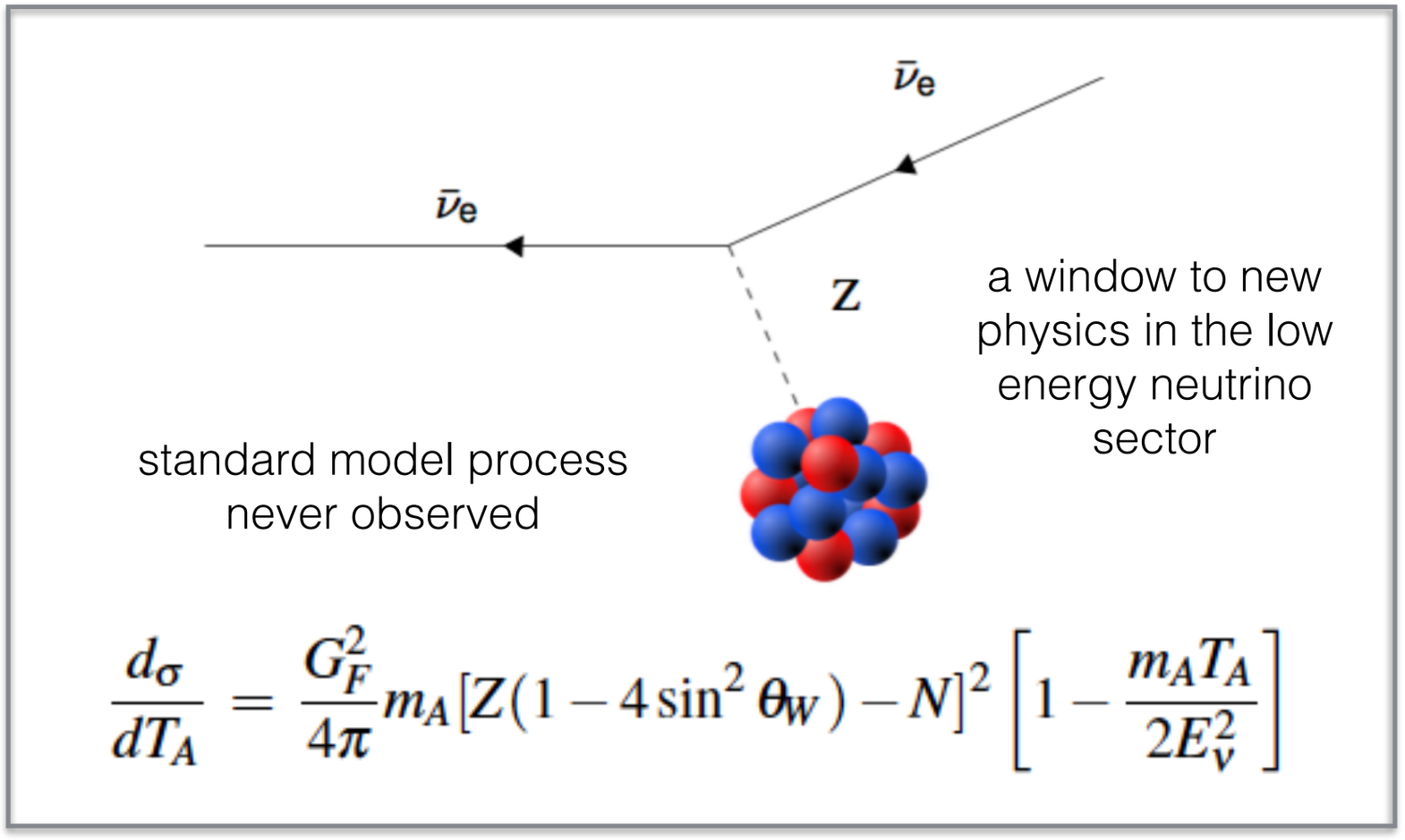
CONNIE

COHERENT NEUTRINO NUCLEUS
INTERACTION EXPERIMENT

Juan Estrada for the CONNIE Collaboration

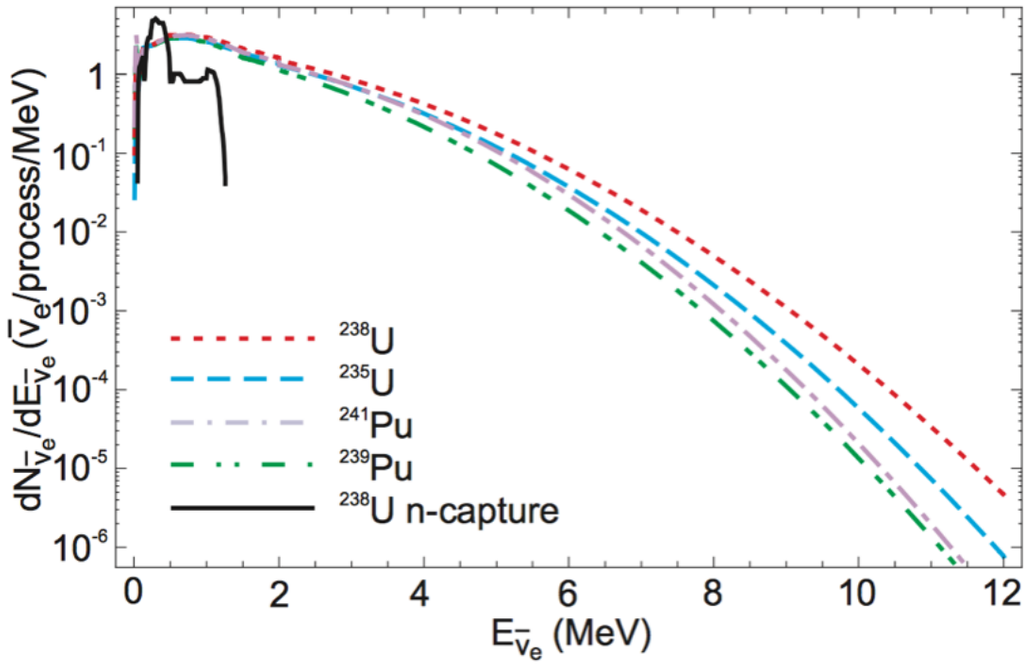
Fermilab

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



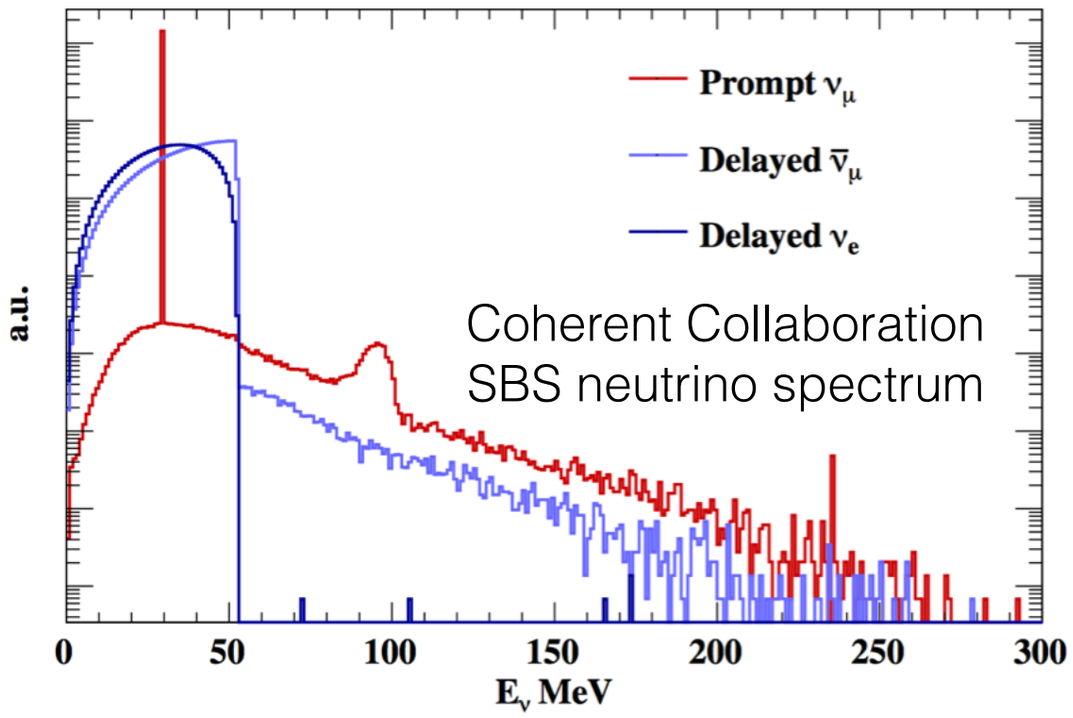
Coherent elastic neutrino-nucleus scattering (CEvNS) is a prediction of the Standard Model.

Two ways to get high flux low energy neutrinos



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**



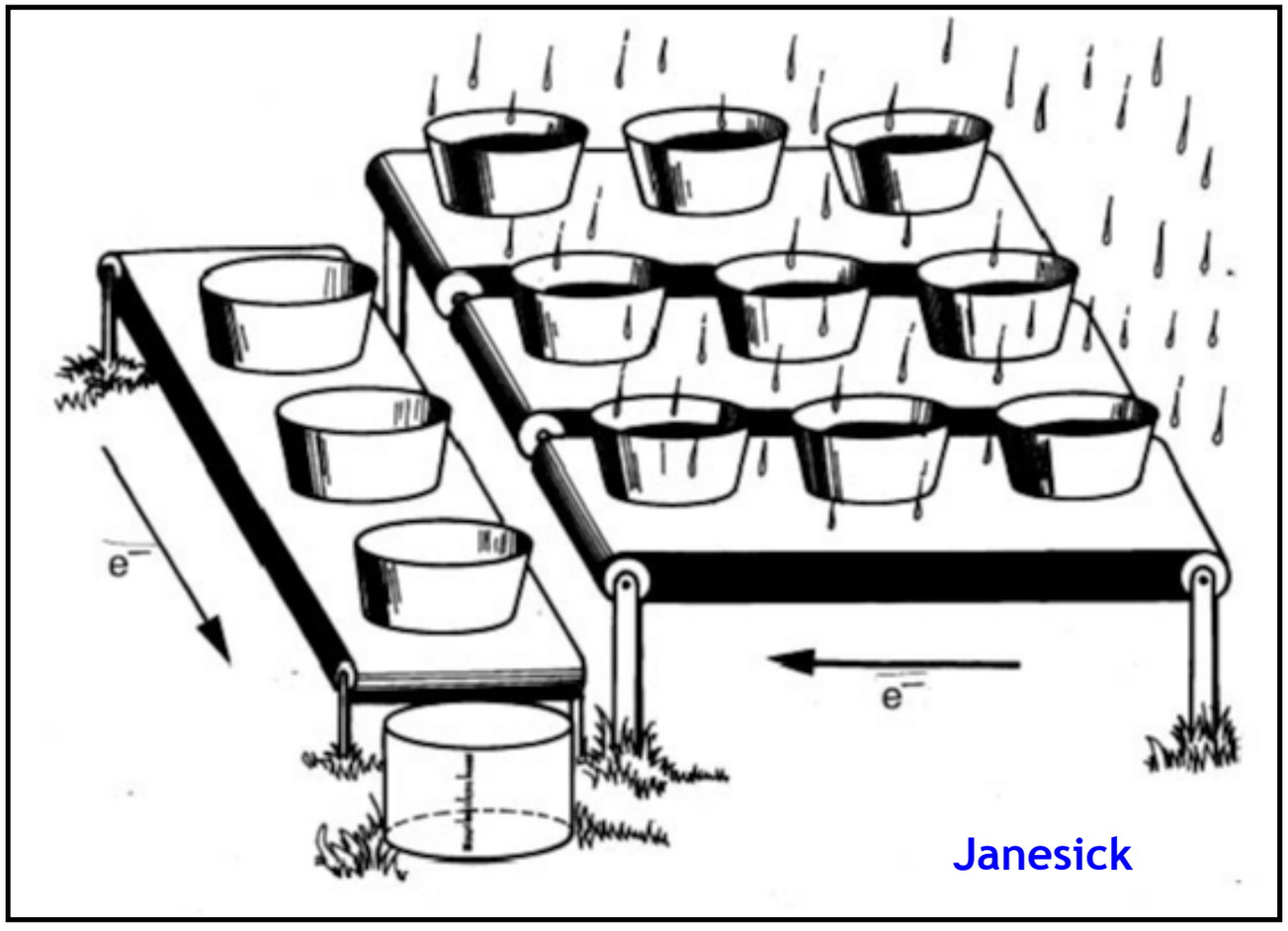
Neutrinos produced by stopped pions (decay at rest).

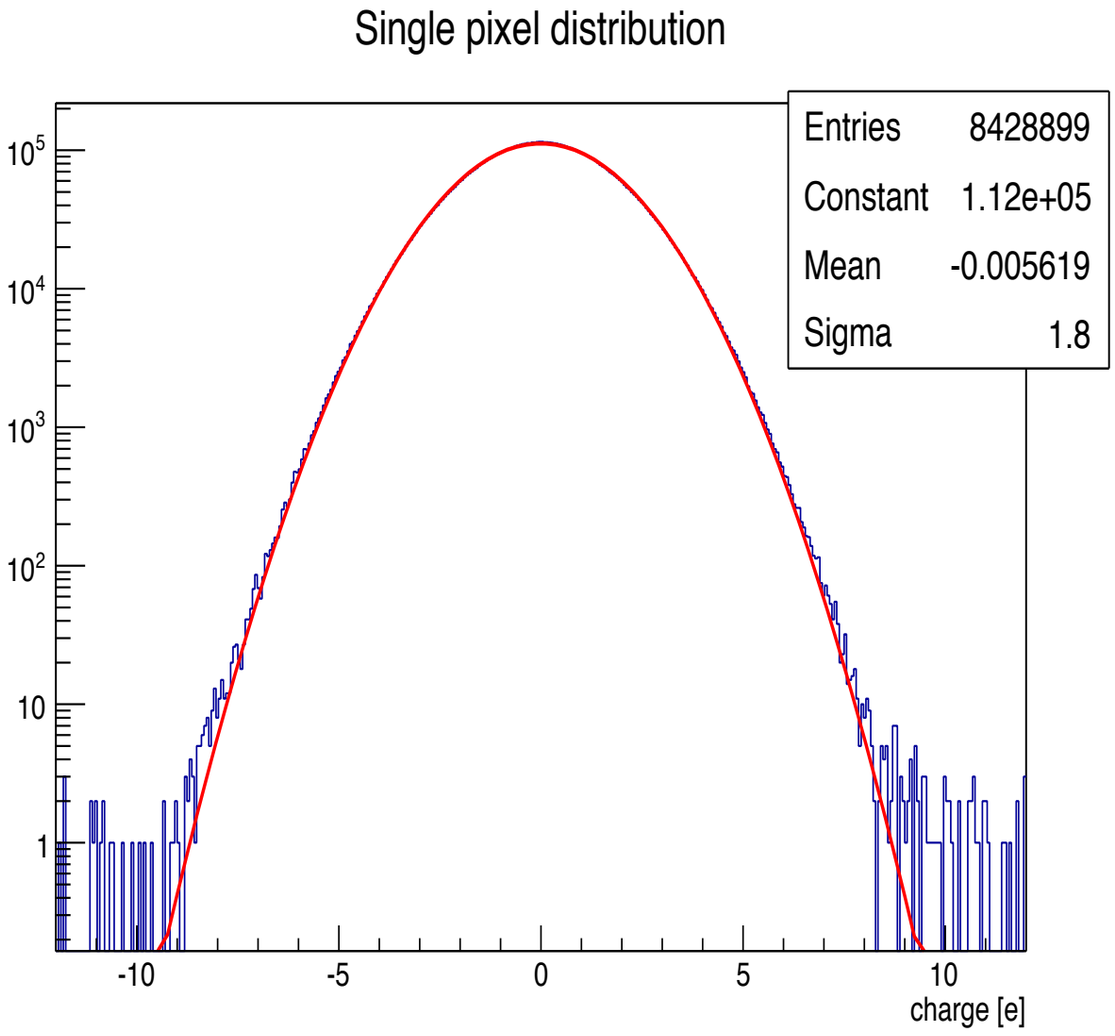
- Higher energy recoils, easier to see
- Pulsed to control background.
- Has to deal with beam associated background.
- COHERENT

COHERENT NEUTRINO NUCLEUS
INTERACTION EXPERIMENT

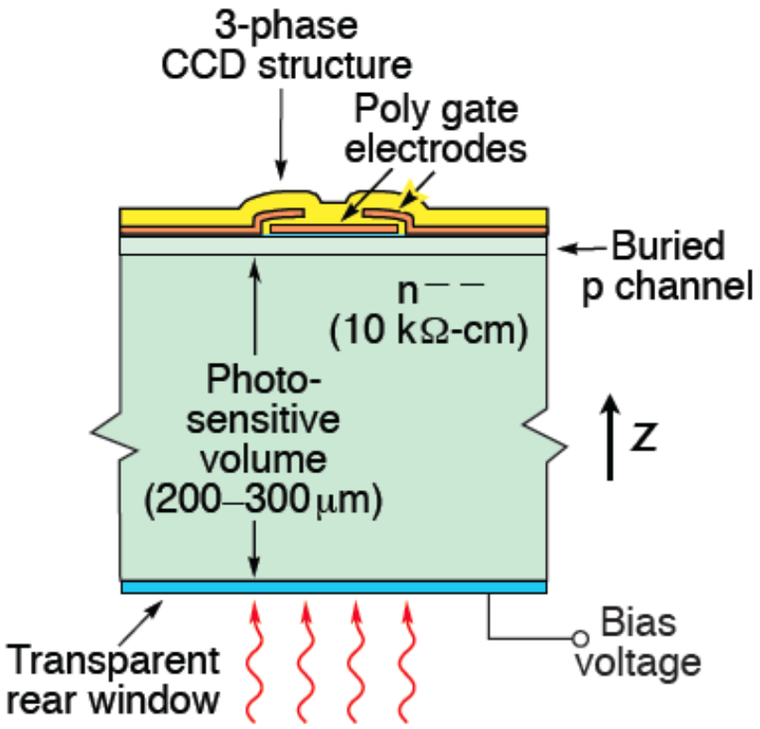
Centro Atómico Bariloche, Argentina
Centro Brasileiro de Pesquisas Físicas, Brazil
Universidad Nacional de Asunción, Paraguay
Fermi National Accelerator Laboratory, USA
Universidad Nacional Autónoma de México, Mexico
Universidad Nacional del Sur, Bahia Blanca, Argentina
Universidade Federal do Rio de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

Detector: CCD readout

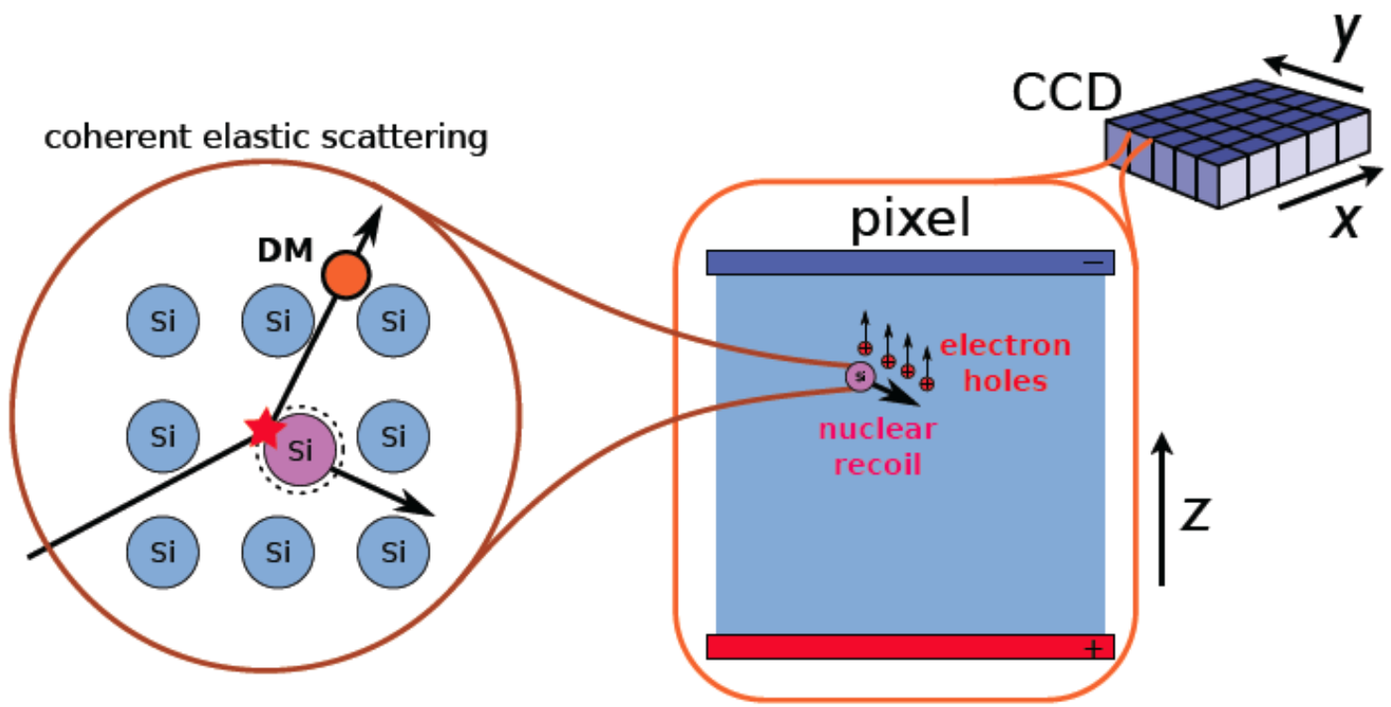




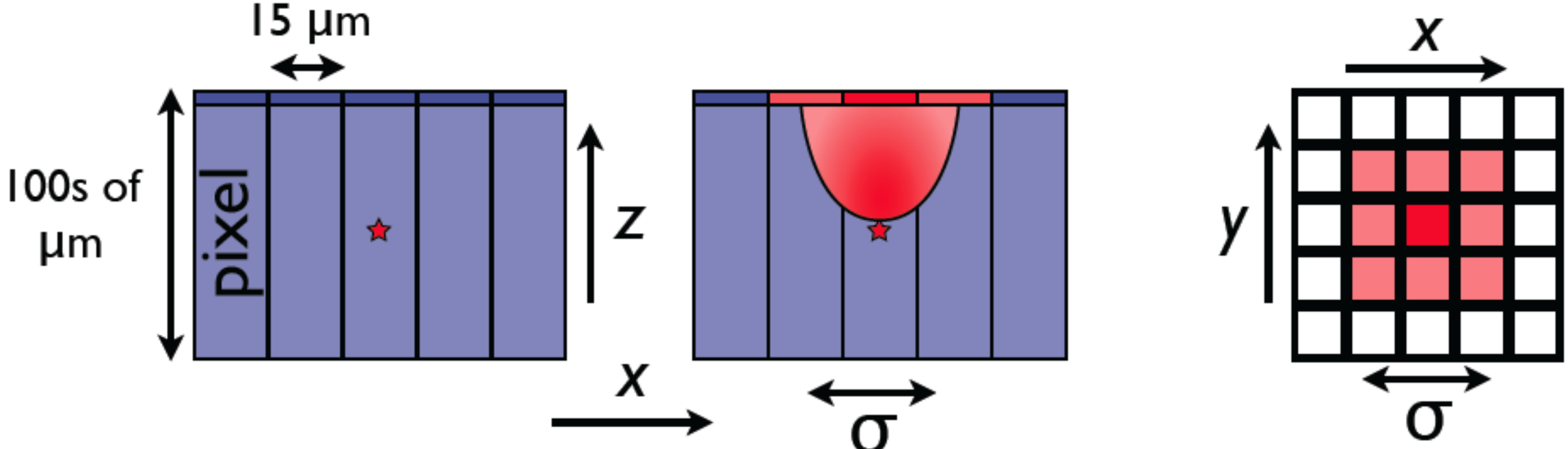
Charge coupling makes the detectors ideal for low noise measurements, typical noise for scientific CCDs is 2e- RMS (7.6eV). Very recent work pushing this to “0” noise.



(a) A CCD pixel

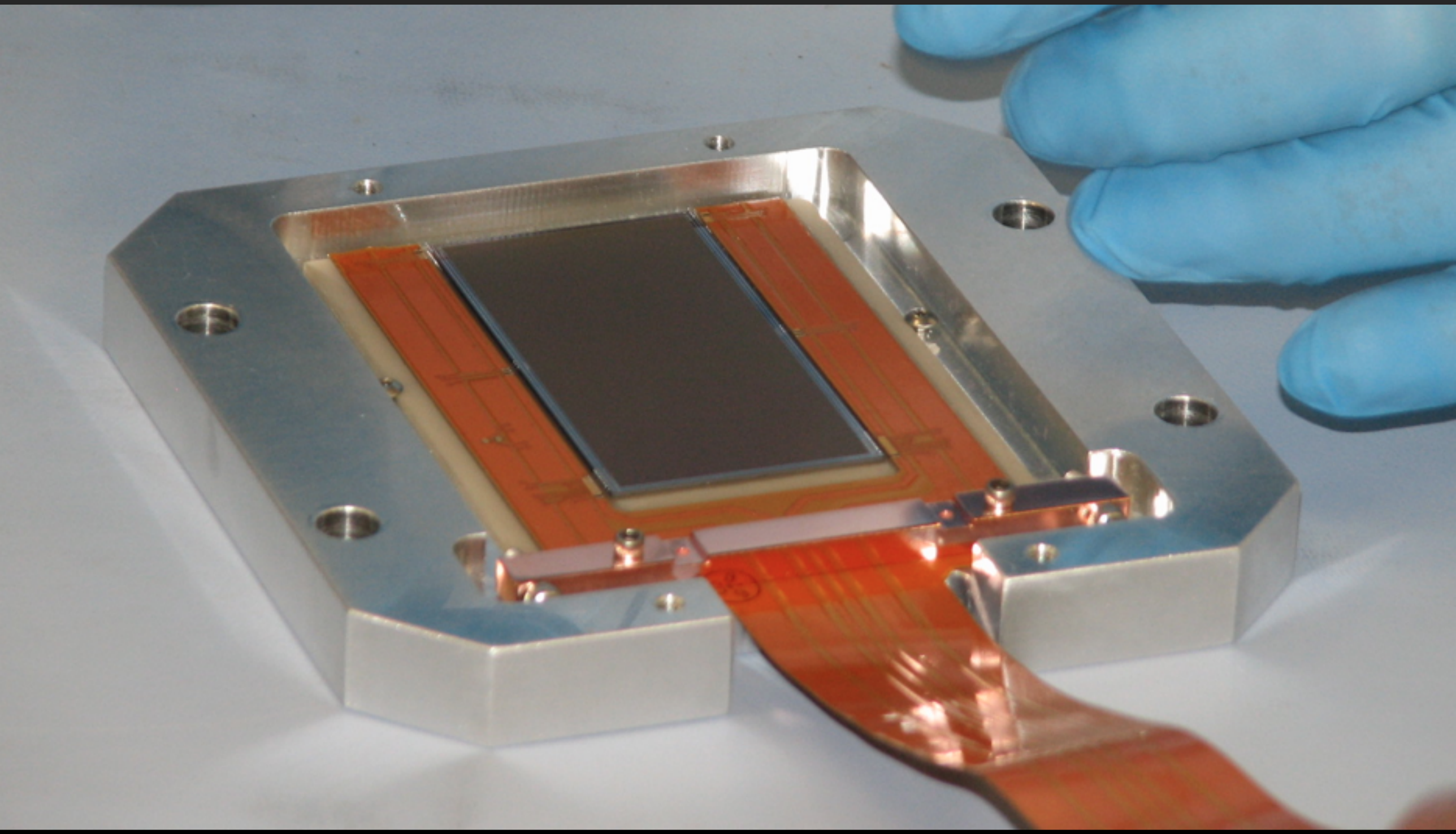


(b) WIMP detection principle



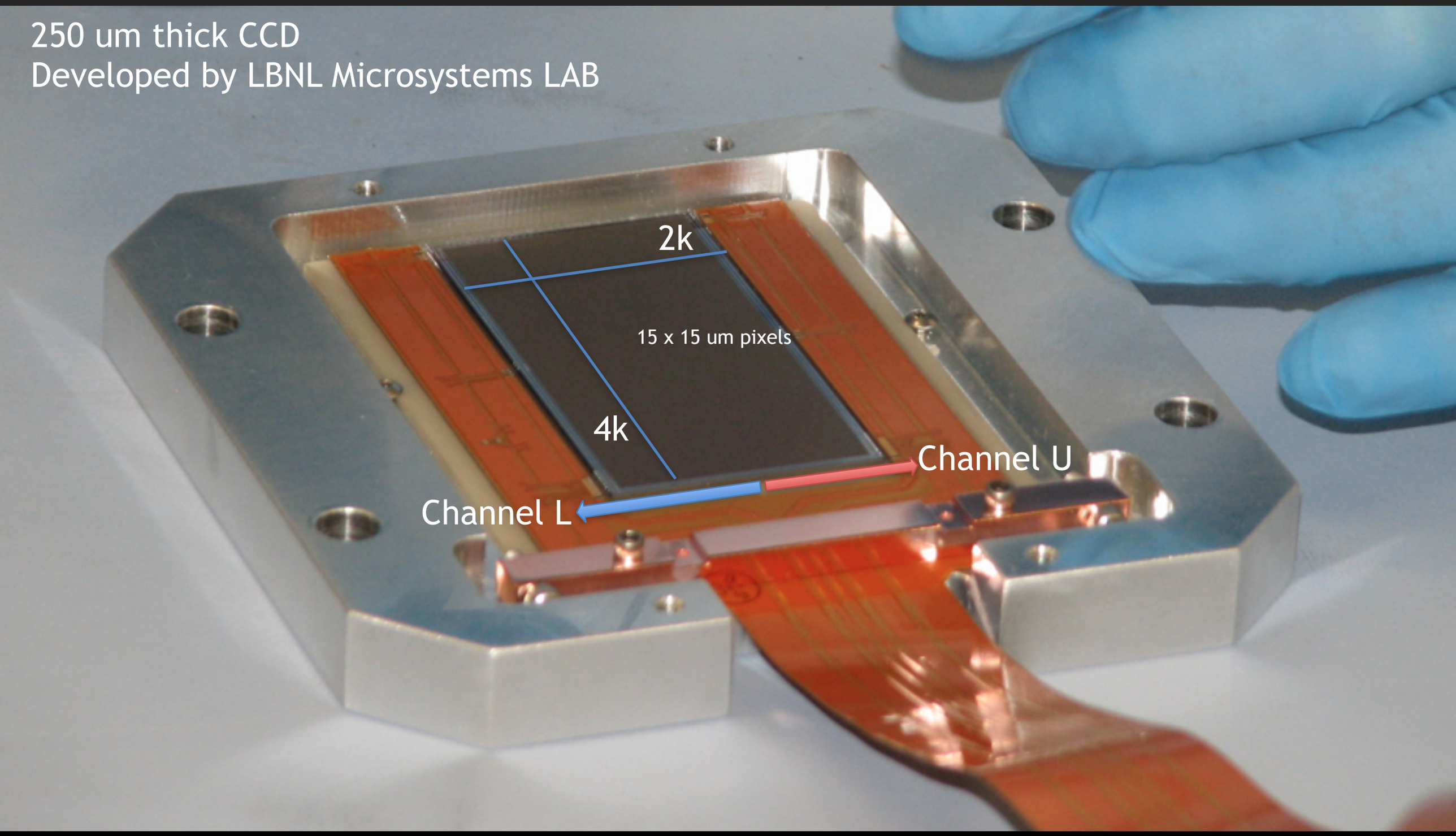
Recent developments by the MSL group at LBNL has allowed the fabrication for “massive” CCDs. 675 um is now possible.

CONNIE 2014-2015 sensor:



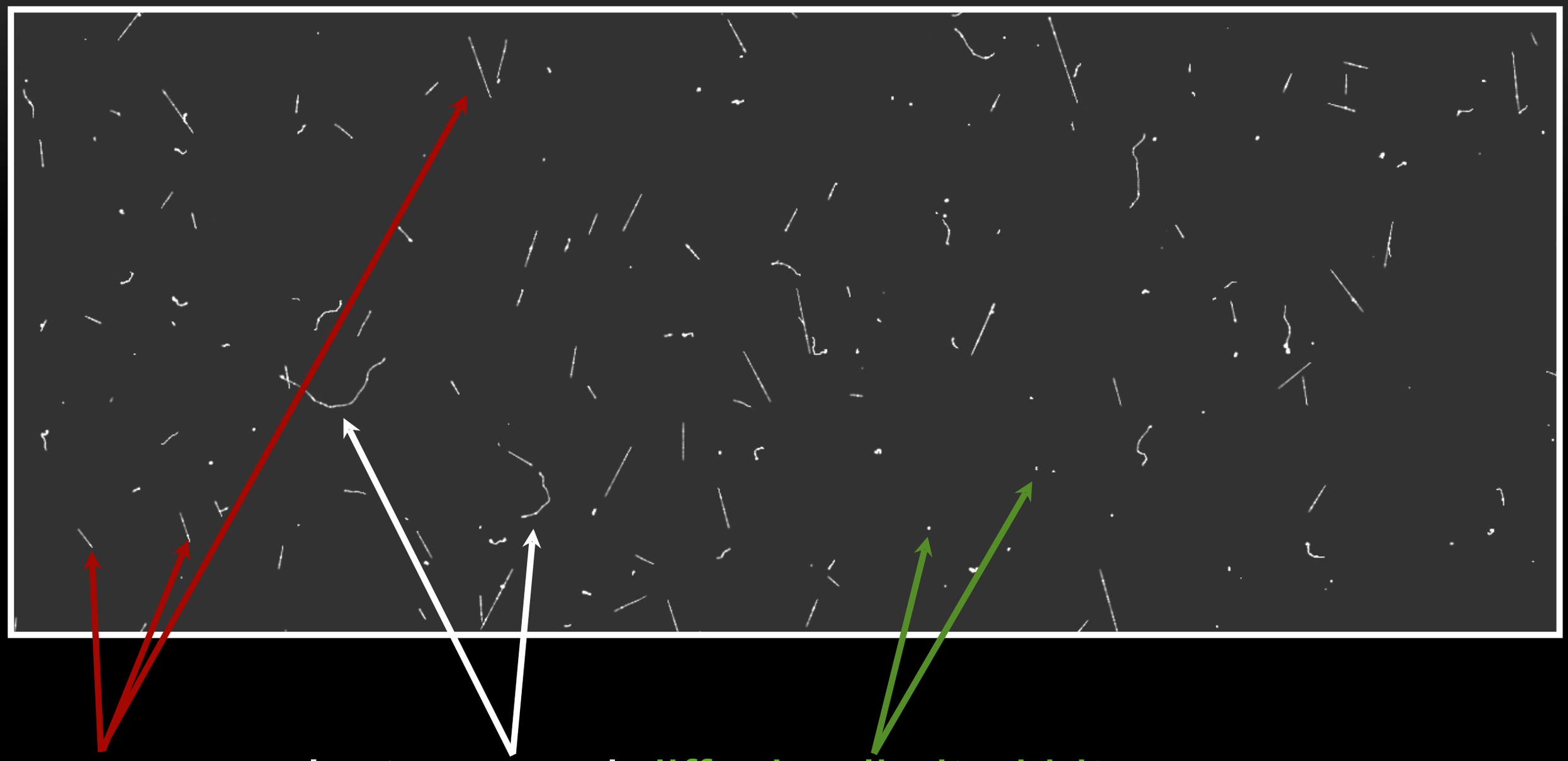
CONNIE 2014-2015 sensor

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!

Particle identification in a CCD image

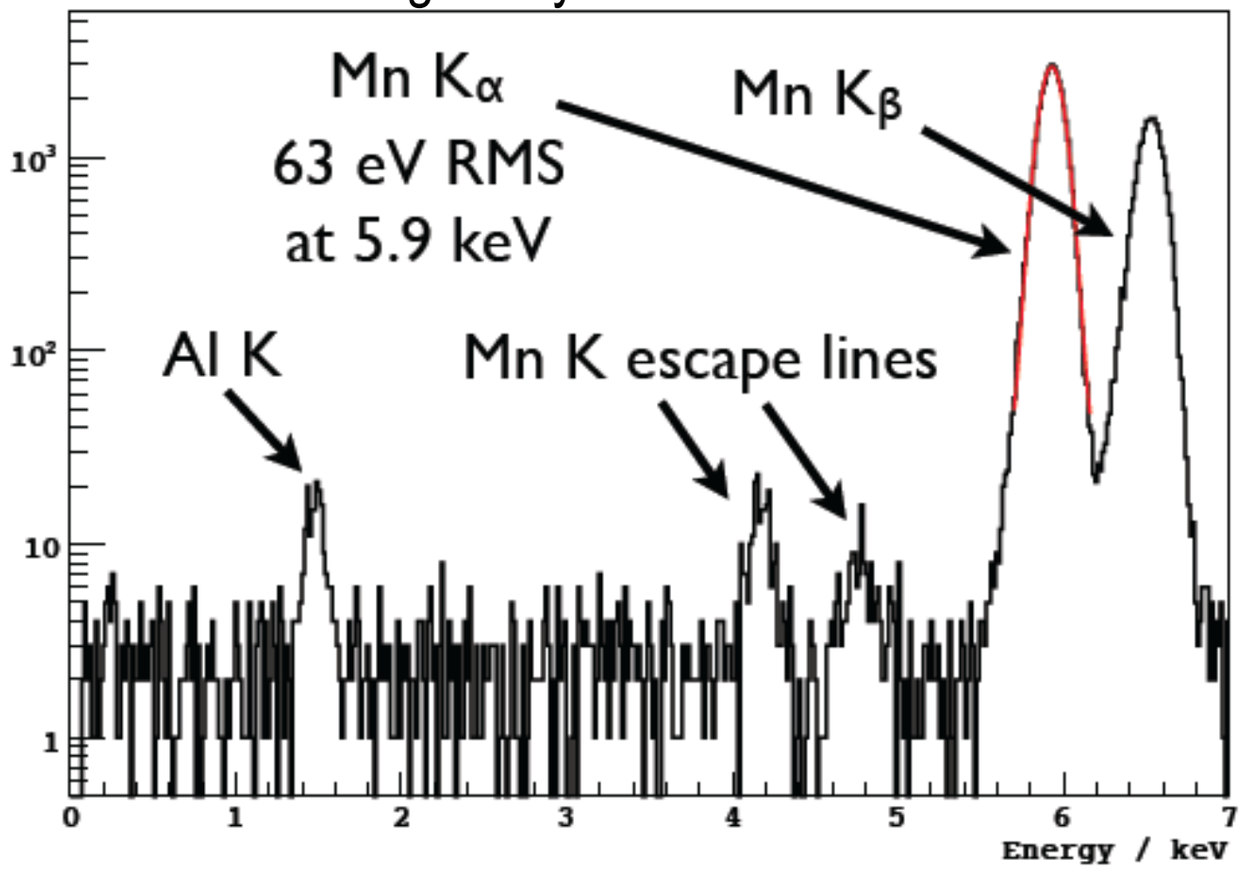


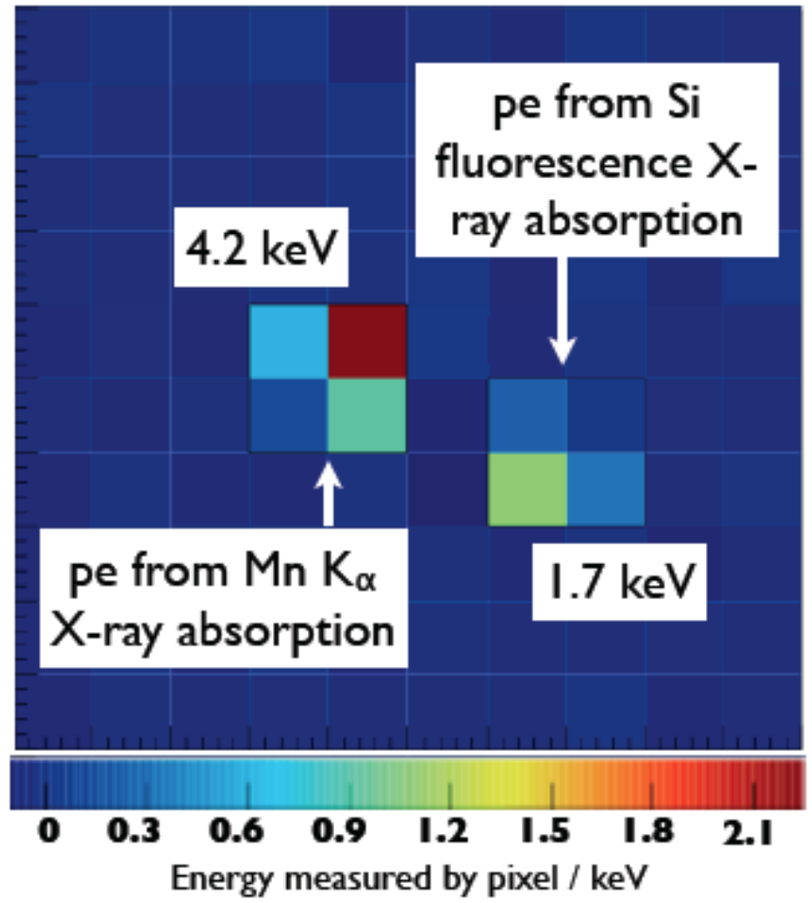
muons, electrons and diffusion limited hits.

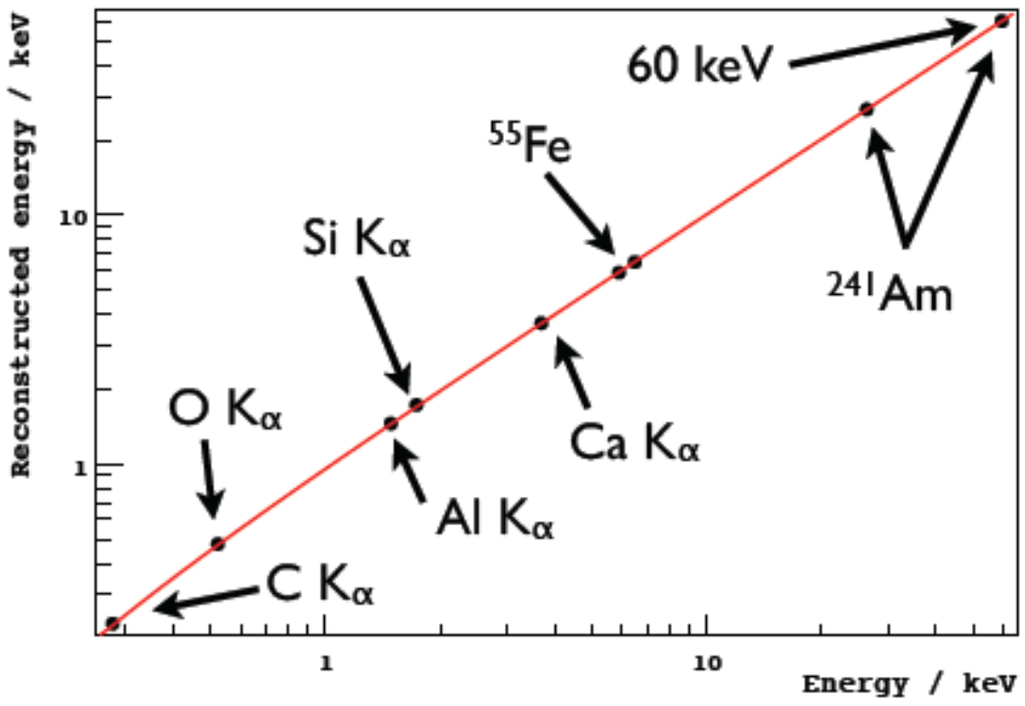
Nuclear recoils will produce diffusion limited hits. Neutrinos from reactor are expected to produce nuclear recoils at a rate of 10,000 per day for each kilogram of detector.

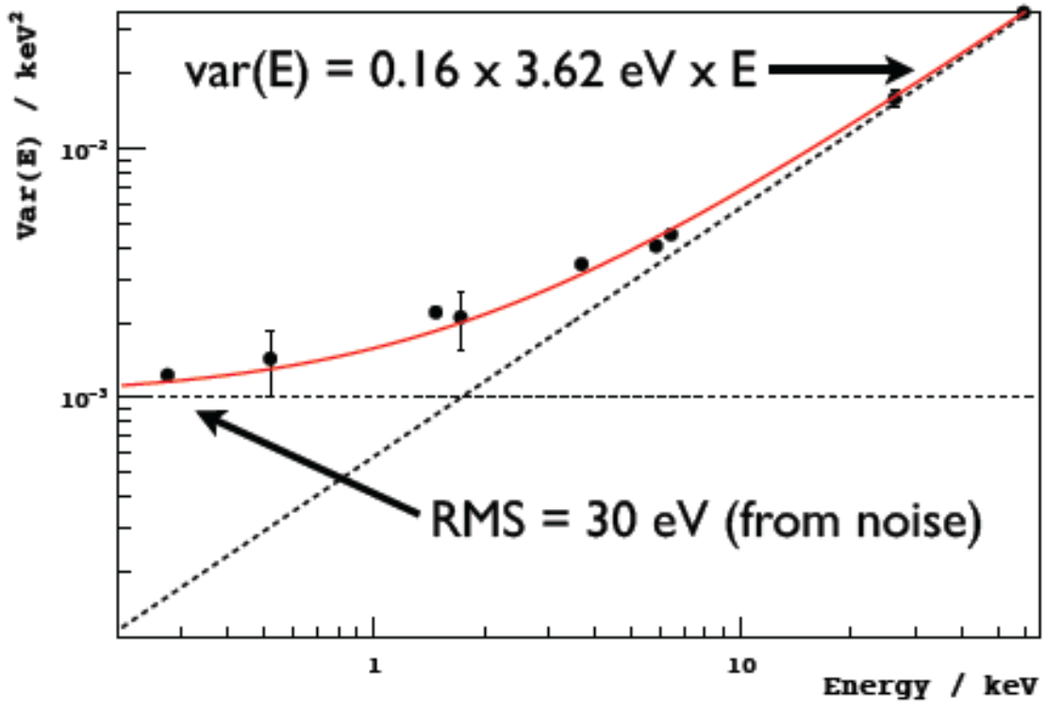
arXiv:1408.3263

Calibration using X-rays



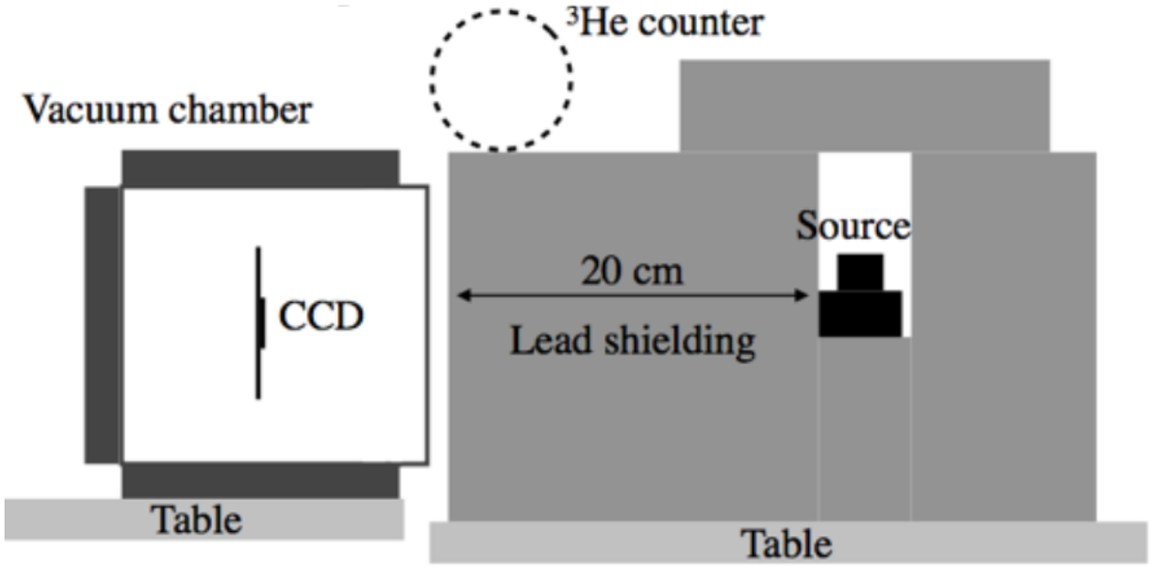






Nuclear Recoil Calibration (A.Chavarria et al)

arXiv:1608.00957



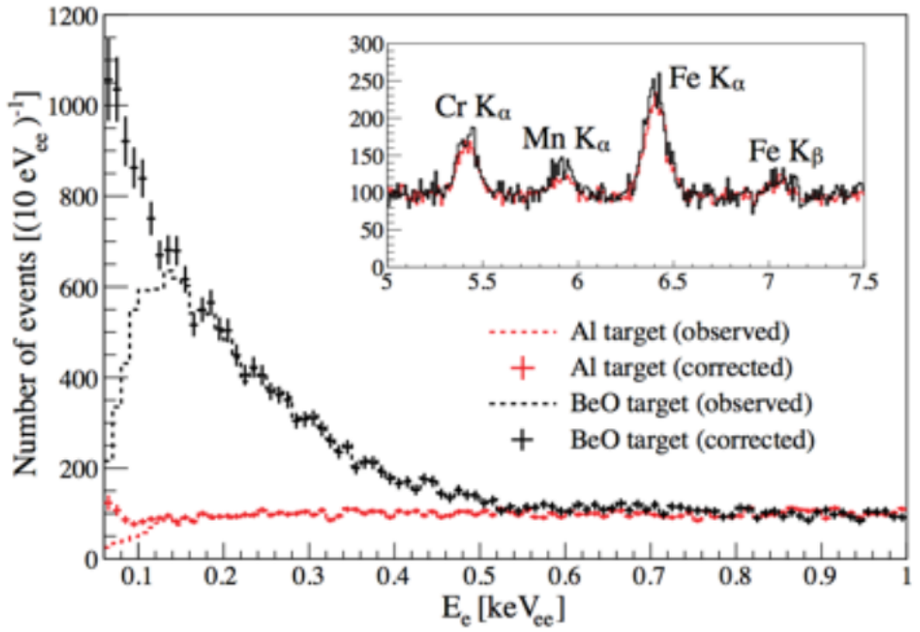


FIG. 2. Measured ionization spectra with the full BeO and Al targets (dashed lines). Solid markers represent the spectra corrected for the energy-dependent event selection acceptance. The inset shows the spectra in the 5.0–7.5 keV$_{ee}$ range, with in-run calibration lines from fluorescence x rays originating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

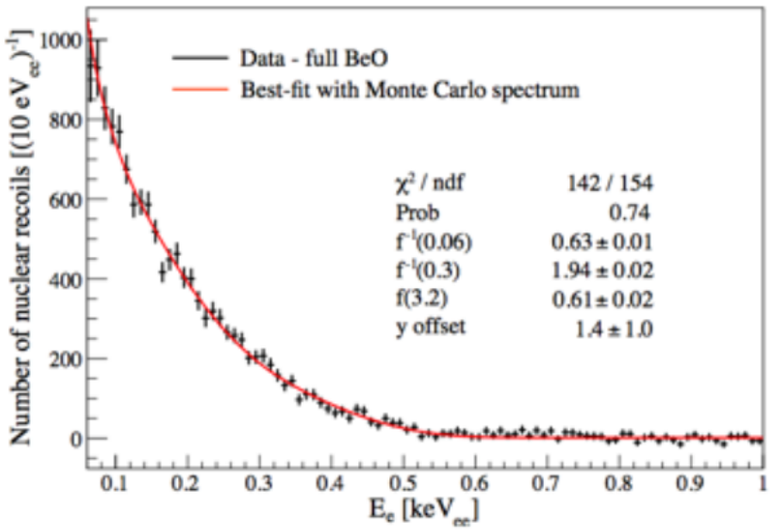
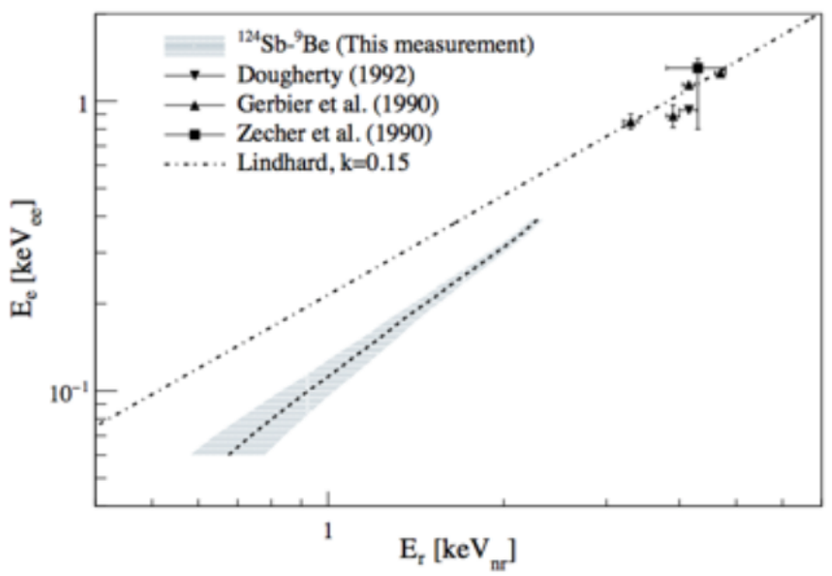


FIG. 4. Ionization spectrum of nuclear recoils induced by neutrons from the full BeO target source (black markers) and best fit to the data (solid line). The fitting function was obtained by applying a cubic spline model f of the nuclear recoil ionization efficiency to the simulated recoil spectrum and 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)

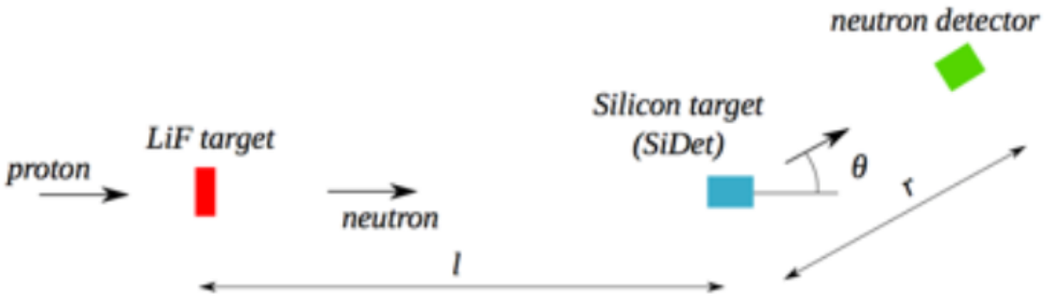
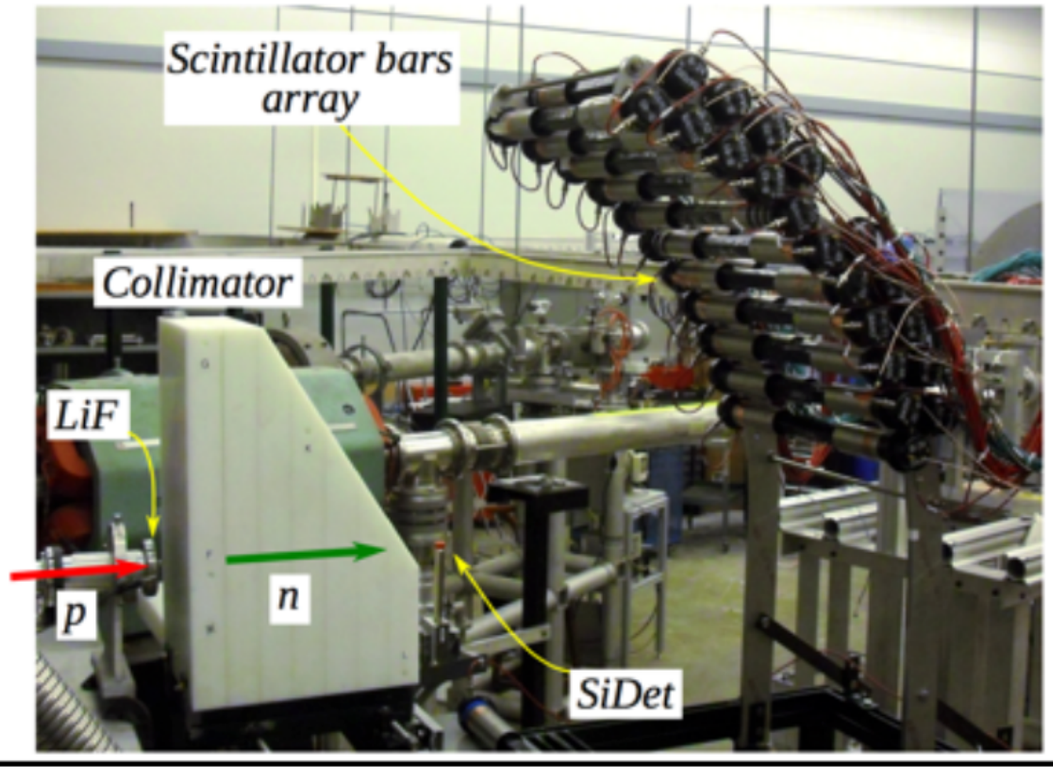
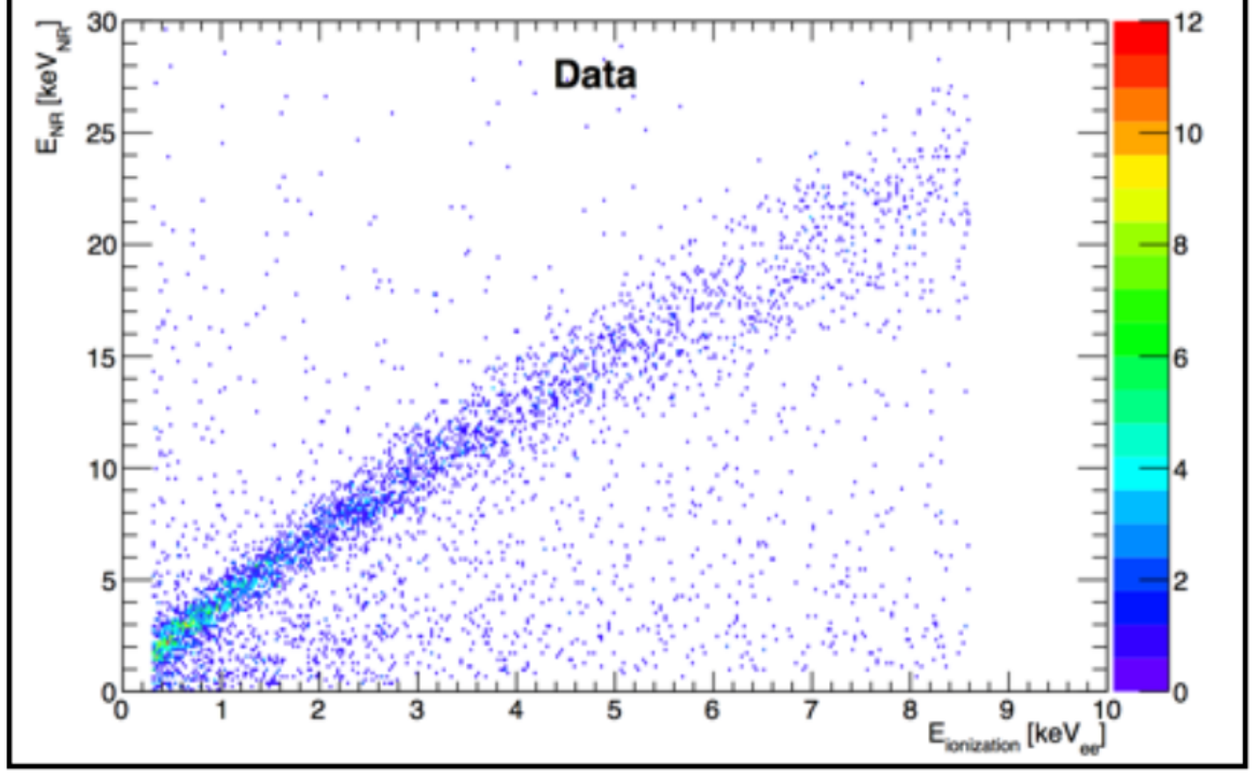
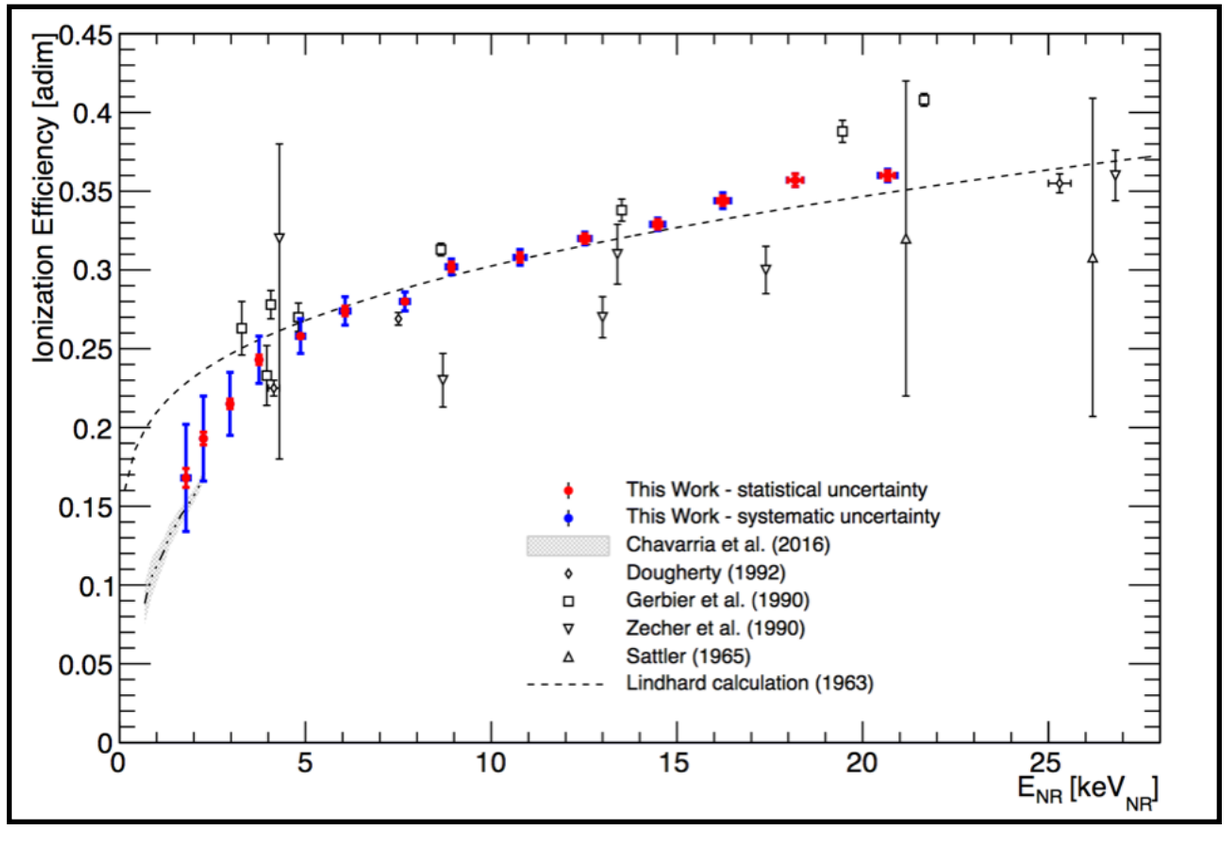


Figure 1: Schematic layout of the experimental arrangement.

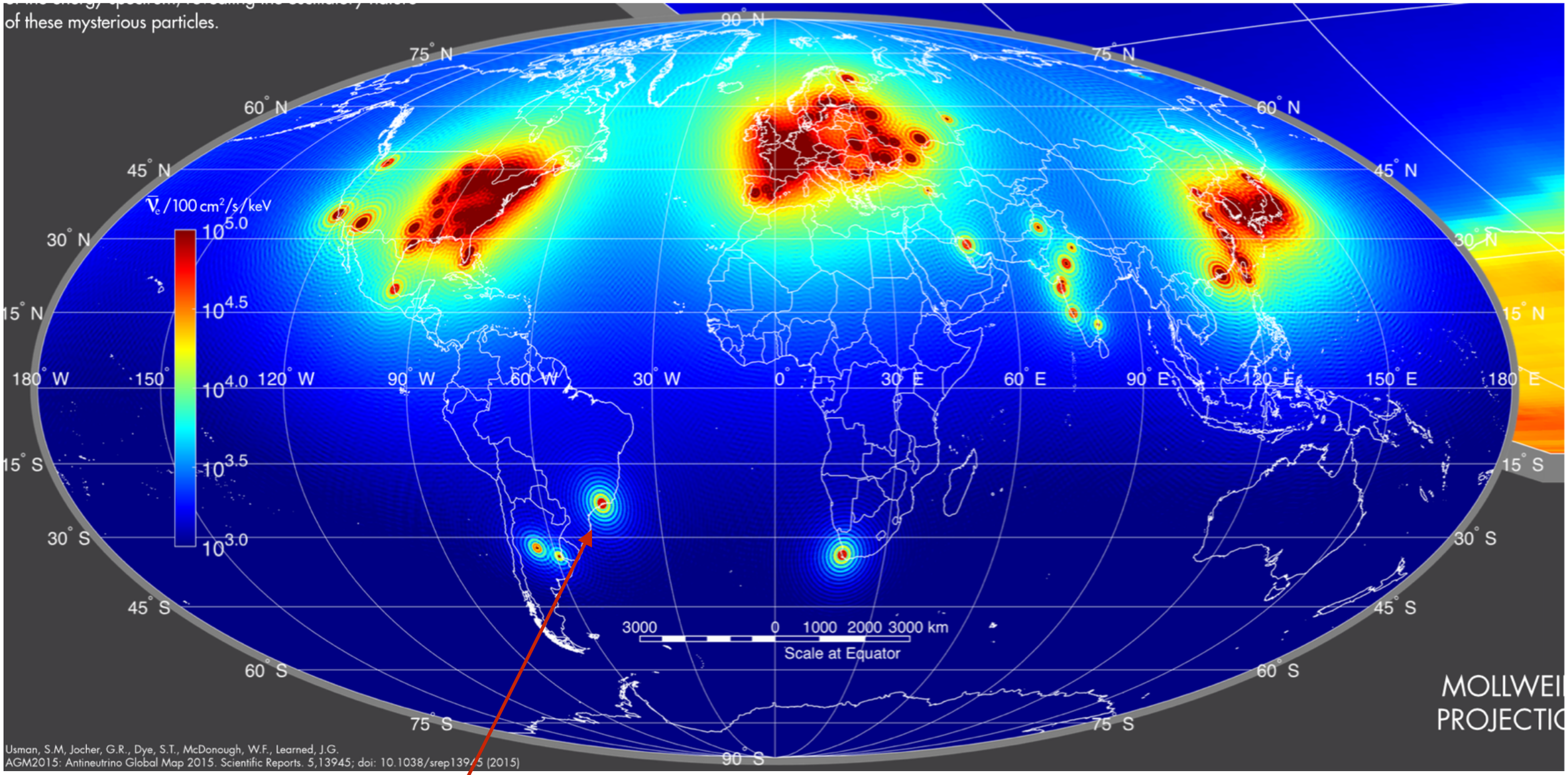






Complete calibration down to our threshold for CONNIE.

of these mysterious particles.

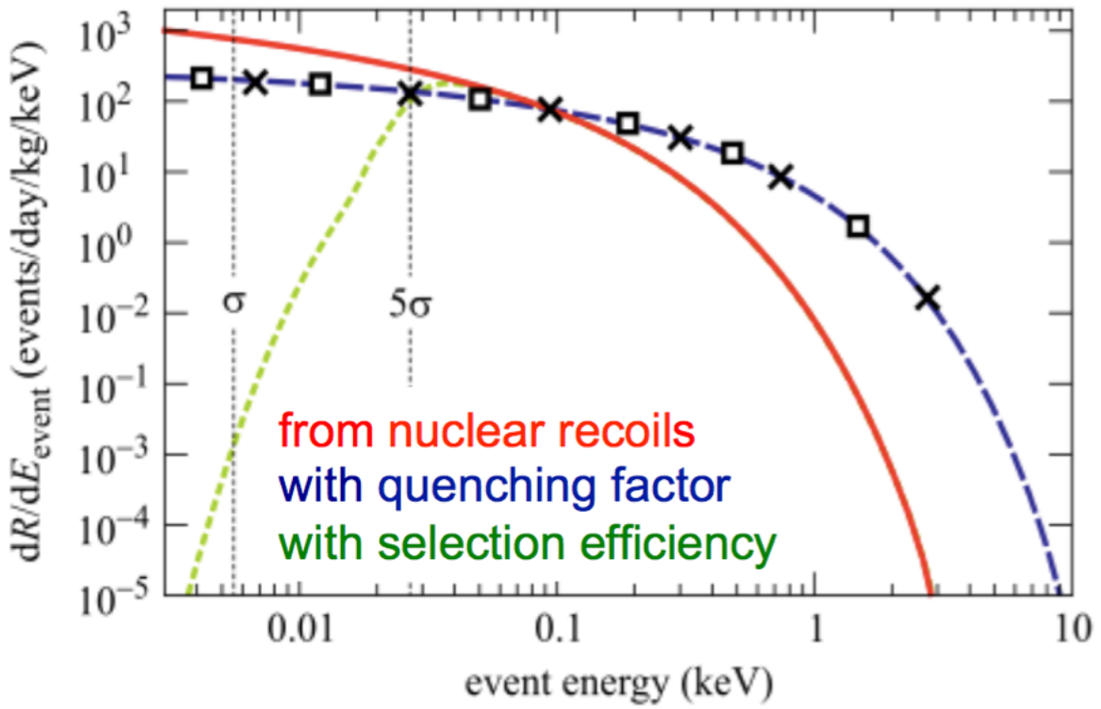


Usman, S.M, Jocher, G.R., Dye, S.T., McDonough, W.F., Learned, J.G.
AGM2015: Antineutrino Global Map 2015. Scientific Reports. 5,13945; doi: 10.1038/srep13945 (2015)

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

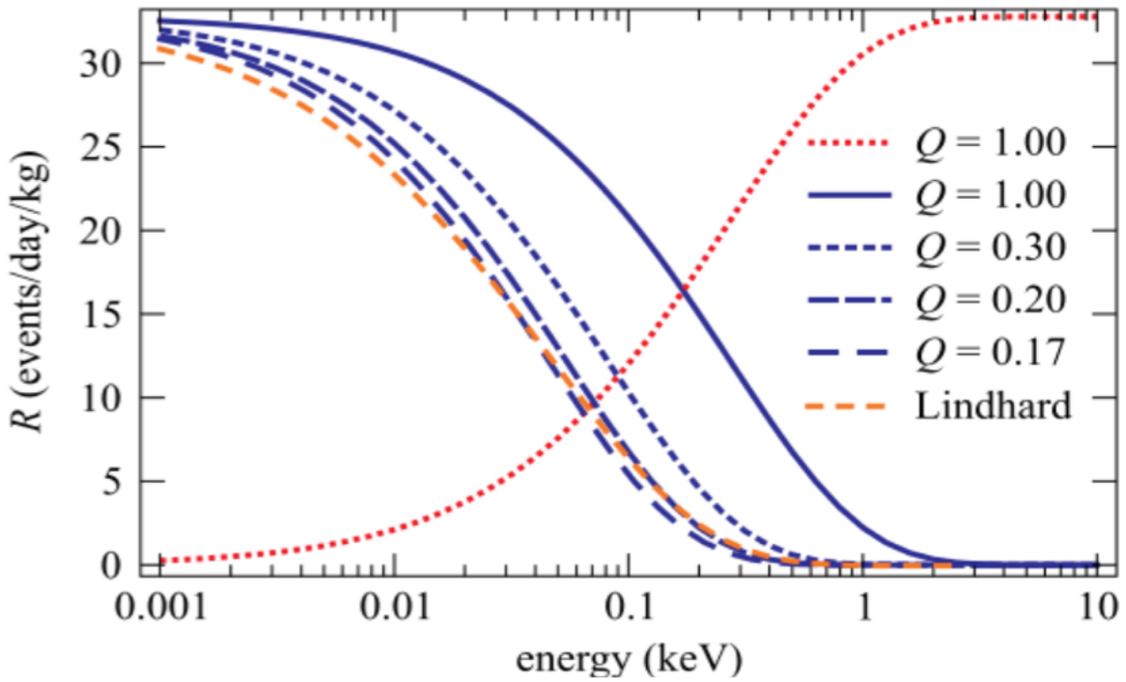
CONNIE rates

Energy spectra in silicon detectors



Phys.Rev. D 91, 072001 (2015)

Total number of events vs threshold energy for different quenching factors



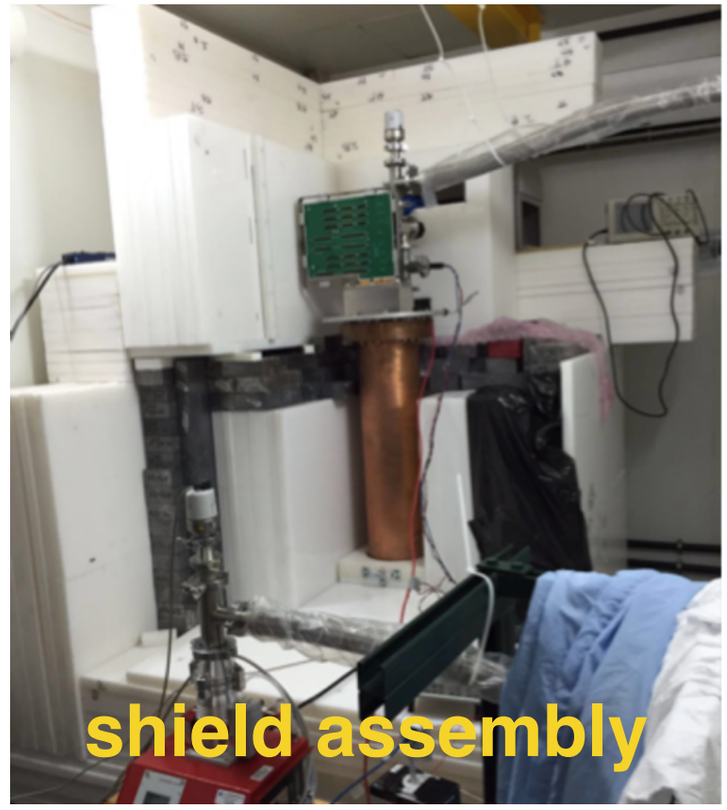
Total events vs max. detectable recoil for Q=1

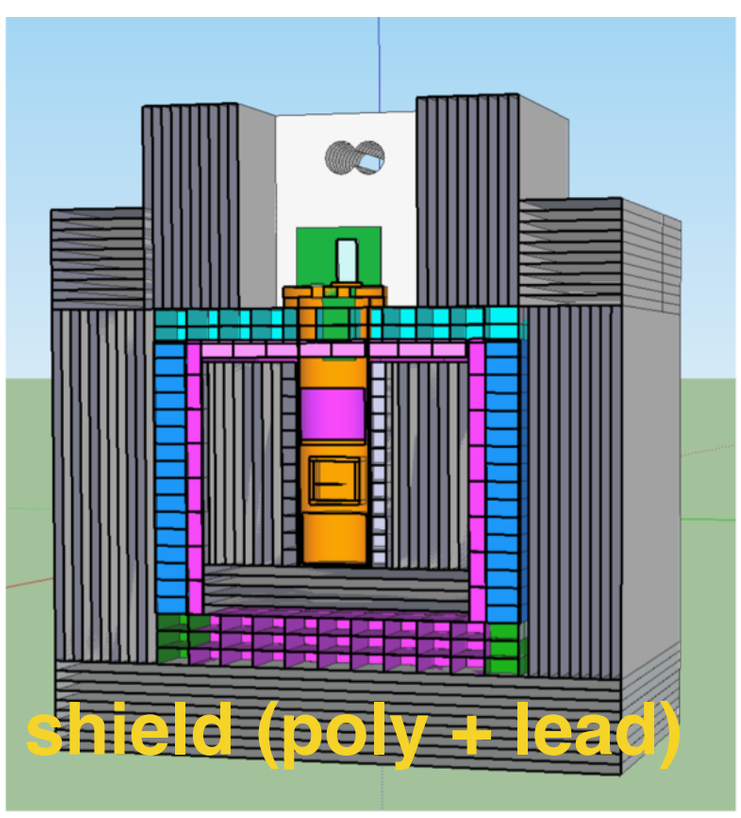
$Q = 0.20$

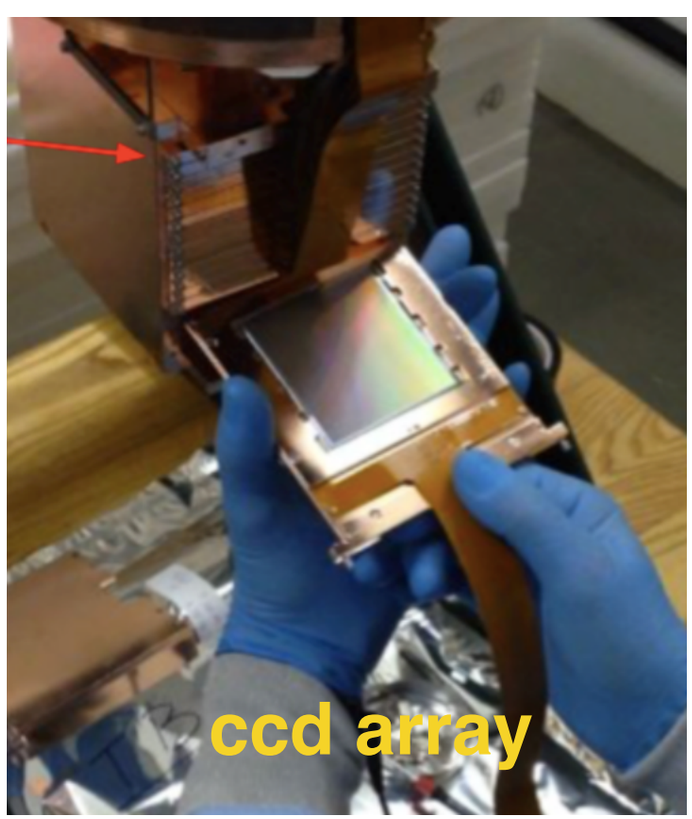
Expected number of events (event/kg/day)

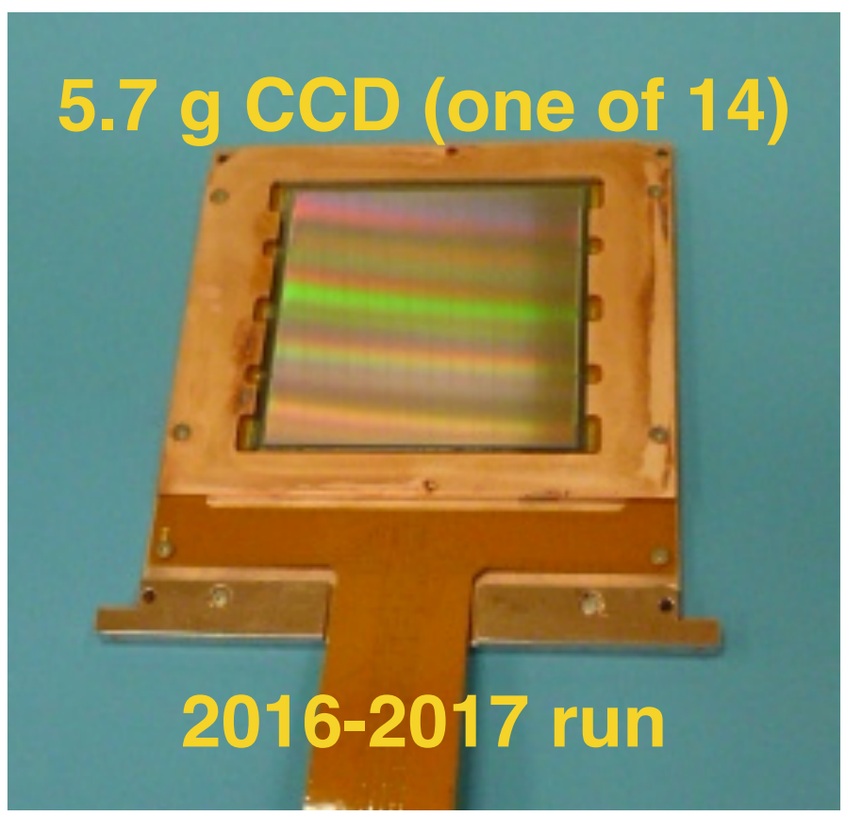
E_{th} = 5.5 eV ($1\sigma_{RMS}$)	~ 28.3
E_{th} = 28 eV ($5\sigma_{RMS}$)	~ 18.1

our site

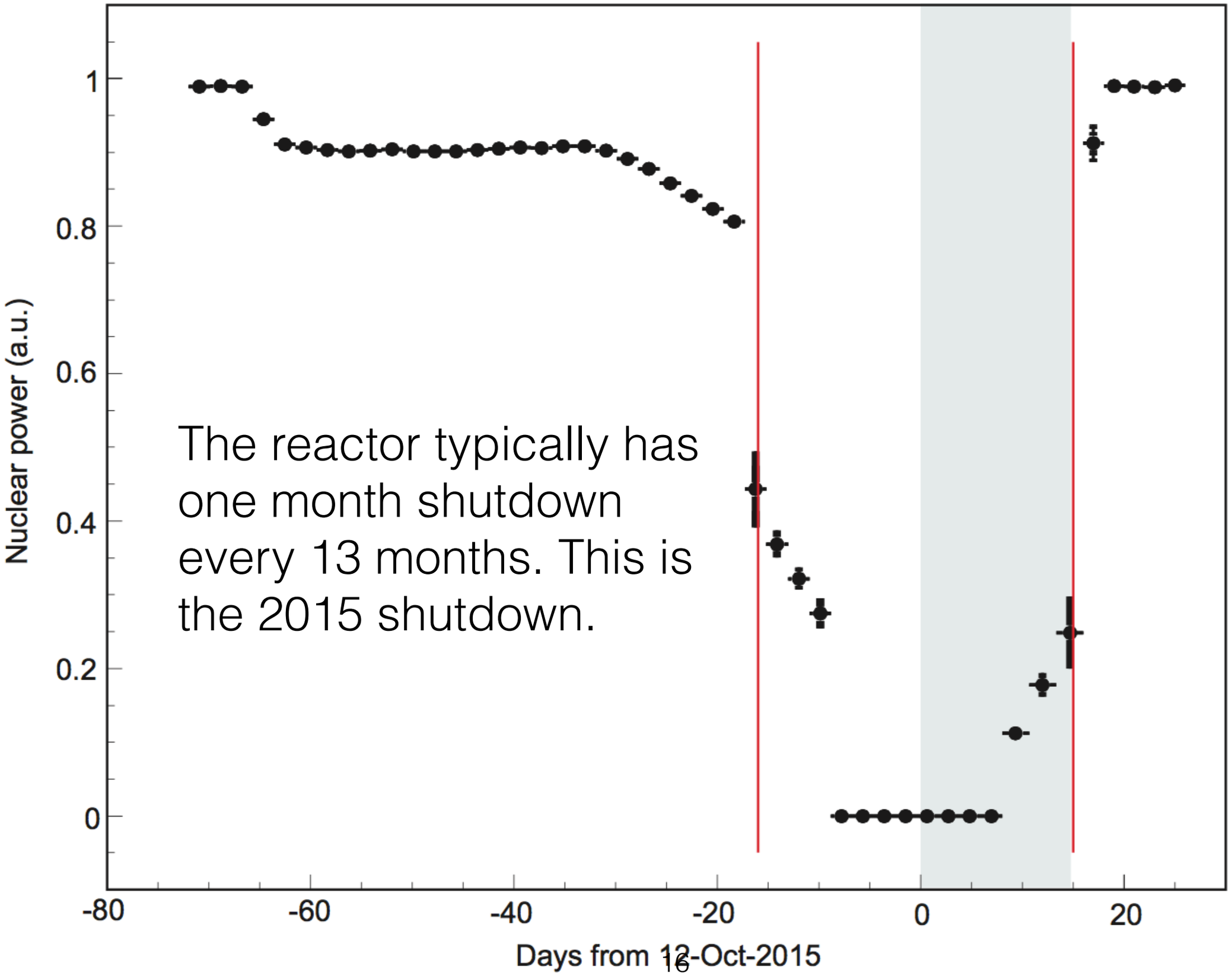

shield assembly


shield (poly + lead)


ccd array

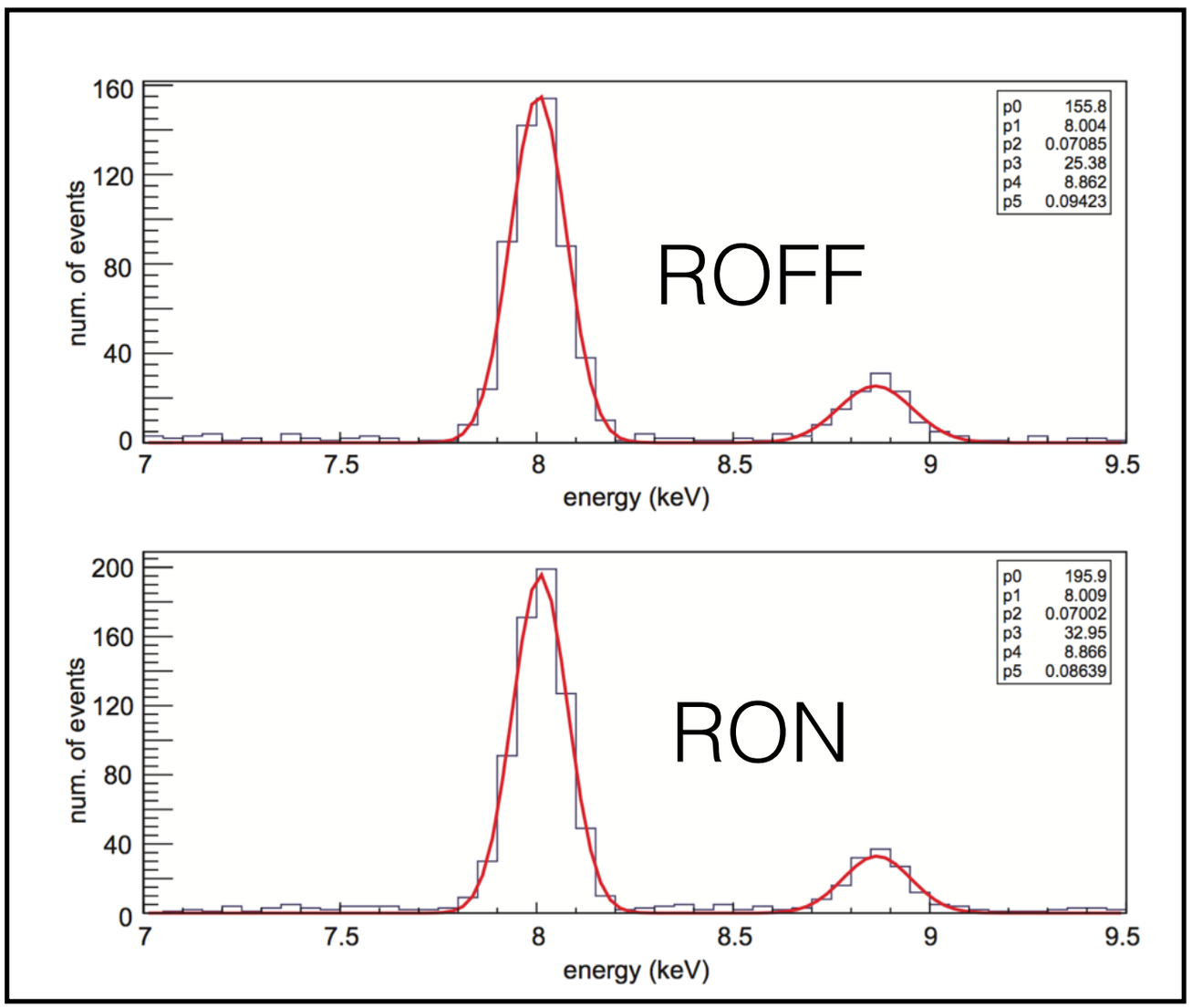

5.7 g CCD (one of 14)
2016-2017 run

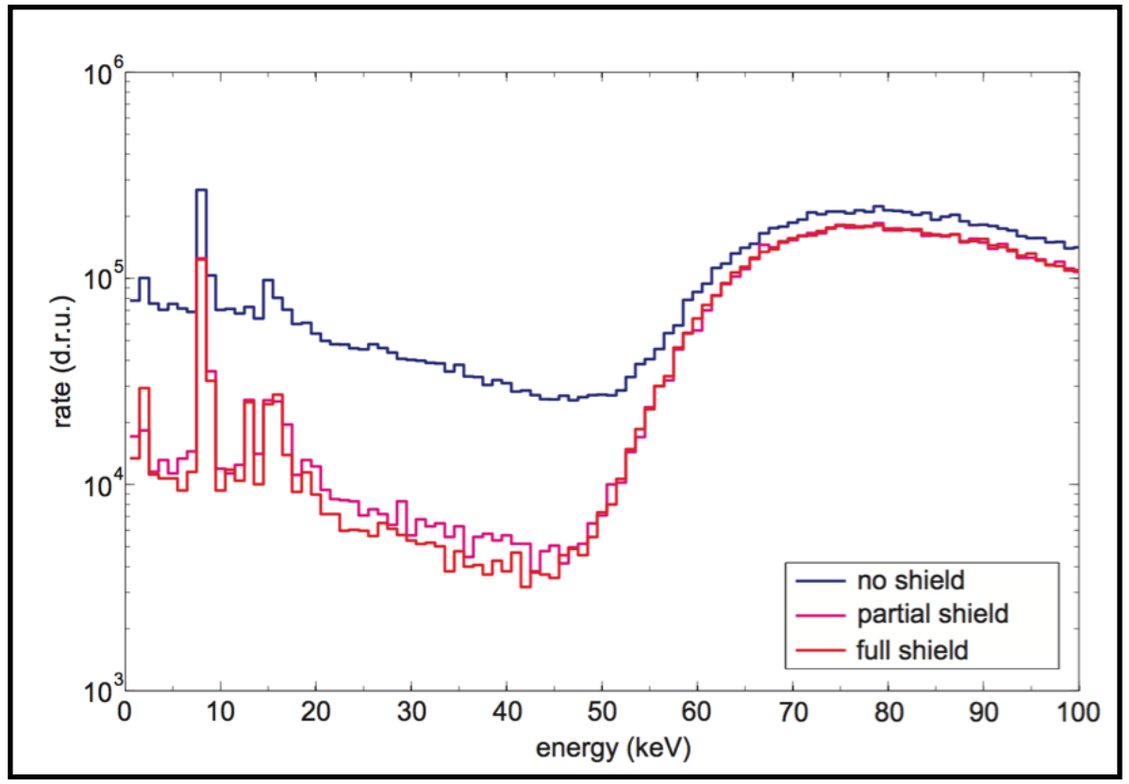
2015 Engineering Run

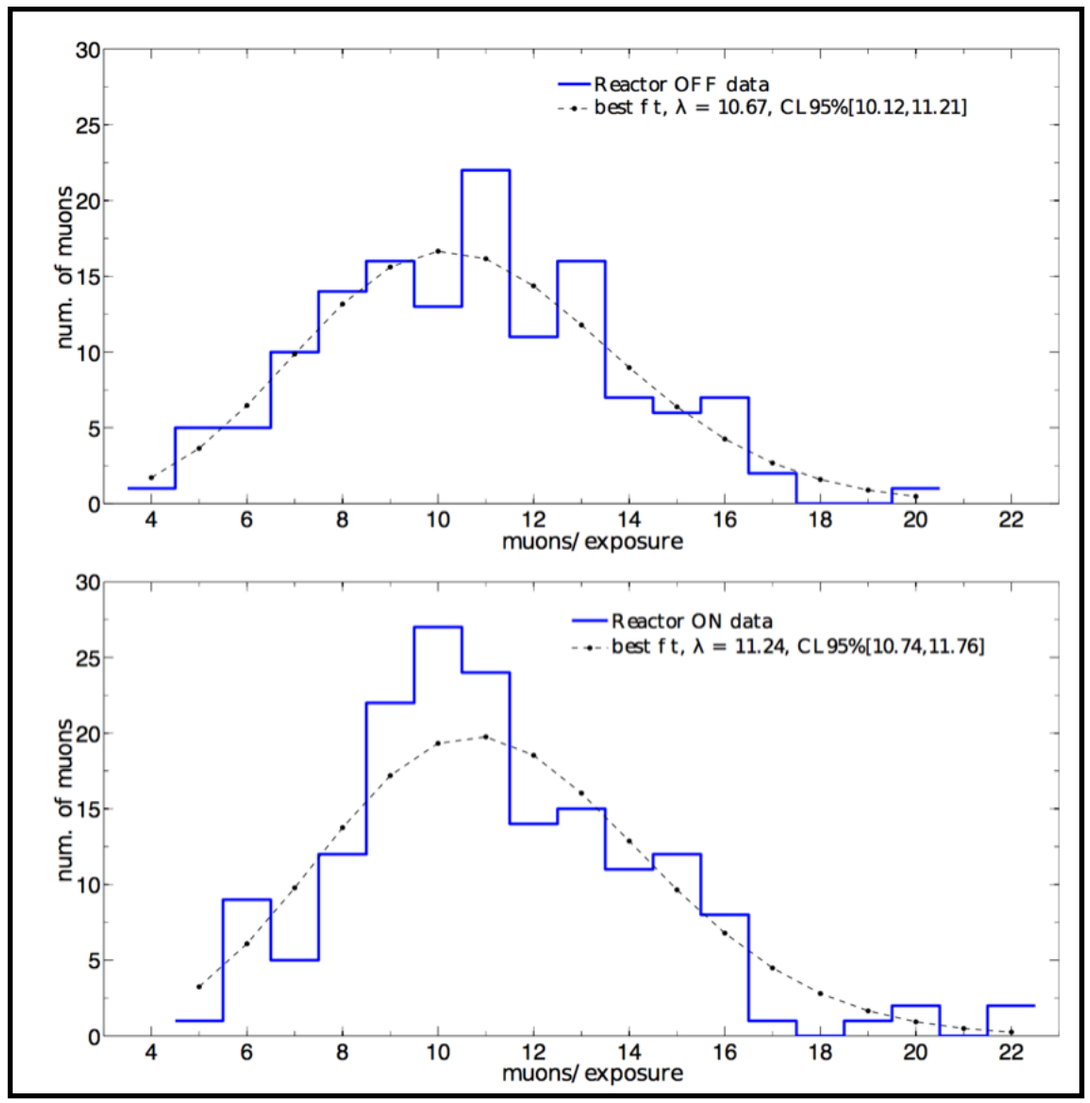


2015 engineering run FNAL-LDRD program (1g active mass, 1 CCD)

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

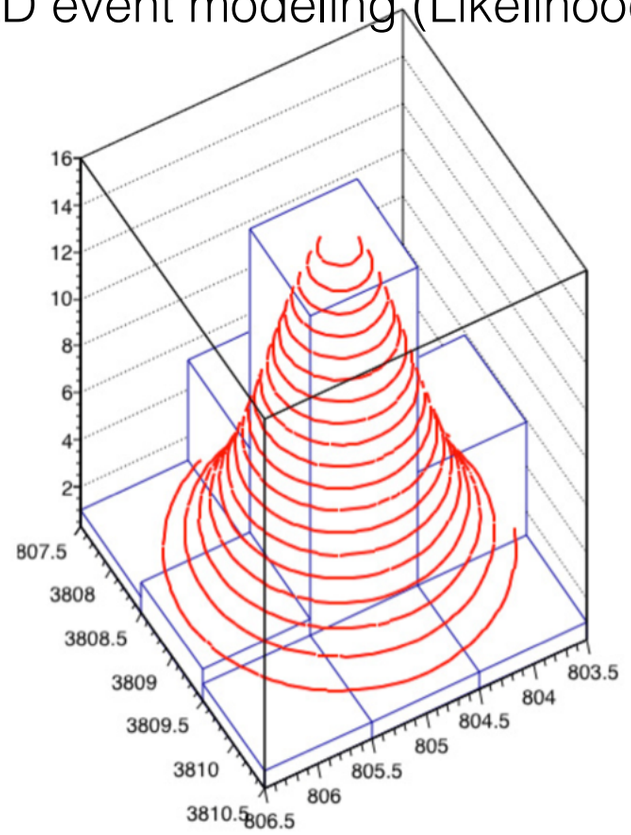






2015 : no excess

2D event modeling (Likelihood)



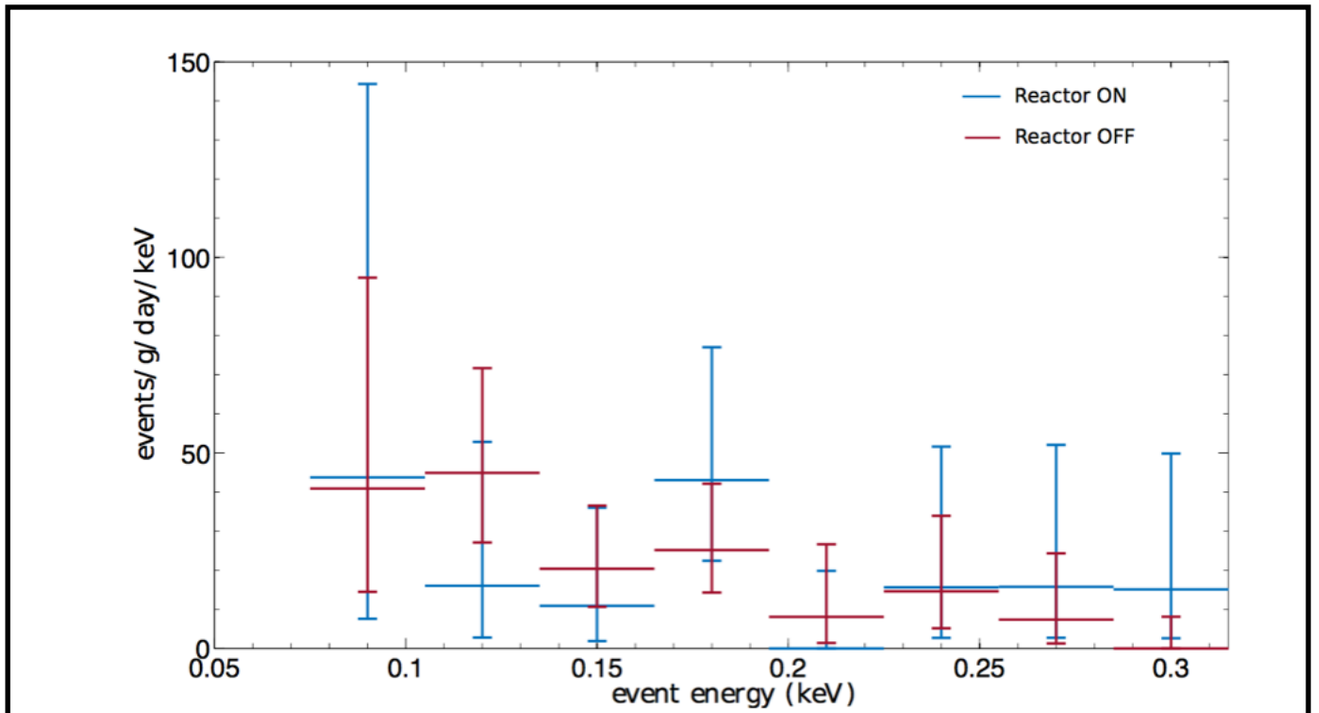
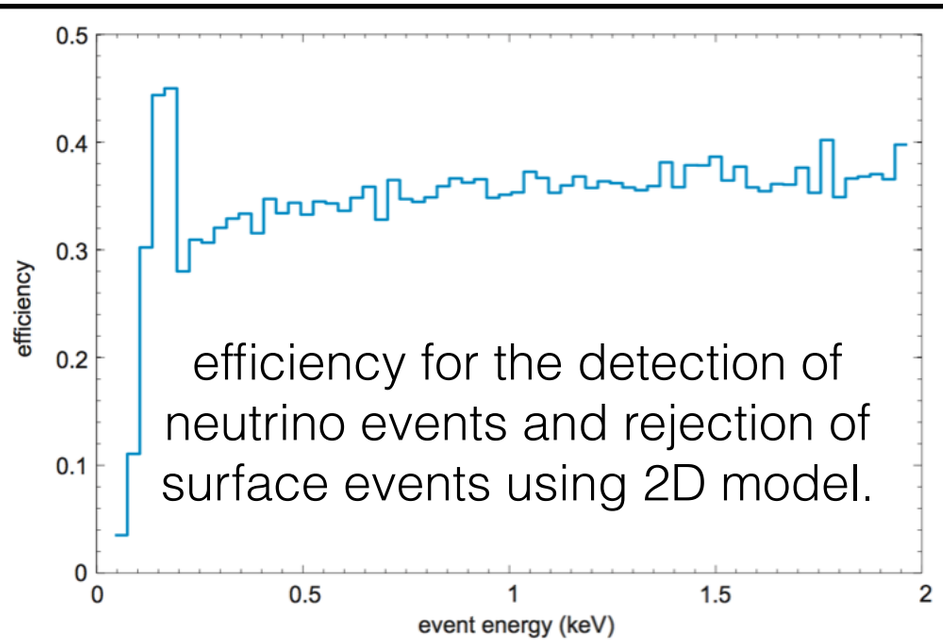
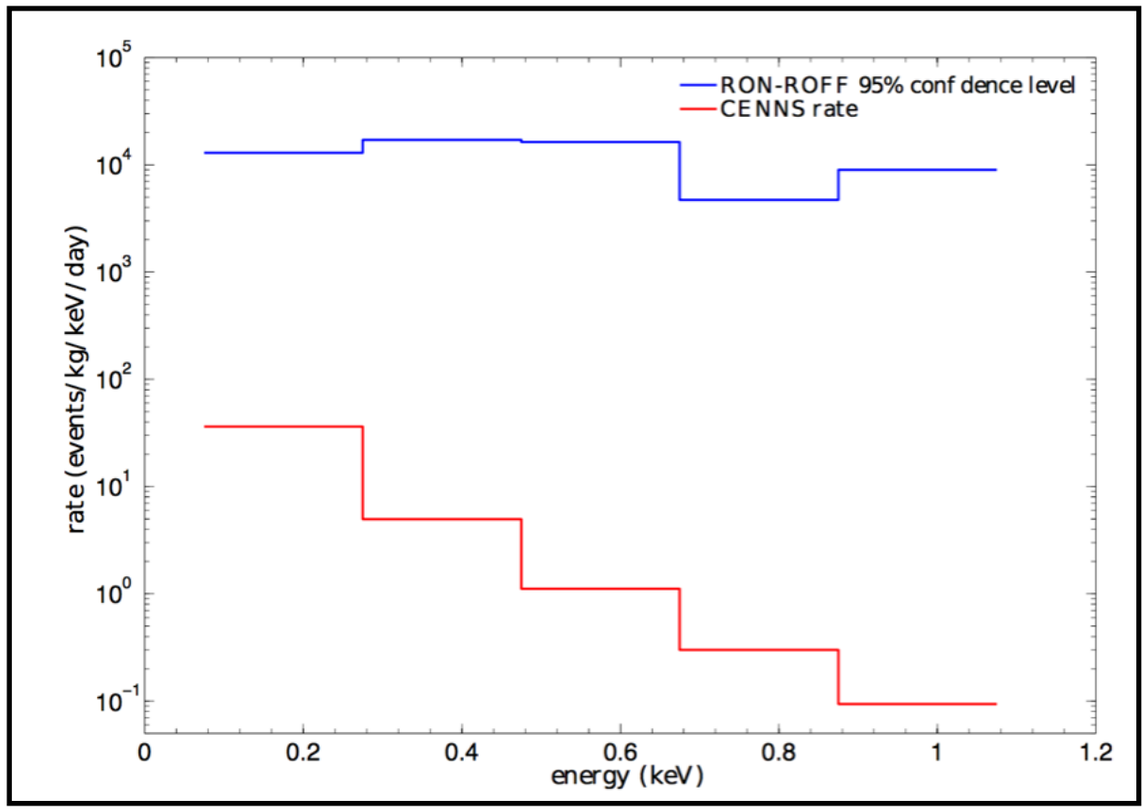


Figure 17: Same as Fig.16, the error bars correspond to 68.27% probability assuming a Poisson distribution for each energy bin.



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



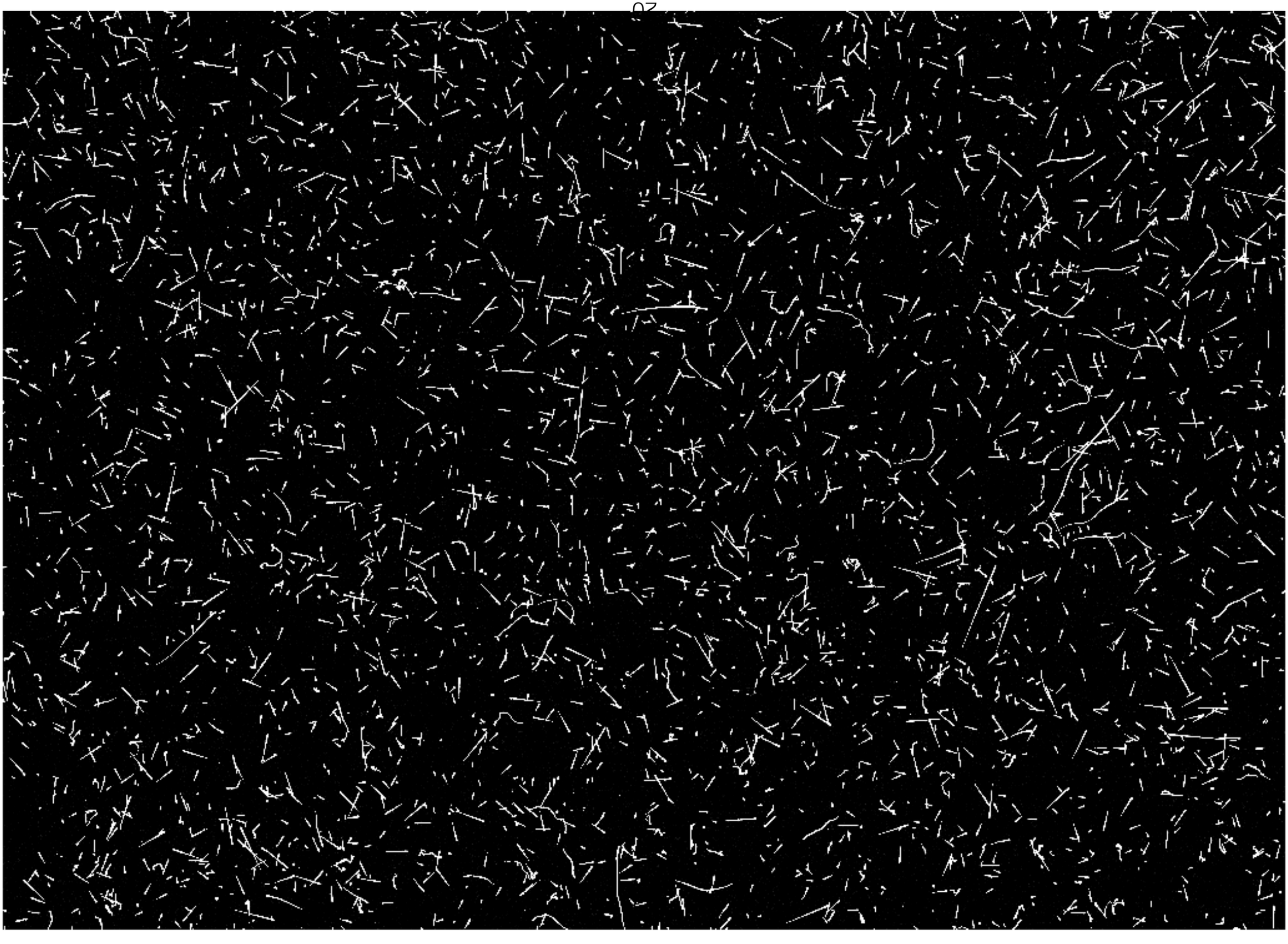
2016

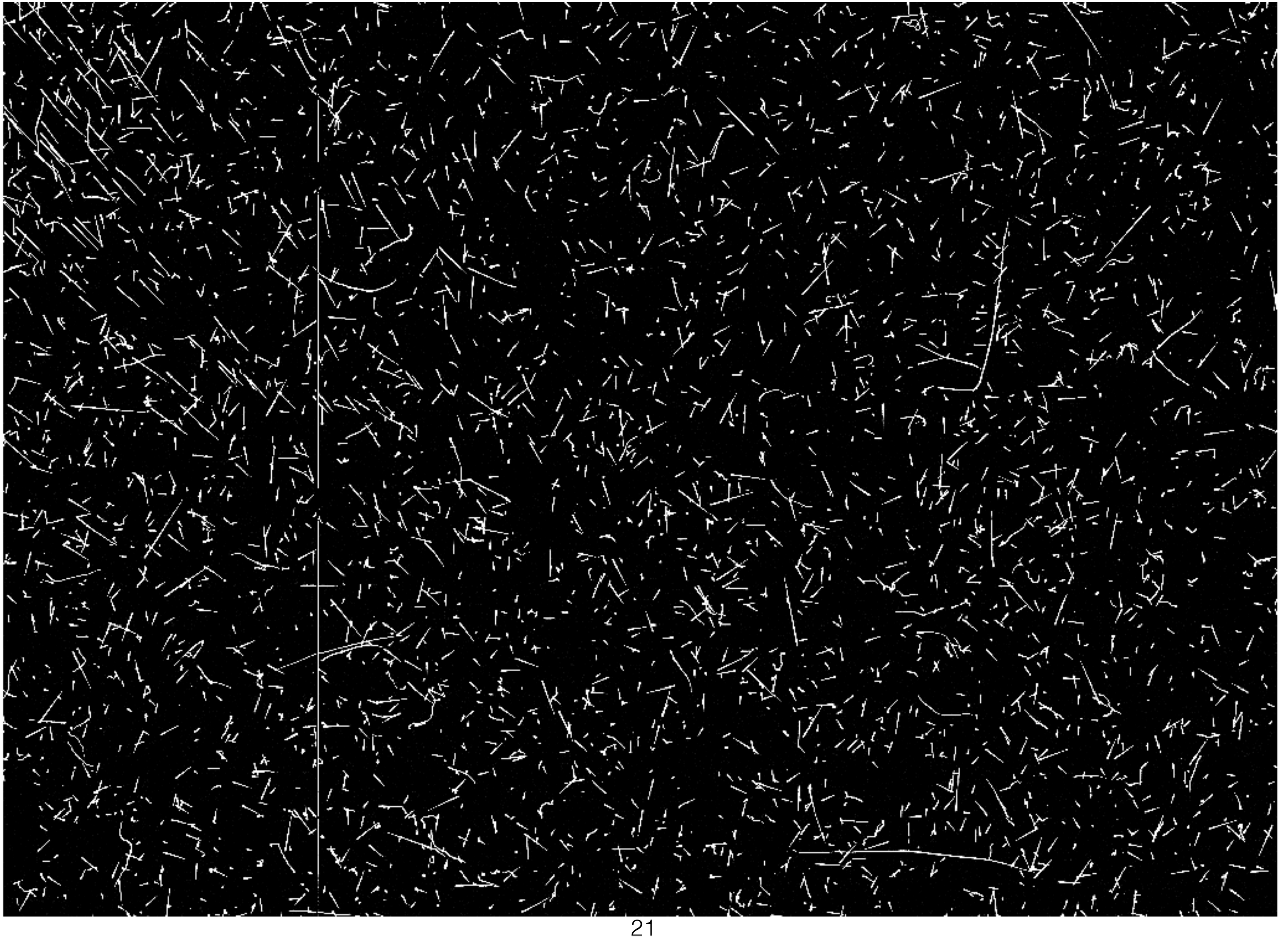
- Exposure increase x 130:

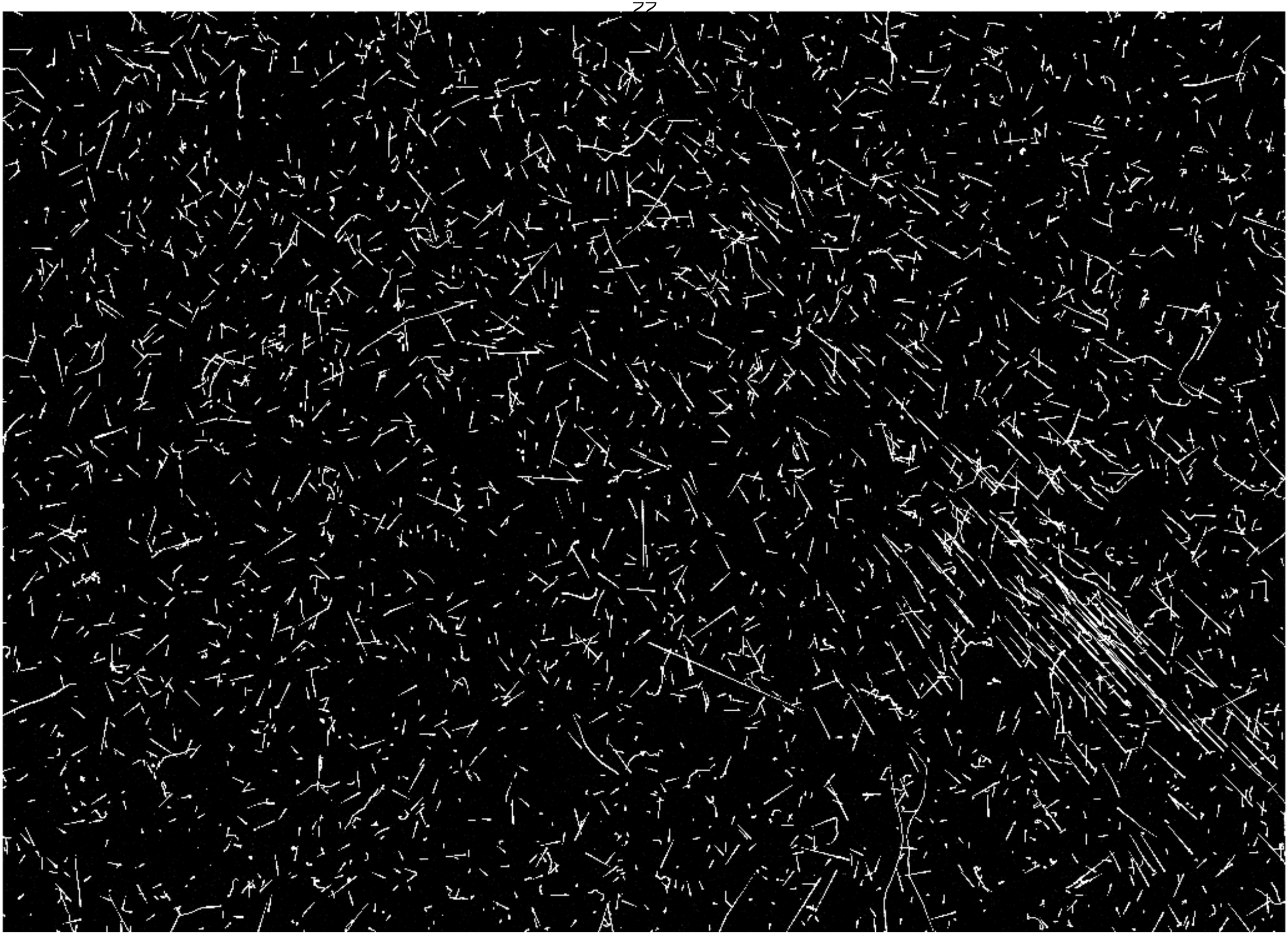
  Reactor OFF exposure 1.9 kg-day (30 days x 80 g x 0.8 eff) compared to 15 d-day in 2015.

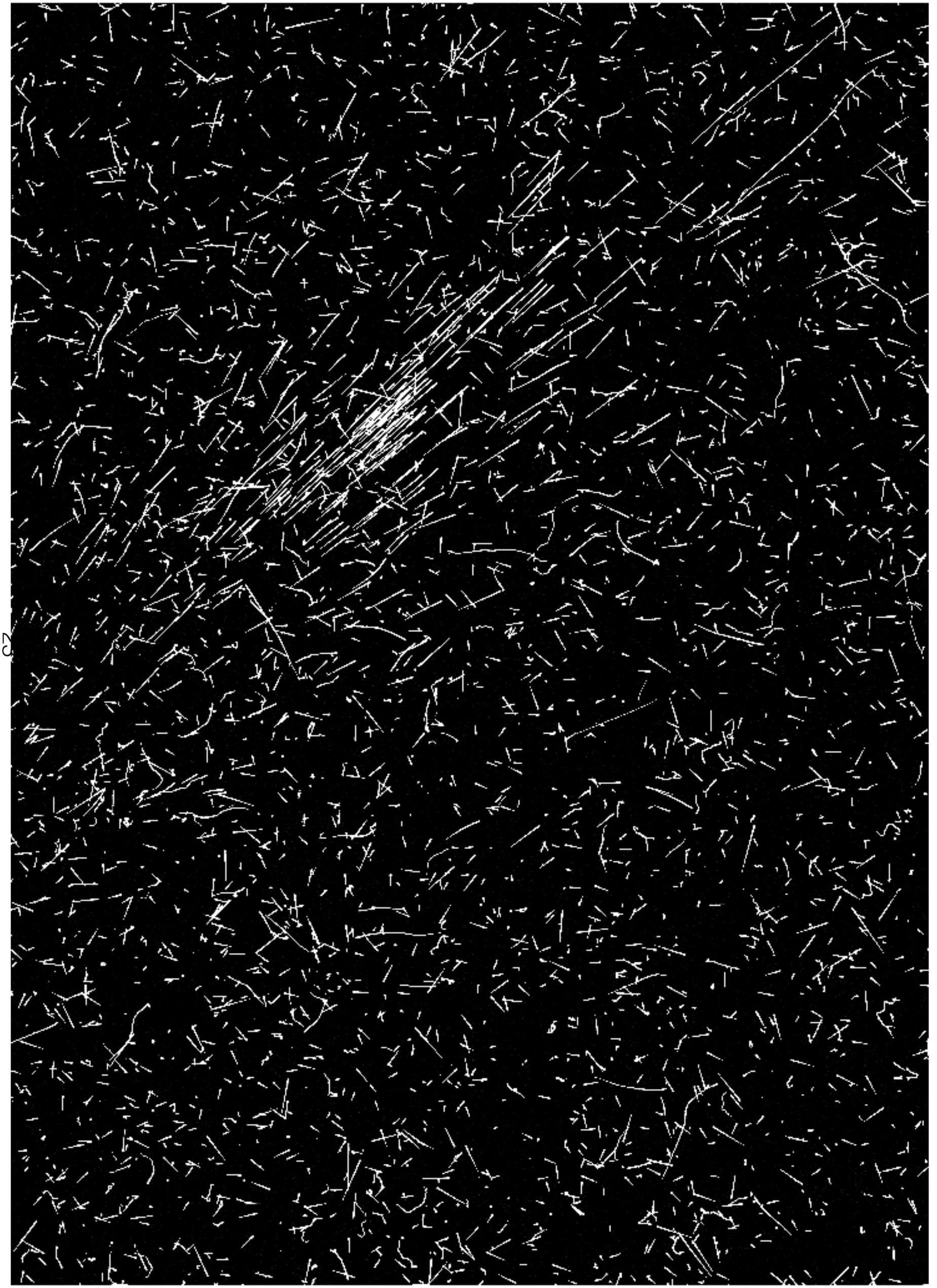
- Lower noise
- Lower background

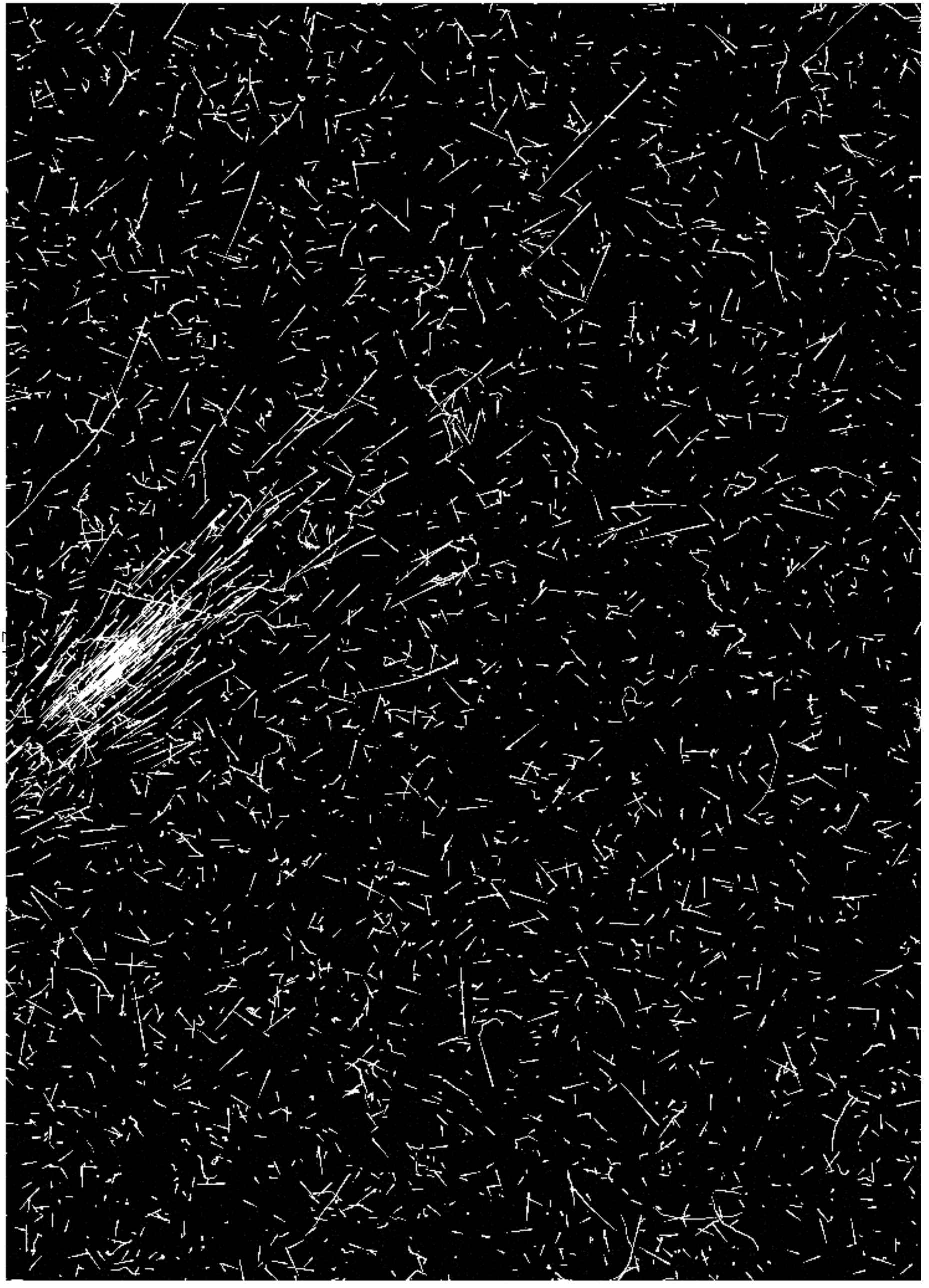
(we are not ready to show the results, but will try to share our excitement about this data)



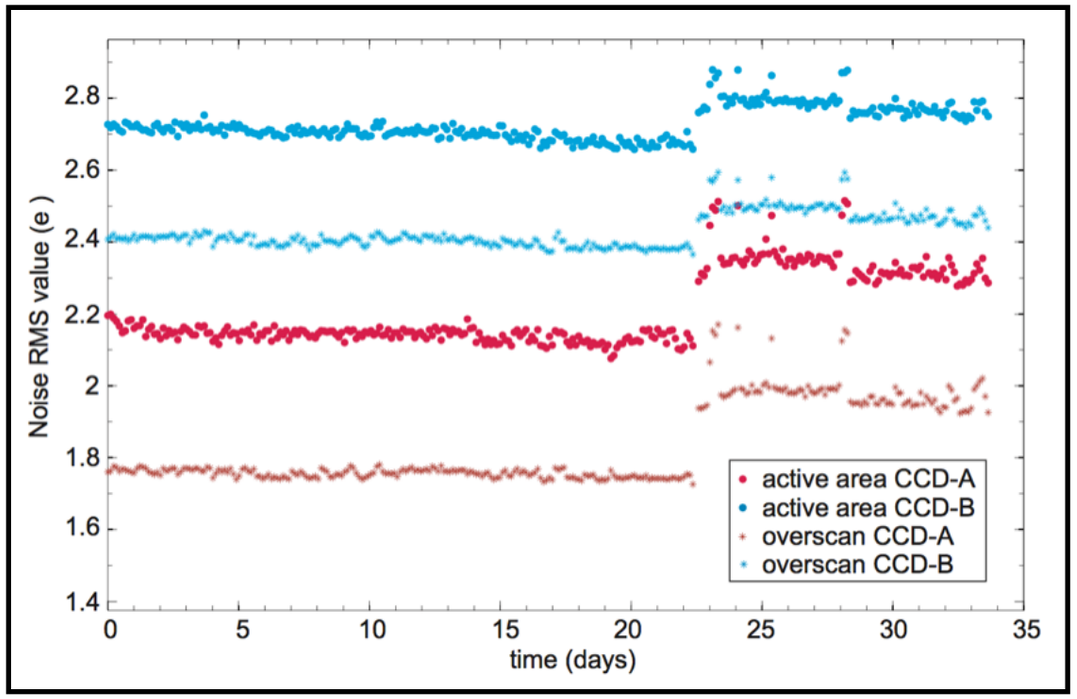








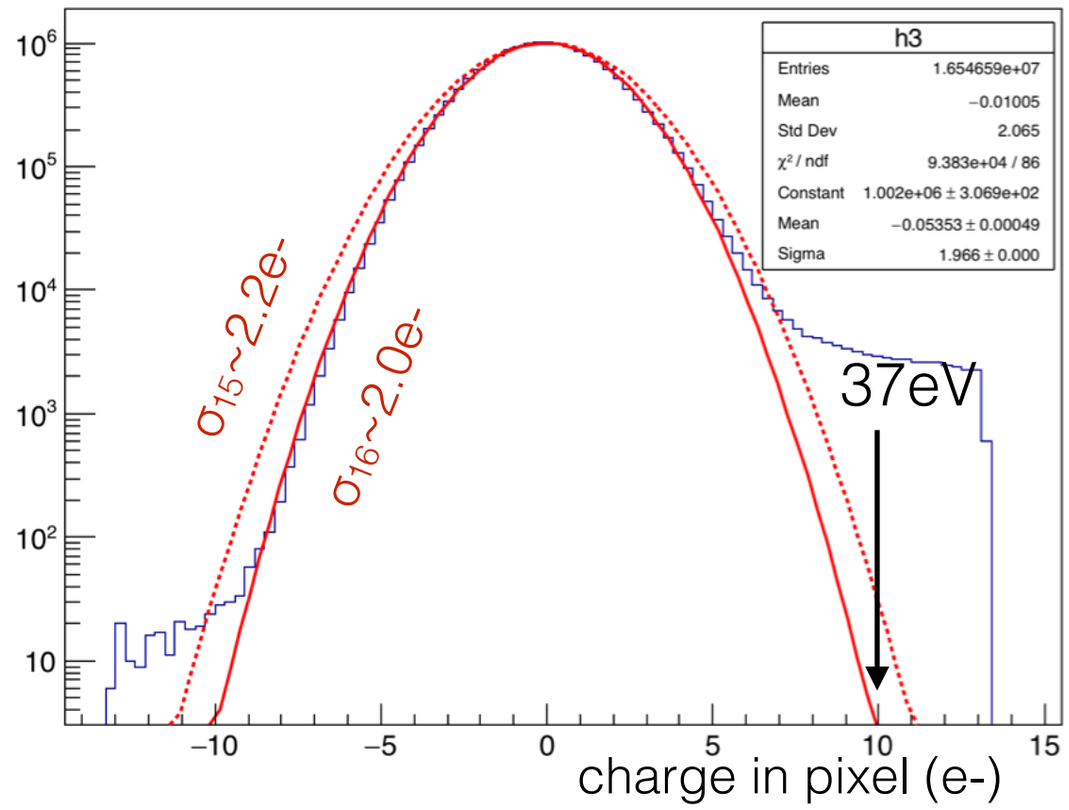
2015 engineering run

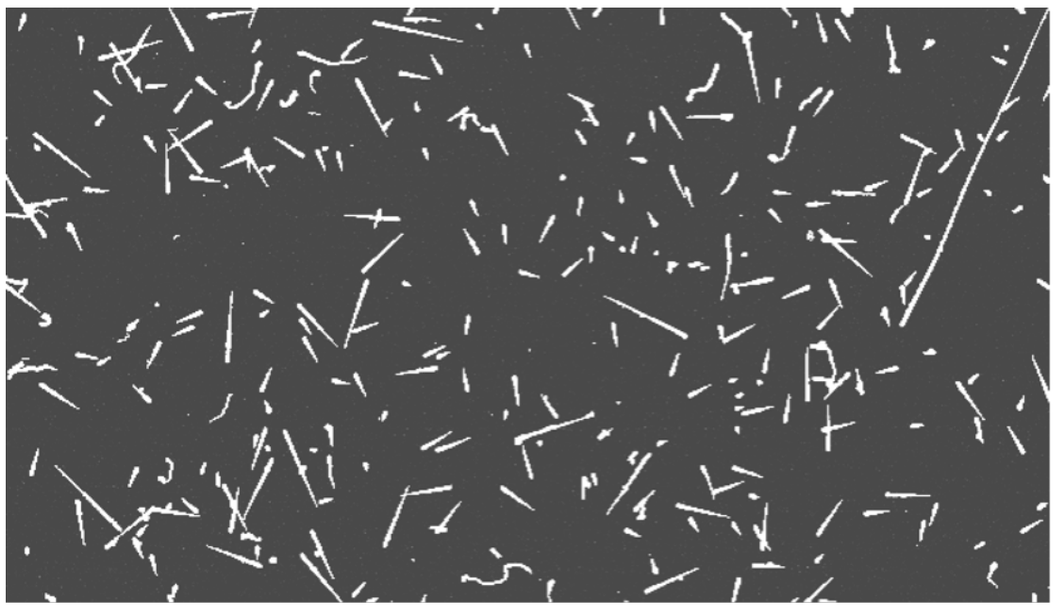


2015 we had a 2.2e- noise in the best CCD for the active area of the detector. This means that we had dark current, or IR photons hitting the detectors.

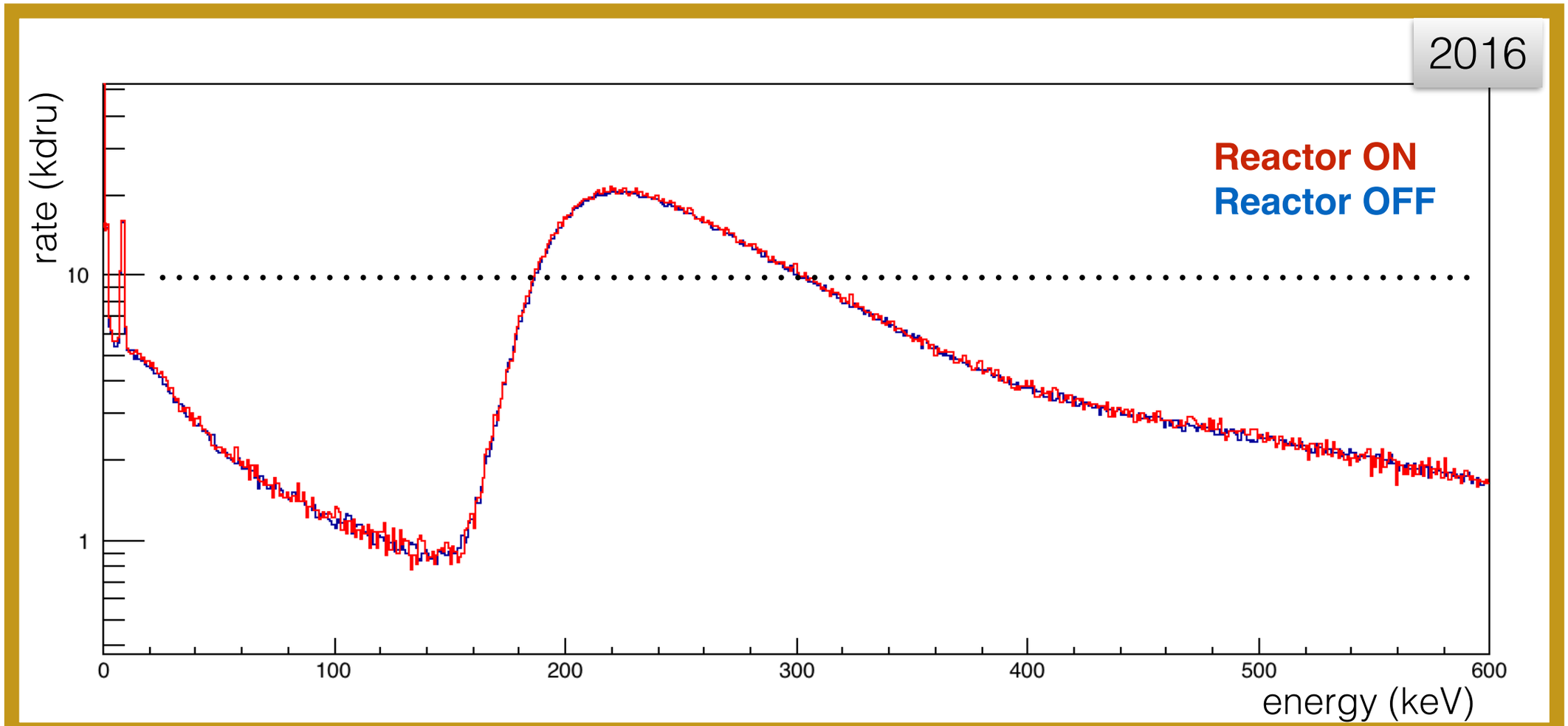
This 10% decrease in the noise is a big deal. It corresponds to ~10 increase in the rate of noise hits at ~35 eV.

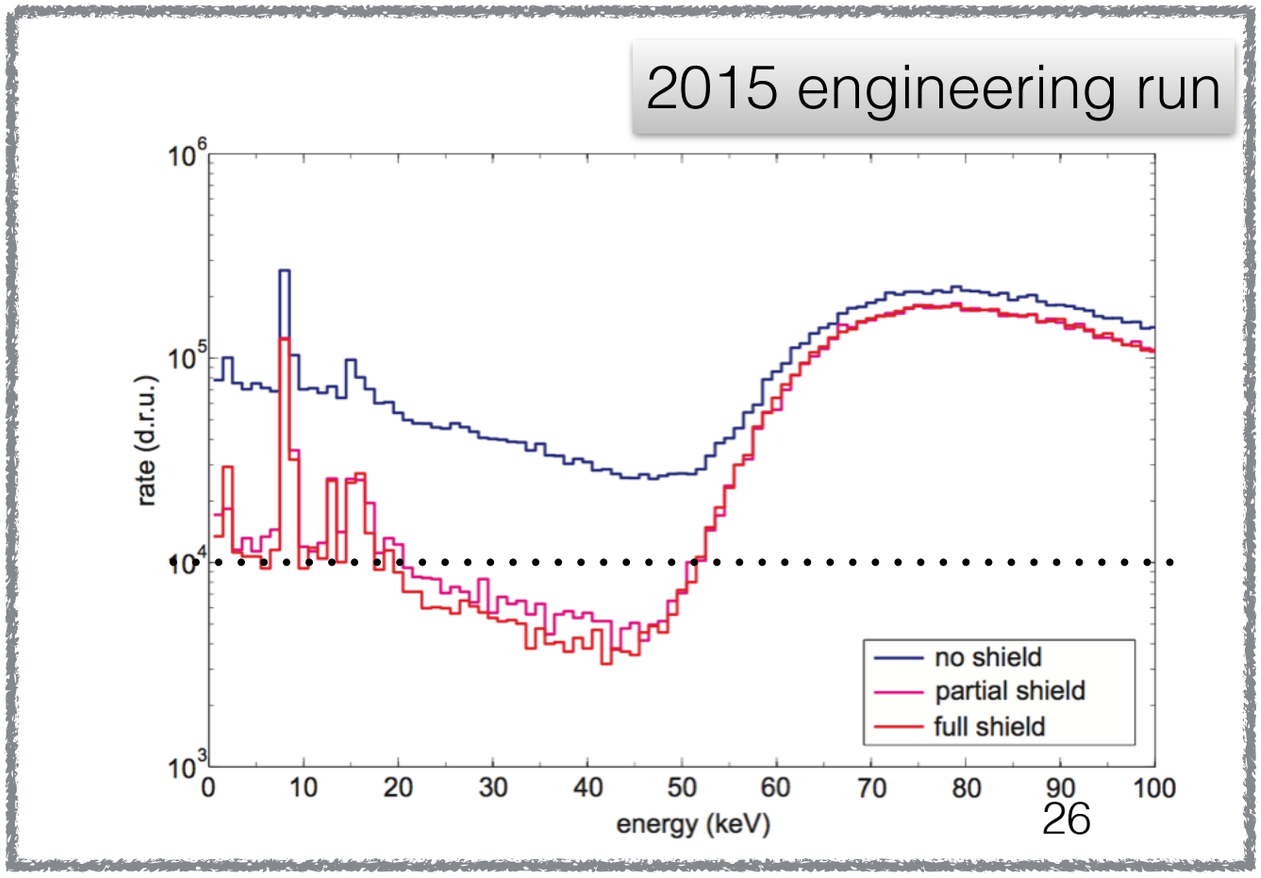
2016 image example





the histogram above also shows the hits from real tracks.





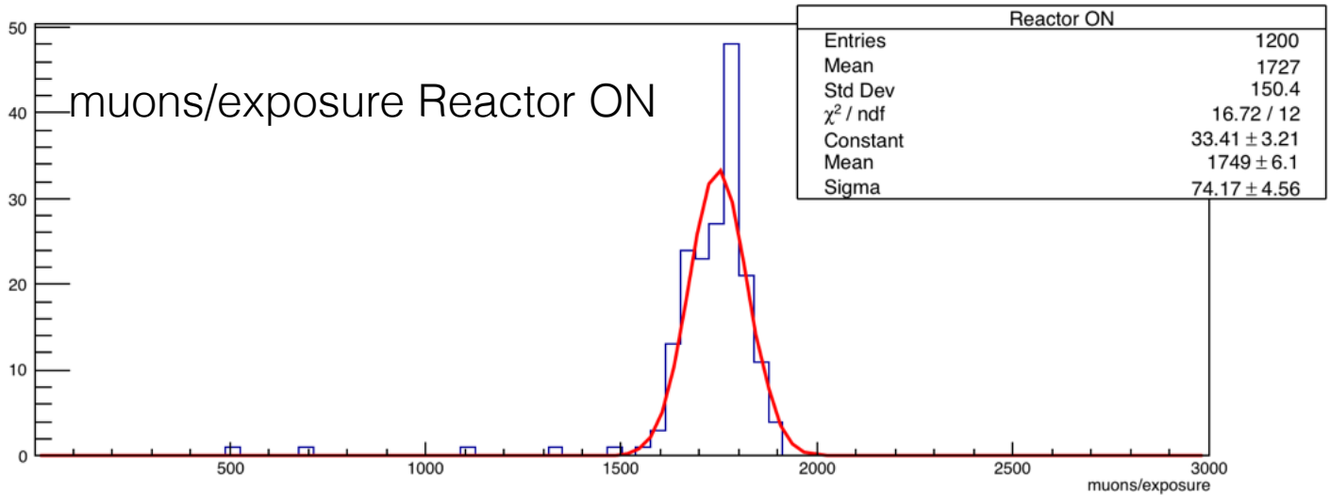
background improvement in the new configuration. We eliminated ceramic spacer (AIN) in the detector package. This eliminated all the ~15 keV lines produced by the U and Th decays. It also lowered the background significantly.

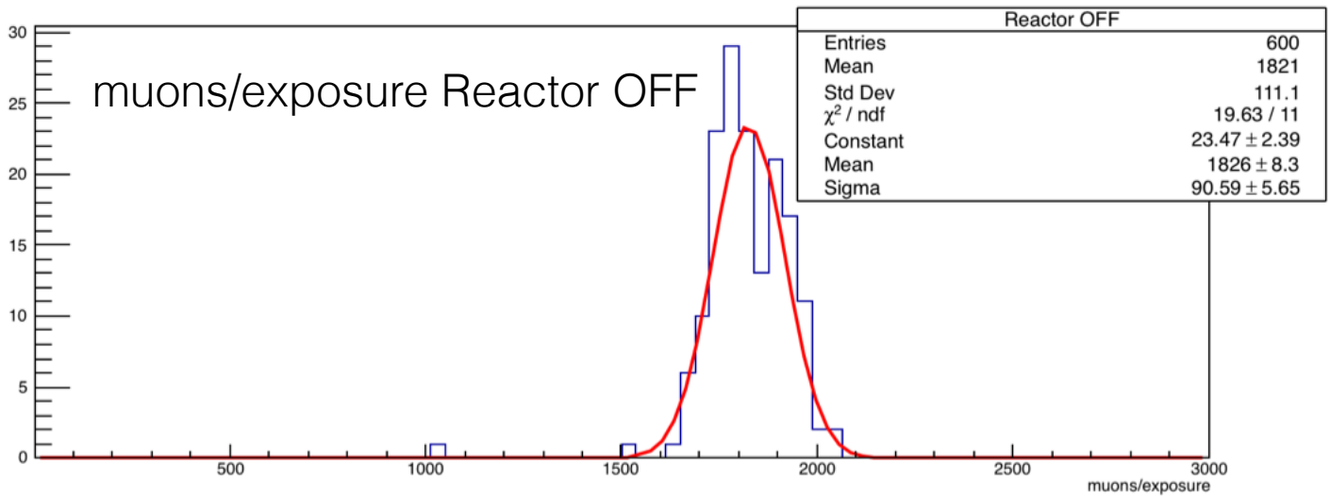
The bump from muon tracks is now at 250 keV because we went from 250um silicon to 675 um.

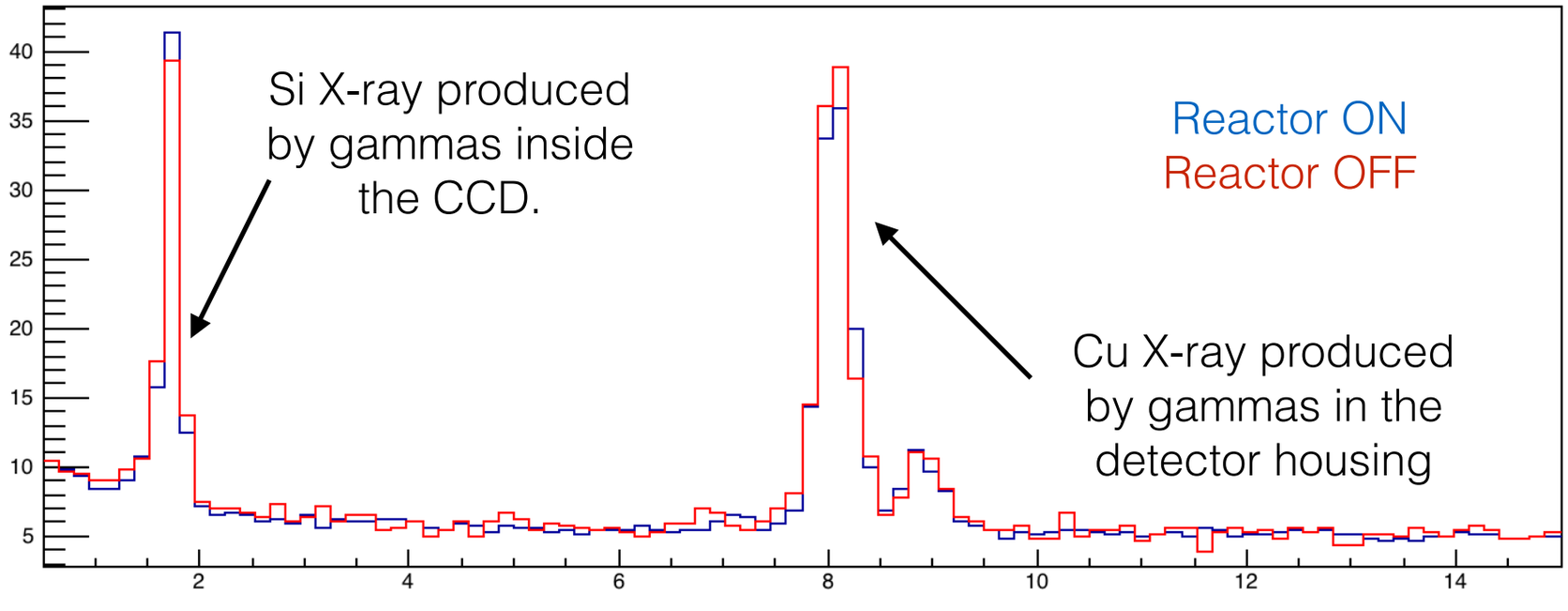
Comparing Reactor ON/ OFF backgrounds.

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.

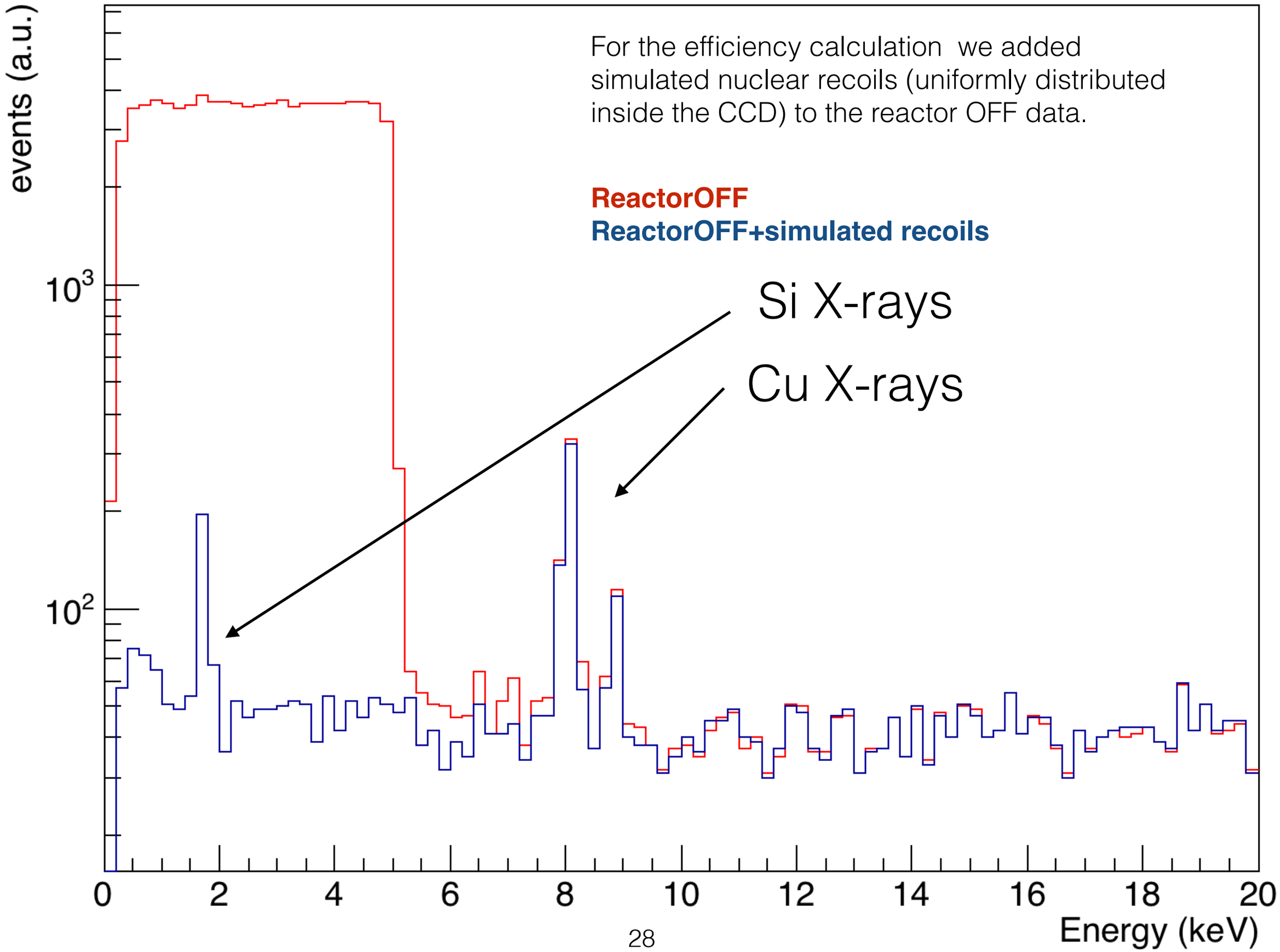


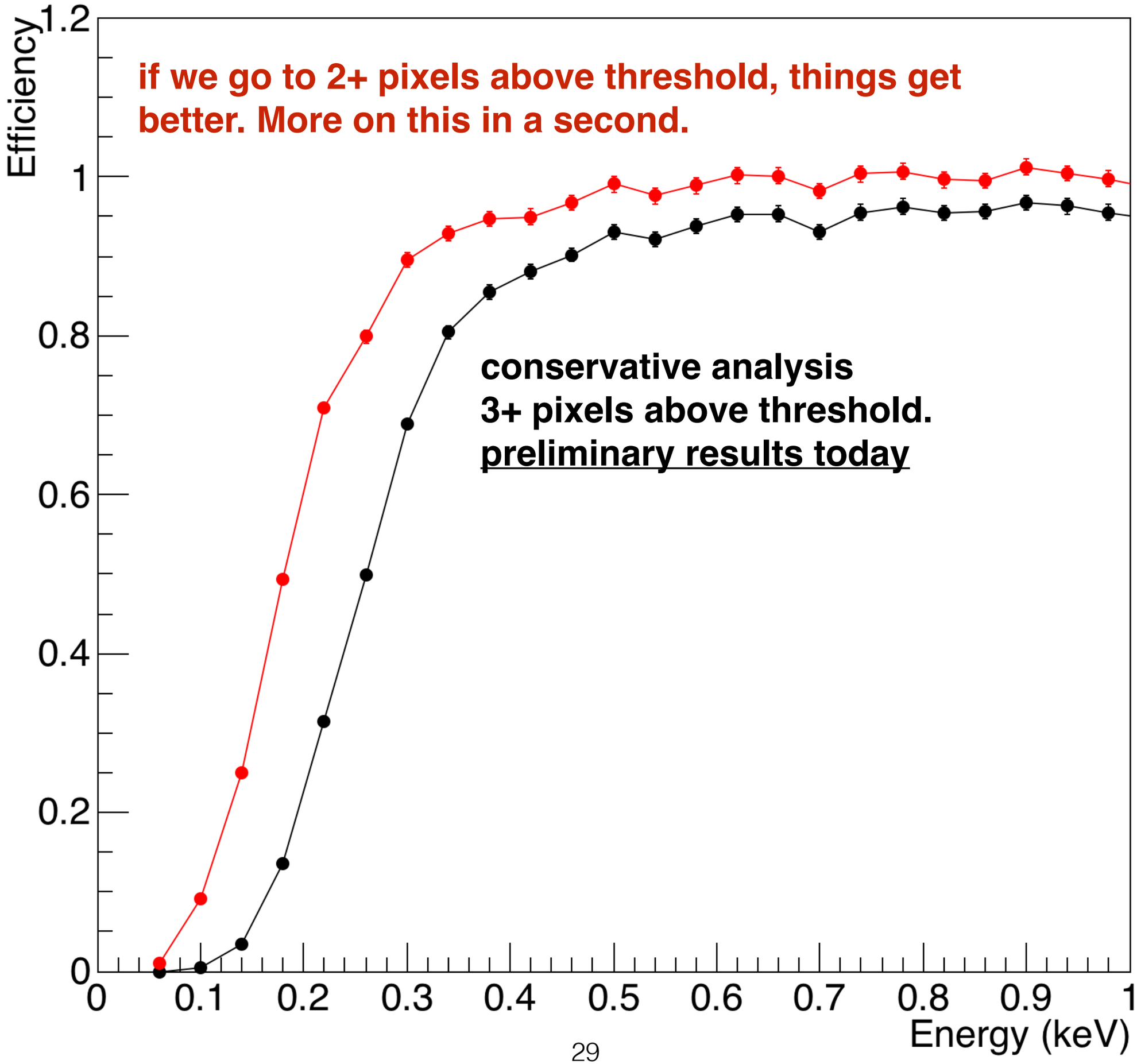




For the efficiency calculation we added simulated nuclear recoils (uniformly distributed inside the CCD) to the reactor OFF data.

ReactorOFF
ReactorOFF+simulated recoils




if we go to 2+ pixels above threshold, things get better. More on this in a second.
conservative analysis
3+ pixels above threshold.
preliminary results today
Efficiency
Energy (keV)
0
0.2
0.4
0.6
0.8
1
1.2
0.1
0.3
0.5
0.7
0.9

2016-2017 data

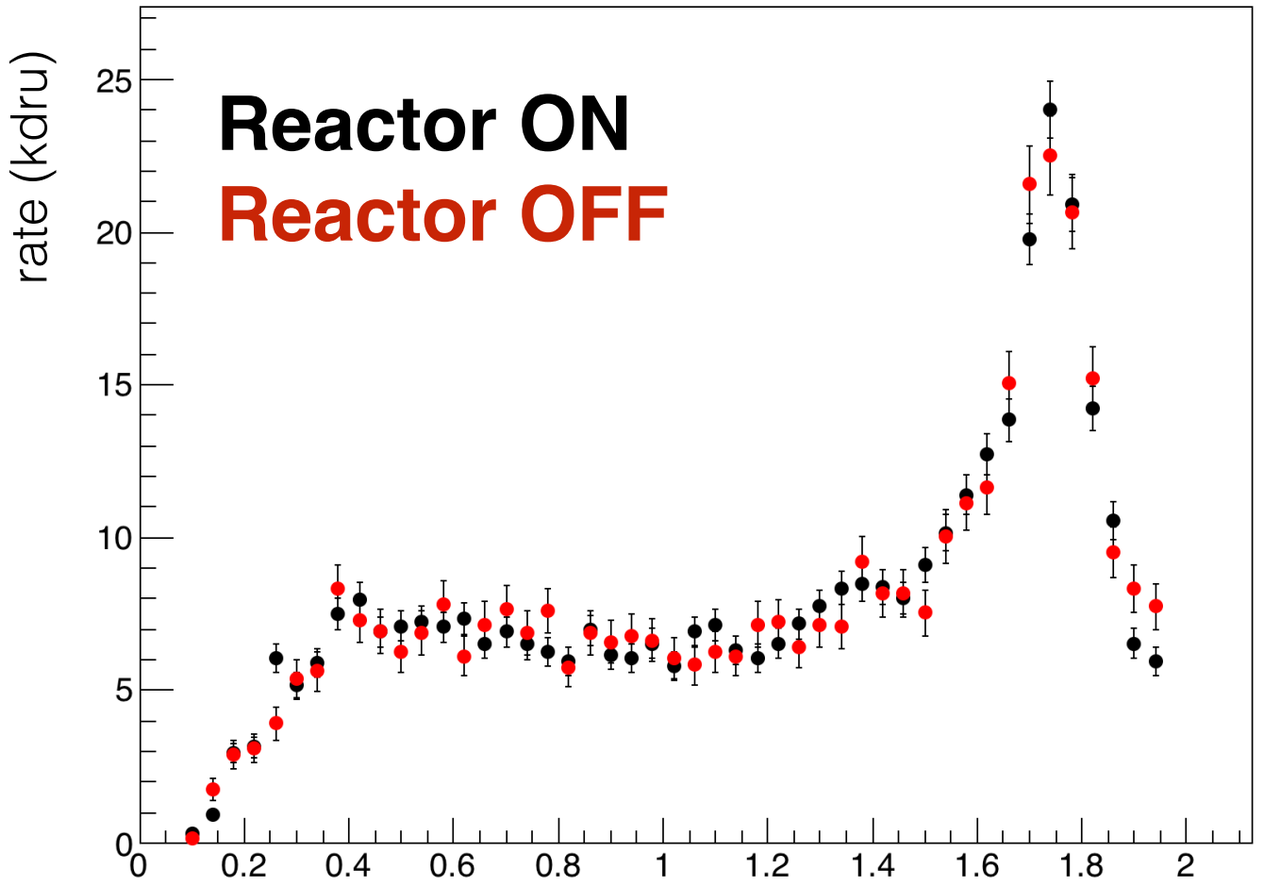
Preliminary

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

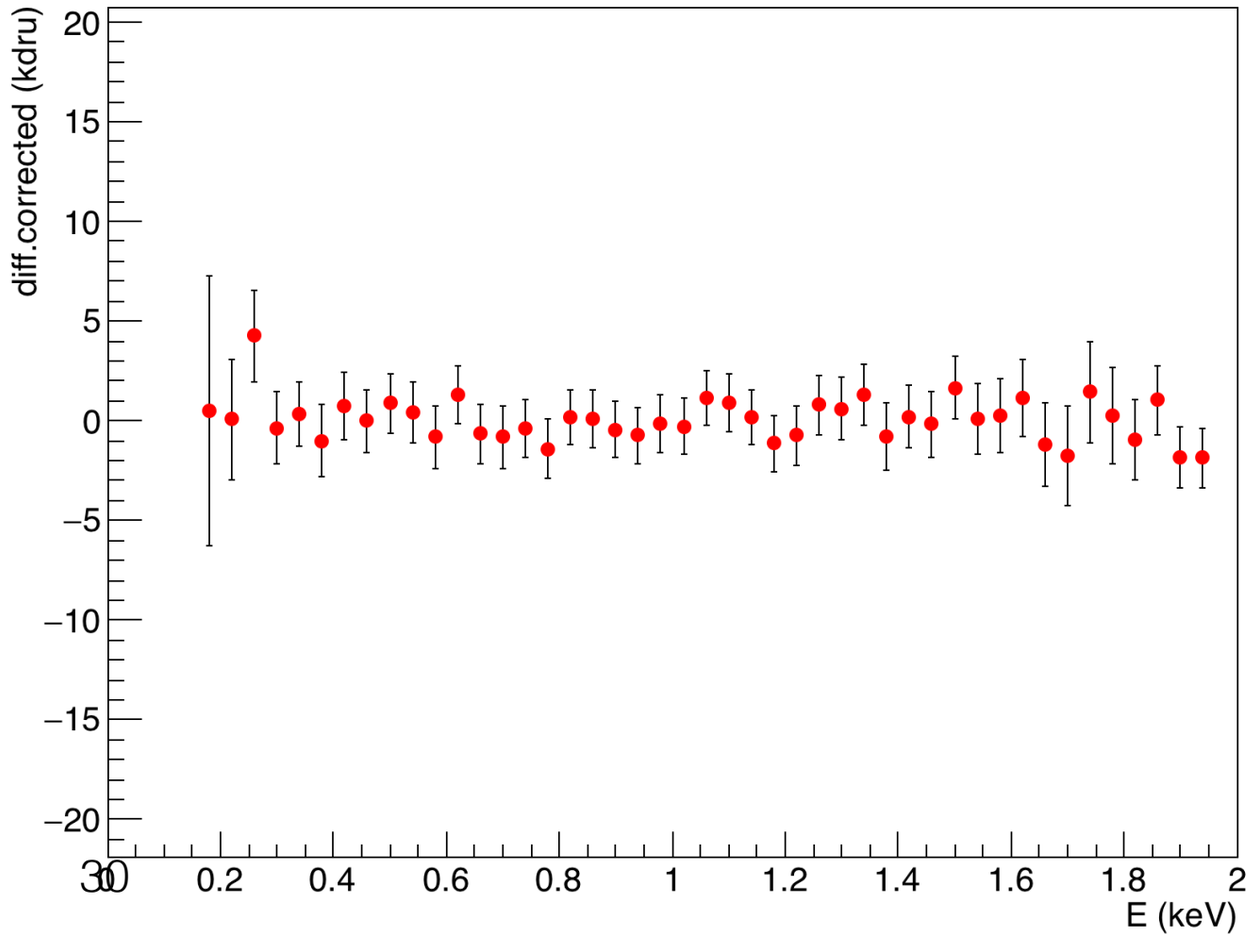
Exposure RON = 704 g-day

Exposure ROFF = 339 g-day

2+ pixels above threshold



Data collected between September 2016 and Feb2017.



2016-2017 data

Preliminary

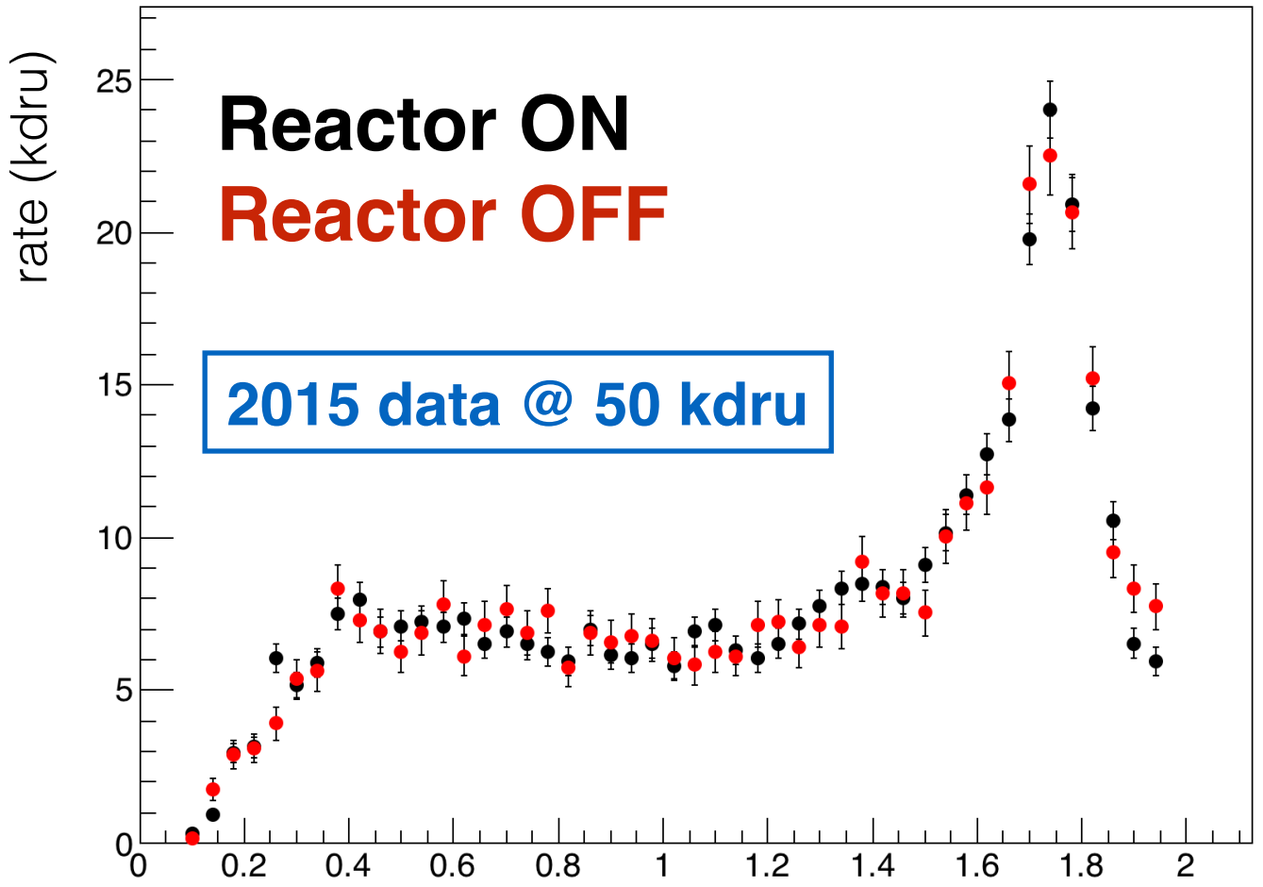
For this analysis we selected the detectors with less “cosmetic” defects.

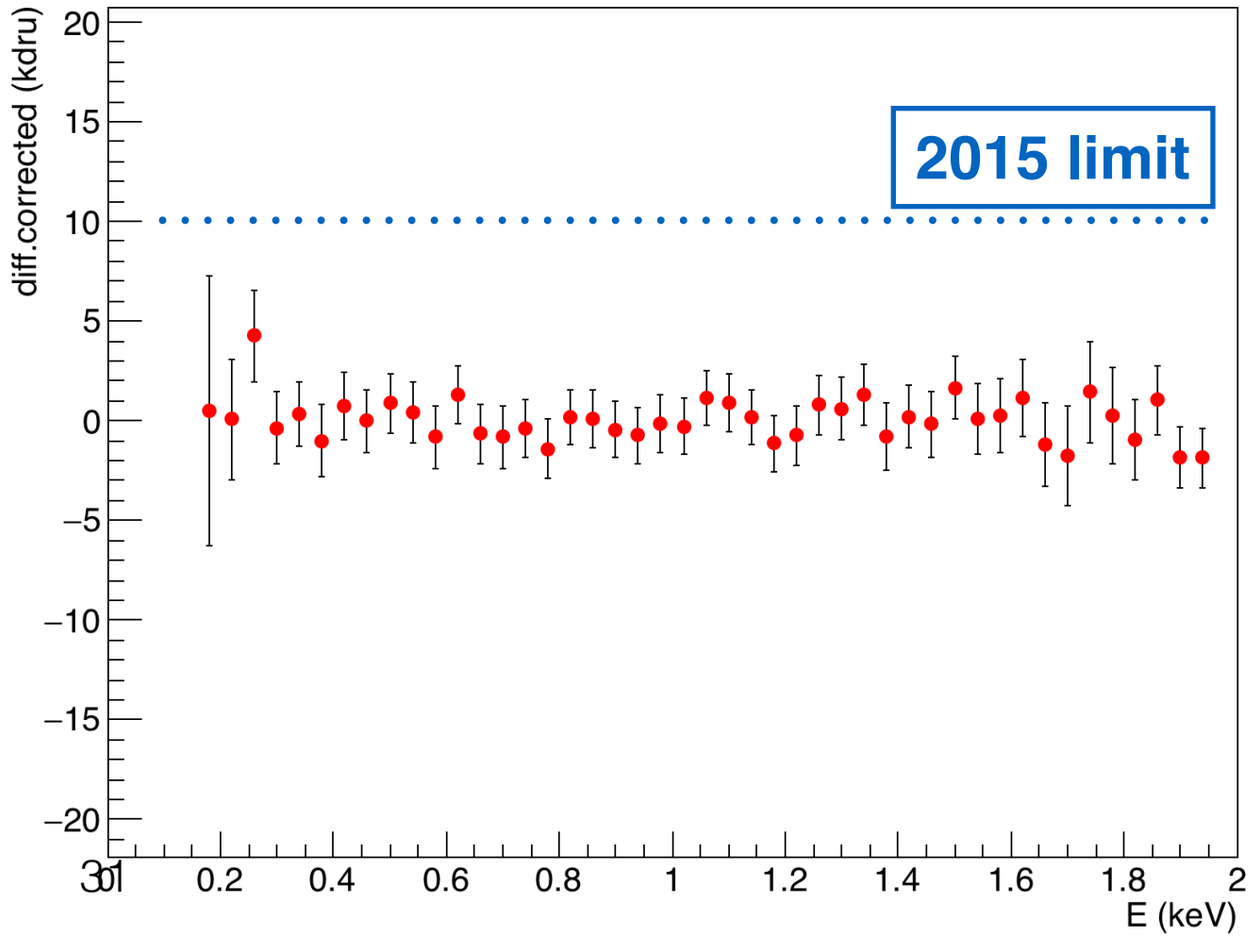
Exposure RON = 704 g-day
Exposure ROFF = 339 g-day

2+ pixels above threshold

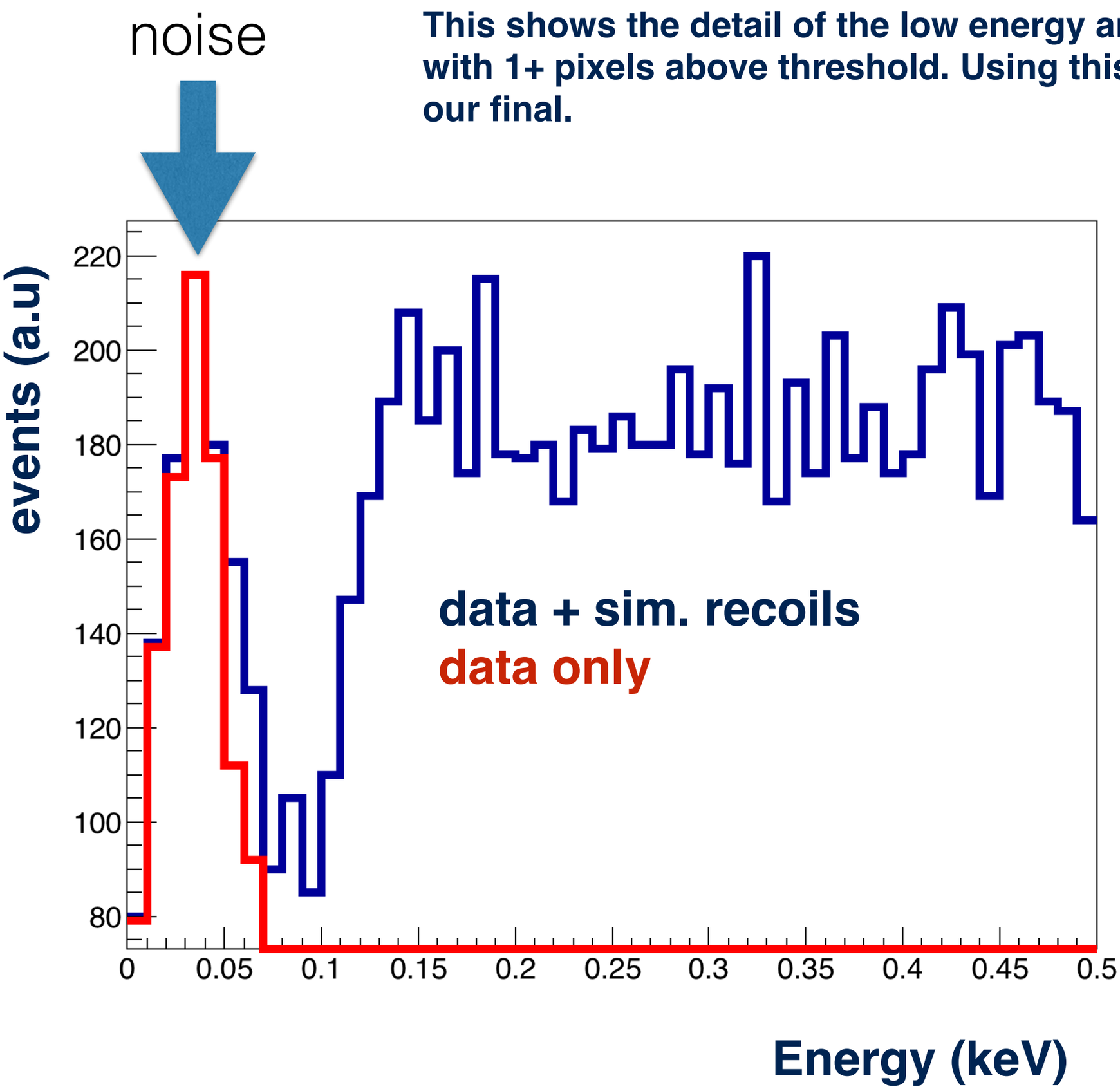
Data collected between September 2016 and Feb2017.

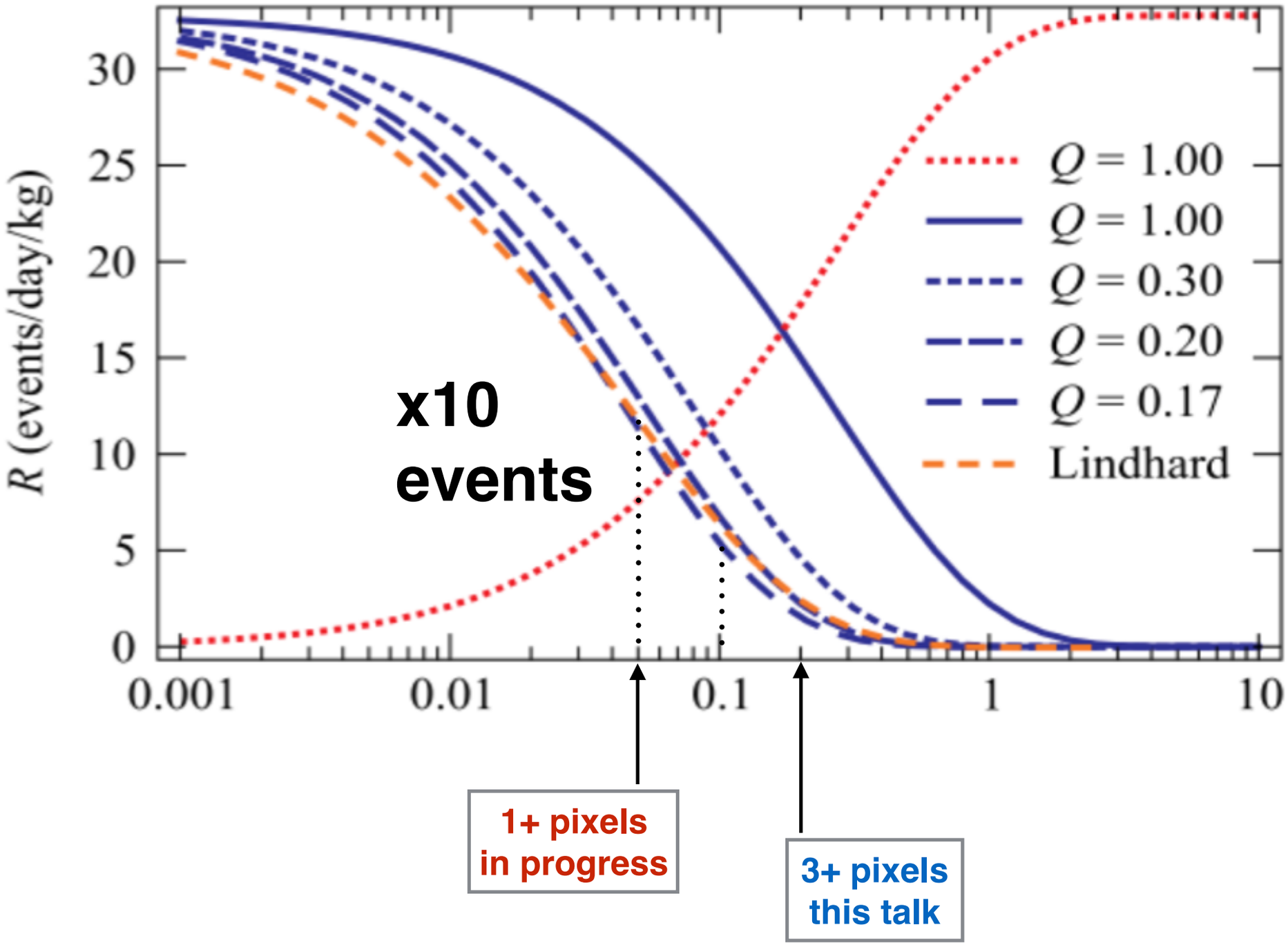
big improvement over engineering run 2015-2016





This shows the detail of the low energy analysis with 1+ pixels above threshold. Using this events is our final.



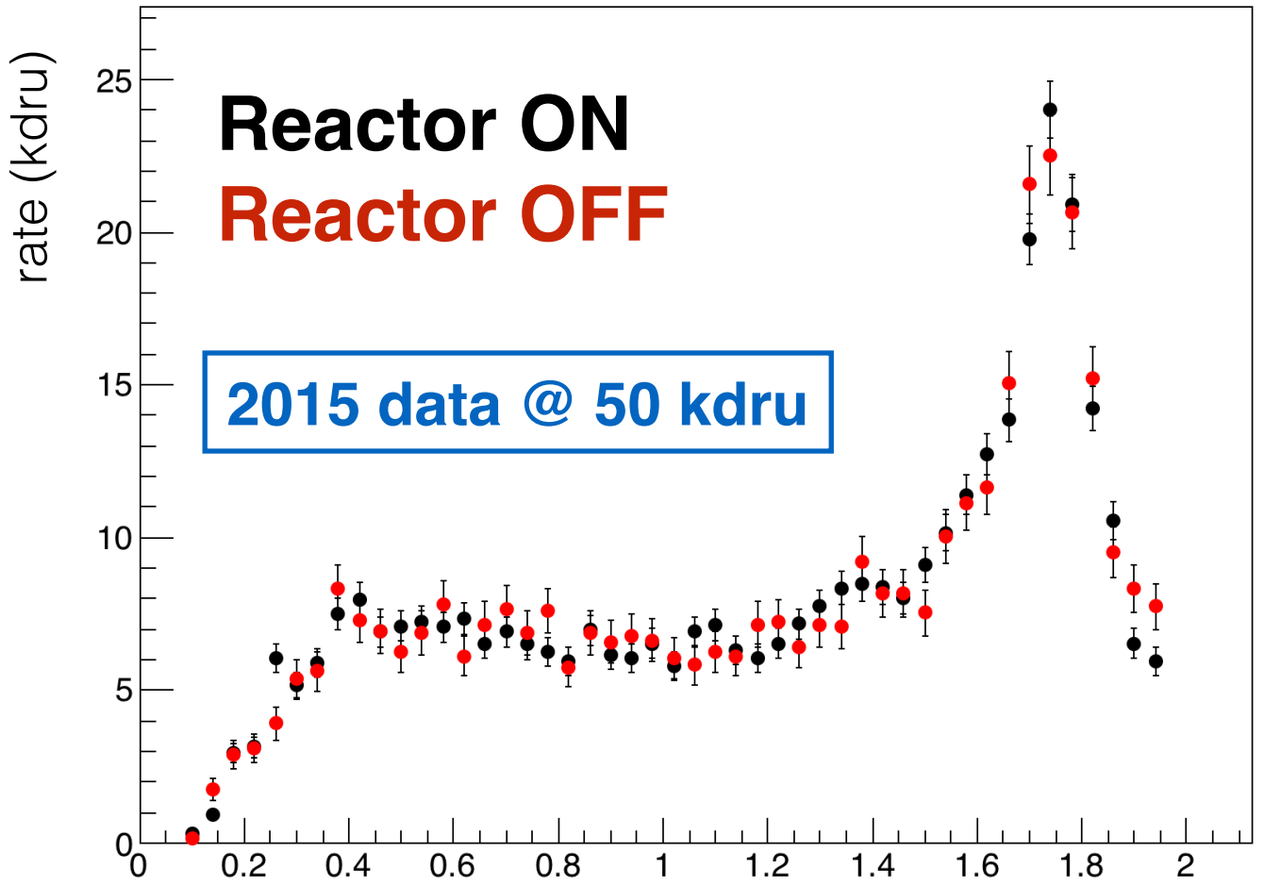

R (events/day/kg)
30
25
20
15
10
5
0
0.001
0.01
0.1
1
10
x10
events
Q = 1.00
Q = 1.00
Q = 0.30
Q = 0.20
Q = 0.17
Lindhard
1+ pixels
in progress
3+ pixels
this talk

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

2+ pixels above threshold

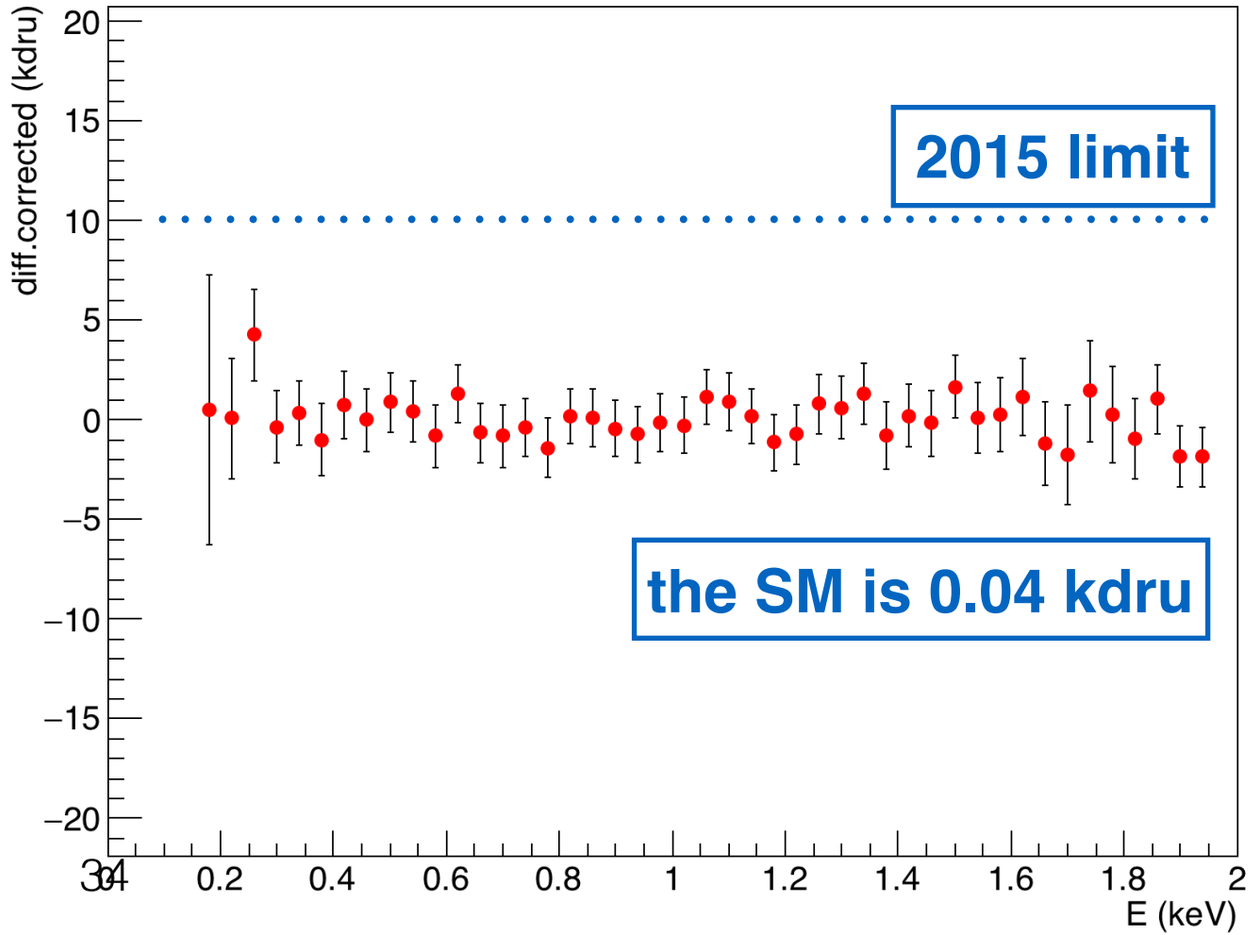


Data collected between September 2016 and Feb2017.

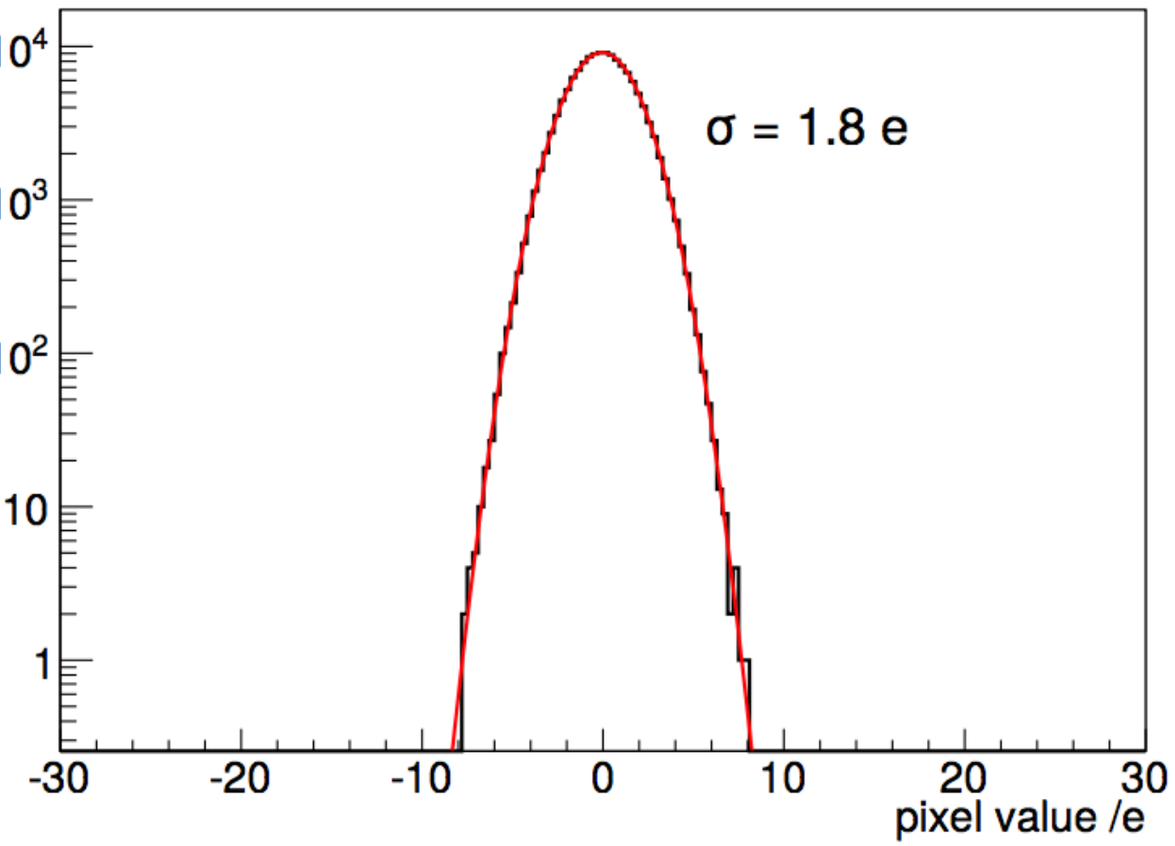
SM expectations : 0.04 kdru @ 0.22 keV
here uncertainty is 1.8 kdru @ 0.22 keV bin

using 1+ pixels above threshold, efficiency starts at ~60eV, SM signal goes up by ~10.

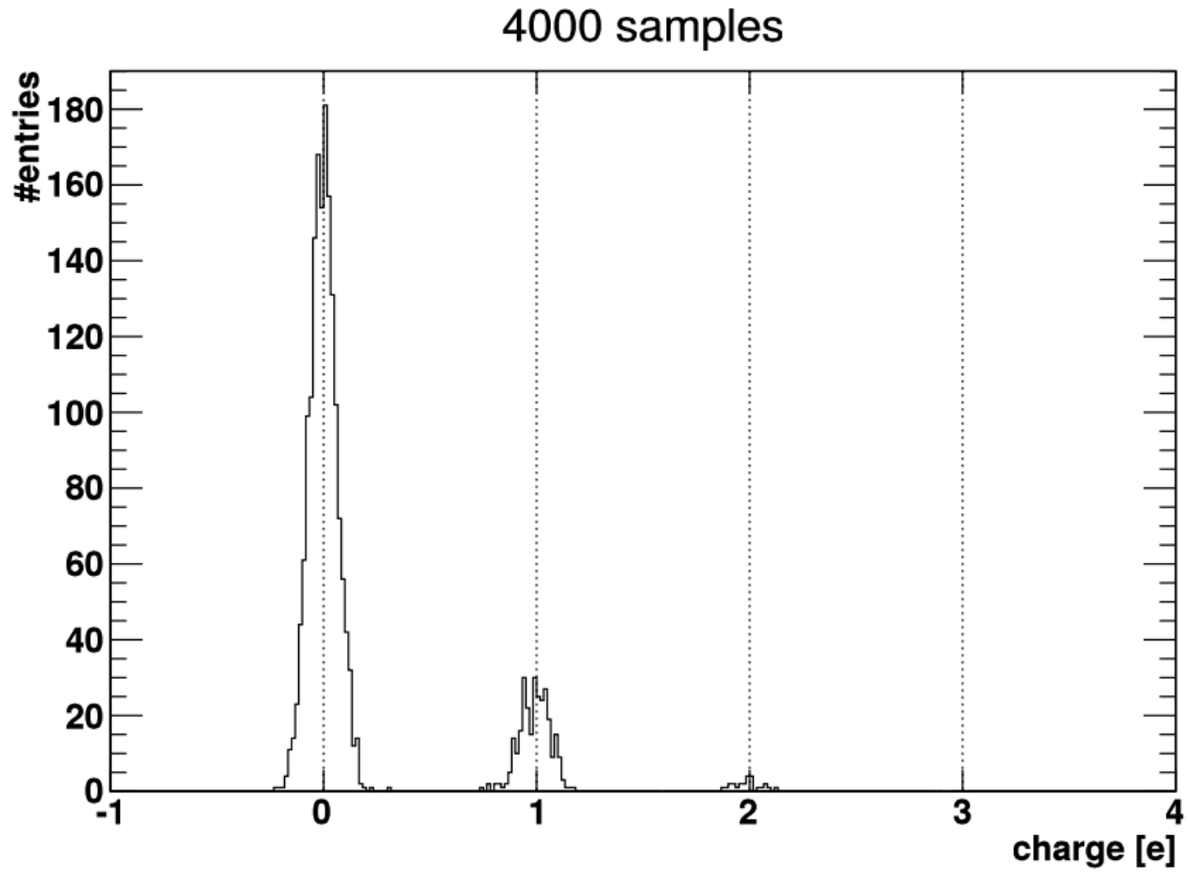
We plan to have 3 times the data after the shutdown in early 2019. SM within reach!



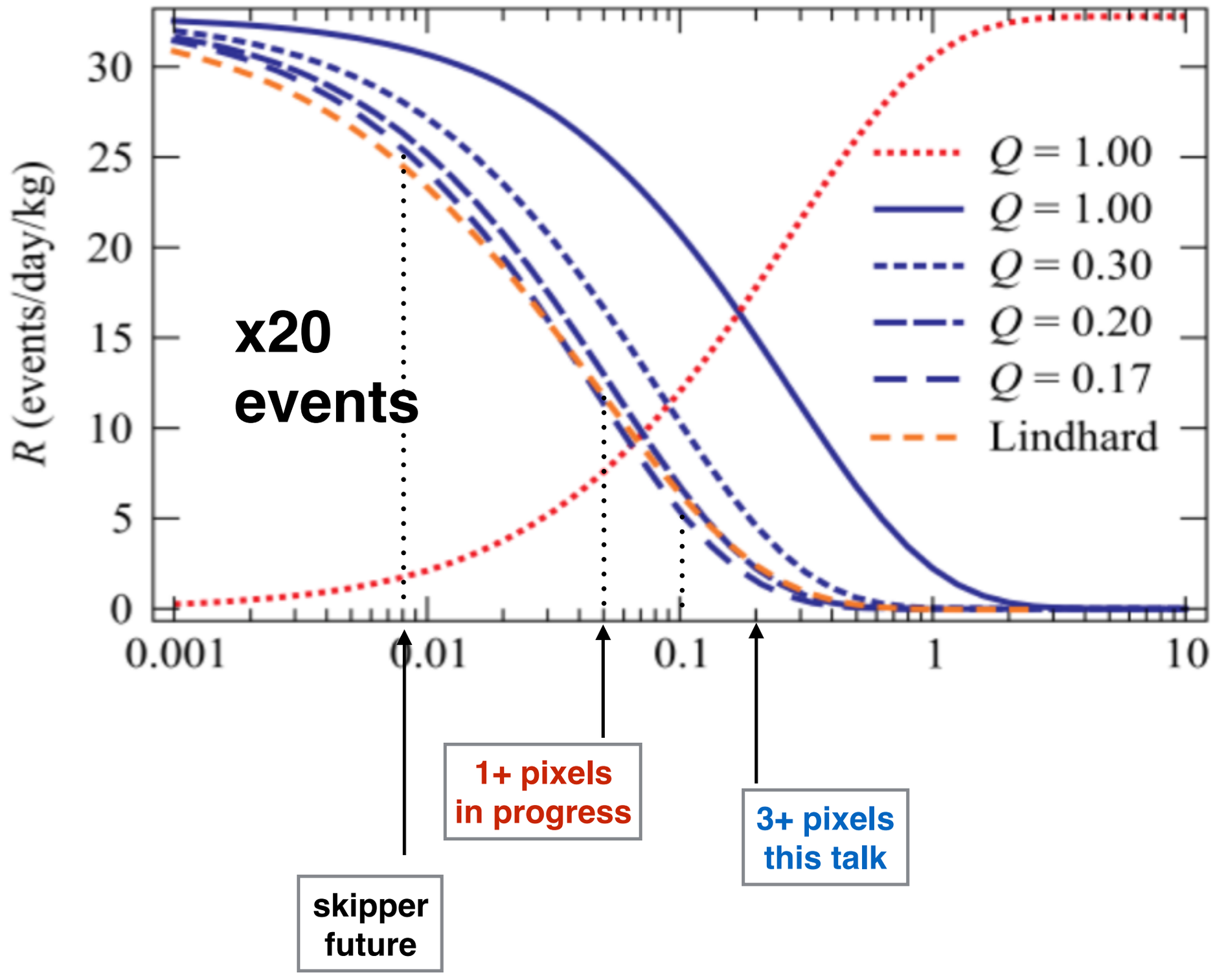
CONNIE now



skipper CCD



New CCD technology demonstrated this summer 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
x20
events
skipper
future
1+ pixels
in progress
3+ pixels
this talk

Conclusion

- Preliminary analysis of high energy events (200 eV) show tremendous improvement over engineering run.

- Current plan is to run for around two more reactor shutdowns with higher operations efficiency to reach SM.

- Longer term, we are considering lowering the threshold a factor of 10 with the demonstrated Skipper CCD.

- Looking forward to join COHERENT in the fun!

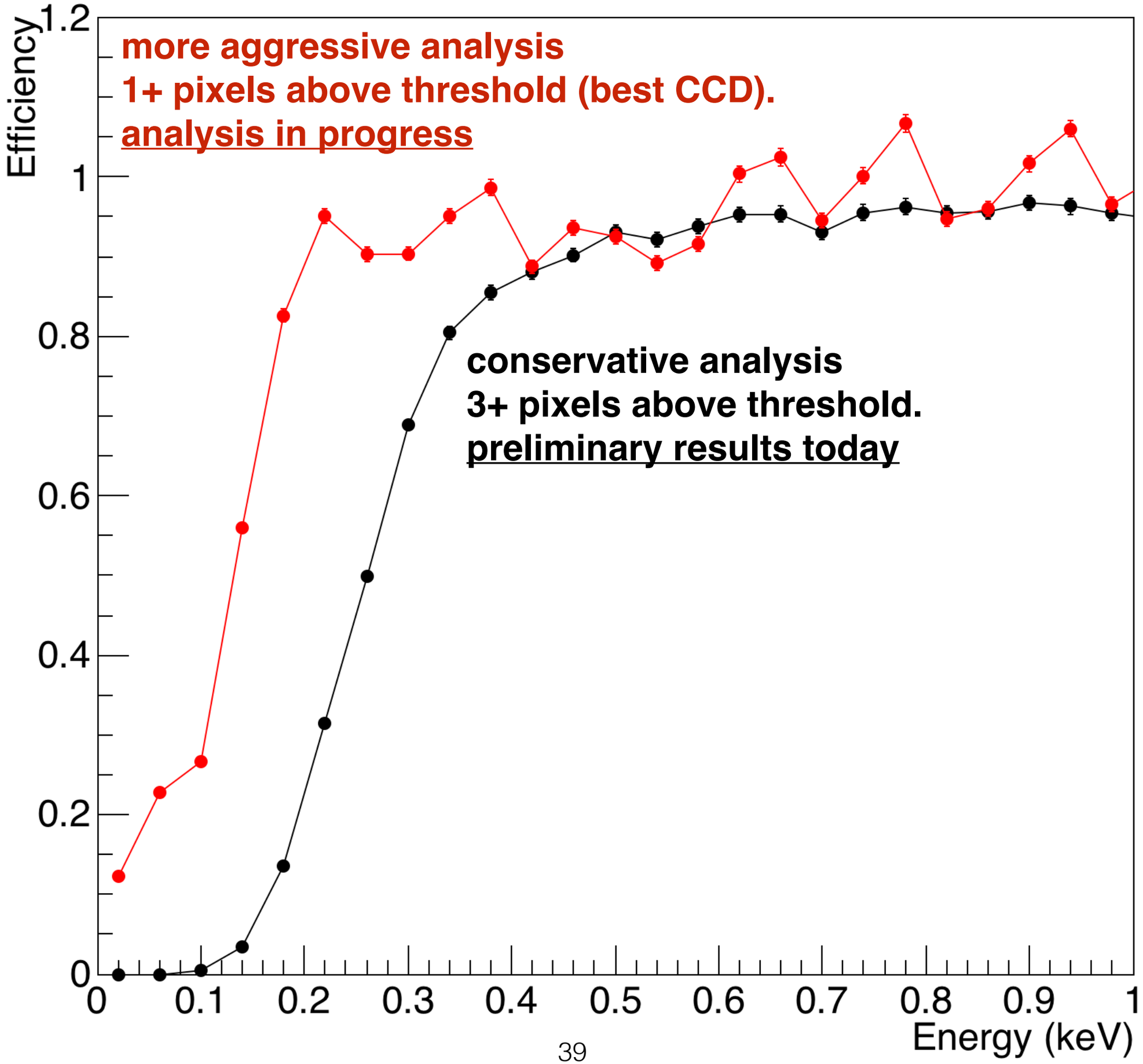

more aggressive analysis
1+ pixels above threshold (best CCD).
analysis in progress
conservative analysis
3+ pixels above threshold.
preliminary results today
Efficiency
Energy (keV)
0
0.2
0.4
0.6
0.8
1
1.2
0.1
0.3
0.5
0.7
0.9

Image from data

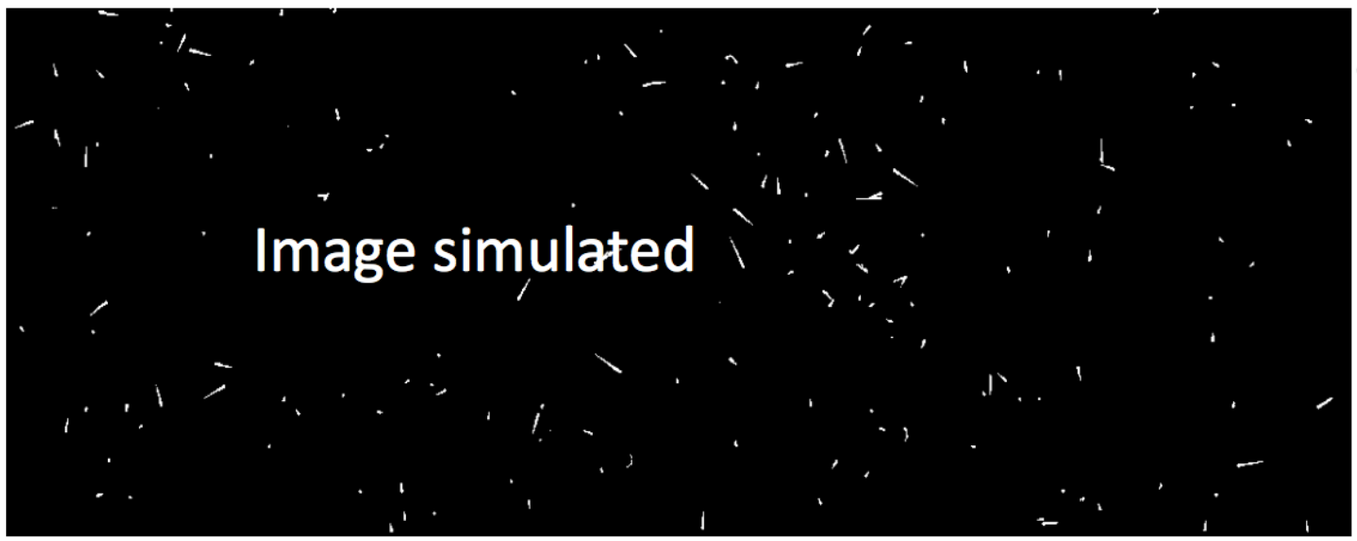
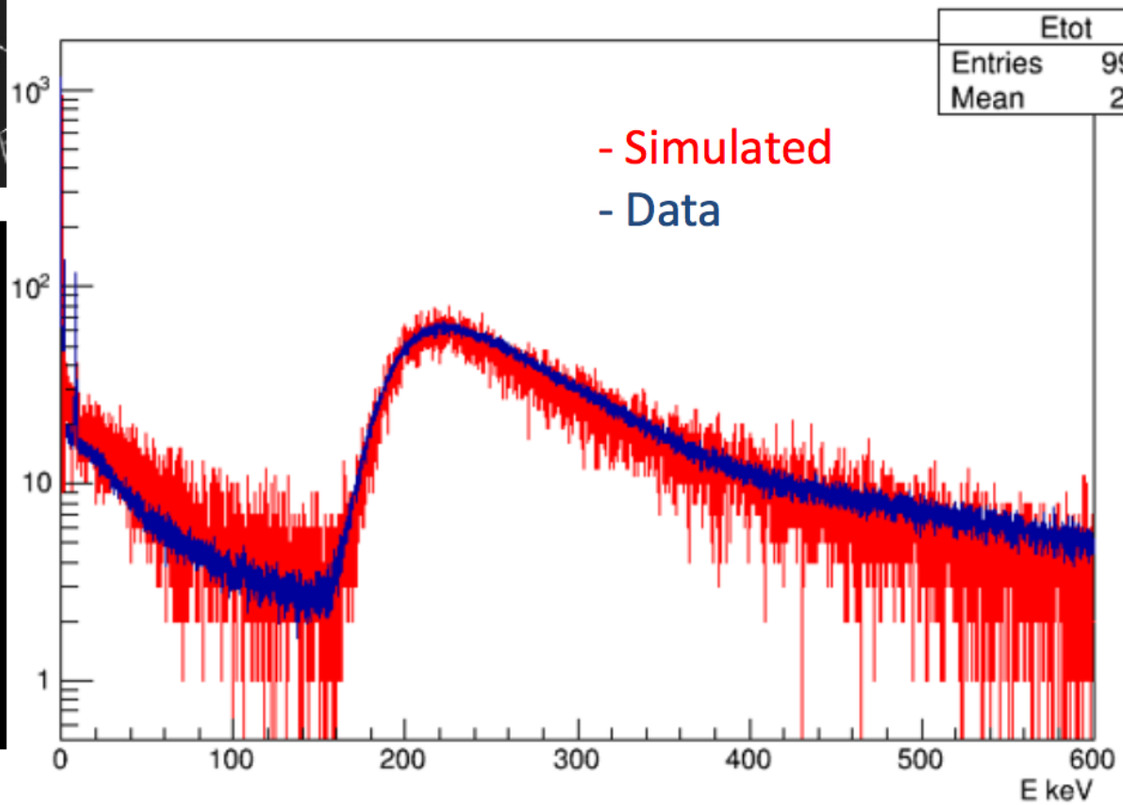


Image simulated


Etot
Entries 99107
Mean 251.6
- Simulated
- Data
10^3
10^2
10
1
0
100
200
300
400
500
600
E keV