NUCLEUS Experiment

on behalf of the NUCLEUS Collaboration

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Magnificent CEvNS 2020
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NUCLEUS experiment

- Goal: high-precision measurement of the coherent elastic neutrino-nucleus scattering (***CEνNS***) at low energy with cryogenic detectors

- Site: the experiment will operate at the **Chooz B** nuclear power plant in France (operated by EDF)

- Detector: **$CaWO_4$** and **Al_2O_3** gram-scale crystal with ultra-low energy threshold, operating at mK and placed inside active and passive shields

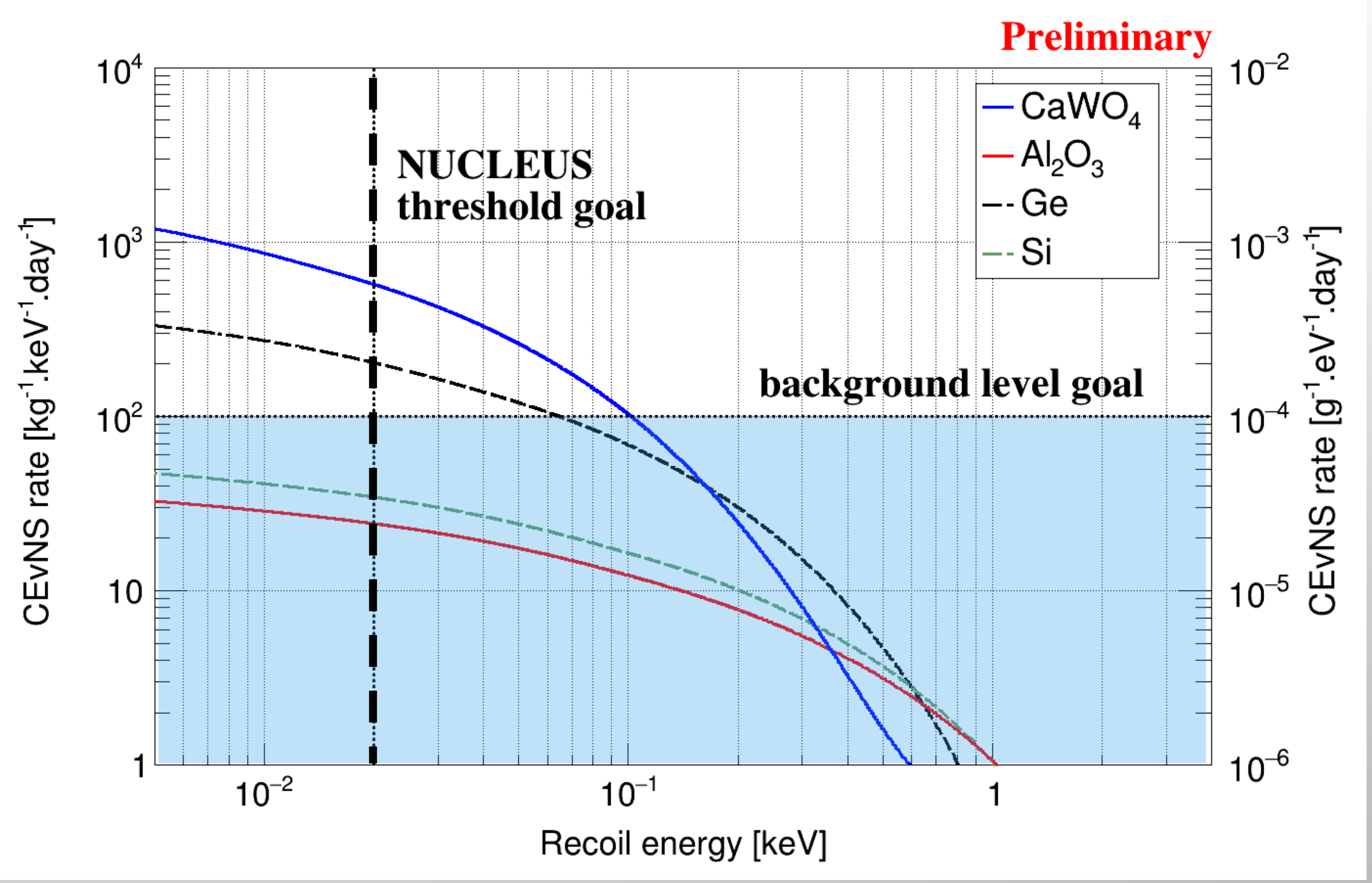
6 Institutions, **40** members

The Goal of NUCLEUS

- Nucleus in its first phase will employ a 10 g target detector to measure the ***CEvNS signal*** *down to* ***20 eV***

- Target **background** level in 20 eV-1 keV: **100 cpd/kg/keV**

Expected CEνNS signal rate in different target material

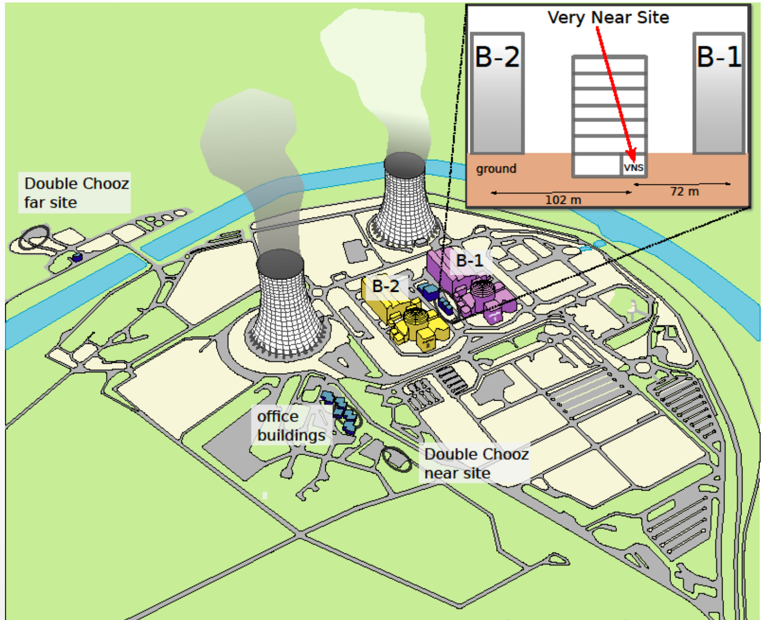


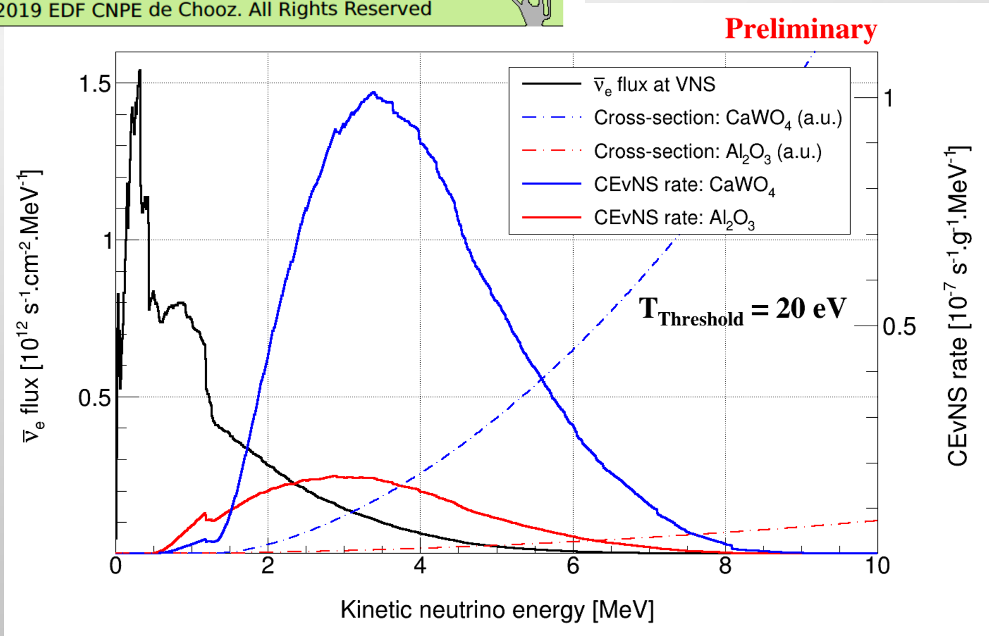
VNS at Chooz Nuclear Power Plant

- The experimental site (VNS) is located at 102 m and 72 m from the 2 reactors of the Chooz B plant of EDF, at ≈ 5 m.w.e depth

- Reactor nominal thermal power: 2 x 4.25 GW_{Th}

- The expected average neutrino flux at VNS: $1.7 \times 10^{12}\ \bar{\nu}_e/(s \cdot cm^2)$





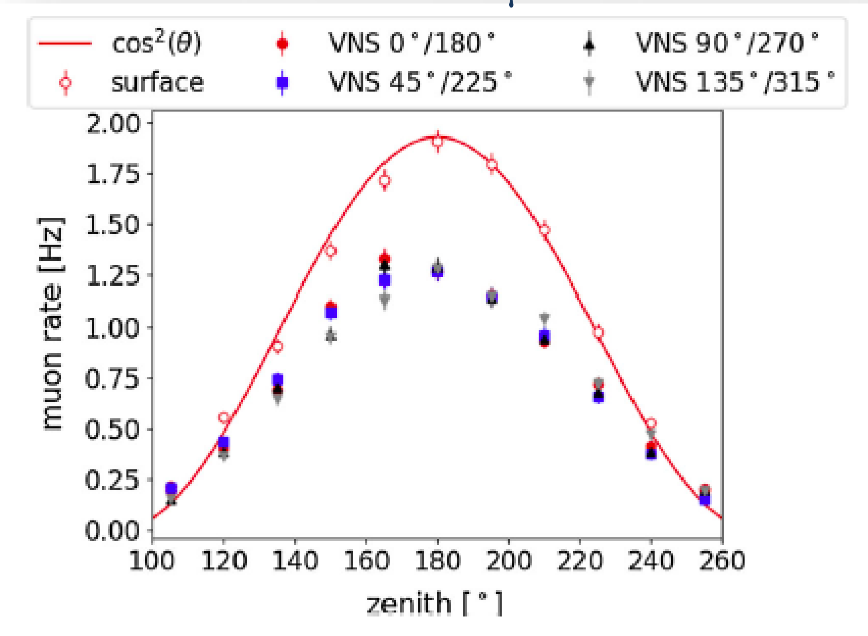
Background at VNS

Eur. Phys. J. C (2019) 79:1018

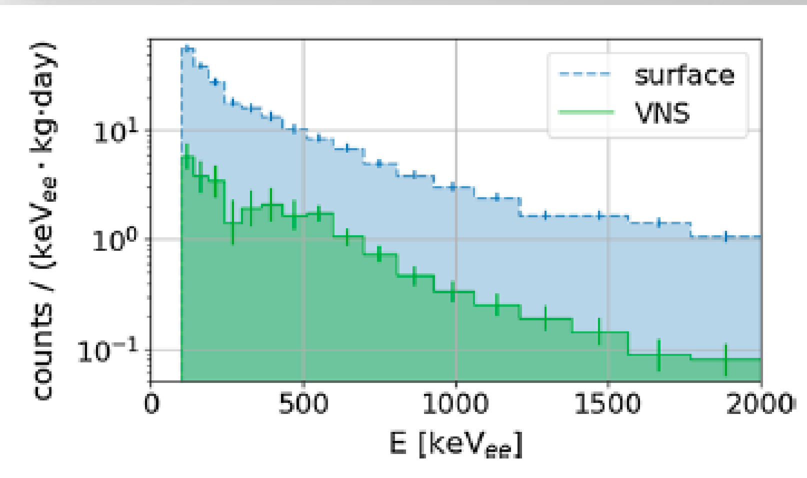
Characterization of the VNS site:

- ≃ 0.7 relative reduction of the cosmic muon flux measured at VNS with respect to the surface
- ≃ 8 reduction fraction of atmospheric neutrons (up to 2 MeVee)
- gamma background measurement and vibration measurement performed (data under evaluation)
- further neutron background measurements and Radon monitoring foreseen

Cosmic μ

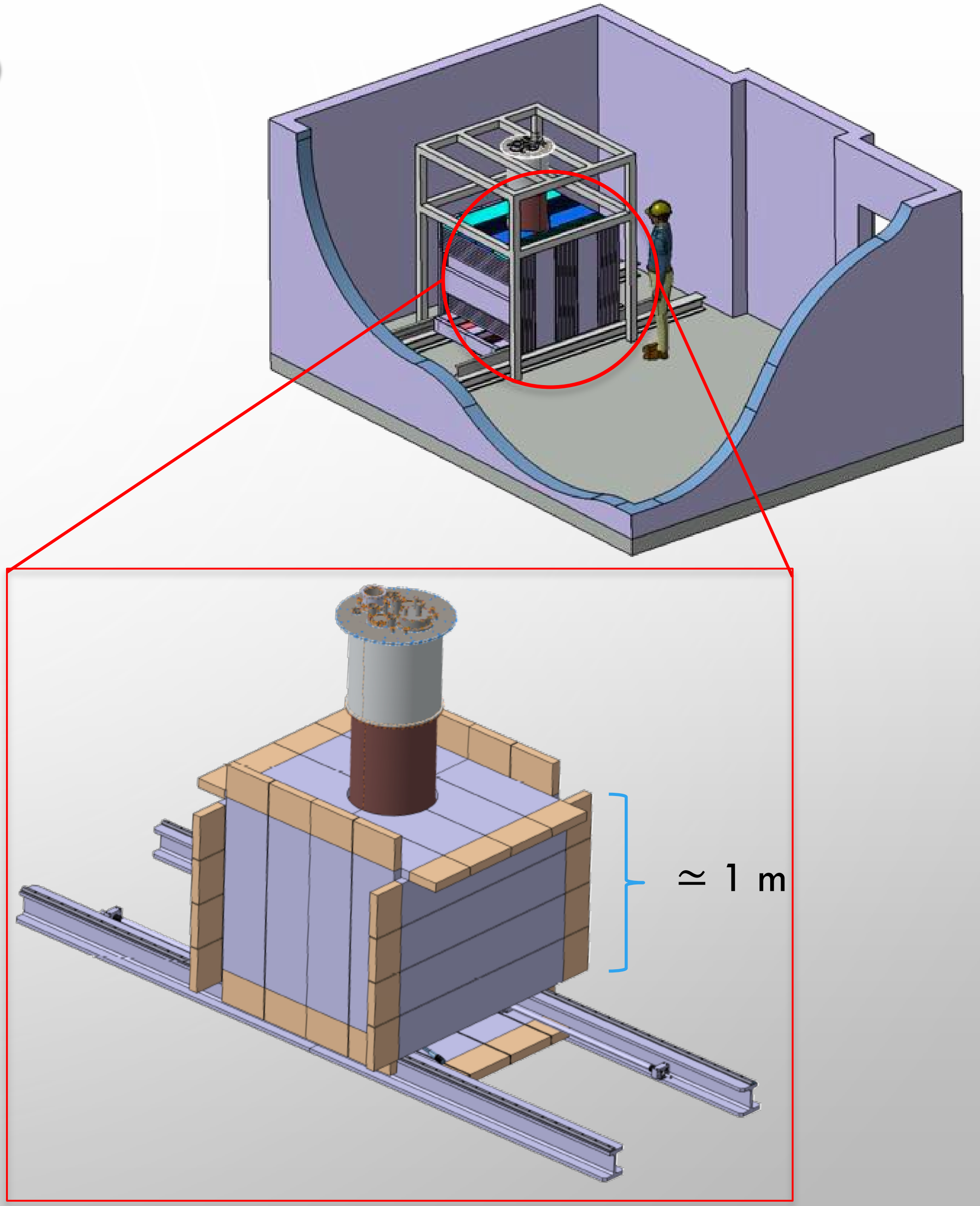


Fast neutrons



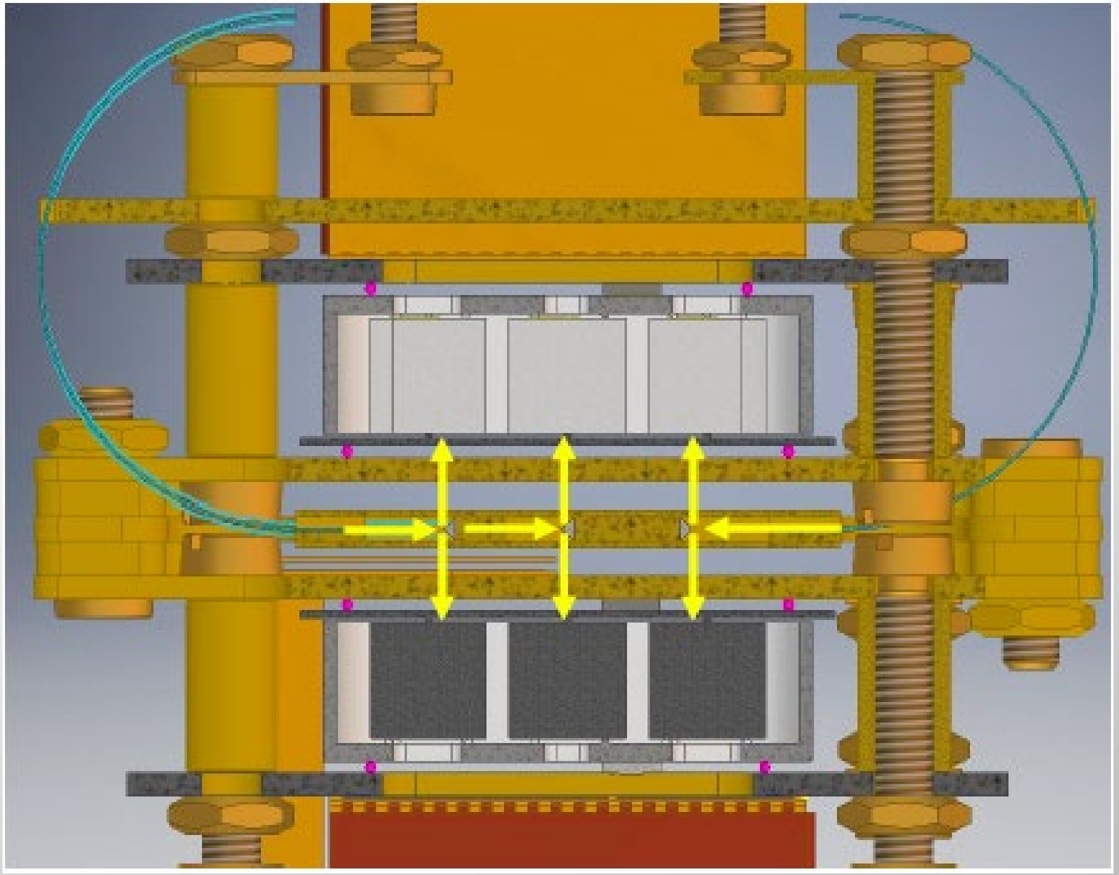
Overview of the NUCLEUS setup

- “Dry” dilution refrigerator from Bluefors
- External 4π **Muon Veto** active shield
- Multi-layer **passive shield** (Lead/Borated PE)
- Inner “cold” shield
- **Ge cryogenic active Veto** surrounding the inner target detectors
- **Si cryogenic active Veto** holding and encapsulating the crystals
- Arrays of 3 x 3 cryogenic crystal calorimeters (9 **$CaWO_4$** and 9 **Al_2O_3**) operating at mK
- **UV-VIS** Calibration system + **radioactive** sources on site



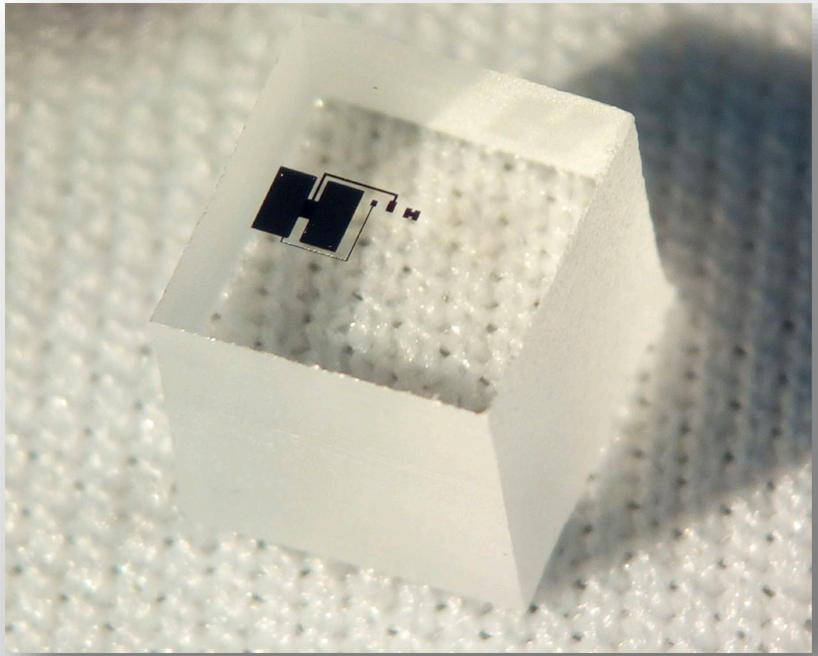
NUCLEUS detectors

- Two arrays of 3 x 3 cryogenic crystal calorimeters with ultra-low energy threshold
- 9 **$CaWO_4$** ($\simeq$6 g) and 9 **Al_2O_3** ($\simeq$4 g) crystals operating at mK
- **Si Inner Veto** holding and encapsulating the crystals
- **UV-VIS** Calibration system



$CaWO_4$ and Al_2O_3 crystals

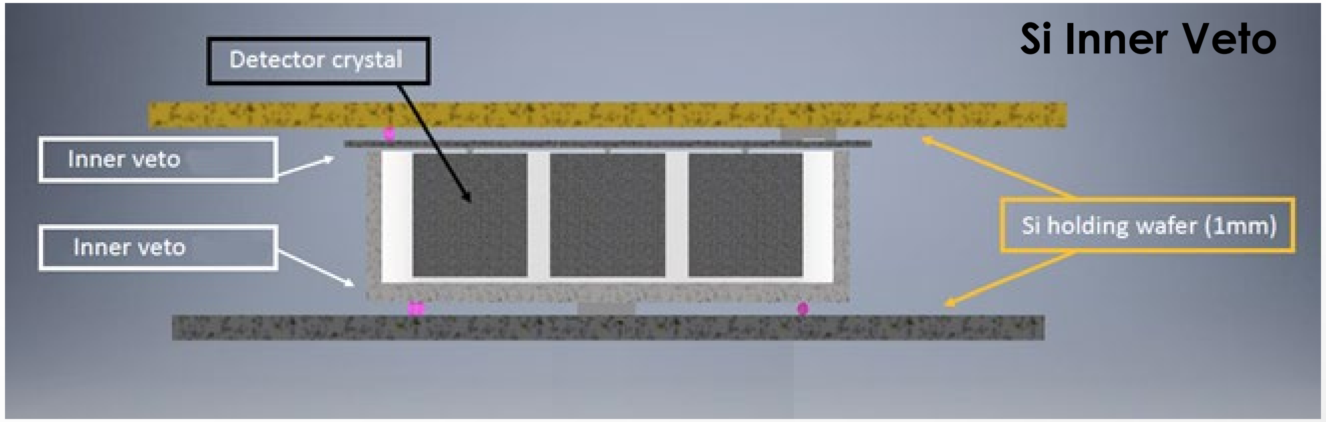
- Multitarget approach
- Cryogenic calorimeters based on CRESST technology
- Equipped with transition edge sensors as highly sensitive thermometer
- Optimized to reach (19.7±0.9) eV energy threshold [PRD 96, 022009 (2017)]

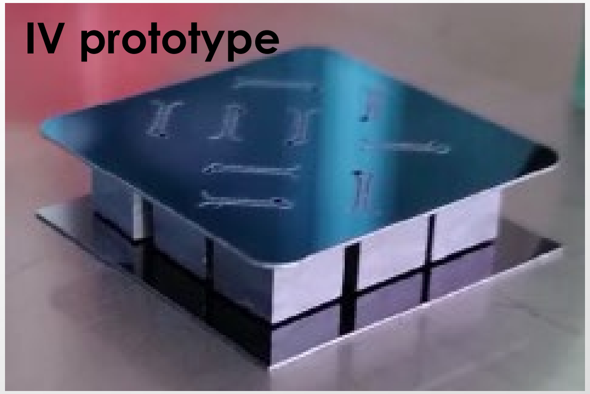


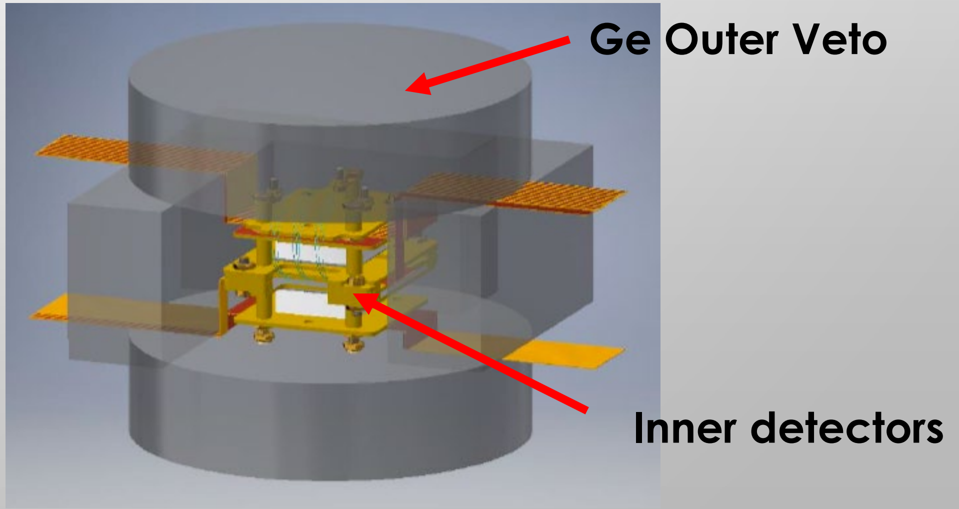
5 x 5 x 5 mm^3

Inner & Outer active Veto

- Inner & Outer Veto: 4π coverage of the target detector
- Si inner veto backer and wafer to hold and encapsulate the crystals; readout by TESs
- Inner veto pressed between 2 Si holding wafer where TES connection and copper cables will be connected
- 2 kg and 2,5 cm thickness Ge Outer Veto; active ionizing detector surrounding the inner detectors

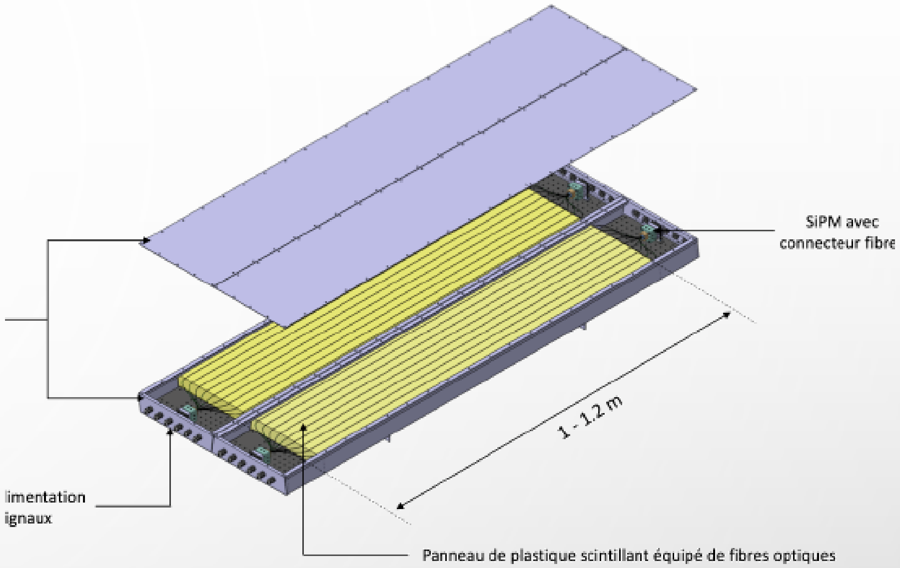


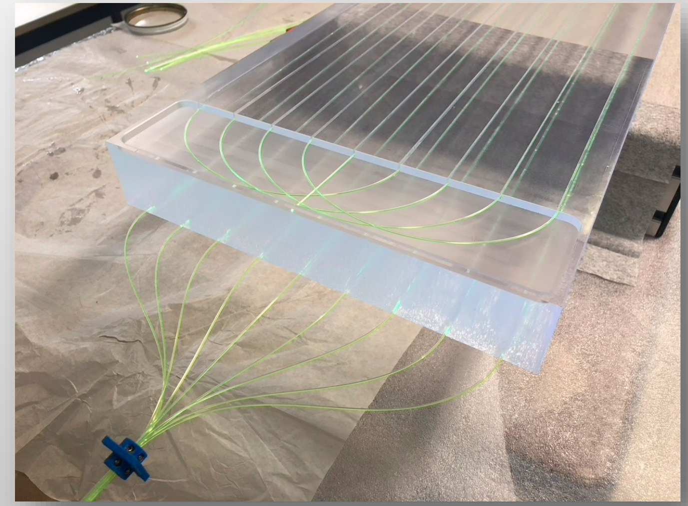




Muon Veto

- 5 cm thick plastic scintillator plates
- SiPm & WLS-fiber readout
- high efficiency for muon detection
- high uniformity in light collection
- 4π coverage of the set-up



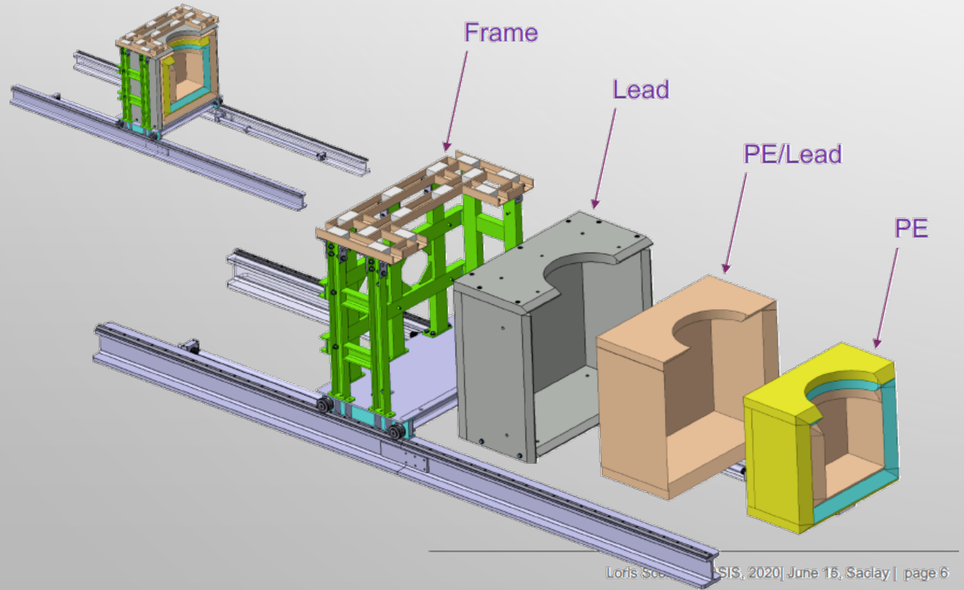


expected μ counting rate of ~500 Hz (O(1%) dead time)

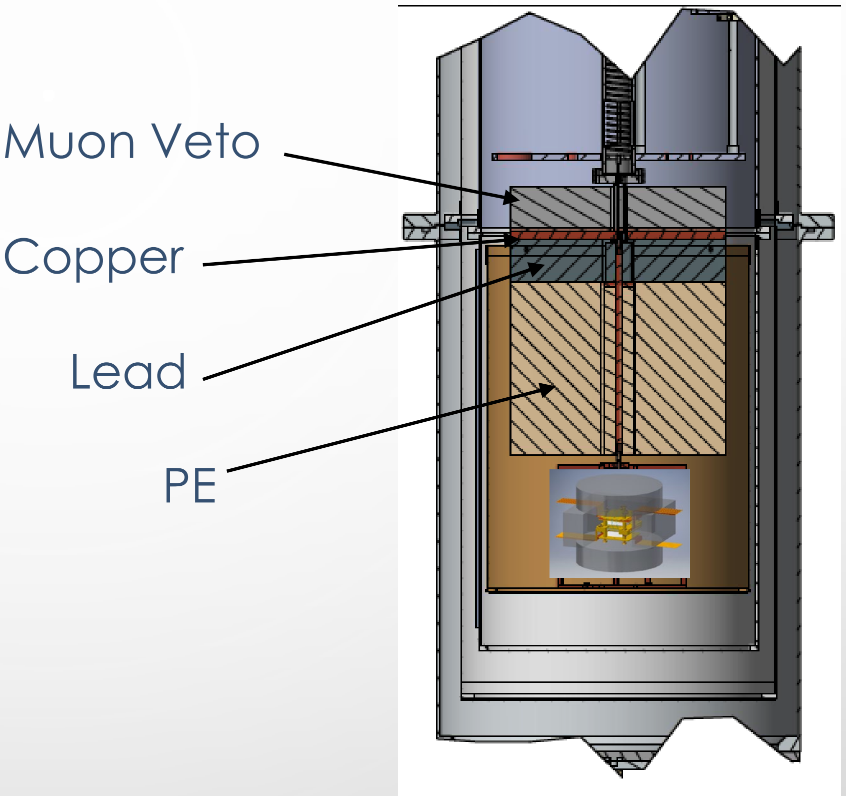
See A. Wex and A. Erhart presentation in the Poster Section

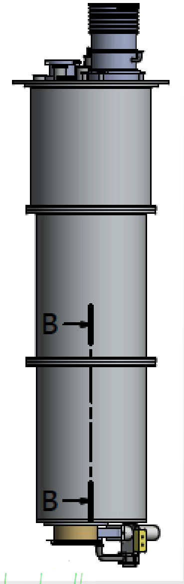
Passive Shield

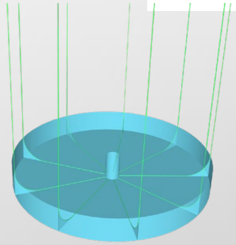
- Multilayer Passive Shield made of Lead and Polyethylene
- Movable mechanical structure to allow easy opening/closing procedure
- Ambient gamma background reduction
- Attenuation of neutron background (Borated PE)
- Minimize neutrons in the inner part of the shield induced by μ interaction with shield materials



Inner "Cold" shield







Cryogenic Muon Veto

- Aligned with external Active and Passive shield
- Just above the detectors to close the external shield
- Muon Veto, Lead, Copper support (acting also as a thermal contact), PE
- Thermalized at 600 mK

Setup optimization by Monte-Carlo simulations

Simulation studies based on Geant4 to optimize the NUCLEUS setup design:

- μ-induced secondaries (*n*, γ, e, *p*, etc) in the set-up to constraint the amount of material to employ

  ⇒ secondaries mostly γ's but 2 order of magnitude lower than ambient gamma

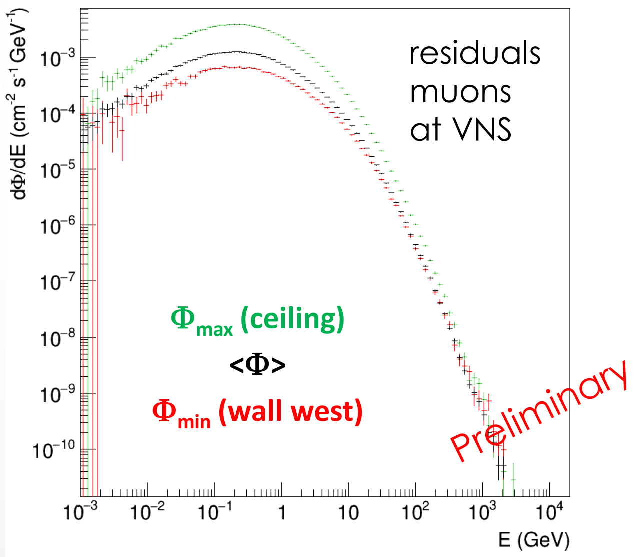
  ⇒ muons flux reduction at VNS ≃75%

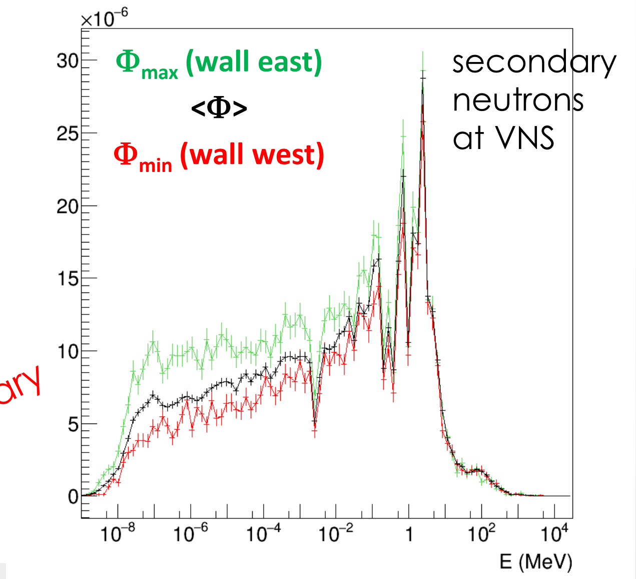
  ⇒ secondary *n* flux is a factor 35 lower than atmospheric

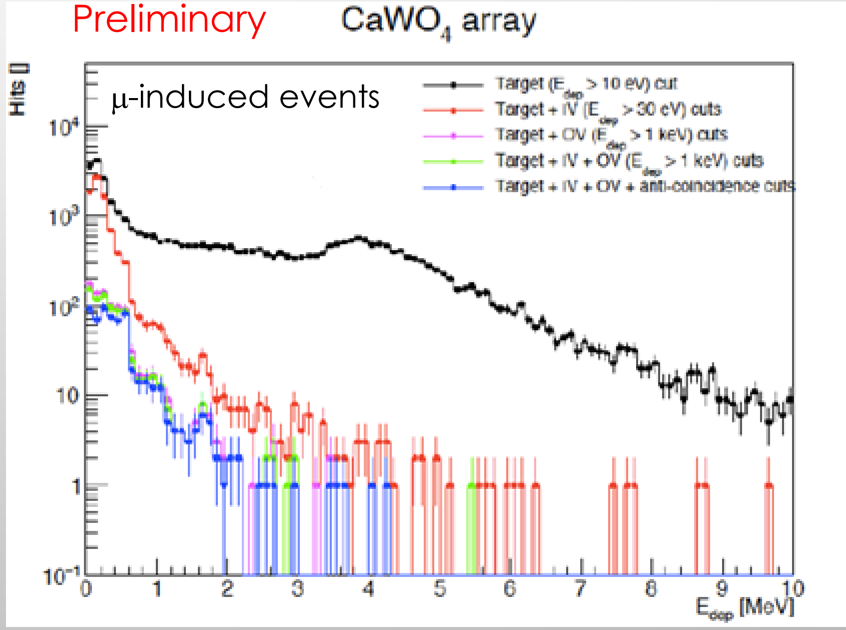
- Estimation of flux of atm. *n* at VNS

- Evaluation of the Outer Veto Rejection power considering different materials (Ge, Si, $CaWO_4$, $LiMO_4$), thickness and shape

  ⇒ 2.5 cm Ge OV thickness







Setup optimization by Monte-Carlo simulations

Simulation studies based on Geant4 to optimize the NUCLEUS set-up design:

- Estimation of the background for different passive shield configurations

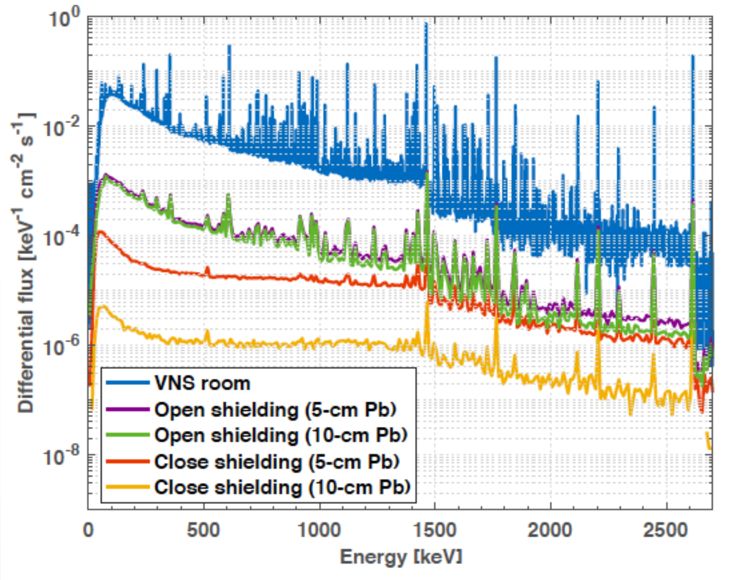
  ⇒ low-Z material in the shield inner layer

  ⇒ borated PE reduce n background without enhancing γ contribution

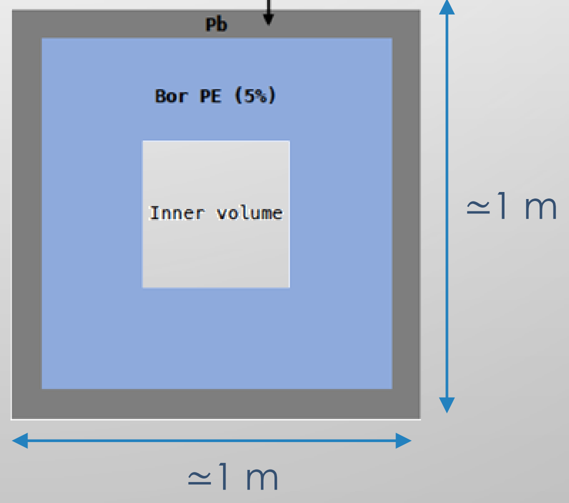
  ⇒ 5-10 cm single Pb layer to reduce ambient γ's

- Environmental gamma background contribution
- Effect on the background level of different level of ^{210}Pb contamination in the lead of the shield
- Muon Veto efficiencies

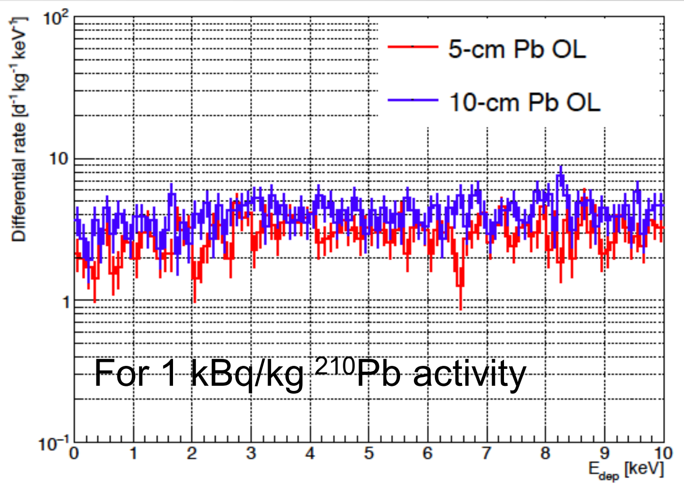
Shielding attenuation to ambient γ's



Schematic view of the passive shield



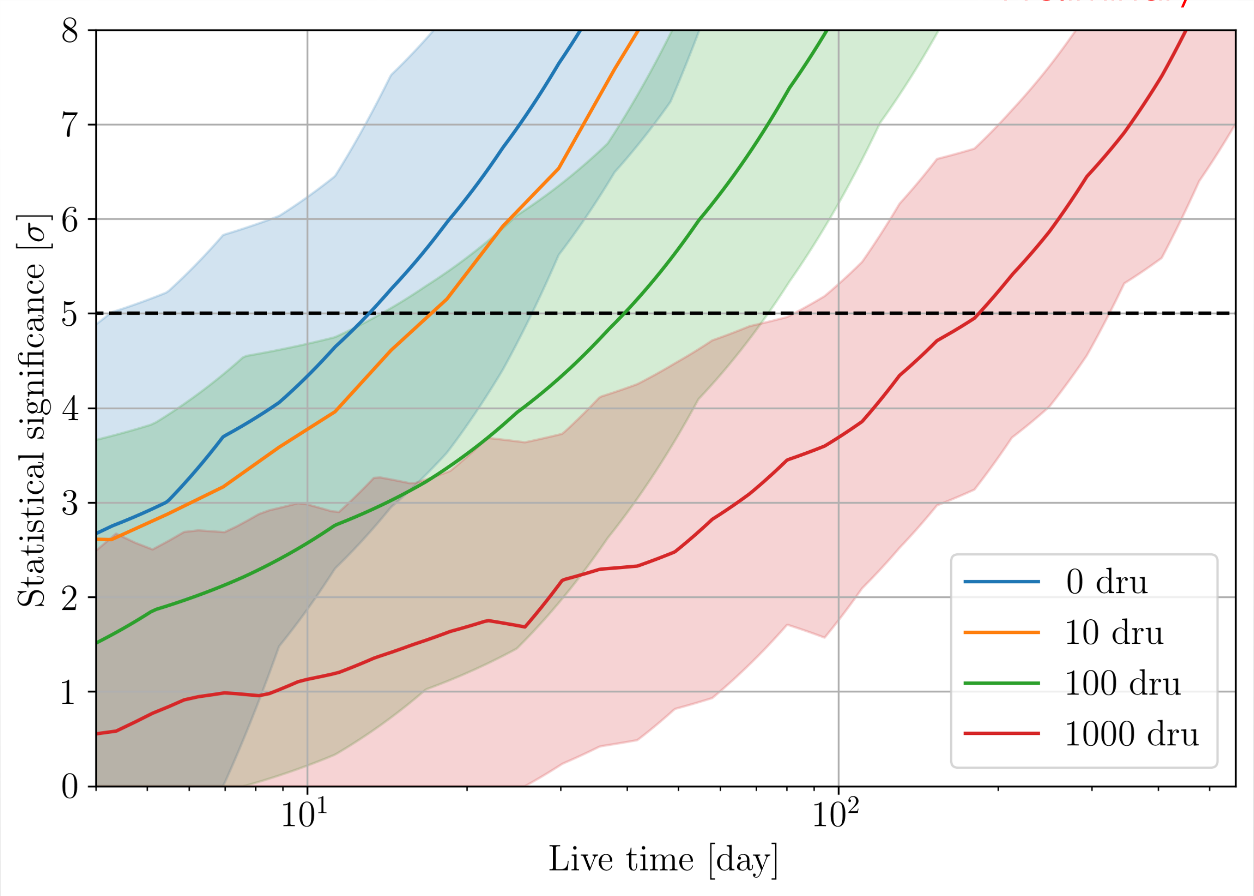
Expected rate in CaWO4 from ^{210}Pb



NUCLEUS 10g sensitivity

- 20 eV energy threshold
- Average reactor power 80%
- Flat background

Preliminary

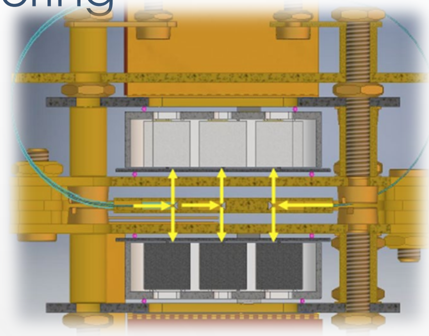


In about 40 days with a background < 100 cpd/kg/keV
CEνNS signal observation at **5σ**

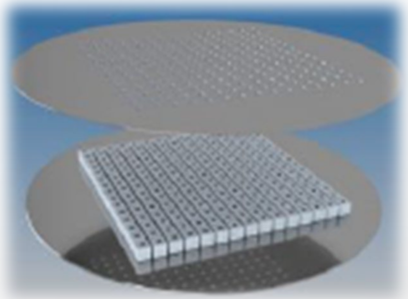
NUCLEUS: a 2 phases project

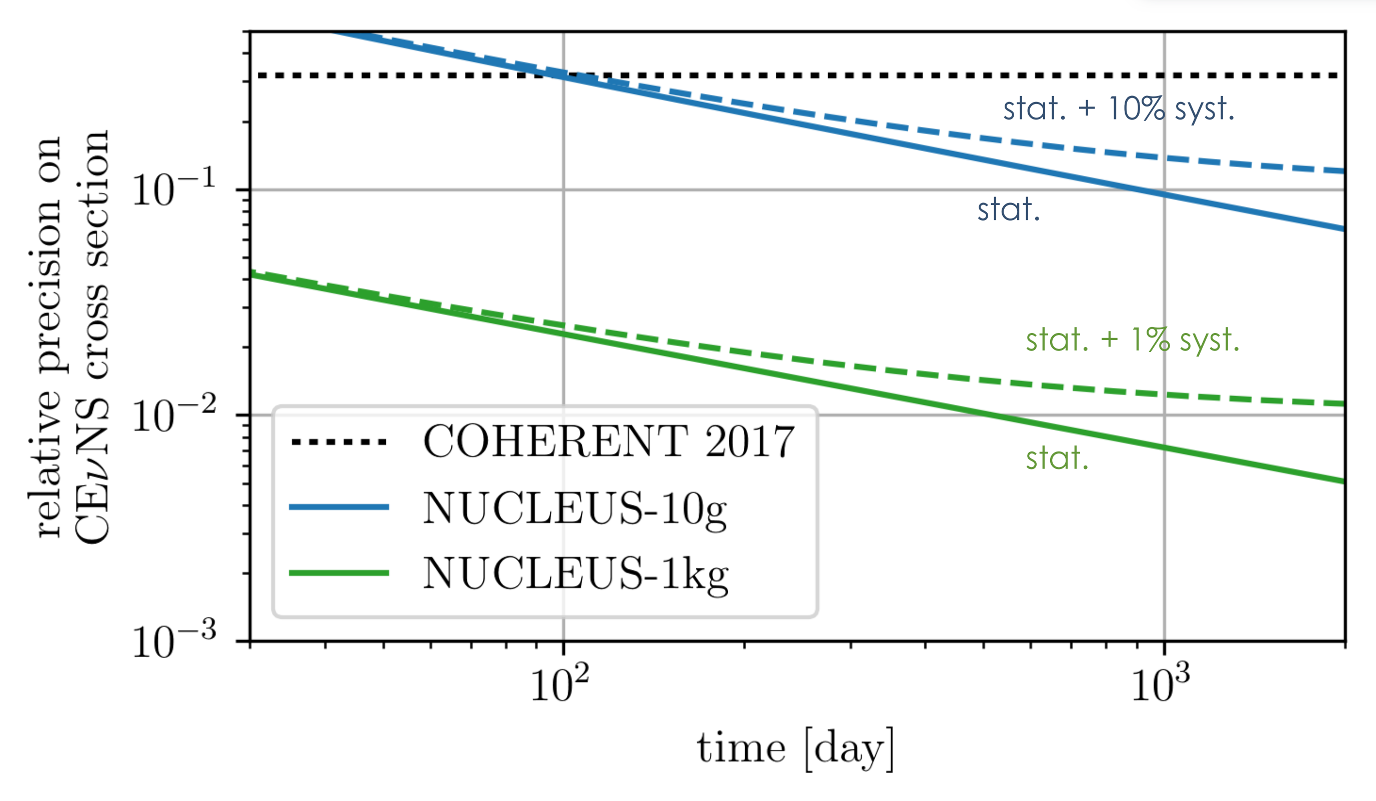
10 g target detector: detection of neutrinos coherent scattering

2021	Commissioning at TUM
2022	Installation at Chooz
2022	Start data taking



1 kg scale: high-precision measurement (2024)





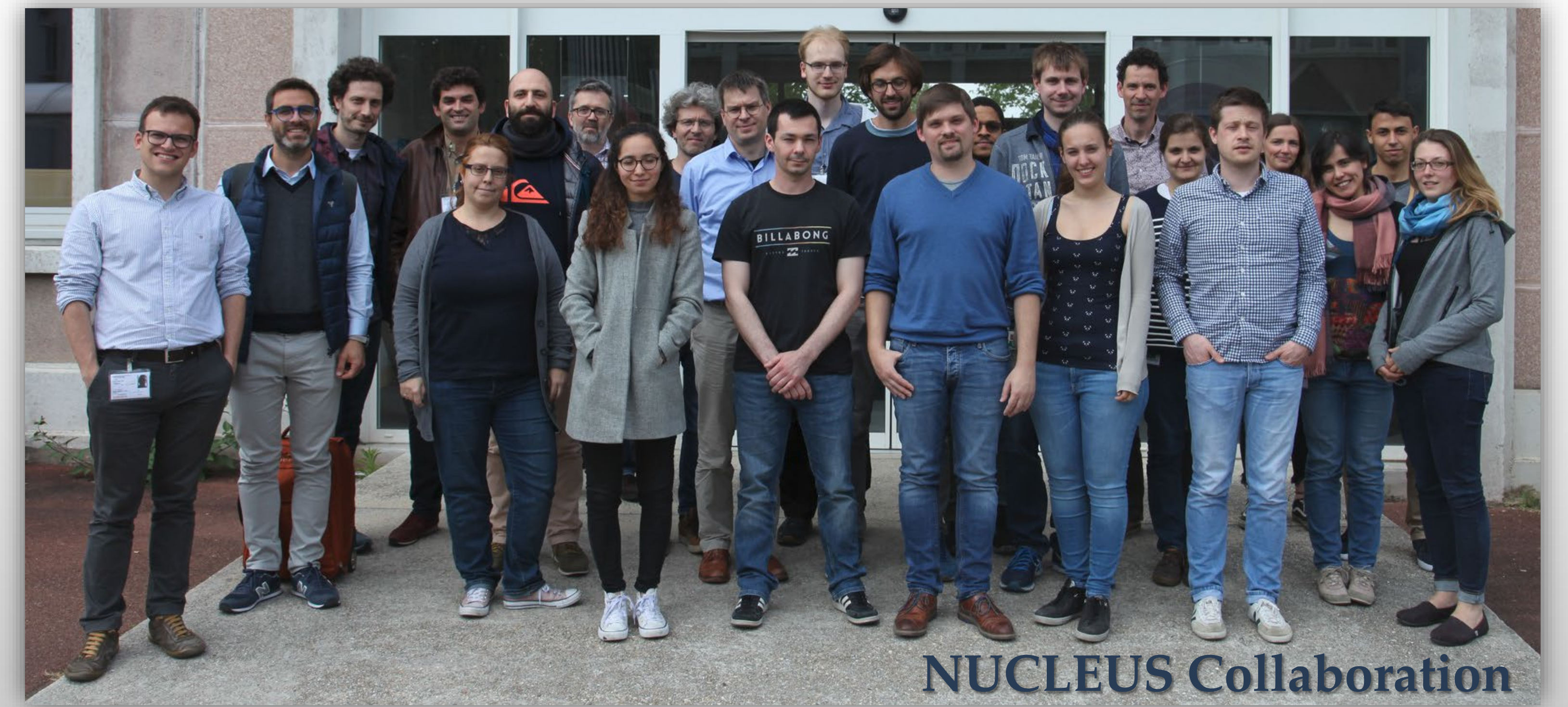
1st phase: stat limited

2° phase: syst limited

Conclusion

- **The NUCLEUS** experiment aims at the exploration of ***CEvNS*** at low energy with cryogenic detectors
- The experiment will operate at the **Chooz** nuclear power plant in France
- In the 1st stage **10 g** scale target mass will allow in **2022** to measure the CEvNS signal by using $\mathbf{Al_2O_3}$ and $\mathbf{CaWO_4}$ cryogenic detectors
- **The NUCLEUS** experiment is progressing well despite Covid-19; in **2021** the experimental sub-systems will be commissioned in our labs and finally assembled at TUM
- In **2022** it will be shipped to **Chooz, installed** and **commissioned**
- A **1 kg** mass scale experiment is foreseen for precision measurement at percent level to explore **physics beyond SM**

Thanks for your attention!



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