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WATCHMAN & VIDARR

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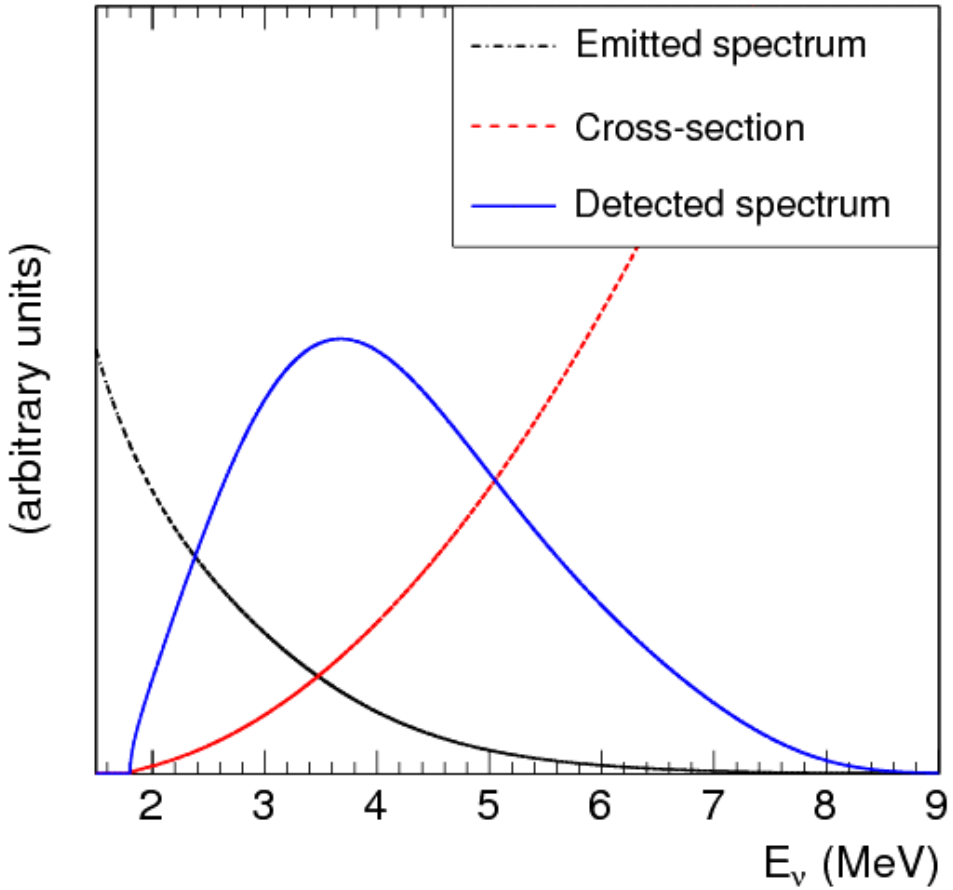
Particle Physics Annual Meeting 2019

ANTINEUTRINO PHYSICS AT REACTORS

- Antineutrinos produced in in active reactors:
  - Antineutrinos produced during β-decay of fission fragments: isotope-specific spectra
  - 2 x 10^{21} antineutrinos per GWth emitted isotropically during operation
- Antineutrino measurements:
  - Cross-section ~10^{-42} cm^{-2}: challenging detection
  - Interesting physics and applications:
    - Short baseline oscillations, spectral anomalies, sterile neutrinos etc.
    - Useful for verifying reactor status & operations
  - Detectors located either in the…
    - Near-field: 10s to 100s of meters
    - Far-field: 10s to 100s of kilometers



From arXiv:1101.2663 [hep-ex]

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FAR-FIELD REACTOR NEUTRINOS: AIT NE-1/WATCHMAN

Andrew Carroll
Jonathon Coleman
Neil McCauley
Carl Metelko
Yan-Jie Schnellbach

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THE AIT NE-1 PROJECT

- AIT (Advanced Instrumentation Testbed): Infrastructure & site
- WATCHMAN (Water Cherenkov Monitor for Antineutrinos):
  Collaboration working on the project
- NE-1 (Neutrino Experiment 1):
  - Objective: "Demonstrate nuclear reactor monitoring for non-proliferation purposes through antineutrino detection using a large, scalable technology"
  - kton-scale Gd-loaded water-based antineutrino detector
  - Standoff distance: ~10s of km for on/off detection
- Selected location: **Boulby Underground Laboratory**
  - Closest reactor site is Hartlepool (~30km)
  - Two reactors at 1.5 $GW^{thermal}$

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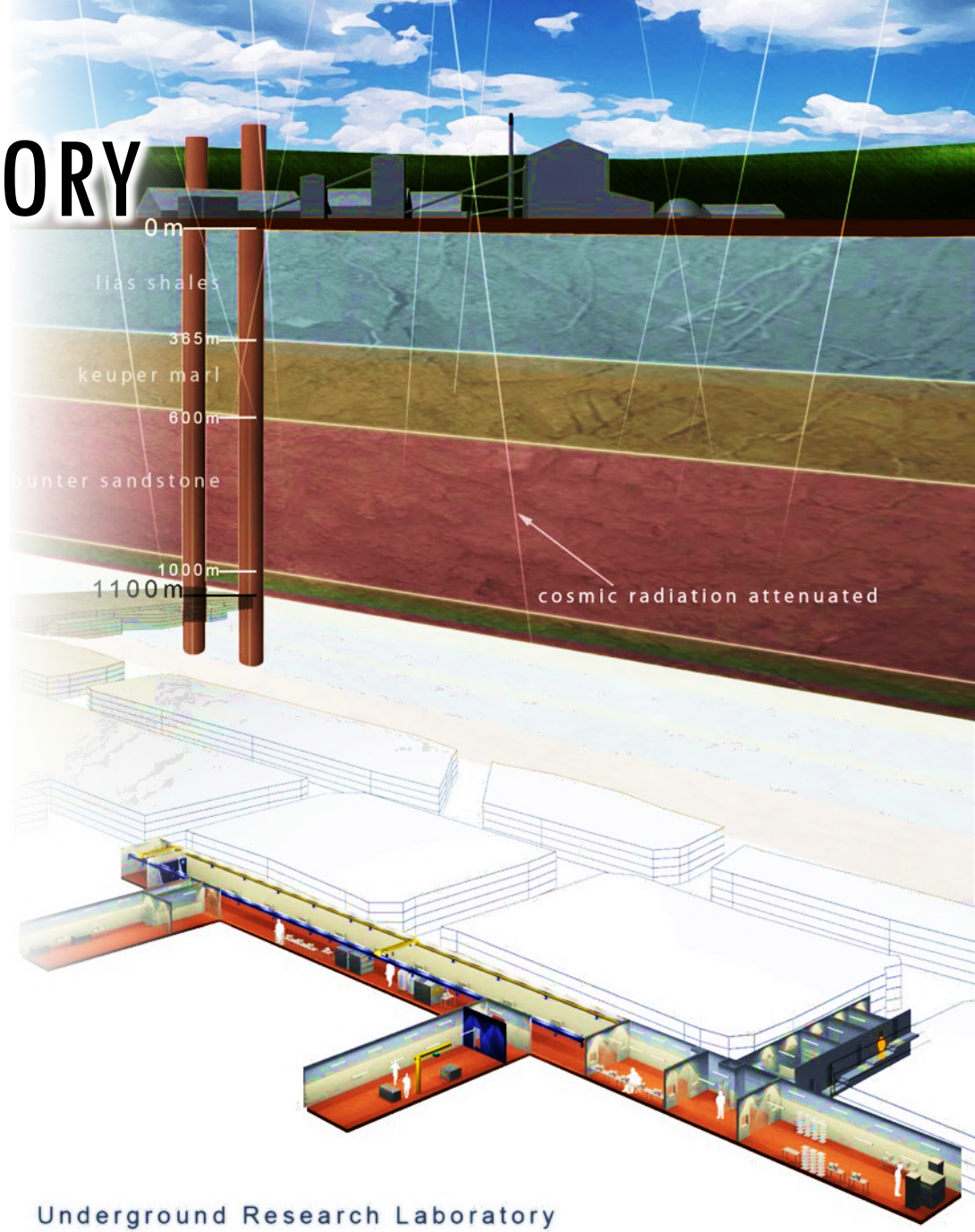
US-UK COLLABORATION

BOULBY UNDERGROUND LABORATORY

- Selected detector site:
  Boulby Underground Laboratory
- UK STFC-operated facility located 1100m underground:
  - Worked on Dark Matter experiments before
- Part of an operating potash/polyhalite mine
- Project will be housed in dedicated new cavern (25m tall, 25m diameter)



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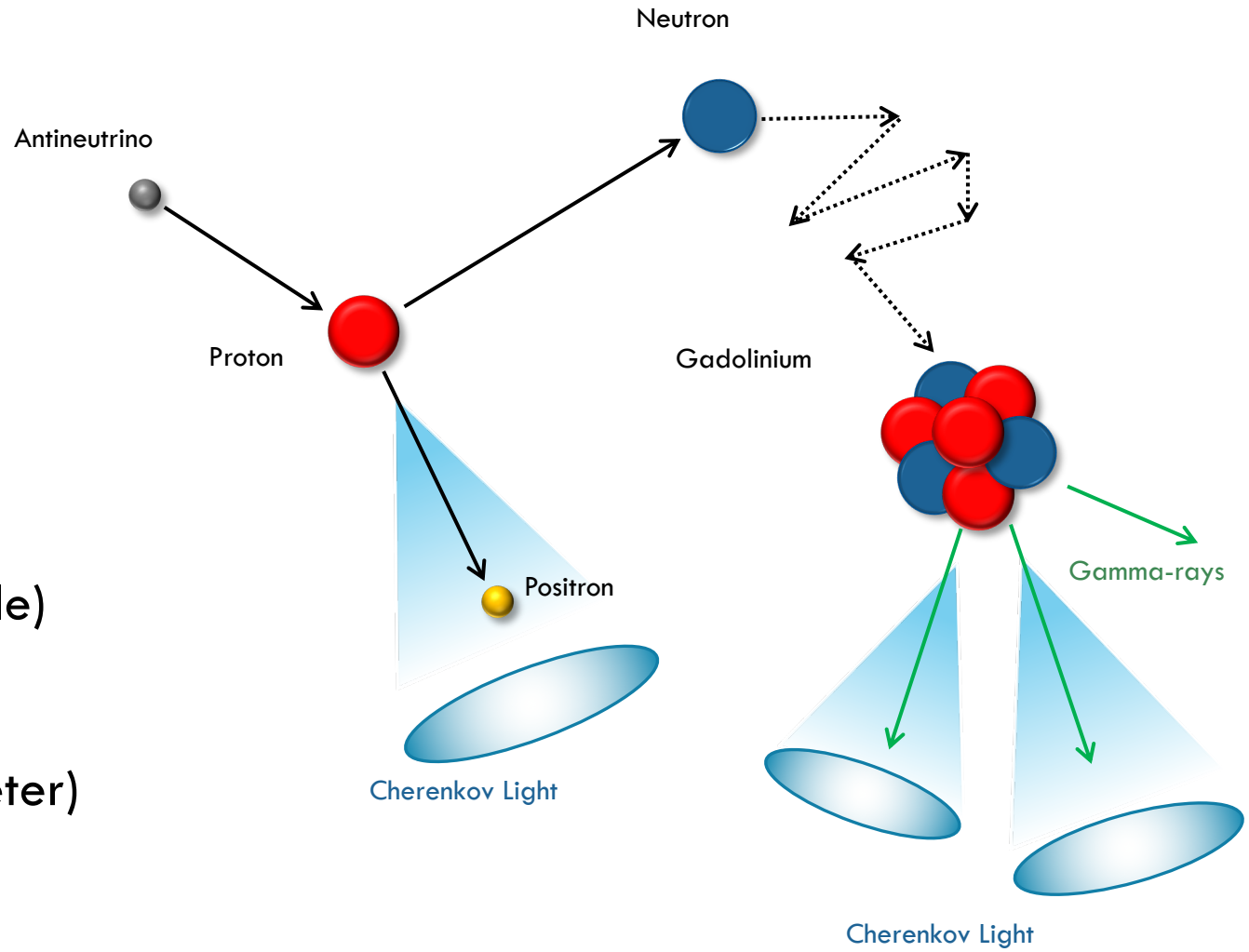
LOW-ENERGY NEUTRINOS IN WATER

- Inverse β-decay detection:
  - Positron + neutron
- Cherenkov detector using gadolinium-loaded water:
  - Positron detected as single ring
  - Neutron capture on Gd produces 8 MeV ɣ-ray cascade (4-5 MeV visible)
- Baseline design:
  - Cylindrical tank (20m tall, 20m diameter)
  - ~1 kton fiducial volume
  - 0.1% Gd loading



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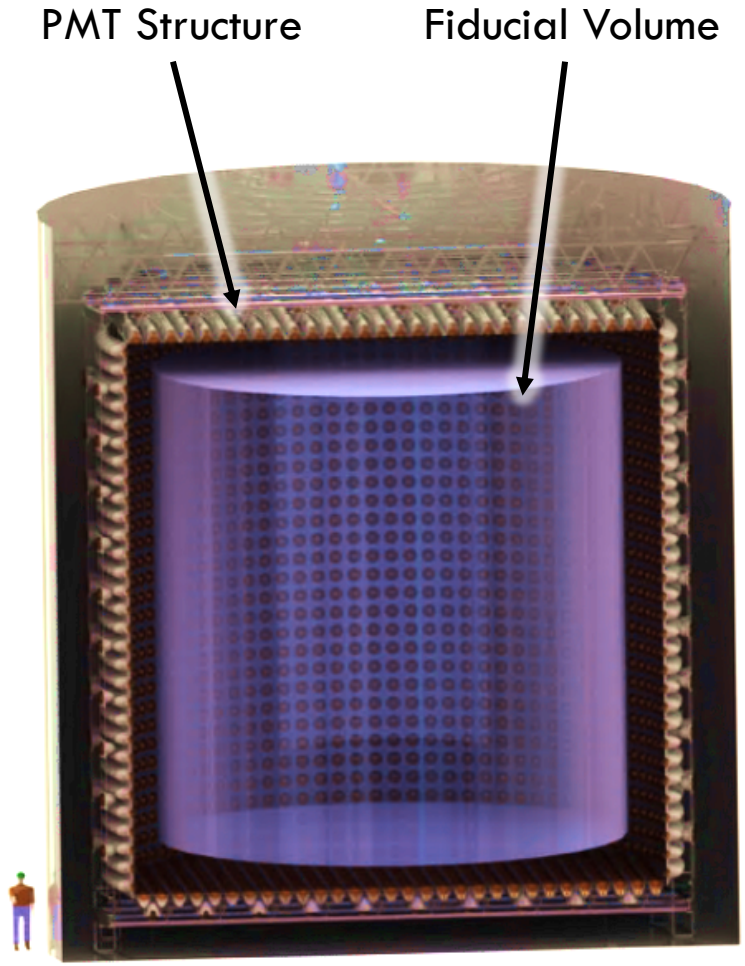

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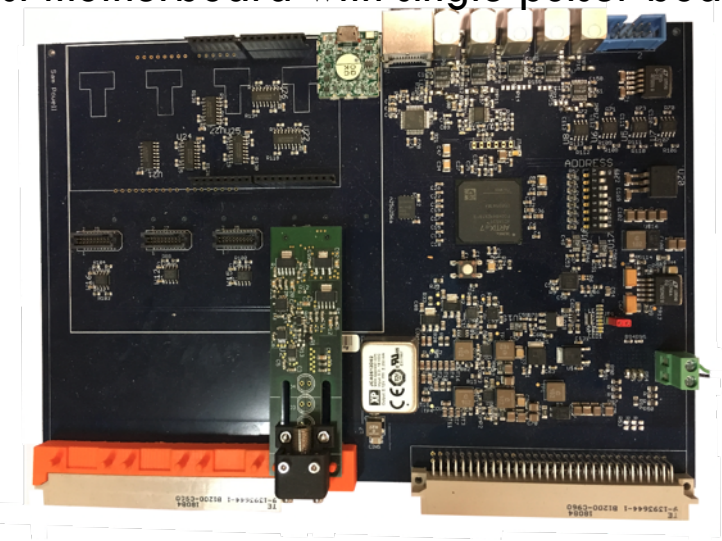
LIVERPOOL ACTIVITIES

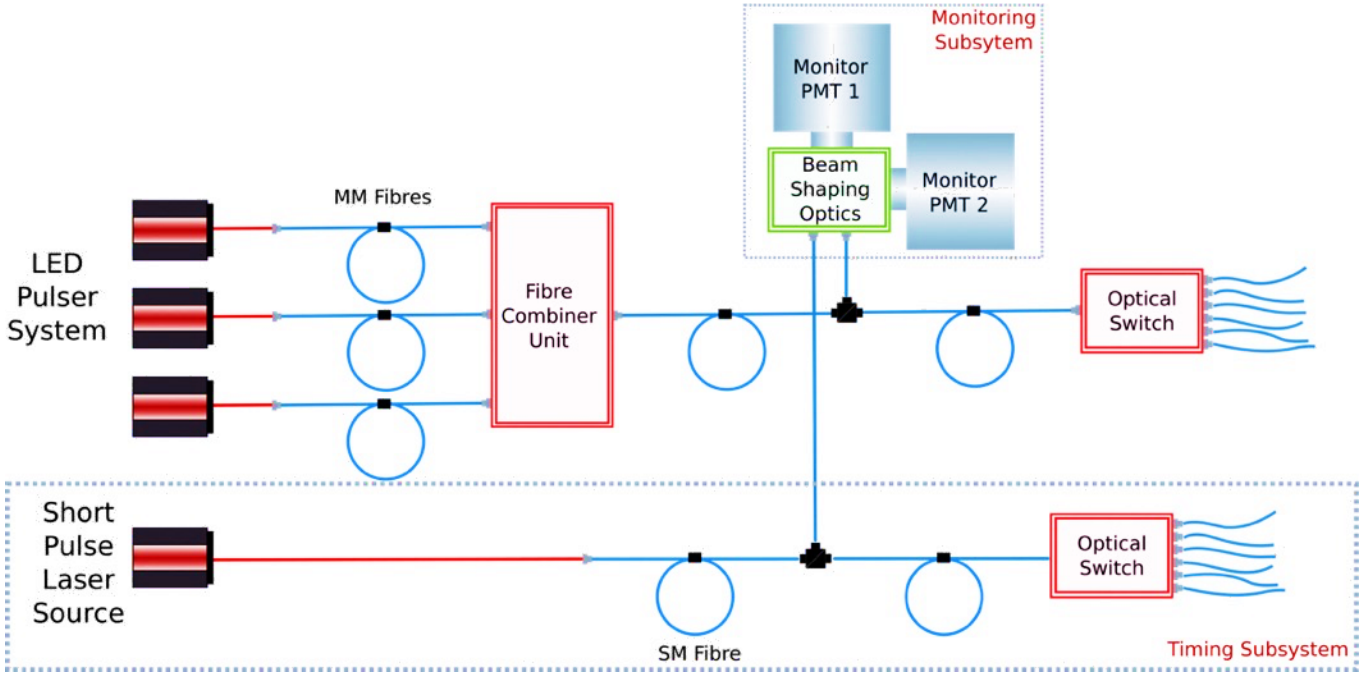
- Liverpool group joined WATCHMAN in 2018
- Contributing to several areas & leading two working groups:
  - Light-injection & Calibration System
  - Supernova Studies
  - DAQ (REBAM)
  - Compensation Coils
  - Near-Field Coordination

LIGHT-INJECTION SYSTEM OVERVIEW

- System leverages HyperK (and LZ) work at Liverpool
- LED pulser system:
  - Gain and water properties
  - Multiple wavelengths
  - Switches between injection points
- Timing subsystem:
  - Laser-based with SM fibres
- Monitoring subsystem:
  - Monitor intensity
  - Cross check between systems

Test motherboard with single pulser board





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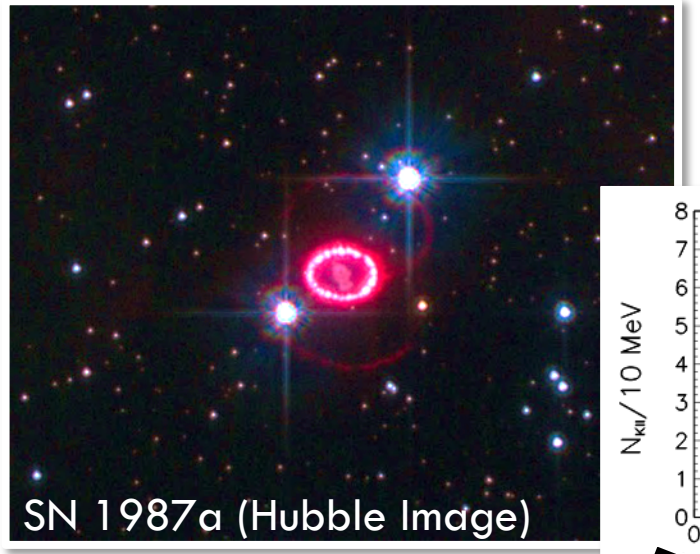
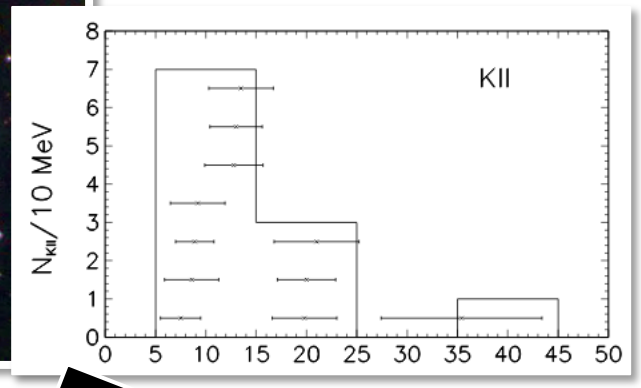
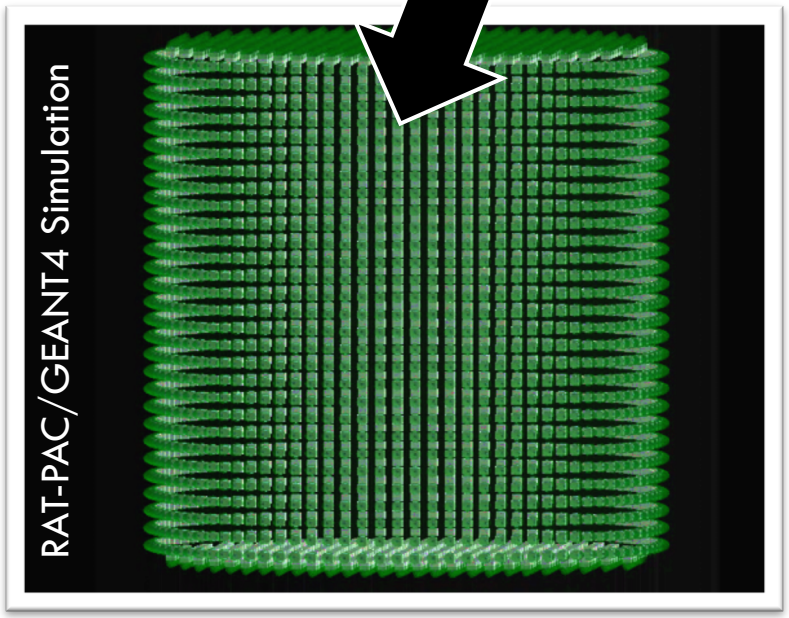
SUPERNOVA STUDIES

- Last supernova was SN1987a
  - Seen at Kamioka Observatory in neutrino spectrum
- Supernova neutrinos major physics motivation:
  - Early arrival acts as warning system for telescopes
  - Spectrum contains information about core collapse – **supernova physics**
- To fulfil these physics goals, NE-1 needs:
  - Detector simulation for SN events
  - Design SN trigger
  - DAQ suitable for peak rates from SN







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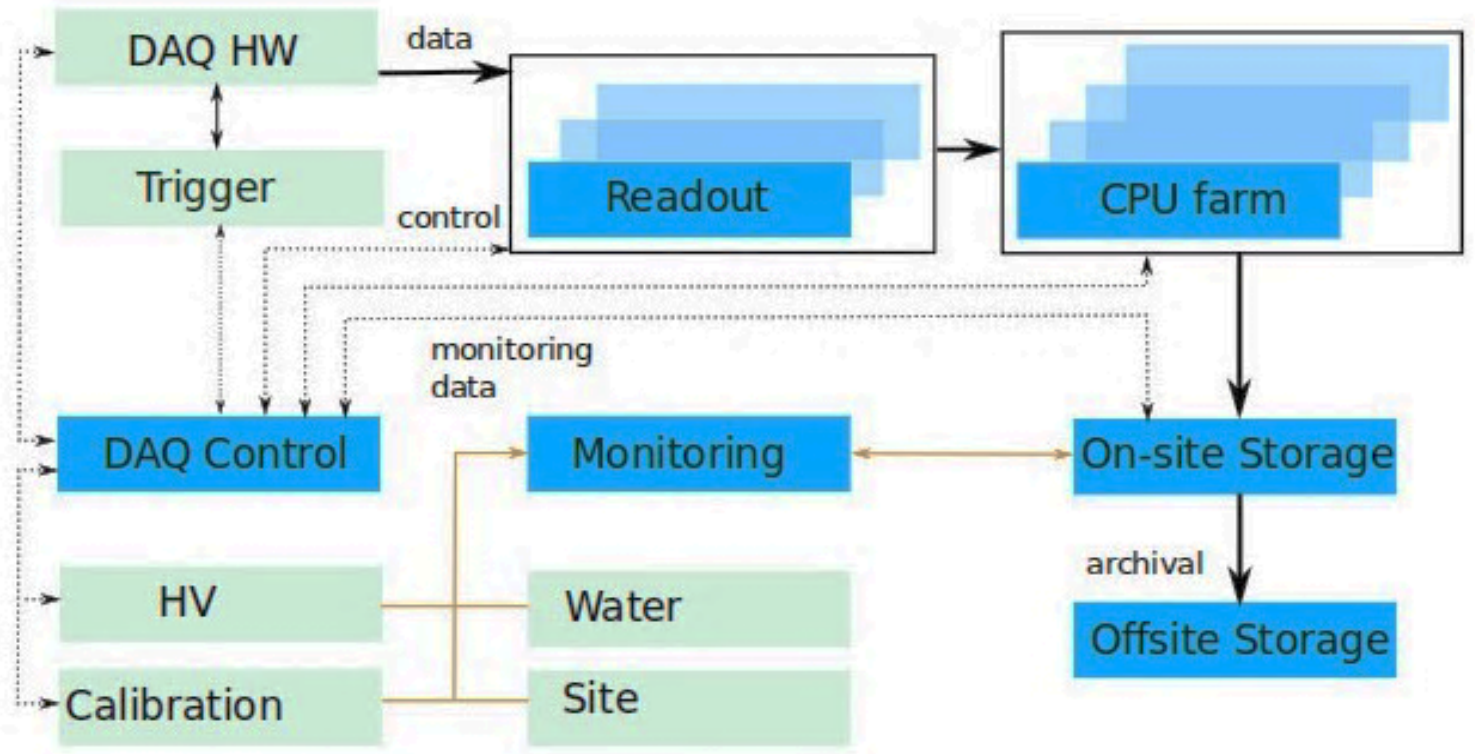
DATA ACQUISITION - DAQ (REBAM)

- DAQ (except HW) is called: **R**eadout, **E**vent **B**uilding **A**nd **M**onitoring (REBAM)
- Liverpool (C. Metelko) leads desig efforts & working group (co-lead with UPenn)
  - Will be designing and testing a vertical test slice
- Includes:
  - Readout computers
  - CPU farm
  - DAQ Control
  - Monitoring (online/offline)
  - On- and offsite storage
- Liaising with GRIDPP to understand processing/data distribution solutions



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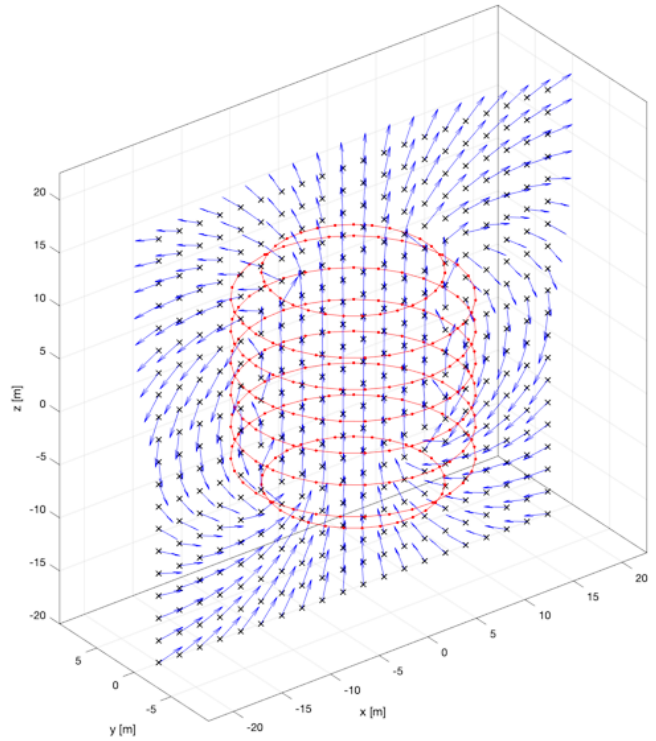
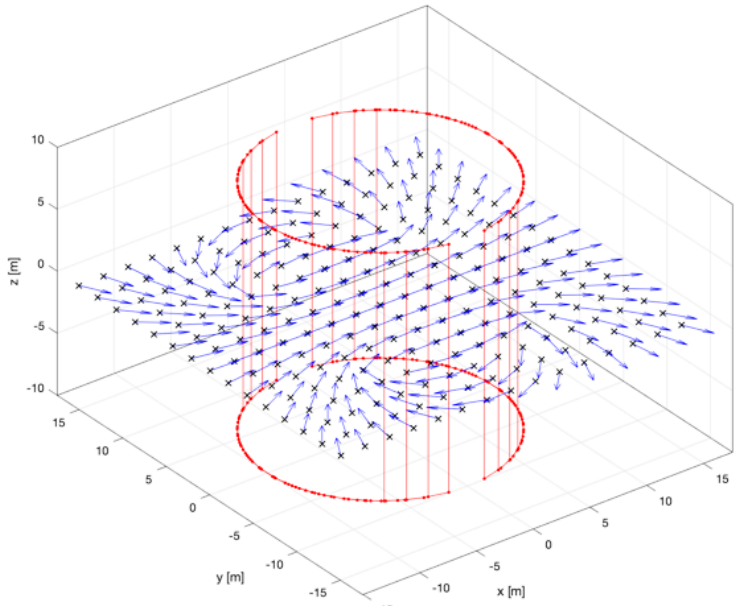
COMPENSATION COILS

- Geomagnetic field at Boulby:
  - **Horizontal Field:** 179.30 ± 01.33 mG
  - **Vertical Field:** 462.68 ± 01.65 mG
  - **Total Field:** 496.21 mG
- Causes ~10% drop in PMT efficiency
- Requires magnetic coils for compensation
- Liverpool work on:
  - Modelling of magnetic field
  - Design of coil layout
  - Selection of power supply, monitoring, protective systems, wiring and connections





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NEAR-FIELD WORKING GROUP

- Liverpool liaises between collaboration and Hartlepool site, leading the working group (J. Coleman):
- The main focus is on:
  - Inputs that inform sensitivity studies
  - The ultimate successful operation of the large detector.
- The most relevant charge relates to getting information that directly affects WATCHMAN sensitivity:
  - Core design, power and burnup
  - Access to reactor history and data
  - Geographical information

NATIONAL NUCLEAR LABORATORY

EDF

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NEAR-FIELD WORKING GROUP

- Understand requirements for near-field detector deployments:
  - Secondary from the WATCHMAN perspective (at the moment)
  - Near-field activity in the currently only proposed, not funded
  - Site scouting for complementary near-field experiments
- Several proposed near-field experiments
- Planned campaign to map detector backgrounds at reactor site

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NEAR-FIELD REACTOR NEUTRINOS:

Jonathon Coleman
Ronald Collins
George Holt
Carl Metelko
Yan-Jie Schnellbach

Innovate UK
THE ROYAL SOCIETY
RSE ENTERPRISE FELLOWSHIPS
NATIONAL NUCLEAR LABORATORY

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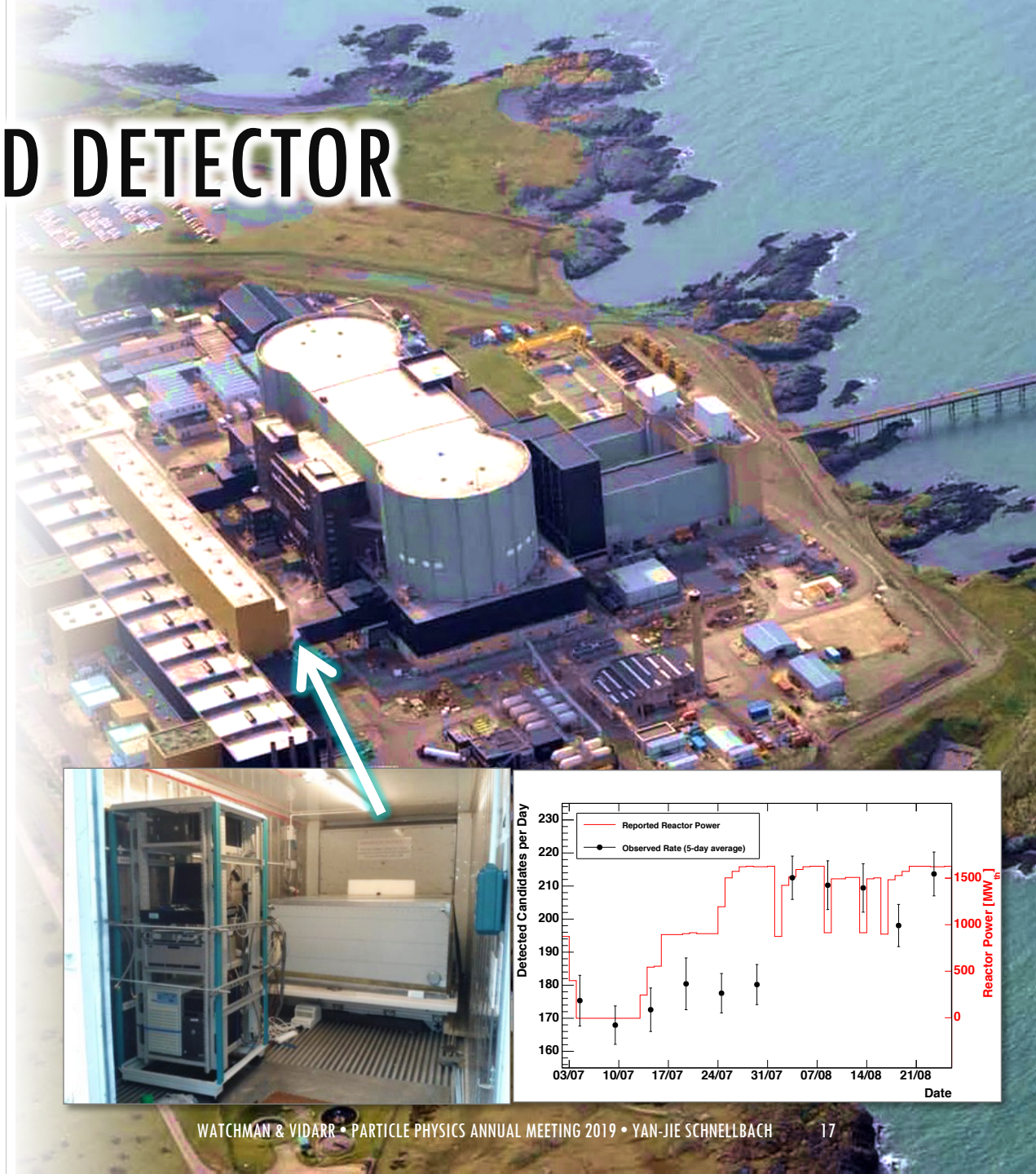
VIDARR: COMPACT NEAR-FIELD DETECTOR

- VIDARR: Verification Instrument for Direct Assay of Reactors at Range:
  - Compact tonne-scale device for near-field deployment (< 100m)
  - Based on T2K ND280 Ecal
  - Based on inverse β-decay detection
- Pre-VIDARR demonstrator was deployed in 2014/2015 at Wylfa Magnox
  - Observed candidate increase during turn-on
- Started upgrade process in 2015 with JCS



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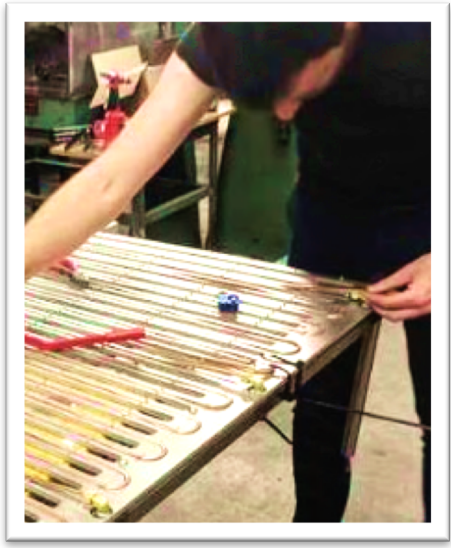
UPGRADE GALLERY

- Key upgrades:
  - Additional scintillator (+50% active mass)
  - Custom DAQ electronics
  - New generation MPPCs
  - Tailor-made thermal solution
- More details in Ron Collins' talk yesterday!



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SUMMARY

- Liverpool has a strong reactor anti-neutrino programme:

- AIT-NE1 /WATCHMAN:
  - Leveraging our HyperK/LZ and near-field experience
  - Physics-motivated programme – more than just reactors
  - Leading two working groups

- VIDARR:
  - Completing detector construction and soon ready for cosmic data
  - Ready to deploy in 2020