VUV Reflectance Measurements for Materials Relevant to Argon and Xenon Experiments

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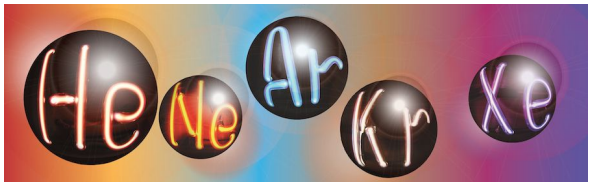

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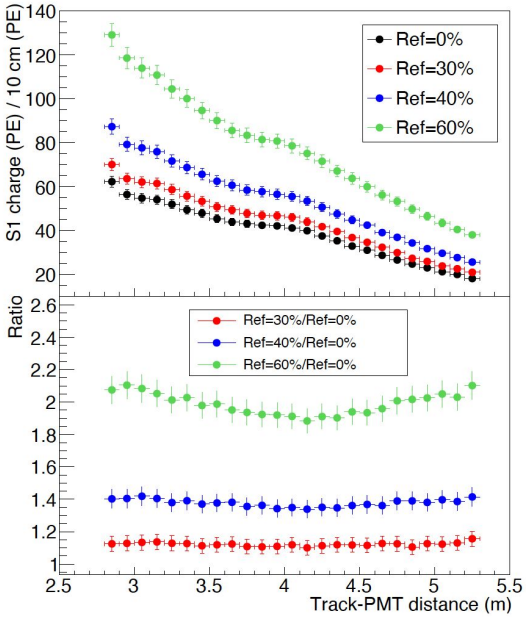
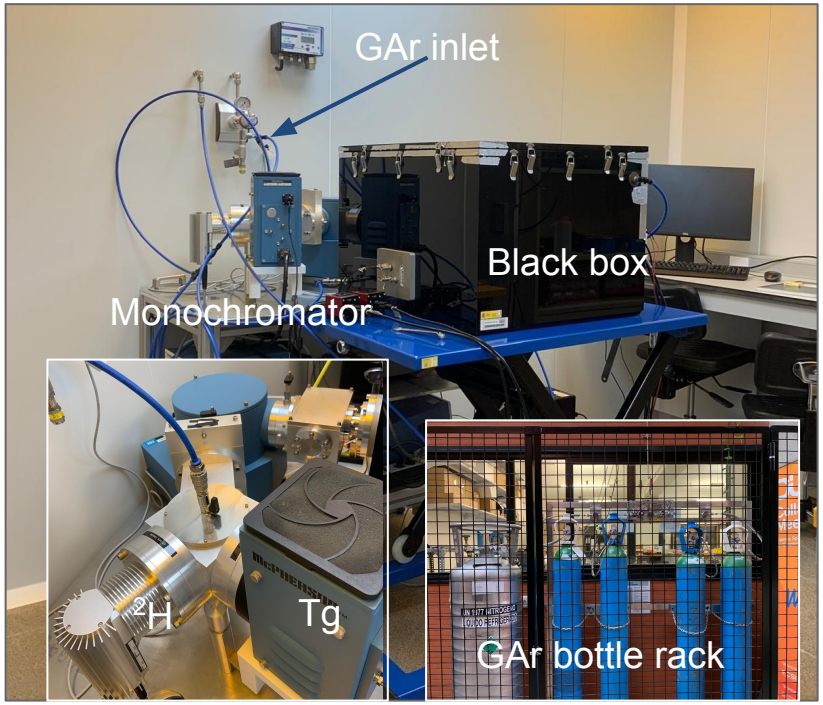
Reflectance measurements at IFIC

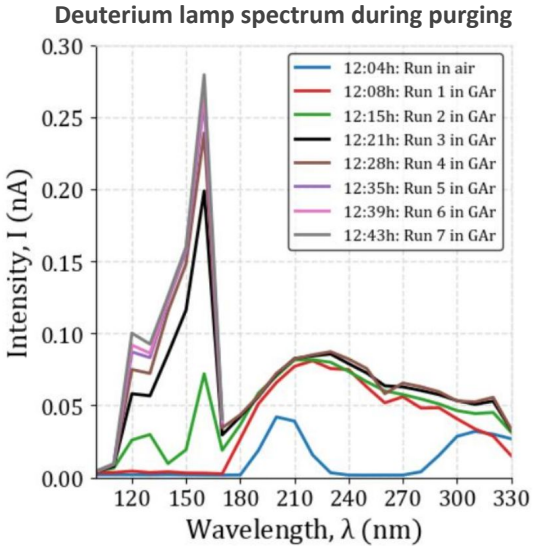
- Optical measurements in the **vacuum ultraviolet** are crucial for a better understanding and **optimization of the photon detection**.
- **Reflectance values** are essential for estimating an accurate light yield for any noble gas detector. In particular, important materials in DUNE are aluminum (Field cage) and stainless steel (cryostat).
- **Reflectance directly affects the light yield and the PDE estimation.** It is crucial to have dedicated measurements to ensure accurate results.
- Reflectance values for VUV light are not well known. Different values can be found in the literature, and **highly depends on the sample** (surface treatment and/or termination).
- At IFIC, we have **dedicated a setup to perform angular-resolved reflectance measurements in the VUV range**. This setup includes calibrated samples to validate the method and measurements of real cryostat and field cage samples from DUNE.
- Additionally, an angular-resolved measurement would allow to improve our understanding of the photon propagation inside the detector, and **refine the simulation implementing an angular distribution**.

Detected light vs distance per muon track in ProtoDUNE-DP (simulation)



VUV optical measurements in a GAr atmosphere

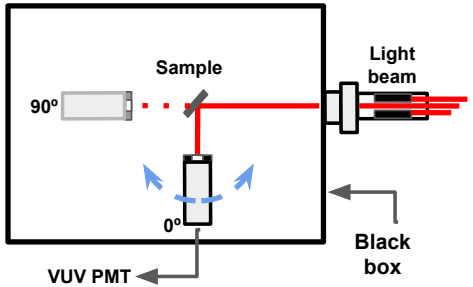


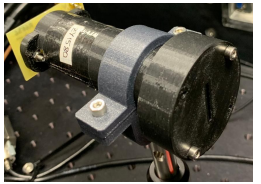


- A D2 lamp coupled to a monochromator and connected to a GAr system in a dedicated dark room.
- Measurements are conducted in a pure GAr atmosphere to enable light transmission in the VUV region.
- The spectrum of the D2 lamp during purging is shown above.
- Using a GAr atmosphere:
  - Protects the monochromator grating from outgassing.
  - **Provide flexibility to fully instrument the black box.**

A setup for angular-resolved measurements

- A 3D-printed assembly that contains two Thorlabs rotary stages and a motorized sample holder.
  - Motor 1: To change samples.
  - Motor 2: To rotate a VUV-sensitive PMT.
  - Motor 3: To rotate the sample holder.
- Additionally, an iris + shutter.
- A rectangular mask of 2x20 mm^2 for the PMT, with an opening of 0.8º, is employed to enhance angular resolution.



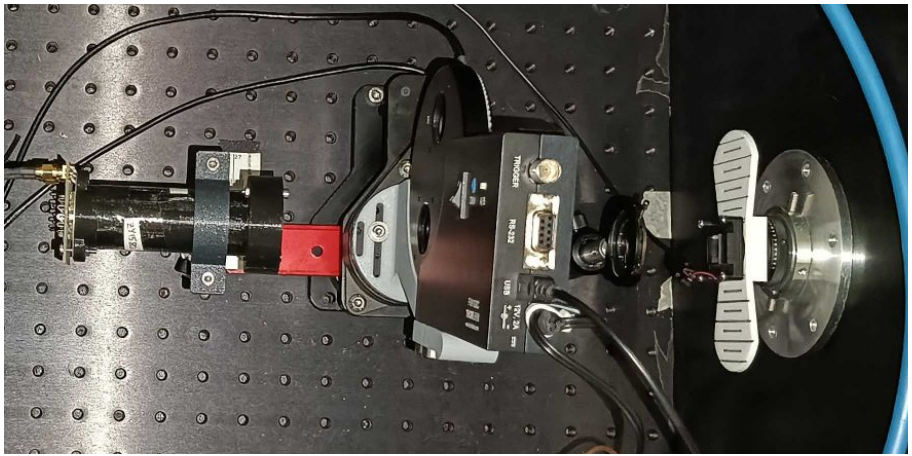


PMT with mask

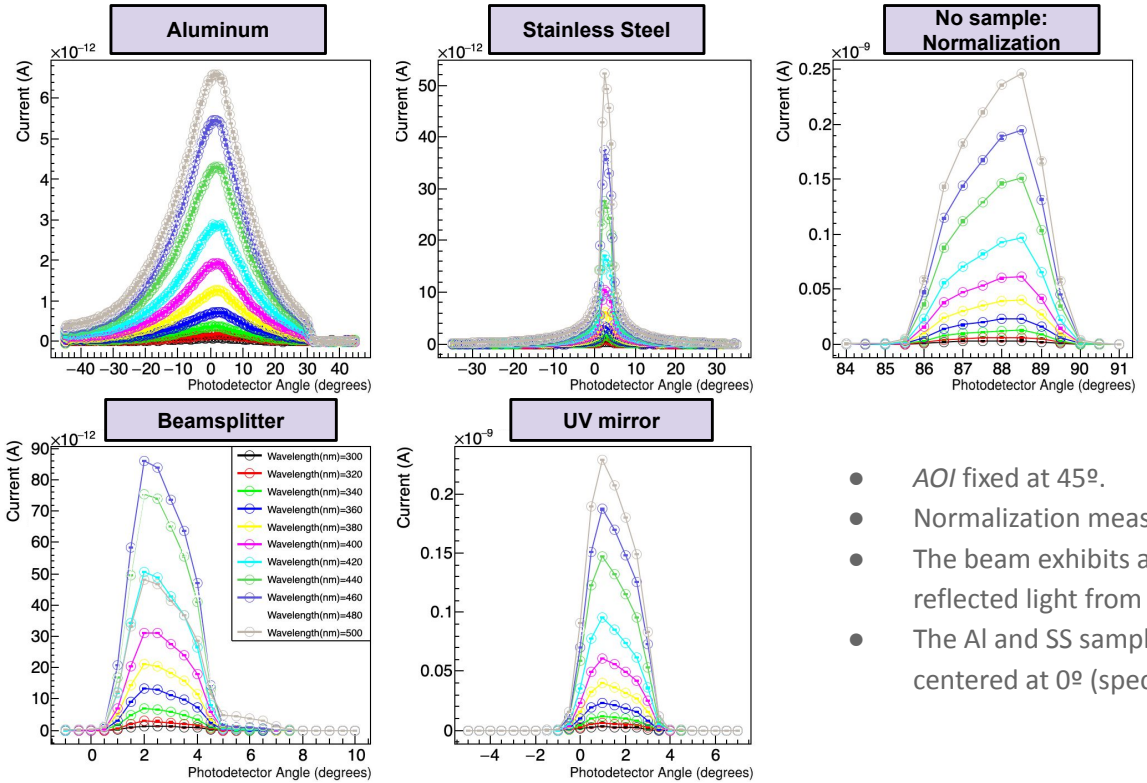
Sample holder

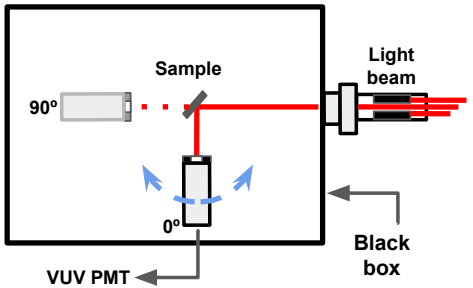
This automated setup enables the measurement of light angular distributions at various angles of incidence (*AOI*) and samples.

- **DUNE Aluminum field cage profiles.**
- **DUNE Stainless steel cryostat membrane.**



Reflectance measurements





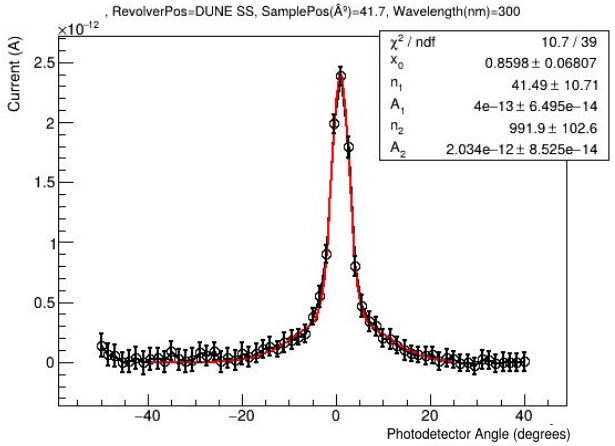
- *AOI* fixed at 45º.
- Normalization measurement taken for every wavelength.
- The beam exhibits an asymmetrical profile, which is evident in the reflected light from the specular samples.
- The Al and SS samples exhibit a broad distribution (diffuse-like) centered at 0º (specular-like).

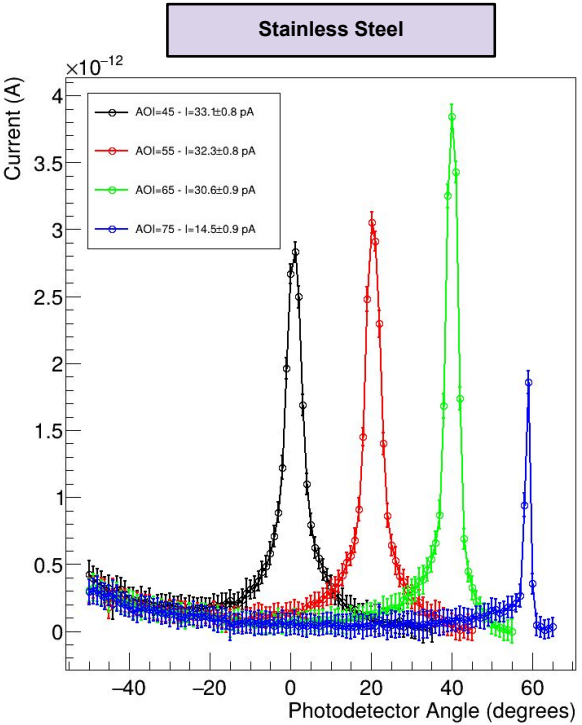
Measurements at different angles of incidence

- An ideal reflector would exhibit a Lambertian distribution.
- The samples under study demonstrate a hybrid distribution that aligns well with this equation derived from the Phong model [1]:

$$\sum A_i(cos(x - x_0))^{n_j}$$

- The parameter *n* corresponds to the surface termination.

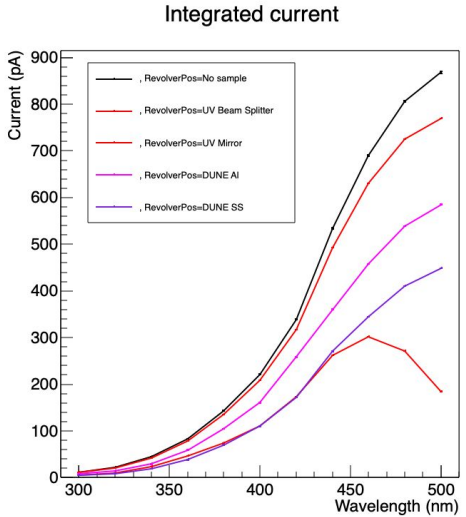


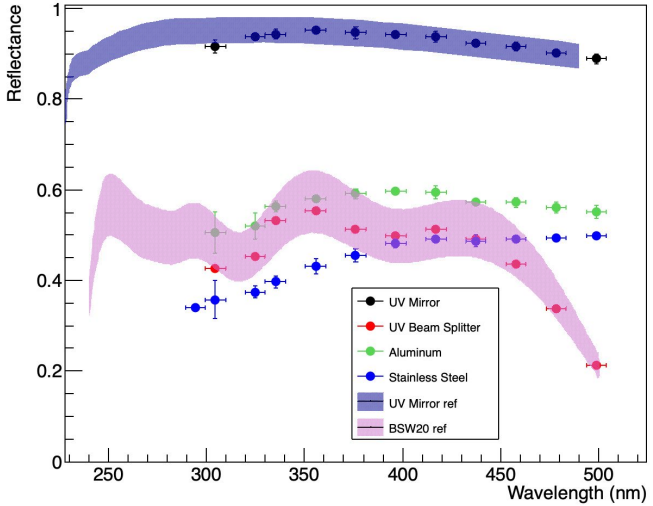


[1] Phong, Bui Tuong. Illumination for Computer Generated Pictures. Communications of the ACM, 18(6), 1975, (pp. 311-317.)

Reflectance measurements using Tg lamp (300-500nm)

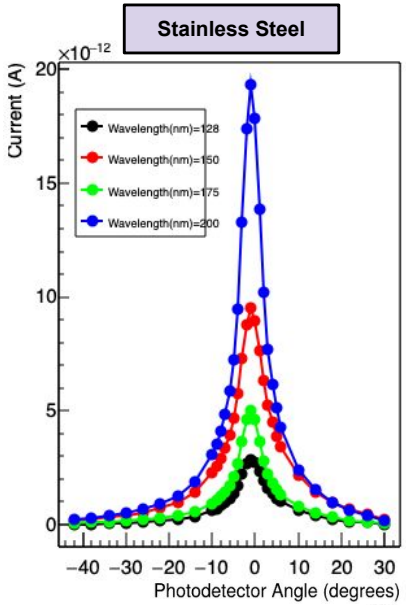
- Reflectance is obtained by integrating the angular resolved measurement, and dividing by the normalization.
- A correction is applied to diffuse samples (Al and SS), assuming angular symmetry, to estimate the light not collected in the scan (at wide angles).
- Control samples (mirror and beamsplitter) reproduce well the reference values.
- Reflectance measurements indicate approximately 70% for aluminum and 40% for stainless steel in the UV-VIS region.

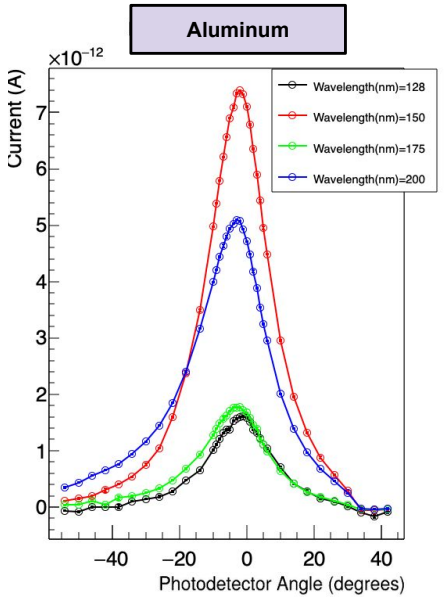


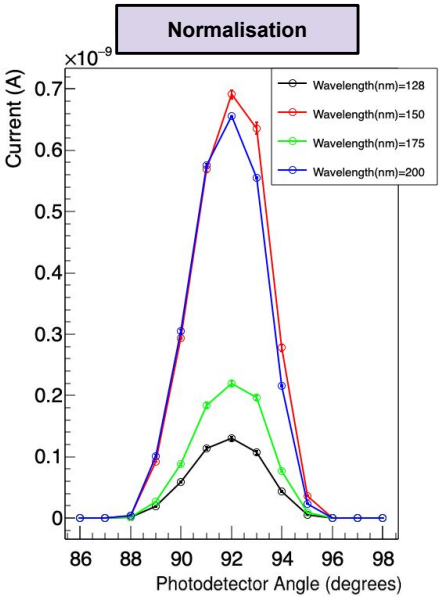


Reflectance measurements using D_2 lamp in GAr (VUV)

- Despite the small signal, we have successfully detected reflected light in the VUV spectrum for both samples.
- Normalization measurements are taken before and after each sample, to ensure the atmosphere transmission is stable.
- Stainless-steel reflects more specularly.

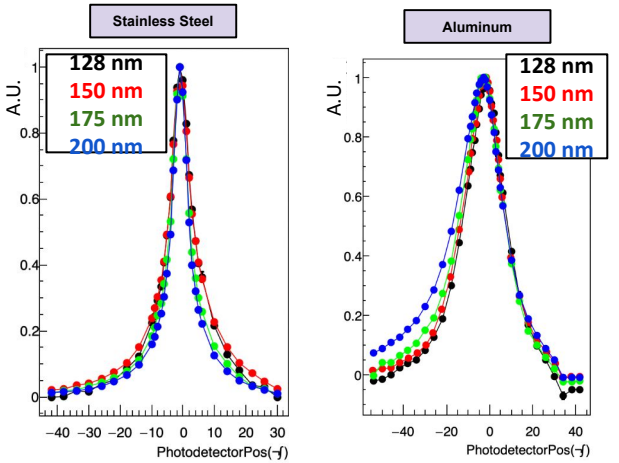




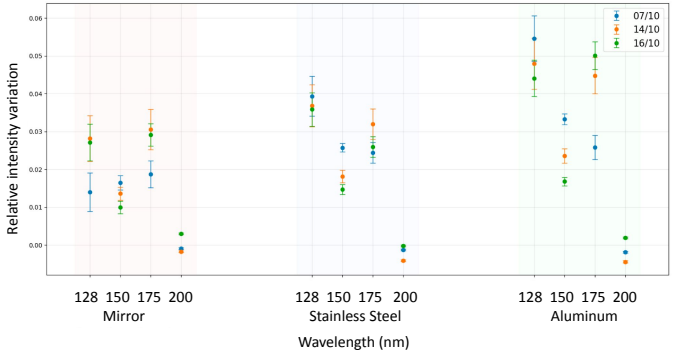


Reflectance measurements using D_2 lamp in GAr (VUV)

- Angular distribution looks very similar at different wavelengths.
- Aluminum seems to be slightly more specular at shorter wavelengths.

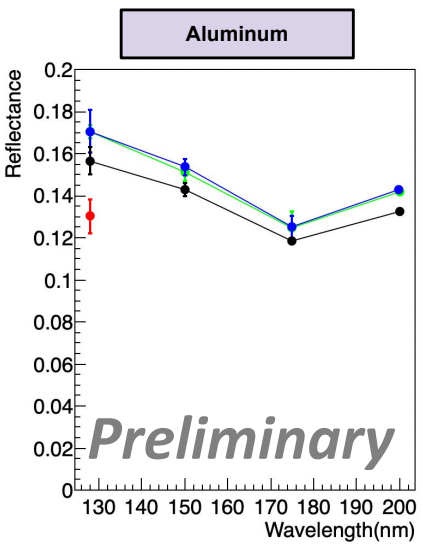


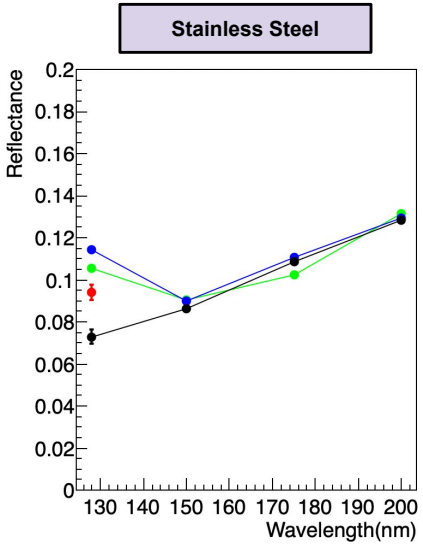
- Normalization measurements points to a light **transmission stability through the GAr atmosphere better than 6%**.



Aluminum and Stainless steel reflectance in the VUV

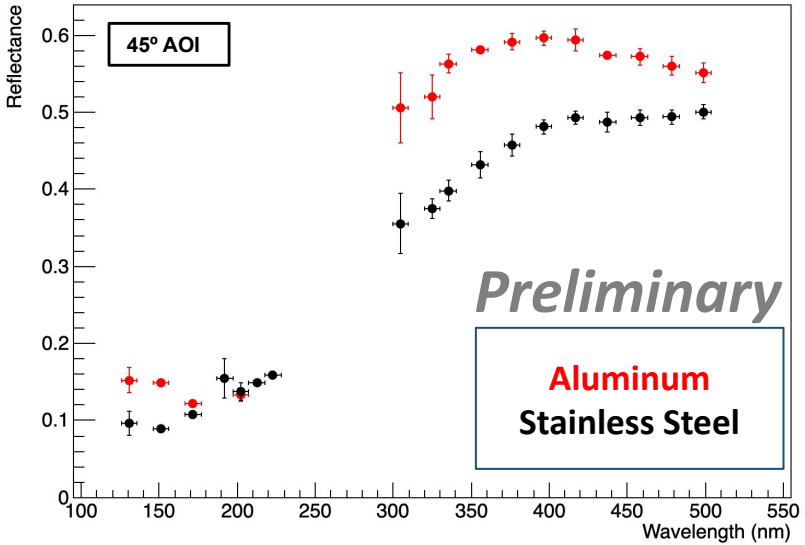
- Reflectance measurements for Al and SS indicate approximately 10-15% at 45°.
- A better **understanding of the systematics** is currently being investigated:
  - Effect of the GAr atmosphere stability.
  - Beam size and collimation (iris).
  - Extrapolation to 2π.





Summary of results and next steps

- A setup to performed optical measurements in the VUV range using a gaseous argon atmosphere is available at IFIC.
- The system allows to perform sophisticated measurements that would be more challenging in vacuum.
- Preliminary measurements points to reflectivity values in the range of 10-15% for aluminum and stainless steels samples.
- Better understanding of the systematics is under study.



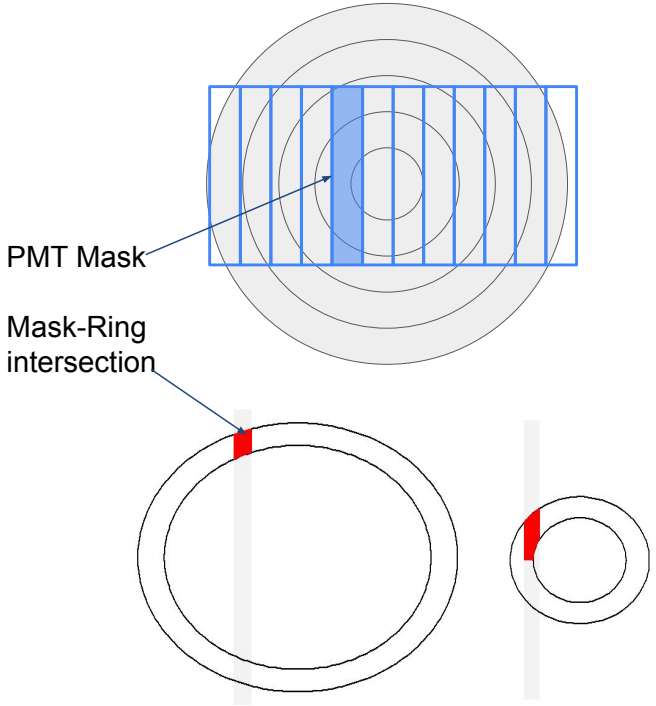
Backup

A *Ring model* to extract the integrated emitted light

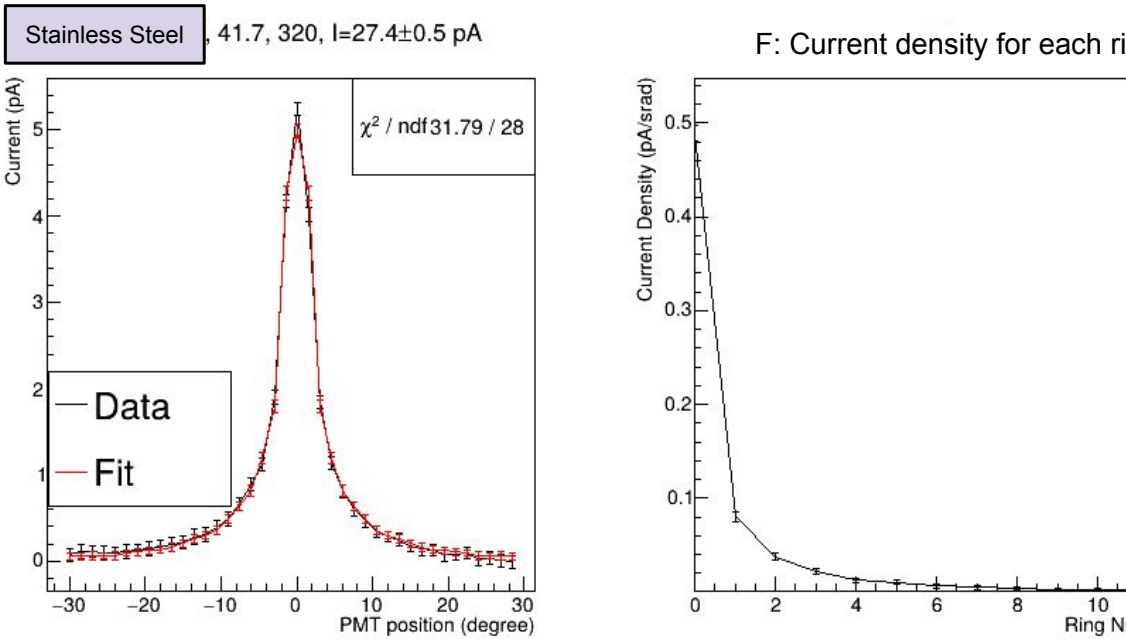
- In diffuse samples, light is emitted in a 2π pattern, and the PMT does not collect all light.
- By assuming radial symmetry, we can correct for the non-collected light.
- If the PMT is covered with a mask of known size *M*, a simple ring model can be proposed: $I_i = \sum_j A_j \cap M_i \, F_j$

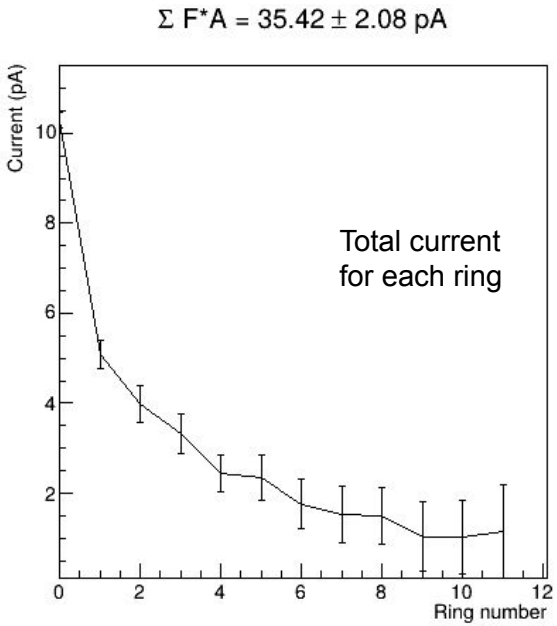
Variable	Definition	Units	Comment
I_i	Current in position *i*.	A	Our data.
A_j	Area of the *j* ring.	m^2	Intersection can be solved analytically.
M_i	Mask area at i position.	m^2	
F_j	Average photo-current density in the whole ring.	A/m^2	Obtained by fitting the data.

Total emitted light = $\sum_j A_j \, F_j$



The Ring model performance





- The model adheres to the requirement of symmetry.
- It provides an estimation of the total emitted light, which is 50% higher than the directly measured value.
- However, the error associated with this estimation is also increased.

O_2 molecular absorption in the UV-VUV range