Recent Results and Future Prospects with Skipper CCDs in the CONNIE Experiment

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Introduction

CONNIE (Coherent Neutrino-Nucleus Interaction Experiment) aims to measure the coherent elastic scattering (CEνNS) of reactor antineutrinos with silicon nuclei in CCDs and to probe beyond the standard model physics [1,2].

This scattering phenomenon involves the interaction of low-energy neutrinos with a nucleus coherently, mediated by a Z boson. Its detection requires a low threshold detector and a high flux of antineutrinos.

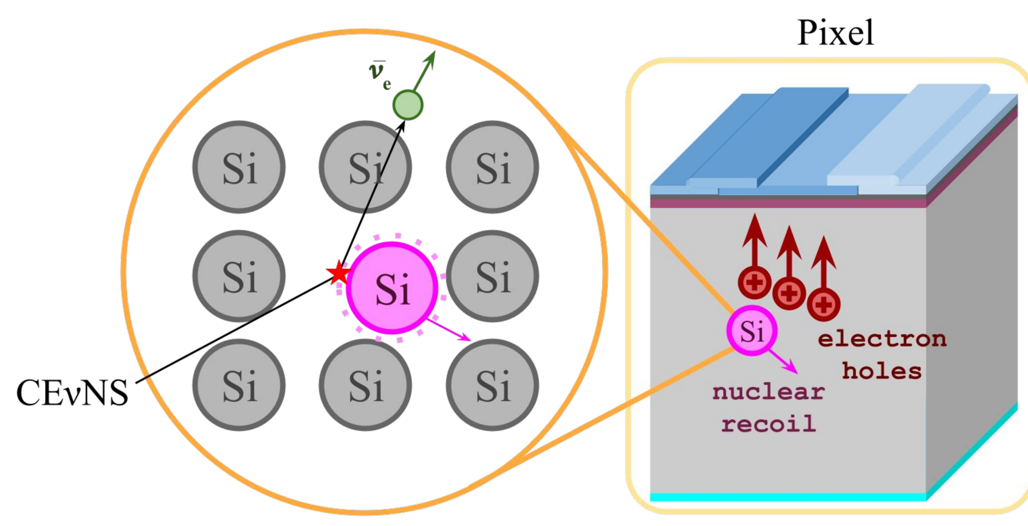

Fig 1. Illustration of the coherent neutrino-nucleus scattering process.

Skipper-CCDs

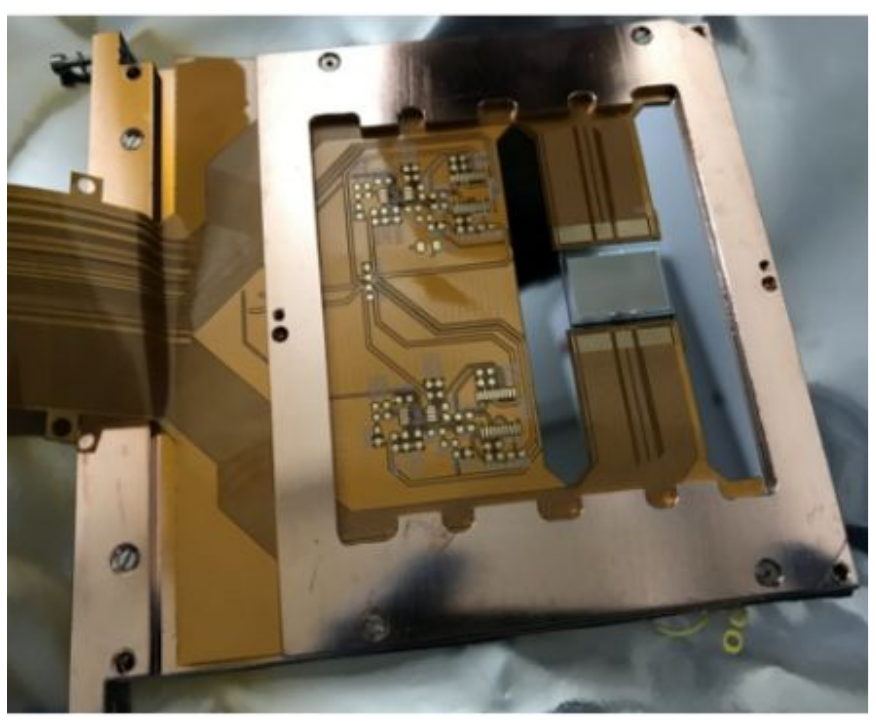

Fig 2. CONNIE Skipper CCD (15μm×15μm) (675μm×1022x682 pixels).

These devices consist of an array of metal oxide semiconductor capacitors arranged in pixel shapes. When the substrate is ionized, electron-hole pairs are created, and the charges are collected, transferred, and read out by changing voltages and potential wells.

The Skipper-CCDs differ from standard CCDs in their ability to read multiple independent and uncorrelated measurements of charge in each pixel [3,4]. This capability reduces noise by the square root of the number of samples.

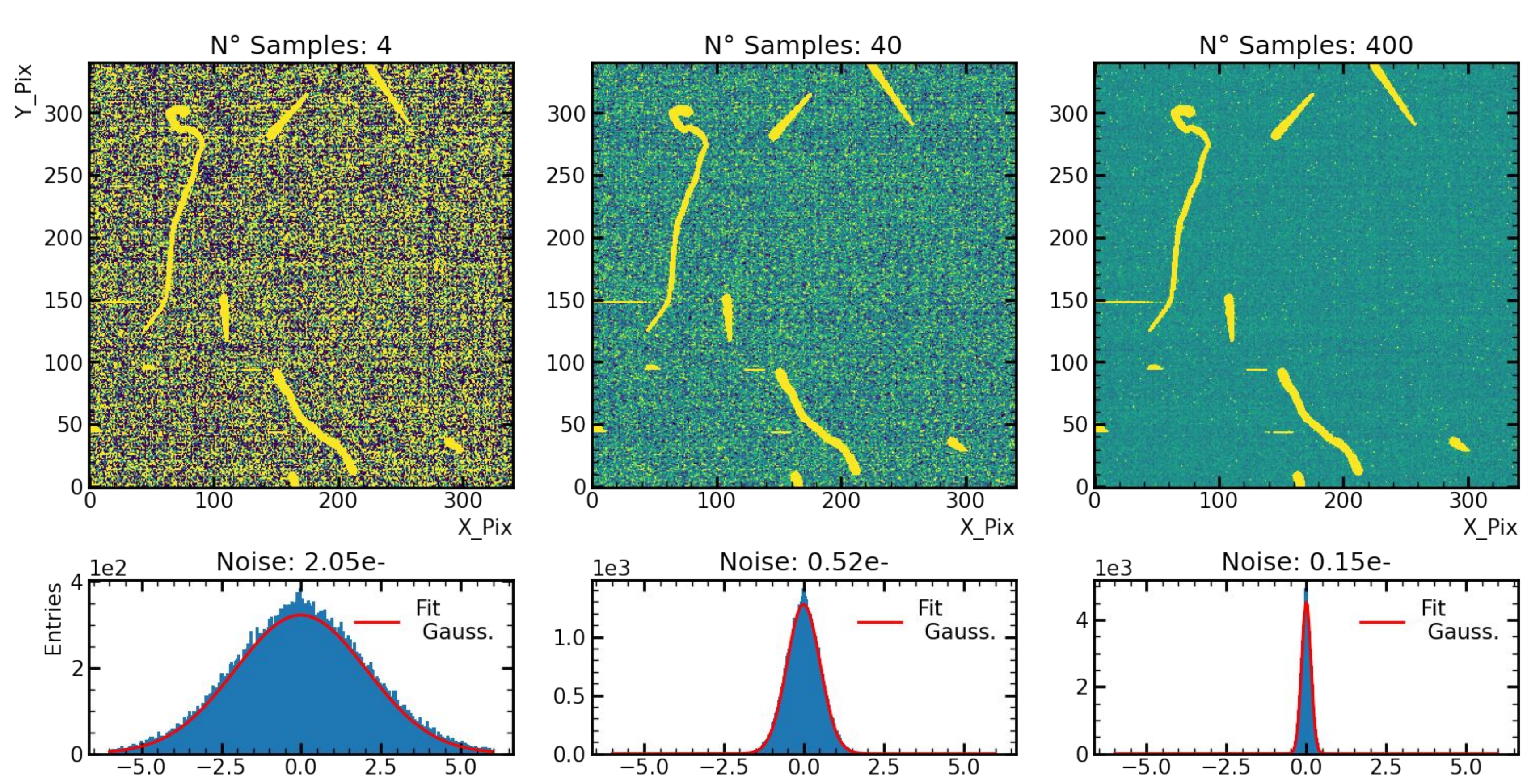

Fig 3. Impact of the Nº of samples in the sharpness of the image and in the Readout Noise.

Reactor Location

Located 30 meters from the 3.8 GW Angra2 reactor in Angra dos Reis, CONNIE benefits from a high flux of approximately 7.8×10^{12} $\bar{\nu}_e$/s cm², due to the fission reaction of Uranium.

Fig 4. CONNIE site in the Almirante Álvaro Alberto nuclear power plant, in Angra dos Reis, Brazil.

Detector Setup

Fig 5. A view of the CONNIE detector and its shielding.

The CONNIE detector is surrounded by a passive shielding consisting of outer and inner layers of polyethylene to block neutrons and an inner layer of lead. The CCDs are kept in a vessel cooled to 100 K in a vacuum. A Low Threshold Acquisition readout board is utilized for data acquisition [5].

To achieve CONNIE goals, background measurements are done in reactor shutdown periods and compared with data obtained when the reactor is operational.

Event Selection

A masking routine was developed to identify and mask background events and its impact is a 99.94% reduction of the number in low-energy selected events.

A new threshold of 15 eV for particle extraction was established

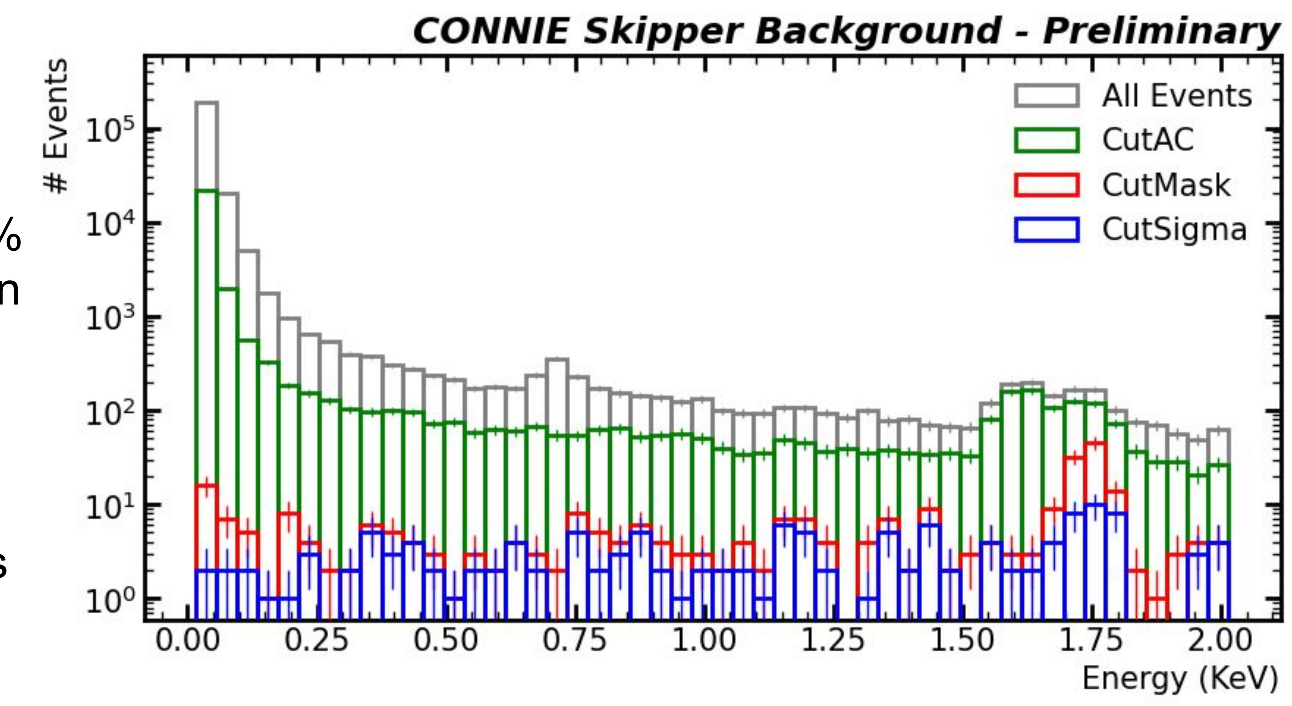

Fig 7. Impact of selection cuts and masking routine on the number of low-energy background selected events.

Results

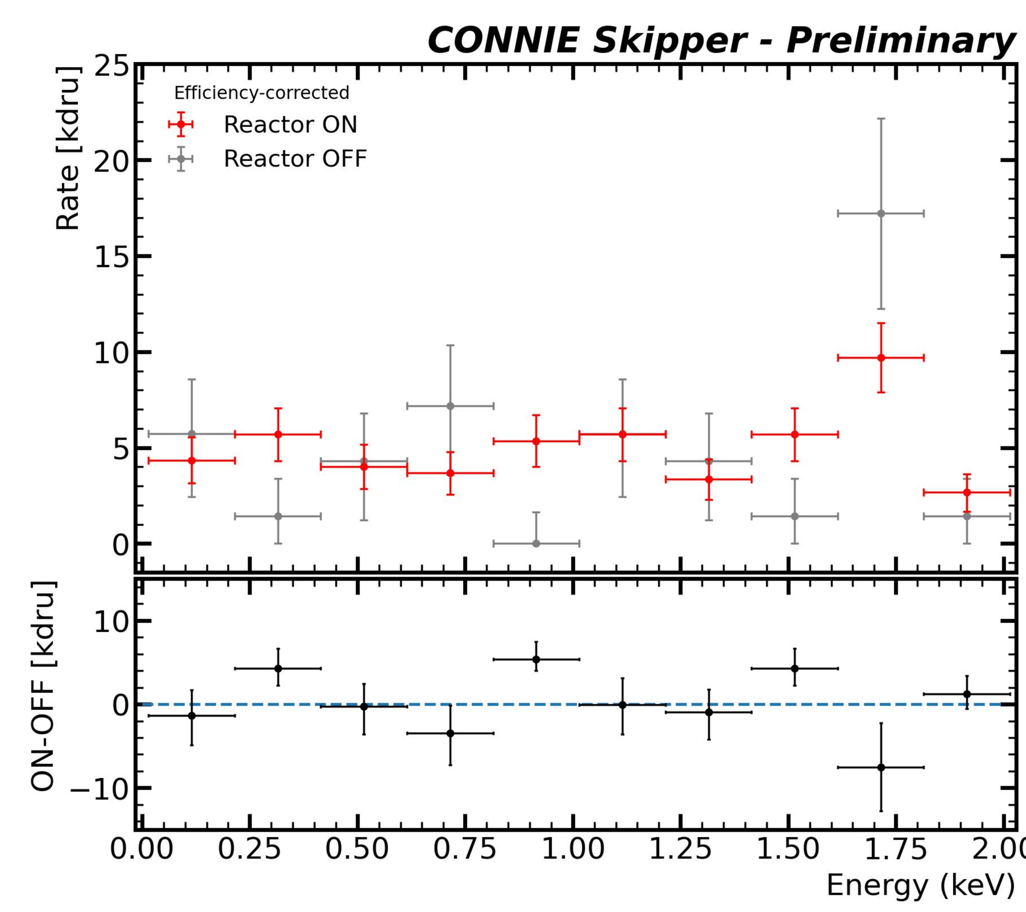

Fig 8. Reactor ON-OFF subtraction with CONNIE Skipper data.

With 2 Skipper-CCDs (~0.1g each) and the explicit parameters in Table 1, it was possible to construct the subtraction plot.

Table 1. Exposure parameters

Reactor Periods	Readout Time	Exposure Time	Total Exposure
OFF	1,1 months	17 days	3.5 g.day
ON	5 months	75 days	15 g.day

A flat Reactor-ON and OFF spectra are observed. As expected, due to the small size of the detector, the Reactor ON-OFF is consistent to zero.

Background Analysis

Comparing with the previous result [6], the efficiency-corrected background spectrum shows that with Skipper-CCDs it is possible to achieve a lower and flat background level and also a greater efficiency in very low energies.

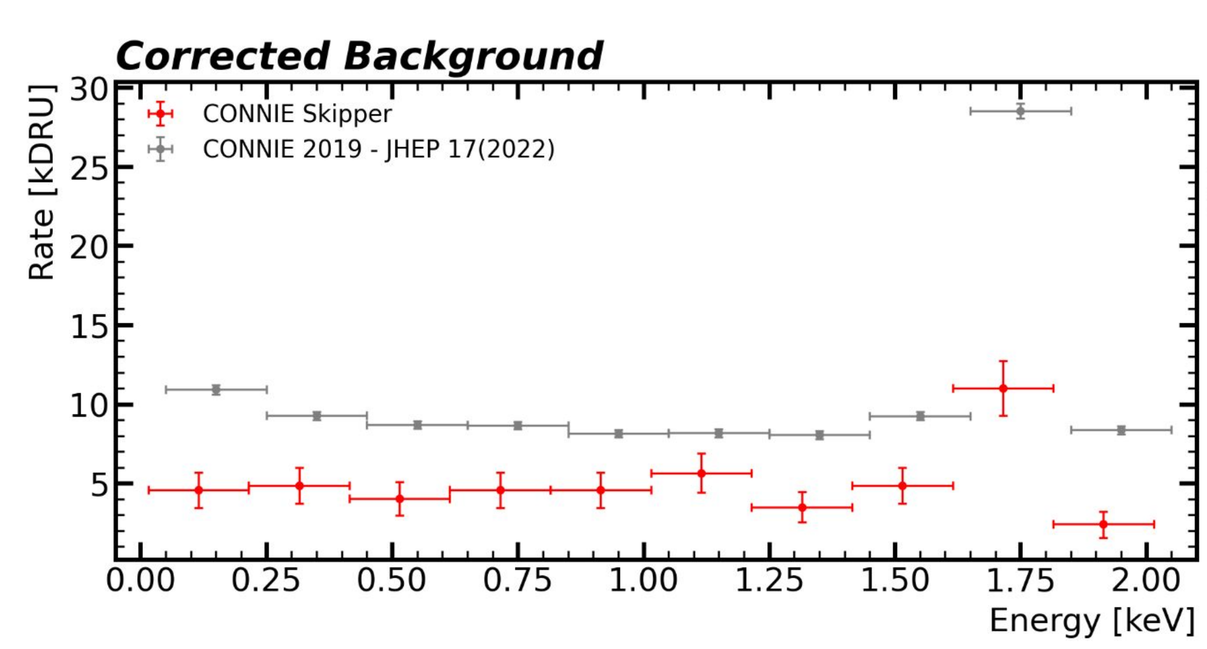

Fig 9. Low-Energy Background Spectrum comparison.

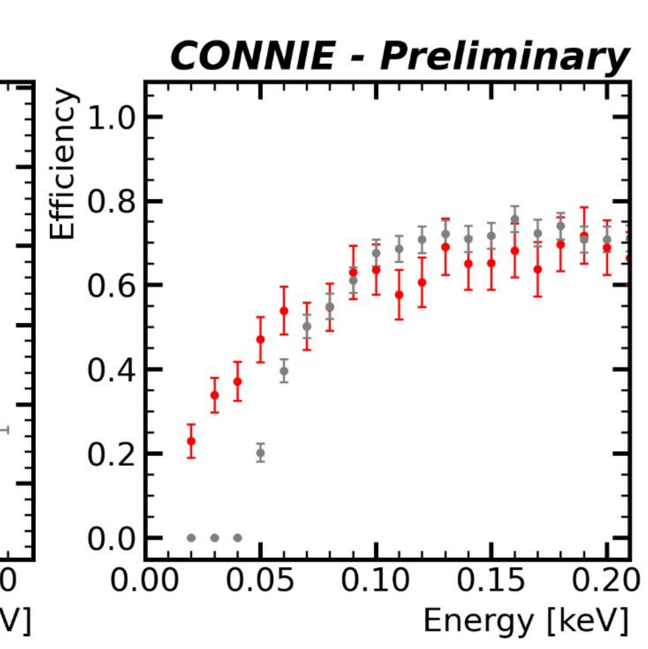

Fig 10. Efficiency comparison.

Future Perspectives

- Assuming the new threshold, we expect a CEνNS rate 2.2 times higher than 2019;
- Plans to increase the sensor mass:
  - New compact sensor arrangement;
  - New shield design;
  - New Vacuum Interface Board
- Negotiations with Angra underway to move at 20 m from the reactor core, inside the dome;
- New physics analysis (DM and Millicharged particle search) with Skipper data ongoing.

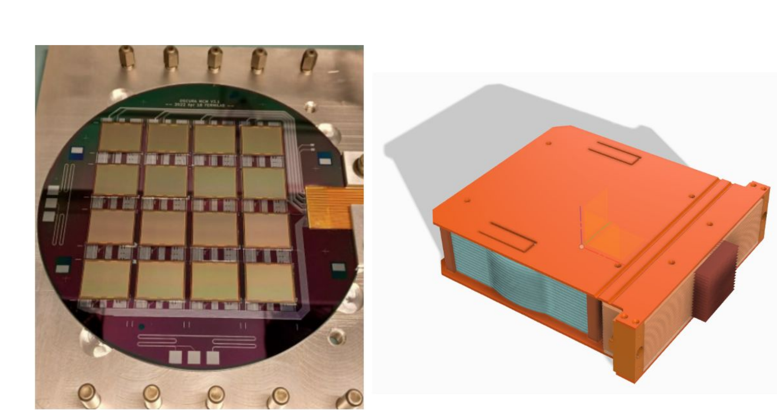

Fig 11. Oscura Design of Multi-Chip-Module (MCM) and a Super Module with 16 MCMs [7].

References

[1] CONNIE Collaboration, Aguilar-Arevalo A. et al., Exploring low-energy neutrino physics with the coherent neutrino nucleus interaction experiment, Phys. Rev. D 100 092005 (2019).
[2] CONNIE Collaboration, Aguilar-Arevalo A. et al., Search for light mediators in the low-energy data of the CONNIE reactor neutrino experiment. J. High Energ. Phys. 2020, 54 (2020).
[3] Tiffenberg J. et al, Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD, Phys. Rev.Lett. 119, 131802 (2017).
[4] Janesick J. et al, New advancements in charge-coupled device technology: subelectron noise and 4096x4096 pixel CCDs, Proc. SPIE 1242, Charge-Coupled Devices and Solid State Optical Sensors, (1990).
[5] Cancelo C. et al, Low threshold acquisition controller for Skipper charge-coupled devices, JATIS 7, 1 015001. (2021)
[6] CONNIE Collaboration, Aguilar-Arevalo A. et al., Search for coherent elastic neutrino-nucleus scattering at a nuclear reactor with CONNIE 2019 data, J. High Energ. Phys. 2022, 17 (2022).
[7] Brenda A. et al, Skipper-CCD sensors for the Oscura experiment: requirements and preliminary tests. JINST 18 P08016 (2023)

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