# UK DAQ Plans for Hyper Kamiokande


Helen O'Keeffe

Lancaster University, UK


5th International Hyper Kamiokande meeting

Vancouver, July 2014

# UK DAQ institutions

- Several UK institutions will participate:
  - Lancaster University

    H.M. O'Keeffe, L. L. Kormos, A.J. Finch
  - Queen Mary, University of London

    S. Short, F. Di Lodovico
  - STFC Rutherford Appleton Laboratory

    T. Nicholls, M. Thorpe, T. Stewart
  - University of Edinburgh

    G. Cowan, M. Needham
  - University of Oxford

    G.D. Barr, D. Dewhurst

***Bridging funds to spend between Jan. 2014 and Sept. 2014***

***Proposal submitted to STFC for R&D funds, May 2014***

# UK DAQ Group

- **DAQ Physics**
  - Physics studies to develop detailed requirements for DAQ design
  - Gain in-depth understanding of detector
  - Work with TITUS group to study Gd option
- **DAQ Technical**
  - Implement results of physics studies into DAQ architecture
  - Slow control monitoring

***Two way process – both groups work together to develop HK DAQ systems***

# UK DAQ interests

- ***Design and development of DAQ for Hyper Kamiokande***
  - Develop detailed requirements for DAQ design
  - Investigate possible DAQ frameworks
  - Detailed system design based on chosen framework
  - Development of fast trigger algorithms for noise rejection
  - Slow control of PMT parameters

- ***Design and development of DAQ for TITUS***
  - Adapt HK DAQ design and trigger algorithms for use in TITUS
  - Investigate use of LAPPDs
  - Study effect of Gd-doping - advantageous if HK Gd doped

# UK DAQ interests

- ***Participation in 1 ktonne prototype***
  - Following meeting on Saturday, interest registered
  - Currently under discussion

- ***Data transfer and storage***
  - Investigate methods for data transfer and storage
  - Ensure sufficient local capacity in the event of a supernova

# Event readout + triggering

- ***Main trigger strategy – like Super-K: Nhits***
  - Good enough for atmospheric events, proton decay, beam neutrinos
- ***Dominated by dark noise coincidences***
  - Limits threshold for low energy physics
  - Important to consider for gadolinium physics
- ***Additional "smarter" trigger to separate low energy physics events from random dark noise coincidences***
  - Very important for gadolinium
  - Important to attempt to reduce solar neutrino threshold
  - Helps with supernova physics

# Data rates

***Important to consider rate in full detector volume***

- Background rates based on SK levels
- 10 kHz dark noise per PMT
- Assume 12 bytes per PMT hit, 100,000 PMTs in the detector
- Assume $^{238}U$, $^{232}Th$ and $^{222}Rn$ events have 10 hits per event

| Event class | (estimated) rate (Hz) | Estimated data rate |
|---|---|---|
| PMT noise | $10 \times 10^3$ (per PMT) | 12 GB/s |
| $^{238}U$ chain | 158 | 20 MB/s |
| $^{232}Th$ chain | 475 | 57 MB/s |
| $^{222}Rn$ | 2772 | 332 MB/s |

**External events have been ignored**

**Dark noise may be more optimistic**

# Super Kamiokande

***SK achieved a threshold of 3.5 MeV***

- Read out most  data
- Analysis selected events based on solar zenith angle distribution
- Background was flat

***Aim to keep and if possible improve the very low energy threshold achieved by SuperK***

# Hyper K/TITUS

***TITUS will use Gd for neutron capture***

Neutrons have a flat distribution for solar zenith angle

Intrinsic backgrounds have flat distribution

***Need something more sophisticated for threshold!***

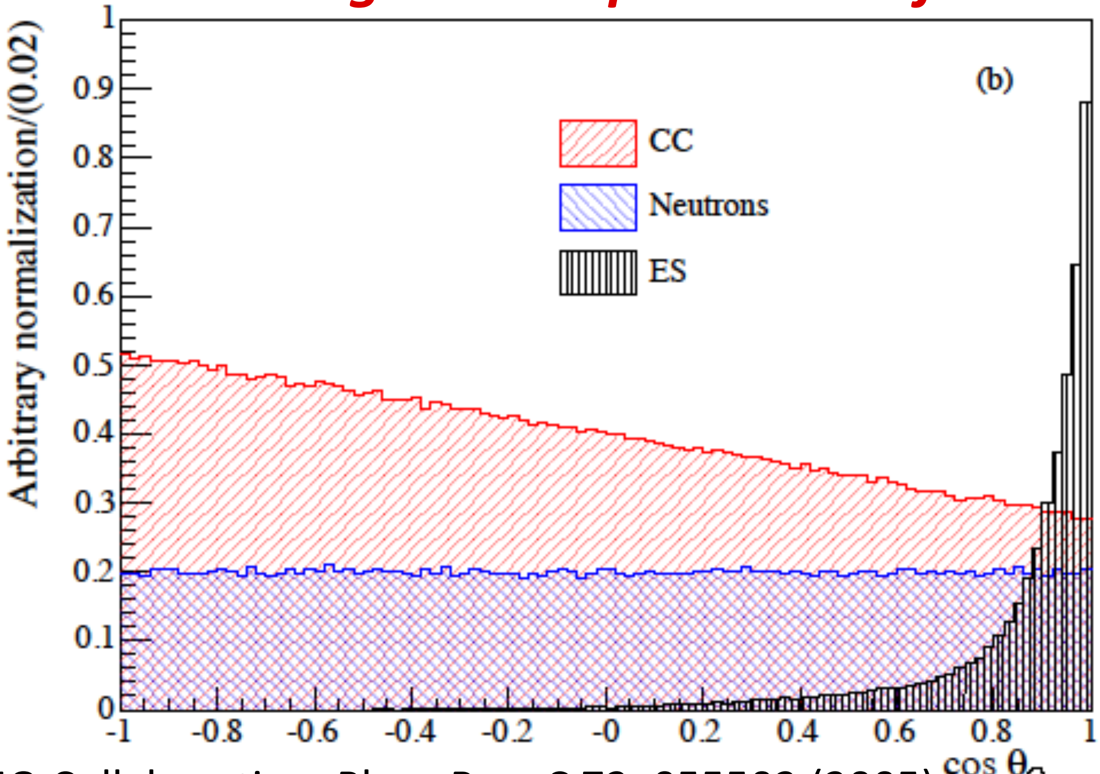
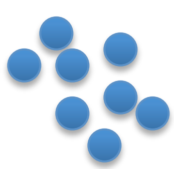


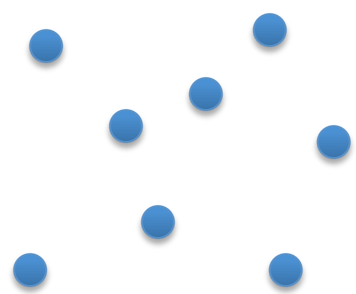

Figure from: SNO Collaboration, Phys. Rev. C 72, 055502 (2005)

# Possible trigger variables

- ***Could use following***
  - Timing - dark noise hits are random within a trigger window
  - Charge
  - Angular distributions – dark noise more isotropic in detector (experience from SNO)



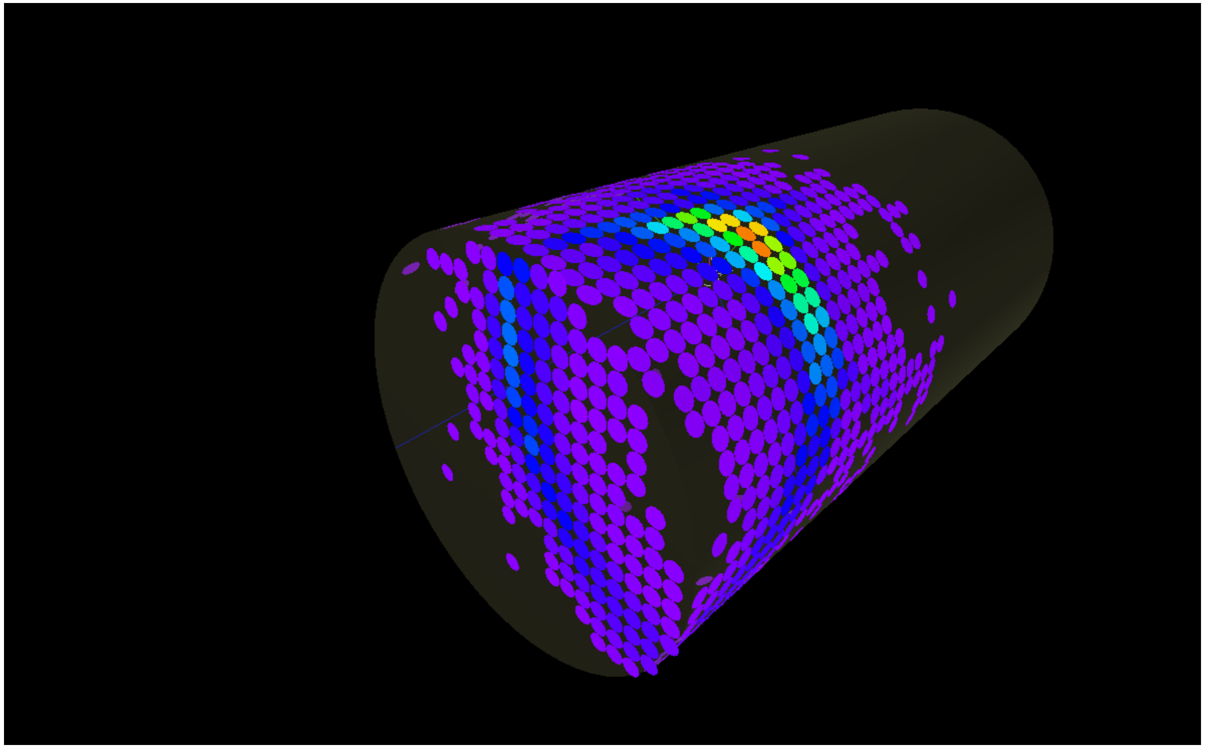
Low E event
Average angle between hits is small



Noise “event”
Average angle between hits is larger

# Initial physics studies

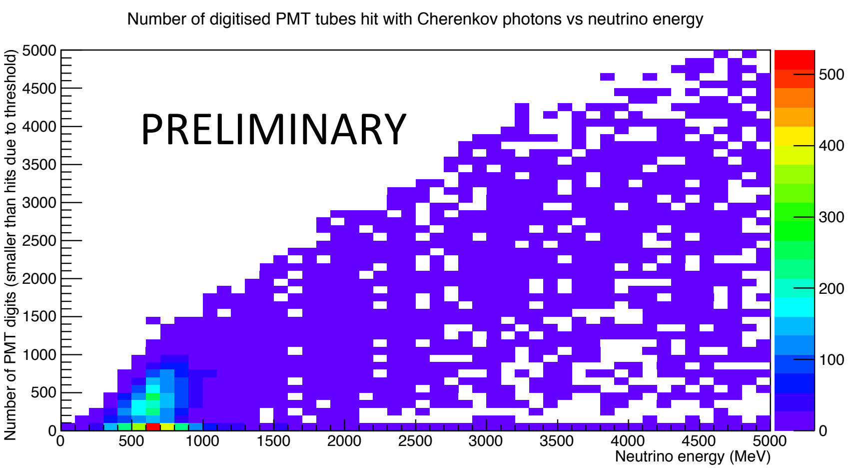
- ***Event display***
  - Look for differences in Gd and non-Gd events
  - Suspect event isotropy will be a strong indicator of event type

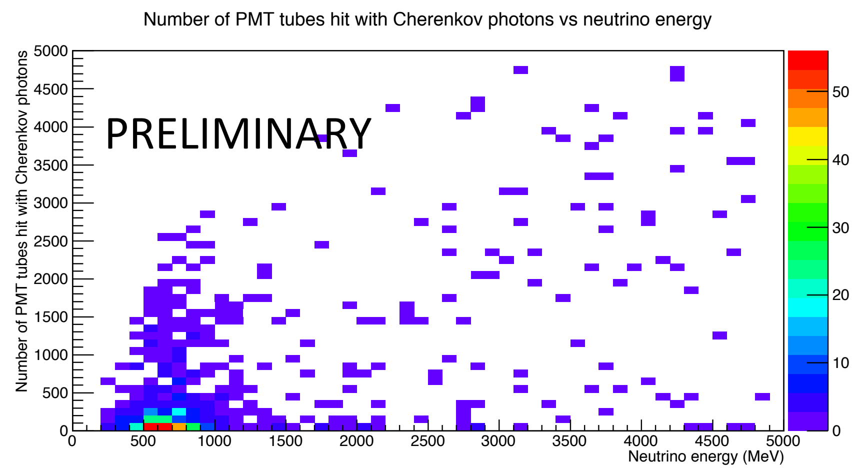


Example event display, using output from WCSim
*A. Finch, Lancaster*

# Initial physics studies

- ***Threshold studies***
  - Look at relationship between Nhits and energy
  - Idea of energy scale and threshold effects

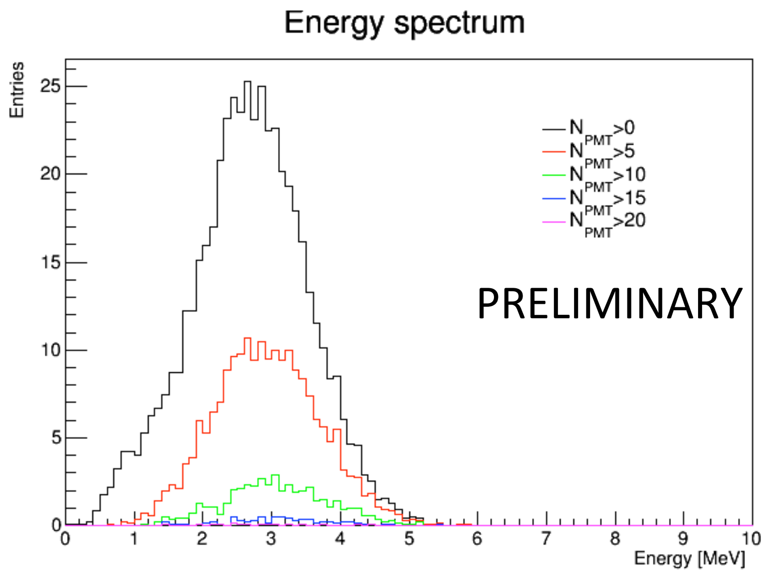


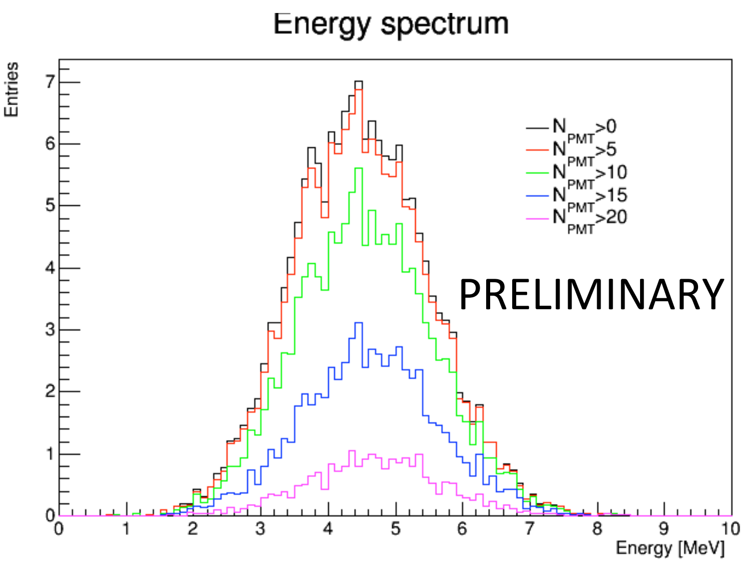




Plots made using output from beam simulation and WCSim
Left = HyperK, Right = TITUS
*S. Short, QMUL*

# Initial physics studies

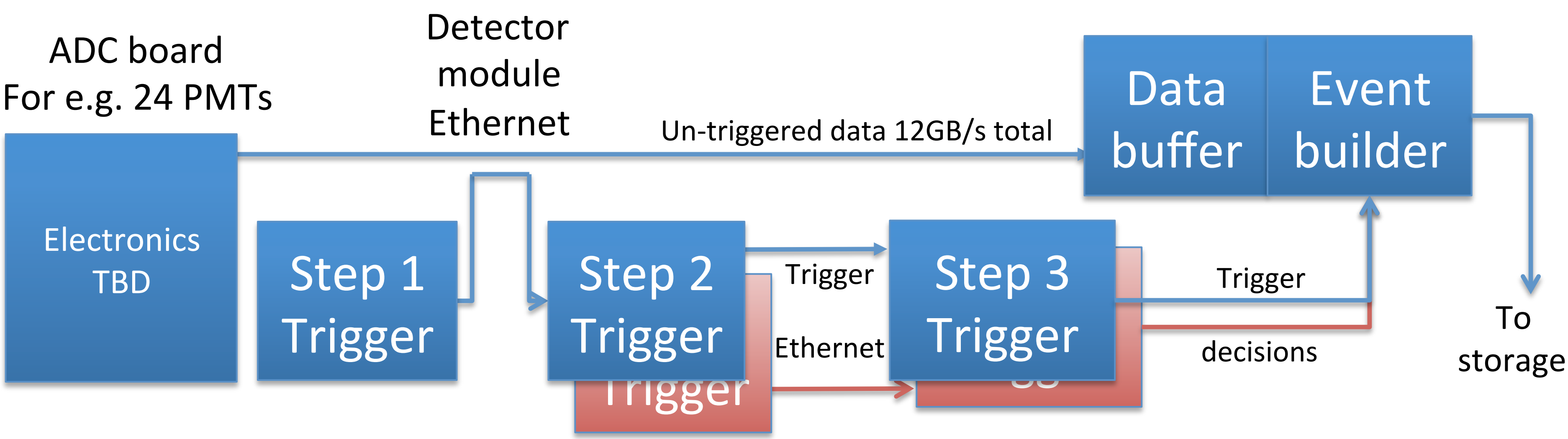
- ***Threshold studies***
  - $^{208}$Tl and $^{214}$Bi decays now simulated and processed through WCSIM
  - Look at effect of threshold on low energy events




Effect of Nhits cuts on (true) energy spectrum
*T. Stewart, STFC-RAL*

# Event readout + Triggering



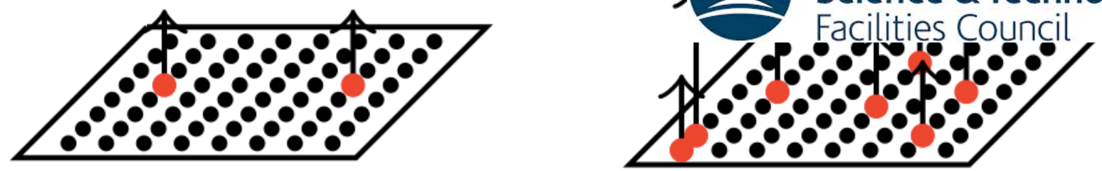

| | | |
|---|---|---|
| ***Step 1: On Board Coincidence (OBC)***<br>Trigger processor attached to each readout board | ***Step 2: Regional Processing Node (RPN)***<br>Rearrange trigger info into 'pads' | ***Step 3: Trigger Algorithm Node (TAN)***<br>Decisions in farm: Each node sees all data for a given time window |

Un-triggered data buffered to wait for trigger decision to build events

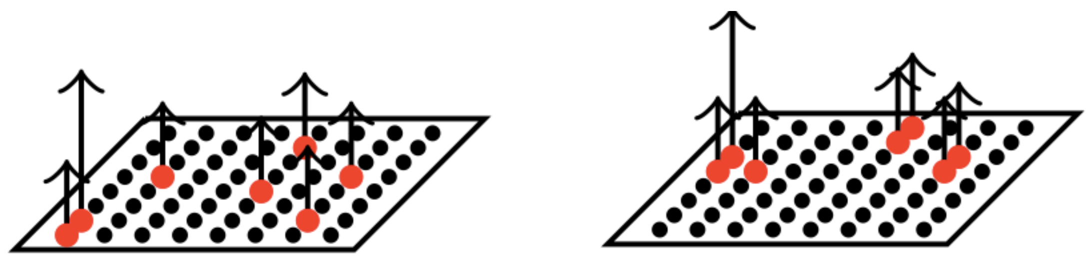
***Data buffer could be extended to store Super Nova Cached data: 1 hour = 400TB***

# Step 1: On Board Coincidence (OBC)

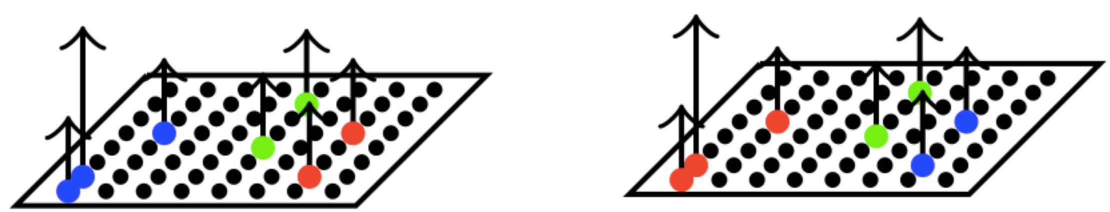
Nhits



Spatial moments



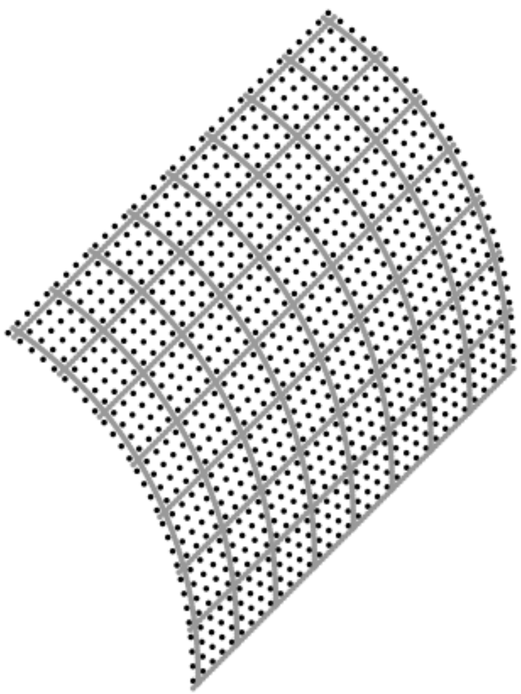
Timing



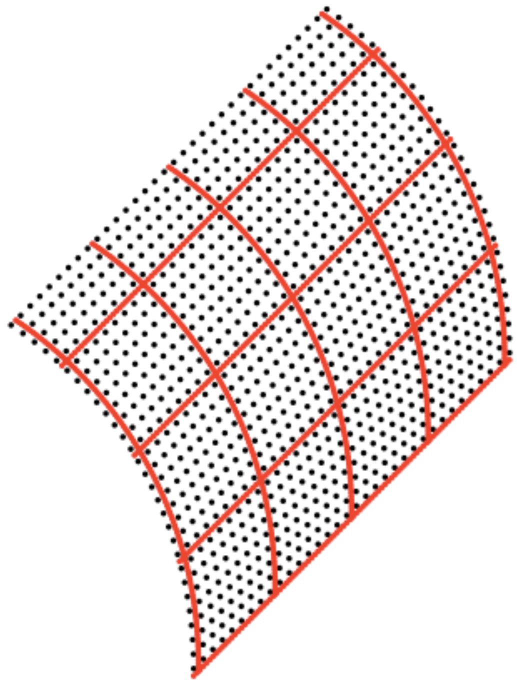
Compute for each local pad, for time bins of O(100ns).

Send local-pad#, overall time, overall PH, Nhits, x and y spatial moment, x and y time moment to trigger

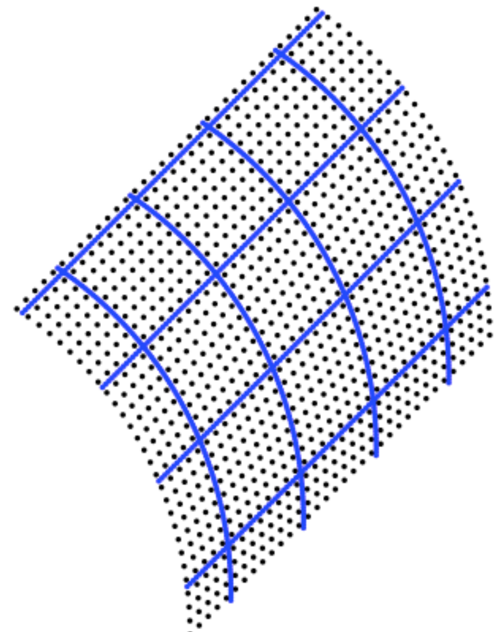
# Step 2: Regional Processing Node (RPN)



Local Pads from step 1

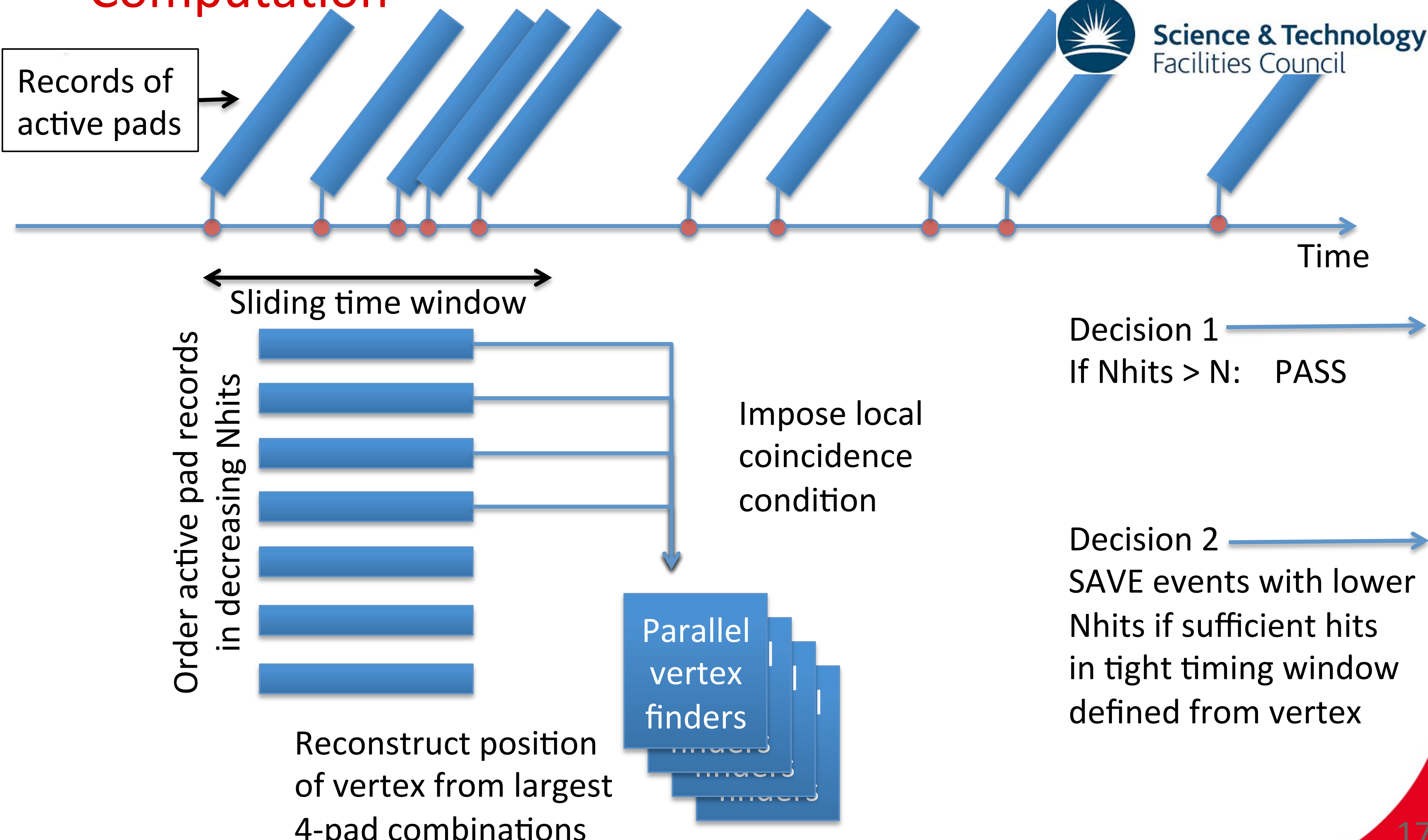


Pads for step 3



Displaced pads for step 3

# Step 3: Trigger Algorithm Node (TAN) Computation



# Step 3: Trigger Algorithm Node (TAN)

- Processor assigned for each 10usec time interval.
  - Include data from last 0.5usec of previous time interval to avoid problems with time boundaries.
- **Events passing Nhits criteria always pass**
- Collect additional low-energy events with cuts to select clusters and not random noise combinations
- Sliding window in time:
  - Impose local coincidence requirement
  - Sort pads by NHITS starting with highest
  - Use parallel processing to consider best pad combinatorics
    - Reconstruct vertex with 4 big pads, consider if other pads are consistent

**Remember: We don't need to consider the most complicated combinations - they are accepted by the simple Nhits trigger**

# Event readout + Triggering

**Stage 1: On Board Coincidence (OBC)**

Collect hits from 24 channels

| Nhits | Time | ϑ-X | ϑ-Y | X | Y | | |
|---|---|---|---|---|---|---|---|

Approximately 420 of these OBCs (number determined by channels read out on electronics board)

**Stage 2: Regional Processing Node (RPN)**

Combine information from 4 x 24 channels (OBCs)

| Nhits | Time | ϑ-X | ϑ-Y | X | Y | | |
|---|---|---|---|---|---|---|---|

Combine data from 4 OBCs. Approximately 105 RPNs + 105 RPNs from shifted configuration. 210 RPNs in total

**Stage 3: Trigger Algorithm Node (TAN)**

Combine information from RPNs and divide data into time slices.

Data from RPN sent to TAN. Approximately 210 nodes required.

# Conclusions

- Significant fraction of HK UK institutes are interested in developing DAQ systems.
- Small amount of money to spend on technical support between Jan. and Sept. 2014.
- Awaiting decision from STFC about 3 year R&D funding
- Focus on design of data readout systems and triggering, i.e. “Backend” DAQ systems
- Physics studies are underway
- Participation in 1kT prototype is anticipated and is under discussion

# Backup slides

# Nhits trigger overview

| | | |
|---|---|---|
| Step 1 | • Calculate quantities in local pad<br>• e.g. 6x4=24 PMT or 8x8=64 PMT (depending on readout board)<br>• Linear (additive) variables, simple to compute | • Close coupled to readout, handshake ≈ 1usec<br>• Ideal for FPGA design |
| Step 2 | • Aggregate local pads into pads<br>• "Displaced pads" concept<br>  • Duplicate steps 2 and 3 to avoid spatial boundary inefficiencies | • Transfer step 1 to step 2 over Ethernet. Canadian redundant path idea.<br>• Algorithm easy if step 1 quantities are additive |
| Step 3 | • Now have ≈ 50-200 pads in each compartment of HK<br>• Physics motivated cuts:<br>• Always accept if Nhits > N<br>• Accept more events with low energy signatures<br>  • Local coincidence<br>  • Trilateration reconstruction, localize vertex and reduce time coincidence window | • Step 2 to step 3 over separate Ethernet network,<br>• Parallel processing farm<br>• Designated node for each 10usec window in time (+0.5usec for overlap)<br>• Trilateration may be suitable for SIMD or GPU |

# Event readout + Triggering