The ANDES Deep Underground Laboratory

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Abstract: ANDES (Agua Negra Deep Experiment Site) is a unique opportunity to build a deep underground laboratory in the southern hemisphere. It will be built in the Agua Negra tunnel planned between Argentina and Chile, and operated by the CLES, a Latin American consortium. With 1750m of rock overburden, and no close-by nuclear power plant, it will provide an extremely radiation quiet environment for neutrino and dark matter experiments. In particular, its location in the southern hemisphere should play a major role in understanding dark matter modulation signals.

Keywords: underground laboratory, dark matter search, neutrino physics

1 Introduction

Deep underground laboratories are one of the main actors of astroparticles physics nowadays. In the past half-century they provided unique ways of studying weak interactive particles. Super-Kamiokande can be taken as a perfect example of the importance of deep underground experiments and their impact both in astrophysics and particle physics, hence of their role in astroparticle physics. Today, a dozen deep underground laboratories are running or under construction, offering experimental area at up to 2300 m below ground to run neutrino physics studies, dark matter search, or low radioactivity background measurements. All of them are located in the northern hemisphere, with the southernmost one being the planned INO, close to 10°N.

In the past, some temporary laboratories have been set up in the southern hemisphere, but none of them has been maintained. One of them, in a gold mine in South Africa, contributed to the discovery of atmospheric neutrinos in 1965 [1] (together with [2]). Another experiment was looking for Dark Matter oscillation signal in an iron mine in Argentina in 1995 [3]. Searches for a suitable mine in Brazil and Chile have been performed in the past, but without success.

There is currently a growing demand for a southern hemisphere laboratory, as more signals of Dark Matter appear. For years, DAMA/LIBRA has claimed the observation of a yearly modulation of their signals and attributed it to Dark Matter [4]. In the standard Cold Dark Matter models, the ones most favoured by our current understanding of cosmological measurements, our galaxy should have a halo of Weakly Interactive Massive Particles (WIMP) in which we would be moving as the Sun moves through the galaxy (at ≈232 km/s). The movement of the Earth around the Sun at 30 km/s will make a modulation of the resulting WIMP wind. The maximum signal is expected in June, when the Earth is moving towards Cygnus, while the minimum is expected in December. DAMA/LIBRA observes such a modulation at an 8.9 σ significance. However, it is not clear if this effect is indeed a genuine Dark Matter effect or if it could be some atmospheric or weather related effects. Different interpretations are available in the literature [5]. Recently, more signals were reported by CoGeNT [6] and CDMS II [7], and to get a clear confirmation of the modulation first observed by DAMA, one would need an experiment in the southern hemisphere observing the same modulation. The observation of an opposed modulation would support the signal as coming from an atmospheric effect. As no southern hemisphere laboratory is available, an experiment to the south pole, DM-ICE [8], is being conducted, in a very hard to work environment.

The news that a new road tunnel would be built in the Andes to link Argentina and Chile was seen in 2010 as a unique opportunity to build a deep underground laboratory in the southern hemisphere, in a similar way the LNGS and LSM were built in Italy and France.

2 The Agua Negra tunnel and the ANDES deep underground laboratory

The Andes represent a natural barrier between Argentina and Chile in the southernmost part of America. It has become of strategic importance for Argentina and Brazil to be able to access the Asian market. The main tunnel currently used to cross the Andes in Argentina is the Cristo Redentor tunnel between Mendoza and Santiago de Chile. It can however close during winter because of strong snows, and is not fully adapted to the increasing commercial exchanges.

For years, various options have been proposed to complement the Cristo Redentor tunnel. With the increasing political stability in South America and the development of MERCOSUR and UNASUR, these projects were brought back to improve the regional integration. The main project to improve the connectivity between Argentina and Chile is the Agua Negra tunnel, between San Juan and Coquimbo.

A pre-feasibility study for the Agua Negra tunnel was finished in 2005, and in 2008 a geological study campaign was started. In 2012, the final project was proposed. In the meanwhile, the project was pushed forward politically in numerous integration meetings in the region, such as the treaty of Maipu (2009), the San Juan MERCOSUR meeting (2010), and in March 2012 the presidents of Argentina and Chile gave the green light for the public tender. The public tender process started in January 2013, and the international call for companies to compete in the tender was issued in May 2013. The tender process is expected to last for the whole 2013, given the difficulties of the bi-national civil

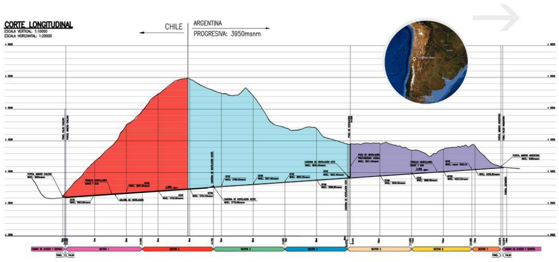

Figure 1: Longitudinal cut of the Agua Negra tunnel and its location.

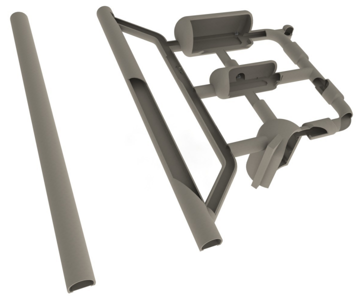

Figure 2: Conceptual view of the ANDES deep underground laboratory, located at km 4 of the Agua Negra tunnel.

work. The construction of the tunnel should start in 2014, and last for 7 years.

The tunnel design consists in a double 14 km long road tunnel, each 12 m of diameter, separated by 60 m. The entry points are at high altitude, 4100 m above sea level on the Argentine side, 3600 m on the Chilean side. Given the slope, most of the ventilation for the tunnel is natural, with a forced ventilation system used in case of emergencies. The deepest point of the tunnel is located below the international limit between both countries, at about 4 km from the Chilean entry. With 1750 m of rock overburden, this spot is ideal to host a deep underground laboratory, the ANDES deep underground laboratory. ANDES can be read as an acronym for Agua Negra Deep Experiment Site. It would be at a depth equivalent to Modane, shallower only to Jin-Ping and SNOLab.

Given the relatively high altitude of the laboratory and its international location, two support laboratories are planned for ANDES. There are no close-by towns to the tunnel. The Argentine laboratory is expected to be in Rodeo, a small town at 60 km from the tunnel entrance. It will be the closest support laboratory and be mostly used for day to day activities and the running of the experiments in ANDES. The Chilean laboratory will be located in La Serena, at 180 km of ANDES but in an internationally connected city, with strong scientific presence (such as the ESO for example). It will be mostly used for the preparation of the installation of the experiments and their testing.

The ANDES underground laboratory itself is foreseen to have a main hall of 21 m width, 23 m high and 50 m long, to host large experiments and a big pit of 30 m of diameter and 30 m of height for a single large neutrino experiment. 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. 2.

3 ANDES scientific programme

The scientific programme of ANDES is similar to the one of any deep underground laboratories, with some specificity due to its location. The main topics in astroparticle physics are neutrino and dark matter. There will be in addition a low radiation measurement laboratory, a geophysics laboratory, space for biology experiments, and possibly a particle accelerator to do nuclear astrophysics.

In neutrino physics different experiments will be run. On one hand, ANDES could host part of a large double beta decay experiment such as SuperNEMO [9]. On the other hand, the flag experiment of ANDES will be a large neutrino detector similar to KamLAND [10] and Borexino [11], but at a 3 kton scale [12], focusing on low energy neutrinos. This detector would allow complementary observation of neutrinos from a nearby supernova, something essential to properly study the effect of matter on neutrino oscillations. It will furthermore be an excellent geo-neutrino observatory. Geo-neutrinos are produced in the Earth by radioactive decays of Uranium, Thorium and Potassium. These decays are expected to be responsible for a significant fraction of the Earth thermal balance, and have been observed recently through their neutrino emission. When detecting geo-neutrino, one has to face, in addition to the usual background of any neutrino experiment, an extra background from nuclear reactors. Current large neutrino detectors are in areas with numerous nuclear reactors, and they have to deal with a large anti electron neutrino background. ANDES is located in a nuclear quiet region, far from the few reactors in Argentina and Brazil. The signal to noise ratio is expected to be high, as can be seen on Fig. 3.

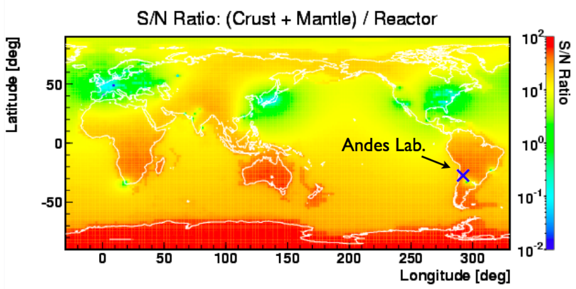

Figure 3: Ratio of expected geo-neutrino signal to reactor background over the Earth, taken from [13]. The nuclear power plants of Argentina and Brazil are the only sources of background in South America, and their influence does not reach the site of ANDES.

As mentioned in the introduction, a critical reason to build ANDES is to have southern hemisphere observation of dark matter modulation. While the current signals reported by different experiments are controversial, being incompatible with the results of Xenon 100 [14], it is likely that in the next 8 years while ANDES is built a genuine signal is observed in a northern hemisphere deep underground laboratory. At that stage, it will be logical to build a similar experiment in ANDES. In addition, the important depth of ANDES will make it competitive for any detection technique and it will likely host a third generation dark matter search experiment.

An important part of the science programme will be dedicated to geophysics. While it is not the main interest of the audience of this conference, the detection of geo-neutrinos for example is a common target for astroparticle physicists and geophysicists. It should be mentioned that the Agua Negra tunnel is located in an area where there is no volcanic activity, and earthquakes close to the surface, due to the peculiar way the Nazca plate goes below the South American plate (a Flat-Slab subduction [15]). This specific location makes the laboratory very attractive to the geophysicist community.

4 Radiation background expected at the ANDES deep underground laboratory

The radiation background was studied for the ANDES site, taken into account the unusual high altitude and its possible impact on muon fluxes and neutron activation.

4.1 Muon flux

The high energy muon flux (the one relevant for deep underground laboratories, of $\approx$ TeV energy scale) are not very dependant on the altitude, given their high penetrating power. Low energy muons fluxes and angular distribution start to change above 4 km of altitude, and some pions can be observed. All this has no relevance after a few hundreds of metres of rock. The high geomagnetic cutoff of the ANDES site does not either have any impact on the high energy muon flux. These assumptions were verified with a set of complete cosmic ray spectrum simulation based on CORSIKA [16].

To determine the rock overburden as a function of the precise location of the laboratory along the Agua Negra tunnel, a preliminary layout of the tunnel was used [17] and the local geography was derived from the Shuttle Radar Topography Mission [18]. The vertical and minimum omnidirectional depth were determined first considering the laboratory to be 100 m south of the tunnel axis, and then moving the laboratory on the north-south axis around the deepest location. The computed depths can be seen in Fig. 4, reaching 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 given the expected average density of 2.65 g/cm^2, it is expected to be similar to Modane.

4.2 Rock radioactivity

The precise geology at the deepest point of the tunnel is not currently known and will not be determined with precision until the first ventilation tunnel is dug. However, perforation of up to 650 m deep were performed in the exploratory phase and the deepest rock samples are expected to be representative of what will be found 1000 m deeper. The main rocks present are Andesite, Basalt and Rhyolite (volcanic rocks). Rhyolite is the most potential radioactive rock. Its content in potassium in particular strongly depends on how it was formed.

4 samples were obtained from Geoconsult and analysed in the Neutron Activation laboratory at the Bariloche

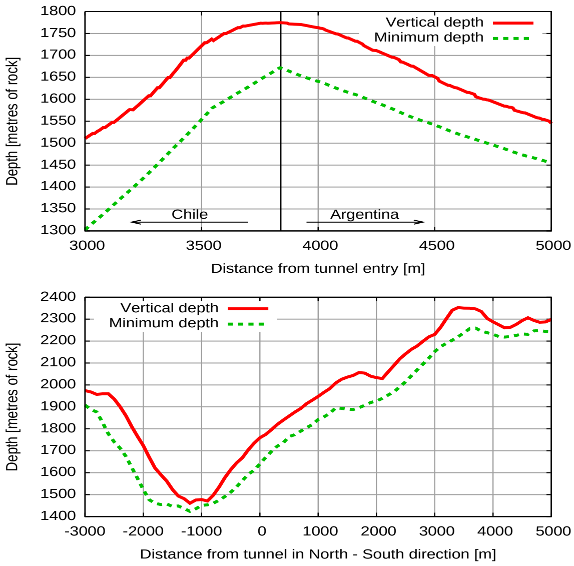

Figure 4: Vertical and omnidirectional minimum depth obtained depending on the location of the laboratory with respect of the tunnel. See text for details.

Atomic Centre, measuring the radiation lines from Uranium, Thorium, and Potassium. All the samples were from deep extraction, between 450 m and 650 m deep. The results can be seen in table 1, compared with measurements from Canfranc [19]. Two samples of rhyolite where analysed and both were found to have low content of potassium. Given these results, the natural radioactivity expected for the final location of the laboratory should be low.

4.3 Neutron activation

While it was shown that the high altitude of the laboratory was not an issue for the muon flux, it is more relevant for the neutron atmospheric flux responsible for neutron activation, lowering the purity of detector material (not in the laboratory itself but in the support laboratories). In rare event experiments, radio-pure materials have to be chosen, such as copper or archaeological lead. However, while copper has no long lifetime isotope, it can be activated by neutrons into zinc, for example ^{65}Zn, with an half life of 243.8 days. The activation rate is given by the neutron flux, which is modulated by the altitude and the geomagnetic latitude.

A simple model for the neutron flux can be obtained by multiplying two factors, one given by the geomagnetic cutoff of the site, and one given by the altitude [20]. The geomagnetic cutoff average values were computed on the globe using Magnetocosmics [21], and the elevation map was taken from ETOPO2 [22]. The resulting neutron flux map can be shown on Fig. 5.

The neutron flux was determined at the two planned locations for the support laboratories, Rodeo (1600 m a.s.l.) and La Serena (sea level). Given the proximity of the geomagnetic equator (which is displaced to the south with respect of the geographic equator in the Americas), the final neutron flux is lower than at other sites. The fluxes at Rodeo and La Serena are found to be 2.2 and 0.9 (referred to the average at sea level on the equator), while for example the fluxes at Modane and SNOLab are 2.3 and 1.4.

	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	$37-880$

Table 1: Radioactivity measurements of deep rock samples from the Agua Negra tunnel. All values are in Bq/kg. Values for Canfranc are from [19].

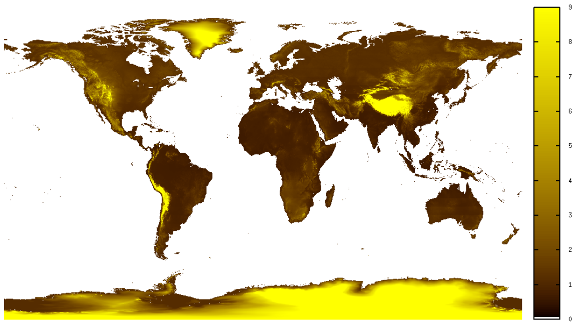

Figure 5: Neutron flux at ground level relative to the average one at sea level on the equator. The primary effect is due to the altitude, and a secondary effect due to the geomagnetic latitude is visible.

5 The Latin American Consortium for Underground Experiments (CLES)

ANDES was considered from the beginning as a unique opportunity not only to build an underground laboratory for the international community but to build directly an international laboratory. Given its location on the borderline between two countries, and the current geopolitical unity displayed by Latin American countries, ANDES was proposed to be run by a consortium of Latin American countries, the CLES (initials of Latin American Consortium for Underground Experiments in Spanish or Portuguese). The CLES is currently formed by Argentina, Brazil, Chile and Mexico, and is foreseen to open to more countries.

The CLES will be the organ in charge of the installation and operation of the ANDES deep underground laboratory and its support laboratories. It will also organise the academic integration of the scientific activities in the laboratory with the regional systems. The CLES should be a pole for underground science in the region.

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. With the international tender process started in January 2013, the construction is expected to start in 2014, and the ANDES laboratory could open in 2021.

ANDES is foreseen as an open international laboratory, coordinated by a Latin American consortium (CLES). It will be hosting both international experiments and regional ones. Its location will make it an ideal laboratory to study dark matter modulation, supernovae neutrinos and geoneutrinos. Its large size and important depth will make it competitive with all existing laboratories. In addition to a rich astroparticle scientific programme, geophysics is expected to be a strong part of the laboratory activity.

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