CONUS

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On behalf of the CONUS Collaboration

MAX-PLANCK-INSTITUT
FÜR KERNPHYSIK
HEIDELBERG

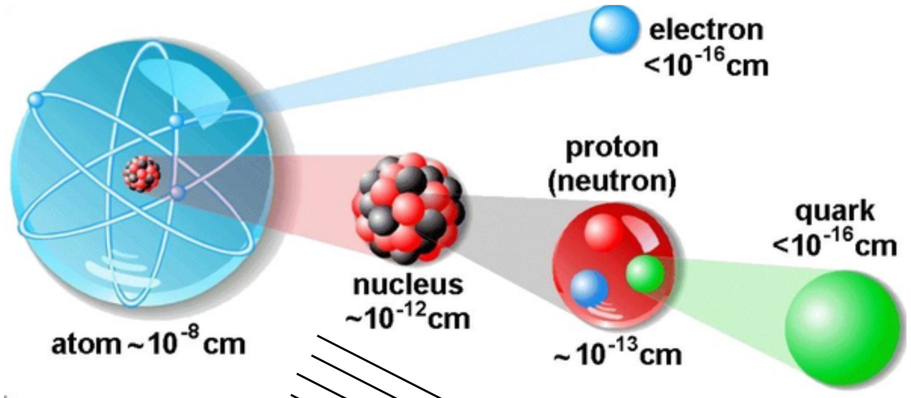
NuTools Mini-Workshop for the Applied Antineutrino Technology Community
July 22 and 24, 2020

Scientific Goals

- **Observe coherent scattering of low energy reactor neutrinos:**
  - CEνS: Predicted 1974 by D.Z. Freedman
  - 1st observed 2017 by COHERENT with ν's from π decay at rest
  - observation at lower energy ←→ complimentary

- **Interesting physics potential ←→ BSM physics:**
  - cross sections ←→ nuclear astrophysics (SN, ...)
  - neutrino magnetic moment
  - precise low energy determination of $\sin^2\Theta_W$
  - NSI's
  - nuclear structure in ν-light
  - dark matter...
  - ...

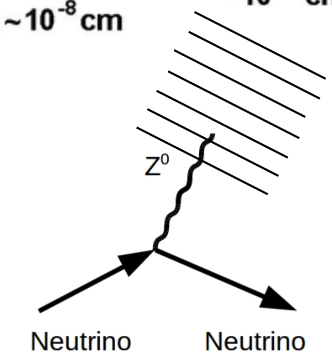
Coherent ν Scattering



Z-exchange of ν's

$Q_w = N - (1 - 4\sin^2\theta_w)Z$ **~ N**

➔ mostly neutrons



coherence length ~ 1/E
size of nucleus ➔ E_ν below O(50) MeV

➔ low E_ν ➔ low x-sections ➔ **high flux** ➔ **close to a strong reactor**

$$\frac{d\sigma(E_\nu, T)}{dT} = \frac{G_f^2}{4\pi} Q_w^2 M \left(1 - \frac{MT}{2E_\nu^2}\right) F(Q^2) \sim \mathbf{N^2}$$

➔ MeV-ish ν's with low recoil energies ➔ very low threshold
Advantage: $F(Q^2) \simeq 1$ ➔ well suited to extract info on new physics

The CONUS Experiment

Combine:

1) very low detection threshold ←→ R&D
2) highest neutrino flux → close to a power reactor
3) best background suppression → "virtual depth"

→ **COherent NeUtrino Scattering experiment**

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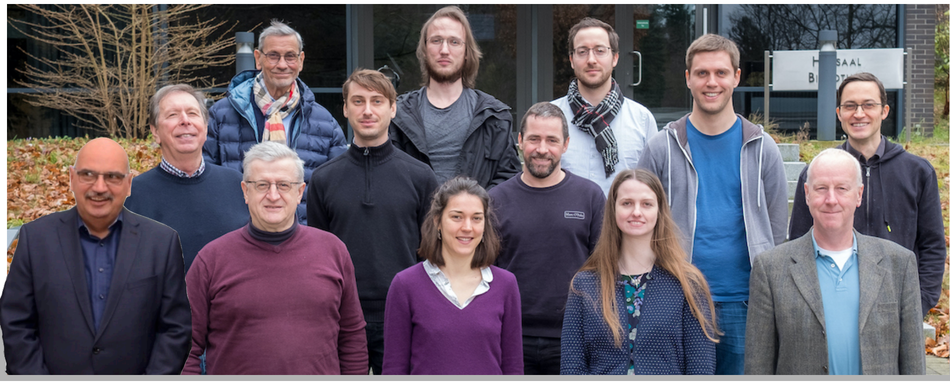
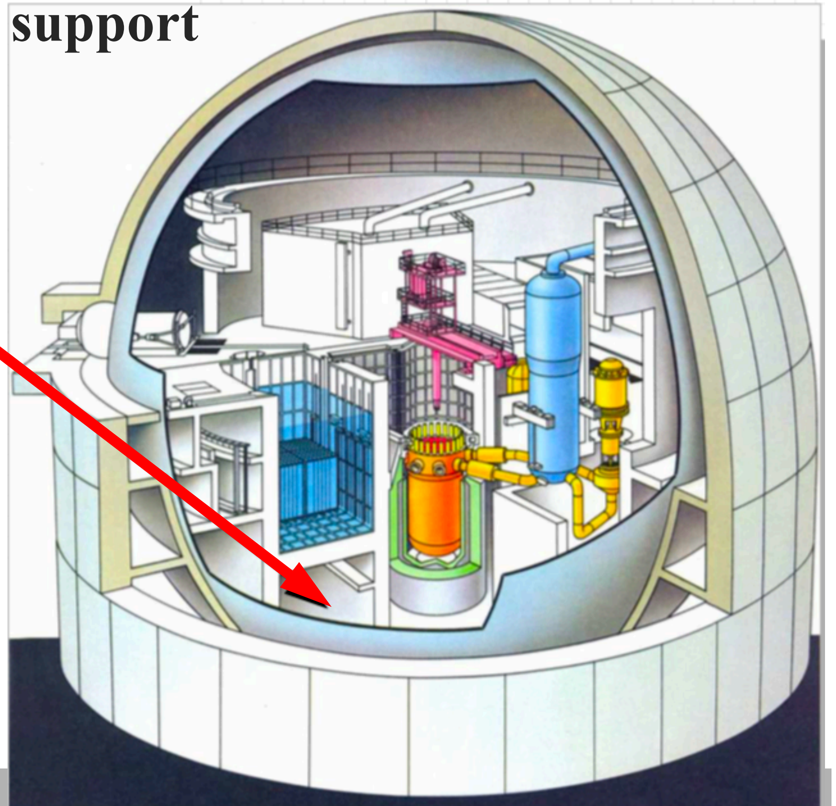
Preussen Elektra



The Brokdorf Reactor Site

Brokdorf (Germany) nuclear power plant:

- thermal power 3.9 GW_{th}
- detector @ d=17m
  ➔ ν flux: 2.4 x $10^{13}/cm^2/s$
  very high duty cycle
- very detailed reactor information & excellent support

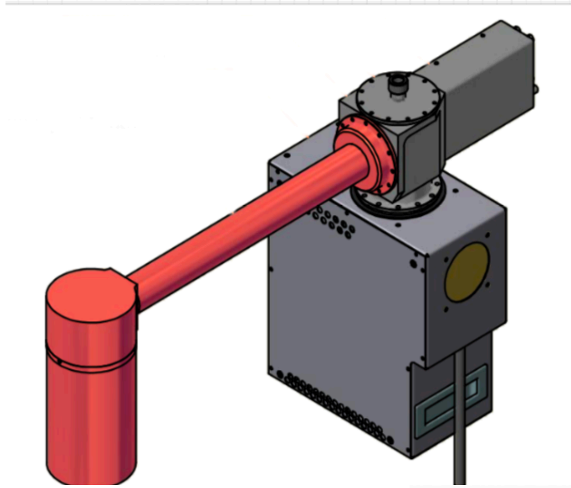


➔ very intense integral neutrino flux
E_ν up to ~ 8 MeV → fully coherent

- overburden 10-45 m.w.e
- access during reactor operation
- measurements of n background
- ON/OFF periods
  ➔ background only measurement

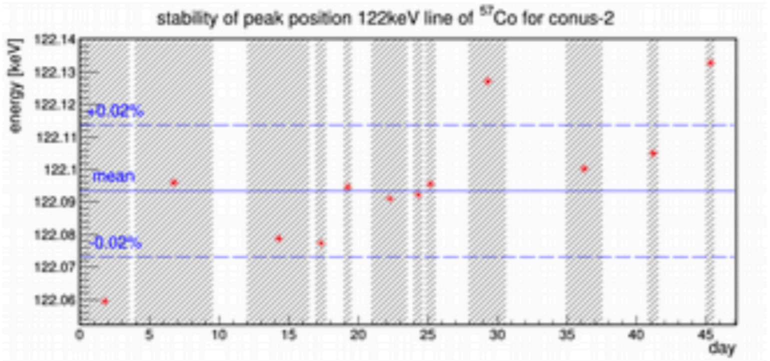
Detectors: CONUS 1-4

- p-type point contact HPGe
- 4x 1kg – **active mass 3.85kg**
- spec. for pulser res. (FWHM) ≤ 85eV
  → noise threshold < 300eV
- **electrical PT-cryocoolers**
- ultra low background components
- close R&D collaboration with Canberra

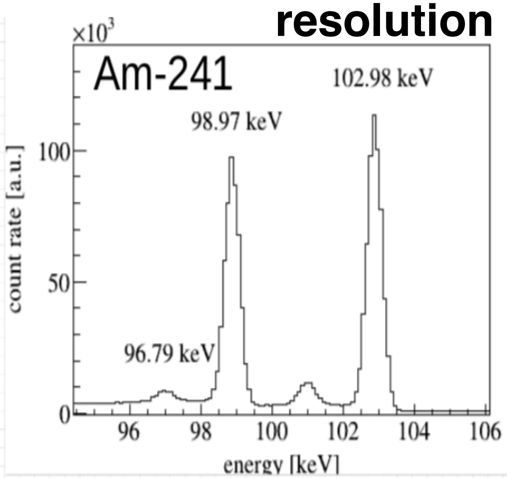


Detector	Pulser FWHM$_P$ [eV$_{ee}$]
CONUS-1	69±1
CONUS-2	77±1
CONUS-3	64±1
CONUS-4	68±1

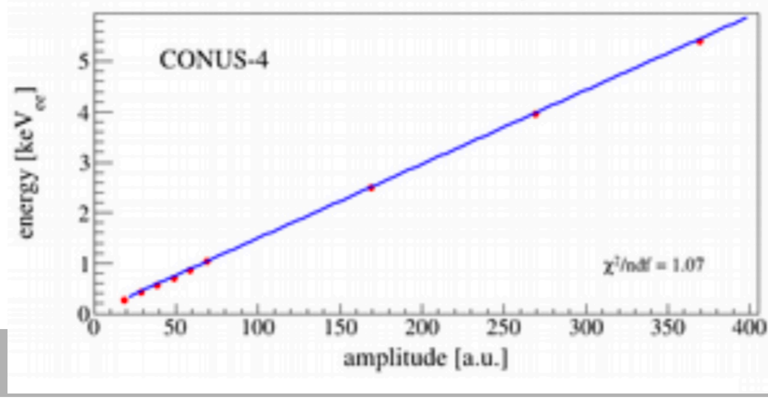
Long term stability
Under lab. Conditions:
stan. dev. of peak position:
+-15eV (+-0.02%)
(within 45 days)



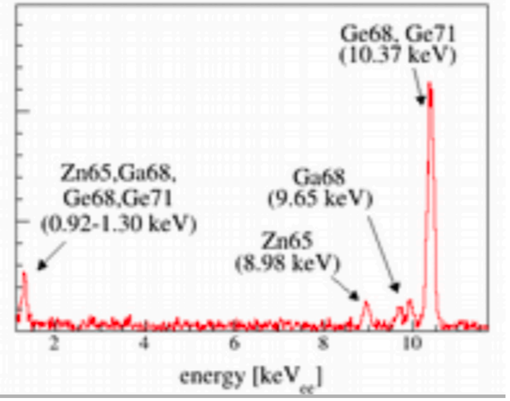
resolution



Linearity of energy scale

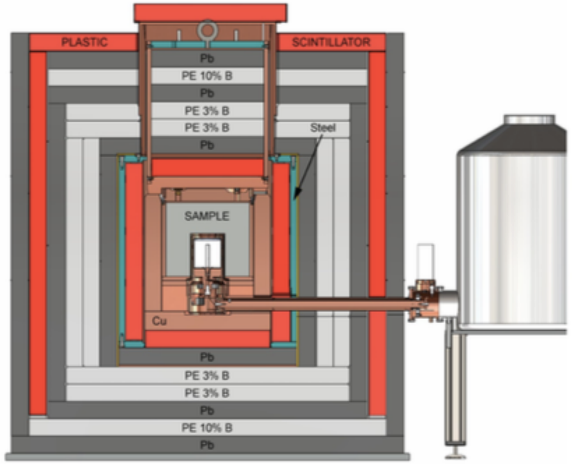


activation lines: calibration

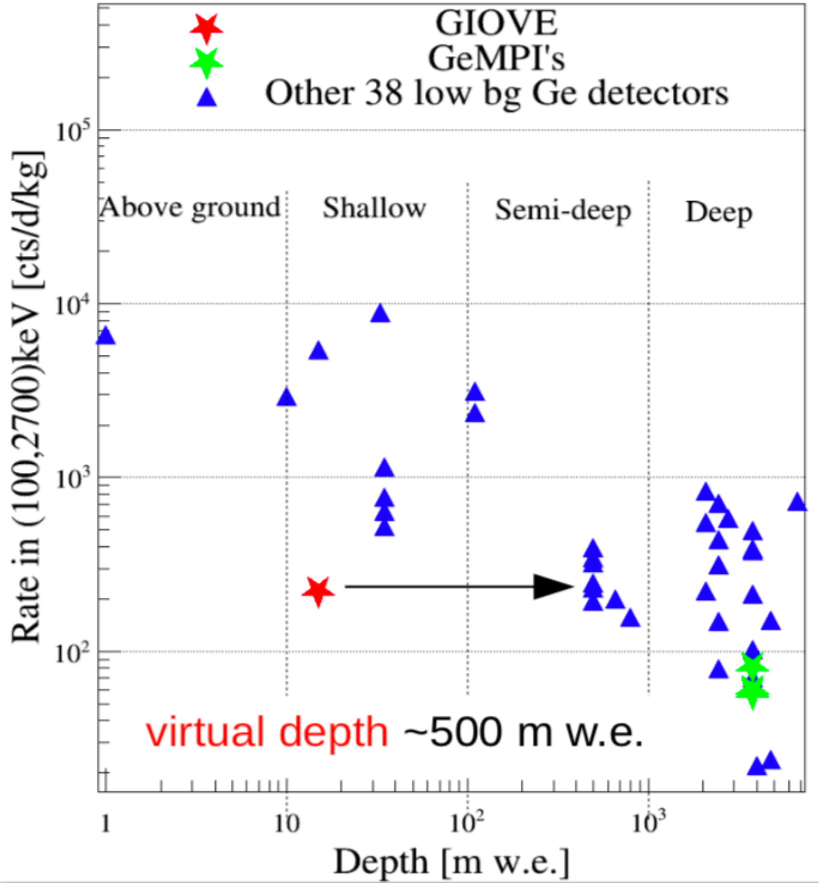


``Virtual Depth'': The GIOVE Shield

GIOVE:
G.Heusser et al.,
Eur. Phys. J. C(2015)75:531



Developed at MPIK
- **main purpose:**
  material screening @ shallow depth (15 mwe)
- **coaxial HPGe detector (m_{act} = 1.8 kg)**
- **optimized radio-pure passive shielding:**
  Pb, B-doped PE, μ-veto, OFHC Cu, ...
- **active veto optimized to reduce μ's and μ-induced signals (neutrons, ...)**
  - plastic scintillators with PMTs
  - 99% muon veto efficiency (dead time ~2%)
- **achieved sensitivity:**
  ^{226}Ra: 70μBq/kg, ^{228}Ra: 110μBq/kg, ^{228}Th 50μBq/kg

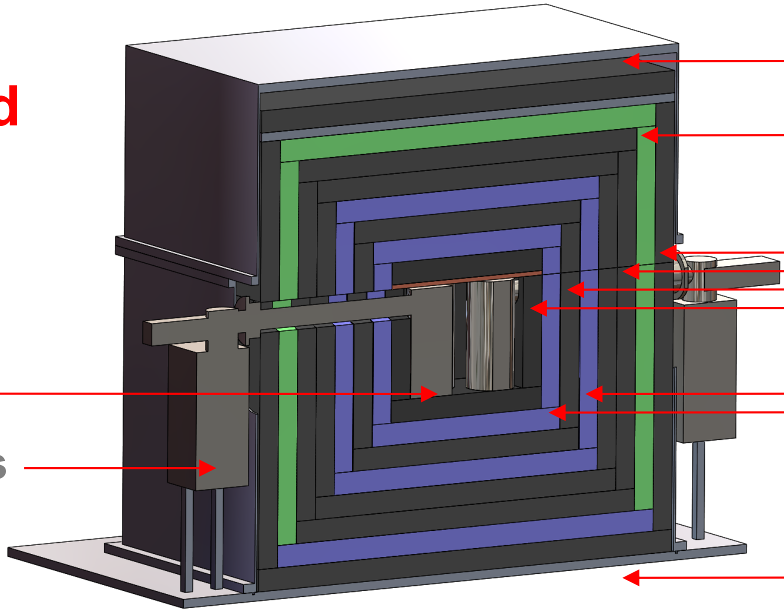


``virtual depth''
➔ UG projects close to surface

The CONUS Detector

<u>The setup:</u>

- 4 Germanium detectors
- PT cryocooling
- "virtual depth" shielding
  - ➔ all ultra low background
  - ➔ ...
- electronics & DAQ
- @ Brokdorf reactor



Combination of three essential improvements:

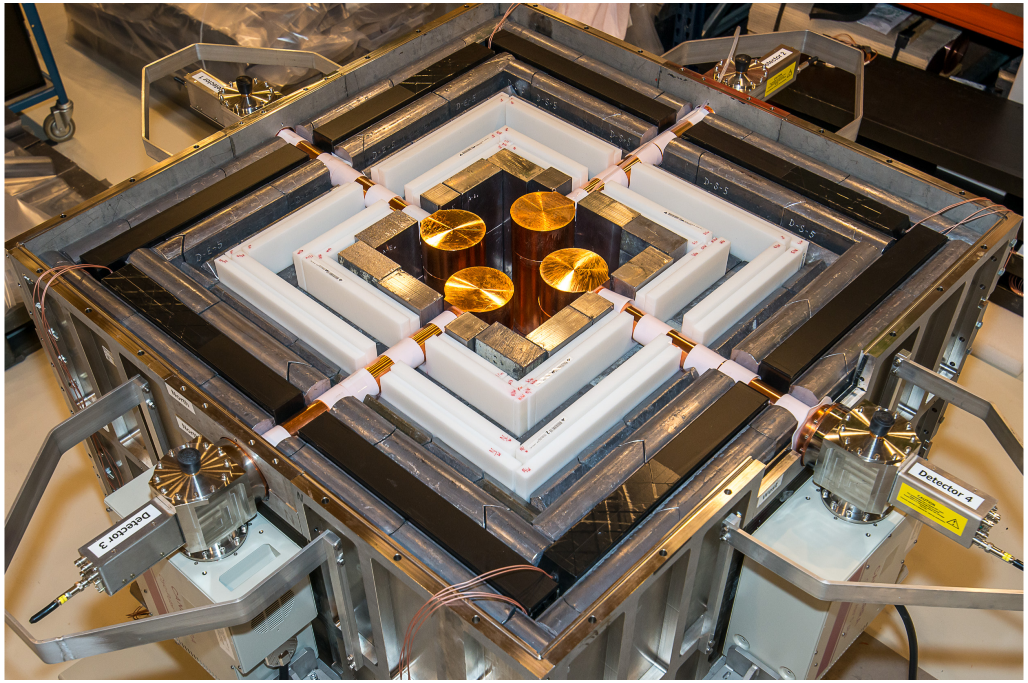
- low background environment ←→ excellent shielding
- detectors with very low thresholds & PT cryocooling
- a site with an extremely high neutrino flux

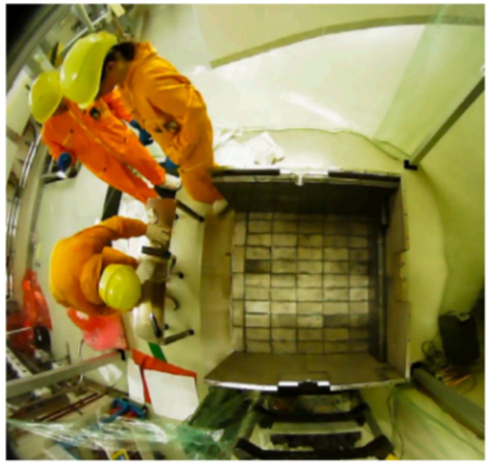
Project start summer 2016 ➔ data taking spring 2018

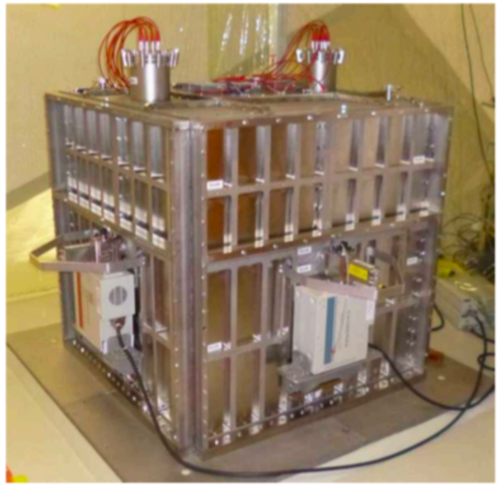
Test Assembly and Installation @ Reactor

assembly at MPIK UG lab
→ characterization
→ commissioning

installation @ Brokdorf
→ full assembly
→ commissioning

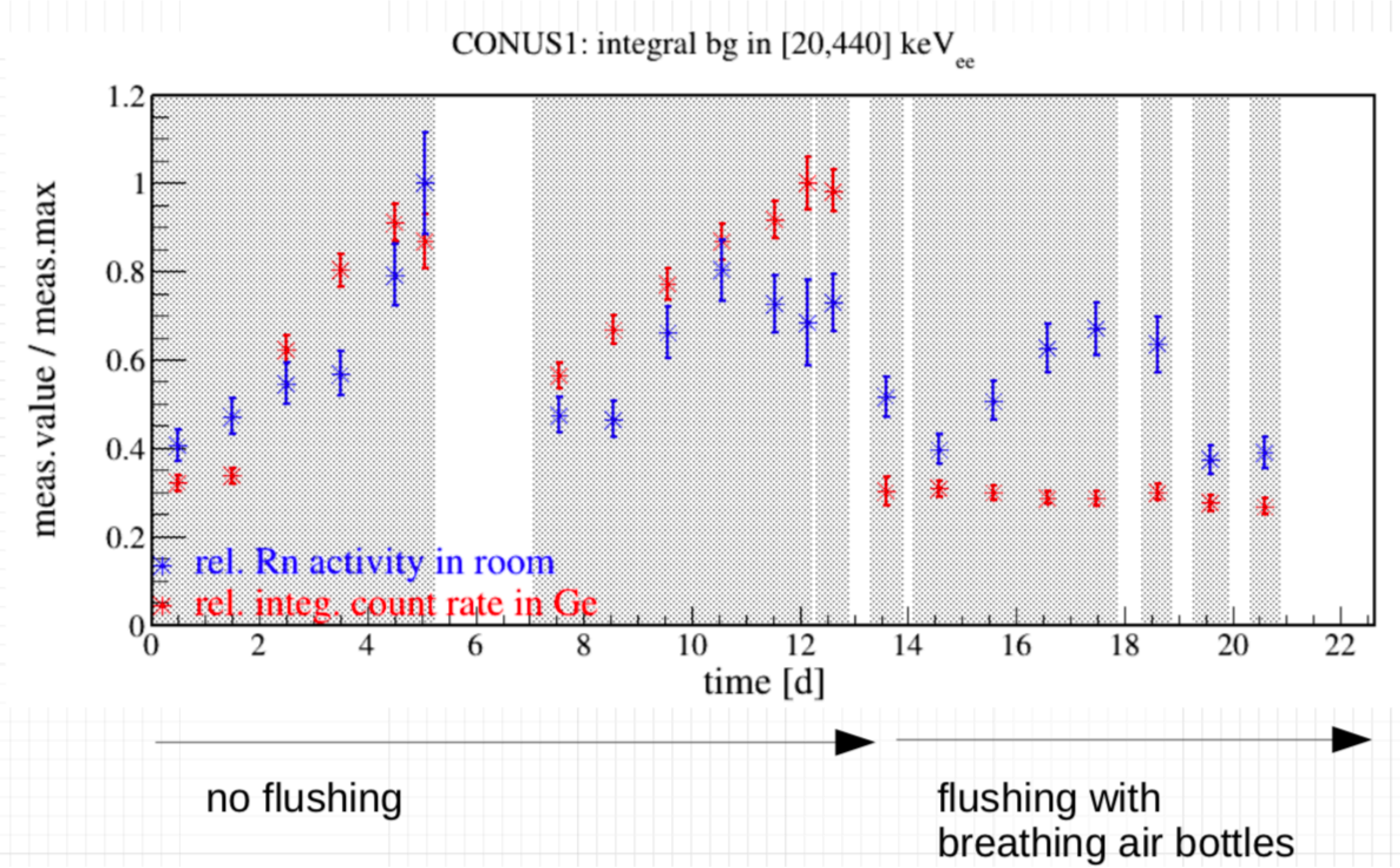




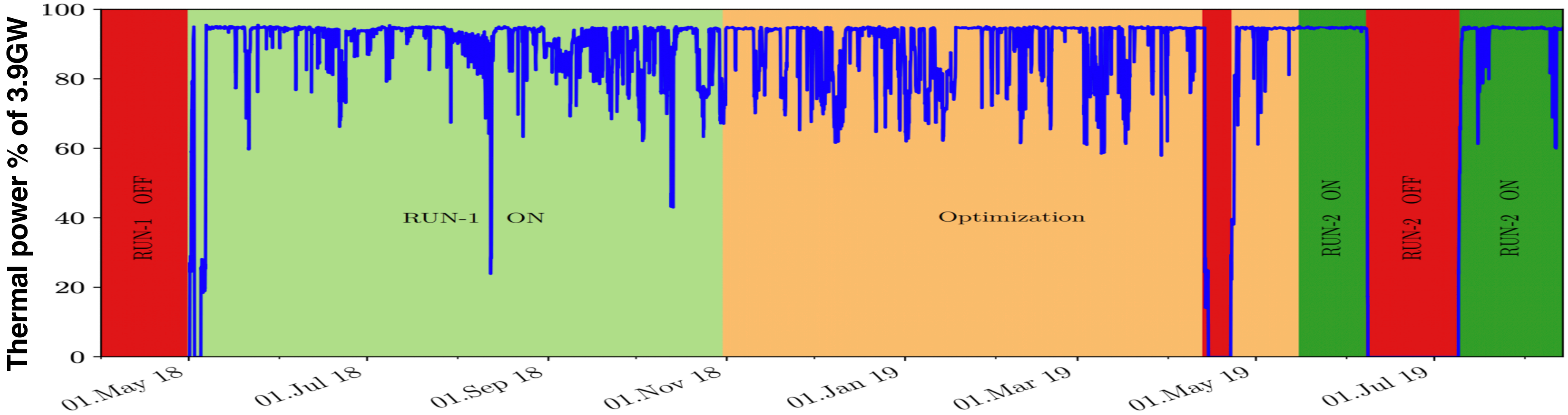


Radon Mitigation @ Reactor Site

radon at reactor site: closed room, thick concrete walls ➔ 100-300 Bq/m^3
half-life of ^{222}Rn: 3.8d ➔ counter measure @reactor site:
hermetical sealing + flush with aged breating air bottles ~1 l/min



Summary



- **Smooth detector operation: reactor ON-OFF (thermal power)**
  - **ON periods: reactor is operated at 95% of maximum 3.9 GW thermal power**
  - **OFF periods: challenging due to environmental stability and less exposure**
  - **Power variations ←→ wind**
  - **"virtual depth" works**: bg rates of 10 (1) cts/d/kg below 1 keV (above 2 keV)

    ➔ lower than what has been achieved by several other DM experiment
  - **Campaigns to understand remaining backgrounds:**

    detailed study of neutrons with PTB: Eur. Phys. J. C (2019) 79: 699

    ➔ reactor correlated neutron background inside shield neligible

    detailed background modelling ←→ fully consistent

    stability studies

    other ...
  - **Reactor neutrino spectrum, ...**