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A cryogenic system for measuring in the VUV range the absolute quantum efficiency of light detectors with large sensitive area

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1 – Introduction

Most of experiments for neutrino physics and rare event search exploit the scintillation light coming from liquefied noble gases. Light is usually emitted in the VUV range and is detected by large sensitive area detectors, typically photomultiplier tubes (PMT), directly immersed in the liquid and so operating at cryogenic temperature. Considering the great difficulties in producing large window other than glass, the VUV scintillation photons are first shifted to visible light by a wavelength-shifter deposited on the glass windows of the light detectors [1].

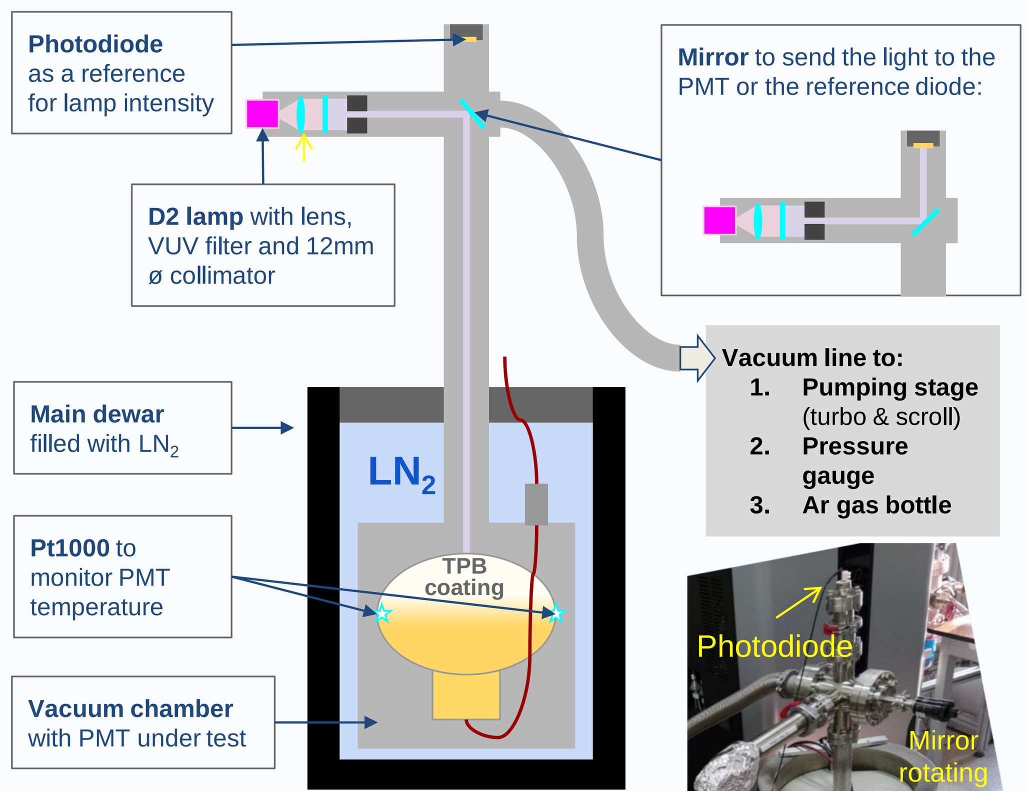
The measurement of the overall quantum efficiency (Q.E. - wavelength shifter and photocathode) in VUV range is usually carried out at room temperature, since this measurement at liquefied gases temperature is rather difficult and requires dedicated instrumentation and tests [2,3].

A system for this kind of measurement has been developed in the INFN-Pavia laboratory. This is made with a stainless steel vacuum chamber designed to house the PMT under test. The chamber is placed in a dewar filled with liquid nitrogen or liquid argon which brings the PMT to cryogenic temperature from the outside. The device temperature is continuously monitored by means of PT1000 sensors. VUV light from a deuterium lamp, directly connected to the vacuum chamber, is selected by a narrow VUV filter and is used as a monochromatic light source to illuminate the PMT.
The system allows the measurement of either the variation of the photocathode behavior between room and cryogenic temperatures, as well as the absolute Q.E. comparing the photocatode current with a NIST calibrated phododiode placed inside the chamber but kept at room temperature.

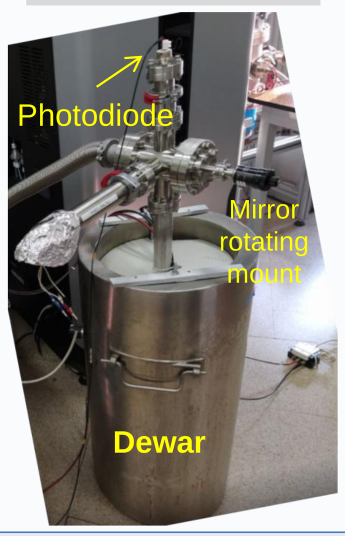
In this presentation, the main technical characteristics and performances of the system are shown together with results coming from preliminary tests on the 8" Hamamatsu R5912-MOD PMT.

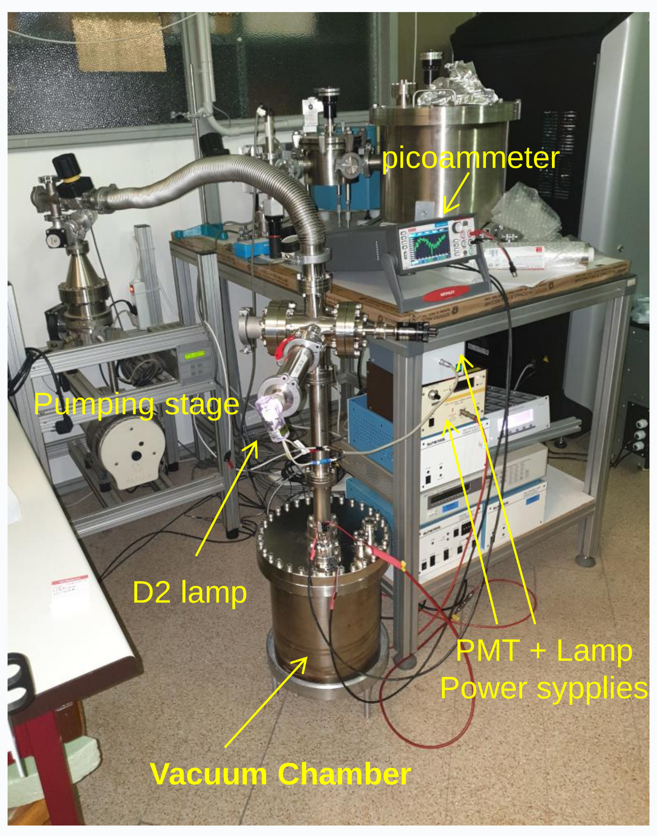
2 – The apparatus

The test apparatus consists of a stainless steel vacuum chamber designed to house the PMT under test and a set of stainless steel pipes which realize the illumination system (see Fig. 2). The chamber is placed in a dewar that can be filled with liquid nitrogen or liquid argon leaving the upper part of the apparatus at room temperature. The temperature inside the chamber is continuously monitored during the tests by means of two PT1000 platinum sensors connected to a PC acquisition board.
VUV light is generated by a deuterium D2 lamp, provided with lens, a VUV filter (130 nm, FWHM 20%) and a 12 mm diameter collimator. Light is focused on a rotating mirror which can send the light to a reference photodiode or to the PMT windows.



Picture describing the test apparatus.





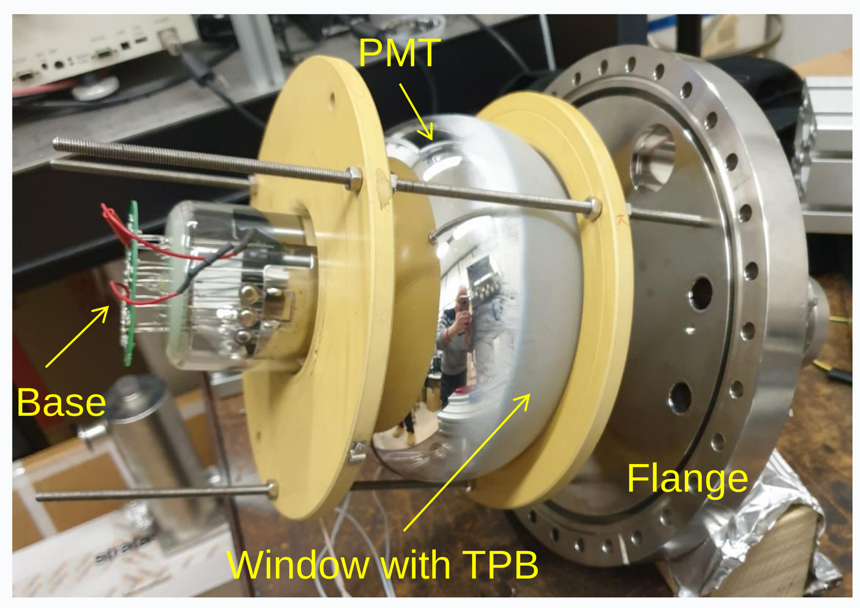
Pictures showing the implemented test apparatus. In the upper picture the vacuum chamber is shown before the installation in the dewar, as displayed in the picture on the left.

3 – PMT under test

Hamamatsu R5912-MOD and R5912-MOD2 PMTs are widely used for the detection of scintillation light produced by de-excitation and recombination phenomena occurring after the passage of ionizing charged particles in liquid argon. Among them ICARUS, MicroBooNE, SBND at Fermilab, ProtoDUNE at CERN and ArDM at Canfranc. The devices are made of an 8" diameter window in borosilicate glass, a bialkali photo-cathode (K2CsSb) with Platinum under-coating (MOD versions) and they are available in two different configurations, with 10 and 14 dynode stages (addressed as R5912 and R5912-02 respectively) but with the same sensitive stage (photocthode and focusing grids). Since the PMT glass is not transparent to the 128 nm wavelength scintillation light produced in liquid argon, each unit is usually provided with a wavelengh shifter coating to convert the VUV photons to visible light.

The PMT selected for the test is a R5912-MOD provided with a ~200 $\mu g/cm^2$ coating of tetra-phenyl butadiene (TPB) by evaporation on the glass window. The absolute quantum efficiency (photocatode + coating) at 128 nm was previously measured in [1-3], resulting in ~12%.

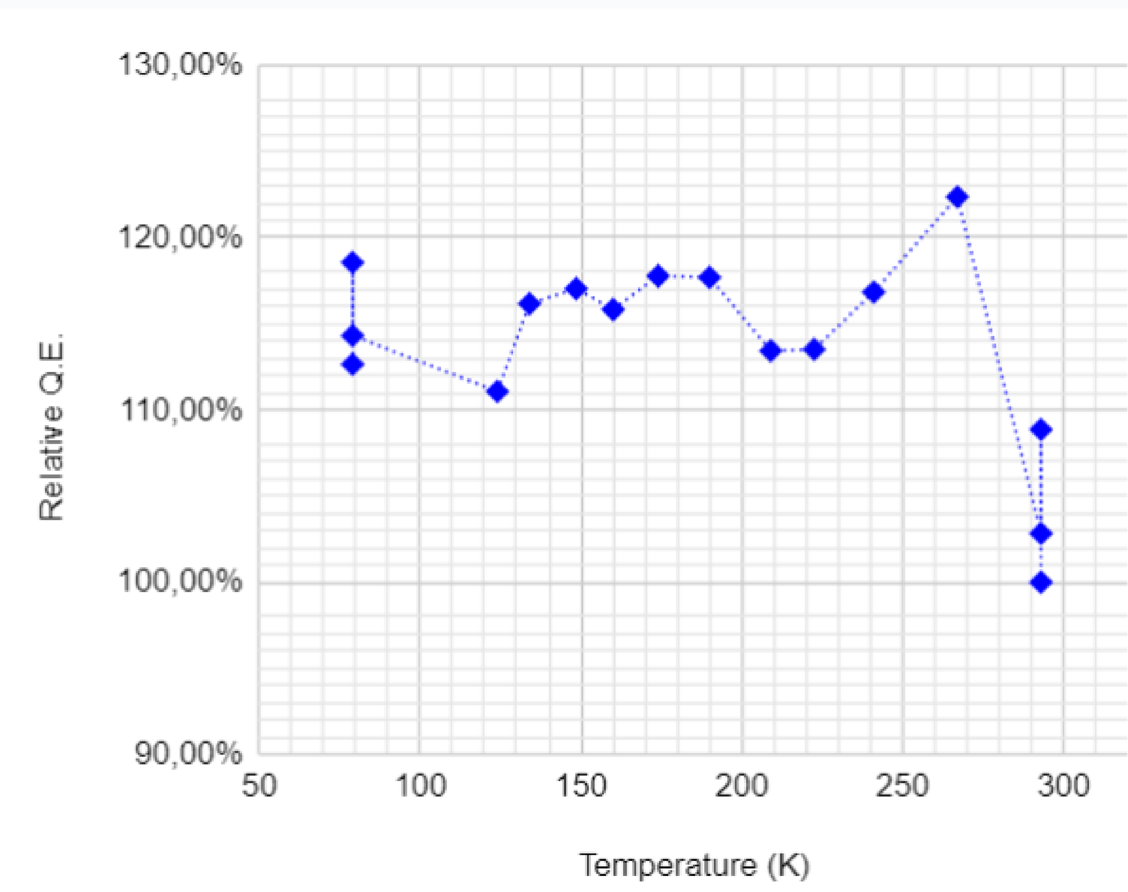
The PMT was operated as a photodiode. To this purpose all the dynodes and the anode were tied together in the PMT base as a single electrode set at +100 V. The current from the cathode was measured by means of a pico-ammeter, connected in shunt between the photocathode and GND and readout by a PC.



4 – Preliminary results

The following picture shows the obtained preliminary results. On the Y axis is the Relative Q.E. i.e. the Q.E. efficiency normalized to the value obtained at room temperature in the first measurement, which was considered as reference point.

- ✓ **3 measurements at room temperature:** ranging from 100% to 109%
- ✓ **10 measurements during the cooling down:** from 111% to 122%
- ✓ **3 measurements at cryogenic temperature (79 K):** from 113% to 119%



5 – Conclusions and future perspectives

Preliminary results indicates an increment of the Q.E. at low temperature in the range 15-20%. Taken into consideration a measurement uncertainty of 10% (see points at room temperature) this test seems to exclude the hypothesis of a significant decrease of the Q.E. al cryogenic temperature with respect to the room one.

Improvements of this system foresees the use of a monochromator for the wavelength selection and the installation of a new NIST calibrated photodiode, allowing the absolute measurement of the Q.E.

[1] M. Bonesini et al, *An innovative technique for TPB deposition on convex window photomultiplier tubes* JINST 13 P12020 (2018).

[2] P. Agnes et al, *Characterization of large area PMTs at cryogenic temperature for rare event physics Experiments* JINST 9 C03009 (2014).

[3] B. Burak et al, *Comparison between photon detection efficiency and tetraphenyl-butadiene coating stability of photomultipliers tubes immersed in liquid argon* JINST 15 C04021 (2020).