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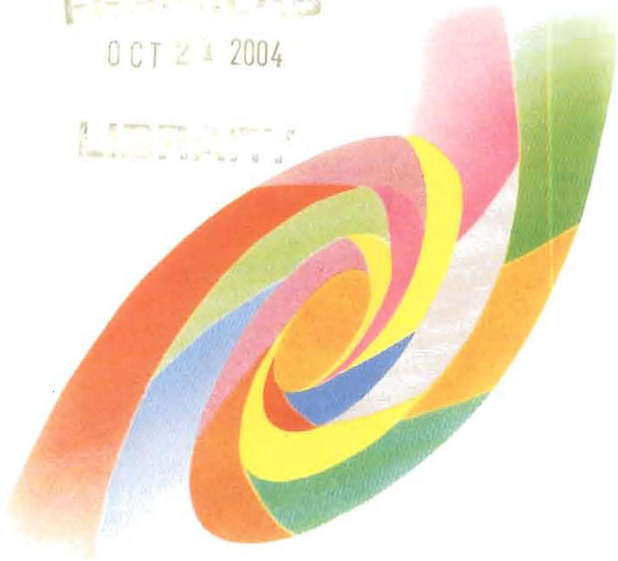

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Dark matter experiment
(results and future programme)

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Talk given at the 1st Yamada Symposium on Neutrinos and Dark Matter in Nuclear Physics, Nara (Japan), June 09-14, 2003

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1st Yamada Symposium
on Neutrinos and Dark Matter in Nuclear Physics

June 9th to 14th, 2003 at Nara (Japan)

L. Mosca
CEA-Saclay and Fréjus Laboratory

The Edelweiss Dark Matter Experiment

Results and future programme

Grenoble (CRTBT/SPM/CNRS), Lyon (IPNL/IN2P3/CNRS), Orsay (CSNSM/IN2P3/CNRS), Paris (IAP/INSU/CNSR), Saclay ((DAPNIA and DRECAM)/DSM/CEA)
and
LSM (Laboratoire Souterrain de Modane)

(for the full authors-list see Ref. 1)

Abstract

The status of the EDELWEISS Dark Matter Search Experiment is presented. Nuclear recoils, possibly induced by elastic collisions with WIMPs from the galactic halo, are identified in very low-temperature Ge detectors. Here the ratio of the heat and ionisation signals provide an event-by-event discrimination of nuclear recoils from the dominant background due to β and γ-ray interactions producing electron recoils. Results obtained in the low-background environment of the Fréjus Underground Laboratory (LSM) with several 320g detectors are presented. Prospects for the second stage of the experiment, EDELWEISS II, using an innovative reversed cryostat allowing data taking with (up to) 120 detectors, and recent results of the R&D, are also briefly discussed.

1. Introduction

The EDELWEISS experiment is finalized to the direct detection of Cold Dark Matter in the form of Weakly Interacting Massive Particles (WIMPs) and especially of their most attractive candidate: the Lightest Supersymmetric Particle (LSP) or neutralino. WIMP's Direct Detection means the measurement of the recoil energy of a target nucleus elastically (or inelastically) scattered by an incoming WIMP (see: Goodman and Witten – 1985, Ref. 2). The challenge in trying to perform such a measurement comes from two basic facts: 1) the rates of these events is small (less than one per day and per kg of absorber), and 2) the recoil energies are also small (from few keV to few tens of keV). This imply that the threshold must be low (in the keV region), the mass of the detector as large as possible and that the background rate must be as low as possible compared to the expected signal.

This experiment is based on heat-ionization Germanium cryogenic detectors. The interest of the double detection feature lies in its extremely powerful background rejection capability (event by event discrimination) allowing to obtain essentially background-free results. The principle of this discrimination is based on the fact that the ionisation power of nuclear recoils (WIMP interactions) in a Germanium crystal is about three times less then that of electron recoils (radioactive γ and β background) of the same kinetic energy.

The EDELWEISS I set-up, which correspond to the first stage of the experiment (the "1 kg" stage) is installed in the Fréjus Underground Laboratory (Laboratoire Souterrain de Modane – LSM) at a depth of 4800 meters of water equivalent (1750 meters of rock). This rock covering reduces the charged secondary cosmic rays (mainly muons) flux by a factor of about two millions, leading to a residual muons flux of $\approx$ 4 muons /m^2 /day. The residual neutron flux in the laboratory is of about 1500 neutrons (> 1 MeV) /m^2/day and is mainly due to nuclear reactions in the rock (spontaneous fission and (α,n) reactions). By the end of this year the installation of the set-up of the second stage of the experiment should start with an innovative type of cryostat much larger (nearly 100 litres) than the present one ($\approx$ 1 litre).

2. The experimental set-up (Ref.1)

A stack of three heat-ionization 320 g Germanium detectors are operated at 17 mK inside a low radioactivity cryostat surrounded by a 10 cm copper, plus 20 cm lead shielding against gamma rays and a 30 cm paraffin shielding against neutrons. Each detector has a disc shape 70 mm in diameter and 20 mm in height, is equipped with a segmented electrode defining two regions : a central part (flat) and a guard ring (skewed), see fig.1.

In 2002 three such detectors have been mounted GGA-1, GeAl-9, and GeAl-10. The GGA-1 detector has a peculiarity with respects to the other two : a thin (70 nm) hydrogenated amorphous Germanium layer has been deposited between each Aluminium electrode and the Germanium crystal. The purpose was to improve the charge collection problem for the events produced near the surface of the crystal. In fig. 2, where the (^{57}Co) calibration data for the three detectors are compared, the spectacular effect of this layer can be seen.

In the fall of 2002 the three mentioned detectors have been replaced by a second series of new detectors : GGA-3, GSA-1 and GSA-3. The GGA-3 is, in principle, identical to the GGA-1 of the previous series, while in the GSA-1 and GSA-3 the hydrogenated amorphous layer in made of Silicium, and is 40 nm thick.

The NTD (Neutron Transmutation Doped) heat sensor is glued on the guard ring region.

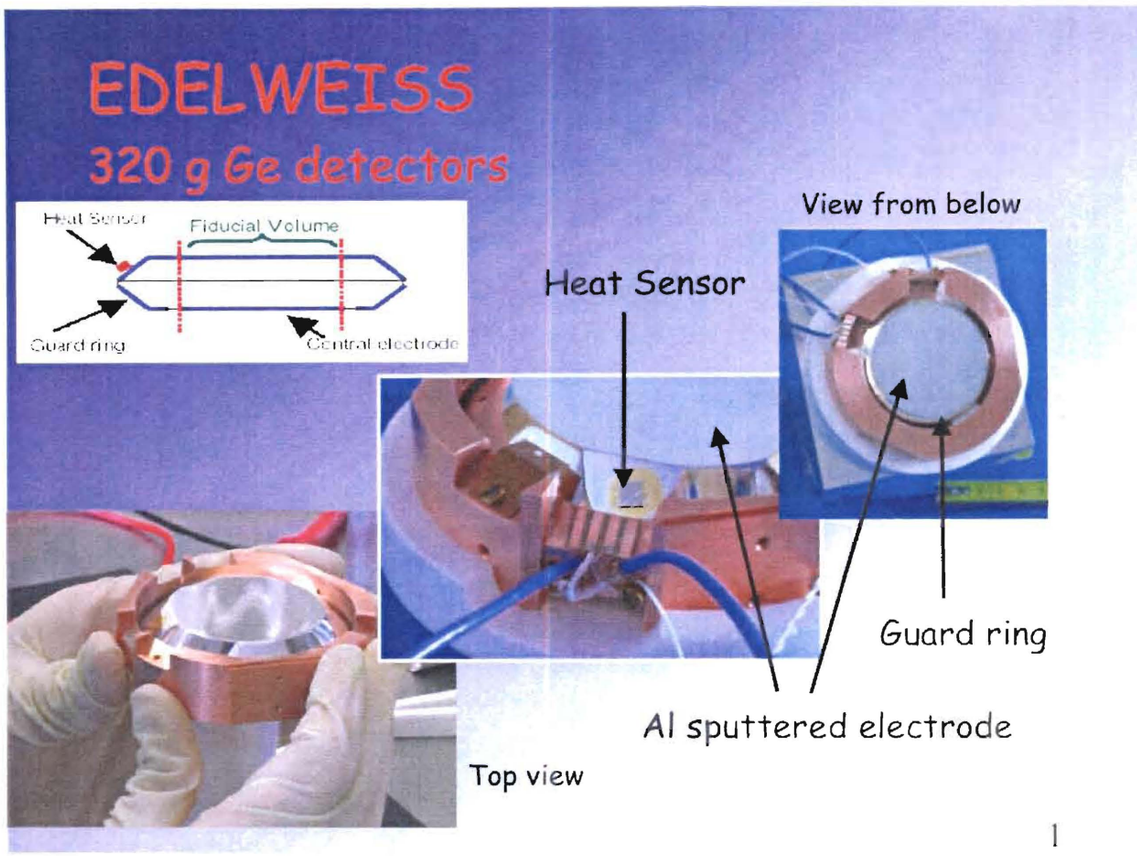


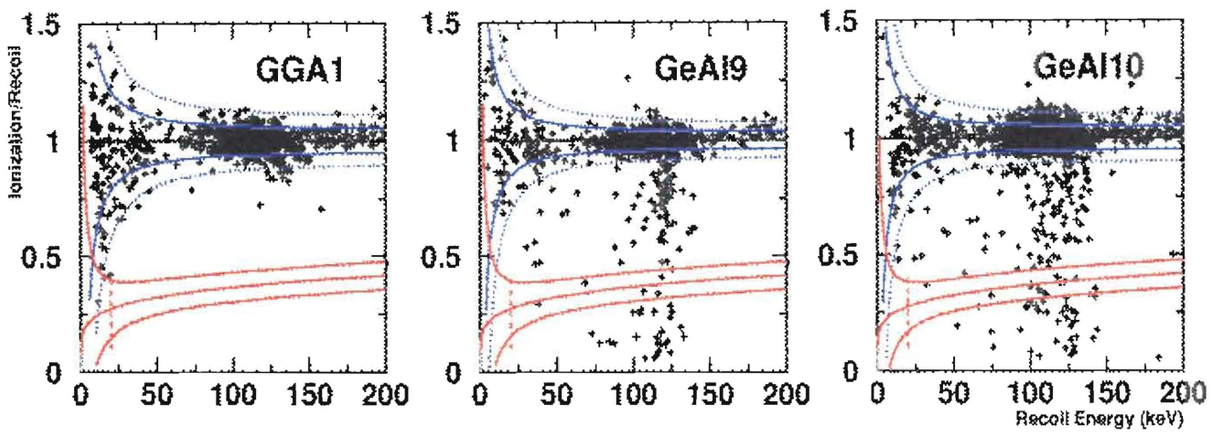
Fig 1. A 320 g ionization-heat bolometer with an NTD sensor and a guard ring.

3. Detector's resolution and trigger threshold (Energy calibration) (Ref. 3)

In Table 1 the values of the energy resolution (FWHM) for both Heat and Ionization channels are given for each of the four mentioned detectors with amorphous layers and for two values of the recoil energy : "zero energy" (baseline) and 122 keV (^{57}Co source). Remarkably good values are obtained in particular for the heat channel of the GGA-3 and GSA-1 detectors. All these data allow of course also en energy calibration for both channels, Heat and Ionization.

The trigger for the data presented in this paper has been applied on the Ionization channel. The corresponding values for each of the four mentioned detectors with amorphous layers is quoted on the last column of table 1. These trigger threshold values are for the row data and correspond to 50% trigger efficiency (see below § 5). The "analysis" threshold values will be discussed in the following (see § 5).

Fig 2. ^{57}Co calibration. Charge collection



Detector with amorphous Ge surface treatment ← Other detectors →

Few miscollected surface events
99.9 % background rejection (^{60}Co)

More miscollected events
97.8 - 98.7 background rejection (^{60}Co)

4. Detector calibration and "Quenching factor" (Ref. 3)

In the detector calibration two quantities are concerned : the Recoil Energy and the "Quenching Factor". Recoil Energy calibration has been considered in the previous paragraph. Let us now concentrate on the important notion of "Quencing Factor" : this is the ratio of the Ionization intensity due to a nuclear recoil (WIMP interaction or neutron interaction) to the Ionization intensity due to an electron recoil (radioactive γ and β background) of the same kinetic energy. As already anticipated in the Introduction, the fact that in this type of detector the value of this ratio is much less then 1($\approx$ 0.3), associated with their very good resolution, is a very important property, because it allows extremely powerful background rejection capability (event by event discrimination) and, as a consequence, essentially background-free results.

This "Quenching Factor" calibration for the GGA-1 detector, using a neutron (and gamma) source (^{252}Cf), is shown in Fig 3. The neutron/gamma discrimination is very good (> 99.9%) for a recoil energy larger than 15 keV.

Table 1. Resolutions and Trigger Thresholds

	FWHM @ 0 keV (KeVee) baseline		FWHM @ 122 keV (KeVee) ^{57}Co		Trigger Treshold (KeVee) (at 50% efficiency)
Detector	**Ioniz.**	**Heat**	**Ioniz.**	**Heat**	**Ionization**
GGA-1	1.3	1.3	2.8	3.5	3.5
GGA-3	1.3	0.4	3.1	2.7	2.9
GSA-1	1.2	0.6	3.1	2.8	3.5
GSA-3	1.1	1.4	3.3	3.3	3.0

5. Efficiency curve, fiducial volume and acceptance (Ref. 3)

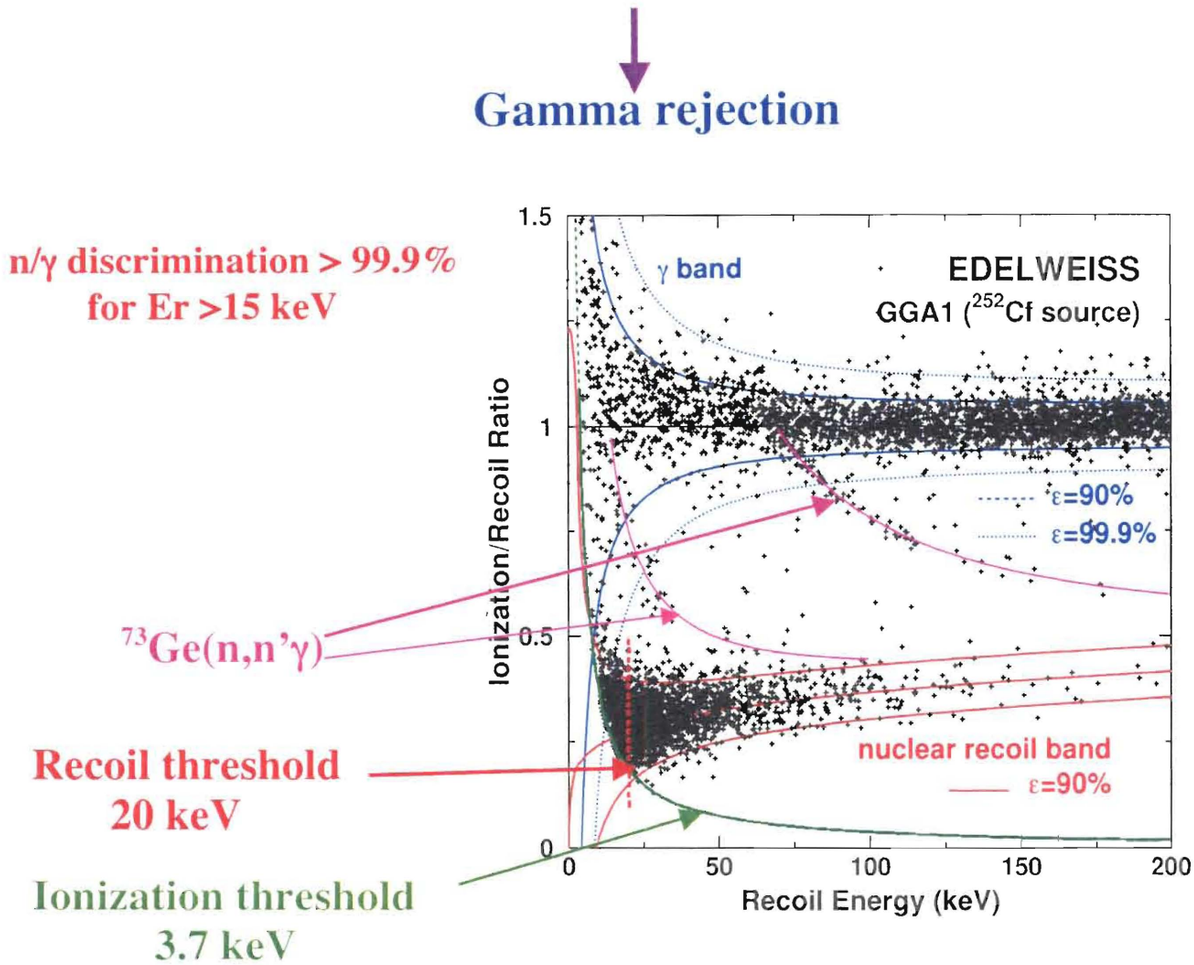
The efficiency of the detectors has been determined in two different ways:

a) with a ^{60}Co gamma source exposure of the detectors, by fitting the low energy part of the Compton plateau, to determine the efficiency for the electron recoils (γ and β background), and

b) with a ^{252}Cf neutron source exposure of the three detectors by making, for each detector, e.g. GGA-1, the ratio of two experimental distributions : the first with a trigger in coincidence between GGA-1 and at least one of the other two detectors, and the second with a trigger "or" between these two detectors. This second method is more important than the first one because it gives the efficiency of nuclear recoils, directly relevant to WIMP interactions. With a trigger threshold around 3 KeV of ionization energy, the nuclear recoil efficiency reaches 100% at 20 keV of recoil energy (see Ref. 3).

The two methods, respectively with gamma and neutron sources give consistent results.

Fig. 3 "Quenching-Factor" calibration



A fiducial volume is defined in order to exclude events occurring in the peripheral region of each detector as this region is more exposed to external sources of radioactivity and to charge collection problems. The selection cuts require that at least 75% of the total charge must be collected on the central electrode. Two methods are used to evaluate the corresponding fiducial volume. The first one uses data obtained with the ^{252}Cf source : the fraction of nuclear recoil candidates passing the fiducial cuts is compared to the results of a MonteCarlo simulation of neutron interaction in the detector including the effects of multiple scattering. The second method exploits the uniformity of the distribution within the detector of the 65 Zn and 68Ge decays from cosmic activation (8.98 and 10.37 keV). The two approaches give the same result : (57 +- 3)%.

The acceptance (ε) for nuclear recoils concerns both the "nuclear recoil band" in the Q versus recoil energy plot, chosen at the value ε = 90% (+- 1.645σ), and the cuts in recoil energy. The lower bound ("analysis" threshold) is set at 20 keV for the GGA-1 and GSA-3, and at 30 keV for the GGA-3 and GSA-1 detectors; the upper bound correspond to 95% of all WIMPs-induced recoils above the "analysis" threshold.

6. Neutron background

In the neutron background we have to distinguish two different origins, corresponding to two different energy intervals :

a) nuclear reactions : essentially from U/Th chains natural radioactivity (spontaneous fission and (α,n) reactions), producing neutrons in the few MeV range of energy, and
b) muons interactions, producing neutrons of much higher energy.

Both types of process can take place in the surrounding rock (or concrete) and in the detectors shielding (mainly selected Pb and Cu)

In table 2 are given the expected rates in the present EDELWEISS 1 installation, for two different energy thresholds (10 keV and 30 keV) and two different shielding configurations : Pb and Cu with and without paraffin.

With the present values of threshold and exposure and the present shield configuration the EDELWESS data are not yet disturbed by the neutron background.

Table 2. Expected Rates in Ge detectors of EDELWEISS-I from neutrons at LSM

Shielding	Rate for Er > 10 keV (evts/kg/day)	Rate for Er > 30 keV (evts/kg/day)
Pb + Cu only	3.7	1.0
Pb + Cu + 30 cm of paraffin	0.05	0.014

7. Results and discussion (Ref. 1)

The overall running period with the GGA-1 detector in 2002 is 54 days, which correspond to a total exposure of 15.1 kg.day, and to 8.61 kg.day in the fiducial volume (57%) and to 7.4 kg.day when taking into account the detector acceptance both in terms of Q and recoil energy ranges. On Fig. 4 (Q vs. recoil energy for these data) the recoil band is essentially background free between the "analysis threshold" (20 keV) and 200 keV recoil energy, except one event very close to the border of the band at 119 keV, which correspond to a WIMP mass larger than 10 TeV with 95% efficiency (see §5). The corresponding "exclusion plot" (WIMP-Nucleon Cross-Section versus the WIMP Mass), has been calculated from these data taking into account the phenomenological standard model described by Lewin and Smith (Ref.4).The red curve on Fig 5 corresponds to the cumulated data of 2000 and 2002. This curve represents the best published limit above a WIMP mass of 35 GeV. We can also see that the EDELWEISS results start to exclude some of the most "optimistics" SUSY Model predictions.

The central solution of the "DAMA region" (M_{WIMP} = 52 GeV/c^2 and σ_n = 7.2 10^{-6} pb) would correspond to 9.8 events in our recoil band, while we observe zero events. (This configuration corresponds to a probability of 0.006 %). Moreover Copi and Krauss (Ref. 5) recently showed that this incompatibility is essentially model-independent.

More recently about 20 kg.day exposure have been added by running the second series of detectors : GGA-3, GSA-1 and GSA-3 (see § 2). Two events compatible with nuclear recoils have been recorded in a short and noisy period (CL for a poissonian distribution < 1%). See Fig 7 for the data of each detector and the corresponding exclusion plot obtained with the conservative hypothesis accepting the mentioned noisy period. This limit, practically coincide with the previously published one. (The rejection of the noisy period would have improved this limit by roughly a factor of two).

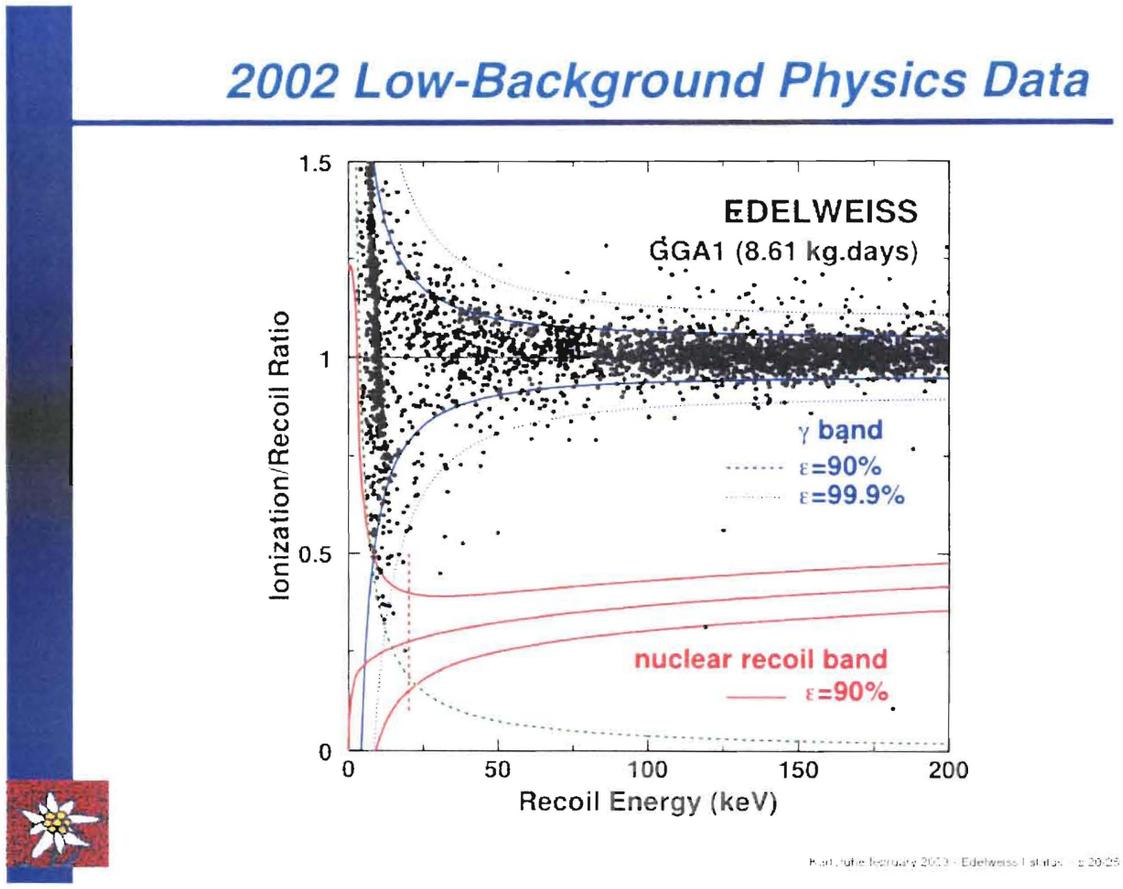
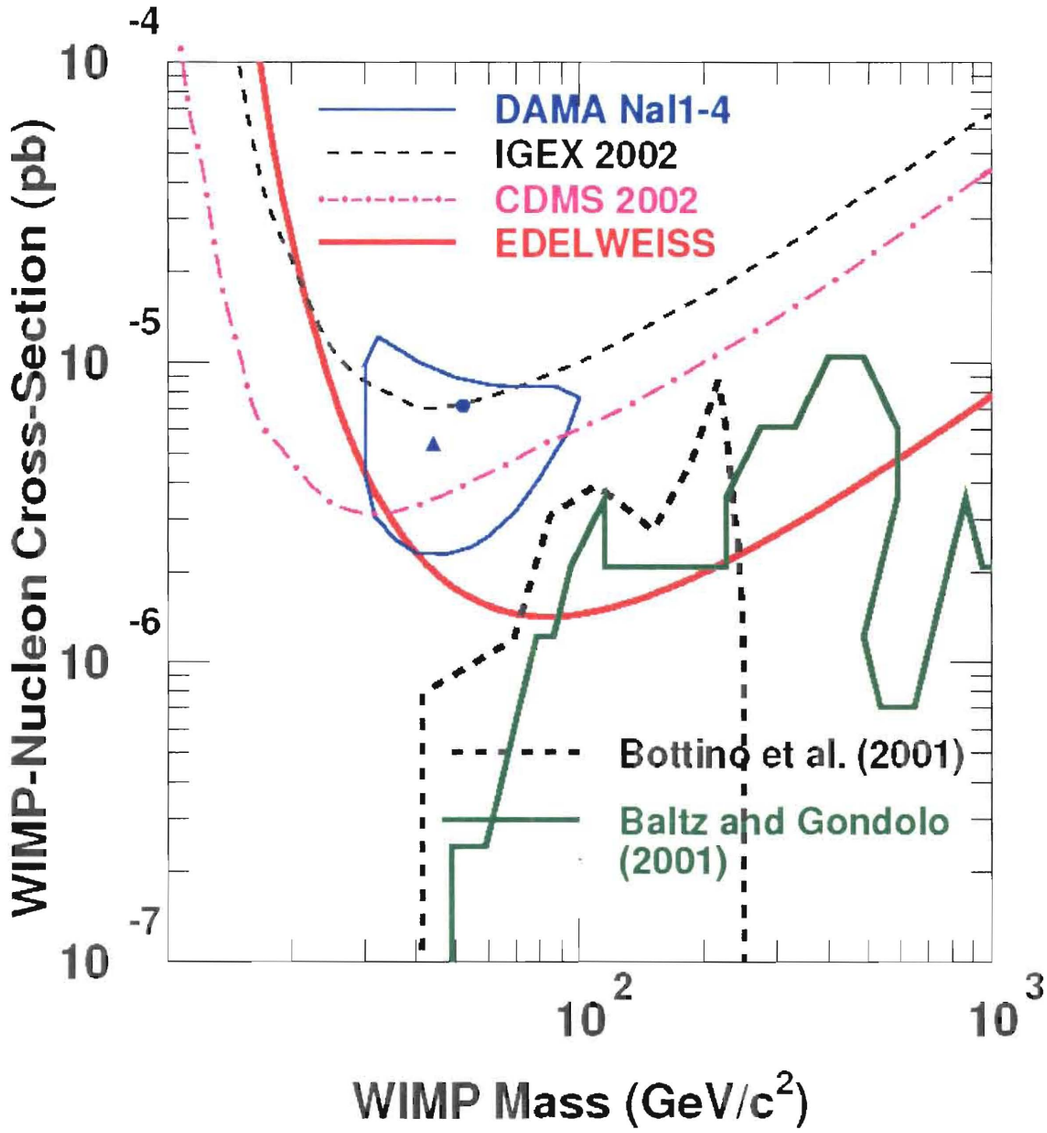


Fig. 4 **Q versus Recoil Energy for the GGA-1 detector (8.61 kg.day effective exposure)**

8. R&D for an "active" rejection of the near surface events

The "passive" rejection of the near surface events by the introduction of the Ge (or Si) amorphous layers produced a spectacular improvement of this situation (see § 2 and Fig 2), nevertheless, to reach a new substantial improvement of the WIMP-nucleon Cross-section limits an additional type of discrimination is needed, that is an "active" rejection of the near surface events. The presently most promising approach is the one based on out-of-equilibrium phonons detection with co-evaporated NbSi thin film sensors. This discrimination is possible due to the appearing of a sharp peak at the beginning of the Heat signal when the events is produced near the detector surface (see fig.7). Three such prototypes will be tested before the end of this year at the LSM.

Fig. 5 Present sensitivity for spin independent WIMPs



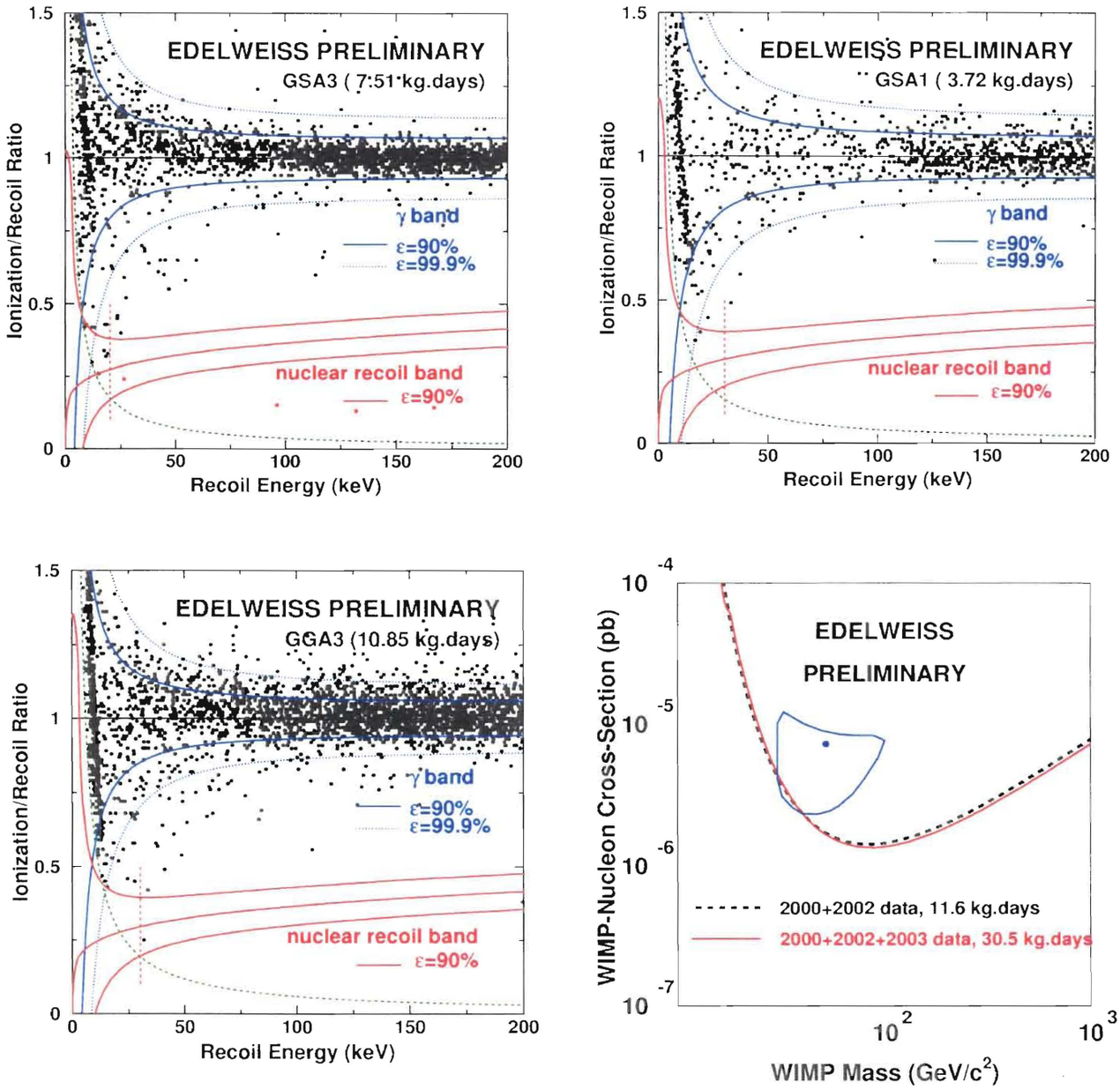


Fig. 6 Q versus Recoil Energy for the GSA-3, GSA-1, GGA-3 detectors (about 22 kg.day effective exposure), and the corresponding exclusion plot.

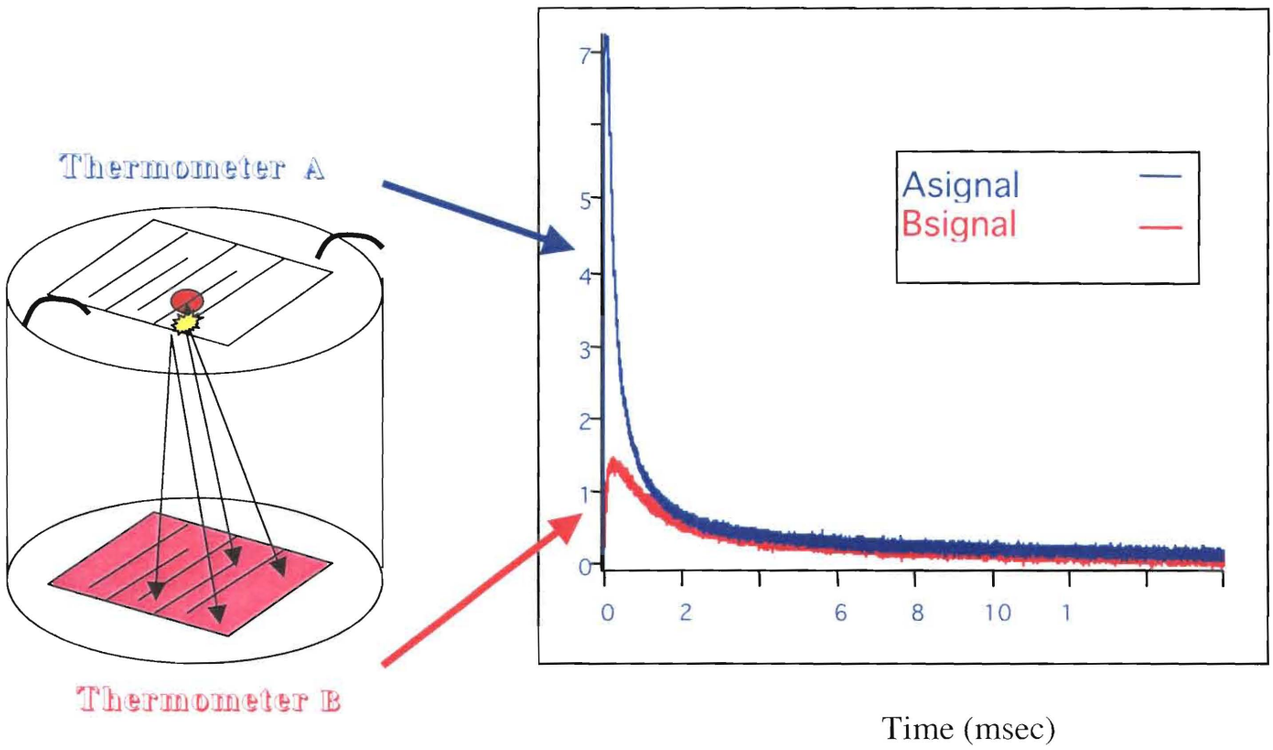


Fig 7 Schematic view of a prototype bolometer with Nb/Si thin film sensors and the corresponding position-dependent signals.

9. Outlook and Conclusion

The running of the EDELWEISS I experiment will still continue during few months, with a new type of trigger (phonon trigger) in order to decrease the threshold in the recoil energy, then this installation will be temporarely dismounted in order to allow the mounting of the next generation EDELWEISS II set-up (see fig 8). A large (100 litres) innovative (reversed-like) cryostat will be installed with 28 new detectors (≈ 9 kg) : 21 will be similar to the present EDELWEISS I detectors and the additional 7 will be equipped with NbSi thin film sensors. In a future step it will be possible to exploit the full capacity of the new cryostat by installing 120 detectors of about 300 g each (≈ 36 kg).

As a conclusion, the cryogenic ionization-heat approach has proved its ability to achieve an impressive e.m. background rejection power. The "surface events" have been strongly reduced by a passive rejection method using thin Ge (or Si) amorphous layers between the Aluminium electrodes and the Germanium crystal. This allowed to obtain (nearly) background free results at the level of the present exposure (≈ 30 kg.day) and, as a consequence, the best presently published limits on the WIMP-Nucleon cross section for a WIMP mass larger than 35 GeV. To still improve this situation an active rejection method is needed. For that three prototypes detectors with Ni/Si thin films sensors are ready to be tested in the Fréjus Laboratory.