Measurement procedure

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Abstract

This document outlines the baseline procedures and configurations to follow when taking fluorescence measurements with the VULCAN setup.

1 Sample preparation and cleaning

The procedure in this measurement plan is outlined for the first measurement of fluorescence detection from a sample of PTFE from the XENON1T experiment. This can be later repeated for a sample from the XENONnT experiment and the XAMS setup which use PTFE from the same manufacturer. Here, the preparation of samples is described for all three experiments for completeness.

The PTFE will be taken from the spare block in the XAMS lab and machined to size (3x3x0.04cm). An Aluminium sample will also be used as a reference sample for some measurements, since this material does not fluoresce but does reflect VUV light so can be used to study the effect of incident light that is reflected towards the SiPMs. The following describes the cleaning and preparation of the samples.

- Aluminium sample
  - Wash with detergent and rinse with deionised water
- XENON1T PTFE [1]
  - Immerse in acetone if possible - alternatively, wash with detergent and rinse with deionised water
  - Immerse in 5% HNO3 solution for 5 hours
  - Rinse several times with deionised water
  - Immerse with ethanol for 3 hours to soak residual water from PTFE pores
  - Dry with N2 blowing
  - Evacuate if possible, if not continue N2 blowing for as long as possible
- XENONnT PTFE [2]
  - The surface of the PTFE reflectors are shaved ∼1.5mm with diamond-tipped tool. It is currently unclear whether we will have the ability to recreate this at Nikhef, so for now this step is left as optional. Other PTFE pieces in the XENONnT experiment do not undergo this step.
  - Elma clean 65 neutral soap 5% for 15 minutes at 40C (if the sample was not shaved in the previous step, do this in an ultrasonic bath)
  - Rinse with DI
  - HNO3 5% solution for 2 hours at RT - 15 minutes in an ultrasonic bath if not shaved
  - Immerse in DI water bath for 1 hour to remove acid residuals
  - Rinse with DI
  - Dry with N2 blowing

- XAMS PTFE (from Maricke - this was performed before initial assembly but is not routinely repeated when opening the setup)
  - Clean with detergent in US bath
  - Rinse with DI water
  - Dry with N2 blowing

Once cleaned, these samples should be stored (details to come soon).

2 Sample chamber preparation and cleaning

Preparation of the sample chamber should be completed before anything is placed into the sample chamber. This requires a judgement call to be made on whether the system is clean enough or the cleaning procedure should be repeated. The procedure for cleaning the setup is laid out below.

- Clean chamber
  - Take apart
  - Clean modules - BOSIMANITE AL-29 followed by ROGYPAL CA-307 Z, bake for 80$|circ$C for 18 hours
  - Clean O-rings - isopropanol
- Clean sample holder - ultrasonic bath
  - Central piece
  - Three frames
  - Three doors
  - Suspension support
  - Screws/springs
- Clean cooling apparatus - isopropanol
  - Cooling braids
  - Screws/springs
- Clean readout equipment which will be inside chamber (wires) - isopropanol
- Clean SiPM holder - isopropanol

The setup should be reconstructed as soon as possible after cleaning to avoid contamination from the environment. Components which are not immediately put into the chamber should be sealed in tin foil until needed. Store unused components in the correct boxes in the lab.

3 Once-only calibrations

This section lists the set of calibrations that should be completed without any sample in the chamber, and only need to be undertaken once.

3.1 SiPM dark count rate

SiPMs have a dark count rate which is strongly dependent on their temperature, following a probability given by

$$p(T) = CT^{3/2} \exp \frac{-E_q}{2k_B T} \tag{1}$$

where T=temperature, E_q=the bandgap energy, and C=proportionality constant. E_q and C are generally dependent on the doping material used in the SiPM. Equation 1 demonstrates that the temperature is an important factor to note when taking measurements.

The SiPMs should be operated at a bias voltage 4V above the breakdown voltage, given as 53±5V. This corresponds to ∼57±5V. The voltage applied over a SiPM will affect its gain, influencing the size of the signals that we observe. This should be checked for all SiPMs.

3.1.1 Configuration

The SiPM dark count rate can be determined with the SiPMs inside the sample chamber, or in a dark box environment, where no light enters the system. The configuration used will depend on the access to the setup and resources available. In the dark box setup, the temperature will be controlled by a Peltier element.

The characterisation of the dark count rates are planned to be completed in January so the configuration of the setup is left as part of this exercise. Each SiPM should be measured for its dark count rate as a function of temperature and bias voltage.

3.1.2 Measurement

The following procedure should be repeated once for all SiPMs, varying temperature, and again for all SiPMs varying bias voltage.

- Connect the SiPM to the readout electronics and the DAQ and seal dark box.
- Check the DAQ to determine whether the signals are clear enough and to check the trigger level.
- Cool the SiPM to the desired temperature or bias at relevant voltage.
- Monitor the other variable to keep it stable.
- Take 20 sets of 1000 waveforms. This will give a total of 0.32s of data. This number has been used to achieve the initial dark count estimates at room temperature. This may be modified for different measurements if the temperature reduces the statistics for the dark counts significantly.
- Turn off the lamp and SiPM readout electronics.
- Turn off the pump and allow the chamber to return to atmospheric pressure and room temperature.

Depending on the studies to be undertaken afterwards, return the SiPMs back in their storage or make a note that they remain in the chamber.

3.1.3 Analysis

The waveforms taken should be treated for baseline fitting and single-photon peak identification. This is currently based on a trigger threshold being passed. All signals should be single-photon in this setup and any larger signals will originate from a light leak in the system. The signal peaks are identified for each waveform taken and then the peaks in each waveform are summed and divided by 16μs (the length of each measurement time) to determine the rate in that waveform. These rates are then plotted in a histogram. The dark count process is a Poisson distribution, but due to the large number of measurements (and the imperfect nature of the measurements) this can be approximated by a Gaussian. The dark count rate is given by the mean of this distribution R_{DC} and one standard

deviation gives the uncertainty on this number σ_{DC}. Here the standard deviation is determined by $\sigma_{DC} = \sqrt{\frac{\sum (x-R_{DC})^2}{N}}$, where x indicates each bin and N is the total number of bins in the histogram.

The dark count rate should be calculated for all SiPMs under their operating conditions. Fitting the rate against temperature should show an exponential dependence, and fitting the rate against the overvoltage should show a linear dependence on the overvoltage. Thus, for SiPMs operated under various conditions, an estimate of their dark count can be extracted from these fits.

3.2 SiPM gains

The signals obtained through the dark count measurements give a large sample for the integrated area under single-photon peaks. The area under peaks is dependent on the number of photons that the signal was generated by, and the gain of the system which is dependent on the SiPMs and the electronics implemented.

This study will be useful for later analyses where the size of signals can indicate the mechanism which which they were produced and the total photon numbers that we detect in the setup. This should be repeated if the electronics are changed.

3.2.1 Configuration

Producing peaks with multiple photon origins can be achieved with a less intense light source than that of the lamp in the VULCAN setup, such as an LED.

The suggested configuration for this setup is to place the SiPM in a dark box and use an LED which is capable of emitting low levels of light. The SiPM should be able to detect light down to the single-photon level.

In measurements taken in the sample chamber before cleaning, some multiple-PE signals were visible in the spectrum. There may be enough of these signals to determine how many photons the peak originate from, and therefore do this analysis using the data already taken.

3.2.2 Analysis

Signals from the SiPMs should be split into 5 datasets containing peaks originating from 1-5 photon avalanches. In each of these datasets, the areas underneath the peaks should be integrated and plotted as a histogram. The mean of this histogram will give the average integrated area under one peak generated by the relevent number of photons, and the standard deviation will provide the error on this number. This characterisation should be carried out for all SiPMs.

3.3 Excitation wavelength calibration

A calibration to determine the SiPM signals observed for the chosen wavelengths on the monochromator should be carried out each time the monochromator or grating is moved. This is to ensure that the correct wavelength is being chosen by the grating and that the light is correctly aligned with the exit slit, into the sample chamber.

The following measurements should be taken, with wavelengths between 110nm and 400nm. The step sizes are chosen so that they are shorter at wavelengths of interest (where we plan to take measurements and where the features of the spectra are). The wavelengths chosen (in nm) are : 110, 120, 125, 130, 140, 150, 155, 156, 158, 159, 160, 161, 162, 163, 164, 165, 170, 180, 200, 300 and 400.

The following procedure should be followed with both the VUV-sensitive and visible-sensitive SiPMs.

3.3.1 Configuration

- Entrance and exit slits should be set to 0.250mm and 0.050mm respectively. The errors on these values will be ±0.005mm. The small slits are necessary in this configuration to ensure that the SiPMs are not saturated.

- The SiPM should be placed in the holder, which in turn should be placed in the path of the beam. The holder is currently not manufactured so a temporary holder is in use.

- Connect the readout electronics inside the chamber to the SiPMs and the feedthrough. Connect to the DAQ.
- Tightly seal the vacuum chamber door.

3.3.2 Measurement

This procedure described in this section should be repeated for all wavelengths to be measured. Any change in temperature or pressure should be recorded (this may become automated with the new slow control).

- Check that the electronics can bias the SiPM (in the correct direction) and that signals can be read out on the DAQ.
- Pump the chamber to 10^{-4}mbar or lower.
- Set the monochromator grating (for now, by hand) to the wavelength to be measured.
- Turn on the lamp.
- Record the temperature and pressure.
- Check the DAQ to ensure that the trigger threshold is set to the correct value and the signal noise is reasonable (for measurements now, this should be around 1/100th of the size of a 1PE signal).
- Record 5 sets of 1000 waveforms.
- Turn off the lamp and SiPM readout electronics.
- Turn off the pump and allow the chamber to return to atmospheric pressure and room temperature.

Depending on the studies that will be carried out after this, place components back in their storage or note that they are still in the chamber.

3.3.3 Analysis

These measurements should be analysed to determine discrepancies between the stated wavelength on the monochromator and the location of peaks in the measured spectrum.

The waveforms taken should be integrated below the peaks (after baseline fitting, dark count correction and peak identification). The integrated area can be plotted against the wavelength on the monochromator to generate the spectrum that is observed through the DAQ. This spectrum should then be corrected for SiPM and monochromator response curves. The resulting points can be superimposed against the given spectrum for the lamp. Cross-correlation between the two spectra can determine whether there is an offset with the wavelength that is displayed on the monochromator.

The errors involved in this measurement will originate from the wavelength resolution on the monochromator, given as $\pm$10nm for a 3mm slit and the porpagated uncertainties originating from the dark count measurements for the SiPMs used. These are systematic uncertainties.

3.4 Beam geometry on sample

The incoming excitation beam from the monochromator should fit in the window of the sample holder, even with the slits completely open, as will be used in the fluorescence measurements. This can be estimated knowing the beam size (from previous measurements taken) and the relative location of the sample holder in front of the slit.

A sanity check for this estimation can be run by placing photosensitive paper in the sample holder and shining the lamp light on it for $\sim$20minutes. The UV light should stain the paper in the location that the beam interacts. The paper can then be removed and rinsed off in water (depending on the type of paper used), and the beam size, shape and location can be determined from the pattern created, outside of the chamber. In the fluorescence sample holder, three pieces of paper can be mounted at

once and the process repeated to check the location of the beam for all sample slots and as another sanity check for the rotation needed to turn between the three sample frames. This measurement need only be taken once since the components in the setup are fixed in relation to each other.

3.5 Nuisance light

The nuisance light generated inside the monochromator in wavelength regions above the VUV range can be determined by placing a VUV-blocking filter at the entrance to the sample chamber. By blocking the VUV light from entering the sample chamber, only longer wavelengths will reach the sample. This nuisance light may be generated by higher order wavelengths produced in the grating and be reflected by the sample, or cause fluorescence.

This study of nuisance light can help to characterise whether light-absorbing foil or paint would be necessary to include in the setup. These options can be considered if the light seen by the SiPMs in this setup is visible above the expected dark count level but is not an immediately necessary measurement.

3.6 PT100 readout

The temperature of the sample holder and SiPM holder will be read out with PT100 sensors. These work by using a temperature-dependent resistor value which is 100Ω at 0°C. The temperatures should be measured using standard sources with a known temperature, such as LN2 and ice. A resistance measured at 0°C which is not 0Ω indicates an offset and the relationship between the resistance and the temperature should show a linear dependence, the slope of which can be fitted.

This temperature should be readable to within a few degrees accuracy. The differences of these PT100s in different locations will also give information about the efficiency of the temperature control system in place.

3.7 Lamp spectrum time dependence

Some of the measurement procedures described in this document take place over several hours of measurements. To ensure that there is no change in the lamp intensity over this time, a study of the intensity at one wavelength measured at different times after the lamp was turned on can be taken. For this study, the wavelength chosen is 164nm since this wavelength does not saturate the SiPM, but is a high intensity so that a decrease in the intensity shouldn't fall below the dark count.

3.7.1 Configuration

This configuration is the same as described in Section 3.3.1 but is repeated here for completeness.

- Entrance and exit slits should be set to 0.250mm and 0.050mm respectively. The errors on these values will be ±0.005mm. The small slits are necessary in this configuration to ensure that the SiPMs are not saturated.
- The SiPM should be placed in the holder, which in turn should be placed in the path of the beam. The holder is currently not manufactured so a temporary holder is in use.
- Connect the readout electronics inside the chamber to the SiPMs and the feedthrough. Connect to the DAQ
- Tightly seal the vacuum chamber door.

3.7.2 Measurement

Due to the time constraint introduced by the current DAQ system, taking 5000 waveforms of 16μs takes approximately 10 minutes. Therefore, if measurements are to be taken with time increments smaller than this, a smaller set of waveforms should be taken. In addition to this, the time at which each individual waveform was taken is not recorded and is just averaged over the time taken for all wavelengths to be measured. Shorter measurement times are preferred to reduce the error associated with this averaging. The times that measurements should be taken at (expressed as time after the

Time (mins)	Number of waveforms to record
0	1000
5	1000
10	1000
15	1000
20	1000
25	1000
30	1000
40	2000
50	2000
60	2000
90	5000
120	5000
150	5000
180	5000
240	5000
360	5000

Table 1: Time for measurements to be taken after turning the lamp on, given with the number of waveforms to be recorded.

lamp has been turned on) are given in Table 1 along with the number of waveforms to be taken. The number of waveforms may change when the new DAQ system is implemented.

Measurements should be taken as follows:

- Select 164nm on the monochromator.
- Check that the electronics can bias the SiPM (in the correct direction) and that signals can be read out on the DAQ.
- Pump the chamber down to 10^{-4}mbar or lower.
- Turn on the lamp.
- Record the temperature, pressure and bias voltage. And change to these values should be recorded.
- At the time increments indicated in Table 1, record the associated number of waveforms.
- Turn off the SiPM electronics and the lamp.
- Turn off the pump and allow the chamber to return to atmospheric pressure and room temperature.

Indicate whether components have been returned to their storage or left in the chamber.

3.7.3 Analysis

After undergoing corrections for baseline fitting, dark count corrections and peaks are identified, the waveforms recorded should be integrated below the signal peaks and summed for each set of measurements taken. The time that these peaks are measured at is defined as the median time of the DAQ data taking (for example, taking a 5000-waveform set of measurements takes 5 minutes. The median time here would be 2.5 minutes after the start of the measurement.). The summed values for each measurement can be plotted against the median time of the measurement set. Features to determine from this plot are whether there is a 'warmup' time for the lamp to reach its optimal intensity, and the decay time fit to how quickly the lamp loses intensity. These values can later be used to correct the measured signals for intensity changes.

4 Repeated calibrations

4.1 Sample holder rotation

The angle that the samples are held with respect to the incoming beam and the SiPMs can have a significant effect on the amount of light seen by the SiPMs from reflection. This angle should be calibrated so that the samples are directly perpendicular to the incoming beam. Each time the sample holder is placed in the chamber, the angle of the reference sample with respect to the incoming beam should be re-checked.

The calibration of this angle in order to ensure that the result is the same for each time the samples are replaced is under construction but could be based on a physical buffer, markers on the various constituent parts or extra screws to secure them in place.

The rotation of the sample holder from the feedthrough can be determined by the scale, and the turning for a third of a rotation can be determined when everything is installed. Checking this feedthrough rotation correspondence only needs to be undertaken once since it should be the same no matter whether the sample holder is removed and replaced since it is relative to the initial starting position.

5 Calibrations in situ

5.1 Fluorescence of light on SiPM

SiPMs are available with and without a window to protect the active area, and these windows can be of various materials. The VUV-sensitive SiPMs that VULCAN has available do not have a window, and are cased in ceramic. The visible-sensitive SiPMs have a silicon resin window and are also cased in ceramic. It has been suggested that, whilst ceramic shows no photoluminescence response, the silicon resin windows can fluoresce when excited by UV light. The visible-sensitive SiPMs should be blind to wavelengths in the VUV range, so any light seen by these SiPMs when the excitation light is in the VUV range should be from either the higher order wavelengths generated by the grating or the fluorescence response of the sample or SiPM window.

To test the levels at which the SiPM windows fluoresce a dedicated measurement should be taken which excited the SiPM at VUV-UV wavelengths and measures the resulting photon intensities. SiPM window fluorescence may have a dependence on temperature, so the measurement of the fluorescence should be repeated at different temperatures, likely most conveniently controlled by the Peltier element. Testing this is a topic for future plans and not yet fully formulated.

5.2 Reflection of sample

To test whether the sample reflects light from the excitation beam, we split the problem in two: studying the chosen VUV wavelength, and the visible higher order wavelengths.

The reflection of the chosen VUV wavelength can be tested with the VUV-sensitive SiPMs. The reflectance setup may be able to use here, otherwise a temporary setup can be used to rotate the sample and determine the change in intensity seen by the SiPMs at different angles (for specular reflection). Diffuse reflection can be determined in the fluorescence setup by placing a filter in front of one SiPM. This filter should have a cutoff frequency above the excitation wavelength (but not higher than 350nm since the fluorescence will be in this range). The difference between the two measurements can indicate the reflective power of the sample.

A filter can be used to study the visible, higher order wavelengths in a similar fashion to that described for the VUV light.

5.3 Condensation

Water vapours in the vacuum chamber can condense on cold surfaces in a vacuum environment and freeze. This is troubling since water is very good at attenuating VUV light. Even a very thin film of condensation can prevent VUV light from exciting the sample. This is a difficult effect to account for in the setup.

Previous setups have attempted to mitigate this effect by flash cooling the sample and taking measurements over a very short time period, or tried to account for the effect in their analyses after the measurements, by measuring the formation on a transparent surface. Since the material of the sample will affect the condensation formation time and our setup is unlikely to allow flash cooling, these approaches are difficult to implement in VULCAN.

Cold traps are copper coils which can be placed around the path of the beam in the setup and encourage the formation of condensation layers on the copper surface, rather than the sample. This will be investigated in more detail.

For first measurements, the calculation of how quickly the condensation layers form can be undertaken.

Put calculation here.

6 Metadata

Metadata refers to the information which is important to know for the measurements taken, but not the data from the measurements themselves. In the context of the VULCAN setup, the metadata to record alongside the measurements is:

- Temperature
- Pressure
- Bias voltage
- Which wavelengths are selected
- SiPMs used (and which channels they are read out through)
- Any unusual behaviour of the setup
- Who is taking the measurements
- When the measurements are taken
- If there was any interruption to the measurement procedure (eg. saturation of SiPMs/DAQ downtime/computer screen frozen etc)
- If any changes were made to the setup

The metadata should be monitored through the measurement procedure and any changes should be noted.

The reference sample in this setup is Aluminium which does not fluoresce. This allows a measurement to be taken with a constant base for comparisons, and to monitor the setup changes over time. This should be measured before and after each measurement at the same temperature and wavelength as the measurements.

7 Fluorescence measurements

7.1 Condition requirements

The requirements that should be met before data taking can begin are given below.

- Pressure below $5 * 10^{-4}$mbar is required to ensure at least 99% of light to reach sample
- Temperature stable to within 5°C
- Slit widths as determined by studies above
- Light source switched on 5 minutes before measurement (dependent on study of lamp time dependence above), and off immediately afterwards

7.2 Configuration

For measurements of one or two samples against a reference Al sample, the chamber should be configured as follows.

- Entrance and exit slits on the monochromator should be opened fully to allow as much light to hit the sample as possible.
- Connect the readout electronics.
- The SiPMs should be inserted into the fluorescence SiPM holder and this should in turn be inserted into the sample chamber.
- The samples should be (carefully) placed into the sample holder, minimising the contact on the surfaces or other contaminations. These should be inserted, placed in the sample holder with the cooling braids attached and lined up with the reference sample facing the exit slit of the monochromator as quickly as is applicable, before closing the chamber up. This is to avoid any atmospheric particles from contaminating the surface as possible.

7.3 Measurements

Once the system has been set up and is ready for data taking, the following steps can be followed.

1. Seal the vacuum chamber
2. Check the readout electronics and DAQ to ensure the SiPMs can be biased correctly and signals can be recorded.
3. Cool the samples to -100°C by pouring LN2 into the cooling module. Read the temperature of the samples from the PT100 and slowly top up the module when temperatures start to rise more than 5°C. Take care not to let the LN2 splash out of the cooling module and try to leave enough space for evaporated N2 to escape through the chimney. This process may be enough to control the temperature to within a few degrees. If it is not, a heating element (eg. conducting wire) can be implemented to aid with the temperature control. This has yet to be determined so remains a point for future work.
4. Note down relevant metadata
5. Turn on lamp (wait for lamp to reach nominal intensity - dependent on fluctuation measurements above), open slits to predefined values (note down slit values here) and select a wavelength of 180nm
6. Check the DAQ to make sure the observed waveforms aren't too noisy
7. Take 1 set of 5,000 waveforms (16us) with the blank sample (10 mins). These can be set to take automatically.
8. Save data file to /project folder
9. Rotate sample holder so that the PTFE is in line with the beam. This position should be marked on the feedthrough control.
10. Take 5 sets of 10,000 waveforms (16us each) with the sample of interest (80 mins). These can be set to take automatically.
11. Save data to /project
12. Take 1 set of 5,000 waveforms (16us) with the blank sample (10 mins). These can be set to take automatically.
13. Save data file to /project folder
14. Stop topping up the LN2 and allow it to evapourate

15. Turn off the SiPM electronics and the lamp.

16. Turn off the pump and allow the chamber to return to atmospheric pressure and room temperture.

Once the measurements are completed, shut down the setup by turning off the power supplies and the pump and allowing the system to return to room temperature and pressure. Remember to tightly close the valve after venting the chamber. Return the SiPMs, samples and extra components to their respective storage. Before leaving, ensure that everything is switched off or safely put away and turn off the DAQ. Note down any components that were left inside the chamber or any conditions that the next person using the setup should be aware of.

8 Data handling

Once the data has been recorded and stored in the /project folder, the analysis can be carried out. This section focuses on the analysis and the uncertainties involved in these analyses.

8.1 Uncertainties

A summary of the origins of uncertainties is given here, split into errors from physical parts of the setup and errors from the handling of the data and listed here with a brief description.

8.1.1 Physical uncertainties:

- Condensation: The formation of a condensed water layer on the sample surface will attenuate the VUV light. The formation of this layer depends on time, the material of the sample and the temperature of the sample. This is described in Section 5.3.

- Lamp intensity changes with time: The change in the intensity of the beam over time is measured as described in Section 3.7, with the uncertainty originating from the intervals and the finite number of measurements taken.

- Higher-order wavelengths: When selecting a wavelength on the monochromator, the grating also lets some higher-order wavelengths through. Measuring the intensity of these wavelengths has an uncertainty based on the transmission efficiency of the filter used and the measurement procedure.

- Wavelength-choice uncertainties: The monochromator grating allows a range of wavelengths to pass around the selected value. This, combined with the slit when open at 3mm is given as $\pm$10nm.

8.1.2 Analytical uncertainties:

- Dark count rate: This uncertainty originates from the finite measurements taken, the temperature and bias voltage resolutions, the electronic noise and if there are any light leaks and is defined by the standard deviation of the dark count rate, described in Section 3.1.

- Fluorescence of SiPM windows or filters: If the windows on the SiPMs have some ability to fluoresce when excited by the VUV light reflected off of the sample, this signal will complicate the measurement of the sample fluorescence. Filters placed in the setup to test for the origins of different wavelength light may also fluoresce. The measurement of these effects will return a distribution of rates which will have an uncertainty based on the comparison to the dark counts of the SiPMs used, and the standard deviation of the measured distribution.

- Sample reflection: The visible SiPMs used in VULCAN should be blind to VUV light and only detect the higher-order wavelengths, but may have some sensitivity in the VUV range. This is discussed in Section 5.2 and the uncertainty will be determined by the standard deviation of this measurement.

- Baseline correction - when reading out the signals in the DAQ, some baseline adjustment will have to be implemented to account for fluctuations and ensure all peaks of the same type are of the same height (for triggering purposes). The method used currently is the adaptive least-squares approach taken from [3].

The uncertainties which are expected to have the largest impact on the fluorescence measurements of a sample depend on the conditions that the measurements are taken under. The condensation layer forming on the sample surfaces when the samples are cooled will have a large impact on the amount of VUV light that reaches the sample, and therefore on the fluorescence which it is possible to see. For measurements taken without cooling the samples, nuisance light is expected to have the largest impact on the measurements.

8.1.3 Errors in practice

The measurements taken with SiPMs are effectively rate distributions.

The first step to take is to compare the rate measured, R_{meas} with the dark count rate, R_{DC}. This will indicate whether there was a signal observed above the dark count level. The dark count rate is taken from the characterisation indicated in Section 3.1, with the rate to use corresponding to the SiPM in question, the temperature and the overvoltage applied when taking the measurements. A hypothesis test will determine whether the measured rate is significantly different from the dark count rate. The errors on the dark count rate, σ_{DC}, and on the measured data, σ_{meas} can be combined through error propagation.

In the situation where two different spectra need to be compared, the two distributions of rate first need to each be corrected for the dark count rate, as described above. Other differences between the two spectra will also be present (eg slit width differences). These uncertainties will be combined into one number here which will define α which will have it's own uncertainty, σ_α. Each distribution is then multiplied by their respective α values. The resulting error will be the propagation of the errors from the dark count correction, σ_err, and the standard deviation of the result is found via error propagation rules.

$$\sigma_{tot} = |\alpha * R_{meas}| \sqrt{(\frac{\sqrt{\sigma_{meas}^2 + \sigma_{DC}^2}}{R_{meas}})^2 + (\frac{\sqrt{\sigma_\alpha^2}}{\alpha})^2} \tag{2}$$

Equation 2 can be implemented for each bin in the histograms.

The challenging aspect of handling the errors will be to include all relevant factors and their corresponding uncertainties. The two treatments described here should, however, give an appropriate uncertainty on the measurements taken.

8.2 Significance of observed signal

See [4] for estimates of the required fluorescence for the signals to be visible above the dark count level. This level will also be modified to include the necessary fluorescence to be visible above the dark count + reflection + nuisance light levels.

This calculation can be worked backwards to determine the level of fluorescence yield that is observed. An initial estimate (without error propagation and assumptions stated in link) uses a SiPM solid angle subtending 5% with fill factor 65% and light detection efficiency of 25%. The dark count rate is estimated at 6MHz as given in the spec sheet, and the absorption efficiency of the sample is assumed to be 5%. The fluorescence yield ϕ is defined as the fraction of number of fluoresced photons N_{fl} over the number of absorbed photons N_{abs}. The number of fluorescence photons detected (above the dark counts + reflected light + nuisance light etc) can be related back to the total number of fluoresced photons N_{fl} via

$$N_{fl} = N_{obs} * \frac{1}{0.05} * \frac{1}{0.65} * \frac{1}{0.25}$$

The number of absorbed photons is estimated by taking a measurement of the quantity of signals seen from the lamp light directly N_{dir}, multiplied by the absorption efficiency. N_{dir} will also have to take into account the PDE of the SiPM and solid angle covered which may have changed with the different configuration.

Thus, the fluorescence yield can be given by

$$\phi = \frac{N_{obs} * \frac{1}{0.05} * \frac{1}{0.65} * \frac{1}{0.25}}{N_{dir} * 0.05}$$

$$\phi = 2462 * \frac{N_{obs}}{N_{dir}}$$

The intensity of N_{dir} may be difficult to measure, since the SiPMs so far have been saturated when placed too close to the entrance slit opened all the way. In the case that they do saturate again, this number may have to be some extrapolation from (1) the SiPMs distance from the slit or (2) measuring at a wavelength where the PDE or intensity is lower and multiplying the spectrum.

9 Tasks for further work

There are some parts of this document where information is not yet complete enough to be specific about what is needed. A short summary of the points which are still under construction or with information that is not yet available is given here.

- Determining a consistent and accurate method to ensure that the samples are lined up perpendicularly with the incoming beam.
- The magnitude of the uncertainties when the exit slit of the monochromator is opened to different width values. Here, we know only the uncertainty for the slit open at 3mm which is 10nm.
- The number of waveforms to take for these measurements is estimated in this report but can later be optimised.
- The SiPM holder used currently is a temporary frame. This will later be replaced with a holder designed for these fluorescence measurements.
- The recording of slow control parameters such as the pressure or the temperatures may be automatable. For now, this is recorded by hand.
- The storage system for samples after they have been cleaned is not yet designed.
- The /project folder here is not yet available, but will be where the data from this setup is stored when measurements are taken.
- The measurement or handling of the effect of condensation on the surface of the sample is not yet formulated.
- The method to study fluorescence of SiPM windows has not been formulated.
- How quickly the samples can be cooled with the LN2 cooling system, and the stability of the temperature when cooled is not yet known.

References

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