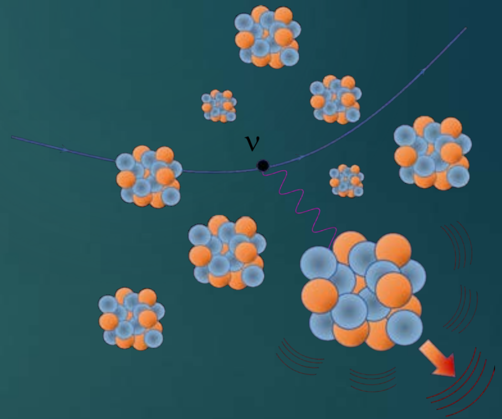
EXPERIMENT

nucleus

NUCLEUS: cryogenic calorimeters to detect coherent nuclear scattering of reactor antineutrinos



RICCARDO CERULLI ON BEHALF OF THE NUCLEUS COLLABORATION

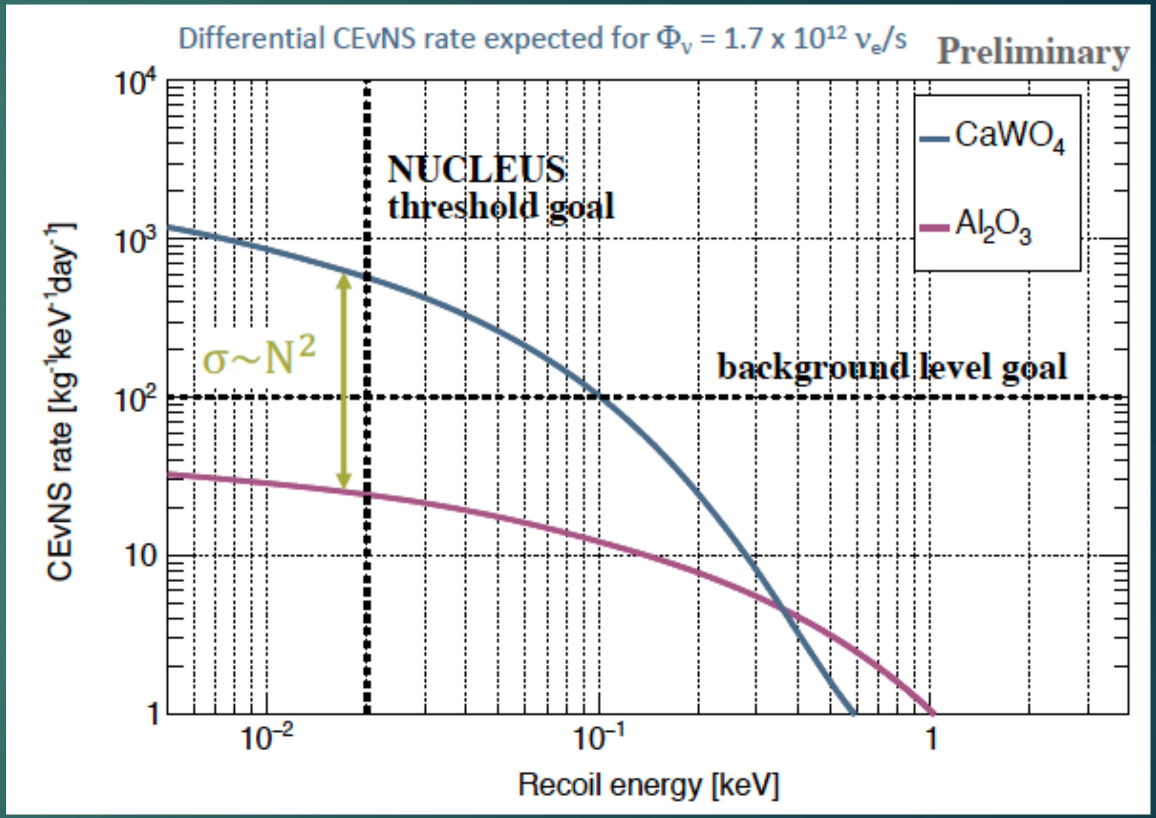
INFN

INFN-Roma Tor Vergata

ICHEP 2022
Bologna, ITALY
July 6-13, 2022

CEνNS signal at nuclear reactors

- Nuclear Reactors are intense source of anti-neutrinos; $E_\nu < 8$ MeV (fully coherent domain)
- Induced nuclear recoils for CEνNS interaction are in sub-KeV range
- Low threshold detectors and low background counting rate are required



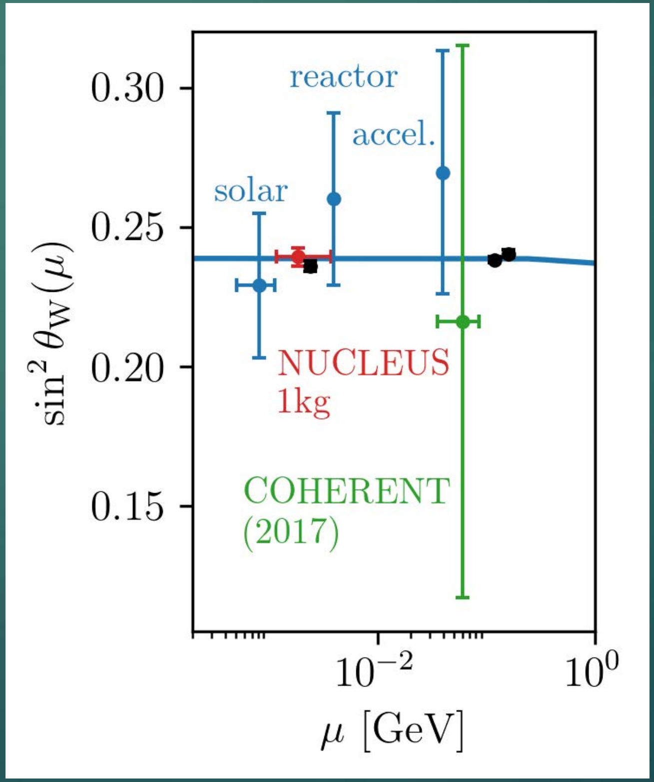
CEνNS signal and new physics

The high precision CEνNS cross-section measurement will open the door for the study of physics beyond the Standard Model of Particle Physics:

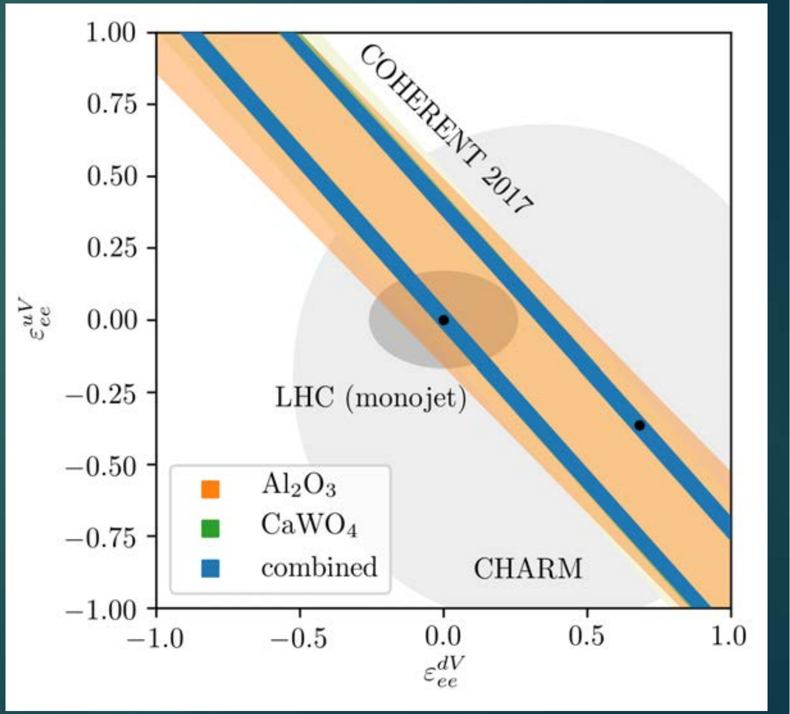
$$\sigma \sim \left[Z\left(g_V^p + 2\varepsilon_{\alpha\alpha}^{uV} + \varepsilon_{\alpha\alpha}^{dV}\right) + N\left(g_V^n + \varepsilon_{\alpha\alpha}^{uV} + 2\varepsilon_{\alpha\alpha}^{dV}\right)\right]^2$$

$$g_V^p = +\frac{1}{2} - 2\sin^2\theta_W$$

- Non-standard neutrino interactions
- Electro-magnetic properties
- Exotic neutral currents
- Sterile neutrinos
- Etc.



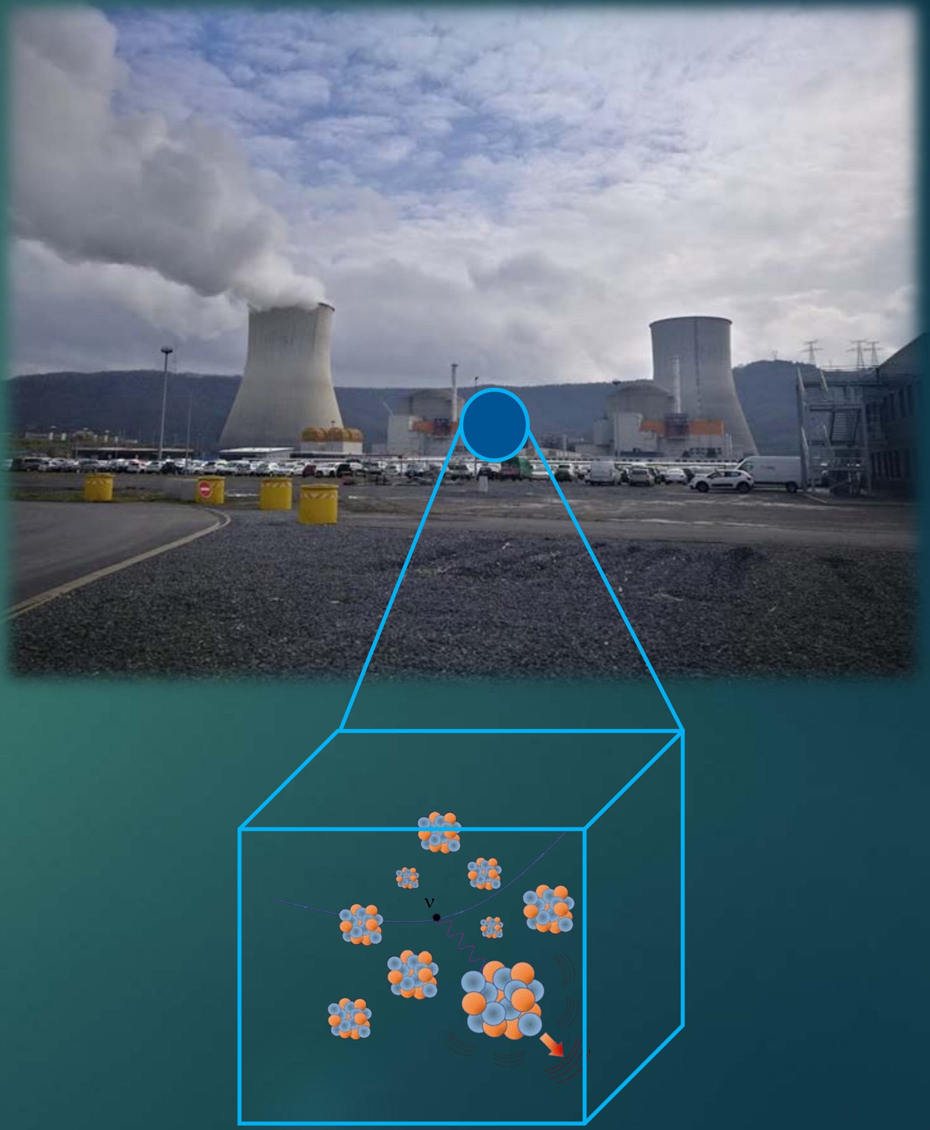
Weinberg angle at low-E transfer



non-standard interactions

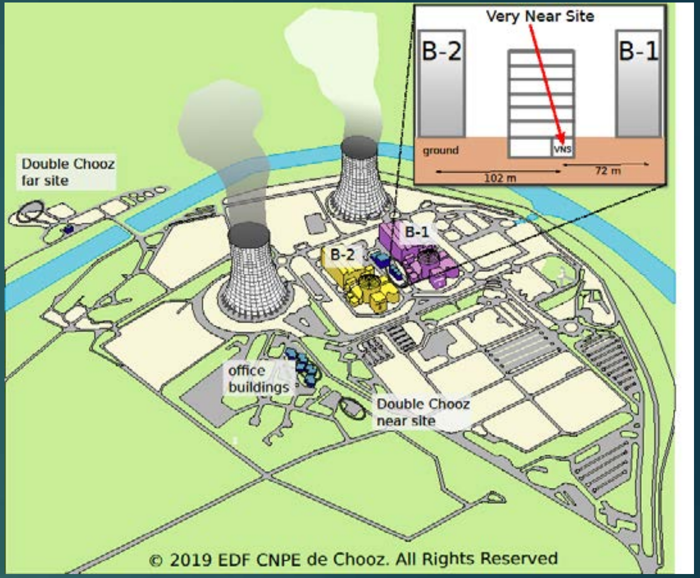
The NUCLEUS experiment

- The goal of the experiment is the high-precision measurement of the coherent elastic neutrino-nucleus scattering at low energy with cryogenic detectors
- The experiment will operate at the Chooz B nuclear power plant in France (operated by EDF)
- It will employ $CaWO_4$ and Al_2O_3 gram-scale crystals with ultra-low energy threshold, operated at mK temperature and placed inside active and passive shields



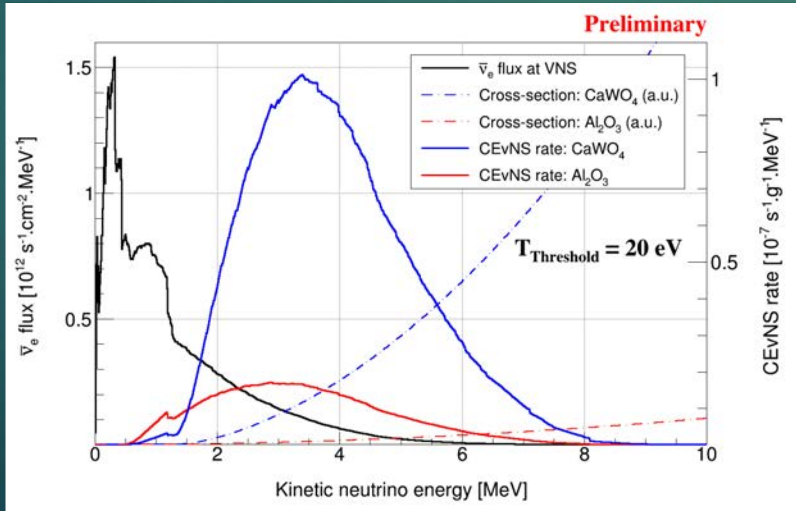
VNS at Chooz Nuclear Power Plant

Eur.Phys.J.C79(2019)12,1018



- The experimental site (VNS) is located at 102 m and 72 m from the 2 reactors of the Chooz B plant of EDF, at ≈ 3 m.w.e depth
- Reactor nominal thermal power: 2 x 4.25 GWTh
- The expected average neutrino flux at VNS:

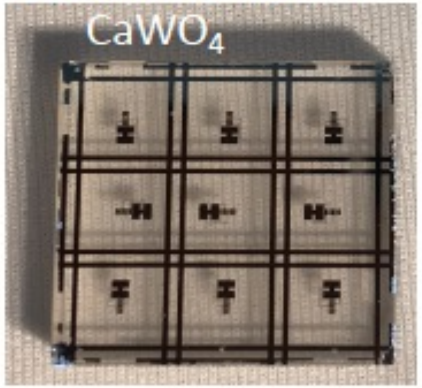
$$1.7{\times}10^{12}\ \bar{\upsilon}_e/(s \cdot cm^2)$$



NUCLEUS target detectors

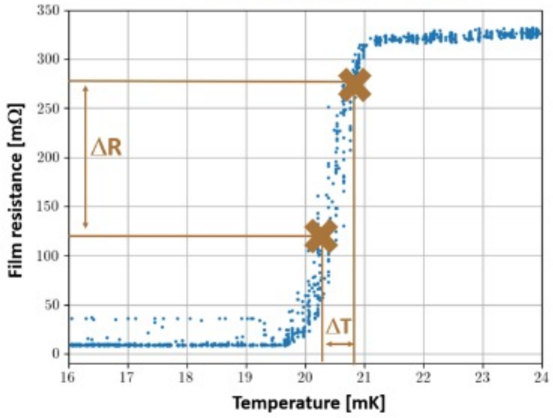
- Two arrays of 3 x 3 cryogenic crystal calorimeters with ultra-low energy threshold, (19.7±0.9) eV for Al_2O_3 are reached [PRD 96, 022009 (2017)]
- Multi target approach: 9 $CaWO_4$ (≃6 g) and 9 Al_2O_3 (≃4 g) crystals operating at mK with transition edge sensors as highly sensitive thermometer
- Crystal arrays produced: cut test performed; for 18 $CaWO_4$ crystals transition characterized and test measurement performed
- Al_2O_3 under test
- **UV-VIS** Calibration system realized

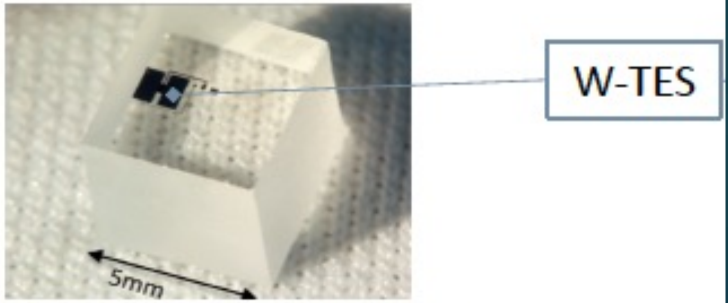
Arrays before cutting with W-TES (20x20x5) mm³



CRESST technology

Transition of W-TES

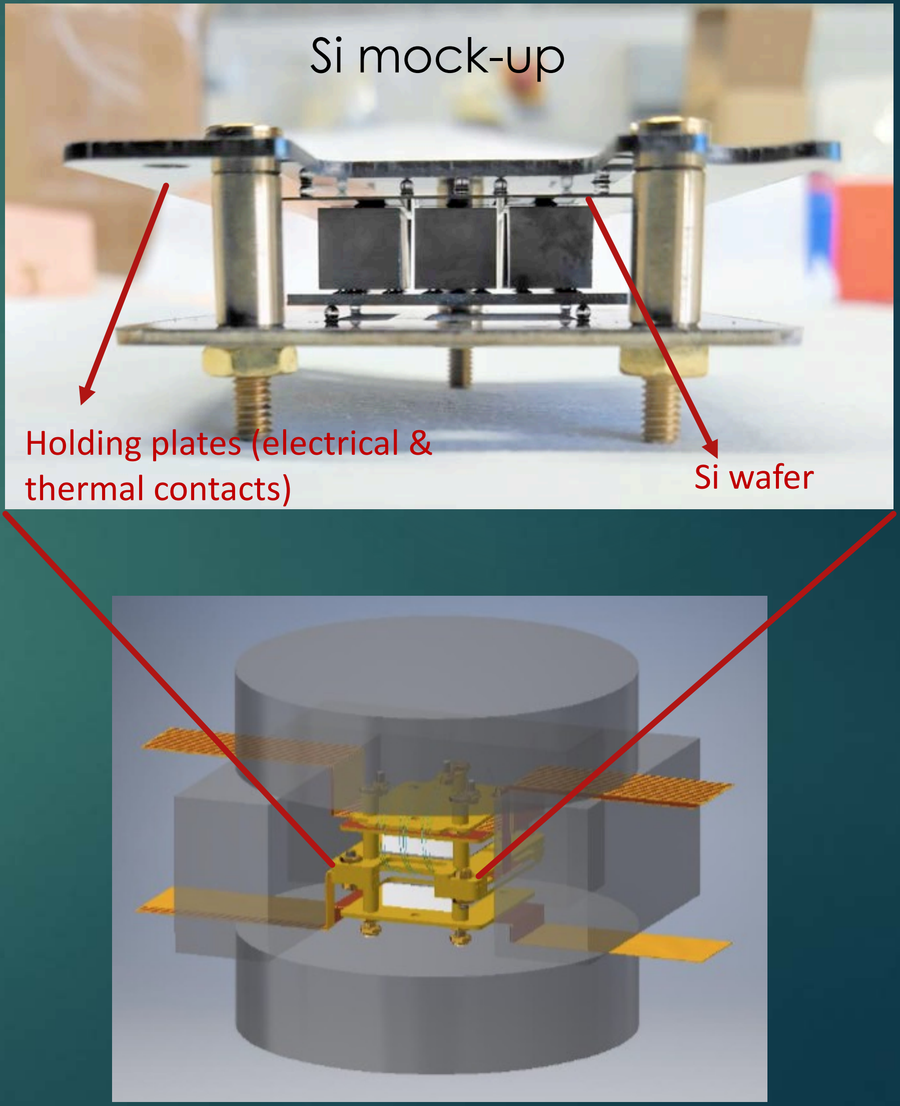




Phys. Rev. D **96**, 022009 (2017)

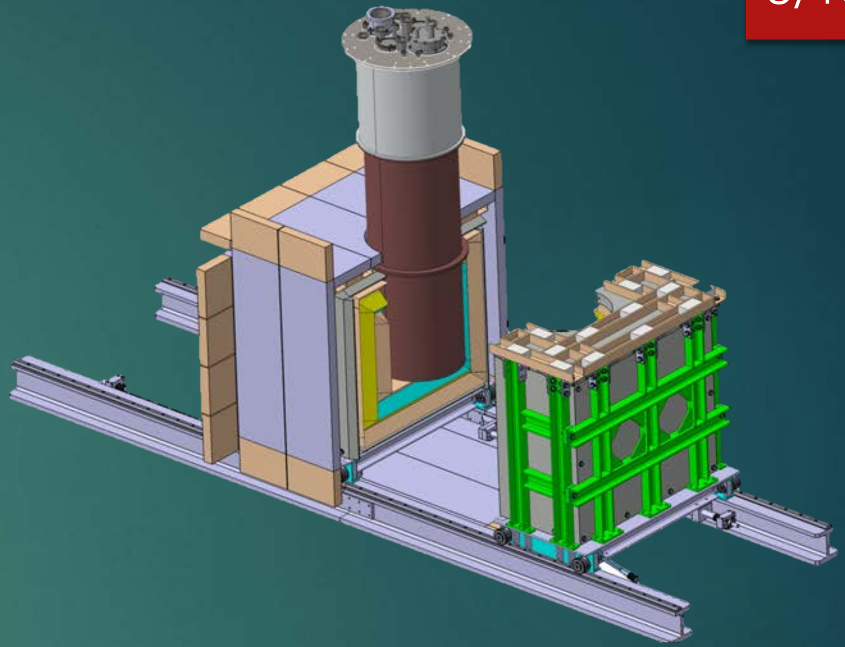
Inner & Outer Cryogenic Veto: 4π coverage of the target detector

- Active inner veto made of a Si beaker to reject surface backgrounds and holder-related events
- Si wafer instrumented with TESs to hold and encapsulate the crystals (mechanical and thermal test concluded)
- Inner veto pressed between 2 Si holding wafer where TES connection and copper cables will be connected
- 4 kg and 2.5 cm thickness HPGe Outer Veto surrounding the inner detectors for active γ/n background rejection (Cylindrical Ge crystals prepared, tested and validated; rectangular crystal in production)



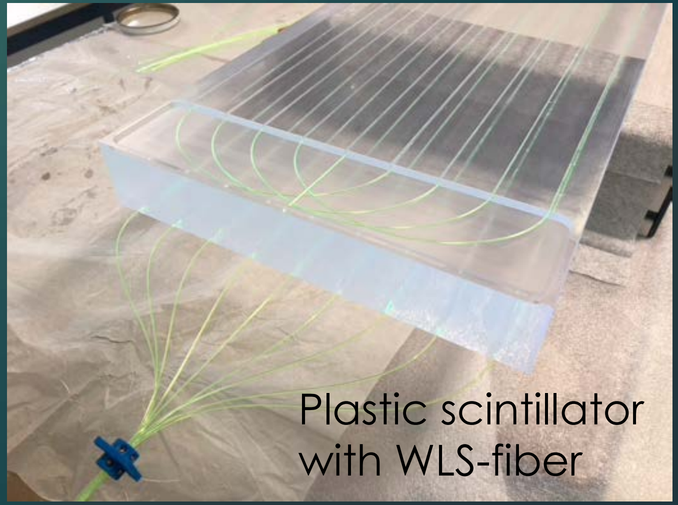
Muon Veto

- 5 cm thick plastic scintillator plates
- SiPM & WLS-fiber readout
- High efficiency for muon detection > 99%
- High uniformity in light collection
- 4π coverage of the set-up
- Cold muon veto: cylindrical shape, thermalized at 800 mK

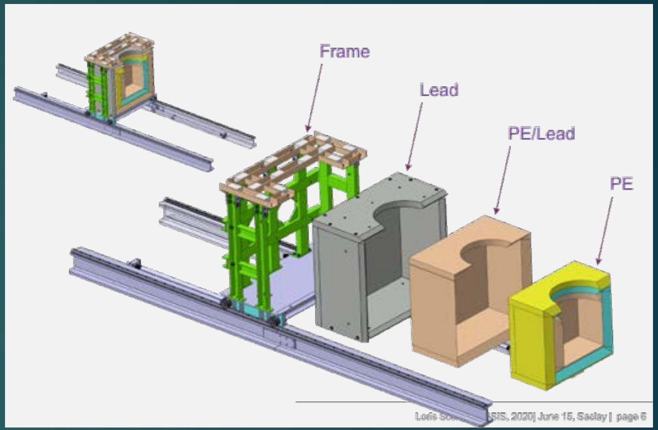


arXiv:2205.01718

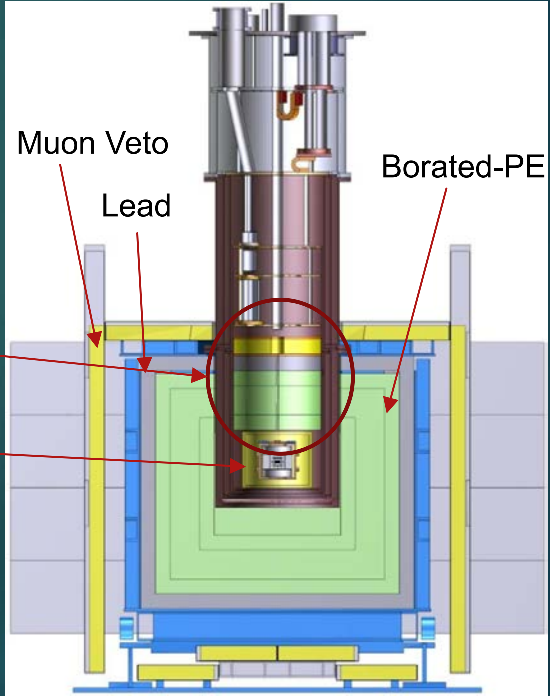
JINST 17 (2022) 05, T05020



Multi-layer active and passive shielding

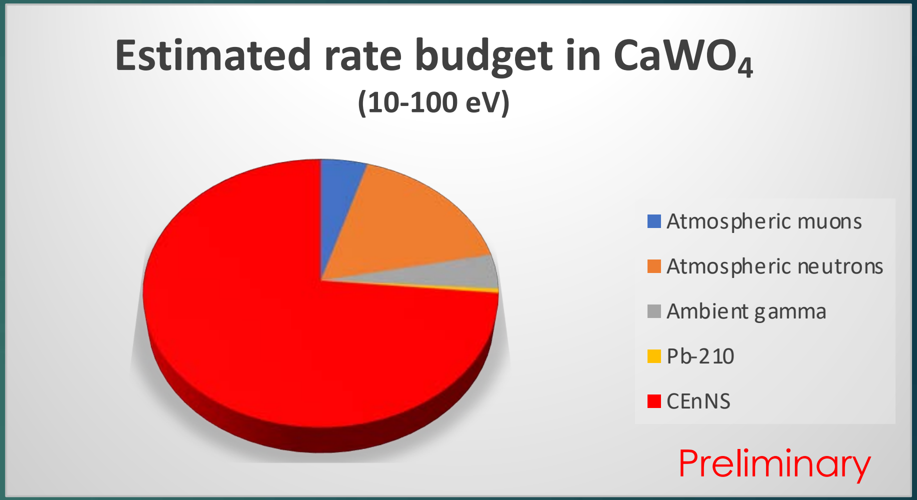


- Movable mechanical structure to allow easy opening/closing procedure
- Muon Veto
- Low radioactive Lead (5 cm)
- Borated(5%)-Polyethylene (20 cm)
- Inner Cold shield thermalized at 800 mK reproducing the external shield with cryogenic muon veto and B_4C layer (4 cm) surrounding the Ge-OV
- Minimize neutrons flux induced by μ interaction and by atmospheric neutrons



Background evaluation

- Simulation studies based on Geant4 to optimize the NUCLEUS set-up design
- No reactor correlated background
- Estimation of the main background contributions for NUCLEUS:
  - Secondary cosmic rays (atmospheric muons and neutrons)
  - Environmental gammas (as measured at VNS)
  - Material radioactive contamination

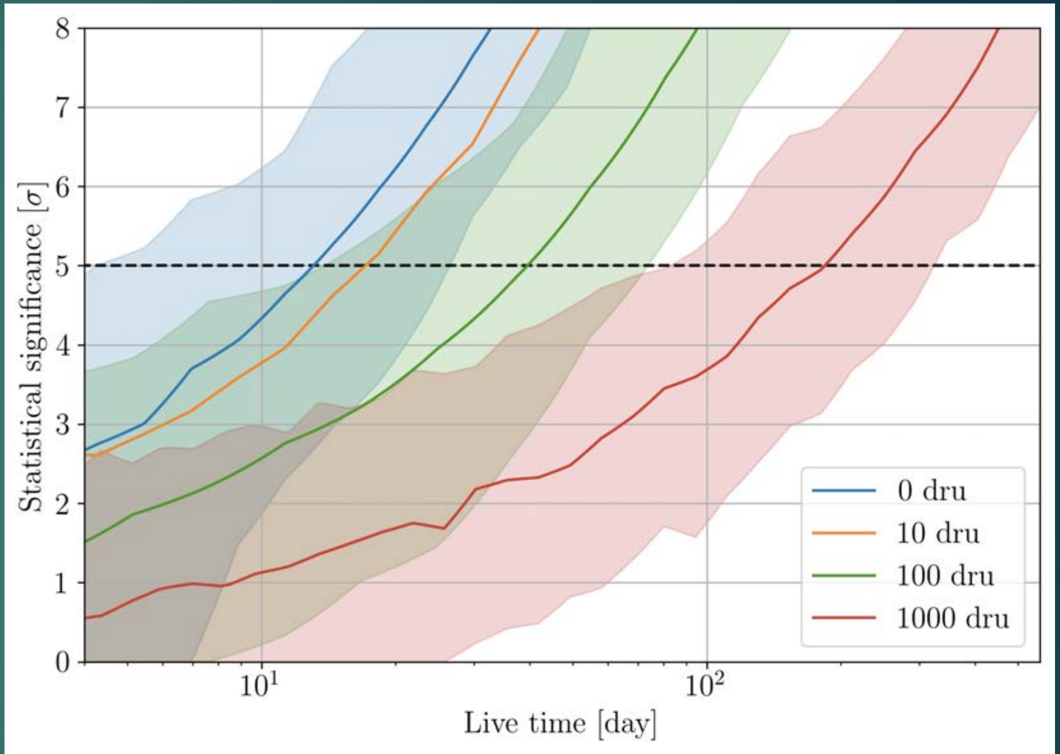


Background level < 100 cpd/kg/keV feasible

Potential sensitivity

- 20 eV energy threshold
- Average reactor power 80%
- In the simplistic hypothesis of a flat background < 100 cpd/kg/keV CEνNS signal observation at 5σ in about 40 days
- In the hypothesis of an exponential+flat backround raising below ≈ 300 eV with amplitude of 3000 cpd/kg/keV, by profiting from the presence of Al_2O_3 and $CaWO_4$ target materials $>5\sigma$ observation in 1 year could be achieved

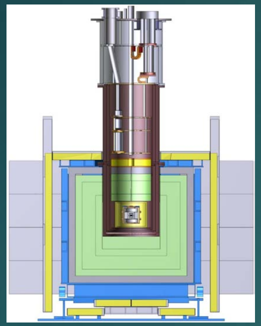
In the optimistic flat background hypothesis



- Excess and its role in the low energy range to be investigated: NUCLEUS veto system can allow to identify different excess components

Toward the blank assembly and beyond

Design (May '22)



- Design finalized

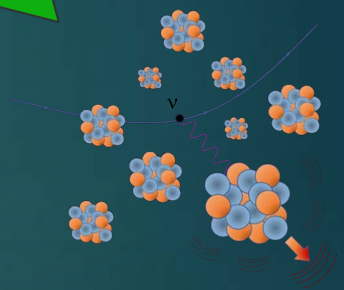
Blank assembly at TUM

- Installation and commissioning
- Performances
- LED Calibrations
- Neutron Calibration (CRAB) (see G. Soum-Sidikov poster)

Set-up will be moved to CHOOZ (2023)

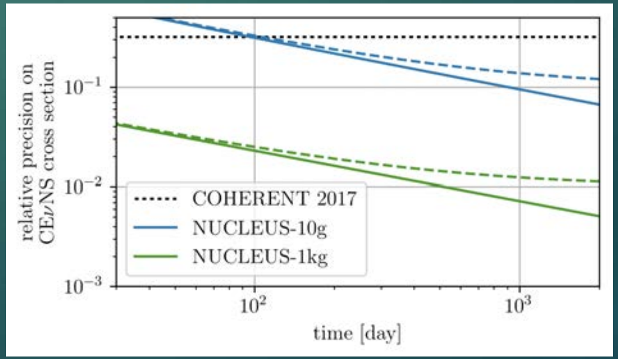
- Installation at Chooz
- Experiment switch on

Physics run



- Reactor neutrinos measurement

Future:
from 10 g to kg scale high-precision measurement



1st phase: stat limited

2° phase: syst limited

Thanks for the attention!

https://nucleus-experiment.org/

7 Institutions, 45 members