CONNIE

COHERENT NEUTRINO NUCLEUS
INTERACTION EXPERIMENT

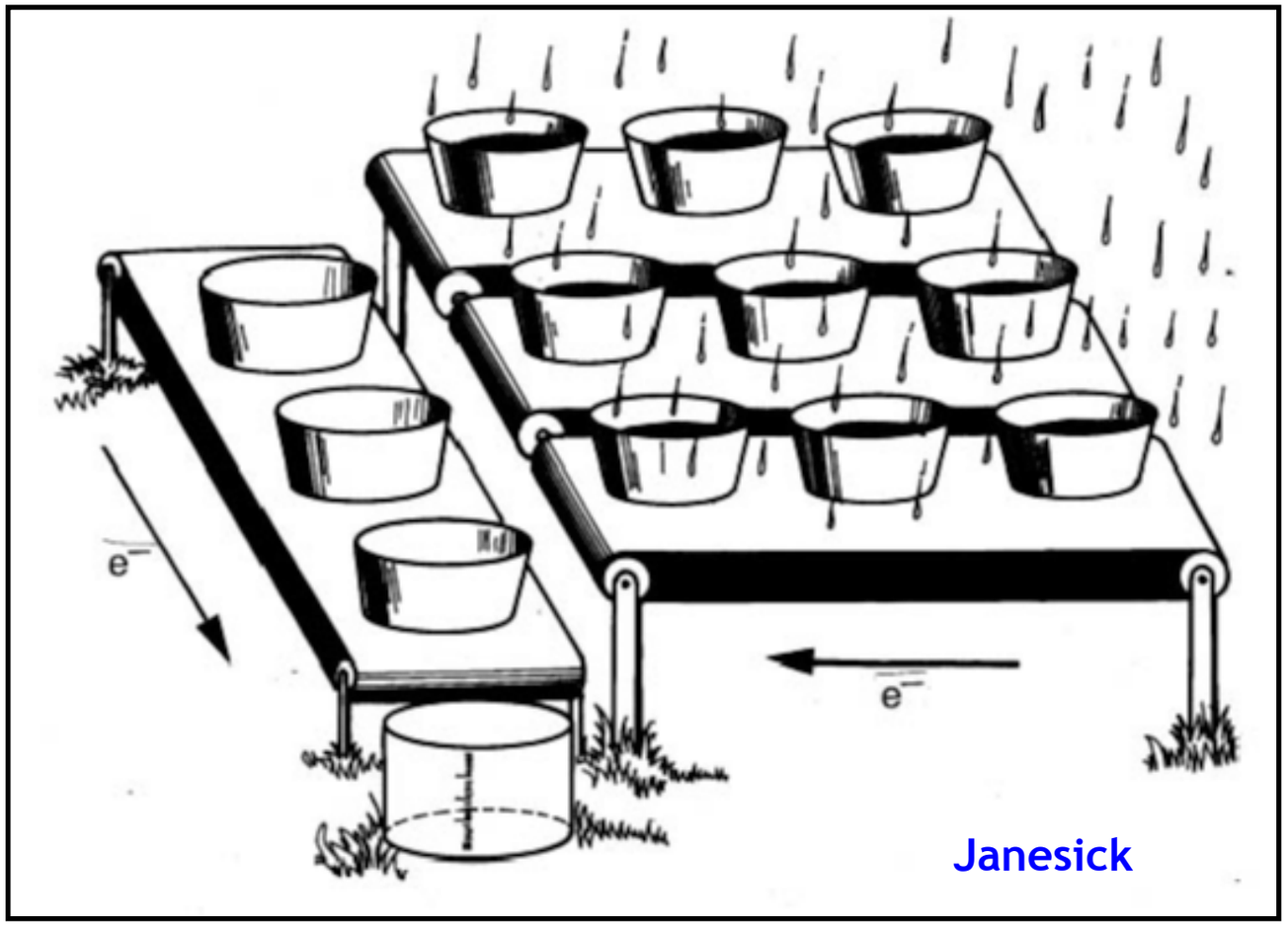
Juan Estrada
with the good slides from G. Fernandez-Moroni and J. Tiffenberg who are here today

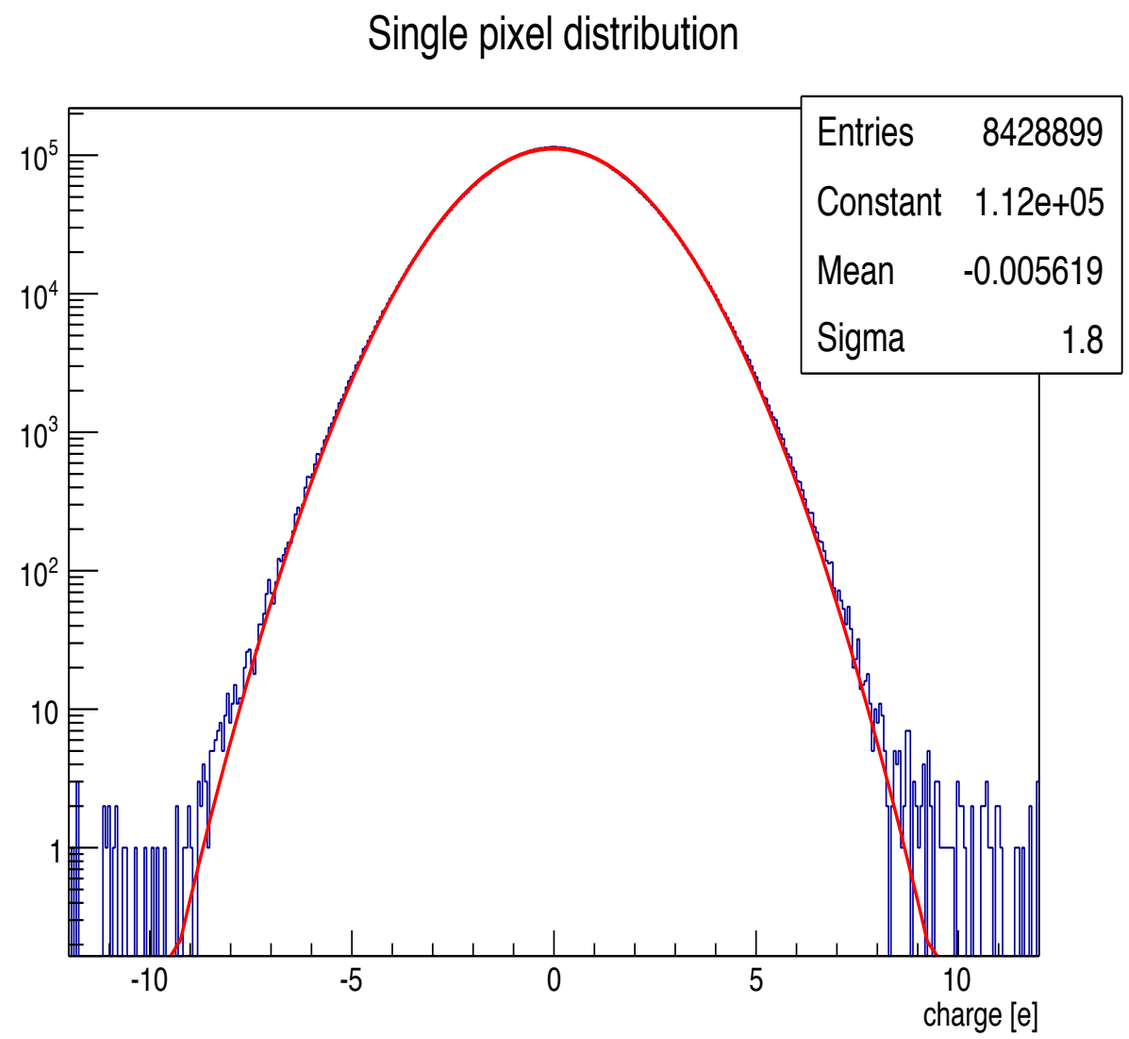
Fermilab

COHERENT NEUTRINO NUCLEUS
INTERACTION EXPERIMENT

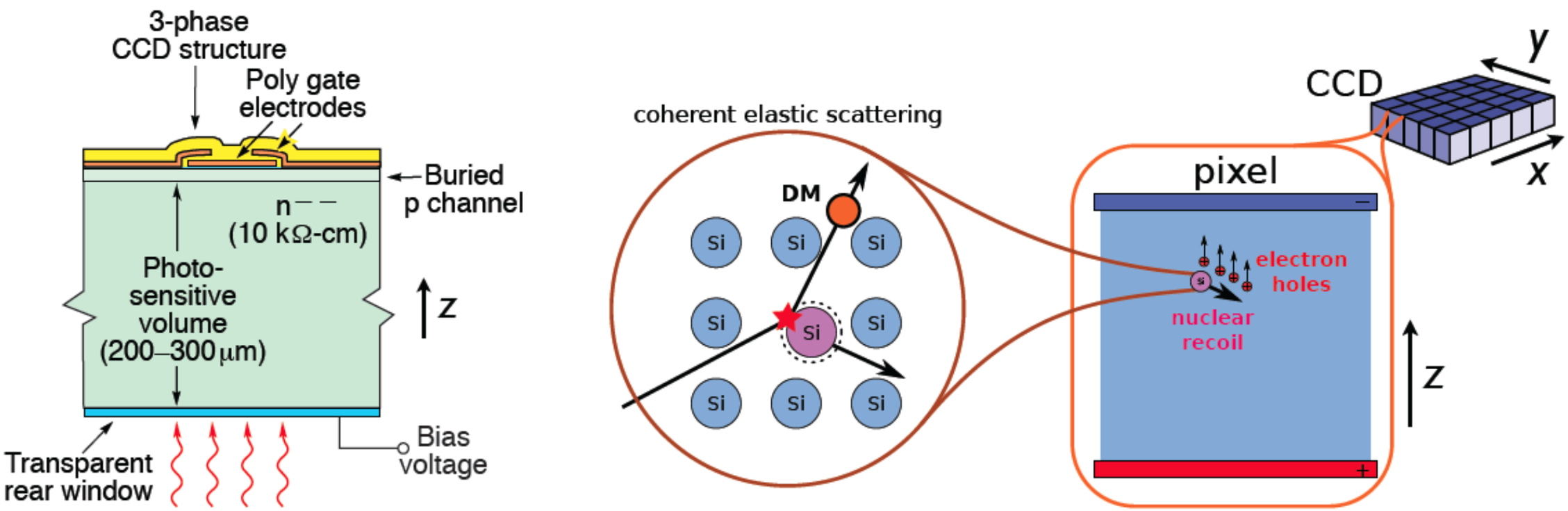
Centro Atómico Bariloche, Argentina
Centro Brasileiro de Pesquisas Físicas, Brazil
Universidad Nacional de Asunción, Paraguay
Fermi National Accelerator Laboratory, USA
Universidad Nacional Autónoma de México, Mexico
Universidad Nacional del Sur, Bahia Blanca, Argentina
Universidade Federal do Rio de Janeiro, Brazil
Universitat Zurich Physik Institut, Switzerland
University of Michigan, USA

Detector: CCD readout



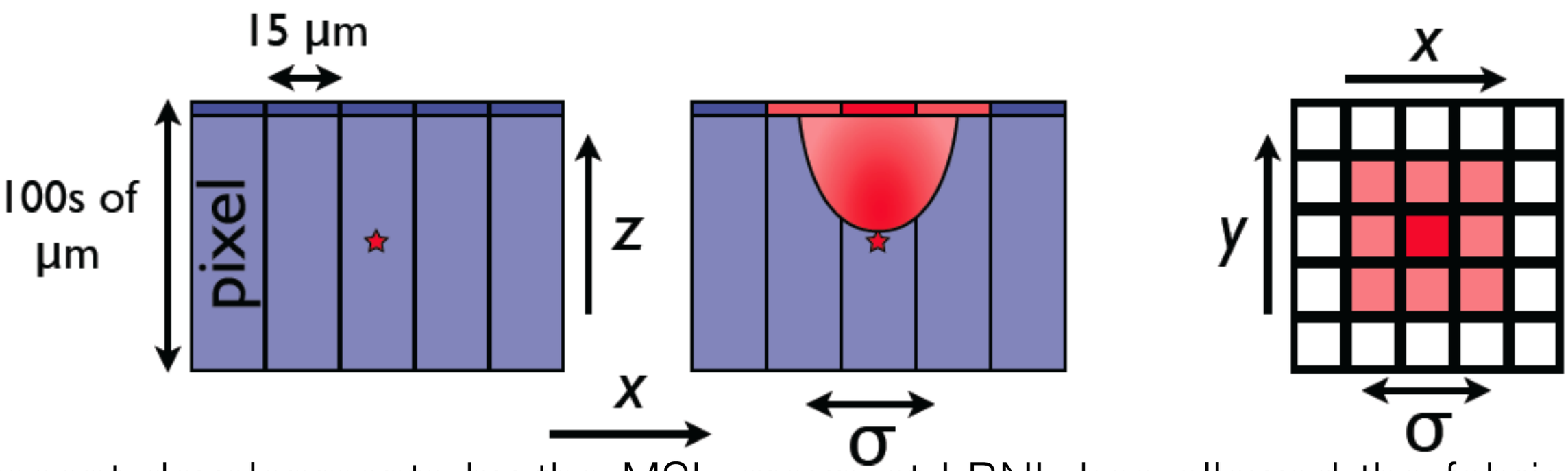


Charge coupling makes the detectors ideal for low noise measurements, typical noise for scientific CCDs is 2e- RMS (7.6eV). Very recent work pushing this to “0” noise.



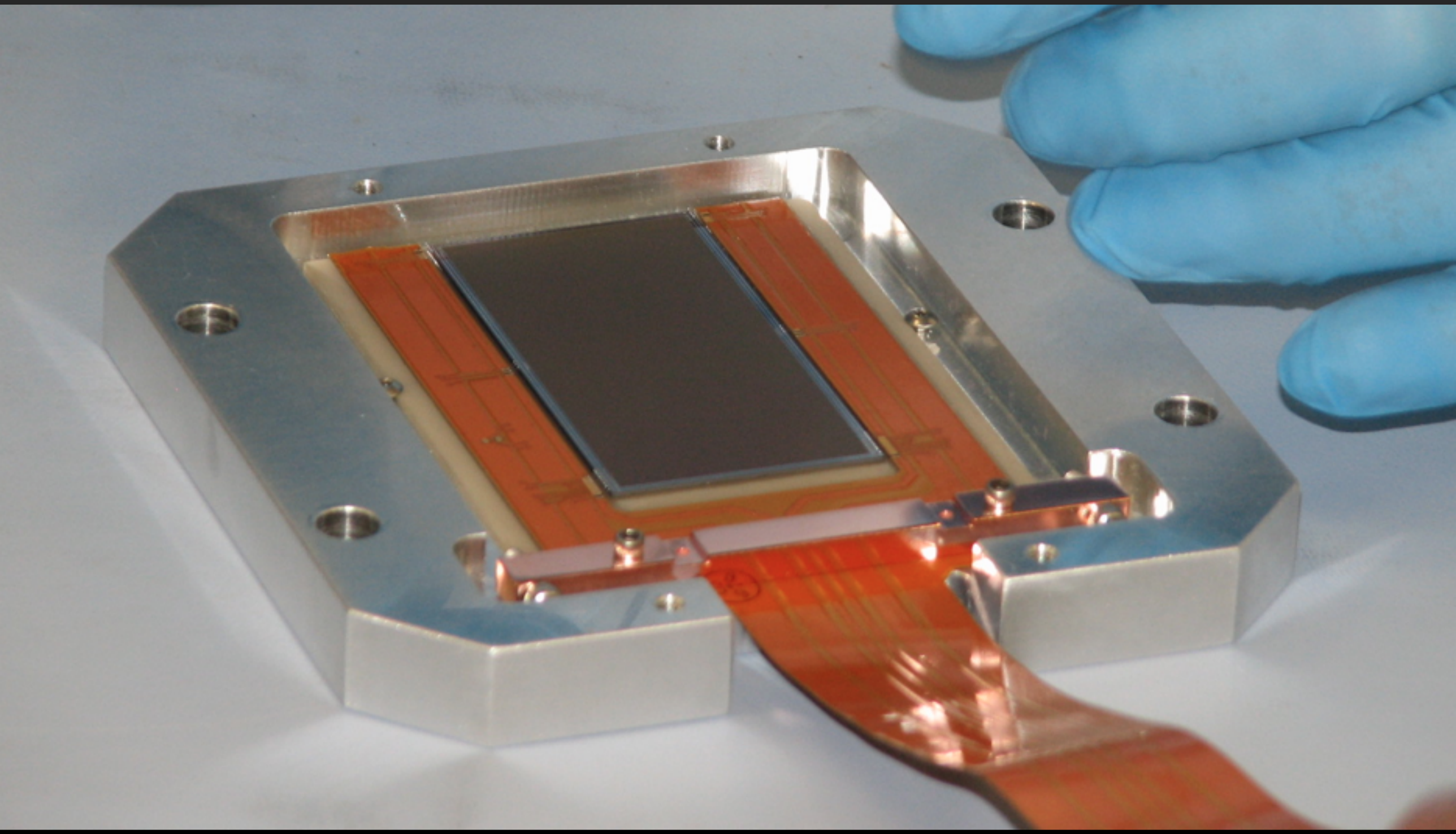
(a) A CCD pixel

(b) WIMP detection principle



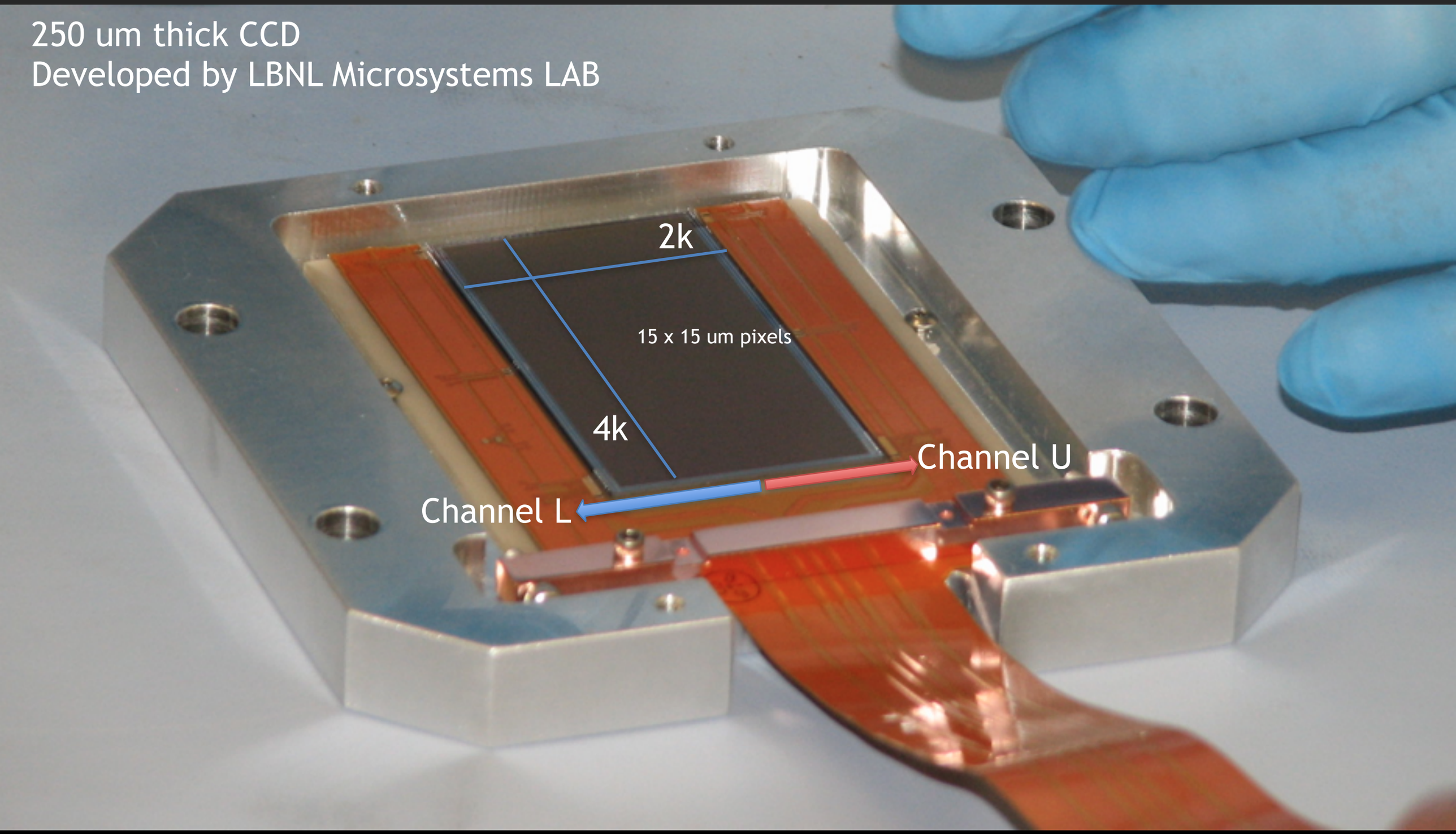
Recent developments by the MSL group at LBNL has allowed the fabrication for “massive” CCDs. 675 um is now possible.

CONNIE 2014-2015 sensor:



CONNIE 2014-2015 sensor

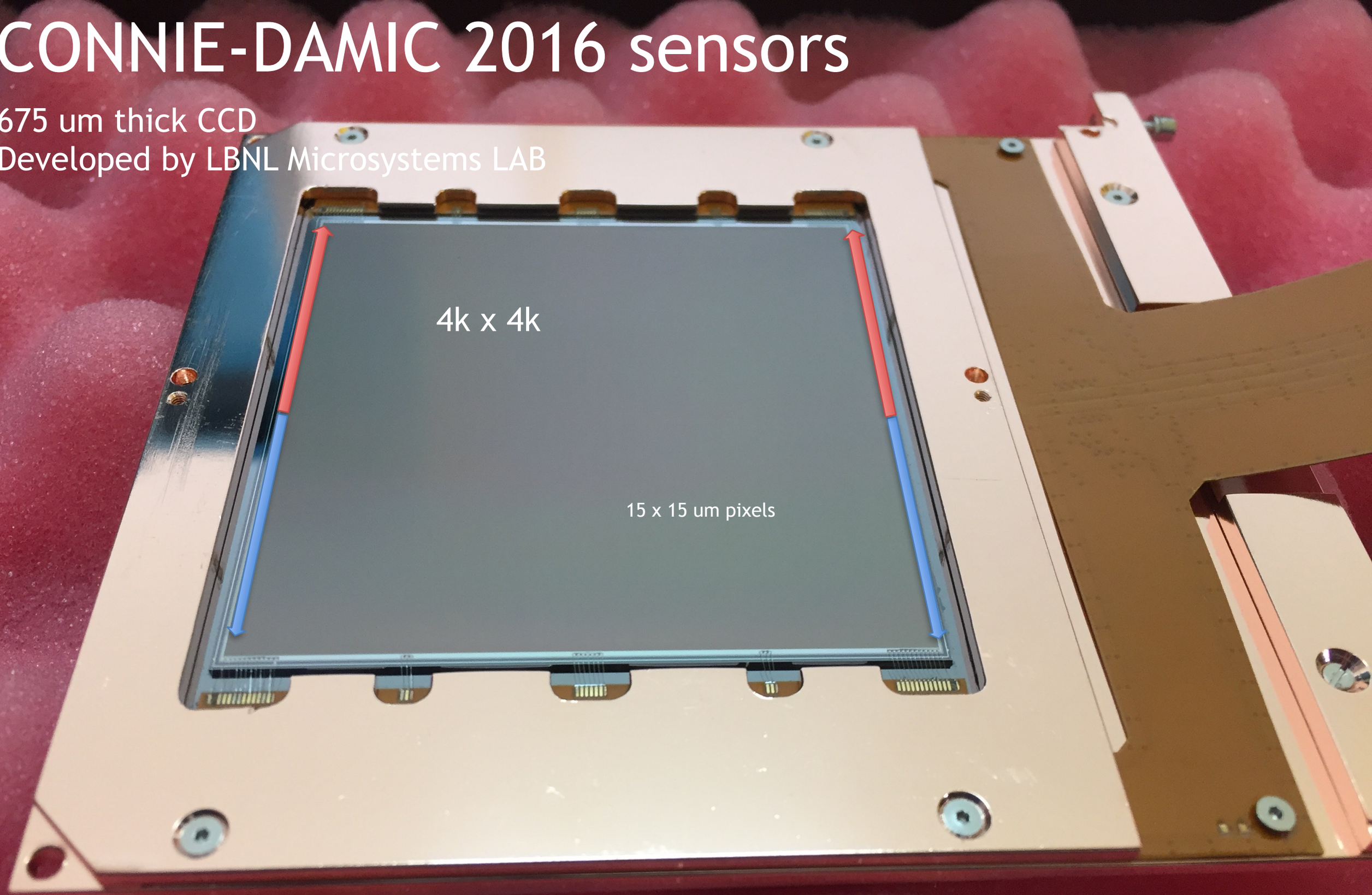
250 um thick CCD
Developed by LBNL Microsystems LAB



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

CONNIE-DAMIC 2016 sensors

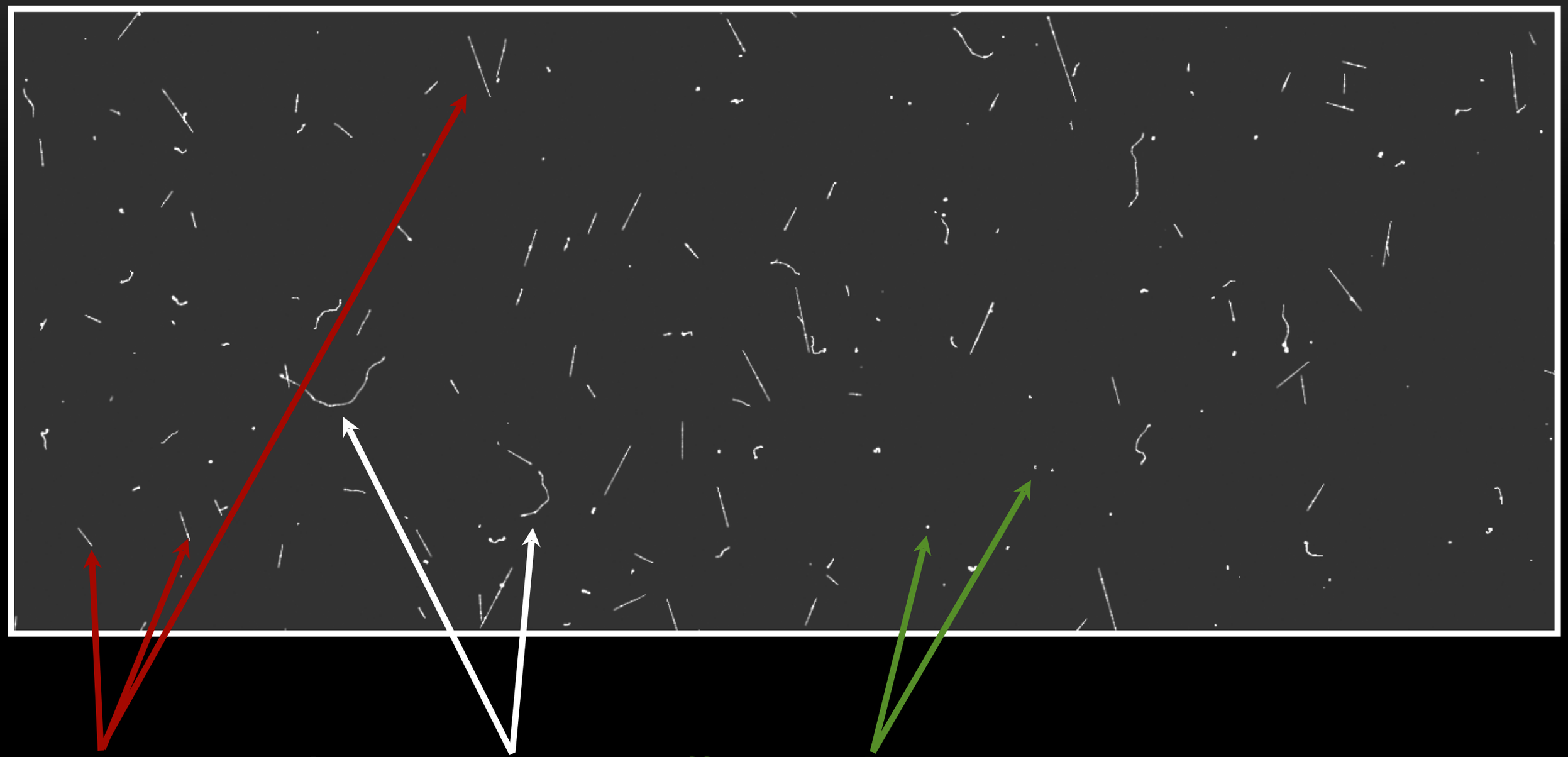
675 um thick CCD
Developed by LBNL Microsystems LAB



4 amplifiers
2e- noise
low background package

16 Mpix — 6g

Particle identification in a CCD image

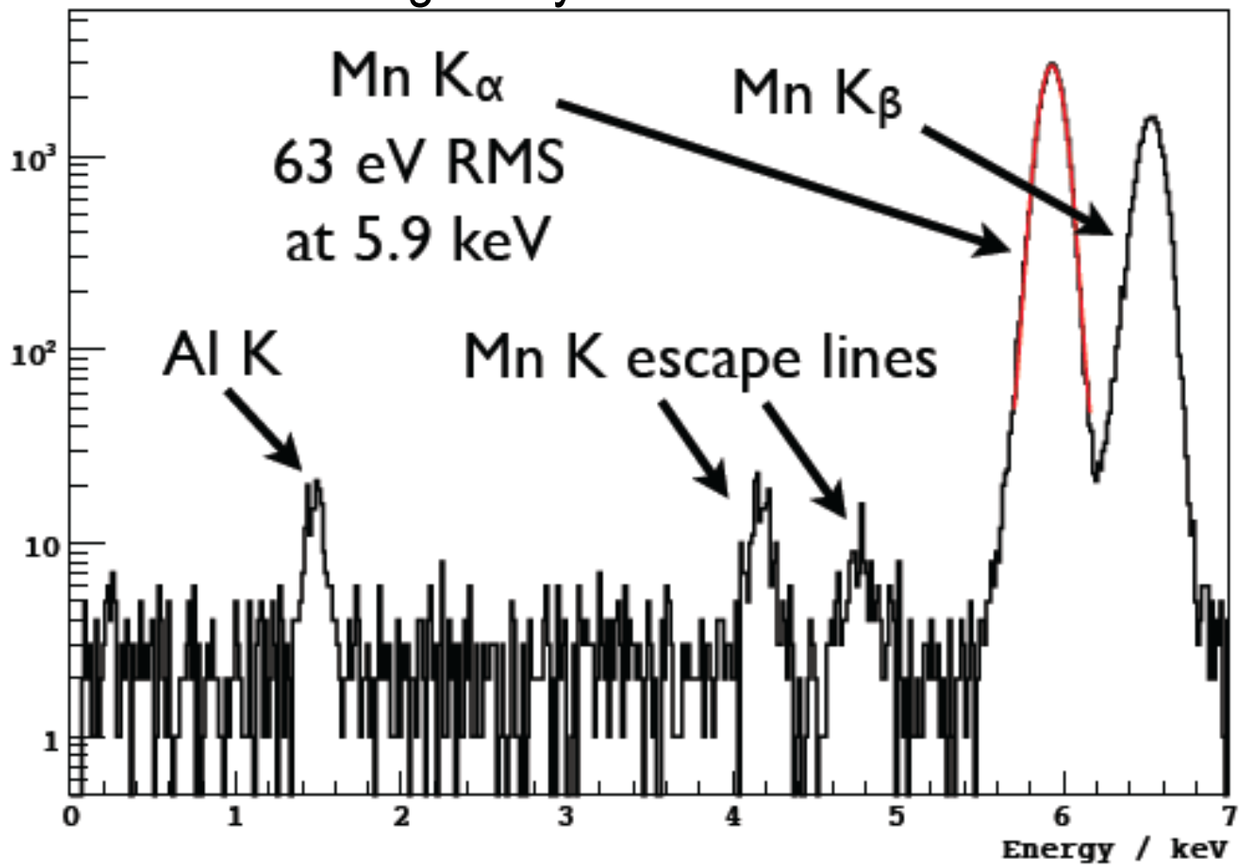


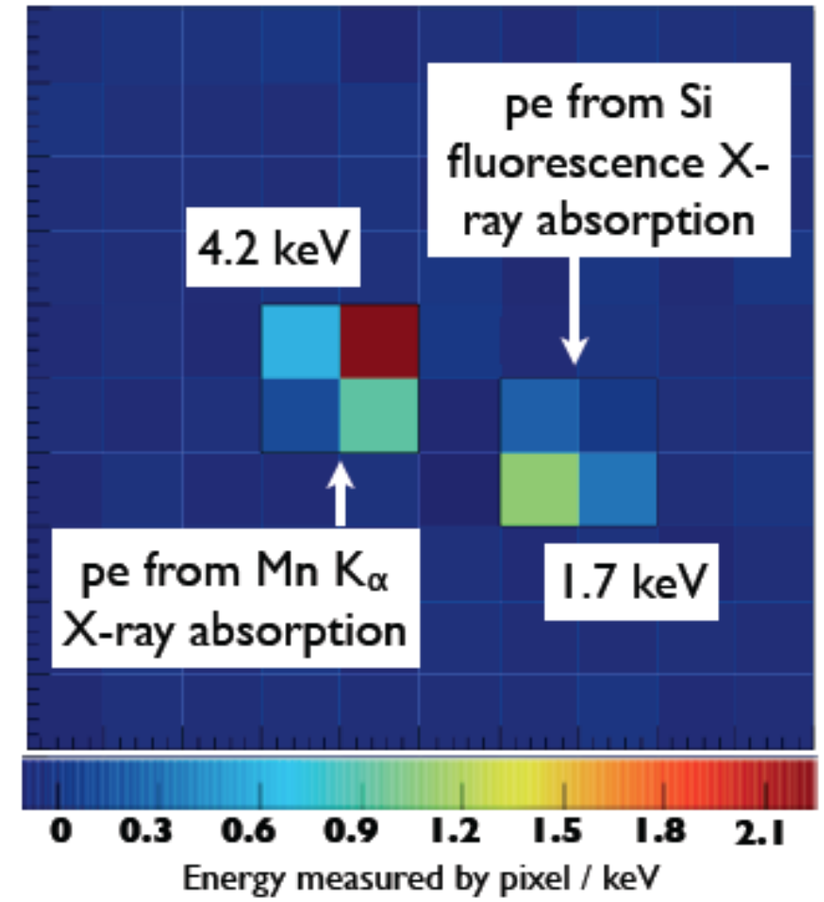
muons, electrons and diffusion limited hits.

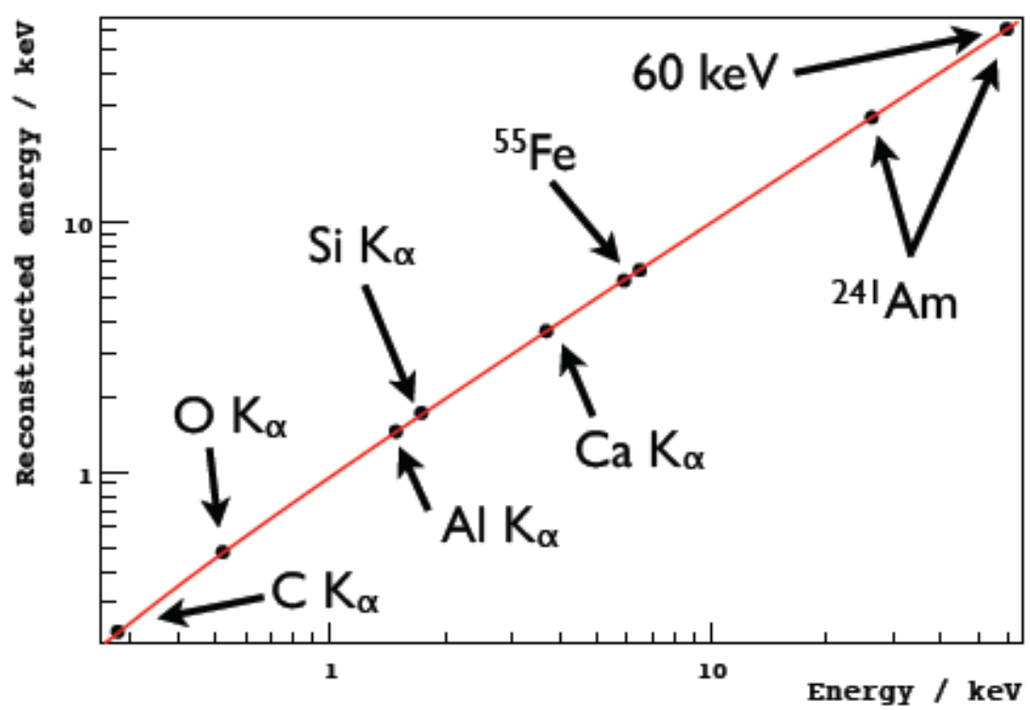
Nuclear recoils will produce diffusion limited hits. Neutrinos from reactor are expected to produce nuclear recoils at a rate of 10,000 per day for each kilogram of detector.

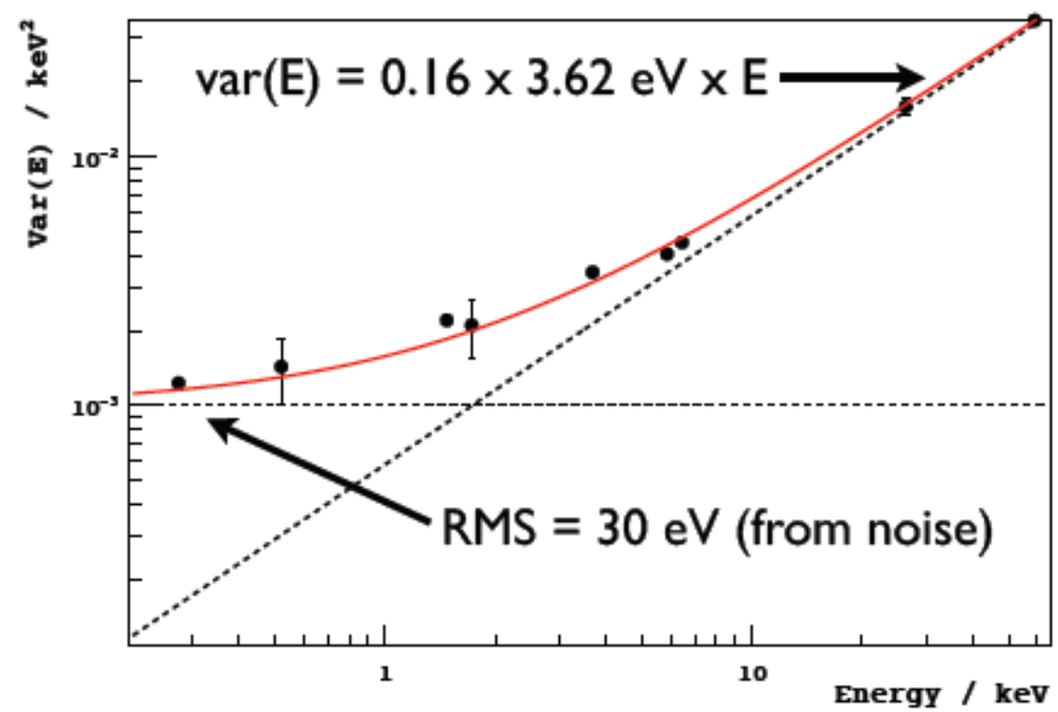
arXiv:1408.3263

Calibration using X-rays



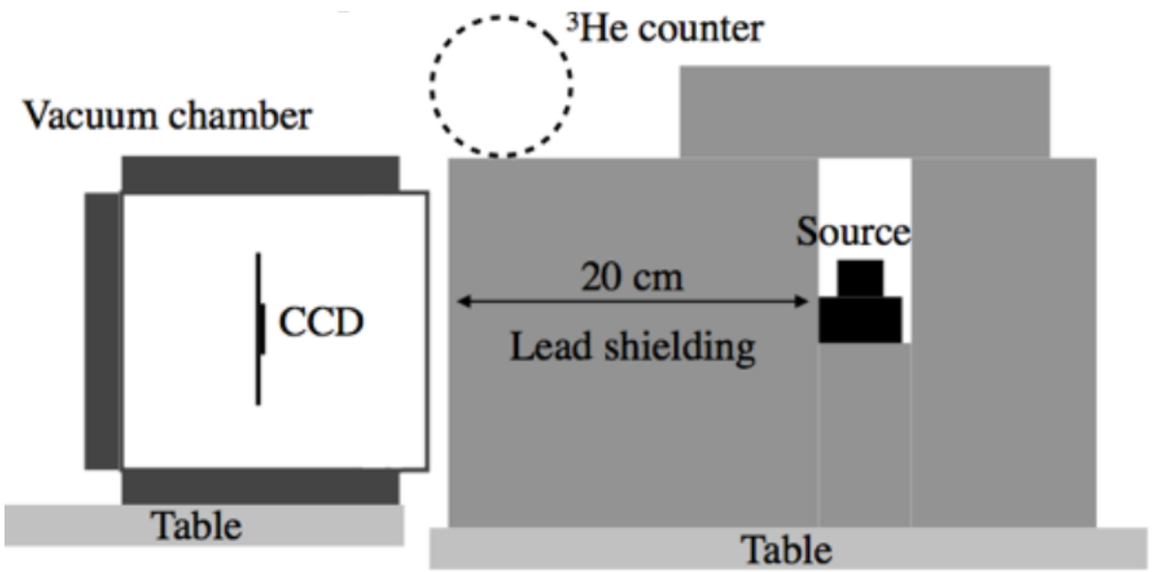






Nuclear Recoil Calibration (A.Chavarria et al) @UChicago

arXiv:1608.00957



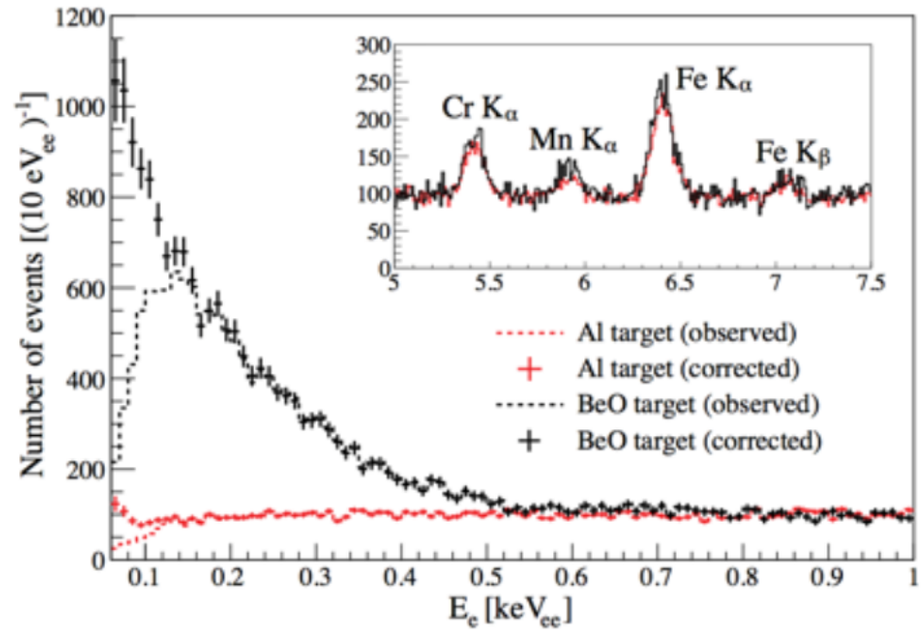


FIG. 2. Measured ionization spectra with the full BeO and Al targets (dashed lines). Solid markers represent the spectra corrected for the energy-dependent event selection acceptance. The inset shows the spectra in the 5.0–7.5 keV$_{ee}$ range, with in-run calibration lines from fluorescence x rays originating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

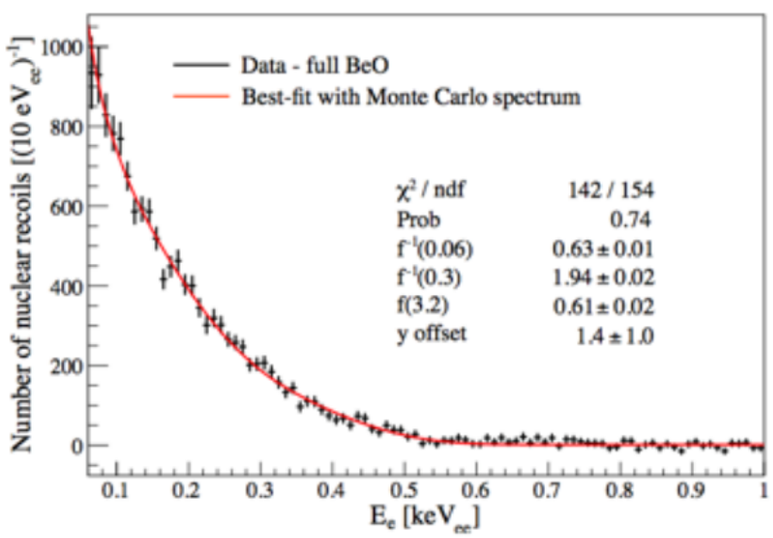
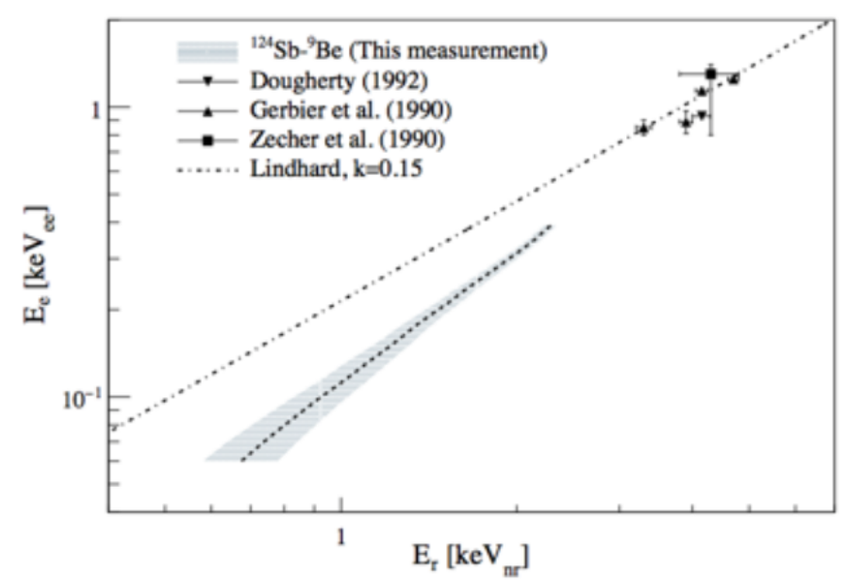


FIG. 4. Ionization spectrum of nuclear recoils induced by neutrons from the full BeO target source (black markers) and best fit to the data (solid line). The fitting function was obtained by applying a cubic spline model f of the nuclear recoil ionization efficiency to the simulated recoil spectrum and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



involving "Juan El Malo".

Nuclear Recoil Calibration (F. Izraelevitch et al)

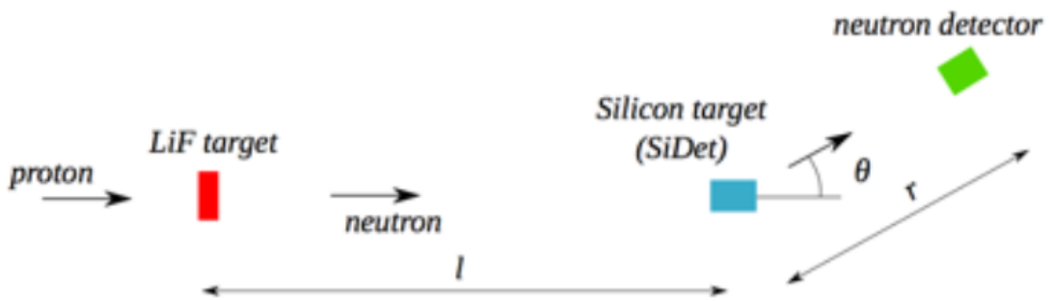
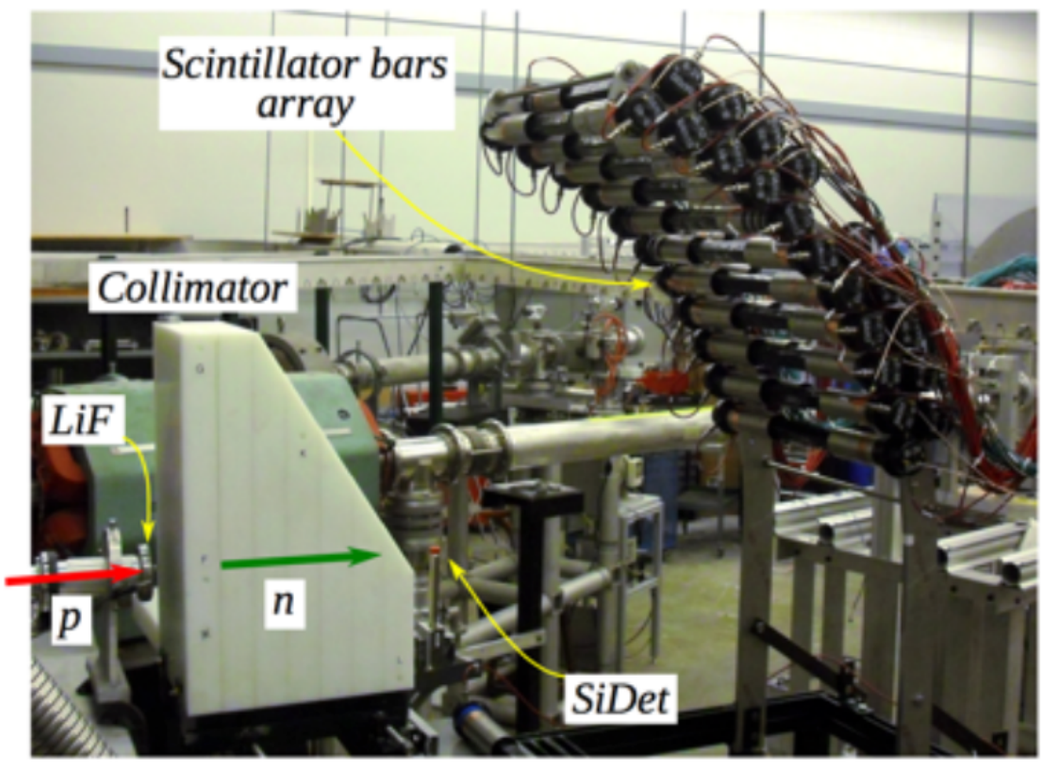
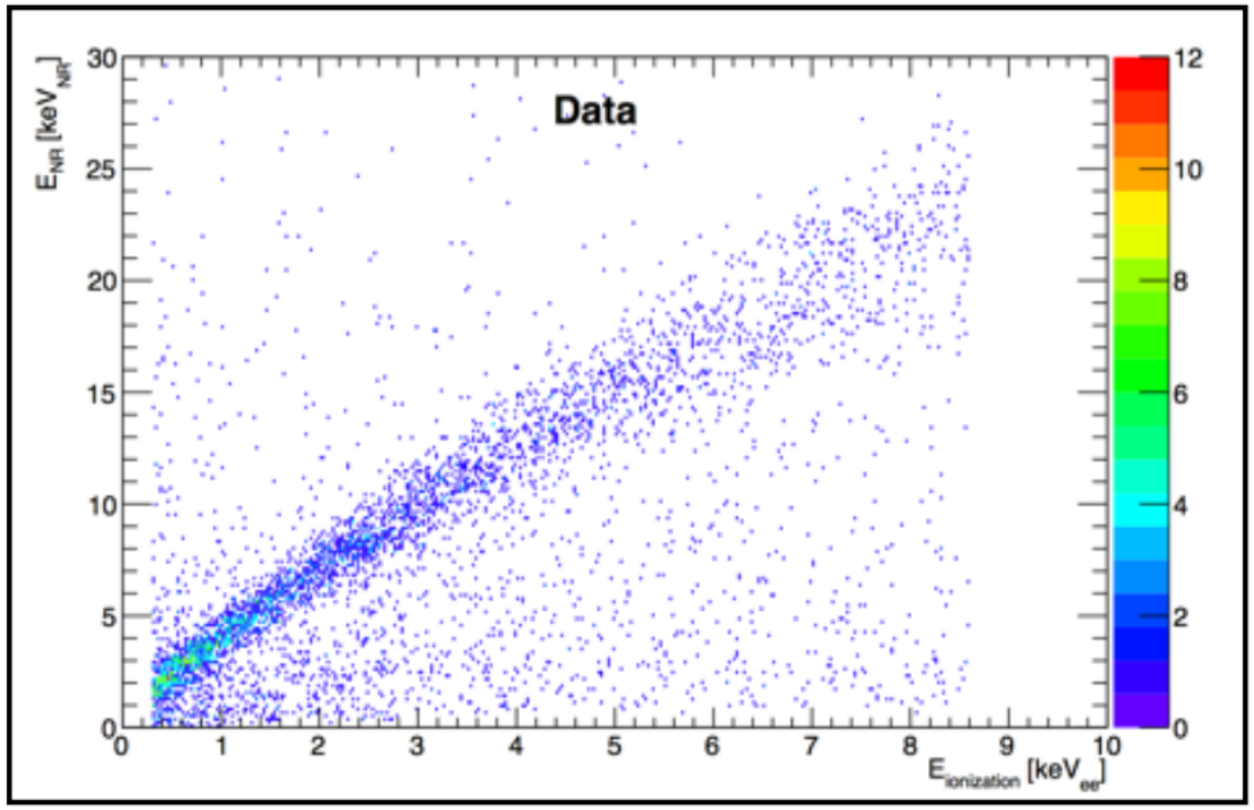
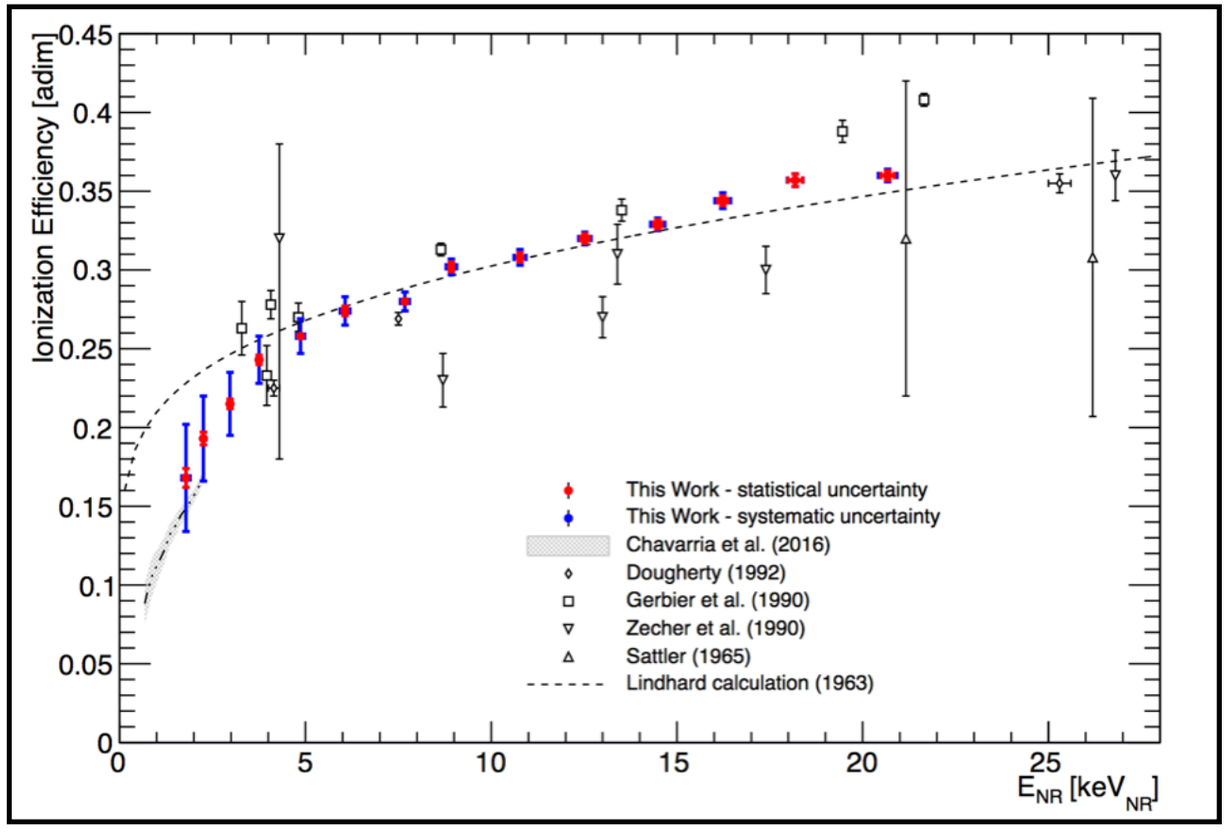


Figure 1: Schematic layout of the experimental arrangement.

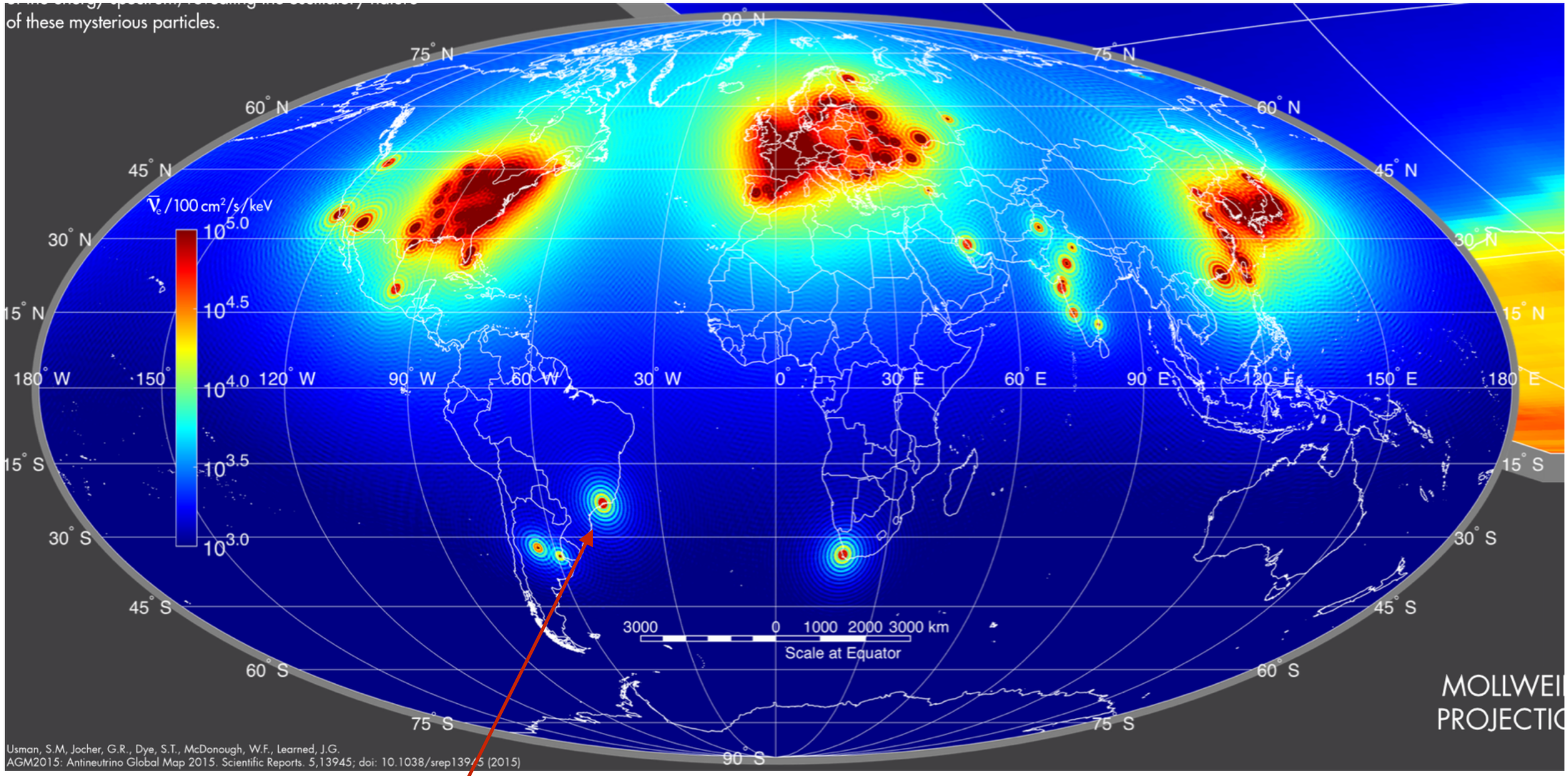






<u>Complete calibration down to our threshold for CONNIE.</u>

of these mysterious particles.

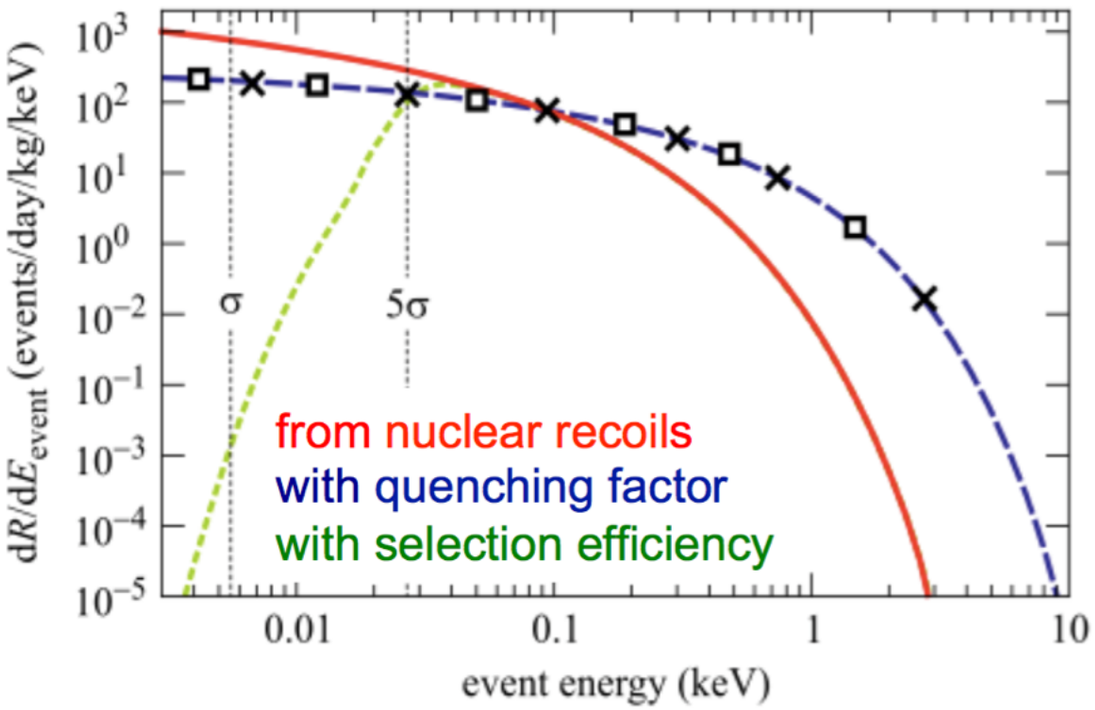


Usman, S.M, Jocher, G.R., Dye, S.T., McDonough, W.F., Learned, J.G.
AGM2015: Antineutrino Global Map 2015. Scientific Reports. 5,13945; doi: 10.1038/srep13945 (2015)

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

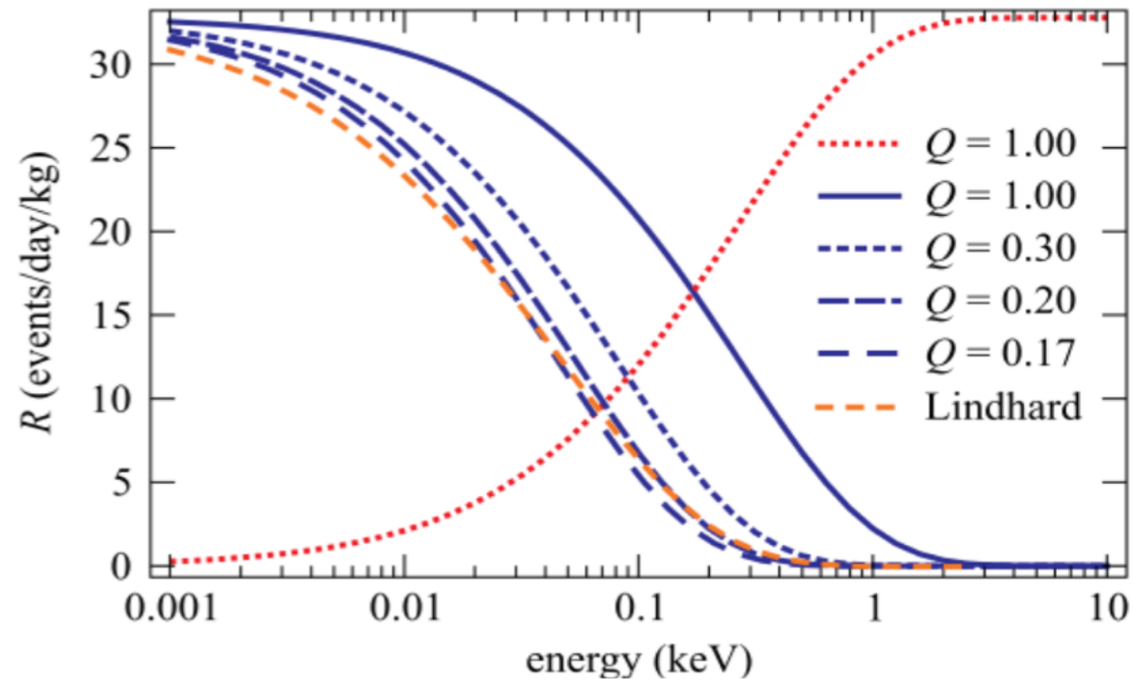
CONNIE rates

Energy spectra in silicon detectors



Phys.Rev. D 91, 072001 (2015)

Total number of events vs threshold energy for different quenching factors



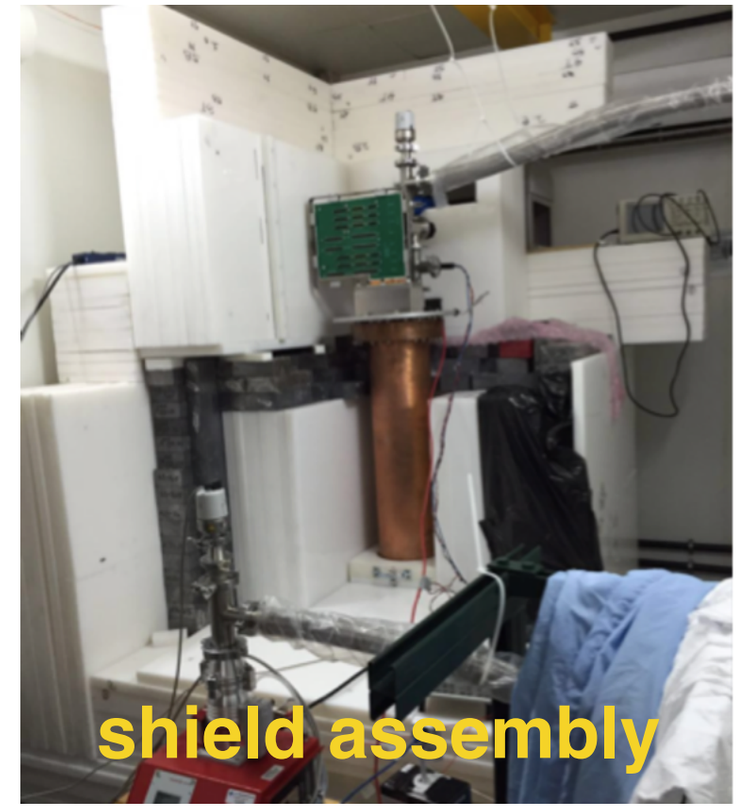
Total events vs max. detectable recoil for Q=1

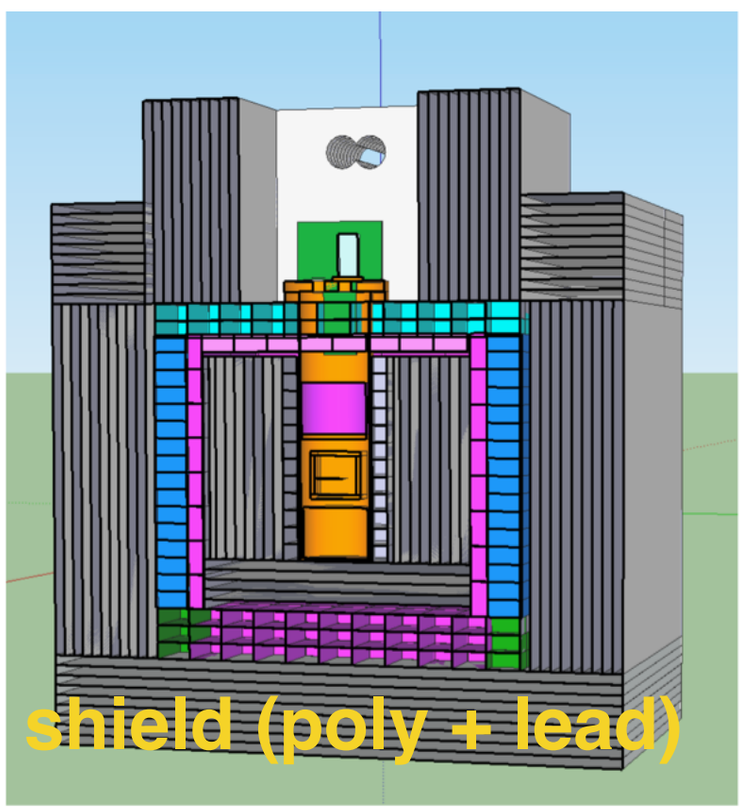
Q = 0.20

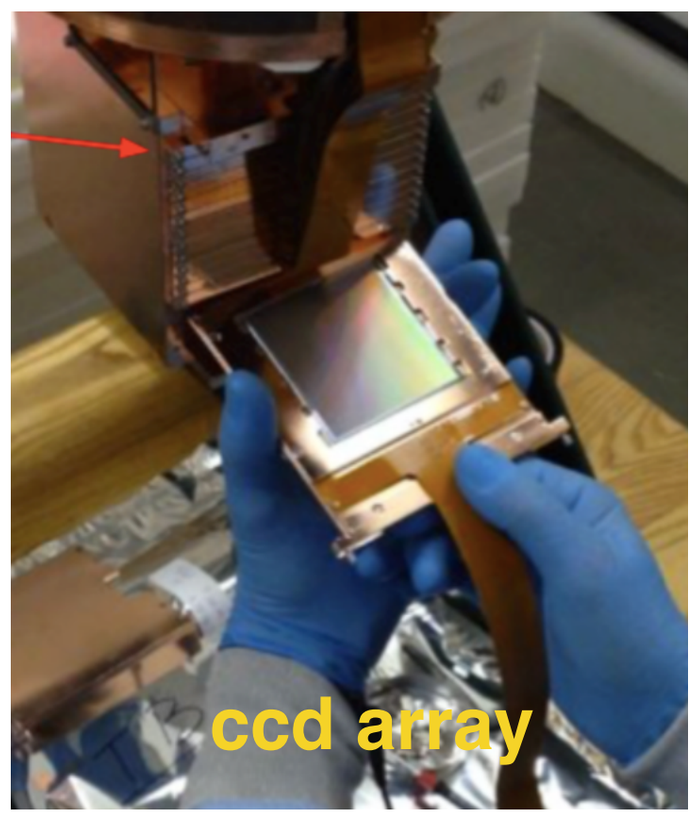
Expected number of events (event/kg/day)

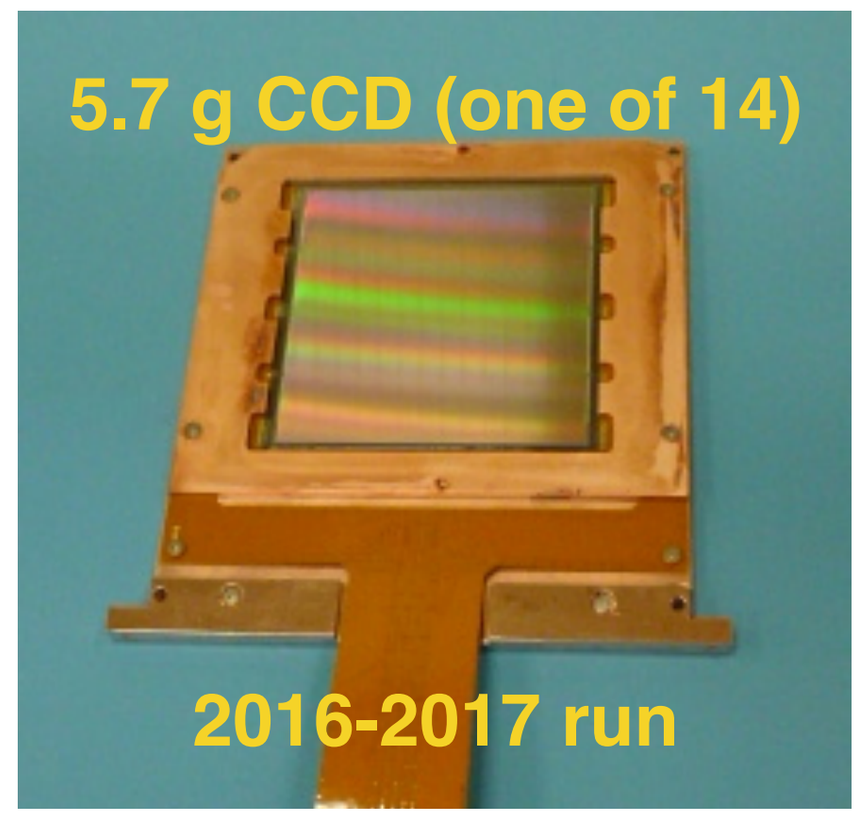
E_{th} = 5.5 eV ($1\sigma_{RMS}$) ~ 28.3

E_{th} = 28 eV ($5\sigma_{RMS}$) ~ 18.1



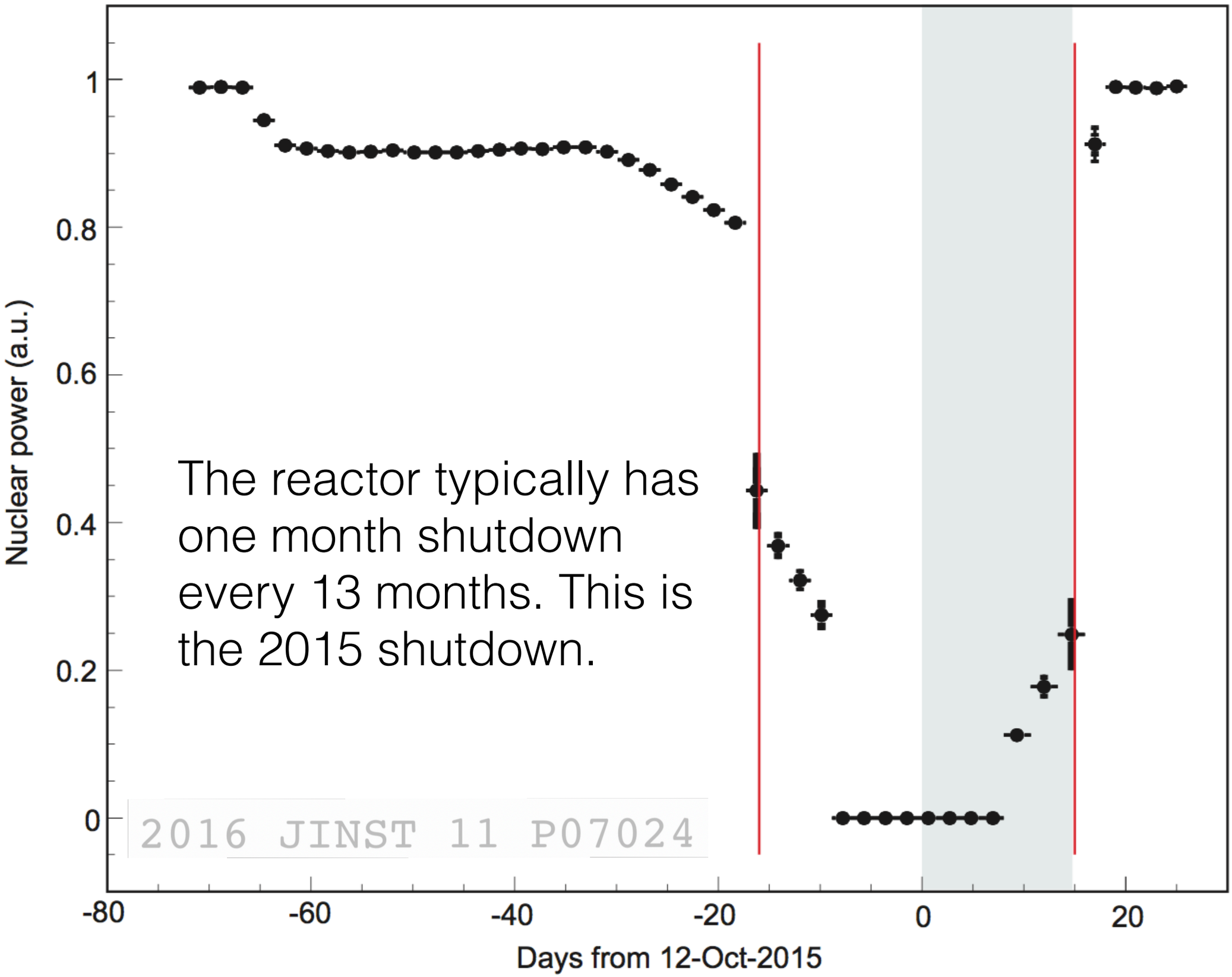






originally we developed this technology for DAMIC (dark matter search)

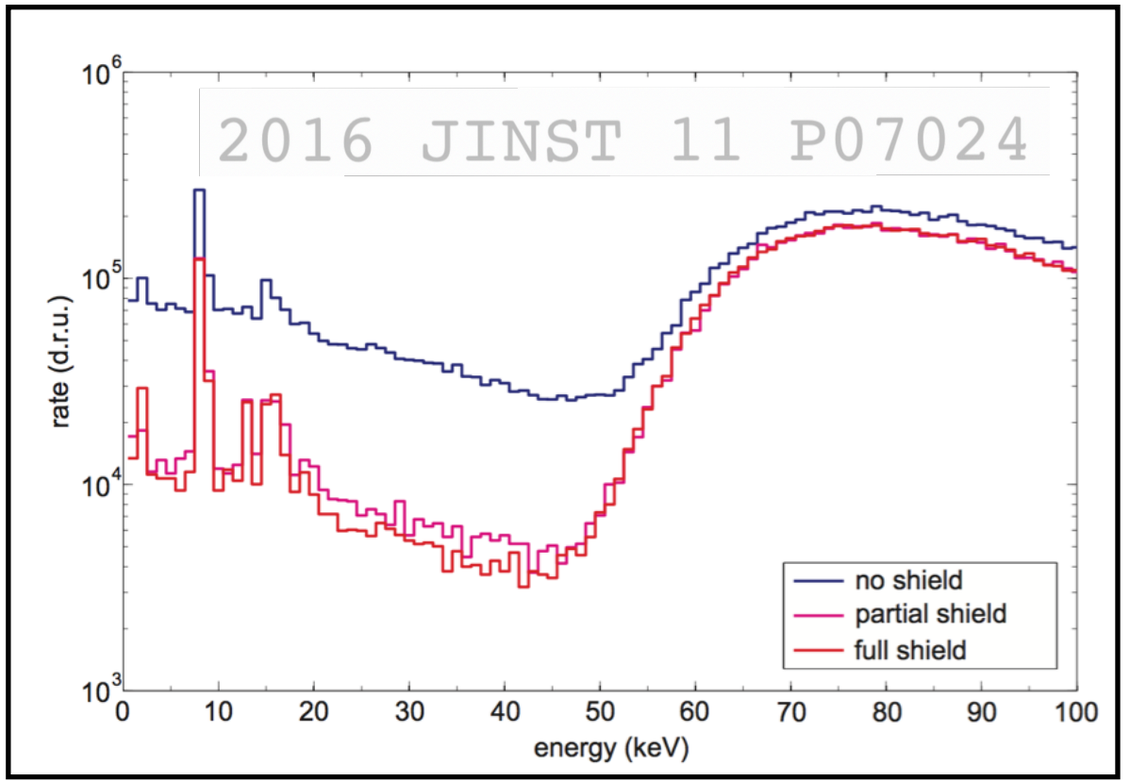
2015 Engineering Run

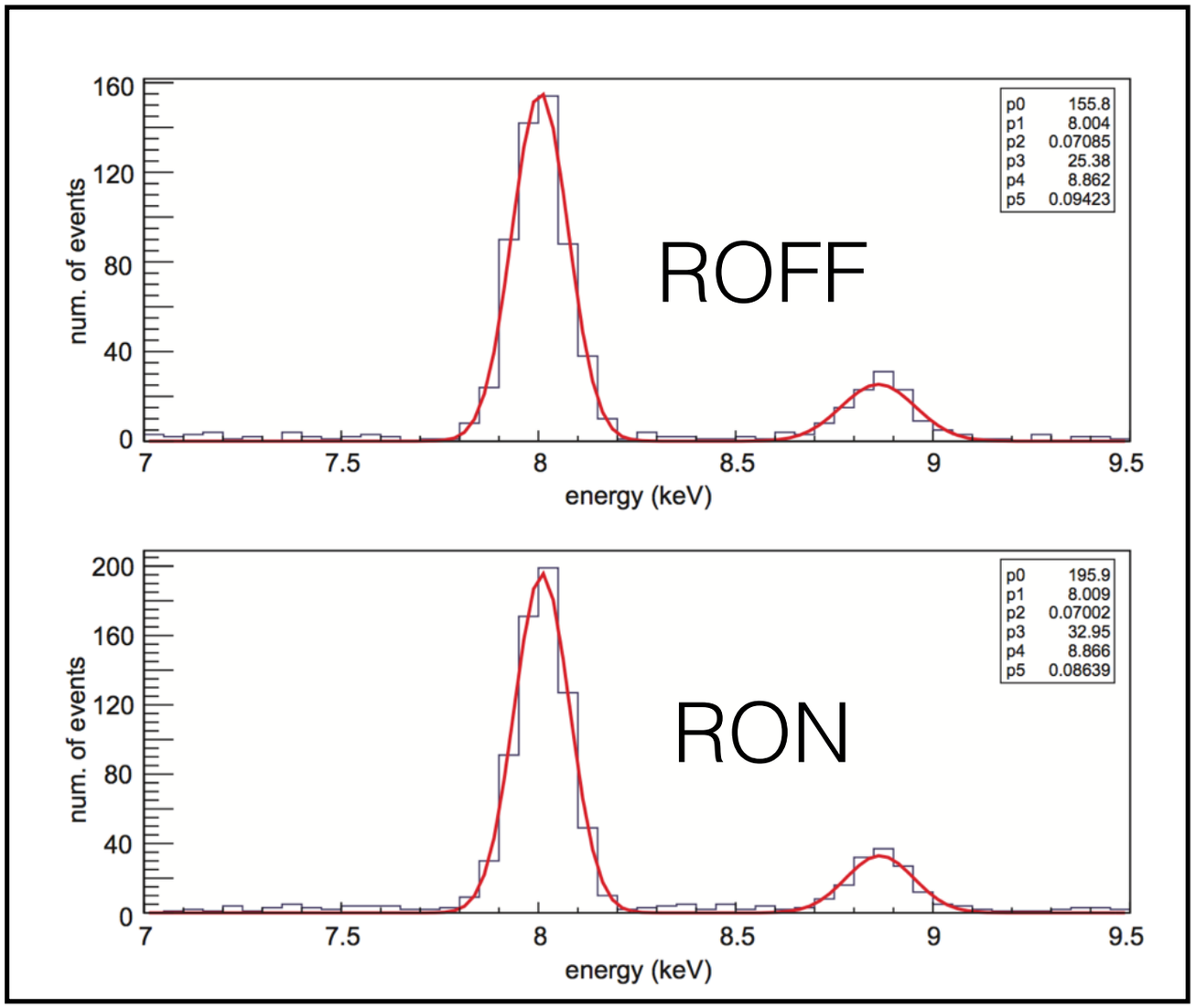


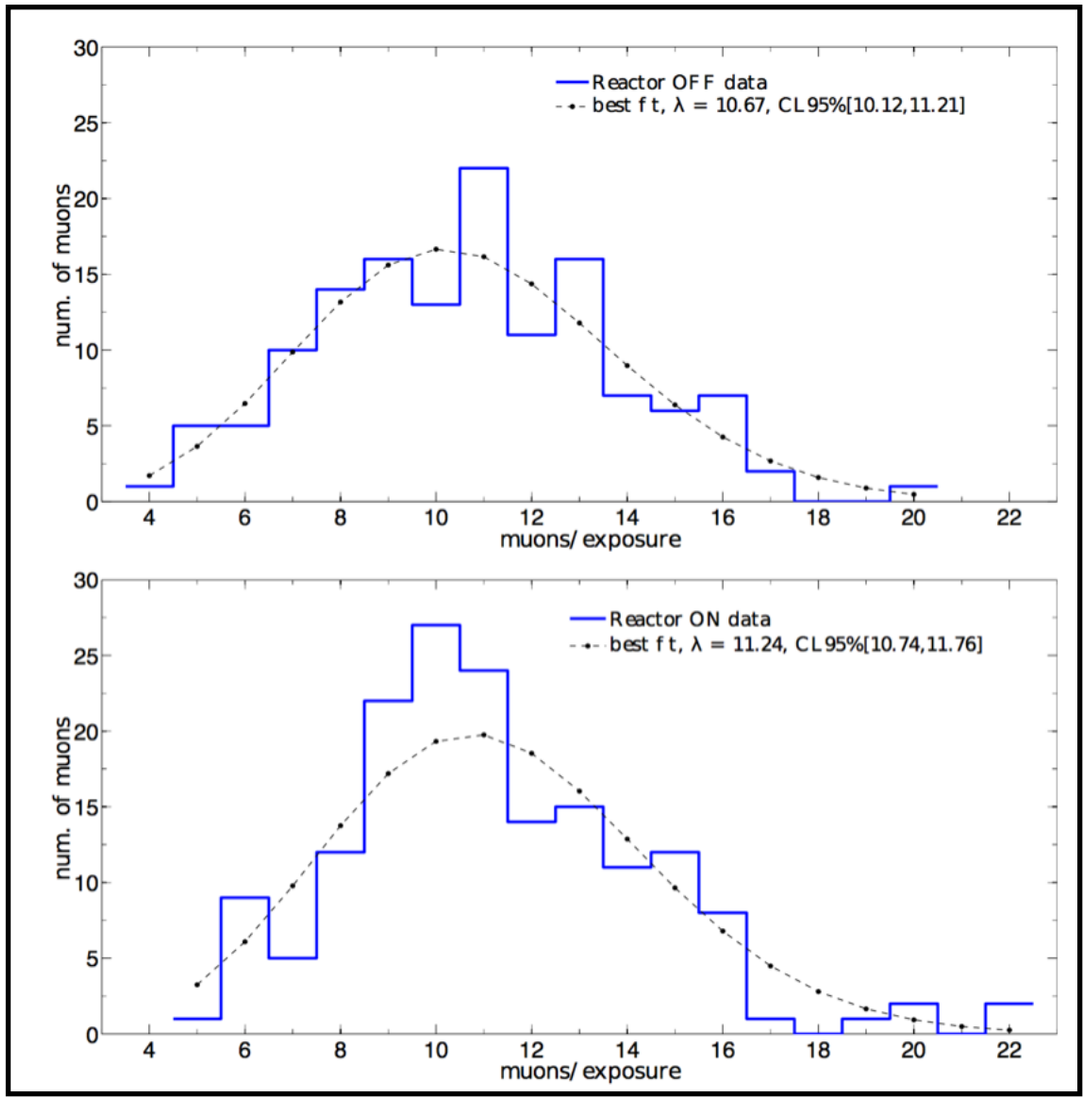
The reactor typically has one month shutdown every 13 months. This is the 2015 shutdown.

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



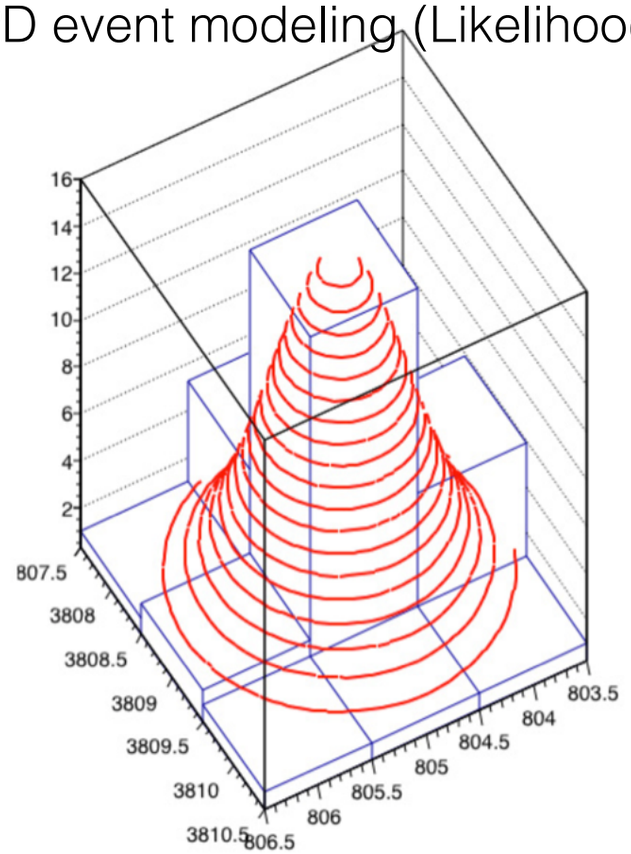




2015 : no excess

2016 JINST 11 P07024

2D event modeling (Likelihood)



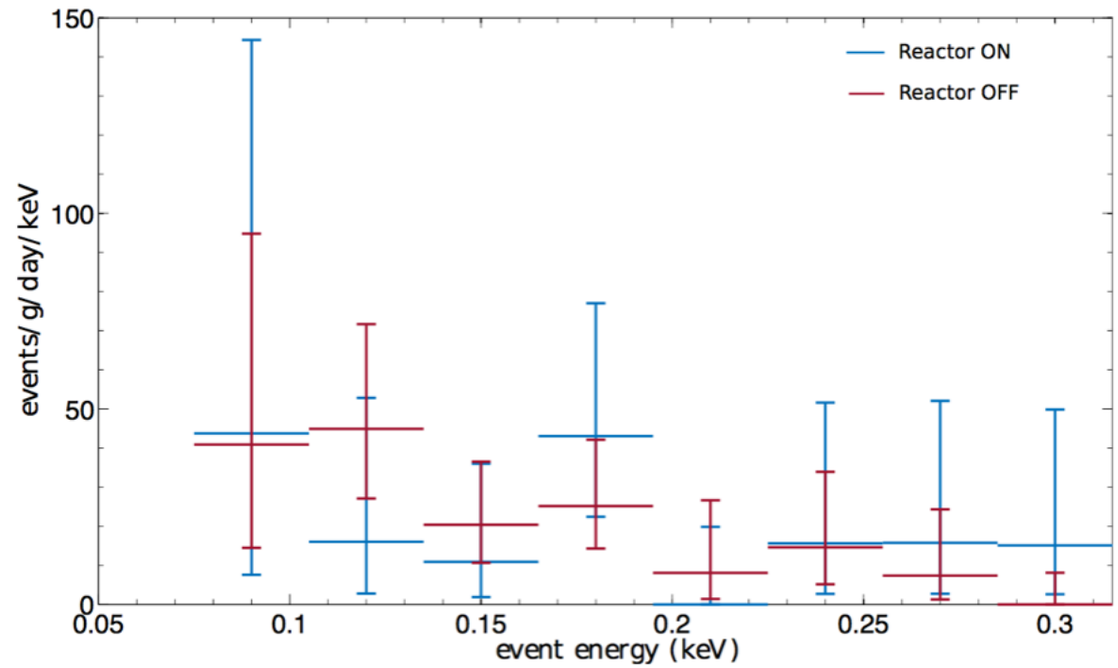
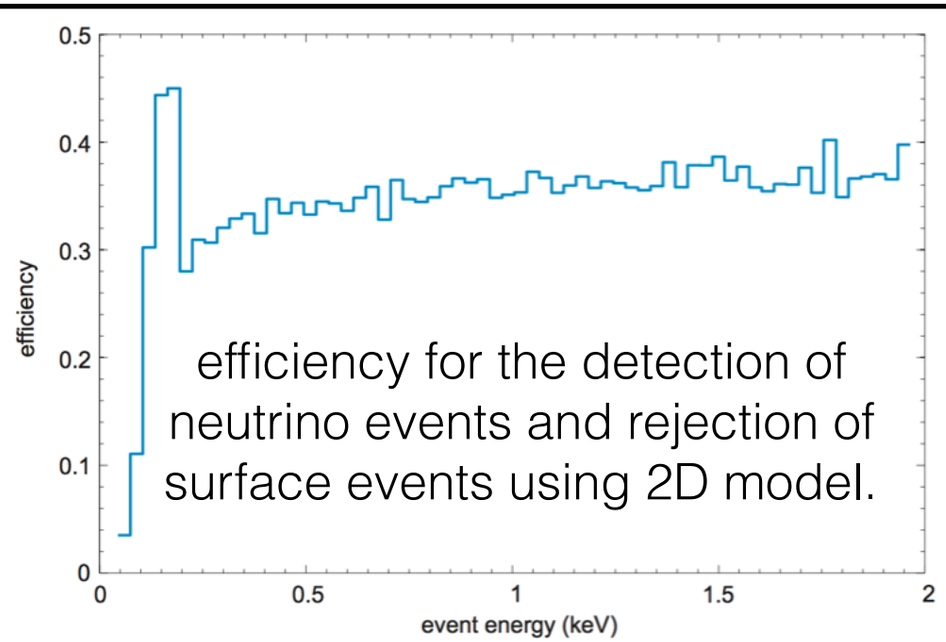
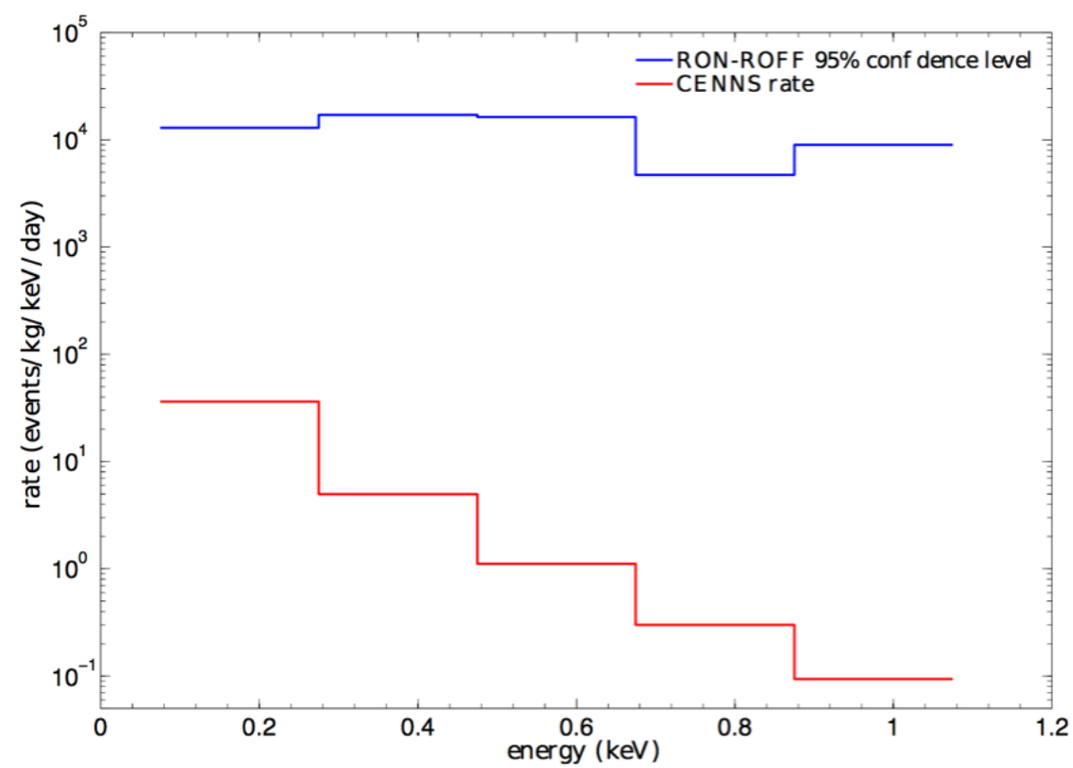


Figure 17: Same as Fig.16, the error bars correspond to 68.27% probability assuming a Poisson distribution for each energy bin.



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



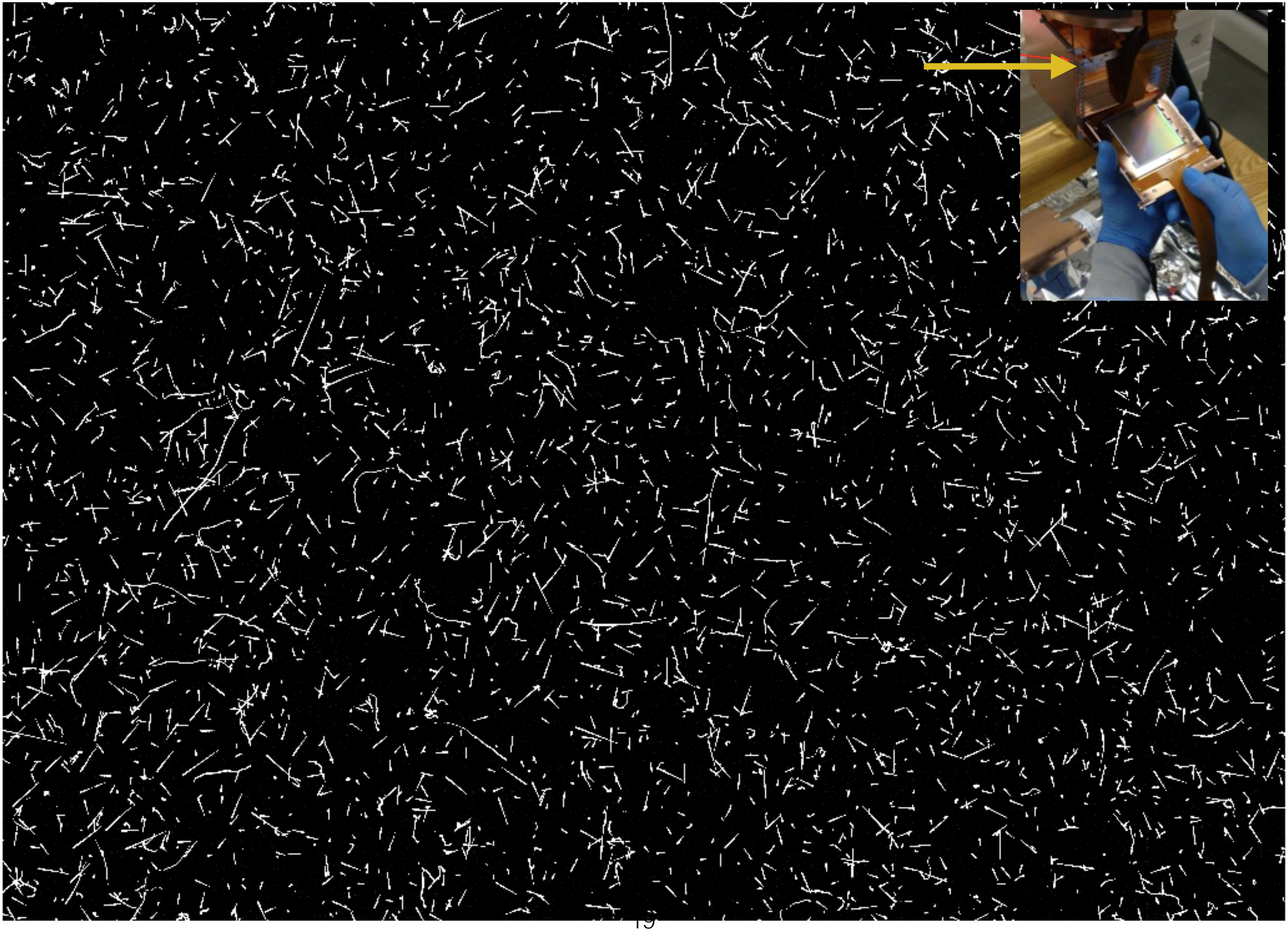
2016

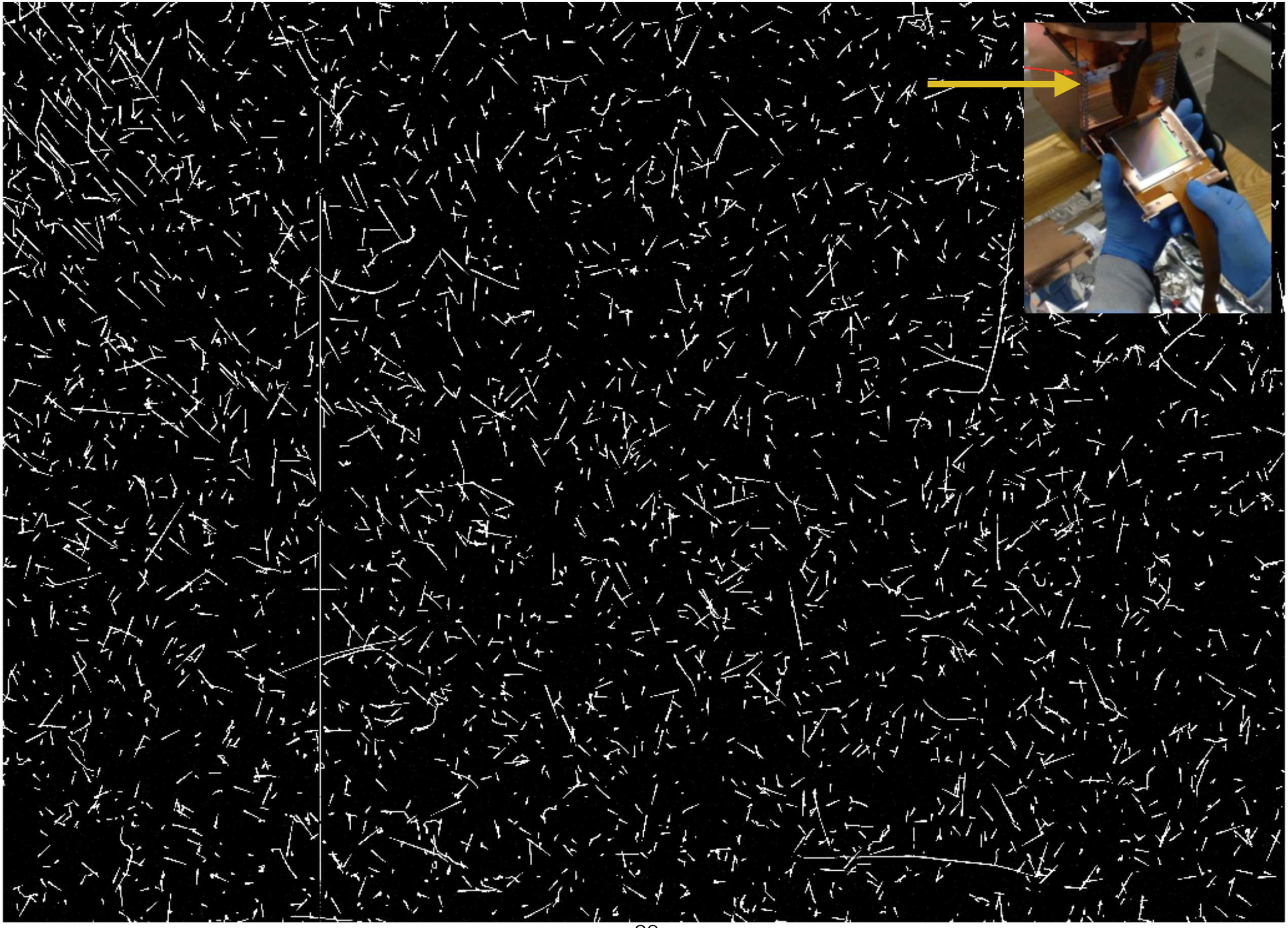
- Exposure increase x 130:

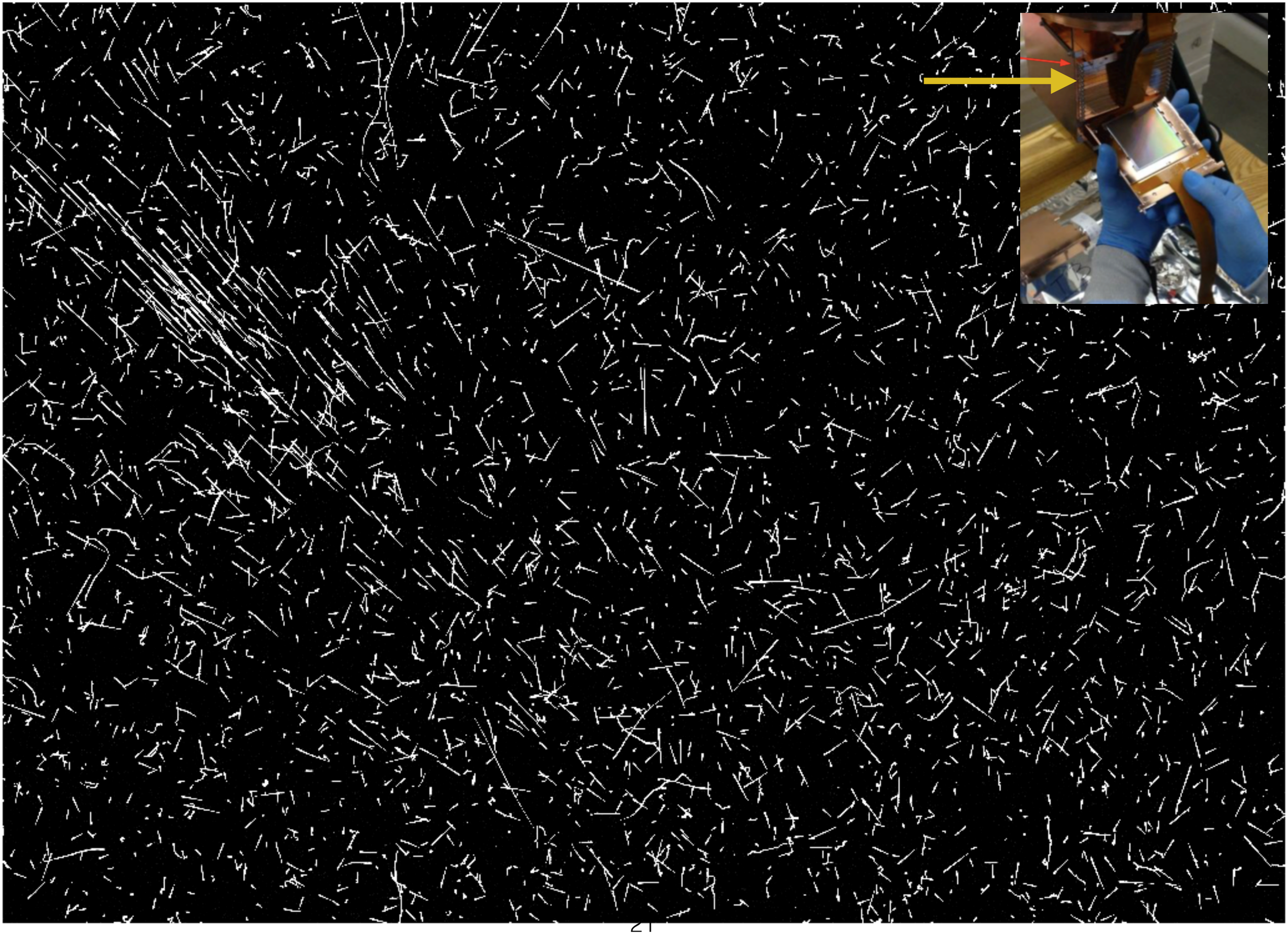
  Reactor OFF exposure 1.9 kg-day (30 days x 80 g x 0.8 eff) compared to 15 d-day in 2015.

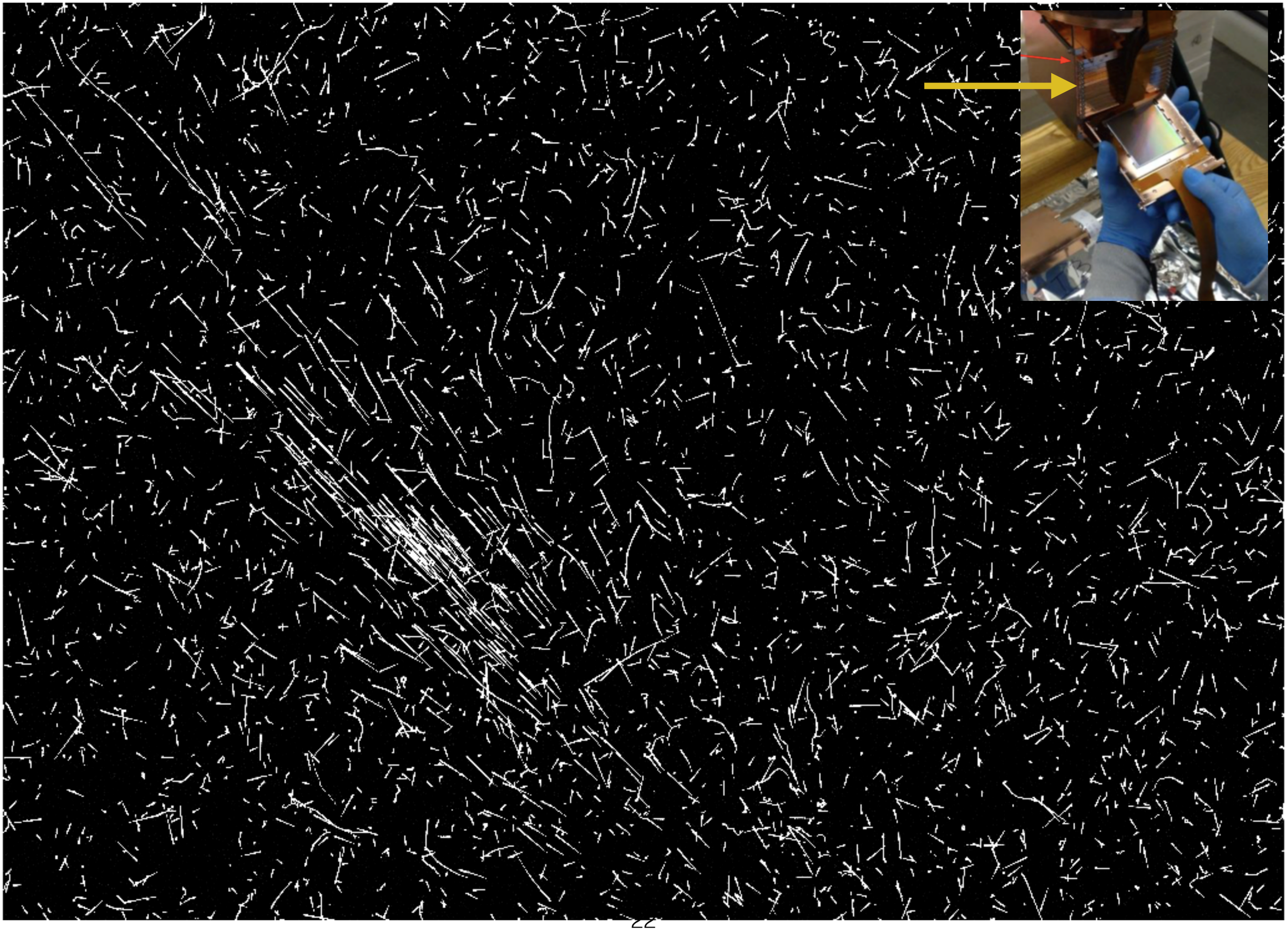
- Lower noise
- Lower background

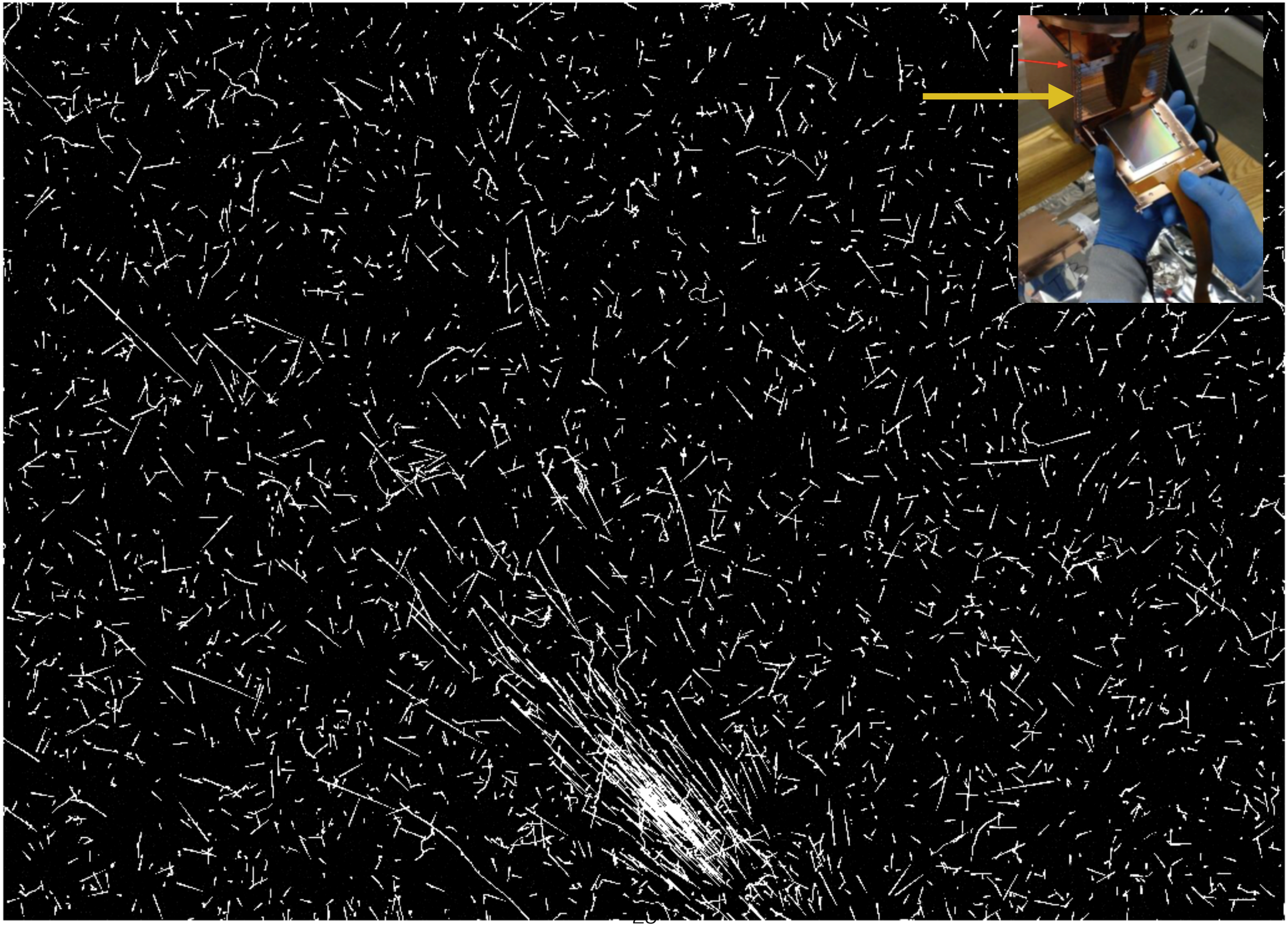
(we are not ready to show the low energy results, but will try to share our excitement about this data)



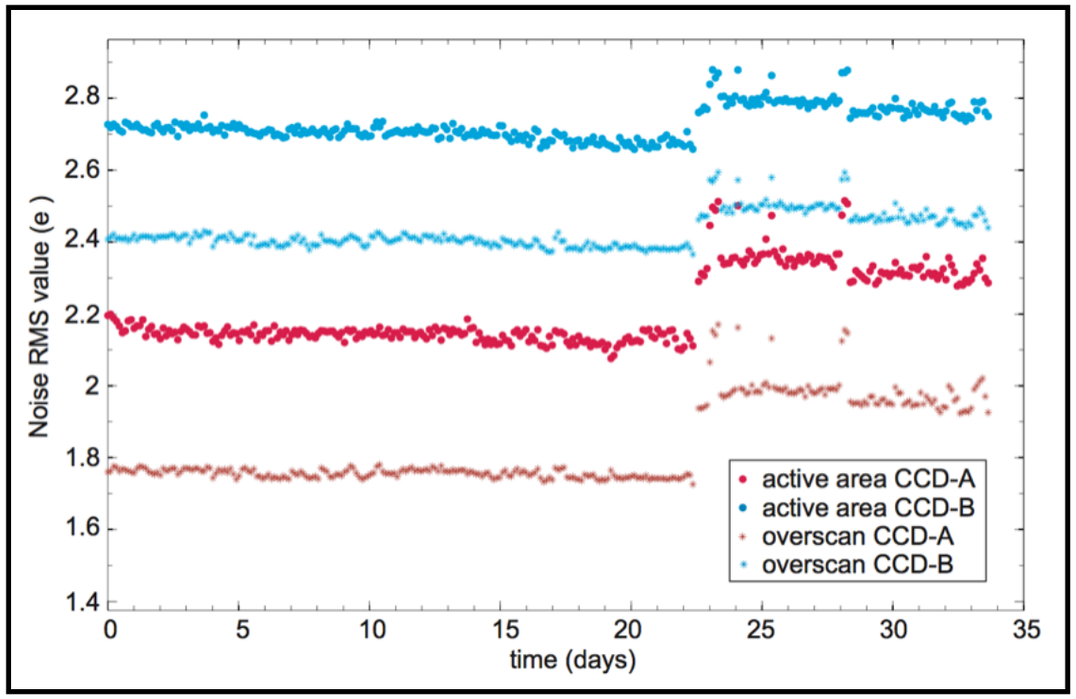








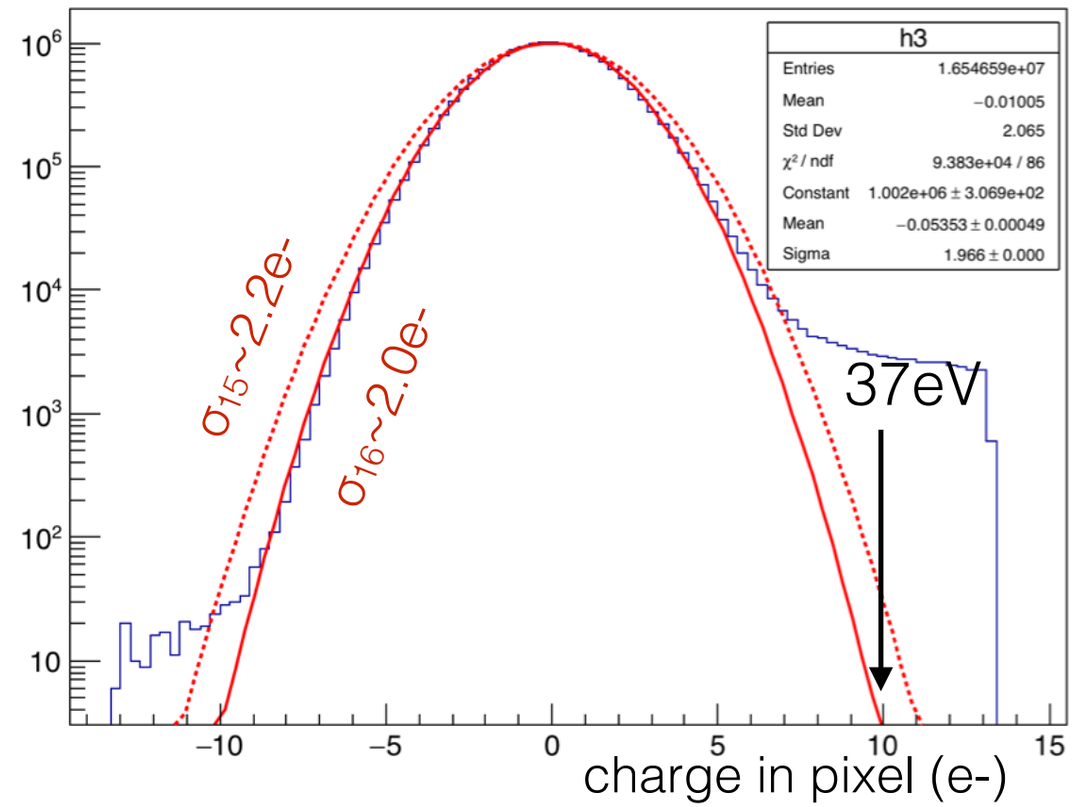
2015 engineering run

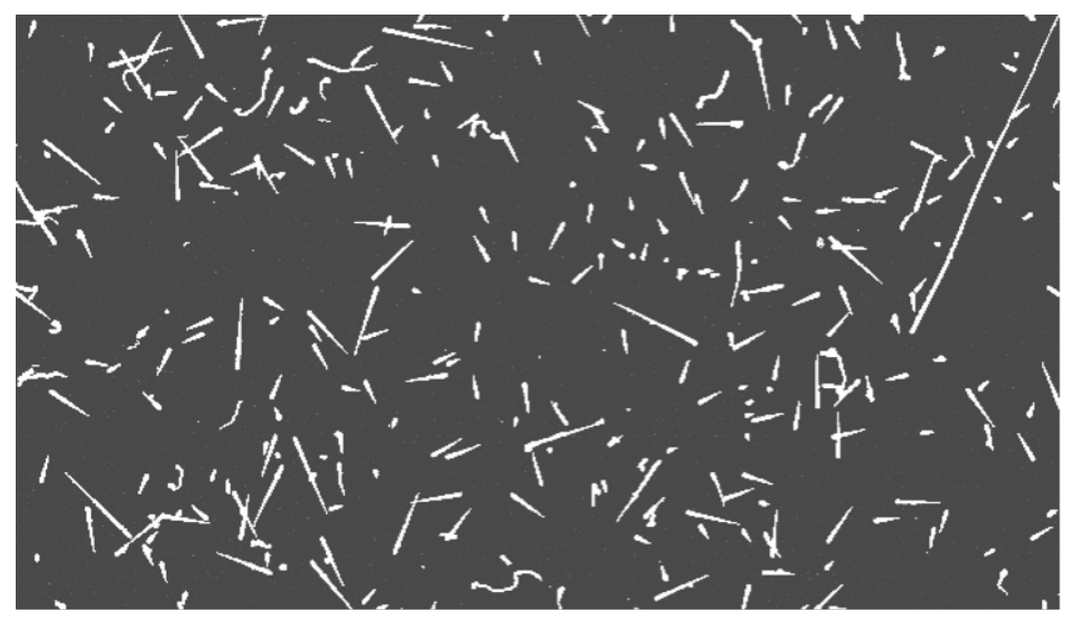


2015 we had a 2.2e- noise in the best CCD for the active area of the detector. This means that we had dark current, or IR photons hitting the detectors.

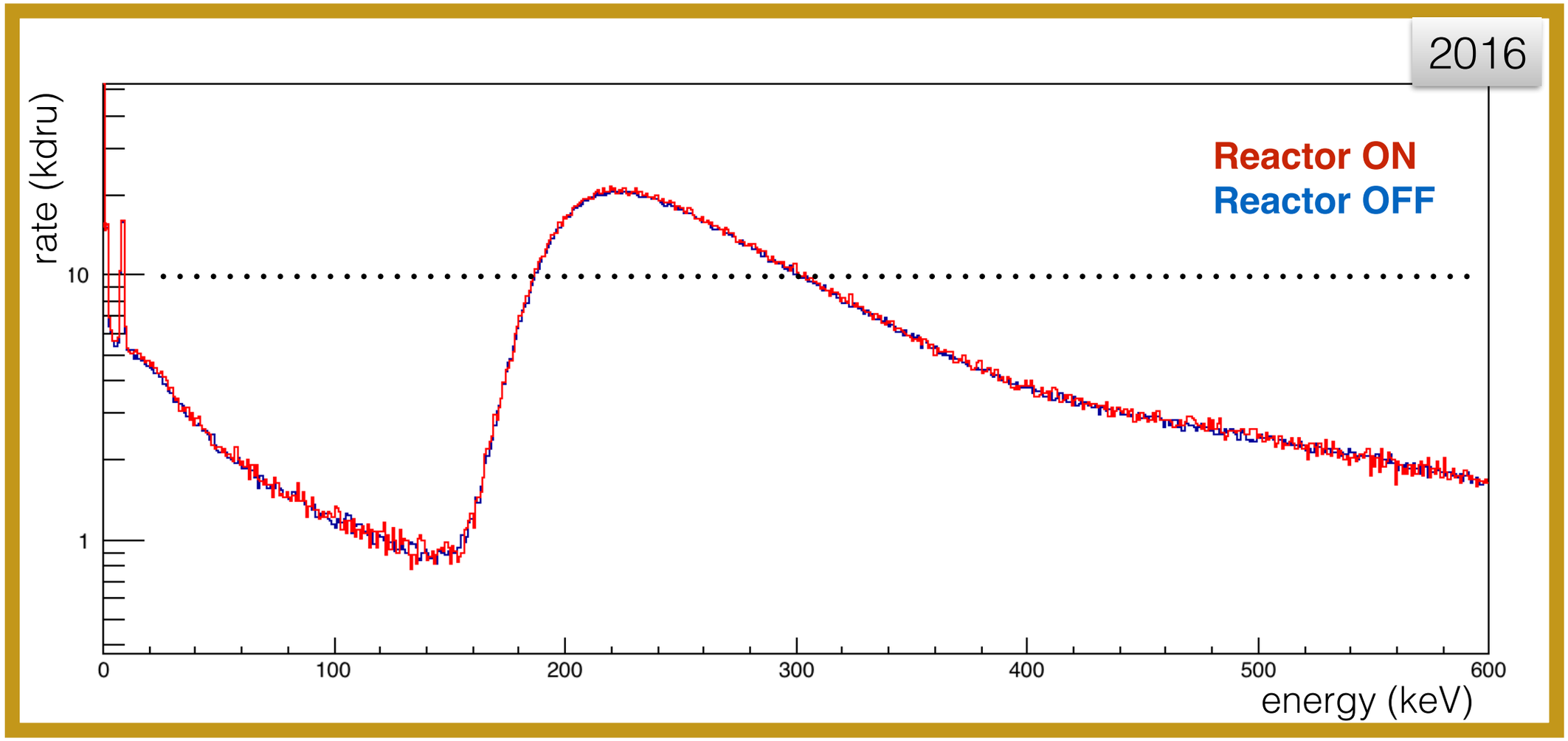
This 10% decrease in the noise is a big deal. It corresponds to ~10 increase in the rate of noise hits at ~35 eV.

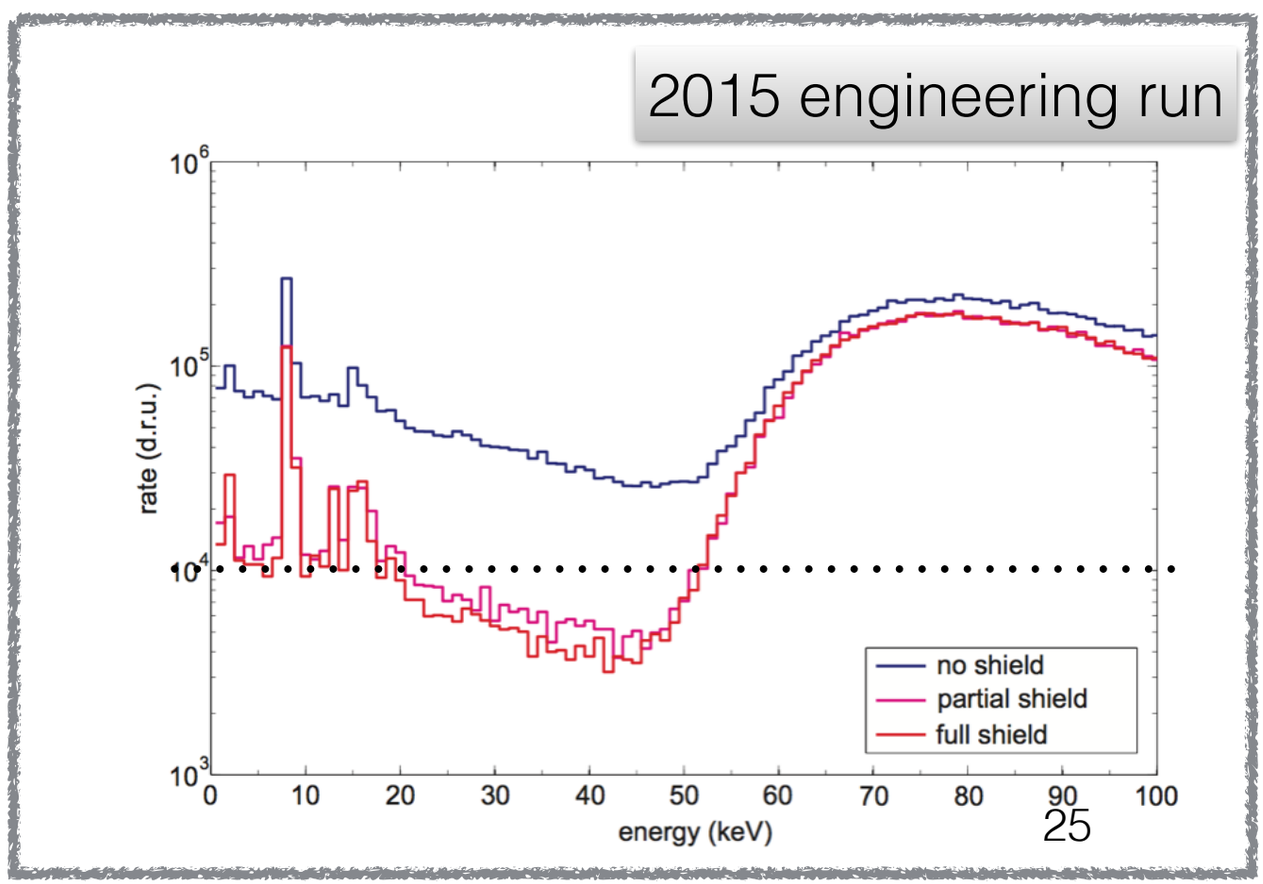
2016 image example





the histogram above also shows the hits from real tracks.





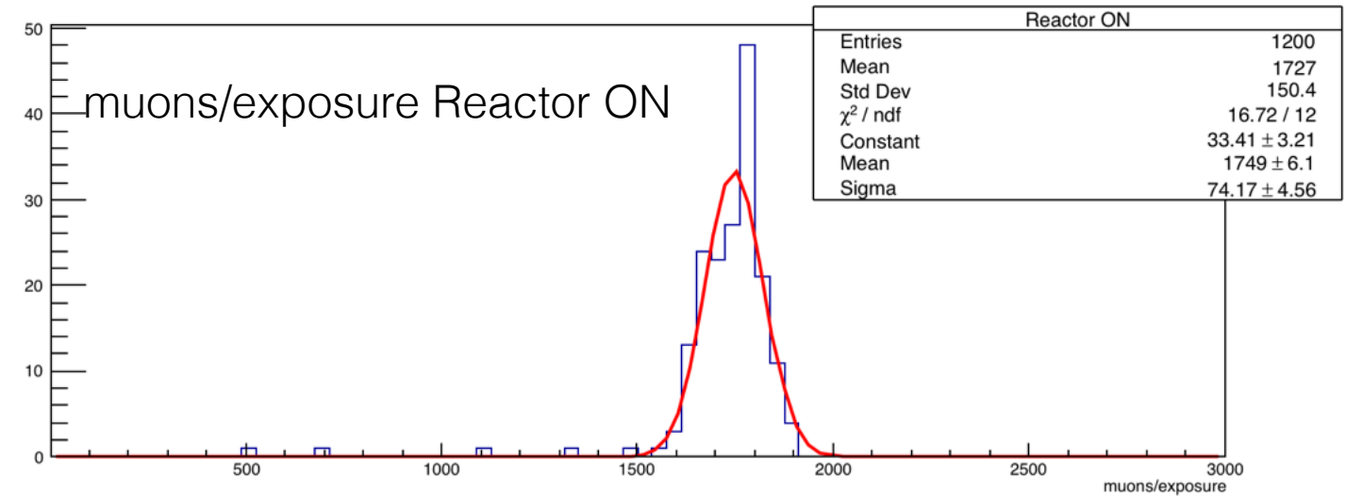
background improvement in the new configuration. We eliminated ceramic spacer (AlN) in the detector package. This eliminated all the ~15 keV lines produced by the U and Th decays. It also lowered the background significantly.

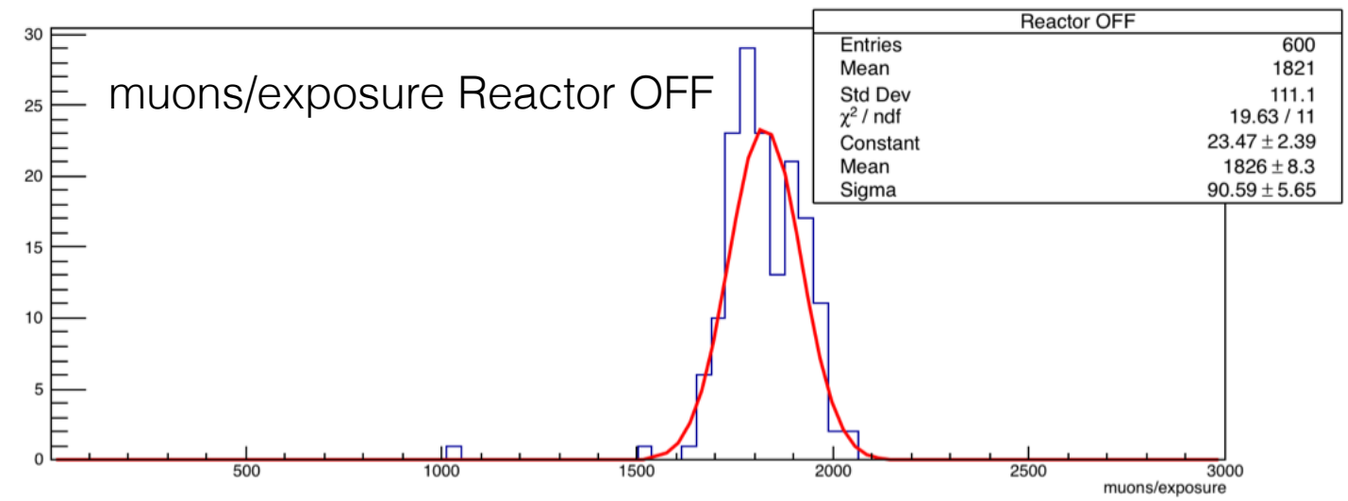
The bump from muon tracks is now at 250 keV because we went from 250um silicon to 675 um.

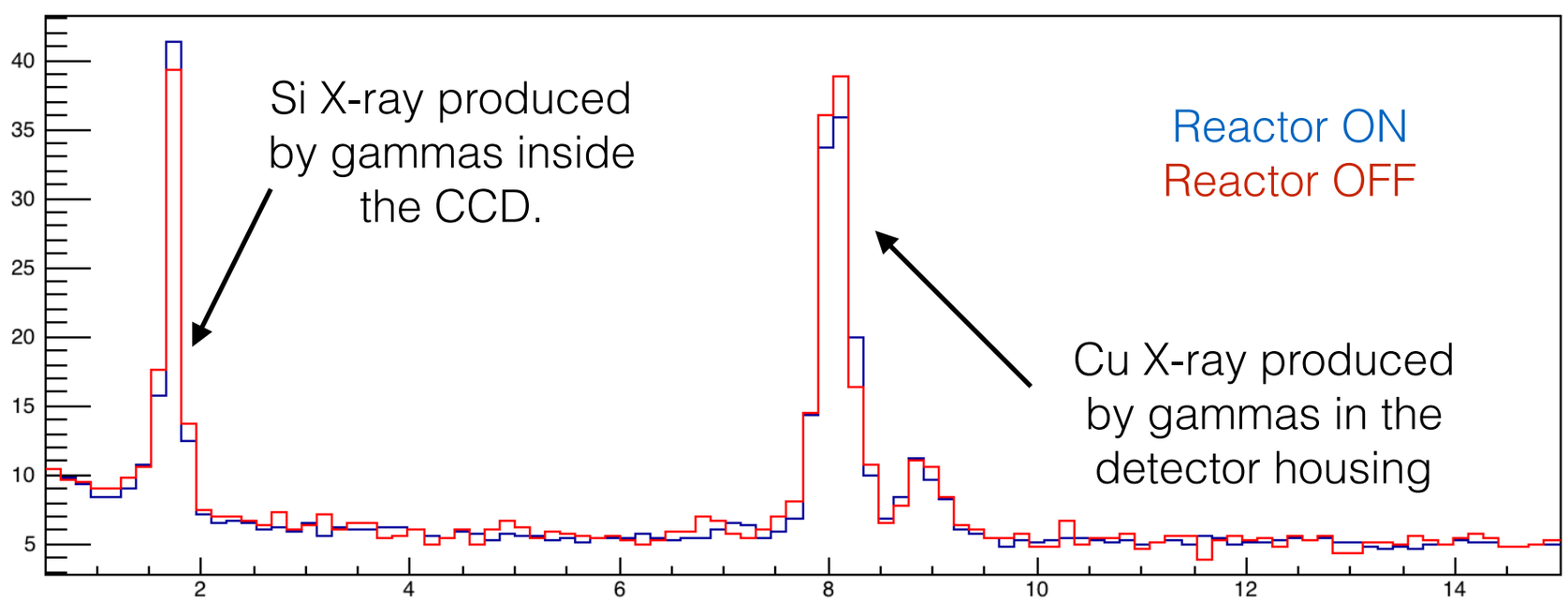
Comparing Reactor ON/ OFF backgrounds.

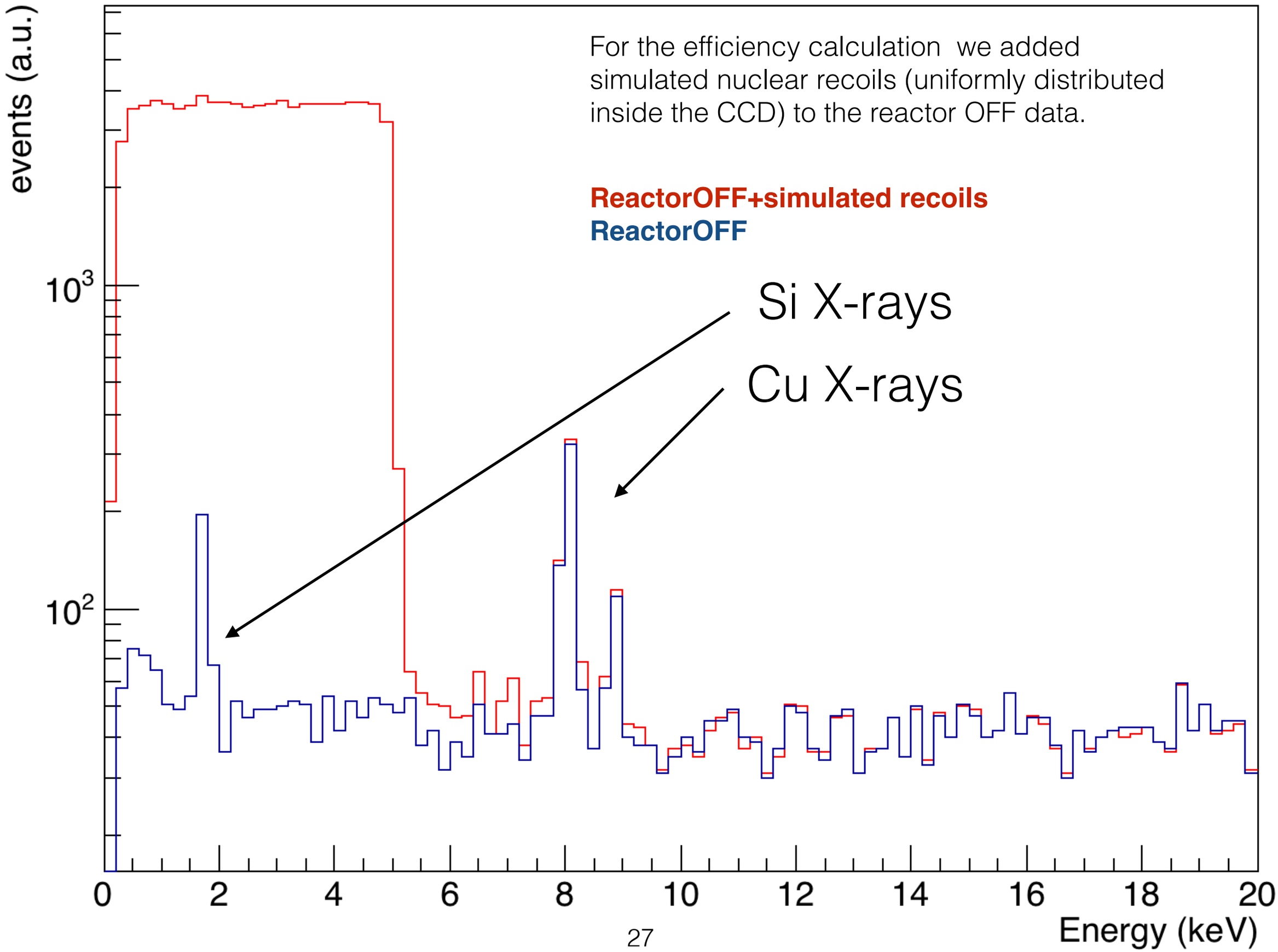
the muon flux is not the same, it is higher when the reactor is OFF. Makes sense due to weather.

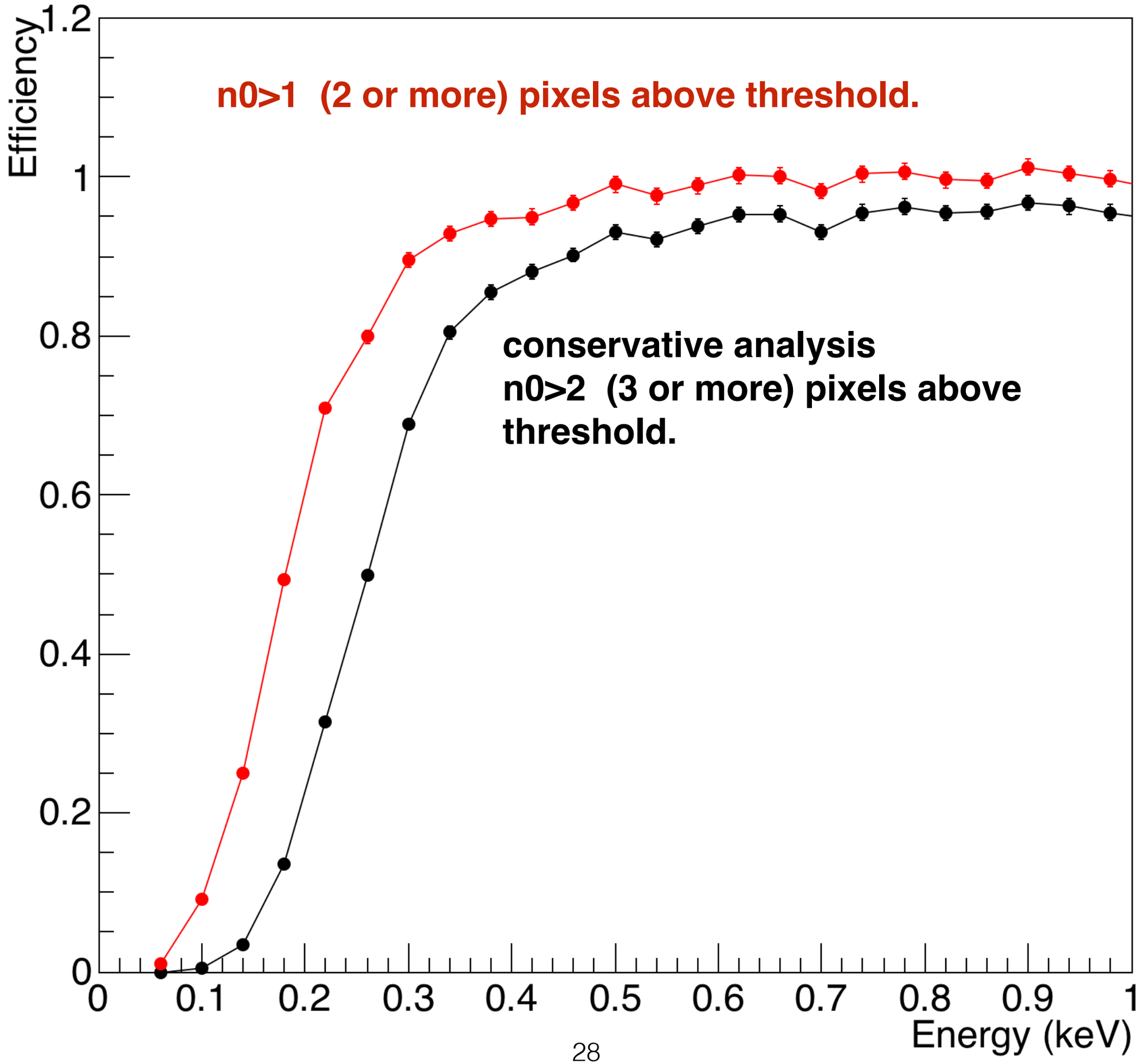
fluorescence X-rays are the same reactor ON/OFF. This point to a stable gamma background.








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)


Efficiency
1.2
1
0.8
0.6
0.4
0.2
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Energy (keV)
n0>1 (2 or more) pixels above threshold.
conservative analysis
n0>2 (3 or more) pixels above threshold.

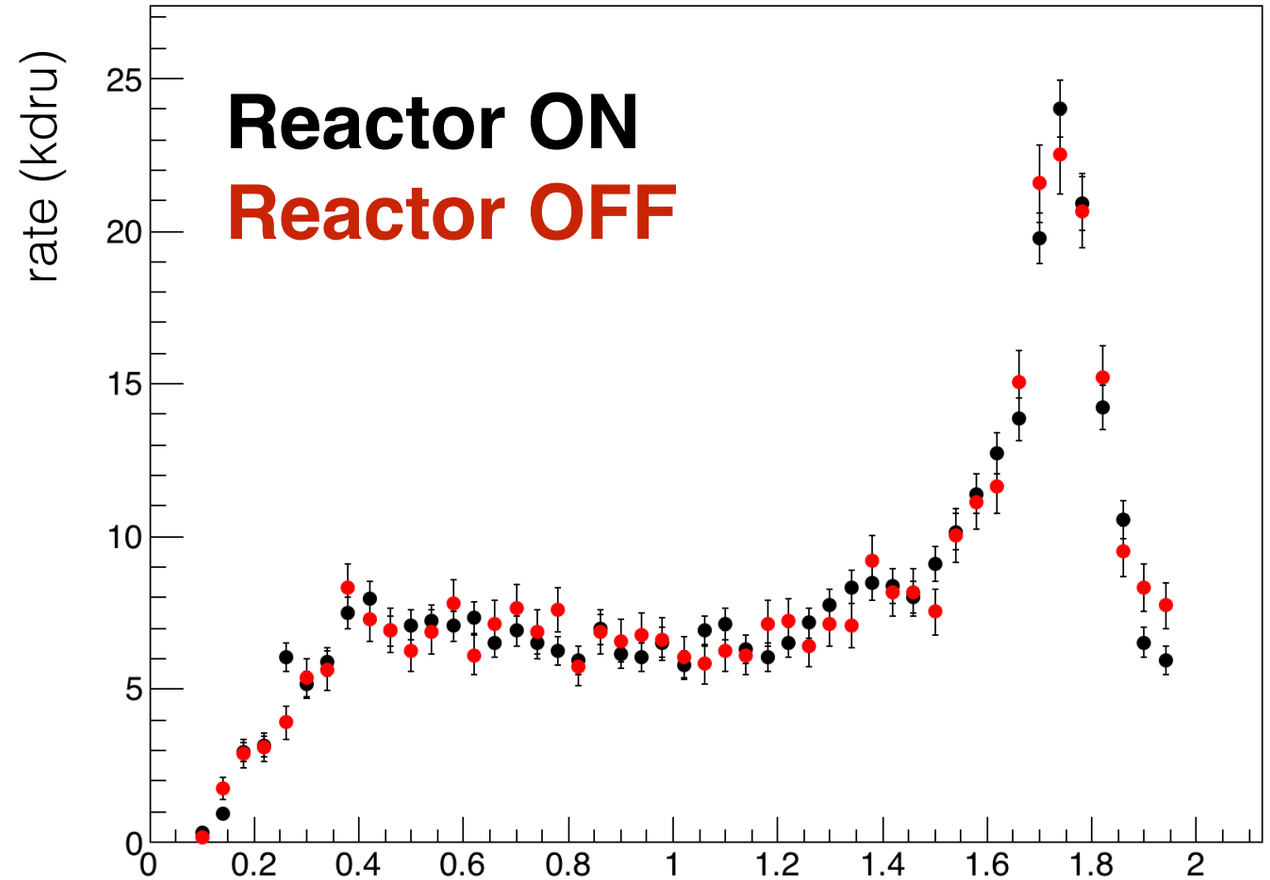
2016-2017 data
Preliminary

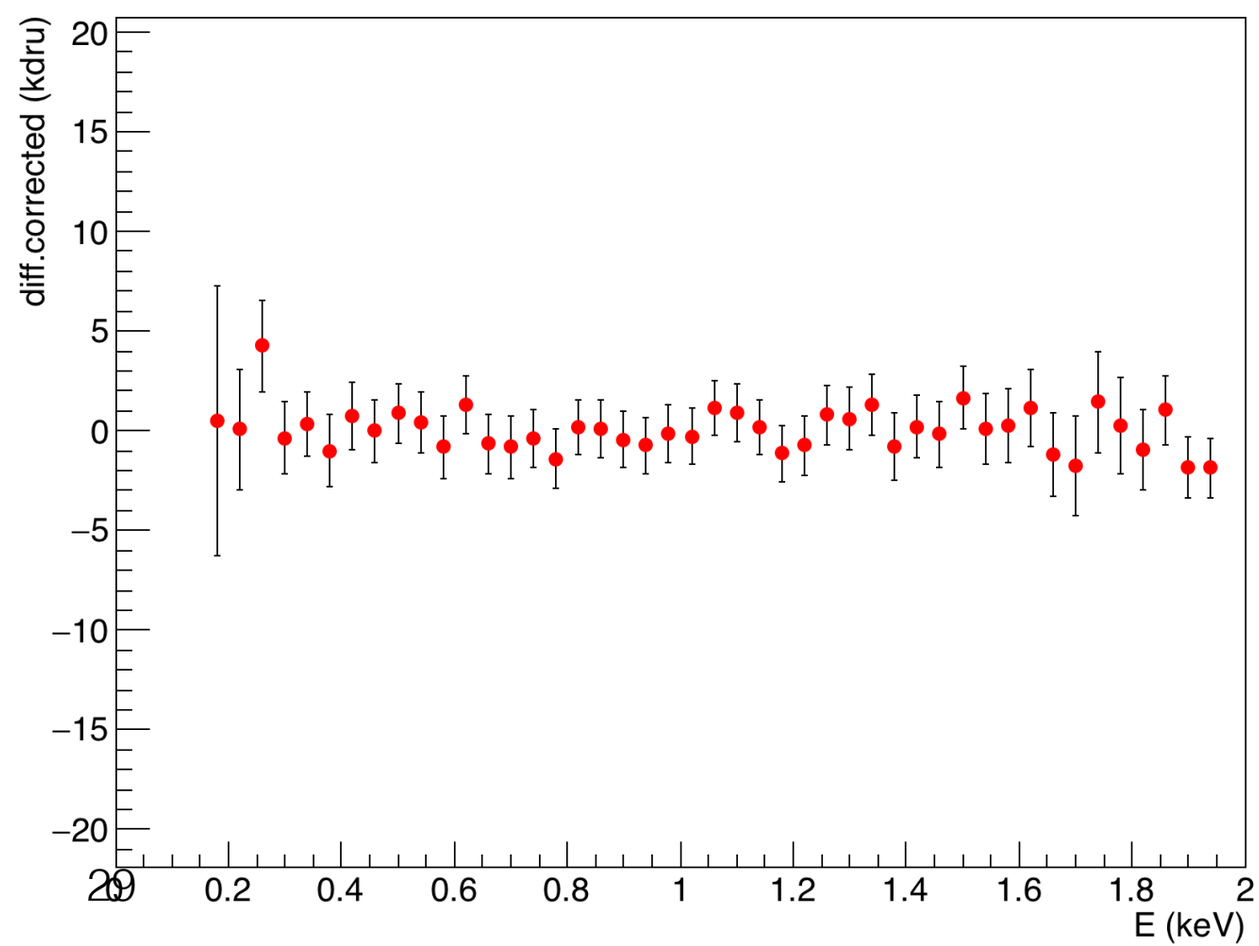
For this analysis we selected the detectors with less “cosmetic” defects.

Exposure RON = 704 g-day
Exposure ROFF = 339 g-day

n0>2

Data collected between September 2016 and Feb2017.





2016-2017 data
Preliminary

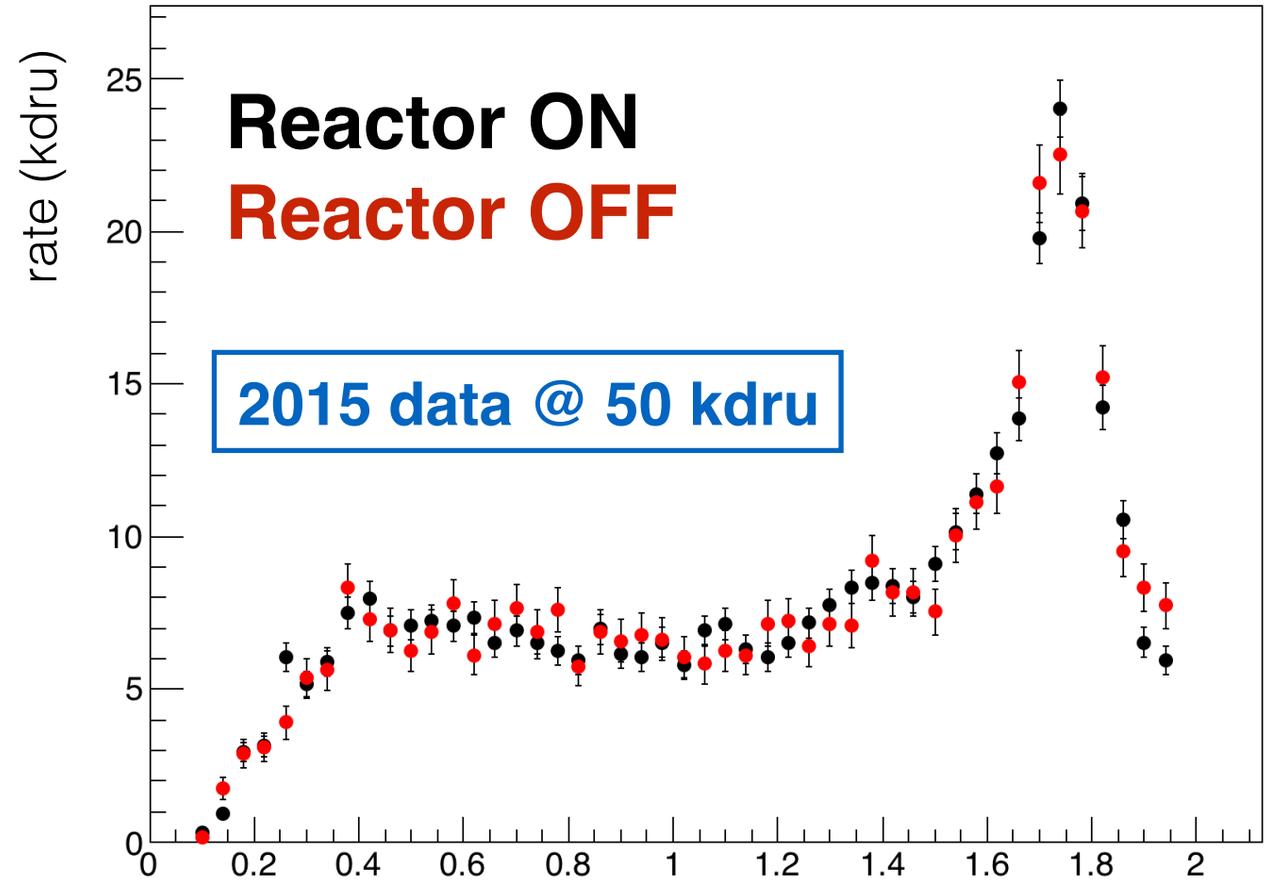
For this analysis we selected the detectors with less “cosmetic” defects.

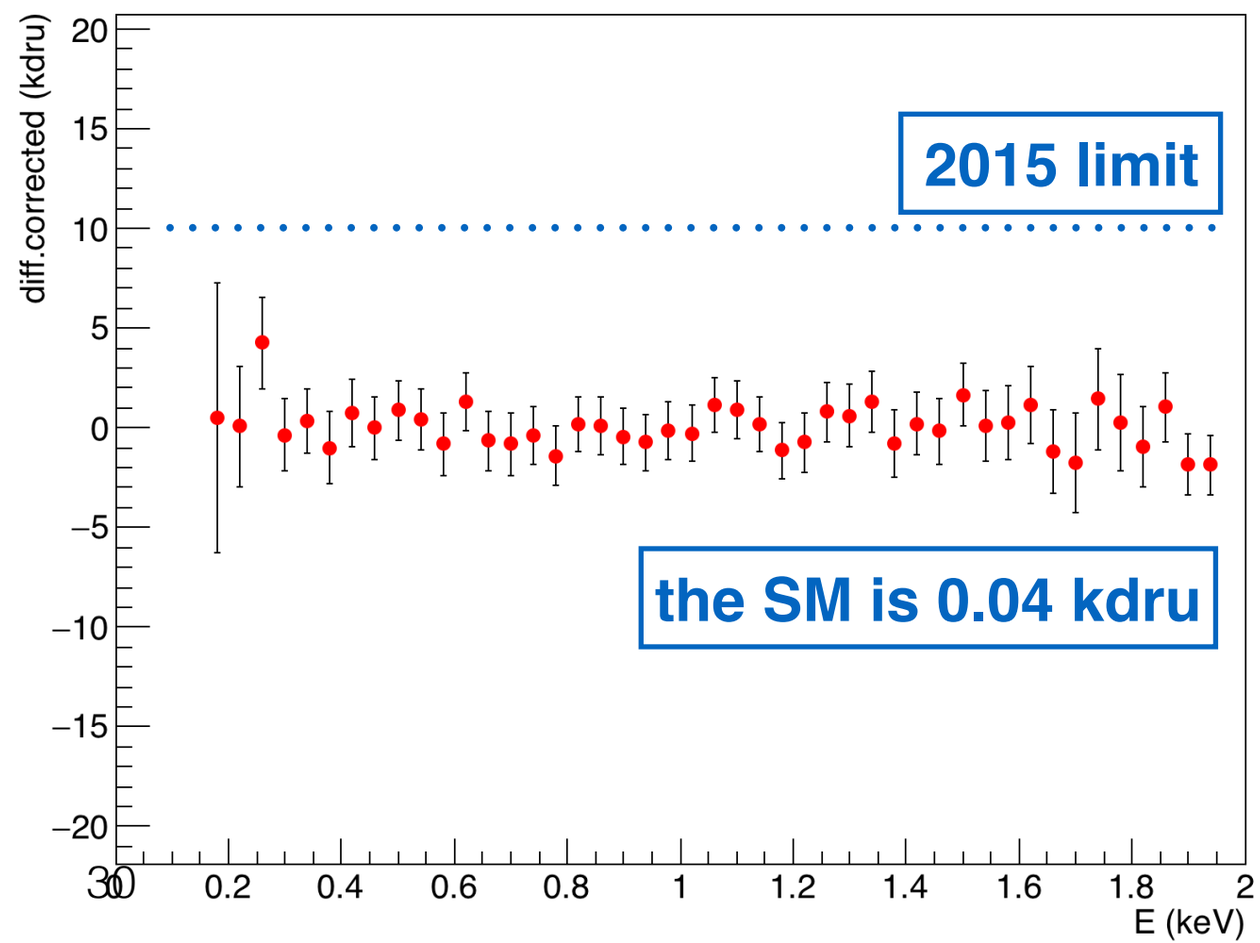
Exposure RON = 704 g-day
Exposure ROFF = 339 g-day

n0>2

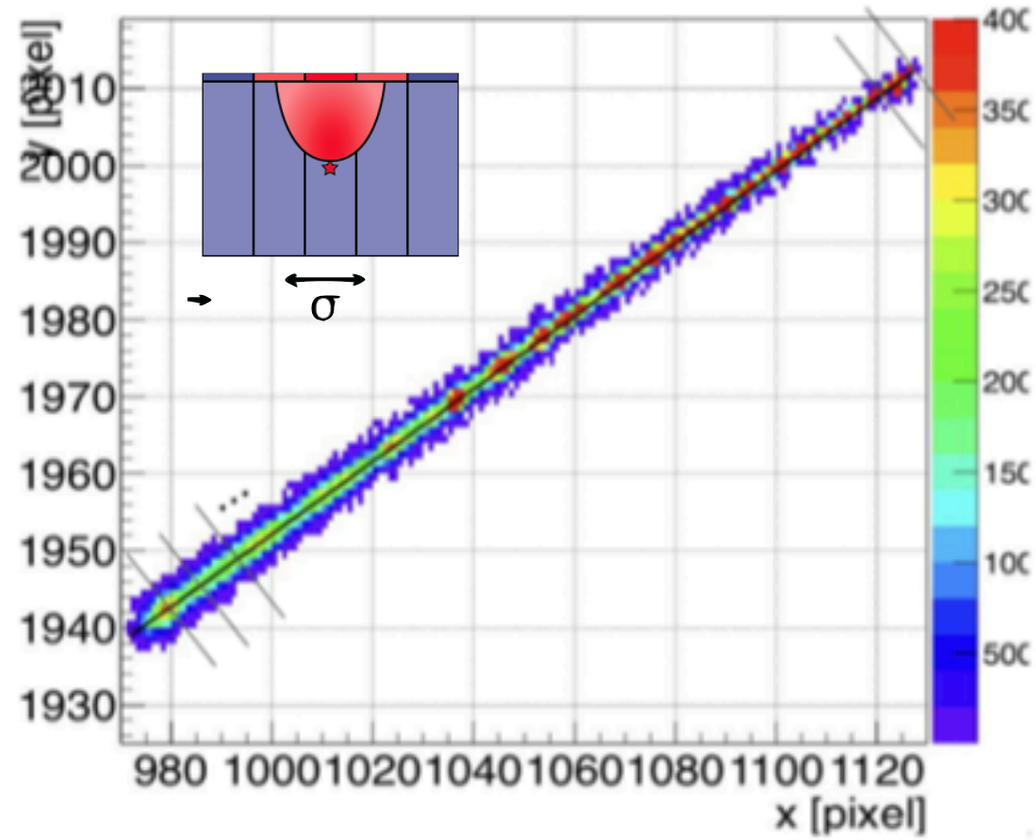
Data collected between September 2016 and Feb2017.

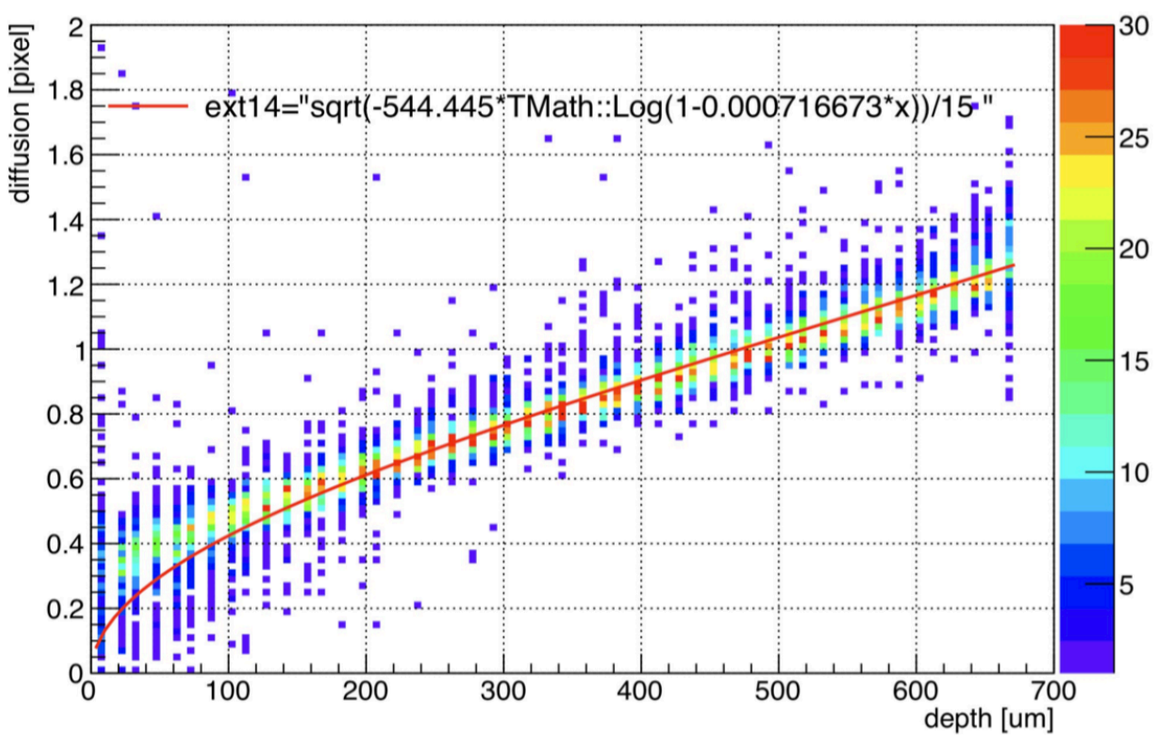
big improvement over engineering run 2015-2016





now selecting the low energy events….

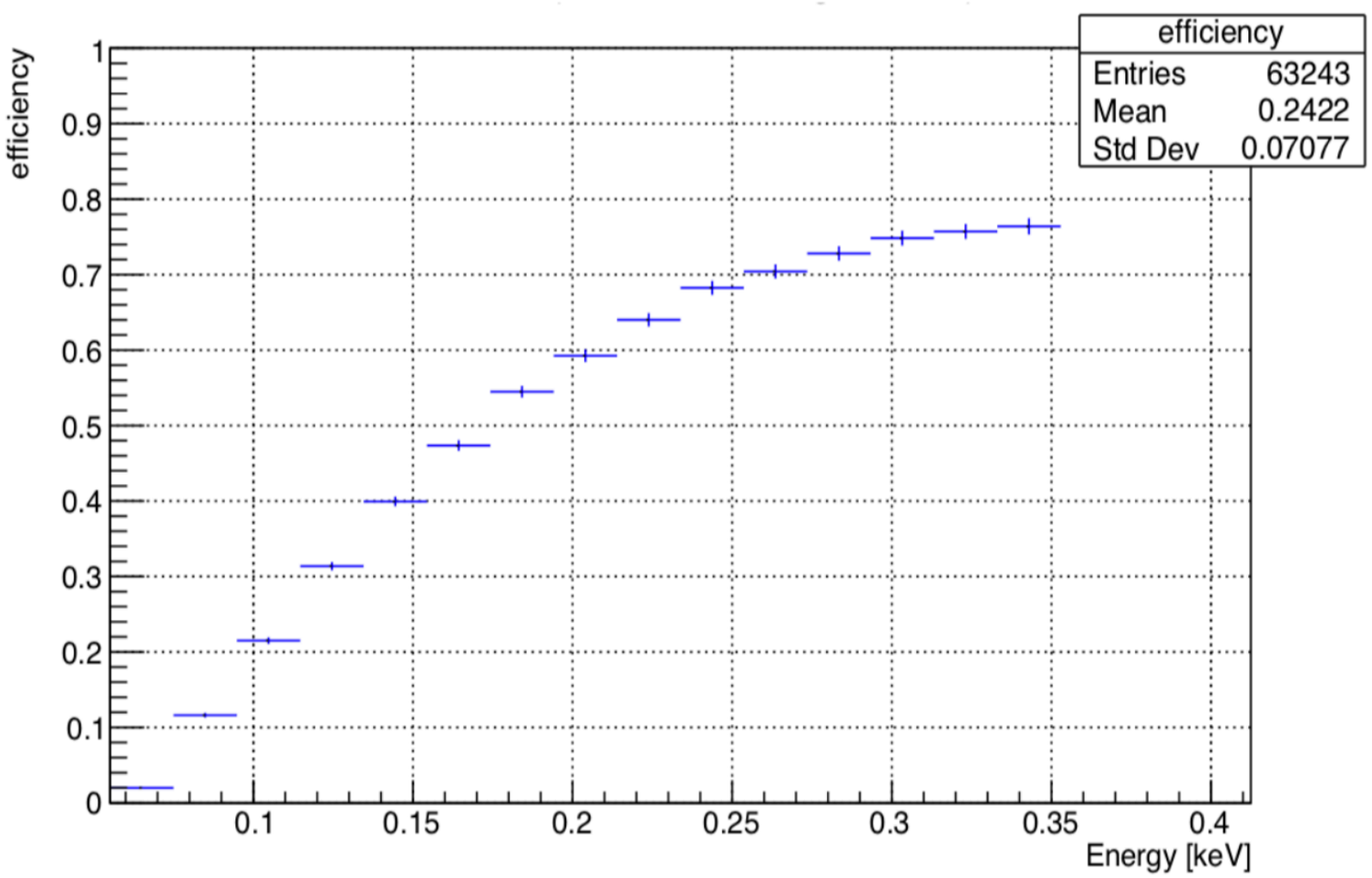




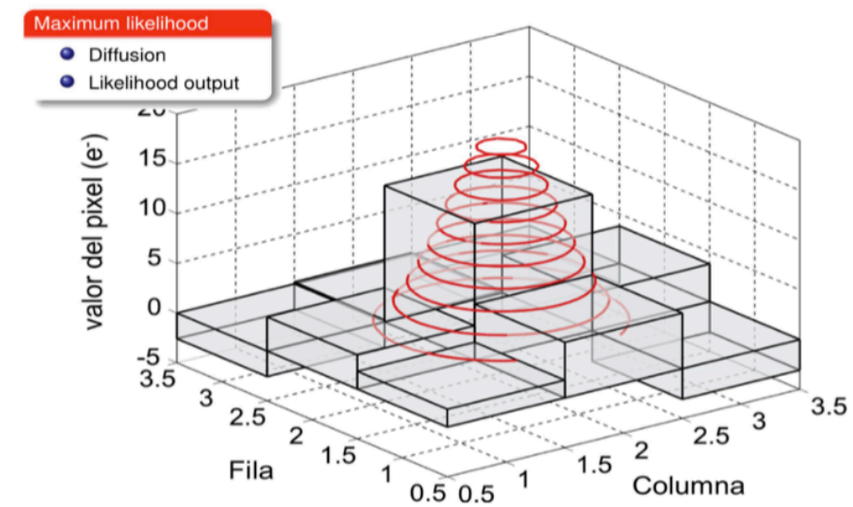
- For each muon measure make a measurement of charge diffusion in the CCD
- Using all the muons in a 10 day period make a model for the detector
- Use this model to eliminate surface events.

coming soon…

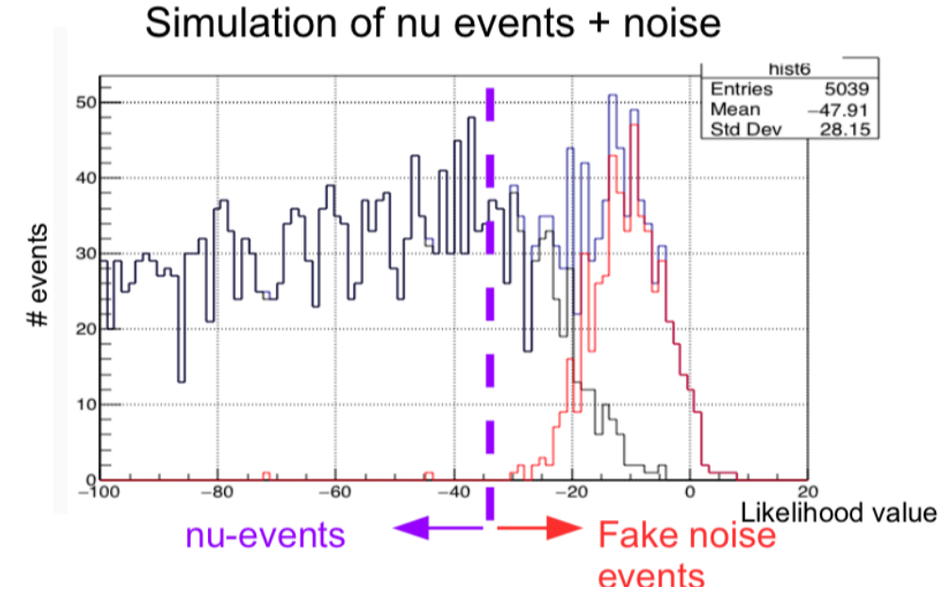
now selecting the low energy events…



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

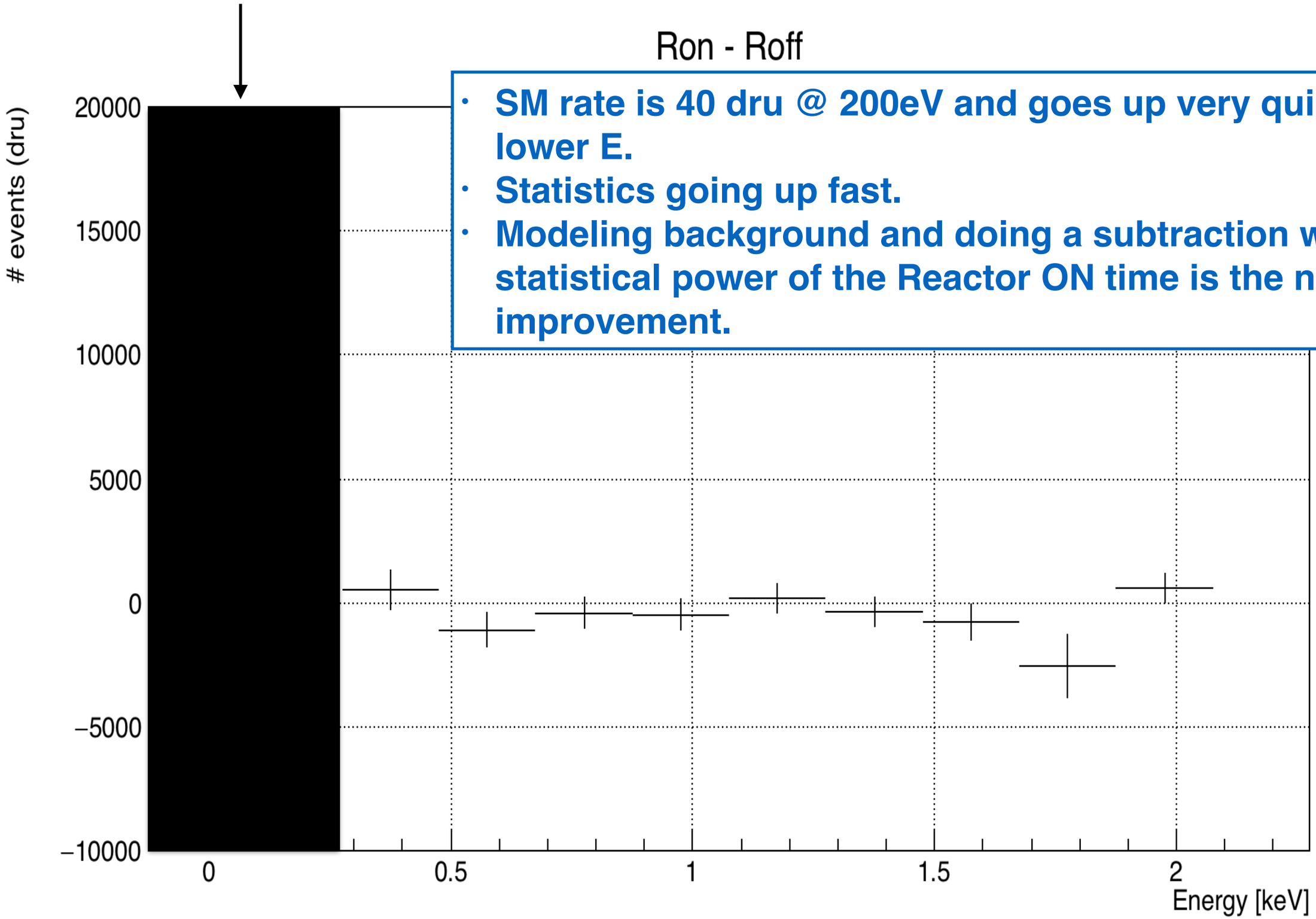


Simulation of nu events + noise

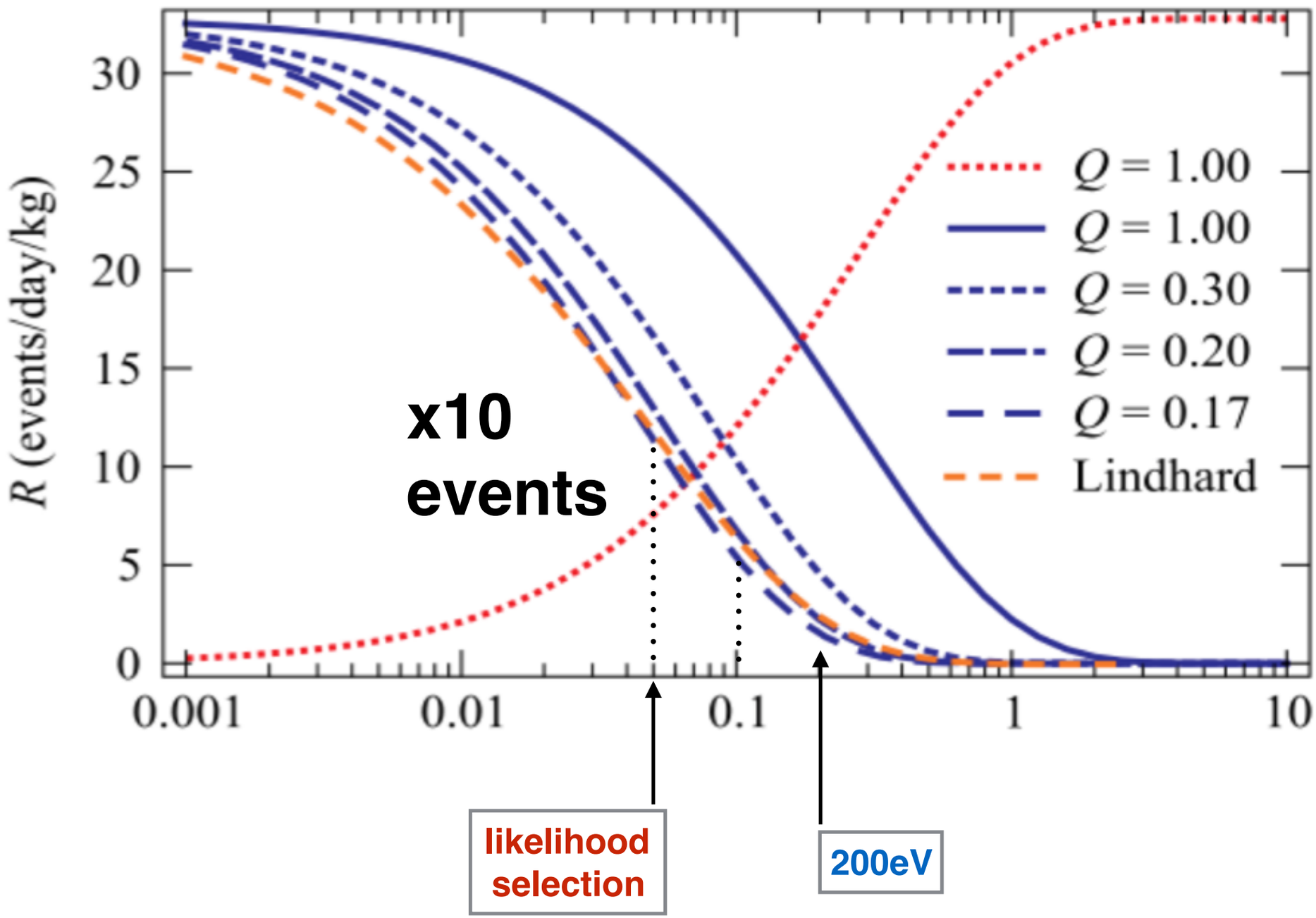


Likelihood measures the probability of the event being compatible with a noise fluctuation. Selection cut in this likelihood variable.

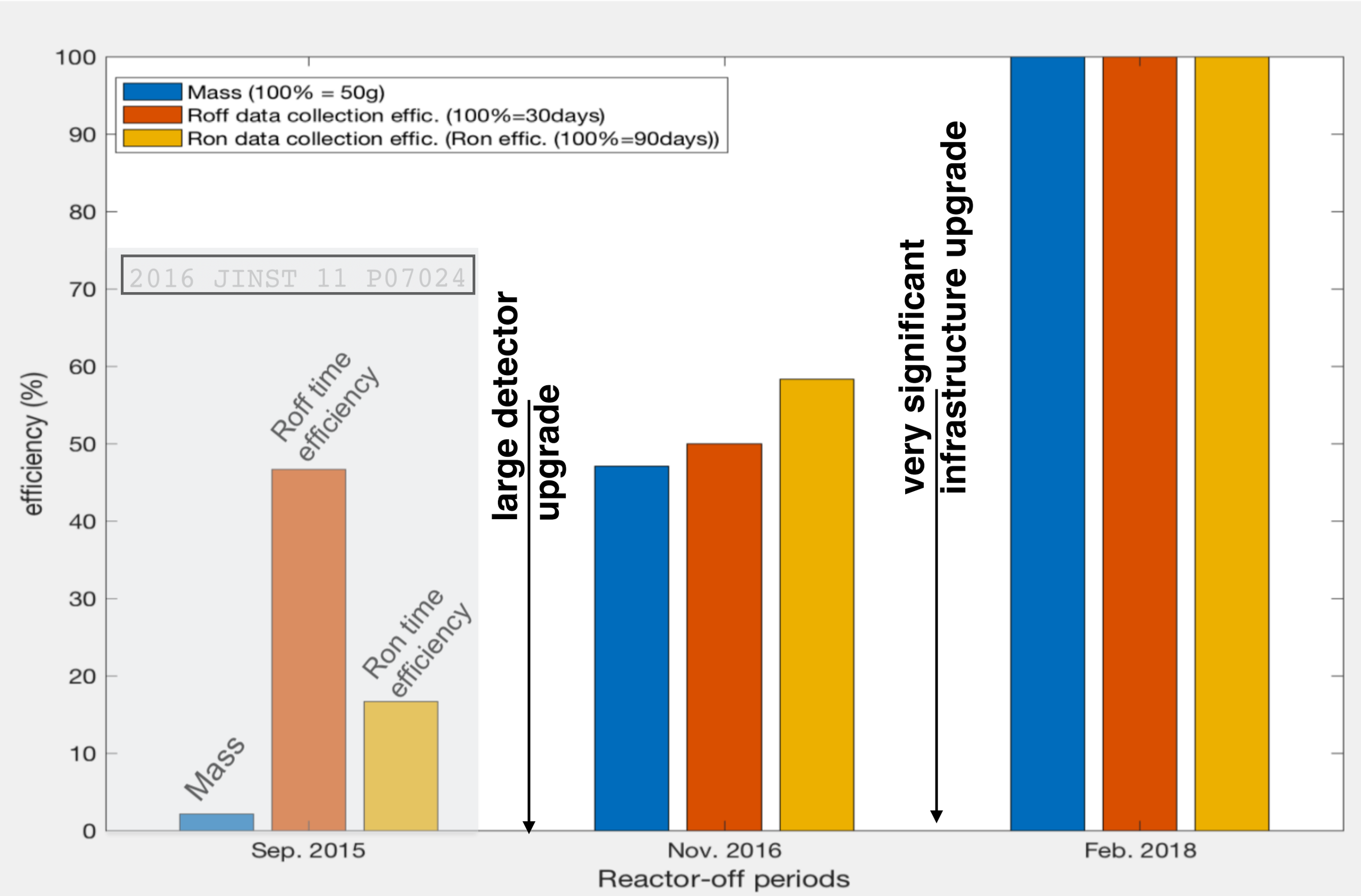
<u>studying systematic effects</u> in this region. Statistical error now is ~ 700 dru! (only using 2016-2017 data)



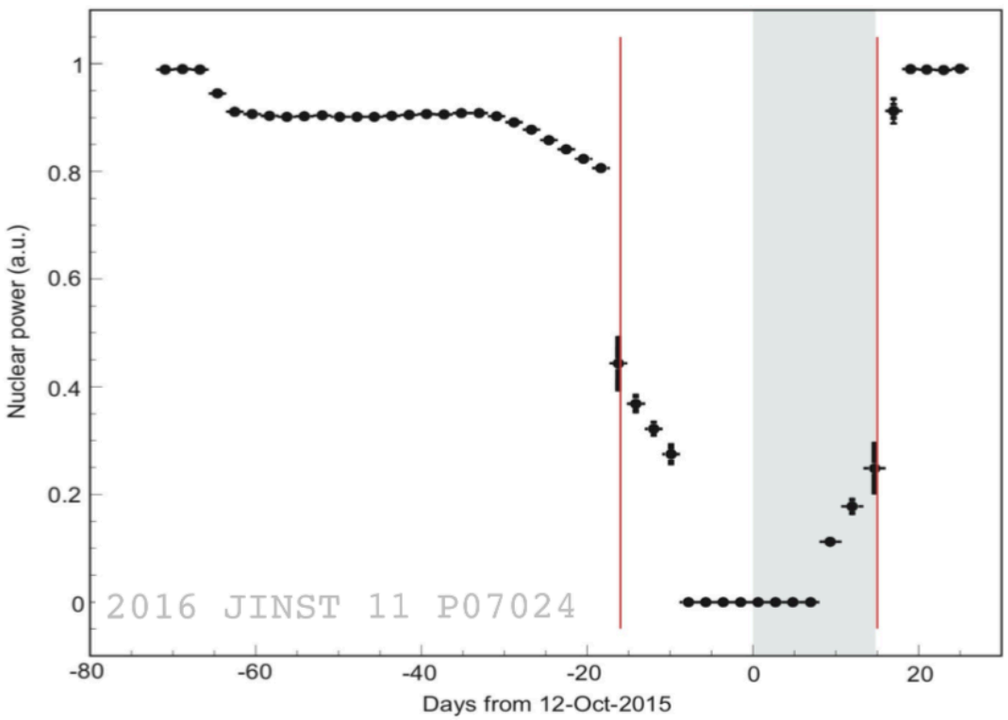
- **SM rate is 40 dru @ 200eV and goes up very quickly at lower E.**
- **Statistics going up fast.**
- **Modeling background and doing a subtraction with full statistical power of the Reactor ON time is the next improvement.**


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
likelihood
selection
200eV

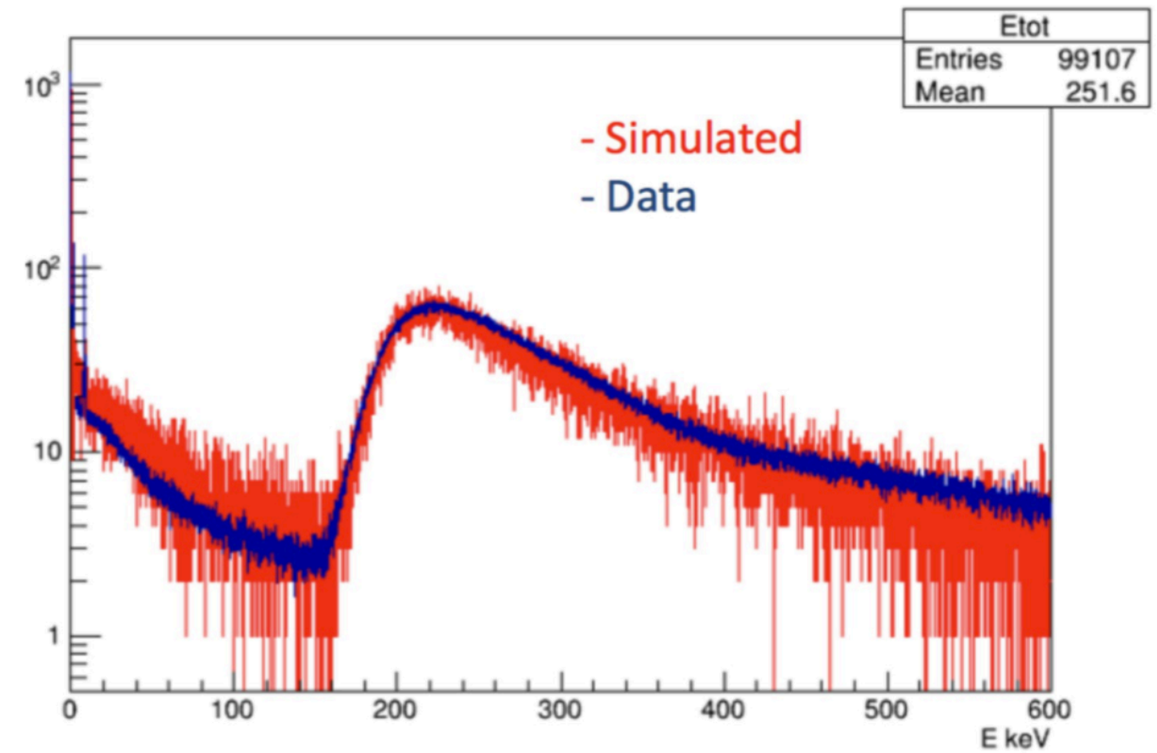
operation improvements in CONNIE : **statistics going up fast. By this time next year we will have 5 times the statistics.**



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

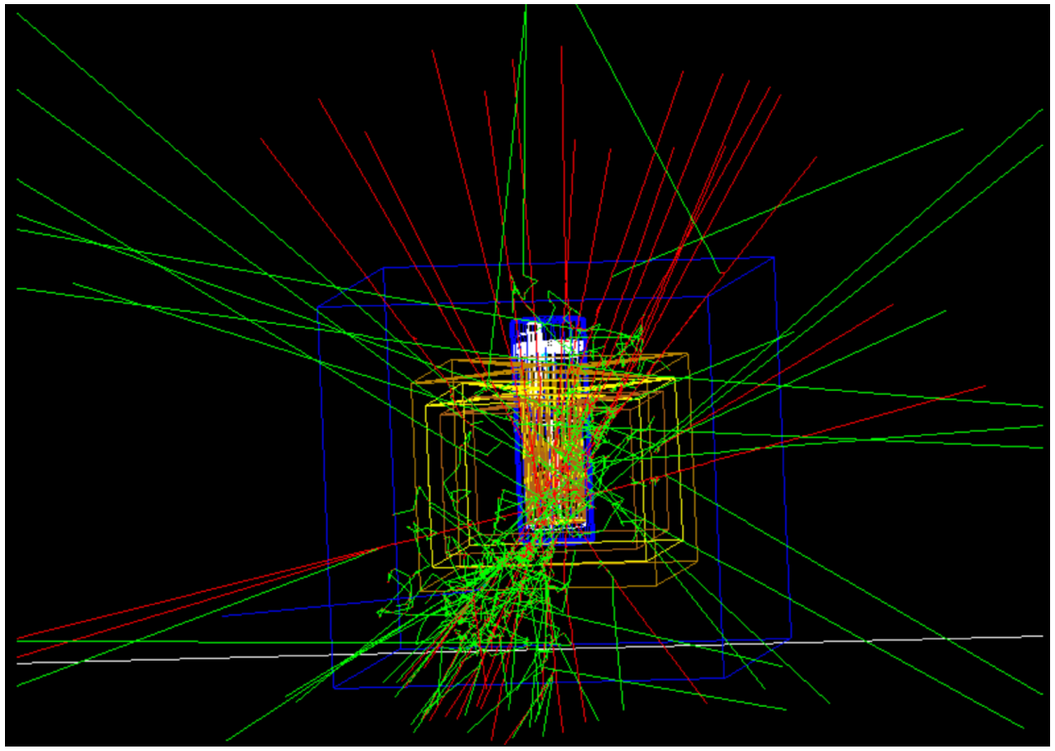


- ~10 times more statistics.
- Extra uncertainty associated with the background model



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!!!**



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Looking at this interesting opportunity.
Thanks Rupak!

Conclusion:

- Interesting results coming soon… analysis almost done.
- Big plans (talk tomorrow by Javier):
    - R&D ongoing to increase in mass by x200 (FNAL LDRDx2, ECA, QIS)
    - new sensors demonstrated a reduction in threshold by a factor of 10