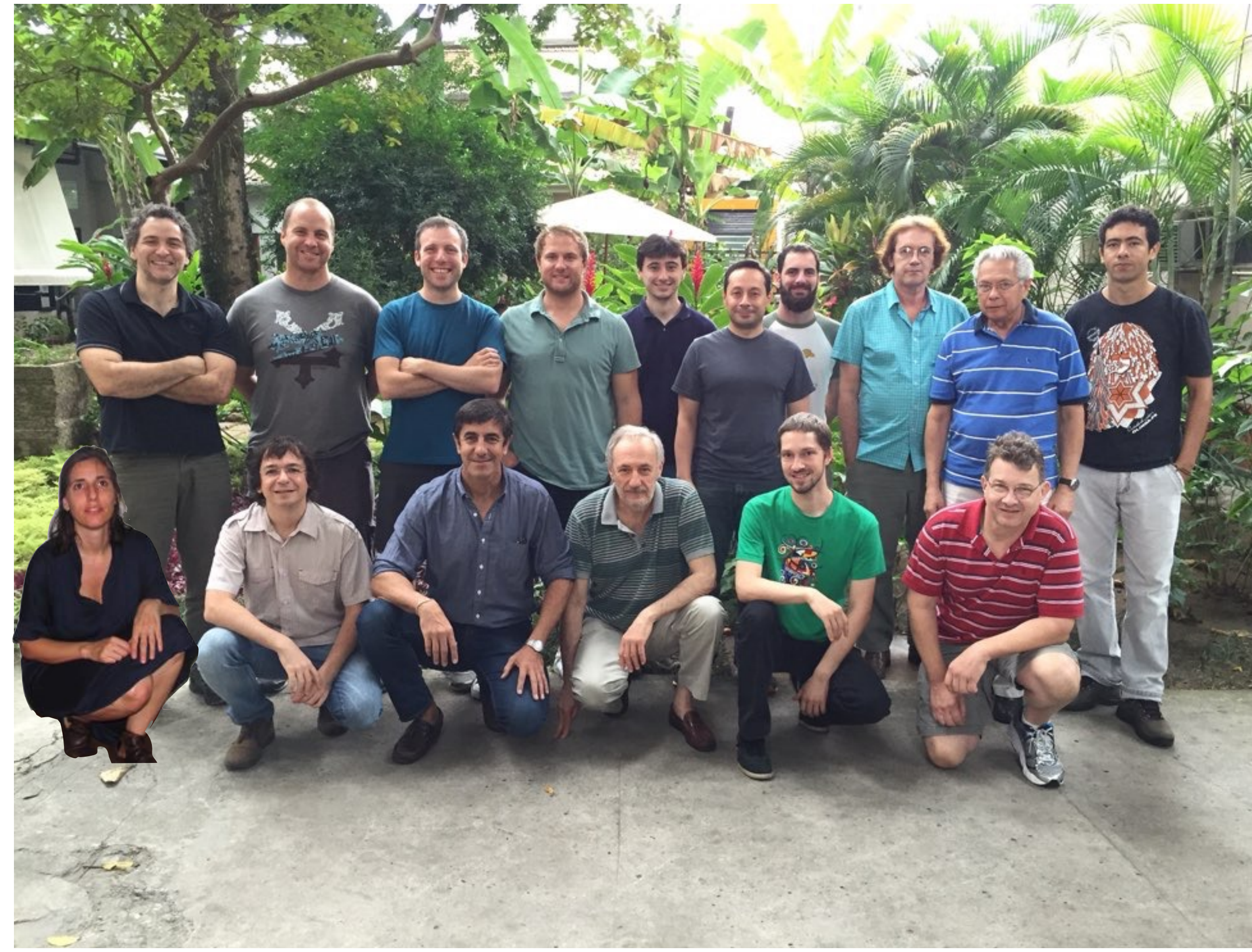
COνNIE

COHERENT NEUTRINO NUCLEUS INTERACTION EXPERIMENT



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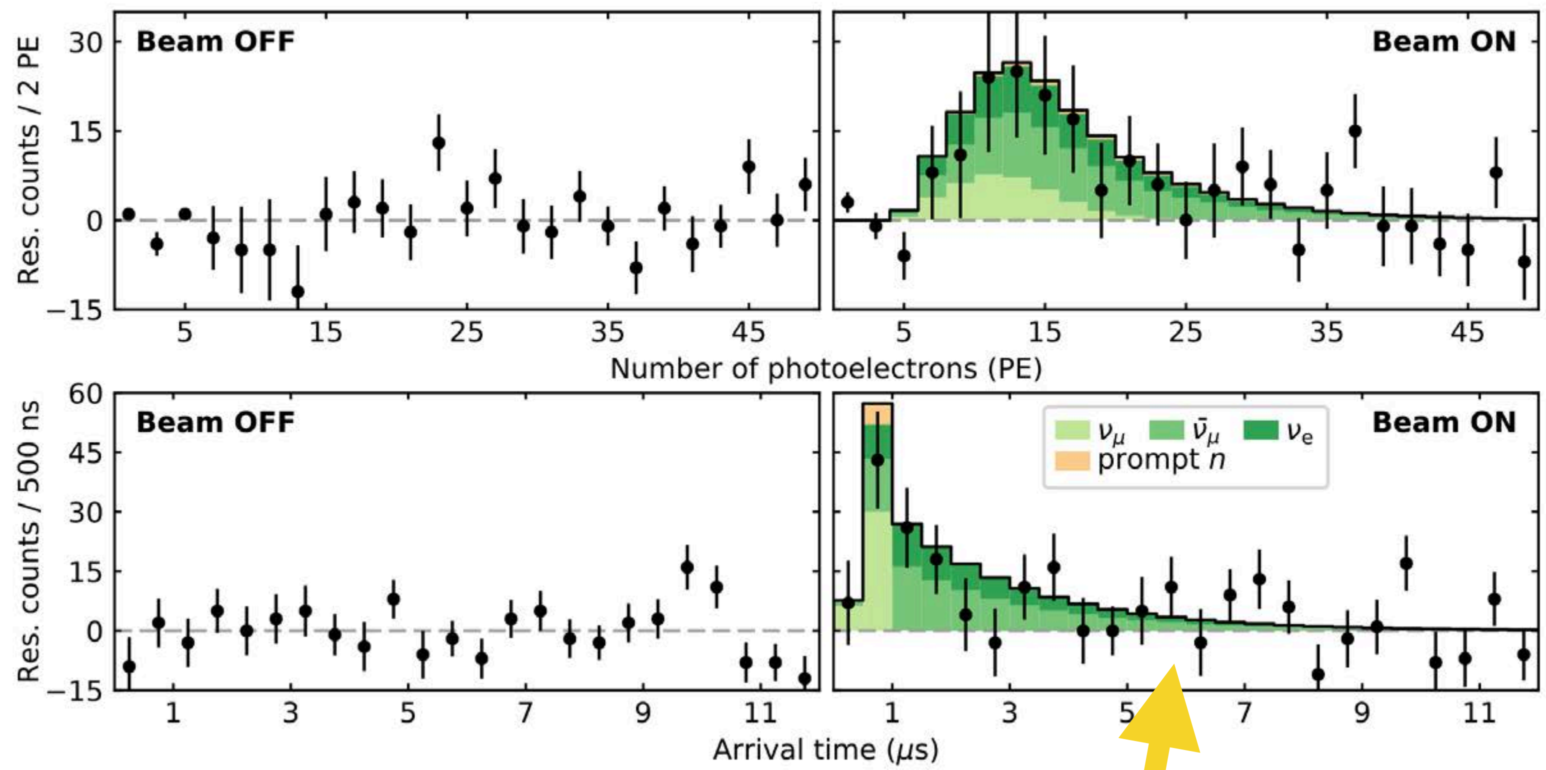
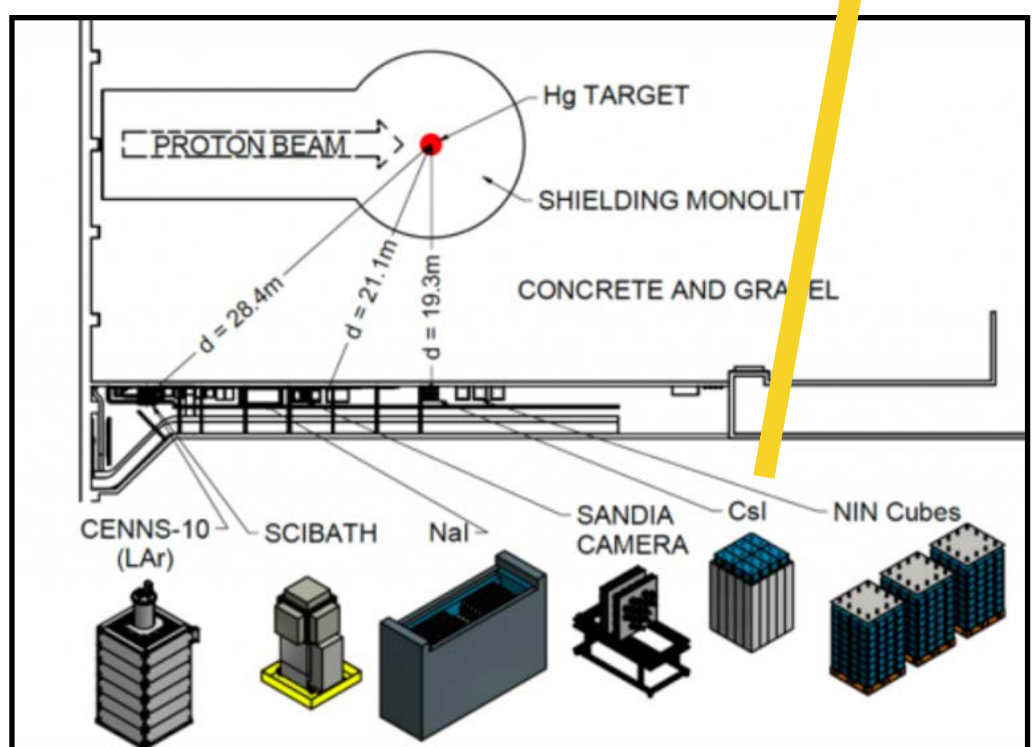
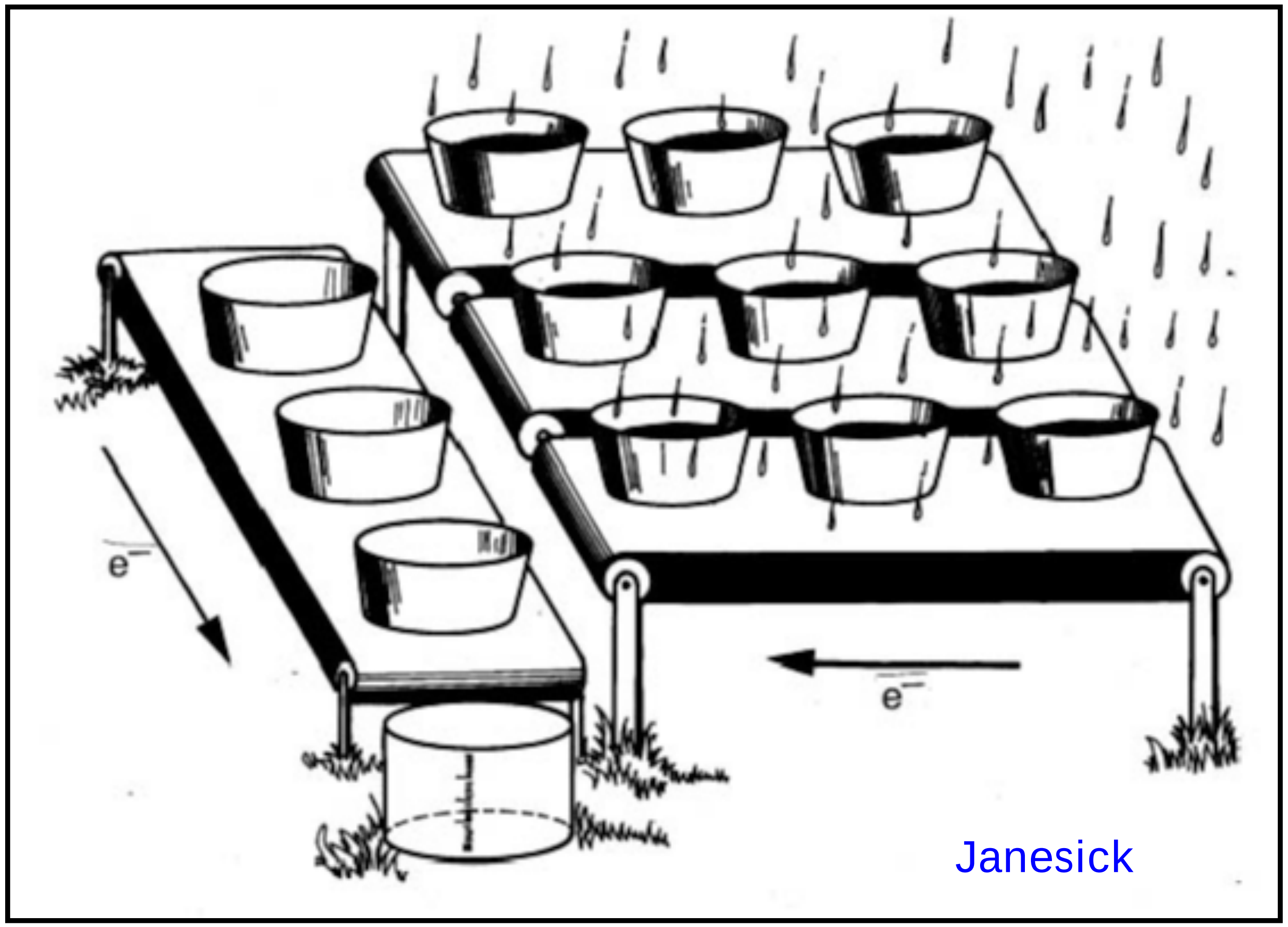
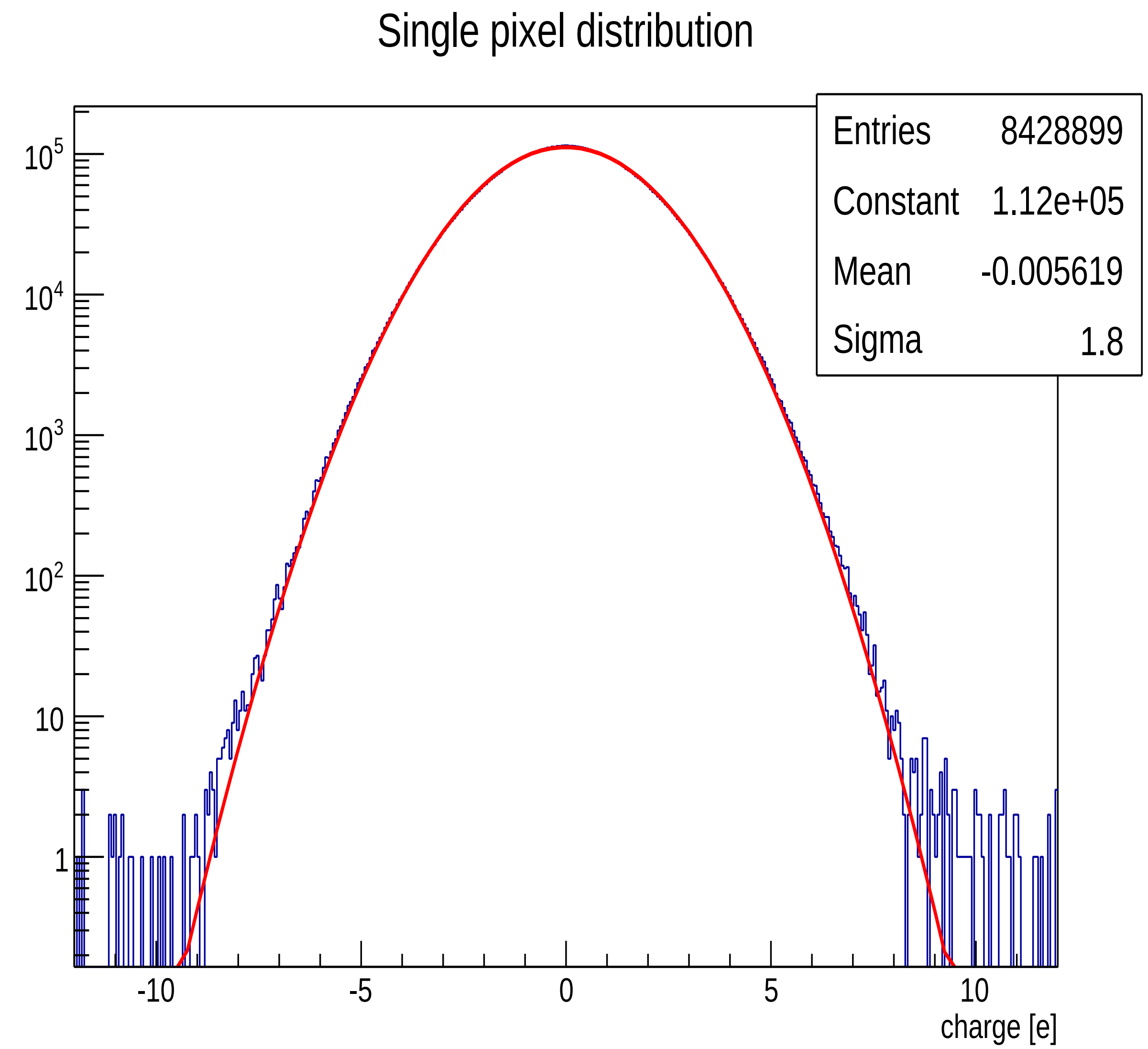
NEWS: First light for CEvNS, "Observation of coherent elastic neutrino-nucleus scattering" by the COHERENT collaboration, published in Science, August 3, 2017



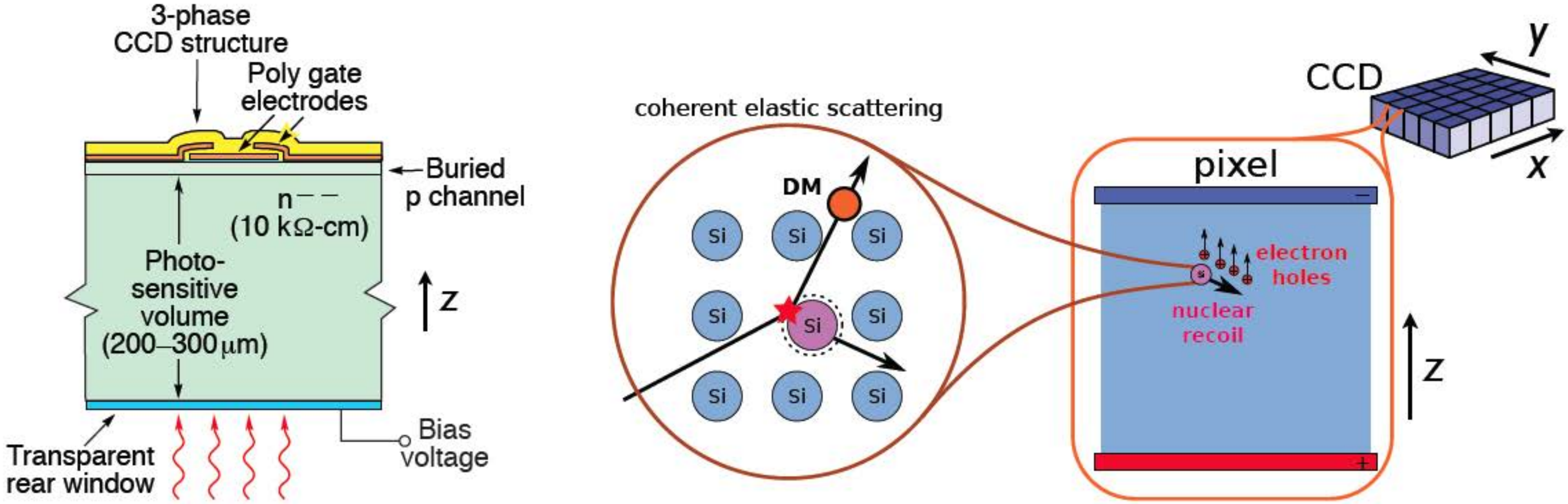


Detector: CCD readout

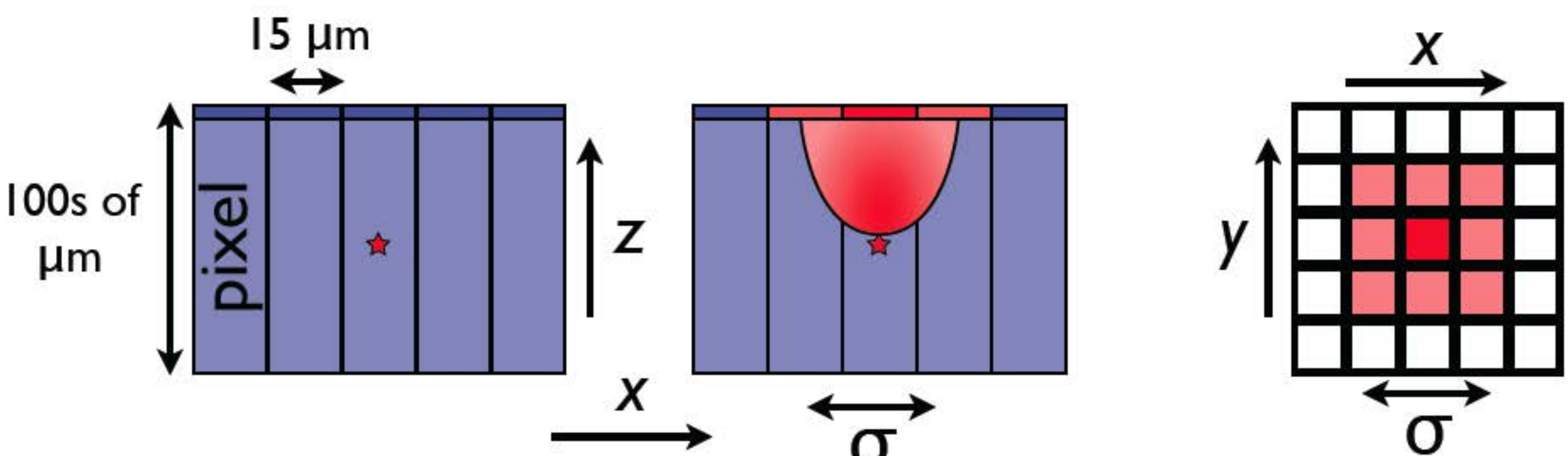




Charge coupling makes the detectors ideal for low noise measurements, typical noise for scientific CCDs is 2e- RMS (7.6eV). Very recent work pushing this to “0” noise.



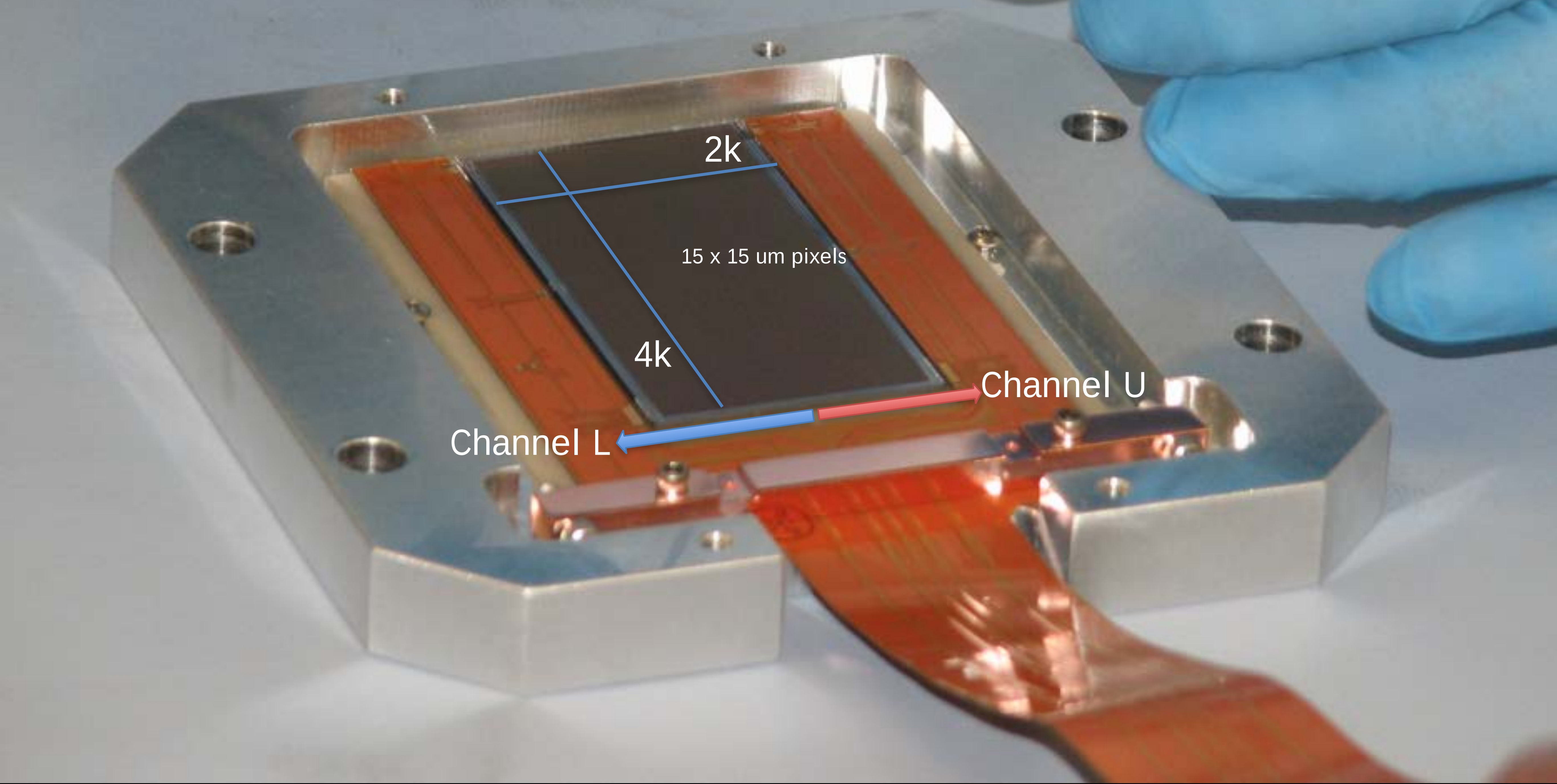
(a) A CCD pixel (b) WIMP detection principle



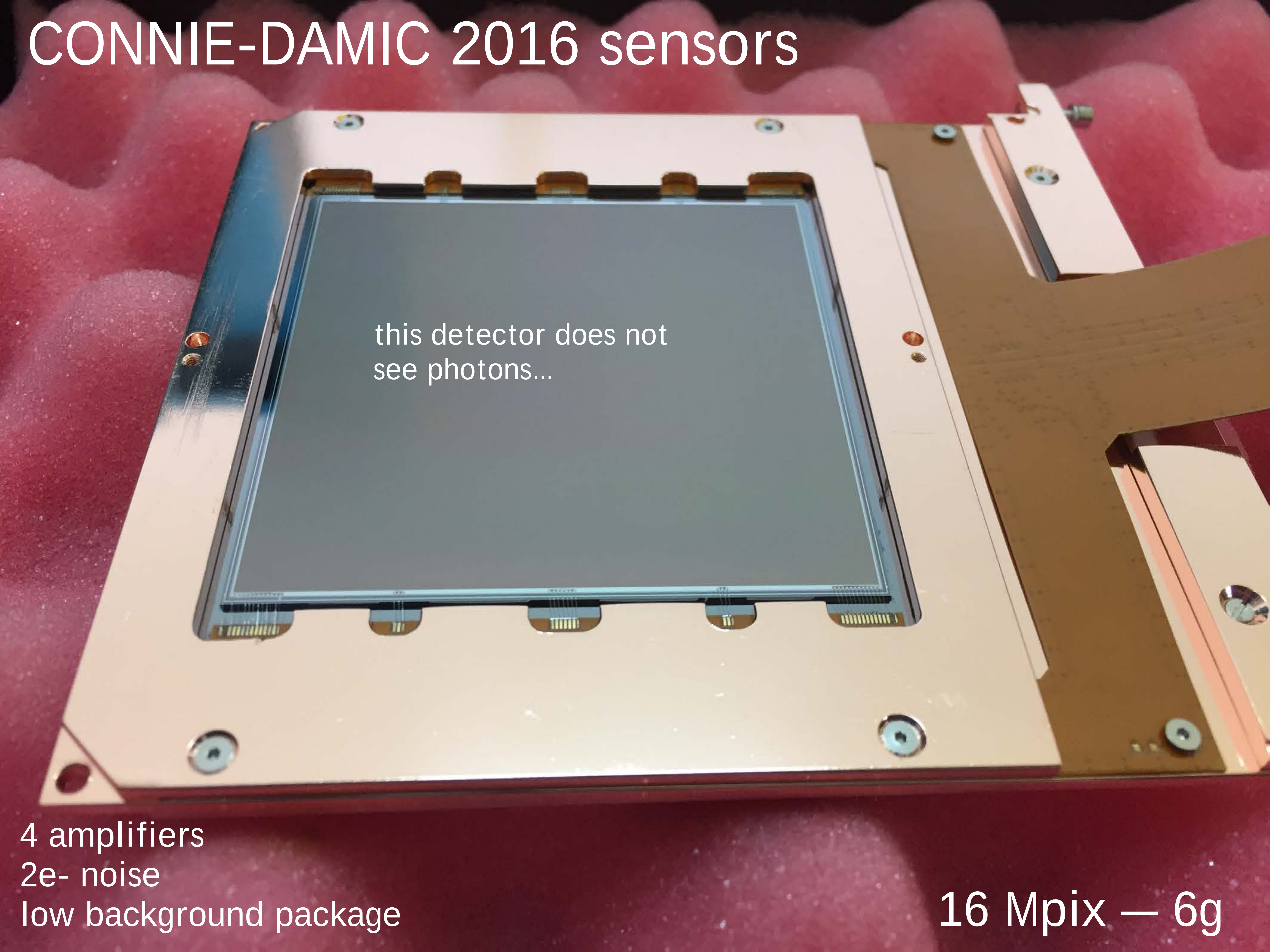
Recent developments by the MSL group at LBNL has allowed the fabrication for “massive” CCDs. 675 um is now possible.

CONNIE 2014-2015 sensor

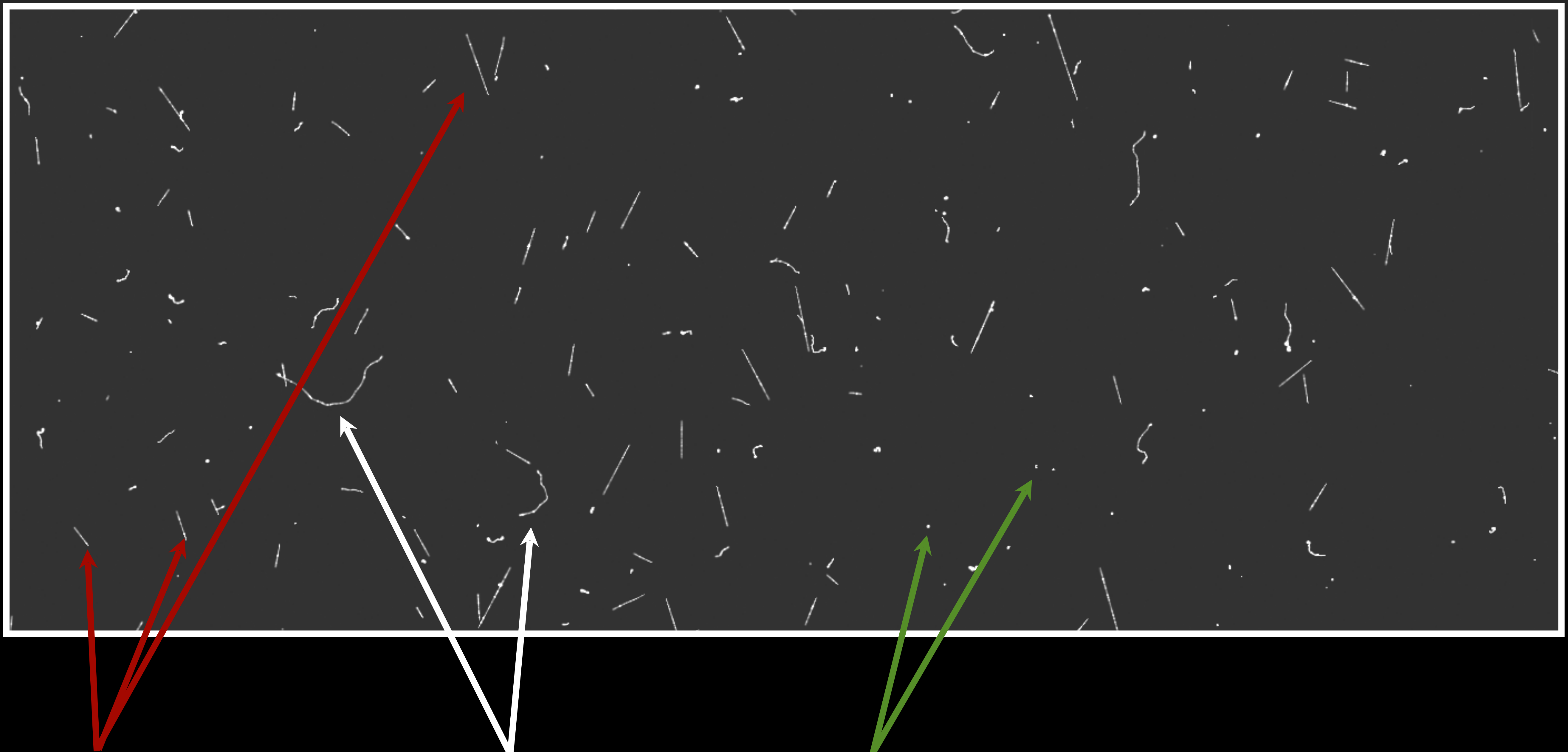
250 um thick CCD
Developed by LBNL Microsystems LAB



detector designed for astronomy, and used for low energy nuclear recoils


CONNIE-DAMIC 2016 sensors
this detector does not
see photons...
4 amplifiers
2e- noise
low background package
16 Mpix — 6g

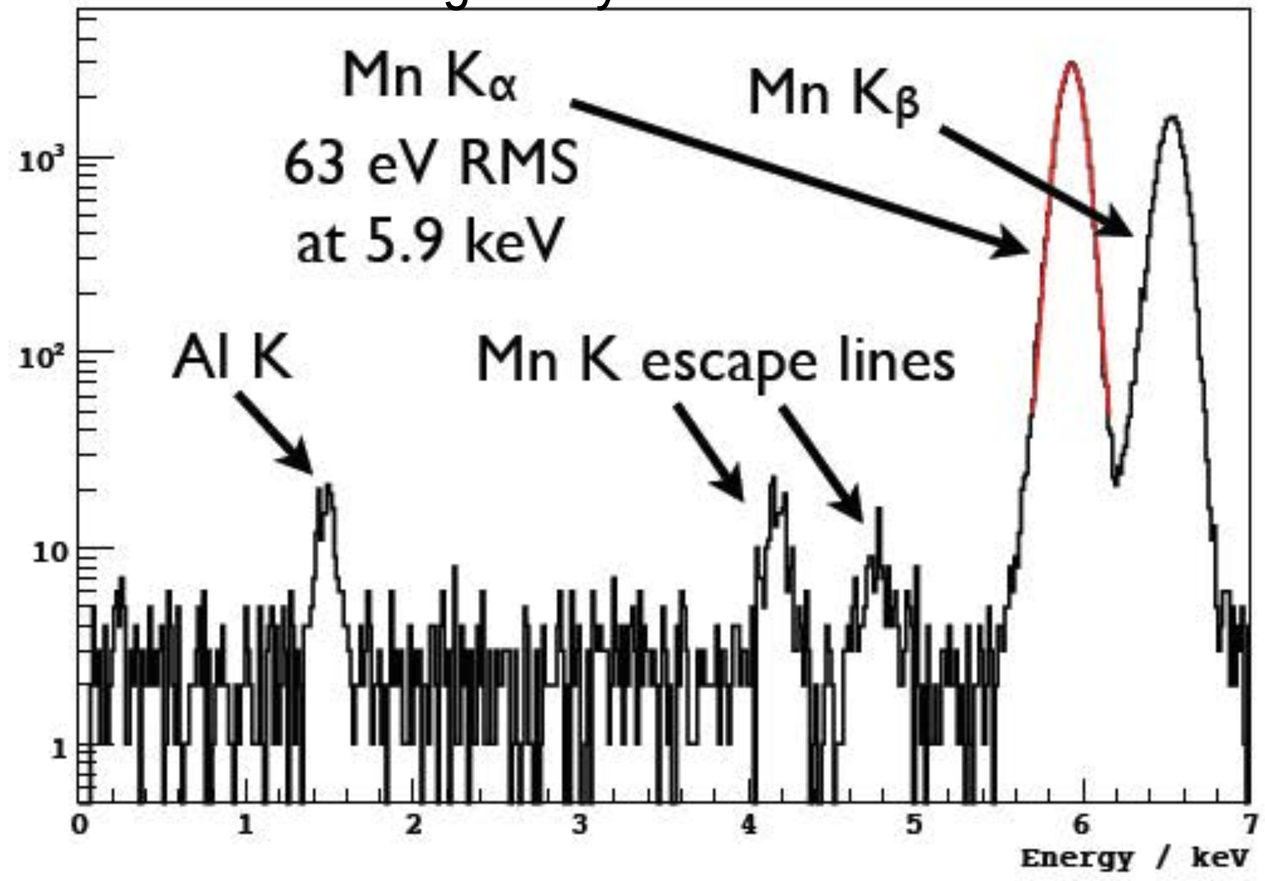
Particle identification in a CCD image

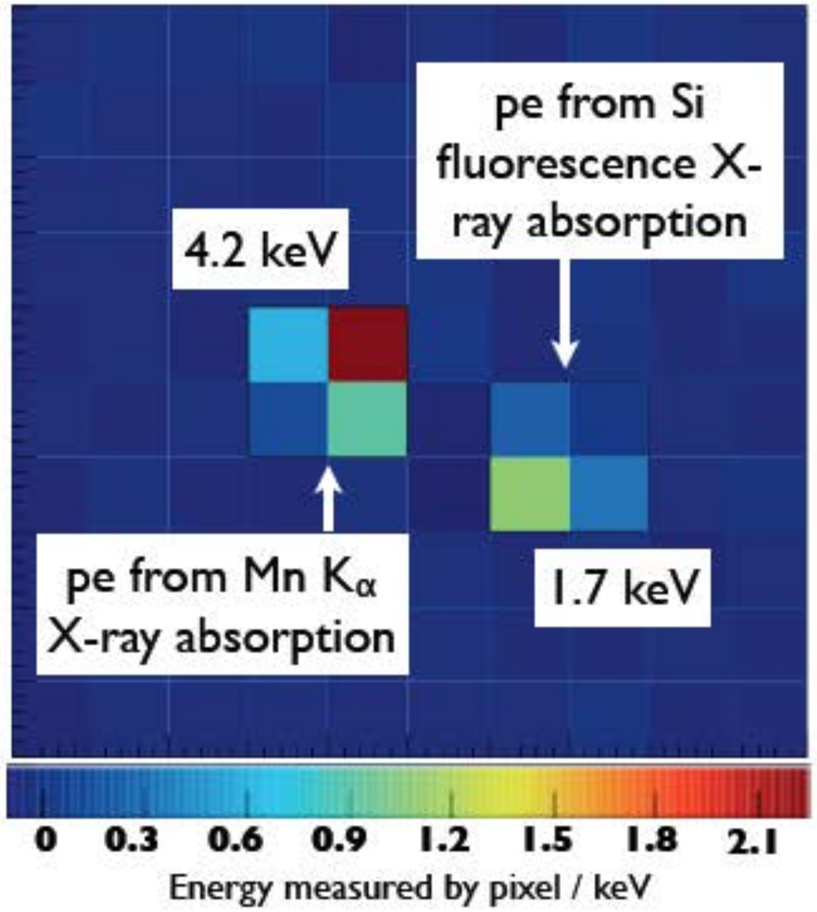


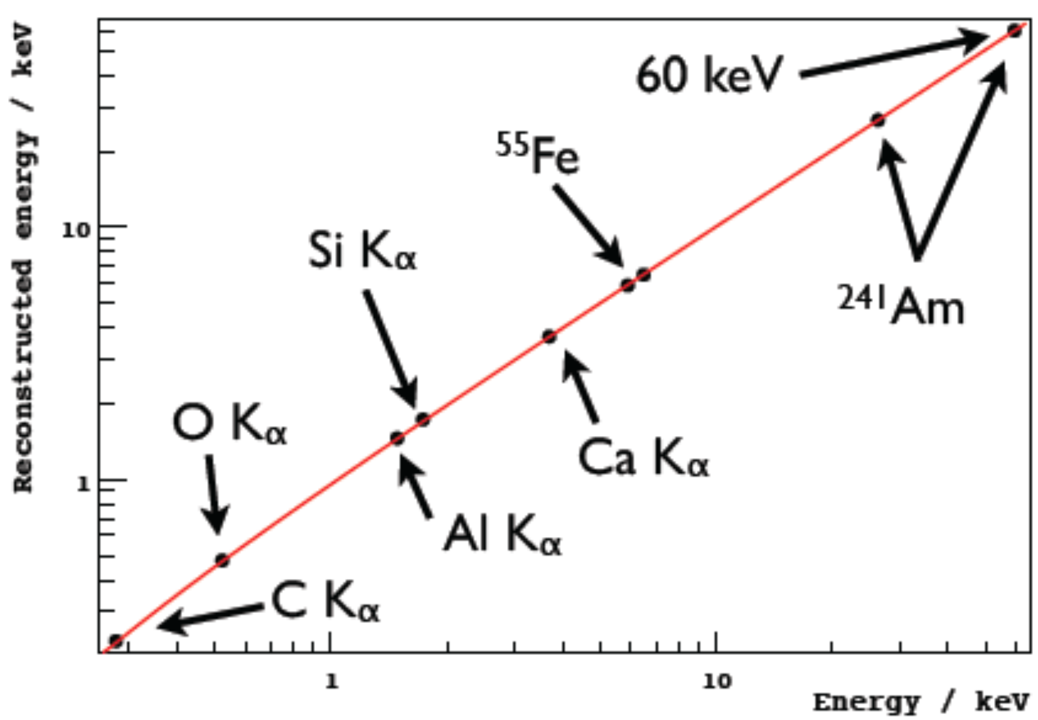
muons, electrons and diffusion limited hits.

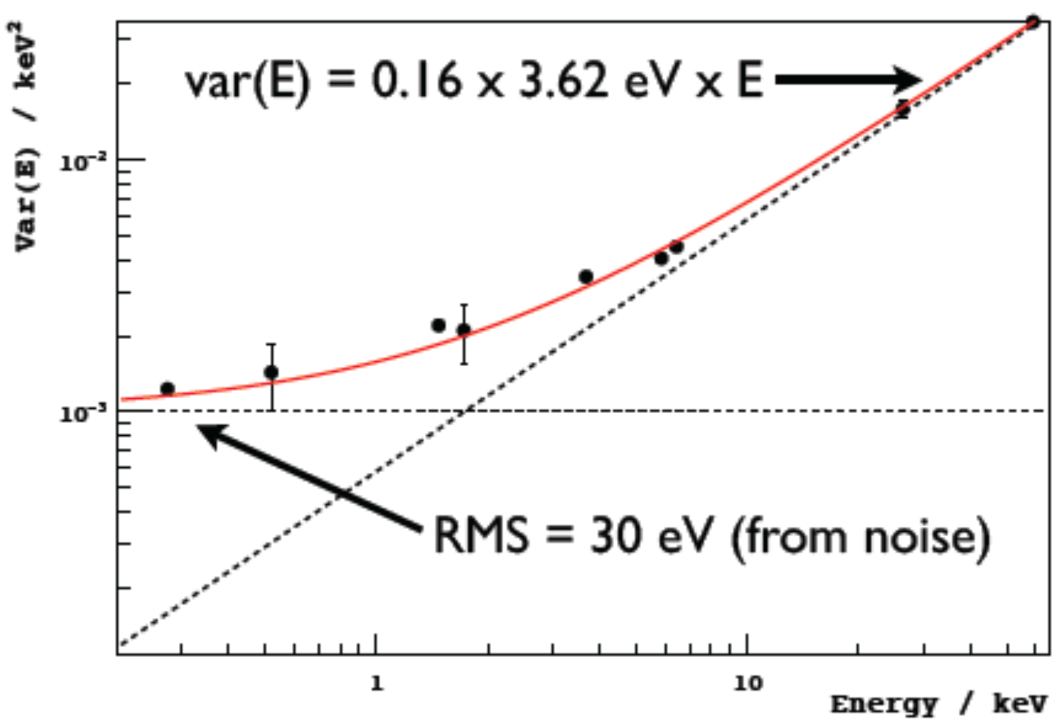
Nuclear recoils will produce diffusion limited hits. Neutrinos from reactor are expected to produce nuclear recoils at a rate of 10,000 per day for each kilogram of detector.
arXiv:1408.3263

Calibration using X-rays

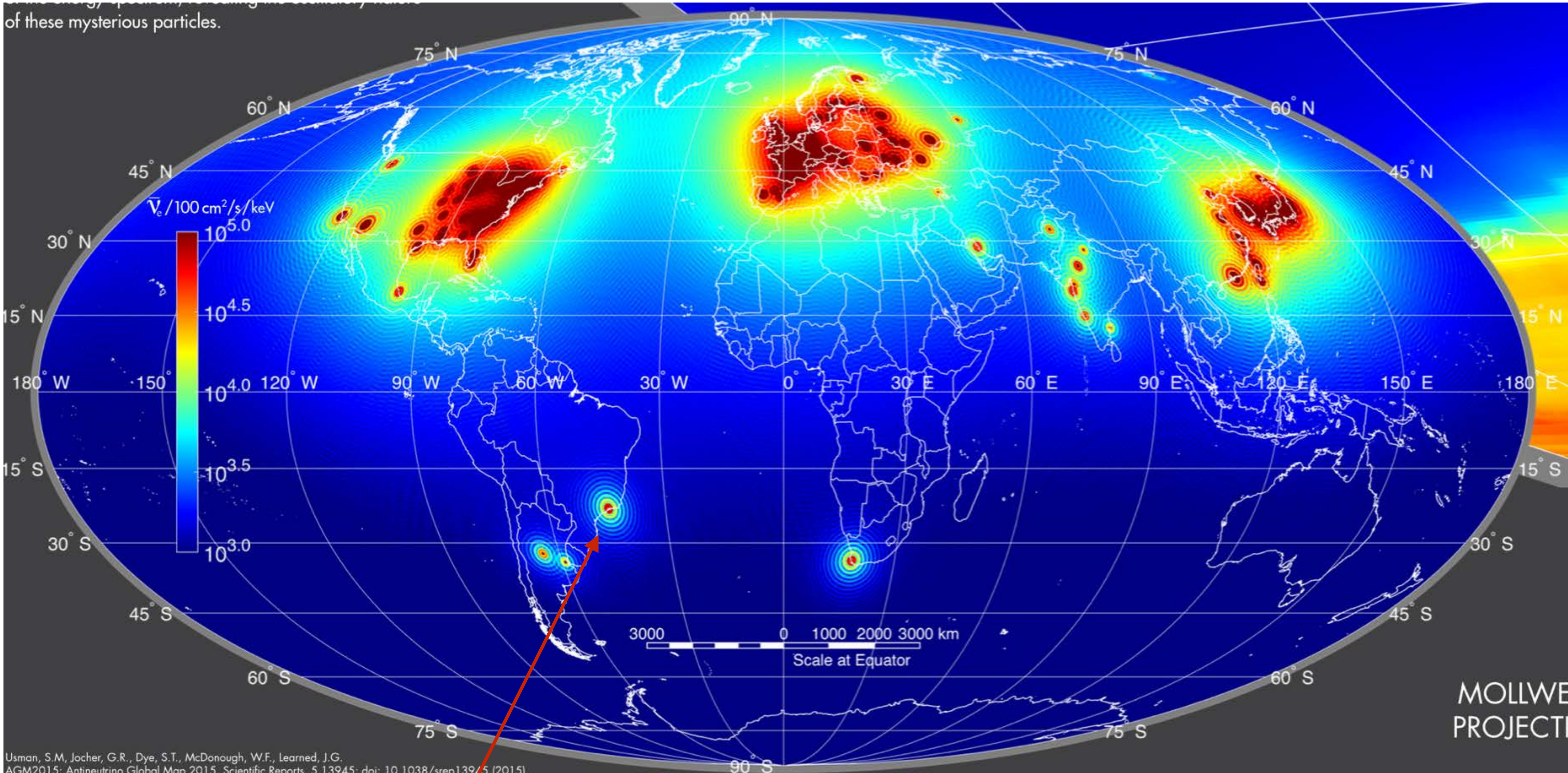








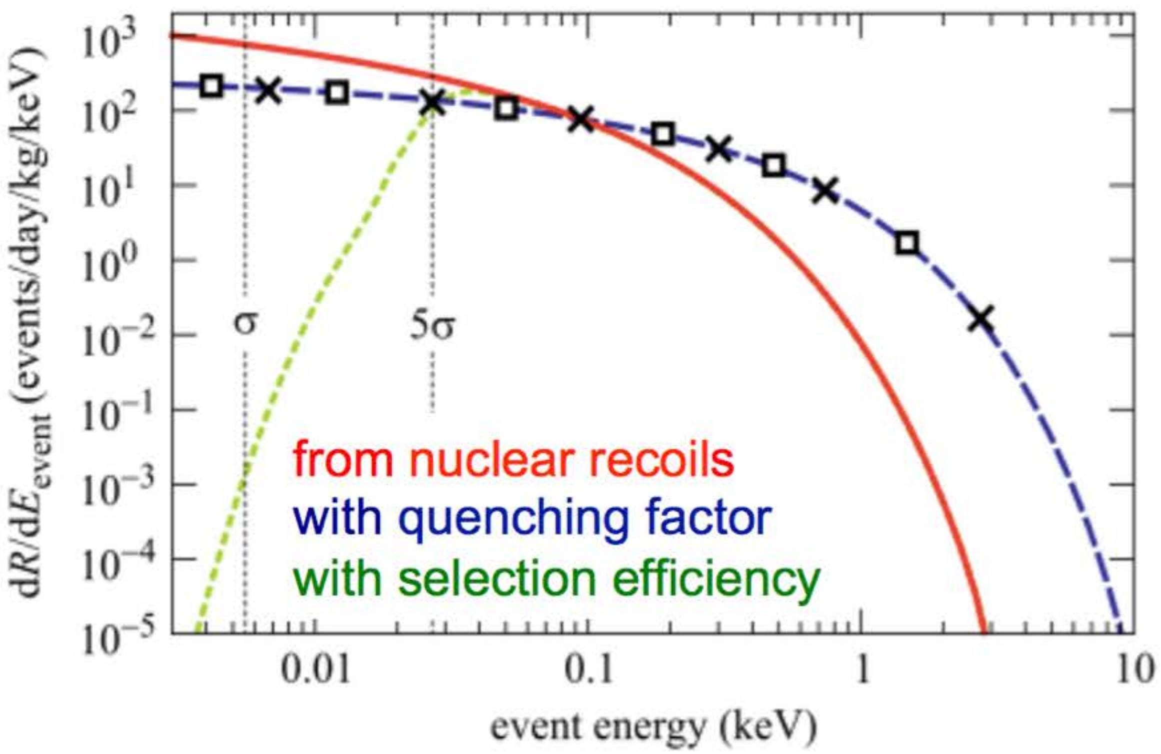
nuclear recoil calibrations are not as easy, but we have them (backup slides)



Angra II Reactor. 4GW thermal power
Angra do Reis, Rio de Janeiro, Brazil.

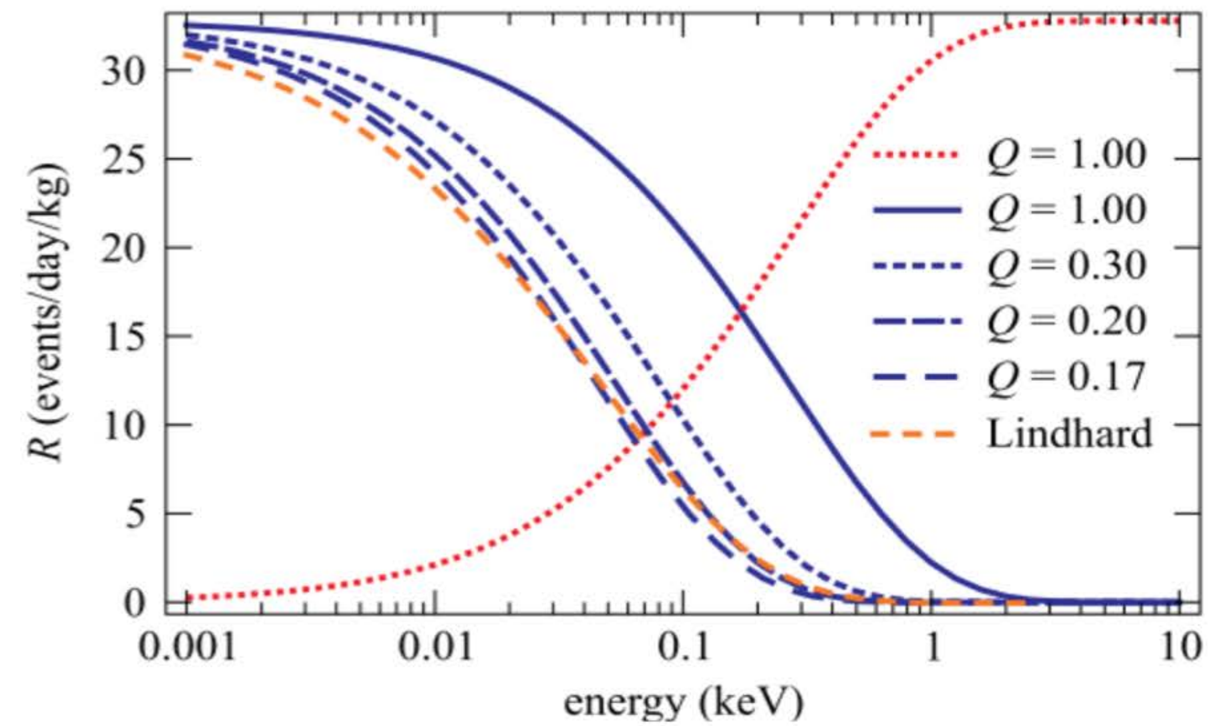
CONNIE rates

Energy spectra in silicon detectors



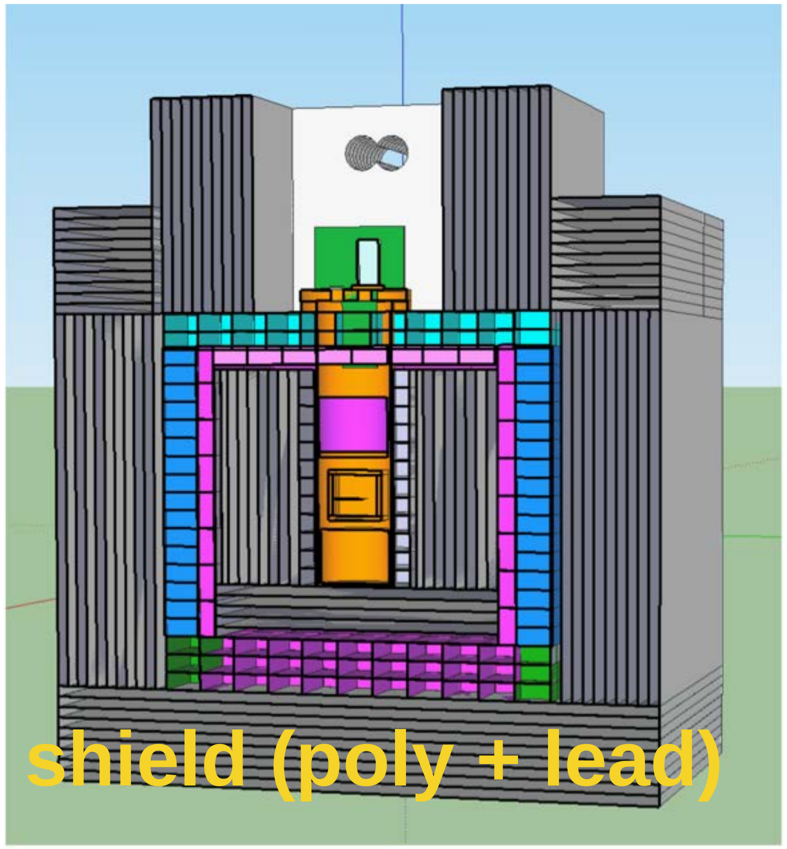
Phys.Rev. D 91, 072001 (2015)

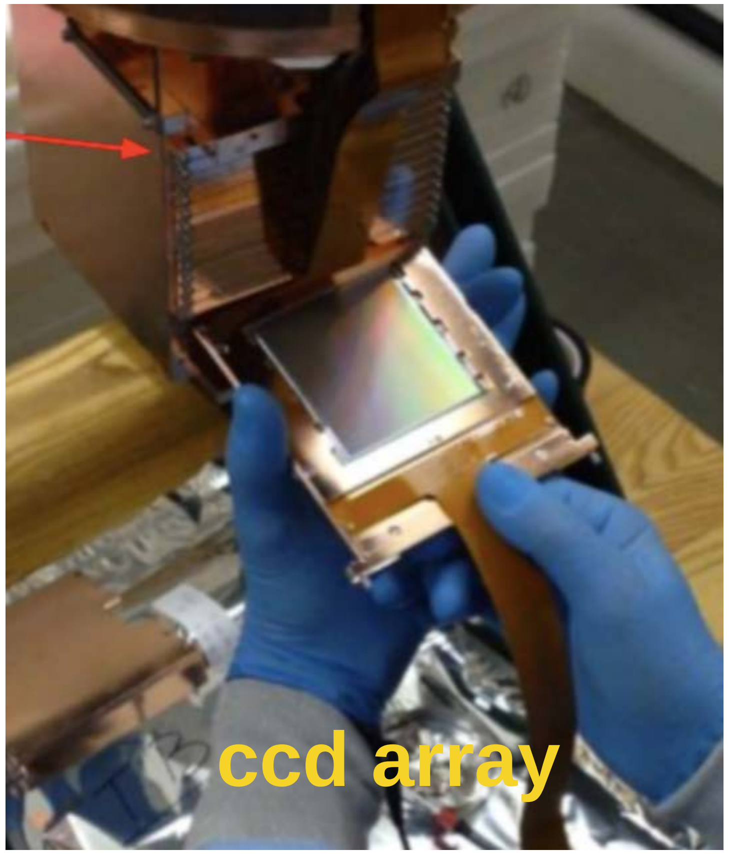
Total number of events vs threshold energy for different quenching factors

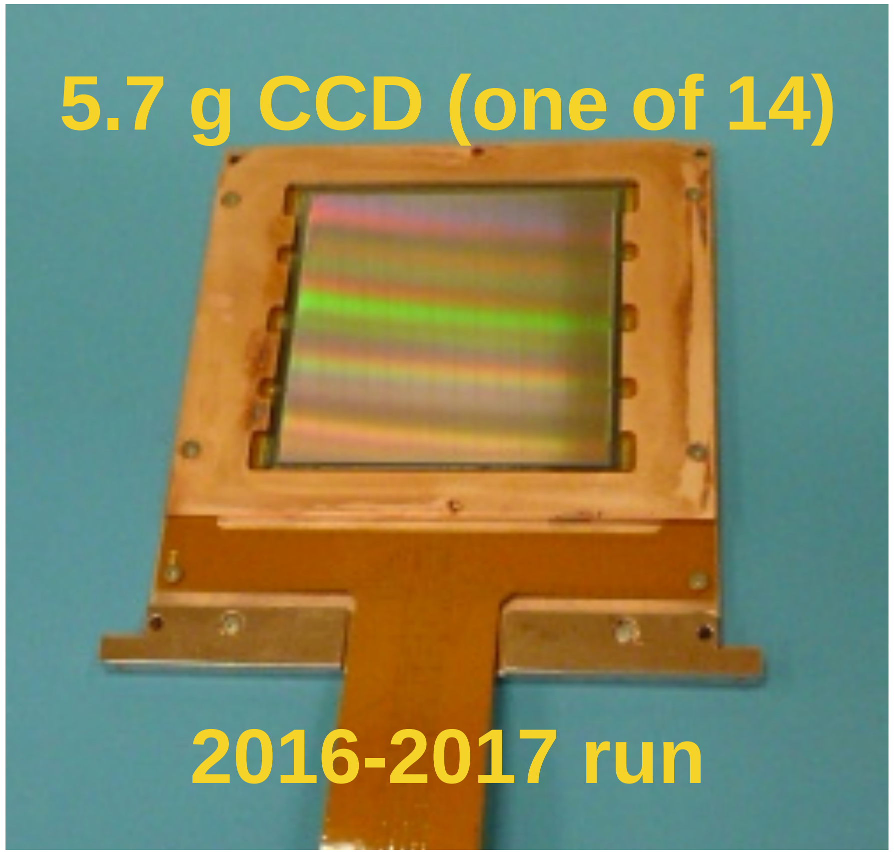


Total events vs max. detectable recoil for Q=1

Expected number of events (event/kg/day)	Q = 0.20
E_{th} = 5.5 eV ($1\sigma_{RMS}$)	~ 28.3
E_{th} = 28 eV ($5\sigma_{RMS}$)	~ 18.1







originally we developed this technology for DAMIC (dark matter search)

2016 JINST 11 P07024

First reactor ON/OFF comparison was done using the shutdown period at the end of 2015. With a detector of **1 gram.**

Technology demonstration.

Now:

- Higher mass (x50)
- Lower noise (20%)
- Lower background (x10)

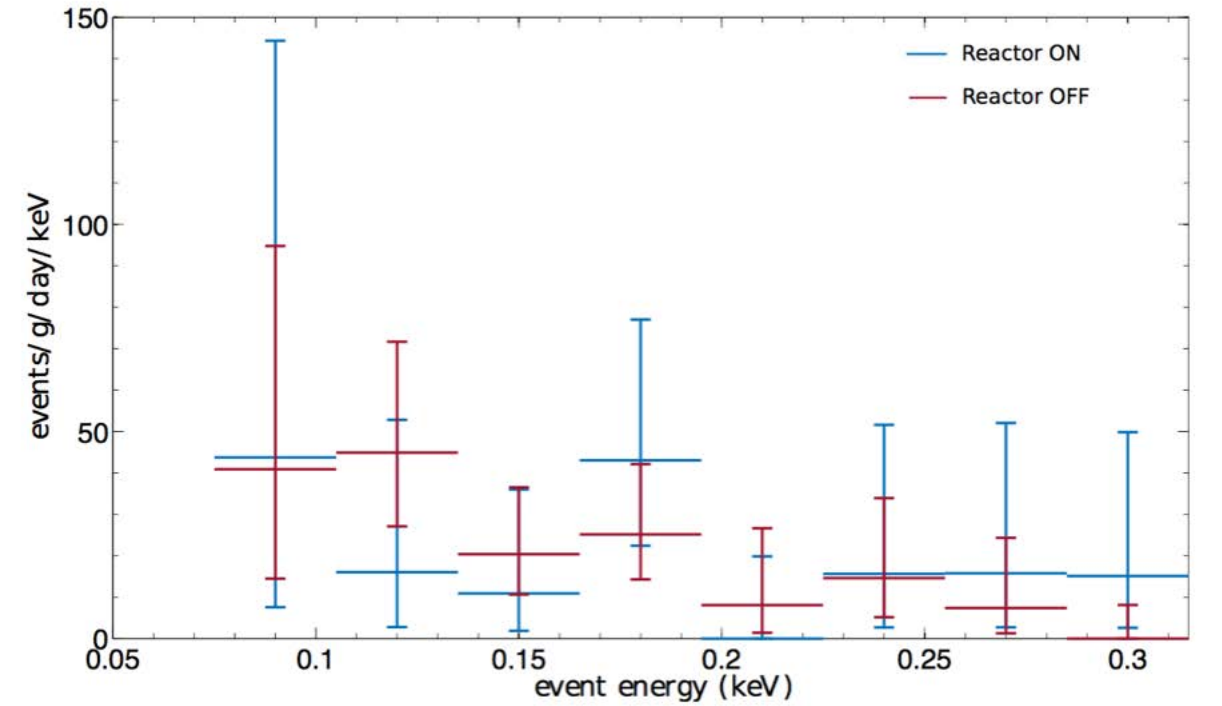
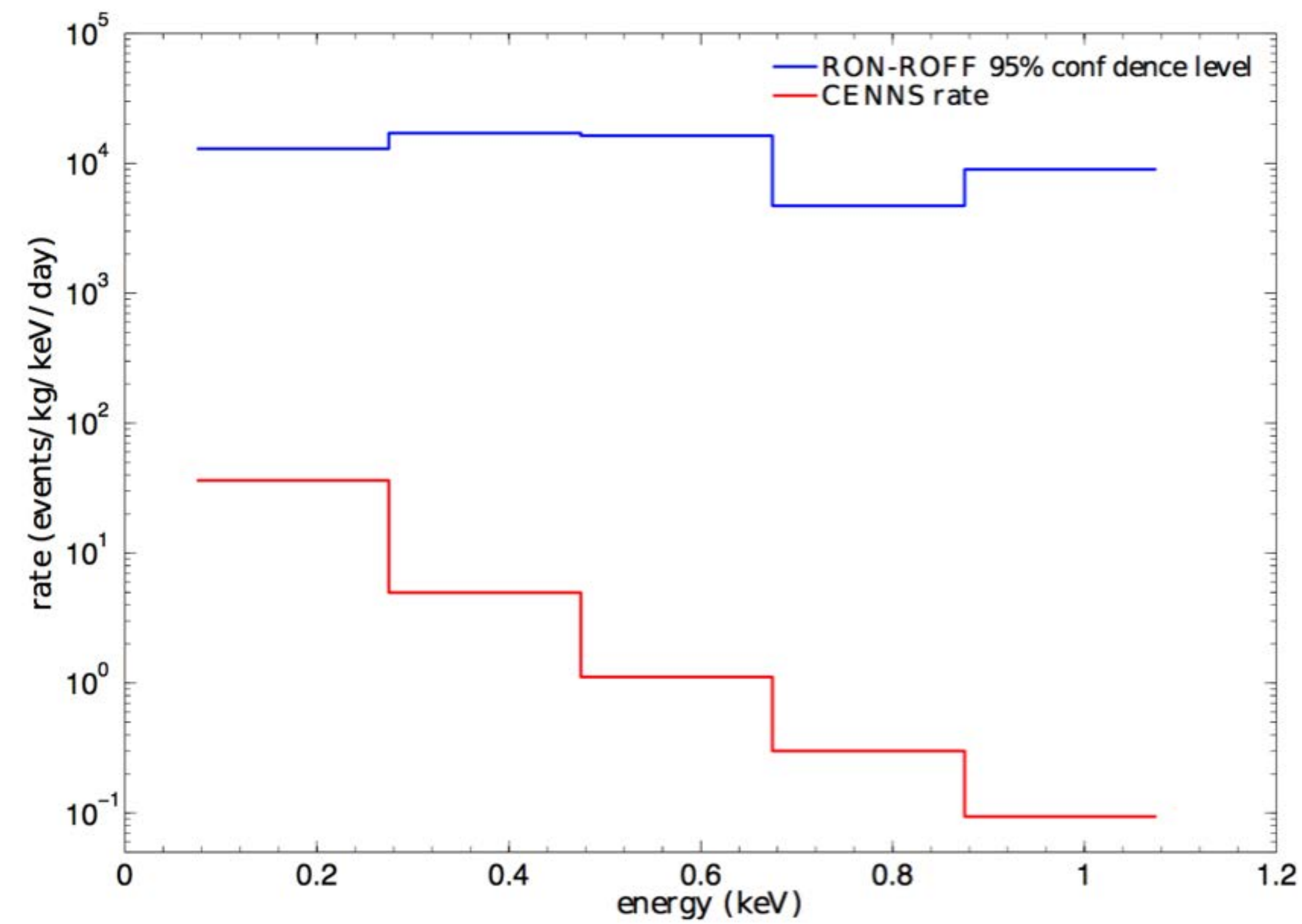
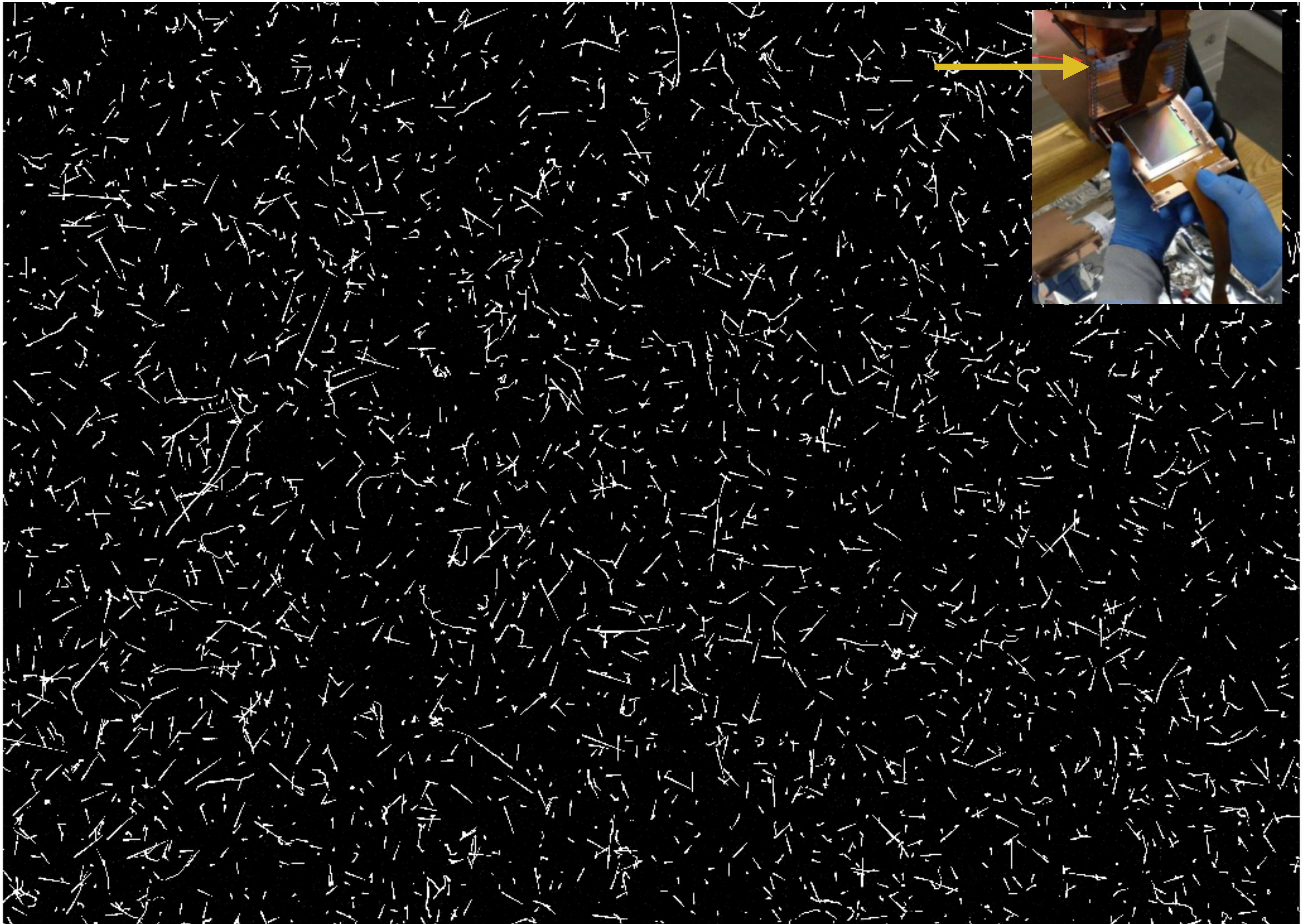
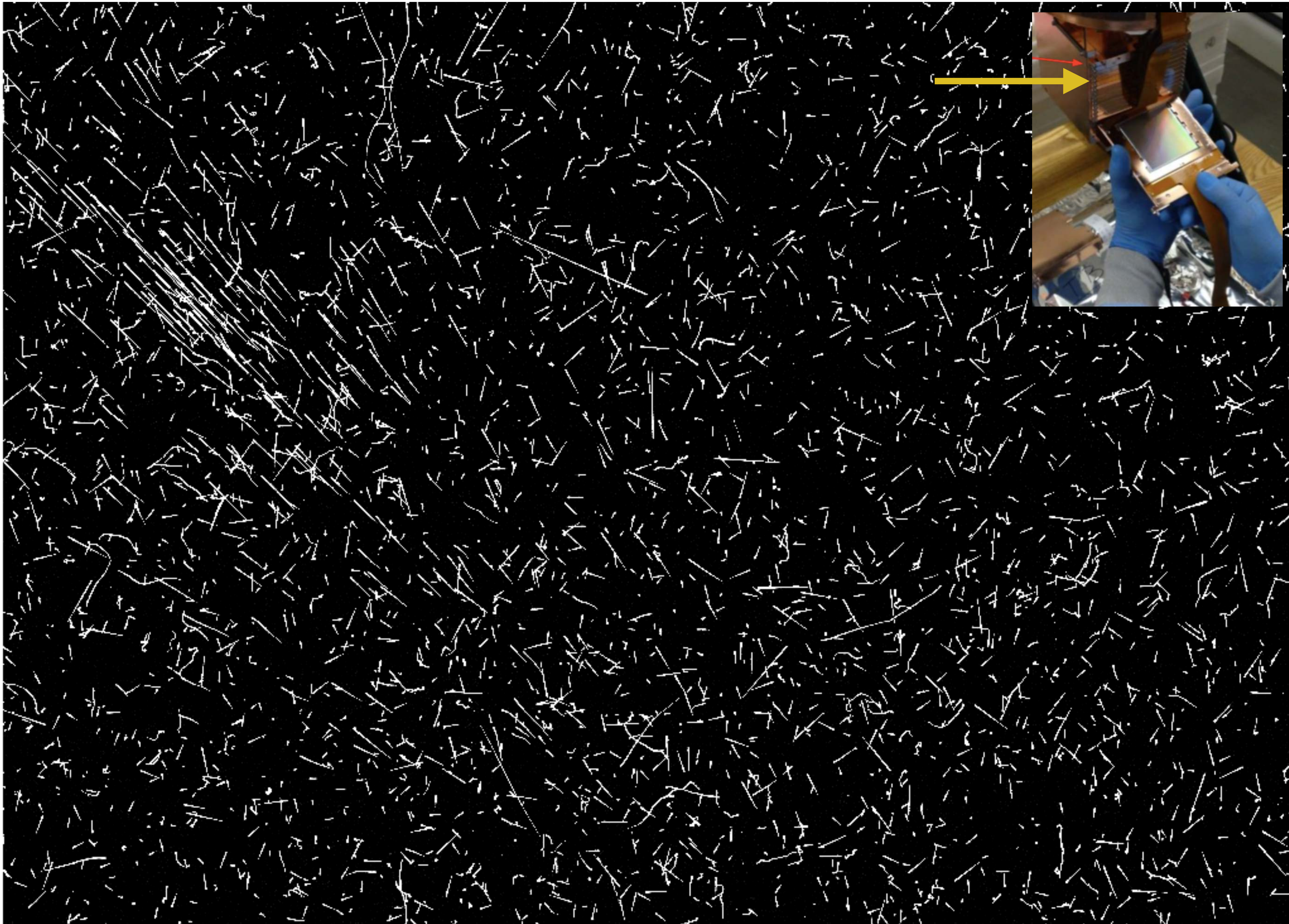
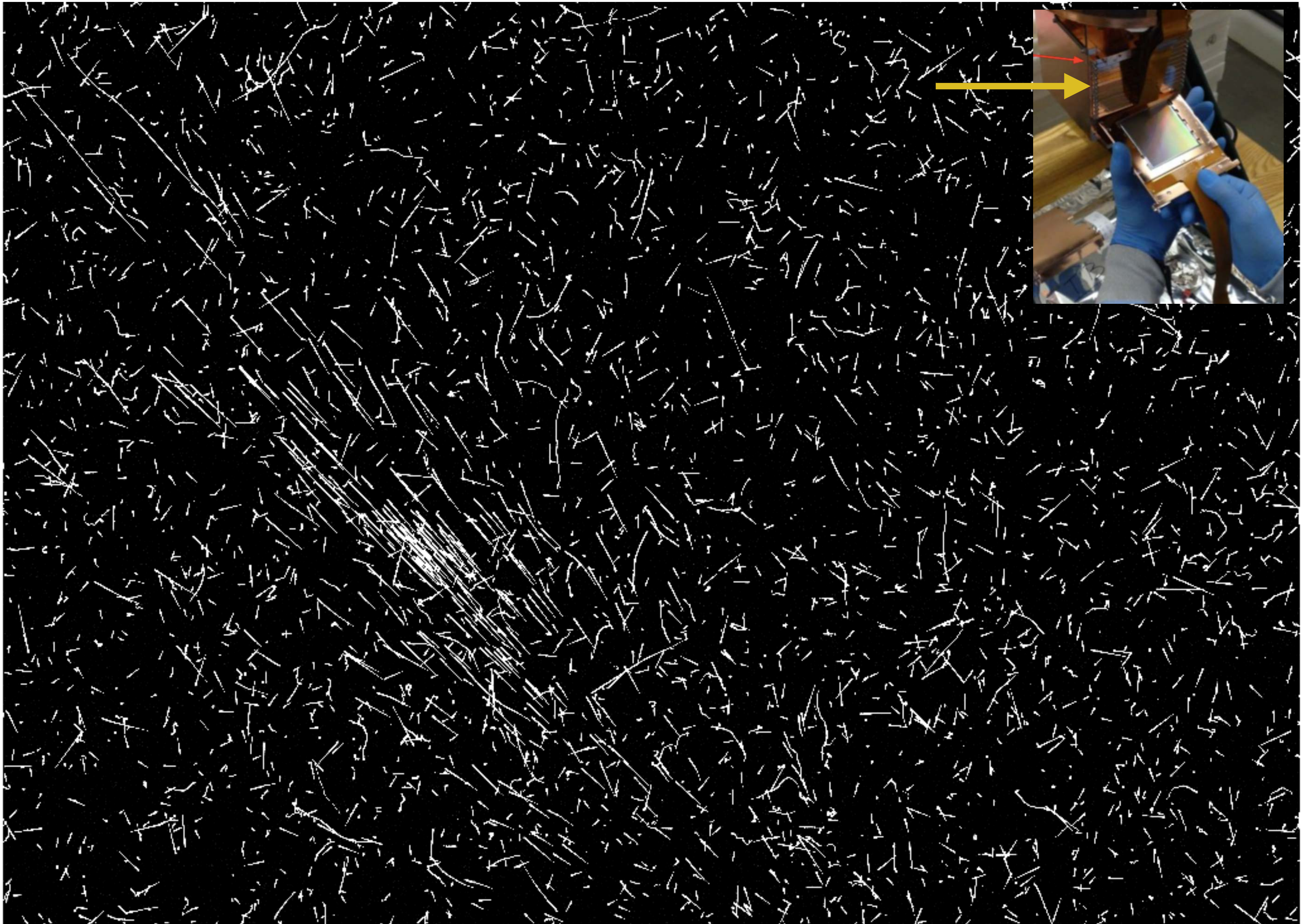


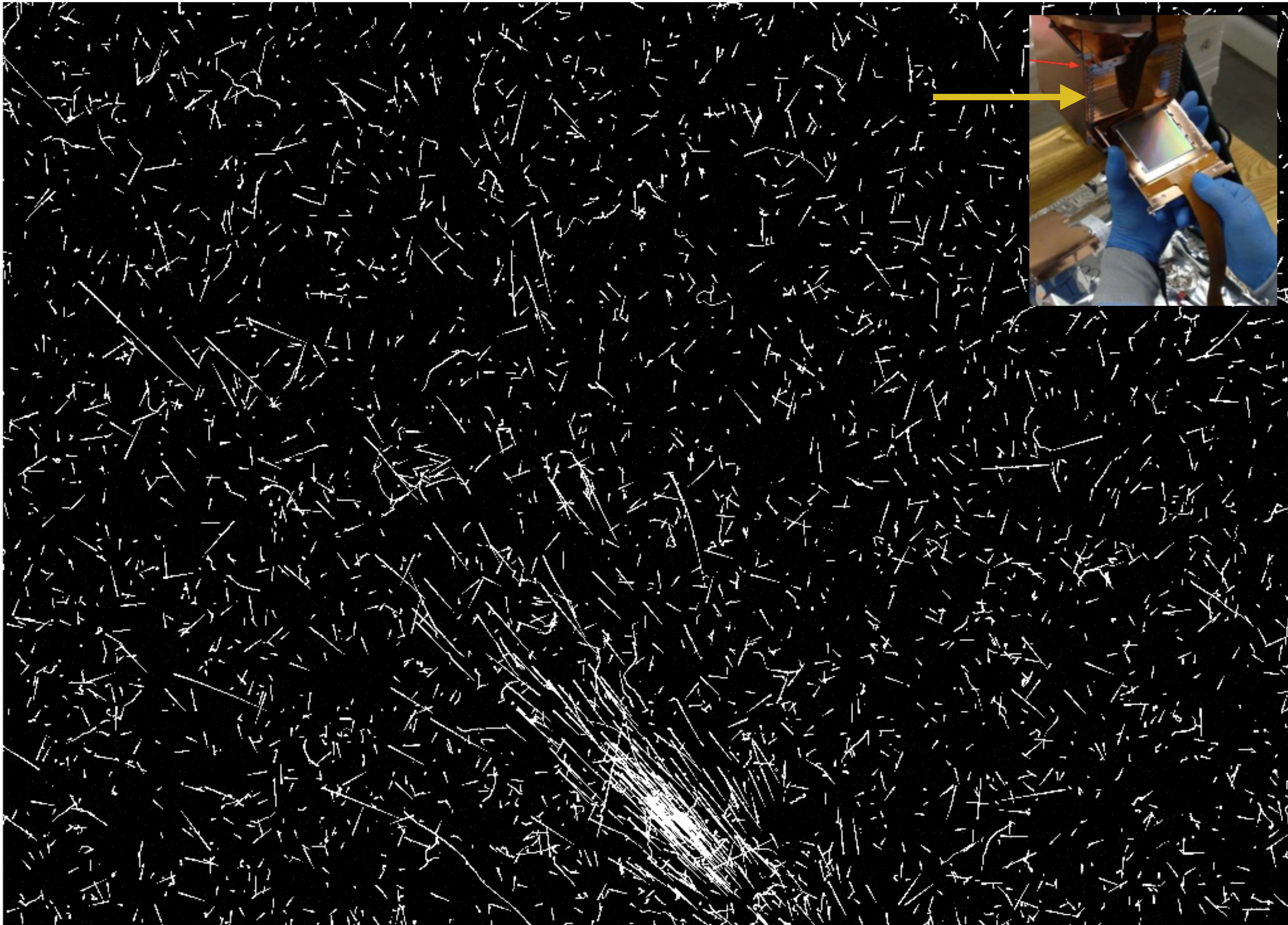
Figure 17: Same as Fig.16, the error bars correspond to 68.27% probability assuming a Poisson distribution for each energy bin.



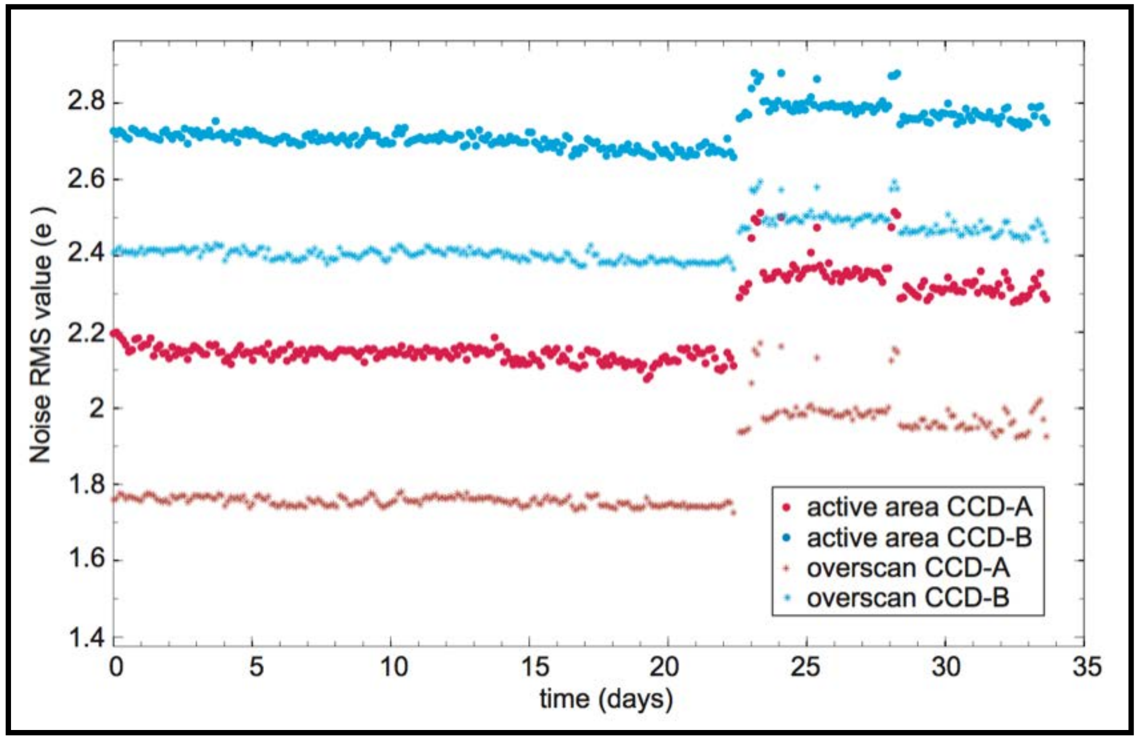








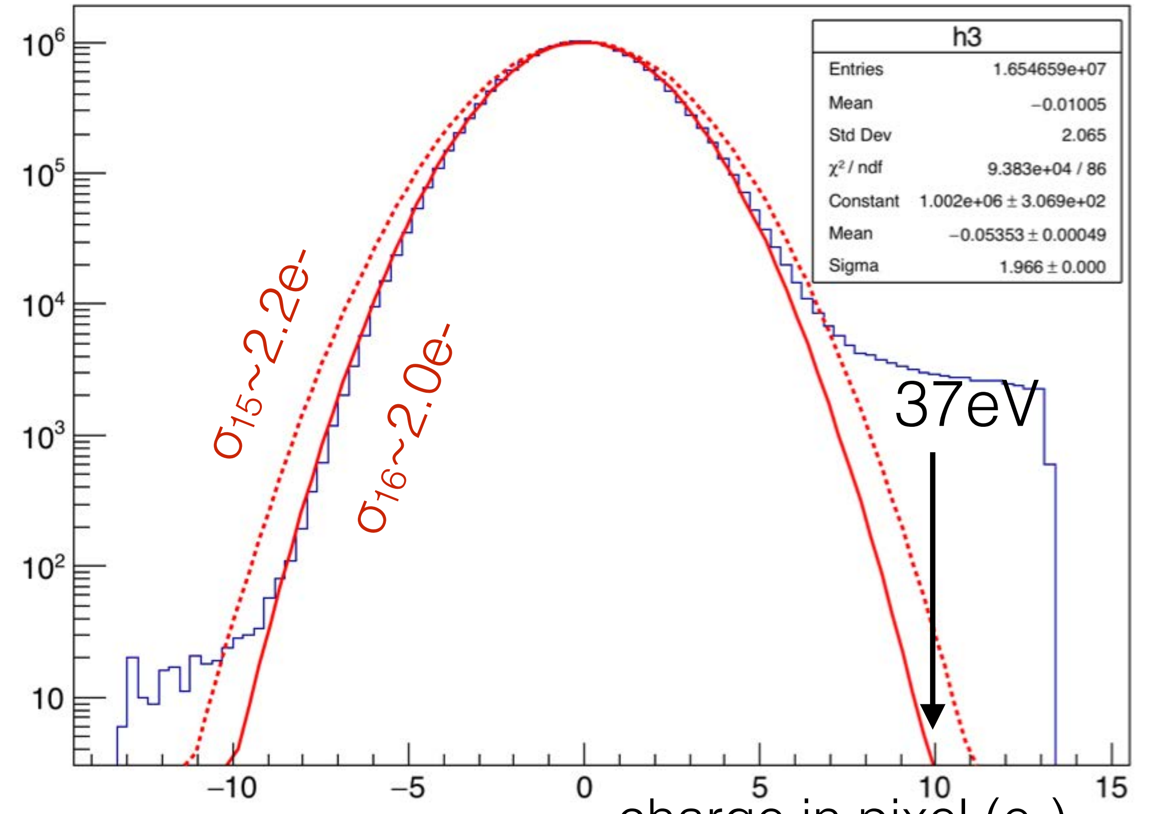
2015 engineering run

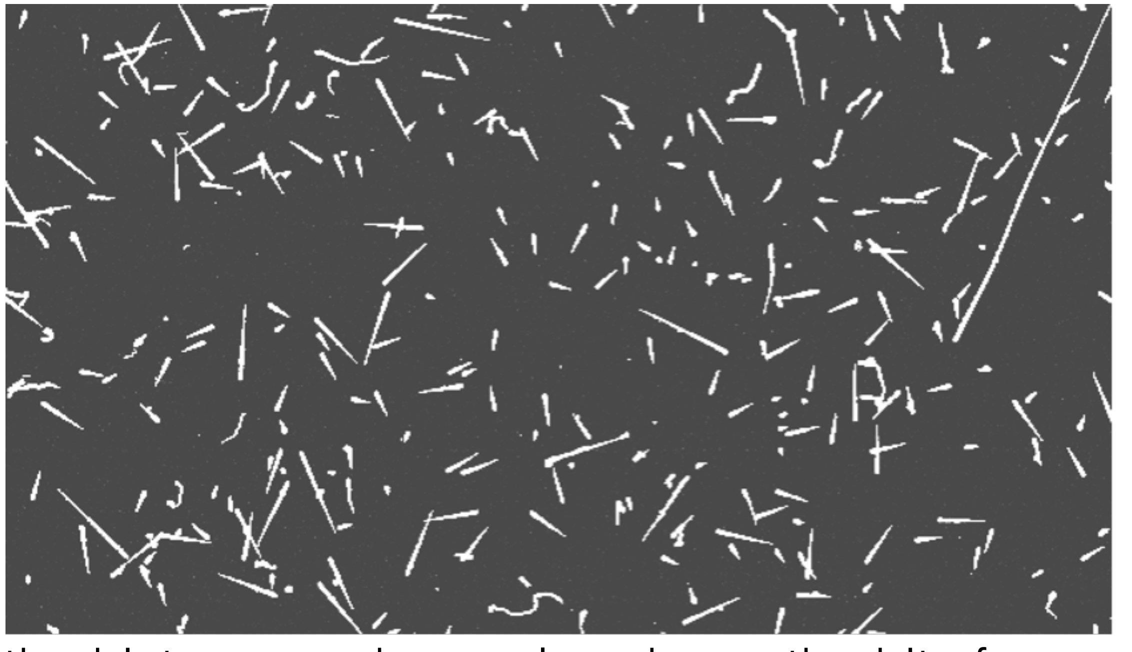


2015 we had a 2.2e- noise in the best CCD for the active area of the detector. This means that we had dark current, or IR photons hitting the detectors.

This 10% decrease in the noise is a big deal. It corresponds to ~10 increase in the rate of noise hits at ~35 eV.

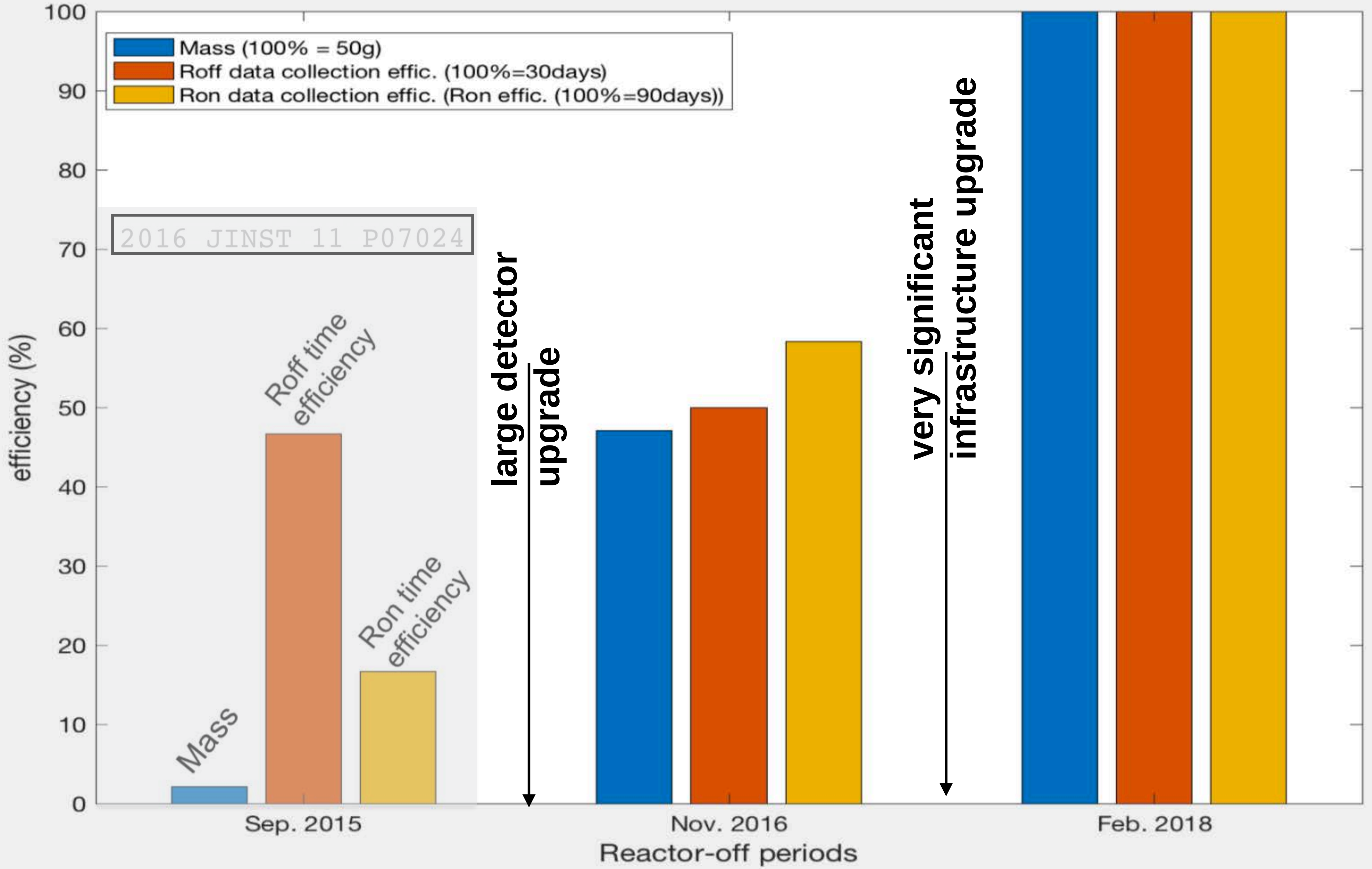
2016 image example

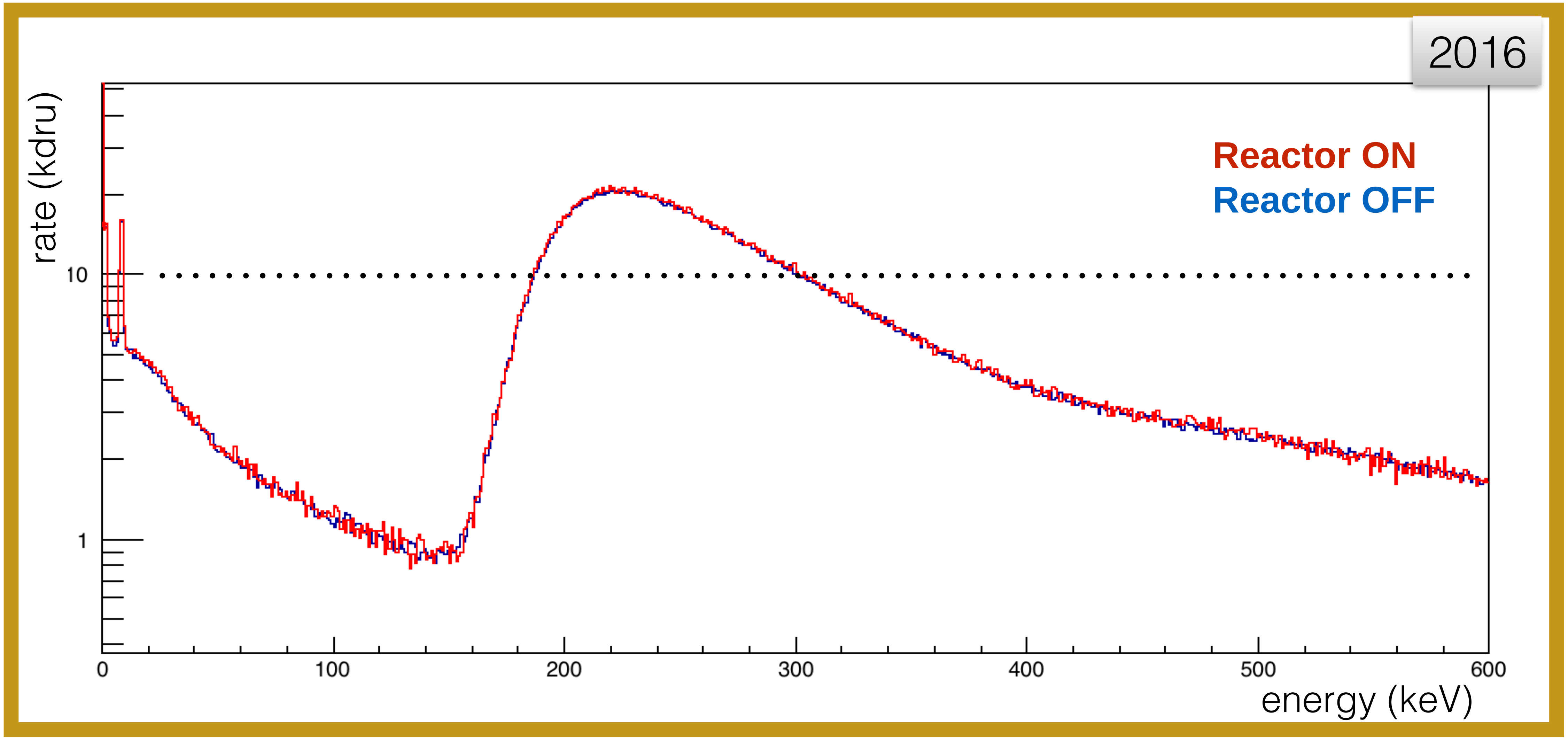


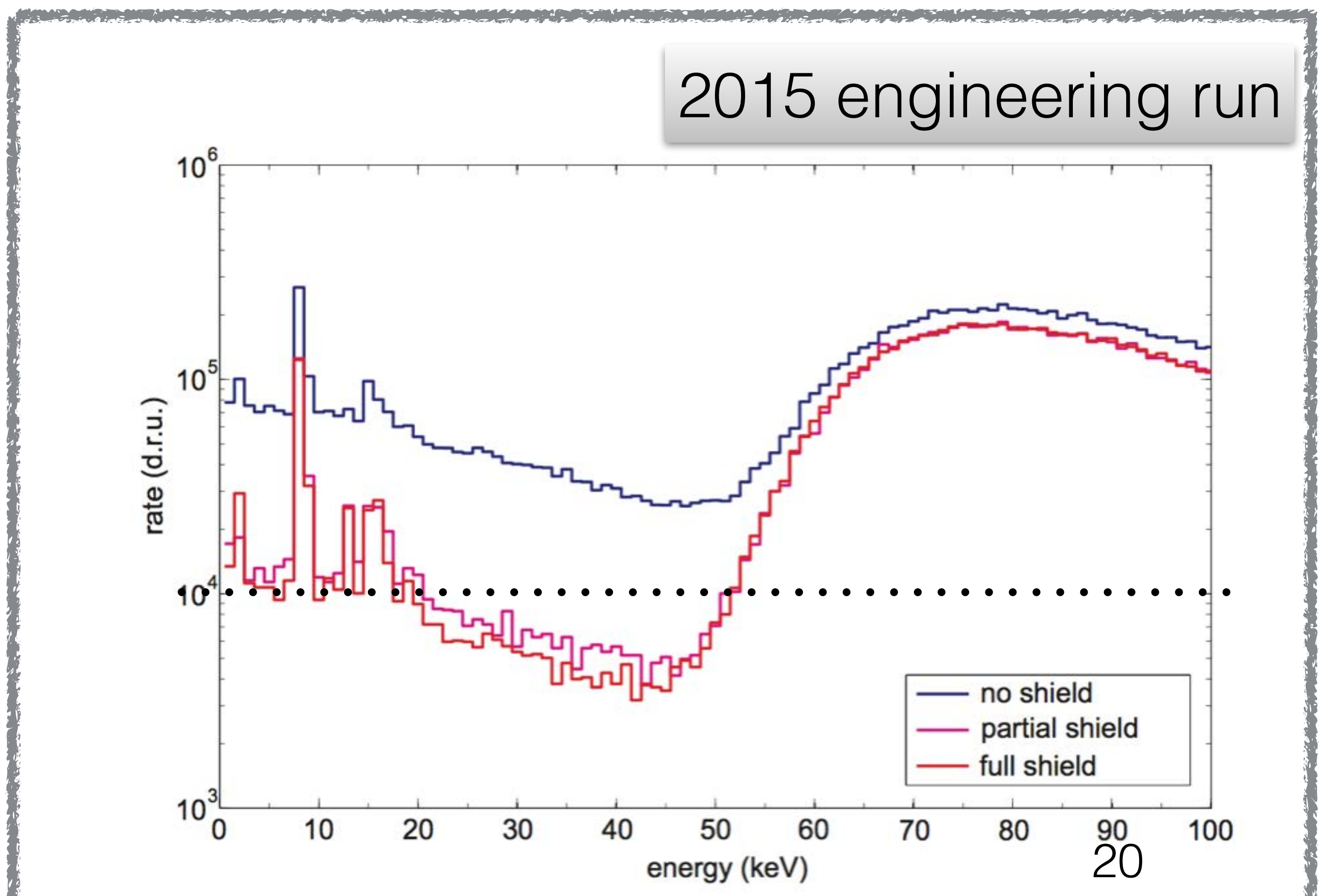


the histogram above also shows the hits from real tracks.

operation improvements in CONNIE : **statistics going up fast. By this time next year we will have 5 times the statistics.**



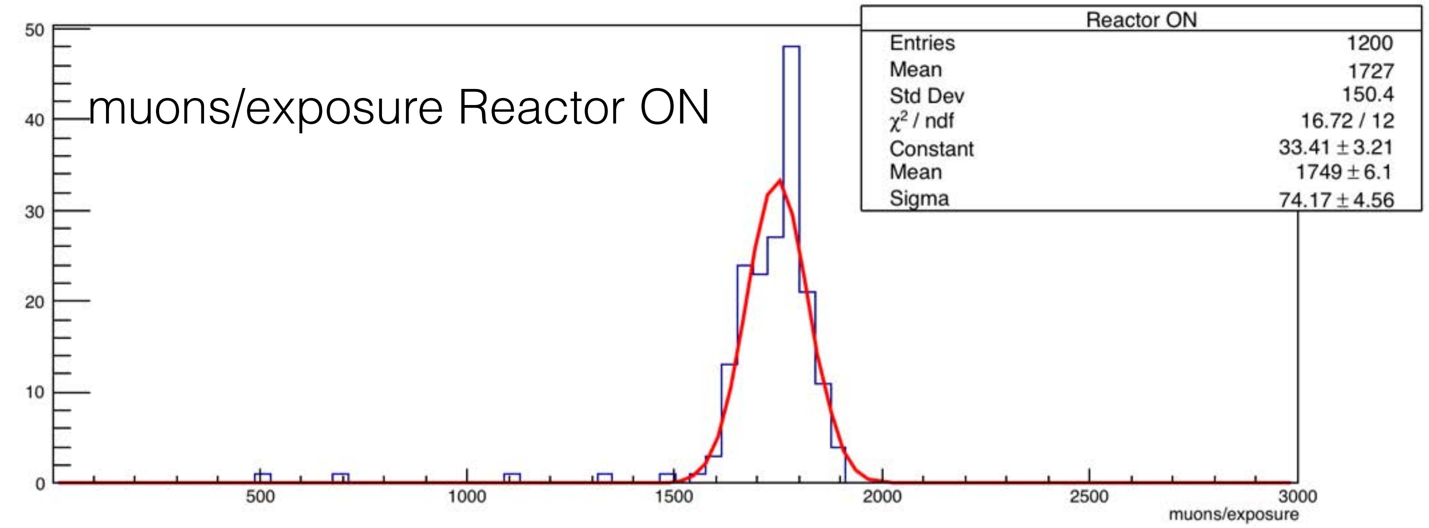




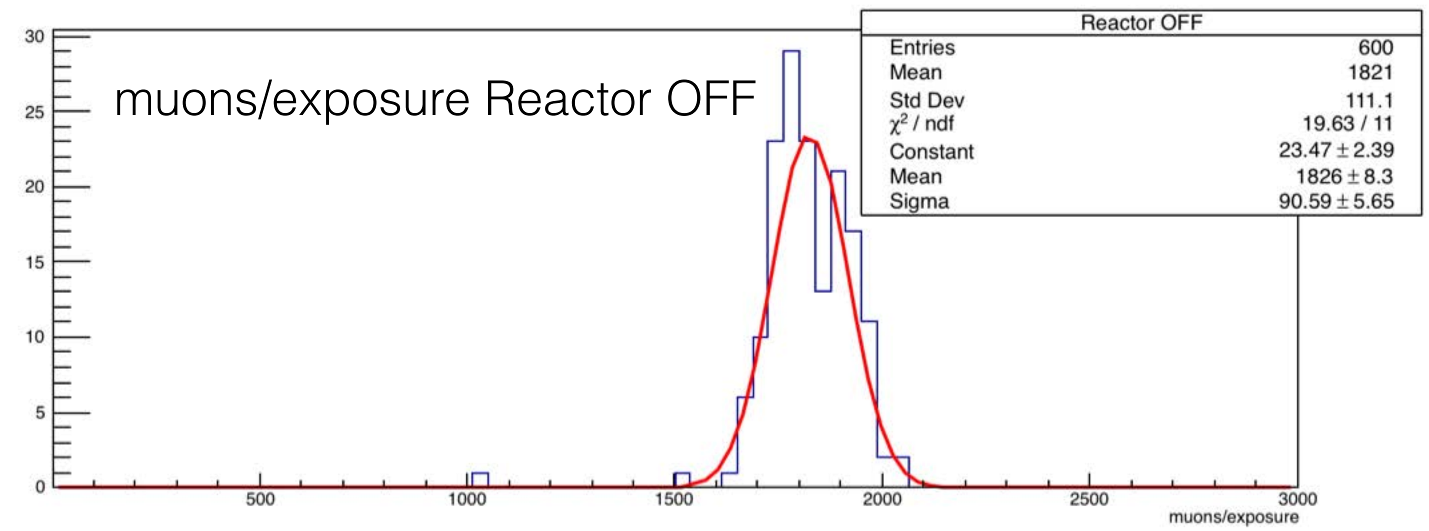
background improvement in the new configuration. We eliminated ceramic spacer (AlN) in the detector package. This eliminated all the ~15 keV lines produced by the U and Th decays. It also lowered the background significantly.

The bump from muon tracks is now at 250 keV because we went from 250um silicon to 675 um.

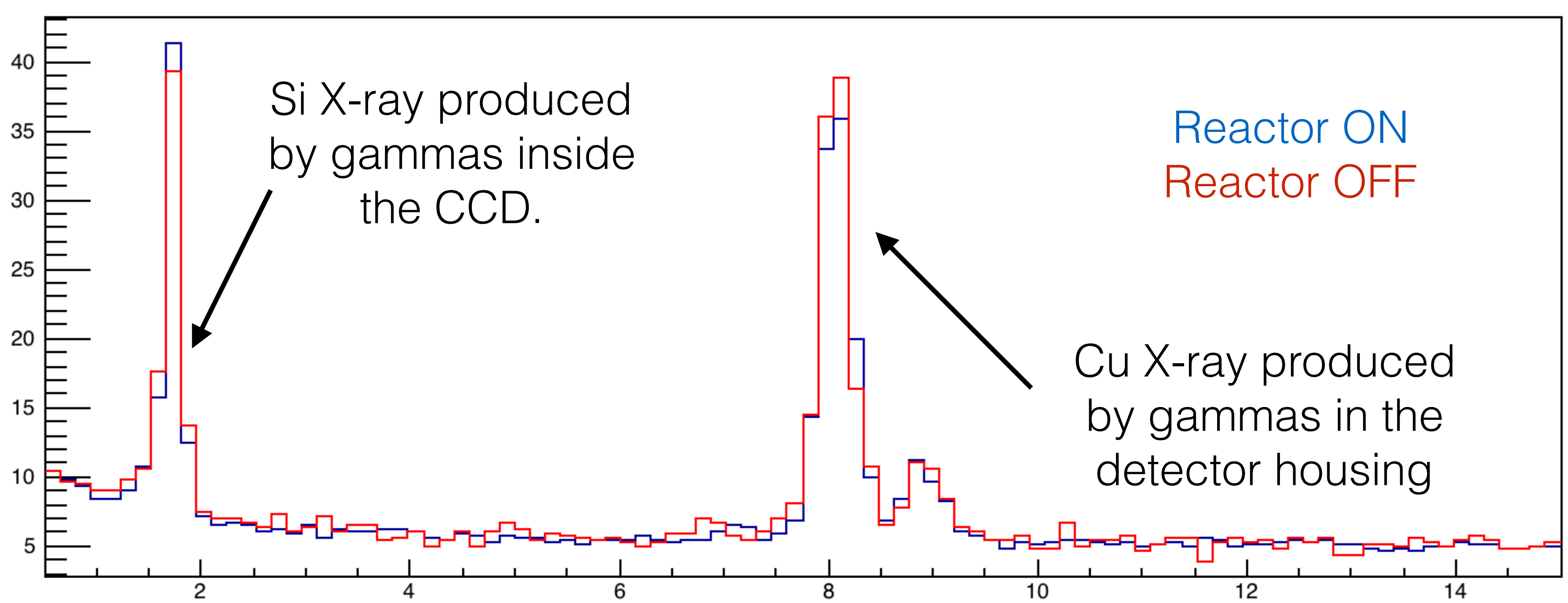
Comparing Reactor ON/ OFF backgrounds.

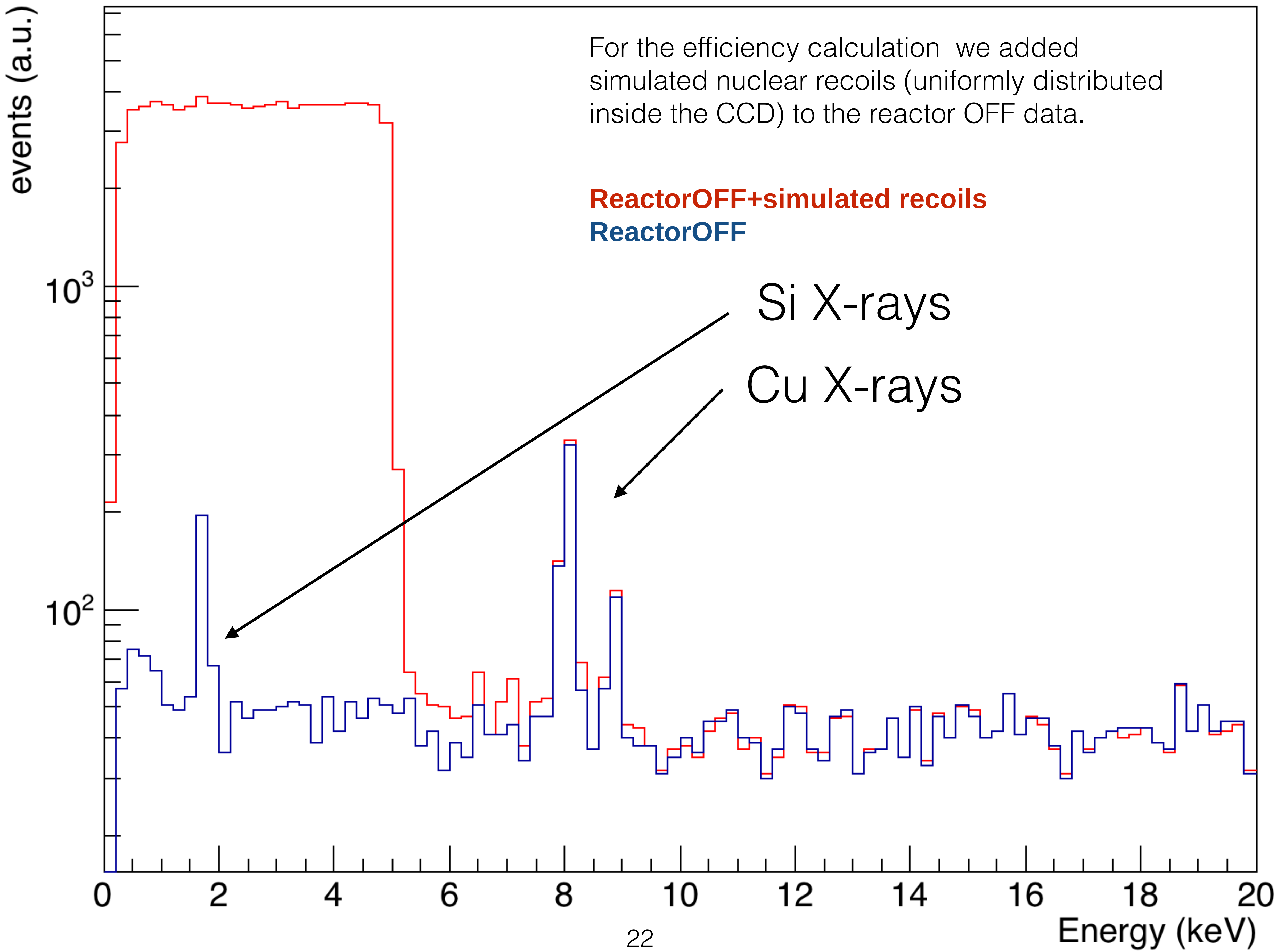


the muon flux is not the same, it is higher when the reactor is OFF. Makes sense due to weather.



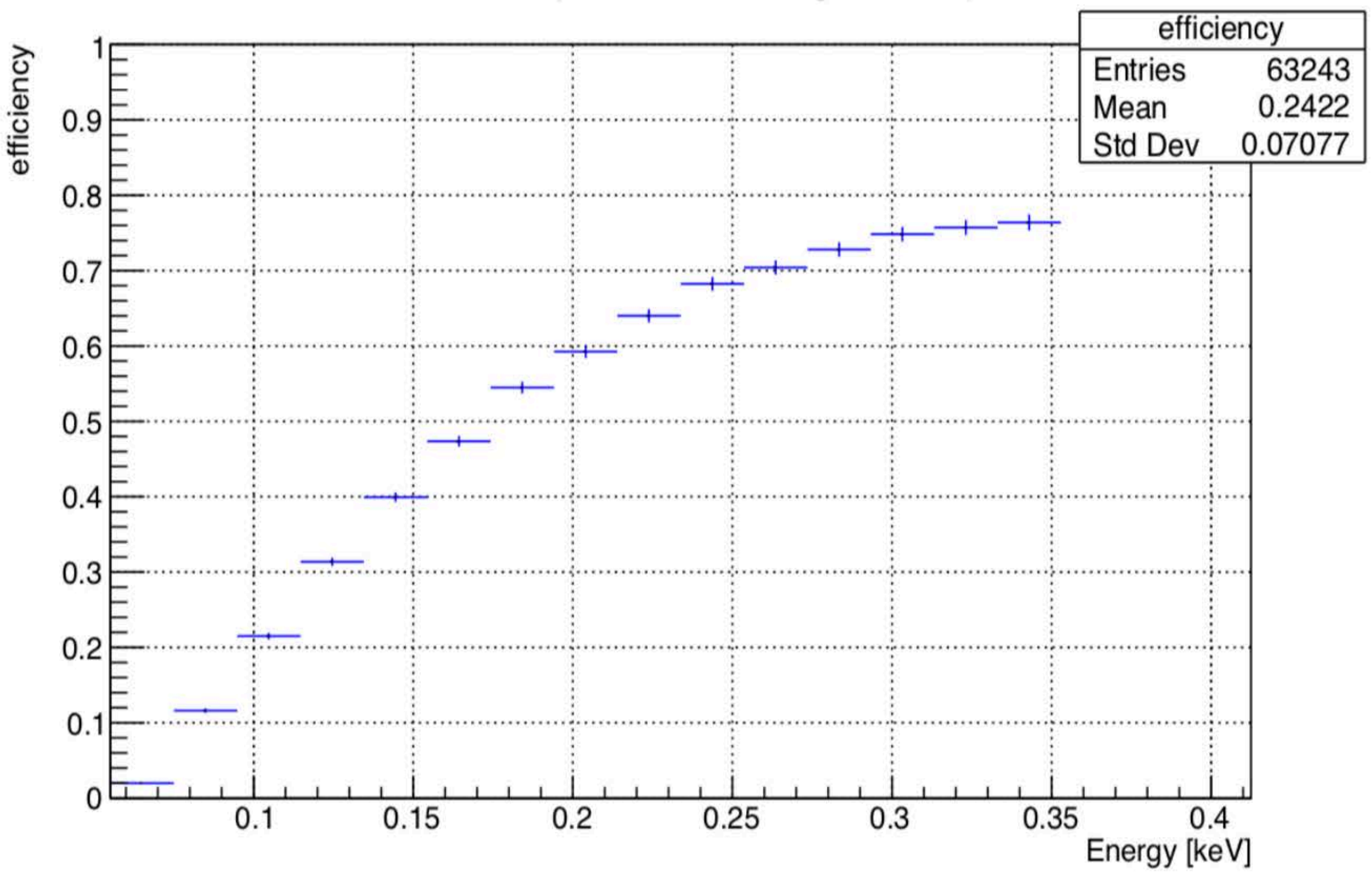
fluorescence X-rays are the same reactor ON/OFF. This point to a stable gamma background.



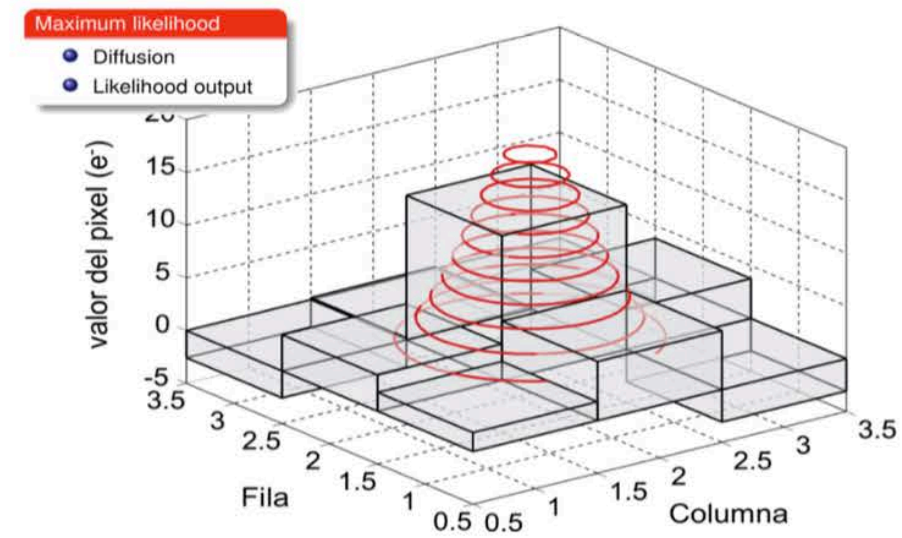


For the efficiency calculation we added simulated nuclear recoils (uniformly distributed inside the CCD) to the reactor OFF data.
ReactorOFF+simulated recoils
ReactorOFF
Si X-rays
Cu X-rays
events (a.u.)
10^3
10^2
0
2
4
6
8
10
12
14
16
18
20
Energy (keV)

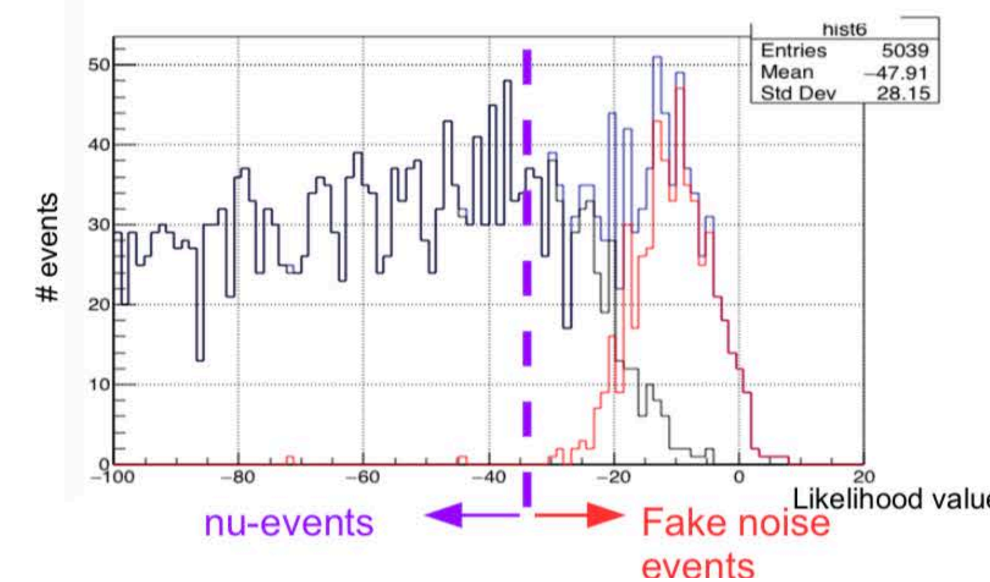
now selecting the low energy events…



- **Need to improve our low energy extraction**
- **Higher efficiency can be get using binning, with the drawback of loosing spatial information of the events.**

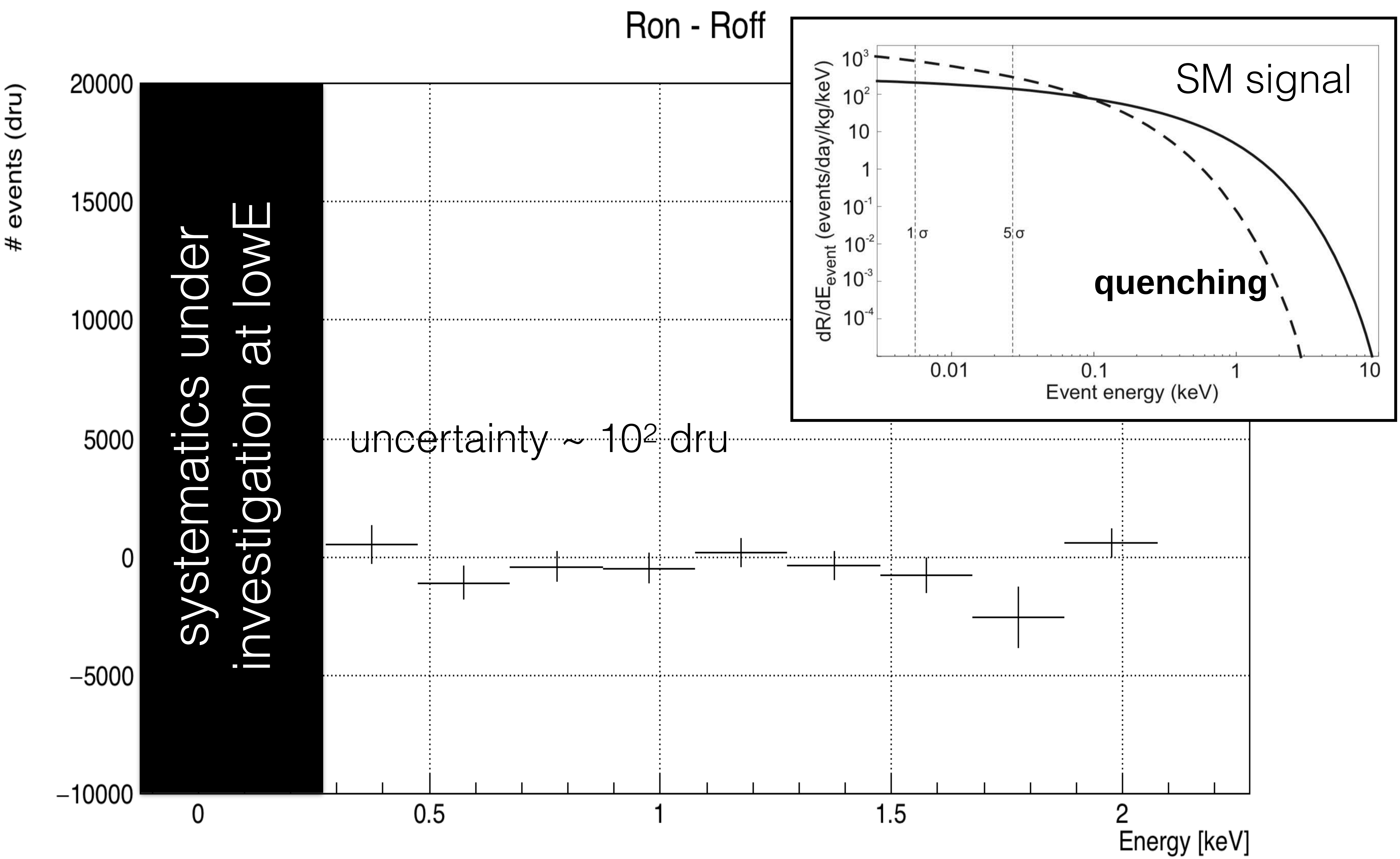


Simulation of nu events + noise



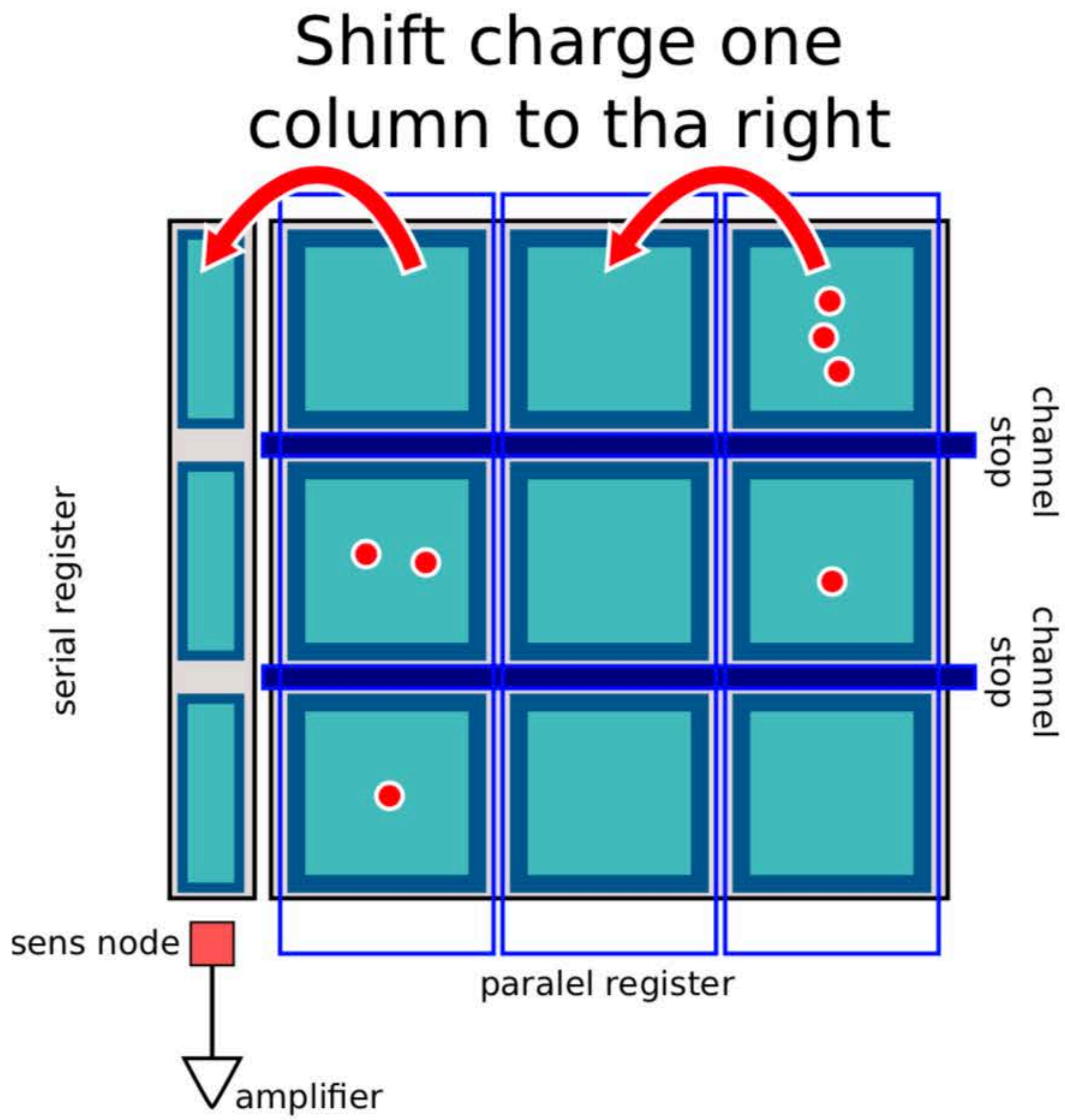
Likelihood measures the probability of the event being compatible with a noise fluctuation. Selection cut in this likelihood variable.

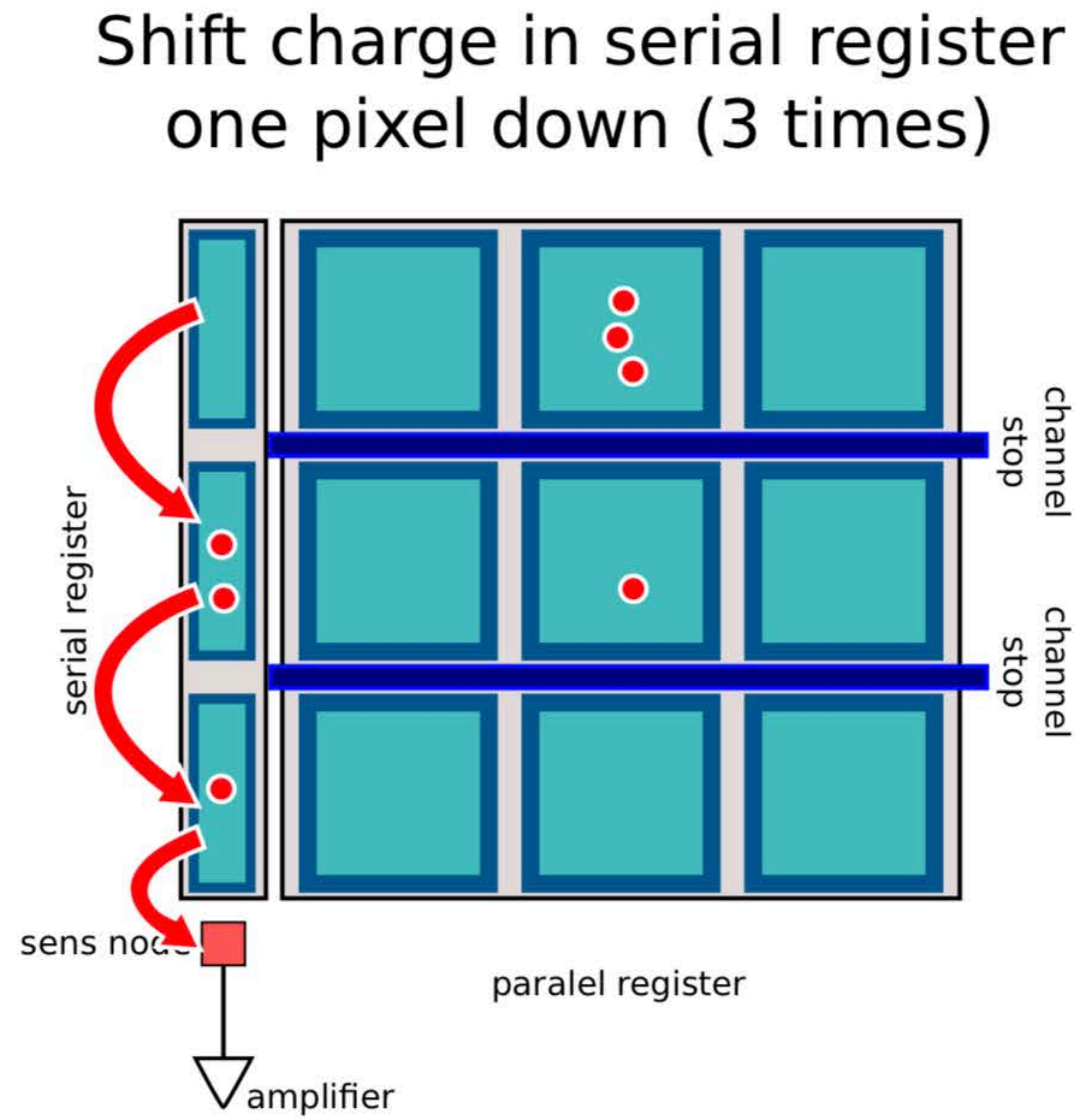
with CONNIE data today, **New results coming soon!**

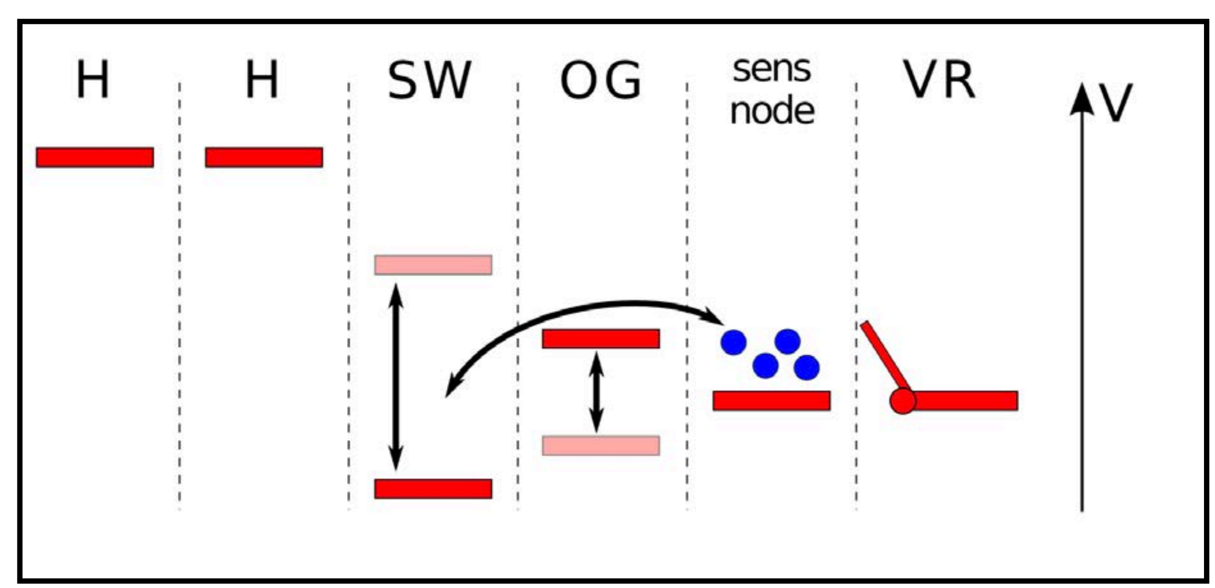


skipper-CCD

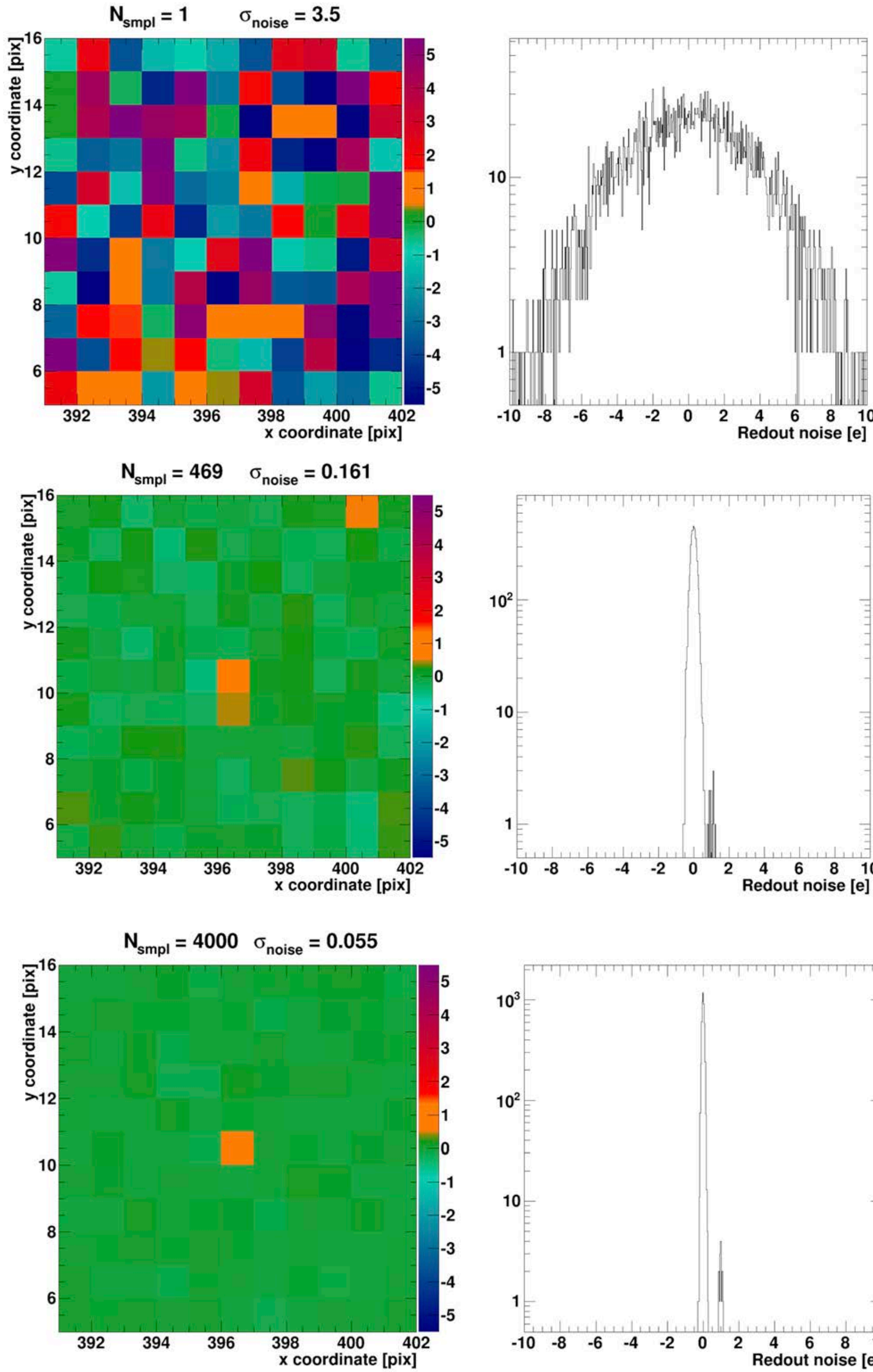
The skipper-CCD is a modification of the output stage of a CCD (Janesik et al -1990). It allows for multiple non-destructive readout of the charge in a pixel.







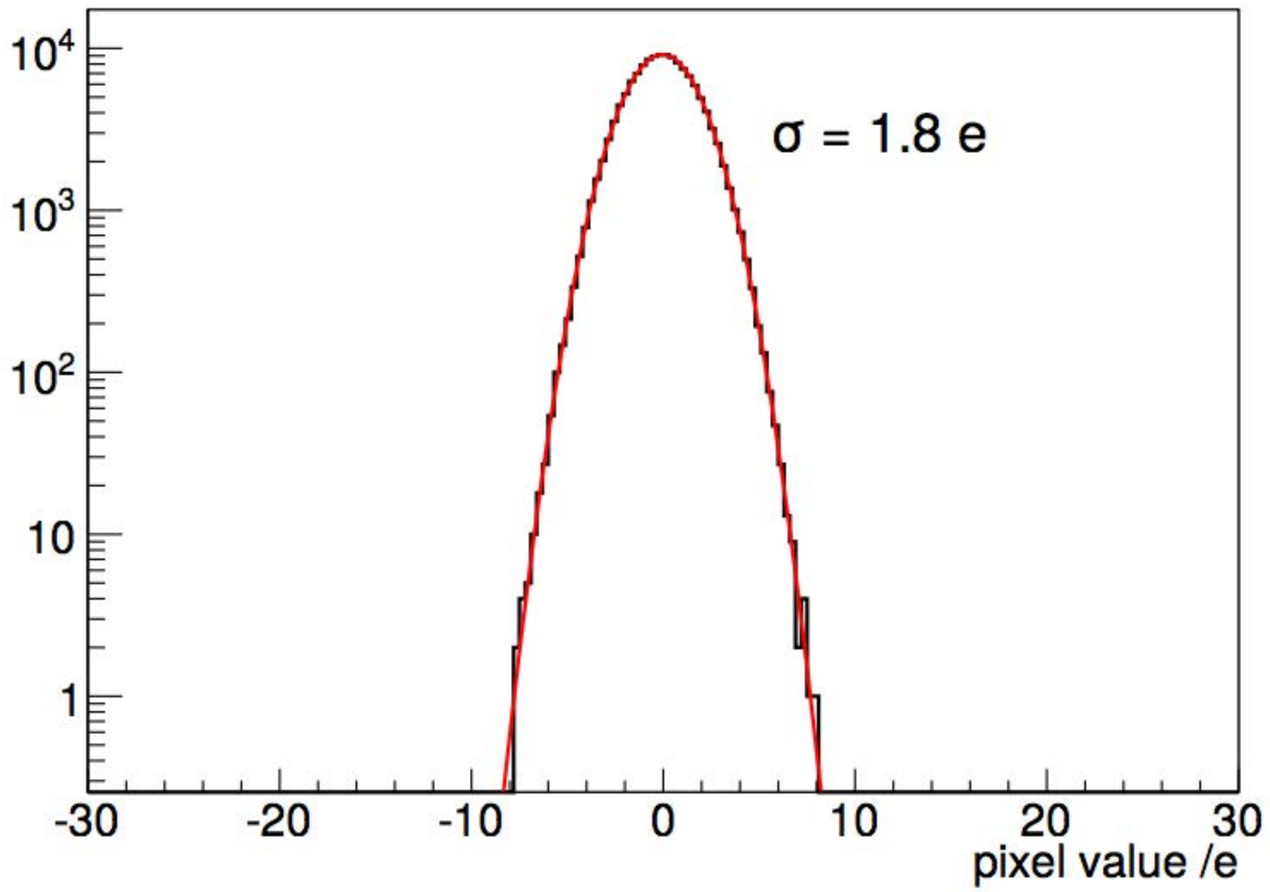
the new skippers



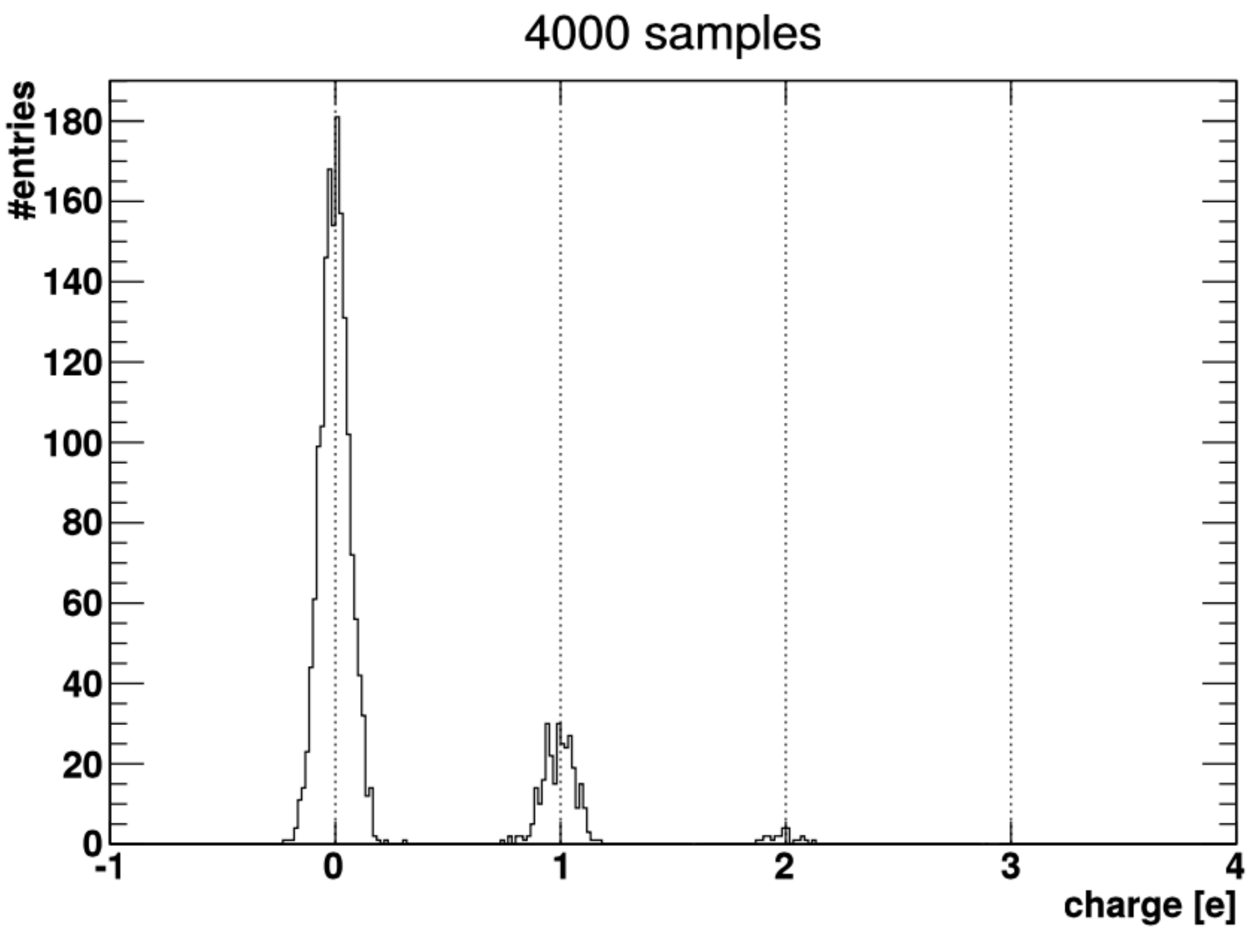
Single-electron and single-photon sensitivity with a silicon Skipper CCD

Javier Tiffenberg,[1,*] Miguel Sofo-Haro,[2,1] Alex Drlica-Wagner,[1] Rouven Essig,[3]
Yann Guardincerri,[1,†] Steve Holland,[4] Tomer Volansky,[5] and Tien-Tien Yu[6]

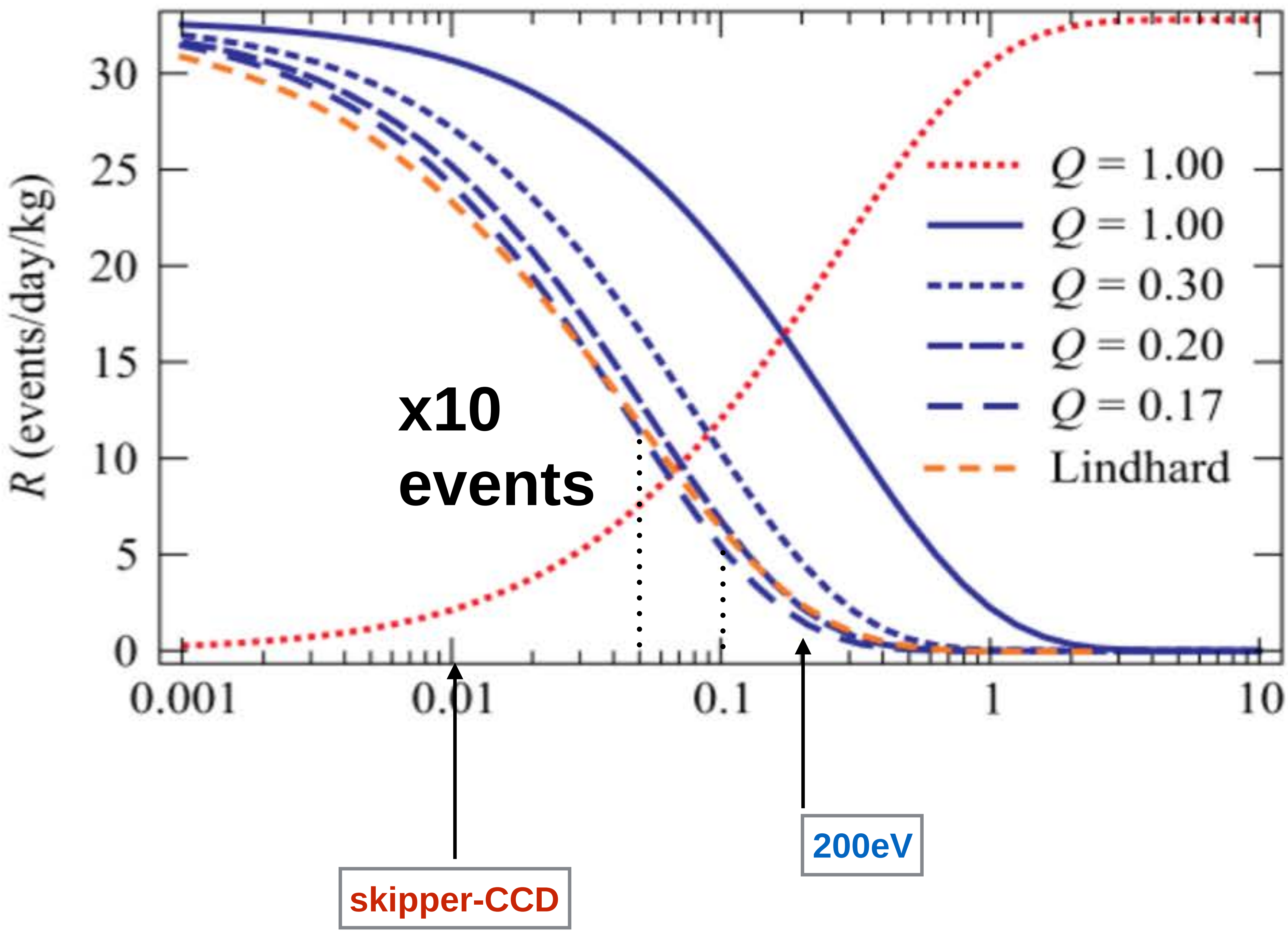
CONNIE now



skipper CCD

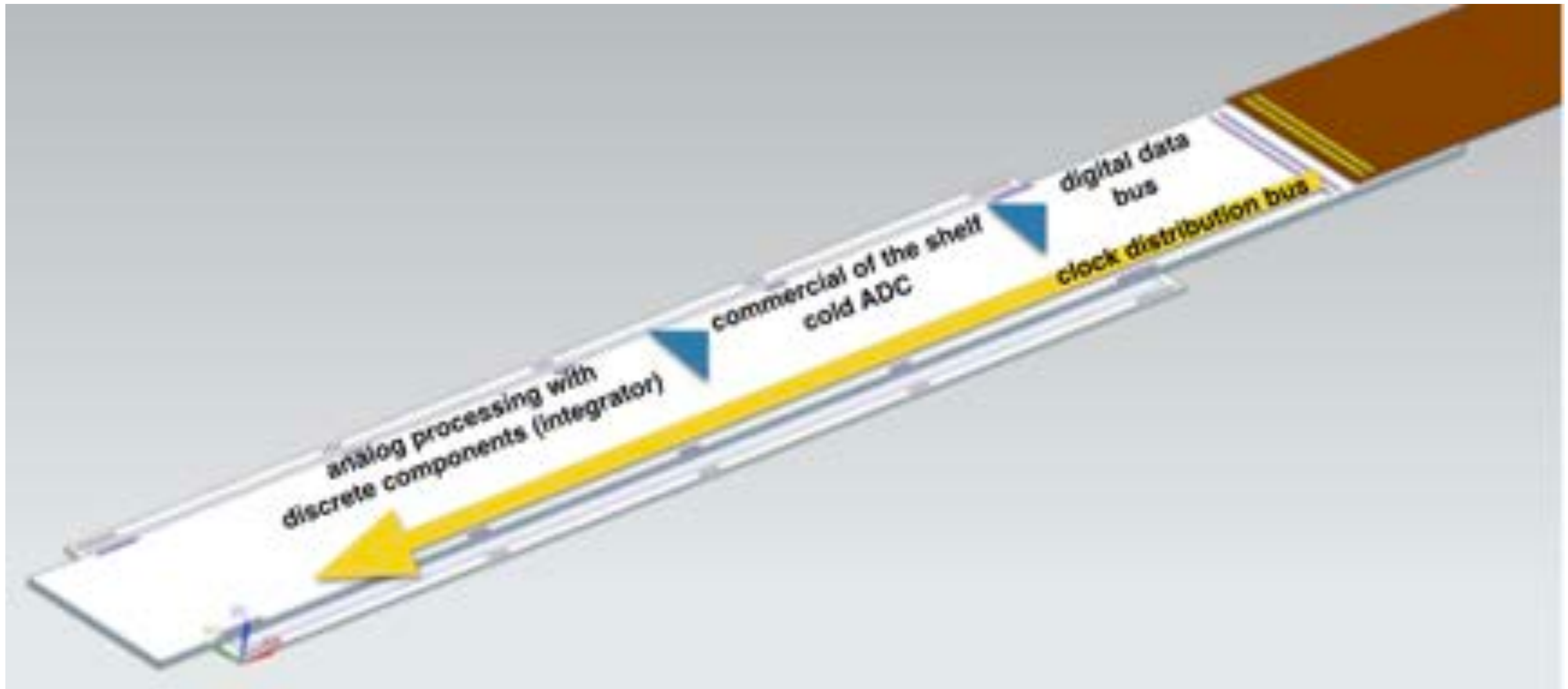


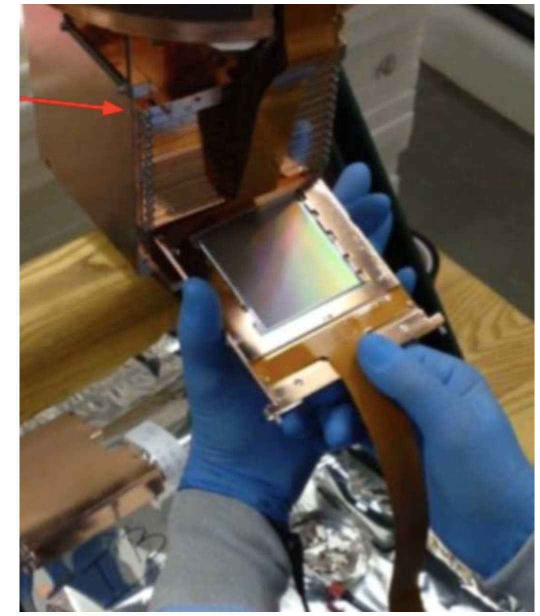
Designed ~30 years ago, but technology first demonstrated summer 2017 by Javier Tiffenberg et al (arXiv:1706.00028) allows reduction of the threshold by another factor of 2. The plan is to install a couple of these detectors in CONNIE also. Will need a new ionization efficiency measurement.

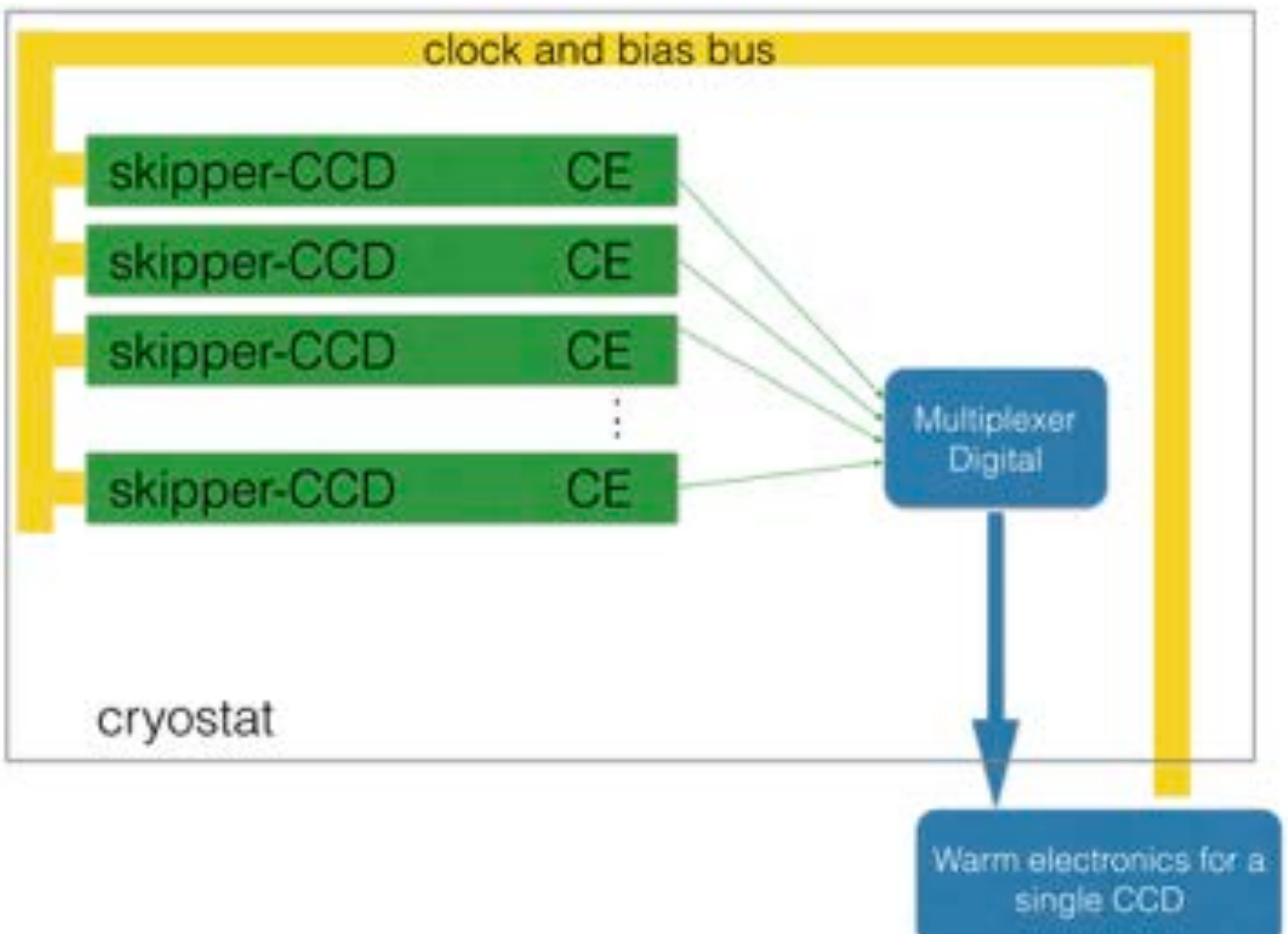


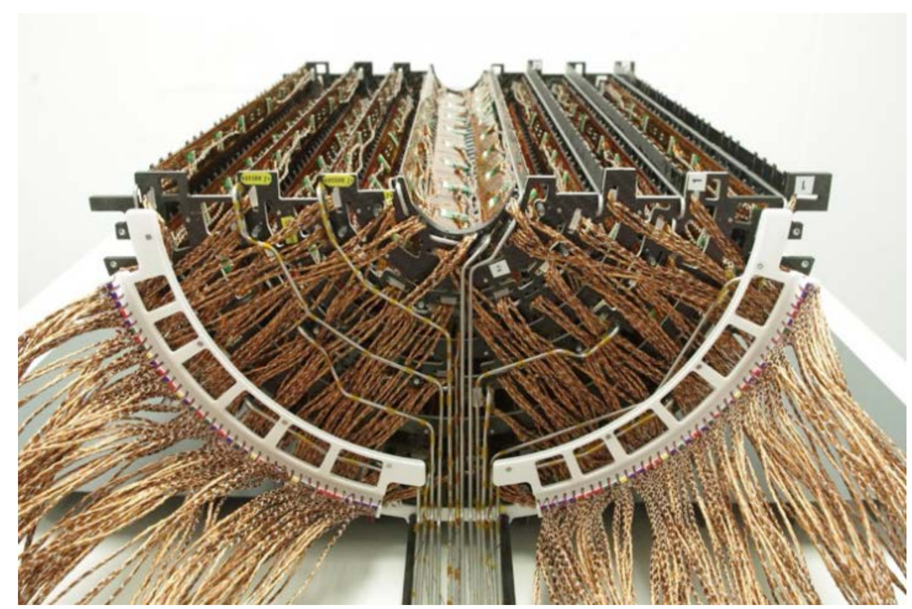
R (events/day/kg)
30
25
20
15
10
5
0
0.001
0.01
0.1
1
10
Q = 1.00
Q = 1.00
Q = 0.30
Q = 0.20
Q = 0.17
Lindhard
x10
events
200eV
skipper-CCD

10 kg skipper Detector (4000sensors)





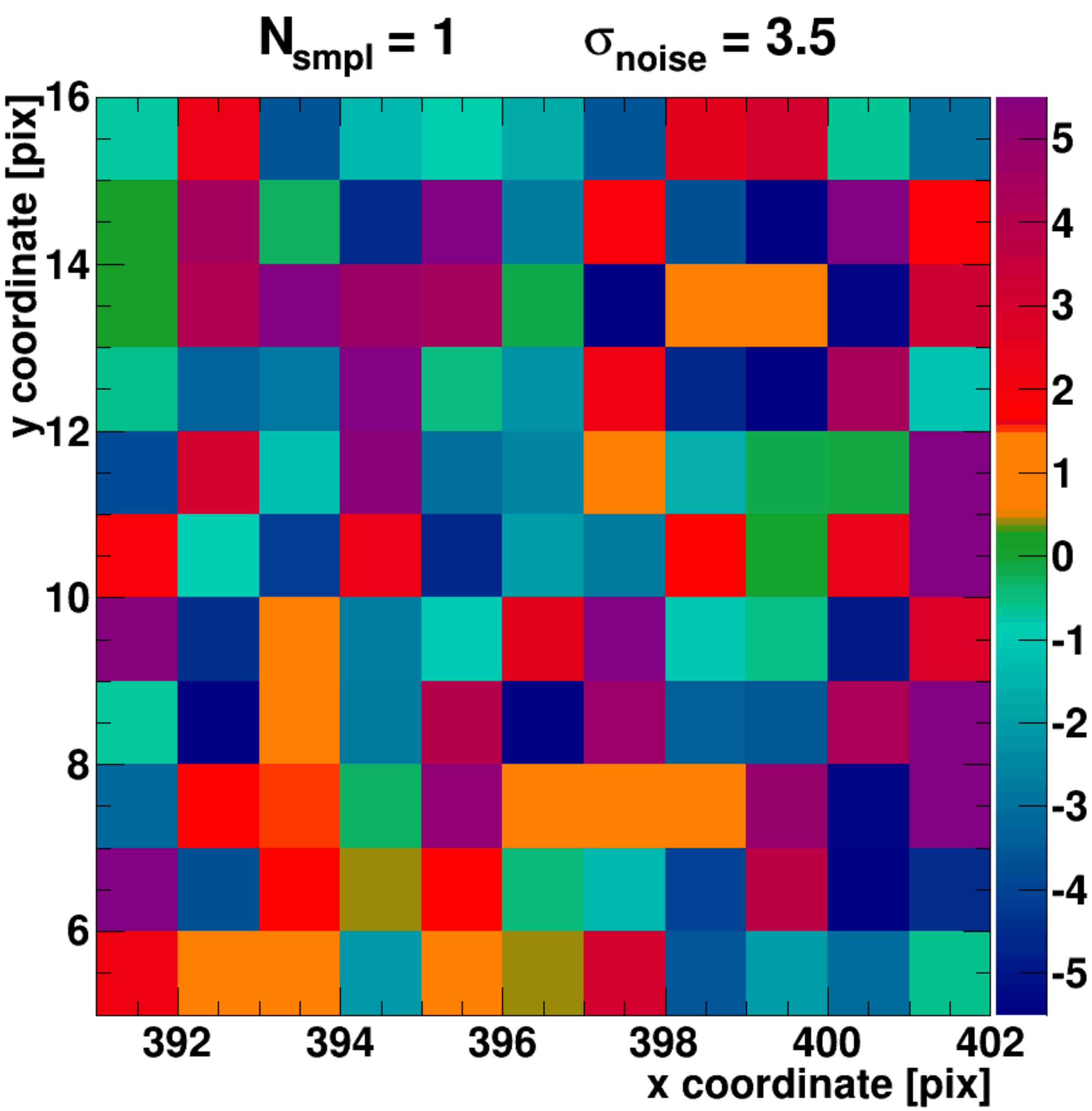


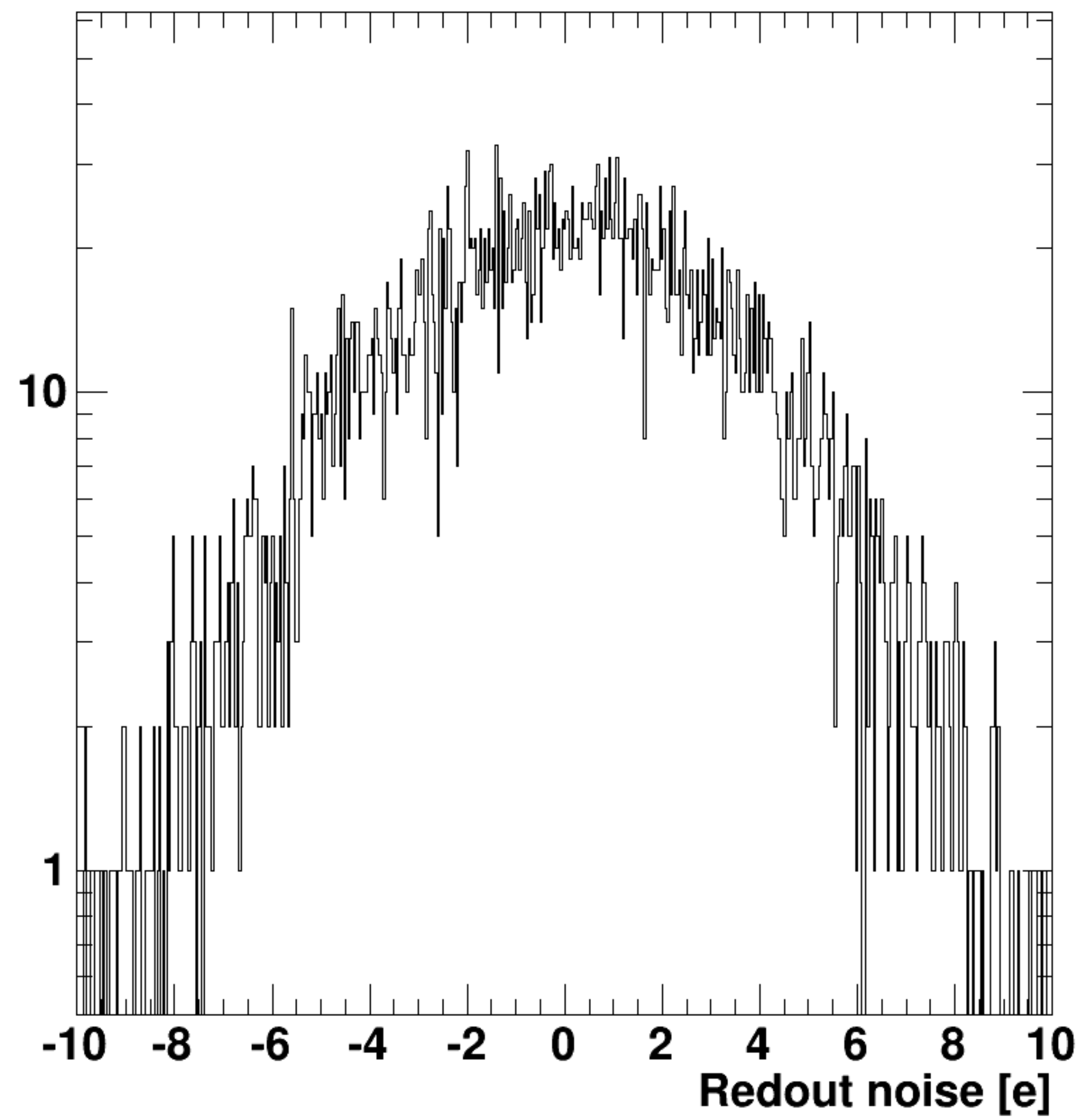


Conclusion

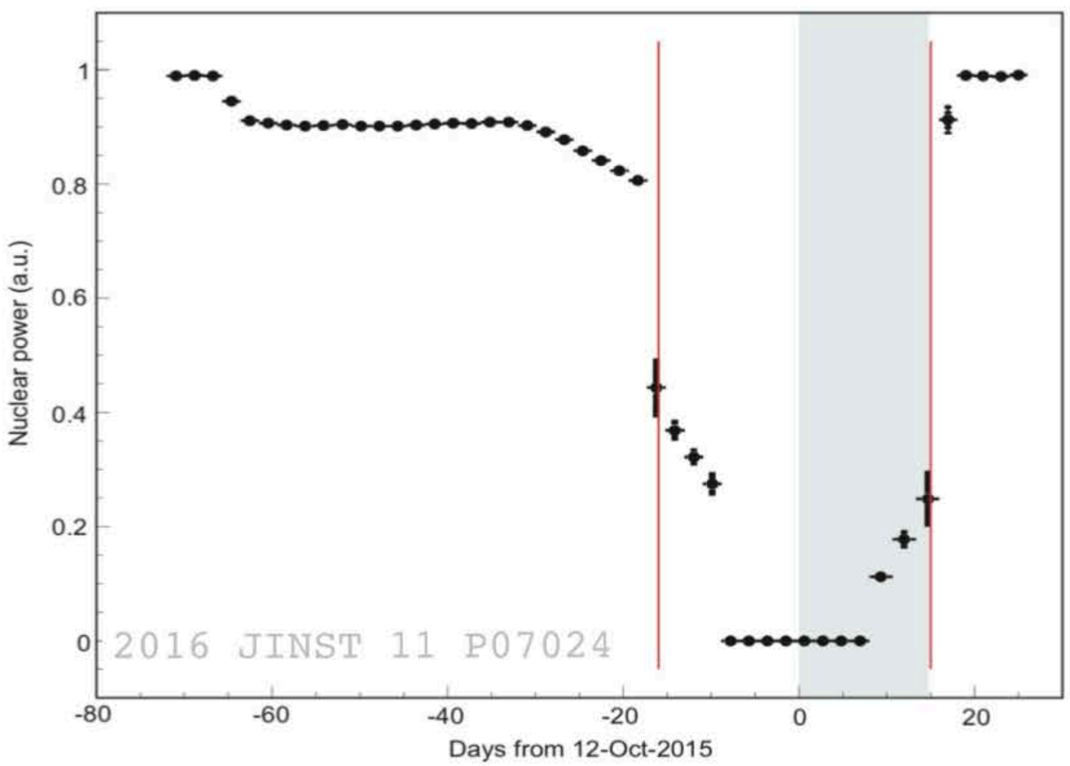
- CONNIE is operating, and has ~3 years of data with increasing quality. (3 one-month shutdowns). During 2018 the experiment had 50g of active mass.
- Low energy analysis to compare with SM and new physics ready late ~~summer~~ 2018.
- Skipper-CCD to remove the electronic noise is coming to CONNIE (reduction to of threshold to 2e-)
- Engineering development to build >10kg experiments ongoing.

the new skippers

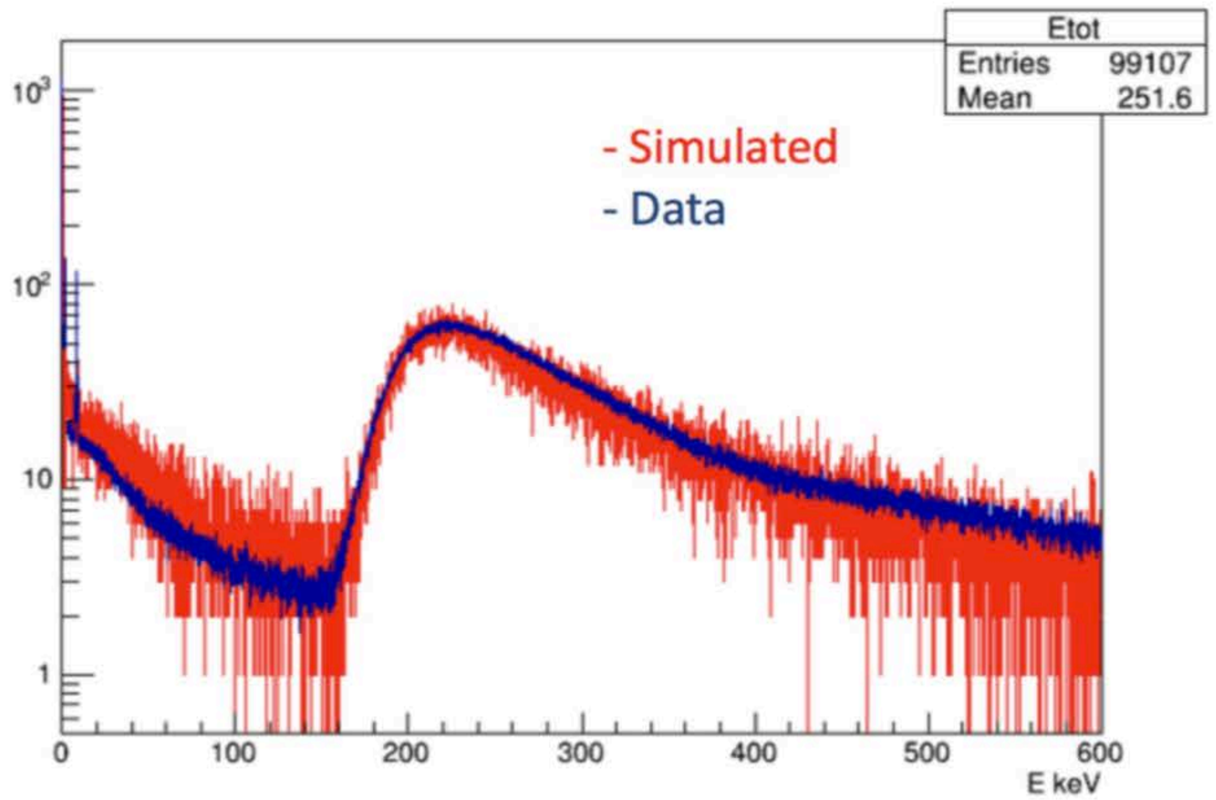




- Statistic limited by the reactor OFF data
- 30 days every ~year

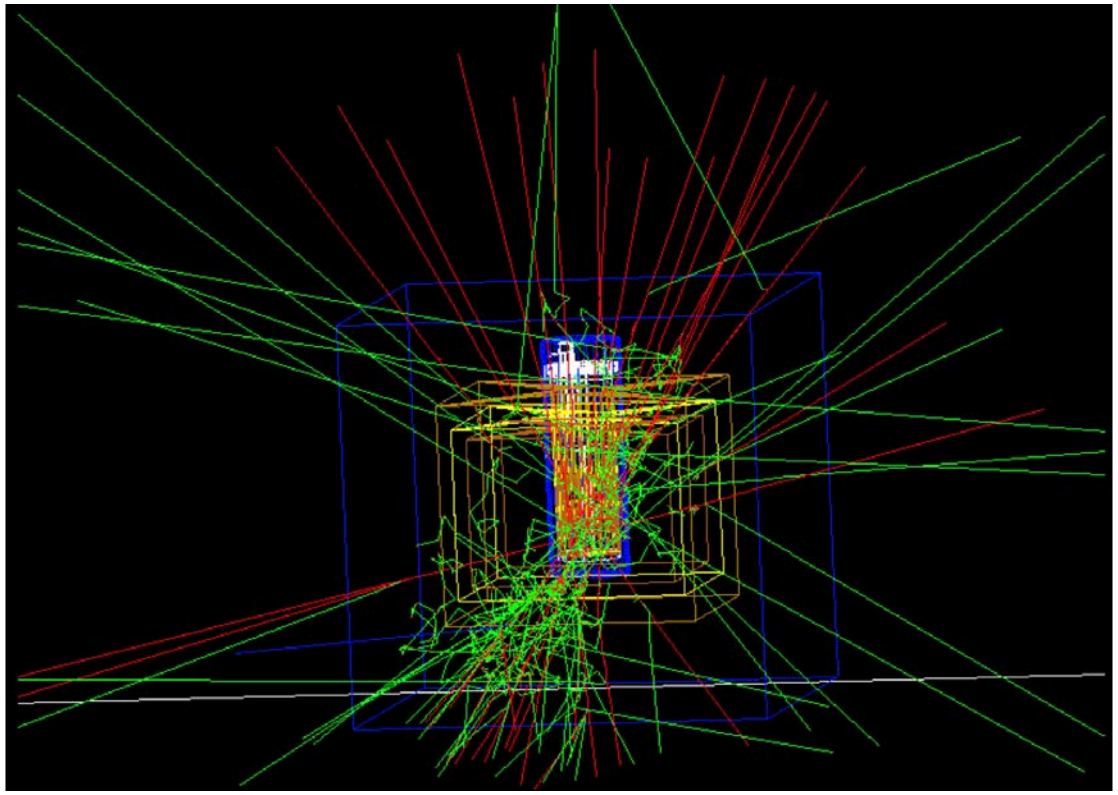


- ~10 times more statistics.
- Extra uncertainty associated with the background model



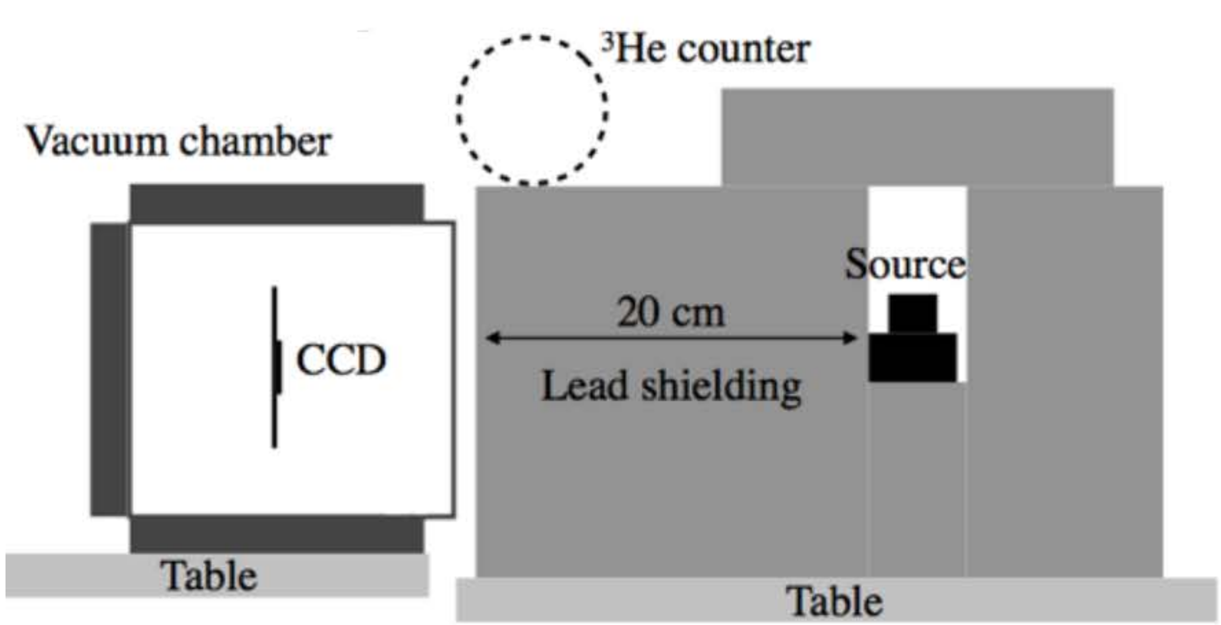
Until now we have been doing RON-ROFF analysis. This is limited by the ROFF statistics.

Now with full geant4 simulations doing modeling the background. **With a solid background model the statistic uncertainty drops by a factor of 10!!!**



Nuclear Recoil Calibration (A.Chavarria et al)

arXiv:1608.00957



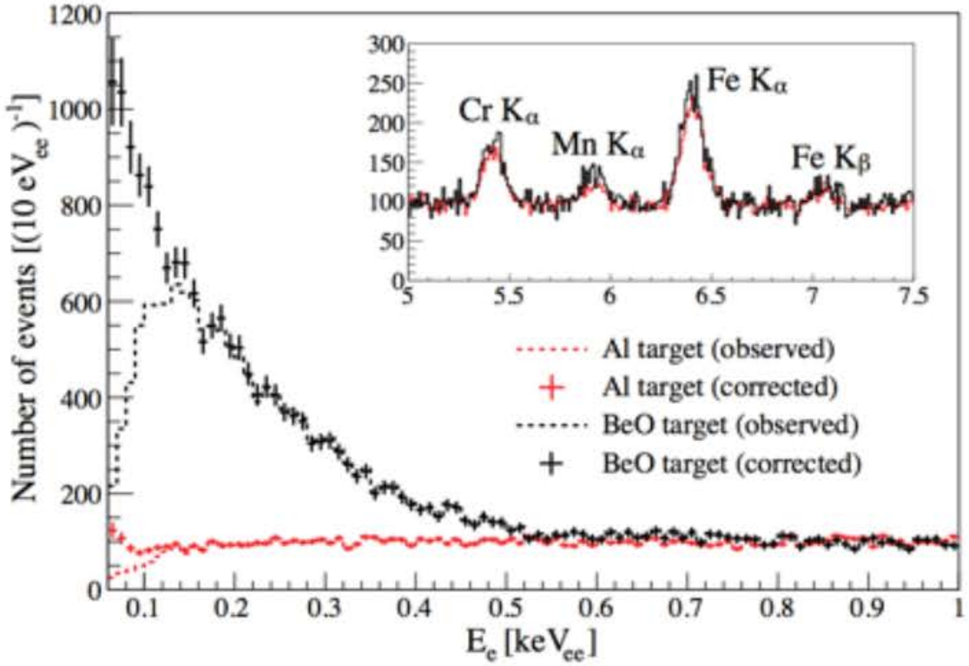


FIG. 2. Measured ionization spectra with the full BeO and Al targets (dashed lines). Solid markers represent the spectra corrected for the energy-dependent event selection acceptance. The inset shows the spectra in the 5.0–7.5 keV$_{ee}$ range, with in-run calibration lines from fluorescence x rays originating in the stainless steel of the vacuum chamber.

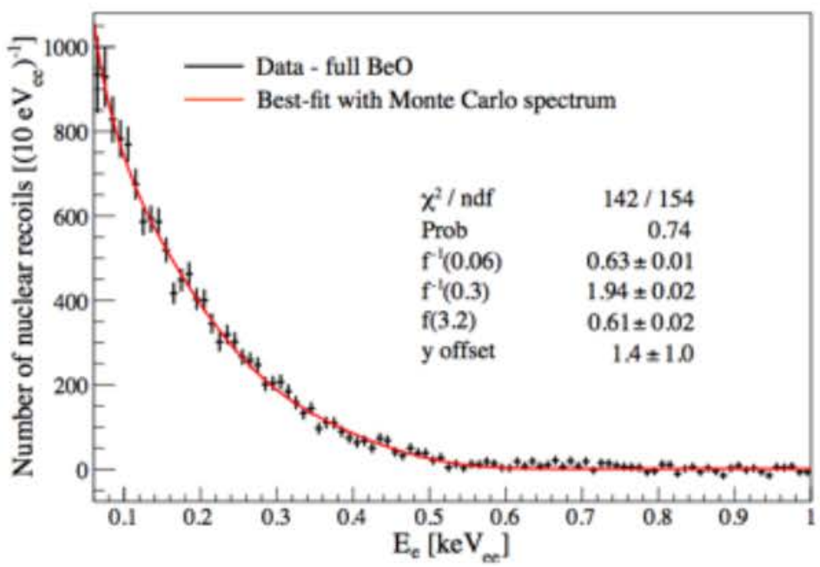
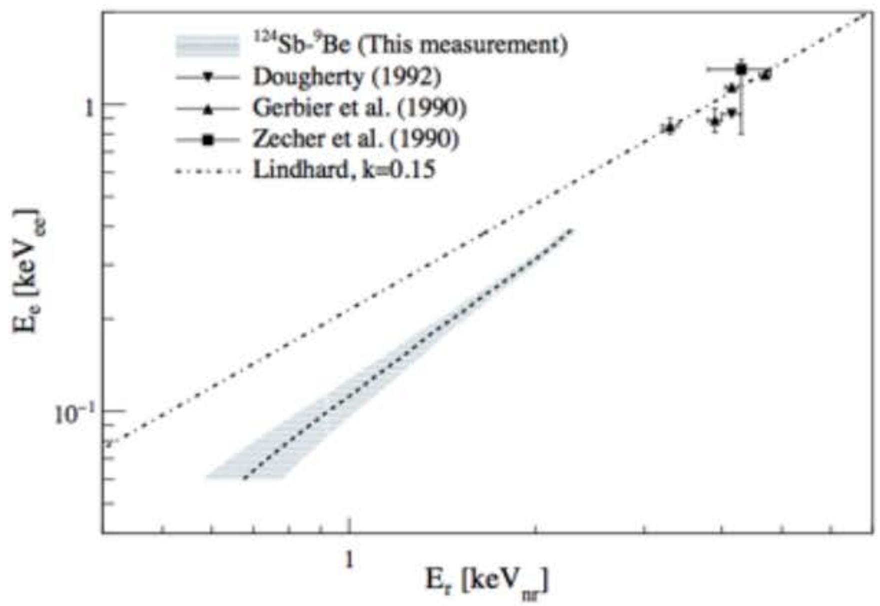


FIG. 4. Ionization spectrum of nuclear recoils induced by neutrons from the full BeO target source (black markers) and best fit to the data (solid line). The fitting function was obtained by applying a cubic spline model f of the nuclear recoil ionization efficiency to the simulated recoil spectrum and convolving with the detector energy resolution. The best-fit parameters of the spline are given in the legend.



Nuclear Recoil Calibration (F. Izraelevitch et al)

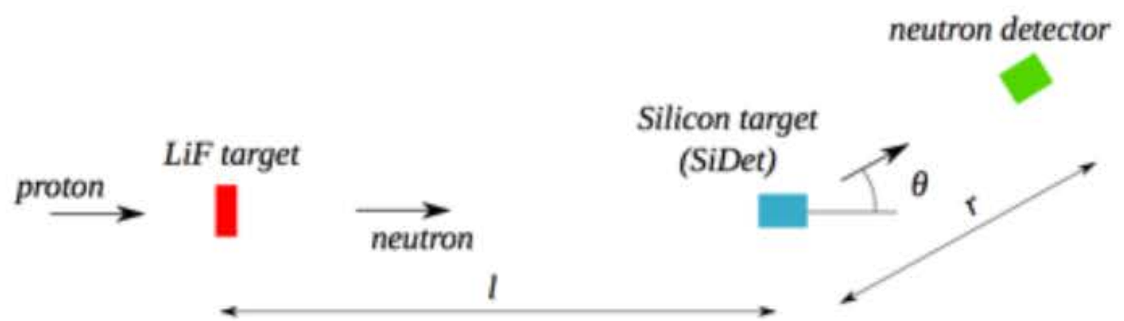
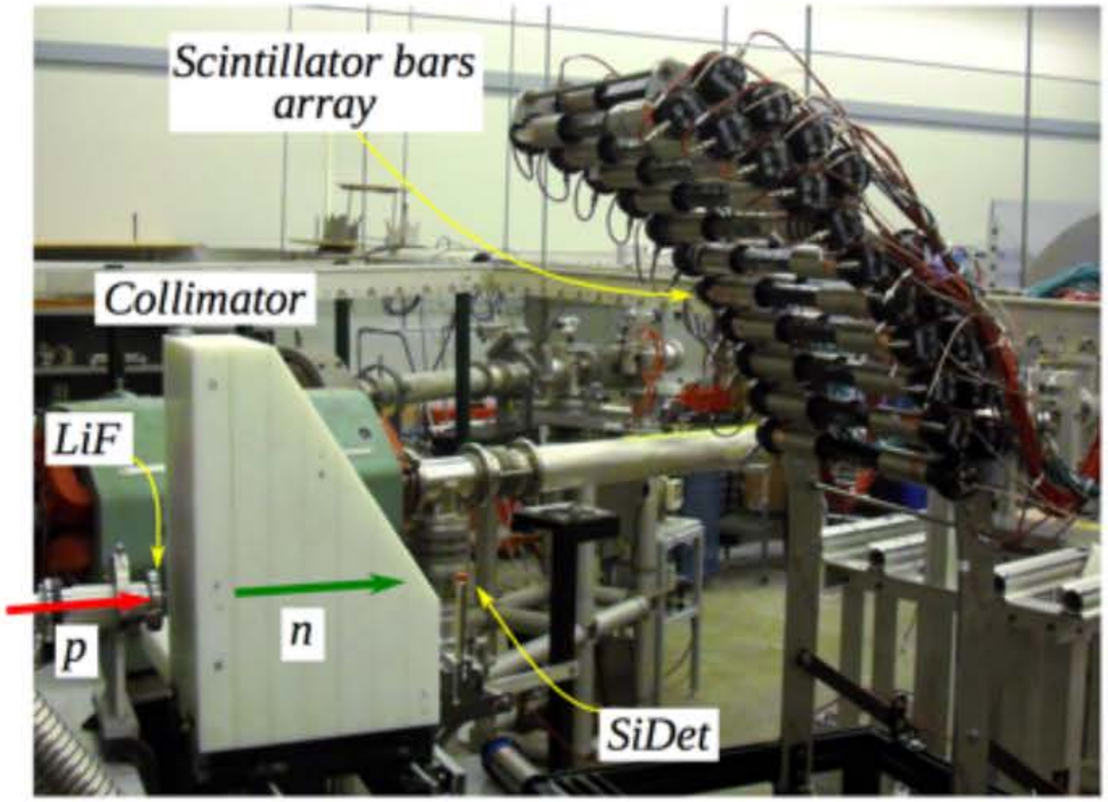
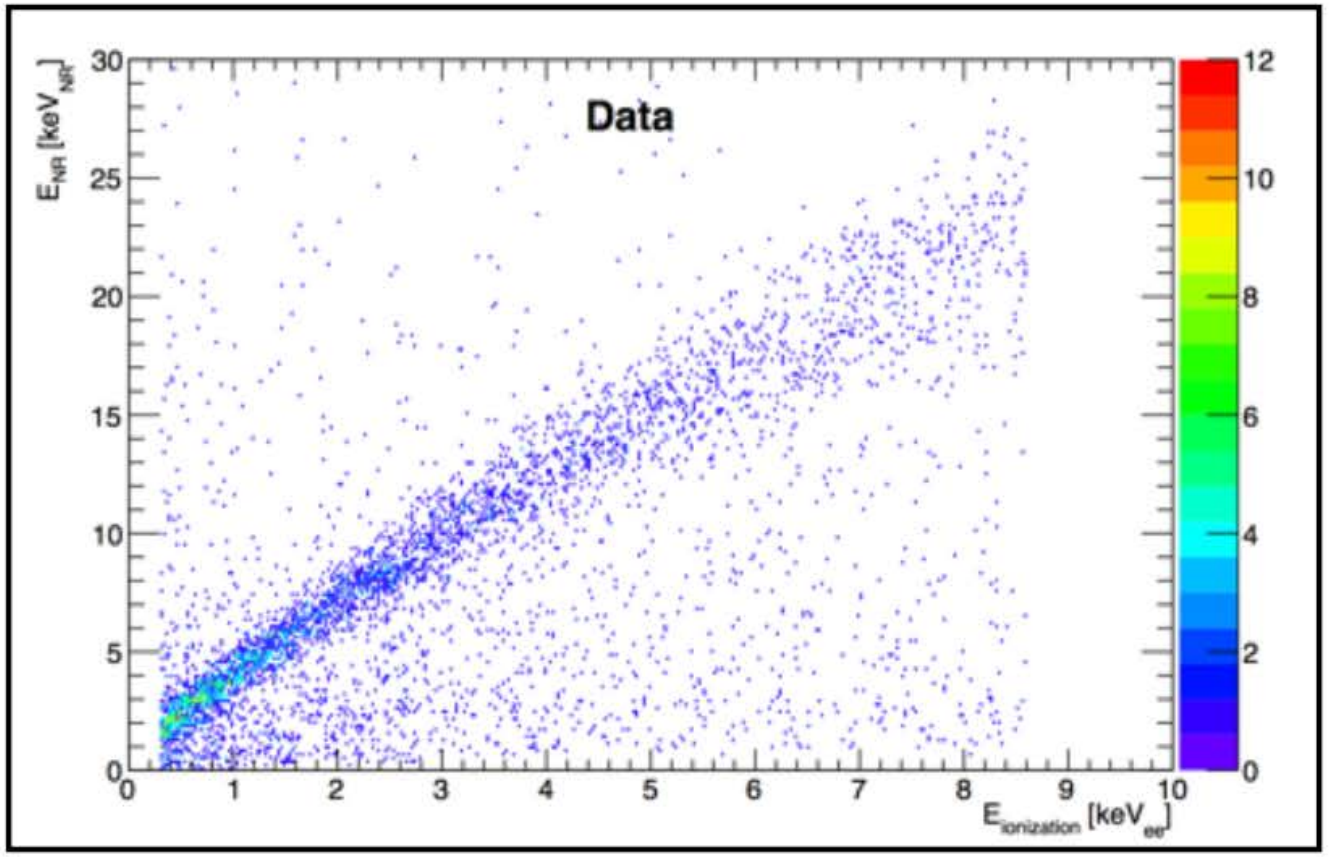
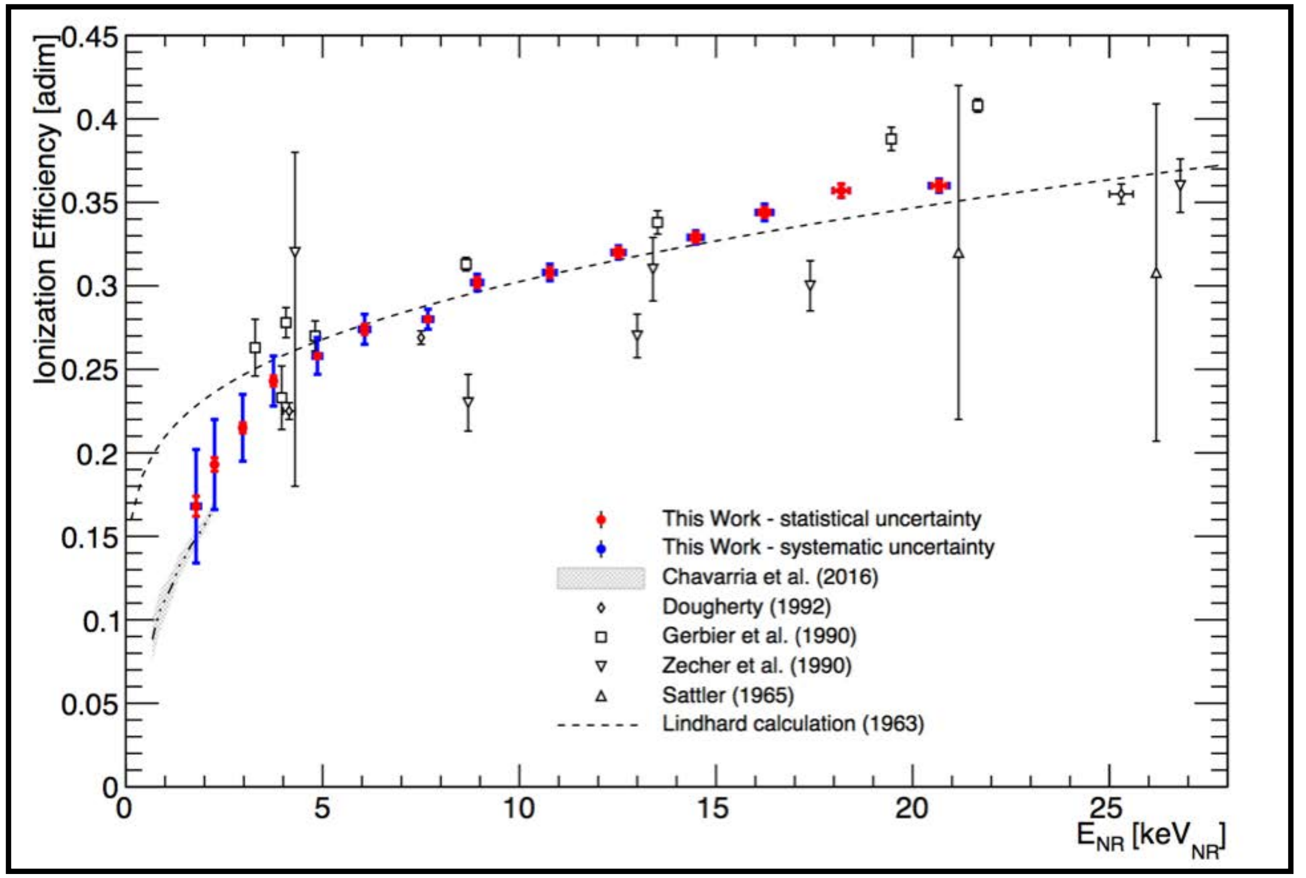


Figure 1: Schematic layout of the experimental arrangement.

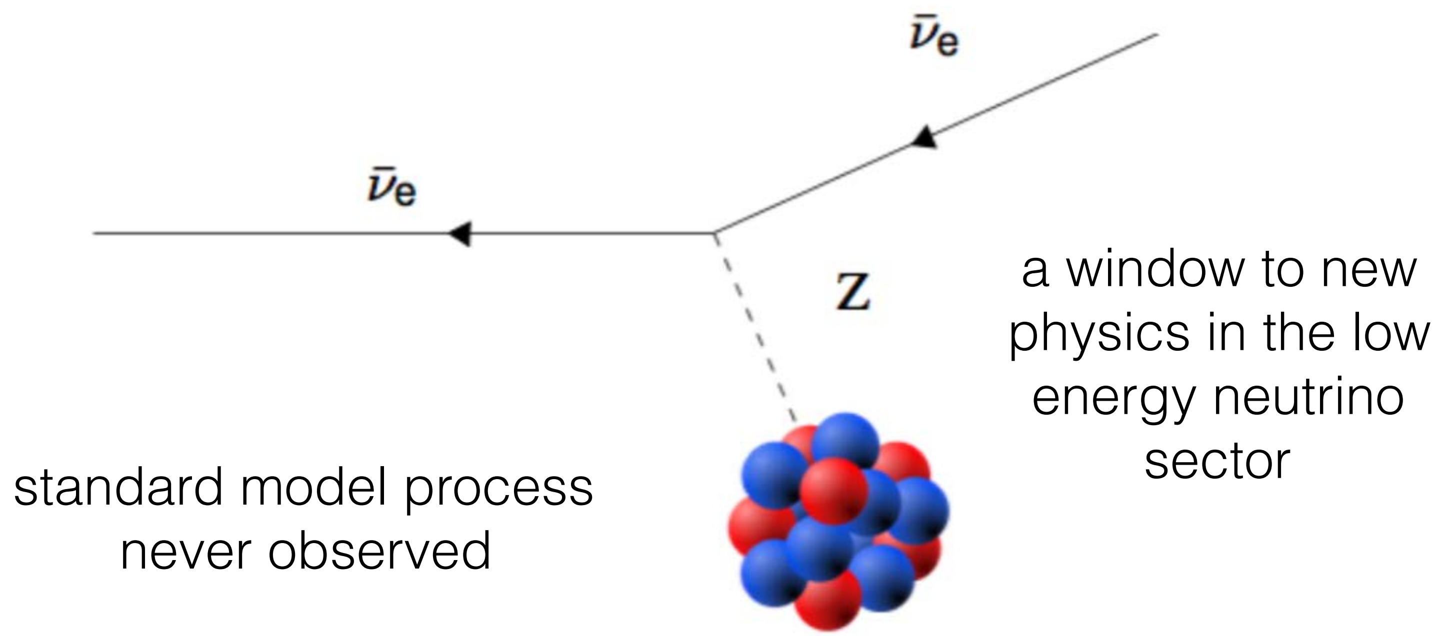






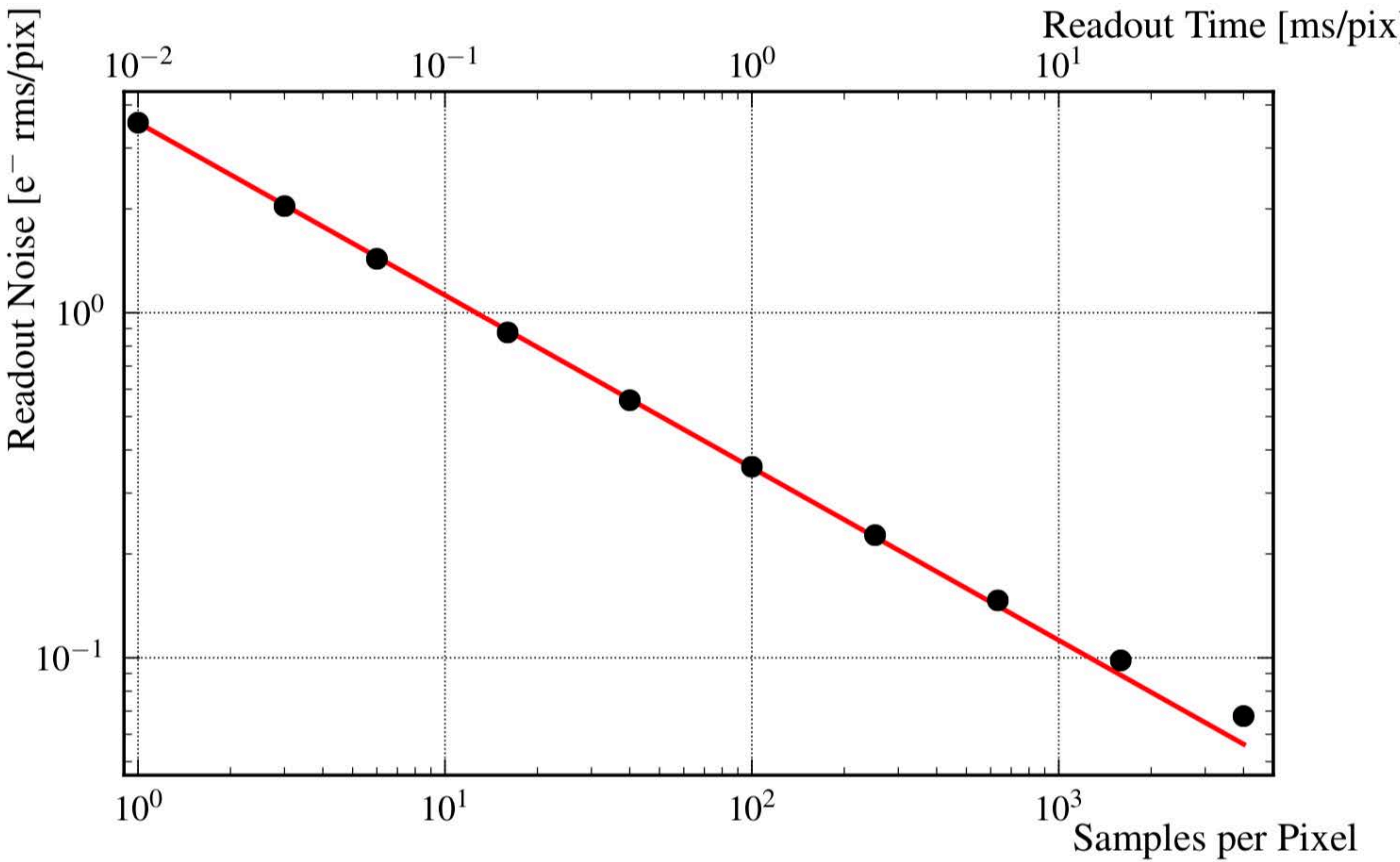
<u>Complete calibration down to our threshold for CONNIE.</u>

At low recoil energies (T_A < 50 MeV) the cross section is enhanced by ~N^2 .

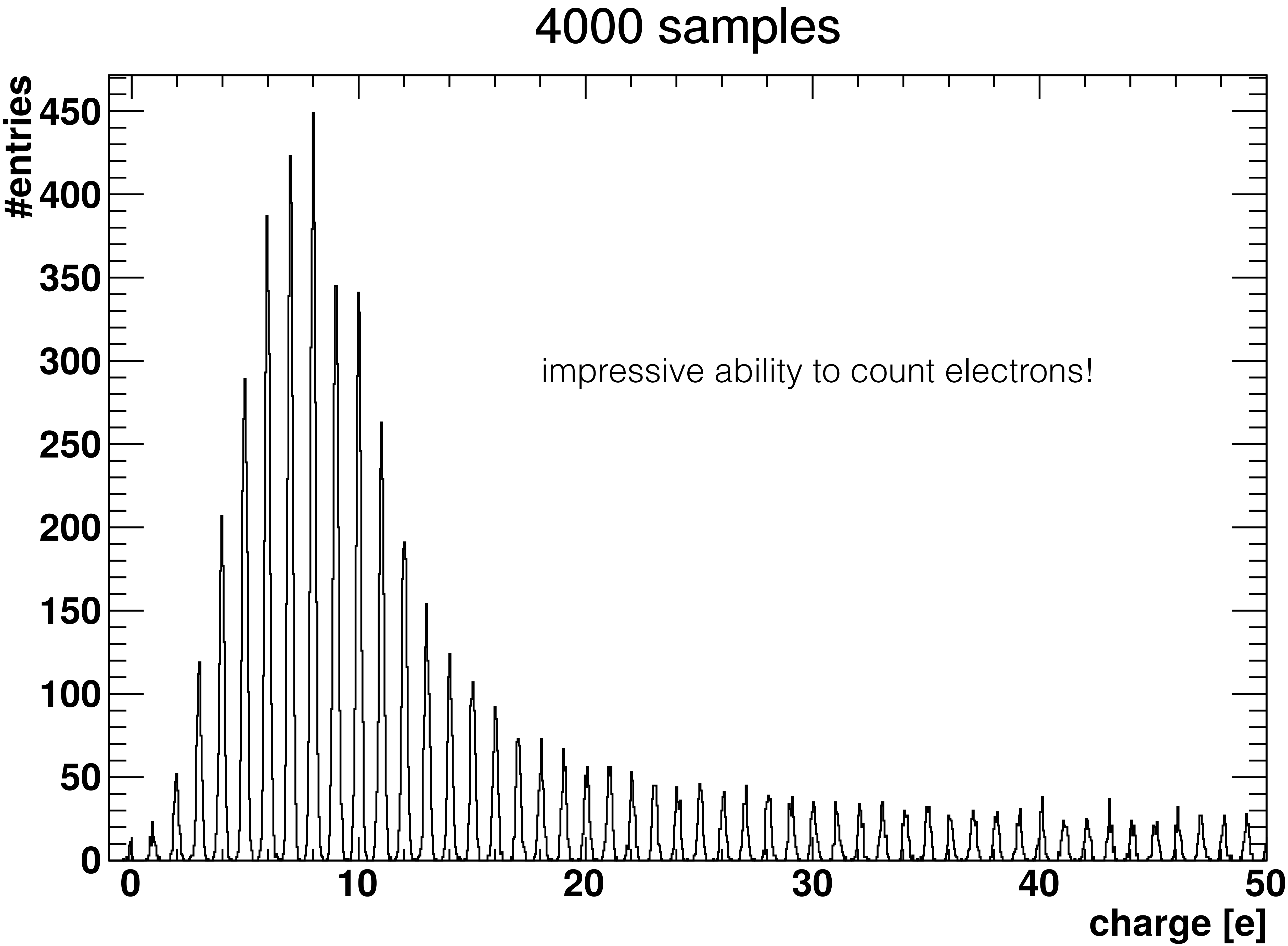


$$\frac{d\sigma}{dT_A} = \frac{G_F^2}{4\pi} m_A [Z(1-4\sin^2\theta_W) - N]^2 \left[1 - \frac{m_A T_A}{2E_\nu^2}\right]$$

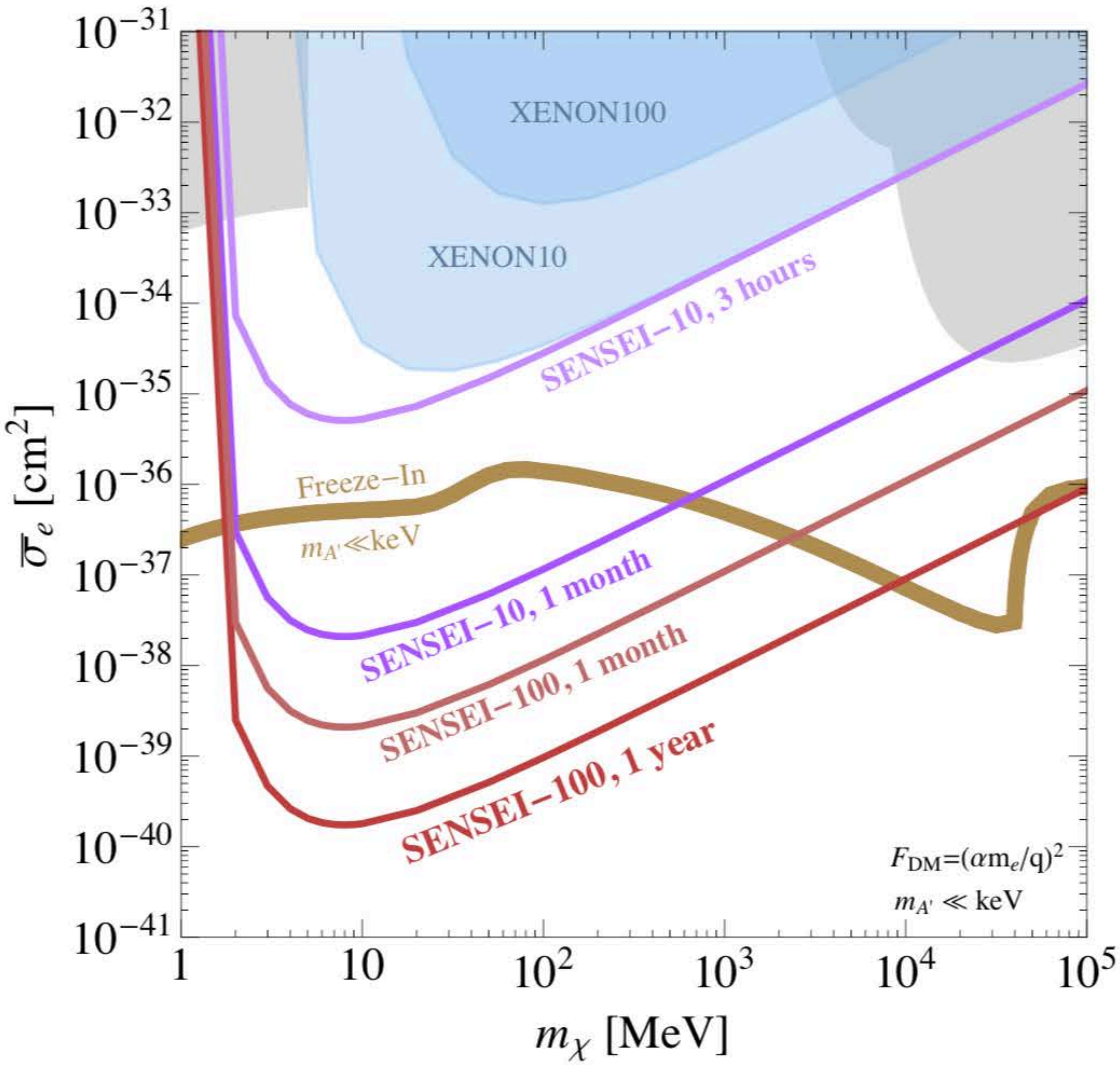
Coherent elastic neutrino-nucleus scattering (CEvNS) is a prediction of the Standard Model.

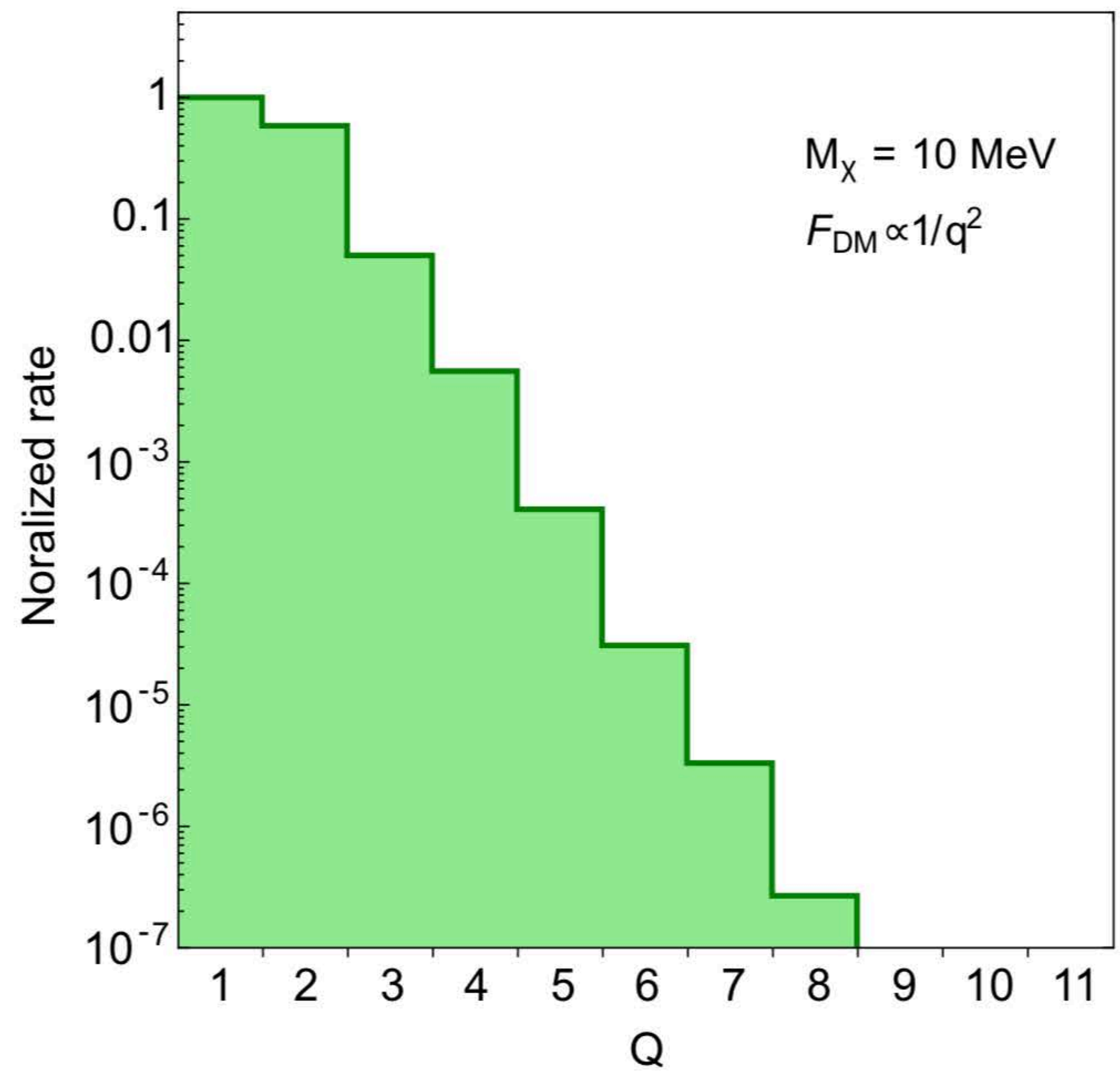


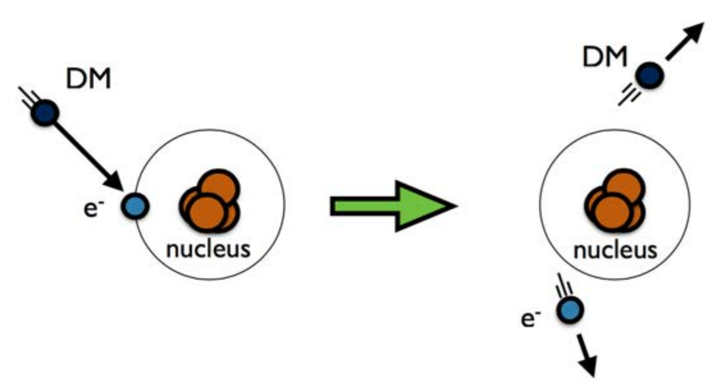
Readout Time [ms/pix]
10^{-2}
10^{-1}
10^{0}
10^{1}
Readout Noise [e^{-} rms/pix]
10^{0}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
Samples per Pixel


4000 samples
#entries
impressive ability to count electrons!
charge [e]
0
50
100
150
200
250
300
350
400
450
0
10
20
30
40
50

Once you can count electrons, you can search for electron recoils produced by very low mass dark matter (dark sector searches). This is what we are planning to do with the skipper-CCD in the **SENSEI experiment.**







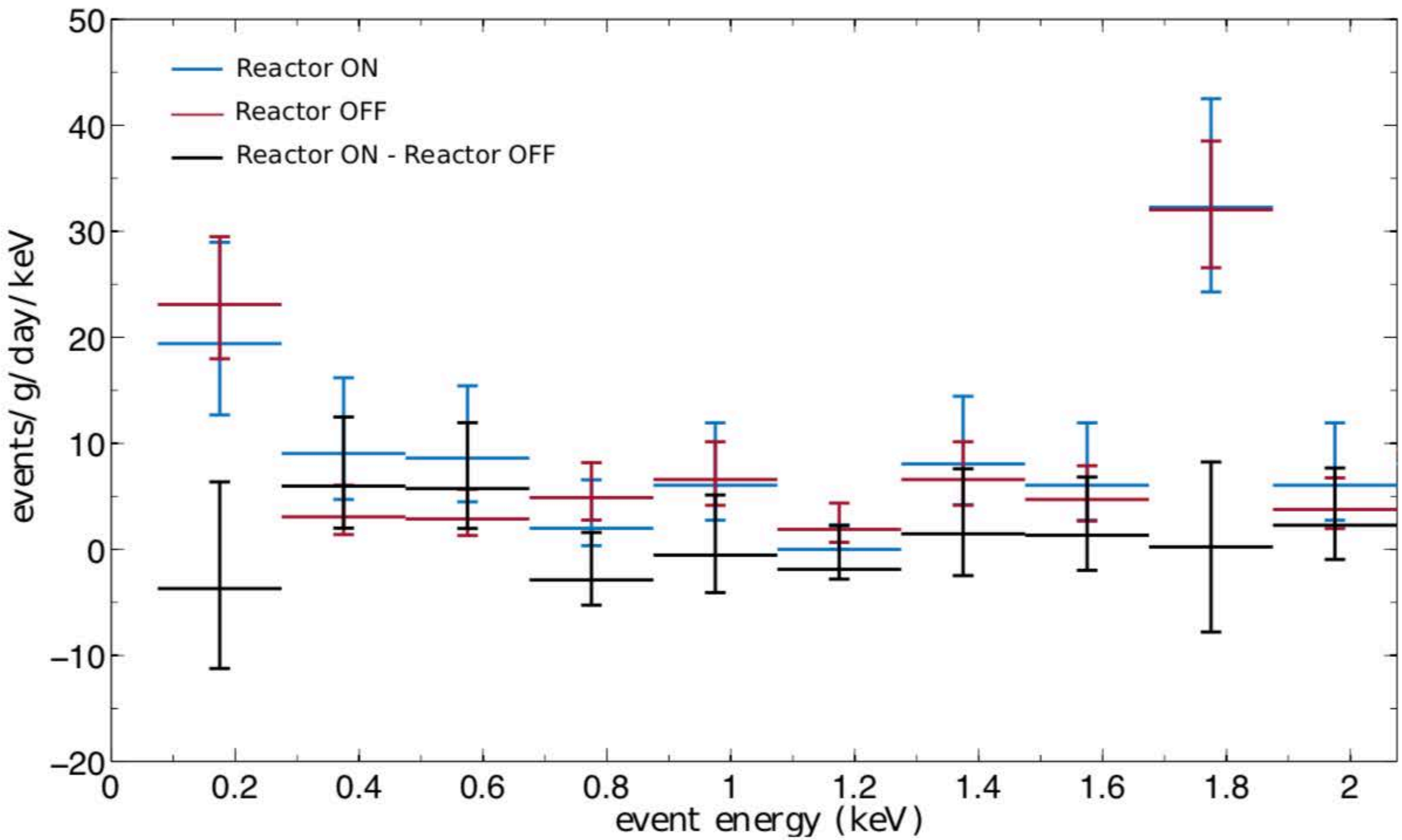
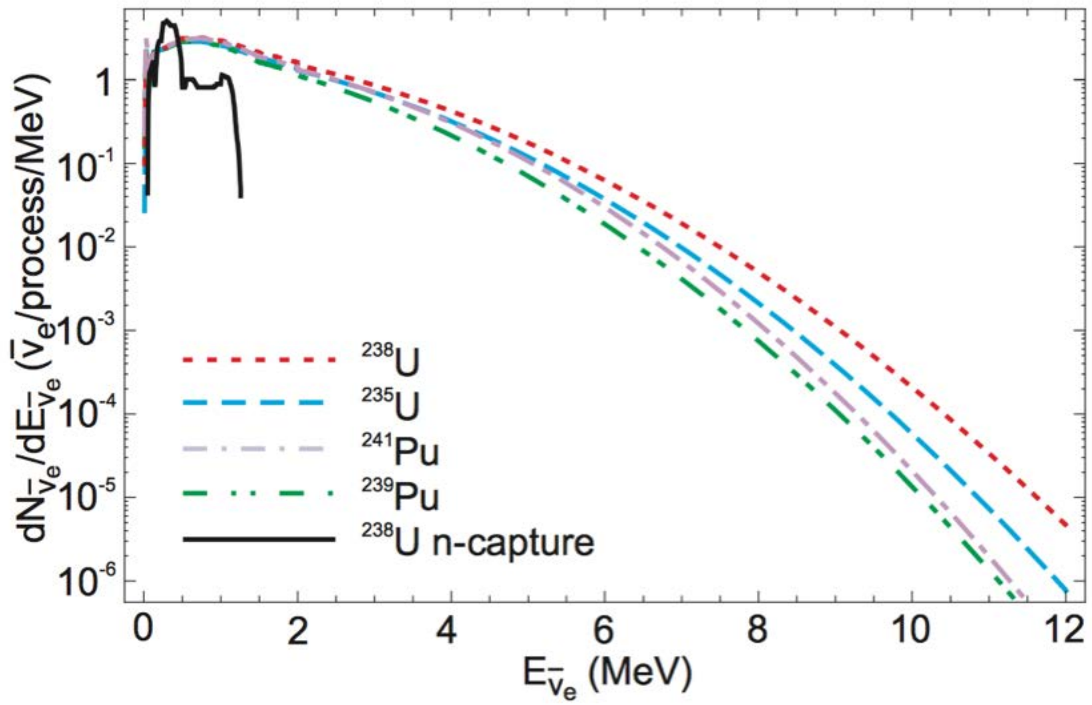
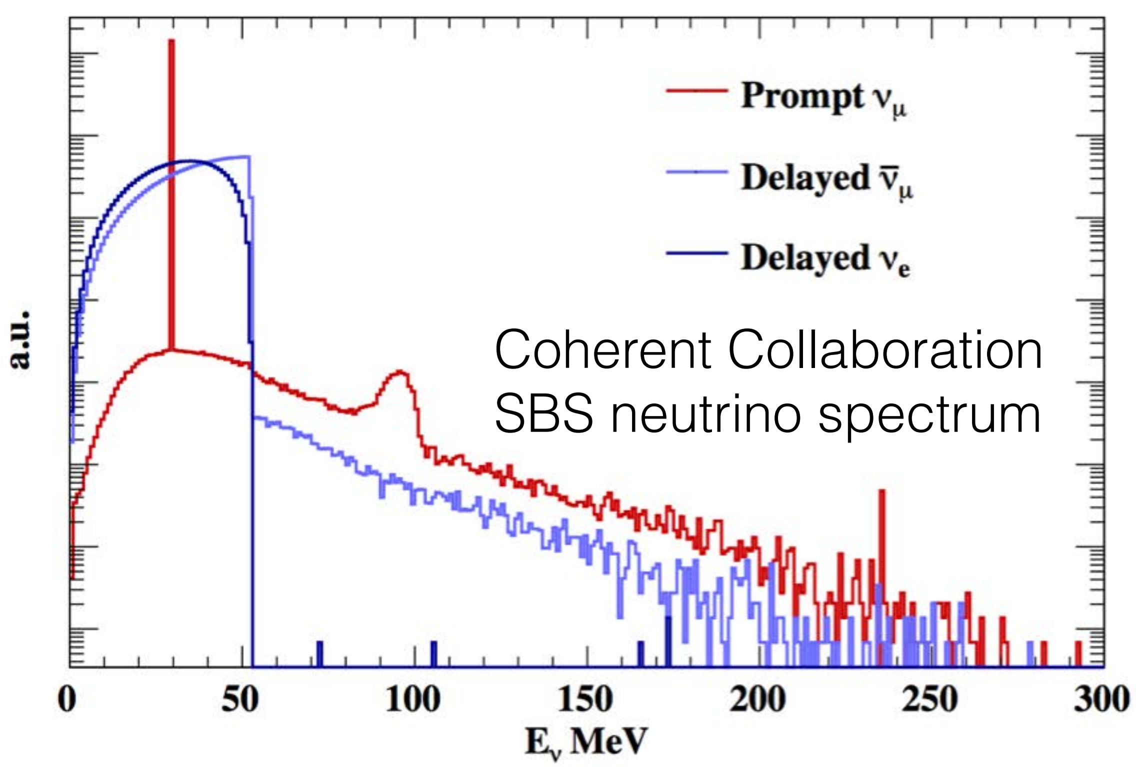


Figure 16: Energy spectrum measured with Reactor on, Reactor off and their difference. Events are selected as discussed in the text, and the rate is corrected for the efficiency of the selection criteria. The error bars correspond to 68.27% probability assuming a Poisson distribution for each energy bin. The higher rate of events at 1.8 keV is produced by the silicon fluorescence X-ray.



Neutrinos from a nuclear reactor

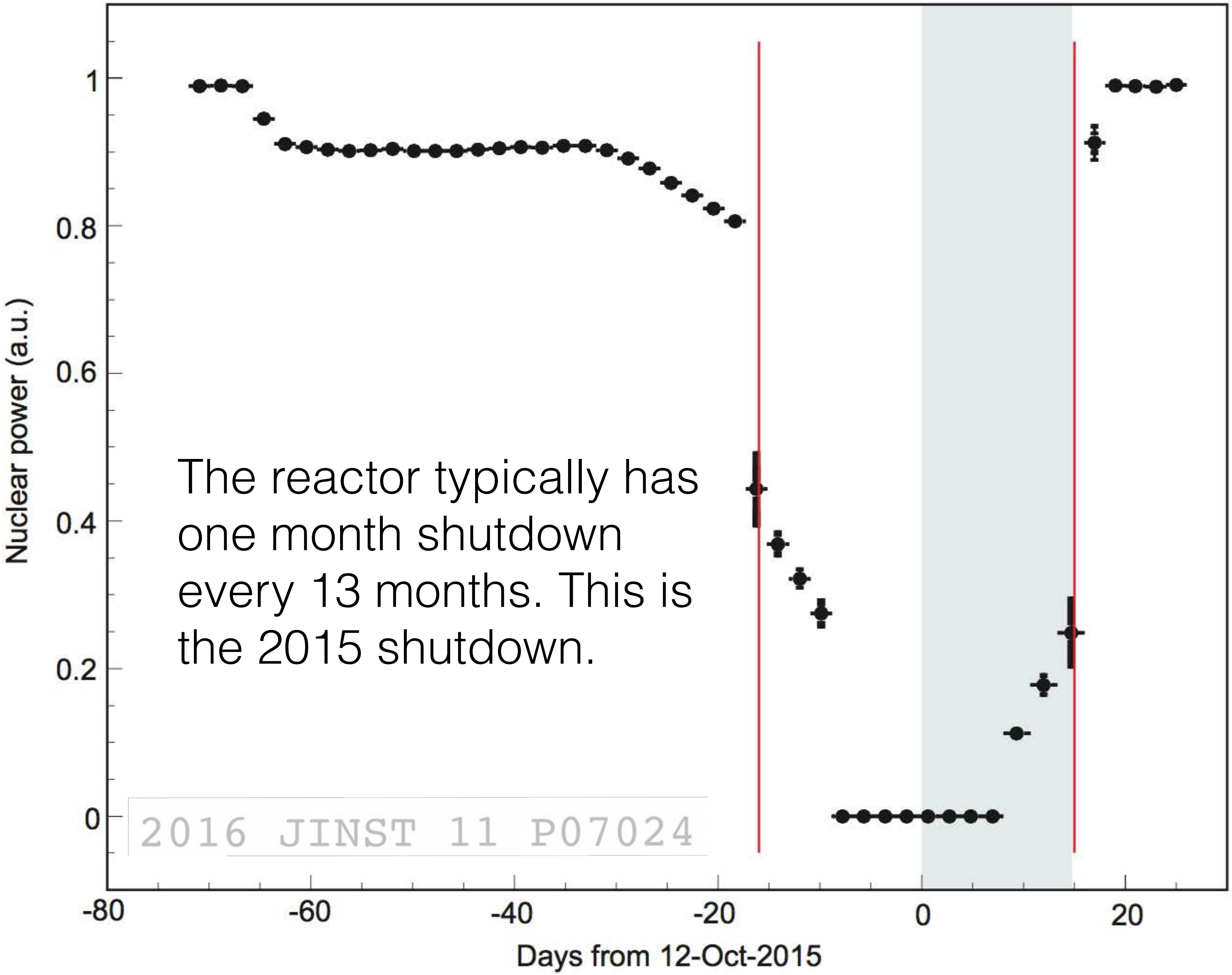
- Very large flux, close to core.
- Low energy recoils, harder to see.
- Deal with background by shielding.
- A window to very low energy neutrino sector.
- MINER, **CONNIE**



Neutrinos produced by stopped pions (decay at rest).

- Higher energy recoils, easier to see
- Pulsed to control background.
- Has to deal with beam associated background.
- COHERENT

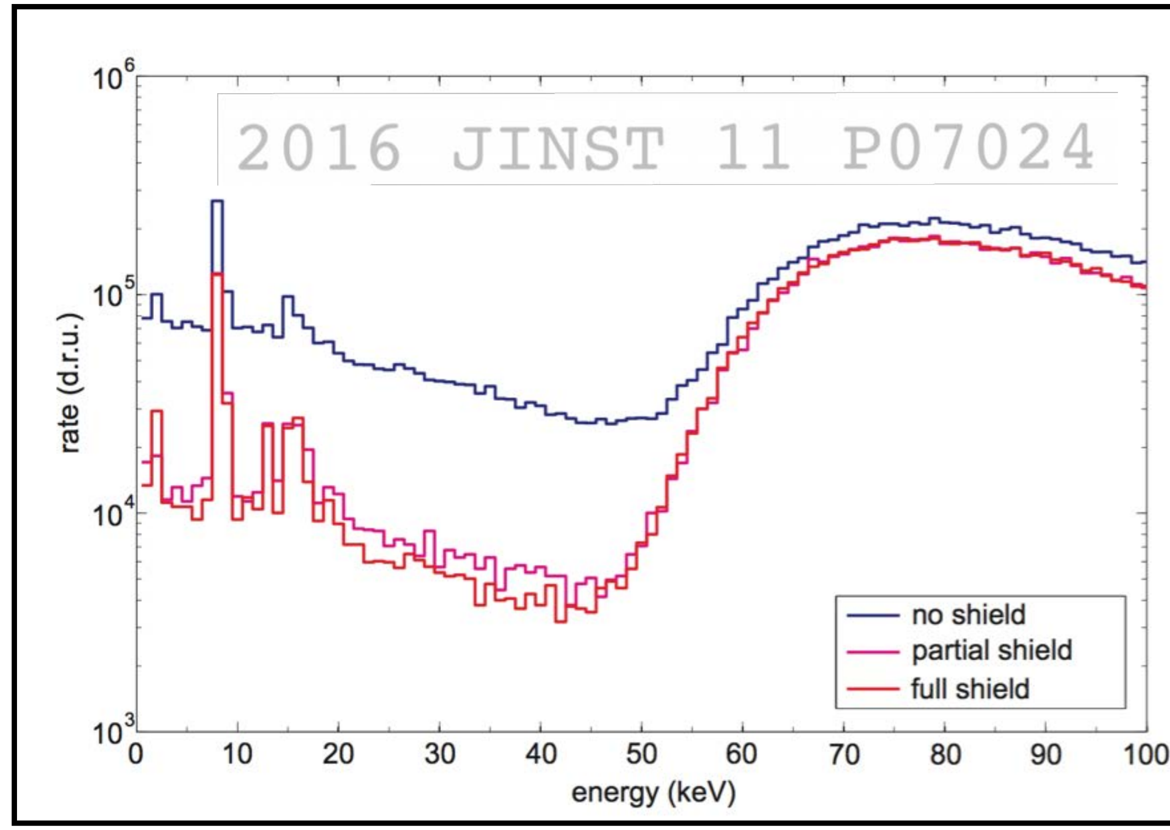
2015 Engineering Run

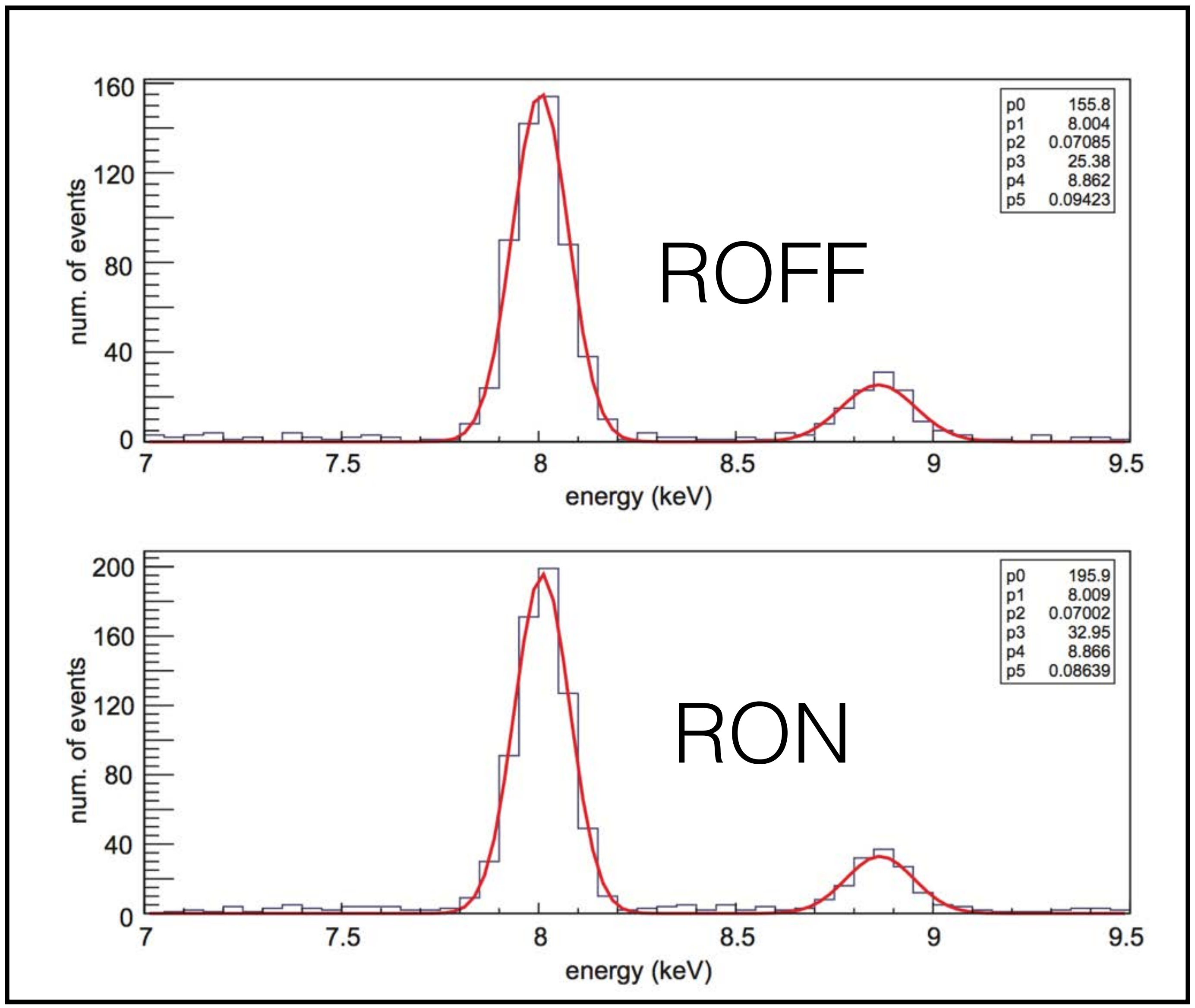


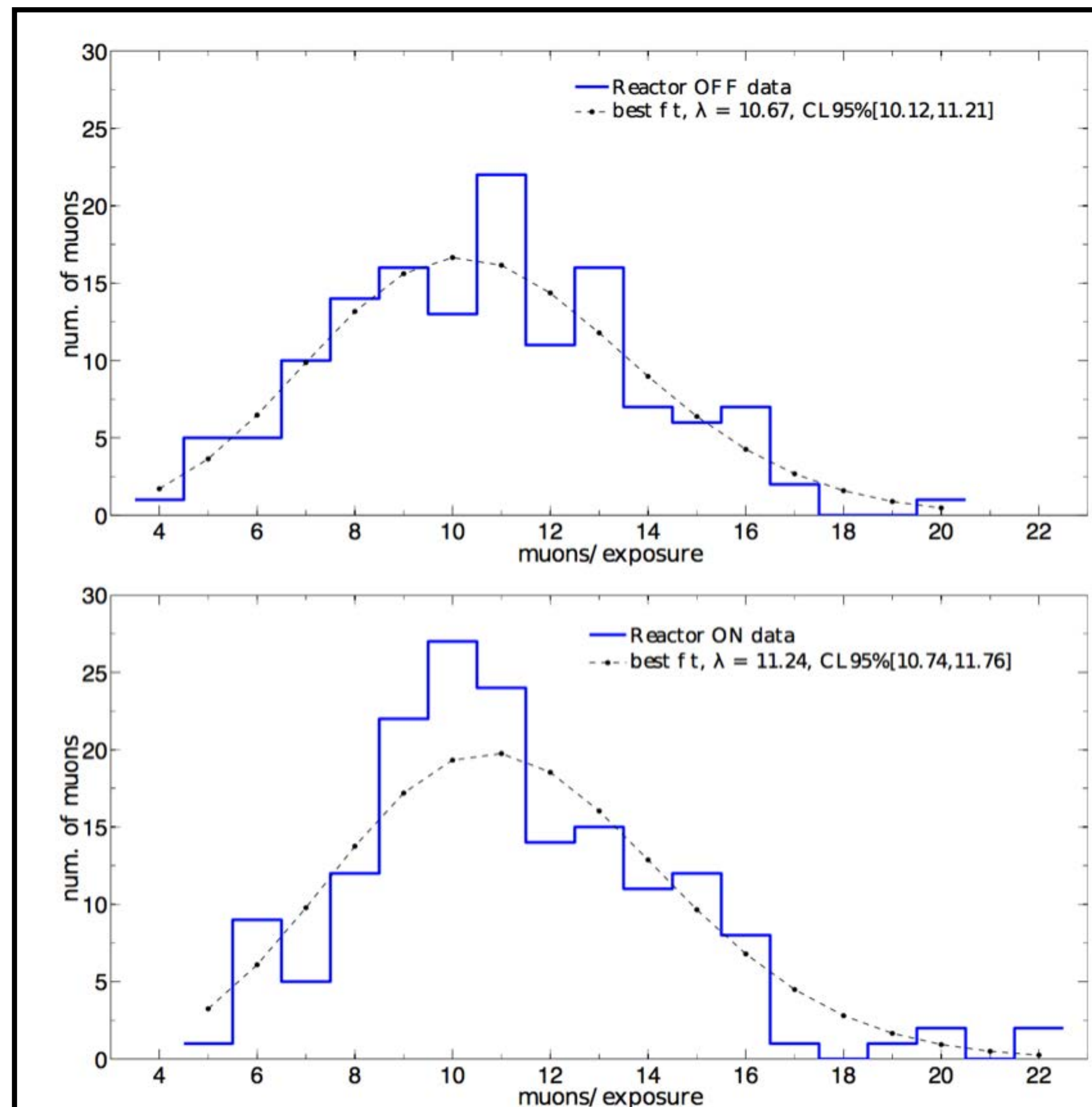
The reactor typically has one month shutdown every 13 months. This is the 2015 shutdown.

2015 engineering run FNAL-LDRD program (1g active mass, 1 CCD)

Reactor	counts (7.8-8.2 keV)	exposure (day)	rate (counts/day)
RON	693	18.0	38.5 ± 1.46
ROFF	557	14.8	37.6 ± 1.61

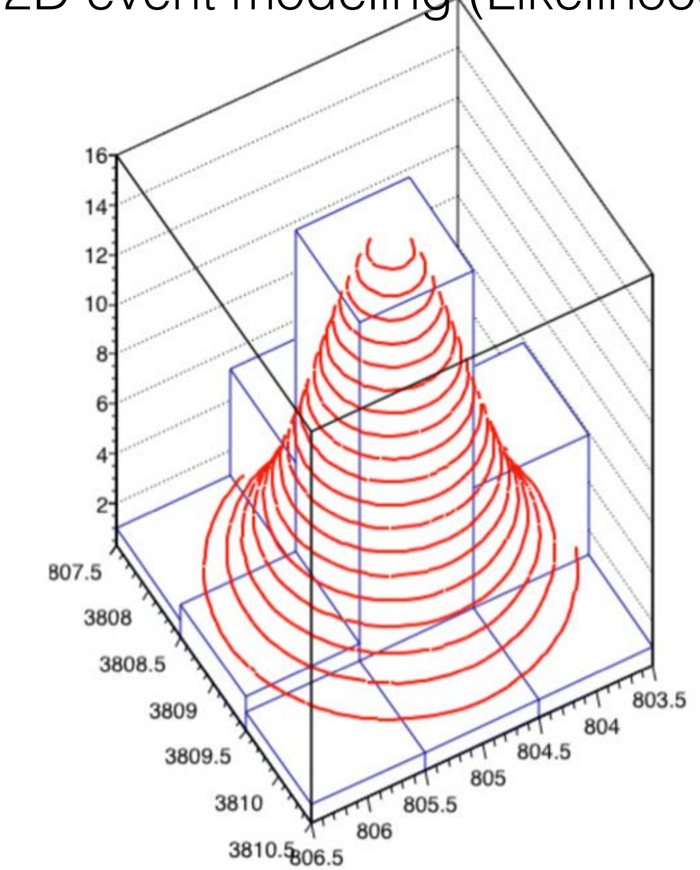






2015 : no excess

2D event modeling (Likelihood)



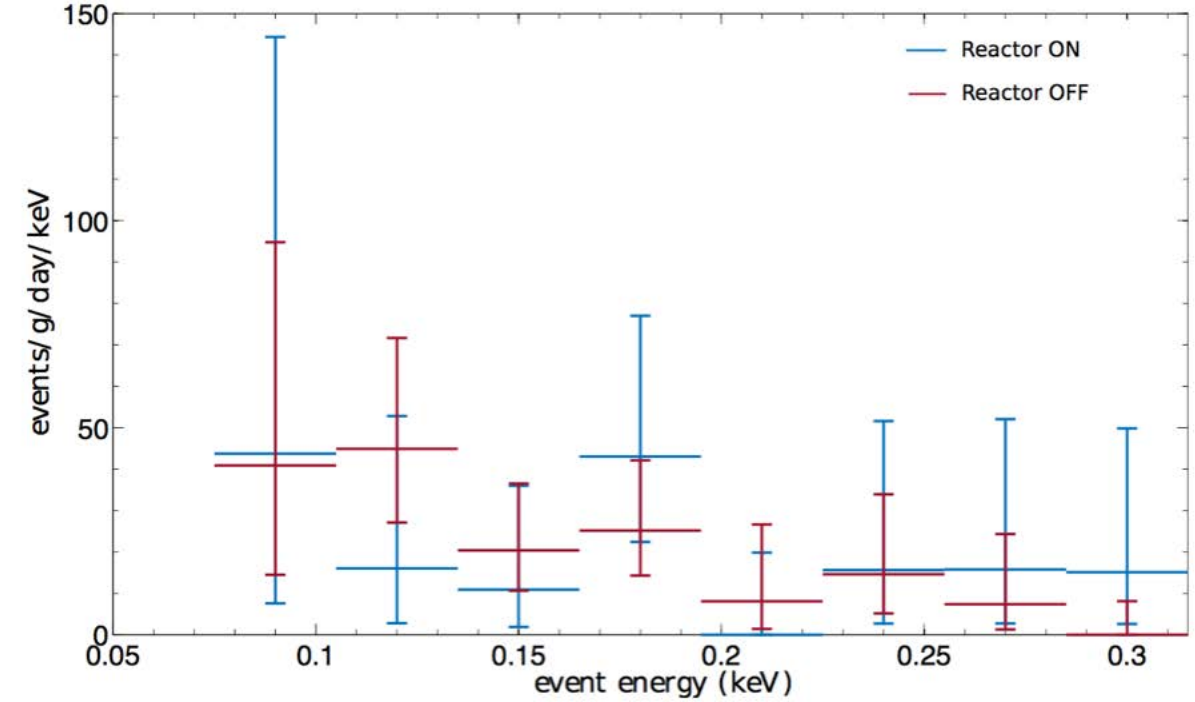
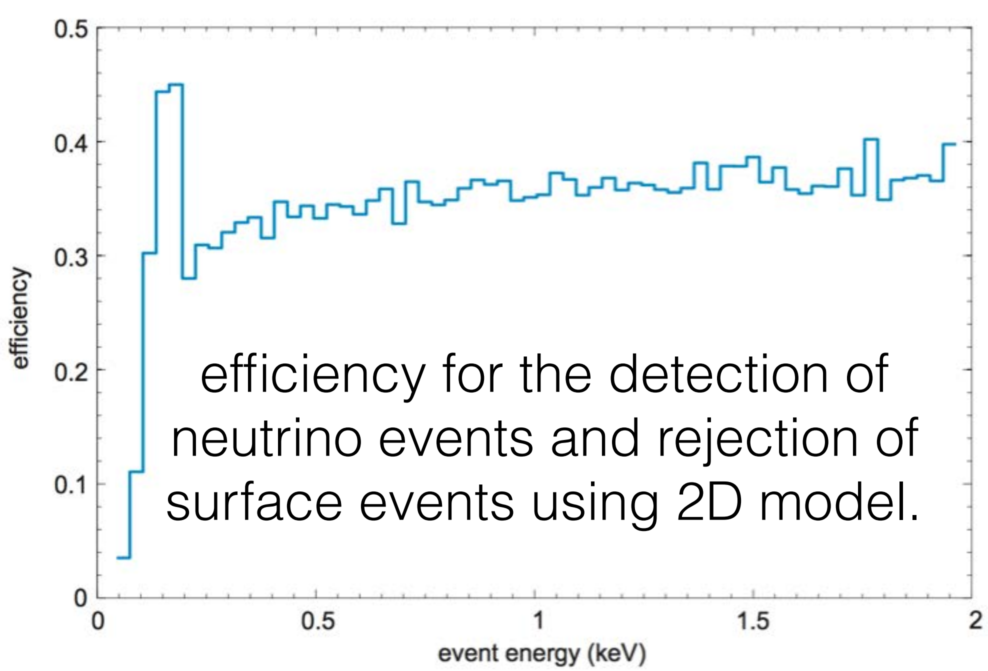


Figure 17: Same as Fig.16, the error bars correspond to 68.27% probability assuming a Poisson distribution for each energy bin.



efficiency for the detection of neutrino events and rejection of surface events using 2D model.