI



HPGe PPC

Strong program at Spallation Neutron Source with stopped pions. Larger energy recoils.

The CONNIE Collaboration

COHERENT NEUTRINO NUCLEUS INTERACTION EXPERIMENT

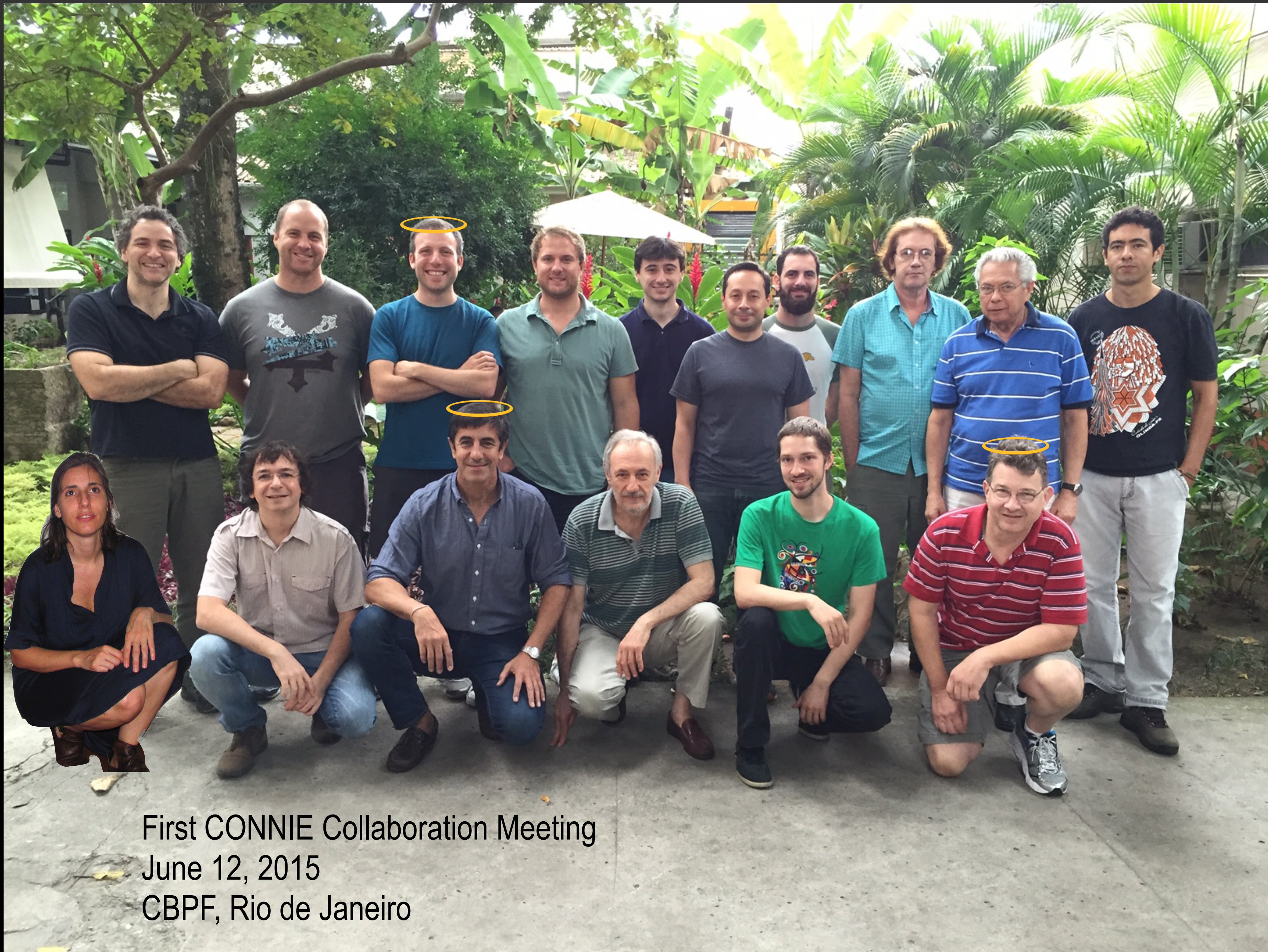
Scientific goal:
First detection of neutrino-nucleus coherent scattering.

Technique:
Measure low energy nuclear recoils in silicon produced by antineutrinos generated at nuclear power plant. Scientific Charge Couple Devices (CCDs) are used for this purpose with a threshold of 40 eV.

Collaboration:
Argentina, Brazil, Mexico, Paraguay, Switzerland and USA

~20 people

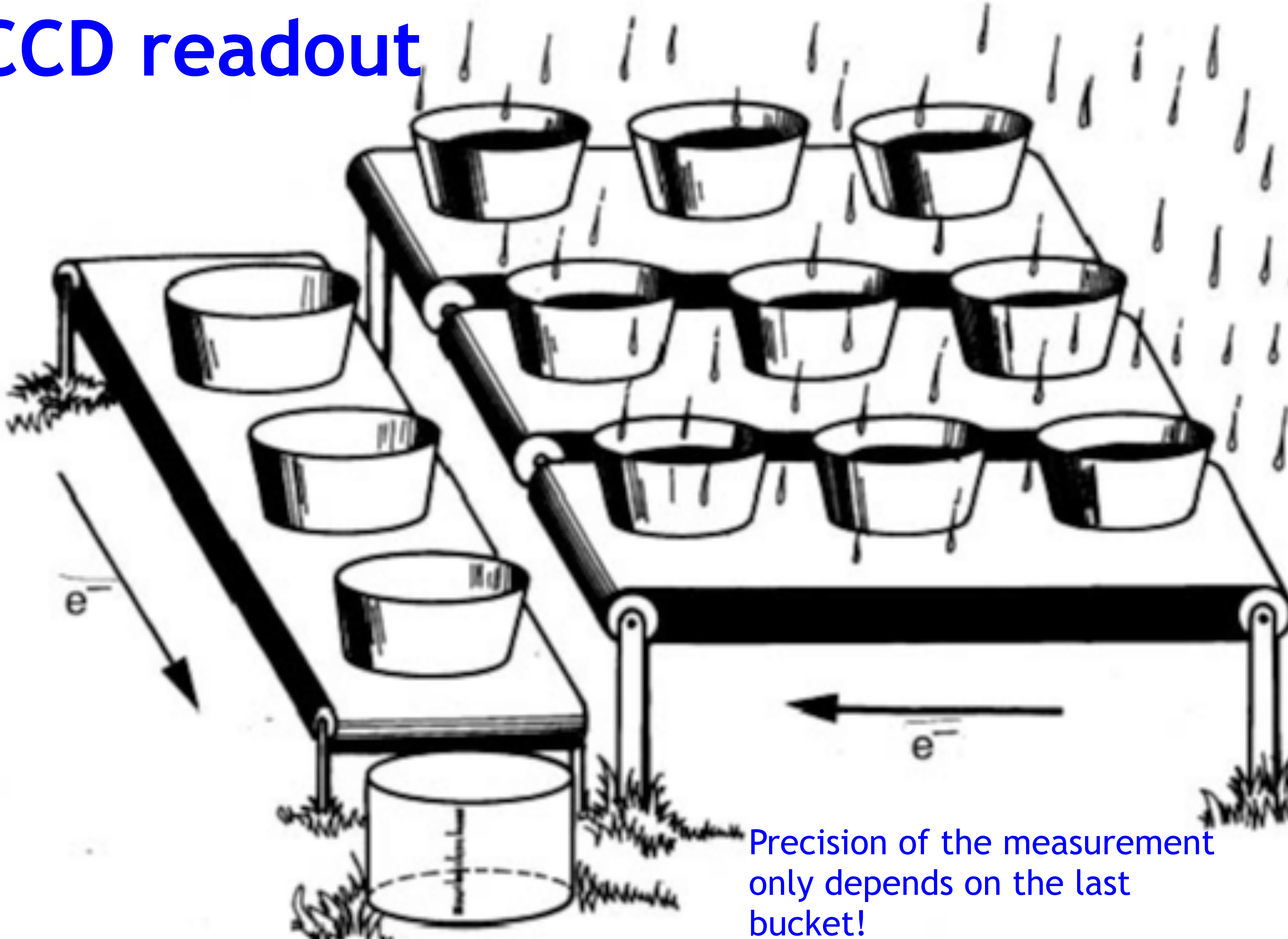

First CONNIE Collaboration Meeting
June 12, 2015
CBPF, Rio de Janeiro


First CONNIE Collaboration Meeting
June 12, 2015
CBPF, Rio de Janeiro

- Ingredients:
    - Strong source of low energy neutrinos.
    - Detector that can see very low energy nuclear recoils.
- Instructions
    - Combine ingredients and wait for the signal.

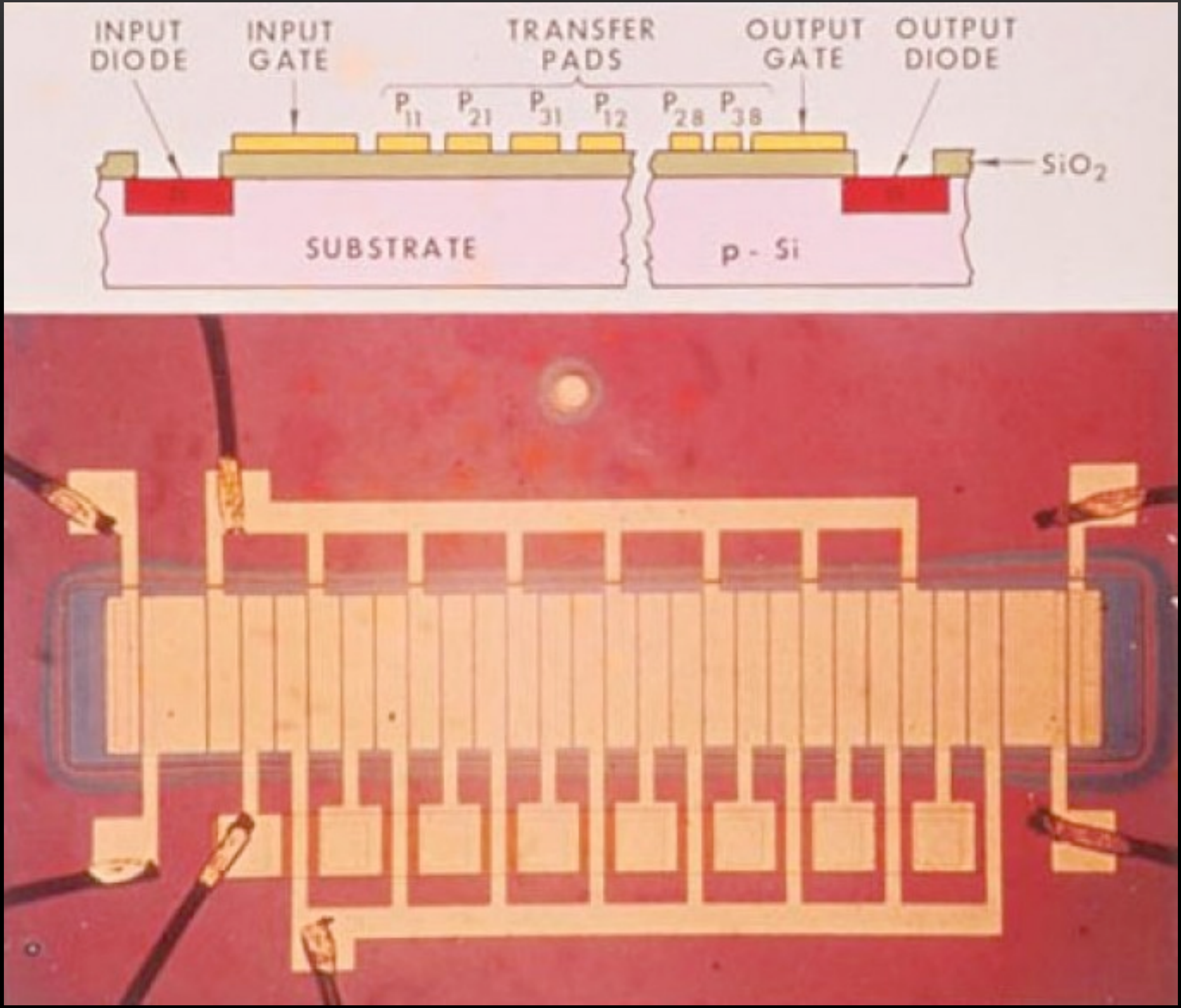
The detector: CCDs

CCD readout

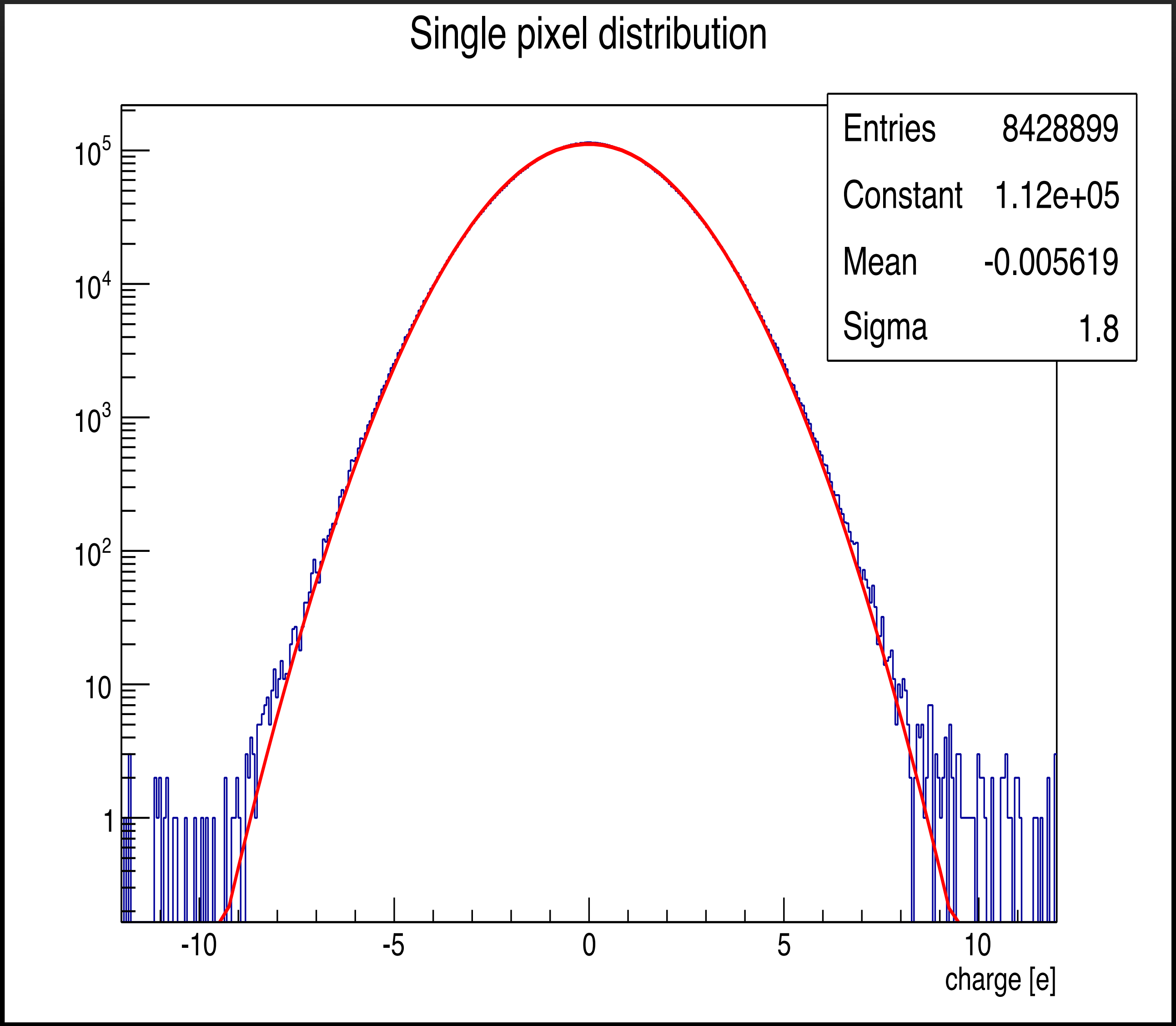


Precision of the measurement only depends on the last bucket!

Janesick


INPUT DIODE
INPUT GATE
TRANSFER PADS
OUTPUT GATE
OUTPUT DIODE
P_{11} P_{21} P_{31} P_{12} P_{28} P_{38}
SiO_2
SUBSTRATE
p - Si

1.8 e- RMS noise: this is what makes CONNIE posible:

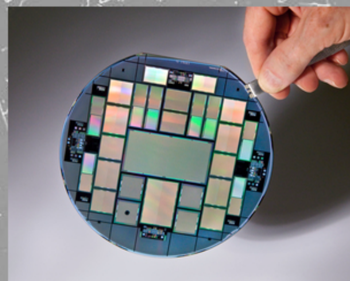


1e ≈ 3.6eV → 40eV threshold is possible

LBNL large-format totally depleted thick CCDs

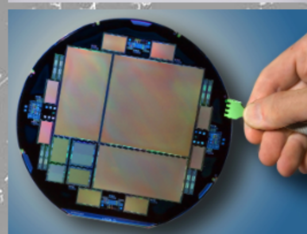
(Click on figures to get a big postscript version)

(Updating intermittently in progress. Links to papers should be OK)



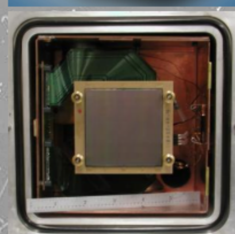
2010 LDRD wafer

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.



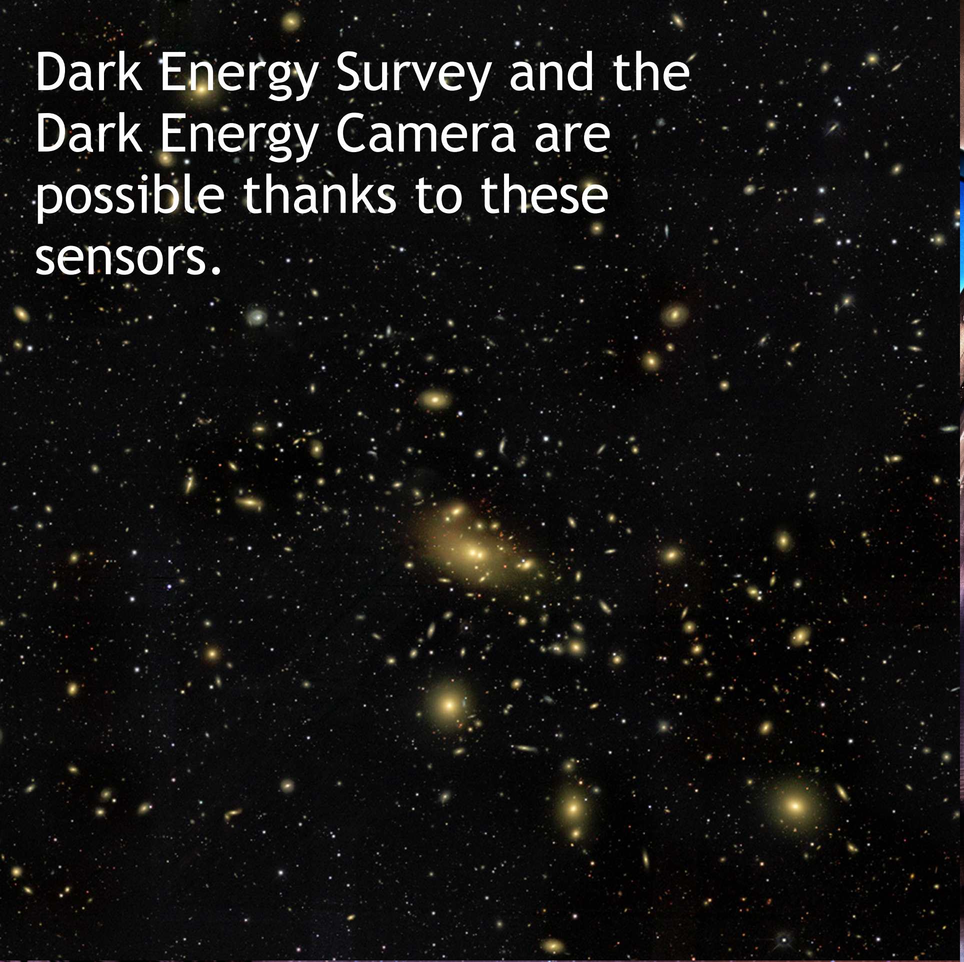
Front-illuminated unthinned (650 um thick) picture-frame packaged 4114x4128 15 um pixel CCD in test dewar; 6 inch rule underneath for scale. CCD has 4-corner readout and high substrate voltage capability. Cosmic-ray muon tracks indidate near depletion at 80 V substrate bias. Preminary measurements show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

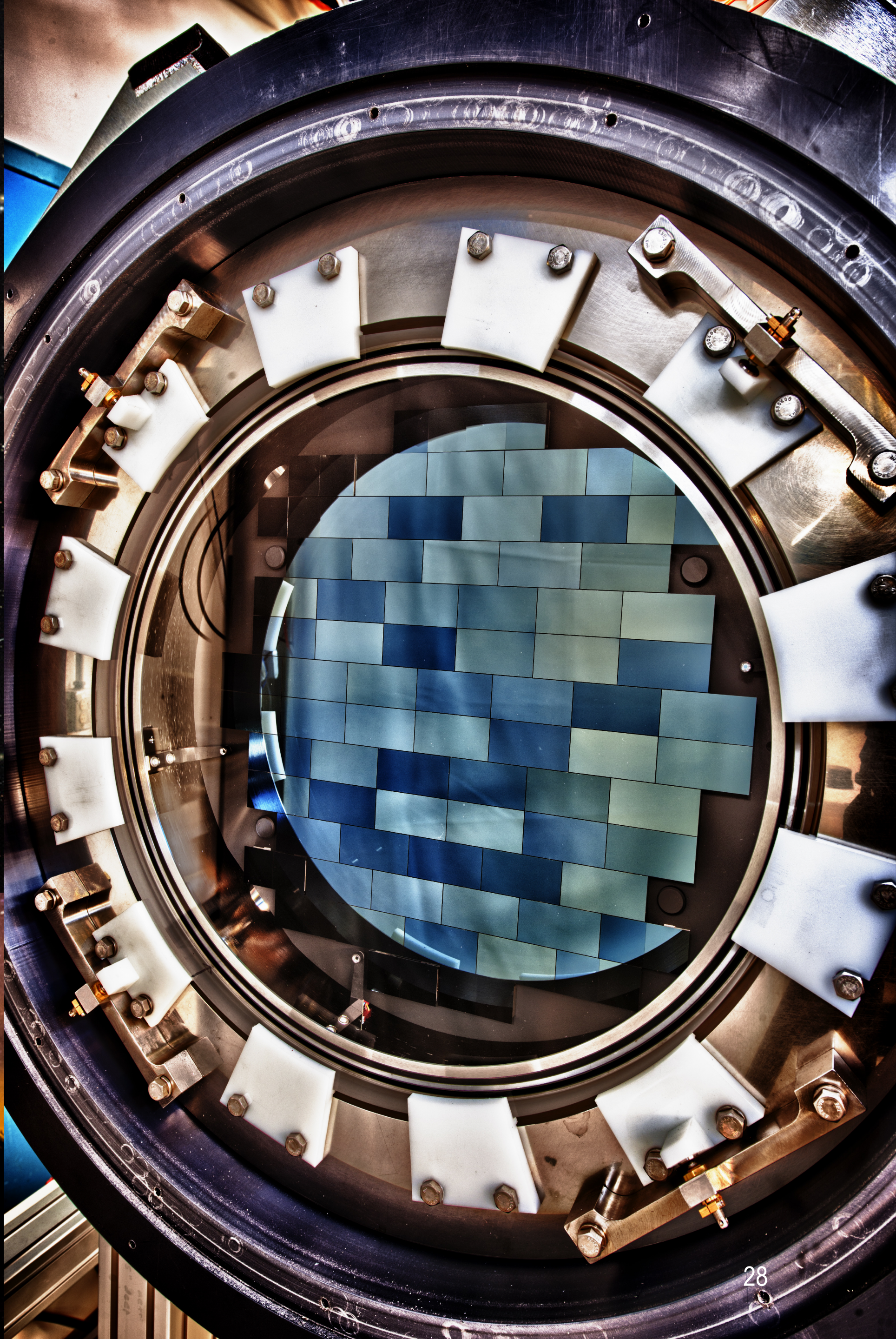
FIRST LIGHT

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.

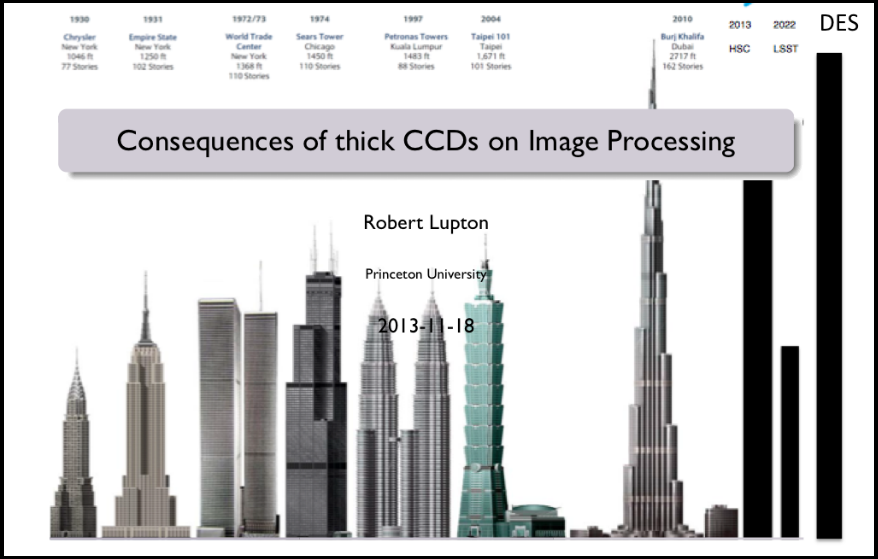
LBNL has developed thick CCDs… massive piece of silicon with 2e- readout noise!

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

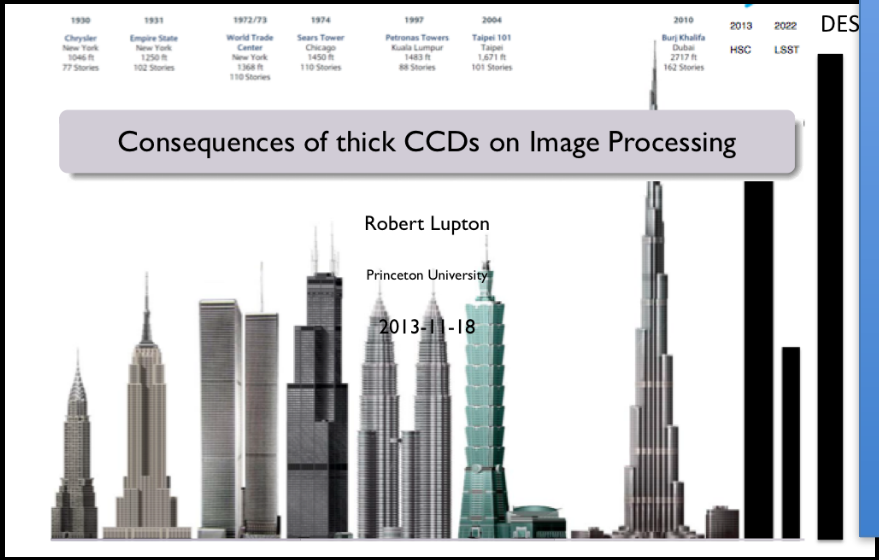




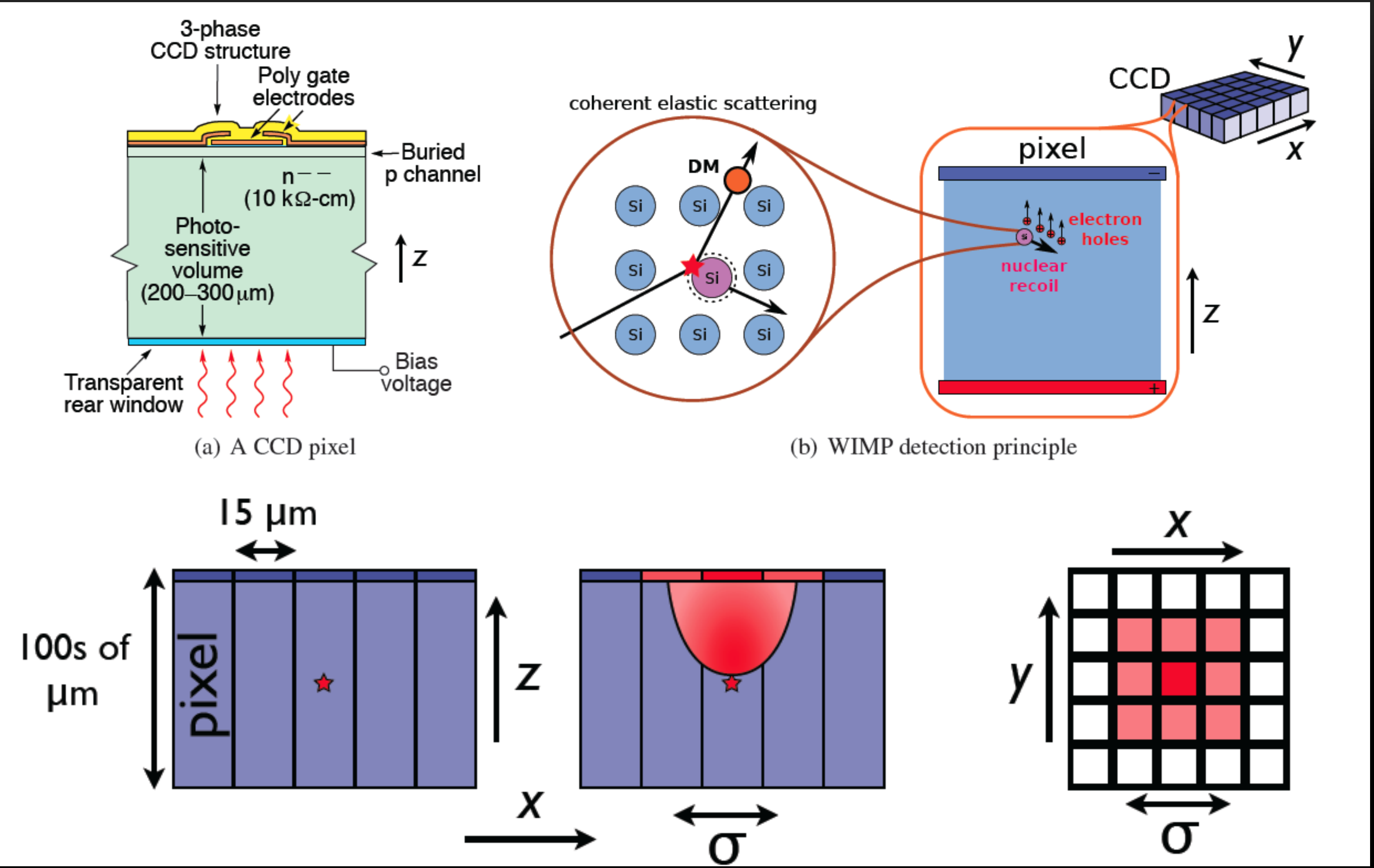
to detect IR photons we use long and skinny pixels.



CONNIE - 2016


1930
Chrysler
New York
1046 ft
77 Stories
1931
Empire State
New York
1250 ft
102 Stories
1972/73
World Trade Center
New York
1368 ft
110 Stories
1974
Sears Tower
Chicago
1450 ft
110 Stories
1997
Petronas Towers
Kuala Lumpur
1483 ft
88 Stories
2004
Taipei 101
Taipei
1,671 ft
101 Stories
2010
Burj Khalifa
Dubai
2717 ft
162 Stories
2013
HSC
2022
LSST
DES
Consequences of thick CCDs on Image Processing
Robert Lupton
Princeton University
2013-11-18

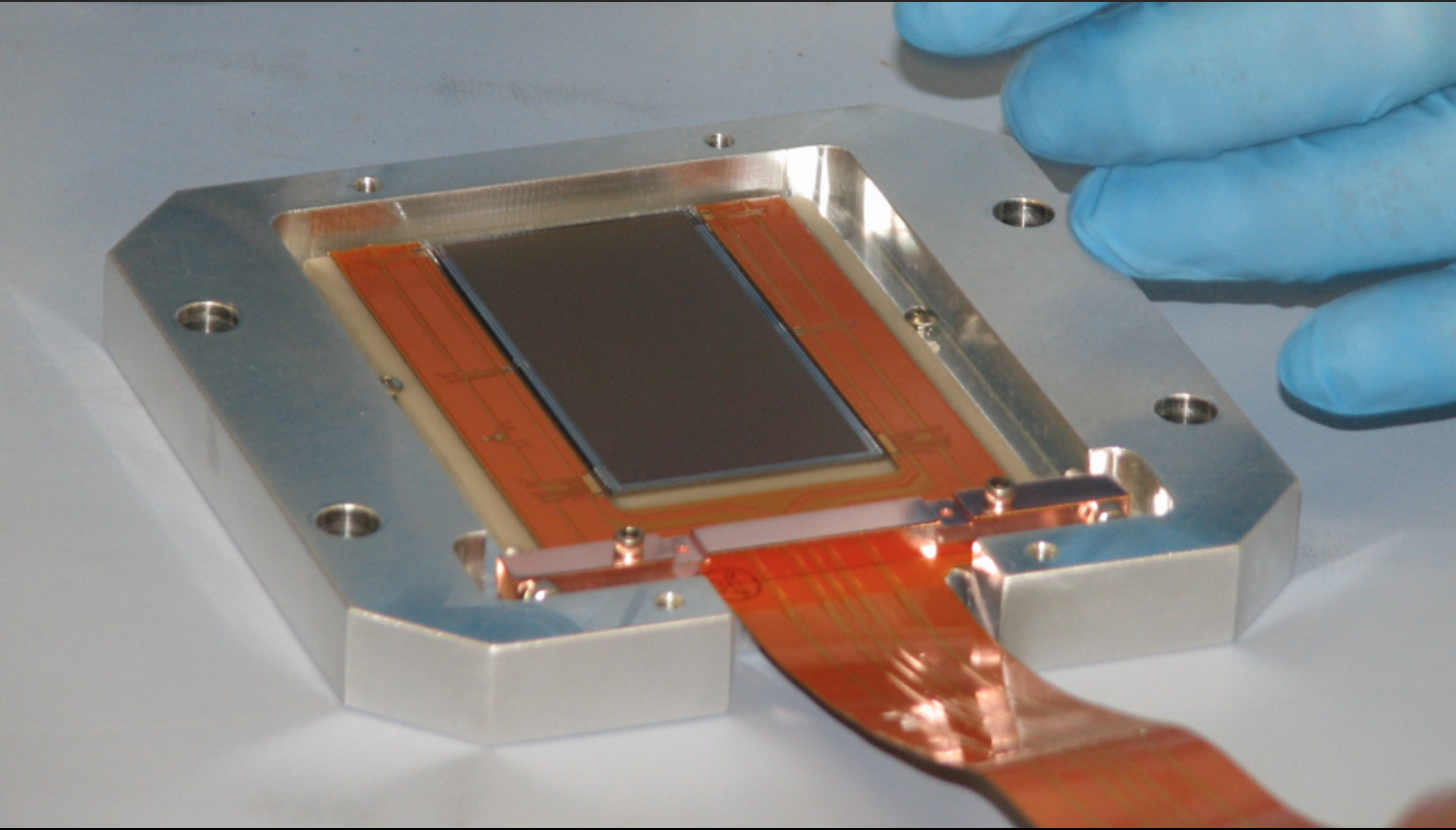
Enabling Technology : thick CCD detectors



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

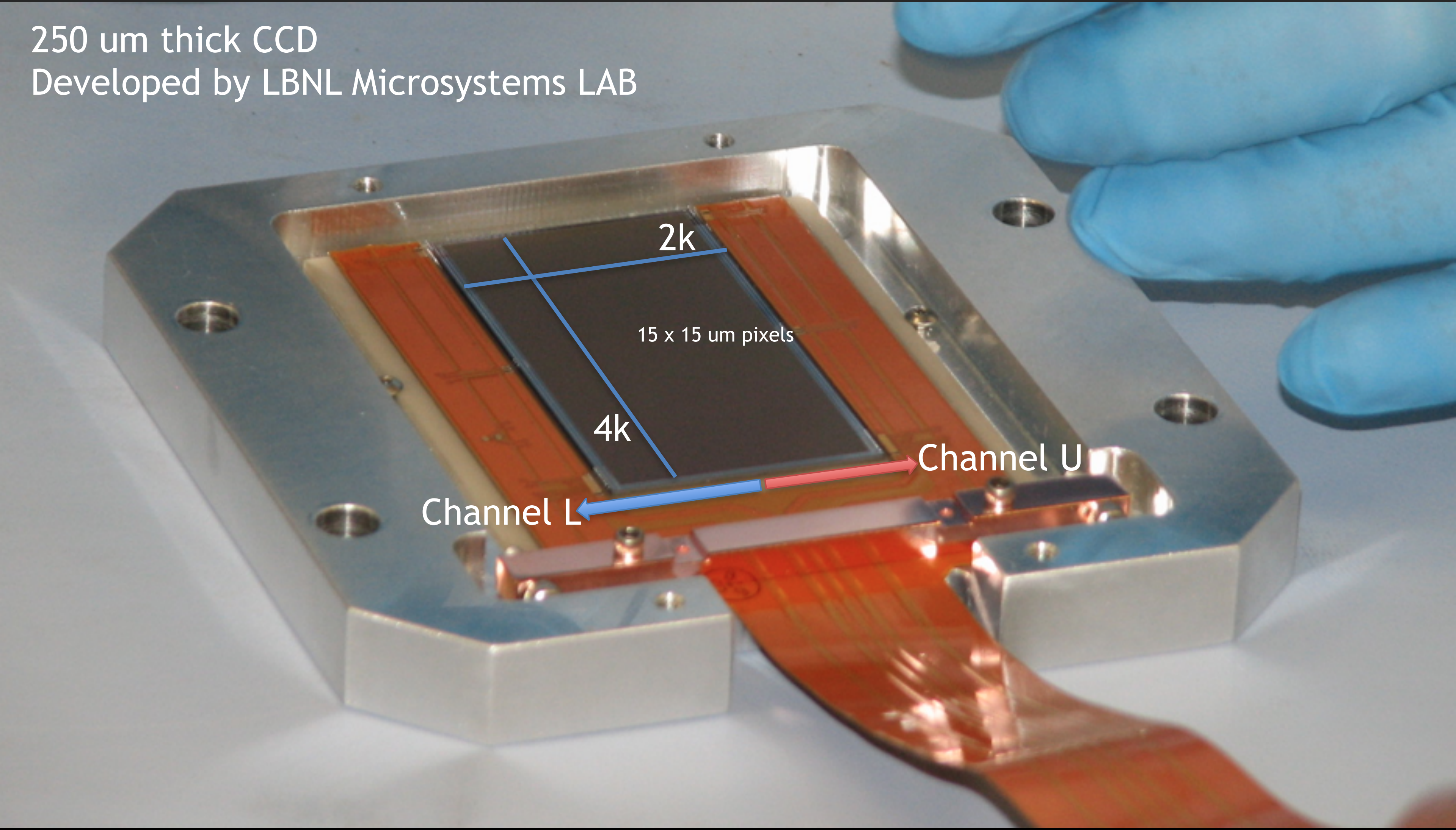
DECam detectors are 250um thick and 8 Mpix, 1g per CCD. DAMIC started with this. DAMIC-100 is now going to 675 um thick and 16 Mpix, 5.2g per CCD. In 2014 installed the first 675um detectors, provided by **LBNL** to test the concept.

CONNIE 2014-2015 sensor:



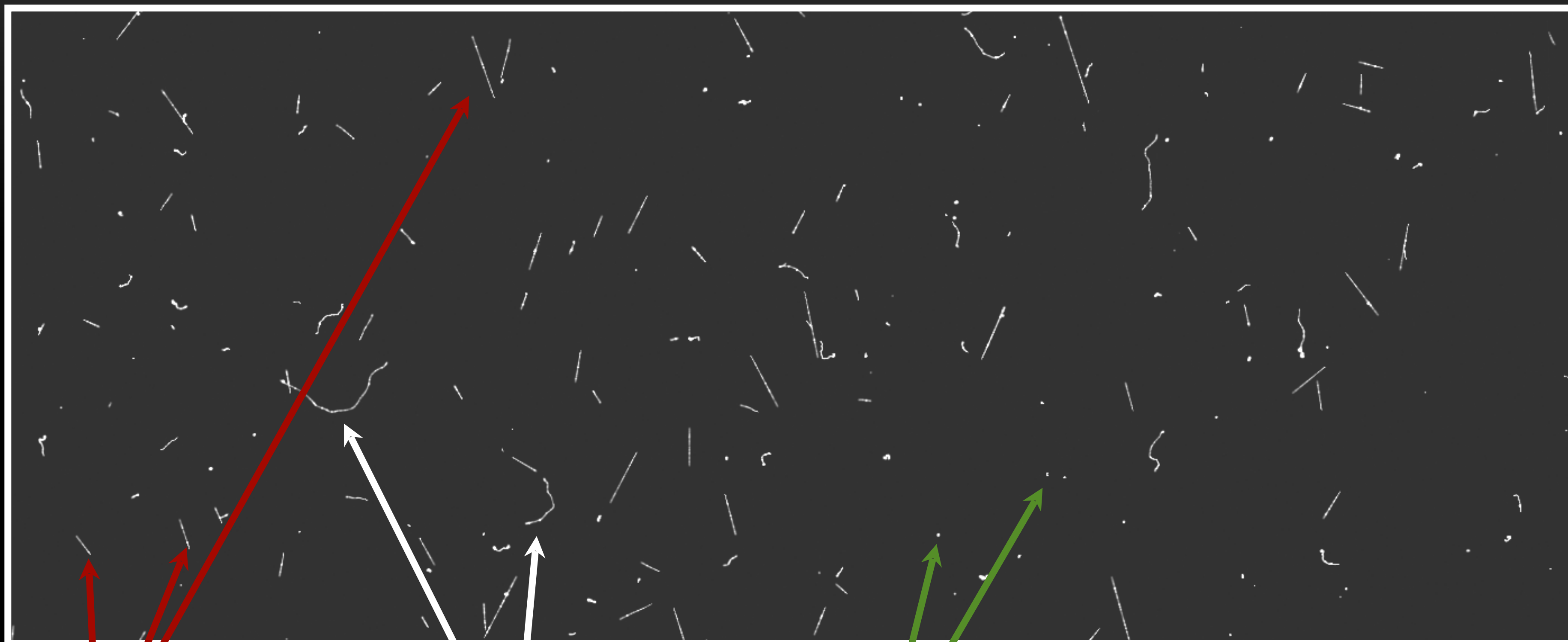
CONNIE 2014-2015 sensor

250 um thick CCD
Developed by LBNL Microsystems LAB



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

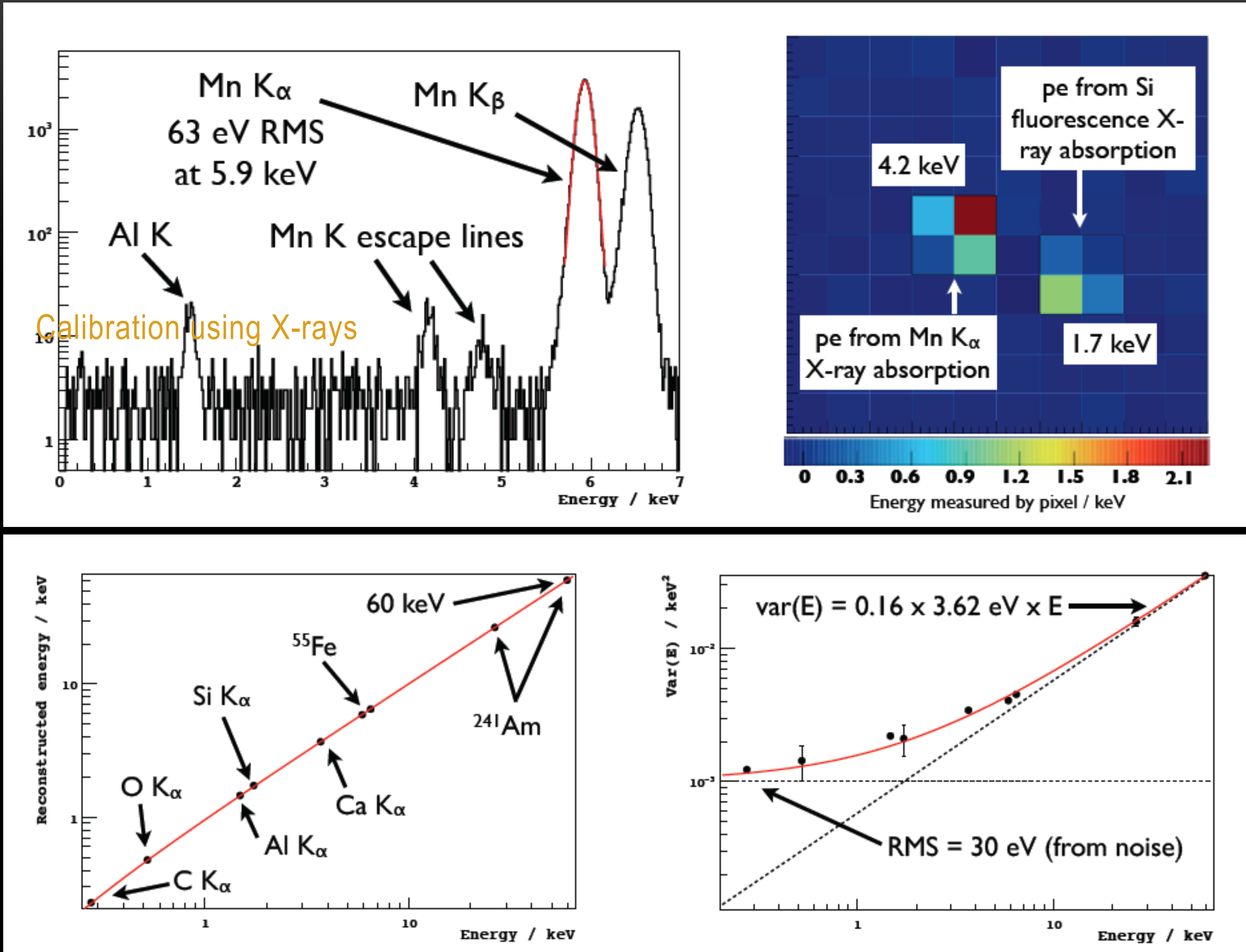


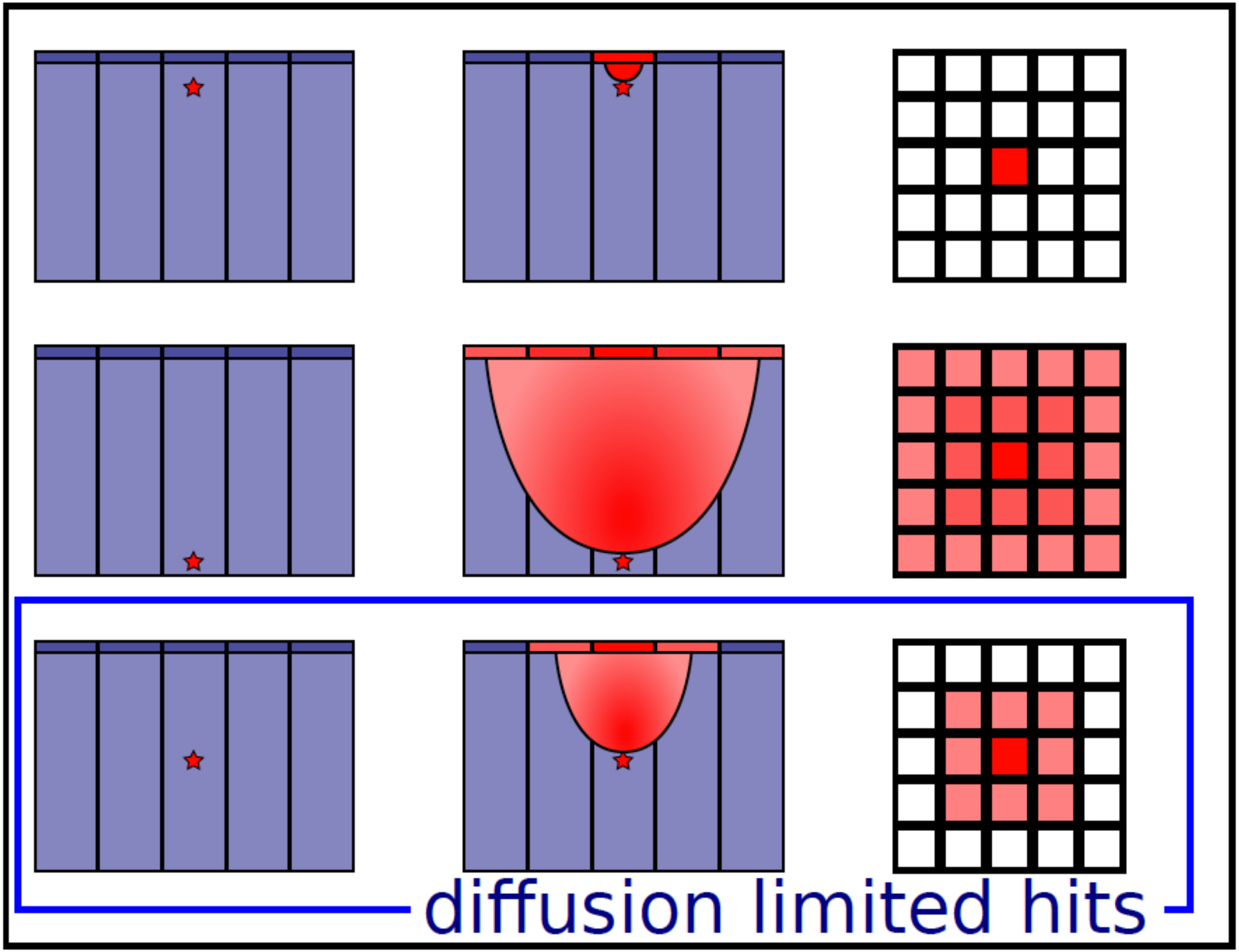
muons, electrons and diffusion limited hits.

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.

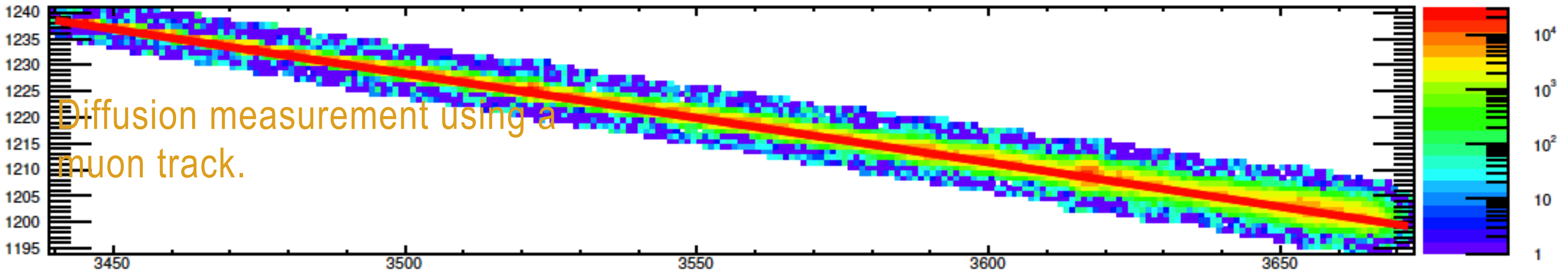
arXiv:1408.3263

Calibration using X-rays



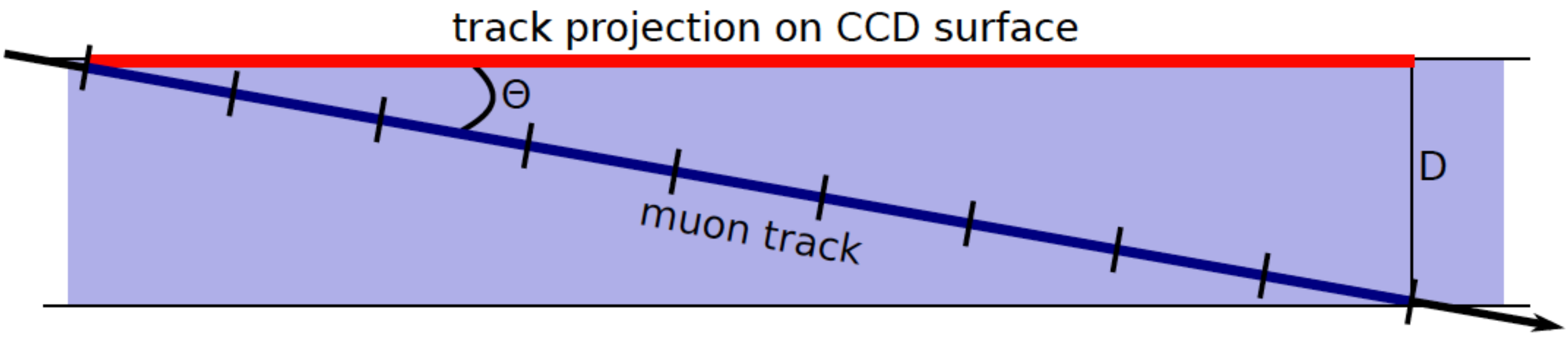

diffusion limited hits

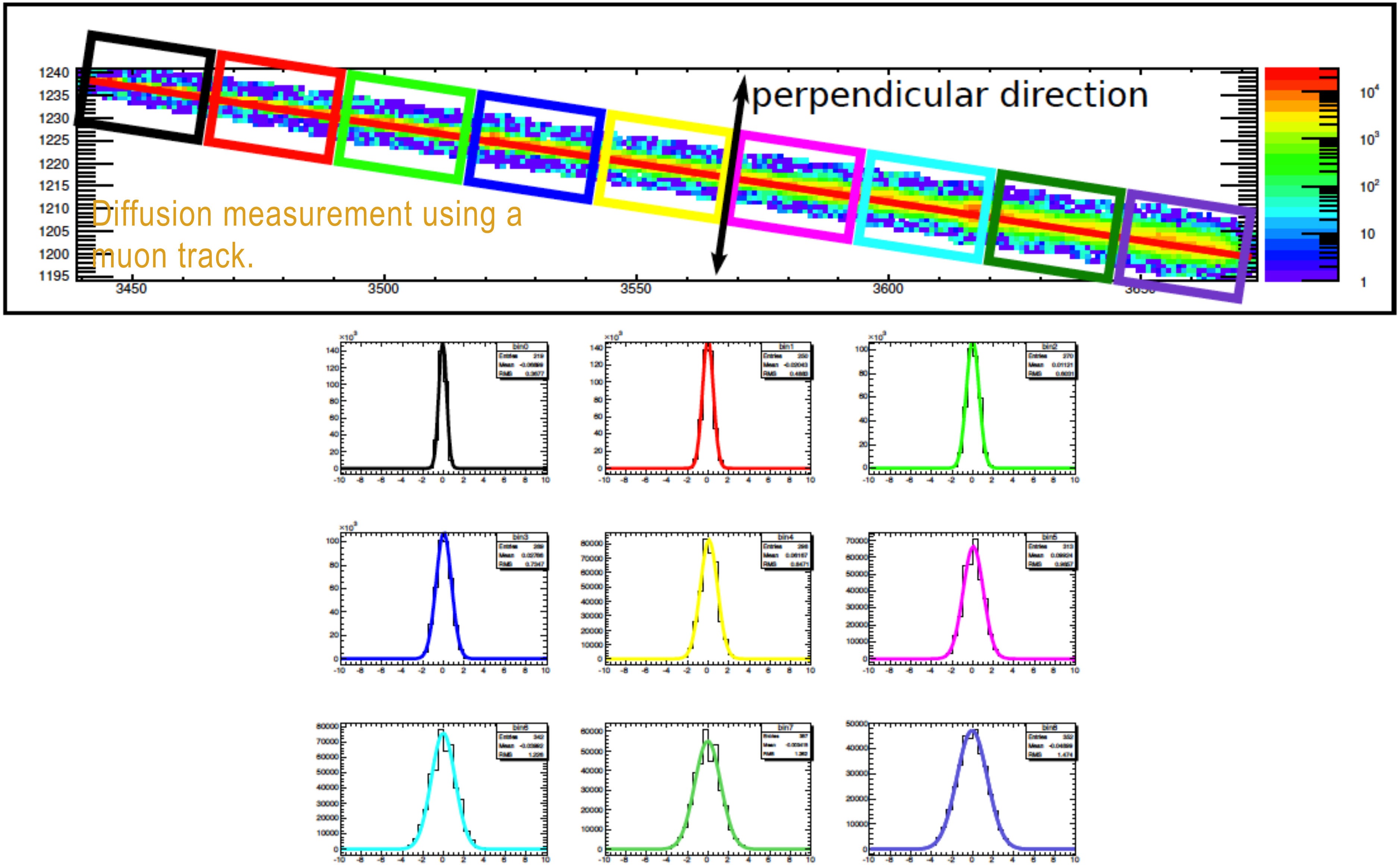
Recorded track: CCD top view



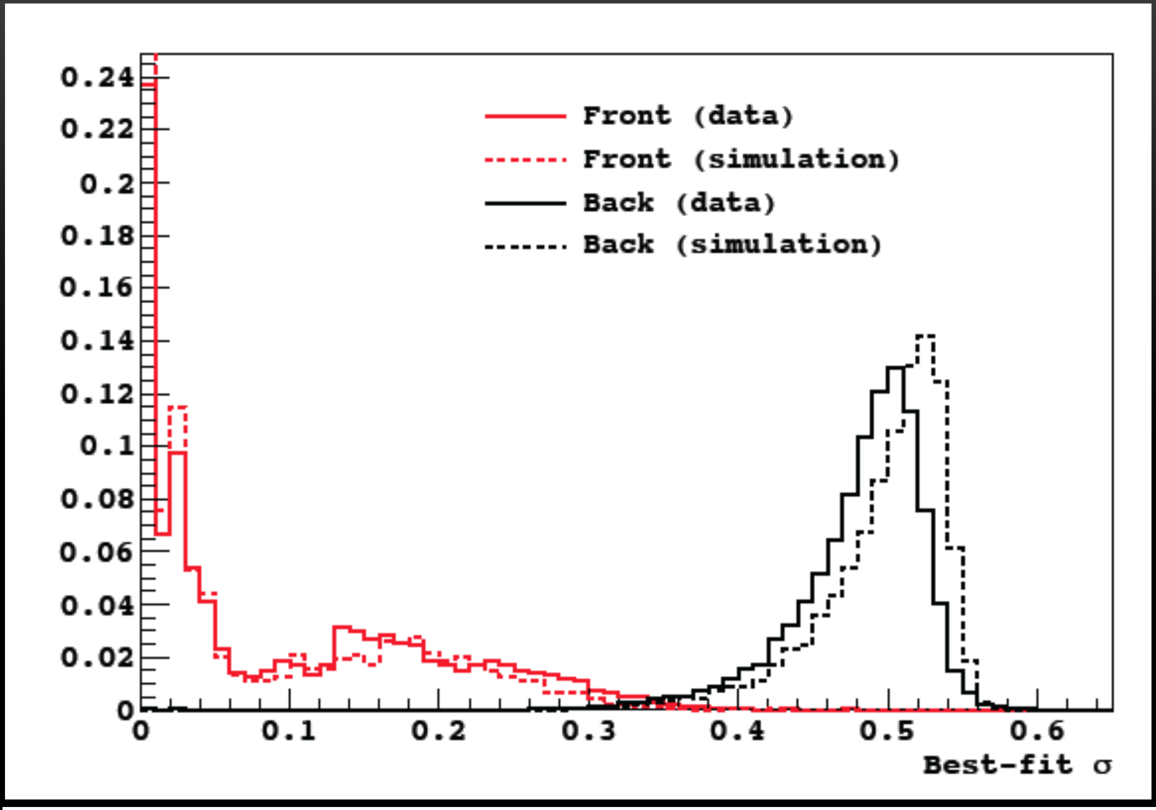
Diffusion measurement using a muon track.

CCD side view



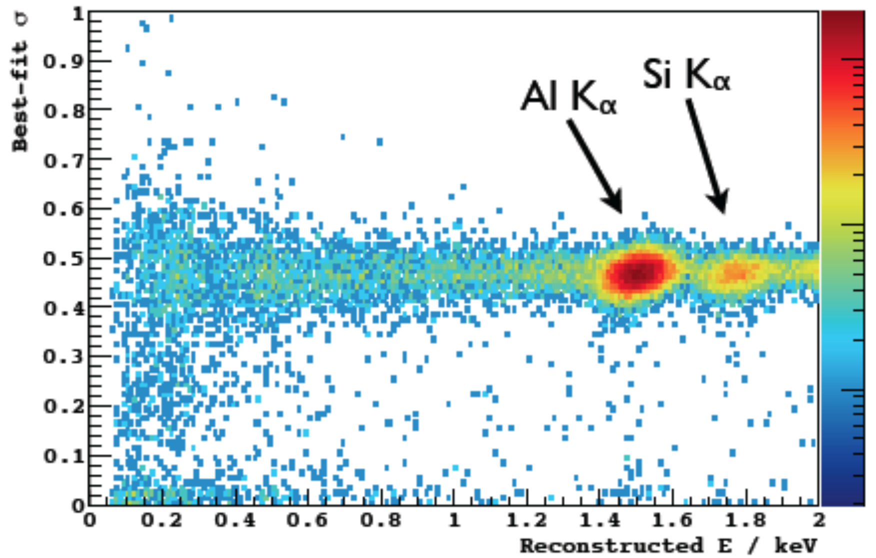


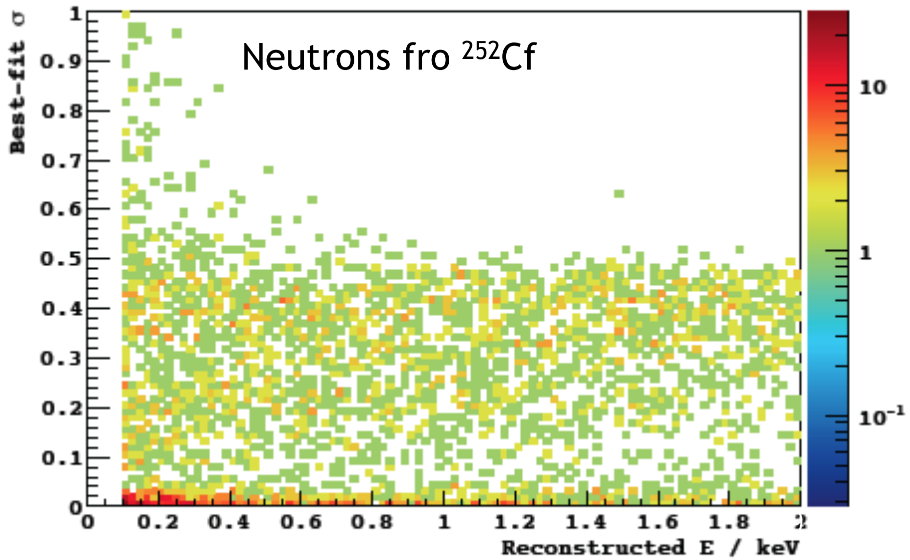
Diffusion measurement using a muon track.



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

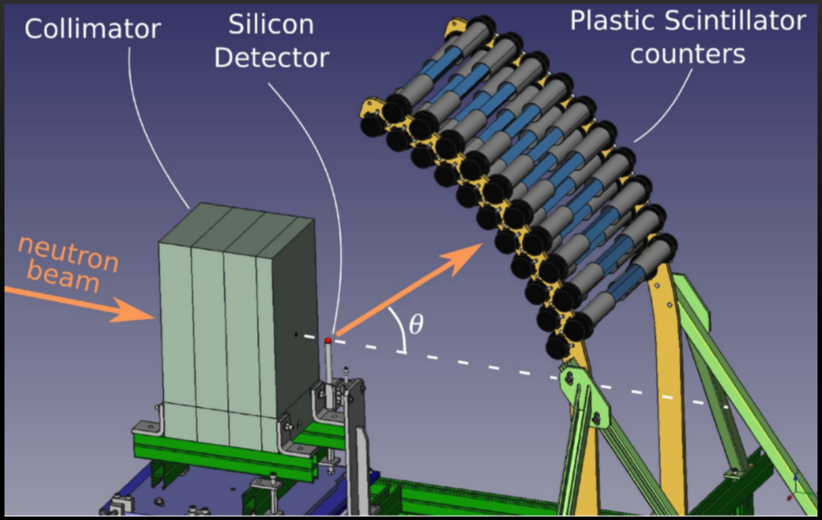
This is important for our DM analysis.

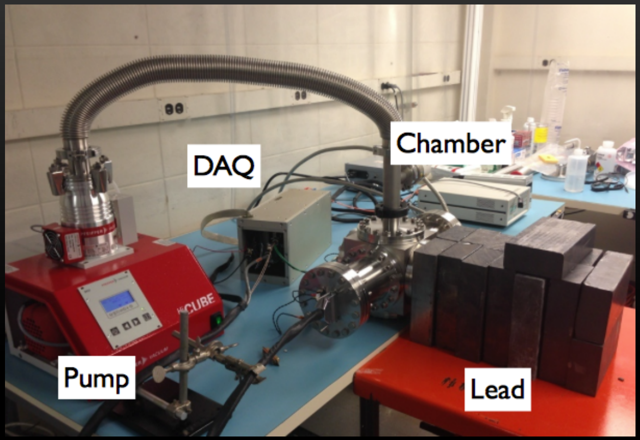


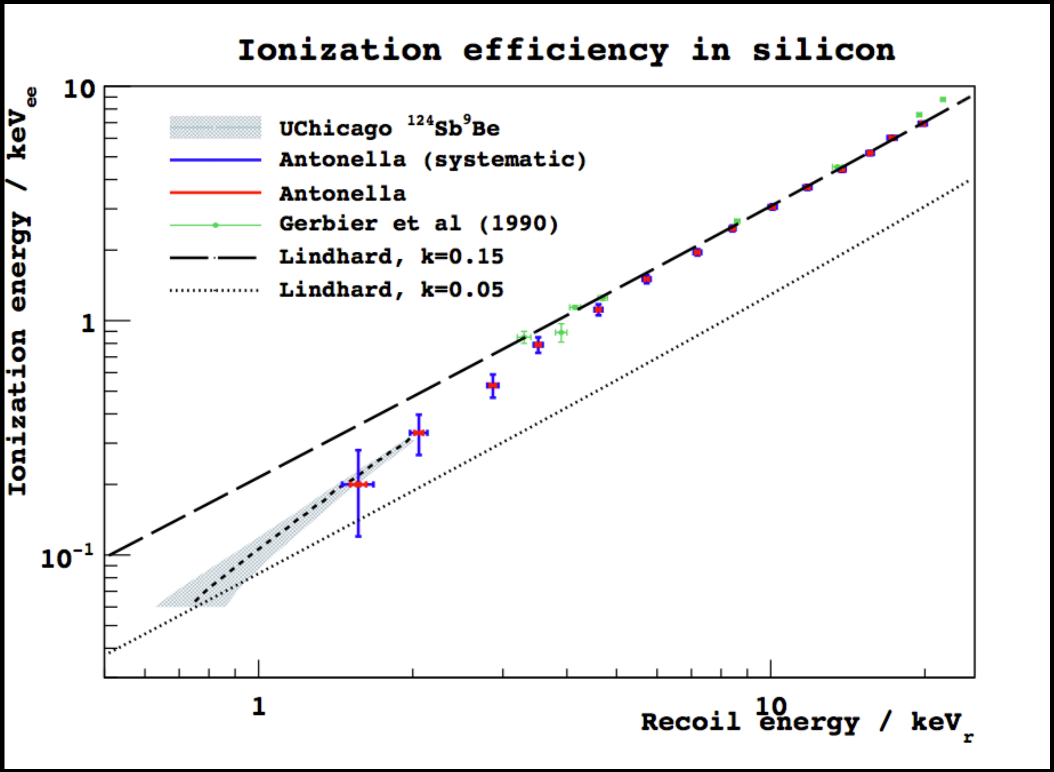


Antonella measurement

UChicago measurement







Antonella @ Notre Dame (Tandem Van de Graaf, 10MV). Collaboration with U.Michigan, U.Zurich, U.Guanajuato, Paraguay.

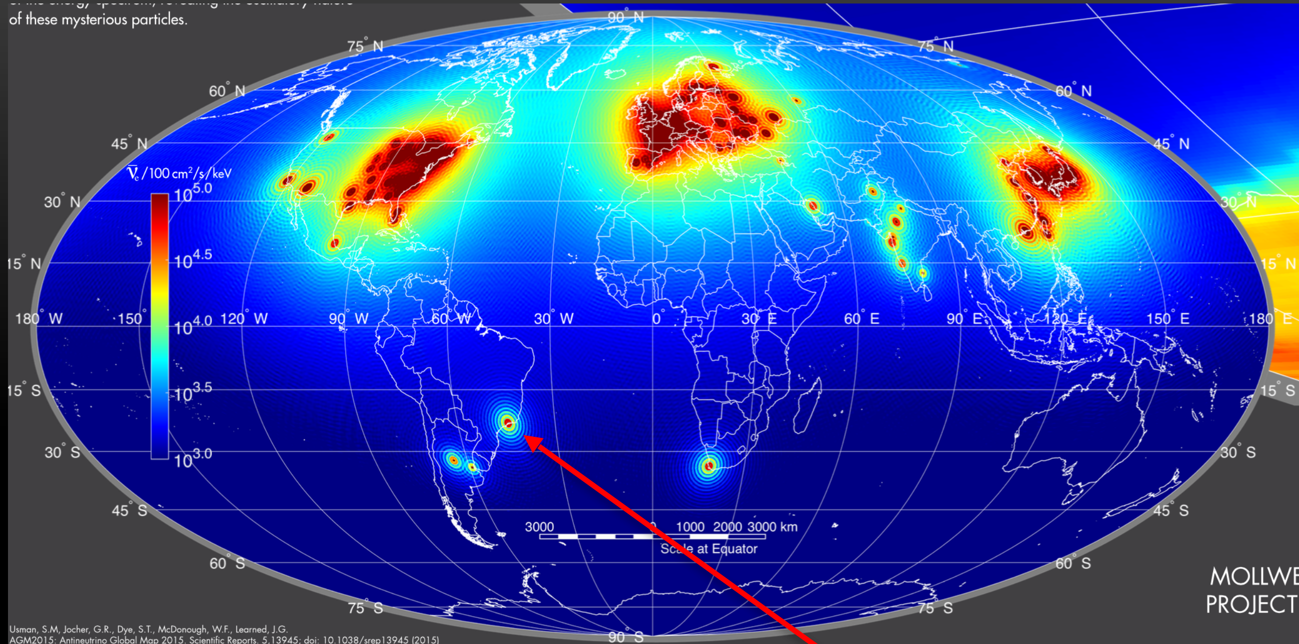
Collaboration with U.Chicago using CCD packages + electronics from FNAL to complete low energy points.

Silicon nuclear coils calibrated to 0.6 keV, 1 order of magnitude lower than before.

2 phd students, several undergraduate

The Source

Angra II - nuclear power plant



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.


Angra II
(4GW)
30 m
Detector
Angra 2
Central Nuclear
Almirante Álvaro Alberto
195 m
Angra I
(2GW)

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.

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

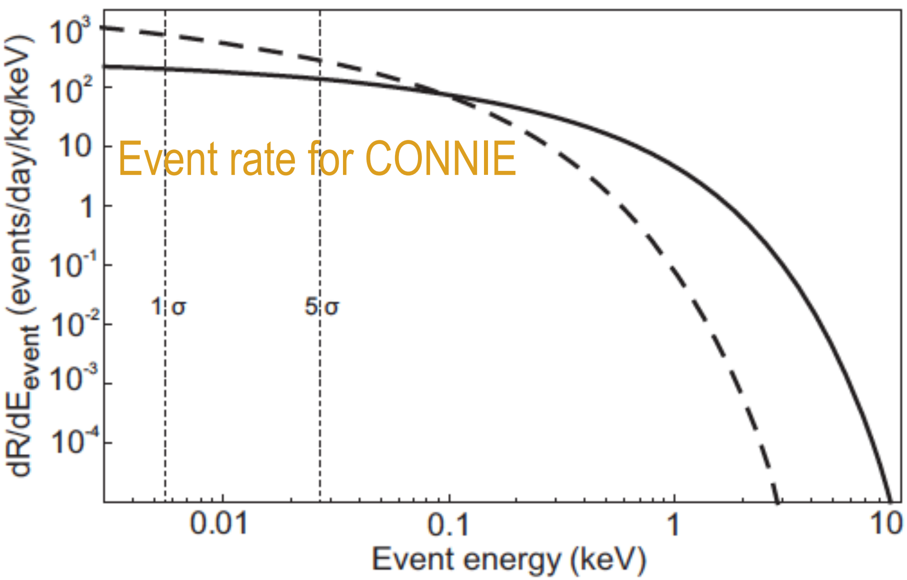


FIG. 8. Energy spectra for events expected in silicon detectors: the nuclear-recoil energy spectrum (—); the spectrum for detectable events (– –), using the quenching factor from Lindhand, *et al.* [28, 29].

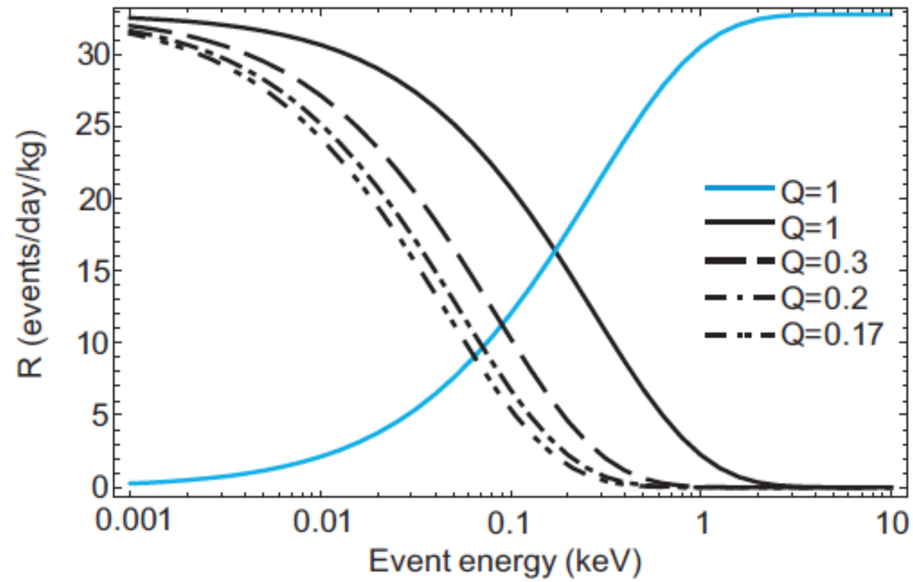


FIG. 9. Total number of events as a function of the threshold energy for different quenching factors: $Q = 1$, $Q = 0.3$, $Q = 0.2$ and $Q = 0.17$ (black curves). The light-blue curve shows the total number of events as a function of the maximum detectable recoil energy using $Q = 1$.

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

3 sigma detection in 90 days!

Moroni et al 2014 arXiv:1405.5761
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

Angra Nuclear Power plant.

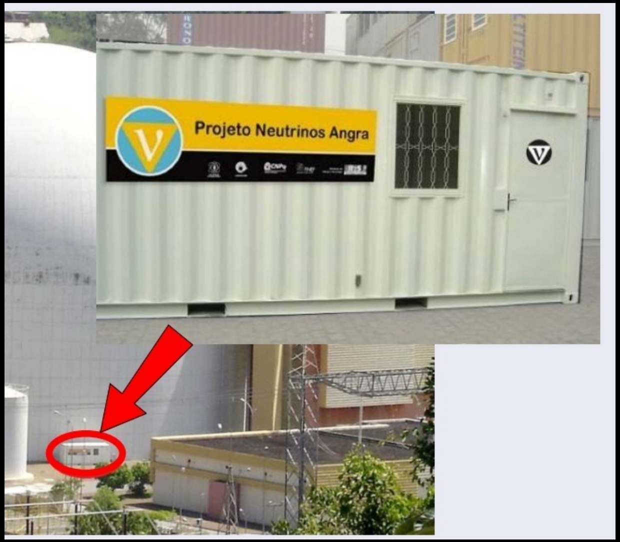
Three reactors. Two operational and one under construction.

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 experiment planned.

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.

Kevin Kuk
our boss during installation.

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

One good reason to visit Rio:

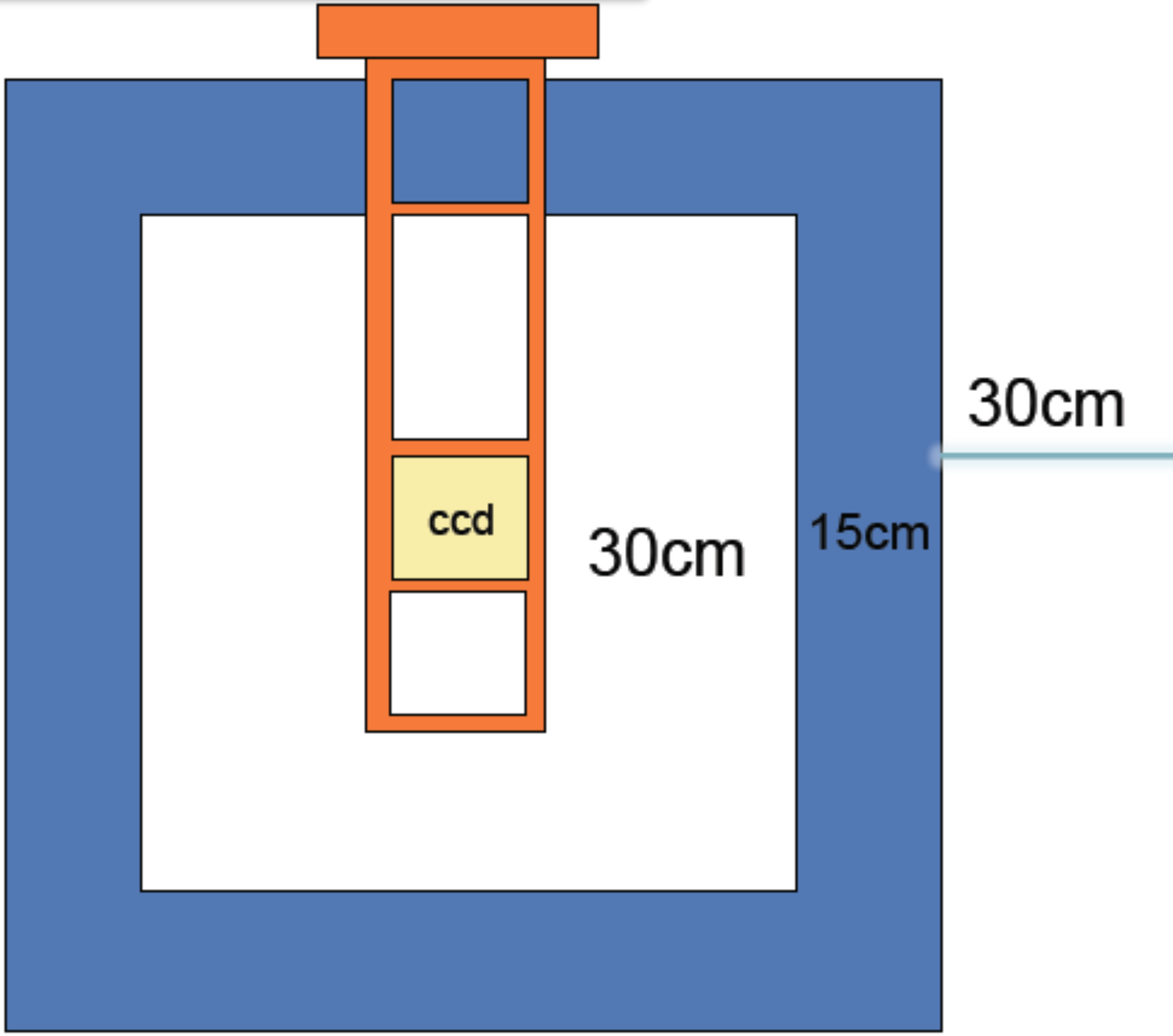
Access to controlled areas without escort (24/7). Reactor is 4hrs drive from Rio de Janeiro, home of our collaborators. Bringing equipment requires paperwork that take 1.5 days.

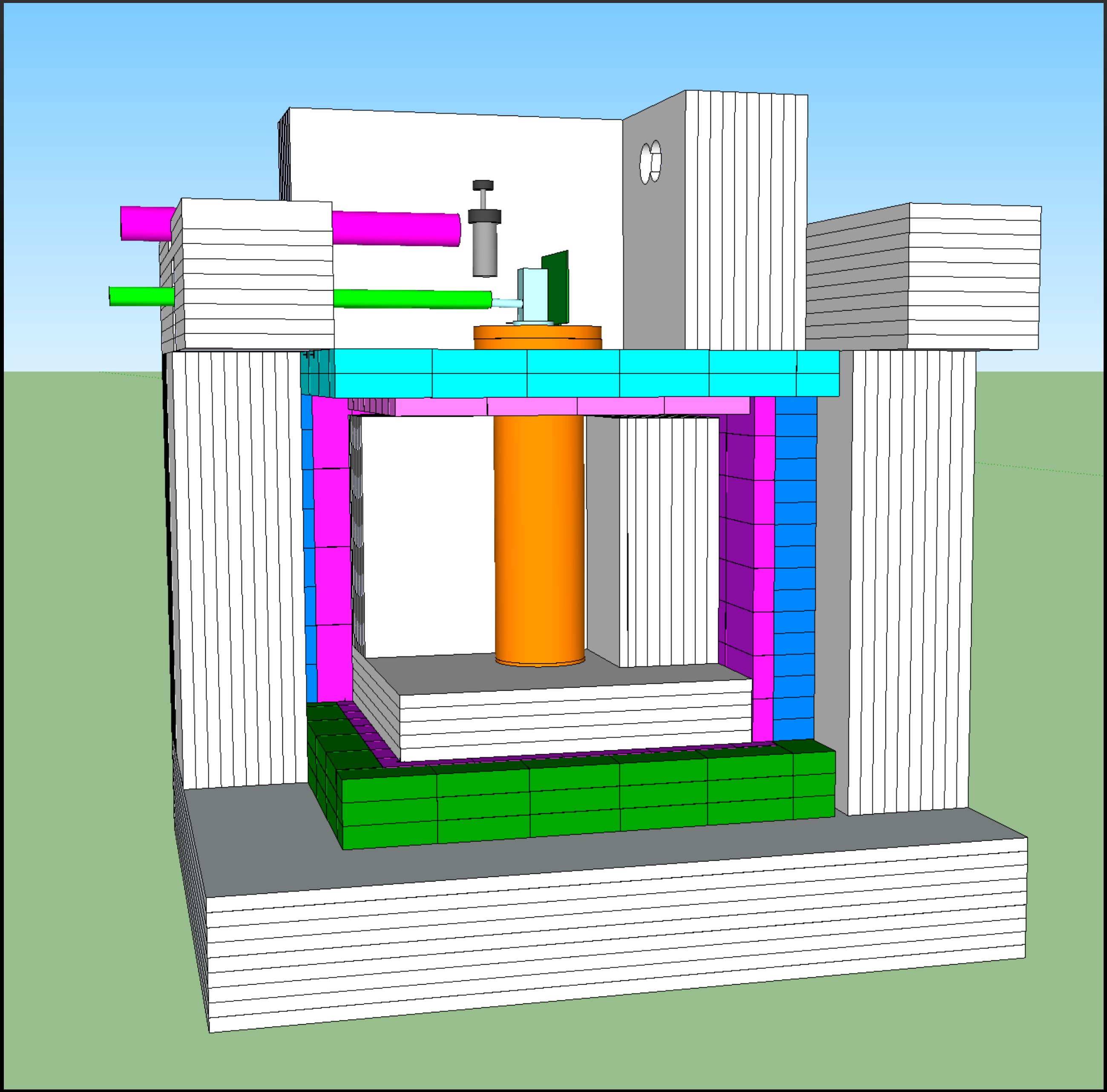
Operating an experiment at a nuclear plant is not easy. In Brazil is possible thanks to our local collaborators. A a lot of support from reactor staff, and “robust” detector make this possible.

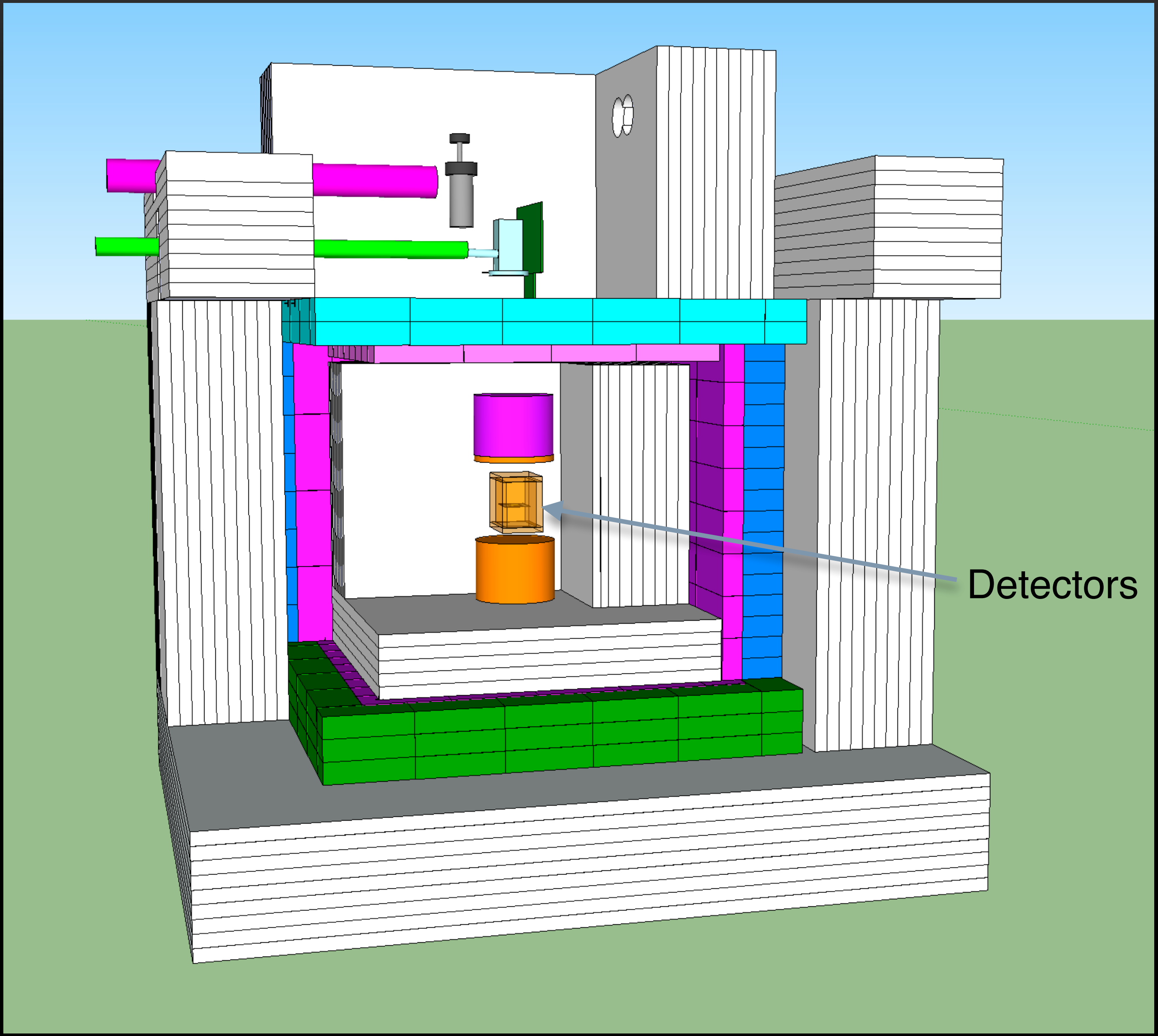
Guillermo Fernandez-Moroni Defended his PhD yesterday.

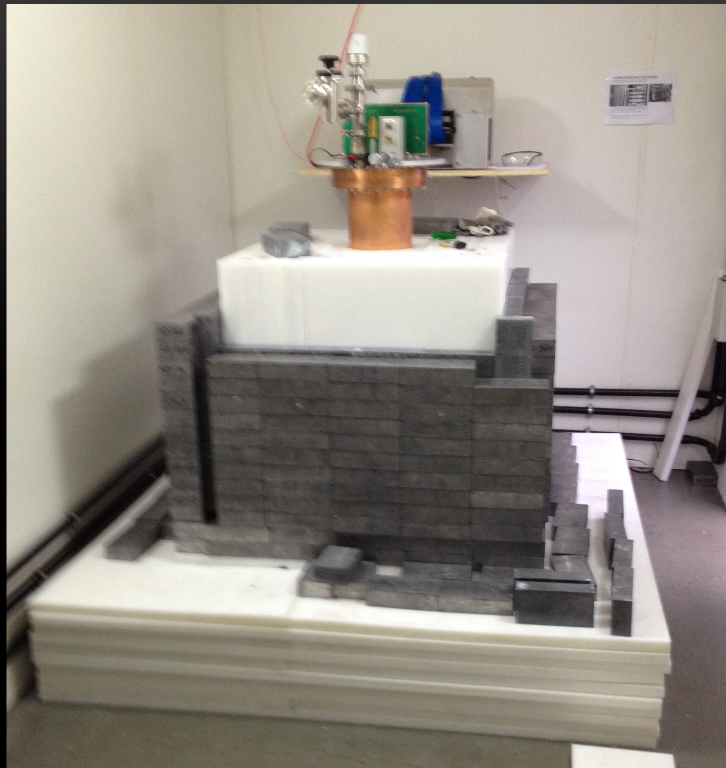
we also shipped some assembly tools from Bahia Blanca (Argentina)

FINAL shield (July 2015) — strike permitting






Detectors

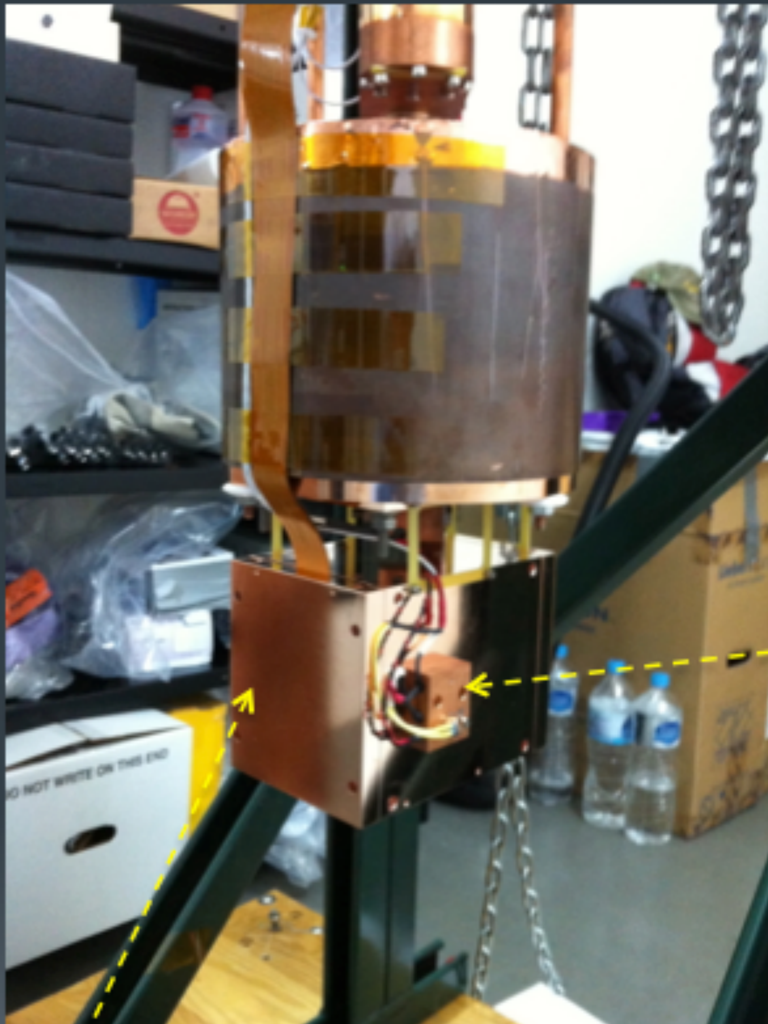



PPD

Division Management is hands on!

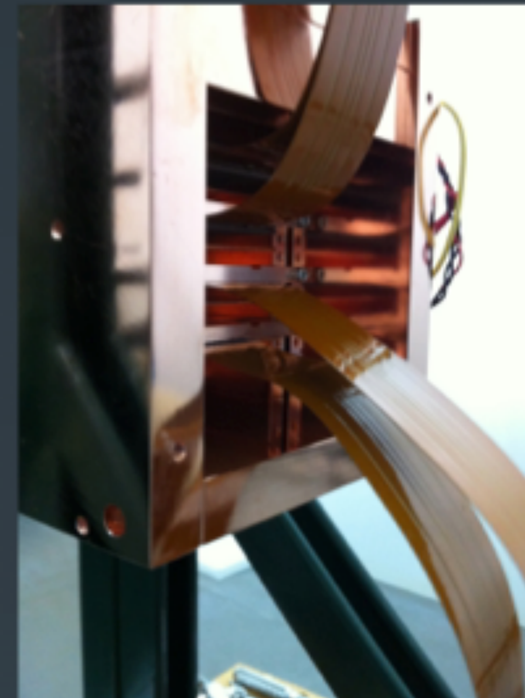
carried a lot of lead and paid for the parts with his own money!!!

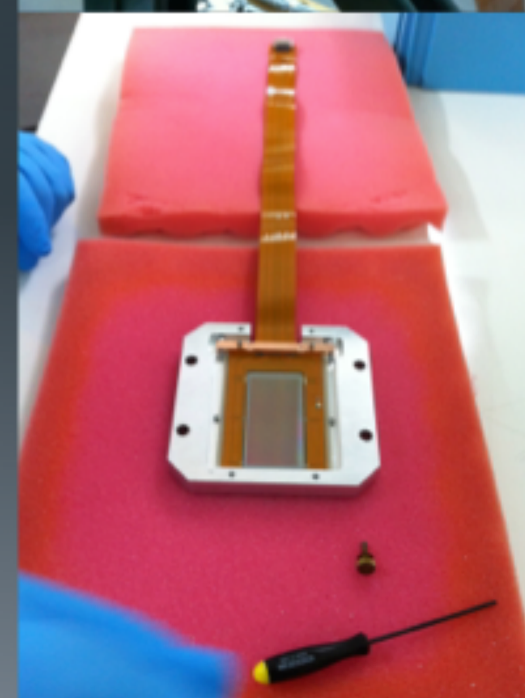
Detector configuration (November 9th, 2014)



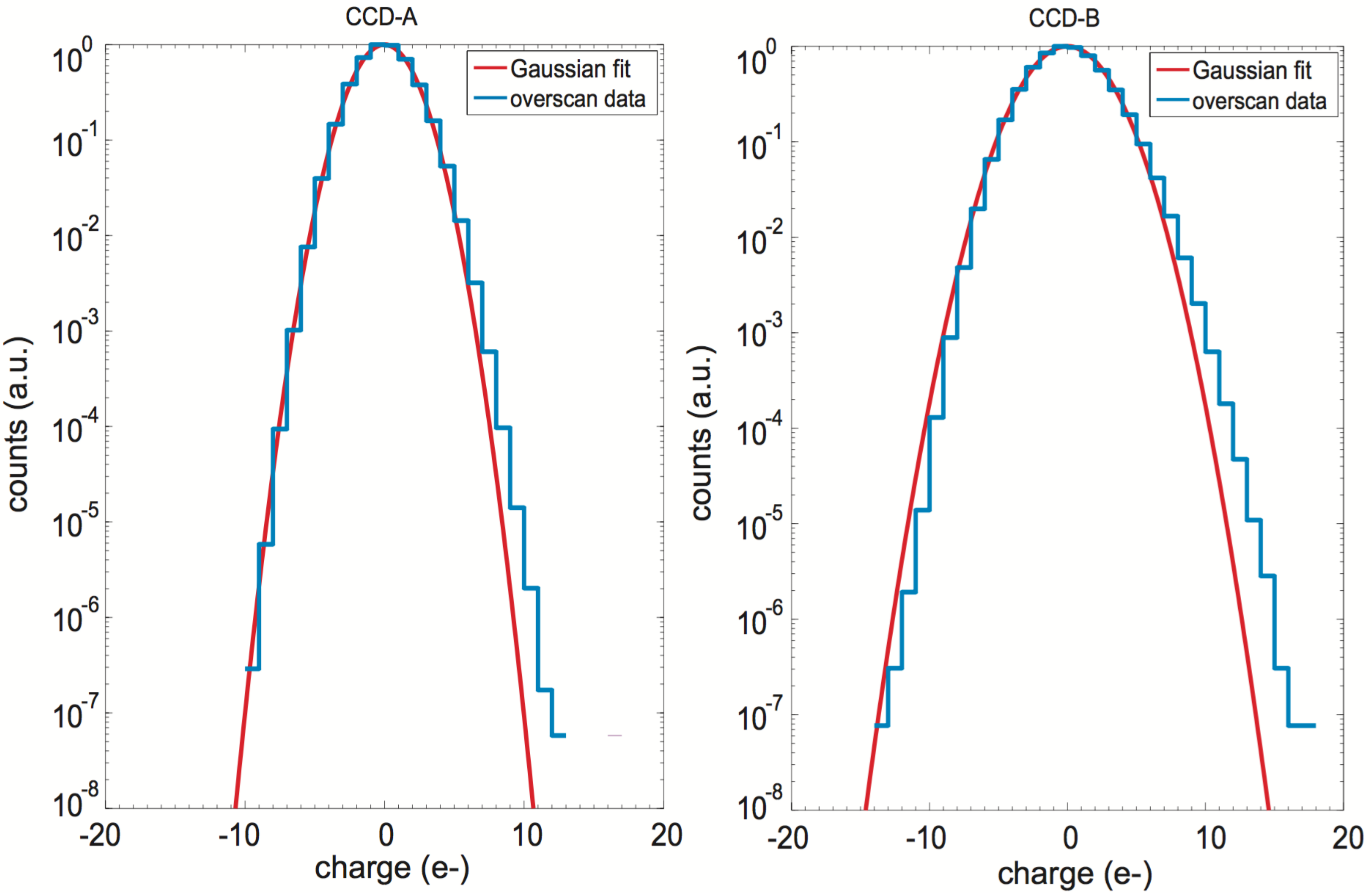
Heater
Temp. sensor

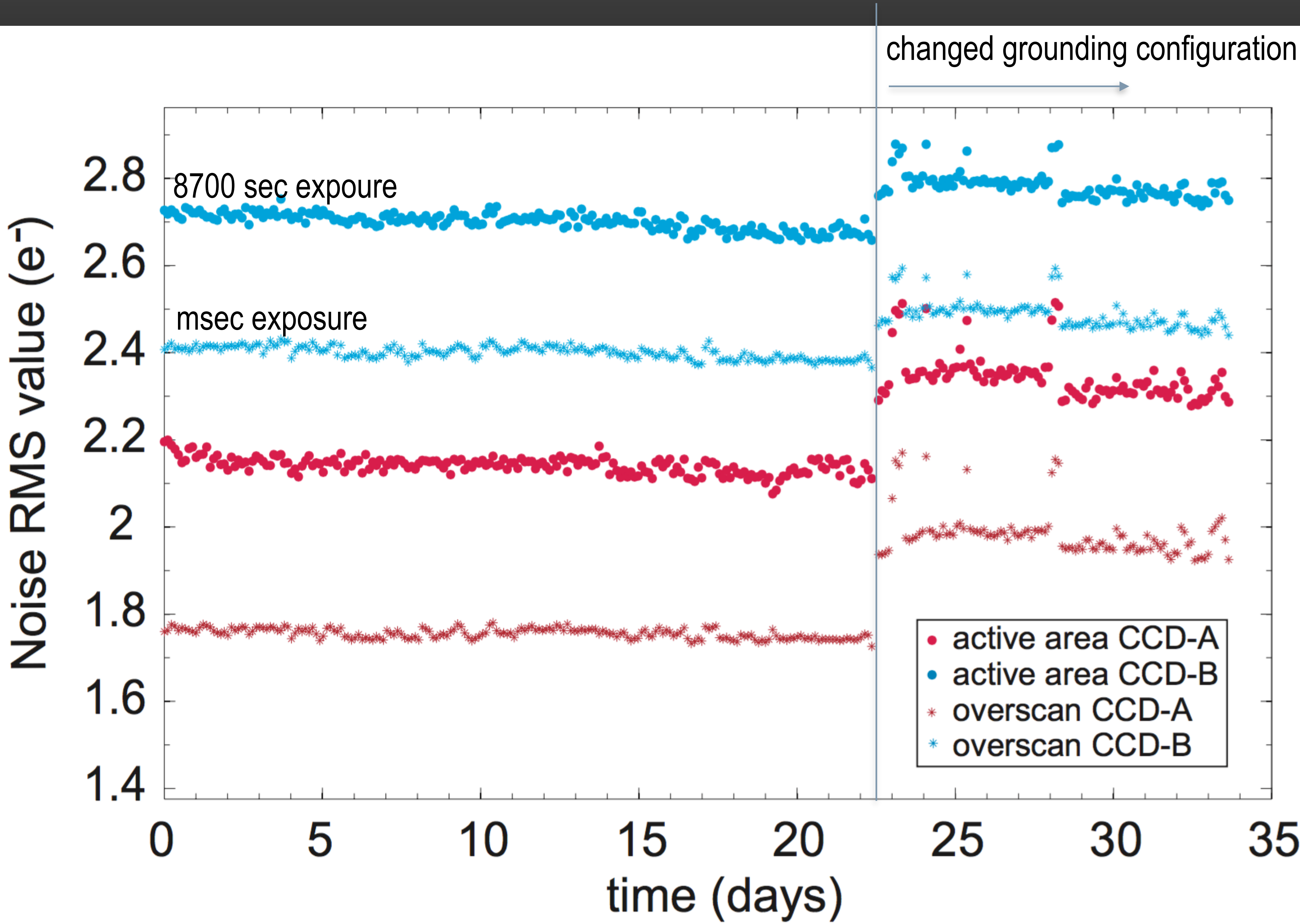
Front door of the Cu-Box (CCD installatioin)

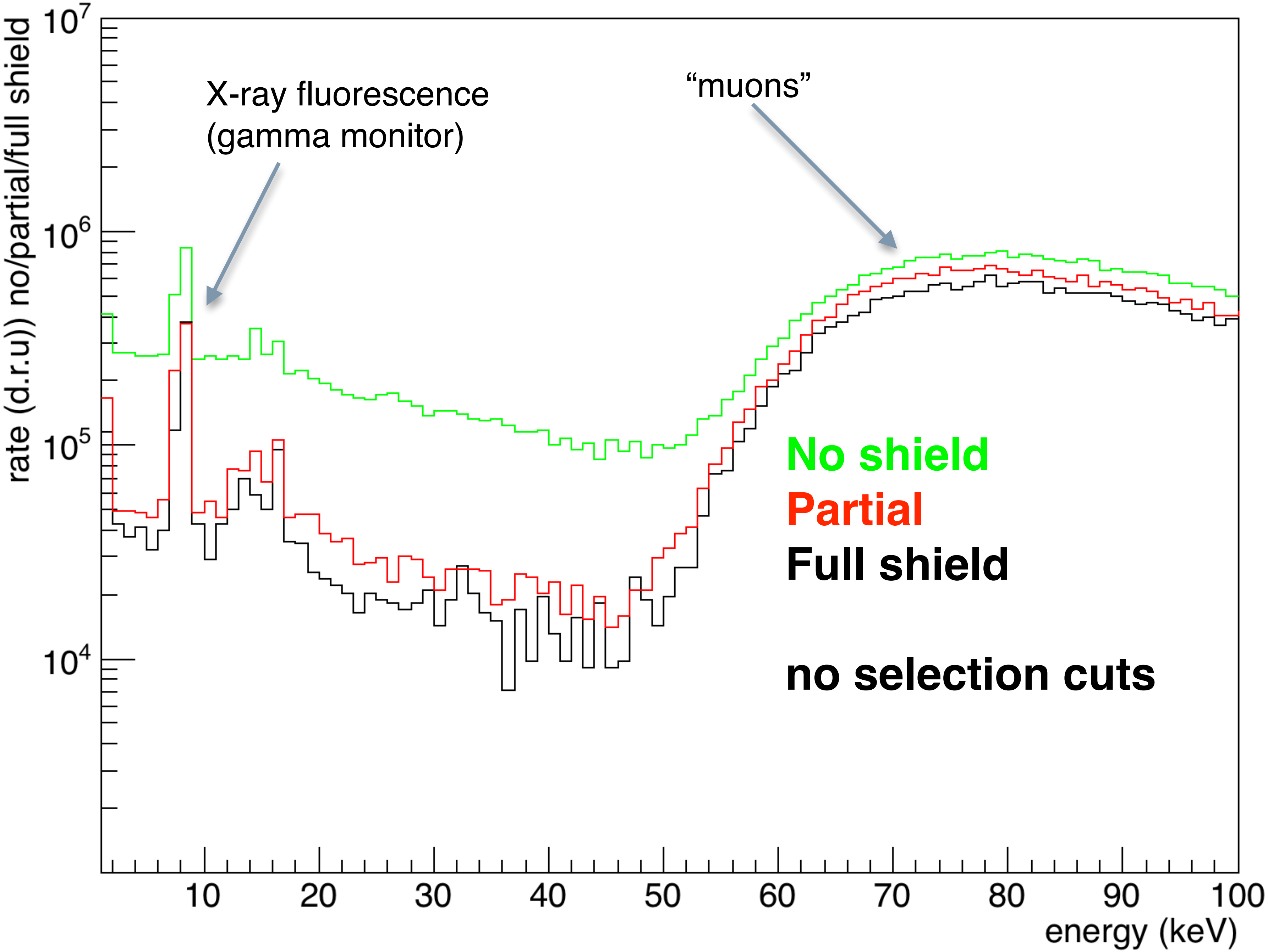


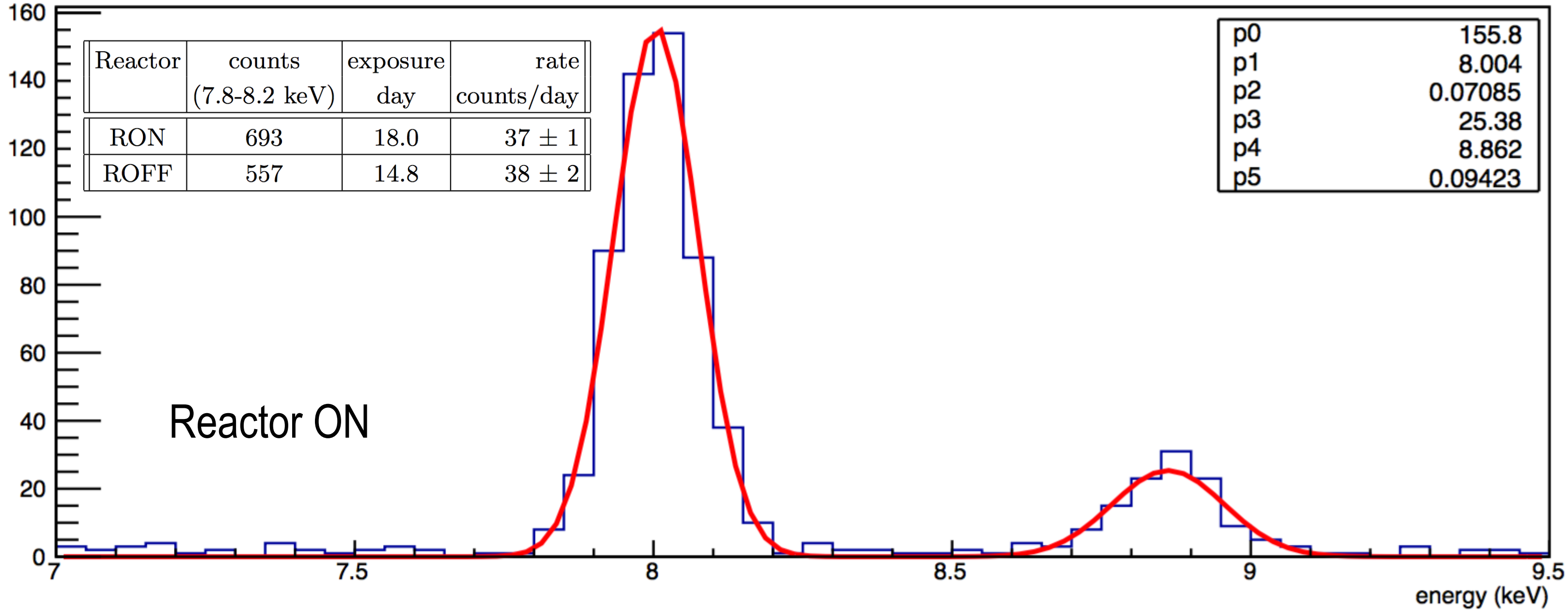


Detector Performance


CCD-A
Gaussian fit
overscan data
counts (a.u.)
charge (e-)
CCD-B
Gaussian fit
overscan data
counts (a.u.)
charge (e-)

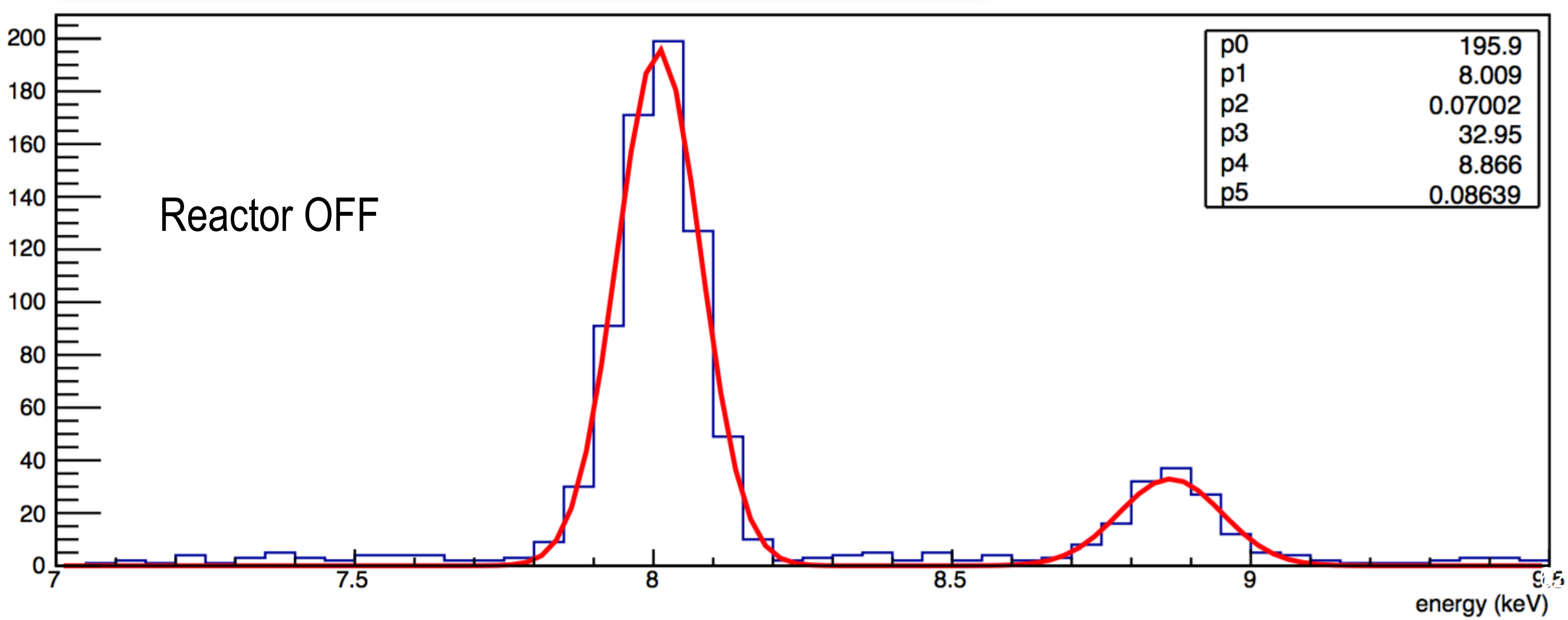

changed grounding configuration
8700 sec expoure
msec exposure
Noise RMS value (e⁻)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
0
5
10
15
20
25
30
35
time (days)
active area CCD-A
active area CCD-B
overscan CCD-A
overscan CCD-B

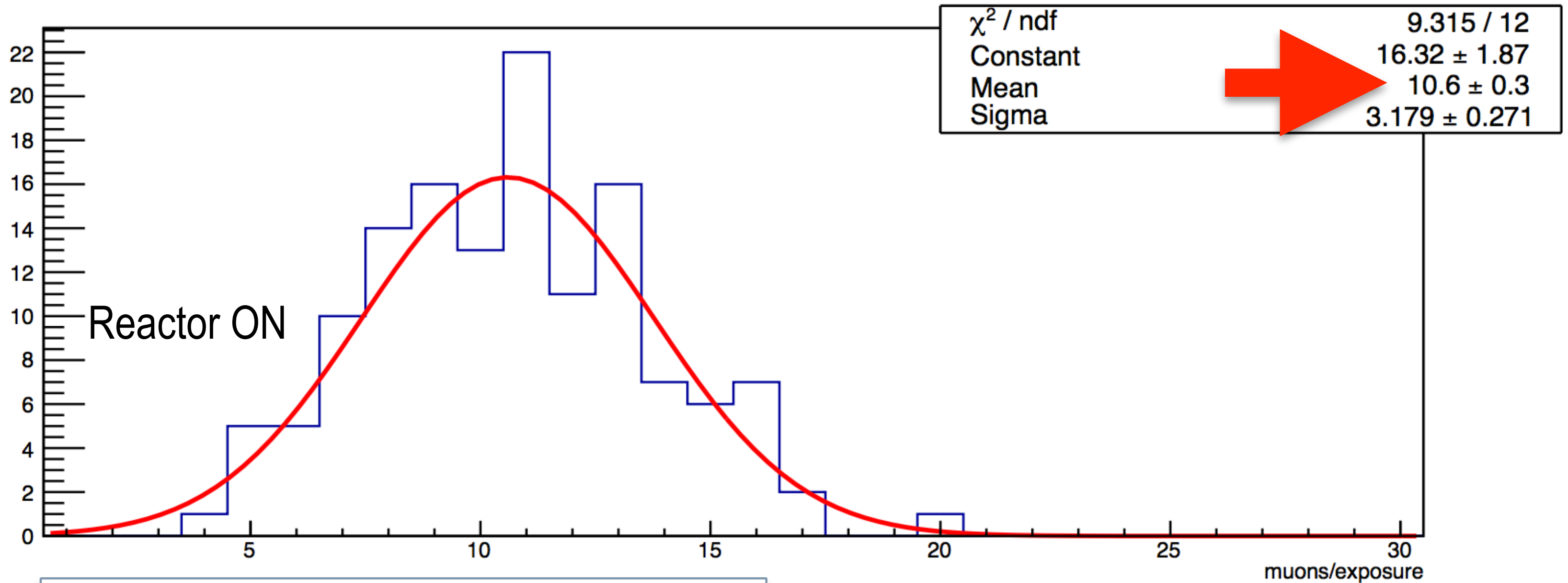

rate (d.r.u)) no/partial/full shield
10^7
10^6
10^5
10^4
X-ray fluorescence
(gamma monitor)
“muons”
No shield
Partial
Full shield
no selection cuts
10
20
30
40
50
60
70
80
90
100
energy (keV)



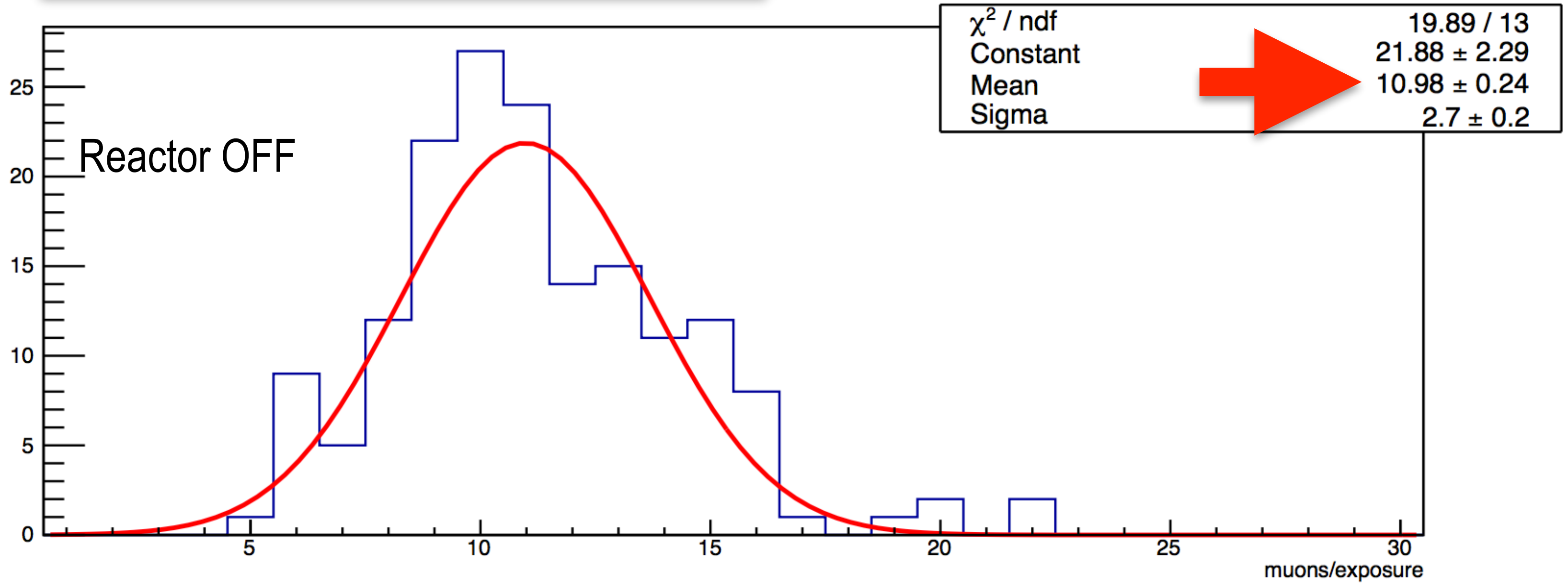
Reactor	counts (7.8-8.2 keV)	exposure day	rate counts/day
RON	693	18.0	37 ± 1
ROFF	557	14.8	38 ± 2

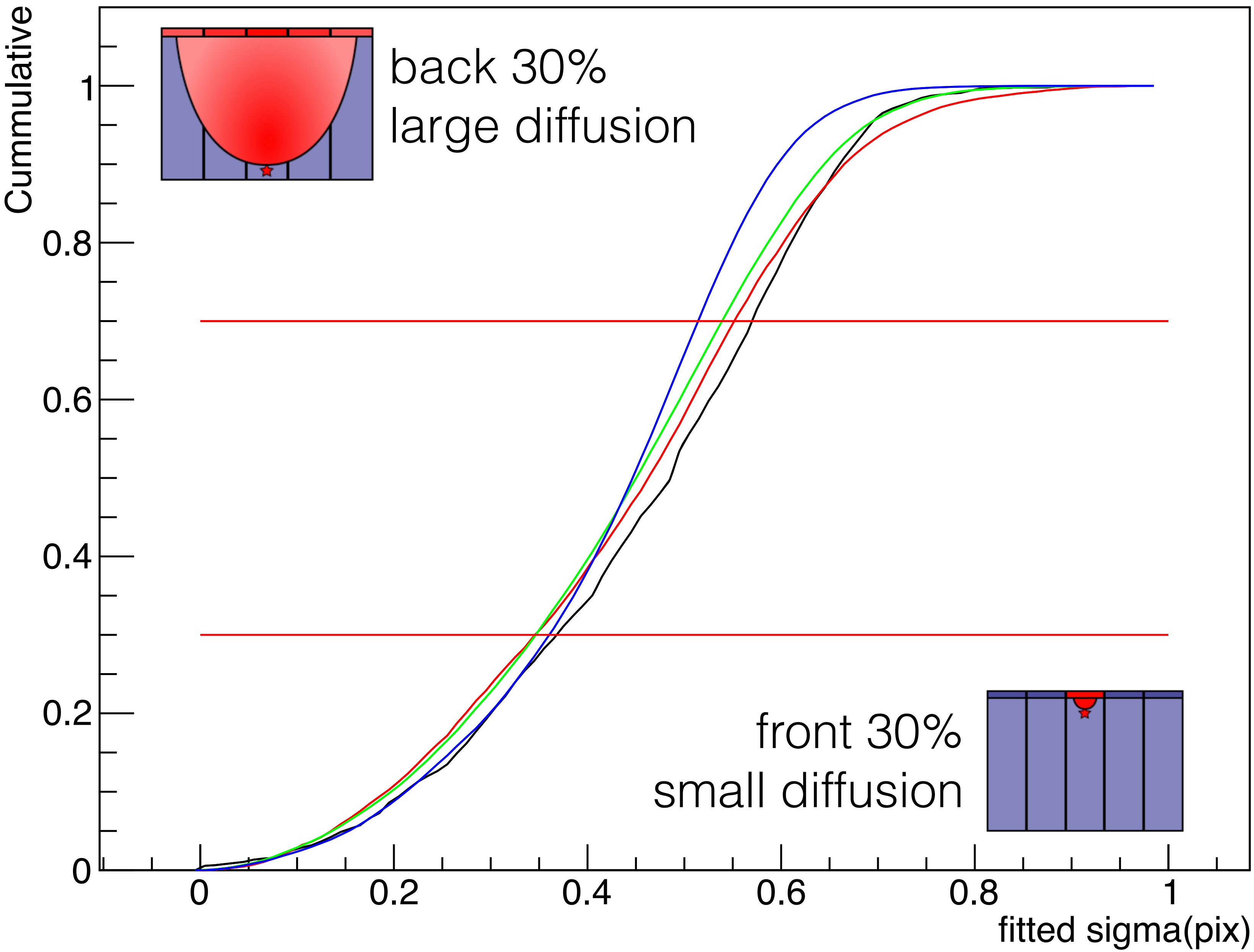
Background stability check #1 : Cu fluorescence peak.



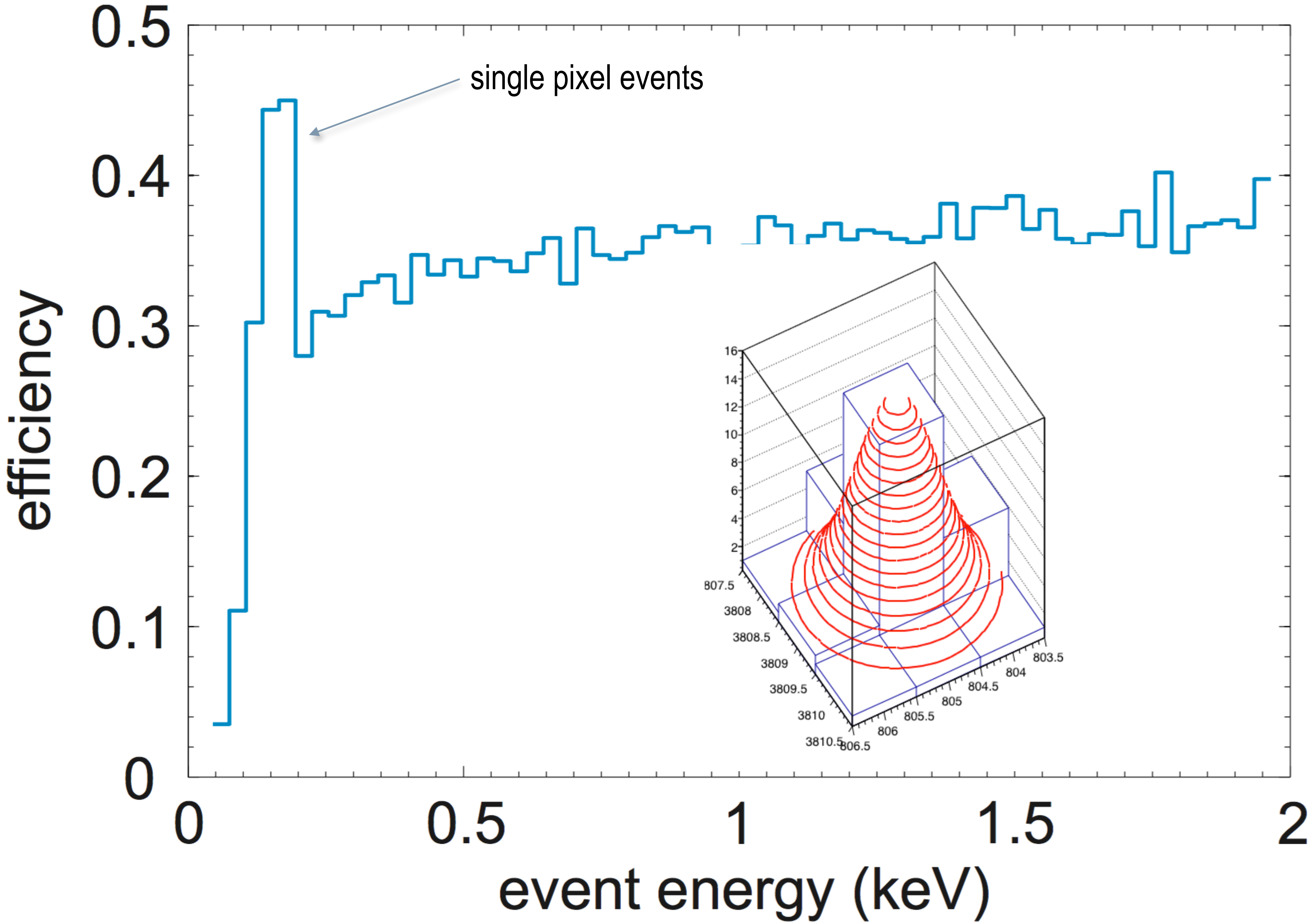


Background stability check #2 : Muon rate



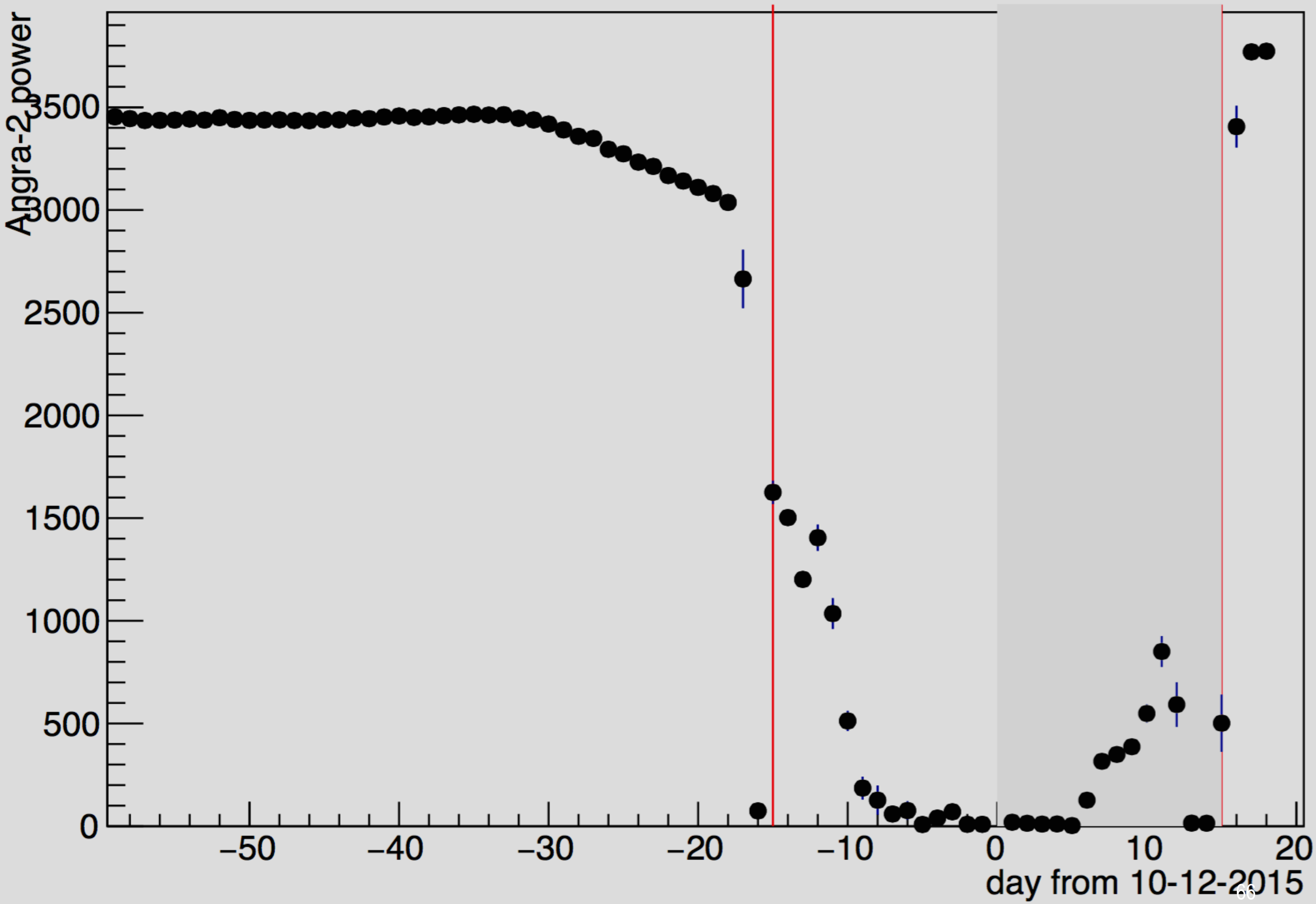


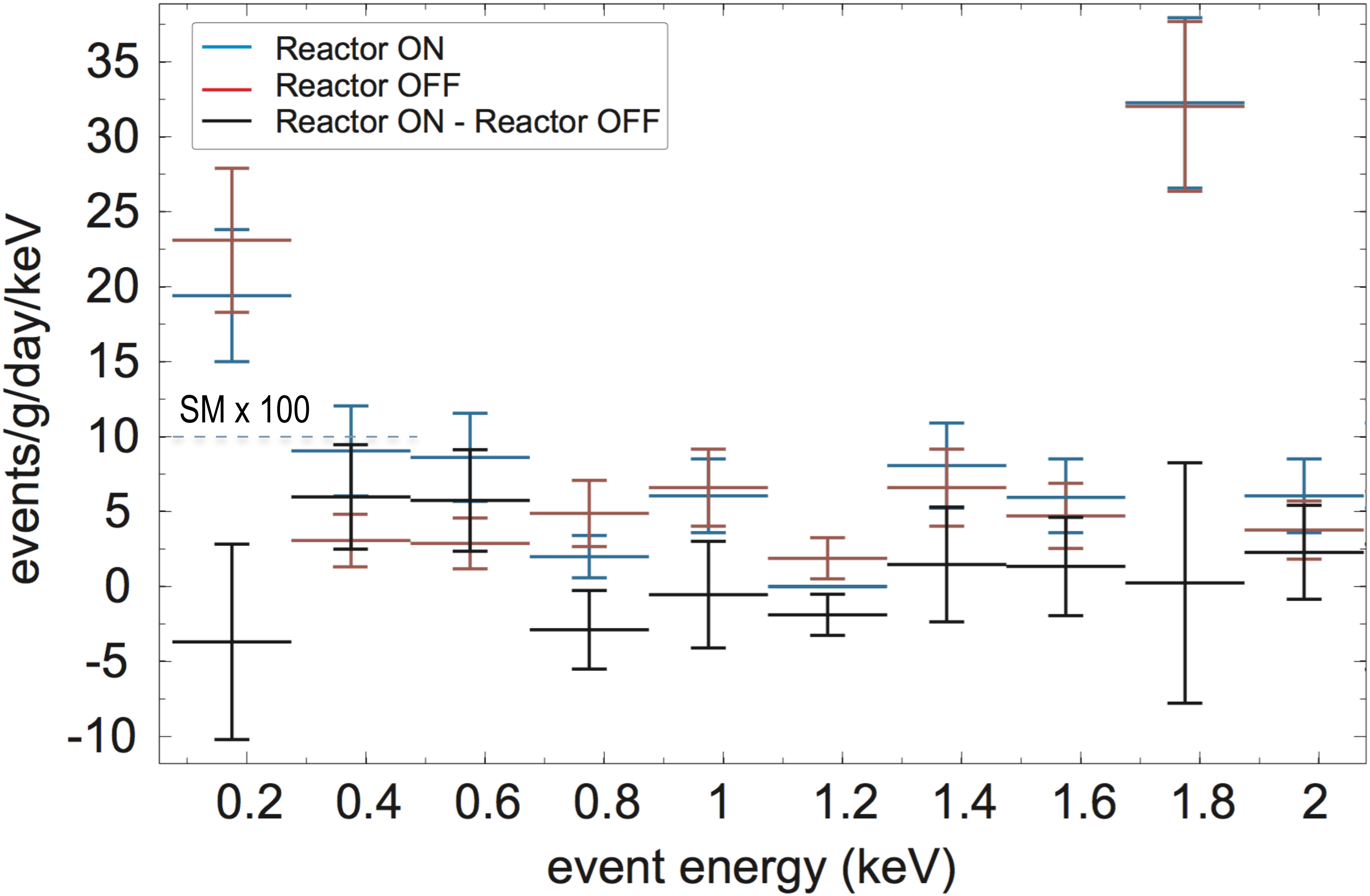
Cummulative
back 30%
large diffusion
front 30%
small diffusion
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
fitted sigma(pix)

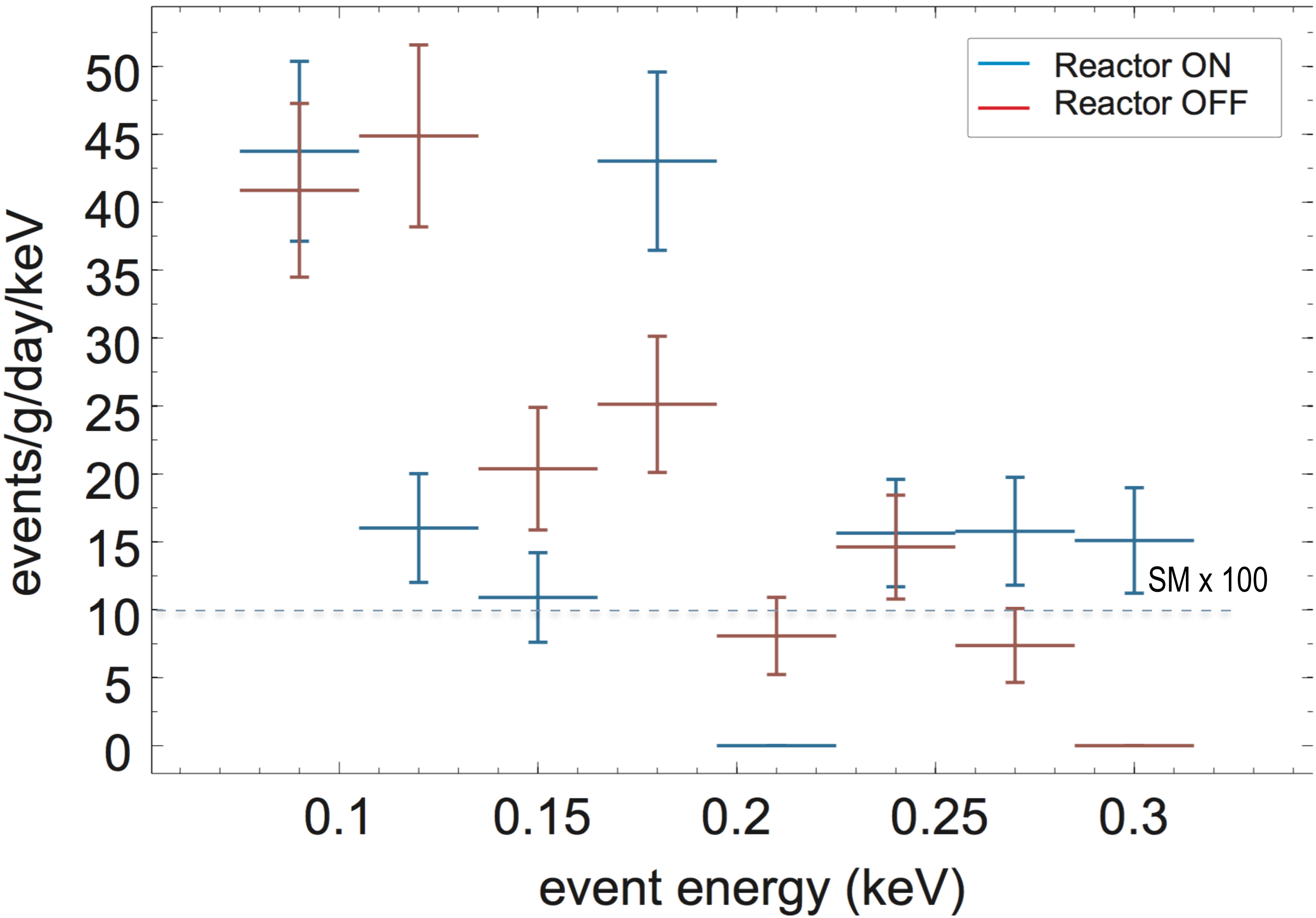


single pixel events
efficiency
0.5
0.4
0.3
0.2
0.1
0
0
0.5
1
1.5
2
event energy (keV)

Power of “a” nuclear reactor like Angra-2 during shutdown

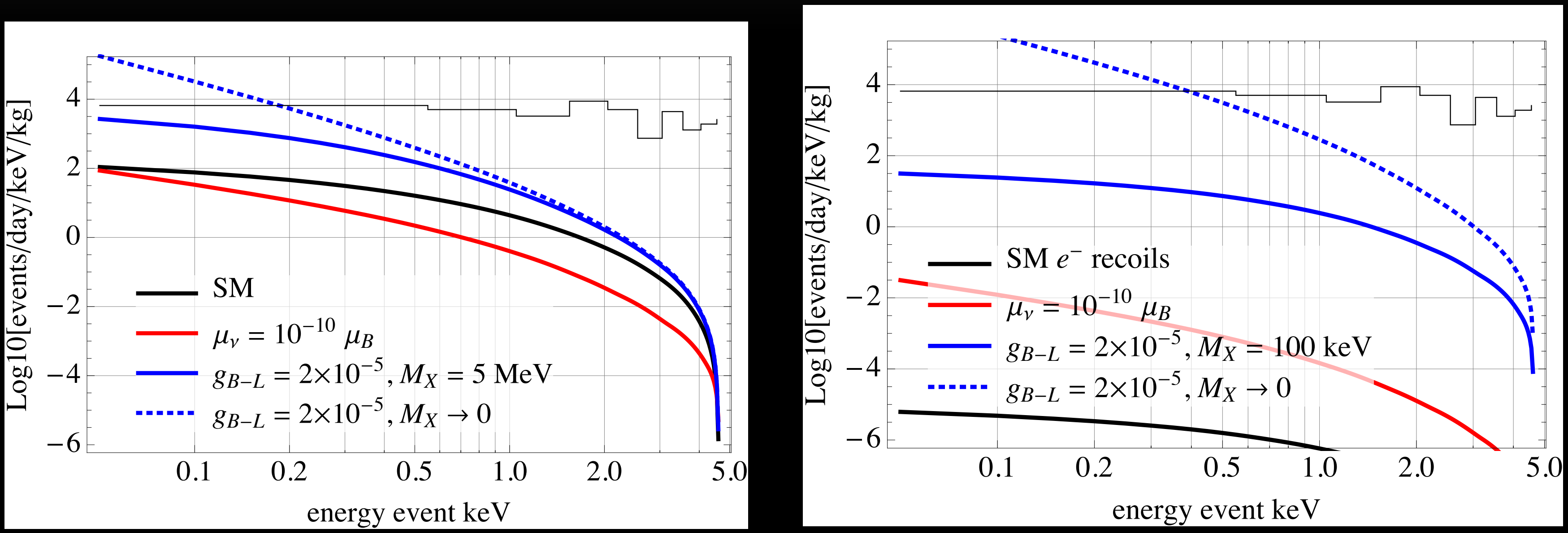



Reactor ON
Reactor OFF
Reactor ON - Reactor OFF
SM x 100
events/g/day/keV
event energy (keV)
35
30
25
20
15
10
5
0
-5
-10
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2



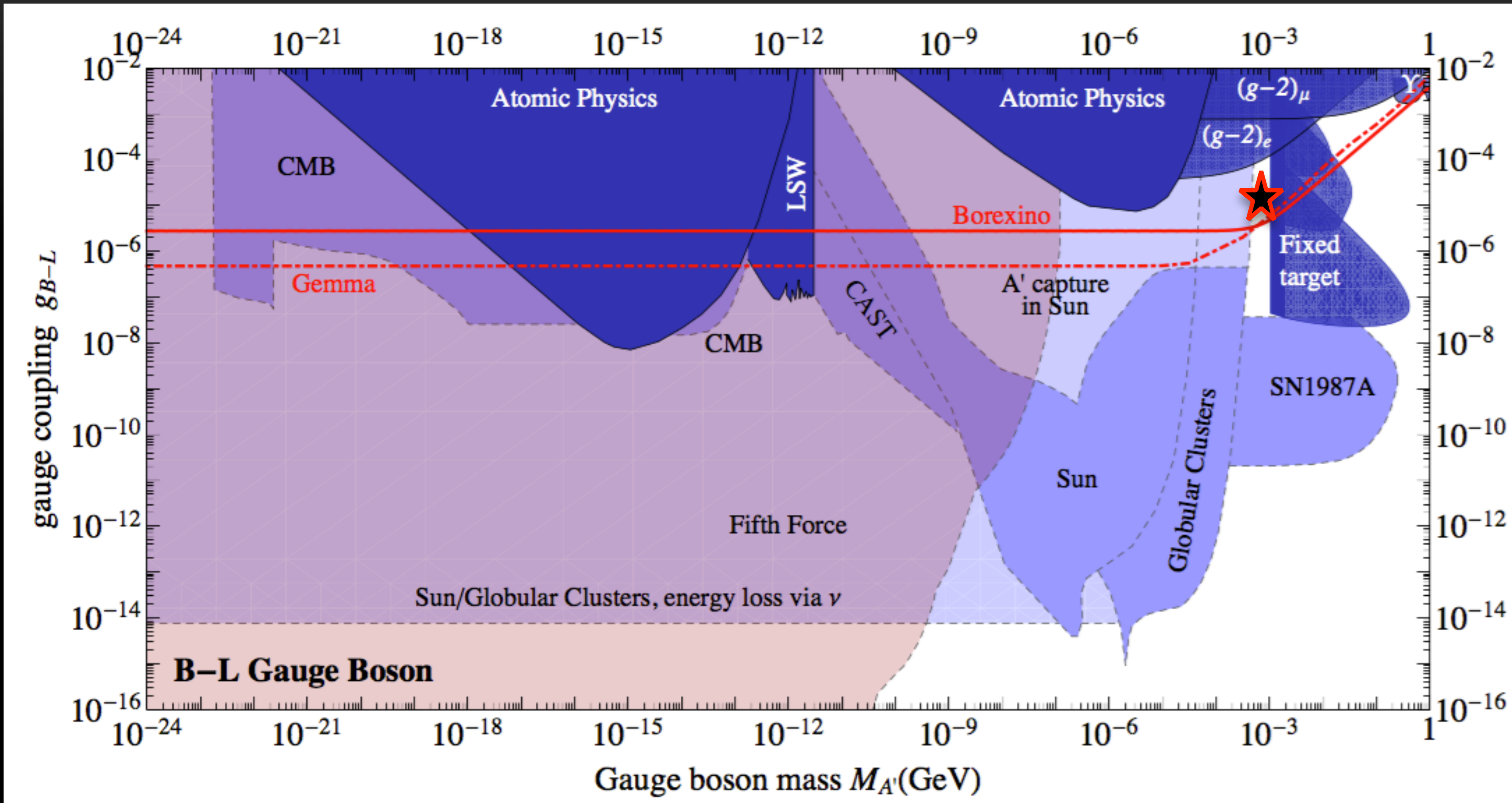
Reactor ON
Reactor OFF
SM x 100
events/g/day/keV
event energy (keV)
0
5
10
15
20
25
30
35
40
45
50
0.1
0.15
0.2
0.25
0.3

Preliminary

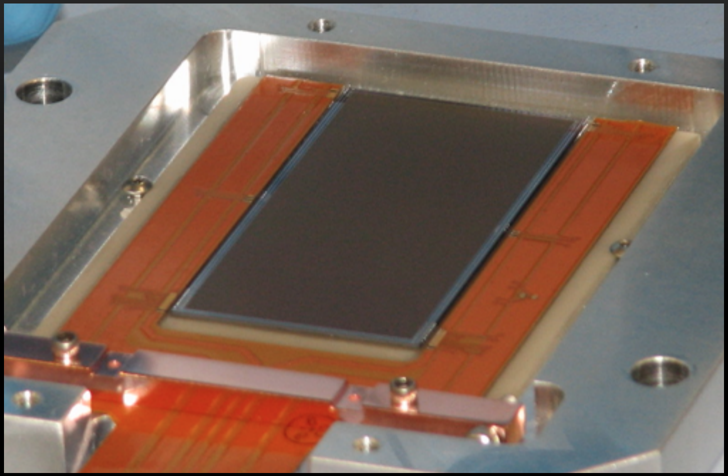


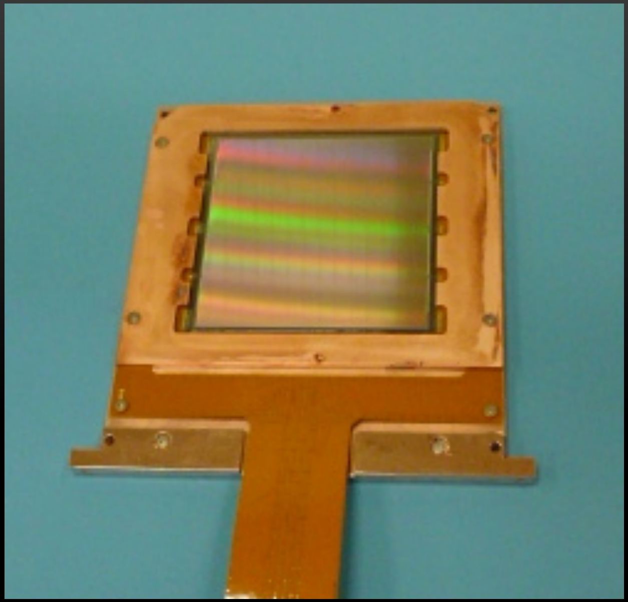
Analysis is still in progress…

Some models of interest compared to events rates similar to preliminary constraints from CONNIE.


Atomic Physics
Atomic Physics
$(g-2)_\mu$
$(g-2)_e$
Υ
CMB
LSW
Borexino
Gemma
Fixed target
A' capture in Sun
CAST
CMB
SN1987A
Sun
Globular Clusters
Fifth Force
Sun/Globular Clusters, energy loss via ν
B−L Gauge Boson
gauge coupling g_{B-L}
Gauge boson mass $M_{A'}$(GeV)

Next: N/Sx100





the sensors are already at FNAL packaging/testing in progress

	2015 Engineering	*2016-2017 Science*
mass	*1g (1CCDs, 1g each)*	*100g (18CCDs, 5.7g each)*
noise	*2.4e-*	*1.8e-*
dark current	*0.5 e/pix/hour*	*0.001 e/pix/day*
package background	*5000 dru contaminated AlN*	*40 dru*
exposure	*15 days*	*90 days*

x10 in S/N

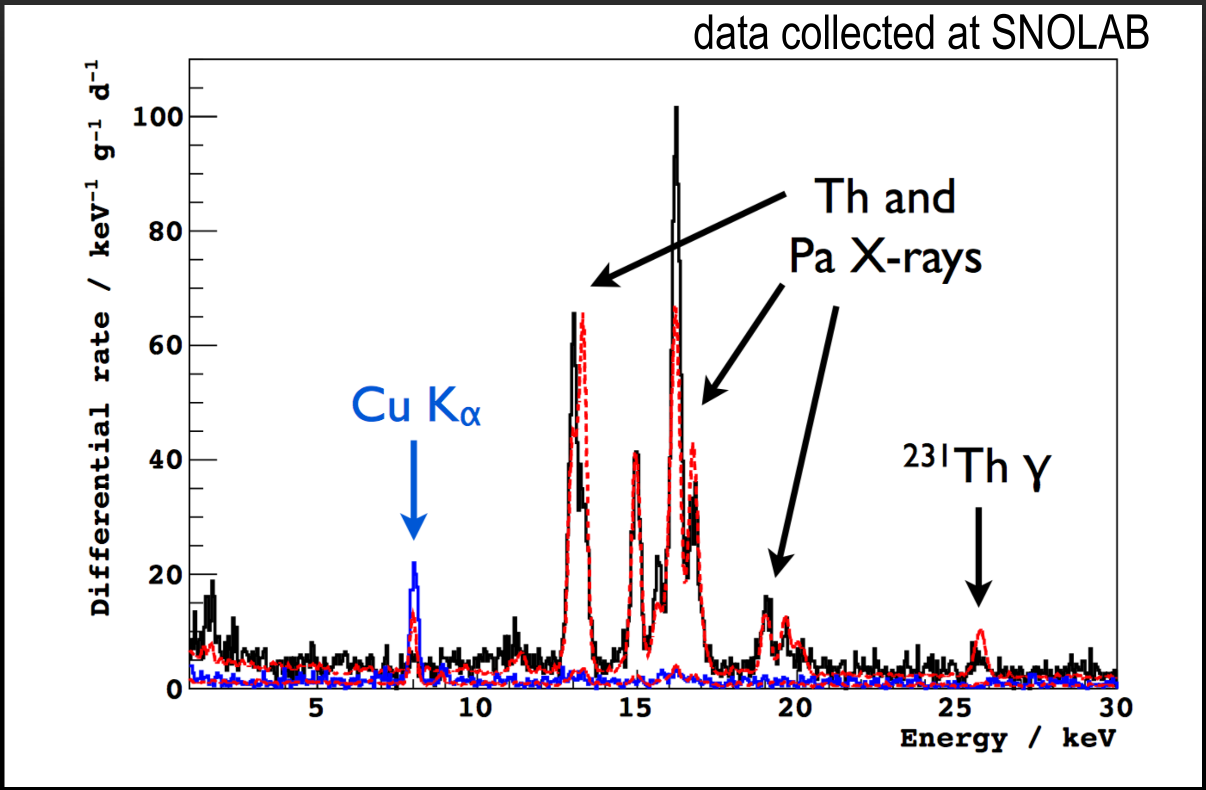
} 100 eV thr → 60 eV thr
x2 in S/N

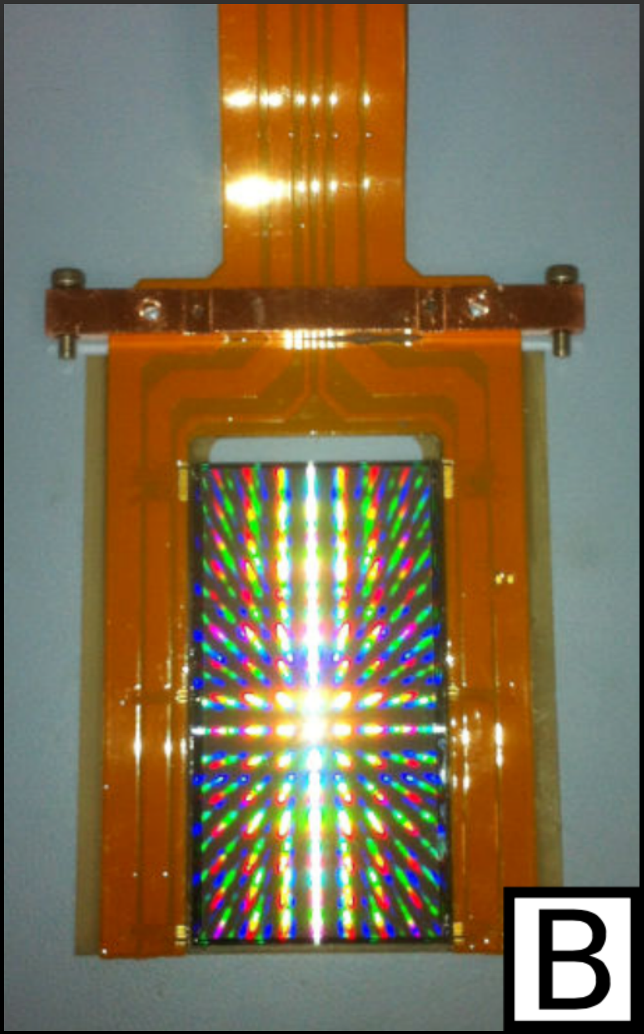
x2.2 in S/N (assuming have 1k dru?)

x2.4 in S/N

SUMMARY

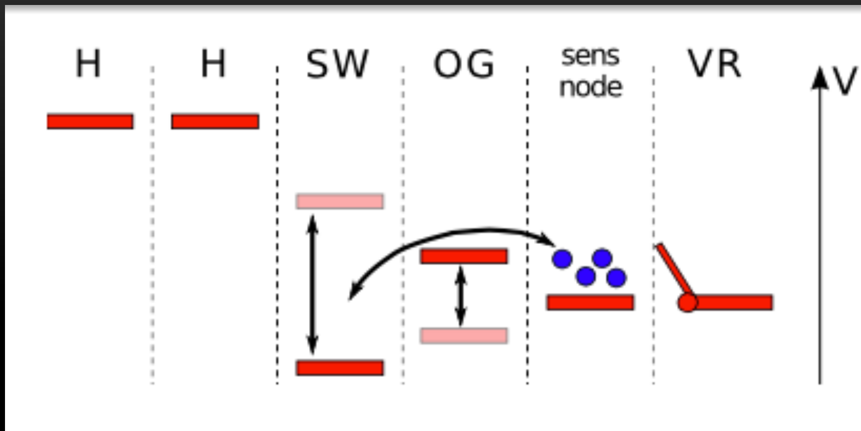
- CONNIE started operations at ANGRA in 2014 with a engineering prototype. **Thanks for all the support to PPD/CD at FNAL!**
- CONNIE is science ready, starting to look into a new region of the parameter space for neutrinos.
- Data shown here is for 1g, operated for about 15 days.
- CONNIE is upgrading to 100g by mid 2016.

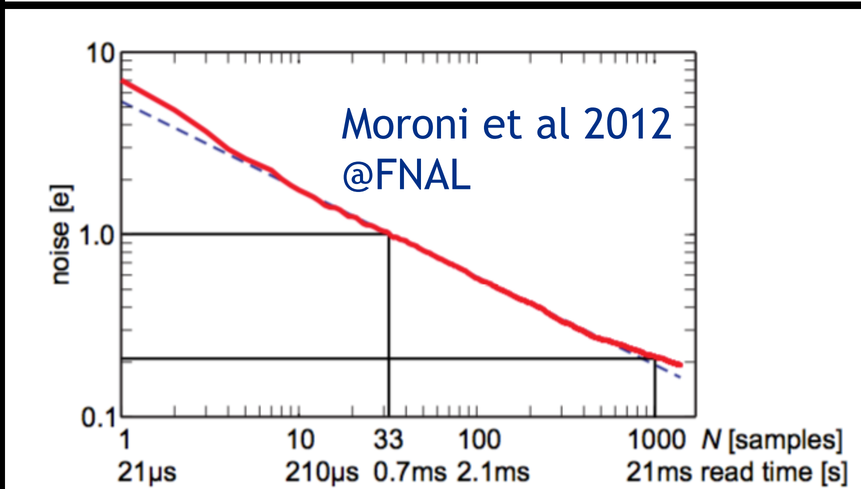




Full AlN
Frame AlN
simulations

at SNOLAB we saw about 5000 dru from the AlN, removing this will improve our background.





2016 LDRD

Project Title: Development of a ultra low energy threshold particle detector

Principal Investigator: Javier Tiffenberg
Lead Division/Sector/Section:
Co-Investigators (w/institutions):
Dr. Juan Estrada (Fermilab)
Dr. Gustavo Cancelo (Fermilab)
Dr. Christopher Bebek (LBNL)
Dr. Jeremy Mardon (Stanford University)
Prof. Rouven Essig (Stony Brook)
Dr. Chiu-Tien Yu (Stony Brook)
Dr. Tomer Volansky (Tel Aviv University)

~1e could be possible in the future

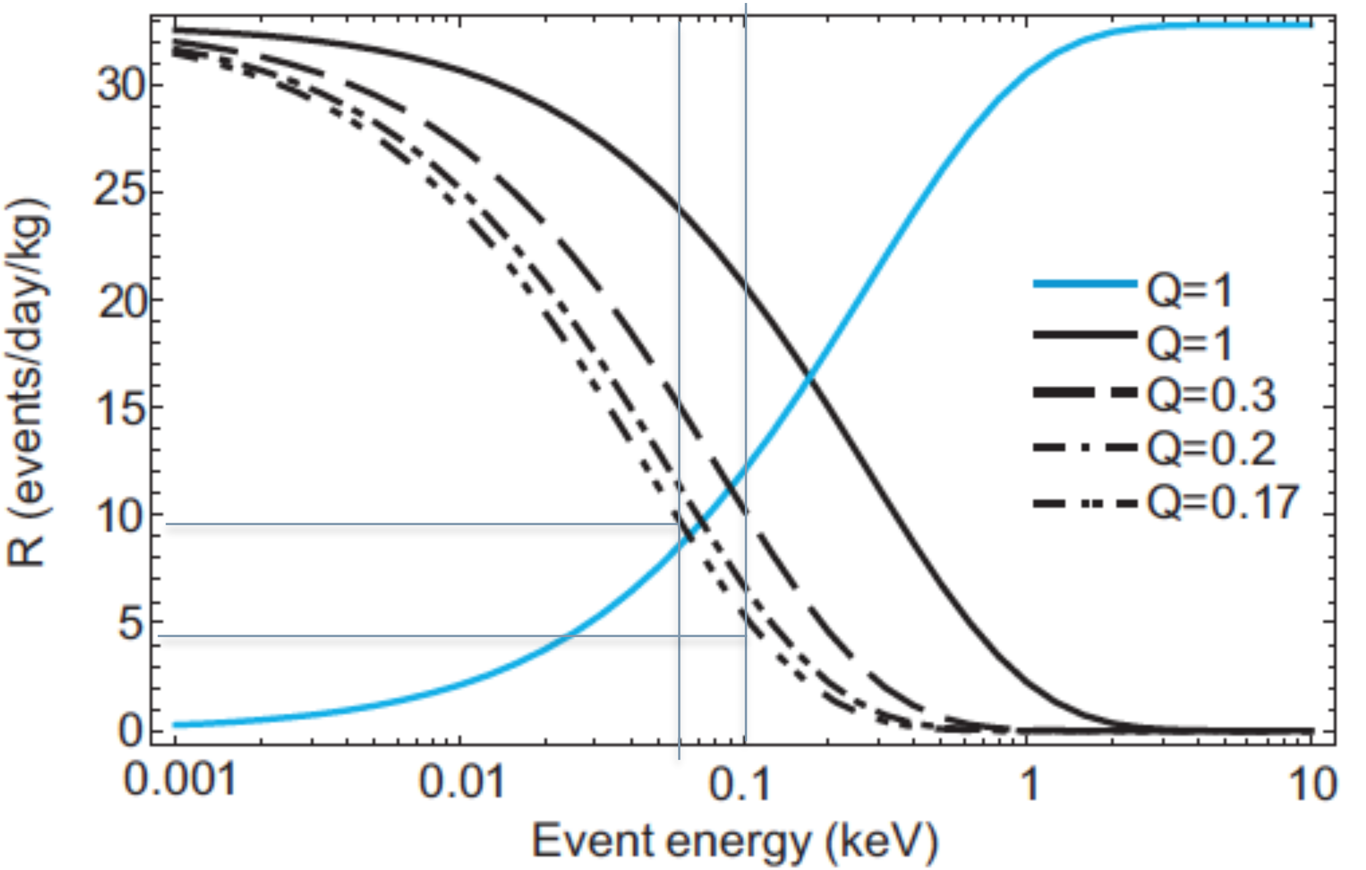
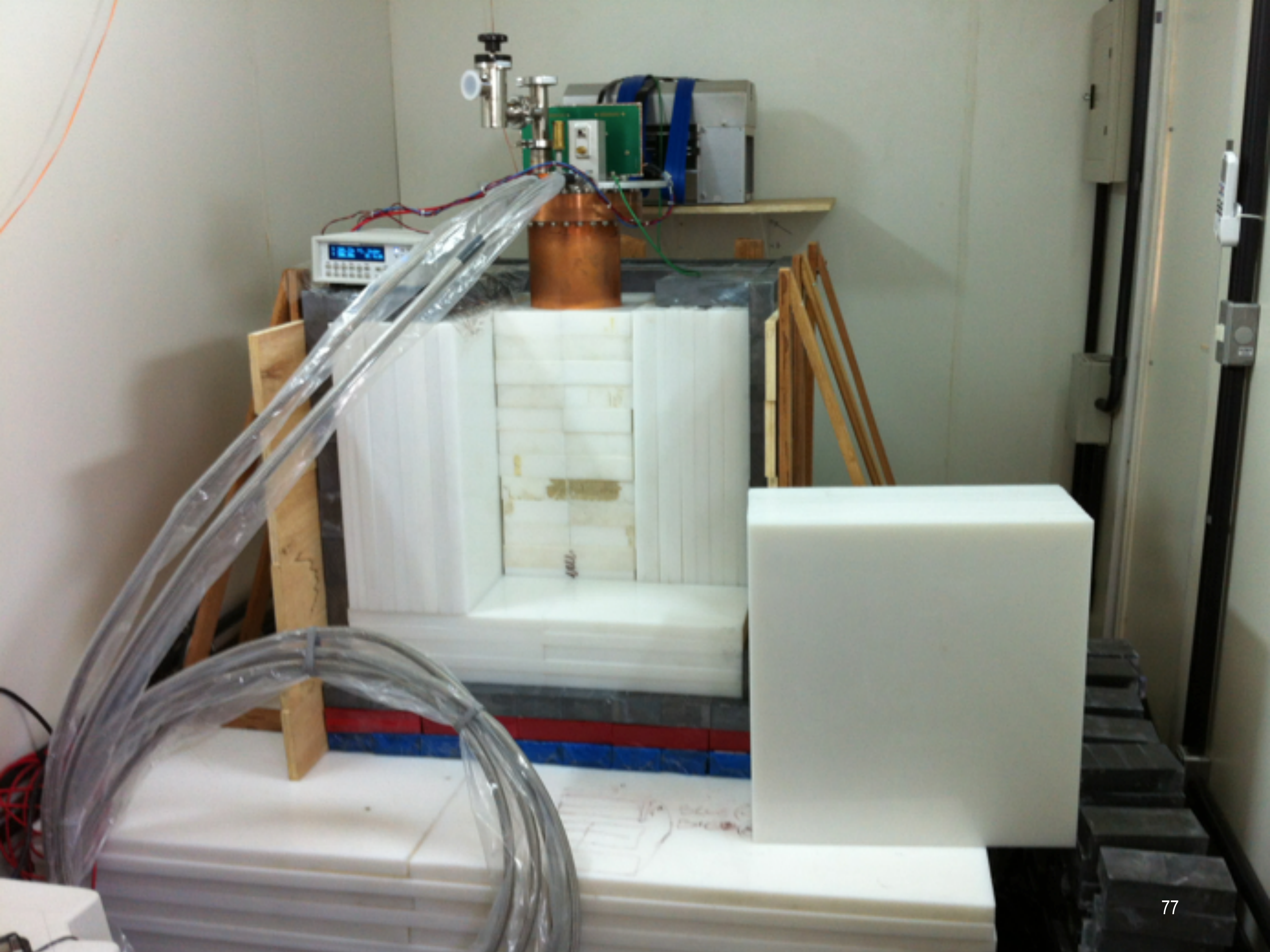
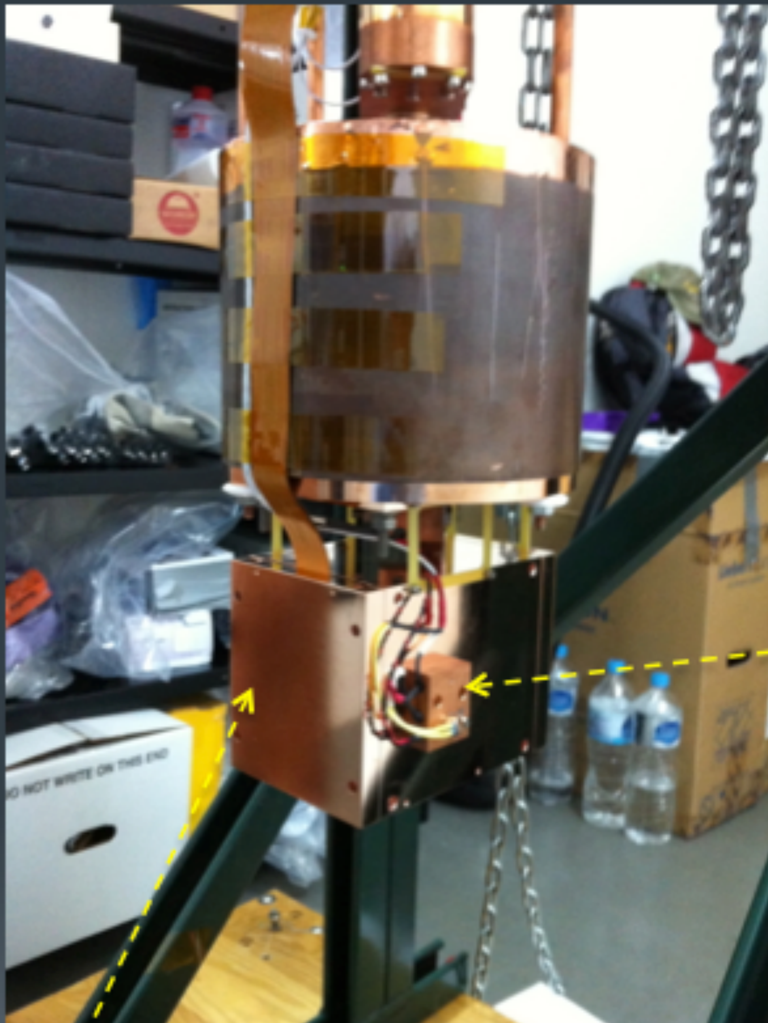


FIG. 9. Total number of events as a function of the threshold energy for different quenching factors: $Q = 1$, $Q = 0.3$, $Q = 0.2$ and $Q = 0.17$ (black curves). The light-blue curve shows the total number of events as a function of the maximum detectable recoil energy using $Q = 1$.

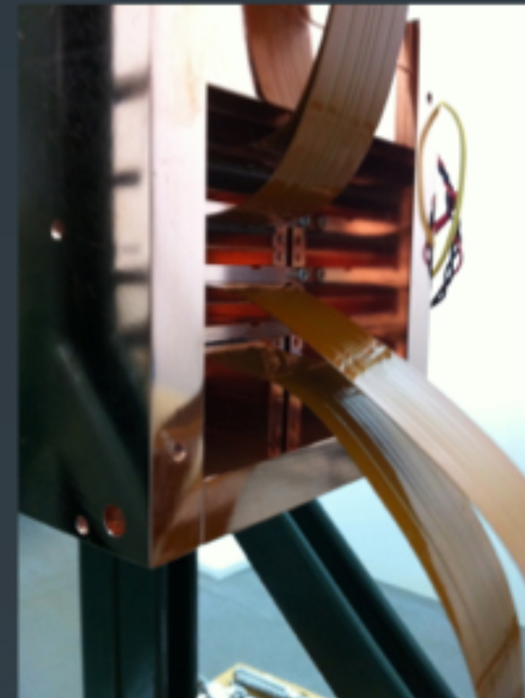


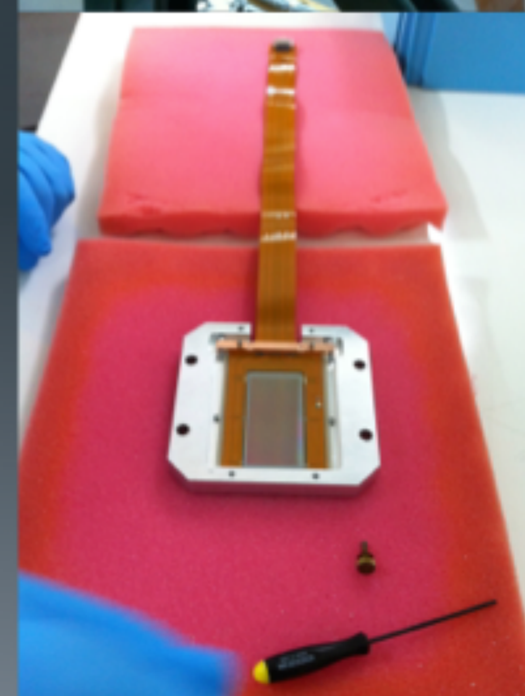
Detector configuration (November 9th, 2014)



Heater
Temp. sensor

Front door of the Cu-Box (CCD installatioin)





other reactor experiments exists, the bigger activity here is with Germanium detectors

TABLE I: Summary table of the operation and performance parameters of the various Ge detectors adopted in this study.

Items	HPGe	ULEGe	pPCGe	nPCGe
Modular Mass (g)	1000	5	500	500
RESET Amplitude (V)	N/A †	8.0	6.8	6.8
RESET Time Interval (ms)	N/A †	700	160	170
Pedestal Noise				
Amplitude RMS σ_A (eV)	812	15	41	49
Charge(Energy) RMS σ_Q (eV)	840	38	58	52
Pulser Width				
FWHM (eV)	1566	80	110	133
RMS (eV)	665	34	47	57
Gamma Line Width	Ga-K X-Ray	^{55}Fe	Ga-K X-Ray	Ga-K X-Ray
RMS (eV)	910	78	110	134
Selected Trigger Level Δ (σ_A)	3.58	4.3	3.86	3.73
50% Trigger Efficiency (eV)	3500	80	180	200
Trigger Rate (Hz)	60	5	25	36
50% Selection Efficiency (eV)	4200	220	275	300
Noise Edge "NoEd" (eV)	5000	320	350	350

† Resistance feedback preamplifier is used in HPGe, so that the RESET timing structures are not-applicable (N/A).

threshold ar about one order of magnitude larger than what we can do with CCDs. (table from Texono Collaboration).