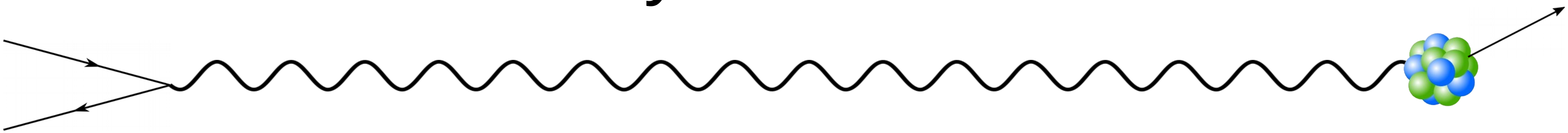
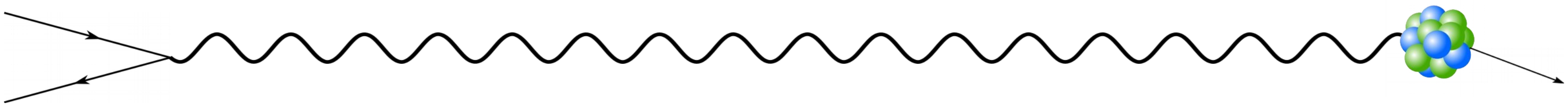
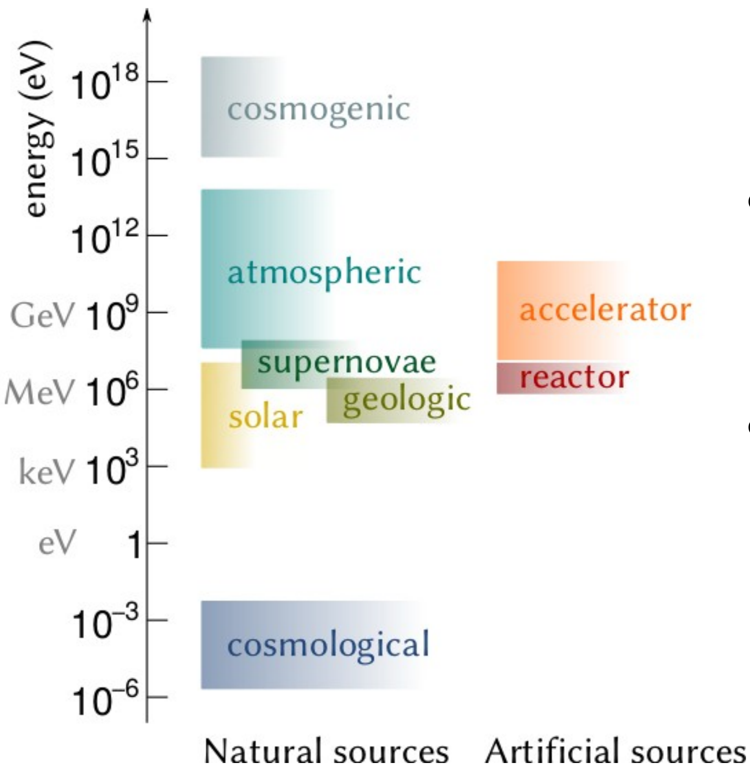
First Constraints on Coherent Elastic Neutrino Nucleus Scattering by CONUS



Thomas Hugle (on behalf of the CONUS collaboration)
Max-Planck-Institut für Kernphysik, Heidelberg
Neutrino Cross Talk, 27.11.2020

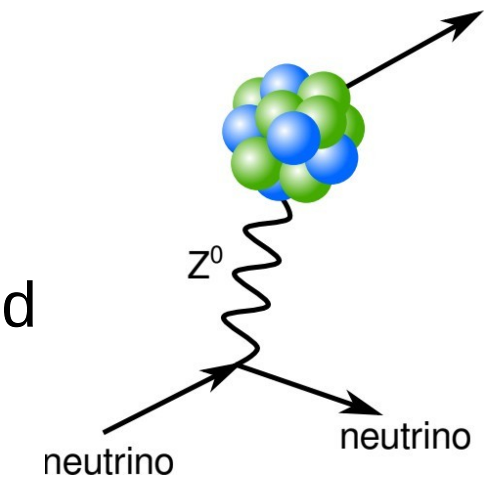
Coherent Elastic Neutrino Nucleus Scattering





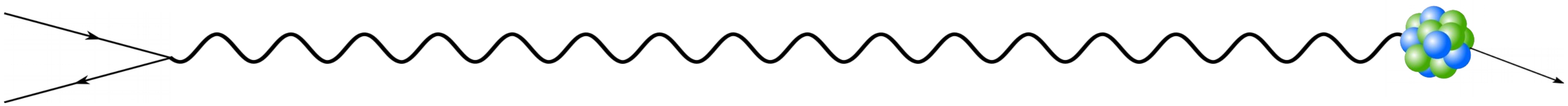
[A. Bonhomme]

- 1973: neutral current discovered at CERN
- 1974: CEνNS predicted by D. Freedman



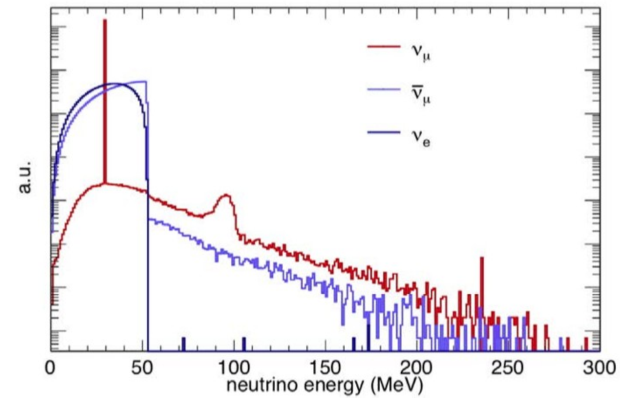
$$\frac{\mathrm{d}\sigma(E_\nu, T)}{\mathrm{d}T} \simeq \frac{G_F^2}{4\pi} \underbrace{[N - (1 - 4\sin^2\theta_W)Z]^2}_{\approx N^2} \underbrace{F^2(q^2)}_{\to 1} M \underbrace{\left(1 - \frac{MT}{2E_\nu^2}\right)}_{\text{kinematics}}$$

Neutrino Sources / Experimental Options



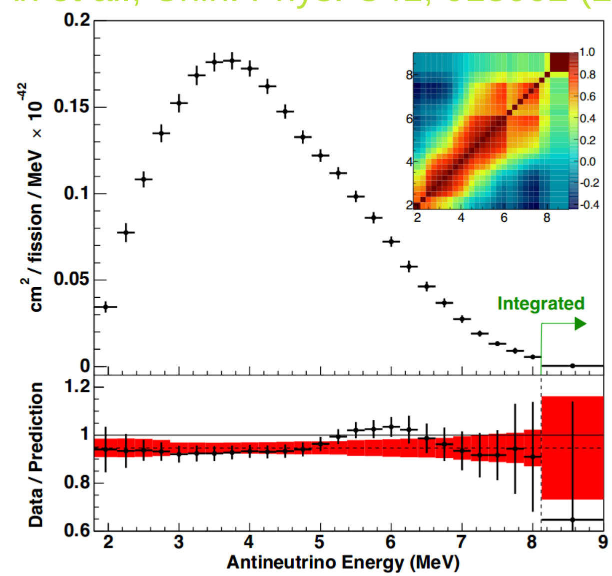
- Accelerators: COHERENT
  - ν from π decay-at-rest (π-DAR)
  - different flavors: ν_e, ν_μ, $\bar{\nu}_\mu$
  - ν energies of ~20-50 MeV

[COHERENT 1708.01294]

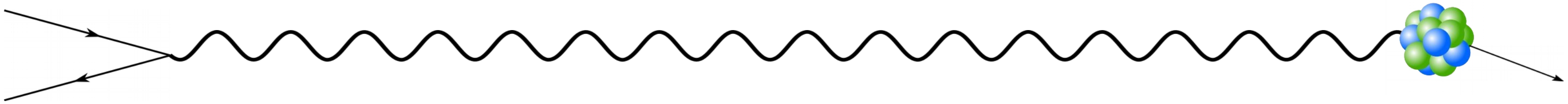


- Reactors: CONUS
  - ν from fission products (high flux)
  - only $\bar{\nu}_\mathrm{e}$
  - ν energies of < 10 MeV

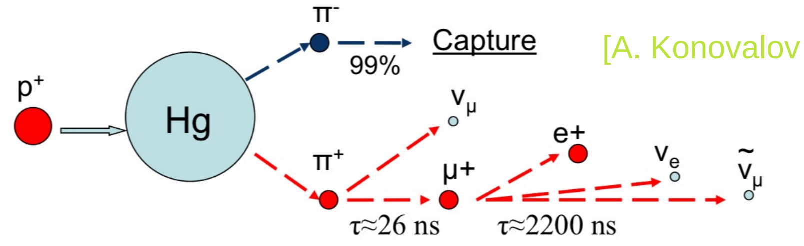
[An et al., Chin. Phys. C41, 013002 (2017)]



COHERENT Experiment



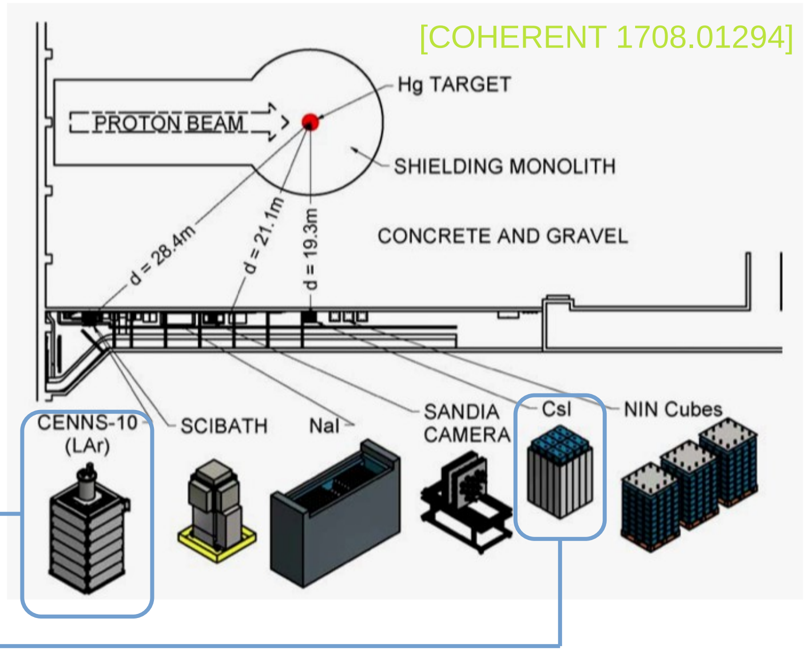
- Located in the US at the Oak Ridge spallation neutron source (SNS)



- Pulsed beam

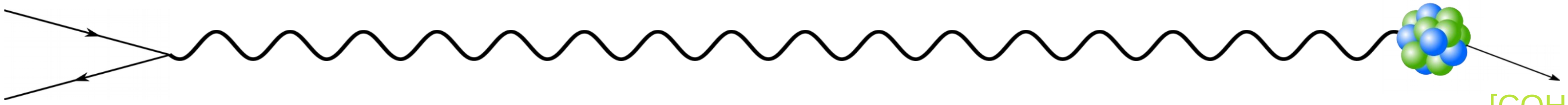
- ν flux: 4.3 * 10^7 cm^{-2} s^{-1}
  @ 20 m distance

- 8 m w.e. overburden



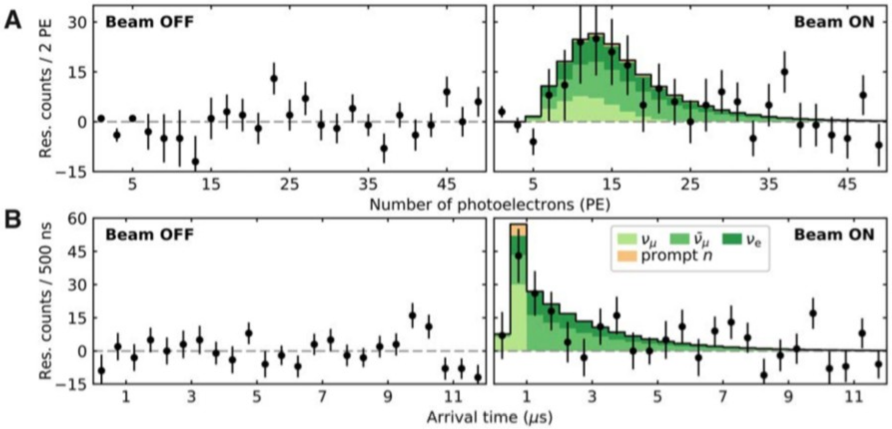
results published

COHERENT Results



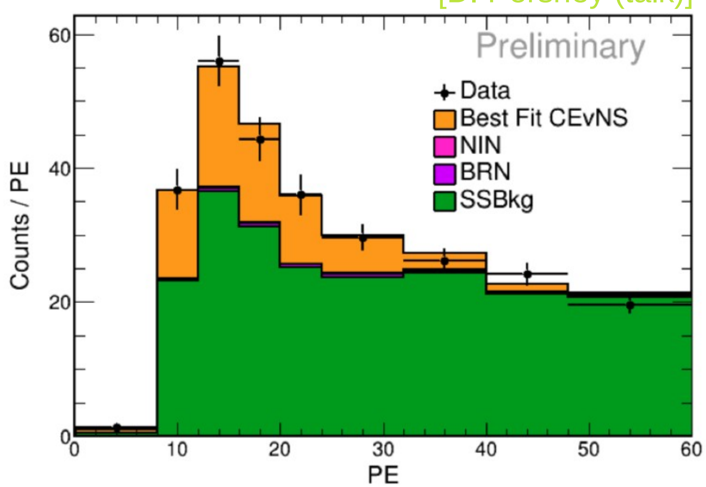
- First CEνNS observation in 2017 (6.7σ CL) with CsI[Na]

[COHERENT 1708.01294]

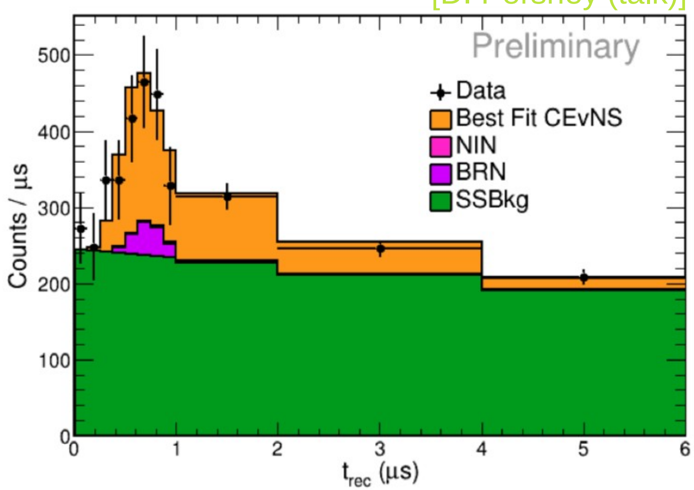


- Updated results at Magnificent CEνNS workshop 2020: twice the exposure, improved analysis (11.6σ CL)

[D. Pershey (talk)]

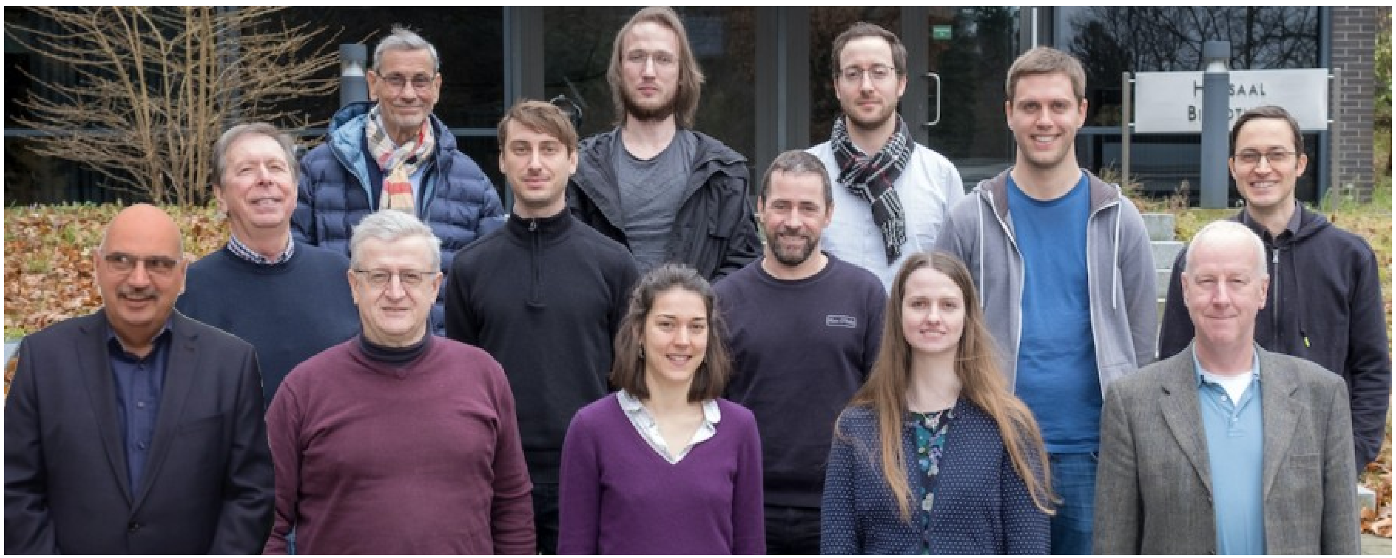


[D. Pershey (talk)]



NIN: neutrino-induced neutrons BRN: beam-related neutrons SSBkg: steady-state background

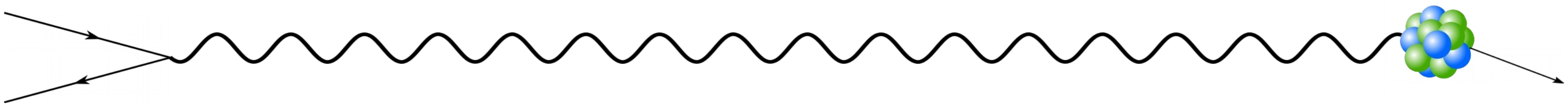
CONUS Collaboration



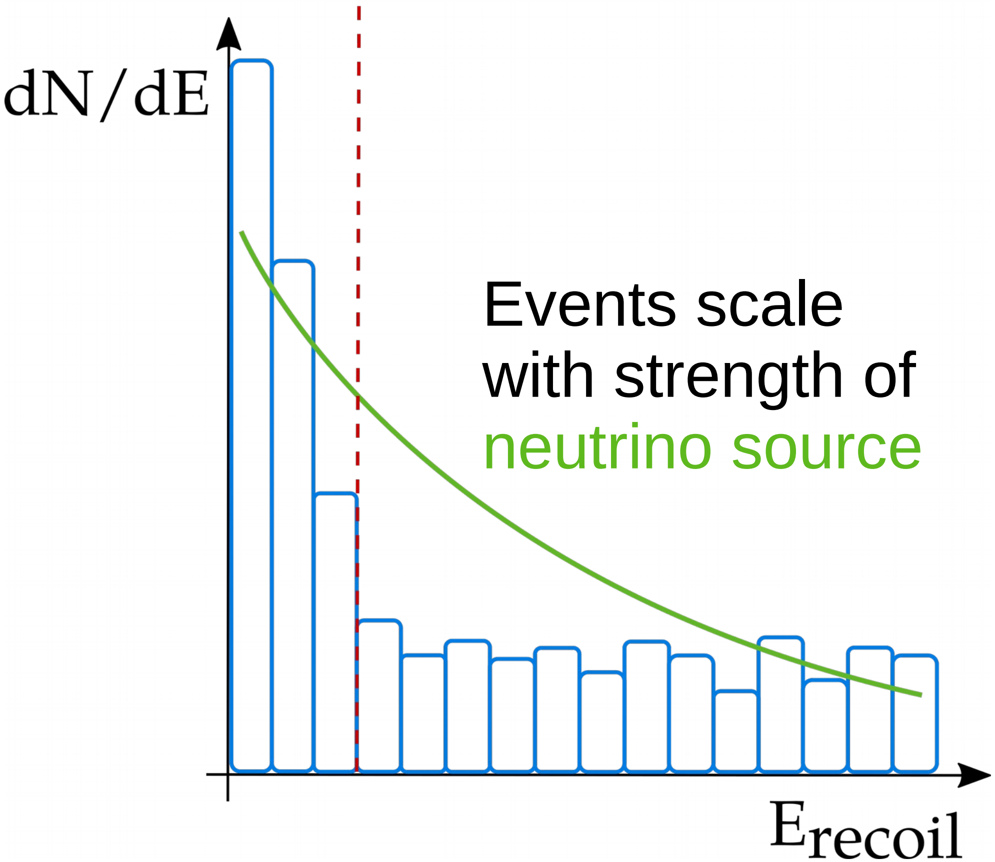
Collaboration:
H. Bonet, A. Bonhomme, C. Buck, J. Hakenmüller, J. Hempfling, J. Henrichs, G. Heusser, T. Hugle, M. Lindner, W. Maneschg, T. Rink, H. Strecker, E. Van der Meeren
- *Max Planck Institut für Kernphysik (MPIK), Heidelberg*

K. Fülber, R. Wink
- *Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR), Brokdorf*

CEνNS at Reactors

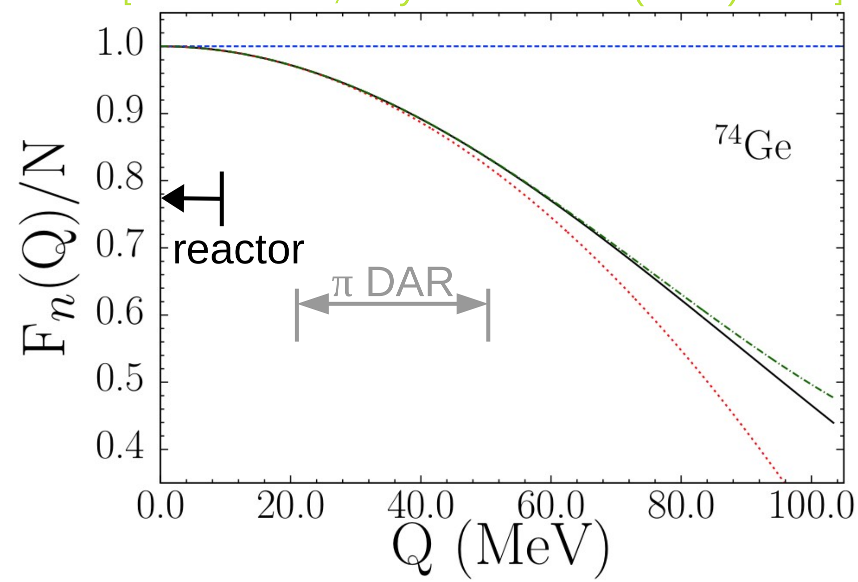


Low noise threshold



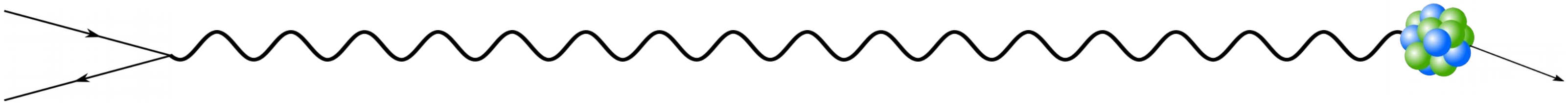
Events scale with strength of neutrino source

[Patton et al., Phys. Rev. C 86 (2012) 0246]



Low background at shallow depth

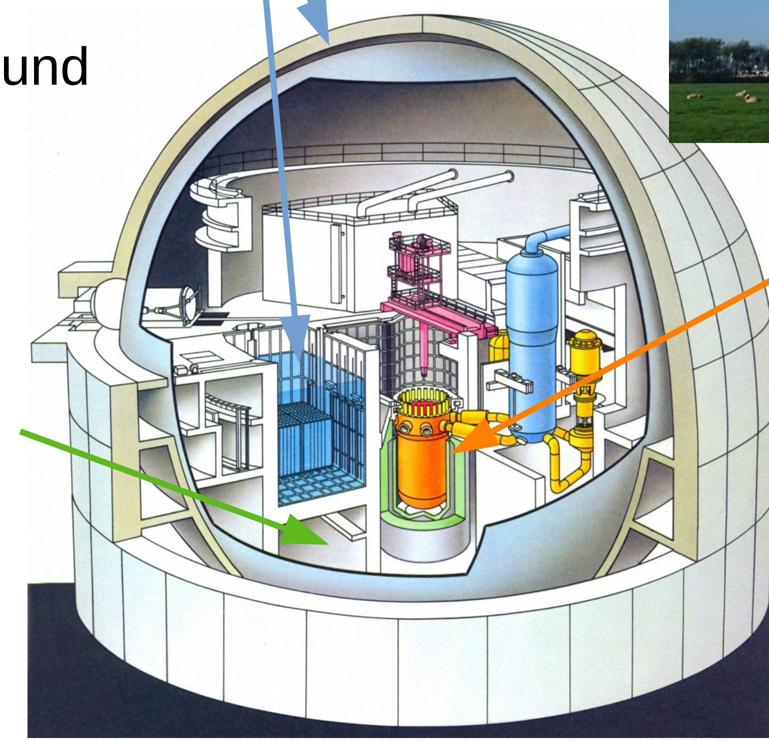
CONUS Experimental Site



[A. Bonhomme]

Overburden:

- 10-45 m w.e. (angle-dependent)
- muon-induced background



Reactor core:

- thermal power
  3.9 GW
- neutrino flux
  $2 * 10^{13}$ cm^{-2} s^{-1}
  @ 17 m distance
- high duty cycle
  (~1 month/yr off)

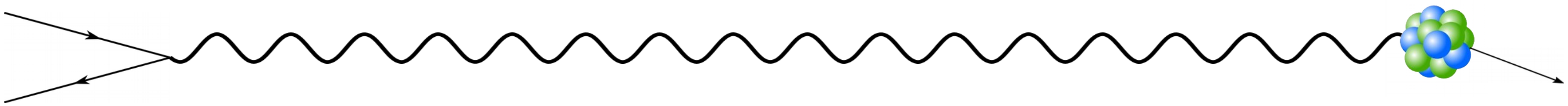
CONUS experiment:

- Four 1kg low threshold Ge detectors
- electric cryocoolers
- elaborate shield

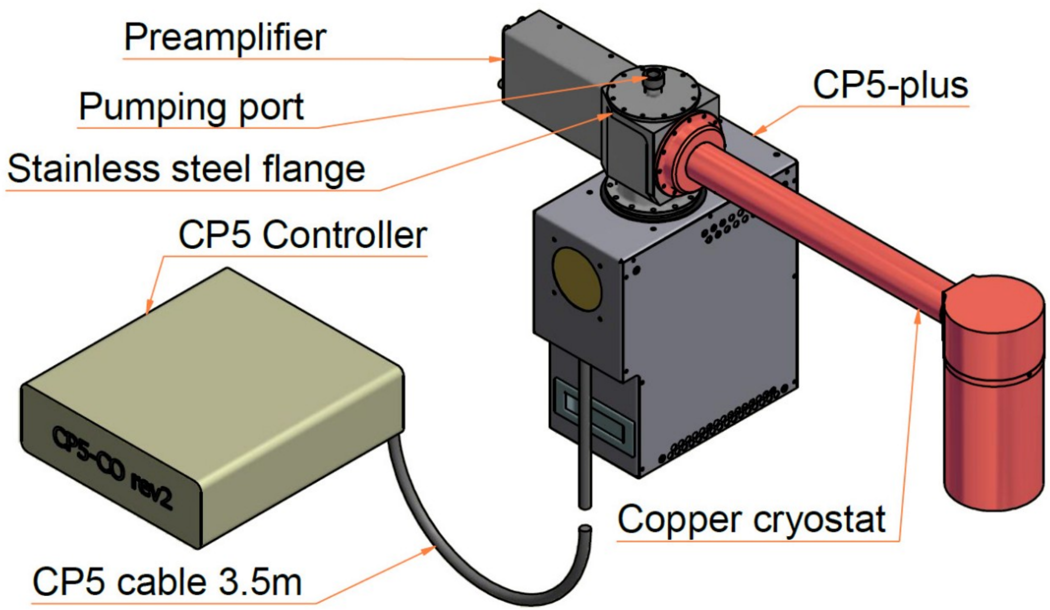
Ain't no lab!

No remote control, no cryogenic liquids, ...

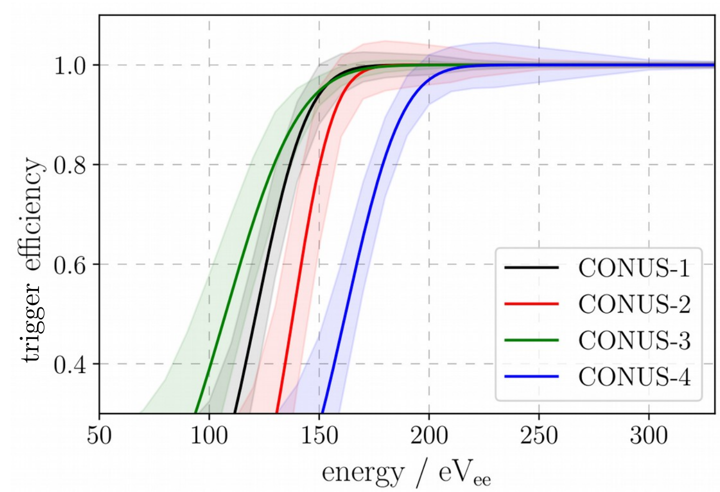
CONUS Detectors



Four p-type point contact HPGe detectors (1kg each)

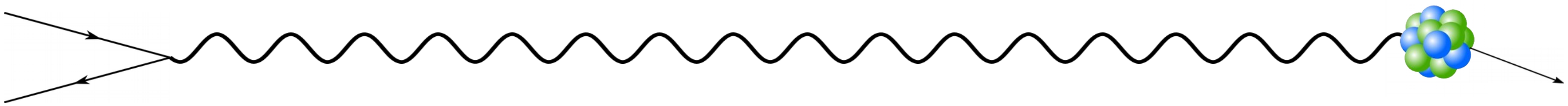


- pulser resolution: ≤ 80 eV_{ee}
- energy threshold: ~300 eV_{ee}
- low background components
- electric cooling (instead of N_2) necessary at KBR



For full discussion see
arXiv:2010.11241 [ins-det]

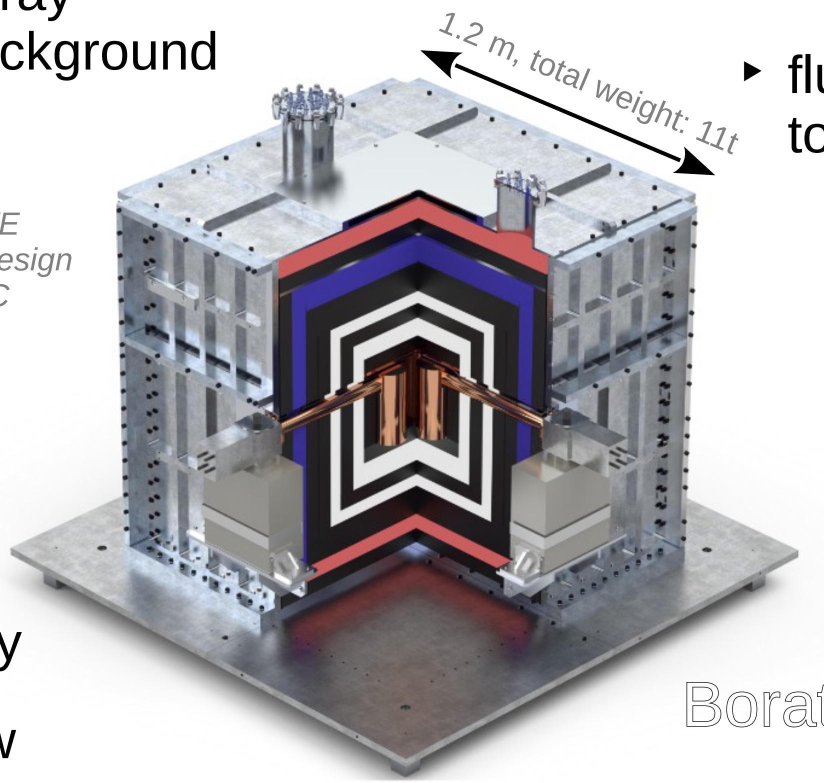
CONUS Shield Design



Active muon veto:

- suppress cosmic ray muon-induced background

[*Inspired by the GIOVE spectrometer shield design (MPIK, Eur. Phys. J. C (2015) 75: 531)*]



Steel cage:

- keep everything together
- flushed with breathing air to reduce radon

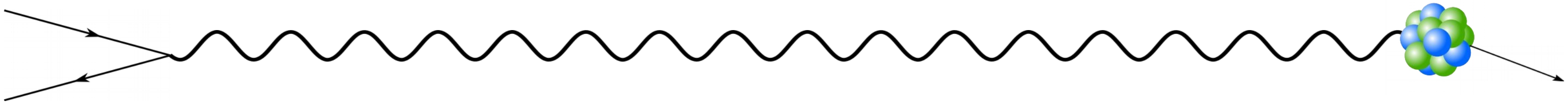
Lead (Pb):

- shield radioactivity
- needs to have low radioactivity itself

Borated PE / PE:

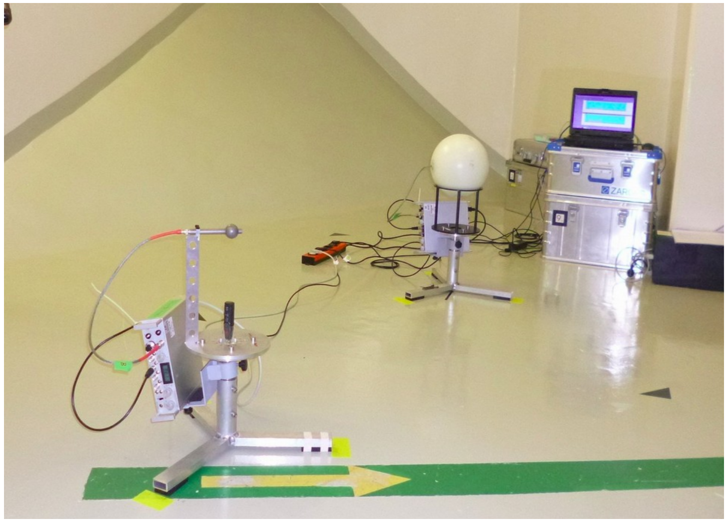
- moderate & capture neutrons

Reactor-Correlated Neutrons

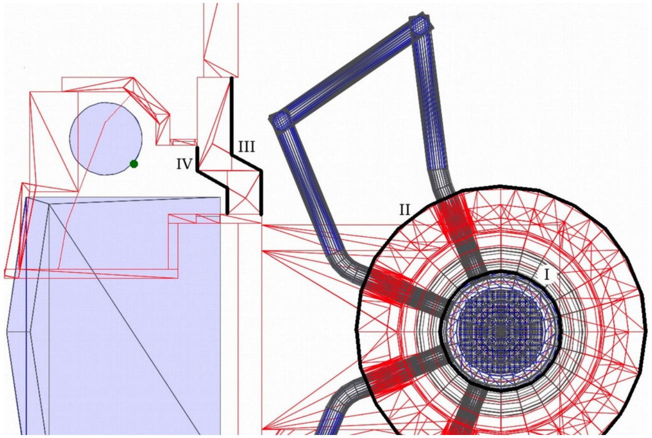


Neutron measurements with Bonner spheres:

- mostly thermalized (~80% of all)
- correlated with thermal power



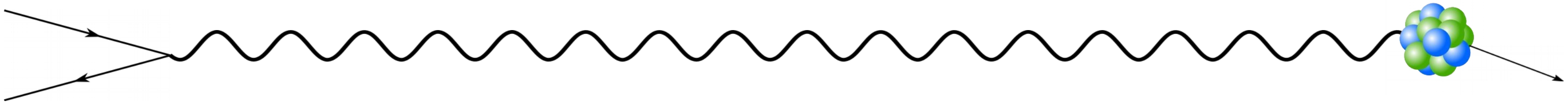
For full discussion see
Eur. Phys. J. C (2019) 79:699
(in cooperation with PTB)

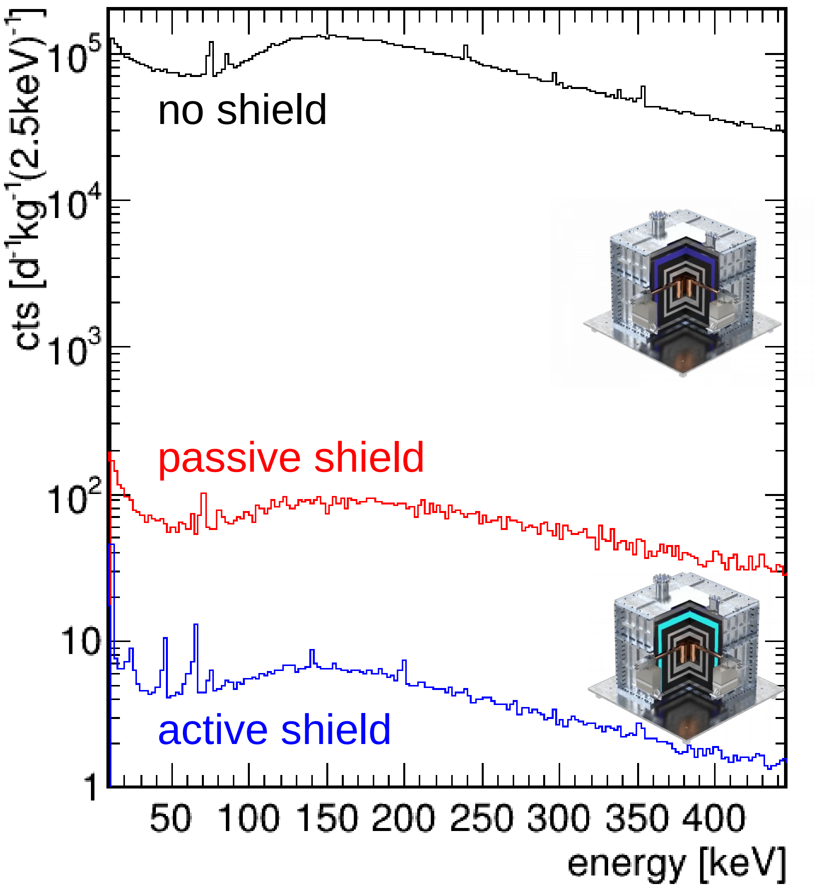


Monte Carlo (MC) simulation:

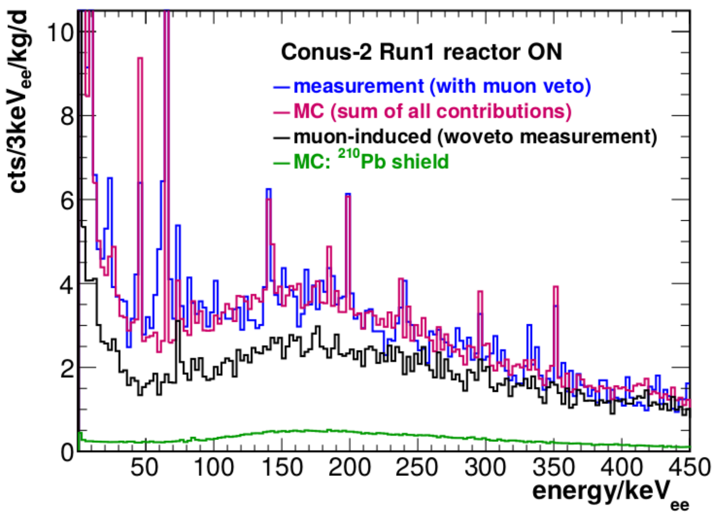
- detailed propagation of n from reactor core to CONUS
- propagate n (and ɣ) through CONUS shield:
  0.012 ± 0.006 kg^{-1} d^{-1} in [0.3, 1] keV$_{ee}$
- negligible compared to CEνNS:
  (~0.2 kg^{-1} d^{-1} in [0.3, 1] keV$_{ee}$ for k=0.2)

Background Suppression





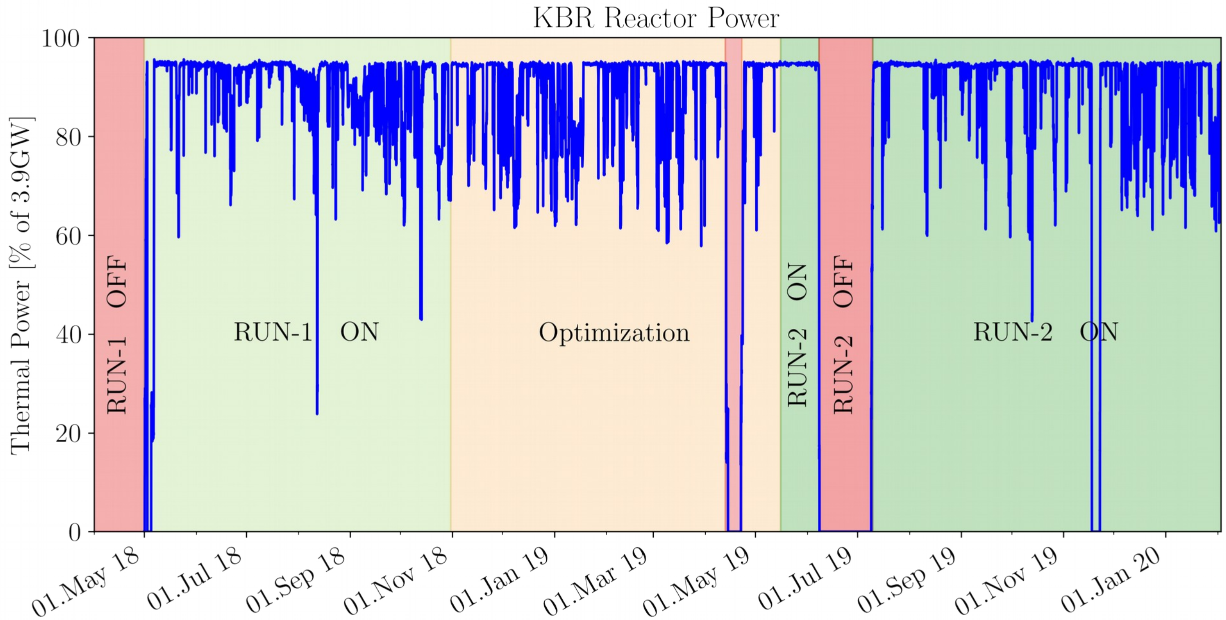
Total suppression factor: 10^4

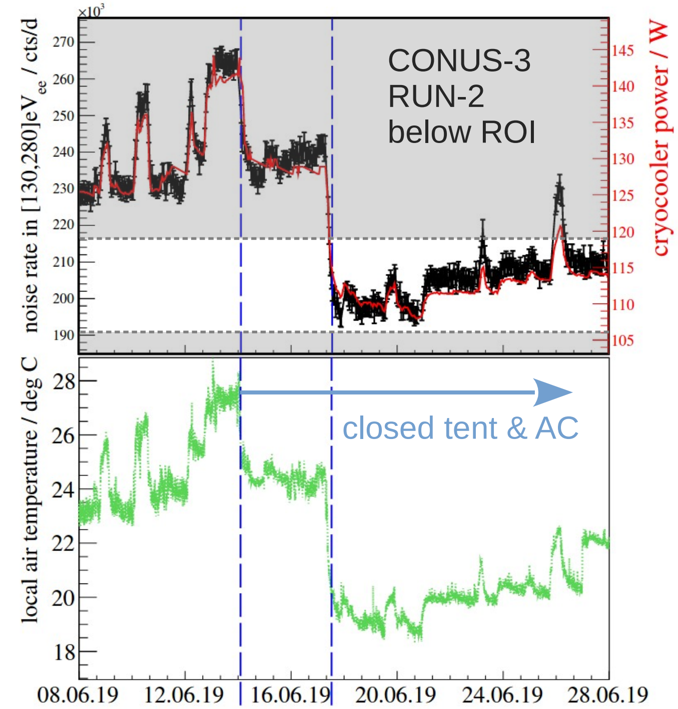


Residual backgrounds described by Monte Carlo simulations:

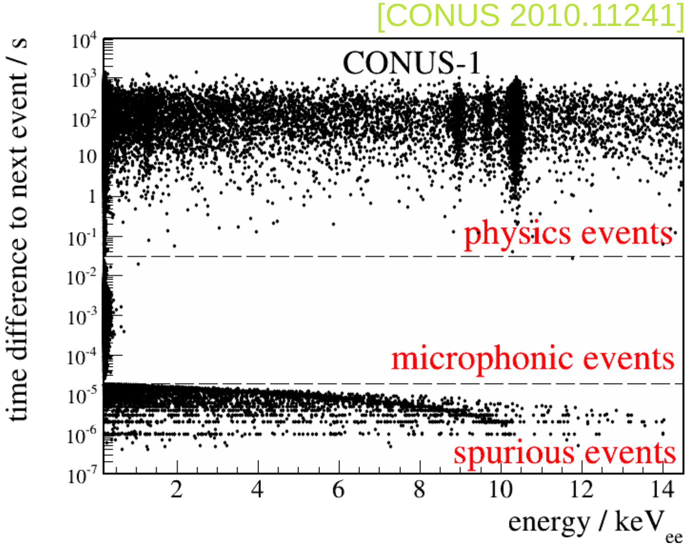
- muon-induced (after ~97% vetoed)
- metastable Ge states
- ^{210}Pb in shield and detector
- radon

Data Selection & Noise Cuts





[CONUS 2010.11241]



Noise-temperature correlation cut

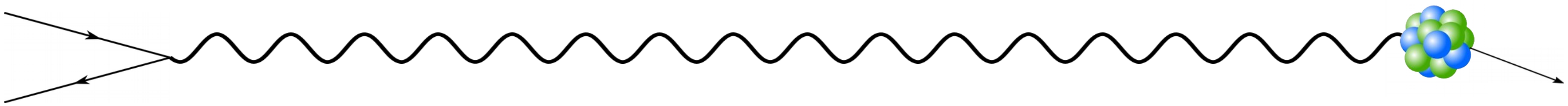
Time-difference distribution cut

Run-1/2 exposure after cuts:

ON 248.7 kg d

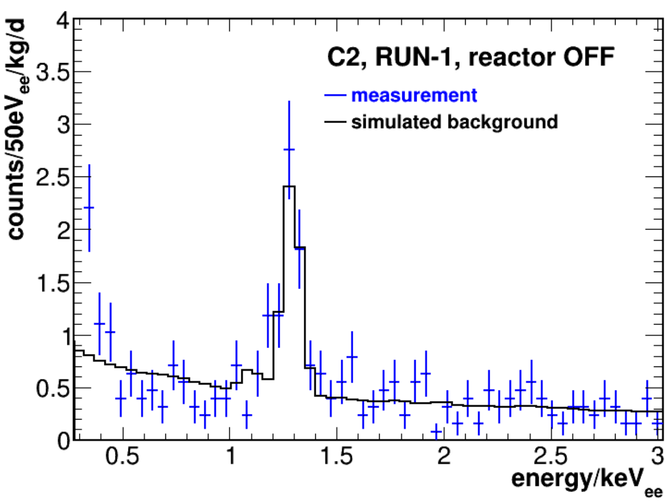
OFF 58.8 kg d

Region of Interest (ROI) for CEνNS



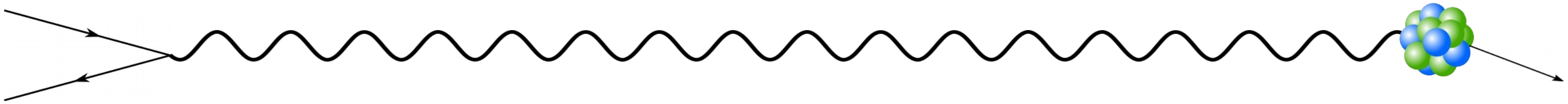
Criteria:

- trigger efficiency: ~100%
- ratio of electronic noise to background MC: < 4
  - fit electronic noise with exponential



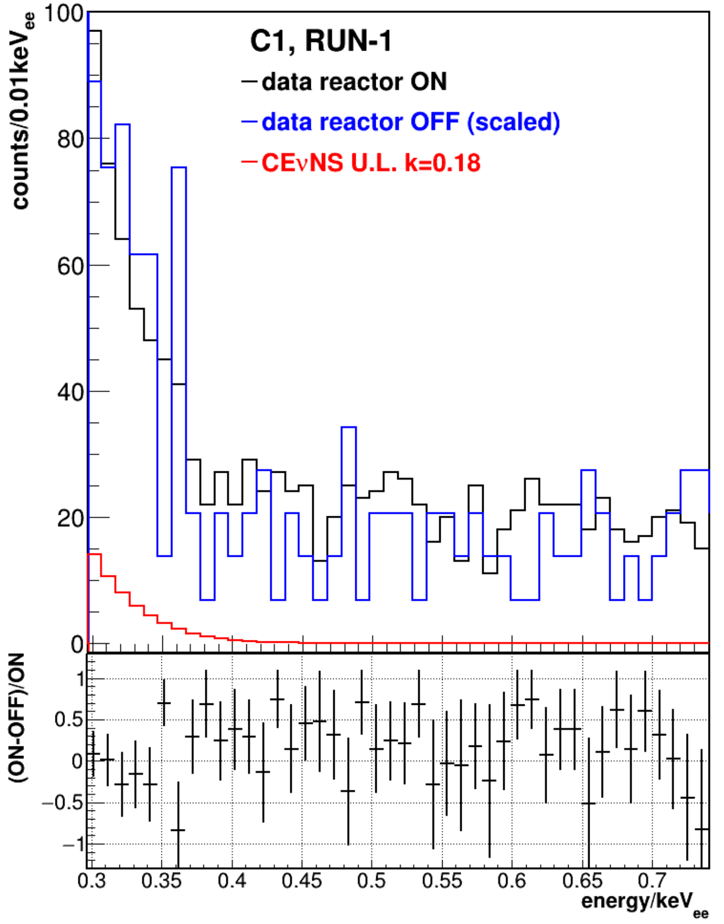
Det.	RUN	ON [d]	OFF [d]	ROI [keV$_{ee}$]
C1	1	96.7	13.8	0.296 - 0.75
C2	1	14.6	13.4	0.311 - 1.00
C3	1	97.5	10.4	0.333 - 1.00
C1	2	19.6	12.1	0.348 - 0.75
C3	2	20.2	9.1	0.343 - 1.00
total		248.7	58.8	

Data Analysis Overview

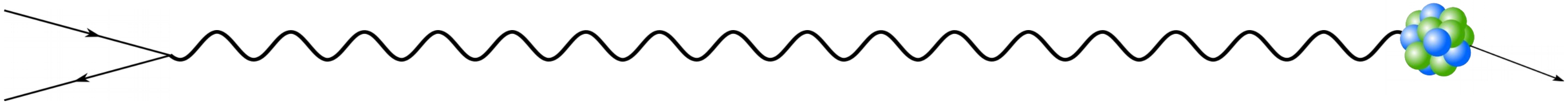


Input for analysis:

- theoretical expectation for CEνNS
- reactor description
  - fission fractions & thermal power known
  - Huber & Mueller parametrization
    + Daya Bay correction
- background description
  - Monte Carlo for physics events
  - exponential fit for electronic noise
- selected data for ON / OFF



(Binned Log) Likelihood



- Fit ON and OFF data together (all detectors and runs)
- Include additional (independent) knowledge via pull terms

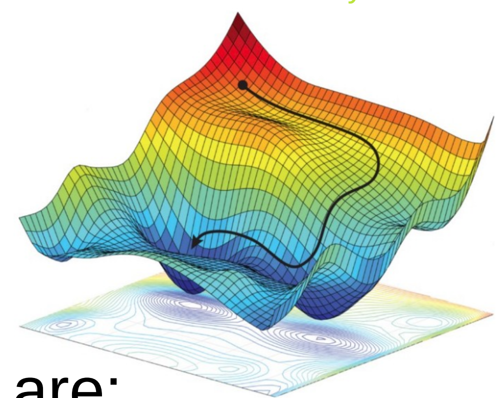
$$\log \mathcal{L} = \log \mathcal{L}_{\mathrm{ON}} + \log \mathcal{L}_{\mathrm{OFF}} + \text{pull terms}$$

with

$$\log \mathcal{L}_{\mathrm{ON}}(s, b, \Theta_{\mathrm{thr}_1}, \Theta_{\mathrm{thr}_2}, \Theta_{\mathrm{rea}}, \Theta_{\mathrm{det}}, \Delta E)$$

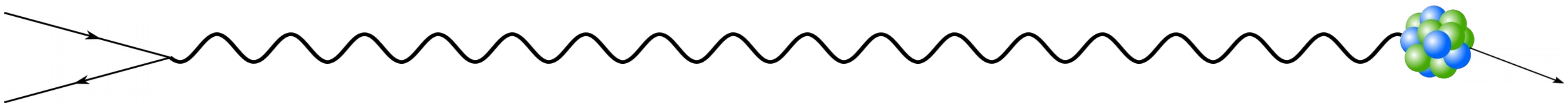
$$\log \mathcal{L}_{\mathrm{OFF}}(b, \Theta_{\mathrm{thr}_1}, \Theta_{\mathrm{thr}_2}, \Theta_{\mathrm{det}}, \Delta E)$$

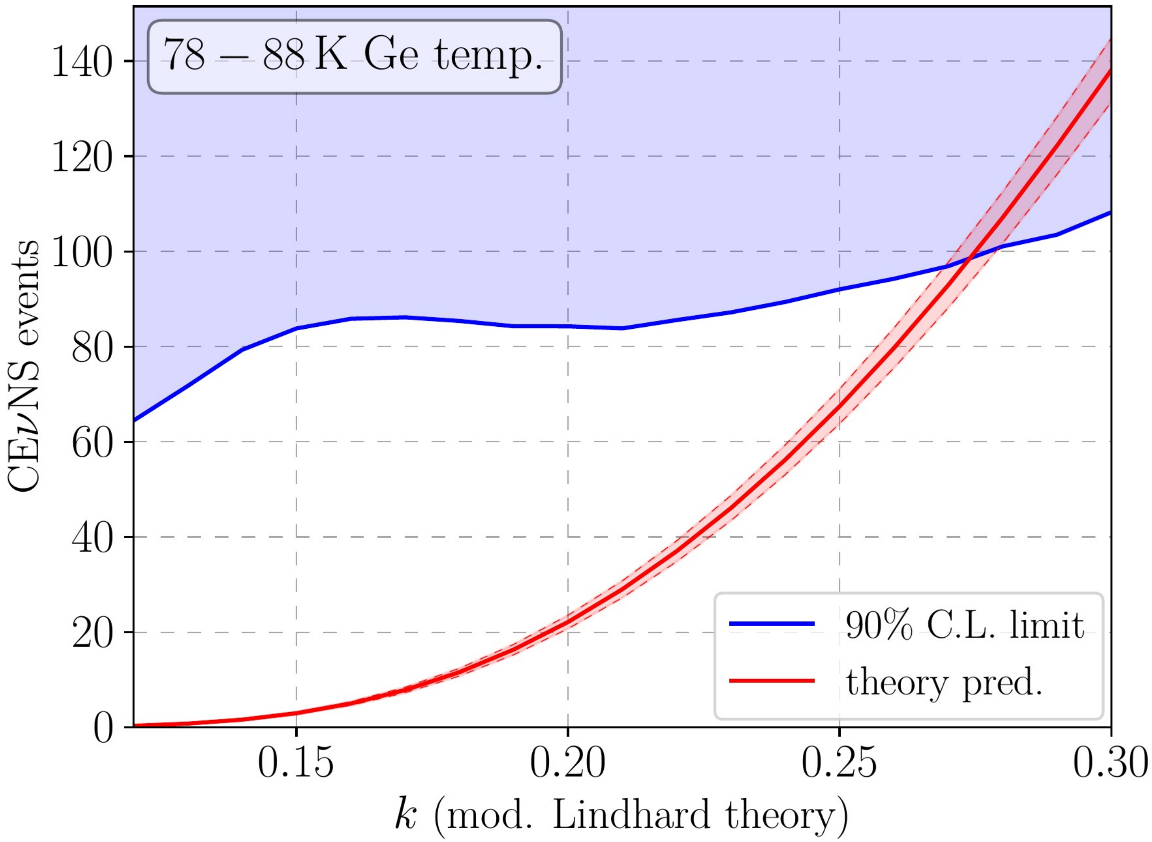
[A. Amini et al. NeurIPS Bayes DL 2018]



- The parameters with uncertainties (in brackets) are:
  - s: signal (scanned over)
  - b: background MC normalization (free)
  - $\theta_{thr1/2}$: electronic noise (free)
  - θ_{rea}: reactor neutrino spectrum (~3%; thermal power, fission fractions)
  - θ_{det}: detector / DAQ (1-5%)
  - ΔE: energy scale uncertainty (10-20 eV_{ee})

First Results by CONUS (Run-1/2)

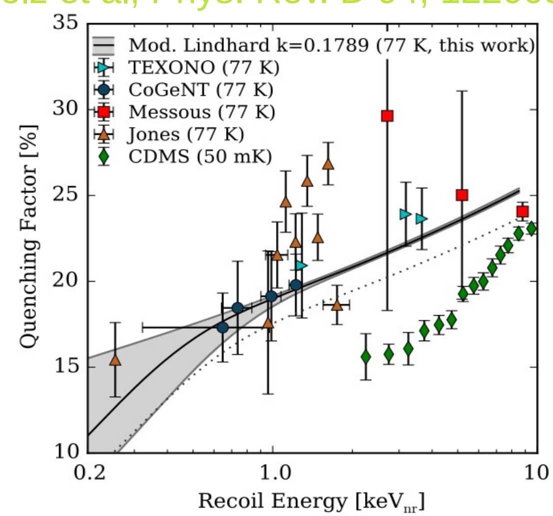




Dominant uncertainty:

- quenching

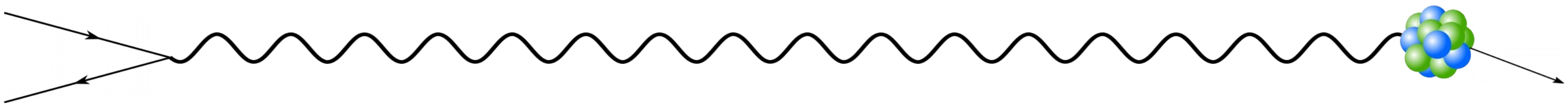
[Scholz et al, Phys. Rev. D 94, 122003 (2016)]



< 0.34 cts d^{-1} kg^{-1} (90% CL) for k = 0.18 (Scholz et al., 2016), k > 0.27 disfavored

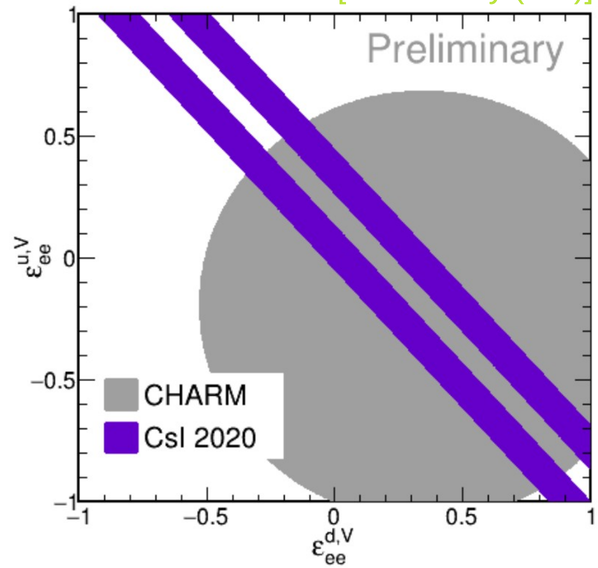
For full discussion see
arXiv:2011.00210 [hep-ex]

Beyond Standard Model Searches

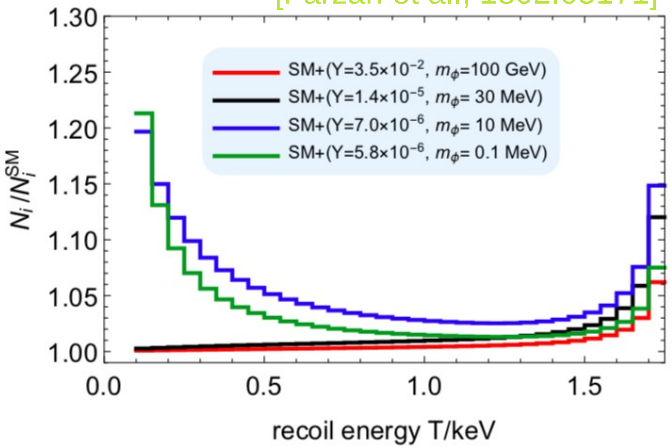


- Neutrino magnetic moment
  - introduces coupling to electrons (& nucleus)
- NSIs (non-standard interactions)
  - general parametrization of neutrino interactions
- Light mediators
  - new scalar or vector mediators
- ...

[D. Pershey (talk)]



[Farzan et al., 1802.05171]



Summary & Outlook

- Overview of CONUS and (short) comparison to COHERENT:
  - first CEνNS results of CONUS (RUN-1/2 data), cf. arXiv:2011.00210 [hep-ex]
    - best limit on CEνNS with reactor neutrinos achieved so far
    - signal expectation highly quenching dependent
    - quenching parameters of $k > 0.27$ excluded
  - a description of the Ge detectors, cf. arXiv:2010.11241 [ins-det]
  - a detailed description of reactor-correlated backgrounds, cf. Eur. Phys. J. C (2019) 79:699
- Future / Current:
  - more analyses (BSM) & data
  - improved control of environmental parameters
  - Brokdorf shuts down end of 2021, leading to significantly more OFF time
  - data acquisition upgrades like pulse shape discrimination and anti-coincidence