The CONUS+ experiment

On behalf of the CONUS+ Collaboration

Max-Planck-Institut für Kernphysik Heidelberg

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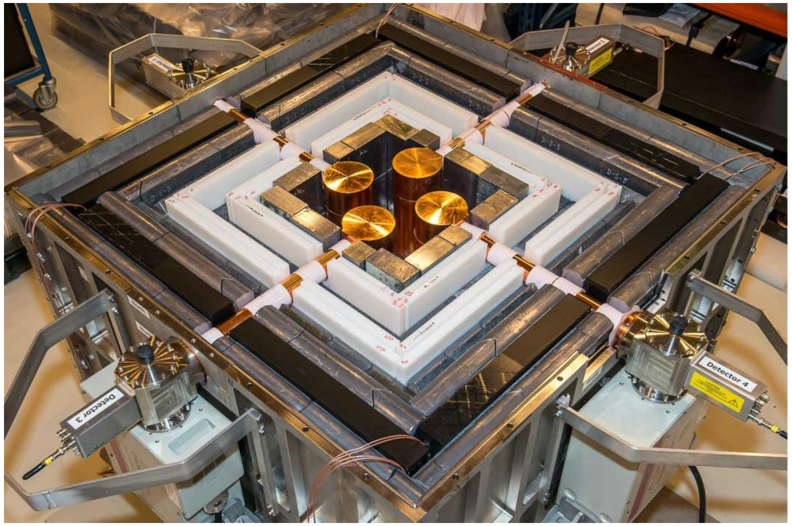
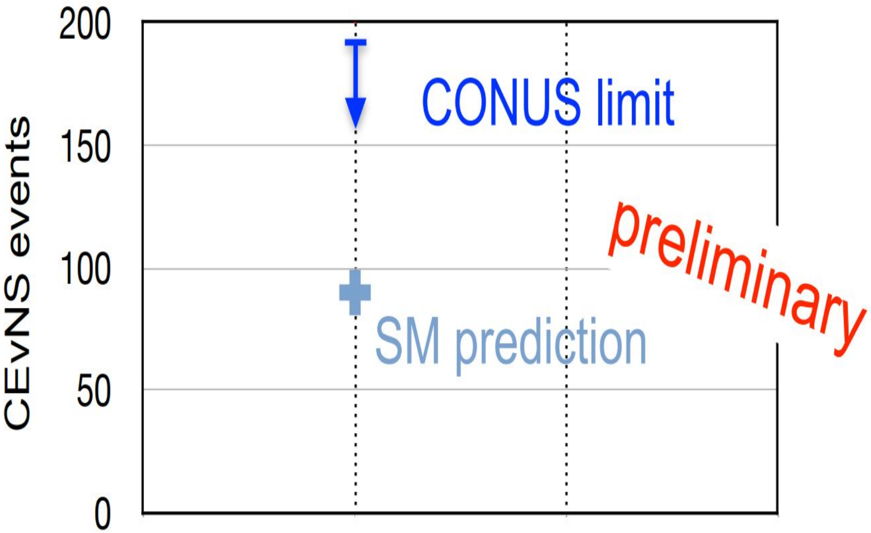
COνUS+

Magnificent CEvNS (Munich), March 2023

The CONUS experiment

- CONUS detector operated in Brokdorf nuclear power plant (Germany) from 2018 to 2022.
- It provides best CEvNS limit at reactor up to date:
  <u>Factor 2 over SM prediction with k=0.162±0.004.</u>
- W. Maneschg talk on Wednesday for more details.
- However, the Brokdorf nuclear power plant stopped its operation at the end of 2021 …





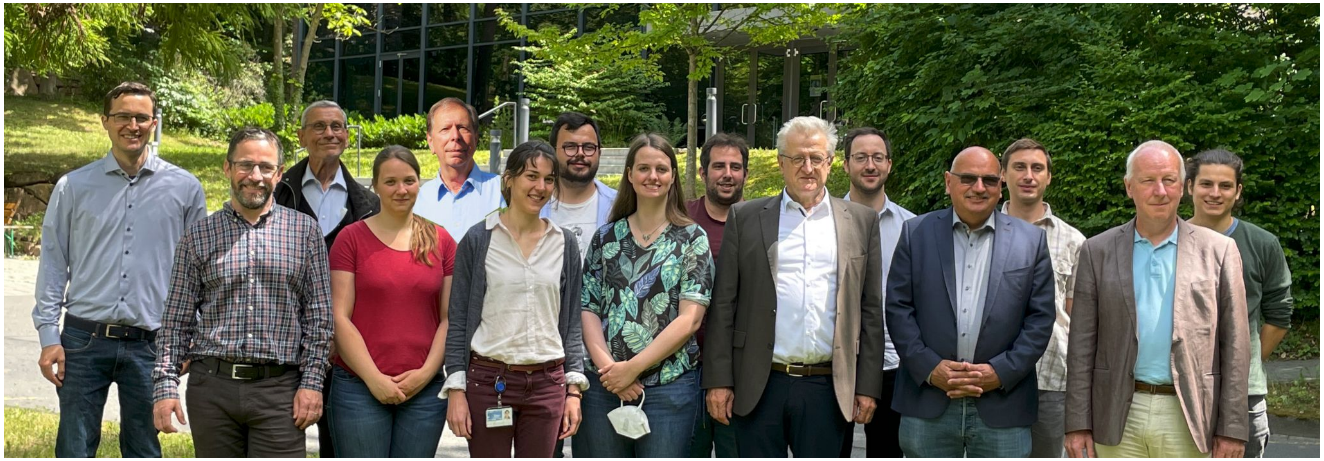
The CONUS+ experiment

CONUS+ is going to be installed in the Leibstadt nuclear power plant (KKL) in Switzerland during summer 2023.

Experimental conditions:

- 20.7 m from 3.6 GWth reactor core → high antineutrino flux expected $1.45 \times 10^{13} \bar{\nu}_e \, s^{-1} cm^{-2}$.
- High duty-cycle: 1 month/year of reactor-off.
- Shallow-depth site (7-8 m w.e.).

CONUS+ Collaboration



Max Planck Institut für Kernphysik (MPIK)

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

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Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR)

K. Fülber and R. Wink

Preussen Elektra

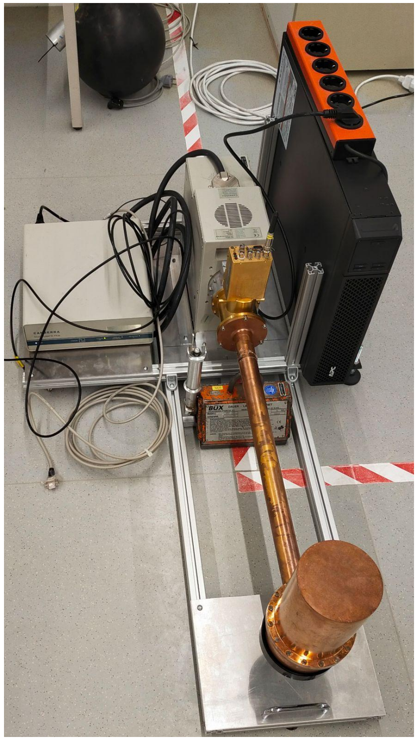
Kernkraftwerk Leibstadt

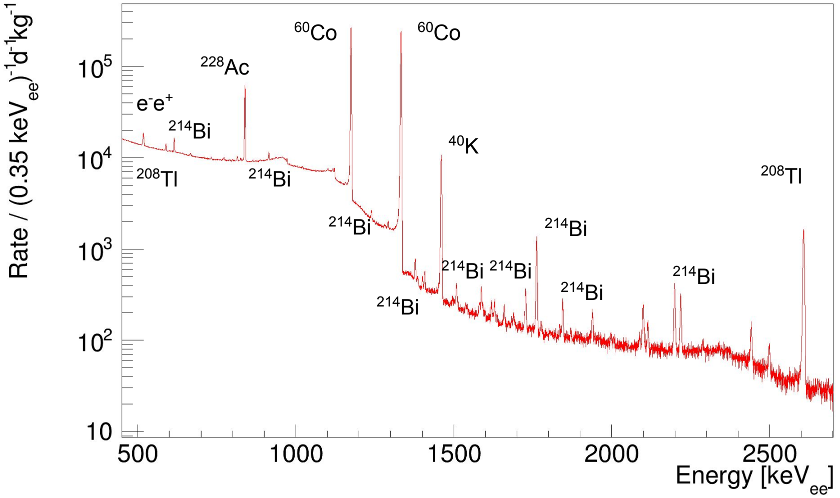
Leibstadt AG , Kernkraftwerk Leibstadt (KKL)

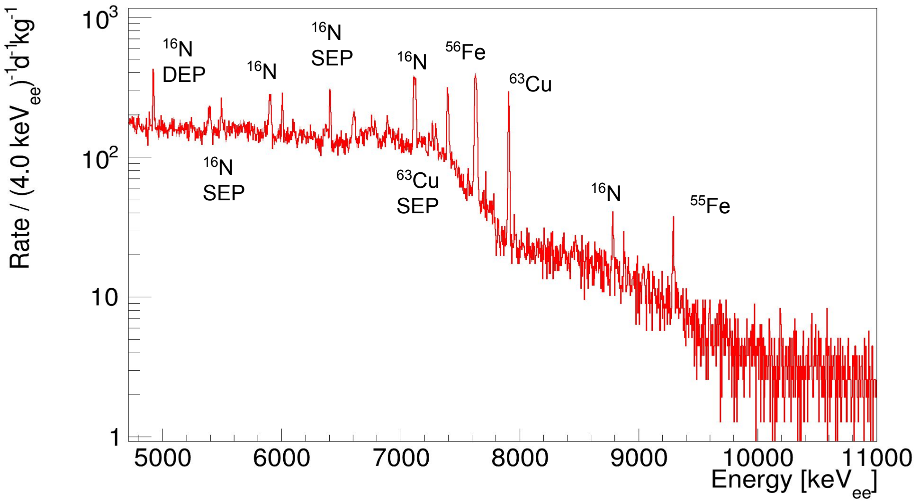
J. Woenckhaus

CONUS+ background: γ's

- Ultra-low background p-type coaxial HPGe detector CONRAD (m =2.2 kg). Electrical cryocooling system.
- Scan over different positions with measurement from few hours to one day.
- High energy gamma contribution (>2.7 MeV) factor 25 smaller than at Brokdorf power plant. Stronger contribution of ^{60}Co lines.

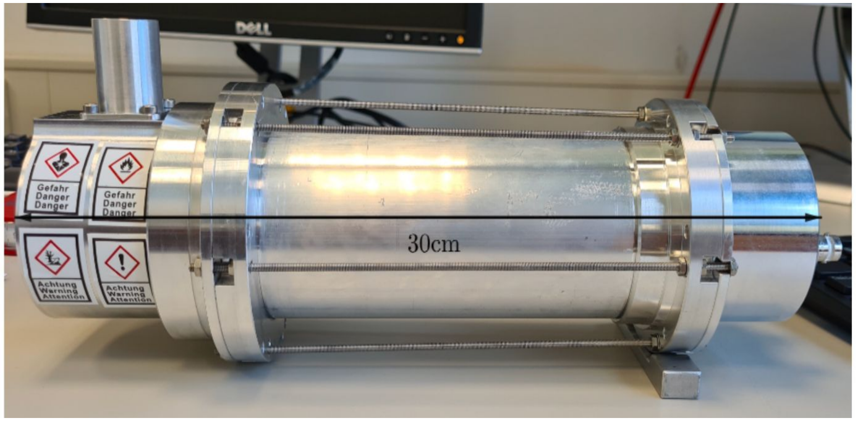


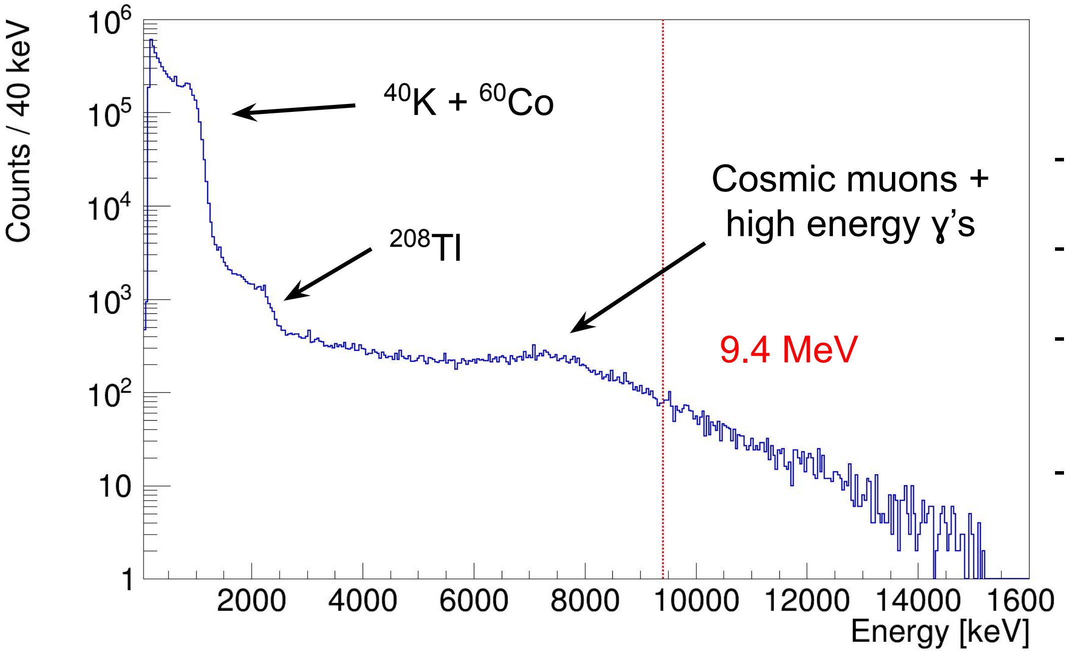




CONUS+ background: Cosmic muons

- Liquid scintillator cell filled with 120 ml of "Ultima Gold". PMT for light detection.
- Measurements at MPIK and KKL for comparison.
- Quality cuts applied: saturation, pile-up.
- Pulse shape discrimination cut to remove neutrons.

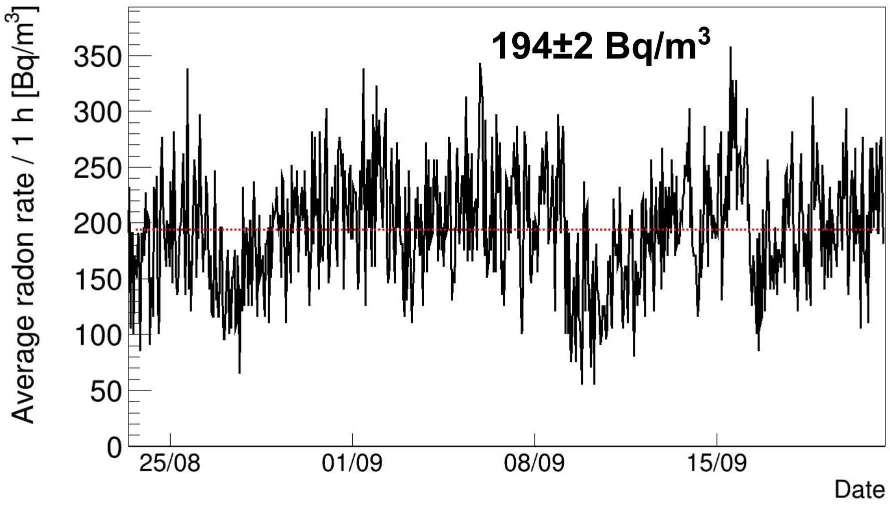


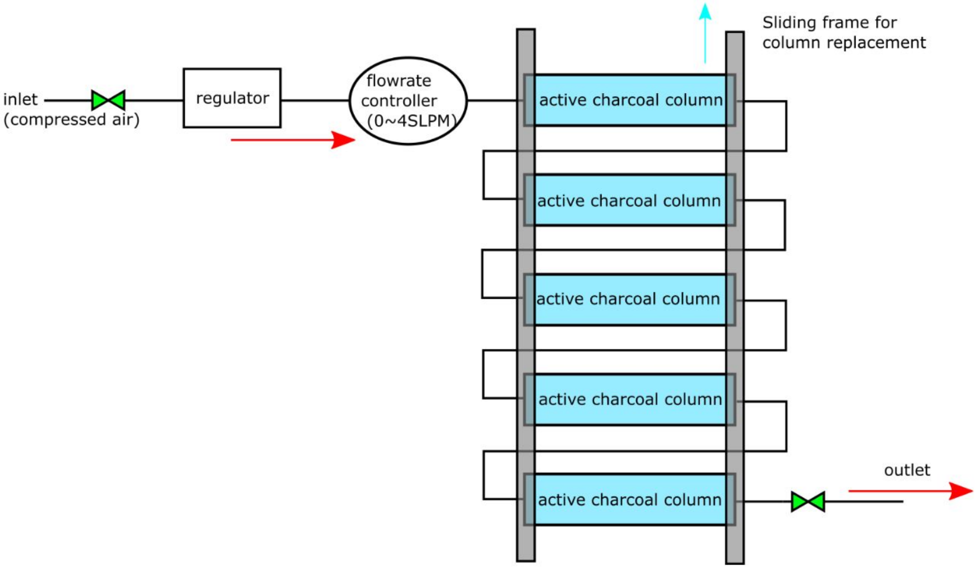


- Energy cut at 10 MeV to avoid environmental radioactivity and high energy gamma contribution.
- <u>Muon rate outside: 0.121 Hz.</u>
- <u>Muon rate in KKL: 0.058 Hz.</u>
- Reduction factor of 2.1 in KKL compare to surface → overburden ~7-8 m.w.e.
- Muon rate factor 2.2 larger than at KBR.

CONUS+ background: Radon

- Monitoring of the radon level in the room during one month.
- Radon concentration value of 194±2 Bq/m^3.
- It is needed to reduce the concentration to at least 1 Bq/m^3 inside the detector chamber.

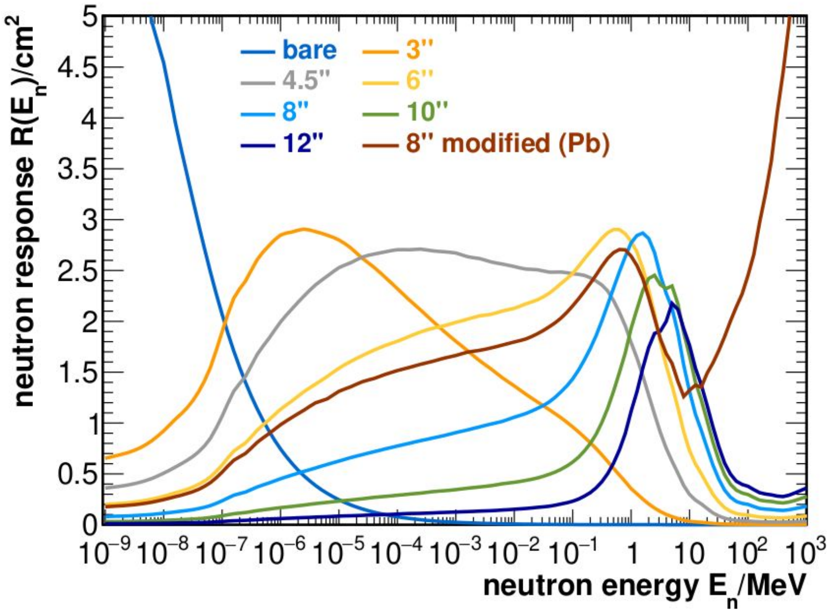


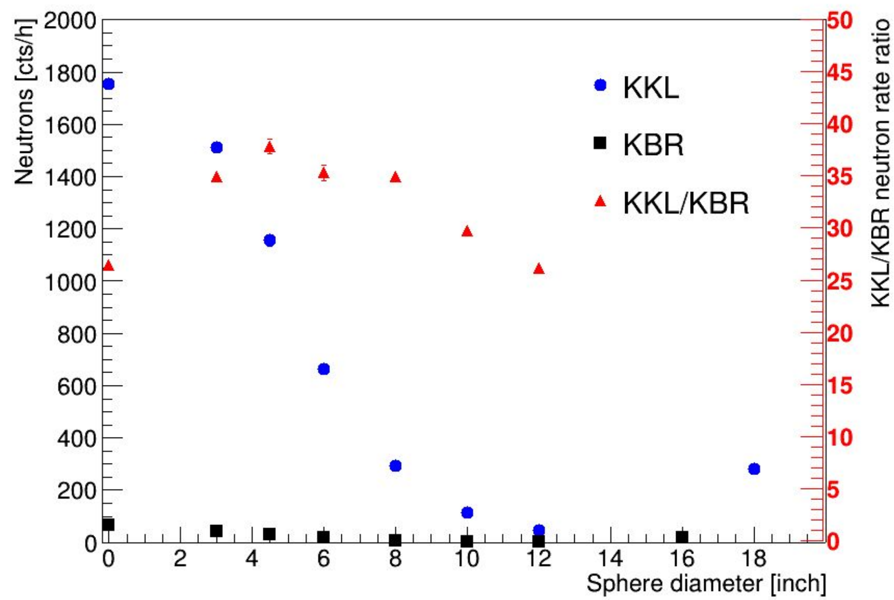


- Detector chamber flushed with radon free air from a radon filtering system.
- Five 7 kg activated charcoal columns for radon reduction factor > 300.
- Pressurized dry air (<1 %) line from outside containment area with lower radon content.
- Stand-alone system. Robust and simple to reduce maintenance operations.

CONUS+ background: Neutrons

- Neutron spectrometry with Bonner Sphere detectors in scientific cooperation with PSI.
- Monitoring of thermal and fast neutrons during whole measurement campaign. Neutron flux stable within 3%.
- Same configuration of spheres as in KBR for direct comparison giving a sensitivity from 10^{-9} to 10^{3} MeV
- Neutron flux ~30 times larger than in KBR. However, it is still a subdominant contribution of the background in the region of interest.



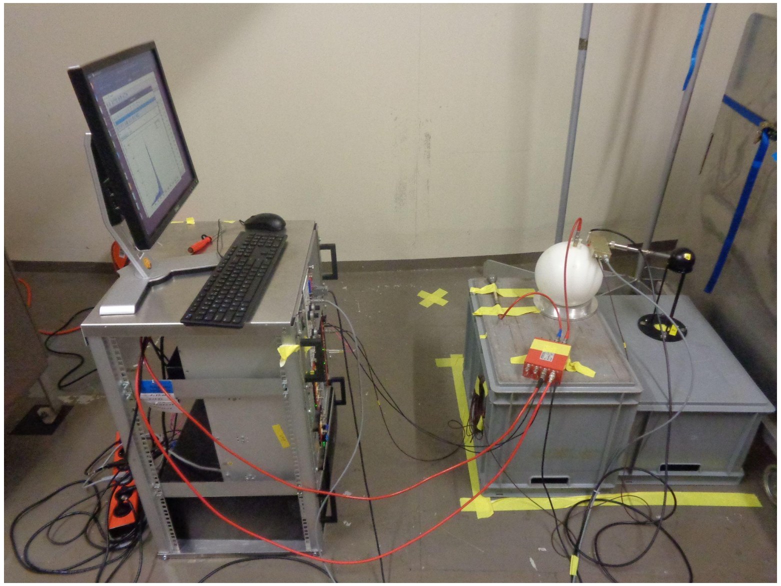


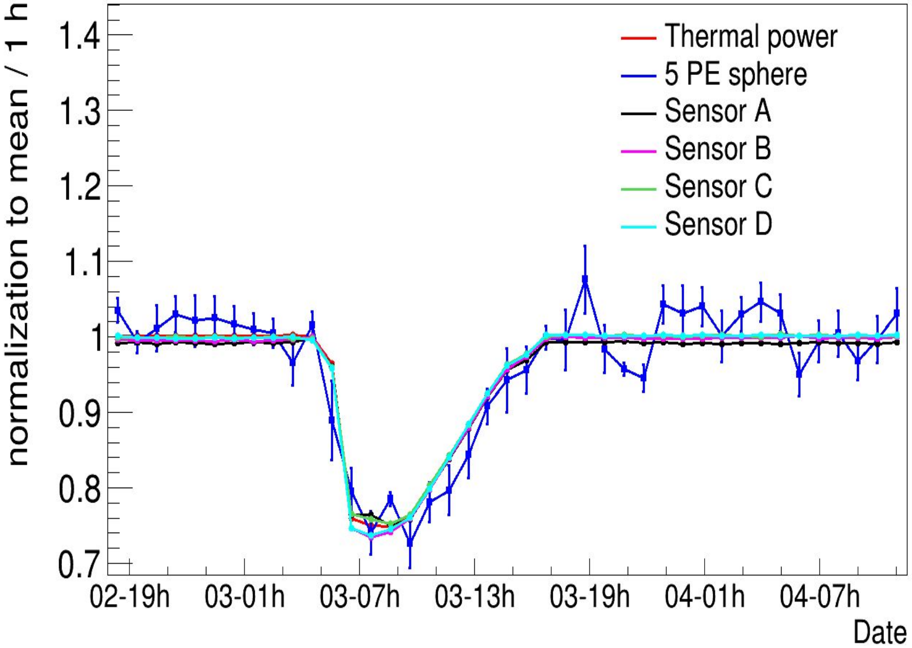
J. Hakenmueller et al., Eur. Phys. J. C (2019) 79, 699

Neutron correlation with thermal power

- Reactor-correlated backgrounds are critical for CONUS since they can mimic a CEvNS signal.

- Monitoring of neutron rate with 5” PE sphere to study correlation with thermal power.



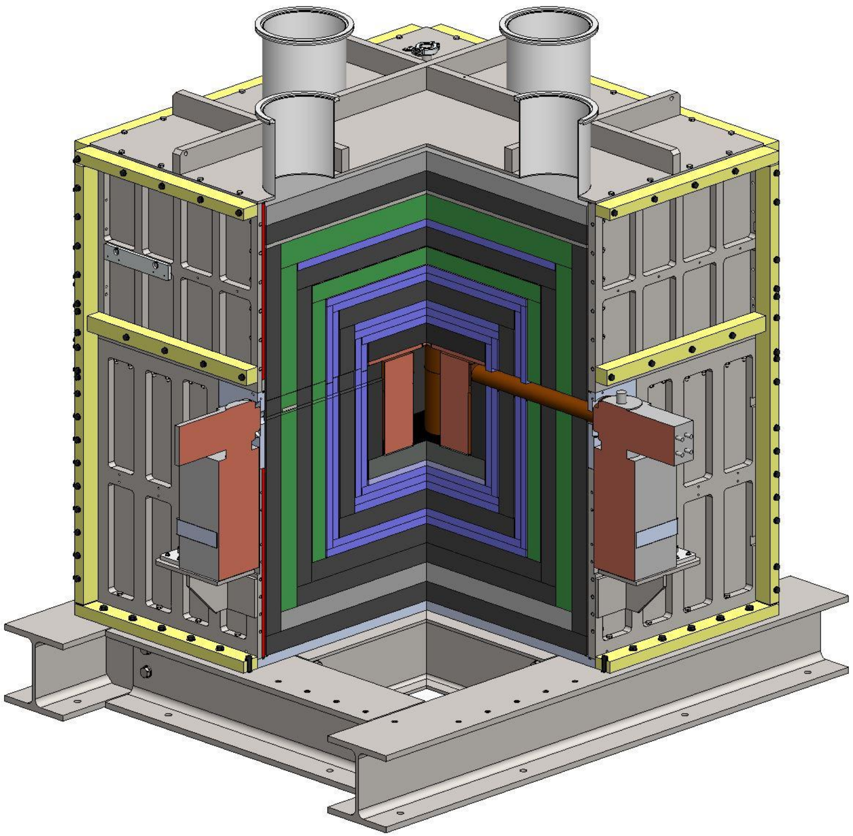


- Good agreement with devices placed close to the fuel elements.

- As expected, the signal is dominated by the neutrons coming from the reactor. Small contribution from cosmic neutrons.

CONUS+ detector

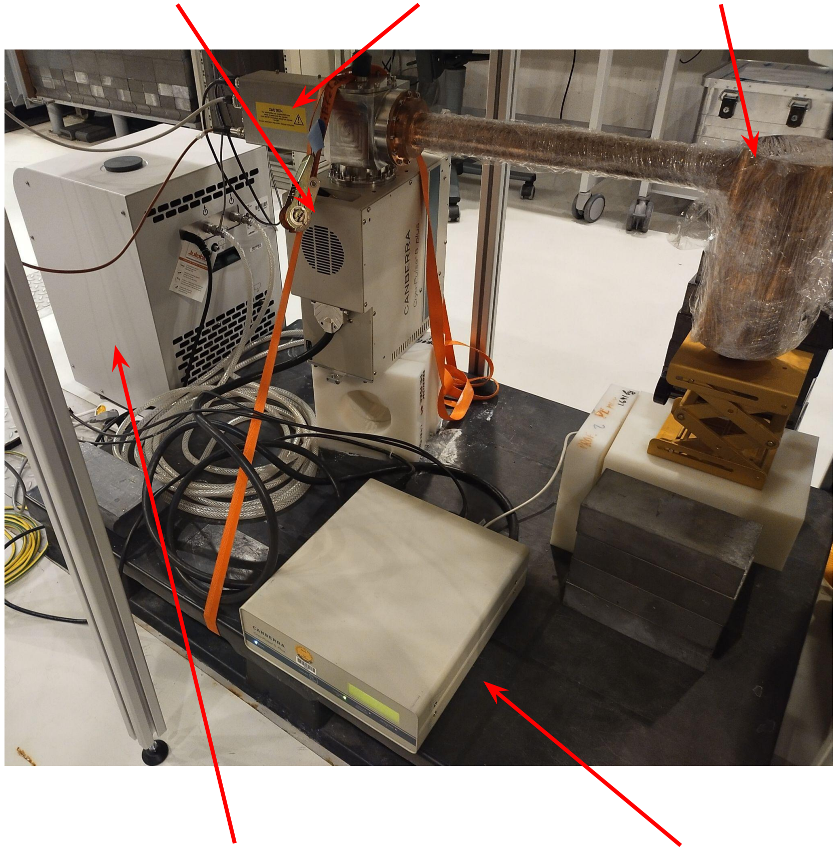
- 4 p-type point contact HPGe with total crystal/active mass: 4 kg /3.74kg as target.
- Active + passive shielding: low ^{210}Pb lead, borated and pure PE and 2 active μ-vetos (plastic scintillator).
- Apply muon veto offline. New DAQ for veto system. Energy deposited stored for each PMT.
- Radon filtering system will provide radon free-air for inner volume flushing.
- Specific space dedicated for CONUS+ with AC for temperature control.
- Network connection to outside containment area. Real-time monitoring and slow control of the experiment.



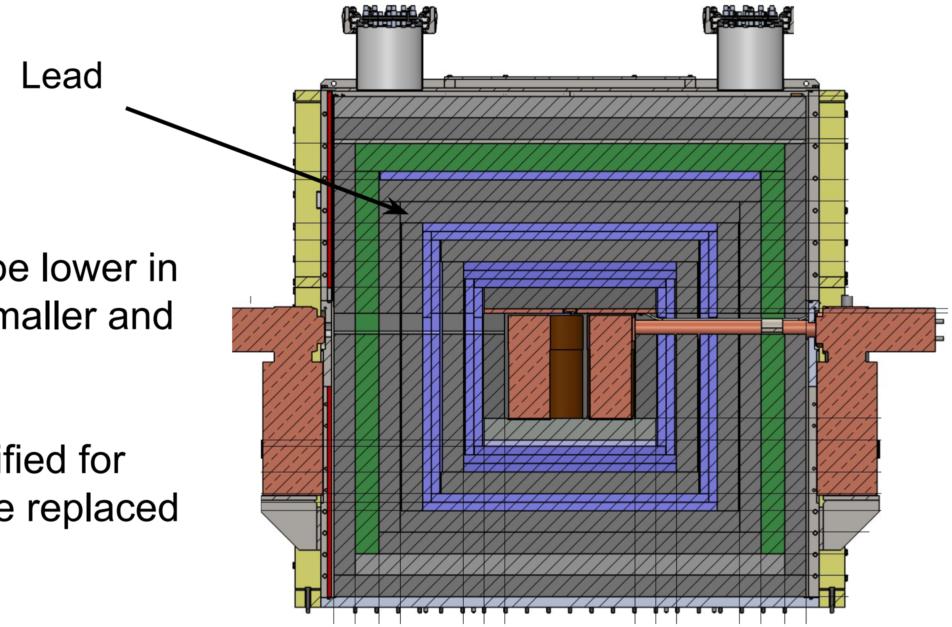
Upgraded germanium detectors

<u>CONUS Ge detectors refurbished for CONUS+</u>

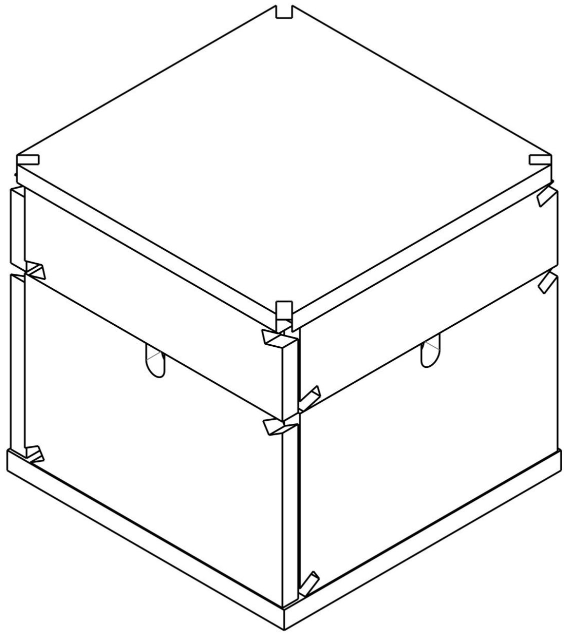
- Point-contact size reduced and new ASIC electronics.
- Water instead of fans for cryocooler cooling → reduce vibrations and environmental dependence.
- Pulser resolution (FWHM) < 55eVee.
- Improved trigger efficiency. Preliminary tests at MPIK show that a threshold lower than 200 eV is achievable.



New veto system



- The high energetic gamma flux is expected to be lower in KKL. However, amount of overburden will be smaller and consequently the muon rate will be larger.
- For this reason, the CONUS shield will be modified for CONUS+. One of the inner lead layers of will be replaced by a second plastic scintillator muon veto.
- 9 plates of EJ-200 plastic scintillator + 20 low background PMTs to minimize material contamination.
- Coincidences of different scintillator plates will reduce the impact of high energy gammas for the veto rejection efficiency.
- Goal: muon rejection efficiency over 99%.



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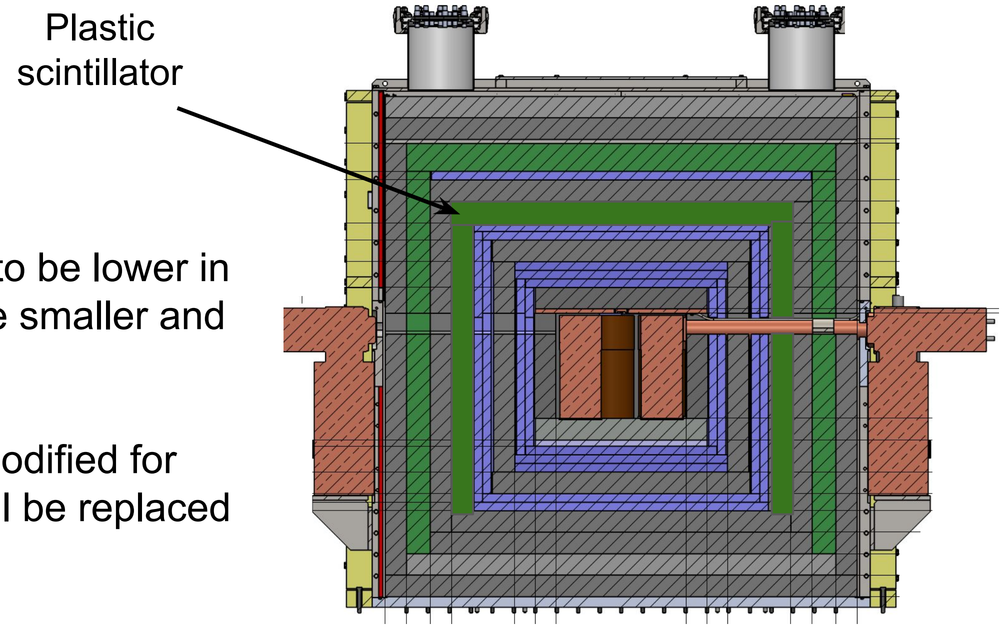

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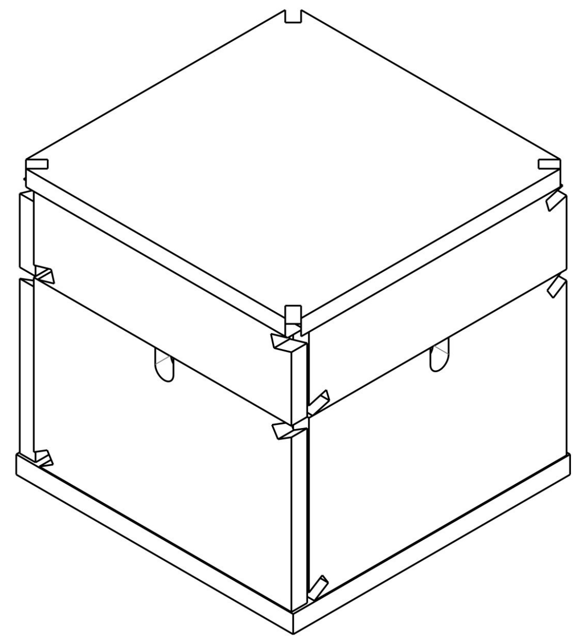
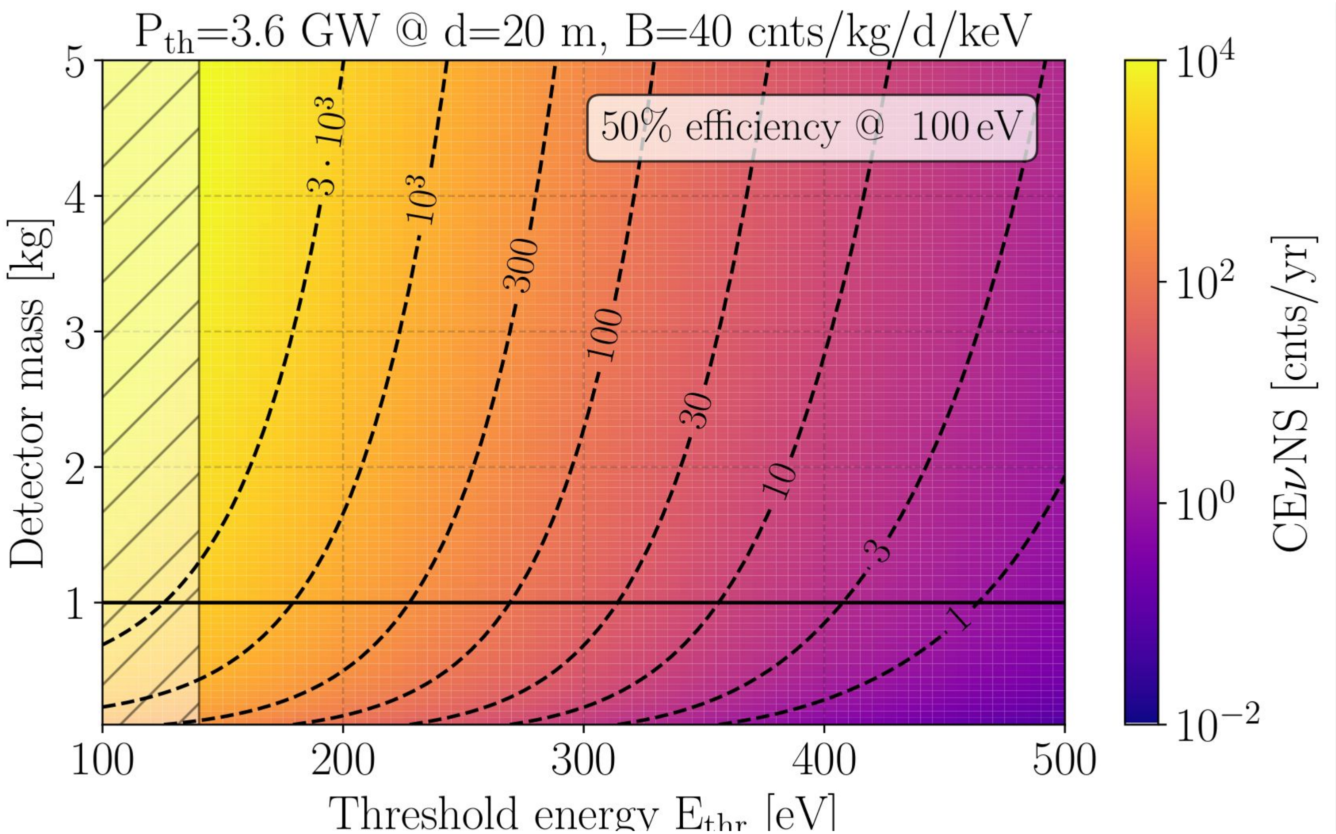


Physics potential



- The energy threshold is a crucial parameter for CEvNS detection. Assuming a trigger efficiency of 50% at 100 eV, improving the threshold from 230 to 140 eV, the number of signal events will increase roughly by a factor ~7.

Summary

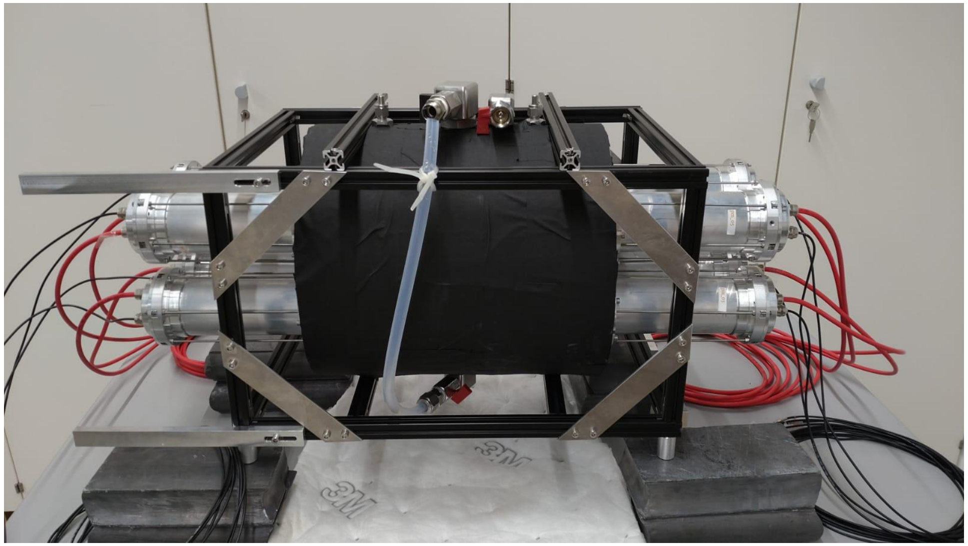
- CONUS+ is a follow-up experiment which aims to detect CEvNS for the first time from a reactor.
- It will be installed in Leibstadt power plant (Switzerland) in summer 2023 at 20 m from the reactor core.
- For this purpose, the 4 Ge detectors of CONUS were upgraded, reducing the threshold under 200 eV.
- Additional plastic scintillator layer to increase muon rejection efficiency.
- The new experimental location background was fully characterized with a HPGe detector, a Bonner Sphere array and a liquid scintillator cell.

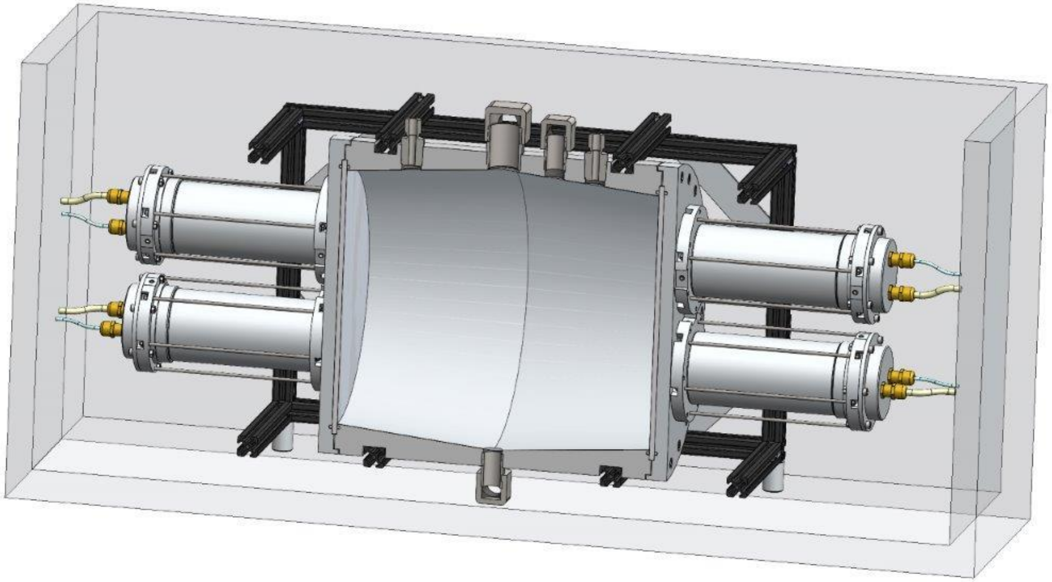
Thank you for your attention

COvUS+

TSLSD detector

- Technical Scale Liquid scintillator Detector (TSLSD) for muon and neutron and background characterization.
- Different option for filling adapted to safety specifications. Possibility to fill with silicon oil as scintillator base: no hazard symbol, low vapor pressure and flash point very high (300ºC). Volume 17 L.
- Certified safety box for transport and operation.
- Muon energy deposition 50-120 MeV.





Comparison KKL vs KBR for gammas