Summary of the PMT measurements at CIEMAT

CIEMAT-IFAE Meeting (12-01-2018)

Ana Gallego on behalf of CIEMAT group

Outline

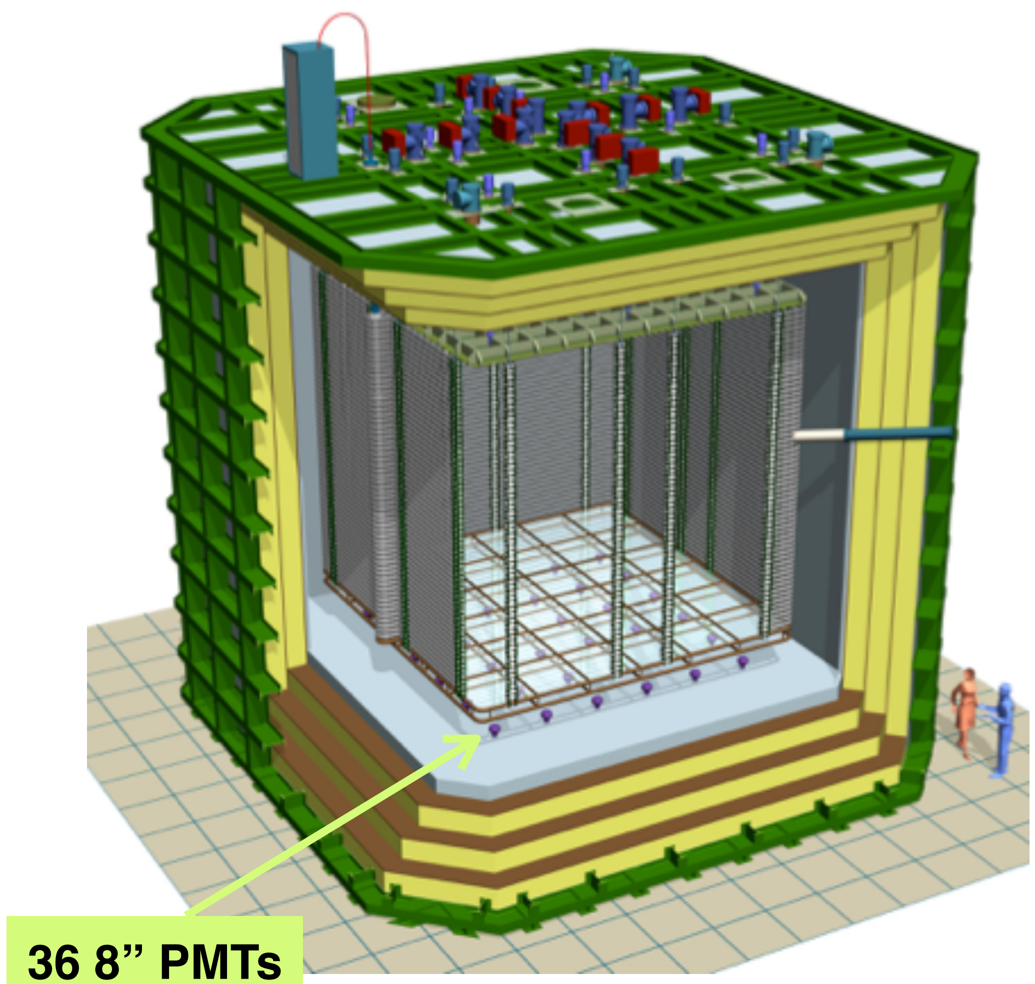
* Introduction
* Experimental setup at CIEMAT
* Results at room temperature
* Results at cryogenic temperature
* Gain change due to temperature
* Interaction with Hamamatsu
* Summary and next steps
* Paper about PMTs characterization

Introduction

ProtoDUNE dual phase

6x6x6 m^3 (fid.) DLAr TPC under construction @ CERN

TDR: arXiv:1409.4405



BASIC CONFIGURATION OF THE LIGHT DETECTION SYSTEM

- **36 8" cryogenic photomultipliers**
- Wavelength-shifter: TPB coating on PMT
- Voltage divider base + single HV-signal cable + splitter (external)
- Light calibration system
- DAQ system (external)

Introduction

PMT testing @ CIEMAT

✳ Validation of PMT base

✳ Detailed characterization of 40 PMTs at warm and cold

✳ Measurements:

- **Gain vs. HV:** to determine the optimum operating high voltage (40 PMTs)
- **Dark current rate vs. HV:** to reject noisy PMTs (40 PMTs)
- **Waveforms:** at 10^7 gain (40 PMTs)
- **Light linearity:** to define the dynamic range for a linear response
- **Light frequency linearity:** to avoid PMT saturation

8” Hamamatsu R5912-02mod PMT of 14 dynodes

Experimental setup at CIEMAT

Characterization of PMTs at

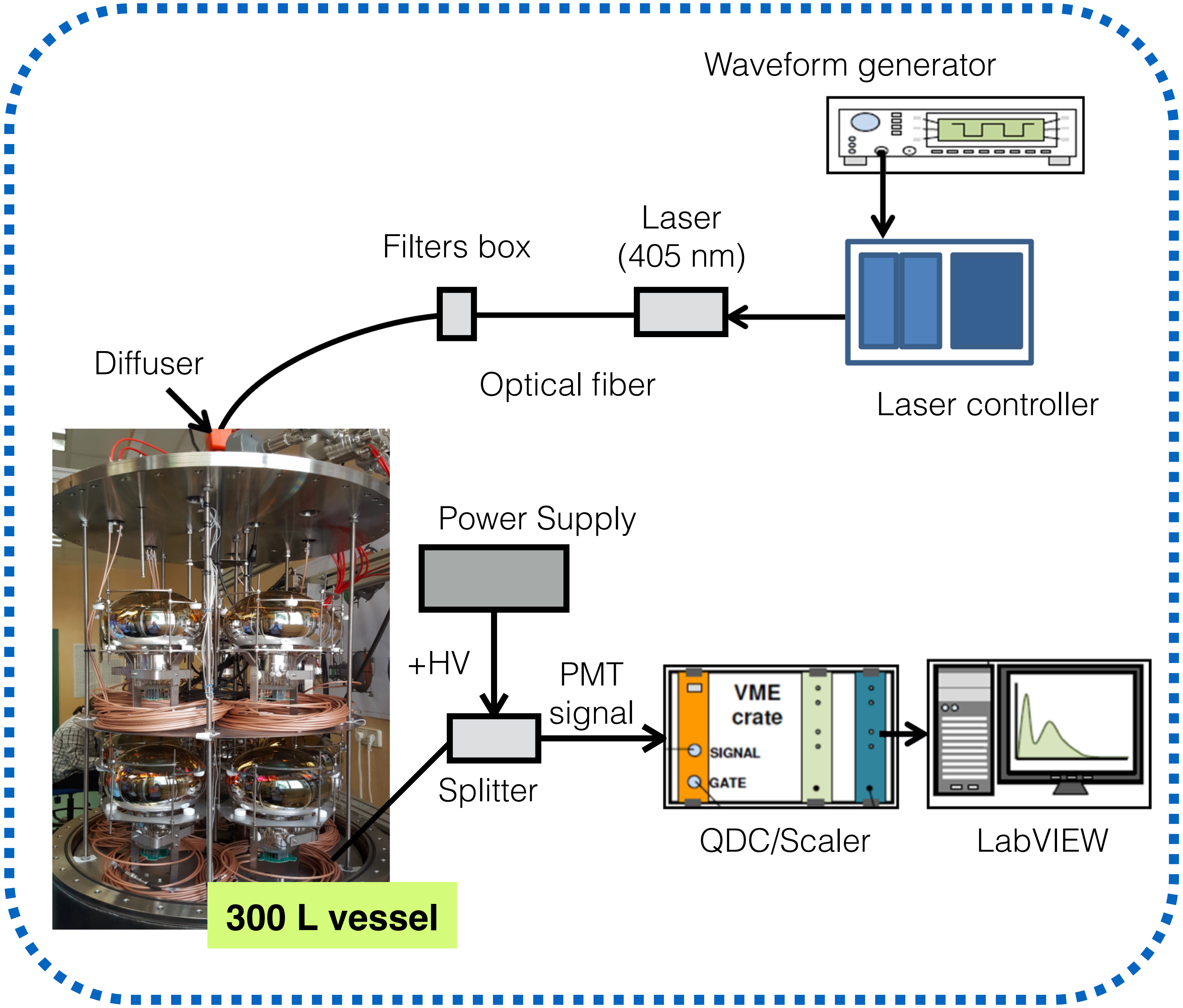
- **Room temperature (RT)**
- **Cryogenic temperature (CT)**

✳ Dedicated setup to test PMTs immersed in liquid nitrogen

✳ At least 3 days for thermalisation

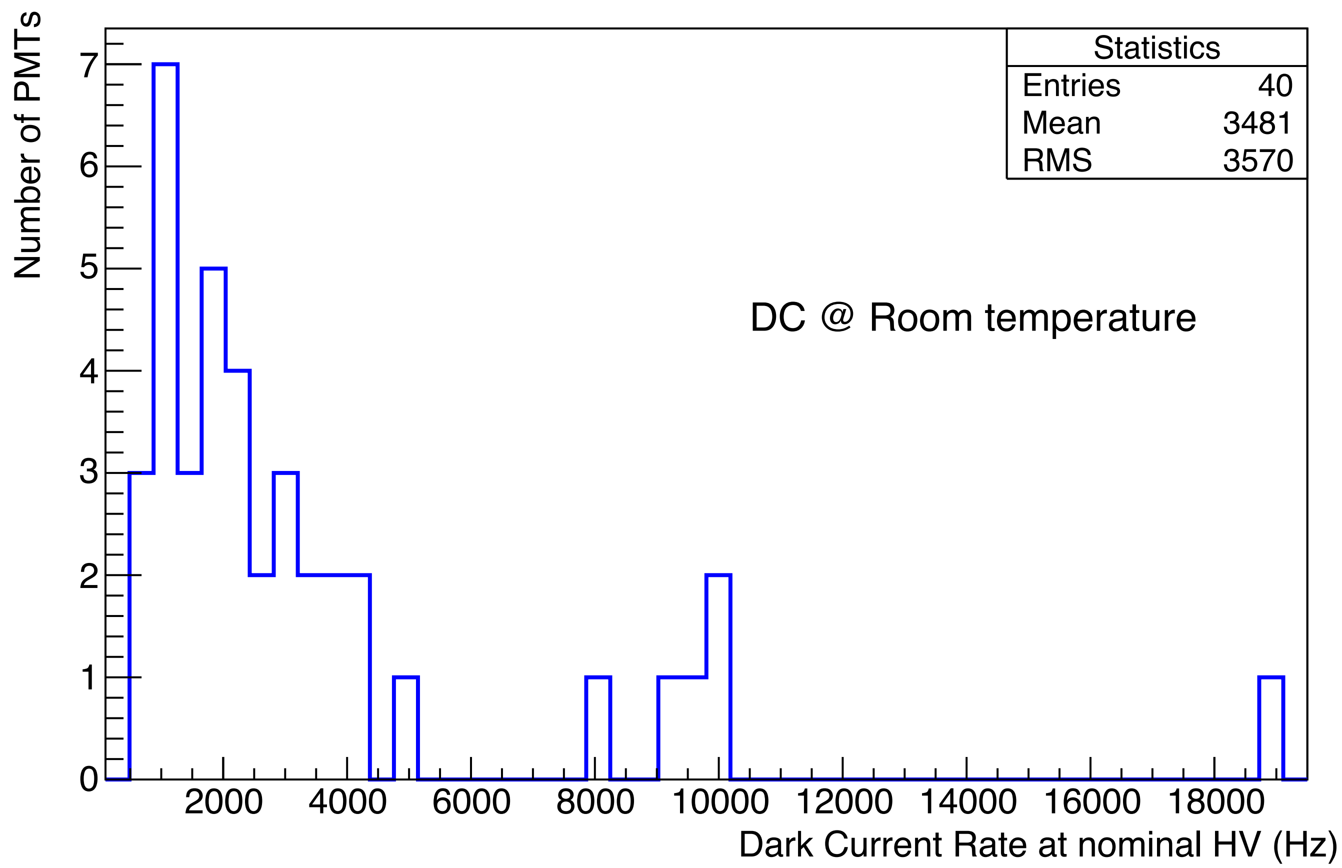
✳ Configurable amount of light

✳ Possibility of testing up to 10 PMTs at once



Results at room temperature

A) Dark current @ RT

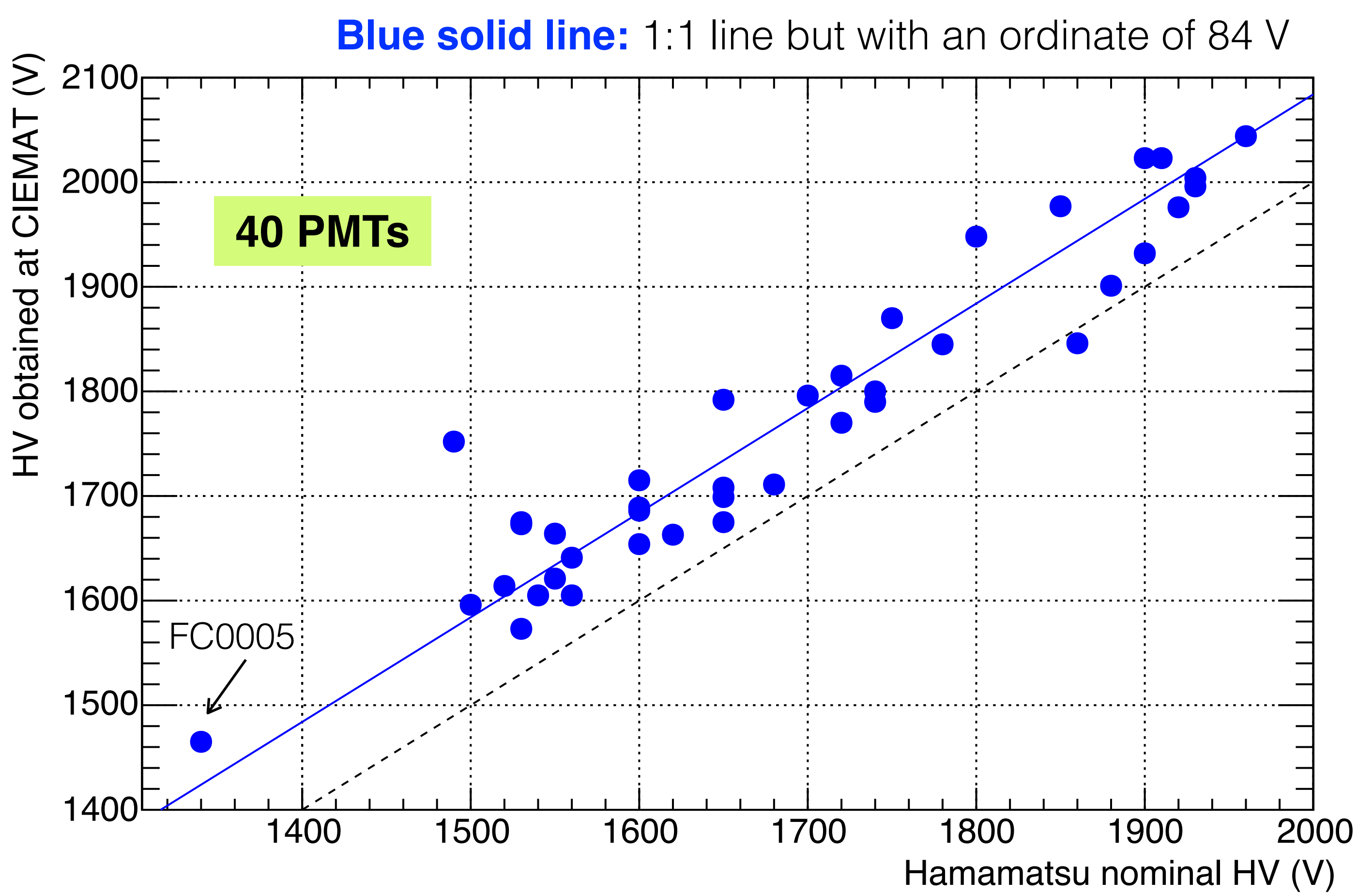


- PMTs in **darkness for at least 2 days** before measurements
- DC measured at several HVs and at the corresponding HV for a 10^9 gain (nominal HV)
- CIEMAT threshold: 1/2 SPE amplitude at 10^7 gain (trigger over noise at any PMT gain)

Results are similar to those given by Hamamatsu

Results at room temperature

B) Gain @ RT

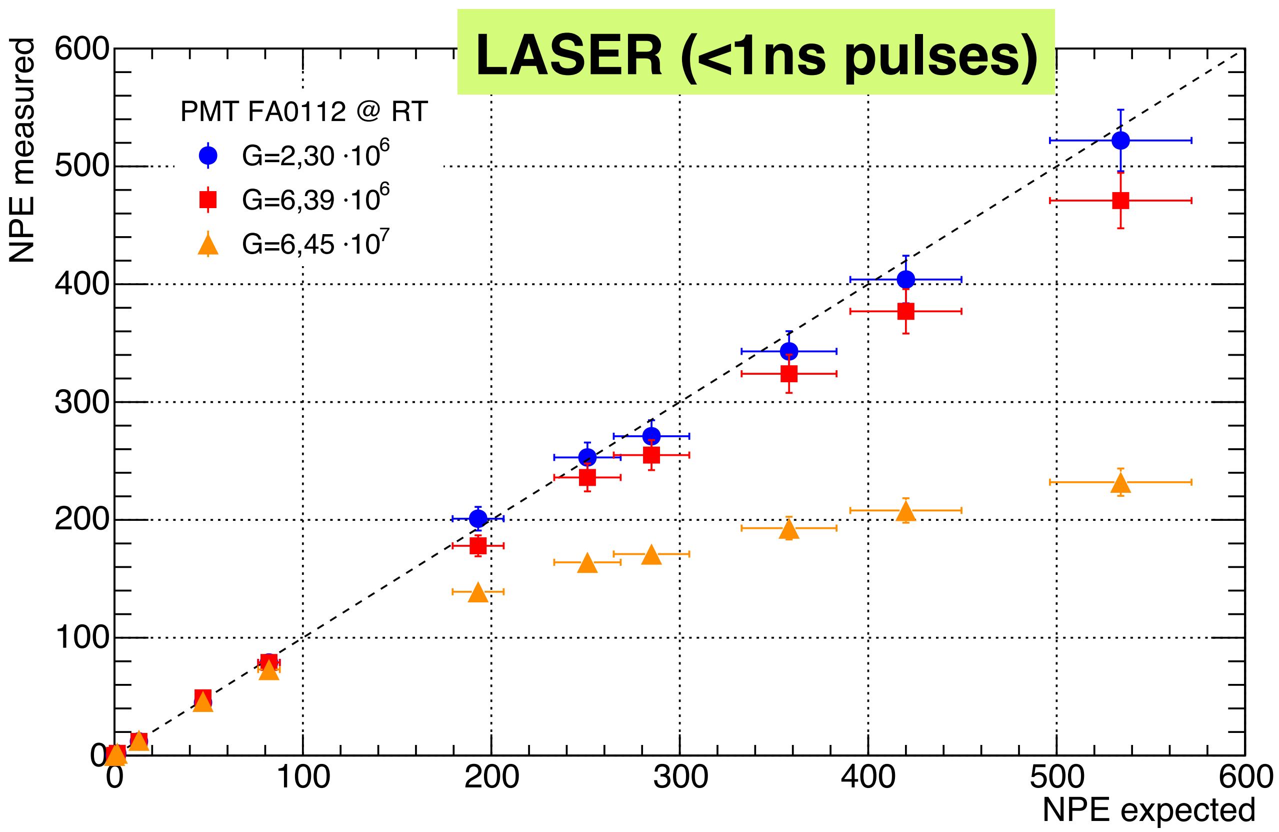


- ✴ Good correlation between our results and Hamamatsu
- ✴ **The discrepancy obtained was expected by the positive base design**
- ✴ The splitter sends to the PMT base a voltage that is a 6% lower than the one read on the power supply itself

CIEMAT voltages for a 10^9 gain (nominal HV) are ~84 V (~5%) above the values provided by Hamamatsu, on average

Results at room temperature

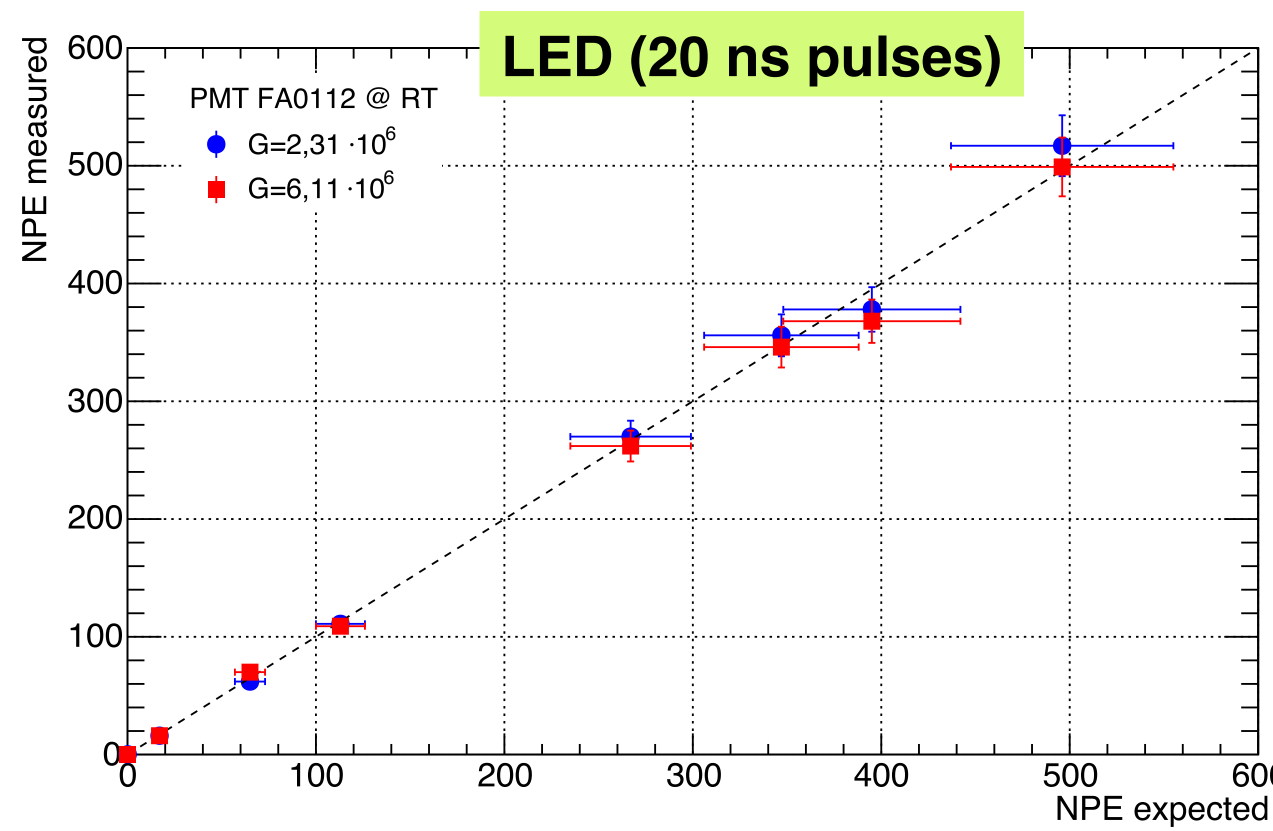
C) Light linearity @ RT



Gain	FA0112 response w/ laser for ~190 PE
$2,3\cdot10^{6}$	Linear
$6,4\cdot10^{6}$	~8% of linearity loss
$6,5\cdot10^{7}$	~28% of linearity loss

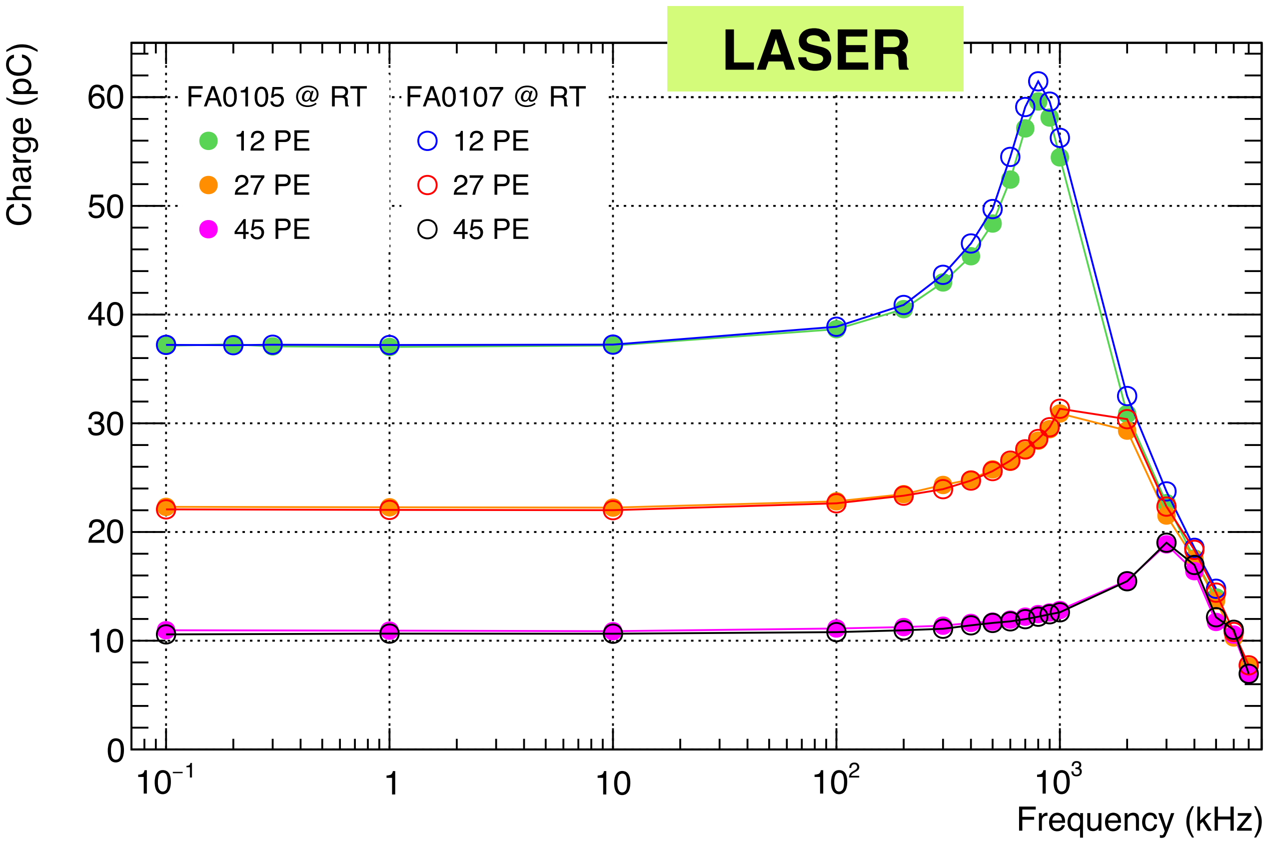
✴ **Preliminary results!** More measurements and analysis will be done

The linearity is not the same with laser and LED because their temporal profiles are different (internal PMT saturation)

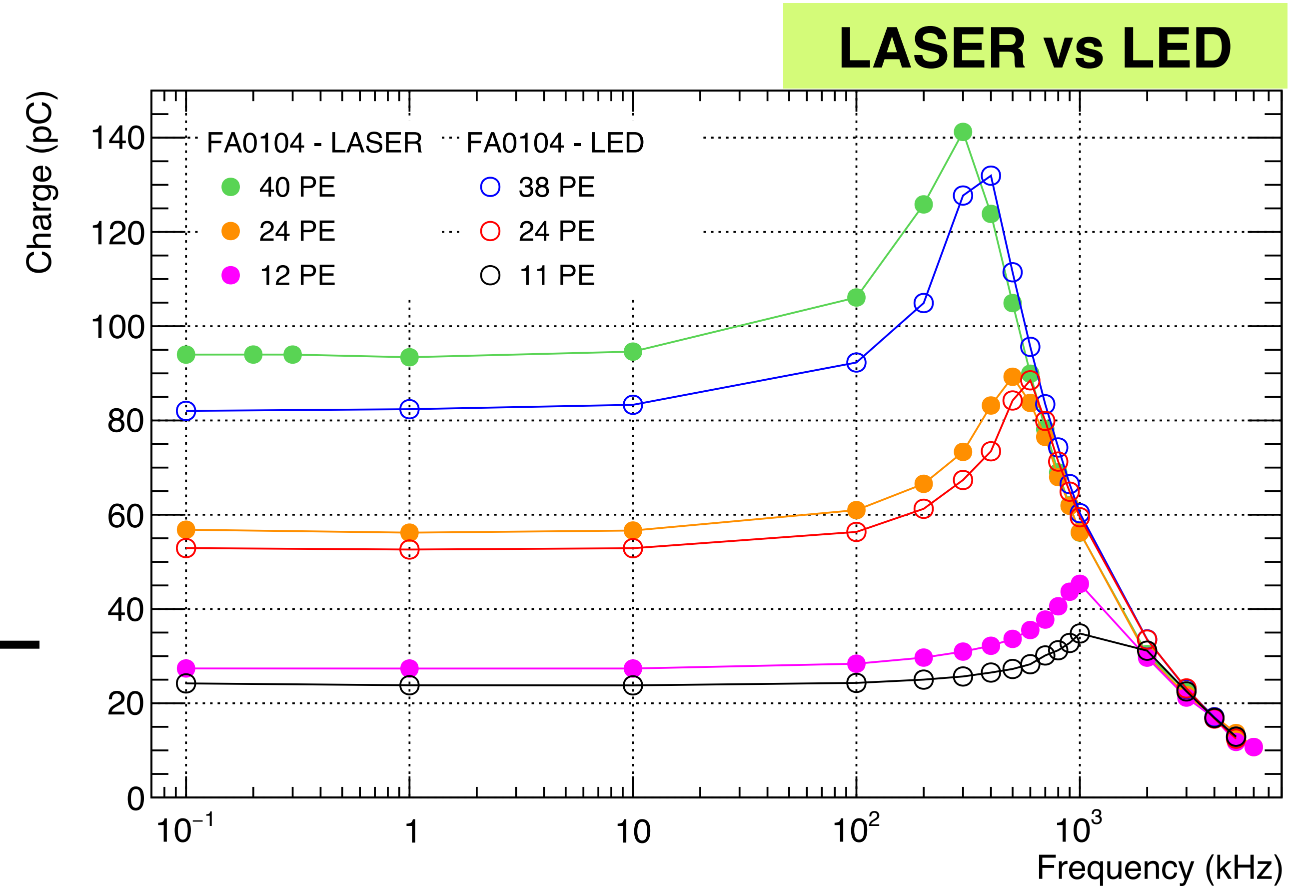


Results at room temperature

D) Light frequency linearity @ RT



The saturation effect is due to the PMT base design (base saturation)



The behaviour is very similar with laser and LED (no internal PMT saturation at low light)

Results at cryogenic temperature

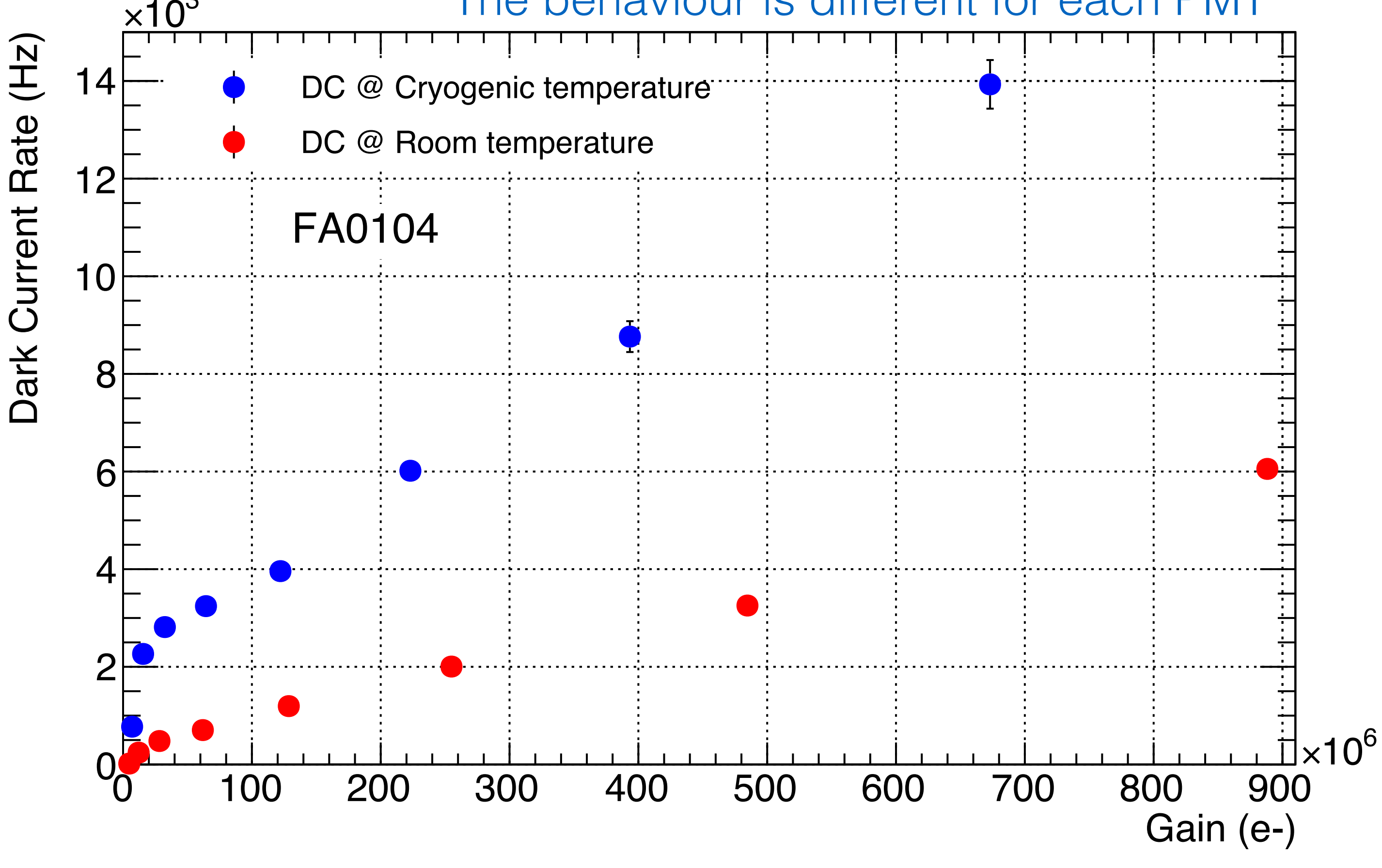
A) Dark current @ CT

✴ The causes at CT are different from the causes at RT

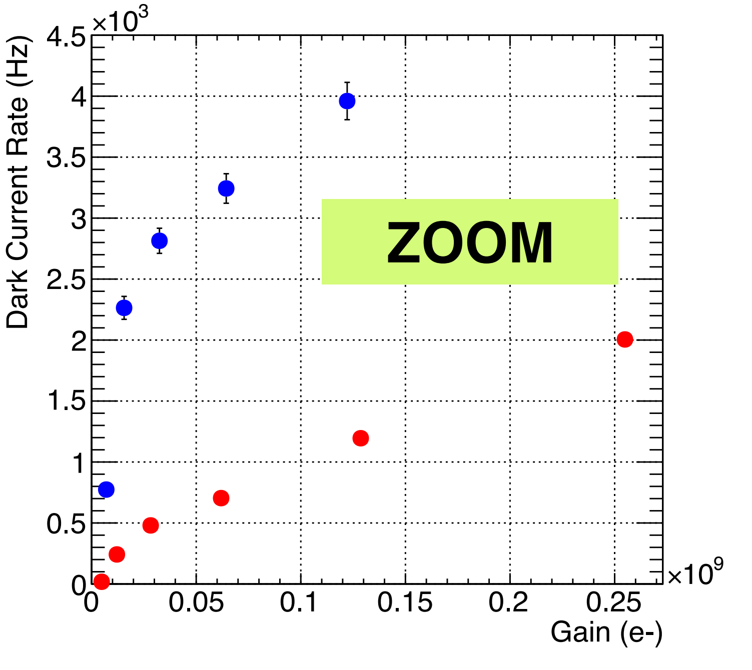
✴ Not all the DC sources are completely understood yet

The DC rate is higher at cold for the same gain

The behaviour is different for each PMT



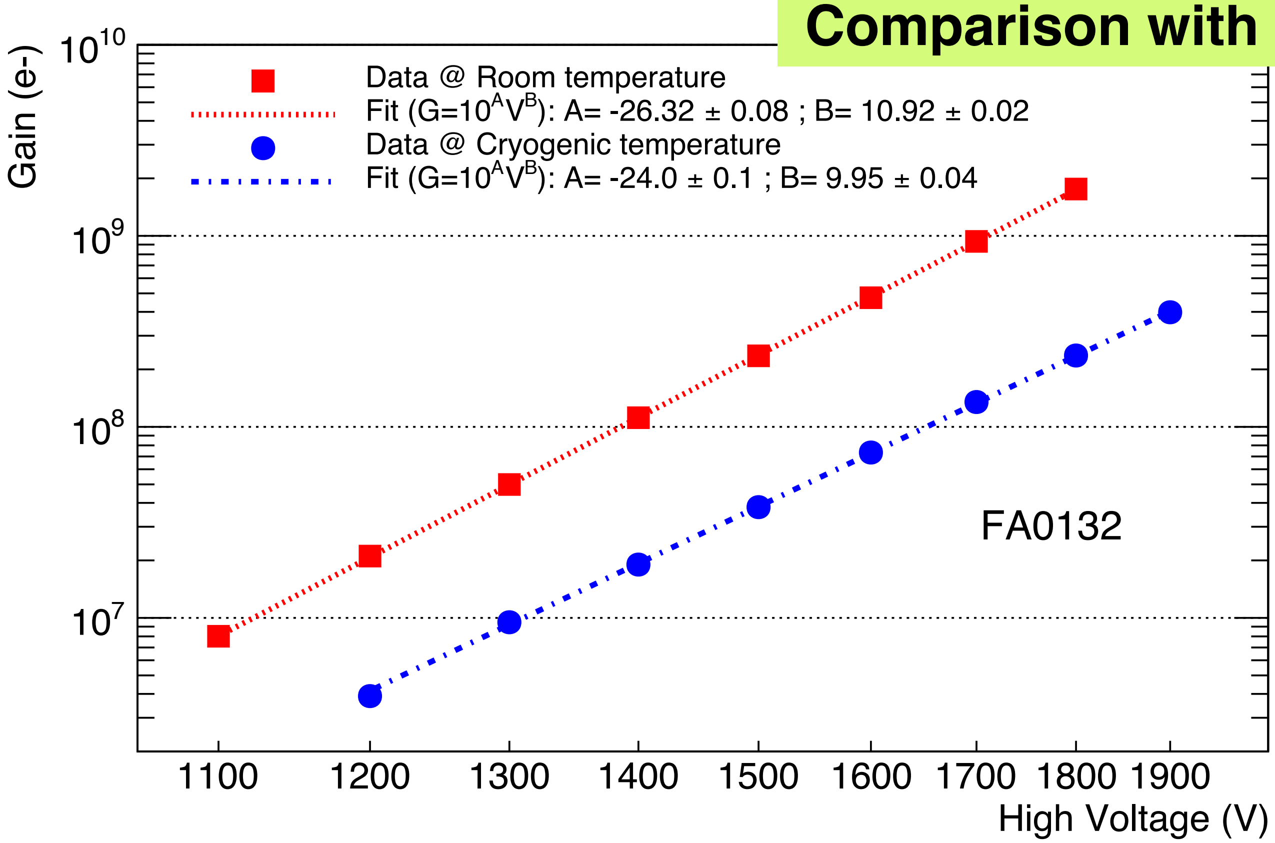
✴ At 10^8 gain, the DC rate increases 4 times



Results at cryogenic temperature

B) Gain @ CT

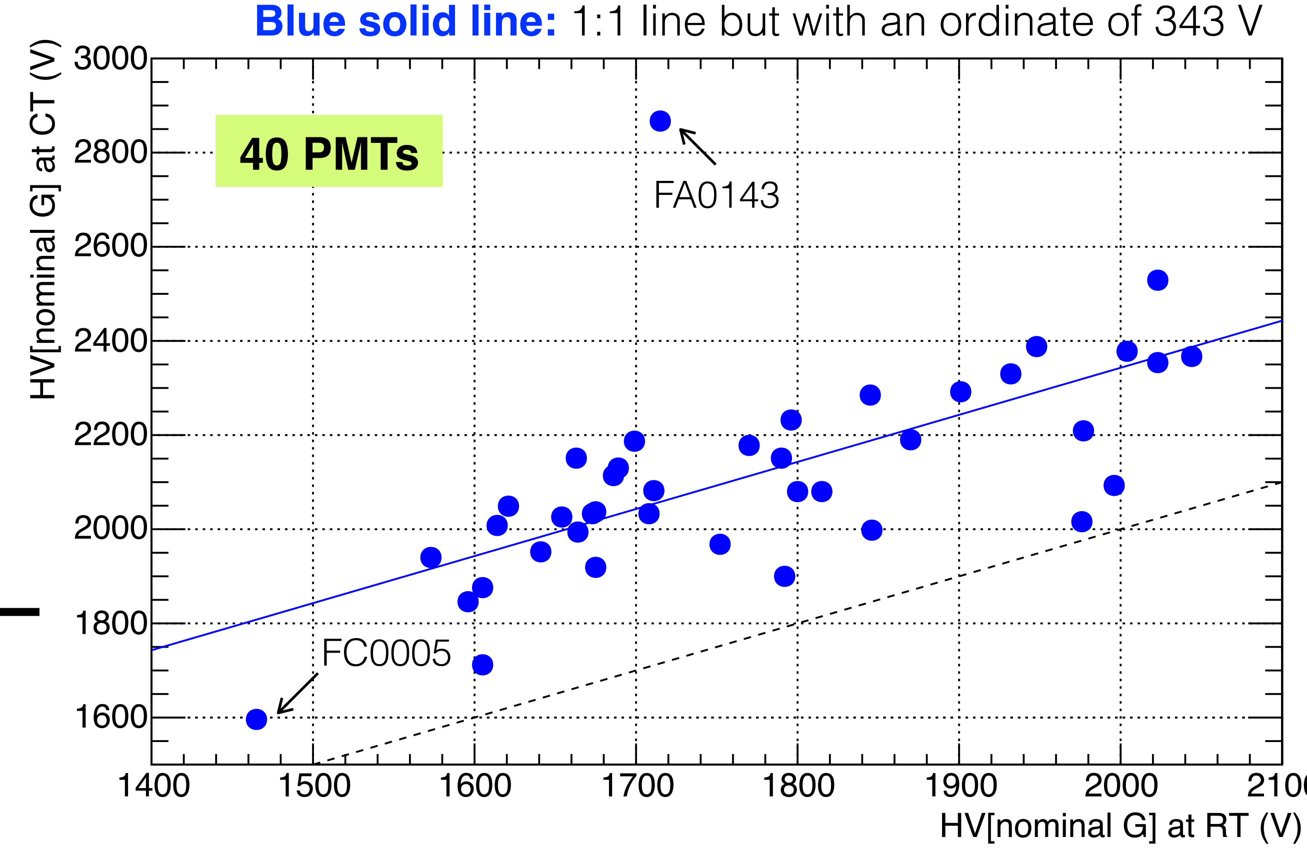
Comparison with RT



- ✳ Gain reduction due to cryogenic conditions is observed, as expected

→ **Higher voltages need to be applied @ CT to obtain the same gain**

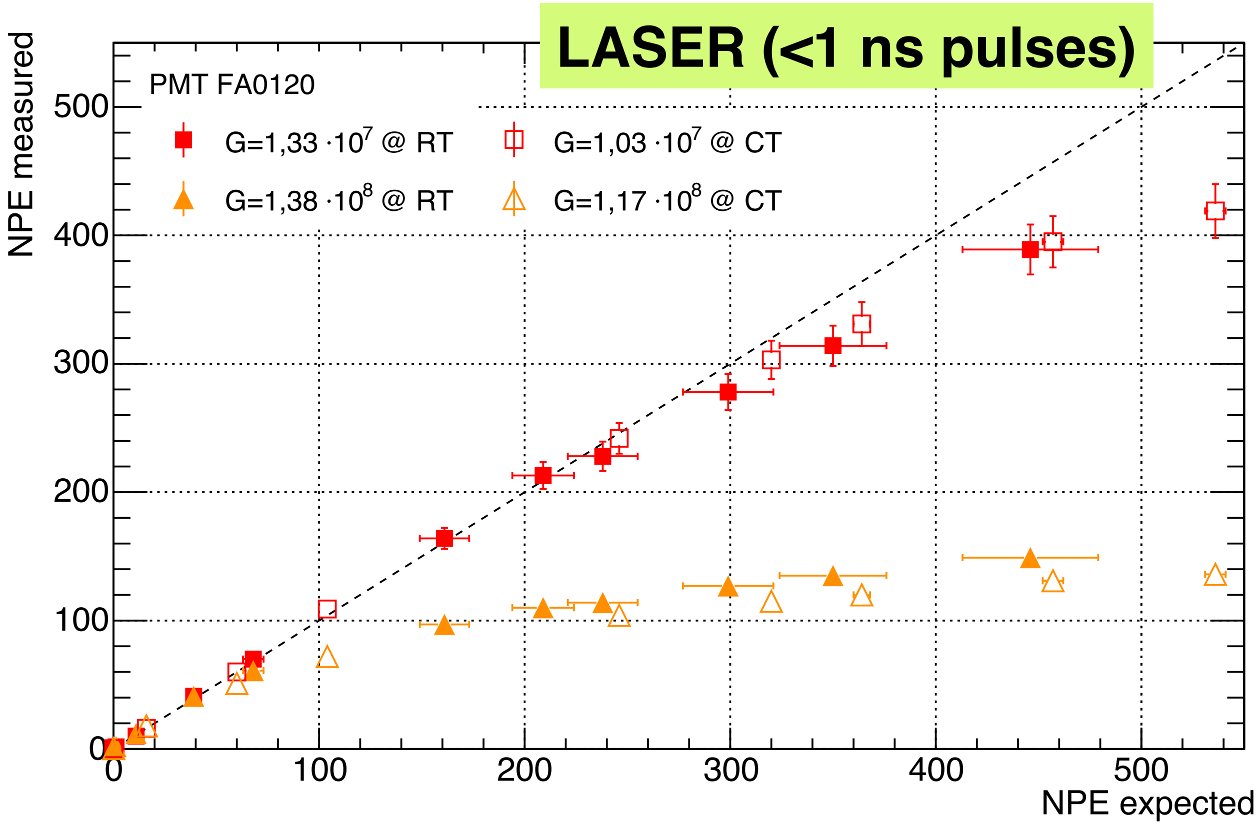
Blue solid line: 1:1 line but with an ordinate of 343 V



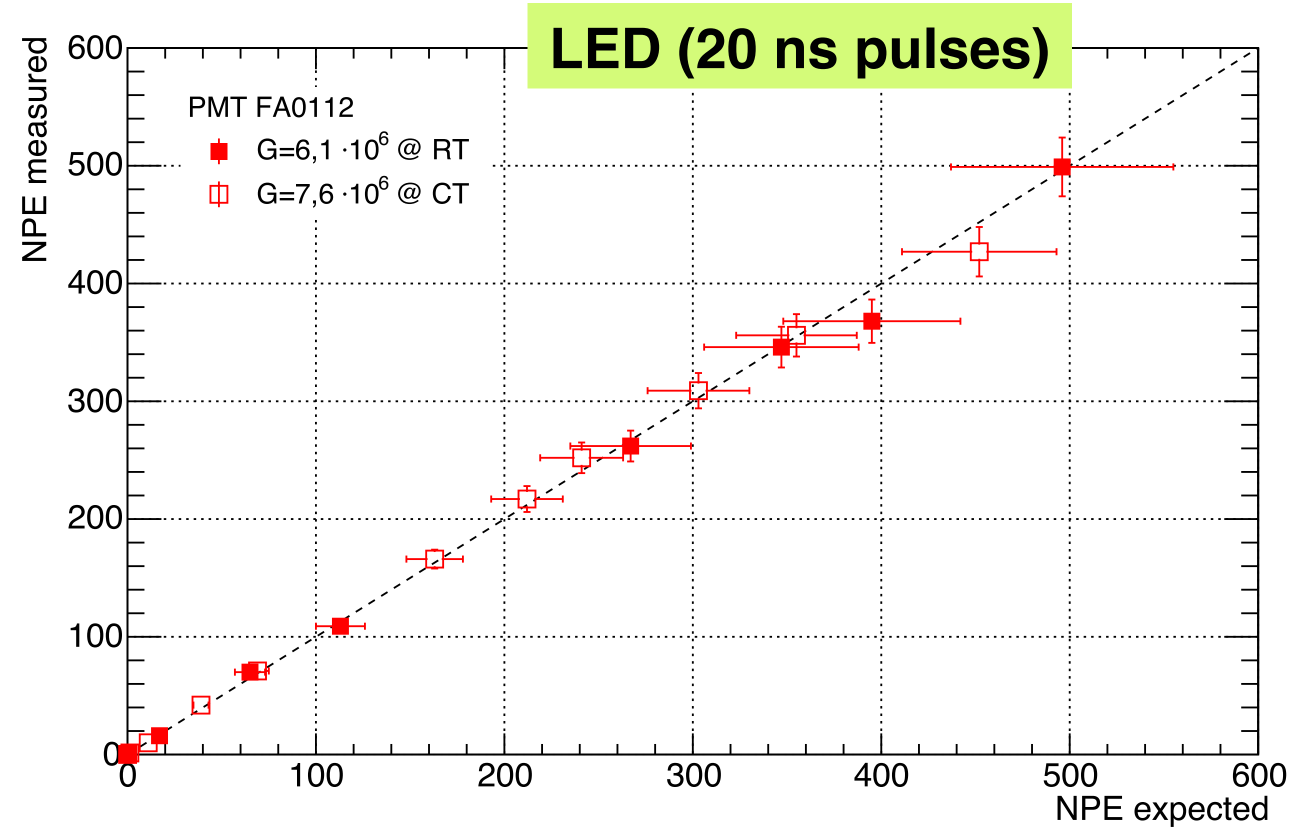
← **HVs @ CT for a 10^9 gain (nominal gain) need to be ~343 V (~20%) higher than HVs @ RT, on average**

Results at cryogenic temperature

C) Light linearity @ CT



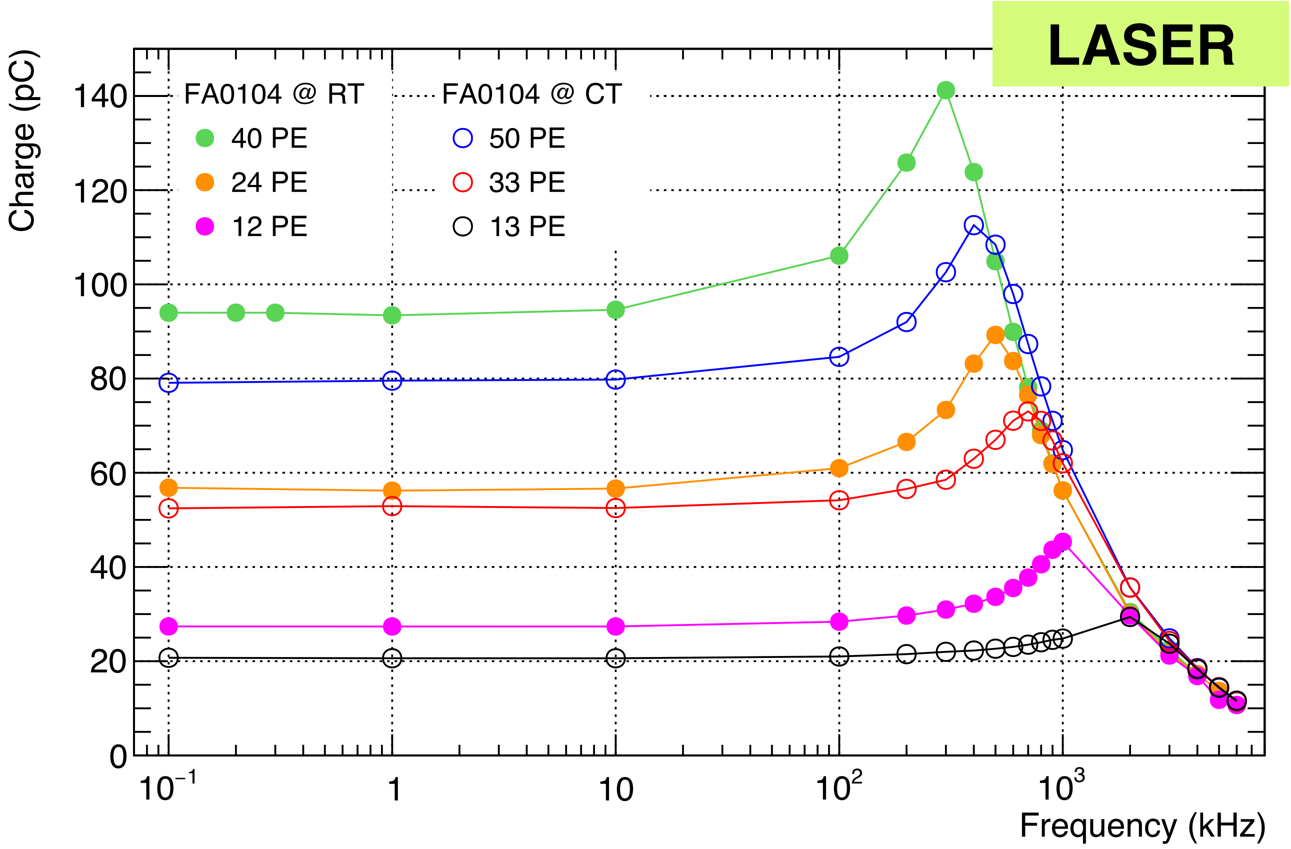
Same behaviour at warm and cold for the same gain



- More **internal PMT saturation** with laser than with LED as @ RT

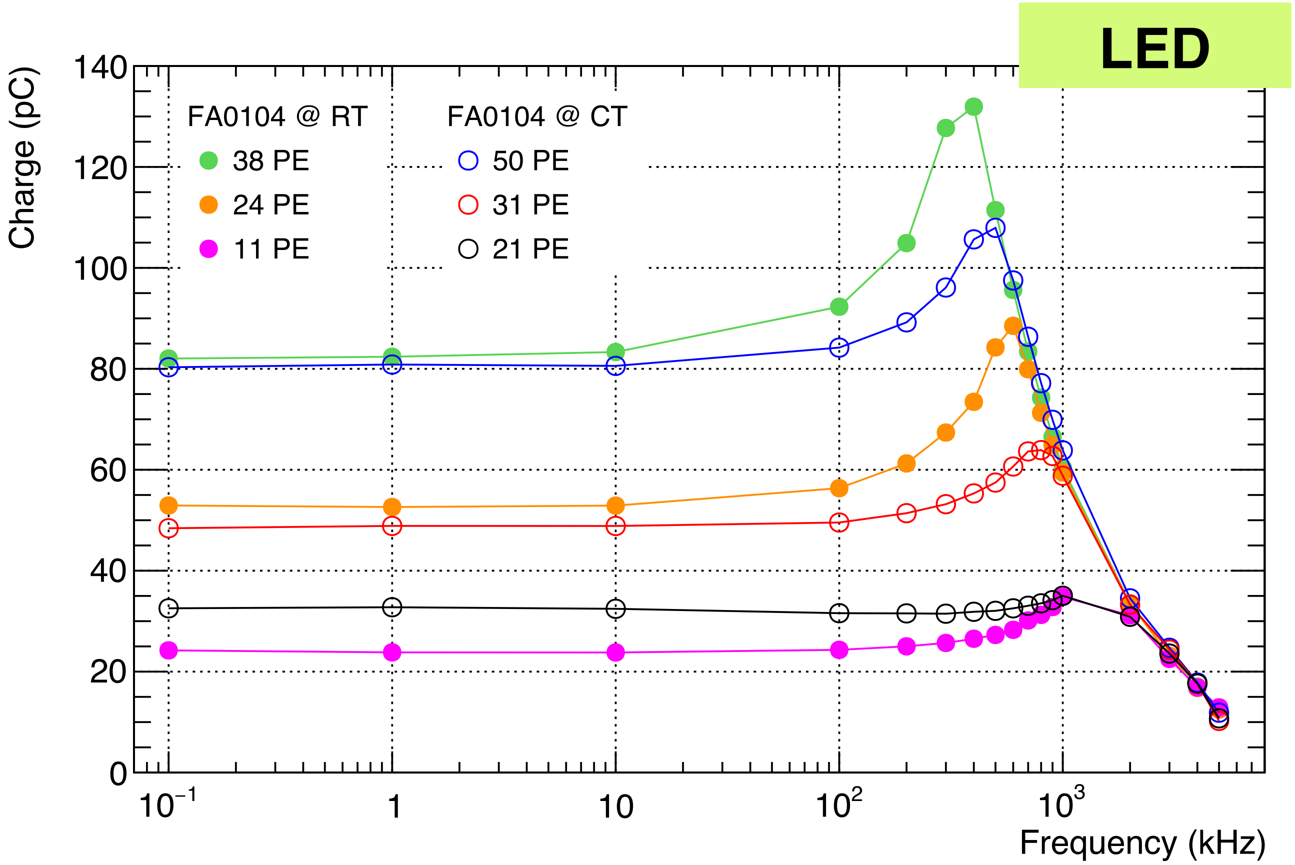
Results at cryogenic temperature

D) Light frequency linearity @ CT



The saturation curve is the same @ RT and CT, as expected (base saturation)

Overlinearity effect is smaller @ CT

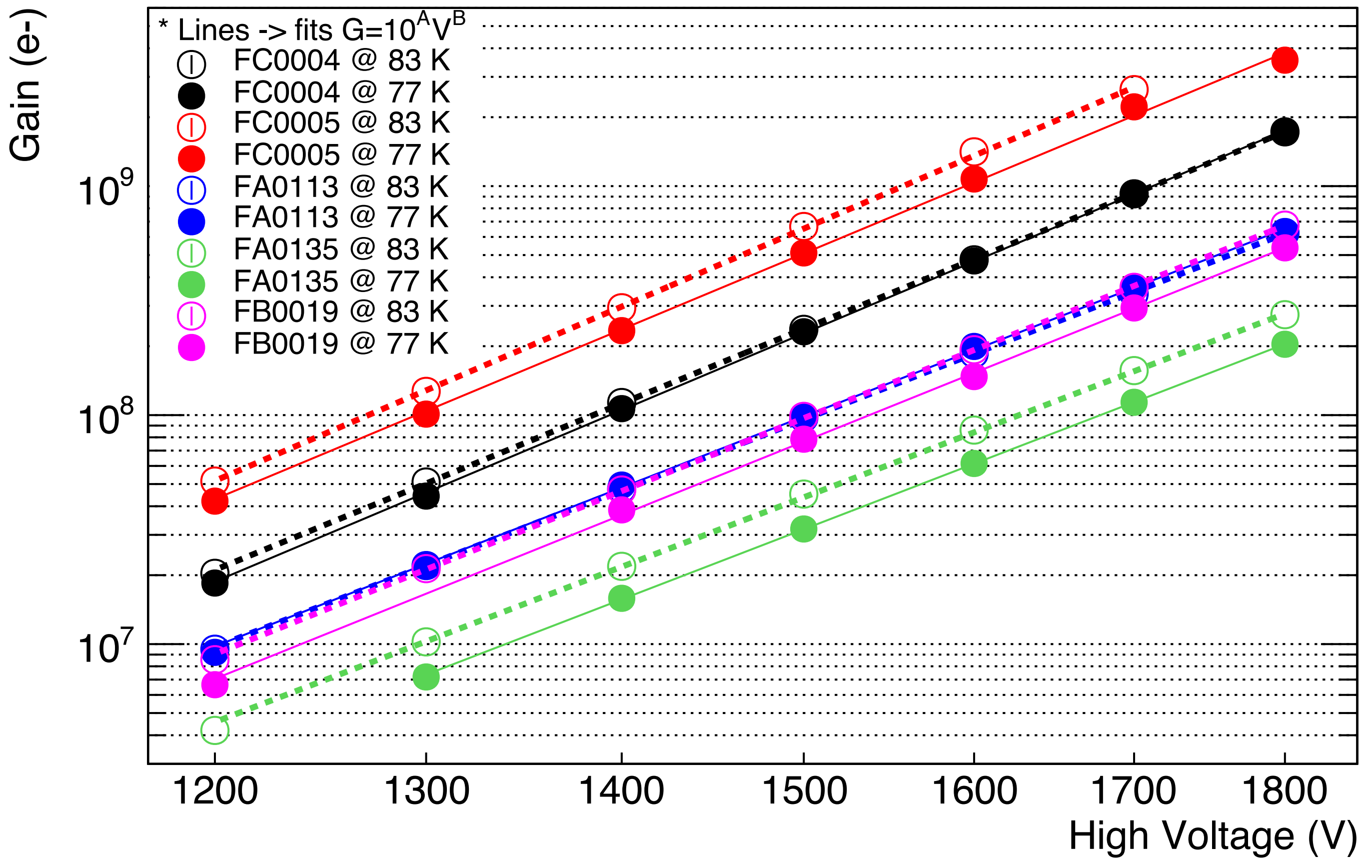


✳ At CT, measurements at high frequency cause that PMT gain falls —> <u>gain recovery can take days</u>

✳ Measurements at CT are done without waiting for gain recovery before changing the frequency!

Gain change due to temperature

- PMTs characterization at CIEMAT has been done using **LN2 at 0 bar (T ~77 K)**
- In the detector, the PMTs will be immersed in LAr (T ~87 K)
- Characterization of 5 PMTs in **LN2 at 1 bar (T ~83 K)** has been done in order to have an idea of the variation with respect to the HV obtained in the characterization (for G=10^7) due to the operation at a higher temperature



The HV variation due to the temperature (77 K vs 83 K) for 10^7 gain is ~2%, on average

***It depends on each PMT**

Interaction with Hamamatsu

- During the characterization process, **seven PMTs** were returned to Japan:

  - PMTs **FA0118 and FA0108** had no signal and very high DC rate, respectively. These two PMTs were replaced by new ones: **FC0004 and FC0005**

  - Five PMTs were inspected and measured by Hamamatsu people: **FA0104, FA0120, FA0112, FA0105 and FA0107**. Their DC rates measured at CIEMAT were very high, but the report from Hamamatsu says that they have normal DC rates. These five PMTs have been characterized again (after being resent to CIEMAT) and they seem to work fine.

Summary and next steps

- ✳ **The characterization of 40 PMTs for ProtoDUNE-DP (36 + 4 spare) is finished:**
  - 40 gain vs. HV curves at RT and CT obtained
  - 40 SPE waveforms at 10^7 gain measured
  - Dark current rates vs. HV at RT and CT measured
- ✳ Additional measurements of linearity (to the amount of light and to the light frequency) have been done for several PMTs
- ✳ A paper for submission to JINST is being prepared
- ✳ PMTs shipment to CERN is expected by April-May 2018 (to be decided)
- ✳ PMTs installation and testing in the detector are expected by Autumn 2018

To-do

- ✳ Complete some light linearity measurements for publication
- ✳ **Update database: introduce all the results of interest for the 40 PMTs**

Paper about PMTs characterization

* A paper about the characterization of the PMTs in cryogenic conditions is being prepared for submission to JINST
* Goal: to present the characterization of the 40 PMTs emphasizing the **original aspects** with respect to other papers

Everyone who wants to participate is welcome!

Most interesting points

* Comparison of different PMT bases (gain, DC rate)
* Study of the time for gain recovery after frequency measurements at CT
* Detailed linearity measurements to the amount of light and to the light frequency: laser vs. LED, different PMT bases, RT vs. CT…

Not included

* TPB coating
* Light calibration system

Cryogenic R5912-20Mod Photomultiplier Tubes Characterization for the ProtoDUNE-DP Experiment

Preliminary!

Contents

1 Introduction [Clara] 2

2 PMT unit [Antonio, Daniel] 2

3 Testing set-up [Enrique, Daniel, Sergio] 2

4 Methodology [Clara] 3
- 4.1 Dark Current [Ana, José] 3
- 4.2 Gain [José] 3
- 4.3 Light linearity [Carmen, Chiara] 3
- 4.4 Light frequency [Sergio, Daniel, Antonio] 3

5 PMT validation measurements [Clara] 3
- 5.1 Dark Current [Ana] 3
- 5.2 Gain [Ana] 4
- 5.3 Light linearity [Carmen, Chiara, Ana] 4
- 5.4 Light frequency [Sergio, Daniel, Antonio] 4
- 5.5 PMT base validation [Daniel, Antonio, Chiara] 5
- 5.6 Overpressure [Ana] 5

6 PMT characterization results [Clara] 5
- 6.1 Dark Current [Ana] 5
- 6.2 Gain [Ana] 5

7 Serviceable results [Clara] 6