BUTTON: Detector Development at Boulby Underground Lab

Workshop on Hybrid Cherenkov/Scintillation Detector Technologies

3-5th June 2025

On behalf of the BUTTON collaboration

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University of Liverpool

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Science and Technology Facilities Council
Boulby Underground Laboratory

Contents

- I’ve removed intro slides for you’re benefit
- The BUTTON collaboration and design goals
- Development and construction of subsystems
- Where we stand currently
- Measurements
- BUTTON future projects

BUTTON Collaboration

Boulby collaboration meetings in UK and the US 2024.

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

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

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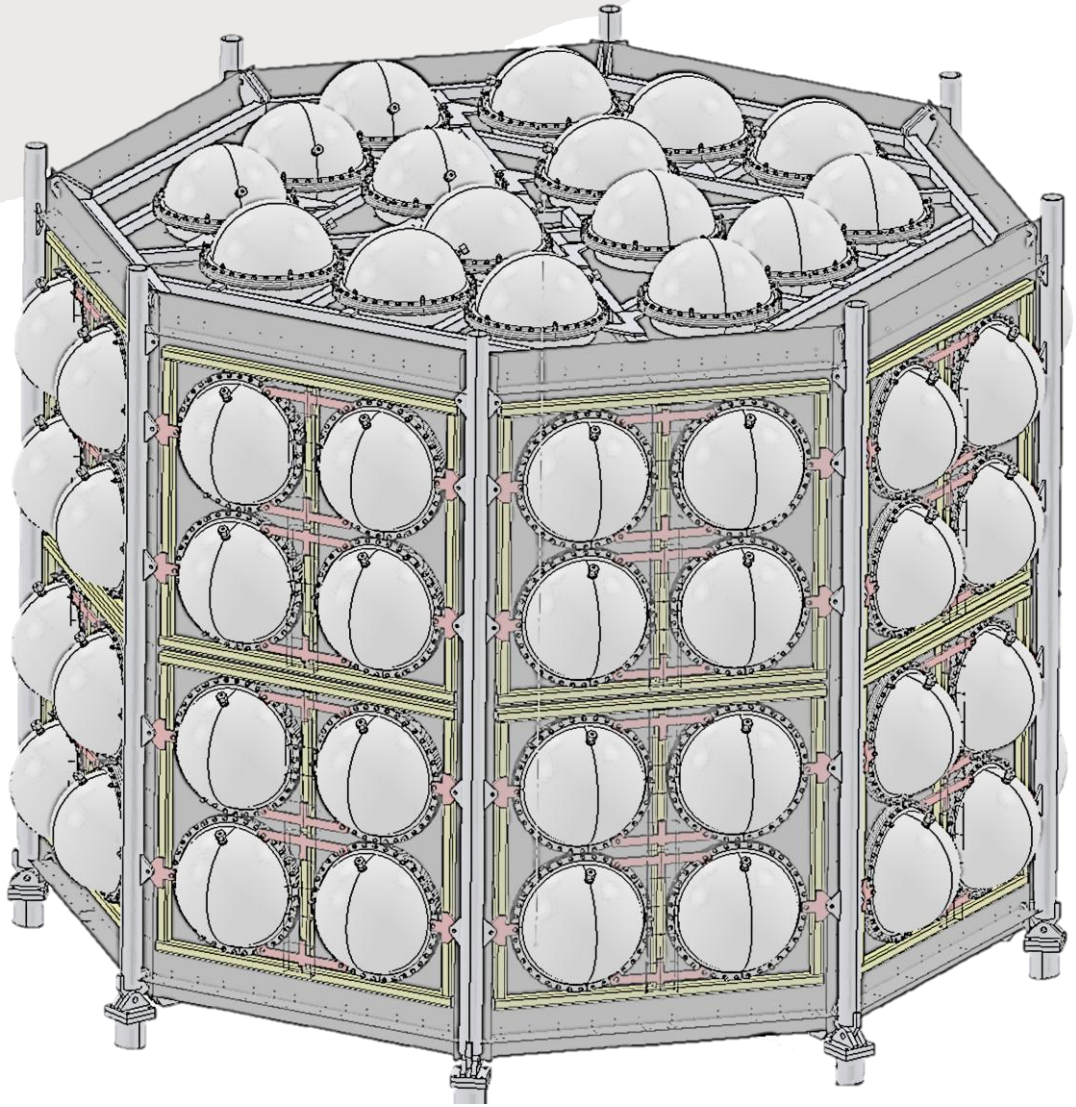
BUTTON development goals/design intent

- Flexibility to test different technologies
- Advanced photosensors
- Advanced fill media
- H2O -> Gd-H2O -> WbLS -> Gd-WbLS -> future fills (LS?)
- Building scientific capability at Boulby underground lab



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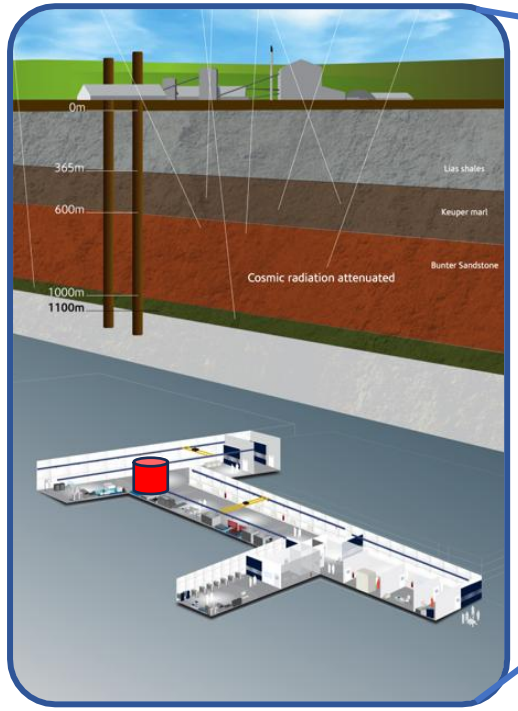
BUTTON UK development

- BUTTON is housed in Boulby ICL mine in the northeast of the UK.
- Building scientific capability at Boulby underground lab is a key goal of the BUTTON experiments with Boulby being a strong candidate to home future experiments such as XLZD
- How does one build such an experiment in a mine like this… BUTTON has proven that we can!



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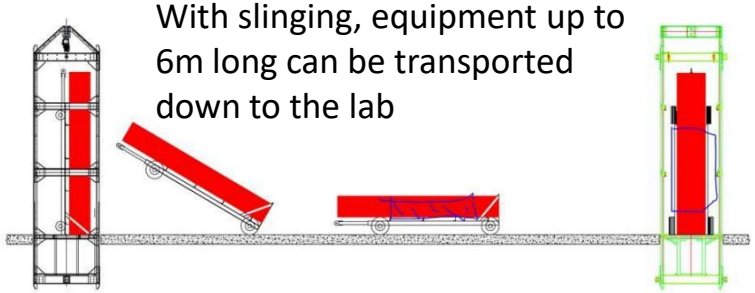


The UK's deep underground science facility operating in a working potash and salt mine.

1.1km depth (2805 mwe). With low background surrounding rock-salt

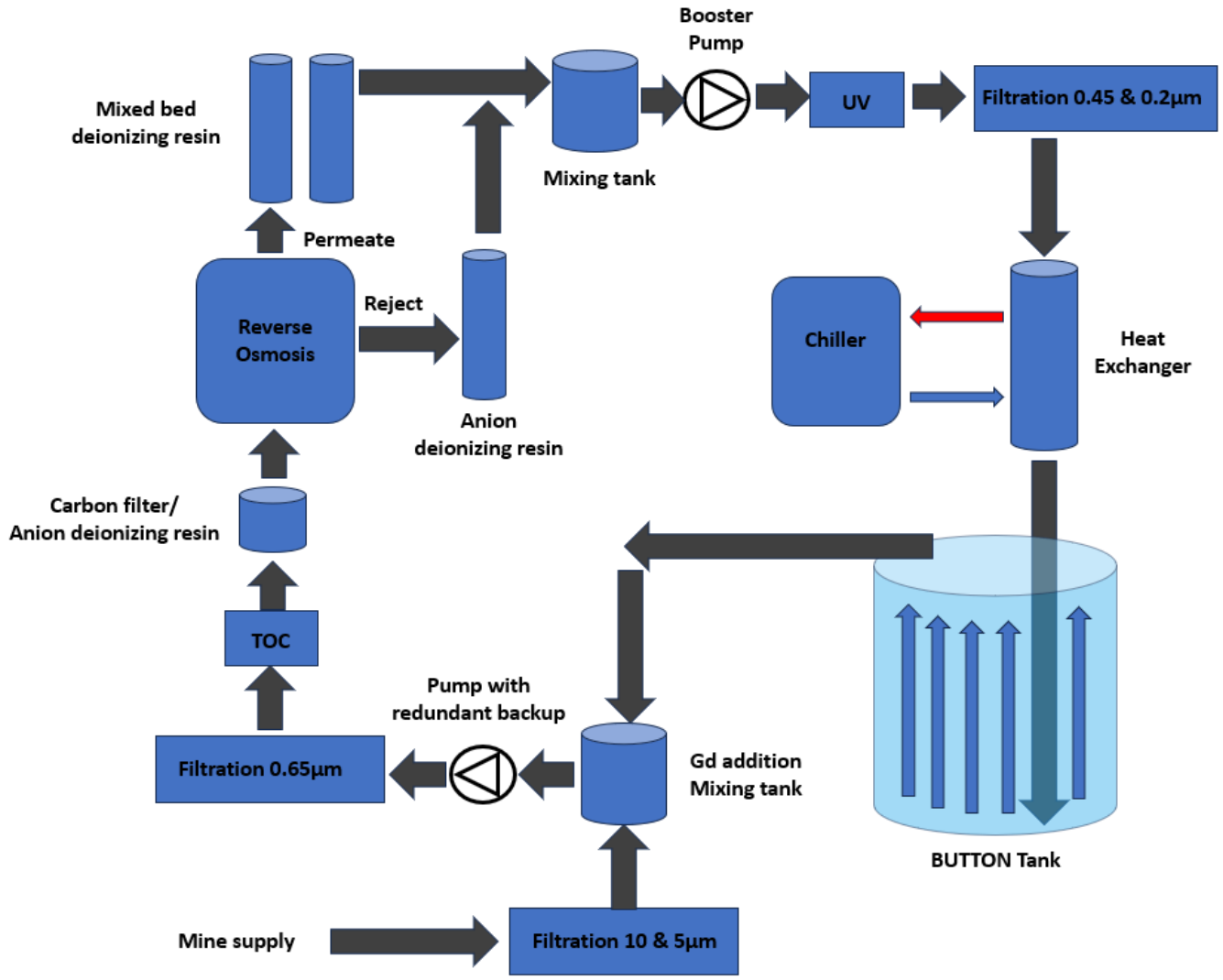
Operated by the UK's Science & Technology Facilities Council (STFC) in partnership with the mine operators ICL-UK

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

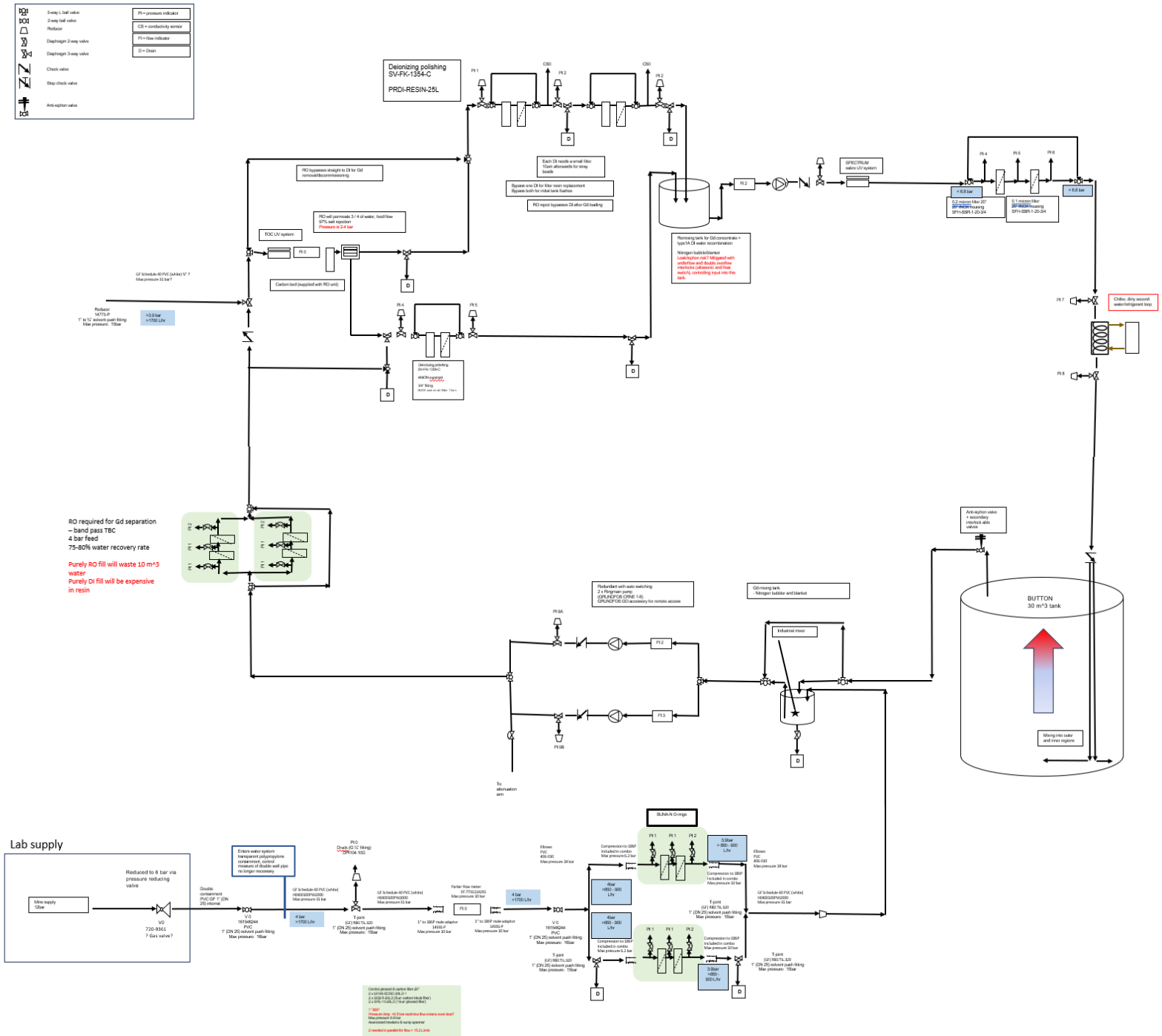
The simplified schematic

Water system development

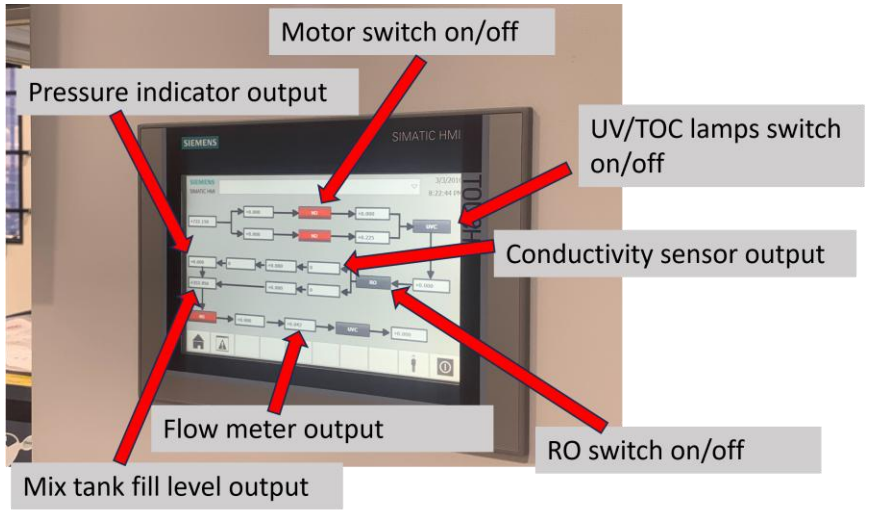
- Gd separation or targeted removal of all other impurities
- Future WbLS compatibility
- Flexibility
- Scalability
- Automation/safety
- “Salt mine safety factor”



The un-simplified version…



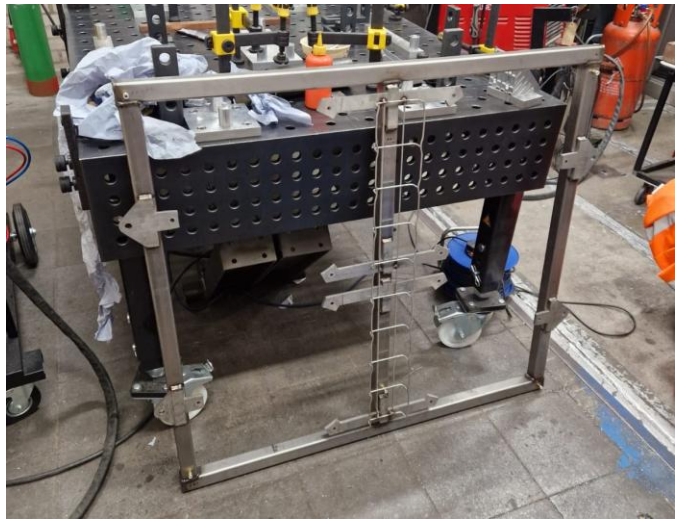
Water system development



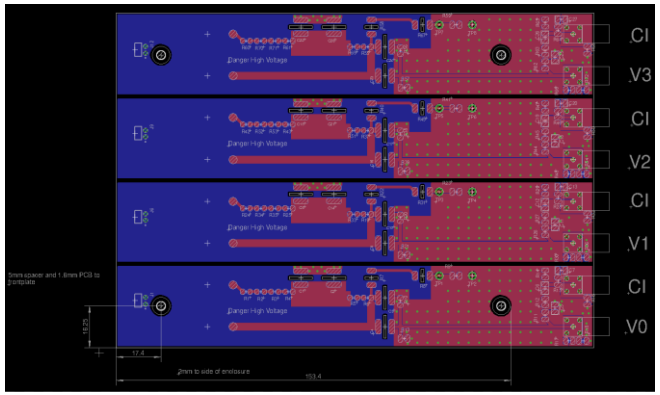
The water system for the BUTTON experiment has been developed and is currently being built and tested in Liverpool by myself and Kieran Bridges

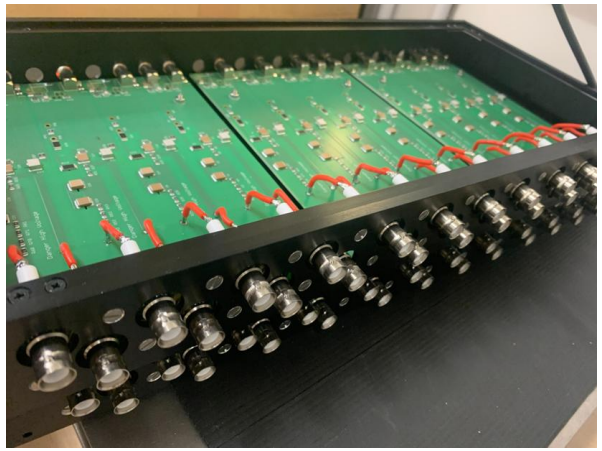
PVDF pipework for heightened compatibility for future fill media.

Construction



Production of the 316L PSUP was undertaken by Liverpool University workshop. This is modular for the later inclusion of advanced photosensors.





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

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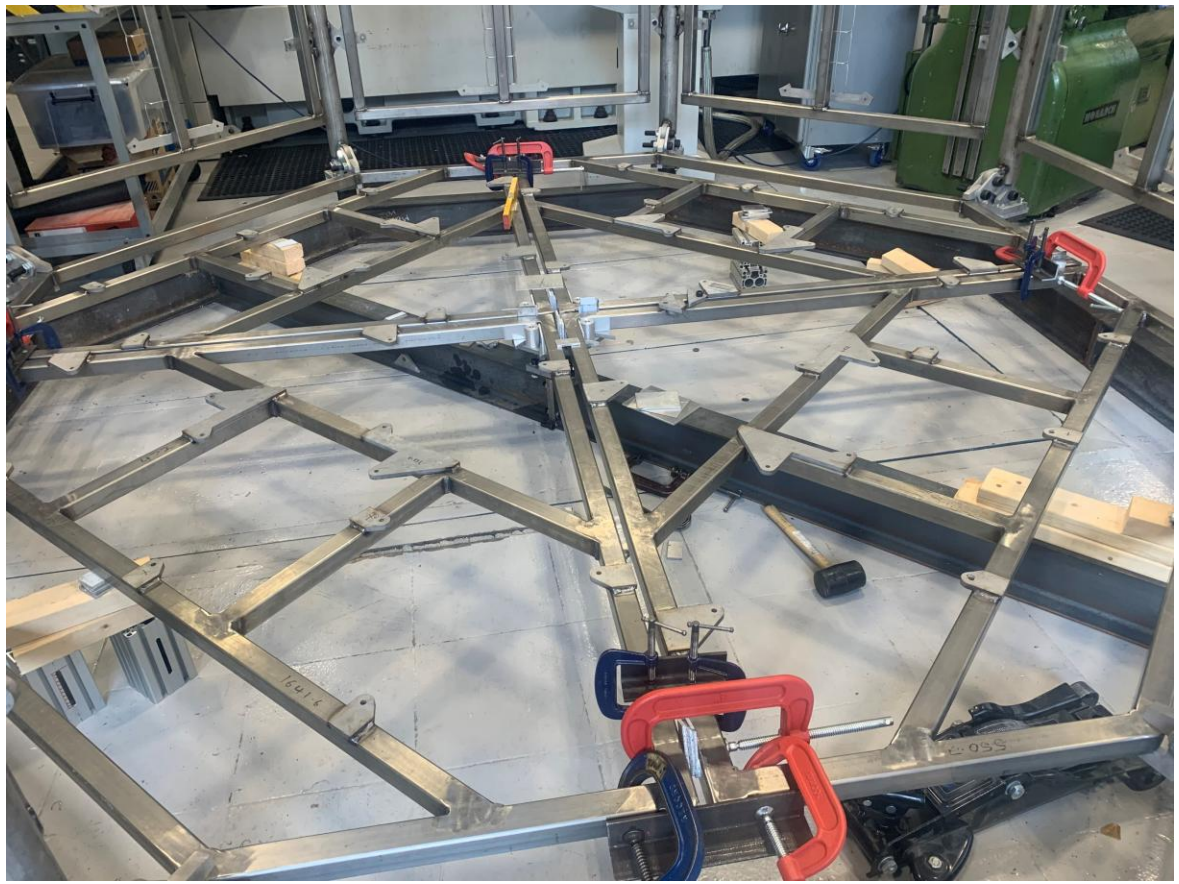
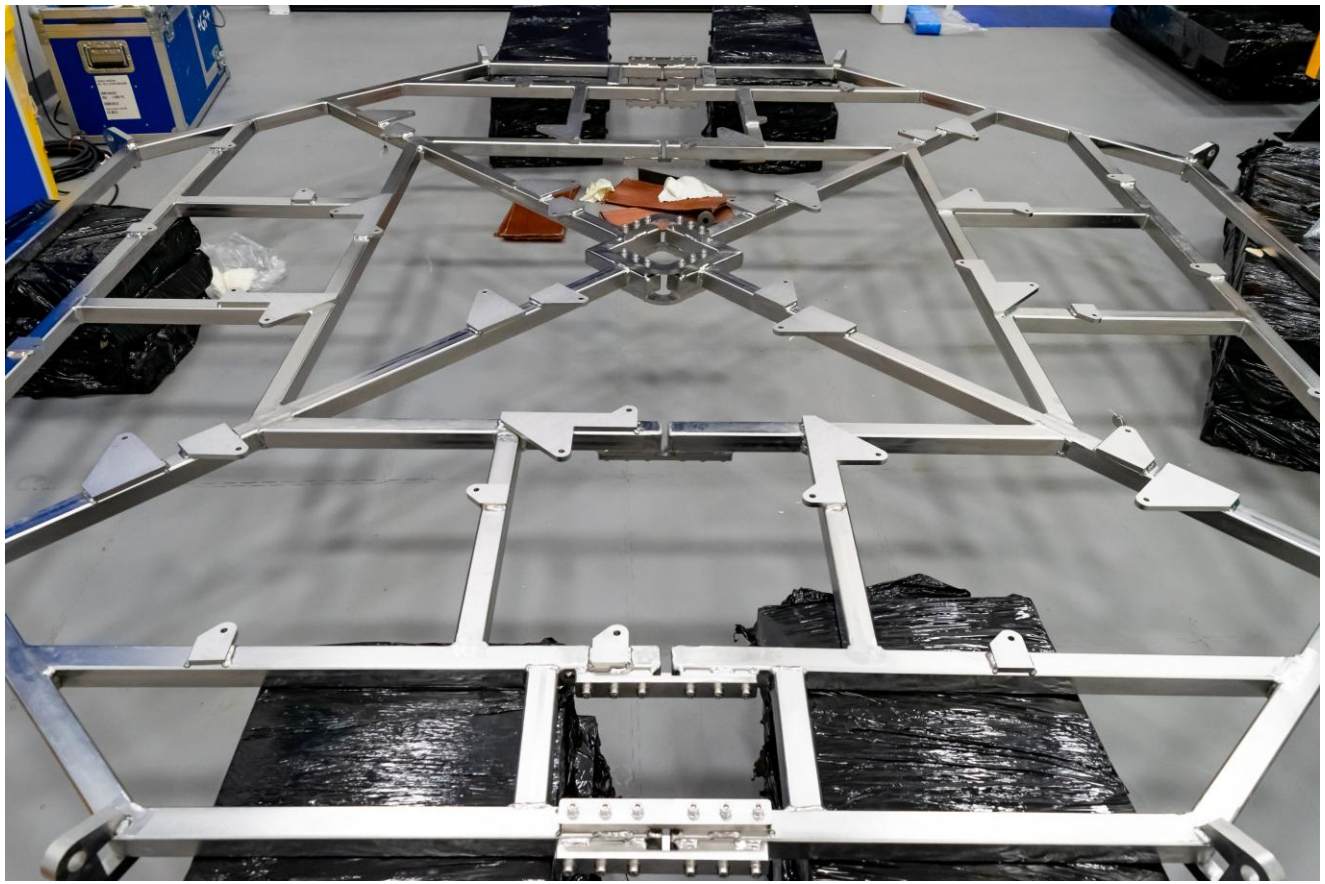
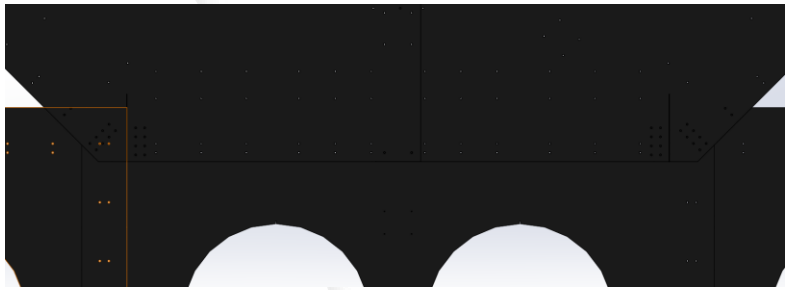
Passivation
-Electropolishing

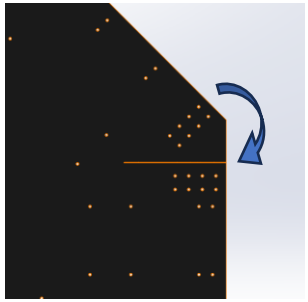




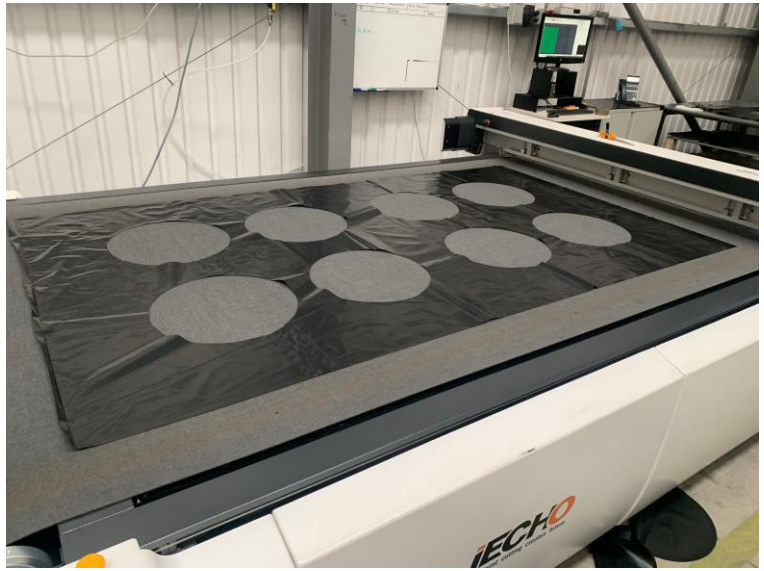
Passivation
-Re-passivation

Liner

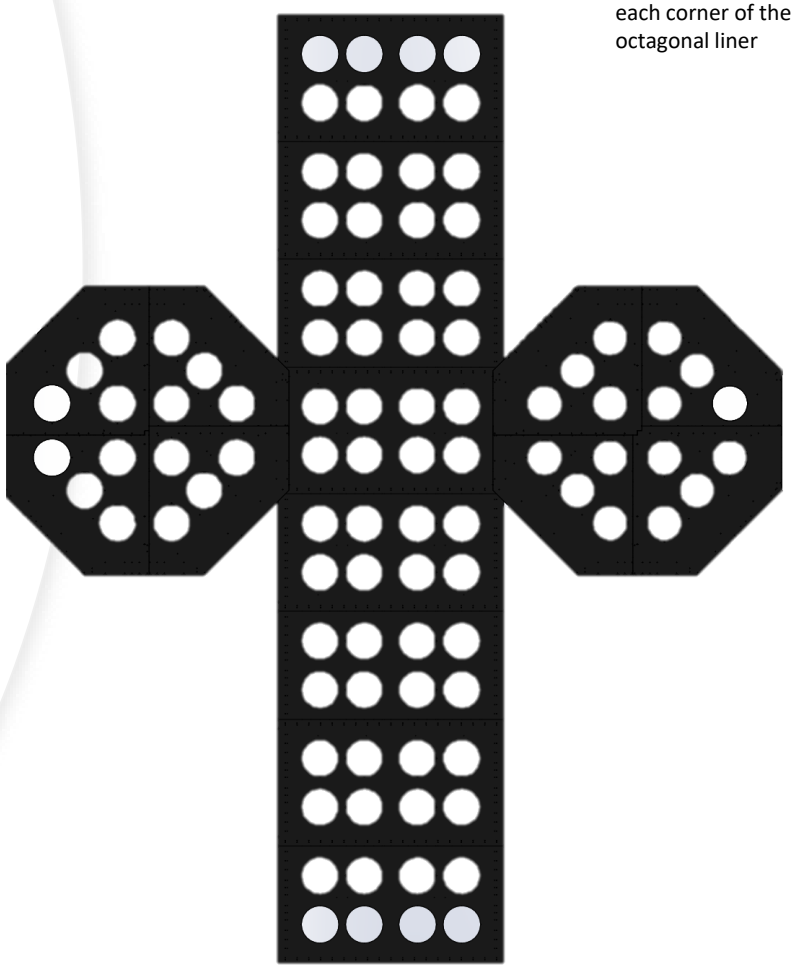




A fold is made at each corner of the octagonal liner



- Very thin polythene
- Two revisions made, both tested for fit and stretching on frame
- Manufacturing was challenging due to size/material
- Installation was challenging due to space constraints and fixturing



Tank Construction

Jan 2024 – Tank build commenced

During Construction

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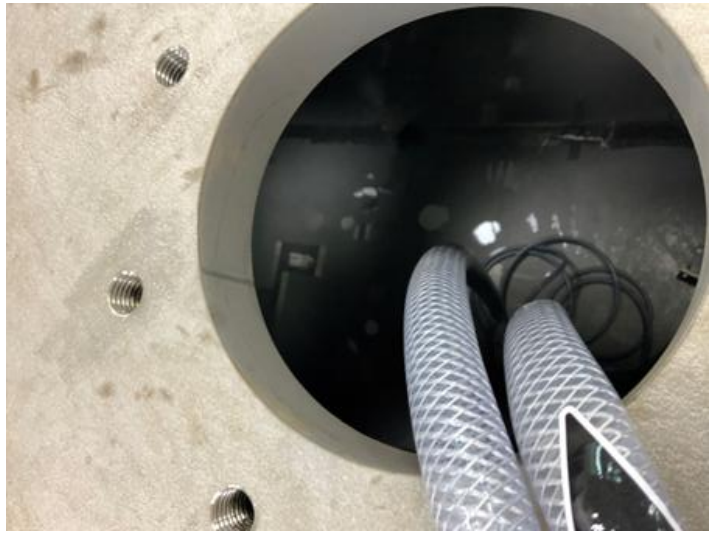
Initial Fill



Dec 2024

An initial water fill was commenced to ensure

- Floor loading
- Tank integrity
- Feed and drain plumbing

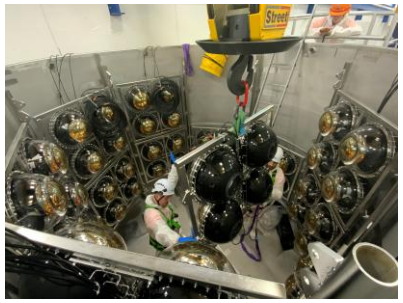
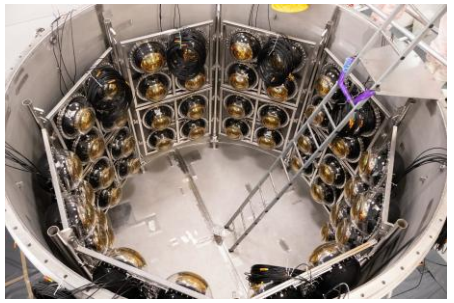
And to wash debris from the tank.

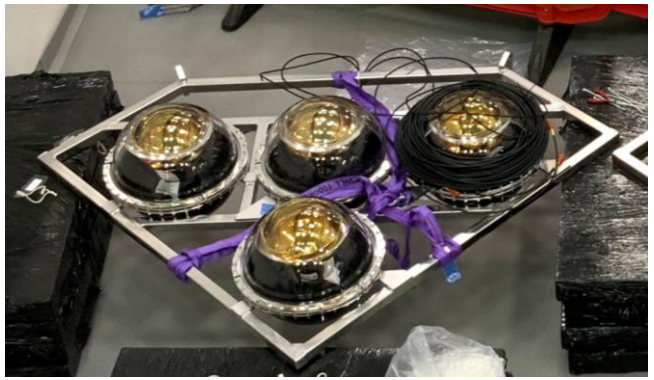
The tank was then inspected, cleaned and passivated in areas with defects. Before the experiment starts the tank will be flushed 3 times

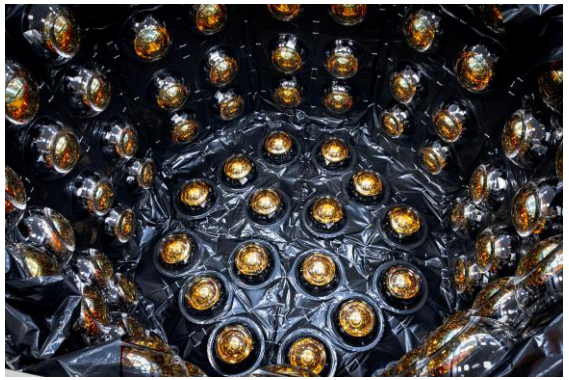
PMT installation storyboard

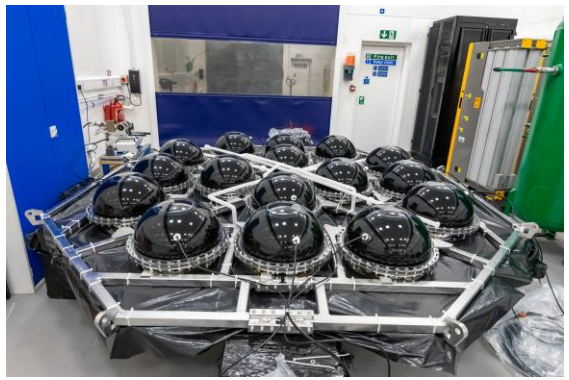
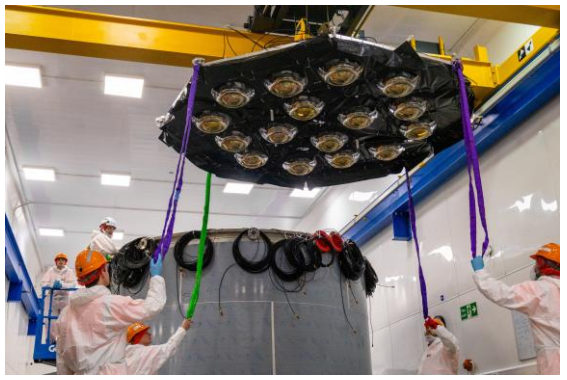
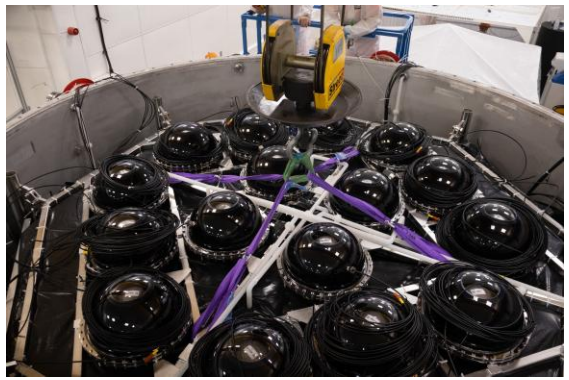
Jan 2025







15/24

April 2025

Current Status

Tank PMTs installed

Tank is now light tight

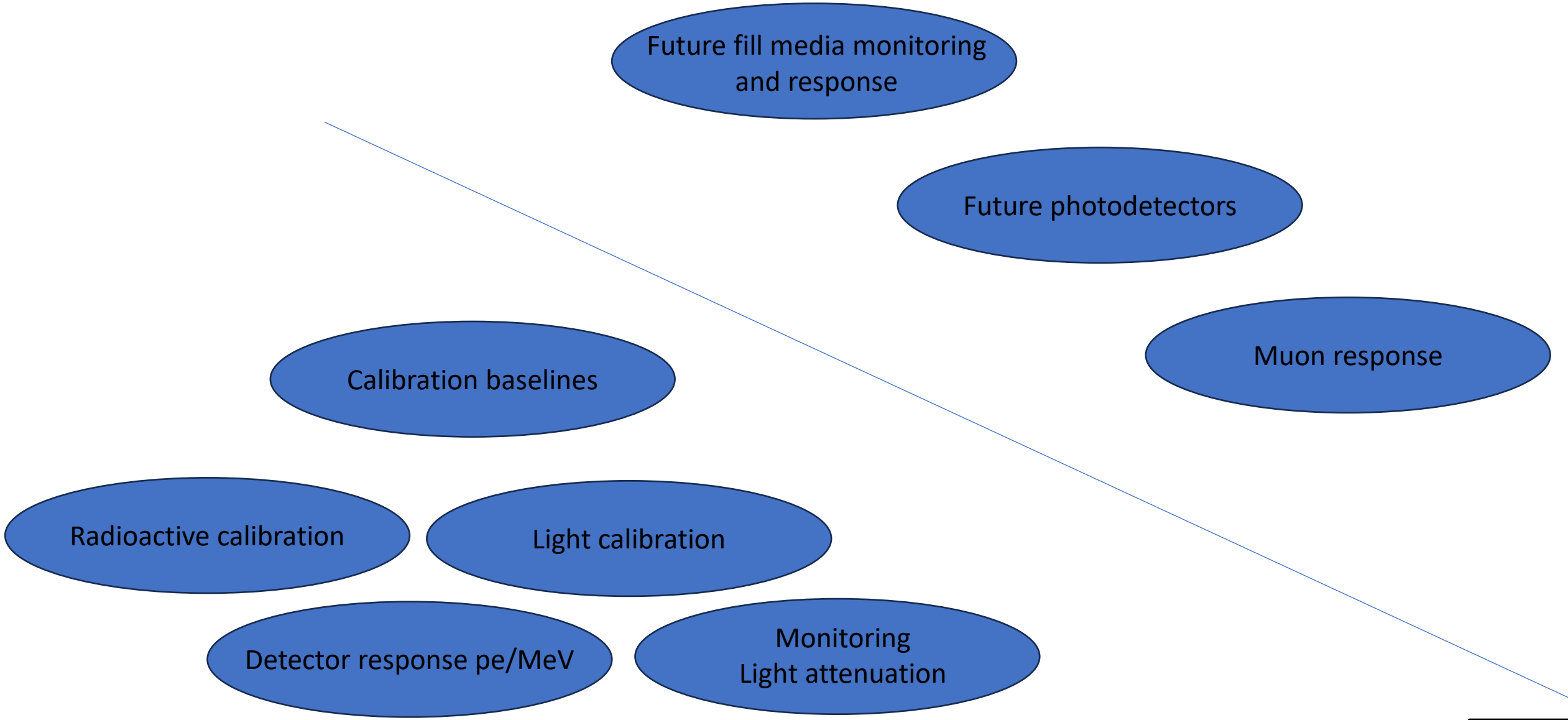
Cabling to the DAQ complete

PMTs powered on 95/96 good (failure indicative of a loose connection)

Water system nearing completion

Calibration systems are being finalized and prototyped

Measurements



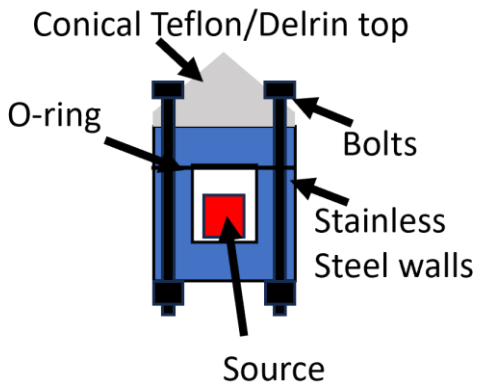
Measurements – Radioactive Calibration Sources

- AmBe – radioactive… - shipping from the US imminently
- 208 Tl – delayed till end of year

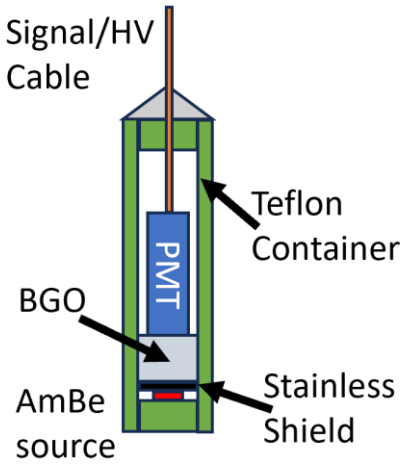
Team:

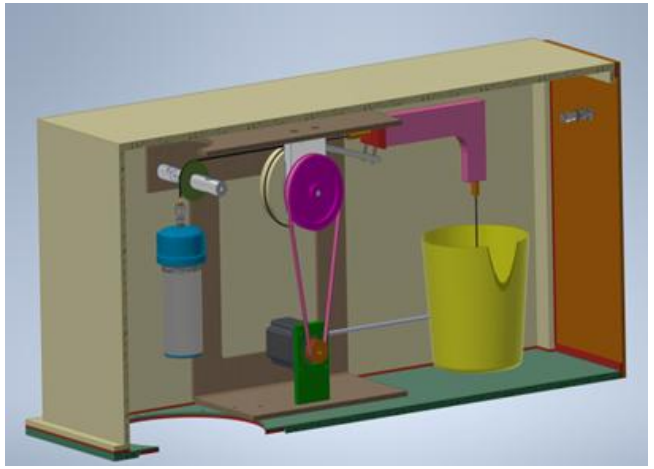
- Steven Dazeley, Slava Li, Sean Durham at LLNL.
- Igor Jovanovic (U Michigan) – ^{208}Tl and switchable AmBe. Possible future experimental source such as the Am^{13}C 6.1 MeV gamma-rays
- Christopher Mauger (U. Penn), Jan Boissevain (mechanical E, U. Penn) and Rick Van Berg (Electrical E, U Penn)

Untagged AmBe and 2.6 MeV ^{208}Tl

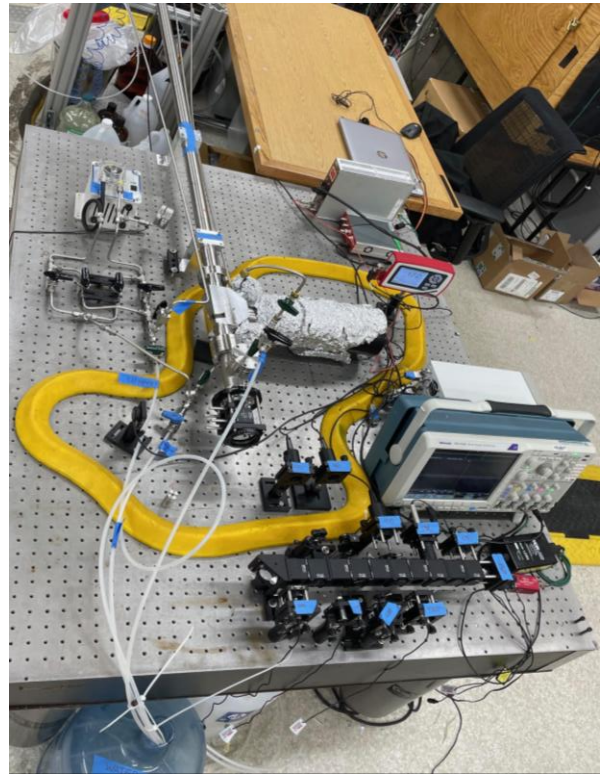


Tagged AmBe

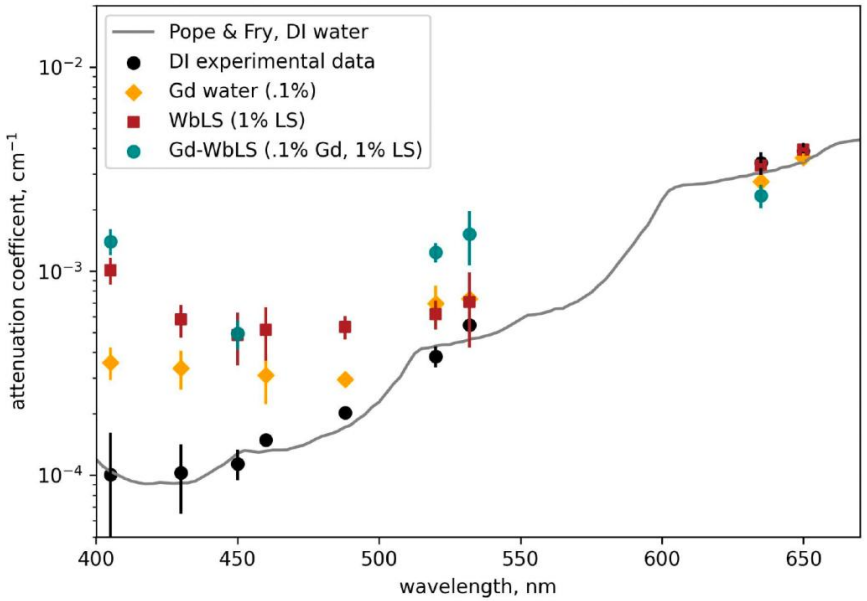


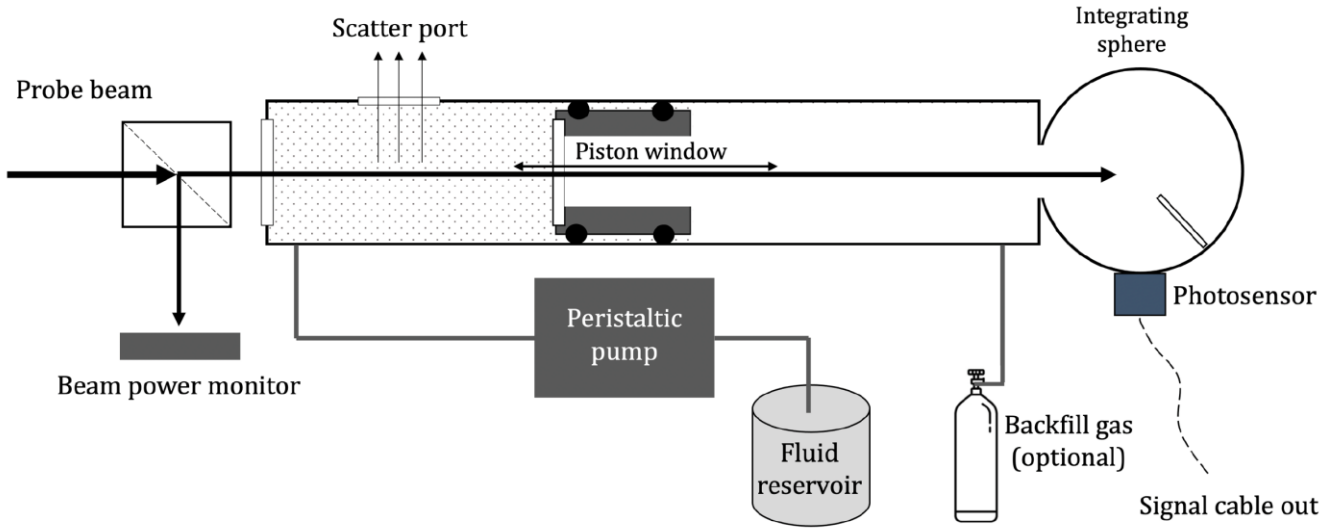


Measurements – Light Sources



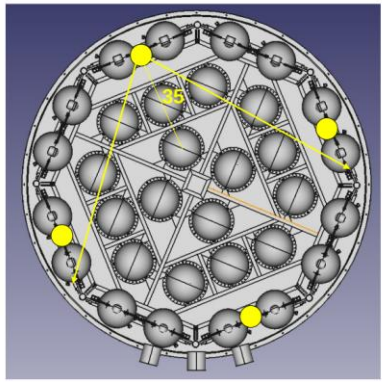
- Attenuation arm… (real time Gd water cleanliness)
  - Simultaneous attenuation and scattering length measurement over full optical spectrum
  - Isolation from atmosphere (oxygen)
  - Delivery BUTTON late 2025

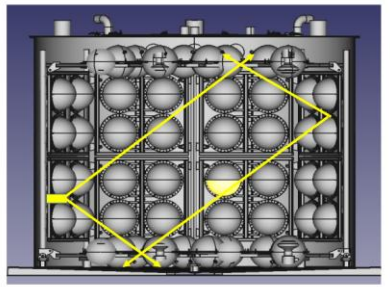




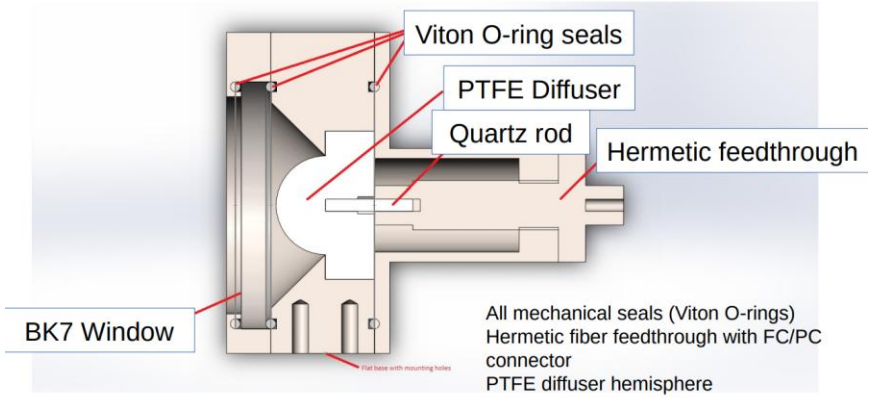
Measurements – Light Diffusers

- HK diffusers
- Disco ball diffuser (ANNIE based)





Four diffusers should illuminate each PMT, albeit at different angles
Emission half-angle around 35° in water



Steve Boyd

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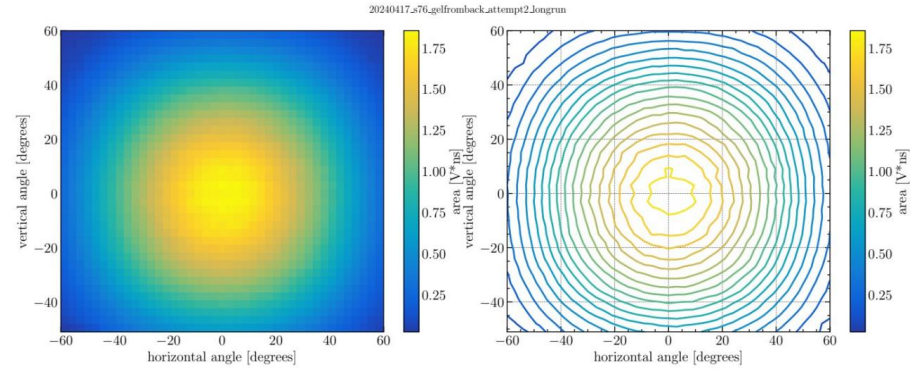
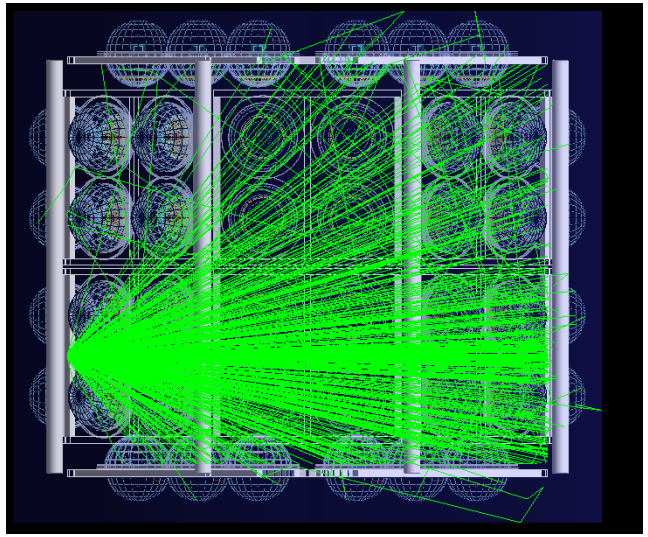
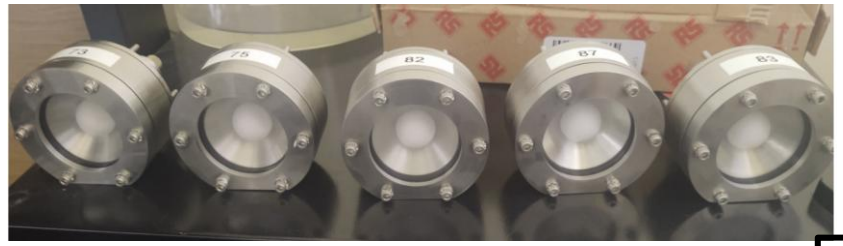
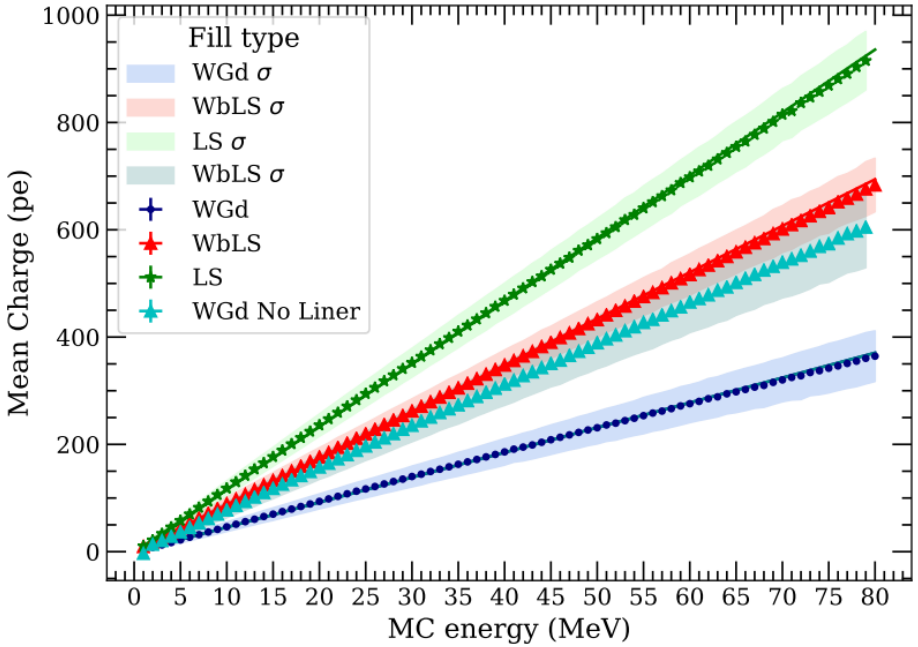






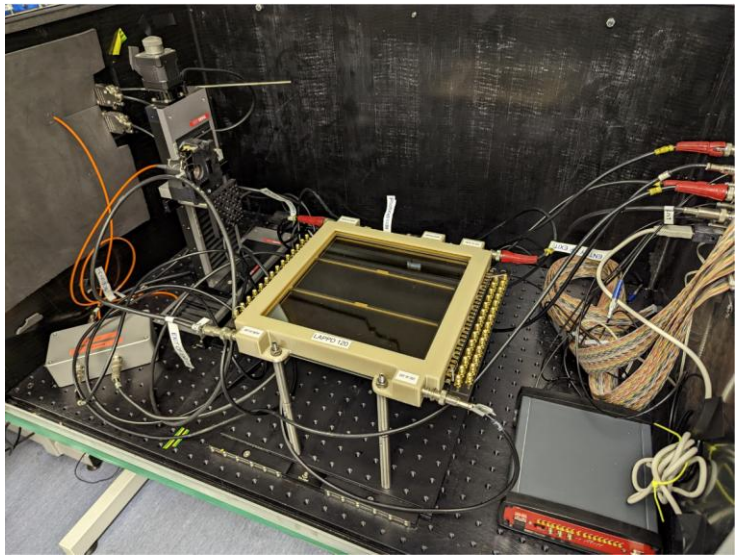
Other measurements

- Pe/MeV
- Muon response
- LAPPD timing separation



Other R&D

- Fill media/cocktails etc
- LAPPD
- Boulby development



Glasgow LAPPD test stand

Future Plans BUTTON/Boulby

S. Paling IOP 2025

Boulby Development Project
Task 1: Site and design Development.

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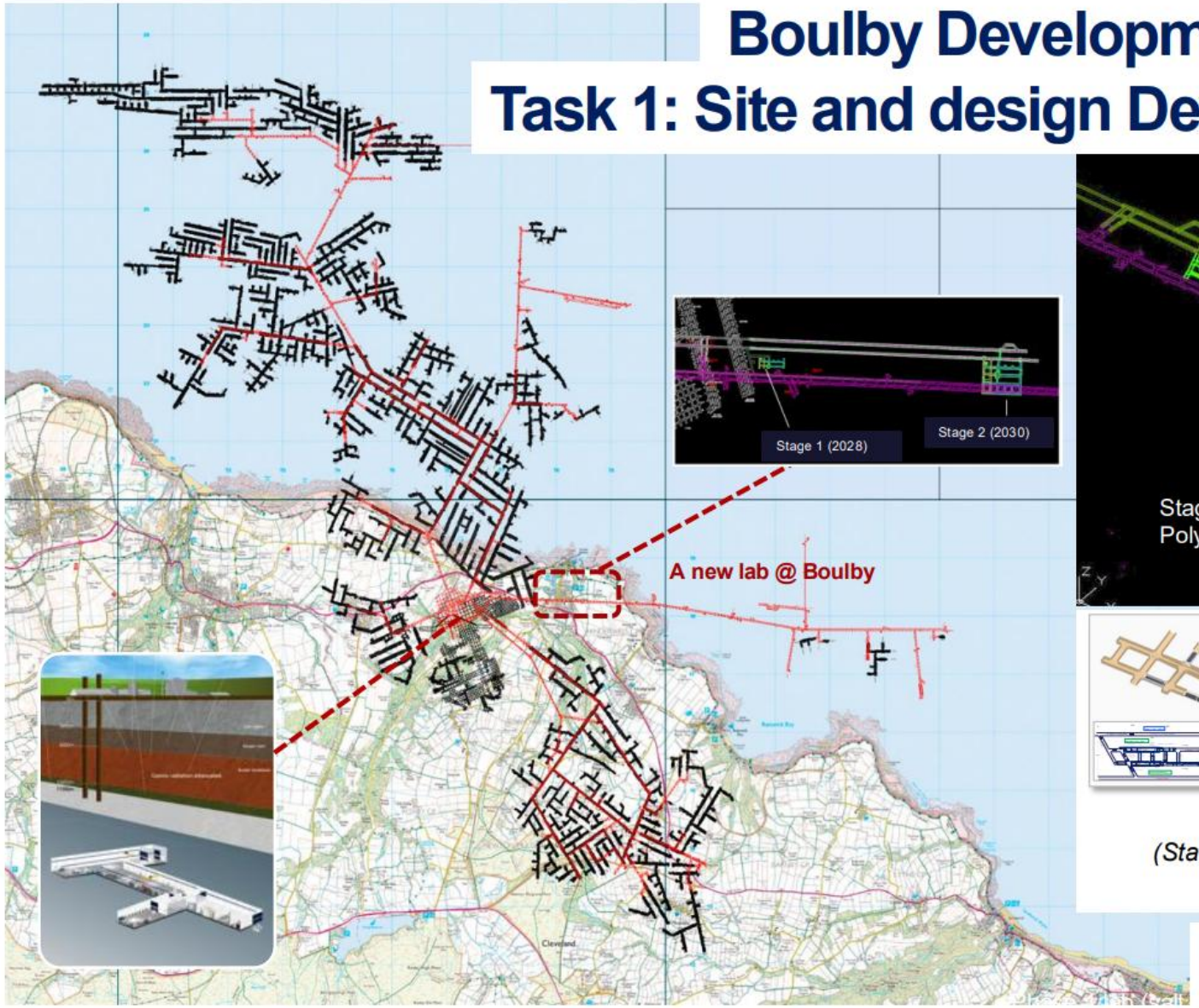
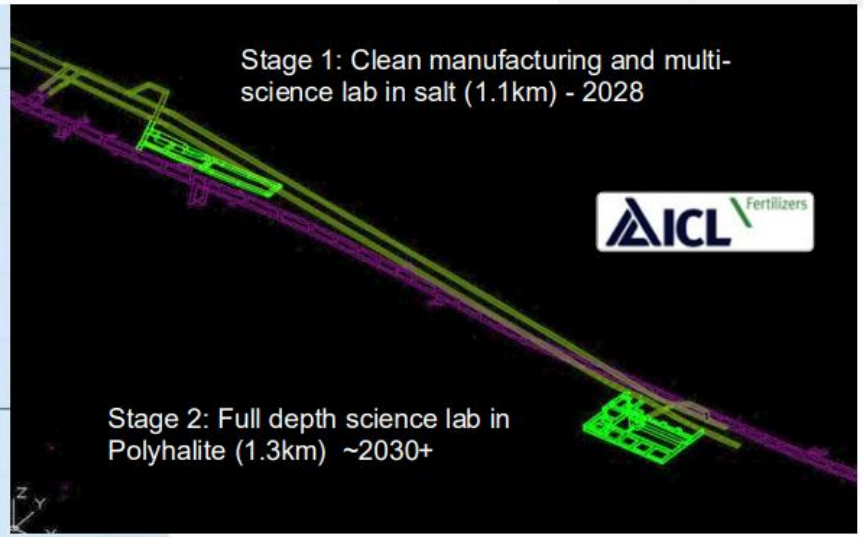
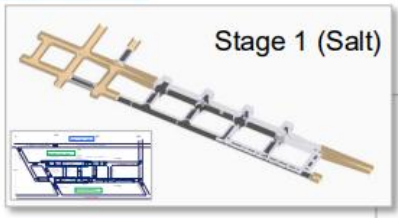
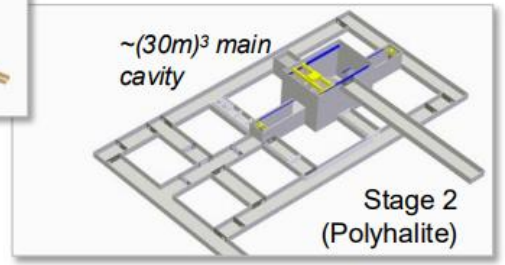






DRAFT: 2-stage Designs

Total volume (Stage 1 + stage 2) ~120,000m³



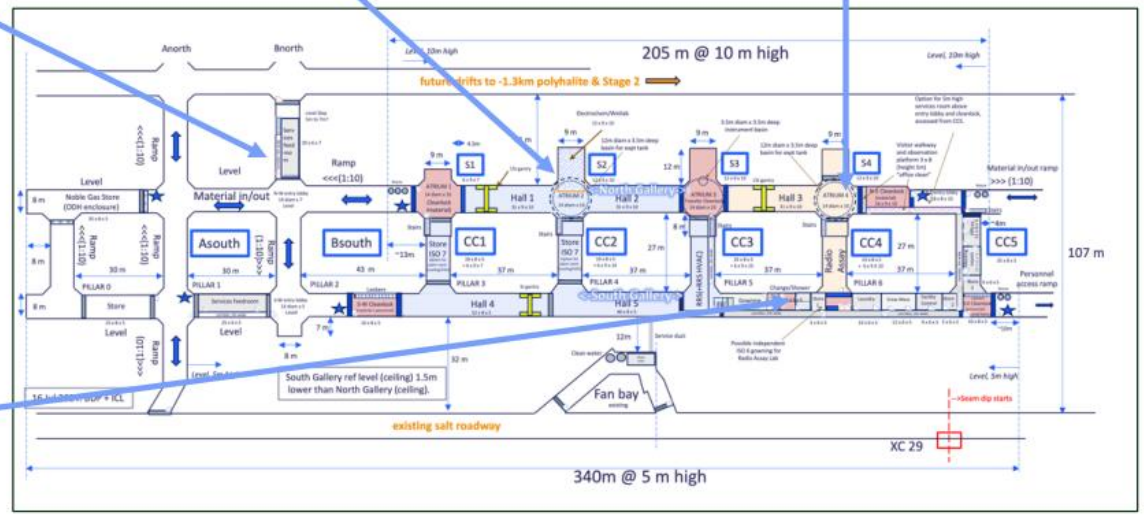
Excavations for stage 1 of expansion currently expected to begin mid-2024.

Future Plans BUTTON/Boulby

Focussing on the a 10.5x10.5m tank

Boulby Development Project:
Stage 1 Excavation

Progress
August 2024

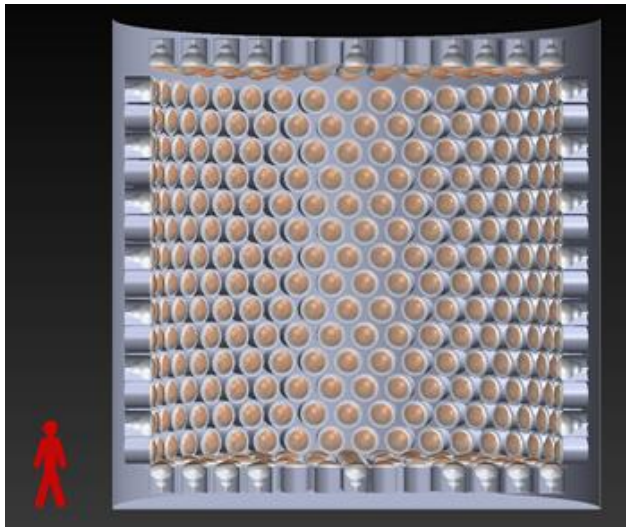


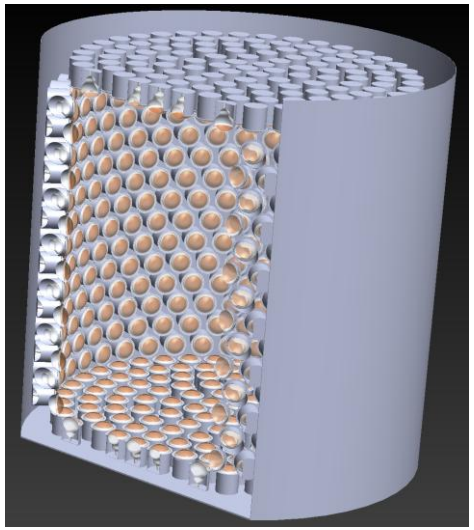
Stage 1 Functional Design

Excavation well underway. Completion mid 2025 (Outfitting ~2028)

Future Plans BUTTON 1kT

40% photo coverage tank possible?



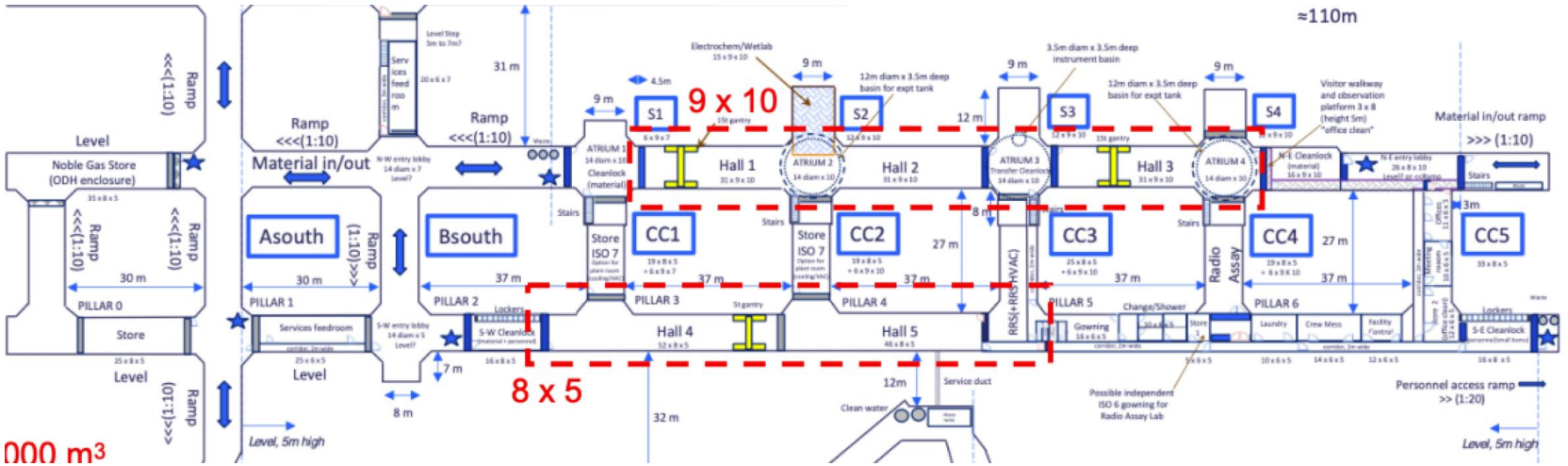


Focussing on the a 10.5x10.5m, 15-20+% photo coverage tank

Simulating reactor IBDs in tank (seeing IBDs)

Need to understand backgrounds (this is still being updated and BUTTON running will help)

From current simulation work confident a 1kT tank will be able to detector reactor neutrinos

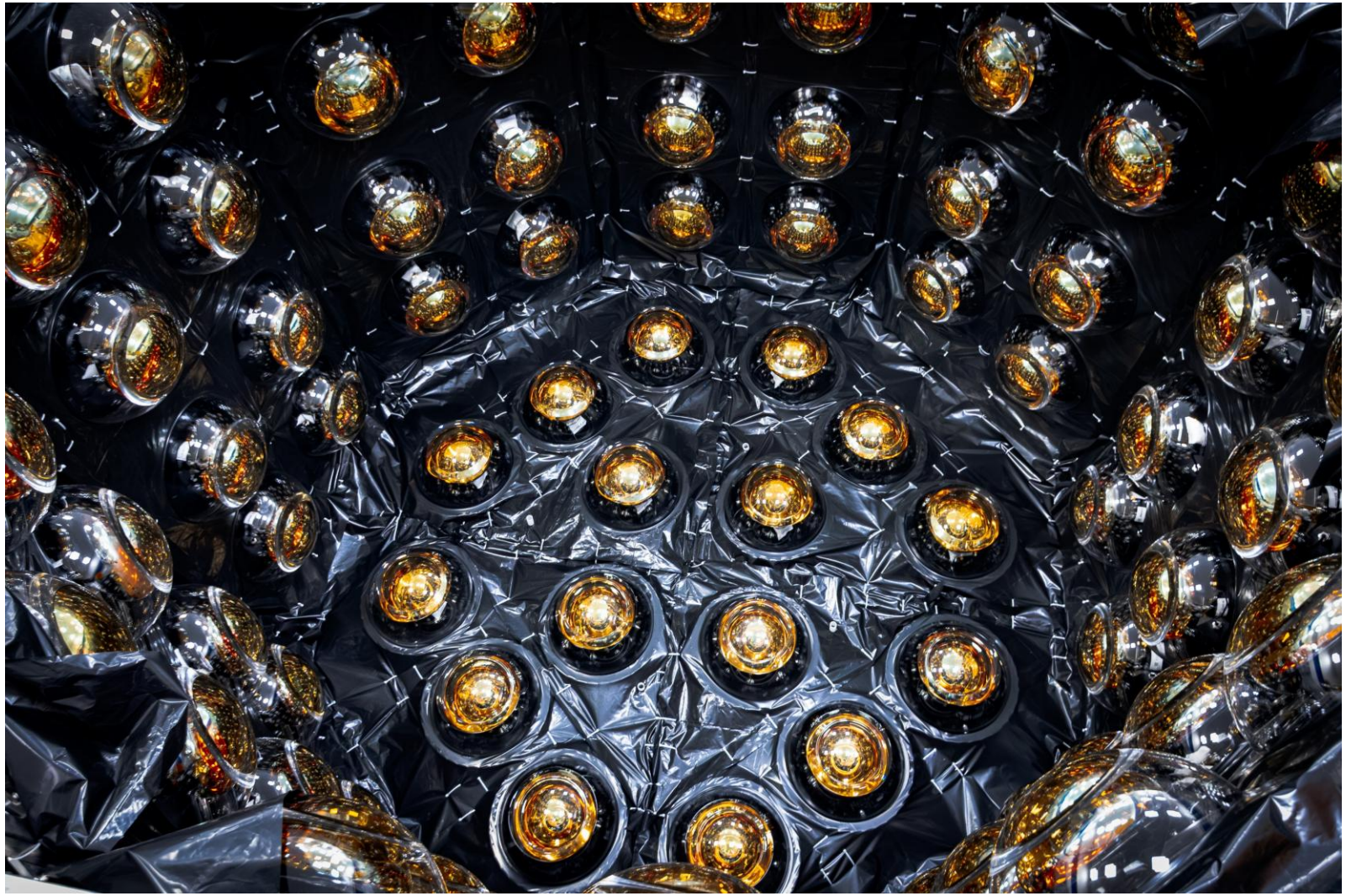


Expansion of Boulby gives us a unique opportunity to for growth

KamLAND 17” and 20” PMTs have been offered to the project

Physics goals:
Reactor neutrino studies
Supernova neutrinos
Diffuse Supernove neutrinos
Full at scale deployment of WbLS

Thank you for listening



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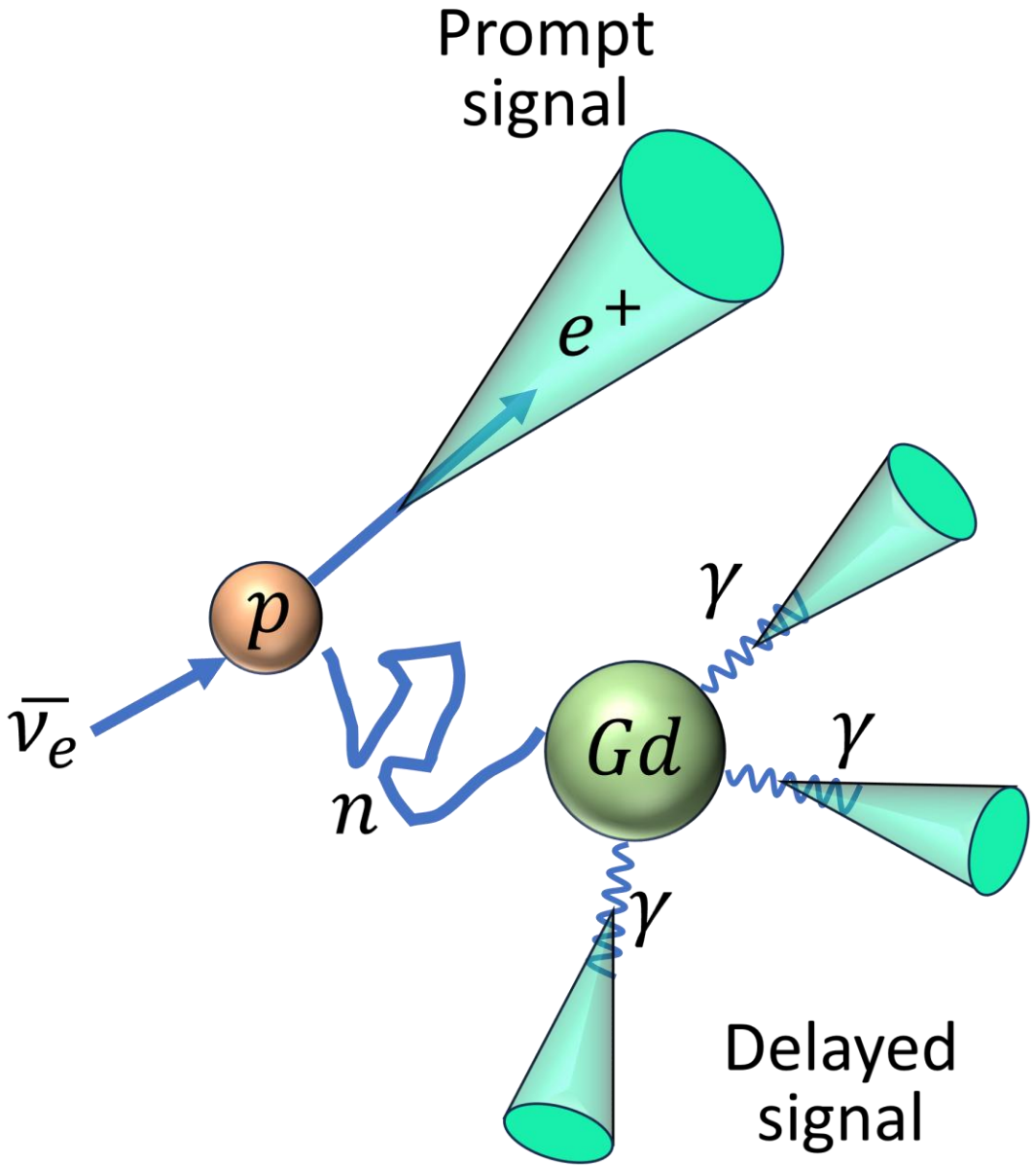
Backup

(Anti)Neutrino Detection

- Gadolinium doped fill media provides a much higher neutron capture cross section which allows better inverse beta decay detection. (~163,000 x) – 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
- $\overline{\nu_e} + p \rightarrow e^+ + n$



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

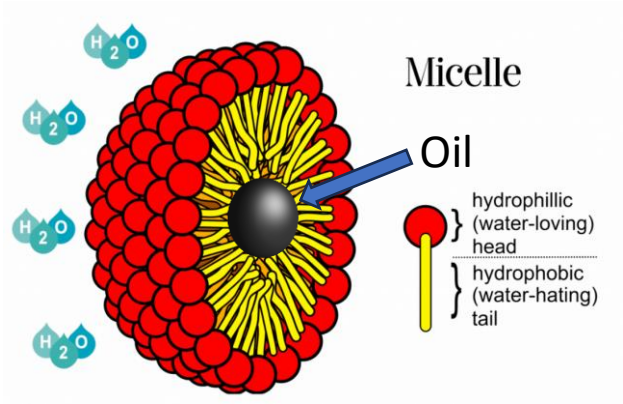


Image adapted from: UC Davis Neutrino Group – Water based liquid scintillator

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

BUTTON Calibration

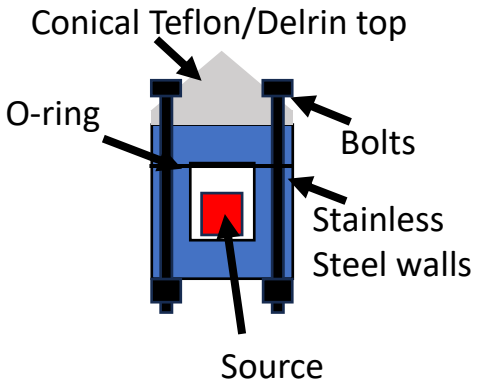
Requirements:

- 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.

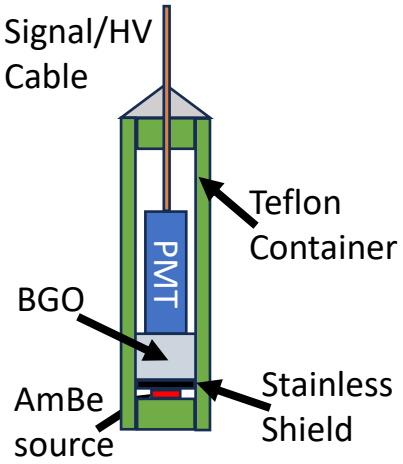
Solution:

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

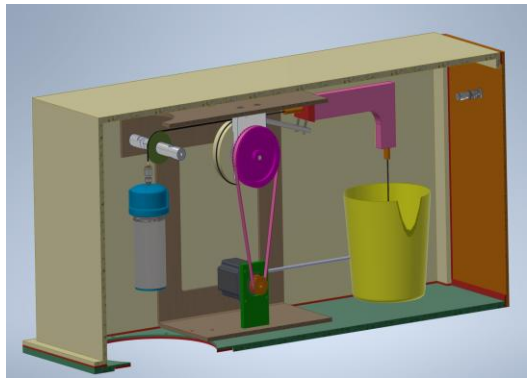
Untagged AmBe and 2.6 MeV ^{208}Tl

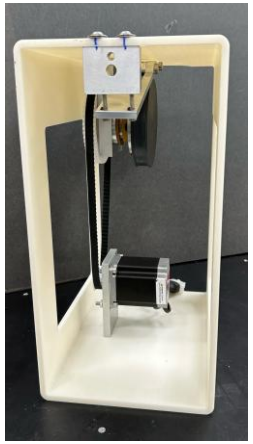


tagged AmBe



Detector top calibration design and Prototype testing





Prototyping and initial steps

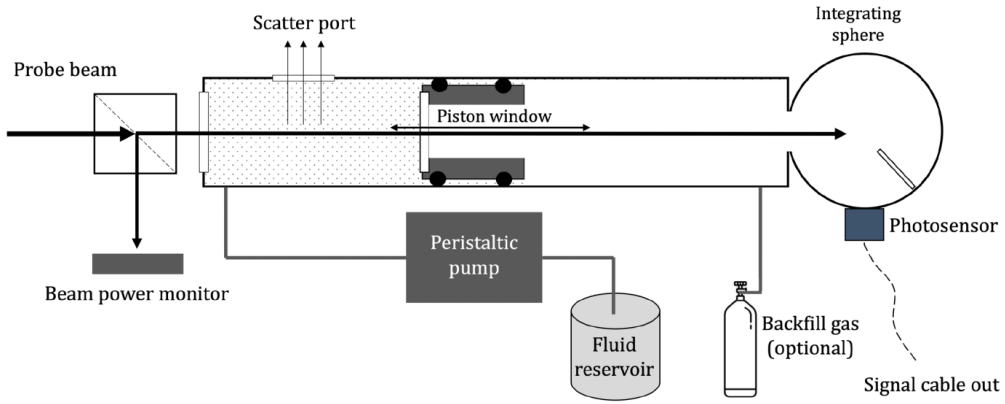
- Prototype deployment cassette - testing nowAmBe source to UK April 2025
- Untagged gamma and neutron source containers, deployment April/May 2025.

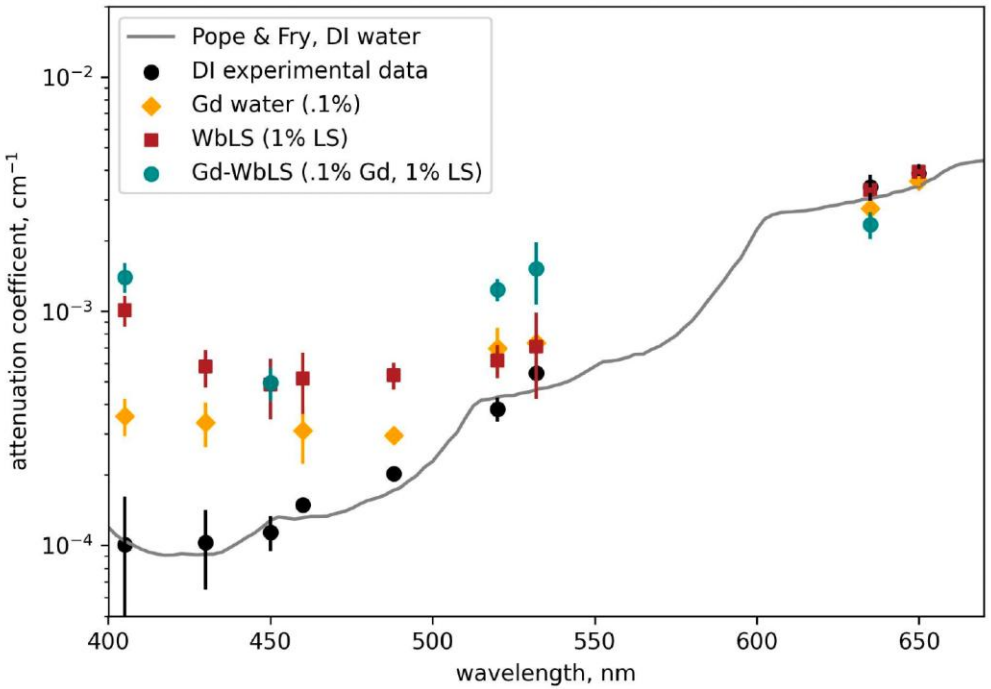
Once cassette prototyping completed

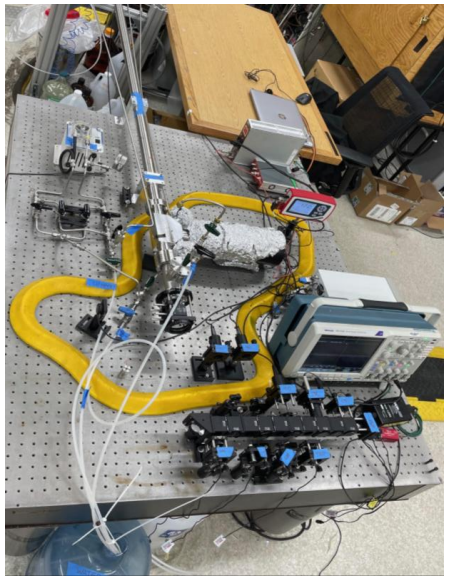
- Adjust designs if needed, build finalized designs and test and deploy at BUTTON (May/June)
- Tagged AmBe deployment device to UK mid 2025.

BUTTON Diagnostics and Software

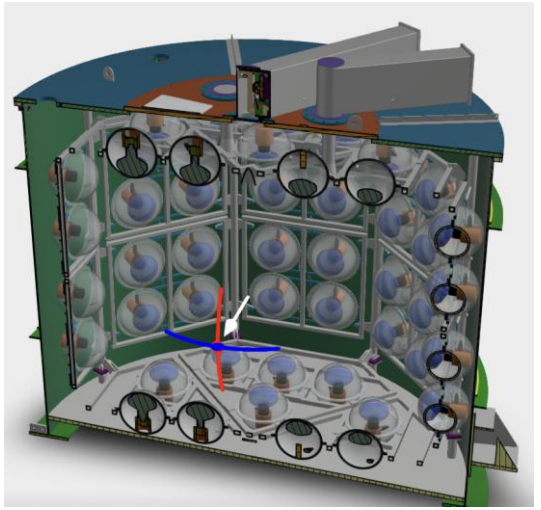
Diagnostics: fluid attenuation/scattering





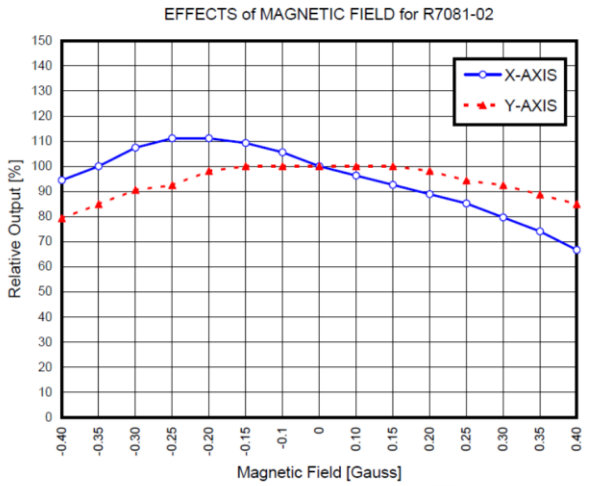


Simulation and Software



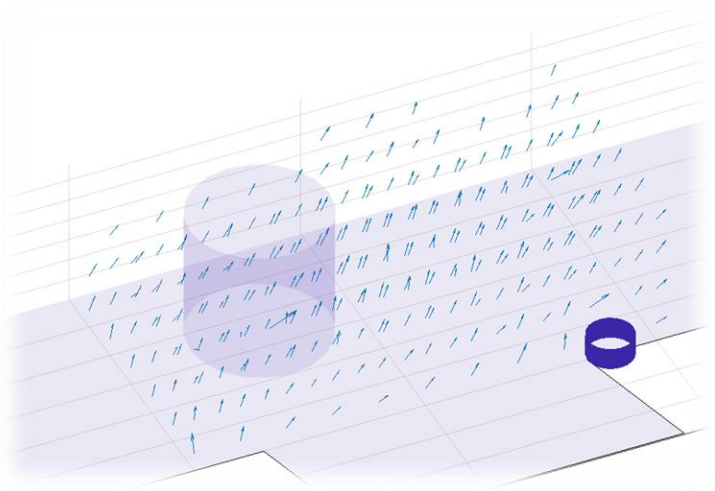
- RAT-PAC2 simulation package
- Implementation of BUTTON PMT encapsulation features, and consult on use of new RATPAC2 features
- EOS/BUTTON commonalities will ensure compatibility, leverage co-developed software

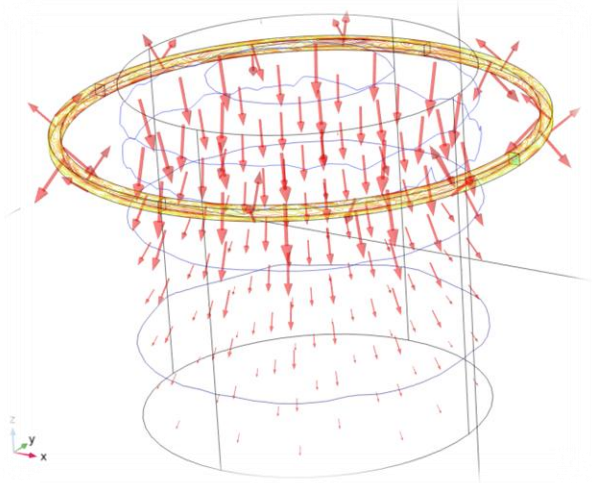
Magnetic field compensation

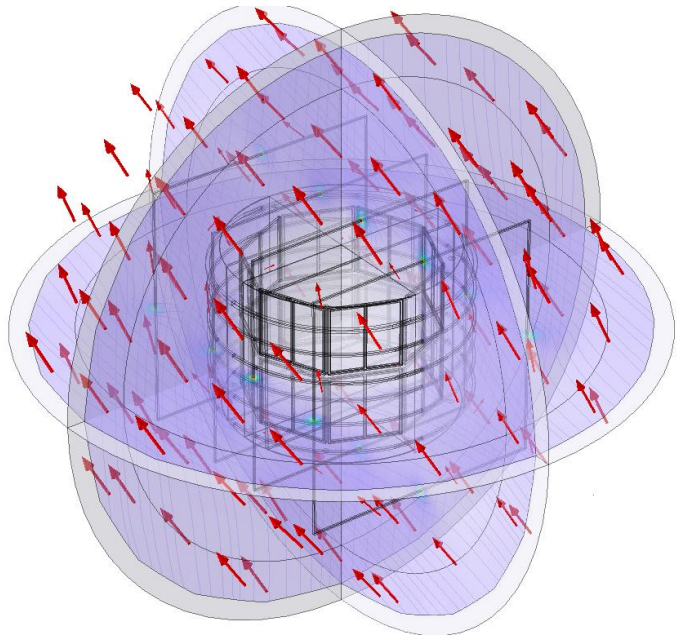


COMSOL simulation

- 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).







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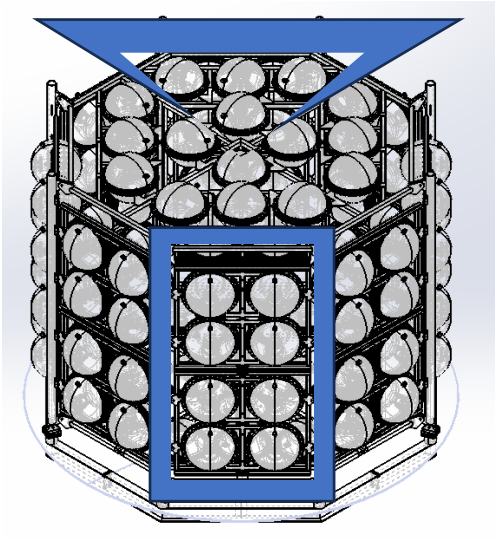
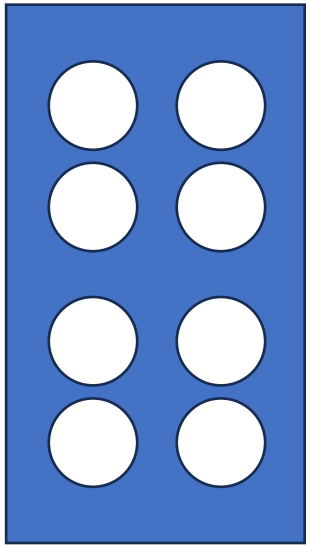
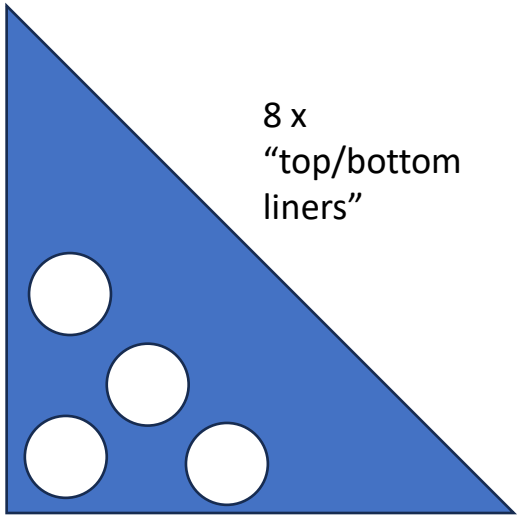
Non-reflective liner

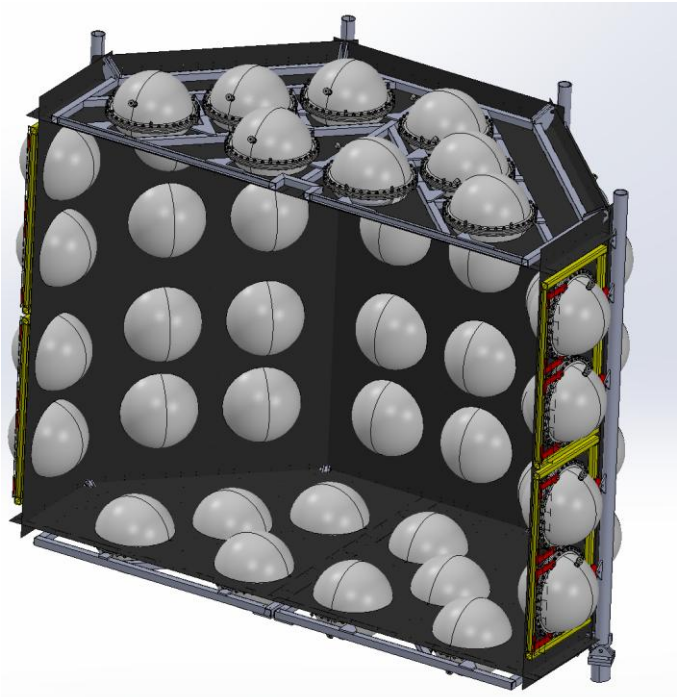


8 x “radial liners”

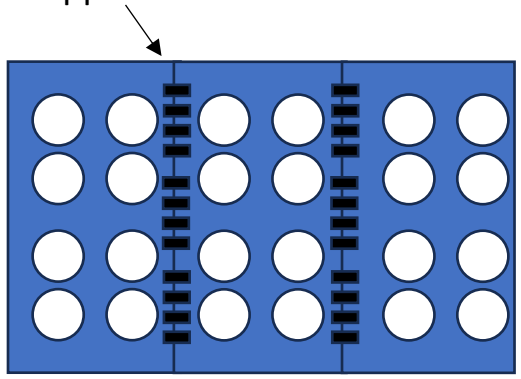


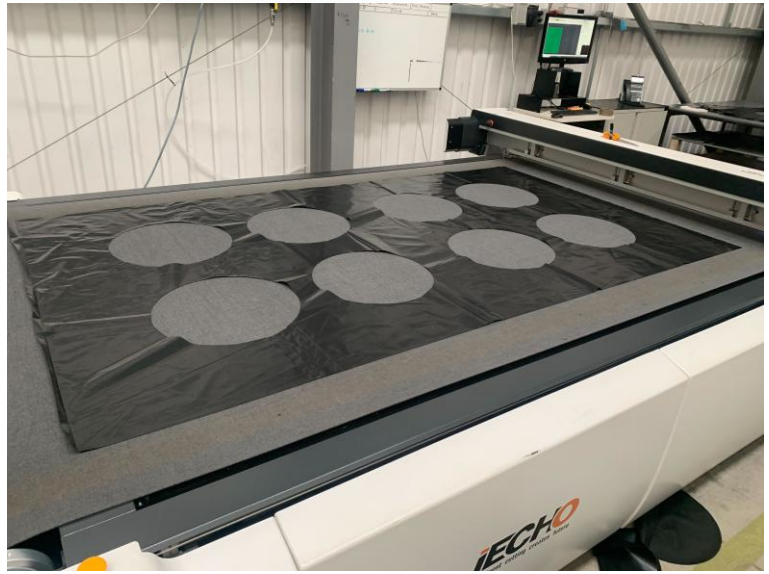
8 x “top/bottom liners”





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

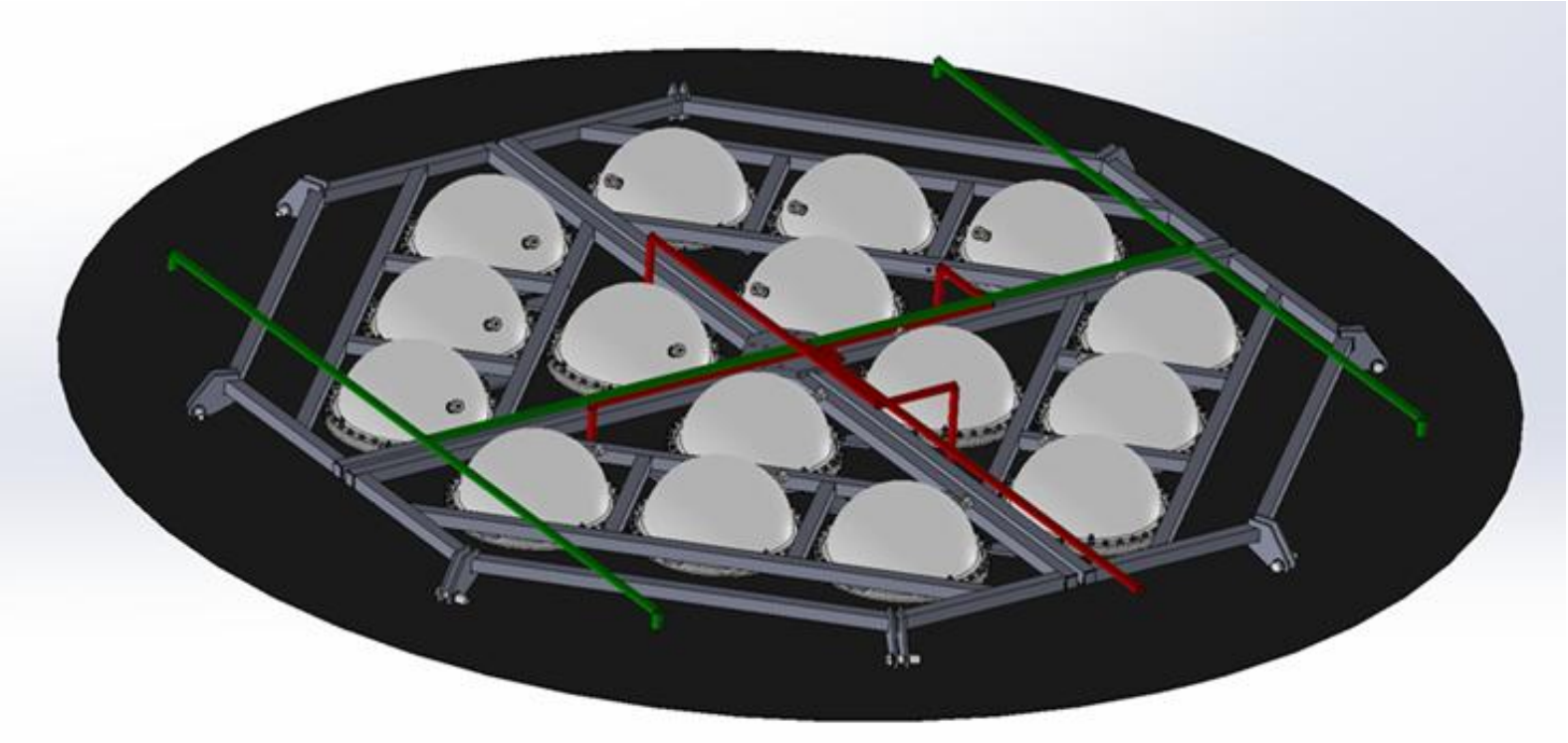




Liners cut from polythene

- 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

Internal manifolds



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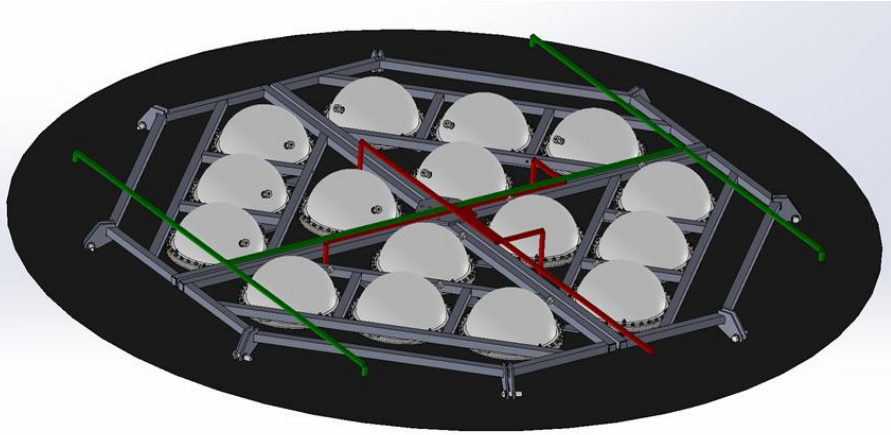
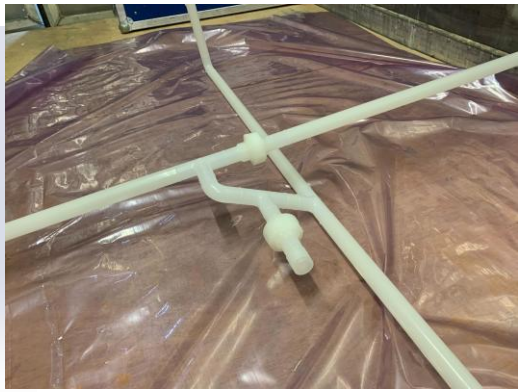
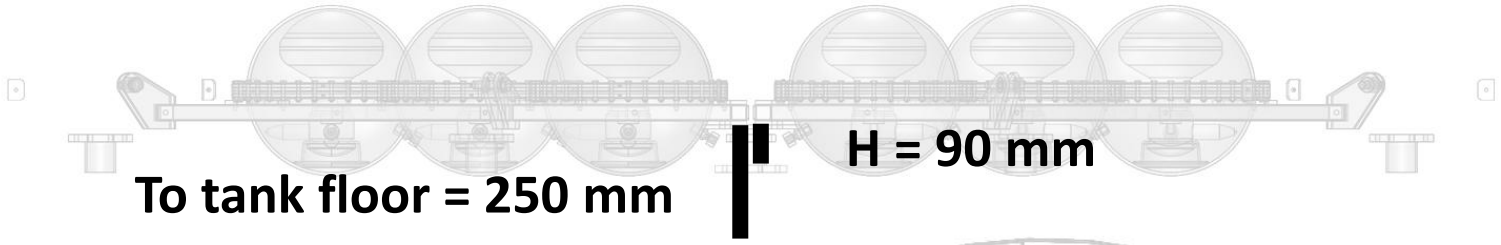




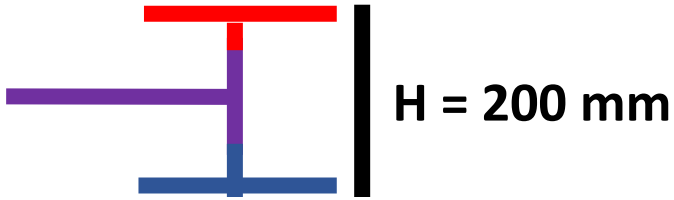
plumbing	Tees	90 degree	Union	Other
Lower outer manifold	3	6	4	3m pipe
Upper outer manifold	3	6	4	
Upper inner manifold	3	9	4	
Plumbing across lab	1	10	10	• Flex hose • Hose barbed fitting • 10m PVDF pipe
Total	10	35	25	13m
				Unions into ¾” bsp SS316

Internal plumbing final plan

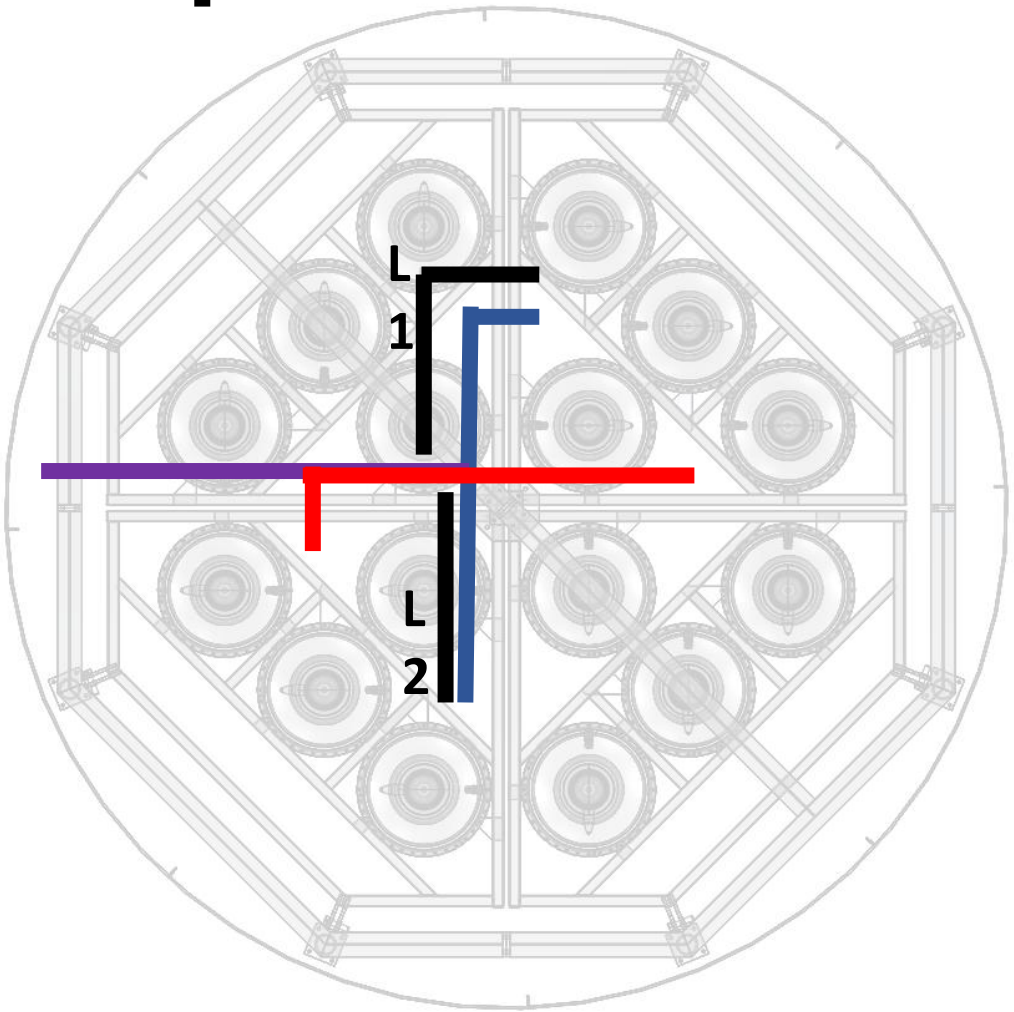


To tank floor = 250 mm

H = 90 mm



H = 200 mm



L1 = L2 for symmetric flow

Inner plumbing - irrigation

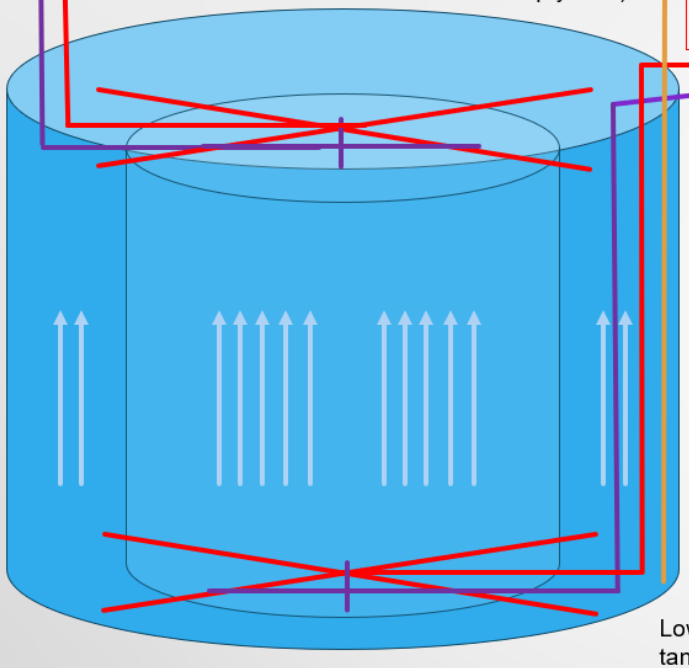
Standard operation outlets mirror inlets at the bottom of the tank

Low point outlet drain (only used to empty tank)

Flow to outer region

Flow splitting control

Flow to inner region

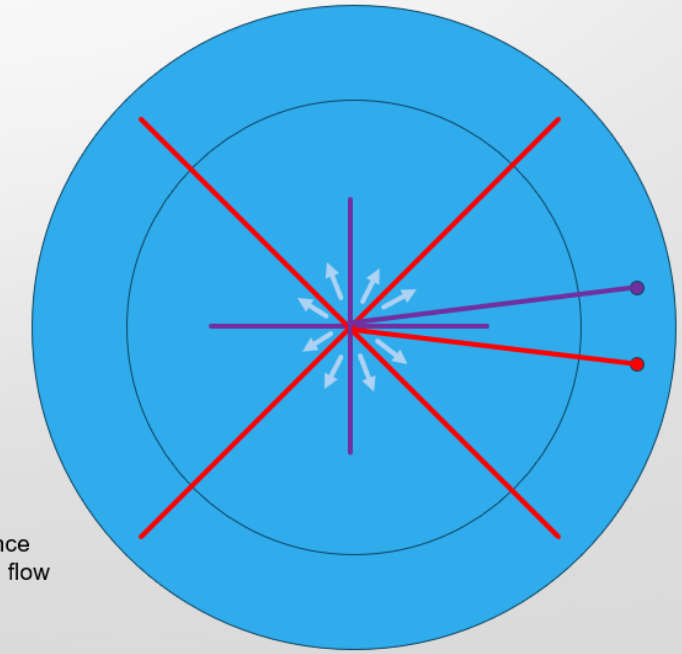


Higher flow on the outer region

Lowest point in tank

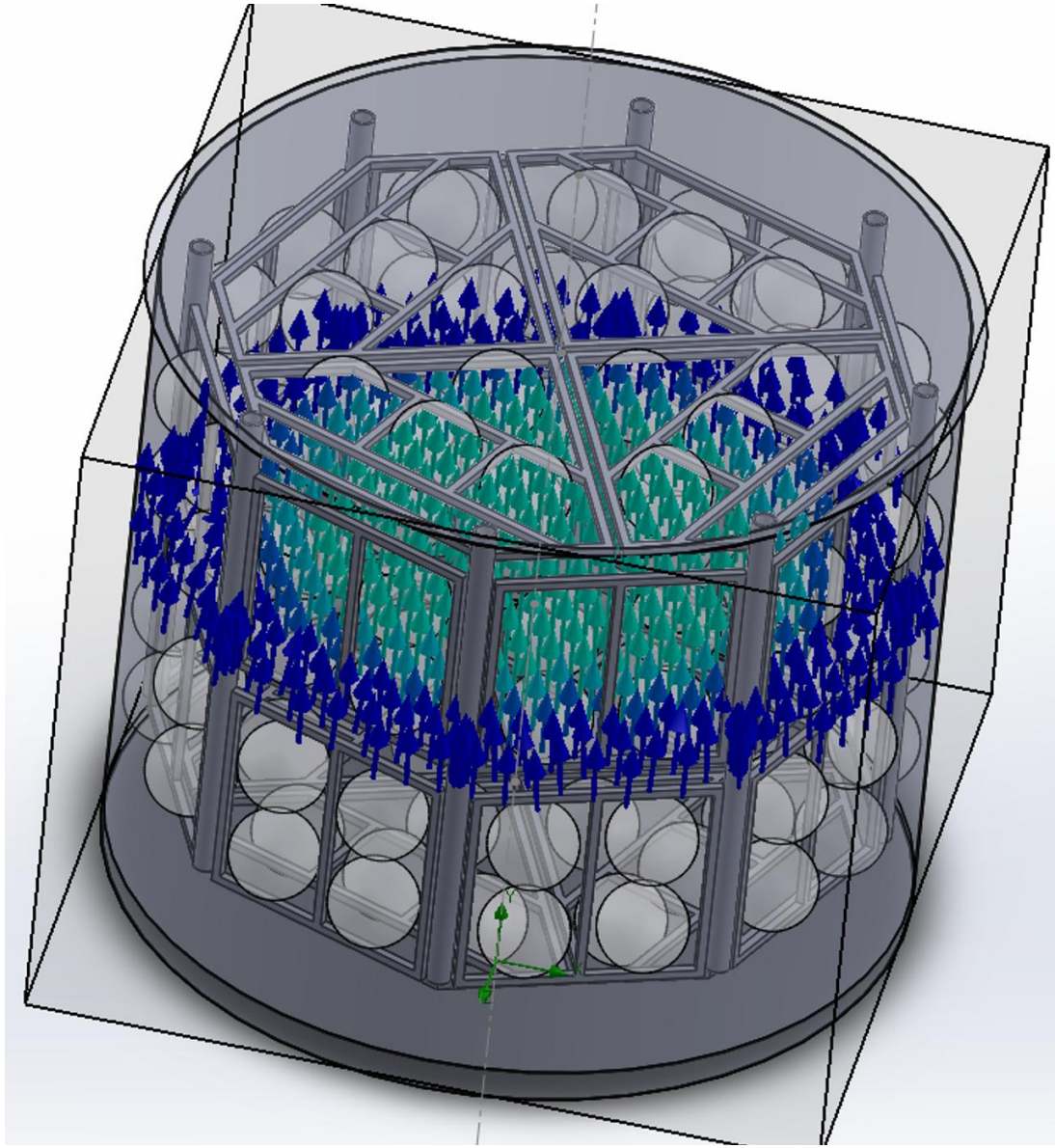
Showerhead/90 degree elbow to avoid light leak

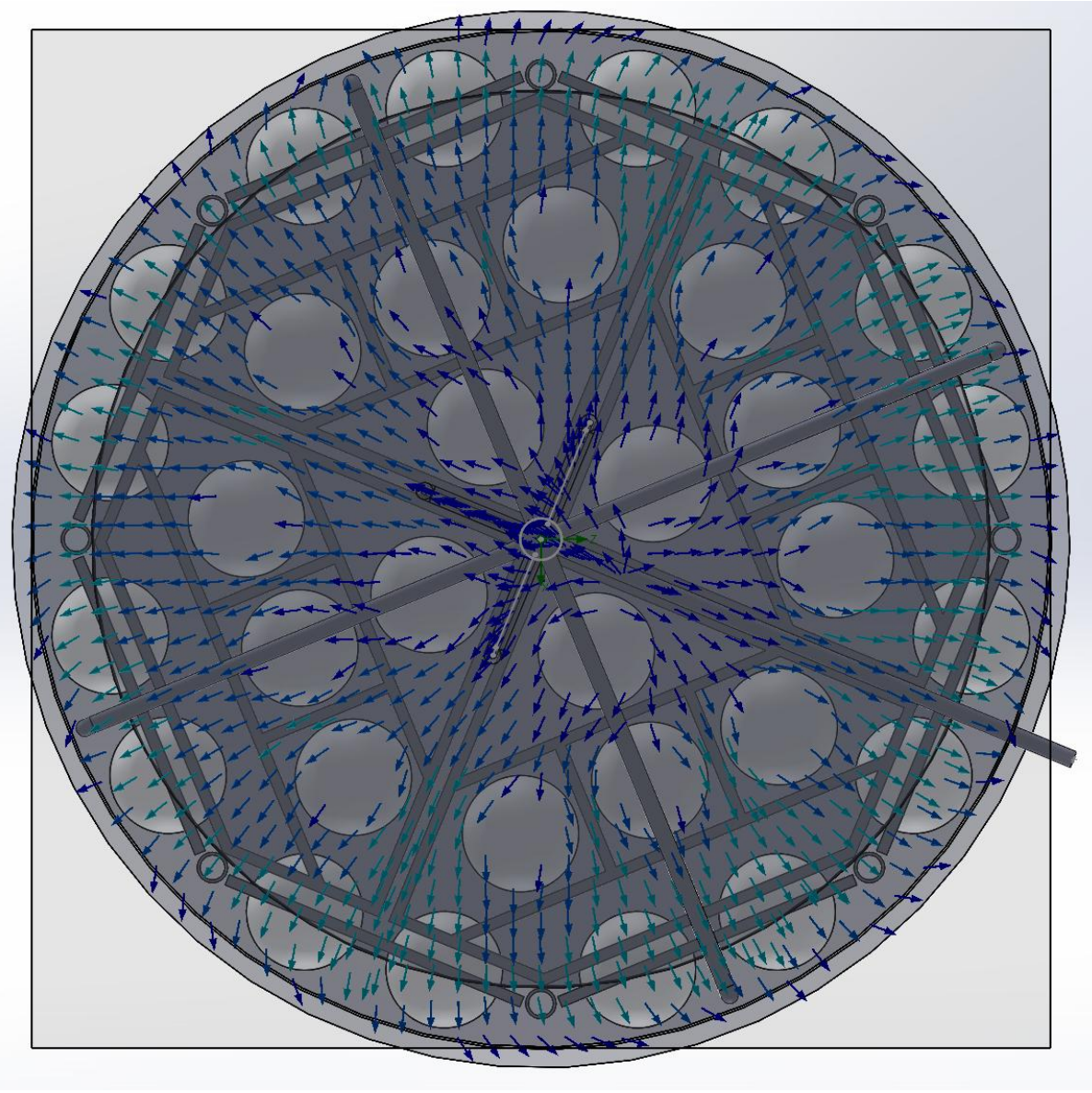
Flow outwards underneath the inner section to reduce stagnation at the bottom

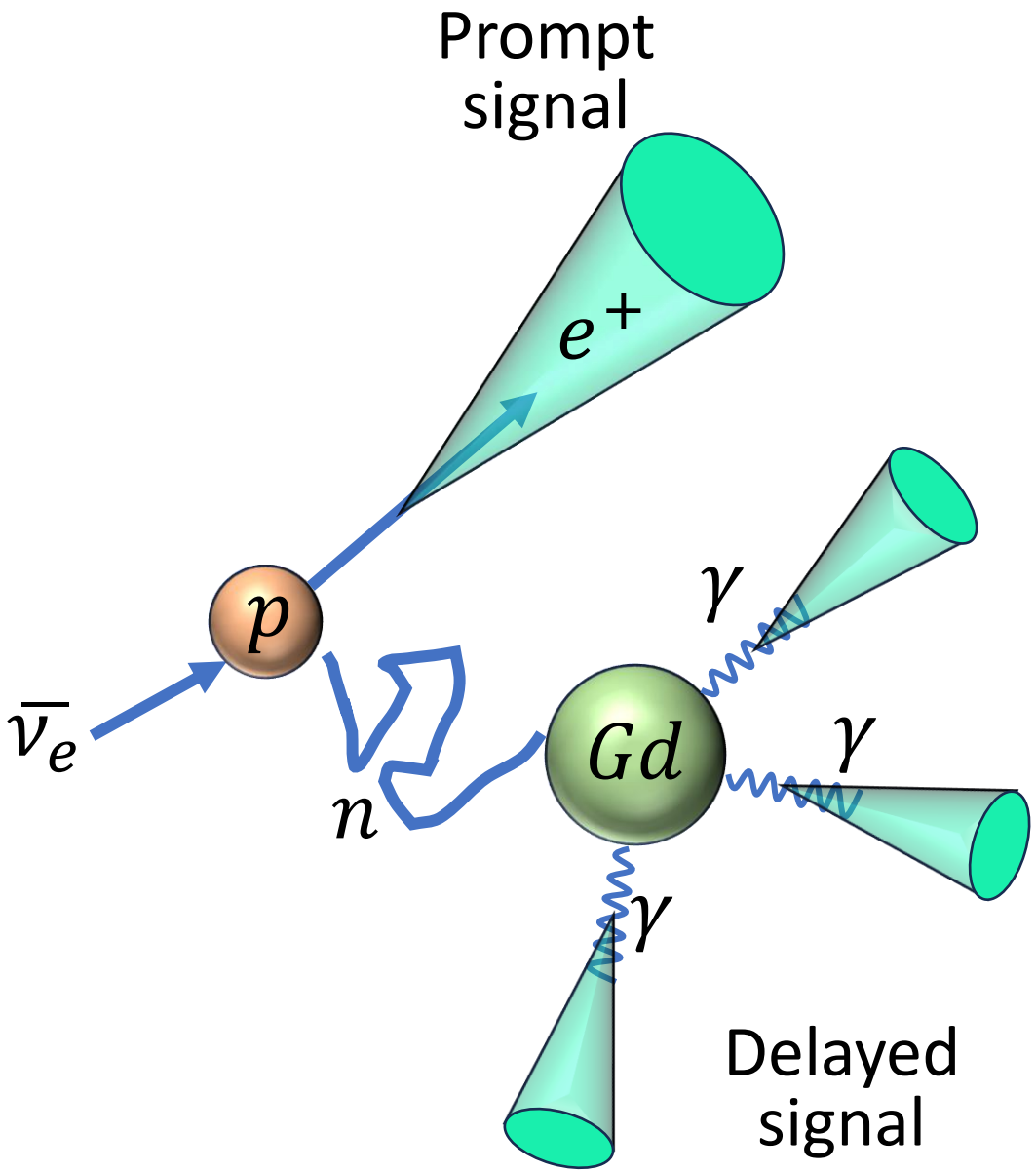


Laminar flow most crucial in the inner region

Ports at equal distance from center for even flow distribution






Prompt
signal
e^+
p
$\bar{\nu}_e$
n
Gd
γ
γ
γ
Delayed
signal