Results on CEνNS from the CONNIE experiment

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on behalf of the CONNIE Collaboration

June 8, 2021
International Workshop on Weak Interactions and Neutrinos

the CONNIE collaboration

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

Mexico
Universidad Nacional Autónoma de México

Paraguay
Universidad Nacional de Asunción

Switzerland
University of Zurich

USA
Fermilab National Laboratory

~30 members

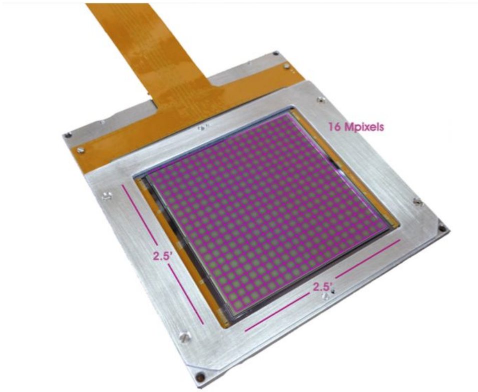
the CONNIE experiment

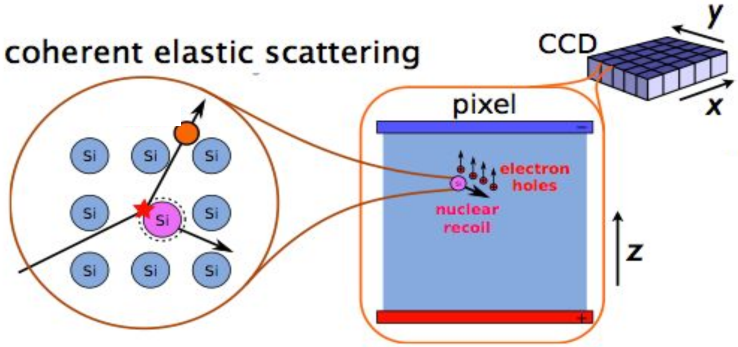
- coherent elastic neutrino-nucleus scatterings (CEνNS) provide a new window into the low-energy neutrino sector; potential probe for new physics

- the main goal of the COherent Neutrino–Nucleus Interaction Experiment (CONNIE) is to detect CEνNS in Silicon Nuclei

- scientific CCDs with high resistivity, low noise and 675μm thickness (5.25 g) created at LBNL and also used in the Dark Matter In CCDs experiment (DAMIC)

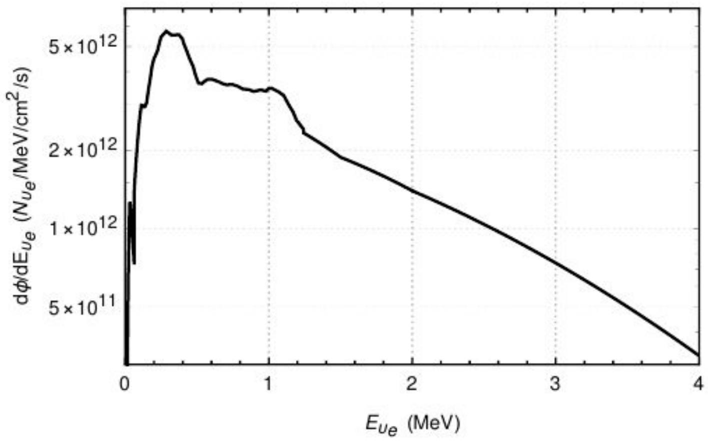
- threshold of ~50 eV for ionization energy of the nuclear recoil (quenching factor)





the CONNIE detector

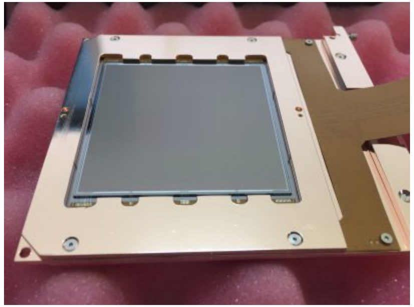
- 30 m from the Angra 2 reactor core, Rio de Janeiro – Brazil
- antineutrino source of 3.8 GW_{th}
- estimated flux of 7.8 x 10^{12} ν s^{-1} cm^{-2} at the detector position
- neutrino flux spectrum

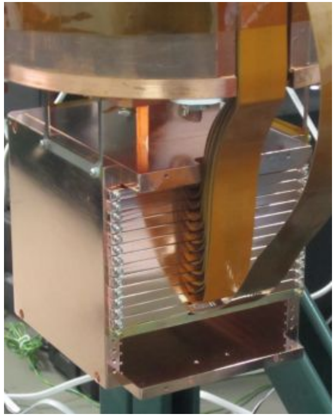


the CONNIE detector

installed in 2014 and upgraded in 2016

4k x 4k pixel
15x15μm
675μm thick





CCDs in
copper box

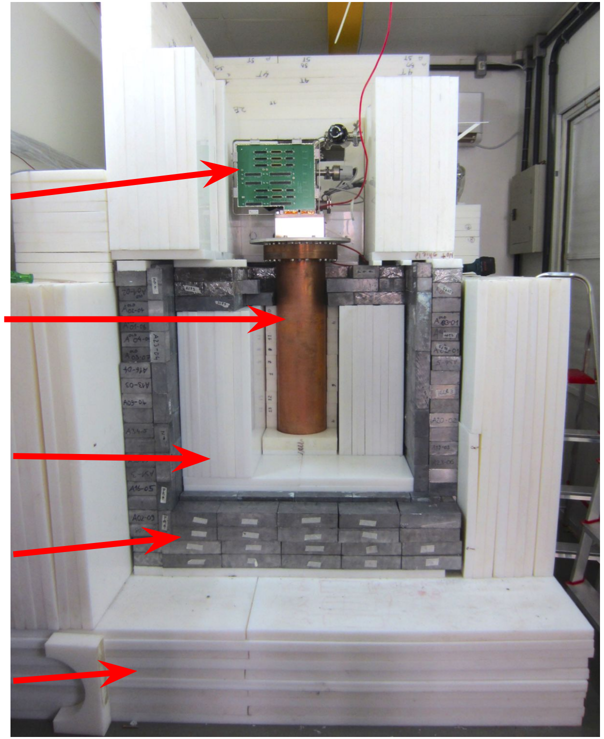
ViB readout board
(signal transport)

Dewar in vacuum

Inner Polyethylene
(neutrons) 30 cm

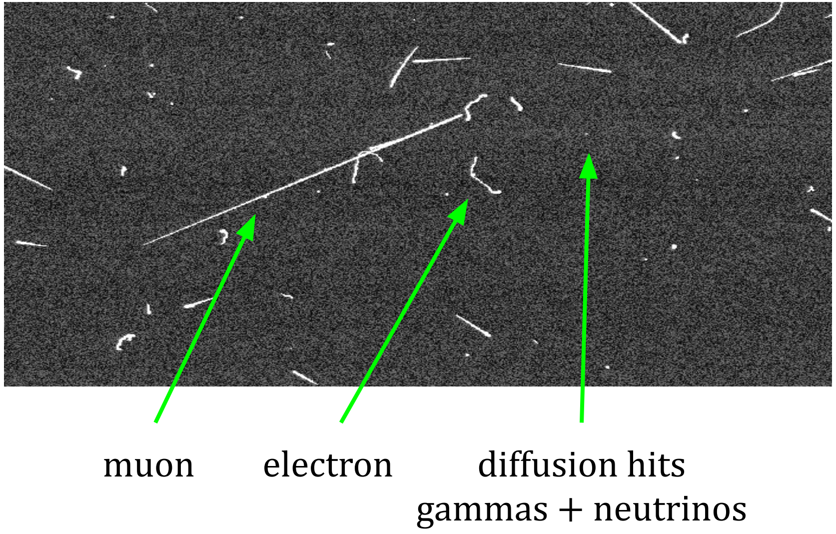
Lead (gamma) 15 cm

Outer Polyethylene
(neutrons) 30 cm

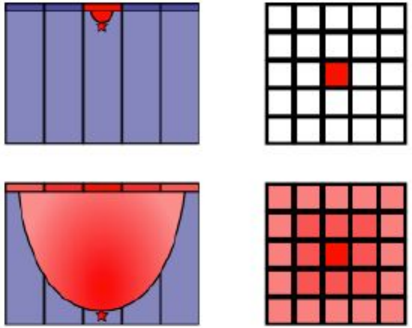


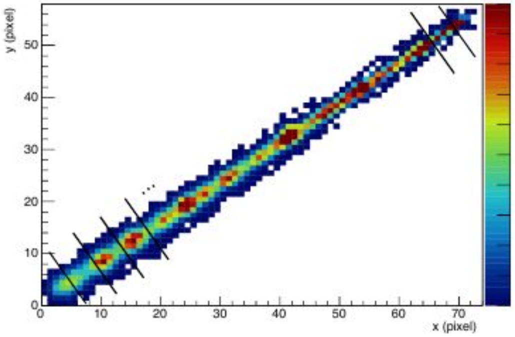
JINST 11 (2016) P07024

event reconstruction



- identify events from track geometry
- energy calibration: Si and Cu fluorescence gammas
- depth calibration: muons



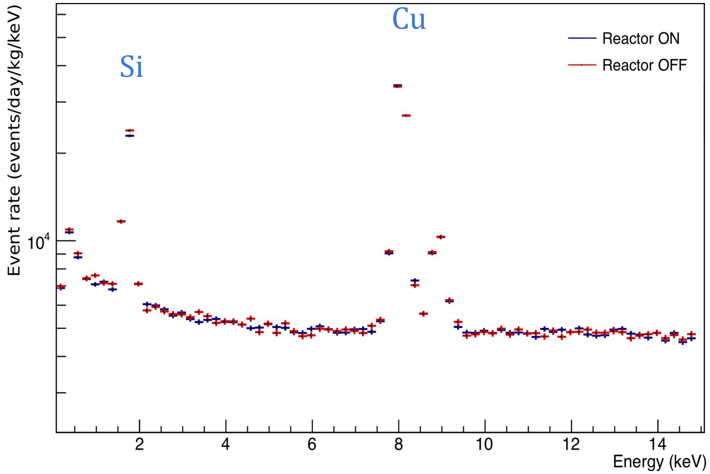


Phys. Rev. D 100 (2019) 092005

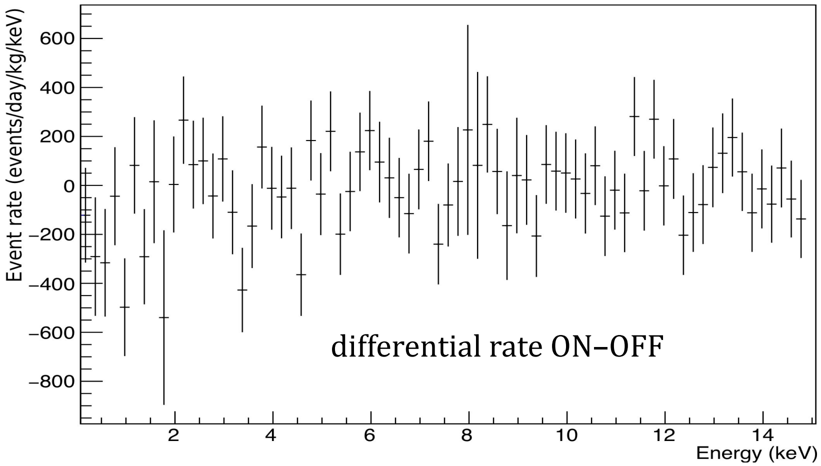
results 2016–2018

control data stability

- read-out noise and dark current
- calibration of Cu and Si peaks
- high-energy event rates



- discard images with high read-out noise and dark current
- remove CCD edge effect and dead pixels
- total exposure:
  Reactor ON (2.1kg·day) and OFF (1.6kg·day)

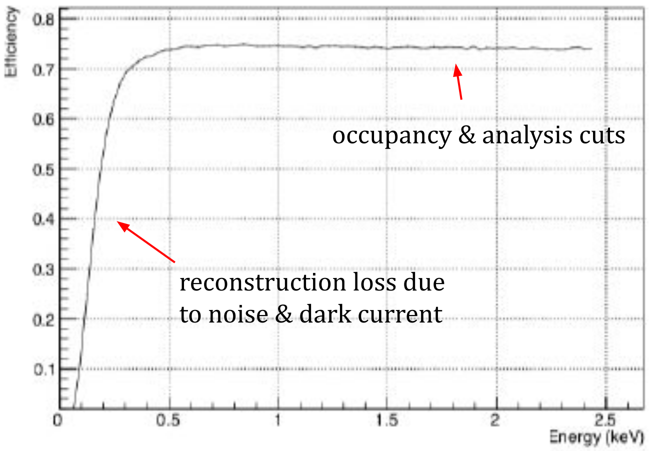


Phys. Rev. D 100 (2019) 092005

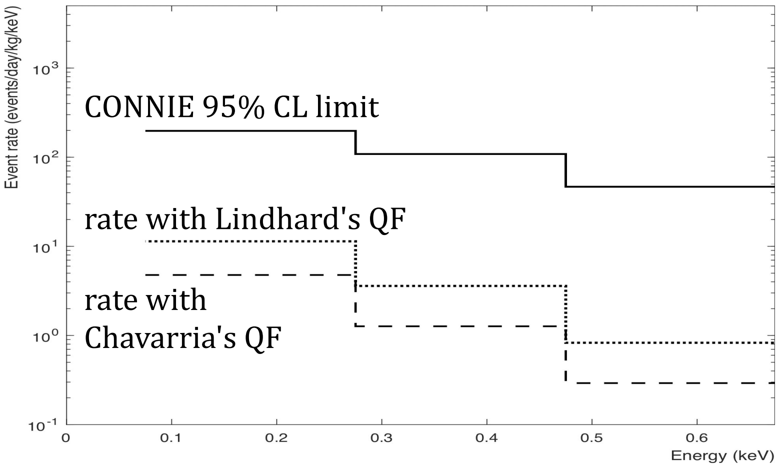
results 2016–2018

acceptance & efficiency computation

- **simulate** low-energy neutrino events in each image and process the full event reconstruction analysis



- uncertain quenching factor (QF)
- place limit at ×40 the SM expected rate



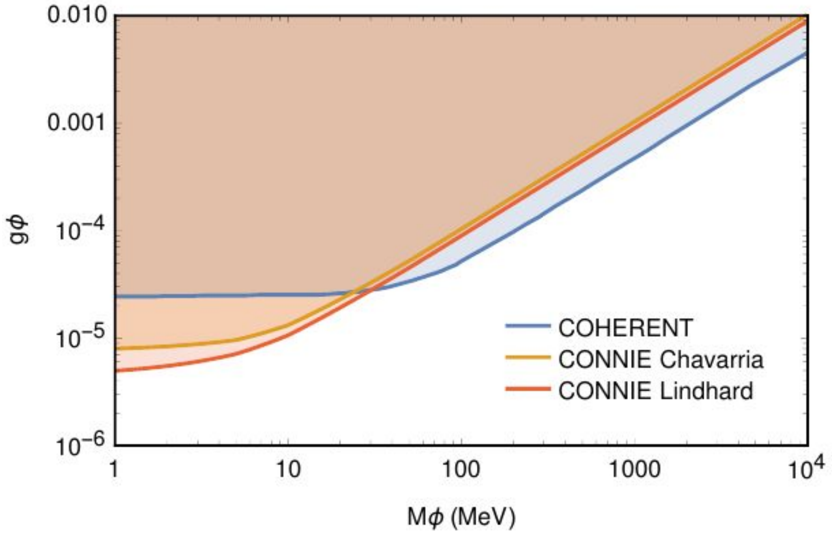
Phys. Rev. D 100 (2019) 092005

constraining BSM physics

- event rates in the lowest-energy bin yield limits on non-standard neutrino interactions:
  - simplified light **scalar** (ϕ) mediator model

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

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



- we obtain the most stringent limits for low mediator masses $M_\phi < 30$ MeV
- first competitive BSM constraint from CEvNS in reactors!

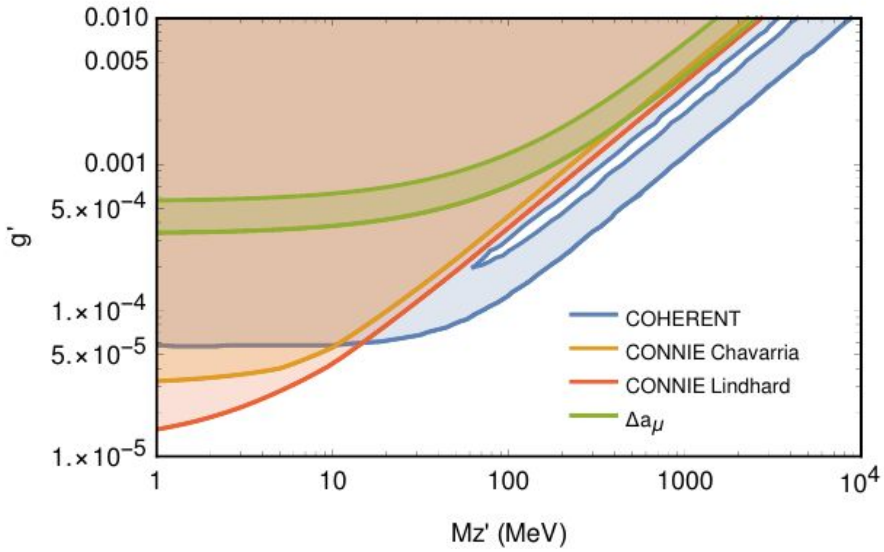
JHEP 04 (2020) 054

constraining BSM physics

- event rates in the lowest-energy bin yield limits on non-standard neutrino interactions:
  - simplified light **vector** (Z') mediator model

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

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



- we obtain the most stringent limits for low mediator masses $M_{z'} < 10$ MeV.
- first competitive BSM constraint from CEvNS in reactors!

JHEP 04 (2020) 054

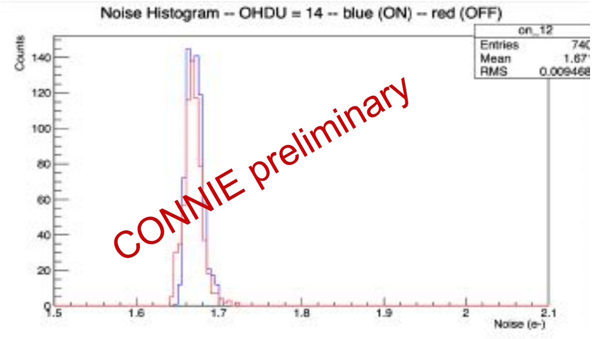
CONNIE 2019 data

1x5 rebinning of the data acquisition (higher acceptance for $E > 100$ eV)

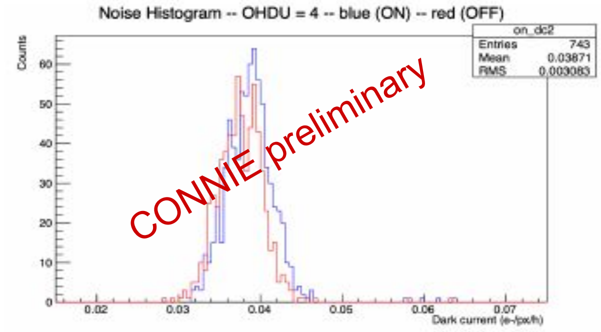
- decrease exposure time (from 3h to 1h)
- recalibration of the depth diffusion
- multiple cross-checks

blind analysis

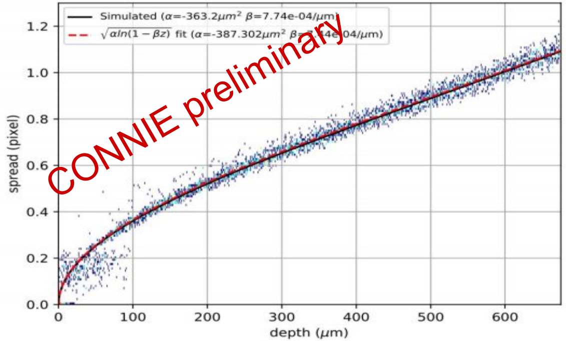
- freeze analysis parameters with reactor OFF data
- stability check-ups with mid to high energy reactor ON data
- unblind the reactor ON 2019 data



- stability of readout noise per each image



- stability of dark current per each image



- depth calibration stability using muons

CONNIE 2019 data

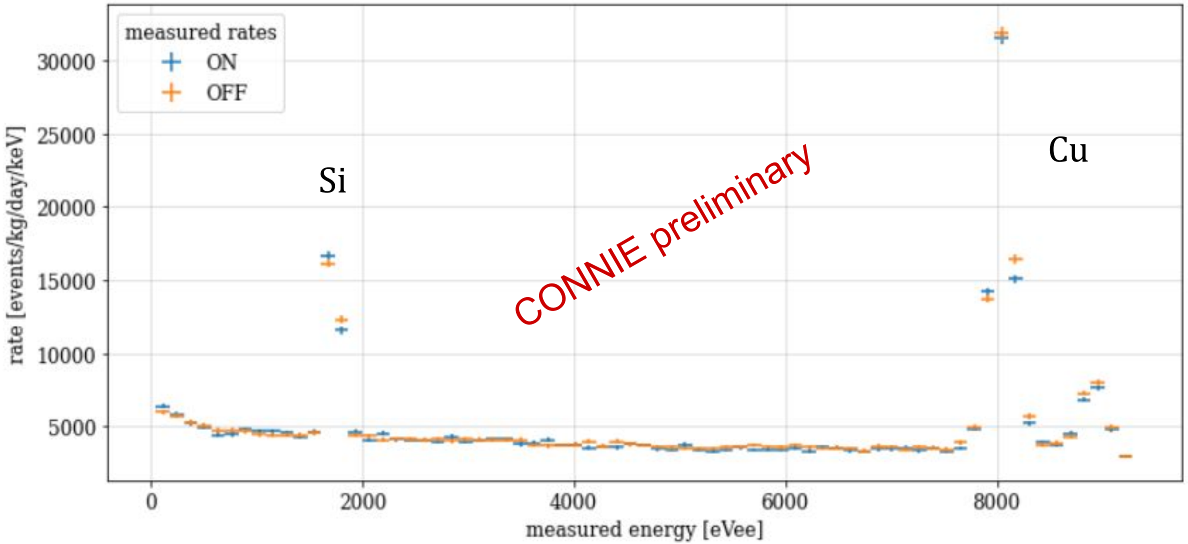
Analysis improvements

- rebinning 1x5
- exposures:
  reactor OFF 1.35 kg·day
  reactor ON 1.52 kg·day

Reactor OFF

- understand and control the low-*E* background
- improvement of event selection

rate of events



CONNIE 2019 data

Analysis improvements

- rebinning 1x5
- exposures:

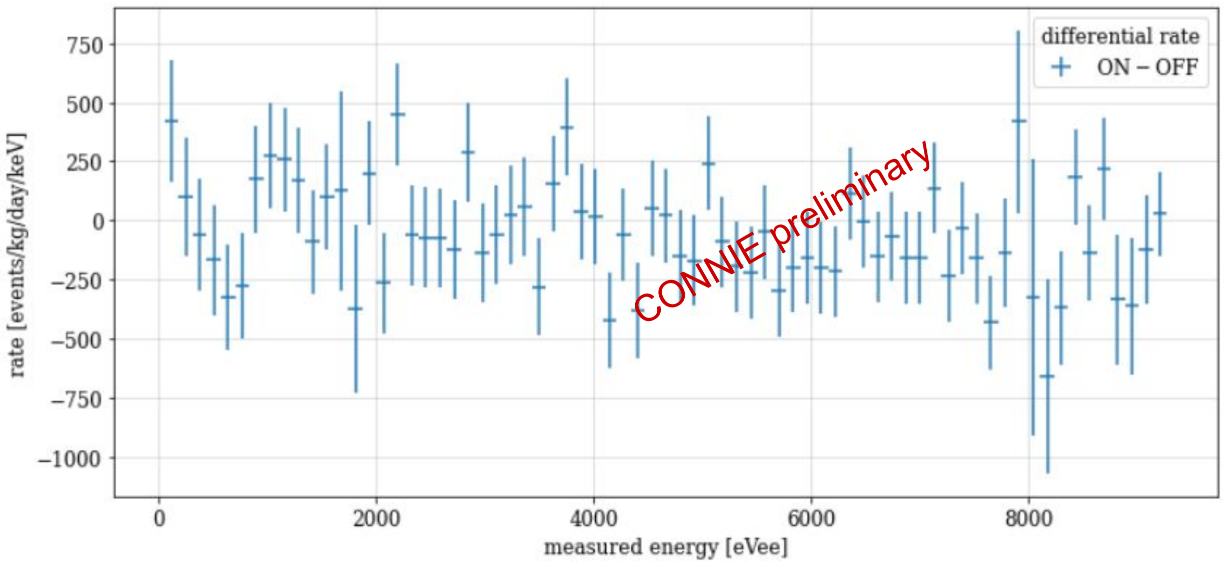
  reactor OFF 1.35 kg·day

  reactor ON 1.52 kg·day

Reactor OFF

- understand and control the low-E background
- improvement of event selection

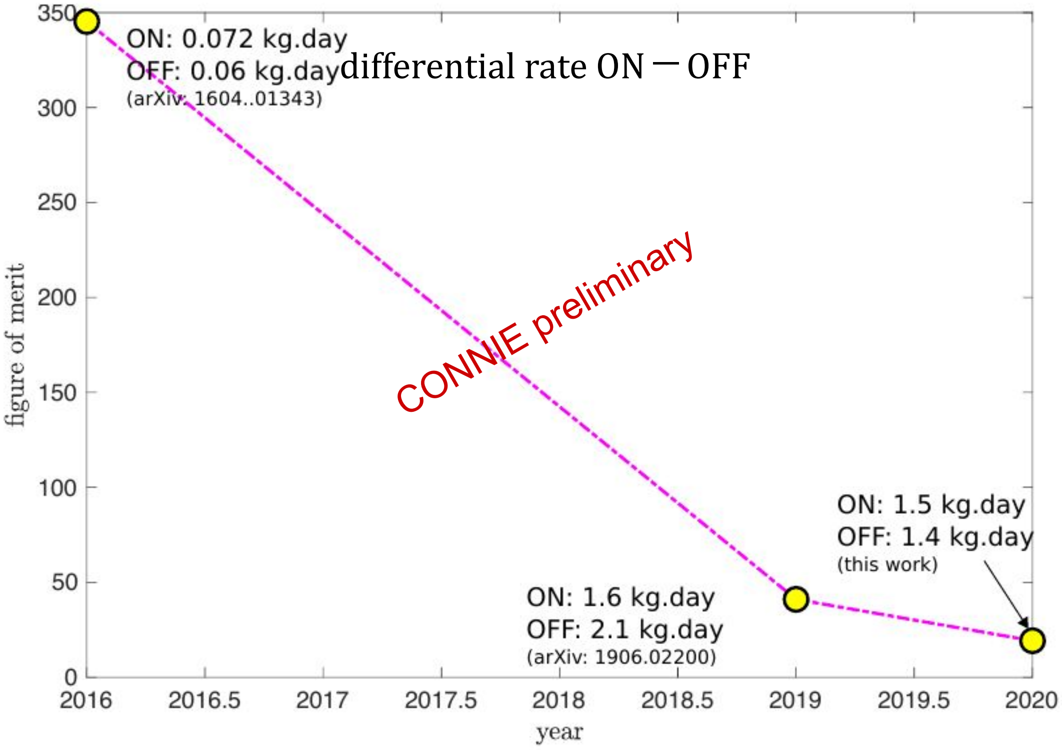
differential rate ON − OFF



CONNIE 2019 data

rebinning 1x5

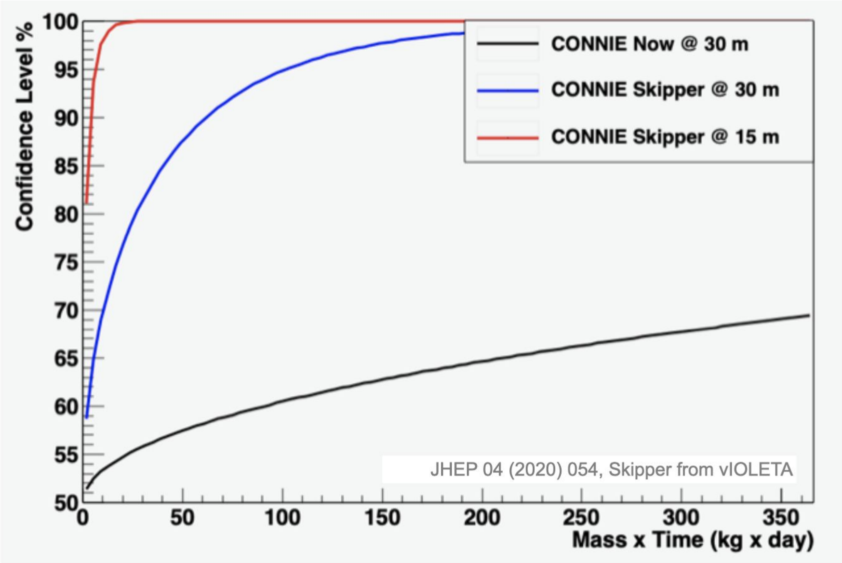
- increased acceptance for E>100 eV
- 2x increase in the neutrino rate
- improved sensitivity



perspectives: skipper CCD

- upgrade CONNIE with new Skipper CCDs late 2021
  - expected increase of up to 6x in neutrino rate
  - threshold of 7 eV
  - better control the background
  - understand skipper performance at sea-level within CONNIE environment

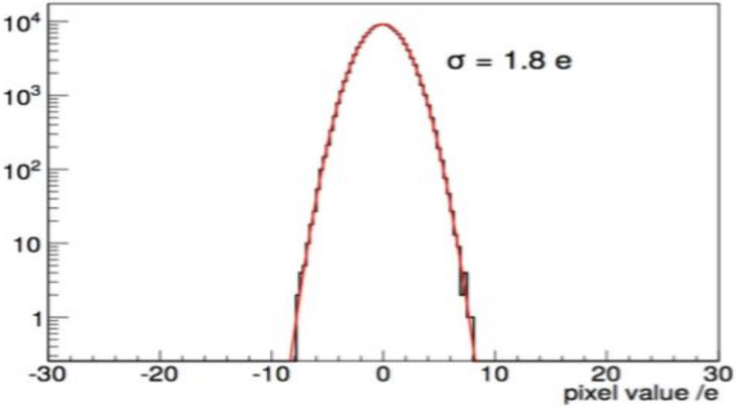
exposure



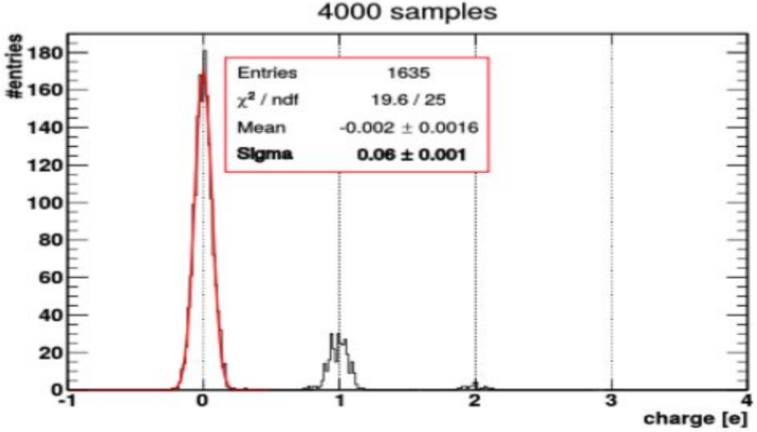
perspectives: skipper CCD

- allows multiple sampling of each pixel during data acquisition
- reduces readout noise with number of samplings $\sigma \propto 1/\sqrt{N}$
- 100% acceptance – detect single electrons
- promising for neutrino and dark matter detection

standard CCD readout noise



skipper CCD readout noise



summary

- CCDs are promising technologies to observe CEνNS at low energies
- the 2016–2018 data allowed us place the most stringent limits on BSM low mediator masses ($M < 10$ MeV)
- improved sensibility with 2019 data
- **paper in preparation**
- **new 2020 data analysis in progress**
- perspective: skipper CCDs greatly reduce the noise and control the background rate