

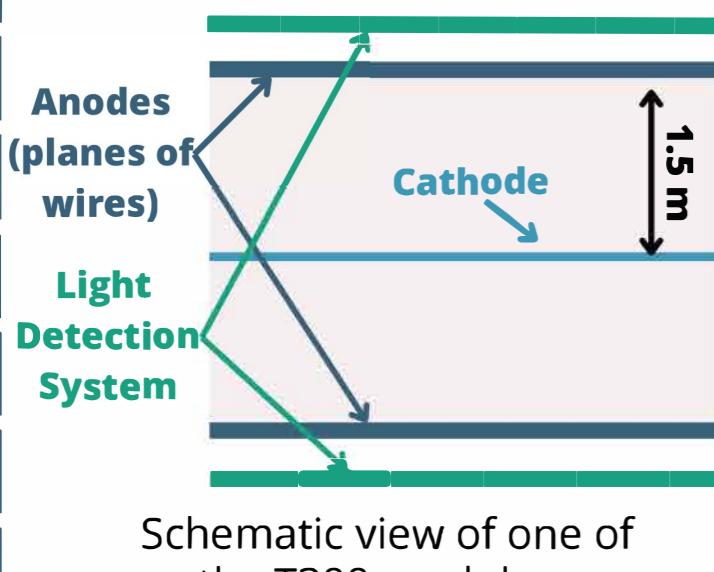
Gain stability of Hamamatsu R5912-MOD photo-multipliers at low temperature

C. Saia^{1 2} - V. Brio² - R. Persiani² - C.M.A. Petta^{1 2} -
G.L. Raselli³ - M. Rossella³ - M. Vicenzi⁴
for the ICARUS collaboration

 clara.saia@studium.unict.it

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ICARUS T600 Light Detection System



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 ($\lambda = 128$ 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 $\lambda = 420$ nm: coated with 200 $\mu\text{g}/\text{cm}^2$ Tetra-Phenyl Butadiene (TPB) as wavelength shifter.
- Typical Gain: 1×10^7 at 1500 V.
- Linear anodic response as a function of the incident light intensity [c].

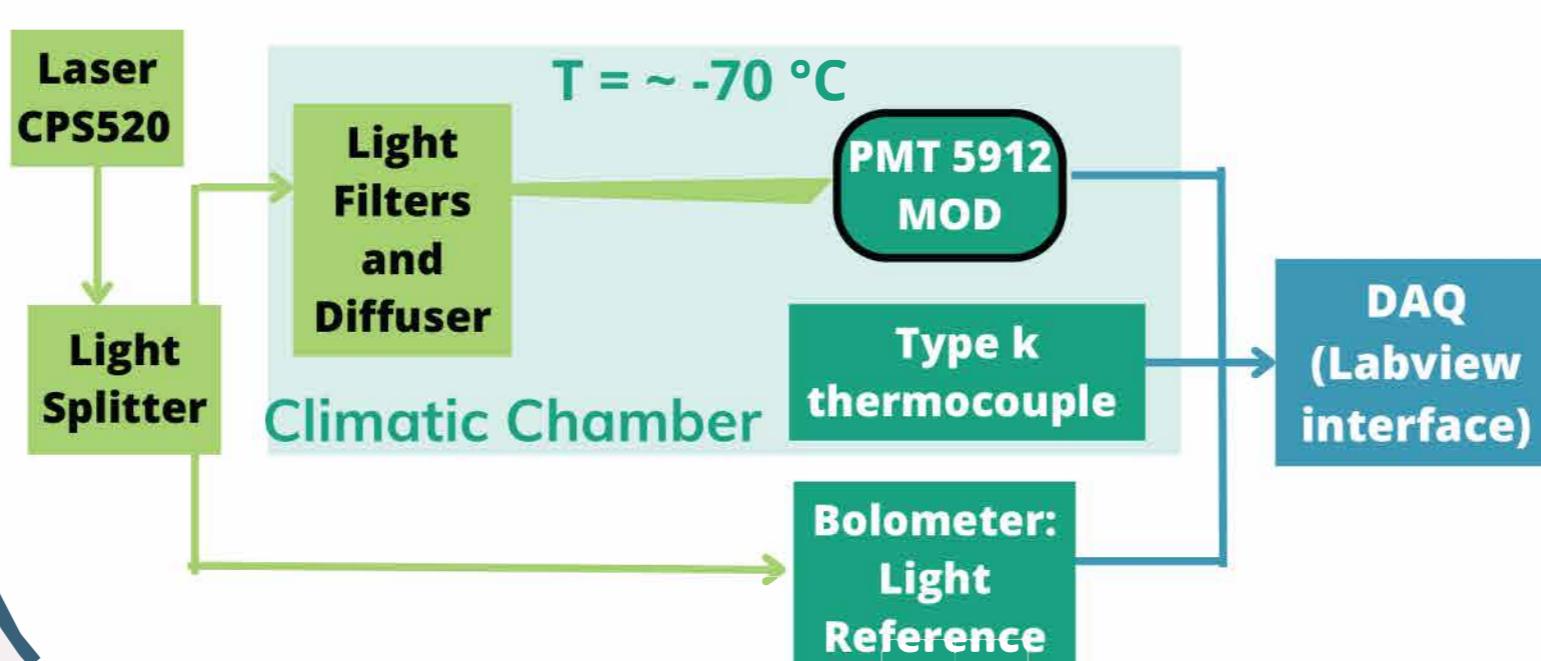
PMTs Gain Loss

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	$0.46 \times 10^7 \pm 2.1\%$
RUN3	0.31% /month	$0.39 \times 10^7 \pm 1.5\%$

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.



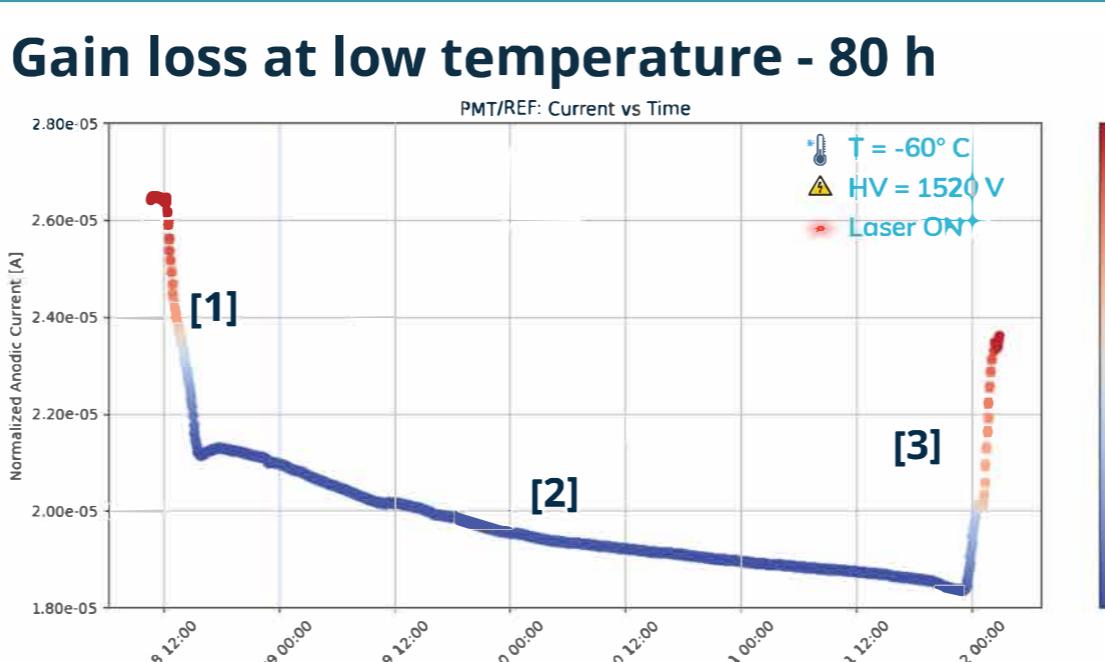
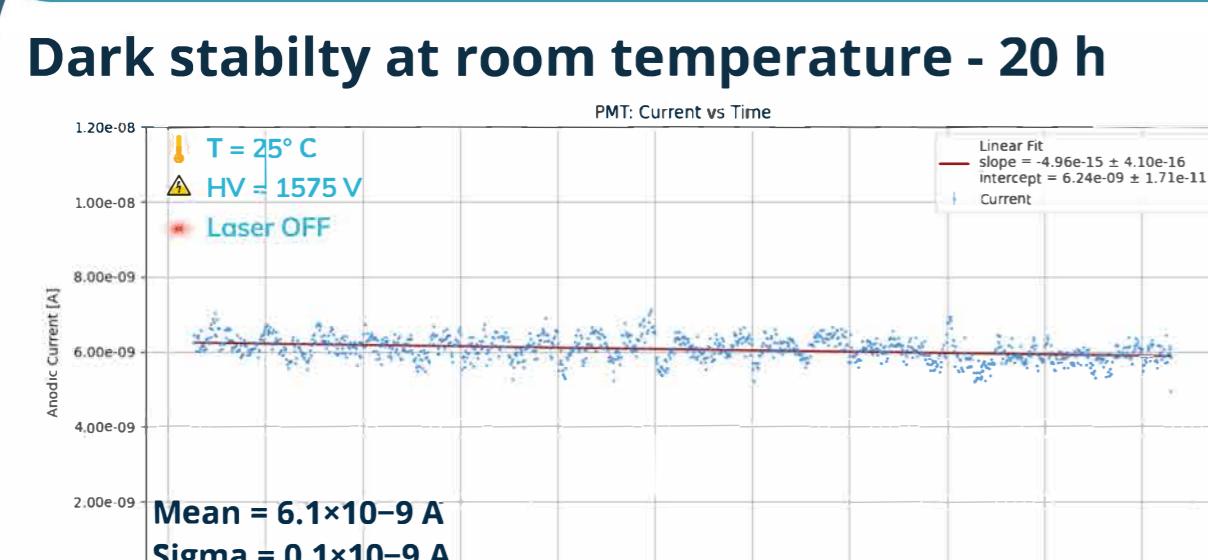
The PMT is illuminated by a **520 nm laser diode source** and operates in current mode.

The laser beam is split into two optical fibers:

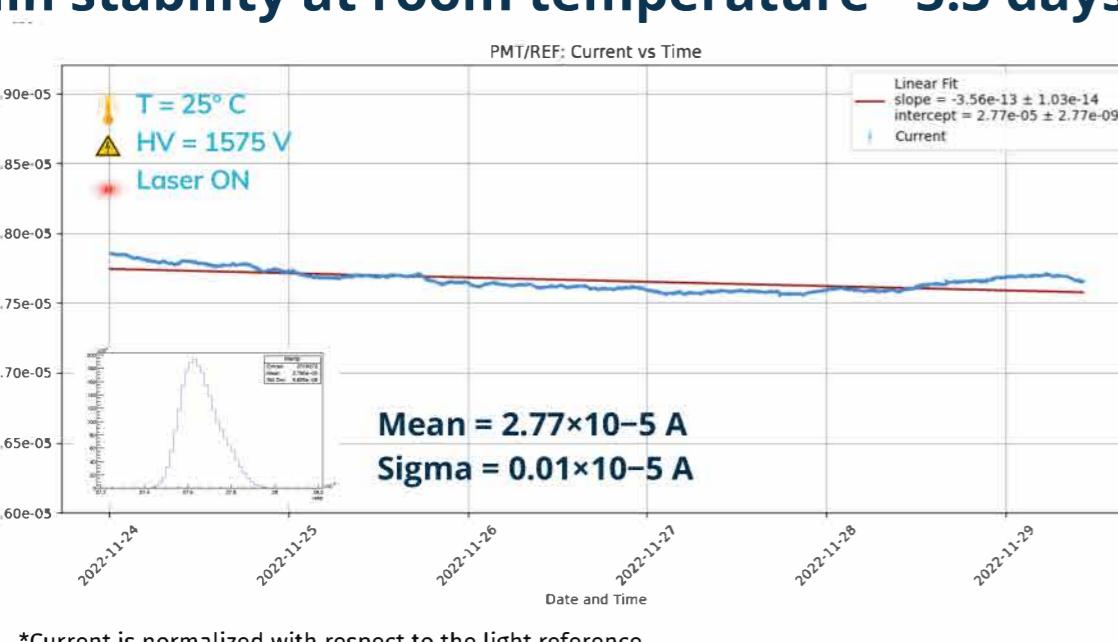
- the first one transmitting light through Neutral Density filters and then diffusing it over the surface of the PMT photocathode;
- the other optical fiber is used for an independent reference measurement of the injected light power via a bolometric photodetector.

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

Stability Gain Measurements



Gain stability at room temperature - 5.5 days



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 6.4×10^{-8} A/°C. The gain loss in [1] is recovered during [3]: it is a **reversible 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 %
	3° Cooling	-70	20.25	1675	3.05 %	2.11	1.45 %
	4° Cooling	-66	150	1675	16.60 %	16.6	1.00 %
	5° Cooling	-60	45	1520	19.68 %	3.49	5.41 %
2024	6° Cooling	-60	79.52	1520	13.39 %	4.20	3.18 %
		-60	62.60	1520	8.88 %	3.87	2.29 %

% lost in PMT gain is evaluated 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. Acciari, et al., arXiv:1503.01520
- [b] B. Ali-Mohammazadeh et al 2020 JINST 15 T10007
- [c] M. Babicz et al 2018 JINST 13 P10030