Simulating the Hyper-Kamiokande Detectors

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1 ABSTRACT

The Hyper-Kamiokande Water-Cherenkov Neutrino detectors are simulated using Monte-Carlo and analytical methods. A few simple events are also simulated and these preliminary results are presented.

2 INTRODUCTION

Neutrinos are the most elusive fundamental particles in the universe. Contrary to popular notions their flux (at the surface of the earth) is very high. At the same time they interact with matter primarily through the weak interaction process making their detection and study rather difficult. This is so since the weak interaction cross-sections are much smaller (typ. $10^{−37}$ cm$^2$) compared to the strong interaction cross-sections (typ. $10^{−25}$ cm$^2$) and electro-magnetic interaction cross-sections (typ. $10^{−2}$ cm$^2$). Neutrinos are produced in very large numbers at the core of the Sun (during the fusion of hydrogen into helium) and also during Supernova explosions that mark the death of massive stars. High energy cosmic rays while traveling towards the earth’s surface interact with the terrestrial atmospheric nuclei and produce neutrinos in these interactions. Large number of neutrinos are produced in nuclear reactors (used primarily for energy production) and also in high energy particle accelerators. The mean energies of neutrinos and their spectral energy distributions produced in different natural and man-made processes are, however, quite different. Study of neutrinos help us in understanding the physics of the processes taking place in the core of the Sun, of neutrino oscillations (the conversion of a particular type of neutrino to another type, say, that of an electron-type neutrino to a muon-type neutrino or say, a muon-type neutrino to a tauon-type neutrino. Due to the extremely small interaction cross-sections ($10^{−37}$ cm$^2$) of neutrinos extremely massive (hundreds of kilotons or megatons) detectors are required to detect significantly large number of events. Also, another very important necessity is that these detectors have to be located deep underground to significantly reduce the very large number of high energy cosmic ray muons that incessantly bombard the earth’s surface.
3 THE DETECTOR SYSTEM

The details of the Hyper-Kamiokande underground detectors are available elsewhere [1]. Here we give only the basic configuration and information that are necessary for simulating events in these detectors. The Hyper-K detector is located underground at a depth of 650 meters in the famous Kamioka mines in Japan. The detector is basically a 'water cherenkov charged particle detector'. Ultrarelativistic charged particles emit electromagnetic shock waves in the ambient medium when their velocities exceed that of the speed of light in the medium. These shock waves are emitted in the form of a cone with the moving charged particle being at the vertex of the cone. This radiation is known as Cherenkov radiation and its wavelength is concentrated in the visible blue or near UV region of the electromagnetic spectrum and may be detected easily using photosensors like photo-multiplier tubes or PMTs. The Hyper-K detector consists of a huge cylindrical chamber filled with ultrapure water. The outer dimensions of the chamber is as follows: its height is 60 meters and its diameter is 74 meters. 260,000 metric tons of water is required to fill the chamber. The wall of the Inner Detector (ID) is a cylinder having a height equal to 54.8 meters and a diameter of 70.8 meters. This Inner Detector (ID) is separated from the optically isolated Outer Detector (OD) by a 60cm wide dead space. The PMT high voltage and electronics cables run through this dead space. The OD has a thickness of 1 meter in the barrel region and 2 m at the top and bottom of the Inner Detector. A total of 39,424 PMTs cover the inside wall of the Inner Detector. These PMTs are hemispherical, each having a diameter equal to 50cm (Hamamatsu Type R12860-HQE). They have a large quantum efficiency (30% at $\lambda = 390$ nm). The collection efficiency is 95% when the gain equals $10^7$. The transit time spread for these PMTs is 2.7 nsec (FWHM). The total volume of the water is separated into two optically isolated detectors by the mechanical structure that holds the PMTs. Thus there is an Inner Detector (ID) and an Outer Detector (OD).

4 SIMULATING THE DETECTORS and EVENTS

Some details about the simulation methods and procedures are available elsewhere [2], [3]. The detector geometrical configuration (the inner and outer cylinders and the top and bottom circular walls) including the positions of
each PMT are calculated using standard analytical formulae. The total number of Cherenkov photons emitted in the wavelength band $\delta \lambda$ is calculated as follows:

$$dN = 2\pi \alpha dl (1 - 1/n^2\beta^2)(1/\lambda_1 - 1/\lambda_2)$$  \hspace{1cm} (1)

Here $\alpha$ is the fine structure constant, $dl$ is the track length of the particle and $\beta$ is the velocity of the particle in units of the velocity of light. $\lambda_1$ and $\lambda_2$ define the boundaries of the wavelength band. All these photons are emitted along the surface of a cone having a vertex angle

$$\cos \theta = 1/(n\beta)$$  \hspace{1cm} (2)

The point of emission of each photon along the particle’s track is calculated using a uniform random number. Using three-dimensional geometry, the path of each photon is traced through the ambient medium and finally the hit-point on the detector’s wall is determined. Also, the time delay due to the propagation of each photon is calculated from the point of its emission to the PMT.

Another important aspect of the new MC code is that it is written almost entirely using the FORTRAN 90/95 language.

5 RESULTS

A computer simulated image of the HYPER-K cylindrical detector is shown in Fig.1. Since the number of PMTs is too large, all the individual PMTs are not resolved in the figure. The RED colored grid is the OUTER cylinder. The center of each red colored PLUS sign is the center of an individual PMT. The GREEN portion is the INNER cylinder. The DEEP BLUE semi-circle is half of the TOP wall. Similarly, the PURPLE semi-circle is HALF of the BOTTOM wall. A simulated event is shown in Fig.2. Another simulated event is shown in Fig.3.

6 DISCUSSIONS and CONCLUSION

Detailed physics have to be incorporated to make the simulations much more realistic. Some of these processes have already been included in the latest procedures and test runs taken. Careful checking is required. These will help in getting accurate estimates of physical parameters. The simulation procedures are to be used to create different event topologies.
Figure 1: The Hyper Kamiokande Inner and Outer Cylinders

Figure 2: A Typical Muon Event (simulated)
Figure 3: A Second Event (HIT PMTs on the TOP Wall are displayed.)

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References

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