

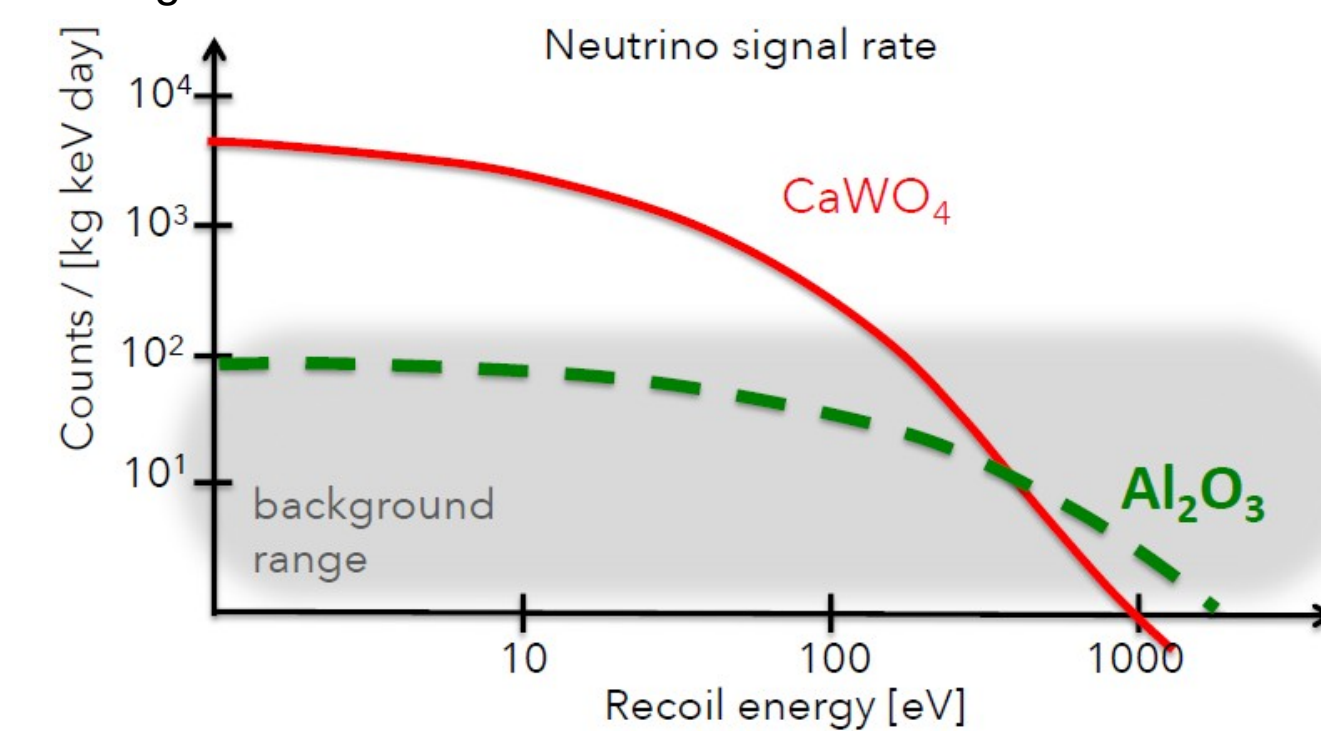
Coherent Elastic Neutrino-Nucleus Scattering: The Potential of NUCLEUS

A precision measurements of the Coherent Elastic Neutrino-Nucleus Scattering (CEvNS) cross-section offers a unique way to study neutrino properties and to search for new physics beyond the Standard Model.

The NUCLEUS experiment will study CEvNS profiting from the following features:

Source: antineutrinos from nuclear reactors
 ⇒ Low energy
 ⇒ High intensity

Detector: gram-scale cryogenic calorimeter
 ⇒ Ultra-low energy threshold ($E_R \approx 20$ keV in prototype)
 ⇒ Low systematics



Multi target with CaWO_4 and Al_2O_3 crystals:
 ⇒ Smoking gun signal
 ⇒ Background discrimination
 ⇒ Test N^2 dependency

Target background level in [20 eV, 1 keV]: 100 cpd/kg/keV

The Experimental Site @ VNS of CHOOZ Nuclear Power Plant

24m² basement room (~3 m.w.e.) in administrative building between two 4.25 GW_{th} reactors

Distance to reactor core: 72 m to B-1 and 102 m to B-2

$\Phi_{\bar{\nu}_e} \approx 1.7 \times 10^{12}$ v/cm²/s; $E_{\bar{\nu}_e} < 10$ MeV

30% reduction of the cosmic μ

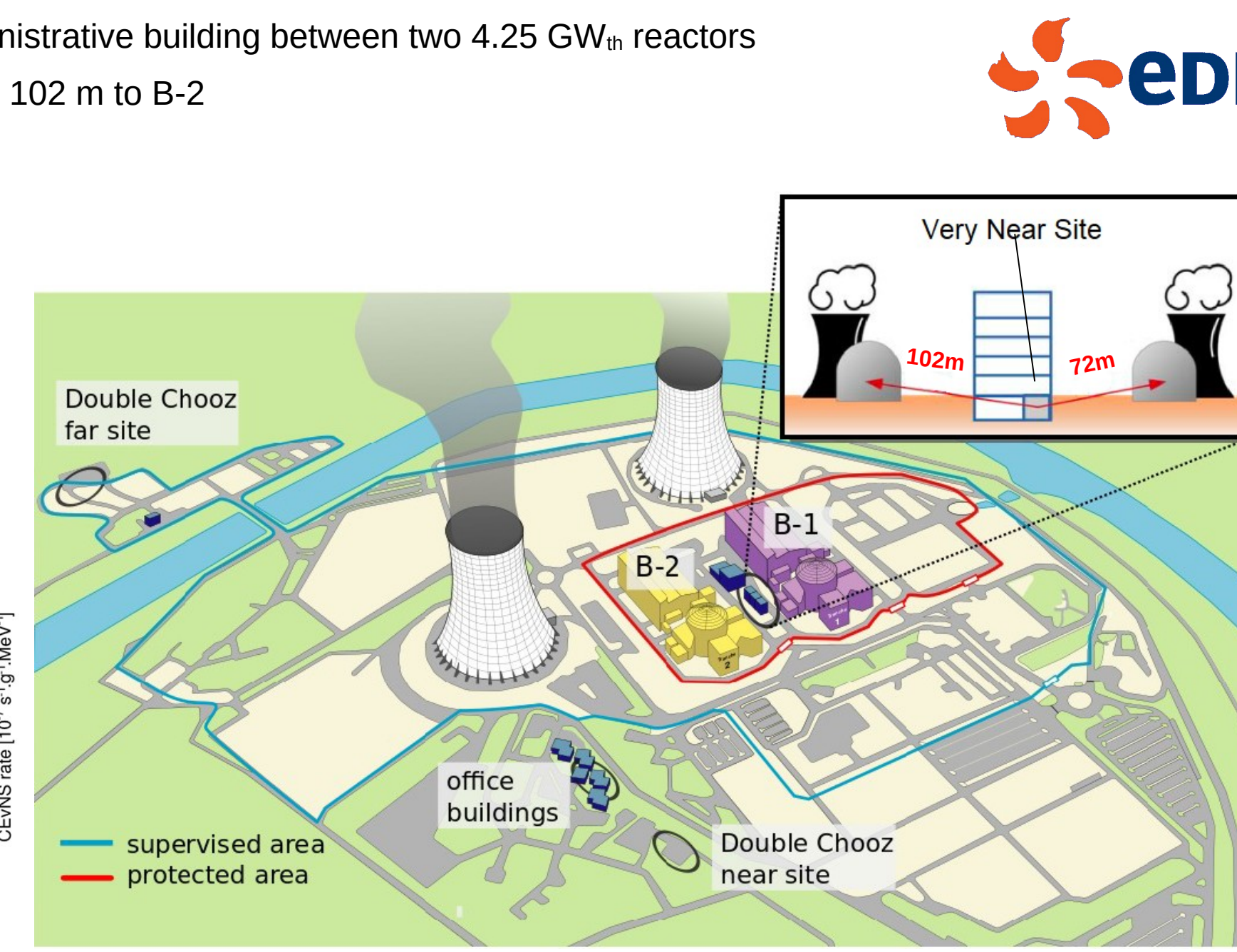
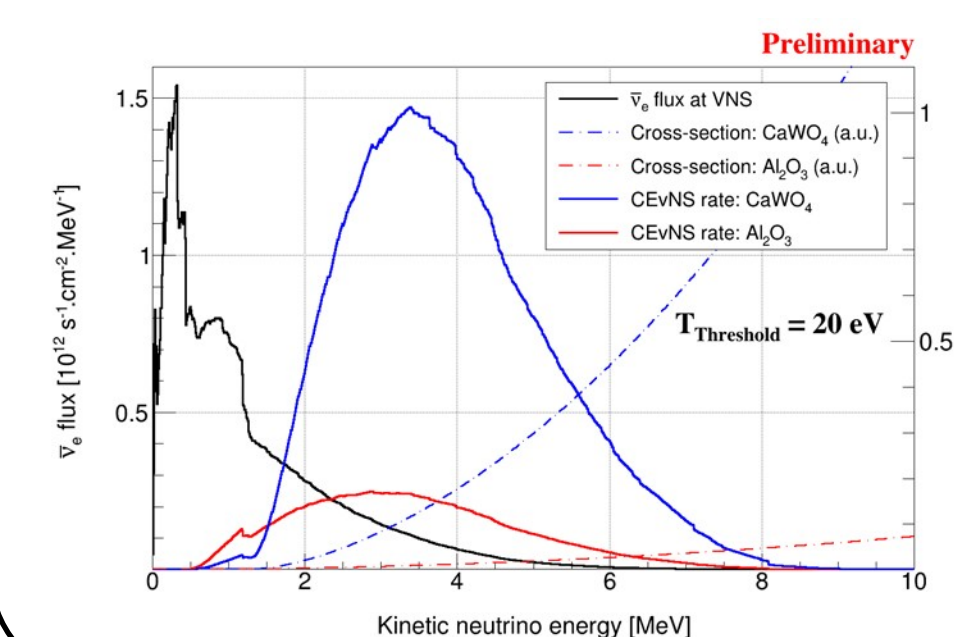
Environmental γ , n and Rn measured:

$\Phi_{\gamma} \approx 3$ γ /cm²/s

$\Phi_n \approx 5 \times 10^{-3}$ n/cm²/s

$R_n \approx 30$ Bq/m³

Vibration measurement performed



The NUCLEUS Cryogenic Detectors

The NUCLEUS cryostat will hold a system of nested cryogenic detectors that will allow the reduction of the background counting rate thanks to the anticoincidence technique

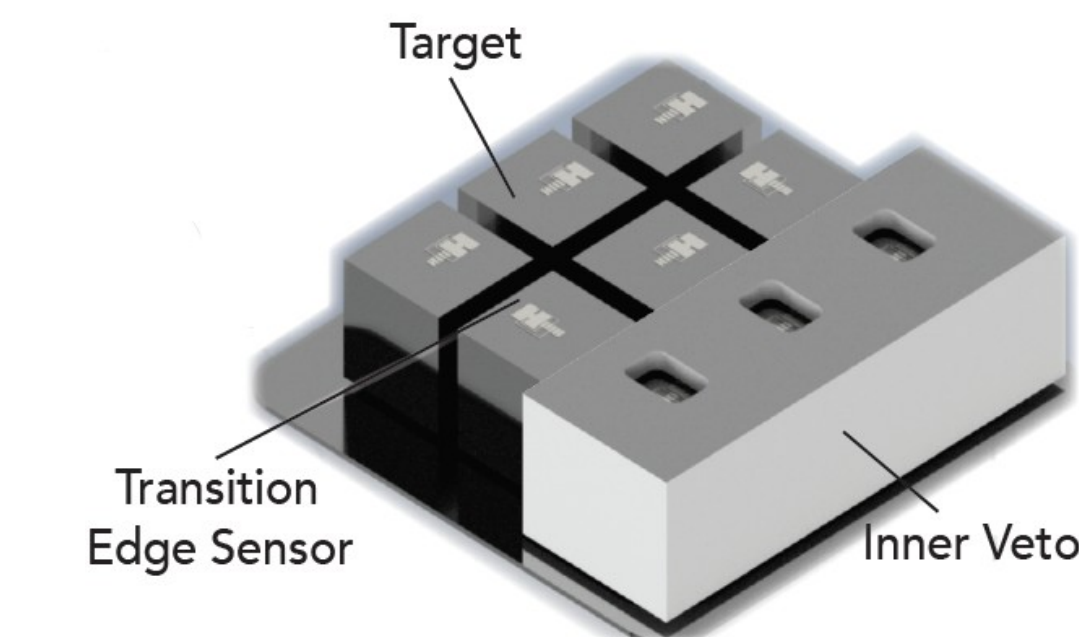
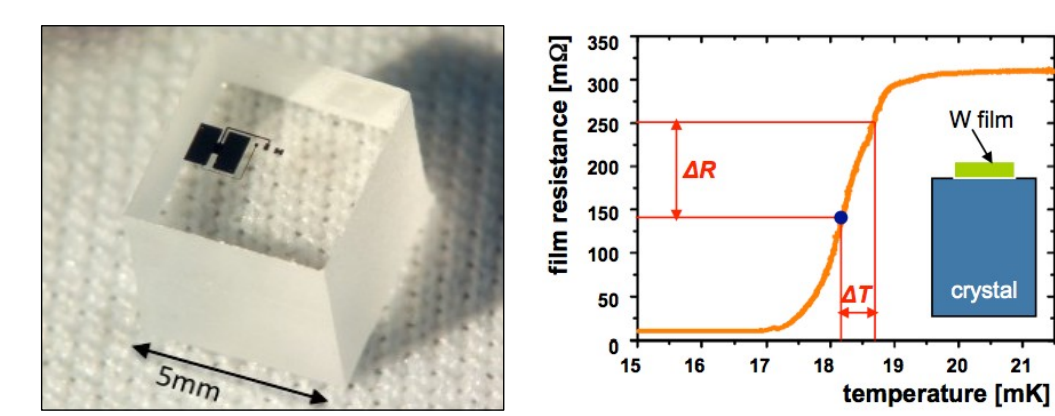
Target detectors

Gram-scale cryogenic calorimeters based on CRESST technology
 Equipped with thin-film tungsten transition edge sensors as highly sensitive thermometers

Optimized to reach at least 20 eV energy threshold

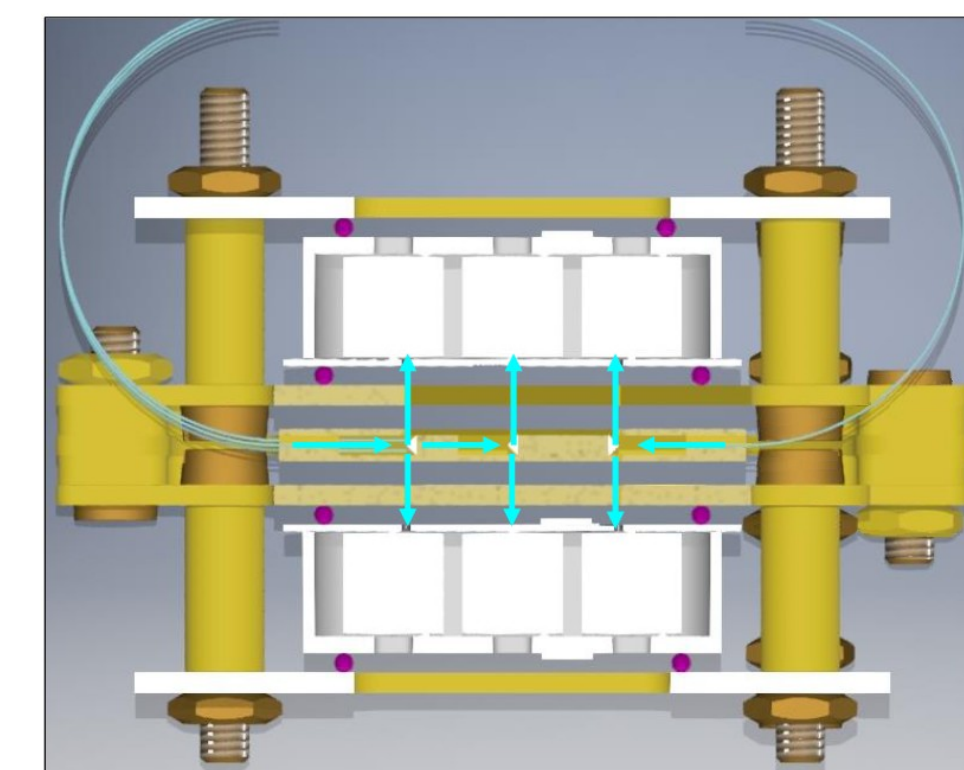
3x3 array with CaWO_4 (6g)

3x3 array with Al_2O_3 (4g)



Inner Veto

It has the dual role of instrumented holder for crystal arrays and veto against α/β surface contaminations:
 Made of silicon beaker and wafer to fully encapsulate the crystal arrays
 Act as sub-keV threshold cryogenic detector
 Readout by transition edge sensors

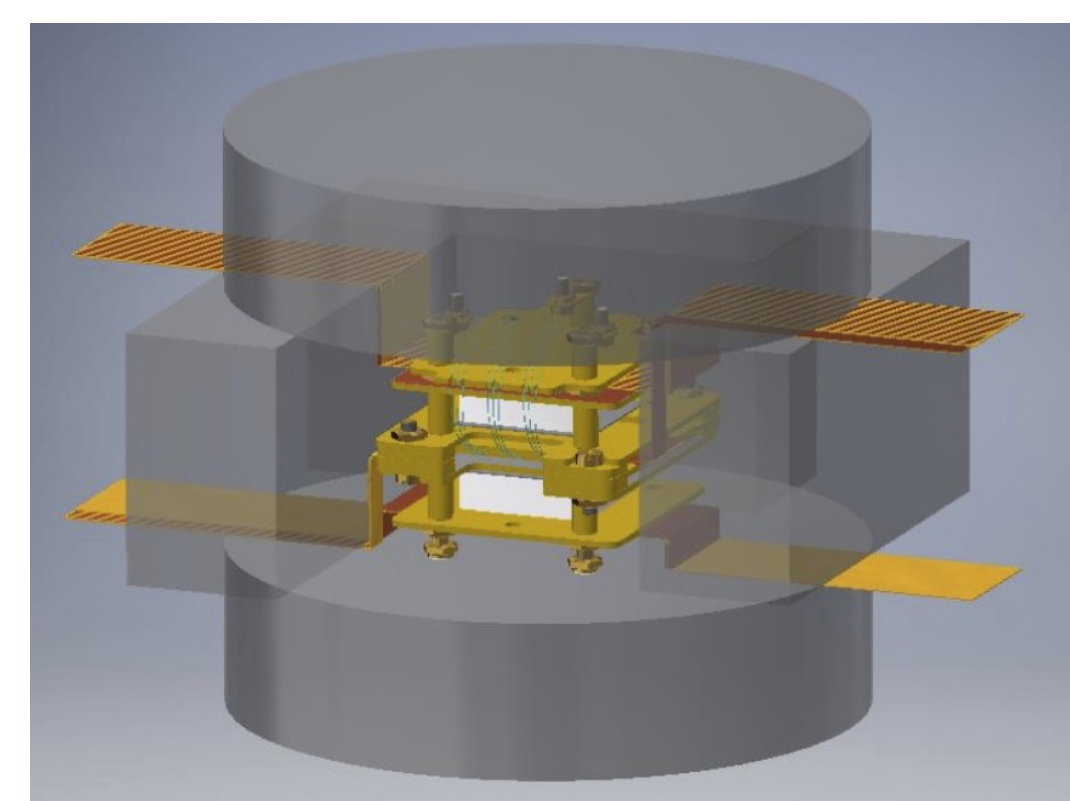


Outer Veto

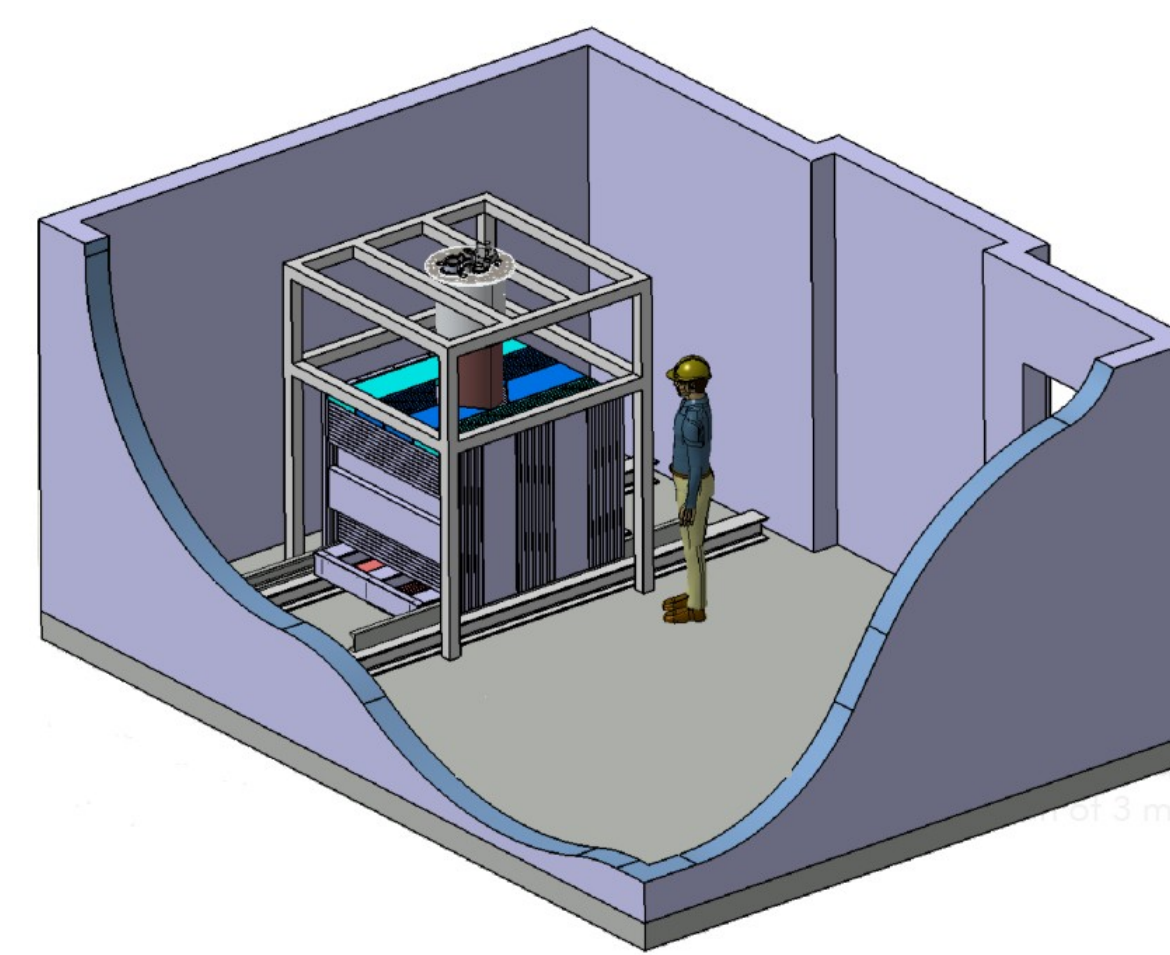
For reduction of external gamma and neutron background
 Active ionizing detectors
 2 kg and 2,5 cm thickness in 6 HPGe crystals
 Enclosing inner veto and target detectors with 4π coverage
 Energy thresholds of O(1 keV)
 Further effective background reduction for secondary particles produced by undetected muons

Calibration system

A system of optical fibers, Ge mirror wafer and collimators is used to illuminate the target detectors with UV-VIS light



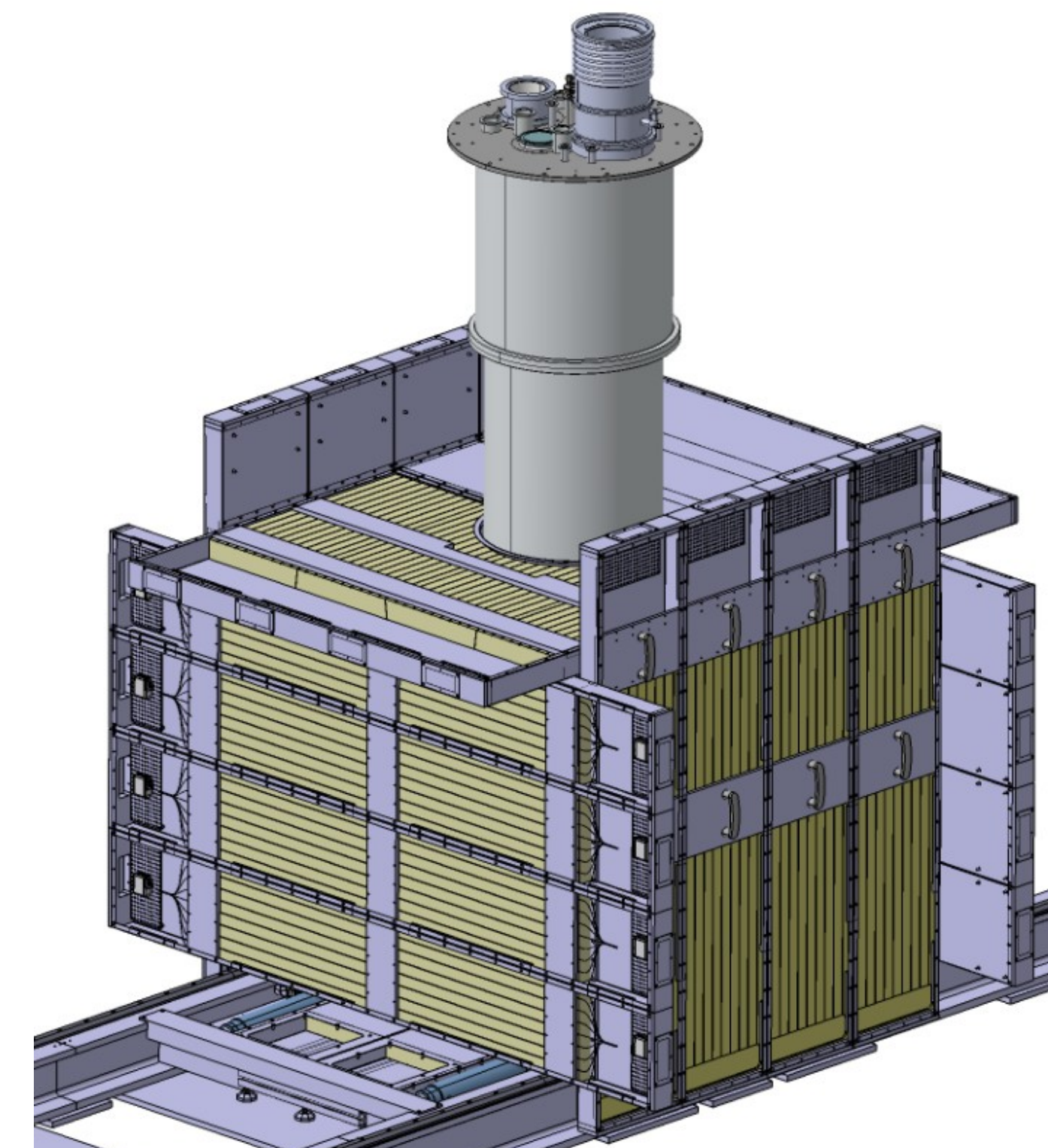
Cryostat: a "dry" dilution refrigerator is used to avoid handling of cryogenic liquids. It has been commissioned in May 2020. The base temperature is of O(10 mK). A dedicated work on vibration decoupling is ongoing.



Preliminary views of the experimental setup to be installed at the Very Near Site of the Chooz nuclear power plant

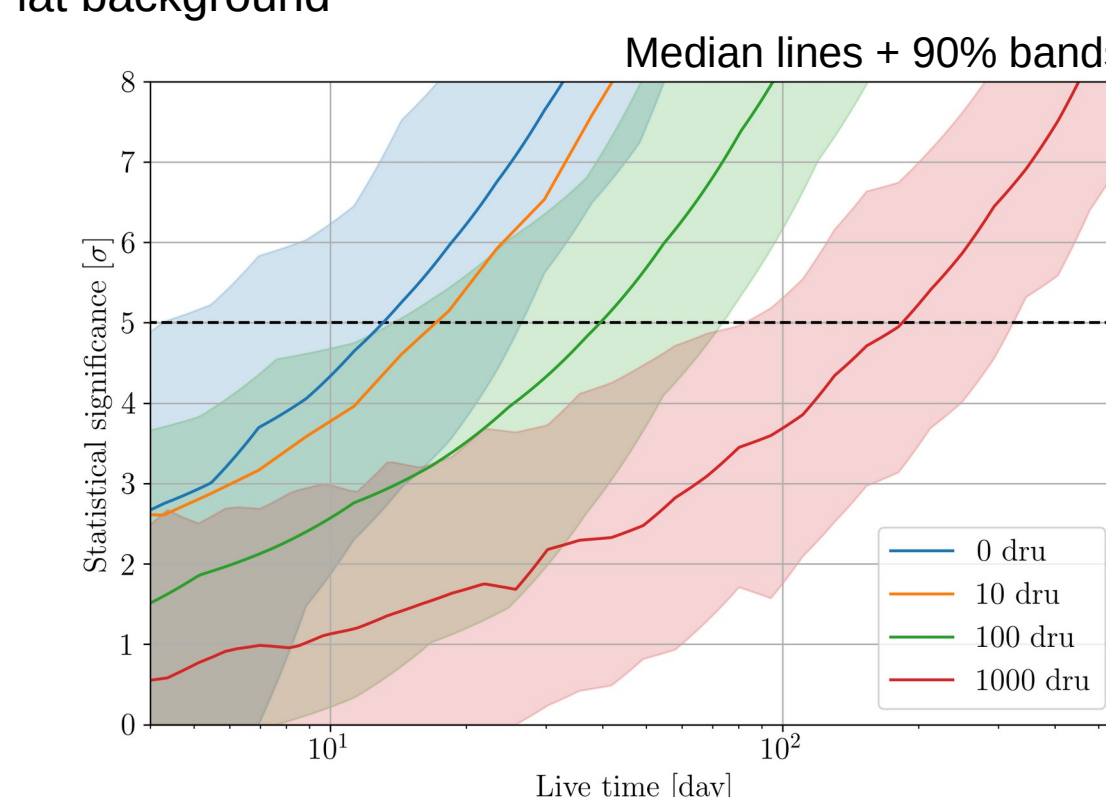
The design of some components of the setup (as e.g. the passive shield and the vibration decoupling system) still has to be finalized

Simulation studies are in progress to determine the best configurations



NUCLEUS 10g Sensitivity

Sensitivity to CEvNS signal for the following assumptions:
 20 eV energy threshold
 VNS neutrino flux at 80% reactor power
 Flat background



5 σ observation of a CEvNS signal achievable in ~40 days of measurement time for a flat background of 100 cpd/kg/keV

A Two Phase Project

Phase 1

10g target detector: detection of coherent neutrino scattering

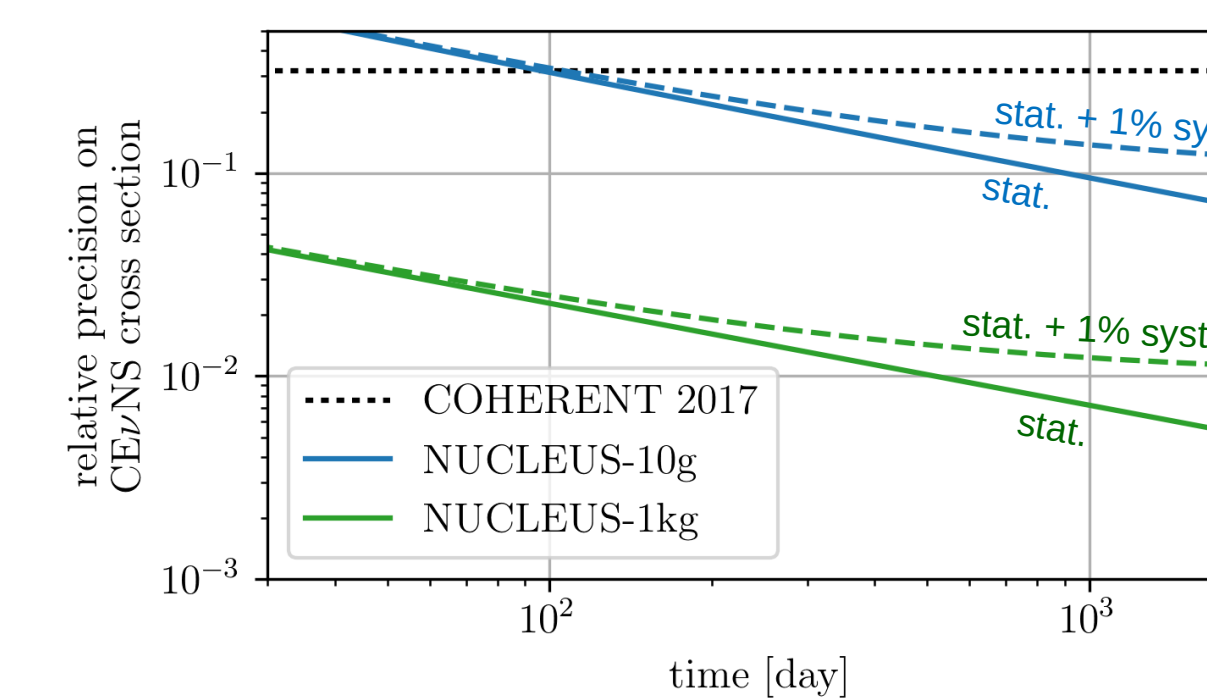
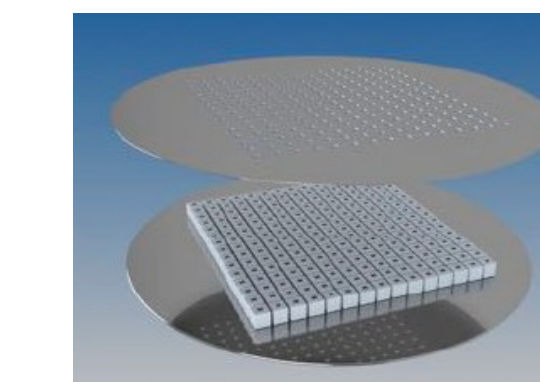
2021 - Commissioning at TUM

2023 - Installation at Chooz

2023 - Start data taking

Phase 2 (2024)

1 kg scale: high-precision measurement



1st phase: stat limited

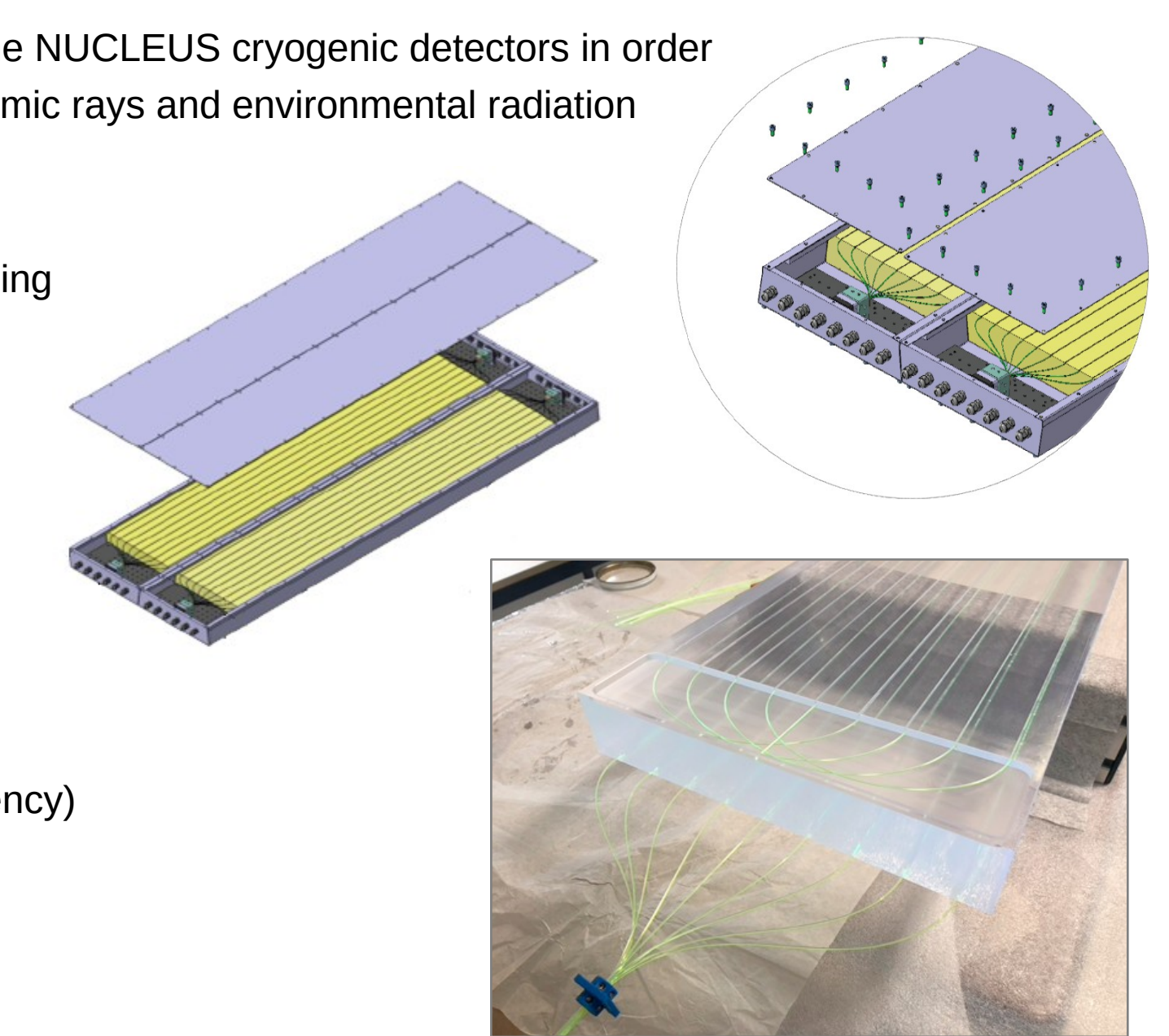
2nd phase: syst limited

The Muon Veto and the Passive Shield

An active muon veto and a passive shield surround the NUCLEUS cryogenic detectors in order to minimize the contribution to background due to cosmic rays and environmental radiation

Main background sources

Cosmic-rays and μ -induced secondaries in VNS building components
 Environmental gammas
 Environmental neutrons
 Radioactive contaminants in the setup materials



Muon Veto

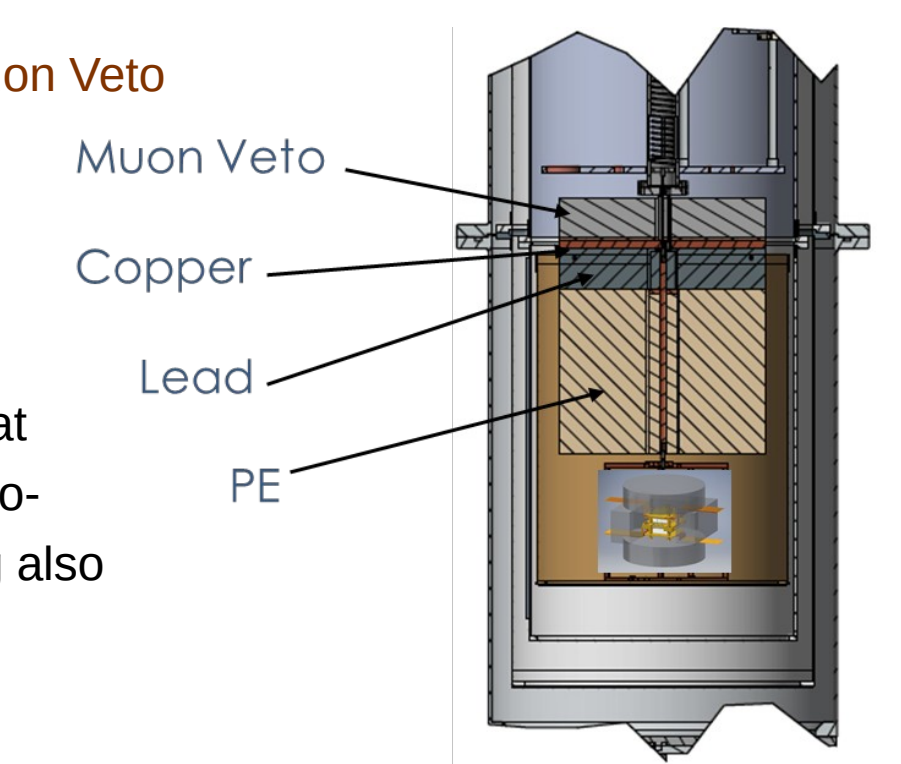
5 cm thick plastic scintillator plates
 SIPM & WLS-fiber based read-out system
 $\approx 4\pi$ coverage of the set-up (> 99% geometrical efficiency)
 Expected count rate of cosmic muons ~700 Hz
 ⇒ detector dead time < 10%

Passive Shield

Extensive Geant4 simulation campaign to optimize the passive shield design:
 External layer: 5 cm low radioactive lead to reduce ambient γ 's (external position reduces the production of μ -induced neutrons near detectors)
 Inner layer: 15 cm borated PE as low-Z material to reduce neutrons
 Movable mechanical structure to allow easy opening/closing procedure

Inner Cold Shield and Cryogenic Muon Veto

Placed inside the cryostat, just above the cryogenic detectors
 Aligned with external shield
 Consists of cryogenic muon veto (plastic scintillators characterized at sub-Kelvin temperatures), low radioactive lead, copper support (acting also as thermal contact), borated PE
 Thermalized at 800 mK



Radiopurity of Materials

Screening of setup materials with HPGe detectors is ongoing
 Evaluation of tolerance levels in setup materials with Geant4 simulations is also ongoing: e.g., upper limits for ²¹⁰Pb level in lead of passive shield and for contaminants in cryostat vessels have been used to select the materials

Main NUCLEUS papers:
 R. Strauss et al., *The ν -ceus experiment: a gram-scale fiducial-volume cryogenic detector for the first detection of coherent neutrino-nucleus scattering*. Eur. Phys. J. C 77 (2017) 506.
 R. Strauss et al., *Gram-scale cryogenic calorimeters for rare-event searches*. Phys. Rev. D 96 (2017) 022009.
 G. Angloher et al., *Exploring CEvNS with NUCLEUS at the Chooz nuclear power plant*. Eur. Phys. J. C 79 (2020) 1018.
 J. Rothe et al., *NUCLEUS: Exploring Coherent Neutrino-Nucleus Scattering with Cryogenic Detectors*. J. Low Temp. Phys. 199 (2020) 433-440.

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 October 6-7, 2021

