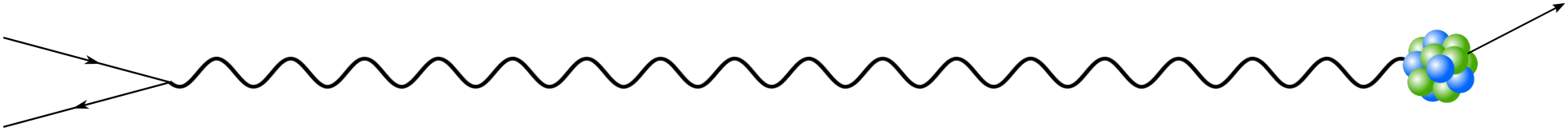
From CONUS to CONUS+: New results and current status



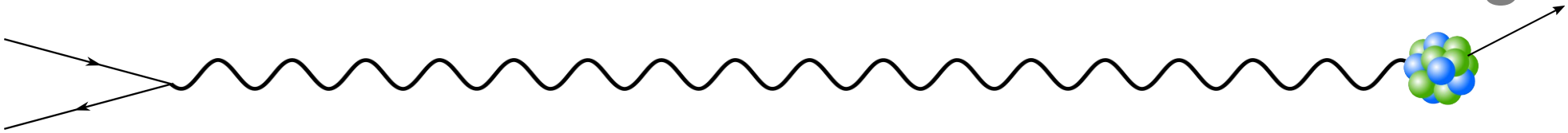
Christian Buck (on behalf of the CONUS collaboration)
Max-Planck-Institut für Kernphysik, Heidelberg
AAP Workshop, York, September, 20th (2023)

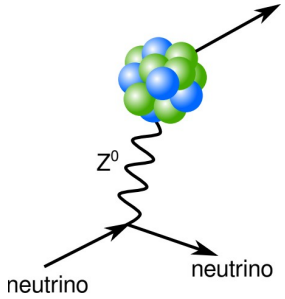
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

CONUS

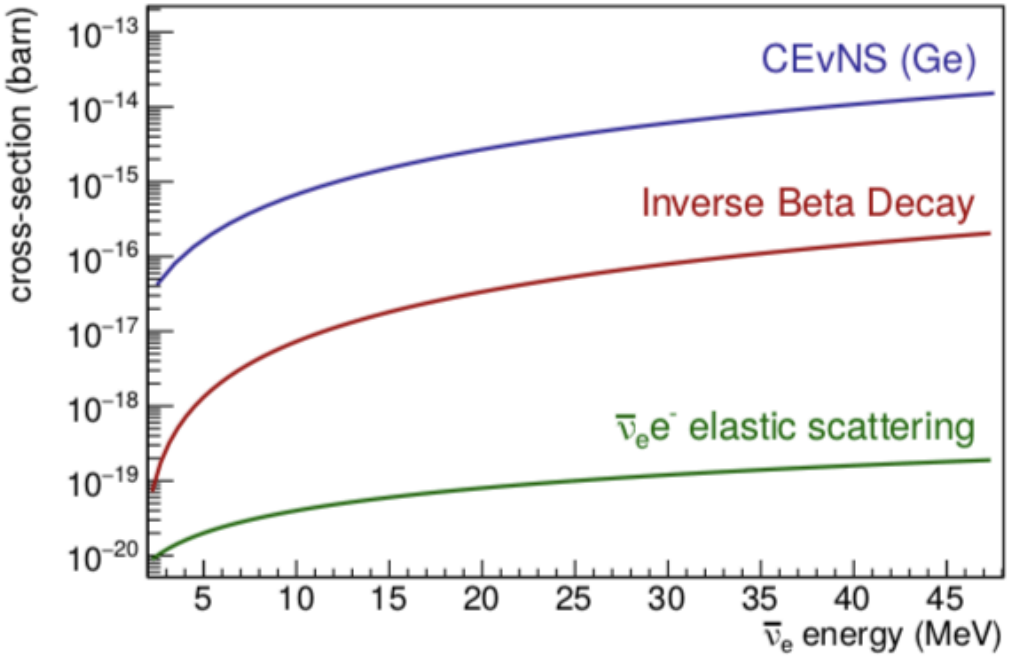
COνUS+

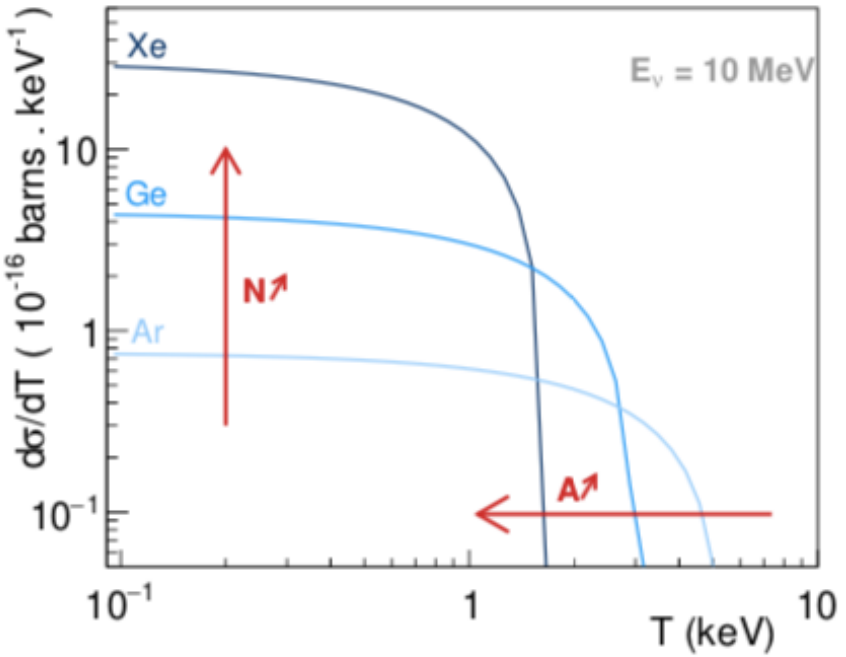
Coherent elastic neutrino nucleus scattering





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

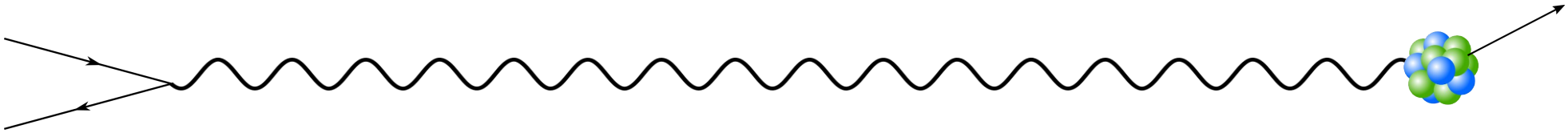


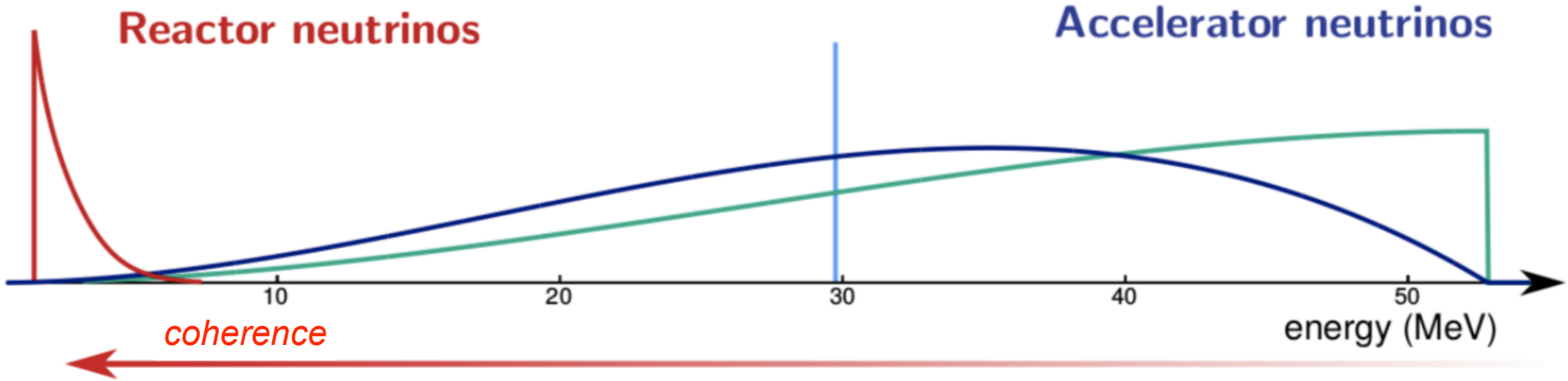


- High cross-section ==> compact detectors
- Interesting for reactor monitoring

- Interaction rate vs recoil energy
- Ge good compromise

Neutrino sources for CEvNS studies



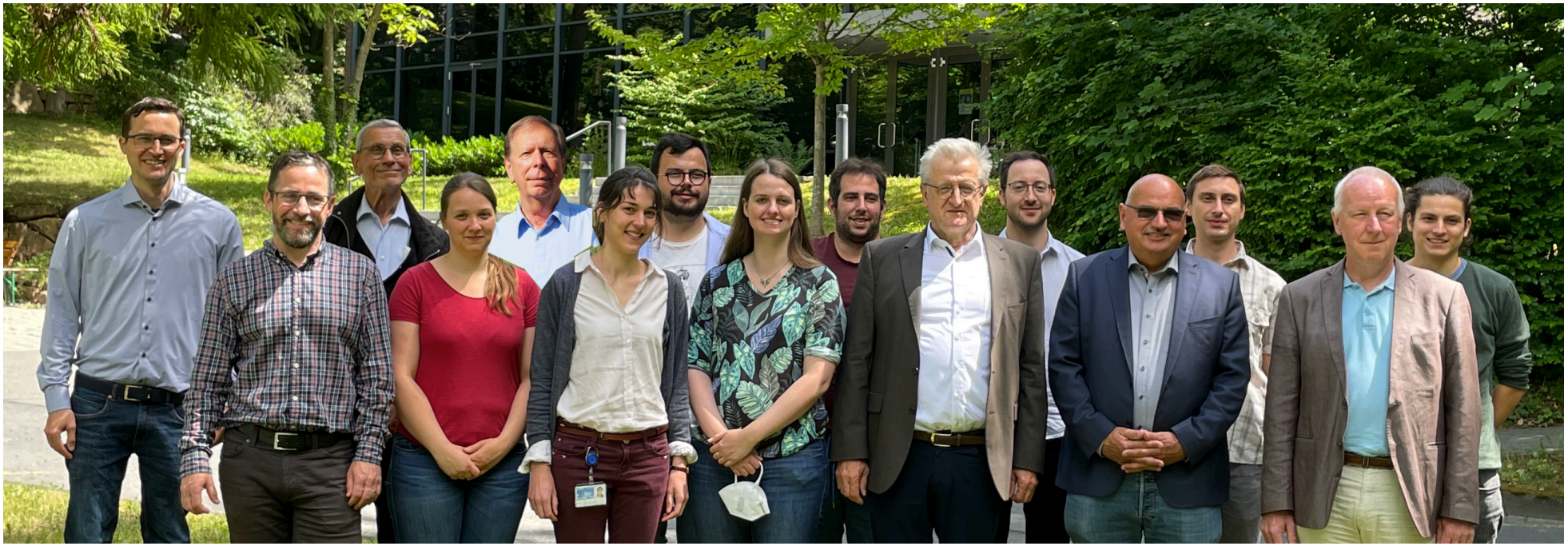


- Pure flux of electron antineutrinos
- E < 10 MeV ==> form factor ~1
- High sensitivity for BSM physics
- CONUS, vGeN, CONNIE, Dresden-II, Nucleus, Ricochet,…

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

Complementarity !

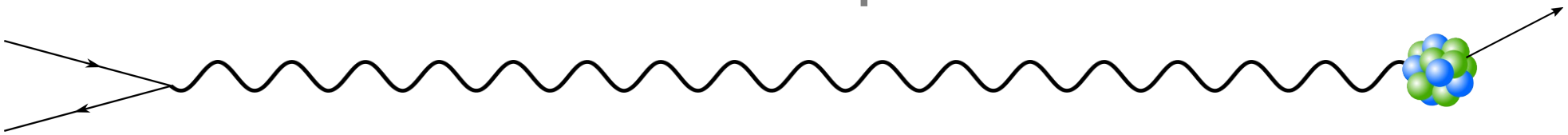
CONUS Collaboration



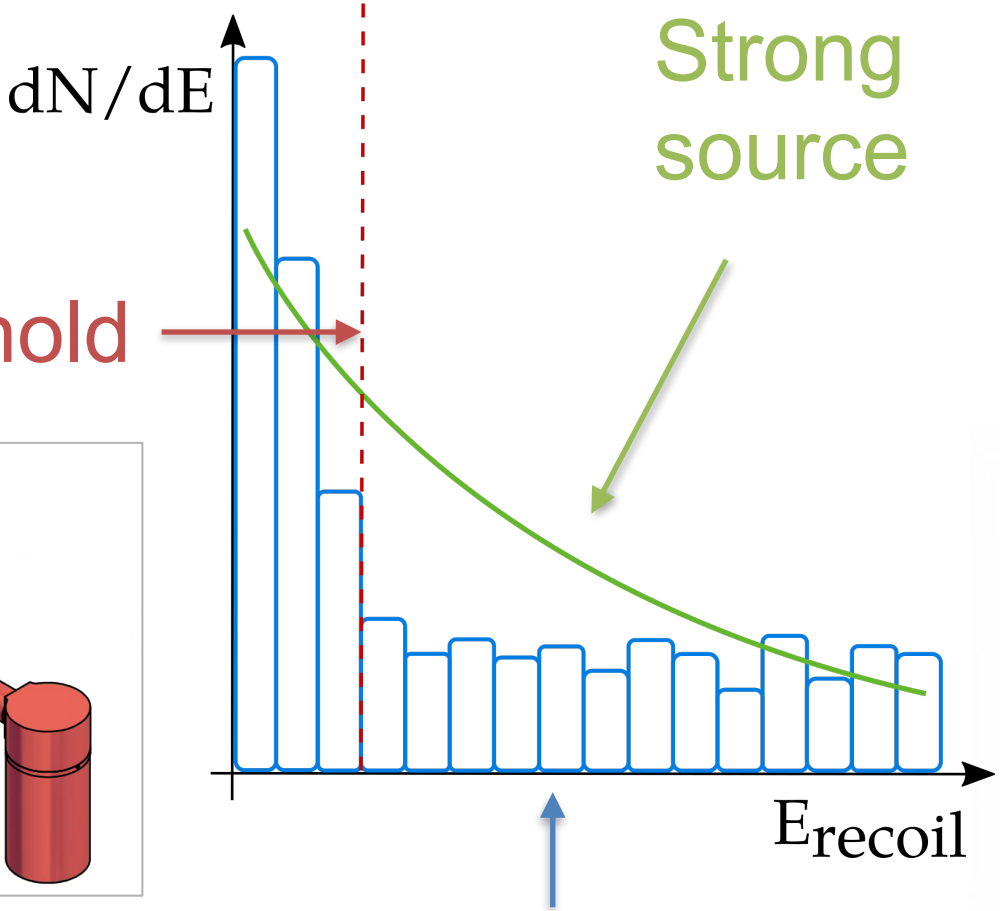
N. Ackermann, S. Armbruster, H. Bonet, A. Bonhomme, C. Buck, J. Hakenmüller, J. Hempfling, J. Henrichs, G. Heusser, T. Hugle, M. Lindner, W. Maneschg, K. Ni, T. Rink, E. Sanchez Garcia, J. Stauber, H. Strecker
Max-Planck-Institut für Kernphysik (MPIK), Heidelberg

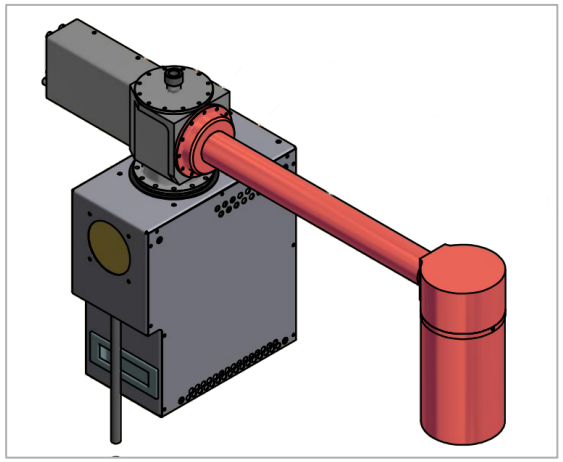
K. Fülber, R. Wink
Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR)

Concept

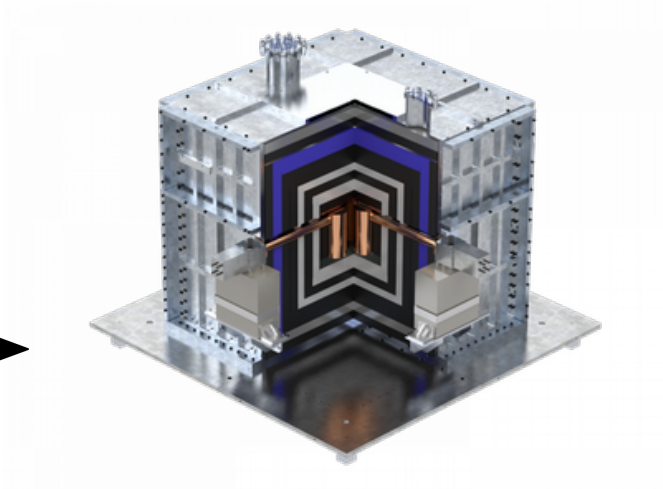


Nuclear power plant
(Brokdorf, KBR)



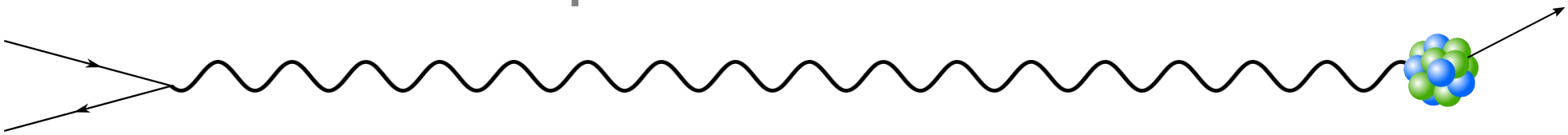


4 x 1 kg point contact
HPGe spectrometer



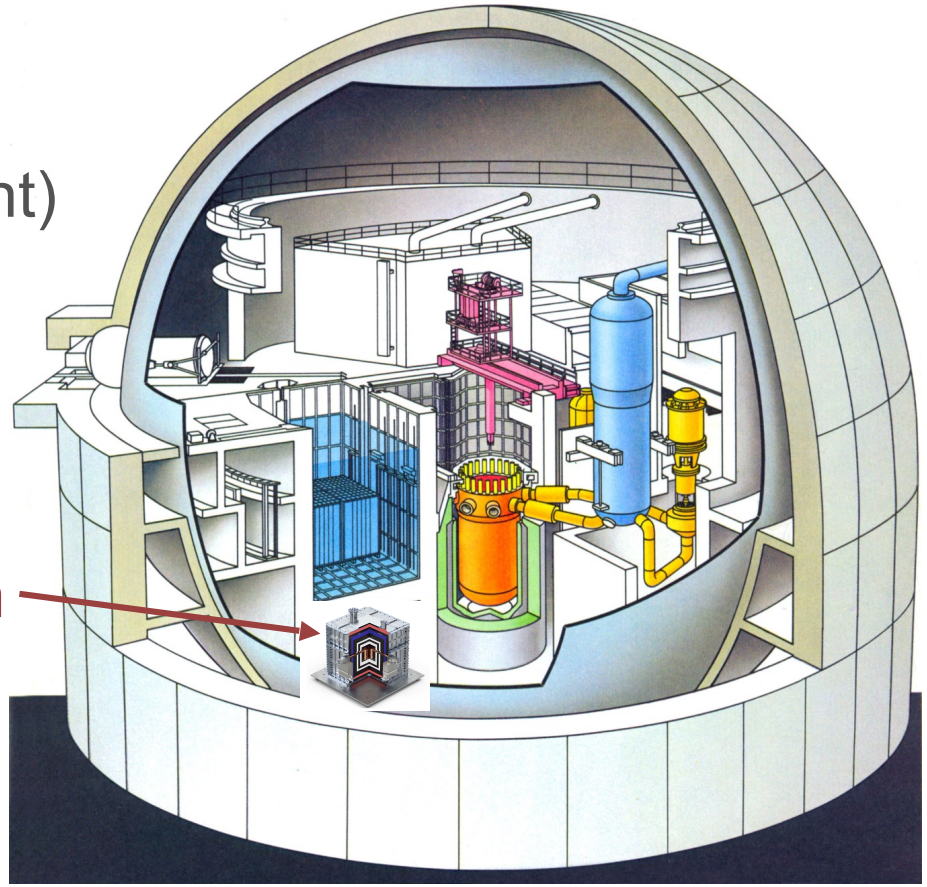
Shield (11 t, 1.6 m^3)

Experimental Site



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

CONUS location

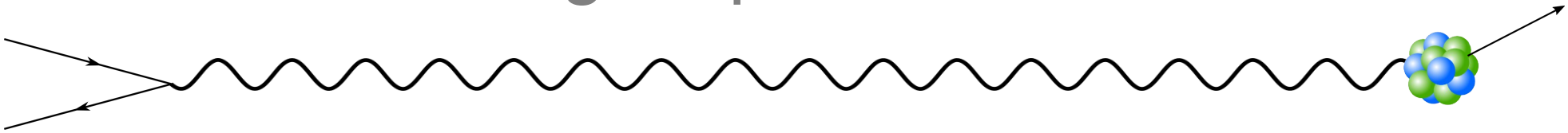


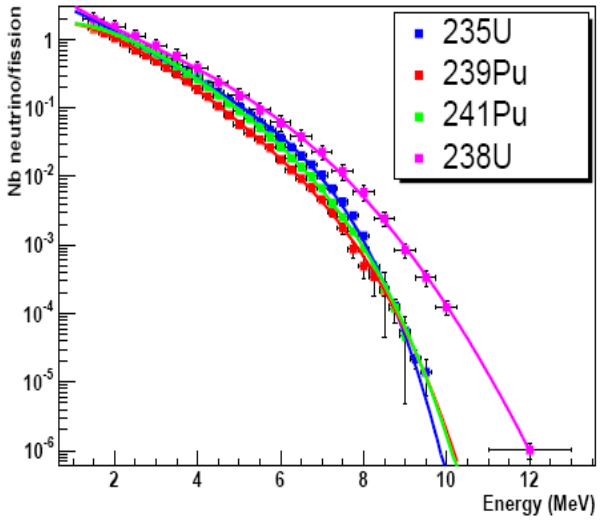
KBR Brokdorf:

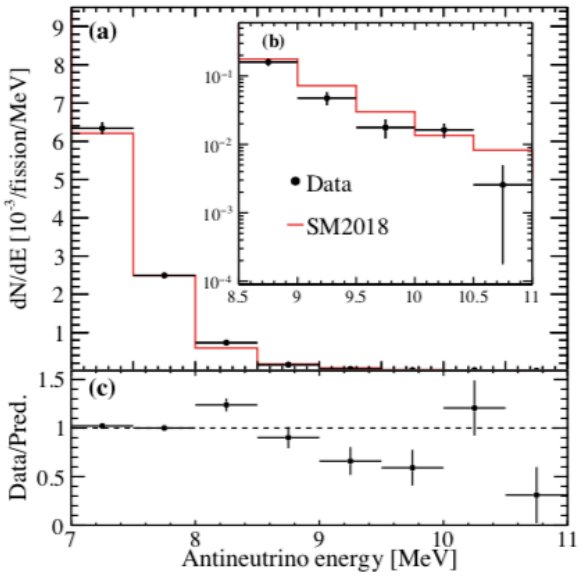
- 3.9 GWth
- Distance 17.1 m
- Data taking 5 years
- Stopped end 2021
- Long reactor OFF measurement in 2022

Challenging environment: no remote control, restricted materials, earthquake safety, access, different ON and OFF conditions,…

Signal prediction

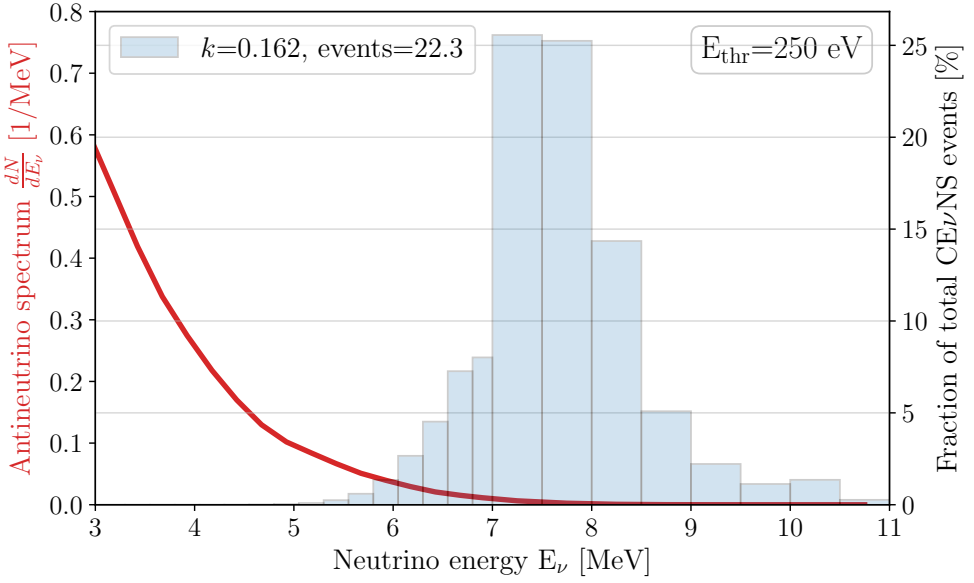




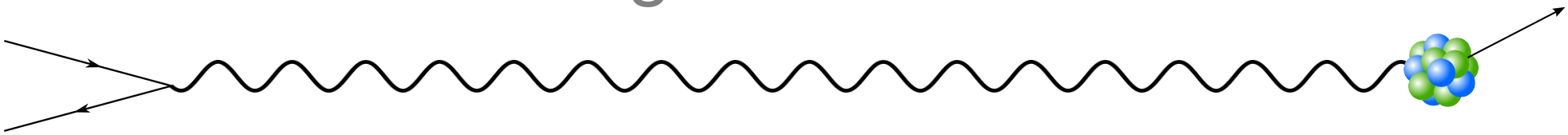


Daya Bay, PRL 129 (2022) 041801

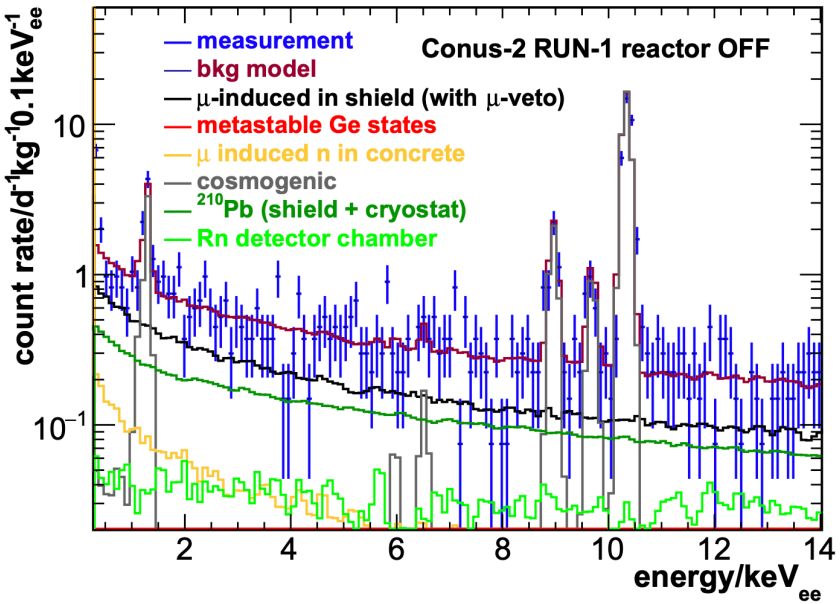
- Thermal power and energy per fission
- Flux at CONUS site: 2.3×10^{13} /(cm^2 s)
- Spectrum: data-based method and high E spectrum from Daya Bay
- Consider evolution of fission fractions
- High quenching factor (f) dependence! (Ionization signal $E_{det} = f * T_{nr}$)

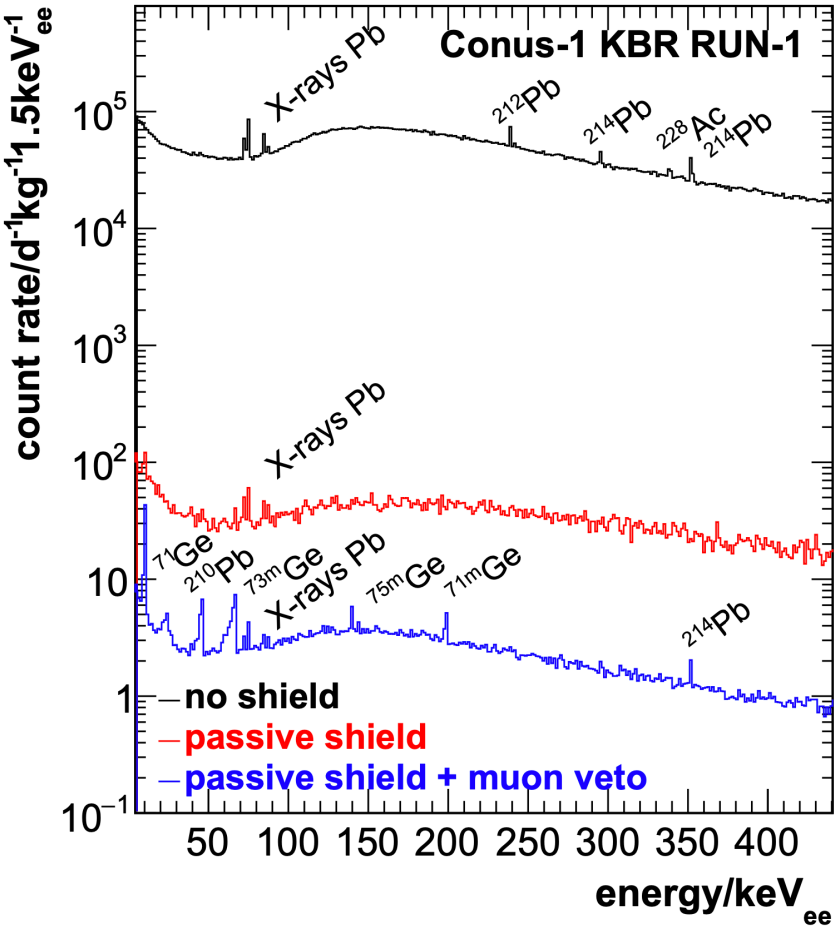


Background model



- Passive + active shield: Background suppression ~10^4
- Rate 0.5-1 keV: ~10 /(keV d kg)
- “Virtual depth”
- Reactor neutrons under control

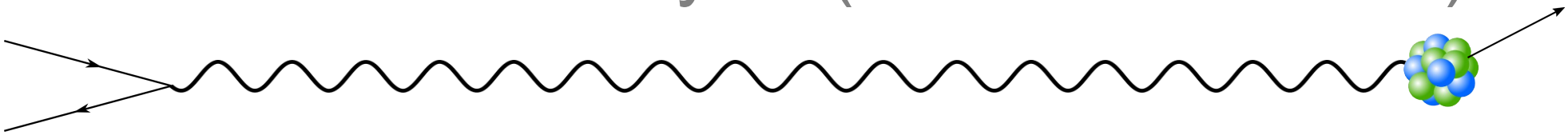




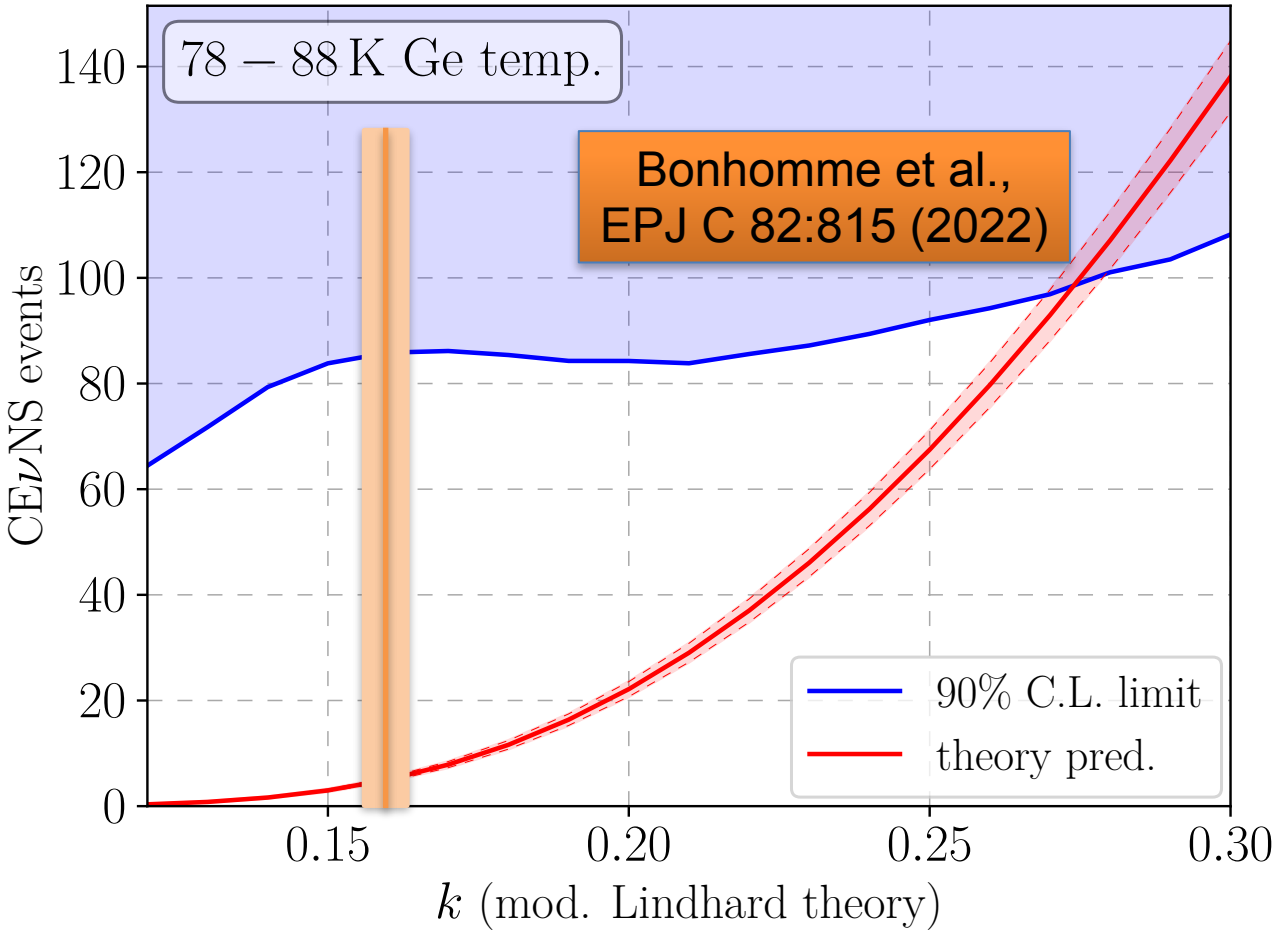
CONUS, EPJ C 83:195 (2023)

CONUS, EPJ C 79:699 (2019)

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



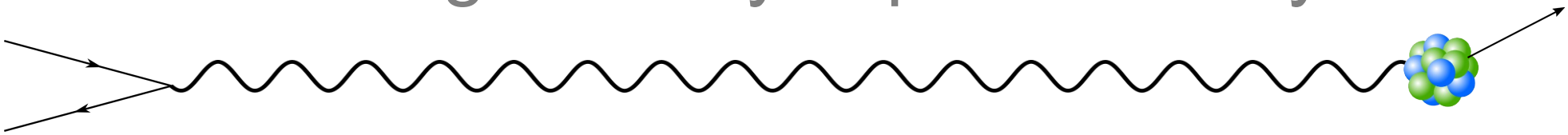
CONUS, PRL 126 (2021) 041804



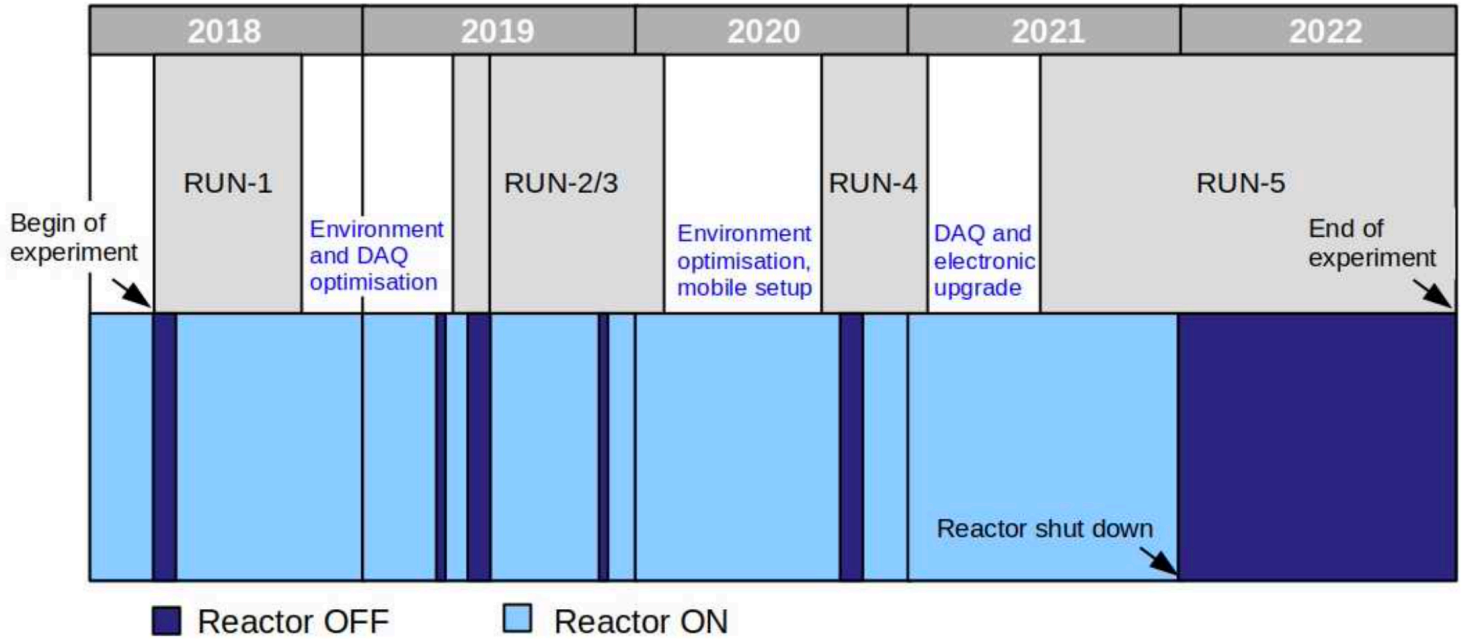
- 249 kg d ON
- 59 kg d OFF
- CEvNS limit: < 0.4 /(d kg)

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

Run-5: significantly improved analysis

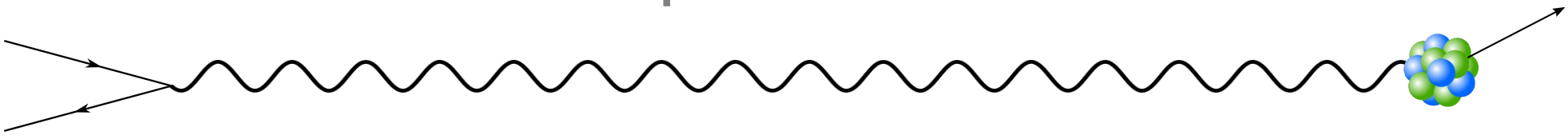


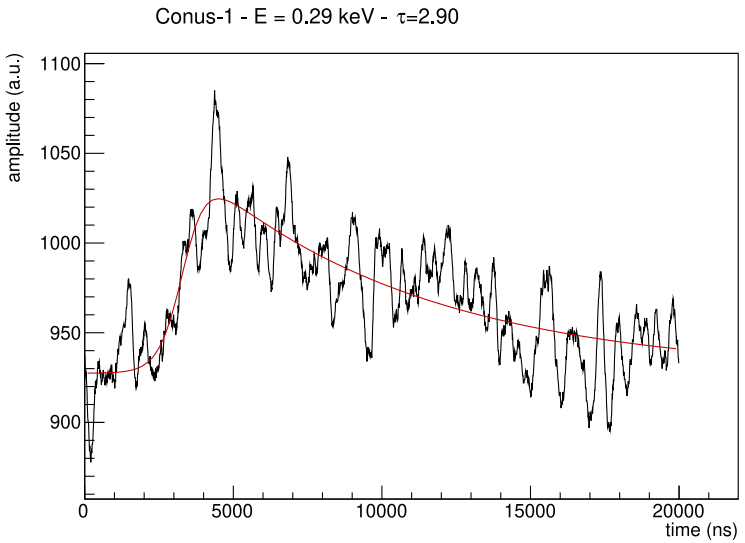
Detectors	ON [d]	OFF [d]	E threshold [eV]
C1, C2, C4	~450	~300	210

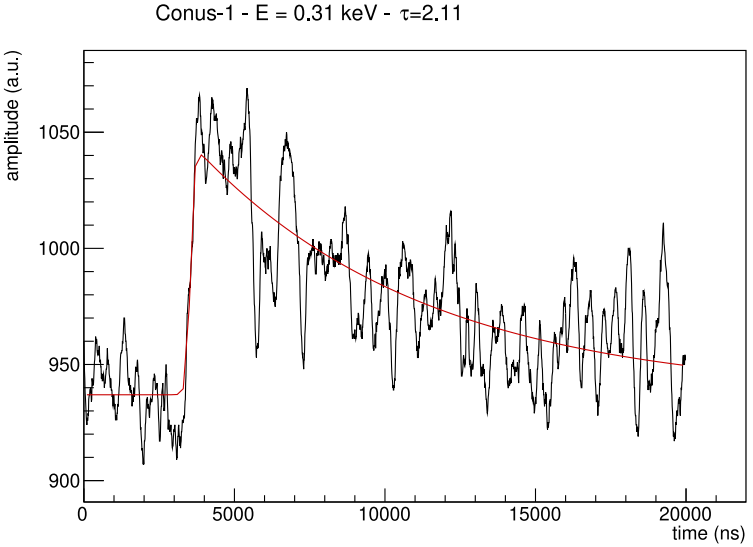


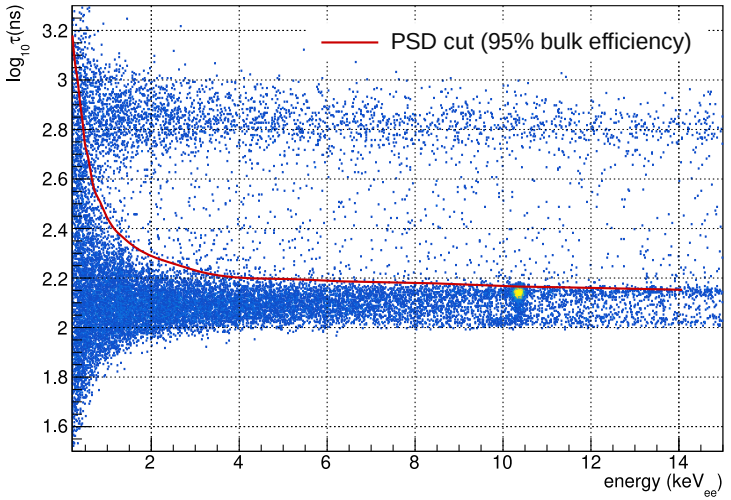
- Improvements: stability, DAQ, E threshold, PSD, OFF statistics…
- Data with high noise variations excluded

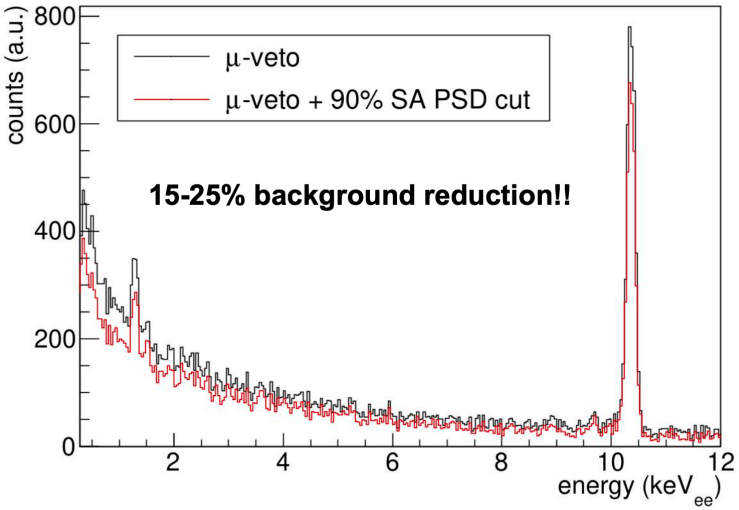
Pulse shape discrimination







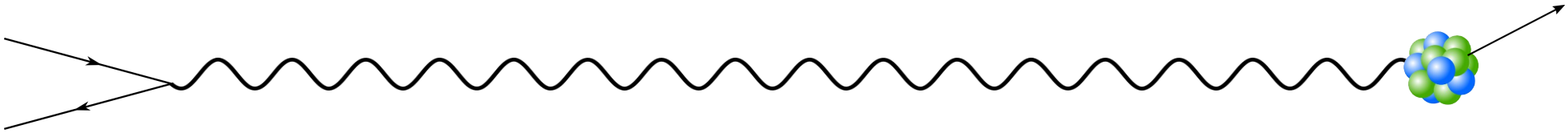


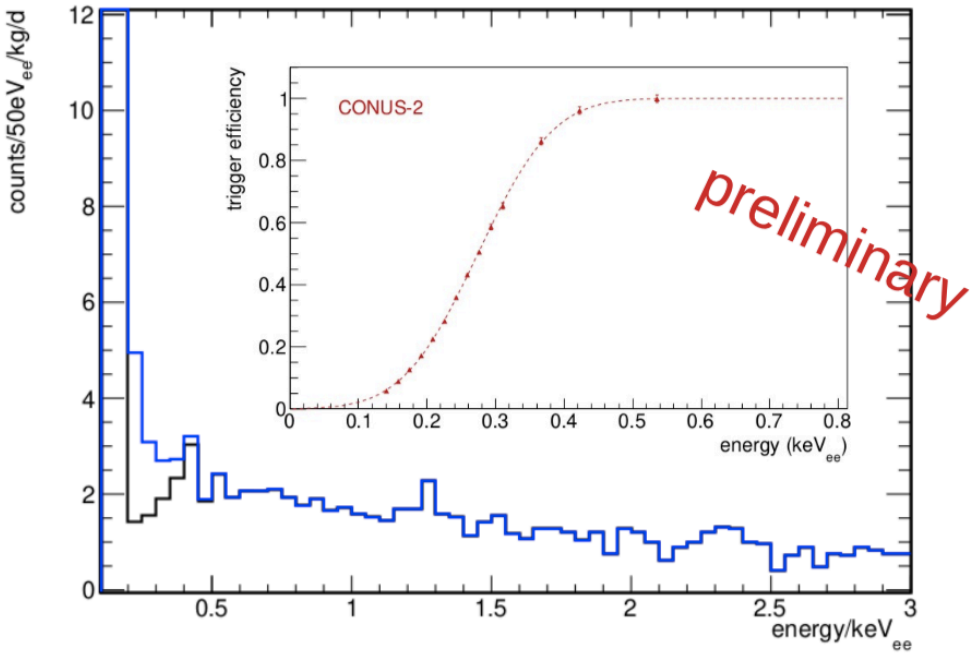


CONUS, arXiv2308.12105 (2023)

Signal acceptance in Run-5: 97%

New result!

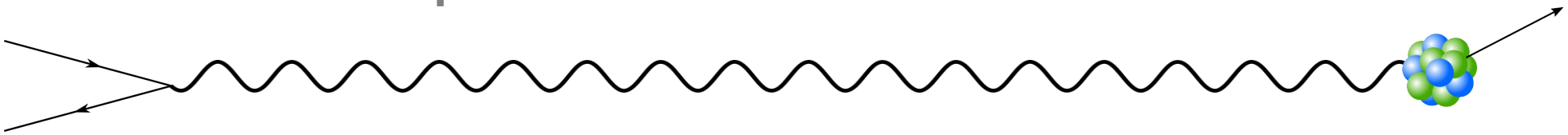




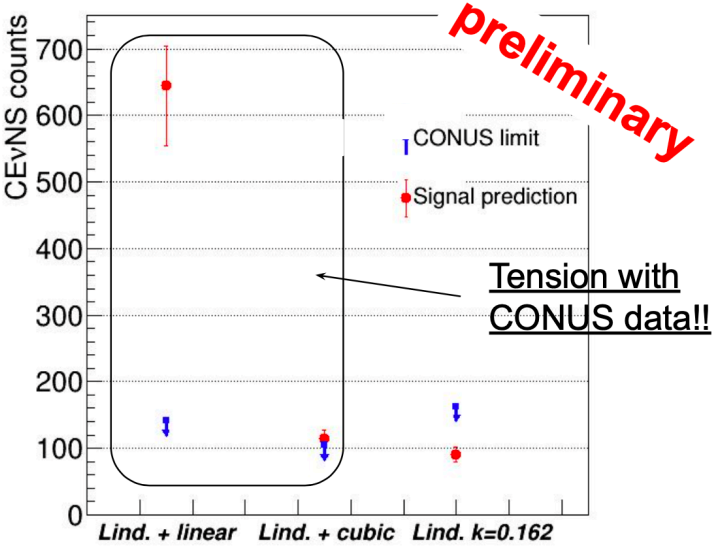
Detector	Signal prediction	Fit constraint (90% C.L.)
C1	42±8	< 59
C2	26±5	< 75
C4	24±4	< 90
All	92±10	< 163

- Limit factor ~2 above predicted SM value (strongest limit at reactor)
- ~ 1 order of magnitude improvement as compared to Run-1+2!

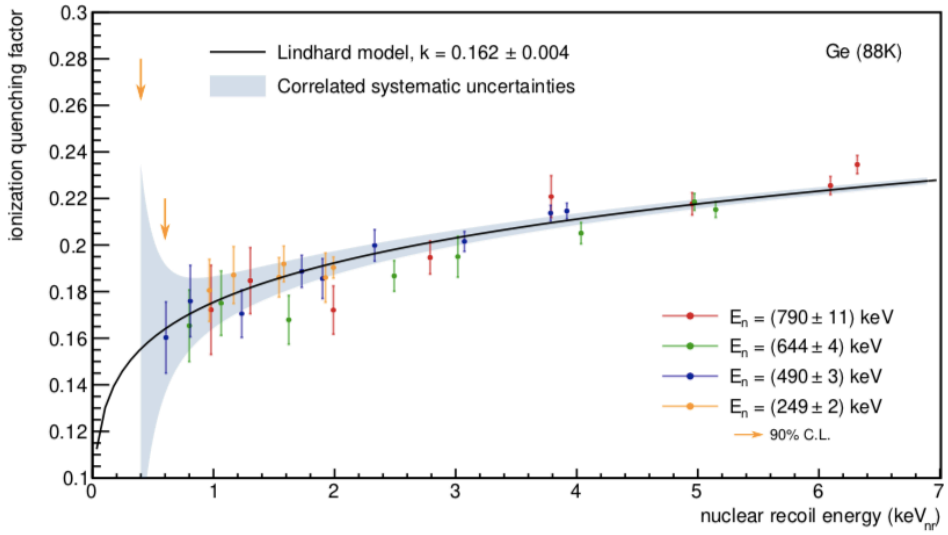
Comparison with other results

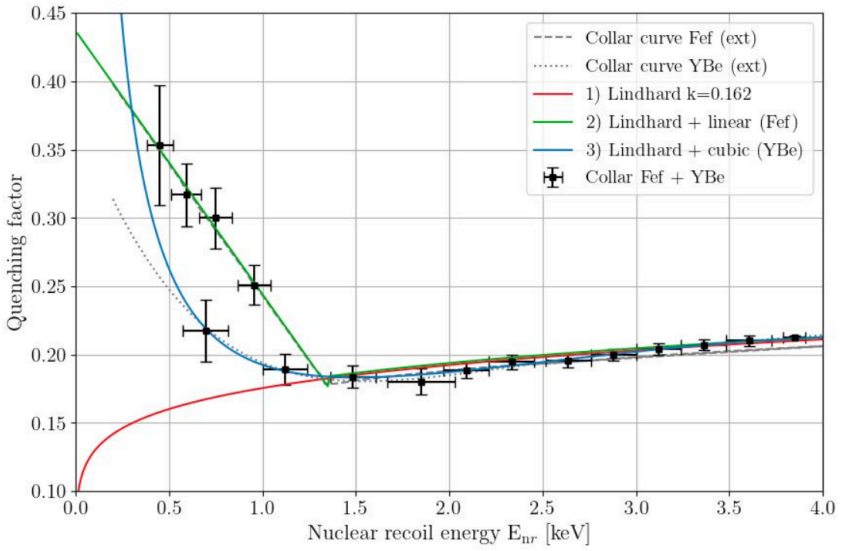


- Constraints from vGen, CONNIE, TEXONO
- Colaresi et al., PRL 129, 211802 (2022)
  - "…very strong preference…for the presence of… CEvNS…"
  - Signal prefers low energy excess compared to Lindhard quenching

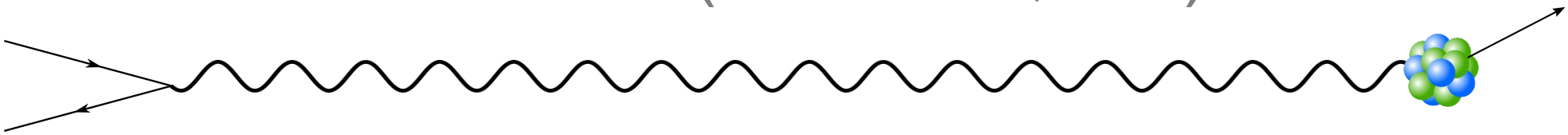


Bonhomme et al., EPJ C 82:815 (2022)

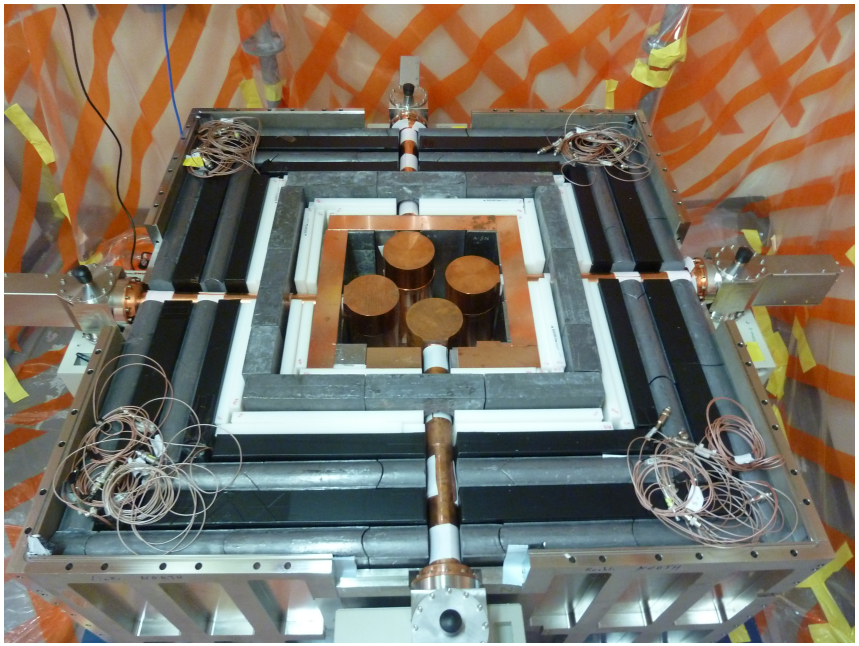




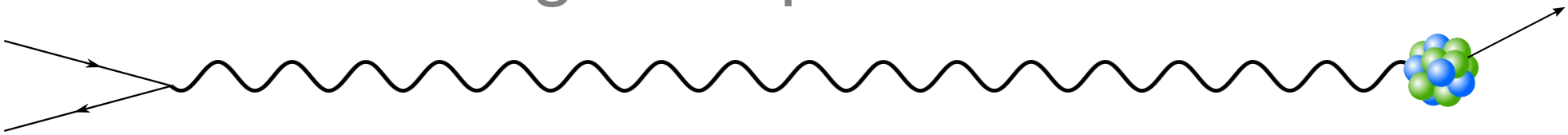
CONUS+ (Leibstadt, CH)



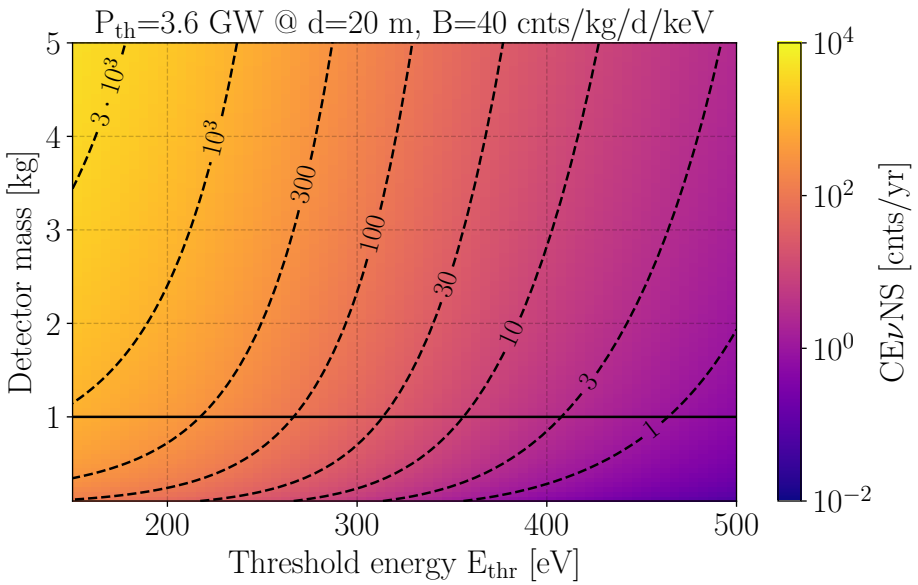
- Site characterisation (d=20.7 m): high E gamma (> 3 MeV) flux lower, neutron flux higher and less overburden (7-8 m w.e.) as KBR site
- Further improve energy resolution, detector thresholds, trigger efficiency and muon veto performance (added additional layer)
- Improved CONUS setup installed last month!



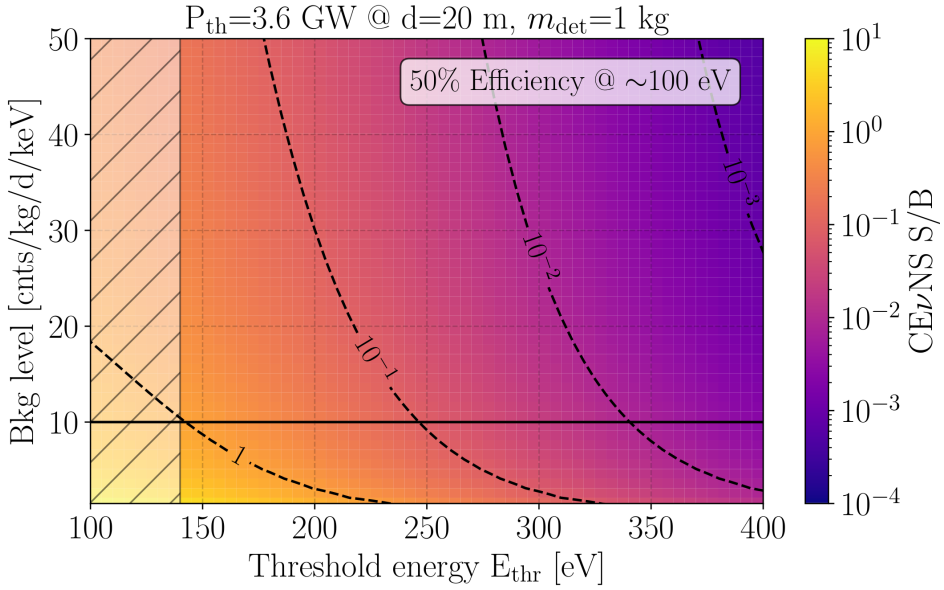
Signal expectation



Event rate per year

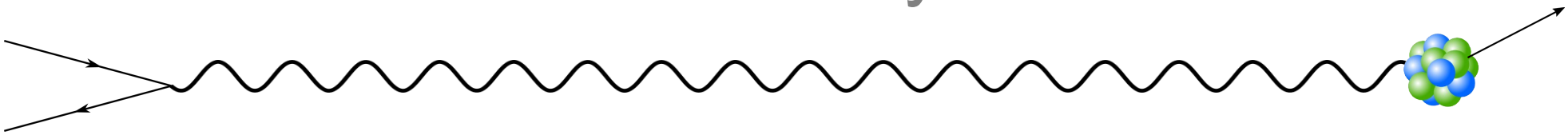


Signal to background ratio

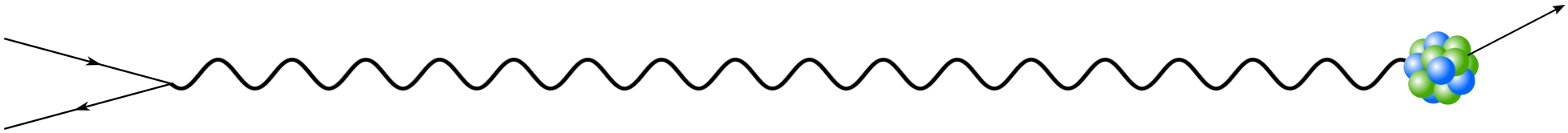


CEvNS signal might be around the corner!

Summary

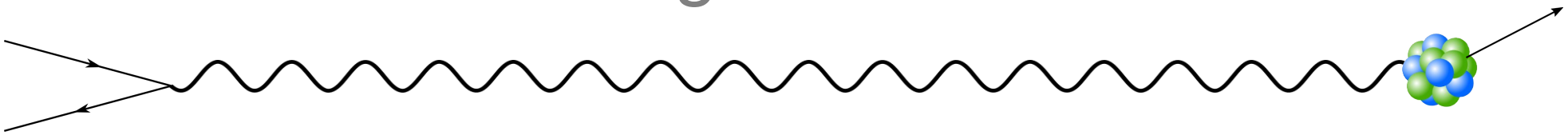


- High cross-section of CEvNS allows for compact neutrino detectors at nuclear reactors (—> reactor monitoring!)
- CONUS: Low energy threshold HPGe-detectors 17.1 m from reactor core (Brokdorf)
- Ge quenching: data consistent with predictions from Lindhard theory
- Strong constraints on CEvNS: factor < 2 above SM prediction
- CONUS+: Continue in Leibstadt (CH) with improved setup (currently in commissioning phase)

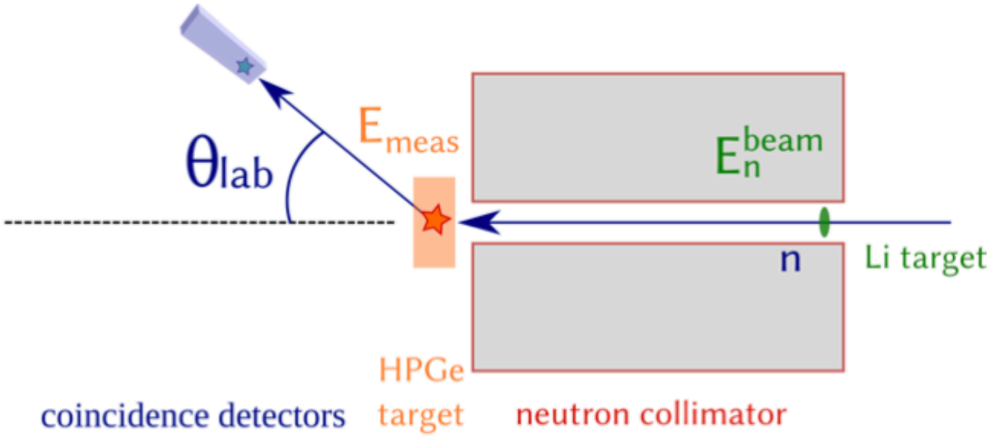


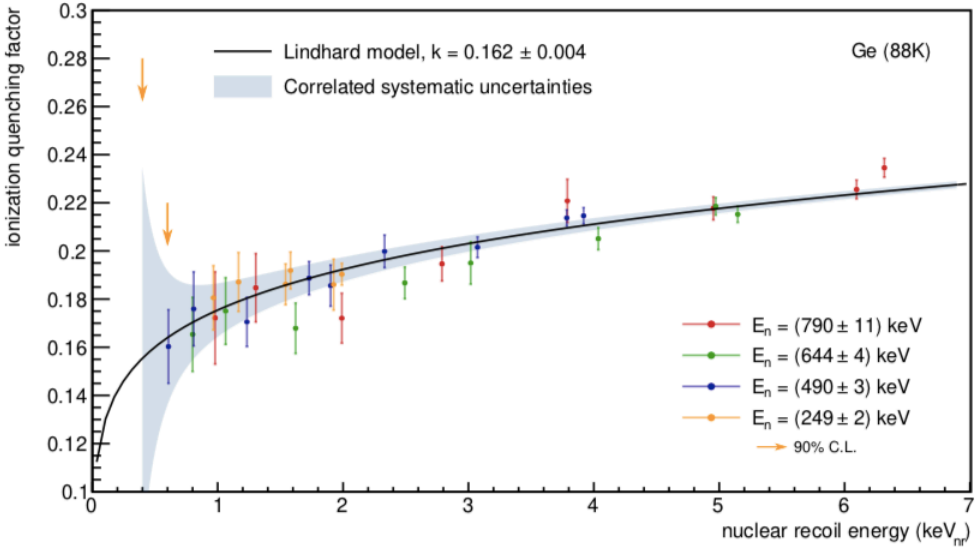
Backup

Quenching measurement



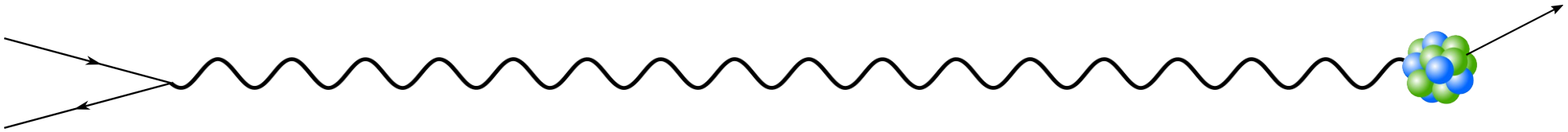
- Experimental setup (beam facility at PTB Braunschweig)
  - Model-independent method
  - Triple coincidence
  - Beam energy 250 - 800 keV
  - Angles 18-45° (1° precision)
  - Nuclear recoils 0.4 - 6 keV
- Results
  - Compatible with Lindhard theory!
  - **k = 0.162 ± 0.004** (stat.+syst.)
  - Challenge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

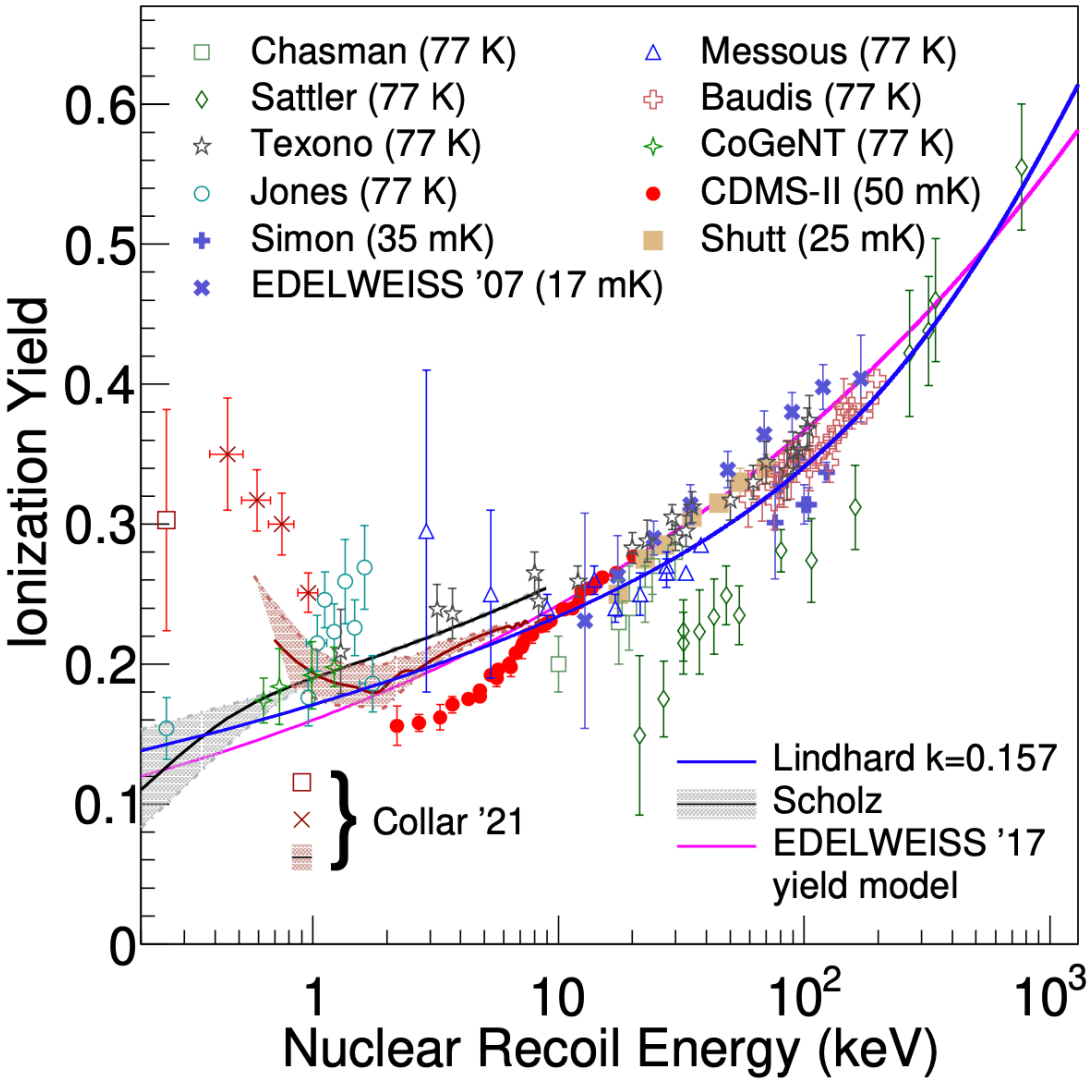




Bonhomme et al., EPJ C 82:815 (2022)

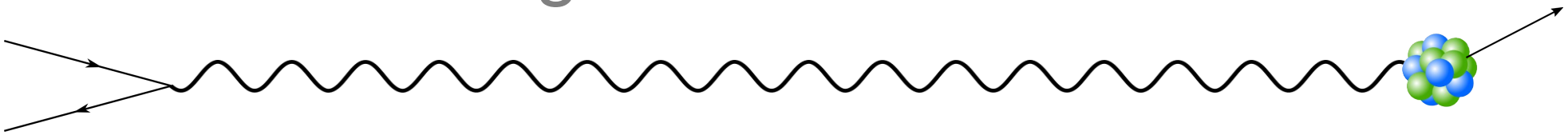
Other QF results





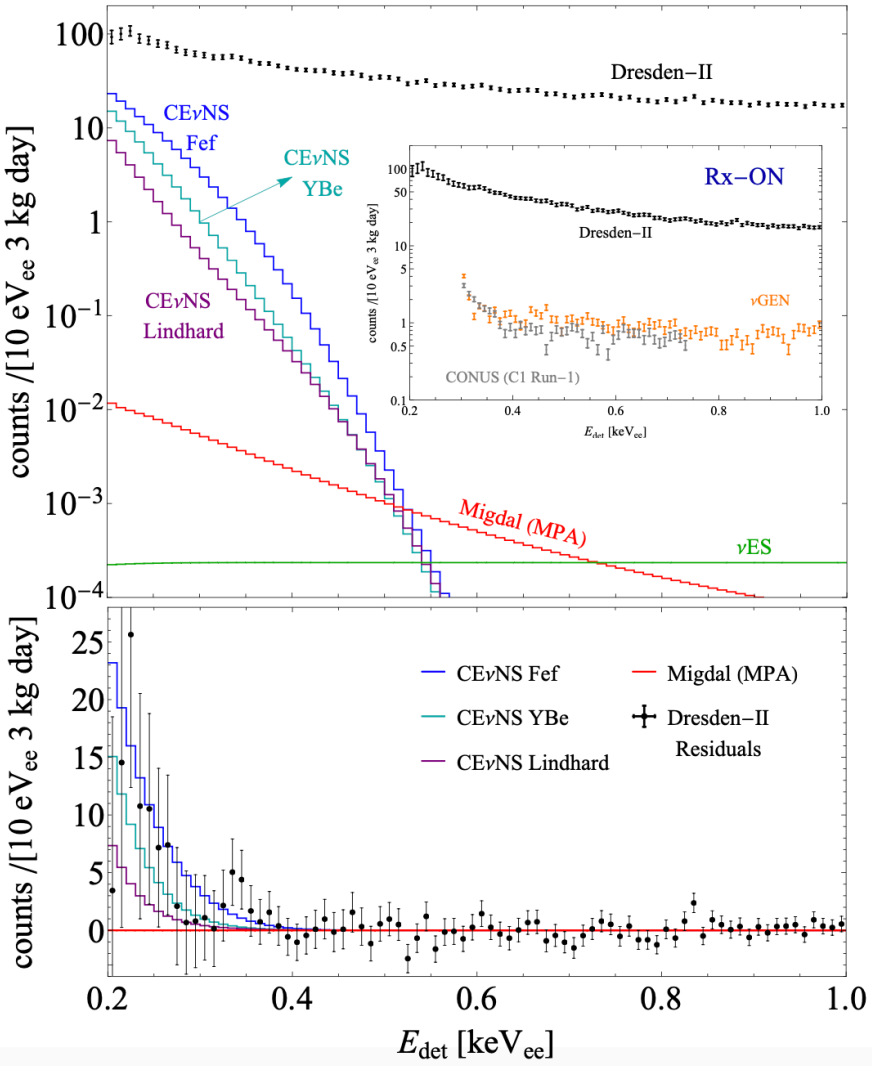
SuperCDMS, PRD 105 (2022) 12, 122002

Migdal contribution



CEvNS expectation and Migdal contribution vs reactor ON data

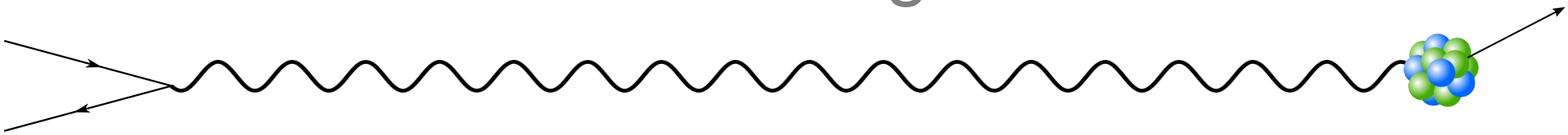
Dresden-II background subtracted



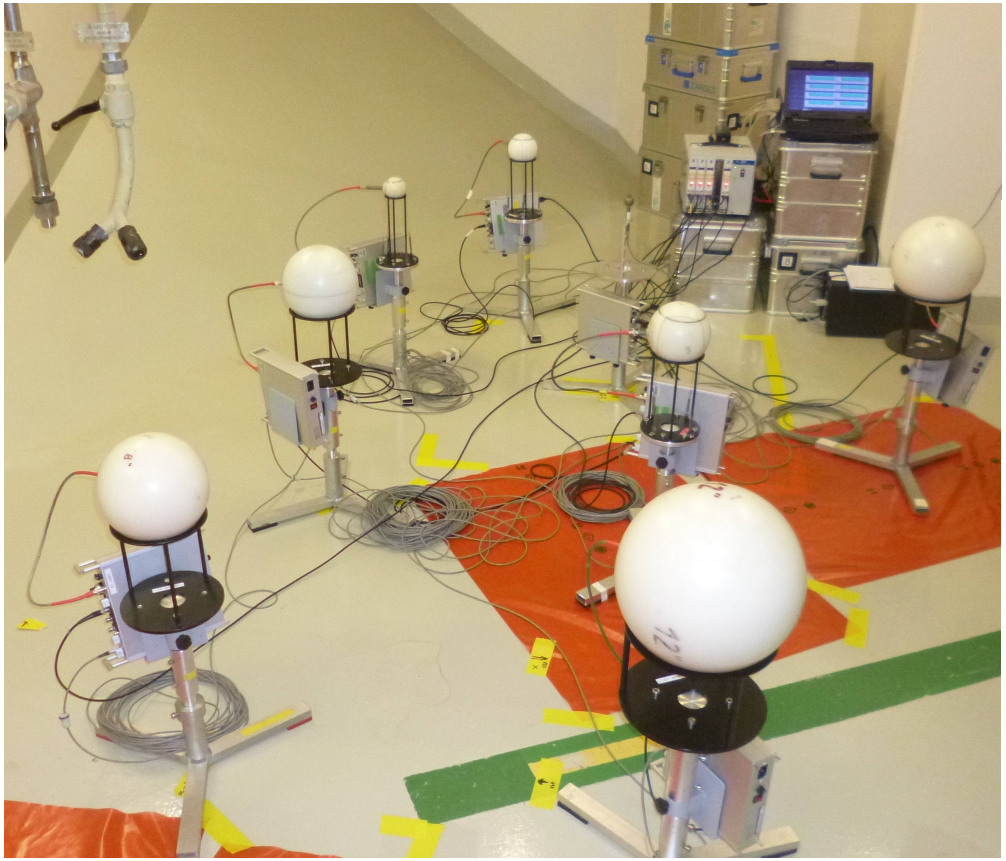
- Blue: quenching from monochromatic filtered n beam
- Cyan: prediction from photoneutron source data (YBe)
- Purple: Lindhard

M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, arXiv2307.12911 (2023)

Neutron background

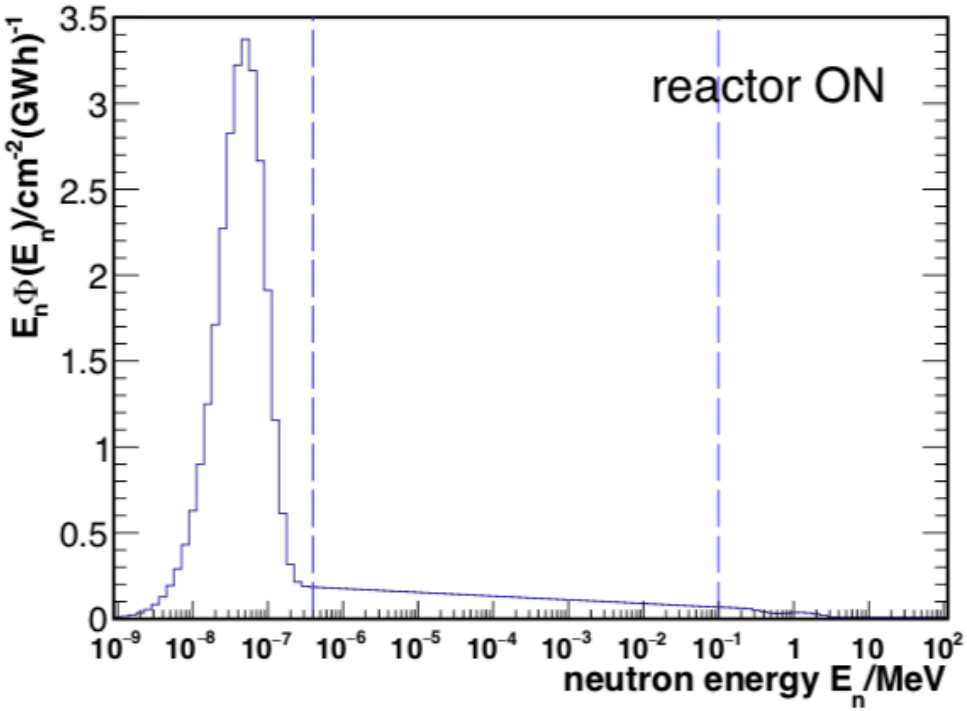


Reactor-correlated!



Campaign with Bonner spheres
(in cooperation with PTB)

- Neutron flux in CONUS room suppressed by factor >10^{20}
- 80% of neutron flux is thermal



CONUS, Eur. Phys. J. C (2019) 79:699