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# Measuring $\overline{v_e}$ from Reactors

- Done initially with Cowan and Reines 1956-1957
  - Discovery of  $\overline{\nu_e}$
- For non-proliferation purposes suggested in 1978
  - Little interest Geopolitics
  - 2007 SONGS1 deployed
  - Proof of concept







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# IAEA "Desirements" for $\overline{v_e}$ non-proliferation

- Technology of interest to International Atomic Energy Authority (IAEA)
- Resulted in IAEA workshop and report: "Final Report: Focused Workshop on Antineutrino Detection for Safeguards Applications", IAEA (2008)
- "Desirement" Not quite a requirement but a desired positive trait









## VIDARR Meeting Those "Desirements"

- Verification Instrument for the Direct Assay of Reactors at Range (VIDARR)
- Can work ~ 60m from reactor, outside major security zone
- ~2 ton of plastic scintillator with 2660 segmented channels
- Revision of the T2K ND280 ECal technology
- Detects emitted  $\overline{v_e}$  from fission fragments







#### Neutrino Production at Reactors

• Fission reactors:

- Fission of U and Pu isotopes
- Produce differing  $\beta$  decay chains
- Thus producing unique  $\overline{v_e}$  flux and spectrum



## **Original Detector**

- From T2K:
  - Scintillating bars with TiO2 coating
  - Wavelength shifting fibres
  - Multi-Pixel Photon Counters MPPCs
- Modifications:
  - Gd sheets in between layers for neutron capture
  - Electronics changed for analysing IBD

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- Shipping container
  - Only needed a plug socket











#### VIDARR Upgrade

- ~50 % mass increase
  - 1.52m by 1.52m by 0.7m
- New readout electronics
  - New MPPCs
  - New readout boards
  - New electronics Rack
- Improved temperature stability :
  - Two large radiators
  - Air-conditioned new container









## Inverse $\beta$ -decay in VIDARR

- Inverse Beta:  $p + \overline{v_e} \rightarrow n + e^+$
- Positrons hit a few bars in close proximity
- Neutron absorbed ~ 10 μs later by Gadolinium sheets
  - Mylar sheets doped with Gd
  - Produces an 8 MeV  $\gamma$  cascade
  - Releases in multiple directions
  - Hits many bars





Neutron event

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#### Monte Carlo Simulation

#### • IBD event -

- Prompt shown in red
- Delayed shown in blue
- Simulated improvements:
  - New channels
  - Better electronics
- Using Geant4 + data driven
  effects such as:



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#### MPPC Dark Noise for Simulation

• Data driven dark noise model – data taken by G.Holt



- Cross talk and after pulsing modelled
- Exponential tail
  - Statistics low past
    ~ 14 mV
  - Therefore modelled as exponential
  - Avoids singular peaks in raw data



# **Quenching for Simulation**

- Scintillator saturation by highly ionising particles
- Determined by Birk's law:  $\frac{dL}{dx} = S$ - $\overline{1+k_B \frac{dE}{dx}}$ • Particle dependant



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#### **Attenuation for Simulation**

- Attenuation (data driven)
- Light travels through bars + fibres
  - Attenuation length 580 mm + 60 mm



 Data measured by George Holt from our light box







#### **Replacing Simulated Gd Model**

- Using a more accurate model than those found in G4
- Watchman result overlaid
  - Based on Danse calorimeter data
  - Cascade difficult to model or measure
  - Energy is conserved
  - <sup>157</sup>Gd peak ~ 8MeV  $\gamma$

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Individual γs

\*Y.Chen, 2015 AARM





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#### **VIDARR's Neutron Trigger**

- Machine learning helps design trigger
- "Efficiency\*" = 76%, "Purity\*" = 92%



\*worst case scenario – normalisation pending, energy spread: 0-10 MeV, should be better with more accurate data





## Wylfa Reactor - Cosmic muon analysis

- Deployment at Wylfa in 2014
- A Cosmic from the Wylfa data Set-
- Revisiting background muon rates
- Measuring reactor building shadow
  - How many cosmic muons blocked?
- 3D track fitter
  - Using Minuit2 + MIGRAD
- Pioneering calibration techniques for upgraded VIDARR





#### Plan Going Forward

- Verify data techniques
- Analyse initial results of the VIDARR detector
- Set up/build VIDARR
- Background measurements of Hartlepool reactor
  - As part of LIV.DAT 6 month placement
- Merry Christmas!





#### Any Questions







#### What is the ML that informs our trigger?

- Support Vector Machine (SVM)
- Best separating hyperplane









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#### Where was our detector?

- Side a = x
- Side b = y





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#### Summed Energy Dicebox



# Dicebox Breakdown

- Most of the cascade is  $\boldsymbol{\gamma}$
- Very few e<sup>-</sup>s
  - Shell type has minimal impact on their energies



## **Dicebox Multiplicities**



- Electrons make up small number of particles
- Mostly the cascade is gammas
- 1e6 simulated

#### Summed Energy vs Individual Energy



Kon Collins – VIDAKK update