Muon background simulation for ICECUBE

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INTRODUCTION

Muon background flux producing the Cherenkov light into the ice can imitate detection of neutrino from supernova. The computation of systematic error due to muon background flux can be performed in frames of the CORSIKA simulation code providing muon flux at the ICETOP observation level and GEANT simulation code do obtain the corresponding responses from ICECUBE DOMs.

Here both the strategy of CORSIKA simulations and results of 5×10^7 simulated primary protons are presented which could be the database for further GEANT data analysis.

GEOMETRY is presented in Fig.1 below

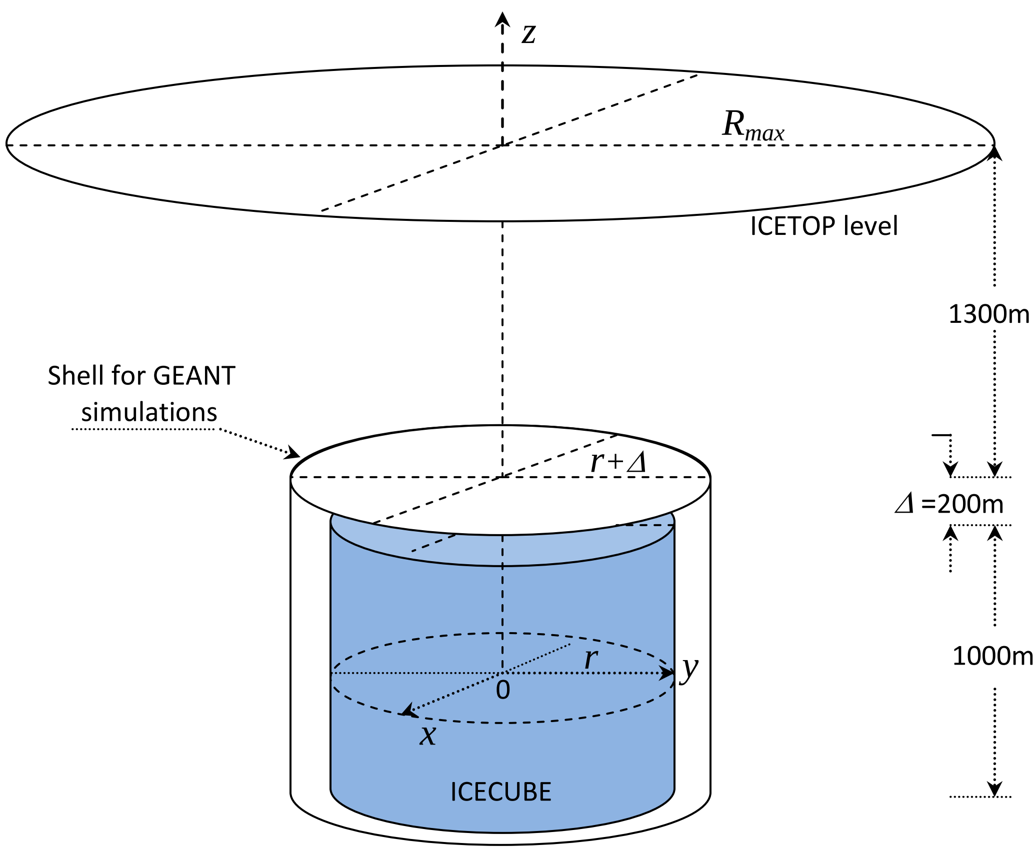

Figure 1. Layout of CORSIKA simulations and reduction of muon flux into the ice. The CORSIKA code provides the muon phase coordinates (p_x,p_y,p_z,x,y,z) over the ice level (ICETOP level). Next stage of simulation is reduction of muon flux due to $dE_\mu/dx=a+bE_\mu$. The surviving muons ($E_\mu>1$ GeV) on the shell of the expanded ICECUBE volume (Δ=200m) make up the resulting database for further GEANT analysis.

CORSIKA

Simulated primary proton (nucleon) spectrum: dI/dE_0= $0.11E^{-2.73}$ ($m^{-2}\cdot s^{-1}\cdot sr^{-1}\cdot TeV^{-1}$).

Primary energy range is $1<E<3\times10^3$ TeV for zenith angles of protons, $\theta<60^0$.

Shower core-coordinates is distributed uniformly into circle of R_{max}<5000m.

Horizontal flat detector mode; SYBILL interaction model; Observation level: 3285 m; Location: North pole.

Primary particle location at observation level was distributed uniformly into circle of radius $R_{max}= 2500\text{m}*tan(60^0)+700\text{m} \approx 5000\text{m}$ (see fig. 1). On the basis of CORSIKA output phase muon coordinates – p_x ,p_y, p_z, x, y, z and x_0,y_0 coordinate of primary particle at the level of ICETOP, the muon trajectory into the ice was calculated. If trajectory of muons are passing through the expanded (Δ=200m) ICECUBE virtual shell, the energy lost of muons were calculated by $\Delta E_\mu=a+bE_\mu$, where *a* and *b* are parameters (*from Chirkin*).

For surviving muons with E_μ>1 GeV, the muon phase coordinates on the expanded shell were recorded in the flux_of_mu_in_ice_from_p.out file along with current number of simulated primary particle. Some of results of simulated database are presented in Fig.2 and 3.

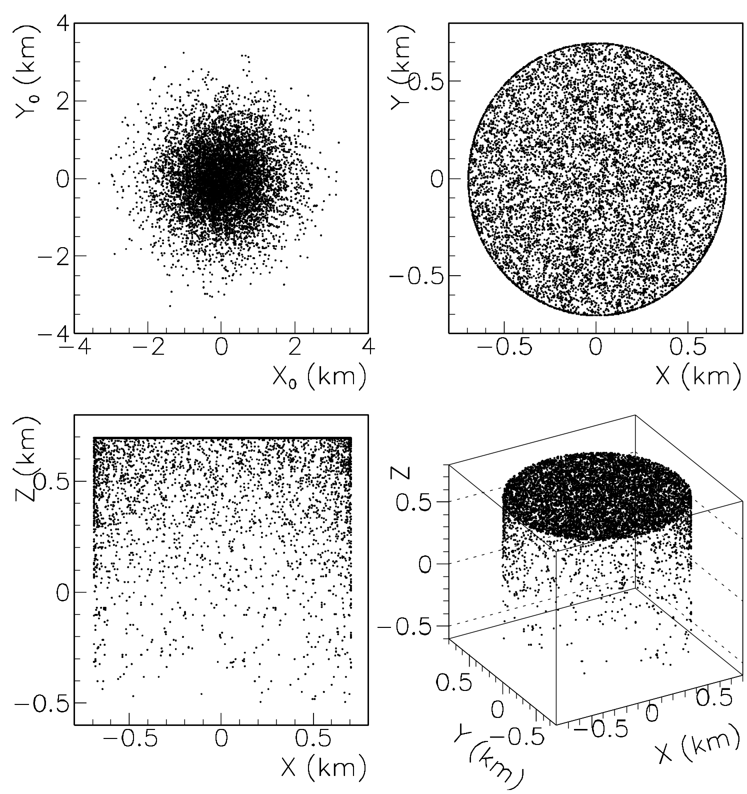

Figure 2. Primary particle coordinate distribution (x_0,y_0) at the ICETOP level and muon coordinate distributions (x,y), (x,z) and (x,y,z) on the expanded ICECUBE shell.

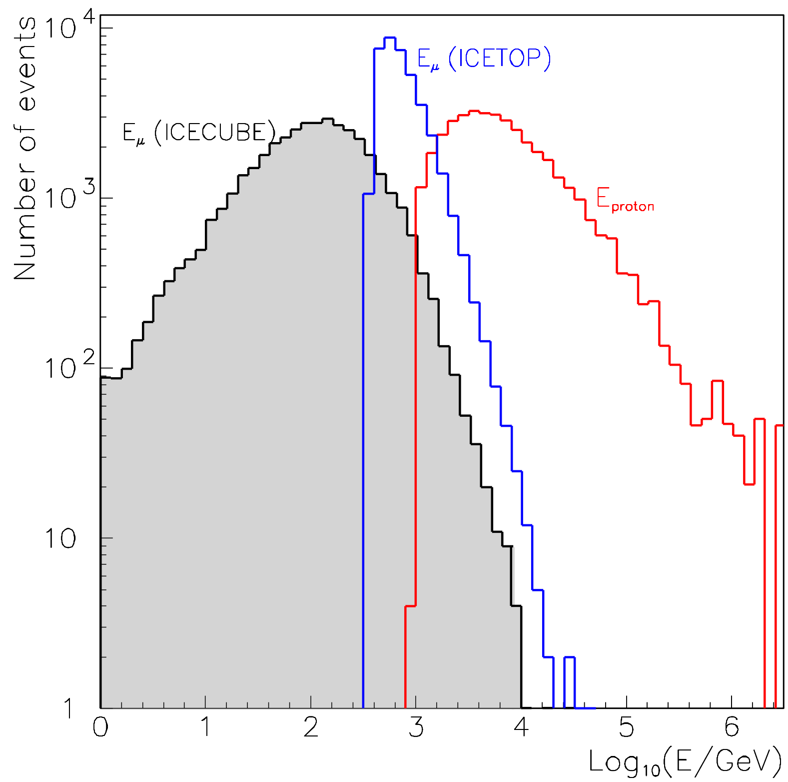

Figure 3. Distribution of simulated primary proton energies (E_p, red color), muon energies at observation level of ICETOP (E_μ, blue color), and muon energies on the expanded ICECUBE shell (E_μ, black color) for further GEANT data analysis.

After GEANT analysis the absolute intensity of the background events can be calculated using following normalizations.

Intensity of primary nucleons (protons) is $dI/dE_0 = 0.11E^{-2.73}$ ($m^{-2} \cdot s^{-1} \cdot sr^{-1} \cdot TeV^{-1}$).

Integral rate for ICECUBE equal to $N = (1/N_{tot}) \int (dI/dE_0) dE_0 \cdot S\cos\theta \cdot d\cos\theta d\varphi = \mathfrak{I} \cdot S \cdot \Omega / N_{tot}$, where

$$S \cdot \Omega / N_{tot} = (1/N_{tot}) \cdot \pi r^2 \cdot [2\pi \cdot (1 - \cos^2\theta_{max})/2] = 3.14^2 \cdot 5000^2 \cdot 0.75 / 5 \times 10^7 = 3.7 \text{ m}^2 \cdot \text{sr}.$$

$$\mathfrak{I} = \int_{Emin} (dI/dE_0) dE_0 = (0.11/1.73)(E_{min})^{-1.73} = 0.11/1.73 = 0.064 \text{ m}^{-2} \cdot \text{sr}^{-1} \cdot \text{s}^{-1}$$

$$N = 0.064 \text{ m}^{-2} \cdot \text{sr}^{-1} \cdot \text{s}^{-1} \times 3.7 \text{ m}^2 \cdot \text{sr} = 0.24 \text{ s}^{-1}.$$

Any selected N_x events of total simulated dataset will have absolute rate: $\mathbf{0.24 \cdot N_x}$ s^{-1}.

Probability to generate muons into ice by the primary proton flux integrated over all angles and energies are $P(E_\mu)$=19850, 11430 and 7195 for muon energy more than E_μ=100, 200 and 300 GeV respectively. Expected muon rate can be calculated

$$[\ S \cdot \Omega / N_{tot}\ ] \times [\ \mathfrak{I}\ ] \times [P] = 3.7\ \mathrm{m^2 \cdot sr} \times 0.064\ \mathrm{m^{-2} \cdot sr^{-1} \cdot s^{-1}} \times P = 4700\ ;\ 2706\ ;\ 1703\ \text{Hz}$$

For **half** of second we will expect: 2350, 1353, 851 muons.

From Ali Fazely GEANT simulations (icecube.wisc.edu/~fazely/i3geant/) the average number of lunched doms per muon is 16.2. Thus, number of muon hits is: 38070, 21919, 13786.

Normalizing to all doms we will have 38070/5200 = 7.2 hits for 0.5 second or ~14-15 Hz the muon contribution.

1. This quantity therefore absorbs the effect of the non-Poissonian behaviour of the DOM noise rates (which leads to a ~1.3 times larger standard deviation than expected from Poissonian statistics).

2. In fact, the width of the significance distribution increased with every IceCube configuration, clearly showing a seasonal effect

The obtained broadening (~1.3-1.5) of significance distribution are not due to **non-Poissonian behaviour of the DOM noise rate**, as it is mentioned in the referred paper. The significance distribution according to definition[1] ($\xi=\Delta\mu/\sigma_{\Delta}$) has to be quasi normal with zero average and unit RMS regardless of noise rate distributions. Moreover, the significance, again according to definition, does not depend on a number of active DOMs (or IceCube configuration). It is well seen in the simulation results presented below

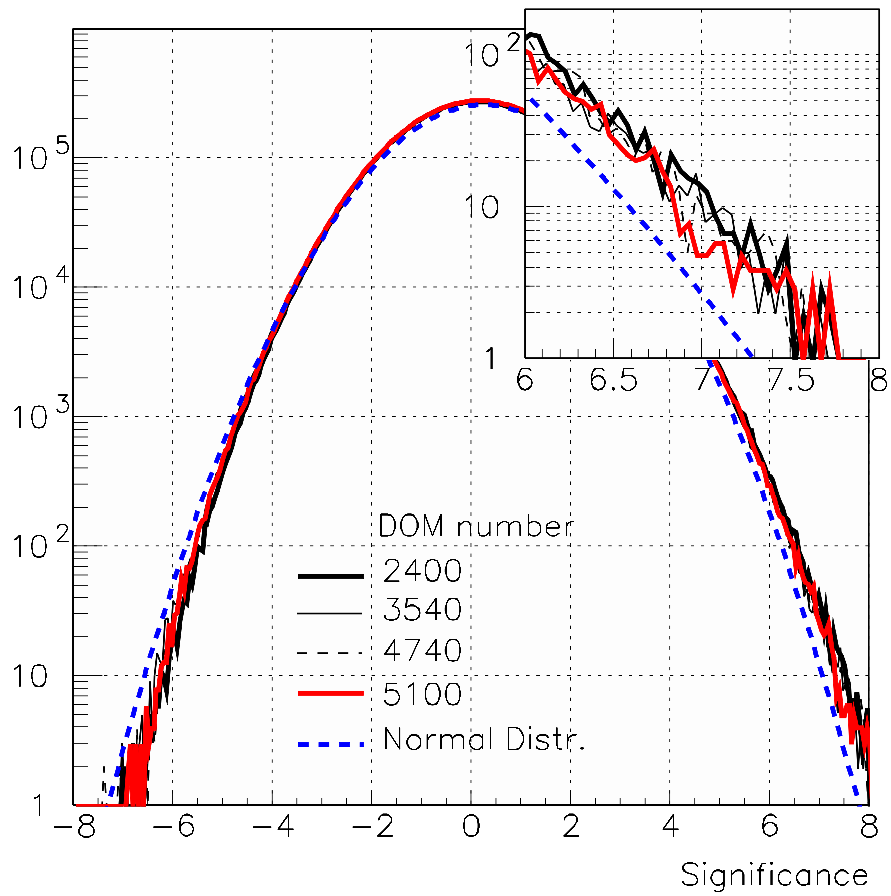

Figure 1. Simulation of Non-Poisson noise rate for 4 configurations of IceCube with different number of DOMs. It is well seen, that width of significance distribution does not increase with increasing number of DOMs but distributions get more and more closer to the normal distribution with zero average and 1.46 Hz RMS (blue dashed line). In the range of statistical errors the RMS values for all presented distributions are the same.

Significance distributions for different DOM's numbers in Fig.1 were obtained using simulations of noise rate according to experimental IC3-40 data taken from[2] and presented in Fig.2.

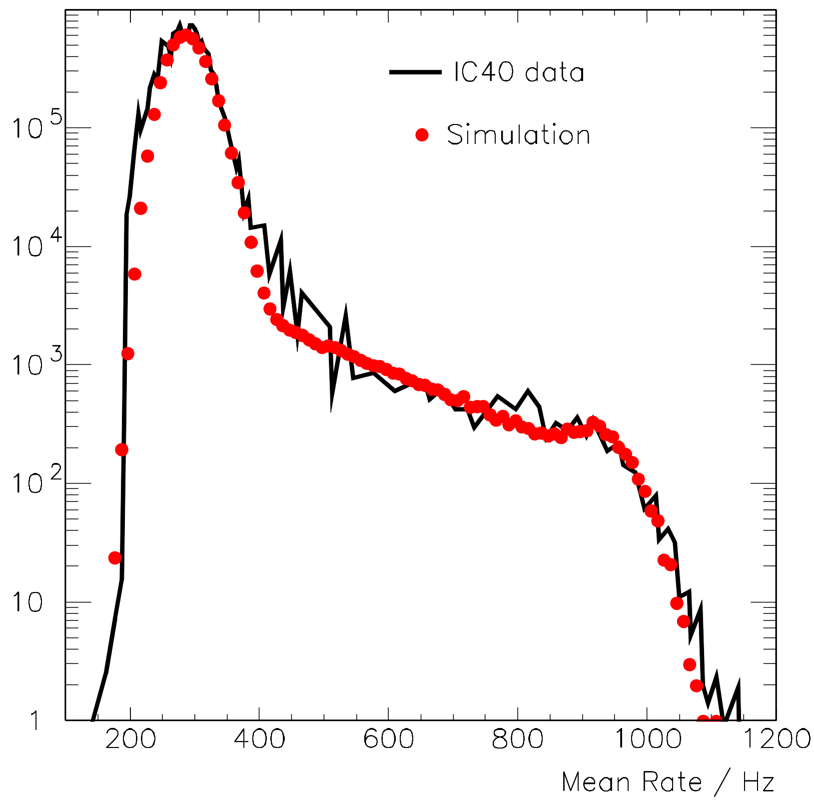

Figure 2. Experimental[2] and simulated noise rate. Average and RMS values for simulated noise rate were 290 Hz and 44.54 Hz respectively.

It is well seen, that obtained RMS of noise rate is strongly differ from accepted RMS of IceCube, which is equal to 20 Hz. This is a main reason for broadening (~1.3-1.5 times) of significance distribution but not non-Poisson form of noise rate. If RMS of DOMs noise rate is equal to actual value (~44.5 Hz) taking into account right shoulder (tail) of distribution, the width of significance distribution will be equal to 1. This statement was checked by our simulation model.

However, as was mentioned in the referred paper **the width of the significance distribution increased with every IceCube configuration.** And this is an experimental fact.

Because from our results presented in Fig.1 stems that **width of the significance distribution** does not depend on number of DOMs, we infer that another course can be responsible for broadening. For instance, the high energy solar neutrino flux increases due to increasing Solar activity. According to our preliminary computations by the GEANT code, the right shoulder of noise rate distribution can be accounted for by these solar neutrino (average neutrino energy ~ 1 GeV). Increasing rate of Solar neutrino should increase the height of right shoulder in Fig.2 and, in turn, it will increase the RMS of noise rate that will result in increasing of width of significance distribution. This statement is very easy to check by the Mainz group investigating the time dependence of the noise rate distributions.

Fortunate for this case, interesting SN trigger was recorded recently (2011-07-26 14:11:16) with very high significance, 8.12 at a very low active number of channels 2242. According to logic of referred paper the combination 8.12 and 2242 is impossible at all.

3. Interpretation of increasing trigger rate by the seasonal variation of atmospheric muon flux is really surprising. We simulated the contribution of muons using CORSIKA EAS simulation code, IceCube geometry and results of GEANT simulations for IceCube muons [4]. For half of second we obtained 2350, 1353, 851 muons ready to pass IceCube volume expanded by 200m in up and side directions with energy 100, 200, 300 GeV. Using log-normal fit of Ali Fazely distribution for effective DOM number [4] (average value 16 DOMs and RMS=13 DOMs) and flux of 100 GeV muons we did not record any significant change of significance distribution.

We know from [3] that the DOM noise rate is actually sensitive to the variation of muon flux and measured magnitude of this variation is less that 1%, whereas muon flux variation at South pole is about ≤10%.
Next interesting known fact is sensitivity of string noise rate to the variation of muon flux from [3]. Again the string seasonal noise rate variations is very low, something about 1%.
Unfortunately we do not have access to experimental database and therefore we could not check your method of extraction of muons from trigger events. We have only one general question to this procedure. You did not extract muons from 300s base intervals. Isn't it? If yes (I couldn't find this info from paper) , you artificially decrease the significance.
However, it would be very interesting to see your corrected trigger rate in comparison with our data presented below. We can sent the numerical values if you need.

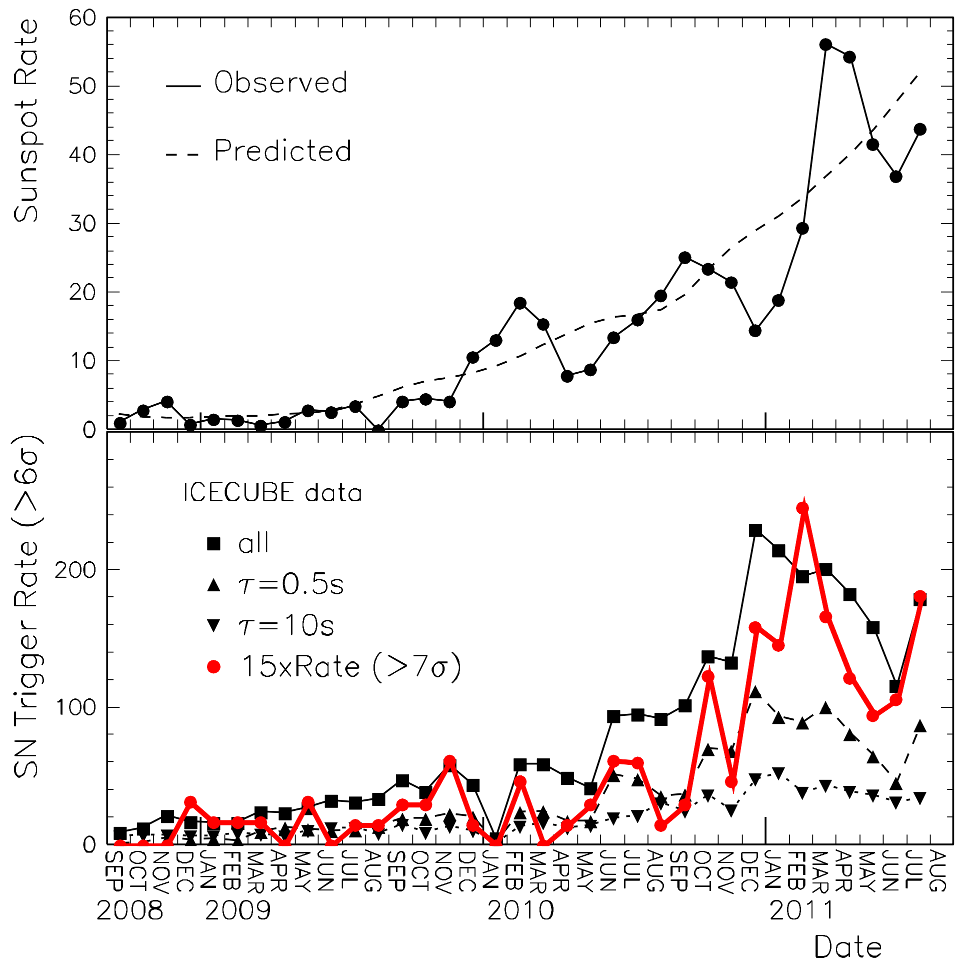

Figure 3. Solar sunspot number versus time (upper patel) and SN trigger number versus time at different time gate and significance thresholds. Interesting to note, that IceCube trigger rate leads sunspots number for about 1 month, that is approximately equal to the time of

CONCLUSION

The form of obtained significance distribution for trigger rate is directly explained by the artificial decreasing of RMS of DOM noise rate in IceCube experiment but not by the contribution of atmospheric muons or non-Poison processes. The observed gain of trigger rate versus time can not be explained by the muon contribution. Natural explanation is a gain of detected high energy neutrino flux due to increasing of solar activity.