



Assembling and test of KM3NeT optical modules

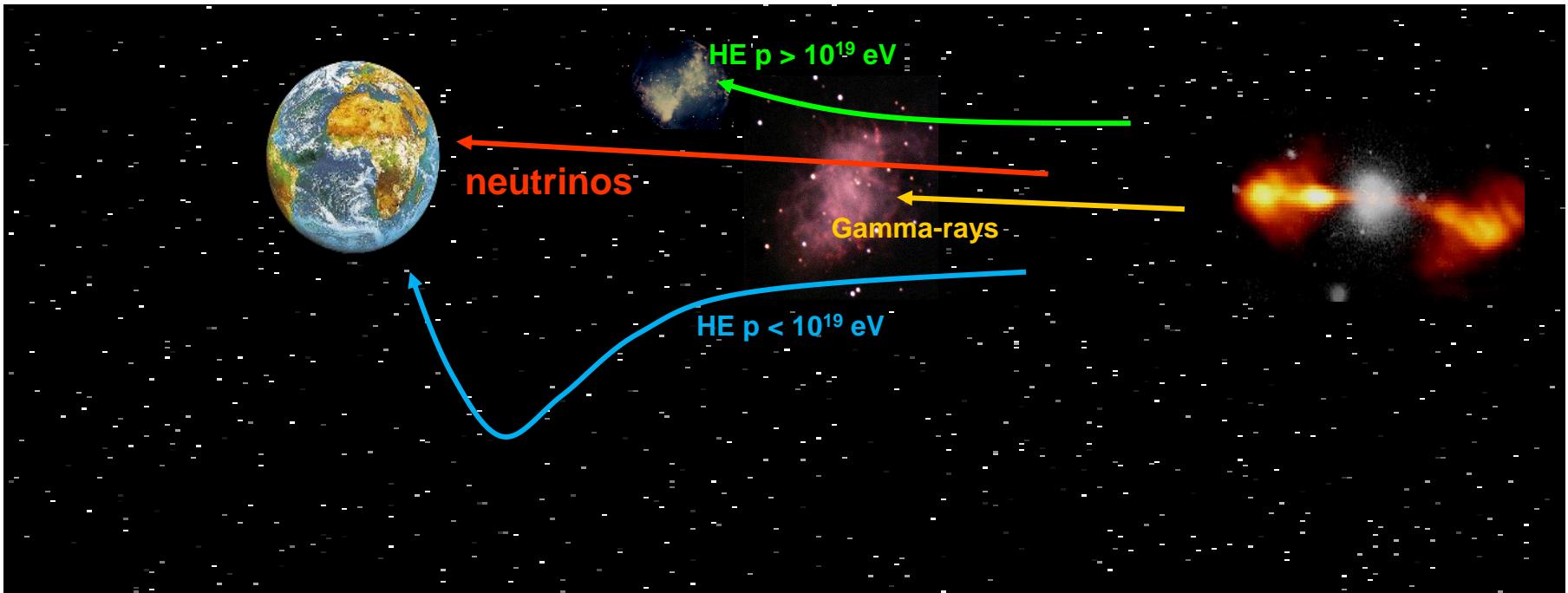
S. Aiello , V. Giordano INFN-Catania

Seminario Nazionale Rivelatori Innovativi
Laboratori Nazionali del Sud INFN
Catania, 10-14 Novembre 2014

Outline

- Introduction on physics of the KM3NeT experiment
- Detection principle
- Properties of photomultipliers tube (PMT)
- Test bench for photomultiplier tubes
- Optical module (OM) description
- Optical modules assembly procedure
- KM3NeT Photos

HE neutrino Astronomy



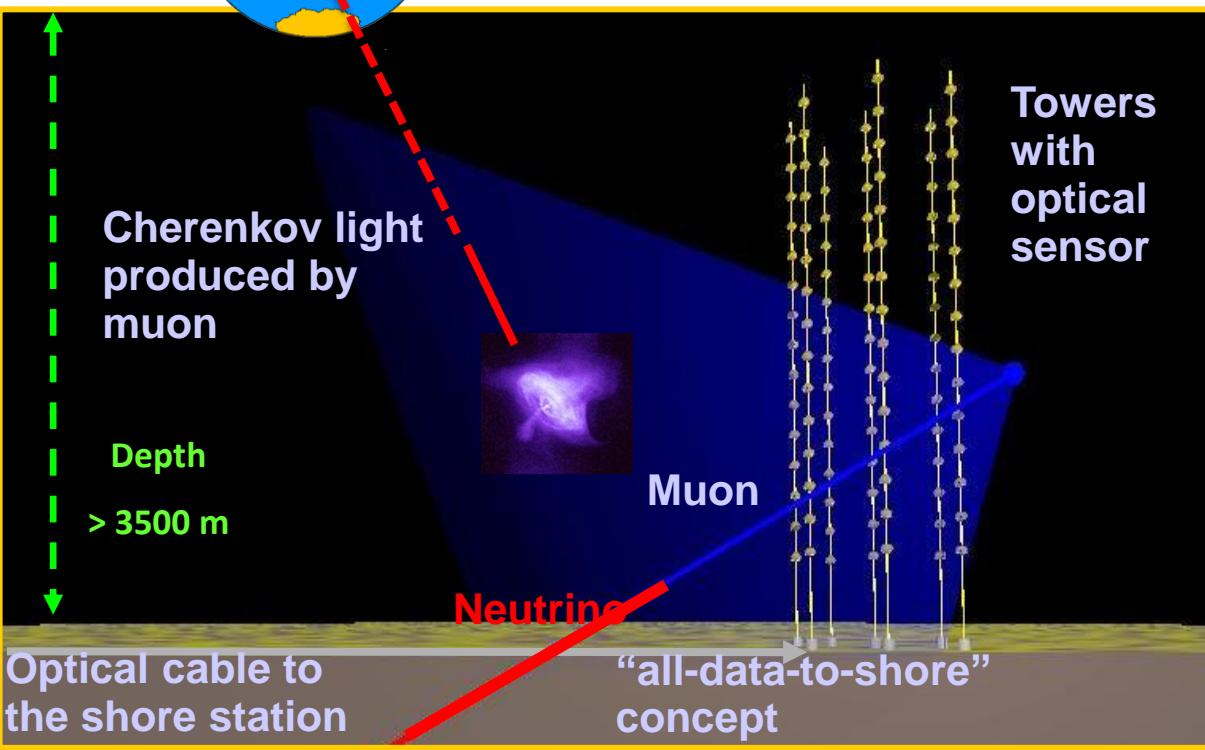
Neutrinos can travel through space without to be deflected or absorbed

- point directly the source in the sky
- internal region of astrophysical sources (non-visible with gamma-ray) can be shown

Neutrinos are mostly produced in high energy hadronic processes



Detection Principle



High energy charged CR + gamma rays

Diffuse and point-like neutrino fluxes estimated

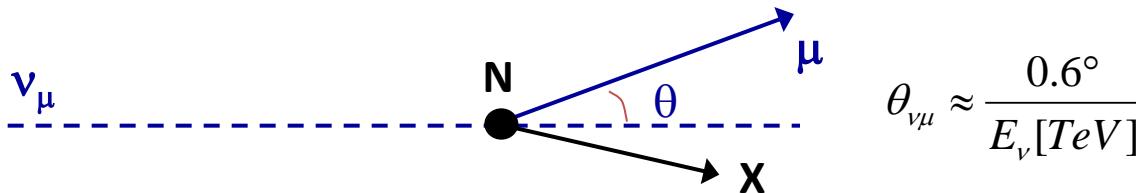
Volumes of detection of the order of km³

Detection principle:

Charged current interaction



At energies higher than TeV muon and neutrino are colinear



$$\theta_{\nu\mu} \approx \frac{0.6^\circ}{E_\nu [TeV]}$$

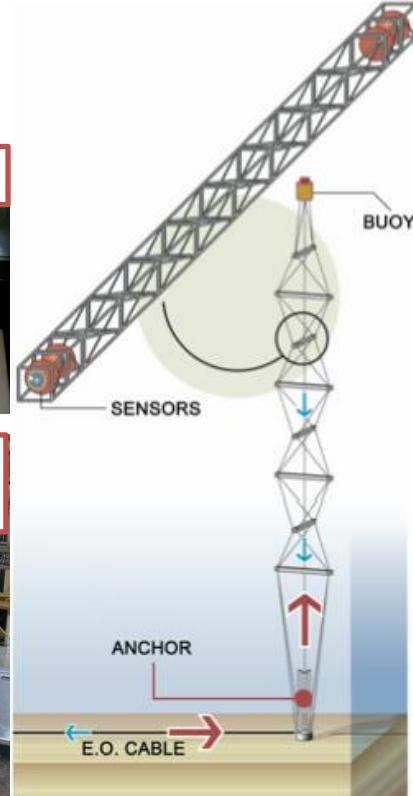
We track the Cherenkov (visible) light emitted by HE muons

Prototype: NEMO Phase-2

March 22, 2013: Deployment of NEMO Phase-2
The detector unit is in data taking

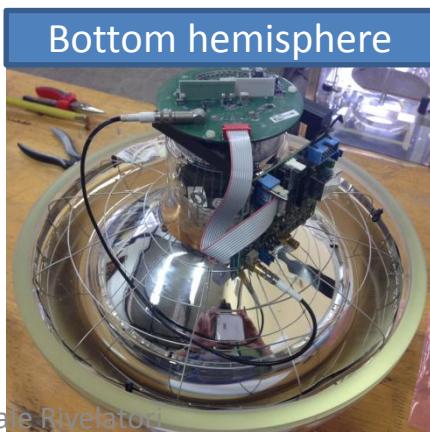
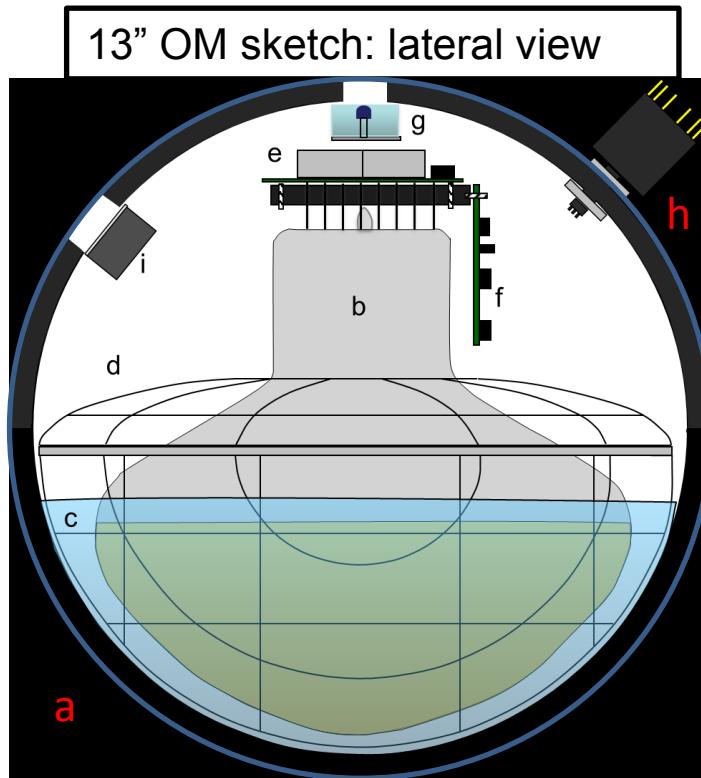
It consists of a new infrastructure at the deep-sea site of Capo Passero, Sicily, at 3500 m depth :

- 100 km cable, linking the site to the shore
- a shore station, inside the harbor of Portopalo di Capopassero
- the underwater infrastructures need to connection
- the final KM3NeT detector :
 - 8 storeys tower
 - 2 Optical Modules (OMs) at each end
(Vertical downwards, Horizontal)
 - 4 OMs per storey

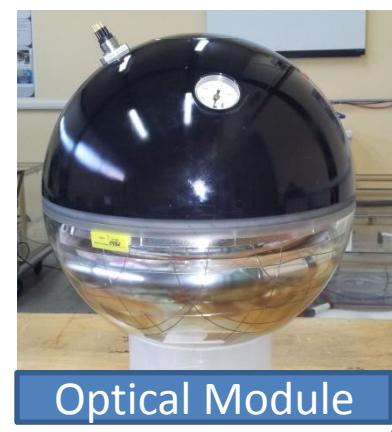
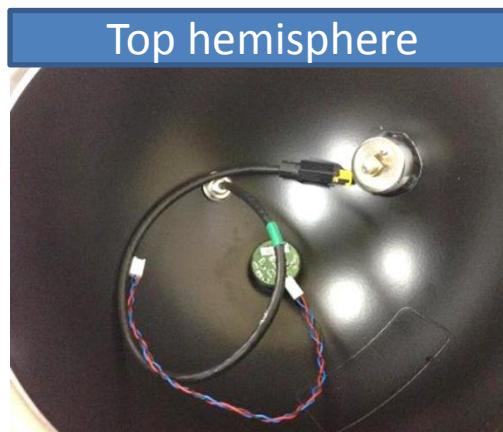


Optical Module in KM3NeT

- A glass sphere 13-inch a transparent and a painted black half- shere (Benthos) (a)
- Single large area photomultiplier : Hamamatsu 10-inc 10 stages PMT R7081 (b)
- Optical gel : Waker SilGel 612 (c)
- μ -metal wire cage (d)
- PMT base circuit : ISEG (e)
- FEM (Front End Module) electronic board (f)
- LED beacon (g)
- manometer (i)
- pin connector (h)



Seminario Nazionale Rivelatori
Innovativi INFN 2014



Detectors of light: photomultiplier tubes (PMT)

In order to detect Cherenkov light, we use photomultiplier tubes PMT of 10-inch diameter by Hamamatsu.

They are powered by an active base by Iseg and stored in the so-called Optical Module (OM).

Hamamatsu 10-inch PMTs:

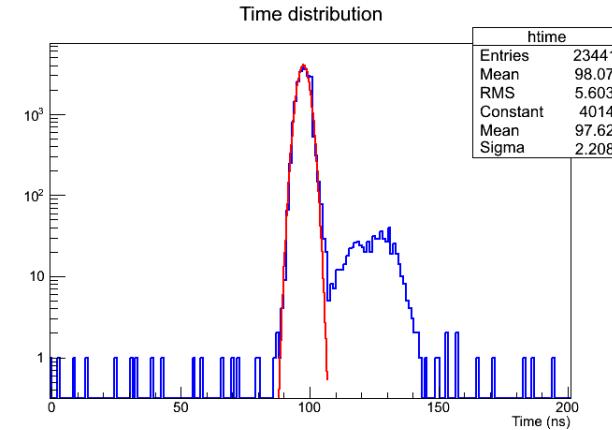
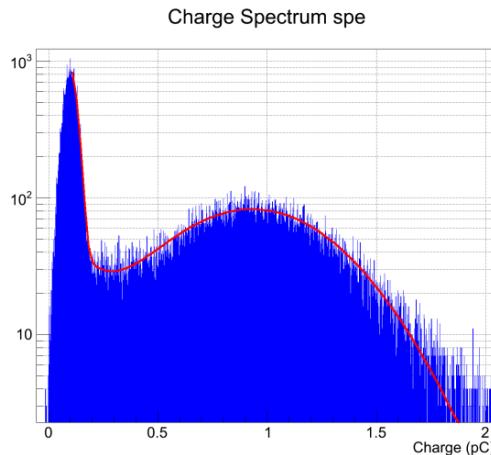
- Large Are PMT Mushroom shape by Hamamatsu
- Bialkali photocathode of 10 inch (QE \approx 25% @ 400nm) (indicated for visible light as Cherenkov)
- 10 stages dynode



Hamamatsu 10-inch PMTs with the ISEG base soldered

PMTs properties

- **Dark current:** Phototubes have “dark” current even with no incident light.
 - Thermionic emission
 - Anode leakage
 - Case scintillation
 - Gas ionization
- **Gain:** the total number of electron collected at the anode output as the result of a single electron emission event at the photocathode.
- **Peak to Valley Ratio (P/V) :** The charge spectrum shows a pedestal peak due to dark pulses and a signal peak of single photoelectron when the photocathode is illuminated with a single photons. The ratio between the signal peak and the valley quantifies the signal-background ratio of a PMT
- **Transit Time Spread (TTS):** when a photocathode is illuminated with a single photons, the transit time of each pulse has a fluctuation and it is the TTS.



Spurious Pulses on PMTs

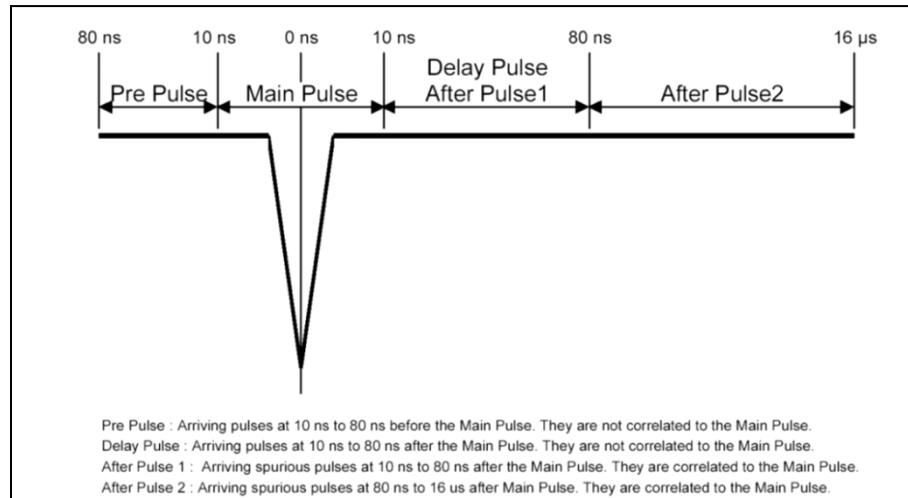
Spurious pulses not correlated with main pulse :

Pre-pulses : due to the direct photoelectron emission on the first dynode from the photons which passed the photocathode without interaction. The arrival time of pulse will be anticipated in confront of the main pulse.

Delayed: The primary photoelectron is reflected from the first dynode without a secondary electron emission, it turns towards the photocathode, makes a loop and only after it creates a cascade of electrons in the dynodes. The arrival time of the hit will be delayed in confront of the main pulse (delay 10ns-80ns).

Spurious pulses time-correlated with the main PMT response:

After pulses(type 1 , type 2, multiple after pulses): noise pulses that appear following the main PMT response to a detected light event. (80ns-16 μ s after Main pulse)



PMTs Test bench



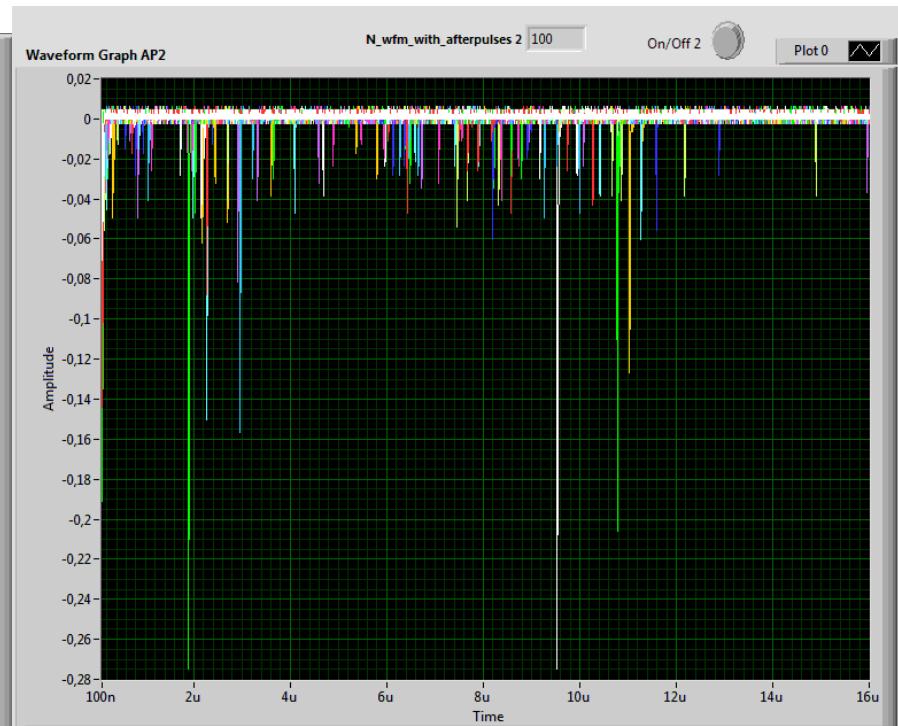
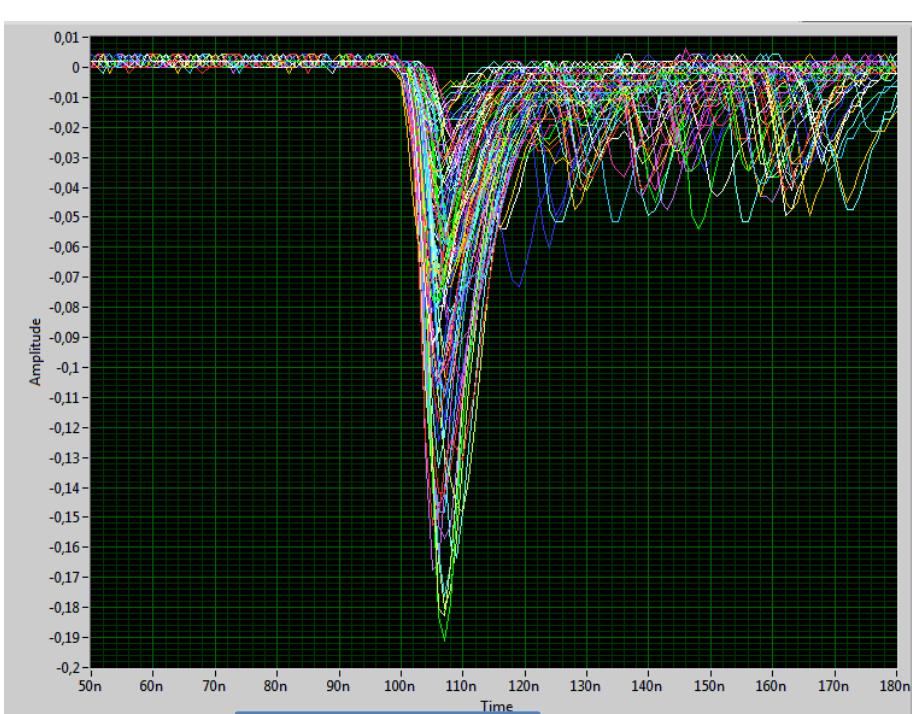
In order to confirm the good performances of PMTs,
we have to test it before of assembly

- **PMT Hamamatsu**
- dark box
- **Optical fiber**
- **Laser Hamamatsu PLP10-040C, i 10kHz (external -trigger)**
- **DAQ done by NI- PCI mounted on laptop pc**



Segnali

We use a Labview code for an online analysis



Labview Code on next slides

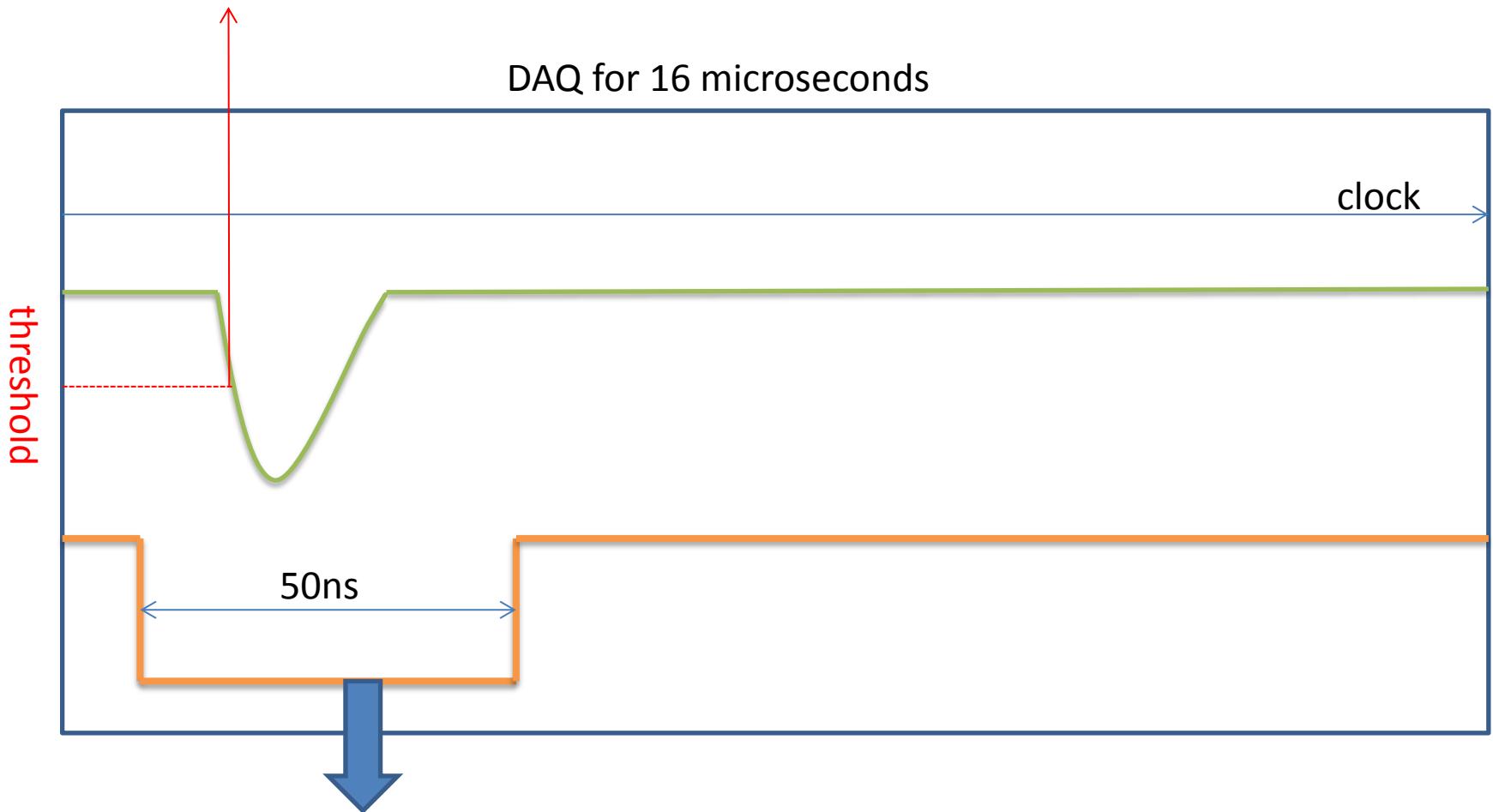


Campionamento
totale di $16\mu s$ per
calcolare impulsi
spuri AP1 e AP2.

Transit Time

Gate = trigger laser

DAQ for 16 microseconds



Integration of signal → Charge distribution

Programmazione scheda NI

La programmazione e l'analisi dati della scheda NI-PCI 5153 si articola in tre step:

- 1) **vi di acquisizione DAQ.vi** : Il trigger del laser abilita il campionamento per 16 μ s. Si può impostare sia un tempo di acquisizione che un numero di forme d'onda. Per ogni forma d'onda si guarda su 16 μ s la presenza di after pulses di tipo 1 o 2 e la relativa percentuale. La VI integra il segnale in una finestra di 50 ns centrata sul main con soglia 20mV generando un istogramma. Sempre la VI con una soglia di 20mV conserva in un istogramma il transit time del segnale in una finestra centrata sul main di 200ns. Altro output della VI è il rate del PMT (che in assenza di laser è il Dark Rate).
- 2) **vi di analisi in carica ChargeAnalysis.vi** : Costruisce un istogramma in carica con risoluzione fissata dall'utente (in funzione della dinamica scelta) e restituisce rapporto picco/valle, risoluzione in carica, gain
- 3) **vi di analisi in tempo Time.vi** : Costruisce l'istogramma temporale in una finestra di 200 ns centrata sul main pulse con una risoluzione temporale fissata dall'utente (in funzione della dinamica scelta) restituendo: TT, TTS , percentuali di pre e delayed pulses.

Le 3 VI vengono «compattate» in un'unica macro che le esegue sequenzialmente e restituisce un led verde o rosso a seconda che i valori in carica, tempo e impulsi spuri soddisfino in modo soddisfacente o meno i valori di capitolato richiesti alla ditta costruttrice. L'operatore ha accesso solo a quest'ultima VI, trasformata in eseguibile!

Charge Analysis vi

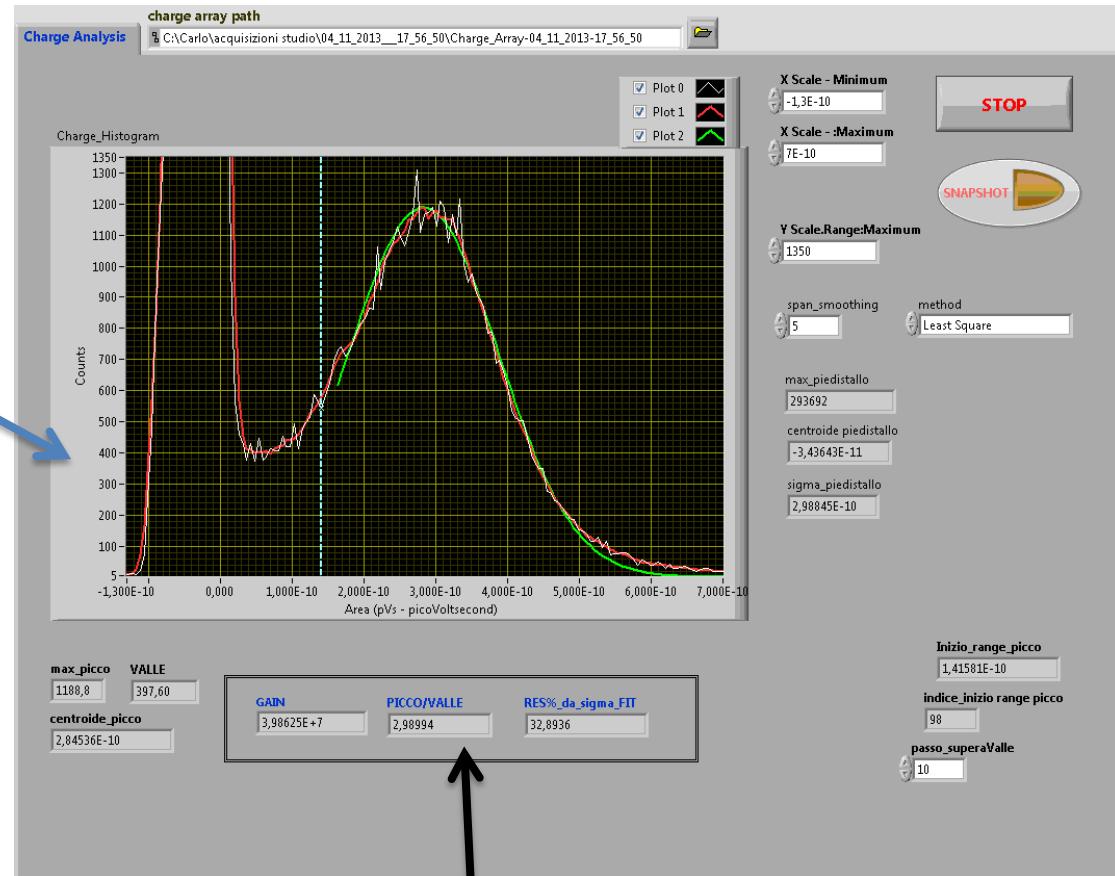
Input: istogramma in carica della vi di acquisizione

Plot bianco : istogramma in carica «grezzo» ottenuto dalla VI di acquisizione.

Plot rosso : istogramma con smoothing su 5 bin. Elimina le fluttuazioni maggiori

Linea tratteggiata azzurra: stabilisce il «range» adatto ad un corretto fit del picco di photoelettrone

Plot verde : fit gaussiano



- Il picco del piedistallo è individuato dal massimo dell'array
- Il picco del singolo pe dal fit gaussiano ottenuto
- FWHM dedotta dal fit gaussiano
- Valore della valle dedotto da uno smoothing dell'istogramma

Output : Valori di interesse

- Rapporto picco/valle
- Gain
- Risoluzione in carica (σ)

Time Analysis vi

Input: istogramma del TT a th=20mV (1/3 pe) della VI di acquisizione

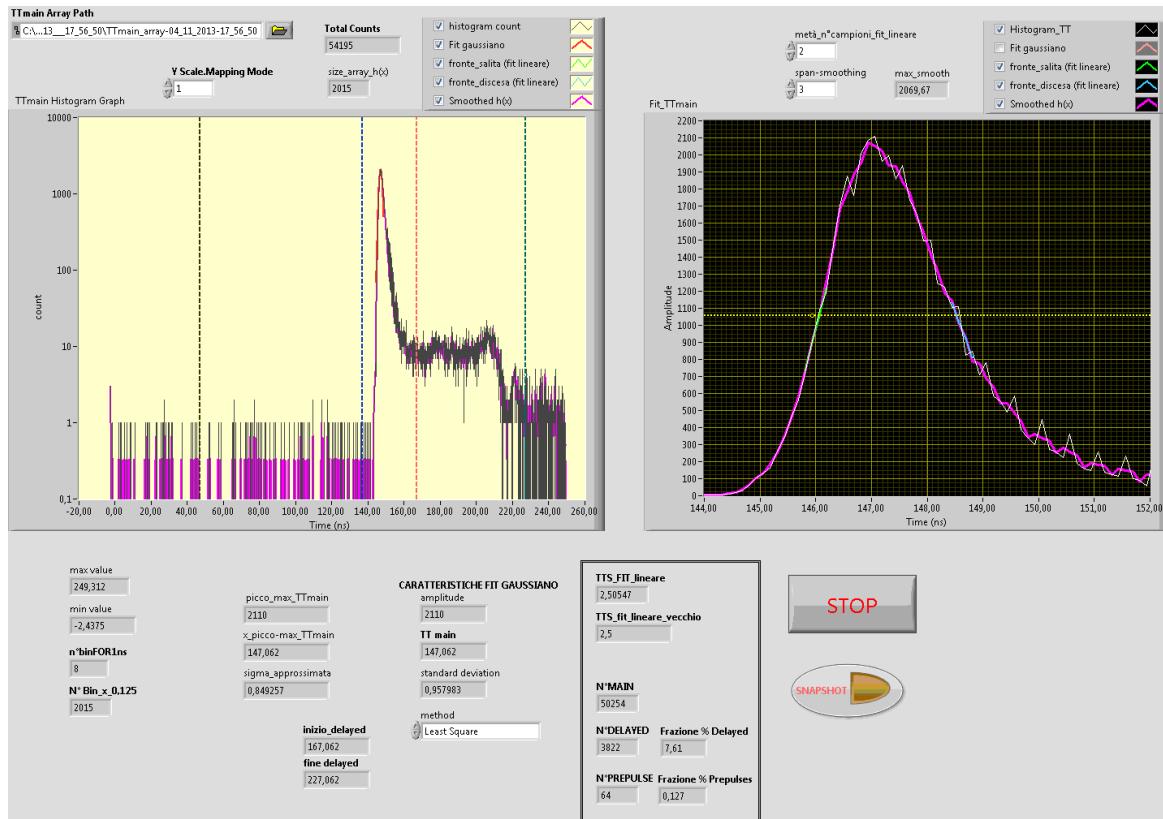
Plot nero (prima figura) e bianco (seconda fig): istogramma in TT «grezzo» ottenuto dalla vi di acquisizione.

Plot fucsia : istogramma con smoothing su 5 bin. Elimina le fluttuazioni maggiori

Linee tratteggiate: stabiliscono i range temporali per il calcolo di main, pre e delayed pulses.

Plot rosso prima figura: fit gaussiano (determina il TT)

TTS calcolato mediante larghezza a metà altezza e fit del fronte di salita e discesa della curva (seconda figura)



Output: Valori di interesse

- Transit Time
- Transit Time Spread
- N°Main
- % delayed (10ns – 80 ns dopo il main)
- % prepulses (80 ns -10 ns prima del main)

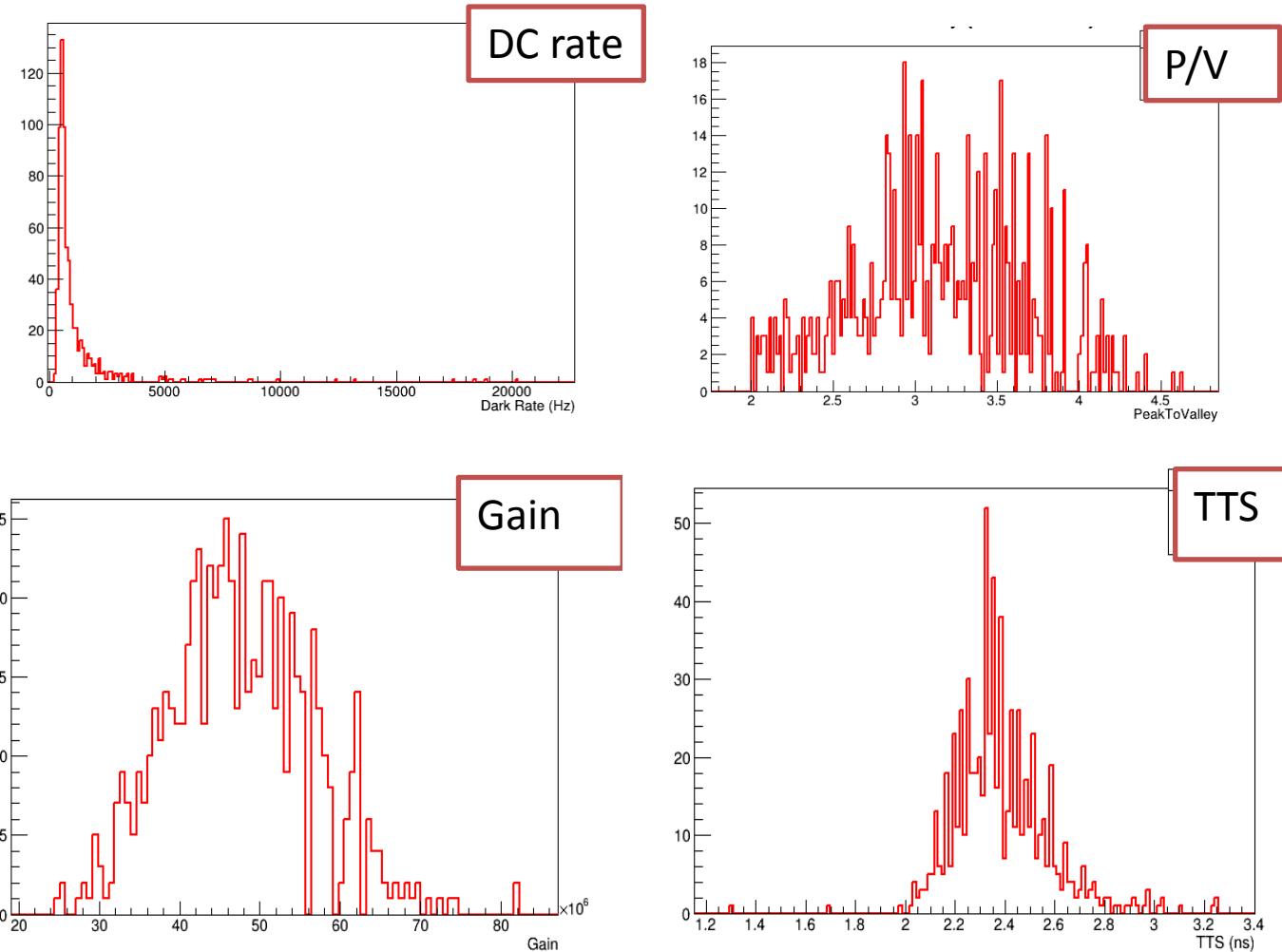
PMTs Test Bench

After the test bench we check if PMT is available or not for the assembly (see values in section «range»)

Example of a Report after test bench:

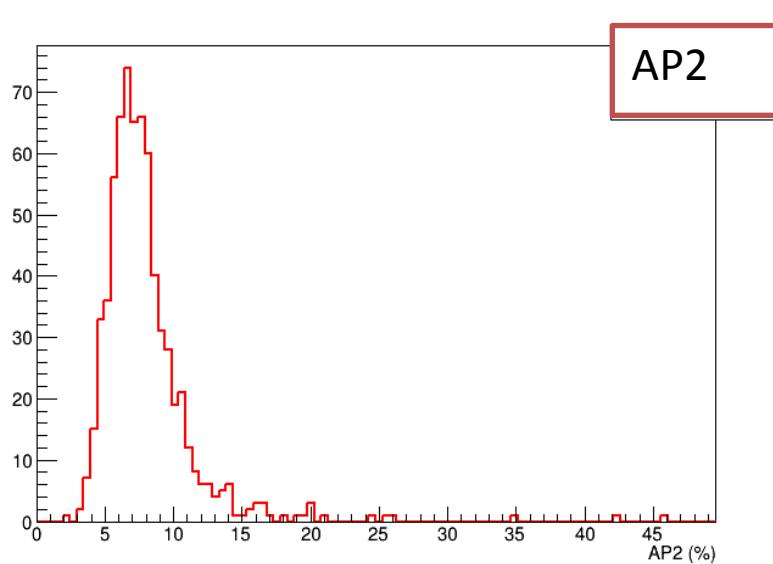
PMT n°	TB0010	Misurati	Datasheet	Range
Valori				
Nominal_Voltage_(V)_=		1670		
PMT_rate_(Hz)_=	835,53			
DC_rate_(Hz)_=	798,21	1000	[0; 8.000]	
AP1_%_=	0,22	0,07	[0; 3]	
AP2_%_=	7,63	6,81	[0; 10]	
Delayed_%_=	4,99	3,84	[0; 8]	
Prepulses_%_=	0,26	0,09	[0; 1]	
TTS_(ns)_=	2,62	2,86	[0; 3,5]	
P/V_=	4,29	4,38	[2; 10]	
Gain_=	5,02E+7			[4E+7; 6E+7]
Semaforo_=	VERDE			

10-inch PMT's properties I

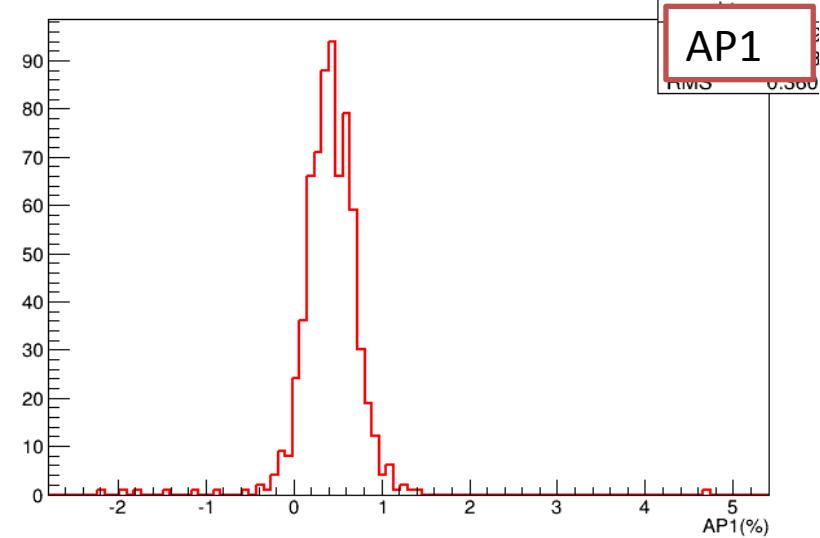


These are the final results for 10-inch PMTs for the first two towers on KM3NET

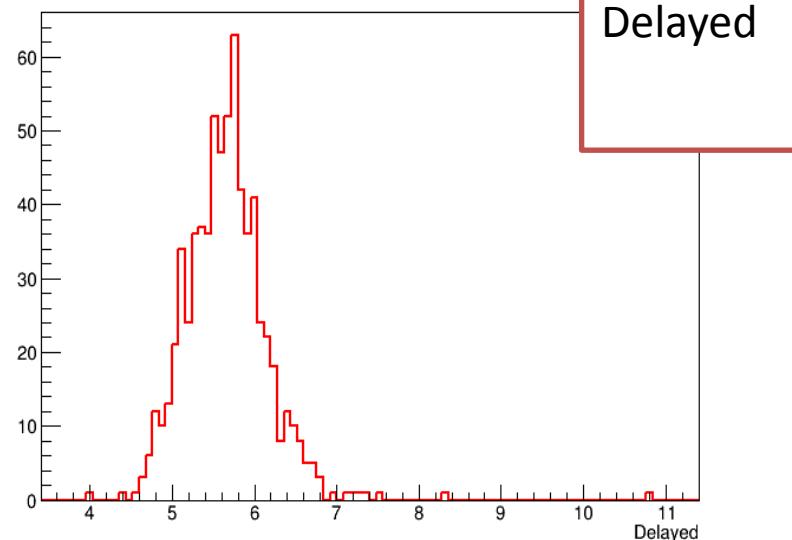
10-inch PMT's properties II



AP2



AP1



Delayed

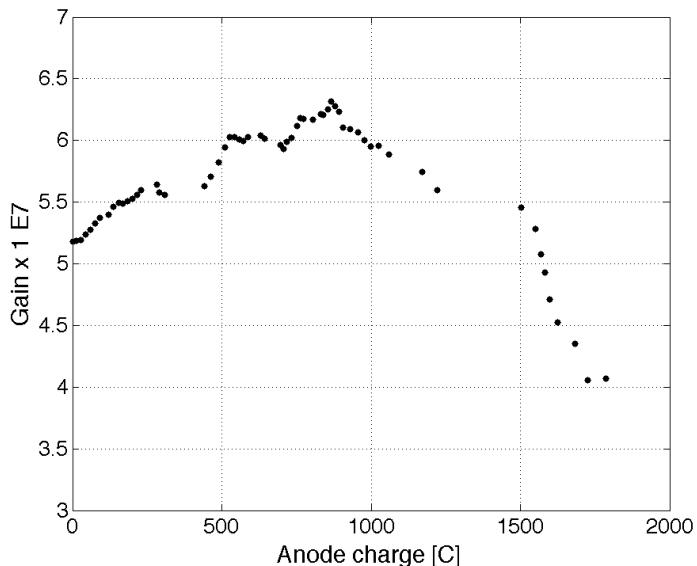
Ageing effect of PMTs

OMs are exposed to a continuous optical background due to ^{40}K decays plus a contribution due to the diffuse bioluminescence.

Two different phases:

- accelerated ageing phase
- full characterization of the PMT in s.p.e. condition

Tests on ageing equivalent of 45 years of 1 pe, 200 kHz



Ageing measurements show that all the PMTs parameters , except gain, do not change.

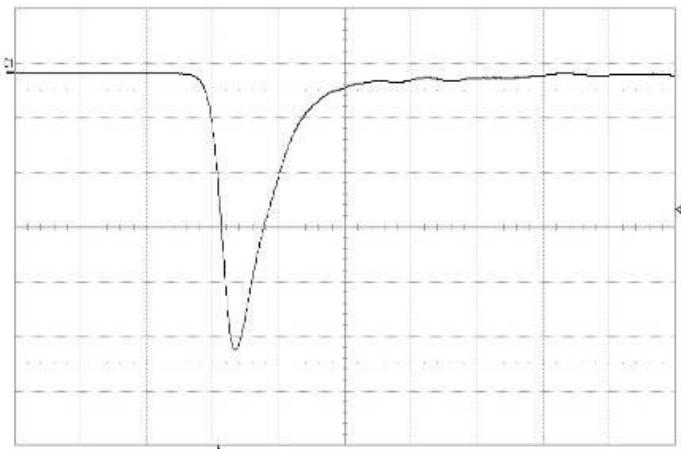
After an initial gain increase of about 10%, with respect to the initial value of $5 \cdot 10^7$, a sharp decrease of the gain of about 30% is observed for larger values of the accumulated anode charge



The high voltage supply board

Main features:

- Active base produced by ISEG
- +5 Volts supply (bipolar voltage supply before modification)
- Cathode-1^dynode and 1^dynode-anode voltages individually controllable
- Anode current max : 100 microAmpere
- Power consumption : 150mW @ 2000 Volts
- Modified on the output on NEMO requirements



Typical signal from PMT of 10''

- no ringing in the signal
- increase in signal rise time and width
- saturation starts around at 100-120 p.e.
- limit about 1 nC for laser pulsed (width of 60 ps)

Measure	P1 area(C1)	P2 dyn(C1)	P3 dyn(C1)	P4 dyn(C1)	P5 ---	P6 ---
ave	-456.22003 pVs	7.263 ns	3.138 ns	50.32 nV		
mean	-434.29381 pVs	7.1838 ns	3.1303 ns	50.64972 mV		
min	-443.23737 pVs	5.902 ns	2.503 ns	41.103 mV		
max	-306.32651 pVs	7.801 ns	3.079 ns	52.746 mV		
sdev	7.3483860 pVs	103.49 ps	54.52 ps	6.4723 μV		
num	937	937	937	937		
status	✓	✓	✓	✓		

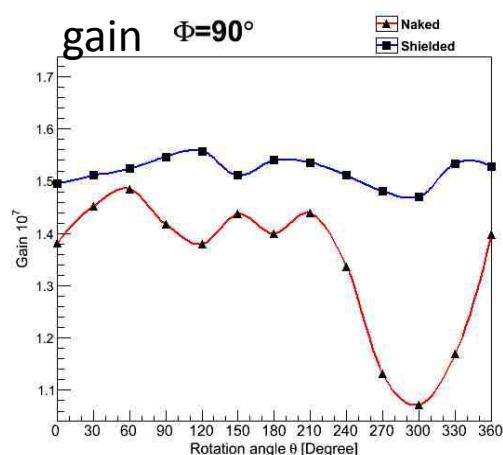
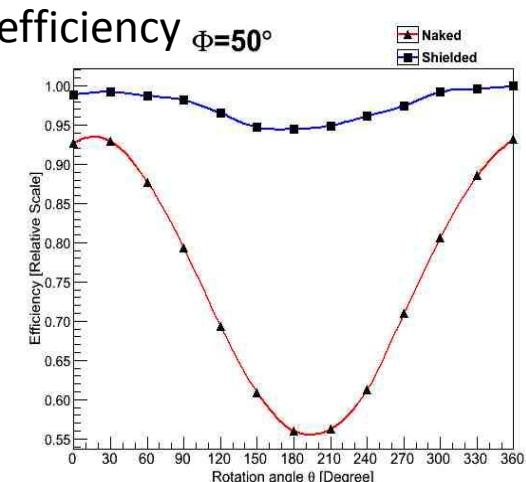
The magnetic shielding

In order to shield PMTs from Earth's magnetic field , a cage of mu-metal wire was chosen. The detection efficiency, gain, P/V ratio, charge resolution, Transit Time (TT), and Transit Time Spread (TTS) were measured simultaneously with the aim of evaluating variations of the PMT characteristics changing the PMT relative orientations with respect to the Earth's magnetic field

Cage produced by ITEP(Russia)

2 parts:

- Hemispherical (30cm diameter, 14 cm height)
- Flat (30 cm diameter disk with an hole in its center)



S.Aiello et al 2013 JINST 8 P07001 doi:10.1088/1748-0221/8/07/P07001

Large variation for the naked PMT

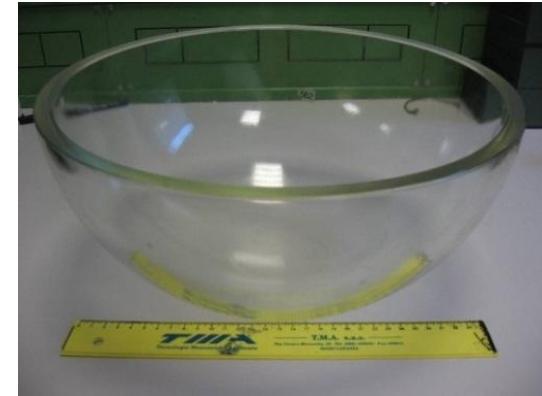
Max variation	Naked	Shielded
efficiency	40%	6%
gain	29%	7%
P/V	41%	14%
Charge res.	50%	20%
TTS	20%	2%

The magnetic shielding reduced strongly the variations in the PMT and even improved performance.

Glass Sphere

- standard 13 inch deep-sea instrumentation vessels in borosilicate glass, produced by Benthos
- two half spheres: $\frac{1}{2}$ transparent, $\frac{1}{2}$ painted black
- no vacuum valve
- unique penetration for the pin connector

Refractive index	1.48
Specific gravity at 25°C [g/cm³]	2.23
Outer diameter [mm / inch]	330 / 13
Glass thickness [mm]	12
Weight in air [kg]	8.6
Depth rating [m]	7000

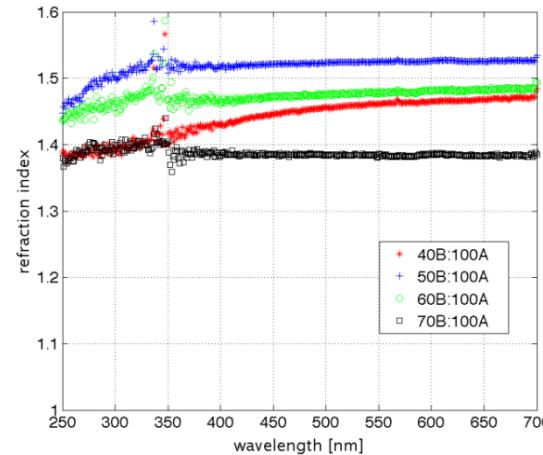
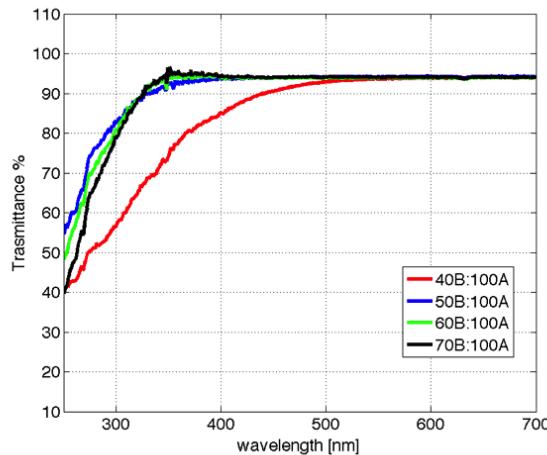


The optical coupling

The main requirements for the optical gel were:

- high transparency;
- a refractive index close to the ones of the glass sphere and sea water;
- a good rigidity to hold the OM components, with sufficiently elastic properties to absorb shocks and to accommodate for the deformation of the glass sphere under pressure;
- stability of the optical and mechanical characteristics over more than 10 years.

The selected material is a two-component (A and B) silicone gel, WACKER SilGel 612



Load resistance tests for the different gel mixtures

Gel Composition	40B:100A	50B:100A	60B:100A	70B:100A
Load / surface [Kg/cm ²]	0,5	1,2	0,6	0,7

55B:91A mixture was selected

OM assembling procedure 1

- Coating of ISEG active base
- Test bench of PMTs
- Mounting LED beacon on black semisphere
- cleaning of each element: optical paper and methyl alcool
- mixture gel preparation (1,5 l per OM)
- pouring the gel into the glass hemisphere
- 2 cycles of outgassing vacuum @ 250mbar + Azotum in order to reduce humidity



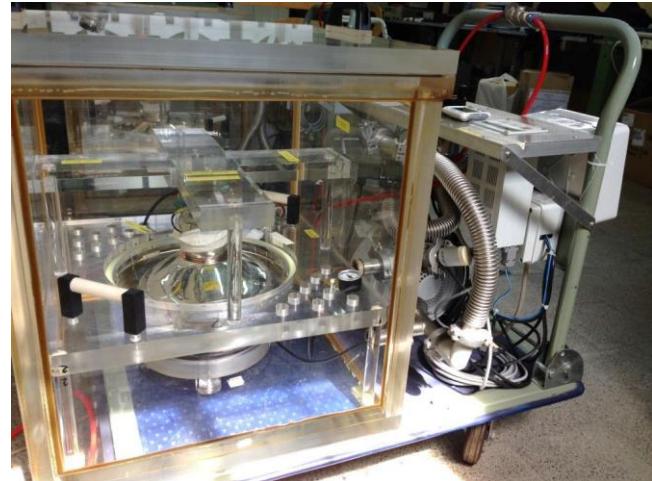
OM assembling procedure 2

- PMT positioning into the sphere by means of the centering cross tool
- 2 cycles of outgassing + Azotum in order to reduce humidity
- Polymerization of the gel @ atmospheric pressure and room temperature (12 h)
- Mounting of electronics : FEM

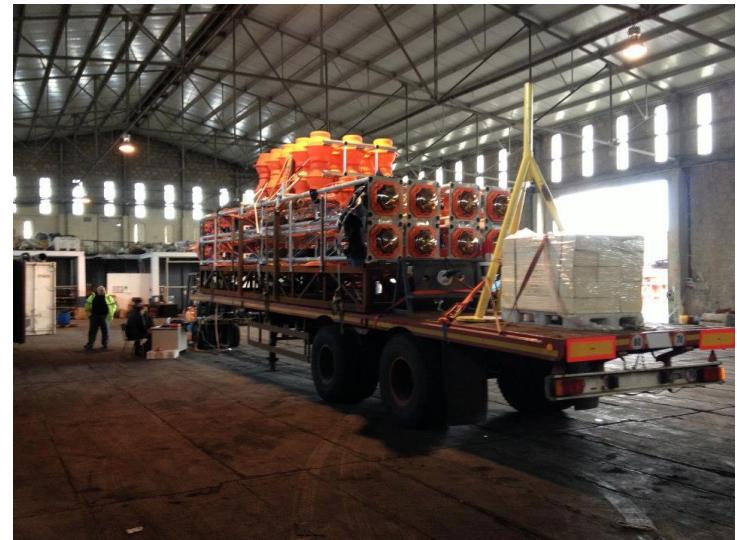
Sealing of the OM :

- hemispheres were aligned and joined
- closed under-pressure at 250 mbar
- external adhesive (Terostat) and tape

The watertight and mechanical resistance of the OM assembled was tested in the hyperbaric chamber of NEMO test site (Catania harbour) up to 350 atm



Snapshot of KM3NeT Tower



ROV



Grazie per l'attenzione