Measurement of Cosmic-ray Muon-induced Spallation Neutrons in the Aberdeen Tunnel Underground Laboratory

Ho-Yin Ngai

jimmyngai@graduate.hku.hk

Department of Physics, The University of Hong Kong, Hong Kong

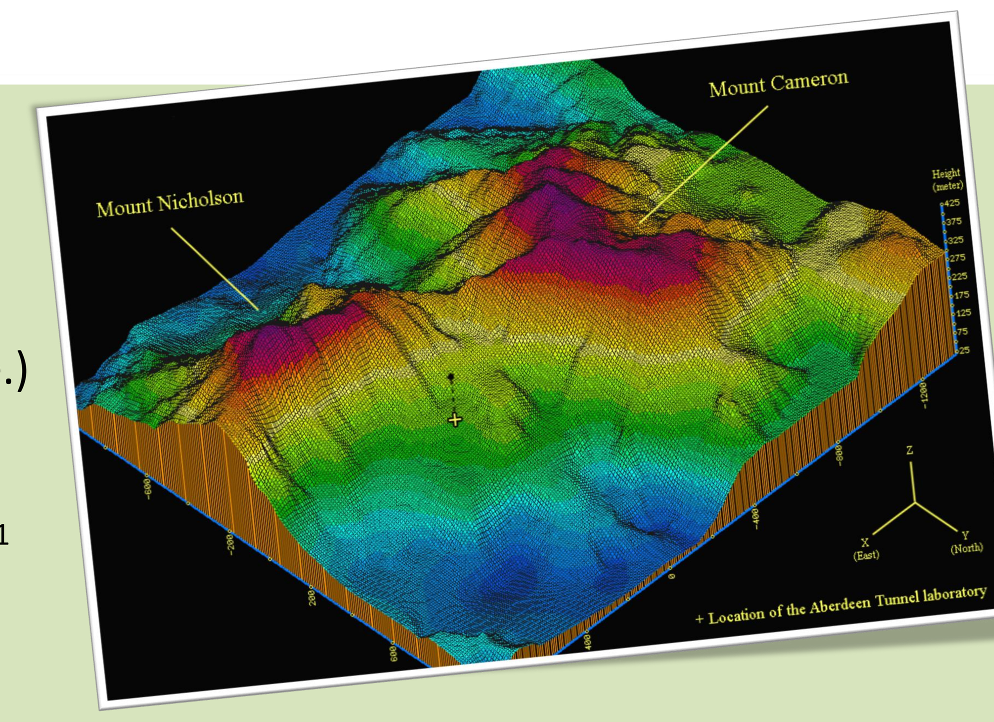
On behalf of the Aberdeen Tunnel Experiment Collaboration

Introduction

Muon-induced neutrons are one of the major backgrounds to various underground experiments, such as dark matter searches, low-energy neutrino oscillation experiments and neutrino-less double beta-decay experiments. Previous measurements on the underground production rate of muon-induced neutrons were mostly carried out either at shallow sites or at very deep sites. The Aberdeen Tunnel (ABT) experiment aims to measure the neutron production rate at a moderate depth of 611 meters water equivalent (m.w.e.).

Experimental Site

Altitude: ~22 m above sea level
Overhead rock thickness: ~235 m (~611 m.w.e.)
Rock composition: mostly granite
Average muon energy (MUSIC): ~120 GeV
Integrated muon flux (MUSIC): ~1 × 10^{-5} $cm^{-2}s^{-1}$



The laboratory is located inside cross-tunnel No. 5 of the Aberdeen Tunnel, Hong Kong.

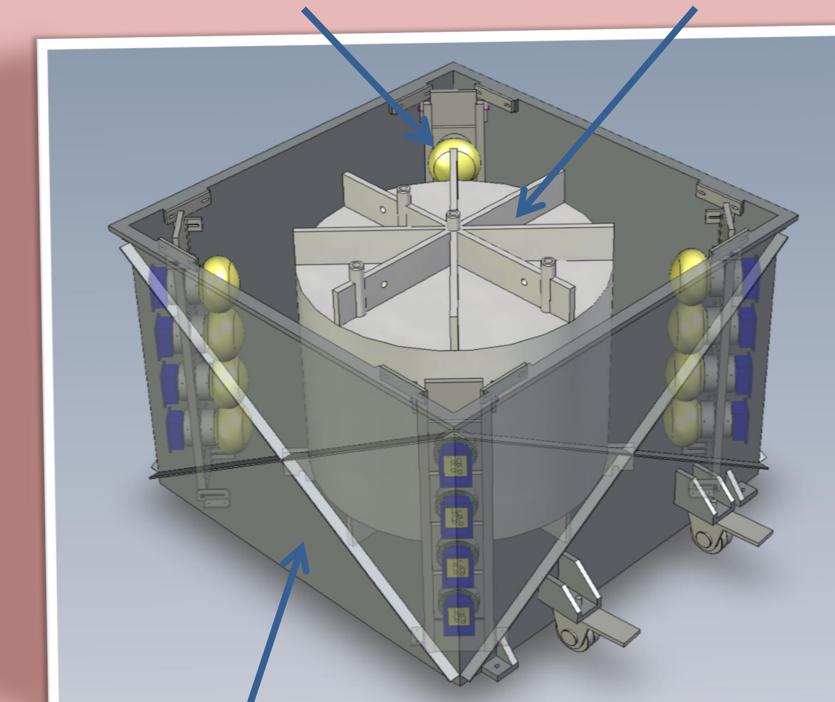
Apparatus

The **muon tracker (MT)** consists of 60 plastic scintillator hodoscopes arranged in three layers. Each layer is made up of two planes of hodoscopes orthogonal to each other for determining the coordinates of a muon passage.

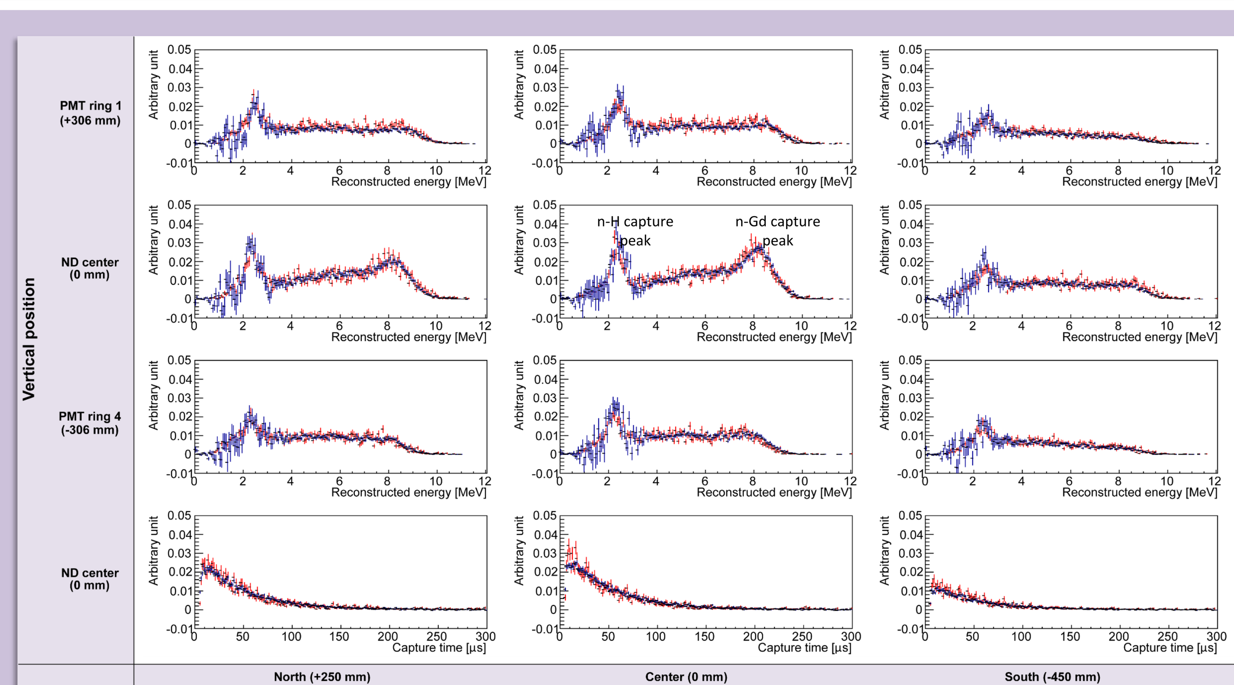
The **neutron detector (ND)** employs a 2-zone design.

- Outer zone: 1900 L of mineral oil (MO)
- Inner zone: 760 L of 0.06% gadolinium-doped linear-alkyl-benzene-based liquid scintillator (Gd-LS)

When the gadolinium captures a neutron, it produces a gamma cascade with a total energy of about 8 MeV. Scintillation photons created by the gamma-rays are detected with 16 Hamamatsu R1408 20-cm photomultiplier tubes.



Detector Performance



Energy and neutron capture time distributions of ^{241}Am-Be calibration runs at different source positions (simulation, experiment)

The MT was self-calibrated using the cosmic-ray muons passing through it. The efficiency along each hodoscopes was uniform, with average efficiency above 95% for most of the hodoscopes.

The ND was calibrated with gamma sources ^{137}Cs (0.66 MeV) and ^{60}Co (1.17, 1.33 MeV) as well as a neutron source ^{241}Am-Be. The neutron detection efficiency was broken down into different contributing components. The values of some components were derived from GEANT4-based simulations. The simulations had been well cross-checked with calibration run data.

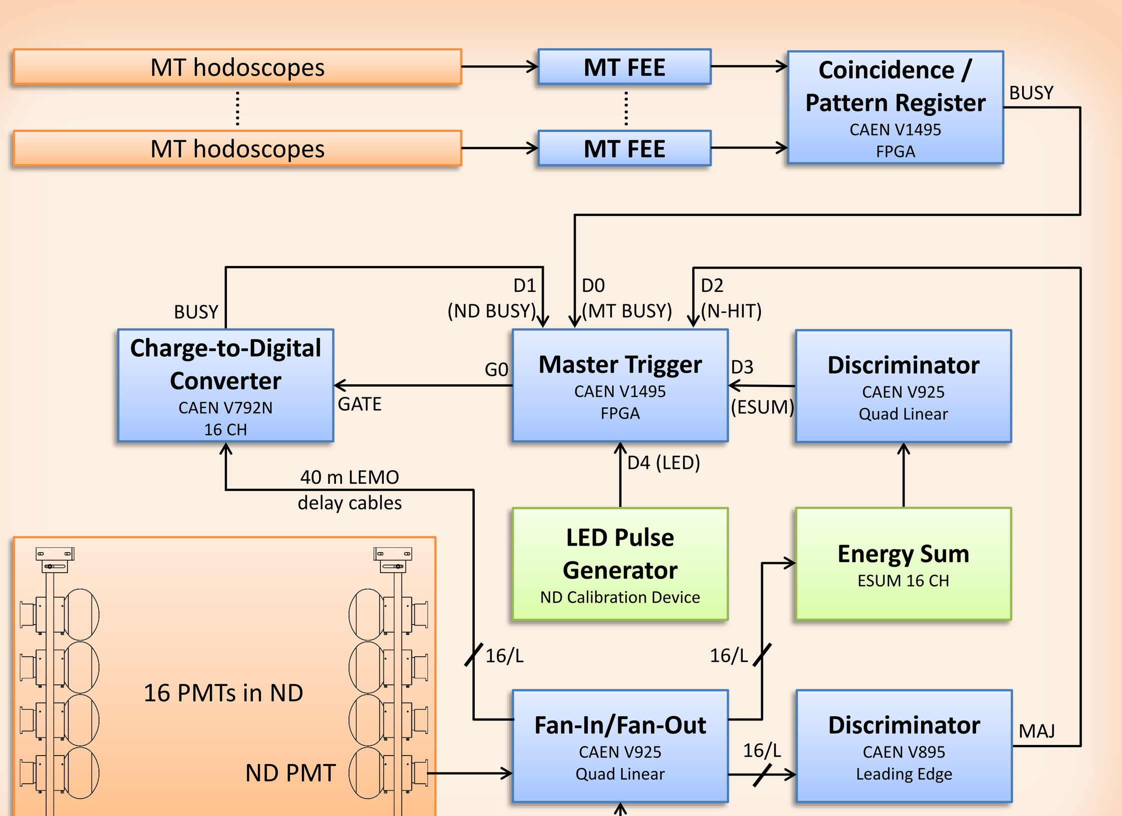
	Efficiency	Error
Muon track length		1%
Energy scale		1%
Energy cut #	52%	2%
Time cut #	87%	1%
Gd capture ratio #	80%	1%
Spill-out #	70%	15%
Spill-in #	128%	
Livetime	95%	1%
Overall	30%	5%

Preliminary

Derived from simulations

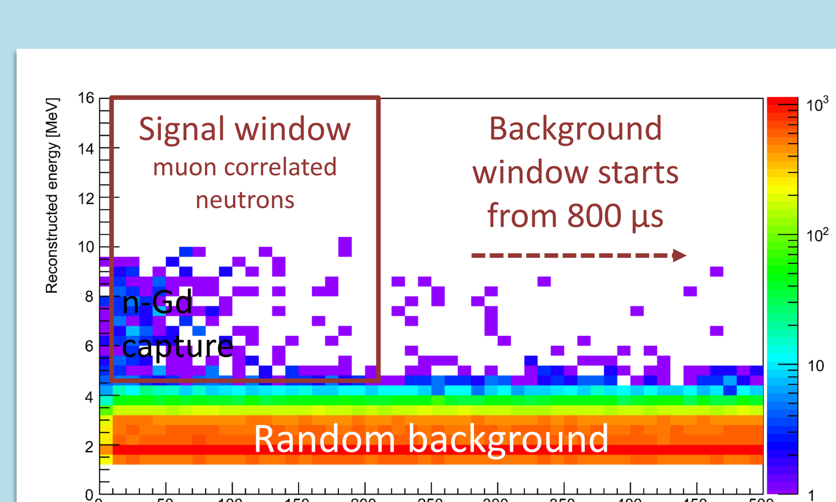
Data Acquisition

The data acquisition (DAQ) system consists of home-made front-end electronics (FEE) for the MT and CAEN remote-controllable **VME** electronics modules.

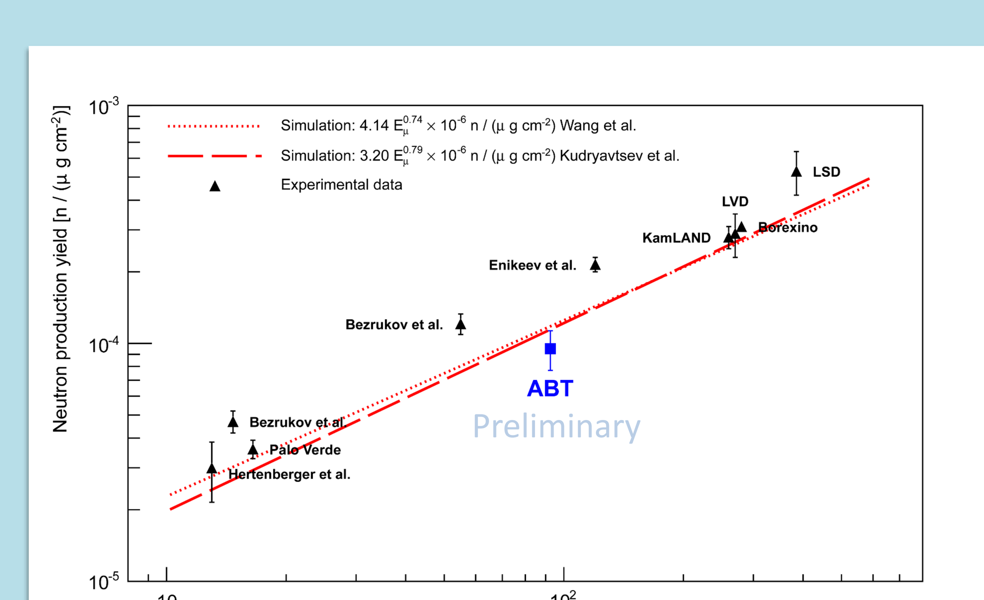


Measurement of Neutron Yield

Muon-induced neutron candidates were selected using the delayed-coincidence method.
A **prompt muon signal** is selected if the MT bottom layer is triggered and both the top and middle layers have a single hit respectively. A **delayed neutron capture signal** is selected if the capture occurs within a certain energy and time window which is close in time after the preceding prompt signal.
The net number of candidates, divided by the neutron detection efficiency, the total muon track length and the target mass density, gave the **neutron yield = (9.5±0.8(stat.)±1.6(syst.)) x 10^{-5} n / (μ g cm^{-2})**.



Delayed-coincidence signal and background windows



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