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Introduction or "Low-temperature detectors: yesterday, today and tomorrow"

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Abstract

I would like first to express my deep gratitude to Flavio Gatti and to the Organizing committee for inviting me to introduce the tenths of these Workshops, which have become more and more stimulating with years. I cannot avoid to emphasize how much I miss, and I am sure we all miss, Sandro Vitale, who started this activity in Genoa. He was for me not only a dear friend, but also, despite our similar ages, an inspiring teacher. I cannot obviously review what will be reported in this week here, which looks already very exciting just at a glance to the program. I will limit myself to some personal recollection and to some arguments which I personally see of great interest for the application of low-temperature detectors in nuclear, subnuclear and astroparticle physics.

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1. Some personal recollections

My first approach started about 20 years ago when I was working with bubble chambers and semiconductors detectors at CERN and saw a paper in Russian by Novikov and Trofinov regarding (only these words I could understand!) double β-decay. I was able to have it translated in French and I went to see Tapio Niinikosky, the best expert in cryogenics at CERN and my first teacher in this field, totally new to me. Tapio was very excited in those days because he had seen during a night pulses in common resistors, likely due to the cosmic rays. These resistors were in some way the first low-temperature detectors . We decided to write a paper on Nuclear Instrument and Methods on the possible use of low-temperature detector to search for rare events like double β-decay (WIMPS were not popular then!).

Dan McCammon was working in parallel in a similar subject and I realized that by chance from the summary of a talk he gave in a meeting of the American Physical Society. Tapio and myself immediately contacted him and started a close connection which is still active today. In the same period Sandro Vitale, exploiting the excellent experience in cryogenics in Genoa, was entering in the same field suggesting the first experiment to determine the neutrino mass in the reaction

$$^{18}\mathrm{Re} \Rightarrow {}^{187}\mathrm{O}_{\mathrm{s}} + \mathrm{e} + \nu_{\mathrm{e}};\ \Delta E \sim 2.5\ \mathrm{keV}. \quad (1)$$

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I also remember 1 or 2 years later a very excited discussion with Bernard Sadoulet who was looking forward for an experiment on Weakly Interacting Massive Particles.

The first workshop, wonderfully organized by Klaus Prezl, was enlightened by two different exciting events: the observation of the 1987 supernova (I believe Leo Stodolsky remember the telephone call we had from his office to Masatoshi Koshiba), and by extraordinary interest of the participants to the possible application of the low-temperature detectors.

The incredible progress since then is well known to all of us: it is sufficient to go through the proceeding of the various LTD conferences.

Even if not expert in these fields, I am greatly admired by the excellent resolution obtained by the microbolometers and the consequent applications in X-ray spectroscopy and material analysis. Beautiful arrays to search for cosmic X-rays were constructed and the single optical photons measured with a resolution of a fraction of electronvolt.

Even the beautiful results obtained in the measurement of the mass of macromolecules seems very exciting to me and I am surprised that they did not yet meet the expected interest in the audience of biologists and medical doctors.

2. Searches on single β-decay

An impressive series of experiments has been carried out by the Genoa group on the decay (1) and on the other single electron and positron processes.

Recently, the bound on the electron antineutrino mass from reaction (1) has been measured by the Milano group to be 15.6 eV at 90% confidence level.

A very interesting discovery and a window open toward a brilliant future in the analysis of materials has been obtained by the Genoa group: the Beta Environmental Fine Structure in metallic Rhenium. This result is now confirmed also for $AgReO_4$.

In a close subject thermal detectors are also considered to measure X-rays and Auger electrons following Electron Capture of ^{71}Ge nuclei produced by interaction of solar neutrinos

$$\nu_e + {}^{71}\mathrm{Ga} \rightarrow e + {}^{71}\mathrm{Ge}. \quad (2)$$

Another "thermal" experiment on β-decay was capable to strongly exclude the existence of the famous (or unfamous) 17 keV neutrino.

3. Searches on α-decay

The excellent resolution ($\sim$4 keV at $\sim$5.400 MeV) obtained for the measurement of the energy of an α particle, open a wide, and not yet sufficiently explored, field in α spectroscopy. A beautiful example is the very recent discovery by simultaneous measurement of scintillation and heat of the decay of ^{209}Bi, so far considered the heaviest stable nucleus in nature

As important sub products in this use of α-decays in different subjects, I would like to quote:

(1) the best measurement of heat capacity of semiconducting chips bombarded by α particles of known energy;
(2) measurements of very low contaminations of ^{210}Pb in lead, by simply detecting the α particles produced by ^{210}Bi, the last radioactive nucleus from the chain of ^{210}Pb.

4. Double β-decay

This very rare decay can occur via one of the following processes:

$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\nu_e$$
$$(A,Z) \rightarrow (A,Z+2) + 2e^- + \chi(\ldots\chi' s)$$
$$(A,Z) \rightarrow (A,Z+2) + 2e^-.$$

The first one, the so-called "two neutrino" double β-decay, is allowed by the standard model and has been detected in 10 nuclei. The second, where one or more massless particles, named majorons are emitted, will not be considered here. The third one, the so-called "neutrinoless" double β-decay can be searched for by looking for a peak in the sum of the two electron energies.

Table 1
Compounds particularly apt to search for neutrino

Compound	Isotopic abundance of the candidate nucleus (%)	Transition energy (keV)
$^{48}CaF_2$	0.0187	4272
^{76}Ge	7.44	2038.7
$^{100}MoPbO_4$	9.63	3034
$^{116}CdWO_4$	7.49	2804
$^{130}TeO_2$	34	2528
$^{150}NdF_2$	4.64	3368

Table 2
Present and future experiments on WIMPS

CDMS II	5 kg Ge + 2 kg Si	Soudan
CRESST II	2–10 kg $CaWO_4$	G.Sasso
EDELWEISS 2	120 kg Ge	Frejus
CUORICINO	40 kg TeO_2	G.Sasso
CUORE	790 kg TeO_2	G. Sasso
ORPHEUS	R&D	
ROSEBUD	100–300 g BGO/$CaWO_4$	Canfranc
HERON	Liquid helium	?
TOKIO	NaF + LiF	Japan

Since the prediction on the rate of this process depends strongly and in an uncertain way from the decaying nuclei, thermal detectors are particularly apt to this search since they allow an ample choice of double β-decay nuclei. Various candidates are shown in Table 1.

The results of a series of experiments on neutrinoless double β-decay of ^{130}Te with massive arrays of TeO_2 bolometers, and recently with CUORICINO, and the plans for CUORE will be reported in this workshop.

5. Searches for weakly interacting massive particles (WIMPs)

The WIMPs interact in a detector leaving in it only the nuclear recoil which is characterized by a very low ionization, but by a large production of heat. This make obvious the advantage of a thermal detector, whose "quenching factor", namely detection efficiency for the energy delivered by the recoil, is expected to be nearly 100%. Particularly powerful in these searches are the detectors where heat is measured simultaneously with ionization. This allows a strong suppression by anticoincidence of the light particles (photons and electrons) which constitutes a relevant part of the background in this experiment. We are looking forward for the exciting results already at this workshop.

An admittedly incomplete list of the planned experiments is reported in Table 2.

6. Conclusions

While at the beginning of this series of workshop, the aim was mainly the development of a new type of very promising detectors, the situation has gradually changed with time. Here in Genoa, where this activity started almost 20 years ago with Sandro Vitale, we are going to witness the great impact of the experiments carried out with low-temperature detectors in nuclear, subnuclear and astroparticle physics. But we are just at the beginning: in the following years low-temperature detectors are going to bring about developments not only in these fields but also outside them, with results that will probably be above our expectations.