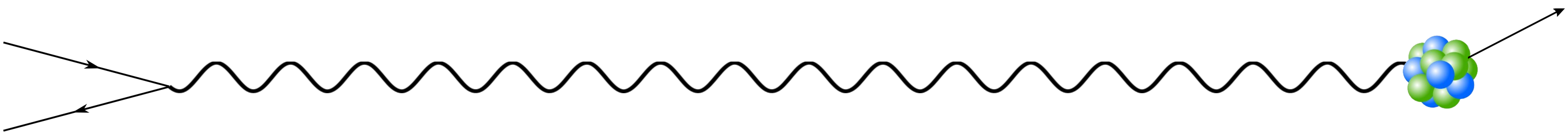
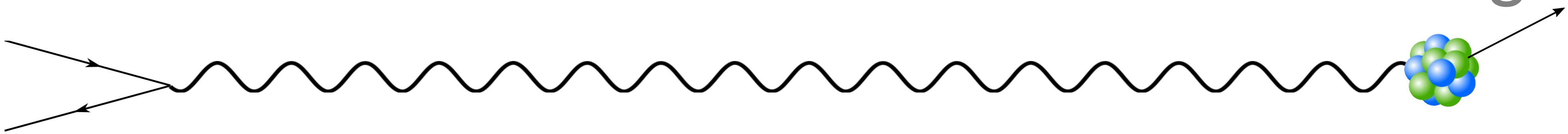
The CONUS Reactor Neutrino Experiment

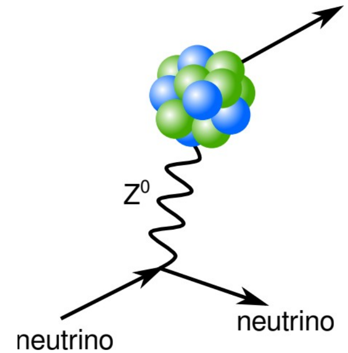


Christian Buck (on behalf of the CONUS collaboration)
Max-Planck-Institut für Kernphysik, Heidelberg
7.KAT Strategietreffen, 04.12.2020

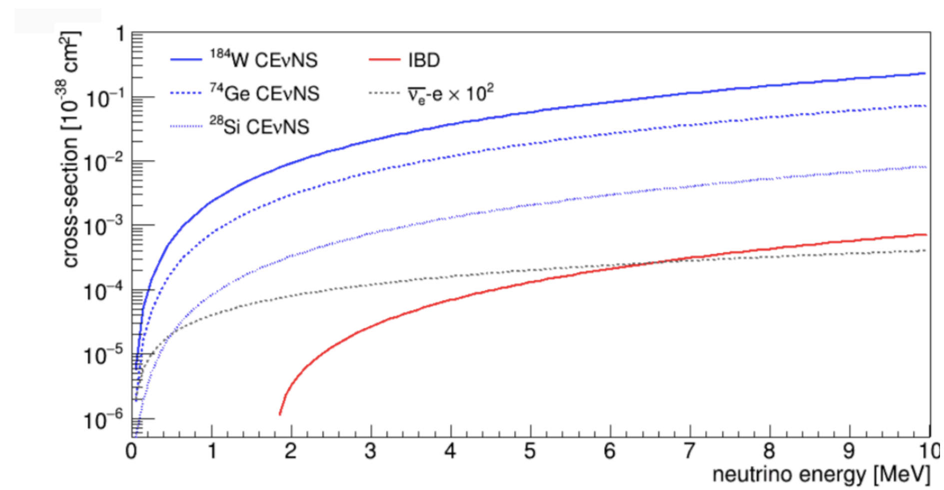
Coherent Elastic Neutrino Nucleus Scattering



- Predicted 1974 (D. Freedman et al.)
- Measured 2017 (COHERENT exp.)
- High cross section ~ N^2
- E^{max} (recoil) ~ $1/m_N$
- Most favorite sources: spallation sources or nuclear reactors



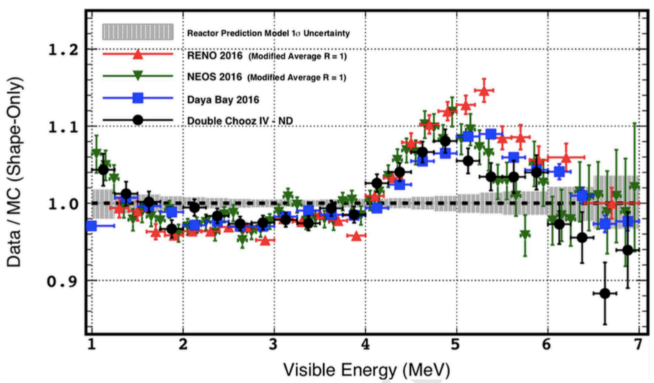
CEvNS



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

Potential

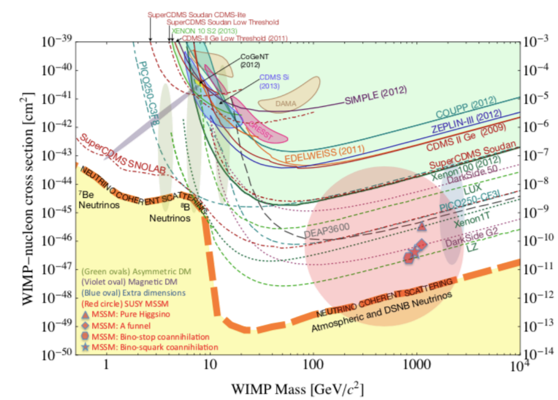
Reactor neutrinos



Double Chooz, Nature Phys. 16 (2020) 5, 558-564

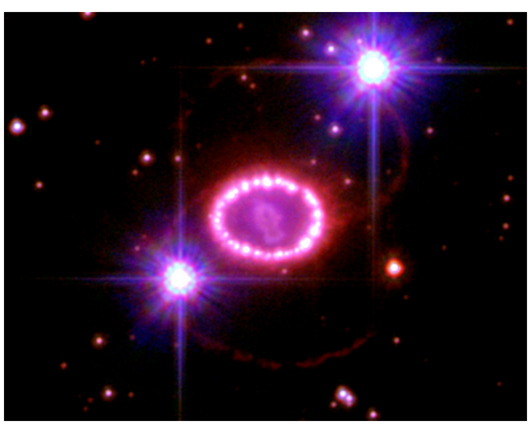
Nuclear structure

Dark Matter



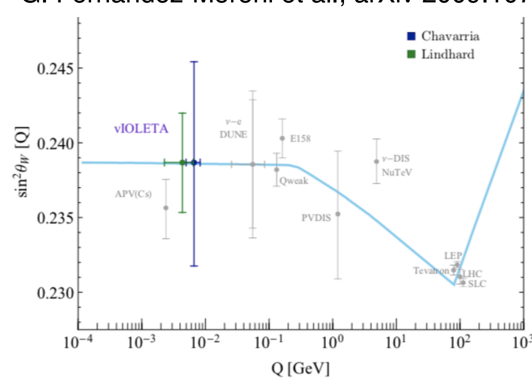
P.Cushman et al., arXiv 1310.8327

CEvNS



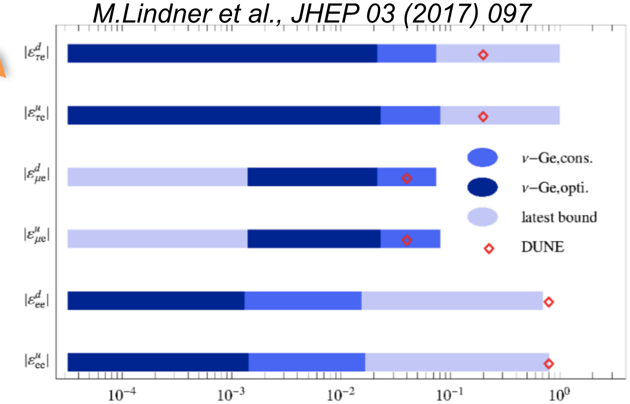
Supernova

G. Fernandez-Moroni et al., arXiv 2009.10741



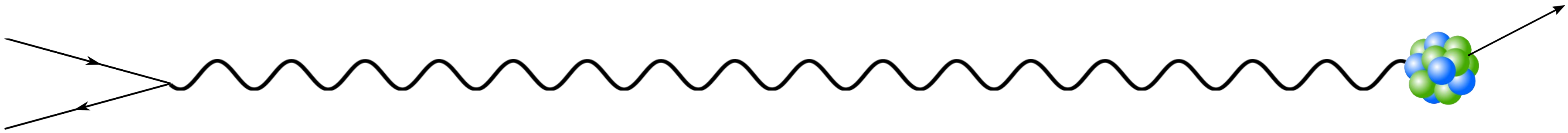
Weak mixing angle

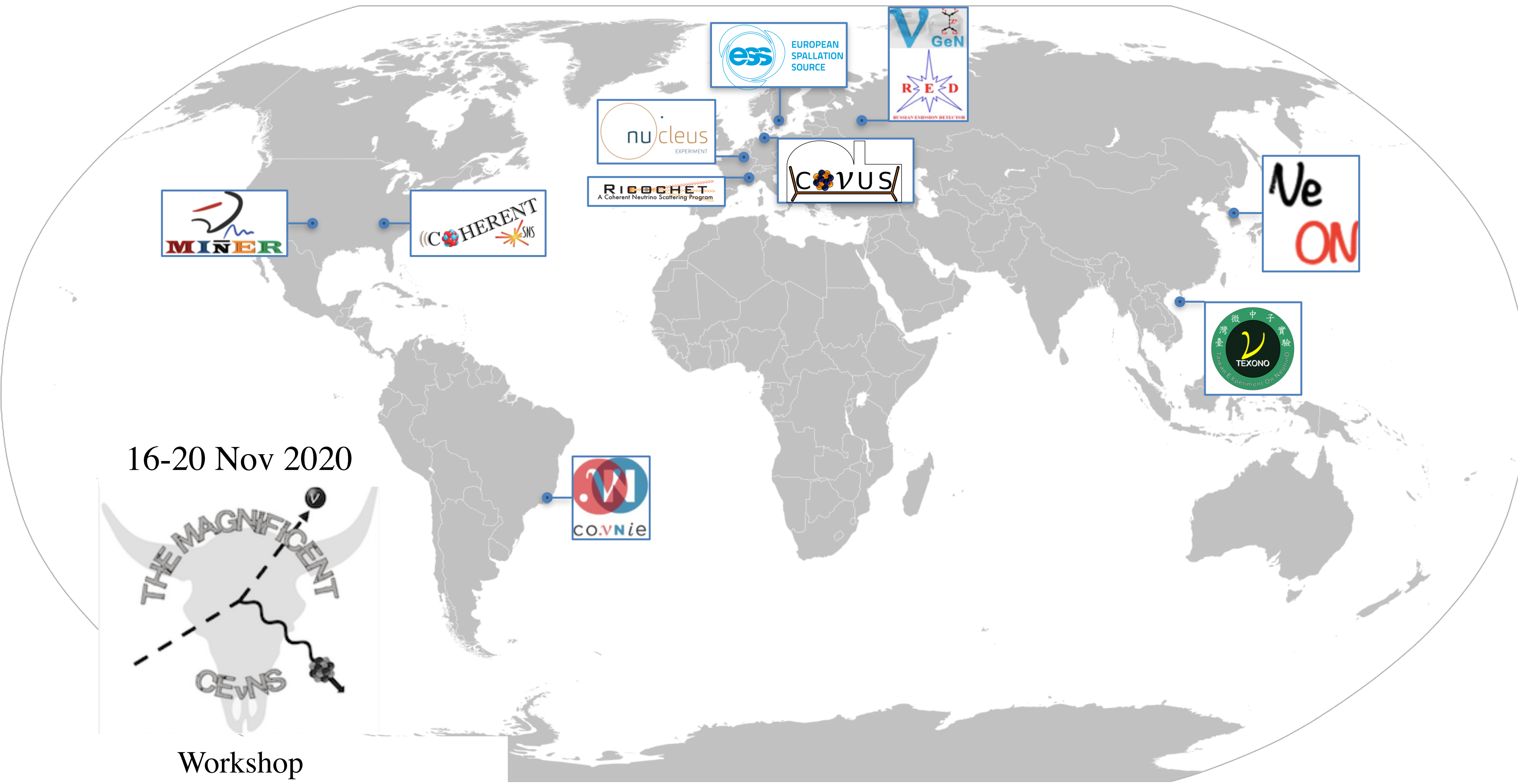
M.Lindner et al., JHEP 03 (2017) 097



BSM: NMM, NSI, light mediators (ALPs),…

CEvNS Worldwide

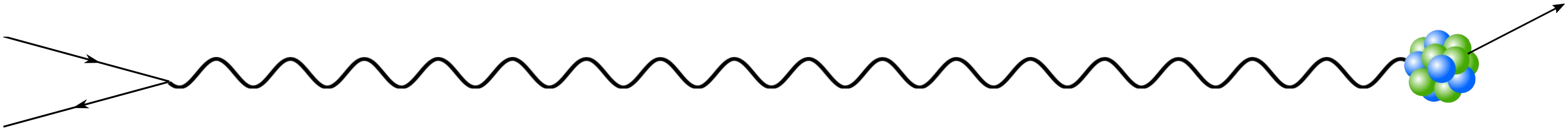


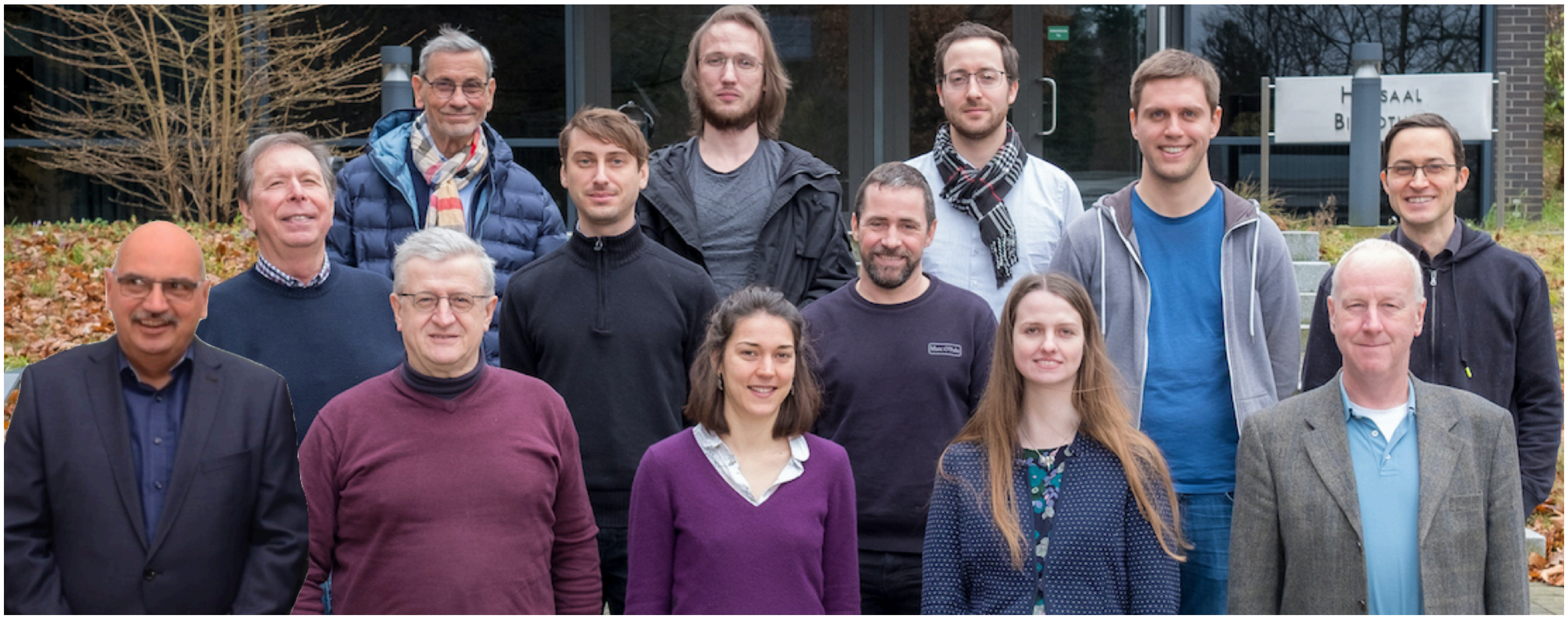


16-20 Nov 2020

Workshop
258 participants
https://indico.cern.ch/event/943069/

CONUS Collaboration





MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Preussen Elektra

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

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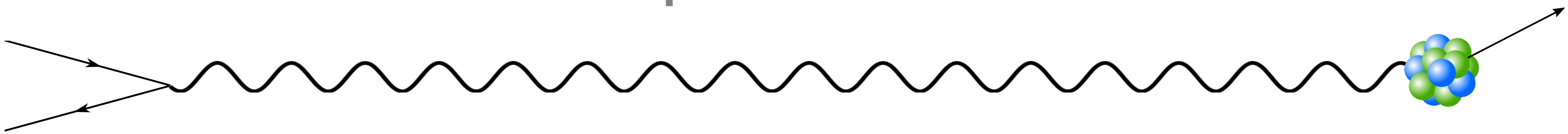
Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR), Brokdorf

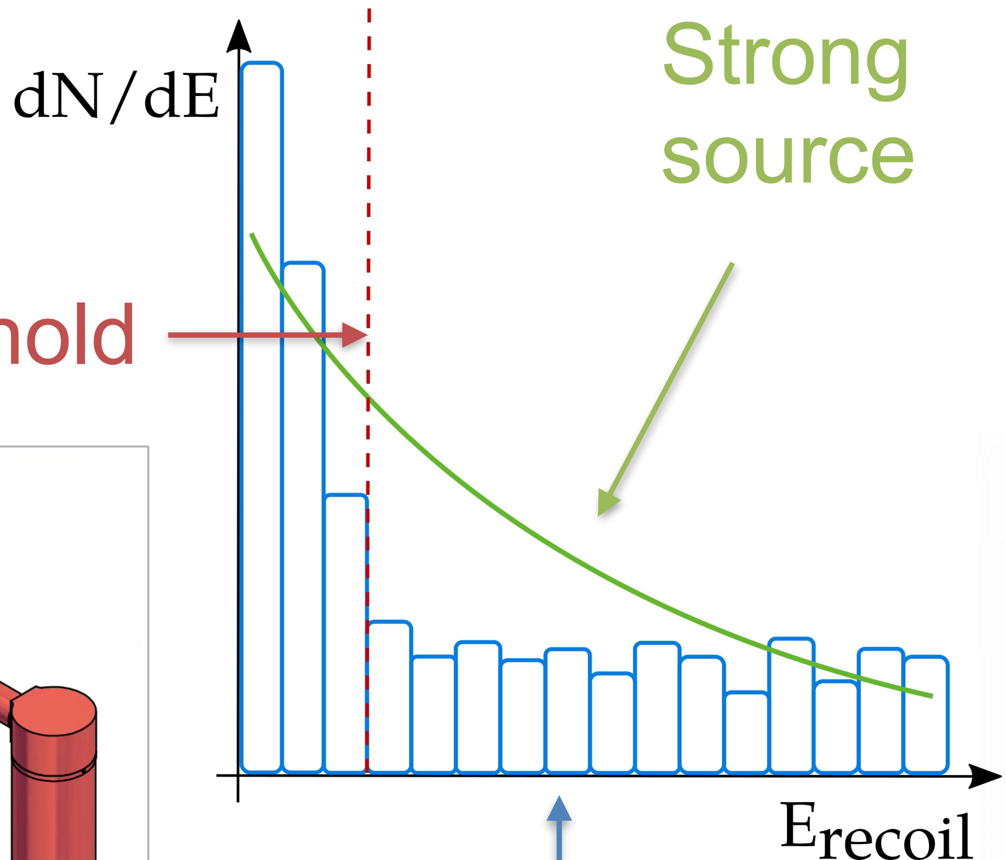
Requirements

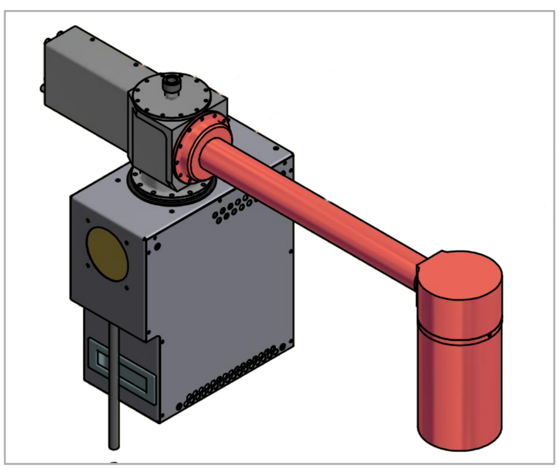


Nuclear power plant (Brokdorf, KBR)

Strong source

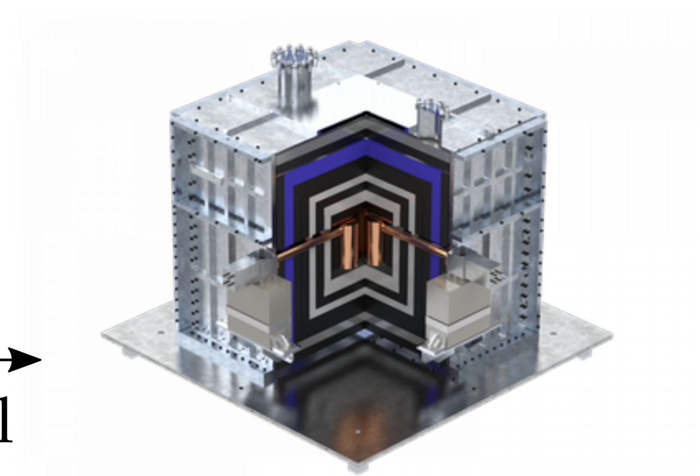
Low threshold





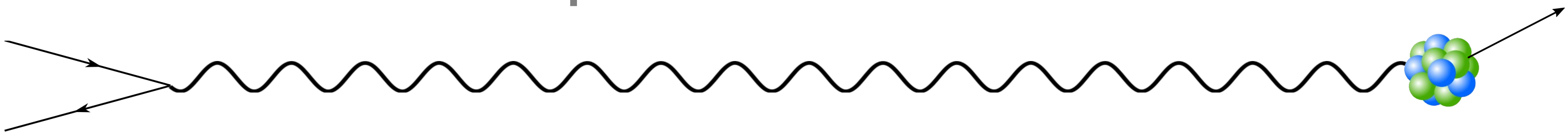
Point contact HPGe spectrometer

Low background

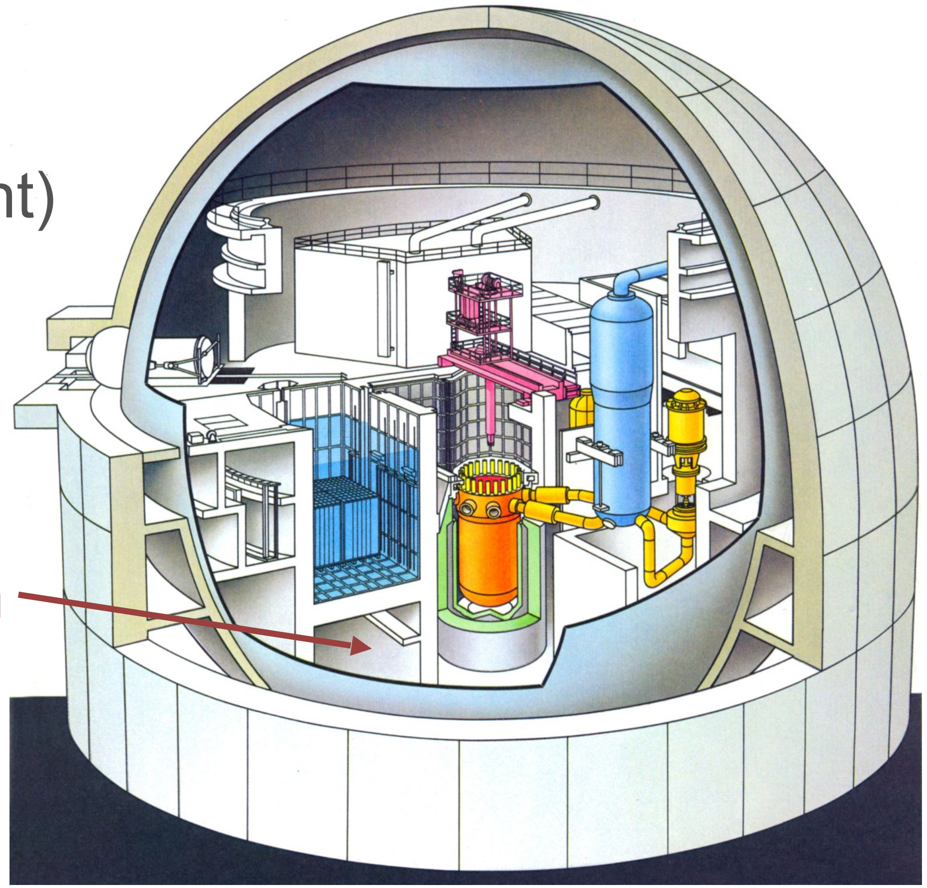


Shield (shallow depth)

Experimental Site



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



CONUS location

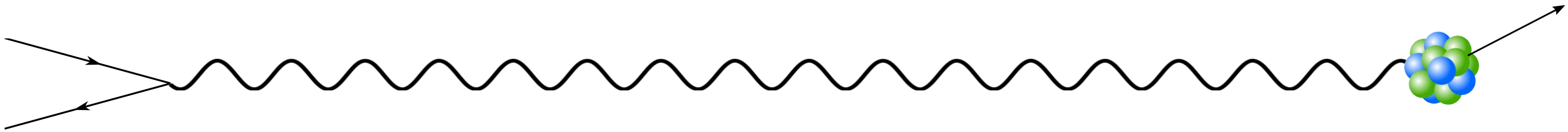
KBR Brokdorf:

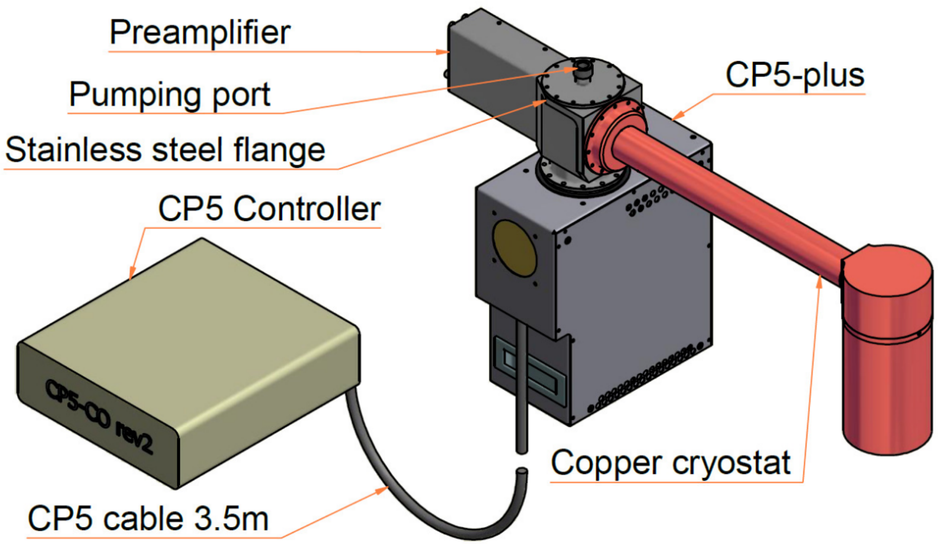
- 3.9 GW thermal power
- Distance 17.1 m
- OFF time ~1 m/y
- Antineutrino energy < 10 MeV

==> **fully coherent**

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

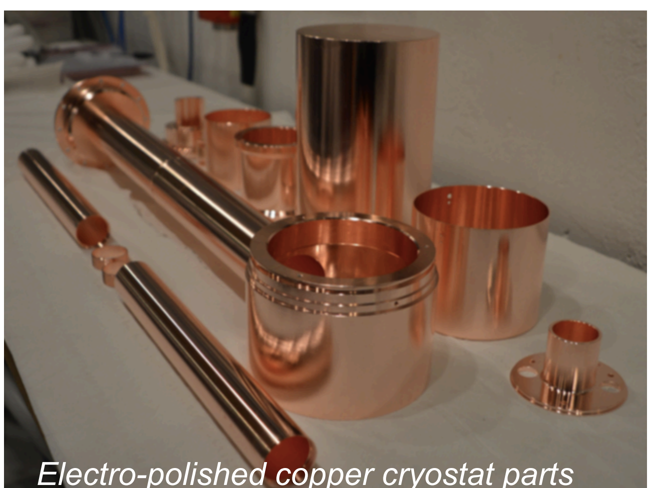
Detectors



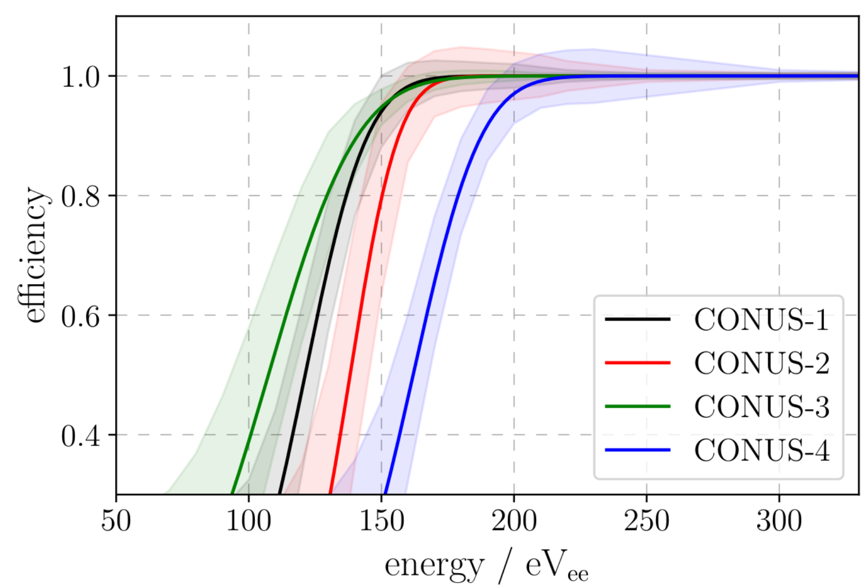


4 p-type HPGe detectors:

- Total active mass: 3.73 kg
- Pulser resolution < 80 eV
- Efficiency ~1 above 200 eV
- Electrical cooling

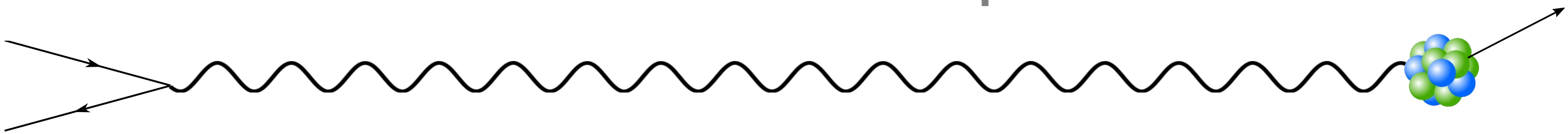


Electro-polished copper cryostat parts

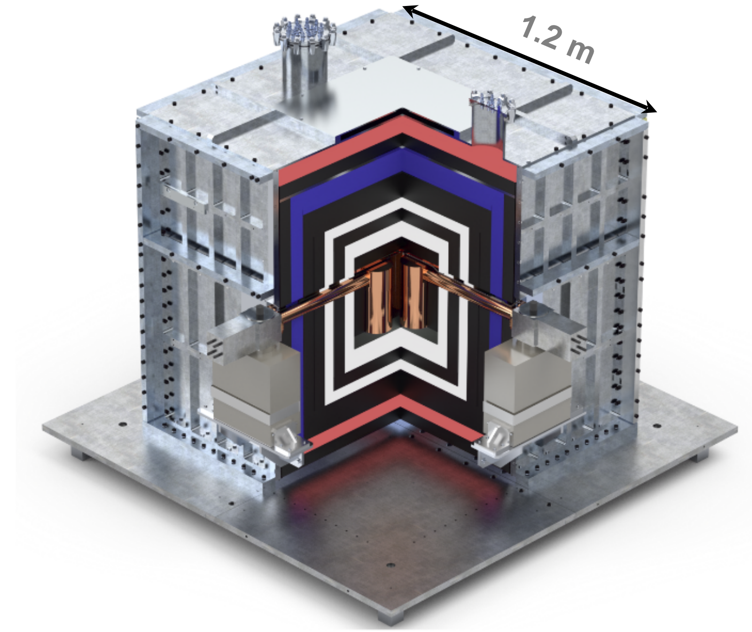


CONUS, arXiv:2010.11241

CONUS setup

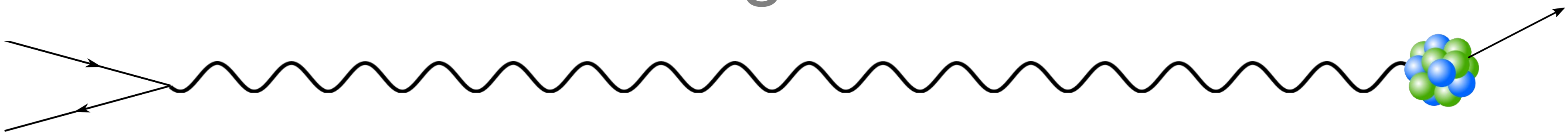


- Design basis: GIOVE (MPIK)
- V = 1.65 m^3, m = 11 tons
- Low radioactivity lead (Pb)
- Borated PE (n moderation + capture)
- Active muon veto (~97% rejection)
- Construction, commissioning and installation: ~2y

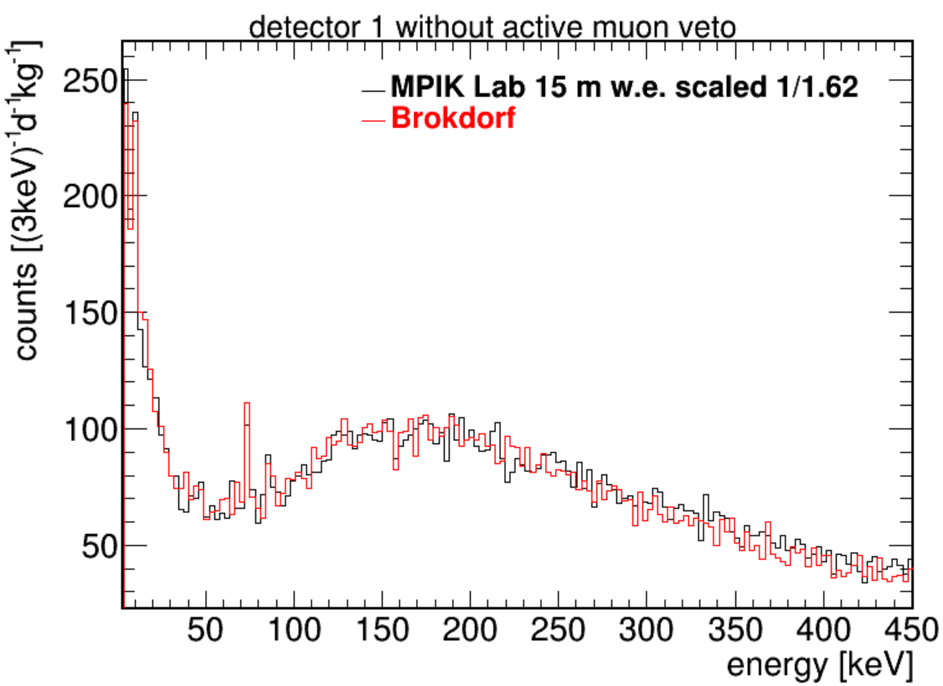


Radon removal:
Flush with air bottles

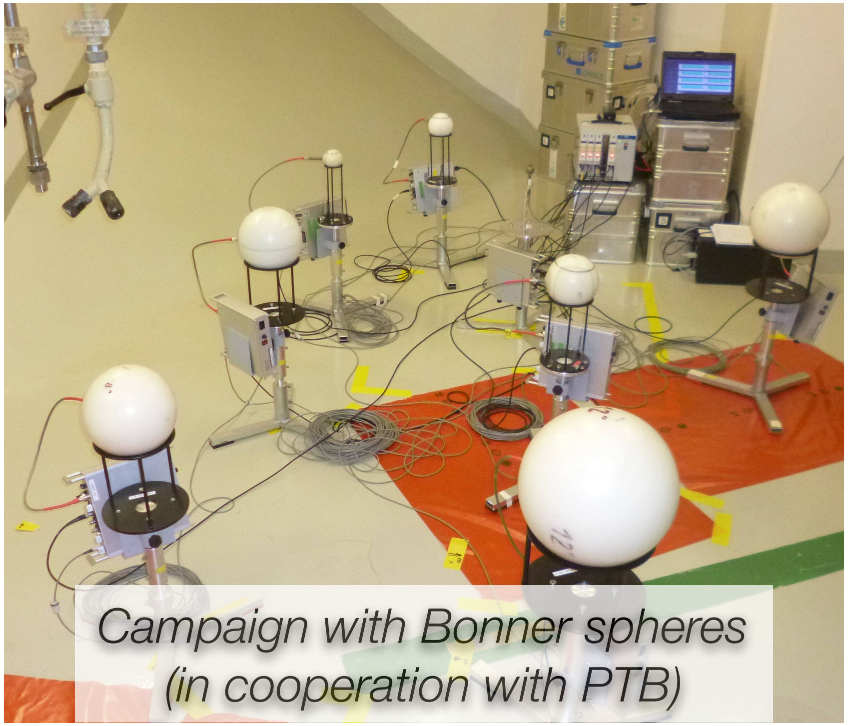
Background



- Background suppression: ~10^4
- Rate 0.5-1 keV: ~10 dru
- Bg spectrum well understood (MC + commissioning @ MPIK)



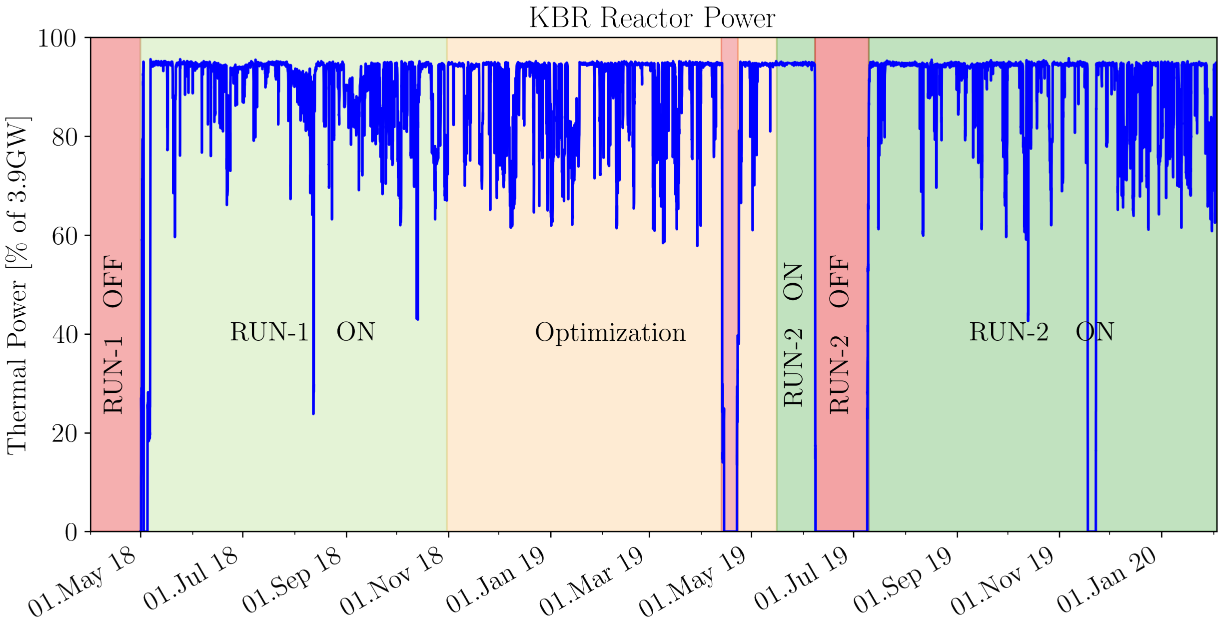
Reactor-correlated: neutrons



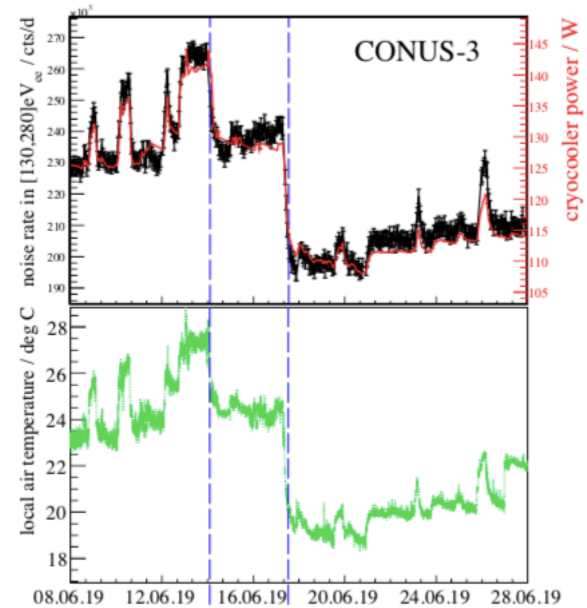
- Neutron flux in CONUS room suppressed by factor >10^{20}
- 80% of neutron flux is thermal

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

Data Selection



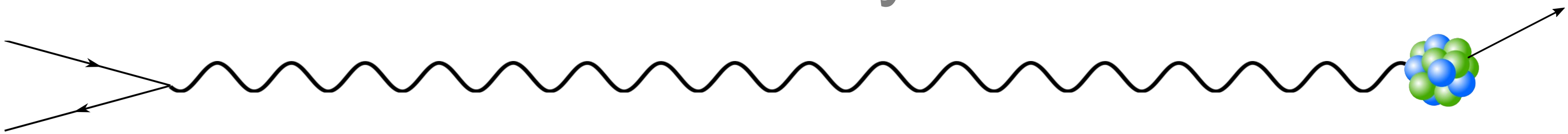
Correlations: T, cooler P, noise



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	

ROI definition:
- Trigger efficiency ~100%
- No rate-temperature correlation
- Electronic noise to background MC < 4

Data Analysis



Reactor spectrum

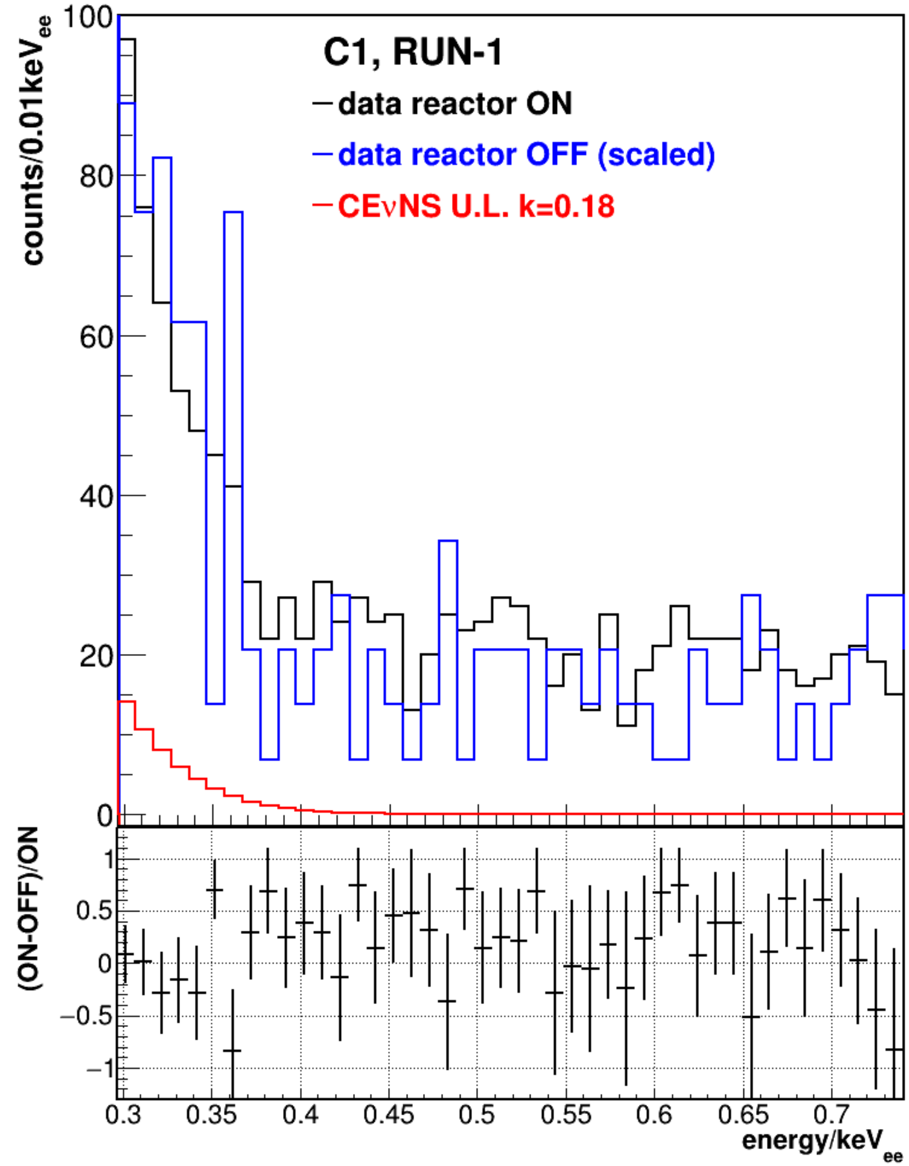
- Thermal power evolution
- Fission fractions (Pu/U isotopes)
- Huber/Mueller + Daya Bay

Background description

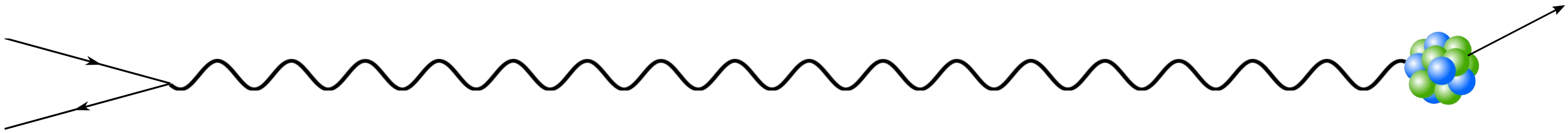
- MC modelling
- Exponential fit for electronic noise

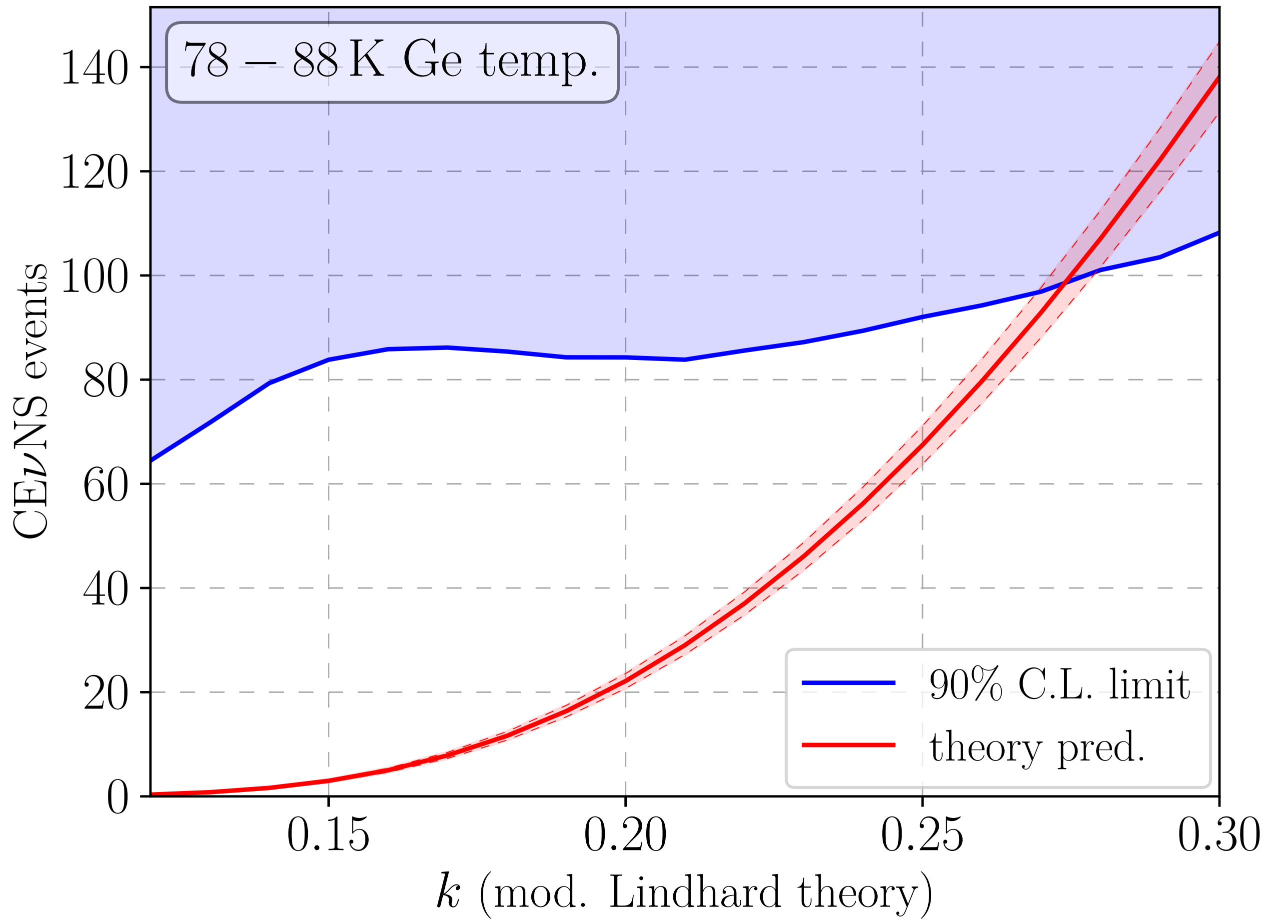
Likelihood

- Simultaneous fit ON/OFF (all detectors and runs)
- Scan over signal parameter
- 3 free bg parameters + pull terms



Best CEvNS Limit at Reactor

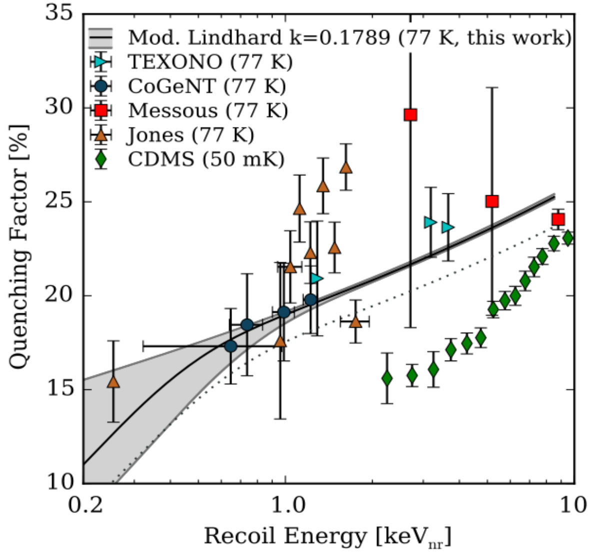




For k = 0.18 < 0.34 ev/(d kg): factor 7 above prediction

CONUS, arXiv:2011.00210

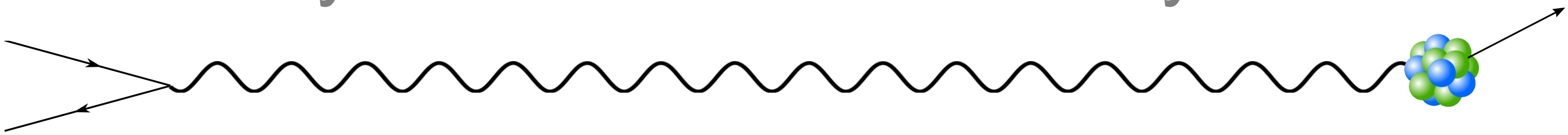
Quenching ?!

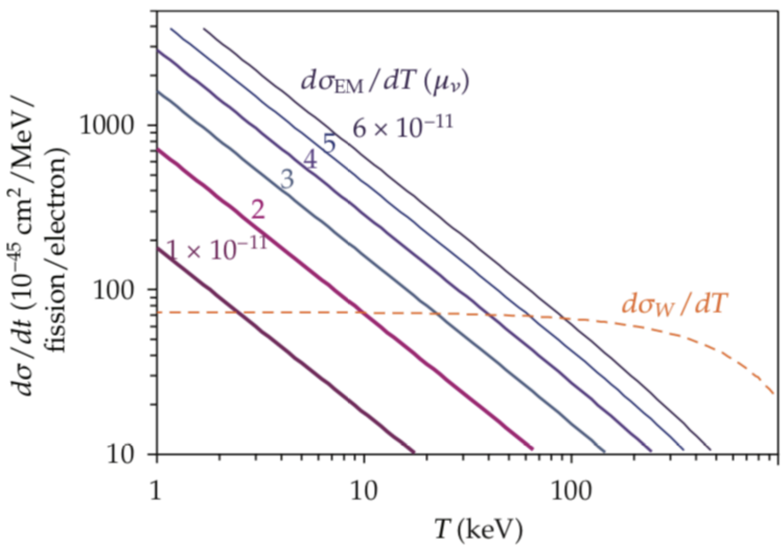


Scholz et al, PRD 94, 122003 (2016)

Quenching k > 0.27 disfavored from CONUS data

Beyond Standard Model Physics

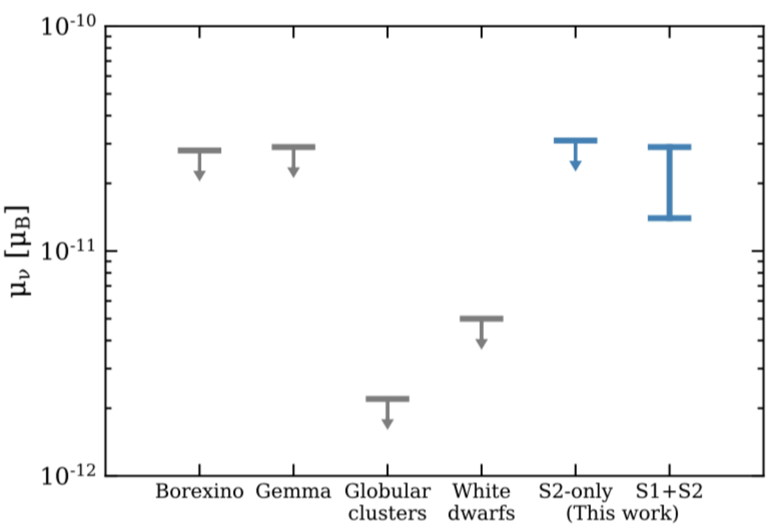




GEMMA Coll., Adv.High Energy Phys. (2012) 350150

Neutrino magnetic moment

	GEMMA	CONUS
μ (90% CL)	$< 2.9 \cdot 10^{-10}$	analysed
Ge mass	1.5 kg	3.73 kg
P_{th}	3 GW	3.9 GW
Distance	13.9 m	17.1 m
E range	2.8 - 55 keV	~0.5 - 8 keV
Background	~2 dru	< 10 dru
OFF statistics	280 kg d	~59 kg d

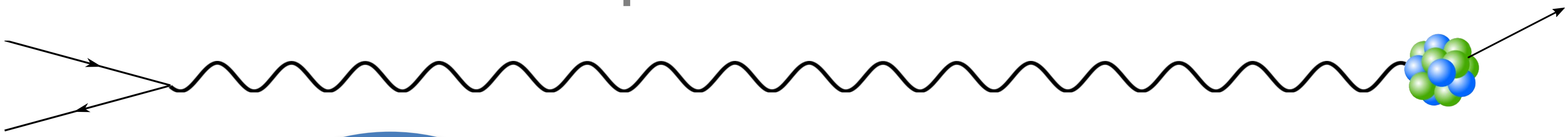


XENON Coll., *Phys.Rev.D* 102 (2020) 7, 072004

More BSM:

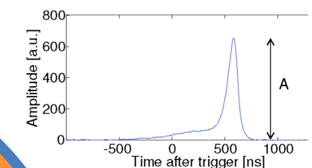
- Non-standard interactions
- Light mediators
  - New scalars (e.g. ALP)
  - Vector mediators (e.g. dark photons)
- ….

Improvements



Statistics

- Additional off periods in 2019/2020
- Reactor stop end of 2021 —> 1 year OFF in 2022



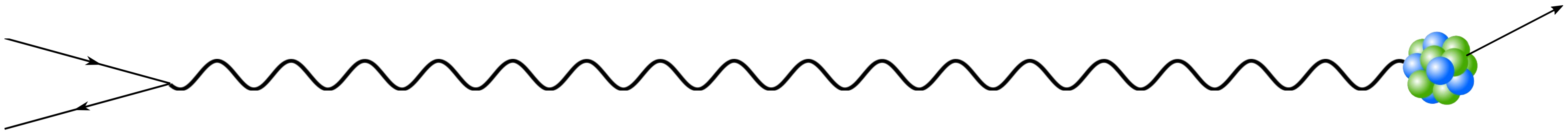
Background

- DAQ upgrade with PSD capability
- Optimize Rn removal
- More MC studies

Stability

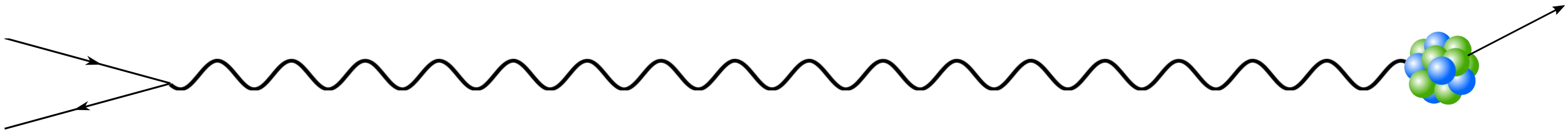
- Constant T in tent
- Impact on noise level
  - Less cuts
  - Lower threshold

Towards CONUS-100?



- Scalable: more detectors and/or larger mass
- Multiple setups: different distances from source
- Further design improvements on detectors and shield under study
- Other technologies: combine different detectors (GeMMC, scintillating crystals,…)
- Sources: nuclear reactor or ESS

Conclusions



- Strong efforts worldwide to detect and study CEvNS
- 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)

CONUS, arXiv:2010.11241

- Good background control/modeling

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

- Best constraints on CEvNS at reactor reported

CONUS, arXiv:2011.00210

- Improvements planned (long OFF time next year)
- BSM studies underway