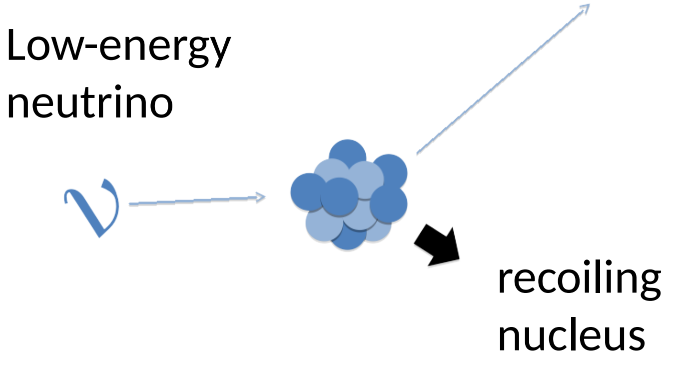
Exploring coherent neutrino-nucleus scattering with cryogenic detectors

Johannes Rothe

Max-Planck-Institute for Physics, Munich

18th International Workshop on Low Temperature Detectors
22-26 July 2019 - Milano, Italia

The Magnificent **CEνNS**

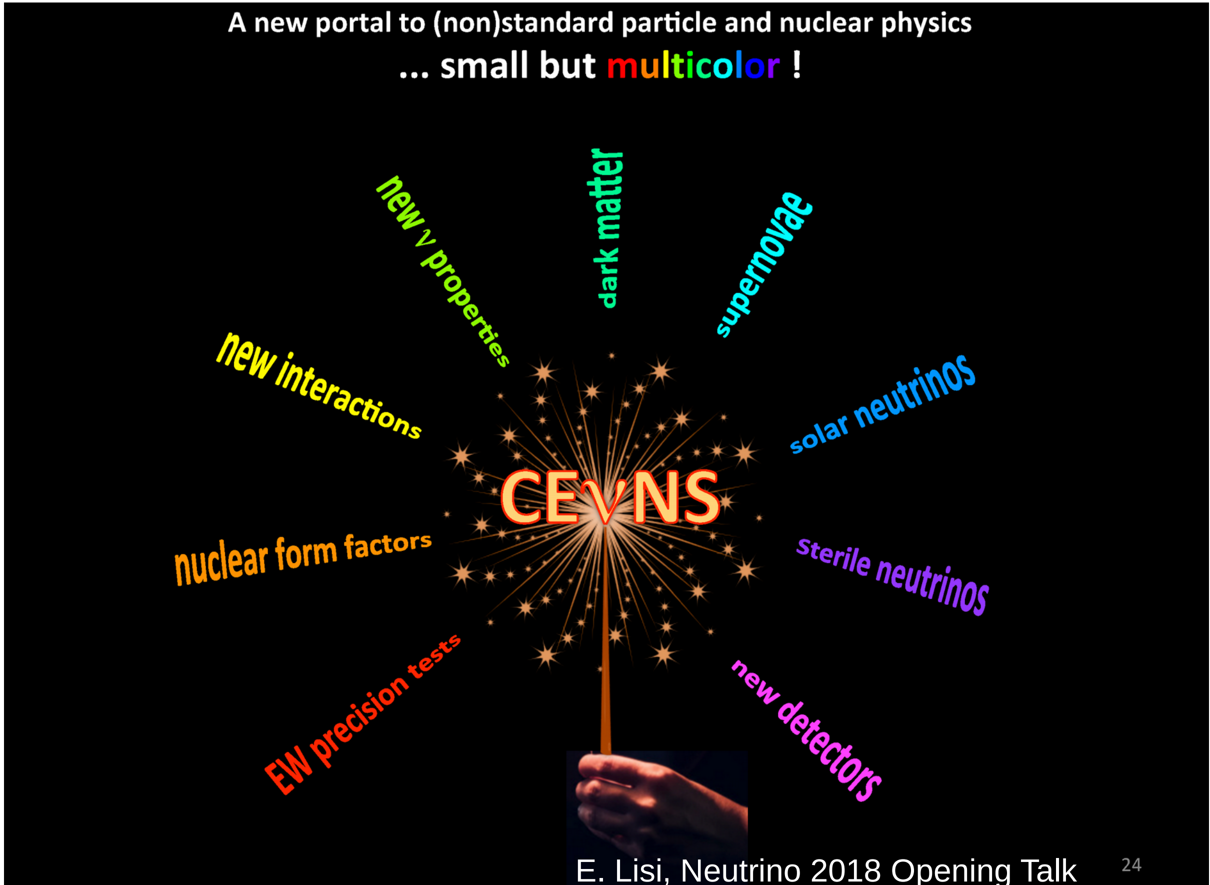


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

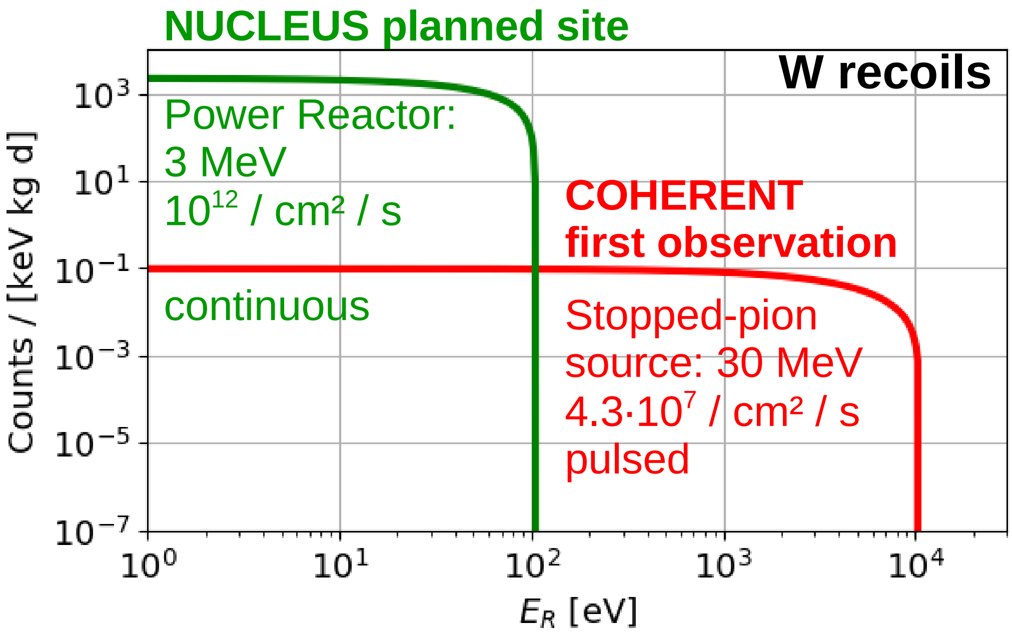
Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering.



CEνNS at a nuclear reactor



Reactor Neutrinos: Promises

Large Flux
→ High statistics possible with small detector

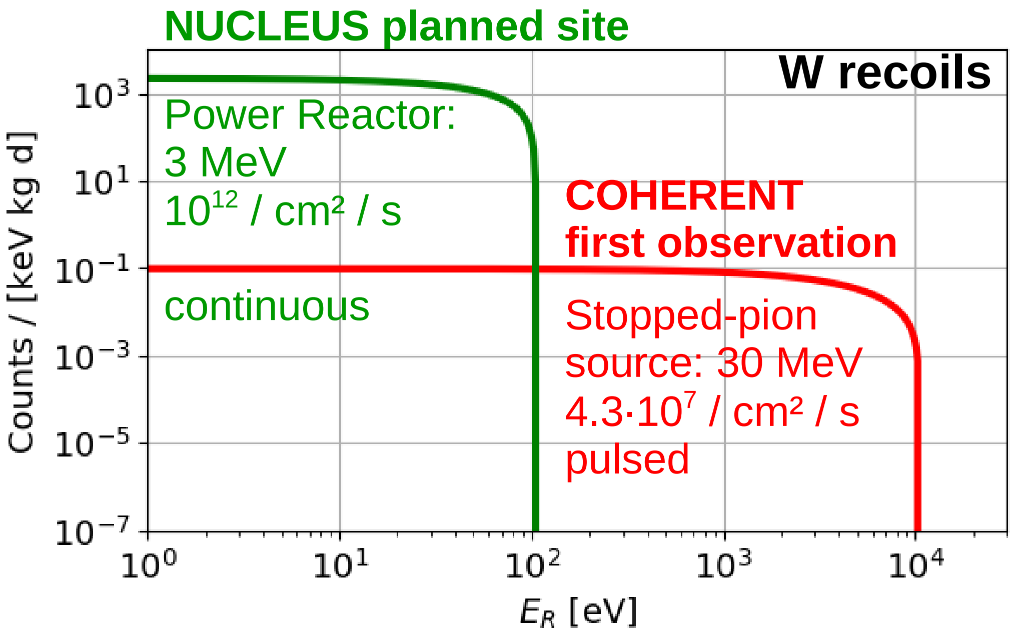
Low energies > 8 MeV
→ Full coherence, New Physics potential

Challenges

Recoil energies below 100 eV
→ ultra-low thresholds required

Shallow depth, continuous source
→ challenging background environment

CEνNS at a nuclear reactor



NUCLEUS goals

Lowest energies

Precision

Low systematics

Reactor Neutrinos: Promises

Large Flux
→ High statistics possible with small detector

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Challenges

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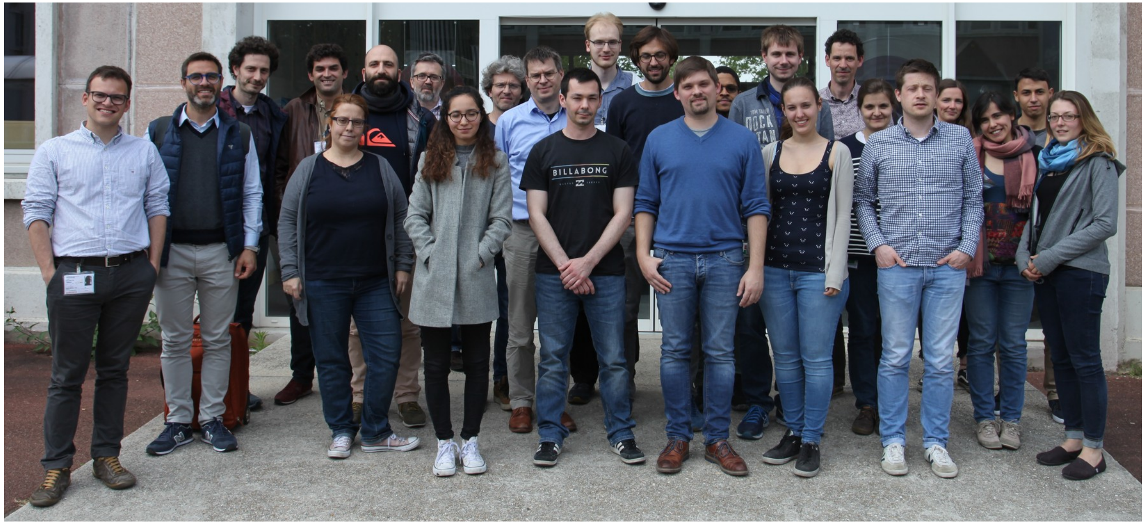
→ challenging background environment

The NUCLEUS collaboration

P.I. R. Strauss



so far 5 institutes
with ~40 members

+ INFN funding
under review

TECHNISCHE
UNIVERSITÄT
MÜNCHEN

LMU

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

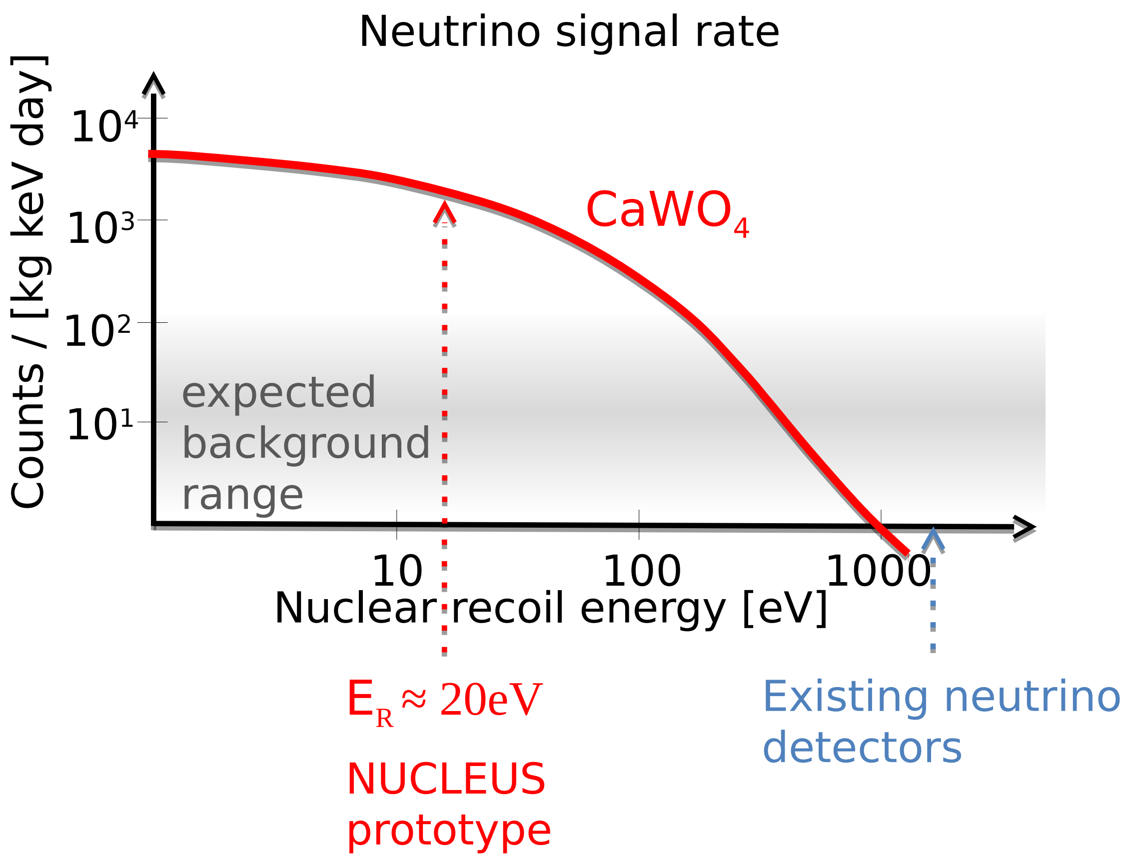
DE LA RECHERCHE À L'INDUSTRIE

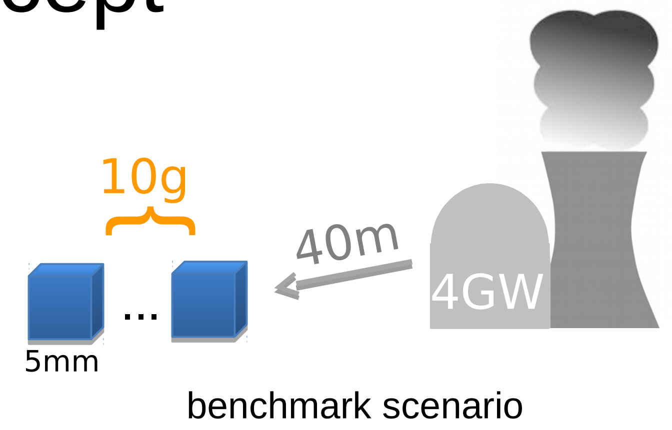
HEPHY
INSTITUT FÜR HOCHENERGIEPHYSIK

TU WIEN

SFB 1258 Neutrinos Dark Matter Messengers

The NUCLEUS concept



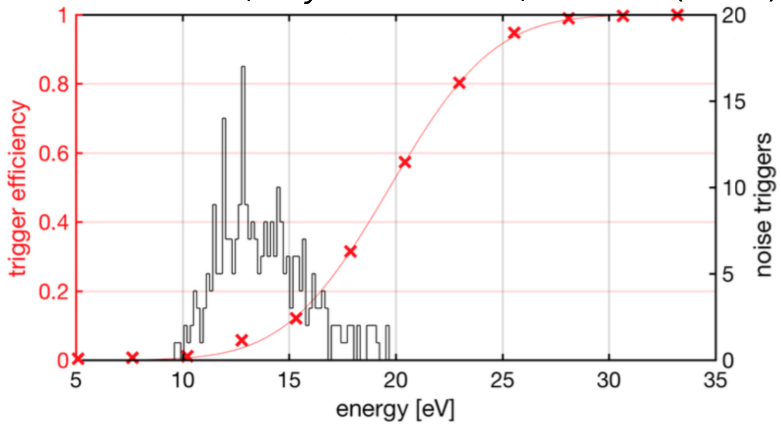


→ CEvNS observation with 10g feasible within 10 days

→ miniaturization of neutrino detectors

The first NUCLEUS prototype (2017)

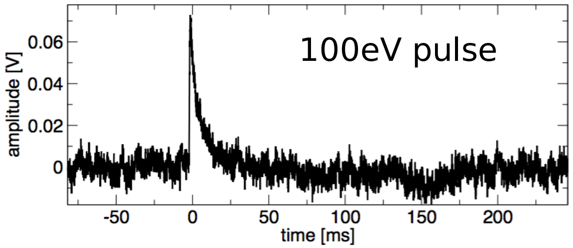
R. Strauss et al., *Phys. Rev. D* **96**, 022009 (2017)



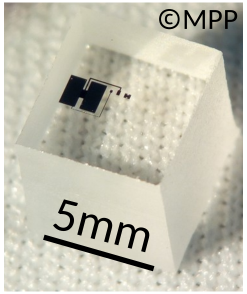
Energy threshold: E_{th} = (19.7 +- 0.9) eV

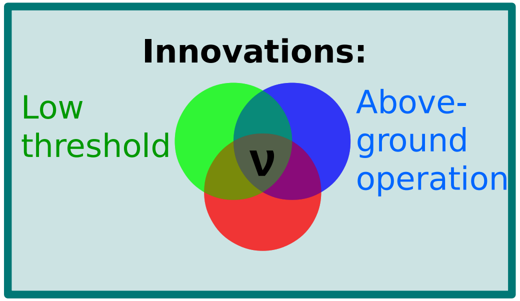
Lowest threshold for nuclear recoils in the field

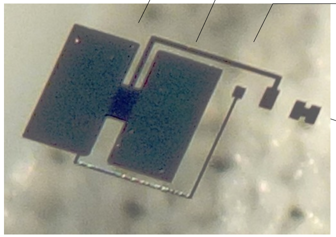
Accurate knowledge of the energy scale



Scaled-down dark matter detector (CRESST technology): 0.5 g Al_2O_3







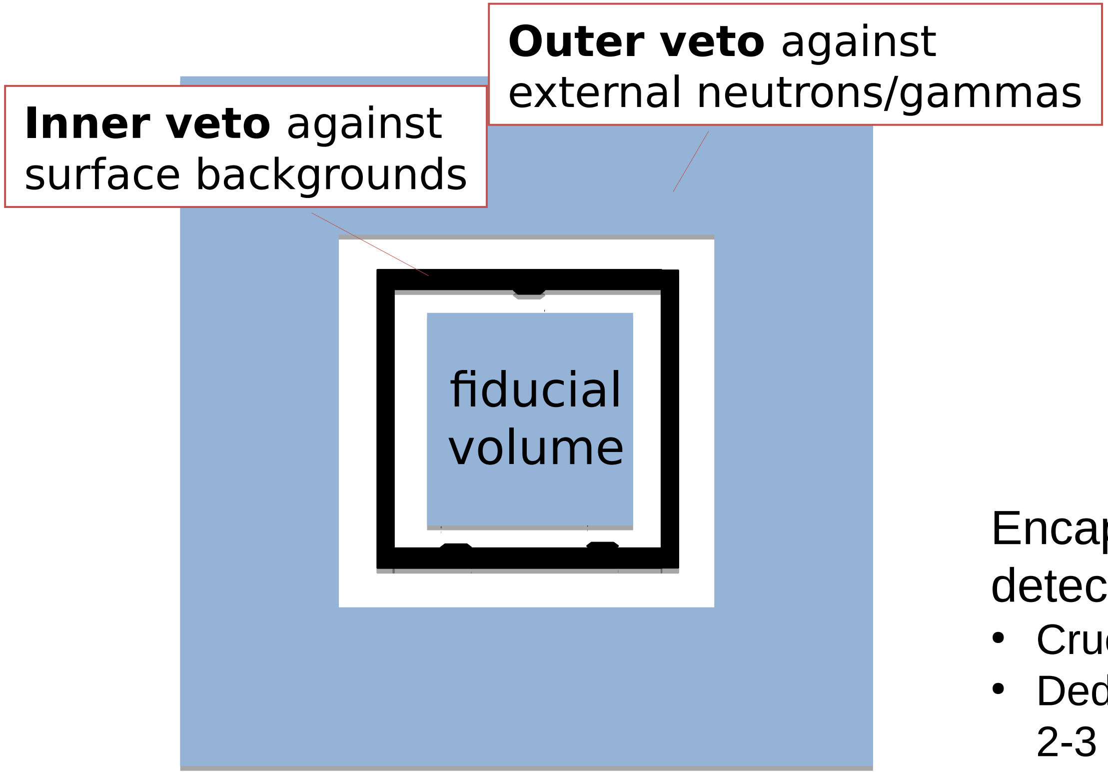
TES (evaporated W), T_c = 15 mK

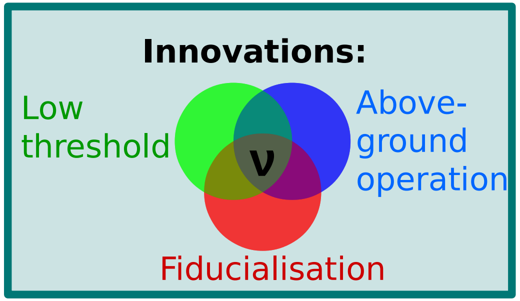
Al phonon collectors

Au thermal link

Resistive heater for temperature stabilization and pulser linearization

The NUCLEUS cryogenic detector



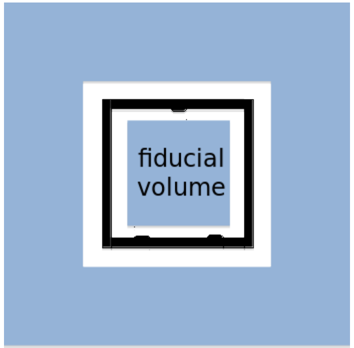


Encapsulation by cryogenic veto detectors:

- Crucial background reduction
- Dedicated MC studies:
  2-3 orders of magnitude improvement

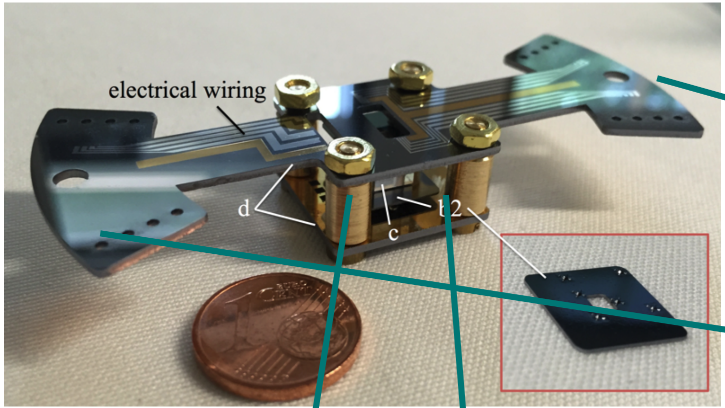
→ Fiducial-volume cryogenic detector

NUCLEUS 1g demonstrator

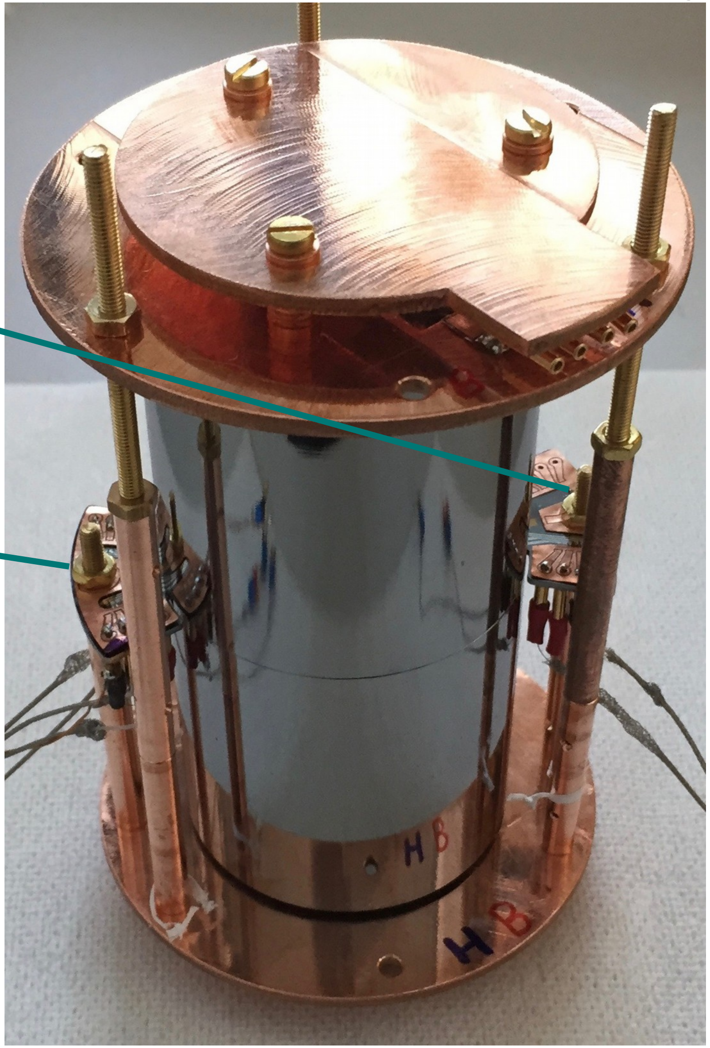


First version of cryogenic detector components
to study co-operation and performance

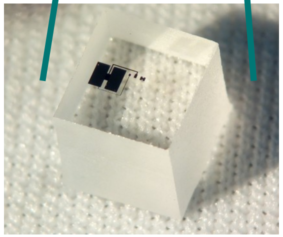
Inner veto and holder



Outer veto assembly

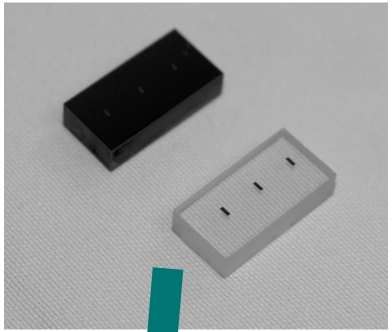


Target detector(s)



Supported by Excellence Cluster
“Universe” 2017, 2018

NUCLEUS target detectors

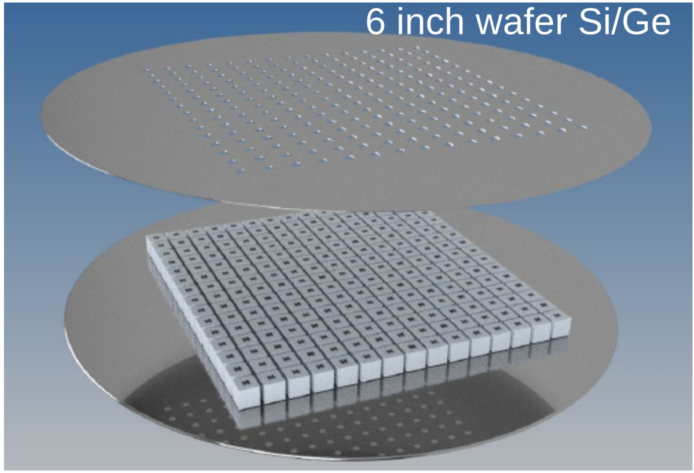


Fabrication
- Film deposition for multiple TES
- Transition testing
- Dicing / Polishing

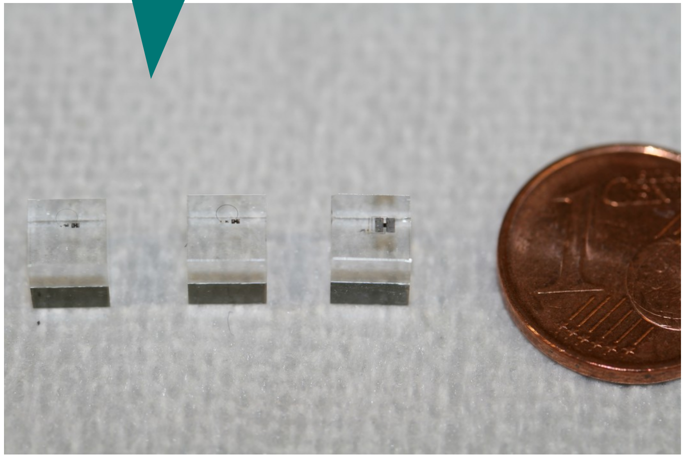
→ Improved homogeneity
of transitions, better reproducibility

→ Important technique for
future mass-production

R&D for NUCLEUS 1kg



Straightforward production
+ requires multiplexed readout



Target Materials
- Multi-material target
(Debye temperature,
CEvNS cross-section ~N^2,
neutron cross-sections)

- currently under investigation:
Al_2O_3, $CaWO_4$, Si, Ge

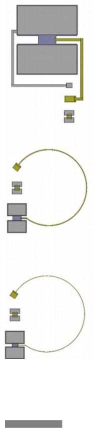
NUCLEUS target detectors

TES structures

NUCLEUS "Light": 1mm²

NUCLEUS "M": 0.16 mm²

NUCLEUS "S": 0.15 mm²



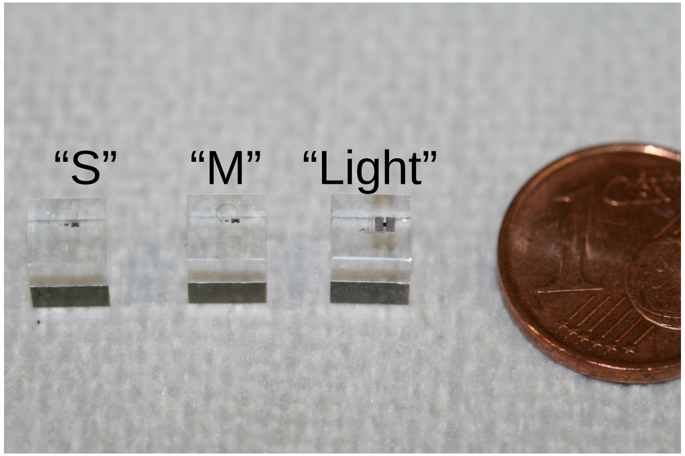
Au links

40µm

20µm

10µm

1mm



Scaling down TES phonon collection area together with absorber size
→ comparable non-thermal phonon lifetime

Smaller W area (heat-capacity)
→ reduce thermal coupling (Au link)
for same relaxation time

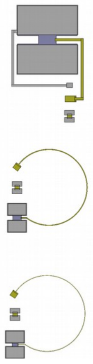
NUCLEUS target detectors

TES structures

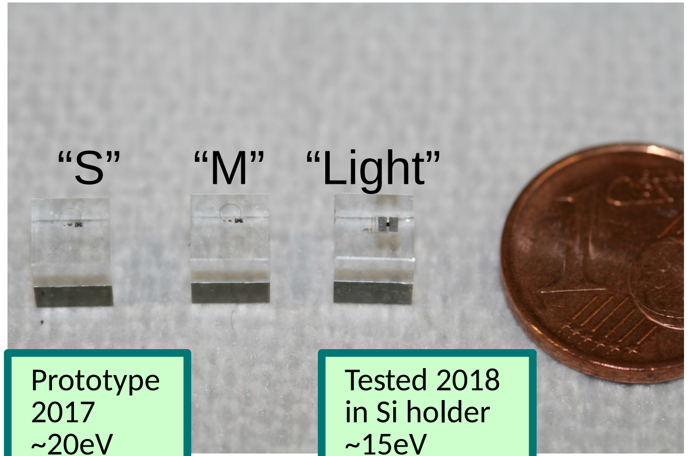
NUCLEUS “Light”: 1mm² — Au links 40µm

NUCLEUS “M”: 0.16 mm² — 20µm

NUCLEUS “S”: 0.15 mm² — 10µm



1mm



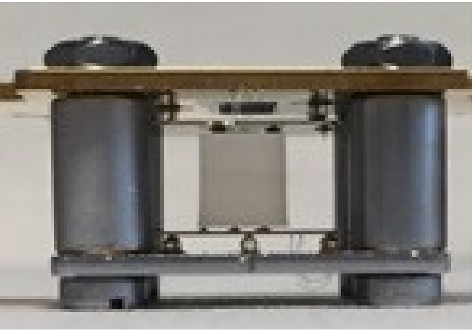
Prototype 2017
~20eV

Tested 2018
in Si holder
~15eV

Scaling down TES phonon collection area together with absorber size
→ comparable non-thermal phonon lifetime

Smaller W area (heat-capacity)
→ reduce thermal coupling (Au link)
for same relaxation time

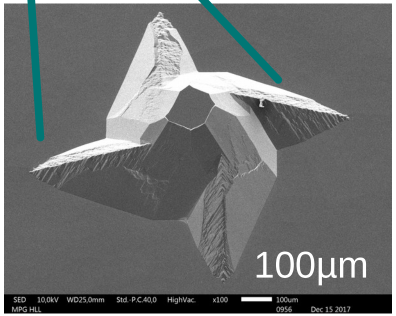
The cryogenic inner veto



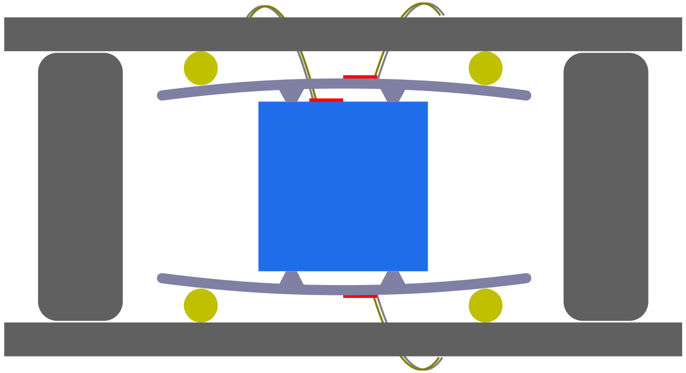
Si wafers (11mm)^2 x 200µm

1) 4π surface veto (sub-keV threshold)

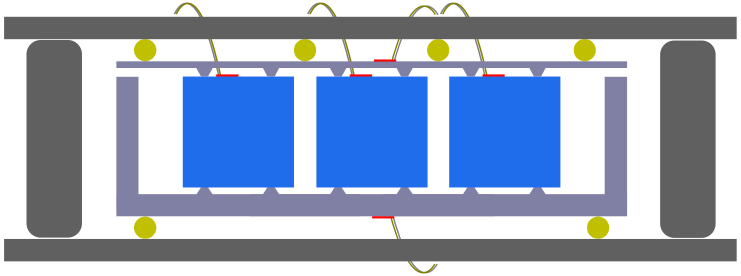
2) Elastic instrumented holder
   - wet-etched pyramid structures
   - point-like contacts to target

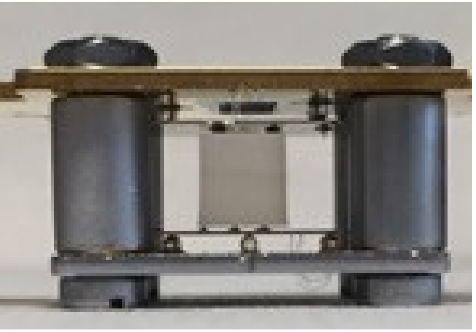


1g demonstrator

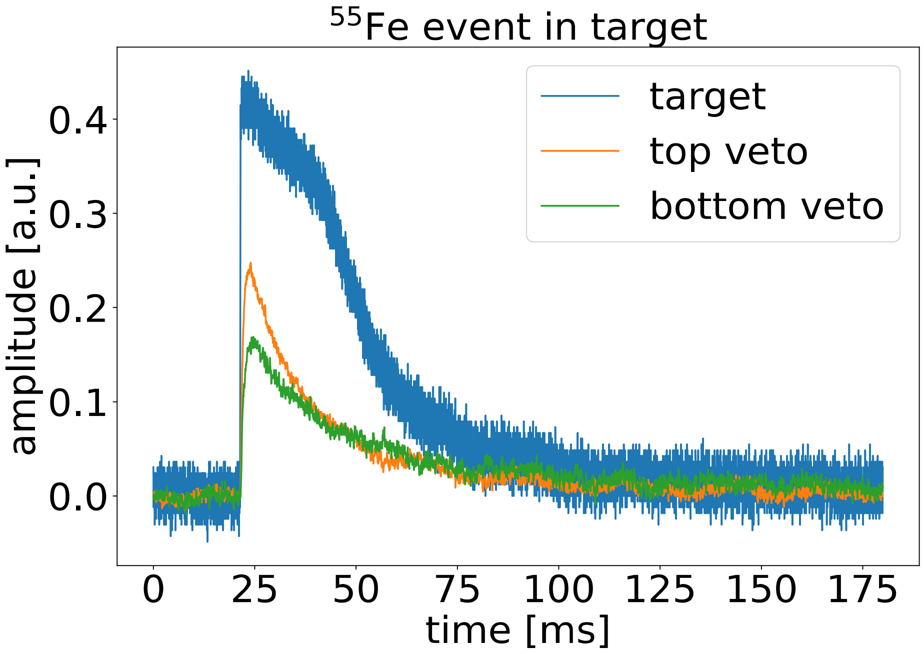


NUCLEUS-10g





Inner Veto Performance



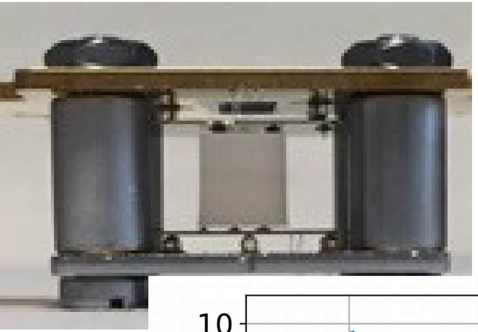
03/2019: First simultaneous detector operation

~5-20% phonon transmission between detectors

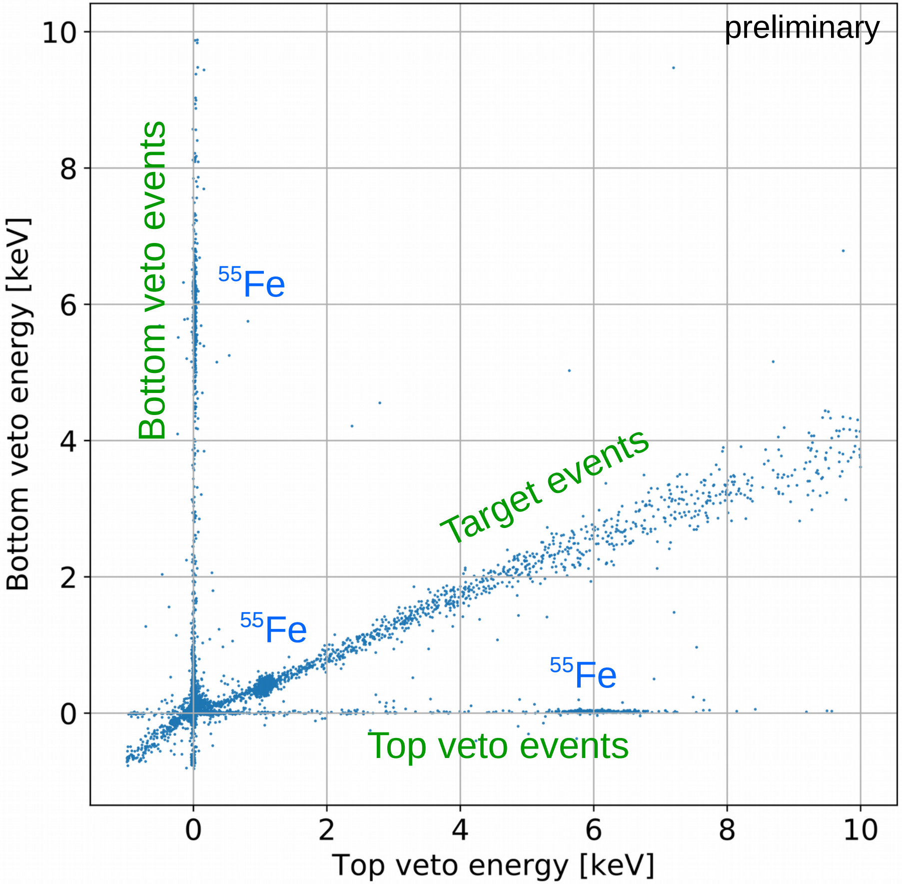
Energy resolutions: 13.4 eV (veto top),
9.1 eV (veto bottom)

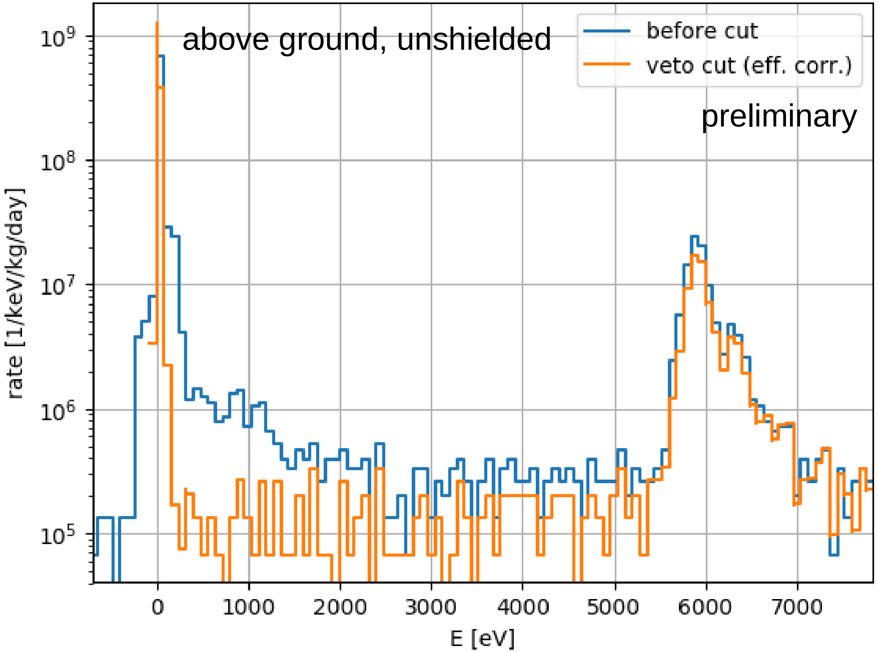
→ trigger thresholds below 100 eV

Inner Veto Performance



Veto vs. Veto



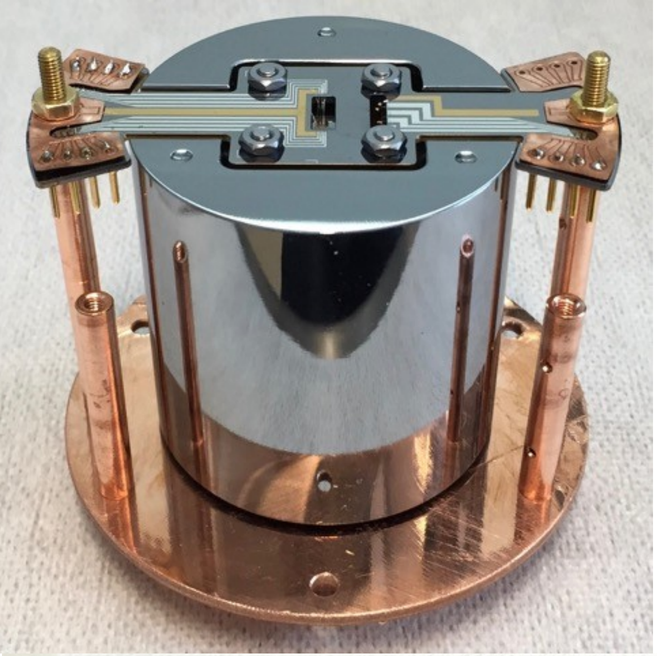


3 bands corresponding to direct energy depositions

Populations between bands can be discriminated:

- Surface contaminations
- Holder-induced events (stress)

The cryogenic outer veto

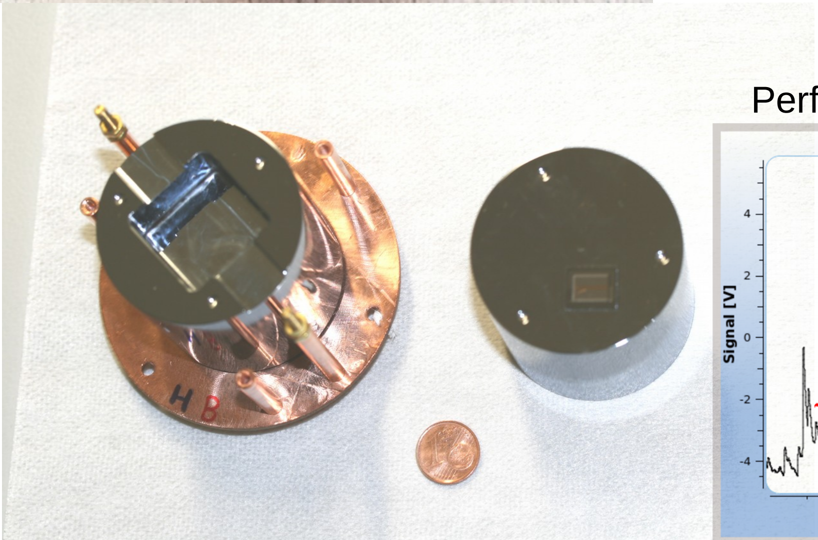


Requirements: massive (O(kg)), high-Z, fast
→ n/gamma anti-coincidence

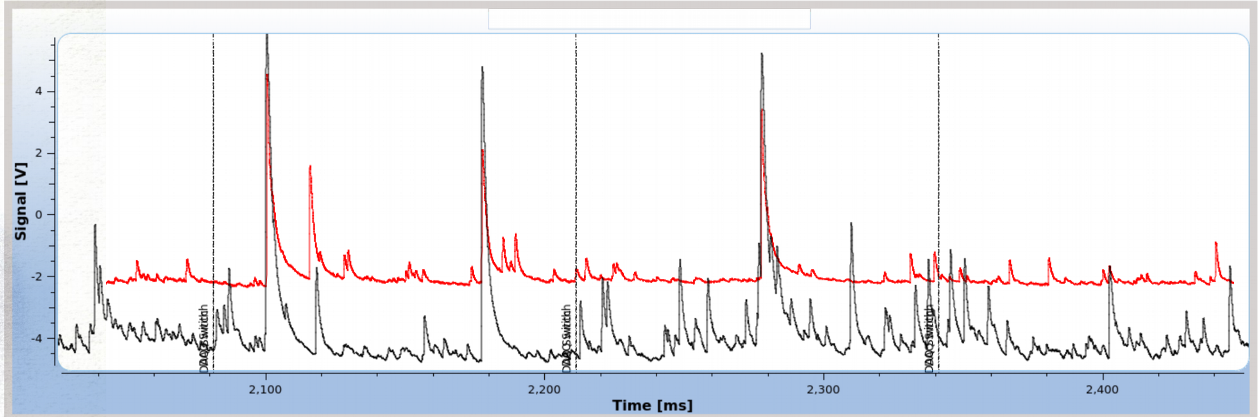
First prototype:
5cm x 5cm Si cylinders (~210g)
large-area (6x8 mm²) TES
→ fast pulses
Cavity for inner detectors

Next steps:

- Characterization at shallow underground lab of TUM (UGL)
- Joint test of all cryo components
- Materials: Ge, Li_2WO_4 (BASKET)



Performance in unshielded surface setup



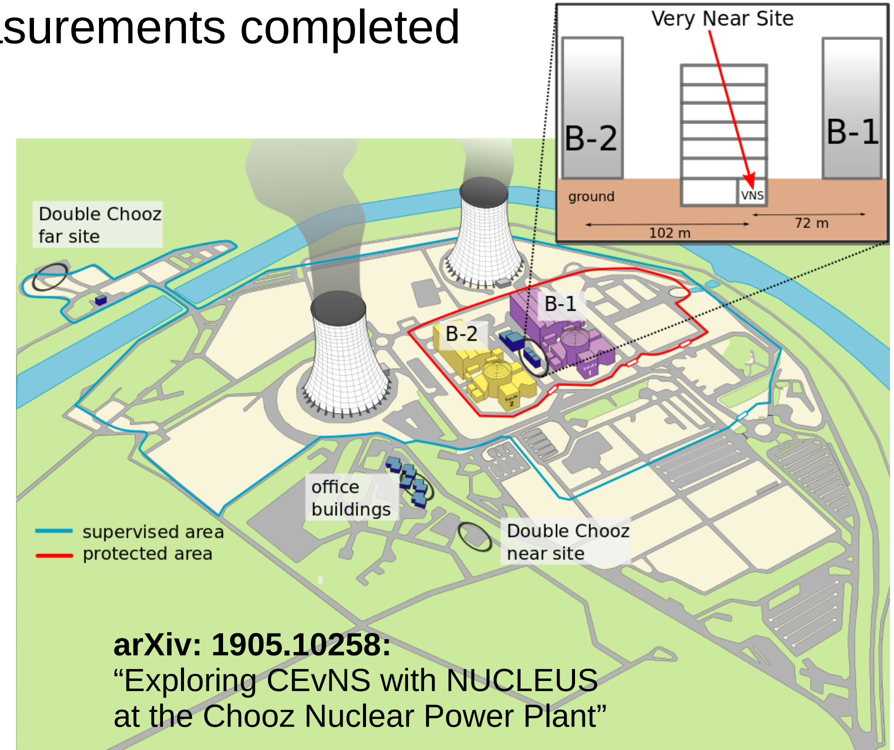
The Very-Near Site at Chooz

New experimental site in a 24m^2 room in an administrative building

Between the two reactor cores

Expected ν-flux: 10^{12} (s cm^2)$^{-1}$

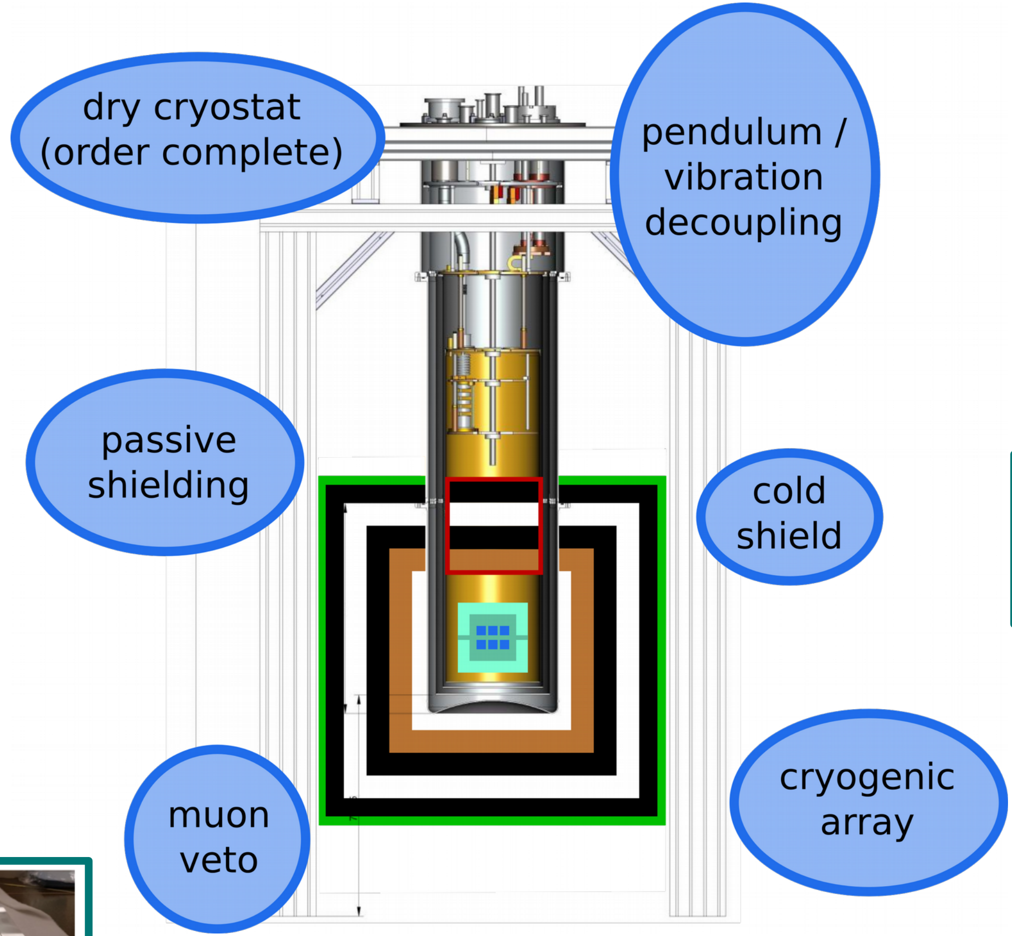
First muon and fast neutron measurements completed



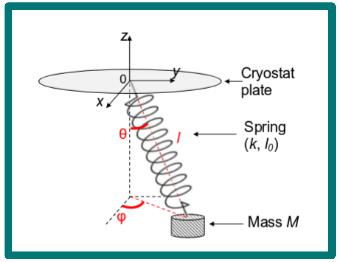
arXiv: 1905.10258:
"Exploring CEvNS with NUCLEUS at the Chooz Nuclear Power Plant"

The NUCLEUS Setup

Bluefors-LD
(delivery early 2020)

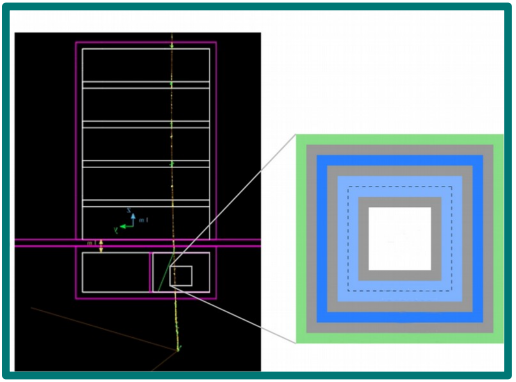


Mass-spring damper



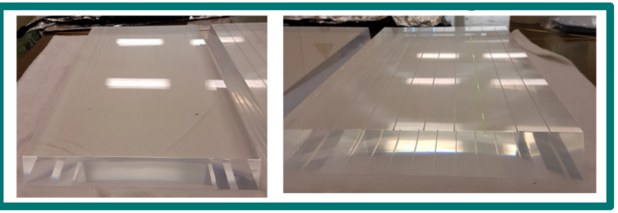
R. Maisonobe et. al. 2018 JINST13 T08009
C. Lee et. al. 2017 JINST12 C02057

Geant4 studies

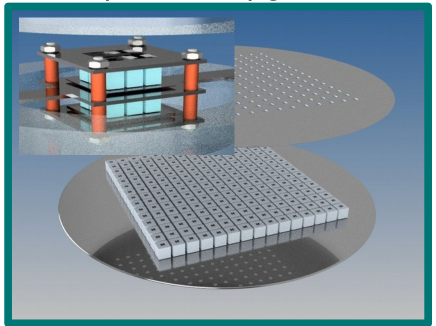


Internal
shielding
around zenith
(~200 kg load)

Prototype testing

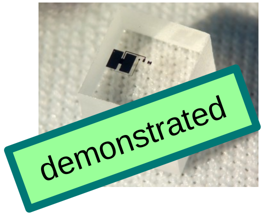


Space for upgrades



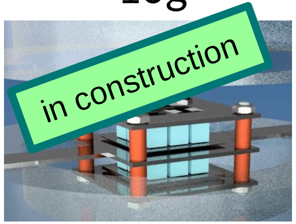
Outlook – Timeline

Proof of principle
1g



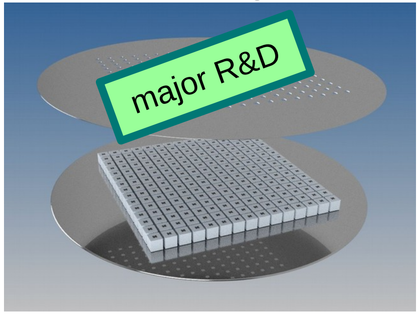
2017-2019

Phase 1
10g



2021

Phase 2
1kg



>2025

detector + electronics development

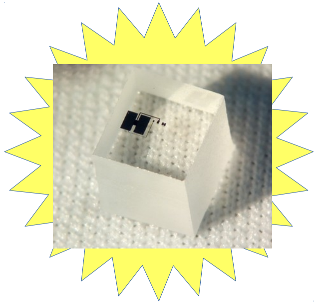
multiplexing

2020 Cryostat delivered to Munich
NUCLEUS 10g cryodetectors commissioned in Munich

2021 “Blank assembly” of all subsystems in TUM underground lab
setup relocation to Chooz + commissioning

2022 NUCLEUS-10g data taking

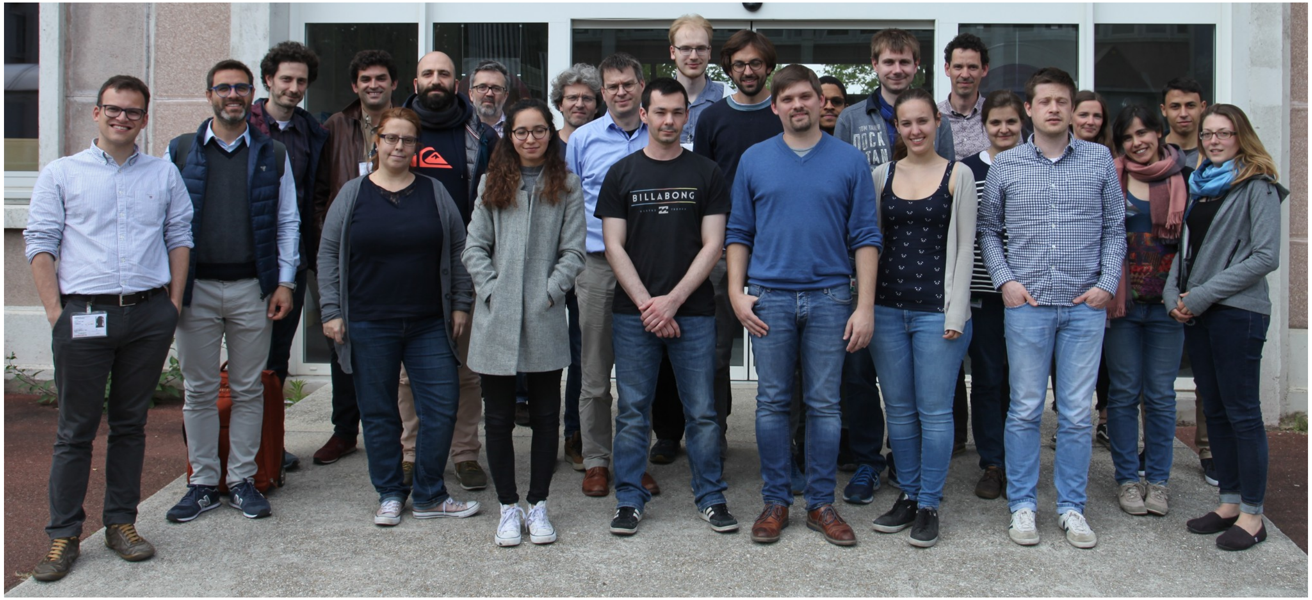
nucleus
EXPERIMENT



developing **tiny** detectors

to study **tiny** nuclear recoils

with **great** physics reach



NUCLEUS – it’s tiny, but it’s great!