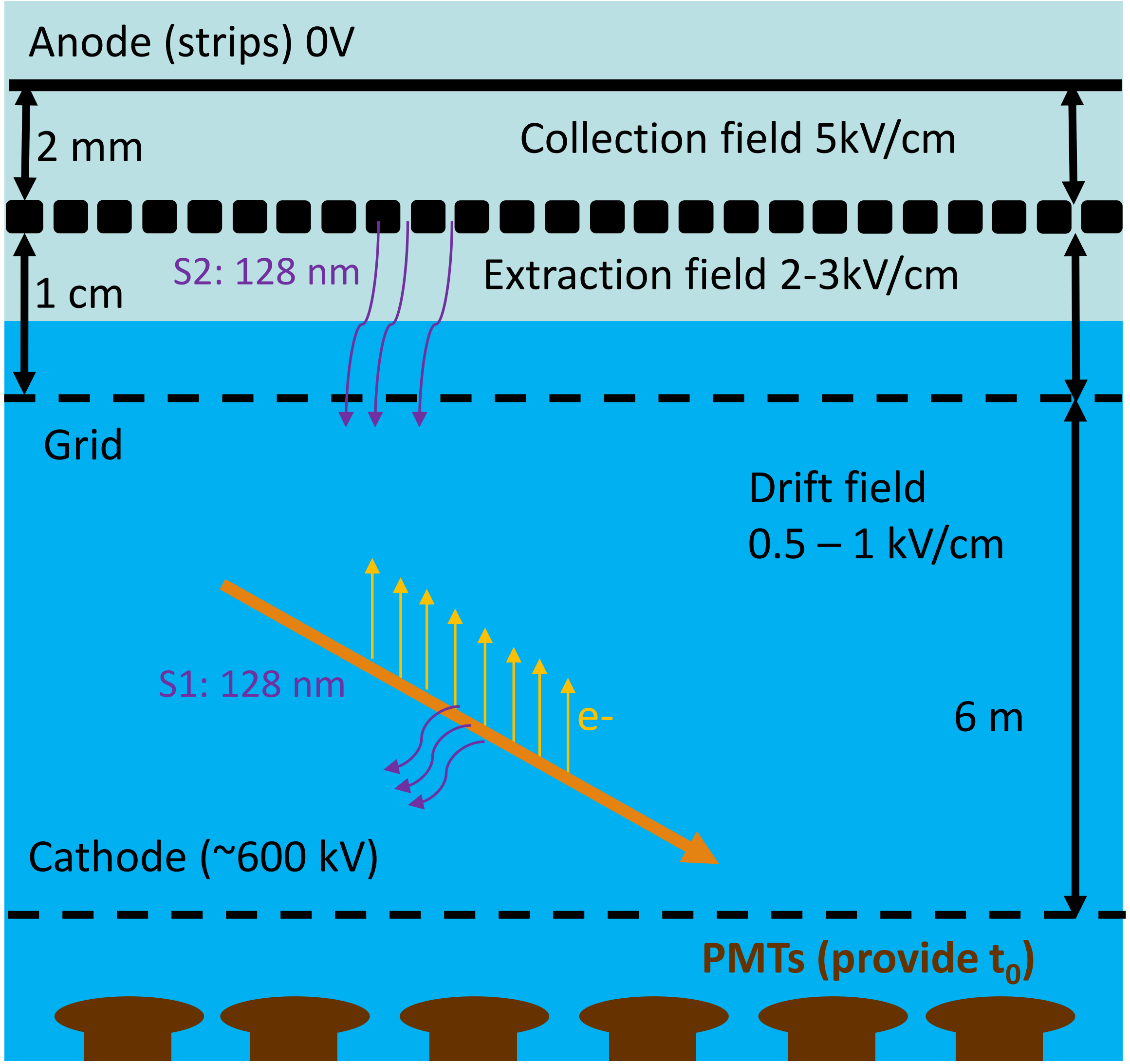
The Light Detection System of protoDune DP

Thorsten Lux
On behalf of CIEMAT and IFAE

Outline

- Motivation
- Baseline design
- Components of the light readout system:
  - PMTs
  - Bases
  - Support structure
  - Wavelength shifter
  - High voltage system
  - Cabling
- PMT monitor and calibration system
  - Objectives
  - Conceptual design

Light in protoDUNE DP



Light sources:

- S1 during ionization process in the LAr
- S2 from the high electric field regions in the gas phase, especially the LEM

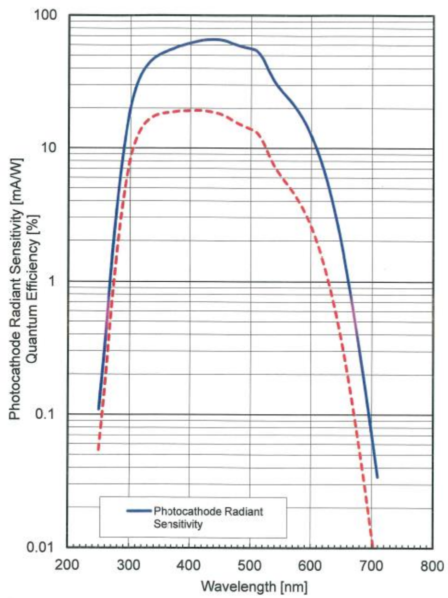
36 PMTs below the cathode to measure the light

Motivation

- Study of the light distribution in view of the DUNE far detector
  - S1 and S2 light distribution (spatial and temporal)
  - Light attenuation
  - Light produced by the different beam particles
  - Testing the triggering based on light
- Tagging of cosmic muons which enter the TPC within readout window

PMTs

- R5912-20 MOD LRI from Hamamatsu
- Same dimensions as ICARUS
- Diameter: 202 mm / 8”
- 14 dynodes => gain up to 10^9
- Q_{eff}@420 nm: at least 15%

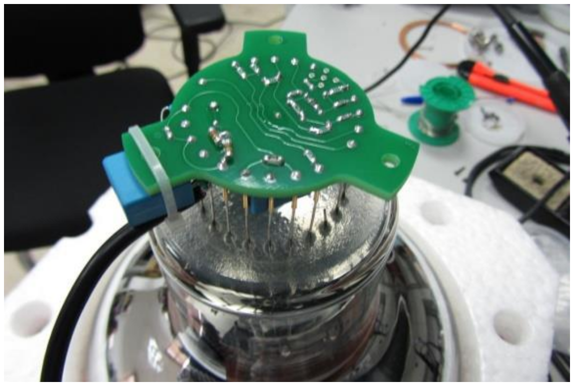


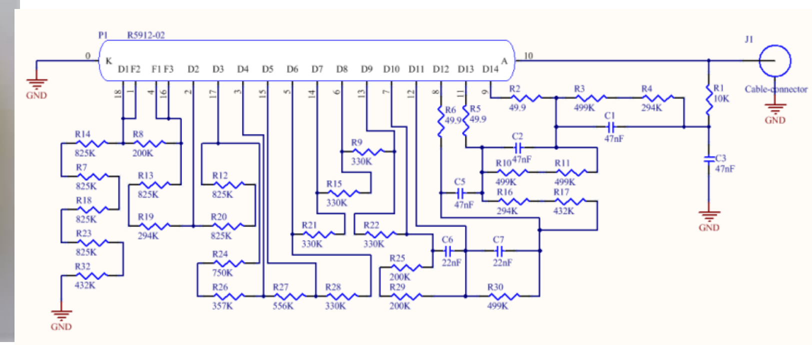
Qeff of IFAE reference PMT

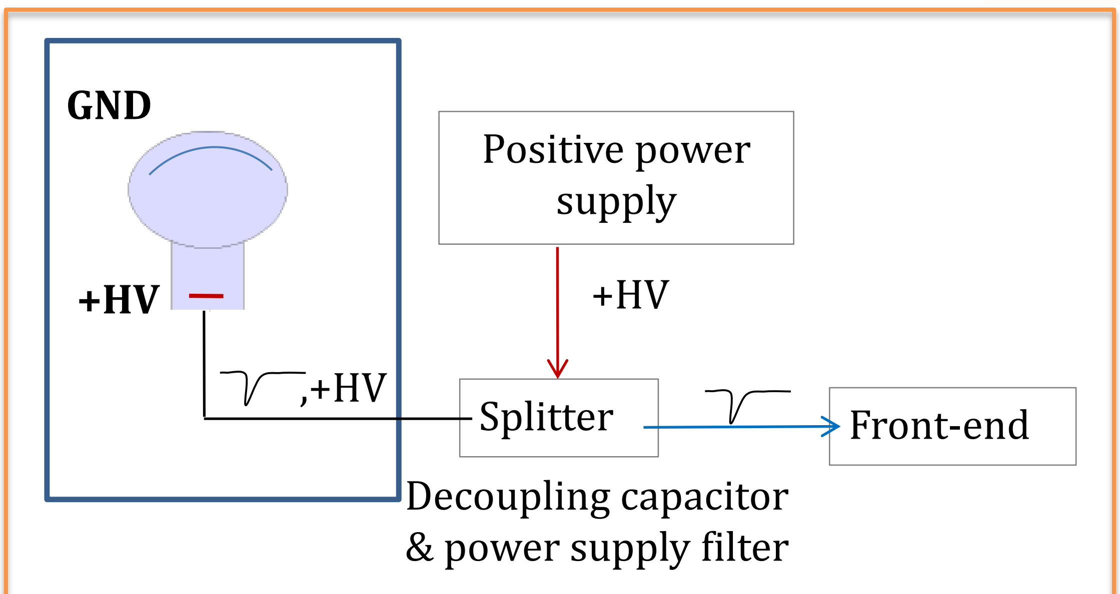
PMT Base

Different PMT bases were studied:

Positive base was selected: 1 cable base (positive HV) + ext. splitter



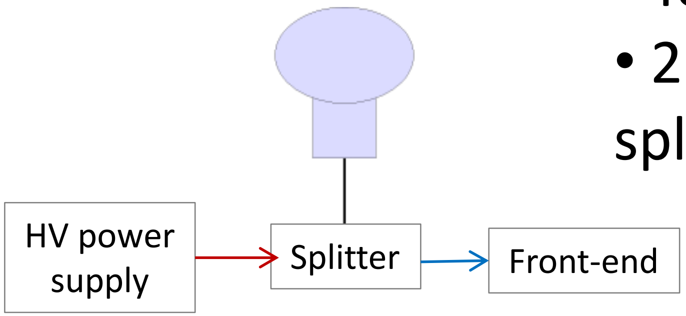


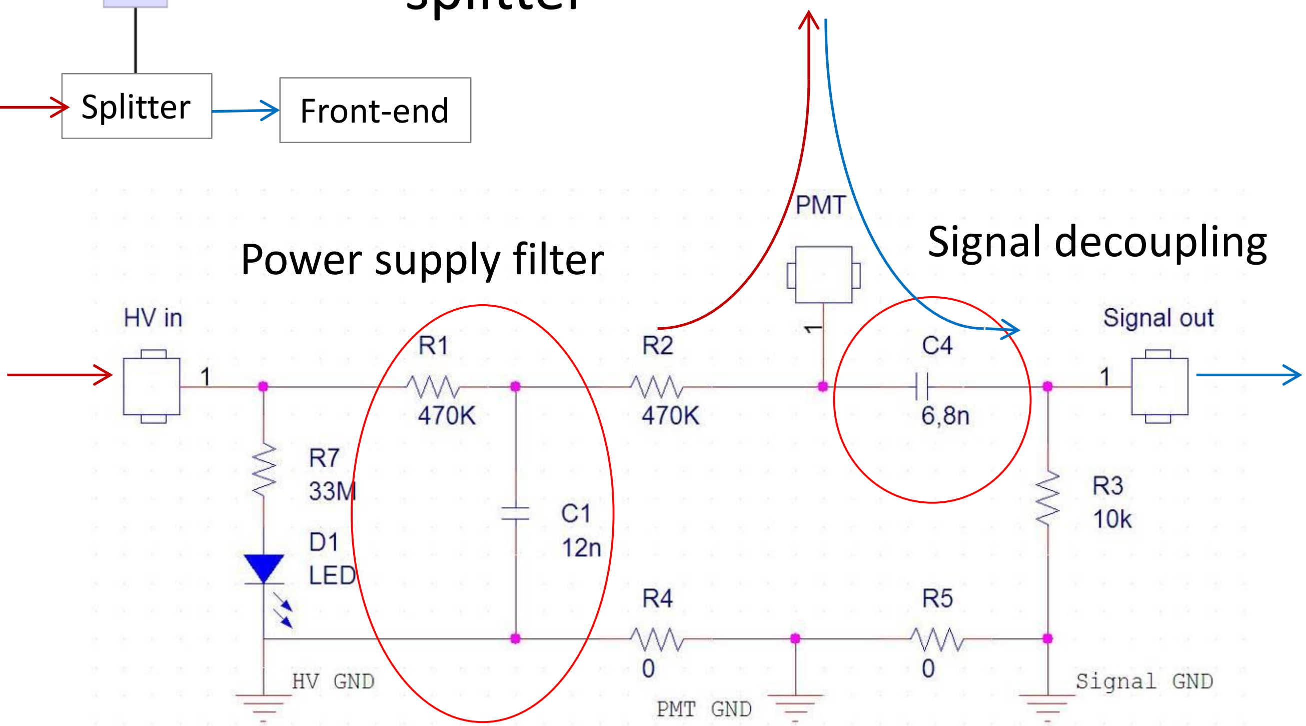


Bases currently produced for starting PMT characterization (see Antonio Verdugo's talk in next session)

PMT Splitter

- Based on experience from Double Chooz
- Tested intensively in LN2
- 2 PMTs of 311 also operated with this splitter

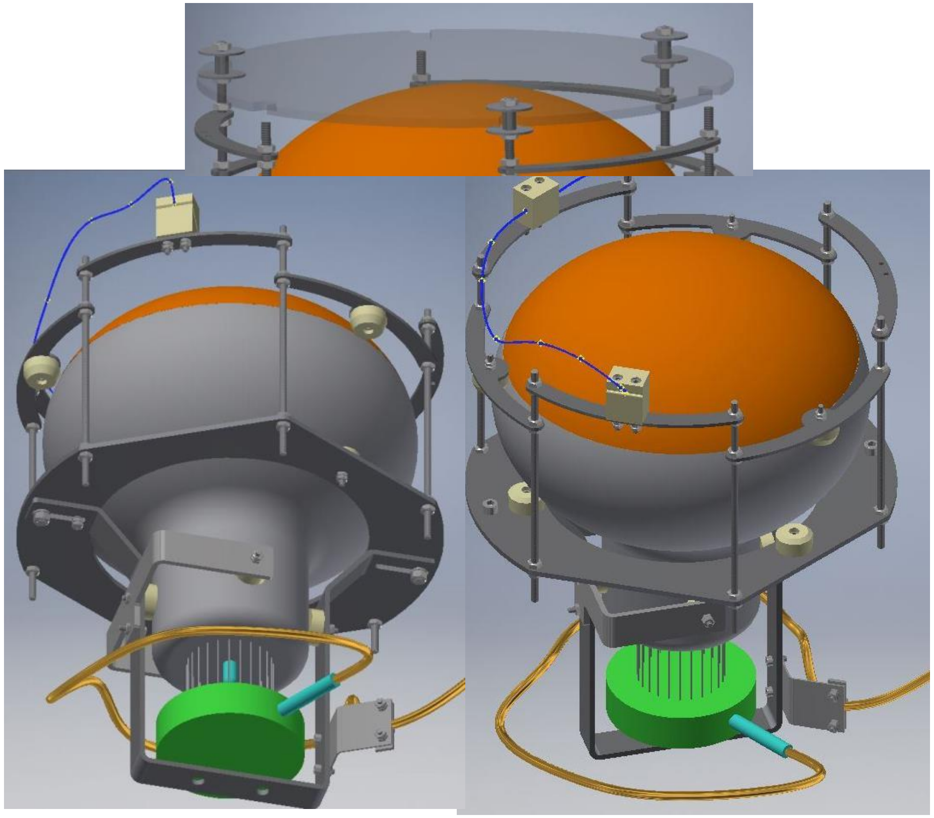




PMT Support Structure

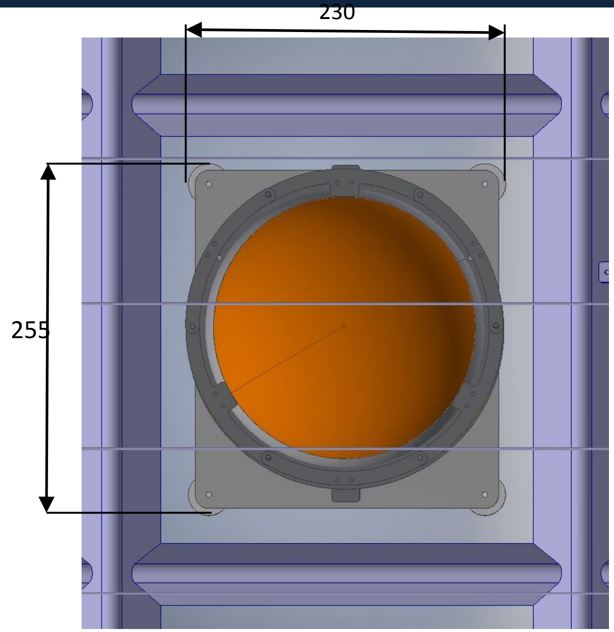
Assembly Composed by:

- Hamamatsu PMT
- Positive base
- Support frame structure of 304 L Stainless steel and Nylon 6.6 pieces assemblies by A4 stainless steel screws
- Design was driven to allow both, direct coating or placing PMMA plate coated with TPB in front of PMT
- Fixation support

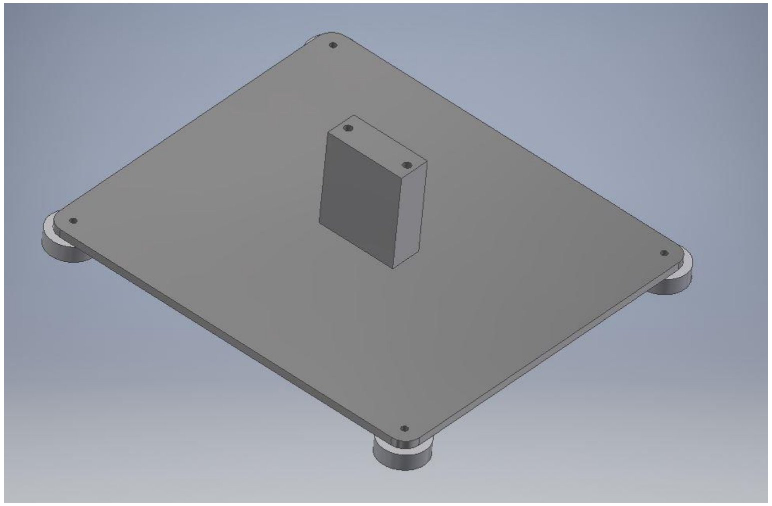


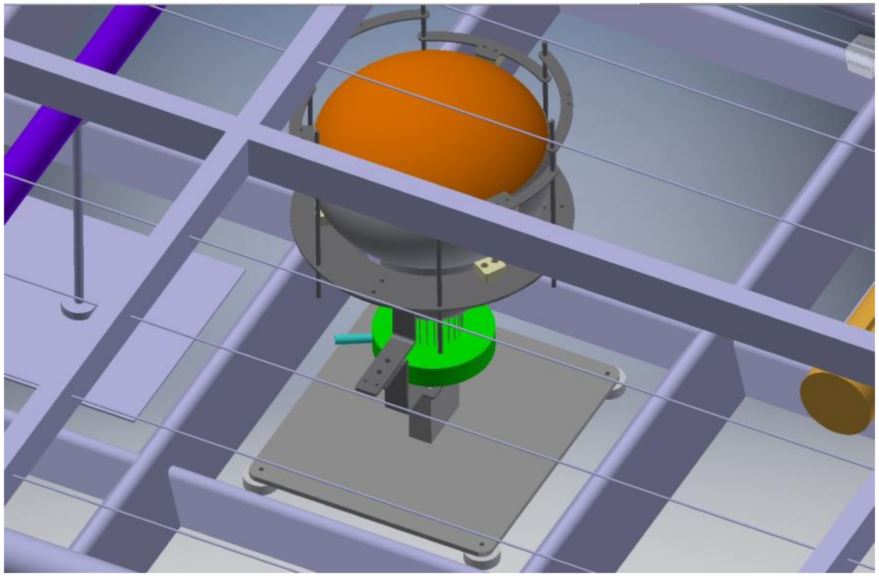
Weight of the PMT +support & base ~6,5 kg.
Buoyancy force of the system ~5,5 kg.
=> Apparent weight when immersed ~1 kg

Tests in 1 bar overpressure (corresponding to 7 m of LAr) and cryogenic temperatures performed.

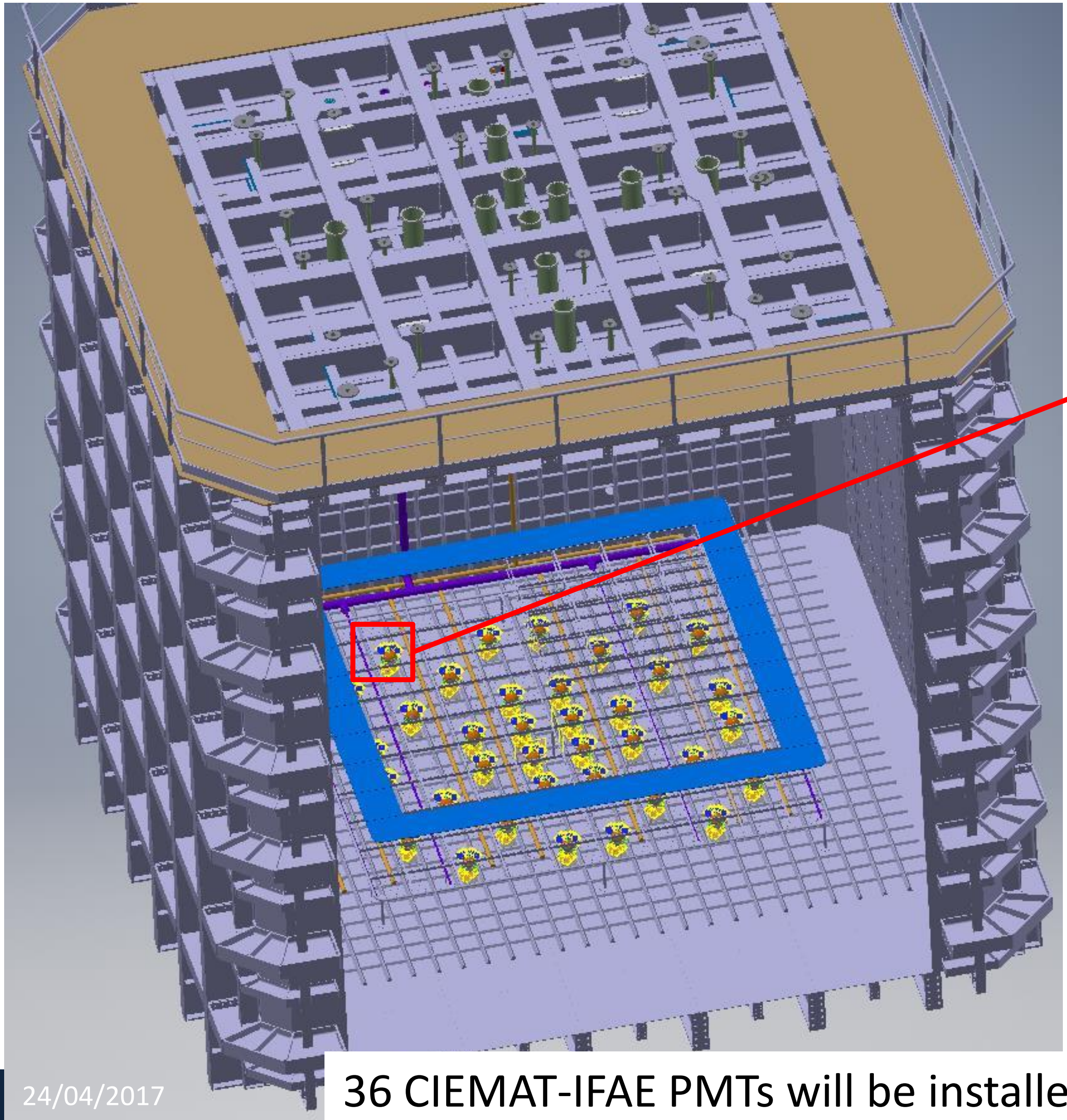


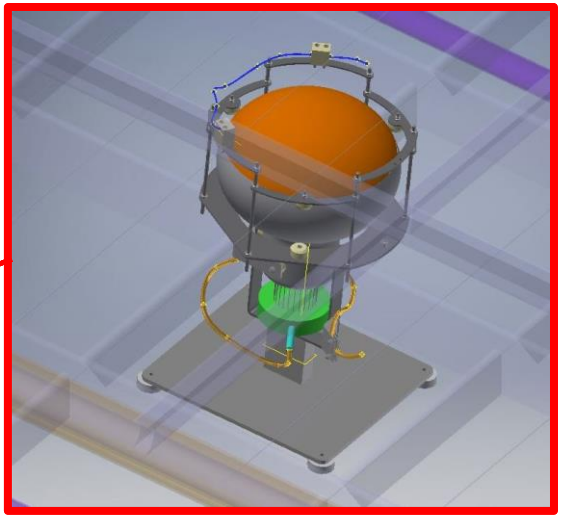
Stainless Steel support base of the PMTs:
4 PTFE Ø30 mm contact pieces on the membrane floor.





PMTs inside protoDUNE DP



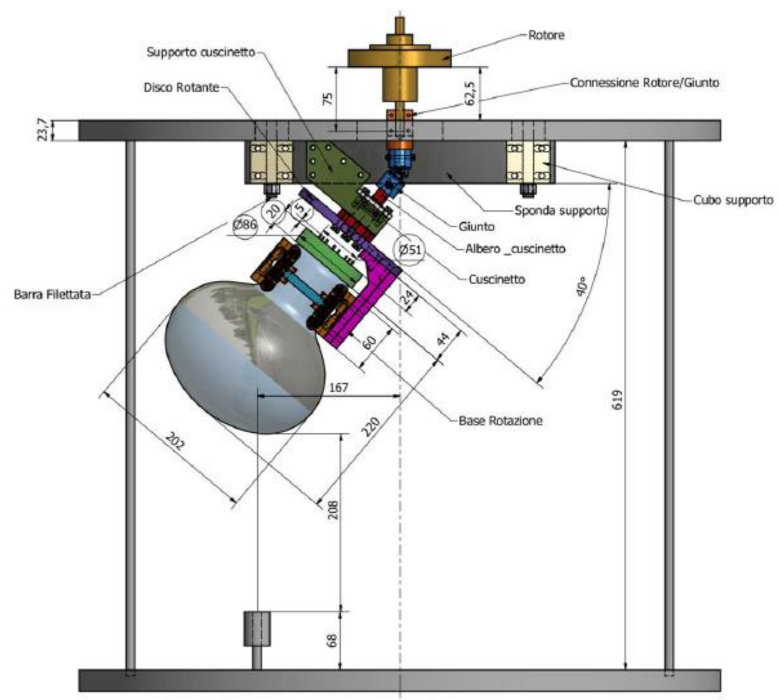


The PMT will be placed on the ‘square’ position between the membrane corrugations.

36 CIEMAT-IFAE PMTs will be installed

TPB Coating

- PMTs will be directly coated with TPB
- Coating with WA104/ICARUS facility at CERN
- Thickness of 500 nm as for ICARUS
- Available between September and December 2017
- PMTs will be shipped from CIEMAT to CERN 09/2017



HV System

Based on CAEN A1536D modules:

- 12 channels per module
- 0 ÷ 3 kV output voltage
- 1 mA current full scale, with 50 nA resolution
- 100 mV Voltage Set/Monitor resolution
- Module with 6 positive and 6 negative channels used in 311 detector

PMT related Cables

To connect the PMT with the HV power supply and the electronics the following cables are needed:

- RG303 coaxial cable inside the cryostat and between cryostat and splitter box

	Material	Detail	Diameter
Centre conductor	Steel, Copper+Silver plated	Wire	0.95 mm
Dielectric	PTFE (Polytetrafluoroethylene)		2.95 mm
Outer conductor	Copper, Silver plated	Braid, 97%	3.6 mm
Jacket	FEP (Fluorinated ethylene propylene)	RAL 8015 - br	4.3 mm +/- 0.1

- RG58 coaxial cable between splitter box and electronics

	Material	Detail	Diameter
Centre conductor	Copper, Tin plated	Strand-19	0.9 mm
Dielectric	PE		2.95 mm
Outer conductor	Copper, Tin plated	Braid, 96 %	3.6 mm
Jacket	PVC II (low migration)	RAL 9005 - bk	4.95 mm +/- 0.15

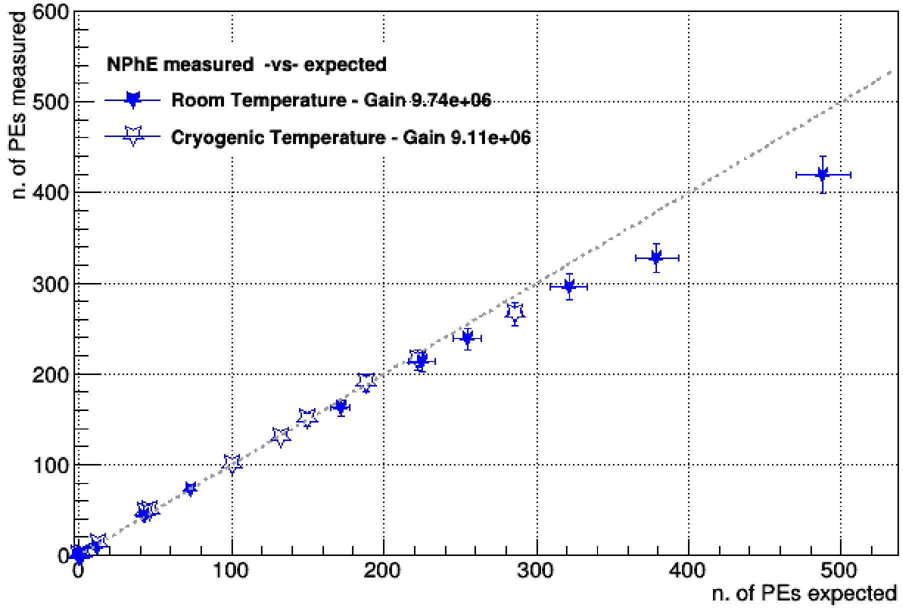
- HTC-50-3-2 SHV coaxial cable between HV power supply and splitter box

Inner conductor	stranded copper wires, tinned, 7x 0.30, diameter 0.90 mm
Insulation	XPE, crosslinked, diameter 2.95 mm
Outer conductor	copper braid, tinned
Wrapping	Al-PET-Al-foil
Sheath	FRNC, flame retardant, non corrosive Copolymer, diameter 5.2 mm
Colour	red RAL 3002

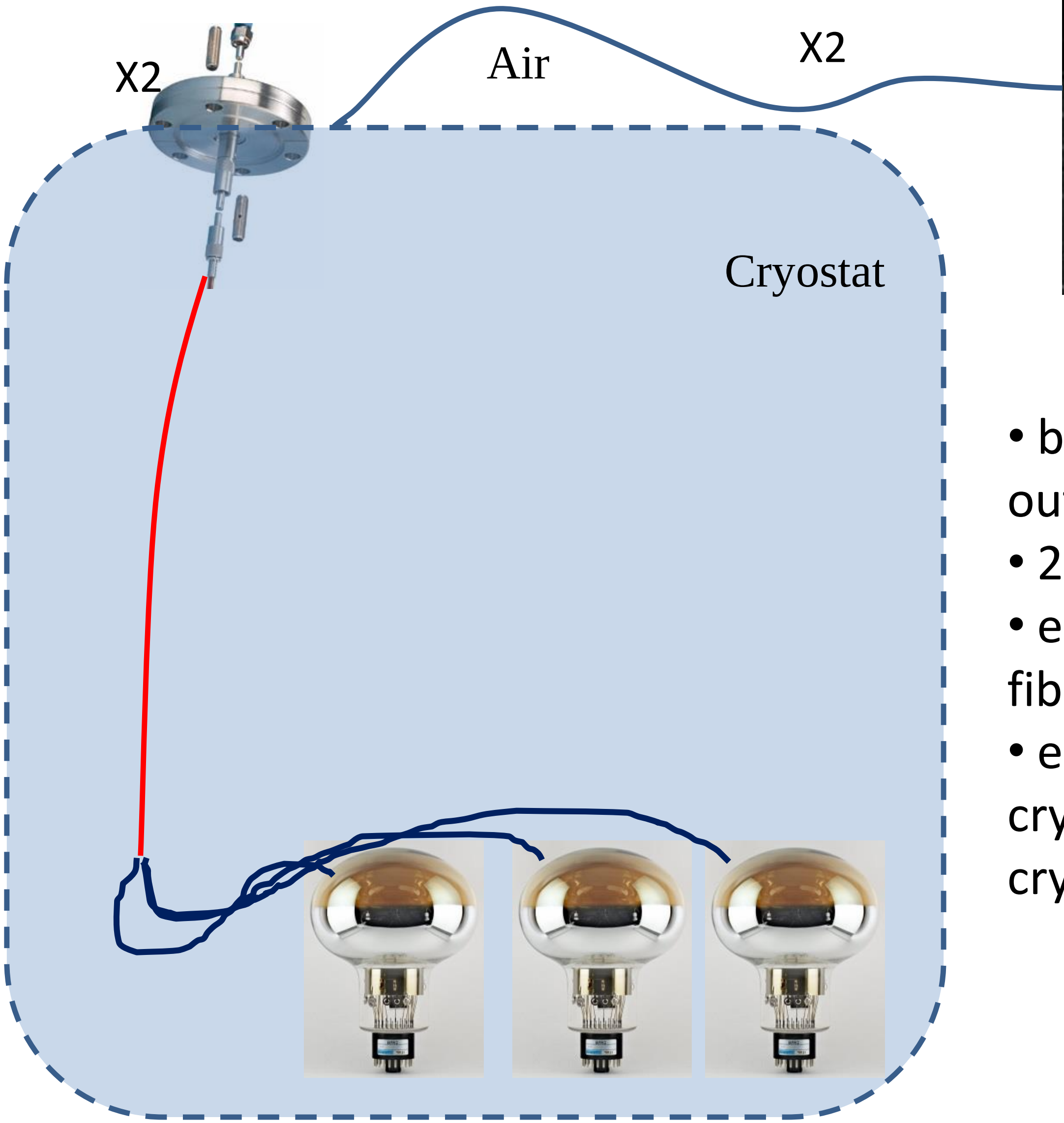
PMT Monitor and Calibration System

Objectives of the system:

- Functionality test of the PMTs independent of TPB
- Linearity response of the PMT
- Gain measurement with single photo electrons



PMT Monitor and Calibration System

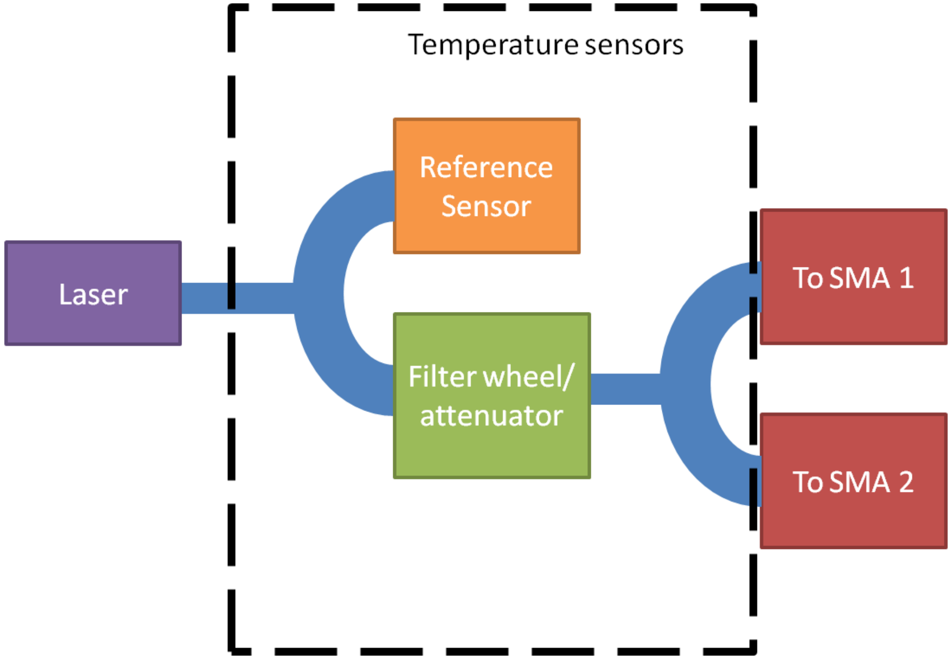


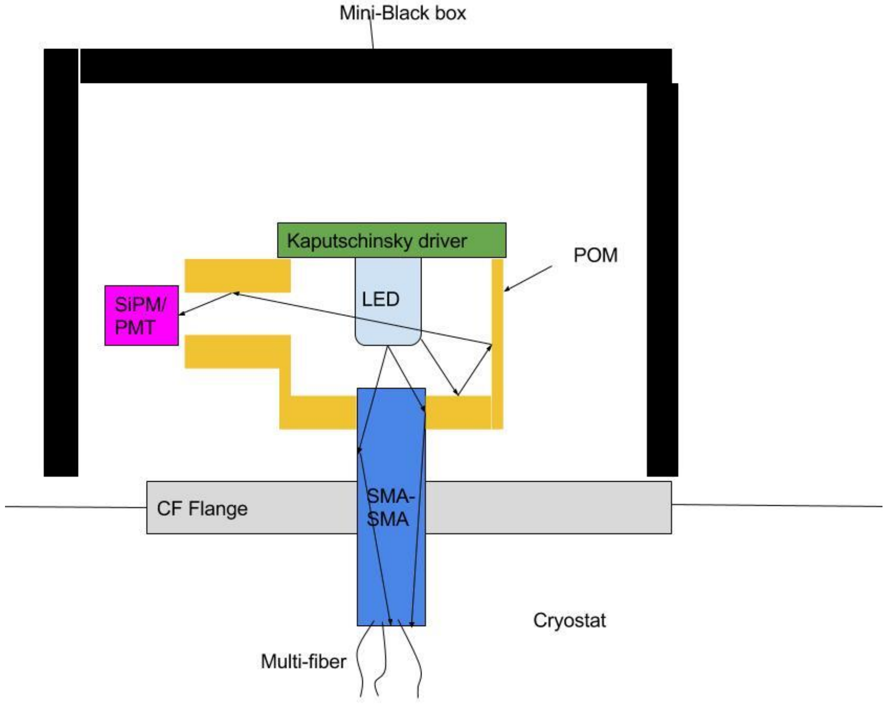
- black box with light source outside of cryostat
- 2 fibers going to cryostat
- each splitting into 20 micro fibers (~200 μm thick)
- either directly on top of cryostat or at bottom of cryostat

Light Monitor and Calibration System

Laser (Class 3b):
• 405 nm wavelength
• installed in DAQ barrack
• laser output split between reference sensor and PMTs
• 2 optical fibers (~30 m) between black box and cryostat

LED with Kaputschinsky driver:
• 465 or 525 nm wavelength
• installed directly on optical feedthroughs
• possibly reference sensor next to it
• similar to Microboone approach but one LED for 18 PMTs



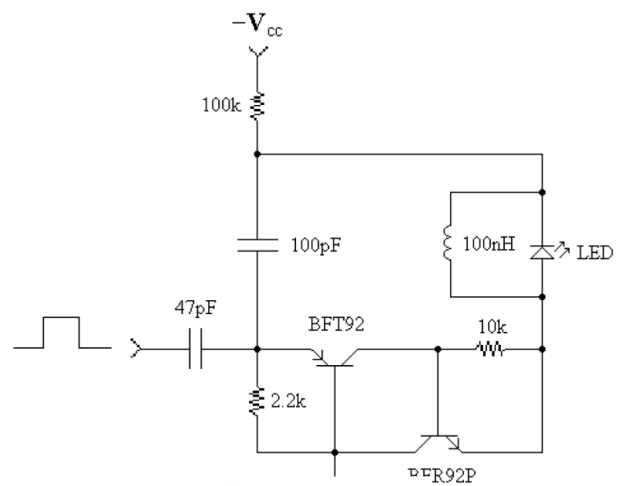


Light Monitor and Calibration System

Light sources:

- Laser: P405-SF10
- Kaputschinsky LED driver

Item #	Info	Wavelength	Power (Typ.)[a]	Typical/Max Drive Current[a]	Pin Code[b]	Package	Compatible Socket	Wavelength Tested	Recommended Mount(s)	Recommended Driver
LP405-SF10		405 nm	10 mW	50 mA / 60 mA	B	Ø5.6 mm SM Pigtail, FC/PC	S7060R[c]	Yes	LDM9LP or CLD1011LP	ITC4001[d]



Optical fibers/bundles under consideration

- Black box – cryostat: SM300 (Thorlabs)
- Cryostat top – bottom: FP1000ERT (Thorlabs)
- Multi-bundle:
  - Fan-Out Fiber Optic Bundles (Thorlabs)
  - Bare multi-fiber (i-fiberoptics)

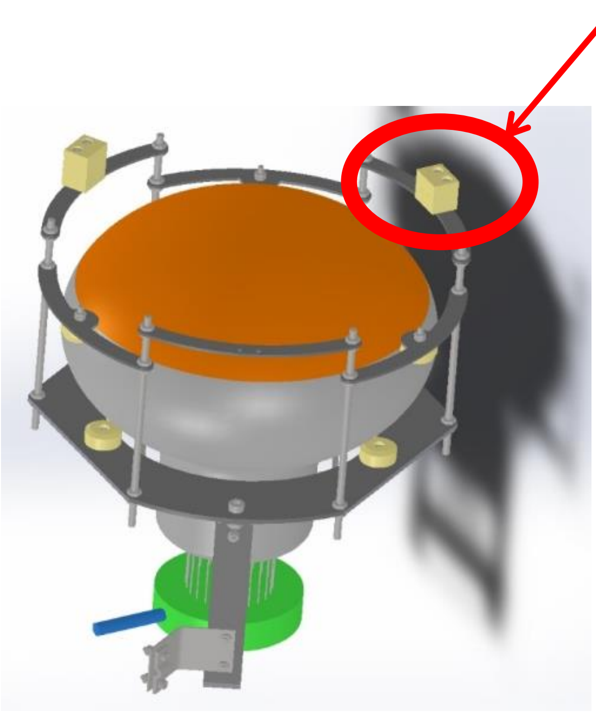
Reference sensors (still optional):

- Powermeter: PD300-UV de Ophir
- PMT/SiPM

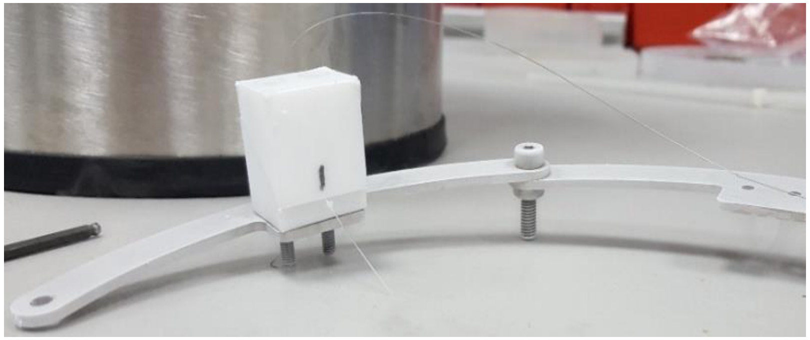
Light Monitor and Calibration System

Optical feedthrough:
- V2H6S (Thorlabs)
- SMA-SMA

Specifications		
Item #	V2H6S	V2L6S
Wavelength Range[a]	200 - 800 nm	400 - 2200 nm
Fiber Core Diameter	600 µm	
NA	0.22 ± 0.02	
Vacuum Level	1×10^{-10} Torr	
Insertion Loss	≤2.3 dB	
Max Optical Power	1 W	
Max Temperature	250 °C	



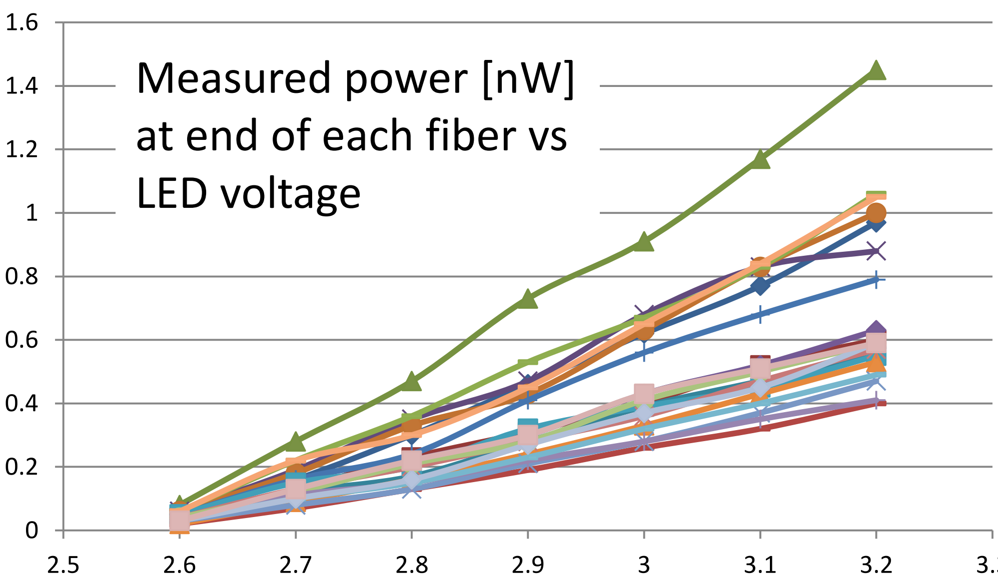
Fiber fixation to PMT:
- design adapted to hold 200 μm fiber
- first prototype built
- already tested in LN2 and fiber holds position



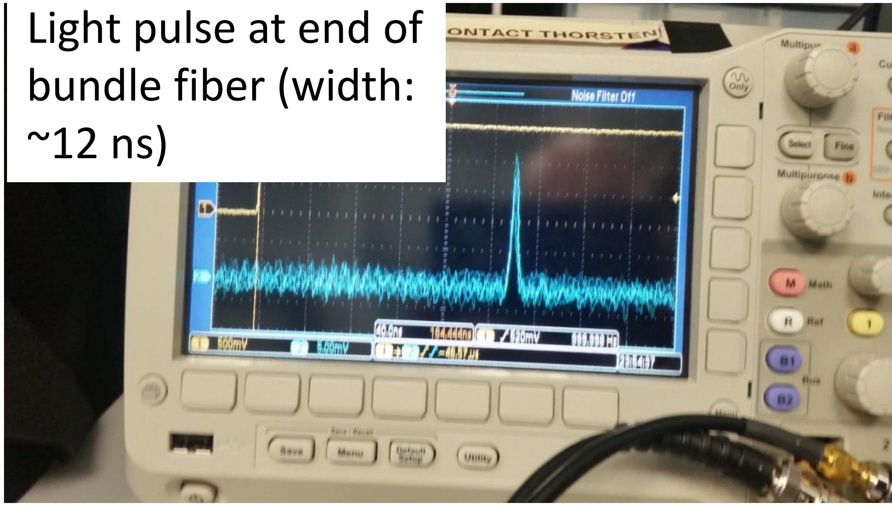
Light Monitor and Calibration System

Decision taking process (until 10/2017):

- Testing performance the different options under consideration at room and cryogenic temperatures
- Other factors beside performance:
  - Safety regulations in the case of the usage of a laser
  - Accessibility during operation for maintenance
  - Costs



Measured power [nW] at end of each fiber vs LED voltage



Light pulse at end of bundle fiber (width: ~12 ns)

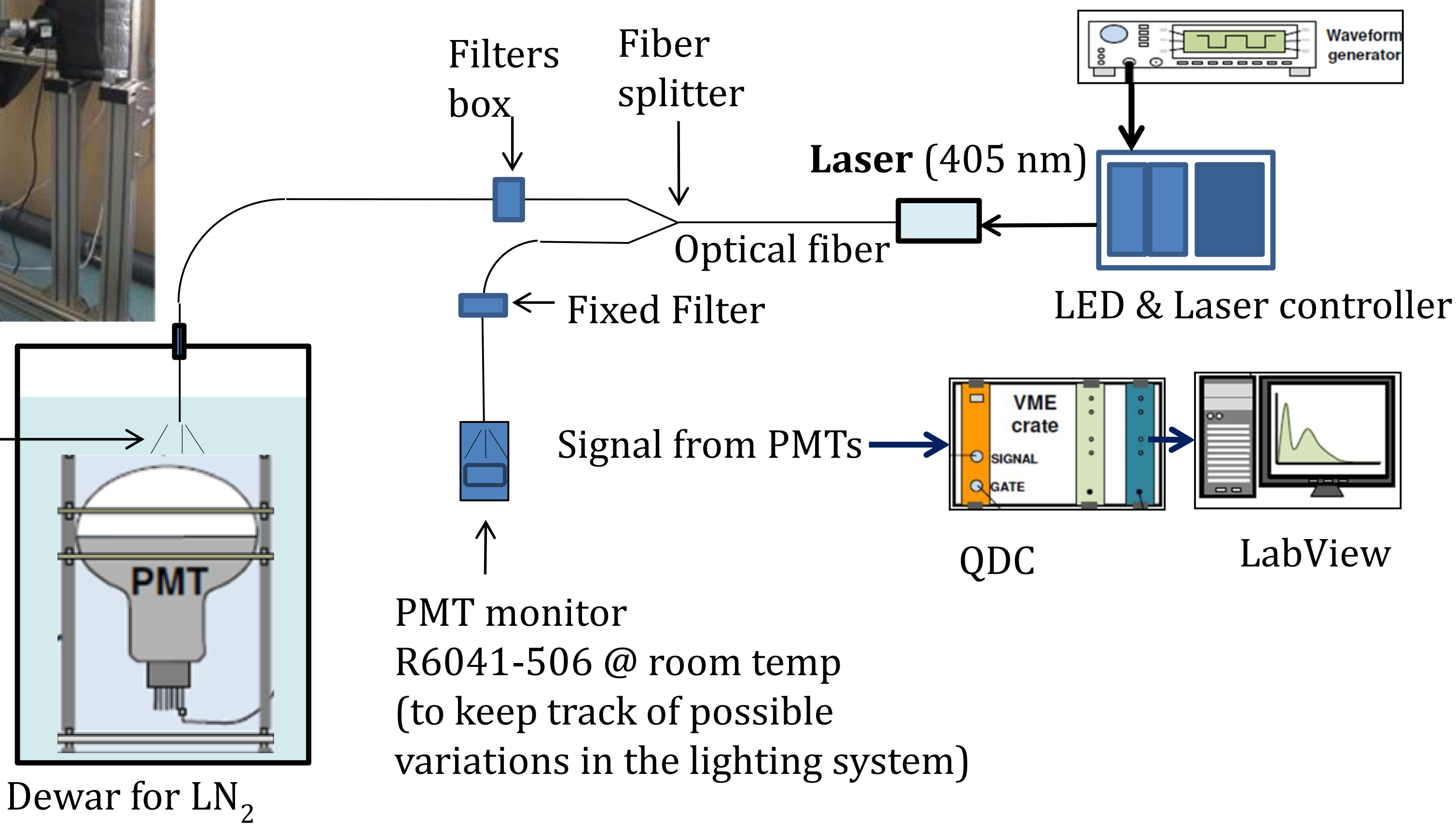
Summary

- protoDUNE DP light system will be based on 36 PMTs
- Overall design of the system well advanced
- Production of bases already completed for characterization of PMTs at CIEMAT
- Support structure was designed to place PMTs inside the cryostat and to hold them in place
- TPB coating will be done at well established ICARUS setup
- Light monitor system design still ongoing
- Currently various tests ongoing at IFAE and CIEMAT to decide some last details of the calibration system by July 2017. No impact on the installation time-schedule

Backup

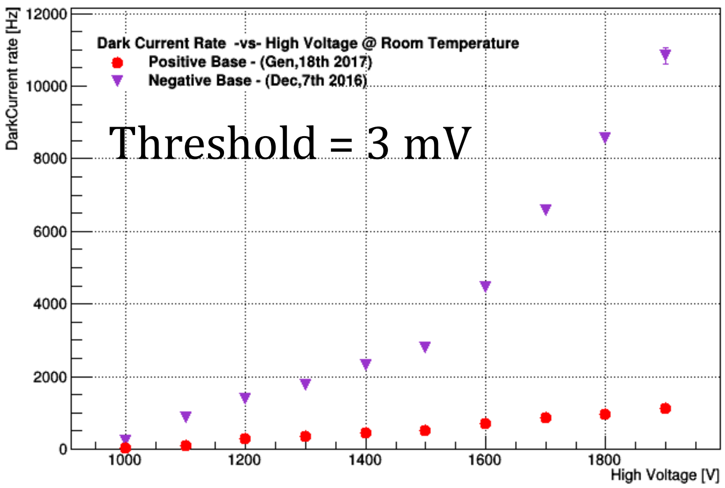
Experimental Setup@CIEMAT

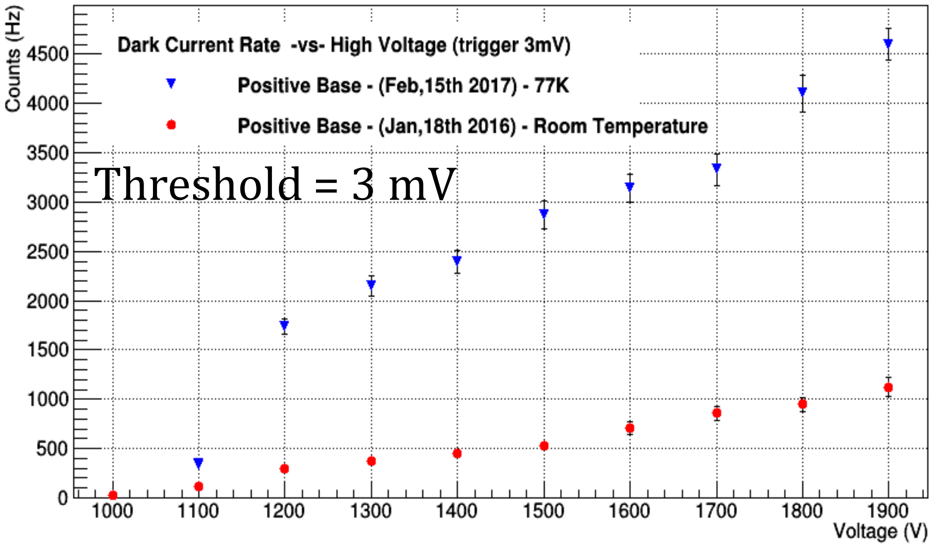
- Designed to test one PMT immersed in LN2 with a configurable amount of light



PMT Characterization@CIEMAT

Dark current (DC)



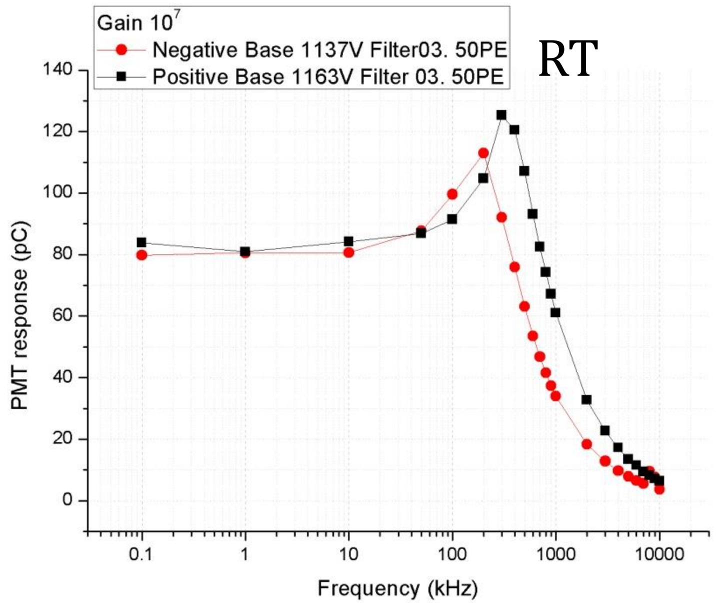


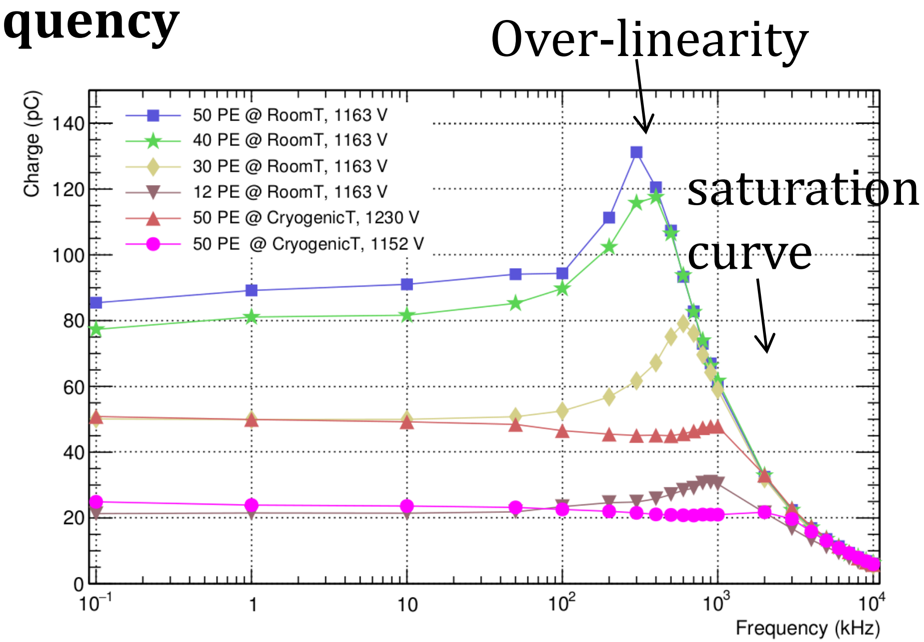
- Positive base lower DC than negative base at RT
- DC at CT higher than at RT

⇒ Positive base will be used for protoDUNE DP

PMT Characterization@CIEMAT

PMT response vs pulsed **light frequency**





- There is a characteristic saturation curve.
- Over-linearity effect is observed previous to the PMT saturation.
- Negative base saturates at lower frequency than the positive base.
- High frequency decreases the PMT gain at cryogenic temperature.

Fibers Attenuation Curves

Aim is to choice fiber and connector combinations which minimize light losses:

- SMA300 => 70 dB/km
- Losses in fiber at 405 nm larger than at 465 or 525 nm

– i-fiberoptics

ESKA™ High-performance Plastic Optical Fiber: SK-10
Manufactured by Mitsubishi Rayon Co., Ltd.
Marketed and sold by Mitsubishi International Corporation

May, 2001

Structure		
Core Material	Polymethyl-Methacrylate Resin (PMMA)	
Cladding Material	Fluorinated Polymer	
Core Refractive Index	1.49	
Numerical Aperture	0.5	
Refractive Index Profile	(Step Index)	
Attenuation (db/m)	0.3	
Approximate Weight (g/m)	0.06	
	Unit	Typical
Core Diameter	μm	240
Overall Diameter	μm	250
Fiber Diameter Tolerance	+/- 9.2%	

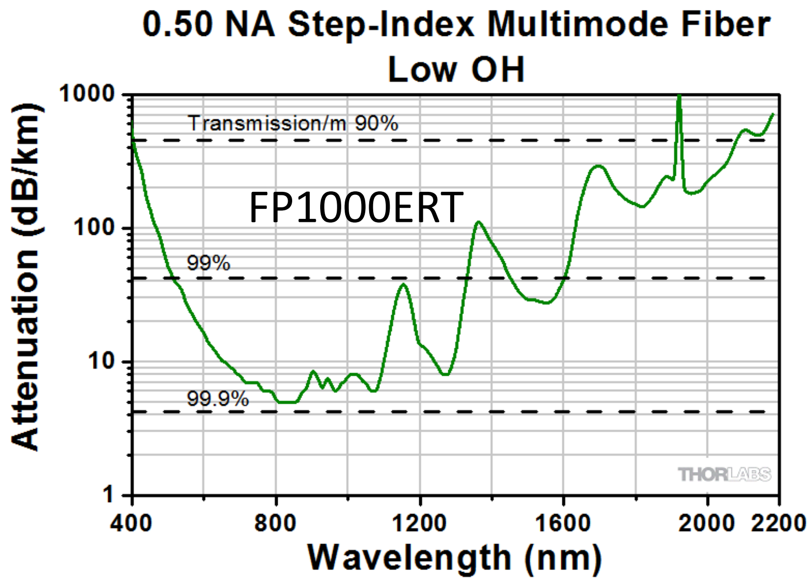
Packaging	
Spool Length (m)	12,000
N weight on spool (kg)	1.4
Spool Weight (kg)	0.68
Carton Size	286 X 286 X 130
Carton G Weight (kg)	1.6
Fiber Code	SK
Cable Code	SH1001
Master Carton	12 Spools

Applications: Sensing

SK grade fibers are typically used for sensing temperatures, speed, liquidity levels and positioning. In addition, medical and general illumination are popular applications

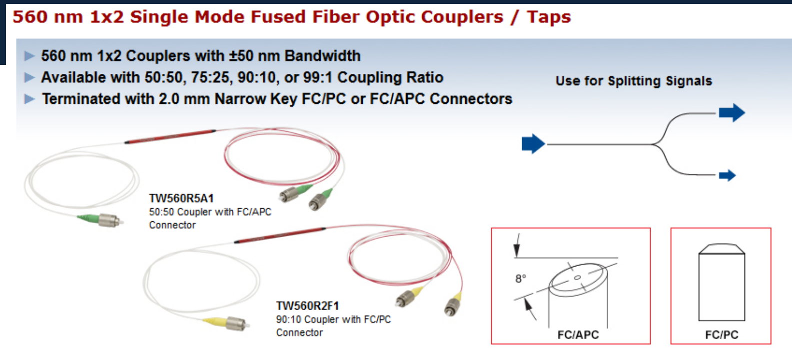
Performance		Criteria for Acceptance and/or Test Conditions	Unit	Values
Temperature Range		No deterioration in optical properties *	°C	-55 -- 70
Operating Temperature Under Conditions of High Humidity		No deterioration in optical properties [95% RH] **	°C	=<60
Optical Properties	Transmission Loss	650nm collimated light (standard conditions) [10m – 1m cutback]	dB/km	=<300
Mechanical Character-istics	Minimum Bend Radius	Loss increment =< 0.5dB [Quarter bend]	mm	=>5
	Tensile Strength	Tensile force at yield point [JIS C 6861]	N	=>3

Notes: Performance tested in conditions cooler than 25°C unless otherwise indicated
* Attenuation change <10% after 1000 hours
** Attenuation change <10% after 1000 hours, except when due to absorbed water



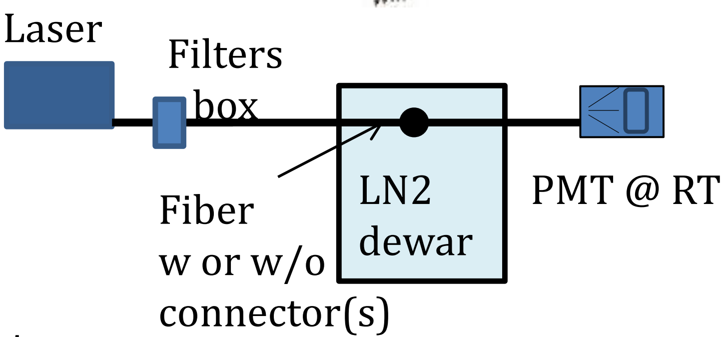
Light Monitor System

- Beam splitler based on fiber coupler from Thorlabs (ordered)
- Reference light source (already at IFAE):
  - Powermeter (default if sensitive enough for pulsed mode)
  - PMT or SiPM (alternative)
- Multi-bundle fiber ordered and delivered this week to IFAE, further tests at CIEMAT:
  - Mechanical / robustness with the final mounting
  - Attenuation / Maximum light transmission
  - Light distribution over the different fibers
  - Long terms stability
  - Direct coupling to feedthrough or at bottom of cryostat?

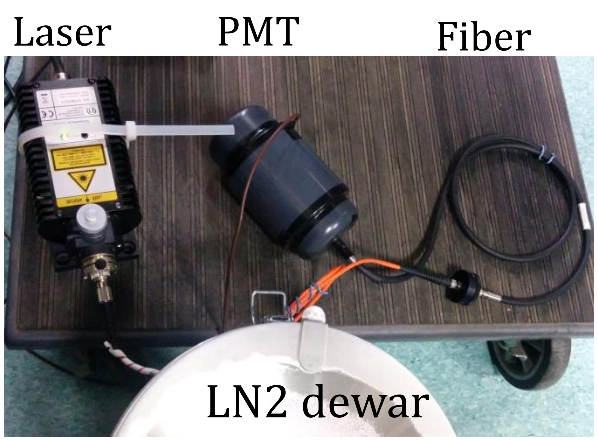


Light Monitor System

- **Connector performance**
  Goal: Decide if the bundle at the bottom of the detector or directly attached to the flange at the top.
  Measurement: Study the relative light loss due do adding an extra connector (on-going).
  Preliminary results:
  Big light loss observed, studying systematics.
  Will measure it also with a power sensor



- **Next:** Characterize the bundle and new connectors to determine the light output difference among fibers (bundle ordered).



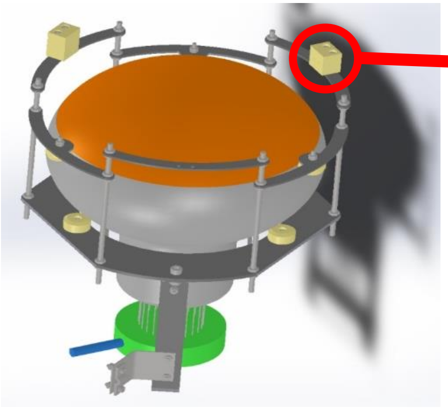
Light Monitor System

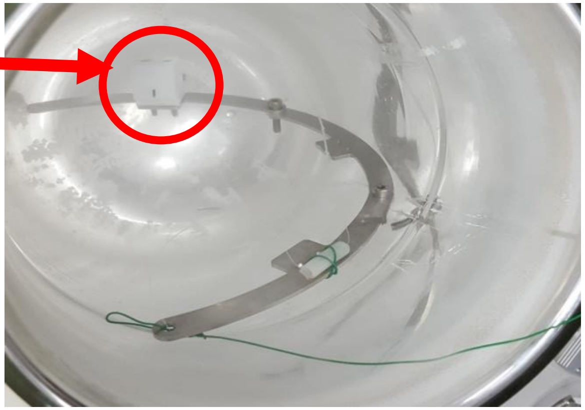
Single fiber testing at LN2 on-going at CIEMAT

- **Fiber Holder Cryogenic Tests**

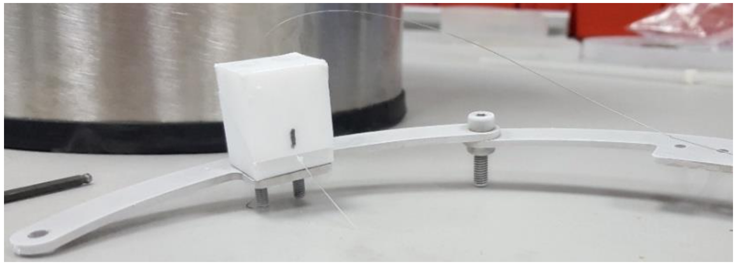
  Goal: check that the fibers stay in place at cryogenic temperature.

  Two configuration tested: one as it is, and the other, with a groove and a strip of Teflon → Both worked fine.





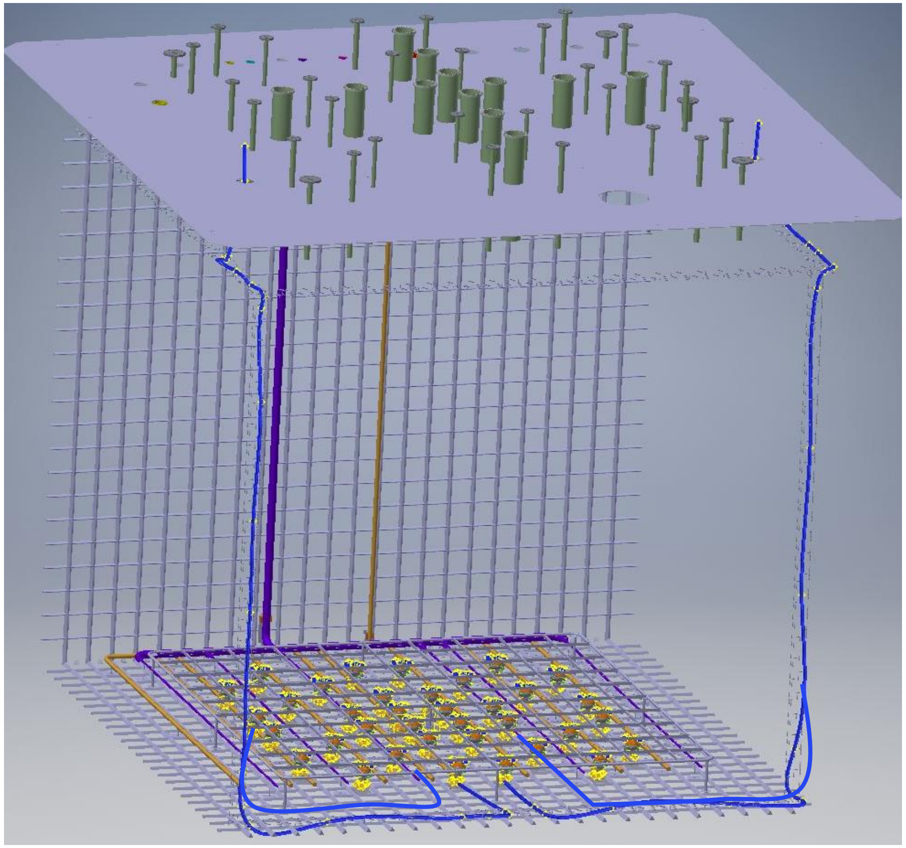
The fiber remains in the same position as before being submerged in LN2 and the light transmission looks fine.

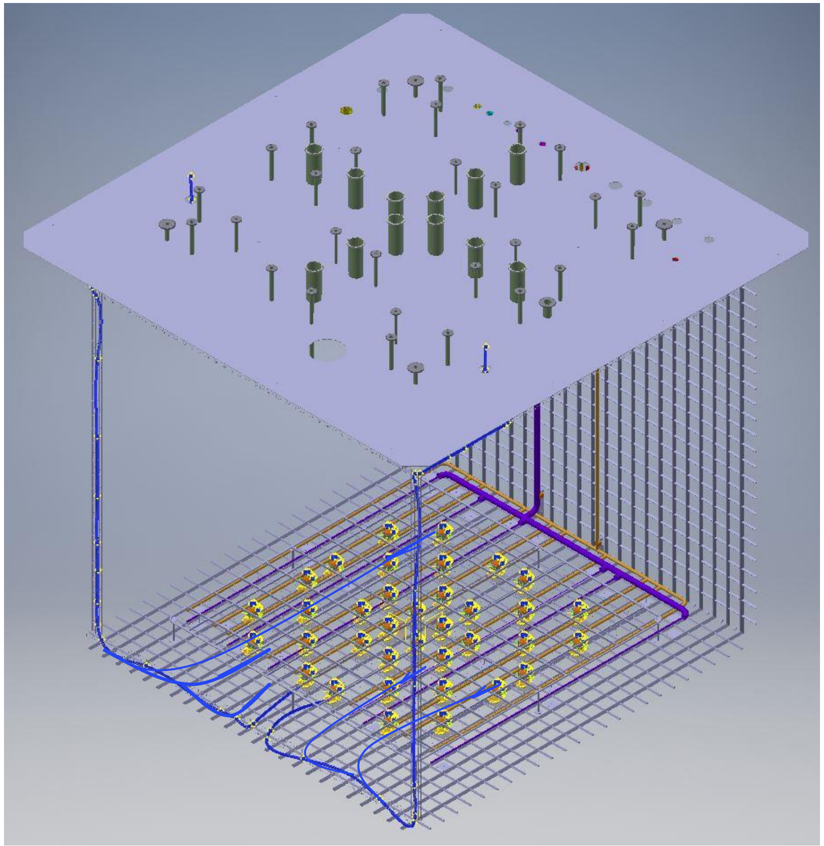


We plan to measure if there is any light loss due to mechanical stress

Light calibration system

2 optical feedthroughs: 2 main fibers from top to bottom of the detector



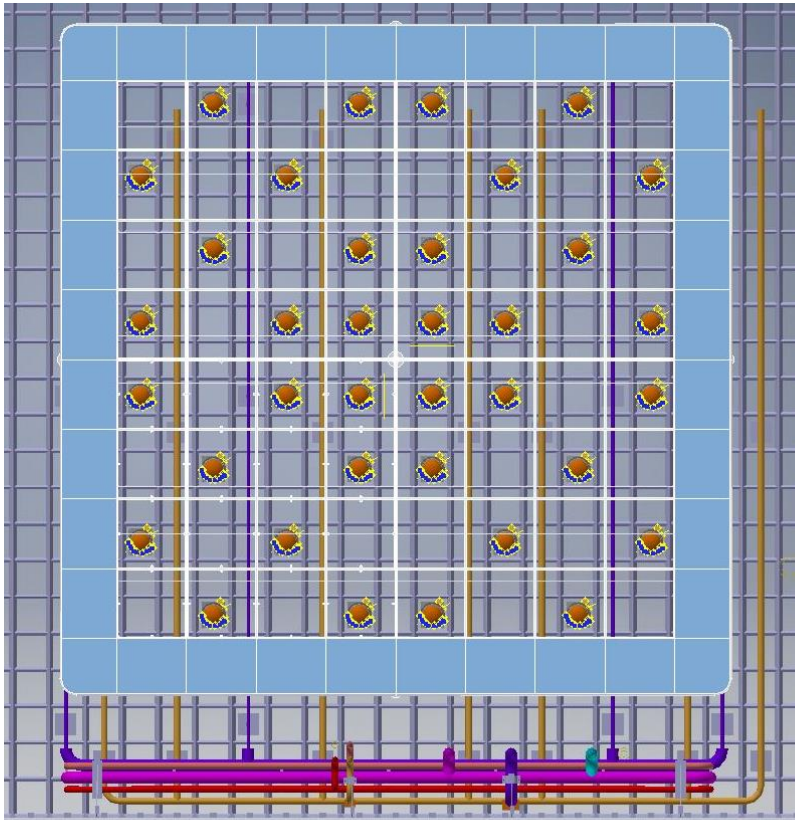


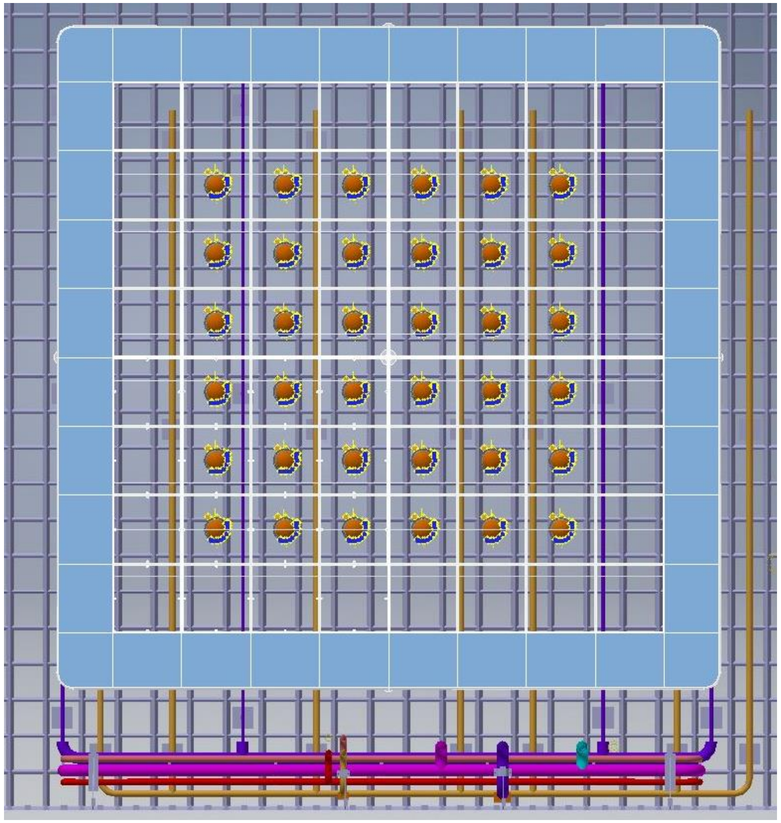
Each main fiber is split in 18 fibers distributed to half of PMTs

Baseline

PMTs layout in the detector:

- 2 options have been studied to avoid interferences with filling tubes and to center the PMTs in the cathode frame structure.

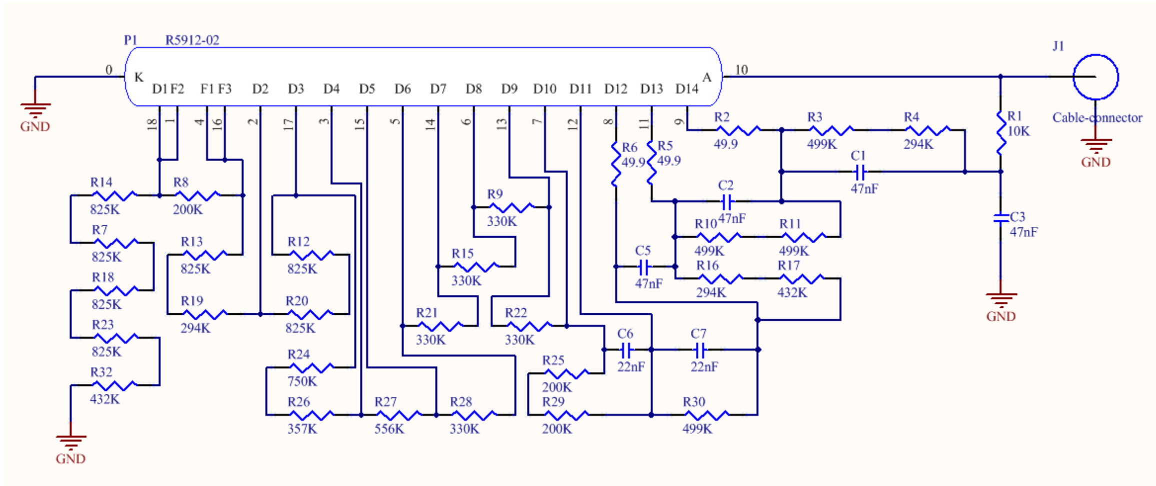




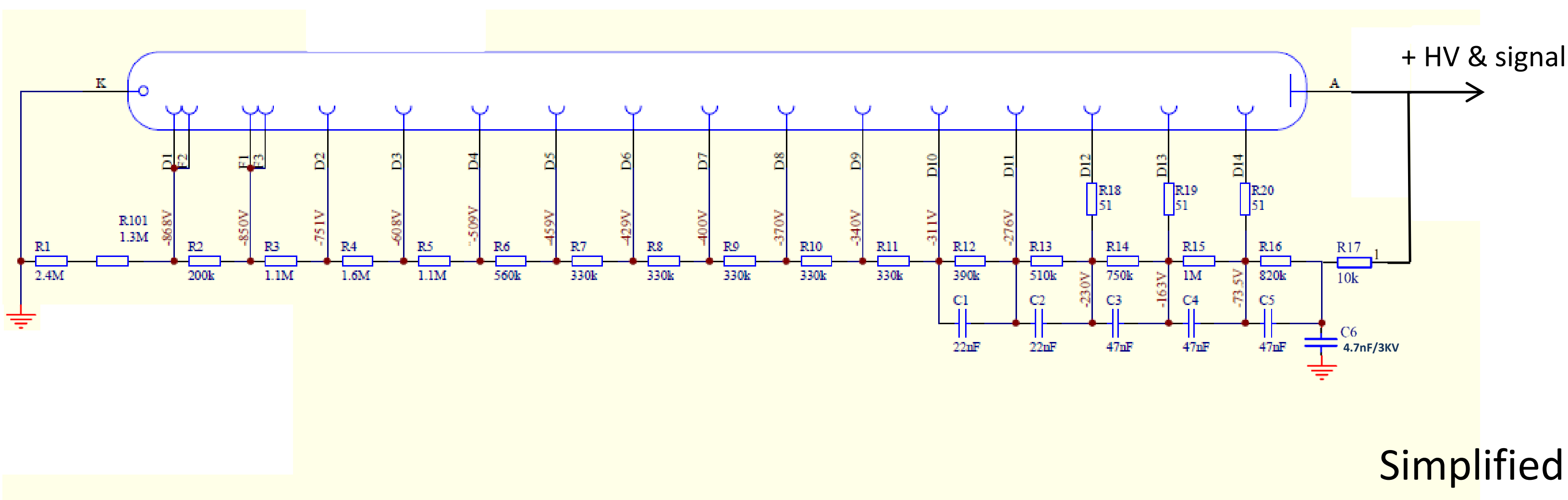
New base for WA105 PMTs

- Use of low temperature coefficient resistors (25ppm/ºC) and capacitors (C0G dielectric) to minimize variations with temperature.
- Use SMD components: less volume, less inductance (no legs), easier to find the best place on the PCB.
- The capacitors are placed as close as possible to the PMT pins to reduce the inductances between them to get faster pulses and less oscillations (ringing).

WA105 PMTs base



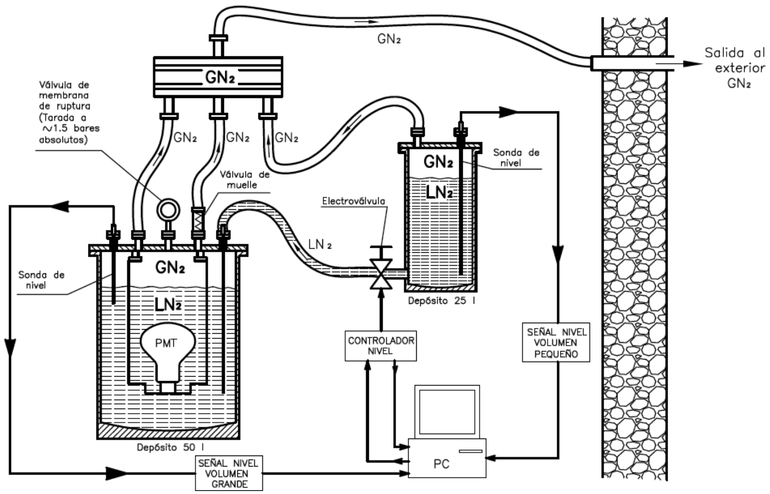
Real



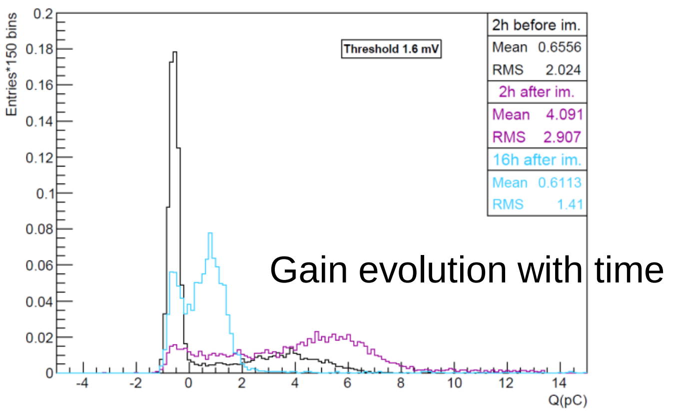
Simplified

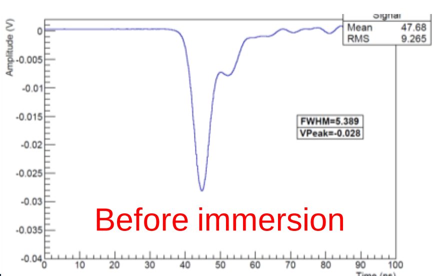
Cryogenic tests at CIEMAT

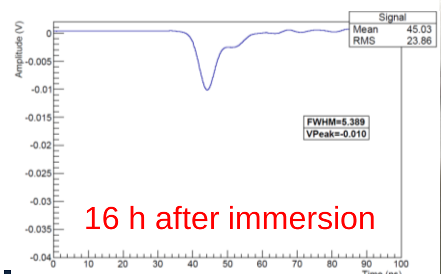
- **PMT system tests in LN_2:**
  - Test of the PD system up to 1 bars (overpressure) (equivalent to ~7m LAr)
  - Test of PMT response in cold with single wire base: dark current, pulse shape, gain



Mechanical and pressure tests @CIEMAT

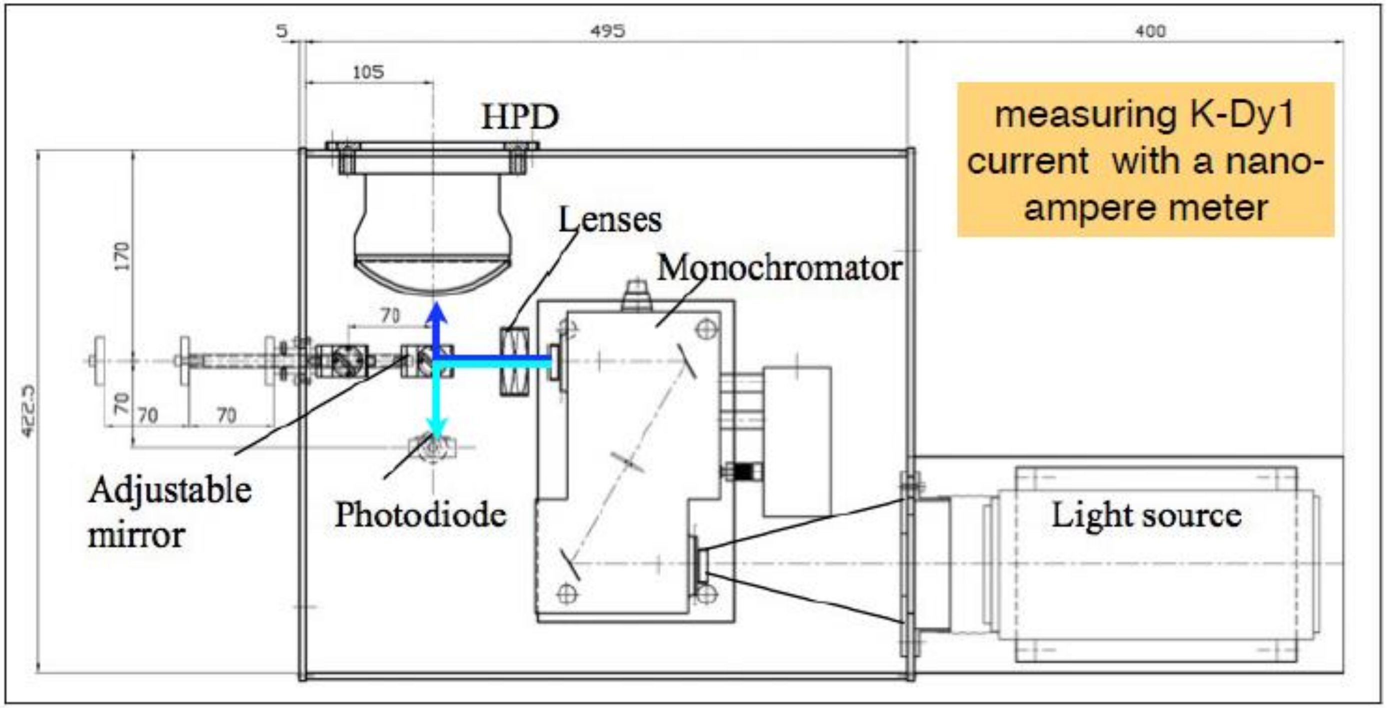




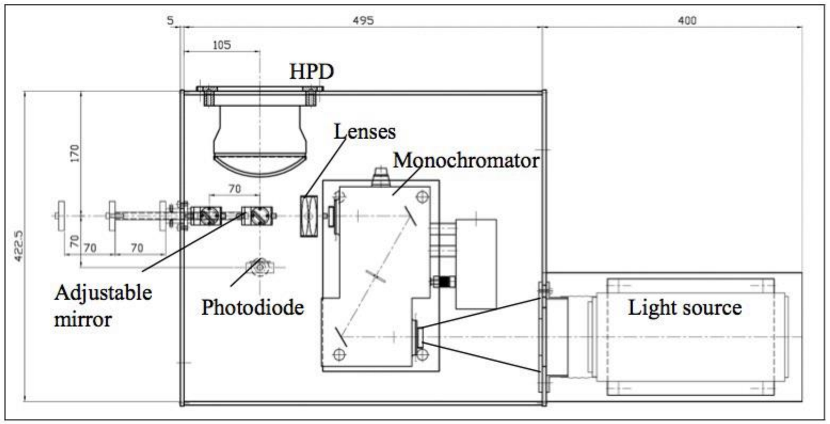


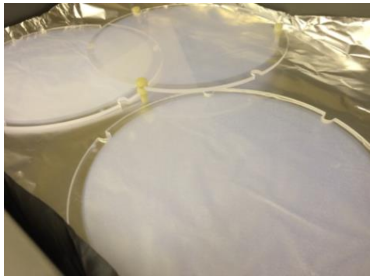
TPB Coating

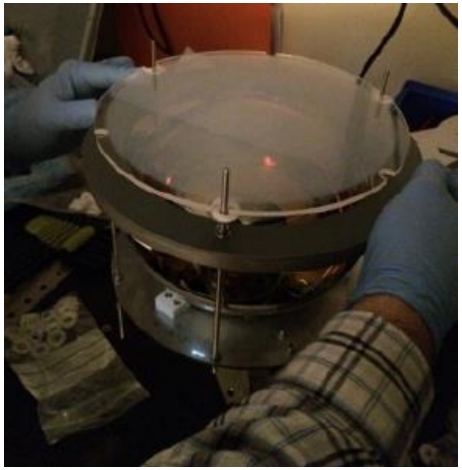
- ICARUS observed excellent coating quality
- Quality test of 4 to 8 PMTs in CERN setup which was already used for 311 PMTs
- Available October/November 2017

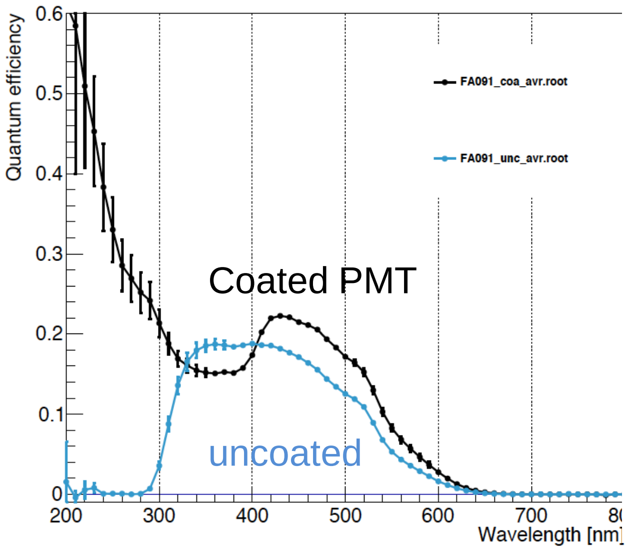


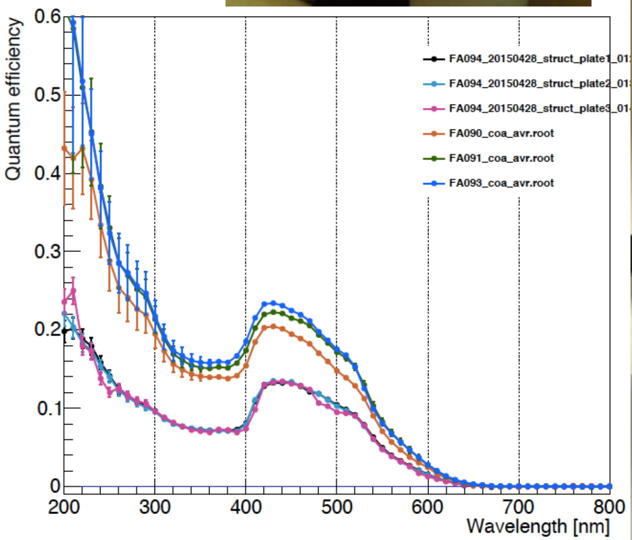
TPB coating and QE measurements @CERN



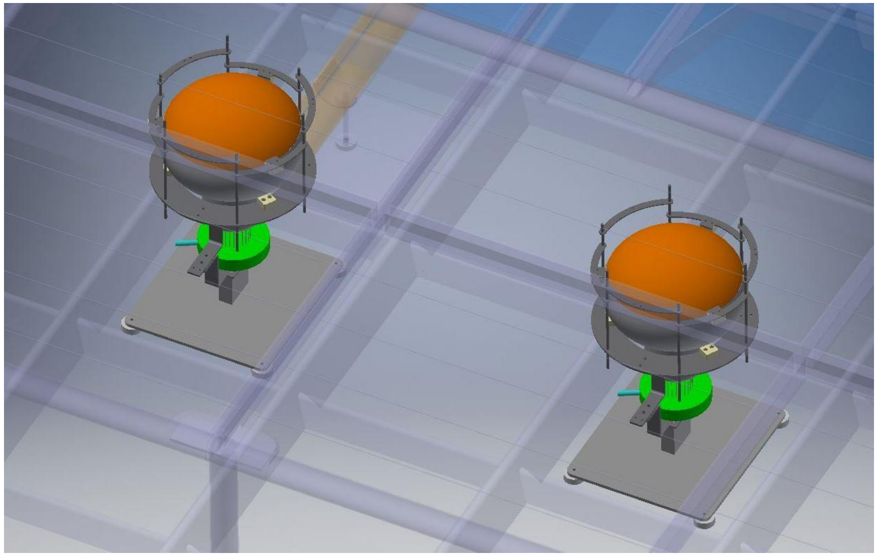


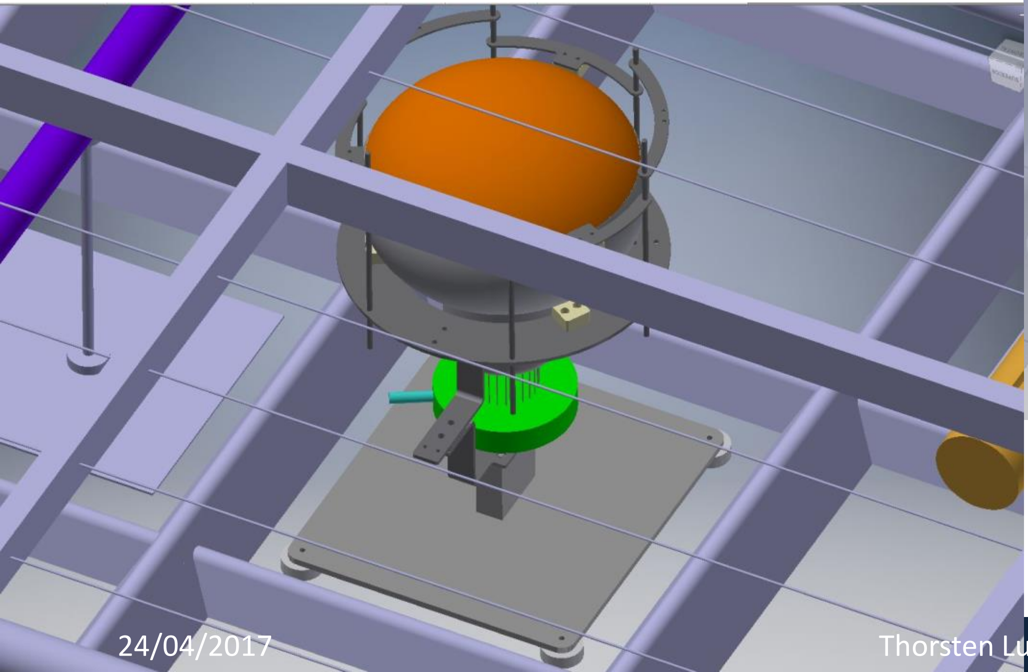


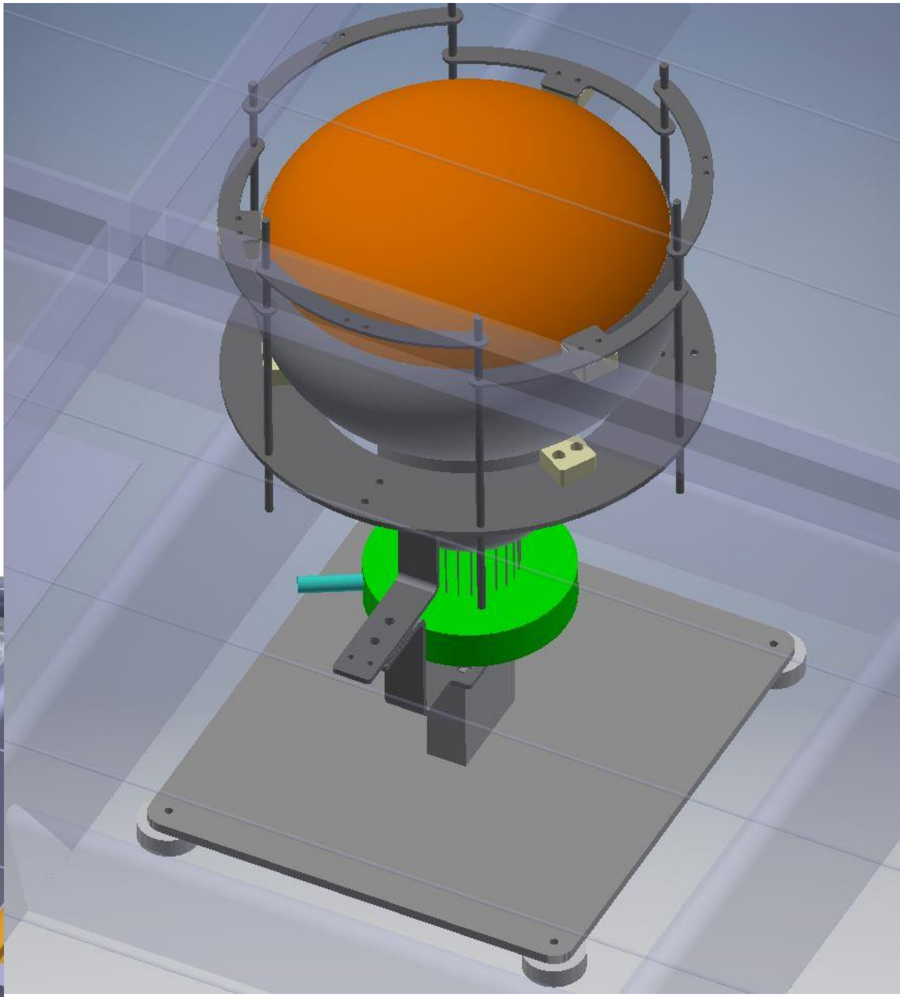




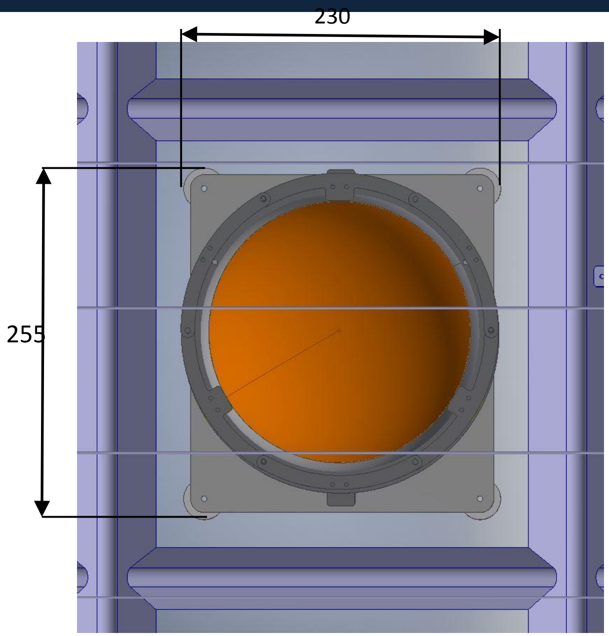
The PMT can be placed on the centre of the ‘square’ position between the stiffener of the shell .







Weight of the PMT +support & base ~6,5 kg.
Buoyancy force of the system ~5,5 kg.



Stainless Steel support base of the PMTs:
4 PTFE Ø30 mm contact pieces on the shell.