ProtoDUNE-DP ($6x6x6\ m^3$)
Light Calibration System
Specifications and Requirements

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LIGHT CALIBRATION SYSTEM DESCRIPTION

In ProtoDUNE-DP, an optical fiber is installed at each PMT in order to provide a configurable amount of light. The calibration light is provided by six blue LEDs of 460 nm using a Kapuschinski circuit as LED driver. Each LED is connected to one fiber that goes to one female optical feedthrough. The six LEDs are placed in a hexagonal geometry. The direct light goes to the fiber (FG105LCA of 105 μm from Thorlabs), and the reflected stray light to the reference sensor, a silicon photomultiplier (SiPM) used as a single reference sensor in the center. Fibers of length 22.5 m (from Thorlabs φ 800 μm, FT800UMT, and stainless-steel jacket) are used inside the cryostat. Each of these fibers is attached to a 1 to 7-fiber bundle (from Thorlabs φ 200 μm, FT200UMT stainless-steel jacket common end, and black jacket at split ends), so that one fiber is finally installed at each PMT. The full system has been validated at CIEMAT, details of these measurements are given in a separate document.

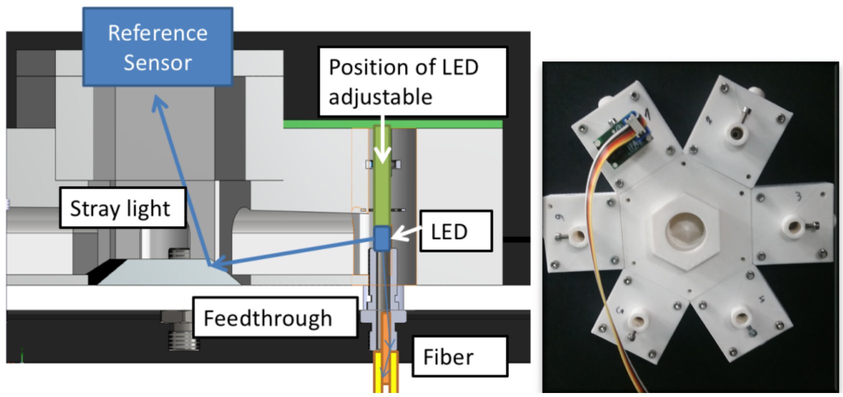

Figure 1. Left: Diagram of the LED and reference sensor system. Right: Picture of the 6 LEDs with the reference sensor placed in the center.

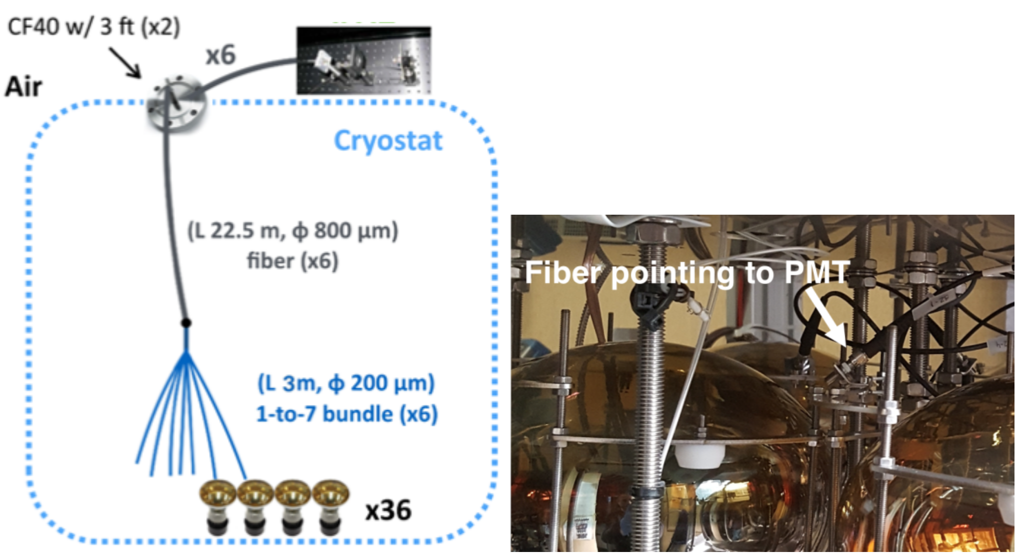

Figure 2. Left: Diagram of the photon calibration system. Right: Picture of a fiber installed.

MEASUREMENTS TO BE CARRIED OUT

The goal of the LCS is to measure the PMT gain (G) and study the PMT stability. In particular, the following measurements will be carried out during the 6x6x6 m^3 operation:

- **Gain stability:** Single photo-electron (SPE) spectrum at the PMT operating high-voltage (HV). The gain is obtained from it. This measurement will be taken every time the PMTs are biased up, and regularly, i.e. every day at the beginning, and every few days if stable operating conditions are reached.
- **G vs. HV:** SPE spectrum at different PMT voltages (1200 – 1900 V, 100 V steps) to obtain the gain calibration curve. This measurement requires more time for the data taking and can be performed approximately once a week.
- **Light response:** the LED voltage can be increased to study the PMT performance for different light levels: from the SPE to several tens of photo-electrons.

In general, the measurements are taken with one LED providing light pulses to 6 PMTs simultaneously at a time, and 6 total measurements have to be taken.

Measurement	Periodicity	# Events/PMT	Size*	Time
Gain stability	Daily	20000	10 MB	~5 min
G vs HV	Weekly	20000 * 8 PMT HV	80 MB	~1 hour
Light response	Weekly	20000 * 3 LED V	30 MB	~15 min

Table 1. Descriptions of the LCS measurements.
**The data size depends on the event size at the front-end output.*

REQUIREMENTS AND INTERFACES WITH OTHER SYSTEMS

For the LCS operation, data taking and data analysis different systems are involved. Figure 3 shows a diagram of the relationships among the systems. In the following the functions and interfaces among them are described.

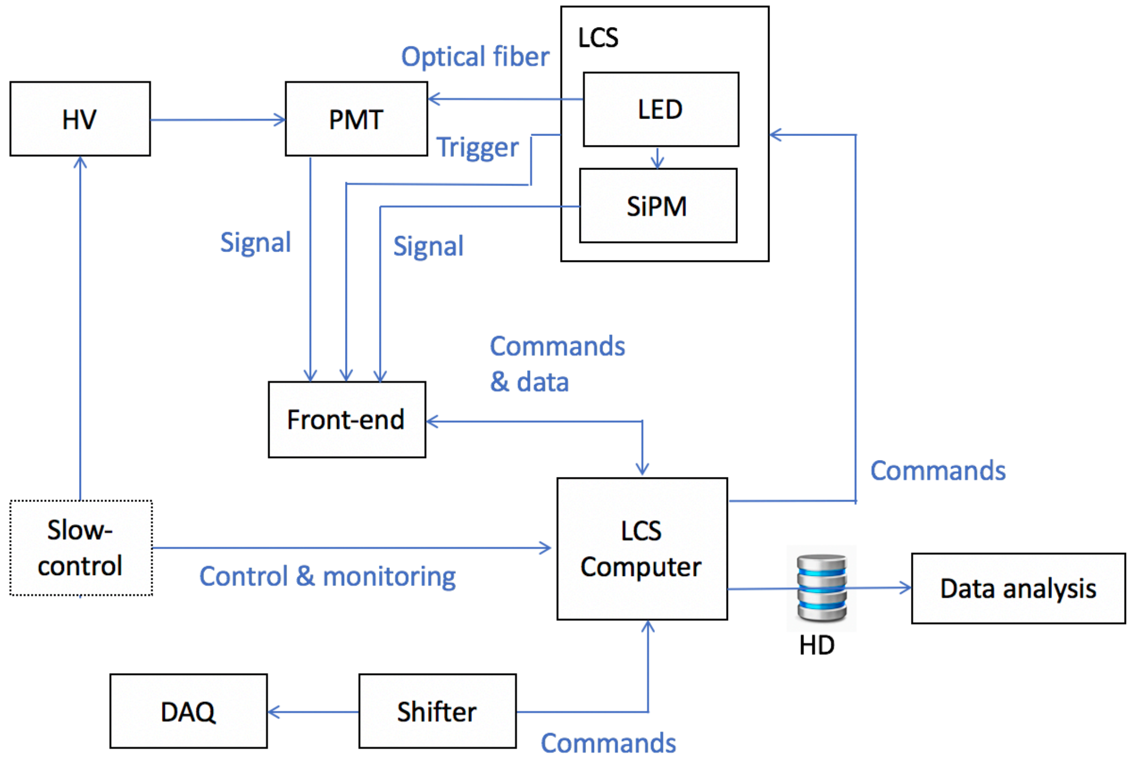

Figure 3. Diagram of the systems involved in PMT calibration.

PMT HV SYSTEM (SLOW-CONTROL) (CERN and slow-control team)

For the G vs. HV measurement, all the PMTs are biased at the same HV (from 1200 V – 1900 V, in 100 V steps). For this, a script to automatically bias all the PMTs at the target HV is needed. After the measurement, the PMT operating voltages are applied again by reading the operating HV from a configuration file.

The gain stability and light response measurements will be carried out at the PMT operating HV. However, if a big gain shift is observed, the PMT operating voltage could be changed by modifying the configuration file.

Interfaces: The HV system needs to be connected to the LCS computer (directly or through the slow-control) to control and monitor the status of the different HV channels.

FRONT-END (Front-end team – IN2P3)

The characteristics of the input signals in LCS mode are the following:

- The LCS will provide a 5 V TTL trigger (3V3 compatible) with rising edge.
- The reference sensor (SiPM) signal will be connected to one of the spare analogue inputs. The dynamic range is 0 to -1 V, as will be inverted to match the dynamic range of the PMT signals.
- The PMT signal will differ among the measurements:
  - G vs. HV: the SPE voltage level will range from mV to few V. The SPE width is ~10 ns. For the right acquisition, the maximum sampling rate must be used.
  - Gain stability: as the PMTs will be operating at the nominal gain, the expected maximum SPE amplitude will be at the mV level.
  - Light response: in this case the voltage level will range from hundreds of mV to few V.
- The time between the trigger and the acquisition start should be programable to ensure the acquisition in the proper time window.

The list of parameters that the front-end needs to considered is the following:

- Number of channels to be acquired: 37 (36 PMTs + SiPM).
- Trigger: External trigger provided by the LCS.
- Sampling rate: 25 ns/sample.

Interfaces: The LCS computer will send to the front-end the commands to start the acquisition in LCS mode. The front-end will send the LCS data with a special header to be identified.

LCS COMPUTER (LCS team – CIEMAT, IFAE)

This computer controls the LCS and acquires the LCS data. It is directly connected to the light readout front-end microTCA rack and to the LCS. It is controlled by the person taking data (shifter)

Data taking: An LCS mode is needed in the front-end. The front-end will enter in this mode under request of the LCS computer by a command. The sequence of actions in the LCS computer is:

- Receive a command from the shifter saying that DAQ is stopped and the calibration can start.
- Change HV settings if needed.
- Set LCS parameters (SiPM voltage, LED voltage and pulse frequency) and start LCS.
- Send to the front-end the configuration command to enter in LCS mode indicating the PMTs to be acquired and type of calibration.
- Start a timer with the time-out value received in the LCS command.
- The PMTs and reference sensor channels are acquired.
- Save LCS data. Include in the file name the character string received in the LCS mode command.
- A visualization tool able to show on-line the SPE spectrum of the PMTs and the reference sensor will help to quickly identify failures of the PMTs, LEDs, and/or reference sensor.

At least, a counter showing the acquired events is required to know that the system is working.
- The run should stop after the number of triggers indicated in the LCS command, manually, or if after the time-out, no trigger is received.
- The LCS computer shows a screen message saying that the calibration has been successfully/unsuccessfully completed.
- Stop LCS.
- Restore HV settings if needed.
- Send a message to the shifter saying that the calibration has finished.

Interfaces:
- HV/Slow-control: send commands to the HV to program the voltage and monitor the values of the setting.
- LCS: send commands with the settings (SiPM voltage, LED voltage and pulse frequency) and receive SiPM monitoring values from the LCS internal ADC if the option to receive them is selected.
- Front-end: the front-end receives an LCS command from the shift control with the contents to acquire.
- Shifter: gives the command that calibration can start and receives the calibration completion message.

SHIFTER OPERATIONS

The shifter needs to stop DAQ and send a command to the LCS computer. Once the calibration has finished the shifter informs the DAQ. This could be done automatically if the DAQ and the LCS computer are connected or manually by the person taking data. The sequence of actions should be as follows:

1- Stop normal DAQ acquisition.
2- Send a command to the LCS computer saying that calibration can start.
3- Inform DAQ that calibration has finished and restart DAQ if needed.

Interfaces:
- LCS computer: gives the beginning command to the LCS computer and receives the calibration completion message.
- DAQ: stops and starts DAQ if needed.

LCS CONTROL (LCS team - IFAE)

The LCS software will allow operating at different LED bias voltages and to loop over all 6 LEDs. The number of pulses and frequency will be selectable. The software will be installed on a BeagleBone board accessed via Ethernet. The signal of the SiPM will be split in two. One of the outputs will be connected to the light readout front-end as mentioned before, and the other output signal will be integrated and digitized by the built-in ADC. For each run, a text file will be generated and optionally sent to the shifter control computer from where it can provide an independent measurement of the light amount.

Interfaces: The shifter control computer sends a set of commands to the LCS. The following commands can be sent:

- Settings commands: SiPM voltage, LED voltage, pulse frequency, number of pulses (or continuous).
- Switch on/off an LED.
- Start and stop trigger signal.

DATA ANALYSIS (LCS team – CIEMAT and IFAE)

No on-line data analysis is foreseen. The PMT gain will be determined with a root macro performing a fit of the SPE spectrum. Fit results will be stored and shifts with respect to previous gain measurements will be quantified.