WIMP ARGON PROGRAMME

Demonstration and comparison of photomultiplier tubes operation at liquid Argon Temperature

Ettore Segreto

LNGS (Italy)

On behalf of the WArP Collaboration

Introduction

- Direct Dark Matter search in the form of WIMPs requires to detect very low nuclear recoil energies (few KeV).
- Liquid Argon based detectors reveal the recoil detecting the scintillation light following energy deposition.
- Light red-out is mainly performed by means of photomultiplier tubes (PMTs).
- A new type of PMT has been recently developed by Hamamatsu Photonics (Mod. R11065) which pushes the Quantum Efficiency up to 35% at liquid Argon temperature (87^{o} K).
- Within the on-going R&D activity of the WArP Collaboration (WIMP Argon Program at LNGS, 2009-11), a first set of R11065 PMTs has been subject to a series of tests aiming at their characterization in reference working conditions
- We operated the PMTs immersed in the liquid and optically coupled to LAr cells of various size.
- A comparison of the R11065 Hamamatsu PMT with a former generation of cryogenic PMT produced by Electron Tubes Limited - Mod. ETL D750 (currently in use with the WArP -100 detector) has been also carried out.

New high QE Hamamatsu PMT

HAMAMATSU

TENTATIVE DATA SHEET
Sept. 2009

PHOTOMULTIPLIER TUBE

R11065

For Low Temperature Operation down to -186 deg. C
Special Bialkali Photocathode (Bialkali LT), Low Radioactivit y
76 mm (3 Inch) Diameter, 12-stage, Head-on Type, Synthetic Silic a

General

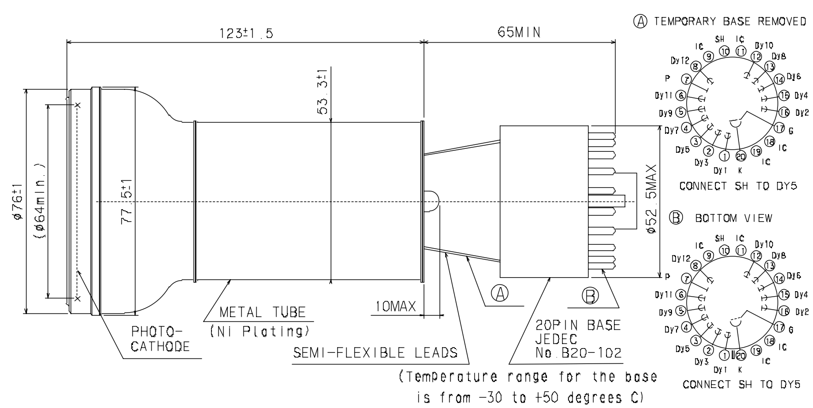
Parameter		Description / Value	Unit
Spectral response		160 to 650	nm
Wavelength of Maximum Response		420	nm
Window material		Synthetic silica	-
Photocathode	Material	Bialkali	-
	Minimum Effective Area	64	mm dia.
Dynode	Structure	Box & Linear-focused	-
	Number of Stages	12	-
Suitable Socket		E678-20A (supplied)	-
Operating Ambient Temperature		-186 to +50	deg. C
Storage Temperature		-186 to +50	deg. C

- •Box&Linear-focused 12-stages PMT
- •Synthetic Silica 3” window (cut-off around 160 nm)
- •Working temperature down to -186° C
- •QE ≥ 30% @ 420 nm
- •Bialkali cathode without Pt underlayer
- •High Collection Efficiency of photoelectrons at first dynode (above 95% with $\Delta V_{K\text{-}D1}$>300Volt)
- •Voltage divider custom made on a G10 printed circuit (according to Hamamatsu specifications)

R11065 TEST DATA

January 12, 2010

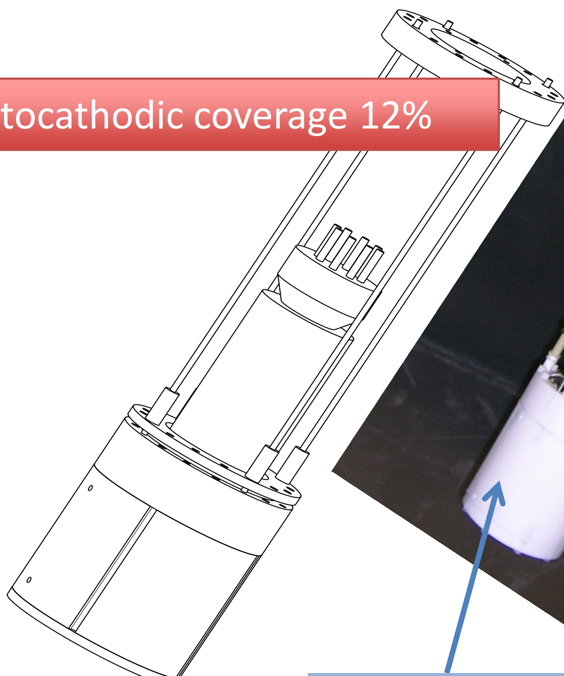
	SERIAL NUMBER	SK [uA/lm]	SKB	SP [A/lm] 1500 V	IDB [nA] 1500V	QE [%] 420 nm
1	ZK4998	124.0	14.70	783	44.0	33.8
2	ZK4999	157.0	15.00	1040	56.0	35.4
3	ZK5001	136.0	14.50	1100	27.0	34.6
4	ZK5002	138.0	14.00	1010	15.0	33.9
5	ZK5006	137.0	13.10	1050	12.0	31.0
6	ZK5172	163.0	14.60	1170	34.0	33.3
7	ZK5173	143.0	14.10	808	32.0	32.5
8	ZK5175	114.0	12.00	777	12.0	29.8
9	ZK5176	110.0	11.20	897	30.0	27.8

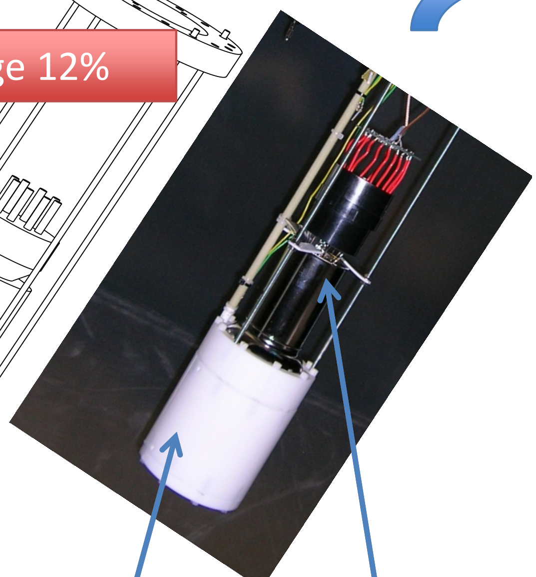


Single PMT test

- PTFE cell containing 0.7kg of LAr (cylinder shaped h=9cm Φ=8.4cm) observed by one 3" R11065 PMT.
- Scintillation photons of LAr are in the VUV range (around 127 nm) and with two (main) different time constants ($\tau_S \simeq 5$ ns for the fast component and and $\tau_T \simeq 1.3$ μs for the slow component).
- Internal surfaces of the cell covered with reflective foils coated by a wavelength shifter -> TPB (peak emission 440 nm);
  - ✓ Multi-layer plastic mirror (3M-VIKUITI ESR) with high specular reflectivity in the visible (~ 99%) ✚ TPB film obtained by deposition with vacuum evaporation technique (about 300 μg/cm2);

Photocathodic coverage 12%

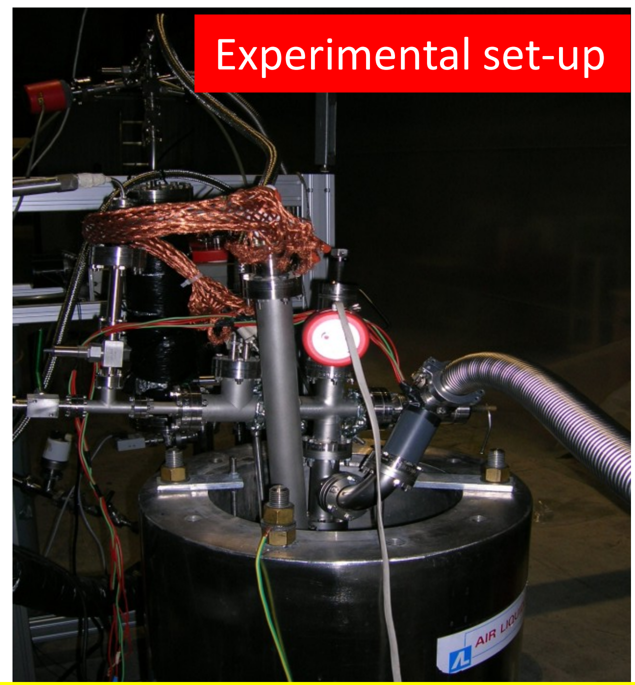




PTFE cell

PMT

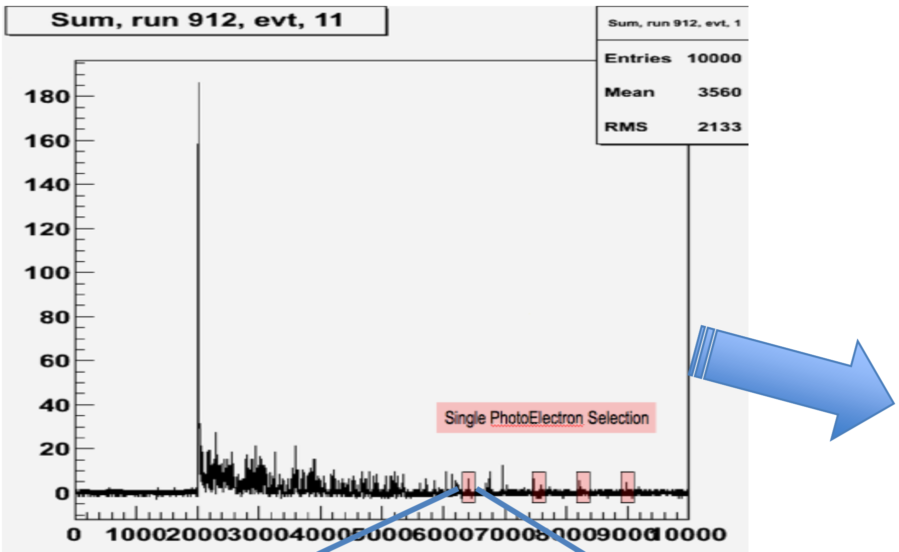
Experimental set-up

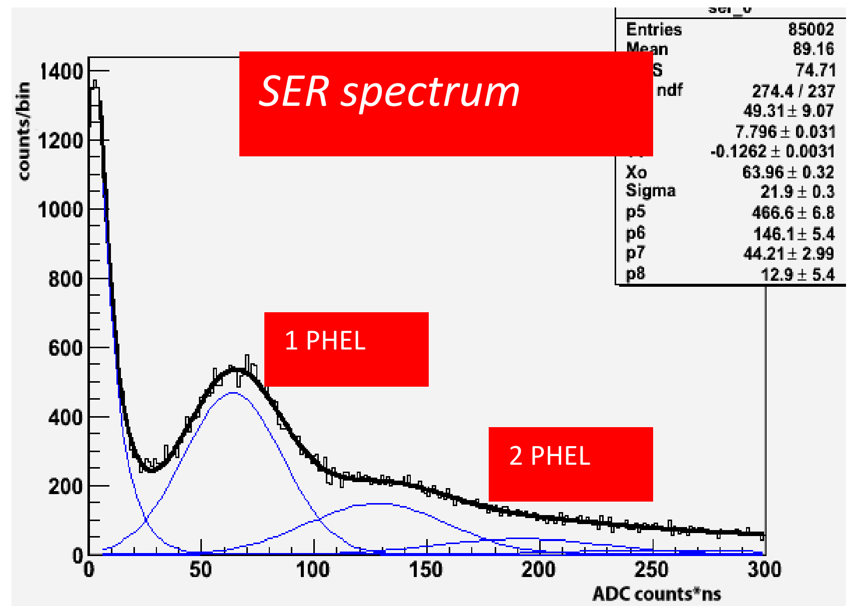


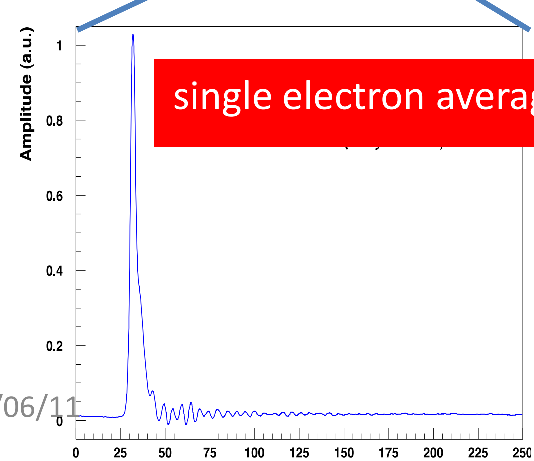
LAr filtered during filling (Oxisorb and Zeolite)

DAQ and calibration

- PMT anode current transmitted to a fast Waveform Recorder (Acqiris, DP235 Dual-Channel PCI Digitizer Card2, 1 GS/s, 8 bit dynamic range) => signal waveform recorded with 1 nsec sampling time over a full record length of 15 μs;
- Detector exposed to a ^{241}Am source with monochromatic γ-emission at 59.54 keV;
- For each source run a Single Photo-electron Response (SER) spectrum is computed.

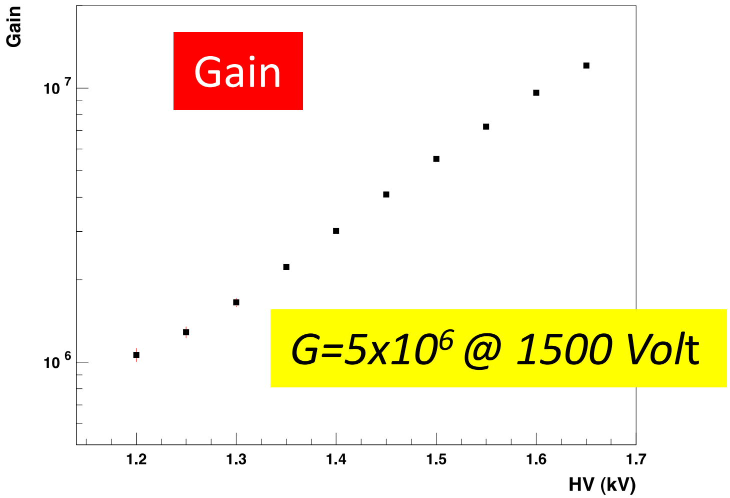


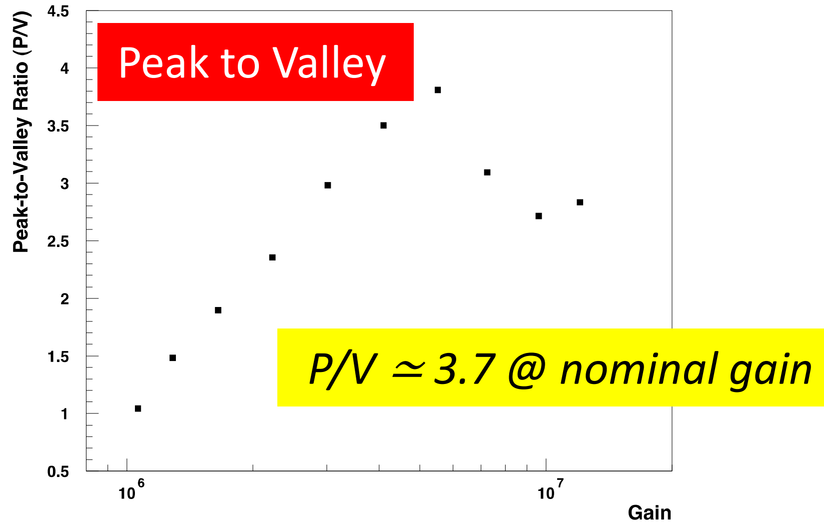


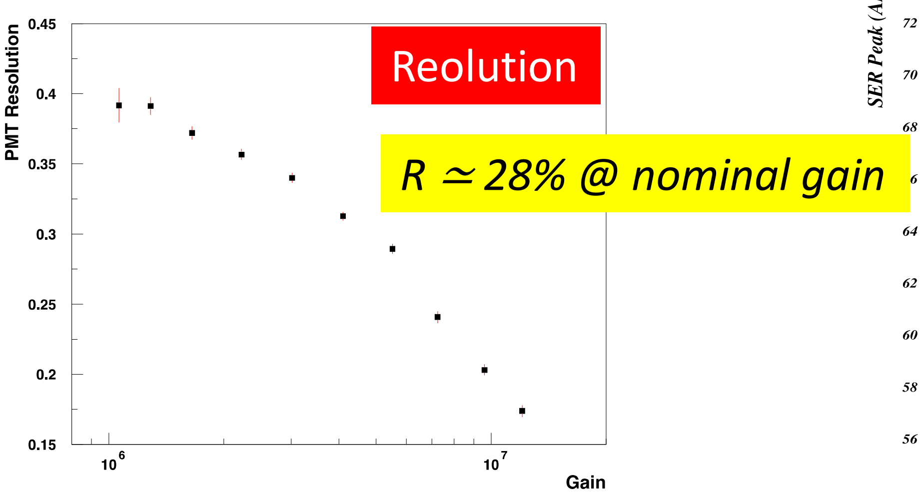


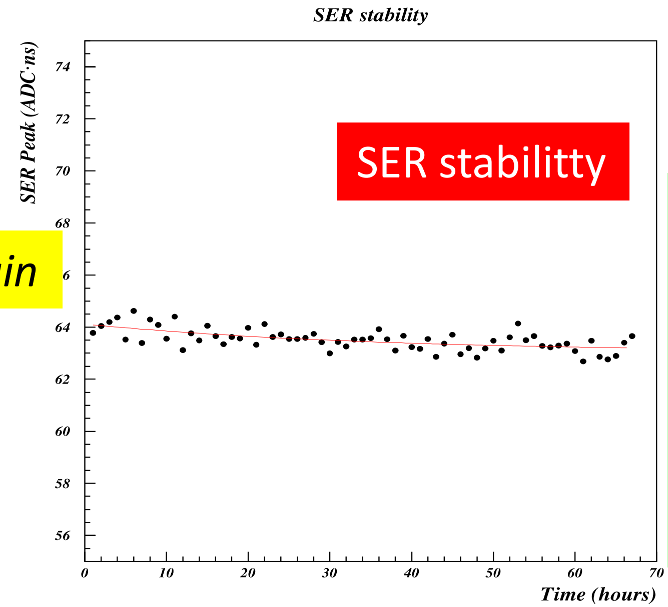
The mean value of the 1PHEL peak is proportional to the actual gain of the PMT and gives the calibration constant per single photo-electron

Gain, Peak to Valley and Resolution





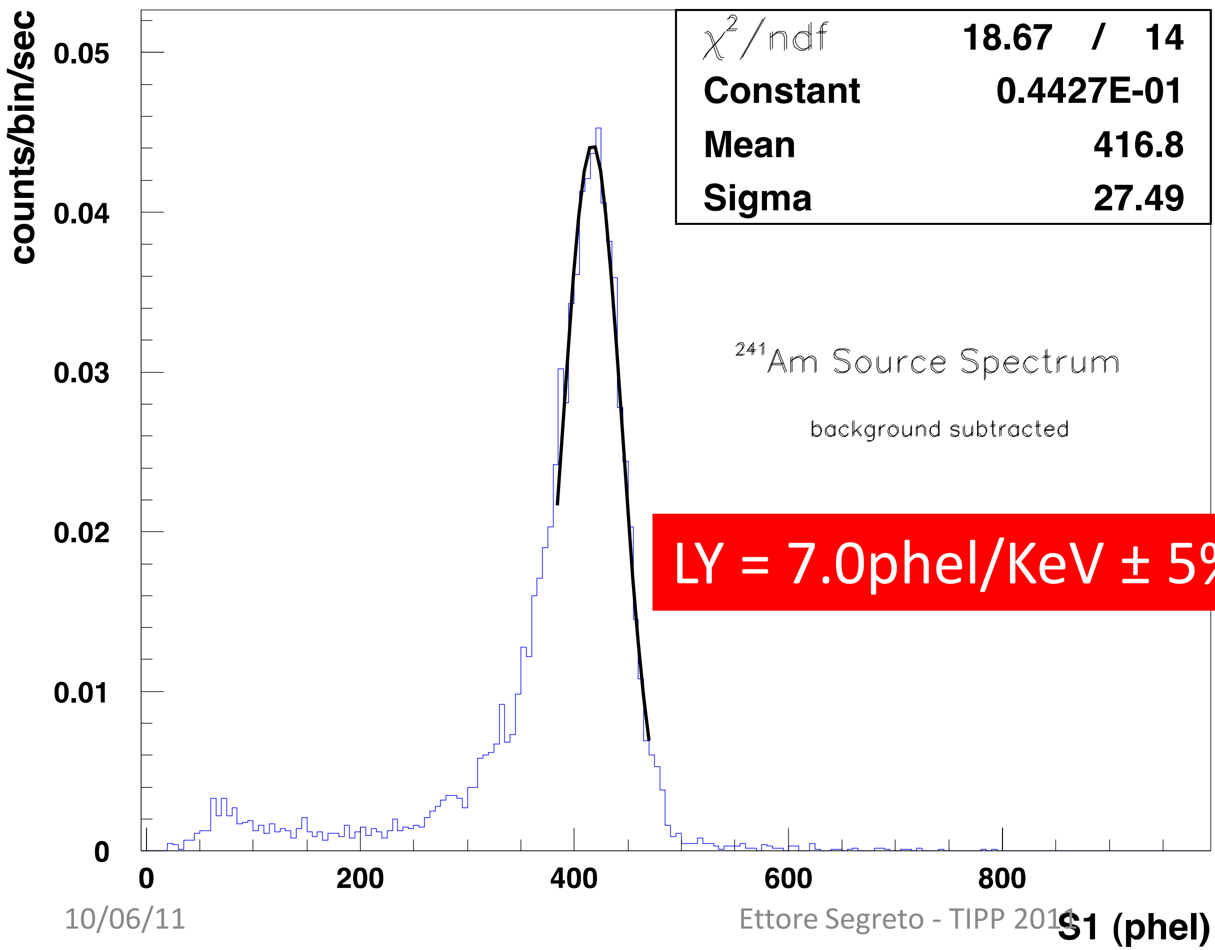




slightly decreasing exponential trend ($\tau \simeq 35$ h) attributed to residual effects of thermalization of the PMT at LAr temperature.

Light Yield measurement

- LY measurement performed by exposing the detector to the ^{241}Am monochromatic γ-source (59.54 keV);
- Pulse amplitude spectrum in photo-electrons obtained by waveform integration and application of the calibration factor determined by SER fit;



LY = 7.0phel/KeV ± 5%

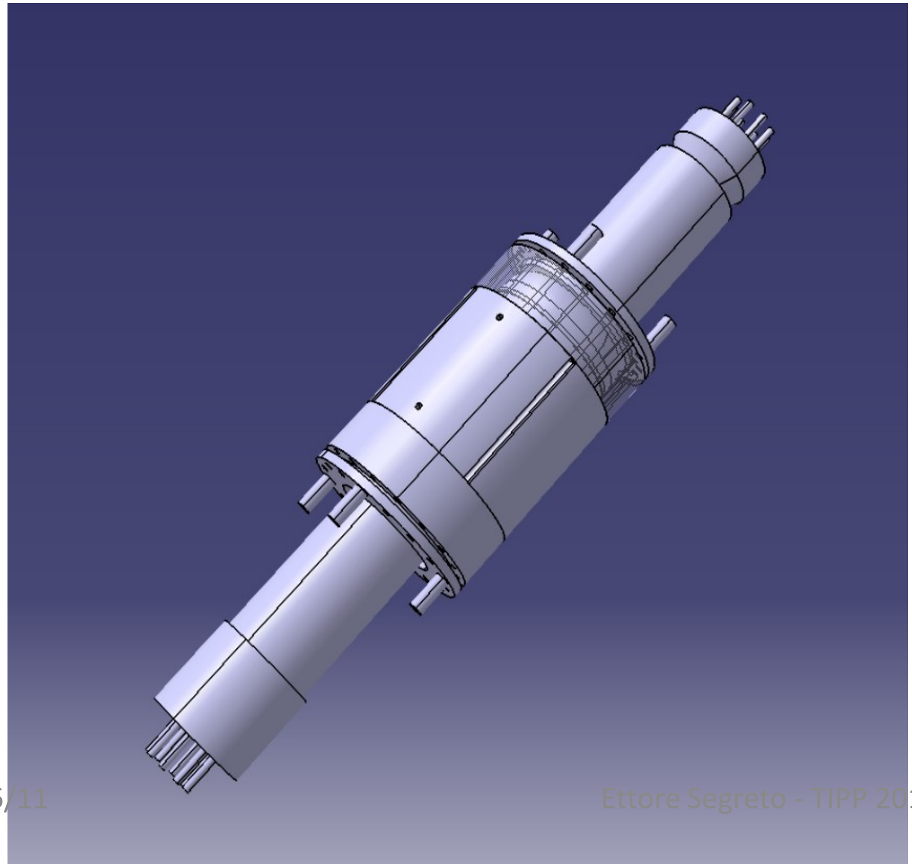
Result fully compatible with MonteCarlo expectation based on standard assumptions

Light Yield very stable during the test: fluctuations within ±1.5%

Test repeated after few weeks (same PMTs, same TPB coated reflector surfaces) -> LY measurements fully confirmed this result.

Two-PMTs test: ETL vs HAMAMATSU comparison

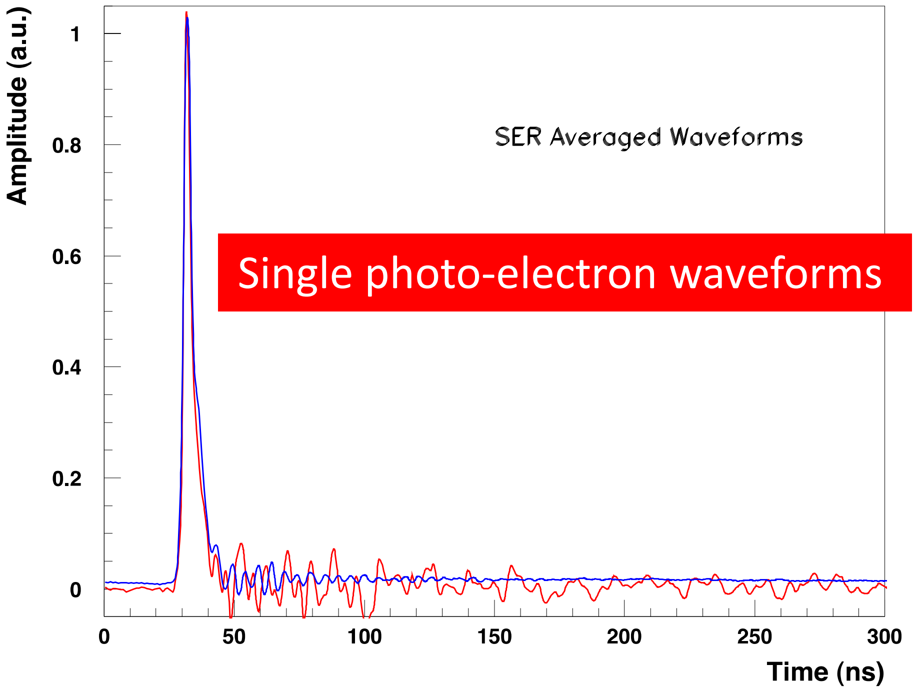
- A second test (mid 2010) for a direct comparative test of two types of PMTs: 3” HQE Hamamatsu R11065 (the same used in the previous test) and 3” ETL - D750 (pre-production series of the PMT in the WArP -100 experiment);
- LAr volume viewed simultaneously by the two PMT => comparison of the light outputs independent from the actual detector conditions;
- A PTFE cell, about 0.4 lt of internal volume (h=8.0 cm and ϕ=7.6 cm), lined with a TPB coated reflector layer on the lateral;

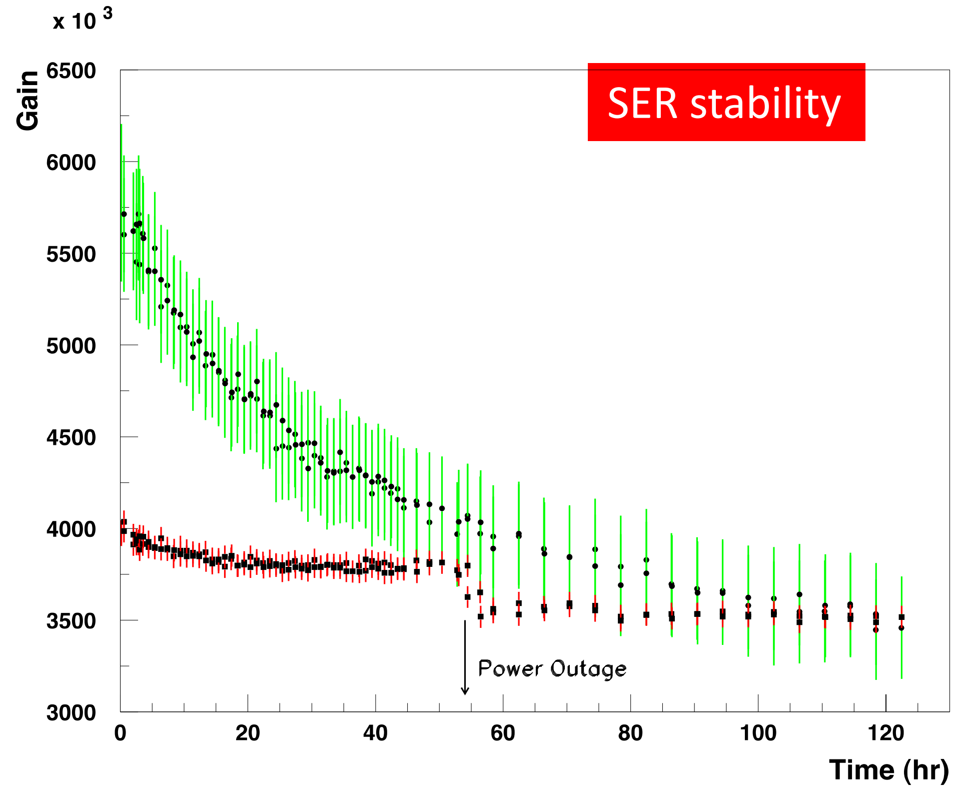


- Signals from each PMT were directly recorded by the 8-bit Fast Waveform 13Digitizer Acqiris board (DP235) at 1 GHz over a 15μs time interval (as for the single PMT test);
- Data treatment and the off-line analysis code -> same as in the single PMT test.

Single Electron Response of the two PMTs

- ✓ Very similar pulse shapes for single electron;
- ✓ The gain of the ETL PMT showed a steeper decreasing trend.
- ✓ The gain of the Hamamatsu PMT has a slight decrease over the first day after activation and then stabilized to a constant value.





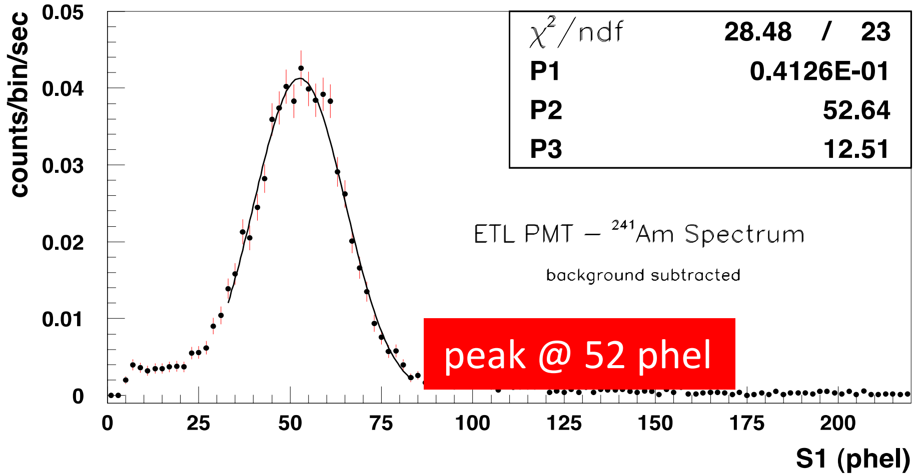
	Peak-to-Valley ratio	SER resolution
Hamamatsu R11065	3.5	32 %
ETL D750 (pre-series)	1.9	50 %

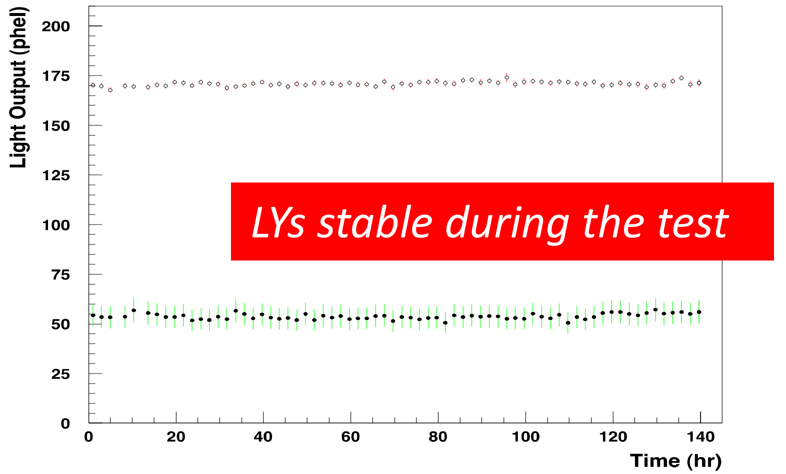
Peak to Valley @ 3.7×10^6 gain

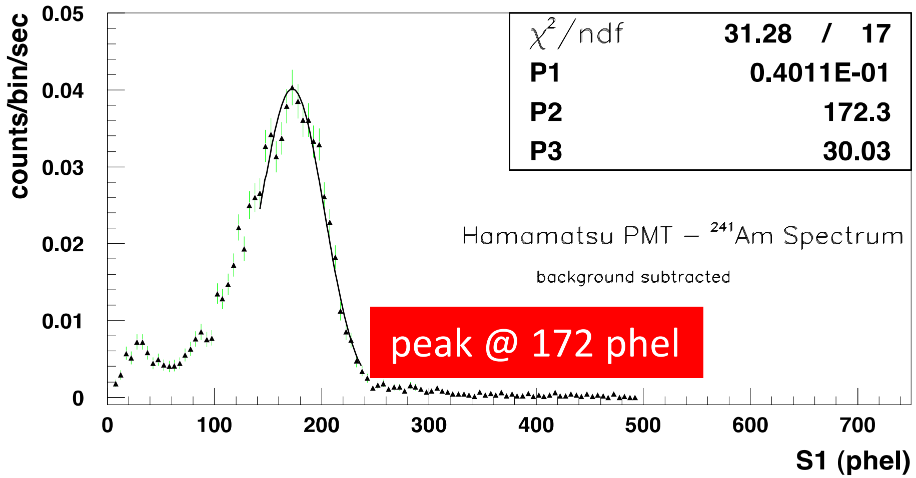
Light Yield measurement

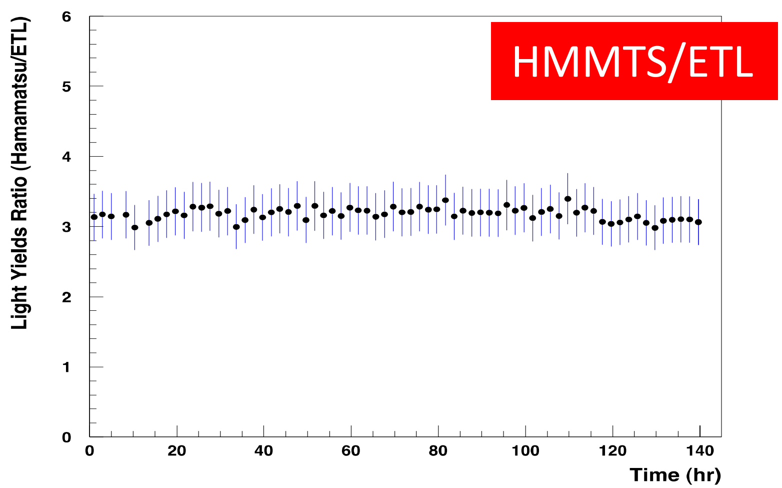
✓ *LYs determined by exposure to the ^{241}Am gamma- source (59.54 keV)*

The Hamamatsu-to-ETL ratio of LY found in the 3 : 1 range → *consistent with the ratio of the QE*



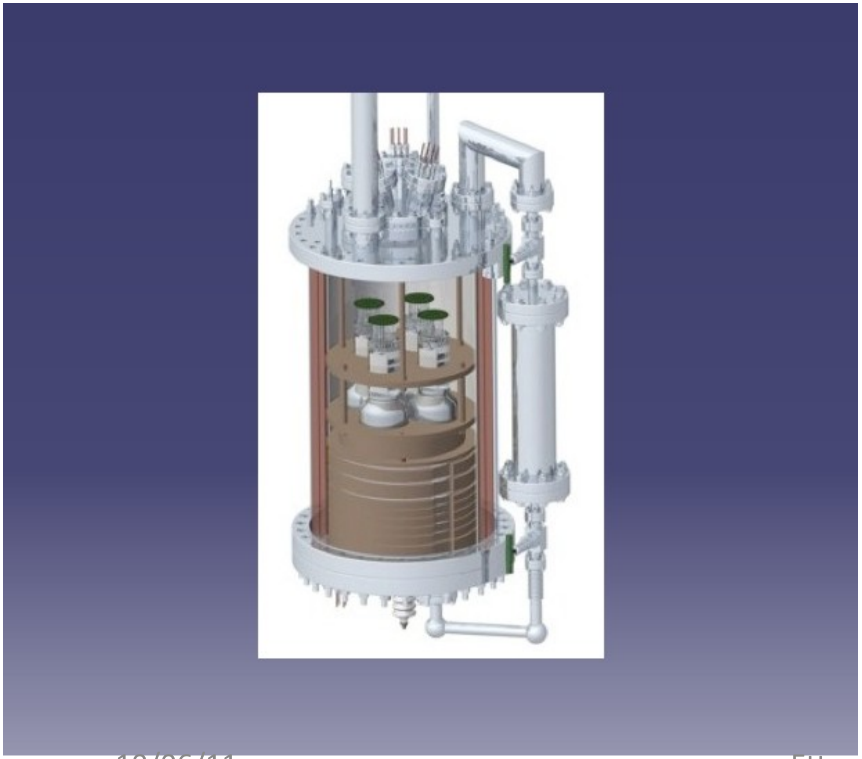






Four-PMTs test

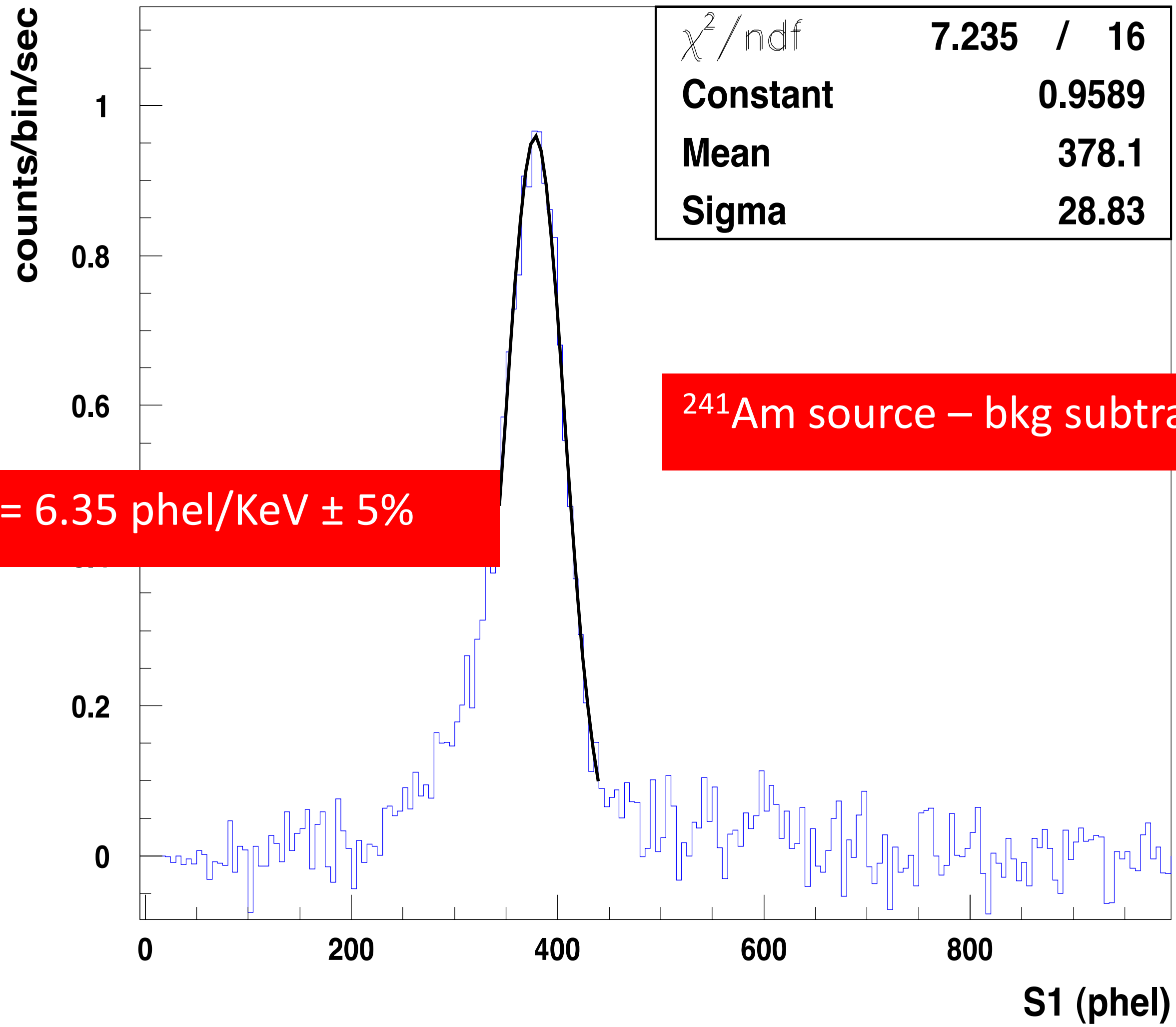
- The scaling-up capability of the implemented technology tested with a detector about ten times bigger than the one with one PMT;
- The WArP 2.3l prototype used for this test (4.3 liters internal volume)-> equipped with 4 HQE Hamamatsu PMTs R11065 (photo-cathodic coverage ~ 12 %) ;
- Internal surfaces covered with VIKUITI ESR reflector layer + TPB (density about 300 μg/cm^2)
- PMT windows naked (no wavelength-shifter);
- 4 PMT anode signals directly digitized by two Acqiris Boards (Mod. U 1080 A, 2-chs. each with 8-bit dynamic range and 1GS/s) at 1 ns sampling time over 15 μs time interval;



- All internal component baked @ 80^{o}C;
- Detector housed in a low-radioactivity stainless steel vessel deployed in a LAr open bath;
- Detector completely filled with LAr -> PMTs' bases immersed;
- LAr filling through an in-line filter (Oxygen reactant and molecular sieve);
- No electric field;
- PMTs equalized @ 3x10^6 gain (around 1400 Volt).

Data Analysis and Results (I)

✓ *Detector exposed to ^{241}Am, ^{133}Ba, ^{57}Co and ^{137}Cs sources*



^{241}Am source – bkg subtracted

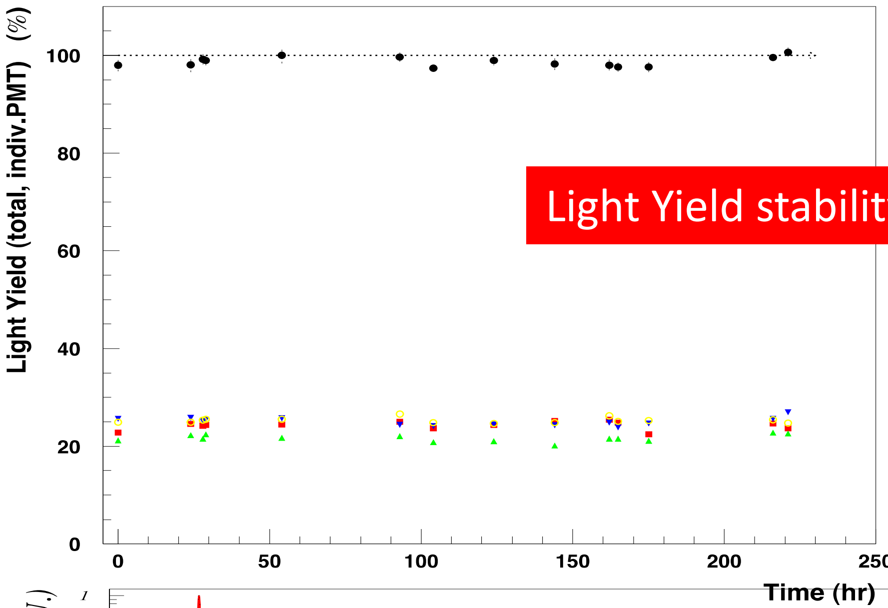
LY = 6.35 phel/KeV ± 5%

LY determined with other sources less accurate but fully compatible with ^{241}Am value

Detector geometry is a scaled-down version of the WArP -100 detector (100 lt of active volume, 37 PMTs, ~ 12% of photo-cathodic coverage);

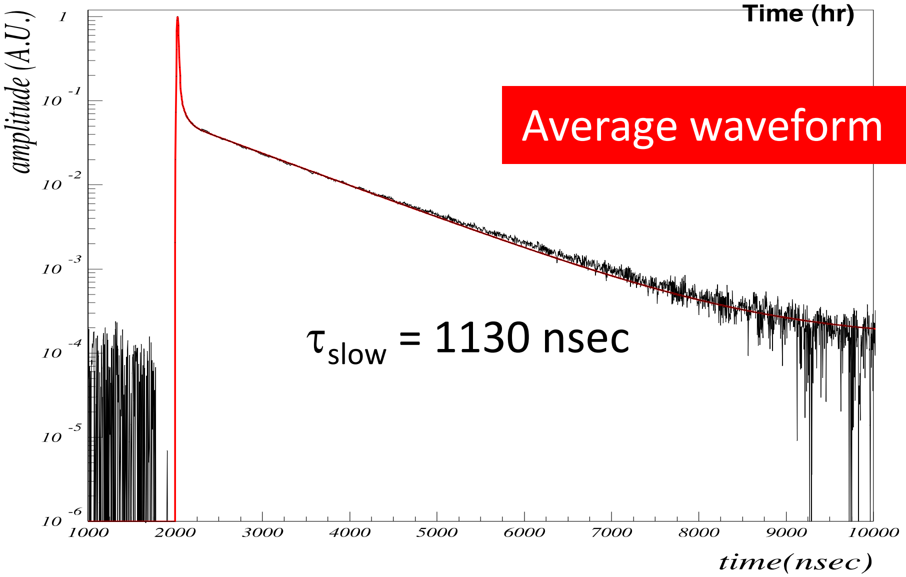
The LY from this detector test can be assumed as predictive of the LY from the WArP 100 Inner Detector, when operated under equivalent conditions.

Data Analysis and Results (II)



Light Yield stability

- LY stable within 2%;
- One PMT has a systematic lower light yield -> not yet understood (PMTs have almost the same Quantum Efficiency);
- With four PMTs working in the same way -> LY ≃ 6.6 phel/keV



Average waveform

- Slope of the slow scintillation component: 1130 ns (1300 nsec for clean Argon). This reduces the light yield of about 10%.
- Direct measurement with mass spectrometer showed the presence of ~ 1 ppm of N_2 (not captured by our filters);

In case of clean Argon the LY would have been in the range of 7 phel/KeV.

Conclusions

- A new PMT type with enhanced Quantum Efficiency photo- cathode and operating at LAr temperature has been developed by Hamamatsu Photonics Mod. R11065 with peak QE up to about 35%. PMT's of this type have been extensively tested along with the R&D program of the WArP Collaboration;

- The main working parameters of this PMT were measured at LAr temperature and its great performances have been clearly demonstrated;

- Liquid Argon detectors with HQE photo-cathodic coverage in the 12% range can achieve a light yield around 7 phel/keV (at null electric field), sufficient for detection of events down to few keV of energy deposition -> suited for direct Dark Matter searches with LAr-based experiments.