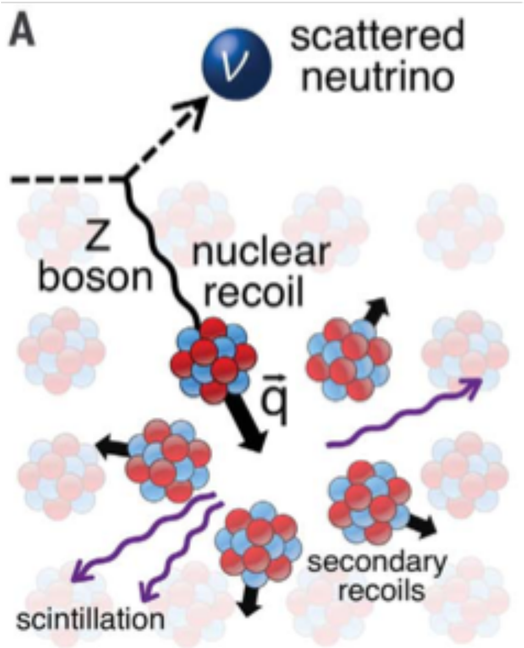
nucleus:

coherent elastic neutrino-nucleus scattering at CHOOZ



EXPERIMENT
nucleus

Riccardo Cerulli
Luglio 2019

Neutrino cross-sections and detectable energy

Coherent Elastic ν-Nucleus Scattering

$$\nu(\bar{\nu}) + A \rightarrow \nu(\bar{\nu}) + A$$

$$\sigma_{\mathrm{CE}\nu\mathrm{NS}} = \frac{G_F^2}{4\pi} F^2(q^2) Q_W^2 E_\nu^2$$

$$Q_W = N - Z(1 - 4\sin^2\theta_W) \sim N$$

$$E_\nu < qR \qquad < T > = \frac{2}{3}\frac{E_\nu^2}{M_A}$$

Inverse Beta Decay

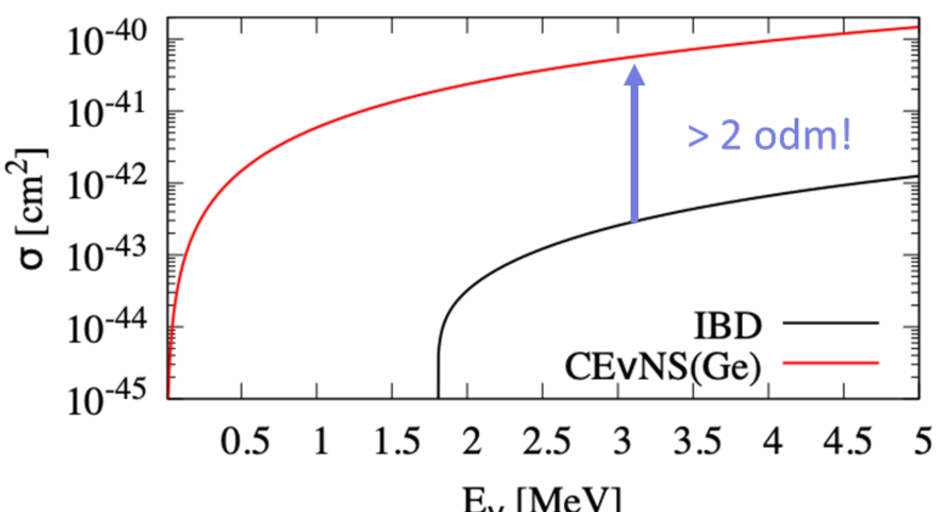
$$\bar{\nu} + p \rightarrow n + e^+$$

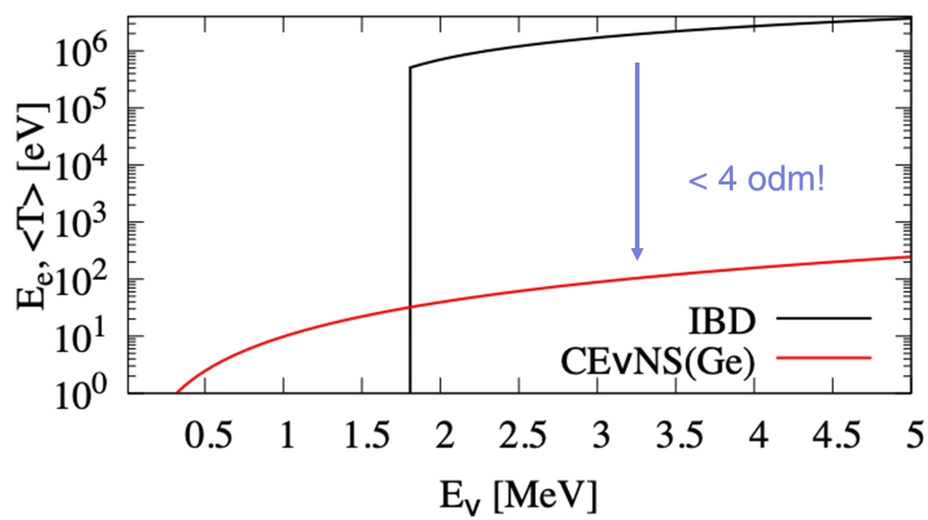
$$\sigma_{\mathrm{IBD}}^0 = \frac{G_F^2 \cos^2\theta_C}{\pi}\left(f^2 + 3g^2\right) E_e p_e$$

$$E_e = E_\nu - (M_N - M_p)$$

$$E_\nu > 1.806\ \mathrm{MeV}$$

$$E_e = E_\nu - (M_N - M_p)$$





43 years to be discovered

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

RESEARCH

NEUTRINO PHYSICS Science 357, 1123–1126 (2017)

Observation of coherent elastic neutrino-nucleus scattering

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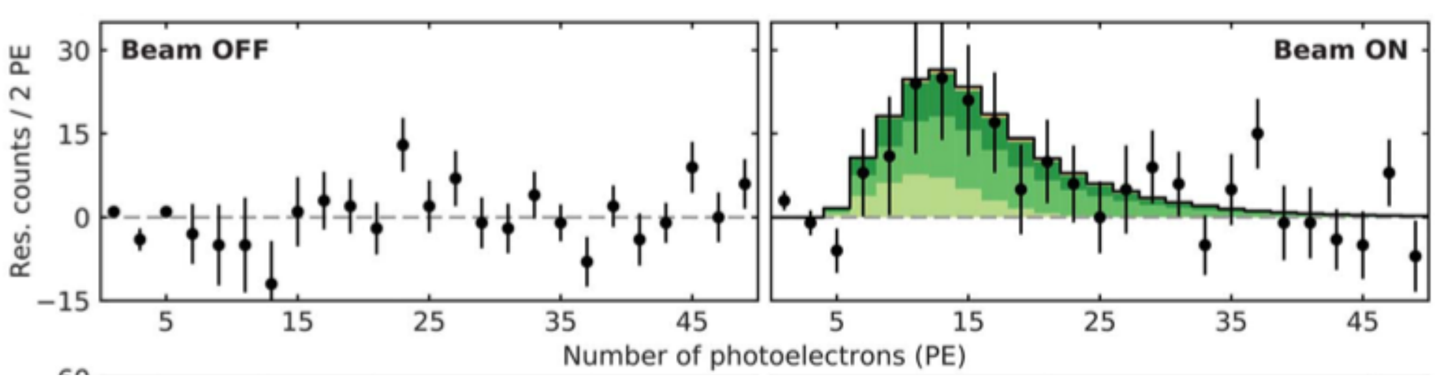
The coherent elastic scattering of neutrinos off nuclei has eluded detection for four decades, even though its predicted cross section is by far the largest of all low-energy neutrino couplings. This mode of interaction offers new opportunities to study neutrino properties and leads to a miniaturization of detector size, with potential technological applications. We observed this process at a 6.7σ confidence level, using a low-background, 14.6-kilogram CsI[Na] scintillator exposed to the neutrino emissions from the Spallation Neutron Source at Oak Ridge National Laboratory. Characteristic signatures in energy and time, predicted by the standard model for this process, were observed in high signal-to-background conditions. Improved constraints on nonstandard neutrino interactions with quarks are derived from this initial data set.

14.6 kg CsI[Na],

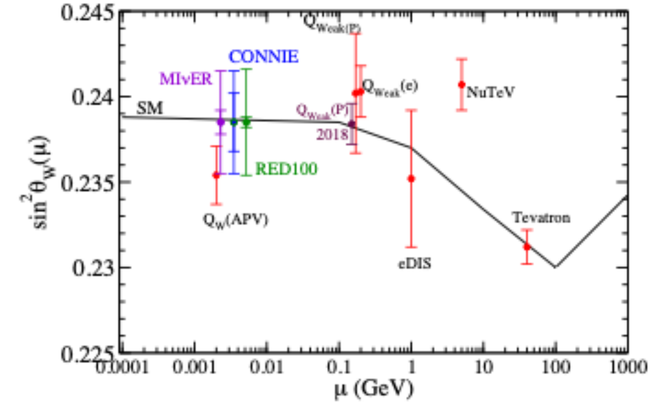
153 days beam off 308 days beam on



Spallation neutron source at Oakridge

Physics with CEνNS and more

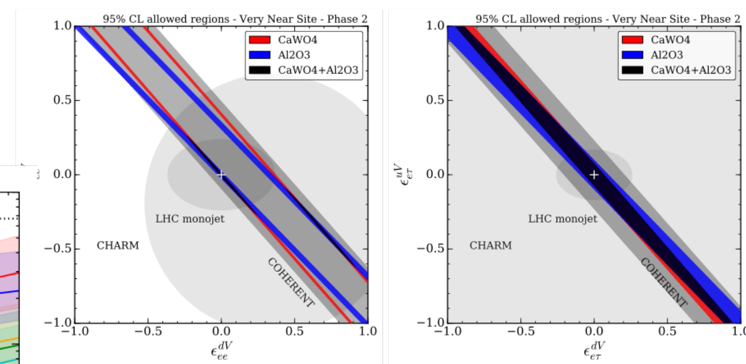
- $\sin^2\vartheta_W$ at low Q



JCAP 1811 (2018) 016

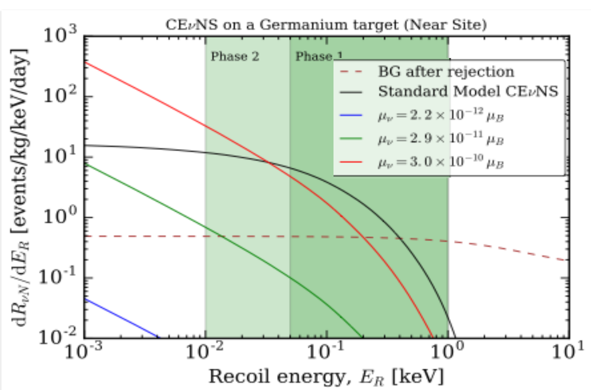
- Non-standard interactions

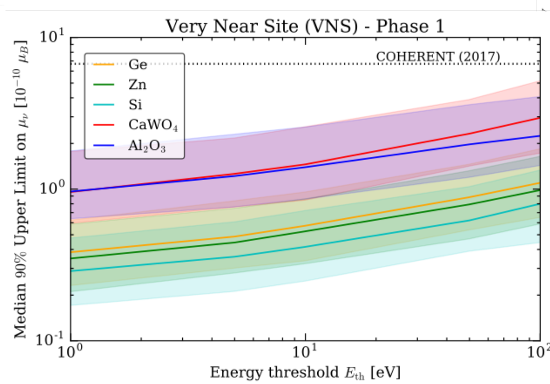
$$\mathcal{L}^{\rm NSI} = -\epsilon_{\alpha\beta}^{fP} 2\sqrt{2} G_F (\overline{\nu}_\alpha \gamma_\rho L \nu_\beta)(\overline{f}\gamma^\rho P f)\,,$$



- Neutrino magnetic moment

$$\frac{\mathrm{d}\sigma_{\nu-N}^{\rm mag.}}{\mathrm{d}E_R} = \frac{\pi\alpha^2\mu_\nu^2 Z^2}{m_e^2}\left(\frac{1}{E_R} - \frac{1}{E_\nu} + \frac{E_R}{4E_\nu^2}\right) F^2(E_R)\,.$$

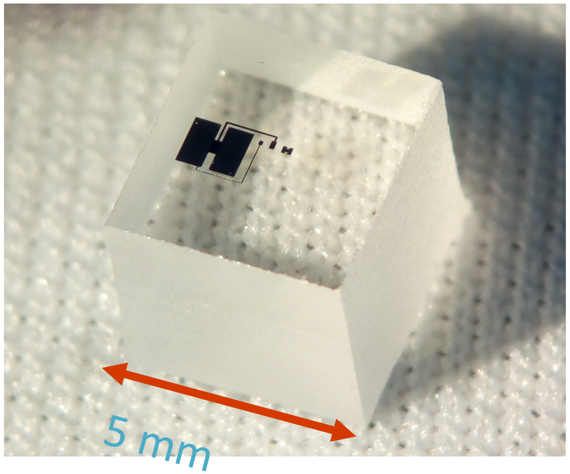




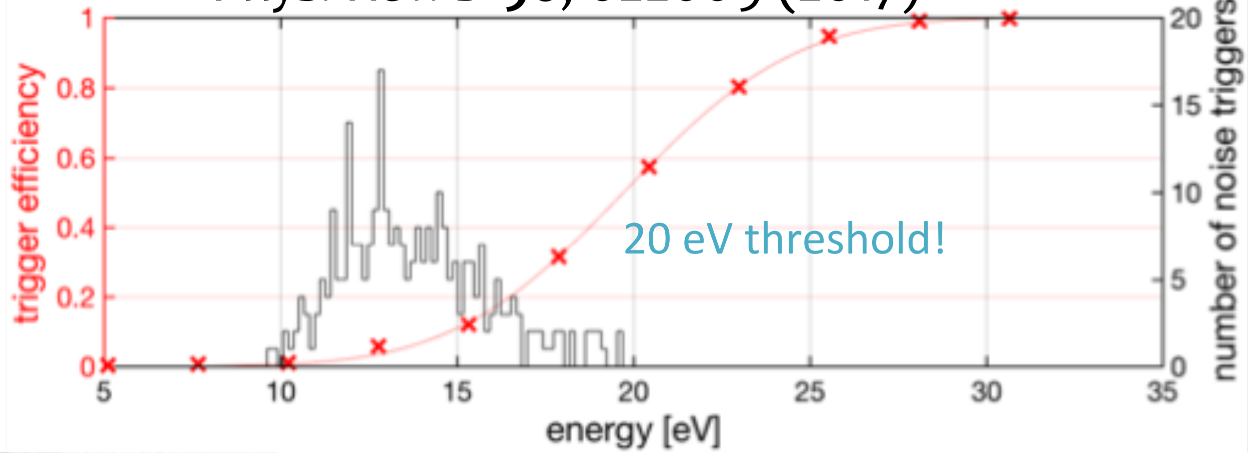
- Non-proliferation: detectors can be used to find out fuel diversion (e.g. Plutonium removal from core, 1811.04737)

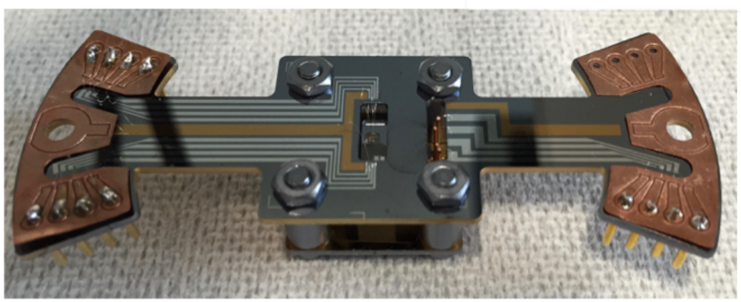
NUCLEUS: detector

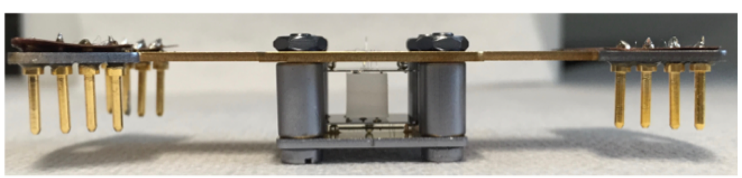
CRESST technology: TES on $CaWO_4$ or Al_2O_3 at 10 mK

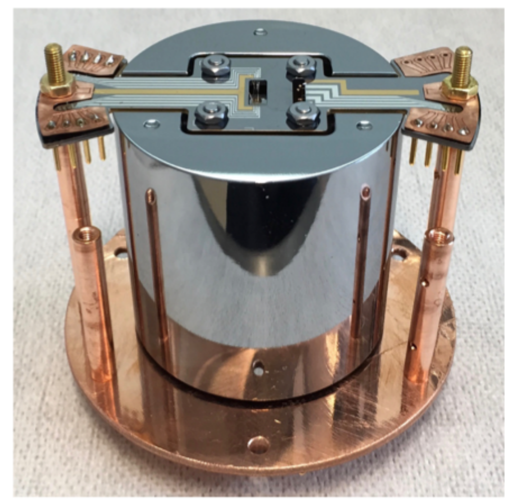


Phys. Rev. D **96**, 022009 (2017)







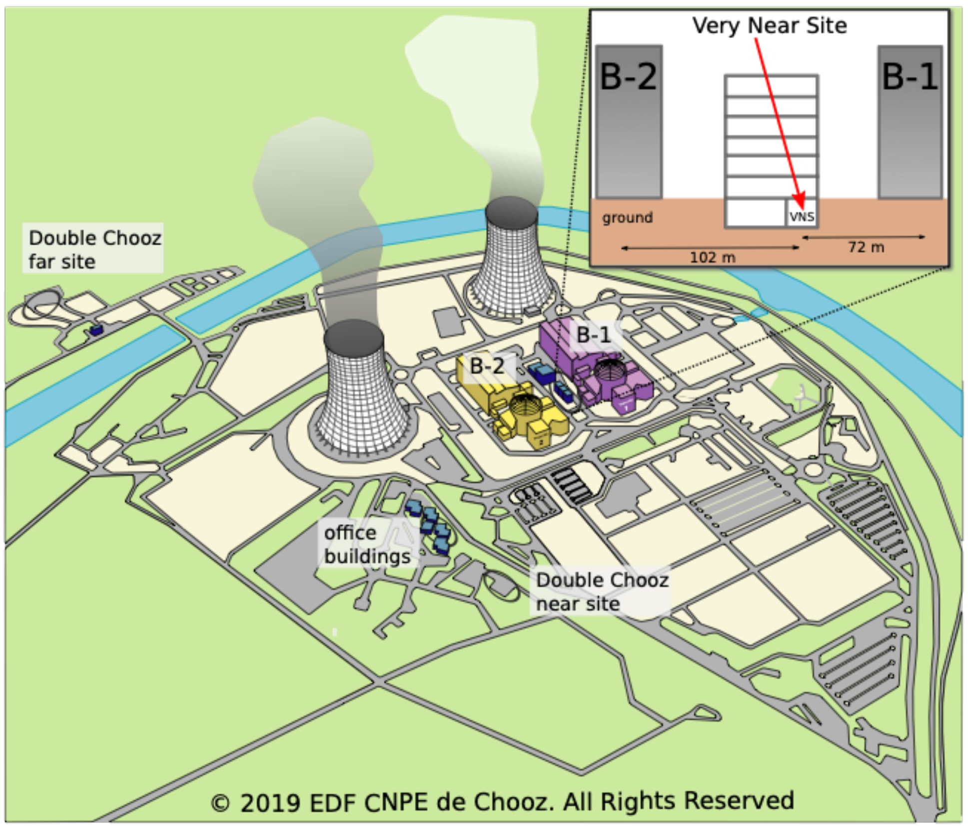


- Sapphire and $CaWO_4$ crystals
- Flexible Si wafers as inner veto detectors

Si outer veto prototype

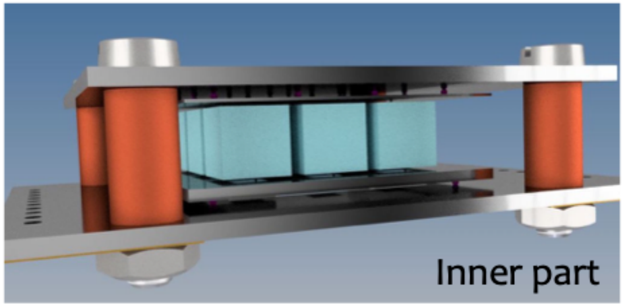
NUCLEUS: site

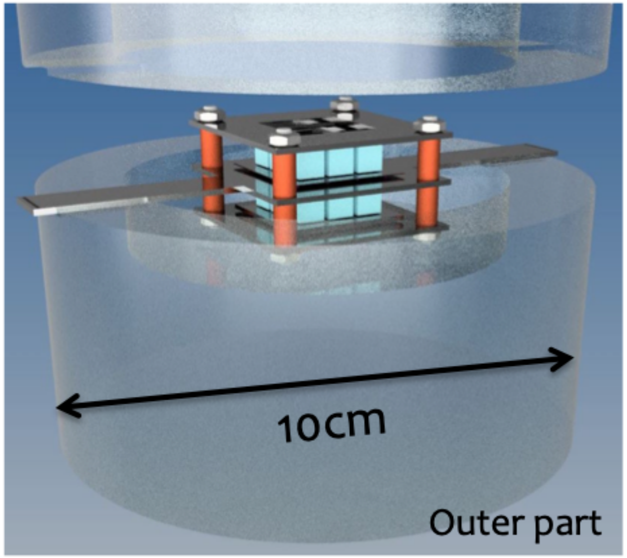
- 10 g of $CaWO_4$ / Al_2O_3 Target
- 18 detectors with 20 eV threshold
- CHOOZ very near site (VNS) (72 and 102 m from 4.5 GWth cores)



NUCLEUS: 2-phase approach

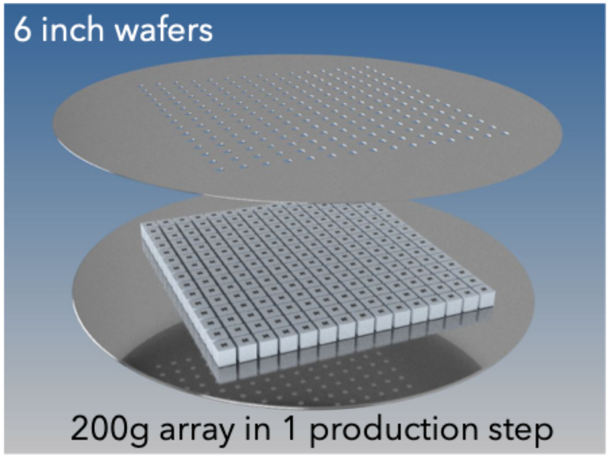
NU-CLEUS 10g





NU-CLEUS 1kg

A scalable cryogenic detector

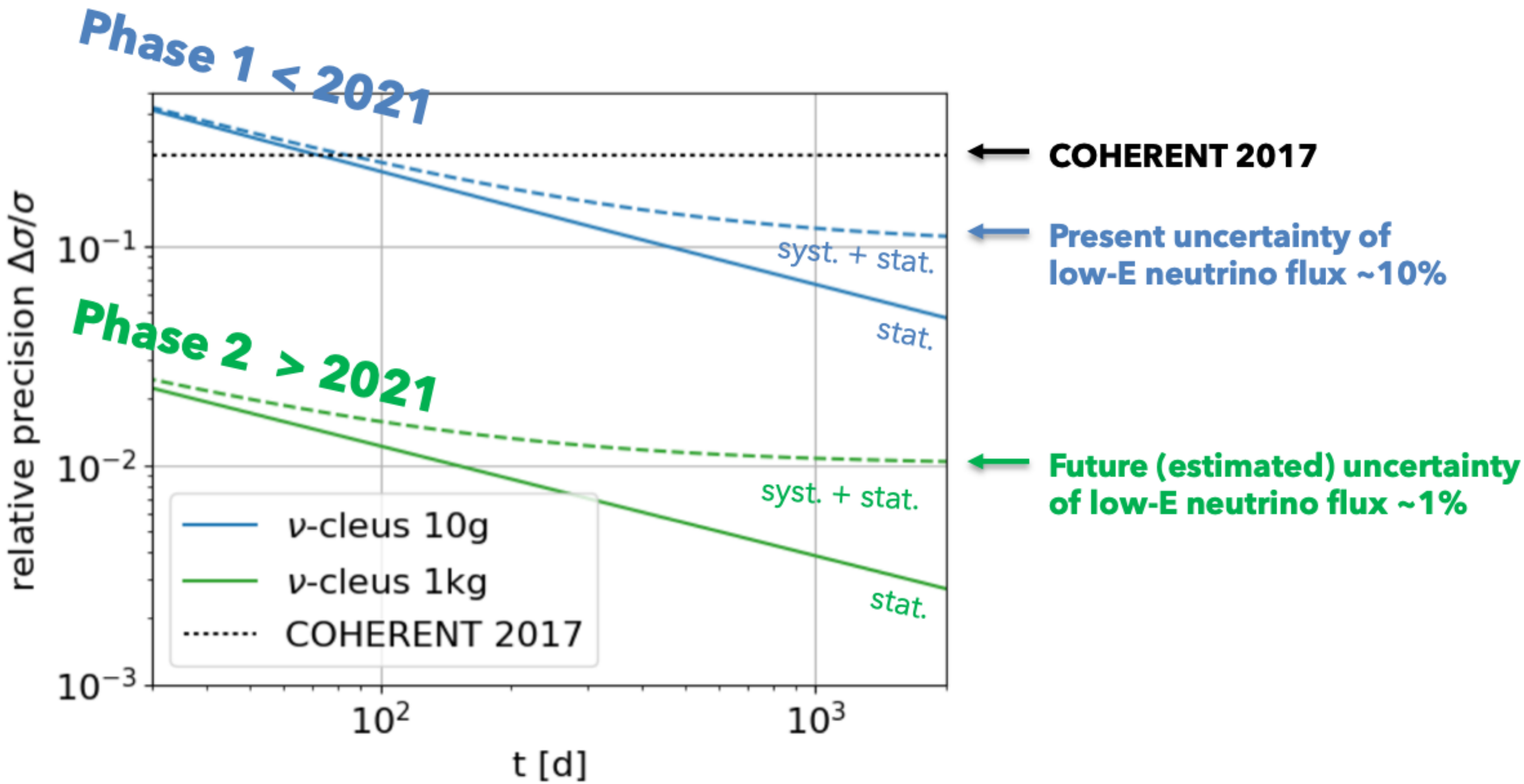


- Exploit semiconductor technology
- SQUID multiplexing

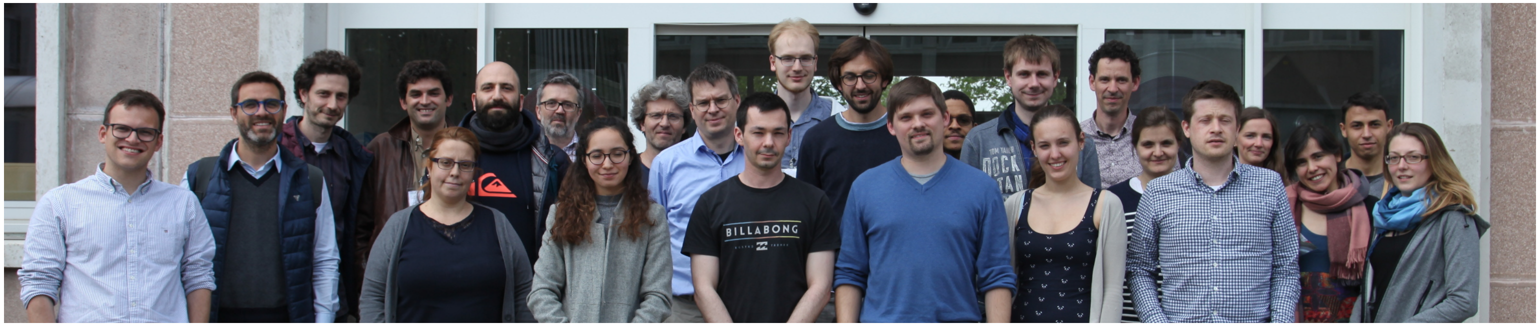
Breakthrough for the NU-CLEUS physics program!

Impact for other cryogenic experiments!

NUCLEUS: sensitivity



NUCLEUS: collaboration



TECHNISCHE UNIVERSITÄT MÜNCHEN	erc	SFB 1258 Neutrinos Dark Matter Messengers
Stefan Schönert	PD	PD
Raimund Strauss	PD	(PhD)
Luca Pattavina	PhD	PhD with CEA (50/50)
Alexander Langenkämper	PhD	
Angelina Kinast		
Tobias Ortmann		
Elizabeth Mondragon-Cortes		
Lothar Oberauer		
Franz v. Feilitzsch		

cea

Thierry Lasserre
Matthieu Vivier
Victoria Wagner
Florence Adellier-Desage
Loris Scola

Claudia Nones

+PhDs...

EXPERIMENT
nucleus

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

Federica Petricca
Johannes Rothe
Franz Pröbst
Dieter Hauff

Michele Mancuso
Lucia Canonica
Antonio Bento
Leo Stodolsky
Gode Angloher

Intersted insitutions:

- INFN, Sapienza
- IBS Korea??
- TU Vienna

HEPHY INSTITUT FÜR HOCHENERGIEPHYSIK

Jochen Schieck
Holger Kluck
Florian Reindl
Christoph Schwertner
Vasile Ghete

INFN

4.7 FTE *+ 0.4*

Roma1 - 2.8
F. Cappella
A. Cruciani
L. Cardani
N. Casali
I. Colantoni
M. Vignati

Roma2 - 0.3
R. Cerulli

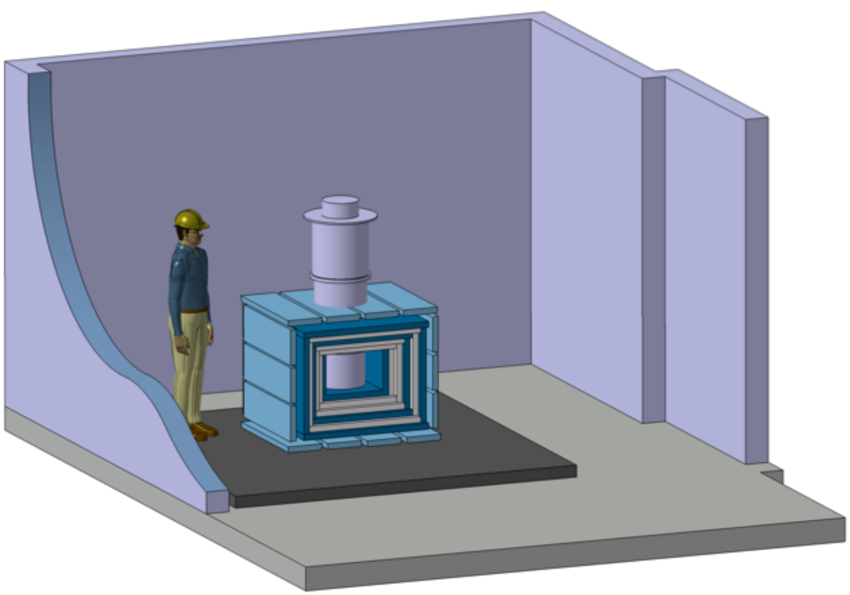
Ferrara - 1.6
L. Bandiera
M. Tamisari
A. Mazzolari
V. Guidi

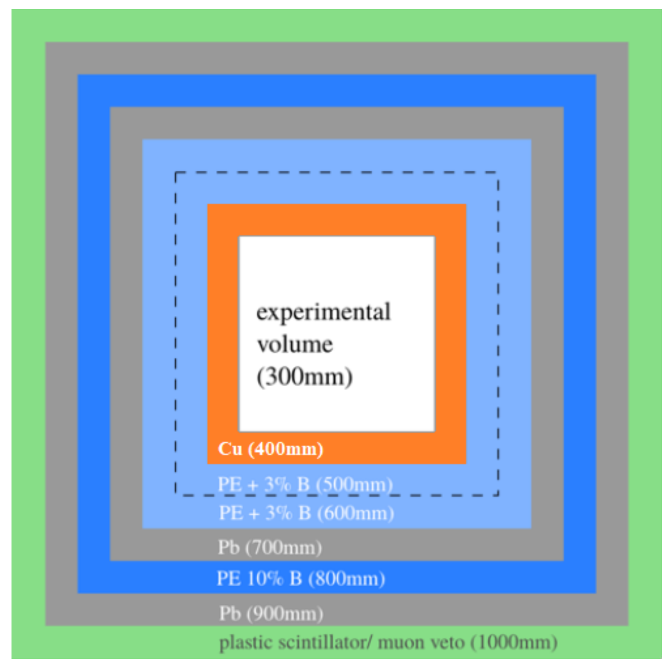
LNGS - 0.4
L. Pattavina
on leave at TUM until 04/19

Activity			2020		2021		2022		Cost
			semesters						k€
NUCLEUS Phase 1 Summary schedule	Procurement and construction		■	■	■				-
	Commissioning at TUM				■	■			-
	Installation and data taking at CHOOZ						■	■	-
INFN contribution to NUCLEUS Phase 1	3.1 Calibration system	RM1	■	■	■				100
	3.2 Inner veto	FE	■	■	■				70
	3.3 Shielding	RM2	■	■					50
	3.4 Material radioassay	RM2/ LNGS	■	■					5
	3.5 VNS bkg. characterization	RM1/2 LNGS	■	■	■	■			25
	3.6 Simulations	RM1/2	■	■	■	■	■	■	5
	3.7 Data analysis	RM1/2			■	■	■	■	
	Travels		■	■	■	■	■	■	108
INFN R&D	4.1 Study of recoil yield	RM1/2 LNGS	■	■	■	■	■	■	n/a
	4.2 Study for ^{51}Cr (travels)	misc	■	■	■	■			16
								Total cost	379

External shield (Roma2)

- Cube of 1.1 m side external.
- Layers of 5 cm:
  - 500 bricks of lead 100 Bq/kg.
  - internal layers of (B?)-Polyethylene.
  - innermost layer of Cu, provided by TUM.





MC Simulations (RM1,RM2)

- Already contributing to the simulation for the shield design (due by 12/19)
- Next contributions:
    - Evaluate the reliability of Monte Carlo codes at very low energy (Geant4 vs MCNP comparison).
    - Simulation for detector shielding design.
    - Simulation for the Veto system design and response.
    - Background model.

Radioassay (RM2 - *LNGS*)

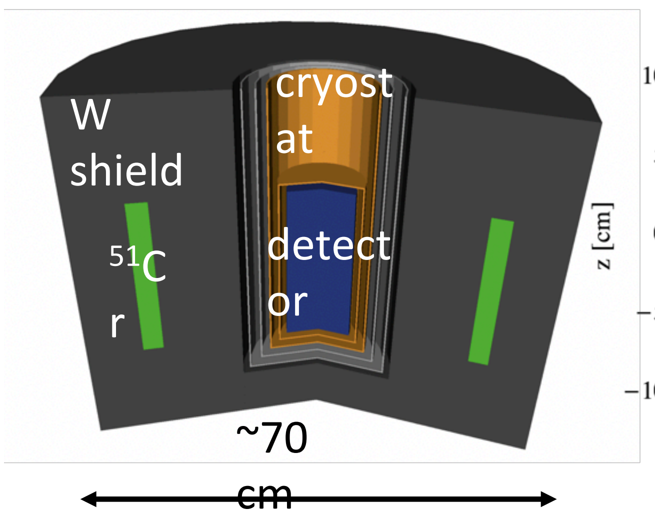
- Energy range 0-100 eV unexplored. Background not known a priori, estimation based on MC (reliable at such low energies?).
- Control of all possible background sources is mandatory O(mBq/kg).
- Measurements at MiB - Laboratorio di Radioattività
    - Detector components.
    - SQUIDS read-out system in proximity of the cryo-detector.
    - Shielding components.
    - Muon veto components

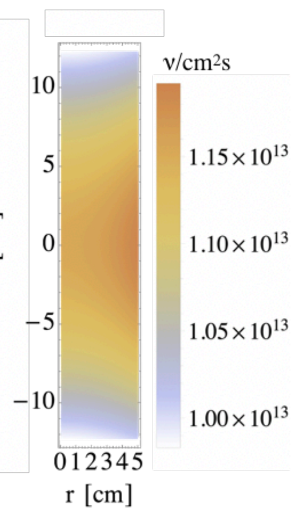
R&Ds for Phase II

^{51}Cr: Reuse of the 36 kg of ^{50}Cr from GALLEX (INFN)

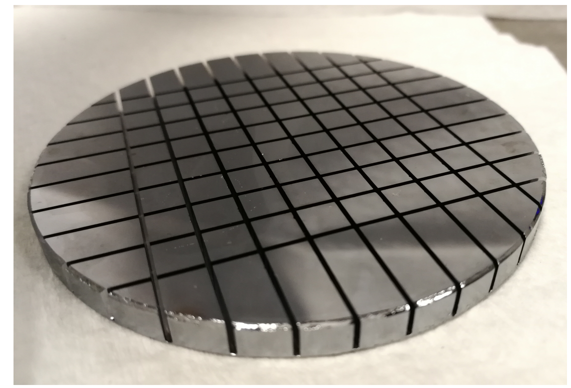
1% precision in 2 months on a 2 dm^3 Ge target

- Need neutron activation to ^{51}Cr
- Need detailed bkg. simulations





BULLKID (CSN5 2019-20): Array of KIDs to reach large targets



- 60 voxels of 5x5x5 mm^3
- Grooved in a 5 mm thick wafer
- KID lithography side opposite to grooves

Recoil yield

- Phase II target: 1% precision.
- The "no quenching" statement of phonon detectors need dedicated measurements at low energies (< 1 keV).

NUCLEUS @ Tor Vergata

Anagrafica

R. Cerulli 0.3

Richieste

- Consumo: 5 kE

- Apparati
  - ✓ 30 kE Schermo di Piombo di bassa raioattività
  - ✓ 10 kE Polietilene

- Inventario
  - ✓ 5 kE Server per simulazioni e analisi dati

Conclusions

- Coherent scattering of neutrino is a new new field of research
- NUCLEUS has a well-defined scientific program (2020-22)
  - Could lead to world-best precision measurement of the x-sec.
  - Significant INFN contribution
- Next generation experiments (2023-):
  - Precision measurements
  - (%).Opportunity for leading INFN contribution.