ProtoDUNE-DP
Photon Detection System

Inés Gil-Botella

LBNC meeting

5 December 2019

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
DUNE

Outline

- The Photon Detection System (PDS)
  - Goal and description of the PDS system in ProtoDUNE-DP
  - Light calibration system
- Data taking conditions
- Summary of data collected in ProtoDUNE-DP
- Analyses ongoing
  - PMT calibration
  - Noise and background levels
  - Purity measurement
  - S1 signal characterization
  - TPB/PEN WLS performance
  - S2 signal identification & characterization
- Improvements for next phase

Photon Detection System

Crucial system to provide event timing, trigger for non-beam events and calorimetric measurements

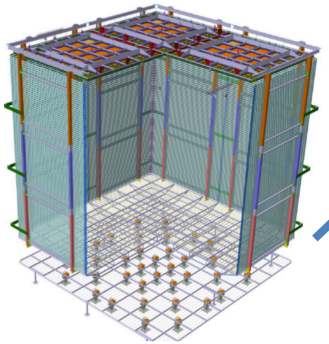
36 8" cryogenic photomultipliers (**PMTs**)

Wavelength-shifter: PEN / TPB coating on PMT

Voltage divider base + single HV-signal cable + splitter (external)

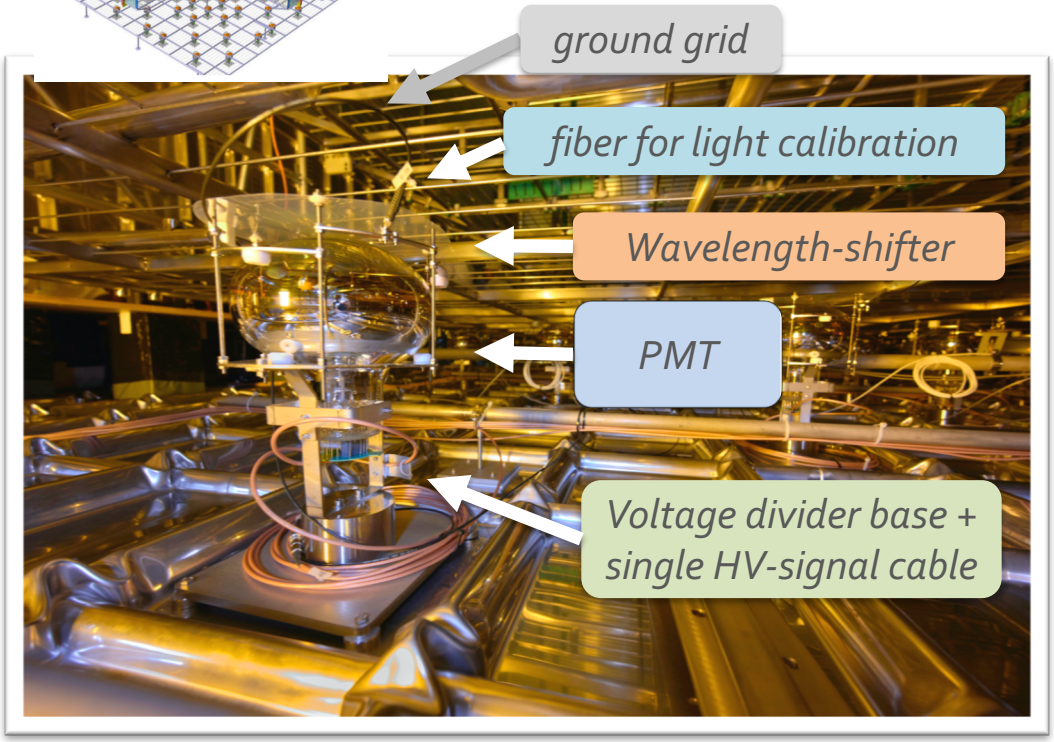
Light calibration system: LED (external) & fiber based

DAQ system (external)



ProtoDUNE-DP

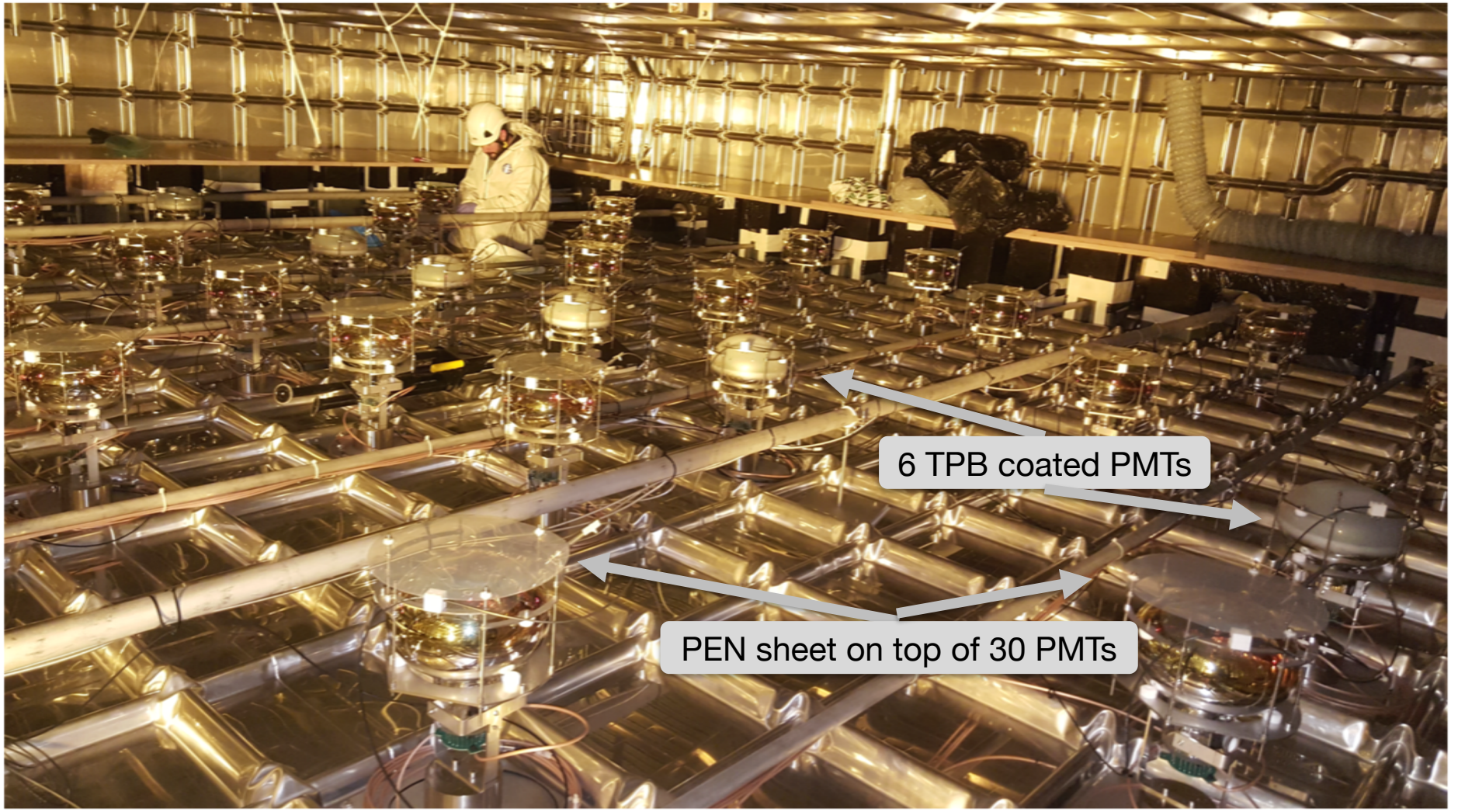
PDS placed below the ground grid



Photomultiplier tubes

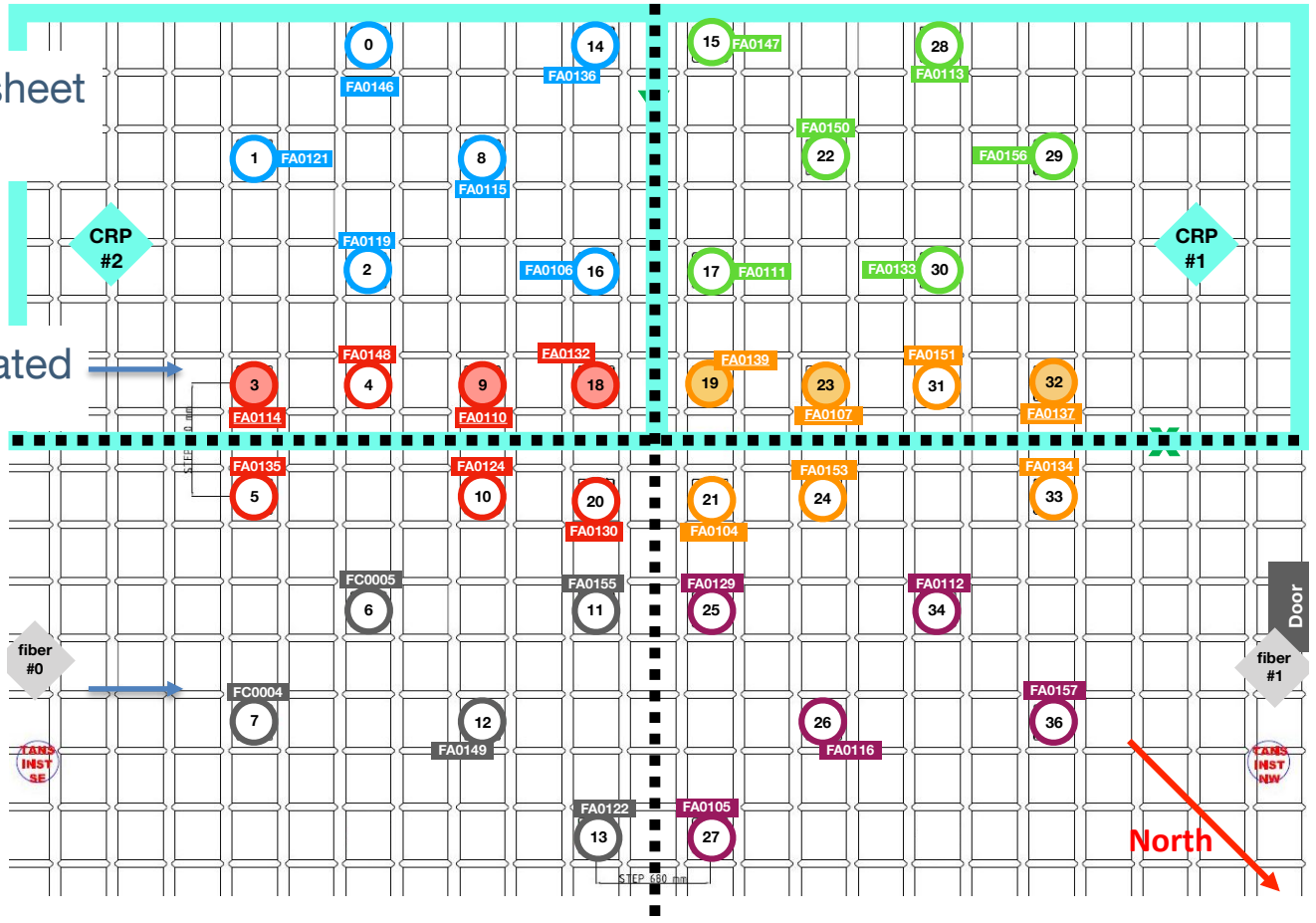
- **36** (+4 spares) 8” cryogenic PMTs (Hamamatsu R5912-20Mod) fully characterized at CIEMAT: gain, dark current, linearity, and light rate at room and cryogenic T *JINST 13 (2018) T10006*
- Installation at CERN in February 2019

Final layout of PMTs



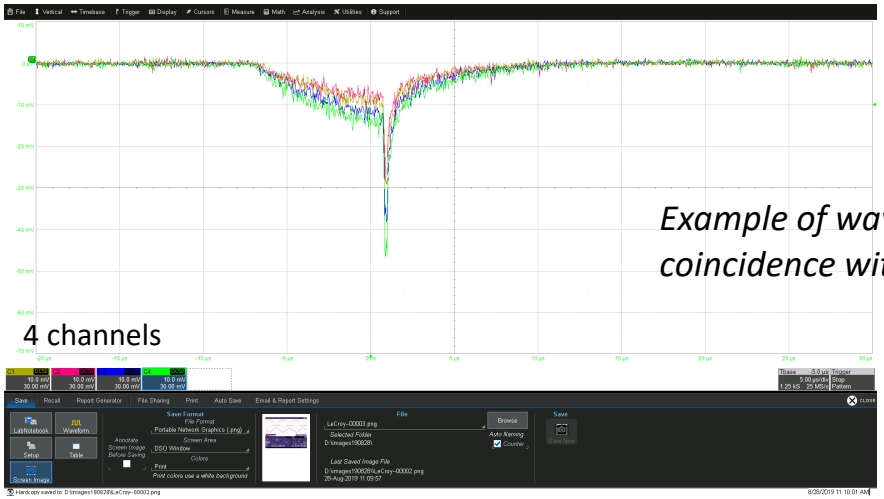
Final layout of PMTs

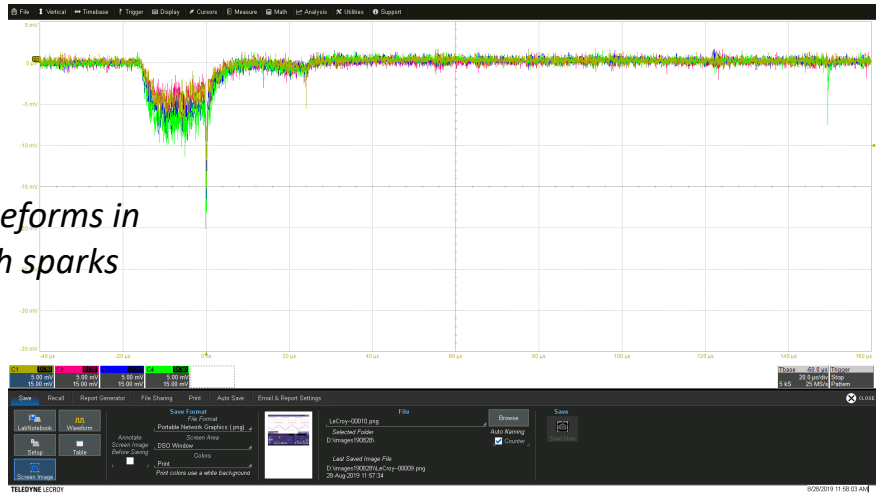
- 30x PEN sheet PMTs
- 6x TPB coated PMTs



Channels 2, 15, 16, 29 connected to the scope

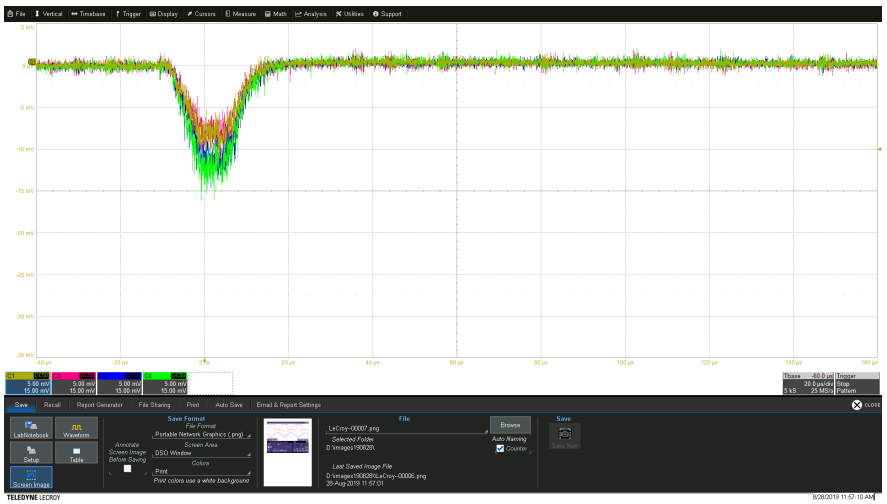
4 PMTs connected to the scope to monitor sparks



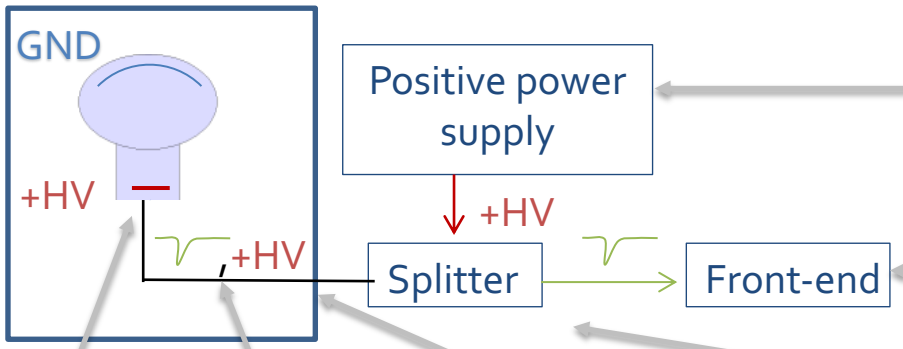


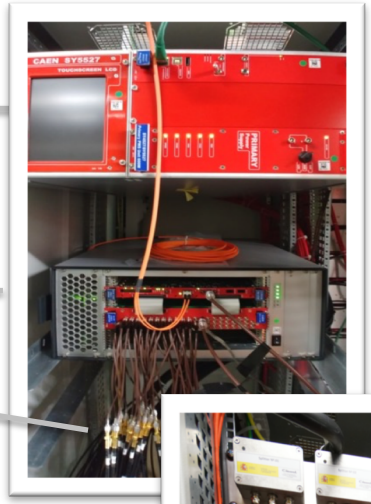
Example of waveforms in coincidence with sparks

4 channels



PMT bases, cables & splitters



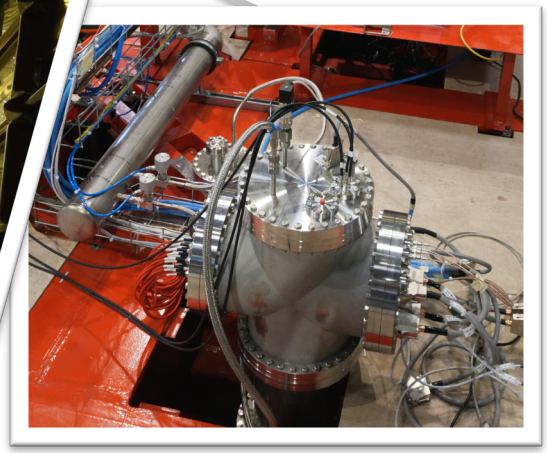


Power supply and ADC

Splitters

PMT base

PDS cables

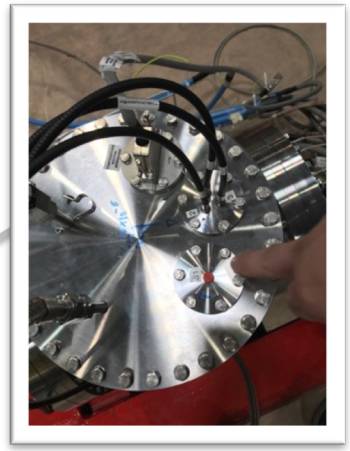


Flange

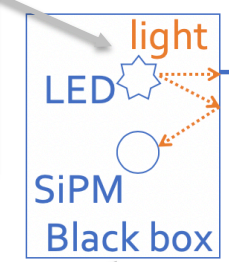
Light calibration system

- LED & fiber based: *JINST 14 (2019) T04001*
- Calibration hardware and software running

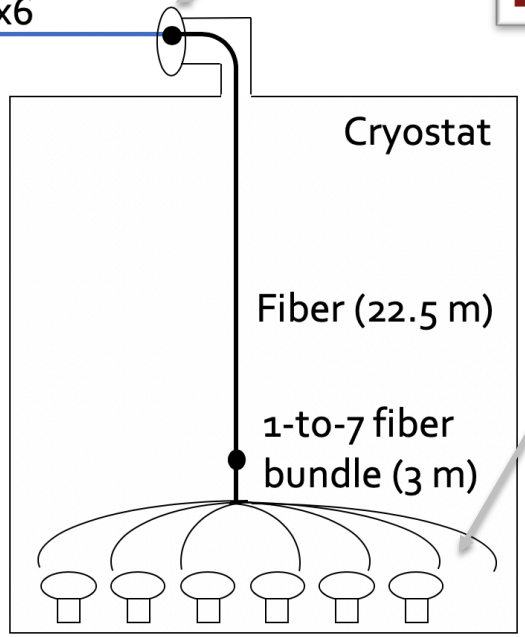
Light source



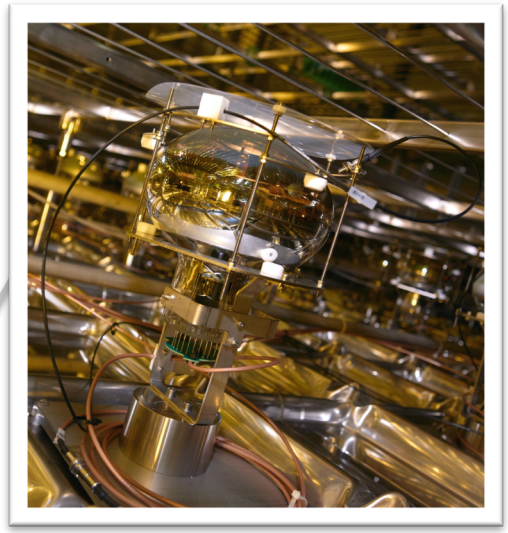
Flange



x6



Fiber pointing at PMT

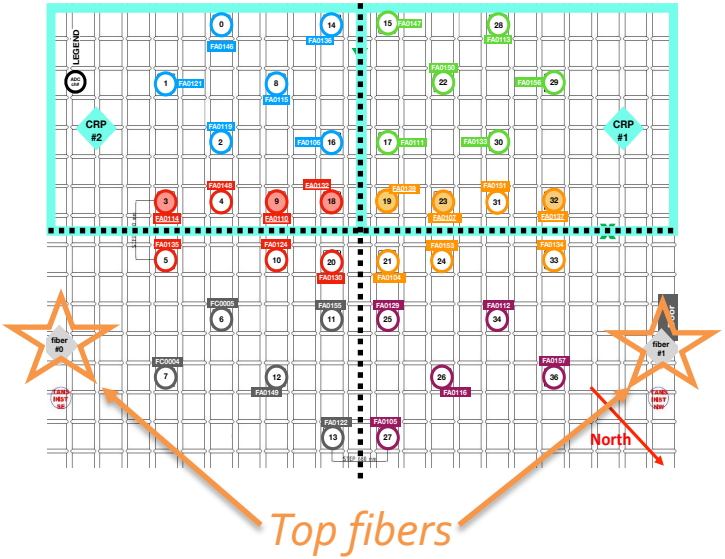


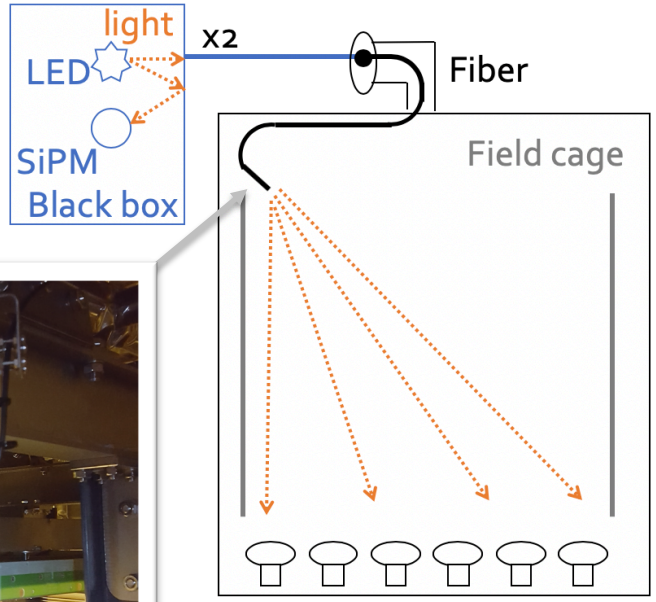
Black box

Alternative light calibration system

Alternative system installed:

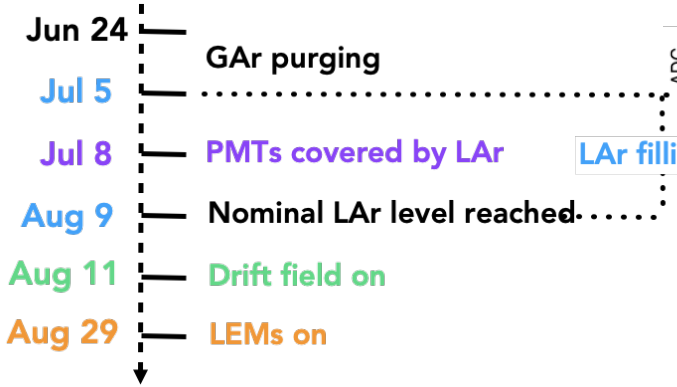
- 2 fibers placed on top of the field cage to calibrate several PMTs with a single fiber
- More convenient for DUNE

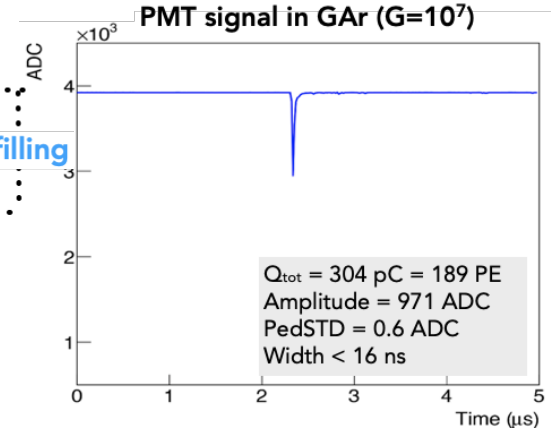


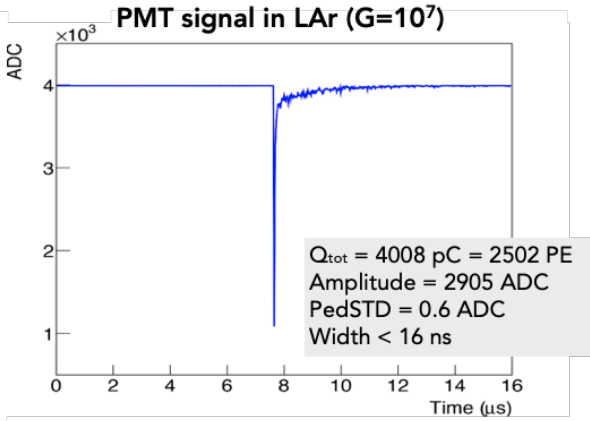


Light data taking conditions

- Scintillation light data acquisition started on June 2019 during GAr purging







- Different triggering data acquired:
  - Light calibration system: (1 kHz) to determine PMT gain
  - Random trigger: (configurable rate) background studies
  - PMT self-trigger: (Hz-kHz) coincidence of several PMTs under different configurations to select tracks
  - Global Trigger (external trigger): light-charge simultaneous analysis
    - Random trigger (10 Hz) in coincidence with charge
    - Temporary scintillator panels trigger (0.45 Hz)

Summary of data collected

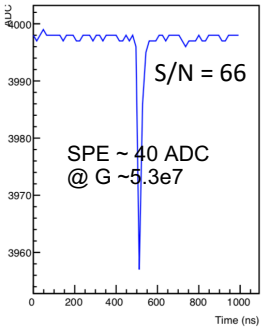
- Data taken almost every day since June 2019
  - PMTs are switch ON-OFF several times per day to allow cameras to survey the liquid surface and purity monitor measurements
- All data is long-term saved in eos:
  - Raw data as taken from MIDAS
  - ROOT data converted
- Midas data is also copied to CASTOR
- > 1000 runs taken
- This represents:
  - 90 hours of data (60M events).
  - 46TB of MIDAS data, 11TB of root files
- ~ Weekly calibrations
- 2 long PMT runs (~15 h):
  - 6/11/19 w/o field
  - 27/11/19 w field (2.9 kV LEMs, 50 kV cathode, 6 kV grid)

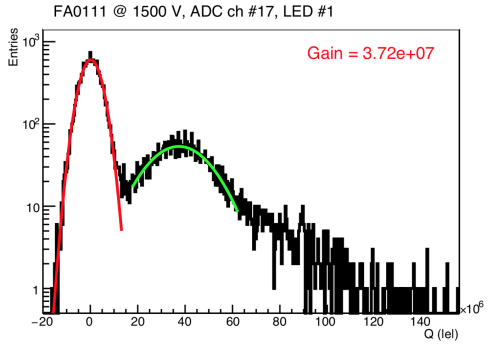
Trigger	# of runs	# of events	time (h)
CRT Panels	3	4.5k	2.9
Random trigger runs	39	7.8M	7.0
Calibration runs	534	10.6M	4.3
PMT trigger runs	462	43.5M	77.1
Total	**1,038**	**61.9M**	**91.3**

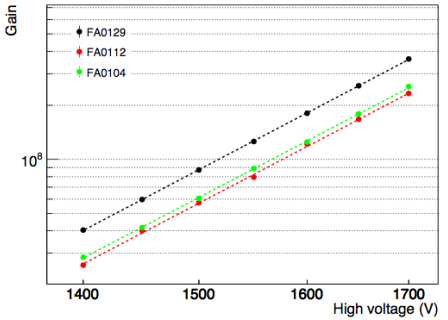
Voltage across LEMs	# of runs	# of events	time (h)
0kV	286	27.9M	23.3
2.7kV	2	56.1k	1.3
2.9kV	42	2.6M	9.8
3.0kV	16	663k	4.6
3.1kV	30	993k	5.1
3.2kV	40	1.1M	0.7
3.3kV	73	1.8M	0.5
Tests	549	26.9M	45.9
Total	**1,038**	**61.9M**	**91.3**

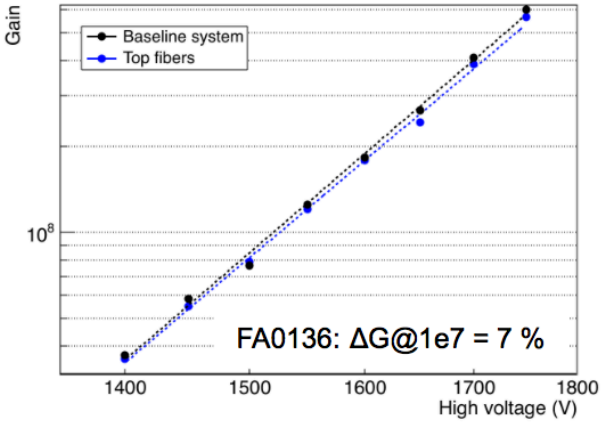
Data analysis: PMT calibration

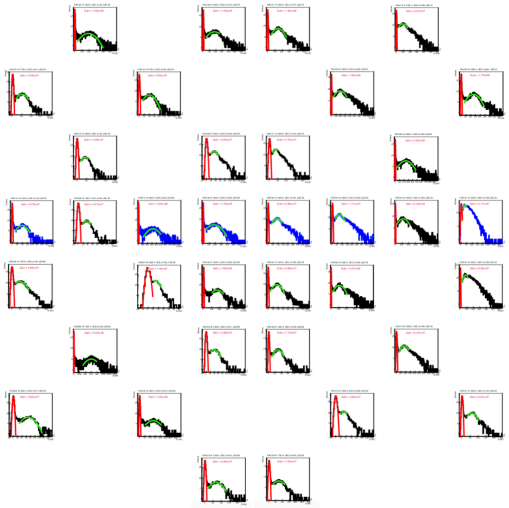
- Using the LED-based dedicated calibration system:
  - SPE integration
  - Fit SPE spectrum (2 gaussians)
  - Gain vs HV curve por each PMT
- PMTs are calibrated regularly and HVs are tuned if needed to keep the gain constant
- The **alternative system** has been validated:
  - 36 PMTs can be calibrated using top fibers (with 2 LED voltage levels)
  - Measured gain variation of ~7% (on average) wrt the baseline system











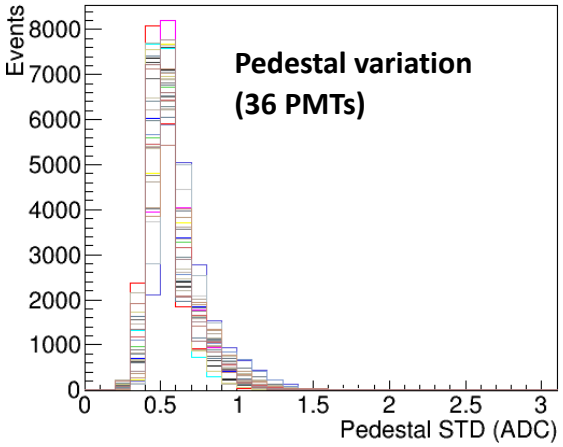
PMTs calibration with alternative system

Data analysis: noise level

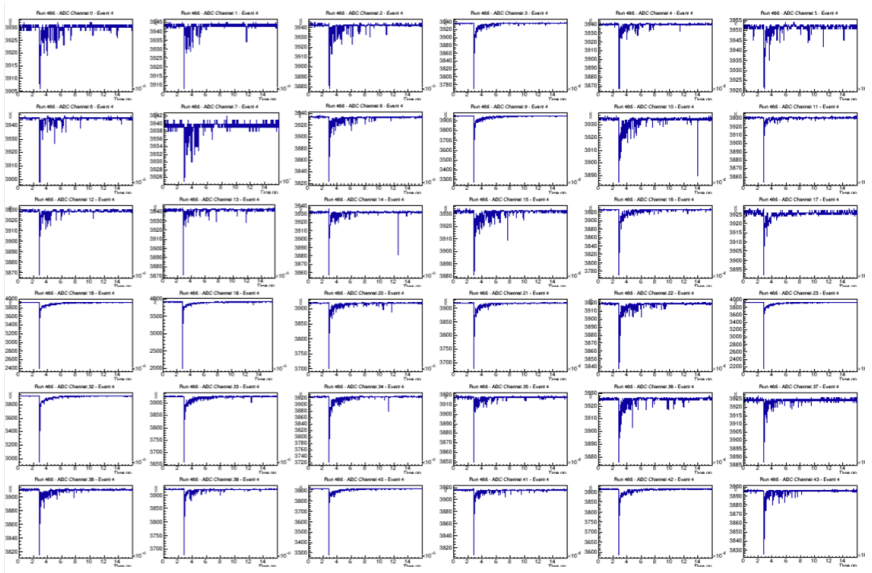
ongoing

- 36 PMTs are operative
- Very low noise level:

  RMS = 0.6 ± 0.1 ADC



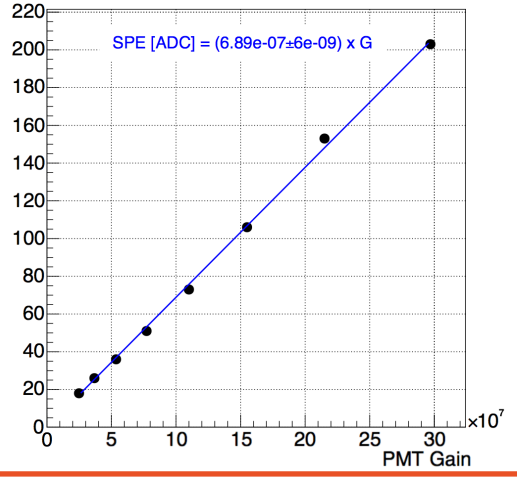
Coincident LAr scintillation light detected in 36 PMTs



< 16 ns time accuracy among channels

SPE amplitude (ADC) - FA0156

- SPE amplitude extracted from data in LAr vs PMT gain (S/N > 11 for SPE at G=1e7)
- Studying the SPE background level for different detector conditions

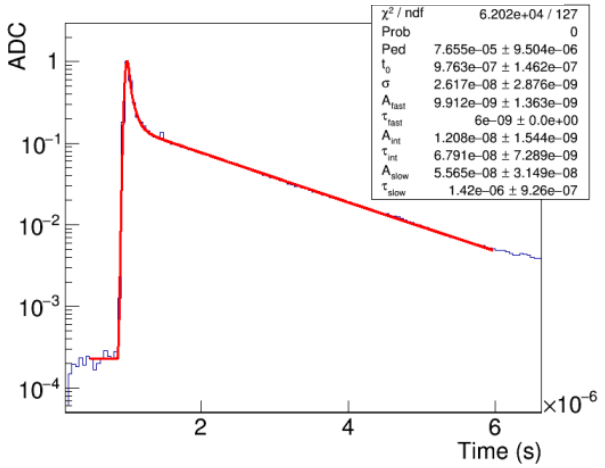


Data analysis: purity

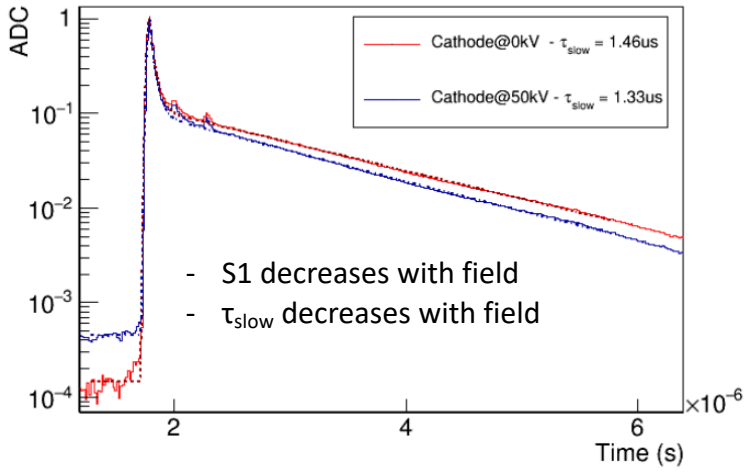
ongoing

- Cosmic muons produce scintillation light on LAr
- Scintillation profile can be obtained averaging waveforms
- No drift field is applied (full recombination of electrons)
- Fit: convolution of 1 gaussian with 3 exponentials
- **τ_{slow} component is an indicator of LAr purity**

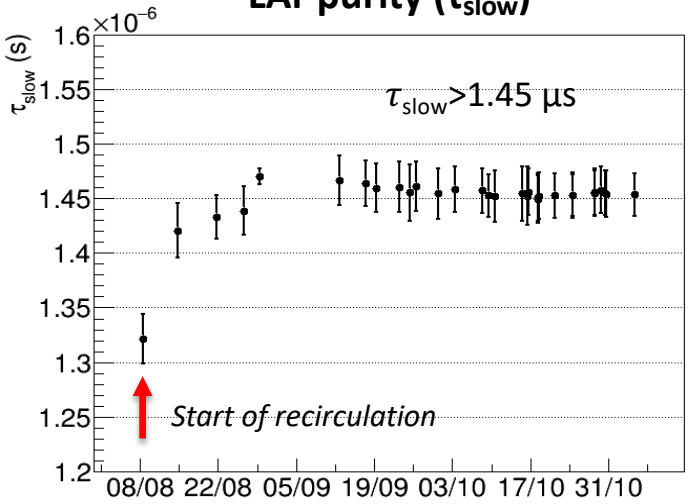
Scintillation light profile



Effect of drift field



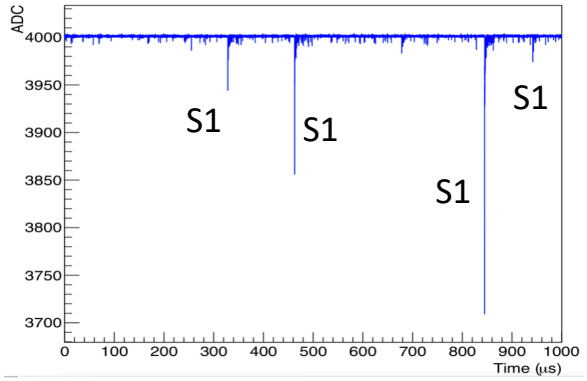
LAr purity (τ_{slow})



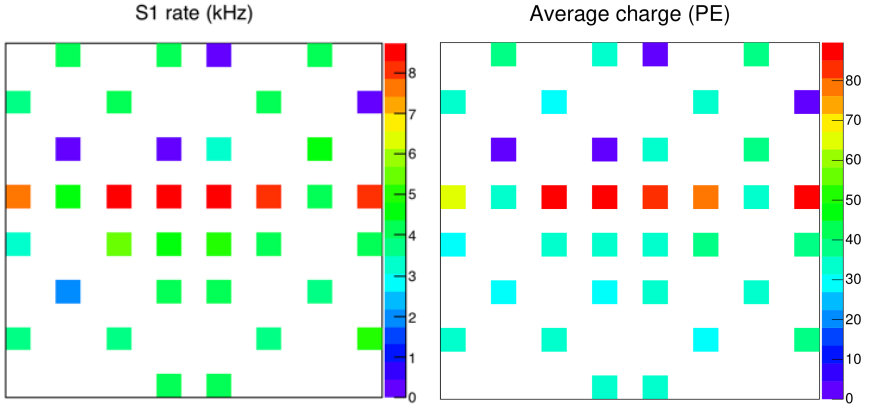
Data analysis: S1 signal

ongoing

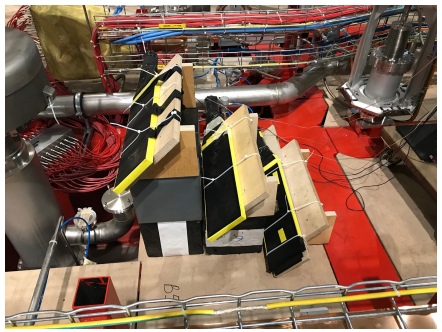
- **S1 identification**:
  - Signal amplitude > 20 ADC (G 1e7)
  - No S1 considered during tau slow
  - Integral: 96 ns around max (S1 fast)

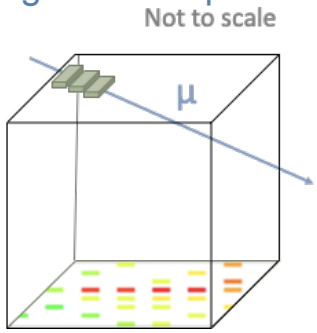


- **S1 rate** (muon rate) preliminary:
  - Random trigger, PMTs at G 1e7, no fields
  - TPB PMTs: 8.3 ± 0.4 kHz
  - PEN PMTs: 4.1 ± 0.7 kHz

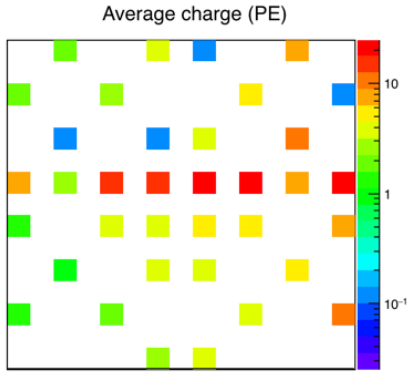


- Triggering with **external temporary scintillator panels**
  - All PMTs detect light following a certain pattern



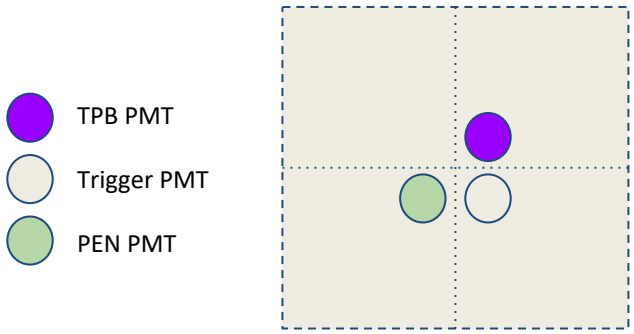


G 1e7, 1473 events, 0.45 Hz



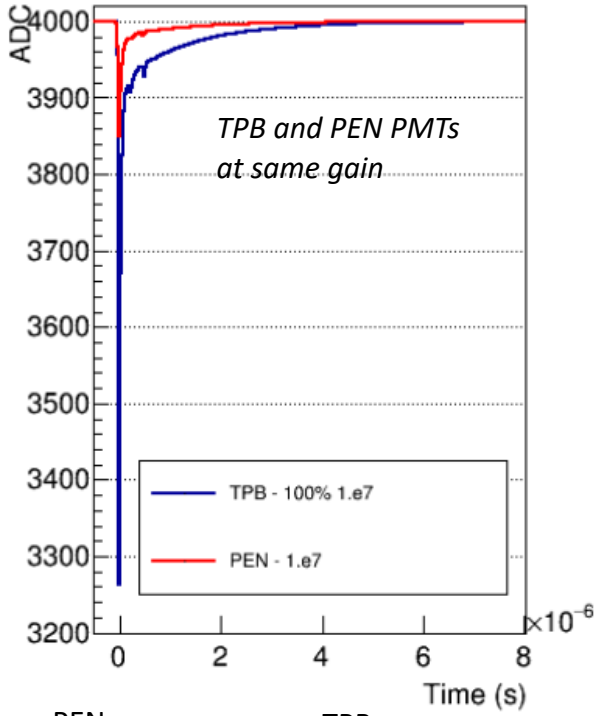
Data analysis: TPB/PEN WLS Performance

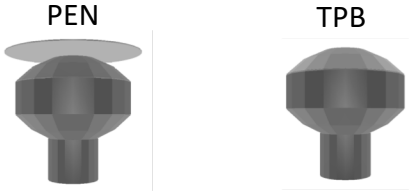
ongoing



- Comparing the S1 amplitude of a PEN & TPB PMTs symmetrically placed in the detector and wrt trigger PMT
- The **average S1 amplitude** ratio:

  PEN/TPB = ~10-20%
- Considering the geometrical differences, the PEN conversion efficiency wrt TPB would be **~20-30%**
- A more detailed analysis on going: taking into account PMT non linearities



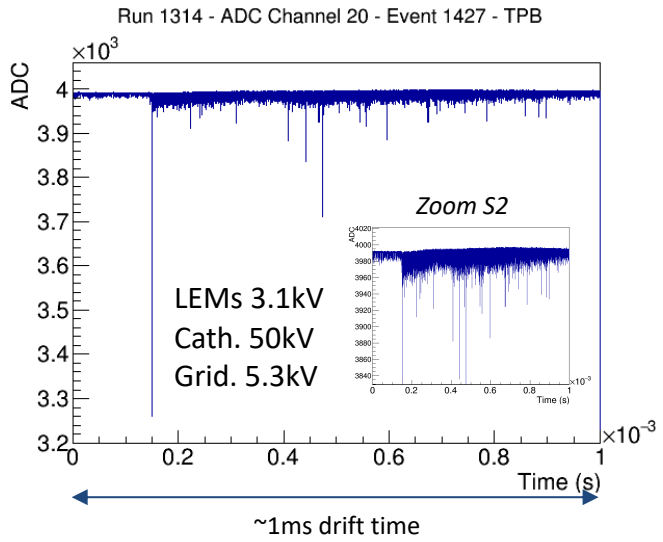


The TPB-coated PMT photocathode receives ~35% more photons due to the geometrical differences of the two systems

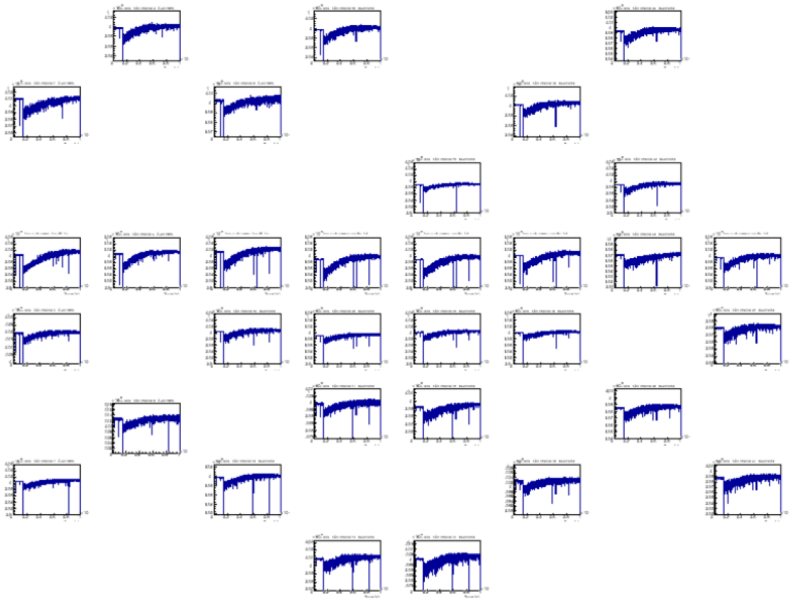
Data analysis: S2 signal

ongoing

- We are able to detect electroluminescence signals in all PMTs
- S2 has different time profile depending on track geometry:
  - S2 right after S1 for tracks crossing the liquid-gas interface
  - S2-S1 distance = electron drift distance
  - Long S2 for tracks crossing the drift length
  - Short S2 for horizontal tracks



Electroluminescence light signals (S2) seen by all 36 PMTs (**6 m away** from PMTs)

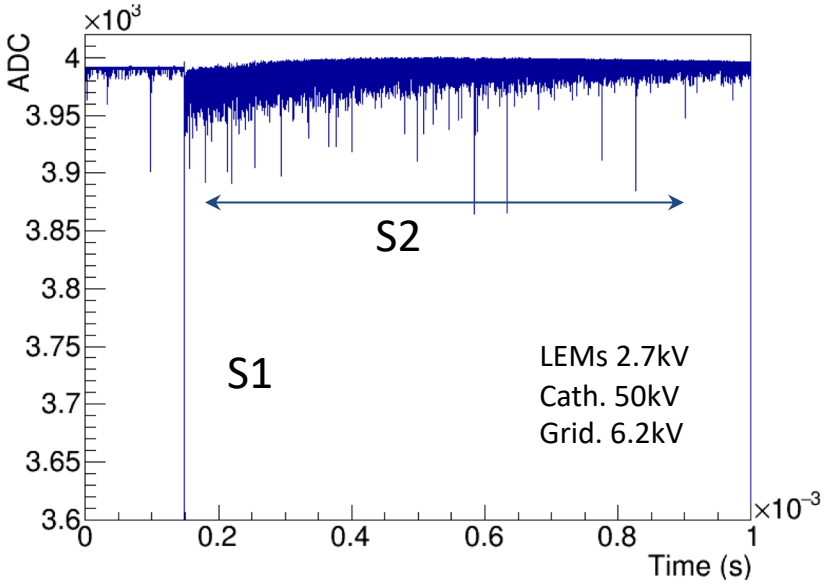


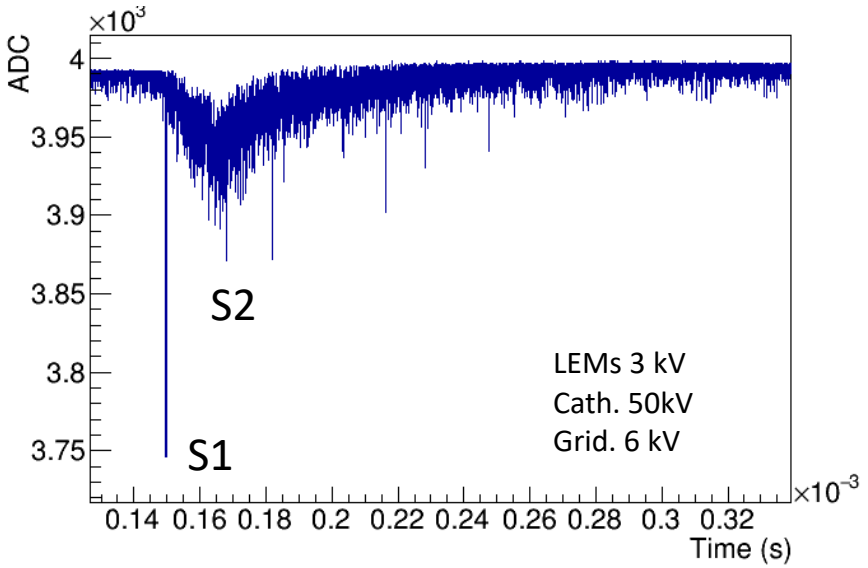
**Not at the same scale: Larger zoom in PEN PMTs to appreciate S2*

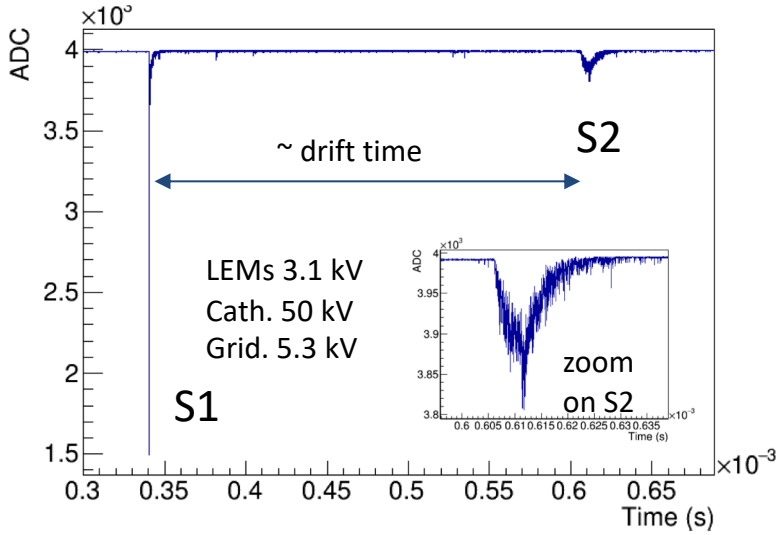
4 PMTs connected to the scope for monitoring sparks in grids-LEMs

LEMs 2.7kV
Cath. 50kV
Grid. 6.2kV

S2 signal analysis ongoing







Improvements for next phase

- Operate the system in stable conditions with long runs (right now we are switching PMT HV ON-OFF several times per day)
- Acquire more data in coincidence with charge readout (development of a combined analysis)
- Data with new external muon panels

- Data with 6m drift (measurement of the electron lifetime, S1-S2 signal correlation, …)
- Test TPB reflective foils to improve the light detector response uniformity
- TPB stability tests
- Reduce signal reflections/overshoots