- The **CONUS** Experiment -

COherent elastic **N**e**U**trino nucleus **S**cattering

C. Buck, J. Hakenmüller, G. Heusser, M. Lindner, W. Maneschg, T. Rink, H. Strecker, T. Schierhuber and V. Wagner

Max-Planck-Institut für Kernphysik, Heidelberg

K. Fülber and R. Wink

Preussen Elektra GmbH, Kernkraftwerk Brokdorf

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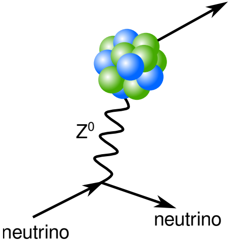
Coherent elastic neutrino nucleus scattering (CEνNS)

Physics of CEνNS

- neutrinos of **all flavors** interact simultaneously with **all nuclei** in a nucleus:
  $\frac{d\sigma}{d\Omega} = \frac{G_f^2}{16\pi^2} Q_W^2 E_\nu^2 (1 + cos\theta) F^2(Q^2)$ with $Q_W = N - (1 - 4sin^2\theta_W)Z$
  form factor ≈ 1 for low momentum transfer
- $4sin^2\theta_W \approx 0.944 \Rightarrow$ number of neutrons N in nucleus is important: $\sigma \propto N^2$
- e.g. more than 10x larger σ than for inverse beta decay (E_ν up to 50 MeV)
- coherence condition: λ(de Broglie) of mom. transfer $>$ size of atom
  $\Rightarrow E_\nu < 50$ MeV (full coherency for Ge: $E_\nu < 30$ MeV)
- predicted 1974: D.Z. Freedman, Phys. Rev. 9(1974)5, so far undetected

Relevance of CEνNS

- precision measurements $\rightarrow$ tests of Standard Model
- deviations $\rightarrow$ physics beyond Standard Model
- neutrino floor in dark matter experiments: similar recoil of WIMPs and νs
- Star collapse: 99% of grav. binding energy carried away by νs $\rightarrow$ explosion & ν scattering



Requirements for Detection of CEνNS

Observable

- recoil energy of nucleus hit by ν

  $T_{max} \approx \frac{2E_\nu^2}{m_{nuc}}$ with $m_{nuc} = m_{Neutron}(N+Z)$

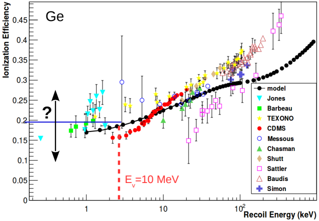
  $\Rightarrow$ push-pull situation: $\frac{d\sigma}{d\Omega} \propto N^2$ vs. $T_{max} \propto \frac{1}{m_{nuc}}$

  e.g. for $E_\nu = 10$ **MeV**:

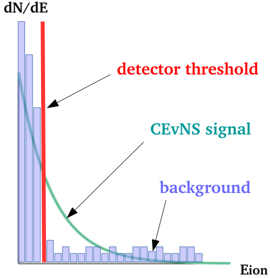
  maximal recoil of T_{max}**=3 keV** in Germanium

BUT quenching factor: not all energy converted into ionization energy (Lindhard Theory)

e.g. for Ge up to 80% loss $\Rightarrow$ signal $<$ **600 eV**



D. Barker, D.M. Mei, 2012 [1]



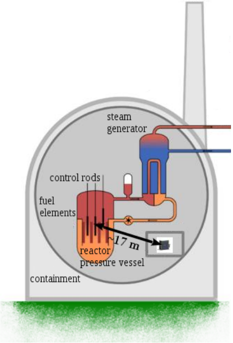
Requirements for CONUS

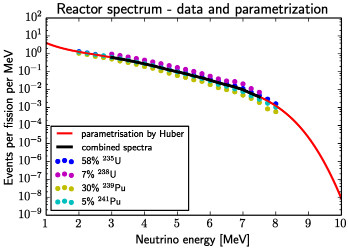
1. strong neutrino source with E_ν in coherent regime
   $\rightarrow$ commercial nuclear power plant
2. detector with low enough energy threshold
   $\rightarrow$ low threshold point contact Ge detectors
3. special background suppression
   $\rightarrow$ shell-like passive shield + active muon veto

The Source: Nuclear Reactor

commercial nuclear power plant in Brokdorf (Germany)

- max. thermal power: 3.9 GW, high duty cycle
- distance to reactor core: 17 m
- expected $\bar{\nu}$ flux: $O(10^{13}\, s^{-1} cm^{-2})$
- $\bar{\nu}$ energy up to 8 MeV $\Rightarrow$ purely coherent
- overburden: $\sim$10-45 m w.e.
- (reactor ON - reactor OFF) spectrum for background reduction





Parametr./Data: from P. Huber [2] and N. Haag [3]

https://de.wikipedia.org/wiki/Kernkraftwerk_Brokdorf

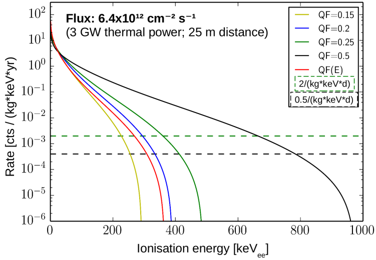
Detectors for CONUS: Threshold + Quenching

Expected signal (**feasibility study**: T. Rink, W. Maneschg, M. Lindner (2016))

- Assumptions:
  - Background level: $1\,kg^{-1}d^{-1}keV^{-1}$
  - 3 GW reactor at 15 m $\rightarrow \bar{\nu}$ flux: $2.4{\cdot}10^{13}\,cm^{-2}s^{-1}$

$\Rightarrow$ S/B ratios:

E_{Ion}^{Th}[keV_{ee}]	Qf=0.15	**Qf=best fit**	Qf=0.2
0.30	0.4	**1.8**	4.0
0.24	3.2	**8.6**	16
0.18	22	**35**	59



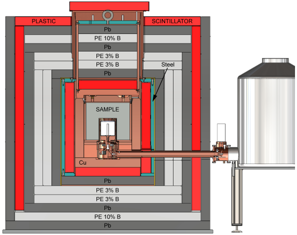
Requirements for **Ge diodes**

- low energy threshold & low-background
  $\Rightarrow$ high-purity point contact Ge detectors
  (prestudy on modified BEGes at MPIK, M. Salathe [4])
- for **CONUS**:
  - ∼4 kg target mass
  - low-background:
    * screening of internal parts
    * close cooperation for Cu cryostats
    * storage underground

Shield Concept at shallow Depth: GIOVE

Comparison of background levels

detector	depth [m w.e.]	μ flux reduction	Bkg rate [45,50] keV [$kg^{-1}d^{-1}keV^{-1}$]
Gemma-I[5]	70	$\sim$ 10	2.1 ± 0.7
Texono[6]	25	$\sim$ 4	1.3 ± 0.5
GIOVE[7]	15	$\sim$2-3	0.4 ± 0.1



G. Heusser et al., 2015 [7]

GIOVE: **Ge** Spectrometer with **I**nner and **O**uter **VE**to

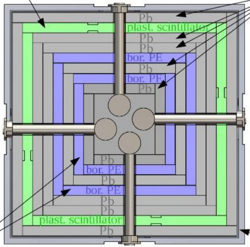
- coaxial high-purity Ge Spectrometer, $m_{active}=(1.8\pm0.1)$ kg
- active μ veto: plastic scintillator with PMTs veto efficiency: ~99% (dead time loss: ~2%)
- passive shield:
  - lead and copper: against nat. radioactivity
  - borated polyethylene: to moderate and capture neutrons
- main purpose: material screening

⇒with overburden of 5-6 m "virtual depth" of **several 100 m w.e.** achieved
⇒optimization of shield for CONUS with focus on low energies

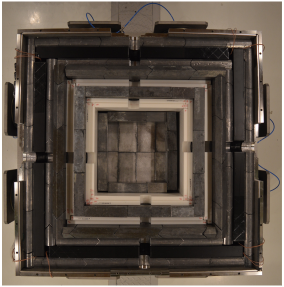
CONUS Shield

Active muon veto:
Plastic scintillator plates
with PMTs

Shield against nat. radioactivity:
Pb, inner layers low ^{210}Pb content



Steel cage

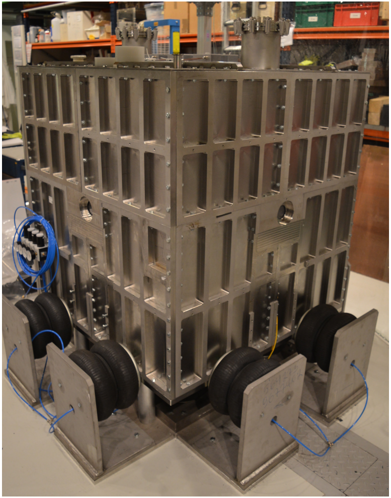


Moderate and capture neutrons:
Polyethylene plates with boron
from boron acid,
boron acid enriched in ^{10}B (equivalent to 3% nat. boron)

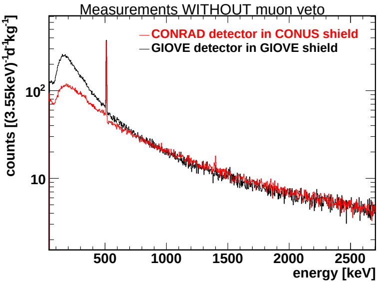
Shield layers

- most inner layer: lead ⇒ suppresses bremsstrahlung's continuum induced by μs
- all materials carefully selected with screening detectors (@MPIK and @LNGS)
- testing at Low Level Laboratory at MPIK (15 m w.e.):
  - mechanical tests
  - muon veto performance (with coaxial high-purity Ge spectrometer CONRAD)
  - radiopurity of shield (with CONRAD)

CONRAD Detector in CONUS Shield - during assembly



Muon-induced Background in CONUS Shield with CONRAD Detector



Bremsstrahlung's continuum:

- more bremsstrahlung in Pb than in Cu ($\propto Z^2$)
- BUT also better self-shielding in Pb ($\propto Z^5$)

$\Rightarrow$ in total lower count rate at low energies

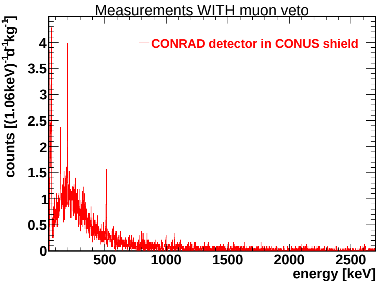
Energy m_{act}	GIOVE 1.8±0.1 kg	CONRAD ≈2.2 kg*
[45,100] keV, cts in $d^{-1}kg^{-1}$	2146 ± 13	1162 ± 8 *
[100,500] keV, cts in $d^{-1}kg^{-1}$	$18\,177 \pm 38$	9799 ± 23*
[45,2700] keV, cts in $d^{-1}kg^{-1}$	$30\,952 \pm 50$	$20\,407 \pm 33$*
511 keV, cts in d^{-1}	1113 ± 17	1203 ± 12

* detector characterization in progress, only stat. uncertainty on meas. data given

CONUS Shield with CONRAD Detector - Muon Veto Performance

Muon veto efficiency

- muon veto efficiency: around 99% (comparable to GIOVE)
- nearly no line background of radioactive contamination
- in region of interest [45,50] keV: $<1\,\mathrm{kg}^{-1}\mathrm{d}^{-1}\mathrm{keV}^{-1}$
  $\Rightarrow$ first design goal achieved!



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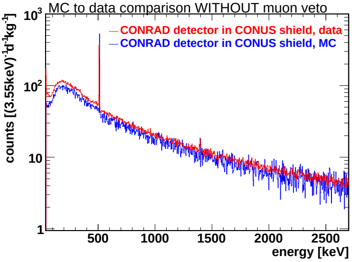
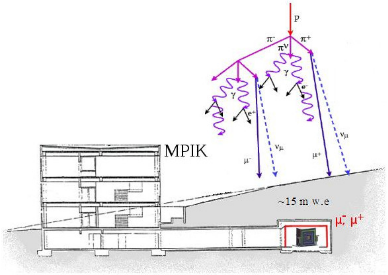
CONRAD	15	$\sim$2-3	0.7 ± 0.1

$\Rightarrow$ "virtual depth" of several 100 m w.e. achieved!

Muon-induced Background: Monte Carlo Simulation for CONRAD Detector





Energy detector	diff* CONRAD**	diff* GIOVE
[45,100] keV	$25 \pm 3\%$	$9 \pm 8\%$
[100,500] keV	$16 \pm 1\%$	$1 \pm 7\%$
[45,2700] keV	$15 \pm 1\%$	$2 \pm 7\%$
511 keV	$7 \pm 3\%$	$8 \pm 5\%$

*diff = (data-MC)/data

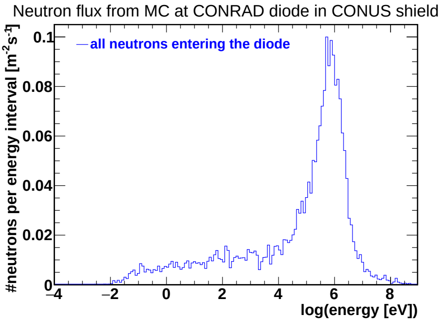
**uncertainty on active volume not known yet

Modeling of cosmic background

(described in JH et al., proceeding, 2015 [8])

- **calculation** of μ flux in lab
- **MC simulation** of μs through shield with MaGe [9], based on Geant4 [10],[11]
- prompt muon-induced continuum:
  - excellent agreement for GIOVE [8]
  - good agreement for CONRAD

Neutron background in CONUS



Neutron background at **reactor site** (10-45 m w.e. overburden)

- **Cosmic ray background**: slightly larger overburden than at MPIK
  - similar conditions expected: muon-induced neutrons in shield dominate
  - background understood and acceptable
- Neutrons **from reactor**:
  - measurement by Nat. Metrology Institute of Germany (PTB Braunschweig) in progress
  - MC simulation from reactor core to exp. site in progress

  $\Rightarrow$ first outcome: - mostly thermal neutrons arrive at experimental site
  - thermal neutrons are shielded well
  - within shield: **mostly** muon-induced neutrons in lead

Summary and Outlook

CONUS experiment

- looking for coherent elastic neutrino nucleus scattering with Ge point-contact detectors

CONUS shield

- similar to demonstrated GIOVE concept, inner layer Pb instead of Cu
- tests with CONRAD detector at MPIK (15 m w.e.):
  - design goal of $<1\,\mathrm{kg}^{-1}\mathrm{d}^{-1}\mathrm{keV}^{-1}$ in [45,50] keV achieved!
  - lower muon-induced bremsstrahlung's continuum than for GIOVE
  - active muon veto efficiency: $\sim$99%
  - nearly no radioactive contaminations of shield materials
  - successful simulation of muon-induced bkg

CONUS Detectors 1-4

- 2 detectors at MPIK, 2 expected soon
- characterization of low-threshold detectors:
  - diode characteristics like active vol.
  - threshold behavior
- test of radiopurity in CONUS shield

Nuclear Power Plant in Brokdorf (GER)

- final approval expected in **3 days from now**!!!
- transport and buildup of experiment, avoid contaminations
- simulation and measurement of neutron background

A lot more to come! Start of data acquisition within **2017**!

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