THE CONUS+ EXPERIMENT

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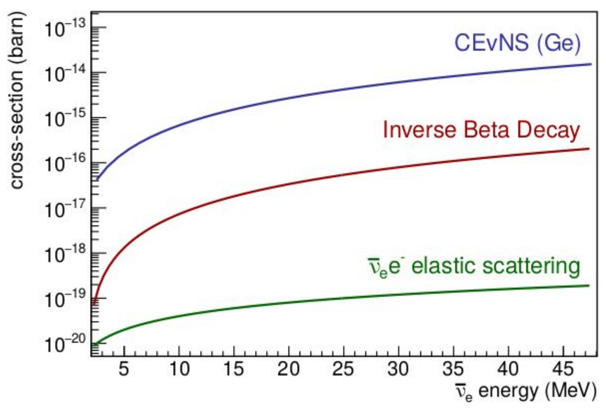
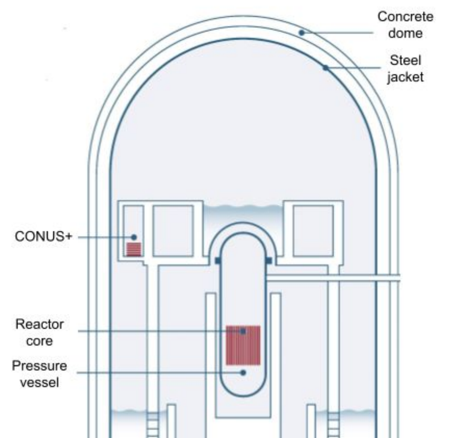
EPISODE I: CONUS+ new experimental location

The CONUS+ experiment aims to detect coherent elastic neutrino-nucleus scattering (CEνNS) of reactor antineutrinos on Ge nuclei.

One distinctive aspect of this process lies in its notably high cross section when compared to other neutrino interactions typically used in neutrino experiments.



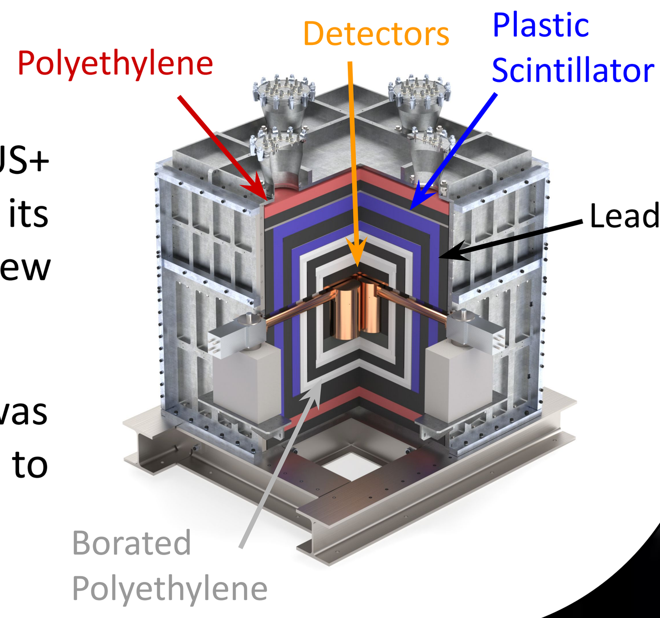


Since November, 2023, the CONUS+ detector is operational at the nuclear power plant in **Leibstadt (KKL), Switzerland. It is placed at 20.7 m from the 3.6 GW reactor core.**

The CEνNS experimental signature is a nuclear recoil, which is measured by **4 p-type point-contact (PPC) high purity germanium detectors (HPGe), with an active mass of 0.94 kg each.**

In order to maintain low background levels, the CONUS+ detector employs an onion-like shield adapted from its predecessor (CONUS) and optimized the new background conditions at KKL.

An extensive background characterization campaign was performed prior to the detector installation, in order to find the best location for the experiment.

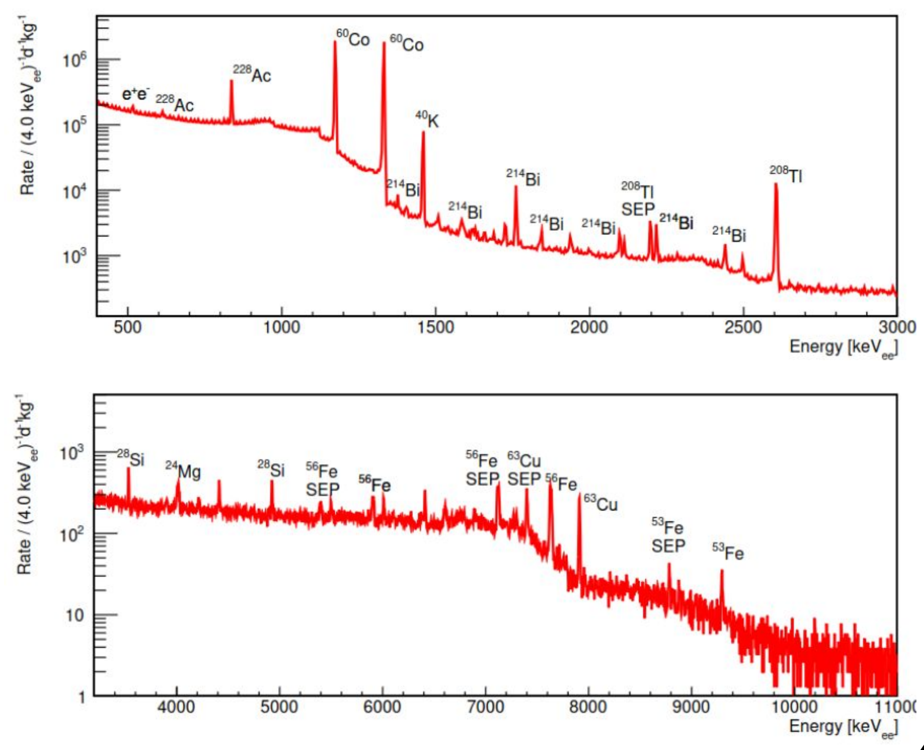


EPISODE II: Reactor correlated γ-ray background

The γ-ray background was studied with the HPGe detector CONRAD [1], previously used in the CONUS location at the Brokdorf power plant (KBR).

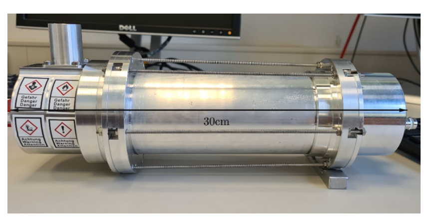
The spectrum below 2.7 MeV is dominated by natural radioactivity. At high energies lines up to 10 MeV are observed, produced by neutron capture reactions.

The rate over 2.7 MeV is reduced 26 times compare to CONUS due to the larger distance from the ^{16}N produced in the reactor cooling cycle [2].



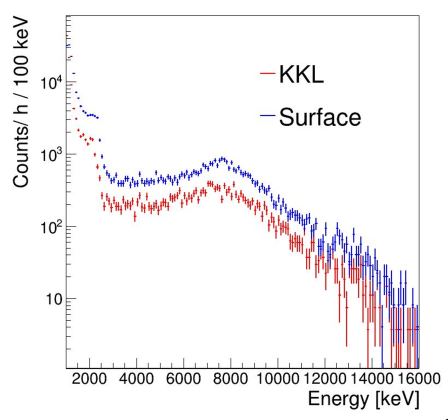
EPISODE III: Muon-induced neutron background

Since CONUS+ has a small overburden a large cosmic-ray flux is expected, which can produce neutrons in the shield and the structural materials of the reactor.



The muon flux was evaluated with a 120 ml liquid scintillator detector which allowed to measure muon tracks up to 15 MeV.

The muon flux is reduced 1.9 times at KKL respect to surface, equivalent to an **average overburden of 7.4 m water equivalent** [3]. At this depth, the number of muon-induced neutrons in Pb is **2.3 times larger than in KBR (24 m w. e.).**

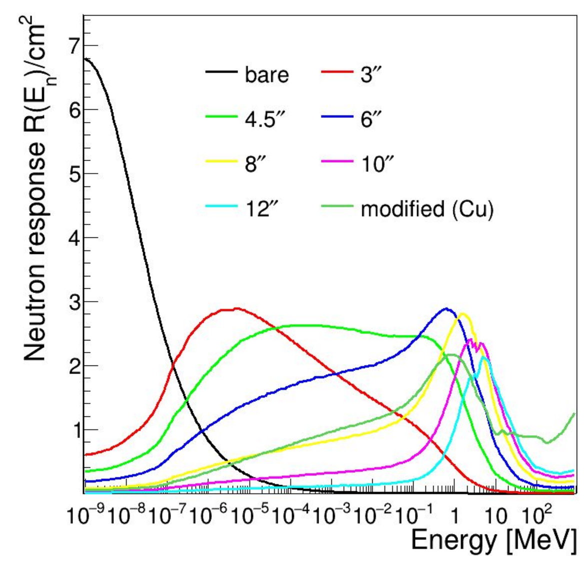


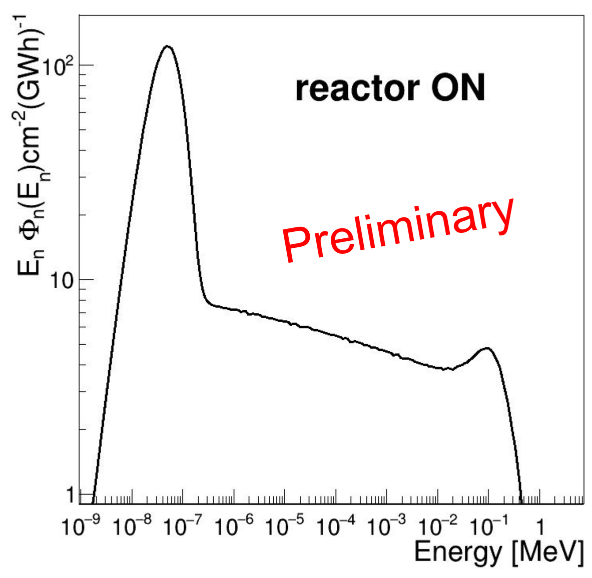
EPISODE IV: Reactor correlated neutron background

The neutron spectrum was directly measured in the CONUS+ position using a Bonner sphere Spectrometer (BSS) in scientific cooperation with the Paul Scherrer Institute (PSI).

The neutrons are detected with spherical proportional counters, filled with 2.3 bar of ^{3}He, through the reaction:

$$n + {}^3He \rightarrow {}^3H + p + Q, \text{ with } Q = 764 \text{ keV}.$$





The BSS consisted of one bare counter and a set of counters embedded in polyethylene spheres with diameters ranging from 7 to 30 cm.

The measurement during reactor ON revealed a **reactor correlated neutron flux in the room 40 times stronger than in KBR.**

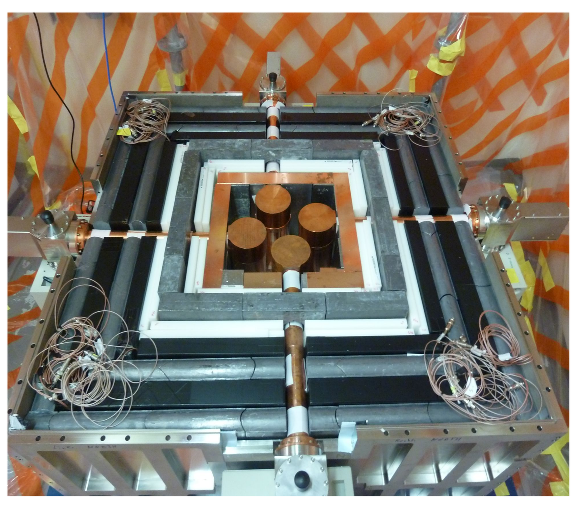
However, GEANT4 simulations proved that reactor correlated neutrons are **still negligible for the CONUS+ background.**

EPISODE V: Installation and detector performance at Leibstadt nuclear power plant

The original CONUS shield setup was dismounted at KBR and moved to the KKL. An extensive wipe test campaign proved that the radiopurity of the shield-detector was preserved.

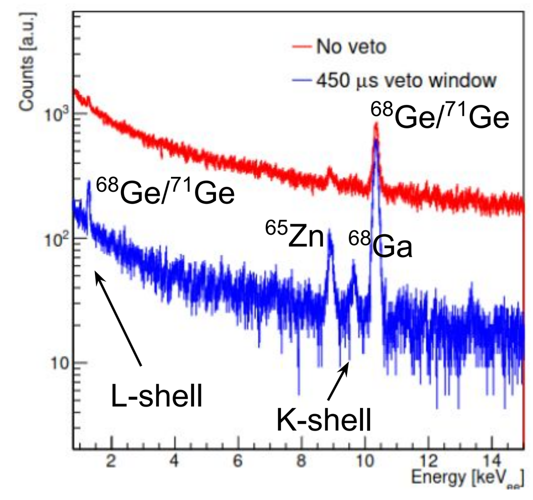
Due to the higher muon rate and lower amount of high-energy γ-rays, **one of five Pb layers was replaced with an additional muon veto system**.

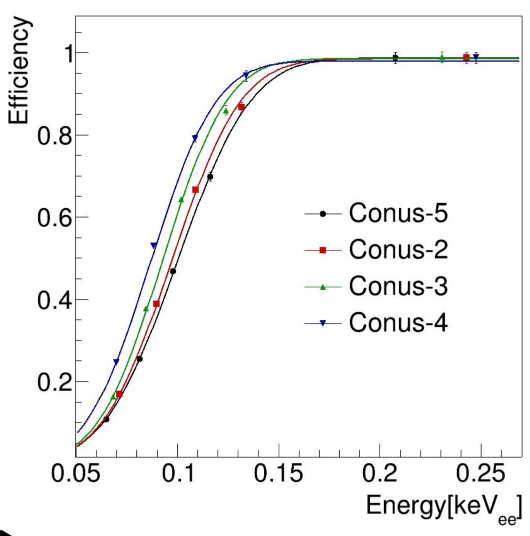
At KKL, real-time monitoring of the experiment is possible through a direct network connection from KKL to MPIK.



The energy threshold is define individually for each detector. **A preliminary value of 150 eV$_{ee}$ is obtained for CONUS+, improving by 60 eV$_{ee}$ the previous threshold of CONUS.**

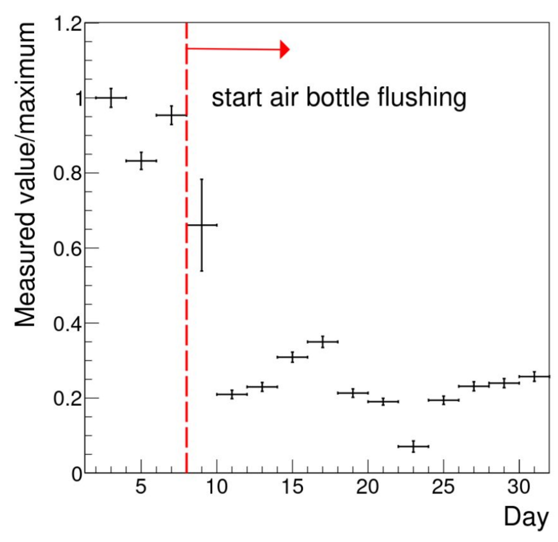
The background is primarily dominated by prompt muon-induced events without veto. **After applying a veto window of 450 µs, over 99 % of the background events are rejected in the [0.15-1] keV$_{ee}$ energy range**, reaching similar background levels like in CONUS.





The HPGe detectors used by CONUS (C1-C5) were refurbished with a new ASIC pre-amplifier, allowing for an **improvement of the trigger efficiency and a pulser resolution < 50 eV.**

The HPGe cooling system was modified to reduce the observed vibrations produced by the cryocooler in CONUS. The 2-fan system was replaced by a water chiller, strongly reducing the noise variations with the temperature.



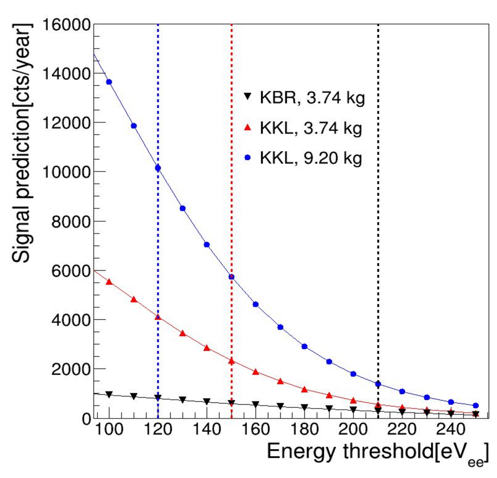
Environmental stability is crucial for the experiment. In particular, the radon concentration level in the CONUS+ room has a concentration of 120 Bq/m^3 with fluctuations up to 80 Bq/m^3 over time.

Because of this, the detector chamber is flushed with a radon-free air system, suppressing the radon contribution and reducing the activity in the [100-400] keV$_{ee}$ energy range.

EPISODE VI: Signal prediction and CONUS+ phase-2

The number of expected CEνNS events is estimated for CONUS and CONUS+ using the corresponding detector and reactor parameters. In both cases the assumed quenching model is Lindhard with k=0.164±0.04 [4].

The signal predictions in CONUS+ increases almost one order of magnitude as compared to the last run of CONUS, due to the different detector improvements.

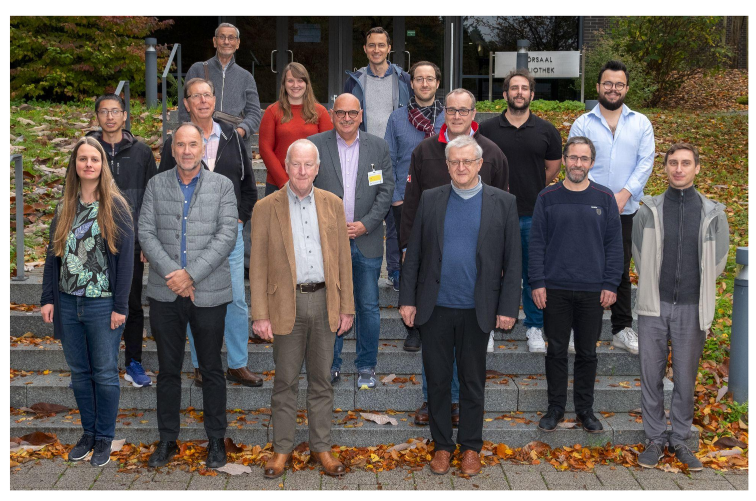


Detector	Signal [cts/day/det]
CONUS	0.19
CONUS+	1.60
CONUS+ phase-2	6.94

An **additional upgrade is planned for the CONUS+** experiment, replacing the current **1 kg HPGe diodes with new 2.5 kg detectors.**

Assuming an energy threshold of 120 eV the expected signal will increase 4 times.

CONUS+



Preussen Elektra

KKL Kernkraftwerk Leibstadt

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

[1] J. Hakenmüller and G. Heusser. Appl. Radiat. Isot., 2023.

[2] J. Hakenmüller et al. Eur. Phys. J. C, 2019.

[3] G. Heusser. Nucl. Instrum. Methods Phys. Res., 1993.

[4] A. Bonhomme et al. Eur. Phys. J. C, 2022.