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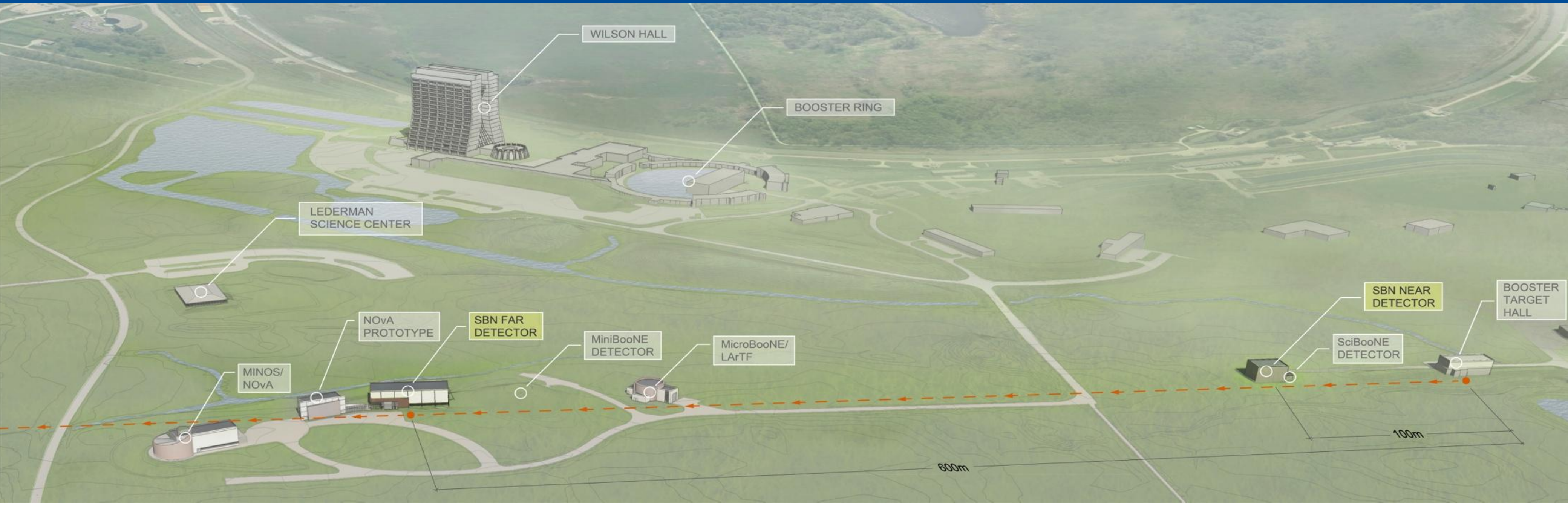

ICARUS PMT System

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Director’s Progress Review of SBN

15-17 December 2015

OUTLINE

- Overview of the T600 scintillation light detection system.
- Status of PMTs procurement.
- Status of PMTs test.
- Status of evaporation system set-up and procedures.
- Status of PMT timing calibration system.
- Brief PMT electronics description.
- Conclusions.

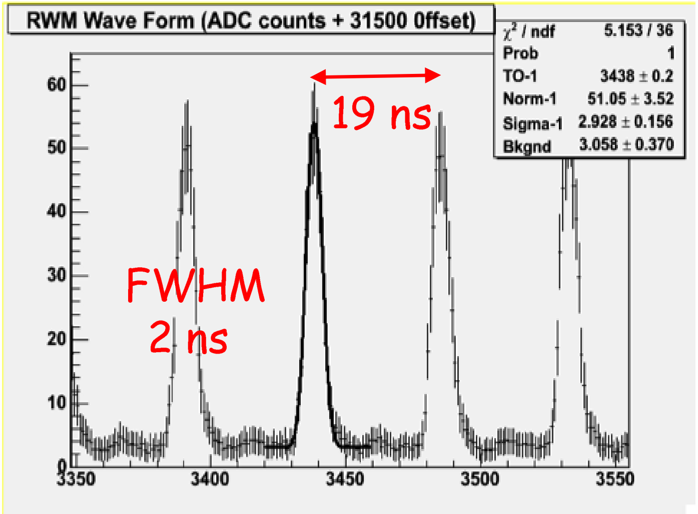
Overview

- The deployment of the T600 detector at shallow depth, exposed to a high cosmic muon rate, implies an upgrade of the light detection system, as discussed by C. Rubbia in arXiv:1408.6431 (2014).
- The refurbished light collection system consists of 90 PMT 8" HAMAMATSU R5912-MOD for TPC, installed behind each wire planes.
- 400 PMT samples have been ordered to Hamamatsu and are being under test at CERN in three different areas.
- A dedicated workshop is equipped and instrumented with an evaporation system. Each PMT will be provided with a TPB (Tetra-Phenil-Butadiene) coating before the final installation in the T600 detector.
- A timing calibration system has been designed and an optical fiber, able to deliver a fast laser pulse, will be installed for each PMT.
- All the components necessary for the upgrade of the light detection system have been ordered and are being delivered at CERN.

Upgrade of the light collection system

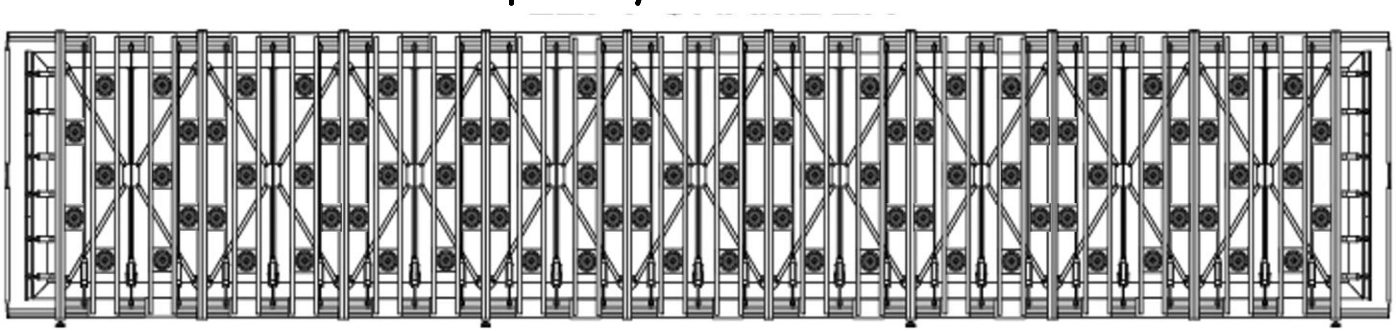
- *The improved light detection system is devoted to:*
  - The generation of a light based trigger signal;
  - The identification of the time of occurrence (t_0) of each interaction with high temporal precision;
  - The initial identification of event topology for fast event selection purposes.

- *Main requirements for the light detection system are:*
  - High detection coverage, to be sensitive to low 100 MeV E_ν deposition in LAr;
  - High detection granularity, to localize events/unambiguously associate the collected light to deposited charge;
  - Fast response - high time resolution, to be sensitive to time and evolution of each event in the T600 drift time window (~ 1.5 ms); a ~1 ns precision is advisable to exploit the available 2ns/19ns bunched beam structure.



New T600 light detection system

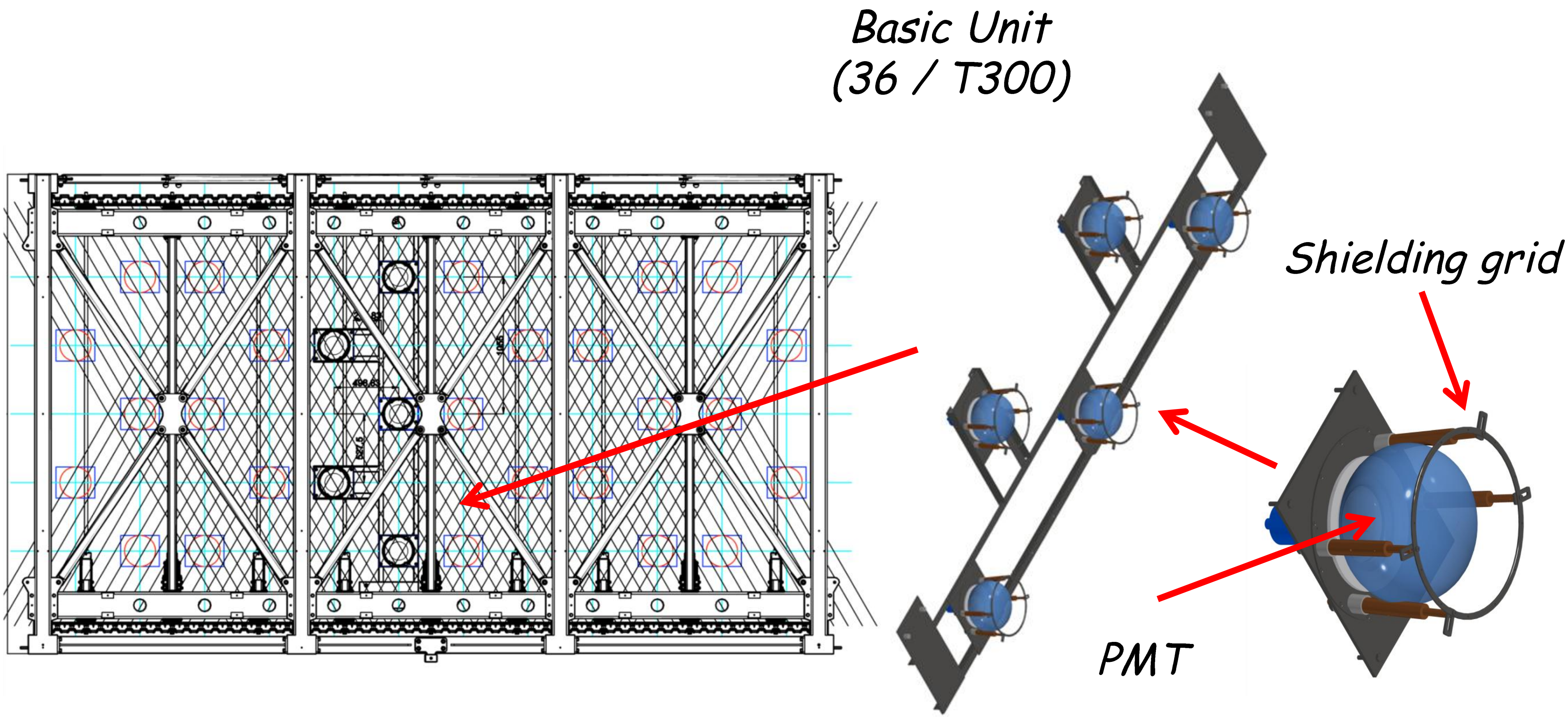
- The refurbished light collection system consists of 90 PMTs 8" HAMAMATSU R5912-MOD for TPC, installed behind each wire planes (360 PMTs in the whole T600). About 200 $\mu g/cm^2$ of TPB wavelength shifter is deposited on each PMT window. The photo-cathode coverage corresponds to 5% of the wire plane area.
- The number of photoelectrons collected per MeV of deposited energy in a single TPC is ~ 15 phe/MeV, allowing the possibility to trigger low energy events with fairly high threshold and multiplicity.



Z axis (beam direction)

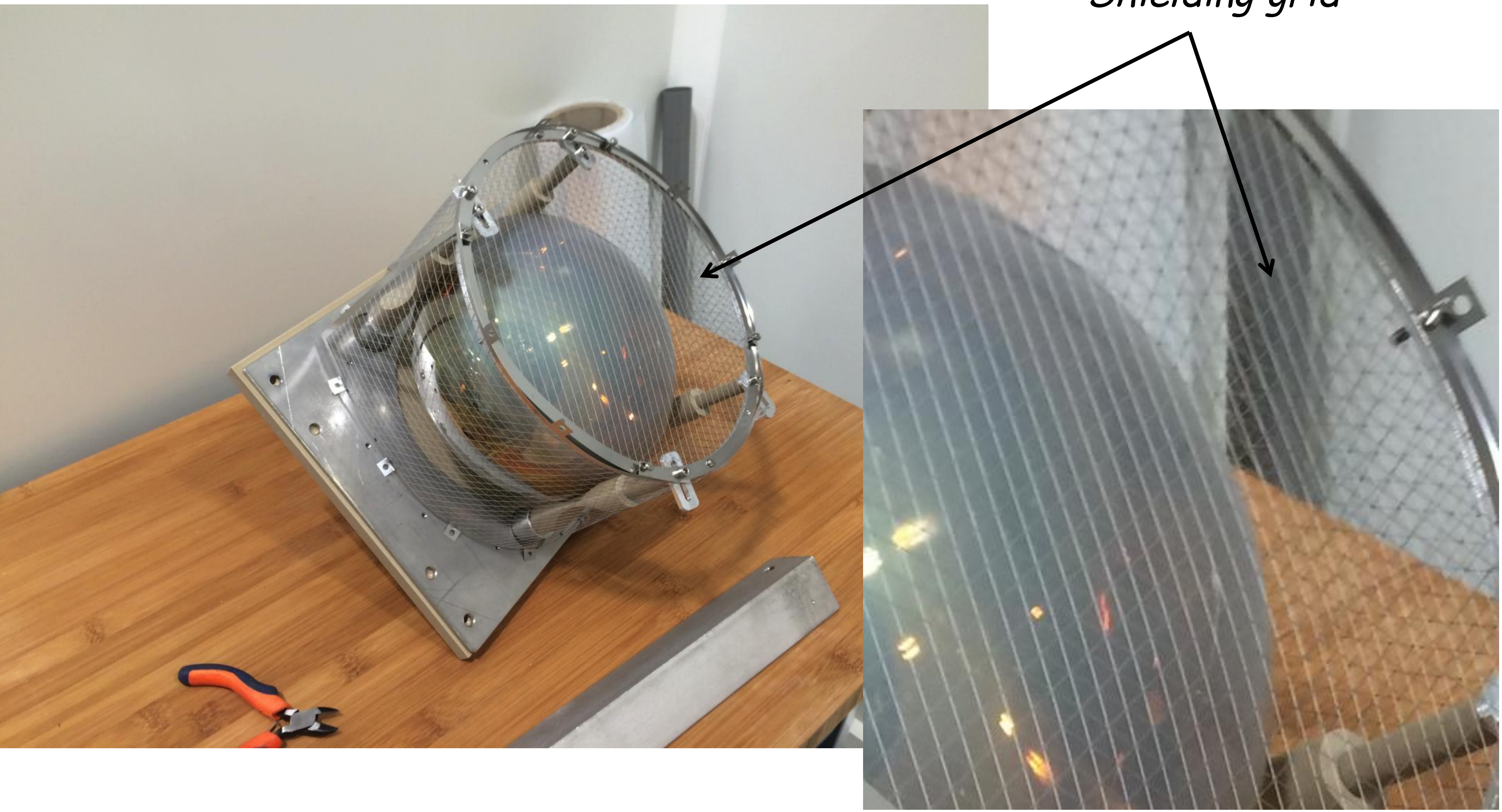
- An event localization better than 0.5 m and an initial classification of different topologies (cosmic μs, e.m. showers, ν_μ CC) can be obtained exploiting the arrival time of prompt photons and the collected light signal intensity.
- Fast laser pulses will be provided to each PMT by a system of optical fibers for timing calibration.

New PMTs mechanics



A new mechanical configuration for the scintillation light collection system was designed. All the components were delivered in November 2015.

PMTs mechanics



PMT procurement status

- The PMT order (400 samples) was sent to Hamamatsu in August 2015.
  - First 20 samples (pre-series) delivered to CERN 5th October 2015.
  - Second batch (80 samples) delivered to CERN mid. November 2015.
  - Third batch (100 samples) is expected for mid December.
- A new cryogenic voltage divider was designed. A pre-series of 50 samples was delivered in September. To overcome an impedance mismatch, a modification of the circuit was necessary. New circuits were delivered at the end of November.
- All the 20 pre-series samples have been tested at room and at cryogenic temperature.
- All the tested samples are compliant with the technical specifications reported in the IT-4126/DG-DI/WA104 Tender Form and fulfill the requirements for installation in T600.
- Test on series production started on 1st December 2015.

PMT tests at CERN

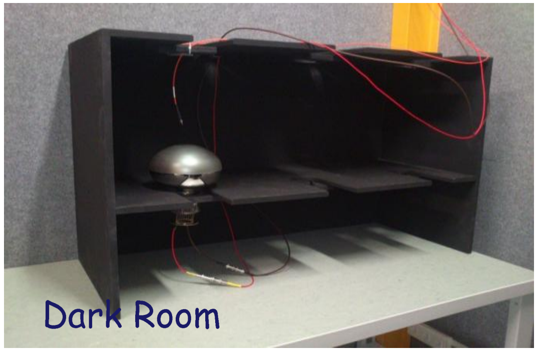
- Test and characterization of all PMTs at warm temperature;
- 10% of PMT is also tested at cryogenic temperature (all PMTs are mechanically tested in LN2 by Hamamatsu);
- Deposition by evaporation of TPB on all PMTs' window.

Activity on the PMTs are organized at CERN in three different areas:

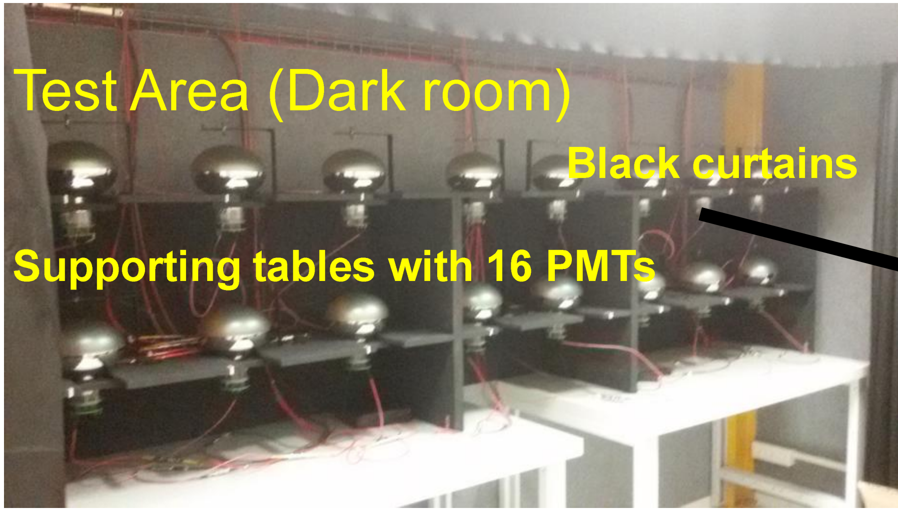
Warm tests
IdeaSquare building (B3179)

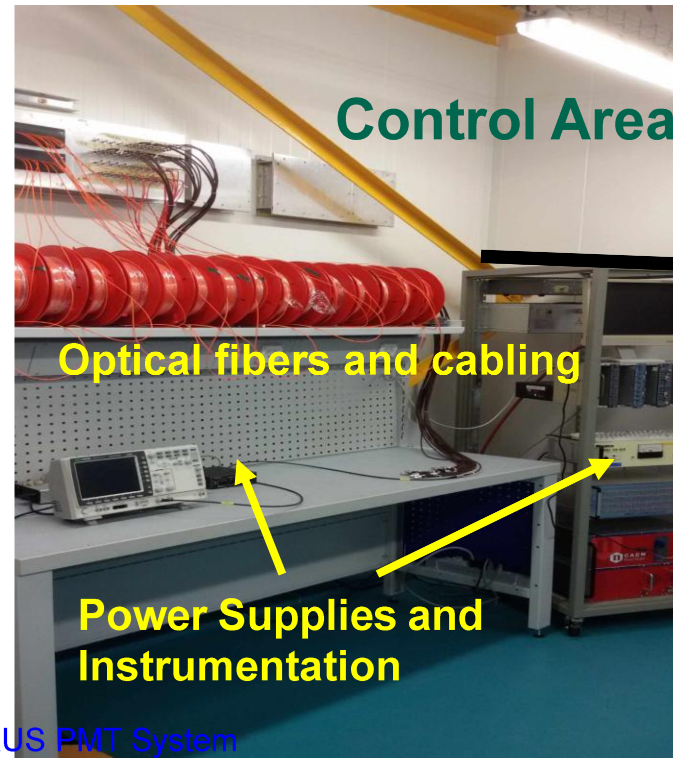
Cold tests
building 182

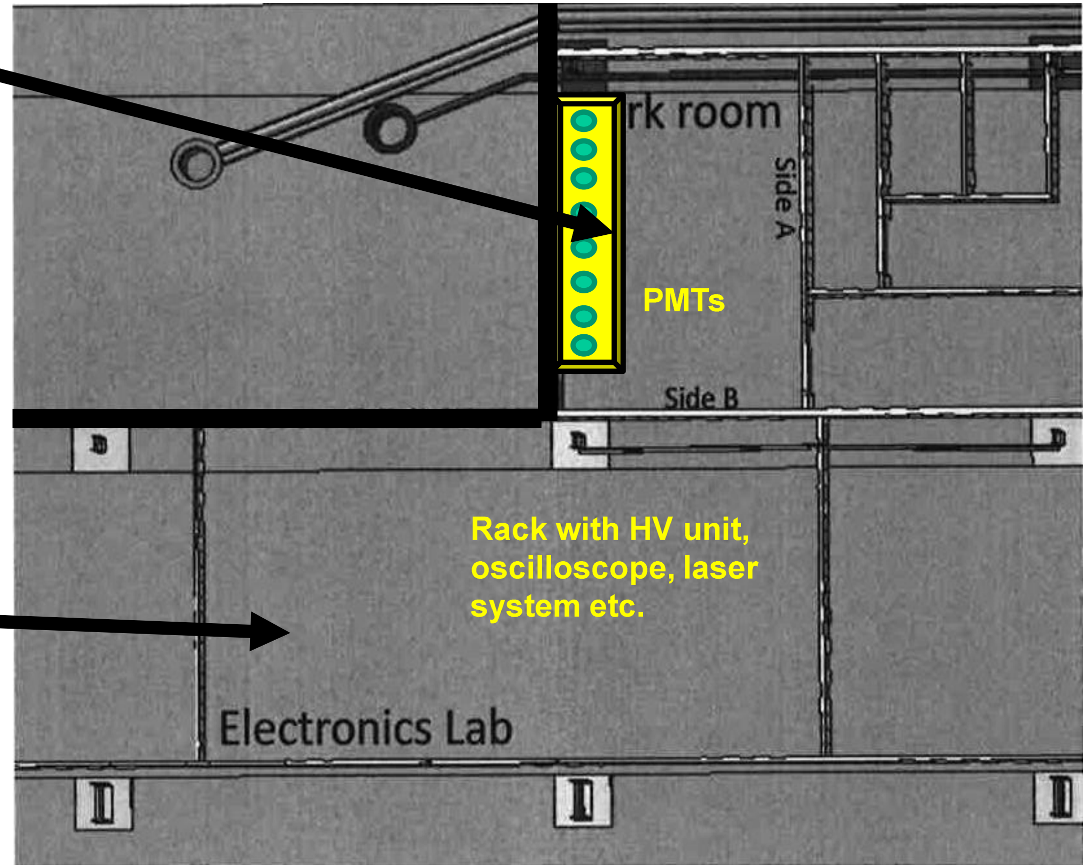
TPB deposition
TE-Laboratory hall (B169)



The PMT warm-test area



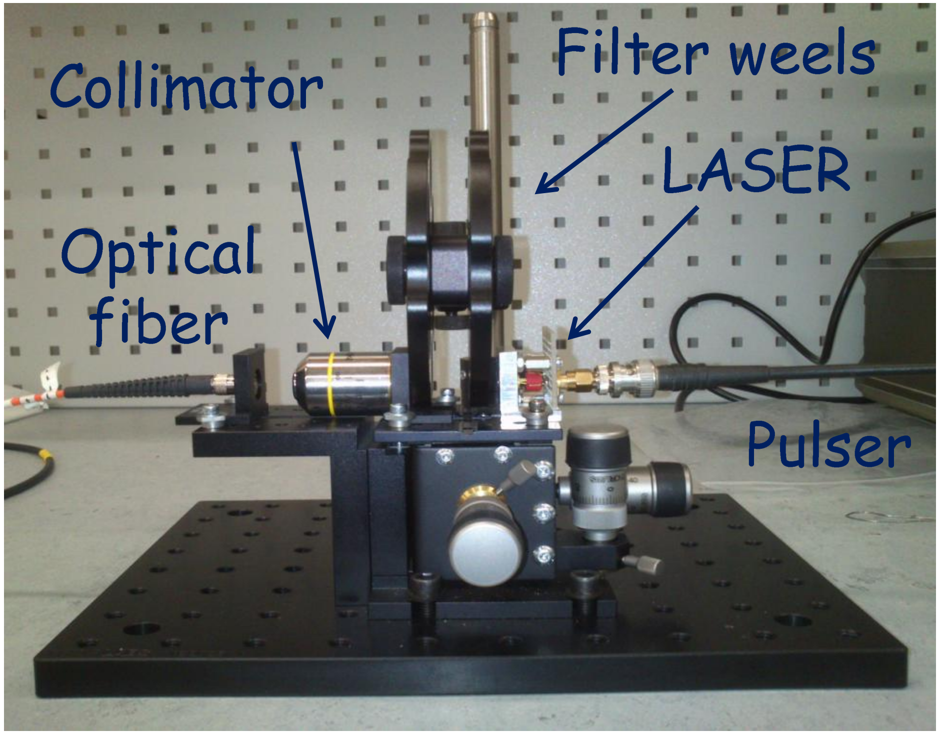


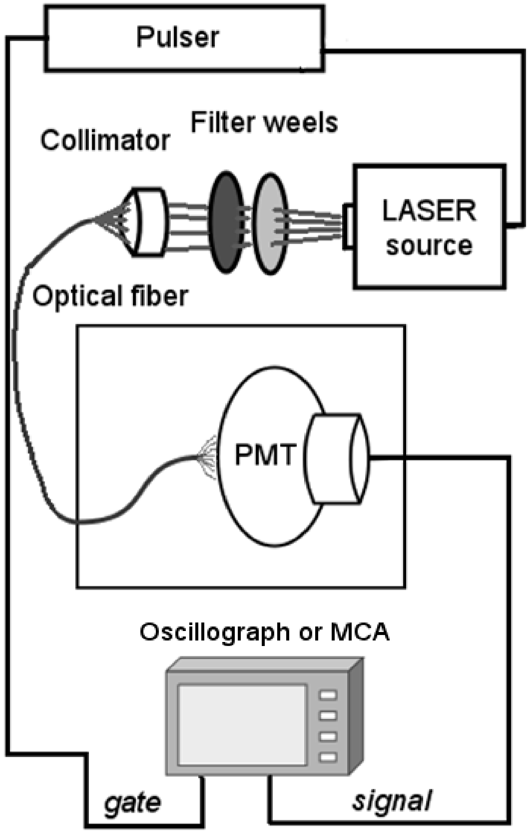


Ideasquare Lab

Main Measurement Set-Up

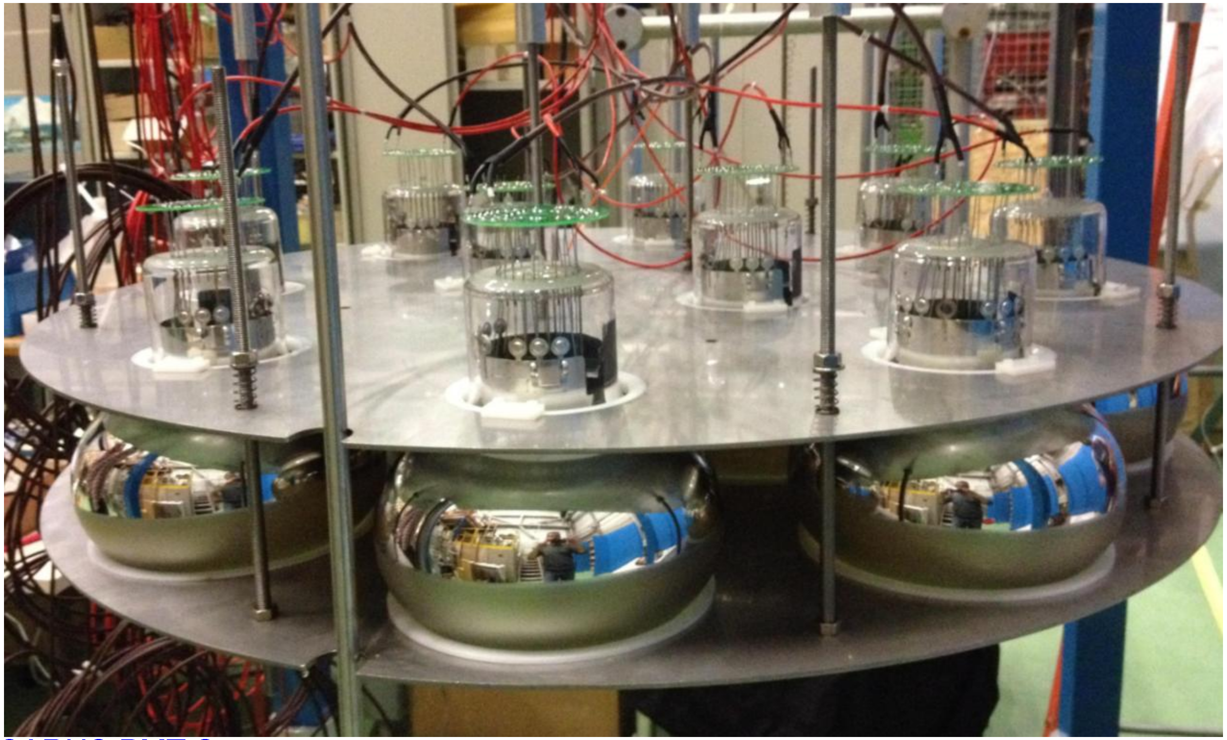
Light is produced by a LASER diode at 405 nm.
A fast pulser is used to feed the LASER source with ~1 kHz repetition rate.
Light intensity is set through optical filters mounted on two weel supports, allowing different attenuation combinations (0÷1000).





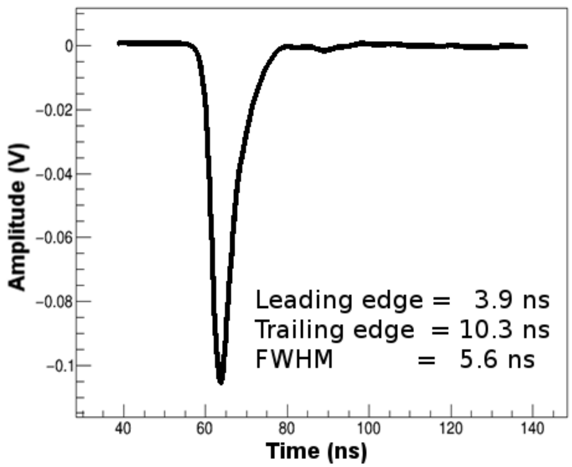
The PMT cold-test area (B182)

This area is equipped with electronics and cryogenic facilities which allows the characterization of the PMTs directly immersed in liquid Argon.

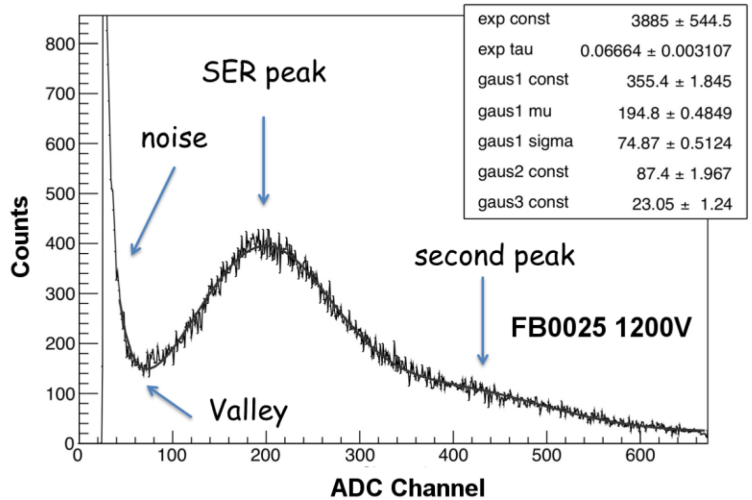


ONE-SLIDE test results

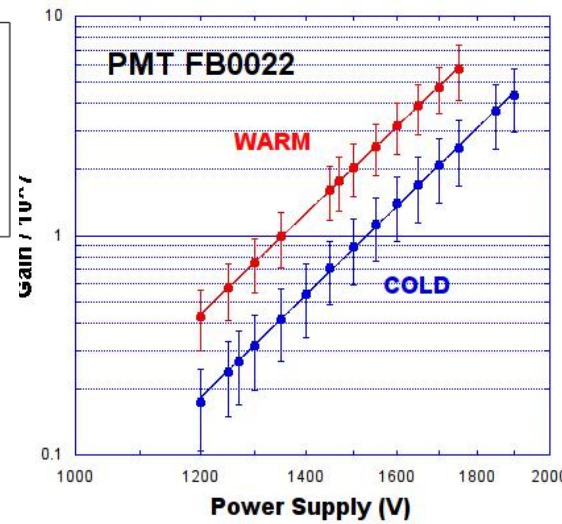
Signal Shape



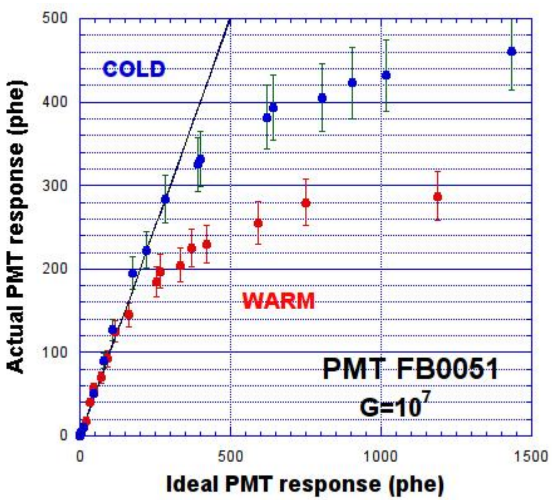
Single Electron Response



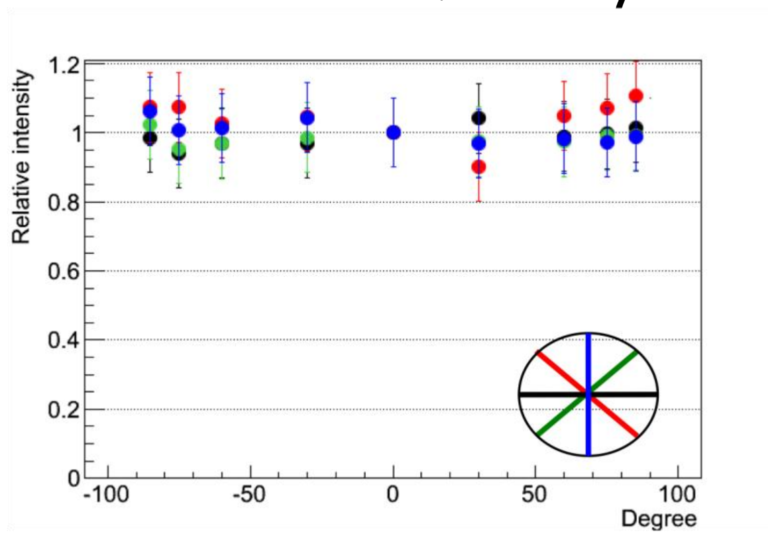
Gain vs. Power Supply



Linearity & Saturation



Cathode Uniformity



and more…

Transit Time Spread

Dark Count Rate

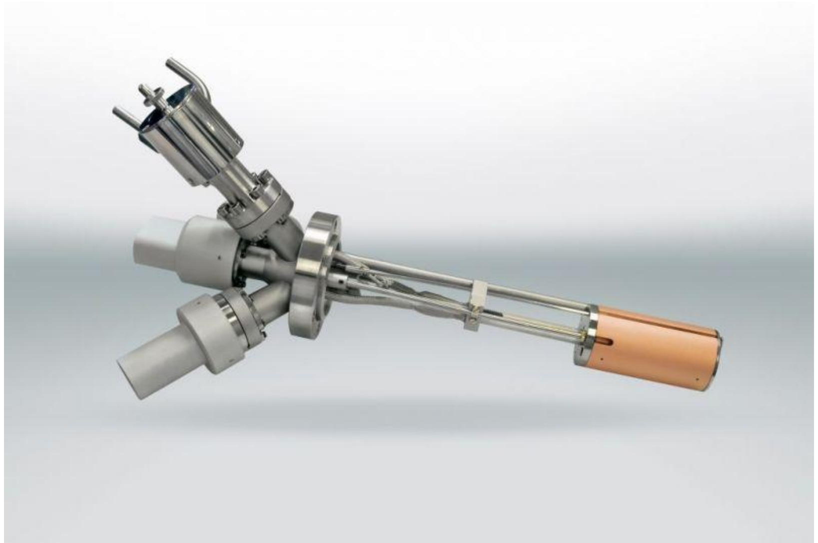
Earth Magnetic Field

Overall Quantum Eff.

The evaporation process

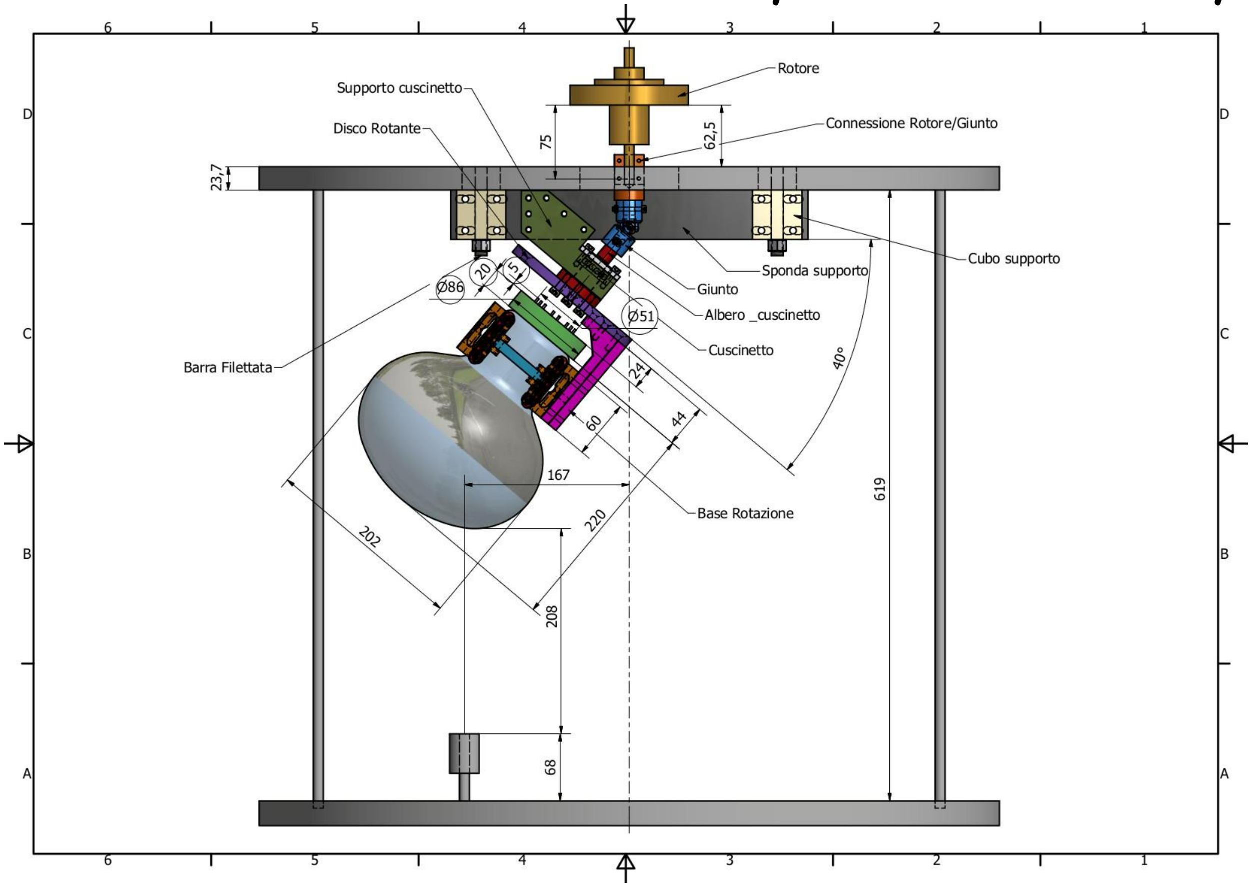
The TPB coating is carried out by means of a thermal evaporation system installed in building B169. The evaporator is made up of a Knudsen cell inside a vacuum chamber (10^{-5}mbar).

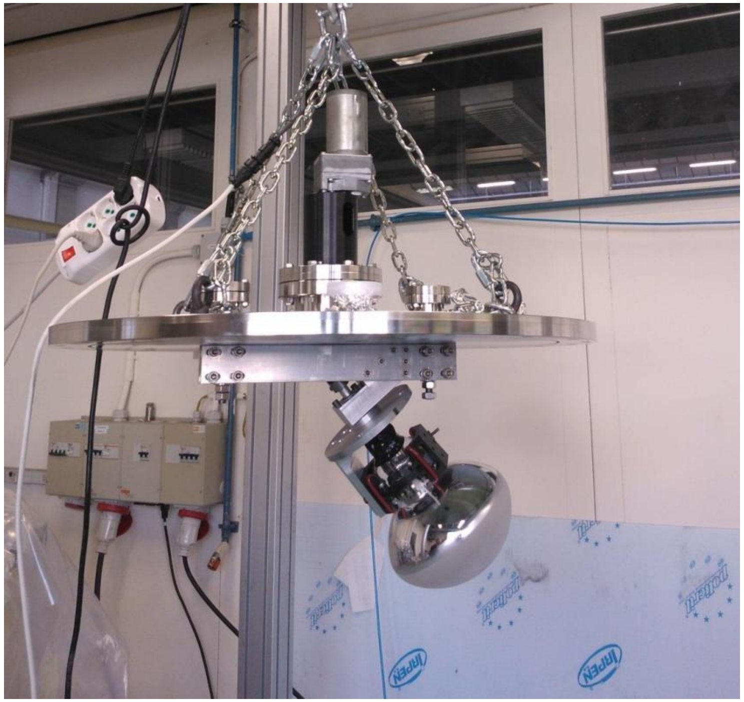
At 210°C, TPB starts to evaporate and produces a coating on the surface of the PMT.



The PMT holding/rotating system

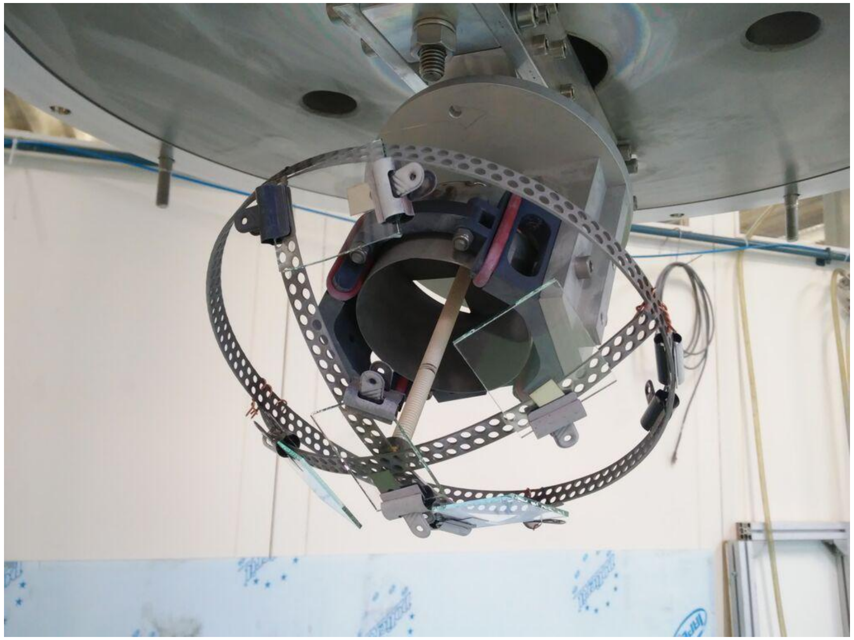
Since the Hamamatsu PMT under deposition has an hemispherical surface (8"), it is connected to the evaporator cap by means of a motored rotating support (about ten turns per minute). A study for the optimization of the evaporation process as a function of the thickness uniformity was necessary.

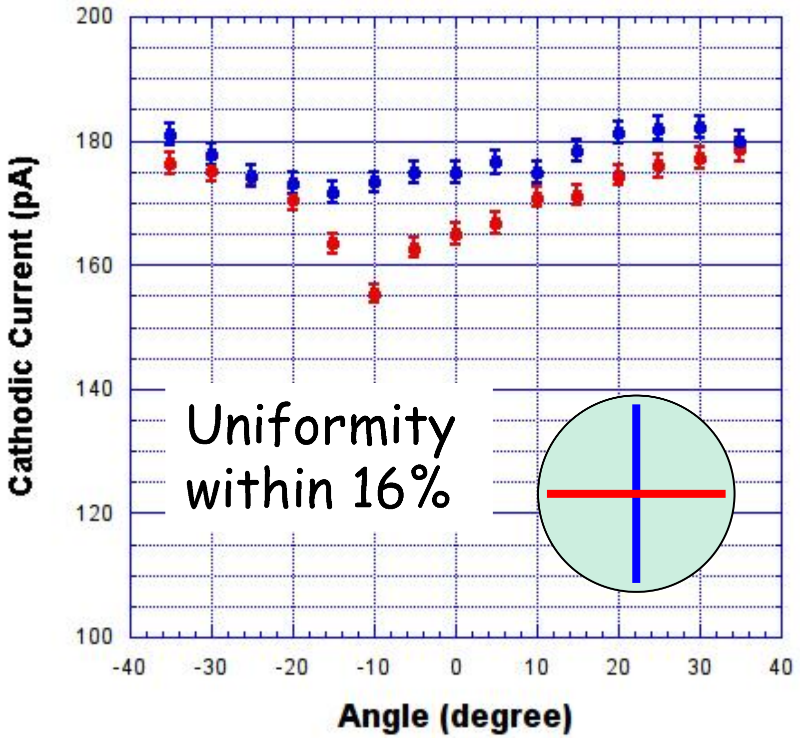




The PMT mockup tests

Deposition thickness and uniformity were studied by installing a PMT mock-up on the evaporator holding structure: some mylar (or glass) samples were attached to the mock-up and evaporated. This allowed measuring the different thickness of the evaporated layers and thus estimating the uniformity and the quantity of TPB needed per evaporation.





Evaporation present status

- The quantity of TPB needed for each evaporation has been defined (0.8g).
- Several tests of thickness uniformity were performed with a PMT mock-up: an average uniformity of around 10% over the whole surface is obtained.
- Quantum eff. measurements carried out on samples with different coating densities and distinct evaporation rates show a quite flat behavior, almost density-independent.
- A first QE estimate was performed on an evaporated PMT, as well, obtaining satisfying uniformity. The same measurements are foreseen on some pre-series samples, once evaporations are completed.

PMT calibration system

A time resolution of~1 ns is required for an efficient rejection of the background but PMT are affected by transit-time drift.

Equalization of each single channel may be obtained by analyzing crossing muons or by routinely delivering a fast laser pulse to each PMT.

A calibration system, made by fused fiber splitters, optical switches and optical patch-cords, has been designed and an optical fiber will be installed for each PMT.

The system will include a fast laser diode, a 1x*N* optical switch and 25 (1x16) or 50 (1x8) fused optical splitters, in addition to the necessary optical feed-throughs and patch-cords.

The internal part has been defined (50/125 optical fibers) and order are being issued.

Some critical issues, such as the availability of high-performance (vacuum tight) fiber feed throughs are under test.

PMT electronics design

The trigger system will exploit the coincidence of the prompt signals from the scintillation light with the proton spill extraction of the Booster Neutrino Beamline (BNB) within a 1.6 μs gate.

PMT pulses are digitized. Thresholds (tens of phe) are set to guarantee the detection of all the events with energy E>100 MeV and reject the low energy background (mainly ^{39}Ar).

Discriminated signals are processed by logic units. The number of hit PMTs (fired discriminators) is summed up for each chamber and logics on multiple PMT signals are calculated to retrieve the longitudinal position of each event occurring in the TPCs.

All PMT signals, recorded by means of fast waveform digitizers with ~1 GHz sampling time, can be used to precisely reconstruct the event time evolution with a 1 ns precision, allowing the investigation of any physical association between an e.m. shower and the muon and the exploitation of the BNB bunched structure. The precise photon arrival time measurement, together with the collected light intensity, permits a fast event topology identification.

PMT trigger and signal recording is still under design but possible solution have been identified and will be tested.

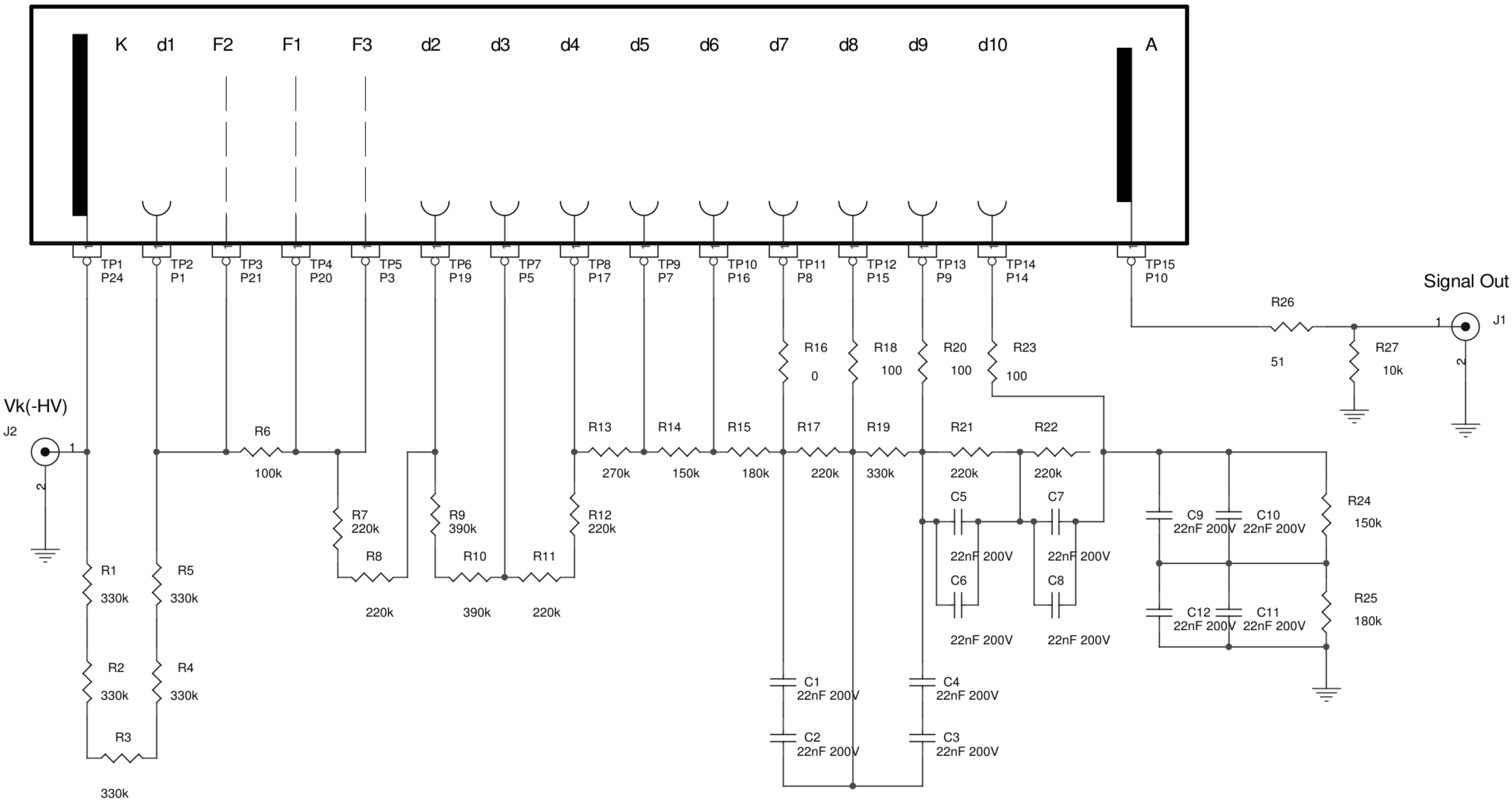
Conclusions

The activities of the upgrading of the T600 light detection system are proceeding according to programmed schedule:

- All the 20 PMTs of the pre-series have been tested at room and at cryogenic (87 K) temperature; the measures are consistent with the nominal values given by the manufacturer and are compliant with the requirements for installation in the T600.
- First PMT batch of series production (80 units) was delivered at CERN and a third batch (100 samples) is expected by December 2015.
- Evaporation area and instrumentation are ready for series production.
- All necessary material and instrumentation for final PMT installation in T600 have been ordered and are being delivered.


Thank you !

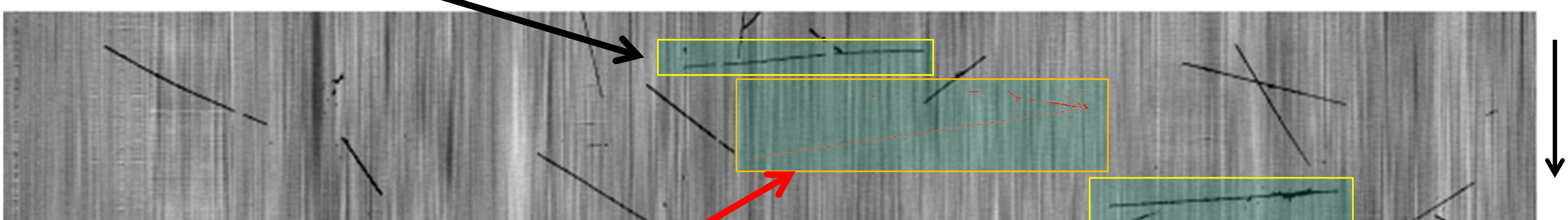
NEW Voltage divider



Exploitation of light detection system

- At shallow depth ~12 uncorrelated cosmic rays will occur in T600 during the drift window readout at each triggering event.
- This represents a new problem compared to underground operation at LNGS: the reconstruction of the true position of each track requires precisely associating to each element of TPC image the occurrence time (t0) with respect to trigger time.
- The t0 identification of each interaction during the T600 drift time window (~ 1 ms), requires to be sensitive to light information during a twofold extended (~2 ms) time window.

Event occurred near the wire plane ~1.5ms after the trigger time



Triggering event

Event occurred near the cathode ~1.5ms before the trigger time

PMT electronics design

The trigger system exploits the coincidence of the prompt signals from the scintillation light with the proton spill extraction of the Booster Neutrino Beamline (BNB) within a 1.6 μs gate.

PMT pulses are digitized by directly discriminating their signal. Thresholds (tens of phe) are properly set to guarantee the detection of all the events with energy E>100 MeV and reject the low energy background (mainly ^{39}Ar).

Discriminated signals are processed by logic units (FPGA). The number of hit PMTs (fired discriminators) is summed up for each chamber and logics on multiple PMT signals are calculated to retrieve the longitudinal position of each event occurring in the TPCs.

All PMT signals, recorded by means of fast waveform digitizers with ~1 GHz sampling time and sufficient dynamic range (>1000), can be used to precisely reconstruct the event time evolution with a 1 ns precision, allowing the investigation of any physical association between e.m. showers and muons, the exploitation of the BNB bunched structure and the possibility to perform a fast event selection.

PMT electronics design hints

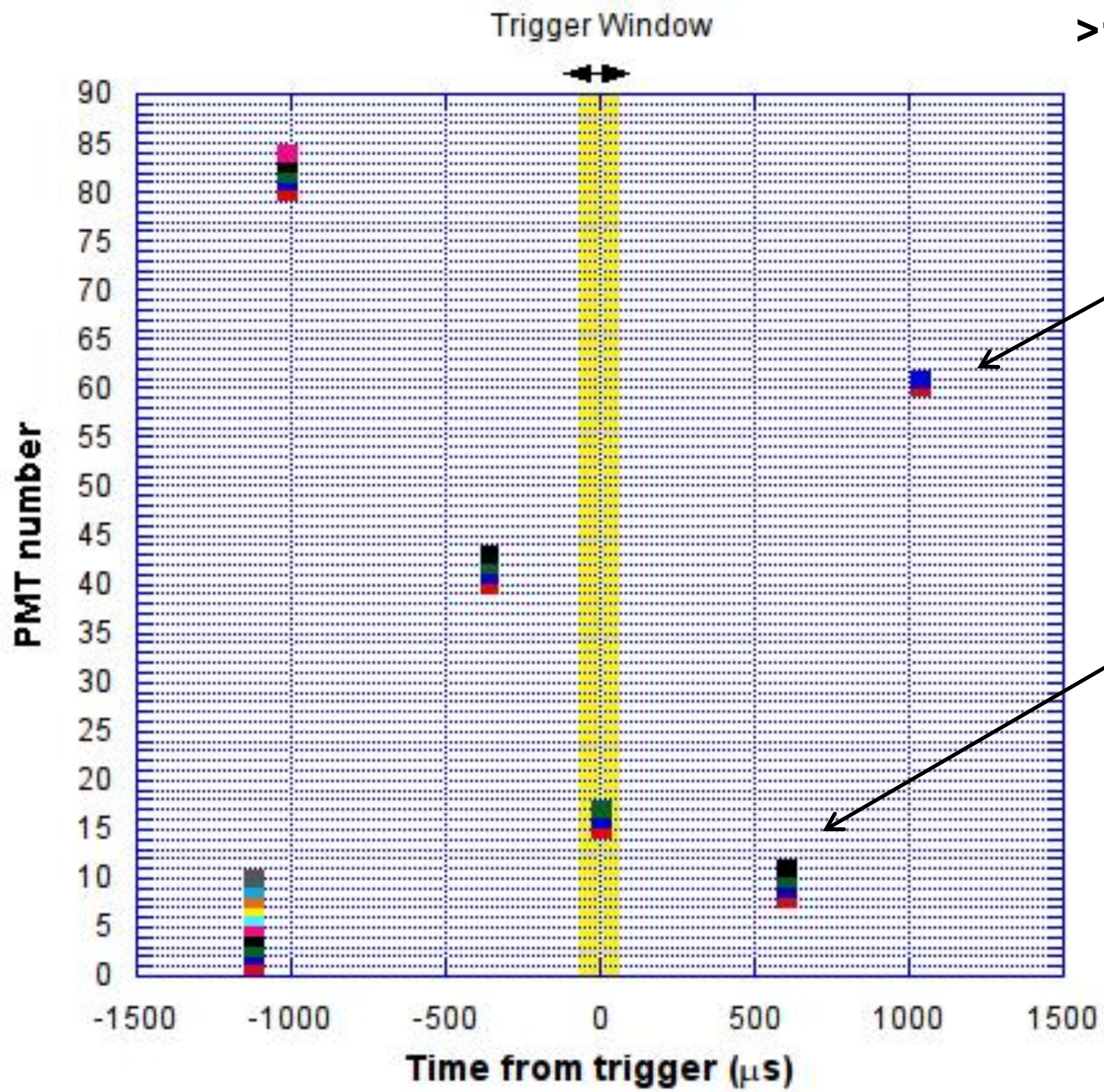
Considering ~1 GHz fast waveform digitizers with 10÷14 bit resolution, it is necessary to handle ~5 MB of data for each PMT, every time the detector is activated.

This corresponds to ~1 GB of data, for each T300.

This dimension can be strongly reduced by considering only the region of interest around each PMT signal, sufficiently extended in order to detect both the fast and delayed LAr scintillation light components (5÷10 μs). Data can be filtered by software or, possibly, directly by hardware.

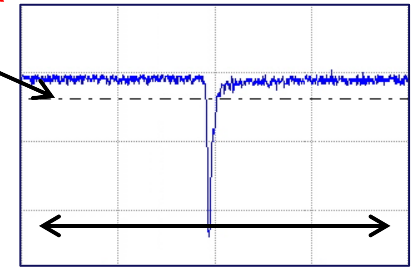
According to a Monte Carlo evaluation, for each track the number of fired PMTs is about 20÷50 for thresholds in the range of 5 ÷ 30 phe. For each trigger, the expected data sampling dimension per TPC is ~5 MB (depending on ADC resolution).

Scintillation light detection



Threshold >10 phe

Region of interest (Hardware or Software)



5÷10 µs (5 ÷10 ksamples)

For each TPC the number of fired PMTs is about 20÷50 for thresholds in the range of 5 ÷ 30 phe. For each trigger, the expected data sampling dimension per TPC is about 5 MB.

PMT electronics: possible solution

Some commercial solution for the PMT signal sampling are being investigated:

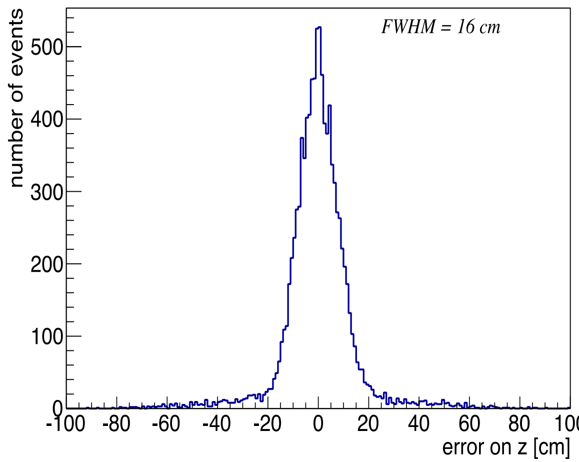
CAEN V1751: 8ch, 1 GS/s, 10 bit, 1Vpkpk, from 1.835 MS/ch up to 14.4 MS/ch, Zero Length Encoding data reduction, CONET transfer protocol.

CAEN V1730: 16ch, 500MS/s, 14 bit, 2Vpkpk, 640 kS/ch or 5.12 MS/ch, Zero Length Encoding not yet implemented, CONET transfer protocol.

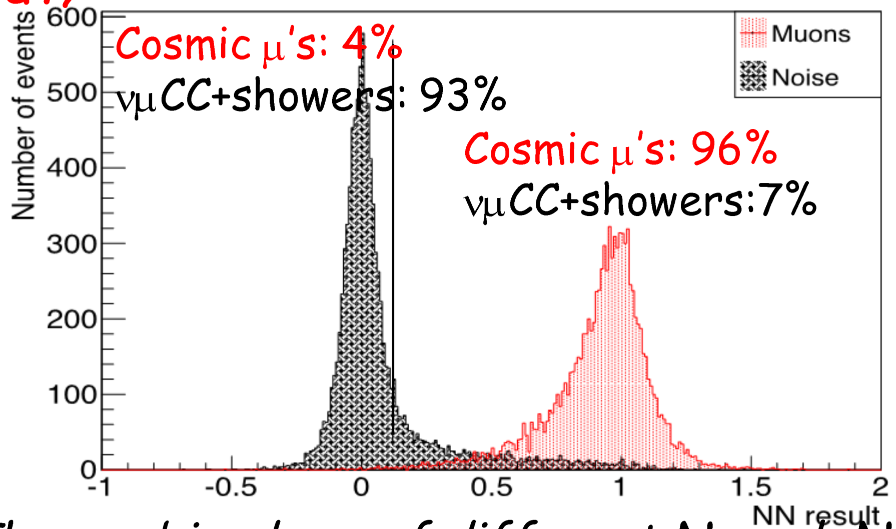
KEYSIGHT M9703A: 8ch, 1 GS/s, 12 bit, 3.6Vpkpk, 64 MS/ch, PCIe backplane data transfer.

On-going activities on New PMTs system

- Monte Carlo study of light produced by cosmic rays and neutrino events to optimize the PMT geometry lay-out;



95 % of events localized along the beam direction within 30 cm using only PMT signals with fast component >10 phe thr.



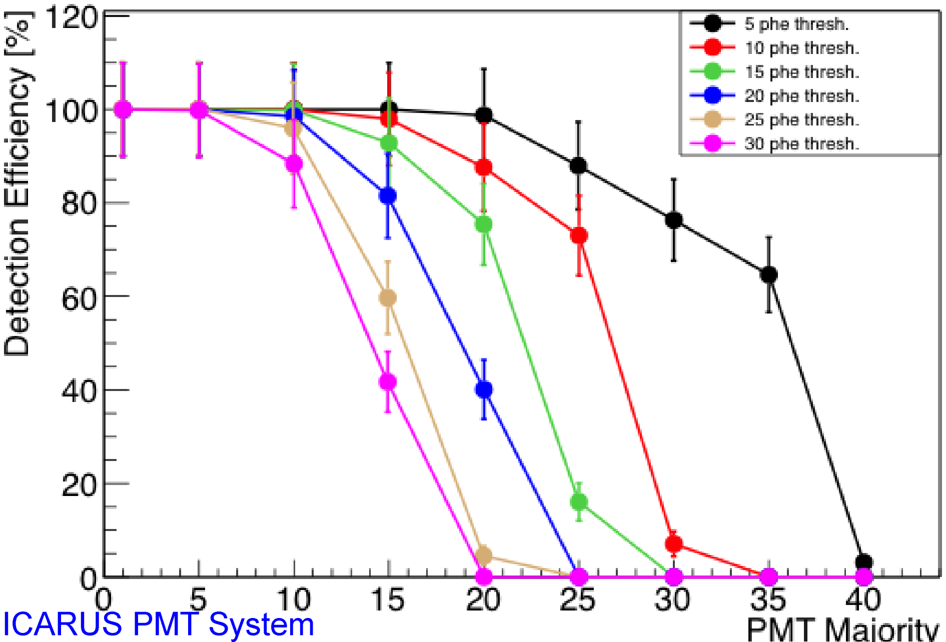
The combined use of different Neural Nets can provide a clear cosmic μ 's identification (~2% residual misidentification).

- Tests on new photomultiplier samples;
- New cryogenic voltage divider. Pre-series has been delivered;
- Procedures for evaporation/deposition of Wavelength Shifter (TPB);
- New PMT mechanical supports. Delivery around half of November;
- Design of a PMT timing calibration system (optical fibers + lasers).

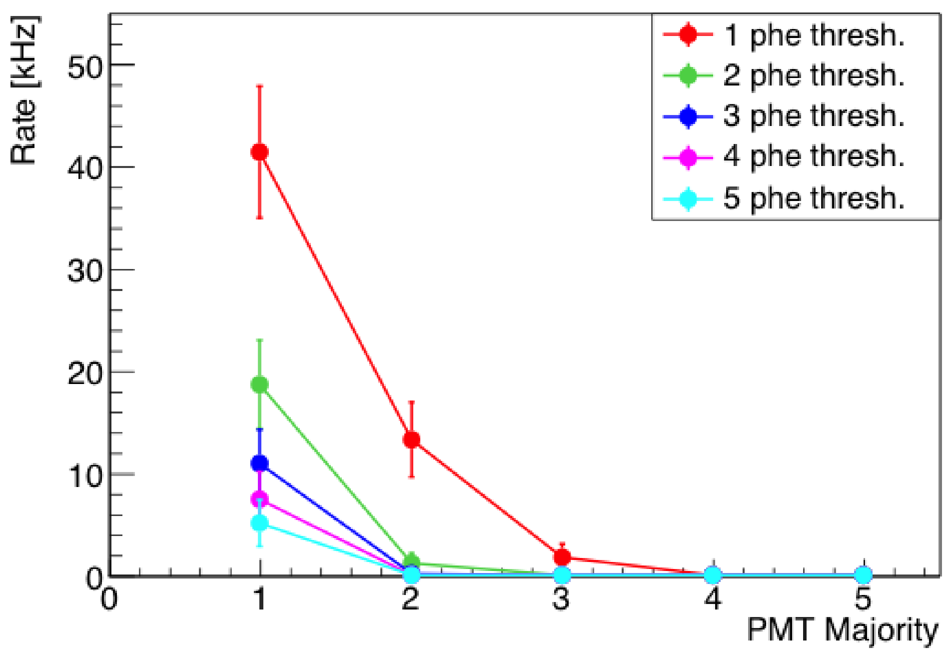
Trigger definition

The trigger system will exploit the coincidence of the prompt (fast) signals from the scintillation light with the proton spill extraction of the BNB (1.6 ⌠s gate). Trigger will start when a certain majority of PMT has a signal above the threshold, to be set at tens of phe, to guarantee the detection of all the events with E>100 Mev and to reject ^{39}Ar background. Many combinations of these parameters permit to obtain the desired result.

Detection efficiency (fast signal) for 100 MeV showers near cathode as a function of the phe threshold and PMT majority

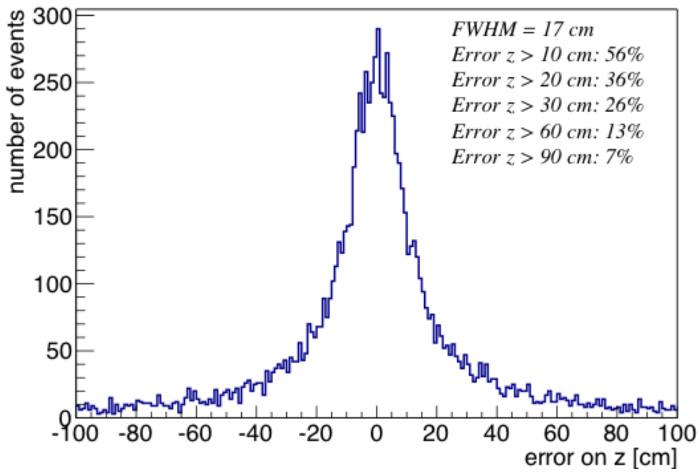


Residual ^{39}Ar rate (fast signal) as a function of the adopted phe threshold and PMT majority.



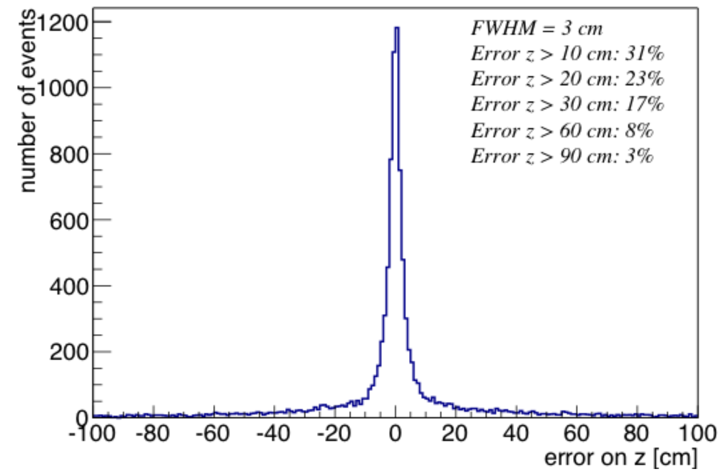
Localization of events

Beam direction Z

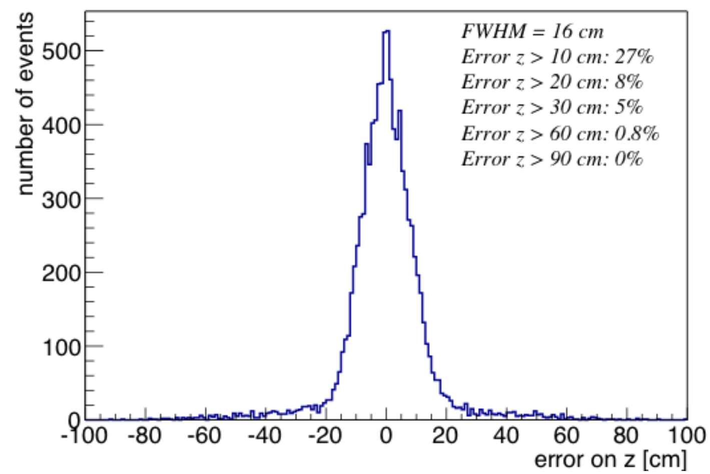


Simple weighted average on PMTs fast signal

Using only PMTs with fast signal above a given threshold (10 phe)



Creating phantom PMT beyond detector borders



Reconstruction algorithms, although already quite satisfactory, can be still significantly improved.