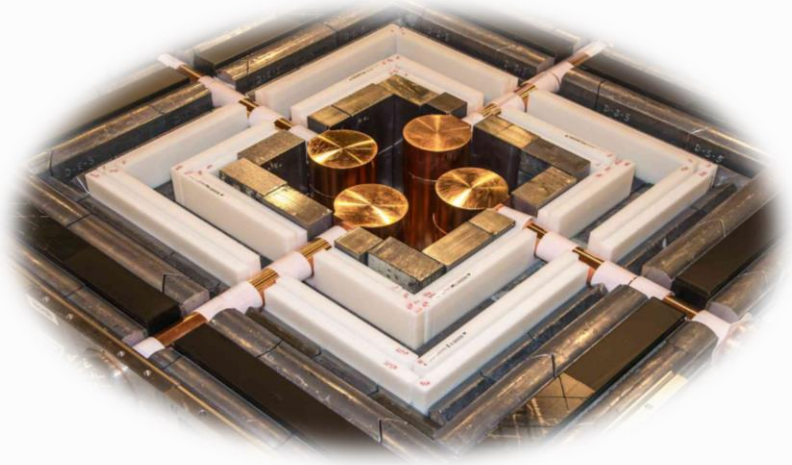
MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

Status of the CONUS+ experiment

Kaixiang Ni – On behalf of the CONUS+ collaboration



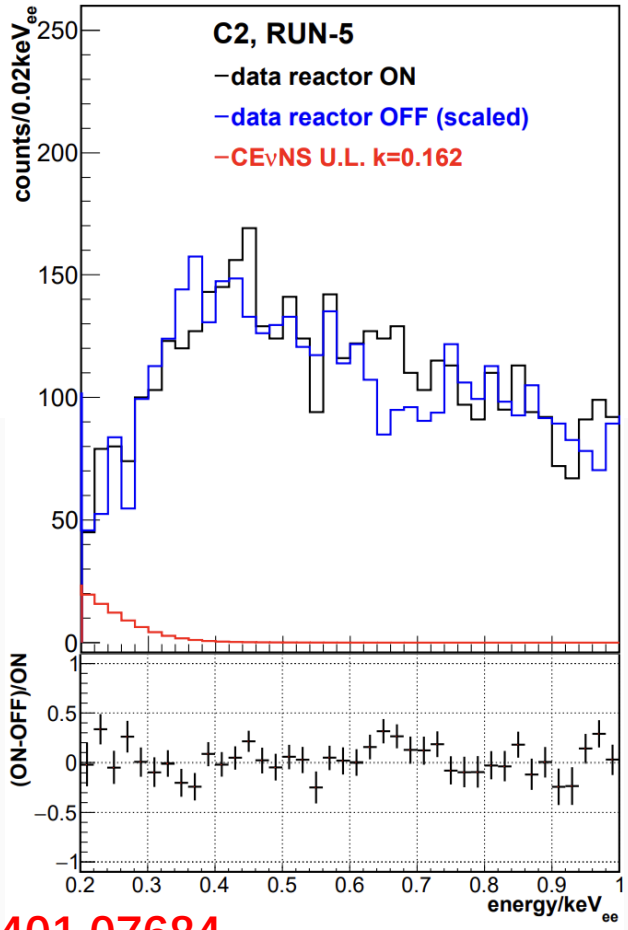
COvUS+

Magnificent CEvNS 2024 University-Enterprise Foundation of the University of Valencia June. 2024

CONUS @ Brokdorf

- Operated in Brokdorf Nuclear Power Plant (KBR) from 2018 to 2022.
- Final result submitted and under review, upper limit: factor ~2 above SM prediction.
- Yet the strongest CEνNS limit from nuclear reactor under Lindhard quenching.
- Details were given in Wednesday's talk.

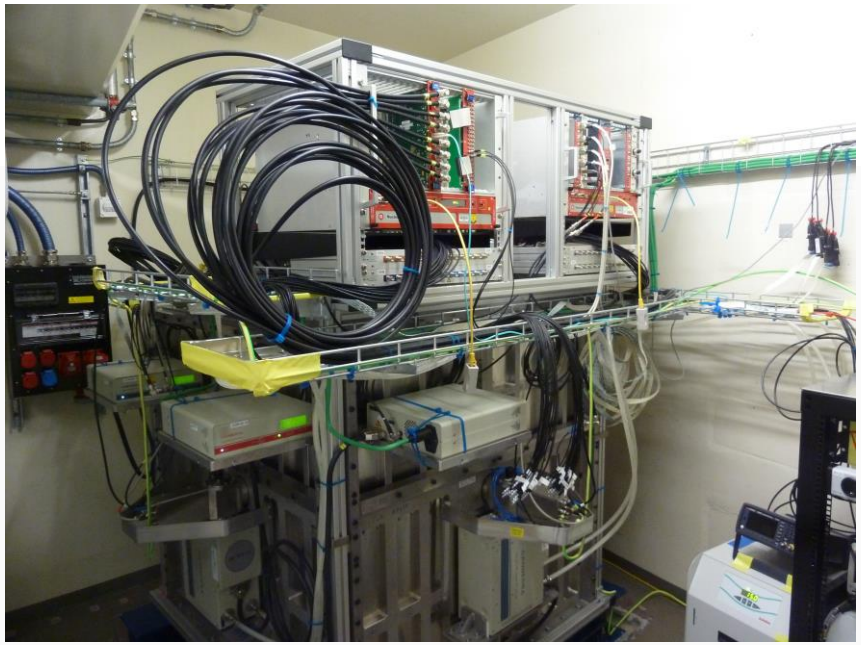
Detector	Exposure (ON/OFF, kg-d)	Anticipated Signals (k=0.16)	Likelihood fit
C1	142/40	42	<59
C2	146/130	26	<75
C4	139/102	23	<90
Total	426/272	91	<143



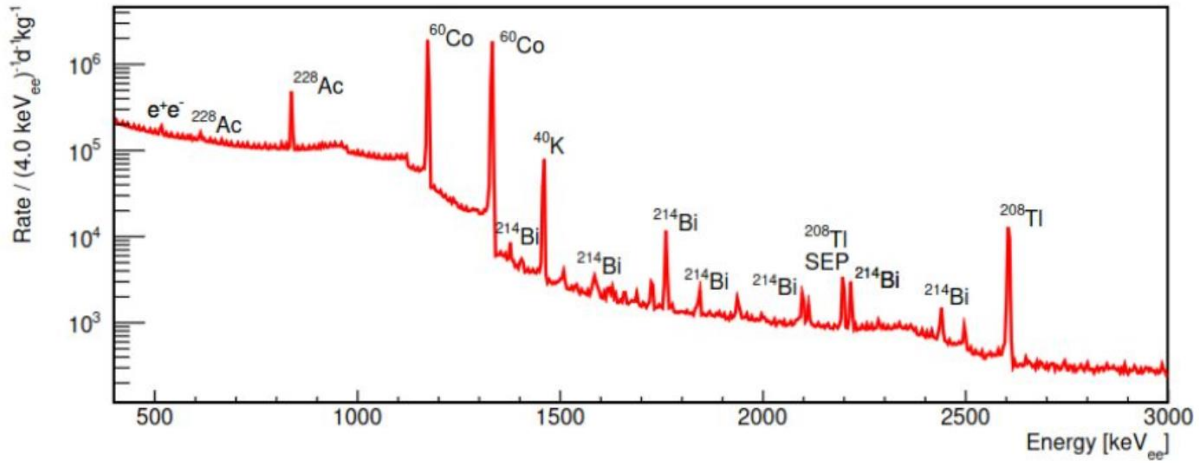
Arxiv: 2401.07684

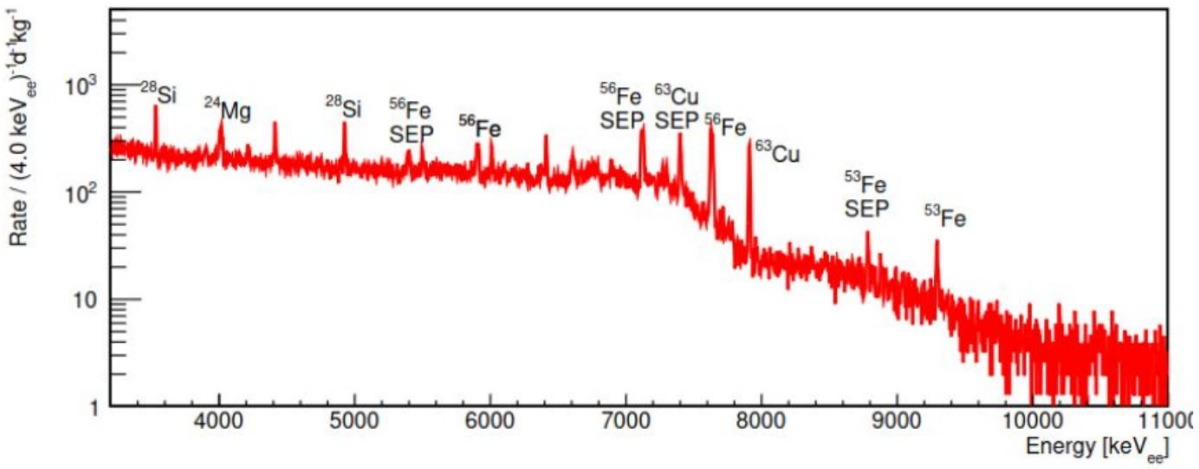
From CONUS to CONUS+

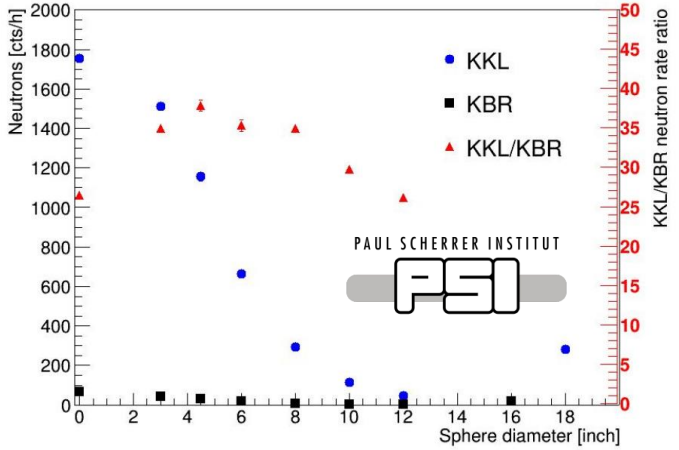
- Nuclear power plants in Germany were shut-down…
- The new site: Leibstadt Nuclear Power Plant (KKL), Switzerland
- Experiment hall: ~20.7m from 3.6 GW reactor core, 1.45 x 10^{13} ν/s/cm^2



Background characterization







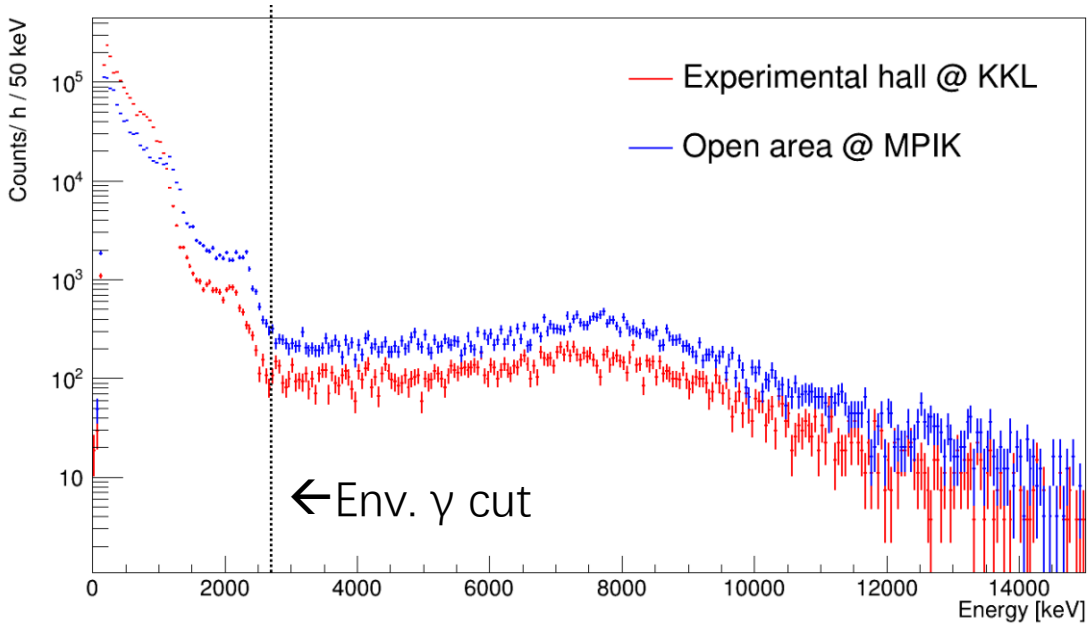
Gamma background:

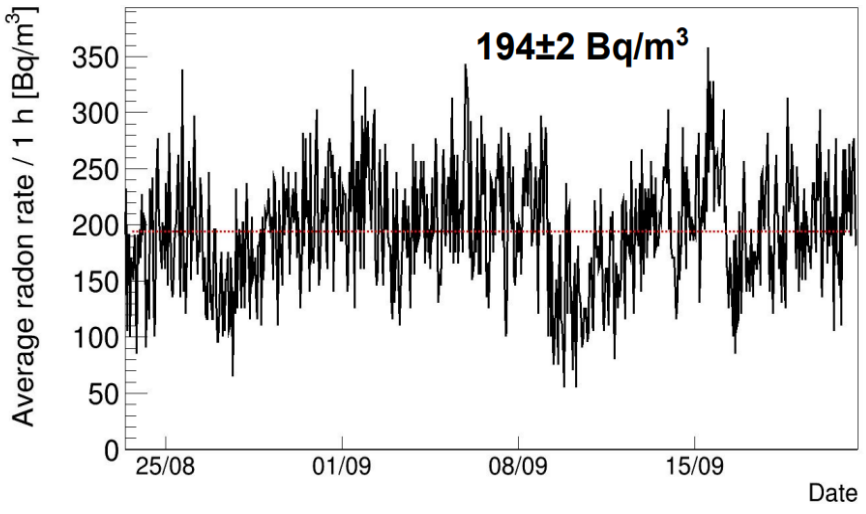
- Measured with CONRAD, a low background p-type coaxial HPGe detector (m =2.2 kg)
- Factor ~25 smaller than in KBR

Neutron:

- Measured by Bonner Sphere detectors
- ~30 times larger than in KBR
- Still sub-dominant in ROI

Background characterization





Muon:

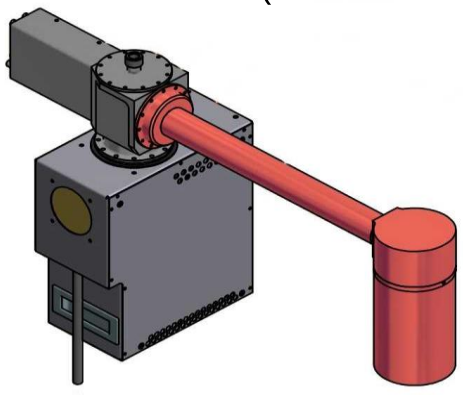
- Measured by a liquid scintillator detector. Compare the rate difference between KKL and open area.
- Shows 7.4 m w.e. of overburden.
- More efficient muon-veto system mandatory.

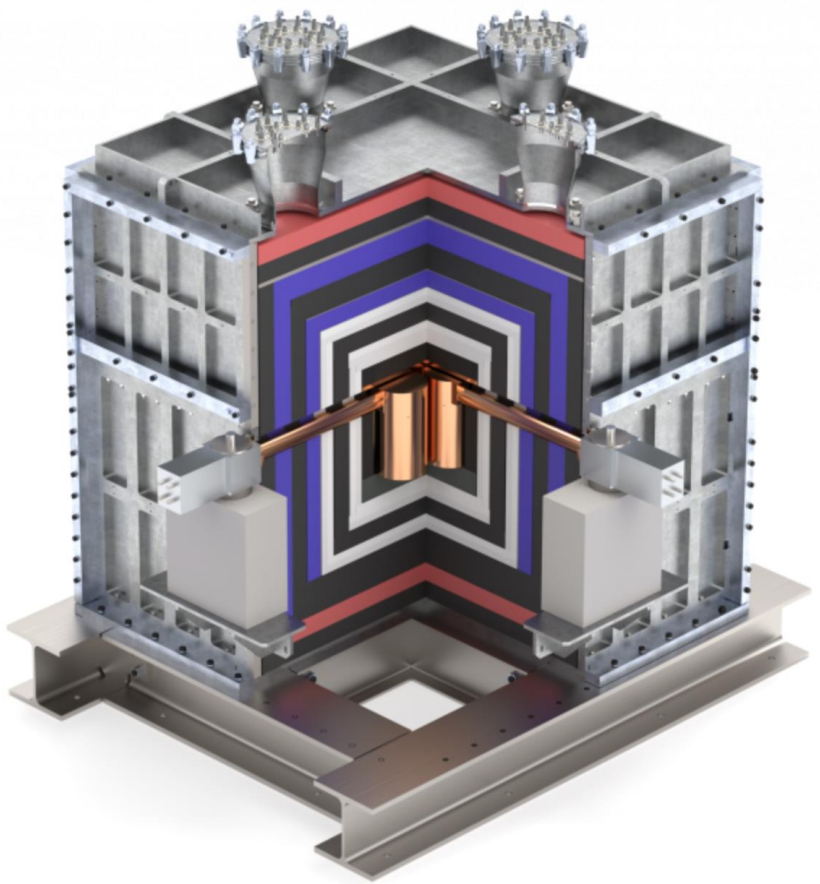
Radon:

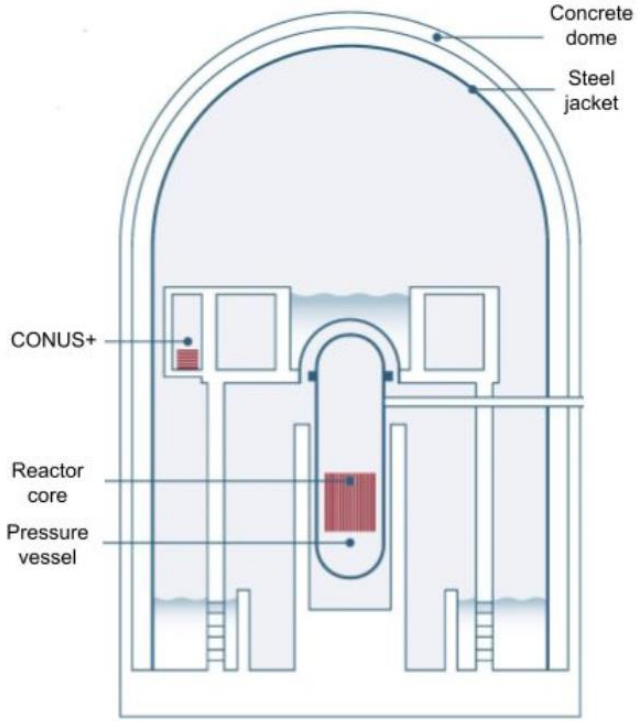
- Measured with RadonScout, a commercial self-protection device.
- Similar rate with KBR. 100~200Bq/m^3.
- Apply radon-free air flushing like in KBR.

Detector and shield upgrade

Ge crystal: reduced point-contact size
ASIC: higher trigger efficiency at low energy.
Cryostat: water-cooled to reduce vibration and microphonic noise.
Muon veto: lead layer replaced by additional plastic scintillator layer.
DAQ: waveform sampling for Ge (4 channels), and muon veto (40 channels).





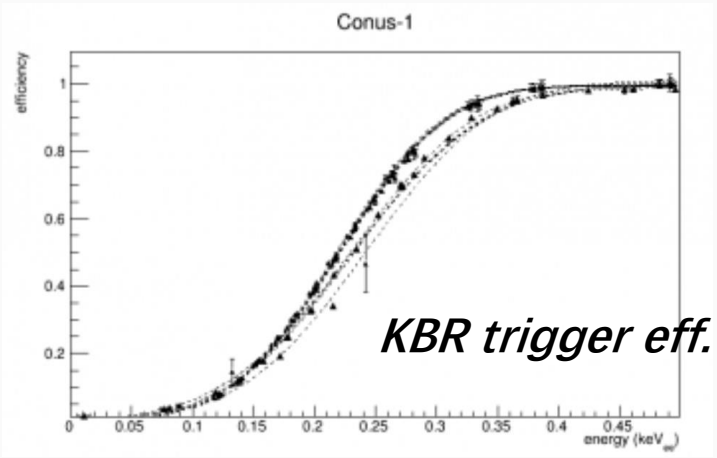


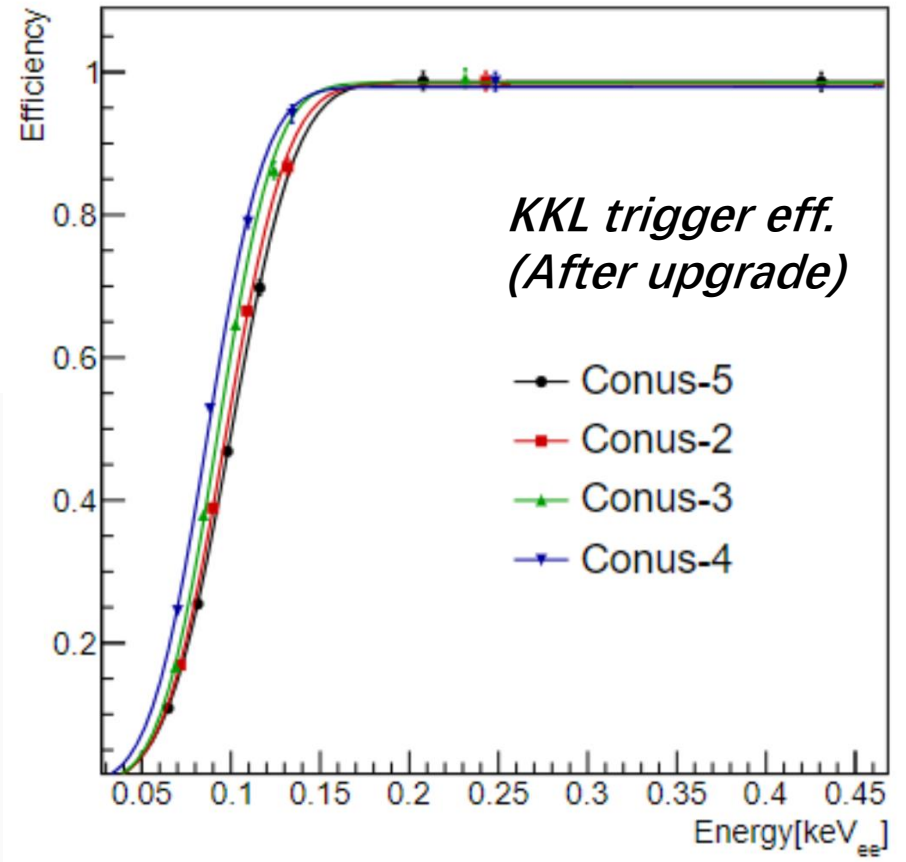
Trigger efficiency & resolution

On all detectors, we achieved:

- > 90% trigger efficiency at 150eV$_{ee}$
- < 50eV pulser resolution

Threshold for CEvNS searching is set to 150eV$_{ee}$ (preliminary)





Background controlling

Special old-Lead soldering wire applied in ASIC

- Pb210 contamination suppressed

Radon flushing with pressurized air

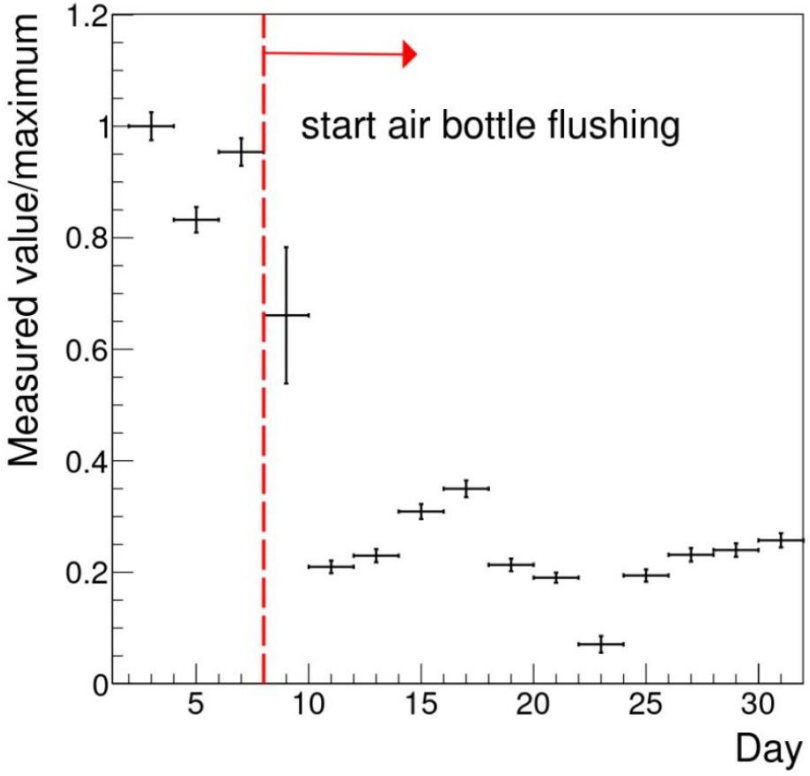
- Significant improvement in high energy count rate

Active muon veto with low background PMTs

- Cut window: 450us
- Reduction: > 99% in [0.15-1] keV range

Pulse shape discrimination

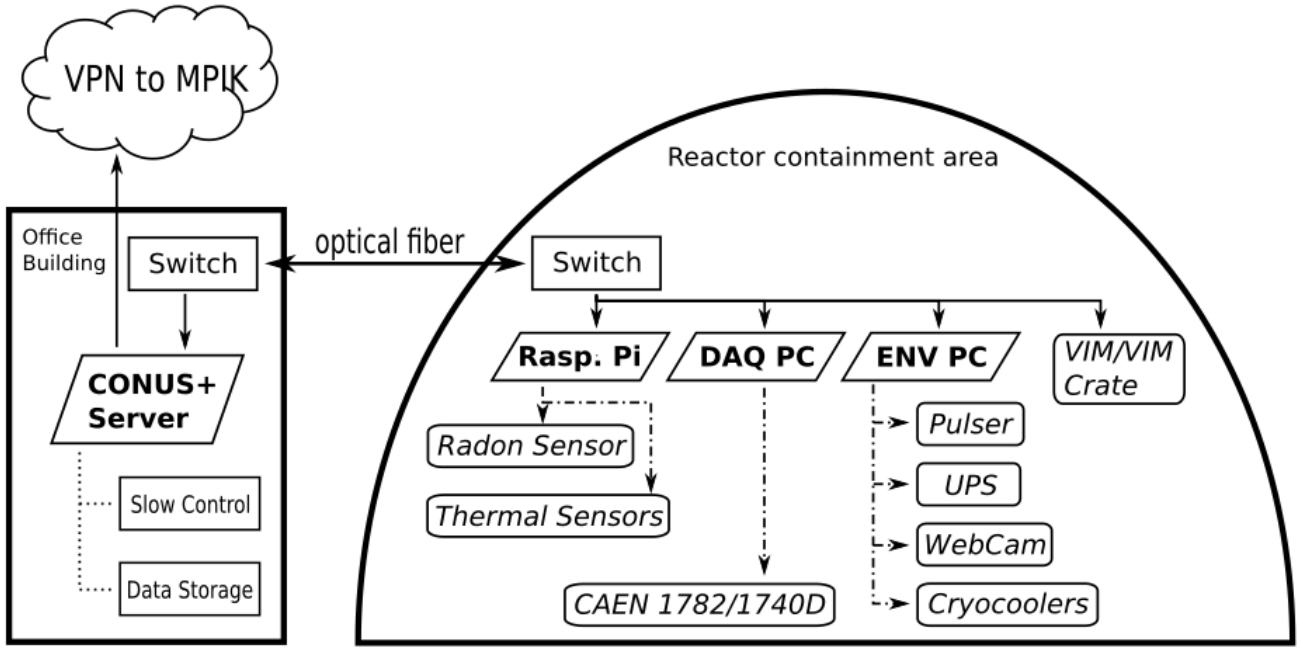
- Reduce surface events

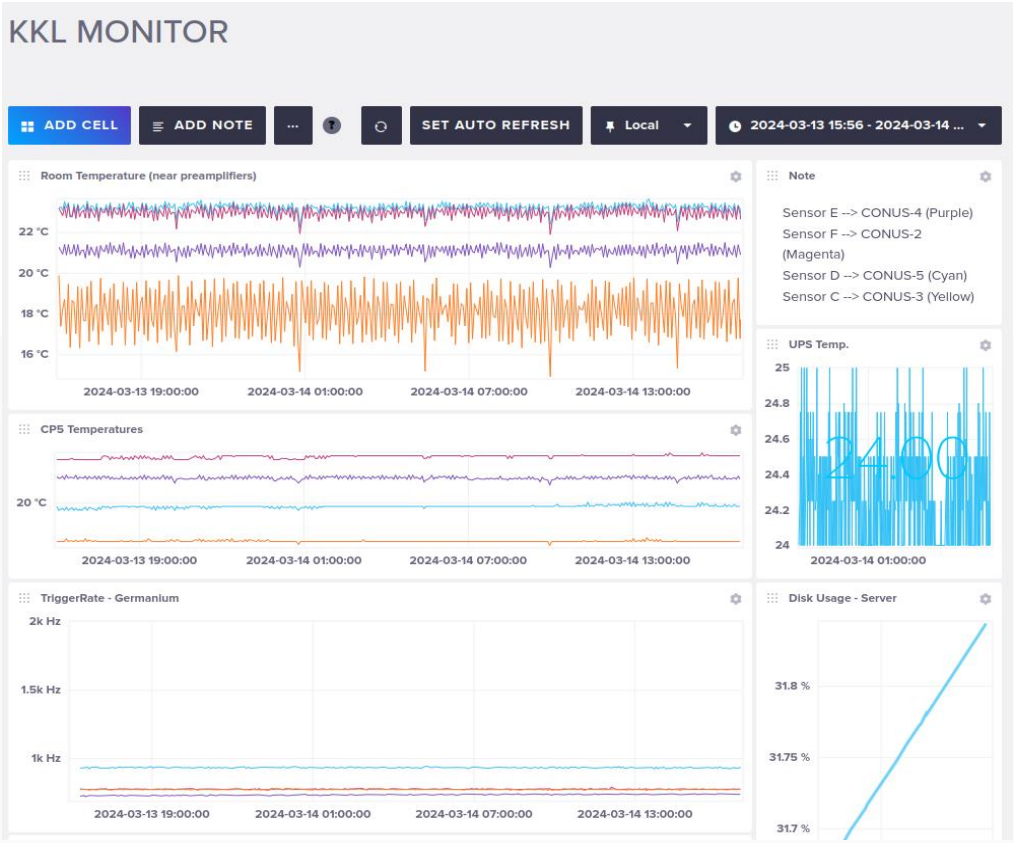


Computation

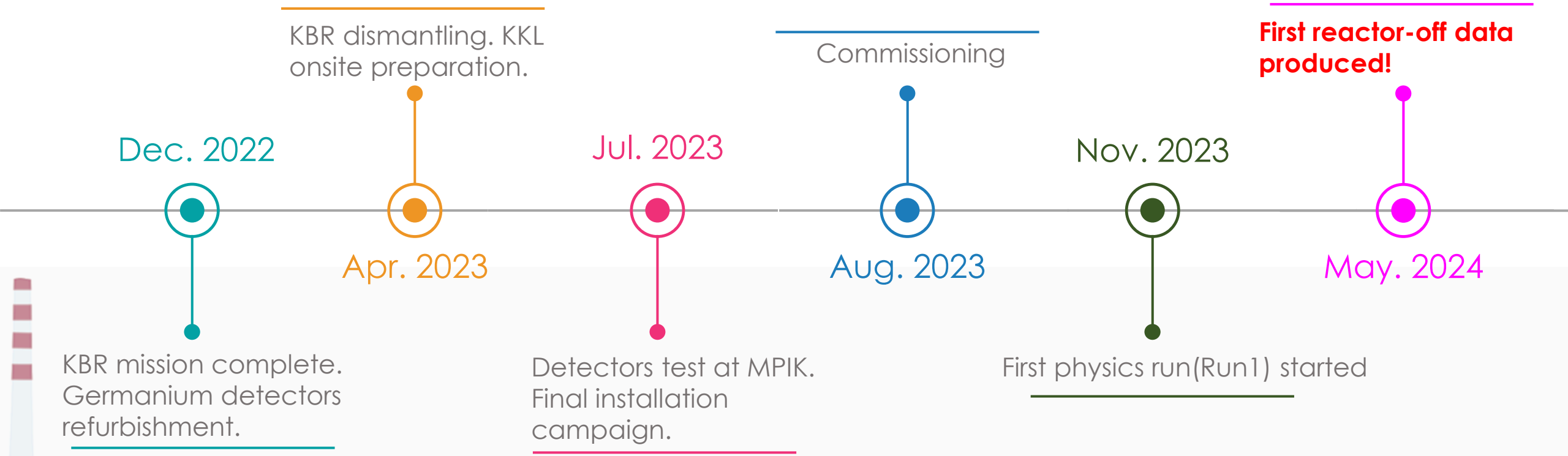
Internet connection dedicated to CONUS and decoupled from the power plant.

- Remote operation: calibration, run, etc.
- Slow control system
- Realtime data transfer & online analysis





Timeline


Dec. 2022
KBR mission complete. Germanium detectors refurbishment.
Apr. 2023
KBR dismantling. KKL onsite preparation.
Jul. 2023
Detectors test at MPIK. Final installation campaign.
Aug. 2023
Commissioning
Nov. 2023
First physics run(Run1) started
May. 2024
First reactor-off data produced!

Preliminary data (Reactor ON)

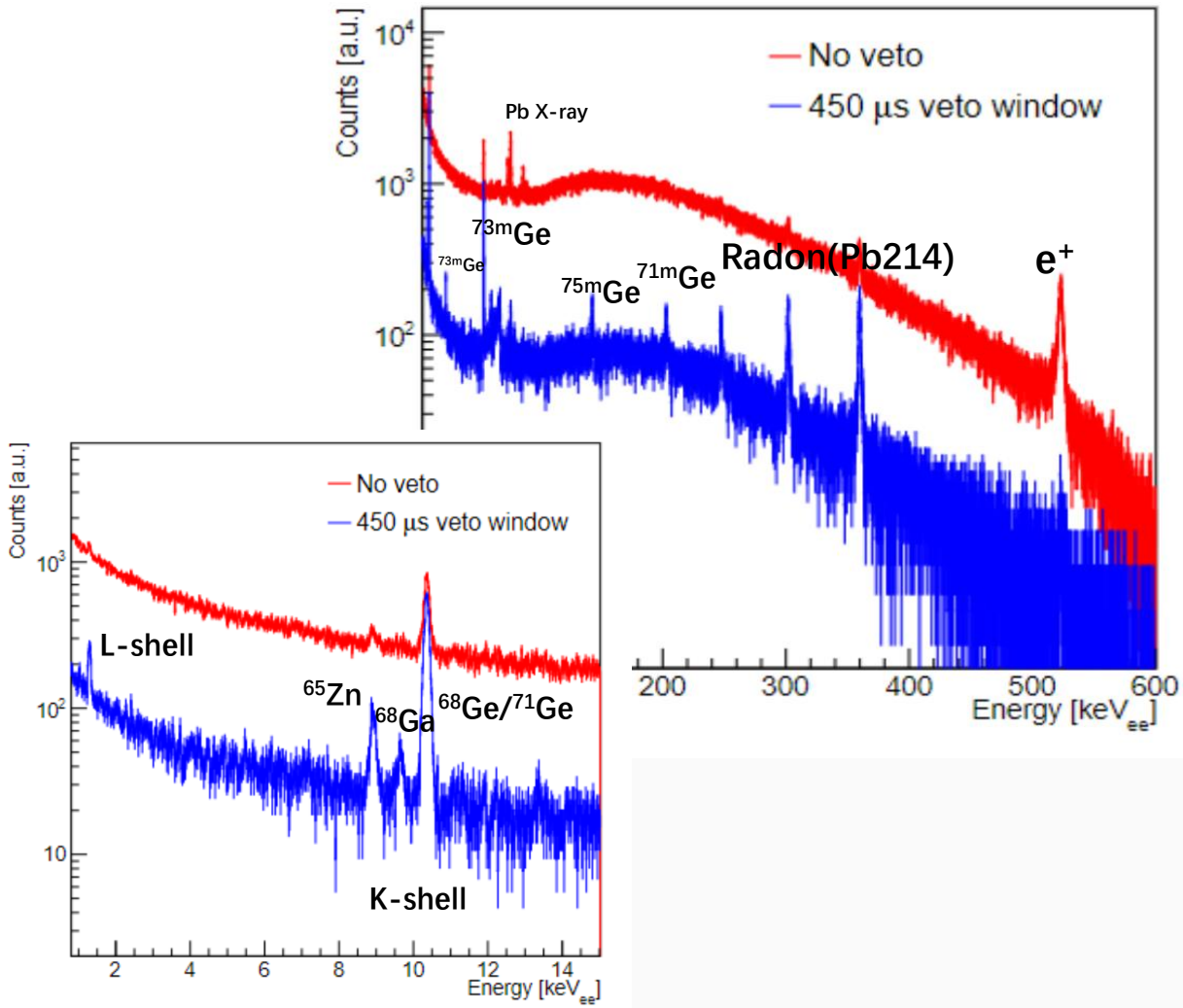
Background components:

- **Radon**
- **Muon**
  - **Induced neutron (fast)**
    - **Cosmogenic isotopes**
  - Induced X-ray on Pb
- Reactor correlated neutrons (thermal)
  - Induced Ge metastable states
- Material contamination (^{210}Pb, Co) → lower than KBR

(Low energy)

- **X-Ray from cosmogenic isotopes**

Precise modeling of background compositions ongoing!



Prospects

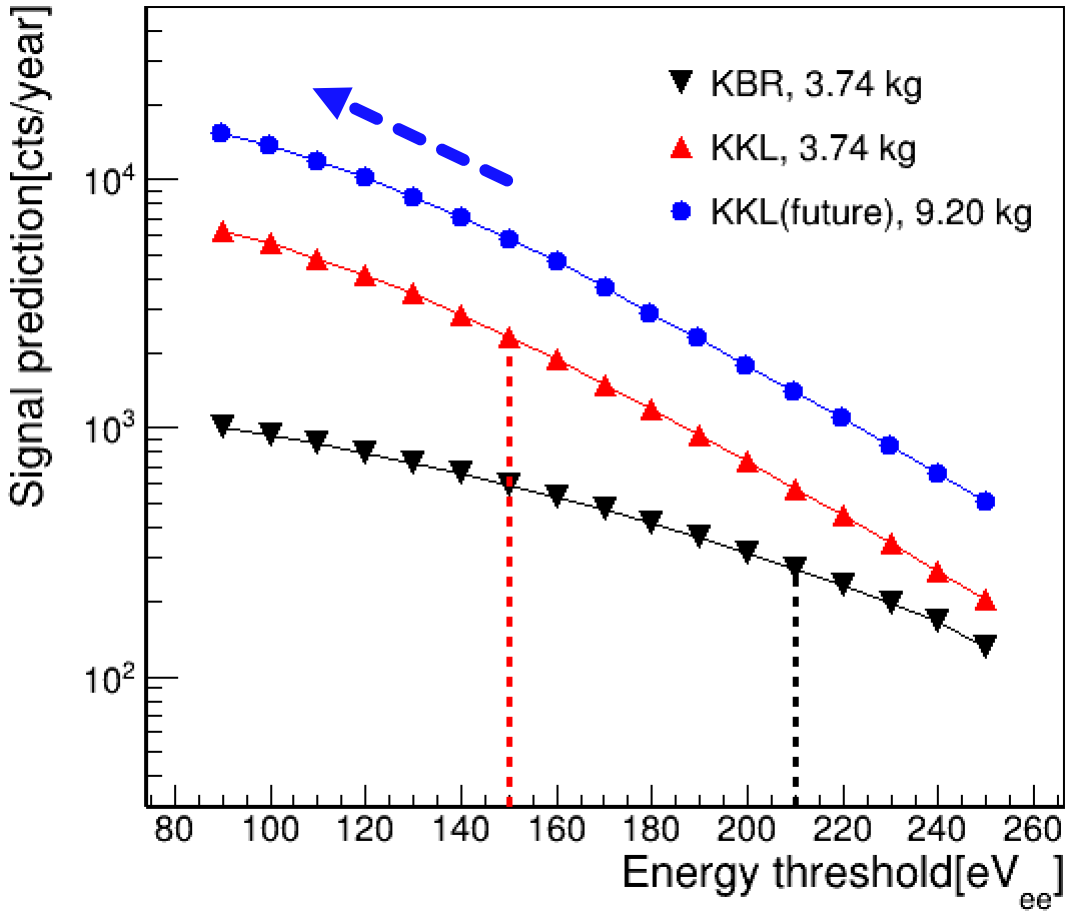
With better threshold and trigger efficiency, we expect CEvNS signals to be ~10x larger!

- CONUS: 70/det/yr
- CONUS+: **580/det/yr**
- CONUS+ future: >1400/det/yr

Additional upgrade for the detector is planned for the next phase of run, applying 2.5kg Ge diode and further low energy threshold.

Stay tuned for the first result!

Assume Lindhard quenching, k=0.164



The CONUS/CONUS+ collaboration

Max-Planck-Institut für Kernphysik (MPIK), Heidelberg: N. Ackermann, H. Bonet, C. Buck, J. Hakenmüller, J. Hempfling, G. Heusser, M. Lindner, W. Maneschg, K. Ni, T. Rink, E. Sanchez-Garcia, H. Strecker
Former collaborators: T. Schierhuber, E. Van der Meeren, J. Henrichs, T. Hugle, J. Stauber, S. Armbruster, A. Bonhomme
Preussen Elektra GmbH, Kernkraftwerk Brokdorf (KBR), Brokdorf: K. Fülber, R. Wink
Kernkraftwerk Leibstadt AG (KKL), Leibstadt: J. Woenckhaus, M. Rank

Scientific cooperations with:

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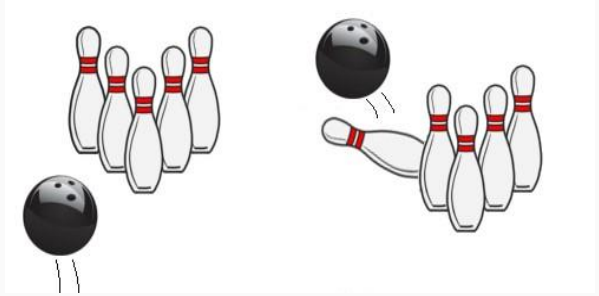
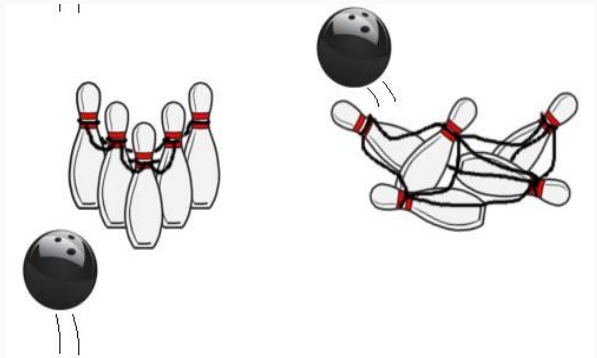
Paul-Scherrer-Institut (PSI), Villigen: E. Hohmann

Summary

- CONUS+, the successor experiment of CONUS, has been relocated to Leibstadt Nuclear Power Plant (KKL).
- Environmental background of the new site is fully characterized.
- Multiple upgrades have been made in CONUS+, including detector, shield and computation.
- Physics data taking (RUN-1) is ongoing. Preliminary data show a good performance and promising prospect.

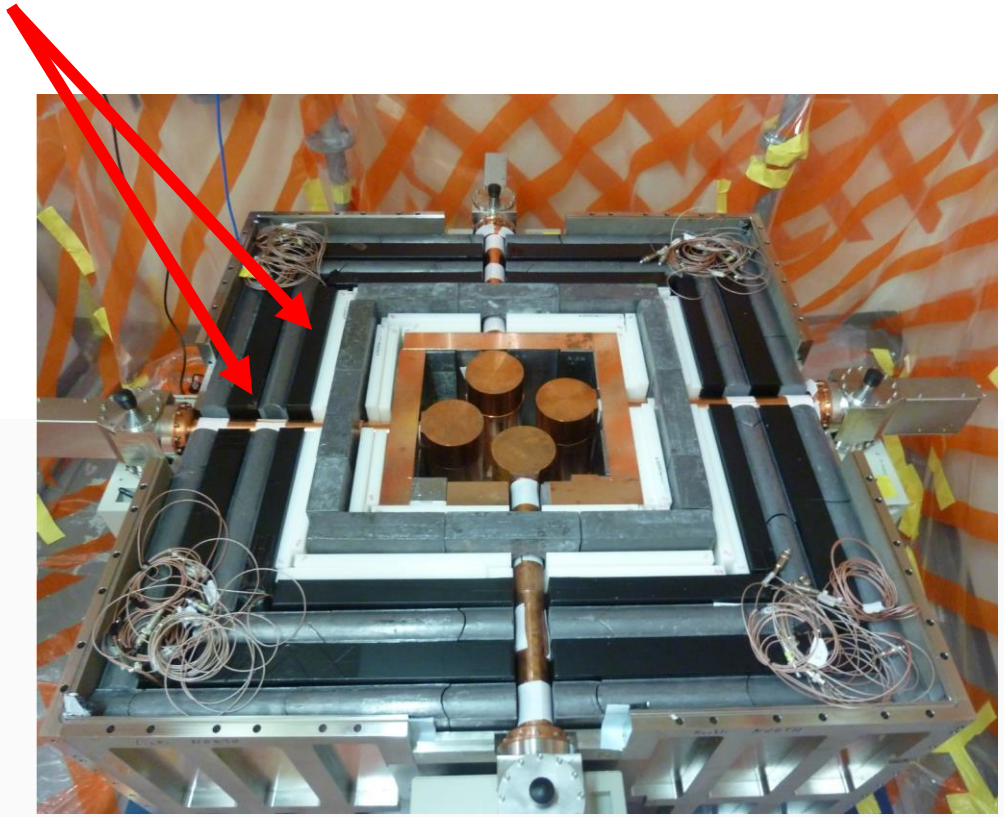




Backup

Double layered muon veto

- In addition to the reused muon veto from CONUS, we replace some inner lead bricks by another layer of scintillators.
- DAQ upgrade: we do independent trigger on each PMT, which enables coincidence for better muon identification
- **Veto efficiency improved to >99% in ROI**

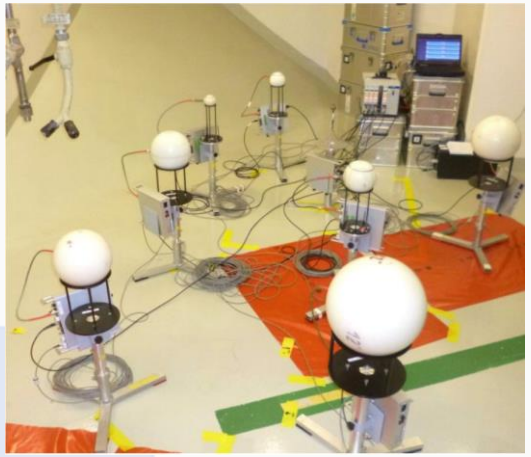


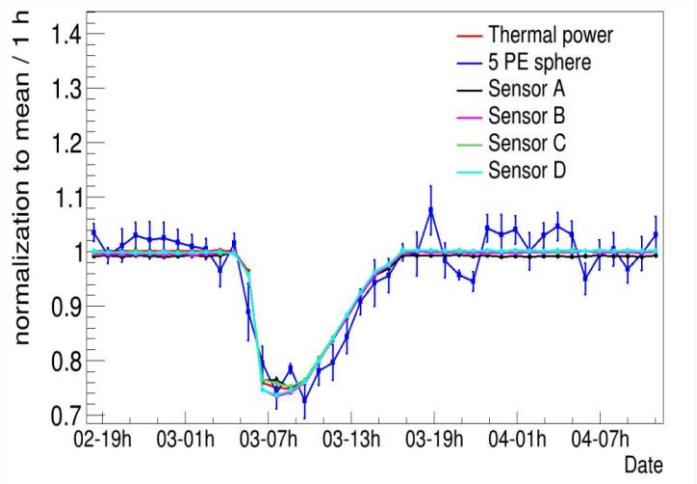
Reactor correlated neutron

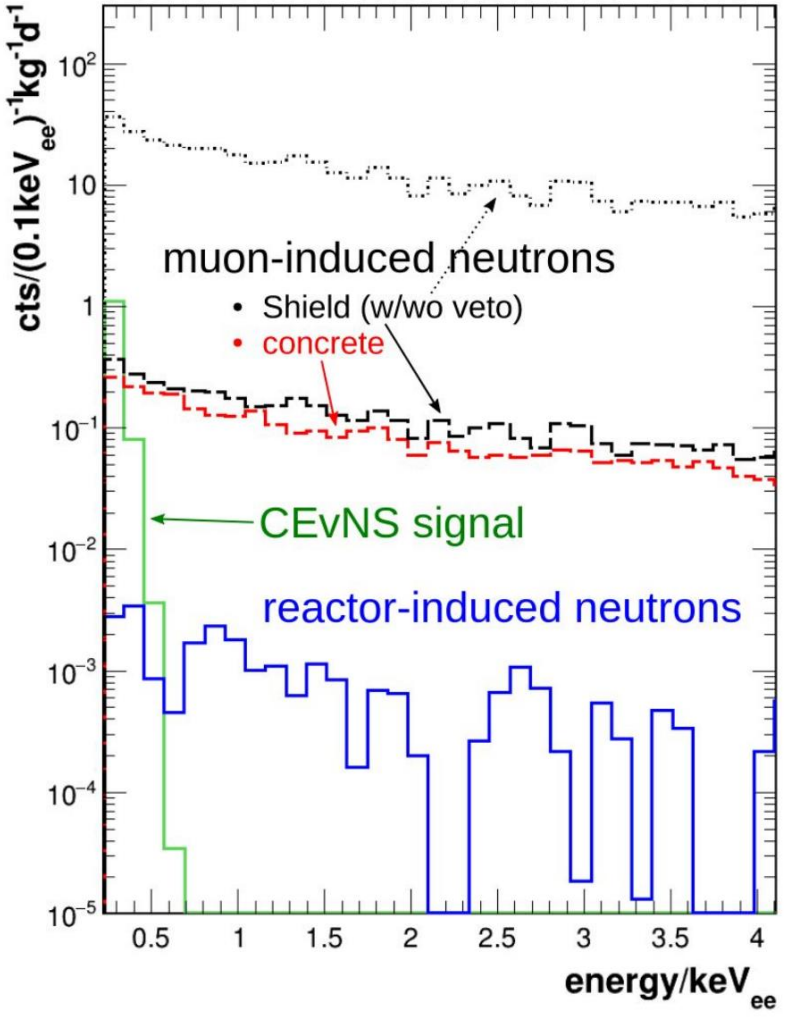
- **Neutron spectrometry with NEMUS detectors by PTB**

→ Highly thermalized (>80%) and correlated with reactor thermal power

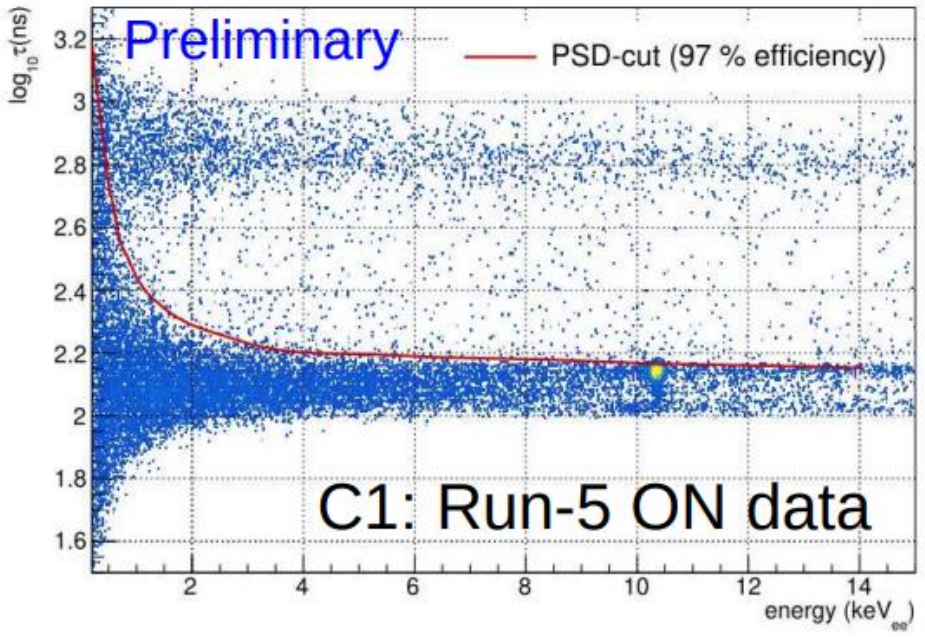
- **Muon induced neutron takes the major role in CONUS background, instead of reactor neutron**





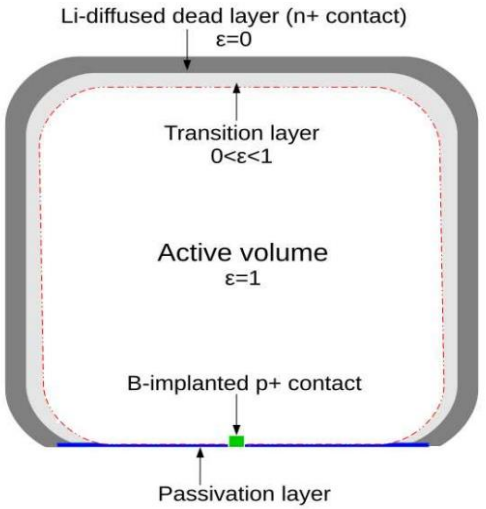


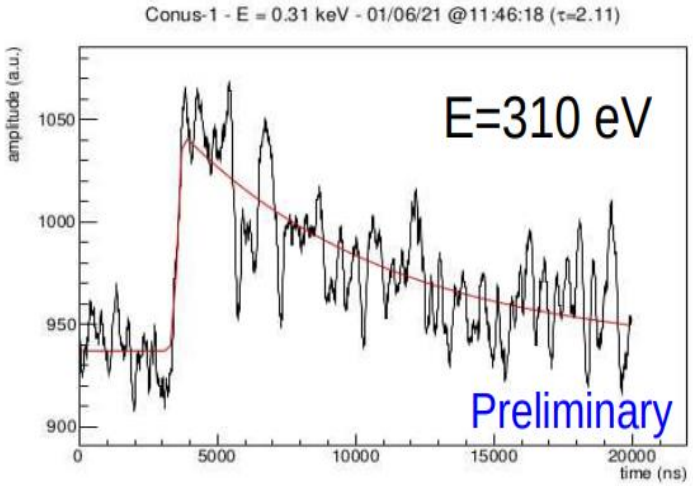
Pulse Shape Discrimination (PSD)



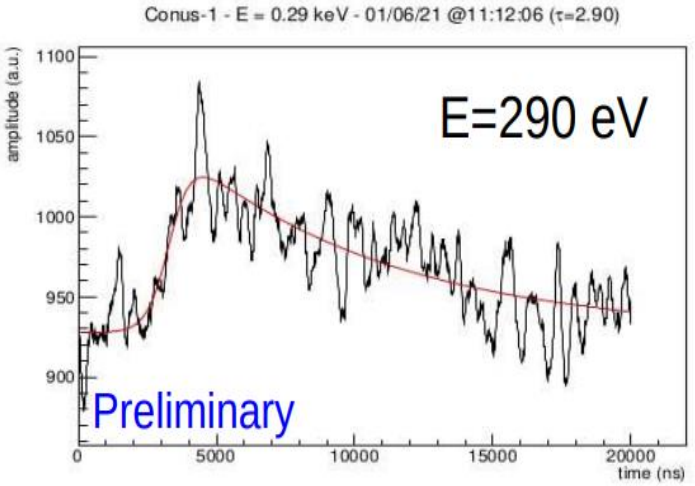
Efficiency: remove ~50% of the surface events at ~300eV with >90% bulk event acceptance

- Energy deposition near the transition edge contributes to a slow signal.
- Removing slow pulses could reduce surface background.





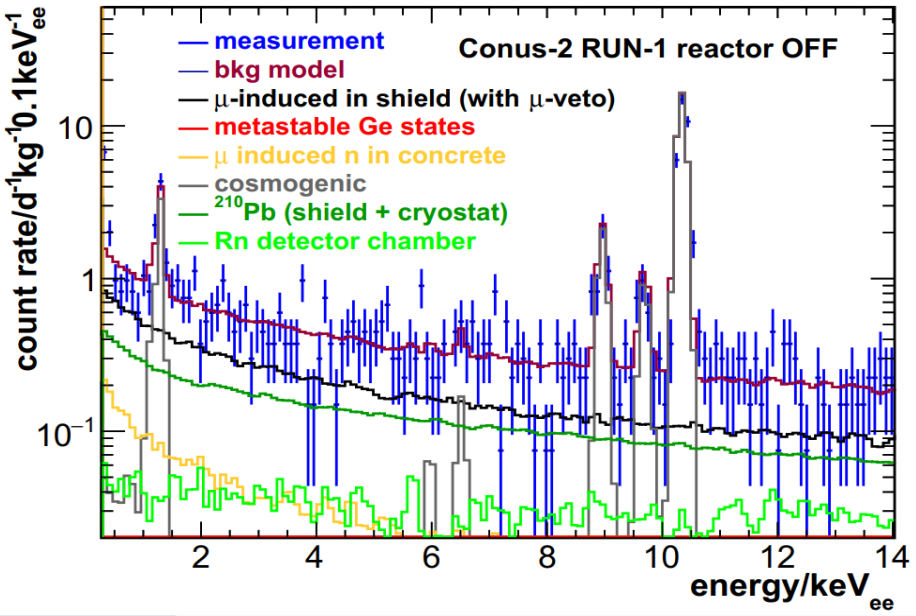
Normal (fast) pulse

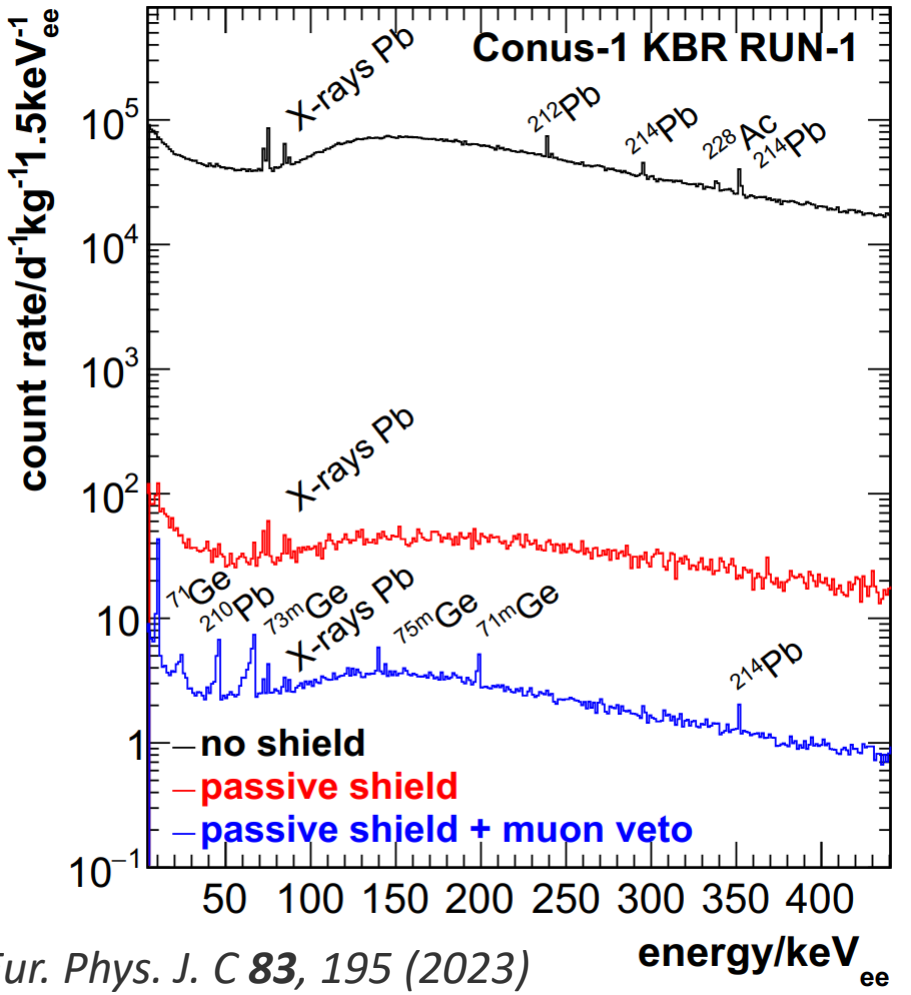


Slow pulse

Background estimation (KBR)

- Suppression factor by shield: >10^4
- Remaining bkg rate in ROI: O(10) cts/d/kg
- Bkg is dominated by muon-induced events and ^{210}Pb events
  - Reactor neutron/activation negligible





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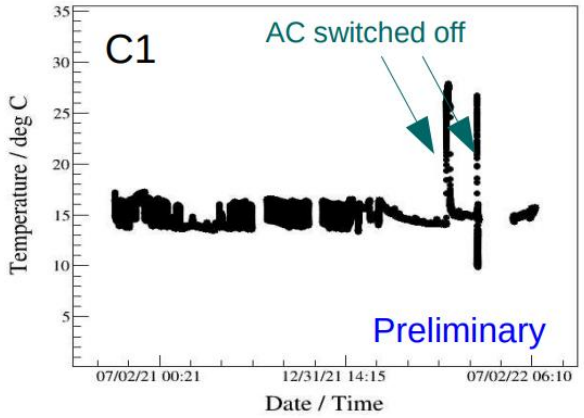
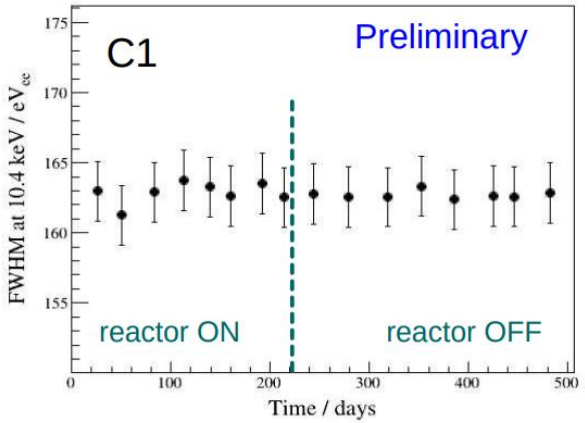
Run stability (Run5)

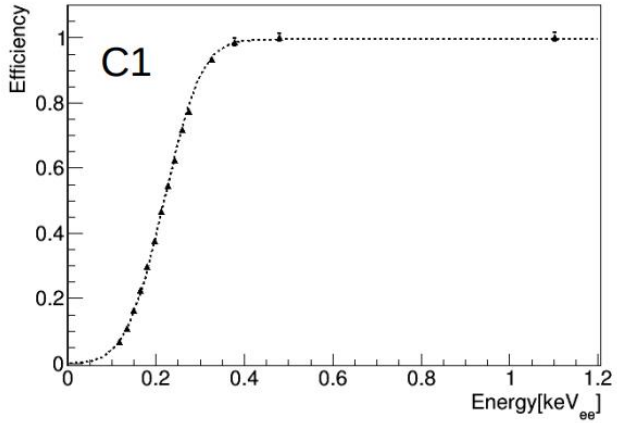
Room temperature



Peak pos. of 10.4 keV line

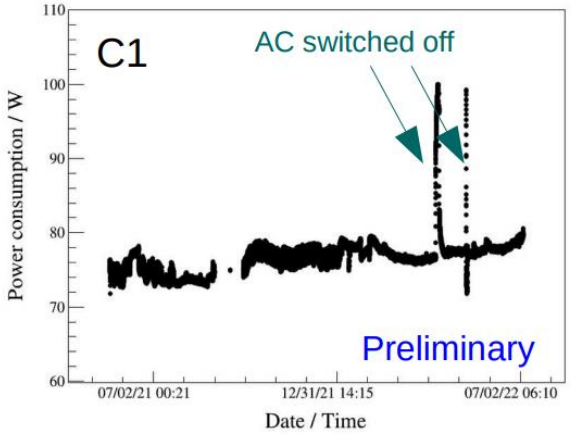


Trigger efficiency curve



Analytical description: 0.5*[1+erf((x-μ)/σ))]

Power consumption



FWHM of 10.4 keV line