



The WArP Experiment

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WArP Collaboration

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The WArP Programme

- The WARP experiment is intended to search for WIMP recoils in LAr with 140 kg fiducial volume and a detection threshold of $< 20 \text{ KeV}_{\text{ion}}$.
- A unique feature of this experiment is that the active volume is tightly surrounded by a ≈ 8 ton, 4π active anticoincidence, also of LAr, in order to veto not only β and γ , but especially, entering and exiting neutrons with a recoil detection threshold as low as $\approx 20 \text{ keV}$.
- The detector is designed to host up to 1 ton active inner volume with no changes in the active anticoincidence shield.
- The WArP technology has been established during several years of R&D, started in 1992 in CERN and prosecuted during the last decade in few INFN Labs (LNGS, Napoli, Pavia and Padova).
- The 100 liters detector was put in operation at the beginning of May, 2009. It was run for about 3 months with no drift field: Electronics and DAQ setting up; tests on light yield. The run was then stopped due to problems on the high voltage system for the drift field.
- A second run was then performed in 2010 after repairs and upgrades. Also in this case the run was stopped due to problems on the HV system most likely consequent to the previous failure.
- The detector design has been completely reviewed between the end of 2010 and the beginning of 2011. Some modifications have been implemented.
- **The 100 liters has been filled with ultra-purified LAr at the beginning of June 2011 and is presently coming back to operation.**

WIMP Detection in WArP

- Three simultaneous criteria to discriminate potential WIMP recoils from backgrounds:

- 1 Simultaneous detection of **prompt scintillation and drift time-delayed ionisation in Liquid Argon**:

- ↙ pulse height ratio strongly dependent from columnar recombination of ionizing tracks.
- ↙ 3D reconstruction of event position.

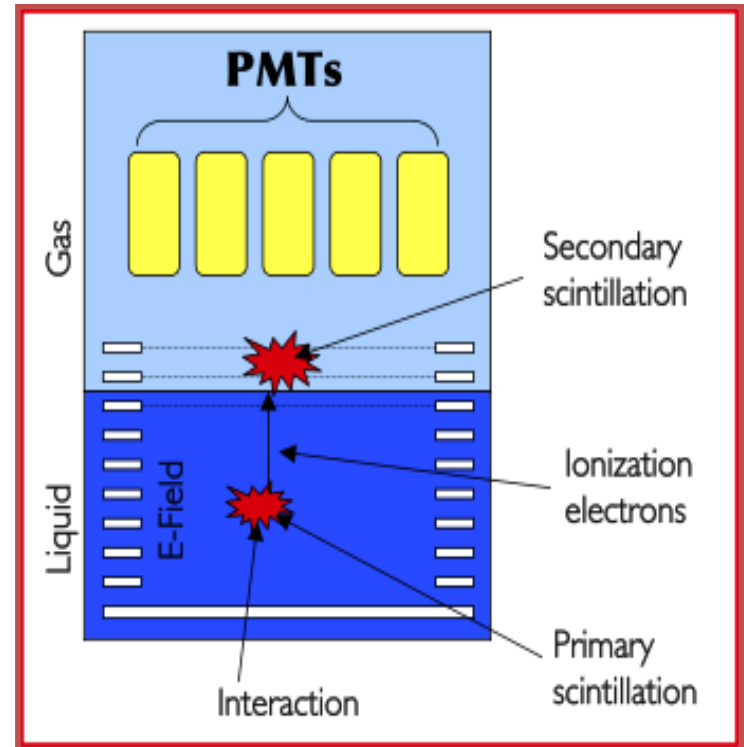
- 2 **Pulse shape discrimination of primary scintillation**:

- ↙ wide separation in rise times between fast (≈ 10 ns) and slow (≈ 1.6 μ s) components of the emitted UV light.

- 3 **Precise 3D reconstruction of event position**:

- ↙ Precise definition of fiducial volume; additional rejection of multiple neutron recoils and gamma background

Double Phase Argon Chamber



**Only detector with triple discrimination technology.
Largest discrimination of γ/β -induced backgrounds.**

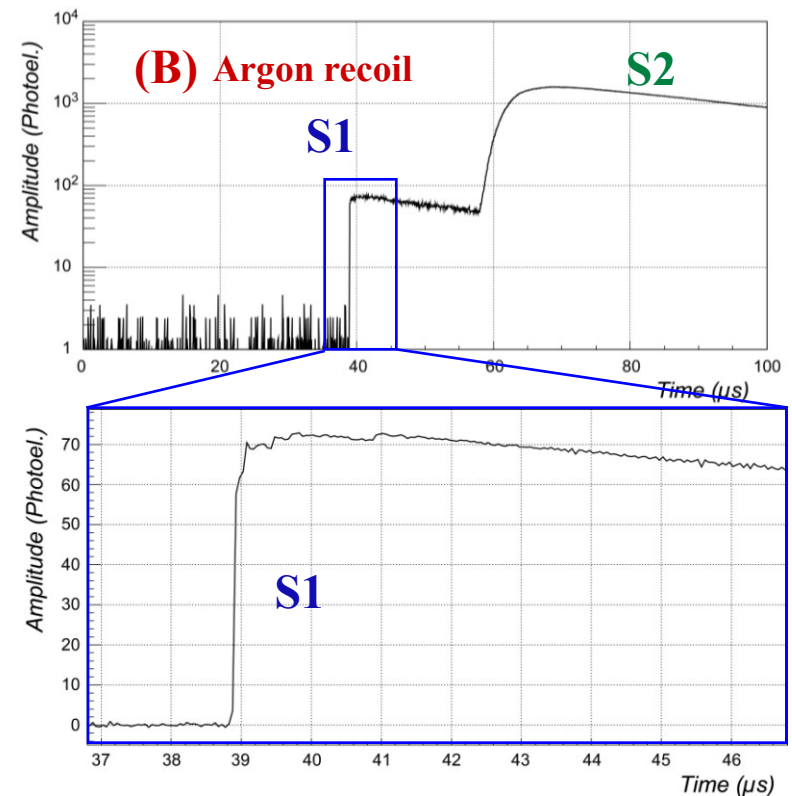
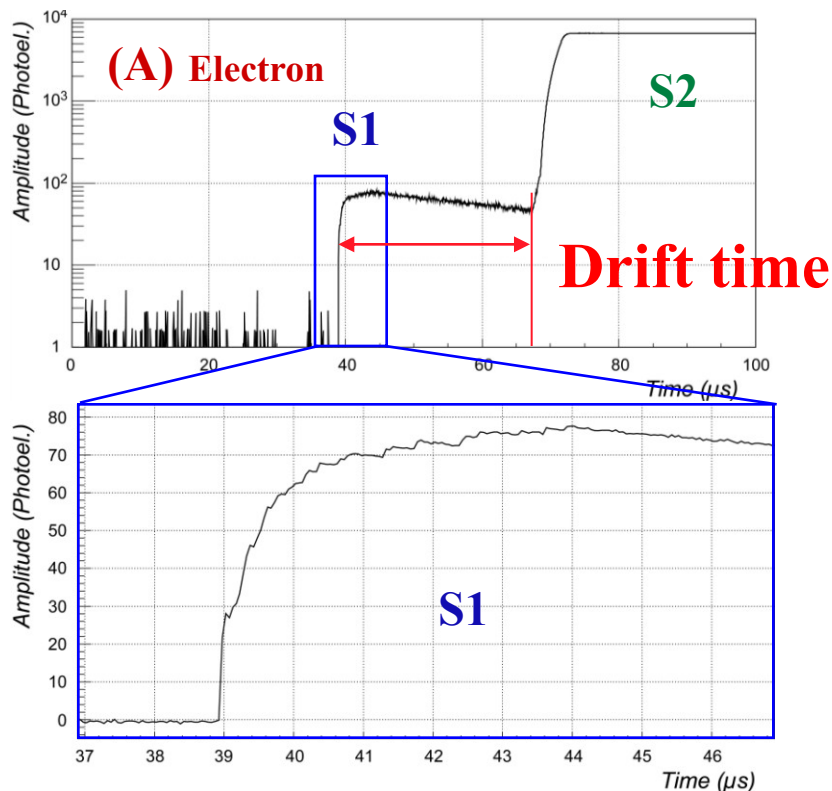
Discrimination Technique

→ **S1** = primary (prompt) scintillation signal

→ **S2** = secondary (delayed) scintillation signal (proportional to ionization)

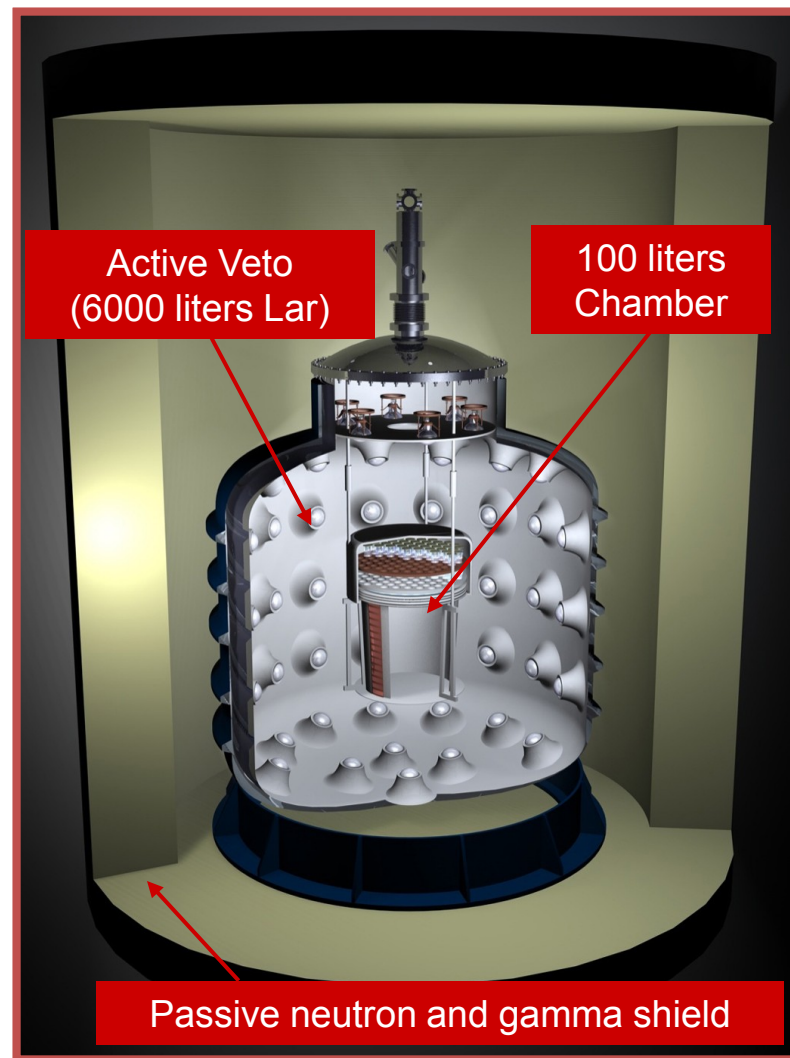
❑ **Minimum ionising particles:** high S2/S1 ratio (~ 100) + slow S1 signal.

❑ **α particles and nuclear recoils (R-like events):** low (< 30) S2/S1 + fast S1.

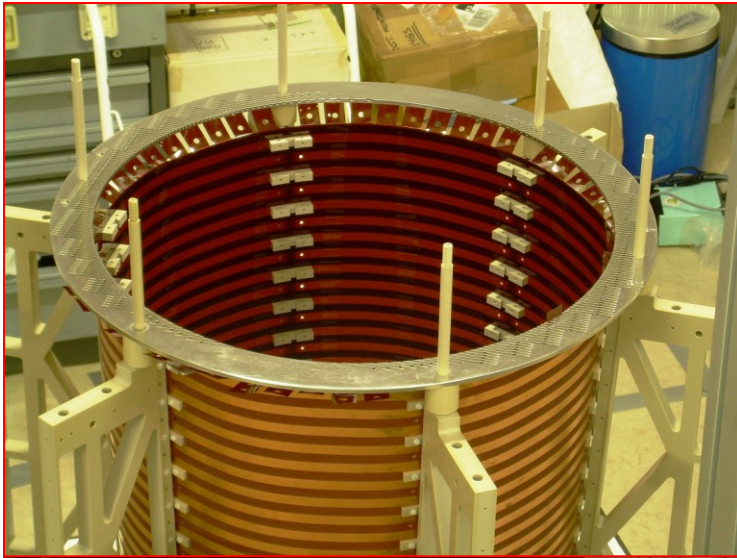


The 100 liters detector

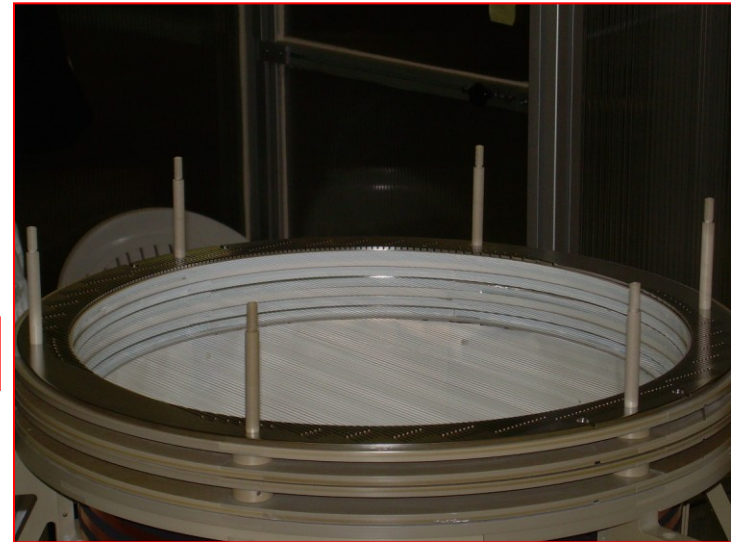
- ❑ Sensitive volume = 100 liters (140 kg).
 - ✦ 3-D event localization by means of:
 - Drift time recording (vertical axis);
 - Centroid of PM's secondary signal amplitudes (horizontal plane).
- ❑ 4π active VETO system:
 - ✦ tags and measures the neutron-induced background with an ID-factor $\approx 99.99\%$;
- ❑ Construction accomplished between mid 2004 and November 2008.
- ❑ Detector commissioning:
 - ❑ Technical runs (2): December 2008 to August 2009, February 2010 to June 2010
 - ❑ Present run: started on March 2011, after repairs and upgrades.
- ❑ **Designed also to host a 1 ton detector.**



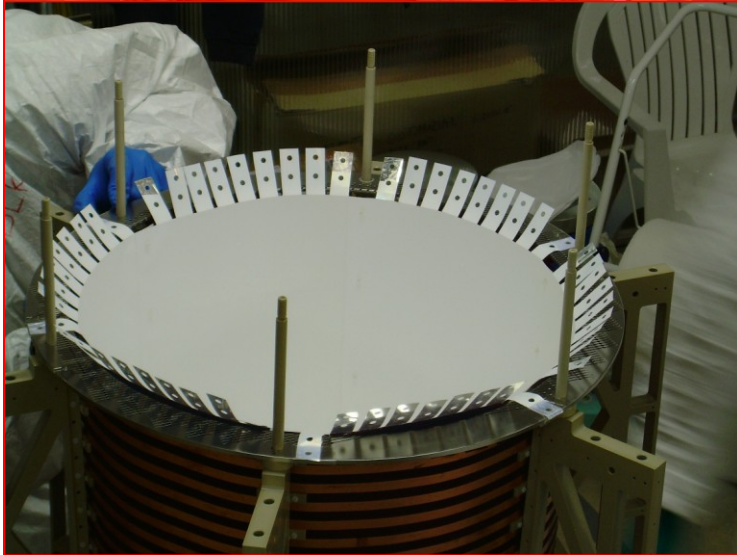
Inner Detector Assembly (Jun, 2008)



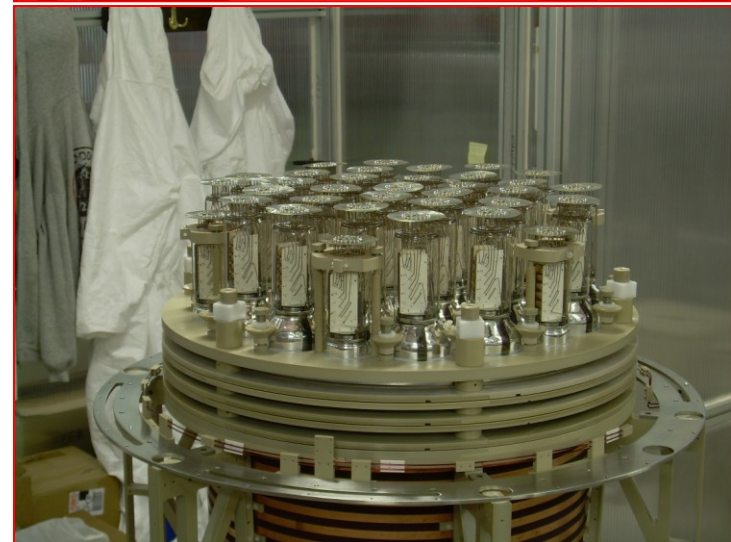
Race Tracks



Grids

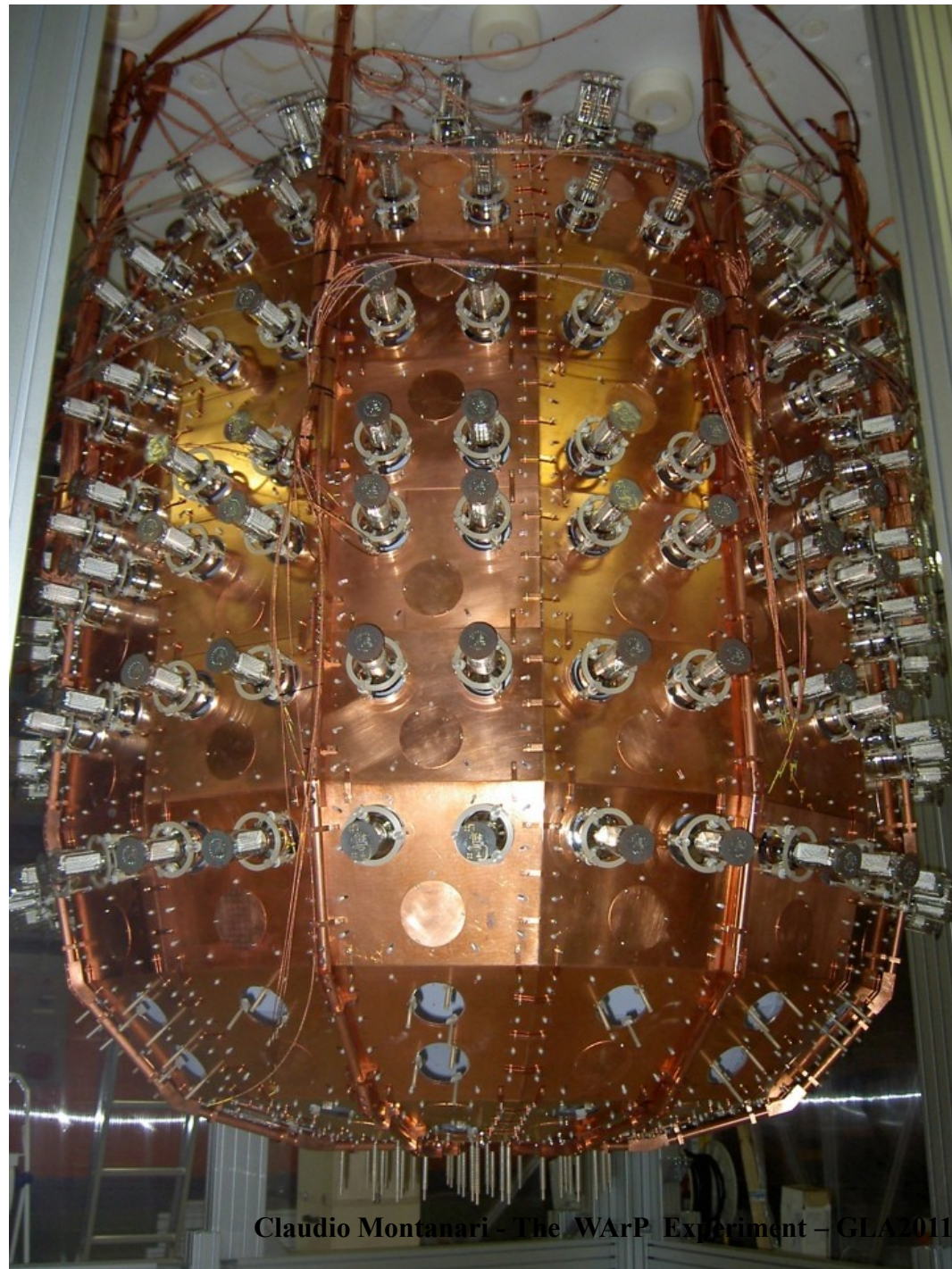


Reflector +
Wavelength
Shifter

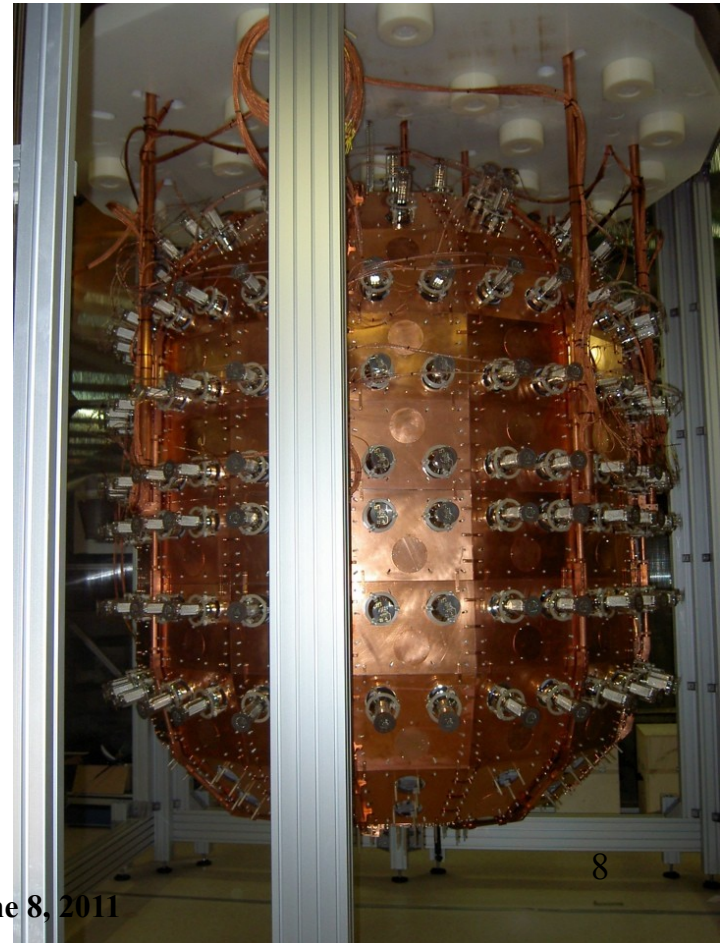


Phototubes

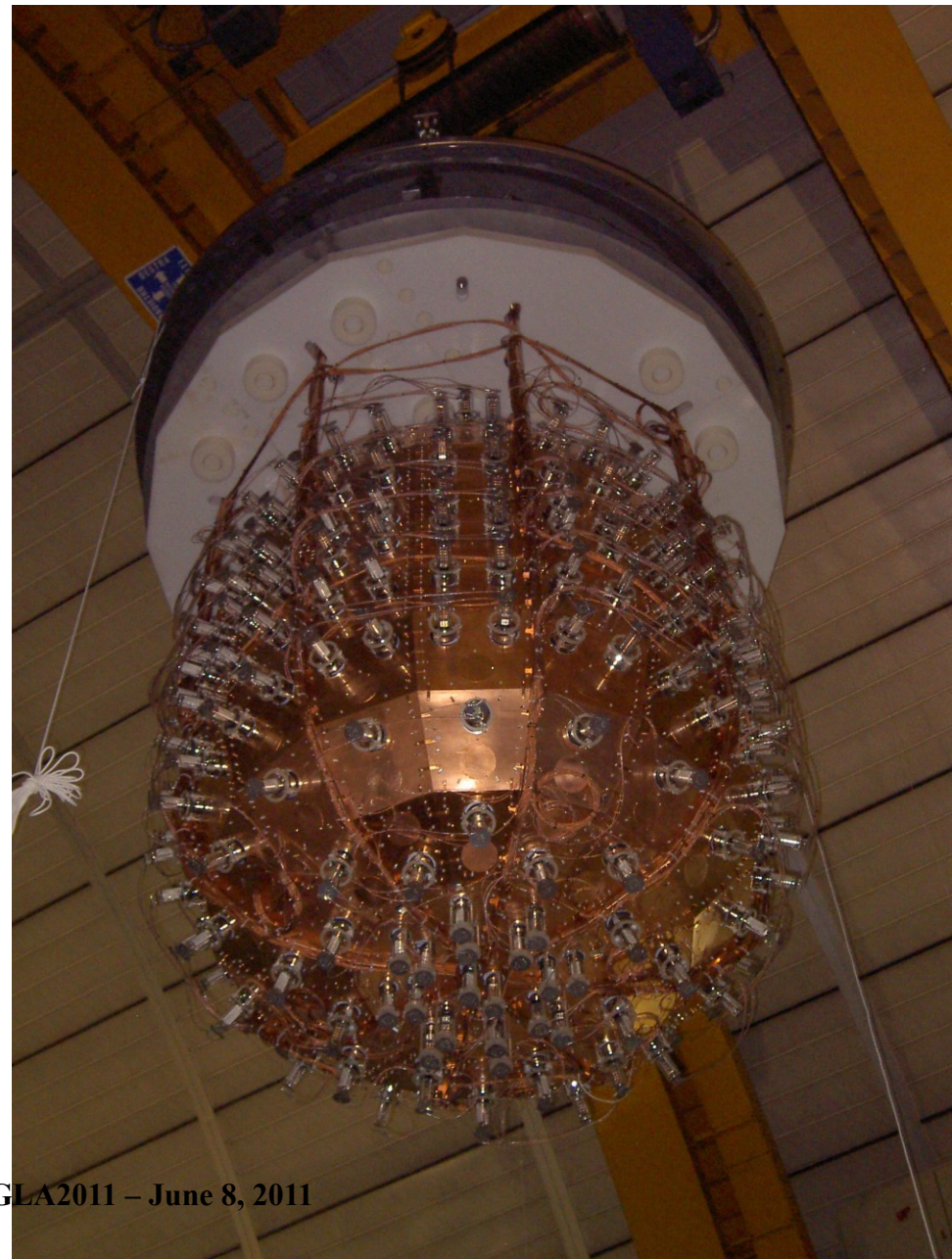
Active Shield Assembly (Nov., 2008)



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Installation in the main cryostat (December 17th 2008)



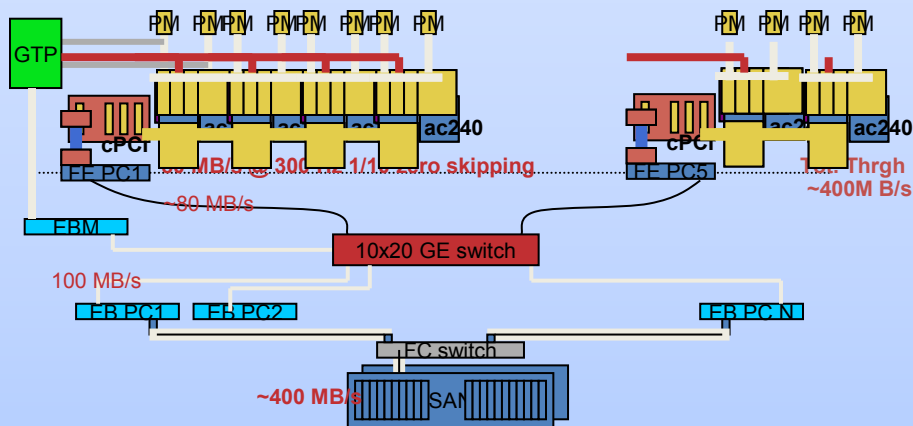
R/O Electronics

INNER DETECTOR

Based on high level commercial solution from Aquiris.

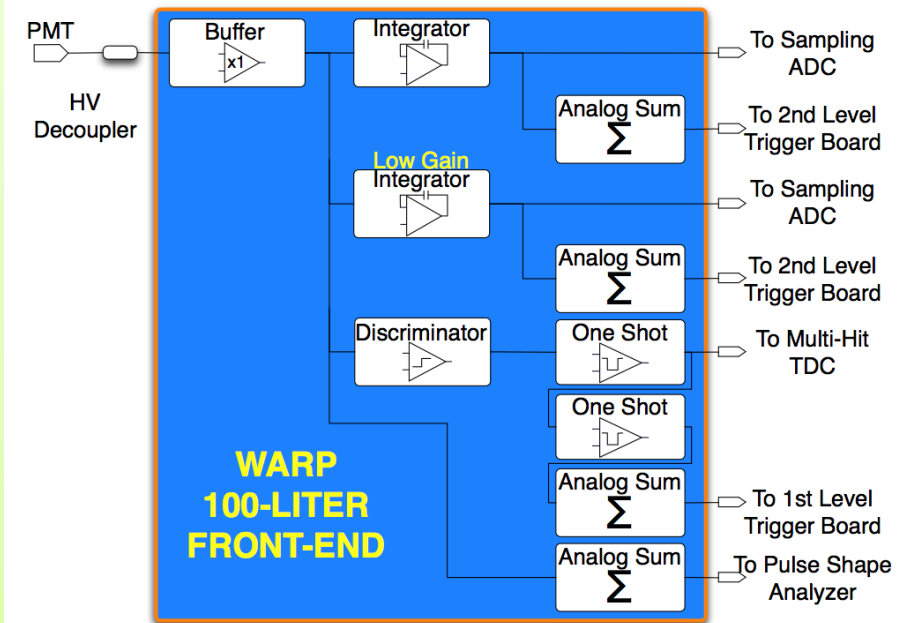
Online data reduction and pre-processing with high speed FPGA

Easily scalable



ACTIVE SHIELD

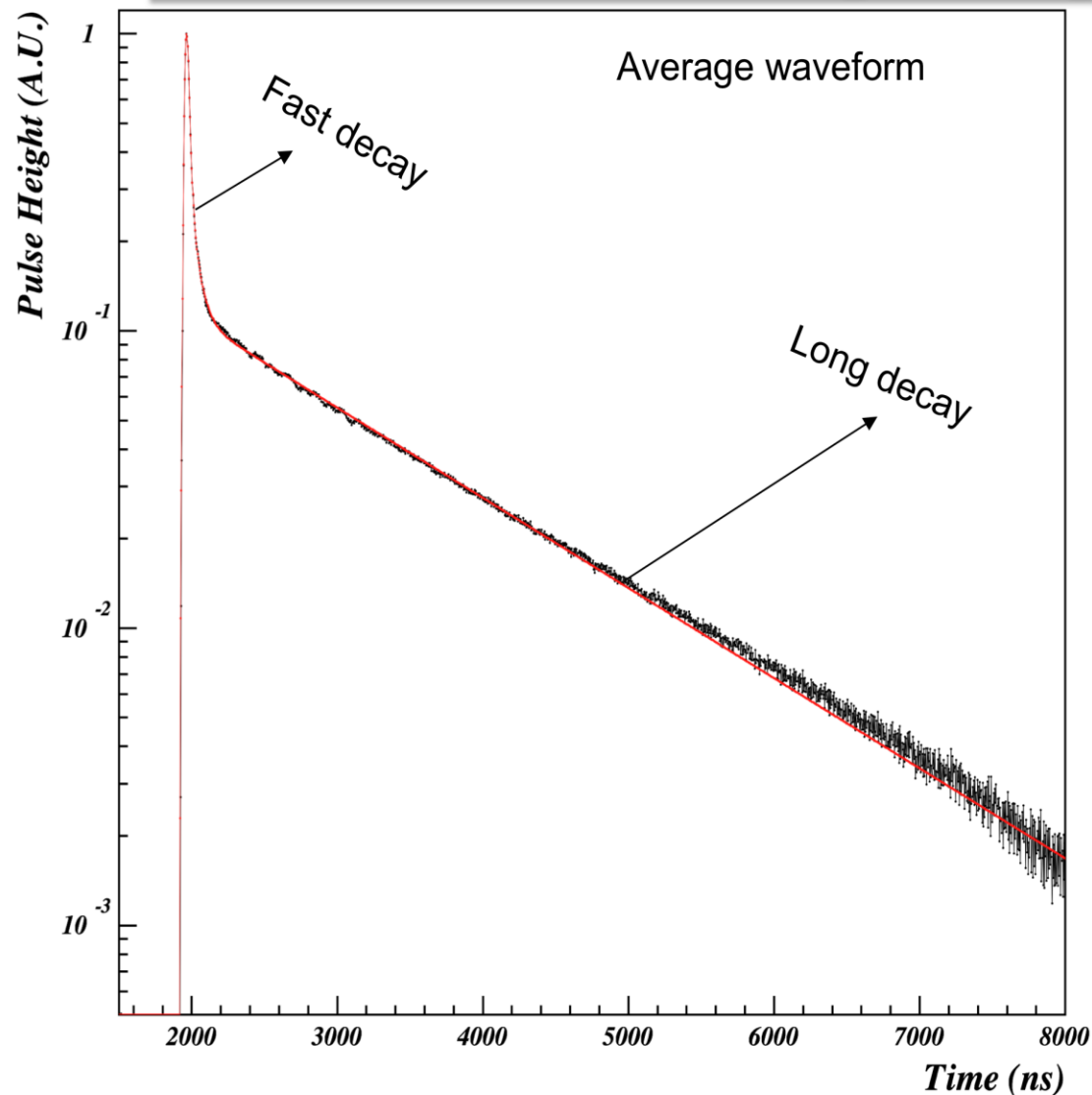
Front-end custom made from CAEN.
DAQ and logic based on commercial components.



WArP-100 First Technical Run

- During the first technical run (December 2008 – August 2009) several functionalities of the detector and the cryogenic plant have been verified:
 - DAQ and performance of the inner detector with no drift field;
 - Functionality and performance of the cryogenic plant (consumption rates, functionality of the Gas recirculation system);
 - LAr purity check by measurement of the scintillation light slow component.
- The first technical run was stopped after the breakdown of the HV feedthrough for the drift field.

LAr contamination (N_2 and O_2)



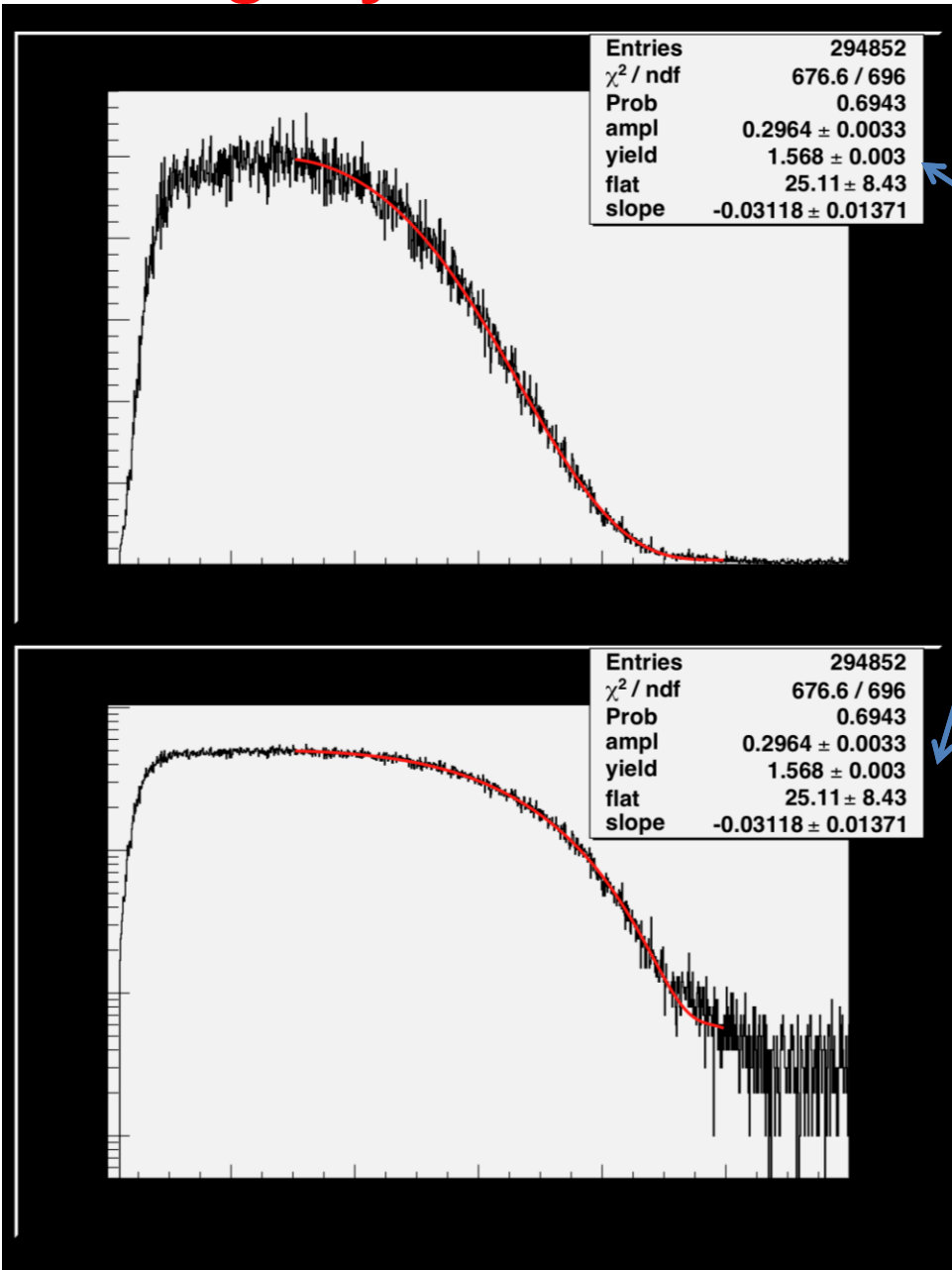
waveform fit
(two exp. components).

$\tau_{\text{long}} \rightarrow$ indication of LAr
purity:

$$\tau_{\text{long}}(\text{fit}) \approx 1.3 \mu\text{sec}$$

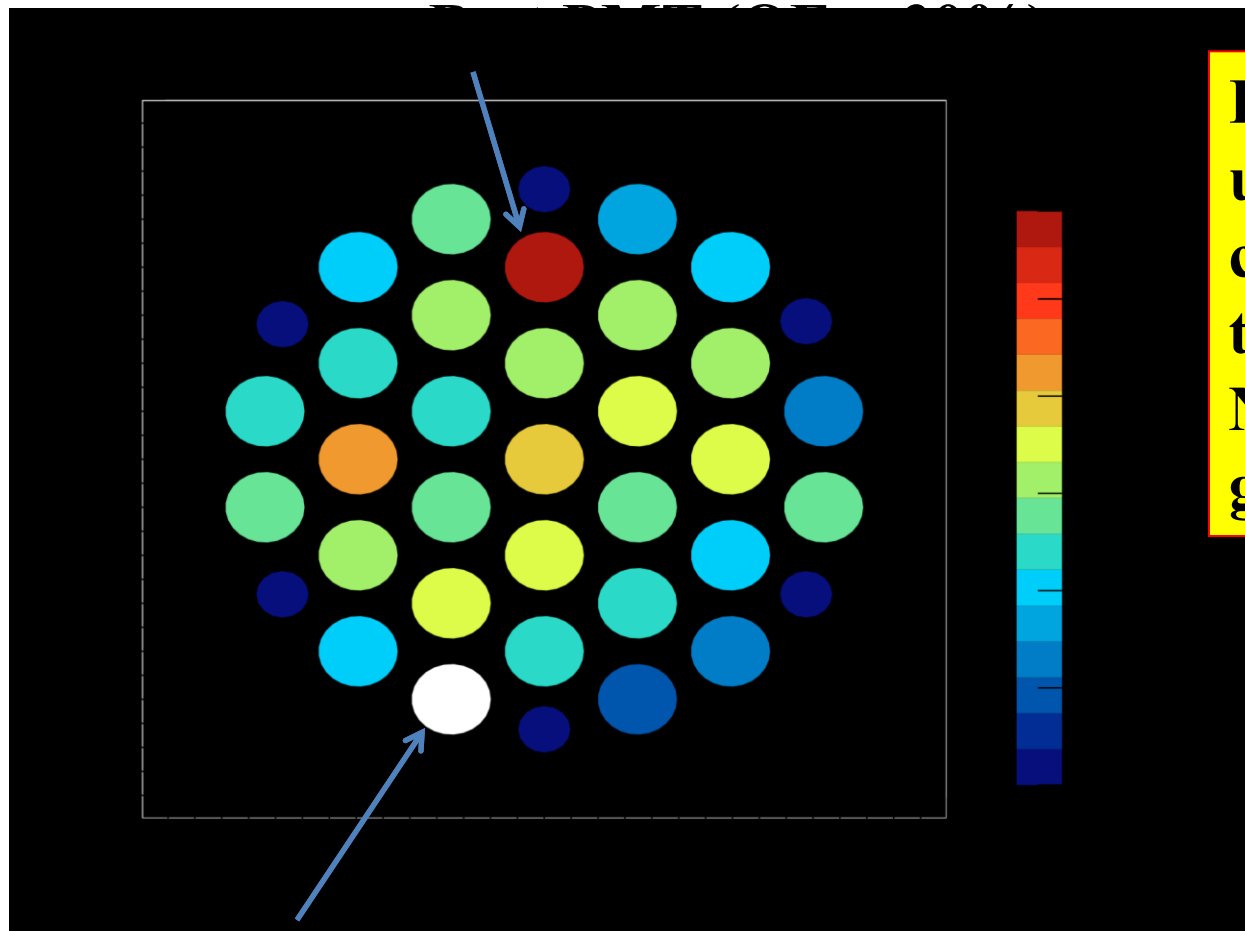
\Downarrow
good LAr purity
(after three months of
recirculation)

Light yield measurement from ^{39}Ar decay



**Measured Light yield
From ^{39}Ar beta decay
Spectrum ~ 1.6 ph.el. / keV**

Light Collection Uniformity



Poor light collection uniformity (also when corrected for the PMTs QE). No evidence of geometrical issues.

Low gain PMT (not used)

WArP-100 Second Technical Run

- The second technical run started on February 2010, after the replacement of the HV feedthrough and cable with a completely revised version and after the replacement of the inner detector waveshifting/reflecting surfaces.
- The detector filling with ultra-purified LAr was completed on March 16, 2010. As for the previous run the detector functionalities at null drift field have been studied and found in agreement both with those of the previous run and with the expectations based on results obtained in our labs.
- The drift field was turned on at the beginning of May, 2010. After about two days of operation the current in the HV circuit suddenly interrupted. As verified after the detector opening, the failure was due to the breaking of few ceramic resistors, most likely damaged by the HV discharge occurred in the 2009 run.
- The run was then interrupted around the mid of June 2010, after additional few weeks of operation to test the performance of the active shield and the cryogenic plant.
- In summary:

with the exception of the new, different failure of the HV system, the detector performances recorded in the 2010 run were in agreement with expectation (based on the results from the 2009 run) and considered as suitable for a physics run.

Preparation for the 2011 run

- After the agreement of the INFN Commissione II, last January 31st, following the interaction with an International Committee that completely revised the experiment design and performance (November 2010 – January 2011), we started the operations for the 100 liters re-activation:
 - A new HV distribution system for the drift field, with high redundancy, have been implemented and extensively tested;
 - Optical shields on the Veto phototubes have been installed and all the phototubes have been checked at room temperature;
 - Modifications of the Veto readout electronics and relative tests have been completed;
 - The gas recirculation system has been modified to reduce the running costs;
 - New filters for both the liquid and the gas recirculation systems have been installed;
 - Other activities in preparation of the new run were also carried on (installation of the Argon pre-filters, update of the DAQ software, development and maintenance of the analysis software);
 - **The detector cooling started on May 25, 2011, filling with ultra-purified LAr ended June 1st, 2011.**
- Activities with the 2.3 liters prototype, to study the new high quantum efficiency phototubes performances are also being carried on in parallel.

The new HV Distribution Chain

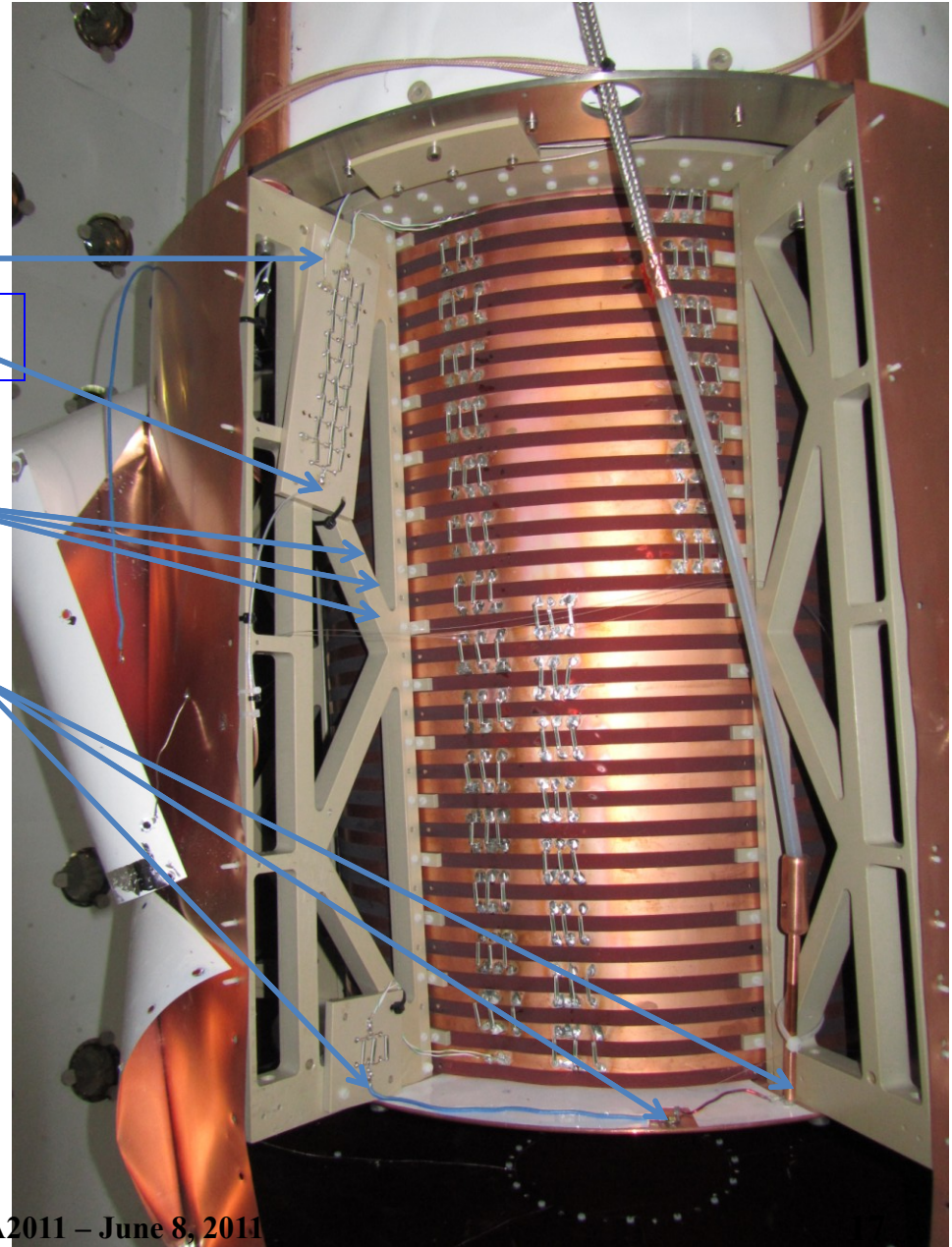
To First Grid (in liquid)

To Ground (or Low Voltage Output)

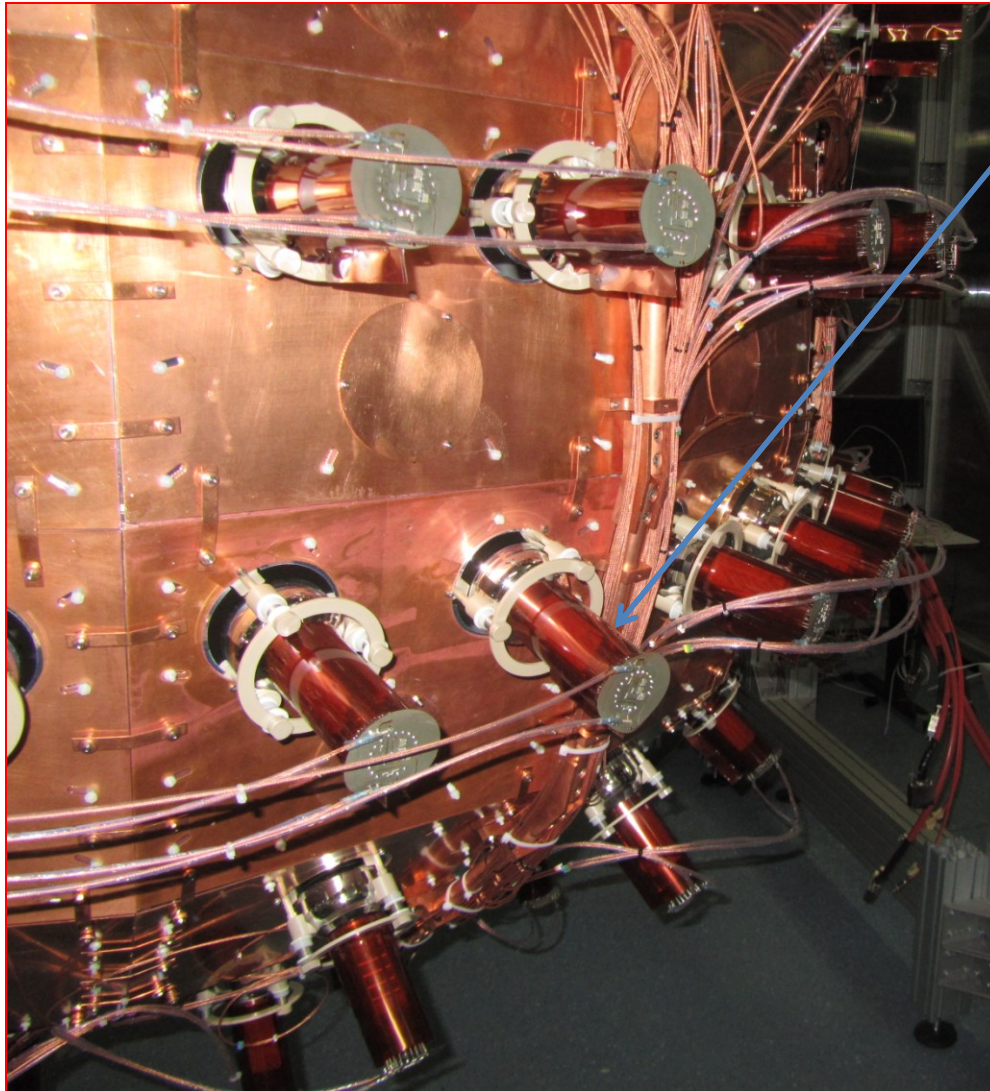
Race Tracks

-HV (from Cathode)

Divider chain from the cathode to the first grid (in liquid) and then to ground (or to low voltage), made by three resistors in parallel. ($\approx 48.5 \text{ M}\Omega$) resistance painted on ceramic substrate.



Optical shields



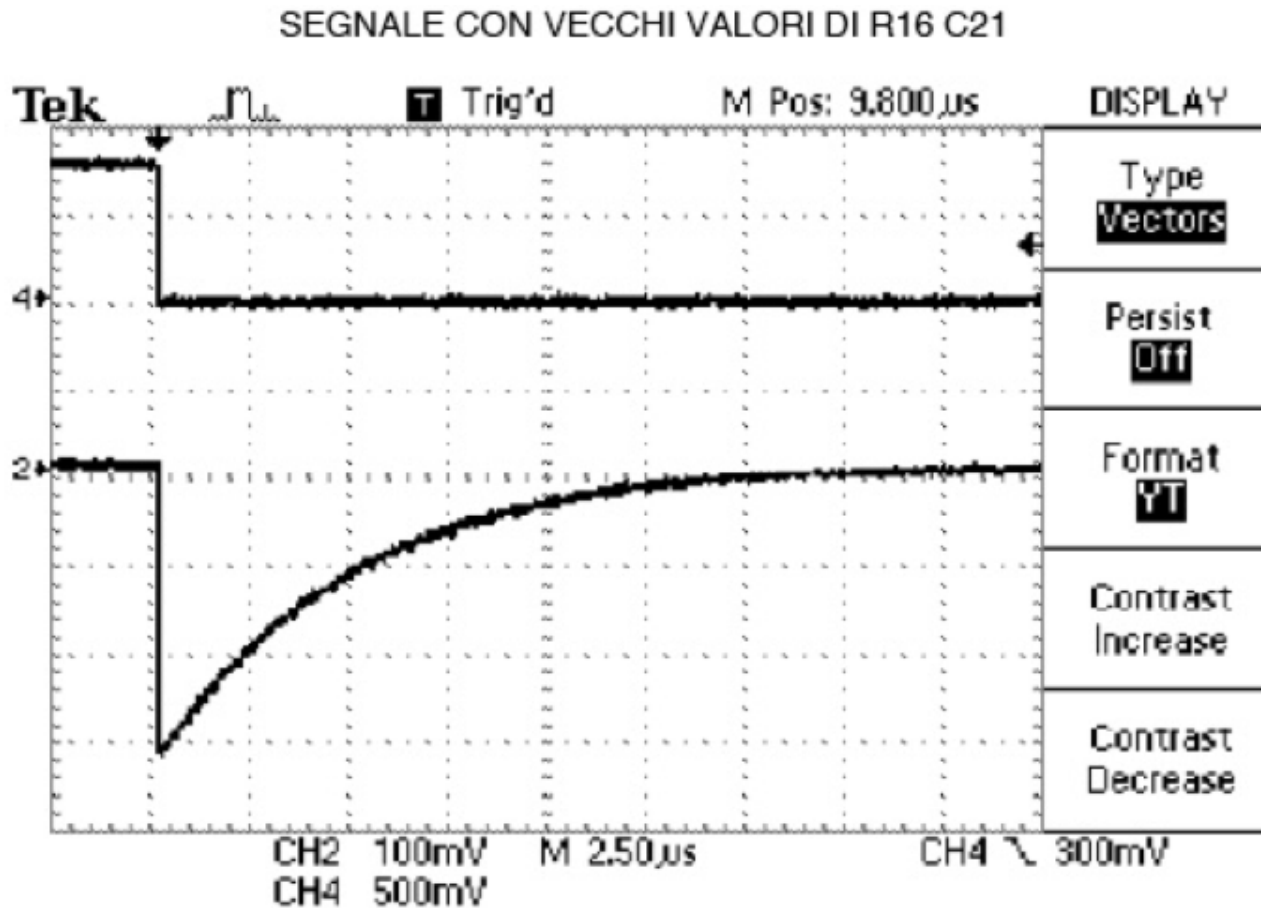
Two superposed Kapton foils (each with 125 μm thickness) wrapped around the cylindrical part of the 3" PMTs body.

Solution tested in liquid Argon for mechanical stability with a spare PMT.

WARP Veto Electronics

- Standard configuration
 - Multiplexing charge pre-amplifiers CAEN N914
 - Standard RC shaping time 100 μ s
 - 100 MHz, 14 bits digitizers CAEN V1724
- Modifications Proposed by WARP Collaboration and Agreed with Battiston Review Committee
 - Modification of RC shaping time
 - 100 μ s \rightarrow 5 μ s
 - Modification of sensitivity
 - 0.8 mV/pC \rightarrow 4.2 mV/pC
 - Test with WARP-2.3L prototype to check
 - Ability to correctly measure single photoelectrons
 - Ability to correctly reproduce spectra recorded in presence of radioactive source

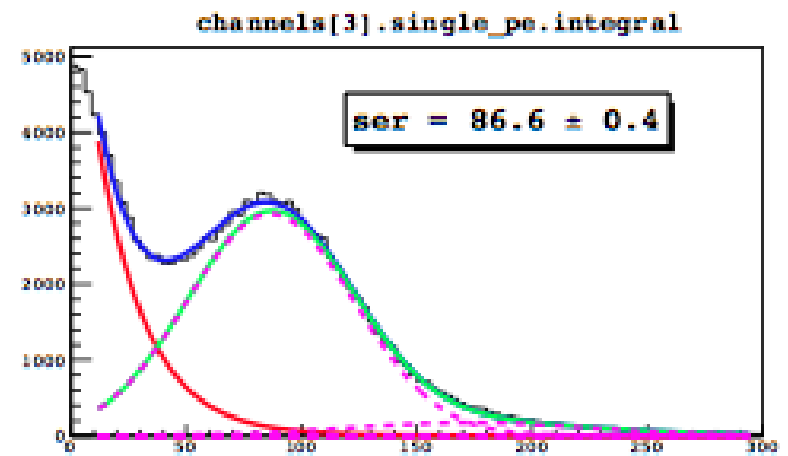
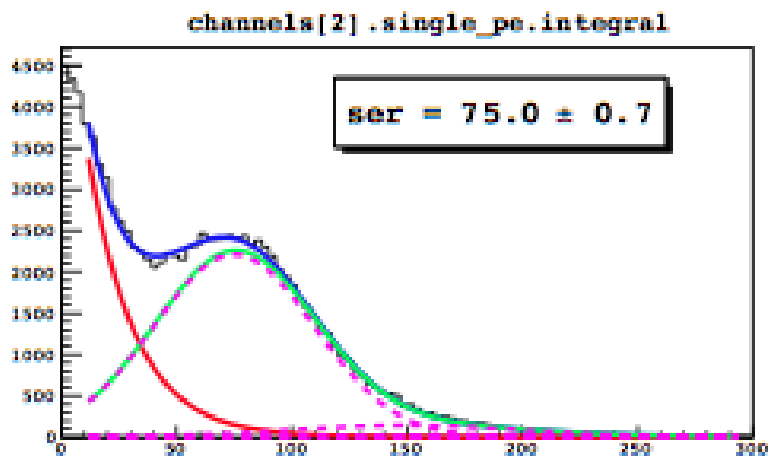
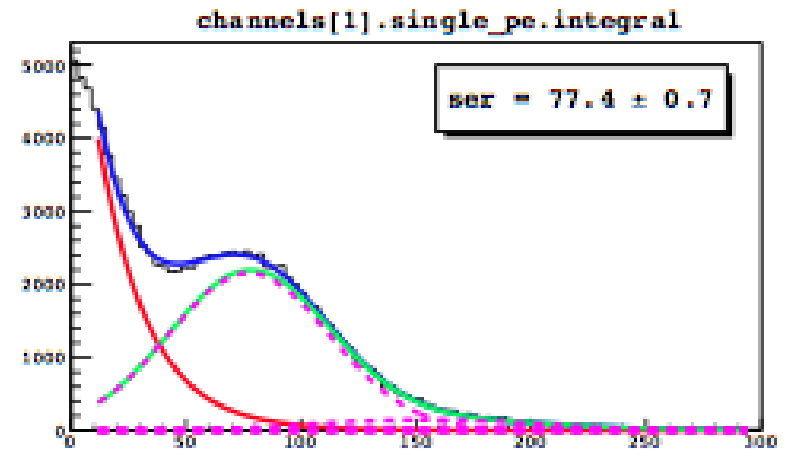
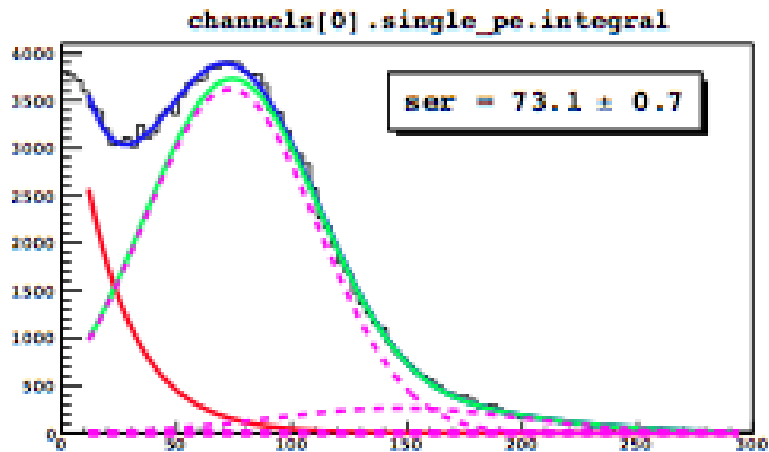
Modification of Boards



SEGNALE CON NUOVI VALORI DI R16 C21

Shown difference in shaping time
All boards modified as of February 2011

Single photoelectron Determination



R&D WORK (PARALLEL Activity):

An extensive set of tests characterized the WArP activity at LNGS all over the last 10 months.

The scaling-up in detector mass and complexity without loss of detector performance is in general not a trivial task. An experimental test has been performed with a detector about four times the size of the one used with the first test of the Hamamatsu PMT (LY=7 phel/keV - 0.5 lt - single PMT – single phase), to check the scaling-up capability of the implemented technology.

The detector composed by the WArP 2.3 lt prototype chamber equipped for this test with 4 *HQE Hamamatsu PMTs* (Mod. R11065).

The boundary surfaces (lateral and bottom) of the 2.3 lt active volume lined with a TPB coated VIKUITI ESR reflector layer, freshly produced at LNGS with standard vacuum evaporation techniques.

PMTs are left “naked” (no wavelength shifter)

The 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 μ s time interval;

Main goals of the test (Jan-Mar., '11):

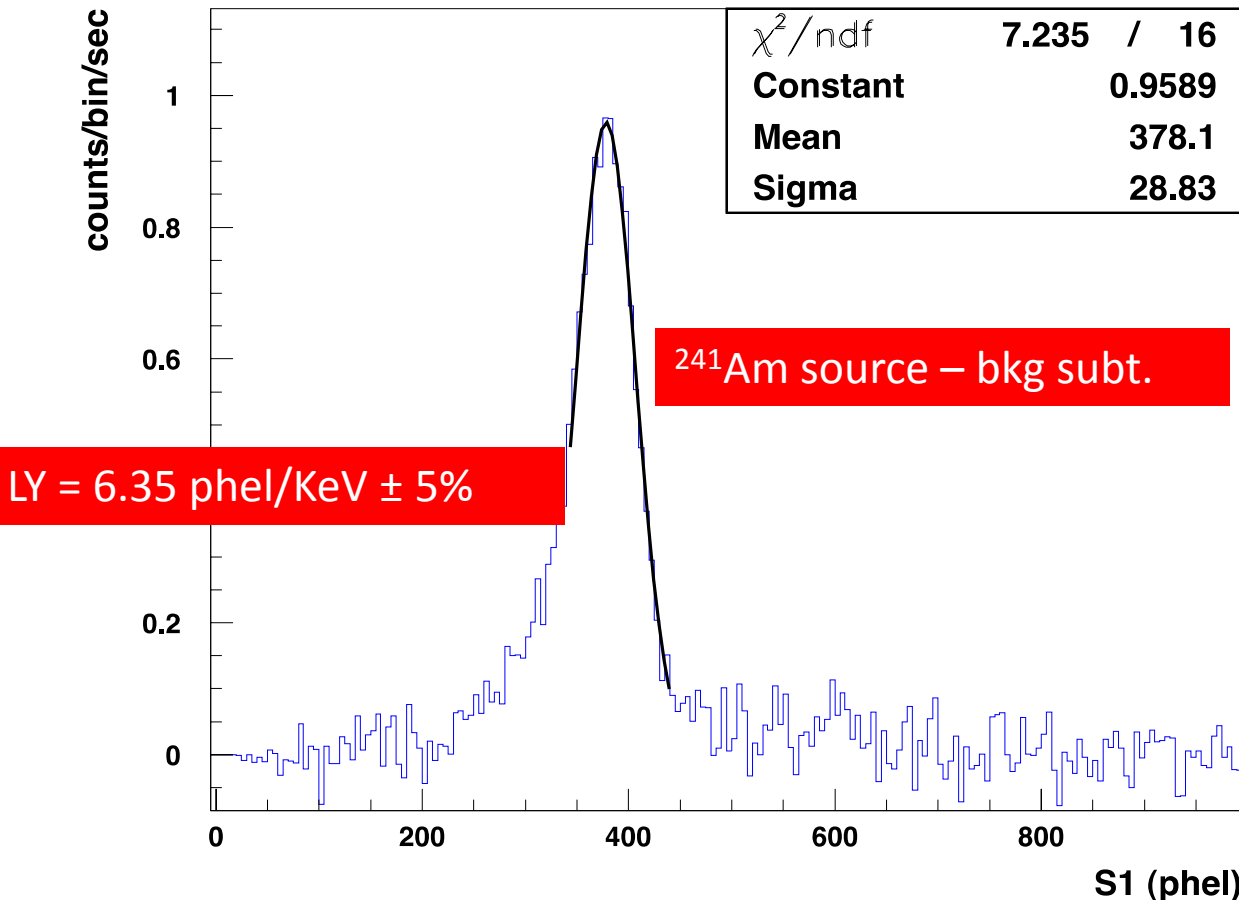
- 1) LY and gain stability in time on long term running period.
- 2) Test of the VETO electronics in experimental conditions by replacing the 4 PMTs ACQIRIS read-out electronics with the first modified CAEN *N914* board.
- 3) Test of a new fast digitizer board (CAEN *V1751*) and comparison with the present ACQIRIS board
- 4) neutron-source run for Pulse Shape Discrimination study at improved LY conditions.

The detector geometry of the 2.3 lt is a scaled-down version of the WArP-100 detector (100 lt of active volume, 37 PMTs, 12% of photo-cathodic coverage); therefore the results from the 2.3 lt test can be assumed to be somehow predictive of the LY from the WArP-100 Inner Detector, when operated under equivalent conditions.



Data Analysis and Results (I)

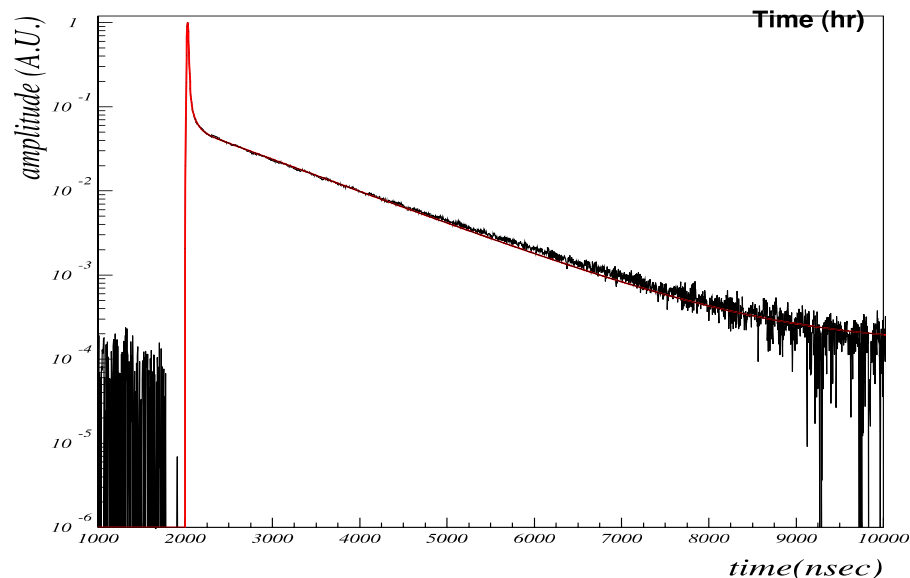
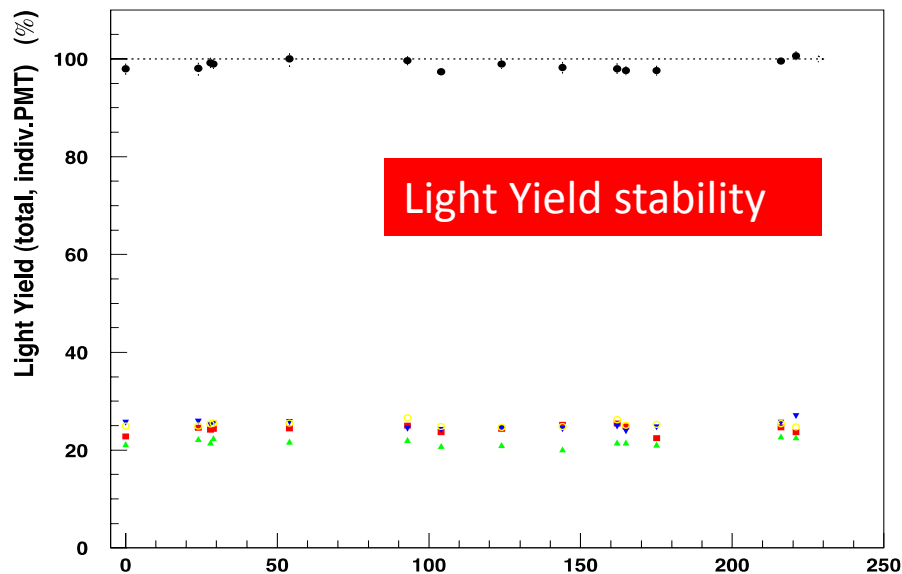
- Detector exposed to ^{241}Am , ^{133}Ba , ^{57}Co and ^{137}Cs sources;



- Number of phel obtained by the sum of the phel detected by each PMT (calibration via SER spectrum)
- The Light Yield determined with other sources is less accurate but fully agree with ^{241}Am value.
- The detector geometry is a scaled-down version of the WArP -100 detector (100 lt of active volume, 37 PMTs, \sim 12% of photo-cathode coverage);

The light yield 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)



- 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 -> $LY \simeq 6.6 \text{ phel/keV}$
- Slope of the slow scintillation component: 1130 ns (1300 ns for clean Argon). This reduces the light yield of about 10%.
- Direct measurement with mass spectrometer showed the presence of $\sim 1 \text{ ppm}$ 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.

WArP Main Extrapolation Data

Electrons total light yield @ no field		1.7(pessimistic)		phe / keVe	
Electrons (20-60 keV) reduction @ 1 kV / cm		0.67			
Electrons total light yield @ 1 kV / cm		1.14		phe / keVe	
Electron energy	30	40	50	60	keV
Fast component fraction (electrons)	0.35	0.32	0.30	0.29	
Fast component for electrons @ 1 kV / cm	0.40	0.37	0.35	0.34	phe/keVe
Slow component for electrons @ 1 kV / cm	0.74	0.77	0.79	0.80	phe/keVe
Lindhard factor @ no field	0.25	0.25	0.25	0.25	
Recoils total yield (any field)	0.425	0.425	0.425	0.425	phe/keVi
Fast component for recoils	0.32	0.32	0.32	0.32	phe/keVi
Slow component for recoils	0.11	0.11	0.11	0.11	phe/keVi
Energy scan					
Recoil energy	30	40	50	60	keV
Fast component for recoils	9.6	12.7	15.9	19.1	phe
Fast component for electrons (identical)	9.6	12.7	15.9	19.1	phe
Slow component for recoils	3.2	4.25	5.3	6.4	phe
Slow component for electrons	17.8	26.9	36.4	45.8	phe
Electrons energy	28.5	38.0	47-5	57.0	keV
Rate above threshold @ $\sigma(p) = 10^{-42} \text{ cm}^2$	0.058	0.042	0.031	0.021	ev/kg/day
Rate for 100 kg WArP @ $\sigma(p) = 10^{-44} \text{ cm}^2$	21.2	15.4	11.3	7.5	ev/year
Rate of ^{39}Ar in 100 kg WArP @ $20\text{keV} < E < 40\text{keV}$		1.1 E 08			ev/year
Rate for 1 ton WArP @ $\sigma(p) = 10^{-45} \text{ cm}^2$	21.2	15.4	11.3	7.5	ev/year
Rate of ^{39}Ar in 1 ton WArP @ $20\text{keV} < E < 40\text{keV}$		1.1 E 09			ev/year
Rate for 10 ton WArP @ $\sigma(p) = 10^{-44} \text{ cm}^2$	21.2	15.4	11.3	7.5	ev/year
Rate of ^{39}Ar in 10 ton WArP @ $20\text{keV} < E < 40\text{keV}$		1.1 E 10			ev/year

WArP-100 Possible Upgrade

- Within the WArP R&D activities a new generation of high Quantum Efficiency PMTs, working at LAr temperature, from Hamamatsu, have been extensively tested.
- Results obtained in the 2.3 liters prototype have shown very good performance yielding a light collection exceeding 6 phel/keV, with a photocathode coverage similar to the one of the 100 liters inner detector and working in single phase mode, in several consecutive runs.
- A set of 40 of this new generation PMTs could be used as a replacement for those presently installed in the 100 liters inner detector. The possibility to roughly double the photocathode coverage by placing an array of phototubes at the bottom of the double phase chamber is also being considered.
- This upgrade could take place at the end of the present 100 liters run, and should bring the light yield in the range of 5 photoelectrons/keV or better.
- This will allow to significantly lower the detector threshold and to increase the rejection power for betas and gammas by several orders of magnitude.

Conclusions

- In 2009 and 2010 the 100 liters detector has undergone two technical runs that lasted about three months. Both runs have been terminated due to the failure of the HV system for the drift field. The second failure was most likely an consequence of the first one that was not detected when the detector was opened the first time.
- With the exception of the failure of the HV system, the detector performances recorded in the two runs were in agreement with expectations from the results of our prototypes and considered as suitable for a physics run.
- The WArP design was examined by an International Review Committee between November 2010 and January 2011. Following some recommendations from the Committee, the WArP programme restarted at the beginning of 2011.
- After some modifications and repairs (HV distribution system, PMTs optical shielding, GAr recirculation transfer lines, active shield electronics), the 100 liters detector started the re-commissioning phase.
- A new filling of the detector with ultra-purified LAr was completed on June 1st, 2011.
- The detector is presently coming back to operation.
- A new technical run is expected for the next three months.
- Extension of the run and possible future upgrades will be discussed after the results of the technical run.