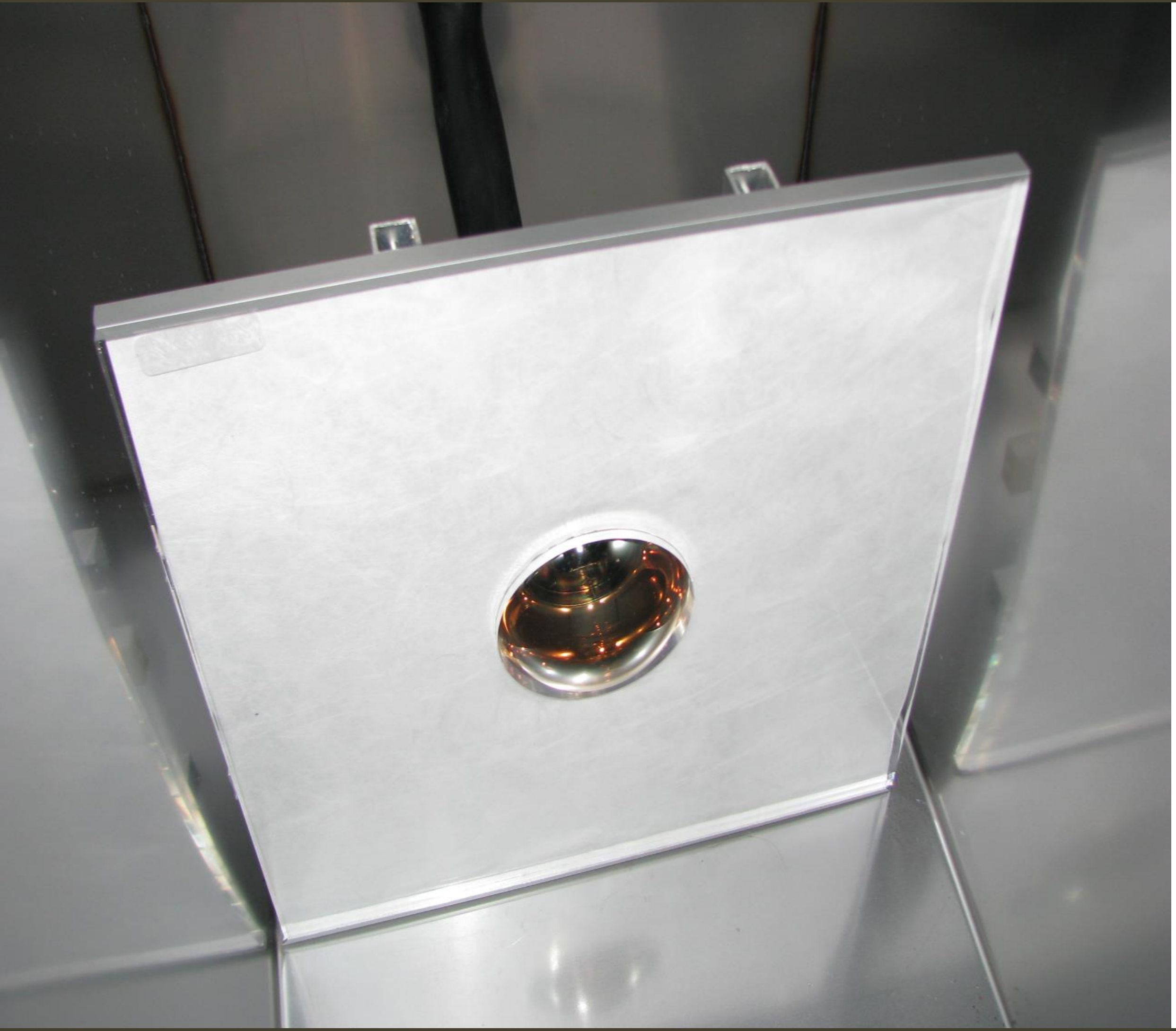
7th INTERNATIONAL CONFERENCE
ON PARTICLE PHYSICS AND ASTROPHYSICS
(ICPPA-2024)



FACILITIES AND ADVANCED DETECTOR TECHNOLOGIES SECTION

PMT/WLS plate optical modules for Cherenkov detectors

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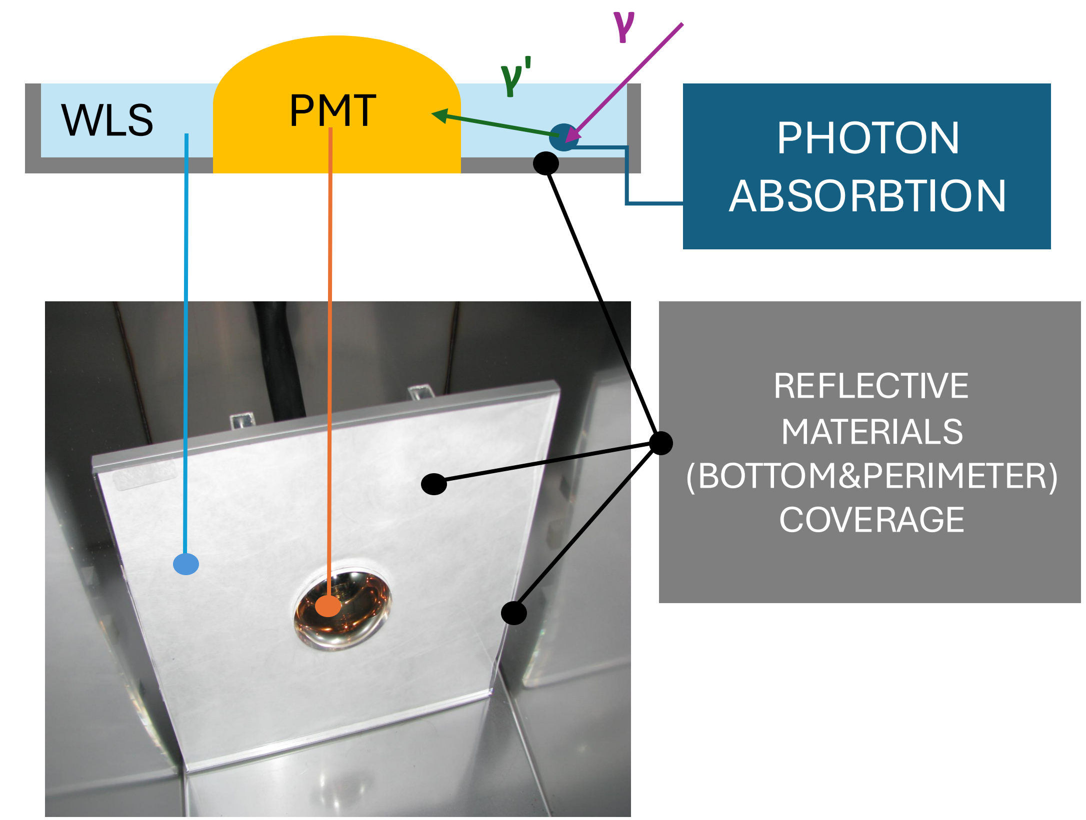
WLS/PMT OPTICAL MODULES

WLS plate **(wavelength shift)** with **PMT (photomultiplier tube)** optical module for Cherenkov detectors: WLS plate **increases useful surface** of detector **for light collection** and **absorbs** Cherenkov's light then **reemits** it **in sensitivity** part of **PMT spectrum**.

WLS plates in report are made from **PMMA** (polymethylmethacrylate, as known as acrylic glass) with WLS dopants in Dzerzhinsk at "SRI Polymers".

Such optical modules can be used in water Cherenkov detectors like a component of veto-systems. For example, **Outer Detector (OD)** of **Hyper Kamiokande (HK)**. **Design** of WLS plates in report is **developed for HyperK OD**. Plate size is 300x300x7 mm^3.



Pic.1. Schematic illustartion of the operating principle of the WLS/PMT optical module. Reflective materials are applied in the form of a film around the perimeter and a substrate at the bottom.

PMT STUDY

Pic.2. Device for cathode sensitivity measuring.

Cathode sensitivity is important characteristic for PMT and WLS plate **optical connection**. There was comparison of two main **3" PMT candidates for** usage in **OD**: **Hamamatsu R14374** and **NNVT 2031**.

Both of them have **identical specification**. The **sensitivity area** of photocathode corresponds for cathode diameter **less** than **72 ⌀mm** due to specification.

Special device was developed for measurements of the cathode sensitivity. It can provide measurements with azimuthal and polar coordinates variation.

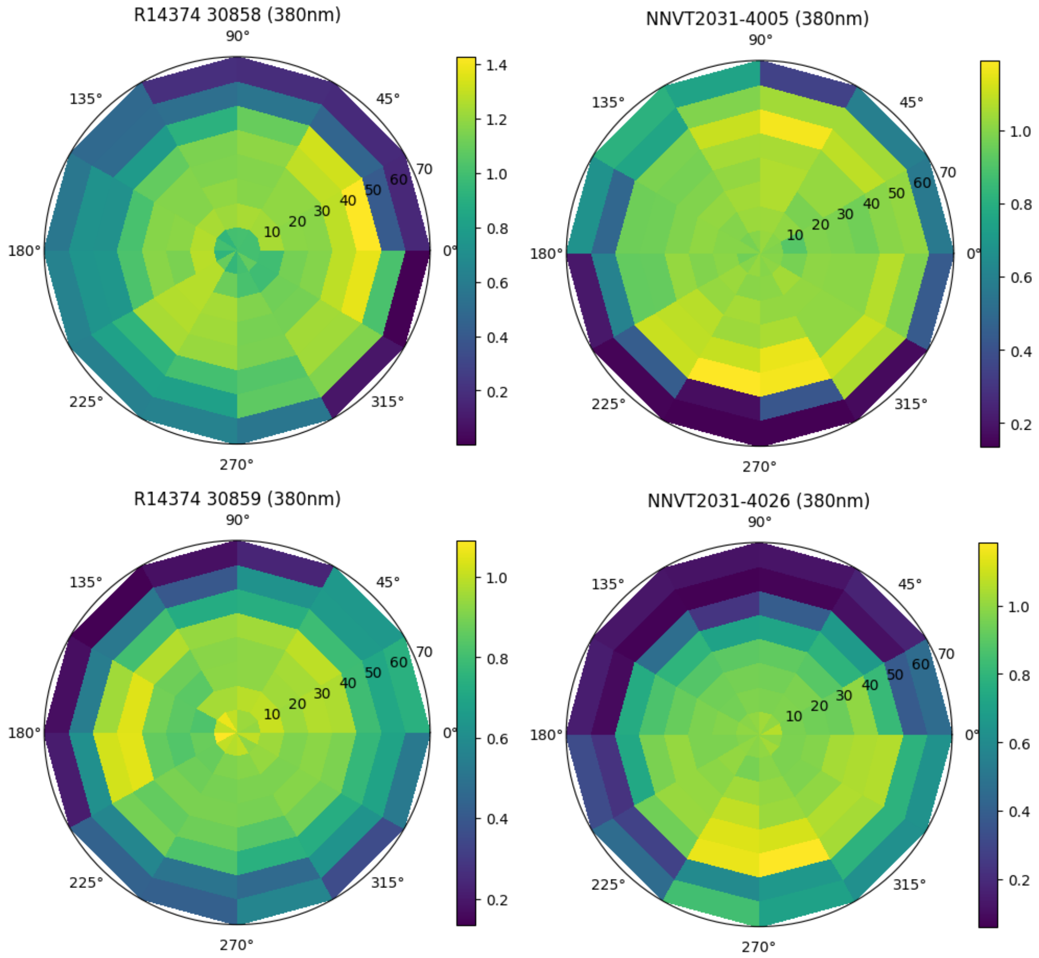
CATHODE SENSITIVITY PRELIMINARY RESULTS

Varying the polar and azimuthal angles made it possible to construct heatmaps of the tested photomultipliers. The sensitivity of the cathode was estimated based on heatmaps.

Result of the test for LED 380nm:

- **All PMTs** have **weaker signal** in **"non-sensitivity"** area

- **R14374** has **more stable** cathode sensitivity, esspecially **in contact area** with WLS

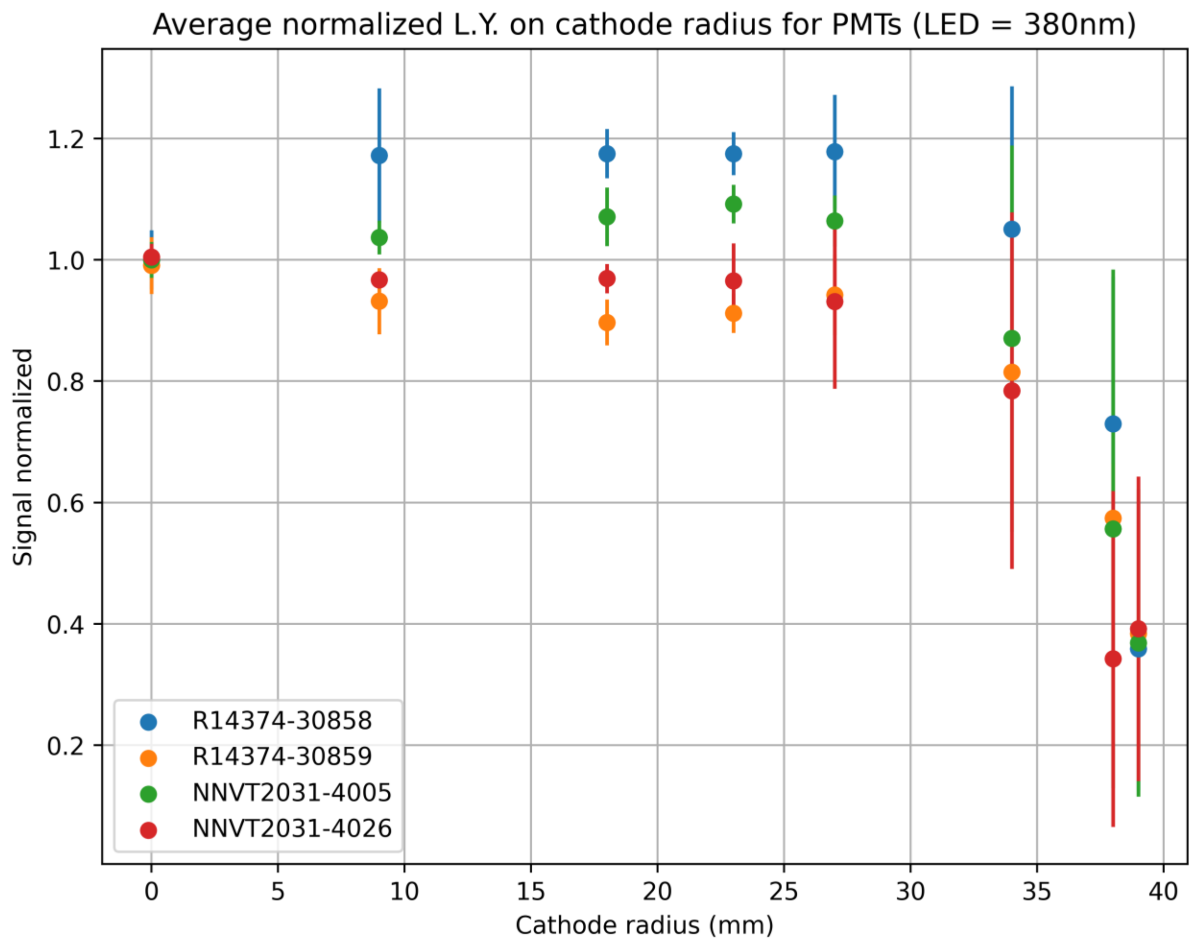


Pic.3. Cathode sensitivity heatmaps: leftside – R14374; rightside – NNVT 2031.

CATHODE SENSITIVITY PRELIMINARY RESULTS

Results for **the signal averaged over the cathode radius** show that R14374 **does not differ** from NNVT 2031 **in** the **sensitivity area** (less than 36 mm of the cathode radius) and is quite stable.

The **non-sensitivity** area starts from a cathode radius of **34 mm,** and the reduction level is about **60%**.



Pic.4. Average signal for cathode radius.

DARK RATE
PRELIMINARY RESULTS

Dark rate measurement for Hamamatsu R14374 with **Threshold 0.3 p.e** and temperature **20 ^{o}C** for fixed **gain** level = **5 x 10^6**.

№	SUPPLY VOLTAGE, V	GAIN X 10^6	DARK RATE, Hz
KM32077	1110	5.0	290
KM30858	1095	5.0	291
KM60330	1075	5.0	245
KM60344	1140	5.0	286
KM30863	1320	5.0	435
KM30859	1225	5.0	478
KM60329	1135	5.0	323

WLS DOPANT REVIEW

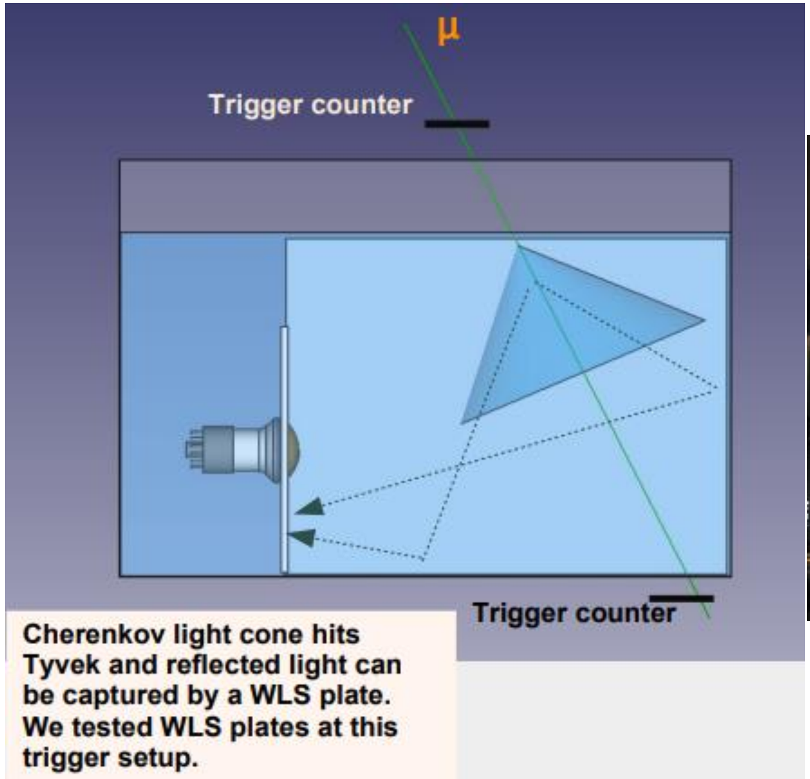
POPOP for **long UV, PPO** for **short UV**

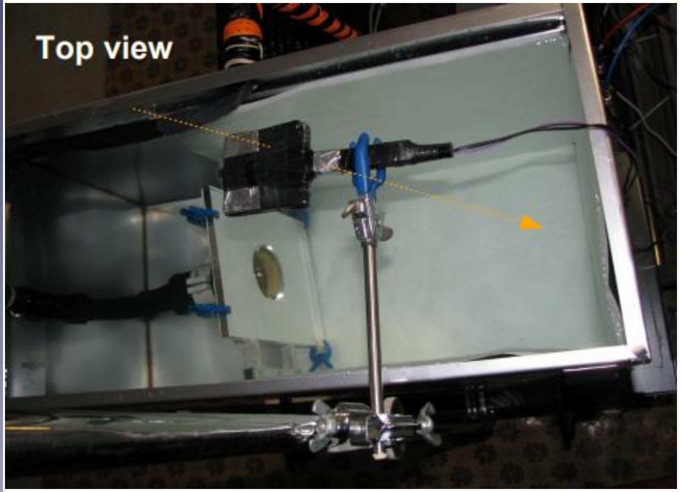
Marker rule: first place – dopant name
Then – concentration [mg/L]

Task:
Check all combination of dopants and it's concentration to find most optimal variant.

WLS	POPOP	PPO
Absorption spectrum, nm	250 - 390 peak: 360	290 - 330 peak 300
Emission spectrum, nm	380 - 510 peak: 390 - 450	320 - 410 peak: 340 - 380

WLS DOPANT SELECTION



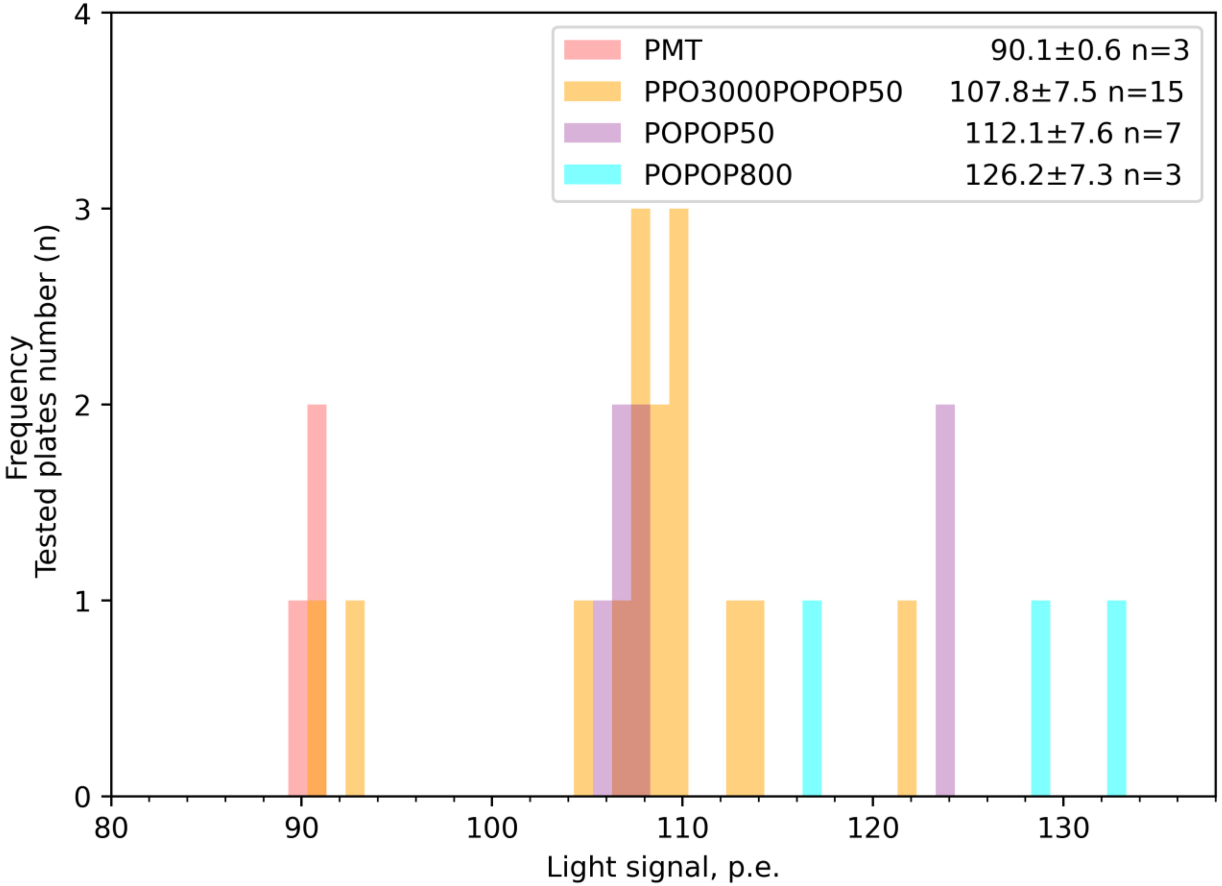


Pic.5. Schematic view of water Cherenkov detector Infant-K.
Trigger telescope is arranged to select cosmic muon tracks inclined in direction away from a WLS plate.

Infant-K is special **water Cherenkov detector** that was created **for WLS plates study.**
Plate size: 7 x 300 x 300 mm3
Double fluor POPOP50-PPO3000 - 15 pcs
Single fluor POPOP50 - 7 pcs
Single fluor POPOP800 - 3 pcs
Light source:
reflected Cherenkov light from cosmic muons
Reflector:
unknown Tyvek, 190 μm thickness
Water: distilled for industry purposes
PMT : Hamamatsu R14374

Measurement cycle has taken over 2 months.

WLS DOPANT SELECTION



Pic.6. Results of Infant-K tests.

Average light yield from a WLS plate (PMT contribution is subtracted):

- POPOP50-PPO3000 : 108 p.e. (15 pcs)
- POPOP50 : 112 p.e. (7 pcs)
- POPOP800 : 126 p.e. (3 pcs)

Spread in light yields: ± 12% from average.

WLS PLATES DARK RATE

Dark rate is important for triggering systems. Low dark rate provides HK with longer exposition time. In this test dark rate was checked with **temperature 13 ºC** like in OD:

WLS plates	Bare PMT	Pure PMMA (no WLS fluor)	POPOP 800	POPOP 400	POPOP 200	POPOP 50	POPOP 50/ PPO3000
Dark rate at 0.25-0.3 p.e. Hz	~ 200	~ 240	~ 800	~ 490	~ 390	~ 300	~ 680

POPOP 50 is the best choice due to **low dark rate** level and **high signal** for Cherenkov's light.

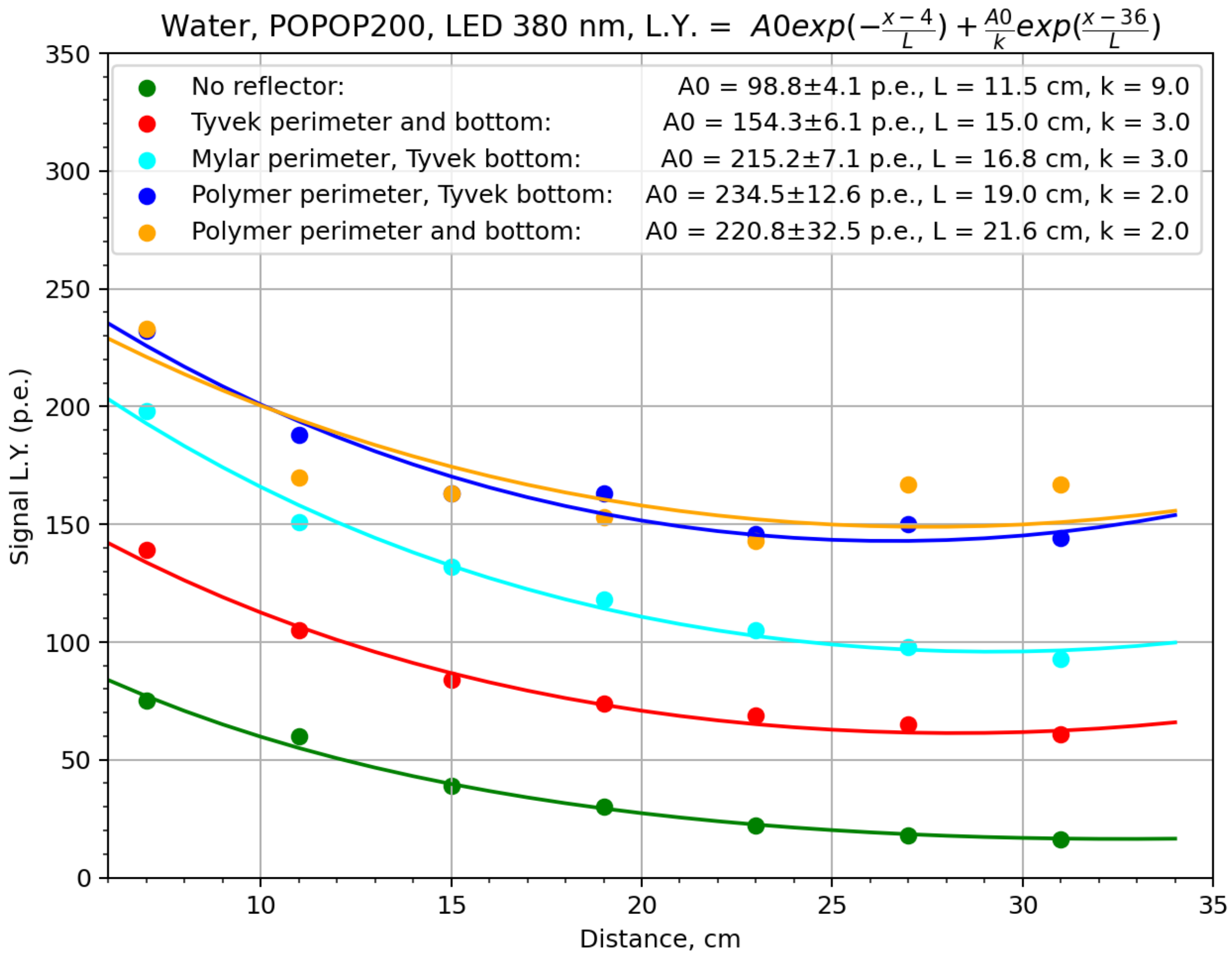
REFLECTORS STUDY

Usage of a **reflector** is a good idea to **increase light collection** of WLS plate. Multireflected light has higher possibility to transfer into sensitivity spectrum of PMT.

There are three types of reflectors to choose:

- Tyvek (polymer, diffusion reflector)
- Mylar (aluminized film, mirror reflector)
- 3D DF2000MA (polymer, mirror reflector)

The most effective combination of reflectors is Polymer Perimeter 3D DF2000MA and Tyvek bottom (**increase of L.Y by 2 times compared to plate without reflectors**)



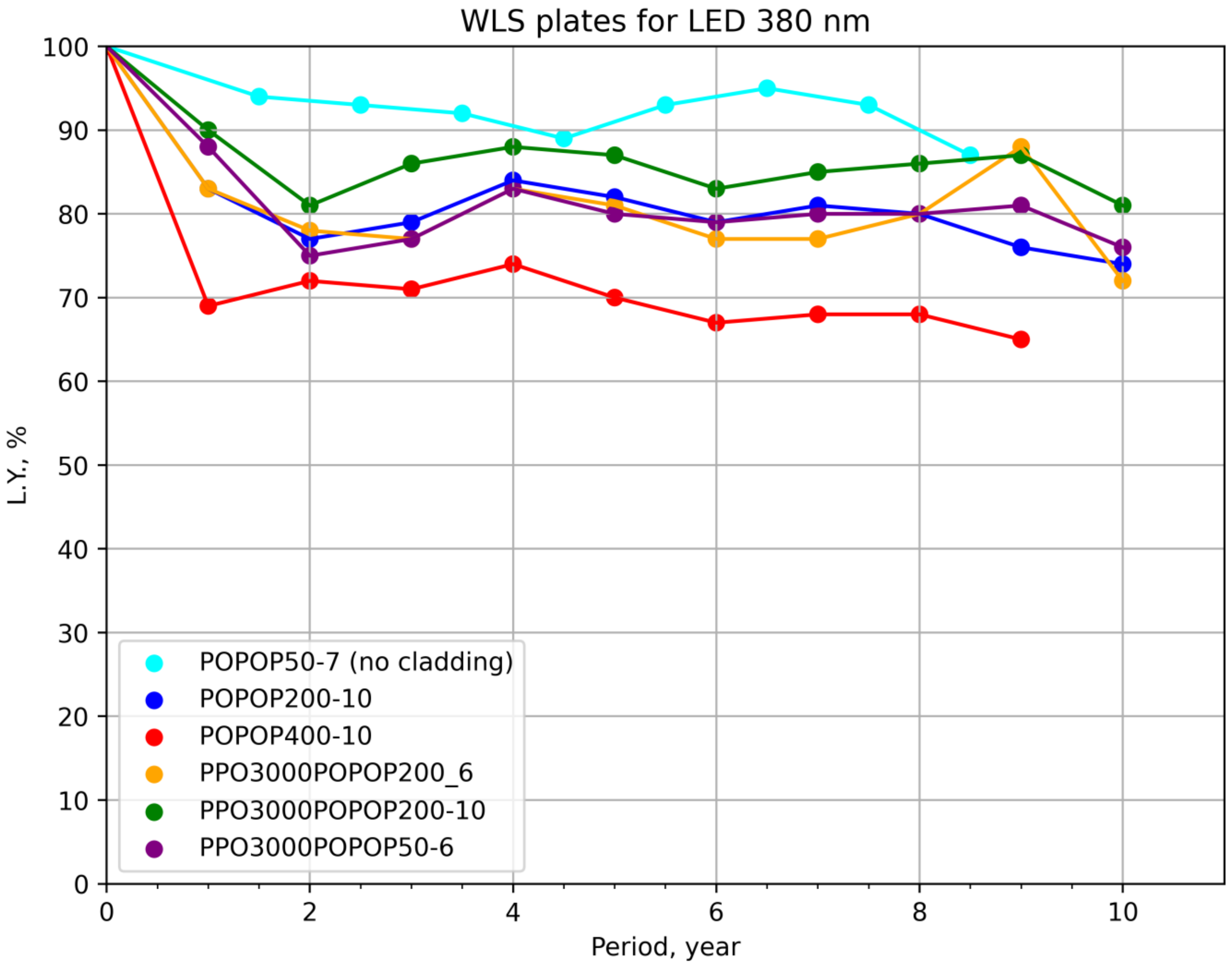
Pic.7. Comparison of reflectors in water.

WLS PLATES AGING

Aging of WLS Plates is an important aspect to measure. All plates were tested in special thermal camera with constantly temperature **59 ºC**. **2 weeks** in camera is equal **one year** at **13 ºC** in **OD**.

Cladding - 3D DF2000MA perimeter. All signals was calibrated on plate signal before aging test.

All plates are practically **stable after first year of heating**. The possible reason of first year aging is **glue** in cladding. Excluding this fact the **aging** is less than **< 2%/year**.



Pic.8. Aging of WLS plates.

CONCLUSION

The results of PMT/WLS plates optical modules for Cherenkov detectors study:

1. **Hamamatsu R14374** has **better cathode surface** than **NNVT 2031**. **Non-sensitivity** area **starts** from **34 mm** cathode radius. The **signal decrease level** in **non-sensitivity** area is nearby **60%** for both PMTs.

2. **Dark rate** for most Hamamatsu **R14374** with threshold **0.3 p.e** and temperature **20 0C** is **less** than **~320 Hz**. Some PMTs have bigger dark rate.

3. **POPOP 50** is the best choice due to **low dark rate** level and **high light signal** for Cherenkov's light.

4. **Reflectors** can **improve** WLS plates **light collection** efficiency **by 2 times**. **The best choice** is **3D DF2000MA film on perimeter** and **Tyvek reflector on bottom side** of WLS plate.

5. **WLS plates aging** is less than **< 2%/year excluding glue factor.**

Thank you for your attention!

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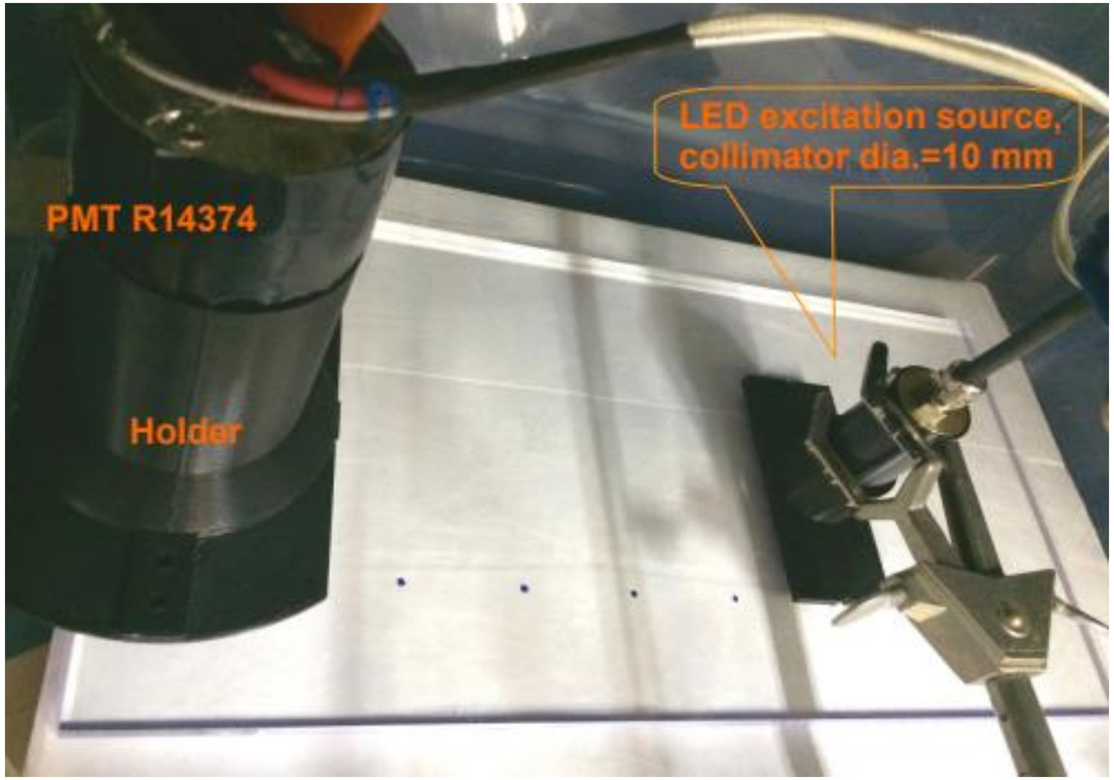
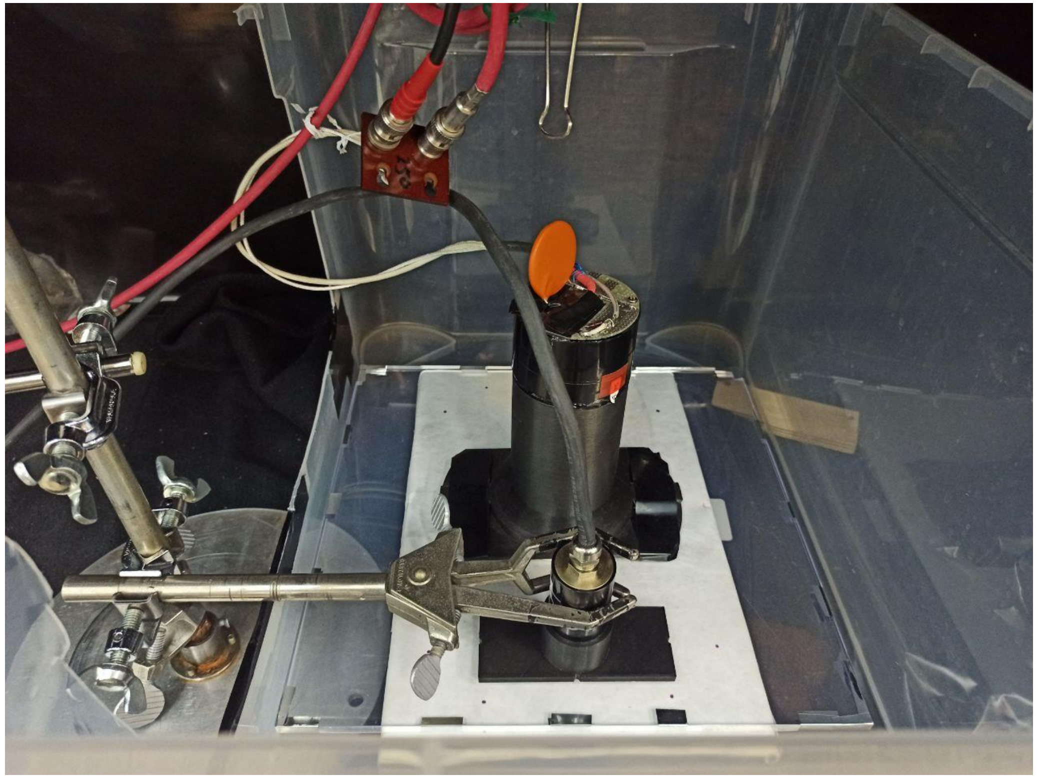
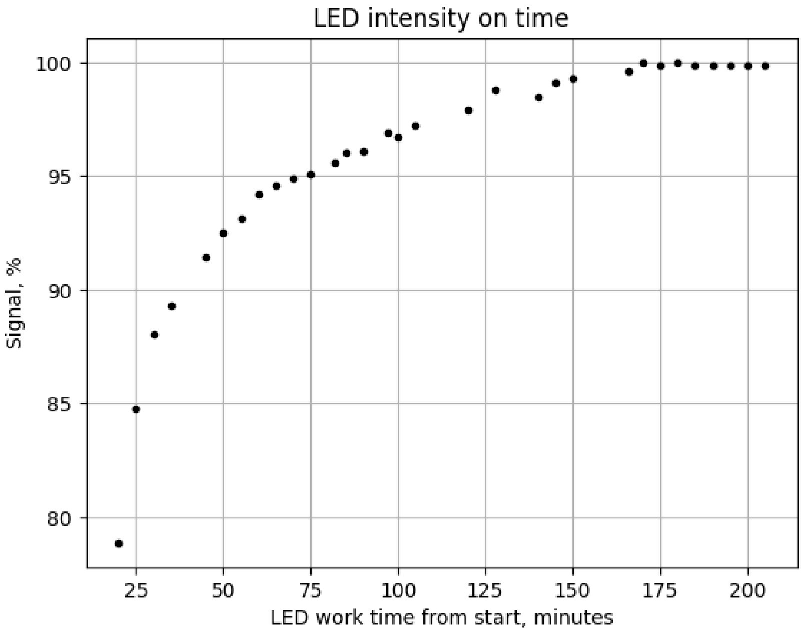
BACK UP SLIDES



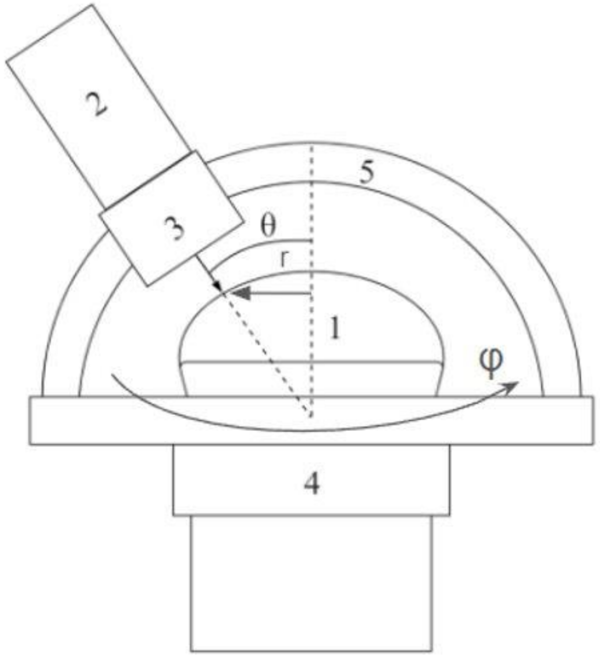


Pic.9. Setup for LED tests of WLS plates. Measuring of L.Y. on distance of LED position.

PMT STUDY



Pic.10. LED stability on time.



Pic.11. Schematic illustartion of device for cathode sensitivity study.

1. PMT
2. LED
3. Collimator 1 ⌀mm
4. Graduated azimuthal ring
5. Arcs for polar angle θ variation and rotation-platform for azimuthal angle φ variation

HAMAMATSU R14374 SPECIFICATION

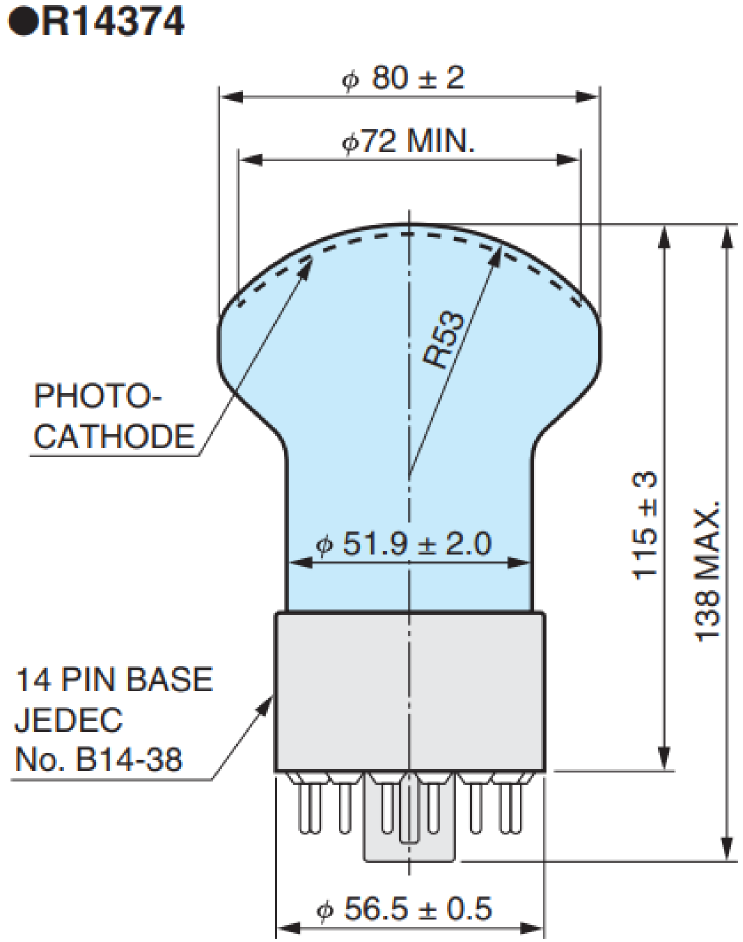


Figure 1: Typical spectral response

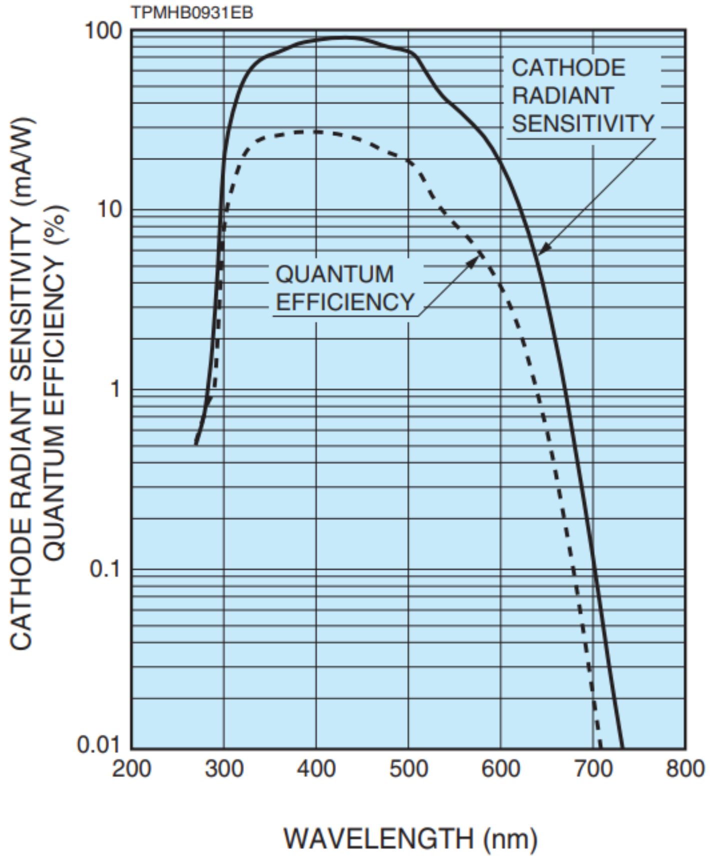
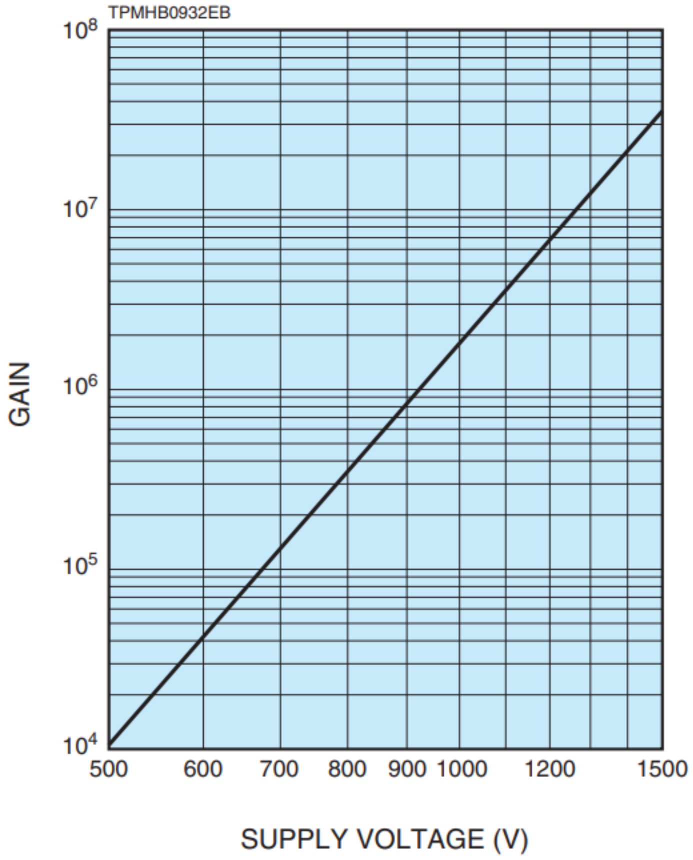
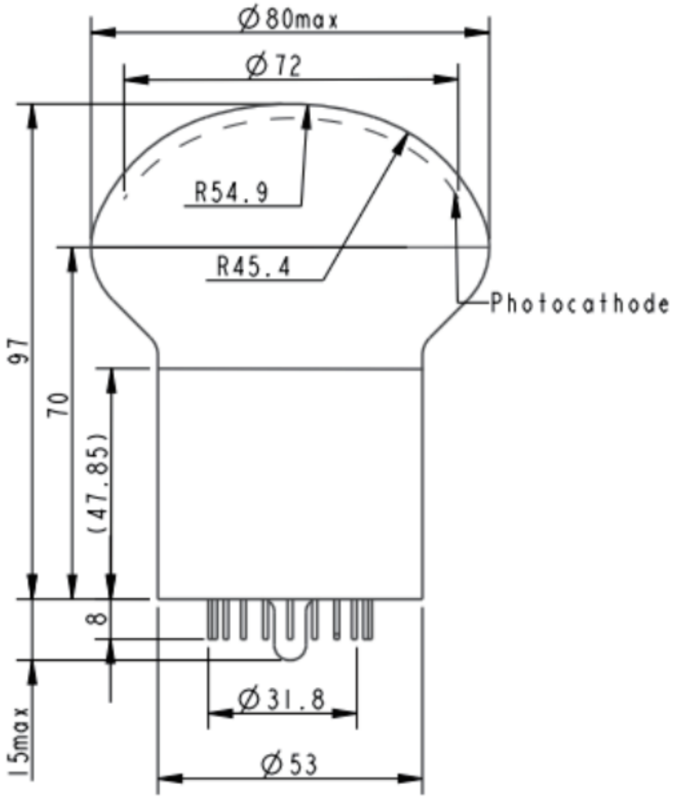


Figure 2: Typical gain

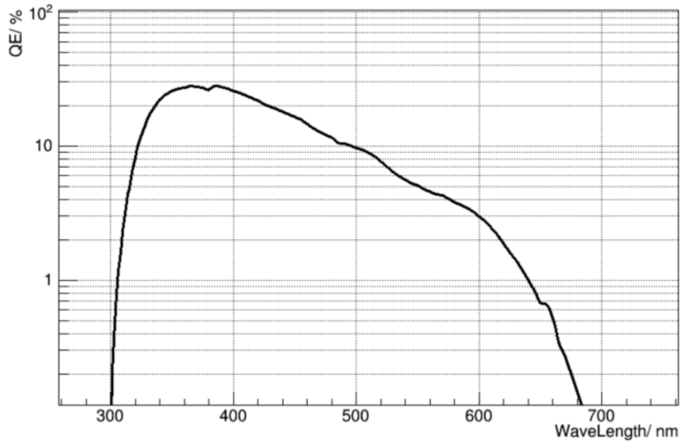


Pic.12. Hamamatsu R14374 specification

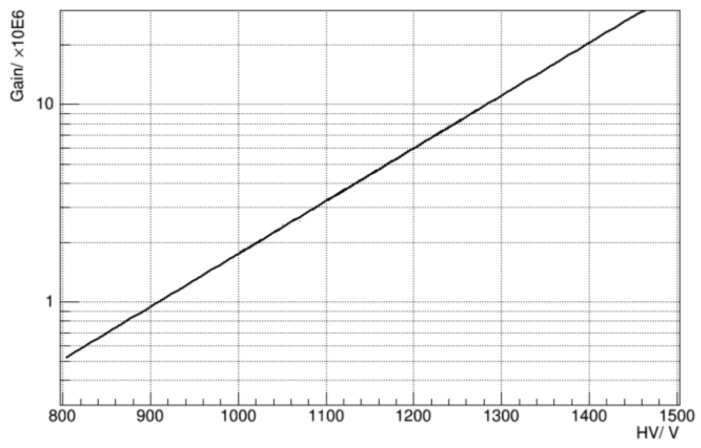
NNVT 2031 SPECIFICATION



N2031光电倍增管结构图
N2031 PMT structure



典型光谱响应曲线
Typical spectral response curve



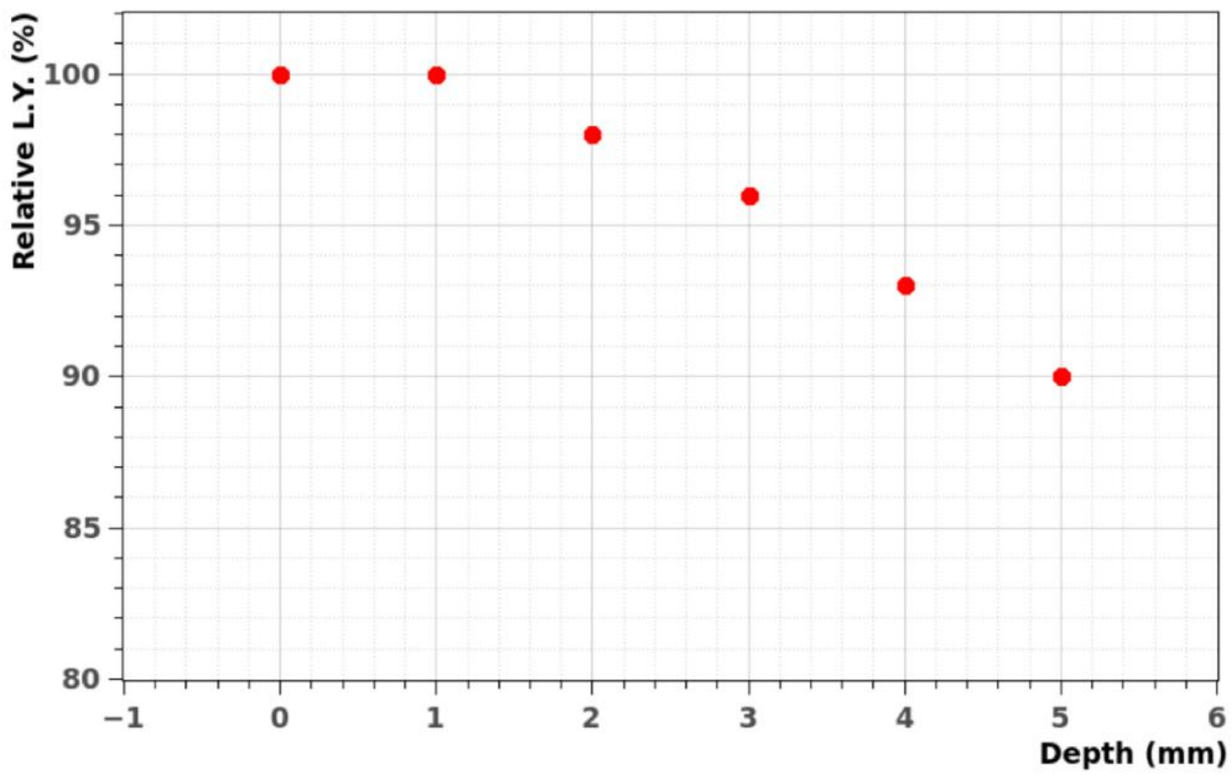
典型增益曲线
Typical gain curve

Pic.13. NNVT2031 specification.

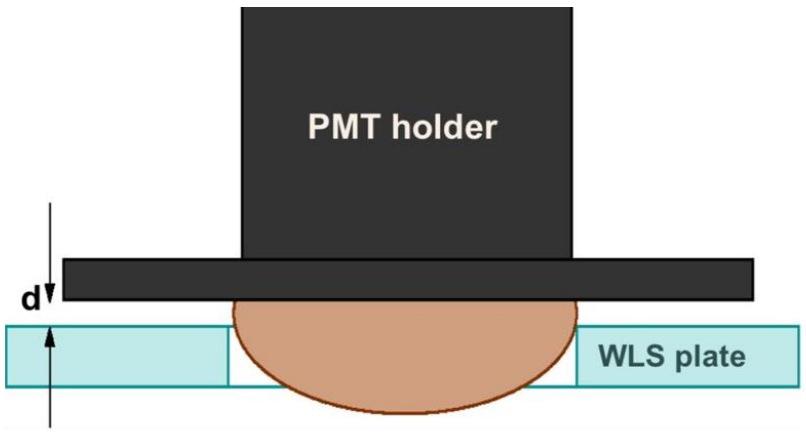
SEAT DEPTH

Seat depth is important parameter for complex usage with PMT. WLS plate covers cathode surface of PMT and influences on direct light. The right distance-parameter can provide the most PDE.

All signals is normalizerd on 0-depth L.Y.
As shown on plot, the most optimal depth is 1mm. Cause PMT bulb doesnt contact the WLS plate.

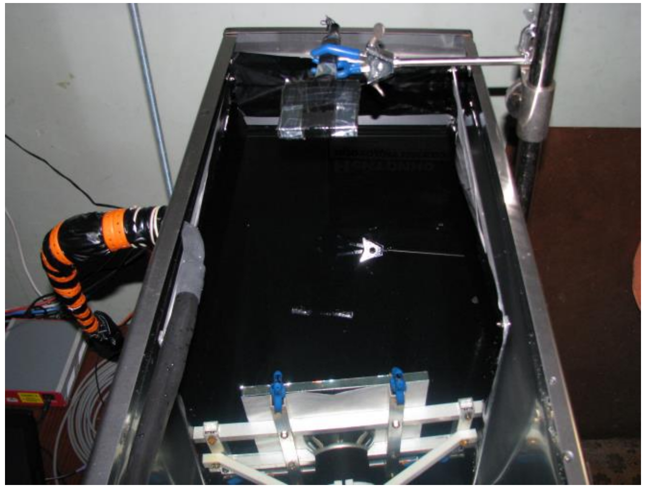


Pic.14. Relative L.Y. on PMT's seat depth against WLS plate.

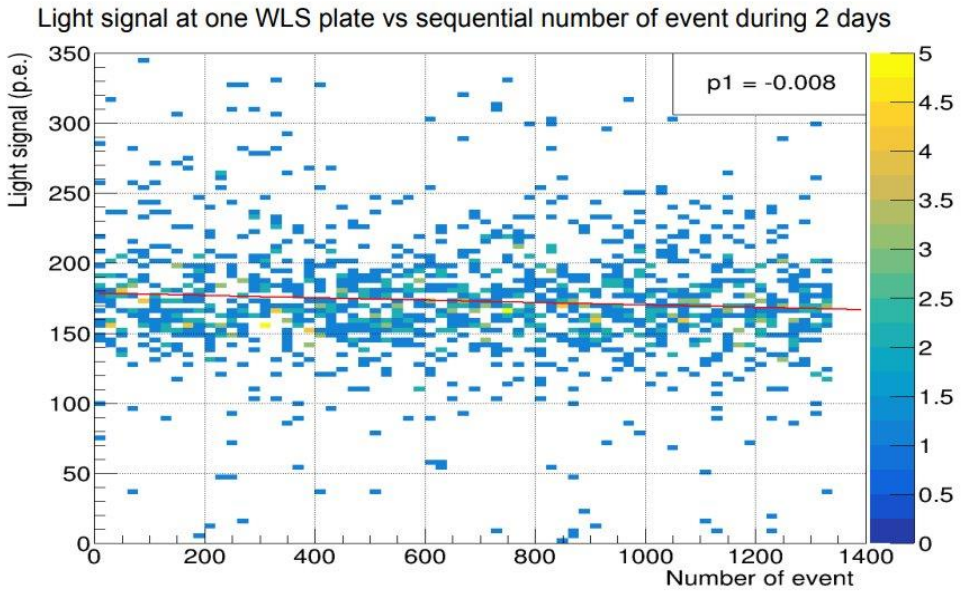


Pic.15. Schematic illustration of PMT's position against WLS plate.

INFANT-K SETUP



InfantK setup is a small water Cherenkov detector (68 x 33 x 58 cm^3).
Volume of water = 100 L.



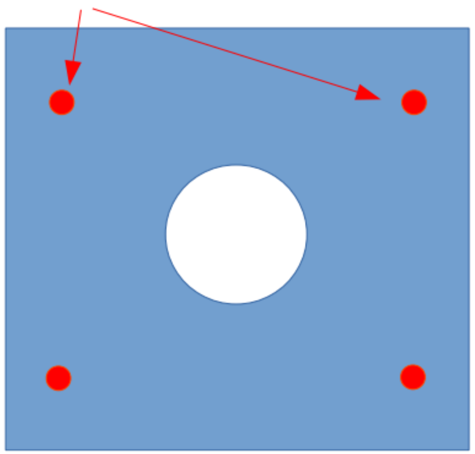
A few calibrations were made to see the rate of degradation. 4 different plates (both single and double-fluor ones) were re-measured with **time interval of ~ 40 days**.

The average light signal degradation was calculated as:
0.86% per day for double fluor plates
0.77% per day for single fluor plates

We have measured the signal degradation over time for only PMT (PMT is optically isolated from a WLS plate). PMT has shown the rate: **0.27% per day.**

No good explanation for difference in degradation rates for PMT and WLS.

SPECTRAL RESPONCE CHECK



Pic.16. LED positions for spectral responce checking.

LED wavelength	265 nm	315 nm	380 nm	405 nm
POPOP 50 — PPO 3000	100%	100%	100%	100%
POPOP 50	13%	133%	124%	118%
POPOP 100	33%	130%	105%	142%
POPOP 200	46%	124%	100%	160%
POPOP 400	84%	154%	117%	230%
POPOP 800	100%	153%	124%	261%

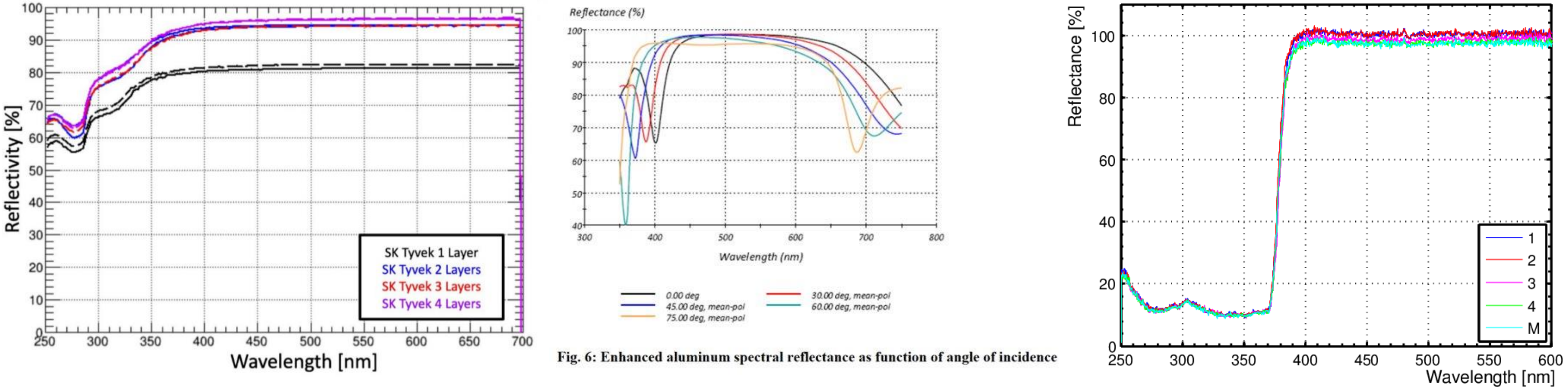
Looks like the WLS plate with double fluor does not see short UV due to InfantK tests. We have to check the spectral responce of the WLS plates to UV range

Measurement procedure for each LED wavelength: LED irradiates a WLS plate in 4 fixed points. The measurement of each plate was done twice. The average of all results for the plate of the same type was calculated. POPOP50PPO3000 is a calibration plate.

Tested plates:

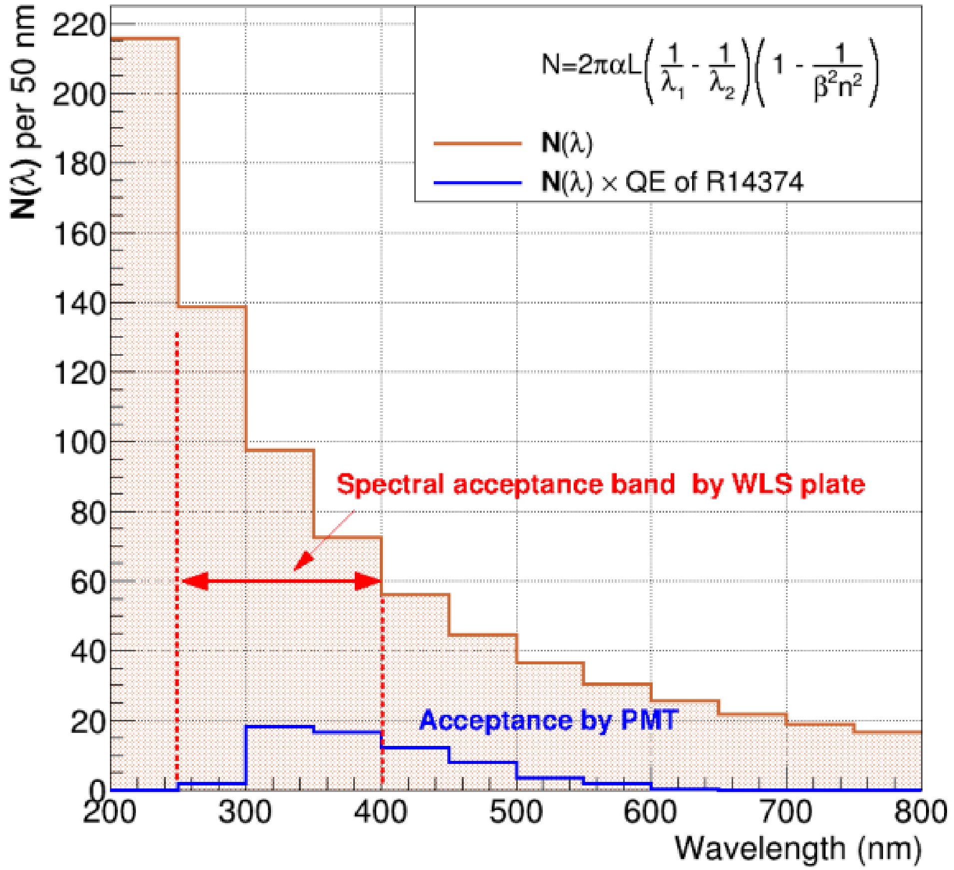
- POPOP50PPO3000 - 3 pcs
- POPOP50 - 3 pcs
- POPOP800 - 2 pcs
- All others - 1 piece

REFLECTORS

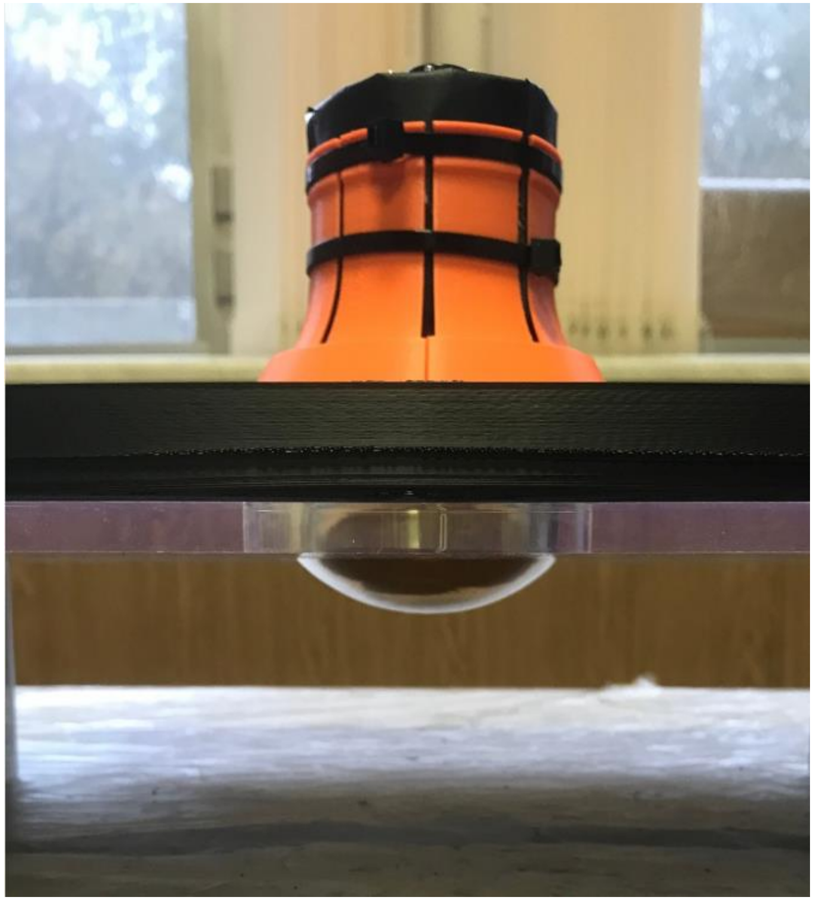


Pic.17. Reflectance for different materials: Tyvek, Mylar, 3D DF2000MA (from left to right).

ADDITIONAL



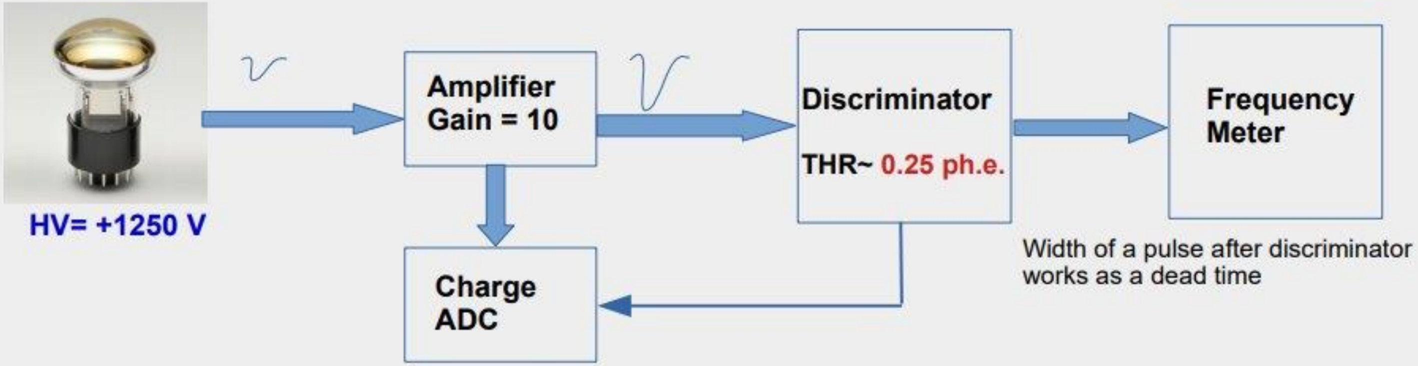
Pic.18. Spectral acceptance for optical module's components.



Pic.19. Mount of PMT and WLS plate.

ADDITIONAL

Dark rate of R14374 Hamamatsu PMT at positive HV



The measurements were made inside a **temperature controlled volume**.

Tested setup: **PMT + WLS plate with a single fluor (POPOP50)** wrapped by 3M DF2000MA cladding reflector.

Discriminated pulse width was set to be **1.5 μs** to suppress:

- the generation of multiple transition pulses with low threshold at falling pulse tail;
- multiple correlated pulses at PMT discharges (pulse bursts)
- afterpuses