THE GLOBAL TRIGGER WITH ONLINE VERTEX FITTING FOR LOW ENERGY NEUTRINO RESEARCH*

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Abstract

Neutrino research is of great importance for particle physics, astrophysics and cosmology. A new global trigger scheme with online vertex fitting has been proposed, aiming at the ultra-low anti-neutrino energy threshold as down to 0.2MeV which is essential for the study of solar neutrino and supernova elastic scattering neutrinos on burst. With the scheme, the time of flight difference of photons fly through the liquid media from the interaction point to the surface of central detector can be corrected online, the trigger window to cover the whole spread of a specific neutrino generated photons can be significantly reduced which lessen the integrated dark noise introduced from the large amount of PMT devices hence a lower energy threshold can be achieved. The scheme is compatible, flexible and easy to implement, it can effectively help the low energy neutrino research topics.

INTRODUCTION

Neutrino research is a very popular and important topic for particle physics, astrophysics and cosmology. Several new neutrino experiments are now under construction or design such as the JUNO [1] (Jiangmen Underground Neutrino Observatory), a multi-purpose neutrino experiment, and CJPLNE [2] (China JinPing underground Laboratory Neutrino Experiment), a water-based LS neutrino experiment focusing on the solar neutrino and geo neutrino topics. The central detectors of those neutrino experiments consist large sphere or cylinder vessel to contain the giant target material which are 20kt Liquid Scintillator for JUNO and few thousand tons of water-based Liquid Scintillator for CJPLNE. PMTs are applied for photon detection due to the large sensitive area and mature technology. Around 16000 20inch PMTs will be installed for JUNO while around 15000 8inch PMTs are estimated to be deployed for CJPLNE.

A neutrino that interacts in the fiducial volume will release charge particles to further generate scintillation light. The light distribute evenly in all directions and finally be captured by the surrounding PMTs and produce electrical signals. The charge and position information of the related event could be further analysed from the PMT signals.

TRIGGER SYSTEM

The information related to one event must be collected to be distinguished by trigger system which could base on the number of PMTs that have generated signals (multiplicity trigger), or base on the total charge information (energy sum) [3]. Since the multiplicity trigger scheme requires only single hit bit information which is very easy to generate, transmit and process, it is the preferred baseline trigger method, especially for experiments that applies tens of thousands of PMTs.

For 20kt LS detector, the physical dimension will be 37meters in diameter, thus the light generated at the edge of the detector will take around 200ns time of flight before reach the PMTs installed on the opposite direction. To cover the TOF time and the slow scintillation components of the LS, the trigger system must open a 300ns time window to cover the full spread of all information from the same event.

PMT generates signal pulses due to thermionic emission which is called dark noise that can't be distinguished from the normal signal. Those dark noise will also be collected during the trigger window that could cause a coincident event. The correspond event rate is a function of trigger window width, dark noise rate and the number of PMT. Figure 1 shows the calculation result of dark noise caused coincidence rate compare to the physical event rate with parameters of 300ns trigger window, 50KHz dark noise for the new developed MCP PMT and 15000 tubes.

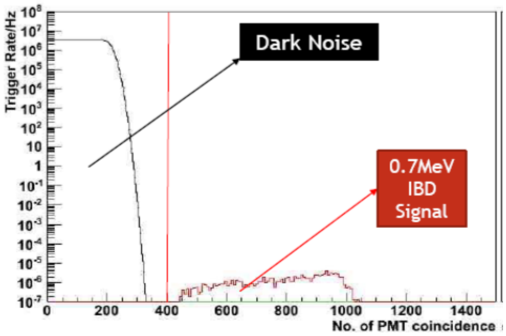

Figure 1: Event rate of PMT dark noise.

By setting the multiplicity threshold to around 400, the dark noise coincidence event can be easily separated from IBD neutrino events that have a minimum deposit energy of 0.7MeV. But for solar neutrino and supernova elastic scattering neutrino physics, many interesting phenomena are located at the energy range as low as 0.2MeV, the multiplicity distribution of such low energy event heavily overlaps with the PMT dark noise.

While approaching the low energy range, the trigger rate increases significantly. Since flash ADC is applied to

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record the waveform of each PMT hit, the increased event rate requires high bandwidth DAQ and make the readout electronics difficult and expensive.

A possible solution to the problem could come from the awareness of the vertex position information in the trigger system. The vertex could be used to correct the propagation time difference to concentrate the correlated PMT hits into a much narrower time region. Then a smaller trigger window could be used which reduces the PMT dark noise and a much lower energy threshold can be achieved.

Furthermore, the threshold could even be adapted to the vertex position, which could better handle the issue of light attenuation effect, spatial effect of energy response and radioactive background at the edge of the scintillator volume due to supporting material.

VERTEX FITTING CONCEPT

To calculate the vertex position, a charge weighted mean position algorithm is widely used in offline analyse. To implement a similar algorithm in the trigger system is very challenging, and the readout electronics will also need to implement real time algorithm to extract the charge information for each hit, otherwise it could just simply transmit raw waveform data for triggered events.

Unlike direct calculation, the vertex fitting method tests the PMT information with all possible positions and finds the most likely one among them. The detailed process contains the following aspects:

- Divide the whole detector volume into certain number of blocks. Since each block is treated as one position, the time difference caused by the dimension of the block should be negligible compare to the trigger window; on the other hand, small block size will cause an unacceptable block quantity. The size of the block should be optimized to compromise the two influences.
- For each block, a TOF correction map can be calculated and applied to the original PMT signals respectively. For events located inside the block, the correction map could approximately compensate the propagation time and merge the widely spread PMT hits to a much narrower time region thus a small trigger window could be applied.
- For each block, a threshold that is adapted with the block position and radioactive background is compared to generate the local block trigger signal.
- All local block trigger signals are logically “OR”ed to generate the final trigger.

The TOF correction, multiplicity calculation and comparison are identical for all blocks that can be handled simultaneously by parallel process architecture.

The concept of vertex fitting is illustrated in Figure 2.

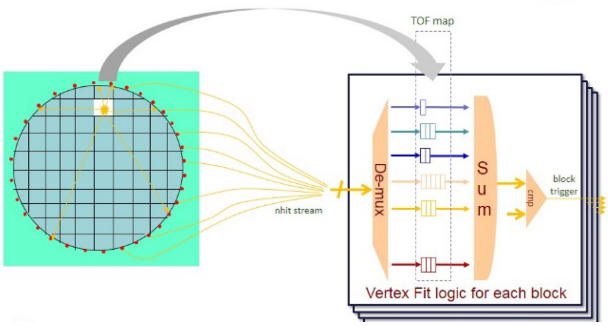

Figure 2: Vertex fitting concept.

SIMULATION AND FEASIBILITY

Simulation result in Figure 3 shows the dependency of event position and PMT hit time distribution in a 37 meter diameter sphere vessel.

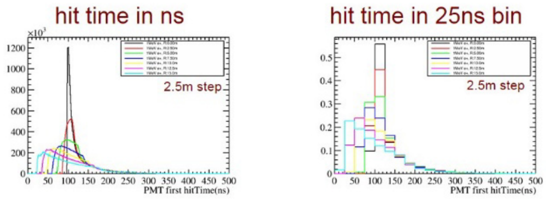

Figure 3: Hit time distribution with vertex position.

The time distribution of events with distance difference of 2.5 meters from the centre can be distinguished clearly even with 25 ns time resolution.

The improvement of energy threshold by reducing the trigger window is shown in the simulation result in Figure 4. With 50 ns trigger window, the PMT dark noise can be removed from 0.2MeV event.

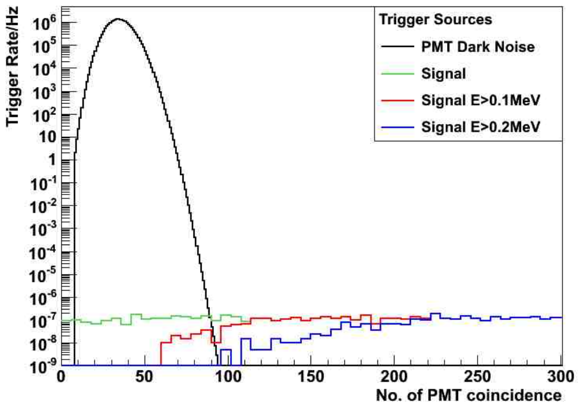

Figure 4: Event rate of PMT dark noise.

From the simulation, 5 meter is taken as a reasonable block size. The time difference inside the block itself is about 35ns, acceptable for 50ns trigger window.

For a 35 meter diameter sphere, the total block quantity is 180.

To avoid events spread cross the 50 ns trigger window boundary, the hit signals from all PMTs will be sampled at 25 ns interval, and two consecutive hit samples are summed to form a 50ns trigger window for multiplicity comparation.

The TOF correction thus can be handled with time granularity of 25 ns. This could be easily implemented by delaying the real time hit information for certain 40MHz clock cycles via register/registers/FIFO.

SYSTEM ARCHITECTURE

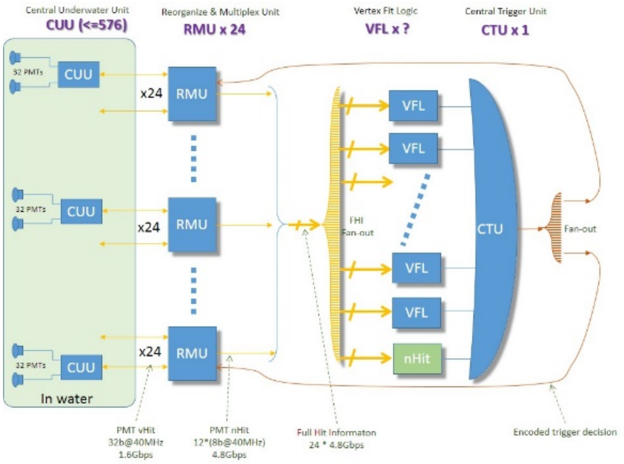

Figure 5 : Vertex fitting system architecture.

The system architecture is shown in Figure 5, the detail of all parts are described below:

PMT Grouping

It is neither possible nor worthy to collect hit signal of each individual PMT. The front end electronics (Central Underwater Unit) interface with 32 PMTs and thus can naturally provide the 32 hit signals at 40 MHz frequency.

For underwater experiment, the PMTs are connected to CUU in an interleaved arrangement to avoid group failure. The CUU sends each individual hit bit in 32 bit vector (called as *vHit32*) via a dedicated optical link. The link speed is 32 bit@40 MHz = 1.28 Gbps and 1.6 Gbps with 8 b/10 b encoding.

The individual hit bit for each PMT could be used for PMT status monitor and hit rate histogram.

Reorganize and Multiplex Unit

Links from 24 CUU are connected to one RMU (Reorganize and Multiplex unit). The hit from the most neighbouring 64 PMTs, forming an 8*8 square slice, are summed up as 8bit digit number called *nHit64*. The 12 nHit64 of the RMU are further multiplexed to transmit in a single optical link. The link speed is 12*8bit@40MHz = 3.84Gbps and 4.8Gbps with 8b/10b encoding.

The system architecture supports up to 24 RMU, which equals to 18432 PMT that is beyond the maximum number of PMT to be used for both JUNO and CJPLNE.

Vertex Fitting Logic/Unit

The output of 24 RMU composes the 24*4.8Gbps full hit information that are used for vertex fitting.

In each vertex fitting logic, the FHI are firstly de-multiplexed to 288 nHit64 channel, the TOF correction is then achieved by delaying each nHit64 via registers for certain cycles as specified in the correction map. The corrected value is then summed up and compare with a threshold value to generate a block trigger.

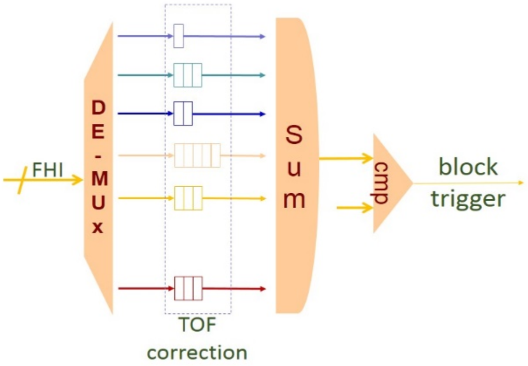

Figure 6: Vertex fitting logic.

The fitting logic has been evaluated on Xilinx V5LX220 device. 288 Delay lines with 8bit wide, 12 byte deep and configurable output tap together with accumulator and comparator utilize less than 5% of the available resource. Thus more than 10 fitting logics could be integrated in single device to reduce the number of vertex fitting unit to around 18 that could be settled in a single crate.

The block triggers of multiple VFL inside the VFU is encoded and transmitted via a single copper cable to central trigger unit.

FHI Multi-sharing

Since as much as 180 vertex fitting logics are running in parallel and they all require the full hit information. FHI multi-sharing is to duplicate the data stream transmitted by the 24*4.8 Gbps optical links for each of these 180 vertex fitting logic, which is done in several stages:

- For each RMU, the identical output is transmitted via several optical links to provide a duplicate factor of 4 to 12 according to the channel number of the optical transmit module.
- The de-multiplexed FHI could be routed to 10 VFL inside the same device which provides a duplicate factor of 10.
- Each optical link can be split into several branches which only depends on optical power budget of

the transmitter/receiver module. A factor of 4 to 8 can be easily achieved.

Combining all these stages, a multi-sharing factor of 160 to 960 is achievable which leaves great flexibility for further upgrade.

Central Trigger Unit

Block triggers from all VFL are logically "OR" in the central trigger unit for final trigger. The CTU also takes responsible to provide interface for calibration system or veto system. Diagnostic features like random/periodic trigger can be generated here as well as the flow control features like throttle, scale.

The fitted vertex position, timestamp, multiplicity number and trigger count information for each event can also be packed by CTU and saved for crosscheck.

The central trigger signal is fan-out and transmit back to RMU and further to all CUU.

Trigger Latency

Trigger latency affects the buffer requirement of the front end electronics. The processing in the trigger system is simple and fixed, the majority of the latency comes from the link delay between modules. 200 meter of fibre between CUU and RMU will end up with trigger latency about 3 us which is far less than the acceptable value.

STATUS AND CONCLUSION

New trigger scheme with online vertex fitting feature has been designed for next generation underground neutrino experiments that are under construction in China. Technical issues has been explored and the complete system structure has been designed. The system is feasible to achieve energy threshold of 0.2MeV that is of importance for related physics topics.

ACKNOWLEDGEMENT

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