Light detection in Large scale cryogenic liquid detectors

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DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT
AIDA 2020
WA105

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- R&D on alternative LROs:
  - SiPM directly sensitive to 128 nm
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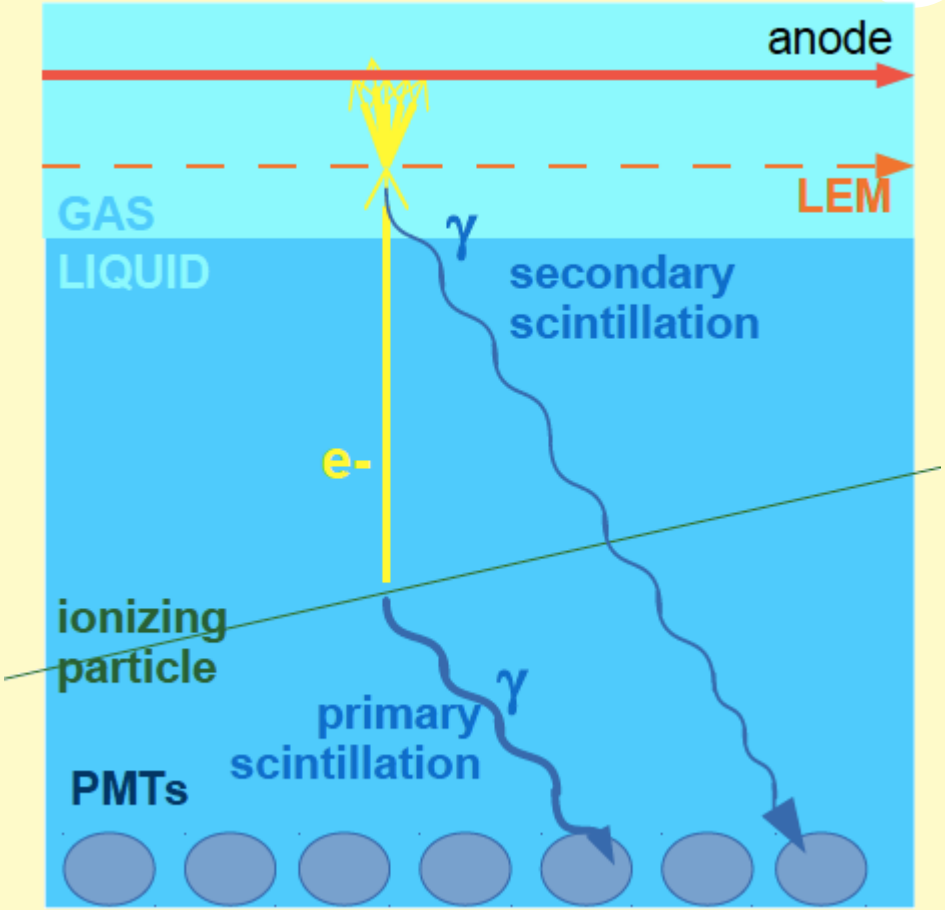
Dual-phase LAr TPC



Ionizing particle in LAr (2.12 MeV/cm for mip)

Two measurements:

1. **Charge from ionization**: tracking and calorimetry

Double-phase: multiplication in gas to increase gain and allow for long drift distances (> 5m) and low energy thresholds

2. **Scintillation light**: primary scintillation (trigger and t0) & secondary scintillation in gas

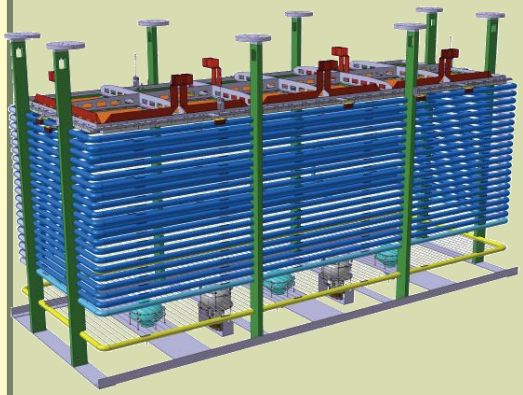
Large surface instrumented with PMTs in LAr

Dual-phase LAr R&D

- **Fundamental step**: realization and operation of large-scale detector prototyping before going to kton scale.

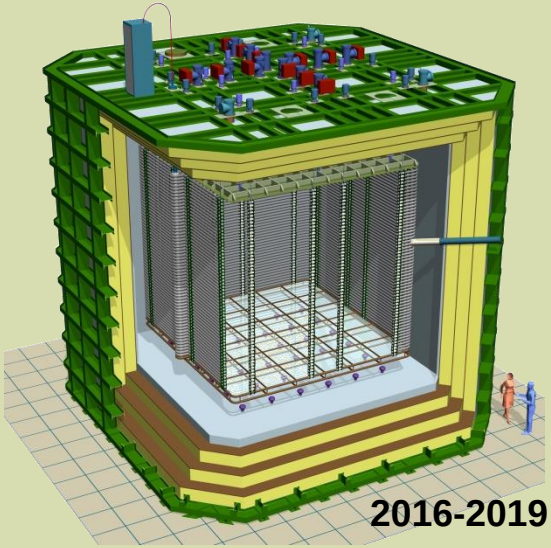
CERN Neutrino Platform

WA105 3x1x1 m^3 proto (~4.2 ton) under installation @CERN



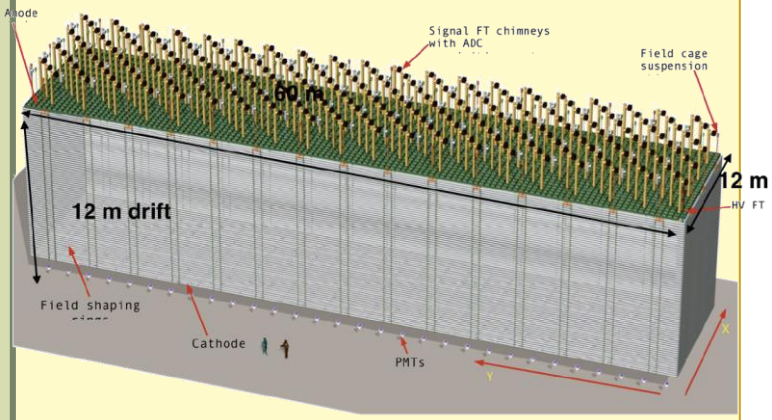
2015-2016

WA105 6x6x6 m^3 (~300 ton) in charged-particle test beam



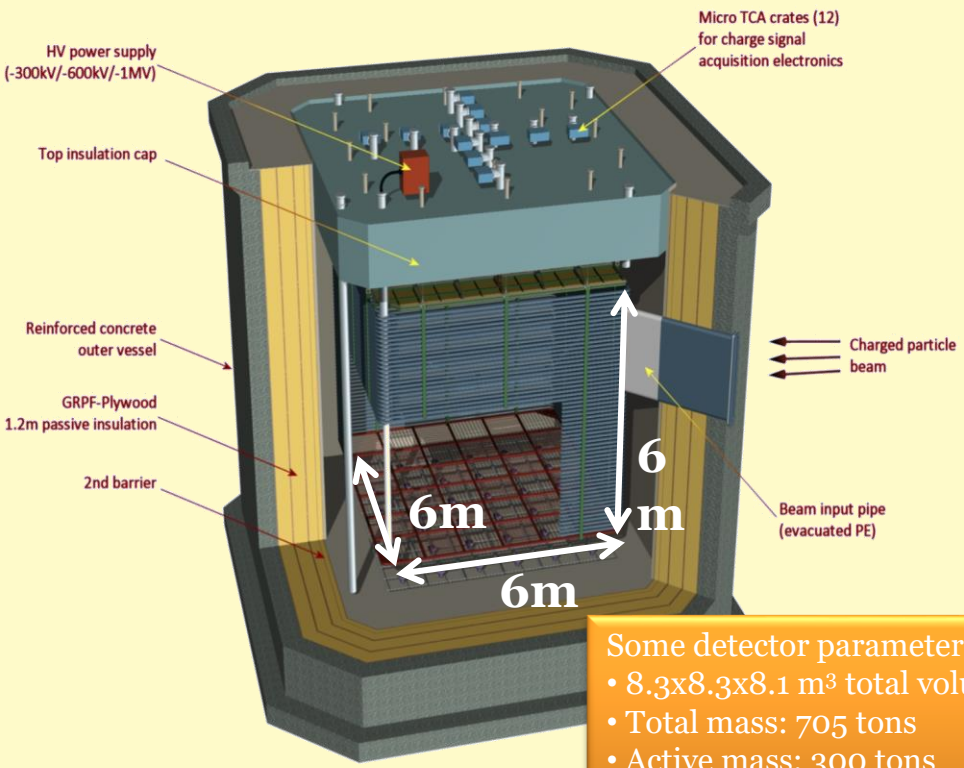
2016-2019

DUNE Far Detector: 10 kton dual-phase LAr detector (12x12x60 m^3)



WA105/ProtoDUNE-dual phase photon system

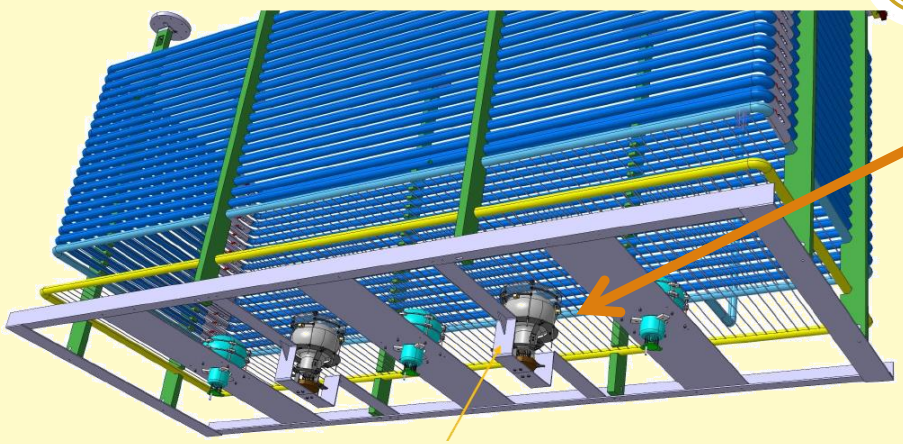
- **6x6x6 m3 (fid.) DLAr TPC @CERN** to test technical solutions and perform physics studies

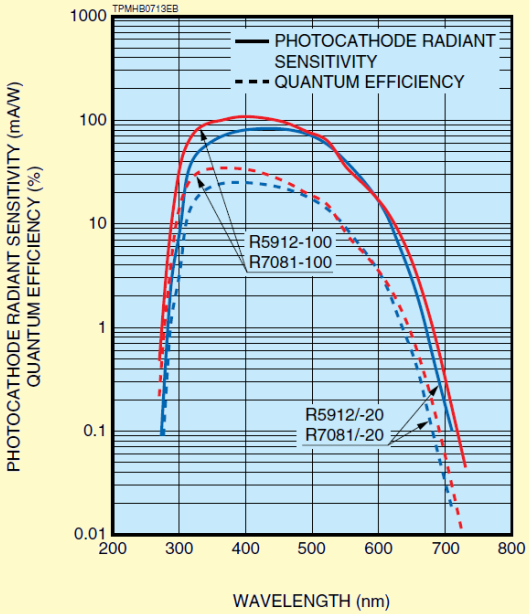


Some detector parameters
- 8.3x8.3x8.1 m³ total volume
- Total mass: 705 tons
- Active mass: 300 tons
- 7680 charge readout channels

- **Basic configuration**:
  - 36 cryogenic photomultipliers
  - Wavelength-shifter: TPB coating on the PMT (or on external plates)
  - Voltage divider base + single HV-signal cable + splitter (external)
  - DAQ system (external)
- **Goals**:
  - Trigger for non-beam events
  - t_0 for both beam and non-beam events (cosmic background rejection)
  - Possibility to perform calorimetric measurements and particle identification

WA105/ProtoDUNE-dual phase PMTs





- Hamamatsu R5912-02mod 8” PMTs
- Suitable for Lar and proven technology in LAr
- Excellent timing resolution
- Dynode stages: 10/14
- Gain: $10^7/10^9$
- Dark counts: 4000 cps
- Diameter: 8”
- Cathode coverage: ~3%

3x1x1 will be perfect test bench to understand light detection for double phase.

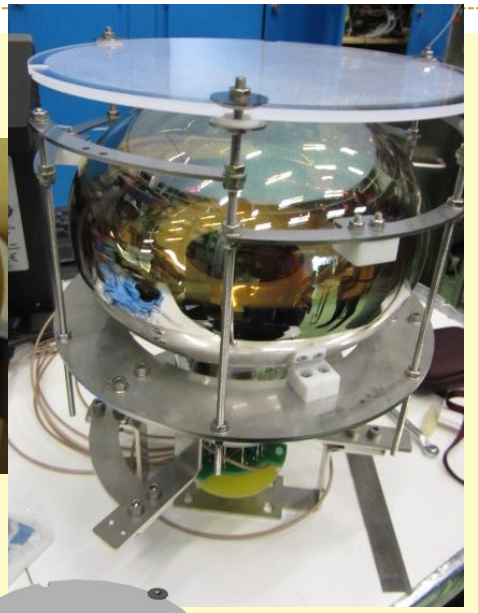
WA105/ProtoDUNE-dual phase PMTs

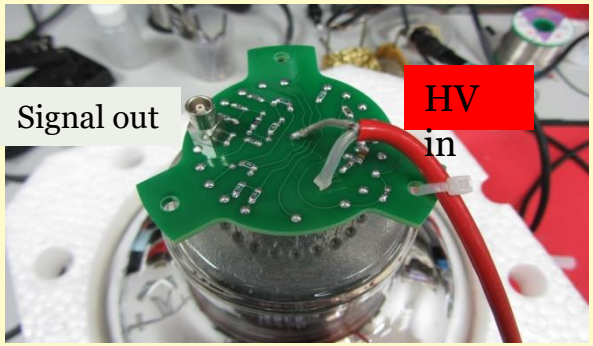
- 2 possibilities are considered for the wavelength shifter
  - TPB on the PMT
  - TPB on external plates

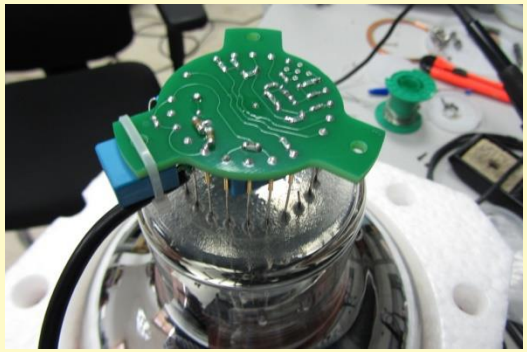
➔Mechanical structure designed accordingly

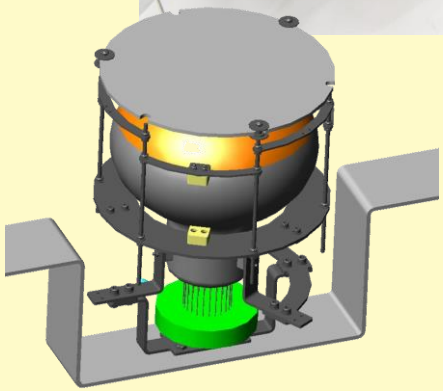
- 2 possibilities for power supply and cabling:
  - Negative HV
  - Positive HV

TPB evaporated on PMT





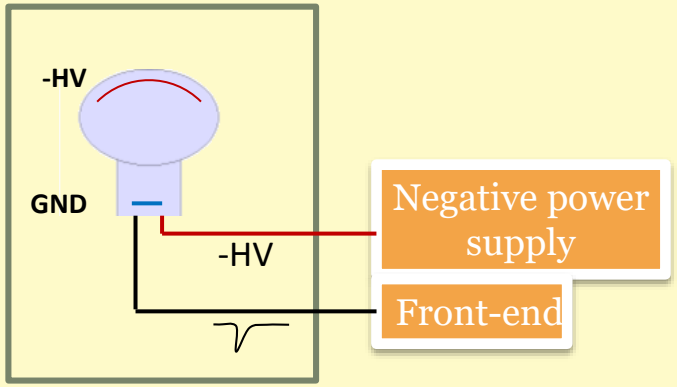


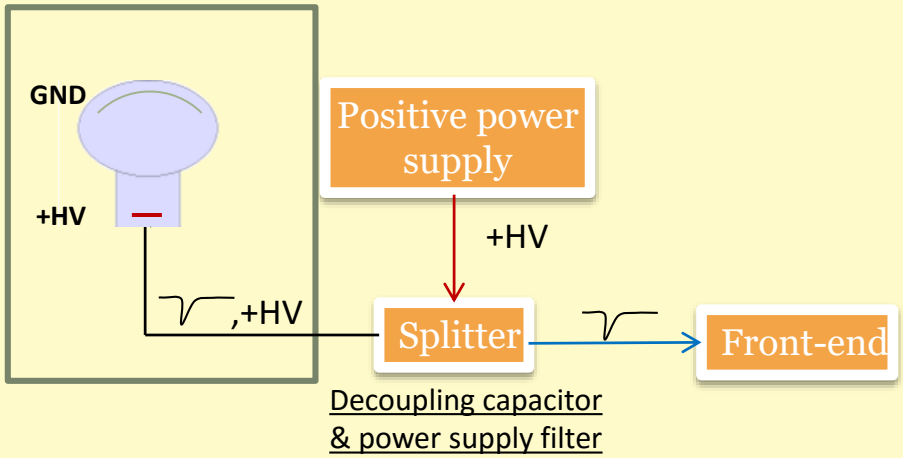


WA105/ProtoDUNE-dual phase PMTs power supplies and cabling options

A) Current design:
- Negative power supply
- 2 Wires per PMT

B) Ciemat Proposed design:
- Positive power supply
- 1 Wire per PMT



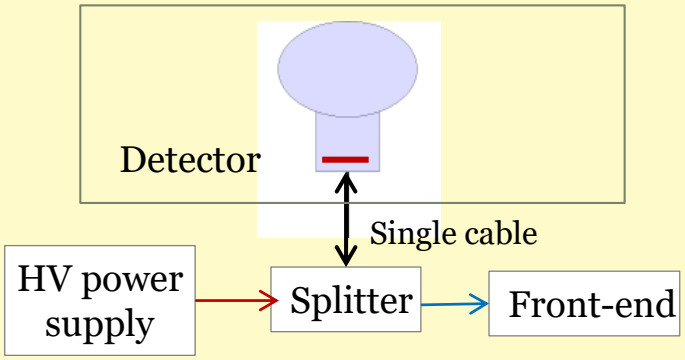


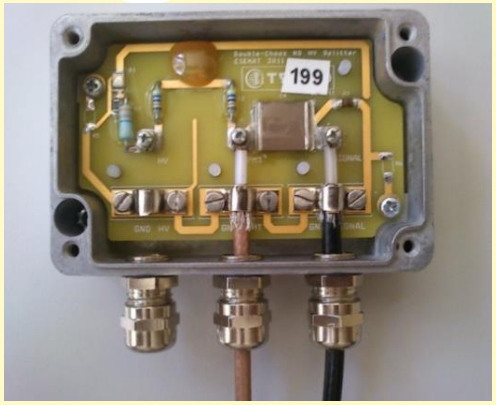
Proposed design pros:
- One cable and one feed-through per PMT in the vessel
- Photo-cathode grounded

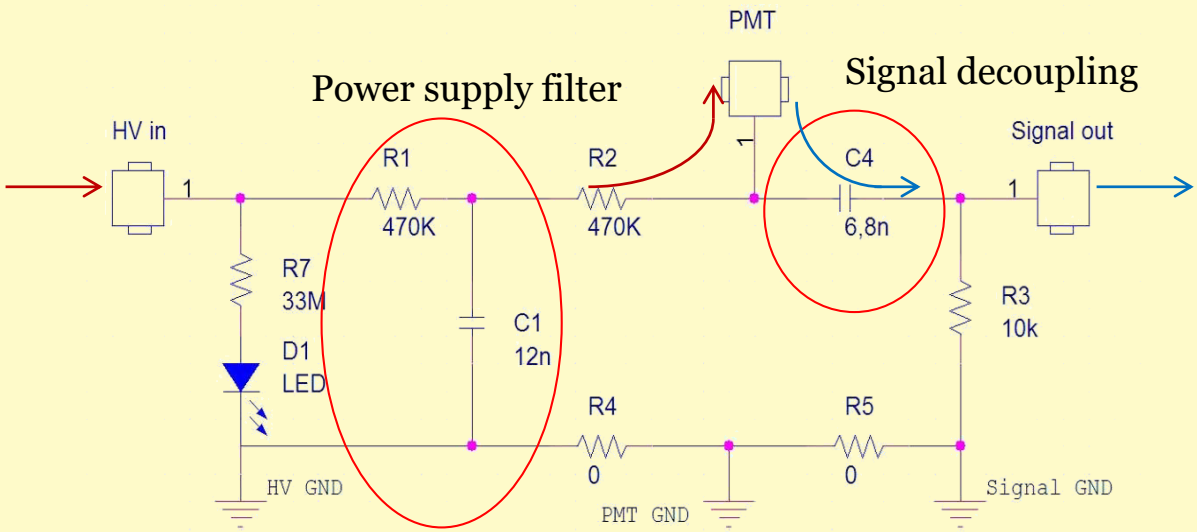
Cons:
- External decoupling (splitter) needed

Same PMT behavior expected (gain, signal shape.. etc) in both options

WA105/ProtoDUNE-dual phase PMTs Splitters





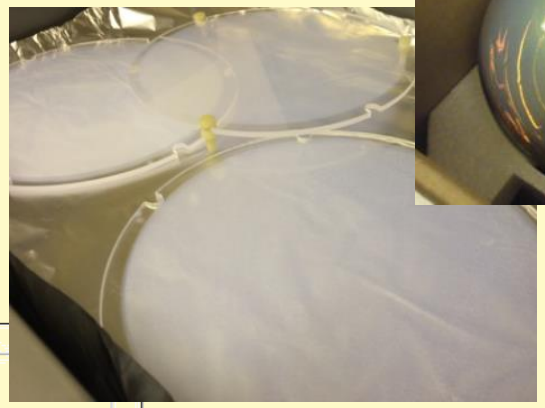


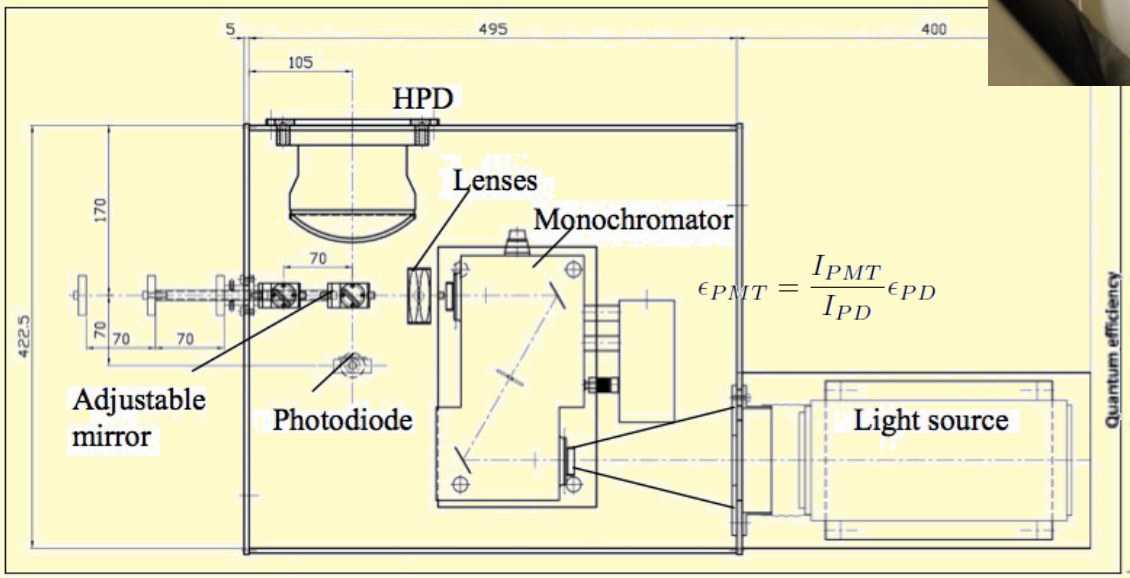
- Each single splitter is enclosed into an aluminum box to reduce EM noise and crosstalk between channels.
- The cables are directly connected to the board by screws and clamps. This reduces costs, the space required inside and outside the splitter boxes is reduced and the cable connections are keep inside the box which is good for noise an humidity.

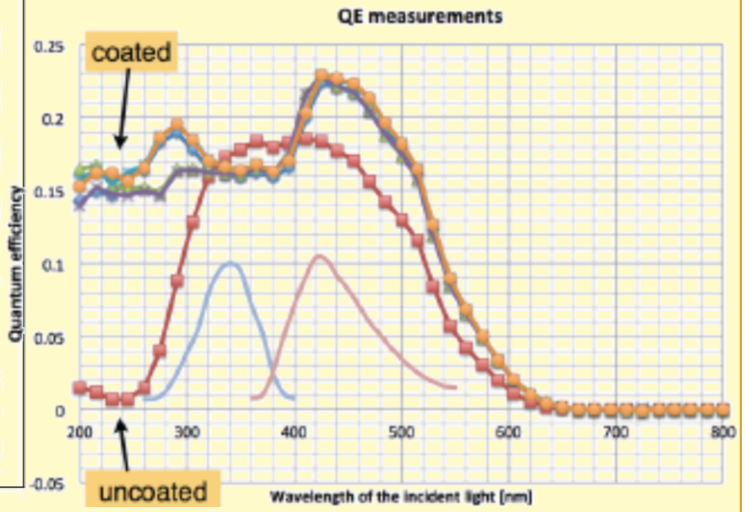
Performed Tests for the 3x1x1 m3 detector PMTs

TPB coating and QE measurements at CERN

- TPB is coated in PMT glass and acrylic plates by vacuum evaporation (0.05 – 0.2 mg/cm²)
- TPB uniformity was checked

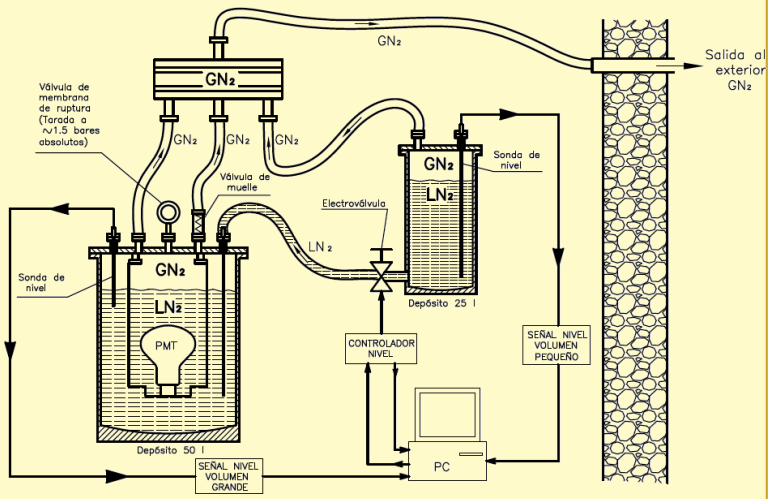


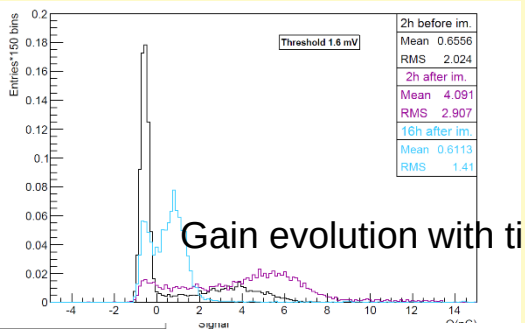




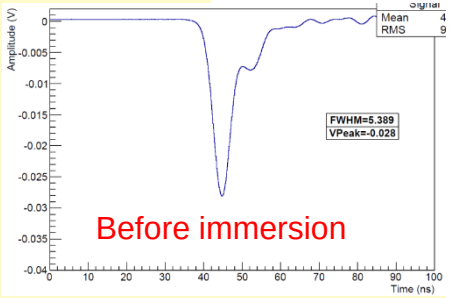
First cryogenic tests at CIEMAT

- PMT test in LN2:
  - Test of the PD system **up to 2 bars** (equivalent to ~7m LAr)
  - Test of PMT response **in cold** with single wire base:
    - Dark current
    - Pulse shape
    - Gain
  - Response of the system for **different light conditions** (in preparation)

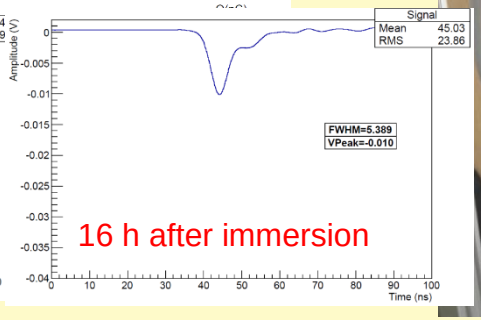




Gain evolution with time



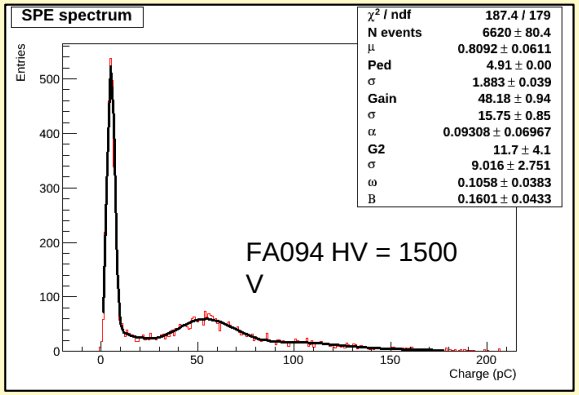
Before immersion

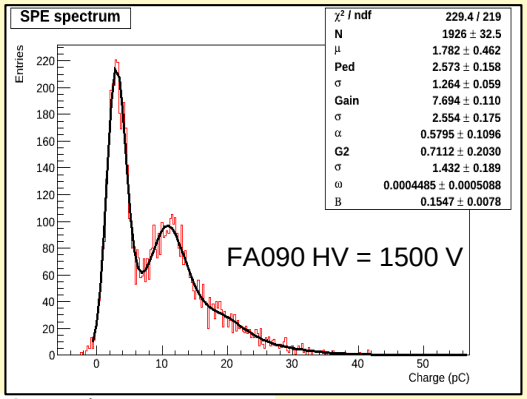


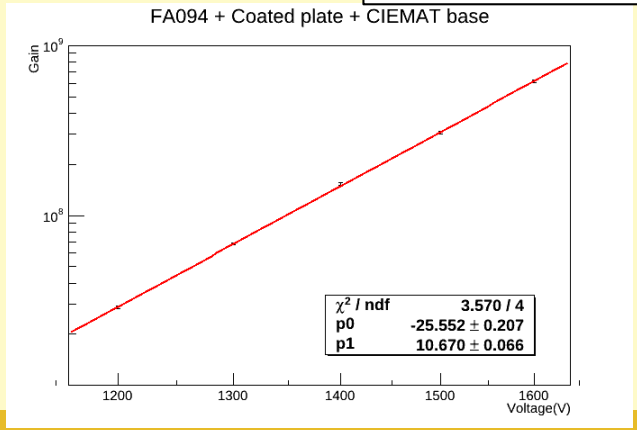
16 h after immersion

Pre-installation PMT tests at CERN

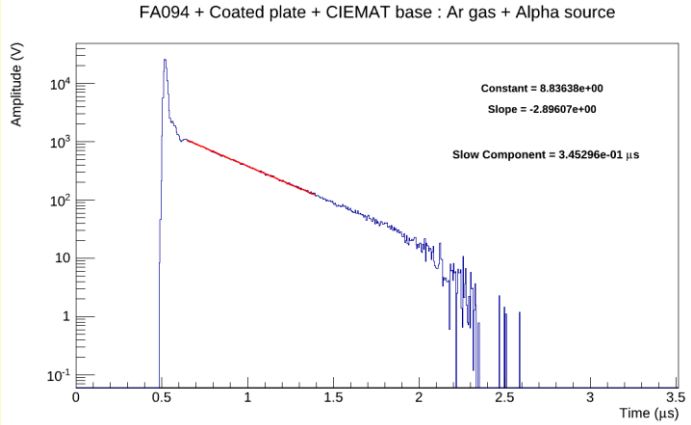
- Tests Performed for the **five** 3x1x1 PMTs
- Assembly of the whole photodetection system
- Gain tests with LED scanning the PMT voltage from 1000 V to 1600 V
- Test in GAr with alpha source for checking **128 nm light detection**

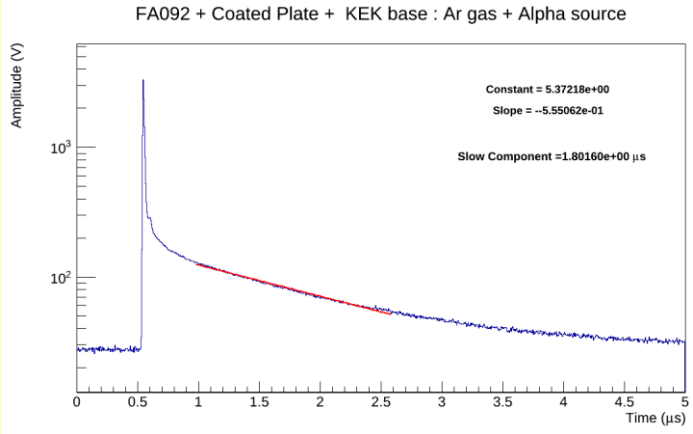






Ar scintillation response

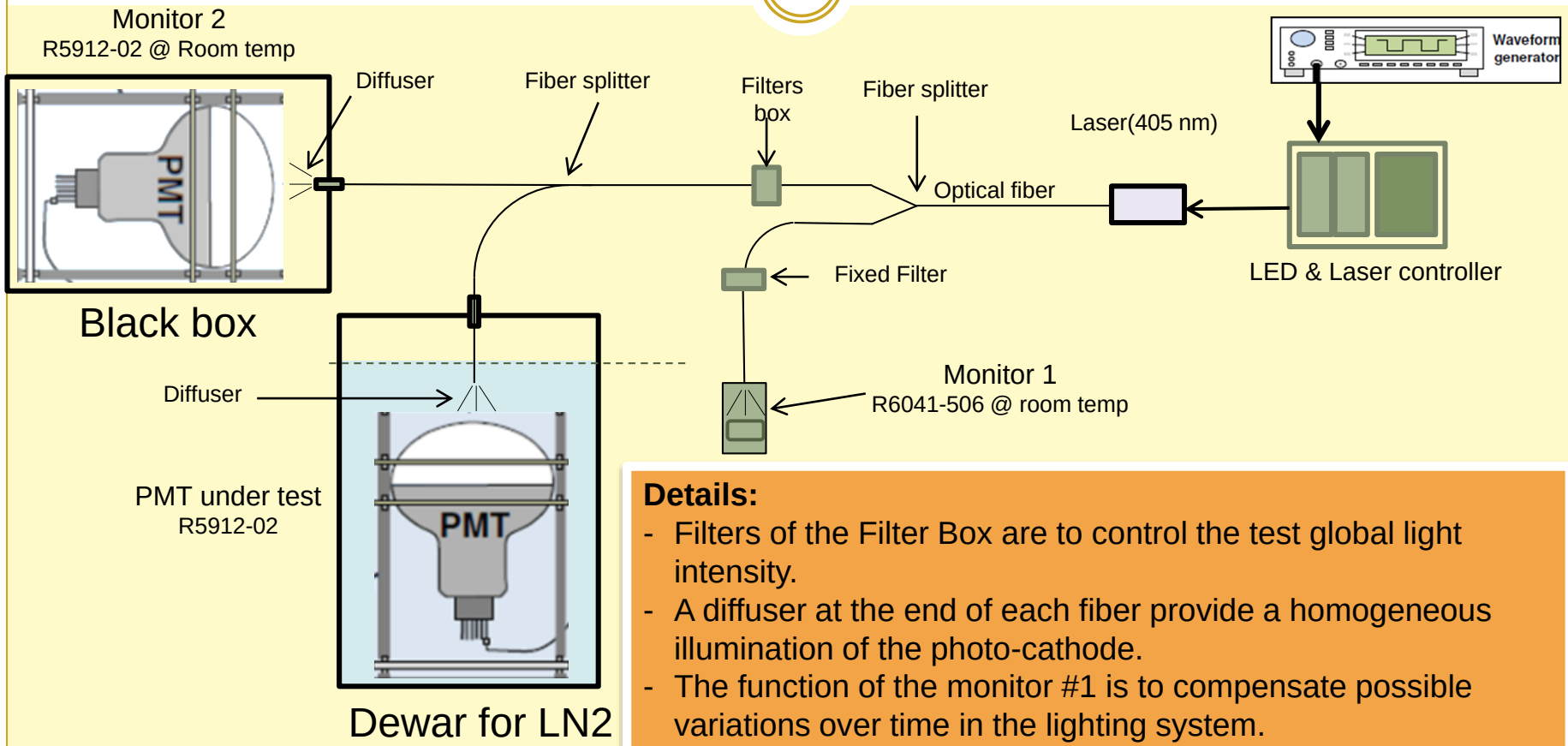




Plans for the PD system for the 6x6x6 m^3 detector

- Tests and setups at CIEMAT
  - **Test 1**: Design validation tests (with a few PMTs)
    - Study the variation of the PMT response with the light intensity and frequency + optimization of the PMT base
    - Setup ready (~60 l vessel)
  - **Test 2**: Characterization tests (with all PMTs)
    - Characterization of all PMTs being installed at WA105 at room and cryogenic temperature (dark current, gain vs HV, …)
    - Setup in preparation (~300 l vessel)
- TPB coating at CERN or Univ. Barcelona/IFAE
  - Uniformity and spectral response to be tested
  - Stability measurements foreseen
- Light calibration system being designed
- The complete PD system should be **operational in 2018**

Test 1 - Light setup

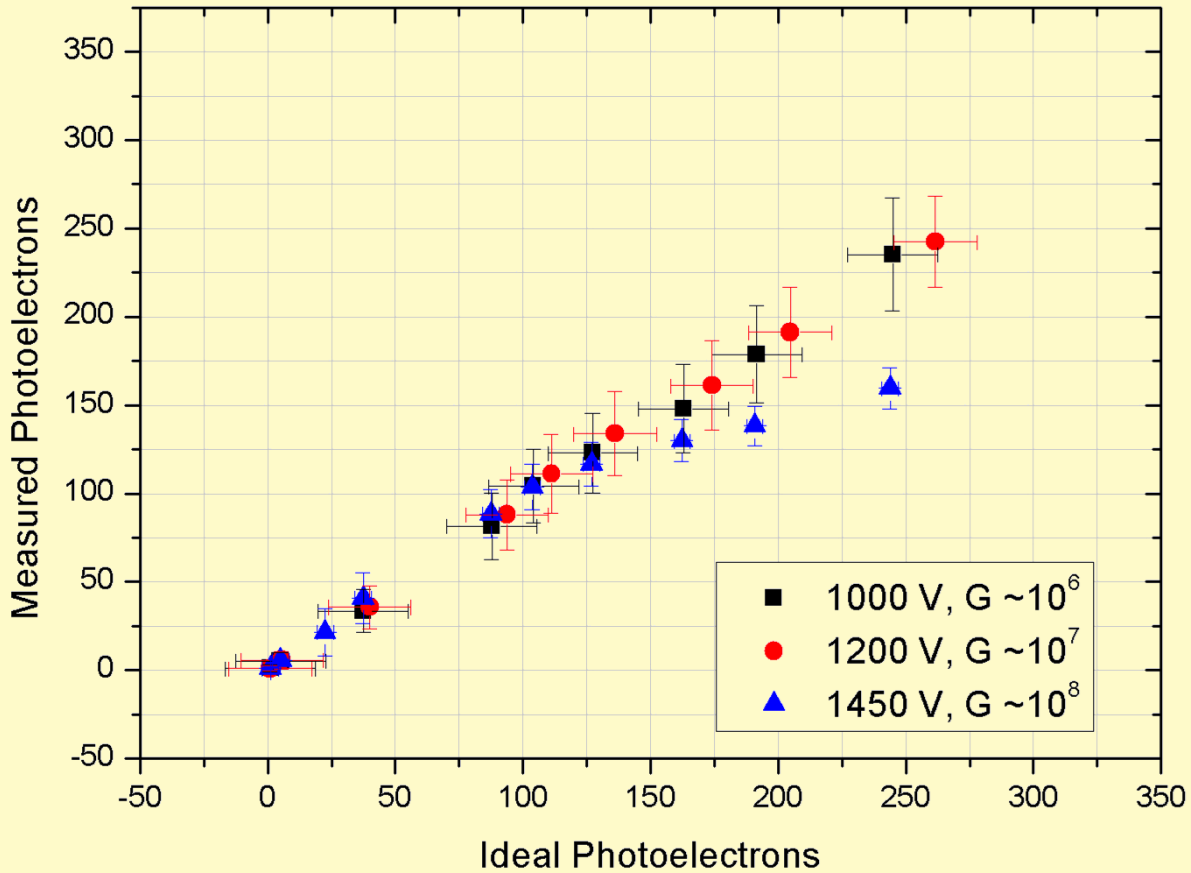


Details:

- Filters of the Filter Box are to control the test global light intensity.
- A diffuser at the end of each fiber provide a homogeneous illumination of the photo-cathode.
- The function of the monitor #1 is to compensate possible variations over time in the lighting system.
- The function of monitor #2 is to get simultaneous outputs of the same PMT type at room temperature and in LN2 for being compared receiving the same amount of light.

The three PMTs are single cable with + HV and signal splitter

Preliminary linearity results at room T



Cryogenic tests will be performed this Summer

Test 2 - 6x6x6 m³ Production tests

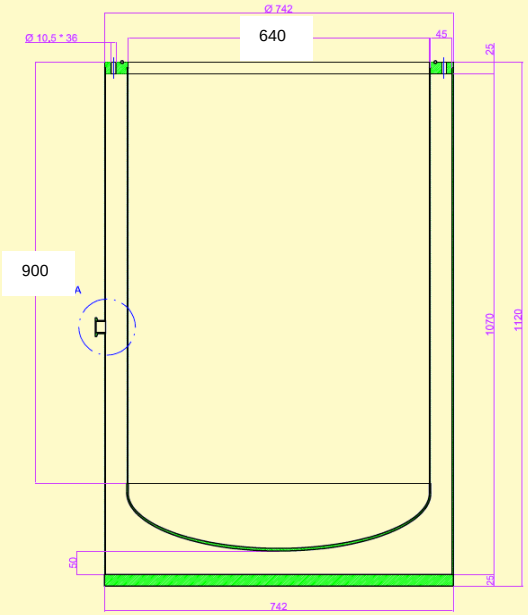
Fast tests to characterize and validate each single PMT+base before installation:

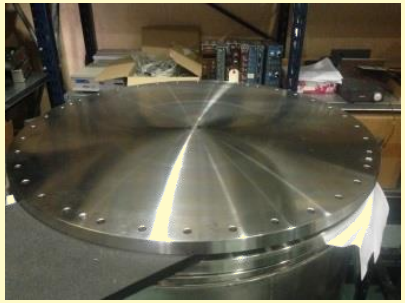
- Gain vs HV
- Dark current frequency

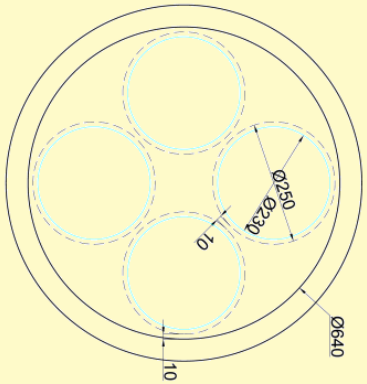
These tests will also be performed at room and cryogenic temperatures.

We have bought a vessel with capacity for 4 PMTs in LN2 to be able to test 4 PMTs/week.

On 2017 All 40 PMTS of the 6x6x6 will be tested at Ciemat.





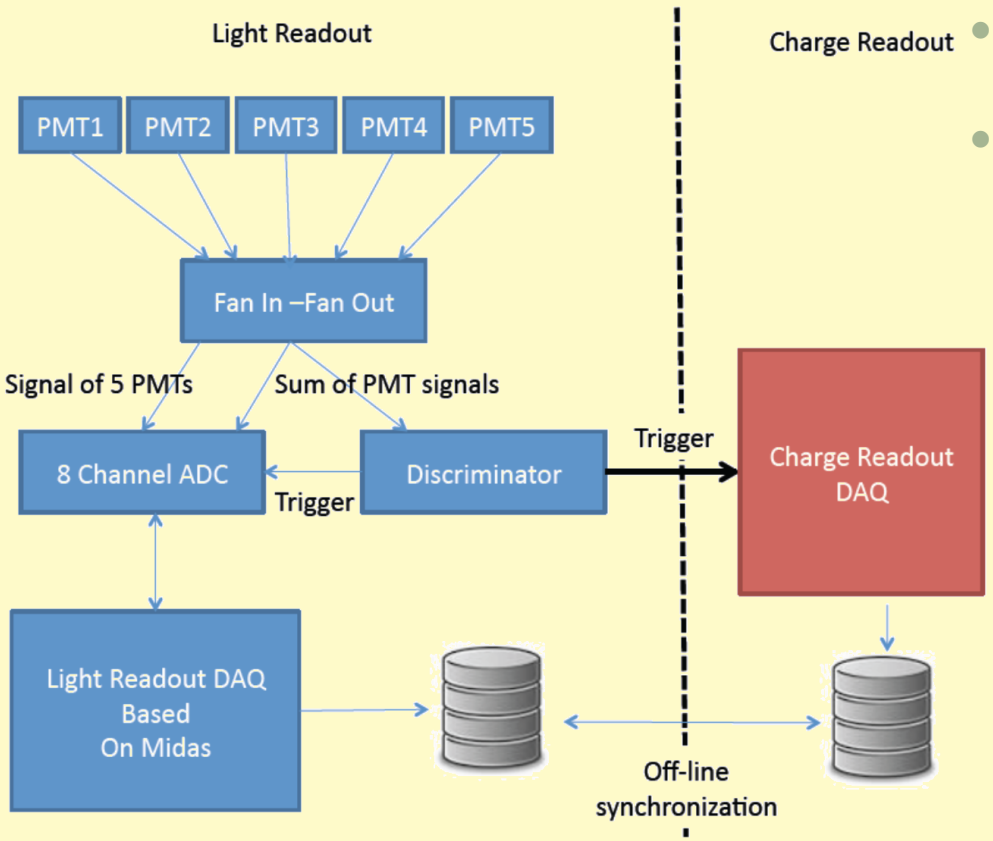


TPB Coating for WA105. IFAE

- **Thin Films Deposition system:**
- Chamber: high 45 cm, ∅: 30 cm.
- Mechanical pump
- Diffusion pump (High vacuum)
- Vacuum meters:
  - Pirani
  - Penning
- High intensity source
- In situ thickness measurement (quartz crystal microbalance)

- **TPB Deposition parameters:**
- Technique: Thermal evaporation
- Base pressure: $< 5 \cdot 10^{-7}$ mbar
- Substrates: glass and Acrylic (5 x 5 cm).

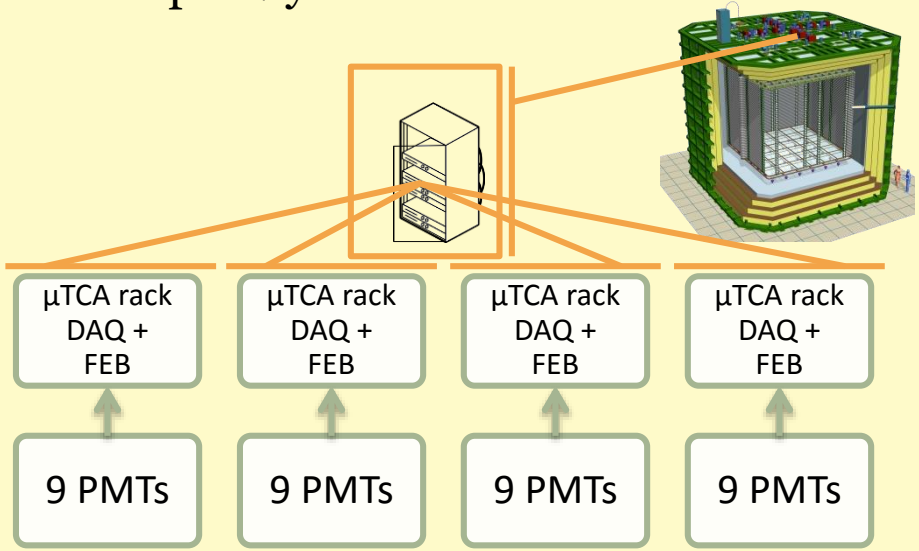
3x1x1 Light Readout Electronics



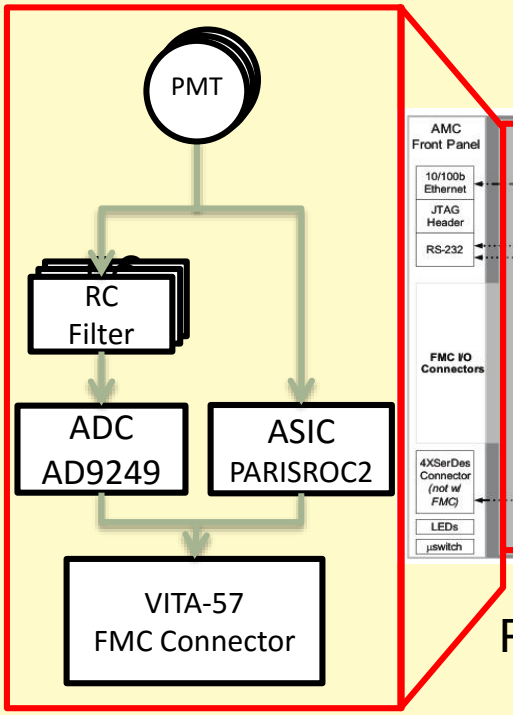
- Linux based DAQ developed byPSI and TRIUMF.
- The DAQ software was used at T2K and at the IFAE electroluminescence setup for DAQ and Slow Control.
  - Web interface.
  - Plenty of experience at IFAE.
  - Easy to setup
  - Tools available for decoding and monitoring.
  - Easy to integrate commercial hardware with C library interfaces.

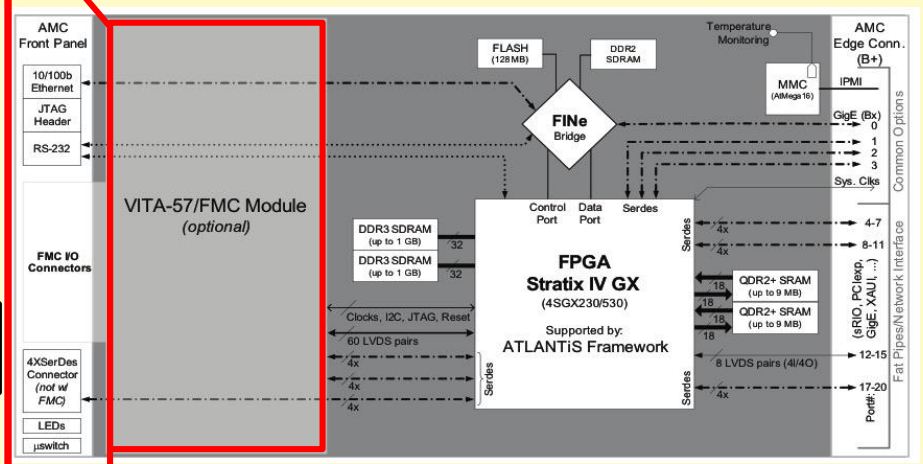
Light Readout Electronics

- Development of **cost-effective electronics** for light readout
- LRO electronics based on the same technology as charge readout = µTCA for easy integration in the global DAQ system
  - MicroTCA = Micro Telecommunications Computing Architecture
- Easy to scale for large detectors
- LRO FEB at room temperature (reliability, maintenance, upgradability)
- WA105 LRO FEB developed by APC-LAPP-OMEGA-IPNL collaboration



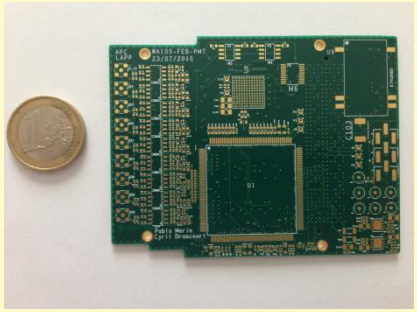
Readout Boards





FEB block diagram

LRO Front-End Board



- **PARISROC2 ASIC**

(Photomultiplier ARray Integrated in Sige ReadOut Chip)

  - 16 inputs for negative signals
  - Time stamping (1 ns precision)

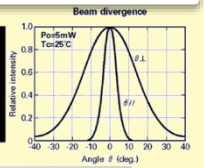
- **ADC AD9249** for charge measurement:
  - 16 channels
  - 14 bits at 40 MHz (T_s = 25 ns). Up to 65 MHz (T_s = 15.4 ns) if needed

Light calibration system

- Measure the gain inside the detector.
- Intercalibrate the optical units.
- Monitor the performances and the stability of the light detection system (QE, TPB conversion…)
- Monitor the detector behavior in "real time" (event rate, purity…)

It will be necessary to produce light inside the detector in a controlled way.

Light Production inside the Detector

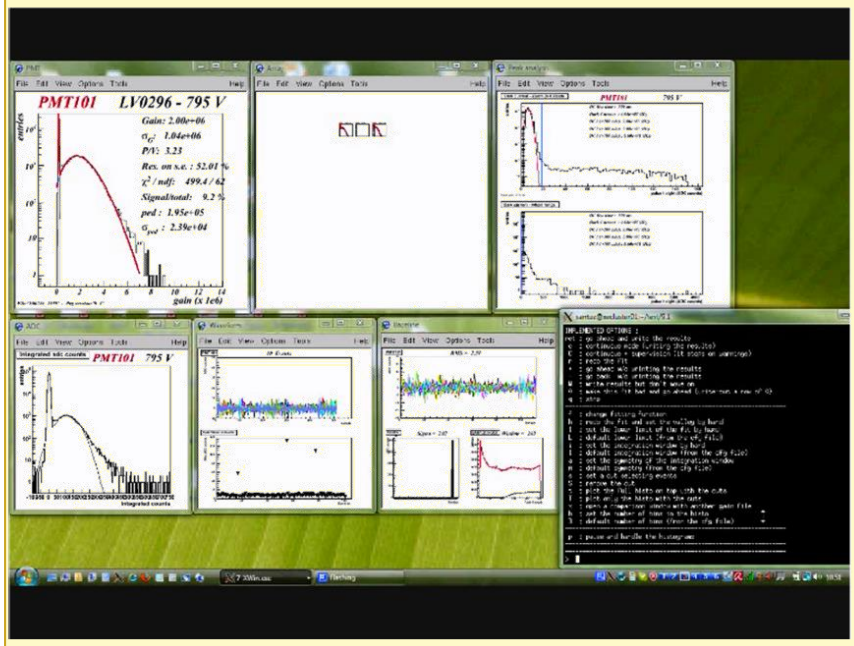


Produce the Light outside the Detector

Light calibration system.

Software

Automatic procedure

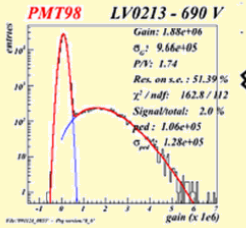


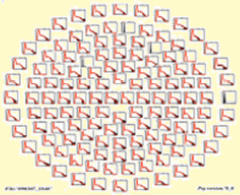
Calibration analysis → Extract PV, Gain, Dark counts ….etc

Monitoring Physics analysis

Automatic procedure:

FIT → ***Calibration Map*** → ***Gain files*** → ***(DB to store /access the data)***

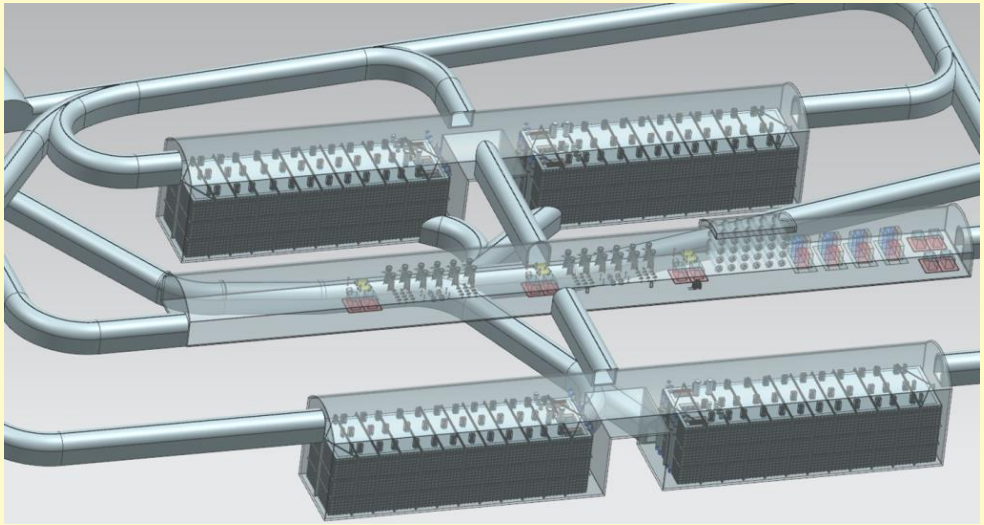




PMT	gain	sigma	gain-ped	sig_ped	p/v	res(%)	chi2	adc/elec	adc-ped/elec	RMS	sig/noise
1	2.57e+06	1.67e+06	2.57e+06	1.75e+05	1.79	64.8	7.96	150.07	149.91	0.00	10.0
2	2.71e+06	2.17e+06	2.68e+06	1.67e+05	1.48	80.1	2.35	158.17	156.21	0.00	10.5
3	1.91e+06	1.07e+06	2.01e+06	1.02e+05	2.85	56.1	1.20	111.45	117.41	0.00	9.5
4	2.43e+06	1.14e+06	2.52e+06	1.31e+05	4.23	46.9	1.51	141.77	147.05	0.00	9.0
5	2.45e+06	1.43e+06	2.56e+06	8.87e+04	3.06	58.4	1.72	143.06	149.55	0.00	8.1
6	2.52e+06	1.21e+06	2.63e+06	1.04e+05	4.79	48.1	4.67	147.13	153.67	0.00	7.6
7	2.06e+06	1.06e+06	2.98e+06	9.40e+04	2.52	65.0	5.59	166.93	173.77	0.00	9.4
8	2.32e+06	1.44e+06	2.51e+06	1.20e+05	2.53	61.9	1.78	135.62	146.67	0.00	6.9

DUNE Far Detector dual-phase light readout system

- Hamamatsu R5912-02mod PMTs + coating, at the bottom of the tank below the transparent cathode (same as WA105)
  - Minimal: 1 PMT/4m² (180 PMTs)
- Mechanical supports implemented for different TPB coating options
- Single cable for HV + signal
- Development prototype of uTCA light readout digitization boards based on Bittware S4AM, 9 channels/card, 36 PMTs in 6x6x6
- Trigger from PARISCROC2 ASIC

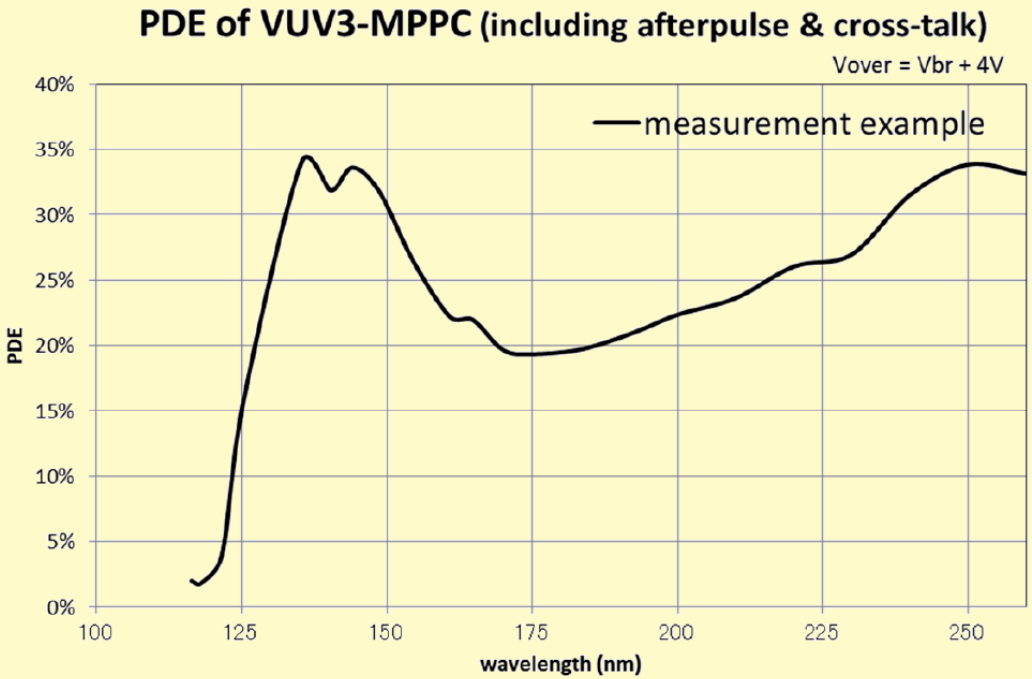


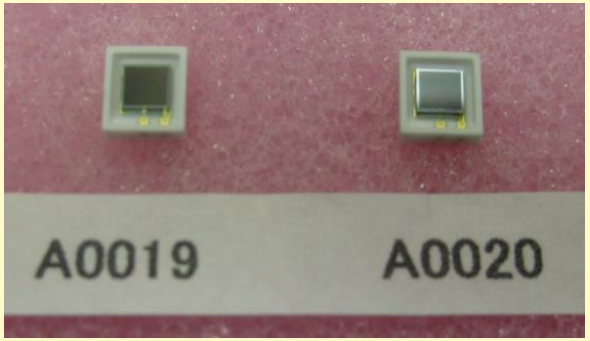
Input from WA105 will be crucial for final configuration of a 10 kton dual-phase DUNE Far Detector

R&D

VUV SiPM Prototype. Performed Tests

- New SiPMs from Hamamatsu (3x3mm – 100um VUV3) sensitive to VUV light without wavelength shifter



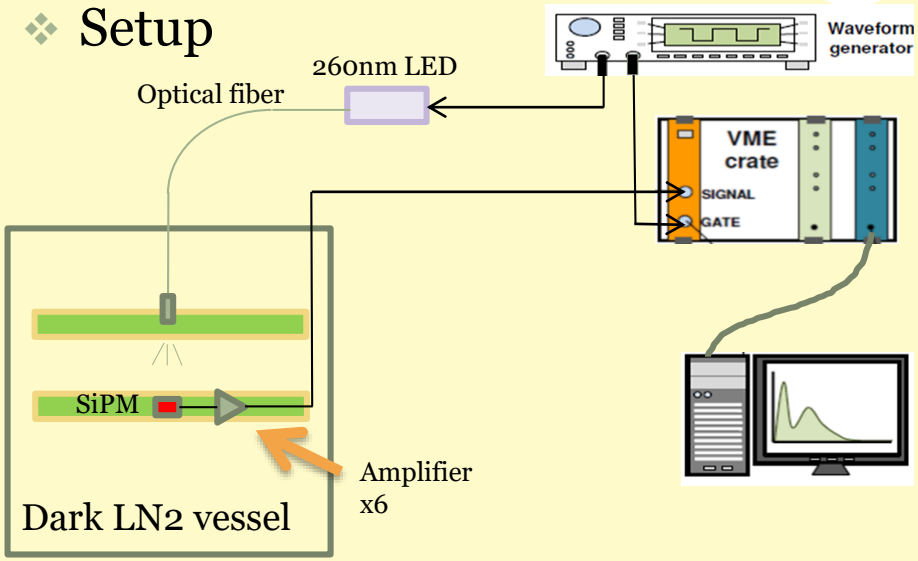


Serial No.	Vop [V]	dark counts (kcps)
A0019	53.53	671
A0020	53.63	607

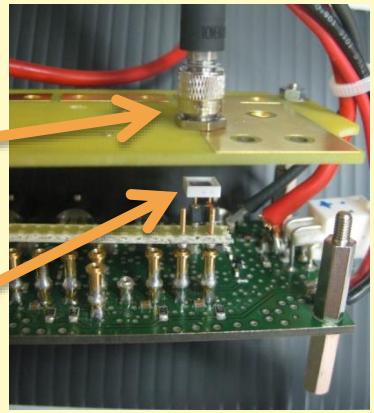
Vop : Operating Voltage at Gain = 5.5x10^6

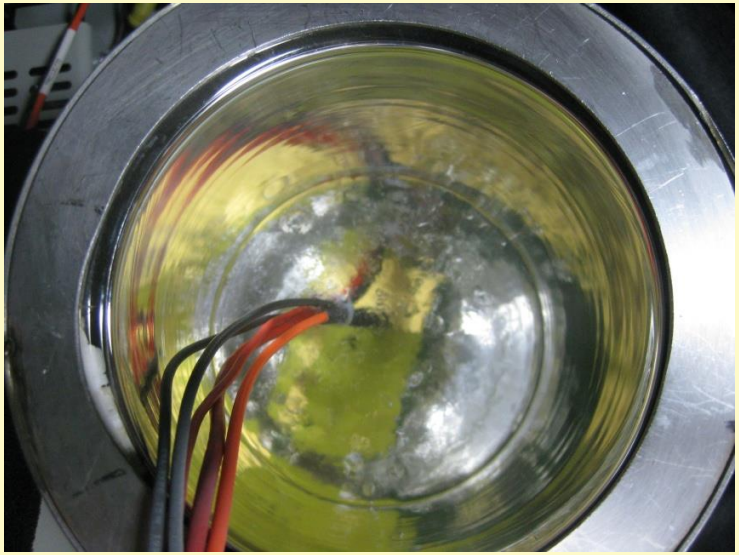
VUV SiPM Prototype. Performed Tests

- Setup



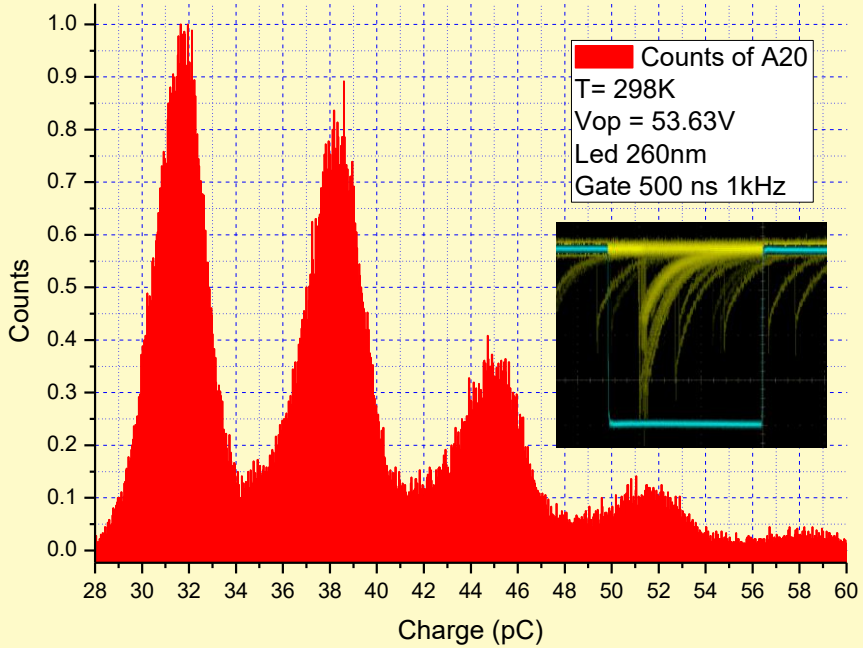
Gali S66 Amplifier (x6)
Thorlabs 260 nm LED
CAEN V965A QDC
Tek AFG3252 Signal Generator

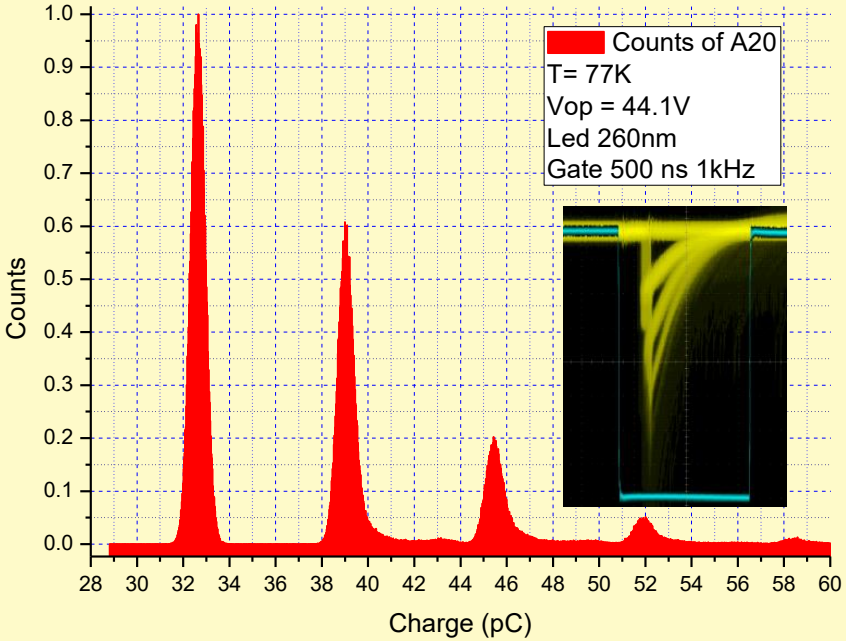




VUV SiPM Prototype. Performed Tests

The aim of this first tests is to check how the devices behave at cryogenic temperatures and low wavelengths



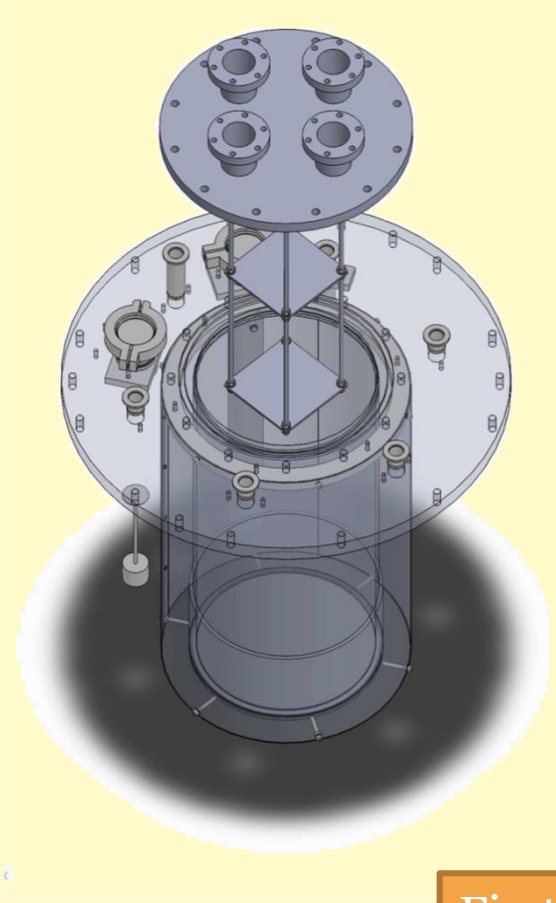


Serial N.	Vop (V)	Dark Counts (cps)	Gain
A0019	53.53	750k	6.40E6
A0020	53.63	675k	6.84E6

Serial N.	Vop * (V)	Dark Counts (cps)	Gain
A0019	44.0	~20	6.93E6
A0020	44.1	~20	6.71E6

*The Temperature coefficient provided by Hamamatsu doesn't work at 77K. Vop for LN2 is an estimation so we have a similar gain than the one we have at room temperature.

VUV SiPM Prototype. New Setup in Progress



- New dewar construction in progress.
- Lid just arrived ➔ **Ready to start the Tests!**

- Replace QDC with fast ADC ➔ Readout Software and post processing already developed.

- The aim of this setup:

  1. *Measure the PDE in Liquid Argon @ 128nm*

  2. *Systematic measurement of dark counts and Operating Voltage*

First results will be available for the end of this summer

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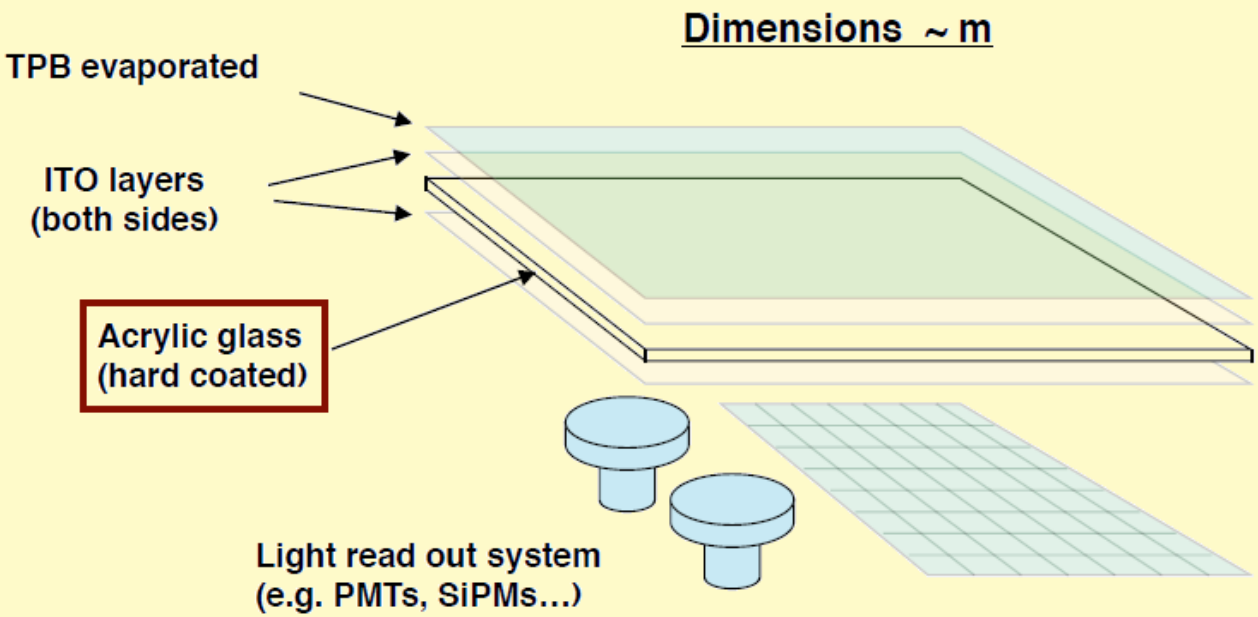
ITO + TPB as Cathode. ETH Zurich

- Idea: Replace grid cathode Transparent cathode built from PMMA plates coated with conductive ITO (Indium Tin Oxide) coating
- TPB coating for VUV shifting



Principle to be tested in the ArDM experiment

Advantages:

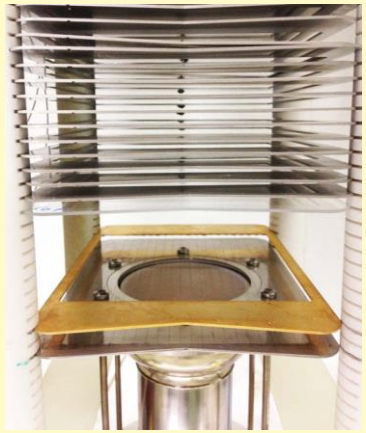
- Uncoated PMTs will not be sensitive to light produced below cathode
- Protection against discharges due to possible bubbles from bottom of the tank

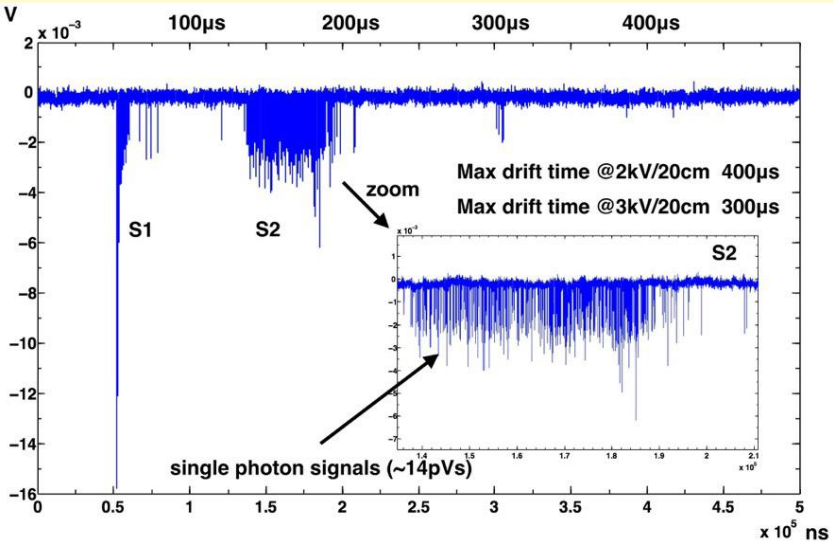
Bit it is….

- Expensive
- Many plates of <=1 m² ➔ gluing them together and align them
- Effect of ions on TPB?

ITO + TPB as Cathode. ETH Zurich

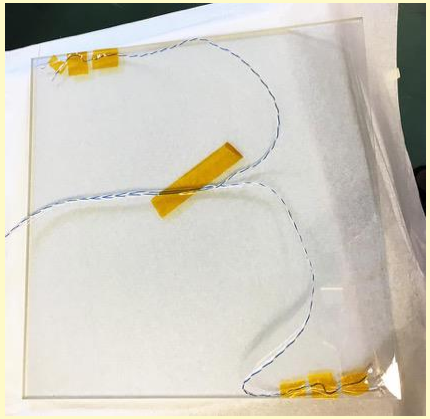
A first proof of principle operation in 3L LAr TPC





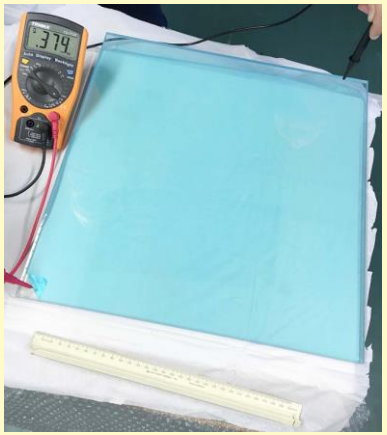
Mechanical and resistive tests of the coating

- Contacts seem also be reliable at low temperature



Gluing Tests:

Excellent mechanical and optical properties



1m open cryostat @ CERN - half filled with LAr

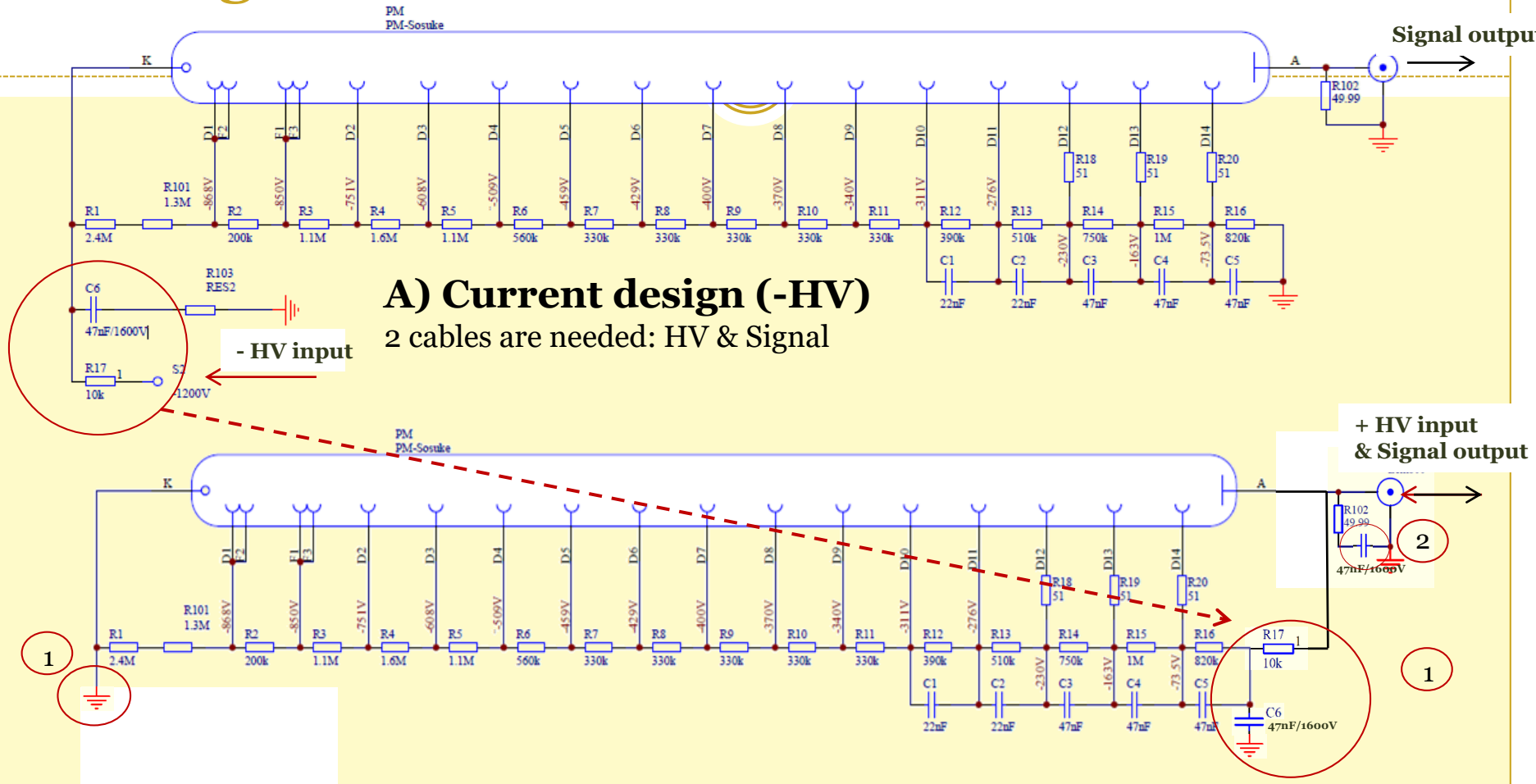
Conclusions

- We are working on the light readout for double phase LAR TPC with PMTs as baselines and other alternatives.
- WA105 will allow us to test all proposed solutions for large scale detectors.
- We will follow closely the evolution of the single-phase proposals and the results DUNE Single Phase light readout.
- From these studies an optimized proposal for 10 KT detector light readout system will emerge.

Thank you for your attention

BACKUP

Negative & Positive PMTs base circuits



A) Current design (-HV)

2 cables are needed: HV & Signal

B) Proposed design (+HV)

Only one cable is needed for HV & Signal.

Circuit changes:

1- Input RC filter is moved from cathode to anode and cathode is directly connected to GND

2- The 50Ω termination resistor is connected to GND by a capacitor

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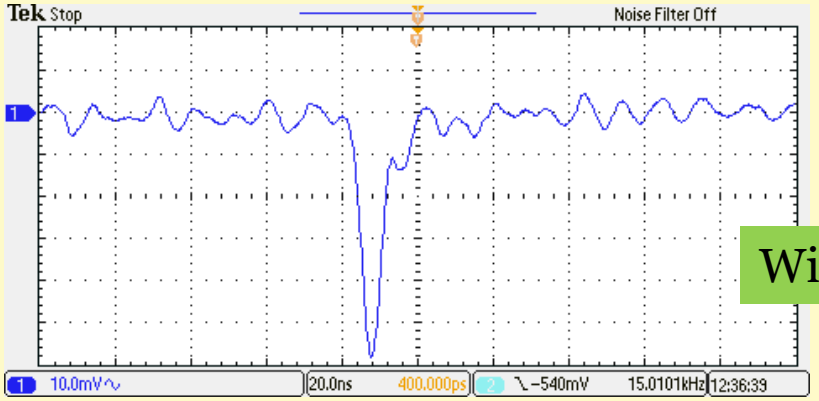
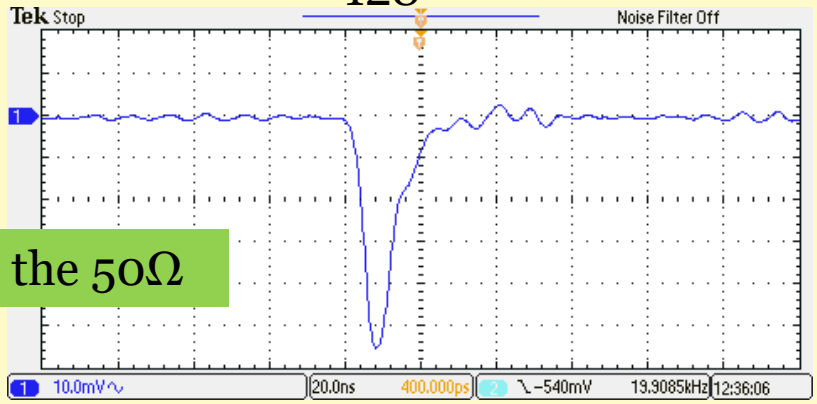
Preliminary Tests – Positive base with/without the 50Ω termination

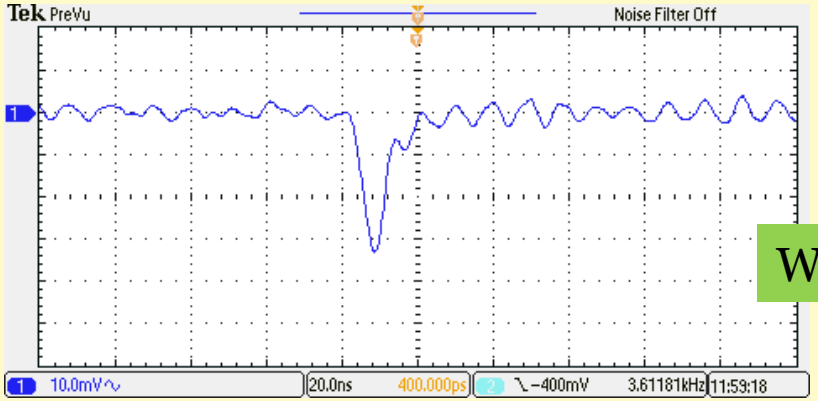
Single waveform

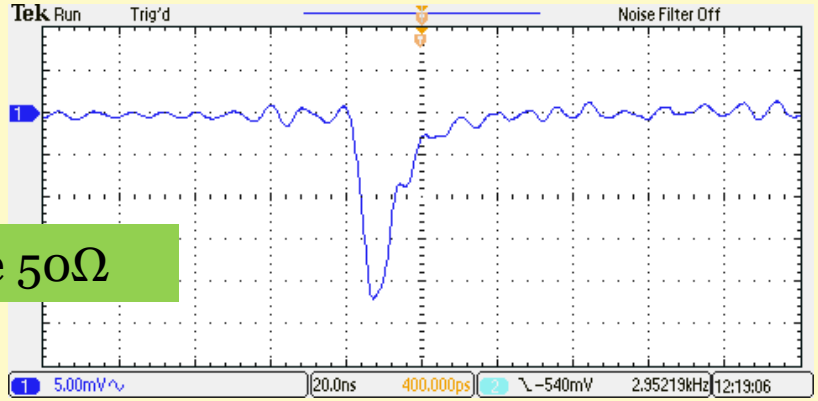


Average of 128



Without the 50Ω





With the 50Ω

No reflections observed removing the 50 termination at the PMT base, so, it's not needed and we save the extra capacitor on the base.

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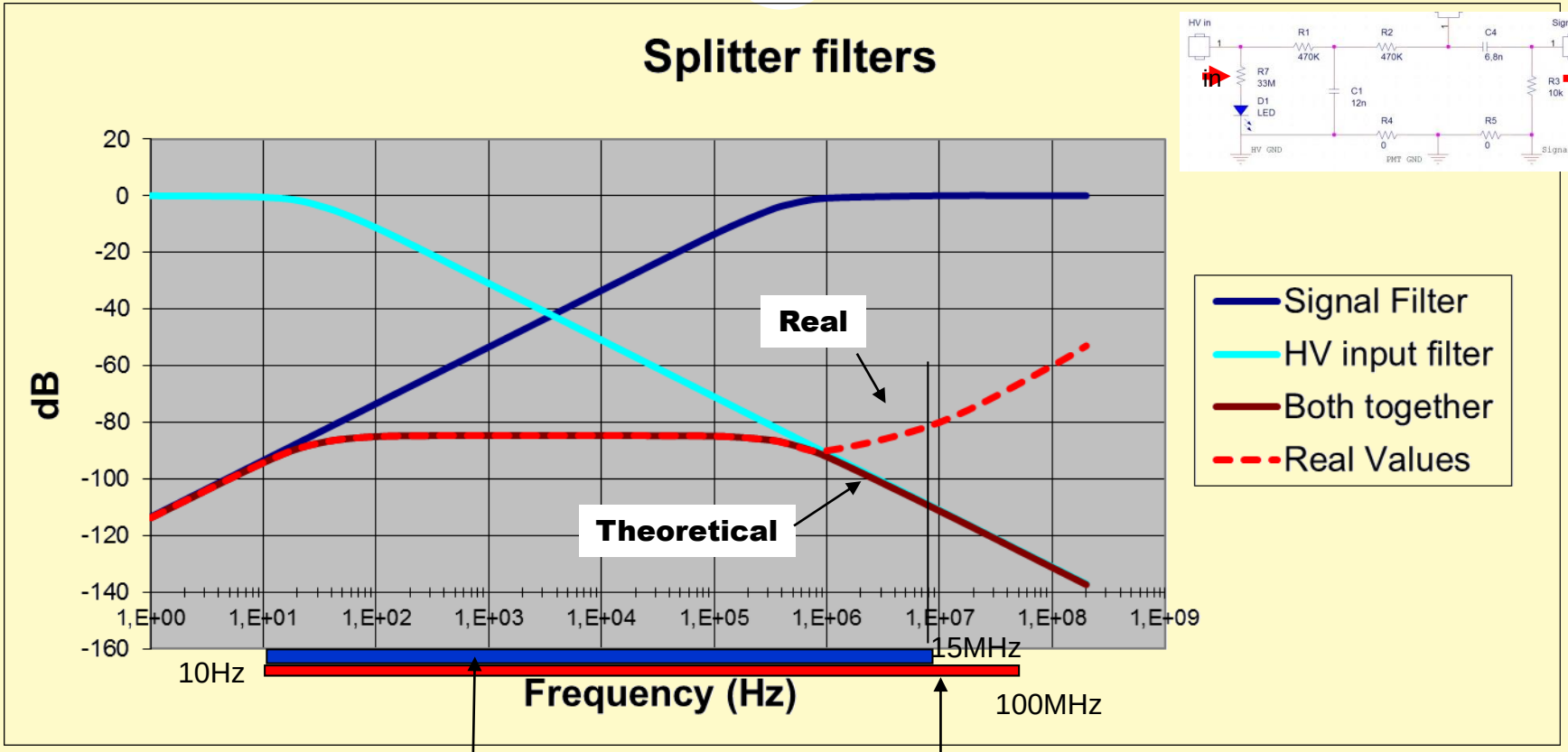
Preliminary Tests - Conclusions

- Dual cable base pick-up more low frequency noise (base line oscilation) which can easily removed by SW.
- Single cable base removes the low freq. noise but pick-up a bit more high freq. noise.
- Same gain for same absolute voltage
- SPE with similar resolution for both bases
- The 50Ω termination is not needed and no extra capacitors are needed in the positive base vs the negative base.

HV to Signal-Output noise transference in the DC splitter



A1535 Voltage ripple specification: 30mV max from 10Hz to 15MHz

A1535 Voltage ripple measurements: ~ 250mV up to 100MHz (worst channel)

With the splitter atenuation (>50dB) Vripple ≤ 1mV

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Some issues for WA105

- Cosmics are normally great for detector characterization but in for WA105 also a challenge

~10 kHz of cosmics

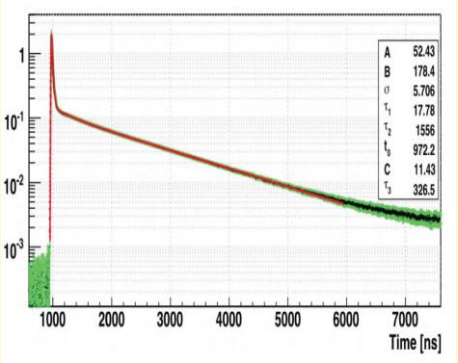
⇒ ~40 cosmics overlapping in 4 ms readout window

⇒ reconstruction of beam event a challenge.

- dE/dx (MIP): ~2 MeV/cm

⇒ 50.000 e/ions, 50.000 γ per cm

⇒ 30 million e/ions and γ per MIP in 600 cm



• Primary light has 2 components:
- fast component, singlet: 6 < τ < 18 ns
- slow component, triplet: ~1.6 μs

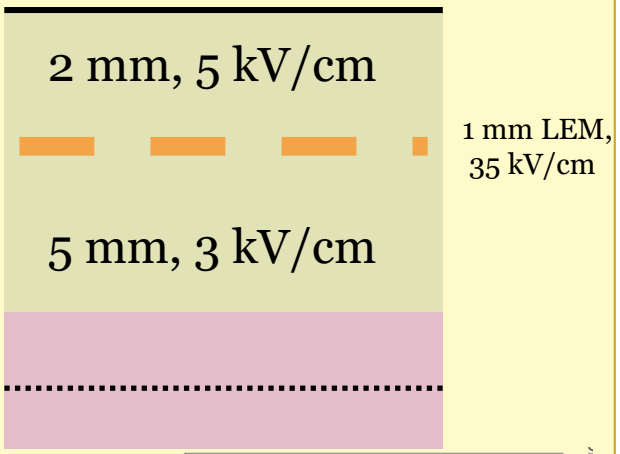
• 30 million photons for straight cosmic

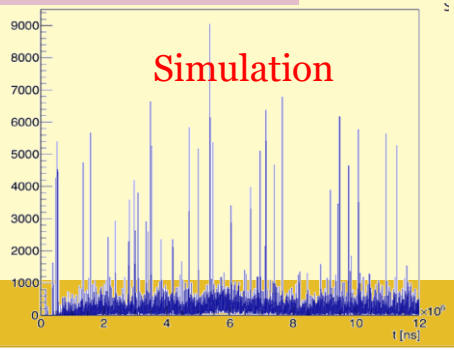
• Most of light for MIPs in fast component => perfect for triggering

• Electroluminescence (EL) in gas phase

• Each e- will produce some hundreds γs

• "constant" background





But we have light background …