Status and outlook of the EDELWEISS experiment

P C F Di Stefano¹, A Benoit², L Berge³, J Blümer⁴, A Broniatowski³, B Censi⁴, B Chamon¹, A Chantelaude⁵, M Chapellier⁶, G Chardin⁷, M De Jésus¹, Y Dolgorouky⁴, D Drain¹, L Dumoulin⁴, K Eitel⁵, M Fesquet⁷, S Fiorucci⁷, J Gascon¹, G Gerbier⁵, E Gerlic¹, C Goldbach⁵, M Goyot¹, M Gros⁷, M Horn⁵, S Hervé⁷, A Juillard⁵, C Kikuchi⁵, R Lemrani⁷, A de Lesquen⁷, A Lubashevski¹⁰, M Luca¹, J Mallet⁷, S Marnieros⁷, L Mosca⁷, X F Navick⁷, G Nollez⁸, P Pari⁶, V Sanglard¹, L Schoeffel⁷, L A Smolnikov¹⁰, M Stern¹, V Villar⁷ and E Yakushev¹⁰

¹Institut de Physique Nucléaire de Lyon, Université Claude Bernard Lyon 1, 4 rue Enrico Fermi, 69622 Villeurbanne Cedex, France
²Centre de Recherche sur les Très Basses Températures, SPM-CNRS, BP 166, 38042 Grenoble, France
³Centre de Spectroscopie Nucléaire et de Spectrométrie de Masse, IN2P3-CNRS, Université Paris XI, bat 108, 91405 Orsay, France
⁴Institut für Experimentelle Kernphysik, Universität Karlsruhe (TH), Gaußestr. 1, 76128 Karlsruhe, Germany
⁵Forschungszentrum Karlsruhe, Institut für Kernphysik, Postfach 3640, 76021 Karlsruhe, Germany
⁶CEA, Centre d’Études Nucléaires de Saclay, DSM/DRECAM, 91191 Gif-sur-Yvette Cedex, France
⁷CEA, Centre d’Études Nucléaires de Saclay, DSM/DAPNIA, 91191 Gif-sur-Yvette Cedex, France
⁸Institut d’Astrophysique de Paris, INSU-CNRS, 98 bis Bd. Arago, 75014 Paris, France
⁹Laboratoire Souterrain de Modane, CEA-CNRS, 90 rue Polset, 73500 Modane, France
¹⁰Joint Institute for Nuclear Research, Dubna, Russia

E-mail: distefano@ipnl.in2p3.fr

Abstract. EDELWEISS is a direct search for WIMPs using cryogenic germanium ionization-phonon detectors and located in the Modane underground laboratory. We summarize the final results of the EDELWEISS I experiment obtained with up to nearly a kilogram of detectors. The increased exposure confirms previous results. We also report on the preparations for EDELWEISS II. Preliminary results are expected in 2006; the experiment could ultimately deploy up to 40 kg of detectors. Goals are to gain two orders of magnitude in sensitivity and to serve as a testbed for an even larger, tonne-scale, experiment.

1. Introduction
Since the existence of dark matter was inferred by Fritz Zwicky in 1933 from the velocities of galaxies in the Coma cluster [1], there have been various attempts to explain its nature. One well-motivated hypothesis is that the dark matter is made up of weakly interacting massive
particles (WIMPs) such as the lightest supersymmetric particle (LSP). Starting in the nineteen-eighties, experiments have sought to detect these particles directly via their elastic scattering off nuclei in a target. Challenges include the small average energy deposits, typically of a few keV to a few tens of keV, and the low event rates, less than a few per kilogram of detector and per year. Currently, the most sensitive experiments [2, 3] use germanium cryogenic detectors in which the temperature rise caused by the interaction provides the deposited energy, while the created charges provide powerful discrimination between the strongly ionizing dominant radioactive background (betas and gammas) and the less-ionizing WIMPs and neutron background. A similar technique with good sensitivity is the simultaneous measurement of heat and scintillation [4, 5].

EDELWEISS (Expérience pour Détecter les WIMPs en Site Souterrain) is a direct detection experiment involving institutes from France, Germany and Russia. The experiment is located in the Modane underground laboratory (Laboratoire Souterrain de Modane, LSM) in the Fréjus highway tunnel beneath the Franco-Italian Alps. The rock overburden, equivalent to 4500 meters of water, greatly reduces the cosmic muon flux to $4.2 \text{m}^2/\text{d}$ through a horizontal surface. The fast neutron flux, mainly from natural radioactivity of the rock, is $1.6 \times 10^{-6}/\text{cm}^2/\text{s}$ [6].

2. Final results of EDELWEISS I
The first phase of the experiment at LSM, EDELWEISS I, used a dilution fridge operating at about 17 mK. The fridge employed liquid nitrogen and liquid helium baths. In its definitive configuration, it was surrounded by 25 cm of lead and copper as shielding against photons and 30 cm of paraffin to moderate the fast neutron background. The first results were obtained by the collaboration in 1995 using a single 24 g sapphire detector [7]. The need for background discrimination soon became apparent and resulted in the successful deployment of a 70 g germanium ionization-phonon device [8]. Subsequent campaigns [9, 10] involved scaled-up, 320 g detectors [11].

In the final configuration of the cryostat and the electronics, up to three 320 g Ge ionization-phonon detectors were run simultaneously, for periods ranging up to four months and with thresholds down to 10 keV recoil. The total exposure after cuts is 62 kg.d: 59 nuclear-recoil-like events remain, mostly between 10 and 30 keV. Full results for the spin-independent interaction are reported in [3]; a spin-dependent analysis is detailed in [12].

The distribution of the ionization-over-energy ratio of the background suggests that at least some of the 59 remaining events are in fact caused by charge mis-collection. It is possible that some of these events are betas coming from $^{210}\text{Pb}$ contaminations on the surfaces of the copper shielding immediately around the detectors. The surface contamination could stem from exposure to radon; high-energy alphas consistent with this hypothesis have been observed in dedicated runs with increased dynamic range [13].

Moreover, one nuclear recoil coincidence was observed between two detectors, which also suggests the presence of some neutrons in the data (neutron issues in EDELWEISS I are discussed further in [14]). However, no background subtraction is attempted, and all 59 events are conservatively kept in establishing the upper limit on the WIMP cross section displayed in Fig. 1. This upper limit confirms the previously published EDELWEISS limit [10] with additional statistics. In late 2003, EDELWEISS I had fulfilled its physics potential. After a series of tests to validate new equipment for the next phase, EDELWEISS I was dismantled by April 2004 to make way for its successor.

3. Status of EDELWEISS II
Along with CDMS II in the Soudan mine [17] and CRESST II at the Gran Sasso laboratories [18], EDELWEISS II will be one of several next-generation cryogenic experiments with total detector masses in the 10–100 kg range and background discrimination. These experiments aim to reach
Figure 1. Spin-independent limits on WIMPs at 90 % confidence level. Standard astrophysical assumptions (local dark matter density 0.3 GeV/cm³, WIMP velocity distribution) and particle physics assumptions ($A^2$ coupling, form factor) are used. Solid dark curve is the EDELWEISS limit [3], dashed dark curve is the CRESST limit from CaWO₄ [4], dot-dashed light curve is the CDMS limit from the Stanford shallow site [15], solid light curve is the CDMS limit from the Soudan mine [16].

A spin-independent sensitivity of $10^{-8}$ pb. EDELWEISS II will be in the deepest underground site of these experiments. It will use a novel 100 l cryostat with a reversed geometry, three pulse tubes to dispense with liquid nitrogen, and a liquefier to reduce liquid helium consumption. From the standpoint of physics, the two challenges for EDELWEISS II are surface events and the neutron background.

3.1. Surface events

To deal with surface events, measures that were successful in EDELWEISS I will be continued. These measures are the use of concentric electrodes to provide a rough but useful radial sensitivity in the detector allowing rejection of the cylindrical surface of the detector [19], and a 60 nm amorphous Ge or Si surface treatment [20, 21]. Additional measures implemented for EDELWEISS II include cleaner materials and environment for the detectors thanks to better screening of materials, a class 100 clean room, and the use of de-radonized air reducing the radon content from 5 Bq/m³ to 0.1 Bq/m³.

A very promising technique for dealing with surface events is the development of detectors sensitive to nonthermal phonons and thus with a form of axial position sensitivity. One design...
uses NbSi thin-films as phonon sensors. A 200 g cylindrical prototype with NbSi films on each end was tested underground in the EDELWEISS I setup before it was dismantled [22]. The enhancement of the athermal signal component of near-surface events allows their identification. Events in the top and bottom millimeter of the detector can thus be identified and rejected, amounting to a 10% reduction in the fiducial volume of the detector but a twenty-fold reduction in the number of mis-collected events as obtained with a $^{57}$Co source. Another possibility to identify surface events is through a better understanding of the pulse shape of time-resolved ionization signals [23].

3.2. Neutrons
To deal with neutrons, various measures will be implemented. The dominant neutron background is neutrons of MeV energy coming from the natural $\alpha,n$ reactions in the rock around the LSM. These neutrons will be moderated to energies too low to affect the experiment thanks to 50 cm of polyethylene around the experiment.

Hard-to-moderate neutrons of energies of 10 MeV or more can be created by the rare 300 GeV cosmic muons that make it to the depth of the LSM and then hit a heavy nucleus in the rock or in the 30 tonnes of Pb shielding right around the experiment. To identify the latter component, the experiment will be surrounded by a muon-tagger made up of scintillating panels from the former KARMEN experiment. Each panel is 5 cm thick and has a surface of 2–3 m$^2$; total surface will be $\approx 100$ m$^2$.

EDELWEISS II could ultimately consist of 120 detectors divided into 10 levels of 12 detectors each. This segmentation of the total mass into units of dimensions comparable to the mean free path of MeV neutrons in Ge means that neutrons could be identified because they are likely to create coincidences in several detectors.

3.3. Installation notes
Installation of EDELWEISS II was proceeding on schedule until June 4th 2005 when there was a tragic fire in the highway tunnel. Though the LSM suffered no serious damage, access was restricted in the aftermath, and work on EDELWEISS II was delayed by some five weeks. As this report is being written in November 2005, most of the shielding (Pb, PE, muon scintillators) and support infrastructure (clean room, pumps) for EDELWEISS II has been installed underground and the cryostat is being tested. The goal is to commission the cryostat and a small number of detectors by early 2006. The year 2006 should bring first results from the first phase of EDELWEISS II consisting of 21 standard NTD detectors and 7 NbSi ones. Results obtained in this first 10 kg phase will determine the mix of NTD and NbSi detectors to deploy in the larger, 40 kg phase involving close to 100 detectors.

4. Conclusion
EDELWEISS I, for a time the most sensitive spin-independent dark matter search, has been retired to make way for a larger experiment. Despite delays from the June 4th 2005 Fréjus tunnel fire, installation of the next phase at the Laboratoire Souterrain de Modane is nearing completion. EDELWEISS II will ultimately deploy up to 40 kg of detectors. Many measure will be deployed to counter problematic surface events and the neutron background. The aims of EDELWEISS II are two-fold. The first is to gain two orders of magnitude in sensitivity thanks to improved detectors and shielding. The second is to serve as a testbed for a much larger, one-tonne scale experiment sensitive down to $10^{-10}$ pb, such as the pan-European EURECA project [24].
Acknowledgments
This work is dedicated to the memory of our colleague Pierre Brun. It has been funded in part by EEC Applied Cryodetector network (Contract HPRN-CT-2002-00322) and the ILIAS integrating activity (Contract RII3-CT-2003-506222)

References
[1] Zwicky F 1933 *Helv. Phys. Acta* 6 110–27
[2] Akerib D S et al 2004 *Phys. Rev. Lett.* 93 211301 (*Preprint* astro-ph/0405033)
[3] Sanglard V et al 2005 *Phys. Rev. D* 71 122002 (*Preprint* astro-ph/0503265)
[4] Angloher G et al 2005 *Astropart. Phys.* 23 325-39 (*Preprint* astro-ph/0408006)
[5] Cebrián S et al 2005 *Nucl. Phys. B* (Proc. Suppl.) 138 519–21
[6] Chardin G et al 2003 In *Proceedings of IDM 2002*, page 470. World Scientific, 2003.
[7] de Bellefon A et al 1996 *Astropart. Phys.* 6 35–46
[8] Di Stefano P et al 2001 *Astropart. Phys.* 14 329–37 (*Preprint* astro-ph/0004308)
[9] Benoît A et al 2001 *Phys. Lett. B* 513 15–22 (*Preprint* astro-ph/0106094)
[10] Benoît A et al 2002 *Phys. Lett. B* 545 43–9 (*Preprint* astro-ph/0206271)
[11] Navick X-F et al 2005 *Nucl. Instrum. Methods A* To appear in the proceedings of LTD11, Tokyo, 2005
[12] Benoît A et al 2005 *Phys. Lett. B* 616 25–30 (*Preprint* astro-ph/0412061)
[13] Fiorucci S 2005 PhD thesis Université Paris XI Orsay http://www.simonfiorucci.com/these-complete.20051013.zip.
[14] Lemrani R et al these proceedings.
[15] Abrams D et al 2002 *Phys. Rev. D* 66 122003 (*Preprint* astro-ph/0203500)
[16] Akerib D S et al 2005 *Phys. Rev. D* 72 052009 (*Preprint* astro-ph/0507190)
[17] Cushman P et al. these proceedings.
[18] Rau W et al. these proceedings.
[19] Martineau O et al 2004 *Nucl. Instrum. Methods A* 530 426–39
[20] Luke P N et al 1994 *IEEE Trans. Nucl. Sci.* 41 1074
[21] Shutt T et al 2000 *Nucl. Instrum. Methods A* 444 340–4
[22] Juillard A et al 2005 *Nucl. Instrum. Methods A* To appear in the proceedings of LTD11, Tokyo, 2005
[23] Broniatowski A et al 2005 *Nucl. Instrum. Methods A* To appear in the proceedings of LTD11, Tokyo, 2005
[24] Kraus H et al these proceedings