The EDELWEISS experiment is a Direct Dark Matter Search using 320 g heat-and-ionization Ge cryogenic detectors. The final results obtained by the EDELWEISS-I stage corresponding to a total of 62 kg.day are presented. The status of EDELWEISS-II, involving in a first phase ~10 kg of detectors and aiming to gain two orders of magnitude in sensitivity, is also described.

1. Introduction
The EDELWEISS experiment is dedicated to the search for non-baryonic cold dark matter in the form of WIMPs (Weakly Interactive Massive Particles). The direct detection principle consists in the measurement of the energy released by nuclear recoils produced in an ordinary matter target by elastic collisions of WIMPs from the galactic halo.

The EDELWEISS detectors are cryogenic Ge bolometers with simultaneous measurement of phonon and ionization signals. The comparison of the two signals provides an excellent event-by-event discrimination between nuclear recoils (induced by WIMP or neutron scattering) and electronic recoils (induced by $\beta$ or $\gamma$-radioactivity).

The experiment is located in the Modane Underground Laboratory in the tunnel connecting France and Italy under ~1800 m of rock (~4800 mwe). In the laboratory, the resulting muon flux is $4 \mu$/m$^2$/d and the fast neutron flux has been measured $^1$ to be $\sim 1.6 \times 10^{-6}$ cm$^2$/s.

During three years, 62 kg.day of data have been accumulated with five 320 g Ge detectors.
2. Experimental set-up

Between 2002 and 2003, three 320 g Ge detectors were operated simultaneously in a dilution cryostat with a regulated temperature of 17 ± 0.01 mK. A passive shielding made of paraffin (30 cm), lead (15 cm) and copper (10 cm) surrounded the experiment.\(^2\,^3\).

The detectors\(^4\) are made of a cylindrical Ge crystal with Al electrodes to collect ionization signals and a NTD heat sensor glued onto one electrode to collect the phonon signal. The top electrode is segmented in a central electrode and an annular guard ring and defines a fiducial volume corresponding to 57 ± 2 % of the total volume.\(^5\) On four of the five detectors used in EDELWEISS-I an amorphous layer (either of Ge or Si) was deposited under the electrodes to improve charge collection of near surface events.\(^6\)

The resolutions and energy thresholds of the detectors are summarized in Ref.\(^5\). Detectors with an amorphous layer show a 99.99 % gamma rejection at a recoil energy of 100 keV and a 99.9 % gamma rejection at a recoil energy of 15 keV.

3. Edelweiss-I results

During the EDELWEISS-I stage (2000-2003), four physics runs have been performed with five detectors. In the three first runs, the trigger was the fast ionization signal. For the last run, the trigger was the phonon signal. Thanks to a better resolution and the absence of quenching factor on the phonon signal, the phonon trigger improves the efficiency at low energy for nuclear recoils. In this last configuration, a ∼ 100 % efficiency has been reached at 15 keV on the three detectors. With the ionization trigger a ∼ 100 % efficiency was reached at 20 keV or 30 keV, depending on the detector. The low-background physics data recorded in the phonon trigger configuration are shown in Fig. 1.

Considering the complete 62 kg.day data set, 60 events compatible with nuclear recoils have been recorded above a recoil energy of 10 keV. The corresponding energy spectrum is shown in Fig. 2, compared with simulations of theoretical spectrum for different WIMP masses, taking into account the recoil energy dependence efficiency\(^a\) of all experimental configurations.

\(^a\)The efficiency calculation takes into account thresholds, resolutions, the 90 % efficiency (1.65 \(\sigma\)) for the nuclear recoil band and the 99.9 % rejection (3.29 \(\sigma\)) of the electronic recoils.
The overall shape of the experimental spectrum is incompatible with WIMP masses above 20 GeV/c$^2$.

Setting our analysis threshold to 20 keV, above which the experimental efficiency is greater than 75%, 23 events compatible with nuclear recoils have been observed. Considering all these events as possible WIMP interactions and taking into account the efficiency versus recoil energy function of each run\(^b\), a conservative upper limit on the WIMP-nucleon cross-section as a function of the WIMP mass has been derived with the Optimum Interval Method\(^7\). This method allows to compute an exclusion limit in the presence of an unknown background. Fig. 3 shows the EDELWEISS-I spin independent exclusion limit, assuming a standard spherical and isothermal galactic WIMP halo with a local density of 0.3 GeV/c$^2$/cm$^3$, a rms velocity of 270 km/s, an escape velocity of 650 km/s and a relative Earth-halo velocity of 230 km/s. Limits from other running experiments are also shown.

\(^b\)For example, for the complete data set of Edelweiss-I a 50% efficiency is reached for a recoil energy of 15 keV.
Figure 2. Energy spectrum for the EDELWEISS-I data, for $E_R > 10$ keV, compared to simulated theoretical WIMP spectrum for $M_{WIMP} = 20, 40, 500$ GeV/c$^2$.

on Fig. 3. With no background subtraction and an extended exposure, the new limit is consistent with the previous published one $^8$.

Although the EDELWEISS-I limit of Fig. 3 is derived assuming all events as possible WIMP candidates, the experimental data reveal some clues as to the nature of possible backgrounds. For example, a two detector coincidence between nuclear recoils has been recorded. This event is very likely a neutron-neutron coincidence, indicating that a certain fraction of events in Fig. 2 could be due to single hits by neutrons. Miscollected charge events, as indicated by the few events lying between electronic and nuclear recoil bands in Fig. 1, are another possible source of background, because they can simulate nuclear recoils. But with the present statistics, limited largely by the number of detectors (the EDELWEISS-I cryostat could not receive more than $3 \times 320$ g detectors), it is not possible to conclude any further.

4. Lessons for EDELWEISS-II

The second phase of the experiment will be EDELWEISS-II, with an expected sensitivity of 0.002 evt/kg/d. Specific improvements are aimed at
reducing the possible background sources, that may have limited the sensitivity of EDELWEISS-I. In addition, the detector number will be increased up to 28 to achieve a Ge mass of $\sim$ 10 kg in a first stage.

4.1. Neutrons

The low energy neutron background, due to the radioactive surrounding rock, is attenuated by more than three orders of magnitude thanks to a 50 cm polyethylene shielding. In addition, a muon veto surrounding the experiment will tag muons interacting in the lead shielding. The increased number of detectors will improve the possibility of detecting multiple interactions of neutrons.

4.2. Surface events

Surface events, namely interactions near electrodes, show a deficit of the charge collection. One of the R&D goals in EDELWEISS is the event-by-
event identification of these miscollected events and their active rejection. A new generation of detectors has been developed with NbSi thin film sensors (instead of the NTD heat sensors for present detectors). They consist in a Ge crystal with two NbSi sensors acting also as electrodes for charge collection. These thin film sensors are sensitive to the athermal component of the phonon signal, acting as near-surface interaction tag. Several tests have been made in the EDELWEISS-I setup with three 200 g Ge detectors showing a reduction by a factor 10 of the surface event rate while retaining a 50% efficiency. Seven 400 g Ge detectors are being prepared in a first stage for EDELWEISS-II. Furthermore, improved radiopurity and clean room conditions are expected to reduce the contaminations and the rate of surface electrons.

5. Conclusion
EDELWEISS-I experiment has reached its limit sensitivity near $10^{-6}$ pb, allowing the exclusion of some optimistic SUSY models. The goal for the future with EDELWEISS-II is to reach more favored models close to $10^{-8}$ pb. The EDELWEISS-I experiment was stopped in March 2004 to allow the installation of the second phase EDELWEISS-II. The first runs will be performed with $21 \times 320$ g Ge detectors with NTD heat sensor and $7 \times 400$ g Ge detectors with NbSi thin film sensor. Data taking in the new setup is scheduled for end-2005.

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