1 Introduction

Hyper-Kamiokande (HK) has been proposed as a next generation neutrino oscillation experiment, capable of observing accelerator, atmospheric, solar and astrophysical neutrinos in addition to possible proton decays, providing a rich scientific program [1]. To be sensitive to such physics, HK will need a robust trigger and data acquisition system (DAQ). Several UK institutions are participating in the development of the trigger and DAQ. Here we present some of the on going studies from the UK DAQ group.

2 Hyper-Kamiokande

HK is designed to be the third generation underground water Cherenkov detector in Kamioka, Japan. It will have a total (fiducial) mass of 0.99 (0.56) million metric tonnes making it 20 (25) times larger than the Super-Kamiokande (SK) water Cherenkov detector. In the baseline design, the HK detector is composed of two tanks with an egg-shaped cross-section 48 m wide, 54 m tall and 250 m long. Each tank will be optically separated into five compartments to allow triggering and event reconstruction to be performed on a per compartment basis. The baseline design specifies an inner detector photocoverage of 20% provided by 99,000 20-inch diameter photomultiplier tubes (PMTs). 25,000 8-inch PMTs are proposed for the outer region of the detector.

For long baseline oscillation studies it is planned to use the accelerator complex at J-PARC, currently used in the T2K experiment [2]. Upgrades are planned to increase the beam power to 750 kW. The beam will pass through the T2K near detector complex located 280 m downstream from the graphite target, where upgrades are also being planned. It will then pass through an intermediate water Cherenkov detector around 2 km from the target and then HK, 295 km from the target. There are currently two proposals for the intermediate detector, one of which is a gadolinium-doped water Cherenkov detector called TITUS.
3 Current baseline design of the DAQ and strategy

The DAQ will collect the raw (digitized) data output from the detector electronics and write the formatted data to storage for offline analysis. It therefore must be capable of accessing all of the physics of interest, whilst discarding non-physics events. The data rate is expected to be dominated by PMT dark noise. For PMTs with 4 kHz dark noise the estimated data rate, assuming 12 bytes per PMT hit and 100,000 PMTs, is 4.8 GB/s. The expected data rate from radioactive backgrounds ($^{238}$U, $^{232}$Th and $^{222}$Rn) is on the order of 30-250 kB/s.

The current designs for triggering beam events are based on the same concept as used during Phase 4 of the SK electronics [3]. All the PMT signals above a certain threshold will be digitized and read out as digitized hits. A simple Nhits threshold cut can then be applied whereby if the number of PMTs fired is greater than the Nhits threshold the event will be read out and stored to disk. This type of threshold cut will not be suitable for low energy events (< 100 MeV). The UK DAQ group are currently performing studies to determine what types of interactions we can expect to recover with the simple Nhits trigger and what interactions may be lost and how we might recover these lost interactions. These studies will inform the technical design of the DAQ and trigger.

4 On going physics studies

Studies are being performed using the official HK detector simulation package. This is a GEANT4-based [4] water Cherenkov detector simulation package known as WCSim [5]. The studies are currently focussing on developing methods to discard non-physics events and understanding the impact of the PMT photo-coverage for being able to access low energy events.

4.1 Threshold studies

Studies are being performed to determine an appropriate Nhits threshold for the main HK trigger. Figure 1 shows $^{214}$Bi and $^{208}$Tl simulated and processed through WCSim v1.1.1 to look at the effect of the Nhits threshold on the true energy spectrum for low energy events. Similar studies are being performed for other physics events of interest.

4.2 Dark noise studies

Studies are also being performed to investigate the most realistic way to implement dark noise in WCSim. Figure 2 demonstrates two different implementations of dark noise for beam events and for 100 MeV electron events using WCSim v1.1.1. One strategy adds dark noise hits to the entire event window before digitization, whereas the other strategy adds hits to each trigger window after digitization, which can be computationally faster but limiting for trigger studies. Other implementations are currently being explored. Future work will also focus on modelling possible correlations in dark noise hits that can occur when the dark noise comes from radioactive decays within the PMTs.
Figure 1: The expected energy spectra for the radioactive decays of $^{214}$Bi (left) and $^{208}$Tl (right) as a function of the true energy, smeared by 21% to account for detector energy resolution, for different Nhits thresholds.

Figure 2: Number of digitized PMT hits per trigger for beam events (left) and 100 MeV electrons (right) with an Nhits trigger threshold of 25, for different implementations of the dark noise. Strategy 1 adds noise hits to each trigger window after digitisation. Strategy 2 adds noise before digitization to the entire 100 ms window.

4.3 Gadolinium doping studies

There are plans for the intermediate detector of HK to be doped with gadolinium (Gd). Event displays have been created to study the differences between Gd-doped and non-Gd-doped events to see if event isotropy can be used to determine event type. Figure 3 shows example event displays for $\nu_\mu$ beam events in HK and TITUS.

5 Summary

Several UK institutions are currently working on the research and design for the HK trigger and DAQ system. Physics studies are underway to determine the requirements for such a
Event display – Look for differences in Gd and non-Gd events.

Suspect event isotropy will be a strong indicator of event type.

IniBal physics studies!

Example event display, using output from WCSim.

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Figure 3: Example event displays for HK (left) and the proposed near detector TITUS (right). Both displays show an example $\nu_\mu$ beam event.

system. These studies will inform the technical design of the DAQ and trigger system for HK.

References

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[5] Subversion repository for WCsim: http://svn.phy.duke.edu/repos/neutrino/dusel/WCSim/.