Exploring coherent neutrino-nucleus scattering with NU-CLEUS

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Invisibles18

SFB 1258 Neutrinos Dark Matter Messengers

European Research Council

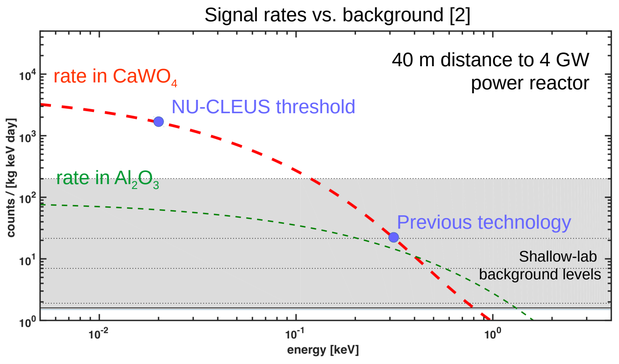
Coherent scattering at power reactors

Large CNNS cross-section allows
- a small (~10g) target
- Distant sites without reactor-correlated backgrounds

Heavy W nucleus in $CaWO_4$ boosts cross-section (~30 over Al_2O_3 below 100eV)

Multi-target approach ($CaWO_4$+ Al_2O_3) for in-situ background characterization:
- essentially no CNNS on Al_2O_3 (only light nuclei)
- similar neutron responses (oxygen)

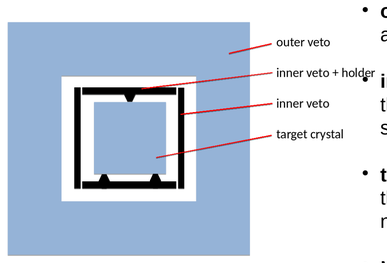
Signal rates vs. background [2]



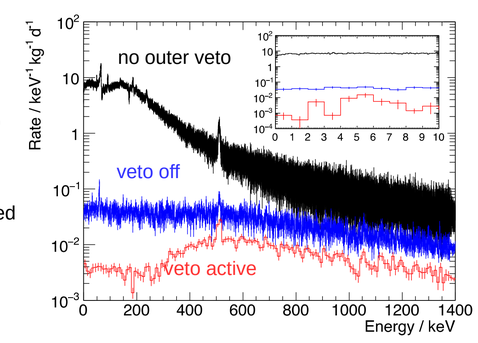
Fiducial volume cryogenic detector

→ High sensitivity with small-scale experiment

A fiducial-volume cryogenic detector



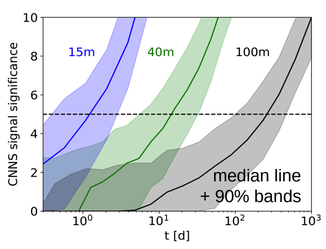
- **outer veto:** kg-scale cryogenic detector against penetrating γ/n backgrounds [2]
- **inner veto**: instrumented holder, low-threshold cryogenic detector against α/β surface contaminations
- **target detector**: fiducialised ultra-low threshold cryogenic detector for ν-induced nuclear recoils
- Monte Carlo studies promise excellent background suppression



→ Background goals in reach

Sensitivity Studies

- Array of 9 x $CaWO_4$ + 9 x Al_2O_3 detectors (10g total)
- 4 GW reactor power at different distances
- Background model: flat at a rate of 200/(keV kg d)
- Unbinned likelihood ratio tests with 2 free parameters: background and signal normalization
- Yields significance of the claim of a CNNS signal with non-zero cross-section in addition to the background
- Additional studies with exponential backgrounds

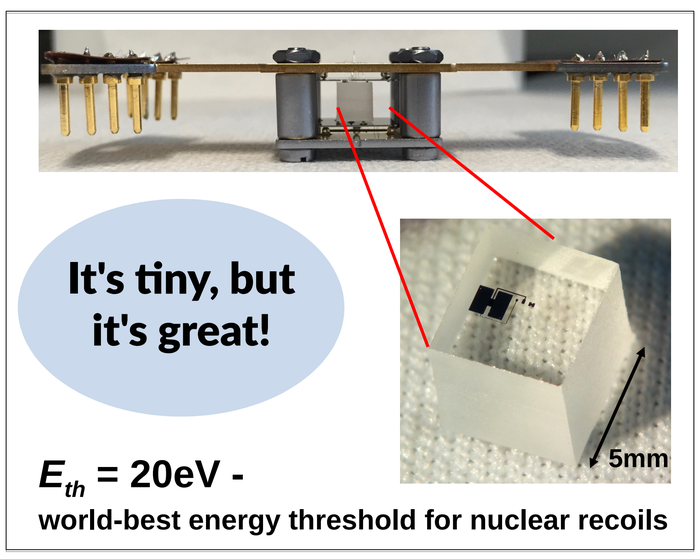


Integrated CNNS count rates between 10eV and 5 keV [2]

d		15m	40m	100m
counts [array d]$^{-1}$	$CaWO_4$	4.75	0.67	0.11
	Al_2O_3	0.49	0.07	0.01

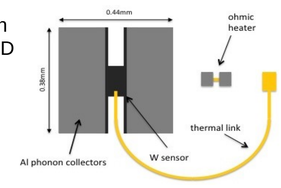
→ Observation within 2 weeks

Gram-scale cryogenic calorimeters

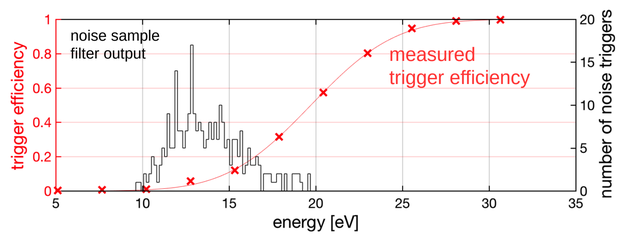


First Detector Results

- **Target detector:** (5mm)^3 Al_2O_3 cube derived from CRESST-technology
- **Above-ground operation** shown in a high-background environment
- **Temperature sensor:** thin-film tungsten transition edge sensor (TES) with SQUID readout
- Energy calibration: 5.9keV and 6.5keV



Ultra-low energy threshold: (19.7±0.9)eV



R. Strauss et al., Phys. Rev. D, 96, 022009 (2017)

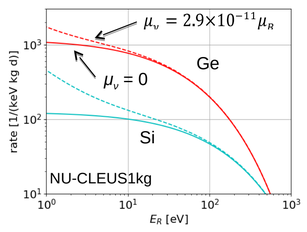
→ Ultra-low thresholds demonstrated

High potential for the future

Numerous BSM observables can be probed, e.g.:
- Neutrino non-standard interactions
- Weak mixing angle at low momentum transfer (~MeV/c²)
- Exotic neutral currents
- Sterile neutrino searches
- Neutrino magnetic dipole moment

Technological applications: Reactor safeguard measures, non-proliferation

Example:
Neutrino magnetic dipole moment



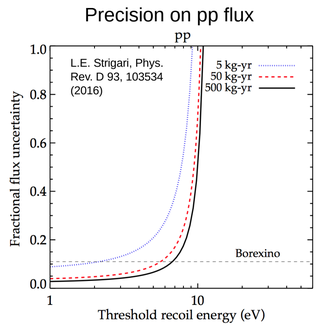
Best sensitivity to μ_ν (~$10^{-12}\mu_B$) within a year!

Dark Matter and solar neutrinos:

NUCLEUS Prototype: First limit on light dark matter for masses < 500MeV/c² [3]
- Future: Significant improvement at shallow sites

A next generation solar neutrino experiment based on NU-CLEUS technology (deep underground)
- Best precision on pp neutrinos with NU-CLEUS1kg
- First measurement of CNO neutrinos in reach with 100kg detector

Precision on pp flux

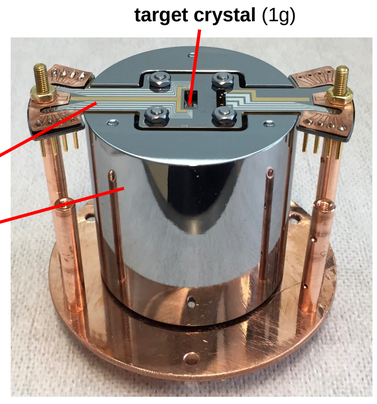


→ New physics with a miniaturized detector

1g NU-CLEUS demonstrator

- Demonstrator fully assembled (target+vetos)
- Commissioned in April 2018
- Exciting measurements ahead!

target crystal (1g)



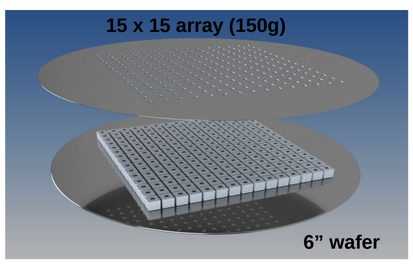
Inner cryogenic veto + detector holder

Outer cryogenic veto: 200g cup-shaped Si crystal (top one not shown for clarity)

Excellence cluster Universe: Seed money funds 2017+2018

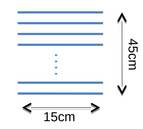
→ NU-CLEUS 1g ready

Scalable cryogenic technology



- Employing standard processes of the semiconductor industry
- **One-step array fabrication** with dicing after TES deposition
- Easy manufacture of larger arrays (10-100 kg feasible)
- Multiplexed SQUID readout

→ 10kg total target mass feasible



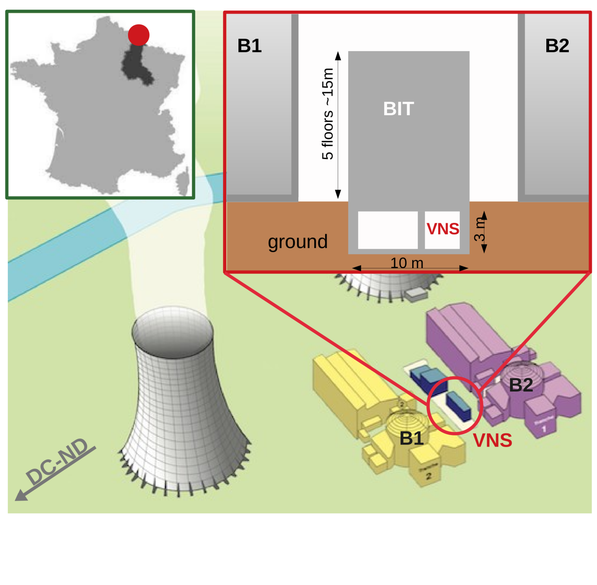
10kg still table top!

The Very-Near-Site (VNS) at the Chooz Power Plant

a new short baseline site at the Chooz nuclear power plant in France to host a CNNS experiment based on the NU-CLEUS technology

The Chooz Power Plant:
- commercial nuclear power plant in the Ardennes region, France
- operated by Electricité de France (EdF)
- 2 reactor cores delivering **4.25 GW_{th}** power each, separated by a distance of 160 m
- host of the Double Chooz (DC) experiment since 2006

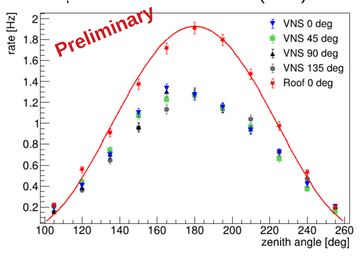
The VNS:
- 24m² basement room in an administrative building (BIT), located in between the two reactor containment buildings
  → need for a **compact shielding**
- baseline of **70 m and 100 m** respectively
- **high expected ν-flux (> 10^{12} cm^{-2} s^{-1})**
- on-going background characterization (μ, neutrons and gammas)



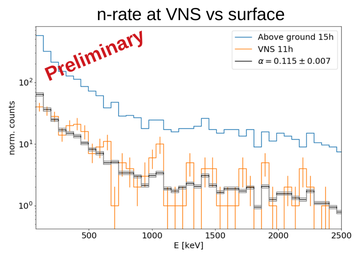
Background Characterization @ VNS:
- started beginning of 2018
- neutron attenuation measured with liquid scintillator cells from TUM
- μ-attenuation measured with cosmic wheel from Centre de Physique des Particules de Marseille (CPPM)

Preliminary Results
n-attenuation ~8
μ-attenuation ~1.4
overburden < 5 m w.e.

μ-rate at VNS vs surface (Roof)



n-rate at VNS vs surface



Dead-time considerations @ VNS:
- dedicated μ-simulations started
  → expected μ-trigger rate of **~500 Hz** for a 1m x 1m x 1m veto
- fast rise-time of NU-CLEUS detectors implies a **dead-time of only 1%**
- with NU-CLEUS-technology a μ-veto up to a size of 2m x 2m x 2m feasible

Next Steps
- further background measurements and full MC simulation campaign
- publications on VNS characterization in preparation [4] & [5]

References

[1] R. Strauss et al., “Gram-scale cryogenic calorimeters for rare-event searches”, Phys. Rev. D, 96, 022009 (2017) arXiv:1704.04317
[2] R. Strauss et al., “The ν-cleus experiment: A gram-scale fiducial-volume cryogenic detector...”, Eur. Phys. J. C, C77(8):506, 2017 arXiv:1704.04320
[3] CRESST Collaboration, G. Angloher et al., “Results on MeV-scale dark matter with a gram-scale calorimeter...”, Eur. Phys. J. C, C77(8):637, 2017, arXiv:1707.06749
[4] V. Wagner et al., to be published
[5] A. Langenkämper et al., to be published