Development of innovative cryogenic detectors for precise measurement of coherent neutrino-nucleus scattering

Bolometers At Sub KeV Energy Thresholds

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NEυTRINO 2018, 4-9 June Heidelberg

Abstract summary: the recent observation of coherent elastic neutrino-nucleus scattering (CEνNS) opens up a new way to search for beyond standard model physics at low energies in the neutrino sector. The development of ultra low threshold cryogenic detectors with fast time response and good background discrimination is a promising way to fully exploit the spectrum of neutrino-induced nuclear recoils and perform precision physics. In this context, the BASKET (Bolometers At Sub KeV Energy Thresholds) R&D program initiated at CEA aims at looking for and studying innovative crystals and thermal sensors for the prototyping of bolometers suitable for the detection and measurement of CEνNS. This poster reports on the first tests of a Li_2WO_4 scintillating bolometer, and presents the overall BASKET program strategy.

Coherent neutrino-nucleus scattering in a nutshell

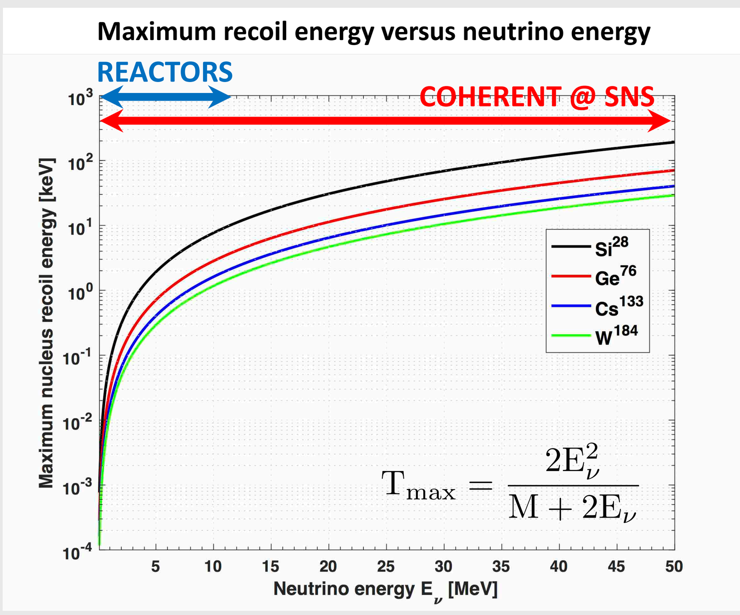
- Neutral current process first predicted by Freedman [1] in 1974, and observed for the 1st time last year by the COHERENT collaboration [2].
- Occurs when the coherence condition $qR << 1$ is satisfied, q being the momentum transfer and R the radius of the target nucleus.
- Many interesting features:

Aluminium: 1/R ≈ 60 MeV
Lead: 1/R ≈ 30 MeV

  - Cross-section mostly scales with the (number of neutrons)^2 in the target nucleus, making it up to 100-1000 times larger than other ν detection channels:

$$\sigma(E_\nu) \approx \frac{G_F^2}{4\pi}\left[Z\,(4\sin^2\theta_W - 1) + N\right]^2 E_\nu^2 \approx 0.42\times 10^{-44} N^2 (E/1\,\mathrm{MeV})^2\ \mathrm{cm}^2$$

  - No energy threshold
  - Allows precise tests of the standard model at low energies and sensitive to a wide range of beyond standard model physics: running of $\sin^2\theta_W$, neutrino magnetic moment, non-standard interactions, etc…
  - Relevant for supernovae dynamics modeling and dark matter searches, interesting for non-proliferation applications.
- Signature is a (very) low energy nuclear recoil: need for low threshold detectors with efficient background discrimination

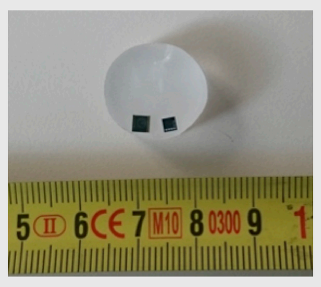


- The heavier the target, the smaller the recoil energies
- **@ SNS [COHERENT]**: T ≲ 10 keV for Cs & I
- **@ reactors**: T ≲ 1 keV depending on target

Push/pull effect between high & low mass nuclei

High cross-section — Small cross-section
High energy recoils — Small energy recoils

First tests of a Li_2WO_4 scintillating bolometer



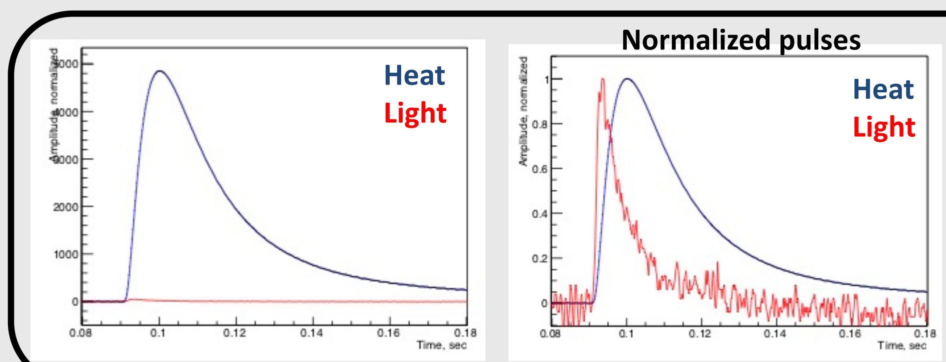
σ(CEνNS) ∝ N^2 → heavy elements as target

$Li_2Mo_{(1-x)}W_xO_4$

Neutrons: challenging background → Tagging and estimation through $^6Li(n,t)^4He$

- Grown by Czochralski method [3]
- Mass = 11 g, density = 4.4 g cm^{-3}
- Cylindric shape: ϕ = 12.5 mm x h = 5 mm
- Ge NTD thermistor
- Neganov-Luke light detector [4,5]

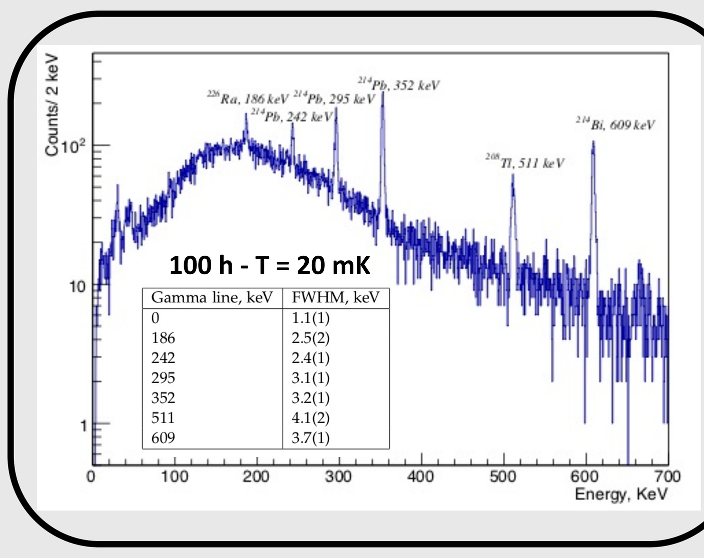
Examples of coincident heat & light pulses



Features of heat pulses at different temperatures

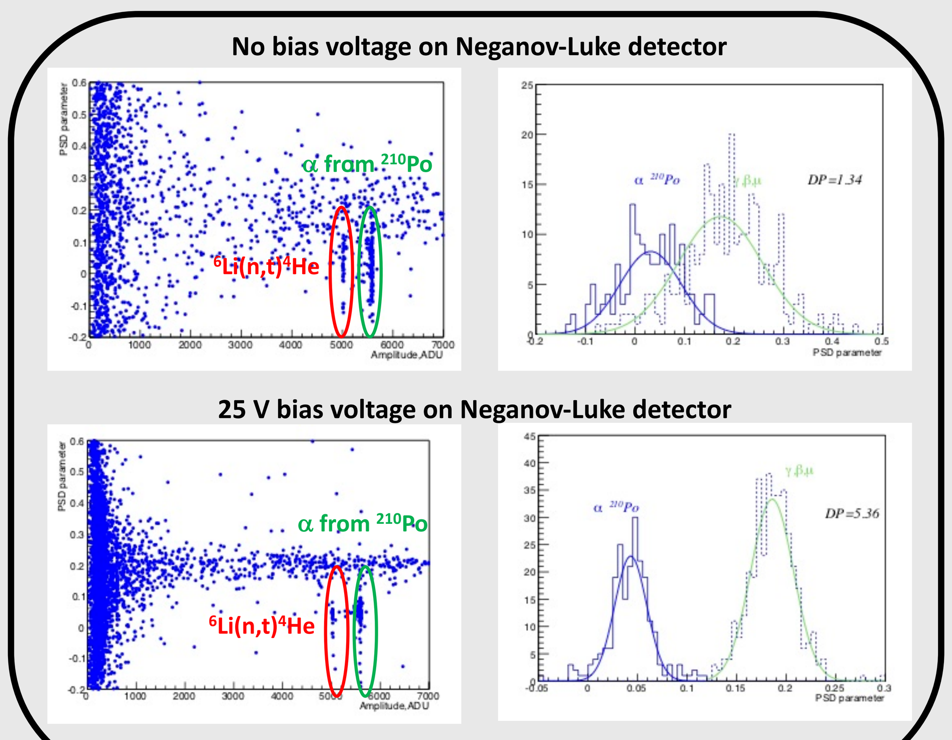
Temperature [mK]	15	17	20
Rise time [ms]	5.8	4.0	3.4
Decay time [ms]	18.8	17.8	19

Background spectrum



Gamma line, keV	FWHM, keV
0	1.1(1)
186	2.5(2)
242	2.4(1)
295	3.1(1)
352	3.2(1)
511	4.1(2)
609	3.7(1)

α/β discrimination with ^{210}Po source

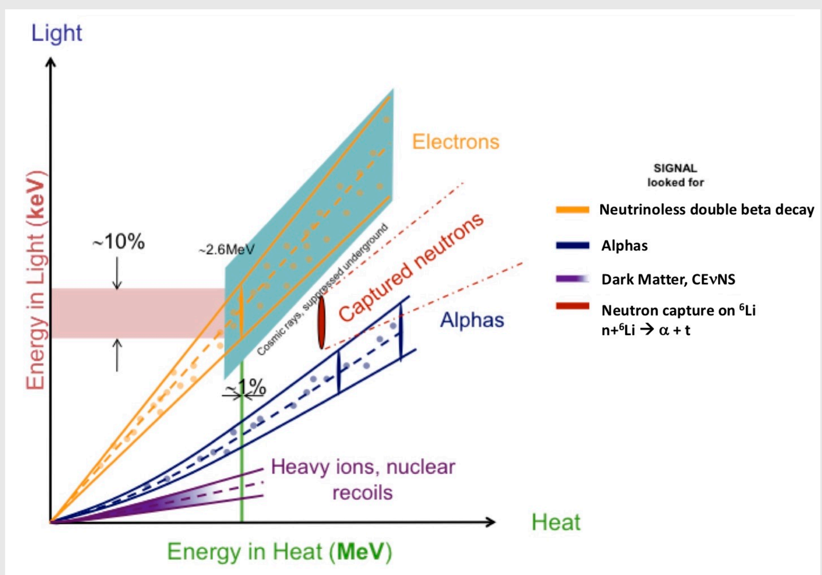


- Good bolometric properties, with excellent α/β particle discrimination
- Tests for the near future:
  - Detailed crystal characterization: light output, thermal properties, etc…
  - Coupling to NbSi TES & MMC sensors: optimization of response time & energy threshold

BASKET program strategy

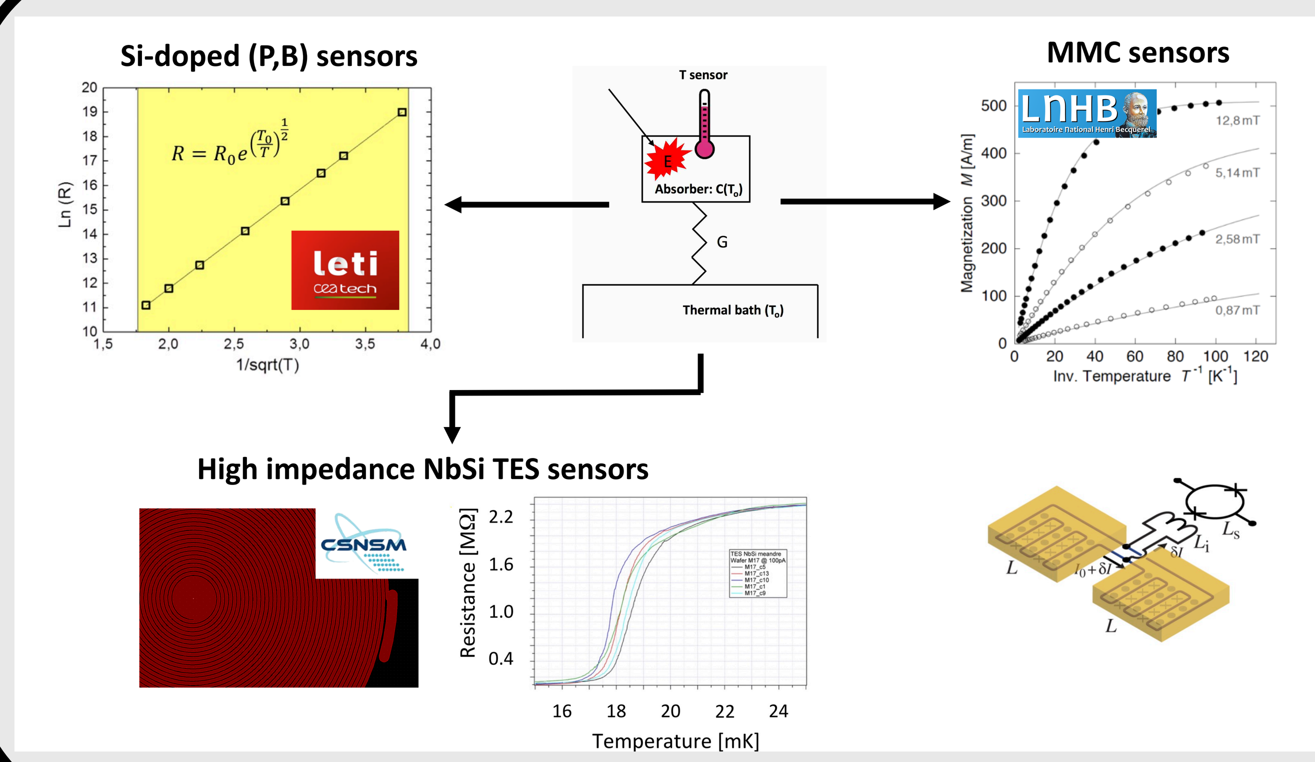
- **Goals:** achieve low energy threshold bolometers, with high energy resolution, fast response time and efficient background discrimination
- **Means:** investigate on new absorber materials & temperature sensors

Absorber materials



- Heat/light readout for particle discrimination
- Optimization of size and geometry for response time

Investigations on thermal sensors



- Study response time, energy resolution and coupling to absorber materials
- Select best configuration for prototyping of a first CEνNS detector
- Sensor typical performances:

	Rise time	Decay time	Energy resolution
MMCs	10-100 µs	several ms	10-20 eV
Si-doped thermistor	100 µs	several ms	10-100 eV
NbSi TES	50-100 µs	several ms	10-100 eV

References

[1] D. Z. Freedman, Phys. Rev. D9 (1974), 1389-1392
[2] D. Akimov et al. [COHERENT collaboration] Science 357 (2017), 1123-1126
[3] O. Barinova et al., J. of Crystal Growth 458 (2017), 365-368
[4] V. Novati et al., Nucl. Instr. and Meth (2018), DOI: 10.1016/j.nima.2017.10.058
[5] L. Bergé et al. Phys. Rev. C (2018) 97, 032501

Acknowledgments: BASKET is a project supported by the direction of cross-disciplinary programs at CEA (PTC "instrumentation et detection" 2017) and by the P2IO LabEx. We would like to thank the group of Prof. O. Barinova for kindly providing us with a first Li_2WO_4 crystal sample, and Prof. F. Danevitch for his support to the project.