The CONNIE experiment

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for the CONNIE collaboration

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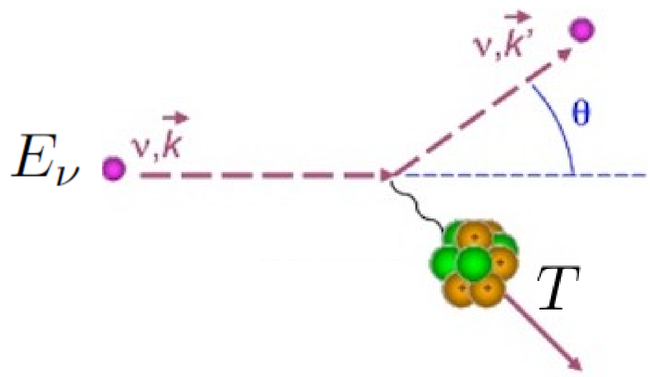
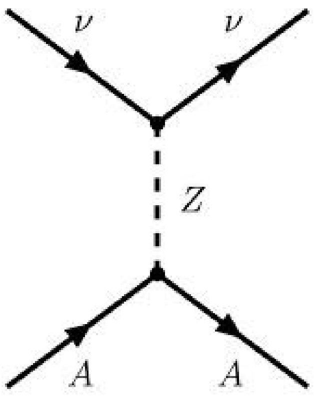
Motivation

- Coherent Neutrino–Nucleus Elastic Scattering (CNNES):
  - → for neutrino energies below 50 MeV
  - → SM prediction but never measured!
  - → new tool for neutrino experiments (very short baseline oscillation experiments – low energy)
  - → MeV-neutrino physics has great relevance for energy transport in supernovae
  - → monitor nuclear reactors through their emitted neutrinos
  - → CNNES of solar+atm neutrinos forms an irreducible background to future direct dark matter searches → *“neutrino floor”*.
- Unique features of high resistivity CCDs designed by Berkeley Laboratories:
  - very low energy threshold detectors: 5.5 eV ($\sigma_{RMS} \sim 1.5\ e^-$)
  - large mass compared to regular CCDs
  - “3D” information: event reconstruction
  - used in the Dark Energy Survey (DES) experiment and Dark Matter in CCDs (DAMIC) experiment

Coherent ν-N Elastic Scattering

CNNES is a neutral-current interaction. A neutrino of any flavor scatters off a nucleus (eg. Si) transferring some energy in the form of a nuclear recoil.





atomic number of the nucleus

neutron number of the nucleus

mass of the nucleus

$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2}{8\pi}\left[Z(4\sin^2\theta_W - 1) + N\right]^2 M\left(2 - \frac{TM}{E_\nu^2}\right)\ |f(q)|^2$$

$f(q)$ is the nuclear form factor at momentum transfer q

For E_ν < 50 MeV the momentum transfer (q^2) is small

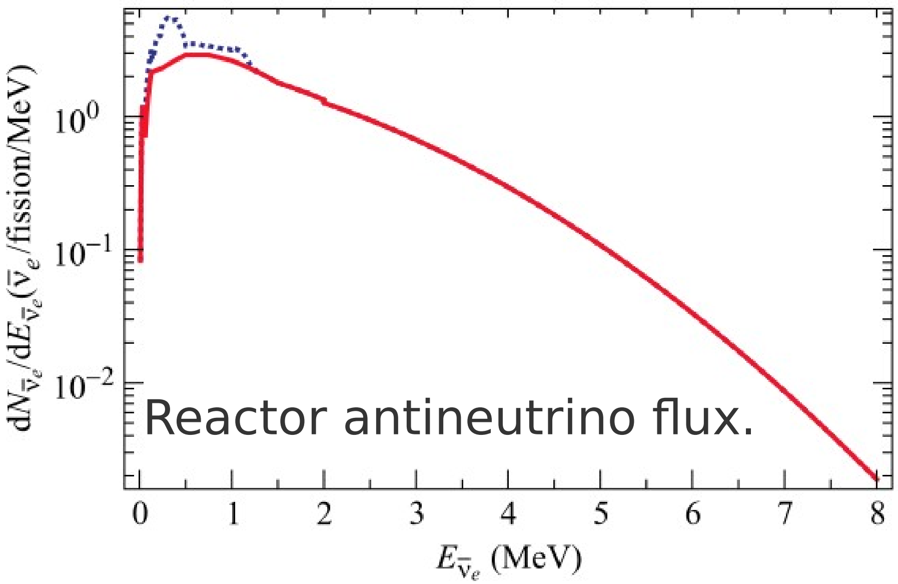
q^2R^2 < 1 (R = the radius of the nucleus)

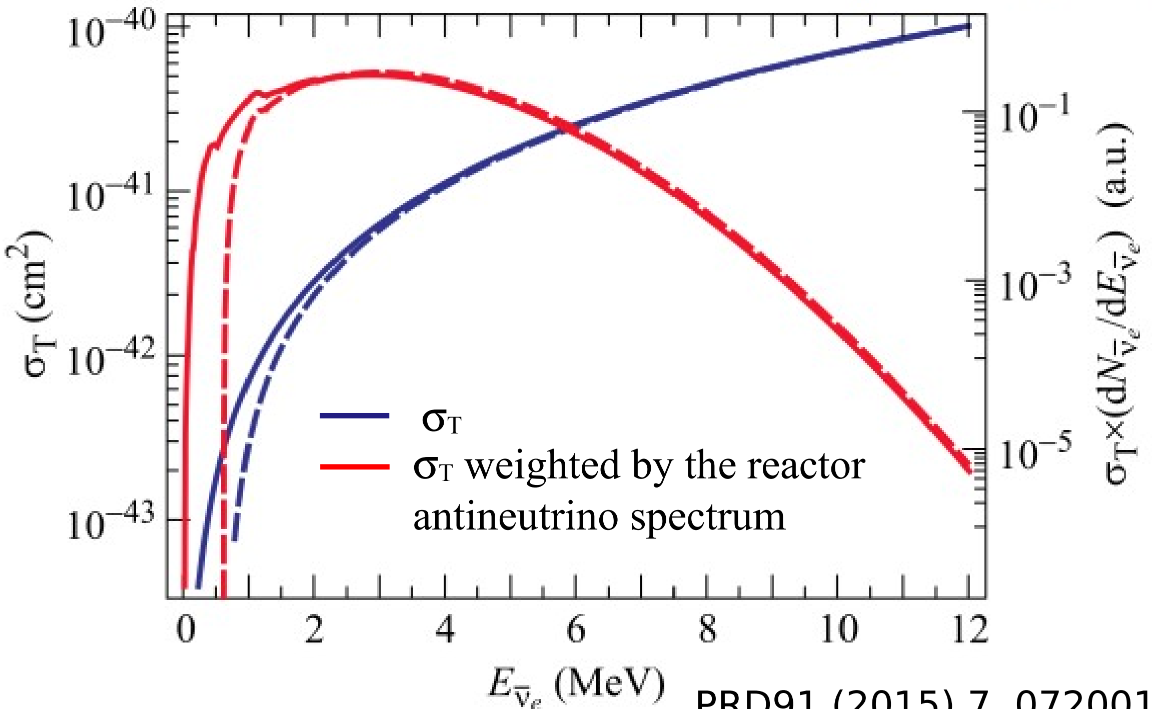
$|f(q)| \approx 1$ within an uncertainty of a few percent.

Coherent ν-N Elastic Scattering

CNNES is a neutral-current interaction. A neutrino of any flavor scatters off a nucleus (eg. Si) transferring some energy in the form of a nuclear recoil.

$$\sigma_{\mathrm{T}}(E_{\bar{\nu}_e}) = \frac{G_F^2}{4\pi}[Z(4\sin^2\theta_W - 1) + N]^2 E_{\bar{\nu}_e}^2$$
$$\approx 4.22 \times 10^{-45} N^2 E_{\bar{\nu}_e}^2$$





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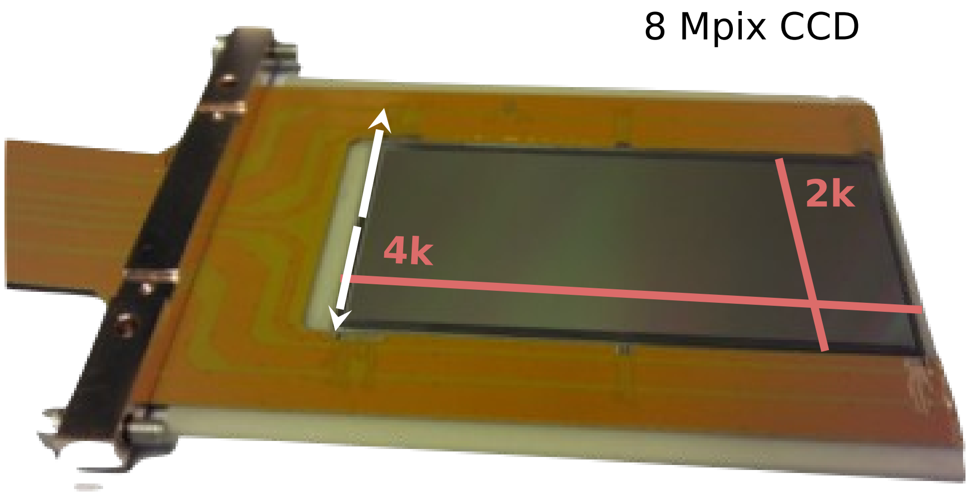
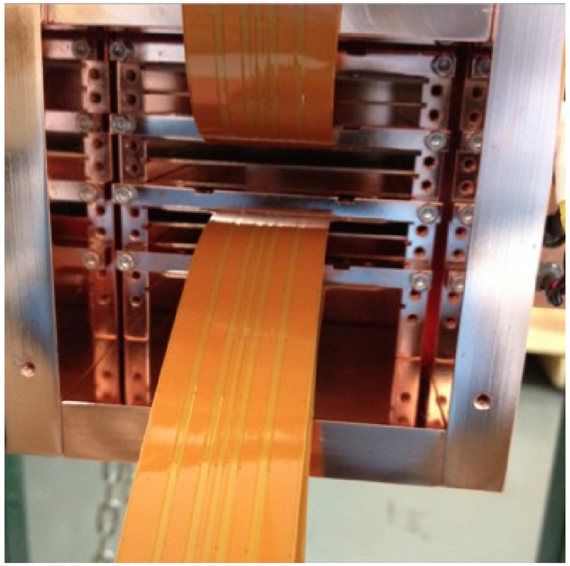
Charge Coupled Device

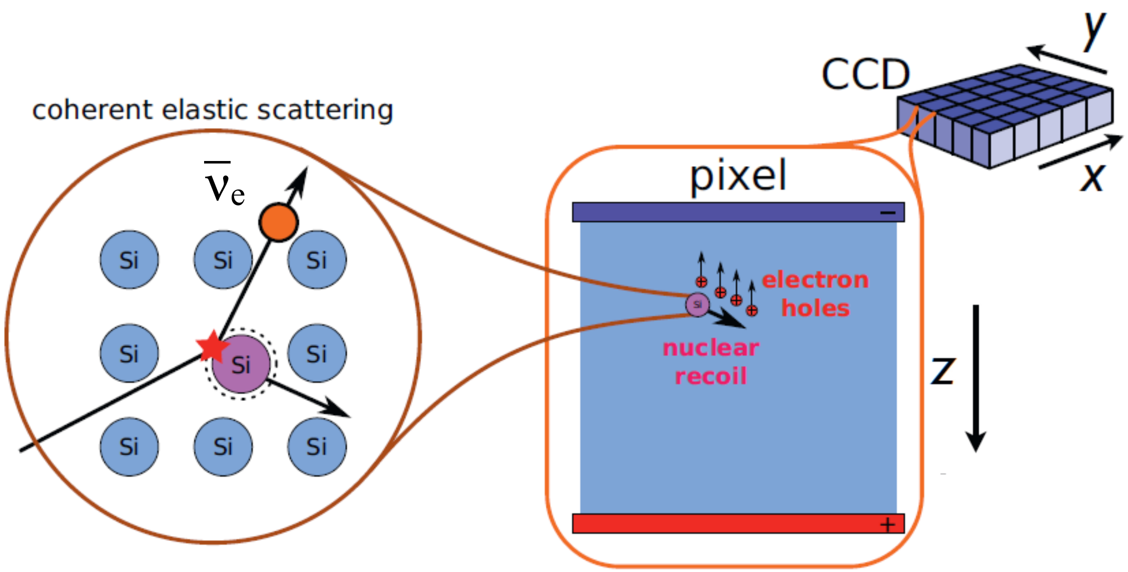




Scientific CCDs developed by LBNL microsystems LAB

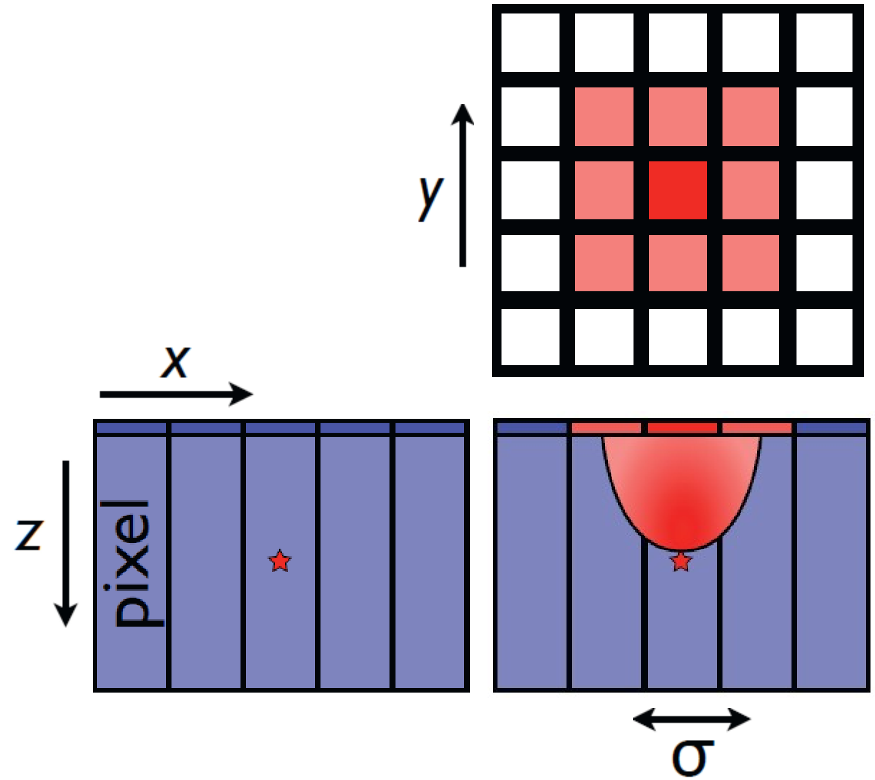
- pixel size of 15 μm X 15 μm
- thicker than most CCDs (250 - 675 μm)
  - up to 5.2 gr/CCD
  - diffusion → 3D reconstruction → rejection of surface events
- CCDs cooled to 140 K to achieve readout noise RMS < 2 e^-
- Energy threshold of ~0.05 keVee

Charge Coupled Device



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

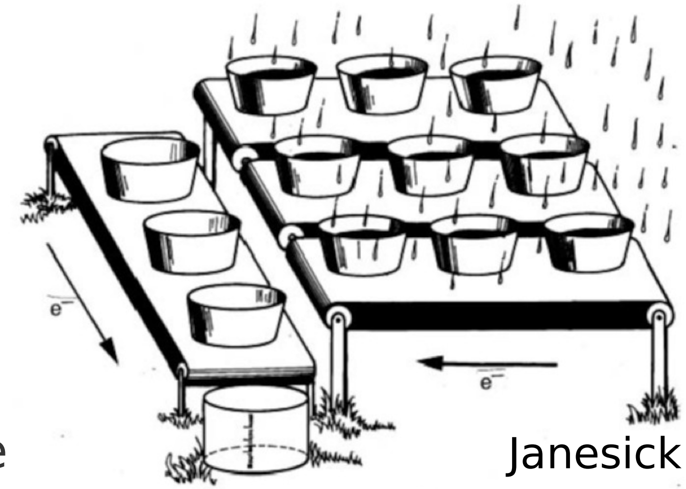
Charge carriers are drifted along z direction and collected at CCD gates



Charge diffuses in *x*-*y* plane as it drifts towards the gates

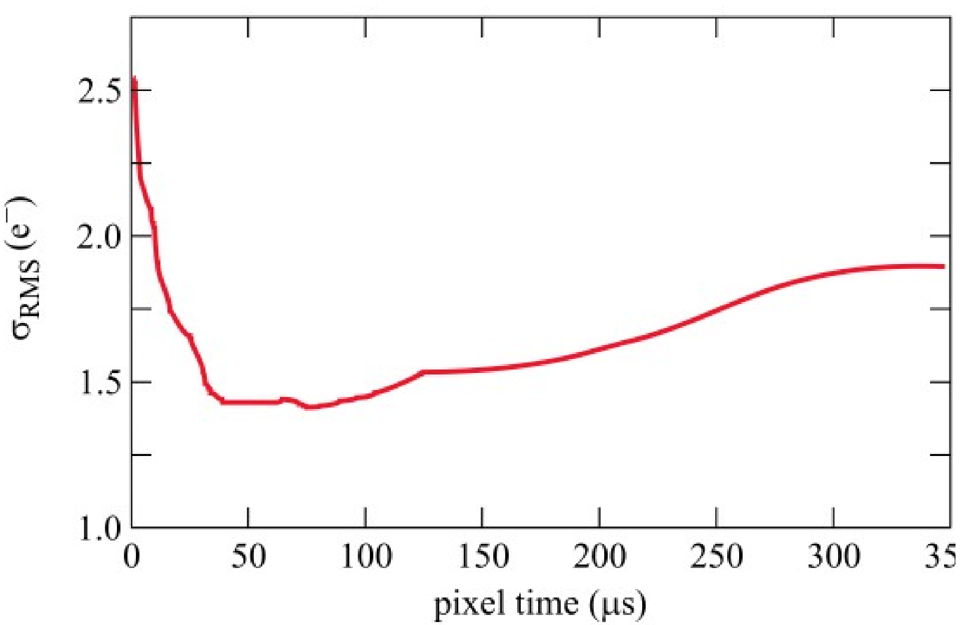
We fit the radial spread of the cluster to estimate its position in z within the CCD bulk

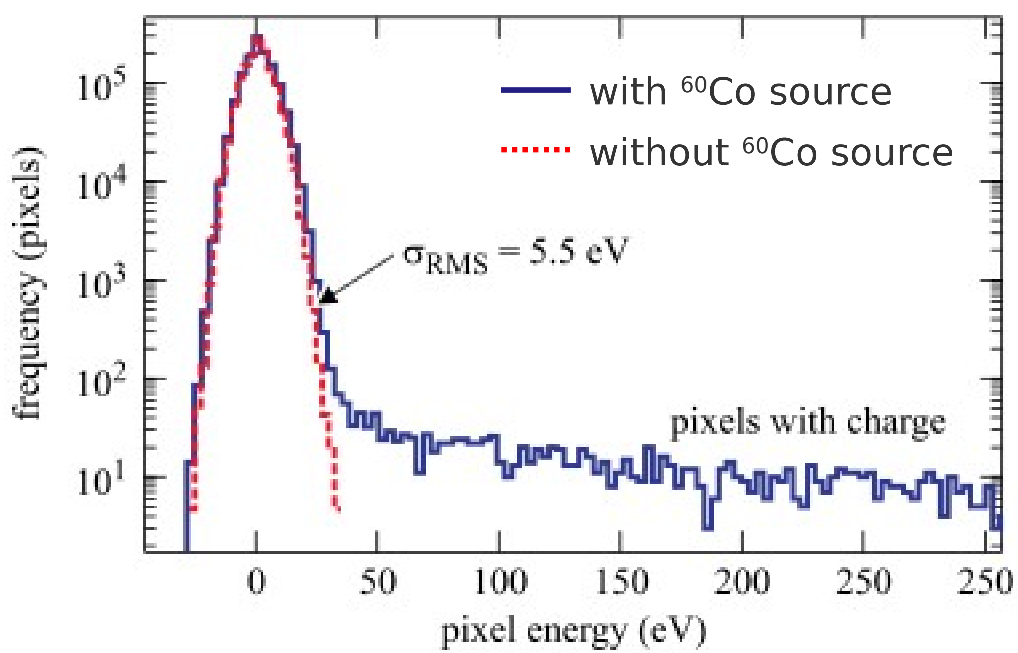
CCD readout - Noise



Janesick

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





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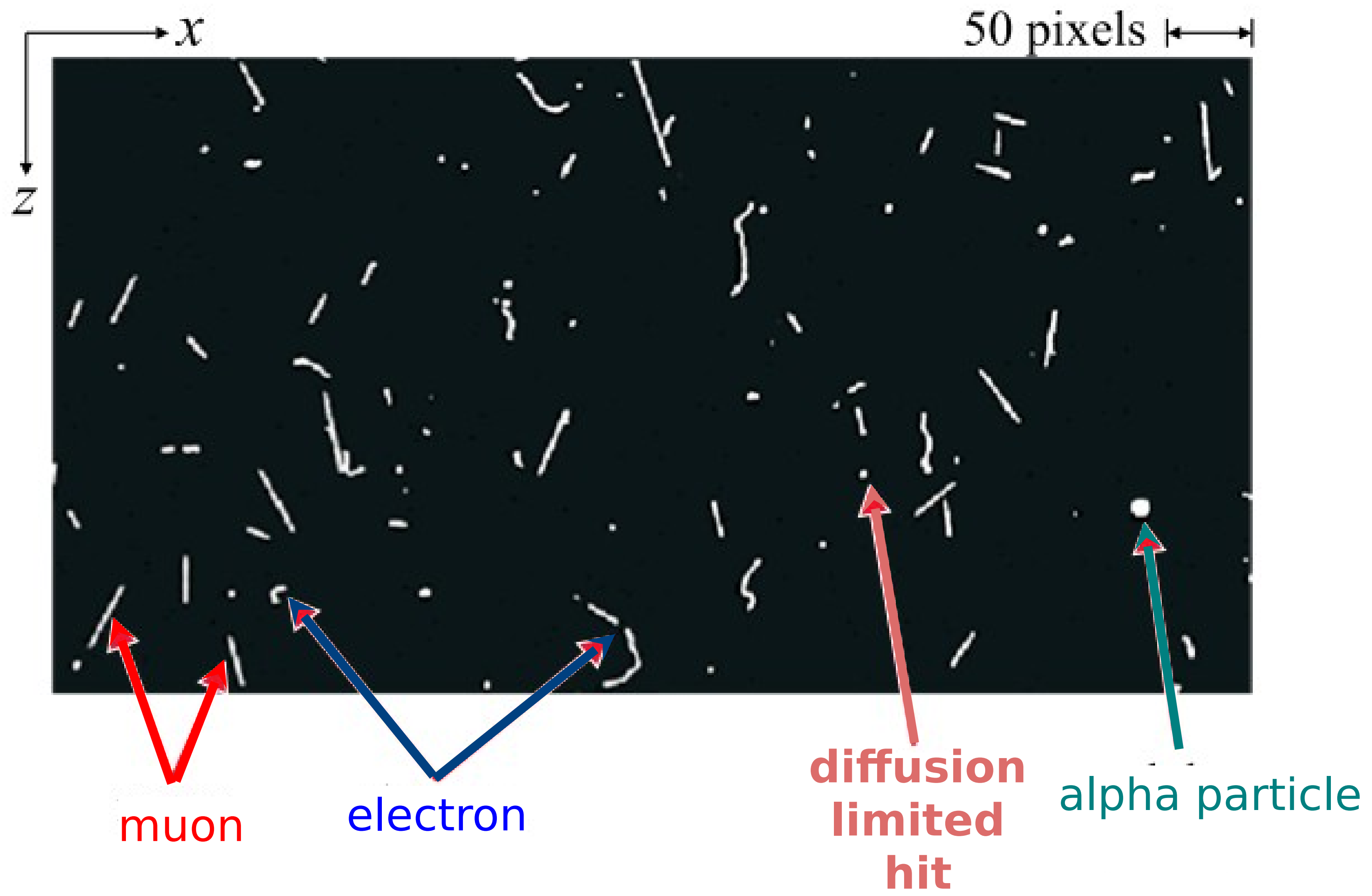
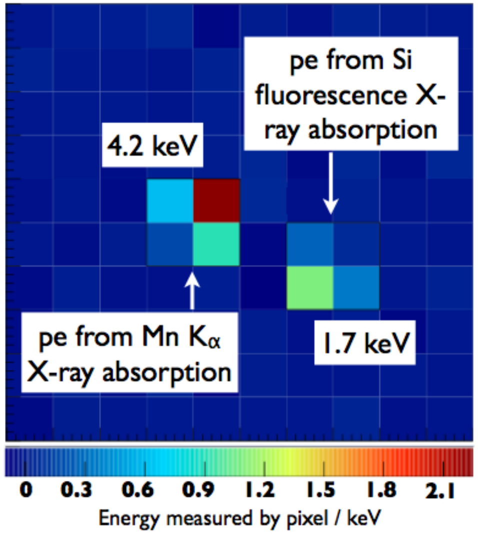
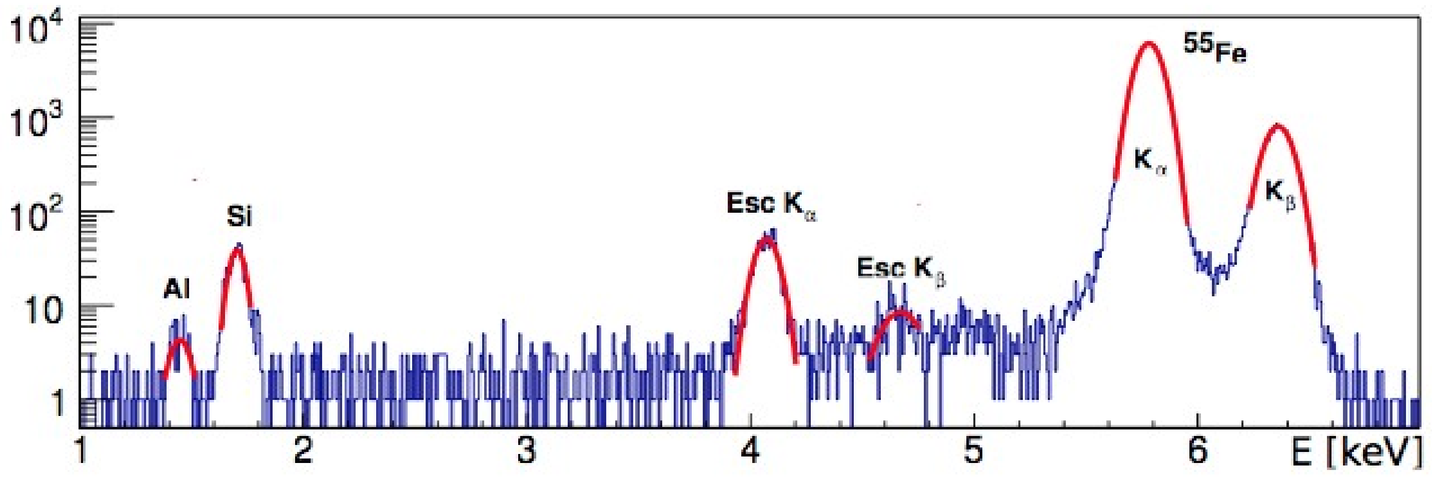
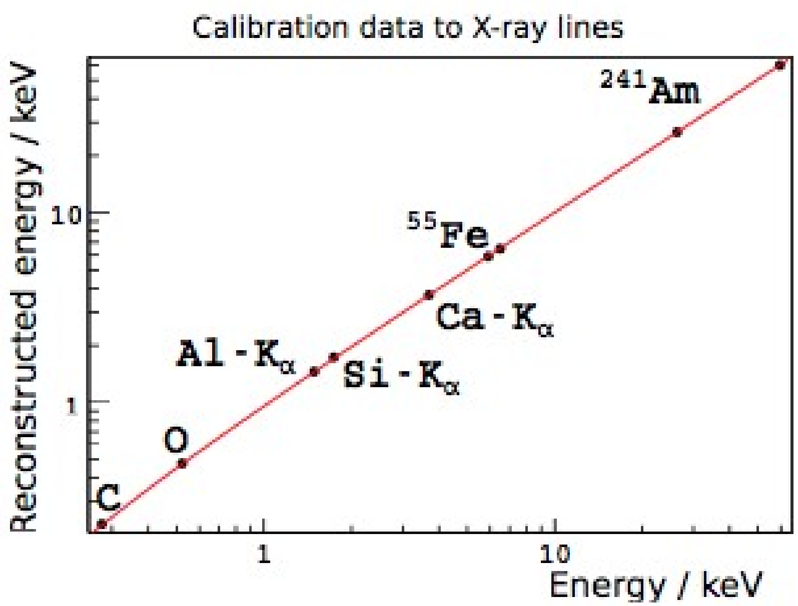
Particle identification CCD

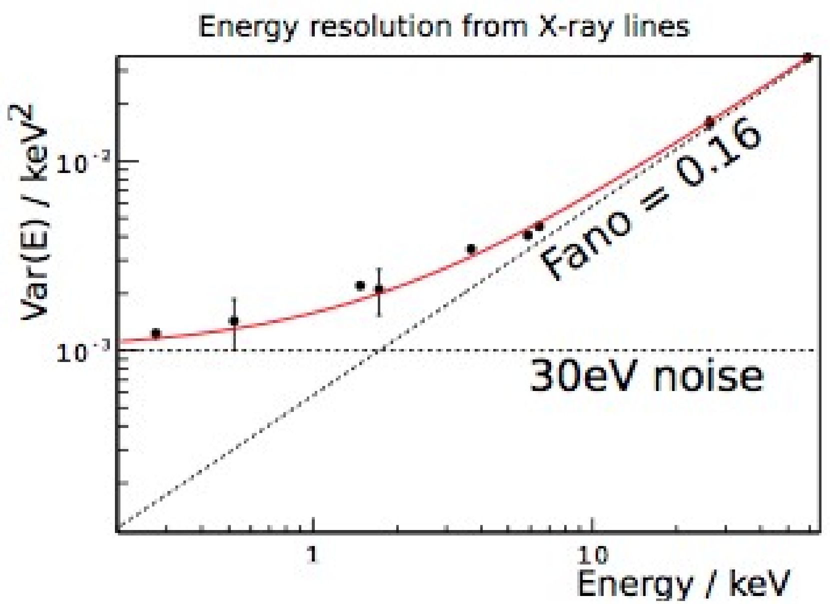


CCDs calibration with X-rays



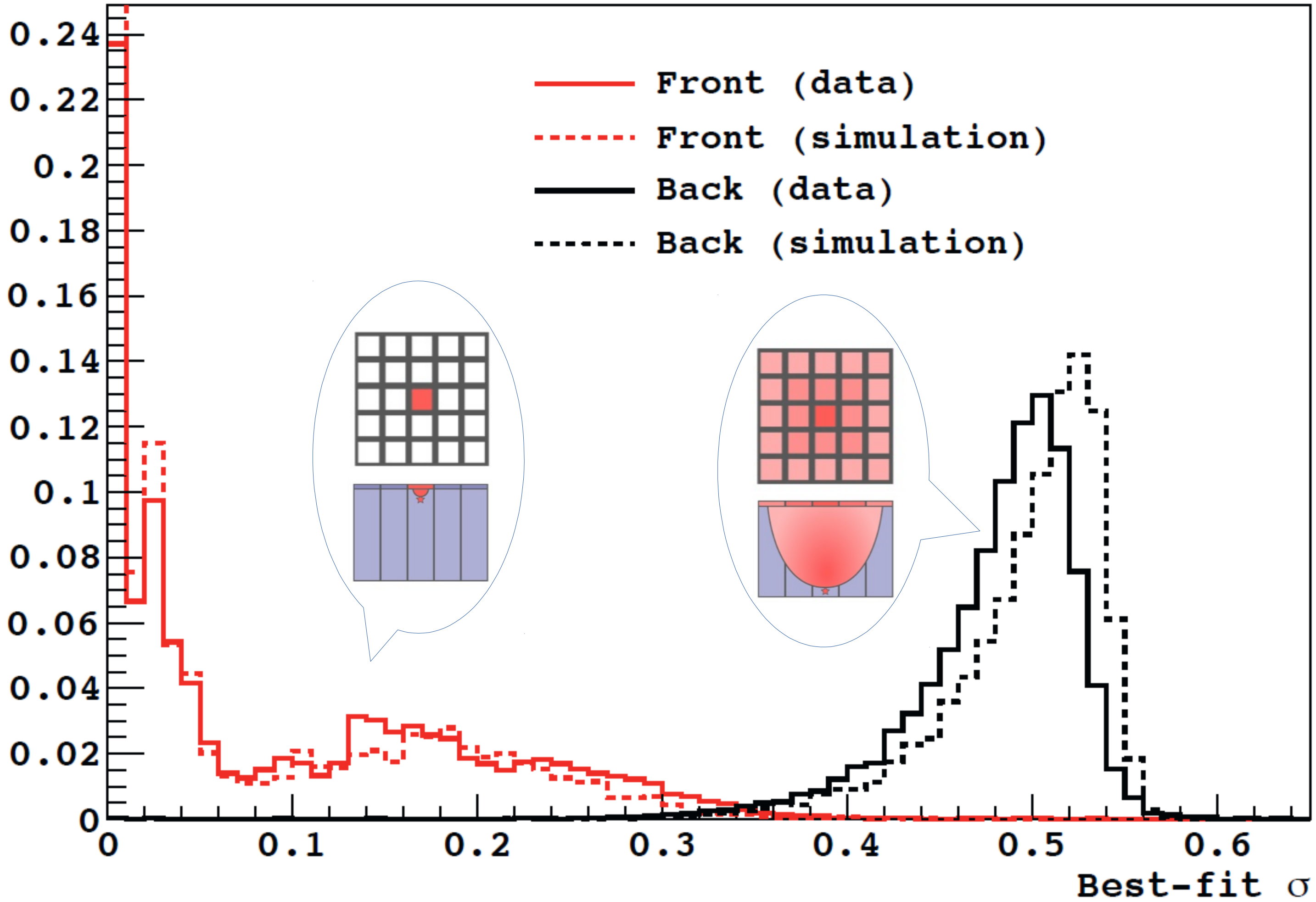






Diffusion from data

X-rays, 250 μm CCD PRD91 (2015) 7, 072001



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

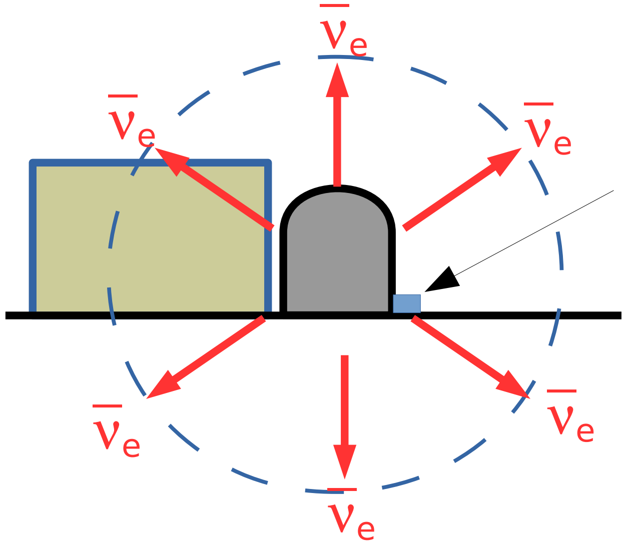
Angra Nuclear Power Plant

Angra Nuclear Power Plant, Flux

Angra-2 is a 3.95 GW_{th} Pressurized Water Reactor (PWR)

Emits ~8.7×10^{20} $\bar{\nu}_e\, s^{-1}$ (2.23×10^{20} $\bar{\nu}_e\, s^{-1} GW_{th}^{-1}$)

At 30 m the flux is ~7.8×10^{20} $\bar{\nu}_e\, cm^{-2}\, s^{-1}$.



$$fisRate = \frac{3.95\ \mathrm{GW}_{th}}{205.24\ \mathrm{MeV/fis}} \approx 1.2 \times 10^{20}\ \mathrm{fis/s}$$

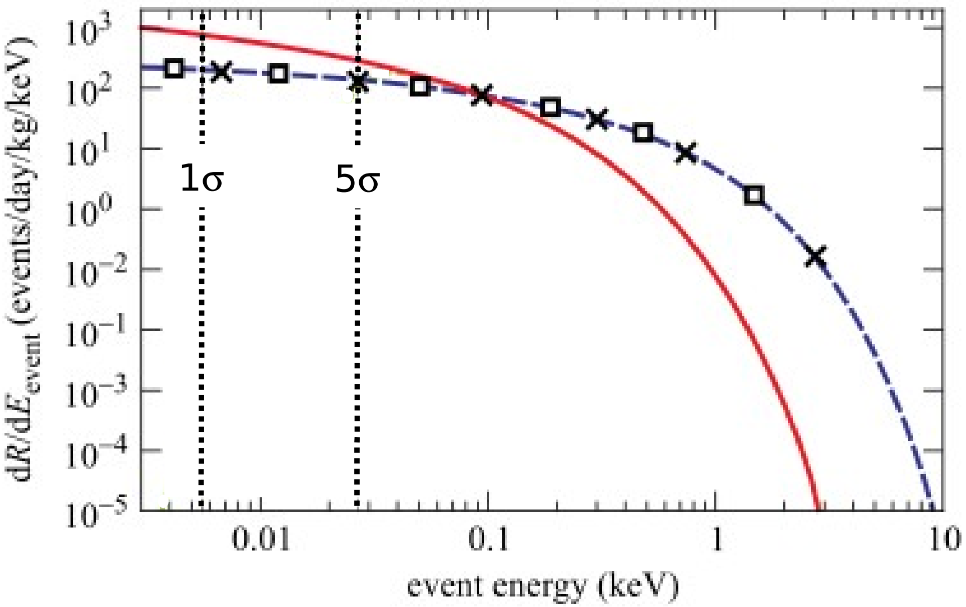
Dominant processes	(E release)	fis.frac.	$\bar{\nu}_e$/proc	$\bar{\nu}_e$/fis
^{235}U fission	202 MeV	0.56	6.14	3.43
^{238}U fission	205 MeV	0.08	7.08	0.56
^{239}Pu fission	210 MeV	0.30	5.58	1.67
^{241}Pu fission	212 MeV	0.06	6.42	0.38
n-capture on ^{238}U	202 MeV	0.60	2.00	1.20

<E rel> = 205.24 MeV/fis

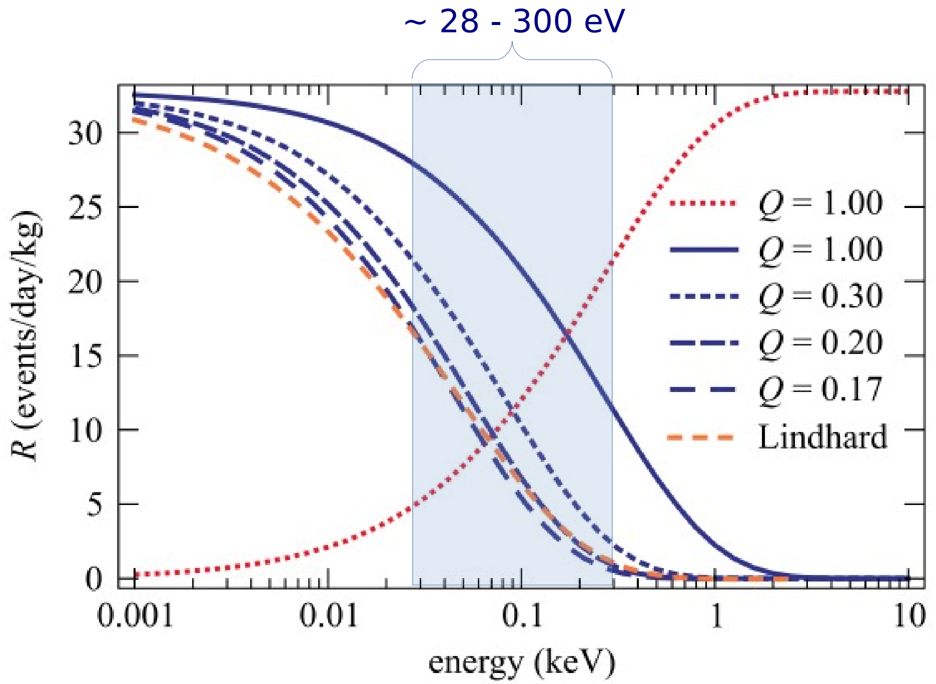
Tot: 7.24

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 quenching factors



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- nuclear-recoil energy spectrum
- spectrum for detectable events using quenching factor

The total number of events as a function of the maximum detectable recoil (Q = 1)

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

$Q = 0.20$

Forecast

- Assuming:
  - a 52 g detector array (10 CCDs with 650 μm)
  - Energy threshold of ~28 eV, signal in 28 – 300 eV window.
  - 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

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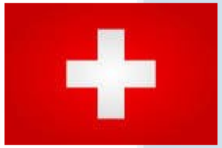
- We need 150 days of running for a 3σ detection

CONNIE collaboration

Argentina
Centro Atómico Bariloche
Universidad del Sur / CONICET

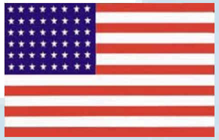
Paraguay
Universidad Nacional de Asunción

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

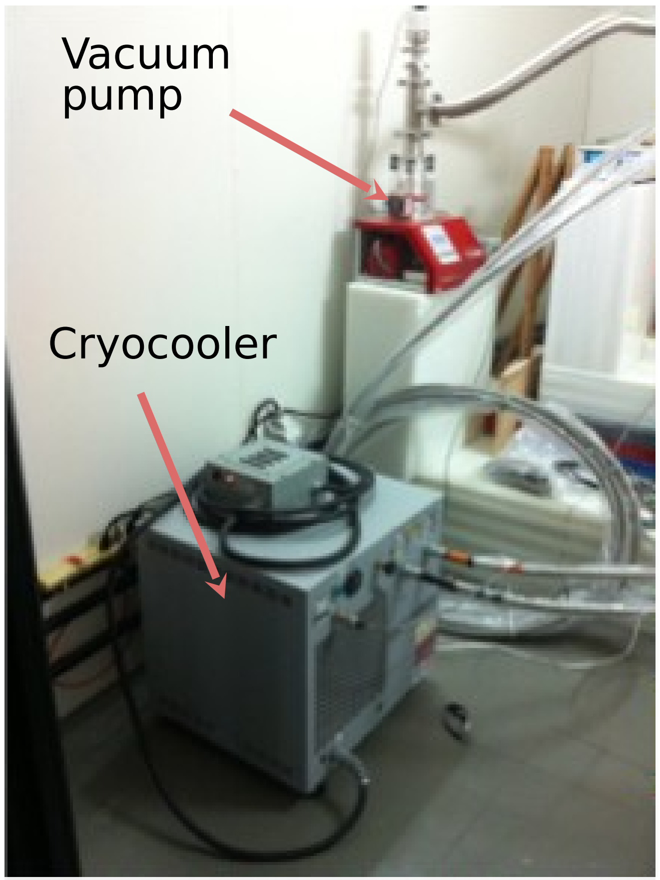
About 20 people

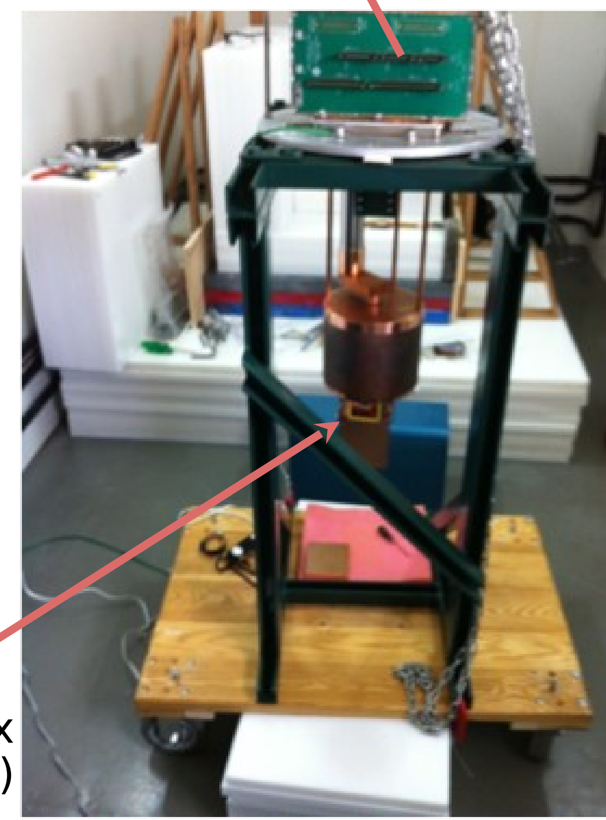
Timeline

- First visit in 2011
- Seriously making a plan in 2013
- Installed a prototype in 2014
  - Detector Shipping August-September 2014
  - Detector installation and first data October-November 2014 (10 grams)
  - Initial operations supported by experts (from USA and Mexico)
  - Continuous operation now supported by local team (Brazil)
  - Full shield assembly completed July-August 2015
  - 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)

The detector

During the installation (Oct-Nov/2014)

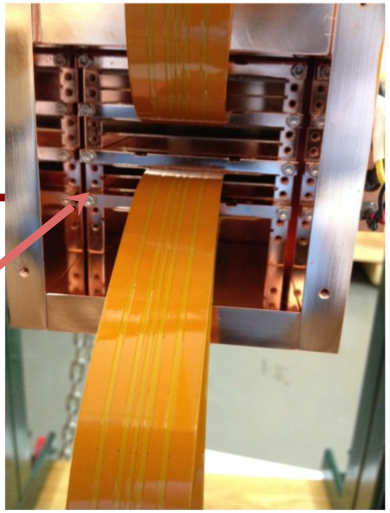


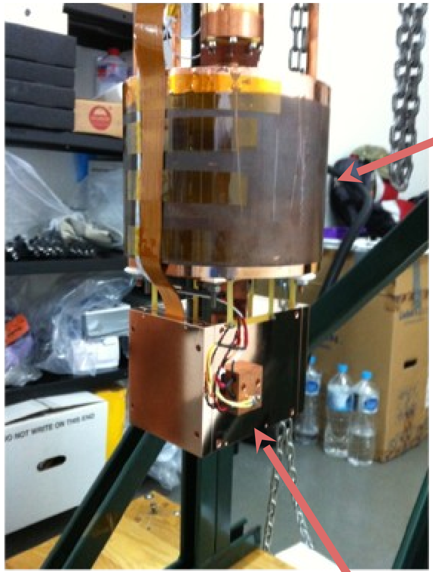


The detector

During the installation (Oct-Nov/2014)

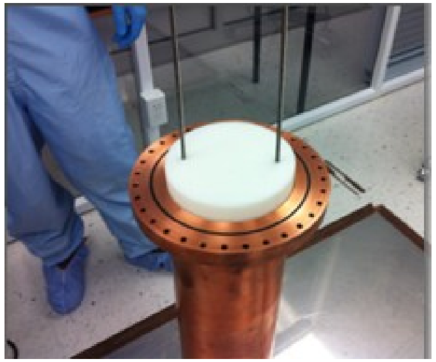
CCDs in the copper box



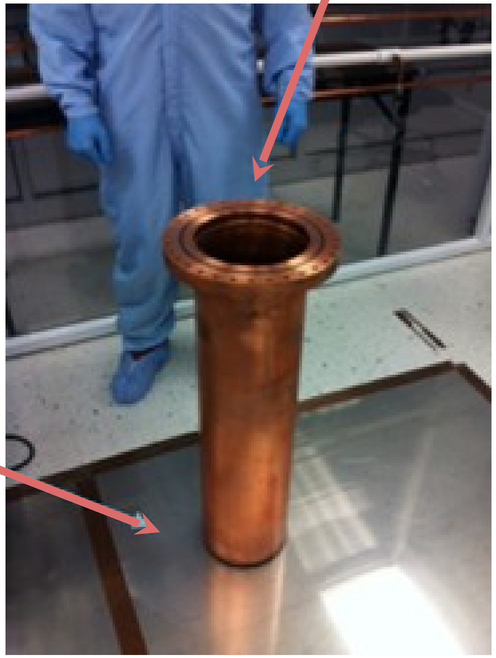


15 cm lead

Copper Box



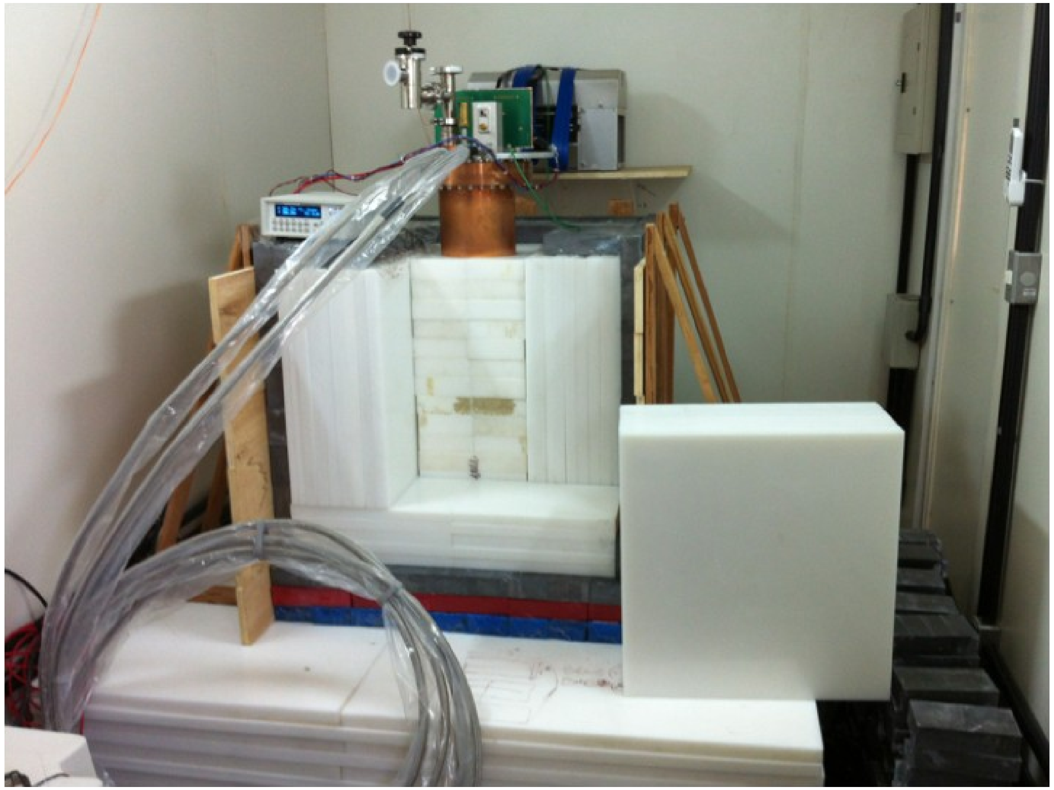
Dewar
(holds vacuum)



Inner polyethylene (half moons)

Polyethylene inside (at the bottom)

The detector – First light

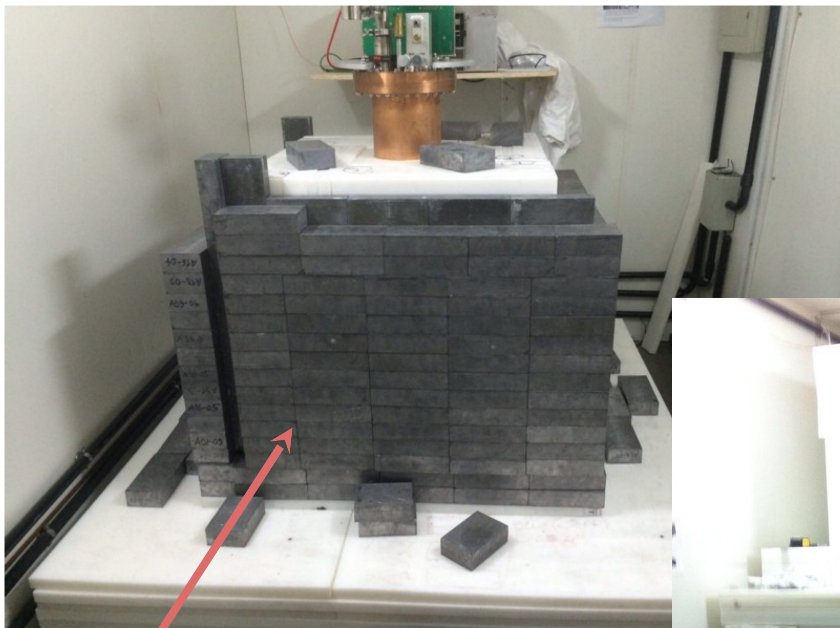


Phase I: Partial shield (30 cm polyethylene and 5 cm lead)

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

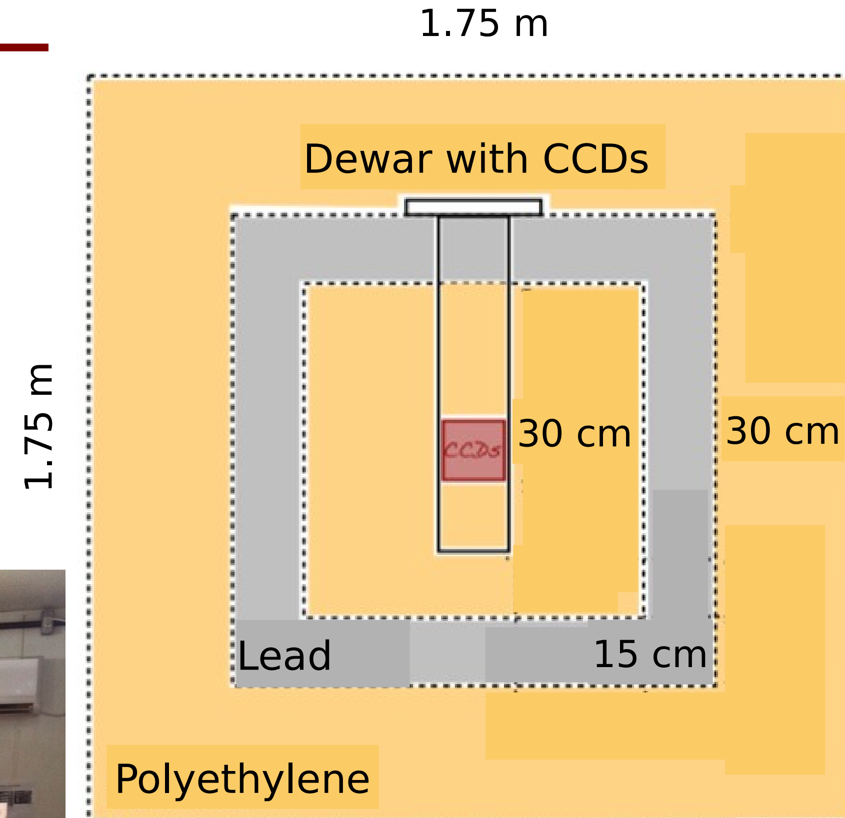
The detector – Full shield

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



15 cm lead around
30 cm polyethylene

Almost finished



Original design

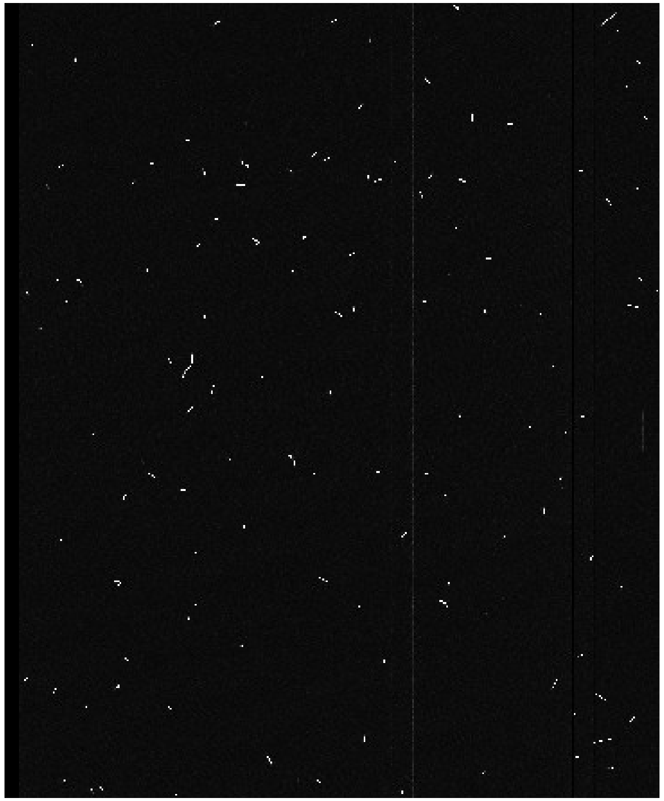
The detector – Taking data

Finishing the shield

Testing the system

The detector – Images

No shield



Phase I

Phase II

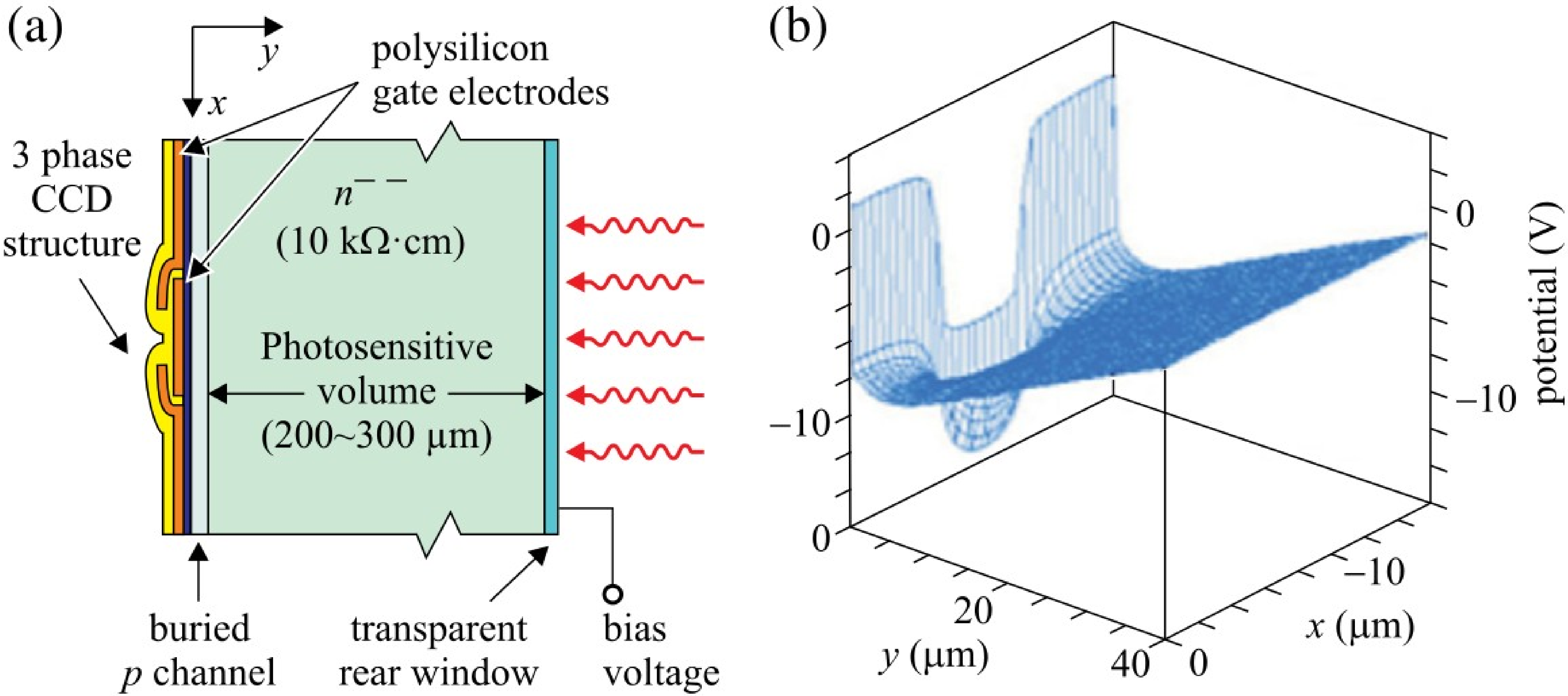
Summary

- CCDs can be used as particle detectors with good resolution and very low electronic noise
- Capability to detect nuclear recoils (DAMIC, CONNIE)
- Can be used to detect coherent neutrino-nucleus interaction 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 (paper coming out this year with first results).
- Current setup is not expected to see coherent scattering, but will measure background and is demonstrating operations at Angra.
- Plan for an upgrade to 100g of active mass in 2016.

Thank you!

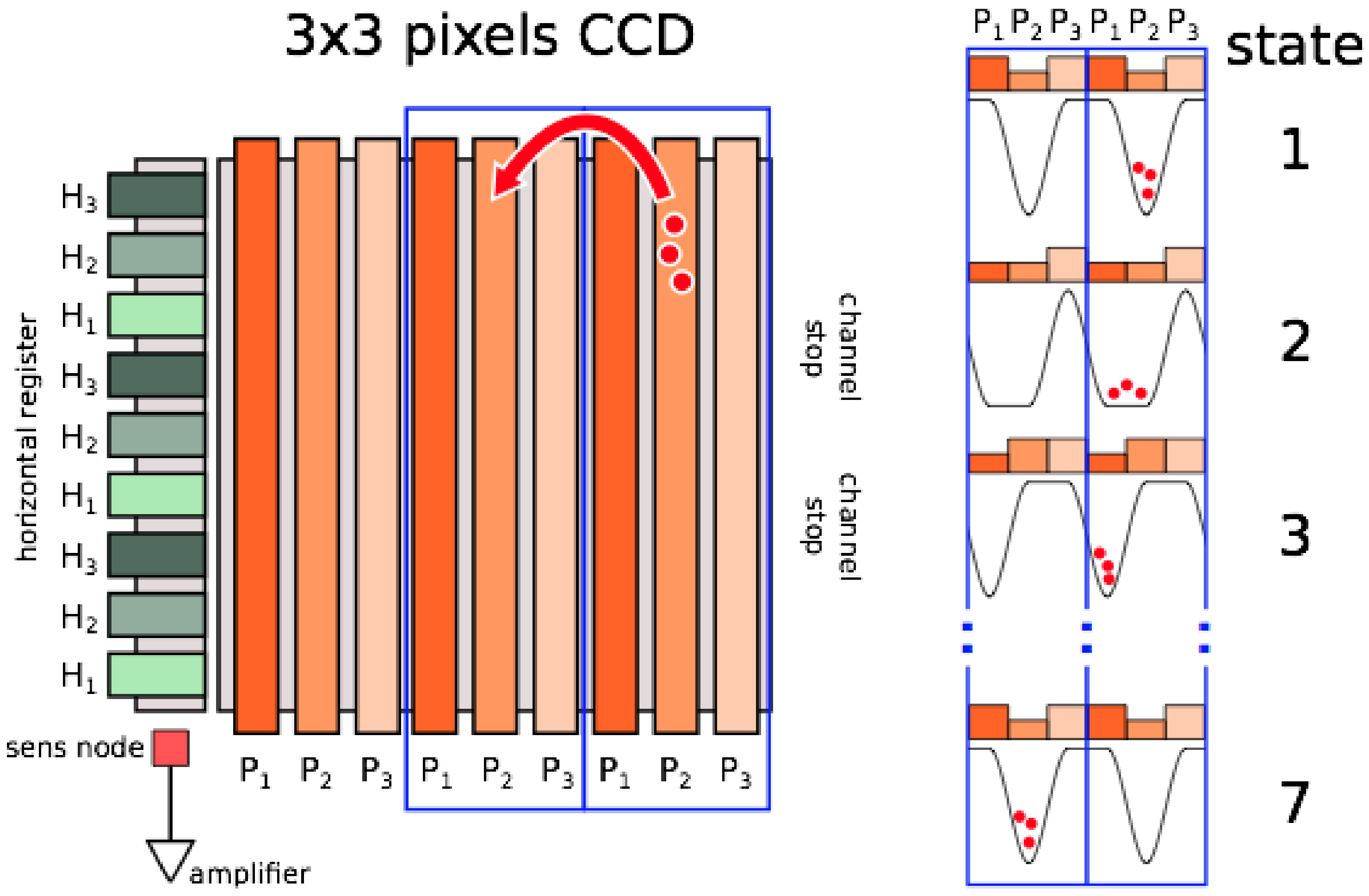
BACKUPS

CCD pixel



(a)
y
x
polysilicon
gate electrodes
3 phase
CCD
structure
n⁻⁻
(10 kΩ·cm)
Photosensitive
volume
(200~300 μm)
buried
p channel
transparent
rear window
bias
voltage
(b)
0
−10
0
20
y (μm)
40
0
−10
x (μm)
0
−10
potential (V)

CCD readout

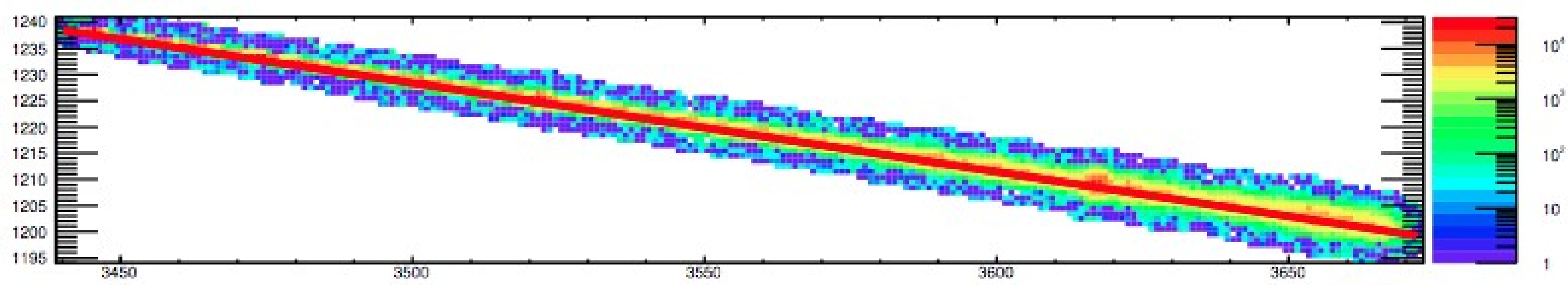


Capacitance of the system is set by the sens node: C = 0.05 pF ⇒ 3μV/e

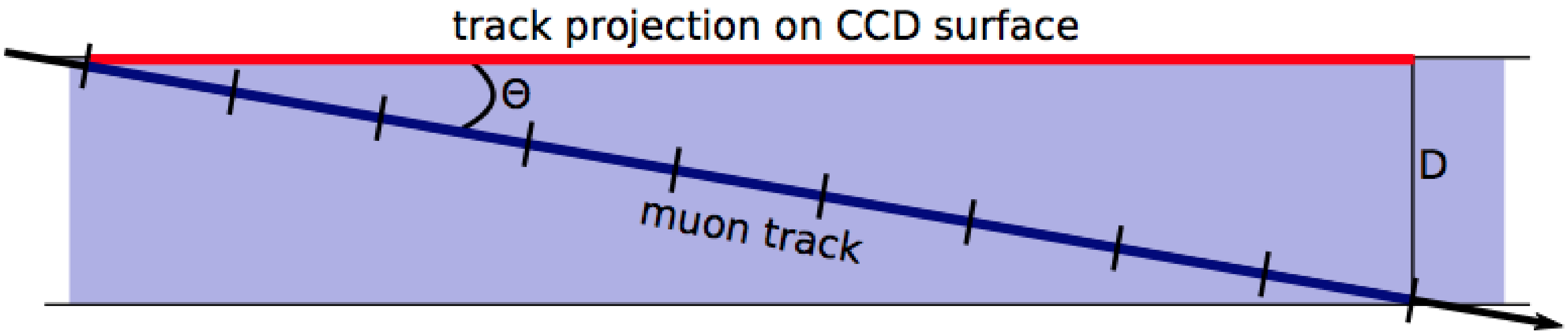
Diffusion from data

Using the muon track in the CCD

- Recorded track: CCD top view



- CCD side view



Tiffenberg

“neutrino floor” for direct DM searches