# CONNIE:
# A neutrino Experiment in Latin America

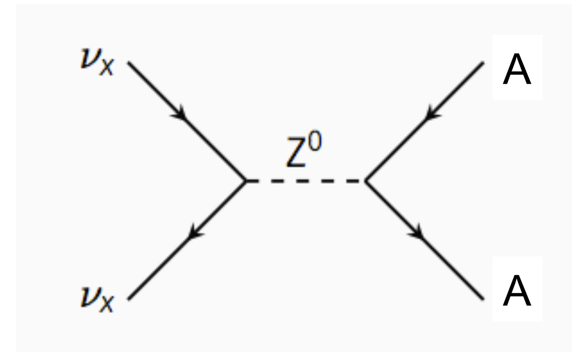
Carla Bonifazi
for the CONNIE collaboration

Instituto de Física
Universidade Federal do Rio de Janeiro

# Coherent elastic neutrino-nucleus scattering

- for neutrino energies below 50 MeV

$$\frac{d\sigma}{d(\cos\theta)} = \frac{G^2}{8\pi}\left[Z(4\sin^2\theta_W - 1) + N\right]^2 E_\nu^2(1+\cos\theta)$$




G = Fermi constant

Z = atomic number of the nucleus

N = neutron number of the nucleus

$E_\nu$ = neutrino energy

$\theta$ = scattering angle

$\theta_W$ = weak mixing angle

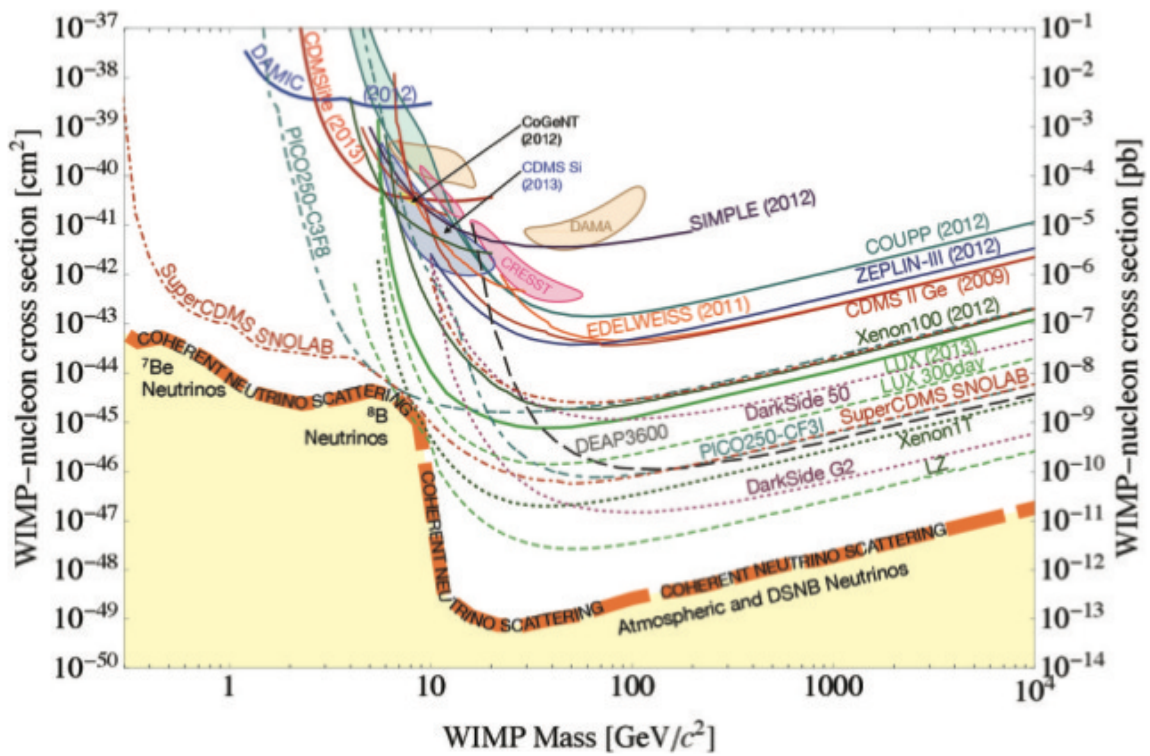
In the coherent neutrino-nucleus neutral-current interaction, a neutrino of any flavor scatters of a Si nucleus transferring some energy in the form of a nuclear recoil.

$$< E_r >= \frac{2}{3}\frac{(E_\nu/\mathrm{MeV})^2}{A}\mathrm{keV}$$

The high cross section for neutrino interactions is counterbalanced by the tiny recoil energies ≲ keV

# Motivation

- Coherent Neutral Current Neutrino–Nucleus Scattering
  - SM prediction but never measured
  - MeV-neutrino physics has great relevance for energy transport in supernovae
  - Irreducible background for WIMP detection
  - Monitor nuclear reactors through their emitted neutrinos
  - New tool for neutrino experiments (very short baseline oscillation experiments – low energy)



# CONNIE collaboration

## COherent Neutrino Nucleus Interaction Experiment

About 20 members

Argentina
Centro Atómico Bariloche
Universidad del Sur / CONICET

Paraguay
Universidad Nacional de Asunción

Brazil
Centro Brasileiro de Pesquisas Físicas
Universidade Federal do Rio de Janeiro

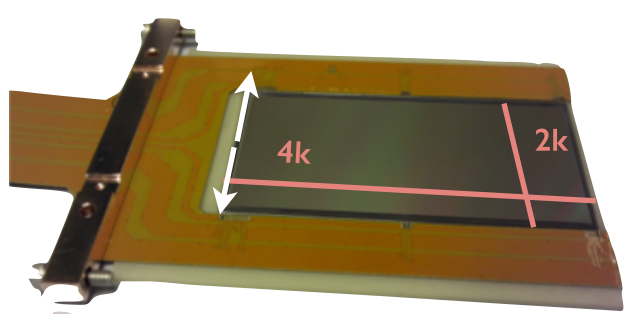
Switzerland
University of Zurich

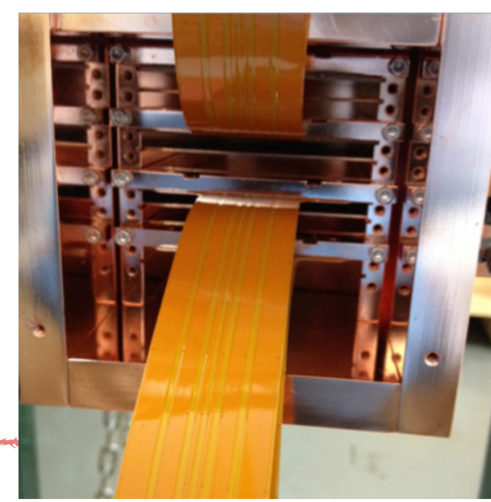
Mexico
Universidad Nacional Autónoma de México

USA
Fermilab National Laboratory

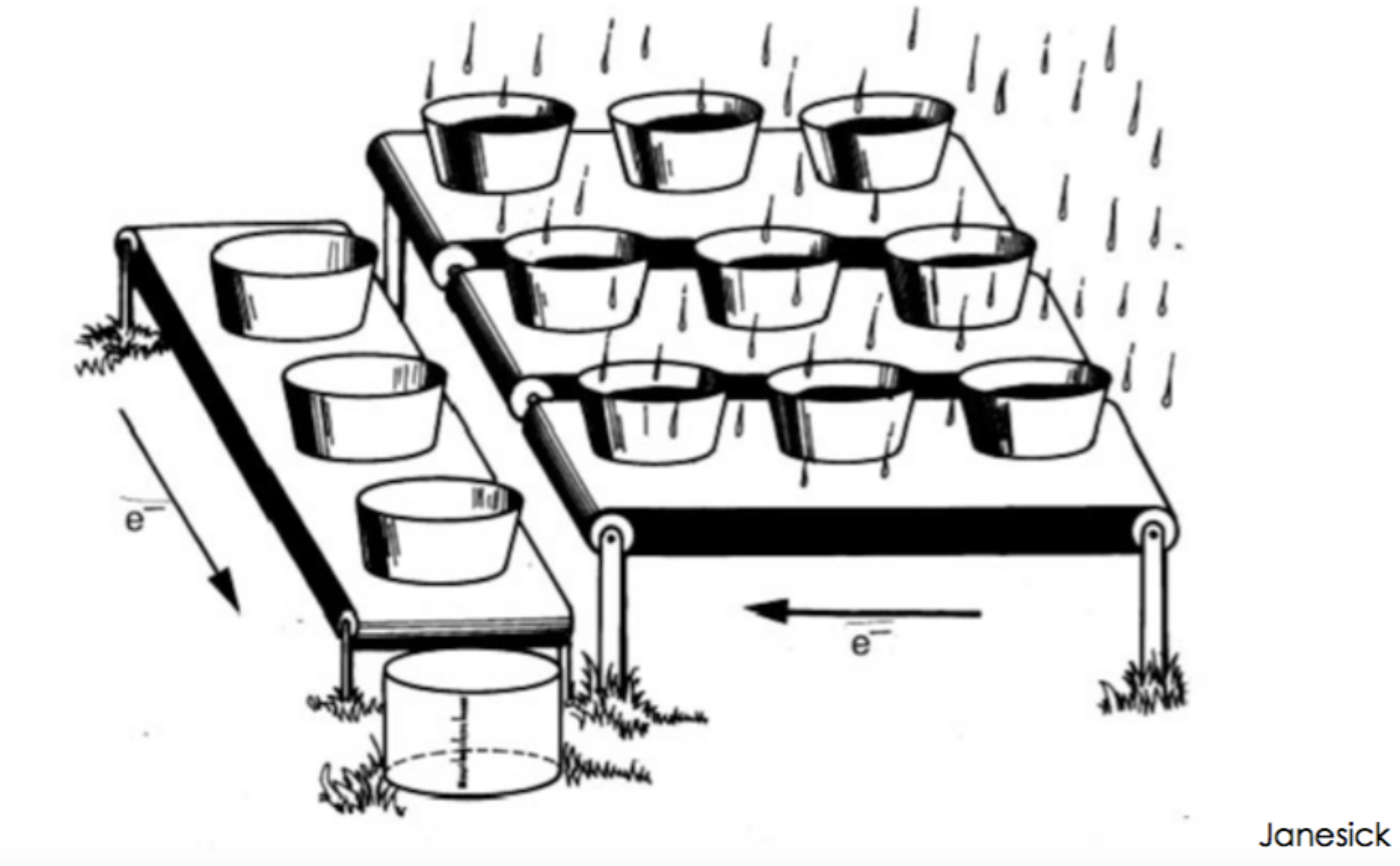
# Charge Coupled Device

- Unique features of high resistivity CCDs designed by Berkeley Laboratories:
  - very low energy threshold detectors: 5.5 eV (RMS < 2 $e^-$)
  - pixel size of 15 $\mu$m x 15 $\mu$m
  - large mass compared to regular CCDs (250/675 $\mu$m)
  - up to 5.2 gr/CCD
  - "3D" information (diffusion): rejection of surface events
  - used in the Dark Energy Survey (DES) experiment and Dark Matter in CCDs (DAMIC) experiment

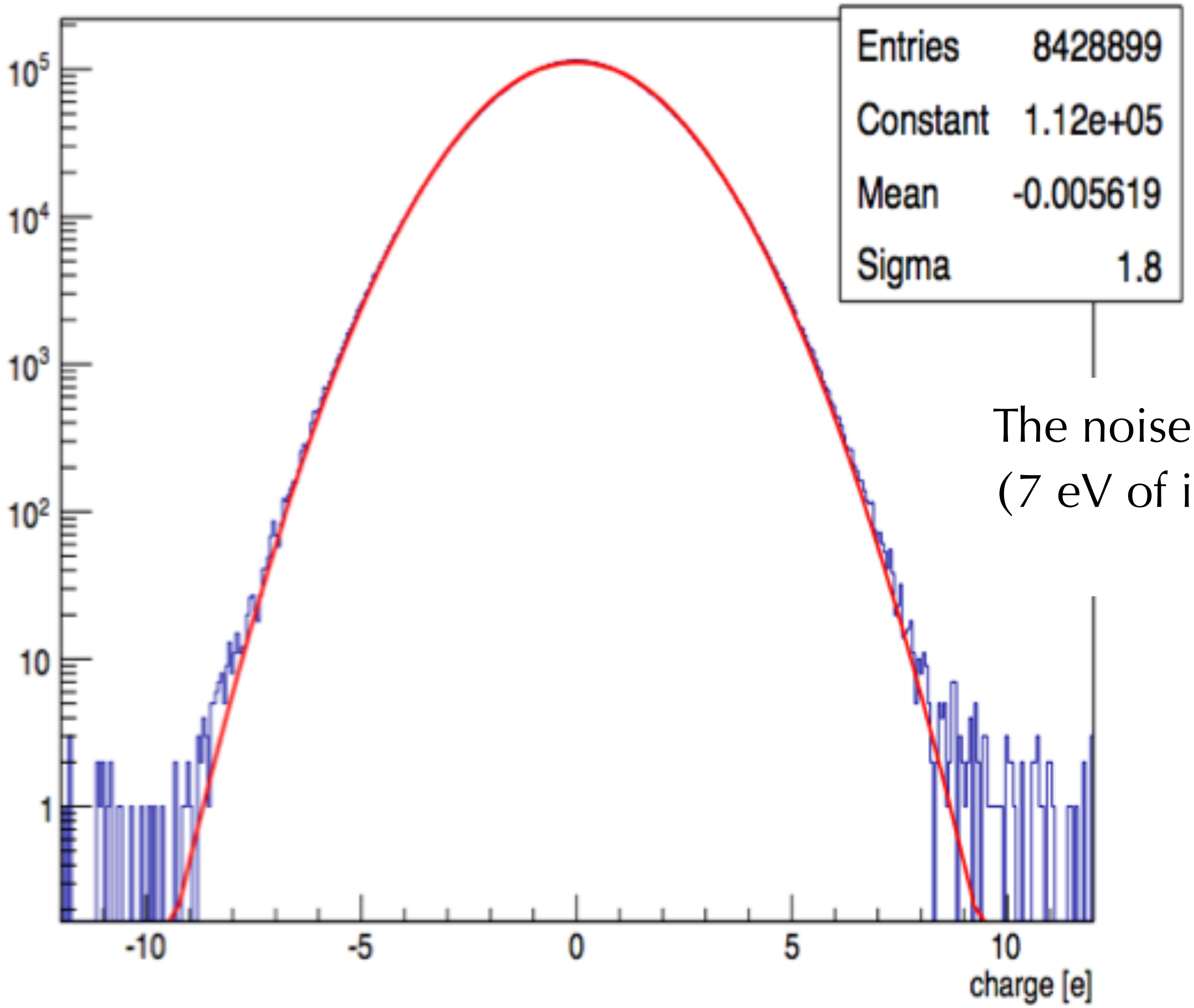


# CCD readout

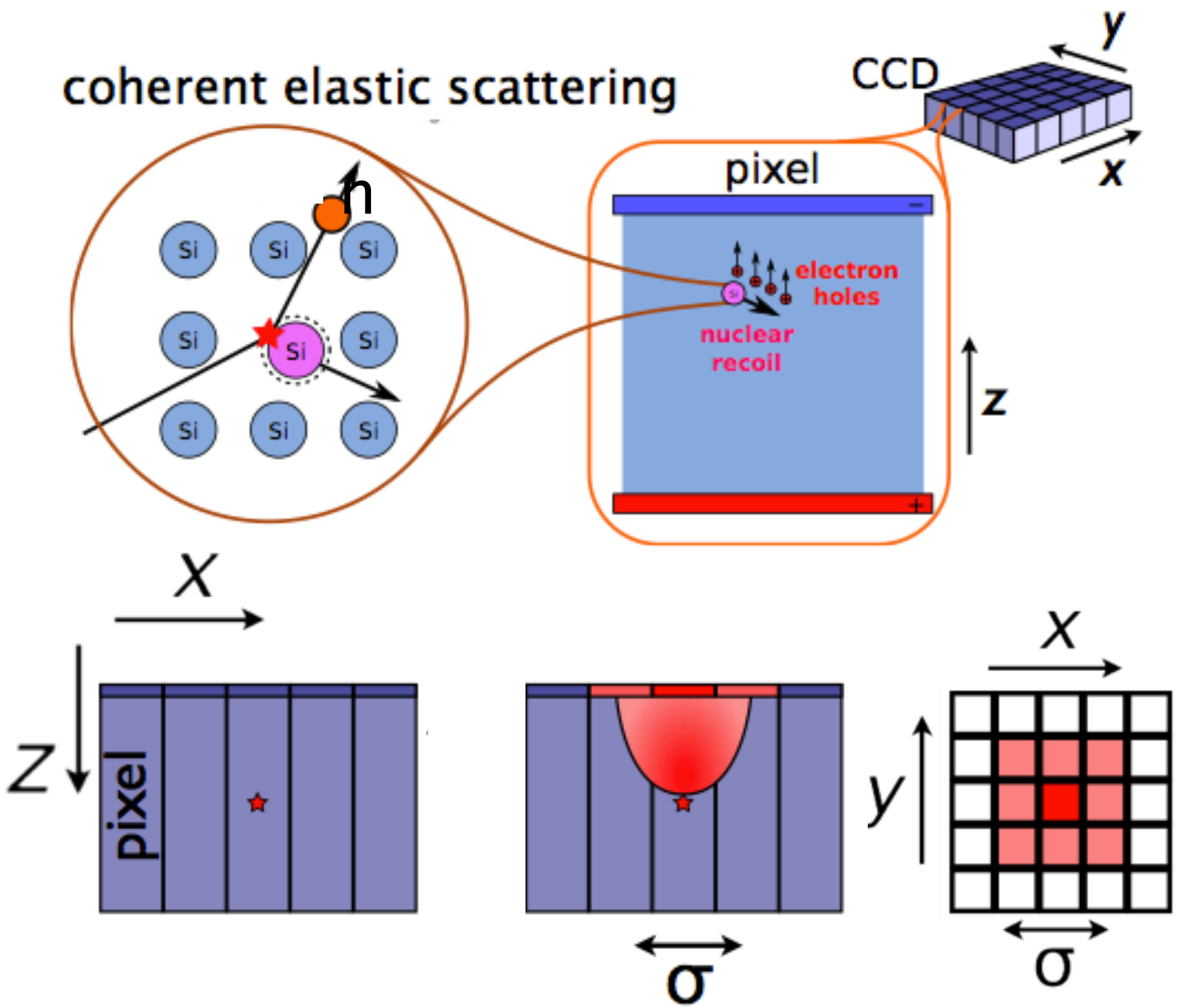


# RMS noise




The noise is 1.8 $e^-$ RMS
(7 eV of ionization energy)

# Charge Coupled Device




The scattering of the n with a Si nucleus leads to ionization

Charge carriers are drifted along z direction and collected at CCD gates

Charge diffuses as it travels

We fit to the radial spread of the cluster to estimate its position in z within the CCD bulk

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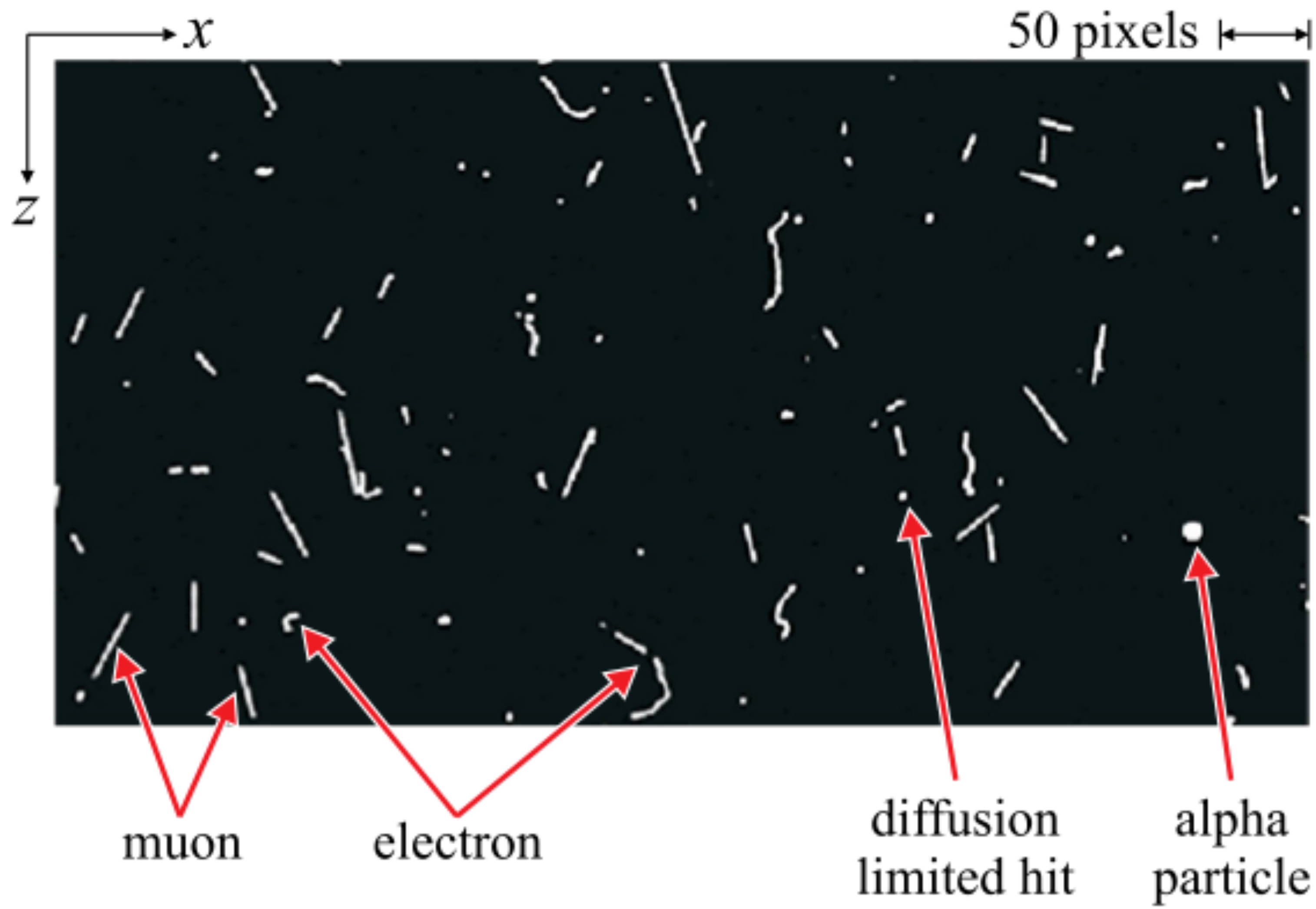
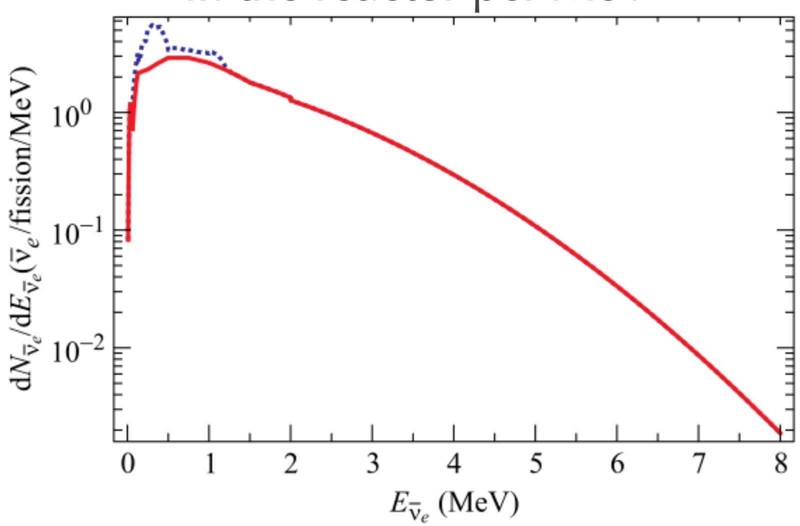
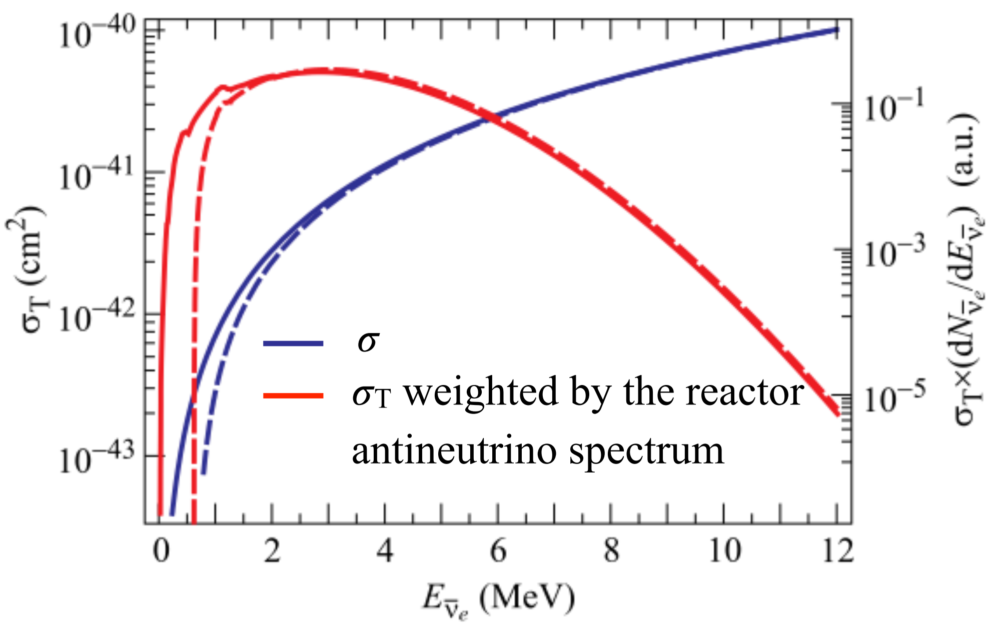
# Particle identification CCD



# Angra Nuclear Power Plant


Total reactor antineutrino spectrum in the reactor per MeV

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# Angra Nuclear Power Plant


# Timeline

- First visit in 2011
- Seriously making a plan in 2013
- Installed a prototype in 2014
  - August-September 2014 – Detector Shipping
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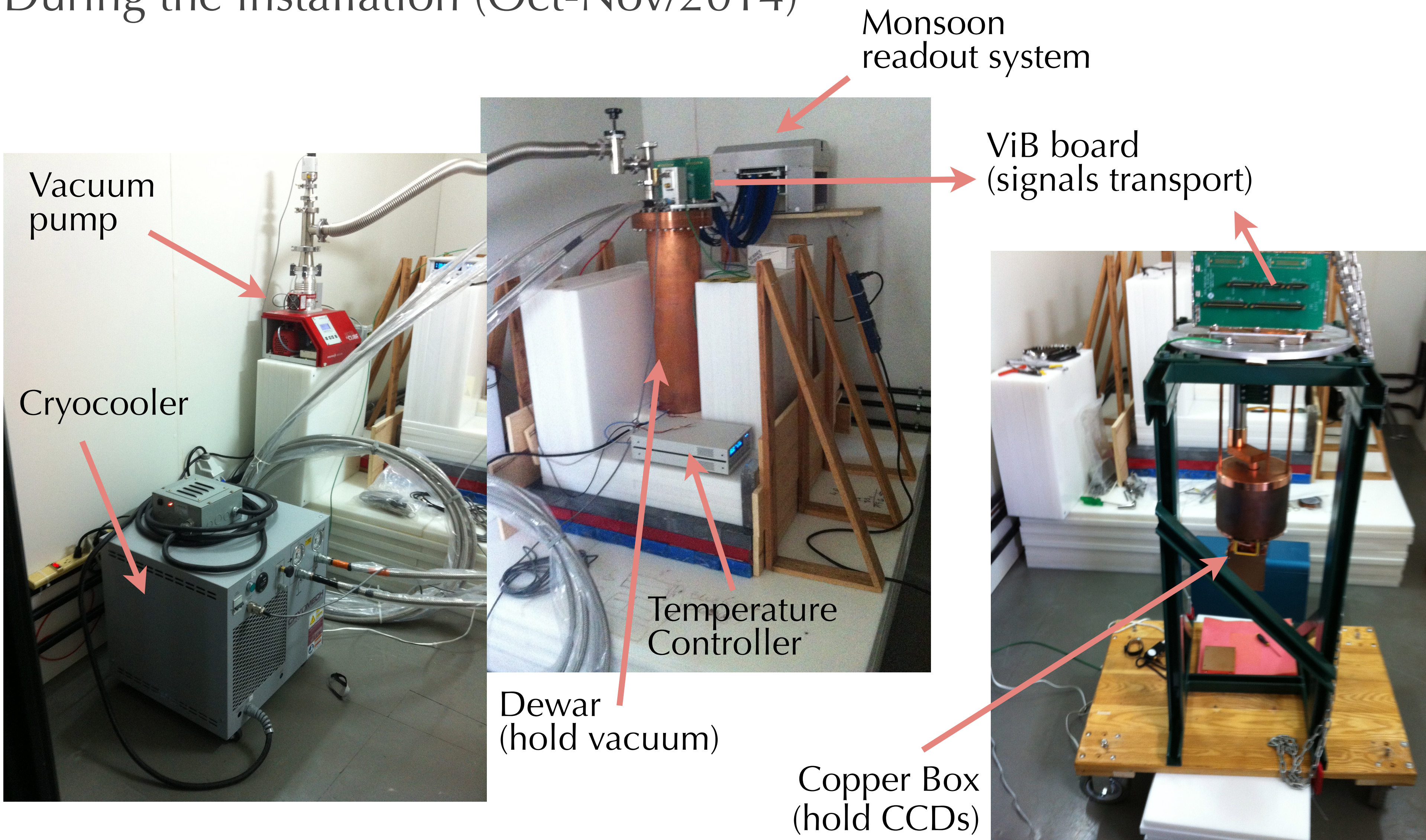
  - Initial operations supported by experts (from USA and Mexico)
  - Continuous operation now supported by local team (Brazil)
  - July-August 2015 – Full shield assembly completed
  - August - September 2015 – More than a full month with reactor ON
  - September - October 2015 – Full month of full reactor OFF
- November 2015 - Now – Noise and performance studies

# The detector

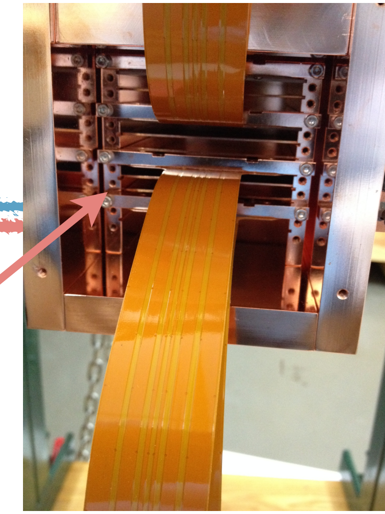
During the installation (Oct-Nov/2014)



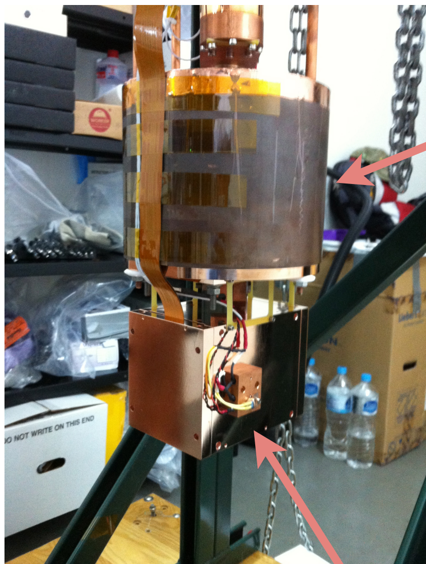
# The detector

During the installation (Oct-Nov/2014)

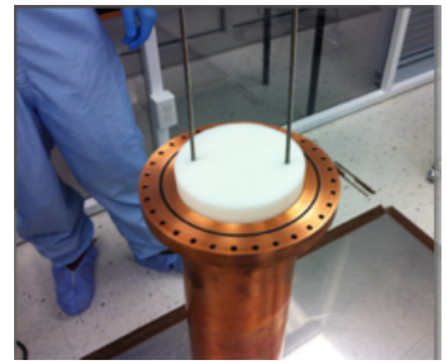
CCDs in the copper box



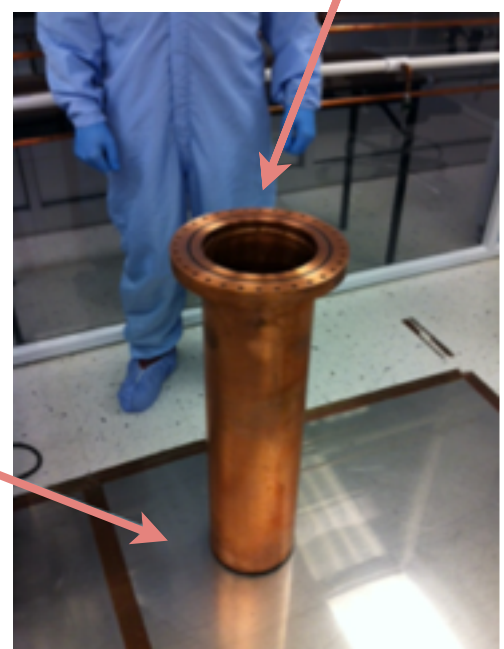
15 cm lead



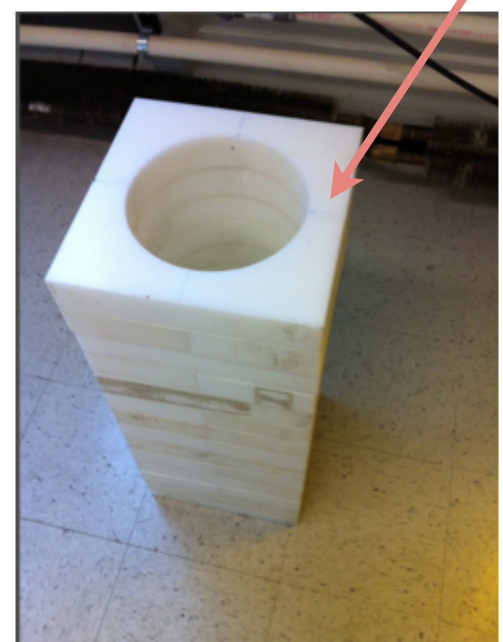
Copper Box



Dewar (hold vacuum)

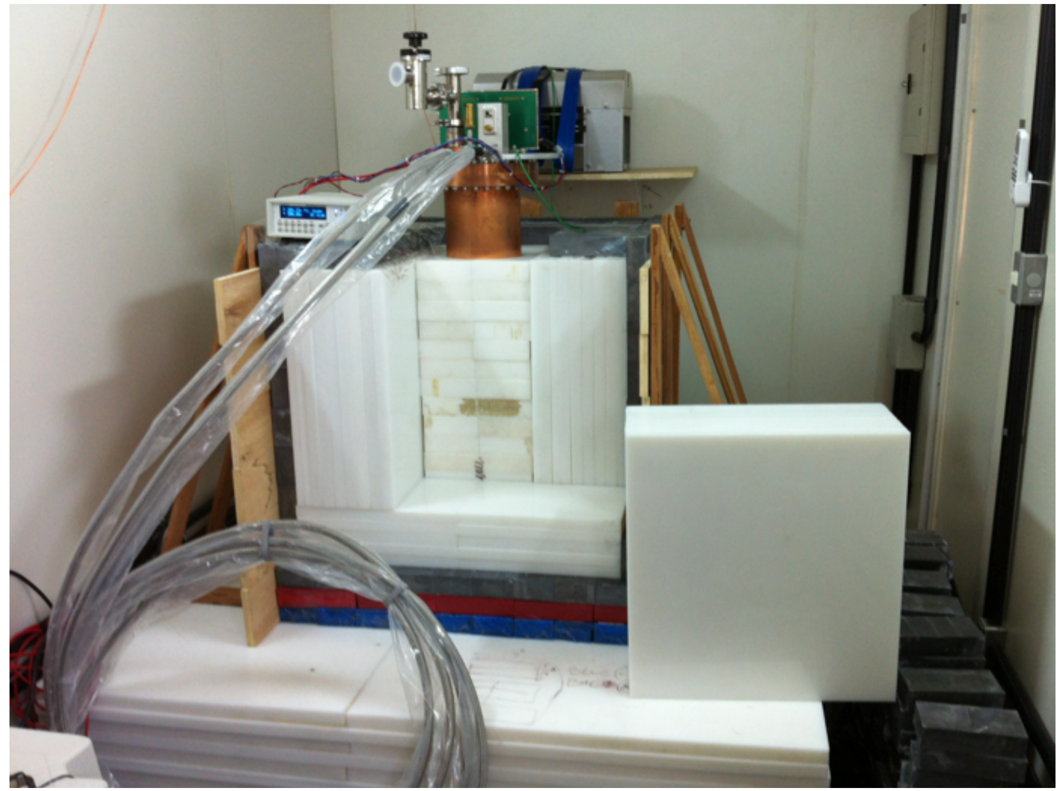


Inner polyethylene (half moons)



Polyethylene inside (at the bottom)

# The detector – First light

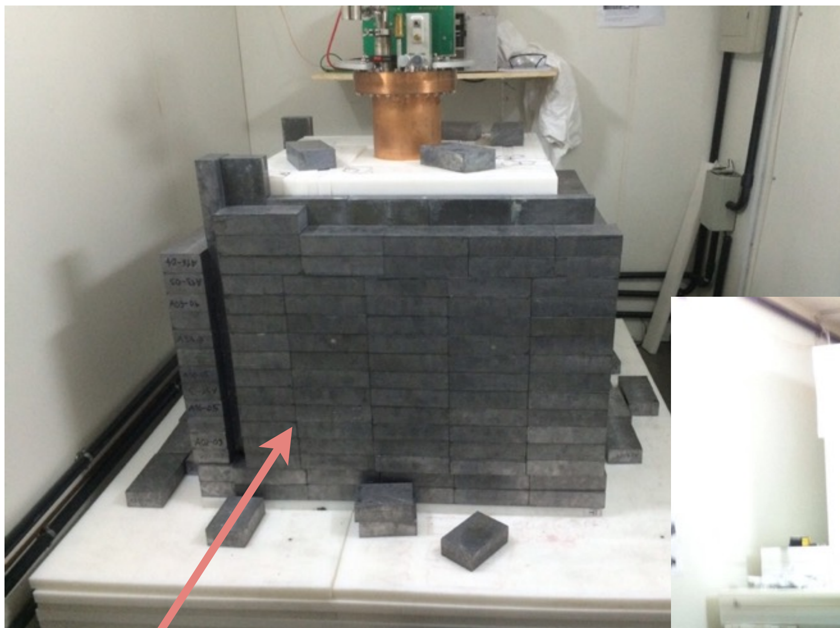



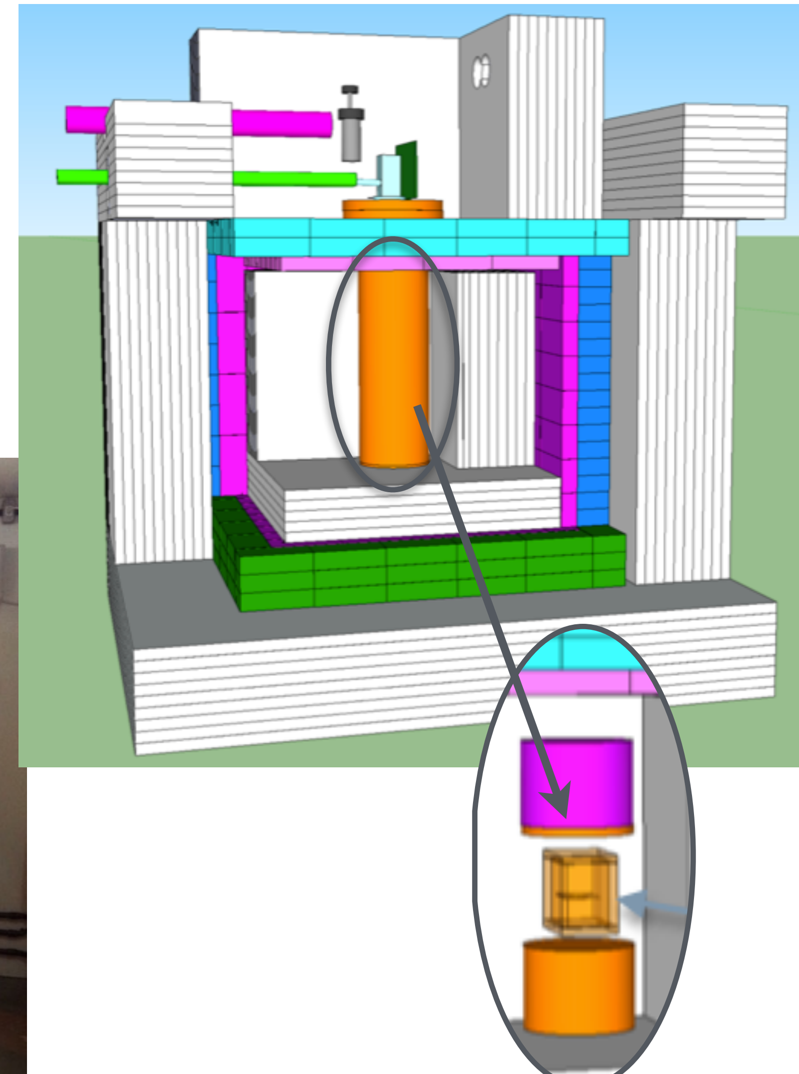
Phase I: Partial shield (30 cm polyethylene and 5 cm lead)

4 CCDs installed and taking data for background studies since Dec/2014

# The detector – Full shied

Phase II: Full shield (installed July-August 2015)

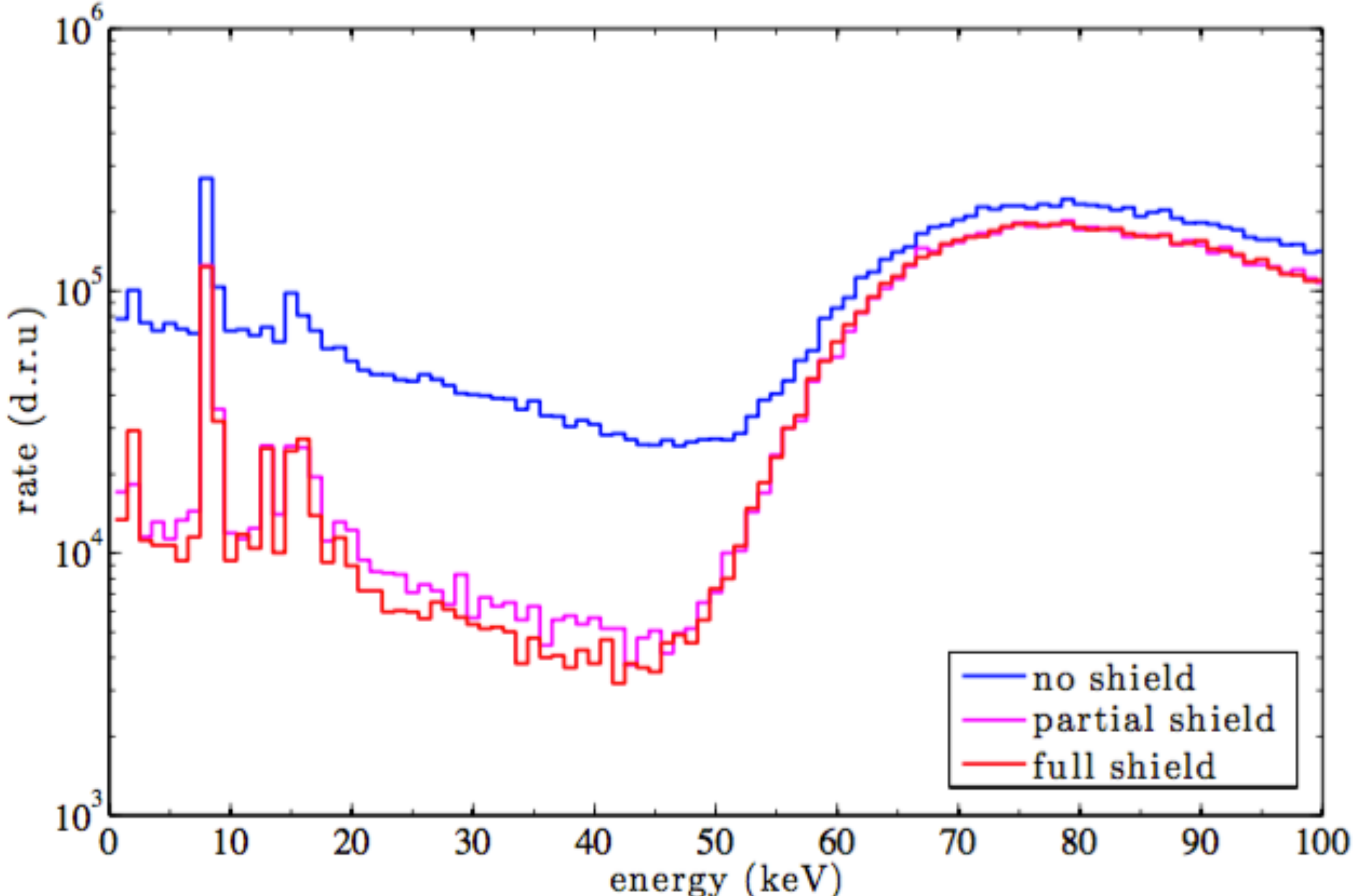




15 cm lead around
30 cm polyethylene

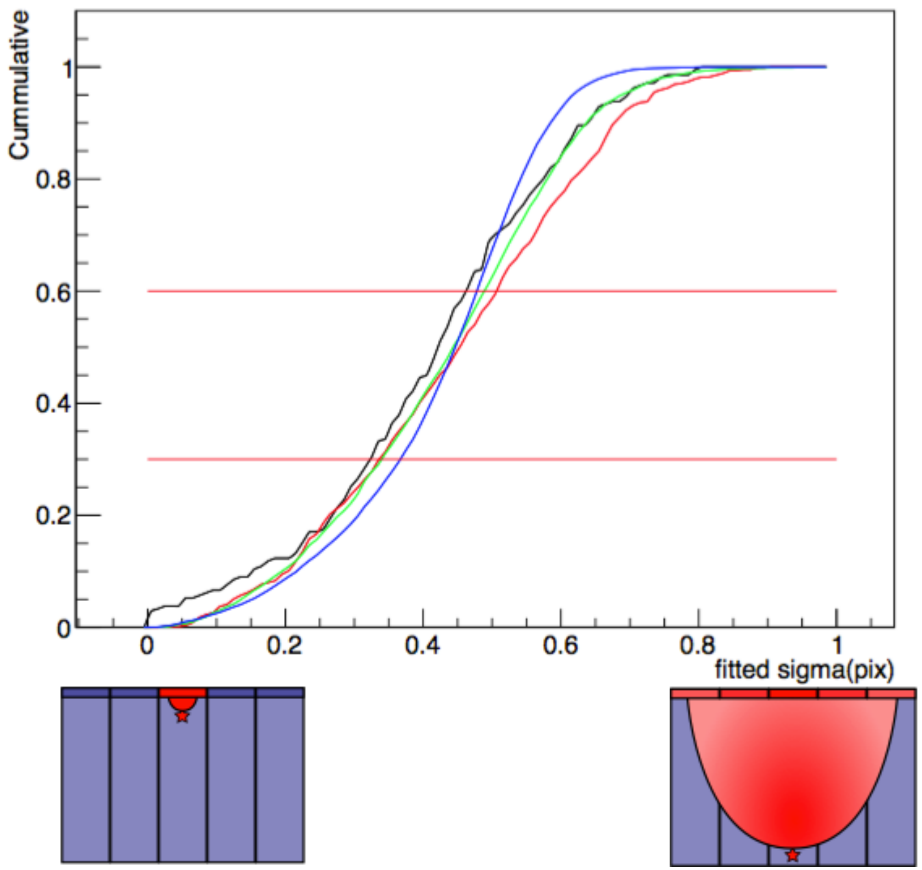
Almost finished

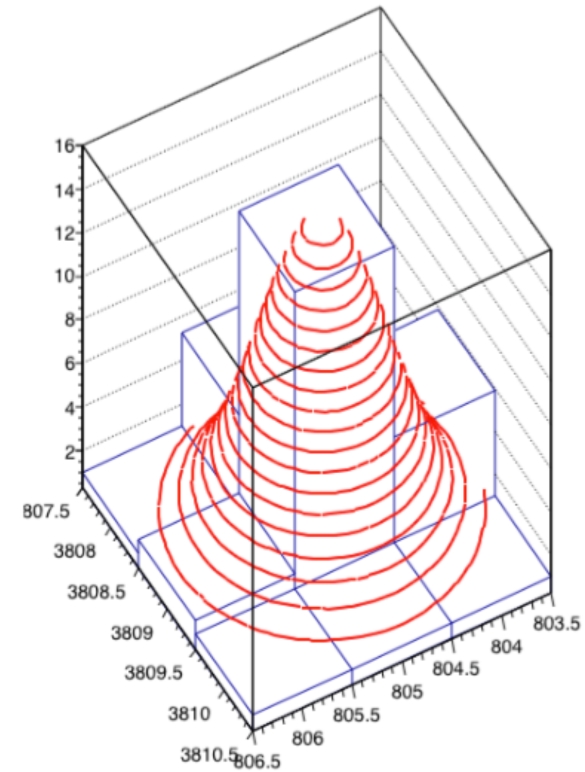
# Energy spectrum




arXiv:1604.01343

# Event selection & Efficiency

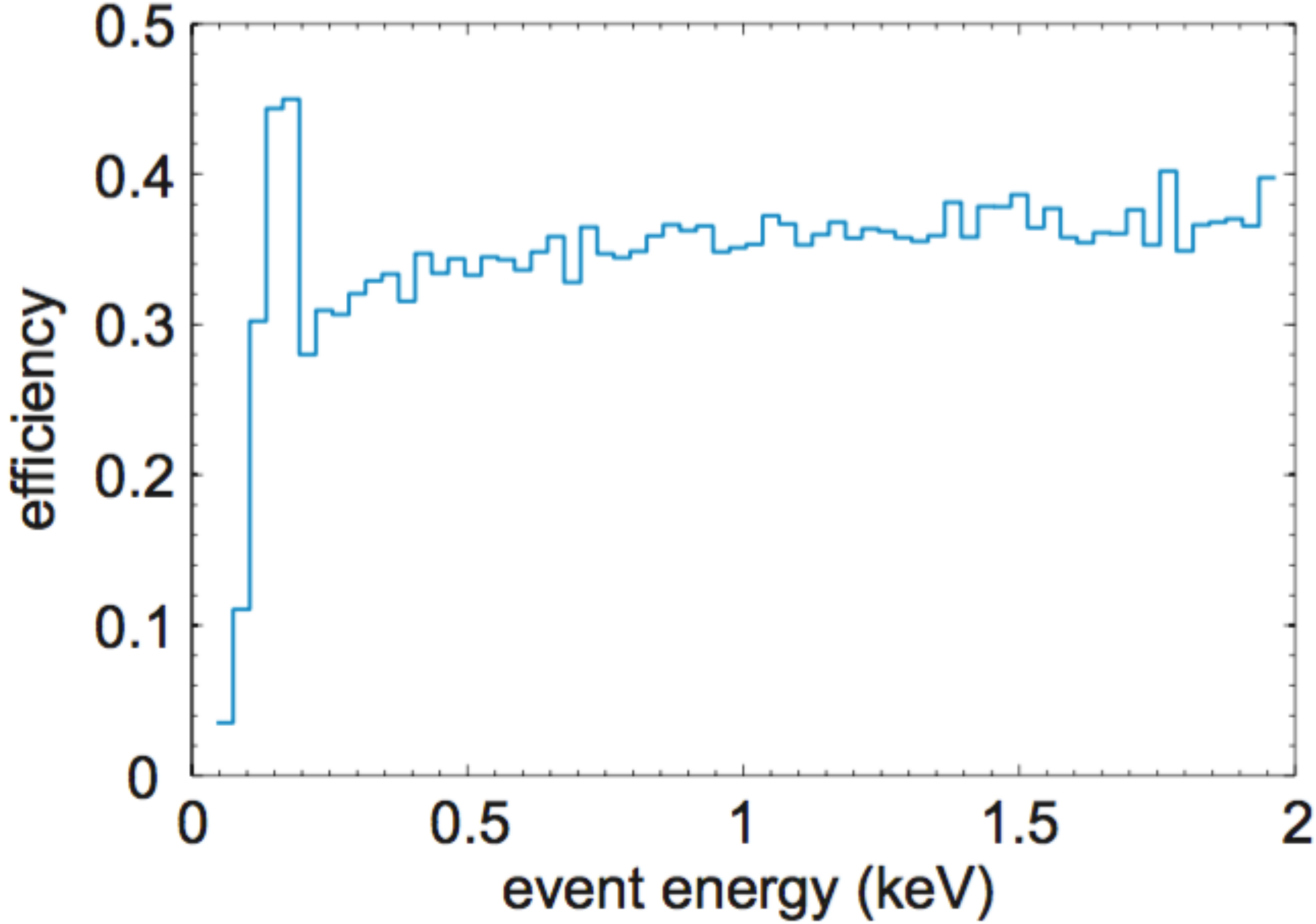



A 2-D Gaussian is adjusted to every hit found in the CCD image using a maximum likelihood technique.

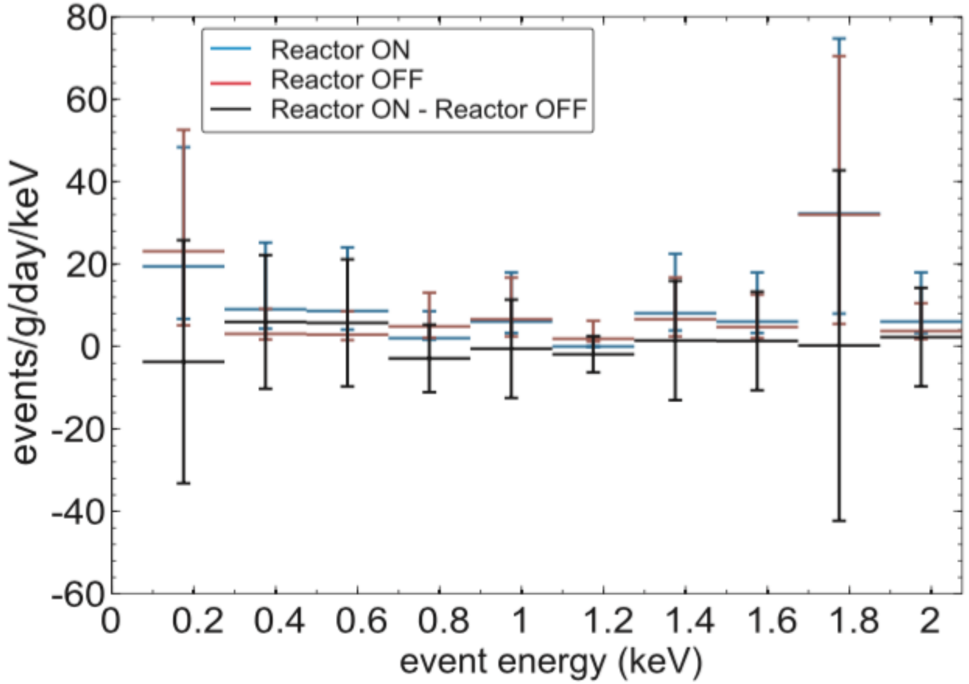
arXiv:1604.01343

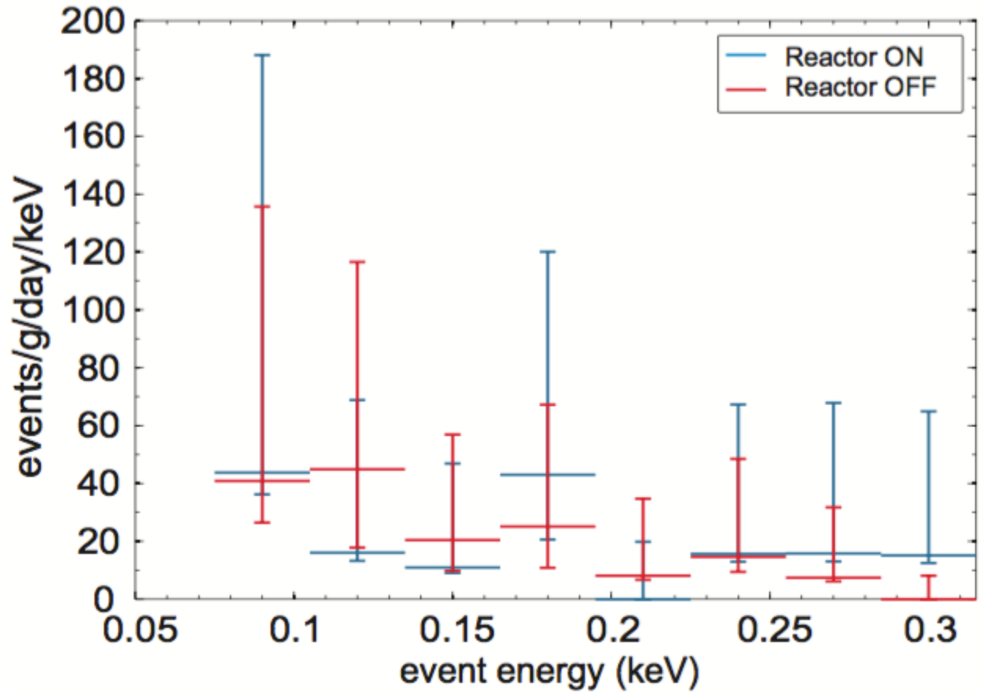
# Event selection & Efficiency




arXiv:1604.01343

# Energy spectrum




Rate of events with the reactor ON and OFF
(corrected for the efficiency of the selection criteria)

The higher rate of events at 1.8 keV is produced by the silicon fluorescence X-ray.

arXiv:1604.01343

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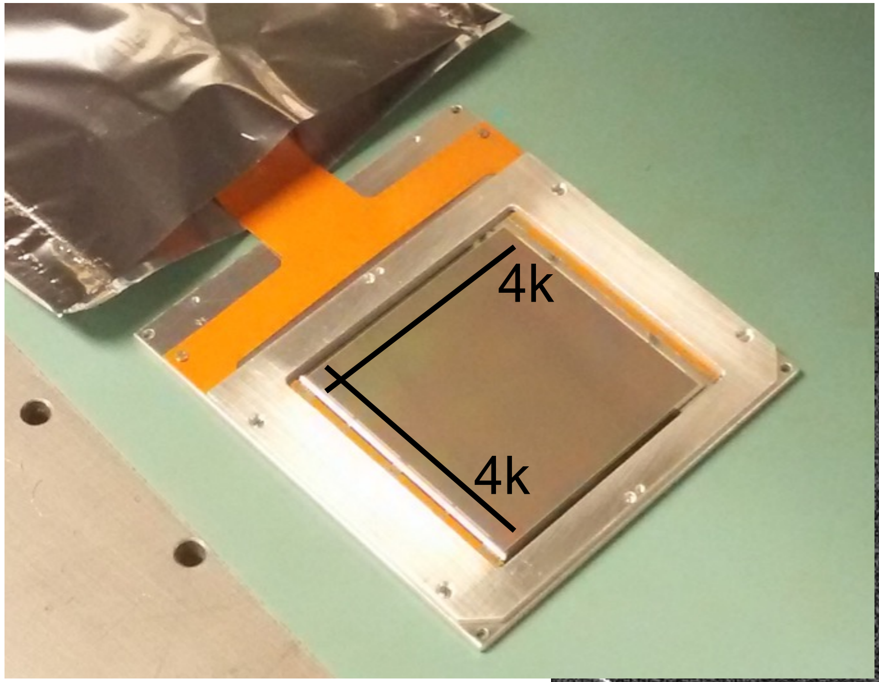
  - Initial operations supported by experts (from USA and Mexico)
  - Continuous operation now supported by local team (Brazil)
  - July-August 2015 – Full shield assembly completed
  - August - September 2015 – More than a full month with reactor ON
  - September - October 2015 – Full month of full reactor OFF
- Upgrade to 100 g mass detector (CONNIE100)
  - January 2016 – Arrival of the new CCDs (4k x 4k & 675 $\mu$m) to Fermilab
  - Now – Packaging the new CCDs and testing them
  - Detector installation planned for July 2016

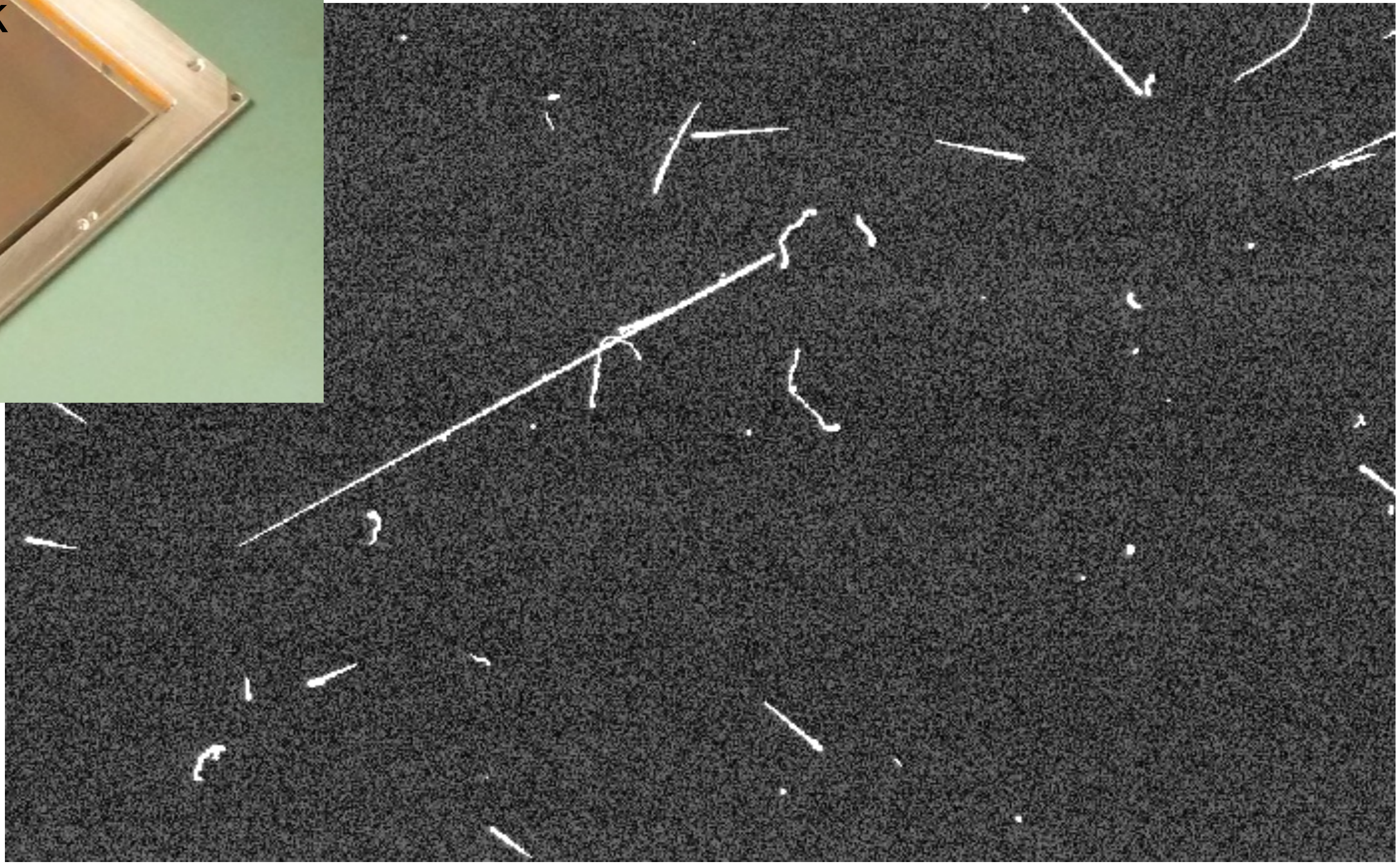
# New CCDs




First CCD for CONNIE 100

4k x 4k

675 $\mu$m



# Summary

- **CCDs** can be used **as particle detectors** with **good spatial and energy resolution** and **very low electronic noise**
- Capability to **detect nuclear recoils** (DAMIC, CONNIE)
- Can be used to detect **coherent neutrino-nucleus scattering** with reactor anti-neutrinos

- CONNIE now **operating at Angra II** nuclear power plant
- Run **with/without shield** and **with power plant on/off** in 2015
- Current setup **was not expected to see coherent scattering**, but allowed us to **measure background** and demonstrated **its performance at Angra** (arXiv: 1604.01343)

- **Upgrade to 100 g** of active mass expected for **July 2016**.
- **We know what to do, we are moving in this direction.**

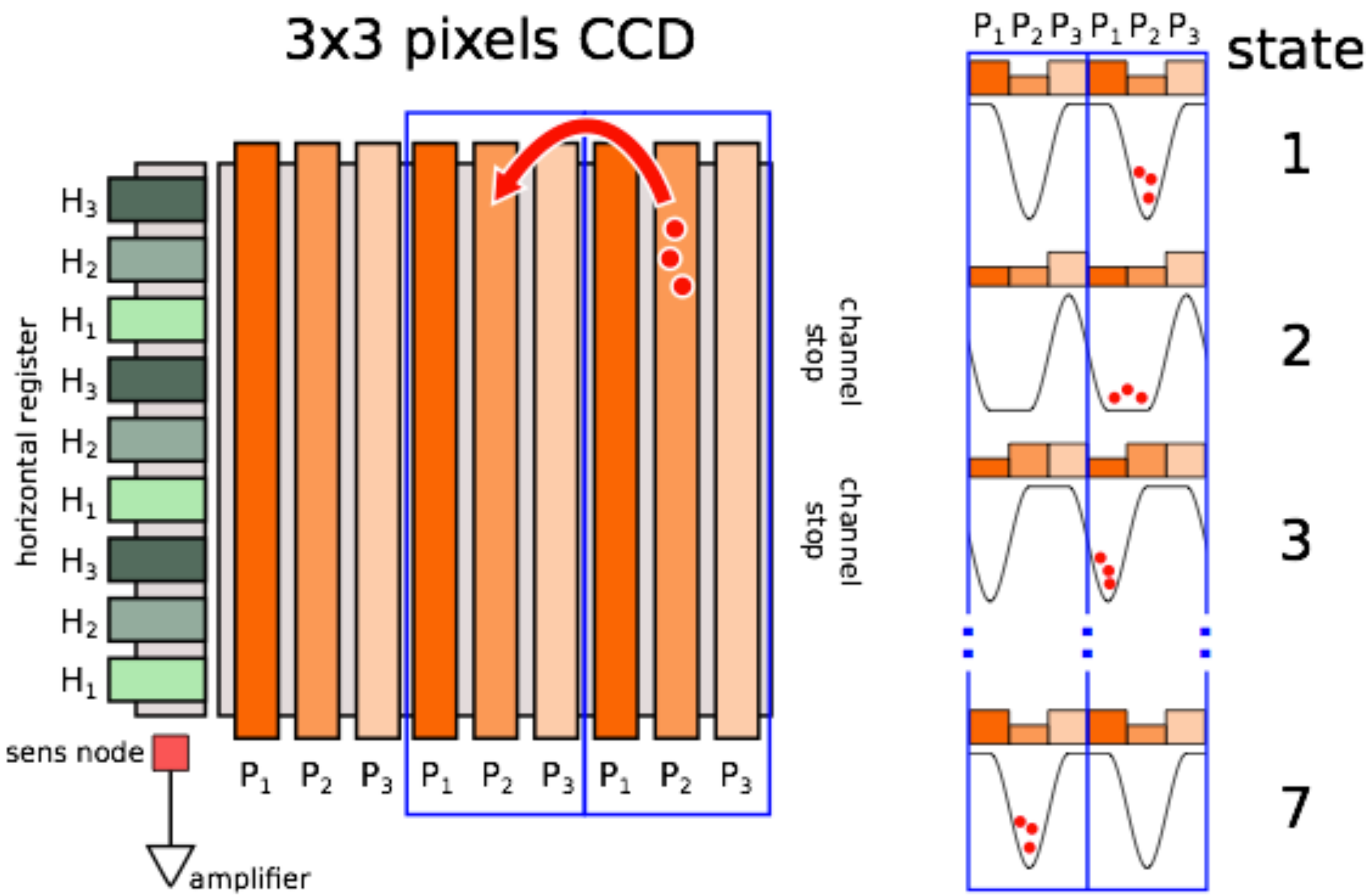
# Summary

- **Fermilab - Latin America Cooperation** for Coherent Neutrino Detection
- CONNIE is a **reactor neutrino facility in Brazil**
- Usually, Latin Americans come to Fermilab. For CONNIE, **Fermilabeans go to Angra**
- CONNIE is **important for the development of neutrino physics in Brazil**: useful to train students/researchers and raise awareness and interest for neutrino physics
- Success may **leverage fund** raising for **neutrino physics experiments**

- Very exciting years to come
- Likely to open a new window for low energy neutrino experiments

# BACKUP

# CCD readout

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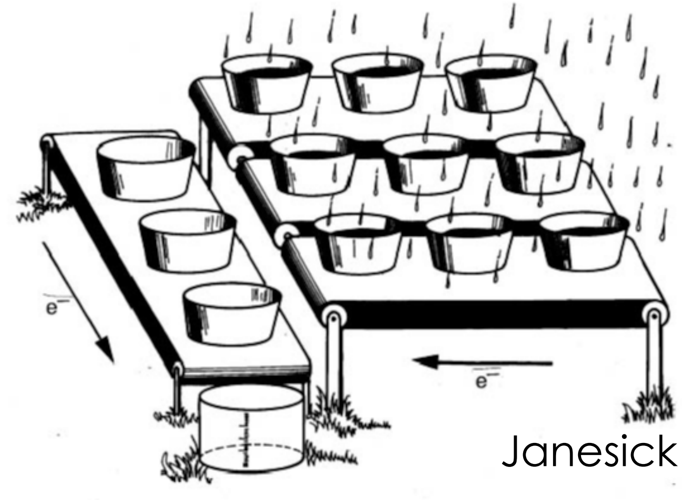
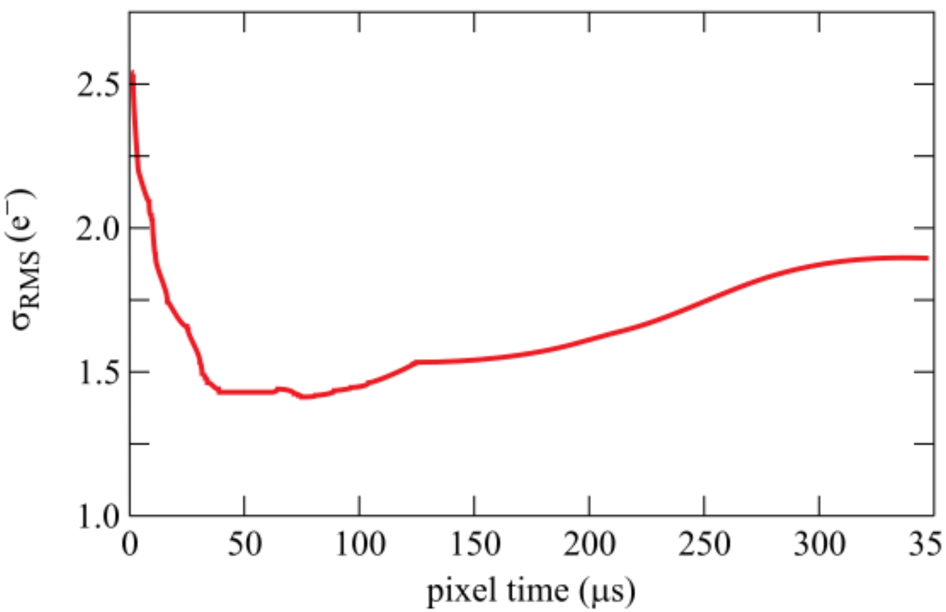
Capacitance of the system is set by the sens node: C = 0.05 pF ⇒ 3mV/e

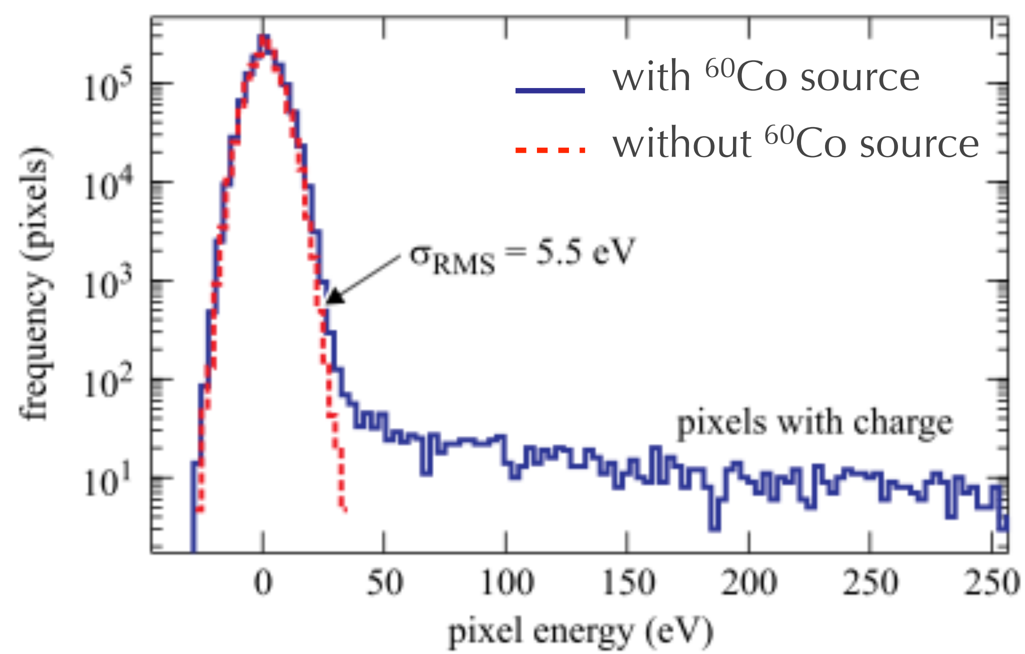
# CCD readout - Noise



Janesick

- Added to each pixel by the output amplifier during the charge packet readout
- Gaussian distribution with $\sigma_{RMS}$ that depends on the readout time of the pixel
- Pixel time = 30 ms ⇒ $\sigma_{RMS}$ = 1.5e- ≡ 5.5 eV of ionization energy

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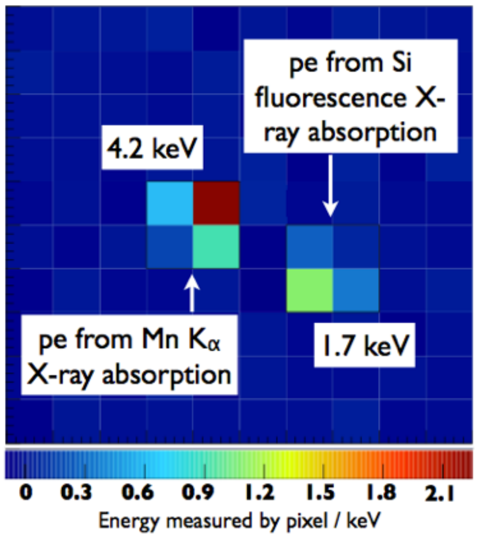
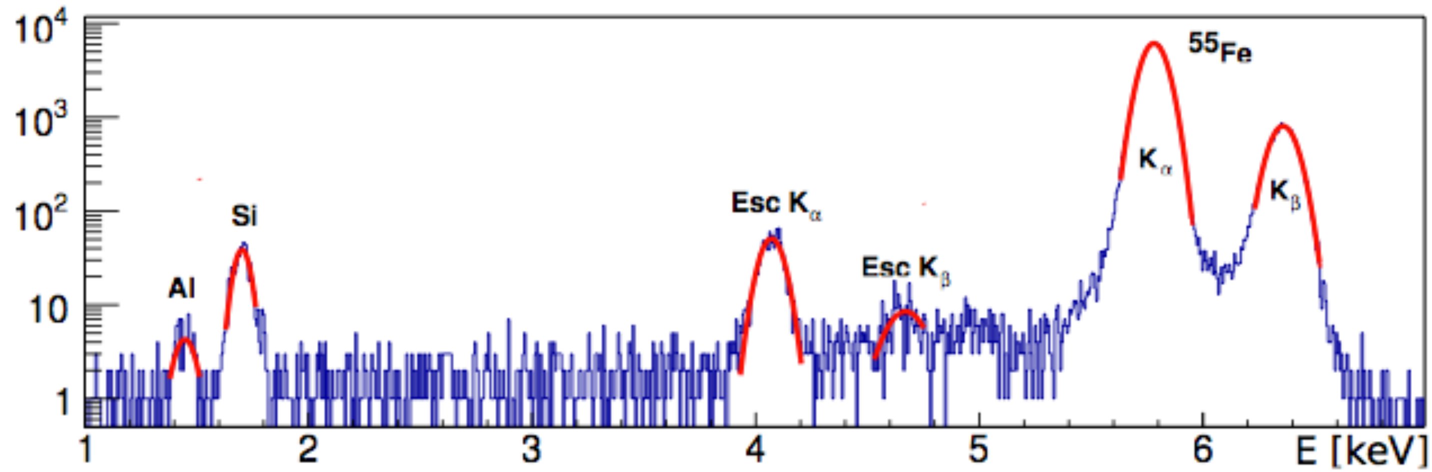
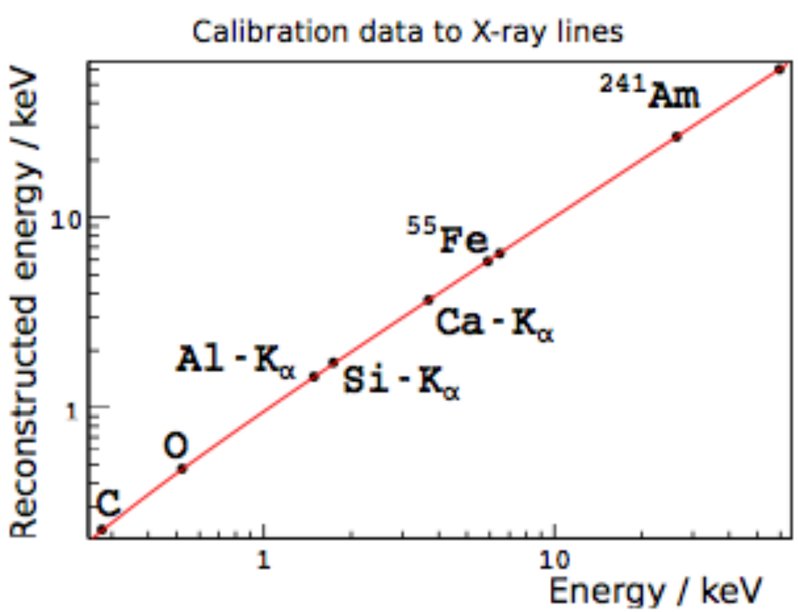
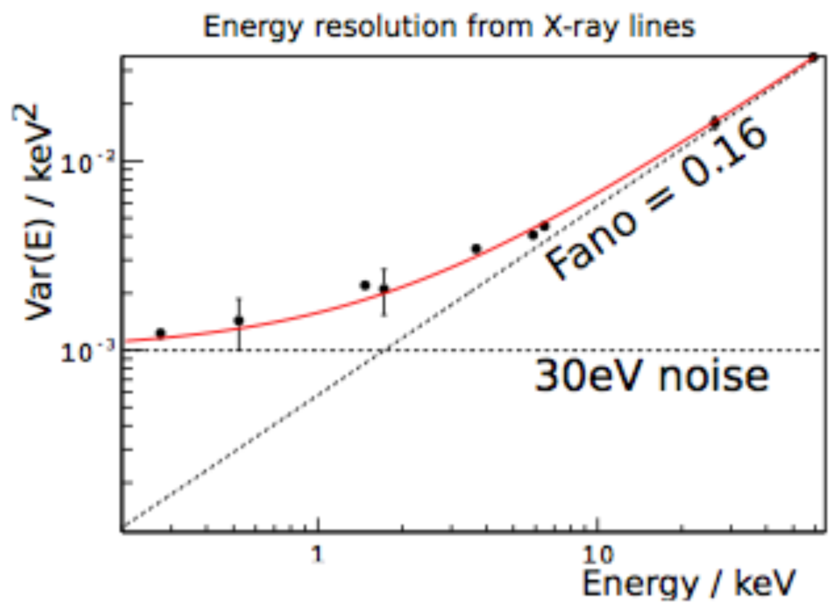
# CCDs calibration with X-rays

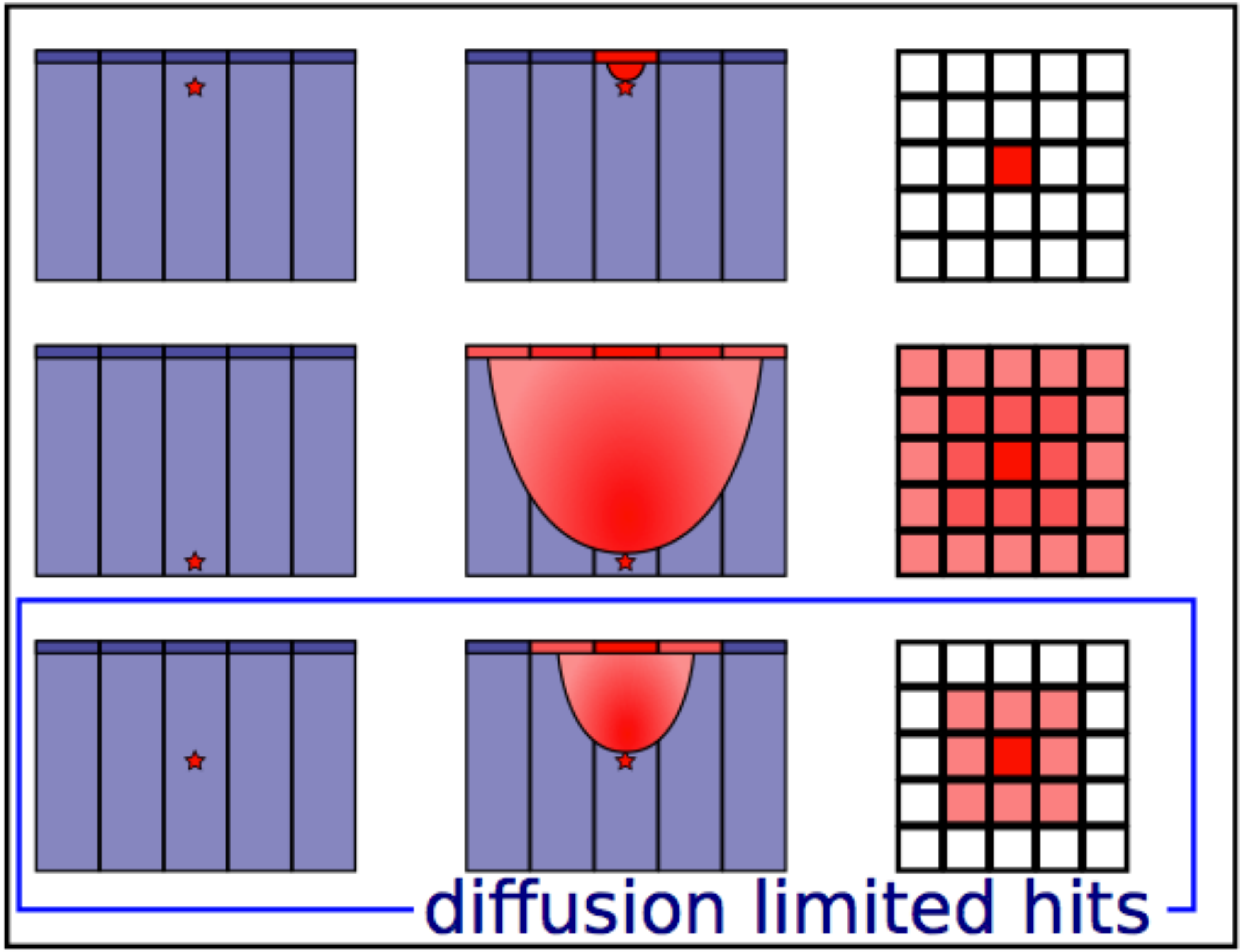


# Charge Coupled Device

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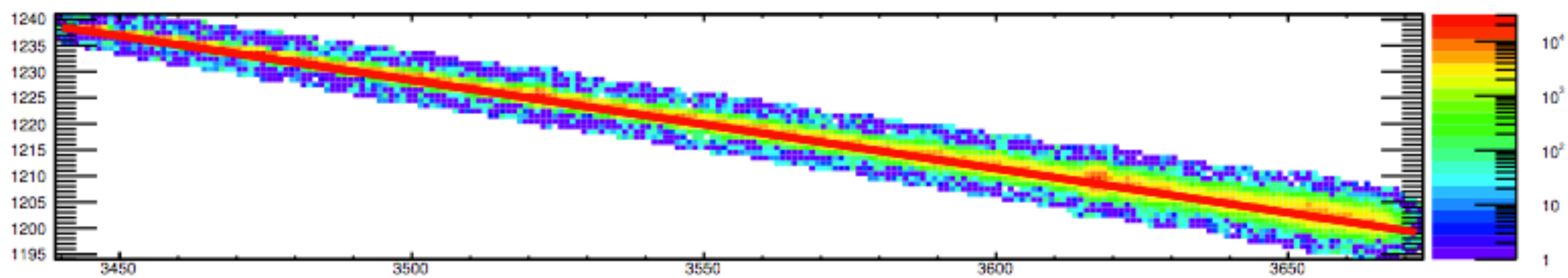
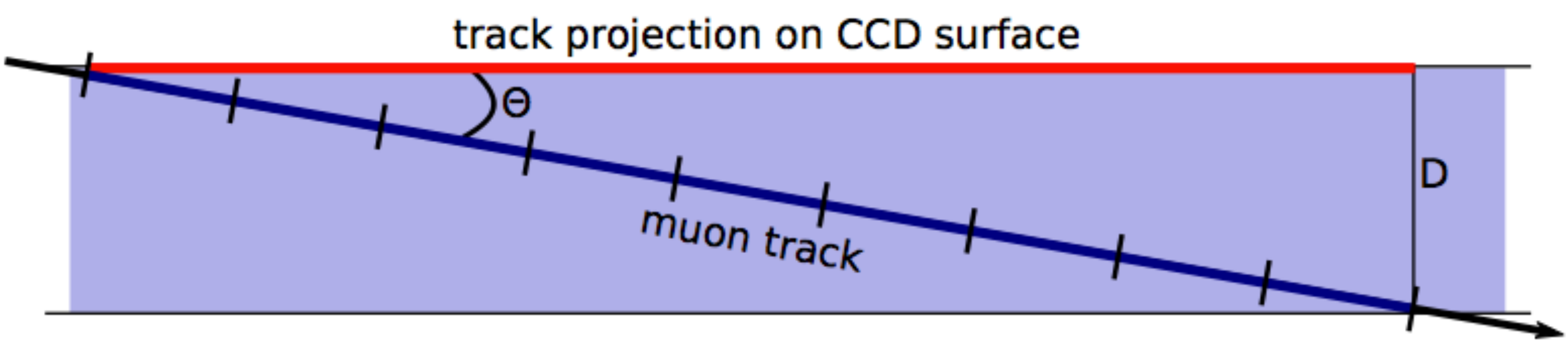
# Diffusion from data

Using the muon track in the CCD

- Recorded track: CCD top view




- CCD side view

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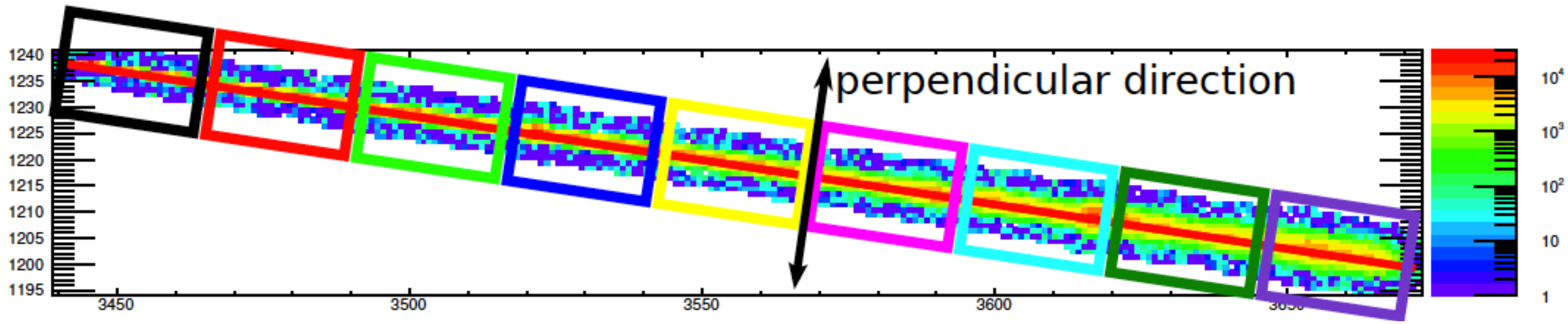
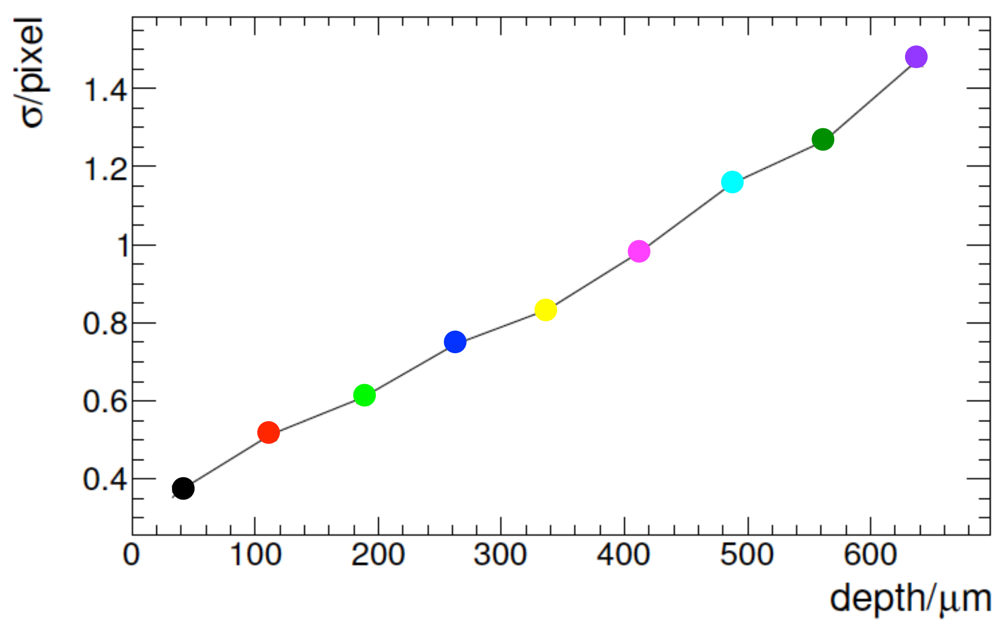
# Diffusion from data

Diffusion can be measured as a function of the interaction depth

No need to rely on models.

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# Diffusion from data

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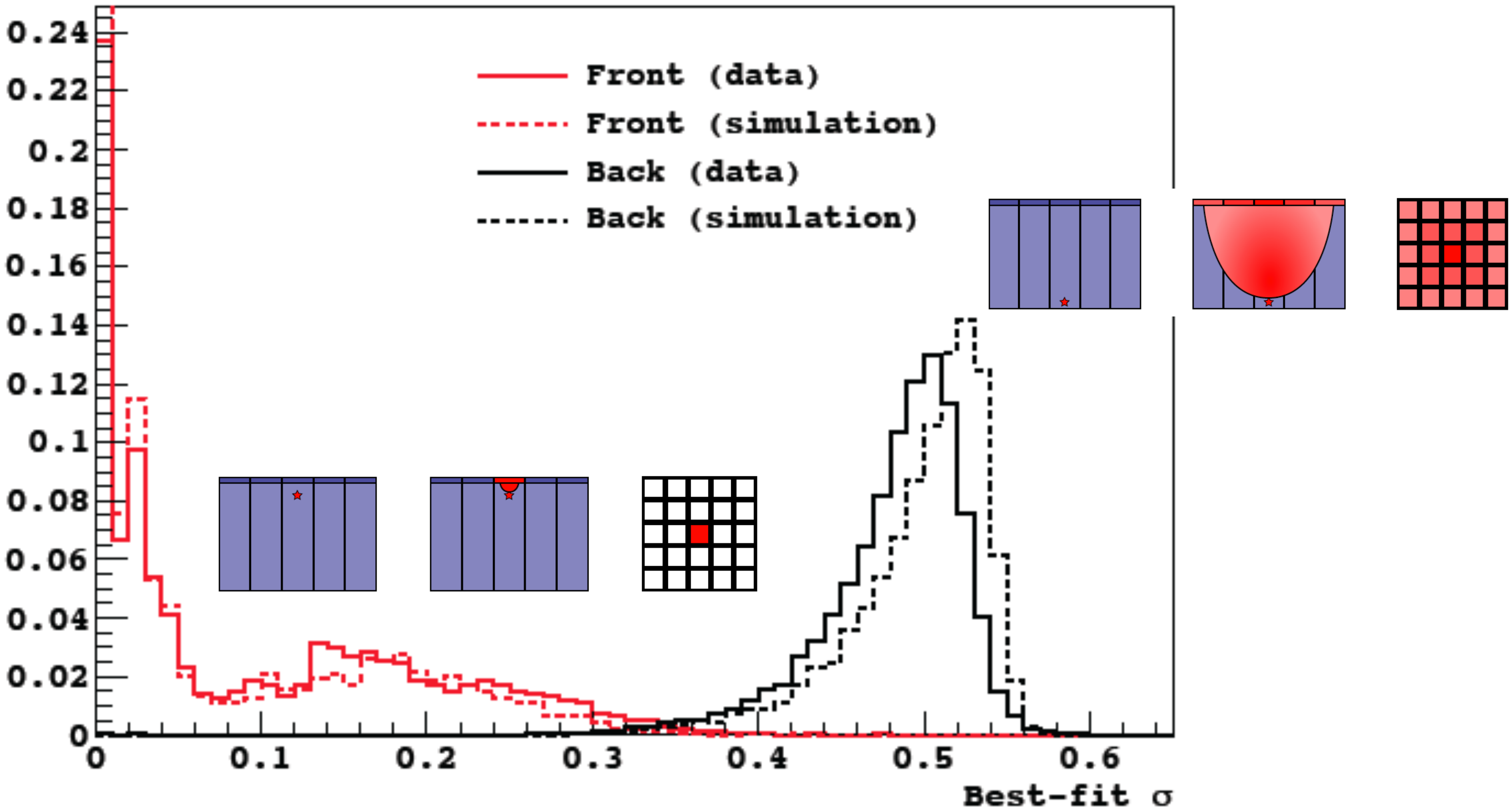
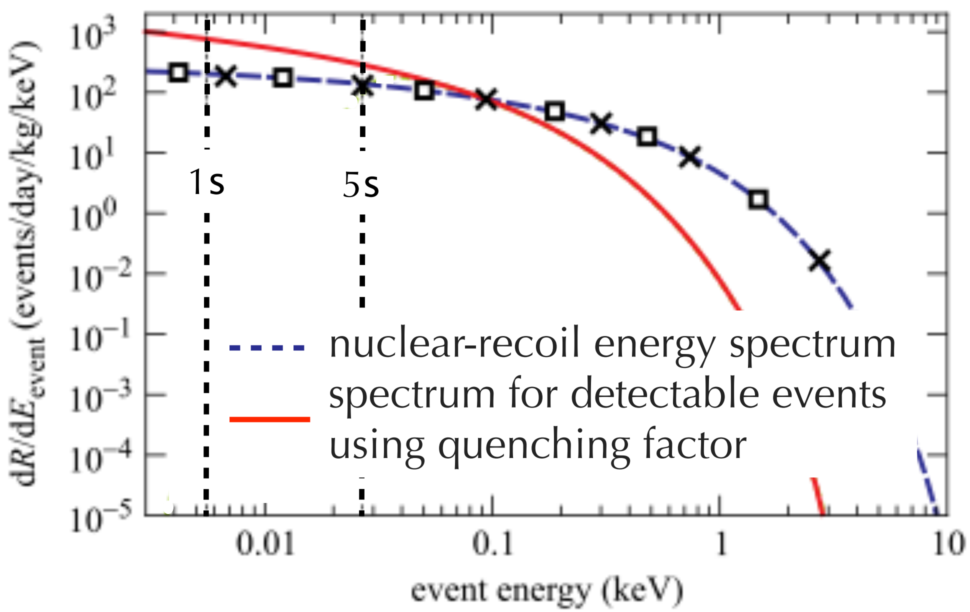


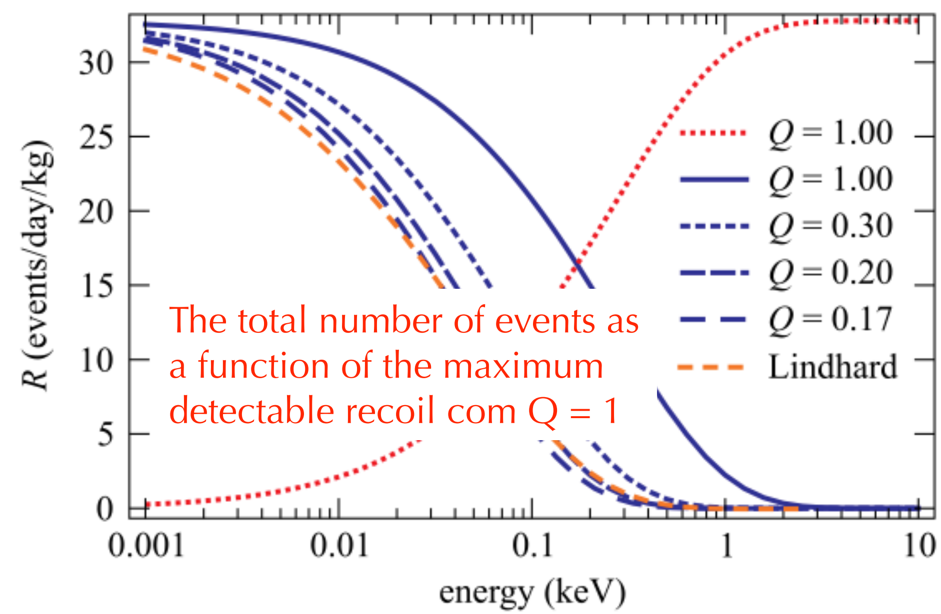

Diffusion can be modeled with a Gaussian distribution with lateral deviation from 0 to 0.55 pixels.

# Expected event rate for the Angra reactor

Energy spectra for expected events in silicon detectors




Total number of events as a function of the threshold energy for different constant quenching factors

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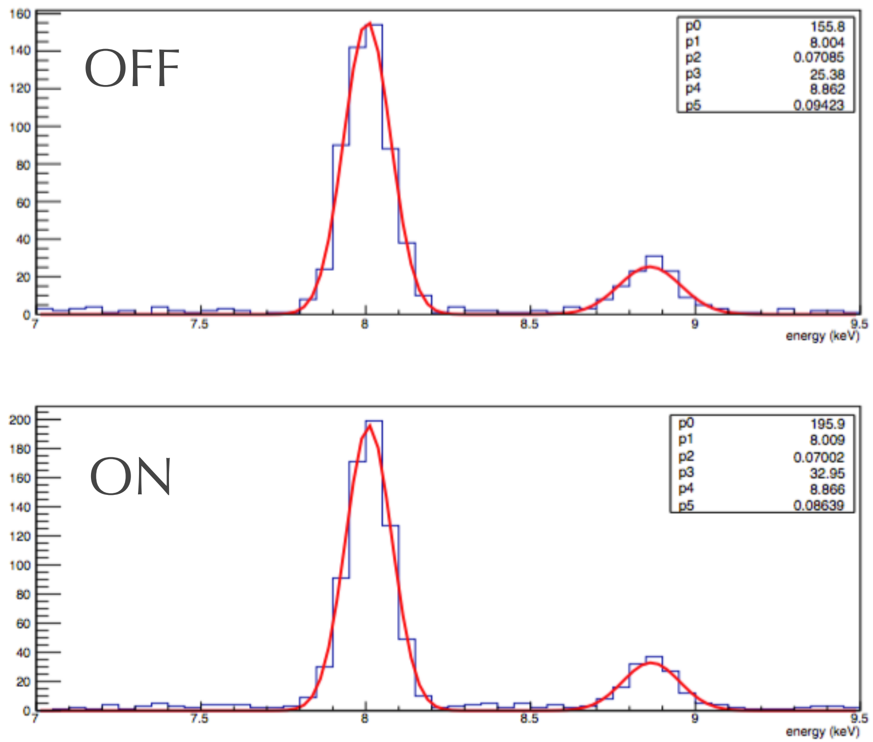
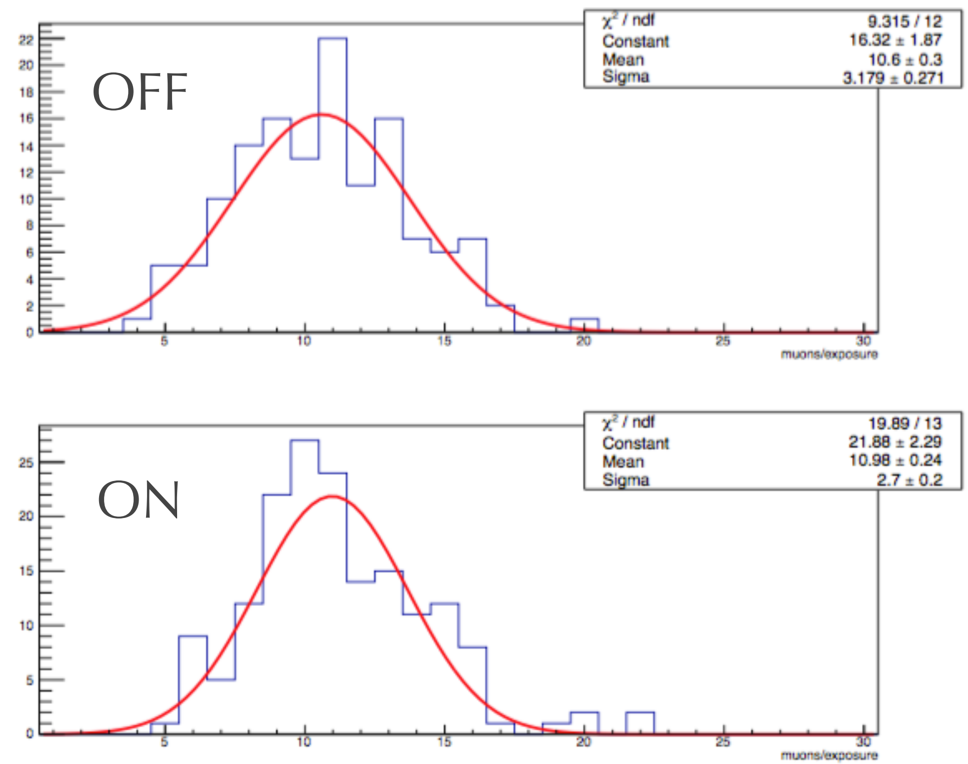
| | Expected number of events (event/kg/day) | |
|---|---|---|
| $E_{th}$ = 5.5 eV ($1\sigma_{RMS}$) | ~ 28.3 | $Q = 0.20$ |
| $E_{th}$ = 28 eV ($5\sigma_{RMS}$) | ~ 18.1 | |

# Performance & Resolution




Cu fluorescence peaks for data collected with reactor OFF and ON




Muon events detected for each 8700 second exposure for reactor OFF and ON

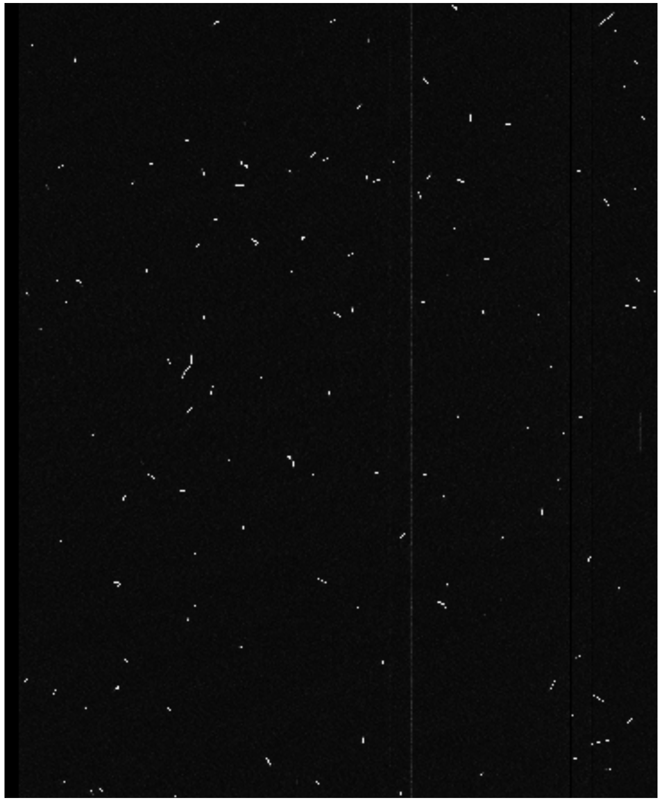
# The detector – Taking data

Finishing the shield

Testing the system

# The detector – Images

No shield



Phase I

Phase II

# Forecast

- Assuming
  - 52 g detector array (10 CCDs with 650 mm)
  - the background at sea level using passive shield can be reduced to **~600 events/keV/day/kg, i.e. 8.5 events/day**
  - the rate of expected false positive is 3.18 events/day
- Expected running time for different CL for a detector's **mass of 52 g**

| CL [%] | T (days) |
| --- | --- |
| 80 | 12 |
| 90 | 28 |
| 95 | 45 |
| 98 | 70 |
| 99 | 150 |

- **We need 150 days of running for a 3s detection**

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