Advances on MagLITe

Deposition and Photocollection efficiency

August 27th, 2024

Bruno Gelli, on behalf of the MagLITe Collaboration

WLS coated PDS systems

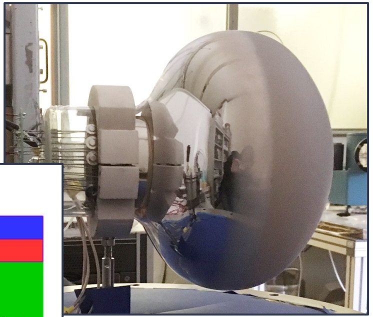
Now in the era of large kton-experiments, **photodetection systems** are still a **major part** of most experiments.

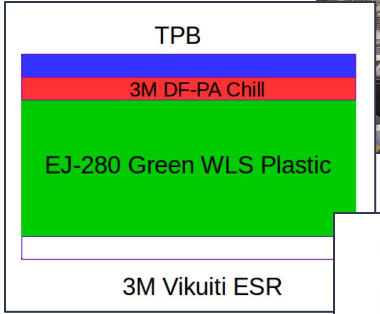
→ Triggering, PID, combined light-charge analysis and futurelly for event matching.

Most large area PDS systems **rely on** the use of **external Wavelength Shifters** (WLS)

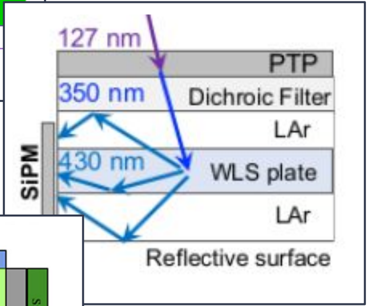
This delicate films can be **negatively impacted** by being exposed.

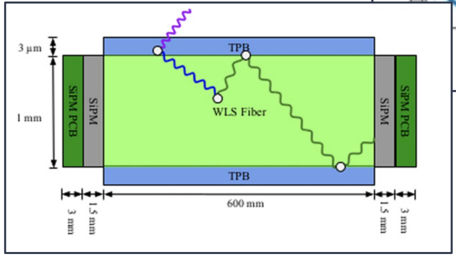
- **Dissolution in liquid noble**
- **Mechanical damage during installation**
- **Factor of 0.5 in efficiency**





Auger, M., et al. (2018). ArCLight—A Compact Dielectric Large-Area Photon Detector. Instruments, 2(1), 3.





Souza, Henrique & et al. (2021). Liquid argon characterization of the X-ARAPUCA with alpha particles, gamma rays and cosmic muons.

MagLITe

The **MagLITe** (**Mag**nesium **F**luoride **L**ight collection **I**mproving **Te**chnique) is a technique in development by our group, and it consists in **coating the external WLS with a protective thin film**.

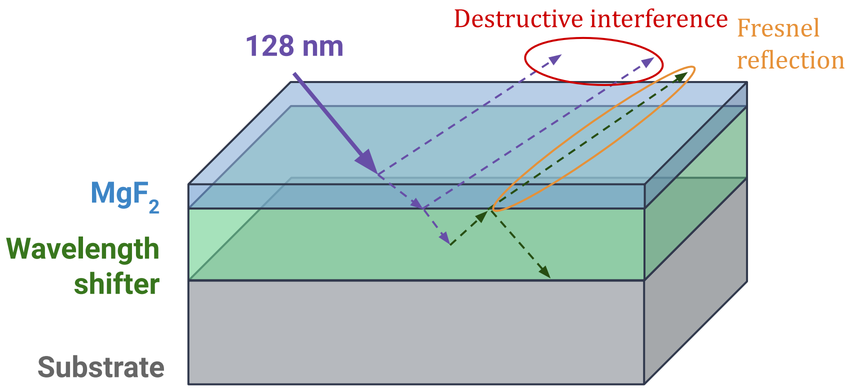
This technique can help with **all drawbacks** discussed

The **emanation problem** can be solved. By having a **physical barrier** between the organic compounds and the noble liquid.

It also helps to **protect the organic films** from mechanical and chemical damage.

And finally, it can also help with the loss of efficiency.

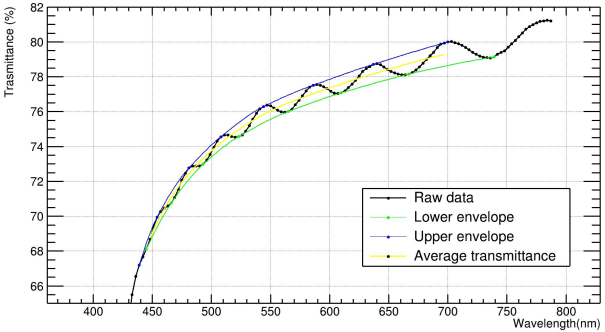
By choosing a material with the **right refractive index** and choosing the right coating thickness, the film can also **act as an anti-reflective coating**

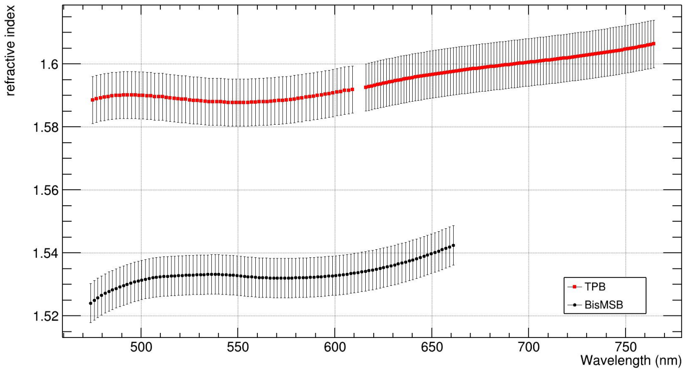


To properly design **MagLITe** it is fundamental to have access to the material optical properties, i.e. **refractive index** and the **extinction coefficient**.

➔ We began a big effort of measuring this properties.

Visible range - Swanepoel method



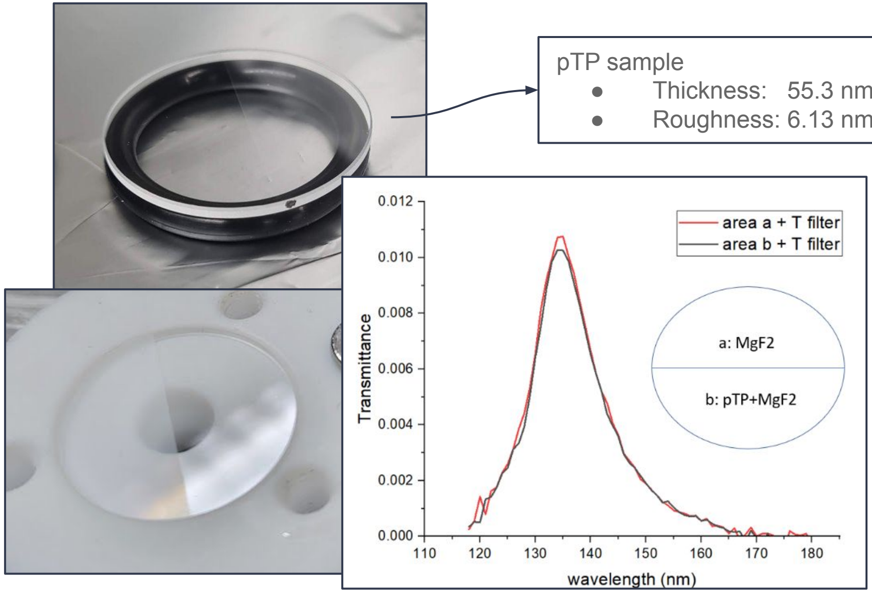


VUV range - Transmittance method

Complex setup and sample production + highly specialized expertise

→ *Grupo de Óptica de Láminas Delgadas* (GOLD) from Madrid.

pTP sample
- Thickness: 55.3 nm
- Roughness: 6.13 nm



Thanks Prof. Juan and Paloma

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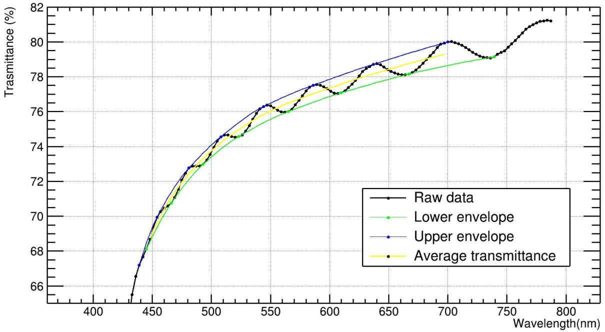

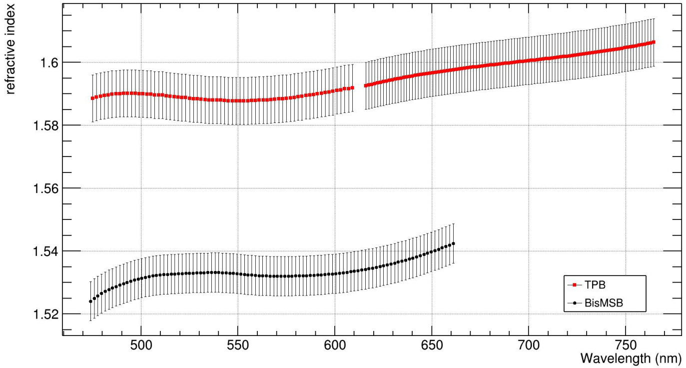

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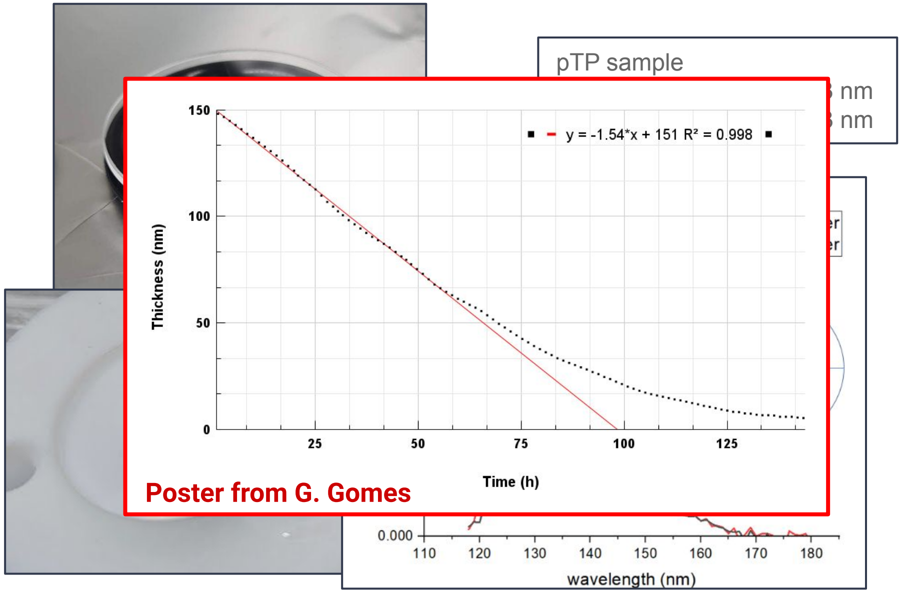
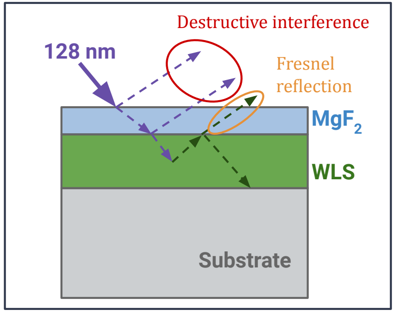
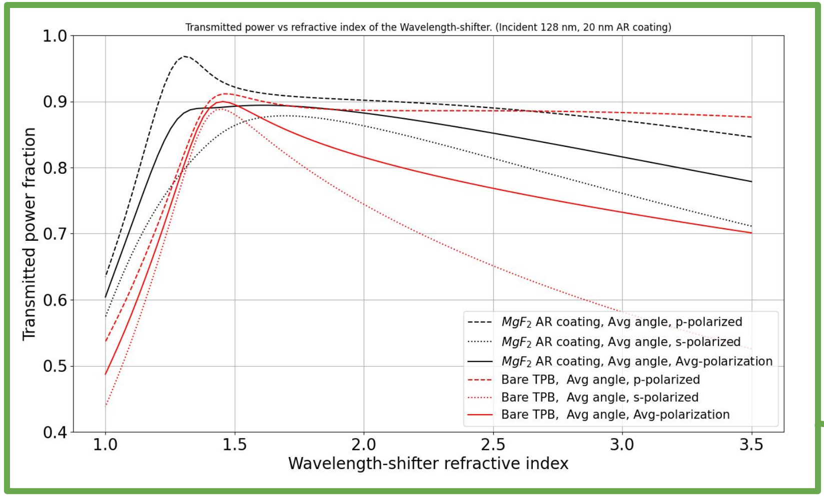


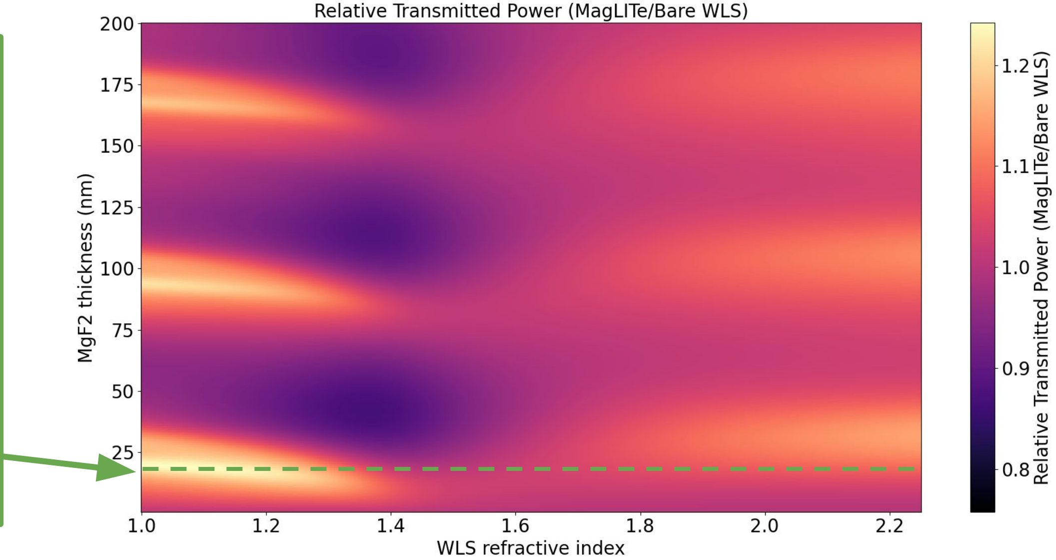
Thanks Prof. Juan and Paloma

To model the optical film, we used a **custom Transfer-Matrix Method** (TMM) script to include the light conversion inside the WLS.

Although many designs are possible, we chose to pursue a simple **λ/4 anti-reflective layer** for pTP over quartz. This was chosen to reflect some of the most common WLS applications.

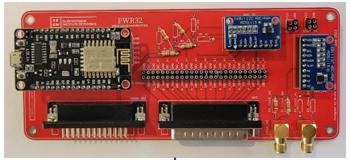






Double Deposition

The key component in constructing **MagLITe** is the deposition of **Magnesium Fluoride over the WLS**. The evaporation **temperature difference** between MgF_2 and pTP (950 ºC vs 200 ºC) makes it a challenging deposition.



Moreover the **surface roughness** has to be O(nm) for the film to work properly

→ Thermal evaporation under **strict deposition protocol**.

Scattering Losses

→ *Rayleigh-Rice* Model

$$\frac{P_{scattered}}{P_{in}} = \frac{16\pi^3}{\lambda^2}\left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 (Sq)^2$$

Degraded Interference Effects

→ *Phase Shift* Model

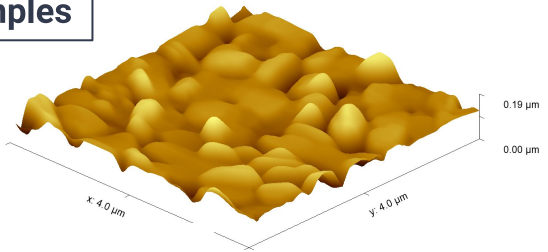
$$\Delta\phi = \frac{4\pi n cos\theta}{\lambda}(Sq)$$

Reduced Reflectivity

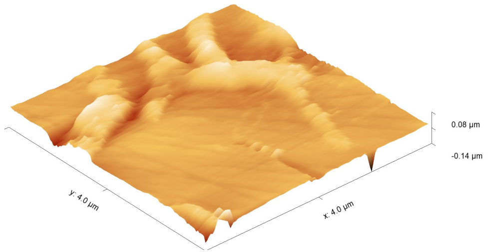
→ *Beckmann-Spizzichino* model

$$R = R_0 \; exp\left(-\frac{(4\pi cos\theta)^2}{\lambda^2}(Sq)^2\right)$$

Thick samples

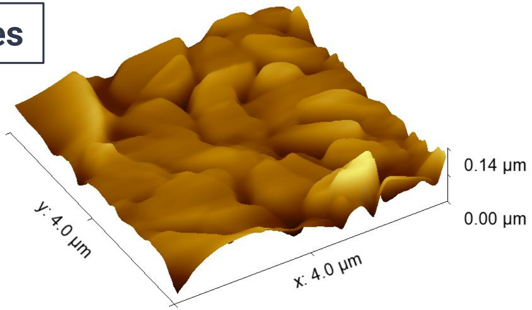


Sq = 15.5 nm

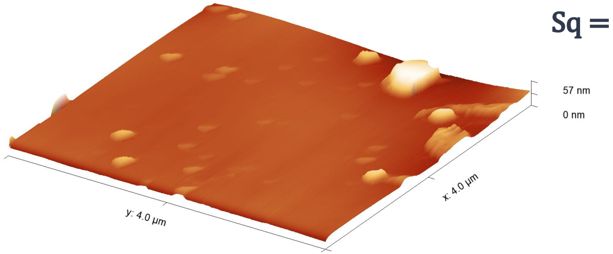


Sq = 4.5 nm

Thin samples



Sq = 10.3 nm



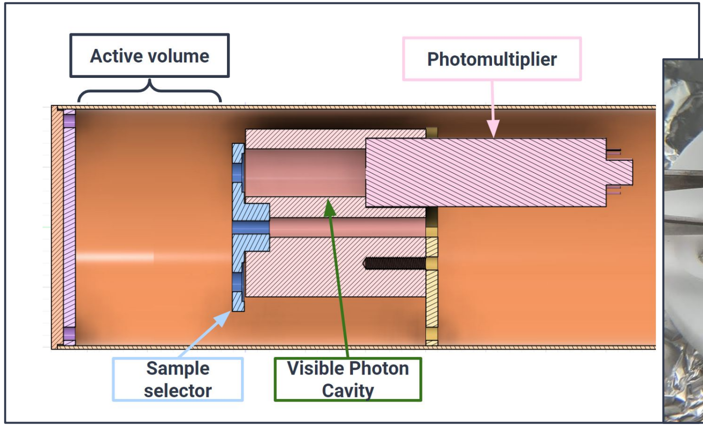
Sq = 2.2 nm

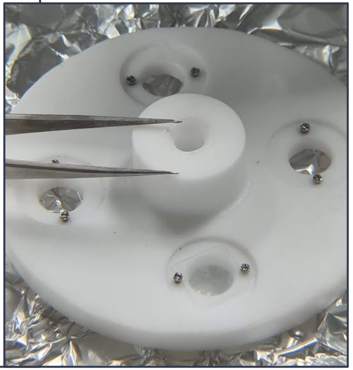
LAr Setup

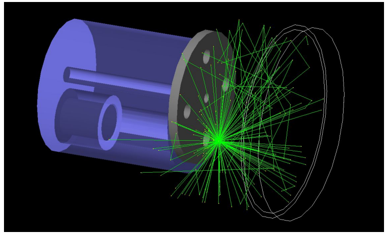
To measure the **MagLITe** efficiency, a **Liquid Argon Test setup** was designed
→ Geometry was **Geant4** validated

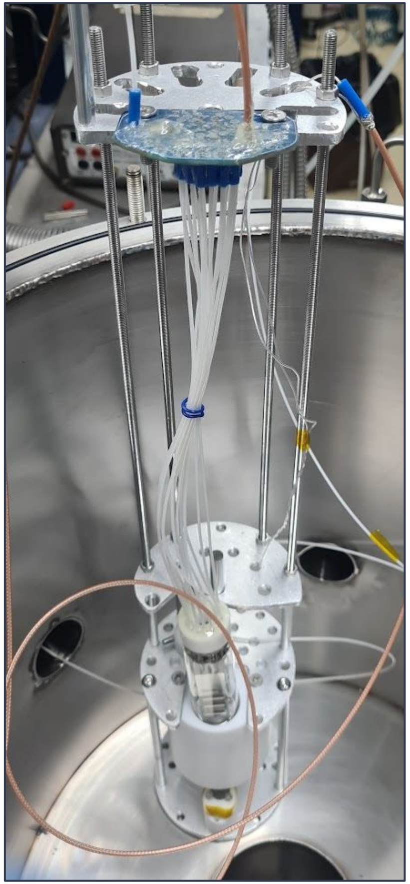
Scintillation light excites the samples and provides the **correct refractive index**
→ **Hamamatsu R1398** photomultiplier

Key feature: samples are sequentially measured
Same run, same environmental condition → **reduced uncertainty**

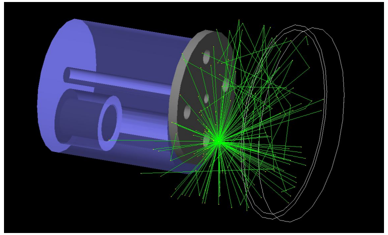






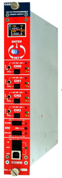


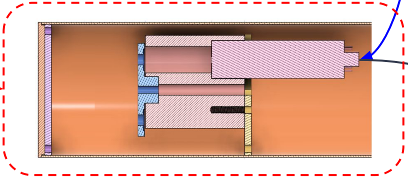
A thin film ^{241}**Am** source (α @ 5.5 MeV, ~33 kBq) was used to excite the liquid argon.
→ Pressure and voltage - slow control to ensure a constant environment.



Data was acquired using **Caen DT5751 Digitizer** at 1 GSa/s, both in **threshold trigger** and in **random trigger** mode.

Data was acquired over several runs producing many gigabytes of data each





Caen DT5751 Digitizer

Data analysis

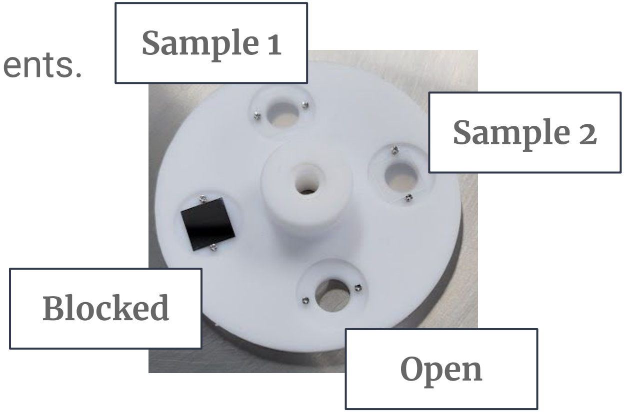
The **data structure of a subrun** was composed of six sequential measurements.

- Sample 1 - Low Trigger → $O(1pe)$
- Sample 1 - High Trigger
- Sample 2 - Low Trigger → $O(1pe)$
- Sample 2 - High Trigger
- Open - Random Trigger
- Blocked - Random Trigger

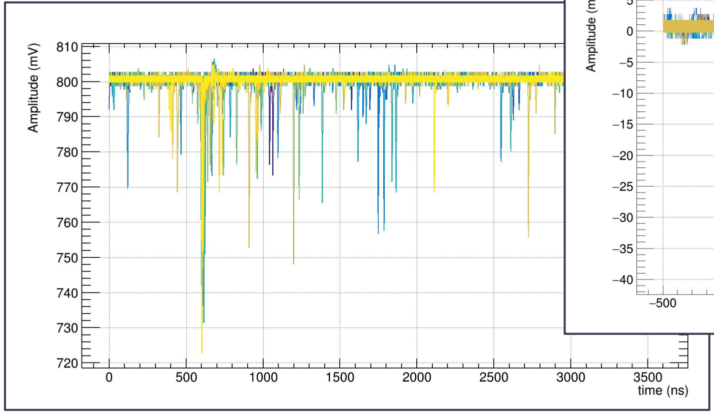
Comparative data (Sample 1 and Sample 2, Low and High Trigger)

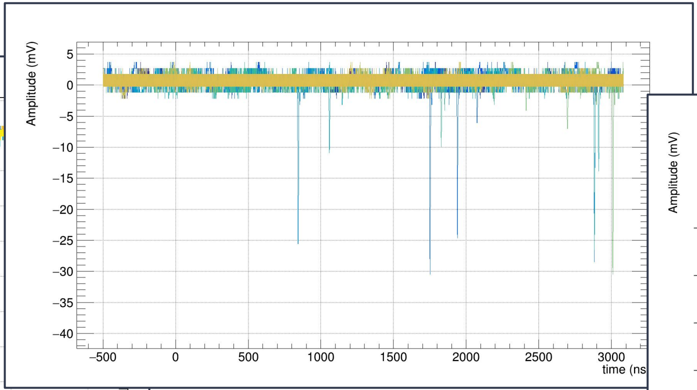
Open - Random Trigger → **Diffuse Light Background**

Blocked - Random Trigger → **Electronic Noise**



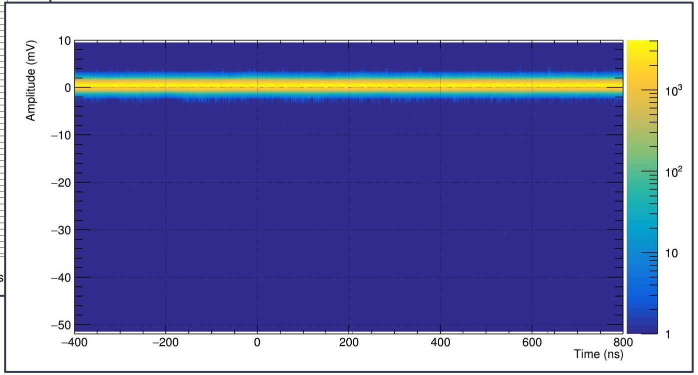
Comparative data





Diffuse Light Background

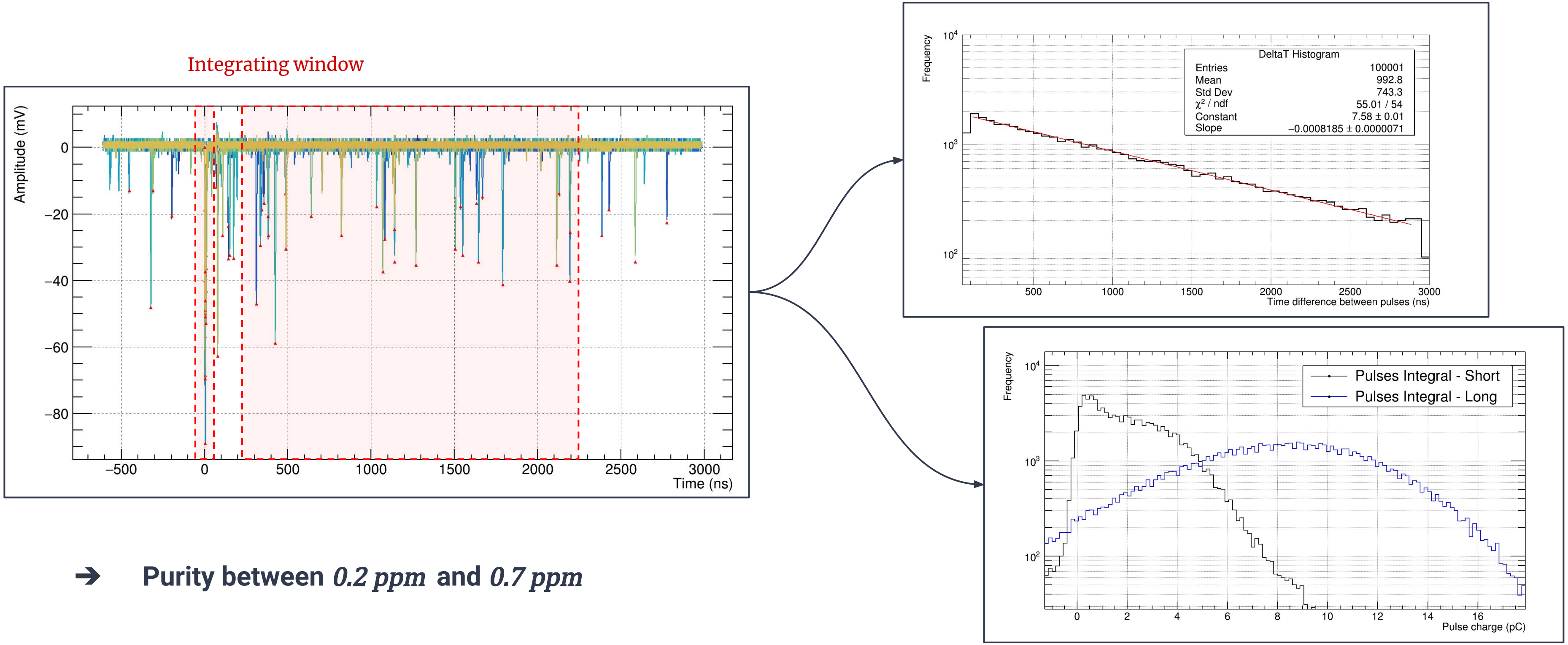
Electronic Noise



The first check is too make sure the **purity is constant** during the acquisition.

➔ **Stable photon yield**

Although the average number of photons was smaller than needed to see the long component of LAr scintillation, as expected from the simulation, it was still possible to extract purity information

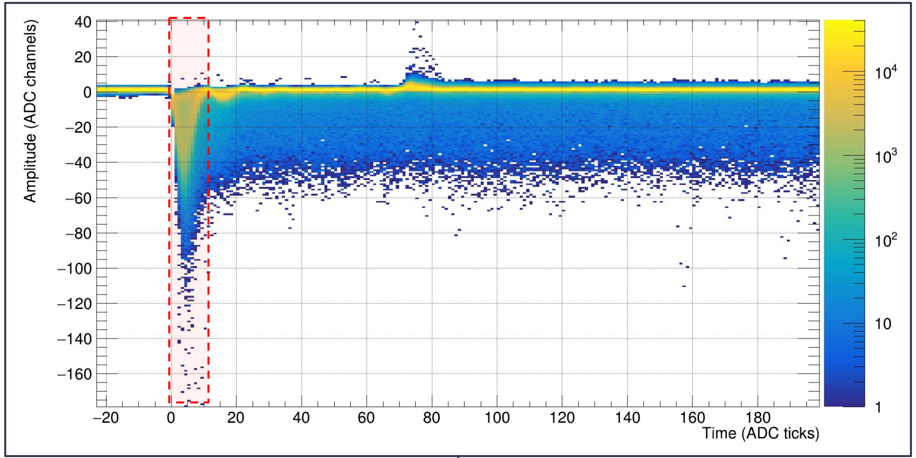


➔ **Purity between *0.2 ppm* and *0.7 ppm***

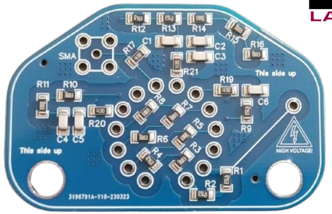
Another check was making sure **to-be compared** measurements had the **same SPE charge**

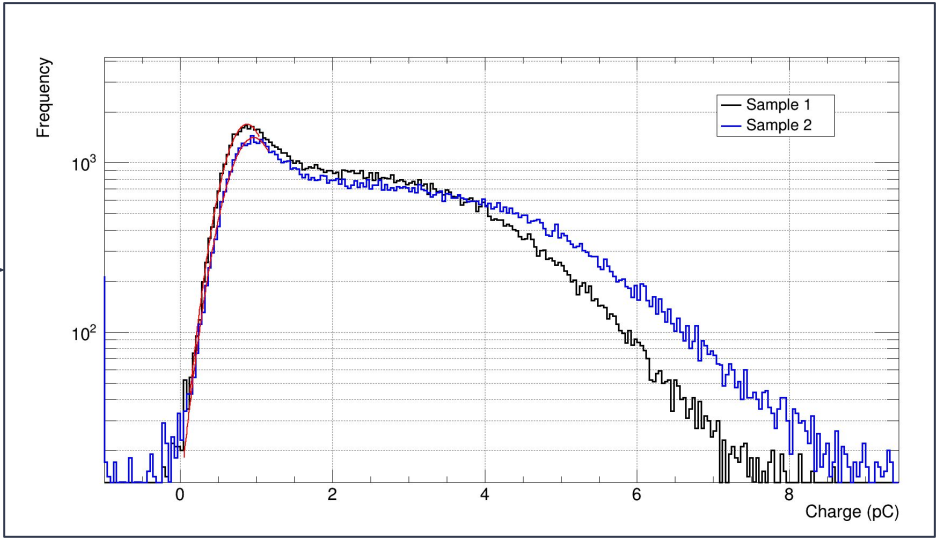
➔ **Stable PMT gain**

Integrating window



LADEP
LABORATÓRIO DE DETECTORES DE PARTÍCULAS



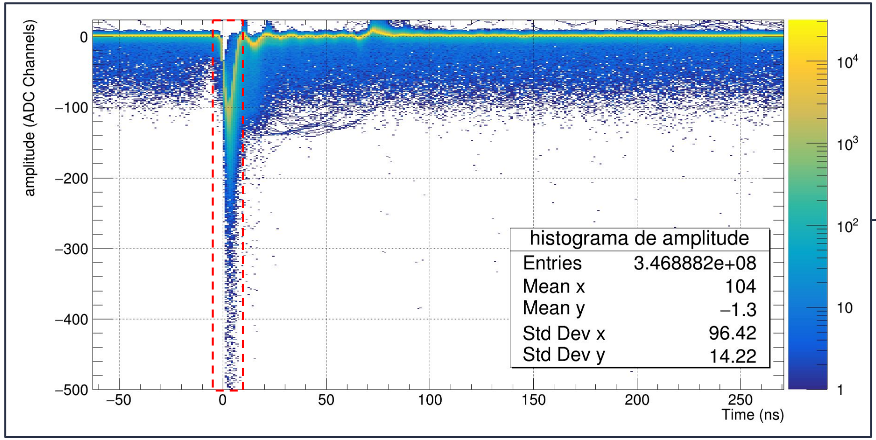


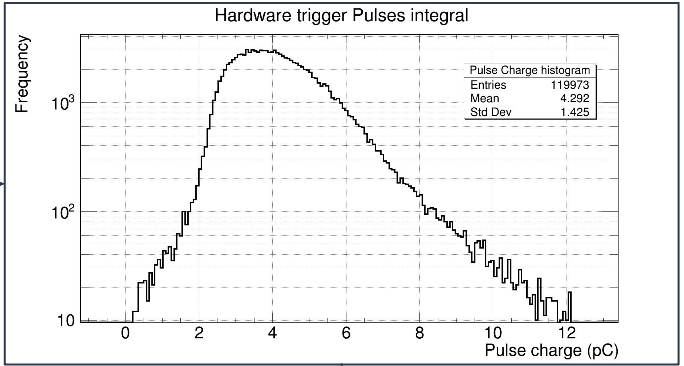
Charge histograms were **normalized** and **gaussian fitted.** Comparing data from the measurements was only done if the SPE charge pass a 99% likelihood test

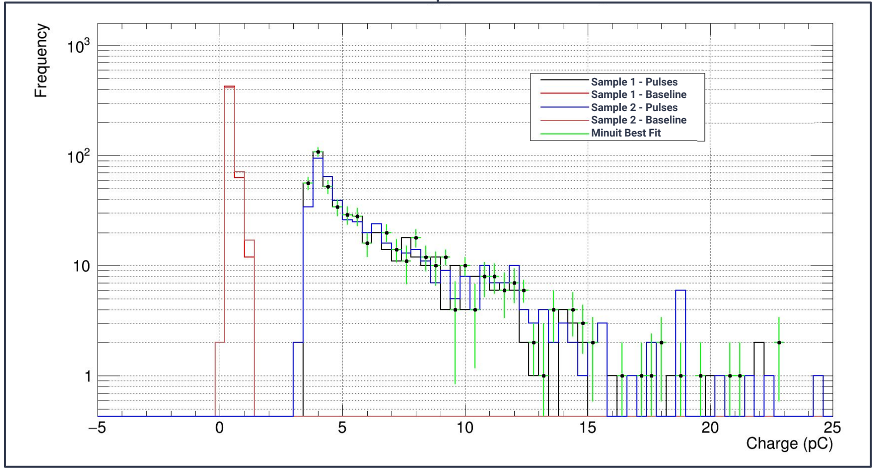
Passing all checks, **samples data** could be **directly compared**

→ Other than efficiency, **all parameters are the same**

Integrating window





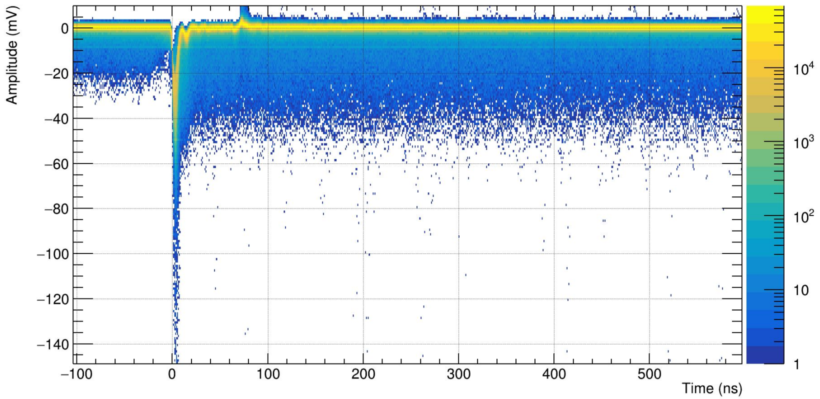


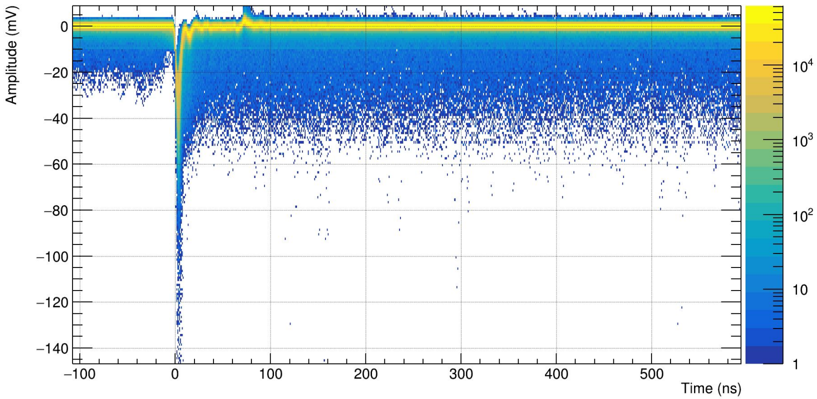
Charge histograms were **normalized** and **MINUIT fitted** to each other.

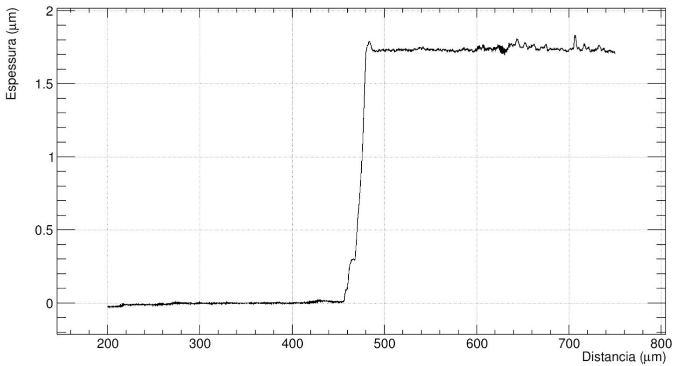
→ The **scaling factor** corresponds to the **relative efficiency** of the samples

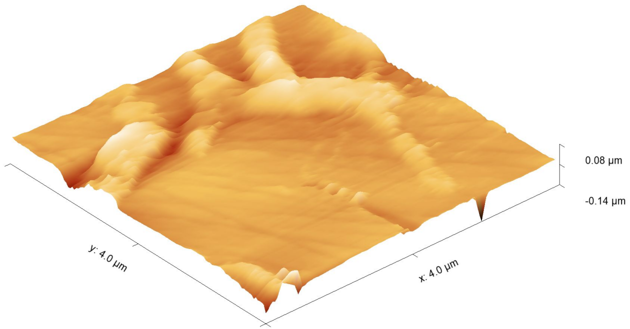
Bare pTP sample

MagLITe sample



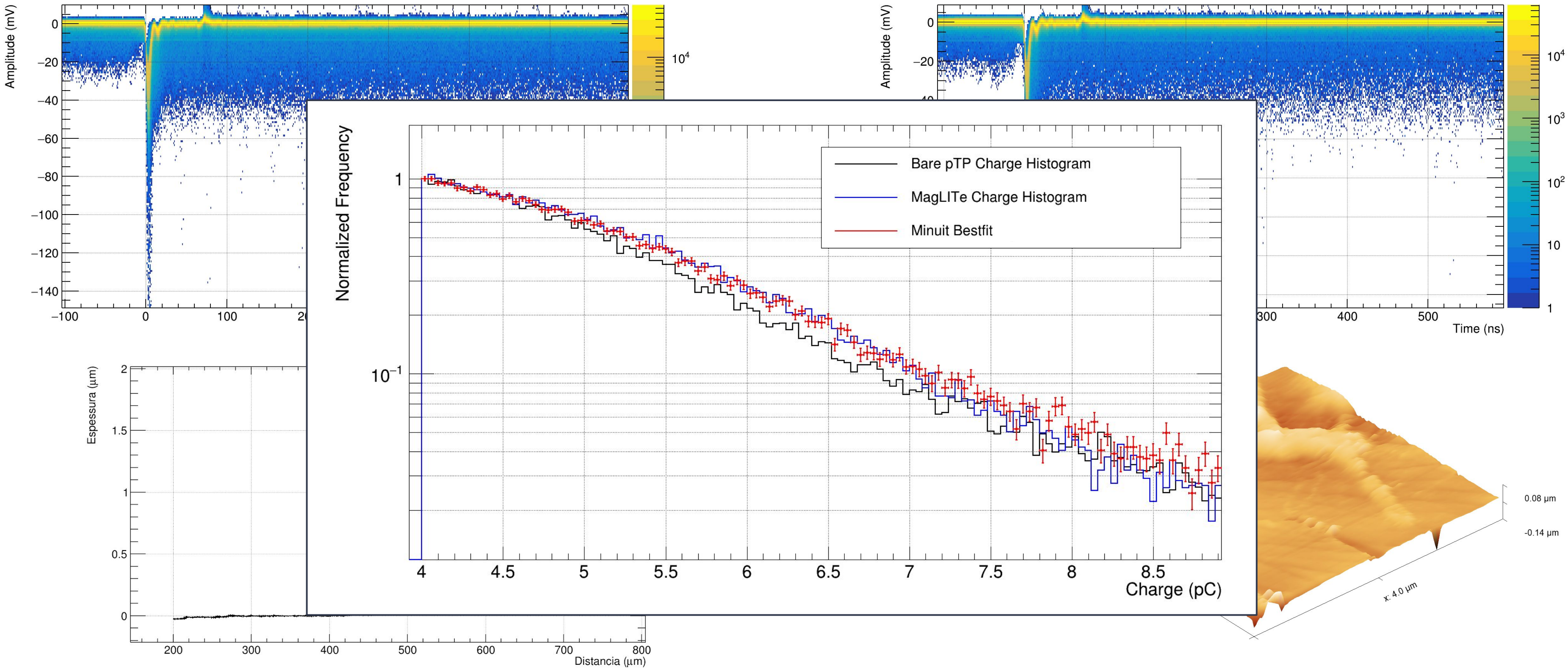






Bare pTP sample

MagLITe sample



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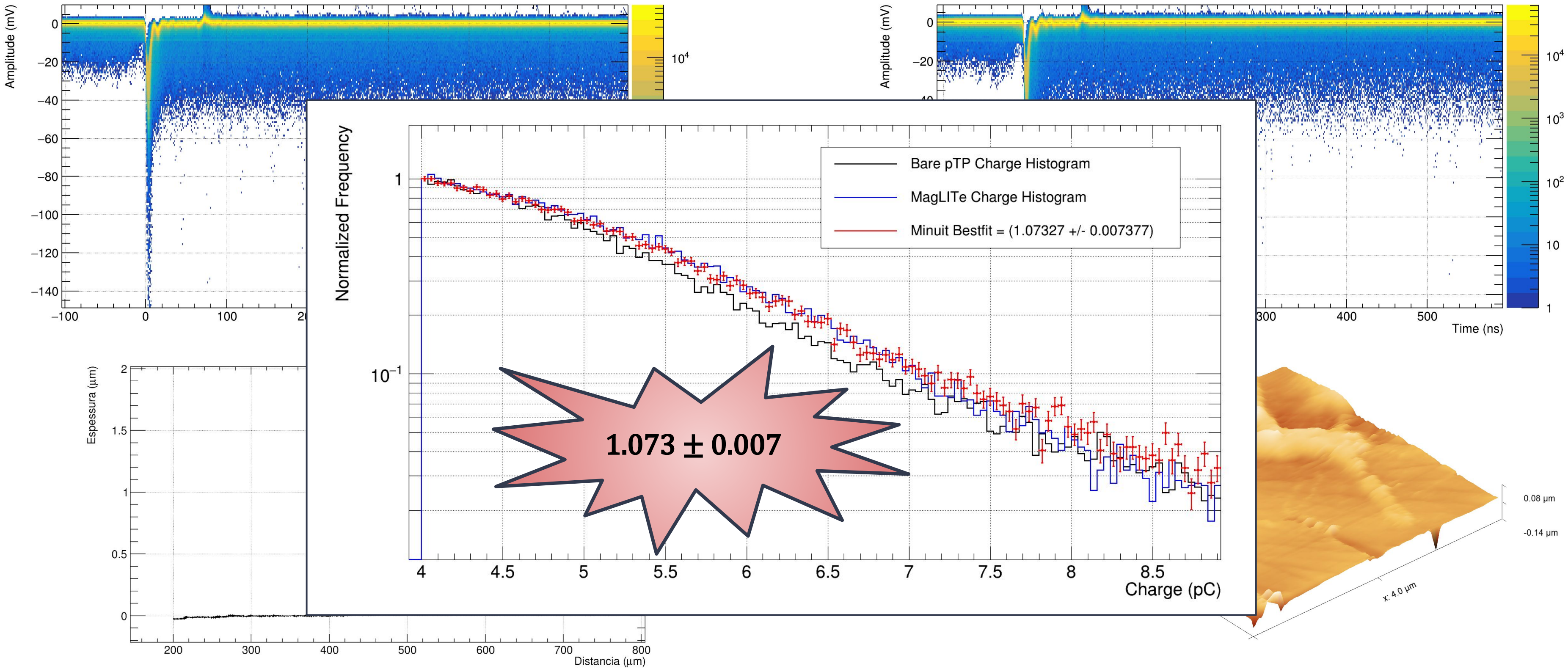
MagLITe sample



Conclusion

In conclusion, MagLITe shows itself as a strong technique for light detection systems.

- **Increase light collection**
- **Protective film**

We were able to construct the MagLITe films and test against standard bare WLS samples, achieving an efficiency increase of **1.073 ± 0.013**.

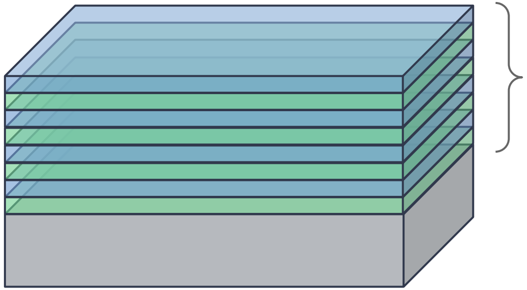
- **Hypothetical 5% efficiency PDS → 5.35%**

Better measurements on the WLS complex refractive index allow new designs, potentially further increasing the efficiency .

- **Multilayer interference filters**

New tests are already on the schedule.

- Other WLS
  - **TPB**
  - **PEN**
  - **BisMSB**

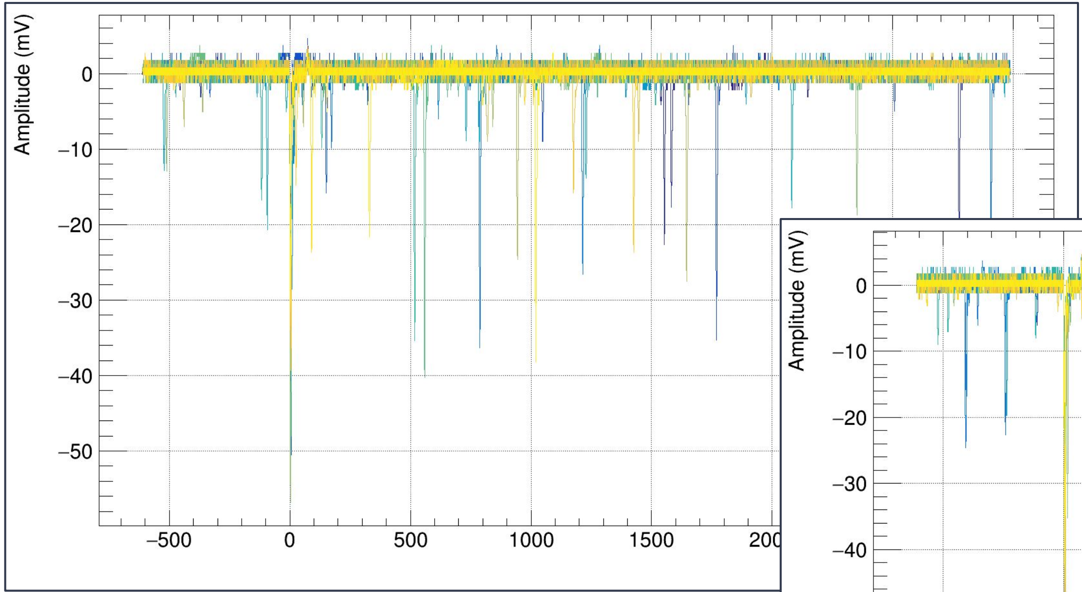


Alternating MgF_2 and WLS
→ High-Low index design

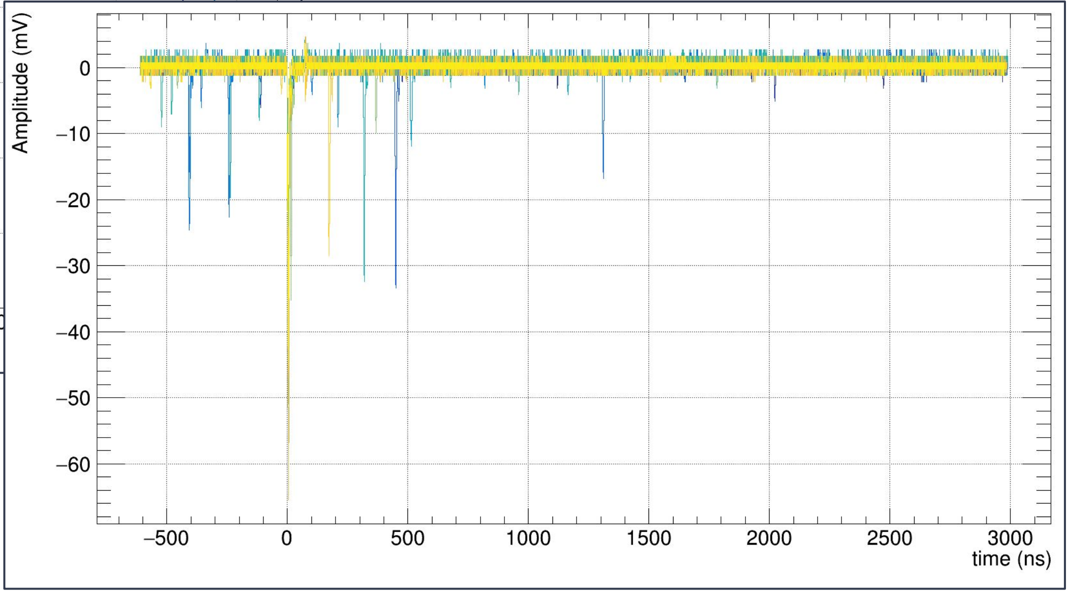
Obrigado!

Backup: Purity

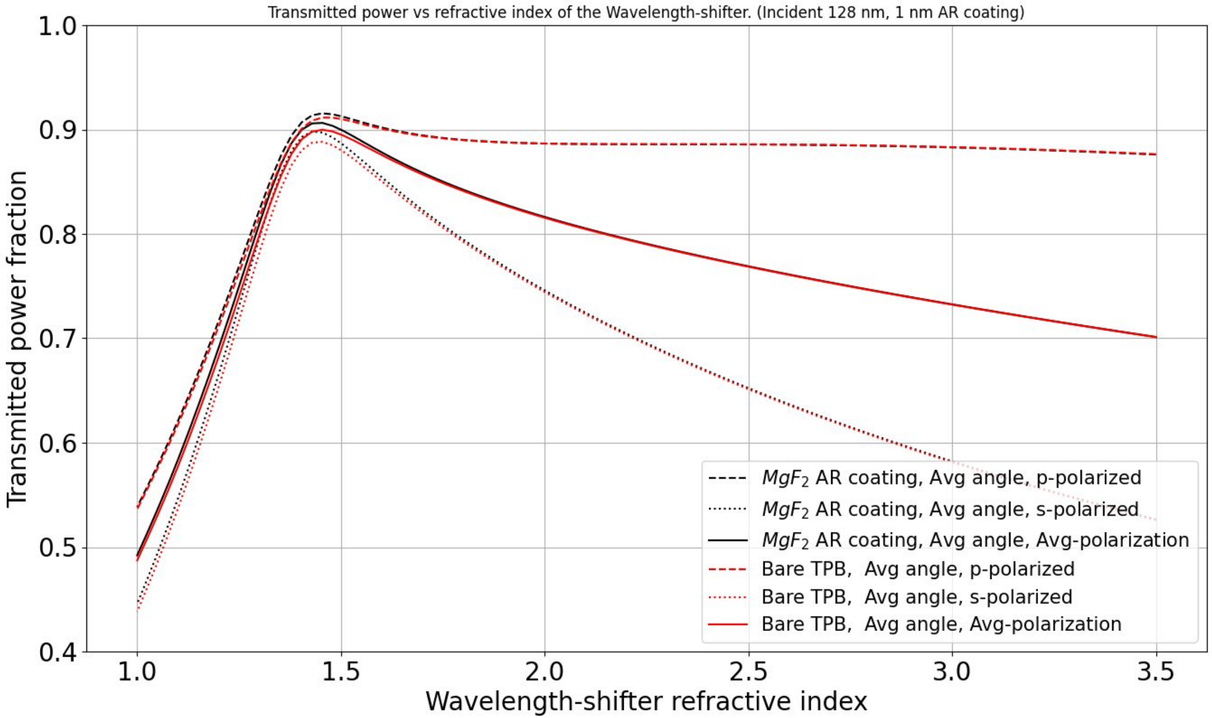
Before N_2 added



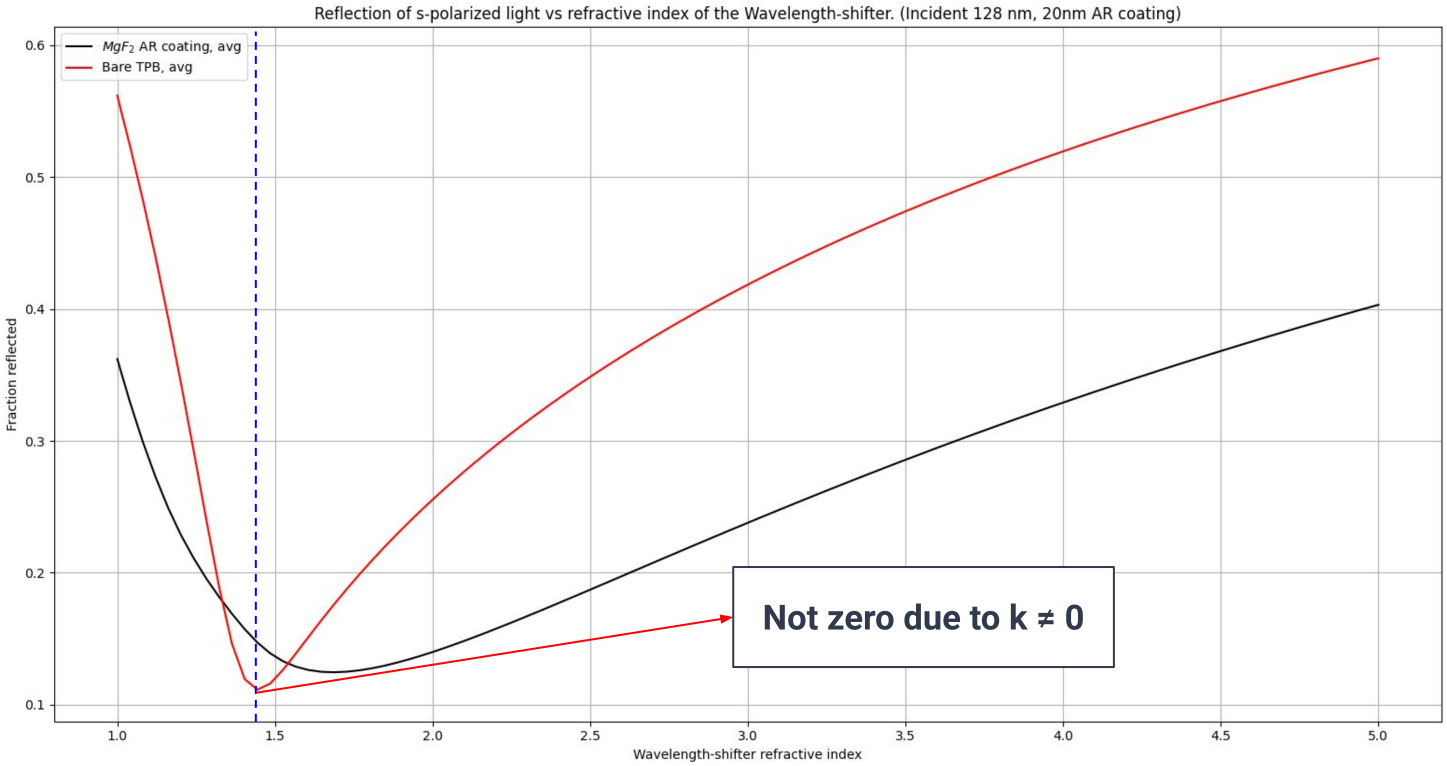
After N_2 added



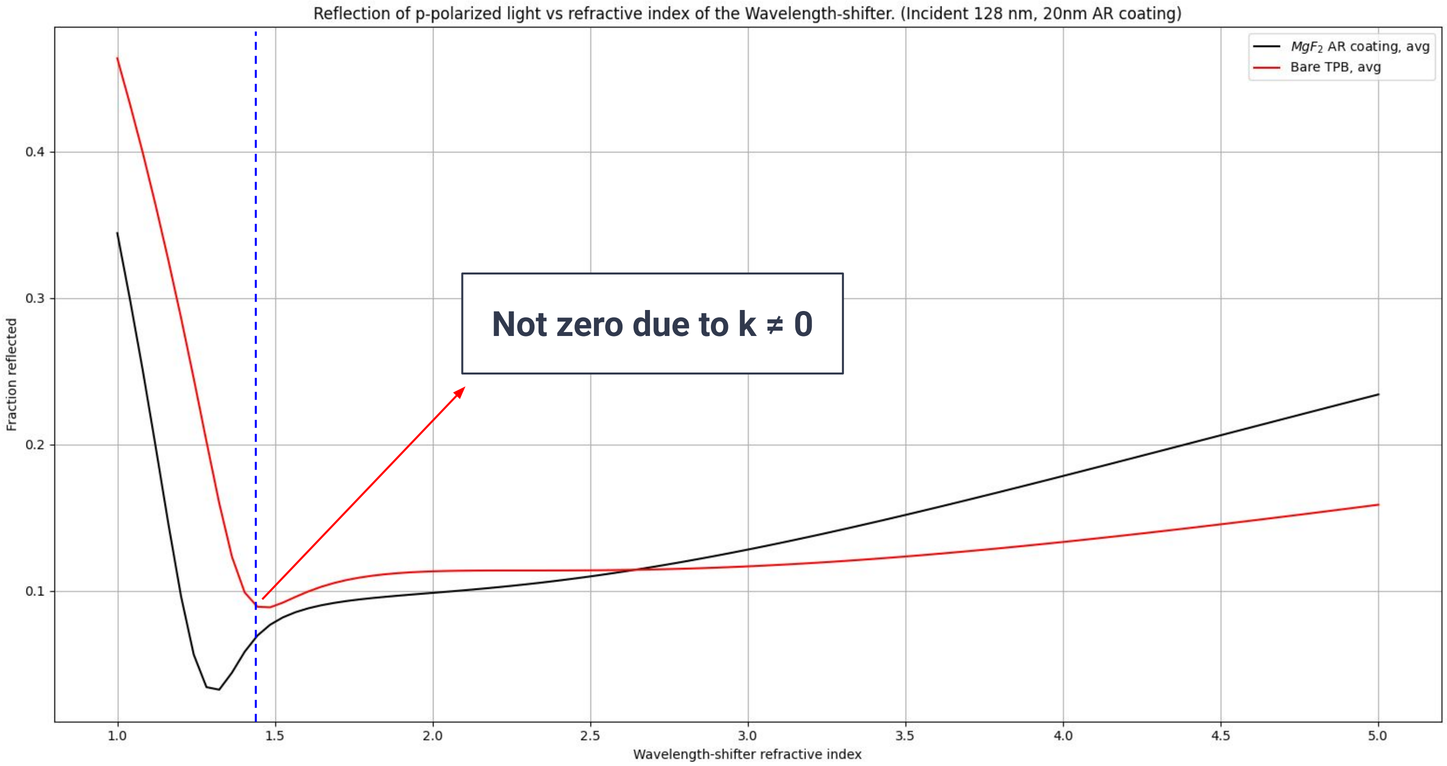
Backup: Filter design vs thickness



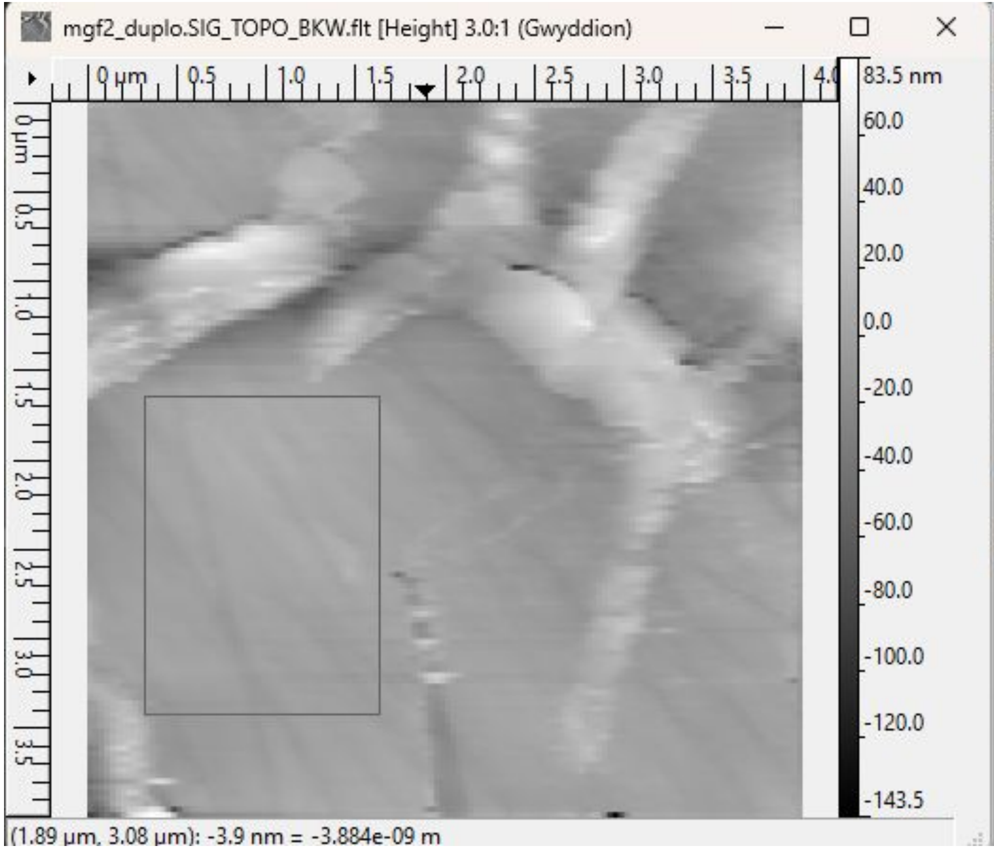
Backup: S-polarized reflectivity



Backup: P-polarized reflectivity



Backup: Sq thick



Statistical Quantities

Origin

X	0.31 µm	10	px
Y	1.62 µm	52	px

Size

Width	1.34 µm	43	px
Height	1.81 µm	58	px

Masking Mode

- ○ Exclude masked region
- ○ Include only masked region
- ● Use entire image (ignore mask)

Options

- ☑ Instant updates

Moment-Based

Average value:	2.35 nm
RMS roughness (Sq):	4.521 nm
RMS (grain-wise):	4.521 nm
Mean roughness (Sa):	3.709 nm
Skew (Ssk):	-11.28×10^{-3}
Excess kurtosis:	-0.4802

Order-Based

Minimum:	-10.71 nm
Maximum:	15.85 nm
Median:	2.14 nm
Maximum peak height (Sp):	13.49 nm
Maximum pit depth (Sv):	13.07 nm
Maximum height (Sz):	26.56 nm

Hybrid

Projected area:	2.436 μm^2
Surface area:	2.440 μm^2
Volume:	5.719×10^{-21} m^3
Surface slope (Sdq):	0.06375
Variation:	0.1279 μm^2
Inclination θ:	0.24 deg

Backup: Sq thin