PMTs in ProtoDUNE-VD

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Ciemat
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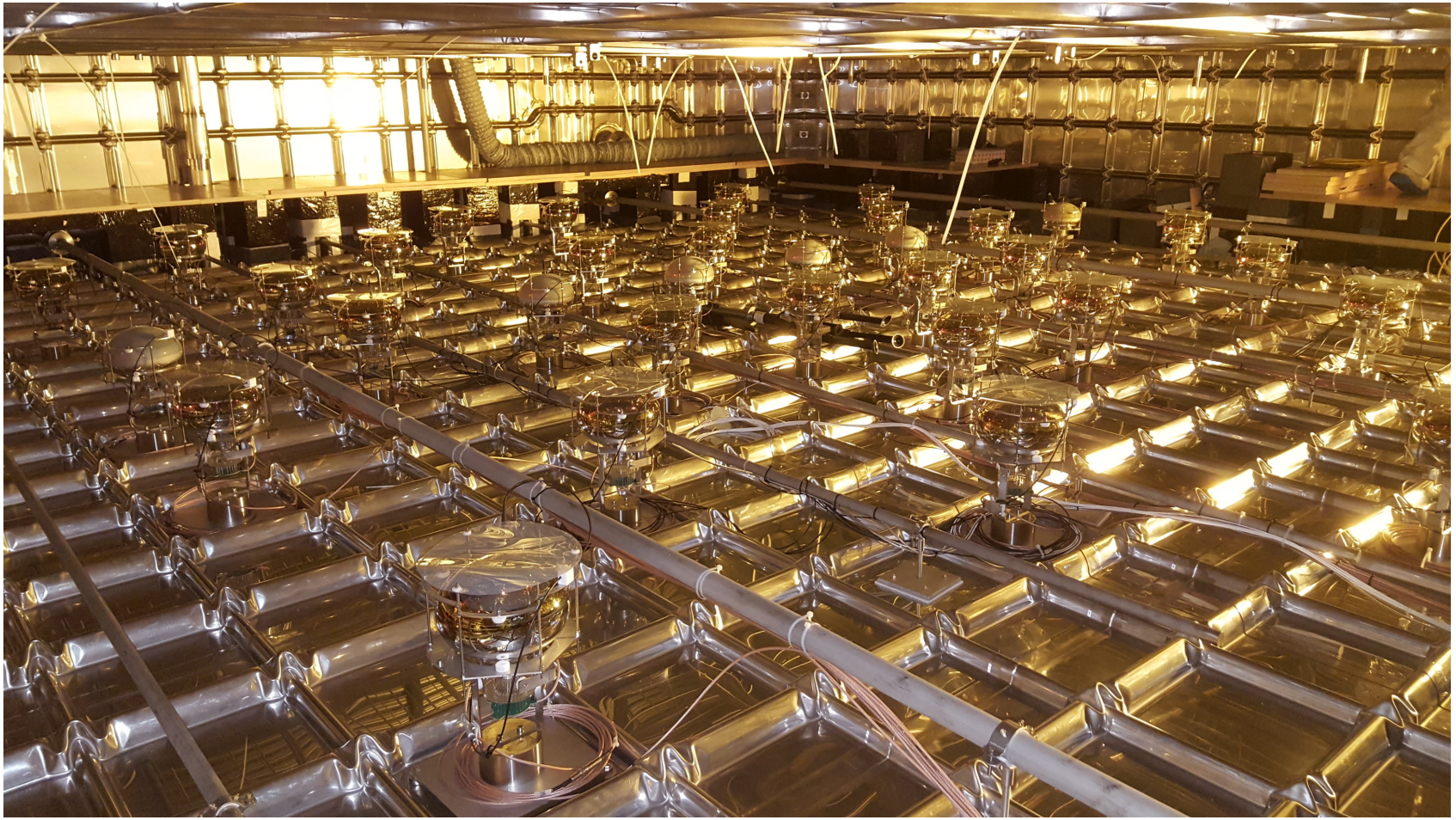
DUNE

Proposal

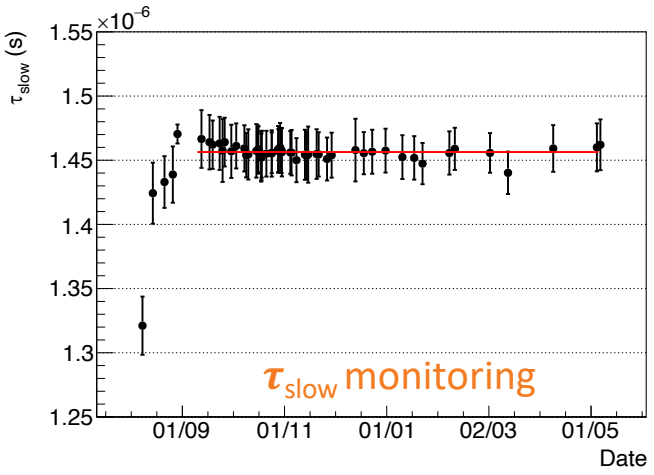
Installing 24 PMTs from ProtoDUNE-DP in ProtoDUNE-VD, outside the field cage.

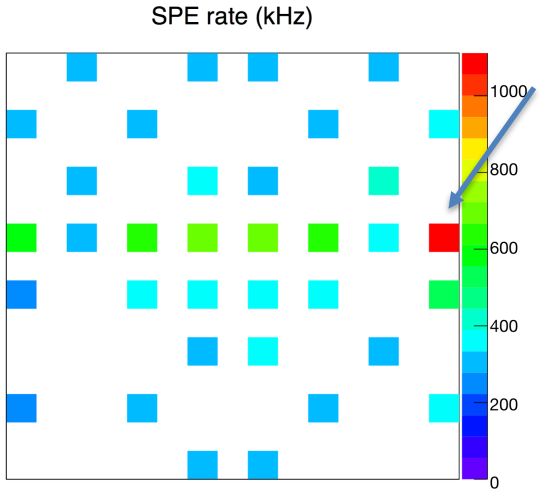


Physics goals

1. Cross-check of photon detection efficiency X-ARAPUCA measurement using PMT efficiency as reference.
2. Study of scintillation light production, propagation and absorption in LAr with Xe doping.
3. Monitoring purposes:
   - τ_{slow} to monitor liquid argon purity (1.45 ± 0.2 µs, monitored regularly in ProtoDUNE-DP indicating LAr purity at ppb level).
   - Identify HV discharges.

Scintillation light detection in the 6-m drift-length ProtoDUNE Dual Phase liquid argon TPC, EPJC 82 (2022) 618





PMT below HV extender identified issue at 60 kV (29/7/20)

ProtoDUNE-DP PMTs

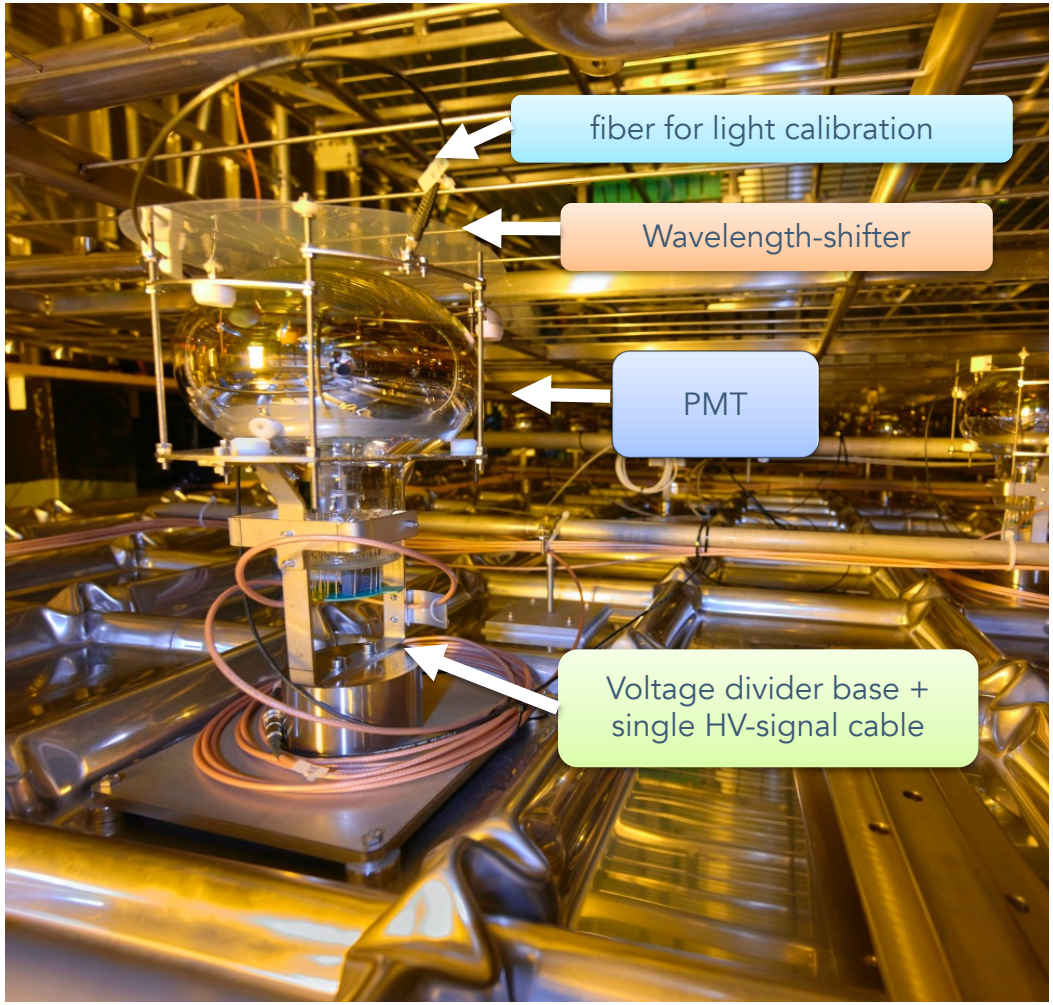
36 8" cryogenic photomultipliers (**PMTs**)
JINST 13 (2018) T10006
JINST 15 (2020) P09023

Wavelength-shifter:
PEN / TPB coating on PMT

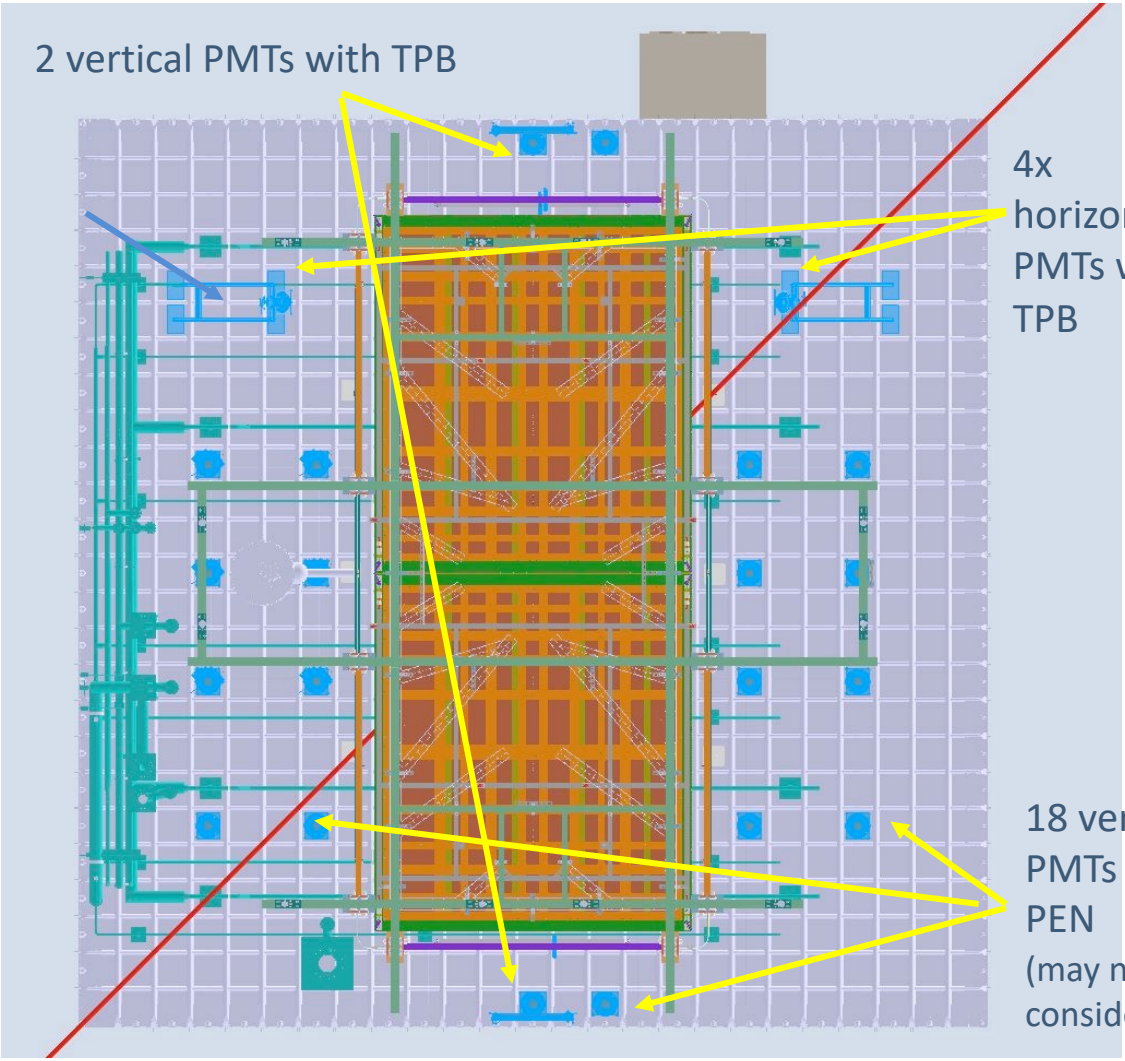
Voltage divider base + single HV-signal cable + splitter (external)

Light calibration system:
LED (external) & fiber based
JINST 14 (2019) T04001

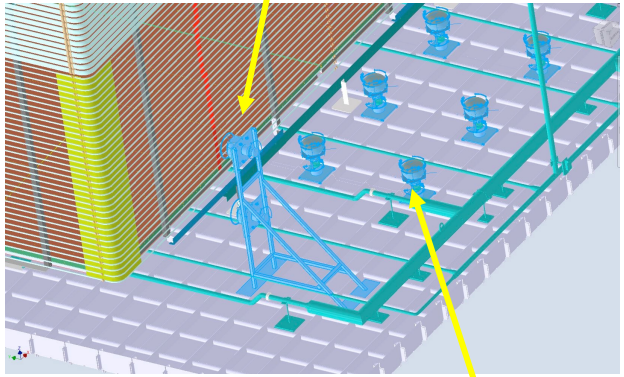
DAQ system (external)
IEEE Trans Nucl. Scie. 68 (2021) 2334



Proposed Layout



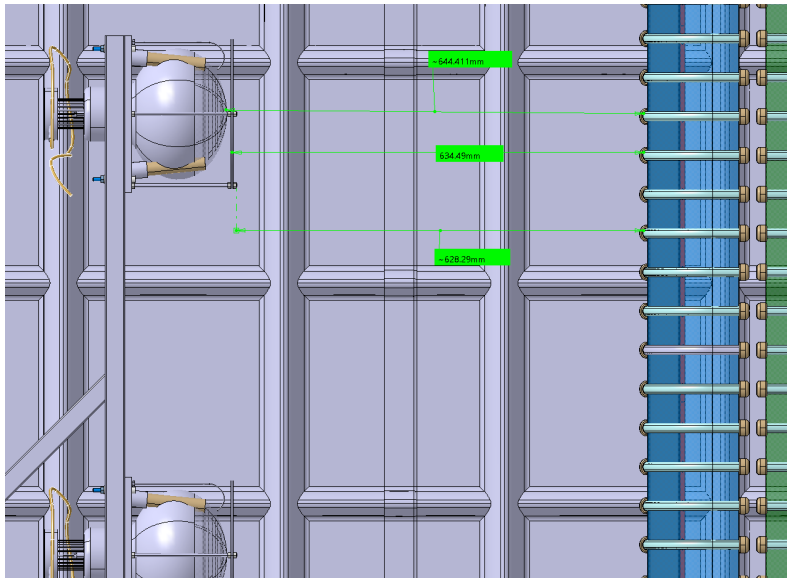
Measurement of photon detection efficiency with horizontal PMTs looking towards the field cage

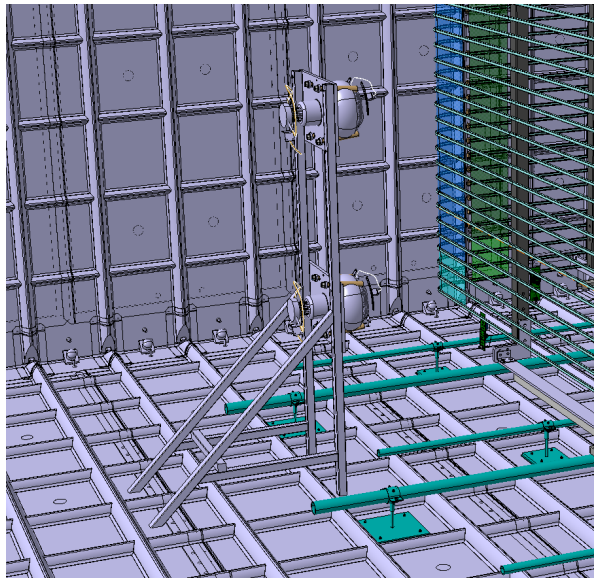


Study of light propagation in 6 m with vertical PMTs

Horizontal PMTs

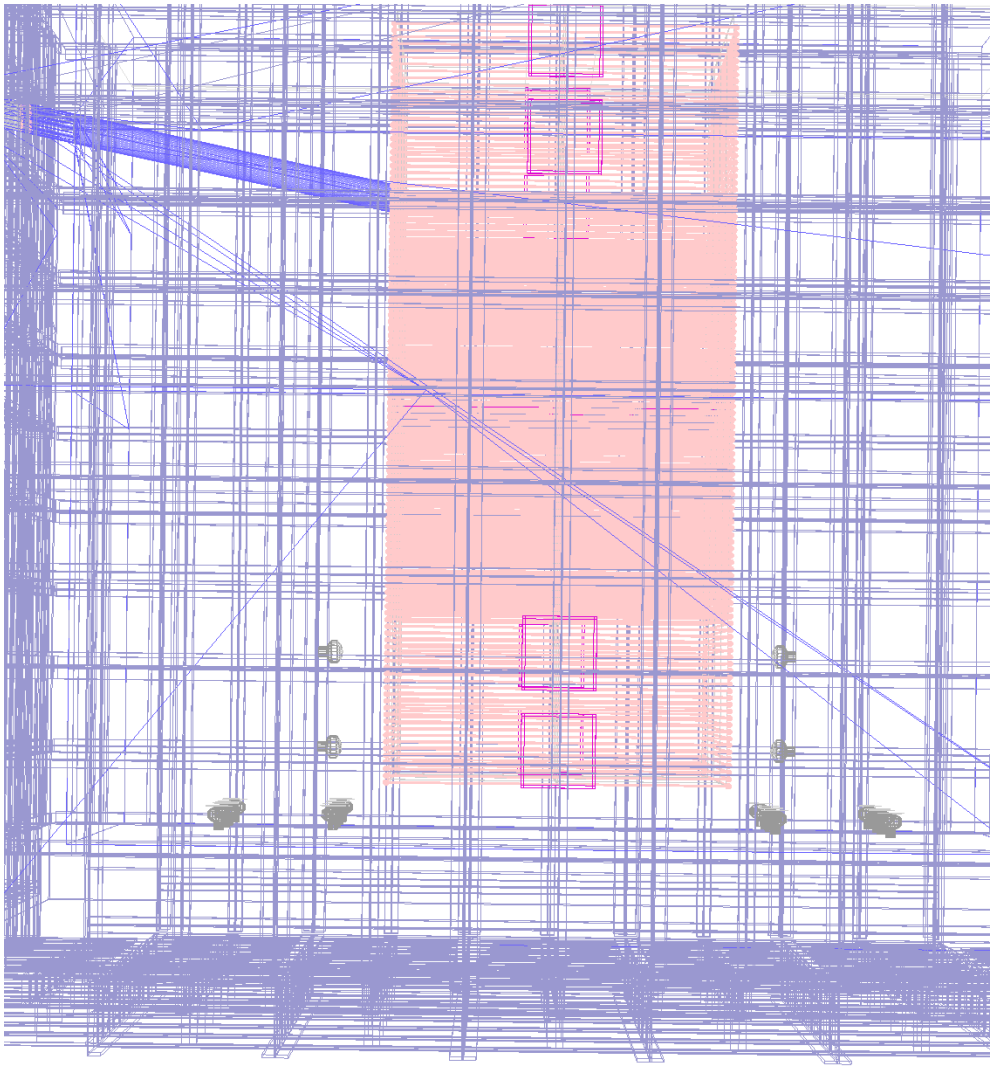
- PMTs looking towards the field cage at the same distance than the X-ARAPUCAs and at the same height. This simplifies the photon detection efficiency measurement.
- TPB coated PMTs as they have better efficiency.
- PMT support designed reusing ICARUS structure. Material available at CERN. (F. Pietropaolo, B. Lacarelle).
- 75% transparency ground grid available at CERN: Gantois - Toile Tissée - VIDE2FIL0.315gantois.com





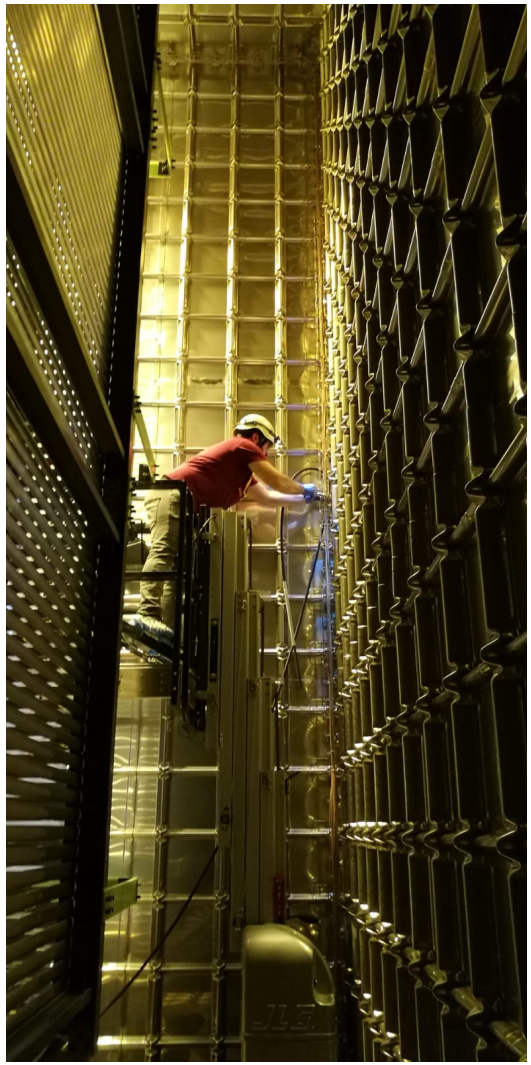
PMT simulation

- PMT geometry implemented in ProtoDUNE-VD simulation (P. Barham).
- Full light simulation for PMTs in process taking into account updated reflectivity values.
- ProtoDUNE-VD geometry being completed: missing realistic field cage.
- Will create visibility maps to validate light arriving to horizontal PMTs is comparable to light arriving to wall X-ARAPUCAS to carry out a relative photon detection efficiency measurement.
- Will use muon tracks as beam does not cross bottom volume.



PMT Installation

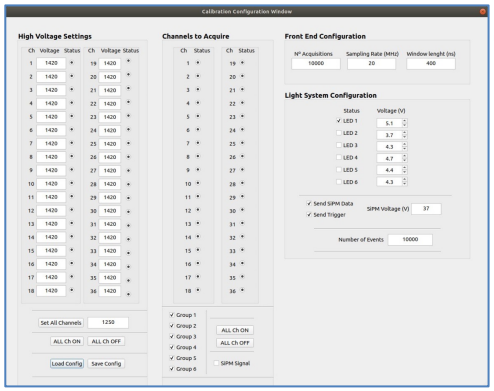
- Long cables and flanges are still installed in ProtoDUNE-VD.
- Only need to place PMTs after other subsystems are installed: introduce them before closing TCO and final placing can be done through manhole.
- Calibration light fibers are also installed, need to install the fiber bundles with the PMTs.



PMT DAQ

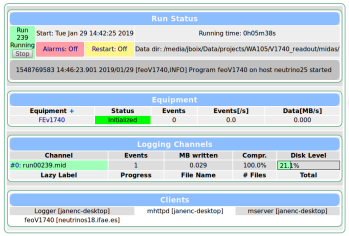
- PMT integration in DAPHNE under testing at CIEMAT:
  - Sampling rate 16 ns.
  - External trigger (cosmic-ray taggers, TPC), self-trigger in coincidence (to be programmed).
  - Sync with TPC same as X-ARAPUCAs.
- Interfaces of power supply with other systems (purity monitors, cameras, etc) to be determined.
- As a backup solution there is a stand-alone PMT DAQ available at NP02: Based on ADC CAEN V1740 and controlled by a PC running MIDAS software and a custom software developed at CIEMAT to integrate the control of the power supplies, the calibration light source and the ADC (throw MIDAS). The light readout front-end was connected to the White Rabbit network for synch with the global DAQ by means of a PCI WR End-node (SPEC card) plugged into the LRO DAQ PC.

CIEMAT acquisition control software



Calibration box

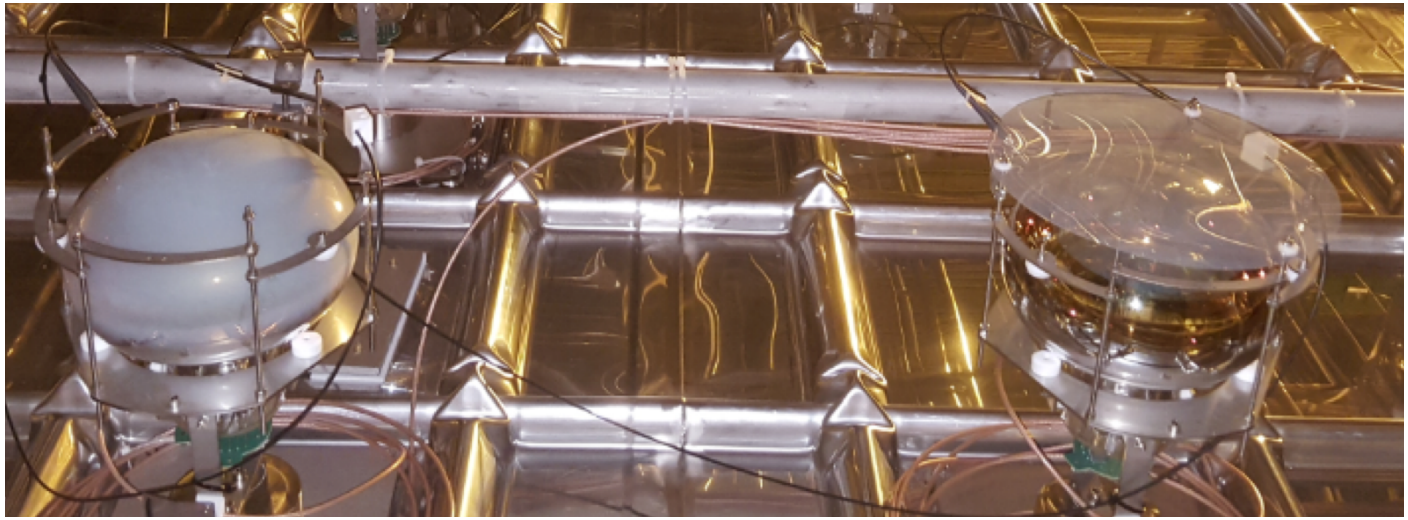
HV Power supply

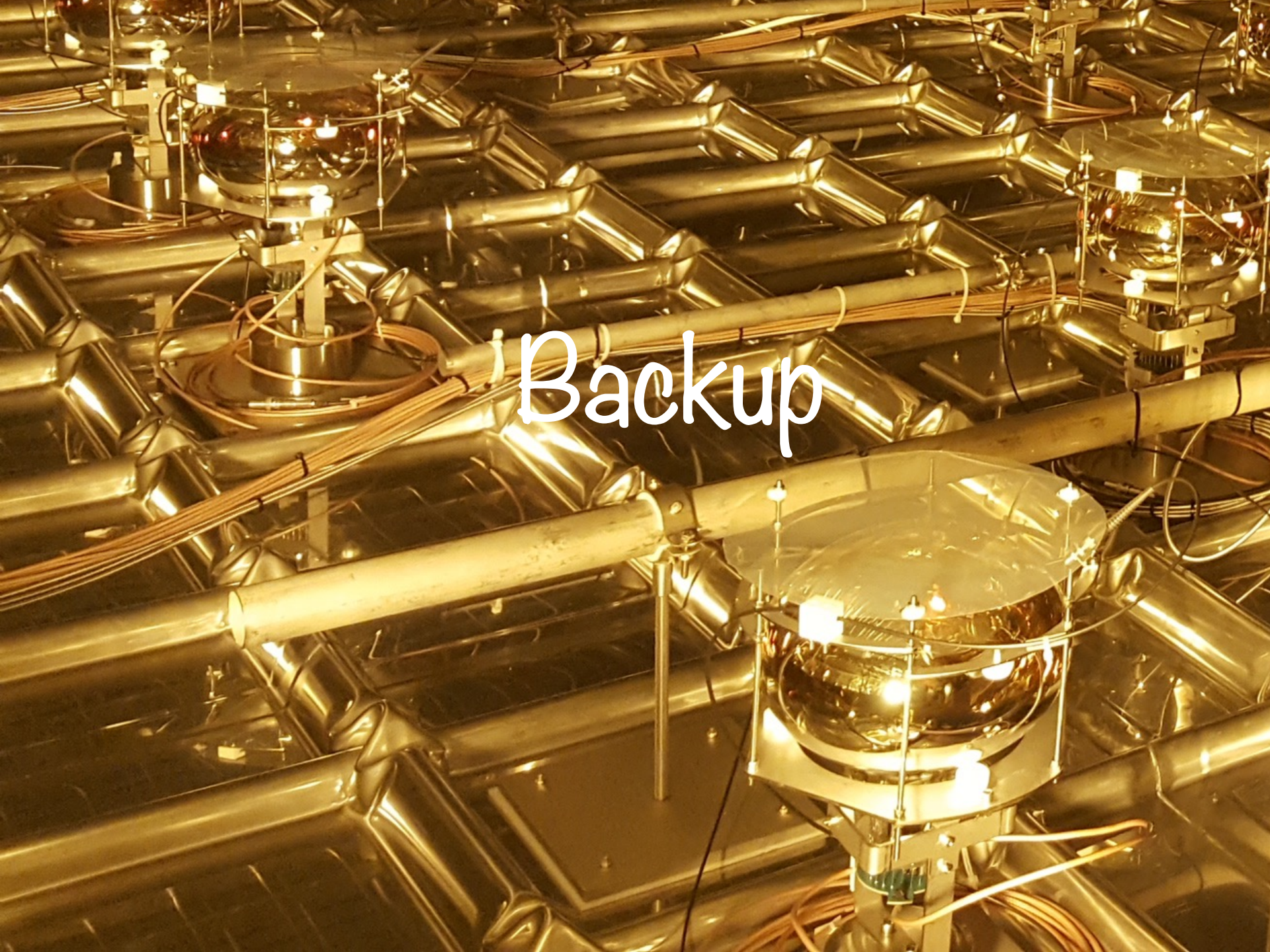


ADC CAEN v1740

Summary

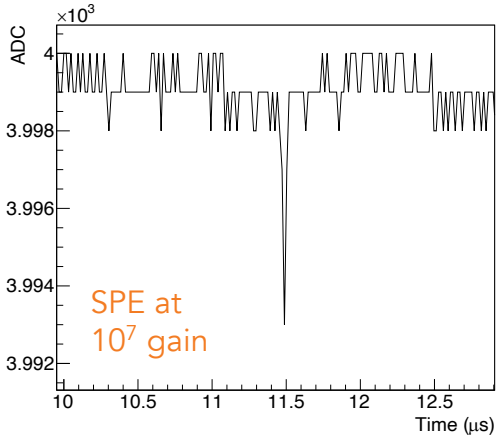
- Proposal for installing 24 PMTs from ProtoDUNE-DP in ProtoDUNE-VD
- Physics goals: photon detection efficiency measuremen, study of LAr scintillation light with Xe doping and monitoring.
- Successful PMT operation in ProtoDUNE-DP: stable and understood performance
- On time for installation and data taking: everything available at Neutrino Platform, light calibration system ready, DAPHNE DAQ, PMTs implemented in simulation.

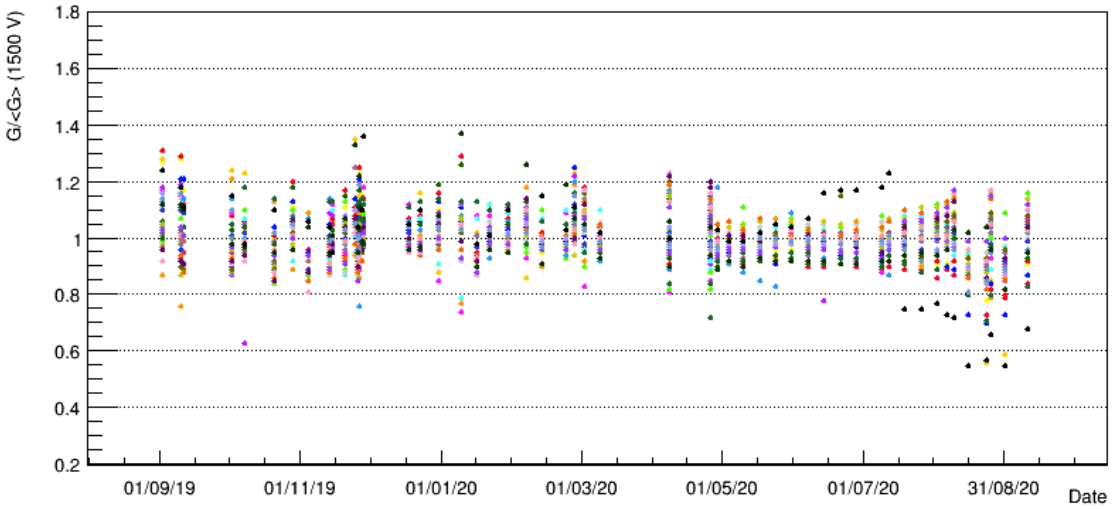



Backup

ProtoDUNE-DP PMT performance

- Time accuracy among the PMTs for the same event better than 16 ns measured.
- Remarkable low noise in baseline (0.6 ± 0.1 ADC).
- Single photo-electron characterization (amplitude, width) as a function of gain. S/N > 11 at 10^7 gain.
- PMTs calibrated weekly to determine the PMT gain and measure light collected in PE.



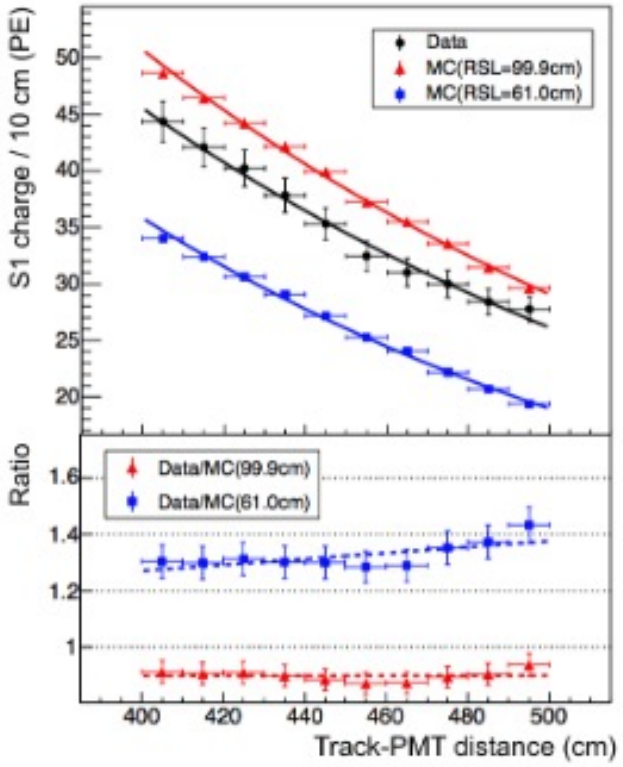


PMT gain stable despite PMTs are switched on daily. (9% gain STD at 1500 V, average 36 PMTs)

ProtoDUNE-DP PMT results

Light propagation in LAr

- ProtoDUNE-DP, the longest drift-distance LAr TPC ever operated → unprecedented study of the light propagation.
- Evaluation of the simulated Rayleigh scattering length.
  - Better agreement between data and the 99.9-cm MC sample than with the 61.0-cm value.
  - Light will undergo Rayleigh scattering before being deeply attenuated due to absorption by LAr impurities or detector elements (excellent LAr purity & large free LAr volume).
- Study of the VUV-photon reflections show that >11 % of the light detected PMTs in the MC from reflected VUV-light in Al or stainless steel.

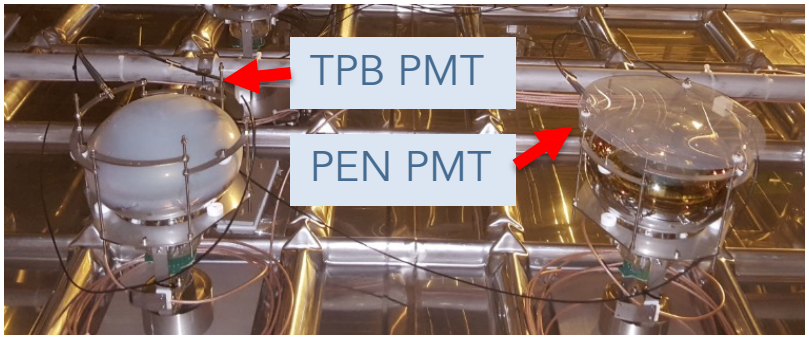


Parameter	λ_{att} (from fit)
Data	180 ± 17 cm
MC (RSL 99.9 cm)	180 ± 10 cm
MC (RSL 61.0 cm)	157 ± 8 cm

ProtoDUNE-DP PMT results

Wavelength shifting: PEN & TPB

- Wavelength shifting required as PMTs are not sensitive to LAr scintillation light in VUV.
- Two methods in ProtoDUNE-DP:
  - PMTs covered with PEN foils, a novel thermoplastic simple to install.
  - TPB coated in a dedicated set up directly over the PMT glass.
- ProtoDUNE-DP results:



Analysis	Value	Result	Comment
Lab measurement[1]	ϵ_{TPB}	1.5 ± 0.3	
PMT-trigger data	$\epsilon_{PEN}/\epsilon_{TPB}$	0.35 ± 0.09	
	ϵ_{PEN}	0.50 ± 0.17	Assuming 1
CRT-trigger data	$\epsilon_{PEN}/\epsilon_{TPB}$	0.32 ± 0.07	
	ϵ_{PEN}	0.39 ± 0.05	From simulation
	ϵ_{TPB}	1.2 ± 0.2	From simulation
Weighted average	$\epsilon_{PEN}/\epsilon_{TPB}$	0.33 ± 0.05	