EPJ Plus

EPJ.org
your physics journal

Eur. Phys. J. Plus (2012) **127**: 104 DOI 10.1140/epjp/i2012-12104-1

The ANDES underground laboratory

X. Bertou

Società Italiana di Fisica
Springer

Eur. Phys. J. Plus (2012) **127**: 104
DOI 10.1140/epjp/i2012-12104-1

THE EUROPEAN
PHYSICAL JOURNAL PLUS

Regular Article

The ANDES underground laboratory

X. Bertou[a]

CNEA/CONICET, Centro Atómico Bariloche, Av Bustillo km 9.5, San Carlos de Bariloche, Argentina

Received: 23 July 2012
Published online: 20 September 2012 –

Abstract. The ANDES underground laboratory, planned for inclusion in the Agua Negra tunnel crossing the Andes between Argentina and Chile, will be the first deep underground laboratory in the southern hemisphere. It will be deep (1750 m of rock overburden), large (60 000 m^3 of volume), and provide the international community with a unique site for testing dark-matter modulation signals. The site furthermore has a low nuclear reactor neutrino background and is of special interest to the geophysics sciences. The laboratory will be run as a multi-national facility, under a consortium of Latin-American countries. Its opening is expected for 2020.

1 Introduction

Deep underground laboratories have provided a unique view on weak interacting particles in the past half-century. Today, a dozen of such laboratories are open and run tens of experiments focused mainly on neutrino physics and dark-matter search. All of them are located in the Northern Hemisphere.

While at first it may not appear important where such laboratories are located, as they focus on particles able to cross the Earth mostly without interacting, numerous effects make having a laboratory in the Southern Hemisphere of importance for the community. A first important study is the modulation signal expected in the search for dark matter, coming from the movement of the Earth in the dark-matter halo of the galaxy. Many possible background modulations are related to atmospheric effects, and observing a same phase for the modulation in both hemispheres would be a unique guarantee that the modulation is not of atmospheric origin. Then, for neutrino physics, the amount of matter crossed by neutrinos before interacting is of great importance due to the MSW effect, and a southern site should bring complementary measurements depending on the location of a source (for example, in the case of supernovae neutrinos).

Historically, there has been some deep physics experiments done in the past in the Southern Hemisphere, mainly one of the two experiments responsible for the discovery of atmospheric neutrinos in a gold mine in South Africa [1] (the other experiment being in India [2]), and a dark-matter search experiment in an iron mine in Argentina [3]. There were some efforts to search for mines to build a permanent deep underground laboratory in Brazil and Chile, but they did not conclude.

The plans to build a new road tunnel in the Andes, between Argentina and Chile, were seen in 2010 as a unique opportunity to build a deep underground laboratory in the Southern Hemisphere, following what was done in Italy and France for the LNGS and LSM.

2 The Agua Negra tunnel and the ANDES laboratory

The Agua Negra tunnel, between the San Juan province in Argentina and the Coquimbo region in Chile, is a 14 km long road tunnel, planned to increase the integration in the MERCOSUR commercial area. It is of strategic importance to the region as it allows raw goods produced in Argentina and Brazil to reach the Asian market via the harbour network of Chile. It had been proposed for years, but in 2005 pre-feasibility studies were started, and in 2008 a geological campaign started together with the detailed engineering of the tunnel.

Politically, the tunnel was pushed forward in numerous integration meetings of the region. In particular, it was part of the integration treaty of Maipu (2009), a central part in the MERCOSUR meeting of San Juan (2010), and

[a] e-mail: bertou@cab.cnea.gov.ar

Fig. 1. Conceptual view of the ANDES deep underground laboratory, located at km 4 of the Agua Negra tunnel.

in March 2012 the Presidents of Argentina and Chile urged for its public tender. It is expected that its construction will start in 2013, and end 7 years later.

The tunnel itself is a double road tunnel. Both tunnels will be 12 m in diameter, and will be separated by more than 60 m. They will be connected every 500 m by emergency access tunnels. The deepest point is located at about 4 km from the Chilean entrance. Given the topology, it is more convenient to locate the laboratory to the south of the East-West tunnels, as the mountain is higher. The entrance to the laboratory will therefore be in the tunnel going from Chile to Argentina. It is worth noting that the tunnel itself is at quite a high altitude, as the Chilean entry is at 3600 m, and the Argentine at 4100 m above sea level.

ANDES (which can stand for Agua Negra Deep Experiment Site) is proposed as a large laboratory, in order to host third-generation dark-matter experiments and large neutrino detection volumes, as it will be the only laboratory in the Southern Hemisphere [4]. The main hall is planned to be 21 m wide, 23 m high and 50 m long, and will host large experiments as will a big pit of 30 m of diameter and 30 m of height. A secondary cavern of 16 m by 14 m by 40 m will host smaller experiments and services, while three smaller caverns (9 m by 6 m by 15 m) will have dedicated experiments and a 9 m diameter by 9 m height pit will focus on low-radiation measurements. A conceptual layout of the laboratory can be seen in fig. 1.

Given the relative high altitude of the laboratory, and its location on the boundary between two Countries, it is planned to have two external support laboratories, one in Argentina and one in Chile. The candidate sites for these laboratories are Rodeo in San Juan and Vicuña in Chile.

3 Specific science case for ANDES

The generic science case for ANDES is similar to the one of the other deep underground laboratories discussed in this *Focus Point*, and will therefore not be developed. There are however some aspects specific to ANDES, given its unique location in the Southern Hemisphere, the absence of close-by nuclear plant, and its location in the Andes mountain range.

The first and maybe most relevant specific aspect of ANDES is its location. As mentioned in the introduction, ANDES will be the only deep underground laboratory in the Southern Hemisphere, making it extremely relevant to the dark-matter modulation signal search. The oldest experiment observing a signal modulation, DAMA/LIBRA, has seen a clear modulation for years (currently at more than 9 sigma [5]). CoGeNT has recently also claimed the observation of a modulation [6]. While the modulation signals can be highly significative, there is no general agreement in the community that this modulation is the one expected from the movement of the Earth in the dark-matter halo of our galaxy, and not an artificial one produced by some atmospheric effects, given that other experiments do not observe the modulations and claim to exclude them (see, for example, Xenon 100 [7]).

It is therefore planned to have at least one experiment in ANDES as similar as possible to one of a Northern Hemisphere laboratory that does observe the modulation. Should the twin experiment observe an annual modulation shifted by 6 months of time, it would indicate the modulation is indeed of atmospheric origin. The observation of the same modulation would be a strong hint at a genuine dark-matter signal.

With respect to neutrino science, a first contribution could be made in the observation of supernovae neutrinos, where a distributed network of detectors over the surface of the Earth is necessary to be able to ensure different

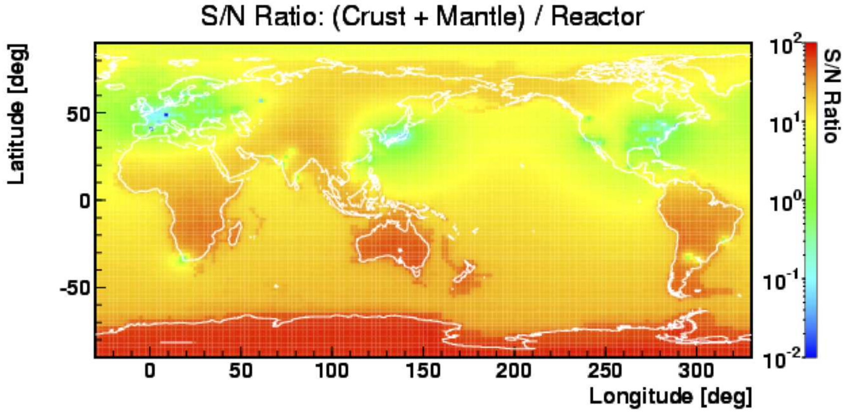

Fig. 2. Ratio of expected geo-neutrino signal to reactor background over the Earth, taken from [10]. The nuclear power plants of Argentina and Brazil are the only sources of background in South America, and their influence does not reach the site of ANDES.

paths of the neutrinos in the Earth in order to properly measure the MSW effect. Another specific contribution of ANDES could be made in the field of geo-neutrinos, neutrinos produced by radioactive decays of uranium, thorium and potassium in the Earth. These are expected to be responsible for a significant fraction of the Earth thermal balance, and the uranium and thorium ones have been recently observed for the first time by KamLAND [8] and Borexino [9] (the neutrinos produced by potassium decays have a maximum energy below the inverse beta reaction threshold, and new techniques should be thought to make their detection possible). In both cases, the experimental challenge is that the geo-neutrinos have to be detected over the strong background of nuclear plant neutrinos present at the sites of Kamiokande and LNGS. ANDES is located in a quiet area, and the signal-to-noise ratio expected for geo-neutrino observation in ANDES is very high, as can be seen in fig. 2.

Finally, the geology of the region of ANDES is of great interest. The Agua Negra tunnel is located in an area where there is a gap in the volcanic activity, and while in Argentina, close to the Andes mountain range, most seismic activities occur deep under the ground, in the Mendoza - San Juan region there are earthquakes occurring close to the surface. This is due to the peculiar way the Nazca plate goes below the South American plate in the area, called a Flat-Slab subduction [11]. In order to study this peculiarity and the more general geological activity of the area, ANDES will host a geophysics laboratory of great interest to the geoscience community.

4 Radiation background expected at ANDES

The background radiation at an underground laboratory is obviously one of the most critical point to take into account. Given the unusual altitude of the site, special attention was given to the particle fluxes calculations.

4.1 Muon flux

The muon flux is not as dependent on altitude as other particle fluxes, due to the high penetrating power of the muons and their high altitude production points. At 4 to 6 km, the fluxes, angular and energy distribution start to differ from the ones at ground, but not significantly, and some pions start to reach ground. A comparison of the energy spectra of secondaries at ground between 4 km and sea level can be seen in fig. 3, as determined by simulations using CORSIKA [12].

The presence of more hadrons or pions at high altitude is not an issue for the underground laboratory, as they will strongly interact in the rock. From the atmospheric flux point of view, there is therefore little difference between a laboratory located at 4000 m and one at sea level.

The rock overburden was determined by comparing a preliminary layout of the tunnel [13] and an elevation map from the Shuttle Radar Topography Mission [14]. The vertical and minimum omnidirectional depth was determined as a function of the possible location of the laboratory along the tunnel, considering first the laboratory to be located 100 m south of the tunnel axis, and then choosing the deepest point location and allowing the laboratory to be located further away in the North-South direction. The depths obtained can be seen in fig. 4, with a maximum of 1775 m of vertical depth and 1675 m omnidirectional at 100 m south of the tunnel axis. More detailed geological studies are required to compute the water equivalent depth of the laboratory, but it is expected to be similar to LSM or DUSEL.

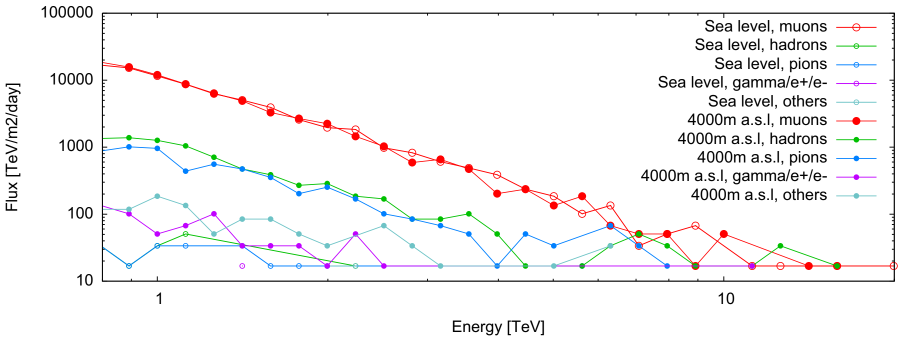

Fig. 3. Energy spectra of secondary particles at ground, comparing 4 km of altitude to sea level. The muon fluxes are very similar. A few pions not having decayed yet into muons and some hadrons reach ground at 4 km of altitude.

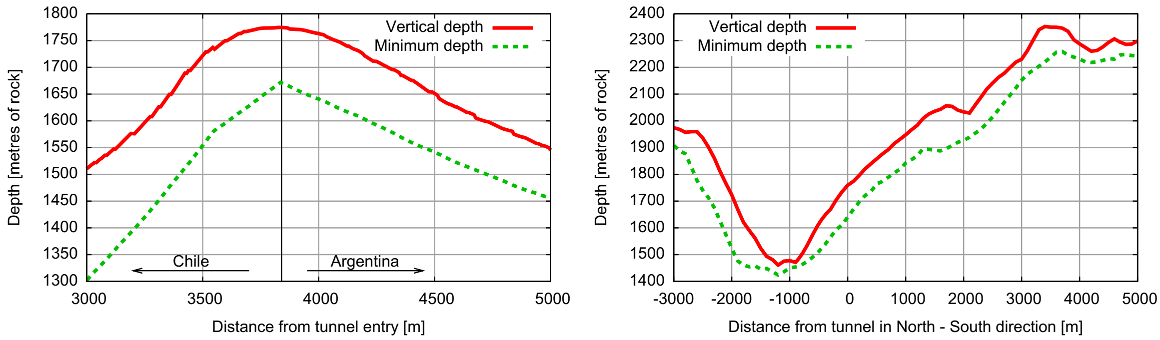

Fig. 4. Vertical and omnidirectional minimum depth obtained depending on the location of the laboratory with respect to the tunnel.

Table 1. Radioactivity measurements of rock samples from the Agua Negra tunnel. All vales are in Bq/kg. Values for Canfranc are from [15].

	Basalt	Andesite	Rhyolite 1	Rhyolite 2	Canfranc
^{238}U	2.6 ± 0.5	9.2 ± 0.9	14.7 ± 2.0	11.5 ± 1.3	4.5–30
^{232}Th	0.94 ± 0.09	5.2 ± 0.5	4.5 ± 0.4	4.8 ± 0.5	8.5–76
^{40}K	50 ± 3	47 ± 3	57 ± 3	52 ± 3	37–880

4.2 Rock radioactivity

While the precise geology at the future location of the laboratory is not known and will not be determined until the first ventilation tunnel is built, preliminary measurements can be done using rocks extracted during the survey. Perforations of up to 650 m deep were done, and the main rocks found were andesite, basalt and rhyolite. Of special interest is the Rhyolite as it may contain higher level of radioactive material, depending on how it was formed.

Four samples were analysed in the Neutron Activation laboratory at the Bariloche Atomic Centre, measuring the radiation from uranium, thorium, and potassium. All the samples were from deep extraction, between 450 and 650 m. The results can be seen in table 1, compared with the measurements from Canfranc [15]. The rhyolite is of a type of low contents of radioactive material and the natural radioactivity expected for the final location of the laboratory should be low.

4.3 Neutron activation

While the high altitude of the laboratory was not an issue for the muon flux, it is more relevant for the neutron atmospheric flux and will therefore have an impact on the purity of the detector material due to neutron activation. It is very important for the highly sensitive experiments that are run in deep underground laboratories to be made of ultra low radioactive material, such as copper, archaeological lead, and similar. However, under the action of cosmic rays, these materials can convert to others with long-lifetime isotopes. For example, while copper has no long-lifetime isotope, it can be activated by neutrons into zinc, ^{65}Zn, with an half life of 243.8 days. The activation rate is mainly proportional to the neutron flux, which depends on the incoming primary cosmic-ray flux (modulated on Earth by the geomagnetic field), and on the site altitude (due to cascading and absorption effects in the atmosphere).

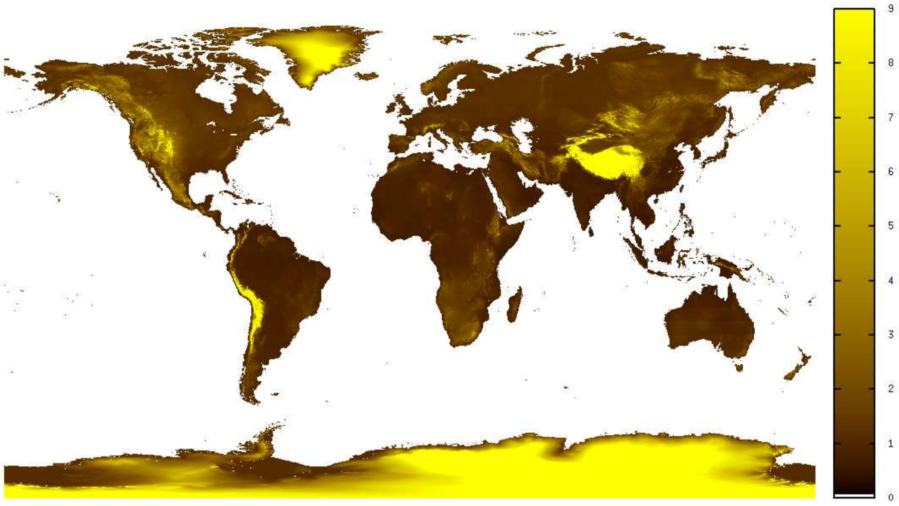

Fig. 5. Neutron flux at ground level with respect to the one at sea level on the Equator. The main effect is due to the altitude, with a secondary effect due to the geomagnetic latitude of the site.

A simple model for this neutron flux can be derived by the multiplication of two factors, one determined by the geomagnetic cutoff of the site, and one by its altitude [16]. The geomagnetic cutoff values around the globe were computed using the Magnetocosmics [17] code, and together with the world map of elevation of ETOPO2 [18], a map of neutron flux with respect of the flux at sea level on the equator was derived. This map is shown in fig. 5.

It is worth noting that while the entry of the Agua Negra tunnel is at 3600 m above sea level, the sites chosen for the external support laboratories are at a much lower altitude (1600 m a.s.l. for Rodeo, 600 m a.s.l. for Vicuña). This, combined with a strong geomagnetic field (the geomagnetic equator is displaced towards the south in the Americas), results in relatively low neutron flux, similar to those at other sites. The relative flux for Rodeo and Vicuña are of 2.2 and 1.1, while for Modane and SNO, for example, they are of 2.3 and 1.4 (always with respect to the sea level average on the Equator).

5 The Latin-American Consortium for Underground Experiments (CLES)

Given its location between Argentina and Chile, and the strong interest of the Latin-American high-energy community in having a deep underground laboratory, ANDES is being planned from the beginning as an international laboratory and not as a national laboratory hosting international experiments. As such, the ANDES laboratory is expected to be run by the Latin-American Consortium for Underground Experiments (CLES for its initials in Spanish or Portuguese), currently formed by Argentina, Brazil, Chile and Mexico. The CLES will not only be in charge of the installation and operation of the ANDES laboratory and its dependencies, but will also have the task of organising the academic integration of the scientific activities in the region. The CLES is therefore planned as a scientific pole for the region, focusing on underground science.

6 Conclusions and prospects

The construction of the Agua Negra tunnel is a unique opportunity for the construction of ANDES, the first deep underground laboratory in the Southern Hemisphere. While of specific interest for the Latin-American high-energy community, it is planned as an open international laboratory, hosting experiments from the region and abroad. Its location will make it an ideal laboratory to study dark-matter modulation signals, supernovae and geo-neutrinos. Its large size and important depth will make it attractive to any future underground experiment. Finally, geophysics is expected to be an important part of the scientific program of the laboratory.

The author would like to acknowledge the opportunity of presenting the prospects of ANDES together with the review of already well-established laboratories. This work has been possible thanks to O. Civitarese, C. Dib, R. Shellard and J.C. d'Olivo, supporting the ANDES initiative, the cosmic-ray simulation and propagation data of H. Asorey and F. Sánchez, the radioactivity measurements of M. Arribere and M. Gomez Berisso, the geomagnetic data of J. Masías, the 3D layouts of J. Venturino, and Geoconsult Buenos Aires SA which provided the tunnel layout and the rock samples. This work has been supported by CNEA and CONICET, the Argentine ministry for science and technology (MinCyT), and the San Juan province government.

References

1. F. Reines *et al.*, Phys. Rev. Lett. **15**, 429 (1965).
2. C.V. Achar *et al.*, Phys. Lett. **18**, 196 (1965).
3. D. Abriola *et al.*, Astropart. Phys. **10**, 133 (1999).
4. X. Bertou, An. Acad. Nac. Cienc. Exactas, Fis. Nat. **63**, 67 (2011).
5. R. Bernabei *et al.*, Eur. Phys. J. C **67**, 39 (2010).
6. C.E. Aalseth *et al.*, Phys. Rev. Lett. **107**, 141301 (2011).
7. E. Aprile *et al.*, Phys. Rev. D **84**, 052003 (2011).
8. S. Abe *et al.*, Phys. Rev. Lett. **100**, 221803 (2008).
9. G. Bellini *et al.*, Phys. Lett. B **687**, 299 (2010).
10. S. Enomoto for the KamLAND Collaboration, talk at the XIII International Workshop on Neutrino Telescopes, Venice, March 10-13, 2009.
11. M. Gutscher, J. South Am. Earth Sci. **15**, 3 (2002).
12. D. Heck *et al.*, Forschungszentrum Karlsruhe Report FZKA 6019 (1998).
13. IB-TAN-A-T00-TU-P001, BUREAU de Projetos e Consultoria LTDA.
14. T.G. Farr *et al.*, Rev. Geophys. **45**, 183 (2007).
15. J. Amaré *et al.*, J. Phys. Conf. Ser. **39**, 151 (2006).
16. M.S. Gordon *et al.*, IEEE Trans. Nucl. Sci. **51**, 3427 (2004).
17. L. Desorgher *et al.*, `http://cosray.unibe.ch/ laurent/magnetocosmics/`.
18. National Geophysical Data Center, National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, `http://www.ngdc.noaa.gov/mgg/global/etopo2.html`.