LArRI

A new setup for **Liquid Argon Refractive Index** measurement

Dune Italia Collaboration meeting - Lecce - 6 Novembre 2023

B. Bottino, A. Campani,
R. Caravita, S. Copello, F. Ferraro

Università di Genova
INFN

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.

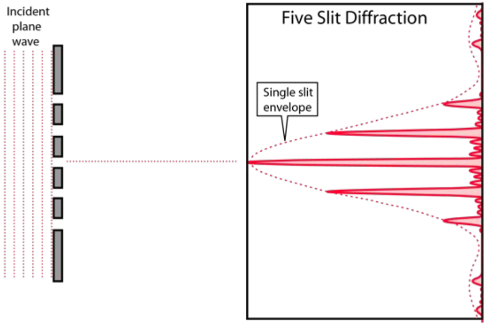
Measurement strategy

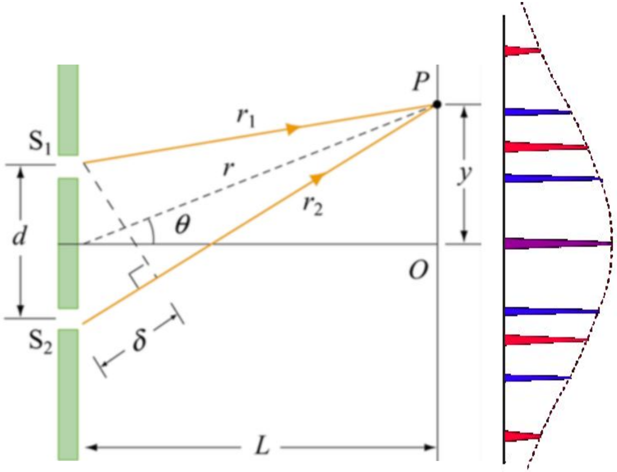
The **key idea** is to measure the refractive index of liquid Argon by **comparing the diffraction patterns** produced using a diffraction grating when the light propagates **in argon and in vacuum.**

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.

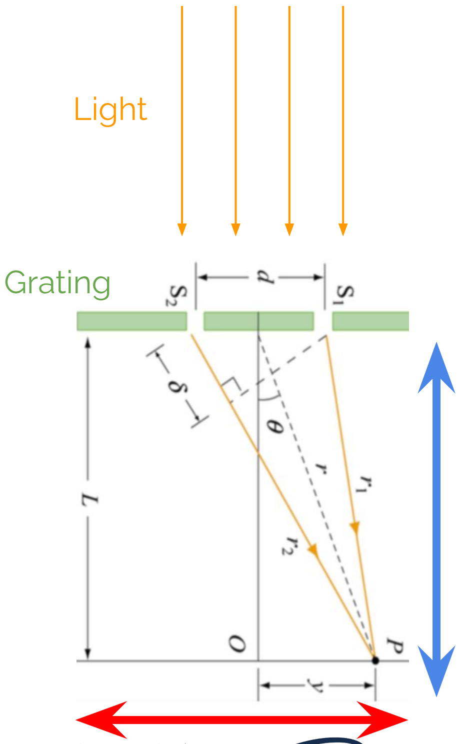
Max in vacuum: $d \sin \theta_o = \lambda_o$
Max in LAr: $d \sin \theta_L = \lambda_L$

We need coherent and monochromatic light





Conceptual scheme of the setup

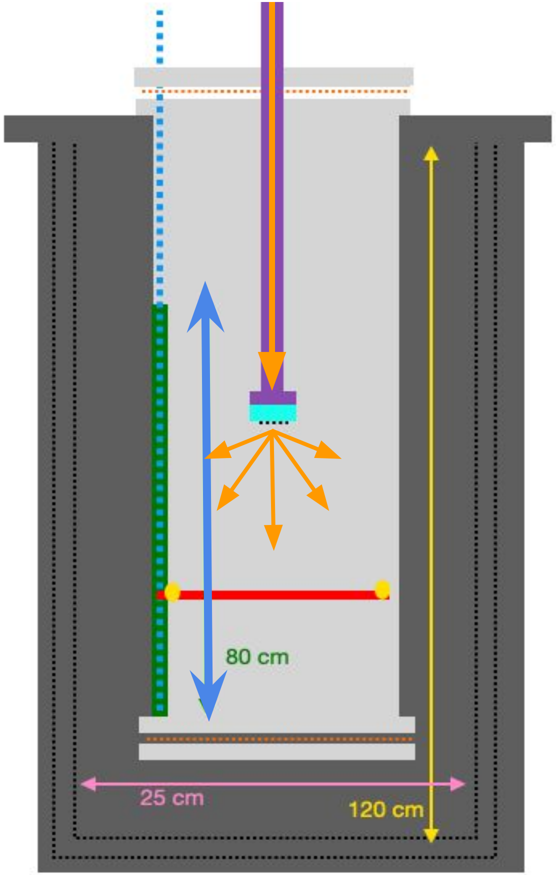


The core of the setup is a cylindrical chamber, that
can be both evacuated and filled with liquid argon. The chamber is contained in a cryostat, to thermalize the system.

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.**



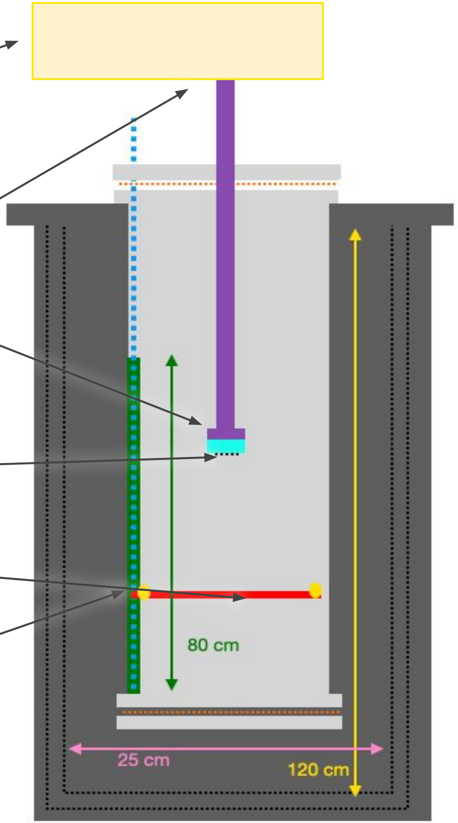
More details on the setup

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 MgF_2 prism is used to select a specific wavelength (184.9 mn as a proxy for LXe scintillation light). A vertical tube closed by two MgF_2 viewports and in vacuum is used to send the VUV light into the cold chamber.

Cold part:

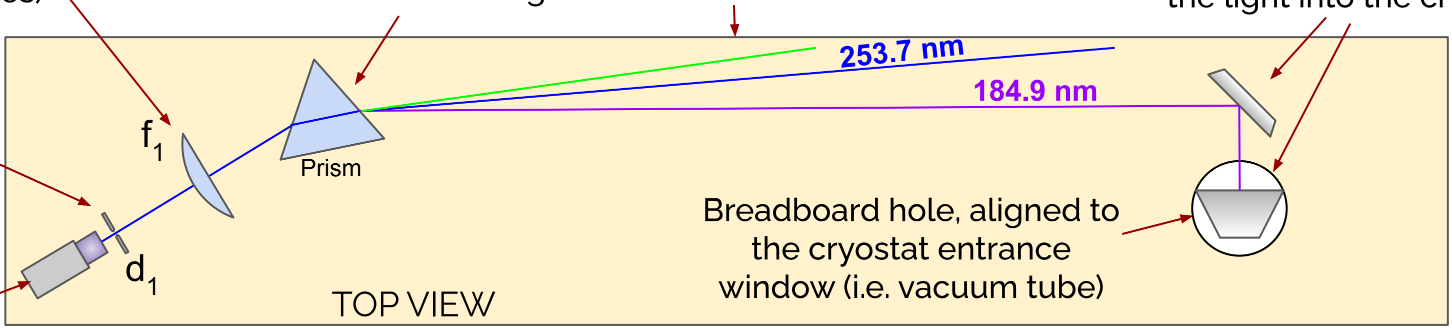
- **Diffraction grating:** made of aluminum deposited on a thin fused silica substrate, 720 nm pitch.
- **Moving system:** a motor by VacuumFab capable to operate both in vacuum and immersed into cryogenic liquids is used to lift a support housing the light detectors.
- **Light detectors:** 5 Hamamatsu (S13370-3075CN) UV-sensitive SiPMs (3x3 mm^2), 4 symmetrically mounted on the moving support, 1 at the center.



A zoom on the optical system

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 chambe passing through a second viewport.

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



Convergent lens with focus in the pinhole (for plane waves)

CaF2 prism to separate different wavelengths

~40 cm of free propagation

Pair of mirrors to send the light into the cryostat

Tunable slit for light spatial coherence

Low pressure mercury lamp

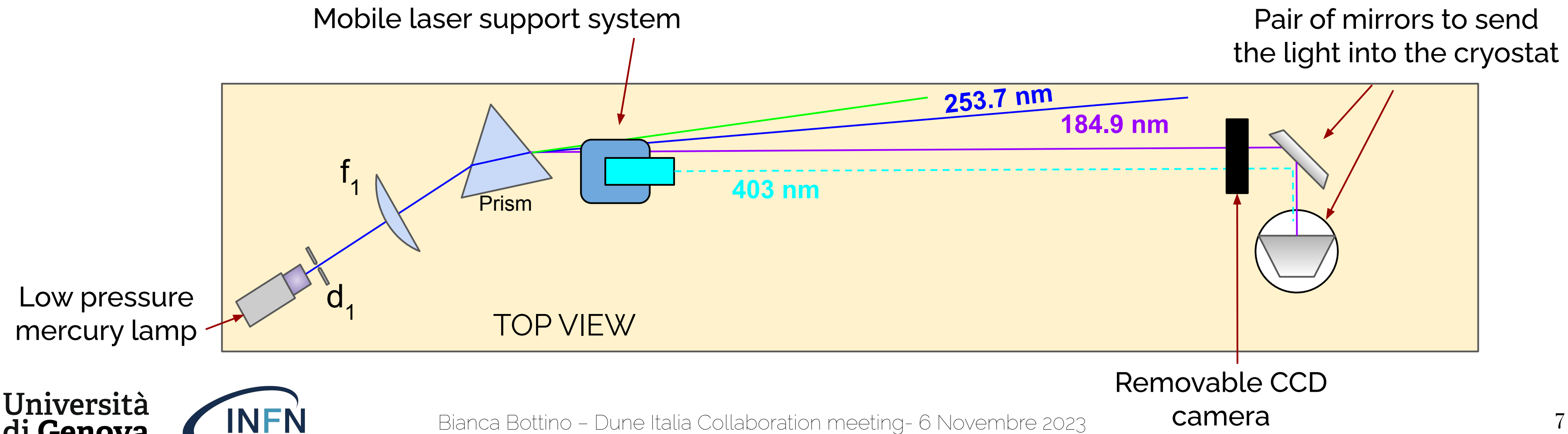
Breadboard hole, aligned to the cryostat entrance window (i.e. vacuum tube)

Alignment procedure

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:

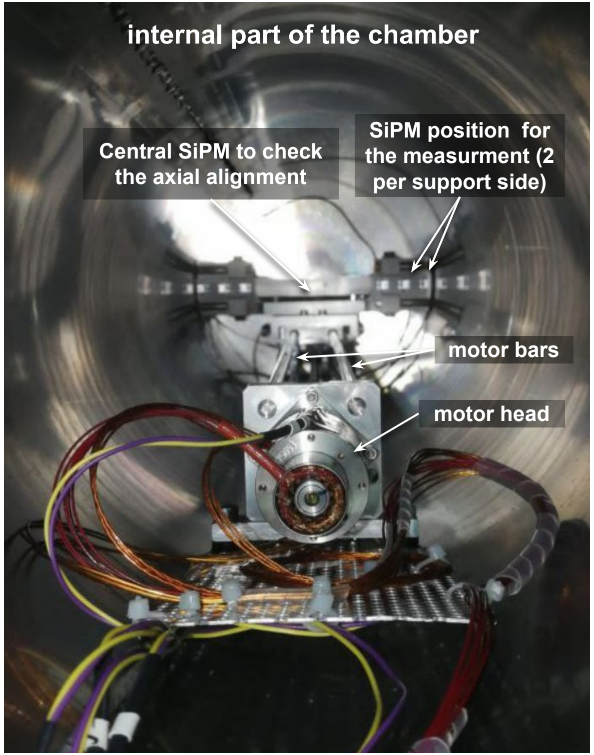
1. Align the 185 nm to a 403 nm laser, using a CCD placed on the bread board;
2. Remove the and align the laser with the central SiPM, tuning the orientation of the mirrors.

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



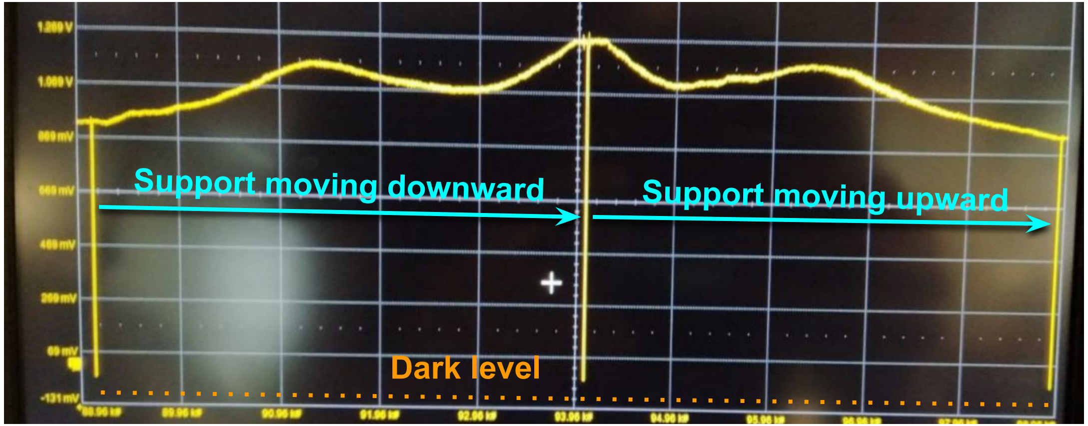
Assembly of the motor…

…and first alignment tests



Internal view of the chamber with the motor installed, moving support with 5 SiPMs and 3 Pt100 to monitor temperature and liquid level.

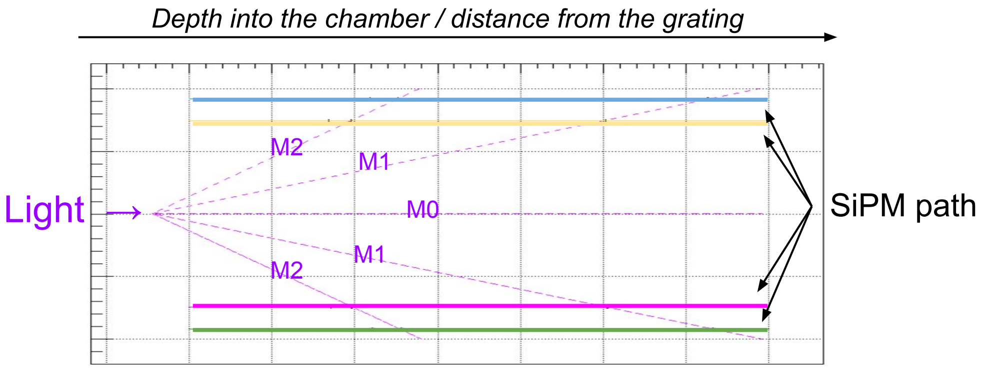
Achieved a good axial alignment with the 403 nm laser and the single SiPM mounted on the central support.



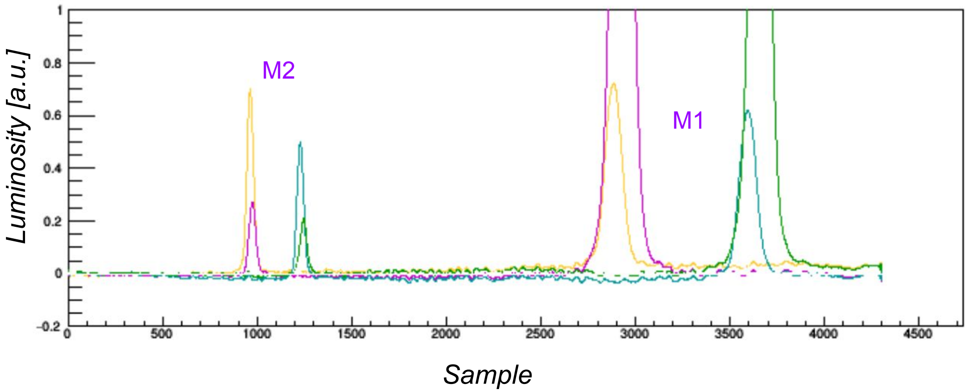
SiPM integrated signal (luminosity) during support movement (40 cm): signal is constant within ~30% and reproducible in the two directions.

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 (τ ~= 100 ms);
- 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



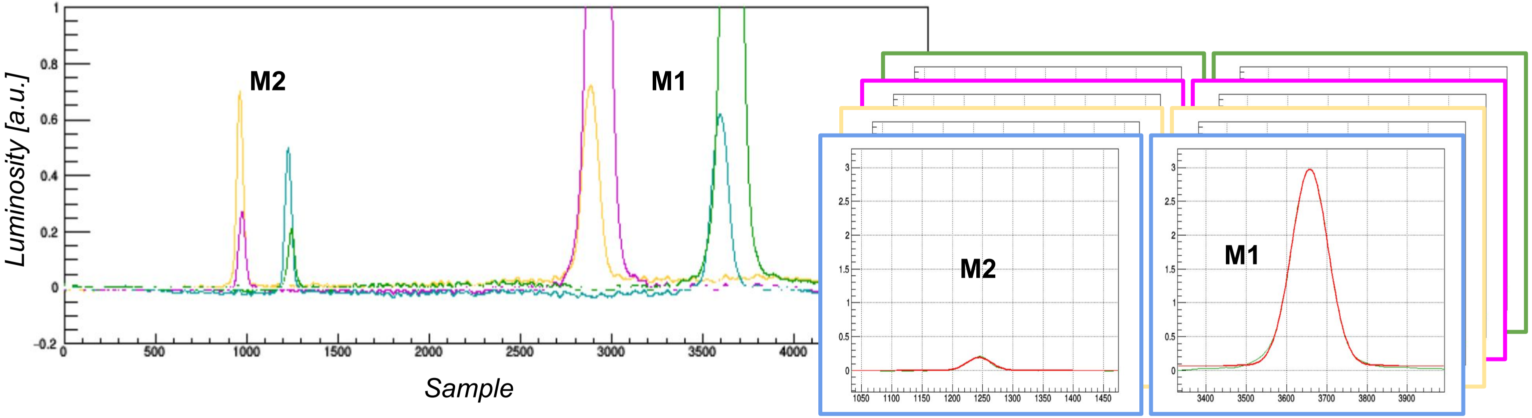
While the motor moves the SiPM support downwards:

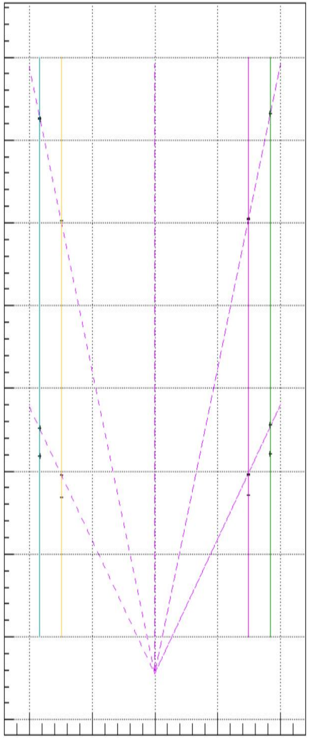


Analysis: first step

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.

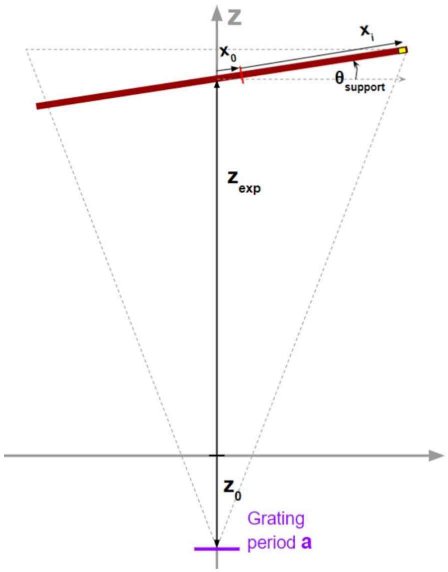
Then by knowing the motor position at the beginning and at the end of a scan we can reconstruct where every SiPM has intercepted the diffraction maxima.





Analysis: second step

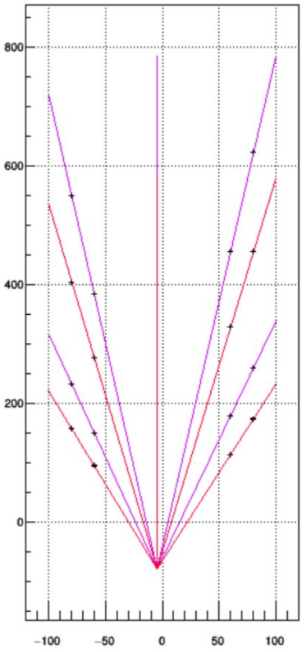
The positions of the maxima acquired in **two scans**, one with the chamber under vacuum and cold and the other with the chamber filled with cryogenic liquid, **are simultaneously fit to measure the refractive index.** The comparison between two scans, including vacuum data, reduces the systematics effects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

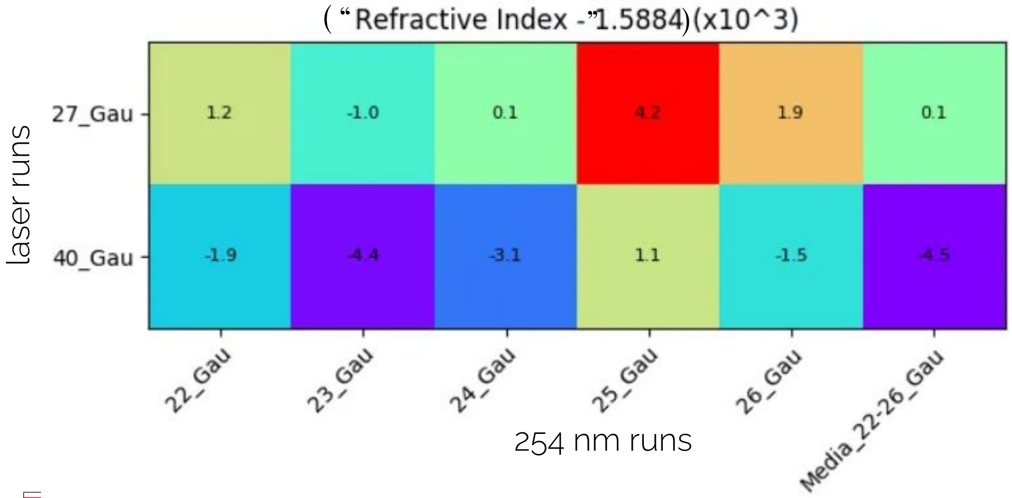
$$z_{exp} = \frac{(x_i + x_0)\cos\theta_s}{\tan\arcsin\frac{m\lambda}{an}} - (x_i + x_0)\sin\theta_s - z_0$$



Consistency check measurements

In alternative to simultaneously fit data from the same wavelength in vacuum and Argon, it is possible to compare data acquired in vacuum but from two different wavelengths. In this case the pattern will change according to the ratio of the λ.
All the analysis can be done in the same way and the expected contraction factor of the pattern value is the ratio between the two wavelengths ($\lambda_1 = \lambda_2 / n$)

We compared 2 scans at 402.9 nm with 6 scans at 253.7 nm :
obtaining compatibility within few parts per thousand.



	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

Expected value = 1.5884 = 402.9 nm / 253.65 nm

Results are shown as deviation from the expected value, magnified by 10^3.

Two scans (#27 and #40) with laser source are analysed with 5 different scans (#22 to #26) with 253.7 nm mercury lamp light. “Media_22-26_Gau” is a dataset composed by the mean position values (peak-by-peak) of the other scans.

Preliminary results in liquid nitrogen

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).

$$n_{LN2}(402.9nm) = 1.203 \pm 0.0005$$

with 2 independent measurements

$$n_{LN2}(253.65nm) = 1.244 \pm 0.009$$

with 8 measurements in vacuum and 8 in liquid nitrogen

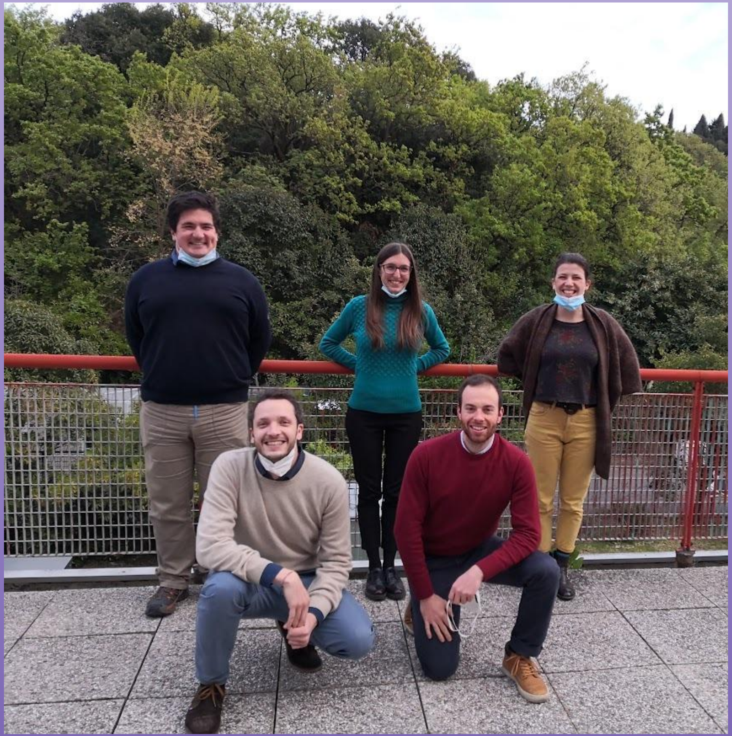
Conclusions and future plans

- Hardware assembled and tested. System operating both in cold vacuum and in liquid (nitrogen);
- Analysis structure ready and working, tested on runs made with laser and 254 nm line of the mercury lamp;
- The first runs acquired with a 185 nm line, the analysis in ongoing

Next steps:

- Improve data quality at 185 nm
- Take runs in LAr to make the goal measurement

Primo meeting di Collaborazione Larri!!



Grazie per l'attenzione

Light source

The choice of lamp is guided by the following requirements or factors:

- Peak (near) 178 nm
- Coherence length (narrow peak)
- Emittance (i.e. also source size and collimation)

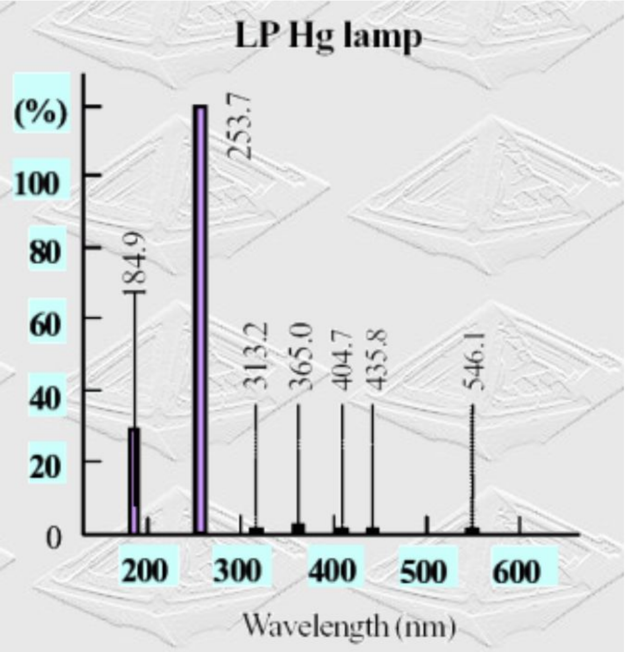
The coherence length is the maximum longitudinal distance between two points having correlated phase. The minimum request is given by:

$$L = N\, m\, \lambda = 1000 \cdot 2 \cdot 190\ \text{nm} = 380\ \mu\text{m}$$

with N number of slits in the lattice, m maximum interference order that we intend to observe.

The most promising hypothesis seems to be that of low-pressure mercury lamps.

They have peaks at 185 nm and 254 nm (power ratio approximately 1:5)



VUV-sensitive SiPM

Hamamatsu S13370-3075CN (9 mm^2)
DCR: < 1 Hz/mm^2 @ 165 K
< 25 mHz/mm^2 @ 77K (S13360-DUNE)
PDE: 24% @ 178 nm (nominal)

<S13370-3050CN / S13370-3075CN>