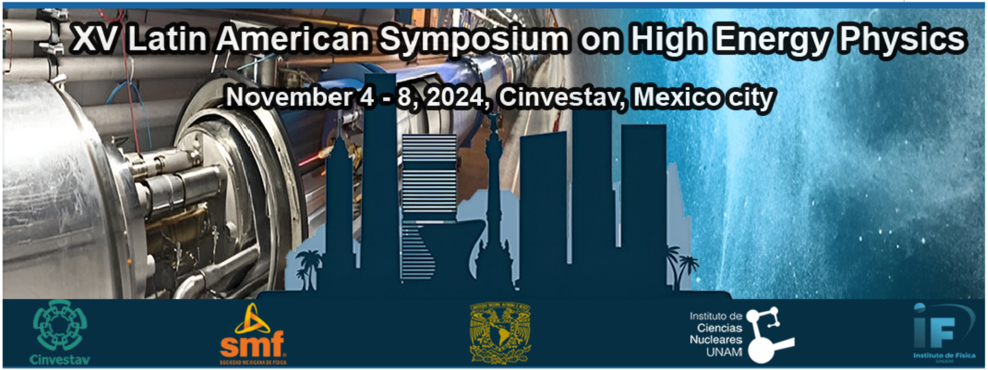


Status and perspectives of the CONNIE experiment

Latest results

Y. Sarkis (on behalf of the CONNIE collaboration)

UNAM-ICN

CONNIE
COHERENT NEUTRINO NUCLEUS INTERACTION EXPERIMENT

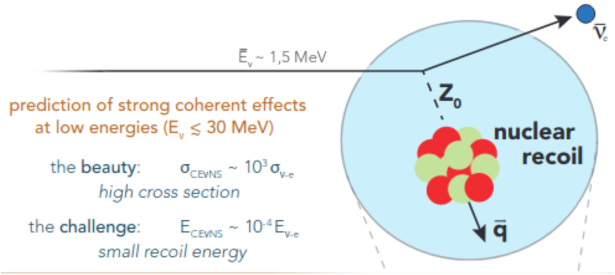
- INTRODUCTION
- CONNIE EXPERIMENT
- SKIPPER-CCD RUN
- CONNIE WITH SKIPPERr-MCM's
- SUMMARY

COHERENT NEUTRINO-NUCLEUS SCATTERING (CEνNS) WITH REACTOR ANTINEUTRINOS

- Occurrence of neutral-current neutrino interactions in the Standard Model.
- The existence of elastic neutrino-nucleus scattering proposed for the first time in 1974 (no energy threshold) [a] .

---

[a]**Predicted in 1975 by D.Z. Freedman in 1973, V.B. Kopeliovich and L.L. Frankfurt, JETP Lett. 19 4 236 (1974)**. First detected by the COHERENT collaboration in 2017 with CsI crystals (2021 and 2024 in LAr and Ge).



Coherent Elastic Neutrino Nucleus Scattering (CEνNS)

$$\frac{d\sigma}{dE_R} = \frac{G_F^2}{4\pi}\left(N - Z\left(1 - 4\sin^2\theta_w\right)\right)^2 m_N \left(1 - \frac{m_N E_R}{2E_\nu^2}\right) F^2\left(E_R\right) \tag{1}$$

It can be use to test (low energy neutrino spectrum $E_\nu < 10$ MeV):

- **Particle physics:** Weak mixing angle, ν-EM properties and NSI like light mediators, etc.
- **Nuclear physics:** Nuclear form factors, neutron radius, etc.
- **Astrophysics:** Solar and supernova neutrinos.
- **New physics:** Sterile neutrinos, dark matter, etc.
- **Applications:** Nuclear security, monitoring nuclear reactors, etc.
- **arXiv:2203.07361** and **O.Miranda, MagnificentCEVNS 2024**

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The CONNIE experiment

Coherent Neutrino-Nucleus Interaction Experiment (CONNIE)

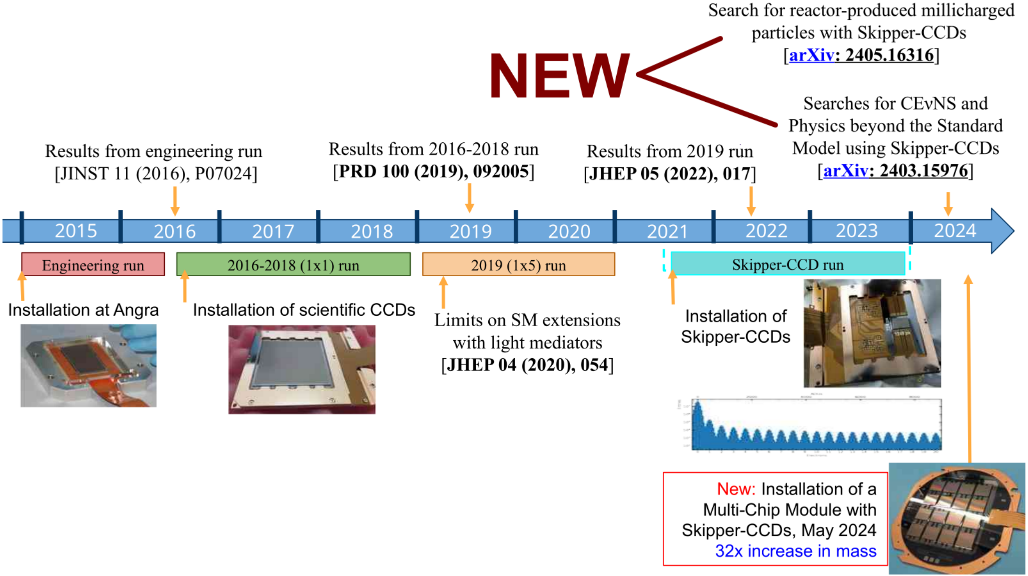
- Its main to detect CEνNS interaction due to reactor antineutrinos in Si nuclei.
- Place limits in BSM physics.
- The detectors are thick (675 mm) scientific CCDs made from high Si resistivity operated at temperatures (< 100 K).

The CONNIE Collaboration

Centro Atómico Bariloche, Universidad de Buenos Aires, Universidad del Sur / CONICET, Centro Brasileiro de Pesquisas Físicas, Universidade Federal do Rio de Janeiro, CEFET-Angra, Universidade Federal do ABC, Instituto Tecnológico de Aeronáutica, Universidad Nacional Autónoma de México, Universidad Nacional de Asunción, University of Zurich, Fermilab [14 inst, 6 count.]

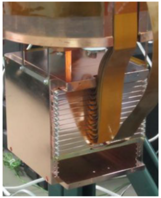
- Located in the Almirante Alvaro Alberto nuclear plant near Rio de Janeiro, Brazil.
- At 30 m from the core of the 3.95 GWth Angra 2 reactor.
- Flux of $\approx 8 \times 10^{12}\ \bar{\nu}_e\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$.

CONNIE Time Line

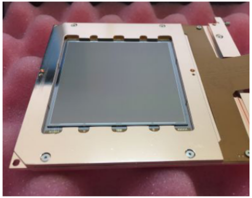


Previous CONNIE publications: HEP

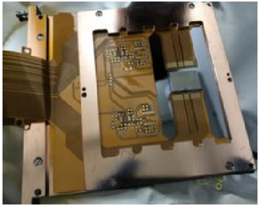
The detector



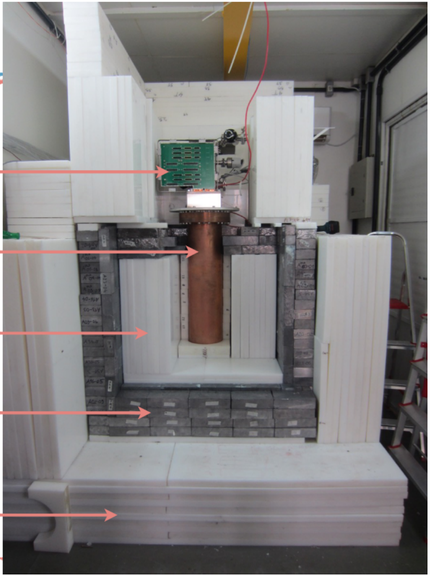
CCDs in copper box
(2016 Upgrade)



4k × 4k, 15 μm × 15 μm pix,
675 μm thick standard CCD



Skipper CCD: 1022×682 pix
$15 \times 15 \mu\text{m}^2$, $675 \mu\text{m}$ thick,
0.5 g total mass.



ViB board
(signals transport)

Dewar
(hold vacuum)

Inner
polyethylene (30 cm)

Lead (15 cm)
~ 800 bricks (Fermilab, USP-Galvão, CBPF and bought to Aurea)

Outer
polyethylene (30 cm)

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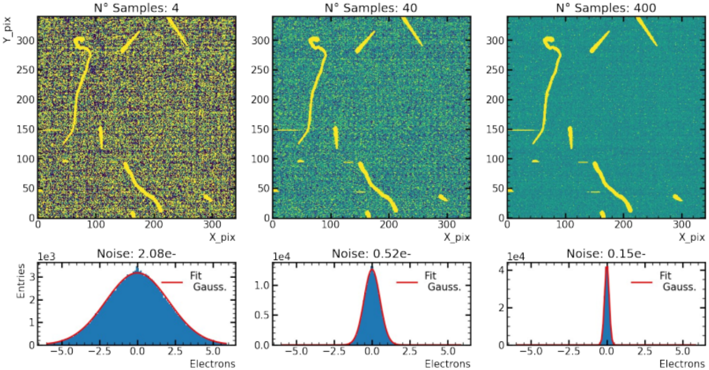
Skipper-CCD

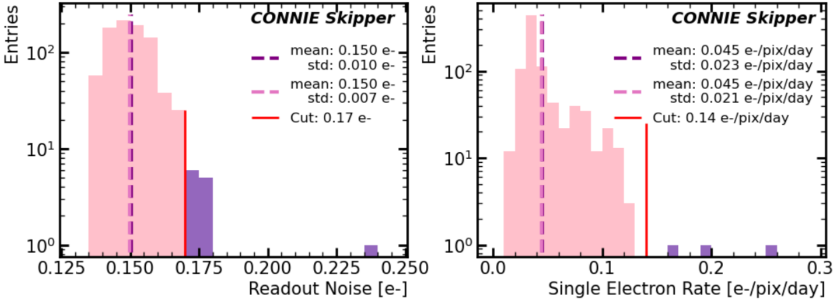
- Skipper-CCD sensors allow to reach very low energies:
- Repeated non-destructive charge measurement.
- Sub-electron noise levels. (*PRL 119 (2017)*)
- Individual electron detection.



- Two Skipper-CCDs were installed at the CONNIE setup in July 2021.
- Low treshold Acquisition readout electronics. *JATIS 7(2021),1015001*

Skipper-CCD performance.

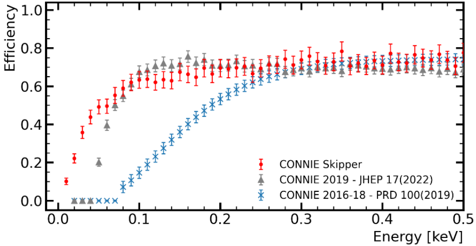
- Each pixel charge is read out with N = 400 samples.
- Ultra-low noise = 0.15 e^-. **Threshold** 15 $\mathrm{eV_{ee}} \approx 250\mathrm{eV_{nr}}$.
- Self-calibrated detector, 1 $e^- \approx 3.7$ eV.
- Single-electron rate = $0.045e^-$/pix/day (low for surface).

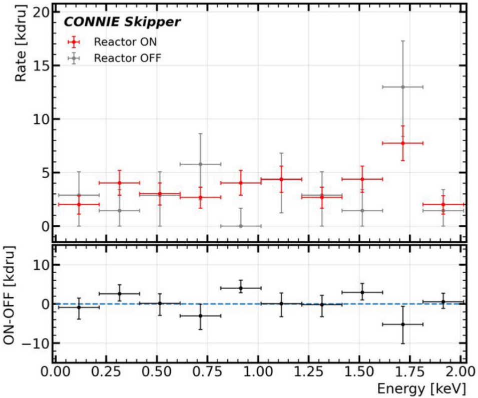


arXiv:2403.15976

Comparison between Reactor-ON and Reactor-OFF event rates.

- 243 days of data with reactor-ON and 57 days OFF.
- Exposure of 14.9 g-days with Reactor-ON and 3.5 g-days with Reactor-OFF.
- **No excess (CEνNS or otherwise) observed.**
- Flat background rate ≈ 4 kdru.





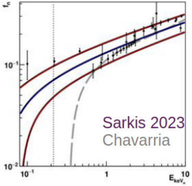
(Top) CONNIE Skipper reactor-on & reactor-off spectra. (bottom) Their difference.

(*arXiv:2403.15976*)

CEνNS search in the lowest-energy bins of reactor ON − OFF rates.

- Updated neutrino flux model with improved antineutrino spectra for ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu.
- Updated Sarkis quenching factor model for Si. (*PRA 107, 062811 (2023)*)
- Improved descriptions of the electronic stopping, interatomic potential and electronic binding at sub-keV energies, $E_{nr} > 0.24\ keV_{nr}$ (15 eV_{ee}).

Measured Energy $[keV_{ee}]$	Sarkis (2023) rate $[kg^{-1}d^{-1}keV_{ee}^{-1}]$	Chavarria rate $[kg^{-1}d^{-1}keV_{ee}^{-1}]$	Observed 95% C.L. $[kg^{-1}d^{-1}keV_{ee}^{-1}]$	Expected 95% C.L. $[kg^{-1}d^{-1}keV_{ee}^{-1}]$
0.015 – 0.215	$29.3^{+4.6}_{-4.7}$	17.7 ± 3.3	2.24×10^3	3.18×10^3
0.215 – 0.415	$2.7^{+1.3}_{-1.2}$	2.20 ± 0.21	7.36×10^3	4.77×10^3
0.415 – 0.615	$0.43^{+0.41}_{-0.39}$	0.36 ± 0.04	3.41×10^3	3.31×10^3

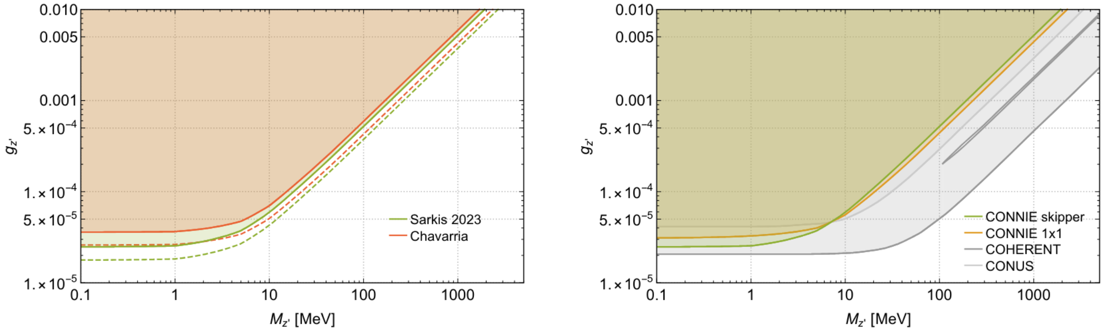


arXiv:2403.15976

- Observed limit at 76x the expected SM predicted Rate (with Sarkis QF).
- Comparable to our previous limit with standard CCDs and 10^3 larger exposure.

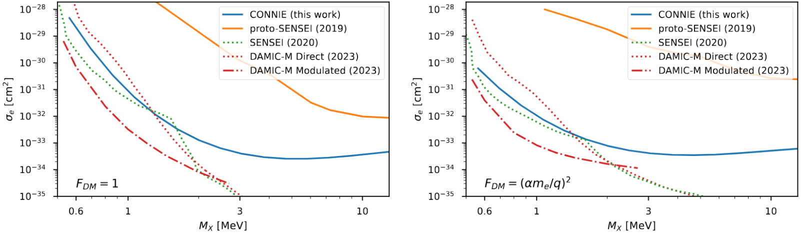
Light vector mediator Z' searches in the CEνNS detection channel

- In the framework of a universal simplified model (JHEP 05, 118 (2016)).
- The rate for additional interactions, $RSM + Z'$, is calculated and compared to limit at 90% C.L.
- Based on the lowest-energy bin (15–215 eV_{ee}).
- Slight improvement at low $M_{Z'}$ on our previous limit in $g_{Z'}$. arXiv:2403.15976



Dark Matter Search

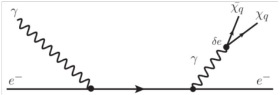
- A search for DM-electron interactions by diurnal modulation.
- Galaxy DM wind comes from a preferred direction 40° N.
- Earth propagation induces a daily modulation.

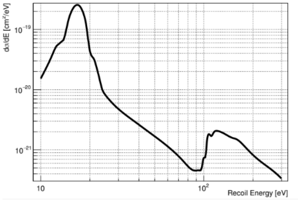


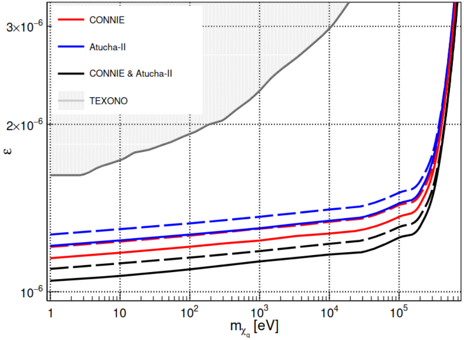
- Binned data are compared to DaMaSCUS simulations.
- MeV-scale DM, kinetically-mixed dark photon.
- Best DM-electron limits by a surface experiment. arXiv:2403.15976

Search for Millicharged Particles arXiv:2405.16316

- Relativistic millicharged particles (χ_q) can be pair-produced from Compton-like scattering of high-energy γ-rays from reactors.
- Interact electromagnetically with matter via ionization.
- Cross-section includes collective excitations.
- Plasmon peak at 10–25 eV. arXiv: 2403.00123
- Joint analysis between CONNIE and Atucha-II experiments.
- World-leading limits on millicharged couplings ($m_{\chi_q} < 1$ MeV).







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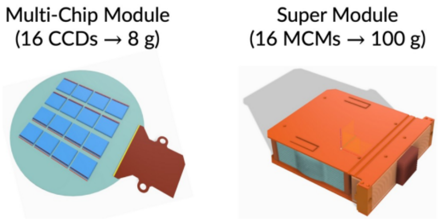
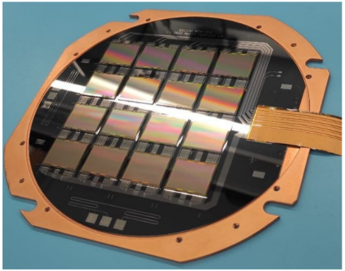
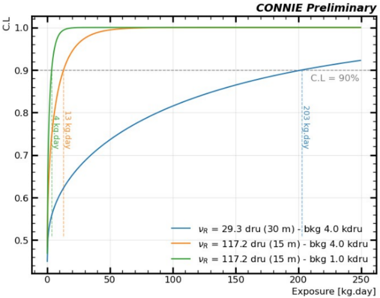
Multi-Chip-Module (MCM) offers a compact arrangement of sensors:

- 16 Skipper-CCD sensors on the same module, 32x increase in mass (8 g).
- Designed for the Oscura experiment.
- Multiplexed readout.
- A MCM was installed at CONNIE in May 2024:
- New vacuum interface and multiplexer boards.



Oscura design [JINST 18 (08), P08016]





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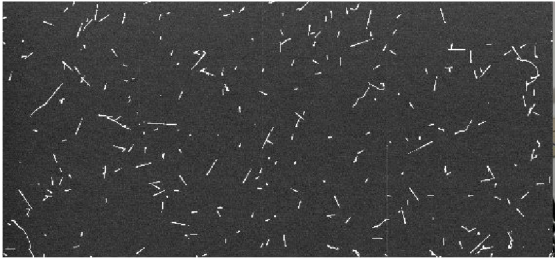
Summary and Outlook

- Skipper-CCDs are very promising for detecting low-energy processes.
- Excellent performance in 2021-2023 with flat background and 15 $\mathrm{eV_{ee}}$ threshold.
- New CEνNS limit with 18.4 g-days is comparable to previous with higher exposure.
- New competitive limits on vector mediator, DM modulation and millicharged particles.
- The experiment started its next phase with a 16-sensor Multi-Chip-Module.



Q & A

Thank you for listening!
Your feedback will be highly appreciated

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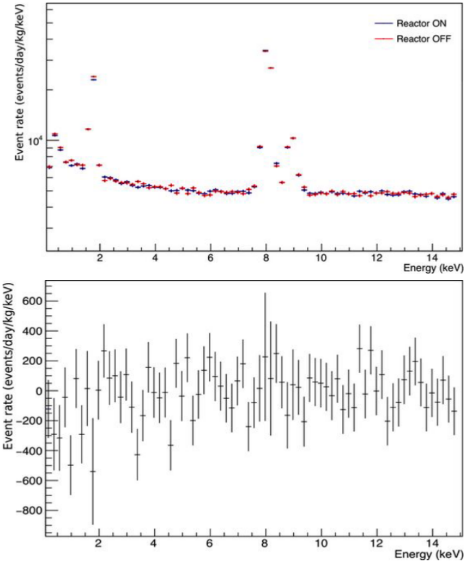
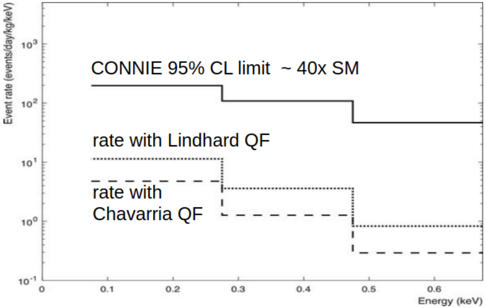
Y. Sarkis acknowledges support from DGAPA-UNAM grants CONAHCYT CF-2023-I-1169, PAPIIT IN104723 and CONAHCYT grant CB2014/240666.

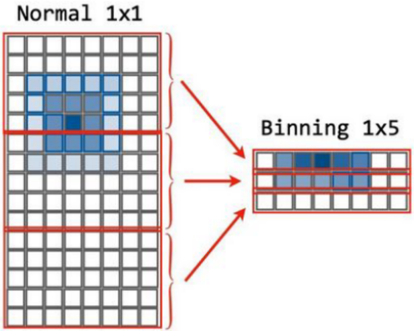


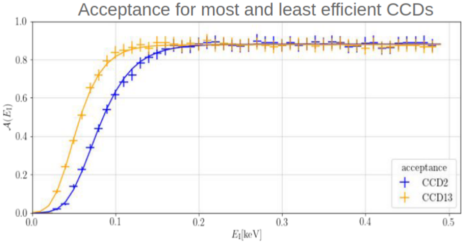
- 2016-18 Run with active mass of 47.6 g.
- Readout noise ranging from 1.7-2.2 e-
- Energy spectrum with reactor on (2.1 kg-day) vs data with reactor off (1.6 kg-day).
- Extract upper limit for the CEνNS event rate.
- Expected rate calculated with different QF models.

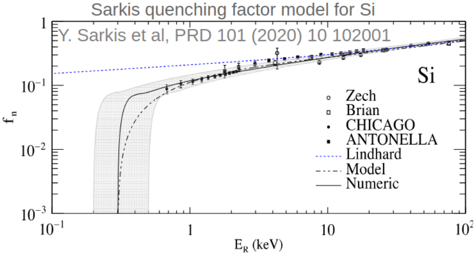


CONNIE improvements made in this run:

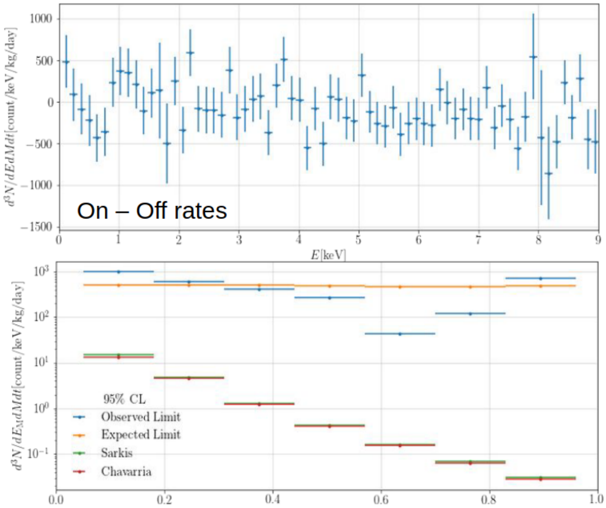
- 1×5 pixel rebinning reduces readout noise .
- Low-energy background characterization and reduction.
- Cuts to remove anomalous large low energy events.
- Simulation of Partial Charge Collection (PCC) layer in the back side of the CCD.
- Ionization efficiency improved model, accounts binding for energy.







- 8 CCDs with total active fiducial mass of 36.2 g.
- Exposures of **31.85** days (reactor on) and **28.25** days (reactor off).
- Total exposure: **2.2 kg-days.**
- Upper limits at 95% CL on the measured CEνNS rate.
- Lowest energy bin: Expected (34-39) and Observed (66-75) times the prediction.



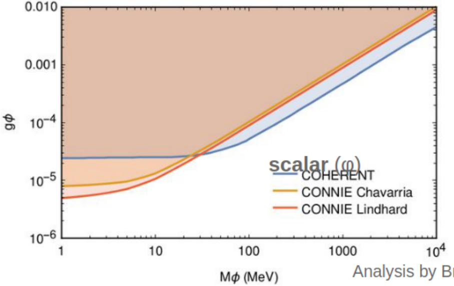
BSM physics results

- Event rate in lowest E bin gives limits to non-standard neutrino interactions: Simplified models with light **scalar** (φ) and **vector** (Z') mediators.
- Restrictive limits for low mediator masses $M_\varphi < 30$ MeV, $M_{Z'} < 10$ MeV.
- First competitive constriction to BSM physics from CEvNS in reactors!
- Best current limit from the CONUS experiment [JHEP, 085, 05, 2022]

NEUTRINO 2020
Community milestone

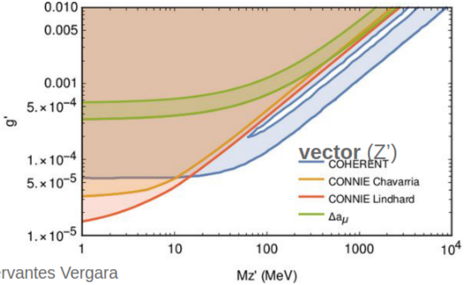
$$\frac{d\sigma_{SM+\phi}}{dE_R}(E_{\bar{\nu}_e}) = \frac{d\sigma_{SM}}{dE_R}(E_{\bar{\nu}_e}) + \frac{G_F^2}{4\pi} Q_\phi^2 \left(\frac{2ME_R}{E_{\bar{\nu}_e}^2}\right) MF^2(q)$$

$$Q_\phi = \frac{(14N + 15.1Z)\, g_\phi^2}{\sqrt{2}G_F(2ME_R + M_\phi^2)}$$



$$\frac{d\sigma_{SM+Z'}}{dE_R}(E_{\bar{\nu}_e}) = \left(1 - \frac{Q_{Z'}}{Q_W}\right)^2 \frac{d\sigma_{SM}}{dE_R}(E_{\bar{\nu}_e})$$

$$Q_{Z'} = \frac{3(N+Z)\, g'^2}{\sqrt{2}G_F(2ME_R + M_{Z'}^2)}$$



Analysis by Brenda Cervantes Vergara