Building the Optical Detector System for BUTTON

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On behalf of the BUTTON collaboration

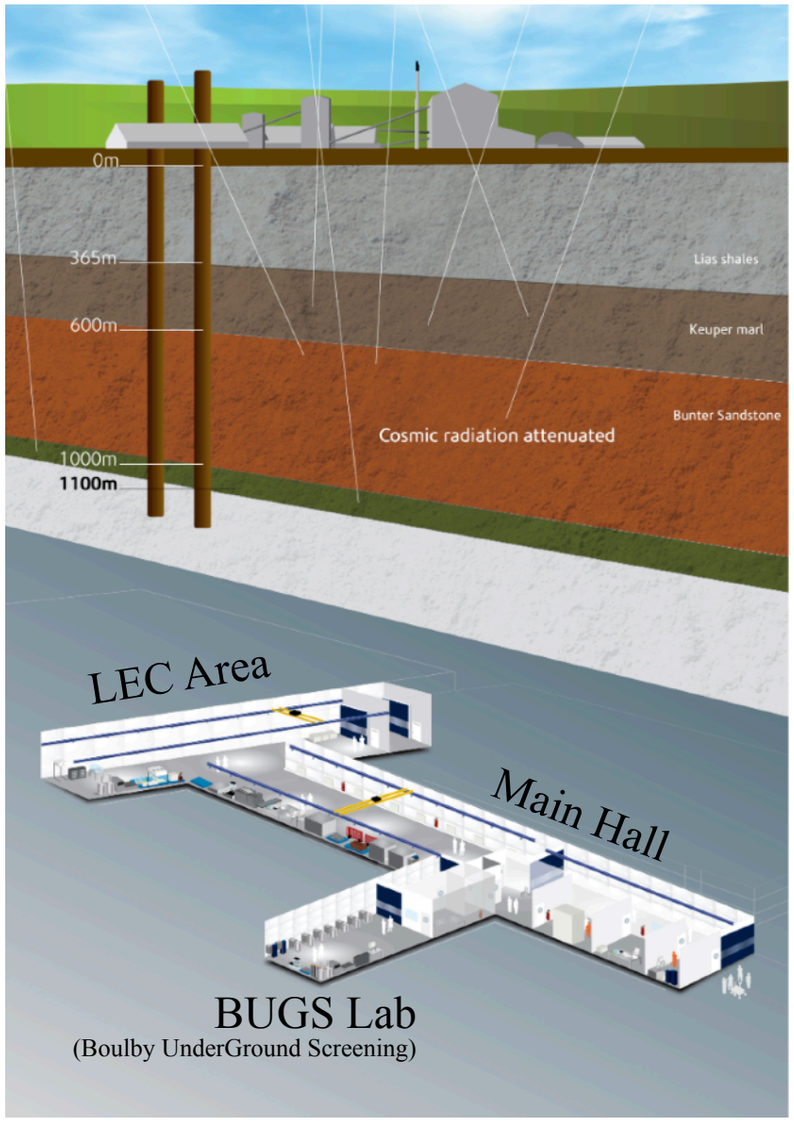
Applied Antineutrino Physics Workshop 28-30 Oct 2024, Aachen, Germany

Overview of the talk:

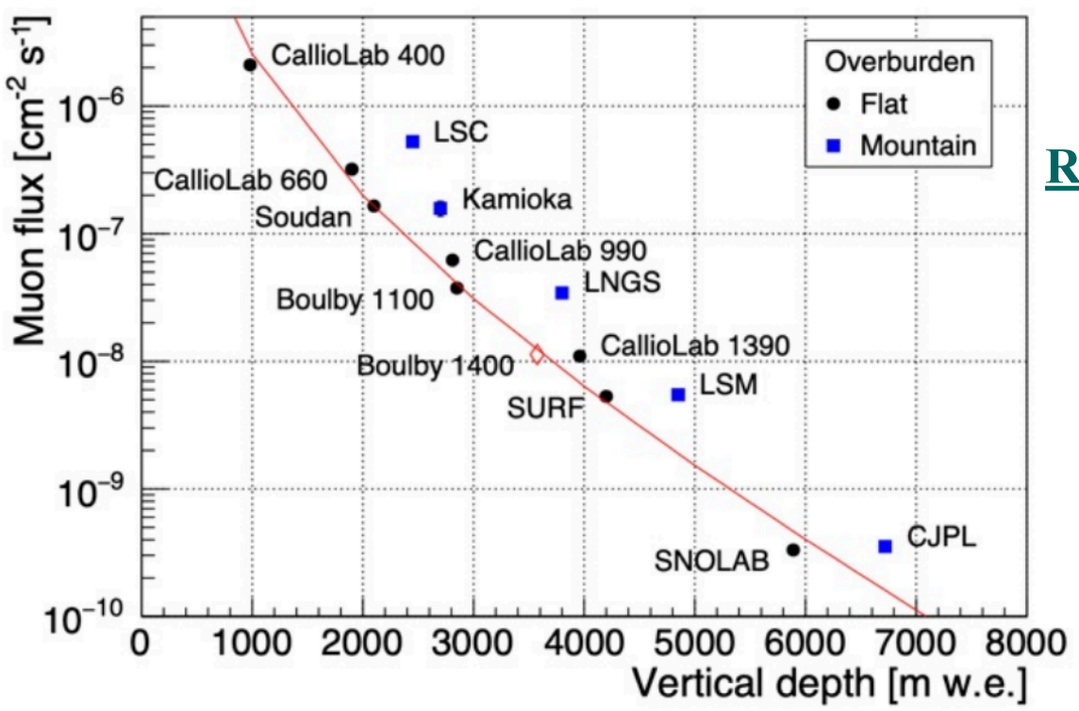
1. Introduction to Boulby and BUTTON
2. The water tank for BUTTON
3. Components of the Optical Detector Modules
4. *Building the Optical Detector Modules*
5. PMT Support system

The Boulby underground test facility

- an active rock-salt and polyhalite mine in North Yorkshire, UK
- deepest mine in Britain (1.3 km)
- more than 1000 km of tunnelling in 50 years (even under the sea)
- low radioactivity of the rock-salt (U ~67 ppb, Th ~125 ppb)
- ideal for low background research



- Muon flux reduced by 10^{-6} at 1.1 km
- Low Radon level: 3 Bq/m^3 .
- 4000 m^3 ISO 6 and 7 clean room lab space
- 3000 m^3 Outside Experimentation Area



Hosted dark matter experiments like **Zeplin** in the last decades

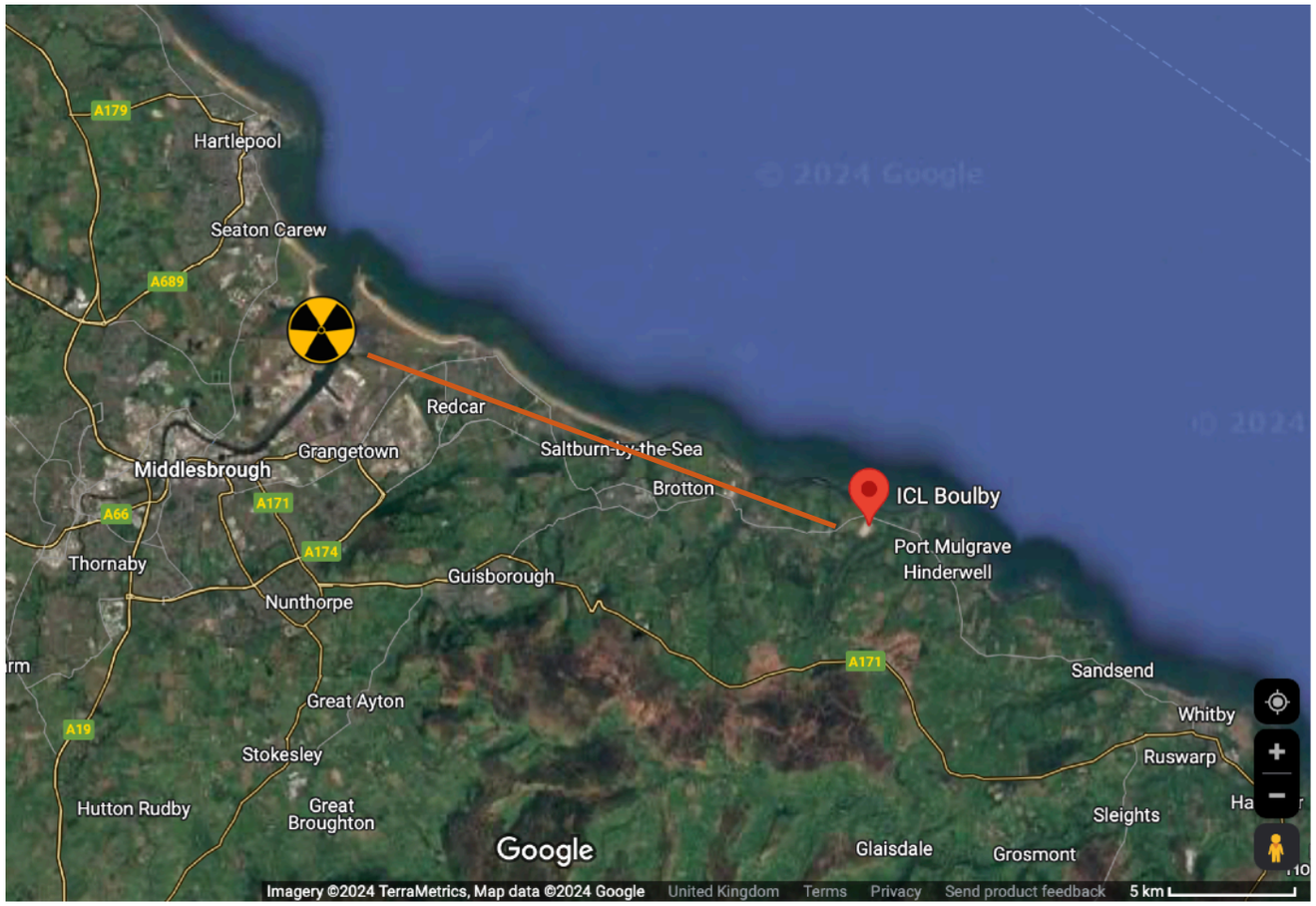
Rich near and far future plans

- Dark matter search
- **Neutrino Physics/ Application**
- Earth/Environmental Science
- Astrobiology

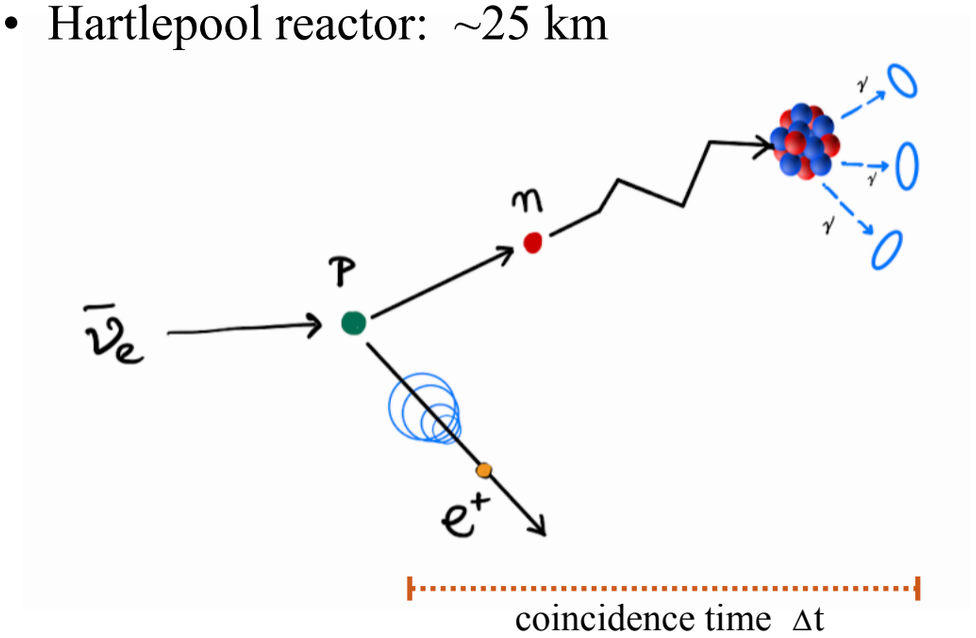
Detecting antineutrino at BUTTON

The **B**oulby **U**nderground **T**echnology **T**estbed for **O**bserving **N**eutrinos (**BUTTON**) is a 30 tonne antineutrino detector

- Classical media: Water, Liquid Scintillator (LS)
- Advanced media: Water-based Liquid Scintillator (WbLS); and Gd loading (water and WbLS)
- Photosensor: 96 PMT
- Advanced Photosensor: Large Area Picosecond Photo Detector (LAPPD)
- Explore the potential for a future kilo-tonne detector



- Detection process: Inverse Beta Decay (IBD)
- Hartlepool reactor: ~25 km

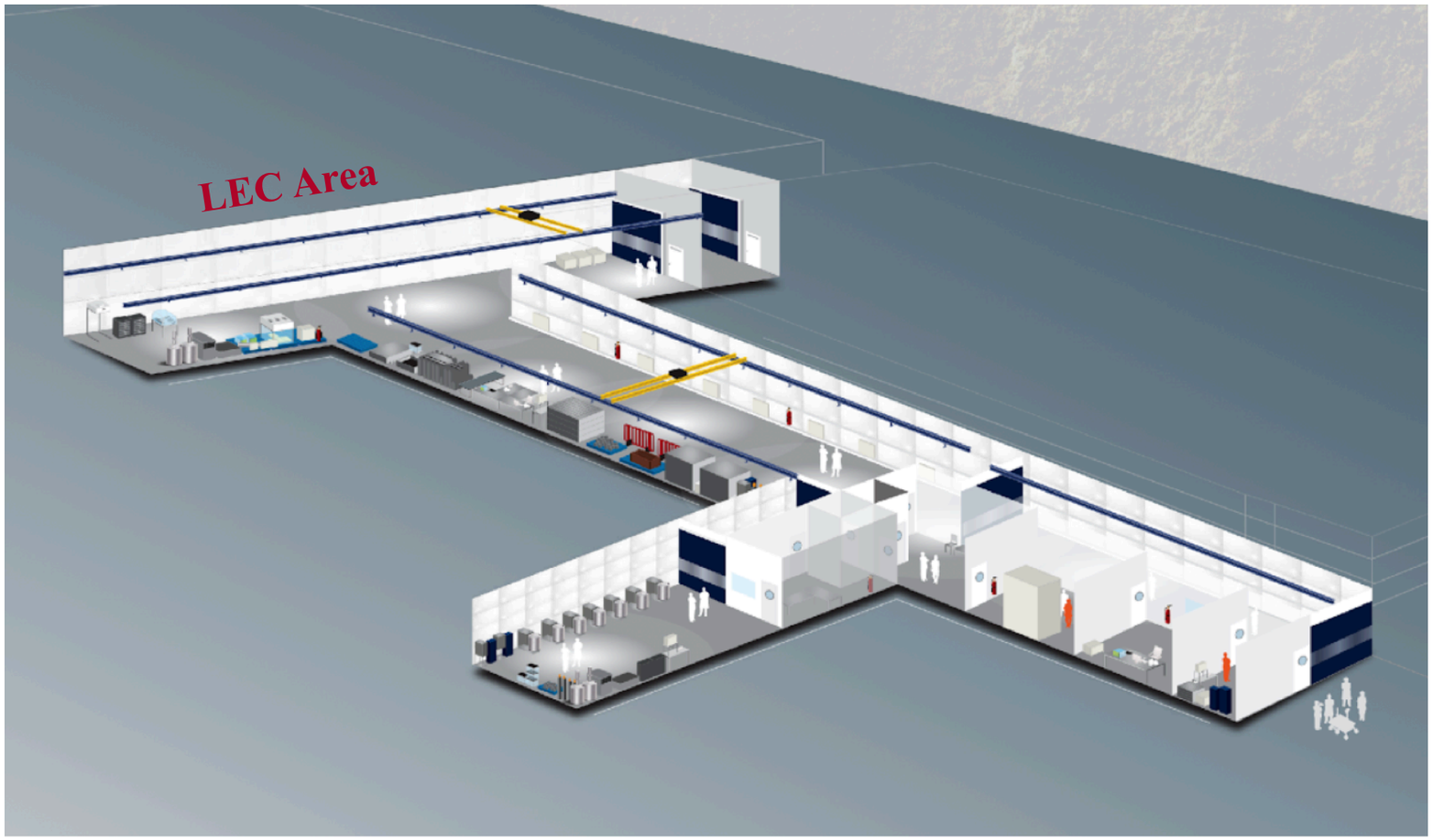


- Pure water (hydrogen) : $\Delta t = \sim 200\ \mu s$ (1-2 MeV)
- Gd-loded water: $\Delta t = \sim 20\ \mu s$ (~ 8 MeV)

- WbLS [*Talk by Minfang Yeh*]: (1) directional event reconstruction + (2) better energy resolution and low threshold

Water Tank:

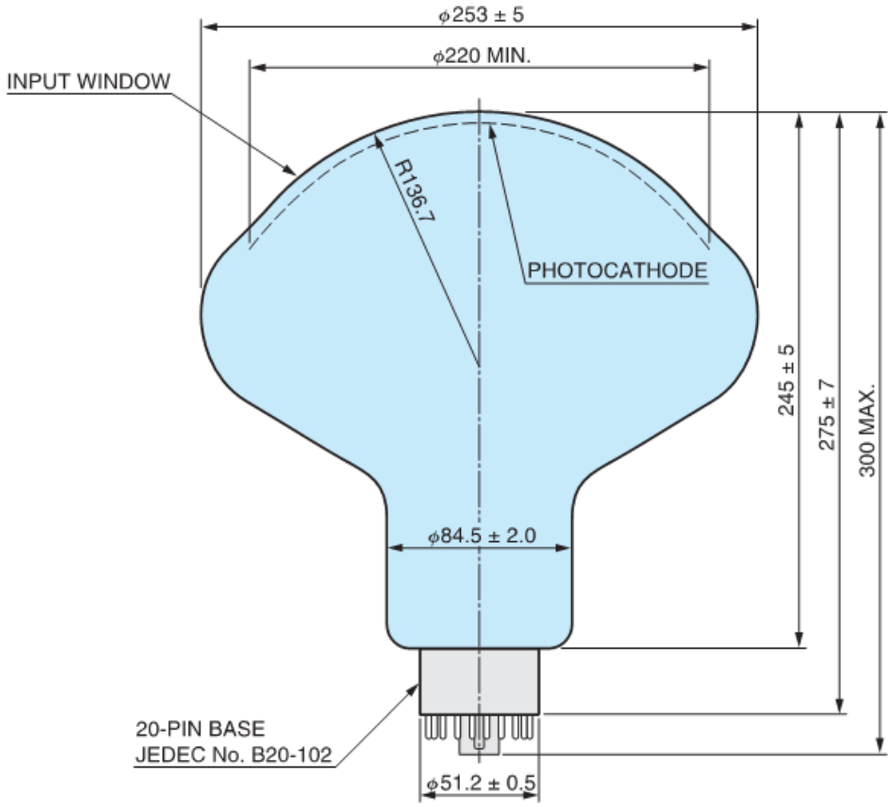
- 30 tonne cylindrical tank, arrived at Boulby (early 2024) in two parts
- inner diameter = 3.7 m
- height = 3 m
- marine grade 316L stainless steel
- inner part is pickled to protect from rusting.
- upper lid with 2 inlets and 2 outlets for water circulation
- installation is nearly complete

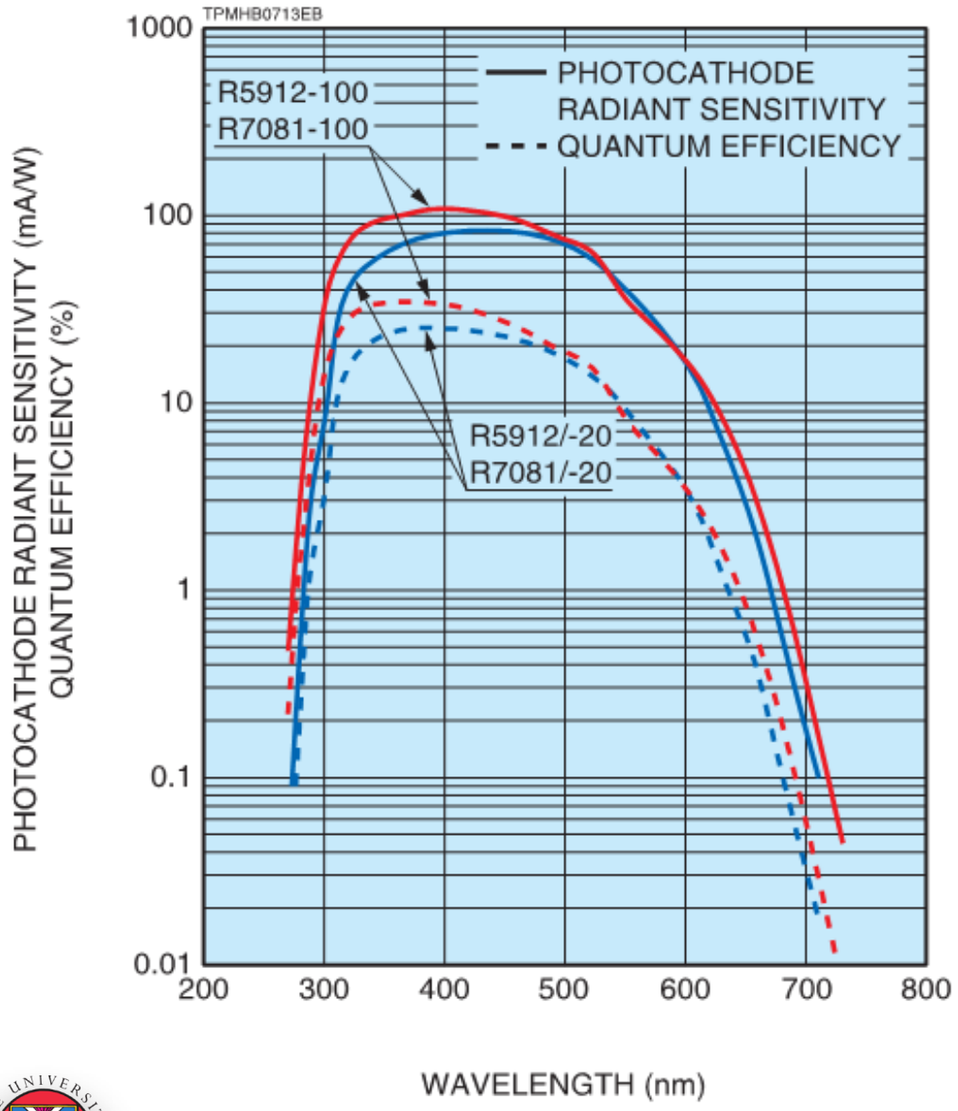


Components of the Optical Detector Module

(1/3) The PhotoMultiplier Tube (PMT)

- 10” Hamamatsu R7081 PMT
- ~ 100 PMTs was procured for WATCHMAN
- Takes +ve voltage; outputs inverted signal
- PMT-base is ok for Gd, but not for WbLS





CHARACTERISTICS (at 25 deg. C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856 K)	80	130	-	uA/lm
	Radiant at 420 nm	-	110	-	mA/W
	Blue Sensitivity Index (CS 5-58)	12.5	13.5	-	-
	Quantum Efficiency at peak	32	35	-	%
Anode Sensitivity	Luminous (2856 K)	-	1300	-	A/lm
	Radiant at 420 nm	-	1.1×10^6	-	A/W
Gain		-	1×10^7	-	-
Anode Dark Current (after 30 min. storage in darkness)		-	500	1000	nA
Dark Count (after 24 hrs. storage in darkness) *1		-	8000	16000	s^{-1}
Time Response	Anode Pulse Rise Time	-	3.8	-	ns
	Electron Transit Time	-	62	-	ns
	Transit Time Spread (FWHM) *2	-	3.4	-	ns
P/V (Peak to Valley) Ratio *2		1.5	2.8	-	-
Pulse Linearity at +/-2% deviation		-	40	-	mA

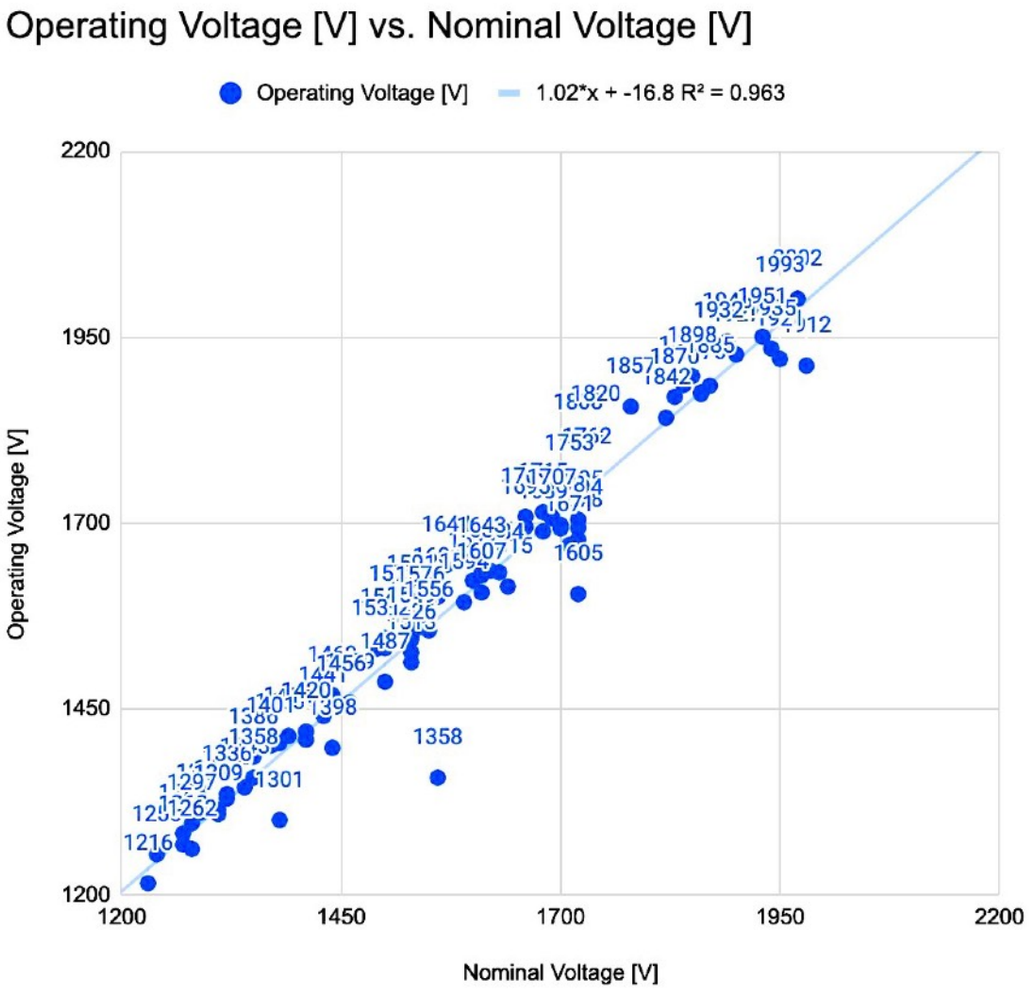
✓ Gain ~ 10^7

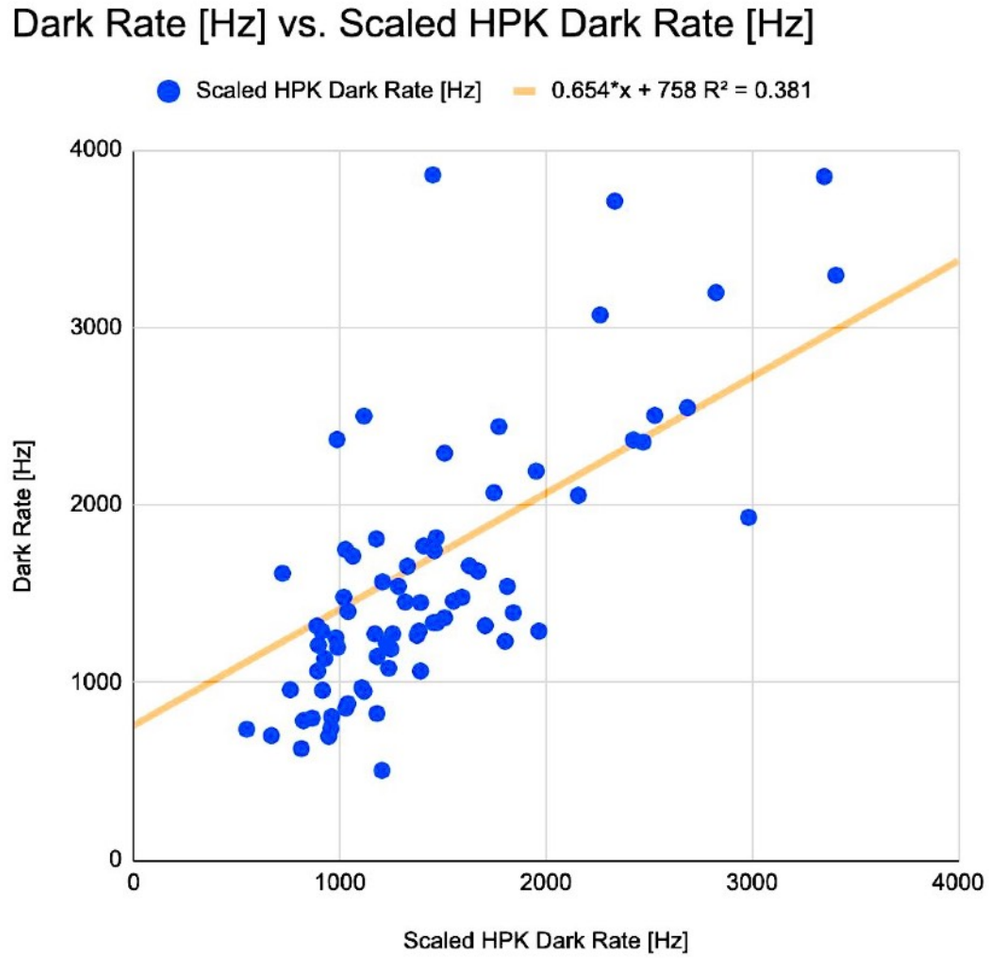
✓ Dark count < 8kHz (above 25C), < 4kHZ (below 25C)

Components of the Optical Detector Module

(1/3) The PhotoMultiplier Tube (PMT)

- R7081 has low radioactivity glass
- Series well tested for Ice Cube, Antares, Double Chooz
    - Undergone acceptance tests
    - Almost all PMTs matched specifications (1 exception)



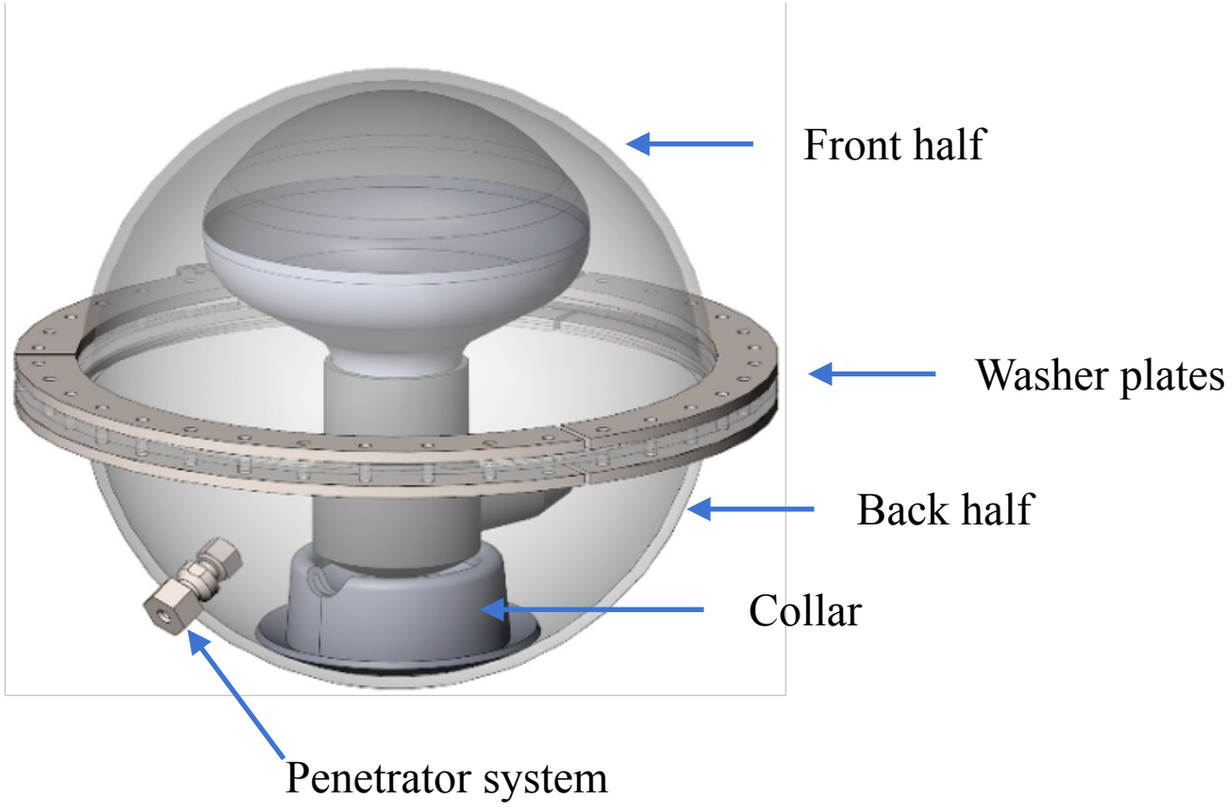


For details on the acceptance test
https://doi.org/10.1088/1748-0221/18/08/P08015

Components of the Optical Detector Module

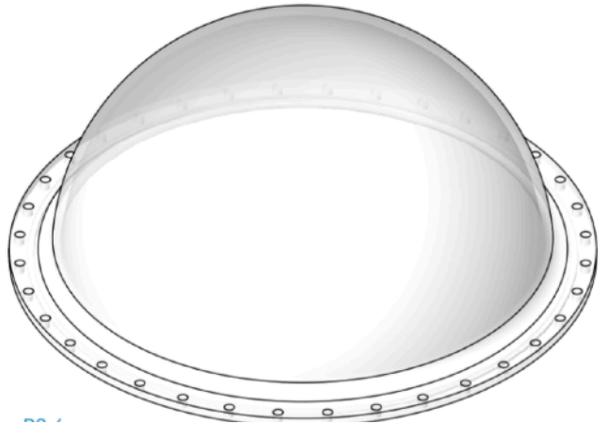
(2/3) The Acrylic housing

- The PMT will be encapsulated within an acrylic housing
- Inner diameter = 40 mm
- Thickness = 8 mm
- Two parts: Front half and Back half
- They are enclosed with 2x3 metal washer plats
- 36 nut-bolts



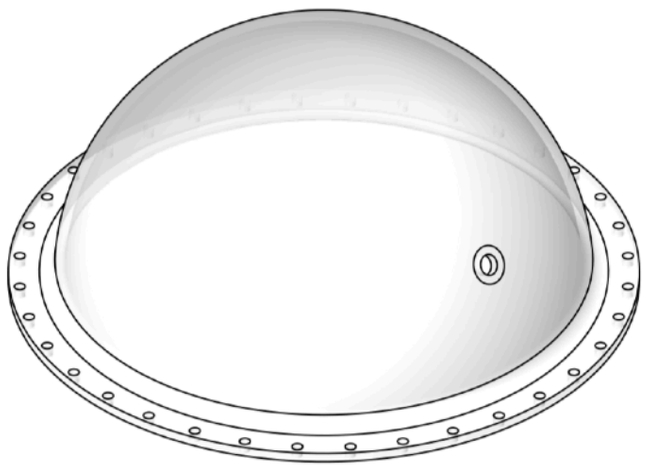
Front half

- UV transparent (randomly tested ~10%)
- PMT and front-half are in contact through optical gel



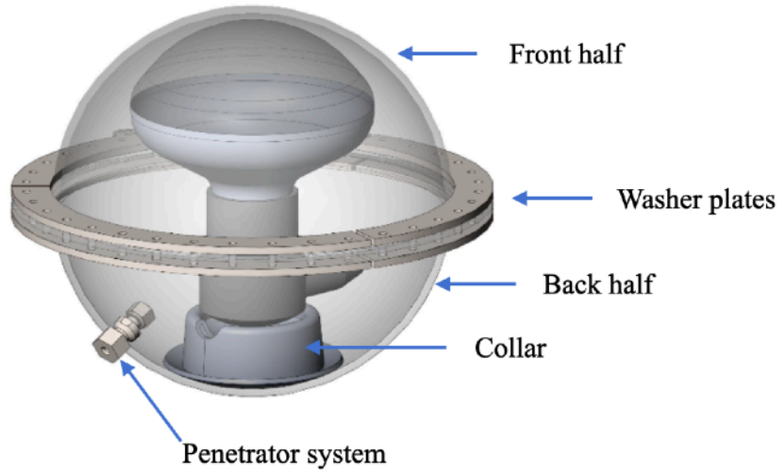
Back half

- Not UV transparent
- Painted in black to block scattered photons
- PMT base is supported on a collar
- The HV/signal cable passes through a ‘penetrator system’



Components of the Optical Detector Module

(2/3) The Acrylic housing

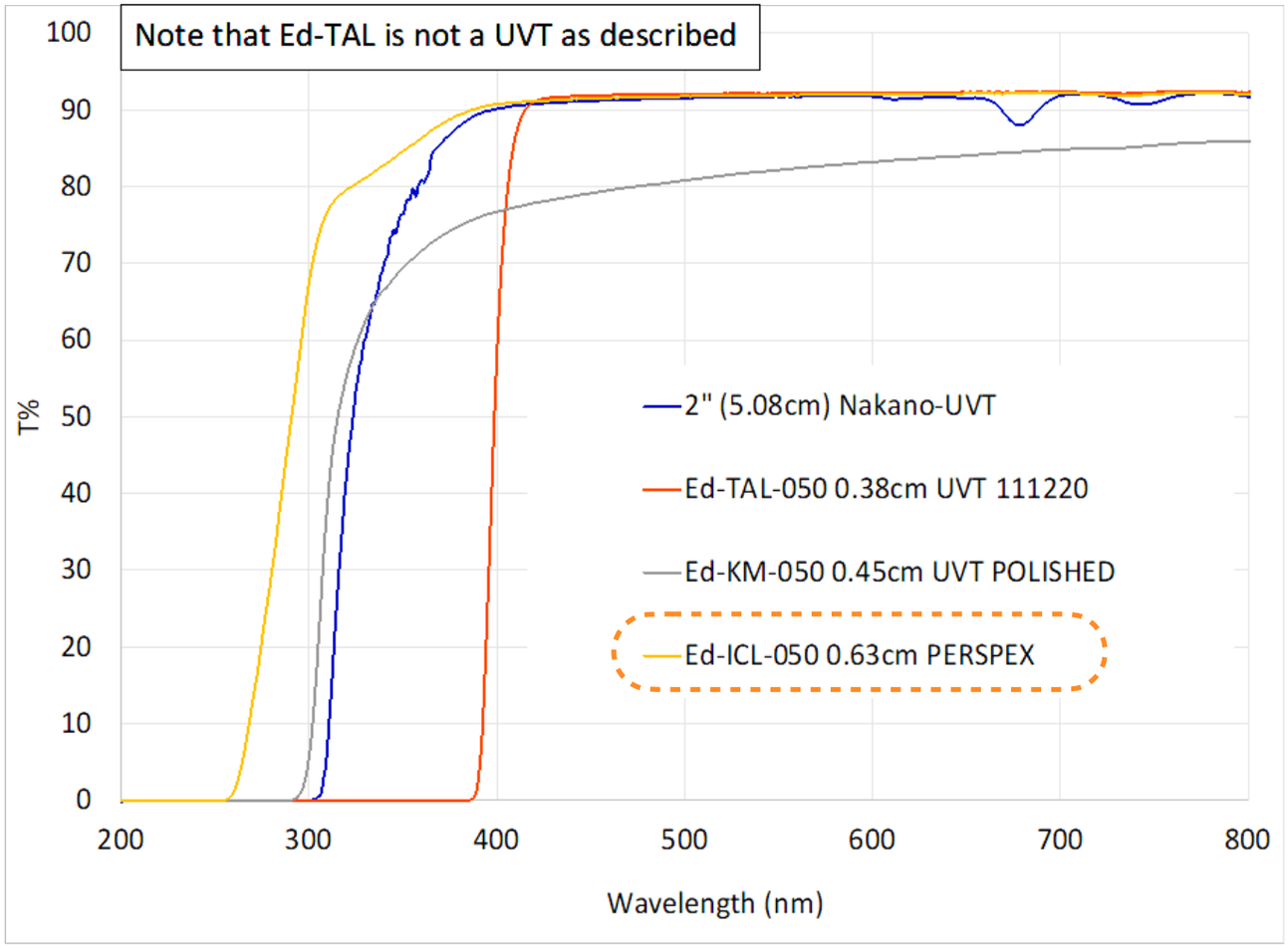


Tests/R&Ds

- Tested for WbLS compatibility
- Tested for the optical properties
- Tested for radioactivity

- Tested to withstand 3 bar over pressure
- Protects PMT-base from WbLS
- Protects PMT from Gd

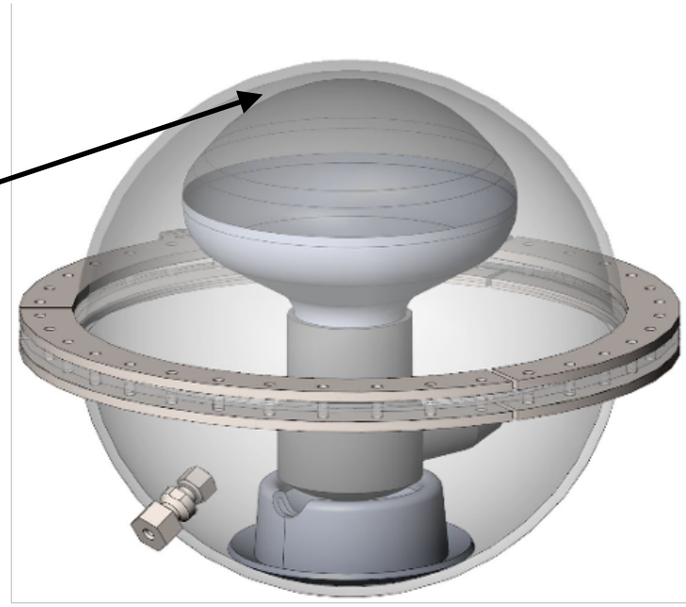
- Chosen material: Ed-ICL (~70% at 300 nm)
- Produced by ICLTech (Glasgow)



Components of the Optical Detector Module

(3/3) The Optical Gel

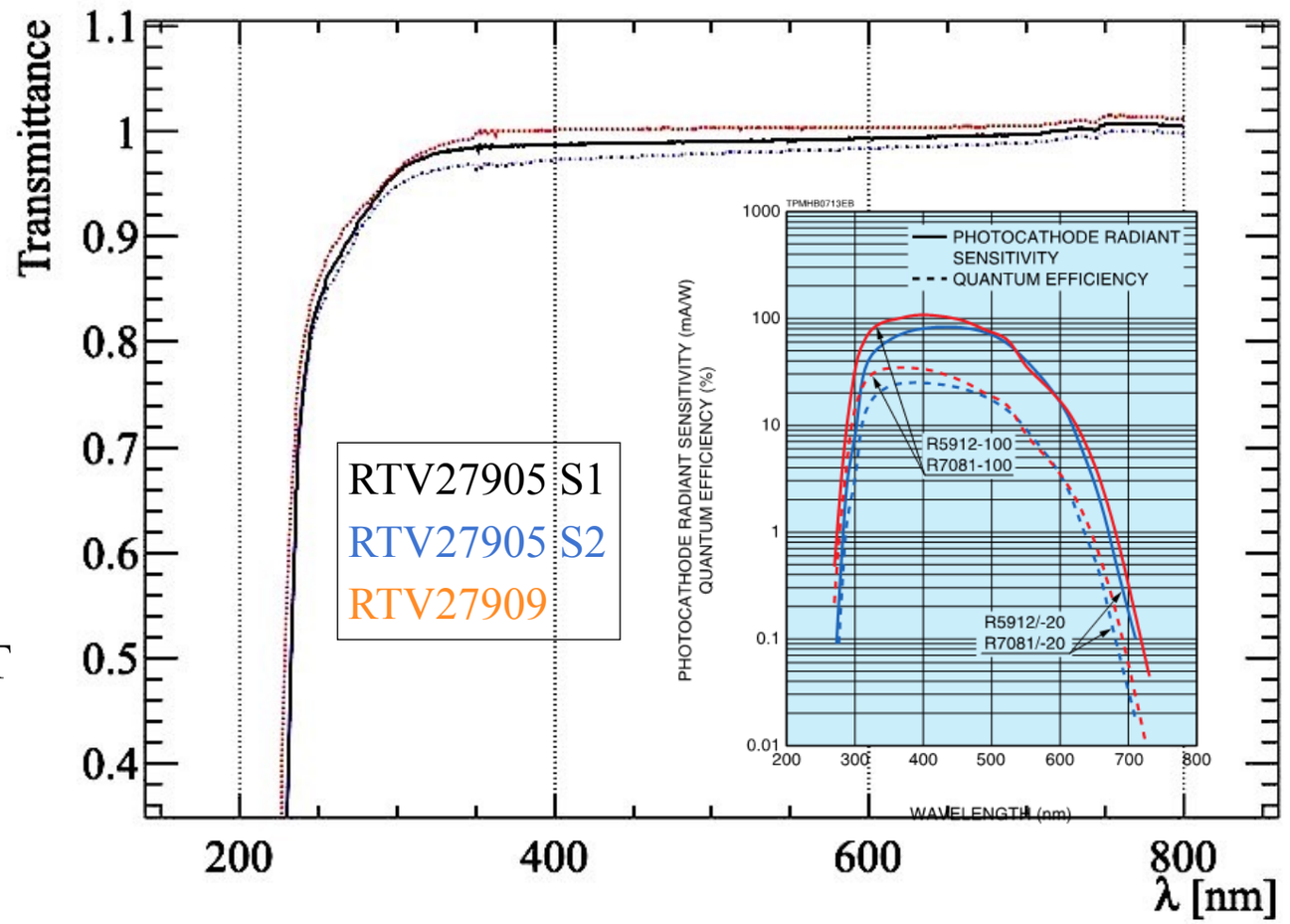
- Optical gel between the acrylic front and the PMT glass
- Optical continuity
- Mechanical support



Choice of the Optical Gel: **RTV27905**

- Based on measurements / R&D
- Availability, Cost, Cure time, other applications

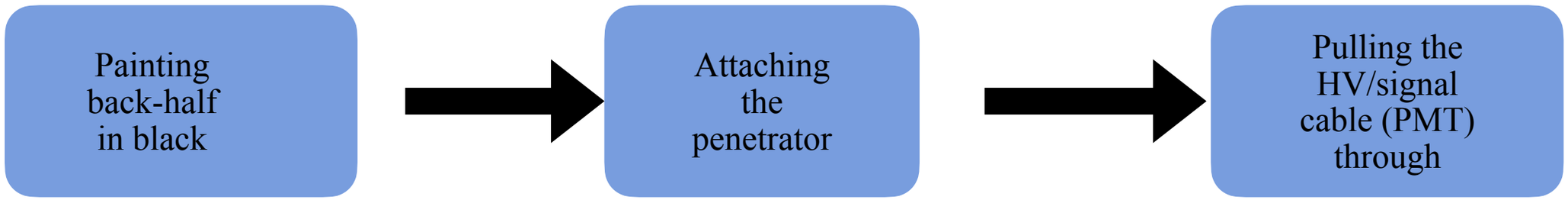
- Refractive index ~ 1.4
- Transmittance measured with Carry 100 bio UV-Vis
- Transmittance matches Quantum Efficiency of the PMT
- Similar transmittance for both gel samples (S1 and S2)



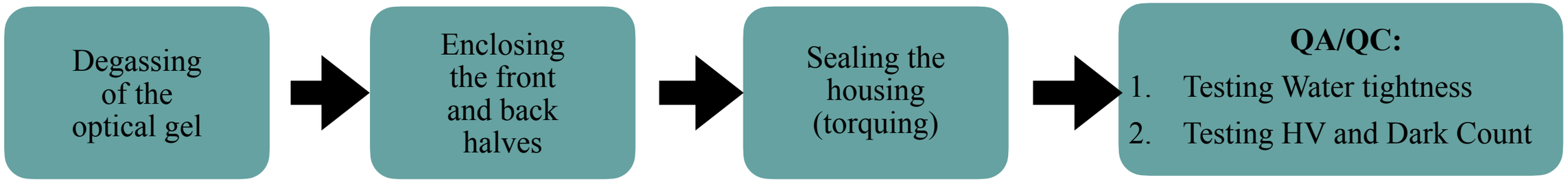
Construction of the Optical Detector Modules for BUTTON

Inspired by the shared experience by the Ice Cube Experts

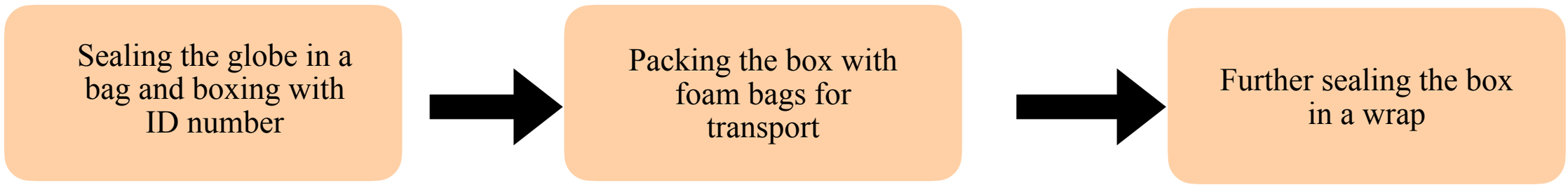
Part 1 : preparing the back-half of the housing



Part 2 : the modular assembly of the housing



Part 3 : preparing the module for transport to Boulby



The steps in between:

- **Safety:**
  - Protective visors, steel capped welly boots, face-shield, Lab-coats in the Lab
  - Anti slippery mat in the Lab/tent
  - PMT handled by two-people
  - Safety instructions are prepared

- **cleanliness:**
  - The gel is slippery and can spread across the Lab
  - Table, floor, instruments, Lab beakers are cleaned regularly

- **Checklist:**
  - A very instructive checklist is prepared to remind the small steps
  - Check list has to be ticked to move on to the next step
    - e.g; it's easy to forget placing the label/desiccator in the housing

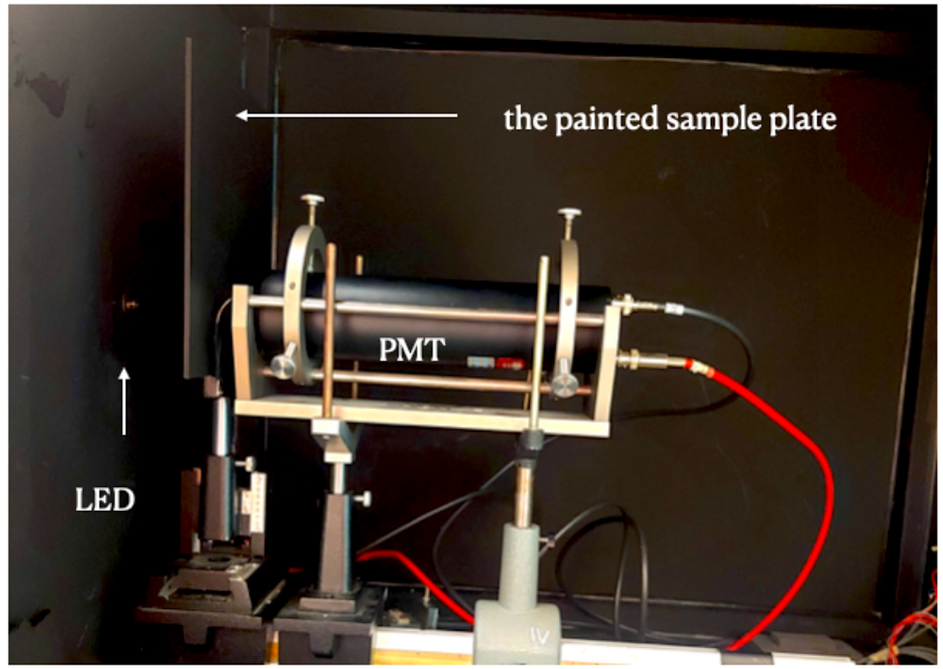
Building the Optical Detector Modules for BUTTON

Part 1 : preparing the back-half of the housing

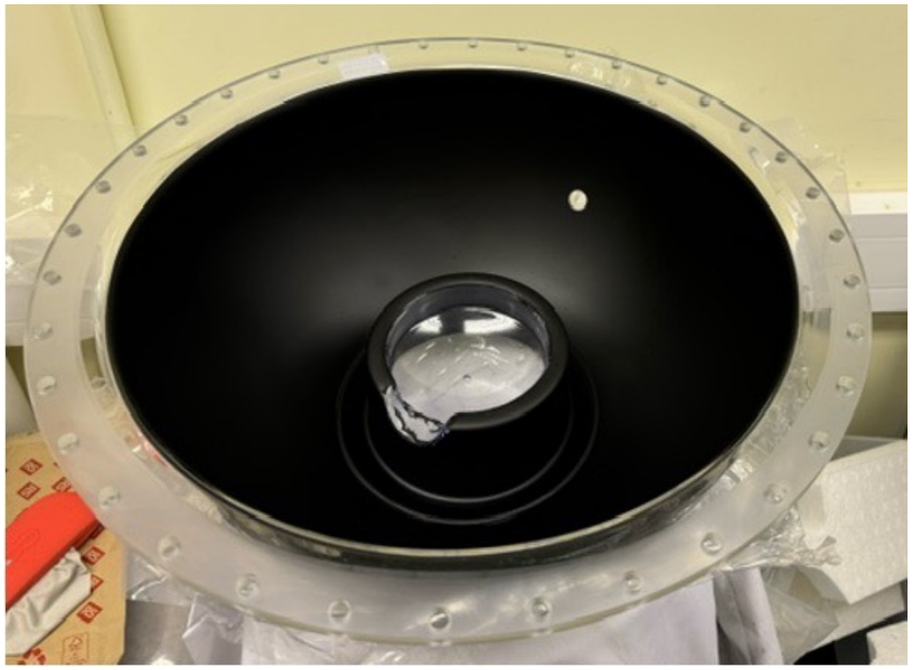
Which paint, and how to paint?

- Primar = Acrylic Primer
- Paint-1 = Matt Black Aerosol
- Paint-2 = Grafite Aerosol

- S+P1 = sanding + Paint-1
- S+Pr+P1 = sanding + Primer + Paint-1
- S+P2 = sanding + Paint-2
- S+Pr+P2 = sanding + Primer + Paint-2



- Painted sample is mounted in front of the PMT
- Dark count is measured [threshold 10 mV]
- LED (465 nm) is turned on
- Pulses are counted [threshold 10 mV]
- Dark count is measured again
- A comparison is made for different paints



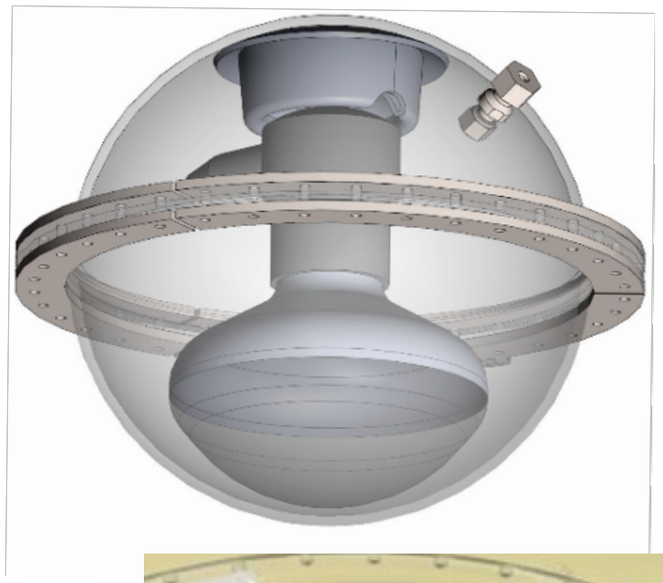
- Paint-1 (Matt Black Aerosol) blocks light better
- Robust (water, optical gel): no need for primer and sanding
- Low background

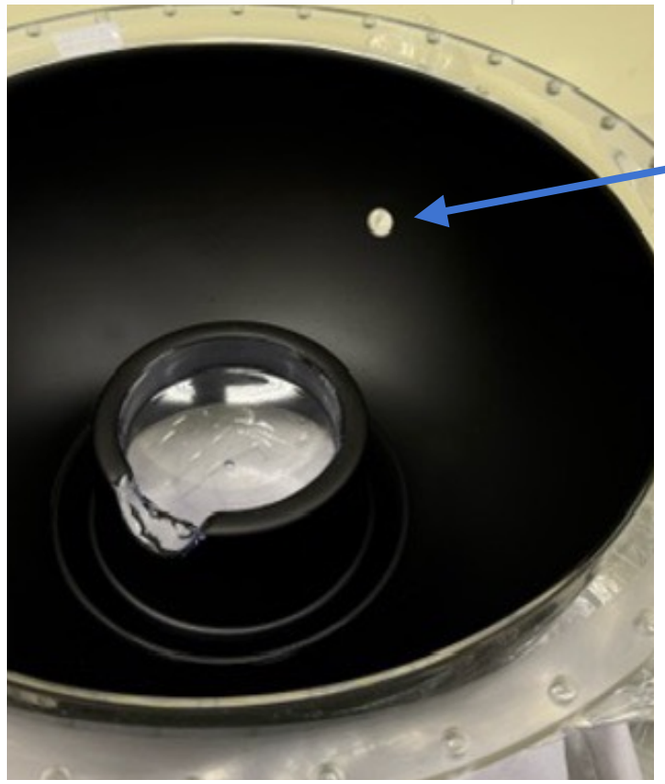
Building the Optical Detector Modules for BUTTON

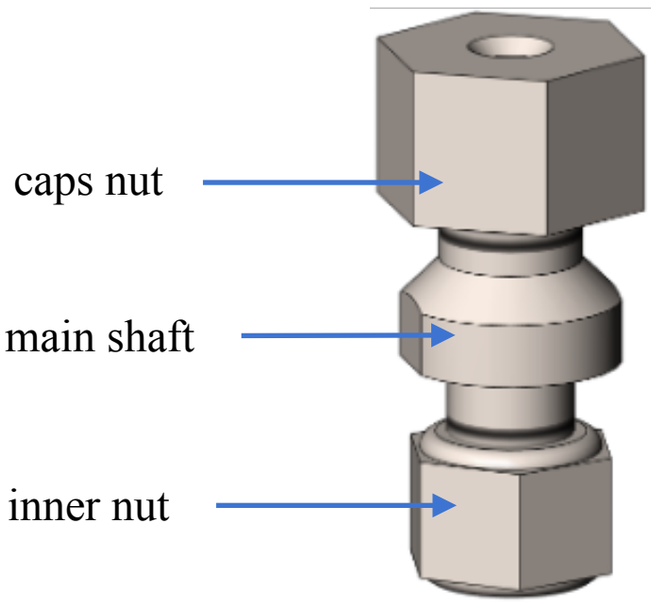
Part 1 : attaching penetrator system and pulling cable

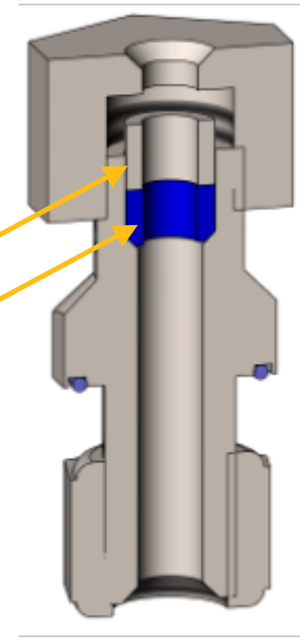
The penetrator system:

- It allows the HV/Signal cable in the housing
- Ensures water-tightness









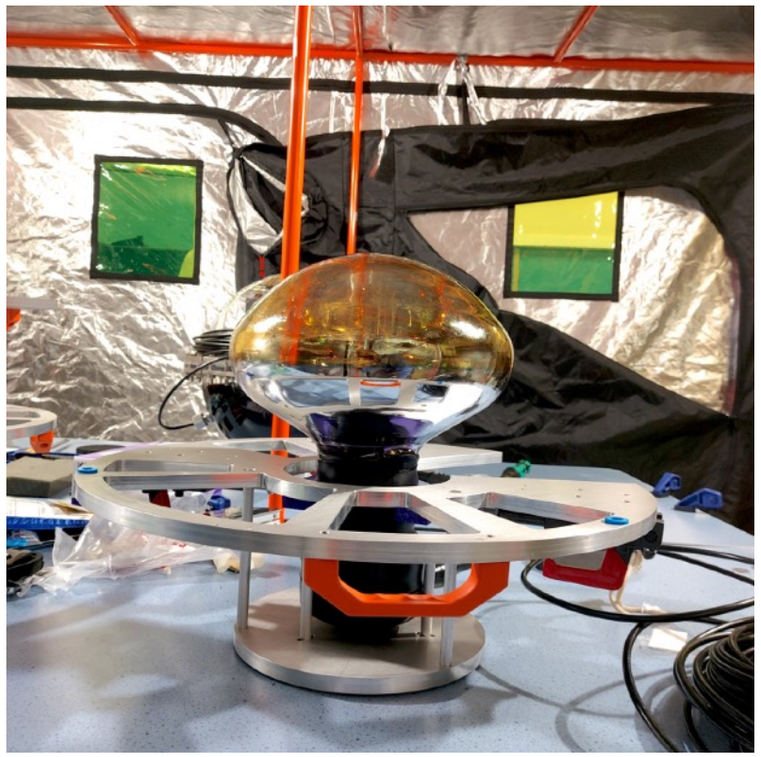
1. The penetrator shaft goes through the hole
2. With the inner nut (and an O-ring) it tightly fixed on the back half
3. The PMT cable goes through the penetrator (cable pulling)
4. The blue seal, metal ferrule, and caps nut come through the cable from outside
5. The caps nut is tightened after the two halves are enclosed

- All the penetrator parts are electropolished
- All parts of the penetrator are enclosed with a measured torque

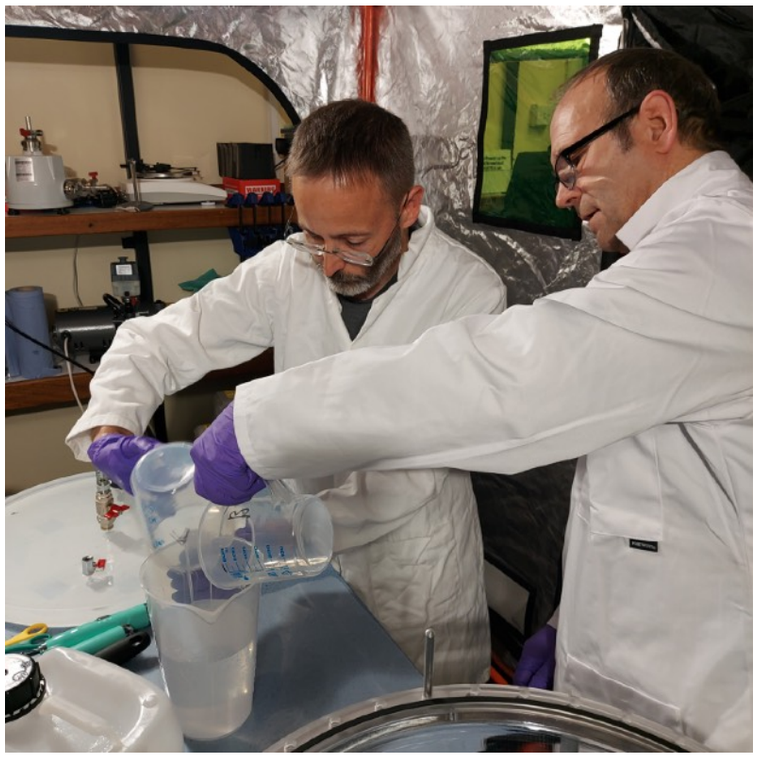
Building the Optical Detector Modules for BUTTON

Part 2 : the modular assembly of the housing

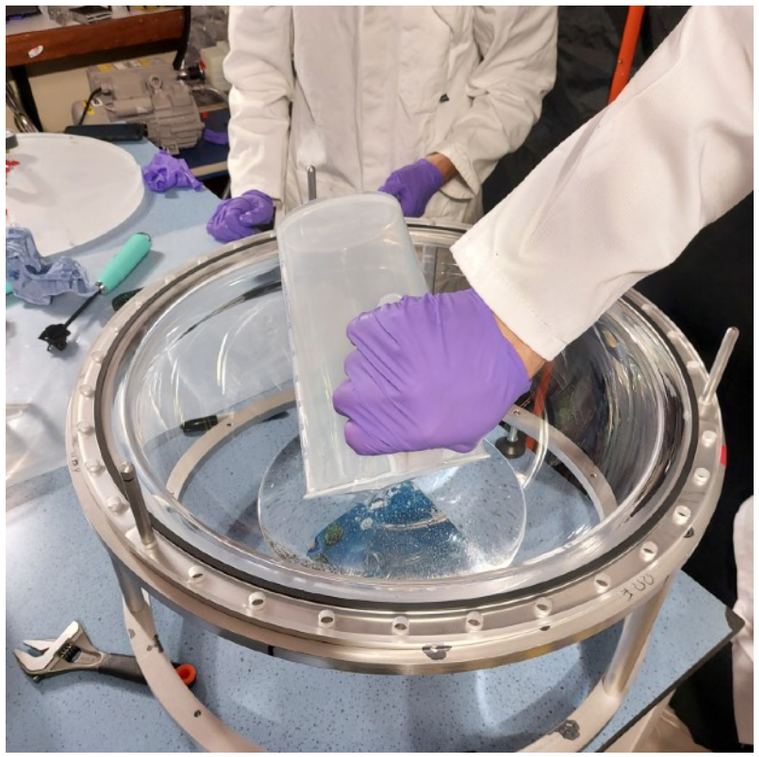
Degassing optical gel:



- The PMT is on the rig-mount
- The back-half is under the table



- Gel-A and gel-B poured separately
- 650 ml each
- They're mixed well (3-4 min)

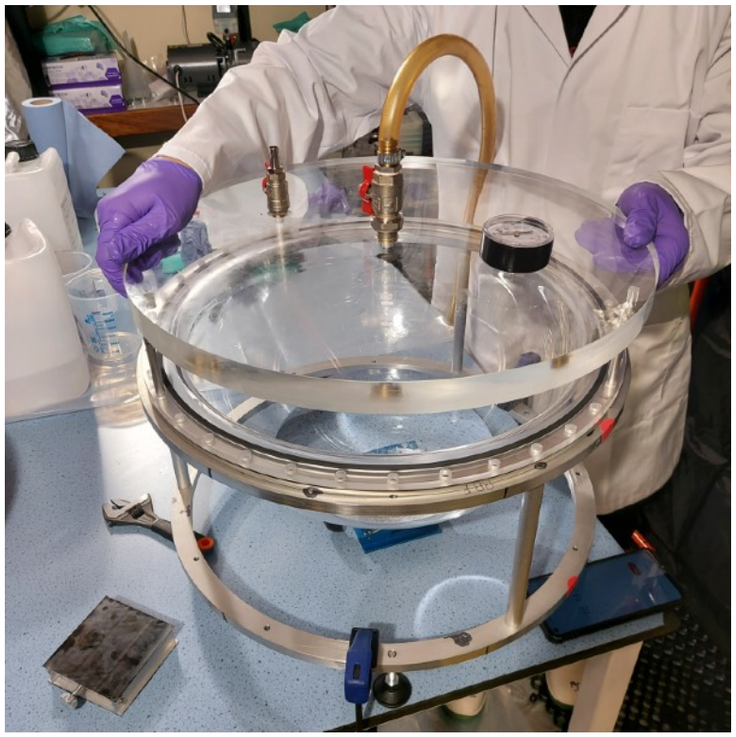


- The front-half is mounted on a rig
- The mixed gel is poured over

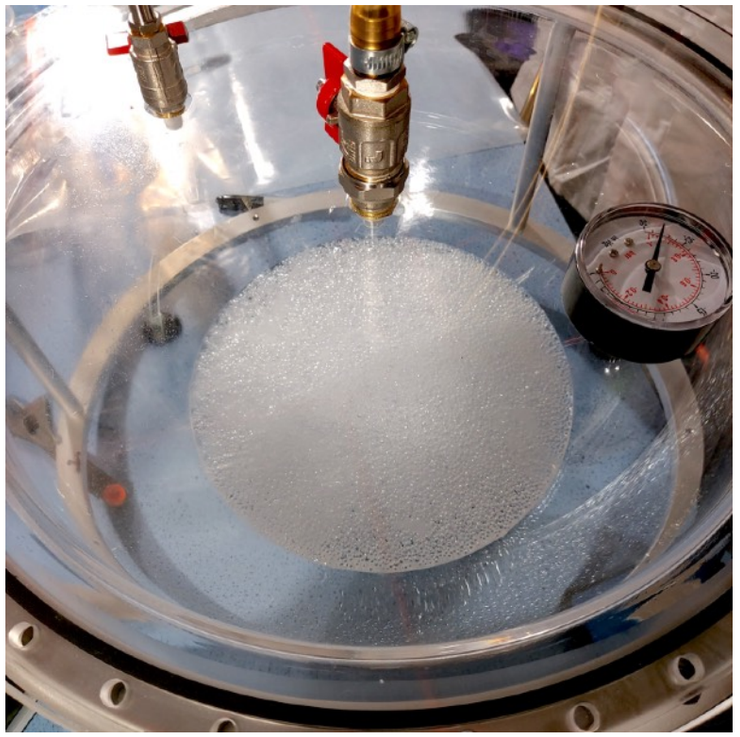
Building the Optical Detector Modules for BUTTON

Part 2 : the modular assembly of the housing

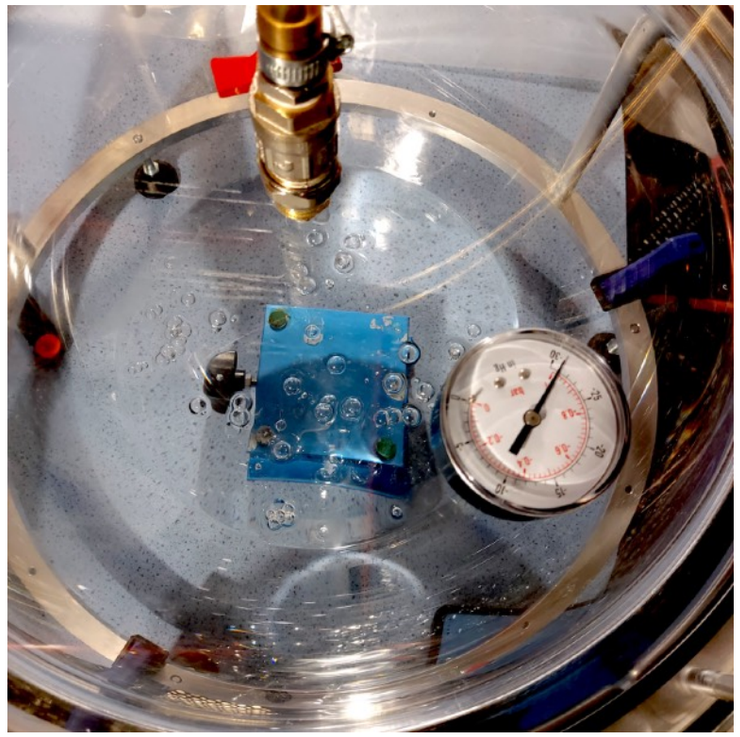
Degassing optical gel:



- Vacuum sealed (O-ring+acrylic lid)

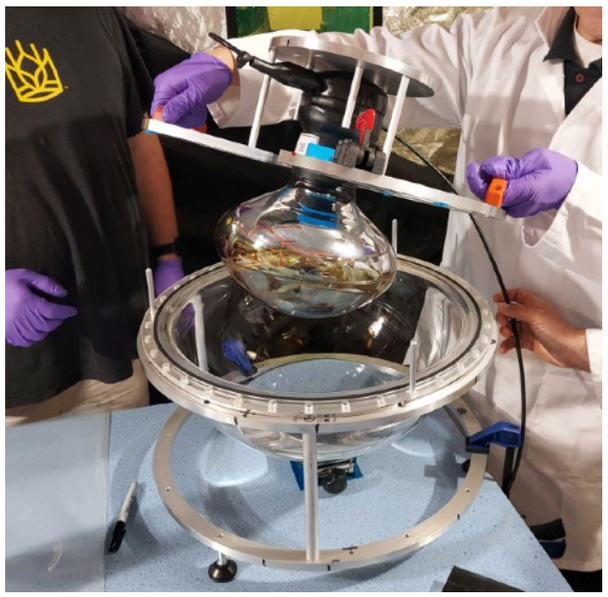


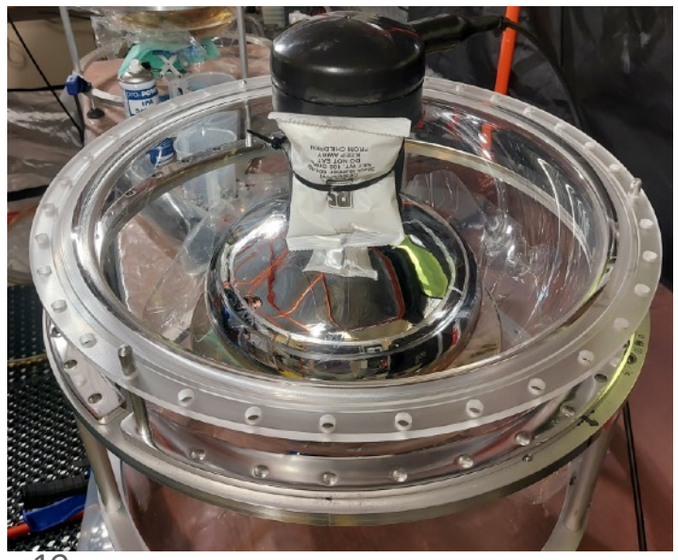
- Boiled at -1 bar for 15 min



- Bubbling slows down after 15 min

- The PMT goes in the gel





- gel is cured after 24 hours
- rig is removed
- gel can hold the PMT

Building the Optical Detector Modules for BUTTON

Part 2 : the modular assembly of the housing

Enclosing the two halves and sealing it water-tight

- A desiccator pouch is attached to the PMT
- A label is attached on the back-half collar
- Two halves are assembled with 2x3 washer plates
- Nuts and bolts are attached with according to PMT position in PSUP
- Housing is taken out of the rigs carefully (lab jack)

- Rest of the nut-bolts are attached
- They are torqued in 4 steps: 4.5 Nm, 6 Nm (3 times)
- A special cyclical pattern is followed to evenly apply the torque
- A 3-D printed template with numbers is used
- The penetrator nut is toured with 15 Nm

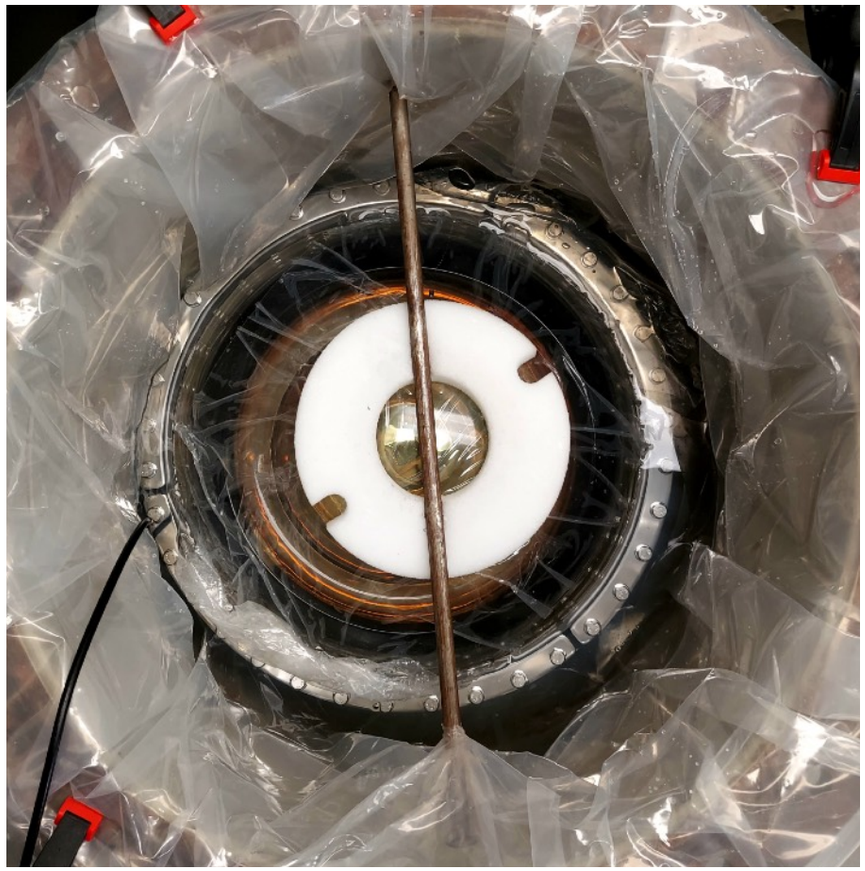
Building the Optical Detector Modules for BUTTON

Part 2 : QA/QC - Water-tightness

QA/QC: water-tightness

Freddie: The pressure tank

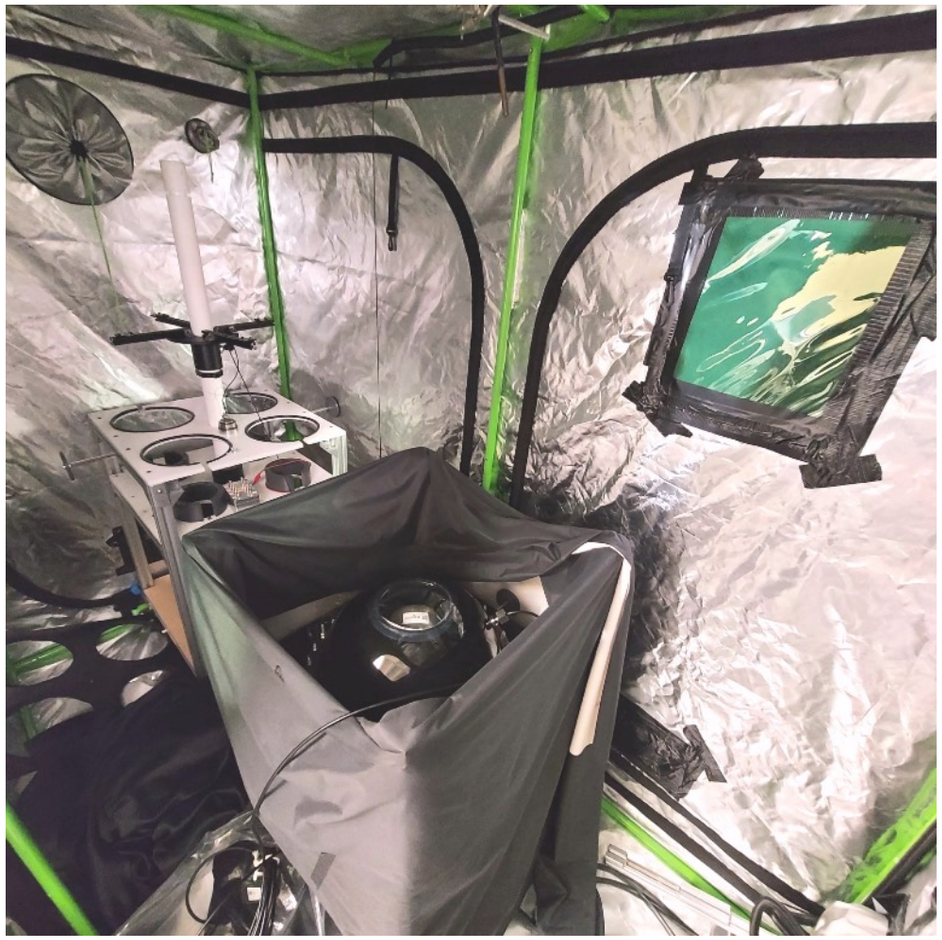
- after torquing is done,
- the housing is dunked in a DI water filled tank (Freddie)
- after 20-30 min, if no leak is observed, it is qualified as water-tight



Building the Optical Detector Modules for BUTTON

Part 2 : QA/QC - Electrical and Optical tests

QA/QC: HV response and dark count



- An SHV connector is connected to dot the bare cable
- It is then placed inside a dark tent
- Nominal HV is applied
- HV and current is monitored for 20-30 min
- HV and current are recorded
- Dark noise is measured by counting the pulses on a fast Oscilloscope at constant threshold (typically -10 mV)

The electrical test is qualified if:

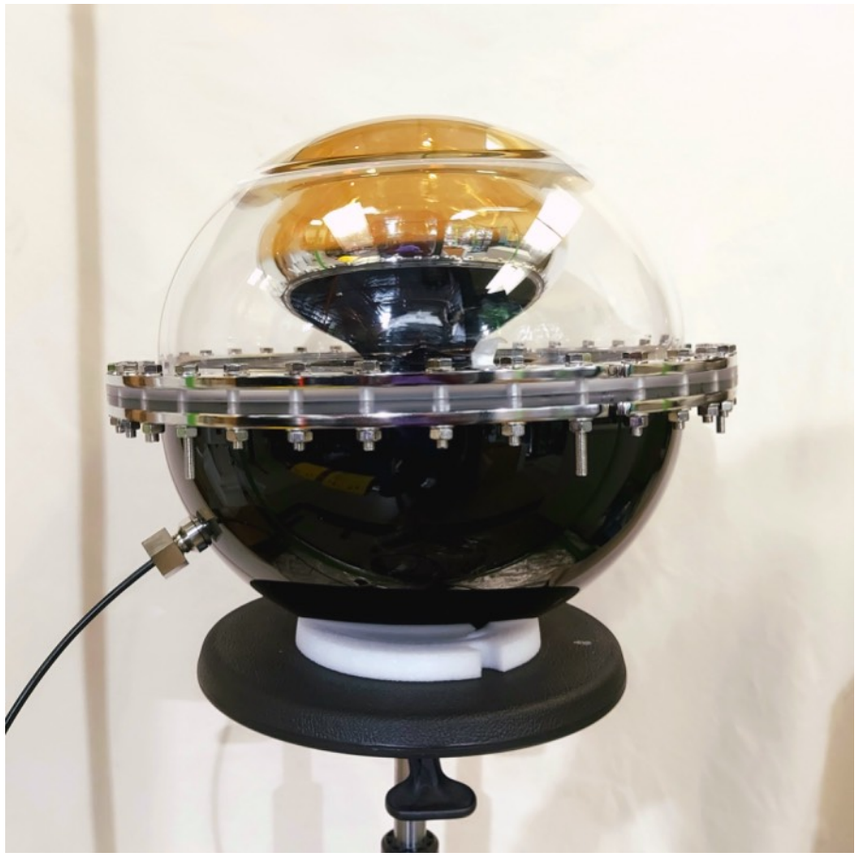
- Nominal HV is reached,
- Current matches previous measurement
- Dark count is within specifications

Building the Optical Detector Modules for BUTTON

Part 3 : preparing the module for transport to Boulby

Bagging, boxing, and sealing

At the final stage



- Torquing of all the the nut-bolts to recheck
- The PMT is thoroughly cleaned /air-blown
- Then placed in a bag and labeled
- The bag goes in a box which is labeled again
- Air-foam cushion bag applied to ensure extra protection
- Another plastic wrapping on the box for dust (splash) protection

We are building

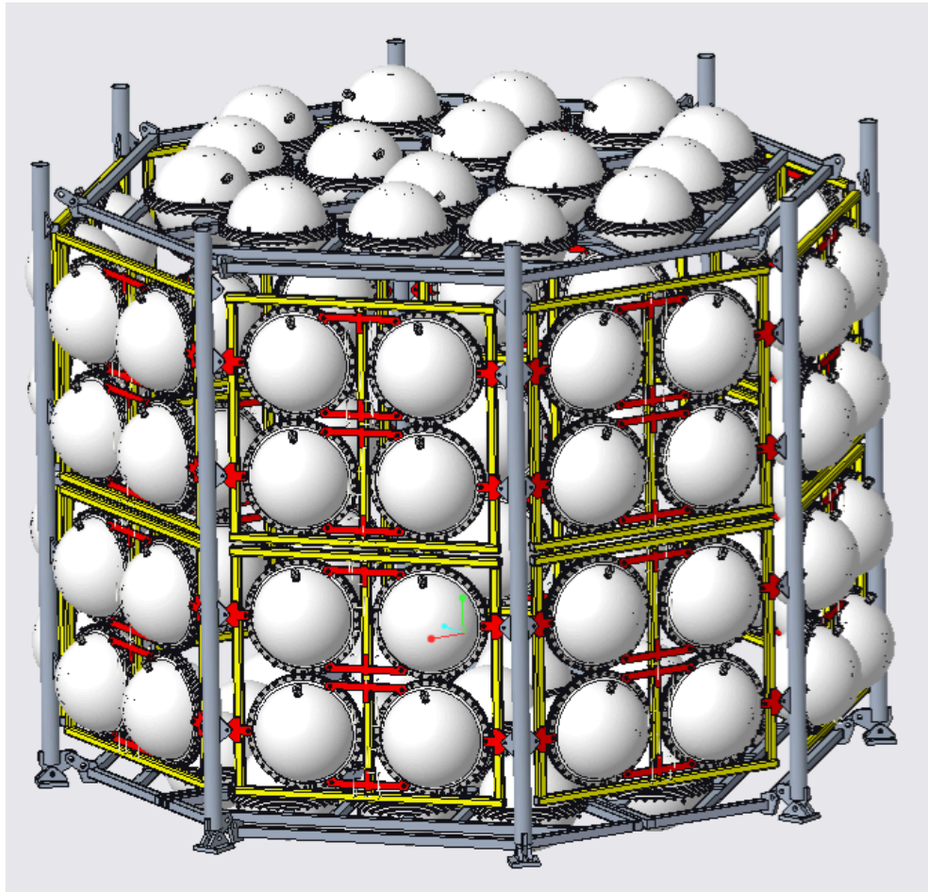
12 modules per week

PMT Support (PSUP):

- Octagonal structure with 2 frames on each side
- 4 Optical Detector Modules (ODM) on each side/radial frames
- Total 64 ODM on the sides

- 3 more frames on top 16 ODM
- 3 more frames on the bottom with another 16 ODM

- Total 96 ODM inside the tank



Some technical challenges

- 316L Stainless Steel for the frames - robust against rusting
- 316LMn Weld filler - robust agains corrosion, non-magnetic
- Radiopurity - number of batches of material is minimised
- Maintaining tolerance over series production
- Leak test done by submerging the frame
- All wetted components will be electropolished

Conclusions:

1. The 30 tonne BUTTON will test
    - classical and novel detection media: Water, LS, WbLS, Gd-loading
    - PMT and advanced photosensors like LAPPD
    - to demonstrate future (kilo-tonne) neutrino detector for physics and applications
2. Onsite tank installation is nearly complete
3. Other subsystems are on the way
4. 50% of the Optical Detector Modules are ready. To be shipped to Boulby soon.
5. Installation is expected to start at the end of the year
6. Commissioning and data taking in early 2025!

The BUTTON Collaboration

We are around 50 people from 13 Institutions/Universities:

University of Edinburgh
University of Glasgow
University of Liverpool
University of Sheffield
University of Warwick
AWE
STFC
BNL
LLNL
PNNL
UC-Berkeley
UC-Davis
UC-Irvine

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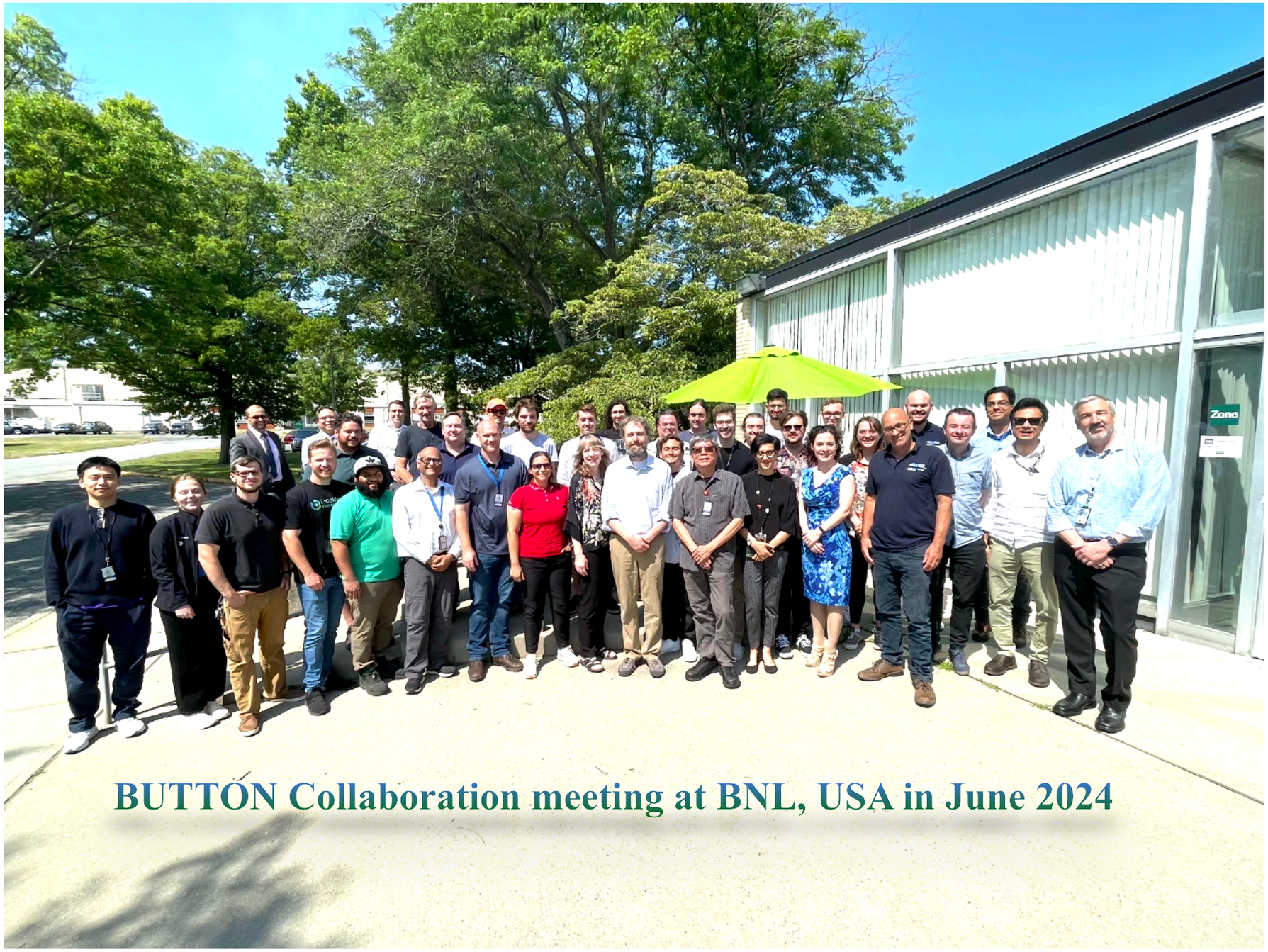

Backup slides

Painting

1. **S+P1** = 2-3 Hz with LED [465 nm, 3.2 V]
2. **S+Pr+P1** = 4-5 Hz with LED [465 nm, 3.2 V]
3. **S+P2** = 160 Hz with LED [465 nm, 3.2 V]
4. **S+Pr+P2** = 105 Hz with LED [465 nm, 3.2 V]