New results from BASKET innovative bolometers for the CEνNS detection

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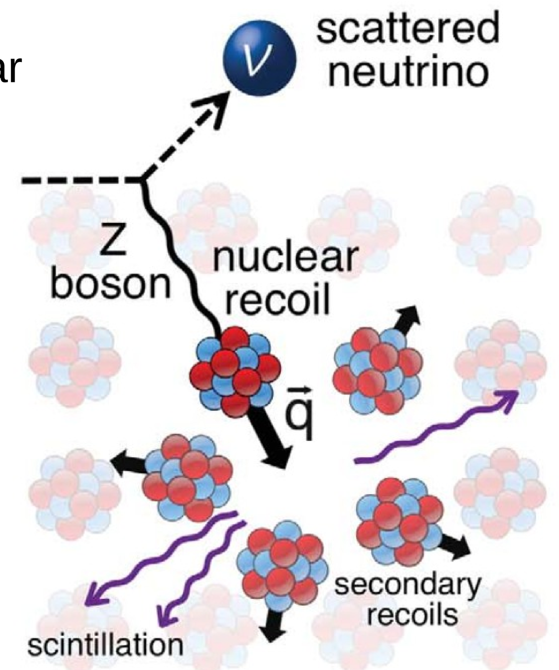
COHERENT ELASTIC NEUTRINO-NUCLEUS SCATTERING (CEνNS)

- Observed for the first time by the COHERENT collaboration in 2017;
- **New way to probe physics beyond the standard model.** It has phenomenological importance for:
  - improved constraints on the weak nuclear charge value;
  - dark matter direct detection;
  - nuclear reactors monitoring;
  - nuclear structure probes;
  - sterile neutrino searches;
  - neutrino magnetic moment;



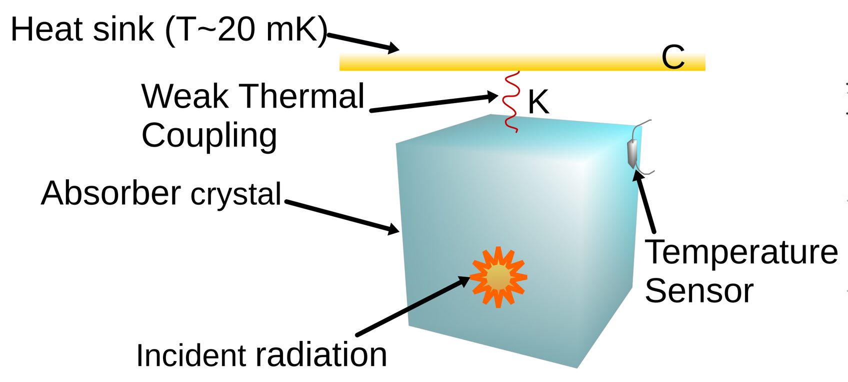
- For sufficiently low momentum transfer, a neutrino **coherently scatters off all the nucleons of the target nucleus** as a whole;
- The CEνNS **signature is a standalone nuclear recoil** with an energy ranging from 10's of eV to a few 10's of keV, depending on the E_ν and the nucleus target;
- Main advantage using this interaction instead of the standard neutrino detection channels is its **cross-section** (10 to 1000 times greater);
  - the neutrino interaction probability increases with the square of the number of neutrons of the target nucleus;
- As consequence, a dramatic **miniaturization of the detector size** (from ton or kilo-ton scale to few kg).

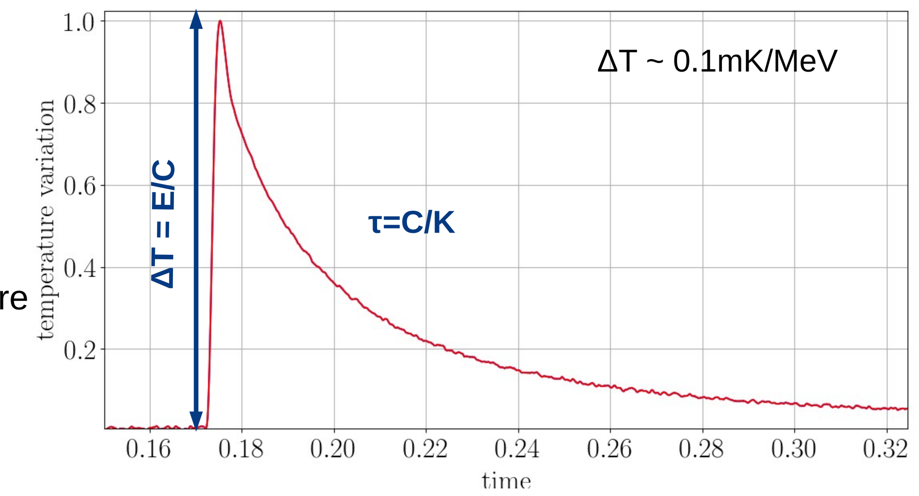
BASKET (Bolometers At Sub KeV Energy Thresholds)

- R&D project developed at CEA;
- Development of **very sensitive bolometric detectors** (energy threshold of the order 10 eV and a response time in range of 0.1-1 ms);
- **Background noise below the expected CEνNS signal** while being operated in close vicinity of a nuclear reactor in above-ground conditions;
- Detectors based on **scintillating materials** (main candidate: Li_2WO_4);
- **Different thermal sensors** coupled to the Li_2WO_4 crystals will be tested in order to evaluate their potential to achieve this challenge.

THE BOLOMETRIC TECHNIQUE

- A cryogenic calorimeter is composed of a crystal, which acts as **energy absorber**, strongly thermally coupled to a **temperature sensor**;
- The particle interaction within the crystal releases energy through ionization and excitation that is converted into thermal phonons causing temperature variations;
- The produced heat flows through a weak thermal link to the **heat sink** until the equilibrium temperature is recovered;

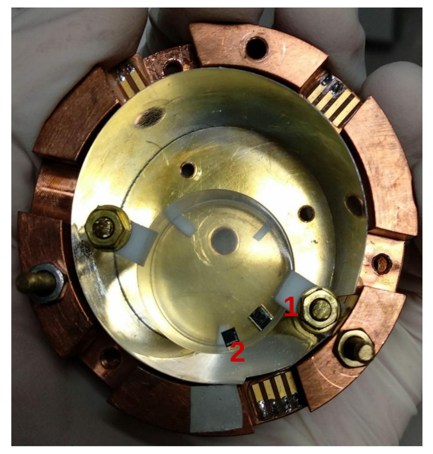




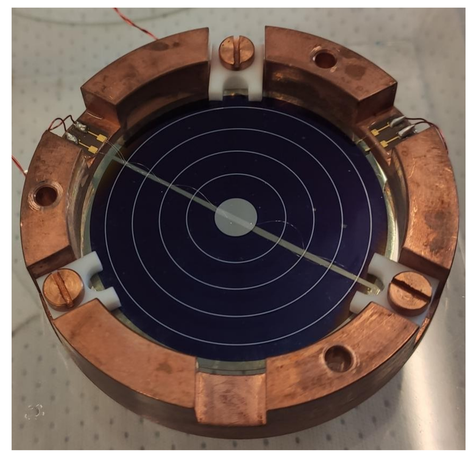
- Temperature variation measurable only if the heat capacity of the crystal is low enough → crystal cooled to cryogenic temperatures (order of tens of mK).

R&D DETECTORS

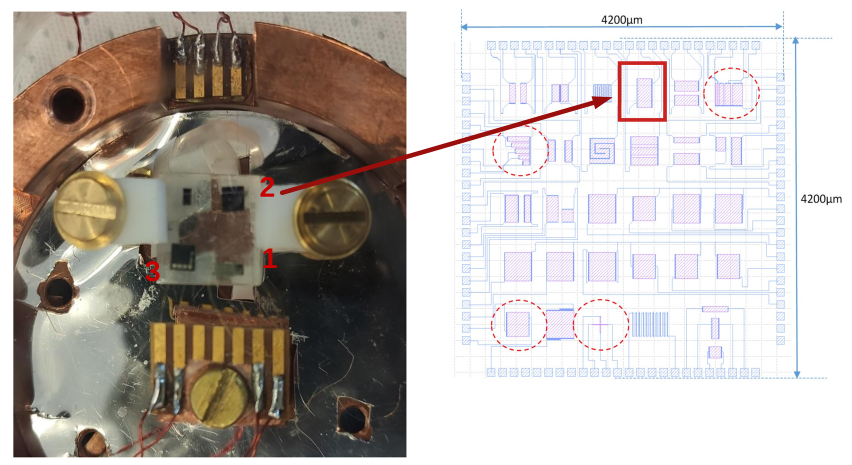
- Li_2WO_4(Mo), a powerful compound:
  - **Tungsten**: the heavy element provides a CEνNS rate increase;
  - **Lithium**: useful to perform a neutron background study exploiting the ^{6}Li(n,t)α reaction;
- crystals produced at the Nikolaev Institute of Inorganic Chemistry (Novosibirsk, Russia) through Czochralski method with Mo doping at 5%;
- crystals with natural content of ^{6}Li~8%.



Cylindrical Li_2WO_4(Mo) crystal (Φ=25mm):
1. Thermal sensor: Neutron Transmutation Doped (NTD) Ge sensor
2. Heater



Ge based (Neganov-Luke) Light Detector (LD) covered with SiO (44x0.17 mm)



Cubic Li_2WO_4(Mo) crystal (1 cm^3):
1. Thermal sensor: NTD
2. Thermal sensor: Doped (P, B) Si sensor
3. Heater

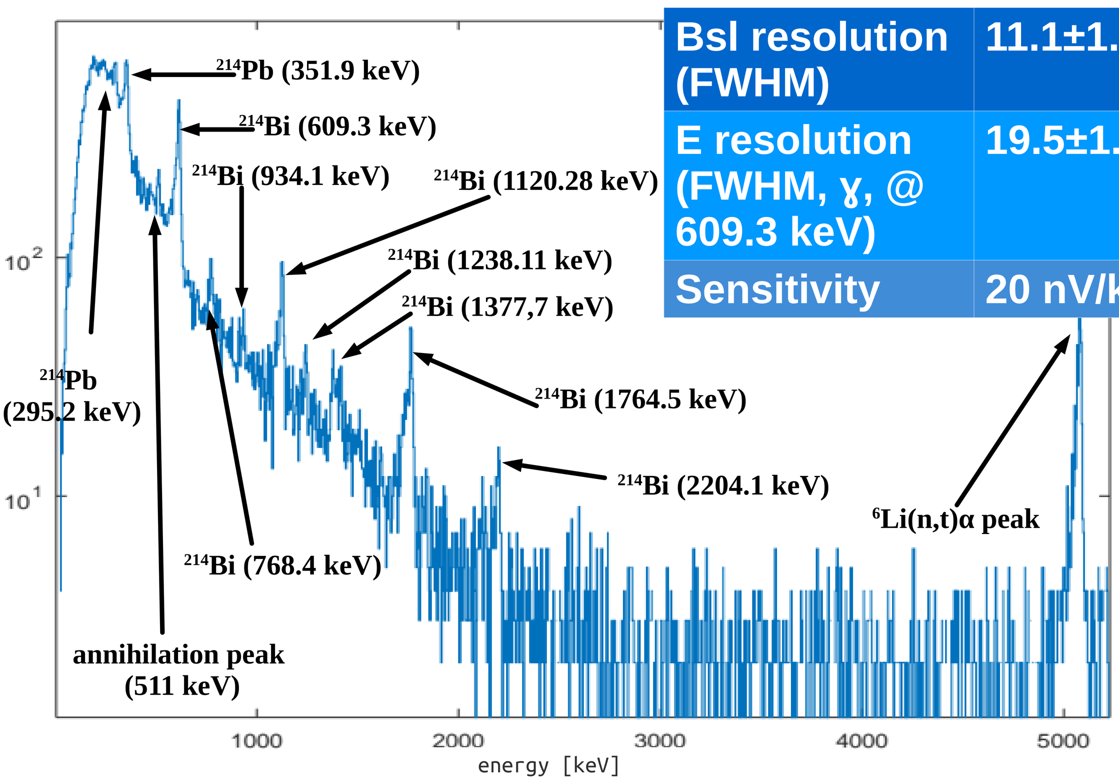
The development and the characterization of the first BASKET detector prototypes are performed at the IJClab (Orsay, France), in above ground conditions.

NTD SENSOR: RESULTS

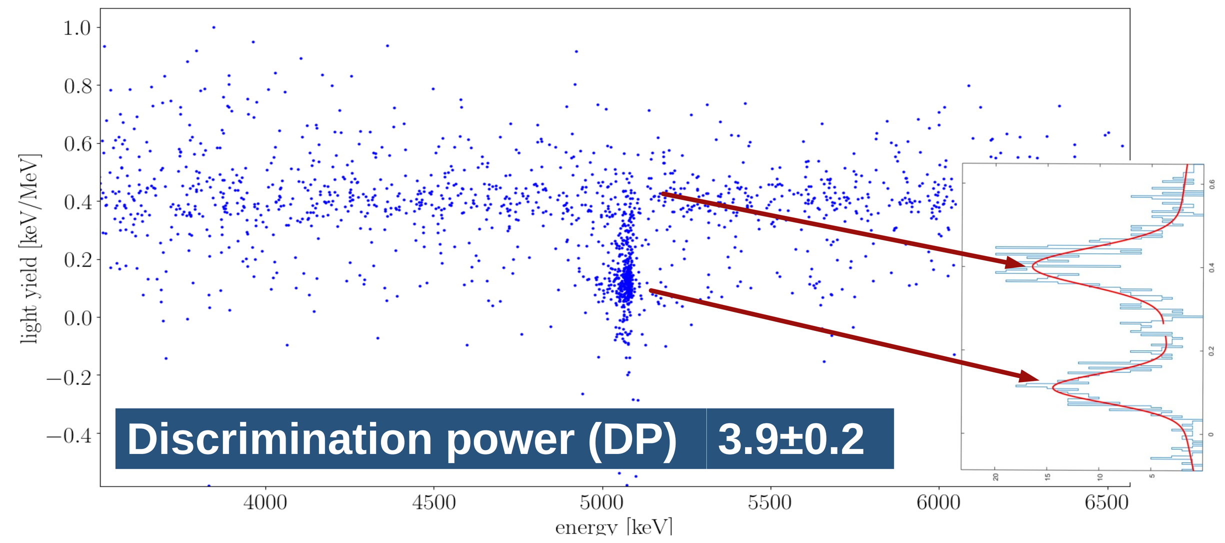
Cylindrical crystal (Φ=25mm)

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



- Using a Neganov-Luke LD operating as a standard LD, i.e. no electrode bias, we can separate the α cluster from β/ɣ band:

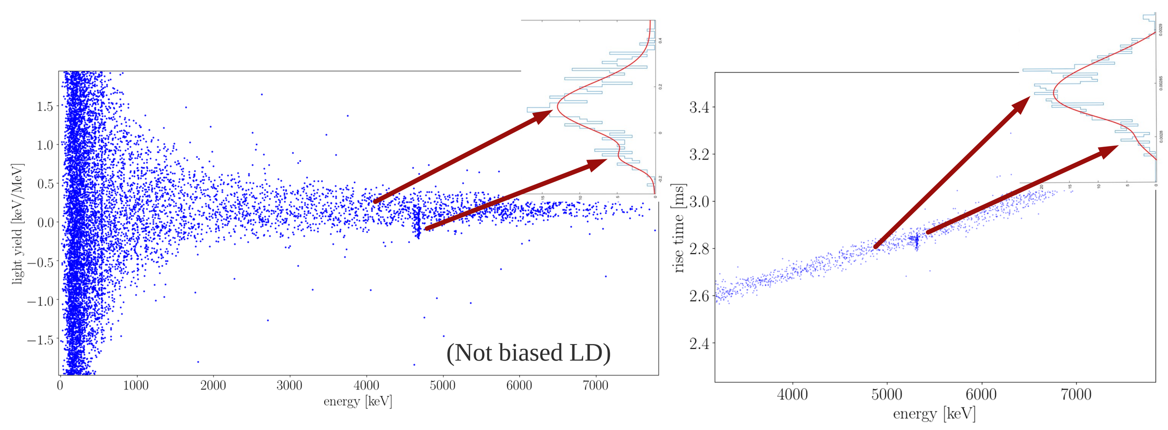


Discrimination power (DP)	3.9±0.2

Cubic crystal (1 cm^3)

- **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):**

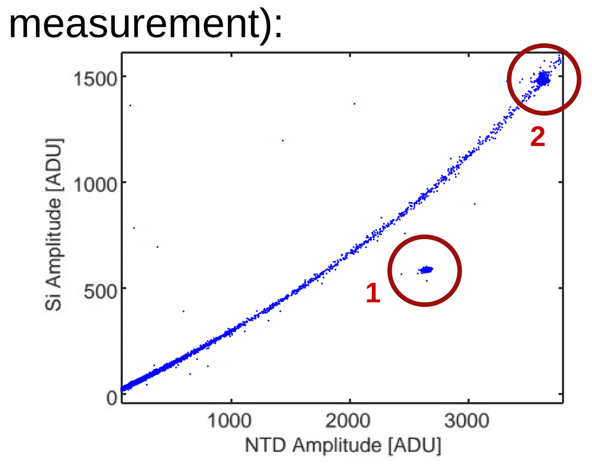
Bsl resolution (FWHM)	1.12± 0.02 keV
E resolution (FWHM, ɣ, @ 583 keV)	3.0±0.2 keV
Sensitivity	0.2 uV/keV

DOPED Si SENSOR: PRELIMINARY RESULTS

NTD and doped Si sensor comparison

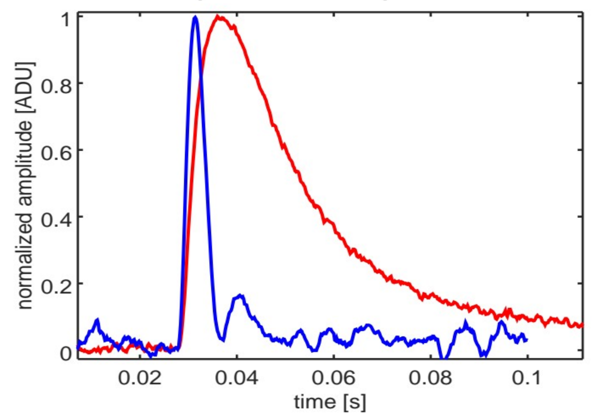
First measurement of the doped Si sensor coupled to a Li_2WO_4 crystal equipped also with an NTD sensor: comparison between the two different sensors.

- Doped Si sensor versus NTD amplitudes (neutron calibration measurement):



1. Heater events
2. ^{6}Li(n,t)α events

- Example of NTD and doped Si sensor pulses in coincidence taken in gamma region:

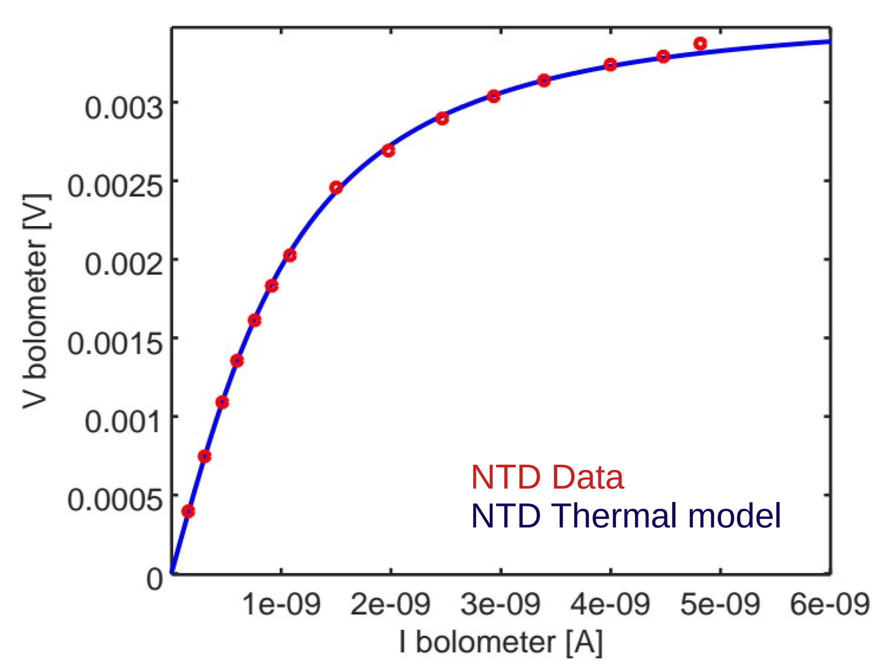


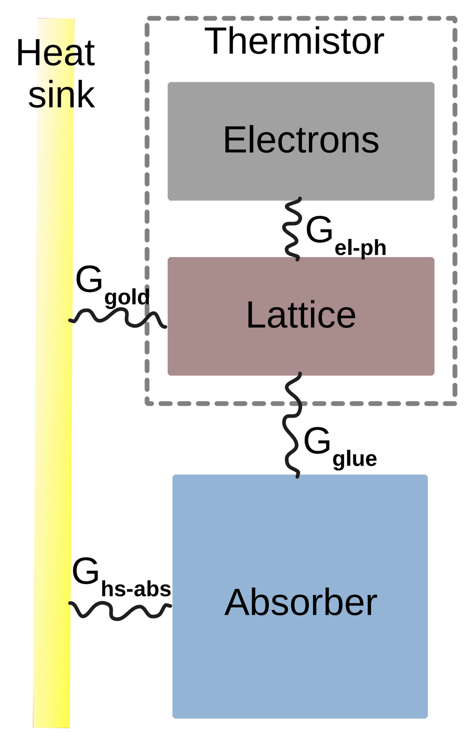
NTD pulse: Rise time ~4.6 ms
Decay time ~21.5 ms

Si pulse: Rise time ~2.1 ms
Decay time ~2.3 ms

Thermal simulation

Static and dynamic thermal simulations of both NTD and doped Si sensors in development!





CONCLUSIONS AND NEXT STEPS

- The Li_2WO_4 shows **promising performance** to undertake the CEνNS detection;
- **First pulses ever observed using a doped Si-sensor coupled to a Li_2WO_4 crystal**;
- Further improvements expected finalizing the analysis with a **biased Neganov-Luke LD**;
- In future, new tests will be performed using a **new silicon sensor geometry and/or a larger surface**;
- In progress:
  - bolometric tests using Li_2WO_4 crystals equipped with **MMC sensors**;
  - **Doped Si thermal simulations** to better understand the sensor behaviour.

References

[1] 10.1126/science.aao0990
[2] 10.1016/j.nima.2019.162784
[3] 10.1103 /PhysRevD.9.1389.