UK DAQ Plans for Hyper-Kamiokande

6th International Hyper-Kamiokande Open Meeting
January 2015

Giles Barr and Debra Dewhurst
on behalf of the UK DAQ group

Overview

- Introduction
- Simulation and physics studies
- Architecture and design
- Summary

Introduction

The team:

Lancaster University: Helen O'Keeffe, Laura Kormos, Alex Finch, Matt Lawe, Tom Dealtry

Oxford University: Giles Barr, Debra Dewhurst, Ann Laube (Masters student), 50% electrical engineer, 50% software developer

QMUL: Francesca DiLodovico, Sam Short, Karen Hayrapetyan (Elec. Engineer), New PDRA

Rutherford Appleton Laboratory: Alfons Weber, Trevor Stewart, Tim Nicholls, Matt Thorpe, New PDRA.

Our resources:

The UK obtained 3 years of funding to work on Hyper-Kamiokande starting October 2014

Introduction

- Our aim is to build something like Super-Kamiokande DAQ + trigger
  - Super-K DAQ has a robust and proven design
  - Update with the technology of 2019 in mind.

- Main trigger will be based on Nhits
  - Studying ways to add additional triggers to collect more low energy samples (sub-Nhits trigger).
  - Processing farm to search for hit combinations pointing back to a specific location, and spacial patterns consistent with low energy neutrino interactions.

- Supernova triggers
  - Big ring buffer storage: can save data if supernova reported hours later. Also local monitoring so we can report a supernova (SNEWS).
  - Trigger processing to recognise statistically significant increase in rate over 10-100 secs

Physics Studies

- Physics studies are being performed to ensure that we can:

  - ✓ Successfully access all physics of interest
  - ✓ Have the ability to handle event rates
  - ✓ Discard non-physics events using a trigger
  - ✓ Handle events from a local supernova

- These studies will be the basis from which the technical design of the DAQ is decided.

- May also be able to help inform decisions regarding PMT choice, PMT coverage and electronics.

Physics Studies

Our studies are being performed using official HK software:

- WCSim being used for simulation.
- UK DAQ group have been extensively testing the noise, digitisation and triggering algorithms currently implemented and providing feedback to the developers.
- UK DAQ group are hoping to contribute to the development of WCSim in the near future.

Current work has been focussing on:

- Developing methods to discard non-physics events.
- Understanding the impact of the PMT photo-coverage for being able to access low energy events.
- Visualizing events using event displays to investigate event isotropy, particularly to study the effects of gadolinium doping.

Trigger Studies

Helen O'Keeffe

- Without a good trigger in place PMT dark noise is expected to dominate the data rates at Hyper-K.
- Currently implemented in WCSim is an SK-I style trigger. Selects events that have > Nhits in a 200 ns time window. Nhits = 25.
- SK-I trigger rates highly dependent on:
  - Nhits threshold
  - Noise rates

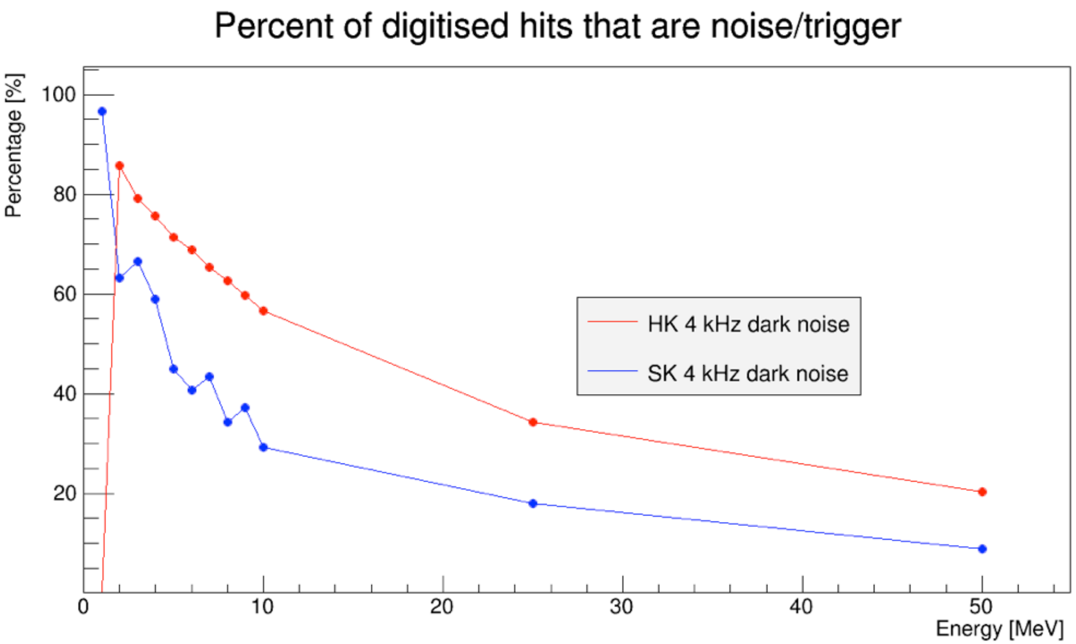
Event class	(estimated) rate (Hz)	Estimated data rate
PMT noise	4×10^3 (per PMT)	4.8 GB/s
^{238}U chain	476	30 kB/s
^{232}Th chain	158	30 kB/s
^{222}Rn	4158	250 kB/s
Solar neutrinos	0.0025	0.8 B/s
Supernova neutrinos	20000	24 MB/s

Rates based on 100,000 PMTs

- For high noise rates can remove more noise by requiring higher Nhits threshold but this limits the observable physics.
- We've been investigating what other things can be used to select events the Nhits cut misses.

Dark noise in Hyper-K

Trevor Stewart



- Single electron MC samples with 4kHz noise.
- HK and SK geometries.
- Nhits threshold > 25, 4kHz dark noise
- SK: Events dominated by dark noise for energy < 5 MeV.
- HK: Events dominated by dark noise for energy < 10 MeV.

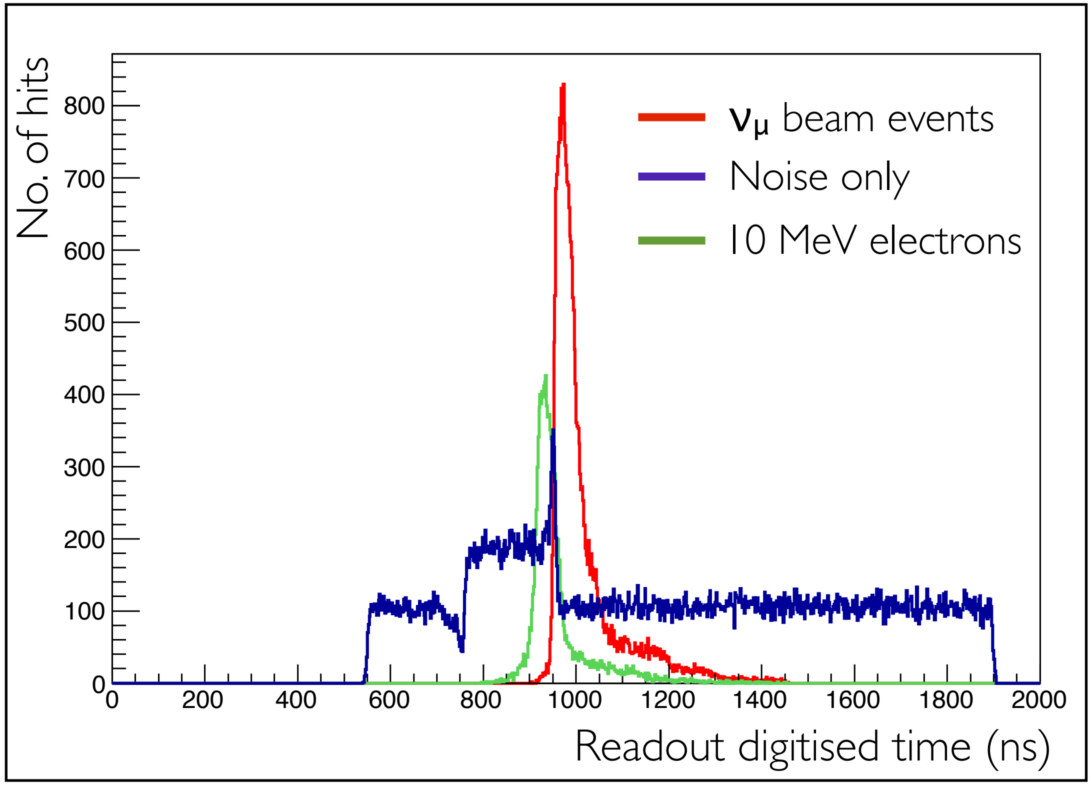
Dark noise in WCSim:

- Currently dark noise is implemented post-digitisation.
- Routine written to implement pre-digitisation, which is more appropriate for our DAQ studies.
- Currently being tested by UK DAQ group but hope to submit it to WCSim developers for inclusion in WCSim soon.

Using timing information

Debra Dewhurst

- Hits from physics events (including transit time of light across the detector) occur in a relatively narrow time window.
- Dark noise has more of a uniform distribution.
- Can we use SNO-like "in-time channel (ITC) cut"* to remove the dark noise?



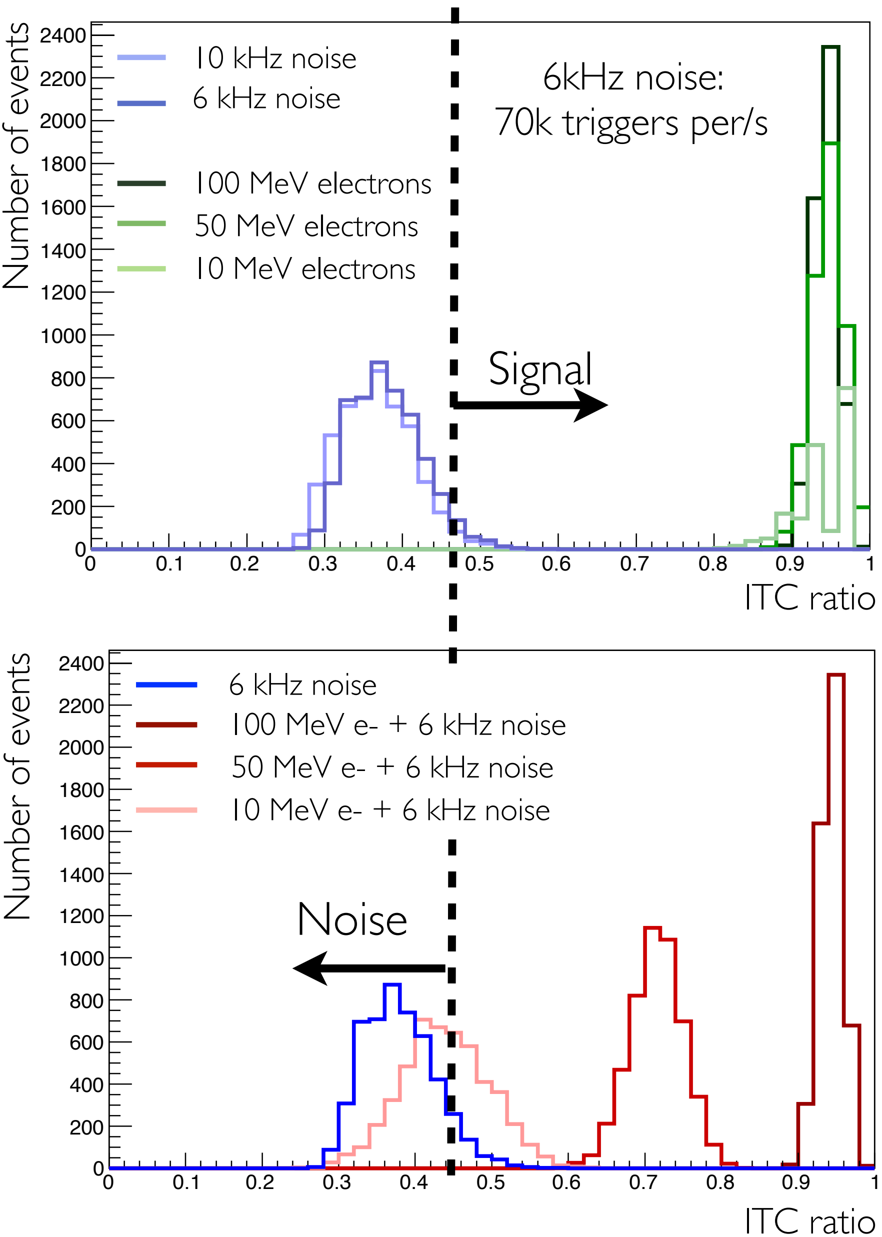
- Find maximum number of hits inside a sliding time window
- Calculate:

ITC ratio = max. number of hits in sliding window / total hits in event

* N. K. McCauley, *Producing a background free data set for measurement of the charge current flux and day-night asymmetry at the Sudbury Neutrino Observatory*, 2001.

Using timing information

Debra Dewhurst



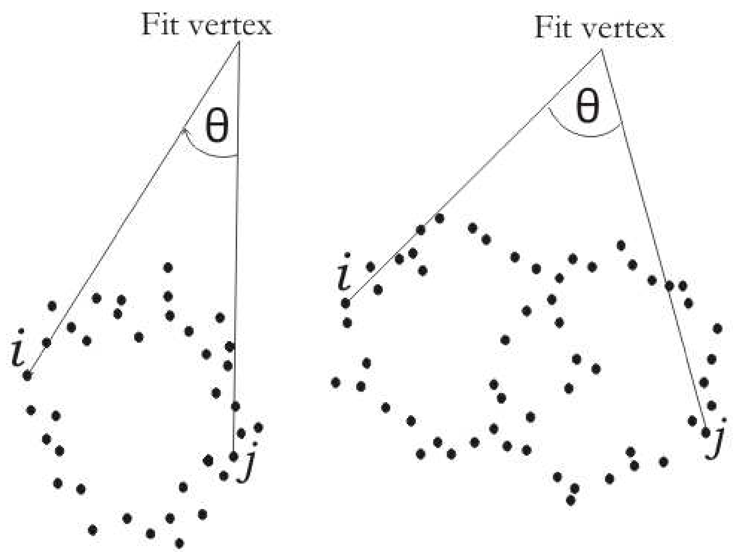
A preliminary look at this variable for HK:

- ITC ratio calculated using 200 ns sliding time window.
- Note: Nhits > 25 applied in these plots as non-trivial turning this off in WCSim at the moment (investigating this).
- As a result looked at higher noise rates (6, 10 kHz) and particle energies (10, 50 and 100 MeV).
- First results promising: good separation between signal and noise.
- Further investigation needed to look at behavior for:
    - Nhits threshold < 25 or no Nhits cut.
    - lower energies and 4kHz noise.
    - more complex event topologies.
    - more statistics (only 2000 events per sample here).
    - smaller/larger sliding window.

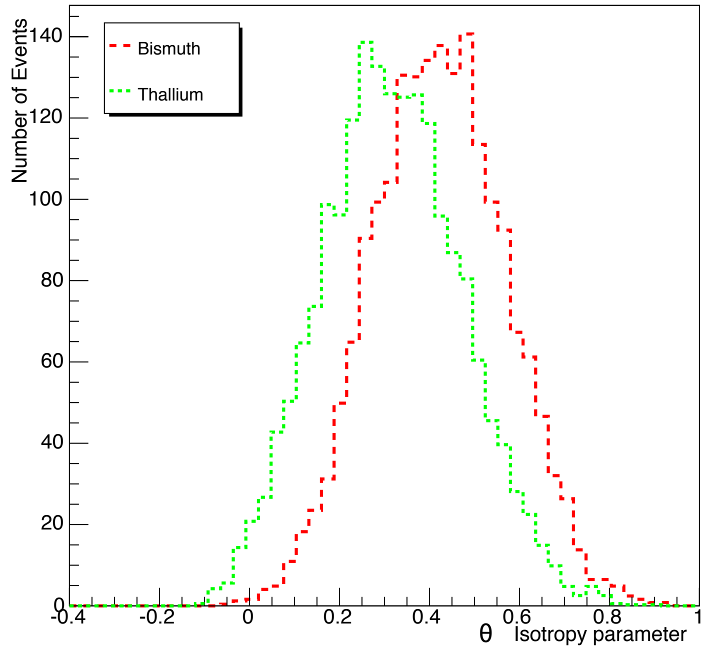
Using spatial information

Helen O'Keeffe

- SNO found isotropy to be useful for discriminating between different event topologies*.



- Angle θ smaller for single ring-like events e.g. solar neutrinos, ^{214}Bi
- Angle θ larger for multi-ring-like events e.g. gadolinium, ^{208}Tl



- Do noise events on average have an even wider angle than multi-ring events?
- Can this be used to separate signal and noise?
- May require fast vertexing at trigger level.

* H. M. O'Keeffe, Low Energy Background in the NCD Phase of the Sudbury Neutrino Observatory, 2008.

Photo-coverage studies

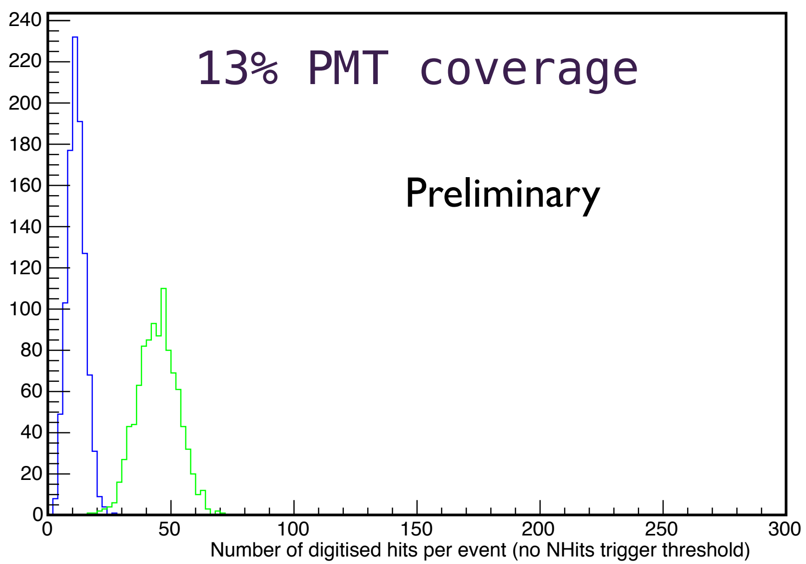
Sam Short

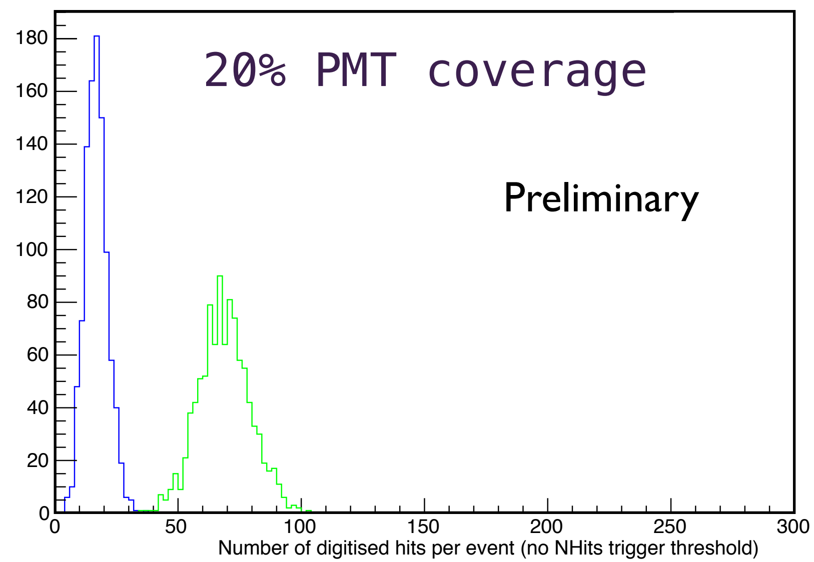
Begun to look at impact of photo-coverage on observable physics:

- 8 MeV gamma single particle MC with and without 4 kHz noise.
- HK geometry with 13% and 20% photo-coverage
- Dominated by noise at either coverage. Going to need more than Nhits trigger to select these events.

PMT Coverage	Mean number of real hits	Mean number of noise hits
13%	11	44
20%	16	68

Real and noise hits (after digitisation) for 8 MeV gammas in Hyper-K:

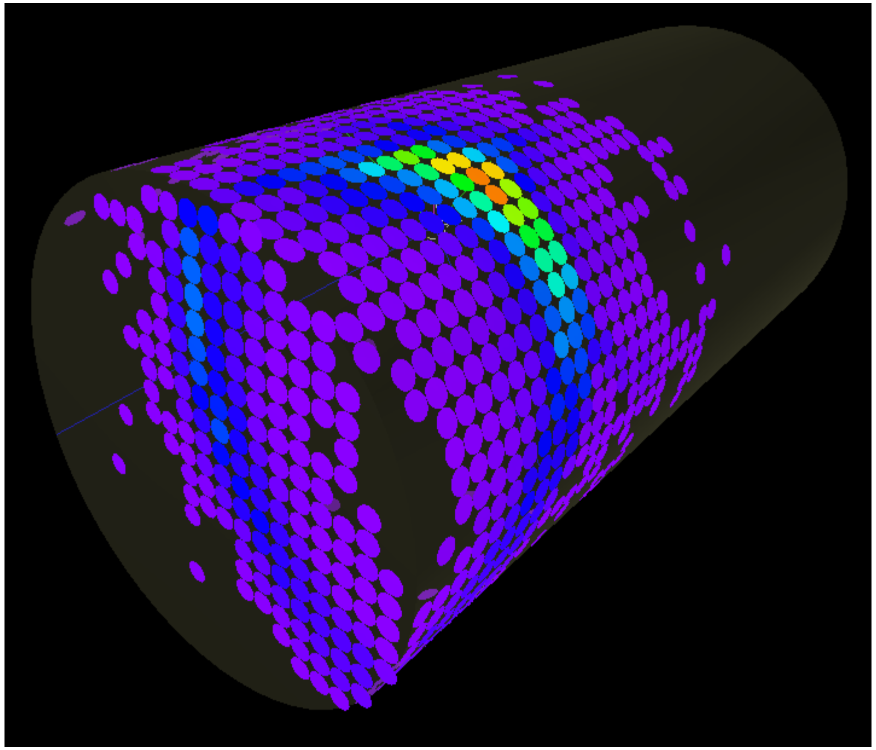




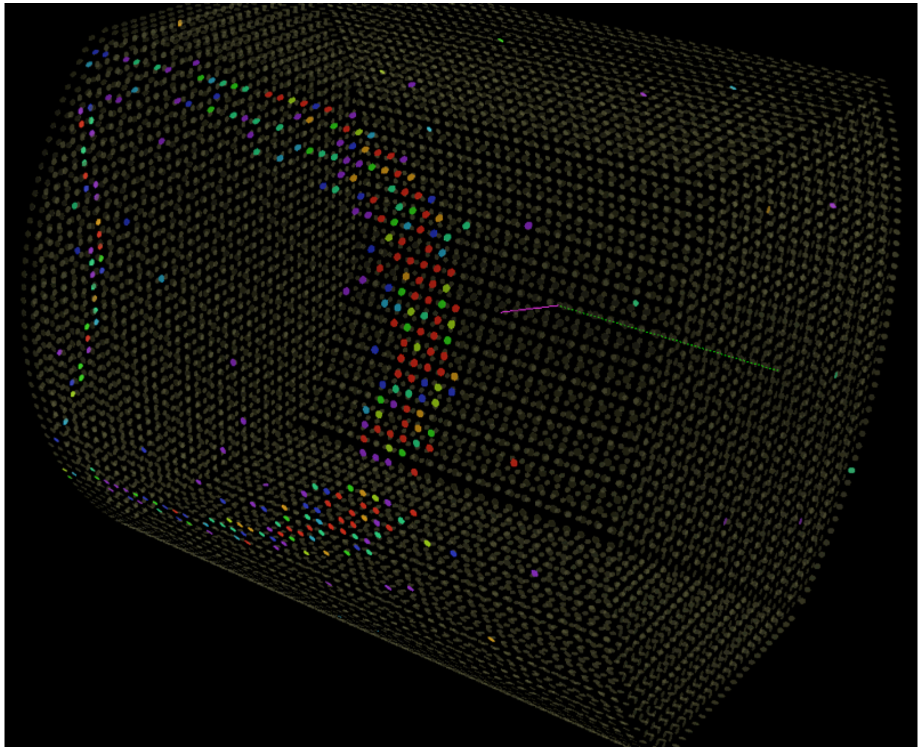
Event Displays

Alex Finch

- There are proposals for TITUS to be doped with gadolinium.
- Event displays have been created to look at the differences between Gd-doped and non-Gd-doped events.
- Investigations in this way to see if event isotropy can be used to determine event type.



Example ν_μ beam event in TITUS



Example ν_μ beam event in Hyper K

Further work

Plans:

- Create a full simulation system for studying DAQ architecture decisions (data rate, queueing performance etc.) and triggering (efficiencies, sensitivities).
- Look at the full range of physics signals we want Hyper-K to be sensitive to e.g. solar neutrinos, supernova, atmospheric neutrinos, and also the backgrounds we want to reject e.g. radioactive decays, dark noise.
- Production of these MC samples are currently underway (some being produced internally within the DAQ group and some externally by other groups).
- Studies for TITUS DAQ - we plan to scale the Hyper-K DAQ for implementation in TITUS. Need to look at effects of gadolinium doping.

How is this information being used to inform the design of the DAQ:

- Regular meetings attended by all UK DAQ members to take the information from the physics studies and use it to inform the technical design of the architecture.

Architecture

Two main topologies being considered for Hyper-K:

1. Trigger collects information for decisions, e.g. Nhits transmits back to electronics to request data from trigger window
2. All hits transmitted from electronics to DAQ trigger farm, decisions made in farm which time windows to keep.

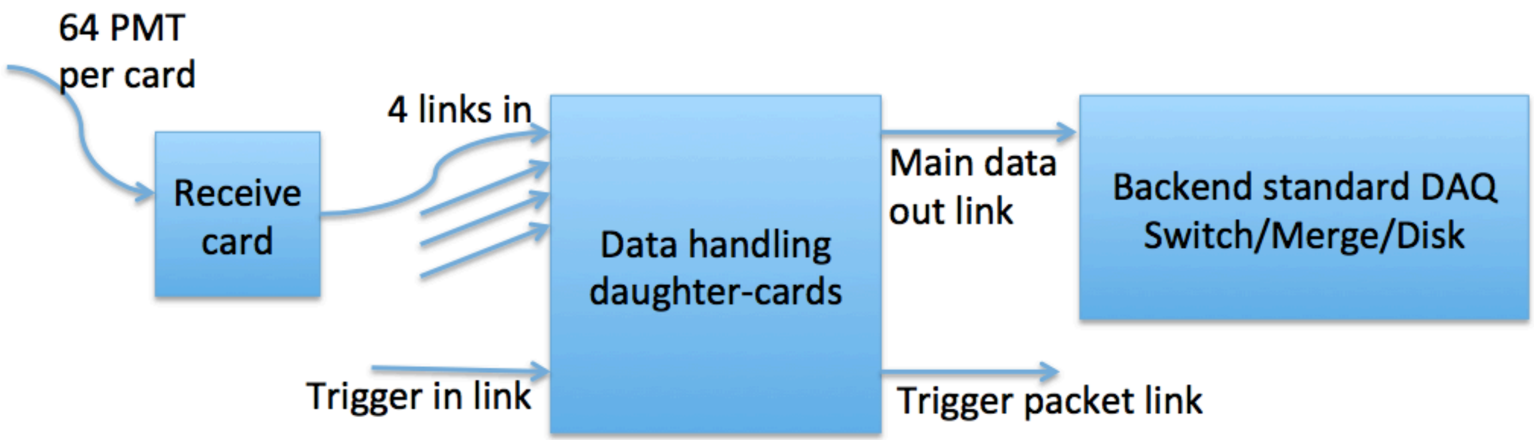
Trying to keep designs flexible to decisions regarding:

- Choice of electronics (ADC/TDC or waveform digitisation, underwater or out of water)
- PMT choice (dark rate and photo-coverage)
- Tank design (multiple compartments, board-to-PMT connection topologies)
- Near detector design (Gadolinium doped?)

Studying each topology may help inform some of these other decisions.

Architecture: Topology 1

Hardware orientated way:



One of 10 compartments = 10,000 PMT
Rates for ADC/TDC option (12 bytes/hit)

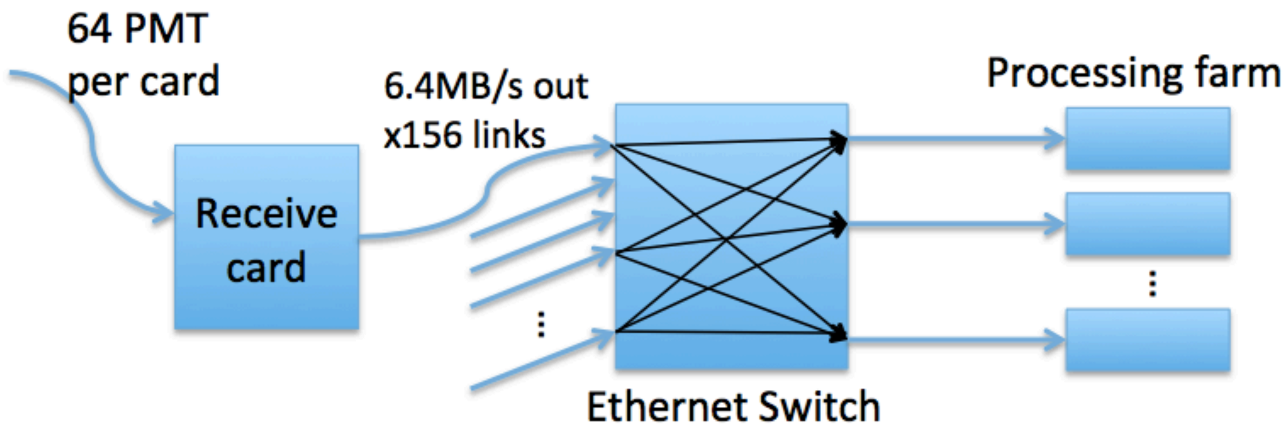
Total PMTs	10,000
PMTs/receive card	64
Number of receive cards	156
Recieve card out data rate	6.4 MB/s
Number data handling units	39
Trigger packet data rate	25.6 MB/s

Data handling daughter cards:

- Store incoming data in circular buffer (~10 s is feasible).
- Count Nhits and send on trigger packet link.
- Send Sub-Nhit data (see later).
- Receive triggers and send data at corresponding times on data link.

Architecture: Topology 2

More software oriented way (like MINOS, NOvA):



One of 10 compartments = 10,000 PMT
Rates for ADC/TDC option (12 bytes/hit)

Total PMTs	10,000
PMTs/receive card	64
Number of receive cards	156
Receive card out data rate	6.4 MB/s
Total pre-trigger data rate	1 GB/s
Number farm nodes	50
Farm node input data	20 MB/s

Switch:

- Large switch (156 inputs), or aggregate output more than one 'receive card' and have smaller switch.

Processing farm:

- Could be farm of Linux boxes, or GPUs or similar.
- Nodes will see all data from whole compartment, divided (to parallelize) by time windows.

Other ideas/considerations

Robustness of the front-end systems:

- If separate compartments used, could make DAQ and trigger for each detector compartment independent for robustness.
- DAQs can run independently so if one tank off for calibration/repair can still take data from other compartments.
- Each compartment self-triggers based on Nhits in that compartment.
- Can receive trigger input from master trigger controller which receives beam spill information and triggers from compartments.

Robustness of the back-end systems:

- Use distributed cluster technology for DAQ and trigger farm such that if one node fails its processes automatically run on another node
- Goal is to exchange faulty computer hardware with minimum disruption

Other ideas/considerations

If Flash-ADC waveform used:

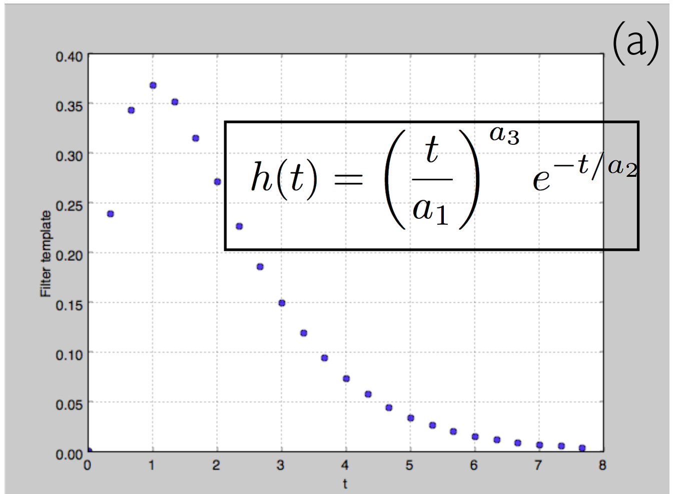
- Canadian proposal to use Flash-ADC waveform. Rates of data is factor O(5) higher than ADC/TDC data which is probably manageable.
- Study algorithms to extract time and pulse-height. Want algorithm for trigger, so should be fast and possible in FPGA
- Finite impulse response (FIR) filtering: (Used on other HEP experiments (e.g. NA48, CMS).

$$Y_n = \sum_{i=0}^{m} c_i x_{n-i}$$

- Allows filter to be applied after digitization to change response of electronics.
- Makes possible use of different shaping optimization for pulse-height and timing algorithm. Need to find the coefficients c_i.

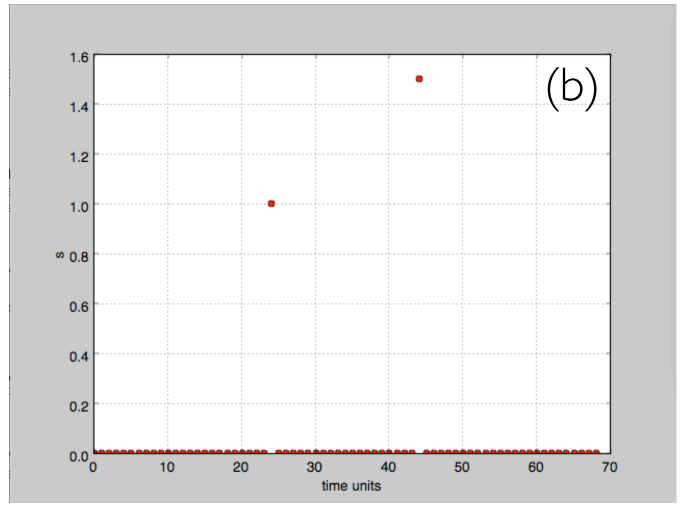
First studies of FIR

Ann Laube



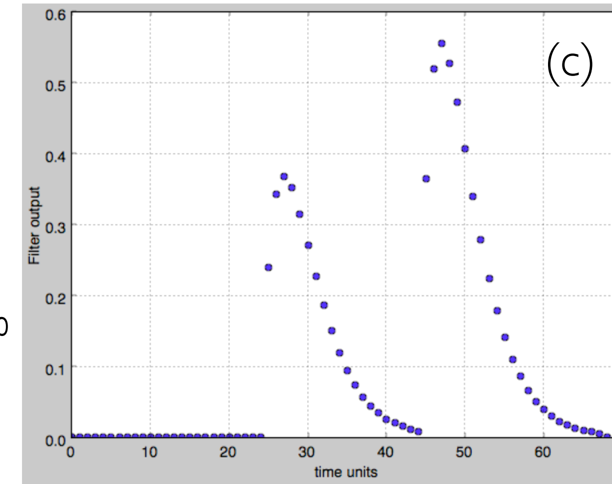
Shape from pulse parameterisation h(t)

convolute with



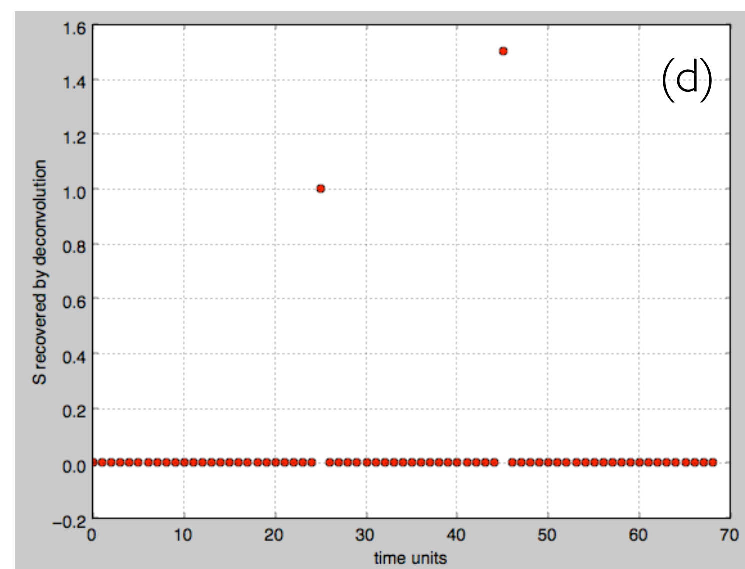
Spikes representing two events

gives



Simulated double pulse x_i

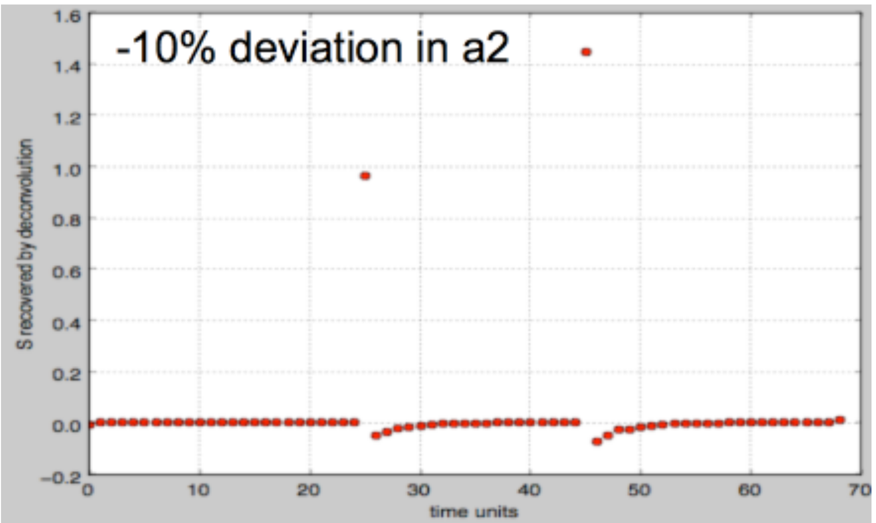
- Derive filter c_i from input pulse shape parameterisation
- Feed simulated double pulse x_i in plot (c) into algorithm and we recover the spikes representing the two particles we put in.
- We obtain y_i in plot (d)

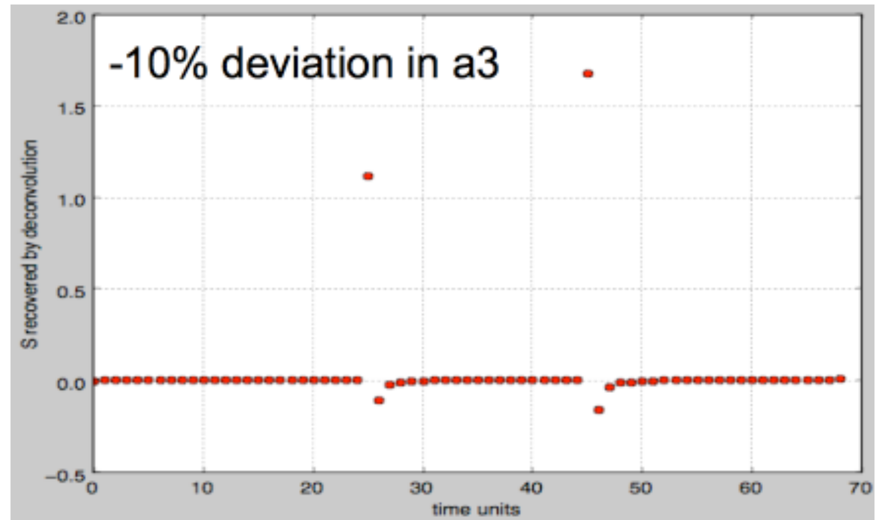


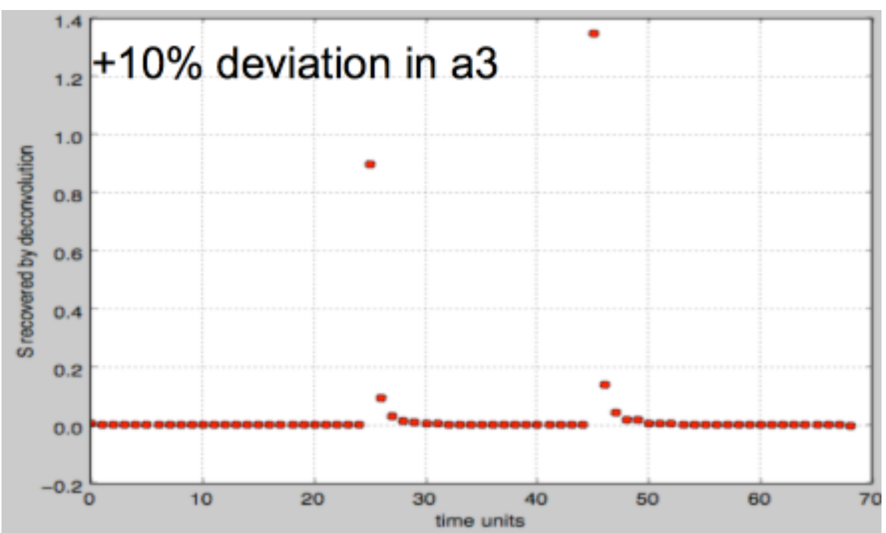
First studies of FIR

Ann Laube

Is reconstruction robust if we don't have parameterization quite right?







nominal values a1=1, a2=? ticks, a3=1

Introducing quite a dramatic (10%) shape difference between template and simulated pulses we still see good reconstruction of initial signals

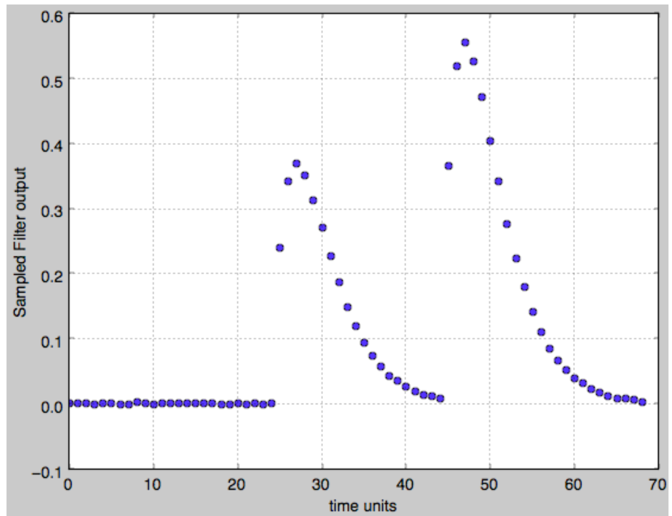
First studies of FIR

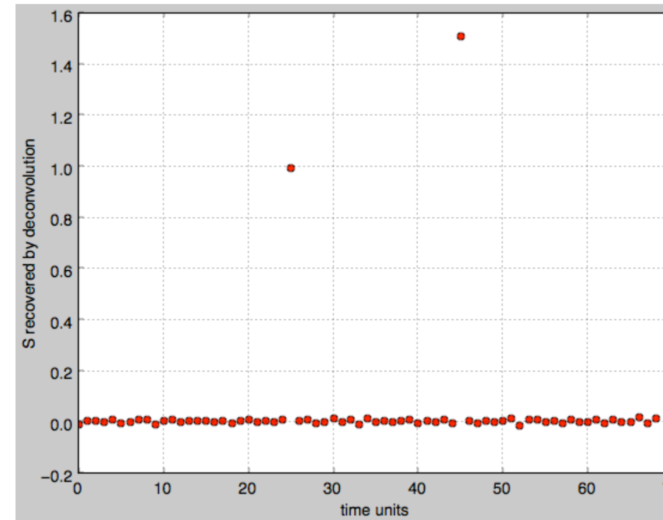
Ann Laube

Now add analogue noise and digitization:

0 to 1 is
ADC count 0 to 1023

Noise 1-sigma = 1 LSB

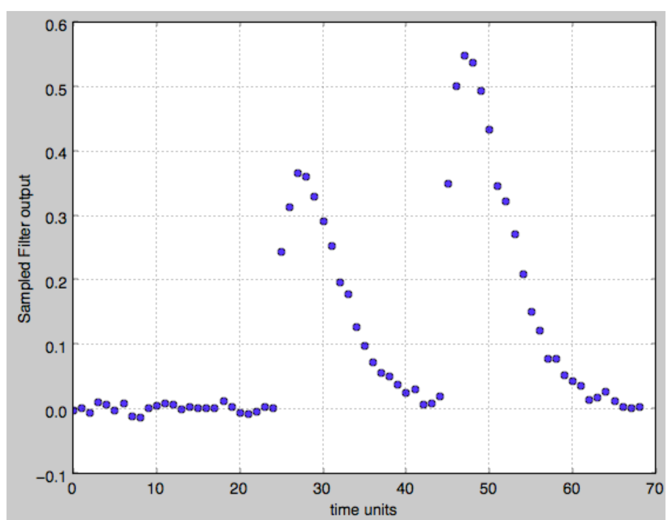


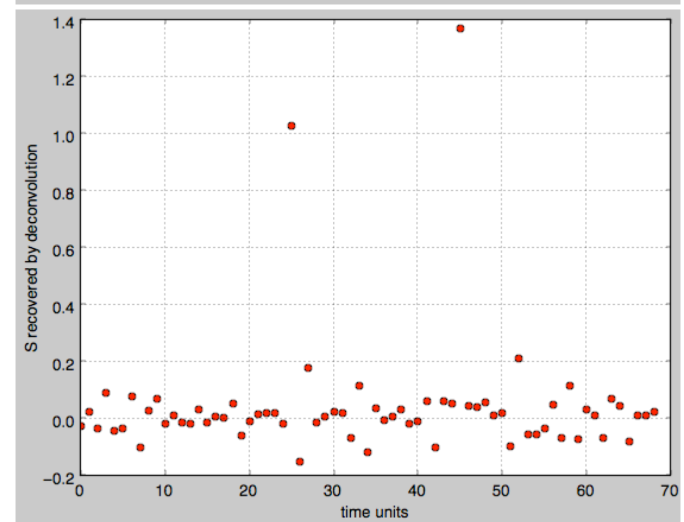


0 to 1 is
ADC count 0 to 1023

Noise 1-sigma = 10 LSB

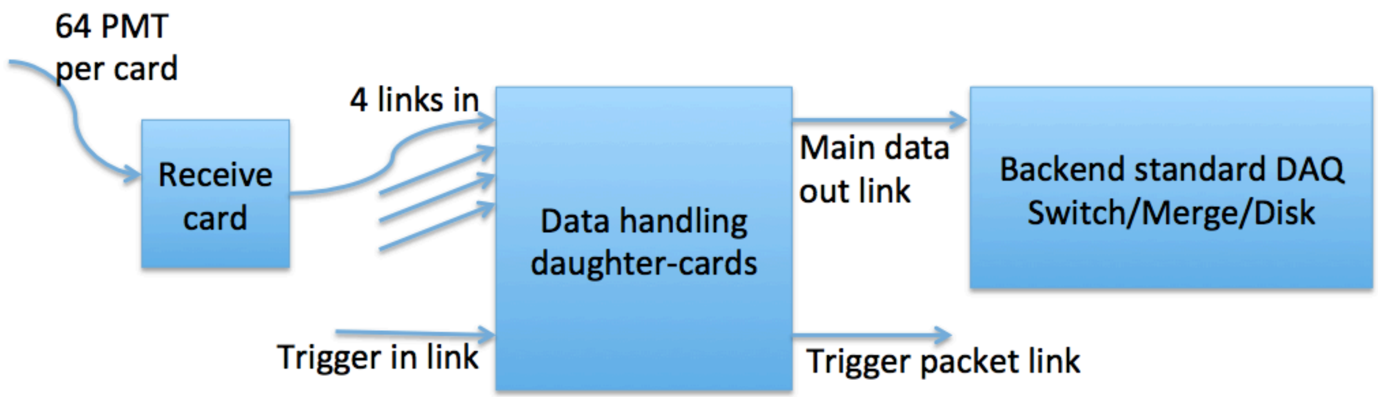
+10% deviation in a3 parameter





Work is ongoing: Trying time and charge integration algorithms next

Extended trigger possibilities



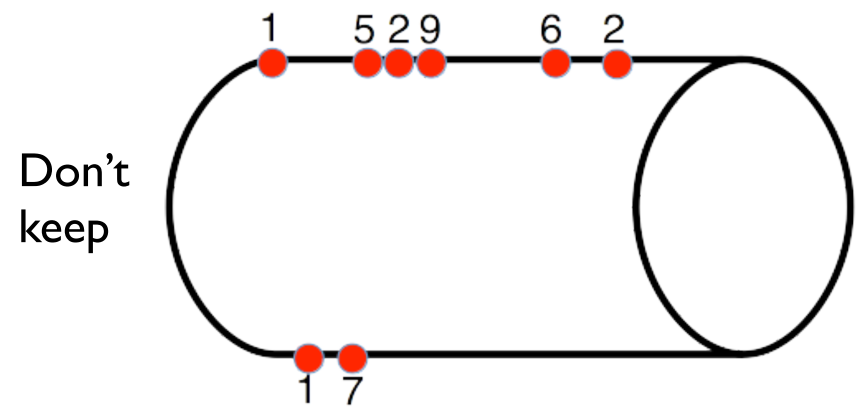
What additional trigger algorithm opportunities exist?

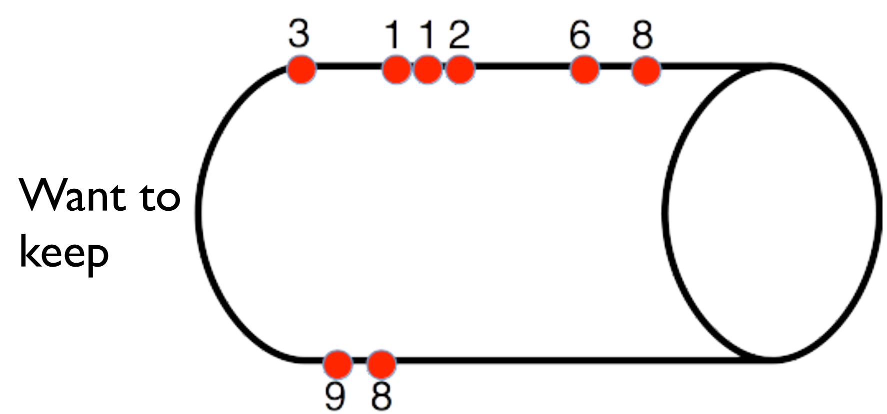
- Can cause trigger to select between readout options e.g.
  - Read all compartments, read one compartment
  - Length of readout window around trigger
  - Some more sophisticated tricks to optimize supernova trigger
- One we are thinking about first: sub-Nhits trigger:
  - For events with < Nhits, look for combinations of hits in time and PMT position in a tighter coincidence time window
  - Possible uses: Solar, supernova, ...

sub-Nhits trigger

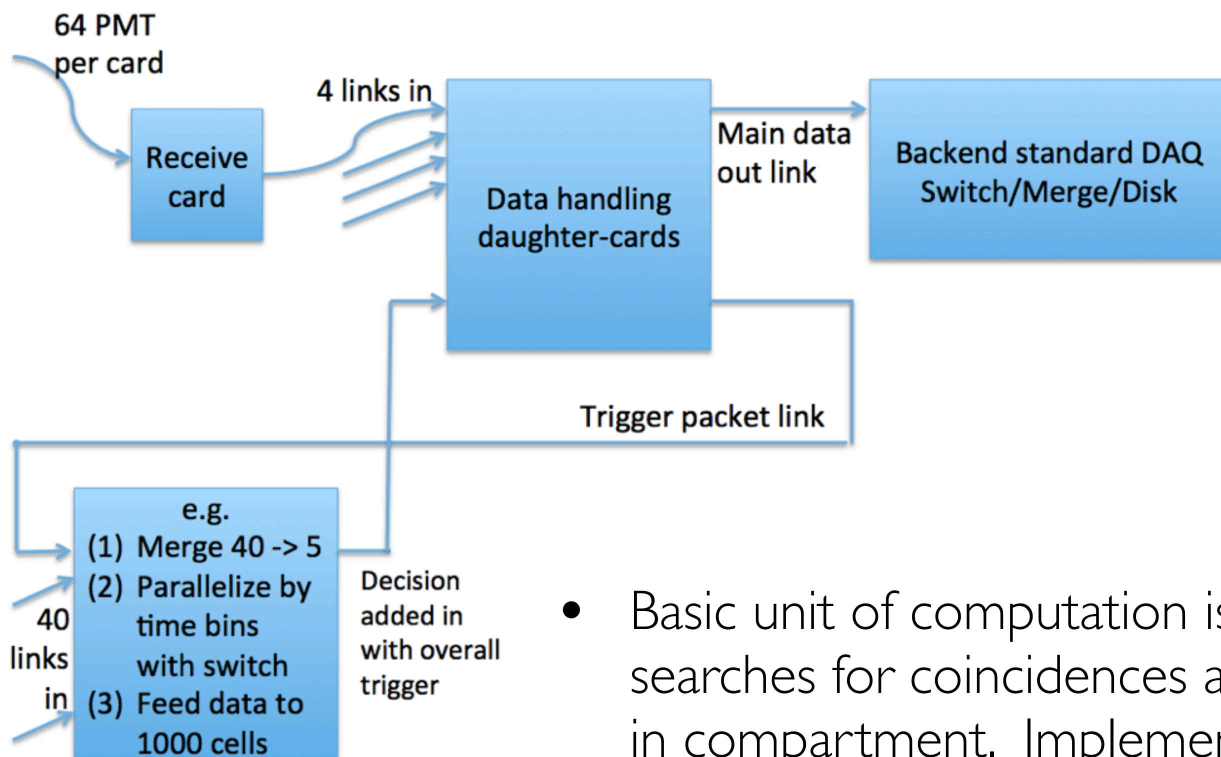
- Top diagram looks like random coincidence of PMT dark noise which won't trigger because Nhits<10
- Bottom diagram has hit times which could be consistent with photons from one place
- Must study if it is possible to do this in real time and whether to implement in hardware/firmware.
- Or may be possible with computer farm, GPUs etc.
- It's not necessary to deal with > Nhits hits, because they trigger anyway.

Numbers give times of hits
Example when Nhits threshold is 10





Hardware sub-nhits possibilities



- Basic unit of computation is the 'cell' which searches for coincidences at a given location in compartment. Implement in FPGA logic.

- Perhaps have 1000 cells overall. Each cell has a lookup table of fixed time offset for each PMT
- Feed data in parallel to all cells in FPGA chip
- Cells look for coincidences in offset-corrected PMT times in time window of e.g. 25ns.

Summary: So far this looks feasible, rates not too high, chips don't need 1000s of pins etc.

Requirements document

- The UK DAQ group have begun to produce a document outlining plans:

Criteria for the development of a DAQ system for HK
Draft: 8th January 2015

- There are five main areas considered in this document:
  - Event rates and triggering
  - Detector readout requirements
  - Data storage
  - Functionality
  - Detector monitoring
- Document to be circulated to collaboration soon after this Hyper-Kamiokande Open Meeting.

Summary

- Large active team in the UK, work is speeding up
- We have funding for 3 years.
- Near term goals:
    - Physics studies to help drive architecture design – well under way, devising and testing trigger algorithms, e.g. sub-Nhits trigger
    - Gather information for architecture choices by collaboration e.g. electronics design, PMT design. Continue considering alternatives.
- Longer term:
    - Prototype when prototype electronics becomes available
    - Prepare for construction grant bid (in UK in 2017)