1 Introduction

This is my initial scketch for calculating 1) effective area, 2) event rate and 3) sensitivity of the IceCube detector to the various models using 'IceSim', the IceTray based simulation package for IceCube experiment. Currently IceSim includes two neutrino event generators, I3Anis and JULIeT. Charged leptons produced by the event generators near detection volume are propagated by either of propagation programs MMC or JULIeT. The JULIeT is capable of event generation and charged lepton propagation, but each functions can be separately treated. The MMC also has ability to inject various types of events but the functionality is not discussed in this note. Each of the two event generators and propagators have been developed in the focus of different primary neutrino energy regions as shown in Table 1, thus can be used for different types of physics analysis as well as offering good place for cross checking as there are much overlap in the primary energy.

Event Generator	I3Anis	JULIeT
Focused energy region	Medium/high energy	Very/extremely high energy
$\nu - N$ crosssection file implemented	10^1 GeV $\sim 10^{12}$ GeV (based on CTEQ5)	10^5 GeV $\sim 10^{12}$ GeV
Charged Lepton Propagator	MMC	JULIeT

Table 1: Neutrino event generators on IceTray

One-by-one comparison of each event generators and propagators should be performed separatry. Comparison of I3Anis and JULIeT as a pure event generator and mmc and JULIeT as a pure muon propagator wil be considered in the following. It must be taken care that because each generators and propagators are different in programing structures, also the structure of quantities calculated as weights or MC simulation from each generators are different. In the following, the way to obtain appropriatelly weighted physically motivated histograms from each generator and comparison of resutls from each program are described.

2 Effective Area and Event Rate

2.1 Basic

The expected differential event rate R_l of observable charged leptons of flavor l which reach to the detector depth per second can be expressed as

$$R_l = J_l \times A_{eff}(E_l). \tag{1}$$

Where J_l is the secondary charged lepton flux near the detector produced from a primary neutrino flux $J_/nu$ at the surface of the Earth, E_l is the energy of secondary charged lepton and the effective area A_{eff} is the area perpendicular to the direction of charged lepton within which the particle is considered to be an observable (effective). The effective area is highly dependent on the energy, direction and flavor of the charged lepton as well as relative position of the track to the detector. Depencence on the direction and position are not explicitly written for simplicity unless it is not clear.

The lepton flux at the detector depth J_l is obtained by integrating the flux J_{ν_i} of primary neutrino of flavor i at the surface weighted by the probability $P_{\nu_i \to l}$ the neutrino produces observable charged leptons of flavor l, as

$$J_l(E_l) = \sum_{\nu_i} \int_{E_l^{min}}^{\infty} P_{\nu_i \to l}(E_{\nu_i}; E_l) \frac{dJ_\nu(E_{\nu_i})}{dE_{\nu_i}}\, dE_{\nu_i}. \tag{2}$$

Summation is over primary neutrino flavors and the integral is over all the primary neutrino energy which contributes to the charged lepton flux of interest with energy threshold indicated by E_l^{min}.

The event rate R_l is obtained in simulation by counting the number of events $R^{MC}_{detection}$ in a time interval and an energy bin $(E_l - \Delta E/2, E_l + \Delta E/2)$ that produce detector response which pass given detection conditions such as a requirement on the total number of estimated pe per event. Similary the charged lepton flux J_l can be considered in simulation as the flux of events $J^{MC}_{observable}$ that generate events which pass the condition to be observable, i.e. the event creates 'visible' charged particle near detection volume. Thus from Eq. 1, the average effective area can be expressed as,

$$\overline{A}_{eff}(E_l;\Delta E) = \frac{\int_{E_l-\Delta E/2}^{E_l+\Delta E/2}(\frac{dR_l}{dE_l})dE_l}{\int_{E_l-\Delta E/2}^{E_l+\Delta E/2}(\frac{dJ_l}{dE_l})dE_l} \tag{3}$$

$$= \frac{R^{MC}_{detection}(E_l;\Delta E)}{J^{MC}_{observable}(E_l;\Delta E)}. \tag{4}$$

3 Neutrino Event Generators and Charged Lepton Flux

Event generator in the content of this memo is a program to inject primary neutrino on the surface of the Earth according to appropriate known spectra and calculate the probability that such flux of neutrino create a flux of secondary charged leptons at a large depth near the detector.

In JULIeT, the secondary charged lepton flux J_l (Eq. 2) is given precalculated in the form of differential flux $\frac{dJ_l(E_l)}{dlogE_l d\Omega}$. In contrast, I3Anis obtains the flux with a combination of MC simulation and calculation of event probability which to be used as a weight by the weigher program (Sec. **??**). This structual difference of simulation programs also leads another difference, which is that the I3Anis only be able to inject primary neutrino of one flavor each per run but JULIeT do inject charged lepton of each flavor.

3.1 Case of I3Anis

For I3Anis, $J^{MC}_{observable}$ without weighting is obtained by MC simulation. It means that it can be obtained by sampling observable events with secondary charged lepton at the detection depth. However, because of neutrino's very small interaction crosssection with matter ($\sim 10^{-10}$ mb at 10 GeV to $\sim 10^{-5}$ at 10^9 GeV incident neutrino energy), the effeciency to calculate the events which passes such condition is extremely low (with L=1km detection length in ice, $\sim 10^{-x}$ at 10 GeV to $\sim 10^{-x}$ at 10^y GeV). Thus effectively, this MC simulation mainly calculate probability that neutrino on the earth's surface survive at the detection depth. As energy increases, because of the increase of crosssection the probability to reach the detection depth decreases, and even though all of neutrinos which reached to the detection depth creates charged leptons, the number of observable events decreases. Thus for such very high energy events, this methods is not effecient.

The charged lepton flux at detection depth to be calculated by I3Anis is expressed as,

$$J^{I3Anis/MC}_{observable}(E_l;\Delta E) \simeq \sum P_{final\ length}(E_n;E_l,\Delta E) \times J^{I3Anis/MC}_{neutrino}(E_n) \tag{5}$$

where $P_{volume}(E_n;E_l,\Delta E)$ is probability that a neutrino of energy E_n interact within the volume and produces charged lepton of energy E_l within bin size ΔE.

The probability distribution that every neutrino arrive at the detection depth interact within final length is just a constant distribution $P_{MC} = \frac{1}{L}$ which is included in $J^{I3Anis/MC}_{neutrino}(E_n)$. To get the flux $J^{I3Anis/MC}_{observable}(E_l;\Delta E)$, an appropriate weight $W(x,E_n) = P(x,E_n)/P_{MC}$ need to be applied on the MC output. Where $P(x,E_n)$ is the probability that particle interact within length x.

Thus in addition to the normalization a factor of

$$W^{I3Anis}(x,E_n) = L(1 - e^{-\rho N_A \sigma(E_n)x}) \tag{6}$$

will be weighted. Whrere ρN_A is the number density of target nucleon $[1/m^3]$ and $\sigma(E_n)$ is the total crosssection $[m^2]$, x is distance from the detection volume entrance to the interaction position [m]. $\rho \cdot x$ gives column depth [g/m^2]. N_A is the number of target in 1[g] of material i.e.,$\sim$ 1/proton mass.

The weight stored and called by weigher program (Sec. **??**) with name 'InteractionProbability' is $P(x, E_n)$ and final total length L is stored separately with name 'DetectionLength'.