BUTTON SIMULATIONS + WbLS

HEP MEETING

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Alexander Morgan

A.P.Morgan@Liverpool.ac.uk

Overview

- $\overline{\nu_e}$ detectors utilise inverse beta decay
- Incoming $\overline{\nu_e}$ interacts with a proton in a medium producing a prompt positron and delayed neutron
- Nuclear Reactors produce around 10^{20} s^{-1} GW_{TH}^{-1}
    - Low energy range
    - Detection technology holds non-proliferation prospects
    - Cherenkov detectors have poor resolution in this range
- Future prospect: WbLS detection medium
    - Lower detection range, higher light yield

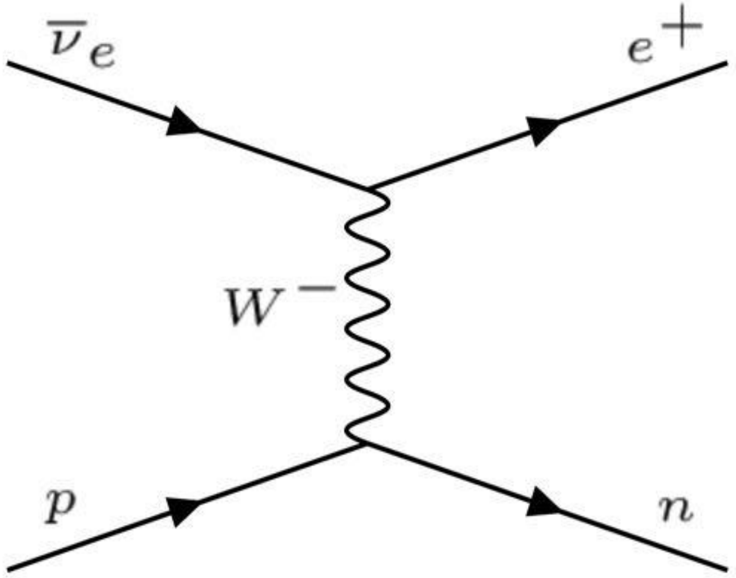


Fig 1: IBD Feynman Diagram

BUTTON DETECTOR + SIMULATIONS

- BUTTON (Boulby Underground Technology Testbed for Observing Neutrinos) is a 30-tonne anti-neutrino Cherenkov testbed - created following end of WATCHMAN
- Aims to assess feasibility of detector at Boulby and de-risk future large detector experiments
- Testbed for novel detection technology
  - Water based liquid scintillator (WbLS)
  - Large Area Picosecond Photodetectors (LAPPDs)
- Potential plans to expand to BUTTON-1000
- Simulations benchmark expected results for BUTTON & inform design
  - Simulations aim to benchmark BUTTON’s response. Ran in RATPAC 2, a framework built on GEANT4
  - Will discuss simulation studies into Cosmogenic Muon backgrounds and development of novel WbLS fill media

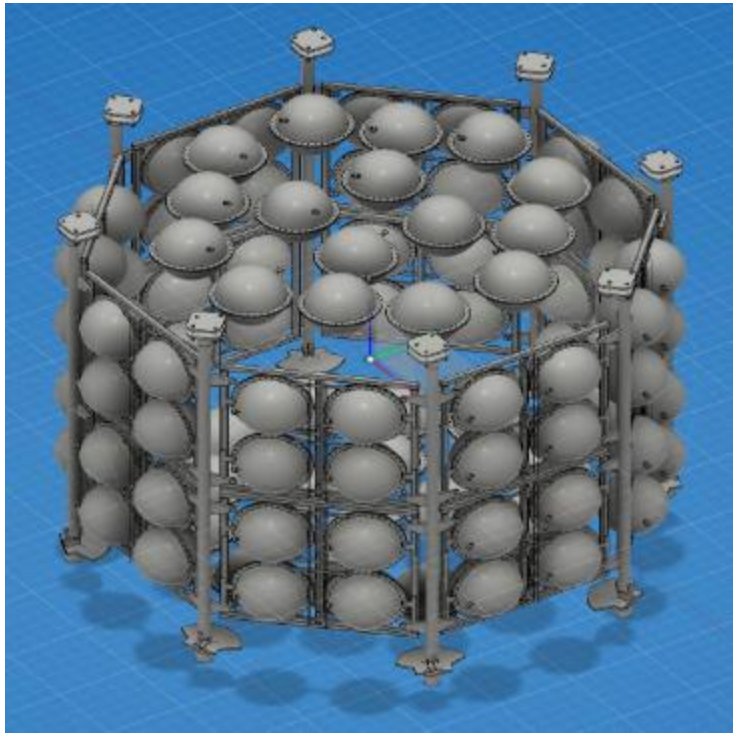


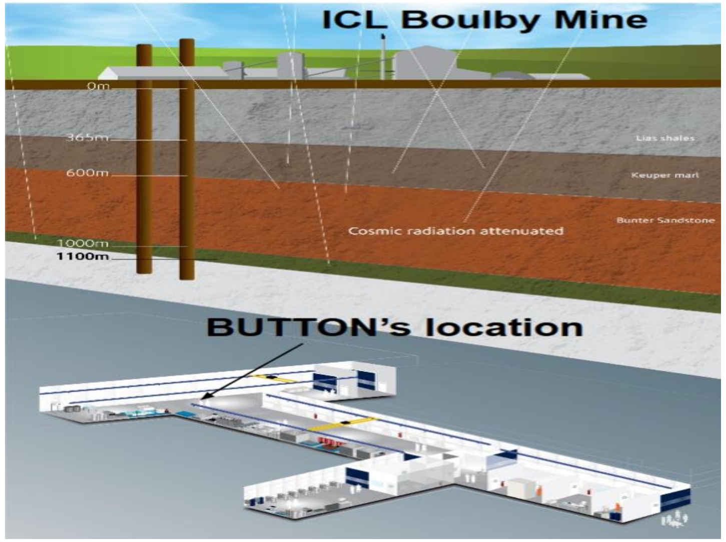
Fig 2: Model of BUTTON-30’s PMTs and frame

Cosmogenic Muon Backgrounds

- Cosmogenic muons major background
- Detector 1km underground at Boulby to reduce effects of cosmic rays – still sensitive
- Boulby lab have studied expected backgrounds ~ 53 muons per day
- Energy range typically between 30 – 500 MeV – will light up detector
- Additionally, cosmogenic muons interact with rock to cause presence of Li-9, He-8 and N-17 in detector

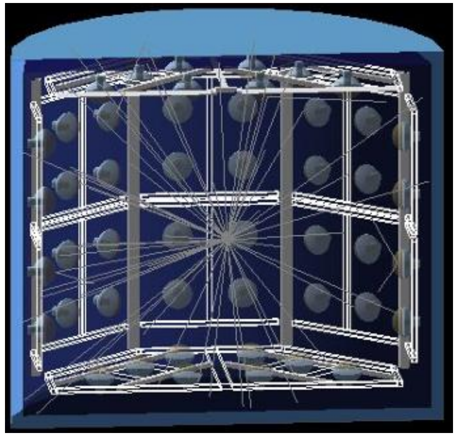
Run start	N_{muons} (E>30 MeV)	duration (days)	rate (day^{-1})
26-7-02	1028	19.830	51.8±1.6(stat)
28-8-02	712	12.886	55.3±2.1(stat)
11-9-02	1097	20.249	54.2±1.6(stat)
Total	2837	52.965	53.6±1.0(stat)

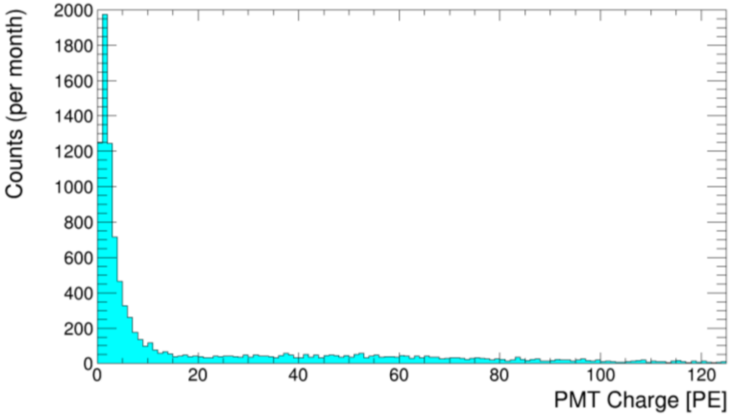
Number of cosmogenic muons measured in Boubly underground
. Available at: https://arxiv.org/abs/hep-ex/0306014

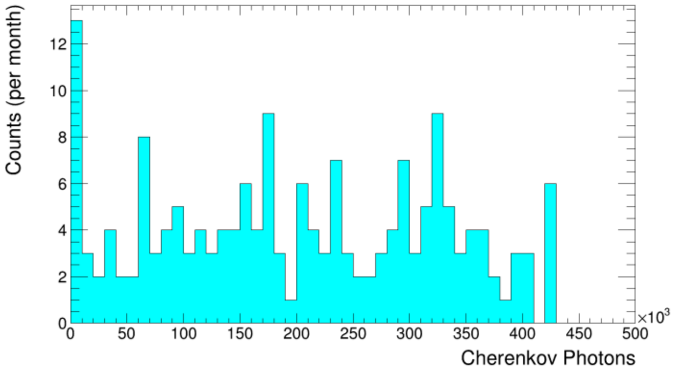


Cosmogenic Muon Simulations

- Implemented RATPAC 2 for compatibility with **C**osmic **R**ay Shower Librar**y (CRY)** software for generation of cosmic ray showers
- Initial results for muon background simulations to lead into study
- Energy deposition of cosmogenic muons far higher than from IBD events
- Current results match study at Boulby
- Taking time slices, can see Cherenkov rings hitting bottom PMTs
- Study to be scaled to generation at surface level to give expected angular distribution
  - Effects from Li-9, He-8, N-17 from muons passing through rock

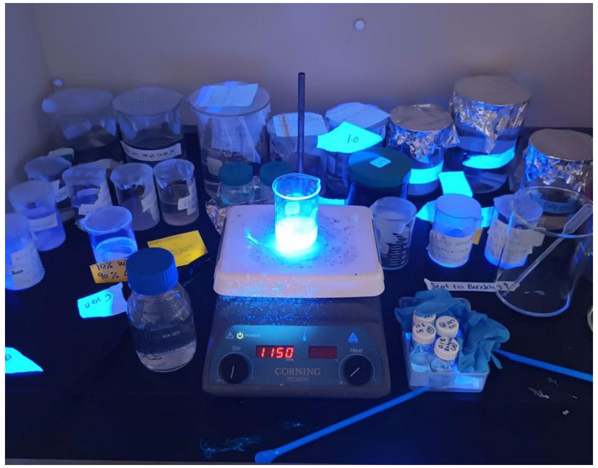


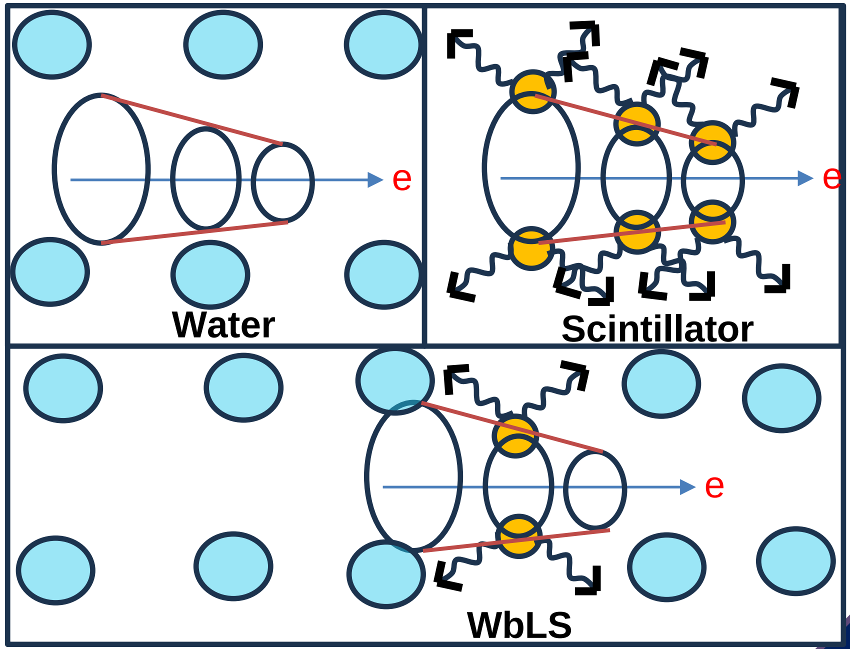




WbLS

- Water based Liquid Scintillator (WbLS) is one of the prospective fill media for the BUTTON detector
- Novel technology aiming to improve resolution at lower energies
  - Sensitive to low energy events and high count-rate efficiency – scintillator component
  - Water component produces Cherenkov rings – directionality
  - Reactor $\overline{\nu_e}$ are typically produced at these energies
- Spent time at UC Davis working on mixing WbLS
- Optimise light yield of liquid scintillator
  - Loading “fluors” into WbLS





WbLS

- WbLS consists of organic liquid scintillator suspended in water through encapsulation in a micelle
- Mixing procedure primarily involved the use of Linear Alkylbenzene (LAB) based liquid scintillator and the loading of a fluor into the solution
- Problem with WbLS – can be difficult to separate Cherenkov and scintillator signals
- Fluors slow re-emission spectra and can provide increase to usable light yield
- Fluors used in development:
    - PPO, Acenaphthene, Pyrene, DPA
    - Acenaphthene and Pyrene mix readily
    - PPO, Acenapthene & Pyrene remain stable for long periods

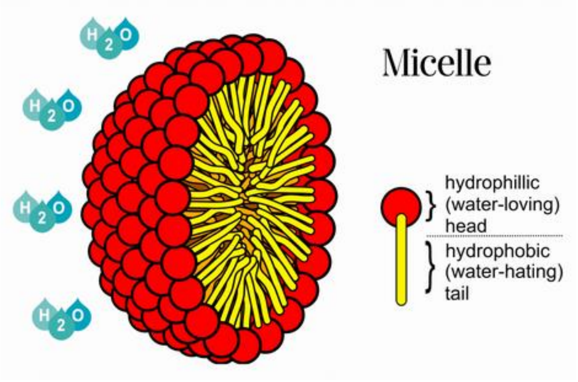


Fig 5. Diagram demonstrating structure of WbLS micelle: https://svoboda.ucdavis.edu/rd-projects/water-based-liquid-scintillator

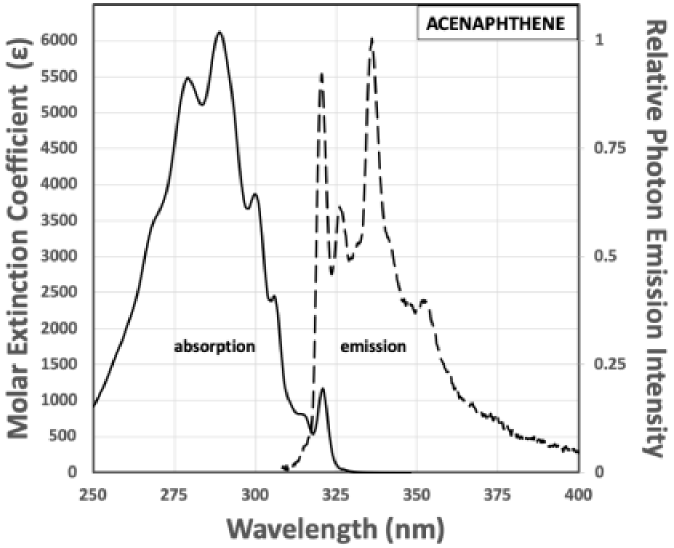
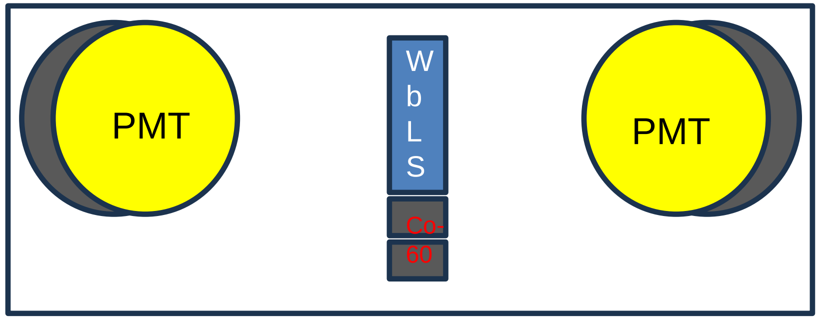
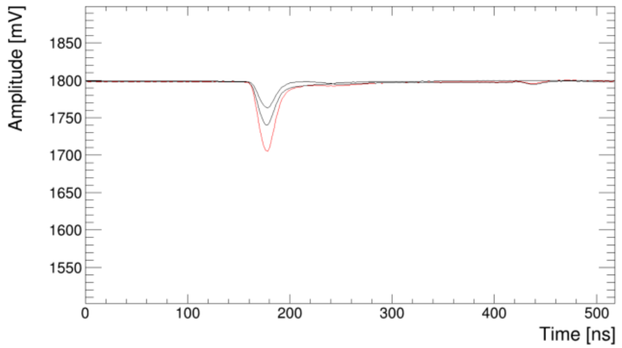


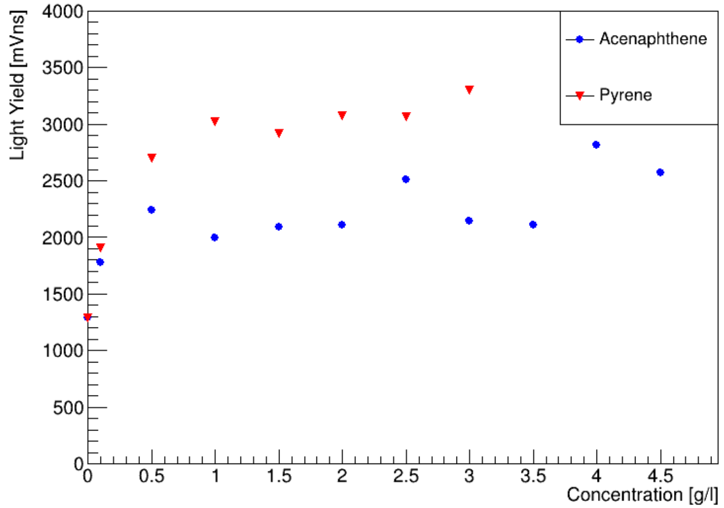
Fig 6. doi:10.1016/j.nima.2020.164106.

Light Yield

- Light yield of the mixtures was measured through irradiation of WbLS samples with 2 Cobalt-60 sources
- Source placed between 2 PMTs
  - Provide double coincidence trigger
  - Measured for 10,000 double coincidence events
  - Calculated combined pulse of both PMTs and average pulse across all coincidences
  - Take an integral across this waveform
- Found that overall ~ 20% increased light yield with Pyrene over Acenapthene (and no fluor loaded)







Summary

- Continued work on BUTTON simulations- currently benchmarking expected backgrounds for cosmogenic muons
- Despite BUTTON's position- still measure significant results from cosmogenic muons
- Simulations of cosmic background underway, with future steps getting angular distribution, effects from Li-9, He-8, N-17

- Worked on research and development of Water based Liquid Scintillator technology
  - Particularly in increasing usable light yield through separation of scintillator and Cherenkov signal
  - Acenapthene and Pyrene readily mix into WbLS and remain stable for a long time
  - Found a 20% increase in light yield through mixing of Pyrene with scintillator liquid compared to Acenapthene

Thank you for listening, any questions?