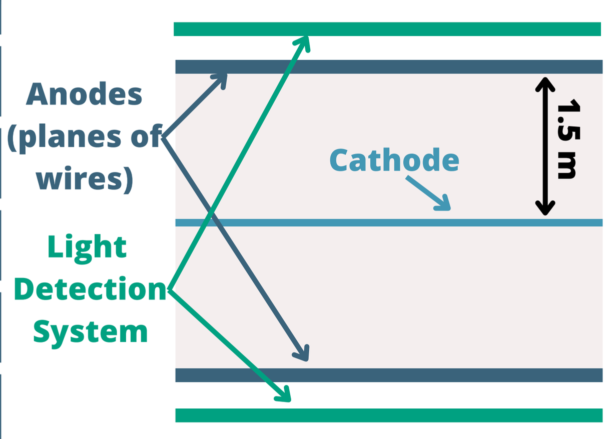
Gain stability of Hamamatsu R5912-MOD photo-multipliers at low temperature

C. Saia[1,2] - V. Brio[2] - R. Persiani[2] - C.M.A. Petta[1,2] - G.L. Raselli[3] - M. Rossella[3] - M. Vicenzi[4]
for the ICARUS collaboration

clara.saia@studium.unict.it

1. University of Catania (Italy); 2. INFN Sezione di Catania (Italy); 3.INFN Sezione di Pavia (Italy); 4. BNL (USA)

ICARUS T600 Light Detection System



Schematic view of one of the T300 modules.

The ICARUS detector at FNAL consists of two identical T300 modules each containing a TPC filled with liquid argon. In each module, electrons, produced by ionizing particles, drift from a common central cathode towards the anodes, made of three parallel planes of wires.
These ionizing particles also produce **scintillation light** in the VUV range (λ = 128 nm), collected by the PMTs light detection system: behind the planes of wires **360 8" photo-multipliers R5912-MOD** are installed (90 each side).
The PMTs are mainly used to perform the trigger signal for readout, improve the spatial and timing resolution of particles identification and contribute to cosmic rays veto [a] [b].

PMT R5912-MOD

- Bialkali photocathodes on a Pt under-layer (allow to operate till -200 °C).
- Peak sensitivity at λ = 420 nm: coated with 200 μg/cm^2 Tetra-Phenyl Butadiene (TPB) as wavelength shifter.
- Typical Gain: 1 x 10^7 at 1500 V.
- Linear anodic response as a function of the incident light intensity [c].


8" diameter

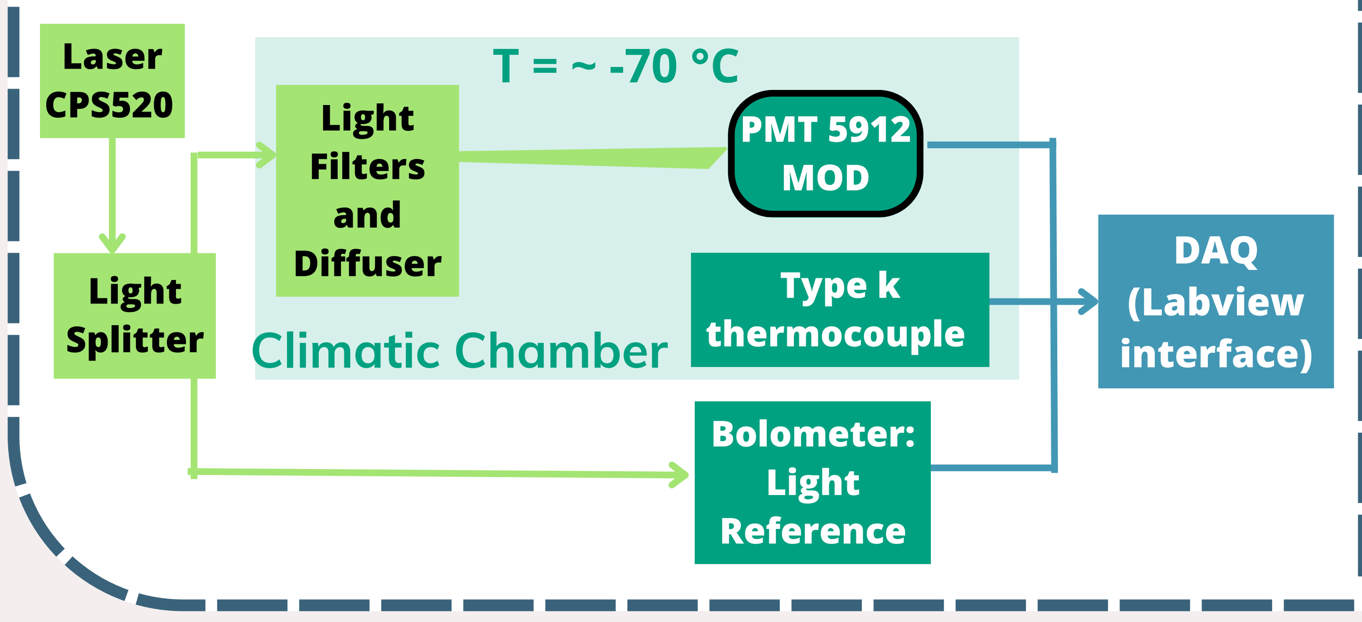
PMTs Gain Loss

During these years, since June 2020, the PMTs have shown **gain loss as an aging effect** while operating at liquid argon cryogenic temperatures (T = 87 K).

	Gain loss rate	Mean gain
RUN2	0.64% /month	0.46 × 10^7 ± 2.1%
RUN3	0.31% /month	0.39 × 10^7 ± 1.5%

Experimental Setup

Using a **climatic chamber,** we arranged an experimental setup to verify the PMTs gain stability or loss, using one of the spare PMTs - non-TPB coated. The climatic chamber allows to reach temperatures till -70°C.



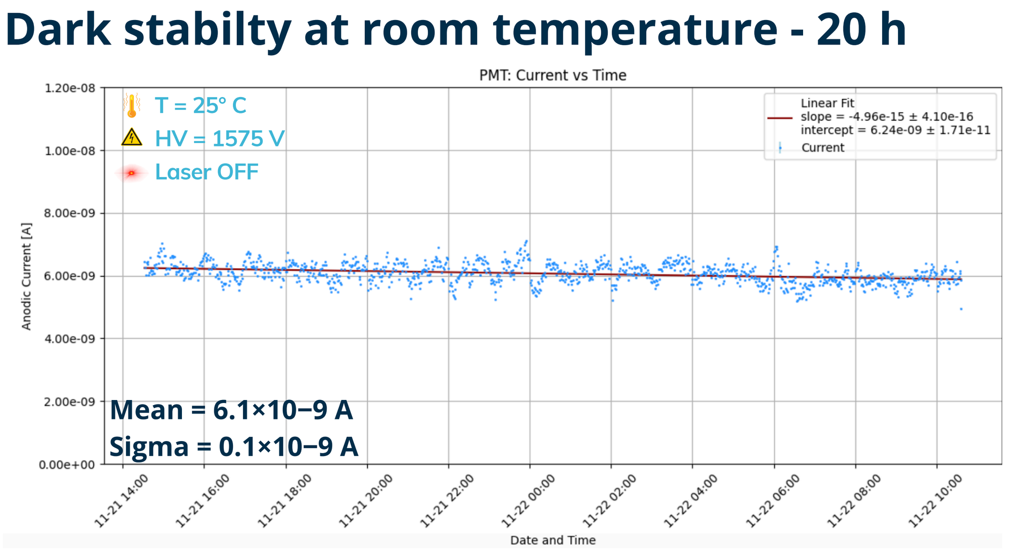
The PMT is illuminated by a **520 nm laser diode source** and operates in current mode.
The laser beam is split into two optical fibers:

- the first one transmitting light through Neutral Density filters and then diffusing it over the surface of the PMT photocathode;
- the other optical fiber is used for an independent reference measurement of the injected light power via a bolometric photodetector.

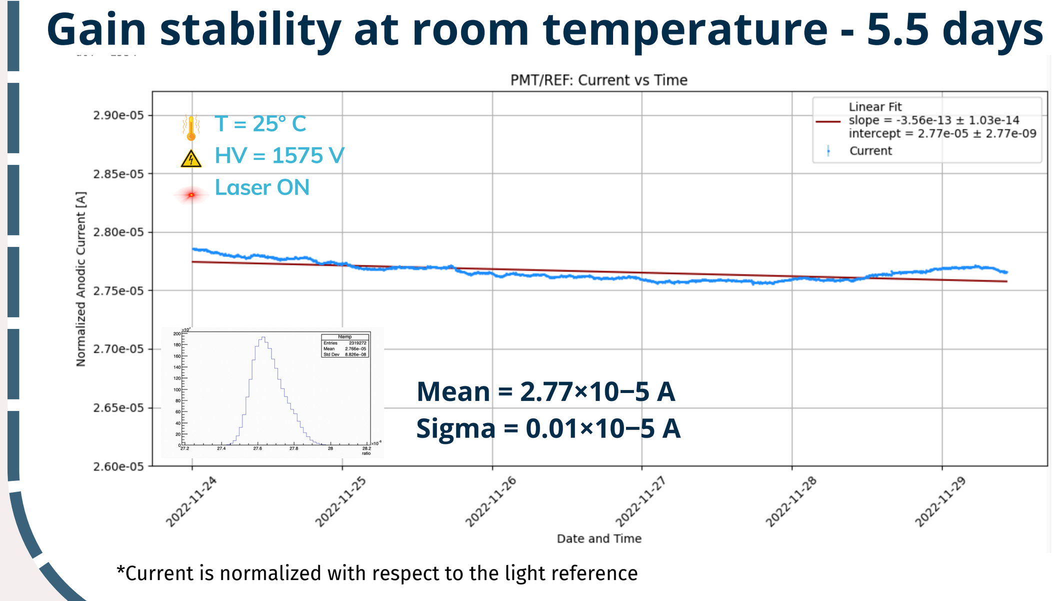
The temperature is measured via a type k thermocouple located near the PMT photocathode.

Stability Gain Measurements

Dark stabilty at room temperature - 20 h

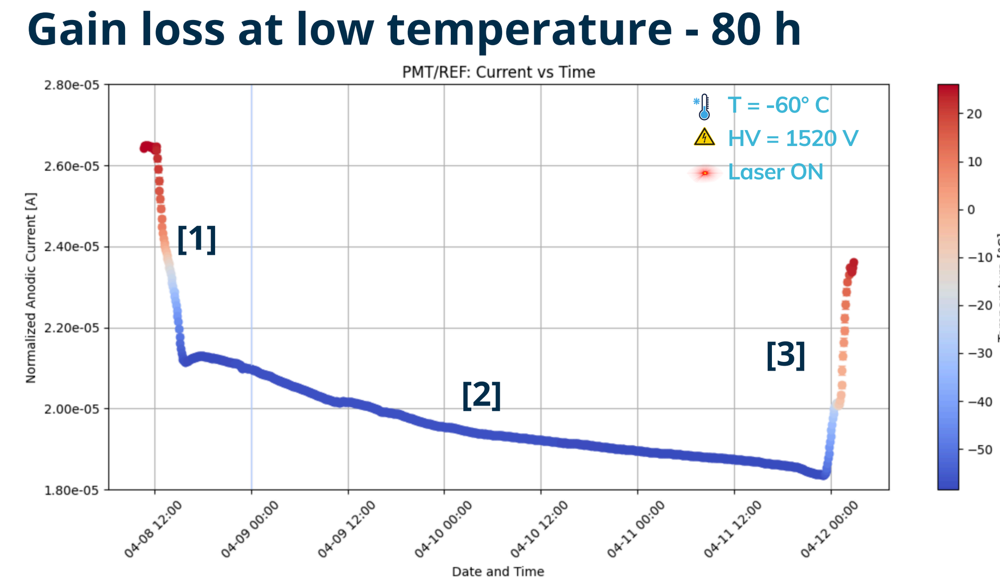


Gain stability at room temperature - 5.5 days



*Current is normalized with respect to the light reference

Gain loss at low temperature - 80 h



During each run of measurements at low temperature we identified three phases :

1. gain loss during cooling from room temperature;
2. gain loss at a constant low temperature (-60°C);
3. gain increase during temperature raising.

The slope during the cooling [1] is equal to the slope during the rise [3], approximately 6.4 x 10^{-8} A/°C. The gain loss in [1] is recovered during [3]: it is a **reversibile loss.**

Permanent loss insight

		Temperature (°C)	Time (h)	HV (V)	% lost in PMT gain	Charge (C)	% lost in PMT gain / charge
2022/23	1° Cooling	-74	20,5	1575	7,29 %	1,89	3,86 %
	2° Cooling	-70	95,3	1575	12,50 %	6,81	1,84 %
	2° Cooling	-70	20,25	1675	3,05 %	2,11	1,45 %
	3° Cooling	-66	150	1675	16,60%	16,6	1,00 %
2024	4° Cooling	-60	45	1520	19,68%	3,49	5,41%
	5° Cooling	-60	79,52	1520	13.39 %	4.20	3,18%
	6° Cooling	-60	62,60	1520	8,88 %	3.87	2,29 %

% lost in PMT gain is evalueted calculating the % loss in current during phase [2]
Charge is evaluated by numerical integral of current in time

During phase [2], we observed a **permanent loss**: no gain recovery was obtained by bringing the PMT back to room temperature.

We carried out two sets of measurements, one in 2022/23 and another one in 2024, with different illumination conditions of the PMT photocathode. In both cases, we see that the % loss/charge decreases over time.

Conclusions

- Our experimental study confirms the PMTs gain loss at the liquid argon cryogenic temperature (87 K) observed at Fermilab in the ICARUS detector.
- We don't see any loss at room temperature but we confirm the gain loss at low temperatures.
- We plan to investigate more deeply this gain loss effect in different experimental conditions in order to explain the irreversible contribution.

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Main References:
[a] R. Acciarri, et al., arXiv:1503.01520
[b] B. Ali-Mohammadzadeh et al 2020 JINST 15 T10007
[c] M. Babicz et al 2018 JINST 13 P10030

INFN CATANIA Istituto Nazionale di Fisica Nucleare Sezione di Catania
Università degli Studi di Catania