Efficiency of the Photon Detection System in DUNE Far Detectors

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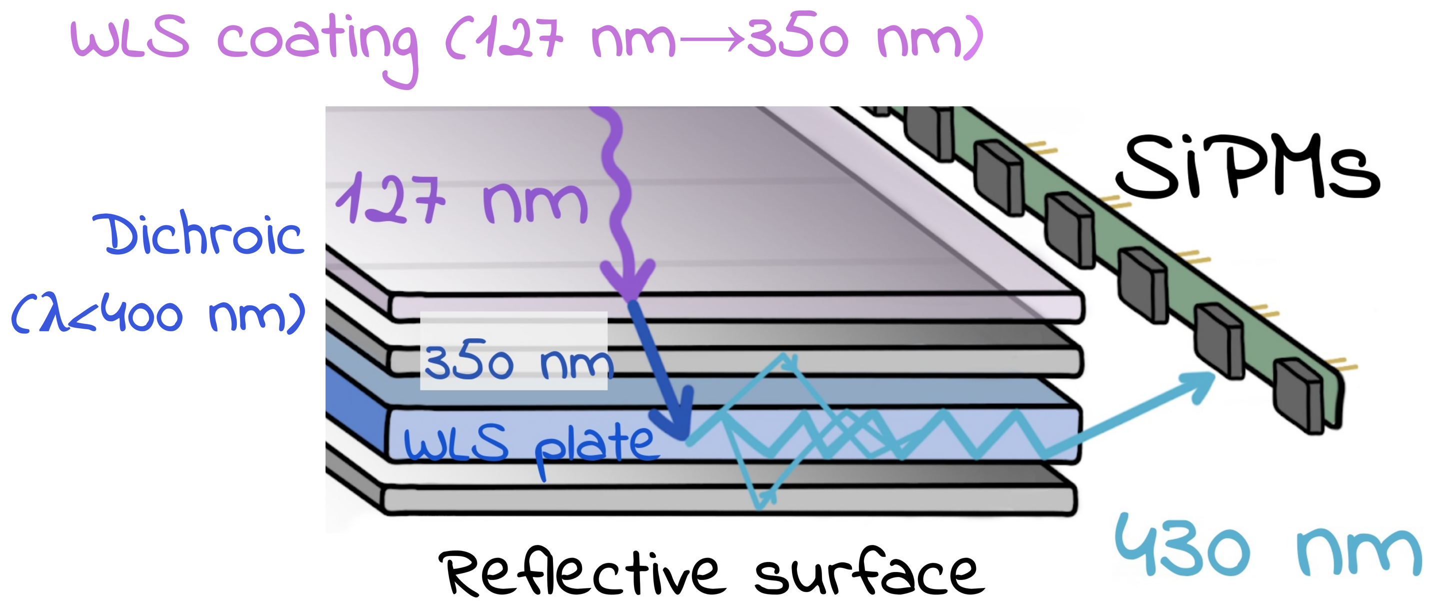
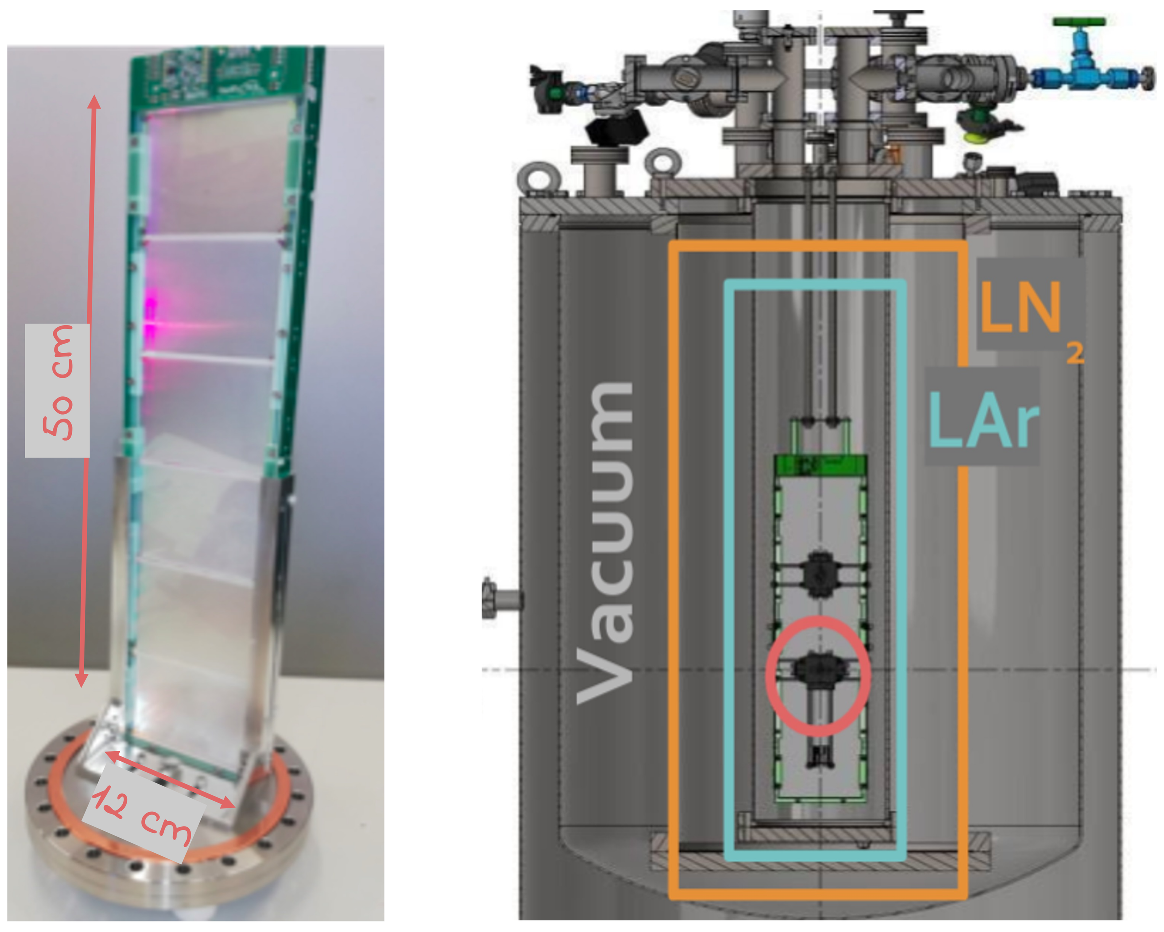
THE DUNE PHOTON DETECTION SYSTEM

DUNE is a long-baseline experiment for neutrino oscillation studies, able to resolve the neutrino mass hierarchy and CP violation. DUNE will also have sensitivity to supernova neutrinos and processes beyond the Standard Model.

The Far Detector Liquid-Argon TPCs will be equipped with a high-performance Photon Detection System (**PDS**) to trigger on non-beam events and enhance the reconstruction capabilities. A PDS module, the X-ARAPUCA (**XA**), acts as a light trap that efficiently shifts the **127 nm** LAr scintillation photons to the **visible range** and drives them to cryogenic SiPMs through Wave-Length Shifters (**WLS**) bars.





The PDE is the ratio of the number of detected photons to the photons impinging on the XA window. To estimate the latter, we used two different approaches:

- ★ **"Geant4 method"** This method relies on the knowledge of the source activity and a simulation that propagates the scintillation photons to the XA window. Both CIEMAT and Milano-Bicocca groups adopted this method.
- ★ **"Reference method"** Two reference VUV4 SiPMs are used as trigger and to estimate the number of scintillation photons emitted by the ^{241}Am source in CIEMAT setup.

$$N_{ScintPh} = \frac{N_{DetPh}}{\Omega_{PD} \times \epsilon_{PD}}$$

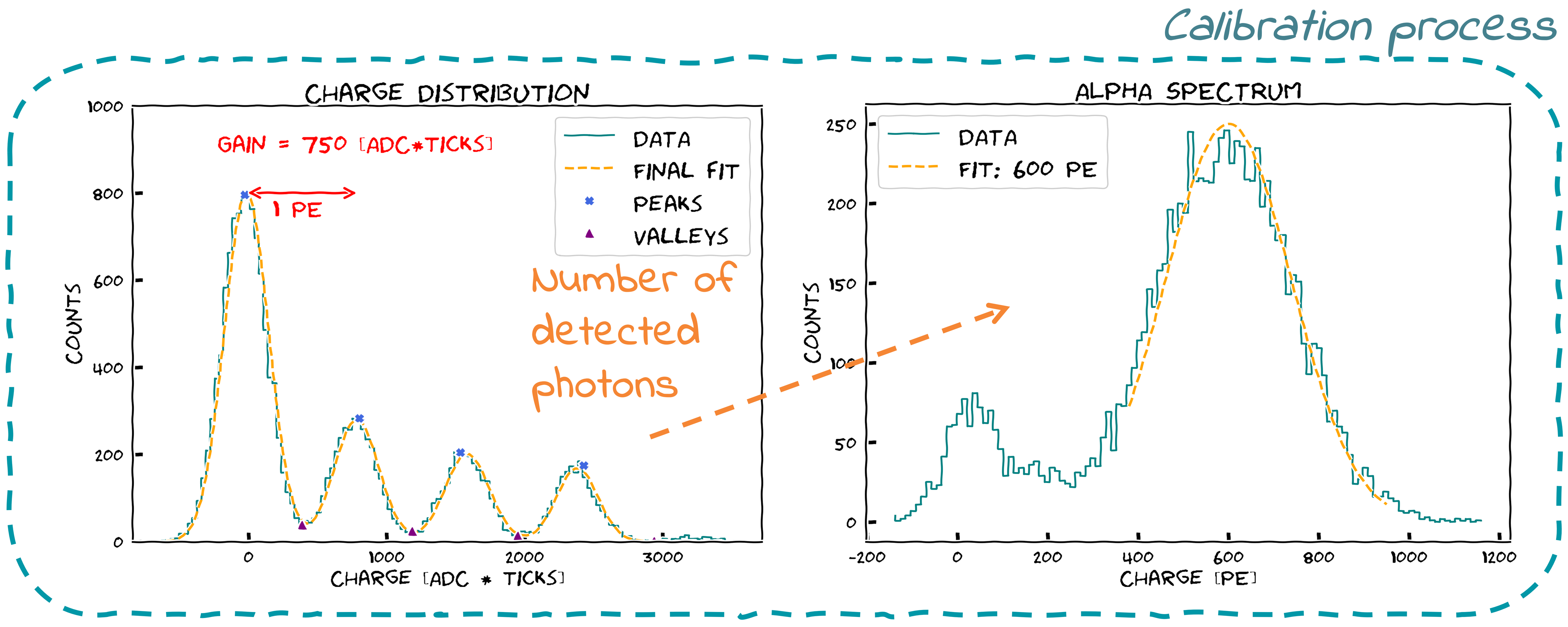
We correct the number of detected photons for the liquid argon purity estimated deconvolving the electronic response.

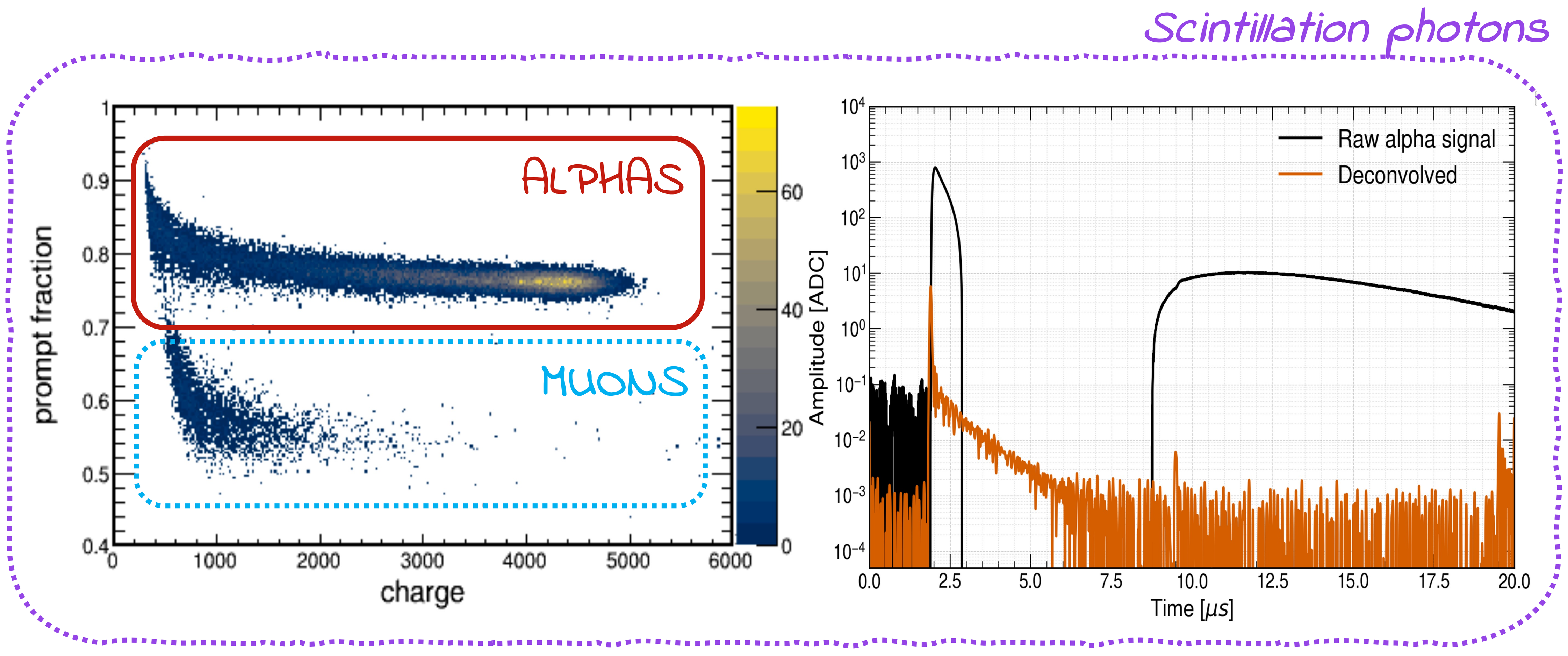
	FBK+EJ	FBK+G2P	HPK+EJ	HPK+G2P
ε_{MAD}	1.34 ± 0.24	-	1.59 ± 0.29	2.13 ± 0.38
ε'_{MAD}	1.61 ± 0.12	-	1.86 ± 0.15	2.50 ± 0.21
ε_{MIB}	1.80 ± 0.15	2.22 ± 0.19	-	2.40 ± 0.20

X-ARAPUCA EFFICIENCY

We assessed the Photon Detection Efficiency (**PDE**) at the operative conditions: **cryogenic temperatures** and at **127 nm**. The XA is submerged in LAr along with a ^{241}Am alpha source.

The number of detected photons is determined through a calibration using LED light, alpha event selection, fitting the reconstructed energy spectrum, and applying correction factors such as the SiPM cross-talk probability and the LAr purity.





RESULTS FROM THE LABS

CIEMAT and Milano-Bicocca groups measured the XA PDE with two SiPM models (**FBK** and **HPK**) and two WLS bars provided by Eljen (**EJ**) and Glass to Power (**G2P**).

We found an absolute efficiency of around the **2%**, with larger values observed for the G2P WLS (results for a Supercell of the Horizontal Drift module).

The difference between FBK and HPK results is under further investigation, as it was not expected operating the SiPMs at the same quantum efficiency level.

By revisiting the optical coupling among the XA components and modifying the light guide geometry, we gain almost a factor 2 in the PDE for DUNE FD1. For more details, see Claudia Brizzolari poster!

PROTODUNE-II VALIDATION

Within the context of the second run of ProtoDUNE, we can estimate the XA efficiency under realistic conditions. Since there is no known radioactive point-like source, we need to take advantage of the **beam run** and the TPC data to compute the particles' energy, momentum and the position of the tracks or showers. The Collaboration aims to confirm the laboratory tests, clarify the difference between WLS and SiPM models tested, and to validate the simulation of the DUNE Far Detectors.

References

[1] DUNE Collaboration, 2020 *JINST* **15** T08009
[2] A.A. Machado *et al.*, 2018 *JINST* **13** C04026
[3] C. Brizzolari *et al*, 2022 *JINST* **17** P11017
[4] C. Cattadori, 2024 *JINST* **06** C06007

Acknowledgments

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SUBMITTED TO EPJC!

For more details check our pre-print !!

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