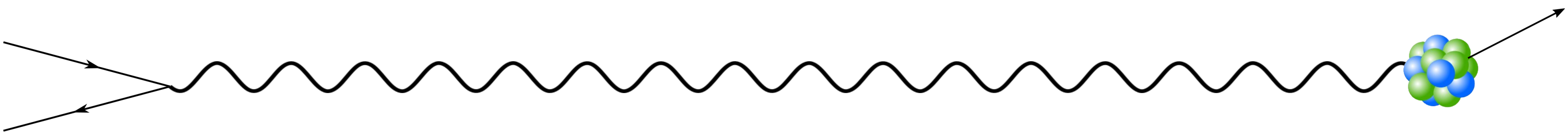
New results of the CONUS experiment

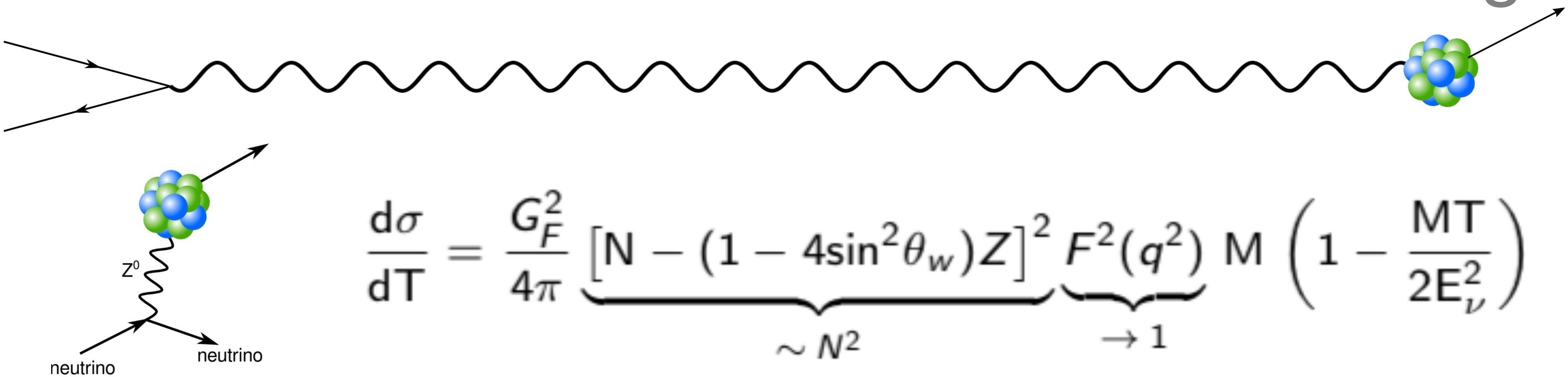


Christian Buck (on behalf of the CONUS collaboration)
Max-Planck-Institut für Kernphysik, Heidelberg
Moriond 2023, March 19th, 2023

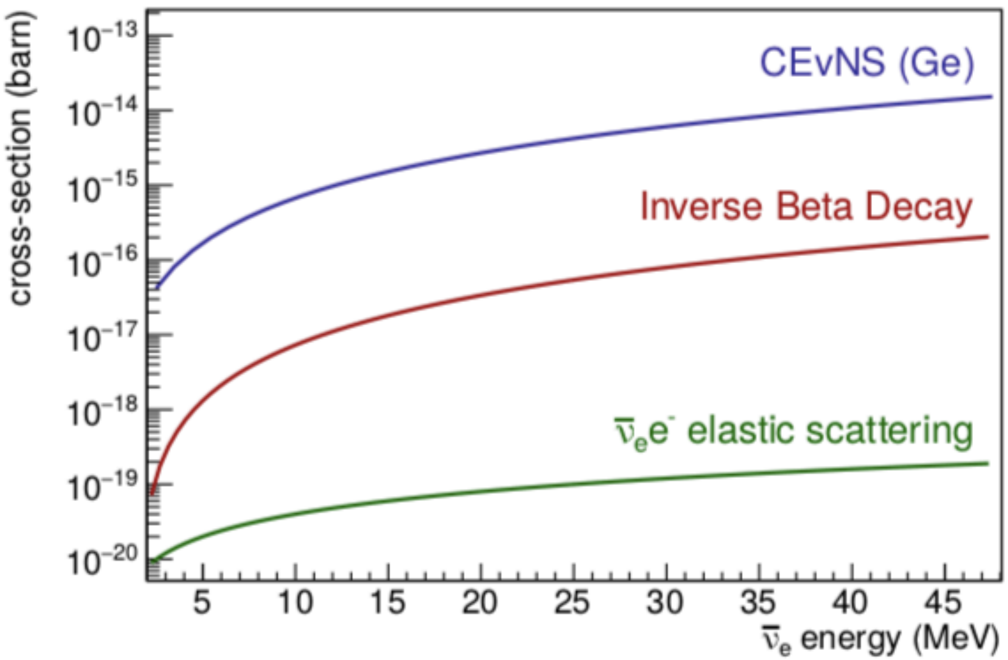
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

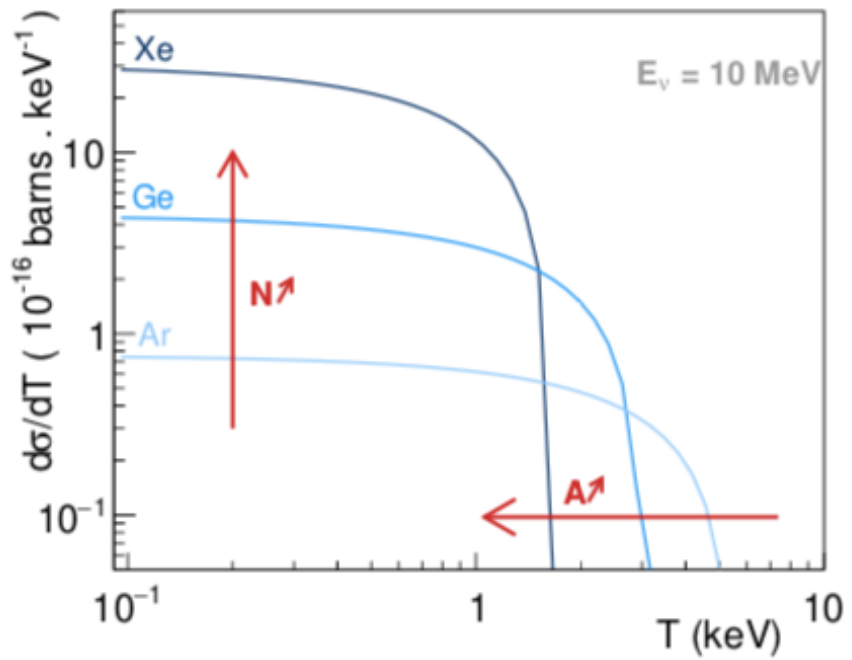
CONUS

Coherent elastic neutrino nucleus scattering



$$\frac{d\sigma}{dT} = \frac{G_F^2}{4\pi} \underbrace{\left[N - (1 - 4\sin^2\theta_w)Z\right]^2}_{\sim N^2} \underbrace{F^2(q^2)}_{\to 1} \, M \left(1 - \frac{MT}{2E_\nu^2}\right)$$

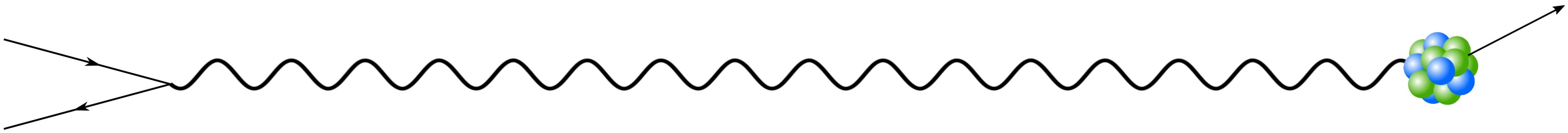


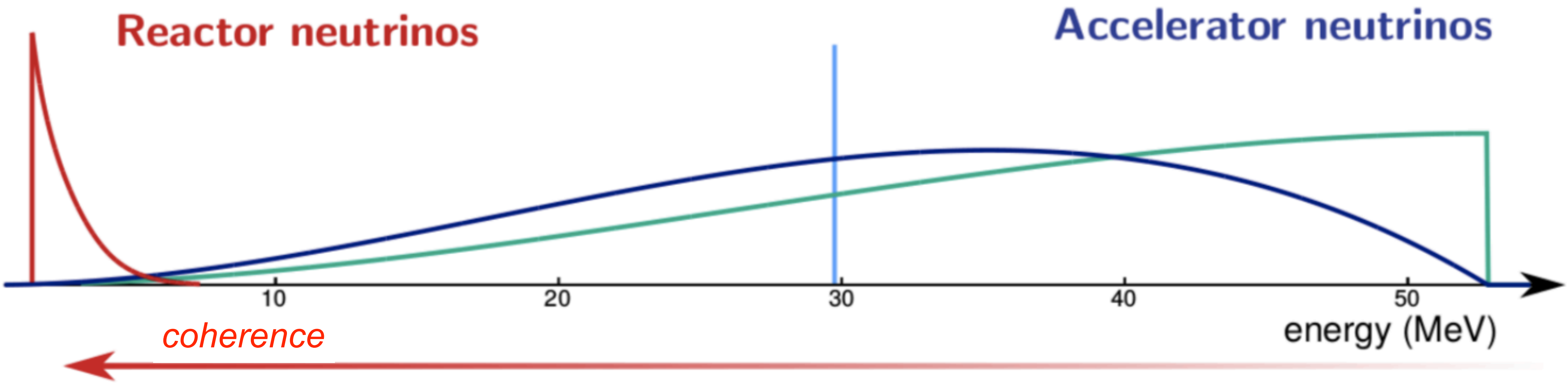


High cross-section ==> compact detectors!

Interaction rate vs recoil energy

Neutrino sources for CEvNS studies



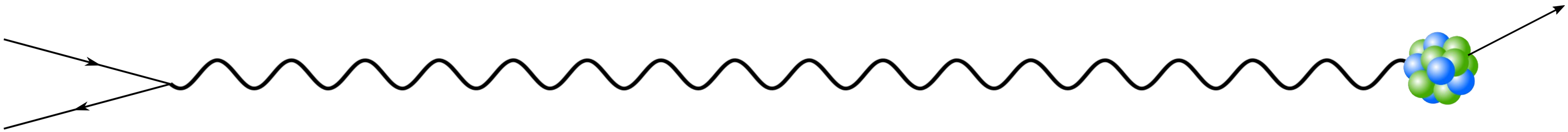


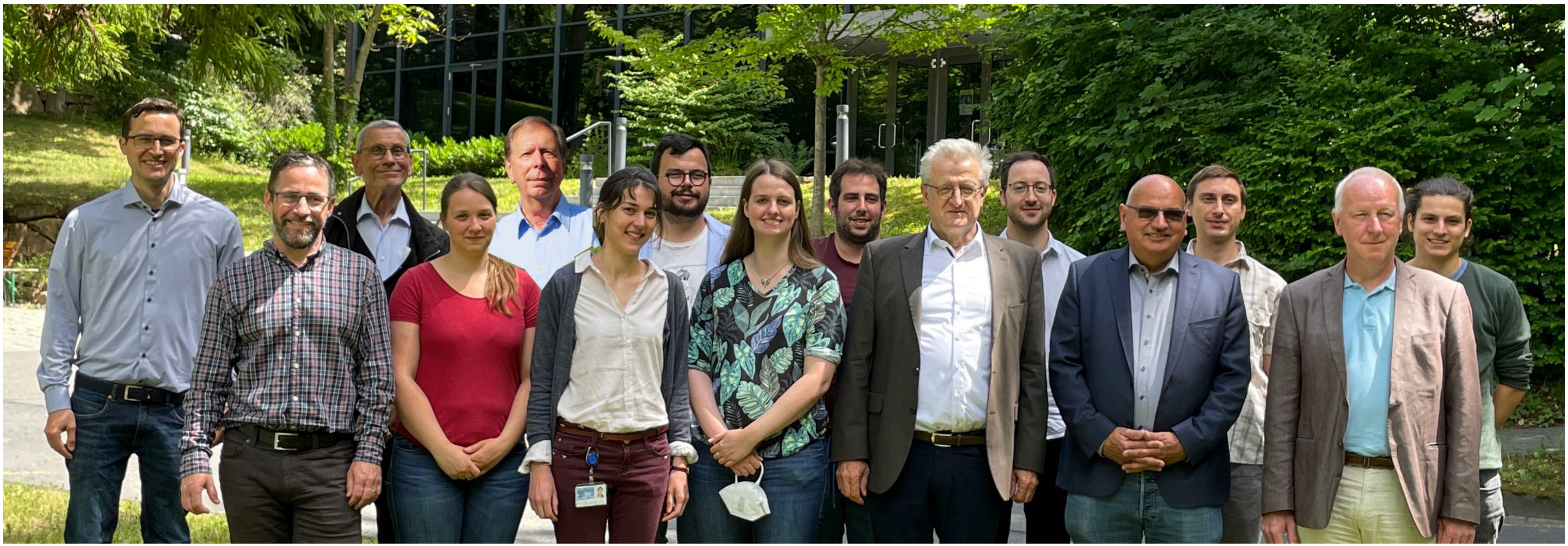
- Pure flux of electron antineutrinos
- E < 10 MeV ==> form factor ~1 (fully coherent regime)
- CONUS, vGeN, CONNIE, NCC-1701, Nucleus, Ricochet,…

- Different neutrino flavors
- E ~ 20 - 50 MeV ==> form factor < 1
- COHERENT: first observation in 2017

Complementarity !

CONUS Collaboration





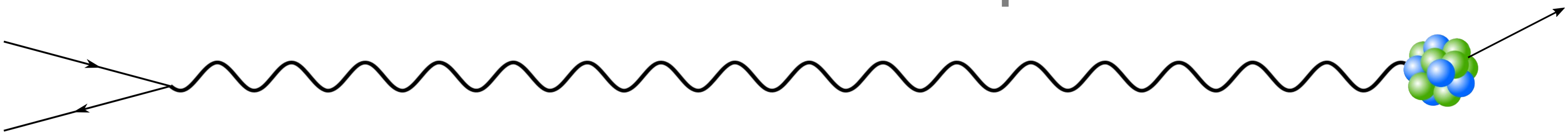
N. Ackermann, S. Armbruster, H. Bonet, A. Bonhomme, C. Buck, J. Hakenmüller, J. Hempfling, J. Henrichs, G. Heusser, T. Hugle, M. Lindner, W. Maneschg, K. Ni, T. Rink, E. Sanchez Garcia, J. Stauber, H. Strecker
Max-Planck-Institut für Kernphysik (MPIK), Heidelberg

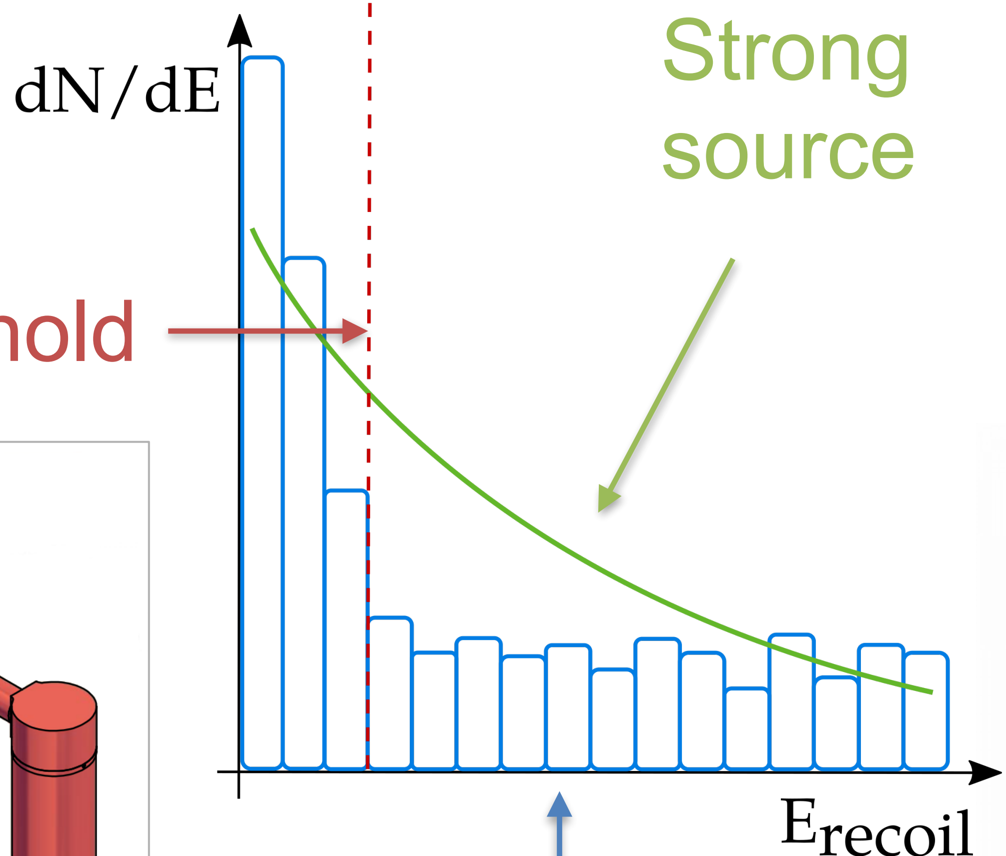
Max-Planck-Institut für Kernphysik Heidelberg

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

Preussen Elektra

CONUS concept



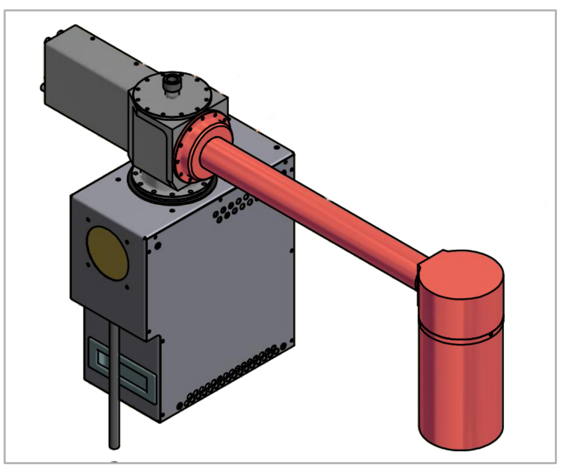


Strong source

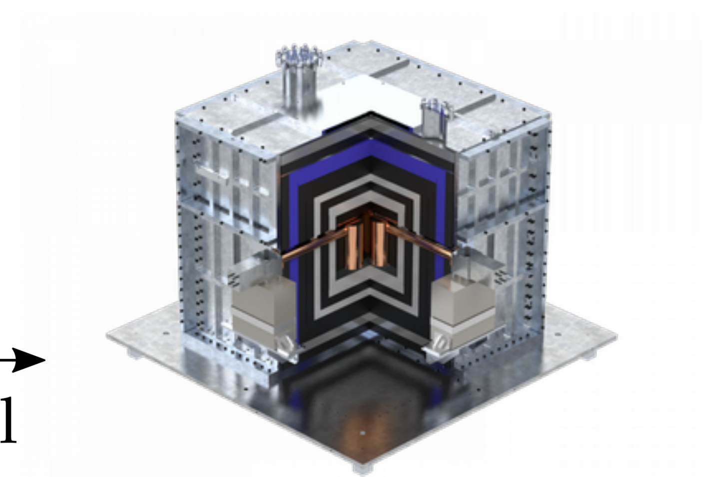
Low threshold

Low background

Nuclear power plant
(Brokdorf, KBR)

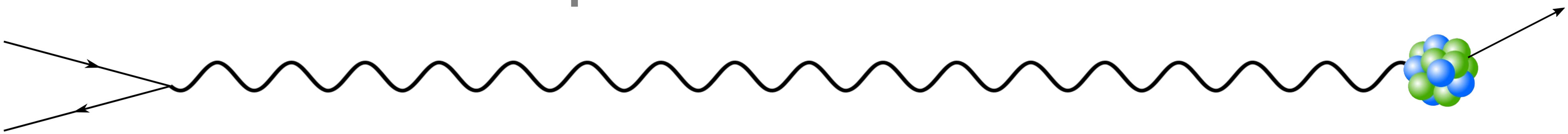


Point contact
HPGe spectrometer



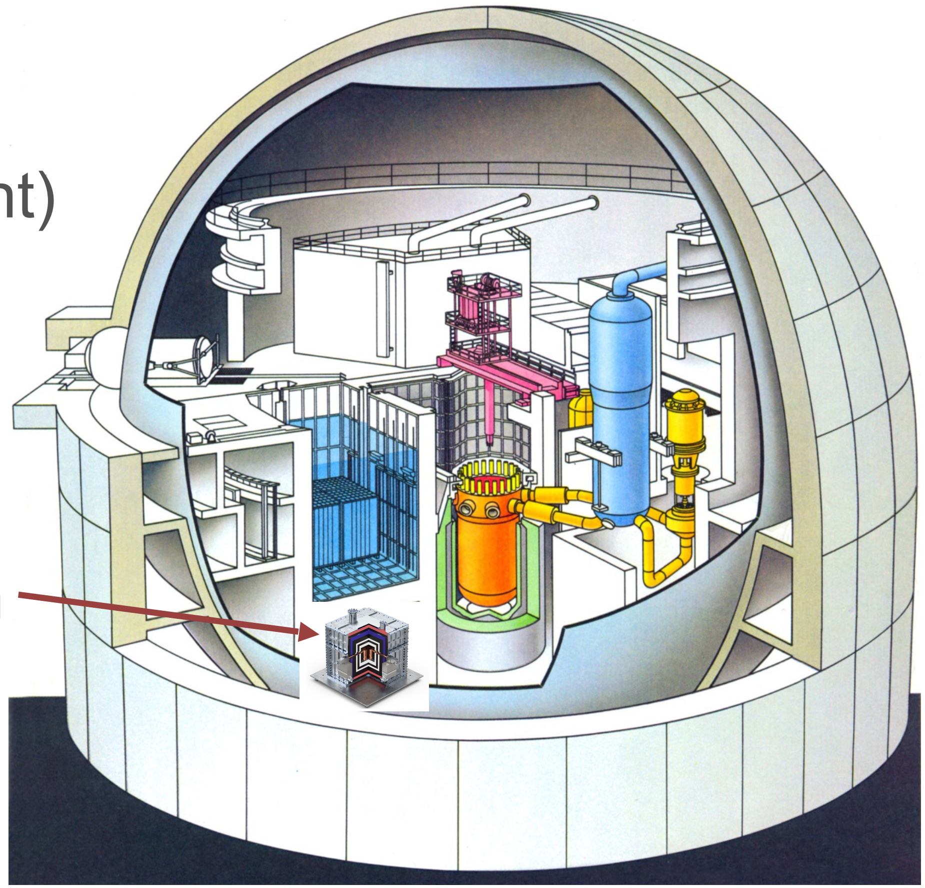
Shield (shallow depth)

Experimental Site



Overburden:
10 - 45 m w.e.
(angle-dependent)

CONUS location

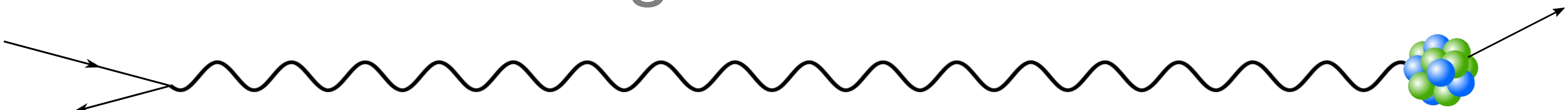


KBR Brokdorf:

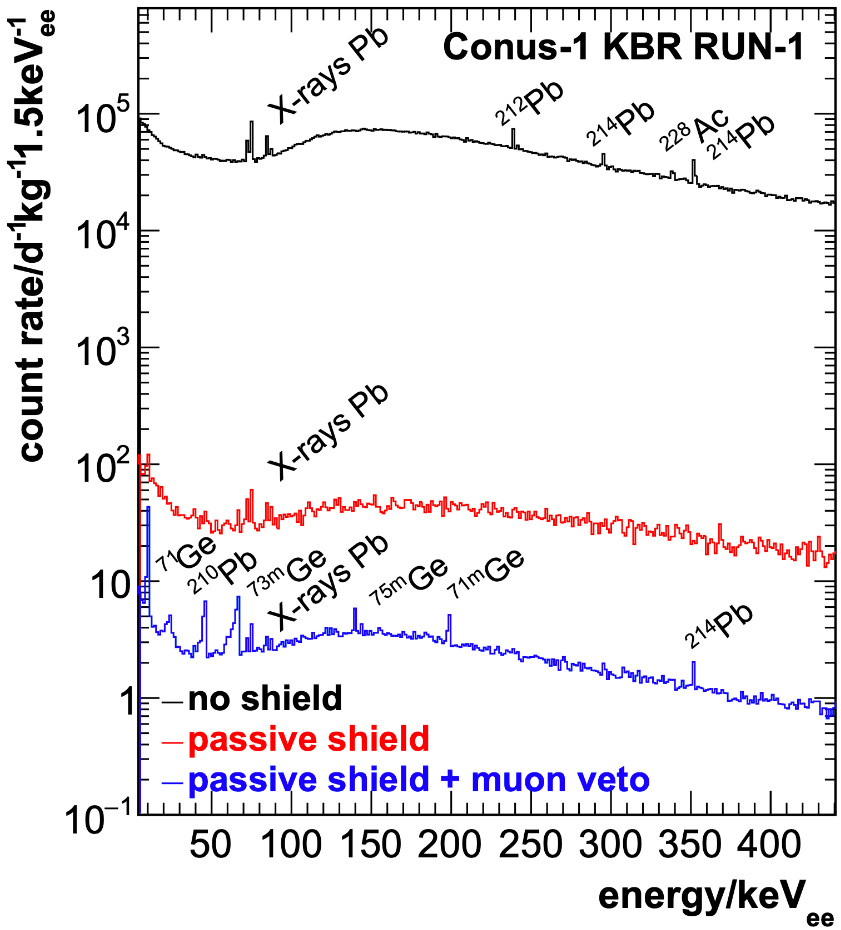
- 3.9 GWth
- Distance 17.1 m
- Flux: $2 \cdot 10^{13} s^{-1} cm^{-2}$
- Stopped end 2021
- Long reactor OFF measurement in 2022

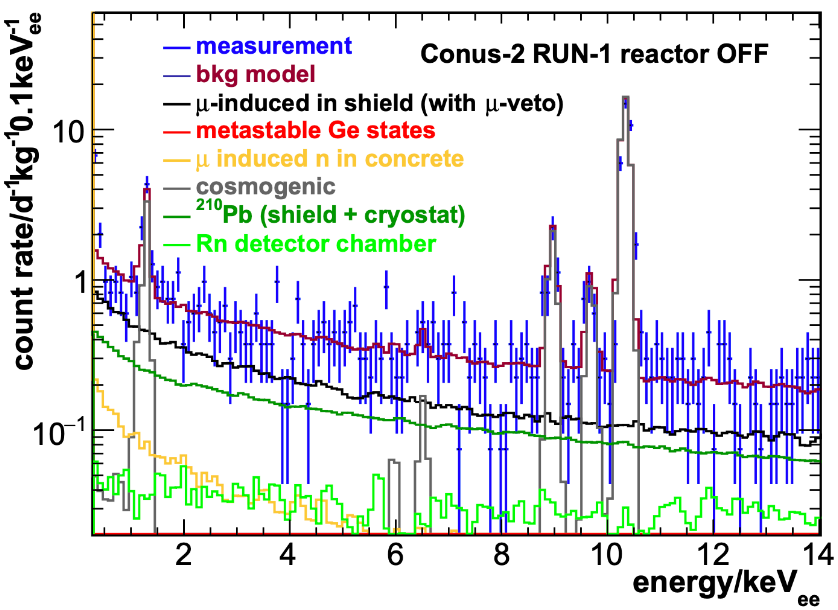
Challenging environment: no remote control, restricted materials, earthquake engineering, access, temperature fluctuations,…

Background model



- Passive + active shield: Background suppression ~10^4
- Rate 0.5-1 keV: ~10 /(keV d kg)
- Bg spectrum well understood
- “Virtual depth”

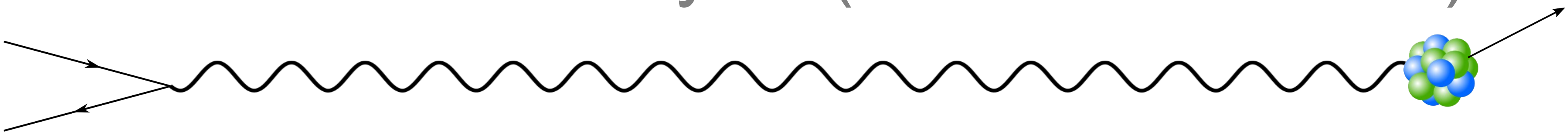




CONUS, EPJ C 83:195 (2023)

CONUS, EPJ C 79:699 (2019)

CEvNS data analysis (Run-1 and Run-2)



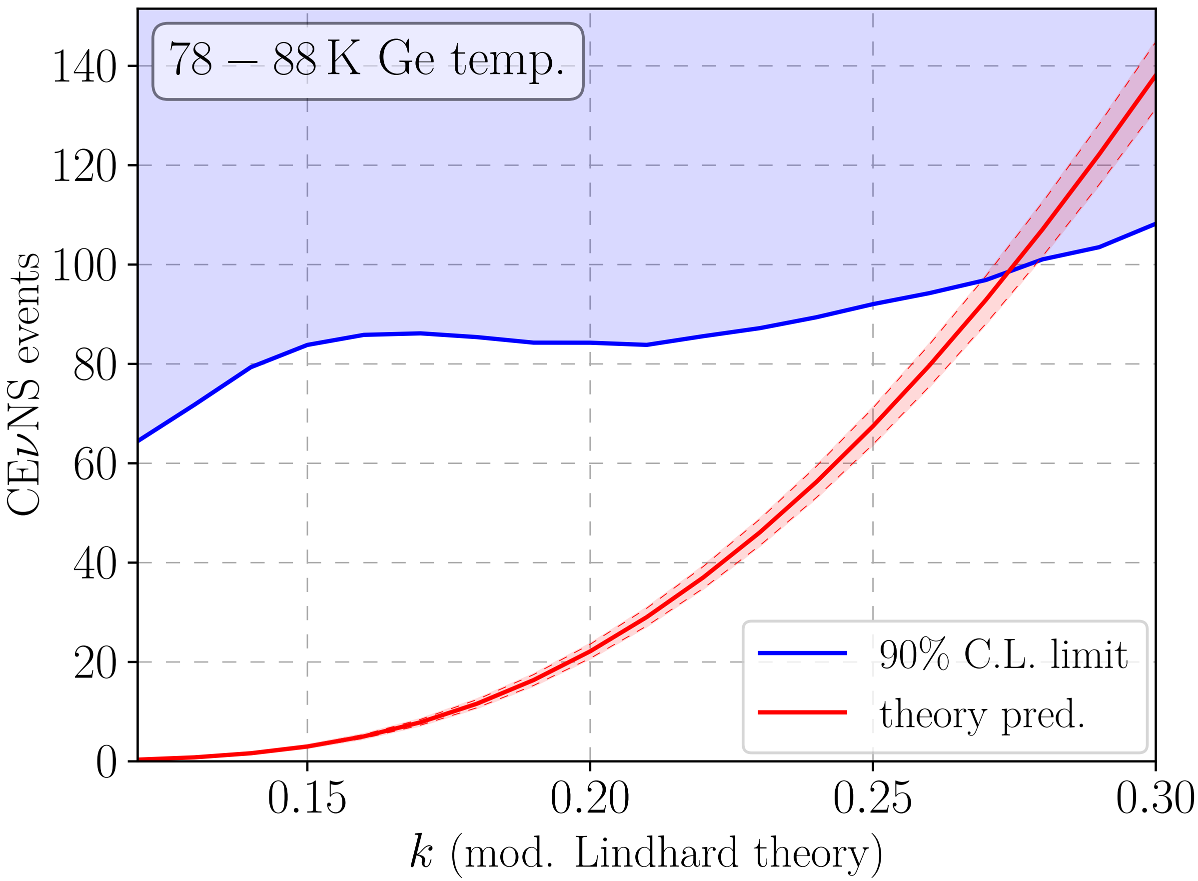
Exposure: ~250 kg d ON

Background treatment

- MC modelling
- Free normalization in fit
- Electronic noise contribution

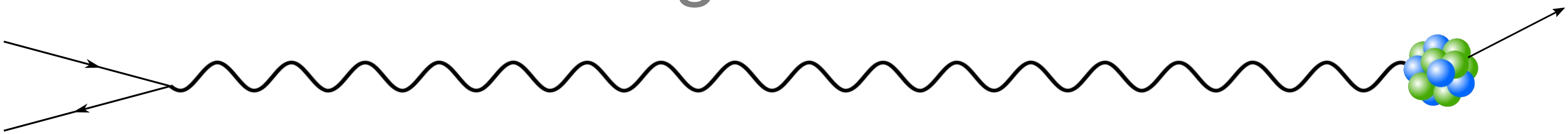
Likelihood

- Simultaneous fit ON/OFF (all detectors and runs)
- Scan over signal parameter
- Systematics via pull terms (energy scale, fiducial mass, efficiency, neutrino flux)

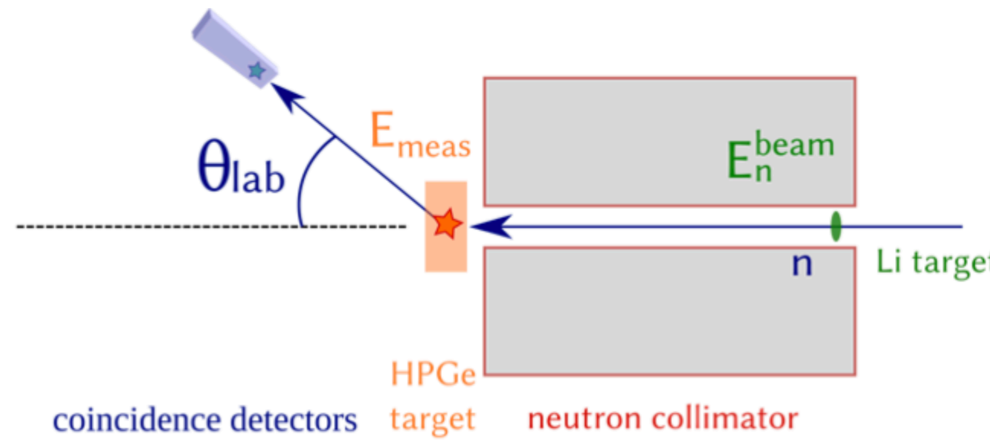


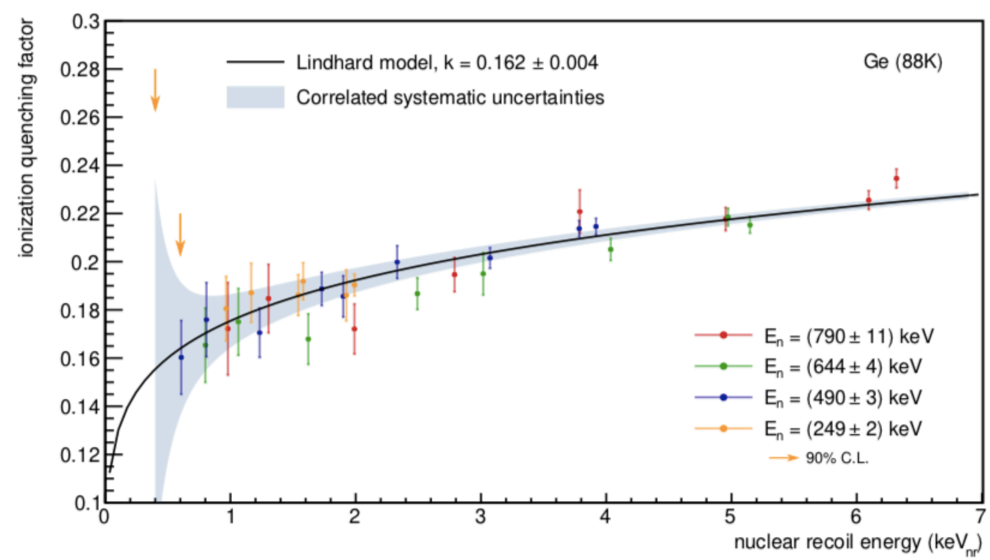
CONUS, PRL 126 (2021) 041804

Quenching measurement



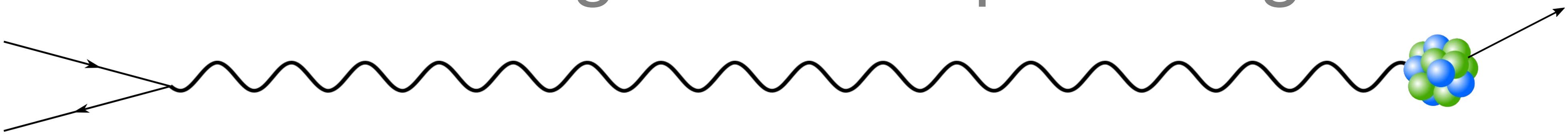
- Experimental setup (beam facility at PTB Braunschweig)
  - Model-independent method
  - Triple coincidence
  - Beam energy 250 - 800 keV
  - Angles 18-45° (1° precision)
  - Nuclear recoils 0.4 - 6 keV
- Results
  - Compatible with Lindhard theory!
  - **k = 0.162 ± 0.004** (stat.+syst.)
  - Challenge for CEvNS signal detection with Ge at reactor

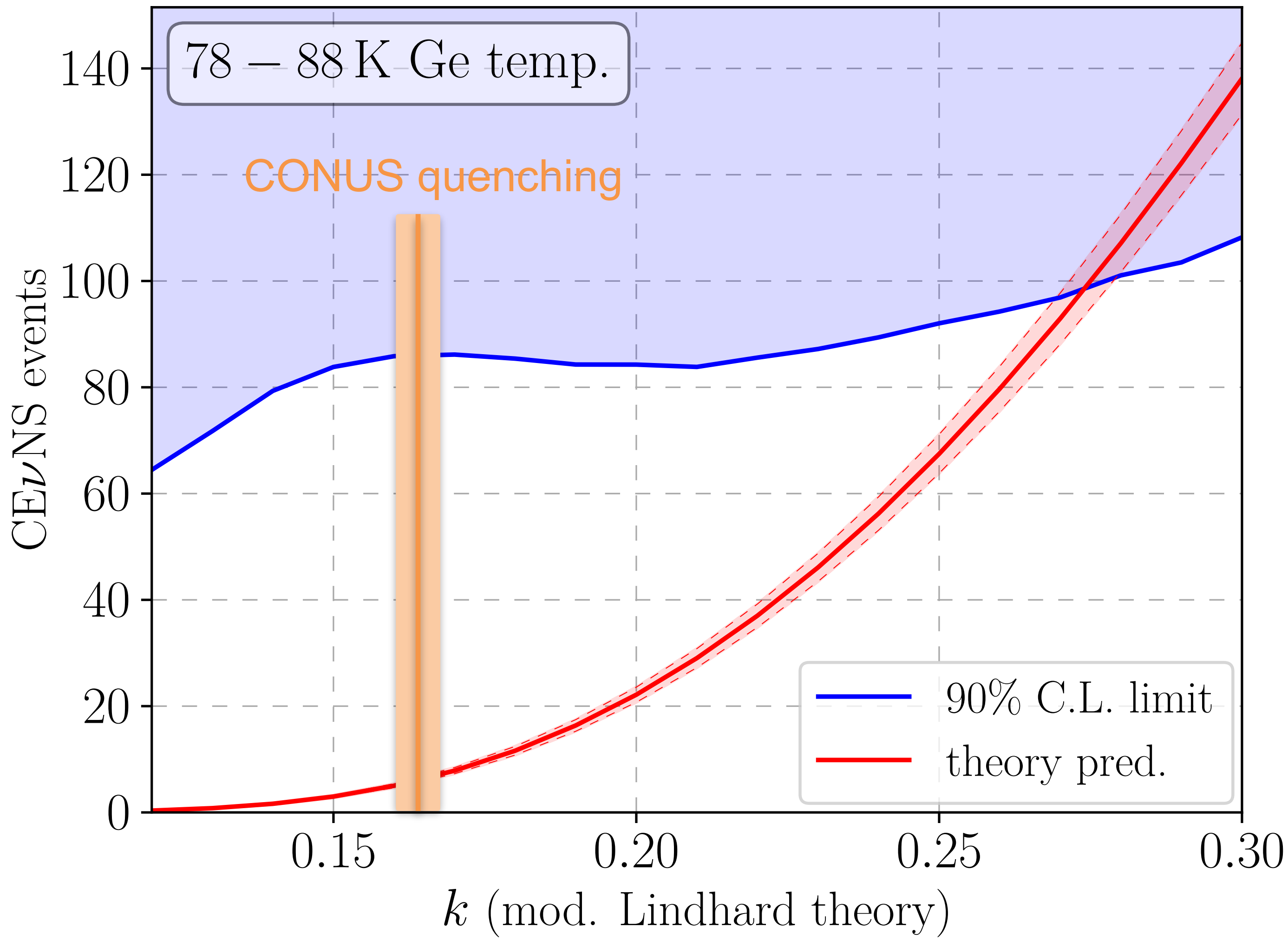




Bonhomme et al., EPJ C 82:815 (2022)

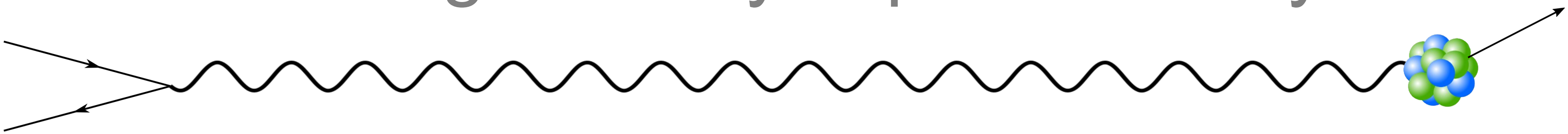
PRL result in light of new quenching data





Run 1+2 limit is 17 times higher than SM signal prediction

Run-5: significantly improved analysis



New DAQ system

Higher OFF statistics

Lower threshold

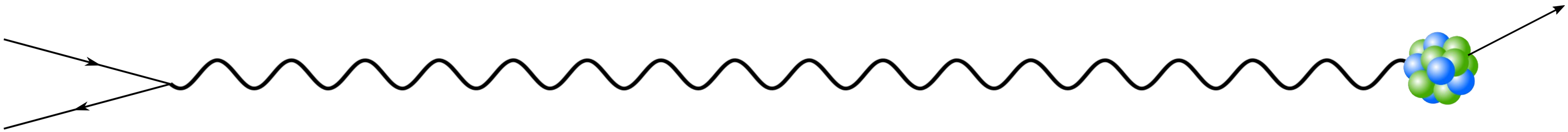
Detector	ON [d]	OFF [d]	E threshold [eV]
C1	151	43	220
C2	154	138	210
C4	153	112	210

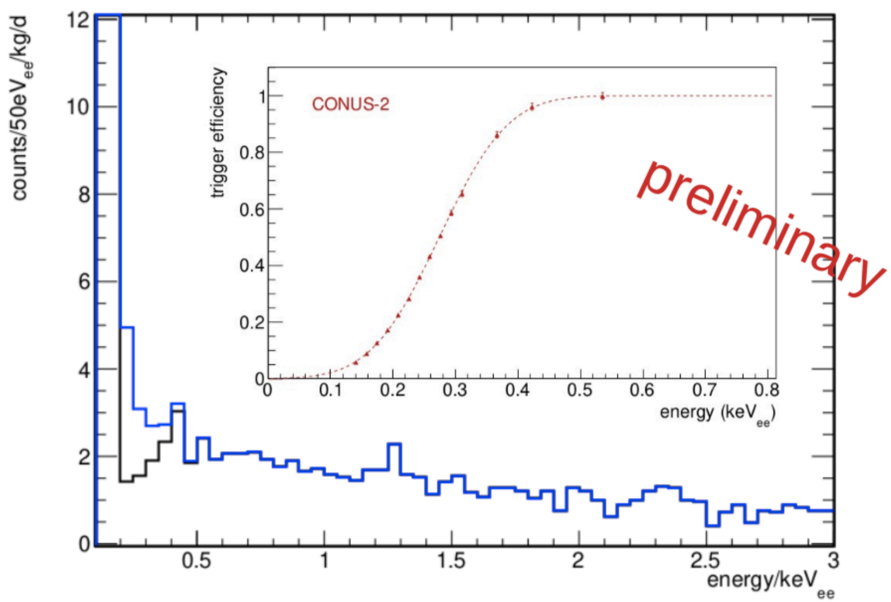
Refined bkg model

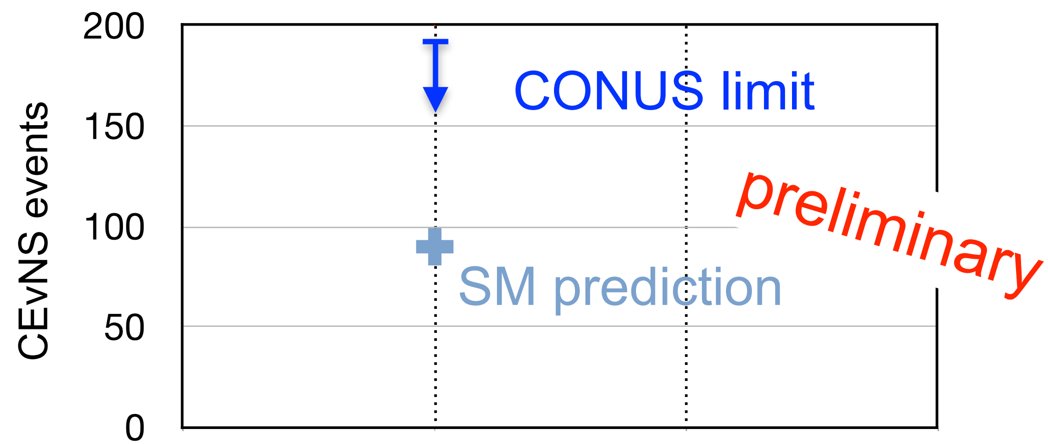
Data with high noise variations excluded

Next: include PSD

New result!



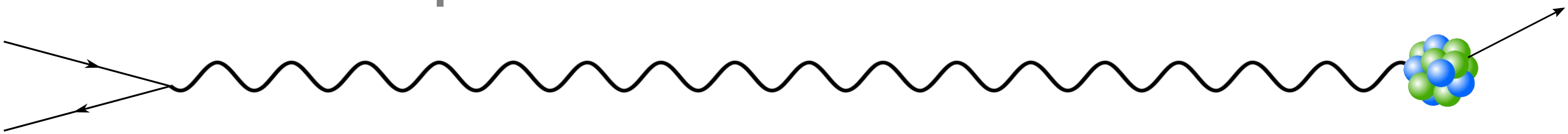




Quenching: Lindhard with k = 0.162

- Limit factor ~2 above predicted SM value
- ~ 1 order of magnitude improvement as compared to Run-1+2!
- Further (slight) improvements expected (PSD, statistics,…)

Comparison with other results



Measurement of Coherent Elastic Neutrino-Nucleus Scattering from Reactor Antineutrinos

J. Colaresi,[1] J. I. Collar,[2,*] T. W. Hossbach,[3] C. M. Lewis,[2] and K. M. Yocum[1]
[1]Mirion Technologies Canberra, 800 Research Parkway, Meriden, Connecticut 06450, USA
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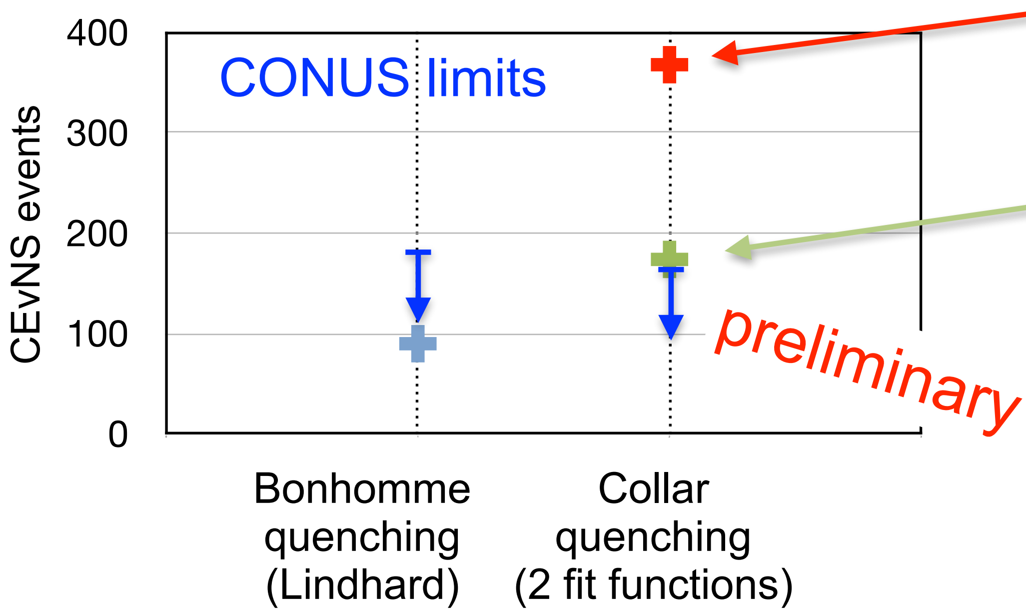
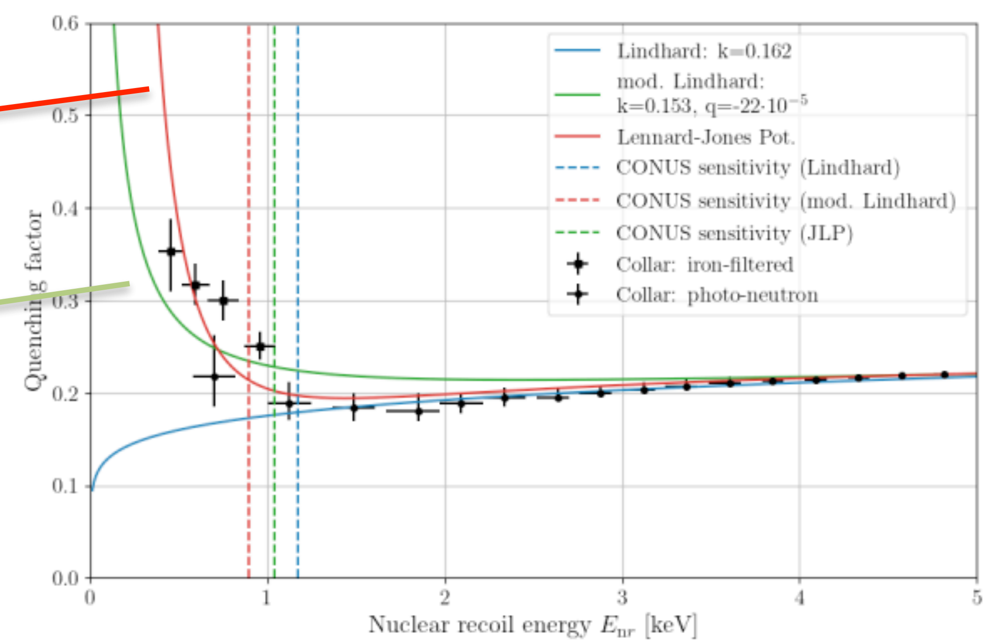
(Received 29 November 2021; revised 21 March 2022; accepted 20 September 2022; published 17 November 2022)

The 96.4 day exposure of a 3 kg ultralow noise germanium detector to the high flux of antineutrinos from a power nuclear reactor is described. A very strong preference ($p < 1.2 \times 10^{-3}$) for the presence of a coherent elastic neutrino-nucleus scattering (CEνNS) component in the data is found, when compared to a background-only model. No such effect is visible in 25 days of operation during reactor outages. The best-fit CEνNS signal is in good agreement with expectations based on a recent characterization of germanium response to sub-keV nuclear recoils. Deviations of order 60% from the standard model CEνNS prediction can be excluded using present data. Standing uncertainties in models of germanium quenching factor, neutrino energy spectrum, and background are examined.

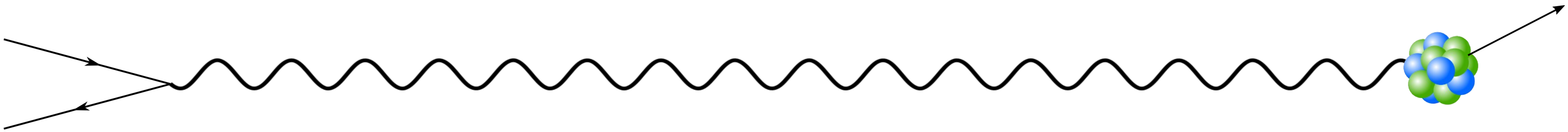
J.Colaresi et al., PRL 129, 211802 (2022)

- Constraints from vGen and CONNIE
- Tension with Collar quenching
- Tension with NCC-1701 signal





Neutrino electromagnetic properties (Run-1+2)

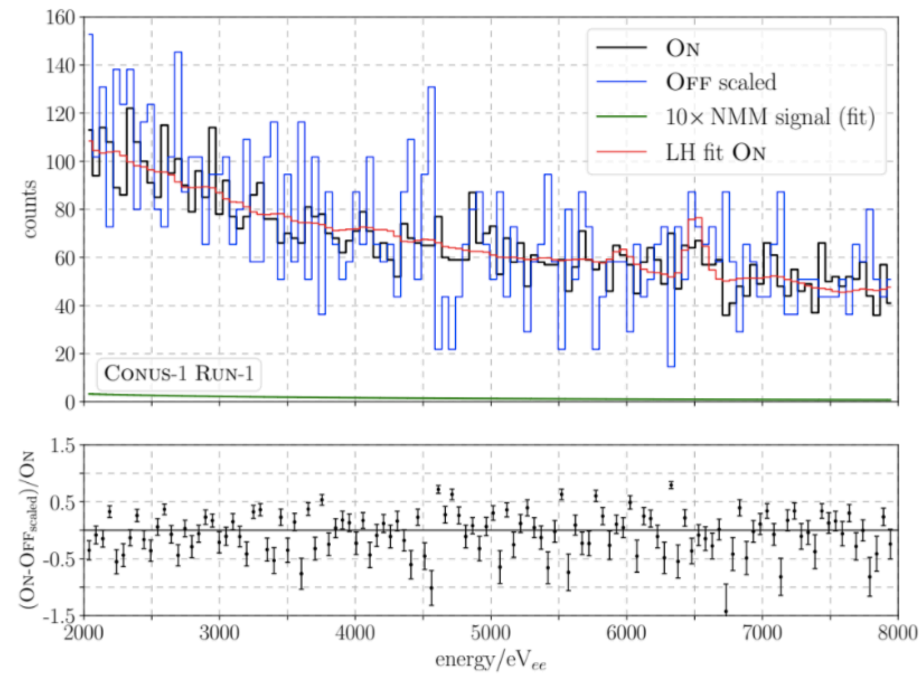


Magnetic moment:

$$\left(\frac{d\sigma}{dT}\right)^{e^-}_{\mu_\nu} = \frac{\pi\alpha_{em}^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)\left(\frac{\mu_{\nu_e}}{\mu_B}\right)^2$$

CONUS bound (90% CL) from ν-e scattering in 2-8 keV window:

$\mu_\nu < 7.5 \times 10^{-11}\,\mu_B$

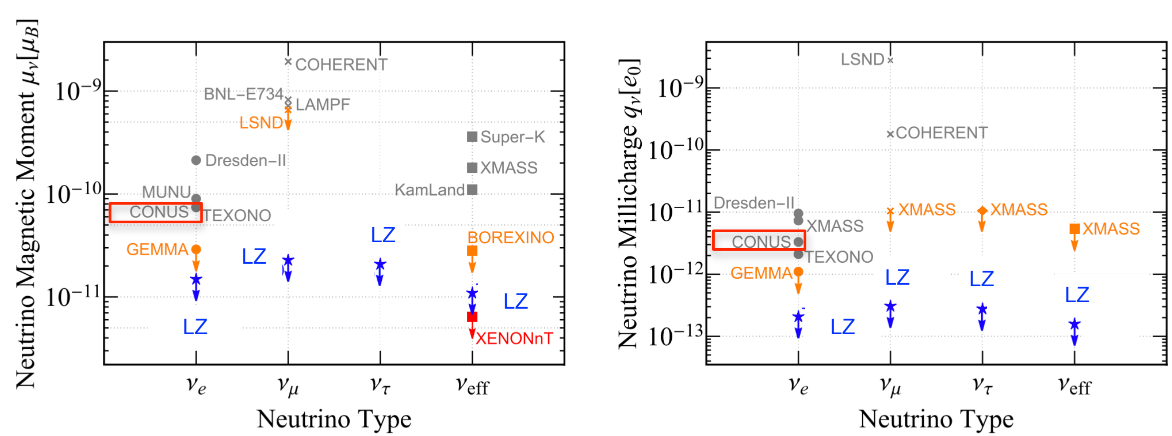


Conversion to millicharge limit:

$$q_\nu^2 < \frac{T}{2m_e}\left(\frac{\mu_\nu}{\mu_B}\right)^2 e_0$$

A. Studenikin, EPL 107(2), 21001 (2014)

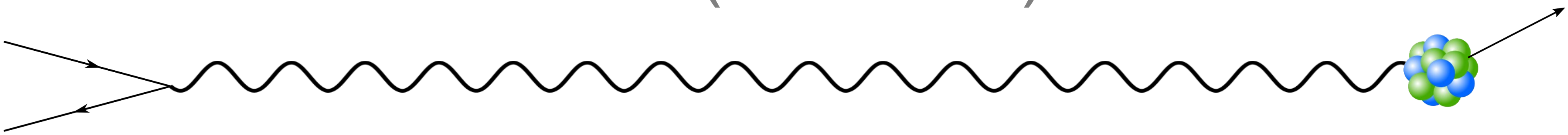
$q_\nu < 3.3 \times 10^{-12}\, e_0$



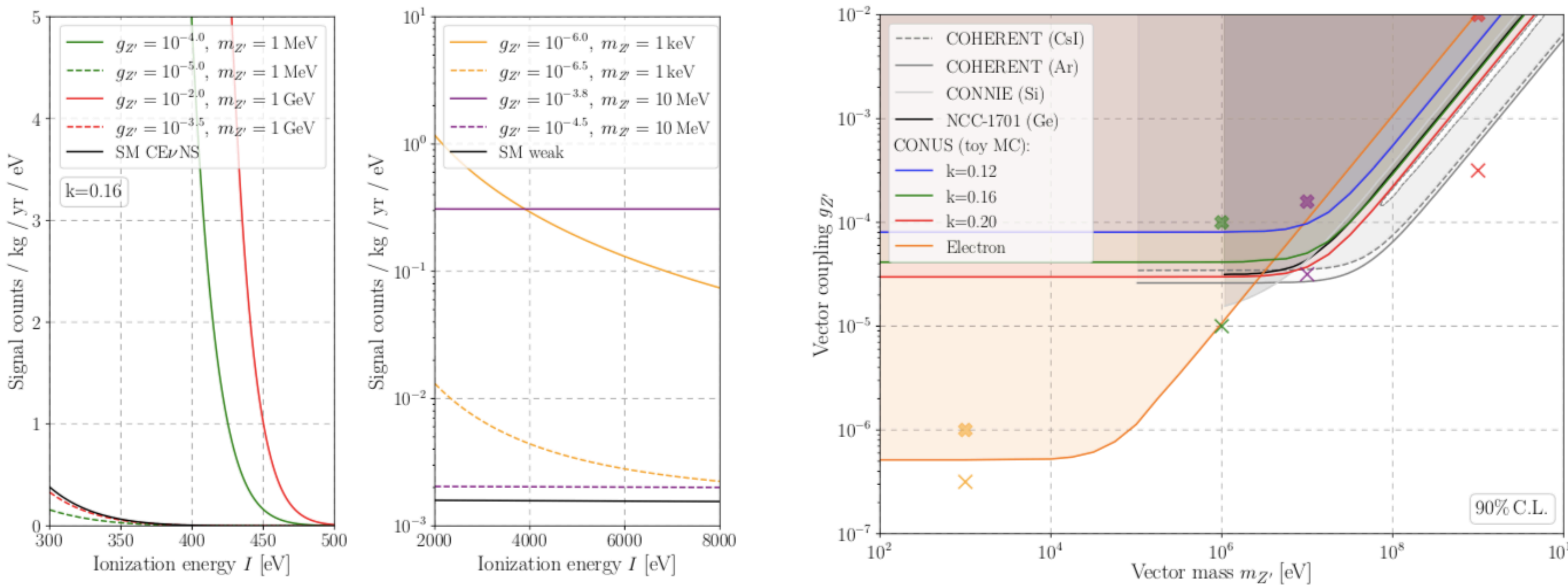
CONUS, EPJ C 82:813 (2022)

M. Atzori Corona et al., PRD 107, 053001 (2023)

BSM (Run-1+2)

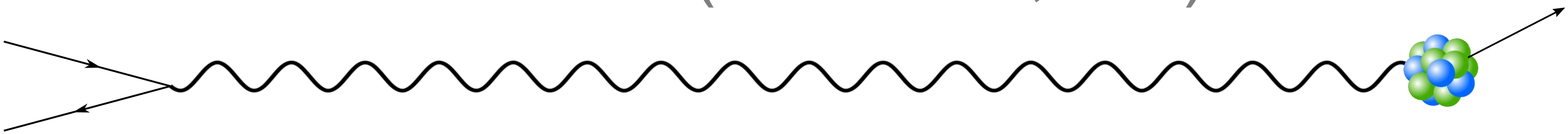


- Non standard interactions
- High sensitivity for light mediators at masses < 10 MeV



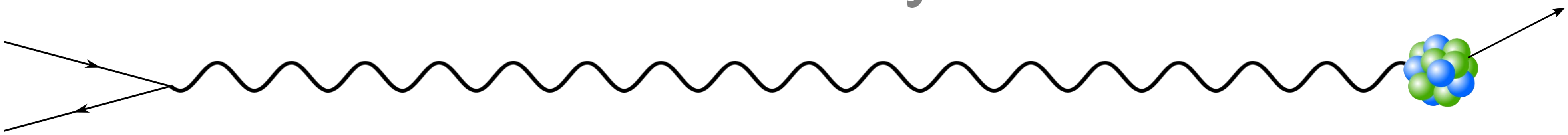
CONUS, JHEP 05 (2022) 085

CONUS+ (Leibstadt, CH)



- Approved by KKL, site characterisation done (20.7 m distance)
- Further improve energy resolution, detector thresholds, trigger efficiency and muon veto performance (add additional layer)
- Improved CONUS setup will move in Spring 2023

Summary



- Nuclear reactors: intense source of low energy (< 10 MeV) electron antineutrinos ==> CEvNS in fully coherent regime
- CONUS: Low energy threshold HPGe-detectors 17.1 m from reactor core (Brokdorf)
- Extensive background studies/modeling
- Ge-quenching study at PTB: consistent with Lindhard theory
- Strong constraints on CEvNS: factor ~2 above SM prediction (new!)
- Constraints on BSM models and electromagnetic neutrino properties
- CONUS+: Continue in Leibstadt (CH) with improved detectors