Underwater characterization of a BUTTON optical module

Deb Sankar Bhattacharya, Domagoj Anticic, Emma Elingwood, Matthew Needham



Detector Informal Meeting Particle Physics Experiment, 29 Oct 2026, University of Edinburgh

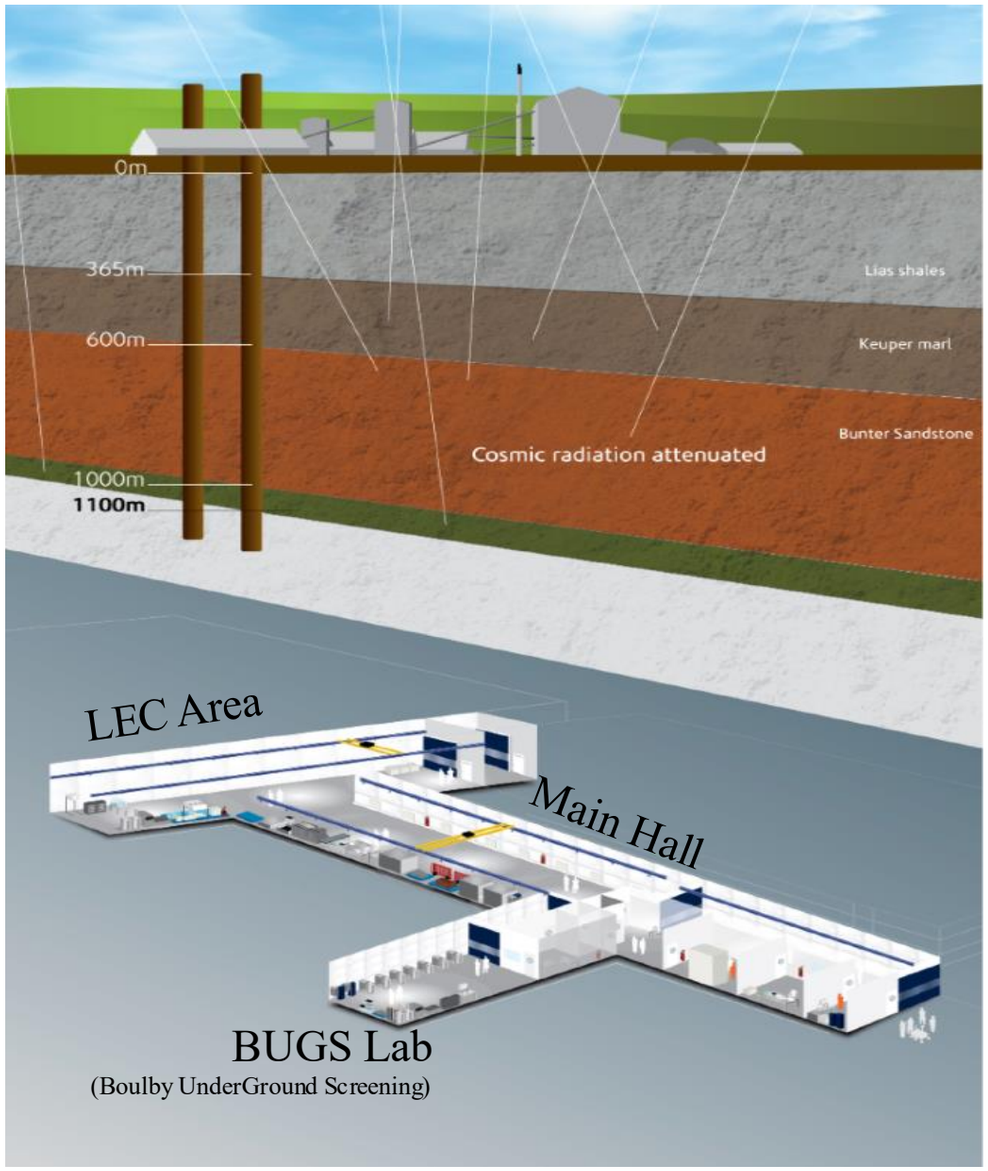
Science and Technology Facilities Council

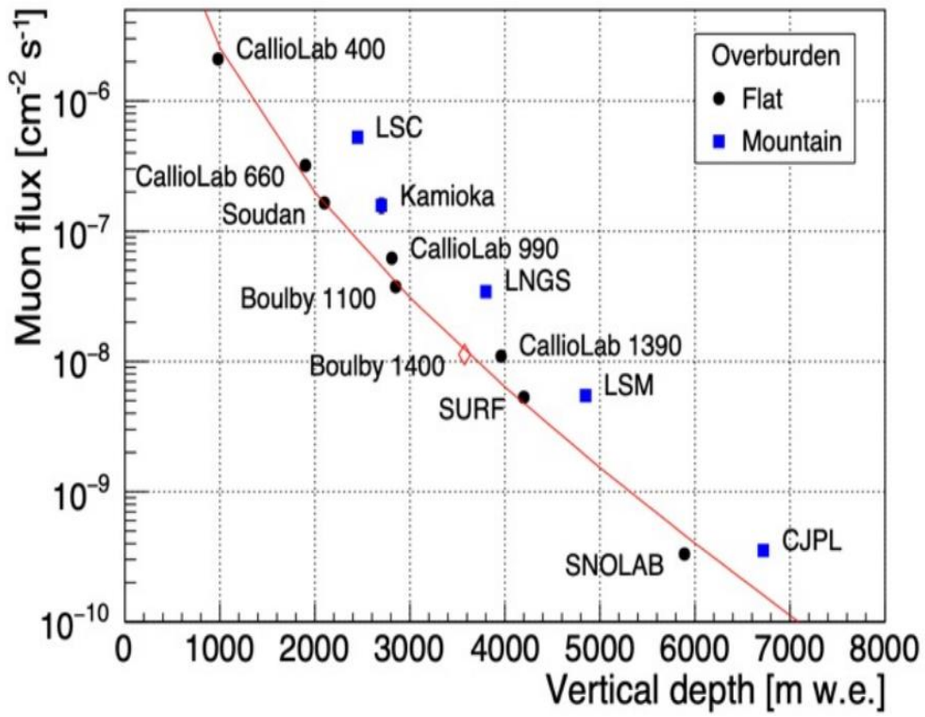
Boulby Underground Laboratory

The BUTTON-30 Experiment

Boulby Underground Laboratory (operated by STFC):

- 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

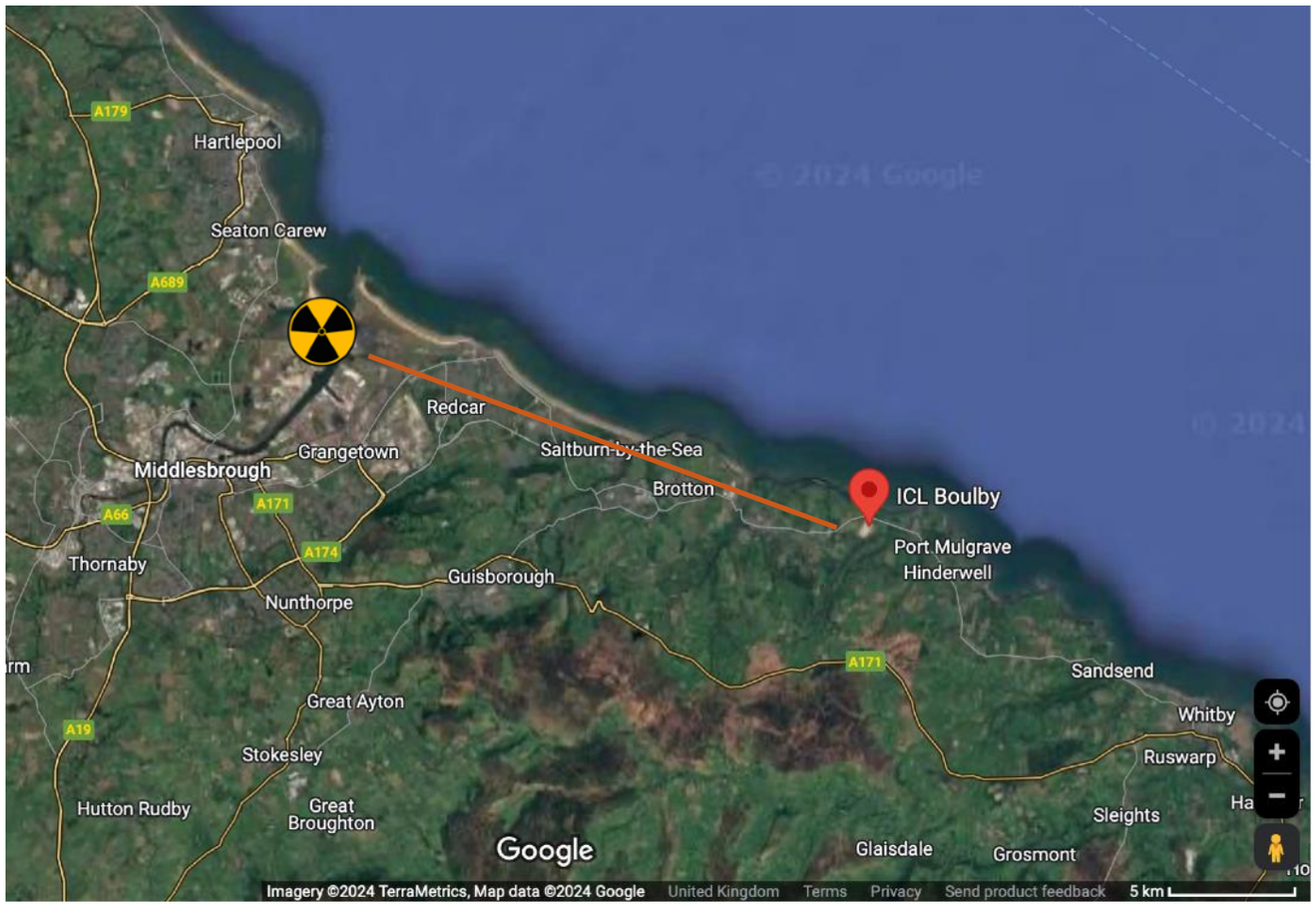
Rich near and far future plans

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

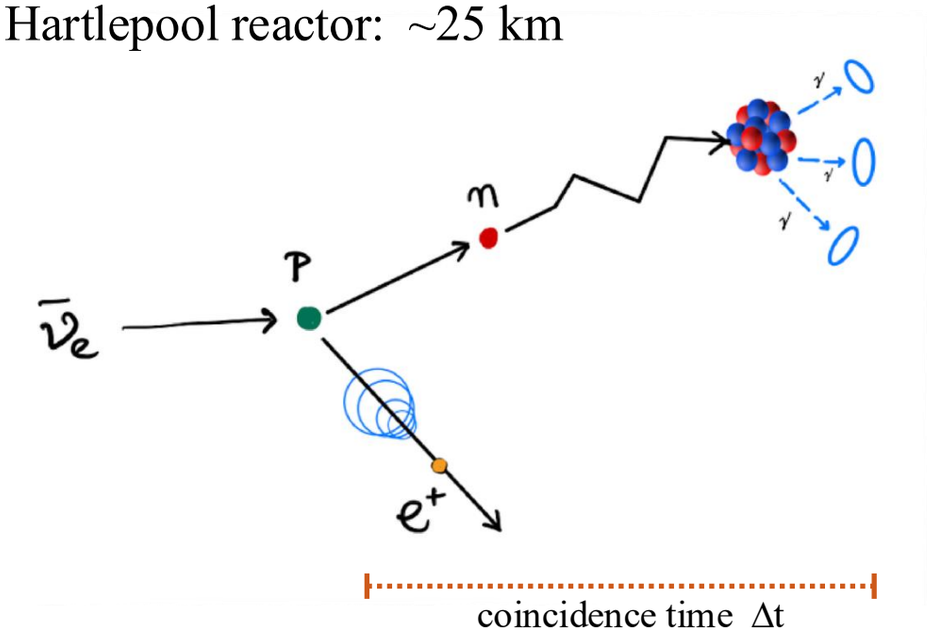
Detecting antineutrino at BUTTON

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

- Traditional 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



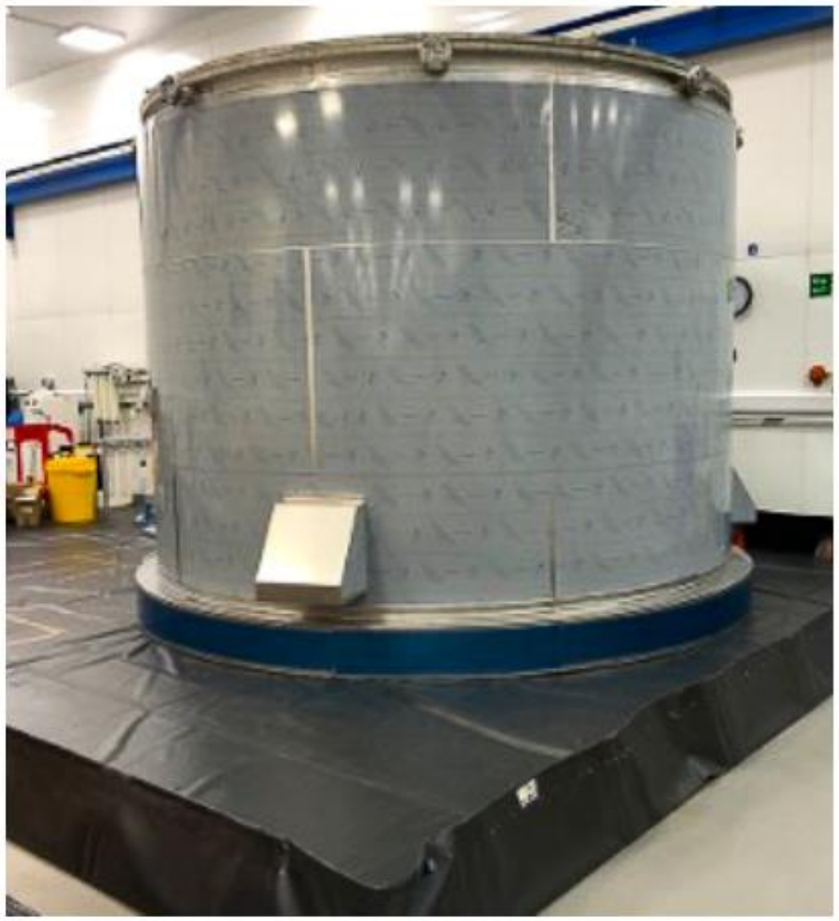
- Pure water (hydrogen) : $\Delta t = \sim 200\ \mu s$ (1-2 MeV)
- Gd-loded water: $\Delta t = \sim 20\ \mu s$ (~ 8 MeV)

- WbLS: (1) directional event reconstruction + (2) better energy resolution and low threshold

Water Tank:

- 30-tonne cylindrical tank,
- inner diameter = 3.7 m
- height = 3 m
- marine grade 316L stainless steel
- Liner material
- Water circulation system: Gd and WbLS compatible
- installation is nearly complete

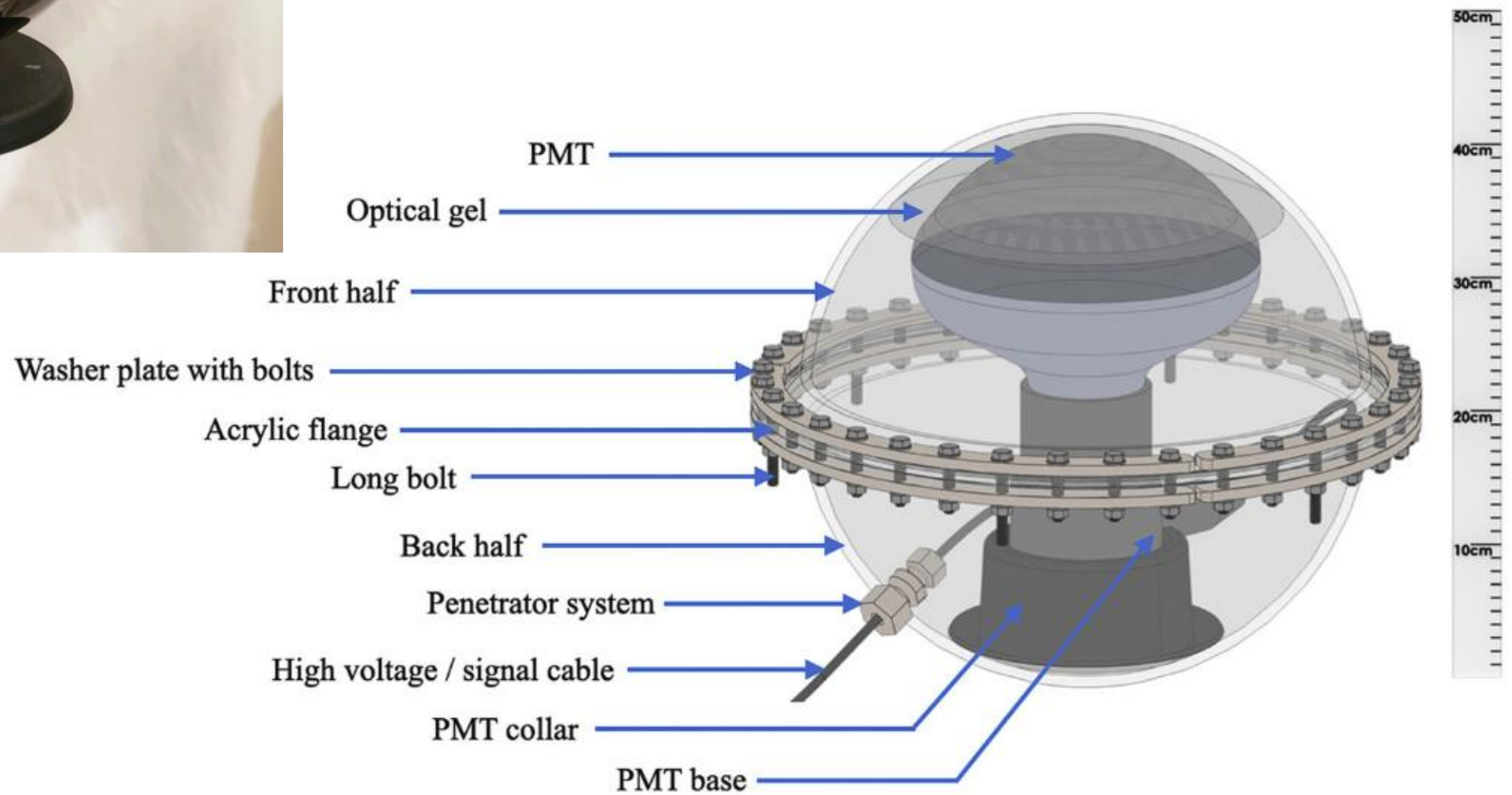




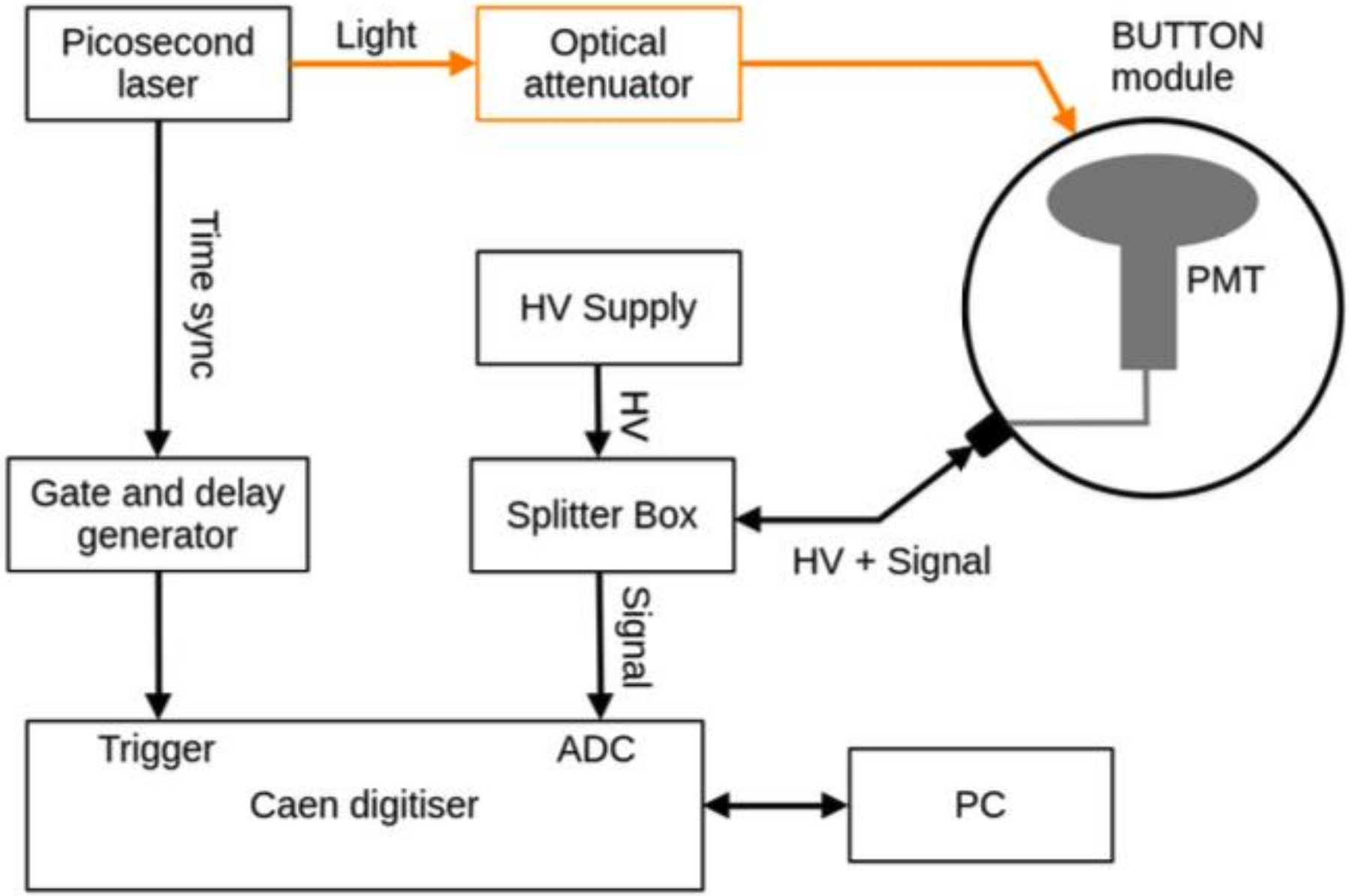


BUTTON Optical Modules for

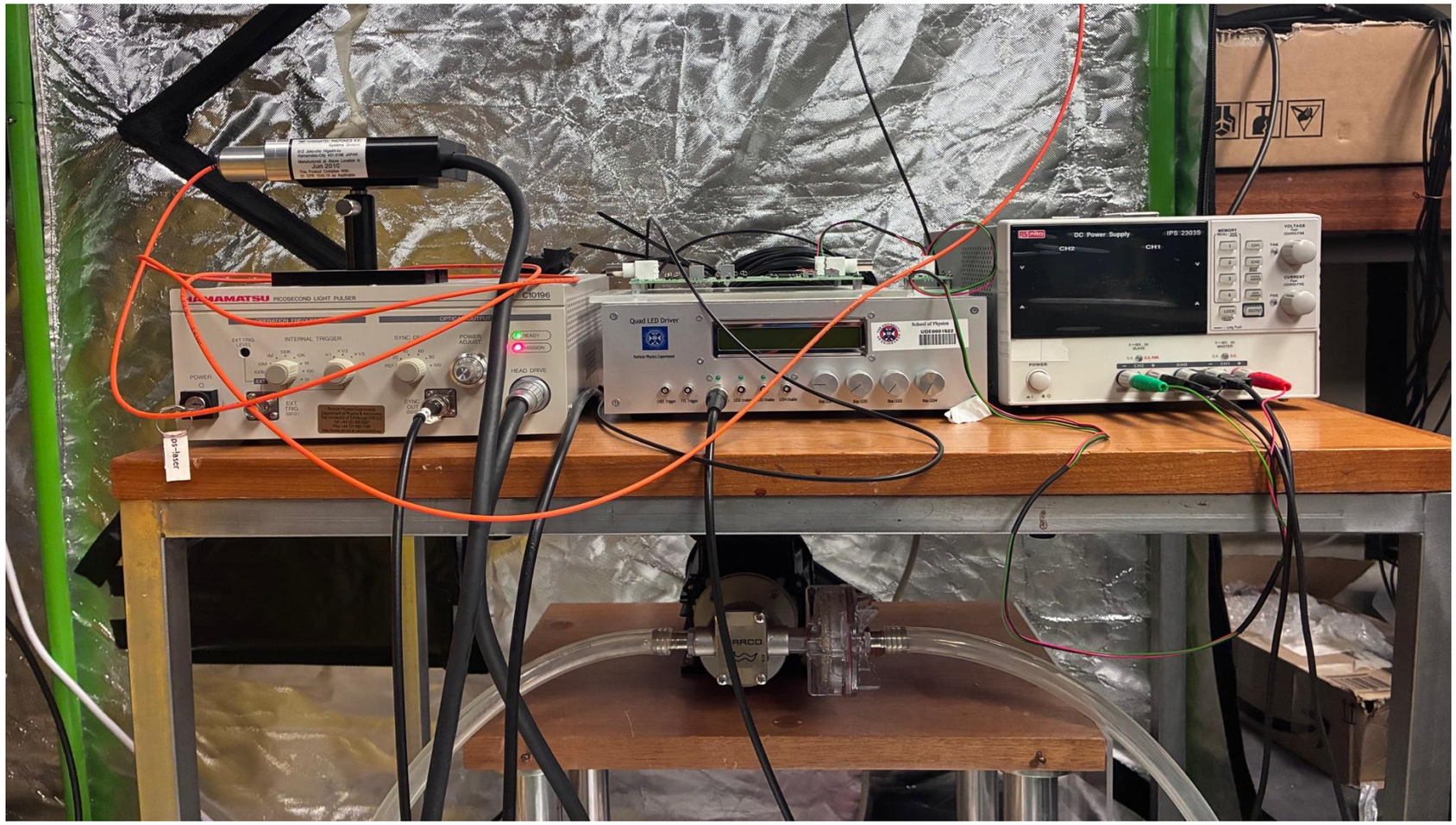




A test stand at Edinburgh



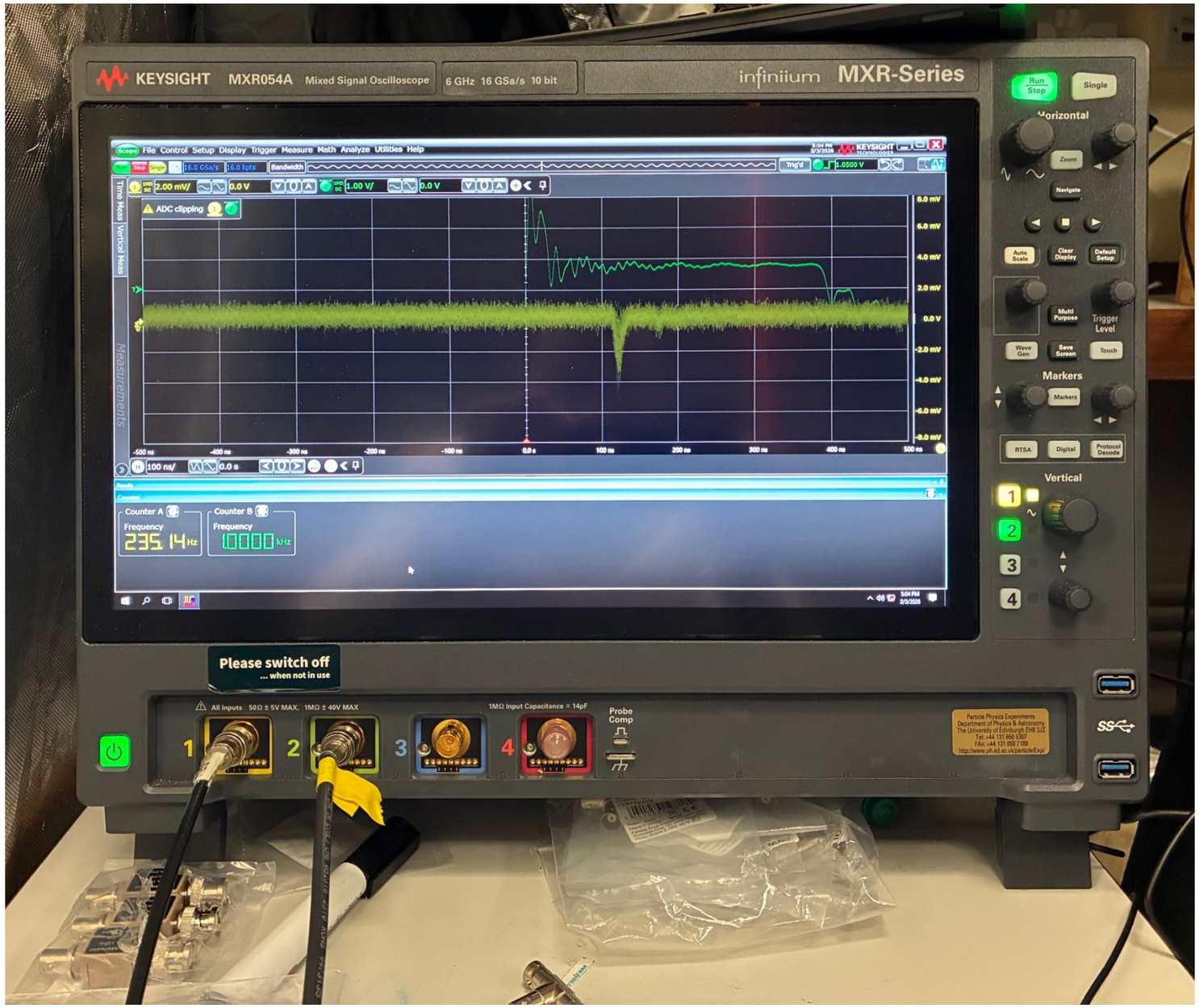
A test stand at Edinburgh



- An LED test driver (4 different frequencies: UV)
- A LV power supply for the LED driver
- A Pulser for the LED driver

- The water pump at the bottom

A test stand at Edinburgh



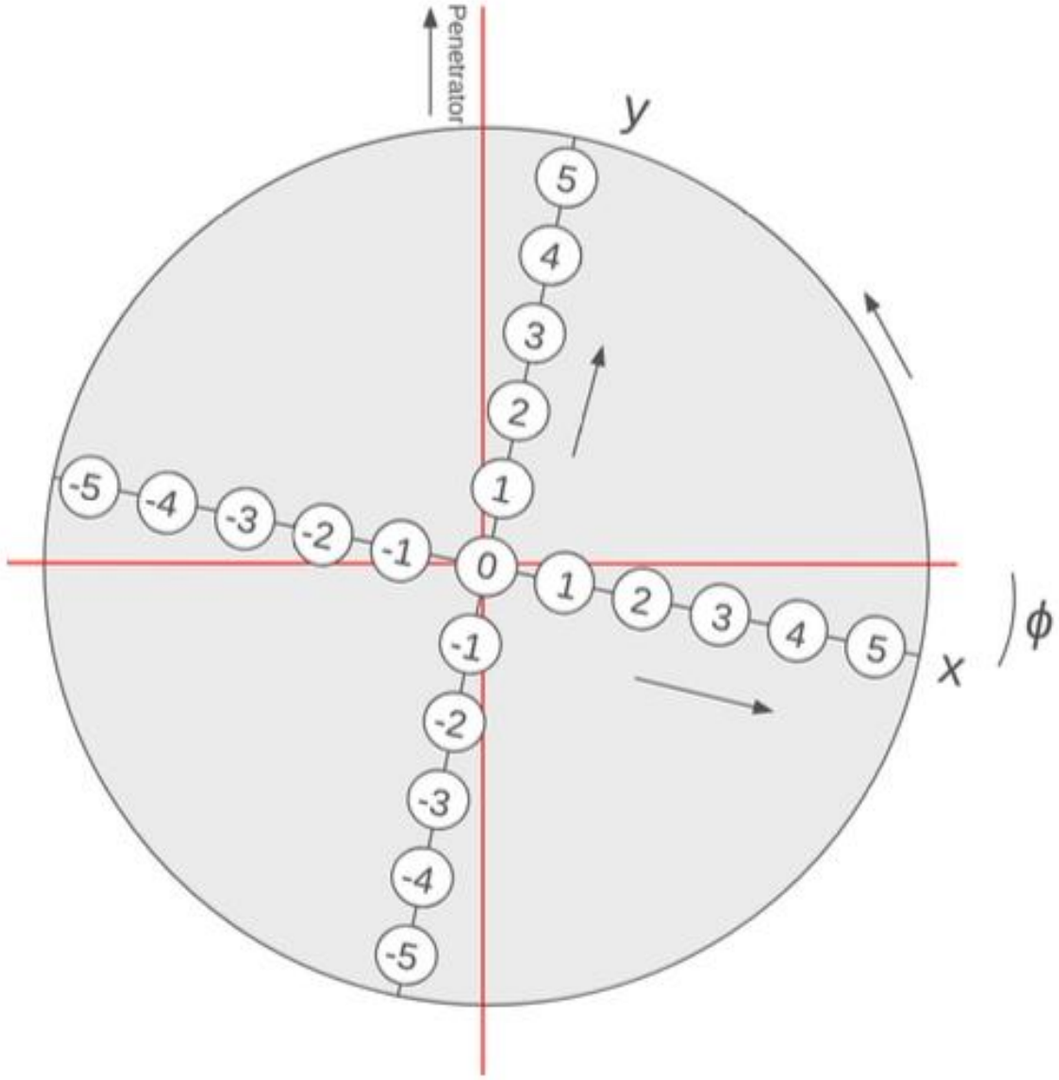
- A Keysight (MXR054A) Oscilloscope: 16 Gs/second, bandwidth newly upgraded 6 GS, 10 bit adc
- An Ortec 416 Gate & Delay Generator
- The Photo-peak is adjusted with the delay with respect to the trigger

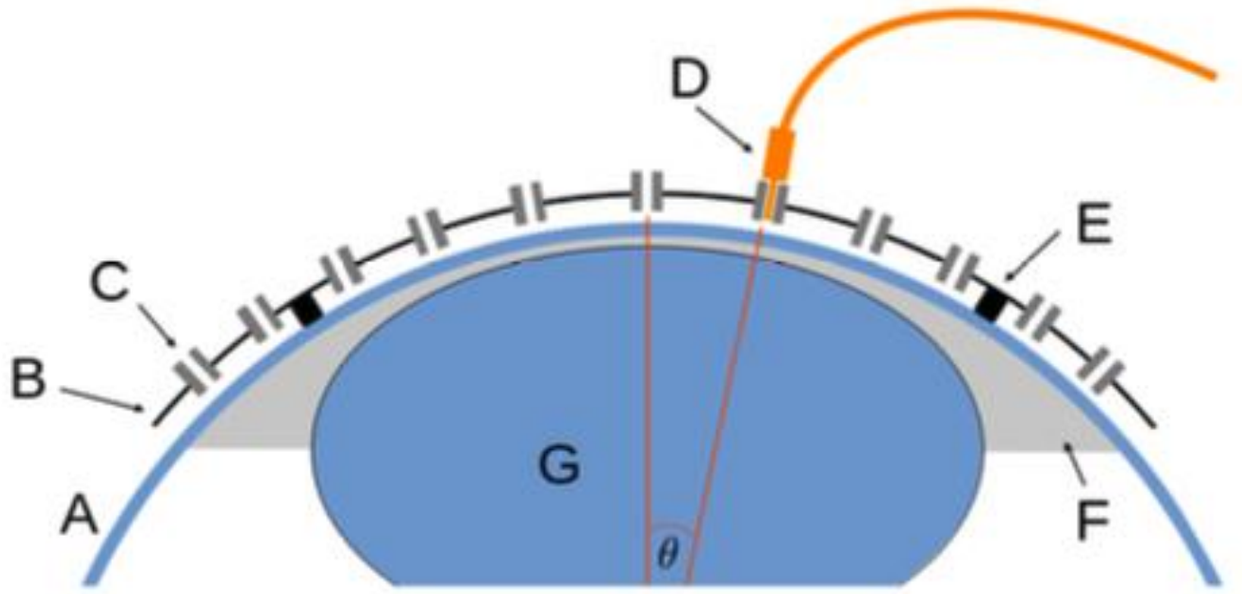
A test stand at Edinburgh



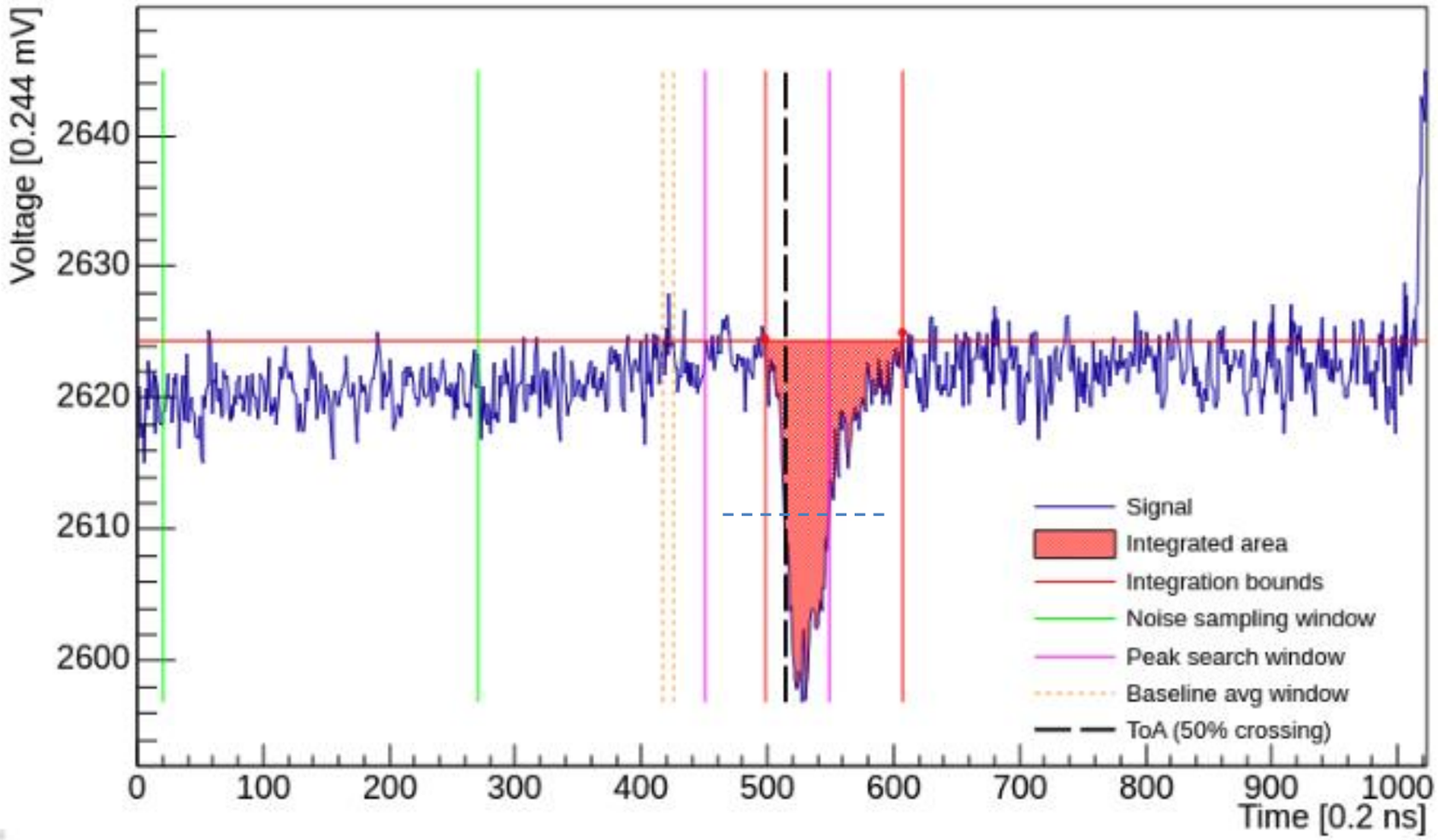
- The final acquisition is a CAEN DT5742
- DRS4 chip-based waveform digitizer
- 12 bit adc with 1 volt peak-to-peak range
- 1024 switch capacitor array => 1024 time samples
- 5 Gs/s => 200 ps width (each 1024 samples) => 204.8 ns time window per event

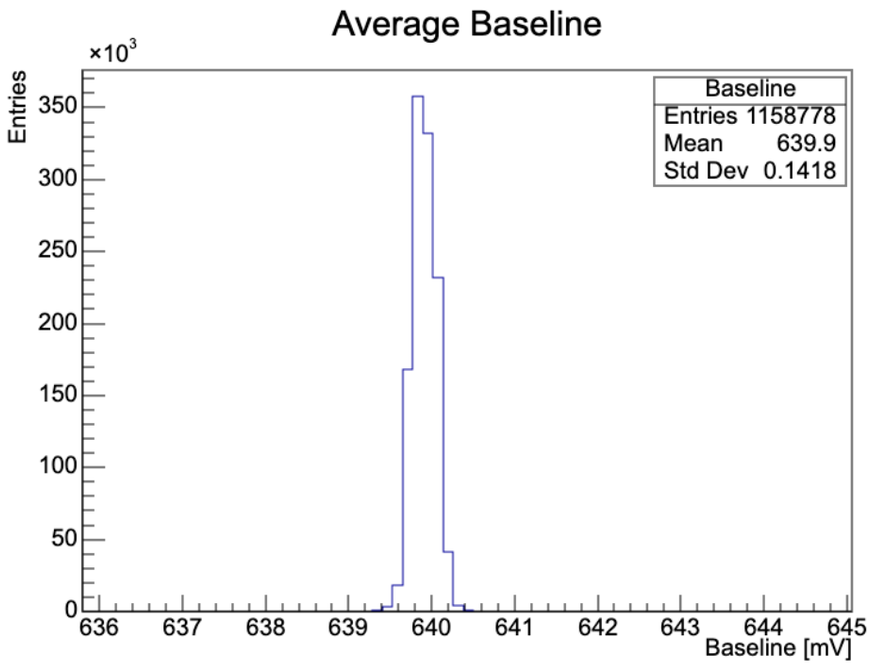
A test stand at Edinburgh

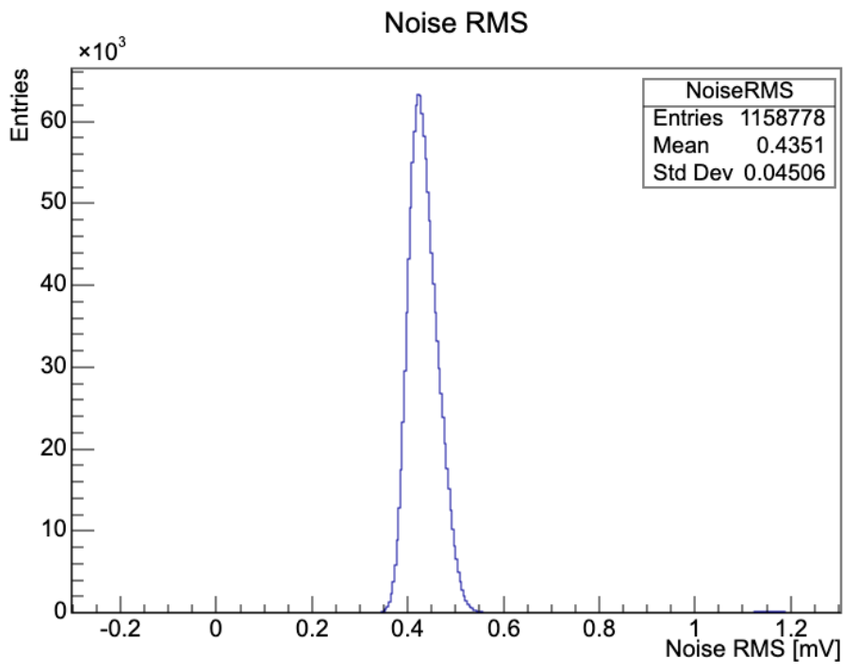




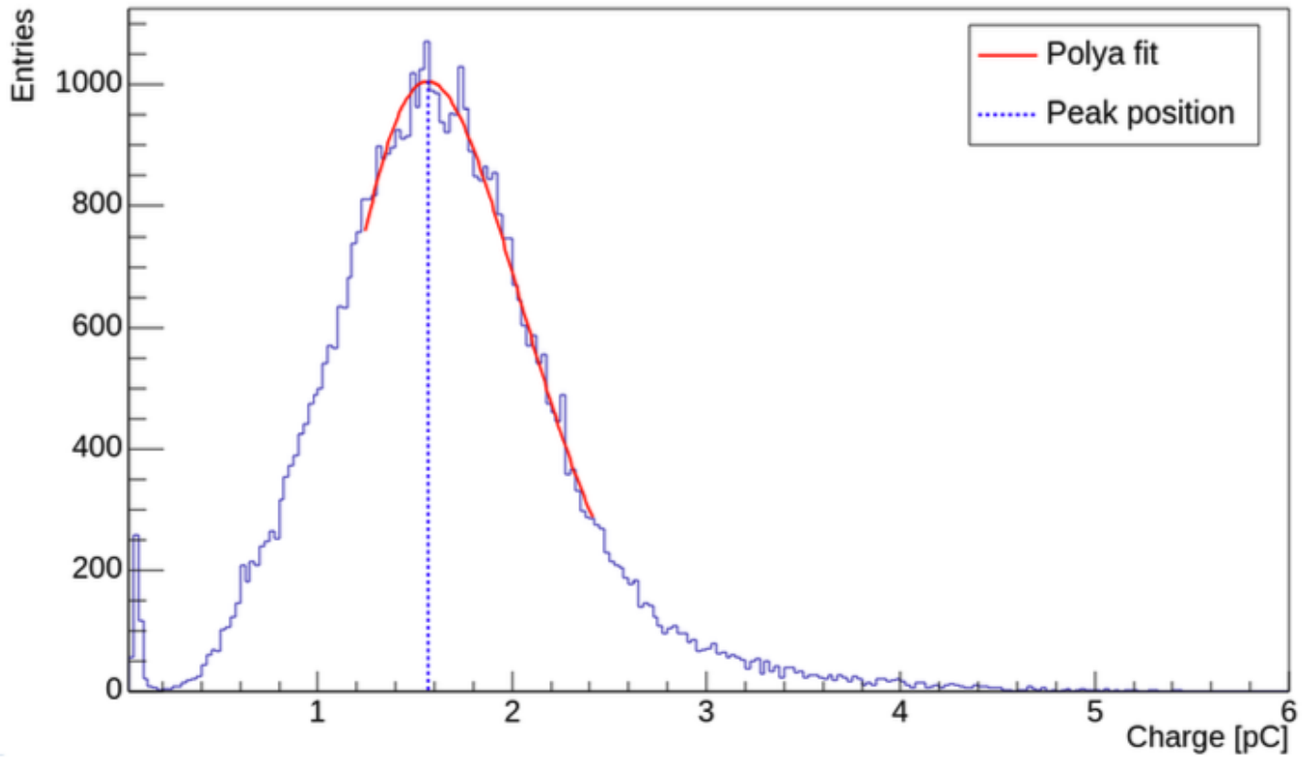
Results

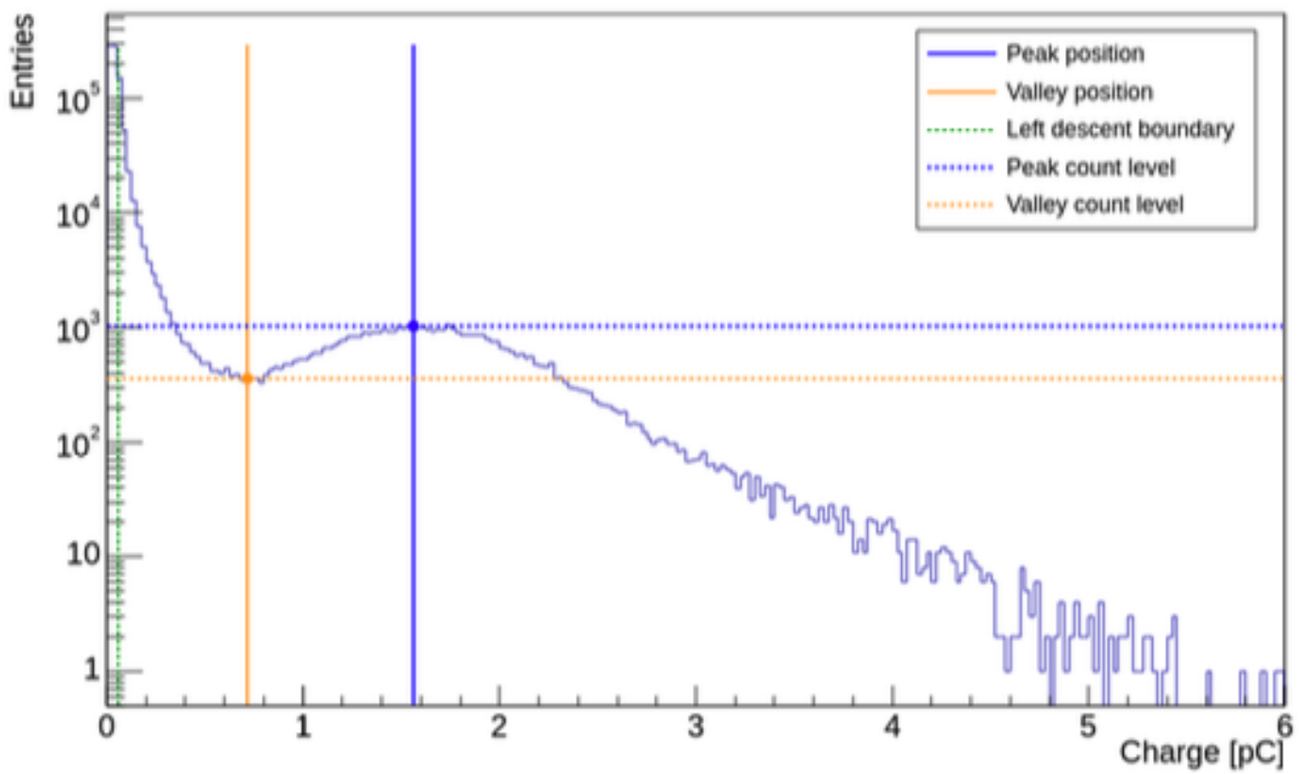

Voltage [0.244 mV]
2640
2630
2620
2610
2600
0
100
200
300
400
500
600
700
800
900
1000
Time [0.2 ns]
Signal
Integrated area
Integration bounds
Noise sampling window
Peak search window
Baseline avg window
ToA (50% crossing)


Average Baseline
×10^3
Entries
Baseline
Entries 1158778
Mean 639.9
Std Dev 0.1418
Baseline [mV]

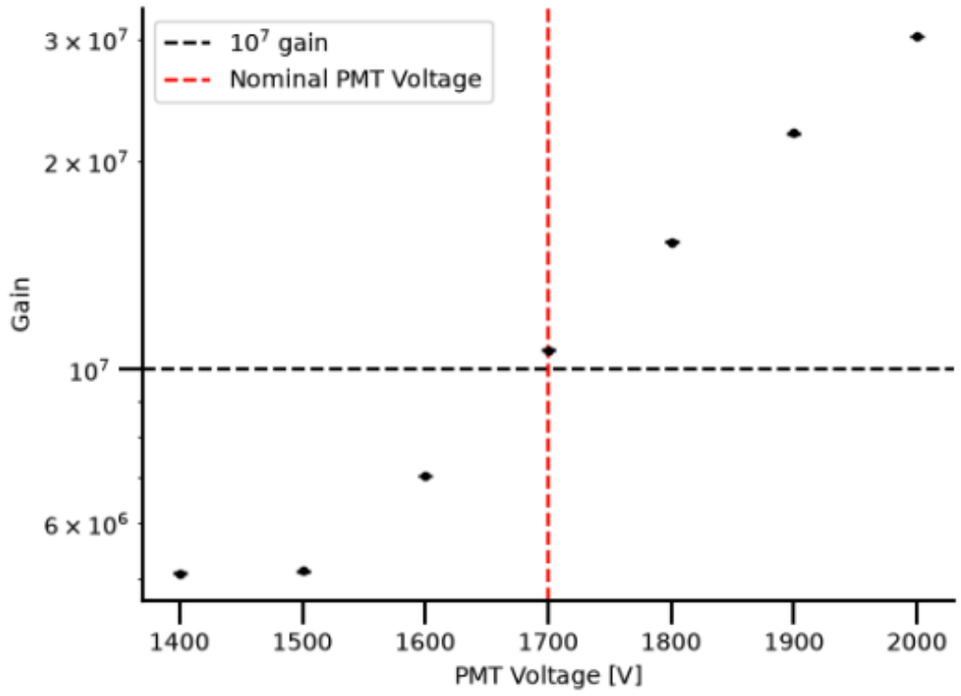

Noise RMS
×10^3
Entries
NoiseRMS
Entries 1158778
Mean 0.4351
Std Dev 0.04506
Noise RMS [mV]

Results

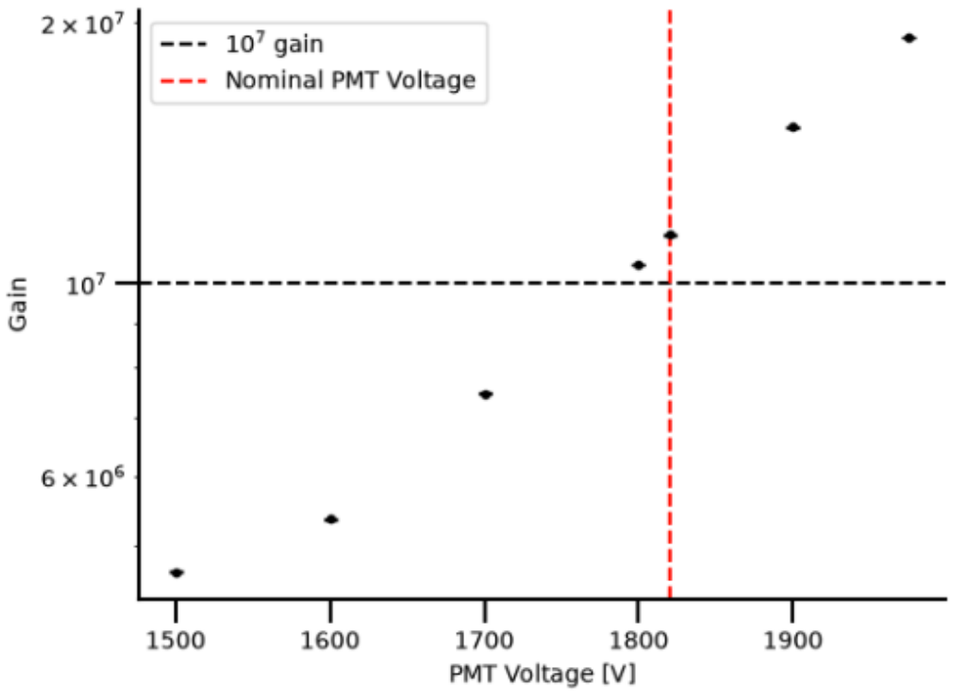

Entries
1000
800
600
400
200
0
1
2
3
4
5
6
Charge [pC]
Polya fit
Peak position


Entries
10^5
10^4
10^3
10^2
10
1
0
1
2
3
4
5
6
Charge [pC]
Peak position
Valley position
Left descent boundary
Peak count level
Valley count level

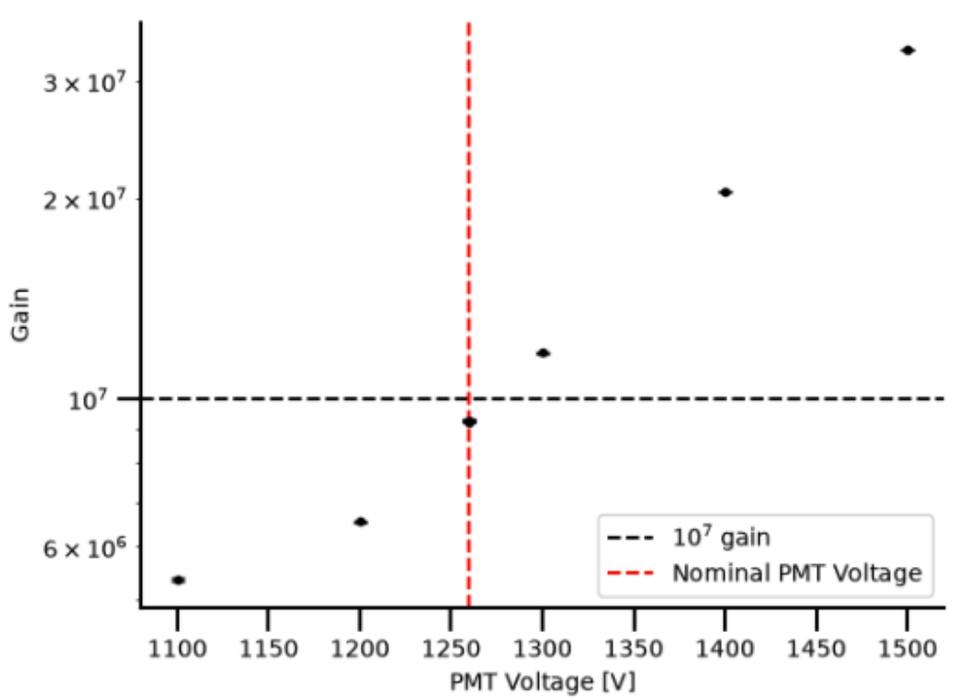
Results



(a) PMT39

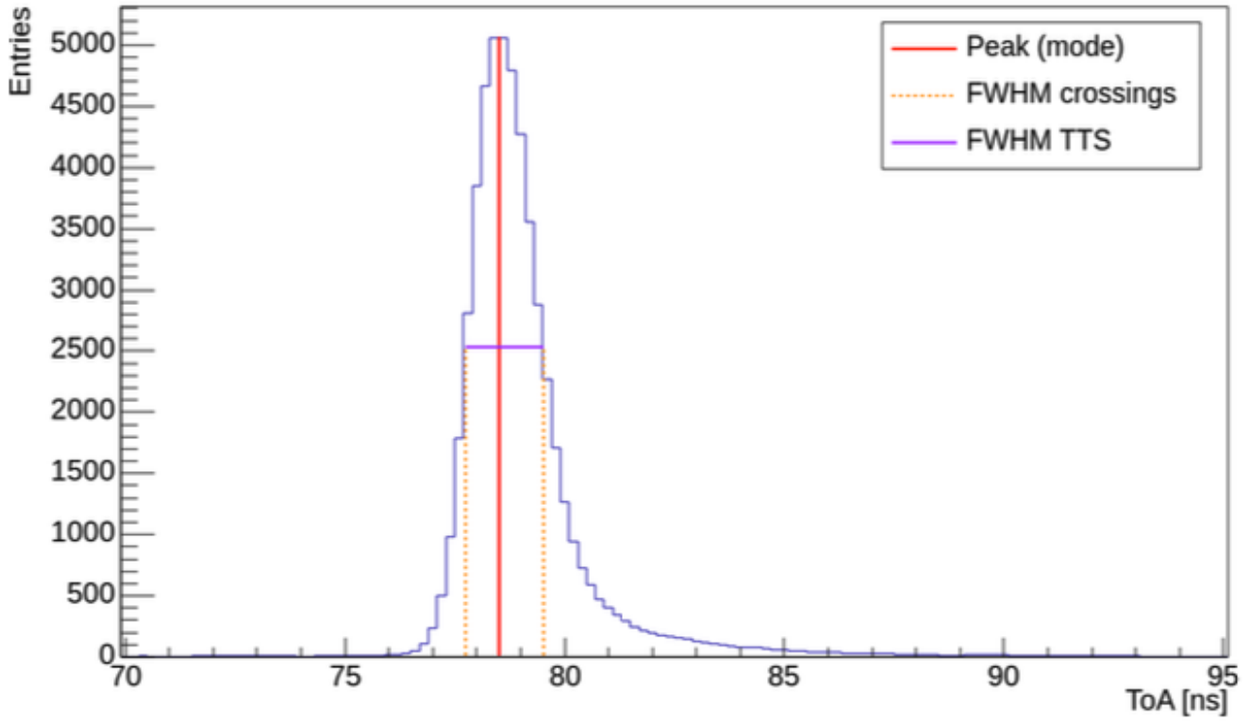


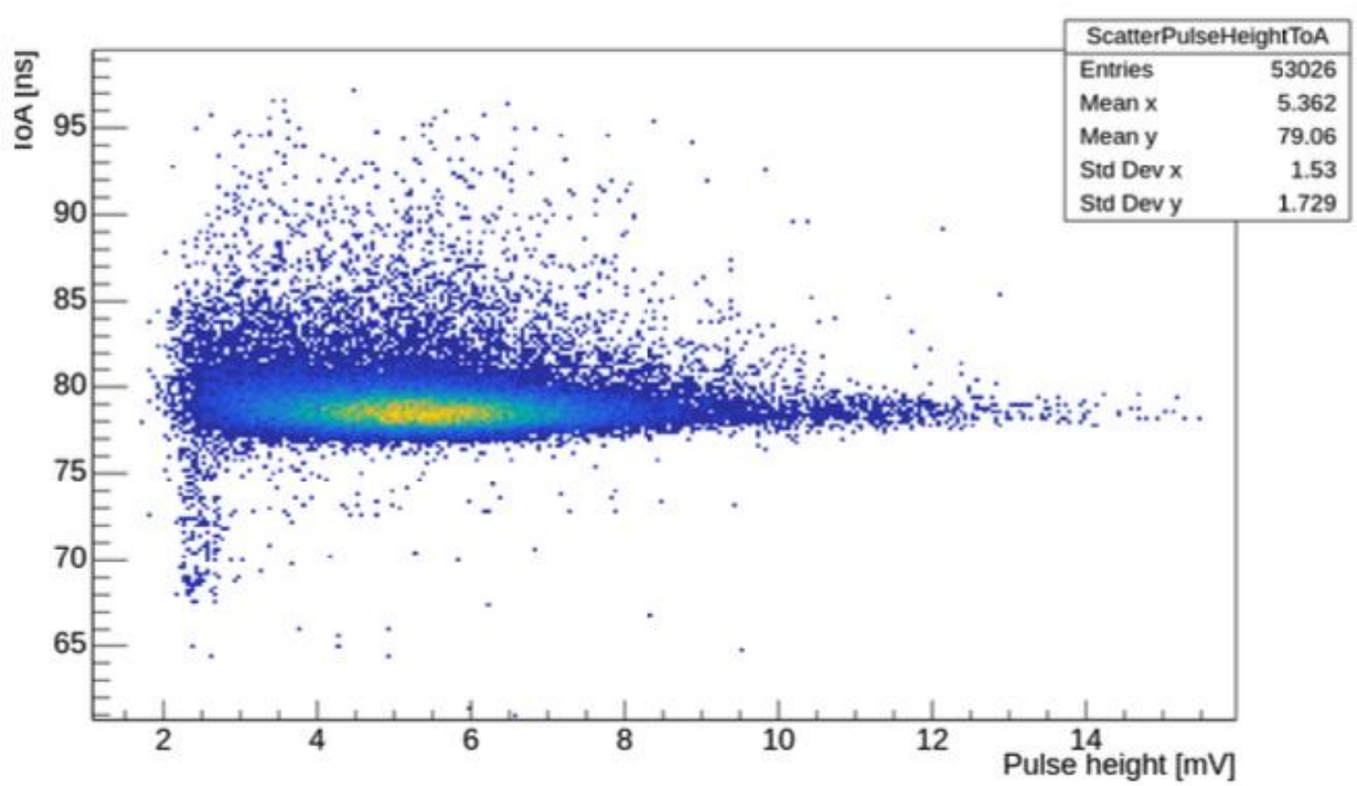
(b) PMT99



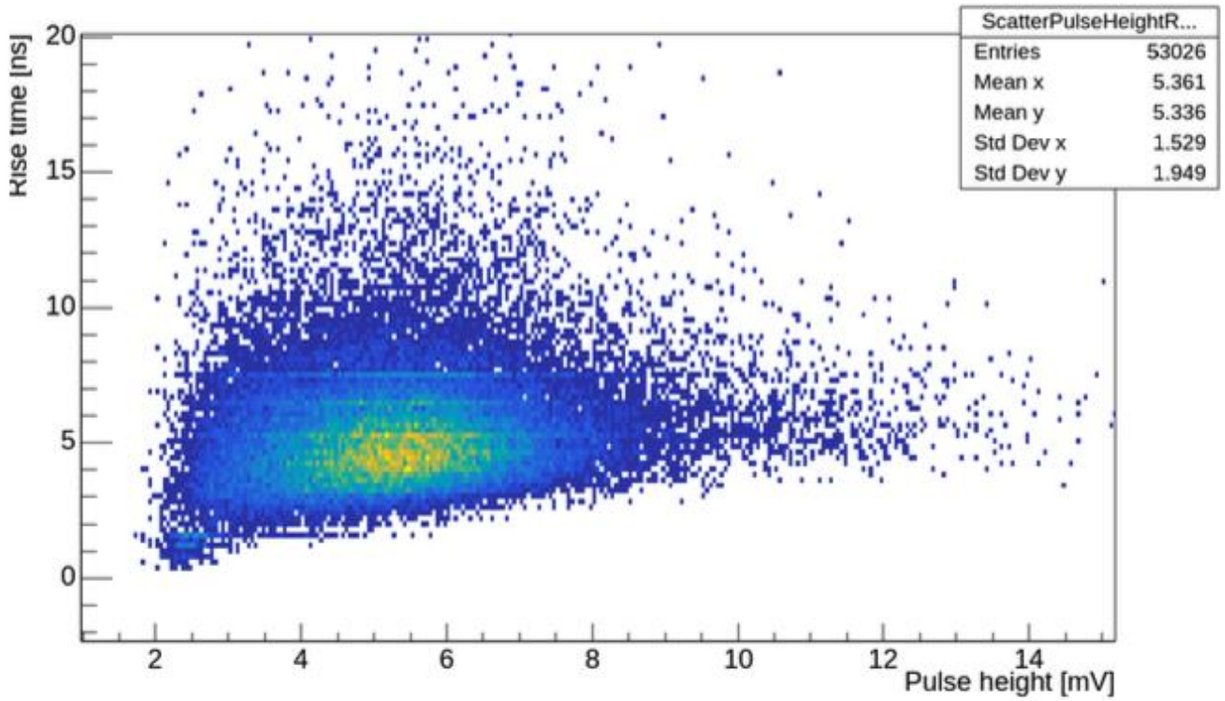
(c) PMT158

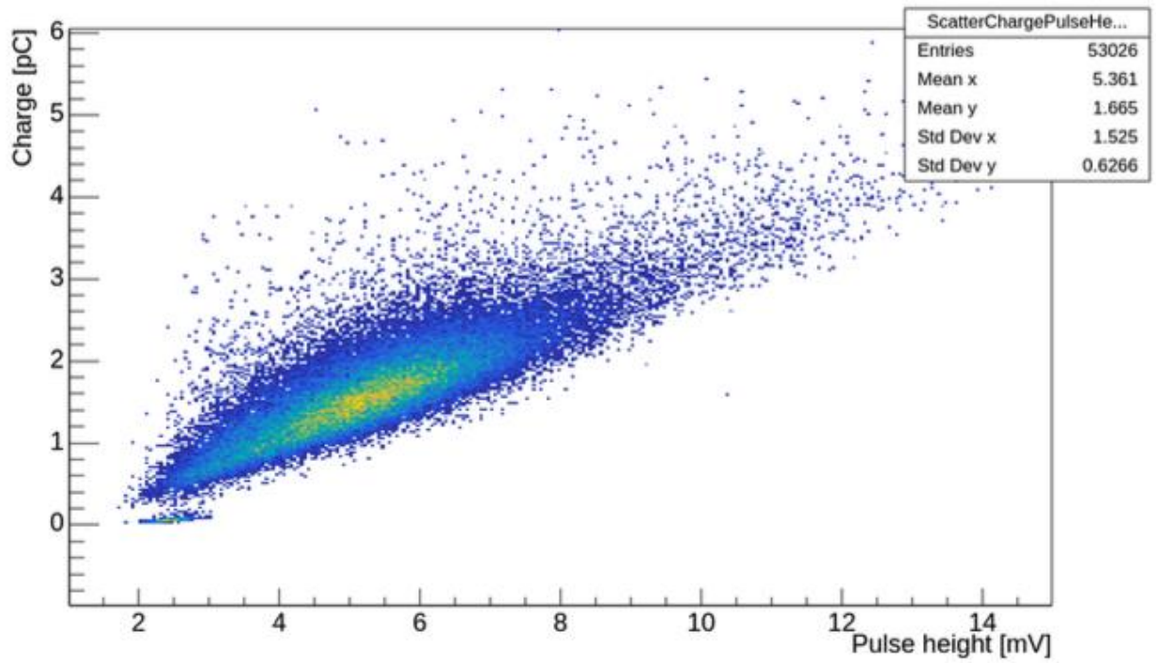
Results


Entries
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
70
75
80
85
90
95
ToA [ns]
Peak (mode)
FWHM crossings
FWHM TTS


ScatterPulseHeightToA
Entries 53026
Mean x 5.362
Mean y 79.06
Std Dev x 1.53
Std Dev y 1.729
ToA [ns]
95
90
85
80
75
70
65
2
4
6
8
10
12
14
Pulse height [mV]

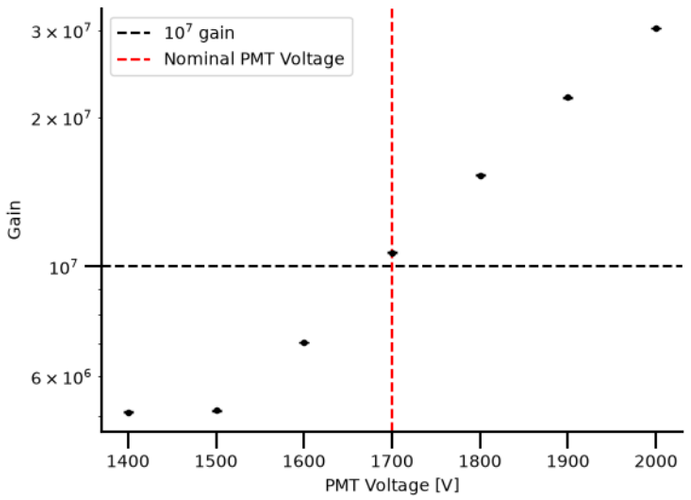
Results

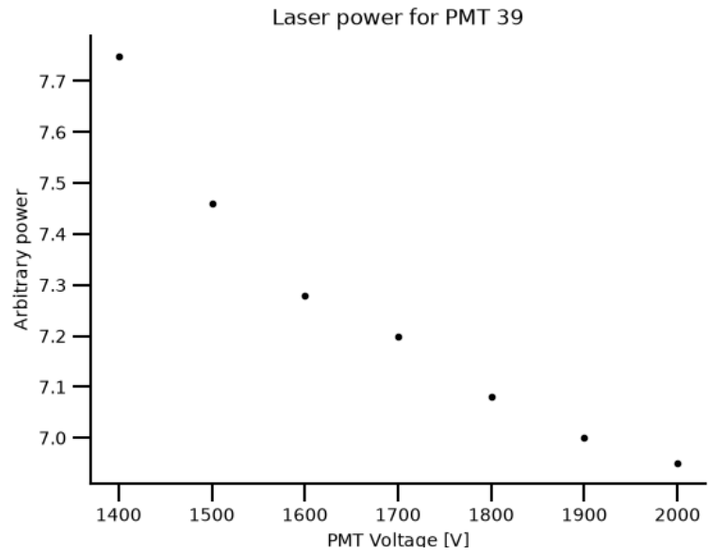

ScatterPulseHeightR...
Entries 53026
Mean x 5.361
Mean y 5.336
Std Dev x 1.529
Std Dev y 1.949
Rise time [ns]
20
15
10
5
0
2
4
6
8
10
12
14
Pulse height [mV]


ScatterChargePulseHe...
Entries 53026
Mean x 5.361
Mean y 1.665
Std Dev x 1.525
Std Dev y 0.6266
Charge [pC]
6
5
4
3
2
1
0
2
4
6
8
10
12
14
Pulse height [mV]

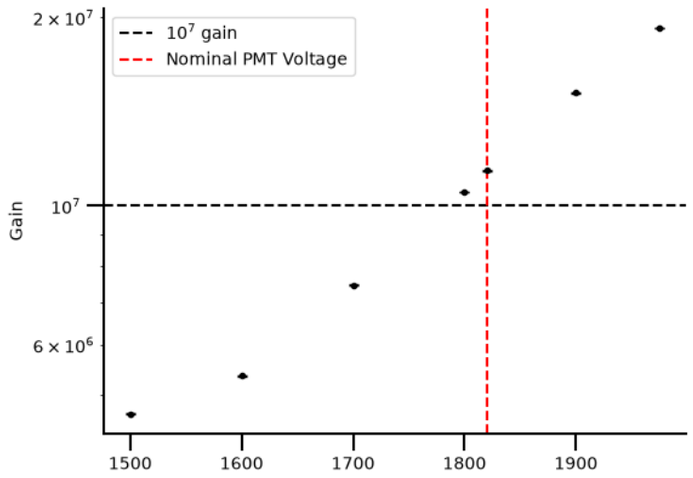
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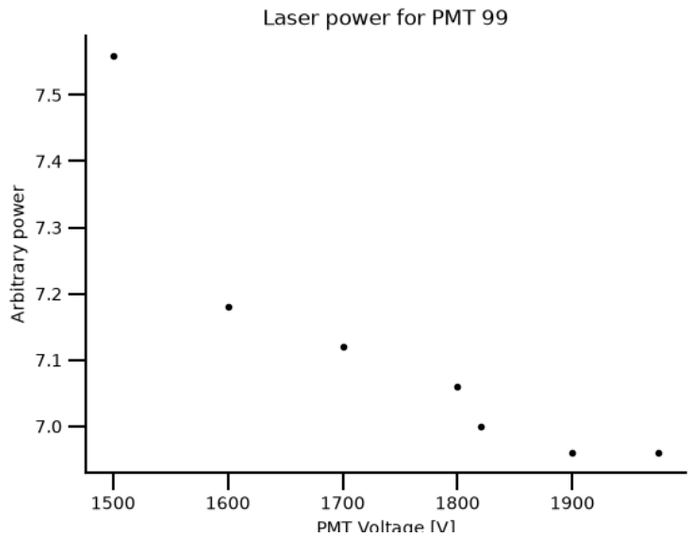
PMT#39 (bare)



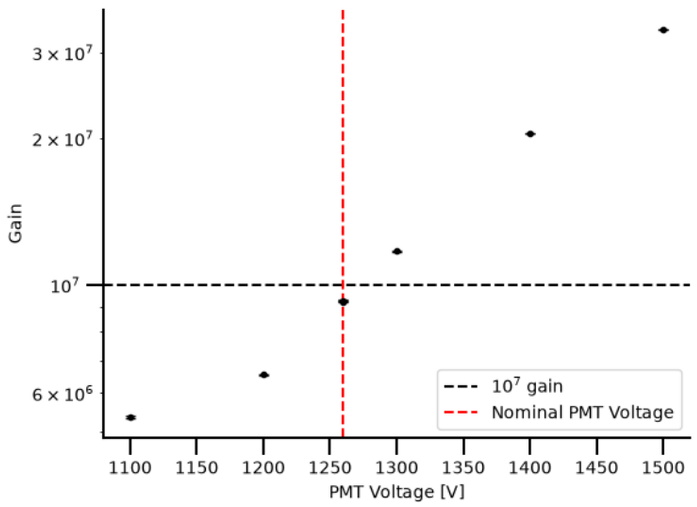


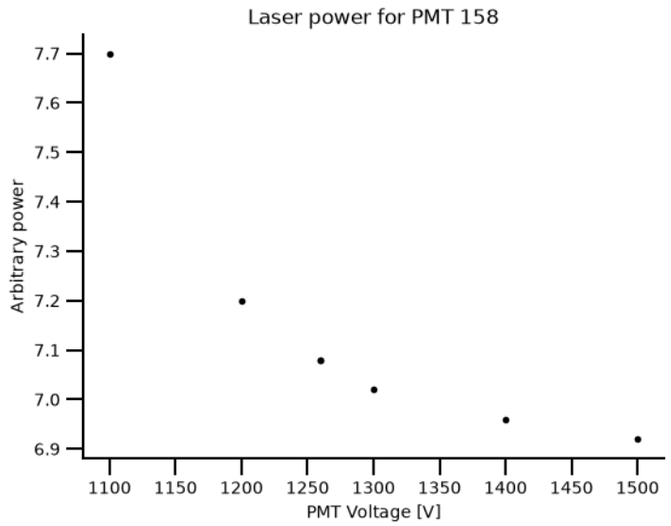
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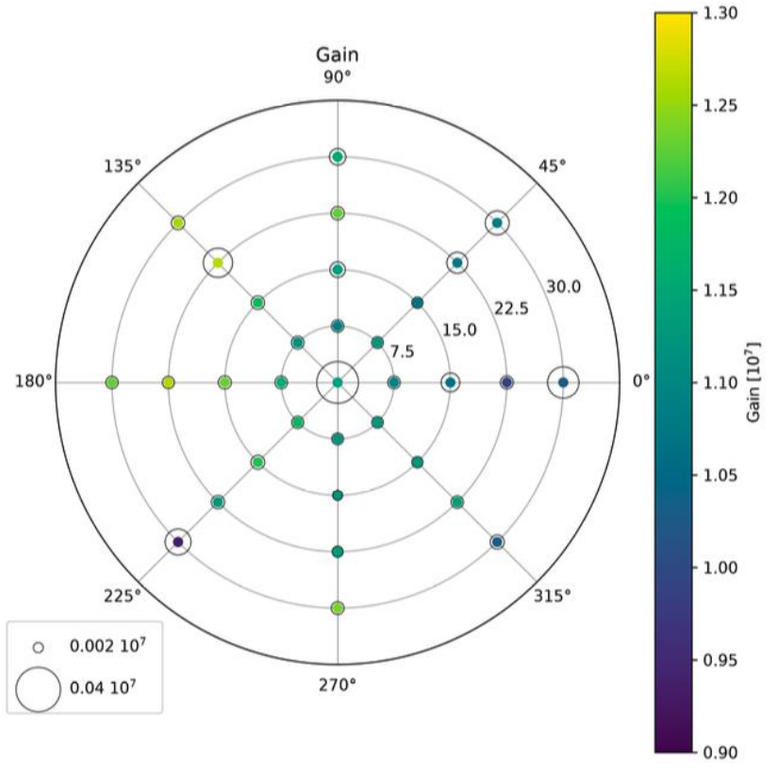


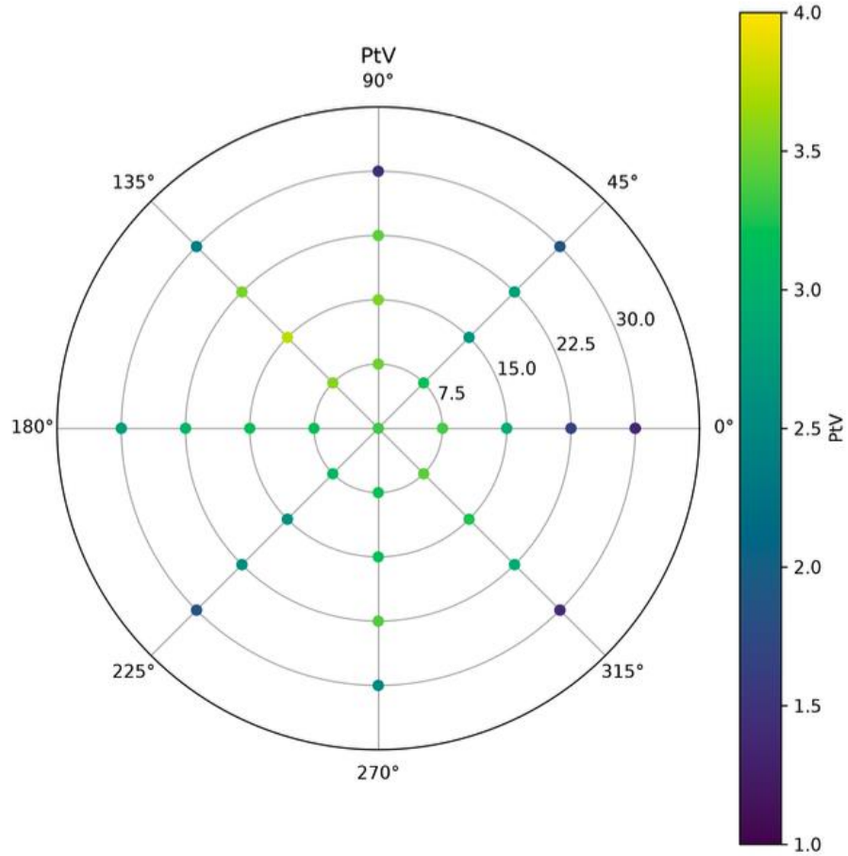
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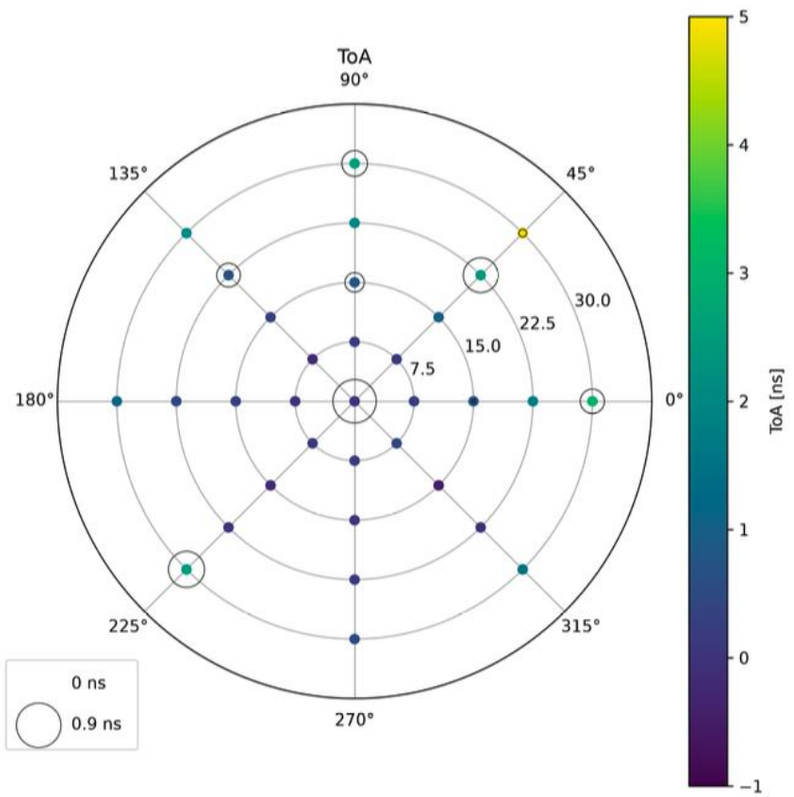


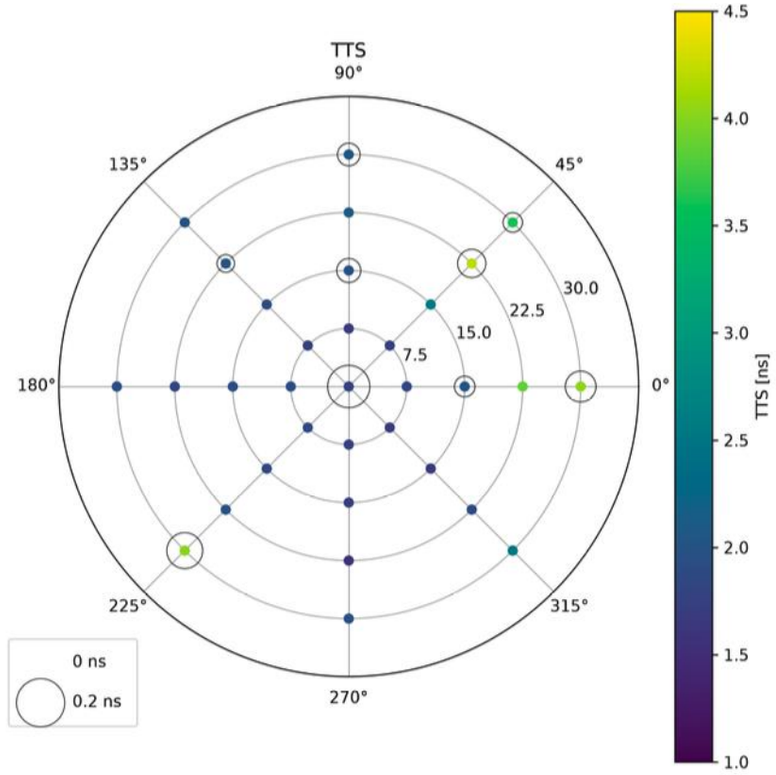


Results: PMT 99 (radar plots)



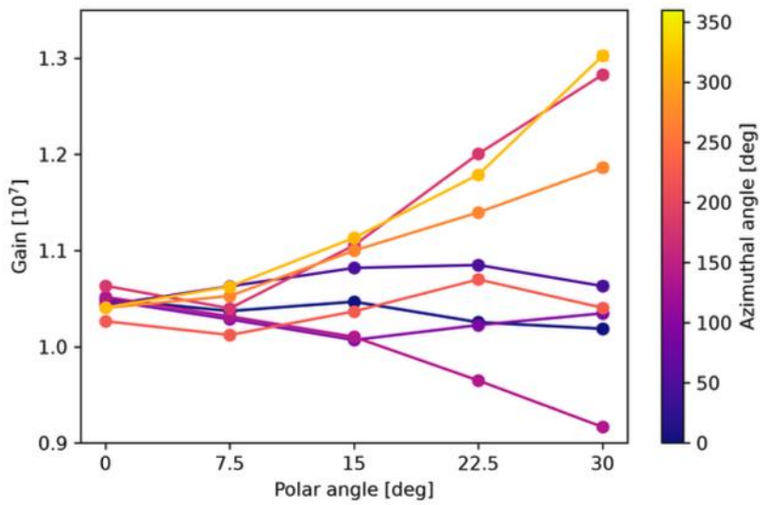


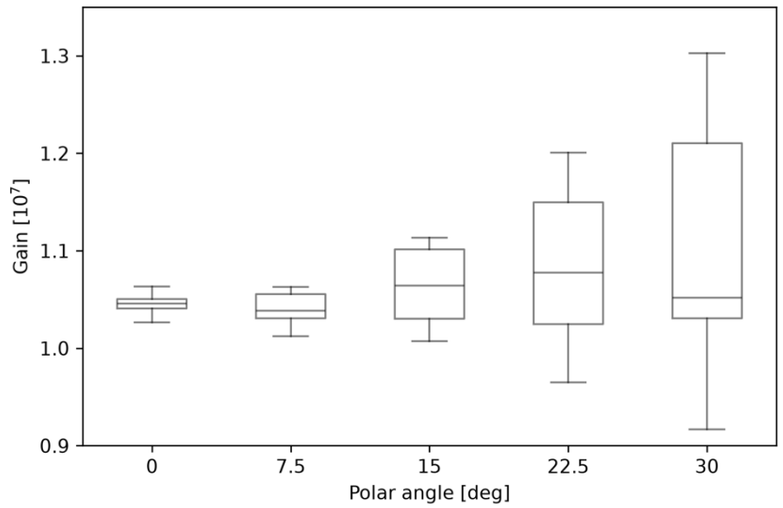




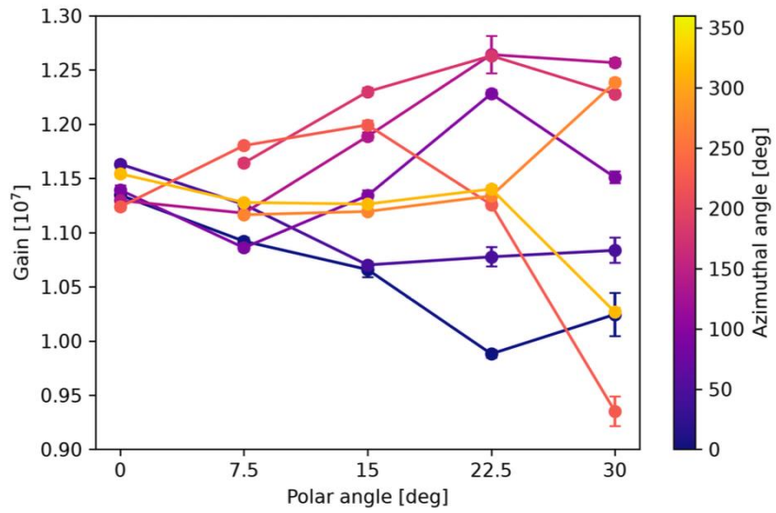
Results: gain

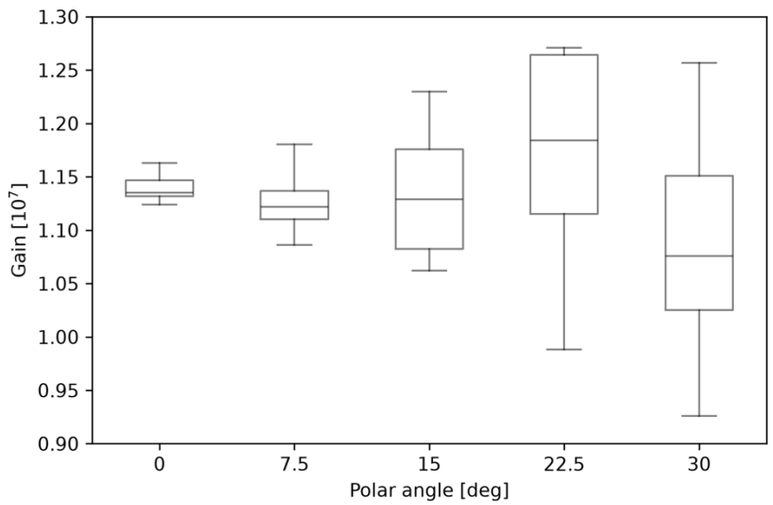
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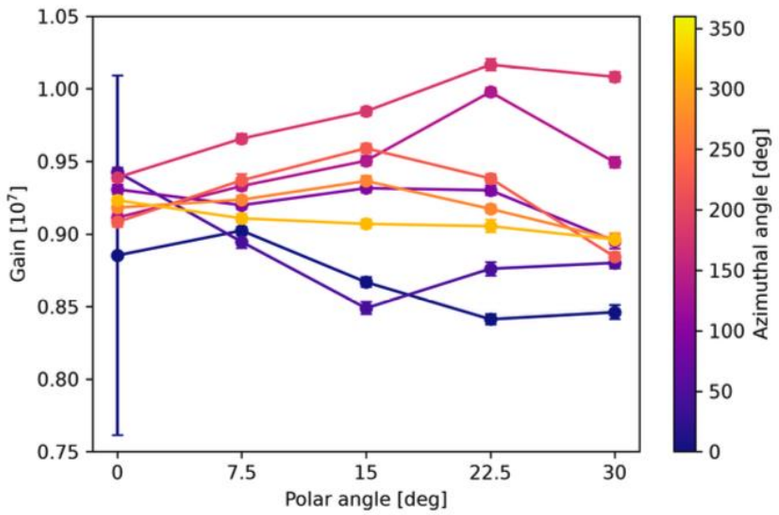


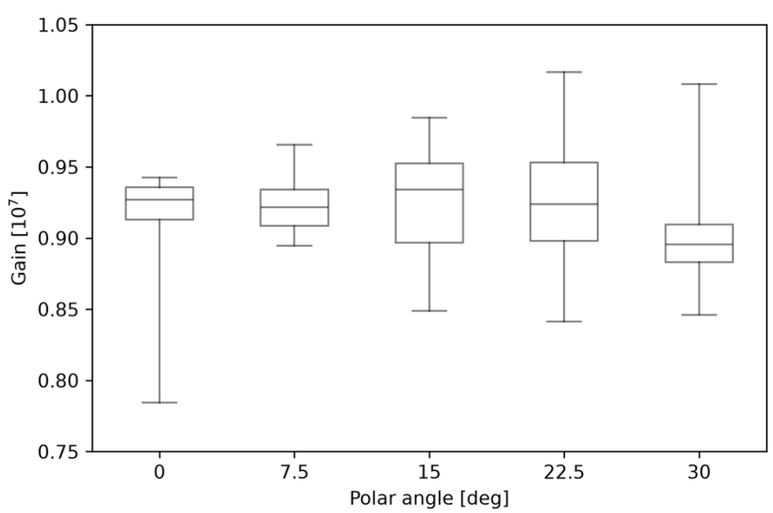
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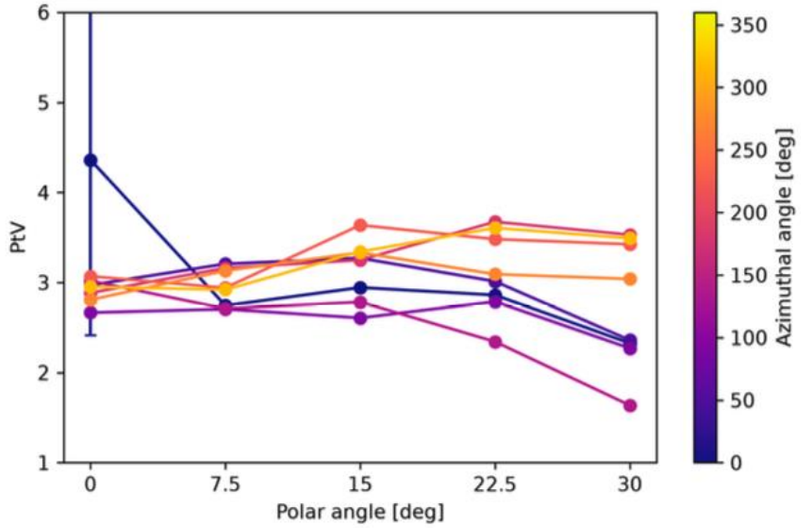
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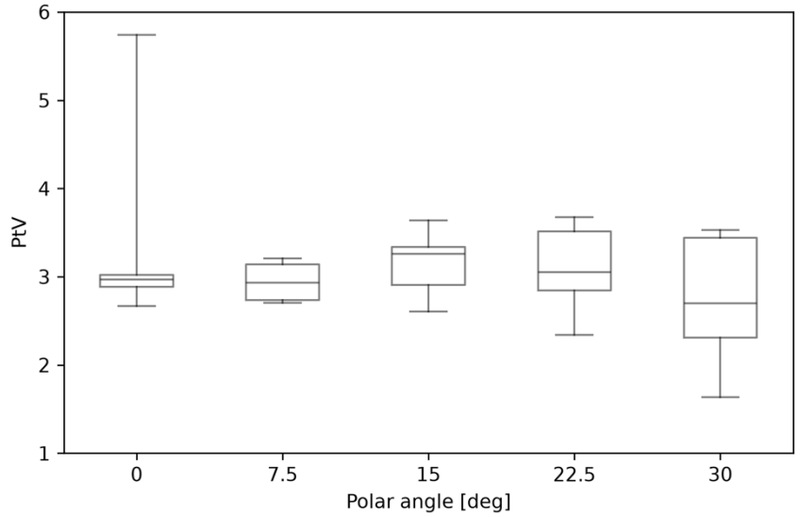




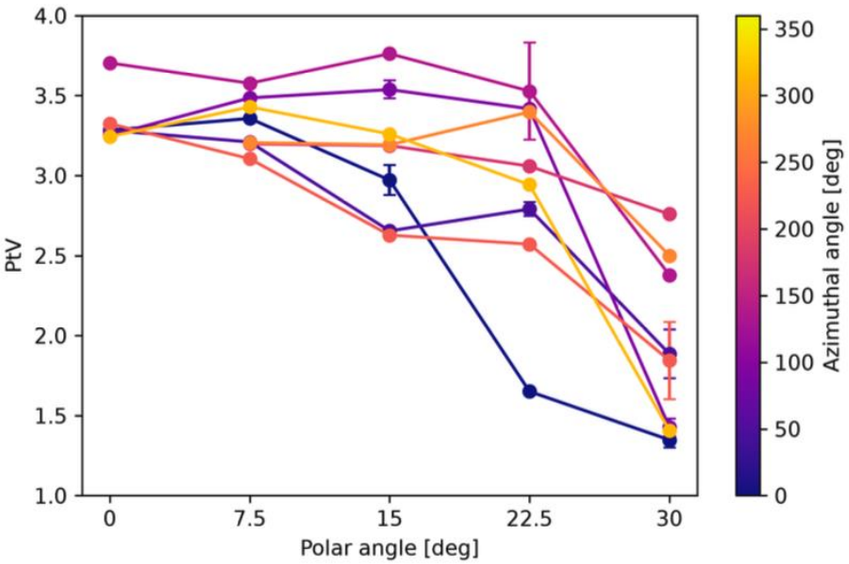
Results: PtV

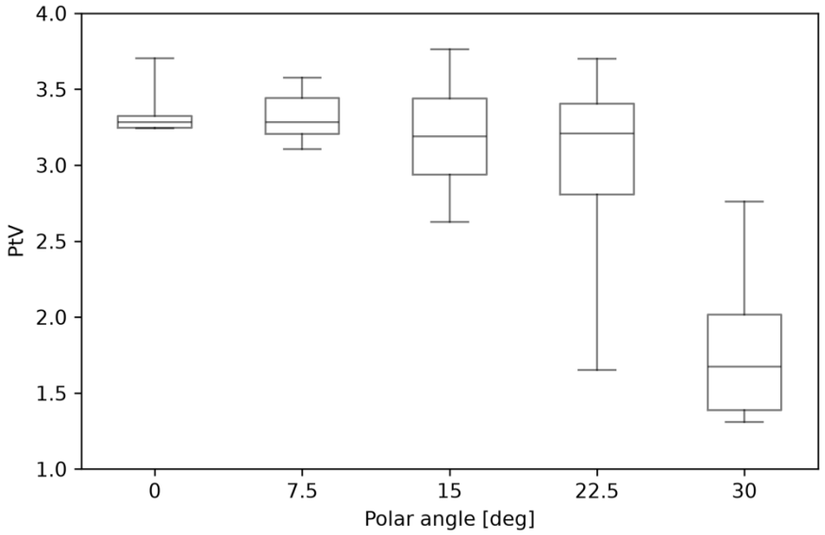
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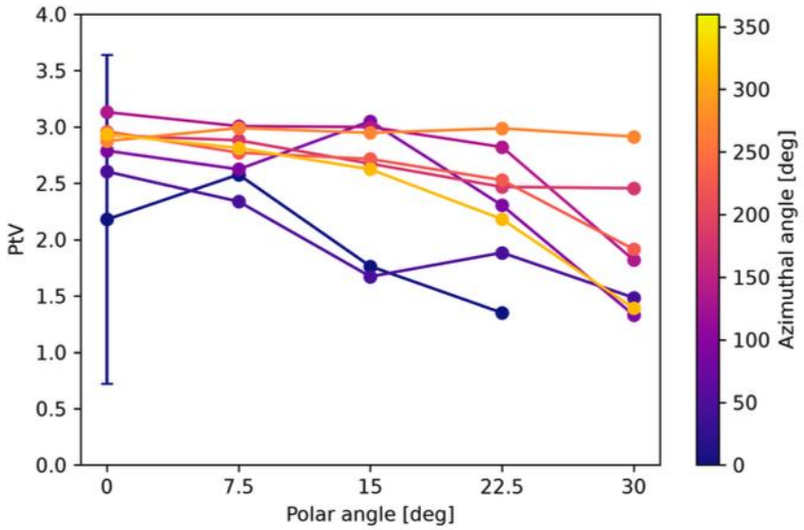


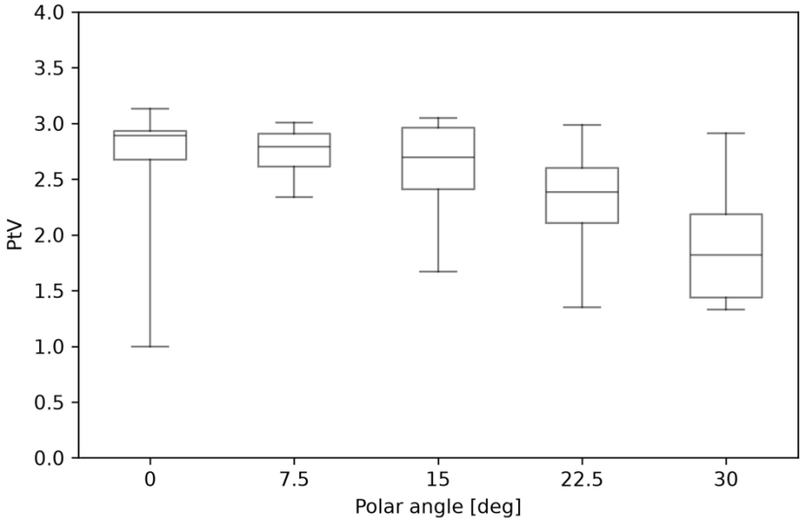
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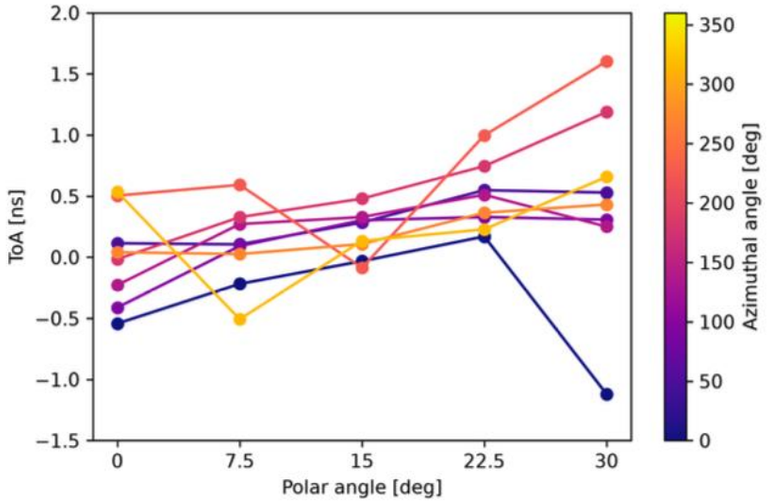
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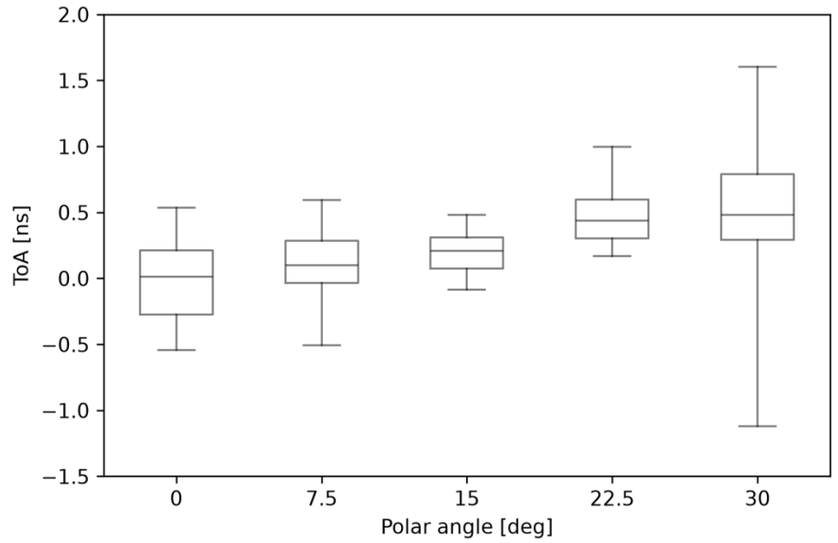




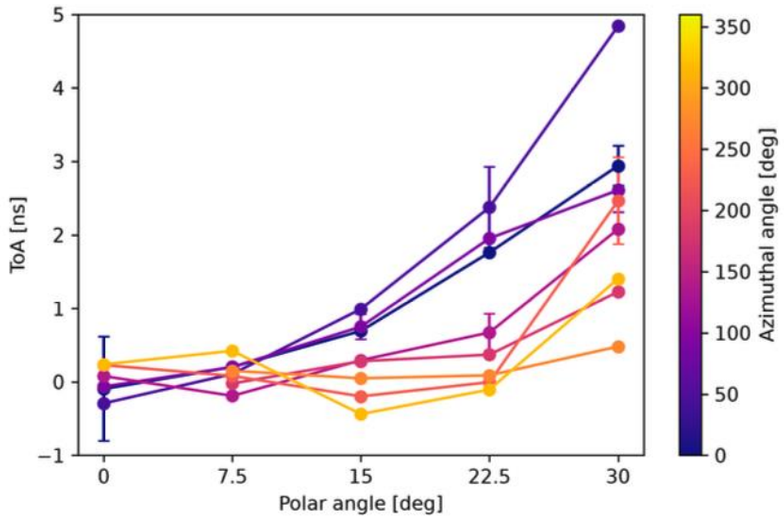
Results: ToA

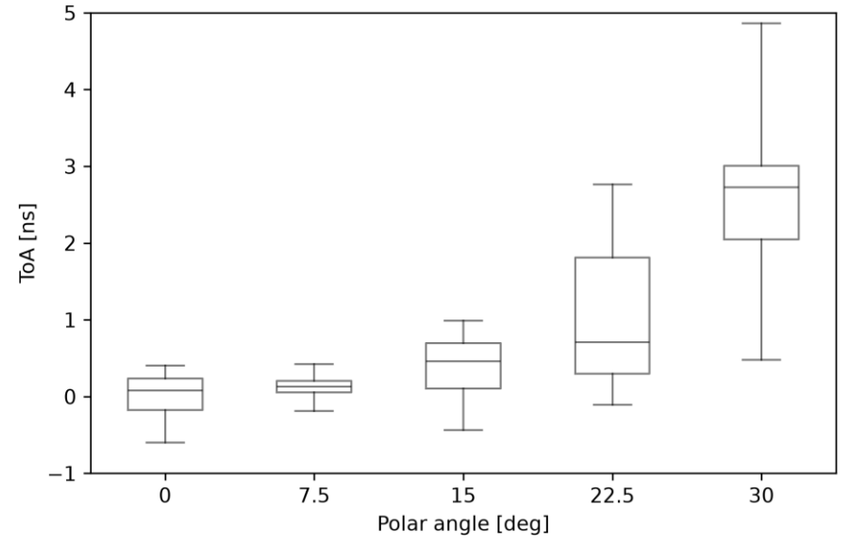
PMT#39 (bare)



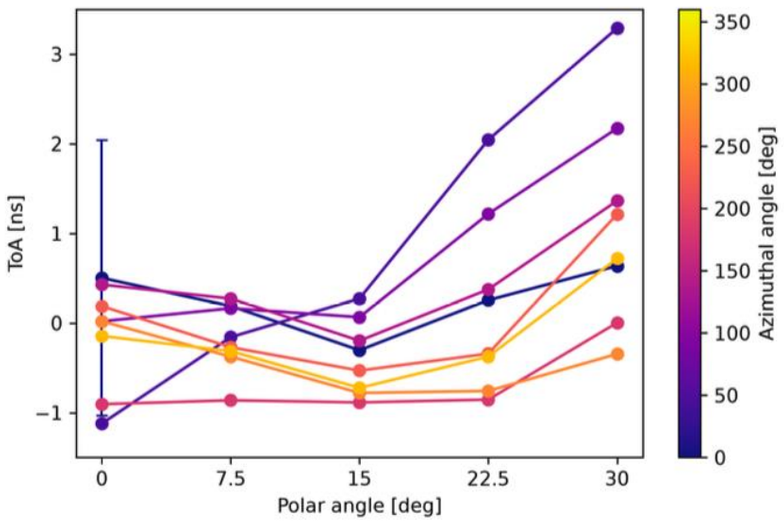


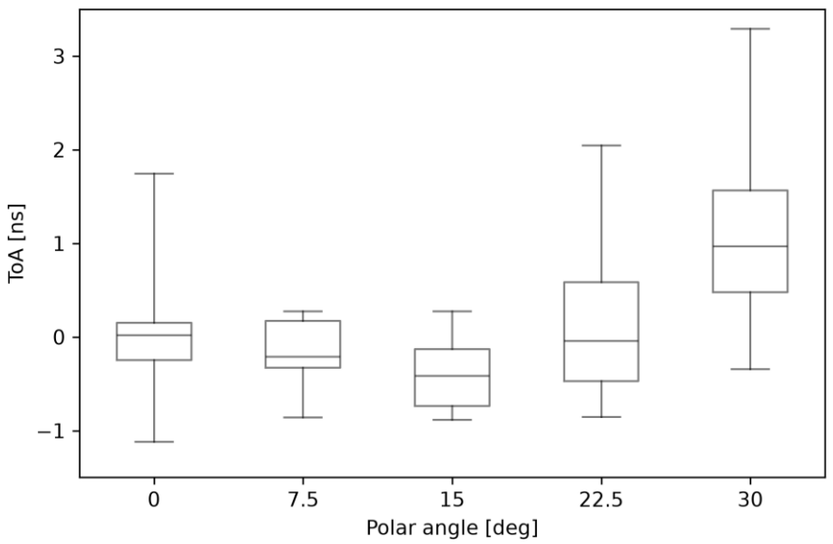
PMT#99 (module)





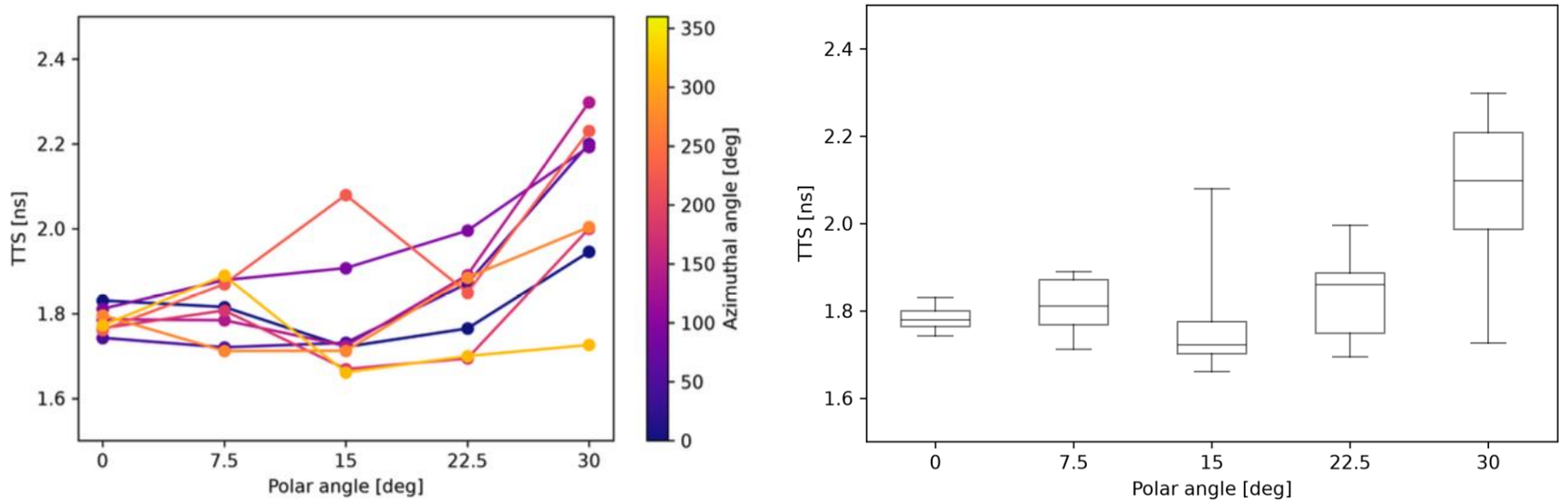
PMT#158 (module)



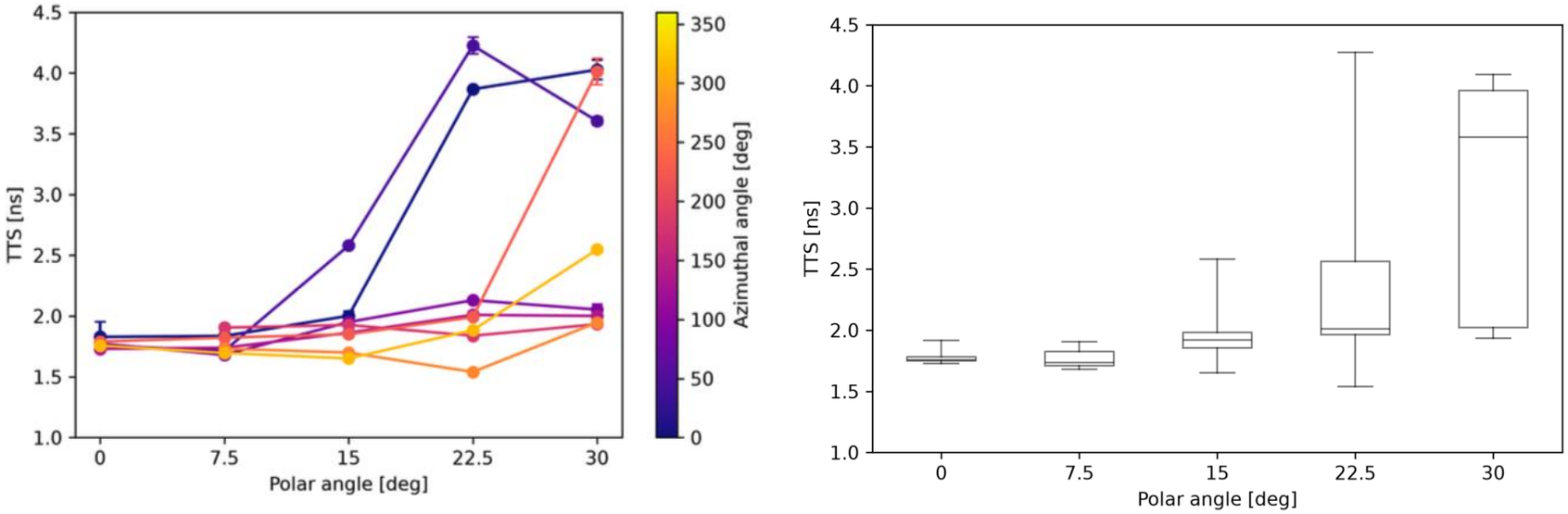


Results: TTS

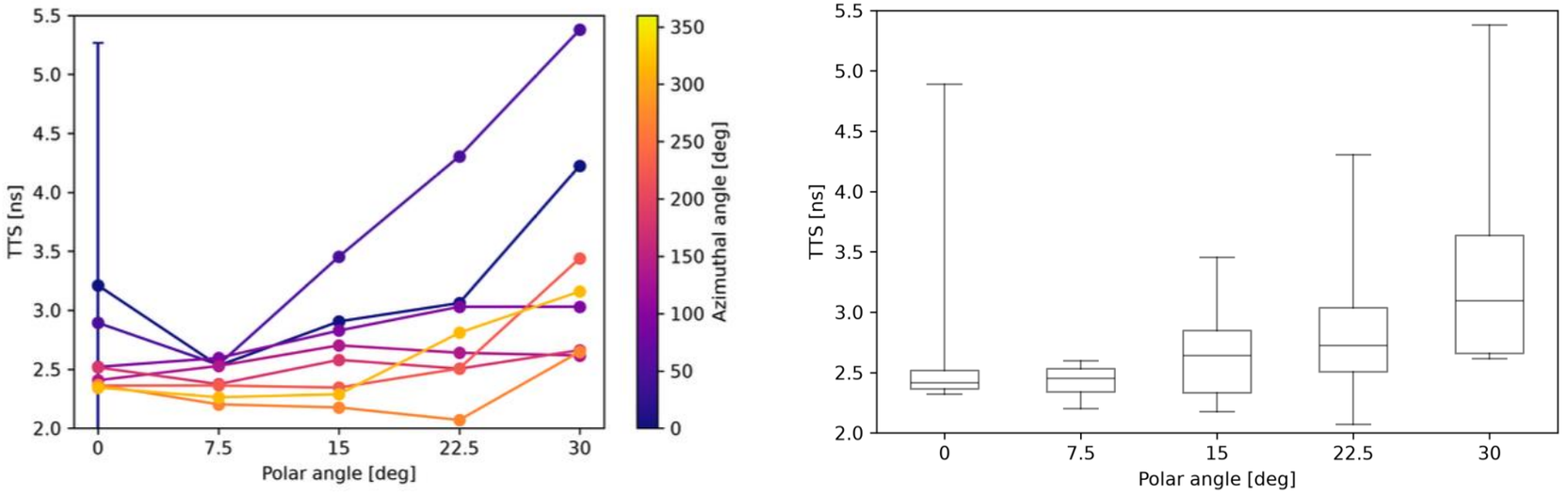
PMT#39 (bare)



PMT#99 (module)

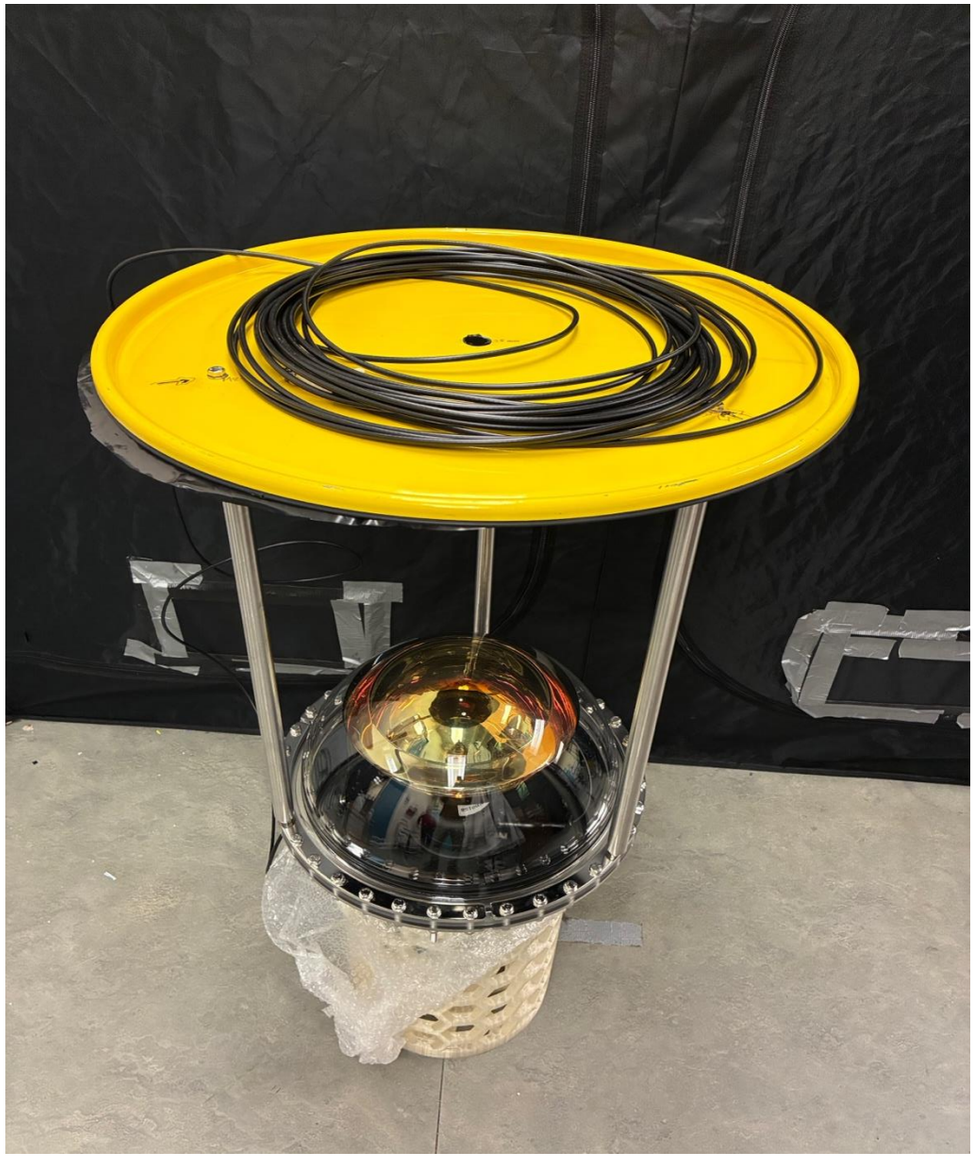


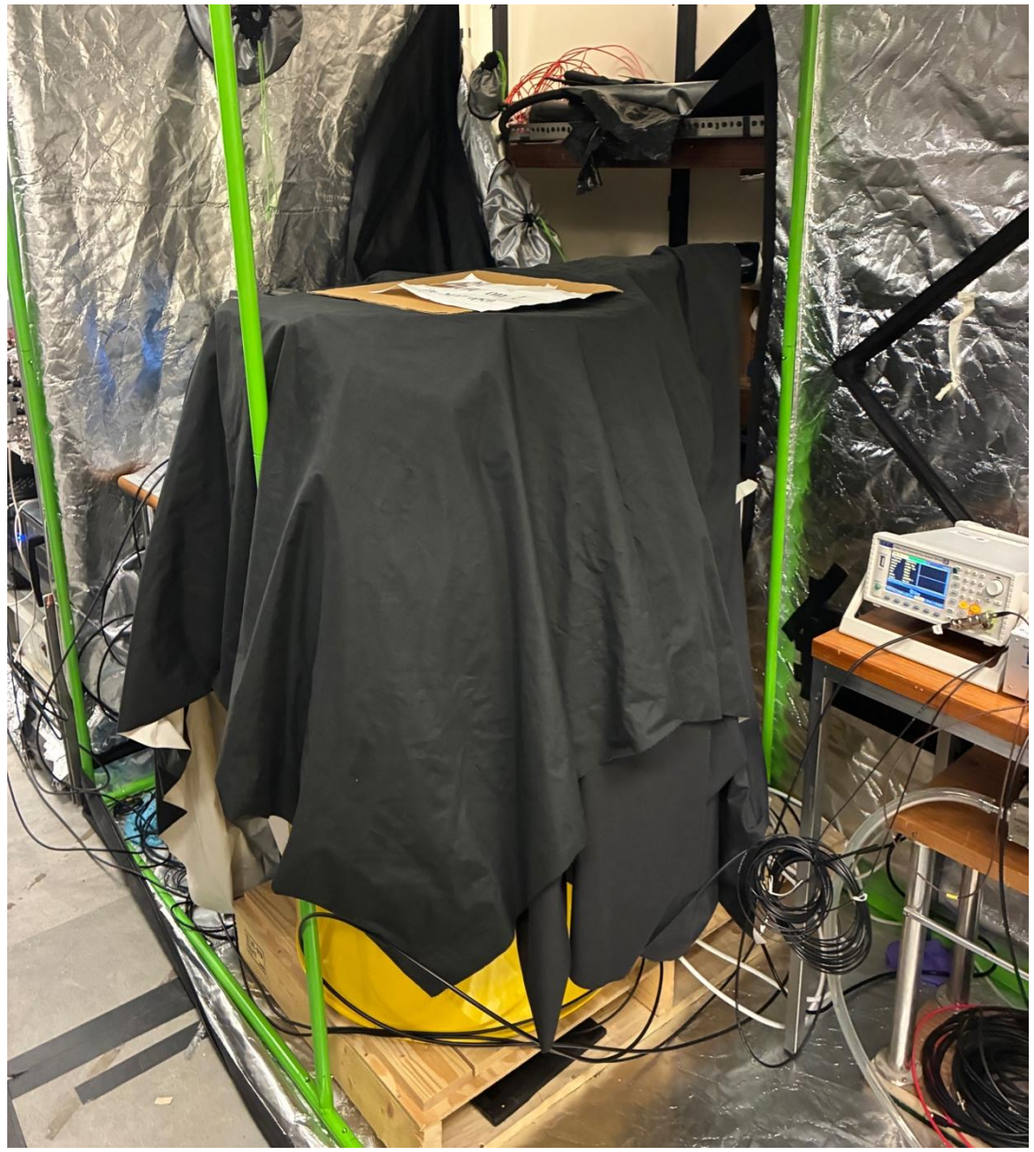
PMT#158 (module)



A test stand at Edinburgh

Under water test of a BUTTON module in 300 liter tank



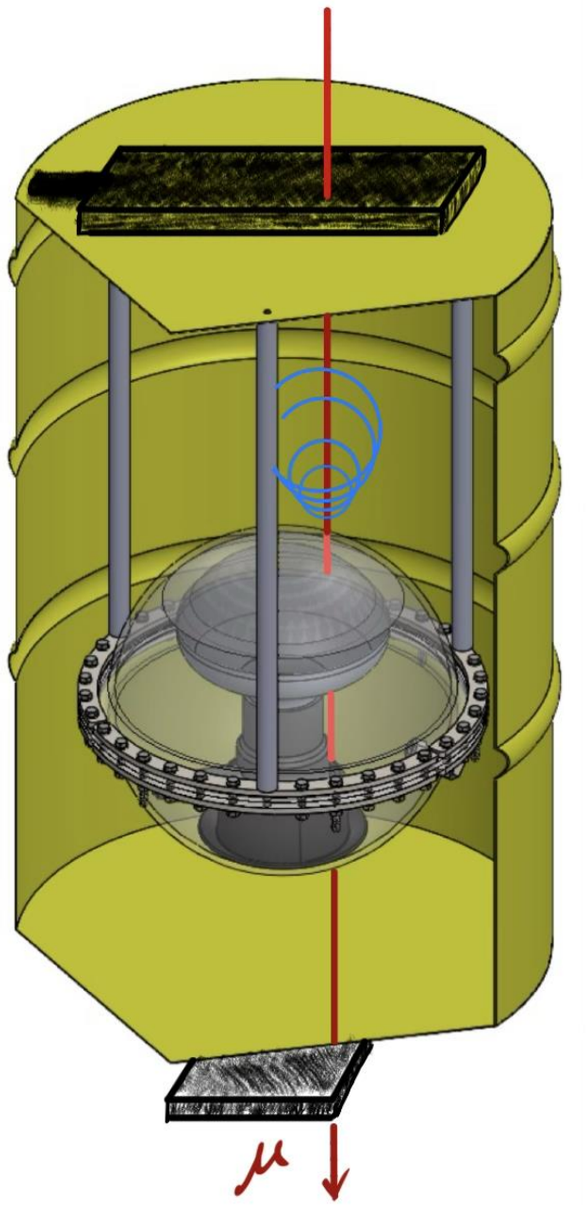


- Two scintillator paddles: one on the top and one at the bottom
- Two-fold coincidence for vertical muons
- Two more scintillators to be installed at the sides (at an angle) for slanted muons

Results:

Under water test of a BUTTON module in 300 liter tank

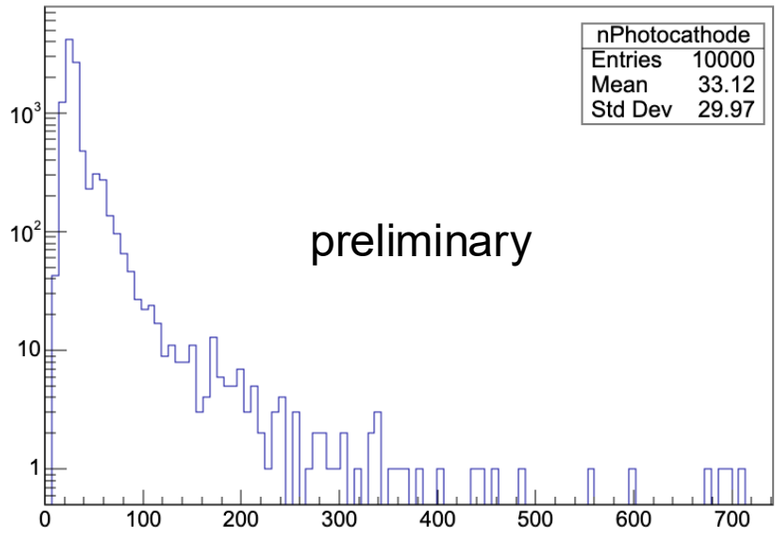
Setup:



GEANT4 simulation



nPhotocathode



Next:

- Testing long term stability of the BUTTON module in pure water
- Measuring light yield/muon in pure water
- Measuring light yield/muon using liquid scintillator (MU4)
- Testing Gd-loading compatibility of the BUTTON module in long term
- Neutron tagging with and without Gd-loading

Helpful addition:

- A water purifier?
- A magnetic stirrer for mixing LS and Gd-loading?

Thank you for your attention!