The Coherent Neutrino-Nucleus Interaction Experiment (CONNIE)

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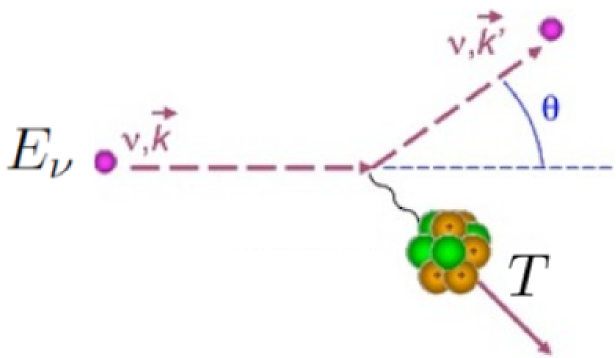
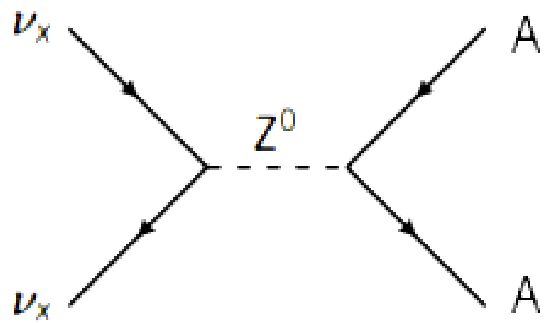
SILAFAE
Antígua Guatemala, Nov. 2016

Coherent elastic ν-N scattering

- Coherent elastic neutrino-nucleus scattering is predicted by the Standard Model, but was never measured





atomic number of the nucleus

neutron number of the nucleus

mass of the nucleus

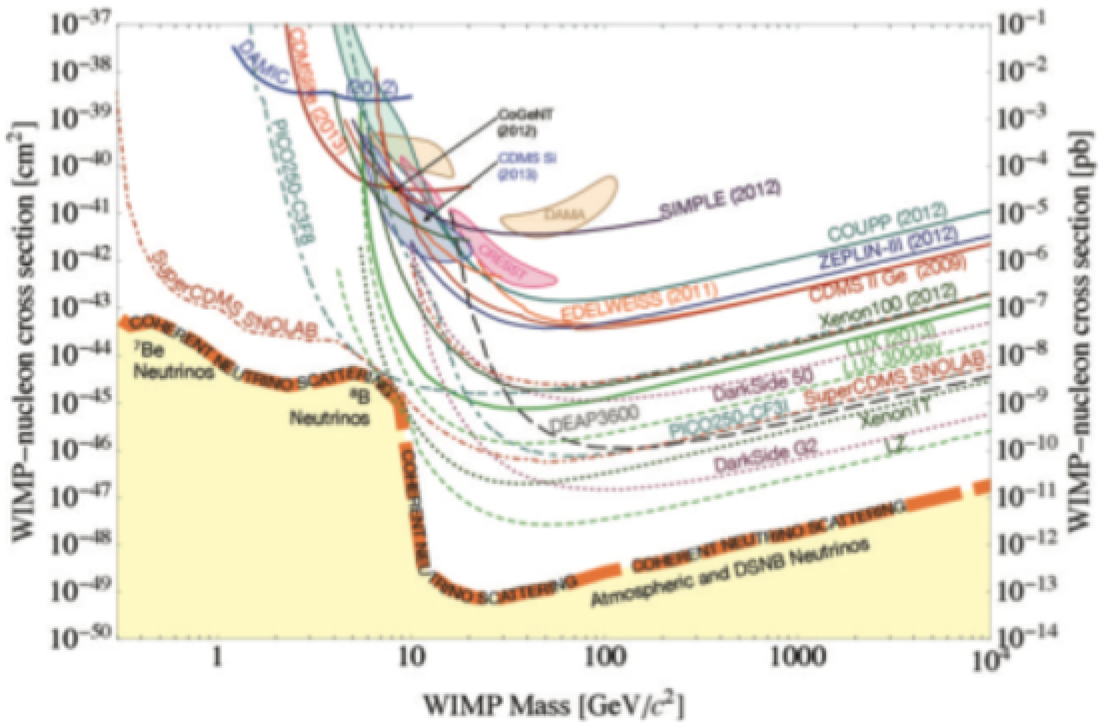
$$\frac{d\sigma}{dT}(E_\nu, T) = \frac{G_F^2}{8\pi}\left[Z(4\sin^2\theta_W - 1) + N\right]^2 M\left(2 - \frac{TM}{E_\nu^2}\right)|f(q)|^2$$

- f(q) is the form factor for momentum transfer q
- When q is small (E<50 MeV), f(q)≈1 with only small uncertainty

Motivation

Why are we interested in coherent ν-N scattering?

- The process was never experimentally measured ⟶ confirmation of the SM
- Precise theoretical CS ⟶ deviations can hint at new physics
- Implication for energy transport in supernovae
- Irreducible BG for WIMP Dark Matter searches
- New tool for neutrino experiments (at low energies, at very short baselines, etc)
- Possibility to monitor nuclear reactors via neutrinos

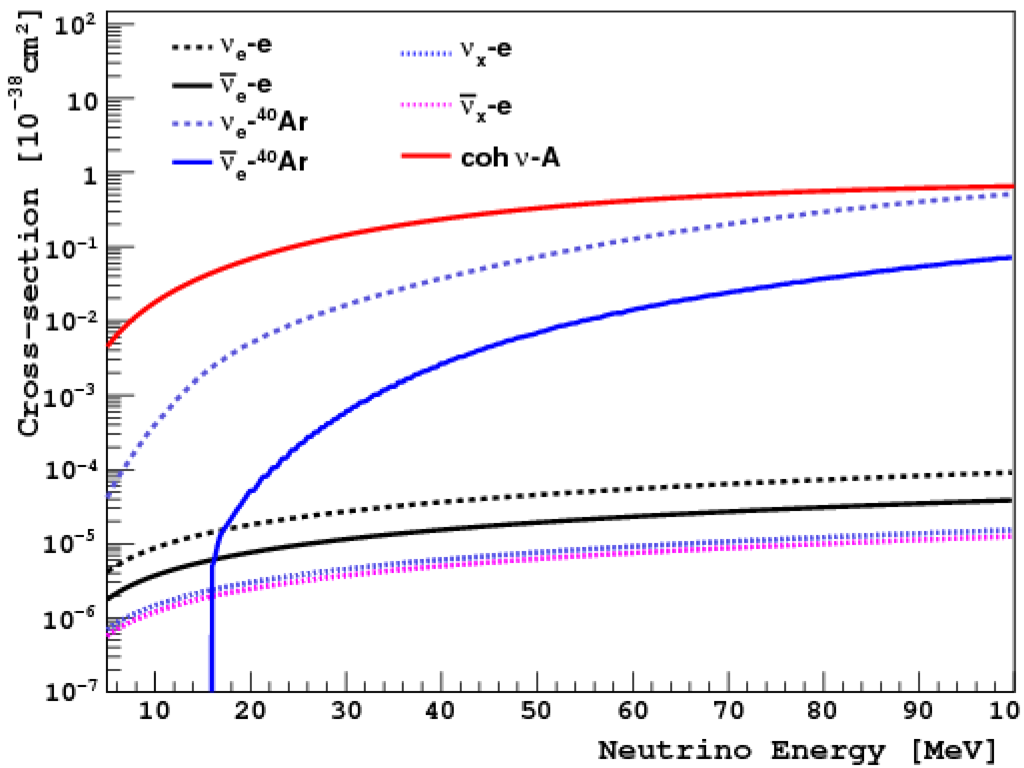


Motivation

- Below ~50 MeV coherent elastic neutrino-nucleus scattering is the dominant interaction process. Why was it never measured before?
- The recoil energies of the nucleus are tiny, in the keV-range!

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

- This is a major experimental challenge!

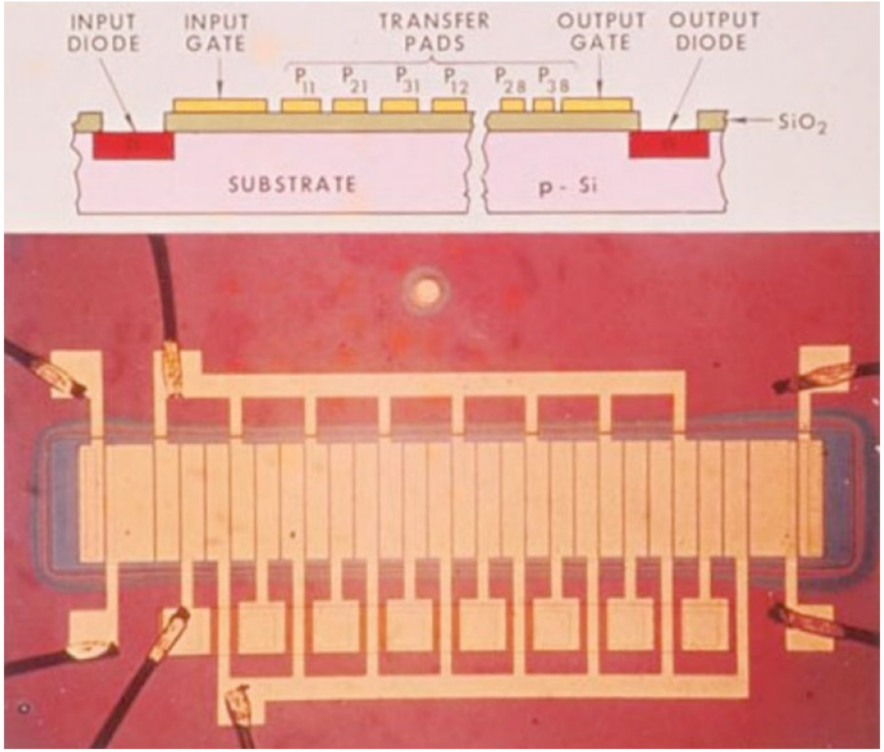


The CONNIE experiment

Charge-coupled devices (CCDs)

Concept: using CCDs for particle detection and „take pictures" of neutrino events

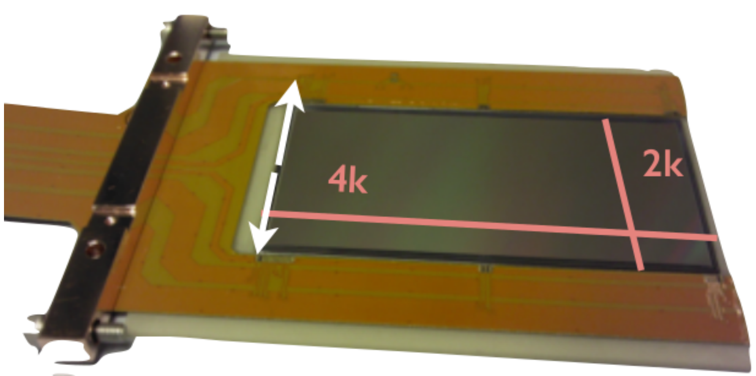
- Established technology with wide range of applications
- First CCD in 1974, Nobel Prize in 2009

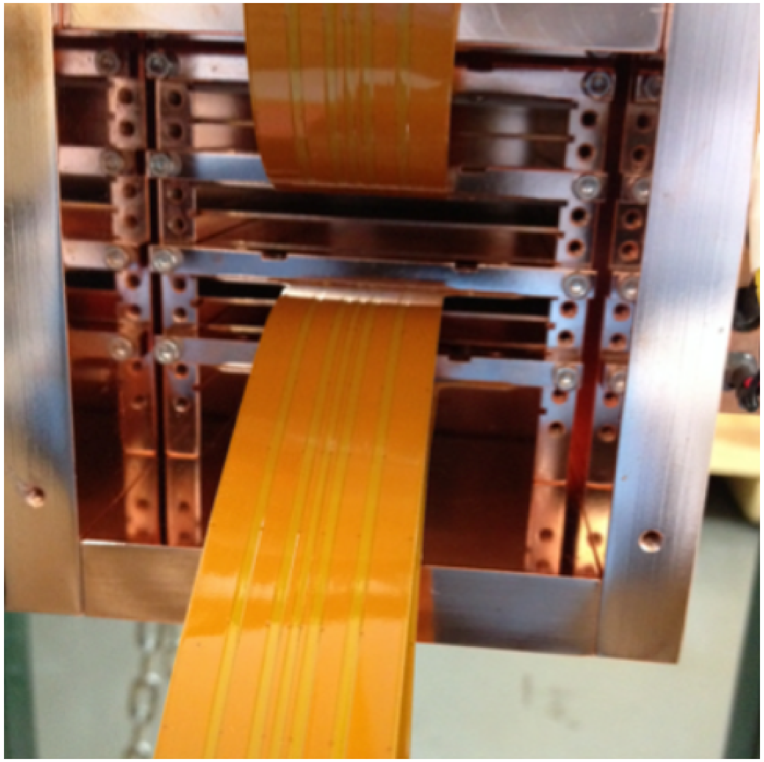


Charge-coupled devices (CCDs)

Special high resistivity CCDs designed by LBNL (USA), used in the Dark Energy Survey (DES) and DAMIC (Dark Matter In CCDs) experiment

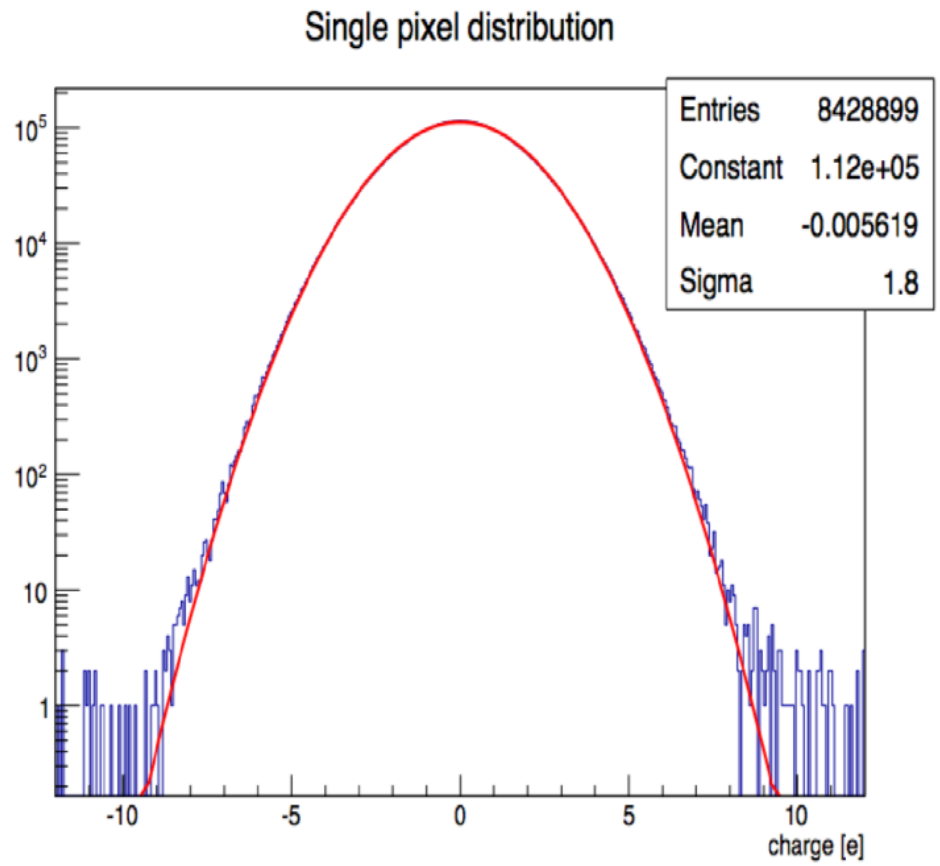
- Very low energy threshold detectors: 5.5 eV (RMS < 2 electrons)
- Pixel size of 15 μm x 15 μm
- Large mass of up to 5.2 g / CCD module
- Thick CCDs (250 / 675 μm)
- 3D information via charge diffusion





Charge-coupled devices (CCDs)

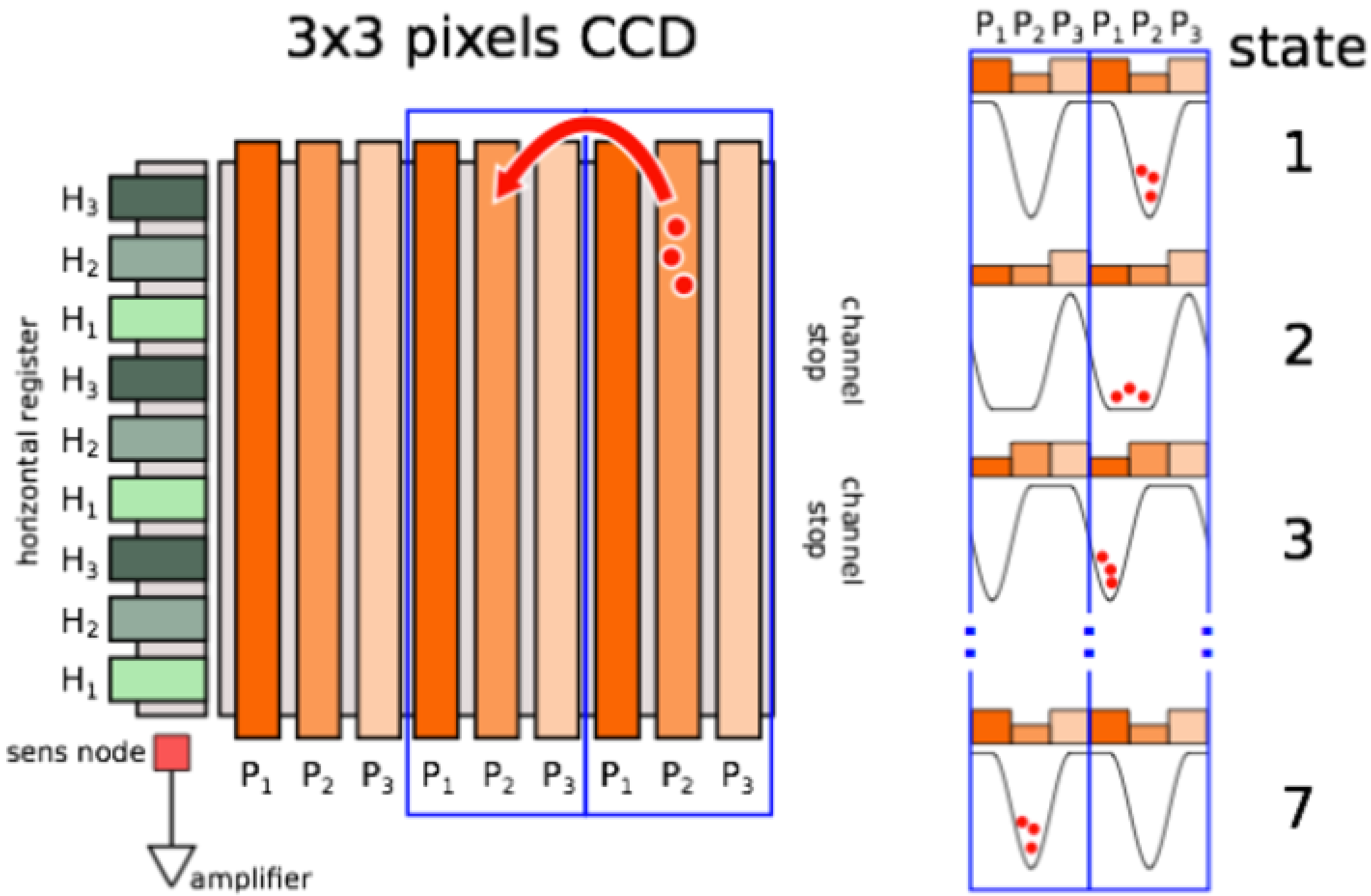
Extremely low noise levels!



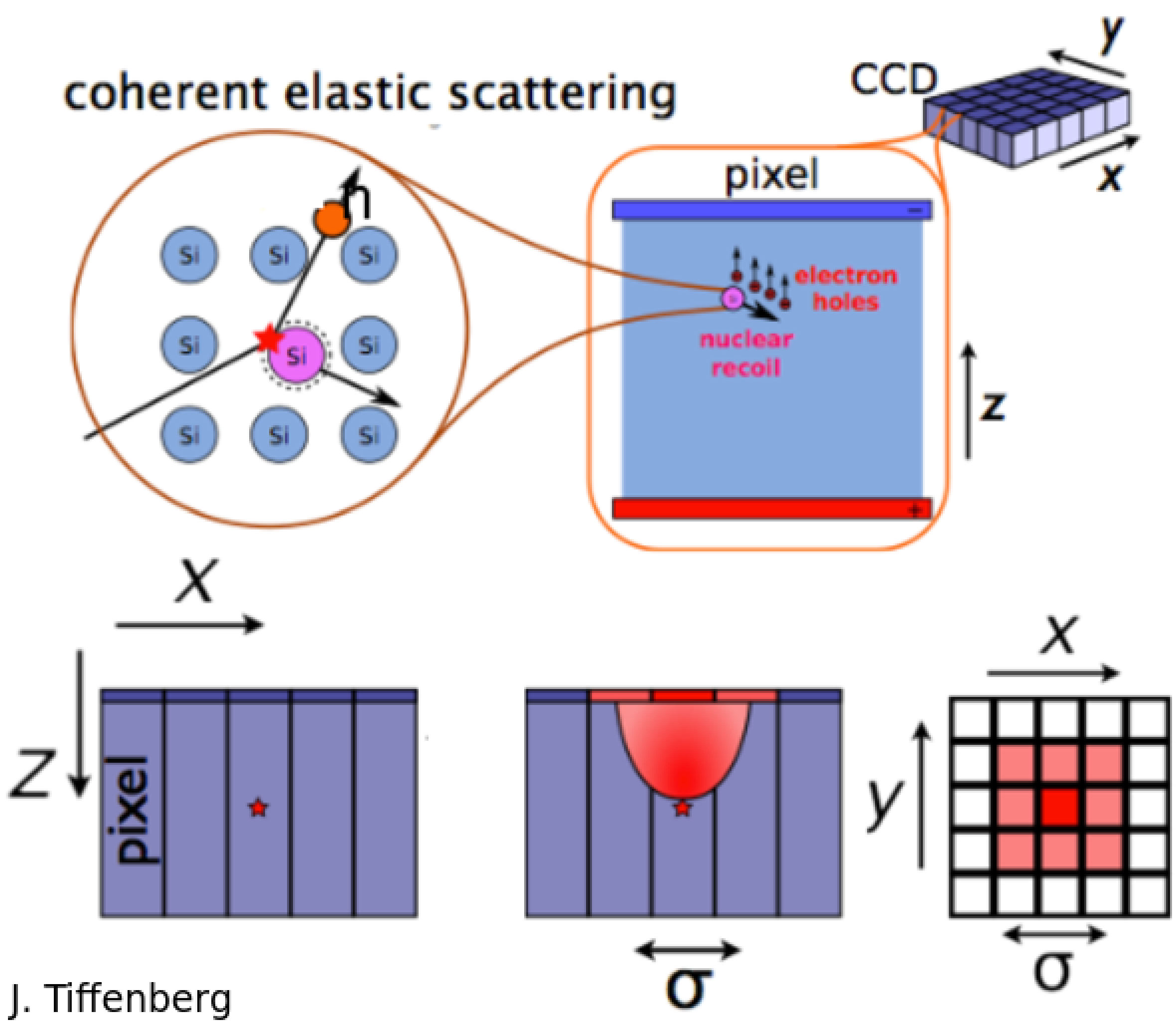
1 e^- ≈ 3.6 eV ⟶ 40 eV threshold is possible!

Charge-coupled devices (CCDs)

Readout of information from CCD modules:



Event detection



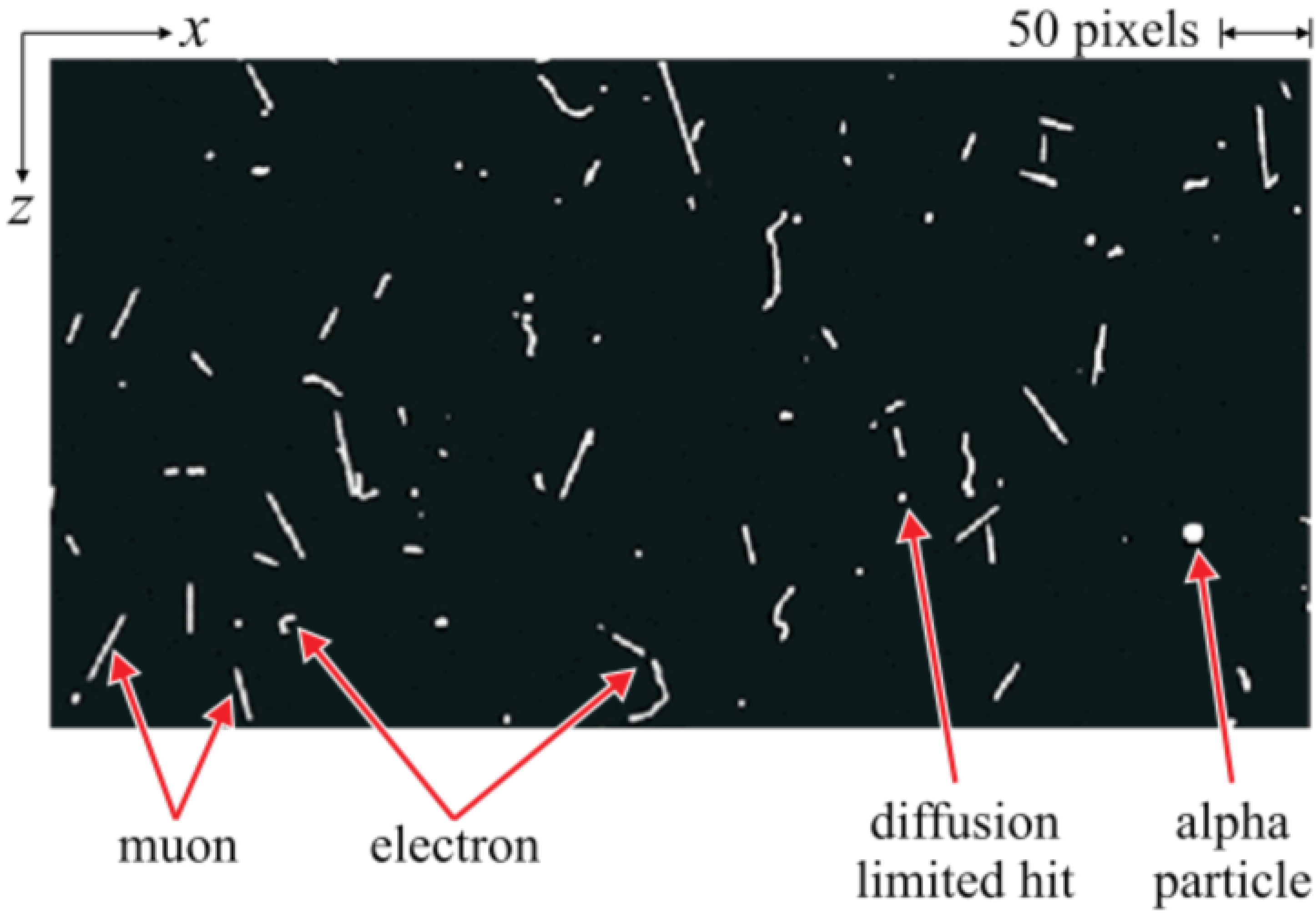
The scattering of the n with a Si nucleus leads to ionization

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

Event detection



CONNIE collaboration

COherent Neutrino-Nucleus Interaction Experiment (about 20 members)

Centro Atómico Bariloche
Universidad del Sur / CONICET

Universidad Nacional de Asunción

Centro Brasileiro de Pesquisas Físicas
Universidade Federal do Rio de Janeiro

University of Zurich

Universidad Nacional Autónoma de México

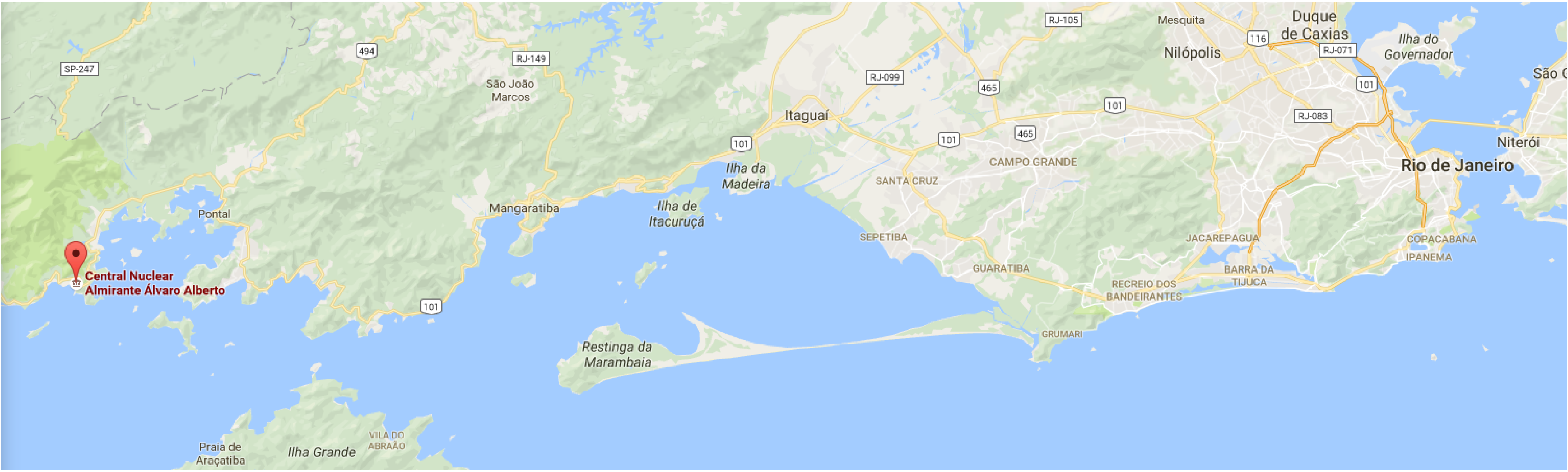
Fermilab National Laboratory

CONNIE collaboration

First collaboration meeting in June 2015 at the CBPF, Rio de Janeiro

The CONNIE detector

The experiment is located at the Almirante Álvaro Alberto nuclear power plant in Angra dos Reis, about 160 km from Rio de Janeiro



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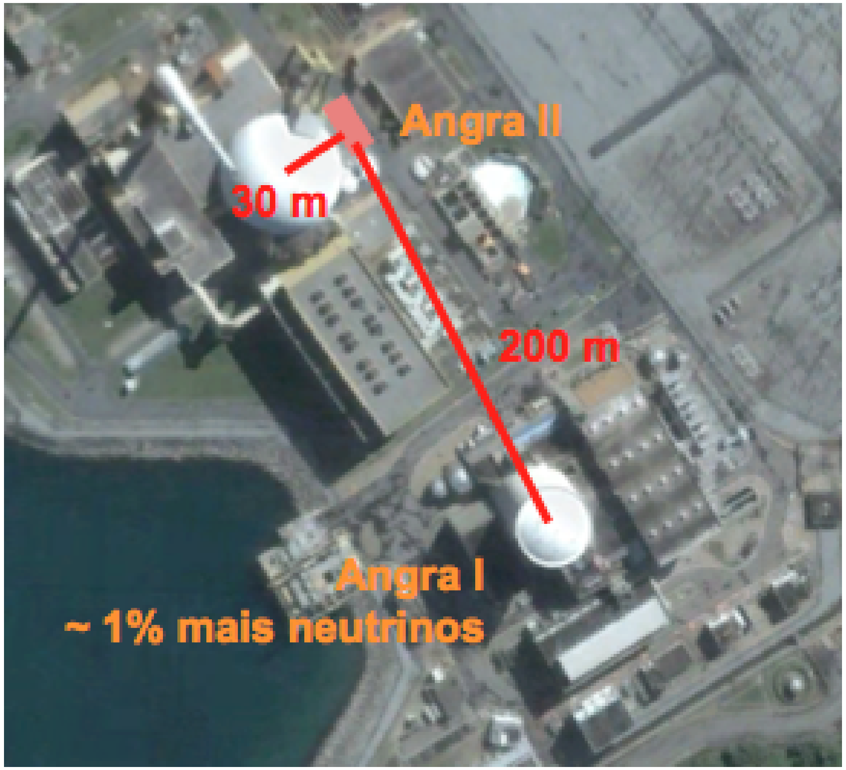
The CONNIE detector



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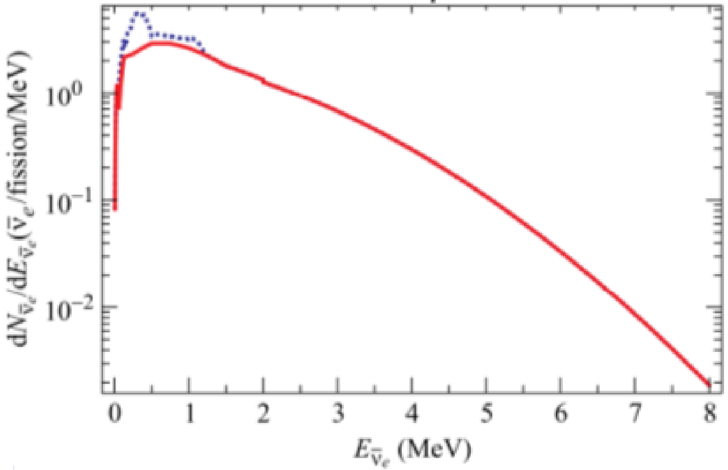
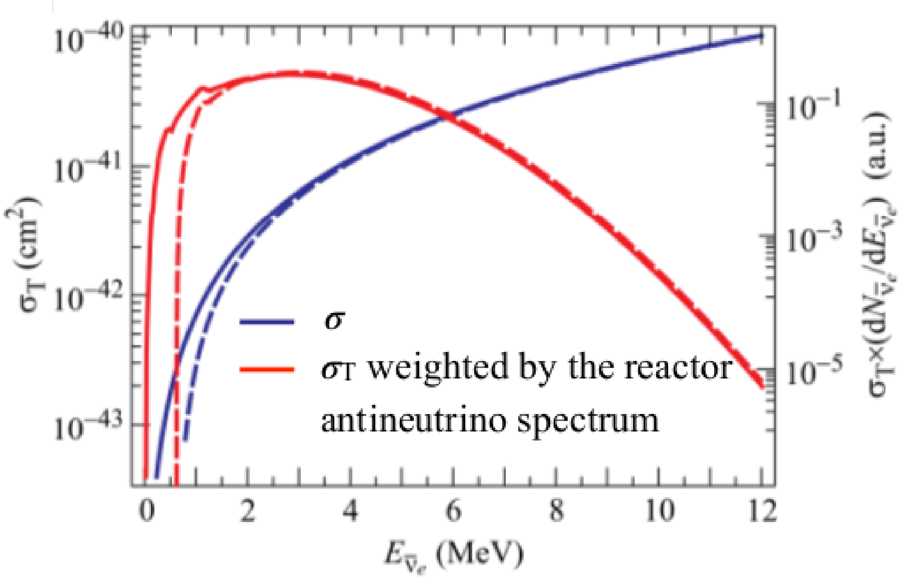
Total reactor antineutrino spectrum in the reactor per MeV





The CONNIE detector

Angra 2 reactor:

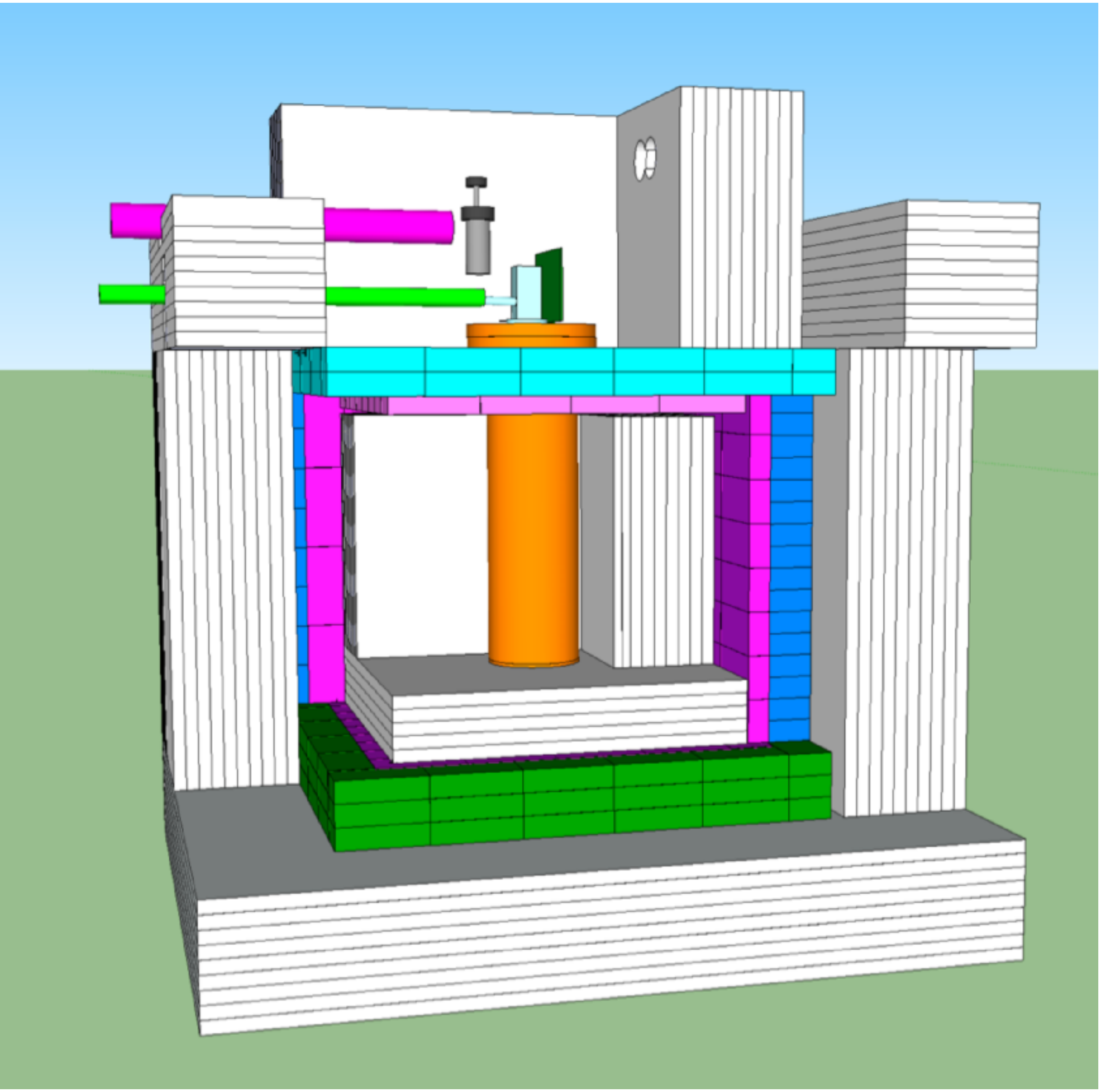
Neutrino source with 3.8 GW_{th}

Flux of $7.8 \cdot 10^{12}\ \overline{\nu}\ s^{-1}\ cm^{-2}$ at detector position

Laboratory container at 25m distance from the reactor core

Also serves as laboratory for the „Angra" experiment for nuclear reactor monitoring and safeguard

The CONNIE detector



Phase 1: Engineering run

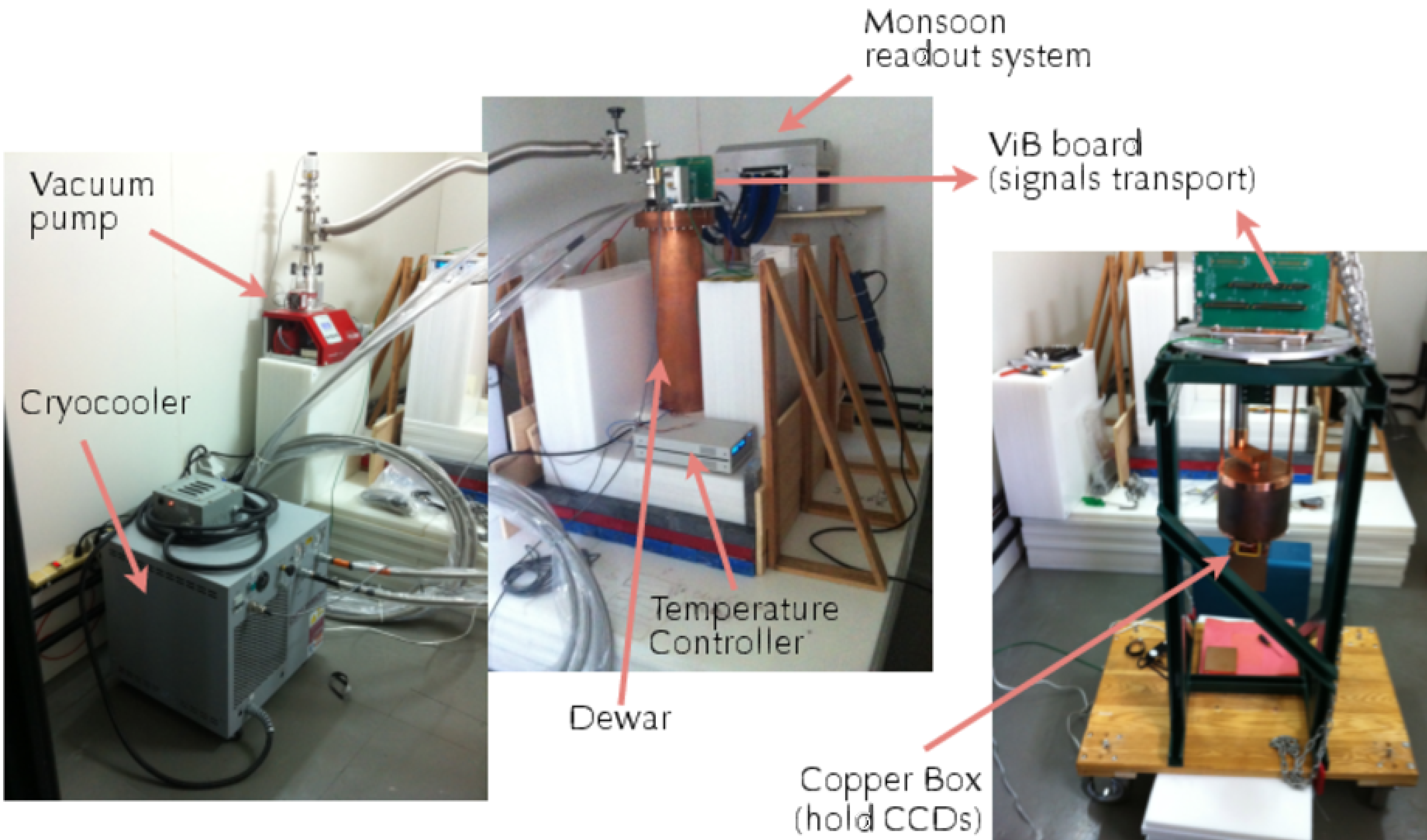
Testing detector and shielding

Timeline: Phase 1

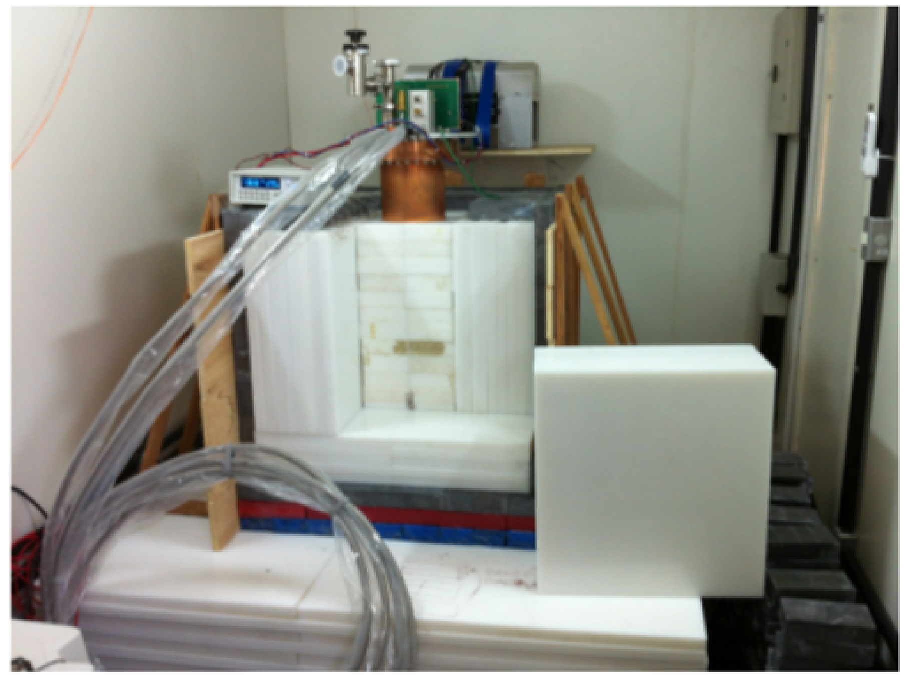
- Studied the possibility of CONNIE at Angra in 2011
- Installation of the prototype in 2014
    - August 2014: shipping of the components
    - Oct.-Nov. 2014: detector installation and first data
    - July-Aug. 2015: full shielding completed
    - Aug.-Sep. 2015: more than one full month of data with reactor ON
    - Sep.-Oct. 2015: one full month of data with reactor OFF

The CONNIE detector

CONNIE detector components



The CONNIE detector



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

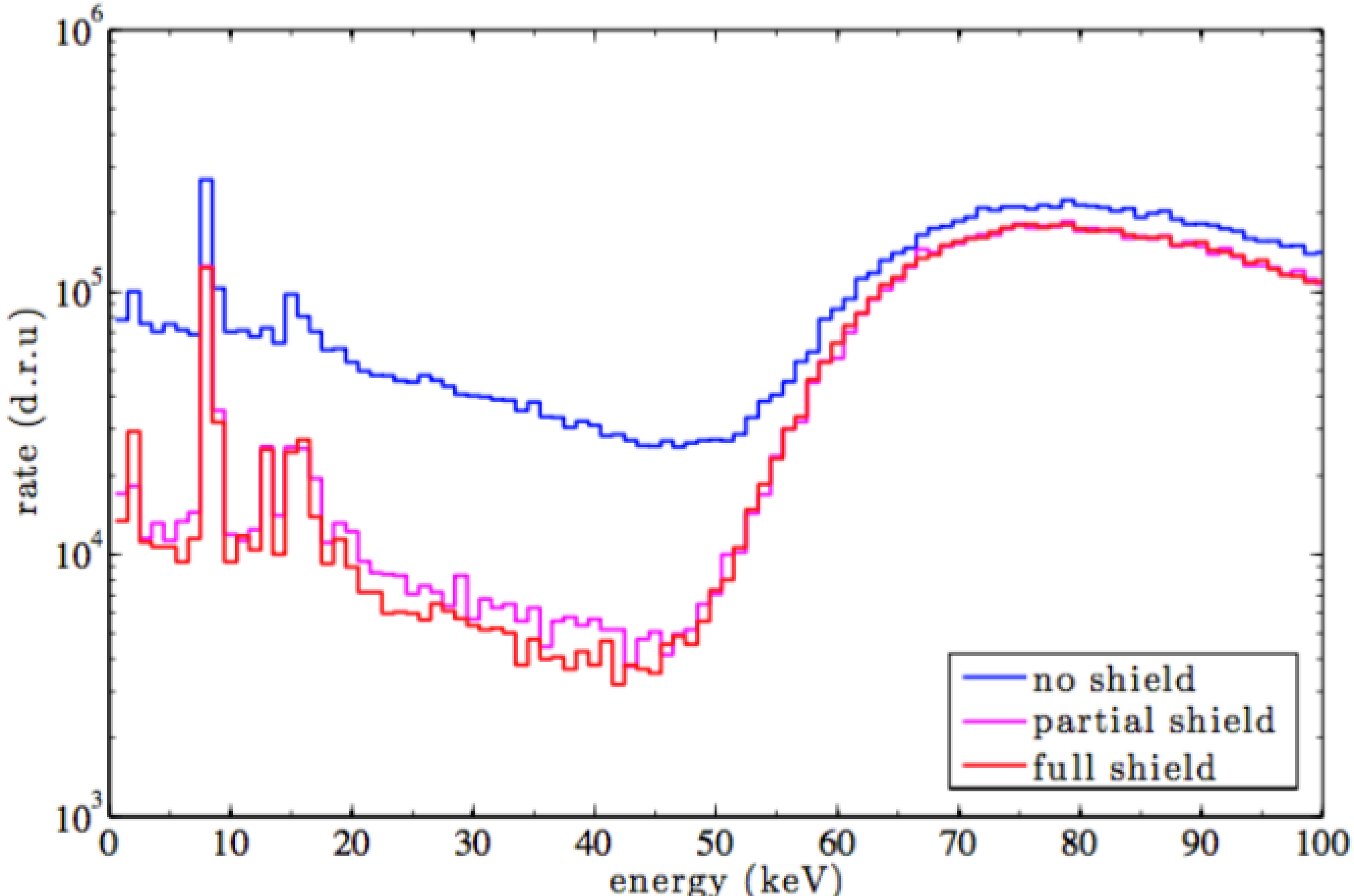
- Four CCD modules installed and taking data since December 2014
- Used for background studies and detector assessment

The CONNIE detector

Inside the container: shielding upgrade in mid-2015

The CONNIE detector

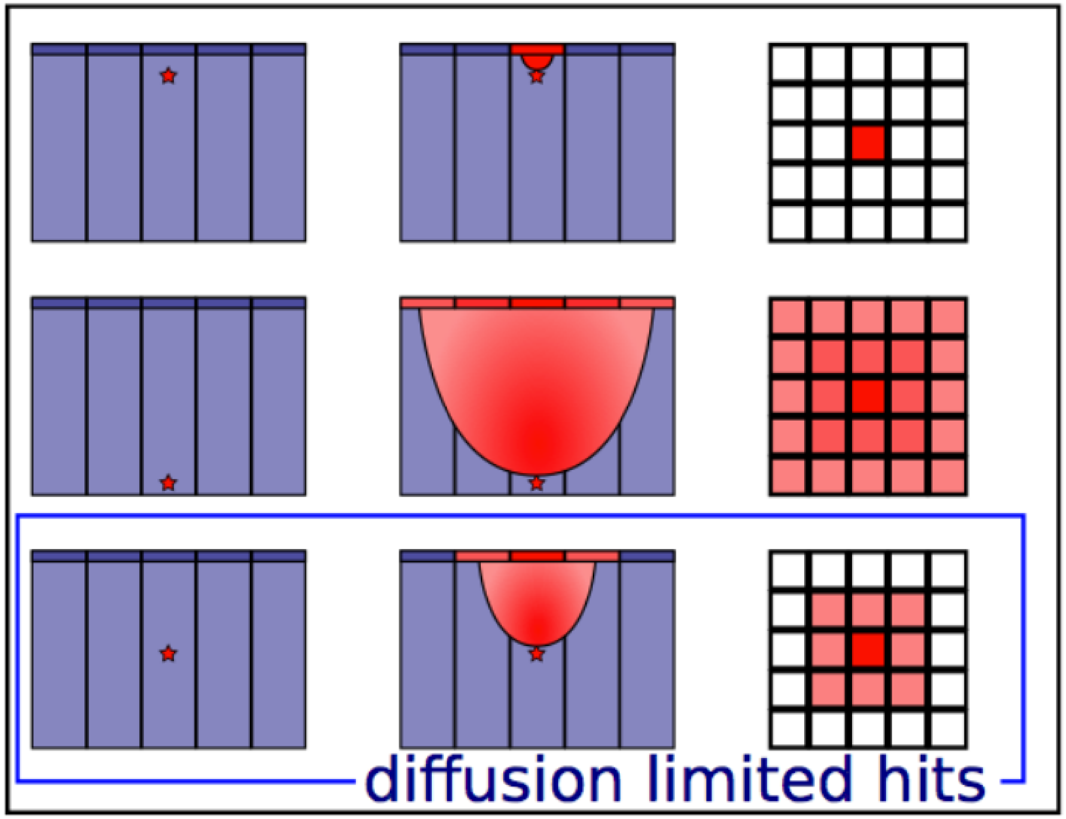
Background reduction with passive lead / polyethylene shielding



arXiv:1604.01343

Example: muon track

Using the engineering run for first analyses and background studies

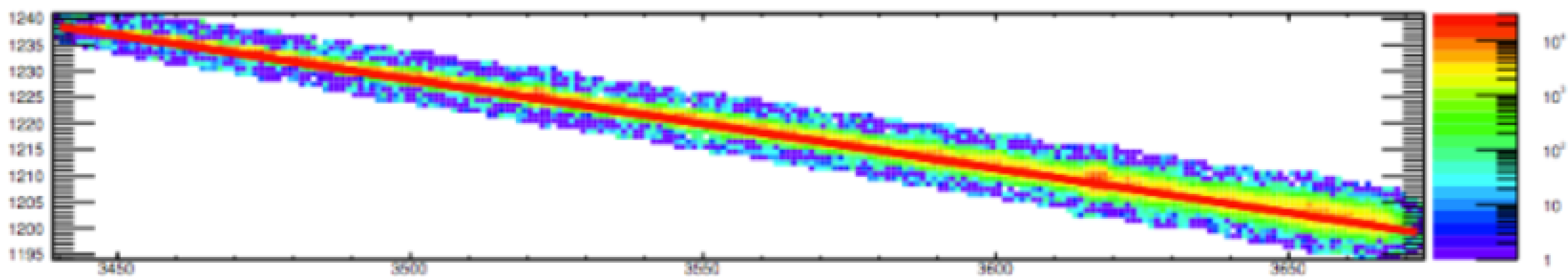


For example: study of charge diffusion, e.g. to define fiducial volume

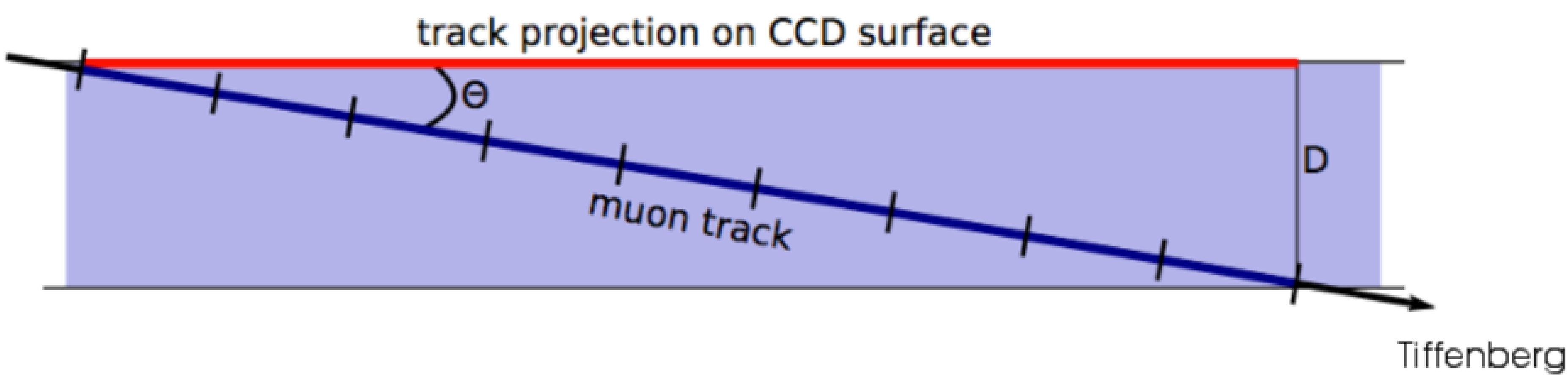
Example: muon track

Using the engineering run for first analyses and background studies

- Recorded track: CCD top view

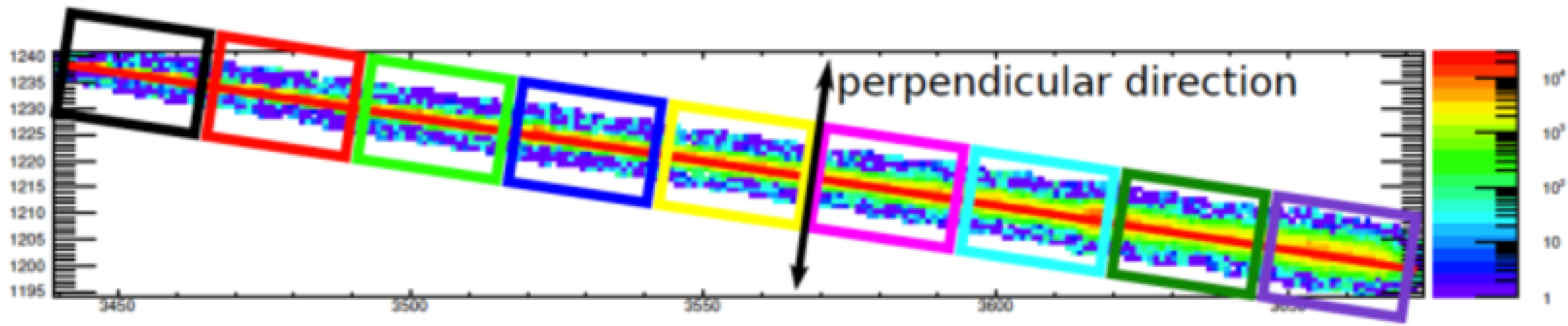


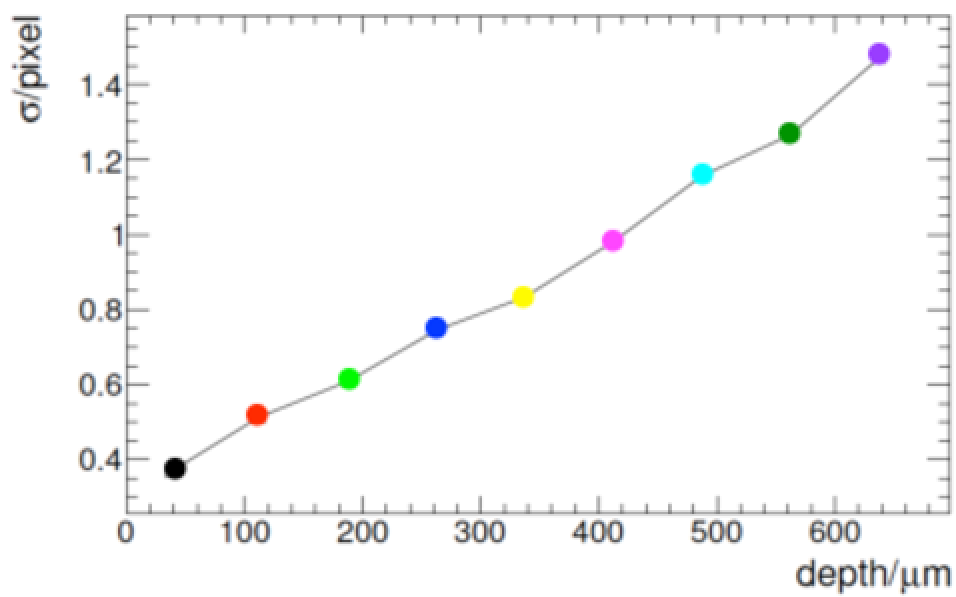
- CCD side view



Example: muon track

Using the engineering run for first analyses and background studies





Tiffenberg

Example: muon track

Verification of simulation with detector data: charge diffusion with depth of the event in the CCD module

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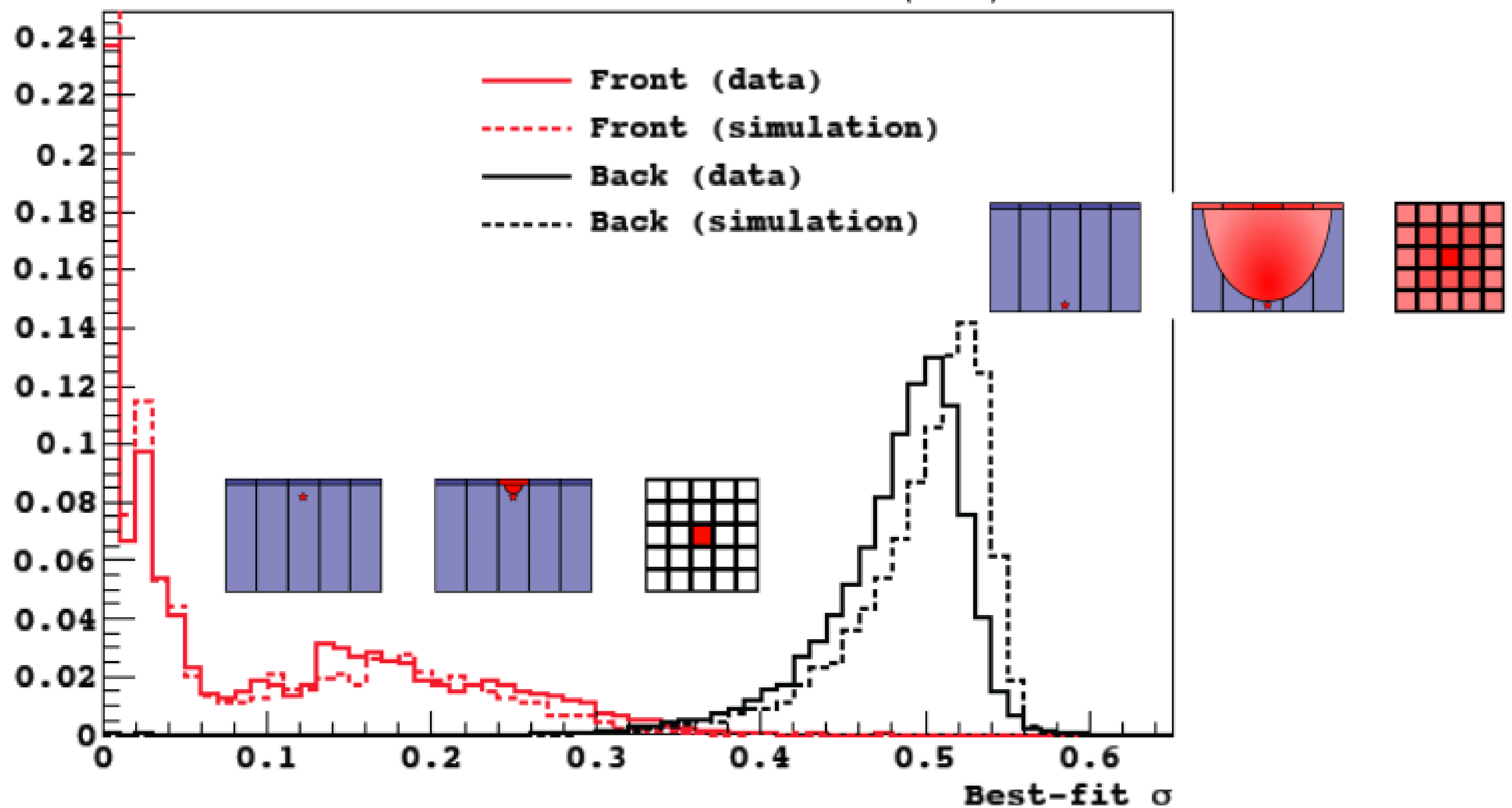
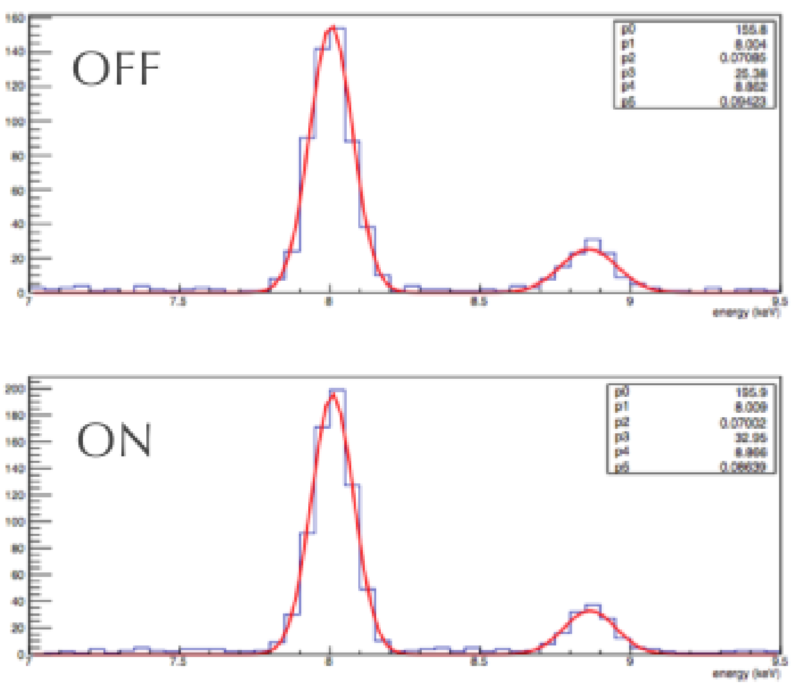
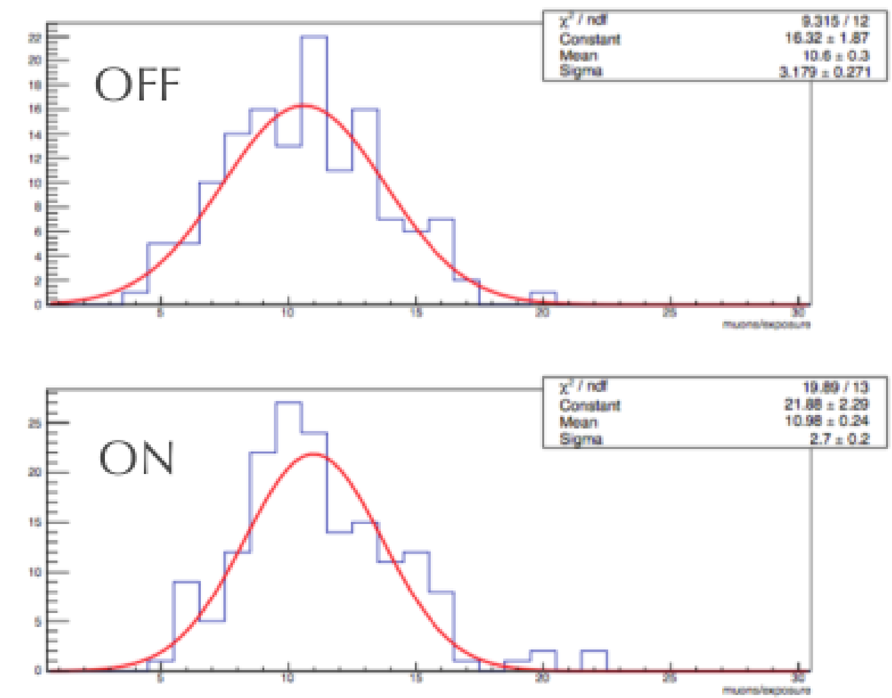


Testing performance

Testing energy resolution and detector stability with backgrounds



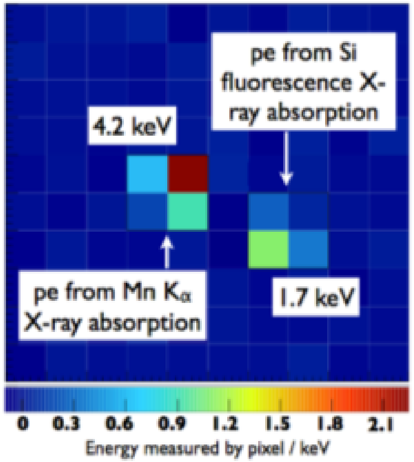
Cu fluorescence peaks for data collected with reactor OFF and ON

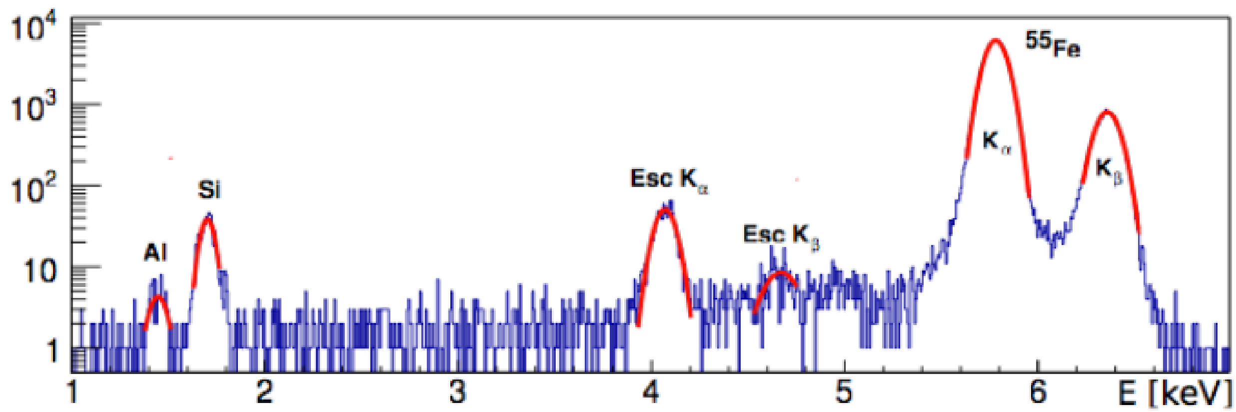


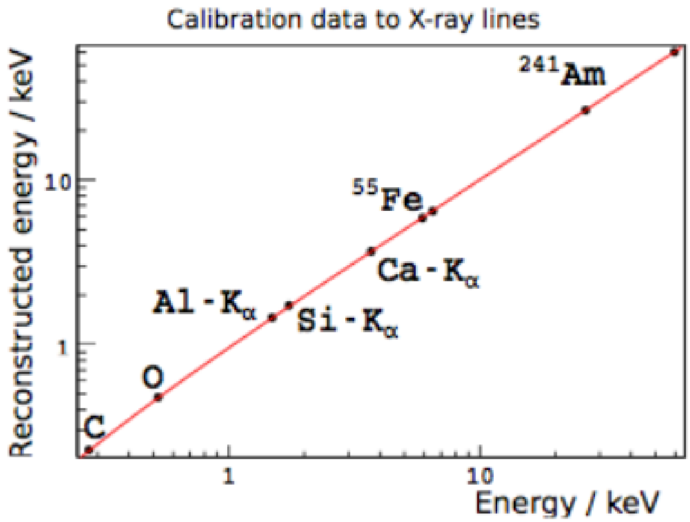
Muon events detected for each 8700 second exposure for reactor OFF and ON

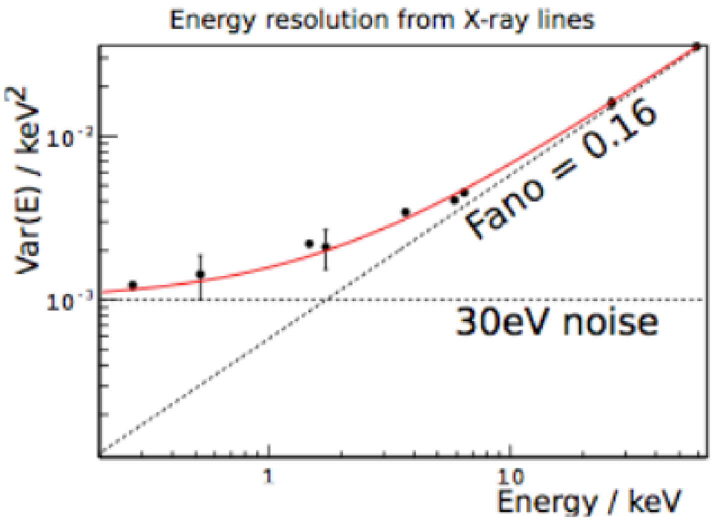
Testing performance

Testing energy resolution and detector stability with backgrounds









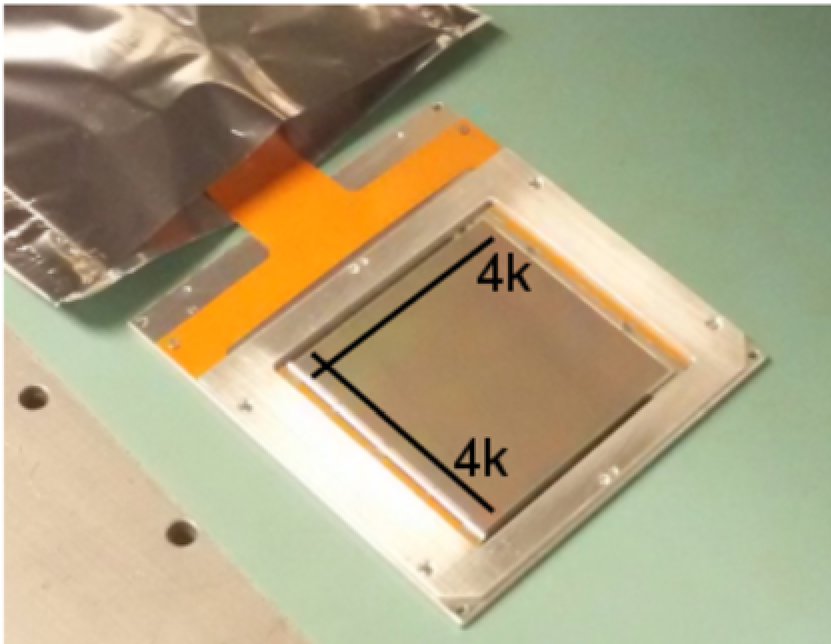
Phase 2: Data taking

Full detector configuration

Timeline: Phase 2

- Studied the possibility of CONNIE at Angra in 2011
- Installation of the prototype in 2014
  - August 2014: shipping of the components
  - Oct.-Nov. 2014: detector installation and first data
  - July-Aug. 2015: full shielding completed
  - Aug.-Sep. 2015: more than one full month of data with reactor ON
  - Sep.-Oct. 2015: one full month of data with reactor OFF
- Upgrade to 100 g detector mass
  - Jan. 2016: new CCDs (4k x 4k, 675 μm) arrived at Fermilab for testing
  - July 2016: detector upgrade with new CCDs in Angra
  - Nov. 2016: first month of data with reactor OFF and full configuration

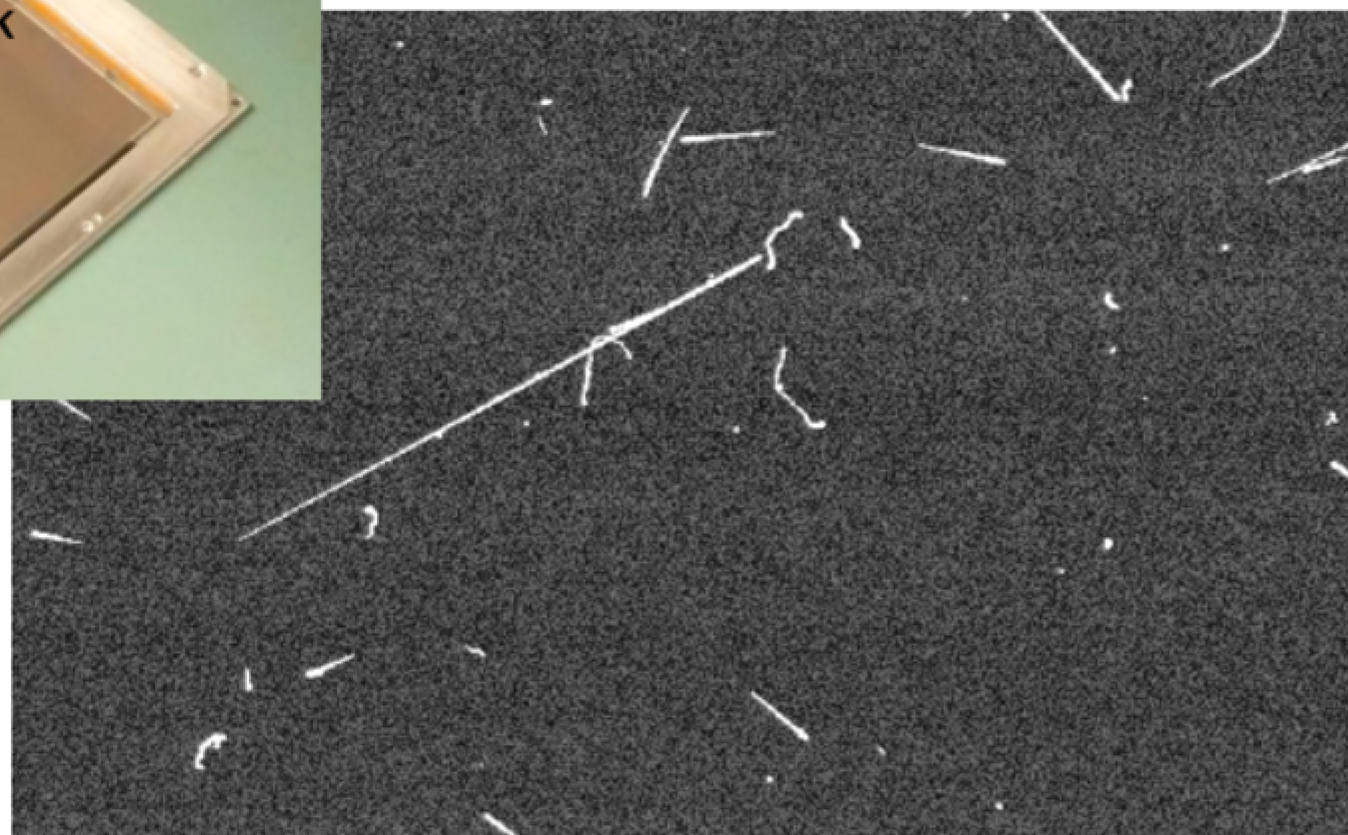
Detector upgrade



First CCD for CONNIE 100

4k x 4k

675 μm



Detector upgrade

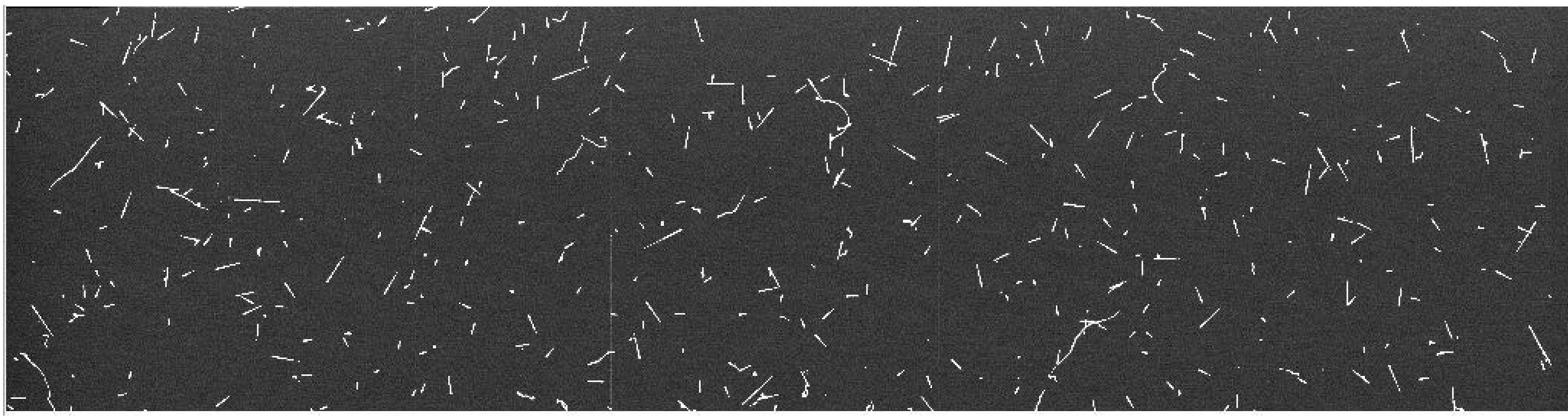
Finishing the shield

Testing the system

Detector upgrade

Beautiful low-noise particle images from a 2h exposure

We are in neutrino heaven!



Outlook

If we assume

- 52 g fiducial detector mass (10 CCDs with 650 μm thickness)
- background level of ≈8.5 events/day with current passive shielding

then the expected live time necessary for a detection is

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

We need only ≈150 days of run time for a 3σ detection of coherent neutrino-nucleus scattering!

...but we need reactor-off data, too

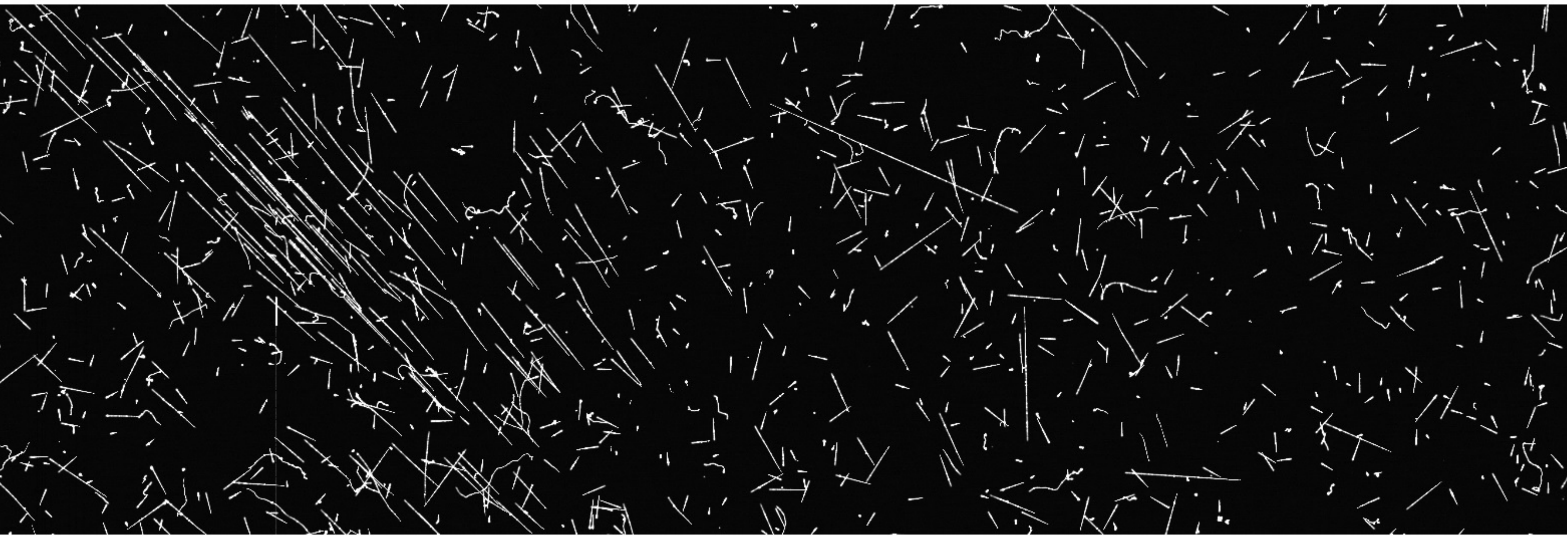
Summary

- CONNIE is an important collaboration between Latin America and the US
- Uses CCDs as particle detectors with good spatial and energy resolution and extremely low electronic noise; Capability to detect low energy nuclear recoils; can be used to detect coherent neutrino-nucleus scattering
- CONNIE is up and running at the Angra-II reactor of the Angra NPP
- First run with/without full shield and with reactor on/off phase completed successfully in 2015 (important to measure background and demonstrate detector performance)
- Finished detector upgrade to 100 g total mass in July 2016. We are taking data and expect exciting results soon!

Bonus image

Bonus image

Image of a muon shower close to the CCD modules, recorded just a few days ago. We can't wait to do the 3D-reconstruction of this event ;)



Thank you for your attention!