Neutron Detector in the Aberdeen Tunnel Underground Laboratory

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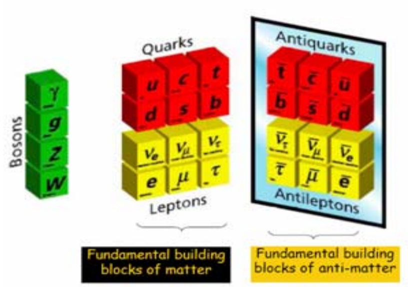
Neutrino Physics

- Neutrinos have mass and can oscillate from one flavor to another
- The mass eigenstates are not the same as the flavor eigenstates (neutrino mixing)
- For three flavors, neutrino oscillations are completely described by six parameters: three mixing angles θ_{12}, θ_{13}, θ_{23}, two independent mass-squared differences, $\Delta m^2_{21} \equiv m_2^2 - m_1^2$, $\Delta m^2_{32} \equiv m_3^2 - m_2^2$, and one CP phase angle δ_{CP}.

Significance of θ_{13}

Standard Model of Matters

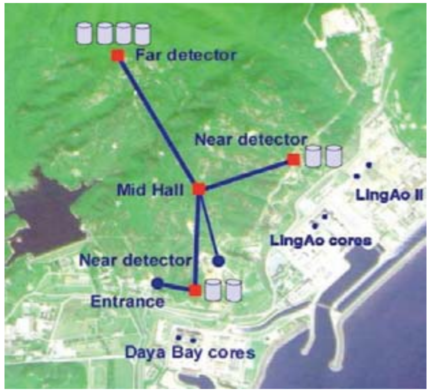


- To date, neutrino oscillation is the only evidence of physics beyond the Standard Model
- Precision measurement of its value will allow design of future experiment for δ_{CP}

The Daya Bay Experiment

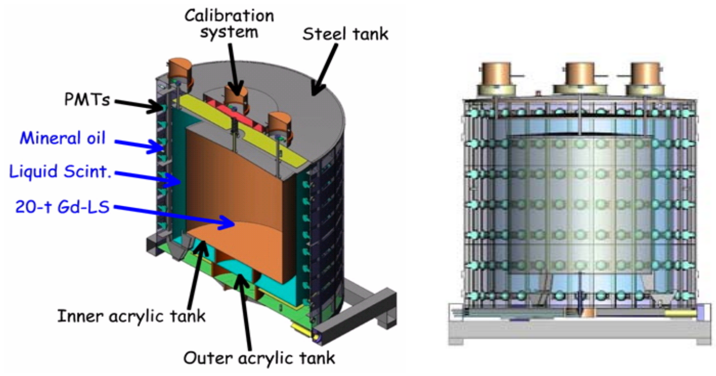
- Reactor based experiment to measure θ_{13}
  - Anti-electron neutrinos emitted from β-decay in nuclear reactors
  - 3 GW (thermal) reactor gives 6 x 10^{20} anti-neutrinos per second
  - Mean energy ~ 4 MeV
- Disappearance experiment
  - Measure fluxes of anti-neutrinos at short baseline (near detectors at ~ 400 – 500 m) and at long baseline (Far detectors at ~1600 – 2000 m)

The Experimental Halls



- 2 anti-neutrino detectors at each of the 2 Near Halls and 4 detectors at Far Hall
- Experimental halls ready from late 2008
- Detectors start taking data from late 2009

Anti-Neutrino Detector

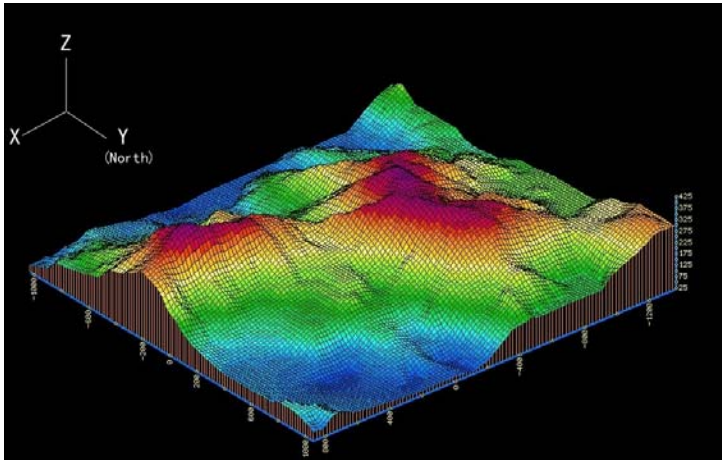


Anti-Neutrino Detector

- Based on inverse beta-decay interaction
  - $\bar{\nu}_e + p \to \beta^+ + n$
  - Event is registered when the two 511 keV annihilation photons from β^+ is followed by the 8 MeV γ burst due to capture of neutron by Gd
- 3-zones design
  - Central Gd-doped liquid scintillator for capturing neutrons and to produce scintillations
  - Gamma capture containing normal LS for capturing γ that have escaped capture in the central zone
  - Outer mineral oil buffer for shielding against external neutrons; γ from rock; from PMTs and from stainless steel tank

Aberdeen Tunnel Laboratory

The Mountain Profile



The Cross Passage

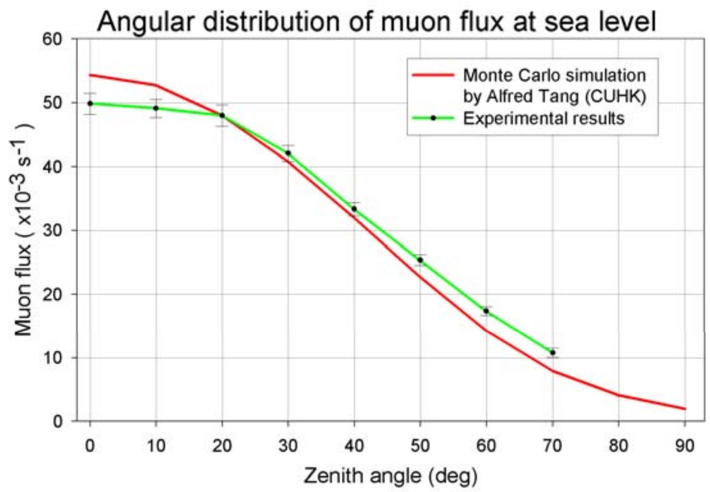
The Laboratory

Characteristics

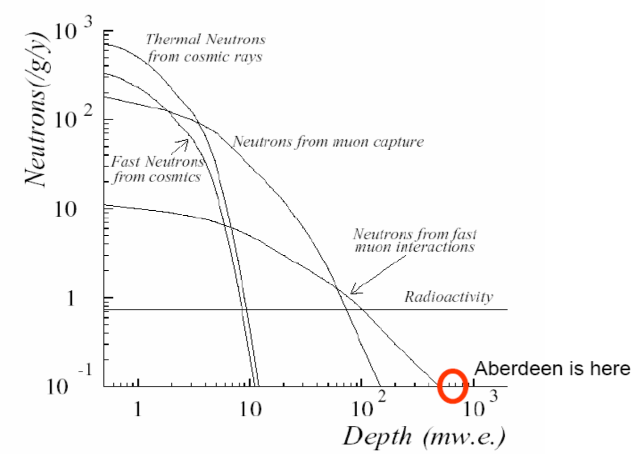
Latitude	N 22º 15’ 41”
Longitude	E 114º 10’ 48”
Altitude	~ 22 m above sea level
Minimum rock thickness over laboratory	~ 240 m
Average vertical muon energy	~ 60 GeV
Average intensity of muons	~ 2×10^{-5} cm^{-2} s^{-1} sr^{-1}

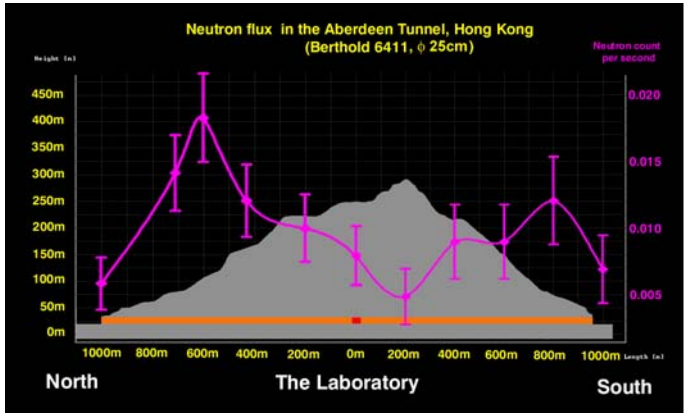
The Objectives

- To study the muon flux, energy and angular distribution in an underground laboratory having an overburden of ~240 m of rock.
- To study precisely the production mechanism of neutrons originated from muons interacting inside gadolinium-doped liquid scintillators.
- Helps to predict and identify the muon-induced neutrons in the Daya Bay neutrino experiment.
- To train students in this field.



Neutrons in Underground





- Measured by a Bonner sphere neutron dosemeter
- Only knows the count-rates; has no information about the neutron energies
- Both high energy (hundreds of MeV) spallation neutrons and low energy neutrons (a few MeV) from (α,n) interactions were measured

Production of Neutrons in LS

- Single or multiple neutrons can be produced in the liquid scintillator by inelastic muon interactions
- $\mu^+ + {}^{12}C \rightarrow \mu^+ + \pi^+ + {}^{12}B^*$

  then $\pi^+ \rightarrow \mu^+ \rightarrow e^+$

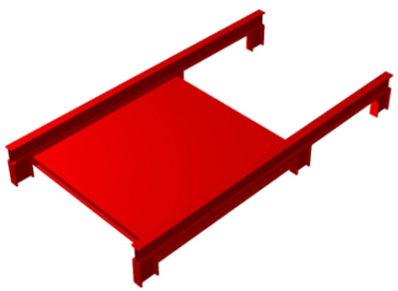
  and B* will potentially emit nucleons
- $\pi^- + d \rightarrow n + n$

  d is a pseudo-deuteron in ^{12}C

The System

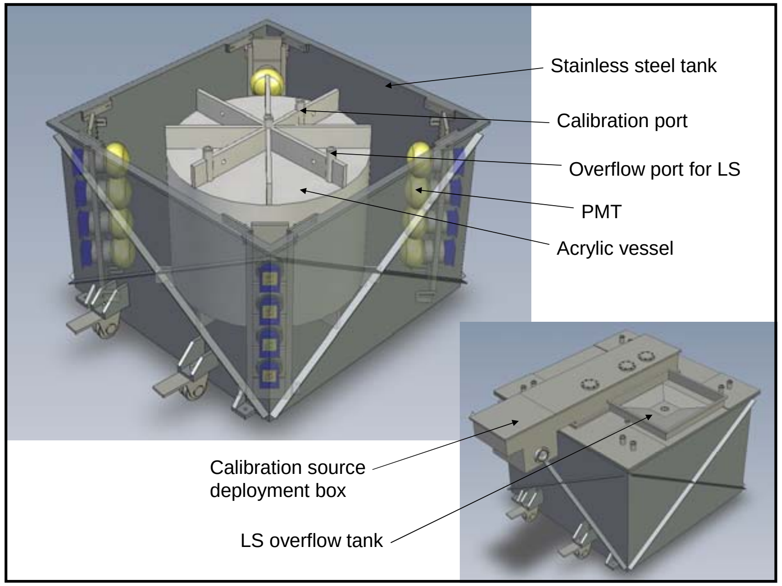
- A muon tracker to track passage and direction of muons
  - 3 layers of crossed proportional counters and plastic scintillators to give x-y coordinates
  - Event is registered when coincidence occurs among the layers
- A neutron detector sandwiched between the muon tracker to detect neutrons produced by muons in the detector body
  - Event is registered when coincidence occurs among the muon tracker and the neutron detector

The System

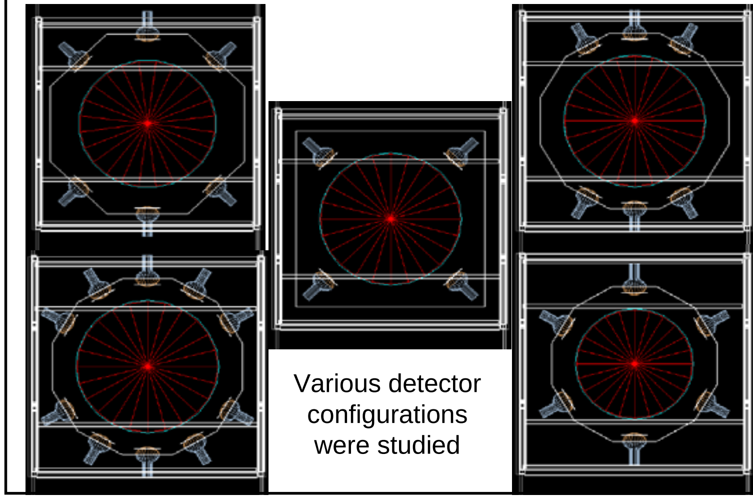


The Neutron Detector

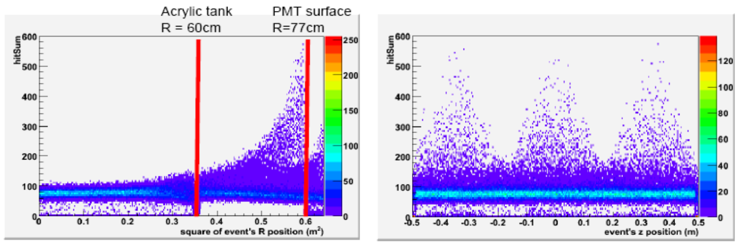
- 2-zone design because limited by space
  - Gd-doped LS (~ 0.7 ton)
    - Linear Alkyl Benzene (LAB)
    - PPO and bis-MSB as wavelength shifters
    - Contained in cylindrical acrylic vessel for light transmission
  - Mineral oil buffer (~ 1 ton)
    - Contained in rectangular stainless steel tank.
- Scintillations are detected by sixteen 8-inch Hamamatsu 1408 PMTs in stainless steel tank.
- Reflectors at top and bottom of steel tank to enhance light collection



Choice of Detector Configuration

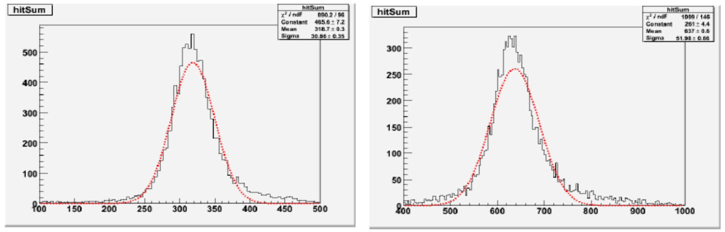


Uniformity of Light Collection



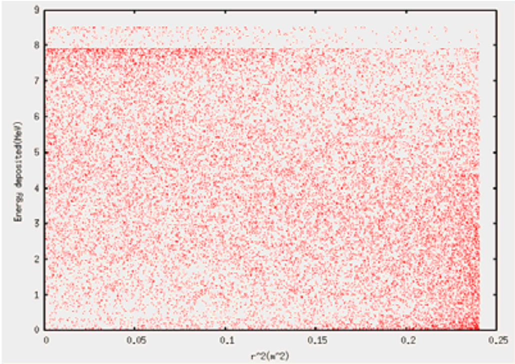
- Studied through simulation
- Recorded signal is higher when event occurs nearer to a PMT
- To maintain a fair uniformity, the PMT surfaces are kept at least 24 cm from the acrylic vessel

Energy Resolution



- 4 MeV and 8 MeV γs are generated and the spread fit for Gaussian
- Energy resolution at 4 MeV = 9.7%
- Energy resolution at 8 MeV = 8.2 %

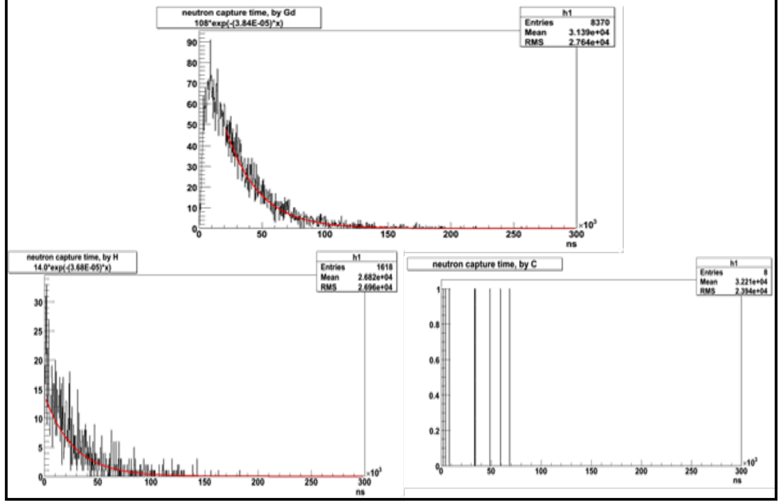
Detection Efficiency



- Energy deposition of γ is almost always incomplete
- Efficiency is best at center of detector and decreases with increase in radial distance

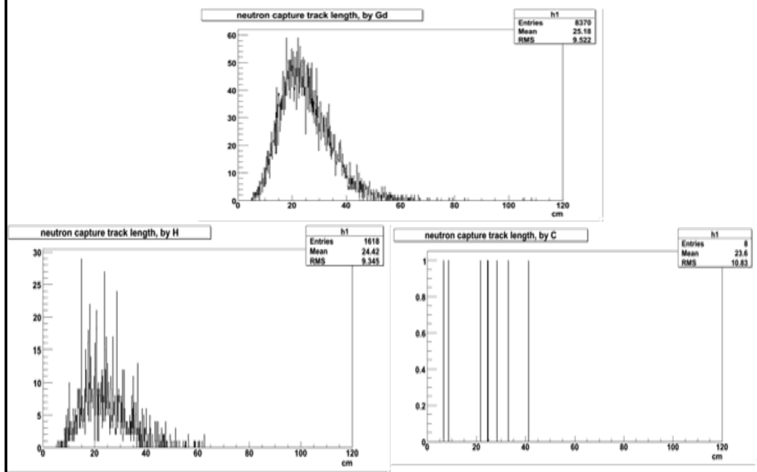
0.1% Gd - ABT

Neutron capture time (by Gd, H and C)



0.1% Gd - ABT

Neutron capture tracklength (by Gd, H and C)



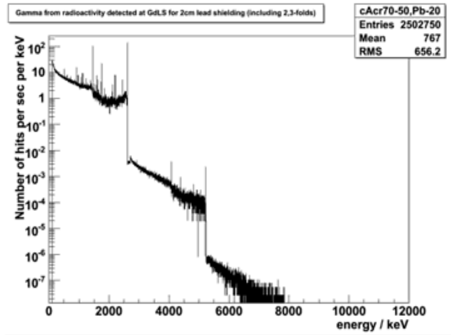
Concentration of Gd

- Simulations of neutron capture by various Gd concentration in LS were done
- Capture time and track length depends on concentration of Gd
- For 0.1% Gd:-
  - Mean capture time ~ 10 ns
  - Mean track length ~ 20 cm
- Neutron capture by H is also significant, but capture by C is negligible

Effect of Ambient Gammas

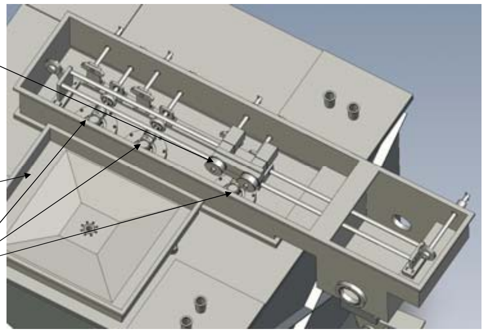
- Gamma radiations are emitted from the rocks, the materials for making the detectors and detector frames
- Genuine signals are those that have this sequence of event:
  - muon arrival – neutron production – neutron capture – emission of 8 MeV gamma burst
- A window of 100 ns will be opened to look for gammas exceeding 6 MeV as an indication of a neutron production
- Gammas from all sources can arrive the detector coincidentally to produce fake event
- Simulations were done which confirmed that coincident rate of gammas was very small even without any lead shielding around the detector

Coincidence Rate of Gammas



- Shows up to 3-fold coincidence rate of gammas inside the detector with only 10 cm of mineral oil
- An energy cut of 5.5 or 6 MeV will prevent all 2-fold coincidences
- 3-fold coincidence rate above 6 MeV is about 0.86 per day or 1.7% of the 50 neutrons expected each day

Calibration System



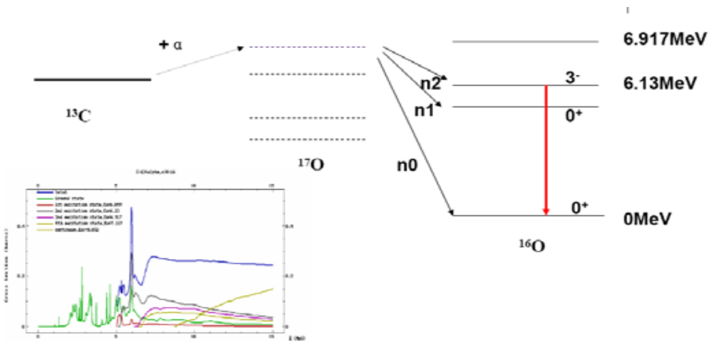
- Deployment box filled with nitrogen gas
- 3 deployment ports for deploying radioactive source or light diffuser ball into the acrylic vessel
- Deployment controlled by stepping motor controlled wheels when the port gate valve is opened

Calibration with Radioactive Sources

- Gamma source: Co-60
- Positron source: Ge-68
- Neutron source: Am-Be & Pu-C
  - Pu-C developed in CIAE
  - Produce 6.13 MeV γ and 4 MeV neutron
  - $N(\gamma)/N(n) = 0.044$

$$^{238}_{94}\mathrm{Pu} \xrightarrow{\alpha\ \ 87.74\mathrm{y}} {}^{234}_{92}\mathrm{U} \xrightarrow{\alpha\ \ 2.455\times10^{5}\mathrm{y}} {}^{230}_{90}\mathrm{Th}$$

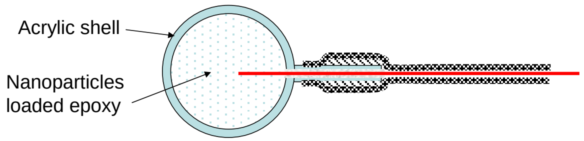
Pu-C



$^{13}C(\alpha,n)^{16}O$ cross section

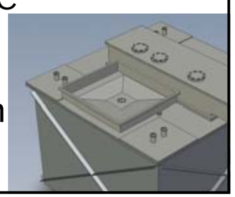
LED Calibration System

- Diffuser ball
  - To act as an isotropic light source
  - 5 ns light pulses generated from a LED and connected to the diffuser ball by optical fiber
  - For setting t_o of the DAQ system
  - For measurement of single photo-electron energy of PMTs



Overflow Tank

- Cater for thermal expansion of LS
- Maximum temperature rise may be up to 10 ^{o}C in the event of power breakdown leading to a volume increase of LS by 5.4L
- Average volume coefficient of thermal expansion
  - LS and mineral oil ~ 7.7 x 10^{-4} /^{o}C
  - acrylic ~ 1.2 x 10^{-4} /^{o}C
  - SS304 ~ 5.2 x 10^{-5} /^{o}C
- Pressure released by a balloon



The End

- The muon tracker has been completed
- The neutron detector is being fabricated and is expected to be finished after the summer
- Data taking will last for at least one year
- Hope to collect important experimental data for use in the Daya Bay Experiment