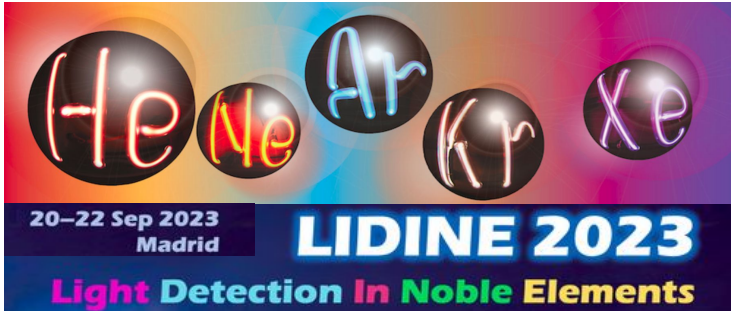
Measurement of the PDE of Hamamatsu VUV4 SiPMs at Cryogenic Temperature

Laura Pérez Molina on behalf of the CIEMAT neutrino group



Motivation

- Photosensor sensitive to LAr scintillation light (127 nm) without the need of WLS

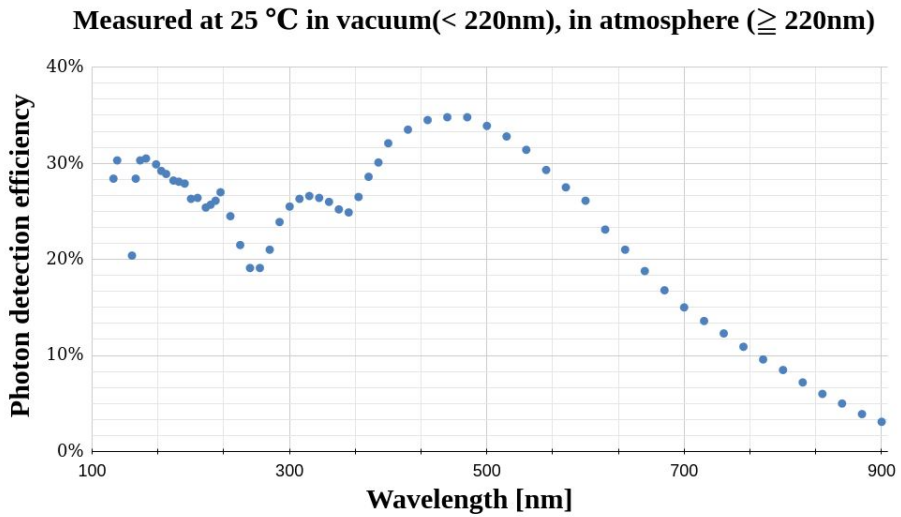
   appealing for DUNE applications (among others)

- Characterization of the Photon Detection Efficiency (PDE) with **wavelength** and **temperature:**
  - Critical to compare simulations with acquired data
  - Reference parameter needed to evaluate performance

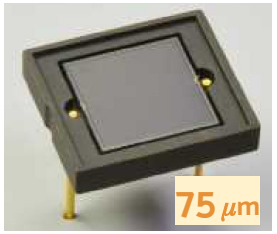
- CIEMAT has dedicated setups to measure the PDE at CT:
  - **Relative measurement to RT**: heat exchanger to measure in a range of [270, 570] nm
  - **Absolute measurement**: PDE at 127 nm using the DUNE-HD X-ARAPUCA setup

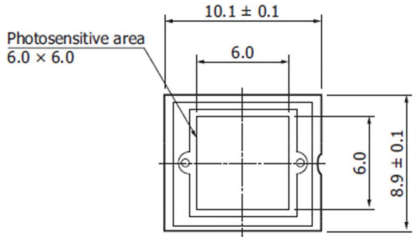
VUV4 SiPMs (series: S13370)

- Directly sensitive to the LAr scintillation light of 127 nm
- Prepared to carry out stable performance at cryogenic temperatures
- 4 VUV4 SiPMs calibrated at RT by Hamamatsu



Hamamatsu DataSheet





Methodology

Measure the PDE at CT relative to the one provided by Hamamatsu at RT

$$PDE_{CT} = \frac{PE_{CT}}{PE_{RT}} PDE_{RT}$$

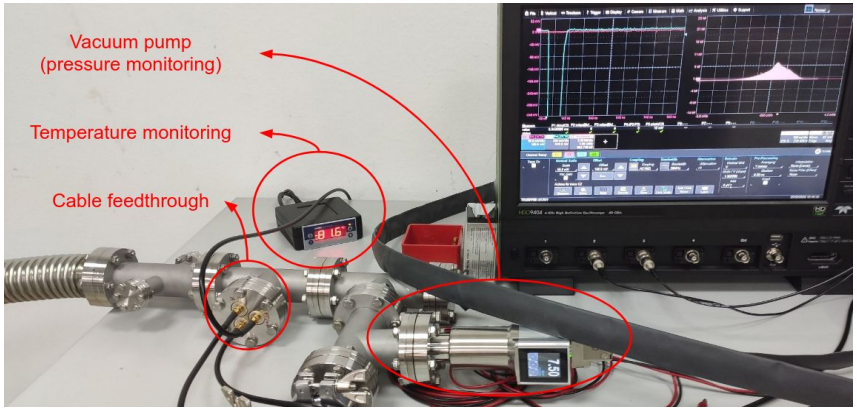
RESULT | CIEMAT Measurement | HPK Calibration

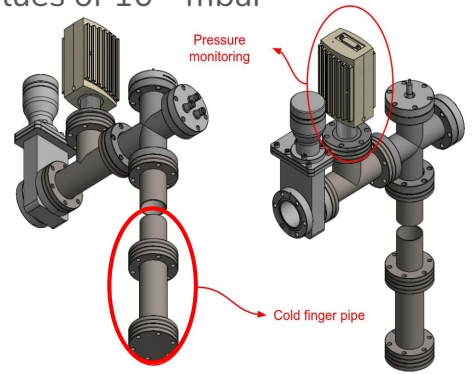
The followed procedure was:

1. **Gain calibration** measurements at RT for three different OV values.
2. **High-intensity light pulse** signal acquisition at RT for wavelengths between 270 – 570 nm.
3. **Cooldown** of the system to LN_2 temperature.
4. **Gain calibration** measurements at CT for three different OV values.
5. **High-intensity light pulse** signal acquisition at CT for wavelengths between 270 – 570 nm.

Relative PDE measurement to RT

- SiPM is cooled down by thermal contact with an stainless steel tube (submerged in LN_2)
- Tube is sealed and a vacuum is created with the pump, reaching values of 10^{-4} mbar





- Temperature sensor in a PCB next to the SiPM
- SiPM placed at the end of the tube facing the light source

Relative PDE measurement to RT

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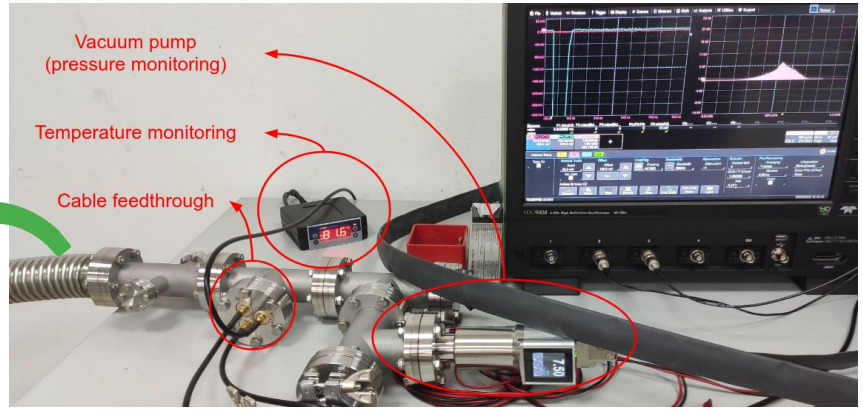
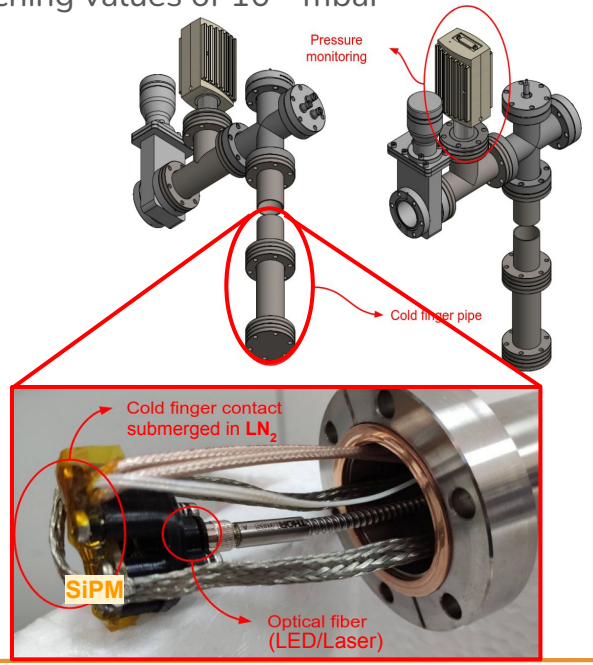


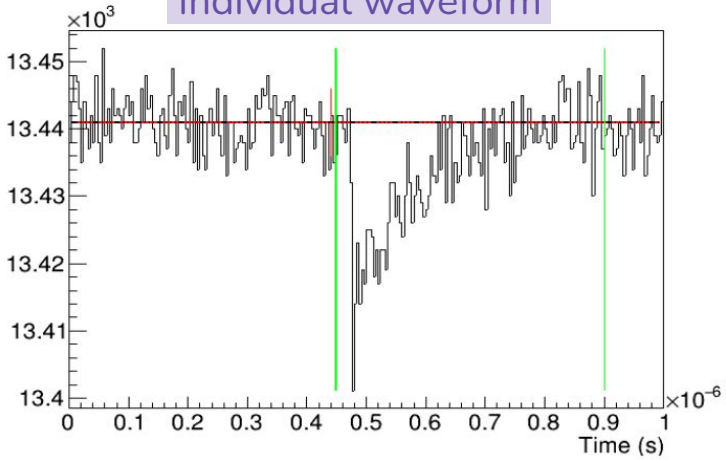


- Temperature sensor in a PCB next to the SiPM
- SiPM placed at the end of the tube facing the light source

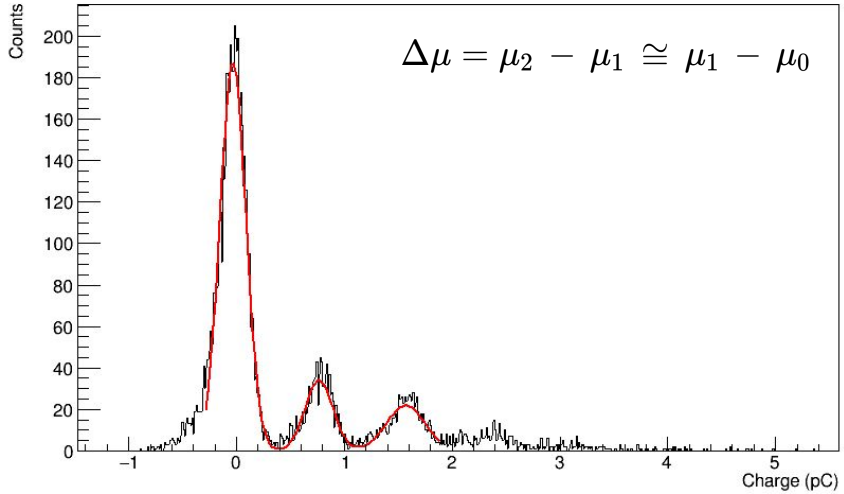
Gain calibration

The gain measurement is performed by fitting the integrated charge histogram to N Gaussians for 3 different OV

Individual waveform

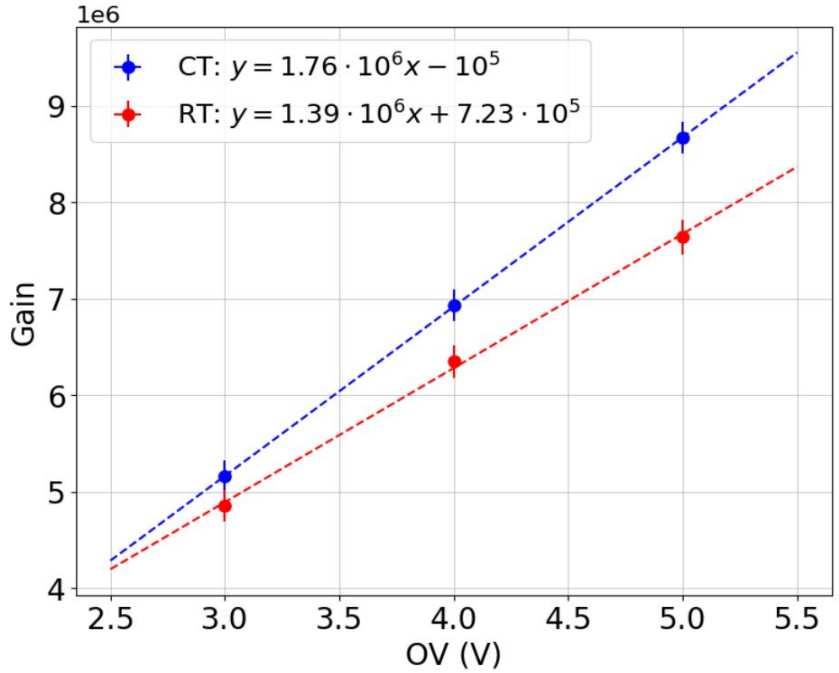


Calibration histogram



Gain calibration

Gain dependance with OV and Temperature



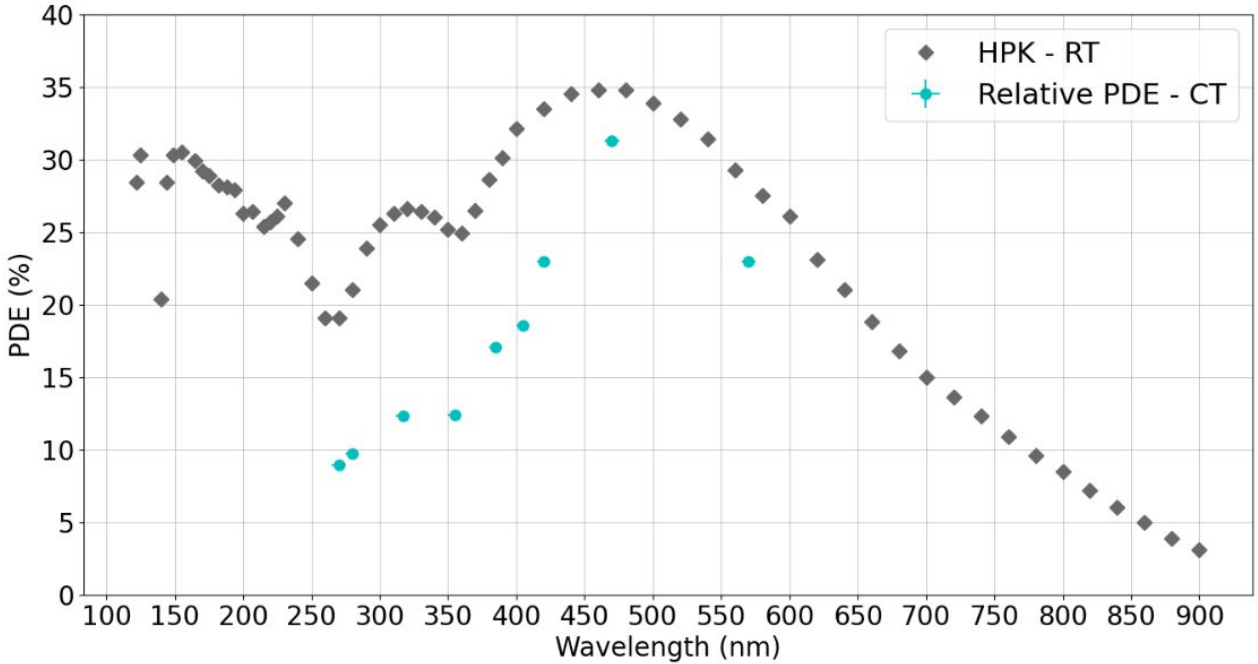
OV(V)	Gain (10^6)	
	RT	CT
3.0	4.86 ± 0.08	5.16 ± 0.08
4.0	6.35 ± 0.08	6.93 ± 0.08
5.0	7.64 ± 0.09	8.67 ± 0.08

$$G = \frac{\Delta\mu}{A\, q_e}$$

- $\Delta\mu$ ≡ distance between gaussians
- A ≡ amplification factor
- q_e ≡ electron charge

Photon Detection Efficiency

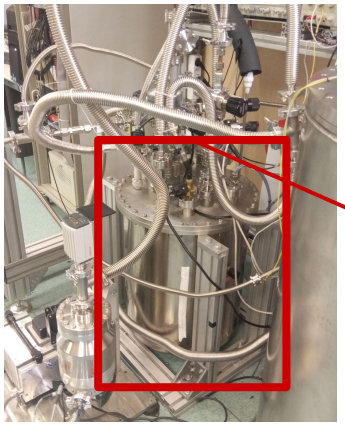
The PDE at CT shows a **decrease** in range 20% to 54% compared to its value at RT

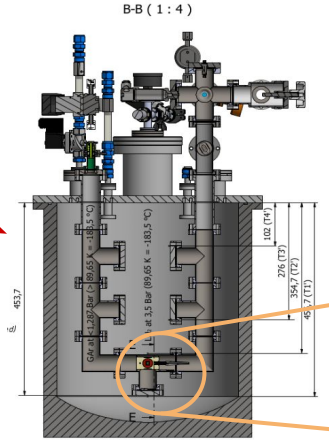


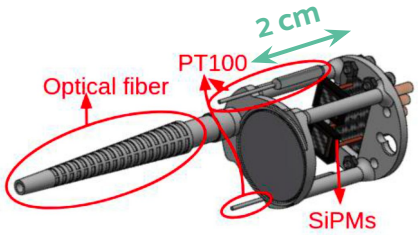
Cross-check measurement in GAr

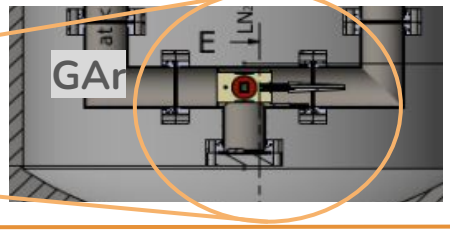
Relative PDE measurement to RT:

- More temperature sensors and closer to the SiPM
- A light diffuser is used to **homogenize** the light reaching the SiPM from the fiber
- Feasibility for operating with GAr + ***α*-source** to measure scintillation light [TO BE USED]









- **50 L** LN_2 vessel
- **U**-shaped tube where **GAr** is continuously circulating
- GAr at overpressure
- SiPM is cooled down by **thermal contact** with an stainless steel tube

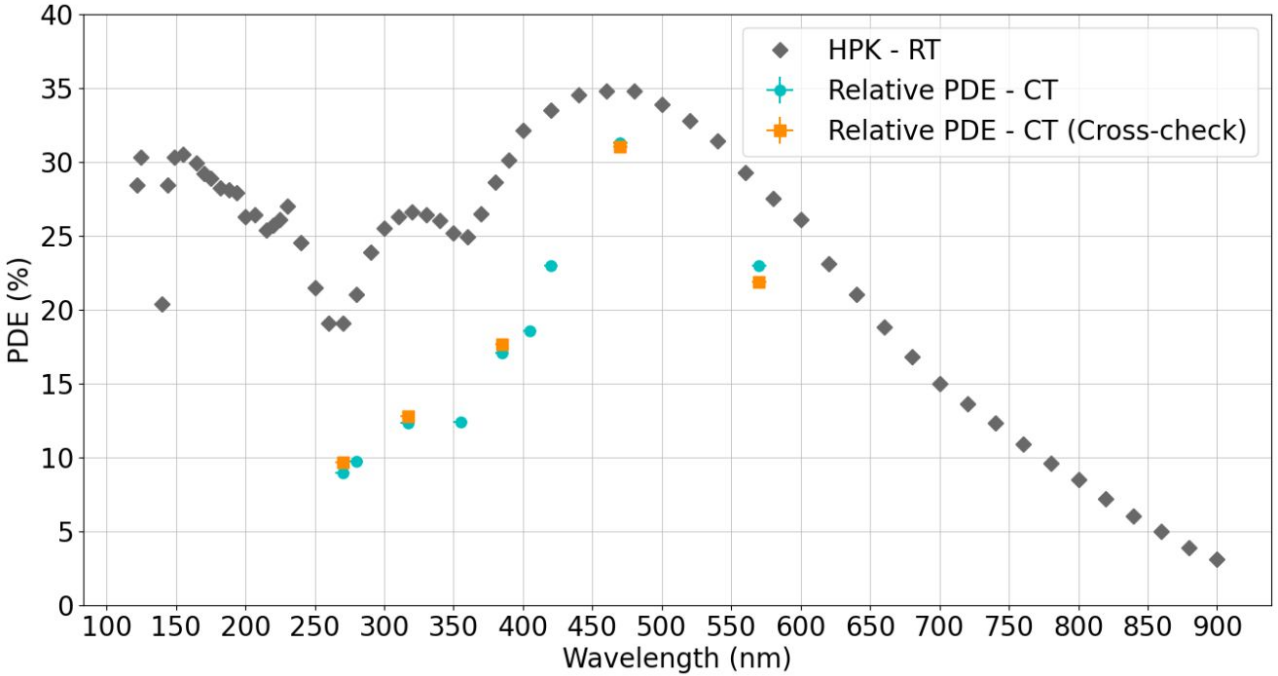
Measure #PE:

➔ SiPM at RT

➔ SiPM at 87K (LN2 at 2.7 bar)

Photon Detection Efficiency

The two setups lead to compatible results at different wavelengths

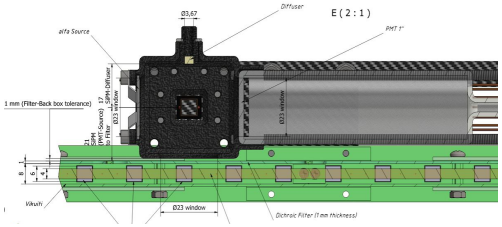


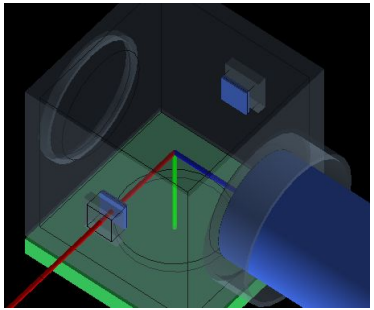
Absolute PDE measurement

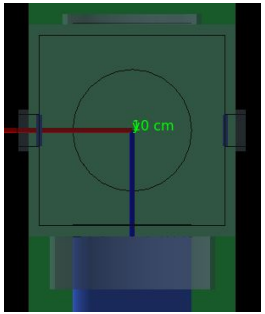
- Black box holding VUV4 SiPMs and α-source submerged in LAr
- Low-activity electrodeposited ^{241}Am alpha source
  - **Energy**: 5485 keV (84.45%); 5443 keV (13.23%)
  - **Activity**: 54.53 ± 0.82 Bq
  - **Rate**: 27.6 Hz

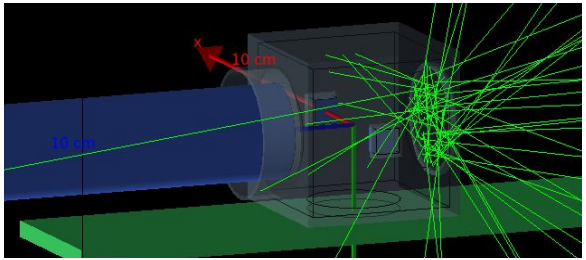
$$\epsilon_2 = \frac{PE_{measured}}{PE_{produced} \cdot f_{ph}} \cdot f_{X-talk} \cdot f_{purity}$$

$$\begin{aligned} PE_{\text{produced}} &= LY_{LAr}\ E_\alpha\ q_\alpha = \\ &= 50000\,\text{photons/MeV} \cdot 5.48\ \text{MeV} \cdot 0.72 \\ &\sim 2 \cdot 10^5\ \text{photons} \end{aligned}$$





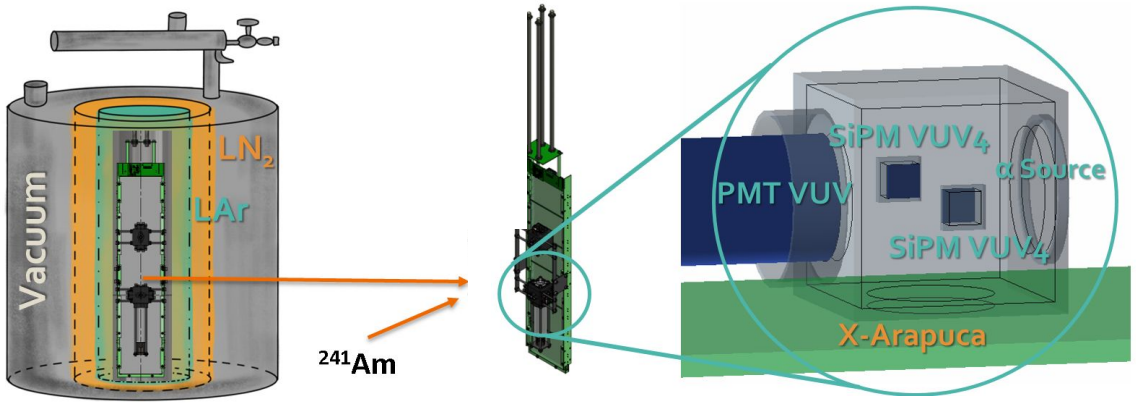




Absolute PDE measurement

Setup from the DUNE-HD X-ARAPUCAS PDE measurement where the VUV4 SiPMs were used as **reference sensors**

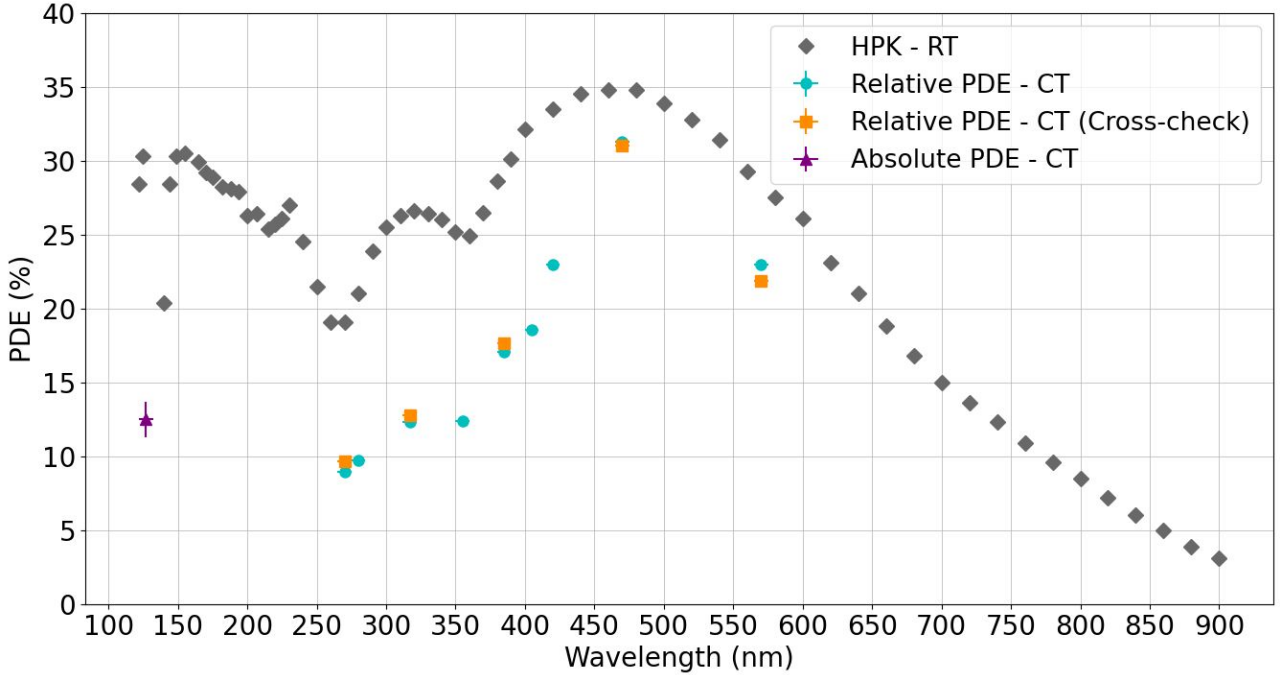
- 300 L vacuum
- 100 L LN_2
- 18 L LAr



GAr 99.9999 % is liquefied with LN_2 at 2.7 bar

Photon Detection Efficiency

The absolute measurement for 127 nm shows a compatible decrease in PDE at CT



Conclusions

- First work to measure the PDE of this SiPM at **CT** and at **different wavelengths**
- Three setups obtain compatible results showing a **decrease** in PDE for the Hamamatsu VUV4 SiPMs S13370 - 6075CN when operating at **CT**
- The difference between PDE at different **temperatures** is also dependant on the **wavelength**: we can see less decrease in the PDE at CT for ~ [450, 480] nm
- The **PDE result for 127 nm** is in agreement with a recent publication (JINST 17 (2022) 04, P04017)
- Publication in preparation. **Stay tuned !!** 

BACKUP

Relative PDE measurement

COOLING DOWN PROCESS