CCD sensors running at surface: CONNIE experiment and Skipper CCD at FNAL

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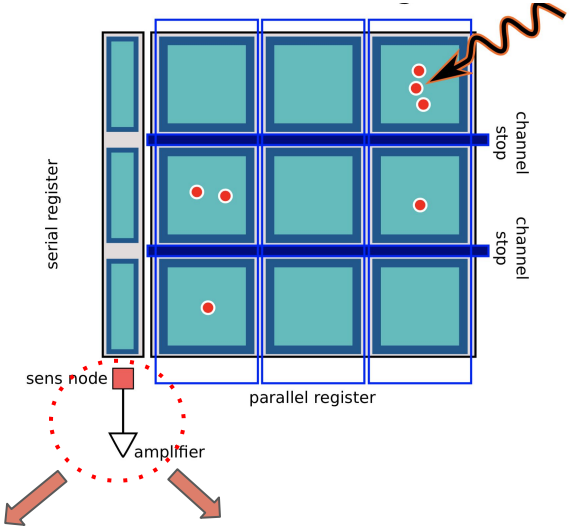
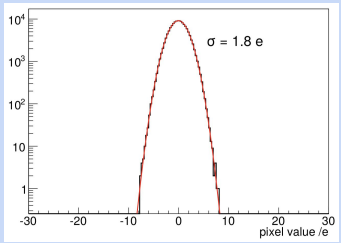
I will present two different CCD experiment running at the surface

- Several million pixels of (15 μm by 15 μm each) made of Silicon
- 675 μm thick.
- **Good spatial information**
- Slow readout: sequential readout of pixels
- **No timing information**



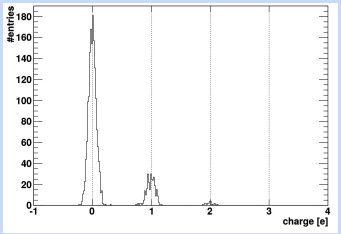
CONNIE experiment

- Standard CCD output.
- Readout noise of 1.8e-/pixel



Skipper CCD running @ Fermilab

- Non destructive readout stage
- Single electron counting



CONNIE detector

- **C**oherent **N**eutrino **N**ucleus **I**nteraction **E**xperiment (CONNIE)
- 30 m from the Angra 2 reactor core, Rio de Janeiro, Brazil.

Argentina
Centro Atómico Bariloche
Universidad de Buenos Aires
Universidad del Sur / CONICET
ICAS / ICIFI / UNSAM

Brazil
Centro Brasileiro de Pesquisas Físicas
Universidade Federal do Rio de Janeiro
CEFET-Angra

Mexico
Universidad Nacional Autónoma de México

Paraguay
Universidad Nacional de Asunción

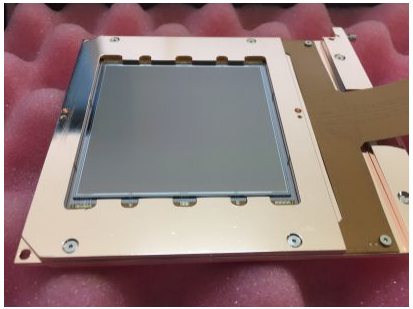
Switzerland
University of Zurich

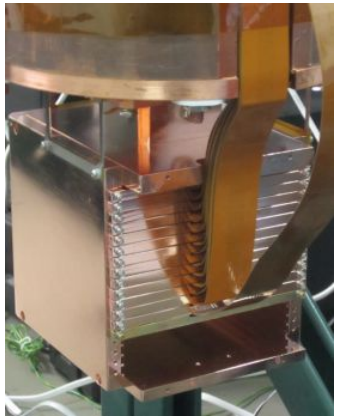
USA
Fermilab National Laboratory

CONNIE detector

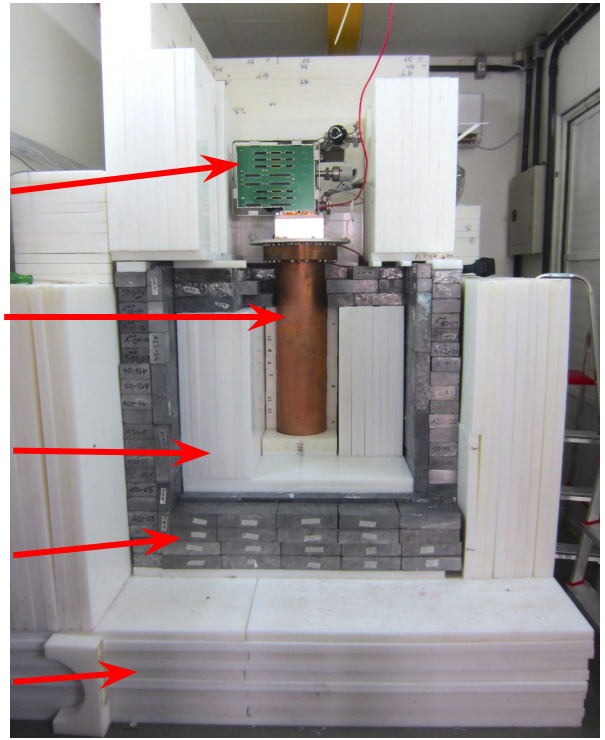
- Installed in 2014 and upgraded in 2016

4k x 4k pixel
15x15μm
675μm thick



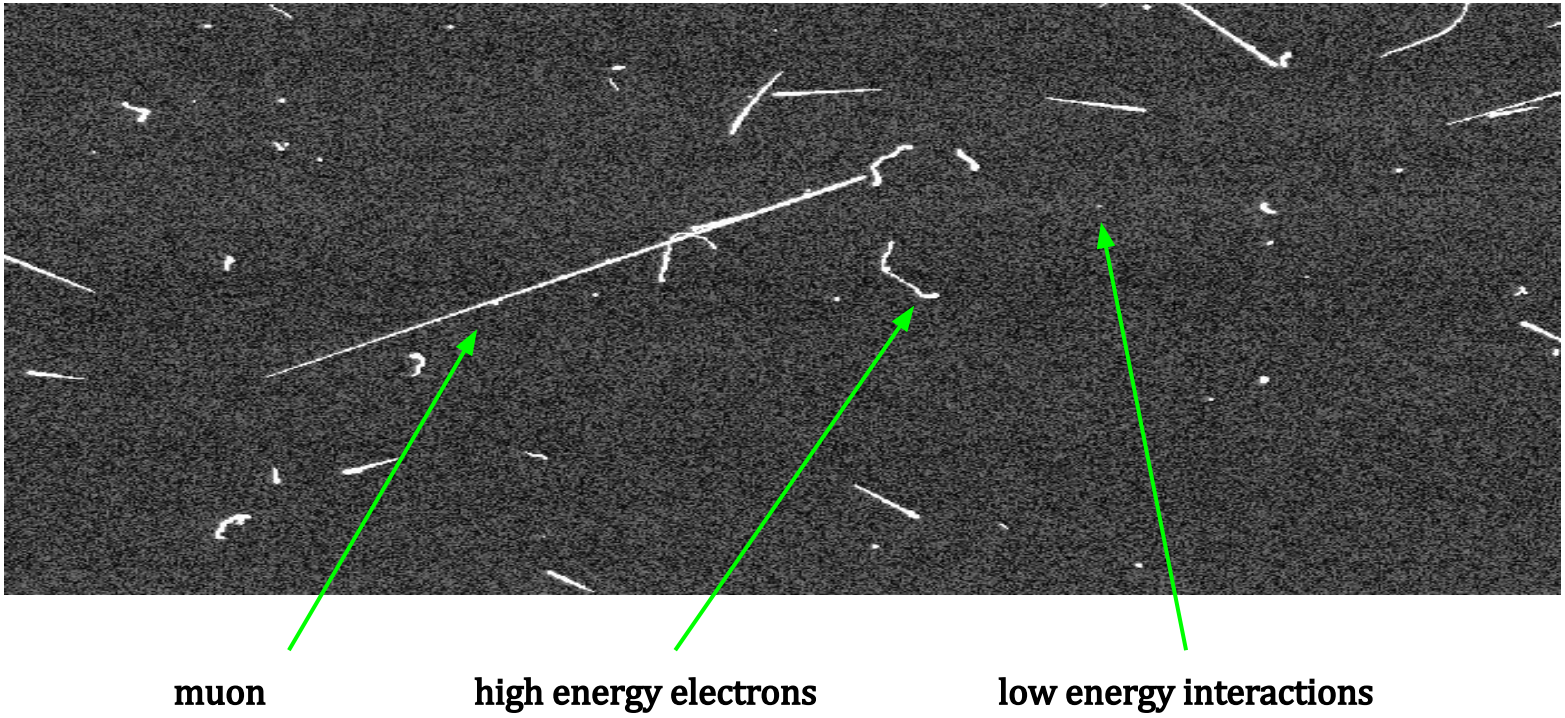


CCD stack in a copper box



arXiv:1906.02200

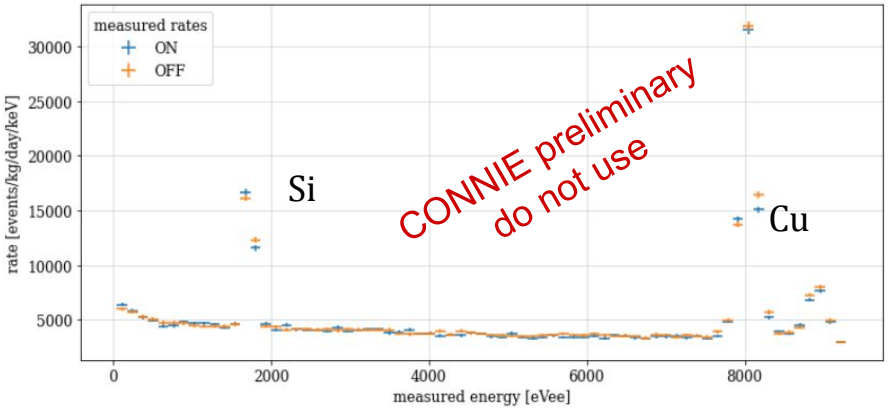
CONNIE output data



CONNIE 2019 data (all preliminary)

Data specs:

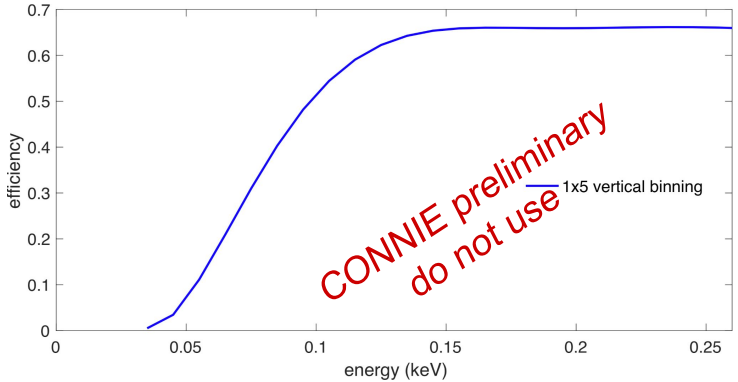
- calibration using X-ray fluorescence lines
- 50 grams of active mass
- exposure:
  reactor OFF 1.35 kg·day
  reactor ON 1.52 kg·day
- plot not normalized by efficiency



Efficiency:

to evaluate the proportion of events passing the selection cuts there are several things to consider:

- extraction efficiency
- acceptance
- energy resolution
- quenching factor (arXiv:2001.06503)



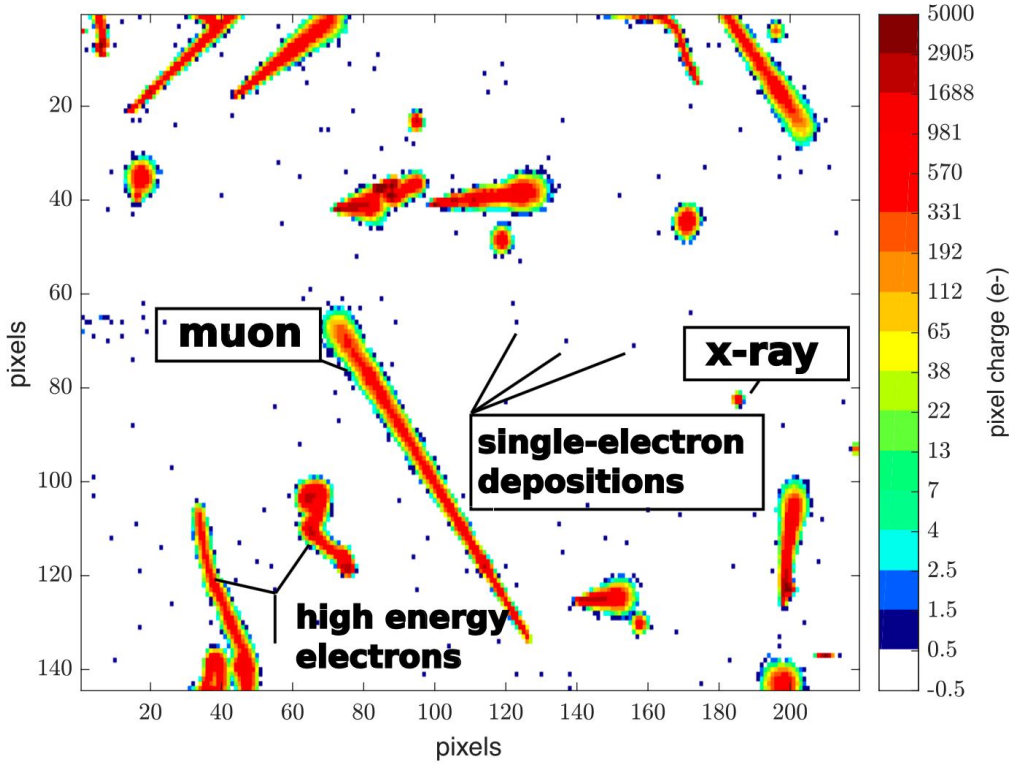
Simplified model of the total efficiency (only as a reference for the discussion today at excess talk, do not use for calculations)

New publication is coming with the full procedure.
Prev. publications: arXiv:1910.04951, arXiv:1906.02200, arXiv:1604.01343

Skipper CCD running at Fermilab

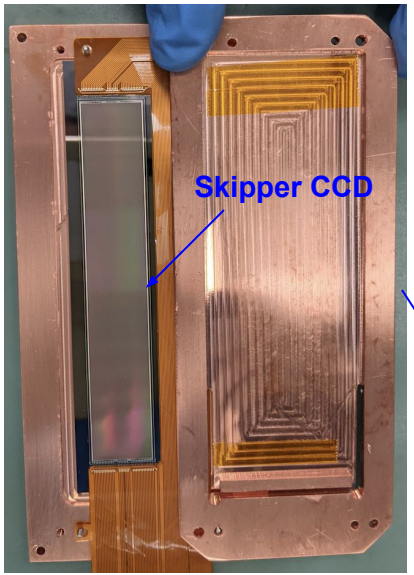
Skipper CCD running at Fermilab

- **Sample image at surface with no shield**



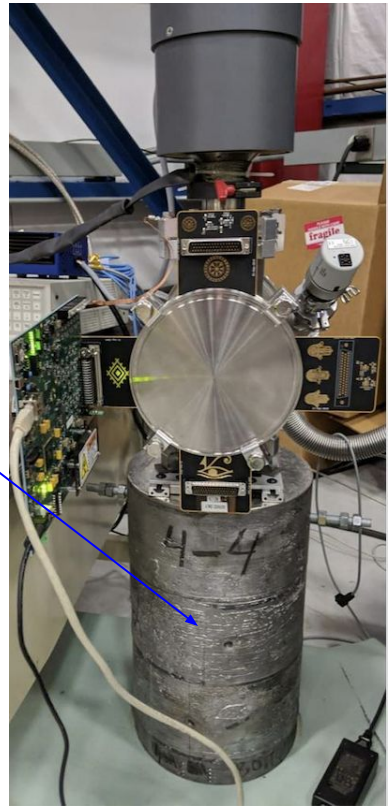
Detector and system

- Slow readout using 300 samples per pixel. Noise 0.167 e-.
- Continuous readout mode using horizontal binning of 10.
- 53.75 minutes per image
- Only two working quadrants.



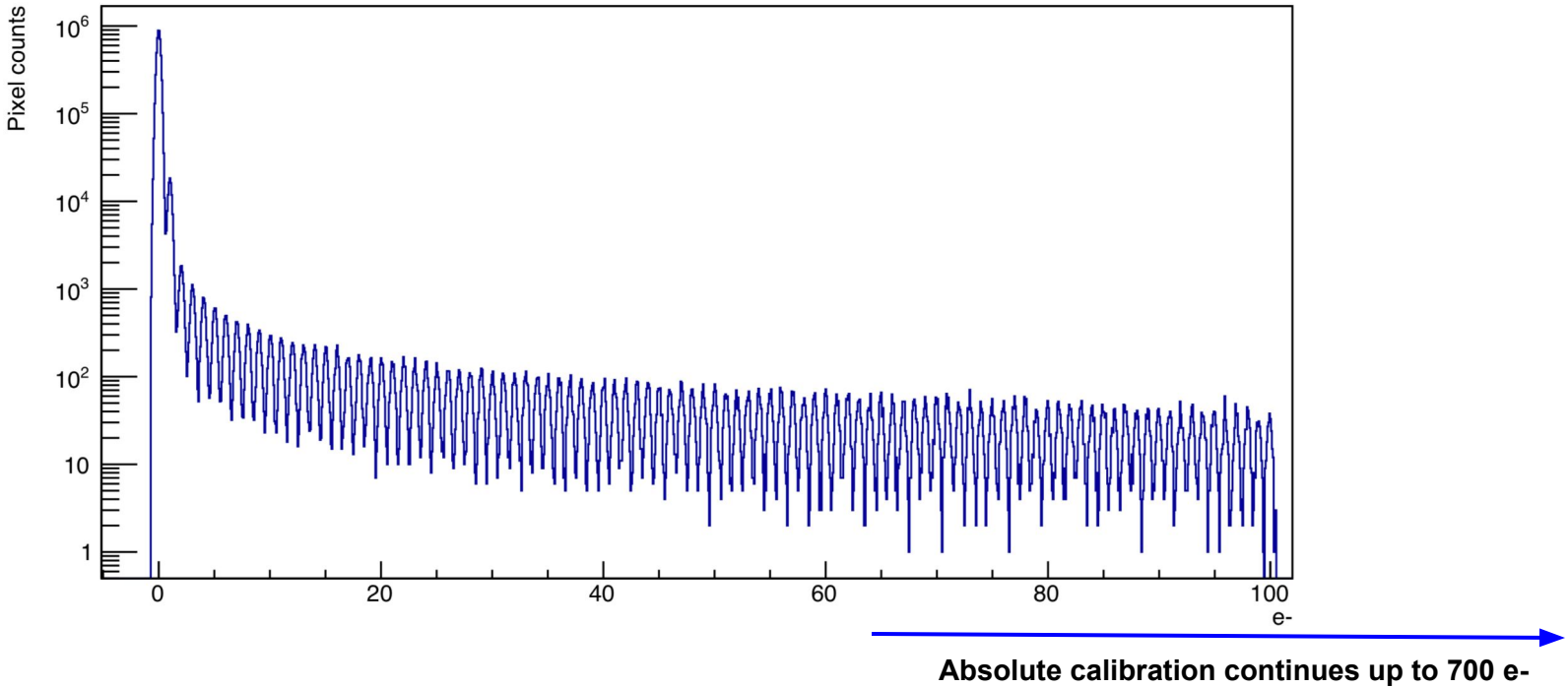
Sensor package:
Skipper CCD + Kapton cable + Copper tray

Sensor stays inside the lead shield



5 cm of lead around the sensor

Absolute charge calibration using same measurements



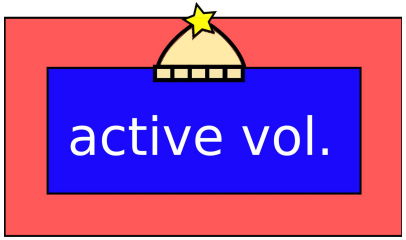
Absolute calibration continues up to 700 e-

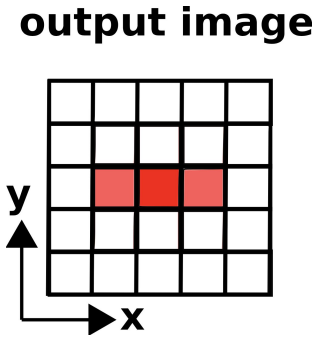
Adopted energy scale (eV) = 3.75 (eV) x Q

Main background affecting the measurement

Horizontal events

charge collected in the serial register





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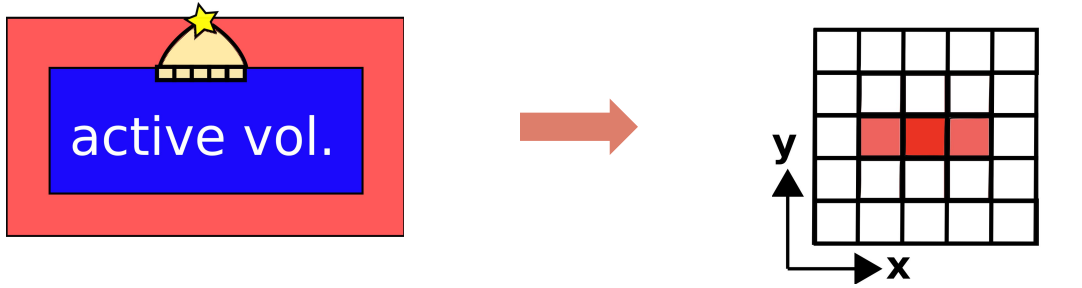
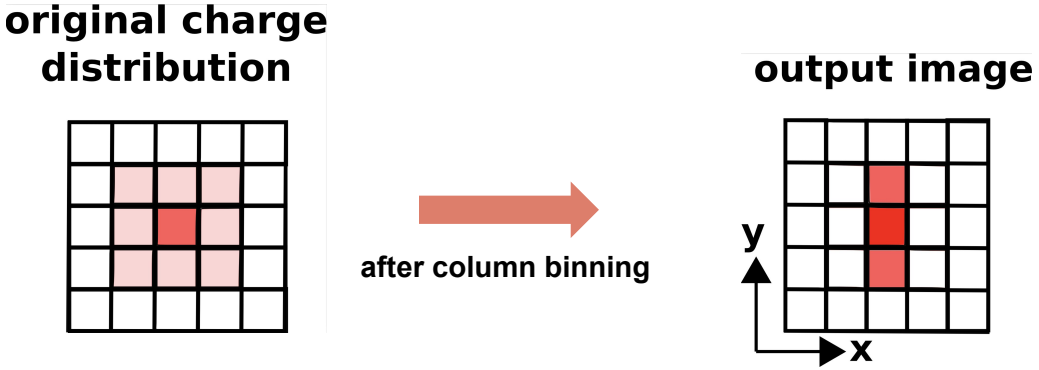
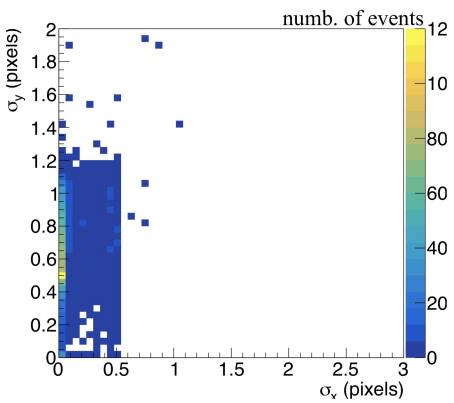


Interactions in the active region



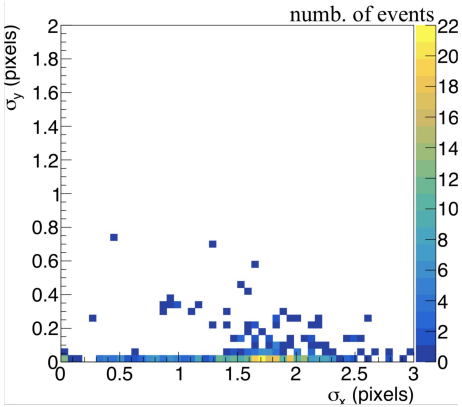
Spatial shape distribution

Interactions in the active region



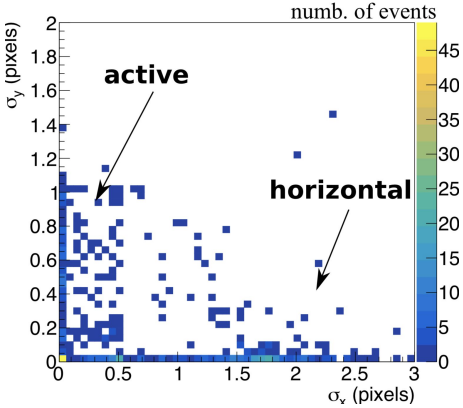
- From simulations
- Very well known charge transport in the silicon

Horizontal events



- Measurements without clocking vertical lines

Full measurements with sensor

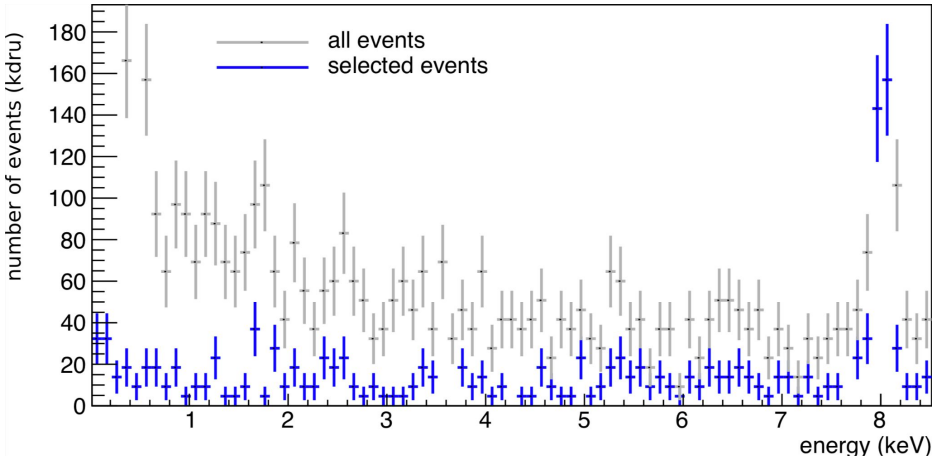


- Data set presented in the WS

Final spectrum and efficiency

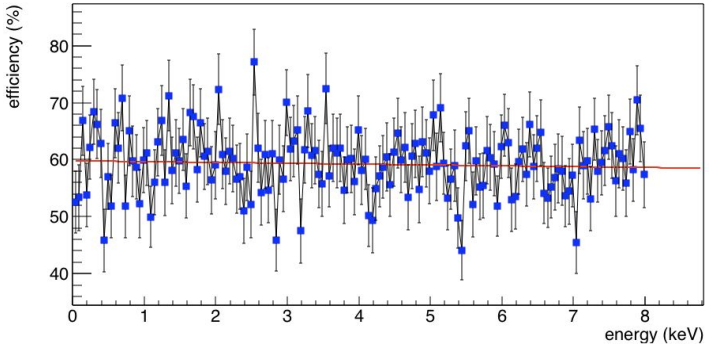
Collected data:

- selection: $0.25 < \sigma_Y < 1$ and $\sigma_X < 1$
- **0.675 grams of active silicon**
- **running for 3.21 days**
- **events with 5e- (18.75 eV) or more**
- spectrum not normalized by efficiency



Selection efficiency

- Evaluated simulating events in the real images
- Best fit: efficiency(%) = 59 - 0.17xE



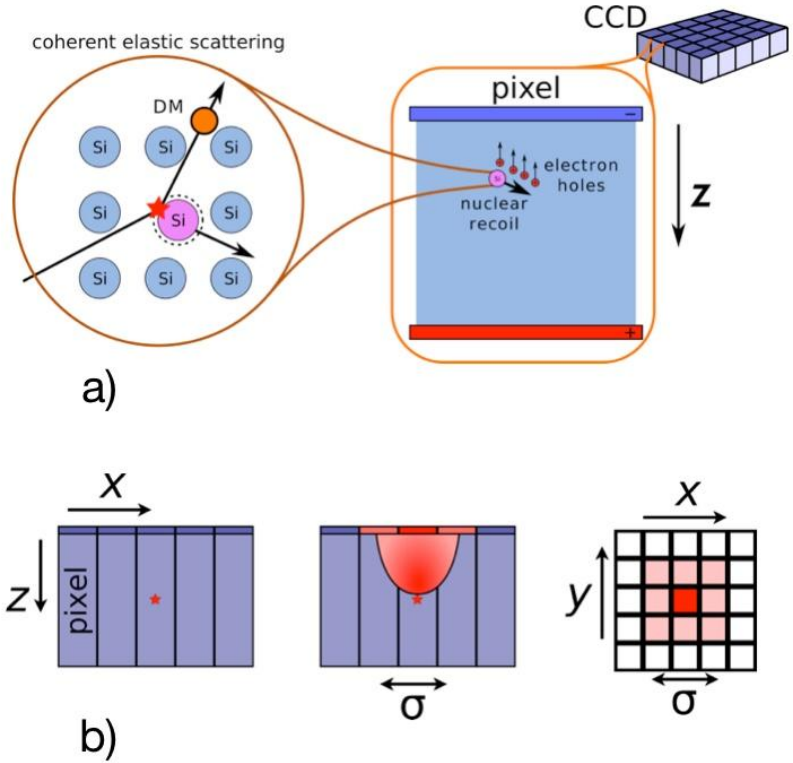
Full analysis to appear in arXiv this week

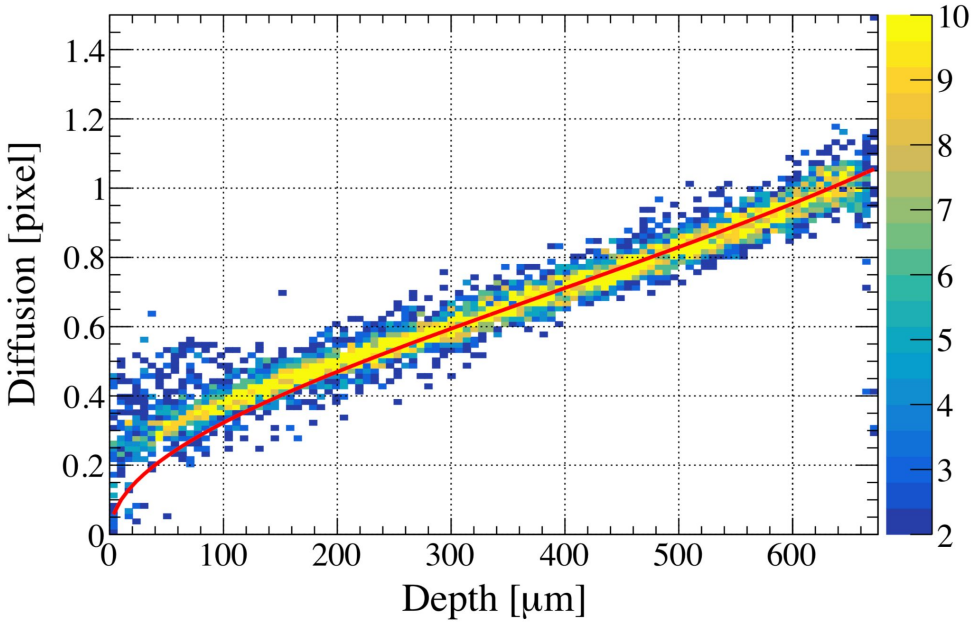
Conclusions

- CONNIE experiment have large exposure using regular CCDs. Publication is coming soon. It will be a valuable data set for the workshop.

- The Skipper CCD allows to reduce the energy threshold. We have recently understood how to operate it at surface. Not large exposure yet, but we should expect more from the coming nuclear-reactor neutrino projects.

Charge transport calibration





Measured spectrum