IL NUOVO CIMENTO **47 C** (2024) 378
DOI 10.1393/ncc/i2024-24378-2

Colloquia: MAYORANA 2023

VULCAN: Vacuum ultraviolet light characterisation at Nikhef

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received 6 August 2024

Summary. — VULCAN is a tabletop experiment at the Nikhef institute in Amsterdam. The experiment is designed to characterise the optical properties of detector components in the vacuum ultraviolet range, which is especially relevant for noble liquid detectors. The setup is in the commissioning phase and in these proceedings we show results from some calibration measurements.

1. – Introduction

In dark matter and neutrino research, many detectors rely on detecting scintillation photons from liquid argon or liquid xenon, which scintillate in the vacuum ultraviolet (VUV) range when an interaction occurs [1]. Detecting these VUV photons presents two main challenges. Firstly, conventional photon detectors, highly efficient in the visible spectrum, are inefficient at VUV wavelengths and, consequently, wavelength-shifting materials need to be used to shift the wavelength from VUV to visible light. Secondly, before reaching a photon detector, the photons may interact with detector materials like polytetrafluoroethylene (PTFE). For a good understanding of the signal in current and future noble liquid detectors, it is critical to understand the optical properties of wavelength-shifting materials and all detector components in the VUV range.

2. – Setup and analysis

The experimental setup is shown in fig. 1. A high-intensity deuterium lamp (Hamamatsu L15094 [2]) produces wavelengths from approximately 115 nm to 240 nm. The light enters a vacuum monochromator via an entrance slit. A grating diffracts the light to select a specific wavelength, which is then directed through an exit slit to a sample and photon sensors in a vacuum chamber. The sample holder can rotate horizontally around its central axis using a rotary feedthrough. It provides space for both the sample under investigation and a reference sample, enabling calibrated measurements without breaking the vacuum. The reflected light is measured using a silicon photomultiplier (SiPM) from Hamamatsu (S13370-3050CN [3]), known for low dark noise and high photon detection

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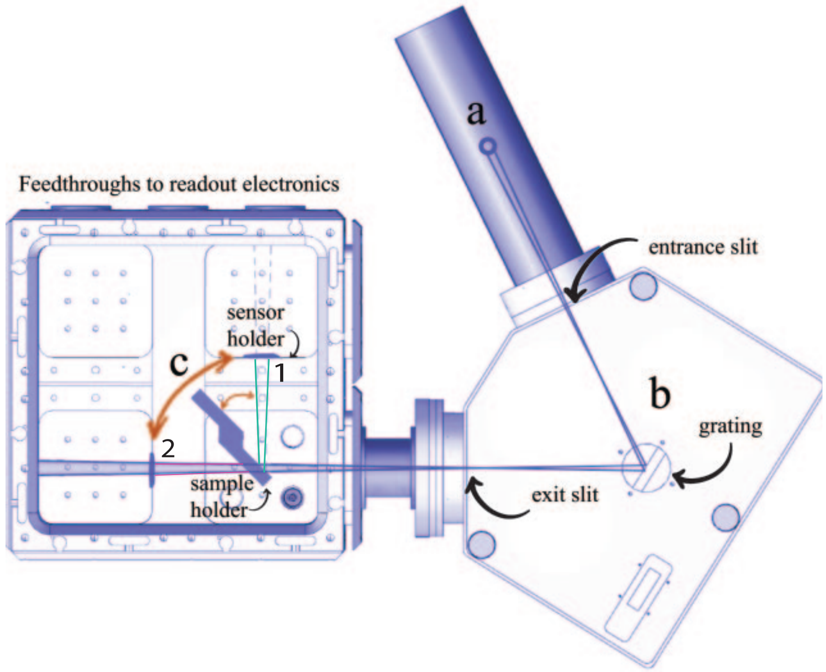

Fig. 1. – A top view of the VULCAN experimental setup, consisting of (a) a deuterium lamp to provide light in the VUV range; (b) a Seya-Namioka type monochromator (McPherson 302) with aberration-corrected diffraction grating; (c) a vacuum chamber with rotatable sample- and sensor holders. Readout electronics connect to the three feedthrough ports on the side of the vacuum chamber.

efficiency in the VUV range. The sensor holder also rotates horizontally which allows us to measure reflection profiles as a function of the angle (fig. 1, position 1), as well as transmission (fig. 1, position 2).

Currently, a single SiPM is installed, with plans for a 3 by 3 array. The SiPM is read out with an amplification factor of 400, using a custom-made box that also supplies the bias voltage. The signal is digitised with a 14-bit, 250 MS/s digitiser. We take data in 13 μs long samples. Baseline correction is applied to each sample, and the peak areas are calculated to determine intensity. Aluminium samples taken from the cryostat walls used in leading dark matter and neutrino detectors are the initial focus of the measurements.

3. – Commissioning results

Commissioning measurements are to confirm that all parts are working and to optimise the positions of the samples and sensors and find the best slit sizes. We present two measurements. First, we measure the spectrum of the deuterium lamp and compare it to the spectrum provided by Hamamatsu to correct for the wavelength-dependent sensitivity of the SiPMs. Second, we measure the reflection of a piece of aluminium. Aluminium oxidises rapidly and therefore we expect a substantial layer of aluminium oxide to have formed on the sample, which diminishes the reflectivity.

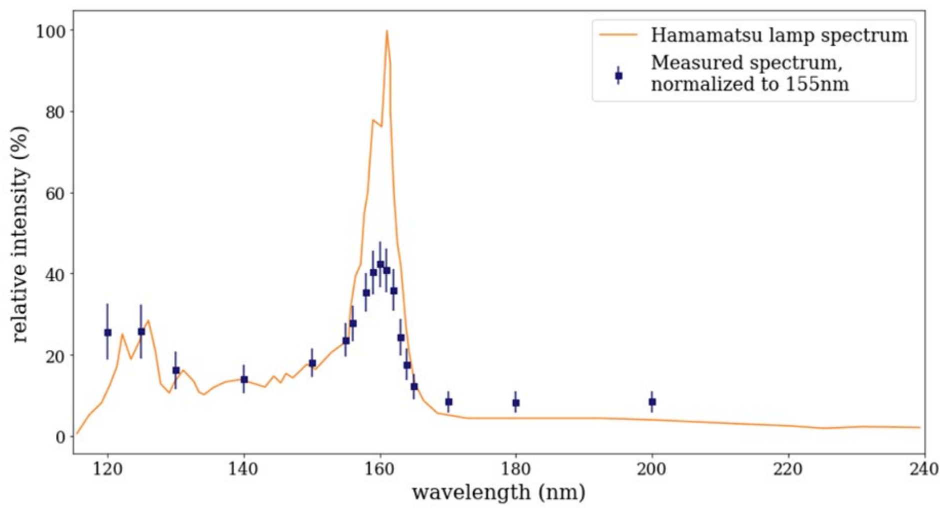

Fig. 2. – The measured spectrum (markers) and the spectrum of the lamp that is provided by the manufacturer of the lamp (line). The measured intensities are scaled to the provided spectrum at 155 nm and corrected for the sensitivity of the SiPMs (as provided by Hamamatsu). The error bars show statistical uncertainties only.

Measurements of the lamp spectrum are taken at a stable pressure of 8×10^{-4} mbar. At this pressure, the absorption of VUV light by air is minimal. The monochromator uses a 0.25 mm entrance slit and a 1 mm exit slit. A dark count measurement is taken before turning on the lamp. The lamp is allowed to stabilise for 15 minutes before starting the measurement. The result is shown in fig. 2, where light intensity is calculated by taking the area under the peaks with numerical integration and corrected for the dark count measurement and wavelength dependent SiPM sensitivity. The measurements are scaled to the Hamamatsu lamp spectrum. We chose to match the spectra at 155 nm, where we have high SiPM sensitivity and moderate light levels. A clear mismatch is visible at the peak around 160 nm, where the SiPMs saturate due to the high lamp intensity. However, reducing the slit size to allow a measurement of the peak intensity would prevent us from detecting any light above the dark count for the other wavelengths.

Results of the aluminium reflection measurement in the VUV range are presented in fig. 3. To mitigate the intensity lost due to reflection, we fix the entrance slit at 0.04 mm and set the exit slit at 2 mm. The measurement is compared with a reflection measurement from [5] where a piece of freshly cut, but unprotected, aluminium is used. Our aluminium sample likely acquired a thick layer of aluminium oxide due to long exposure to air, reducing the reflectivity. The data again show a distinct anomaly at around 160 nm, where the reflectance deviates from the trend. This discrepancy can be attributed to SiPM saturation resulting from the high-intensity peak in the spectrum. Ongoing calibrations aim to identify optimal slit sizes to prevent SiPM saturation. If we cannot establish an optimal slit size, correction for SiPM saturation will be necessary. The data point at 120 nm also stands out. We believe the SiPM sensitivity may in reality be higher than the 3% reported in ref. [3] for this wavelength.

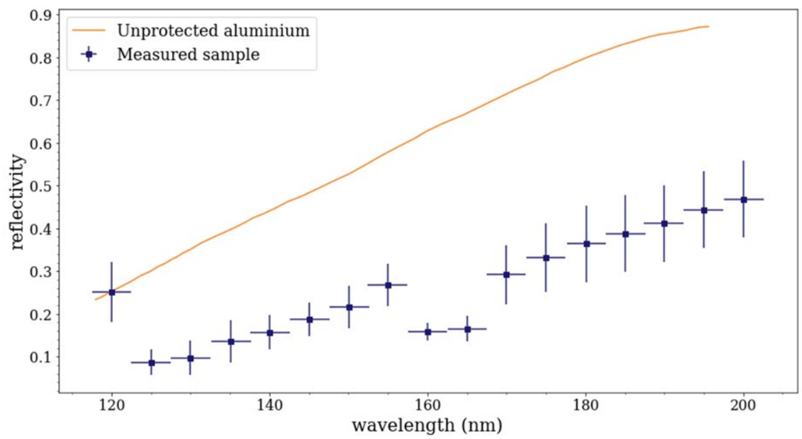

Fig. 3. – The measured reflection of a piece of aluminium (markers) as compared to a measurement of unprotected aluminium (line) [5].

4. – Conclusions

The commissioning measurements look promising for upcoming reflection studies. The SiPMs and the lamp behave according to expectation since the measured spectrum matches the spectrum provided by the manufacturer, except for the lower peak intensity around 160 nm, where the SiPM response saturates due to the high intensity of the light from the lamp. The reflection of our aluminium sample is lower than the reflection measured in ref. [5]. However, a fair comparison is impossible because we lack information about the aluminium oxide layer on our sample. It is worth noting that these measurements were conducted using a single SiPM, specifically positioned to capture specular reflection. If there is a significant diffuse component, it may not be apparent in this particular measurement.

With the knowledge gained from the commissioning measurements and the planned upgrade to a 3 by 3 array of SiPMs, we will be able to make precision measurements of reflection and transmission of wavelength-shifting materials and detector components in the VUV range and, ultimately, offer a more comprehensive understanding of the optical properties crucial for the optimal performance of current and future noble liquid detectors.

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