THE UNIVERSITY of EDINBURGH

Far-Field Monitoring of Reactor Antineutrinos for Non-Proliferation

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On Behalf of the AIT-WATCHMAN collaboration

WIN2019 Bari

The 27th International Workshop on Weak Interactions and Neutrinos

AIT-WATCHMAN Goal

Demonstrate nuclear reactor monitoring for non-proliferation purposes through antineutrino detection using a large, scalable technology (Gadolinium-loaded water).


60°N
Boulby Underground Laboratory
United Kingdom
Lithuania
40°E
Belarus
30°E
20°W
10°W
20°E
Prime Meridian
BOULBY UNDERGROUND LABORATORY
Ukraine
50°N
Czechia
Slovakia
Moldova
Austria
Hungary
Romania
Black Sea
France
Croatia
Serbia
Bulgaria
Italy
Hotel Mercure Villa Romanazzi Carducci
WEAK INTERACTIONS AND NEUTRINOS
WIN
2019
BARI ITALY
Portugal
Greece
Tyrrhenian Sea
Spain

AIT-WATCHMAN @ BOULBY UNDERGROUND LABORATORY

Advanced Instrumentation Testbed

- Situated at Boulby Underground Laboratory (N. Yorks., UK)
- Located 26 km from two 1.5 GWth advanced gas-cooled reactors (Hartlepool)
- Test novel methods for the discovery of reactor cores

Water Cherenkov Monitor of Anti-Neutrinos

- Investigate signal efficiency and radioactive backgrounds
- Operational status recognition (on/off cycles of two reactors)
- Sensitivity for discovery of one reactor in the presence of another

The WATCHMAN Collaboration

19 institutions from US and UK
91 collaborators

Co-spokespersons

Adam Bernstein — Lawrence Livermore National Laboratory

Mark Vagins — UC Irvine

Anti-Neutrino
Production and Detection

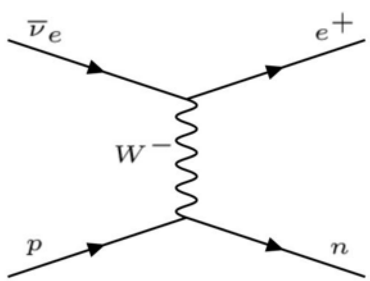
Produced in nuclear reactors

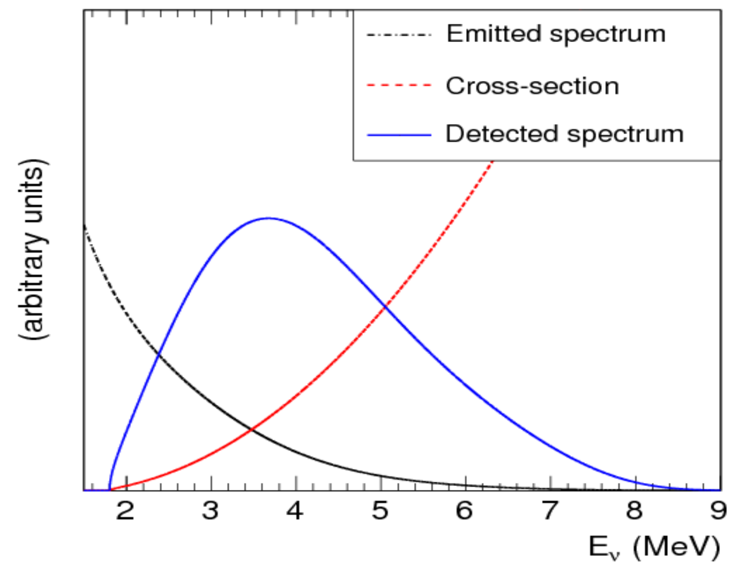
- β-decay of fission fragments
- 2×10^{20} anti-neutrinos per GWth
- isotropic emission

Detectable via Inverse Beta Decay

- low cross-section ~10^{-42} cm^{-2}
- impossible to shield

$$\overline{\nu}_e + p \rightarrow e^+ + n$$





arXiv:1101.2663 [hep-ex]

Anti-Neutrino
Based Reactor Monitoring

Close Proximity (up to 200 m)

- estimate fissile content and relative thermal power
- high statistics operation validation

Numerous experimental efforts

Mid- to Far-Field (200 m – 100+ km)

- low statistics regime
- remote monitoring
- reactor discovery / absence
- large area coverage

Very few Far-Field detectors

Advanced Instrumentation Testbed!

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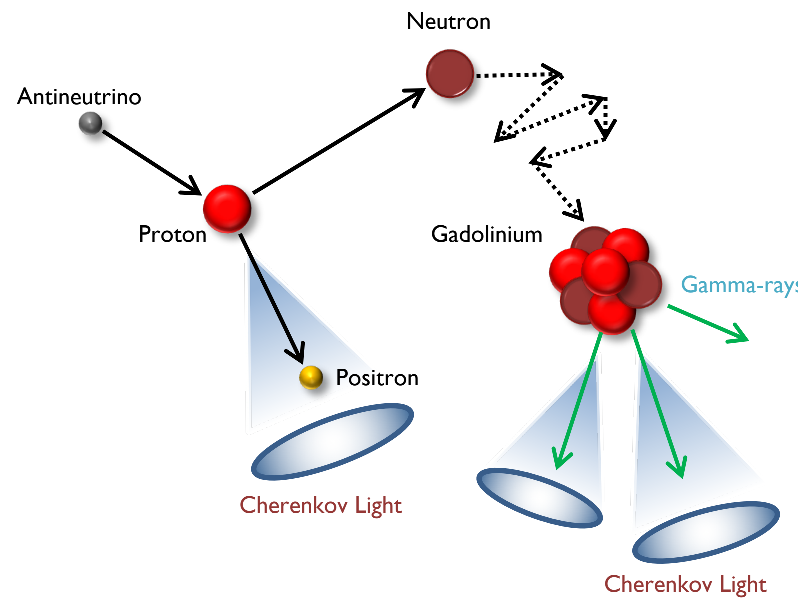
Observation Principle

Load water with gadolinium sulphate

- Gd has 49,000 b neutron capture cross-section (c.f. hydrogen 0.3 b)
- Capture produces 8 MeV γ-ray cascade (4-5 MeV visible)
- Thermalisation takes ~30 μs

$$\overline{\nu}_e + p \rightarrow e^+ + n$$

Achieve ~50% detection efficiency for antineutrinos interacting in fiducial volume



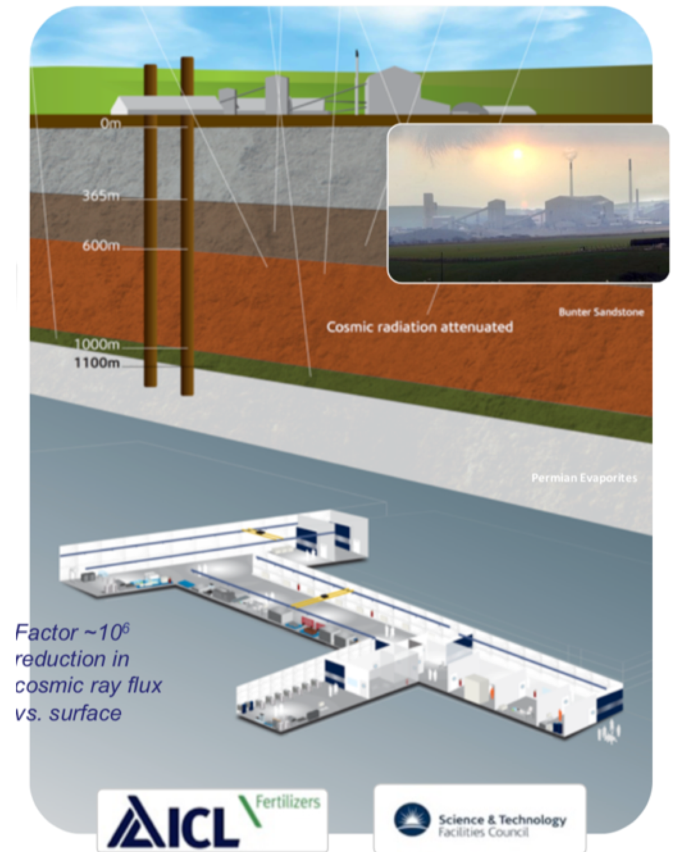
Anti-neutrino heartbeat
Inverse beta decay is detectable via two flashes of light occurring within a short time interval (~100 μs) and in close proximity.

AIT-WATCHMAN Site
STFC Boulby underground laboratory

Working polysulphate mine
Second deepest mine in Europe (1.4 km)

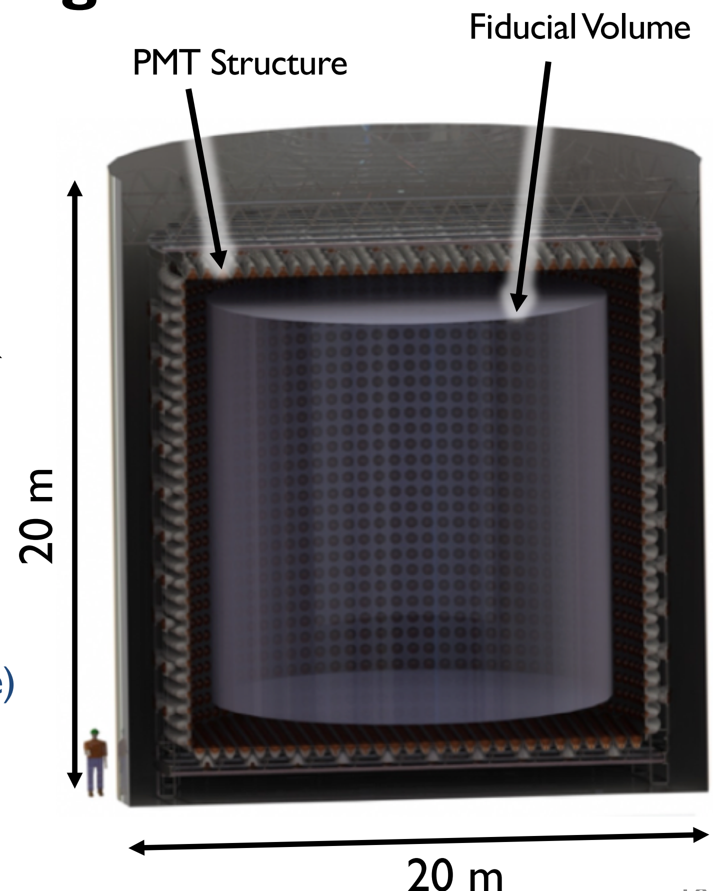
Site choice motivation

- A 30-year record of safe science at Boulby
- longstanding cooperation with AWE
- strong University partnership
- 10^6 reduction in cosmic ray flux vs. surface
- two-reactor site gives a stringent nonproliferation test for the new technology



AIT-WATCHMAN
Baseline Design

- 6000 m^3 tank
- Veto region between tank and PMTs
  (suppress cosmics & natural radioactivity backgrounds)
- Steel PMT support frame 3 m inside tank
  - 3600-4400 photomultiplier tubes (PMTs)
  - Low radioactivity 10" PMTs
  - 20-25% photo coverage
- 1.5 m between PMTs and fiducial volume
  (suppress radioactivity from PMTs & support structure)
- kiloton fiducial volume (virtual)

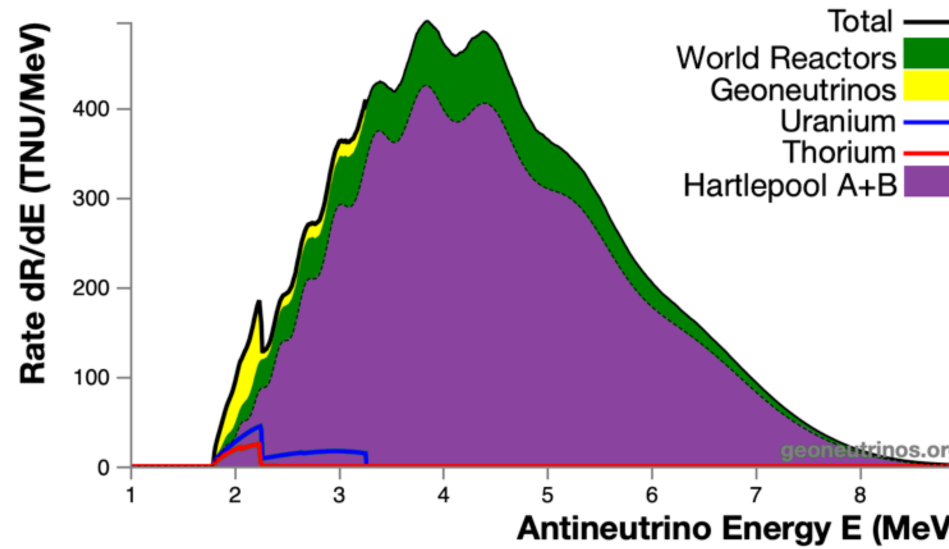


Antineutrino Interaction Rate

- Flux information for Boulby based on the online geoneutrino map project (https://geoneutrinos.org)

  See arXiv:1611.01575 Steve Dye

- Hartlepool provides ~83.4% of total antineutrino flux
- This translates to around 500 interactions/year



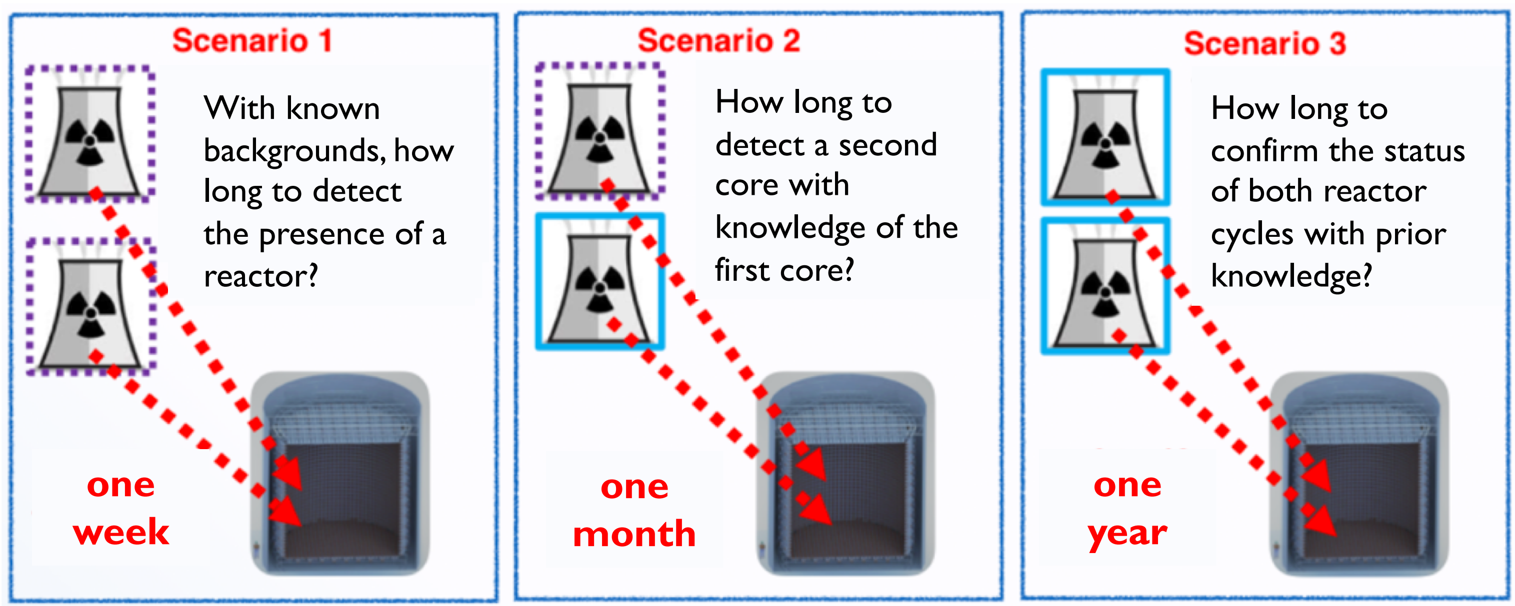
Event Rate Breakdown

Signal / Background Source	Events per week (20% photo-coverage)
Core 1	4.2
Core 2	4.2
World reactors	1.3
Accidentals	0.9
Fast neutrons*	0.6
Radionuclides	0.1
Total Signal	8.4
Total Background	2.9
Total Estimated	**11.3**

* Fast neutron study with FLUKA underway

- The table on the left shows the expected detection rates for one detector configuration
- The effect of varying photo-coverage and volume sizes on event rates is under investigation
- Analyses can include (unblind) or ignore (blind) prior knowledge of the operation of either or both reactor/s

Example Observation Scenarios

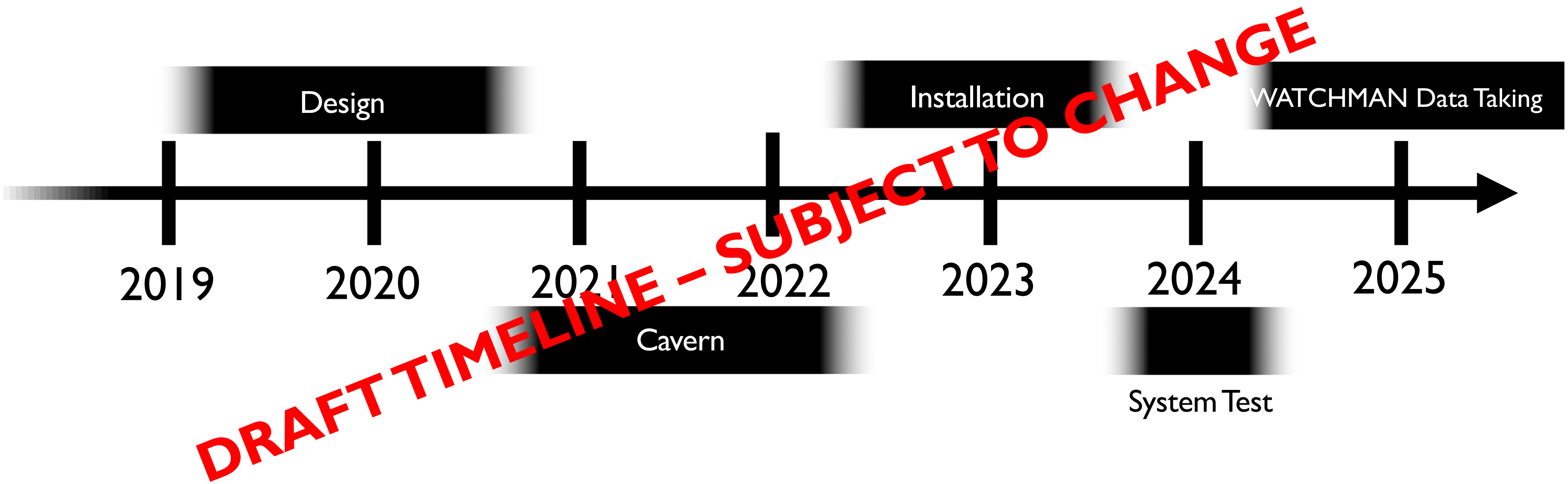


The WATCHMAN detector can be used to test several non-proliferation related observations!

AIT beyond WATCHMAN
Future Studies

Directionality	Detection of reactors at the longest ranges necessitates the addition of directionality information
Supernovae trigger	A dedicated trigger for recording supernovae neutrino events is under study
Fast Timing Detectors (e.g. LAPPD)	AIT will provide a future platform in which to test fast timing detectors such as Large Area Picosecond Photon Detectors
Water-based Liquid Scintillator (WbLS)	A water soluble mixture with fast timing, good spectral response, tunable light yield

AIT-WATCHMAN
Project Timeline



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Summary

- **WATCHMAN** will detect anti-neutrinos from a remote reactor using a tank of Gd-loaded water in Boulby Underground Laboratory.
- The primary goal is to monitor two nuclear reactor cores at 26 km standoff to prove the concept of a scalable monitoring system for non-proliferation
- The Advanced Instrument Testbed (**AIT**) aims to increase sensitivity beyond WATCHMAN
- Design and construction are underway

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Thanks for your attention!

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