A simple simulation of the IceCube neutrino telescope and its relation to the ANDES neutrino detector

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Outlook

I) Introduction
 The role of experiment simulations
 Experiments at ANDES
 Status of computations and prospects

2) From isolated notes to systematic simulations
 Fixed target detector modeling and simulation
 Semi-analytical approach to simulate neutrino detectors

3) IceCube Telescope, our working example
 Description and physics reach of IceCube
 A simulation biased view of our contributions
 Our current simulation of IceCube

4) Application of our approach to ANDES neutrino detector

The idea of this talk is to use our particular research considering the IceCube neutrino telescope to motivate the study and development of experiment simulations for the potential experiments to be installed in the ANDES experiment site. Thus, at the end of this talk we expect to have given good motivations for the support of these simulations, which we are starting to develop based on our current simulation of IceCube and also considering standard tools such as Globus, CORSIKA, Geant4, Pythia, Madgraph, etc.

Introduction: the role of simulations to understand experiments and physics in general

The role of experiment simulations

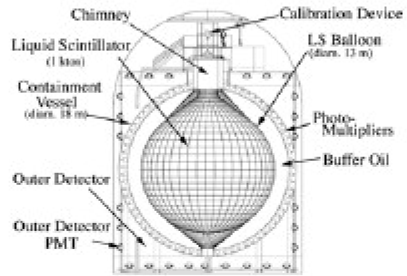
In the area of high energy particle physics phenomenology (hep-ph) the titles of the works rarely make explicit reference to the subject of experiment simulations, however if we pay attention to the abstract and body of these research papers we would find them everywhere. This is because, in general, we need to:

- Specify the model to be studied (beyond the SM model building)
- Compute the observables related to our model, varying from direct to more sophisticated levels of complexity
- Systematize the connection between different versions of our models and different experimental setups (**Experiment Simulations**)
- Project our results to future conditions
- Suggest new ideas about observables
- Suggest new experiments with particular properties

ANDES experiments

Proposed **Large Latinamerican Neutrino Detector**

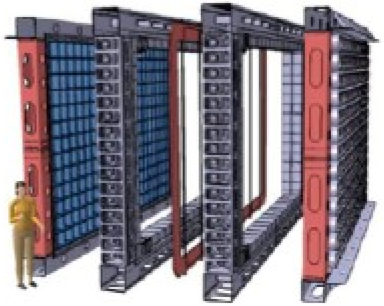
- 3 – 10 kton of liq. Scintillator
- arXiv:1027.5454
- Main topic for next ANDES workshop.



Double Beta experiments:

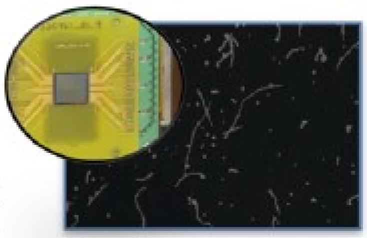
Manifested interest:

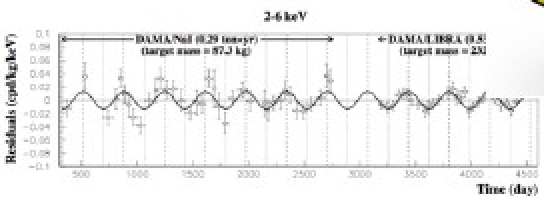
- NEXT
- SuperNEMO modules: ~ 100 kg ^{82}Se



Dark Matter:

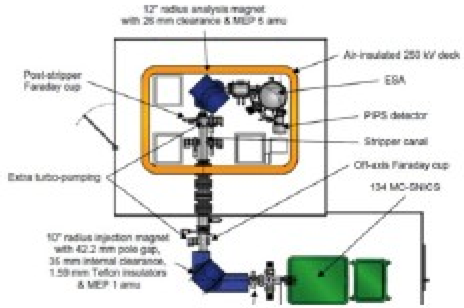
- Host a south copy of a DM experiment with modulation signal.
- Host a next gen. DM experiment.





Nuclear Astrophysics:

- proposal for a 300 keV high intensity ion beam (similar to LUNA)
- Study nuclear reactions of stars



Dib 2017 talk

ANDES experiments

A first step towards the consolidation of these experimental ideas requires the study of their scientific potential. For instance, we can find papers such as Machado et. al. hep-ph/1207.5454 (plus a handful of others) that try to make the case for the ANDES laboratory and experiments

Location	Number from U	Number from Th	Total
Gran Sasso	53.8	14.7	68.5
Kamioka	45.7	12.4	58.1
Hawaii	18.5	5.0	23.5
Sudbury	63.2	17.2	80.4
Pyhäsalmi	66.1	18.0	84.1
ANDES	64.8	17.6	82.4

TABLE II: Expected number of geoneutrino events for our reference 3 kt liquid scintillator detector operating during a year with 80% efficiency at different locations.

We think that in order to improve the case about the ANDES laboratory, in general we need to continue with this approach and, why not, try to systematize it, for instance building one or a set of **experiment simulations**

Status of computations and prospects

In several papers talking about the performance of neutrino telescopes or Dark Matter detectors we can find expressions such as

$$N = N_p \int_{E_{\rm min}}^{\infty} dE \; F_{\bar{\nu}_e}(E) \sigma_{\bar{\nu}_e p}(E)$$

From where we can visualize different blocks of the computations that could enter in the prediction of ANDES neutrino detectors performance

- Flux of neutrinos
- Detector properties
- Cross sections

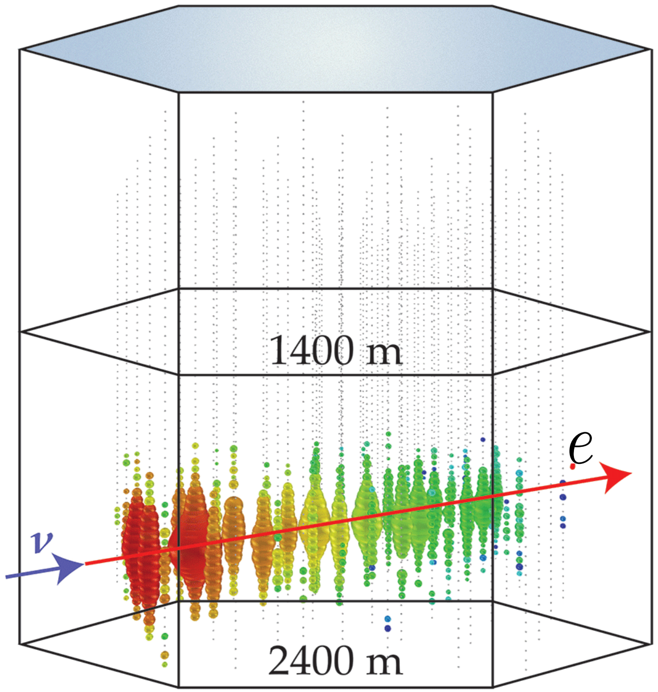
Thus, in order to get a systematic treatment of the potential possibilities to expect and pursue of ANDES, we could take these blocks and connect them such that the computation of observables in different situations is done with an increasing level of efficiency. These are properties that can be achieved by considering as a target the simulation of the experiments, which could be implemented as softwares able to receive diverse types of inputs and generate sensible observables

From isolated notes to systematic simulations

Fixed target detector modeling and simulation

There are several ways to systematize the development of experiment simulations depending on the degree of the accurateness that is needed, sometimes other issues as available money and time also can play an important role, etc. Therefore we find interesting to show our own approach in order to give you a closer view of the ideas that we are pursuing and our current status.

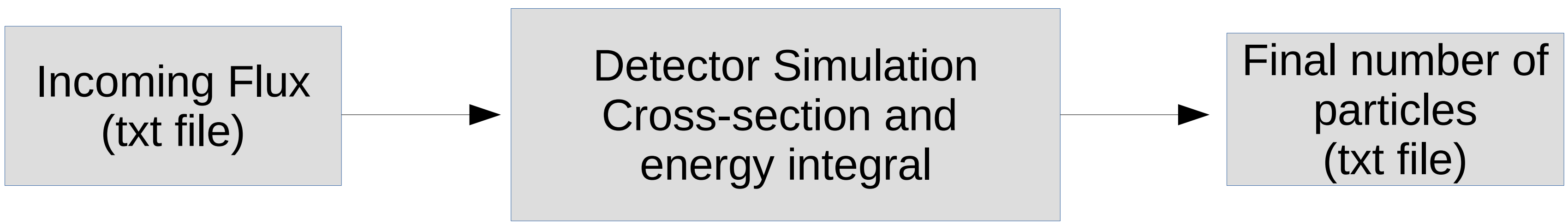
So, let us discuss the most simple modeling of a fixed target experiment, its relation to particle physics and the natural way to break the computation



$$N = N_p \int_{E_{\min}}^{\infty} dE \; F_{\bar{\nu}_e}(E) \sigma_{\bar{\nu}_e p}(E)$$

Semi-analytical approach to simulate neutrino detectors

A very practical way to simulate and systematize the application of the previous model is by considering the breaking of the parts in such a way that the computations of each block can be implemented independently and connected through input and output files. For instance, in this language the previous computation can be seen as the following flux diagram



From this we can figure out a program that reads an input file with the incoming fluxes, process them and finally generate a set of output data containing the number of events as a function of the energy. The final prediction can be compared to data in a posterior part of the analysis pipe.

Several details about the predicted observations can be added to the simulation by extending and adding complexity to the computation of the final observables. With a little bit of imagination also we can figure out how to refine this approach to include more accurately the detection process and generate output information at machine level, which can be directly compared with measured data.

IceCube Simulation: Flux Diagram

Description and physics reach of IceCube

The IceCube neutrino telescope is able to measure the most energetic neutrinos circulating the cosmos, which are most probably related to the origin of cosmic rays but with energies that allow to investigate high energy physics at interesting regimes

During the last month were released some results astro-ph/1807.08794 about the measurement of one high energy neutrino from the direction of a blazar. Its Relationship with the production of CRs has been studied by considering a multi-messenger analysis including gamma rays and other wavelengths astro-ph/1807.08816

On the other hand, the energy of the neutrinos detected at IceCube covers the electroweak regime, so in principle we can measure cross sections at energies not covered by previous neutrino-proton detectors. This is useful to generate new scientific information about SM predictions but also allow for the cross check of collider searches just recently covering this energy regime

$$\frac{dN_\alpha^{\mathrm{c,h,X}}}{dE_{\mathrm{dep}}} = T N_A \int_0^\infty dE_\nu \, \mathcal{A}_\alpha^{\mathrm{h}}(E_\nu) \frac{d\Phi_\alpha}{dE_\nu} \int_0^1 dy \, \mathcal{M}_{\mathrm{eff}}(E_{\mathrm{t}}) \, R(E_{\mathrm{t}}, E_{\mathrm{dep}}, \sigma_{E_{\mathrm{t}}}) \, \frac{d\sigma_\alpha^{\mathrm{X}}}{dy}$$

A simulation biased view of our contributions

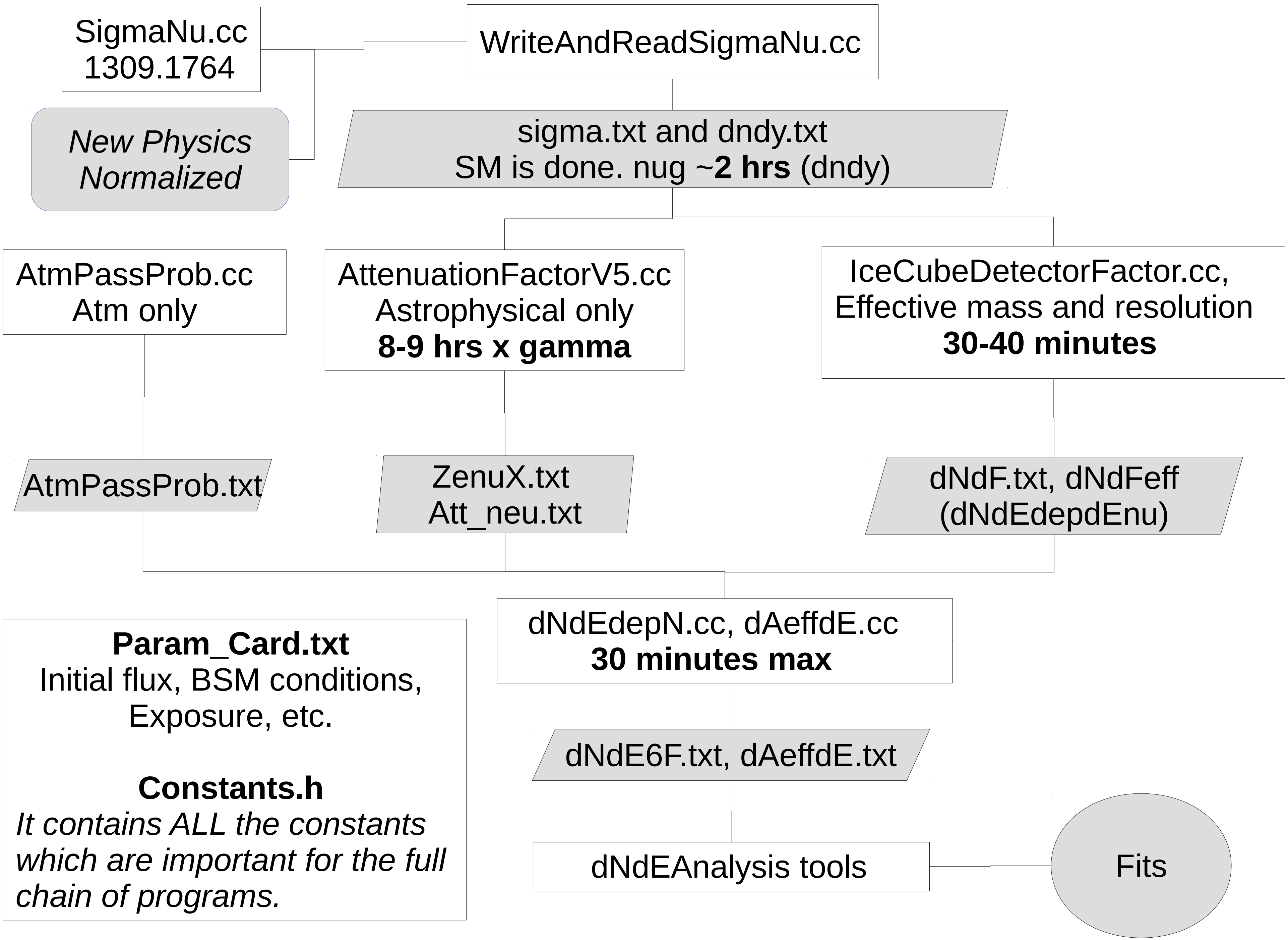
The pace of our work considering the IceCube experiment can be described by the pace as we have added new ingredients and improved methods to the computation of new observables to compare against the IceCube data

- In our first work we considered the search of a DM component on the young data delivered by IceCube in terms of events as a function of energy (Enu = Edet) hep-ph/1411.5318
- Afterwards we added some elements such as energy reconstruction effects and distinction between shower and track topologies (trigger conditions) hep-ph/1604.08595
- We have added the possibility to extend the SM in order to analyze possible BSM signals at IceCube hep-ph/1803.10112

Along these works we have also included the computation of north and south spectrum, which can be extended to full angular coverage, preferable considering DeepCore.

Lastly we have added the double bang topology, which allow us to compare our predictions to analysis done with three topologies.

Our current simulation of IceCube



Application of our approach to ANDES neutrino detector

Given the similarities between the ANDES and IceCube computations we think that our approach is easily applicable to the simulation of the ANDES neutrino detector.

This can be a first approach to the long term endeavor of developing **experiment simulations** to exploit the features of future ANDES experiments

However, by following the spirit of the idea besides of our particular form of the implementation (e.g. IceCube like), we consider that the particular approach to simulate this experiment can go well beyond our semi-analytical approach and can consider more sophisticated and state of the art tools in terms of cross sections, detector performances, etc.

For instance, we are thinking about the option of a simulation of the ANDES neutrino detector by using current neutrino detector simulation environments such as Globus, but this is just a guess that can be replaced or extended by considering other tools

Basically, we think that simulations of ANDES experiments are going to be important and we want to work on this. Advices are welcome!!