Notes from the Workshop between IceCube and ANTARES on dark matter.

The programm and slides of some presentations can be found under: http://indico.in2p3.fr/conferenceDisplay.py?ovw=True&confId=5983

Monte Carlos:

- Atmospheric muon background:

IceCube uses CORSIKA to generate showers in the atmosphere and the resulting muon flux at the surface. They include coincident and triple-coincident muons in the simulation. To run CORSIKA is a CPU-time consuming process and we typically only reach about ~10 days of simulated lifetime. This might be (hardly) enough to cross check the behaviour of analysis variables in analyses that use scrambled data as background, but it can be simply insufficient on analyses that are based on MC to determine their background (dark matter Earth searches for example, where there is no on-source/off-source possibility).

ANTARES uses CORSIKA and also MUPAGE, a muon generator base on CORSIKA parametrizations of the muon distributions at the surface. It is much faster than the simulation of the whole shower for each event, since it just samples from the pre-defined distributions. No coincident muons are simulated (not needed). They simulate 1/10 of the lifetime for each data run. A 'run' in ANTARES is approximately 2.5 hrs of data taking, defined by the time it takes to fill 2 GB of data.

- Atmospheric meutrinos:

IceCube uses Neutrino generator and we generate samples with different indexes.

ANTARES uses Neutrino generator based on Bartol flux only. A large statistic is simulated for each data run. To simulate other spectra (Dark Matter, cosmic E^-2 sources), a reweighting of the neutrino sample is applied.

- WIMP signal:

IceCube uses WimpSim.

ANTARES reweights the atmospheric neutrino sample to the WIMP spectra (previously obtained with WimpSm). In this sense they do not use the output files of WimpSim and propagate the muons there.

This is similar to what IceCube did for the galactic analyses. There the expected neutrino spectrum was obtained from DarkSusy, but what was actually used to gain statistics was the already existing atmospheric neutrino production, reweighted to the DarkSusy spectrum.

Miscelanea:

There was an interesting debate on what is our detectors' energy threshold, and how we could define it, and possibly use the same threshold when quoting results. Given the characteristics of our detectors, there is no a sharp, well-defined threshold, and it can be dependent on the analysis. There were several proposals, but my recollection is that we did not really converged on this. What we did agree on is that we should give the effective area as a function of neutrino energy in our talks and/or publications, so they are available to each other (and to the community at large). The analysis energy threshold can then be estimated from the effective area curve.

Still, how to uniquely define the threshold scaped us. Proposals were ranged from quoting the point which contains 95% of the events when a flux is convoluted with the effective area (this is flux-dependent), to quoting the point where the effective area falls to a given fraction of its plateau (this is kind of arbitrary).

For dark matter, IceCube has been using the known annihilation spectrum to integrate back the results to a muon threshold of 1 GeV (we use Edsjo's conversion scripts, http://copsosx03.physto.se/cgi-bin/edsjo/wimpsim/flxconv.cgi)
This is of course well below the muon detection threshold, but it serves as a reference and allows to compare with low-energy detectors. These kind of reference thresholds can be agreed upon and be easily calculated.

The issue of comparing our limit curves was discussed next. Right now is practically impossible. ANTARES shows neutrino flux limits, while IceCube shows muon flux limits. It is easy to go from one to another (WmpSim provides both) so IceCube decided to provide neutrino flux limits as well in the future. We do quote neutrino limits on point source analyses, so this will be consistent in that respect too.

Systematics:

Of course each detector's systematics are different, but how to include them in the limits can be a common procedure. IceCube used to use the POLE method of Conrad et al (Phys.Rev. D67 (2003) 012002), which includes the systematics in the calculation of mu_90. This method, updated, is implemented in ROOT as the TRolke package. IceCube has gone away from the simple cut-and-count analysis methods and now uses a distribution shape analysis, comparing the normalized angular distributions of signal and background (described in detail here, http://w3.iihe.ac.be/publications/hubert.pdf (chapter 7, page 119).

To use a POLE-based approach here would be quite complicated and time consuming, so IceCube estimates the effect of systematics in the effective volume by running the MC with different parameters (OM sensitivity, ice model,... etc) and then use V_eff - 1 sigma in the calculation of limits as a conservative choice.

ANTARES uses the POLE method. Sotiris Loucatos summarized it in a few slides available from the Indico website (click on the session in the programme page and a pop-up window shows the contributions). The systematics considered are the one on the determination of the effective area and the one on the angular resolution for the signal since a binned method is used for the analysis. The found result is a degradation of the limit of 3%-6% for a total systematic error of about 20%. The effect is even smaller for the discovery potential.

<u>Galactic Halo issues:</u>

We had two informative presentations by phenomenologists, one by Julien Lavalle, from Montpellier, and the other from Emmanuel Nezri, from LAM-Marseille. The slides are available on the workshop Indico website.

The current favoured value for the local dark matter density is rho=0.4 GeV/cm3 which is obtained by different approaches (see references in Julien's slides). However there is still a big uncertainty in this quantity, with values from 0.1 GeV/cm3 to 0.6 GeV/cm3 being mentioned by different authors.

Concerning the velocity of the dark matter component, 270 km/s is an agreed value, but this is the average, and the shape of the distribution assumed is also of key importance. Usually a Maxwellian distribution is assumed, but that might not be what reality has chosen. If the tails of the distribution, both at low and high velocities, are changed, it can have consequences for the capture by the Sun/Earth.

Values of rho=0.4 GeV/cm3 and a Maxwellian velocity distribution with a mean of 270 km/s can be taken as a benchmark in our simulations. But one should keep in mind that this is a choice, and that these parameters have uncertainties on them. The used values are thus to be quoted clearly in our publications and presentations.

Concerning the shape of the dark matter halo, the jury is still out. There are several models out there based on N-body simulations which do not necessarily give consistent results at the center of the galaxy. The addition of baryons in the halo simulations can either enhance or wipe out a central cusp, depending on assumptions made about how stars form. There is no theory of star formation, which would be needed to simulate correctly the evolution of the baryons in the N-body simulations. So there is still a debate on whether the DM halo peaks at the center of the galaxy or is smooth.

Halo substructure: Simulations tend to give clumpy halos, with substructures as small as the solar system. However the inhomogenities of the halo will always give a lower signal than the galactic center (if at all), so any signal from clumpiness will always be lower than the one expected from the galactic center. Moreover, since of course the location of the clumps is unknown, there is no possibility of doing a stacking analysis.

Julien and Emmanuel advocate using the NFW as a benchmark, and one or two other models for comparison if one wants to evaluate the effect of the assumption about the shape of the halo in the results. This is what IceCube has done in the galacic analyses.

What to present: We should present the neutrino flux limit from the GC, as we do with any other source. This is a halo-independent measurement. Then we can use a halo model to extract the <sigma x v> limit, a derived model-dependent quantity.

Scans:

Carlos, Matthias and Guillaume presented how we do scans in each experiment. IceCube did DarkSusy 'brute force' grid scans of the MSSM and these are the ones shown in our results. ANTARES did it similarly but for the CMSSM, using a Random Walk scanning technique. This is what they have been showing in their plots. This is a first step that allows to check the regions of parameter space that we are sensitive to, and compare with other experiments.

Matthias went through the IceCube TeVPA11 slides from Patt Scott (http://agenda.albanova.se/materialDisplay.py?contribId=396&sessionId=255&materialId=slides&confId=2600) where a more advanced way of doing parameter scans is explained, based on the bayesian approach included in SuperBayes. The idea is to include detector information on a model-by-model basis and assign a relative probability to each model taking into account the results of IceCube (and other experiements). This approach links DarkSusy with SuperBayes and detector information. Work is in progress.

ANTARES has also started to use SuperBayes to explore the parameter space of the CMSSM, and also a modified version devoted to scan the mUED parameter space. Work is also in progress there.

We discussed the possibility of using each other scans and/or performing new ones in cooperation. For this we need to agree on what parameter ranges to use, what variables to save and on which format. We decided to keep further contacts on this issue, since it is nothing that could be solved on the spot.

We agreed that the cMSSM is quite challenged by the new LHC results but still a useful benchmark. But we should aim at have scans on other models: pMSSM, nMSSM and mUED are preferred candidates. The NMSSM might also be worth investigating.

Low-E and cascade analyses:

ANTARES has ongoing efforts on cascade reconstruction but mainly for HE neutrinos so their DM analyses have focused on the muon channel up to now.

In IceCube this is also on-going work. Attempts at a hybrid reco, a joint reconstruction of the vertex cascade plus the muon track, have been started, but no conclusions yet (apart than it is difficult). Carsten reported on first attempts to get a sensitivity for cascade analysis from the Sun and Galactic Halo with DeepCore. The angular resolution lies around 30 deg at about 1 TeV. It is definitely not optimal for the Sun, but it still ok for diffuse searches from the halo in an on/off-source analysis.

SUSY searches at LHC :

Steve Muanza (CPPM-ATLAS) gave a summary of where ATLAS and CMS stands in the searches of Supersymmetry. Results where shown with about 1 fb-1 luminosity per experiment (status of Summer Conferences) while 5 fb-1 have been accumulated in total per experiment in 2011. The main sensitivities and thus limits are made on colored sparticles: squarks and gluinos have been excluded up with masses lower than about 1 TeV in the CMSSM. About 15 fb-1 per experiment should be recorded in 2012 at beam energy of 7 or 8 TeV.

The CMSSM is the main studied SUSY scenario. Scans are made by theory groups with programs such as MasterCode (Ellis et al.), SFitter (Zerwas, Lafaye,...) or Fitino (Gornan..). It is interesting to notice that the focus point region of the MSSM which occur for large m0 (several TeVs) gives heavy squarks and is thus not easilly covered by LHC, while it provides the higher signal in a neutrino telescope due to the higgsino nature of the neutralino. The mUED framework is also a little bit studied at LHC.

Conclusions:

It was a useful contact between the two collaborations, with a good dinner at the Vieux Port to enhance the contact between us.

We set up the following wish-list

- We should produce neutrino effective areas for public consumption;
- We should produce limits on the neutrino flux at 1 GeV threshold (if using DarkSusy, this comes out for free in the same way as the muon flux) and provide the effective area of the analysis;
- Limits on cross sections: we both use the Wikstrom/Edsjo conversion, but we agreed we should use the conservative calculation in their paper. This is not what is included in the web-based conversion scripts, which are based on the standard calculation. Contact Joakim to check the possibility to have the conservative version in the web scrips also.
- Galactic analyses: use the NFW halo model as benchmark.
- Cosmological inputs: use the most updated values. This means rho_local=0.4 GeV/cm3 at this point, being aware of not using old values in hidden places (like the conversion scripts between fluxes and cross secrions). Use a generous range of Omega, based on the WMAP value.
- Define together the variables to be stored and the file format in order to share the scans of the models.

It was unanimously agreed to hold a similar meeting between the Dark Matter community of the two Collaborations at the end of 2012.