# WP3: Towards the Hyper-Kamiokande detector

JENNIFER2 General Meeting, INFN and University of Pisa
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JENNIFER 2
EU grant n.822070

# Introduction

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Work Package Number** | 3 | | | **Start/End Month** | | | 1 / 48 |
| **Work Package Title** | Towards the Hyper-Kamiokande detector | | | | | | |
| **Lead Beneficiary** | QMUL | | | | | | |
| **Participating organisation Short Name** | INFN | QMUL | RAL | NCBJ | UGE | CAEN | U-Tokyo |

Deliverables and milestones:

- ☑ D3.1 Decision on UV system to measure-Gd concentration
- ☑ D3.2 Technical note on Outer Detector
- ☑ D3.3 Final report on low noise front end electronics and underwater electronics
- ☑ D3.4 Full simulation and analysis with final photosensors
- ☑ M3.1 Report on waveform digitizers and underwater electronics

# Outer Detector

- One of the themes in WP3 relates to our work on the Outer Detector system in Hyper-K.
- Recently, there has been a revision of the shared OD responsibilities to widen the funding support. Before then the responsibility was only shared between the UK and Russia.
- Although the UK still provides most of the OD funds, other countries contribute to the photo sensing system (Australia, Korea, Japan) and electronics (countries contributing to ID electronics).
- The sharing is currently being finalised. The OD PMT tendering will start soon.

# Outer Detector: Role and Importance

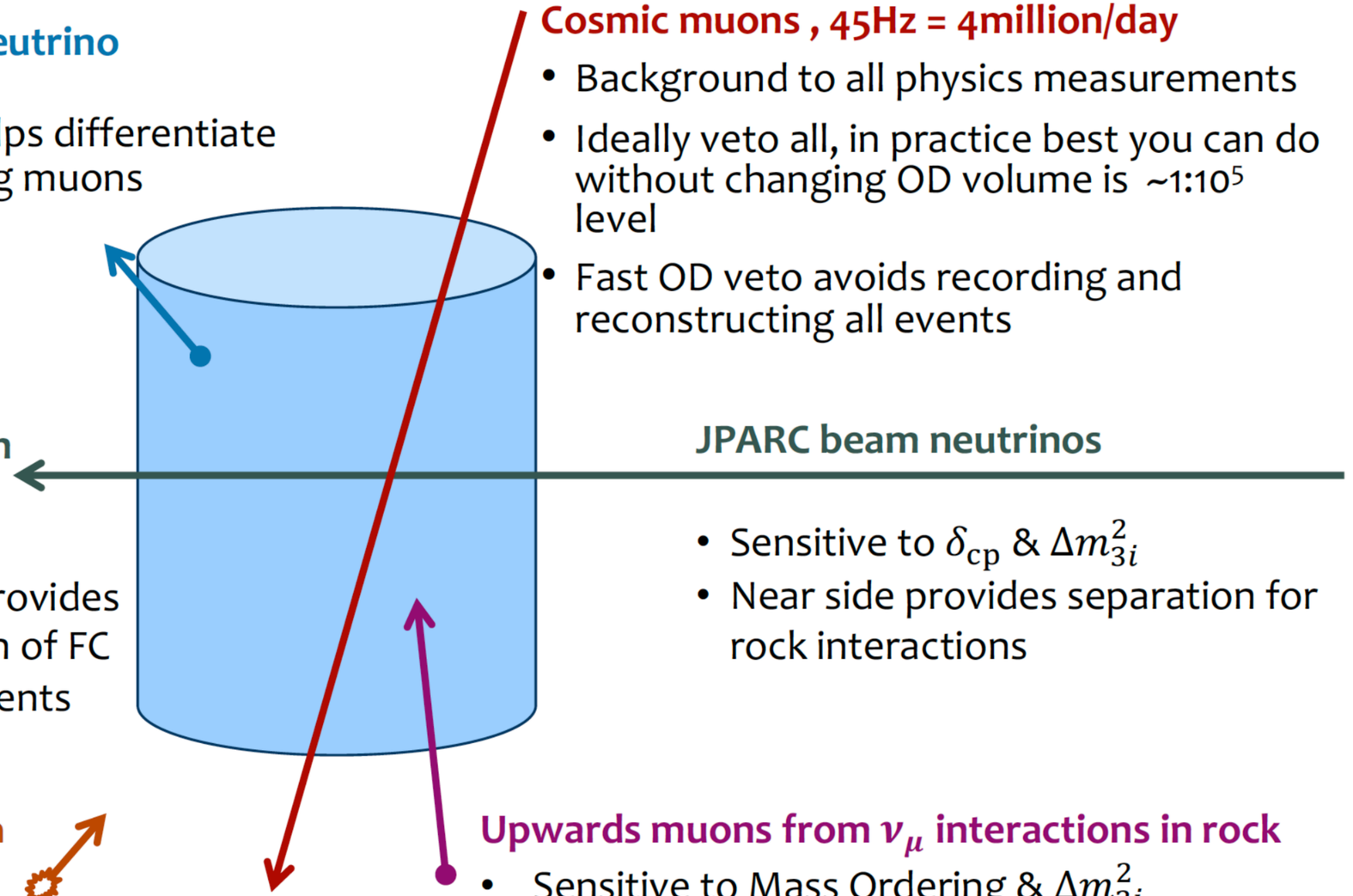
The following slides present a summary of the OD work. They are slides from PAC talks (Wendell, Kralik).

**Partially contained neutrino interaction**

- OD near corners helps differentiate from corner-clipping muons

**Cosmic muons , 45Hz = 4million/day**

- Background to all physics measurements
- Ideally veto all, in practice best you can do without changing OD volume is ~1:$10^5$ level
- Fast OD veto avoids recording and reconstructing all events




- Far side provides separation of FC and PC events

- Sensitive to $\delta_{cp}$ & $\Delta m^2_{3i}$
- Near side provides separation for rock interactions

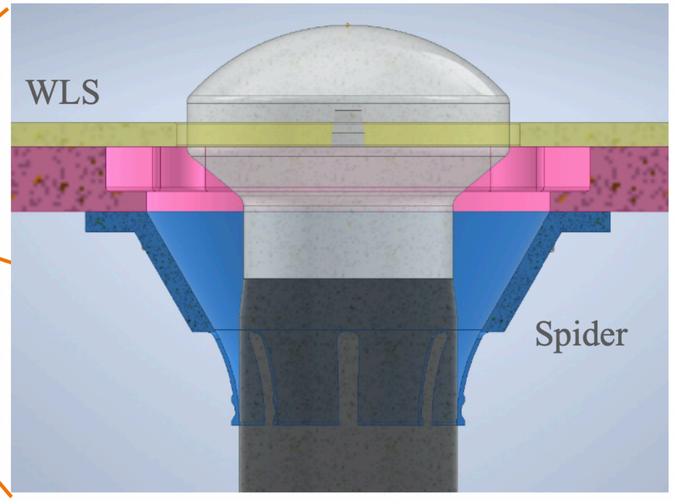
Passive shielding from radioactivity in rock

- Main value to Low-E analyses, does not require PMTs

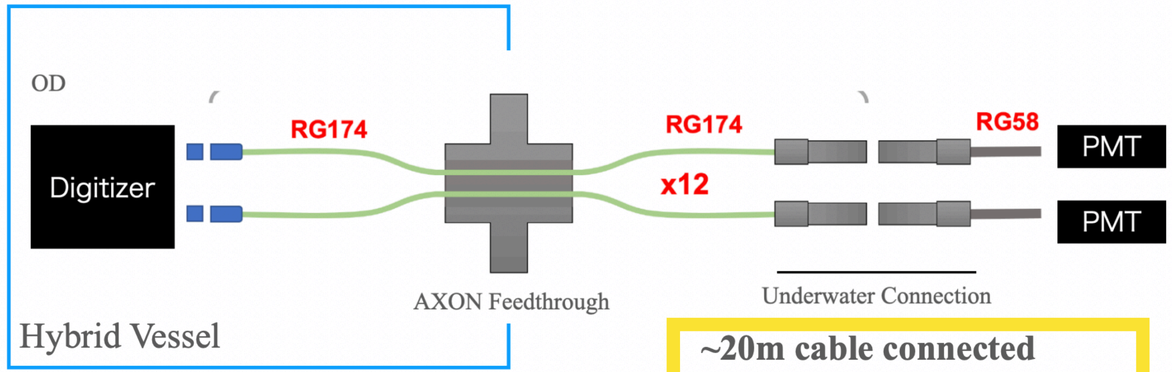
**Upwards muons from $\nu_\mu$ interactions in rock**

- Sensitive to Mass Ordering & $\Delta m^2_{3i}$
- Bottom endcap OD separates these from (lower-*E*) PC events

# Outer Detector System Components


- **3,600 3-inch PMTs**
- **30cm x 30 cm WLS Plate**
- Black/White Tyvek behind WLS Plate
- Injection moulded mount ("spider")



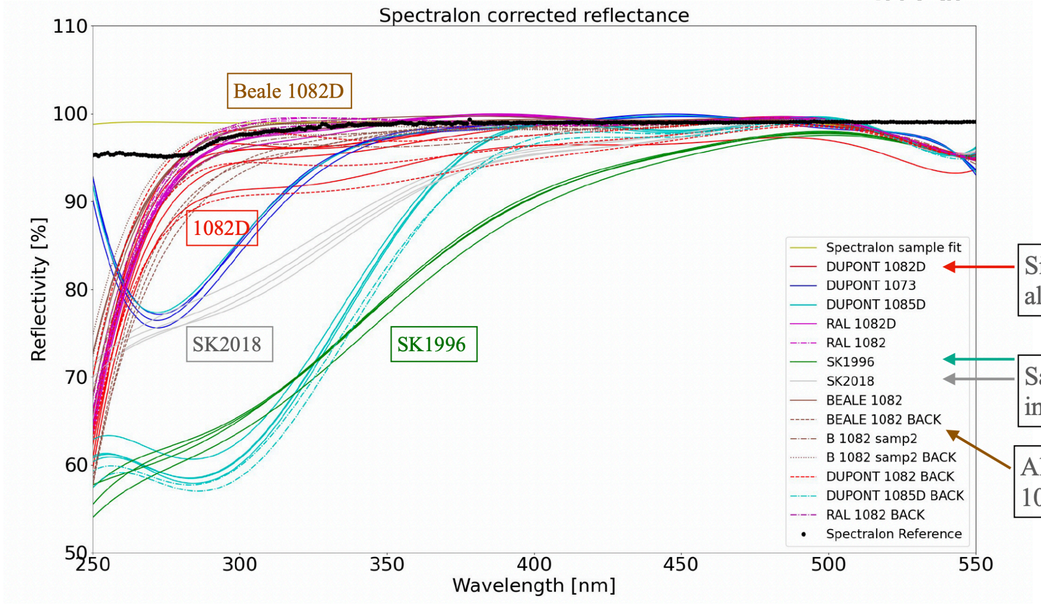

**~20m cable connected underwater** just before electronics vessel

- Single sheet of **"Black/White" (B/W) Tyvek** on structure
  - Reflection into OD region, light shielding into ID

- Double layer Tyvek on floors and outer walls of detector
  - Termed "**White/White" (W/W) Tyvek**
  - Bounce light back into PMTs on structure

# Tyvek

In Air

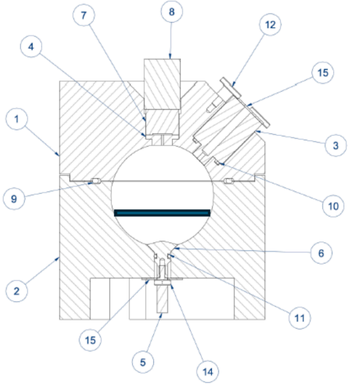



Single-layer Tyvek alternative (front)

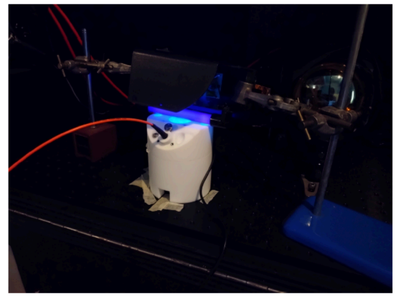
Samples from SK, installed in 1996 and 2018

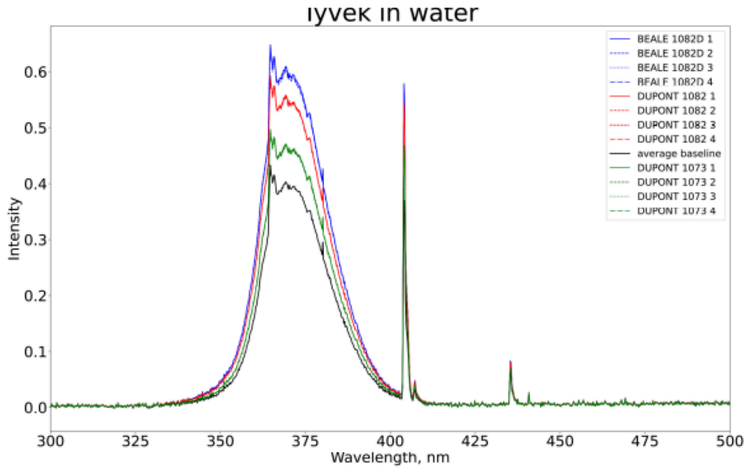
Alternative supplier of 1082D

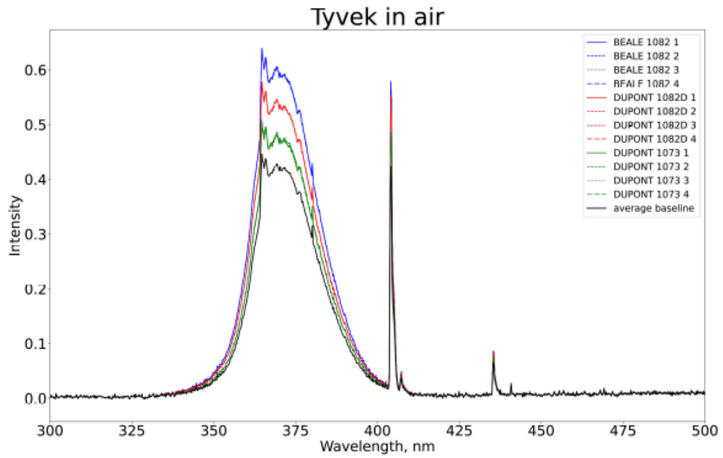
In Water




Sania Lewis
Jeanne Wilson





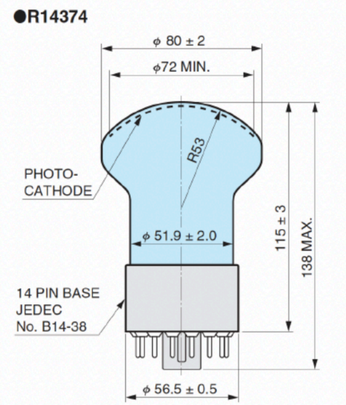



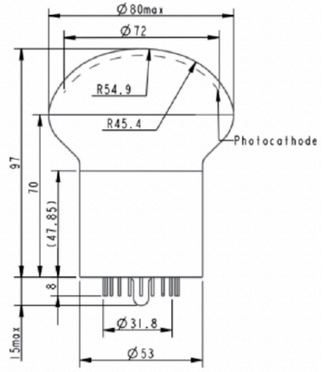

- ~Few % difference of reflectivity between water and air
- Several Tyke types tested, choosing the one with the best reflectivity.

# Outer Detector System and Components

## PMTs : Specs

- Two candidate 3” PMTs
  - Hamamatsu (HPK) R14374-31
  - NNVT N2031
- Towards tendering:
  - Waterproofed HPK Tubes with 20m cables have been characterized
  - Waterproofed NNVT Tubes now characterized




N2031光电倍增管结构图
N2031 PMT structure

HPK

**GENERAL**

| Parameter | | R14374 | R14689 | Unit |
|---|---|---|---|---|
| Spectral response | | 300 to 650 | | nm |
| Wavelength of maximum response | | 420 | | nm |
| Window material | | Borosilicate glass | | — |
| Photocathode | Material | Bialkali | | — |
| | Minimum effective area | φ72 | φ81 | mm |
| Dynode | Structure | Circular and linear-focused | | — |
| | Number of stages | 10 | | — |
| Base | | JEDEC No. B14-38 | | — |
| Operating ambient temperature | | -30 to +50 | | °C |
| Storage temperature | | -30 to +50 | | °C |
| Suitable socket | | E678-14W (Sold separately) | | — |

**MAXIMUM RATINGS (Absolute maximum values)**

| Parameter | | R14374 | R14689 | Unit |
|---|---|---|---|---|
| Supply voltage | Between anode and cathode | 1500 | | V |
| | Between anode and last dynode | 300 | | V |
| Average anode current | | 0.1 | | mA |

**CHARACTERISTICS (Typ.) (at 25 °C)**

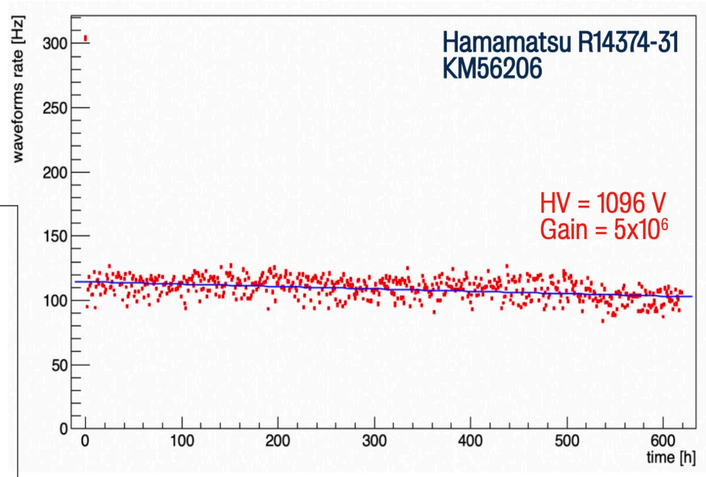
| Parameter | | R14374 | R14689 | Unit |
|---|---|---|---|---|
| Cathode sensitivity | Luminous (2856 K) | 90 | | μA/lm |
| | Radiant at 420 nm | 90 | | mA/W |
| | Blue sensitivity index (CS 5-58) | 11.0 | | — |
| | Quantum efficiency at 380 nm | 27.5 | | % |
| Anode sensitivity | Luminous (2856 K) | 900 | | A/lm |
| | Radiant at 420 nm | $9.0 \times 10^5$ | | A/W |
| Gain | | $1.0 \times 10^7$ | | — |
| Anode dark current (After 30 minute storage in darkness) | | 50 | | nA |
| Time response | Anode pulse rise time | 2.9 | 2.9 | ns |
| | Electron transit time | 35 | 36 | ns |
| | Transit time spread (FWHM) | 1.3 | 1.5 | ns |

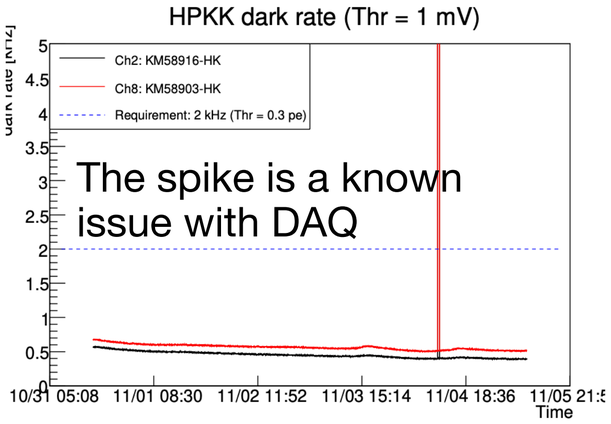
NNVT

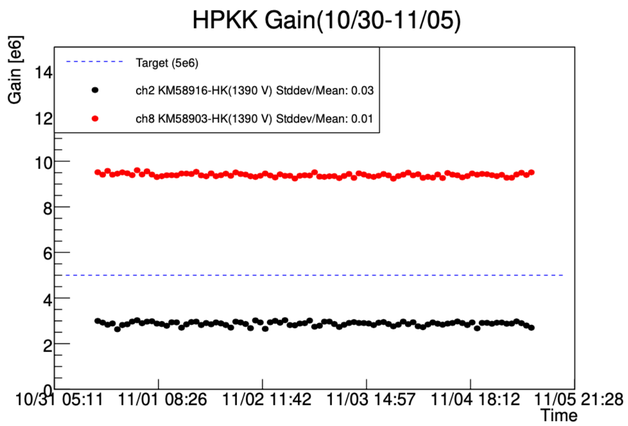
| 产品型号/ Product Model | N2031 | | | |
|---|---|---|---|---|
| 产品结构/ Product structure | 80mm (3") / 10-stage | | | |
| 玻璃材料/Window material | 硼硅酸盐玻璃/ Borosilicate Glass | | | |
| 光电阴极/Photocathode | 双碱/Bialkali | | | |
| 倍增结构/Dynode structure | 盒型和线性聚焦/Box and Linear Focused | | | |
| | Min | Typ | Max | Unit |
| 光谱范围/Spectral range | 290-650 | | | nm |
| 405 nm下的量子效率 /Quantum Efficiency at 404 nm | | 26.5 | | % |
| 增益系数/Gain slope (vs supp. Volt., log/log) | 6.5 | 7.3 | 8.0 | |
| 工作电压/Supply voltage | 900 | 1150 | 1300 | V |
| 增益/Gain | | $5 \times 10^6$ | | -- |
| 暗计数率/Dark count rate | | 1000 | 2000 | Hz |
| 峰谷比/Peak to Valley ratio | | 2.5 | | |
| 上升时间/Anode Pulse Rise Time | | 1.9 | | ns |
| 渡越时间离散/Transit time spread (FWHM) | | 1.8 | 3 | ns |

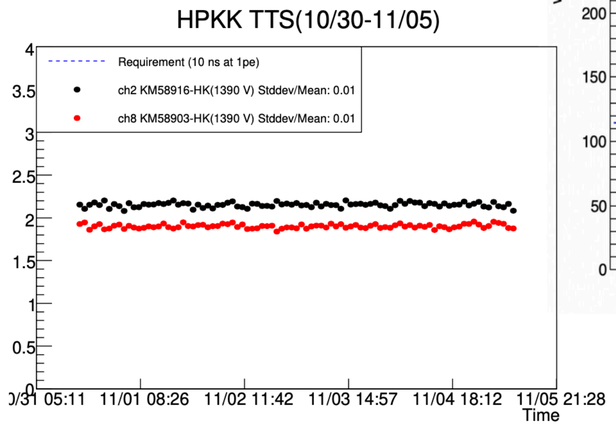
# PMTs Long Term Measurements

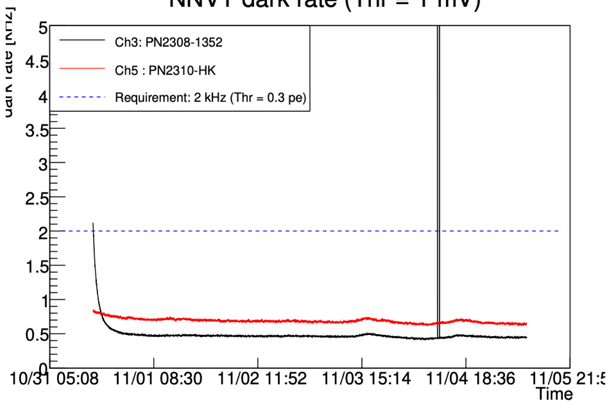
## Good stability of both Hamamatsu (HPK) and NNVT PMTs

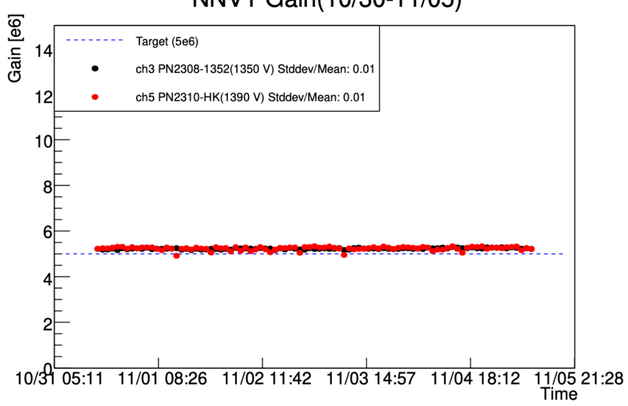


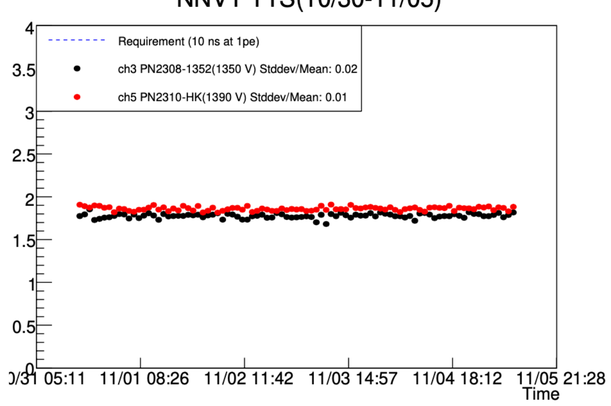



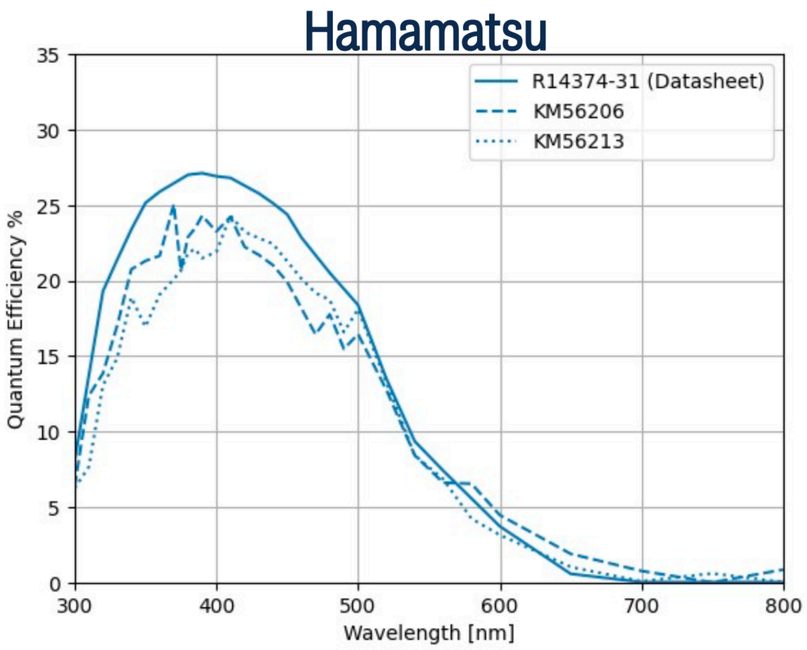



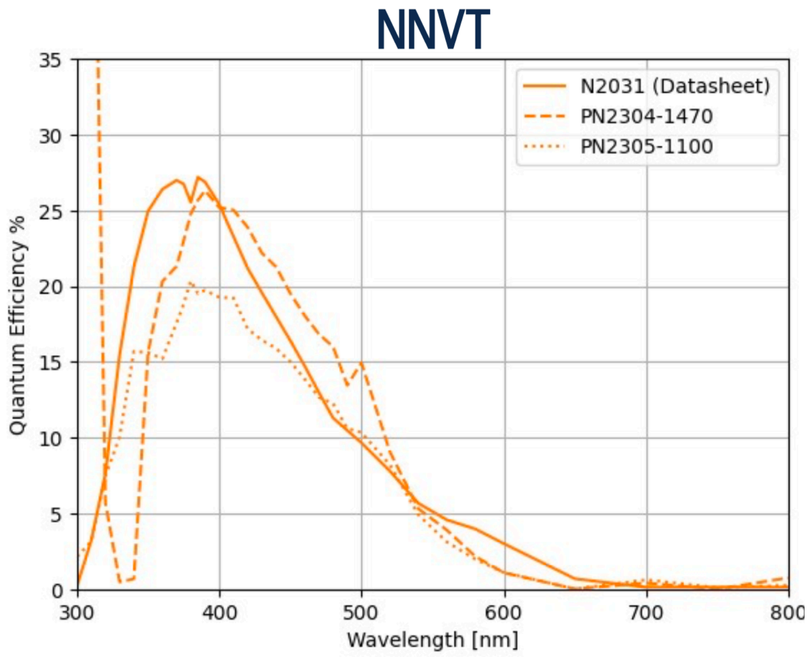



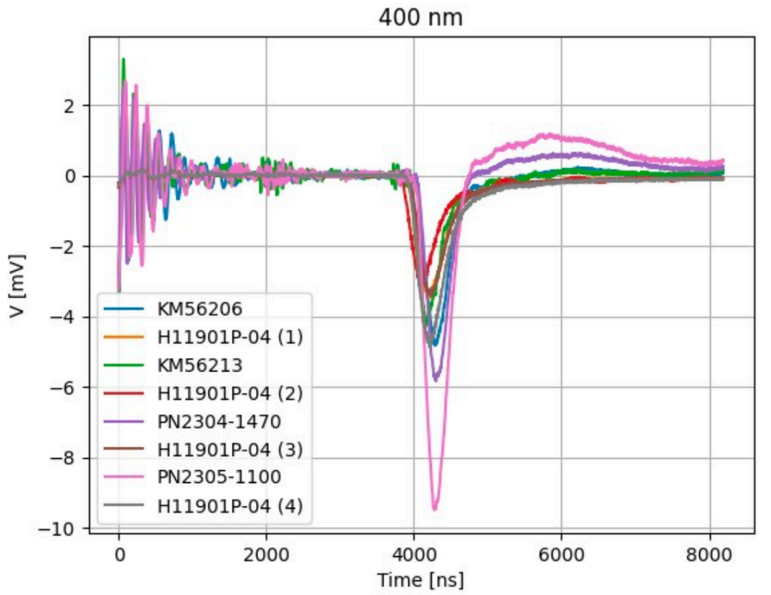
# Quantum Effieciency Measurement

Previously confirmed requirements for peak Quantum Efficiency (QE) for both PMT candidates

- Unable to confirm vendor's specification for absolute QE measurements for different wavelengths
- Now improving wavelength-dependent measurements at KCL (timeline ~weeks)
- Using a xenon-flash lamp with a monochromator
  - Improving setup to limit light pollution – reducing fluctuations
  - Planned magnetic field compensation with a Faraday cage



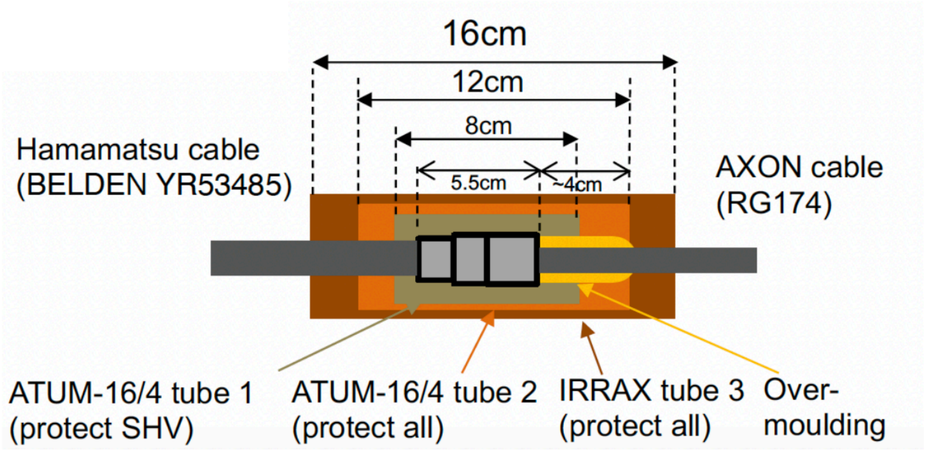



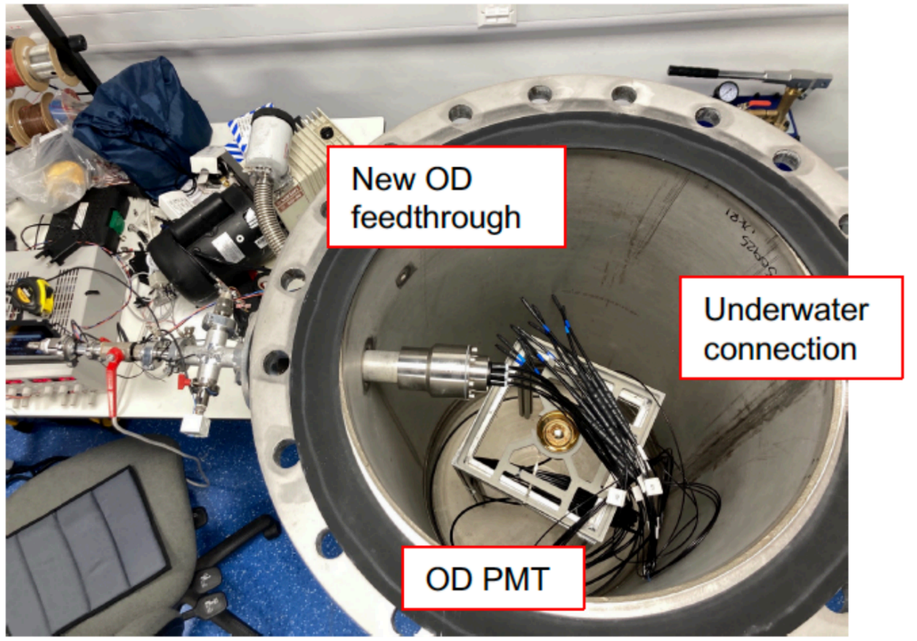



# Connectors

Due to possibility of discharge in HK's degassed water, OD has moved to a mastic-based underwater connection between the electronics vessel and the PMT

- Both PMT vendors will use an RG58-equivalent cable with an SHV plug connector on
- Mastic design follows successful implementation proven on ID side with some modifications



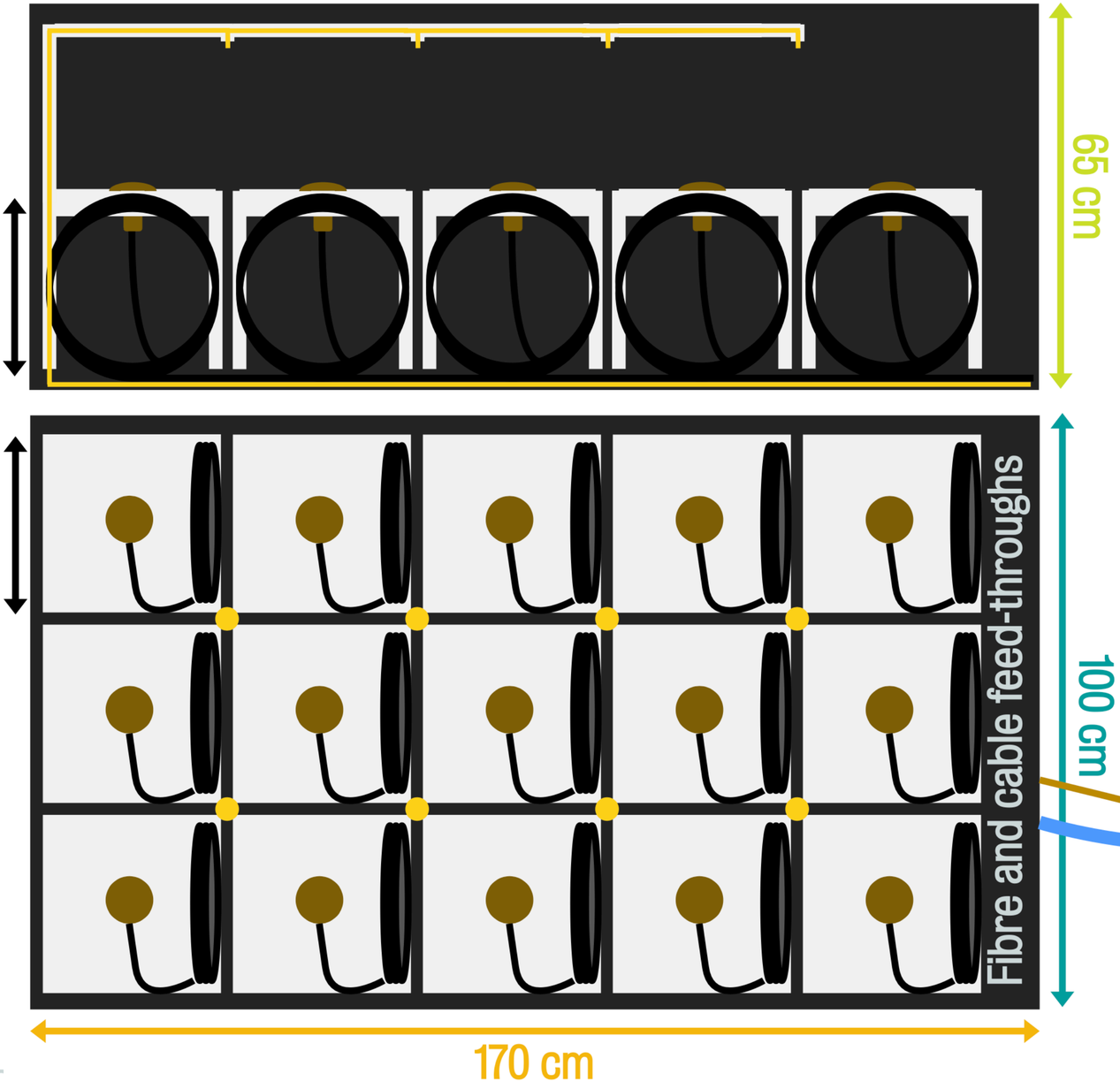

- OD Design has been tested with SMB terminated cables and connectors in pressure vessel to 10 bar => Successful
- Feedthrough with SHV terminated cables delivered in January and being tested

# Quality Assurance

Measure gain vs input voltage, Single PE characteristics, Relative QE, and Dark Rate for all the PMTs

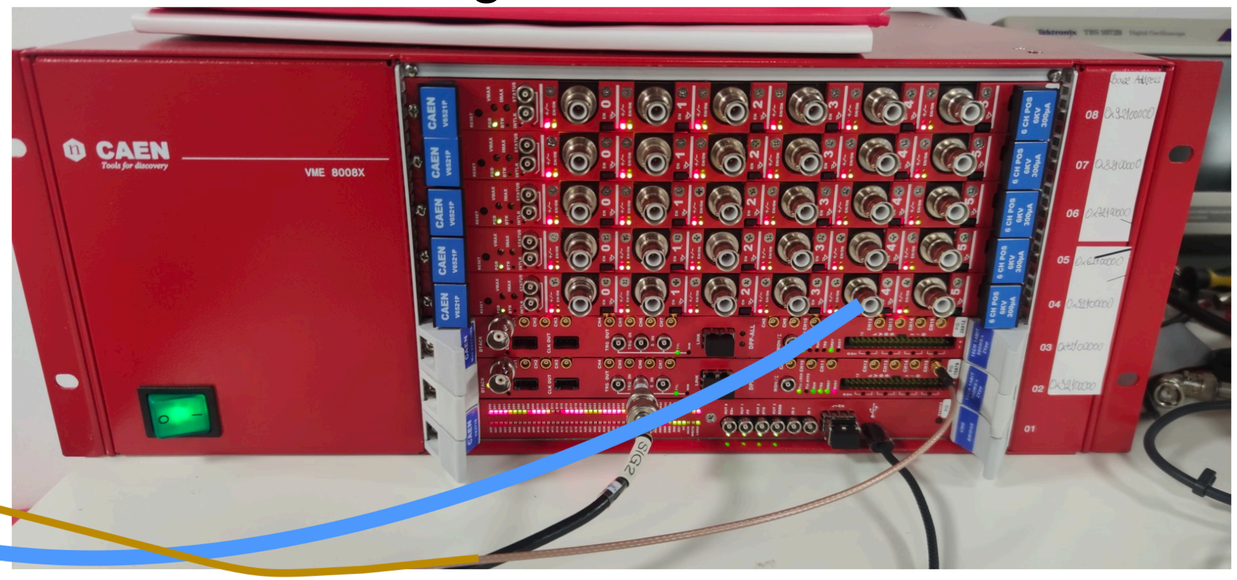
- 2 Dark Boxes with each 14+1 PMTs each per day
- One reference PMT in each box used for validation
- Up to 140 PMTs/week -> up to 560 PMTs/month
- Additional measurements require alternative setup
- Considering measuring PMT+WLS plate setup, angular dep. of collection efficiency, multiple wavelengths

# Quality Assurance Setup

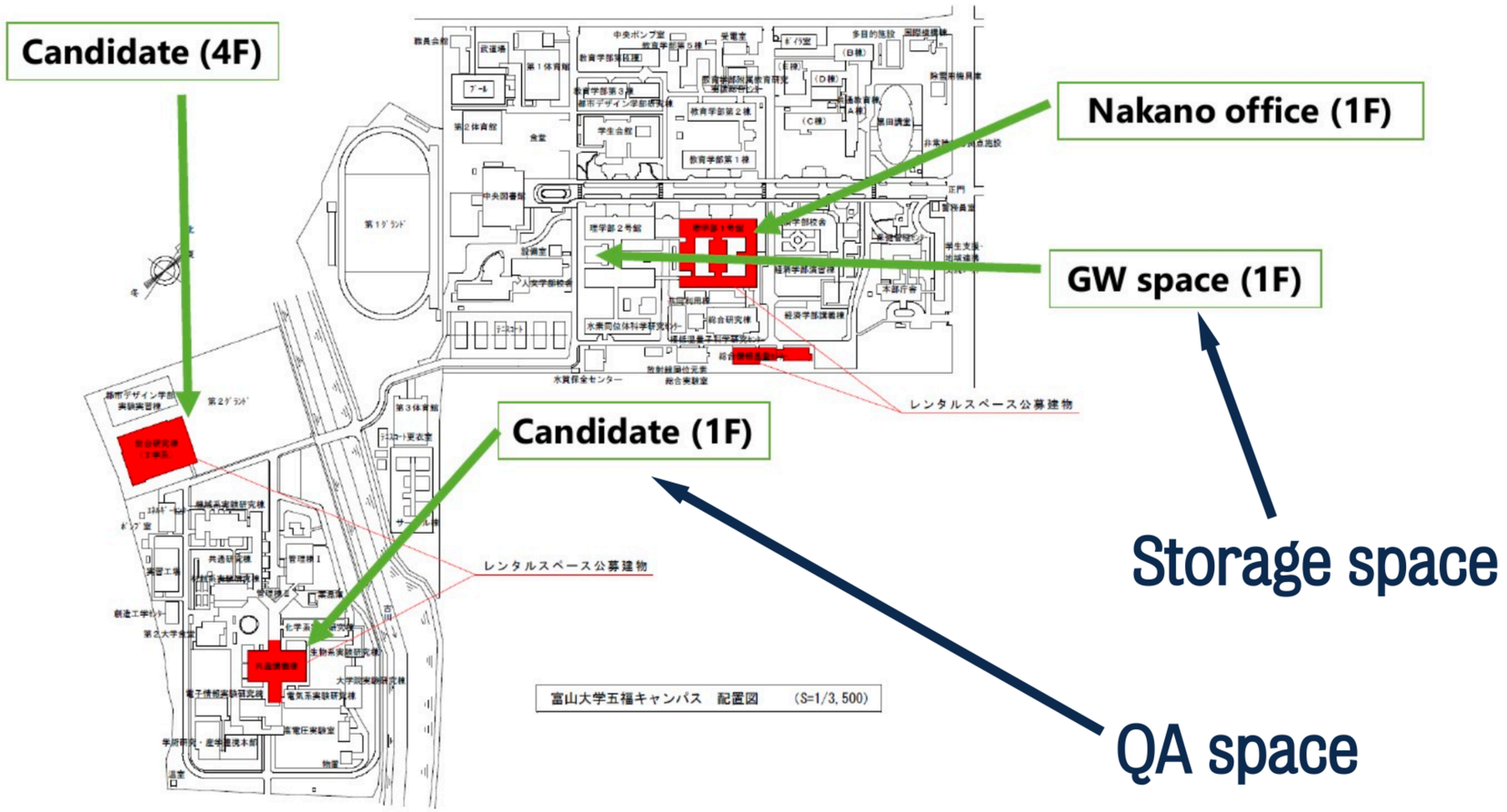



Input voltage and output signal from CAEN VME box

- 5 x HV power supply (6 ports each) CAEN V6521P
- 2x ADC (16 ports each) CAEN VX1730SB
- VME to USB bridge CAEN VX3718



# Storage/Location [confidential]

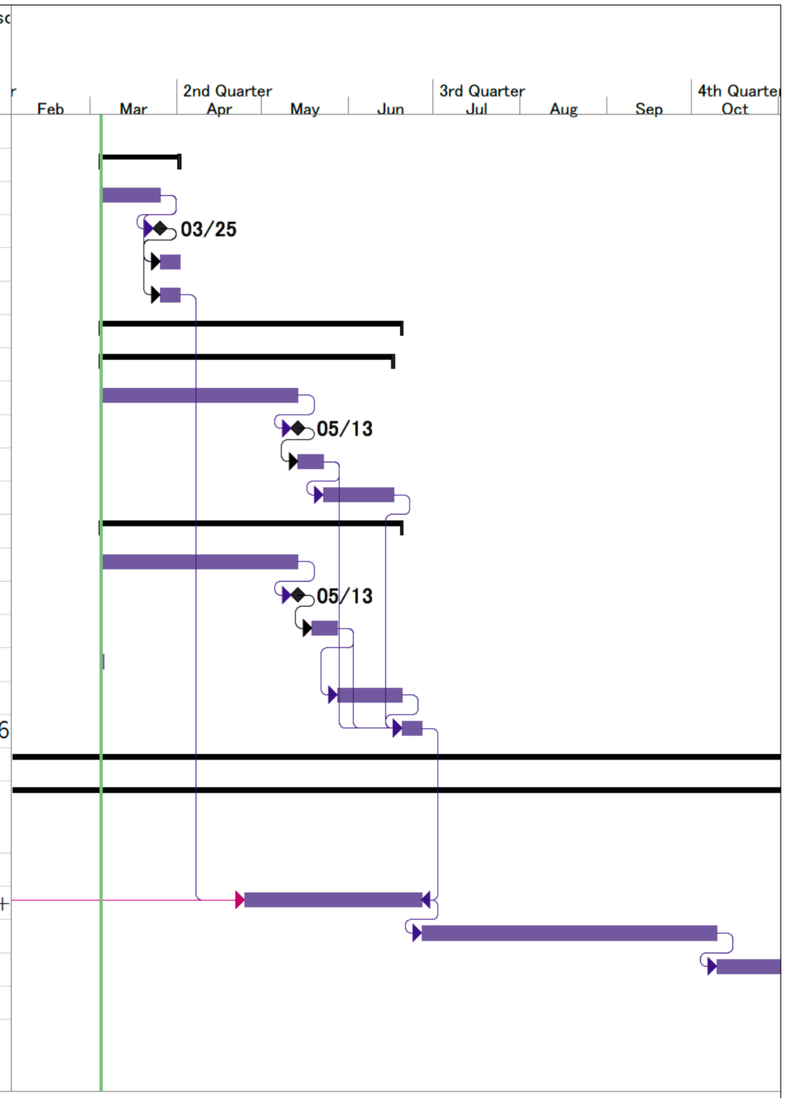



Spaces secured for OD at University of Toyama by logistics group

- Candidate (1F): 8mx9m
- Only need about 3x5m for the QA
- Could also be used for assembly and temporary storage of PMTs
- Not attached to the storage area - requires transportation

# Procurement and Schedule

| ID | Ta Mc | Task Name | Duration | Start | Finish | Predecessc |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | **PMT Specification Preparatic** | **20days** | **2025/03/05** | **2025/04/01** | |
| 3 | | UT Committee Review | 15days | 2025/03/05 | 2025/03/25 | |
| 4 | | Finalize Specifications | 0days | 2025/03/25 | 2025/03/25 | 3 |
| 5 | | Explain Specs To Vendors | 5days | 2025/03/26 | 2025/04/01 | 3,4 |
| 6 | | Specification to UT Office | 5days | 2025/03/26 | 2025/04/01 | 4 |
| 7 | | **PMT Decision Making** | **77days** | **2025/03/05** | **2025/06/19** | |
| 8 | | **NNVT** | **74days** | **2025/03/05** | **2025/06/16** | |
| 9 | | Order NNVT Samples | 50days | 2025/03/05 | 2025/05/13 | |
| 10 | | NNVT Delivered | 0days | 2025/05/13 | 2025/05/13 | 9 |
| 11 | | Jikkentou Testing (NNVT) | 7days | 2025/05/14 | 2025/05/22 | 10 |
| 12 | | Cathode Uniformity Testin | 17days | 2025/05/23 | 2025/06/16 | 11 |
| 13 | | **Hamamatsu** | **77days** | **2025/03/05** | **2025/06/19** | |
| 14 | | Order HPKK Samples | 50days | 2025/03/05 | 2025/05/13 | |
| 15 | | HPKK Delivered | 0days | 2025/05/13 | 2025/05/13 | 14 |
| 16 | | Jikkentou Testing (HPKK) | 7days | 2025/05/19 | 2025/05/27 | 15 |
| 17 | | Visit Hamamatsu | 1day | 2025/03/05 | 2025/03/05 | |
| 18 | | Cathode Uniformity Testin | 17days | 2025/05/28 | 2025/06/19 | 16 |
| 19 | | Decision to Reject or Keep Ver | 5days | 2025/06/20 | 2025/06/26 | 11,12,16 |
| 20 | | **PMT Tender and Purchasing** | **662days** | **2024/09/01** | **2027/03/16** | |
| 21 | | **Production tendering and contract** | **334days** | **2024/09/01** | **2025/12/11** | |
| 22 | | Request for Information | 45days | 2024/09/01 | 2024/10/31 | |
| 23 | | Request for Comments | 45days | 2025/04/25 | 2025/06/26 | 22,6FS+ |
| 24 | | Bidding | 75days | 2025/06/27 | 2025/10/09 | 23 |
| 25 | | Contracting | 45days | 2025/10/10 | 2025/12/11 | 24 |
| 26 | | Contingency - PMT Contract | 0days | 2025/12/11 | 2025/12/11 | 21 |
| 27 | | PMTs -Proceed to mass production | 0days | 2025/12/11 | 2025/12/11 | 26 |



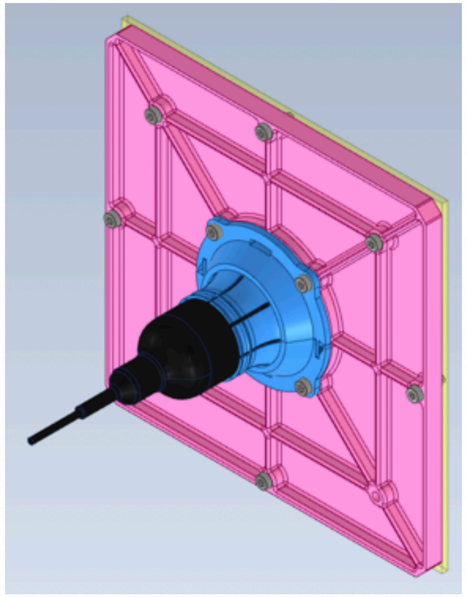

Now reviewing with experts and U.Tokyo specification committee before purchasing.

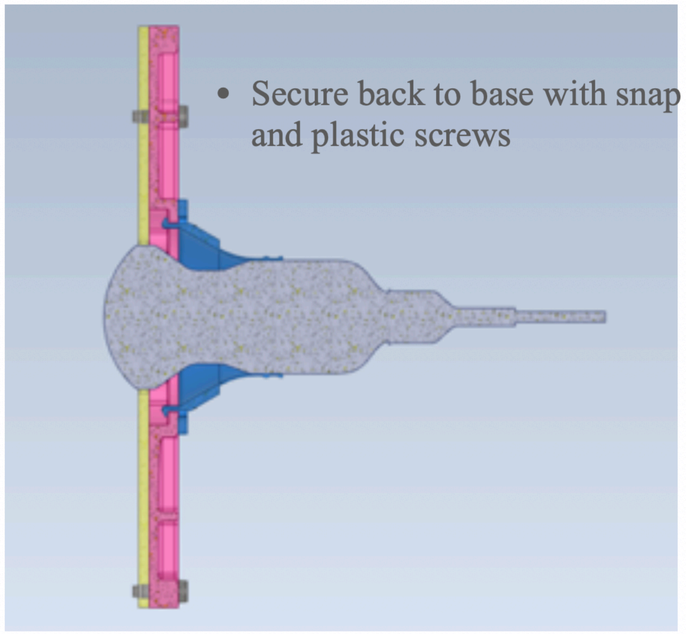
# Additional slides

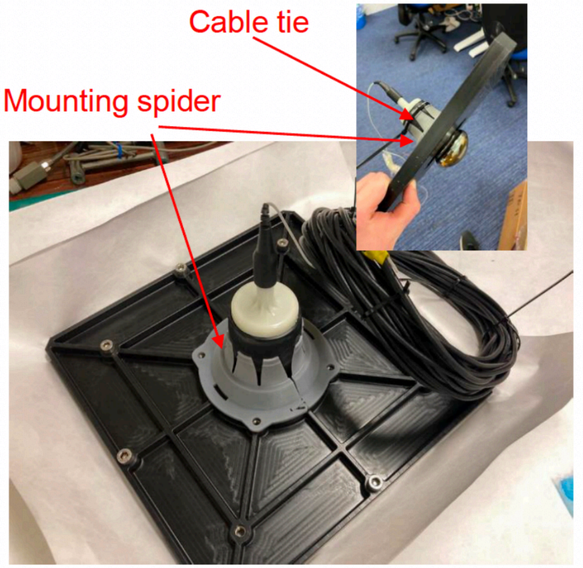
# PMT Mounting

(A. York, Oxford)

- Mostly Light-tight base






- Groove to secure PMT with cable tie

- Minor changes to design reported at December 2023 CM
  - → Converged for HPK tubes
- "Spider" backing produced by injection moulding

- Prototype ready, "shake" testing underway
  - Installation testing etc. with RAL mockup and Japanese mock-up mostly successfull

- No major issues though some design modifications may be needed installation (more later)