



BUTTON: WbLS Detector Development at Boulby Underground Lab

IOP Cambridge 7-9th April 2025

On behalf of the BUTTON collaboration

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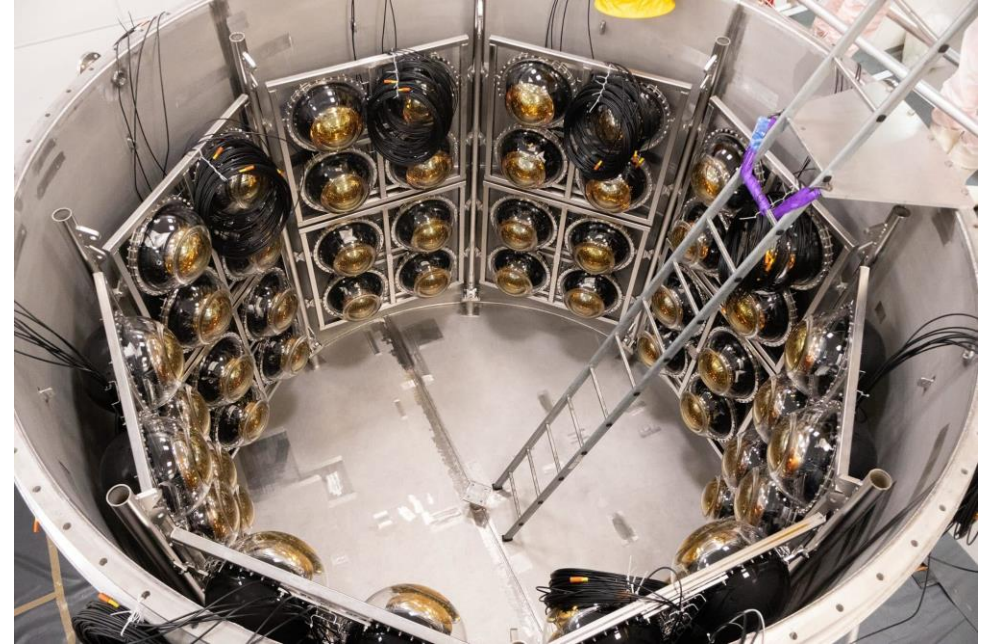
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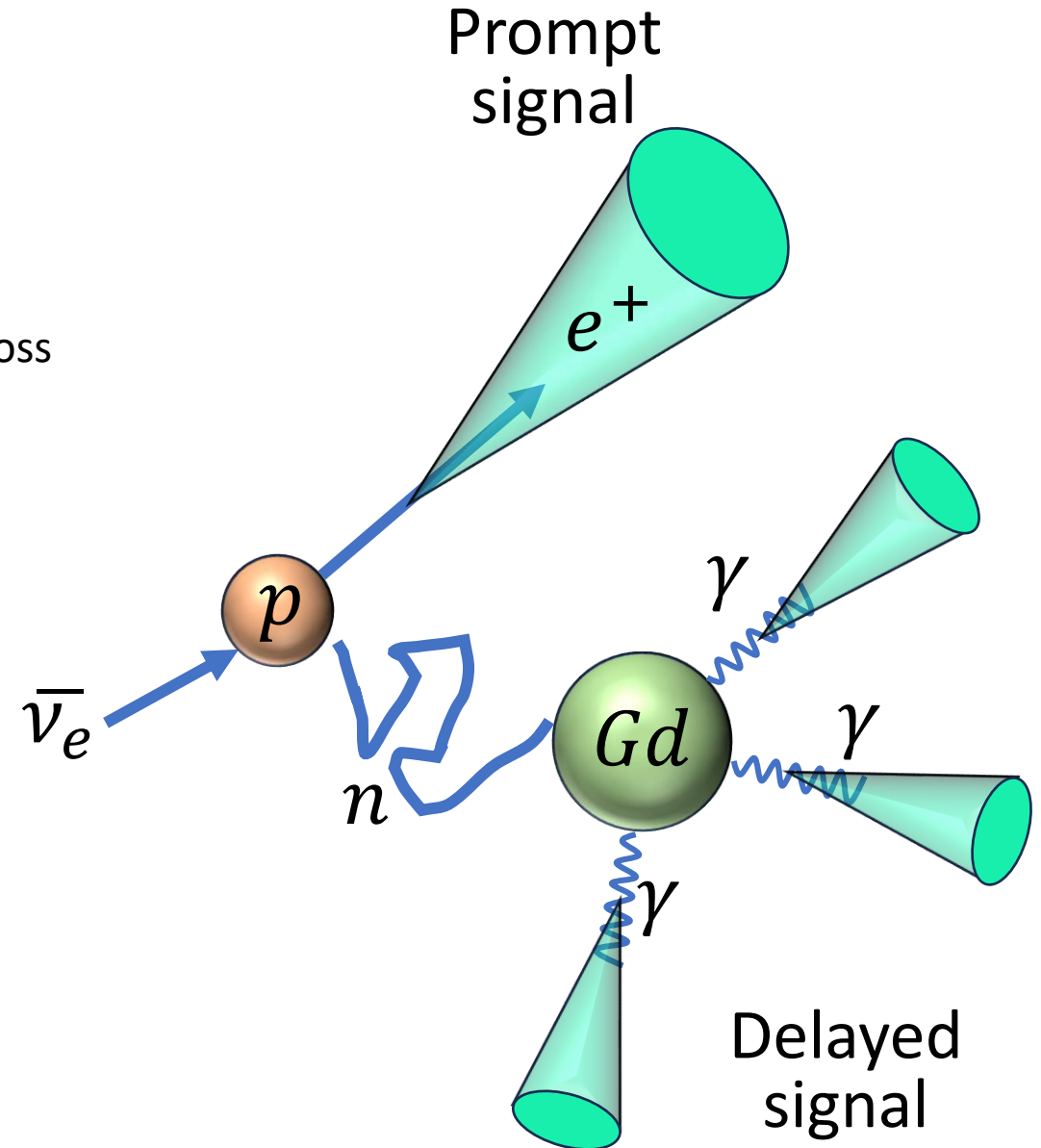
- Neutrino detection and innovative technologies
- The BUTTON collaboration and design goals
- Development and construction of subsystems
- Where we stand currently



(Anti)Neutrino Detection

Gadolinium doped *fill media* provides a much higher neutron capture cross section which allows better inverse beta decay detection. ($\sim 163,000 \times$) – The second largest neutron capture cross section in nature.

- Inverse beta decay in some detector medium
- Neutron detection
- Can be fairly inexpensive for the volume
- $\bar{\nu}_e + p \rightarrow e^+ + n$



BUTTON Collaboration



Boulby collaboration meetings in UK and the US 2024.

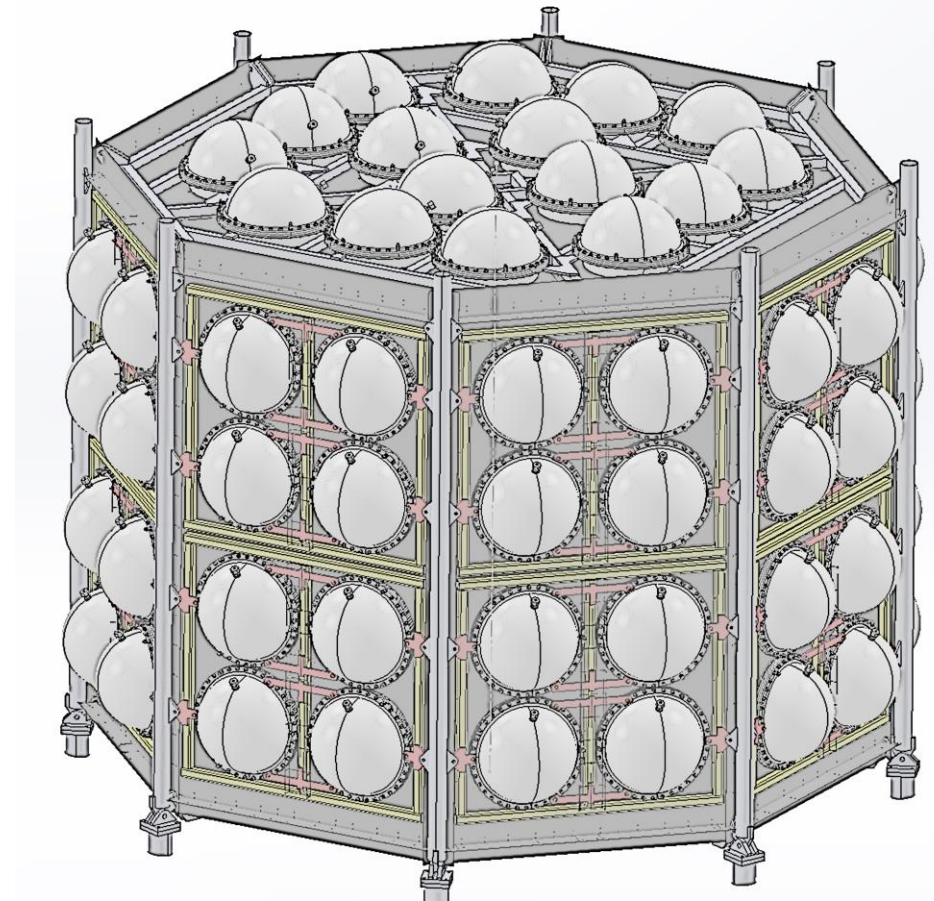
Funded in the UK by STFC from the UKRI Fund for International Collaboration and the MoD.

58 members across 17 institutions in the UK and U.S.

BUTTON (Boulby Underground Technology Testbed Observing Neutrinos)

Development goals/design intent

- Neutrino detection
- Flexibility to test different technologies
- Advanced photosensors
- Advanced fill media
- Building scientific capability at Boulby underground lab

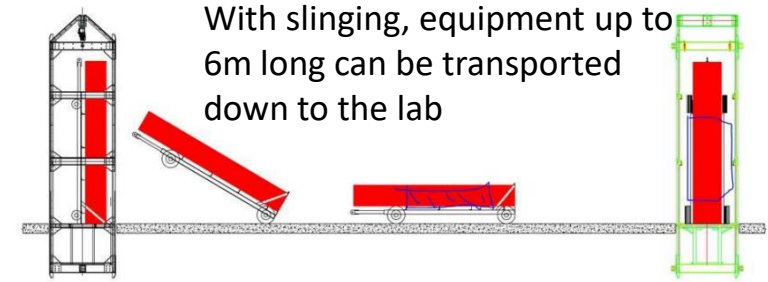




Science and
Technology
Facilities Council

Boulby Underground Laboratory

The UK's deep underground science facility operating in a working potash and salt mine.



Office space, chemistry & clean prep lab, storage and staging space, IT room, conference room,

Surface support and staging building

3000m³ Outside Experimentation Area

Street

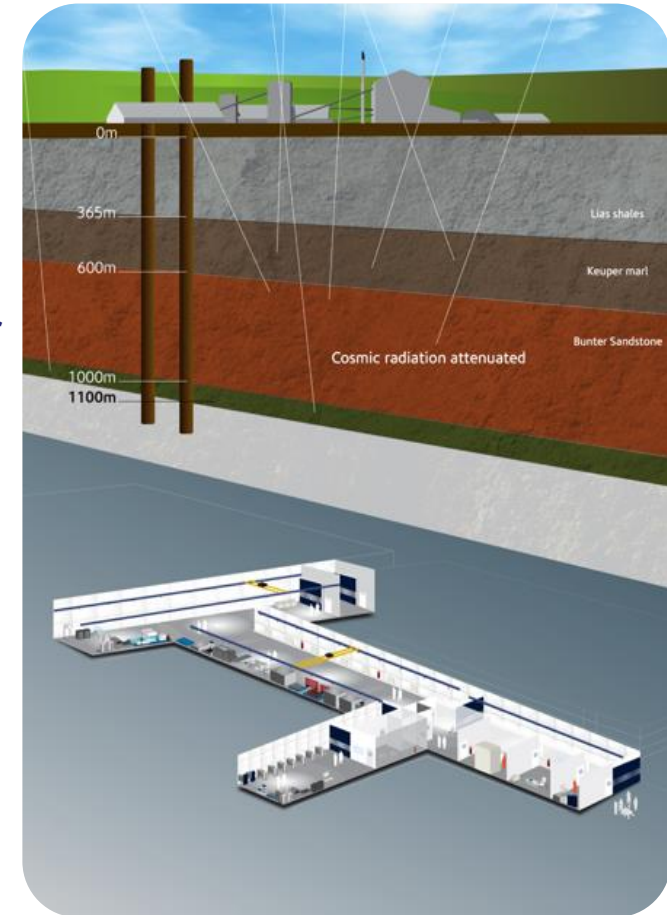
Boulby Underground Lab Facilities 2021:
 >4000m³ class 1k & 10k clean room lab space
 100Mb Internet AC, Air filtration, 5T & 10T lifting, LN generation, fume hood & clean prep
 3000m³ Outside Expt. Area. Power & internet

BUGS+ Material screening

1.1km depth (2805 meter water equivalent). With low background surrounding rock-salt

Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL-UK

Reduction of cosmic ray flux vs surface (10^6)



Water Based Liquid Scintillator (WbLS)

Cherenkov

- Directional information
 - Low attenuation – larger volumes possible
 - Particle ID at higher energies
-
- Cherenkov threshold limits physics visible
 - Low light yield

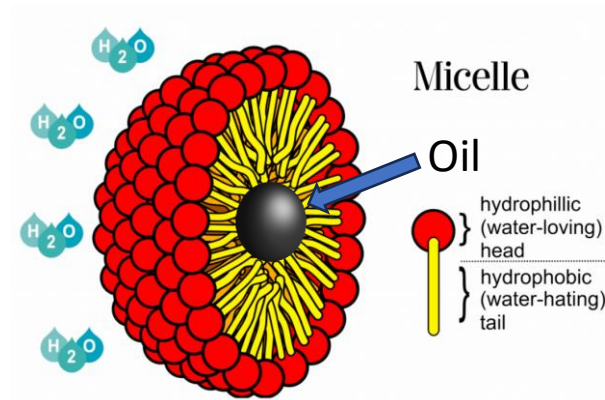


Image adapted from: UC Davis Neutrino Group – Water based liquid scintillator

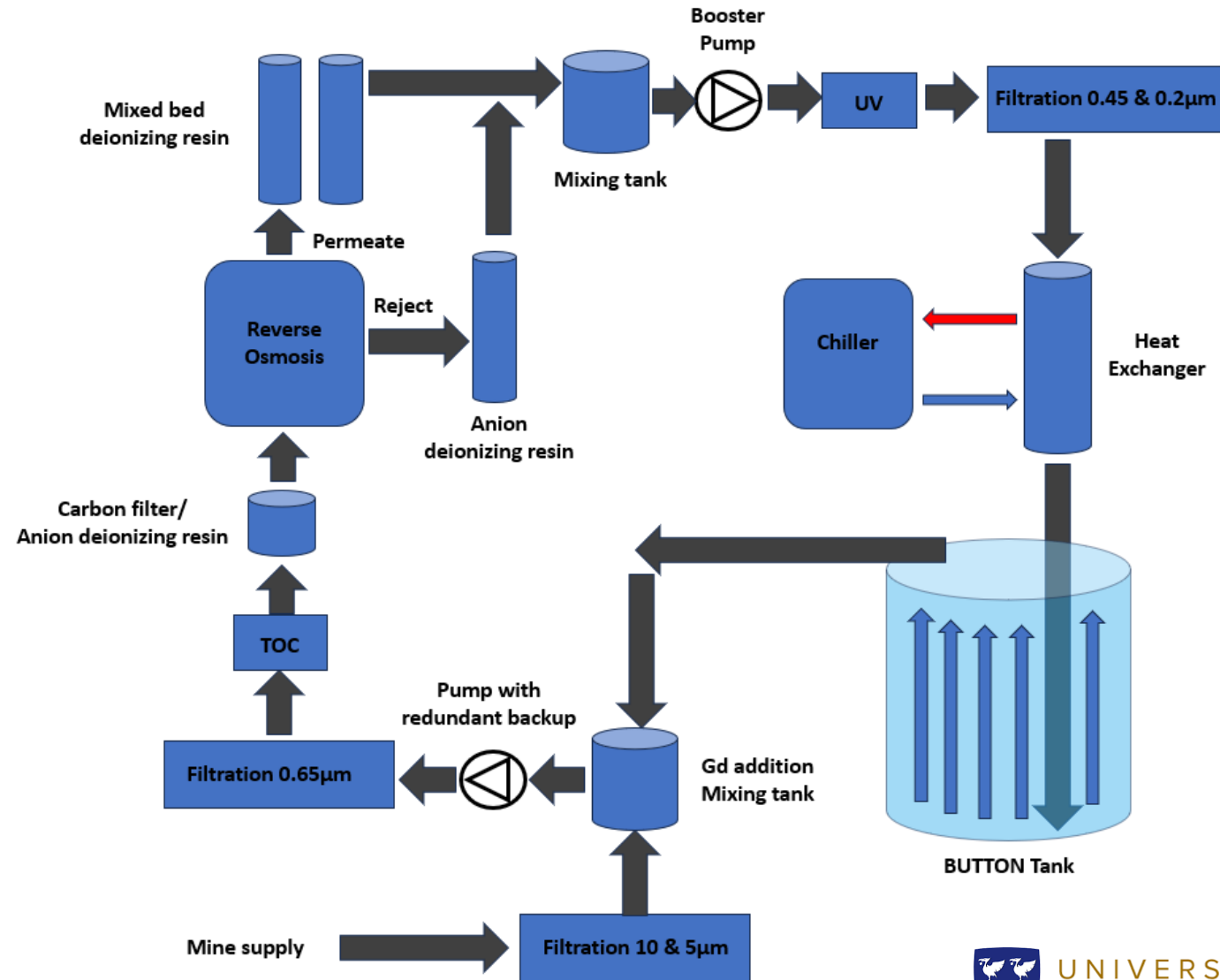
WbLS

- Directional information
 - Lower attenuation than LS allowing larger volumes
 - Higher light yield than water
-
- Unproven at scale -> BUTTON
 - Specific separation and cleansing system required
 - Waste Management

Scintillation

- High light yield
 - No Cherenkov threshold
 - Good energy and position resolution
-
- High attenuation limiting volume
 - Higher cost
 - Little to no directionality
 - More costly waste management

Water system development



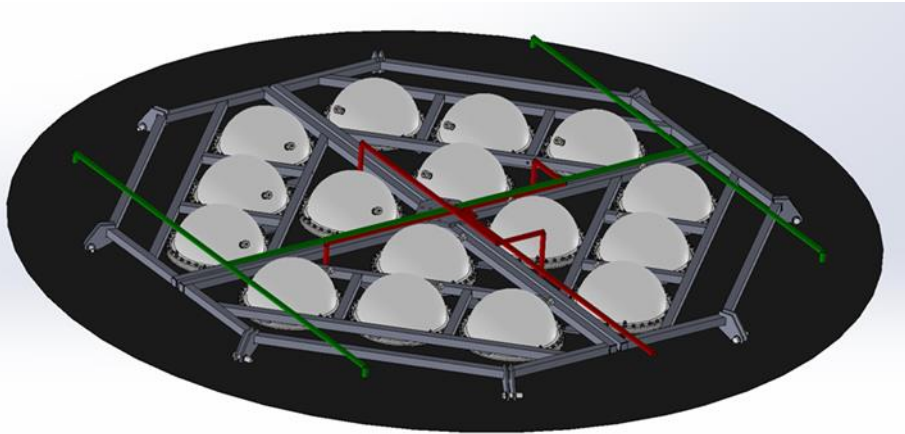
Water system development



The water system for the BUTTON experiment has been developed and is currently being built and tested in Liverpool by myself and Kieran Bridges



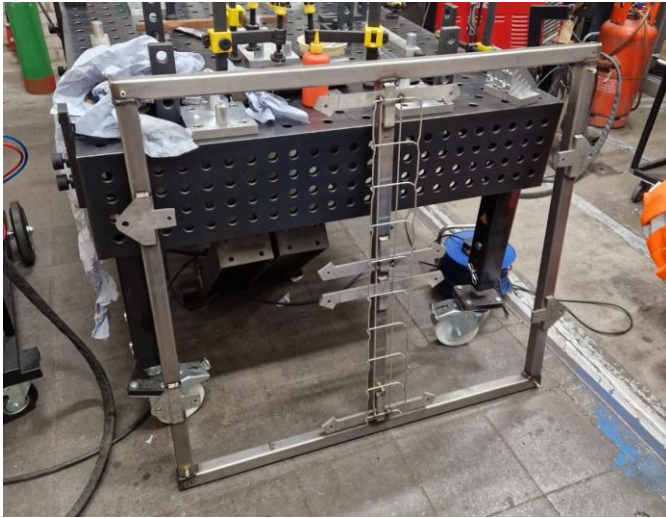
PVDF pipework for heightened compatibility for future fill media.



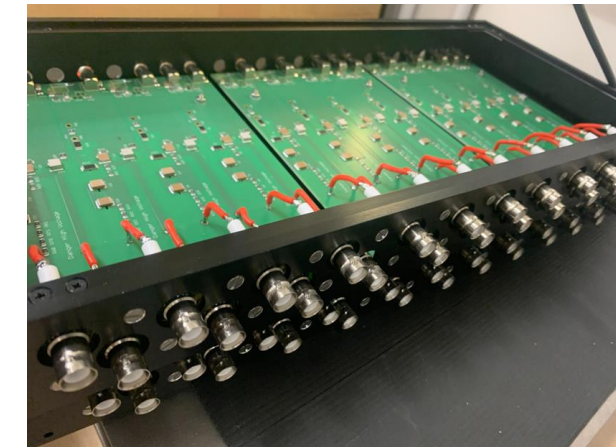
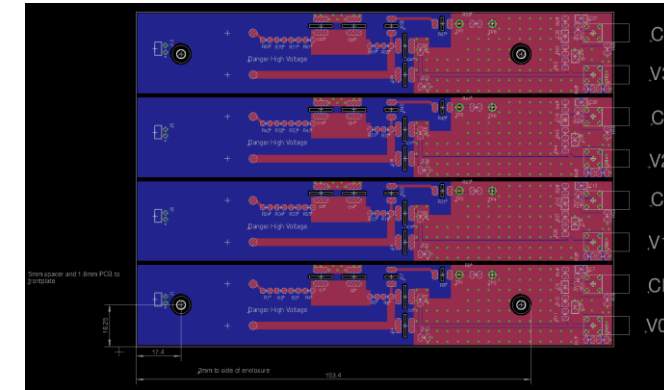
Water system development



Construction

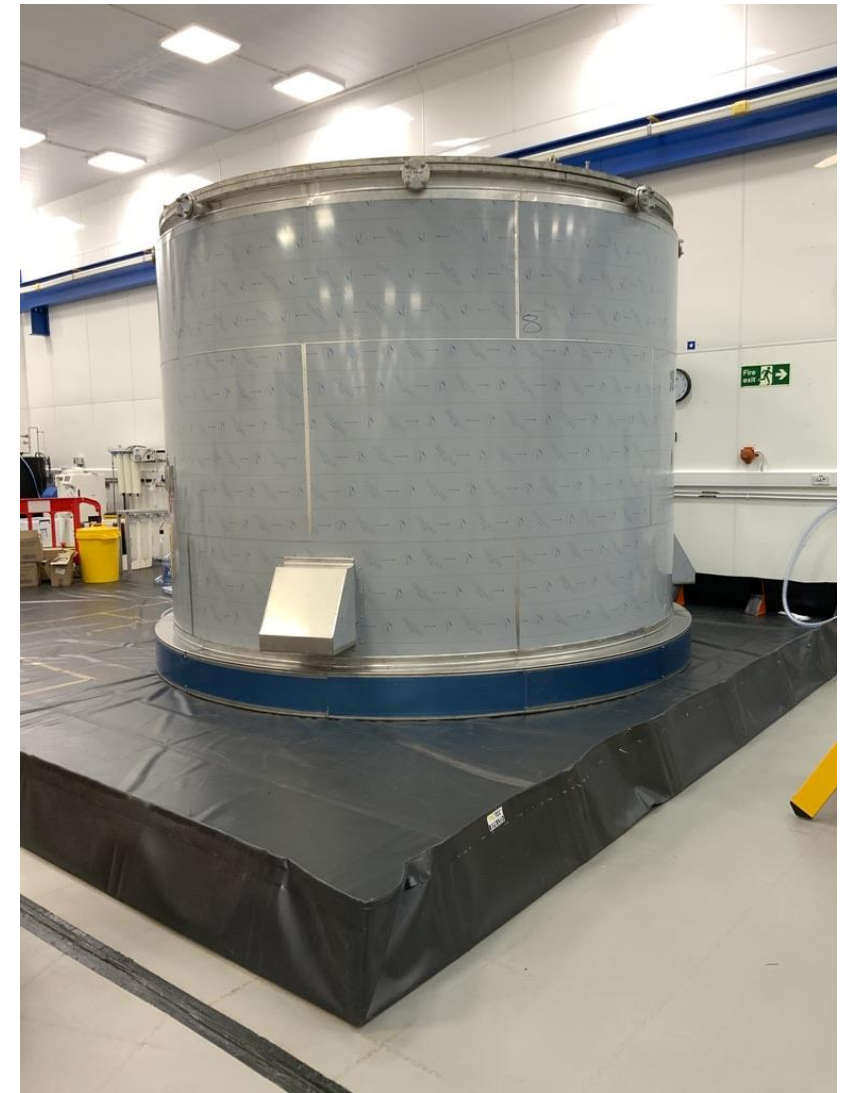


Production of the 316L PSUP was undertaken by Liverpool University workshop and have now been partially installed. This is modular for the later inclusion of advanced photosensors.



Custom data acquisition and electronics system is installed in the lab.

Tank Construction



Jan 2024 – Tank build commenced



Initial Fill



Dec 2024

An initial water fill was commenced to ensure

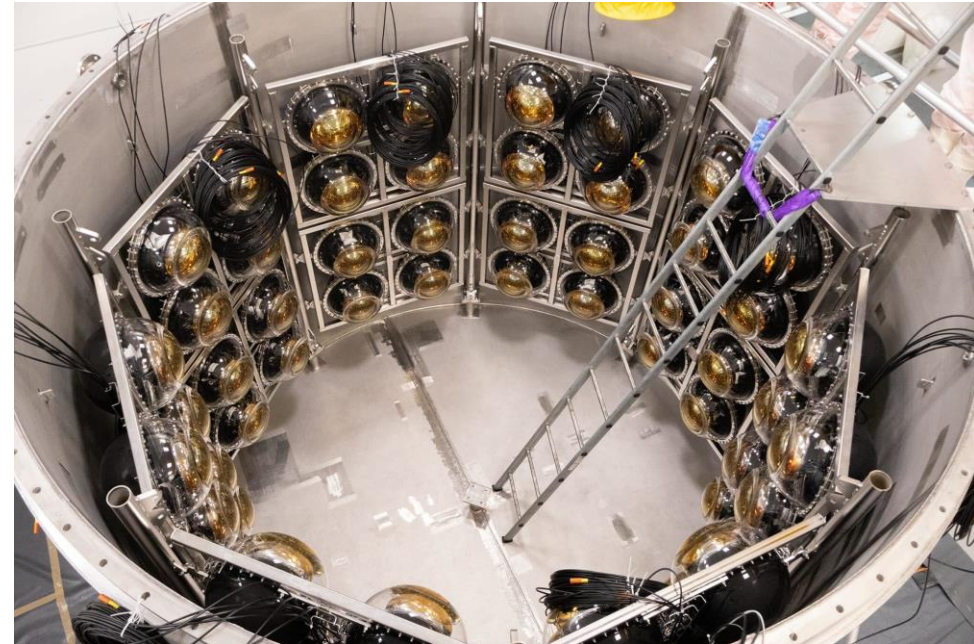
- Floor loading
- Tank integrity
- Feed and drain plumbing

And to wash debris from the tank.



The tank was then inspected, cleaned and passivated in areas with defects. Before the experiment starts the tank will be flushed 3 times

PMT installation



Jan 2025

64 PMT optical modules in the barrel section installed

BUTTON Calibration

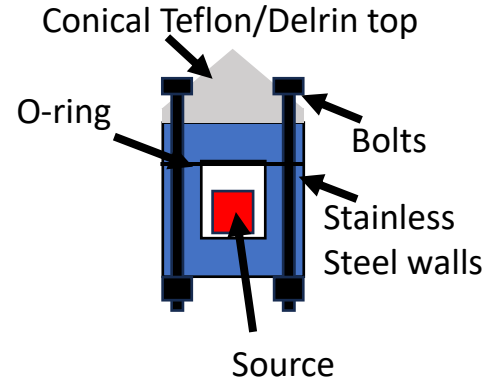
Requirements:

- Need to deploy radioactive sources anywhere in the BUTTON tank safely, cleanly, and do so with very constrained headroom limitations in the Boulby Underground Lab main hall.

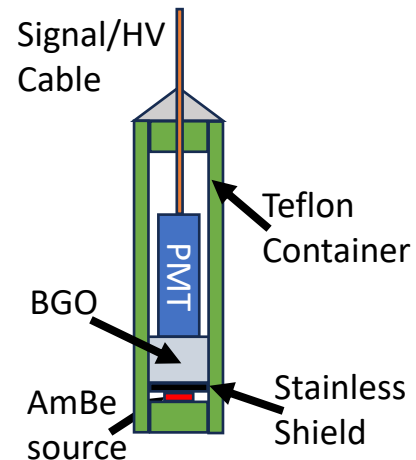
Solution:

- Sources deployed from a removable cassette inside a permanently mounted sealed box.
- 5 deployment ports available at top of tank.

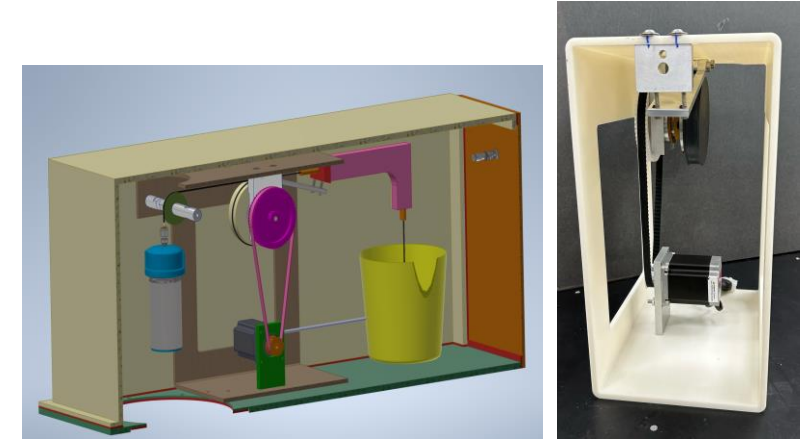
Untagged AmBe and 2.6 MeV ^{208}Tl



tagged AmBe



Detector top calibration design and Prototype testing



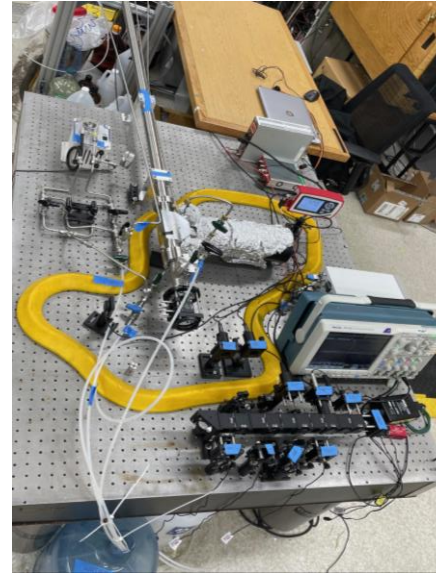
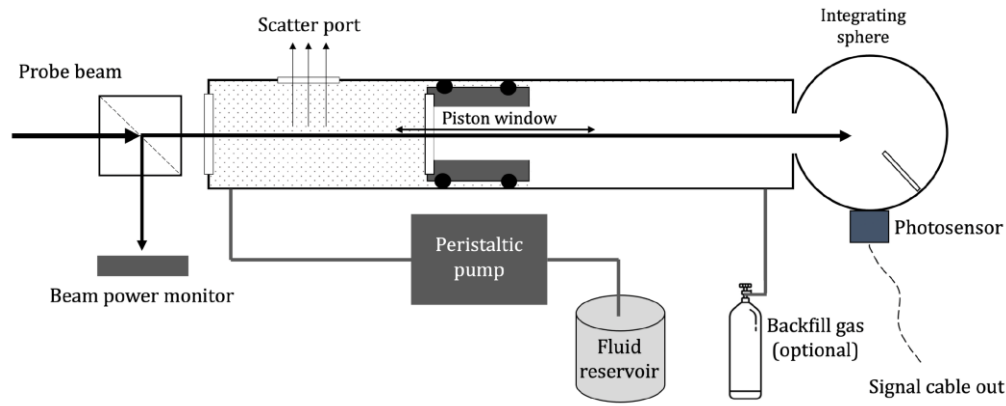
Prototyping and initial steps

- Prototype deployment cassette - testing now
- AmBe source to UK April 2025
- Untagged gamma and neutron source containers, deployment April/May 2025.

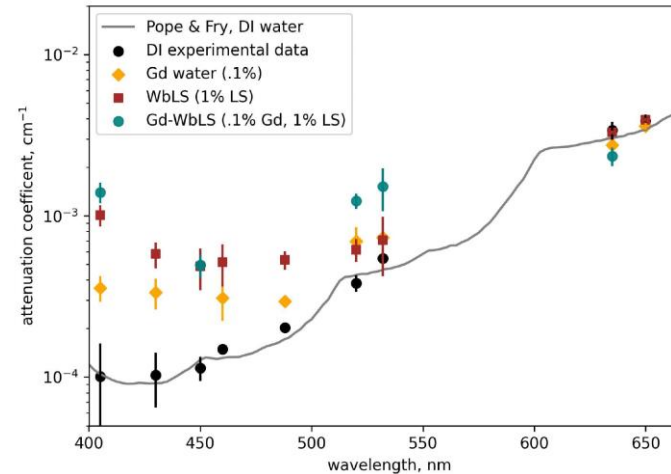
Once cassette prototyping completed

- Adjust designs if needed, build finalized designs and test and deploy at BUTTON (May/June)
- Tagged AmBe deployment device to UK mid 2025.

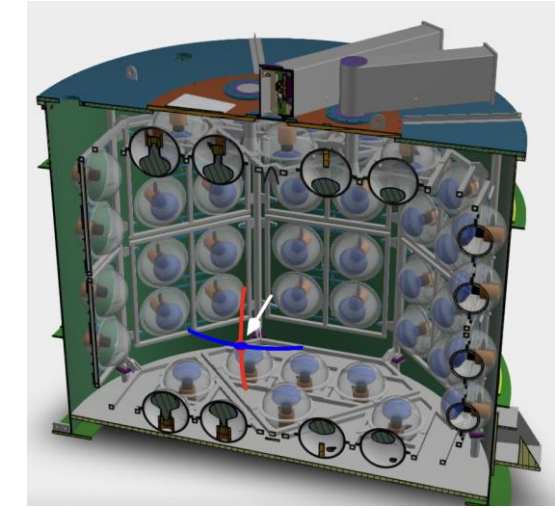
Diagnostics: fluid attenuation/scattering



- Simultaneous attenuation and scattering length measurement over full optical spectrum
- Isolation from atmosphere (oxygen)
- Instrument will be setup and tested then shipped to BUTTON
- Delivery BUTTON late 2025



Simulation and Software



RATPAC

- Continue long running RAT-PAC2 collaboration
- Implementation of BUTTON PMT encapsulation features, and consult on use of new RATPAC2 features
- EOS/BUTTON commonalities will ensure compatibility, leverage co-developed software

Where are we now: Conclusions



- Tank Construction completed underground
- PMT support structure completed and installed
- All PMTs encapsulated
- 64/96 PMTs installed
- Water system Deionizing skid completed and tested
- Water system almost complete and ready to ship to Boulby
- On schedule to turn on in the coming months
- Boulby lab capability for large experiments being built

Thank you for listening!

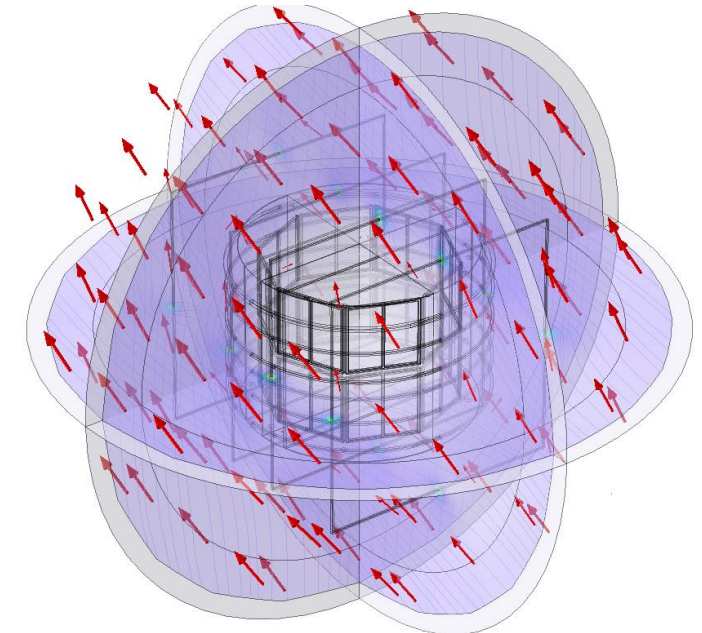
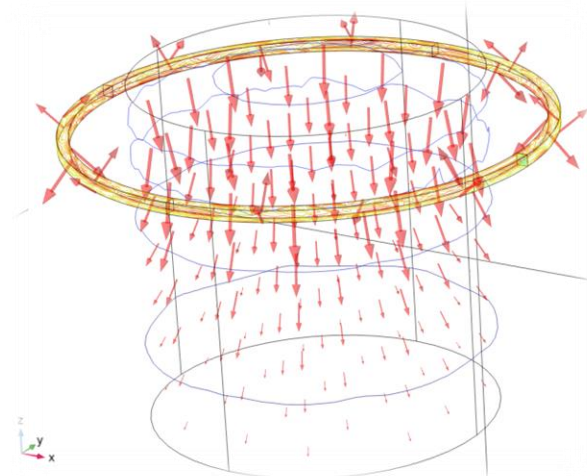
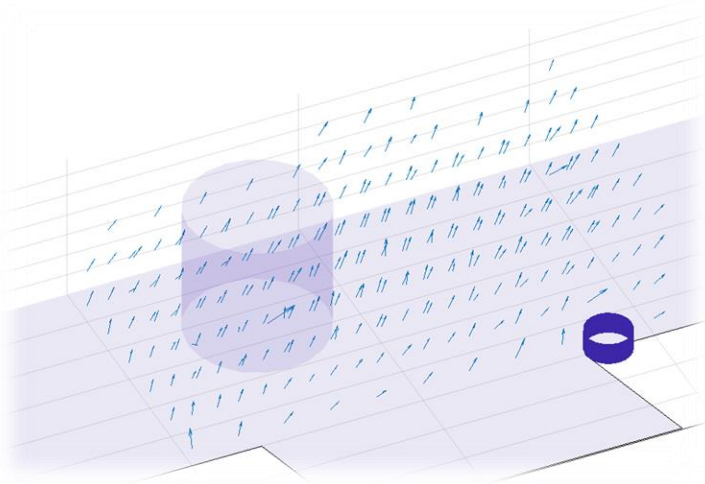
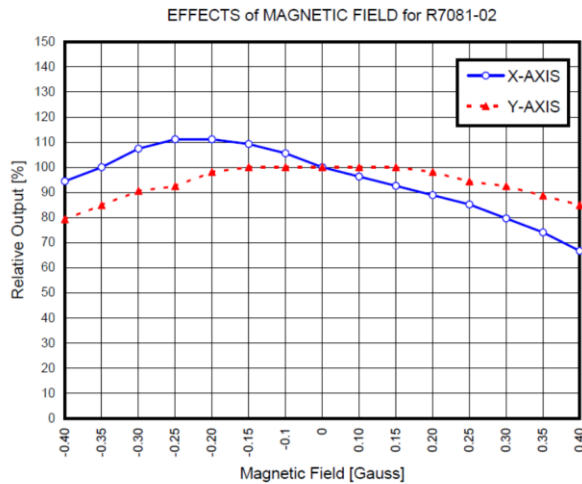
Backup



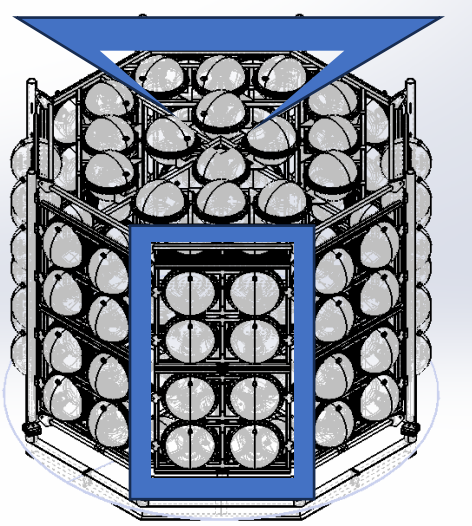
Magnetic field compensation

COMSOL simulation

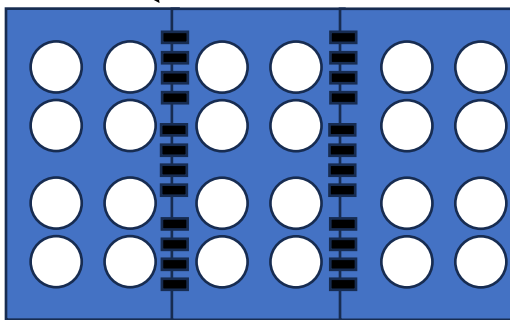
- PMT response is dependent upon external magnetic fields.
- The background magnetic field was measured in the experimental area.
- Simulations of magnetic coils to compensate for these background fields have been undertaken.
- A complete compensation system has been proposed which increases PMT relative output by up to 20% (0.35 Gauss to < 0.1 Gauss).



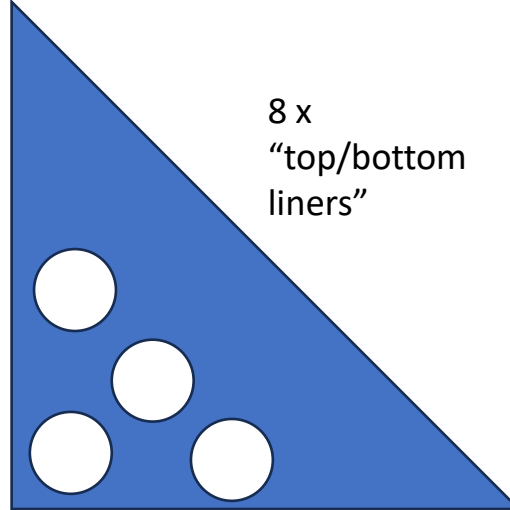
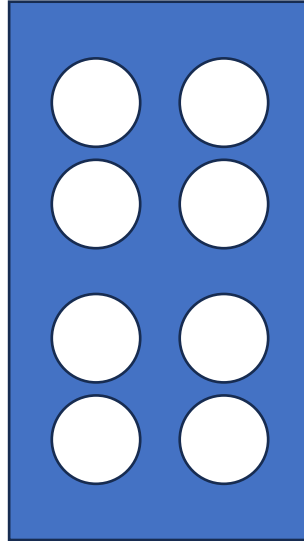
Non-reflective liner



Simply zip tied to the inside of the PSUP frames, with radial liners overlapped



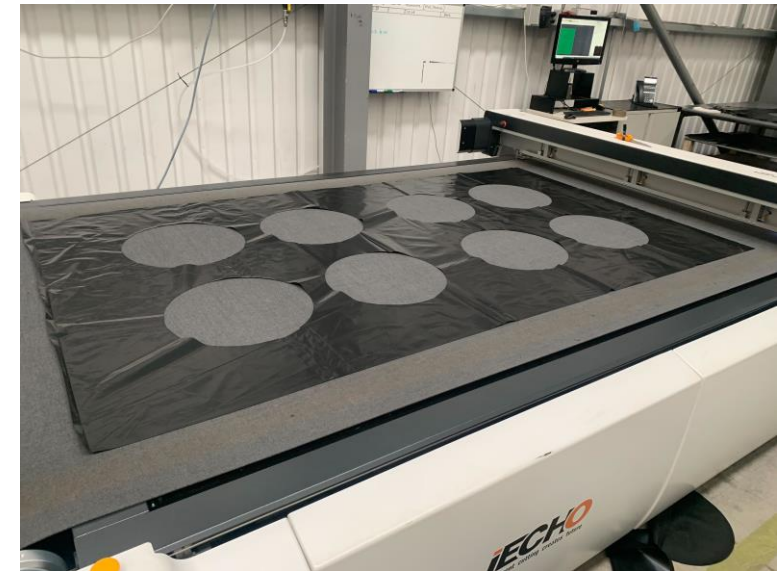
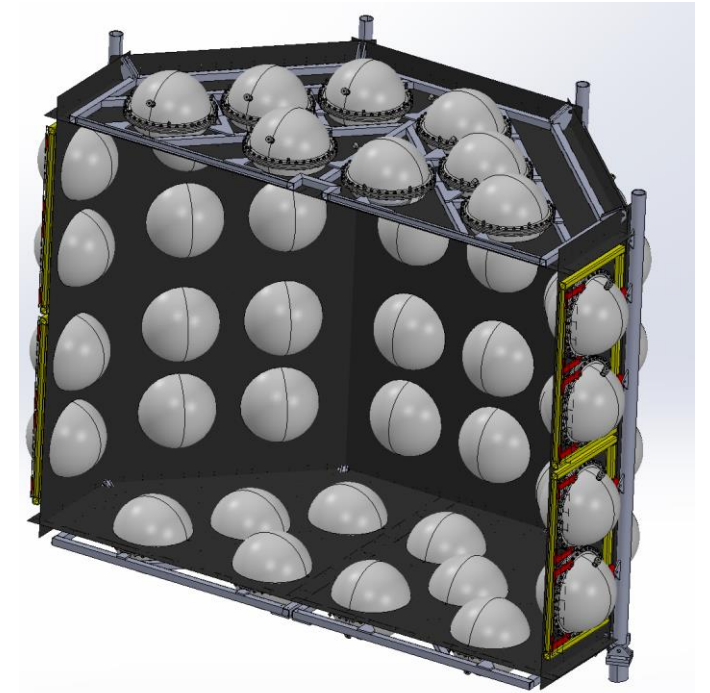
8 x "radial liners"

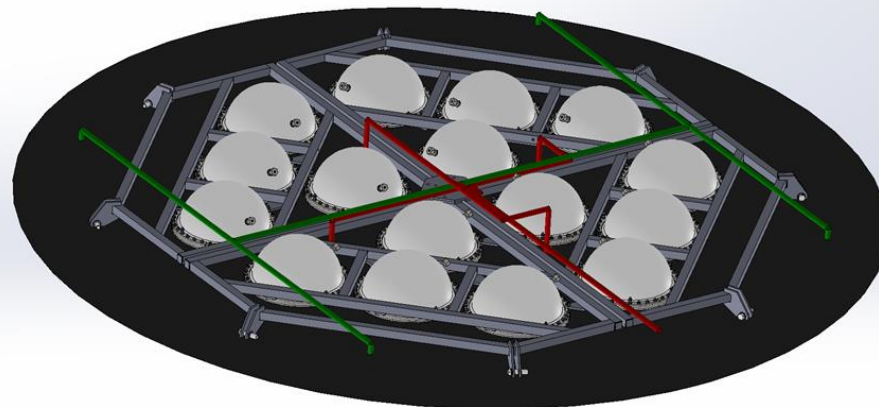


8 x
"top/bottom
liners"

Liners cut from polythene

- Specific material soak tested in concentrated Gd solution
- Soaked in America in WbLS
- UV-Vis tested the "contaminated" water samples
- UV transmission tested
- Several companies test cut samples





plumbing	Tees	90 degree	Union	Other
Lower outer manifold	3	6	4	3m pipe
Upper outer manifold	3	6	4	
Upper inner manifold	3	9	4	
Plumbing across lab	1	10	10	<ul style="list-style-type: none"> Flex hose Hose barbed fitting 10m PVDF pipe
Total	10	35	25	13m
				Unions into 3/4" bsp SS316

