UNIVERSITÀ DEGLI STUDI
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LArRI: a new setup for Liquid Argon Refractive Index measurement

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Why LArRI?

Liquid Argon is one of the most widely used scintillators in particle detection, due to its low cost, high availability and excellent scintillation properties.
Xenon-doping of the liquid Ar has been proven to increase the uniformity and amount of collected light, by increasing the optical scattering length. Xenon-doped LAr has a peak scintillation emission at 175 nm.

It is crucial to measure the optical properties of liquid argon

Main goal: Direct measurement of the refractive index of liquid Argon at wavelengths close to 175 nm.

Secondary goals:
○Measurement at various wavelengths (dispersion relation)
○Measurement of the attenuation length
○Optical measurements with other liquefied noble gases

Project aimed at the development of optical systems, in particular lenses, for Xe-doped LAr imaging

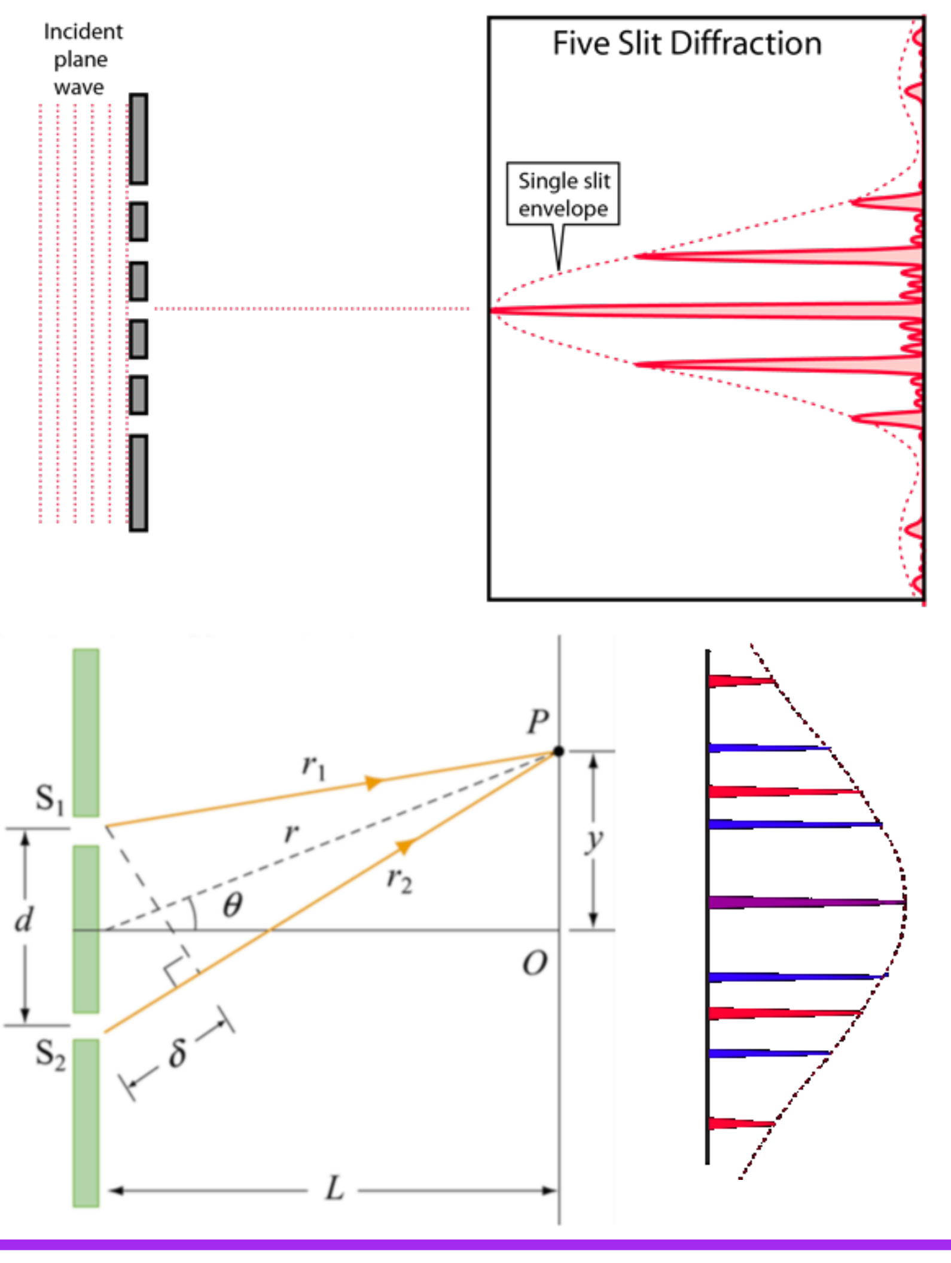
Measurement strategy

The **key idea** is to measure the refractive index of liquid Argon by **comparing the diffraction patterns** produced using a diffraction grating when the light propagates **in argon and in vacuum.**

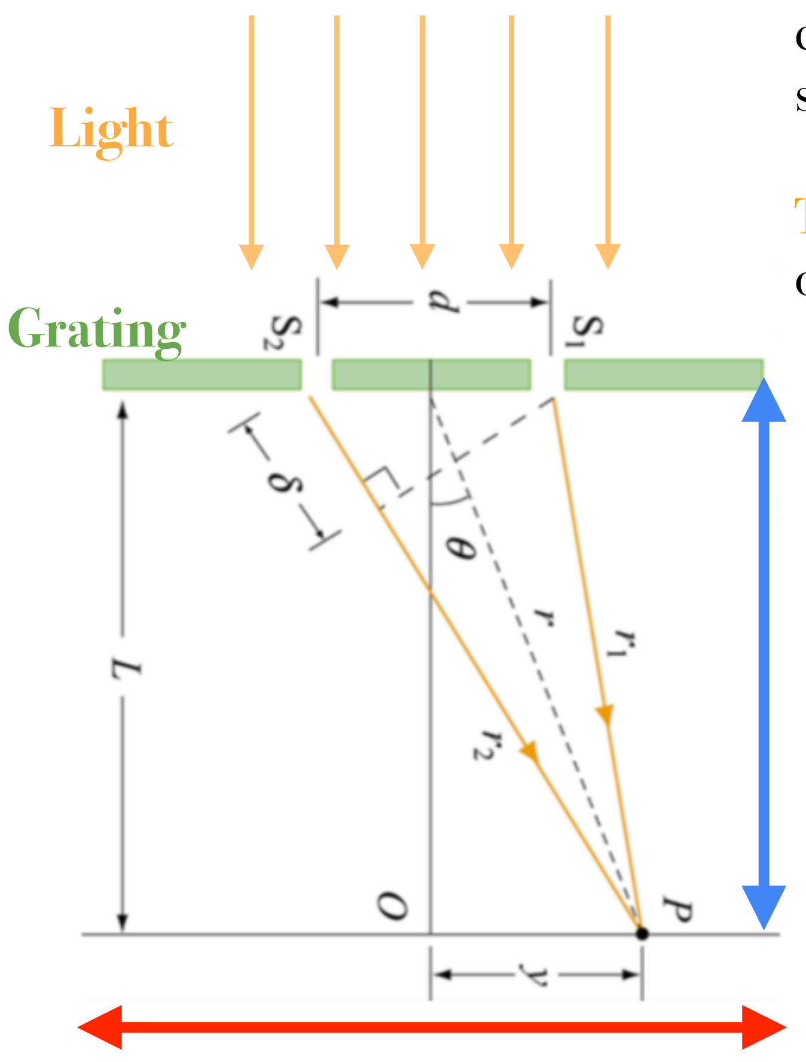
When the grating is immersed in liquid Argon, the position of the diffraction peaks depends on $\lambda_L = \lambda_o / n$.
Where λ_L is the wavelength in liquid, λ_o in vacuum and n is the liquid Ar refractive index.

Max in vacuum: $d \sin\theta_o = \lambda_o$
Max in LAr: $d \sin\theta_L = \lambda_L$

We need coherent and monochromatic light



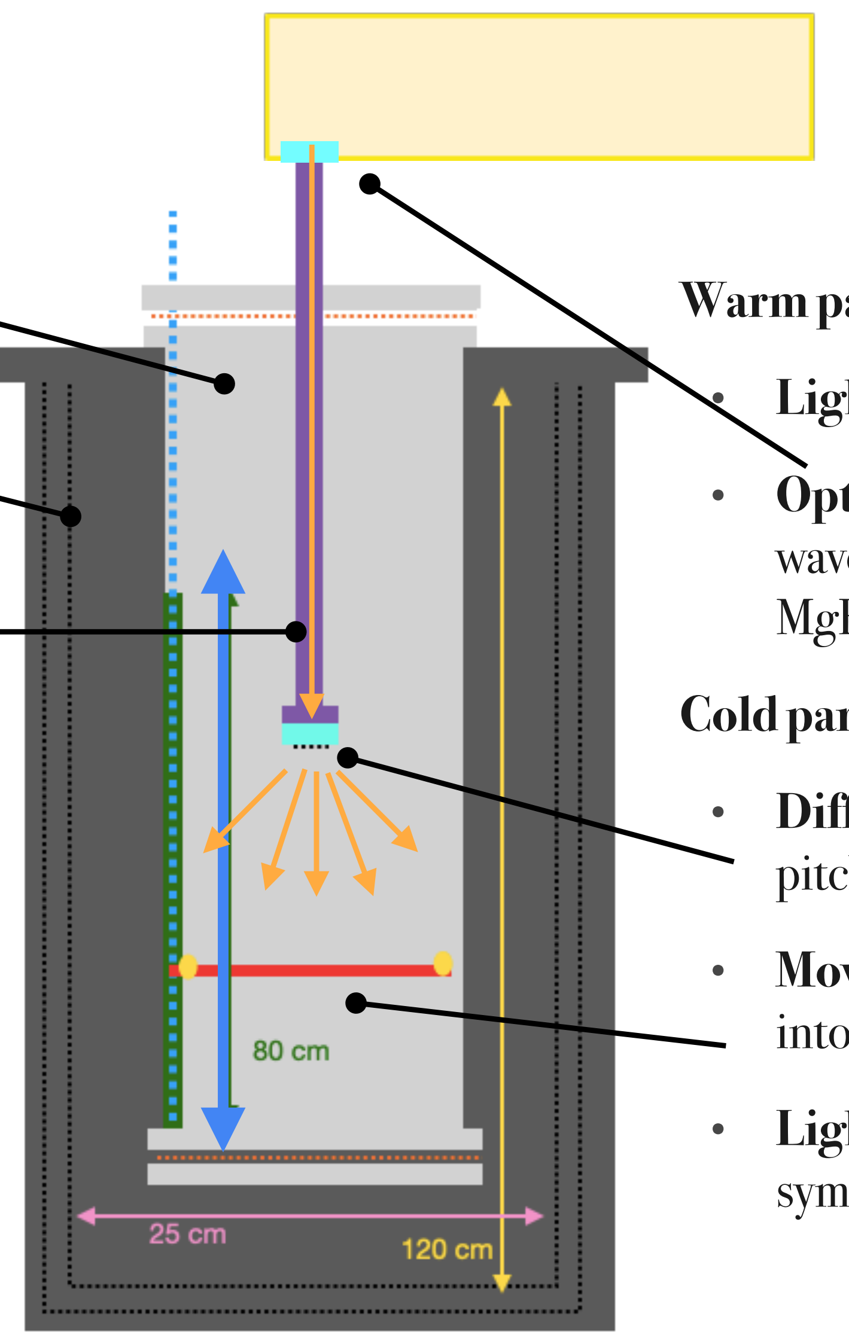
Conceptual scheme of the LArRI setup



The core of the setup is a cylindrical chamber, that can be both evacuated and filled with liquid argon. The chamber is contained in a cryostat, to thermalize the system.

The light, coherent and monochromatic, comes from outside the cryostat, entering from above.

The diffraction pattern is recorded by scanning along the vertical axis using SiPMs mounted on a movable stand.
To compact the apparatus we do not scan on the side opposite to the grating, as is usually done, but on the lateral sides.



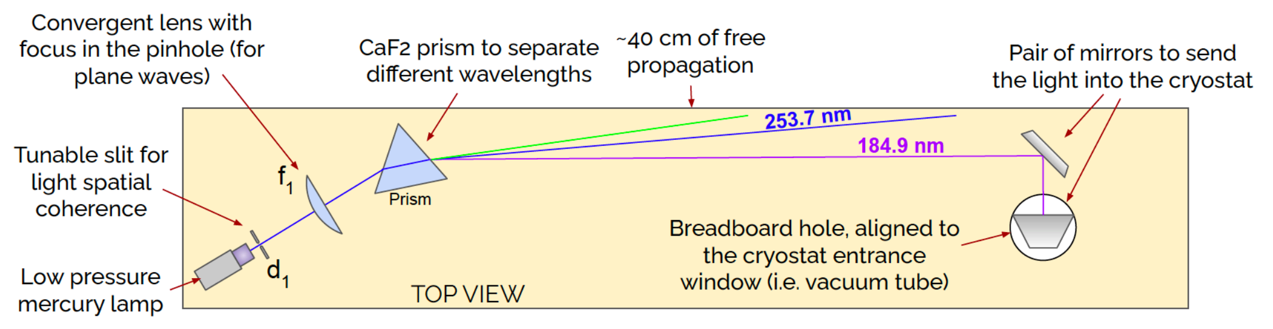
Warm part:

- **Light source**: **low pressure mercury lamp** with emission peaks at 184.9 nm and 253.7nm
- **Optical setup**: produces a collimated beam and a MgF2 prism is used to select a specific wavelength (184.9 mn as a proxy for LXe scintillation light). A vertical tube closed by two MgF2 viewports and in vacuum is used to send the VUV light into the cold chamber.

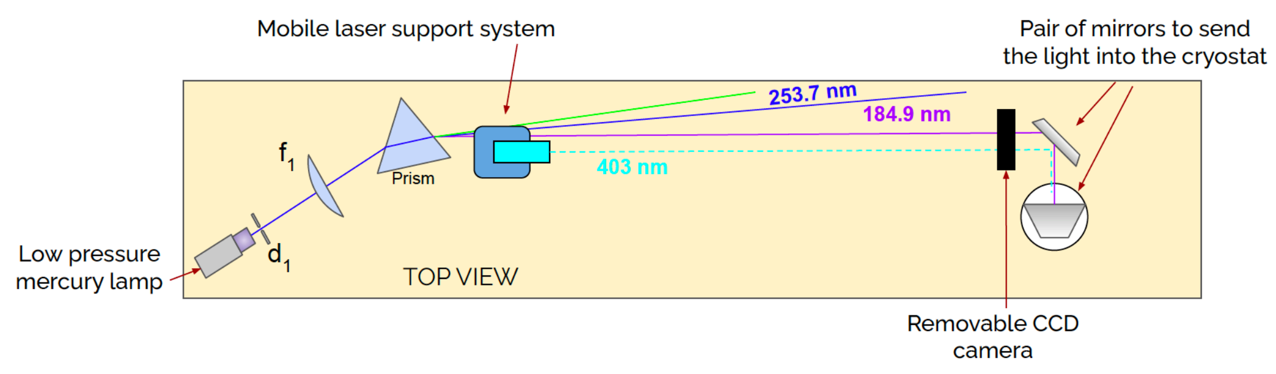
Cold part:

- **Diffraction grating**: made of aluminum deposited on a thin fused silica substrate, 720 nm pitch.
- **Moving system**: a motor by VacuumFab capable to operate both in vacuum and immersed into cryogenic liquids is used to lift a support housing the light detectors.
- **Light detectors**: 5 Hamamatsu (S13370-3075CN) UV-sensitive SiPMs (3x3 mm²), four symmetrically mounted on the moving support, one at the center.

A zoom on the optical system and alignment procedure



All the optical mounting is in air with a roughly 50% light loss at 185 nm.



After the alignment the laser can be removed and the 185 nm line is aligned with the system in the chamber.

The optical assembly is mounted on a breadboard, placed on top of the cryostat. An hole on the breadboard, in correspondence of the final mirror, allows the beam to reach the entrance viewport, go through the vacuum tube and enter into the cold chamber passing through a second viewport.

Due to the limited intensity of the 185 nm line it is not possible to align the beam directly. So we have developed a two-step procedure:
1. Align the 185 nm to a 403 nm laser, using a CCD placed on the bread board;
2. Remove the CCD and align the laser with the central SiPM, tuning the orientation of the mirrors.

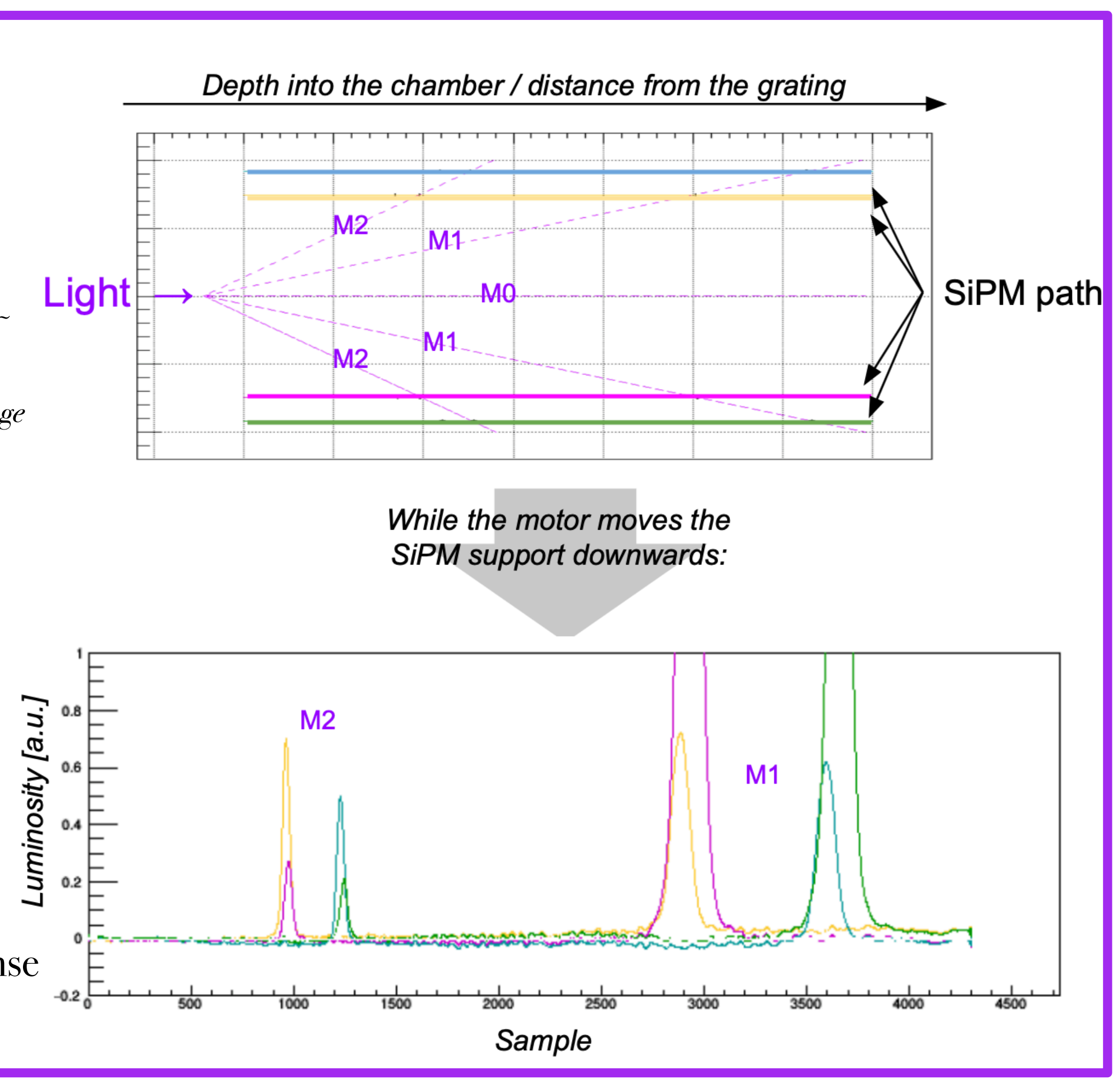
Electronics and DAQ

Two custom made front end boards, placed outside the cryostat at room temperature, route the bias voltage to the SiPMs and integrate their current signals, with a τ ~ 100 ms).
For more details see M. Cariello's poster #185 - "A Wide Dynamics Range Front-End Electronics for SiPMs using High-Speed Operational and Integration Amplifiers"

Signals are then acquired with a Teledyne Lecroy scope in 100 ms long windows, at typically rates of 2-10 Hz.

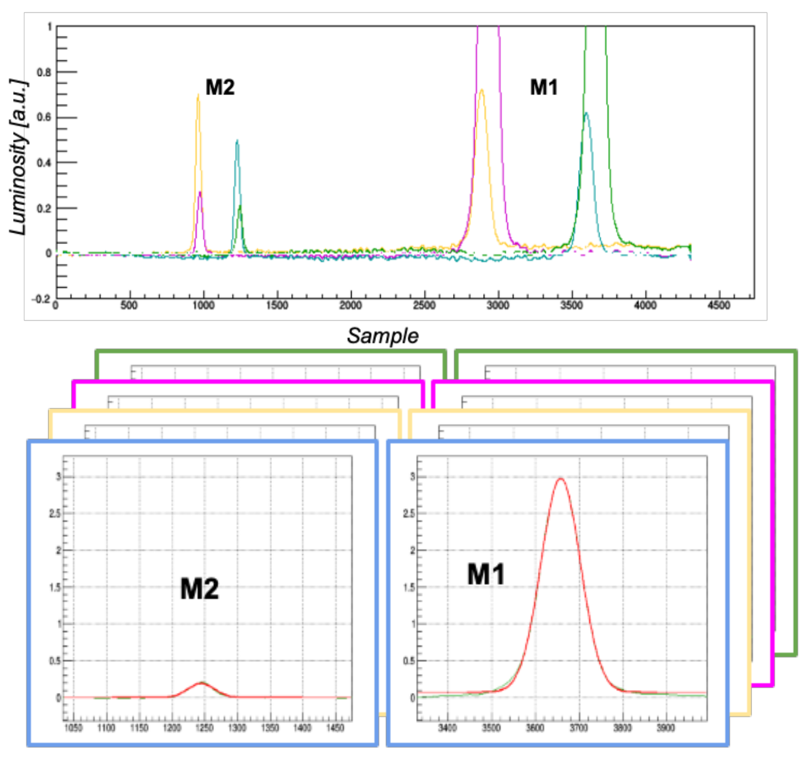
The average value of each acquired window represents a luminosity sample.

During a scan from top to bottom, the 4 SiPMs intercept the interference peaks: first the less intense M2, then the M1 with greater intensity.



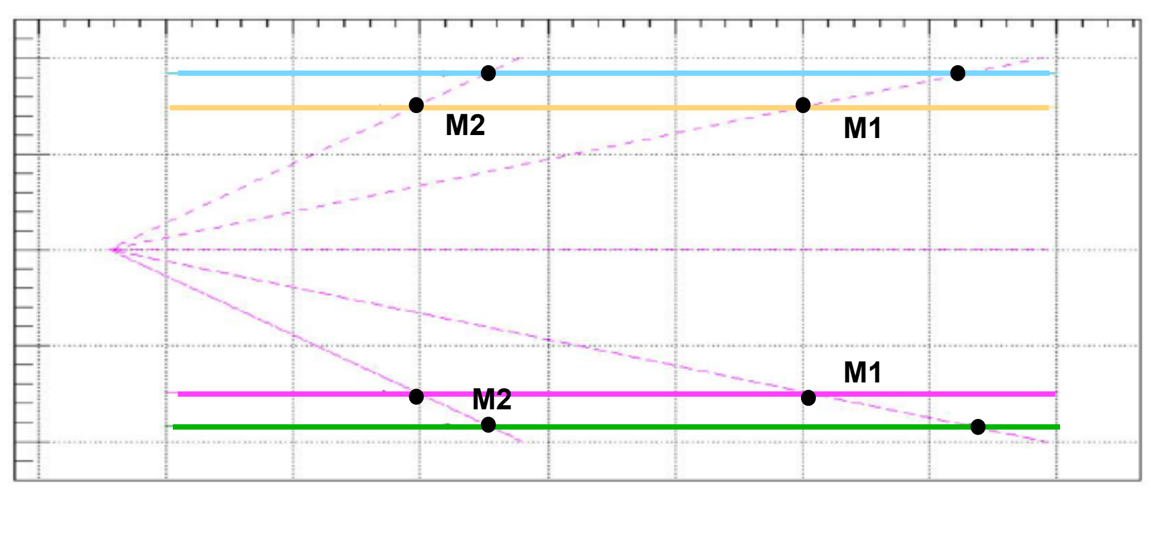
While the motor moves the SiPM support downwards:

Analysis and preliminary results

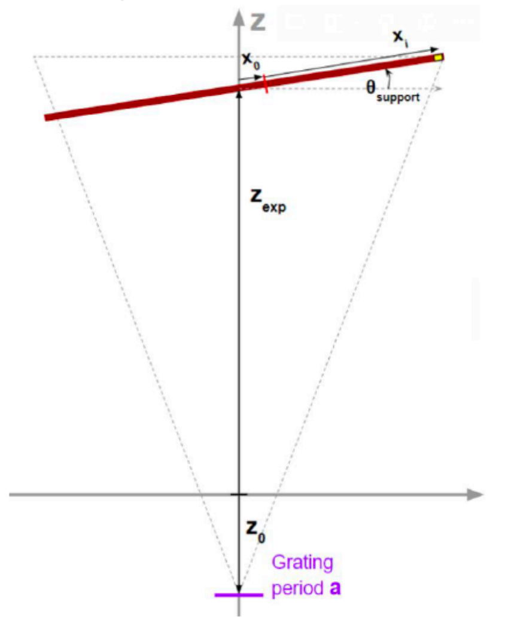


The first step of the analysis considers a **single scan**: for each of the 8 luminosity maxima (M1 and M2 for 4 SiPMs) the mean is found with a gaussian fit.

Then by knowing the motor position at the beginning and at the end of a scan **we can reconstruct where every SiPM has intercepted the diffraction maxima.**



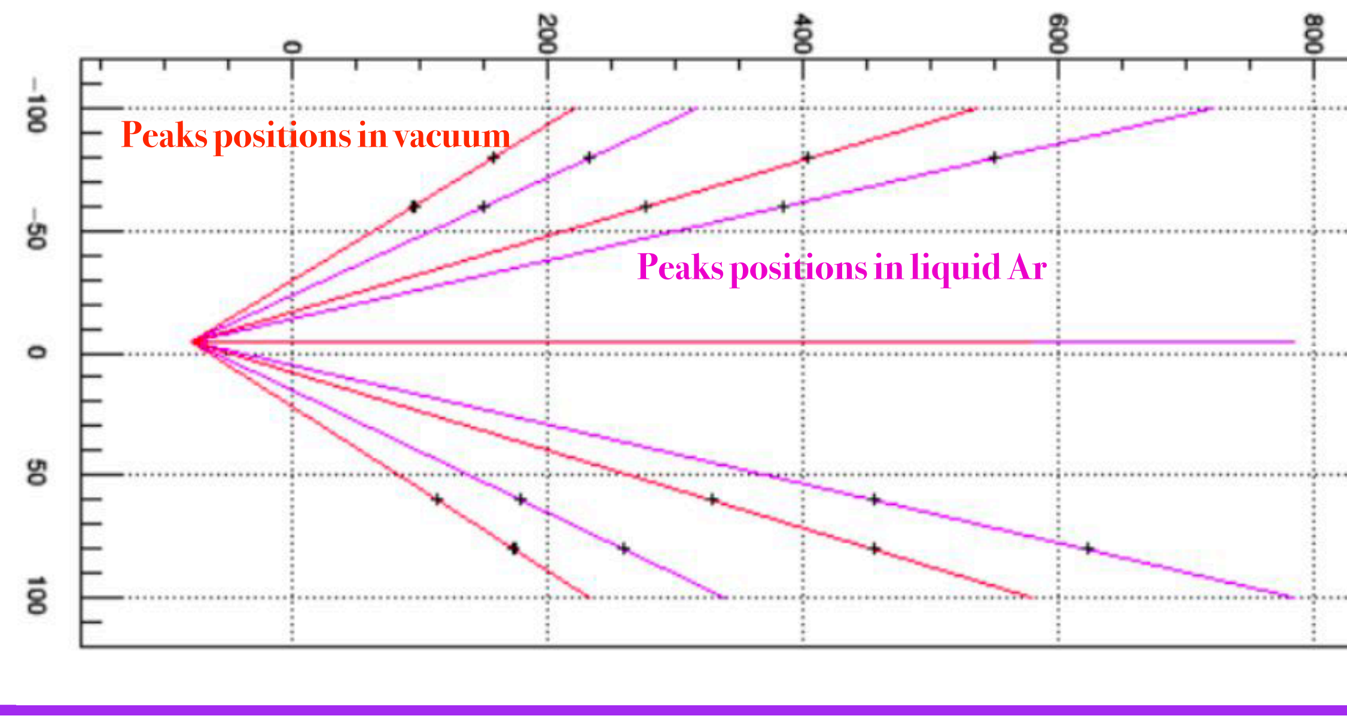
The positions of the maxima acquired in **two scans**, one with the chamber **under vacuum** and cold and the other with the chamber filled **with cryogenic liquid**, **are simultaneously fit to measure the refractive index**. The comparison between two scans, including vacuum data, reduces the systematics effects due to the geometrical non idealities of the setup.



Free parameters:

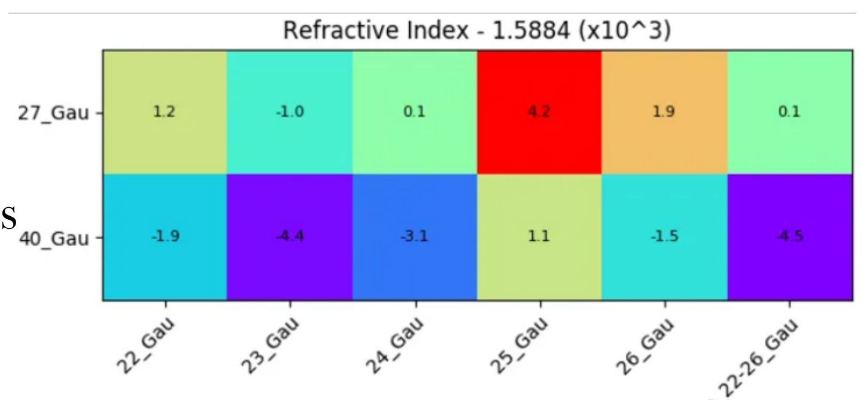
1. z_0 Initial SiPM-support position along the motor axis
2. θ_s angle between the motor axis and the SiPM-support
3. x_0 offset on the SiPM slot positions along the support
4. $a_{grating}$ grating periodicity
5. n ...refractive index!

$$z_{exp} = \frac{(x_i + x_0)\cos\theta_s}{\tan \arcsin \frac{m\lambda}{an}} - (x_i + x_0)\sin\theta_s - z_0$$



To check the consistency of our method **we compare data acquired in vacuum but from two different wavelengths**. The pattern will change according to the ratio of the λ. All the analysis is done in the same way and the expected contraction factor of the pattern (n) is the ratio between the two wavelengths ($\lambda_1 = \lambda_2 / n$).

Two scans (#27 and #40) with laser source at 402.9 nm are analysed with 5 scans (#22 to #26) with 253.7 nm mercury lamp light.



Refractive Index - 1.5884 (x10^3)

	22_Gau	23_Gau	24_Gau	25_Gau	26_Gau	Media_22-26_Gau
27_Gau	1.2	-1.0	0.1	4.2	1.9	0.1
40_Gau	-1.9	-4.4	-3.1	1.1	-1.5	-4.5

Results are shown as the deviation from the expected value (402.9 nm/257.7 nm=1.5884), magnified by 10^3

We obtain a compatibility within few parts per thousand.

We collected data during a **cryogenic test with liquid nitrogen**, obtaining a first **(preliminary) measurement of the LN2 refractive index** at both 402.9 (laser) and 253.65 nm (mercury lamp).

$$\mathbf{n_{LN_2}(402.9nm) = 1.203 \pm 0.0005}$$
with 2 independent measurements

$$\mathbf{n_{LN_2}(253.65nm) = 1.244 \pm 0.009}$$
with 8 measurements in vacuum and 8 in liquid nitrogen