Bolometers At Sub KeV Energy Thresholds

New results from BASKET innovative bolometers for the CEνNS detection at reactors

B. Mauri, PhD student

Physique des 2 Infinis et des Origines

The CEνNS process

- Coherent Elastic Neutrino Nucleus Scattering (CEνNS)
  → predicted in 1974 by Freedman;

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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.

- 1st observation on CsI in 2017 by the COHERENT collaboration;
  → second detection on Ar in 2020;
- New way to probe physics beyond the standard model and nuclear structure.

RESEARCH D. Akimov et al Science 357 (2017), 1123

NEUTRINO PHYSICS

Observation of coherent elastic neutrino-nucleus scattering

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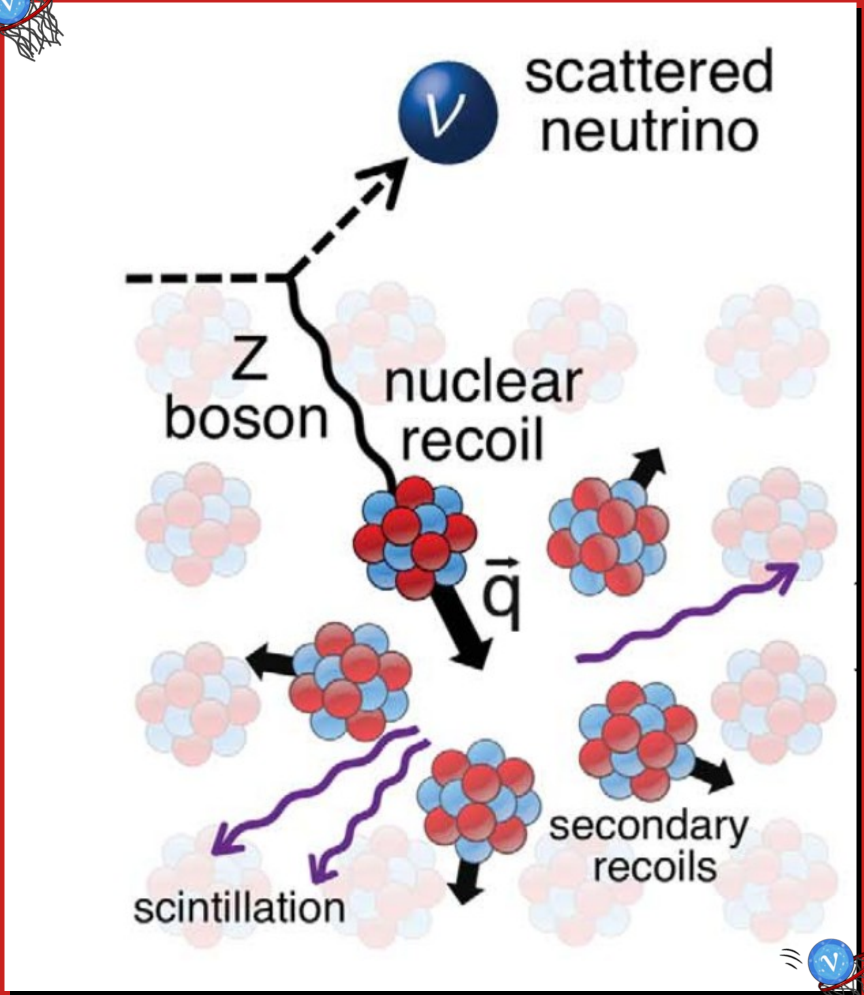
The coherent elastic scattering of neutrinos off nuclei has eluded detection for four decades, even though its predicted cross section is by far the largest of all low-energy neutrino couplings. This mode of interaction offers new opportunities to study neutrino properties and leads to a miniaturization 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.



If sufficiently low momentum transfer:

the neutrino scatters off the target nucleons as a whole;

CEνNS experimental signature:

standalone nuclear recoil with energy from 10's eV to few 10's keV depending on the photons energy, the target material and the neutrino source;

Advantages for the CEνNS detection:

cross section 10 to 1000 times greater compared to the standard neutrino detection channels

→ kg-scale detectors

→ probability ∝ (number of target nucleus neutrons)^2

Bolometer At Sub keV Energy Thresholds

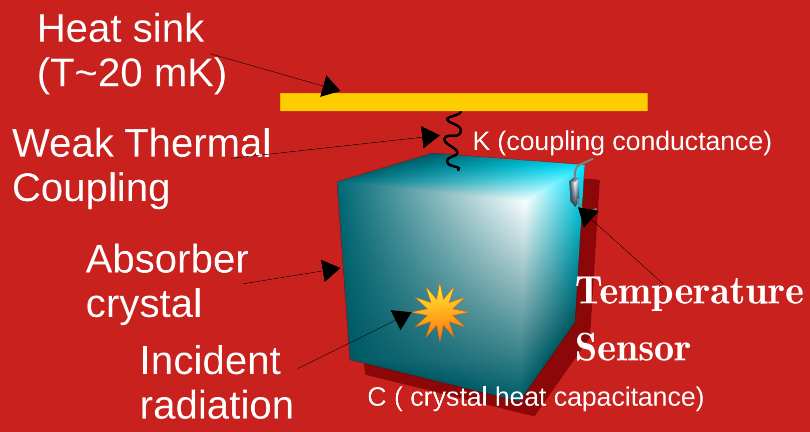
What do we basically need?

- a crystal material in which the expected CEνNS rate is high;
- a suitable sensor to read the signal.

The bolometric technique answers our needs!

- **BASKET: R&D project developed at CEA and IJClab thanks to P2IO funds;**
- **Goal: very sensitive bolometers (energy threshold of the order 10 eV and rise time 0.1-1ms);**
- **Background rejection capabilities;**
- **Detector based on scintillating material;**
- **Different thermal sensors taken into account;**

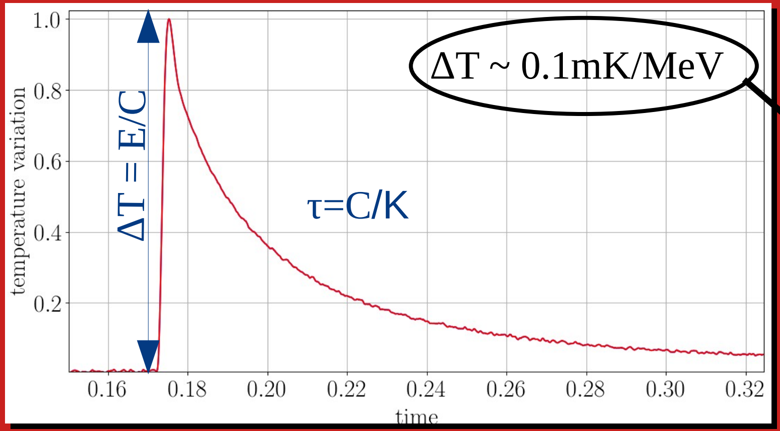
Bolometric technique in a nutshell



The particle interacts in the crystal…

…releasing energy in the crystal through ionization or lattice excitations leading to phonons or scintillation light (in case of scintillating material).

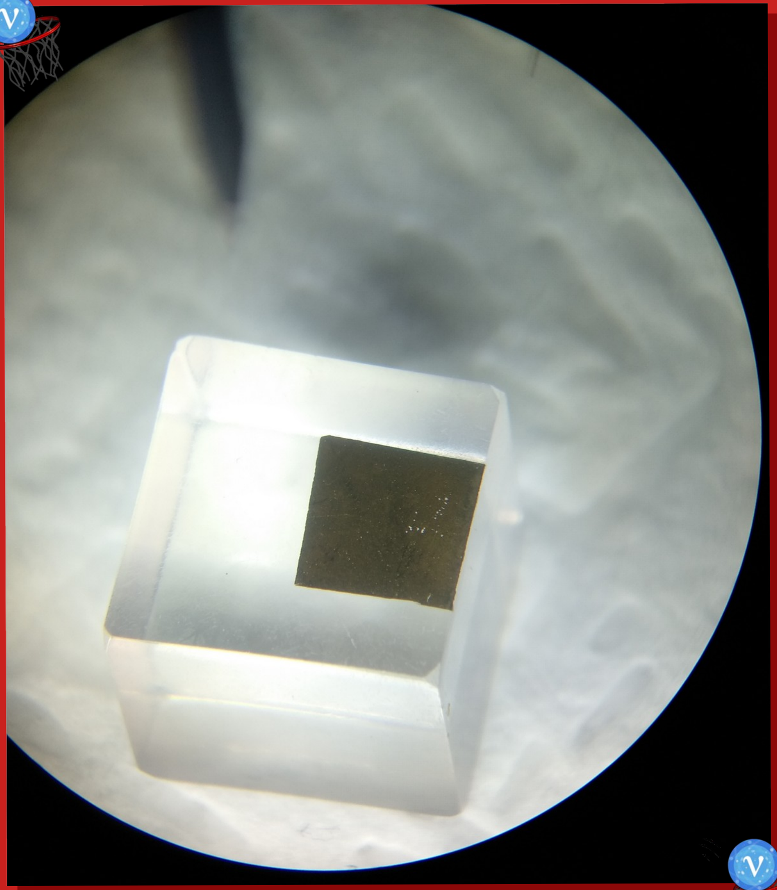
The energy converted into phonons causes a temperature variation.



The heat flows through a weak thermal link to the heat sink until the equilibrium is restored.

The temperature variation is visible only if we work at cryogenic temperatures!

The Li_2WO_4(Mo): a powerful compound



The BASKET detectors are based on

$Li_2(Mo)_{1-x}W_xO_4$ x=0.8-0.9

as absorber material.

Why is this compound a clever choice?

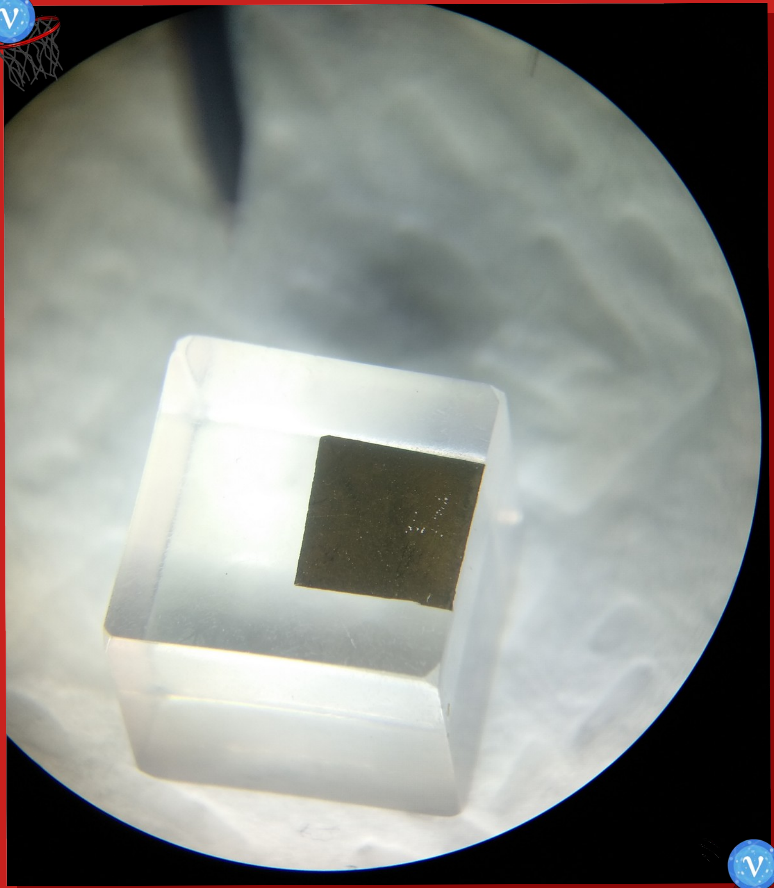
- **Tungsten**: heavy element that provides a big CEυNS rate increase (N=110);

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

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

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

The Li_2WO_4(Mo): a powerful compound



The BASKET detectors are based on

$Li_2(Mo)_{1-x}W_xO_4$ x=0.8-0.9

as absorber material.

Why is this compound a clever choice?

- **Lithium**: useful to perform a neutron background study through the $^6Li(n,t)\alpha$ reaction;

The detector must be able to work in close vicinity of a nuclear reactor in above-ground conditions. Nuclear recoils induced by neutrons are identical to the signature of interest!

Crystals

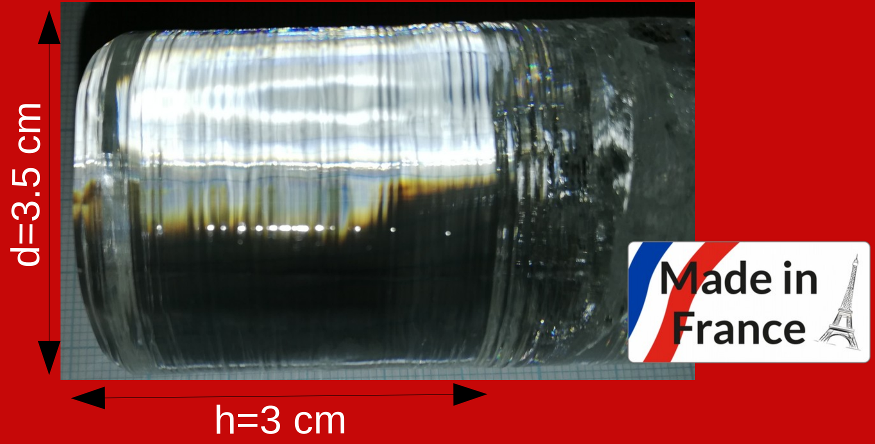
- Crystals produced at NIIC (Nikolaev Institute of Inorganic Chemistry – Novosibirsk);
- Grown by the Czochralski method;

Available crystals:

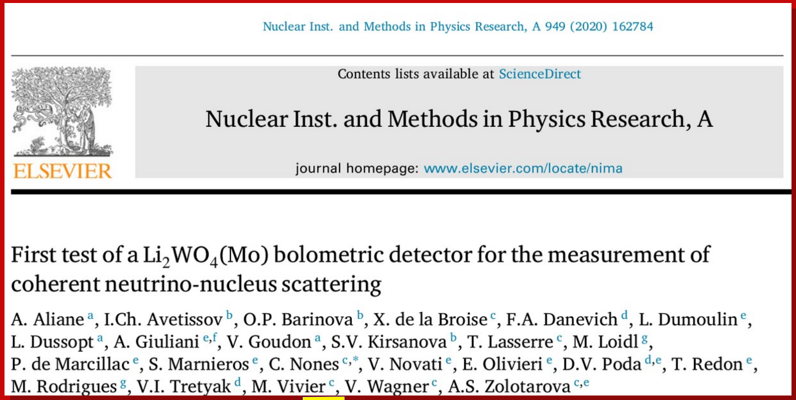
- 2 cylindrical crystals (Φ=25mm, h=25mm, m=51.7g);
- 2 cubic crystals (vol=1cm^3, m=4.5g);

In parallel, thanks to P2IO, we started a collaboration with a new partner (M. Velazquez at SiMAP in Grenoble) for a made in France crystals production.

- Simpler procedure to enrich in ^{6}Li (natural content ~8%).



First BASKET results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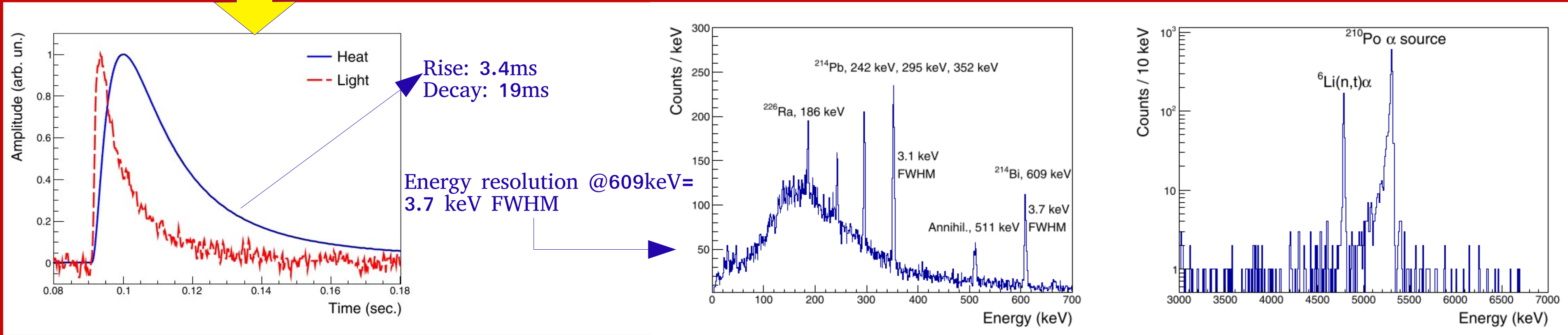
journal homepage: www.elsevier.com/locate/nima

ELSEVIER

First test of a Li_2WO_4(Mo) bolometric detector for the measurement of coherent neutrino-nucleus scattering

A. Aliane [a], I.Ch. Avetissov [b], O.P. Barinova [b], X. de la Broise [c], F.A. Danevich [d], L. Dumoulin [e], L. Dussopt [a], A. Giuliani [e,f], V. Goudon [a], S.V. Kirsanova [b], T. Lasserre [c], M. Loidl [g], P. de Marcillac [e], S. Marnieros [e], C. Nones [c,*], V. Novati [e], E. Olivieri [e], D.V. Poda [d,e], T. Redon [e], M. Rodrigues [g], V.I. Tretyak [d], M. Vivier [c], V. Wagner [c], A.S. Zolotarova [c,e]

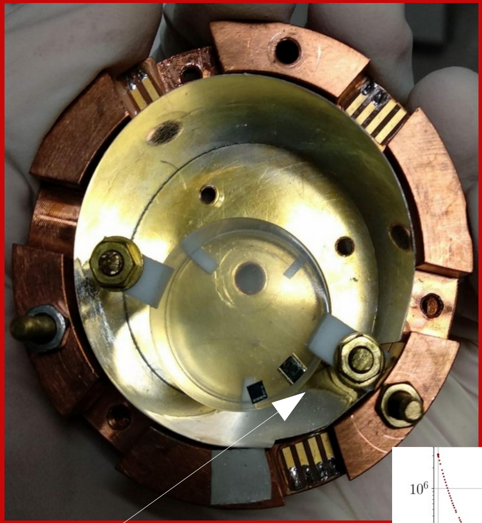
- Li_2WO_4 absorber used for the first time in a bolometer;
- First tests made with Ge Neutron Transmutation Doped (NTD) sensors;
- The first results are published (DOI : 10.1016/j.nima.2019.162784)
- Now: we are coupling the Li_2WO_4 to different types of sensor to establish a detector prototype that fulfill the BASKET requirements...



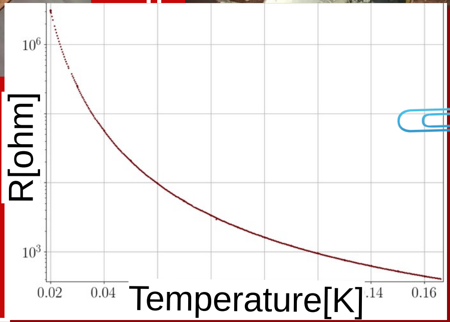
Detector prototypes

...configurations under study:

Li_2WO_4 + NTD* → R(T)

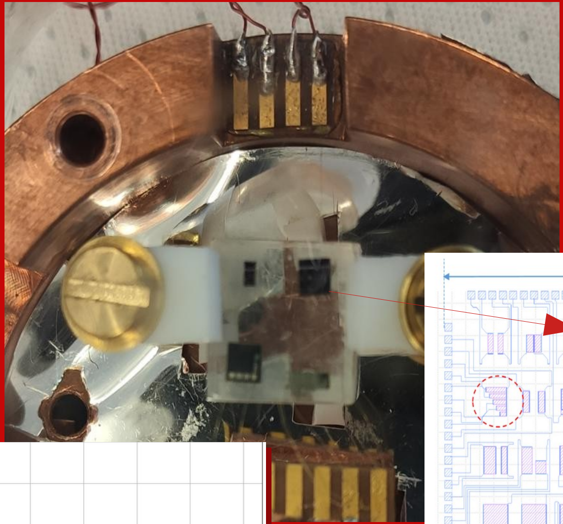


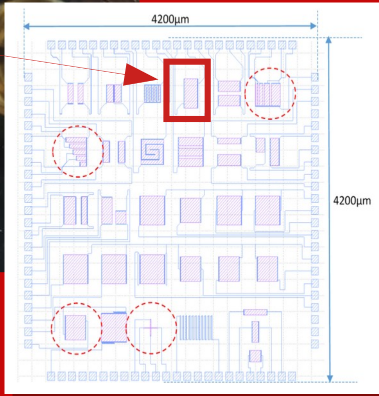
NTD



*Neutron Transmutation Doped

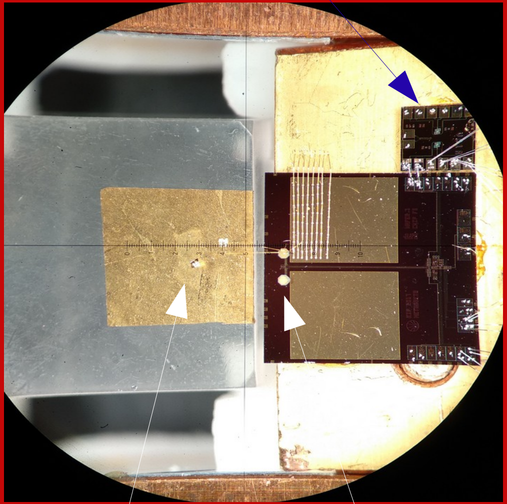
Li_2WO_4 +doped Si sensor (+NTD) → R(T)





Li_2WO_4 + MMC** → M(T)

dc SQUID



Au layer (25cm², thickness 200nm)

MMC

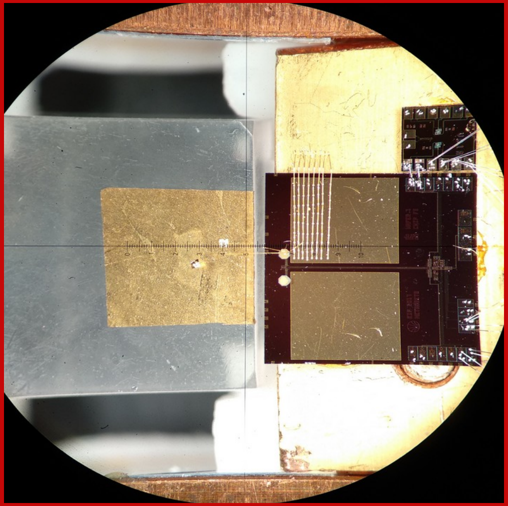
**Magnetic Metallic Calorimeter

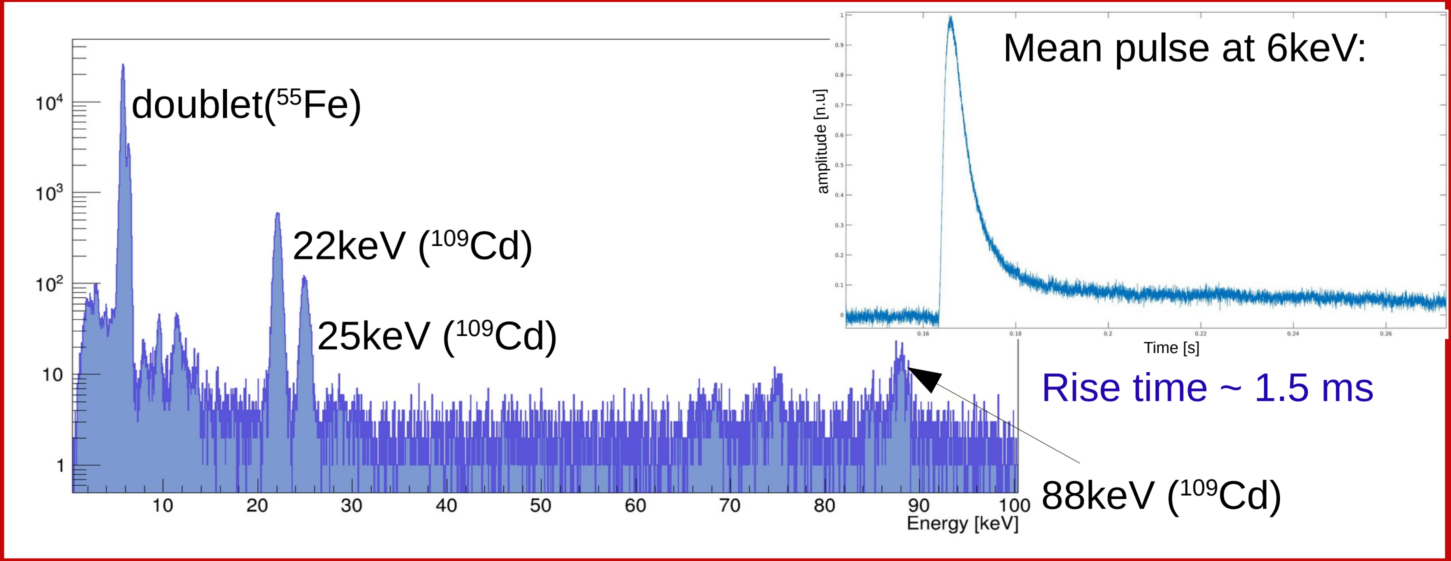
BASKET detector with MMC sensor

FWHM at 5.9 keV = 331 ± 6 eV
FWHM bsl = 194.12 eV
Sensitivity = 170 uΦ_0/keV

Latest results obtained in BASKET:

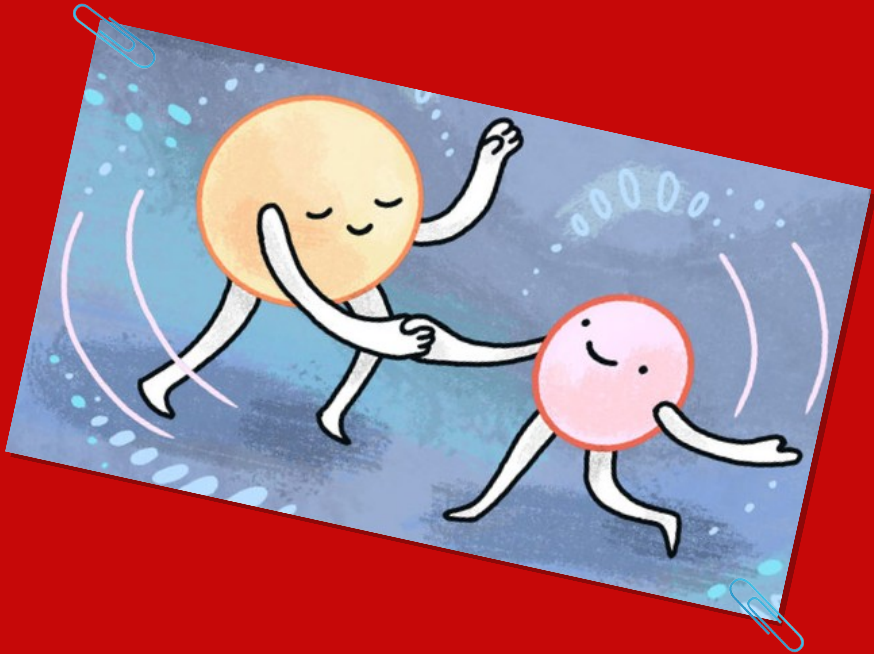
- Cubic Li_2WO_4 (crystal 1 cm³, m=4.5 g) produced thanks to P2IO;
- Measurement performed with a ^{55}Fe and ^{109}Cd source.





Conclusions

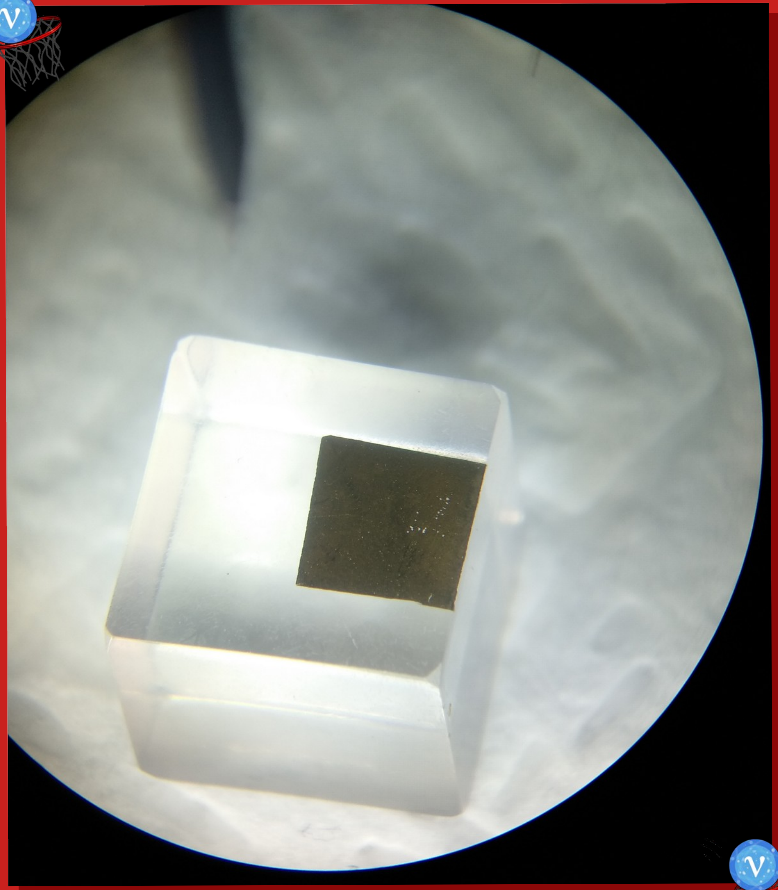
- In the BASKET framework, we are testing new solutions in order to provide an innovative low threshold detector for neutrino physics (CEυNS and 0υ2β);
- Until today, preliminary results very promising;
- Soon we will test new detectors based on the new crystals produced in France;
- BASKET project and results presented in posters at Neutrino2018, LTD-18 and Neutrino2020 conferences;
- We are using a BASKET candidate detector to develop the Outer Veto prototype for NUCLEUS experiment.



Bolometers At Sub KeV Energy Thresholds

Back-up slides

The Li_2WO_4(Mo): a powerful compound



The BASKET detectors are based on

$Li_2(Mo)_{1-x}W_xO_4$ x=0.8-0.9

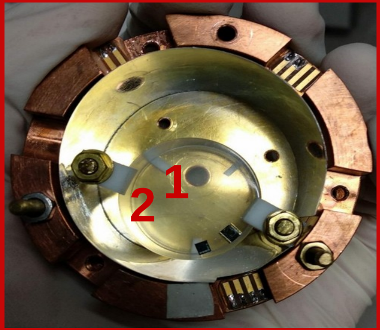
as absorber material.

Li_2WO_4 is a scintillating material!

Thanks to this property, the particle identification is possible. We would like also to test how well we can extend this technique down to the lowest possible energies.

Detector prototypes

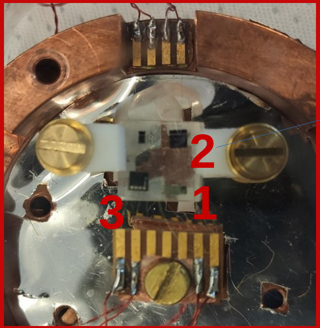
Li_2WO_4 + NTD

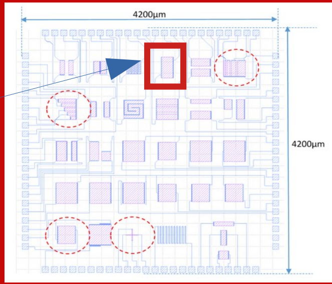


Cylindrical Li_2WO_4(Mo) crystal (Φ=25mm, h=25mm, m=51.7 g):

1) Thermal sensor: Neutron Transmutation Doped (NTD)Ge sensor;
2) Heater.

Li_2WO_4 +doped Si sensor (+NTD)

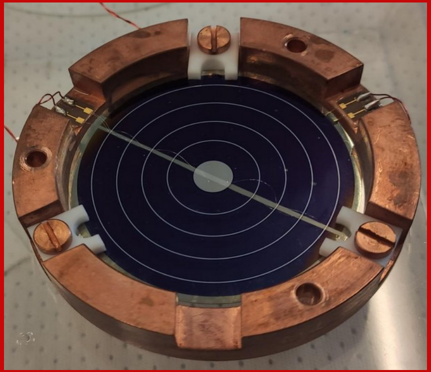




Cubic Li_2WO_4(Mo) crystal (1 cm³, m=4.5 g):

1) Thermal sensor: NTD;
2) Thermal sensor: Doped (P, B) Si sensor;
3) Heater.

Both the detector are coupled to a Ge based Light Detector (LD) covered with SiO (44x0.17 mm)



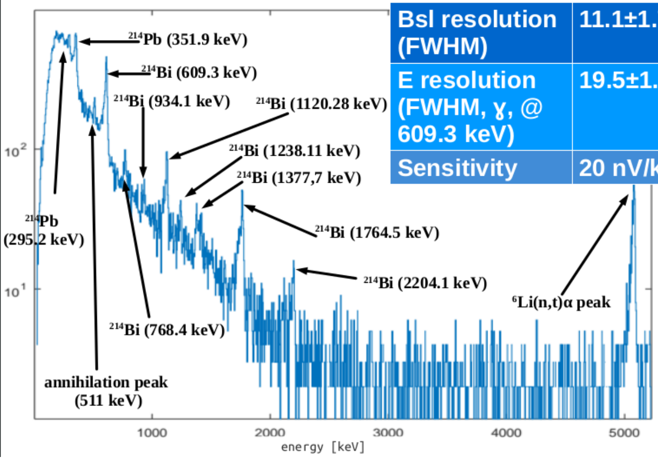
These detectors are characterized at the IJClab (Orsay, France), in above ground conditions.

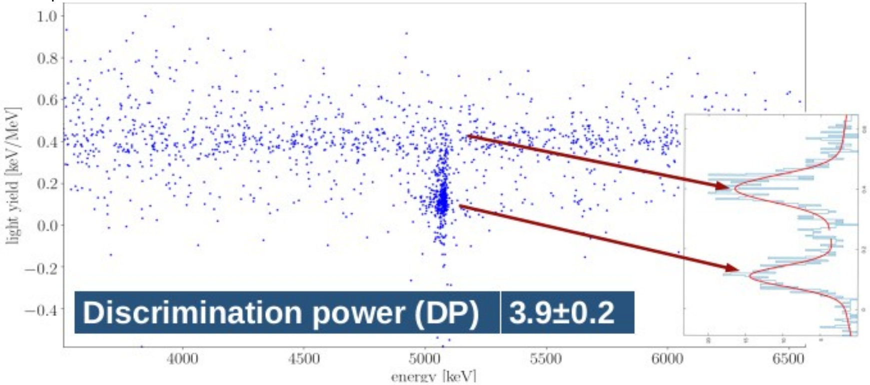
Detector prototypes

Cylindrical crystal (Φ=25mm)

Background measurement @ 22 mK

Bsl resolution (FWHM)	11.1±1.7 keV
E resolution (FWHM, ɣ, @ 609.3 keV)	19.5±1.3 keV
Sensitivity	20 nV/keV





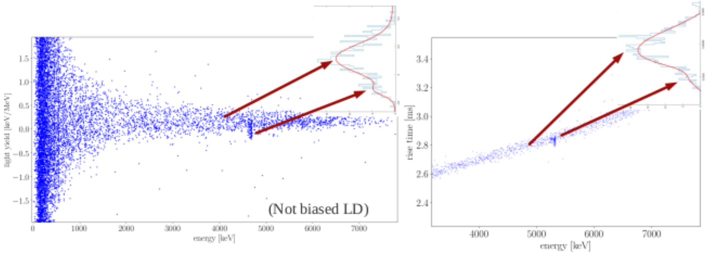
Results in:

https://nusoft.fnal.gov/nova/nu2020postersession/pdf/posterPDF-386.pdf

Cubic crystal (1 cm³)

- **Background measurement @ 27 mK:**

Bsl resolution (FWHM)	0.77±0.01 keV
E resolution (FWHM, ɣ, @ 609.3 keV)	7.2±0.6 keV
Sensitivity	0.5 uV/keV
DP observed from the **LY** scatter plot	2.0±0.8
DP observed from the **rise time** scatter plot	~1.3



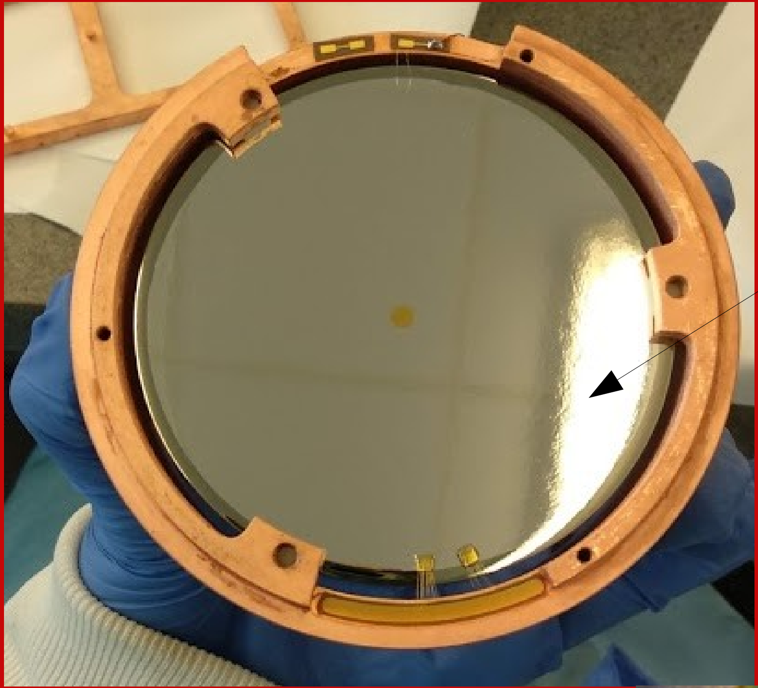
- **Neutron calibration @ 25 mK (^{252}Cf source):**

Bsl resolution (FWHM)	1.19±0.02 keV
E resolution (FWHM, ɣ, @ 609.3 keV)	3.1±0.3 keV
E resolution (FWHM, n)	1.95±0.04 keV
Sensitivity	1.1 uV/keV

- **Gamma calibration @ 20.6 mK (^{232}Th source):**

Bsl resolution (FWHM)	1.12± 0.02 keV
E resolution (FWHM, ɣ, @ 583 keV)	3.0±0.2 keV
Sensitivity	0.2 uV/keV

NUCLEUS Outer Veto



Planar Al electrodes evaporated on the Ge crystal (d=7cm, h=2cm, m=400g) in both sides.

BASKET detector:

Li_2WO_4crystal (d=2.5cm, h=2.5cm) + NTD

Low noise cables