The CONNIE experiment: latest results and upgrade

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on behalf of the CONNIE Collaboration

Magnificent CEνNS 2021
October 6, 2021

The CONNIE collaboration

~30 members from 6 countries

USA
Fermi National Accelerator Laboratory

Switzerland
University of Zurich

Mexico
Universidad Nacional Autónoma de México

Paraguay
Universidad Nacional de Asunción

Argentina
Centro Atómico Bariloche
Universidad de Buenos Aires
Universidad del Sur / CONICET
ICAS / ICIFI / UNSAM

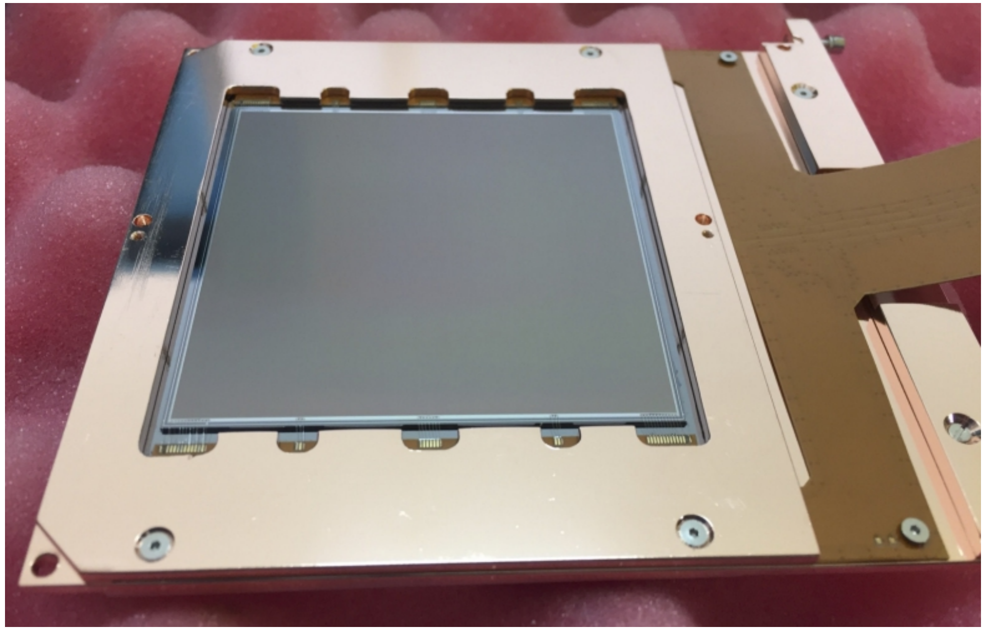
Brazil
Centro Brasileiro de Pesquisas Físicas
Universidade Federal do Rio de Janeiro
CEFET / Angra

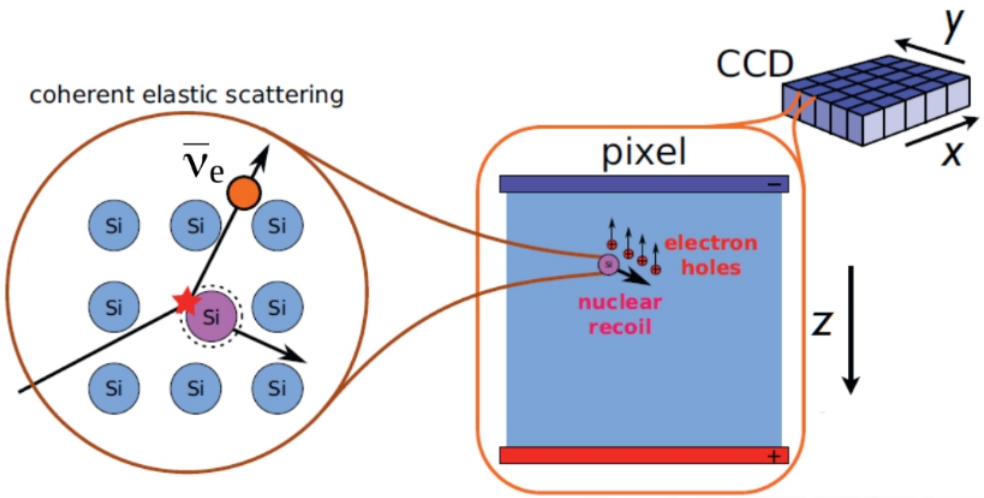
COherent Neutrino Nucleus Interaction Experiment (CONNIE)

Goal → Measure CEνNS of reactor antineutrinos with Silicon nuclei and probe BSM physics

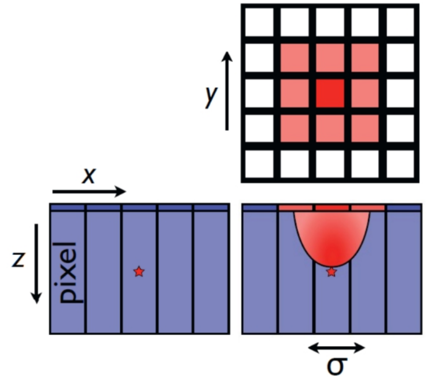
Detectors → Scientific-grade Charge-Coupled Devices (CCDs) manufactured with high resistivity Si

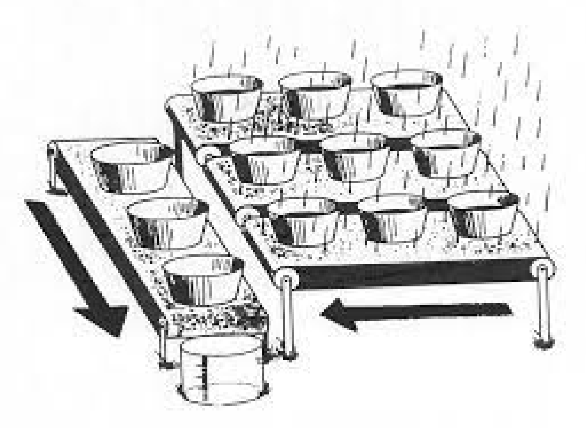
- Low radioactive backgrounds
- Low noise and dark current (DC)
- Low-energy detection threshold





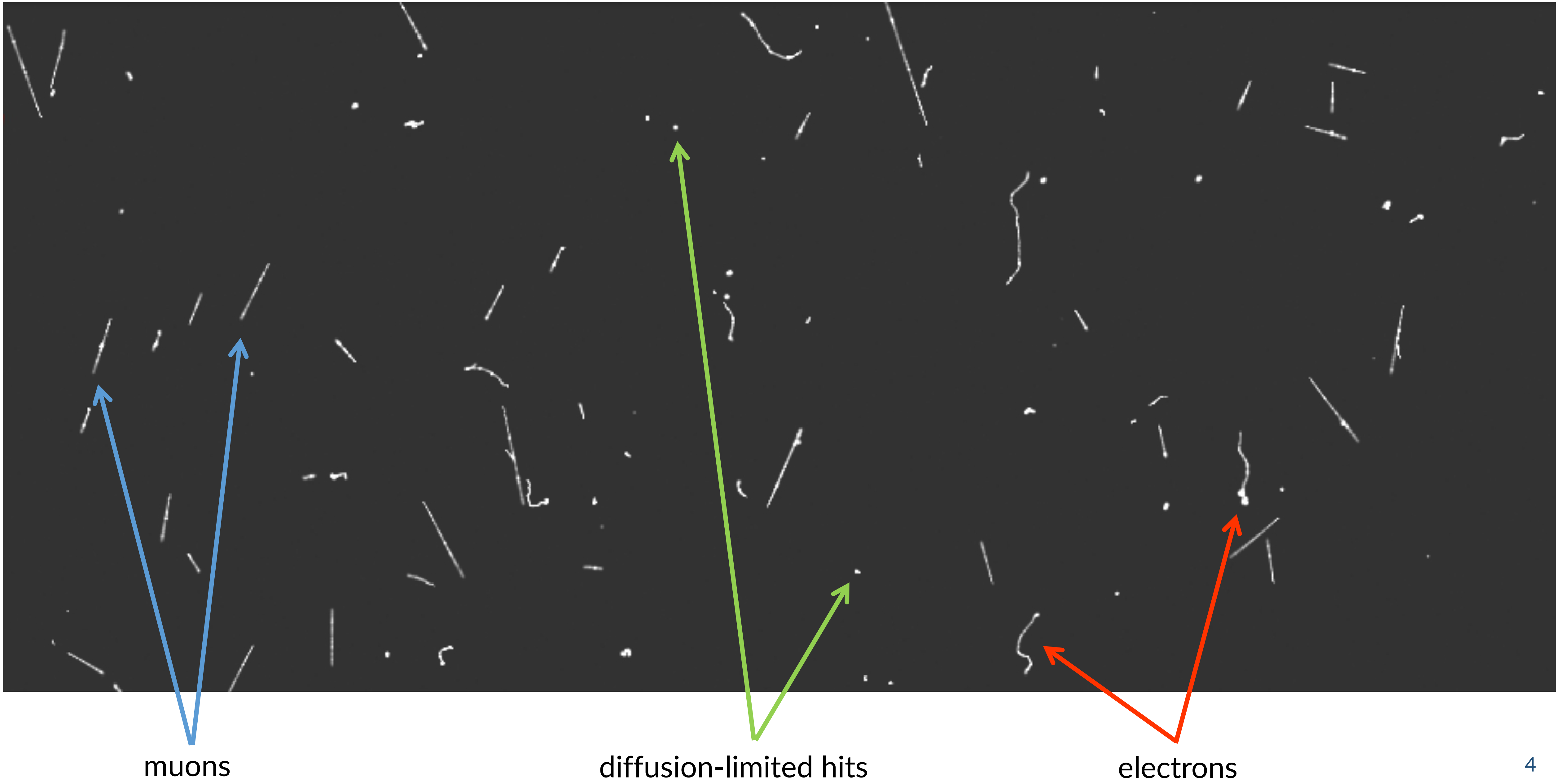
- Operating at T<100 K





Binning improves signal-to-noise ratio

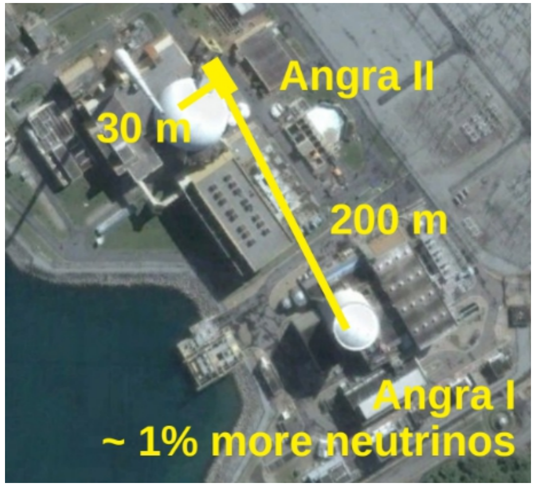
CCDs allow particle identification



COherent Neutrino Nucleus Interaction Experiment (CONNIE)

Site → ~30 m from the 3.8 GW_{th} Angra 2 reactor at the Almirante Álvaro Alberto nuclear power plant, in Angra dos Reis, Brazil

- Flux of 7.8×10^{12} $\tilde{\nu}$/s cm^2 at CONNIE
- Reactor shutdown 1 month every ~13 months (ROFF)

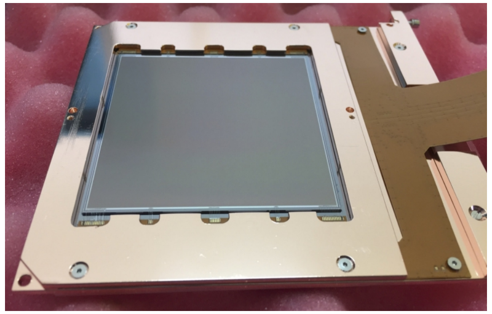


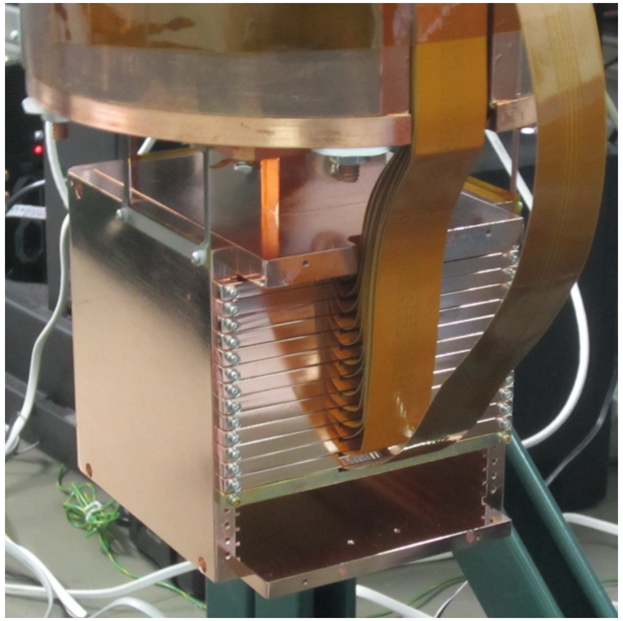
CONNIE timeline and milestones

Installed at Angra in 2014 (engineering run)
First detector upgrade: Aug 2016 → 14 CCDs (5.95 grams each) developed at LBNL installed at Angra

8 CCDs with stable operation and good quality data running until Dec 2020

- 4k x 4k pixels
(15 µm x 15 µm per pix)
- 675 µm thick





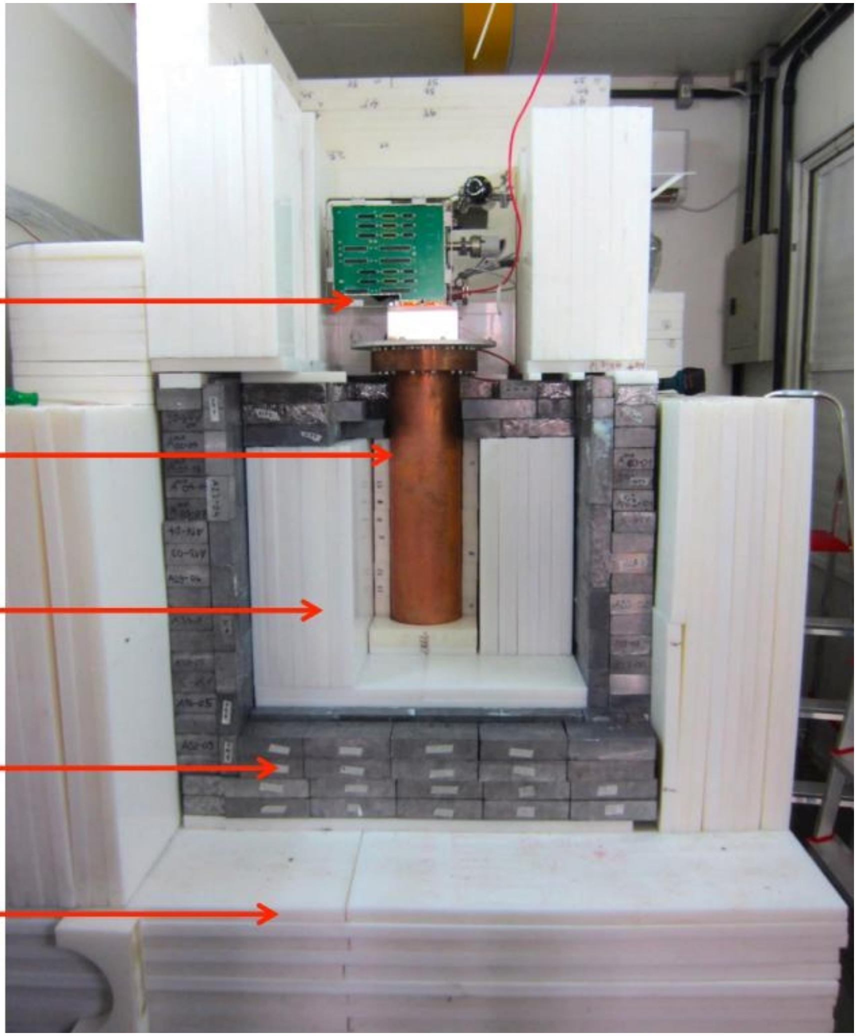
VIB readout board

Dewar in vacuum

Inner polyethylene ~30 cm
(neutrons shield)

Lead ~15 cm
(gammas shield)

Outer polyethylene ~30 cm
(neutrons shield)



CONNIE timeline and milestones

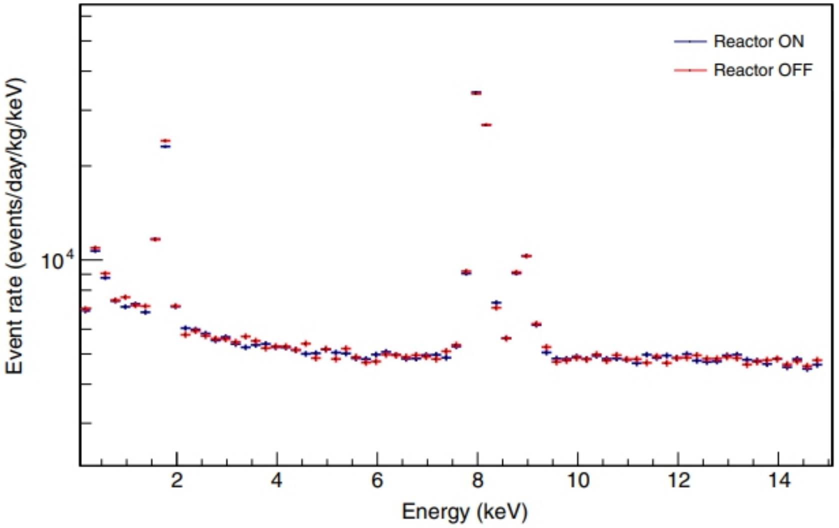
2016-2018 run data: 2.1 kg-day with RON / 1.6 kg-day with ROFF → 1x1 binning

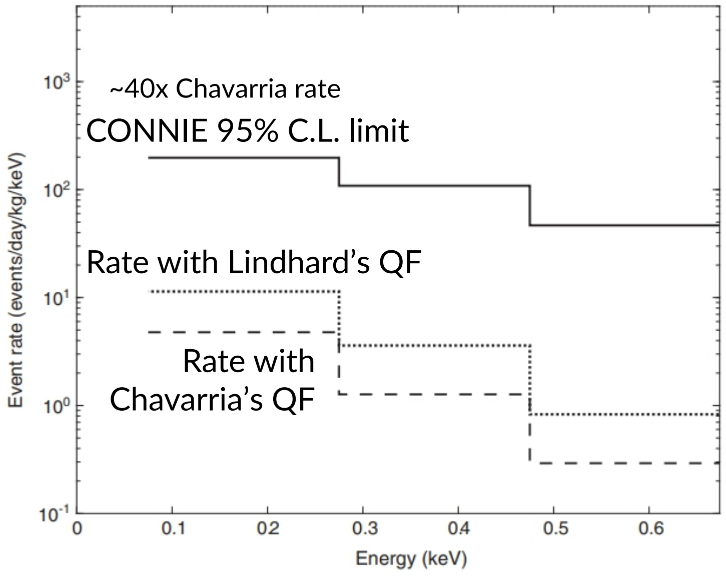
Nov 2019 → Published 2016-2018 run data results **[PRD 100 (2019), 092005]**

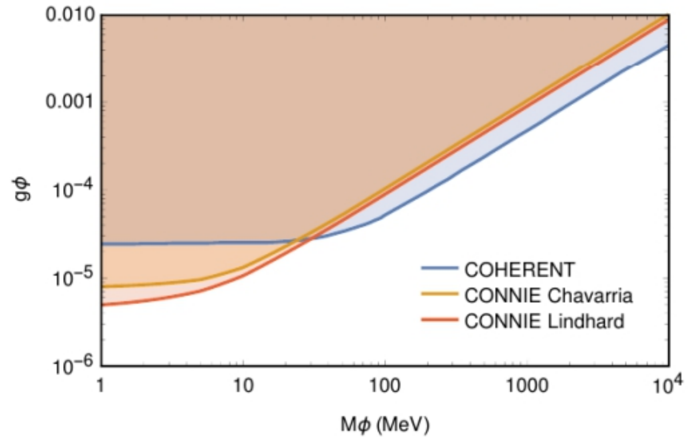
- Stablish a model independent limit on CEνNS rate

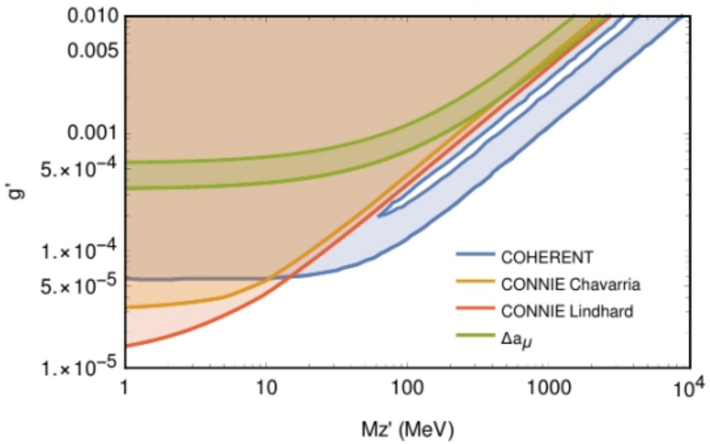
Apr 2020 → Published limits on simplified SM extensions with light mediators **[JHEP 04 (2020), 054]**

- First competitive BSM constraints from CEνNS at reactors









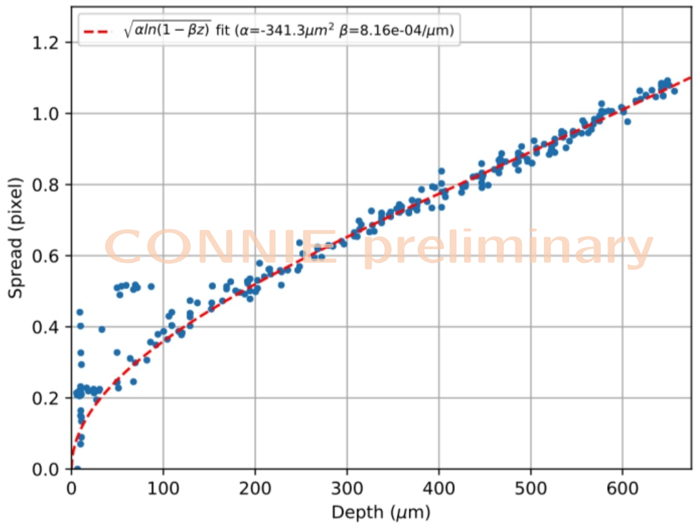
2019 run

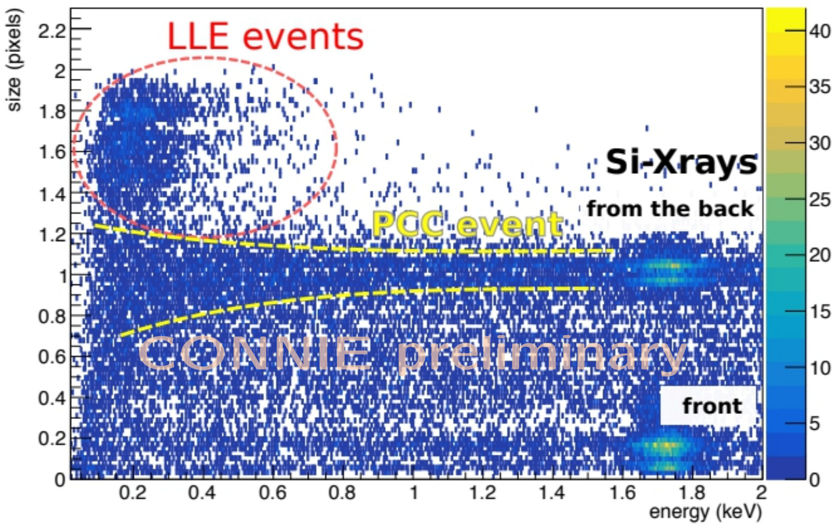
Paper coming soon!

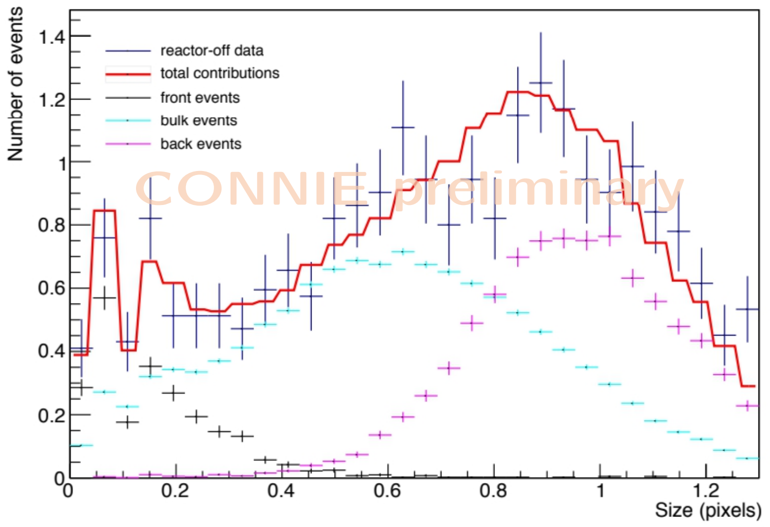
Jan 2019 → New readout configuration with 1x5 binning (lower noise) and 1 hr exposure (lower DC)

Analysis:

- Improved energy and size-depth calibrations
- Better low-energy background characterization and rejection
  - Large low-energy (LLE) events
  - Partial-charge-collection (PCC) layer events
- Implemented spatial uniformity check
- Perform multiple cross-checks







Blind analysis

- Freeze analysis parameters with ROFF data
- Stability checks with mid to high energy RON data
- Unblind low energy RON data

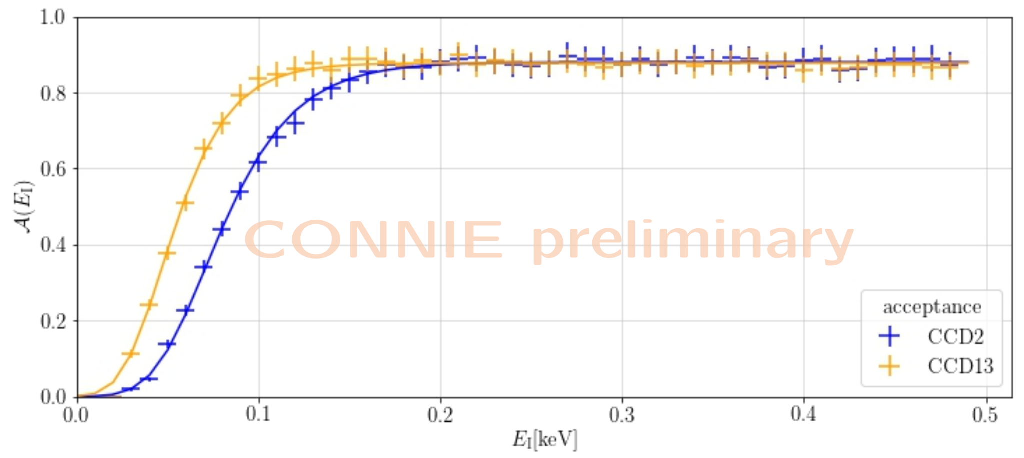
2019 run

Paper coming soon!

Improved detector extraction acceptance and selection efficiency at low energies:

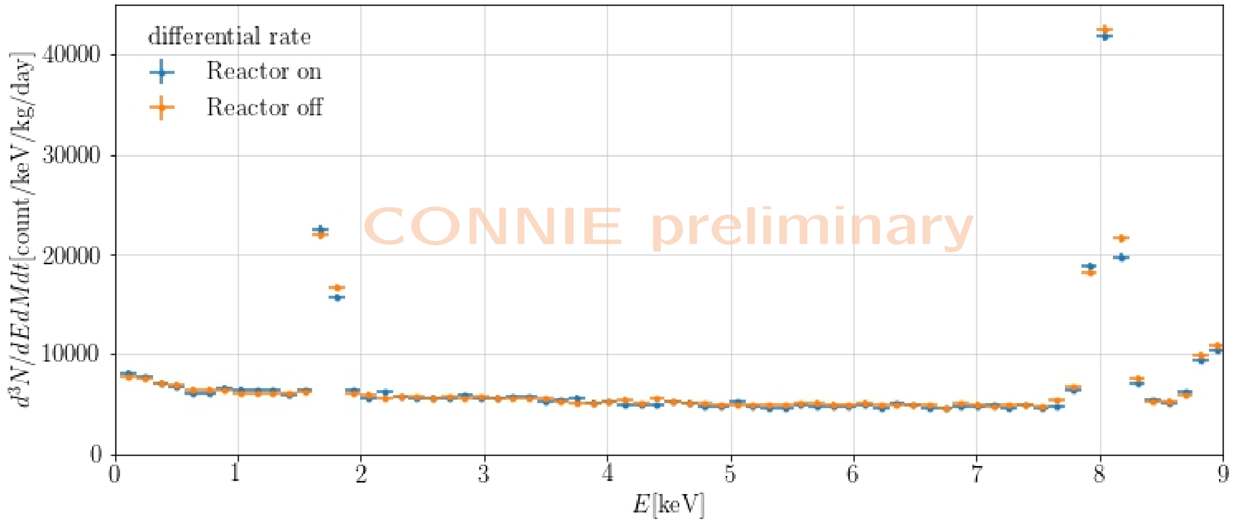
Threshold reduced to ~40 eV

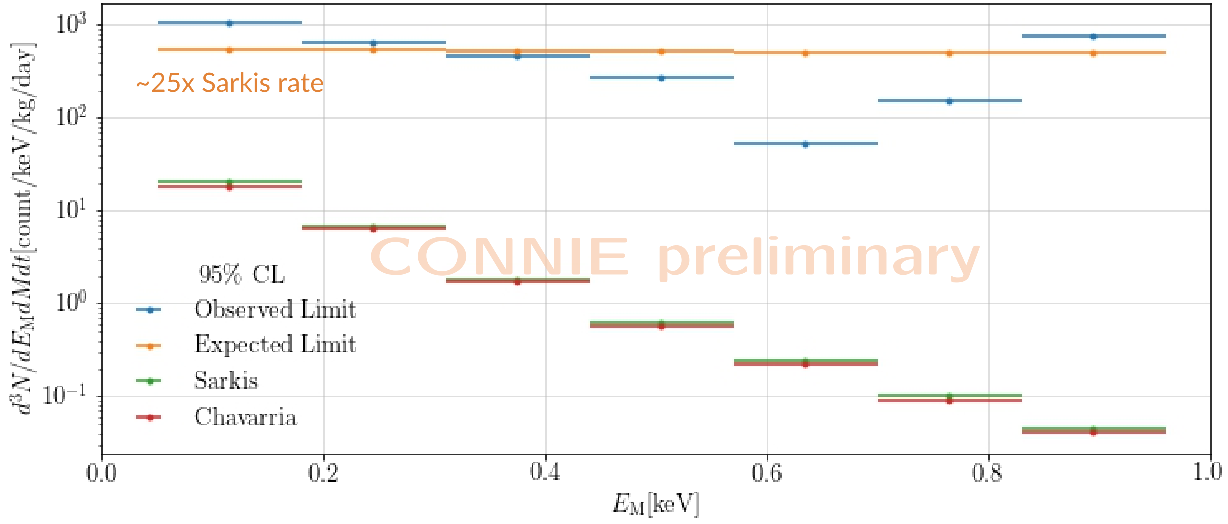
Full acceptance reached at 100-150 eV



Total exposure: 2.7 kg-days (31.85 days with RON and 28.25 days with ROFF)

RON-ROFF consistent with zero → 95% C.L. limit on observed (expected) CEνNS rate



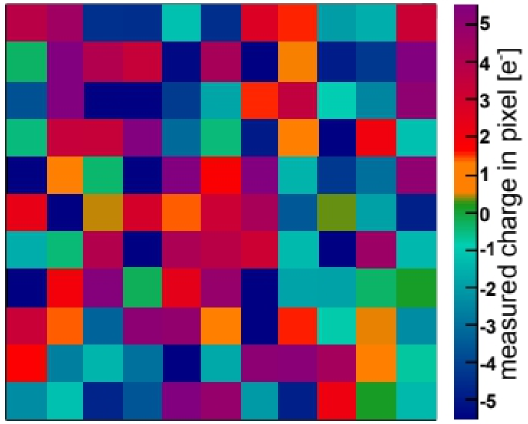


More details about QF model including binding energy (Sarkis) [PRD 101 (2020) 10 102001] → See Youssef Sarkis talk tomorrow!

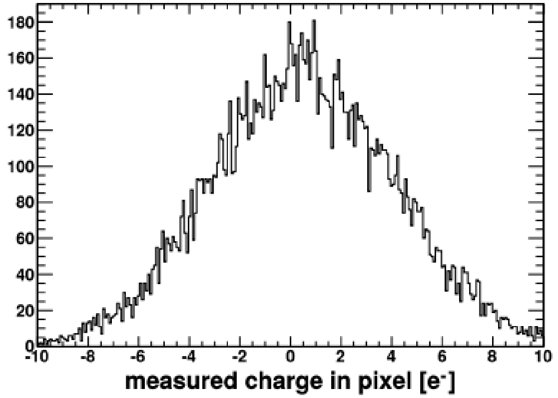
Skipper-CCD technology

- Allows multiple sampling of each pixel during data acquisition
- Reduces readout noise with number of samplings $\sigma \propto 1/\sqrt{N}$
- Allows detecting single electrons!
- Promising for neutrino and dark matter detection

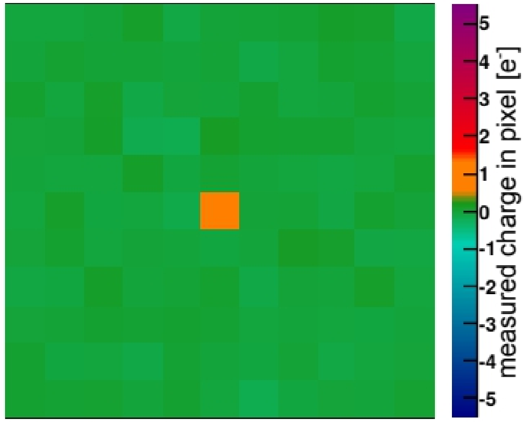
Standard CCD mode: charge in each pixel is measured once



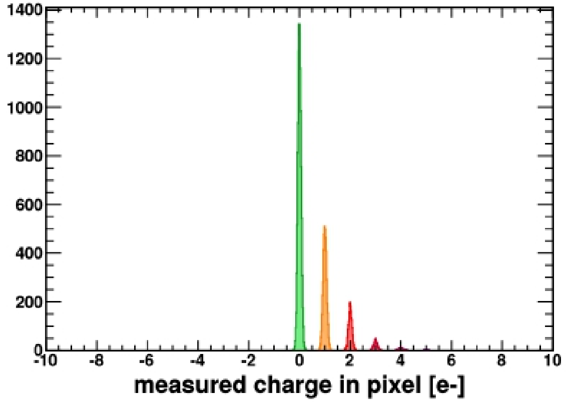
Readout-noise: 3.5 e RMS

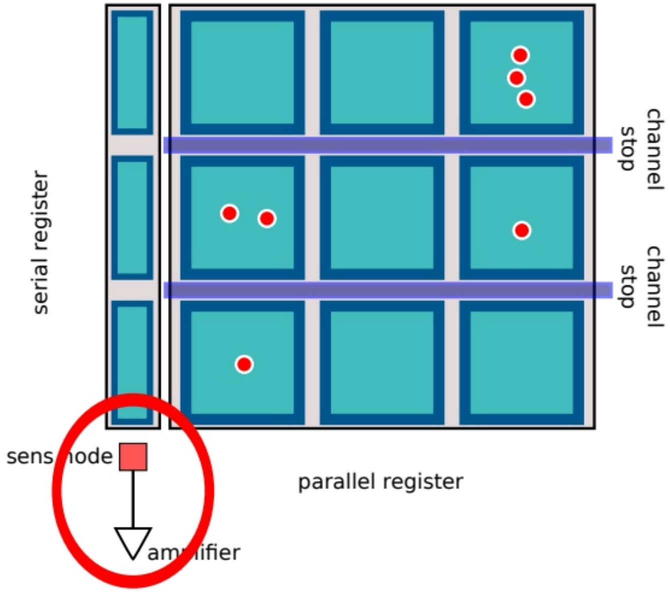


New Skipper CCD: charge in each pixel is measured multiple times



Readout-noise: 0.06 e RMS





Only the readout stage is modified

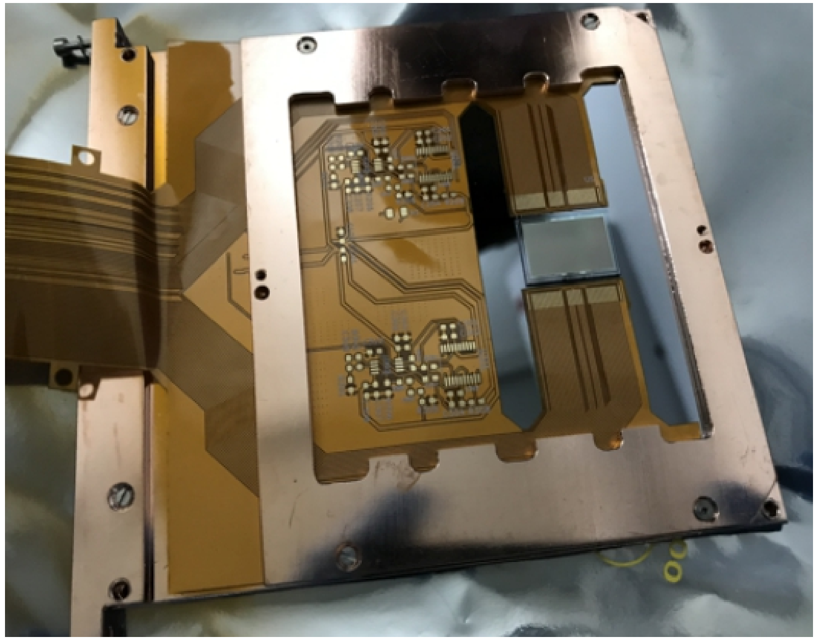
Skipper technology first demonstrated in 2017 [PRL 119, 131802] using a detector designed by Stephen Holland (LBNL)

SENSEI DM experiment currently using skipper CCDs [PRL 125, 171802]

CONNIE upgrade with skipper-CCDs

Jul 2021 → 2 skipper CCDs (768 x 1024 pixels each) installed at Angra

- New Low Threshold Acquisition readout electronics [JATIS 7 (2021), 1 015001]
- New dedicated Vacuum Interface Board

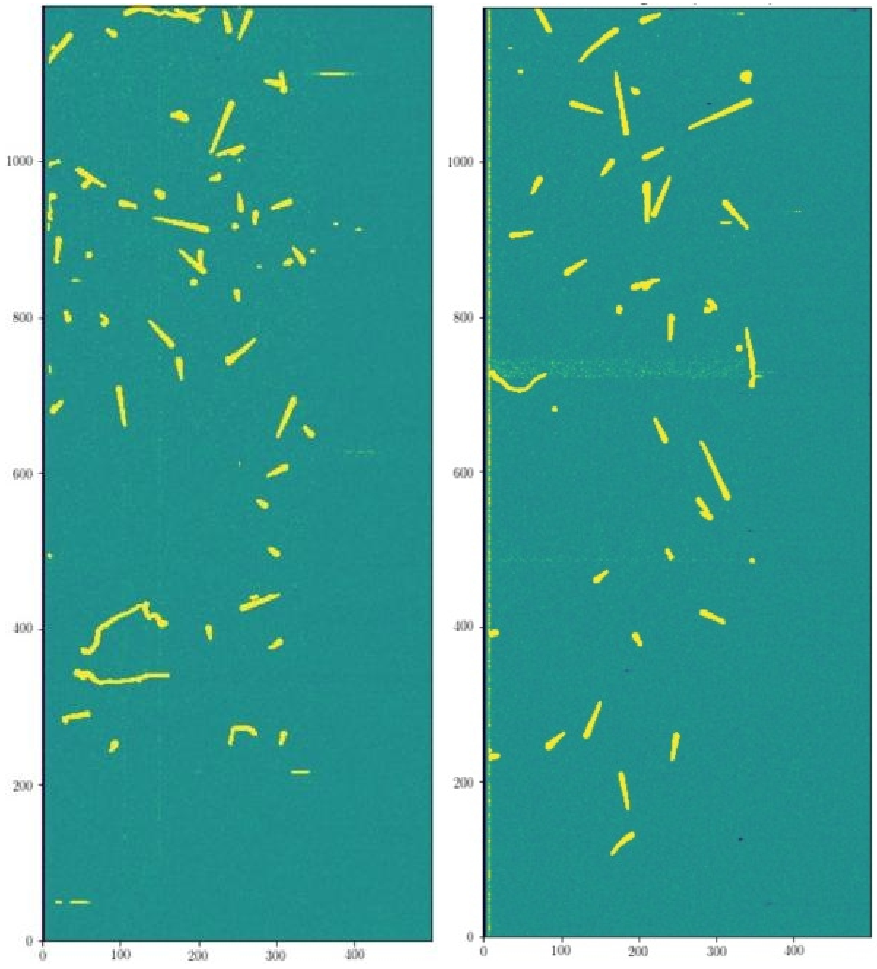



Goals (towards next generation experiments)
- Study skipper-CCDs performance and background at sea level
- Test LTA electronics

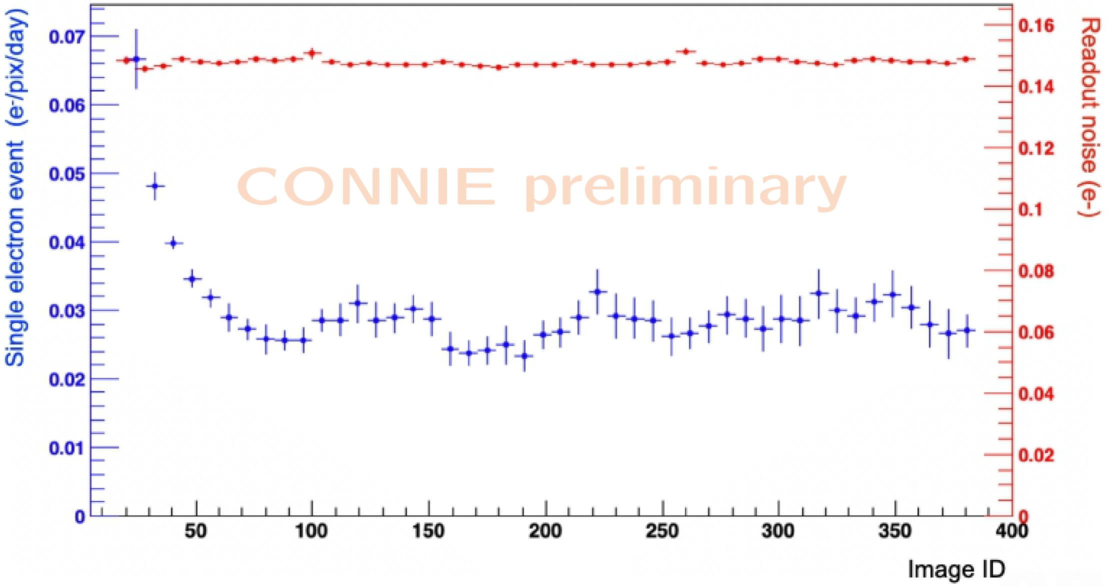
More about installing skipper CCDs at reactors
See Guillermo Fernandez Moroni talk tomorrow!

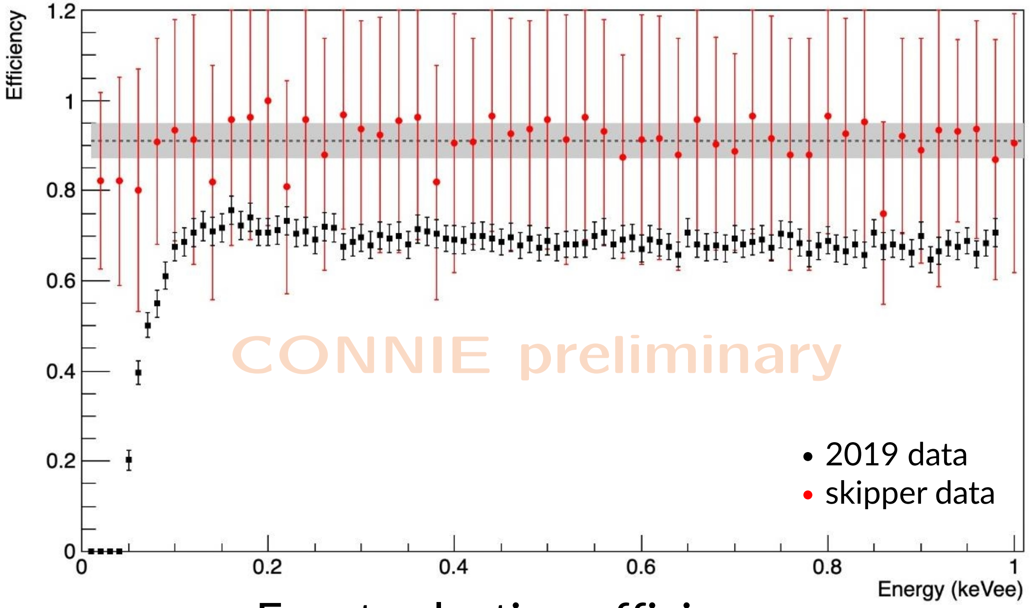
CONNIE upgrade with skipper-CCDs

Ongoing data taking
Running stable → Noise: ~0.15 e-
DC: ~0.03 e-/pix day



Images with 400 samples/pix

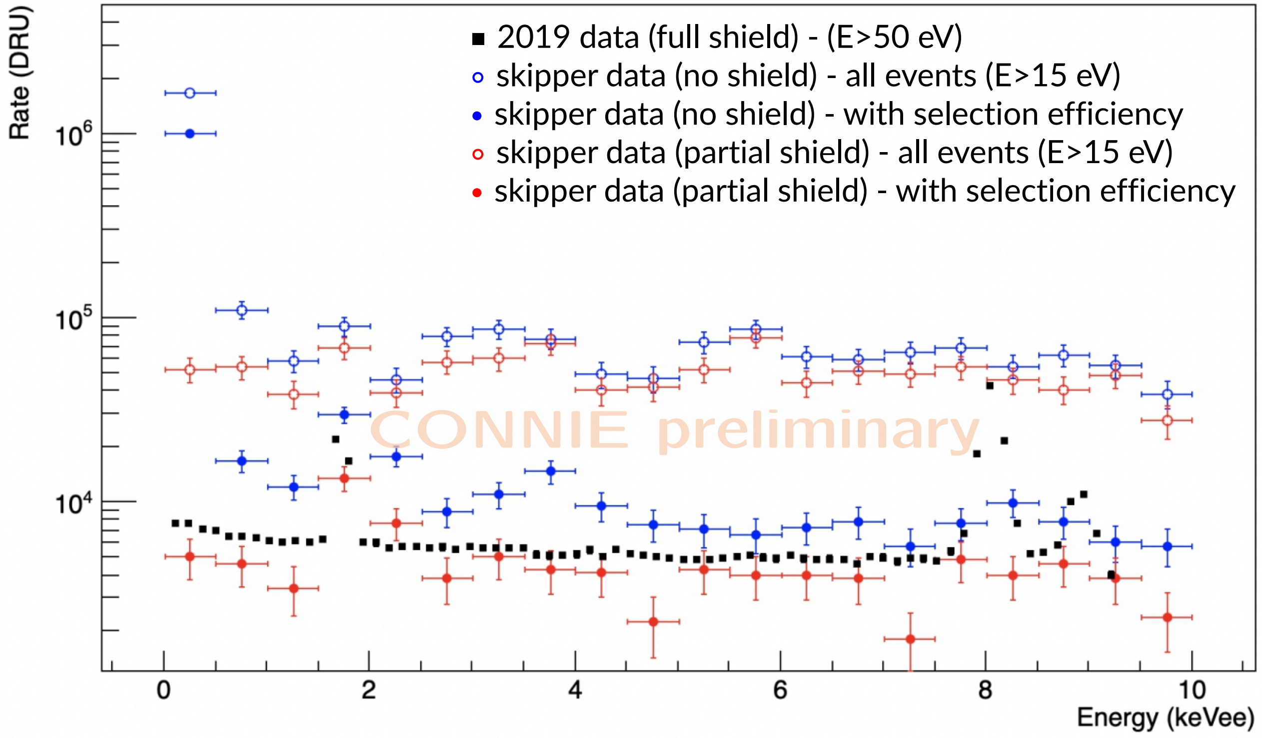


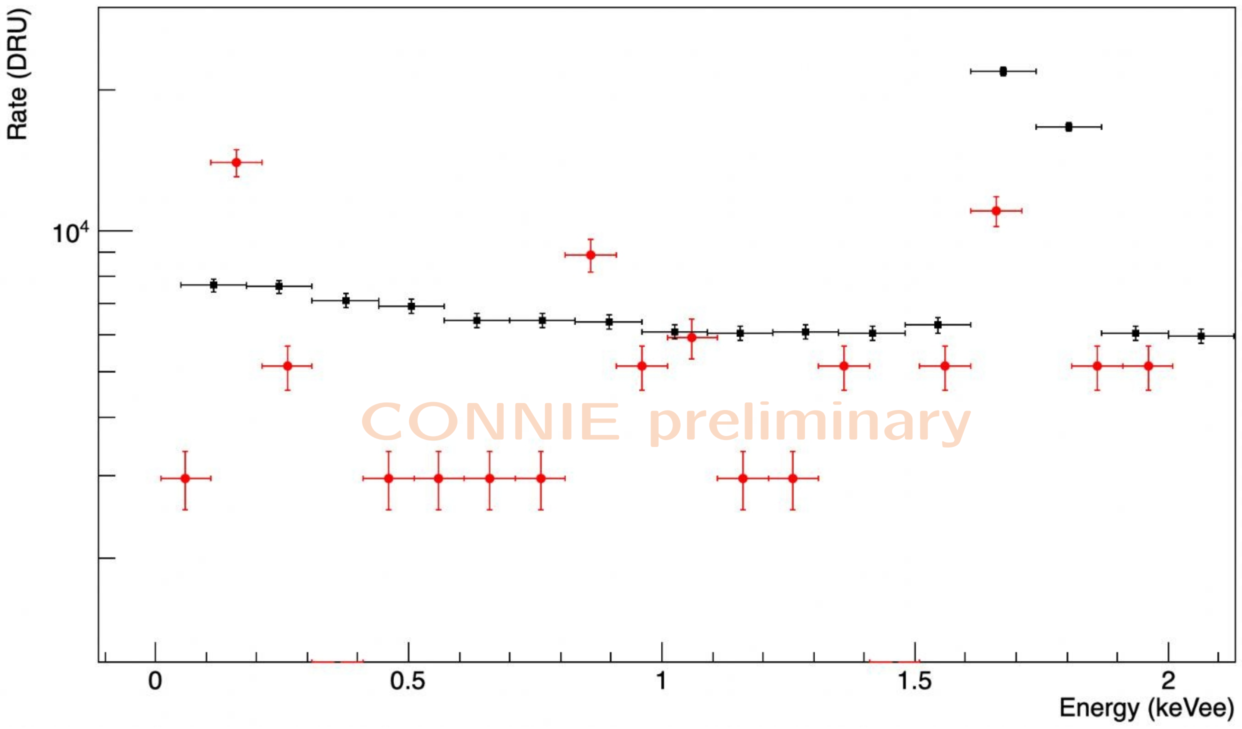


Event selection efficiency

CONNIE upgrade with skipper-CCDs

Current exposure:
Without shield → 4.28 x 10^{-4} kg-day
With partial shield (~30 cm inner poly & ~5 cm lead) → 1.69 x 10^{-3} kg-day





Next steps:
Collect more data / Run with full shield / Install more CCDs to increase mass to ~50 g

Summary

- CCDs are a promising technology for detecting CEνNS at low energies
- CONNIE has demonstrated to be competitive constraining BSM physics
- In 2019 run data analysis we achieved better sensitivity due to binning and improved analysis (paper coming soon!)
- Skipper CCDs allow to improve greatly the low-energy sensitivity
- The first skipper data at a reactor are encouraging → stable, low noise and DC, rate with partial shield competitive with CONNIE 2019 rate
- Characterization of skipper CCDs at sea-level background will help prepare for a future larger-mass skipper CCD experiment*

*Started discussions for installing skipper CCDs inside the dome of the reactor at Angra (~17 m away from the core)

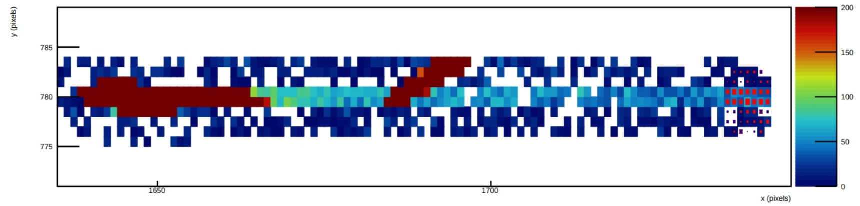
Thank you!

Back up slides

LLE and PCC events in low background

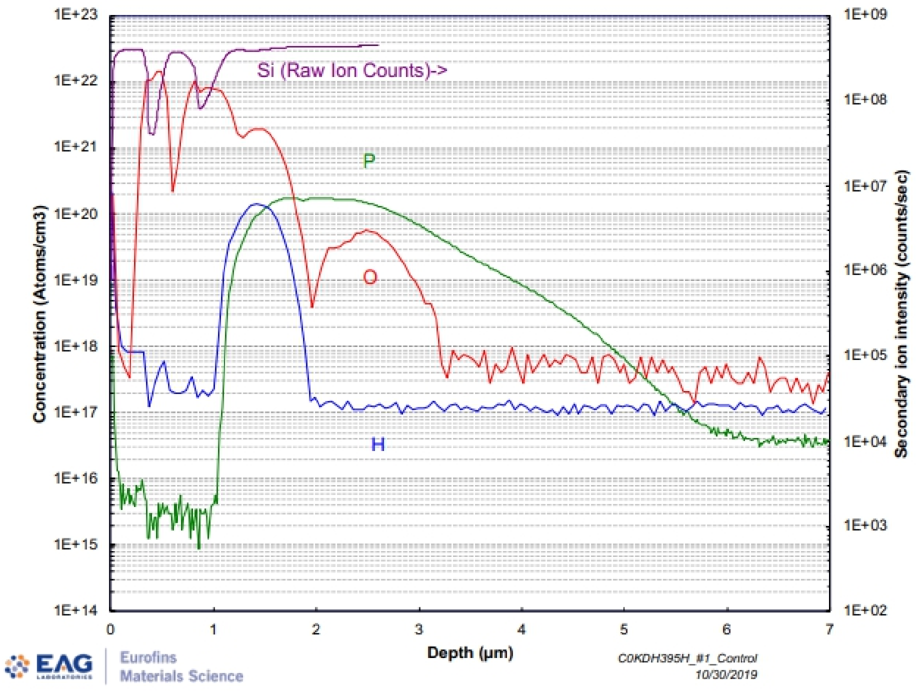
LLE events

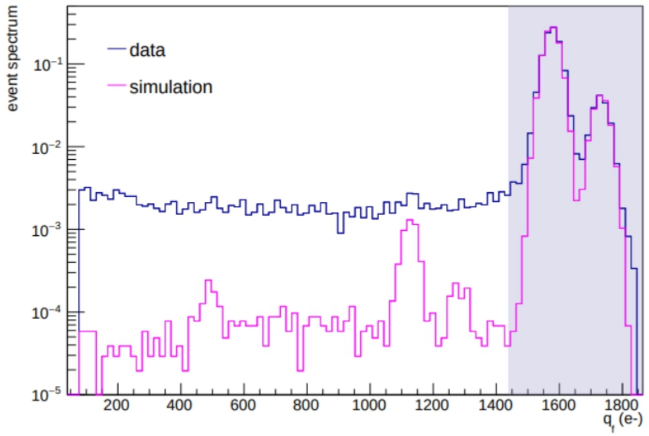
- Tails of very energetic events that do not follow CTI process
- Charge deposition in the inactive volume of the sensor (SR)



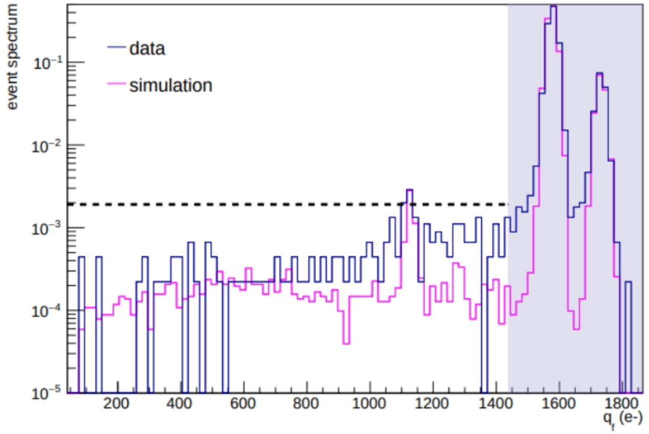
PCC events

- CONNIE CCDs have a ~5 µm layer in the back of the sensors where charge partially recombines because of a gradient in the P concentration ($10^{20} \rightarrow 10^{11}$ P atoms/cm^3)





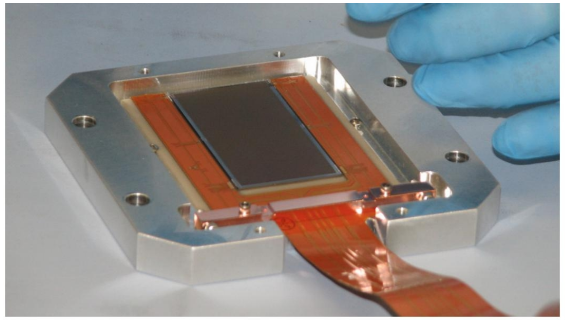
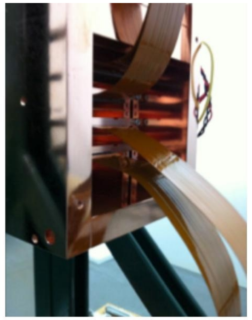
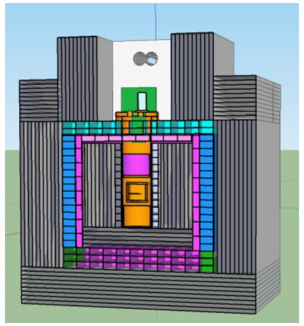
CCD without back treatment



Back-treated CCD

[Phys. Rev. Applied 15, 064026 (2021)]

CONNIE timeline and milestones

Engineering run
Dec 2014 → 4 CCDs (1 gram each) installed at Angra
Aug 2015 → Full shield installed

Engineering run data: 1 month with RON / 1 month with ROFF → 1x1 binning
Apr 2016 → Published engineering run data results **[JINST 11 (2016), P07024]**

- Demonstrated remote operations, low noise (<2 e-) and stable bkgd rates