WARP
WIMP ARGON PROGRAMME

The WArP Experiment

Claudio Montanari
I.N.F.N. - Pavia - Italy

WArP Collaboration

P. Benetti, E.Calligarich, M.Cambiaghi, C. Montanari, A.Menegolli, G.L.Raselli, M.Roncadelli, M.Rossella, C.Vignoli

INFN and Department of Physics at University of Pavia (Italy)

F.Carbonara, A.G.Cocco, G.Fiorillo, G.Mangano

INFN and Department of Physics at University of Napoli (Italy)

R. Acciarri, M. Antonello, N. Canci, F.Cavanna, F. Di Pompeo, L. Grandi, O.Palamara, L. Pandola, C. Rubbia, A. Szelc, E. Segreto*

Laboratori Nazionali del Gran Sasso, INFN and L'Aquila University (Italy)

F. Calaprice, C. Cao, A. Chavarria, C.Galbiati, B. Loer, R. Saldanha

Princeton University (USA)

B.Baibussinov, S. Centro, M.B. Ceolin, G. Meng, F. Pietropaolo, S. Ventura

INFN and Department of Physics at University of Padova (Italy)

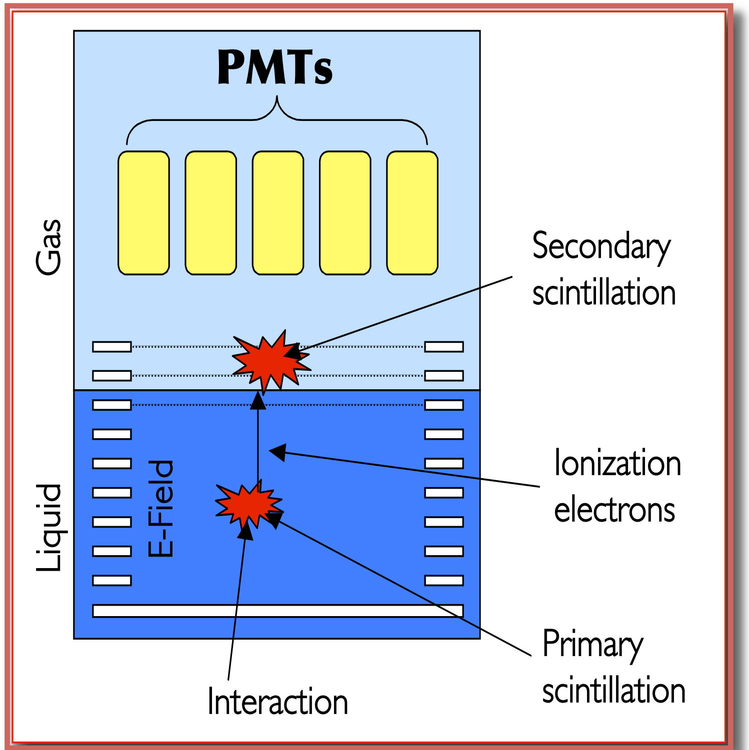
The WArP Programme

- The WARP experiment is intended to search for WIMP recoils in LAr with 140 kg fiducial volume and a detection threshold of < 20 KeV_{ion}.
- A **unique feature** of this experiment **is that the active volume is tightly surrounded by a ≈ 8 ton, 4 π 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 ≈ 20 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. The detector was partially dismounted for repairs and upgrades.
- The 100 liters device has then been re-commissioned, starting from February 2010, and it is now back in operation.
- **The 100 liters is the largest detector for direct dark matter searches presently operating.**

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 (≈ 1.5 μs) 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

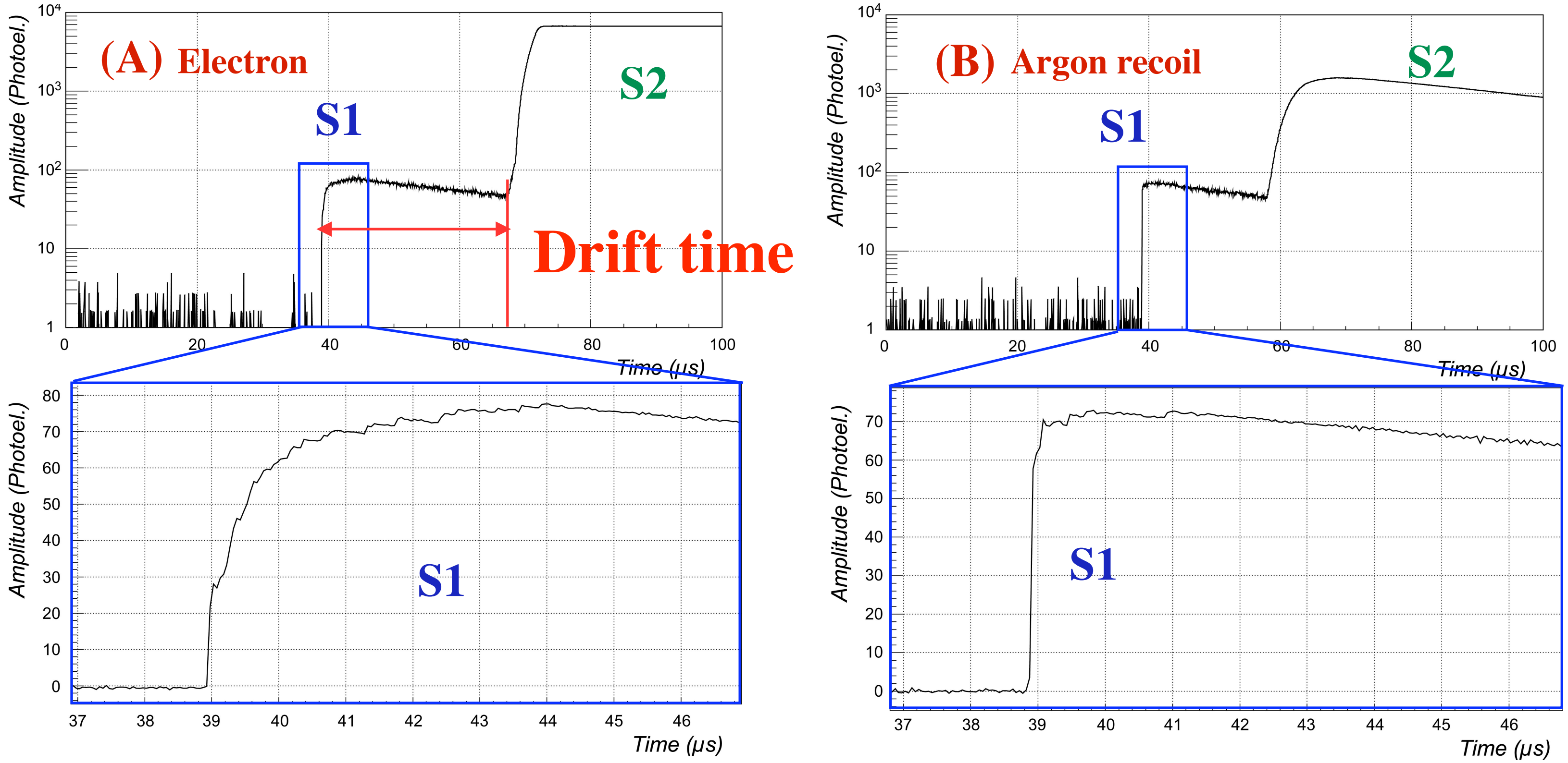


Only detector with triple discrimination technology.
Largest discrimination of γ/β-induced backgrounds.

Discrimination Technique

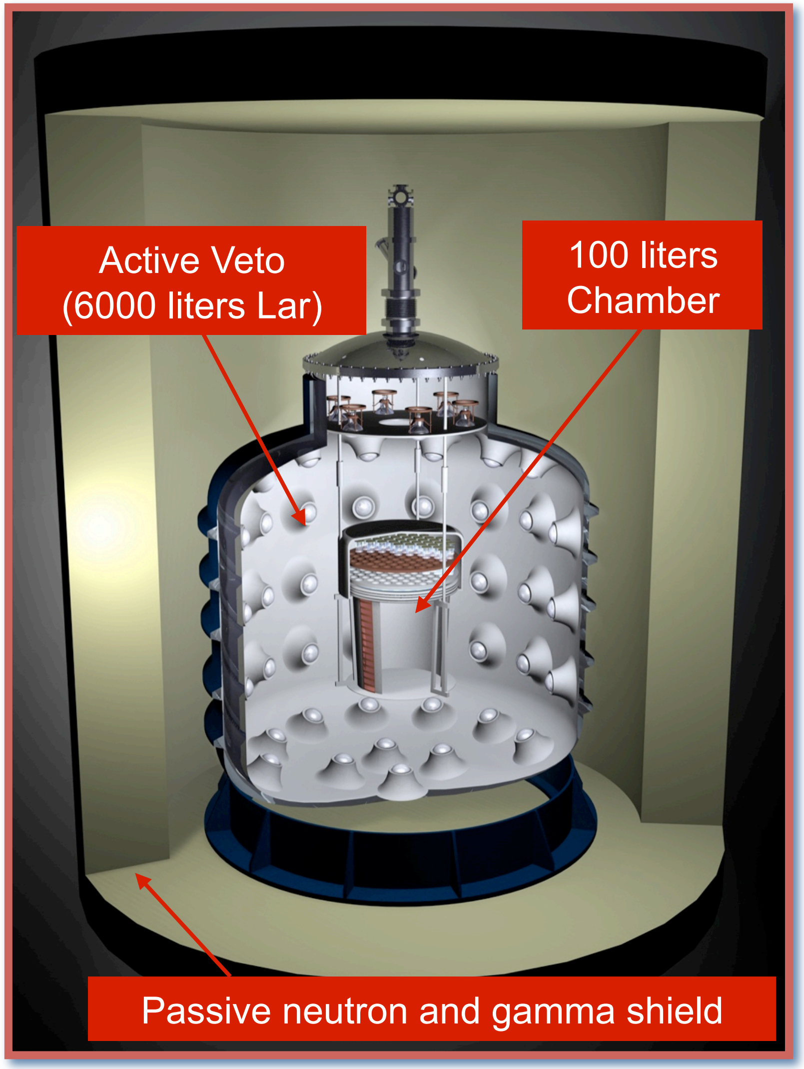
- ➔ S1 = primary (prompt) scintillation signal
- ➔ S2 = secondary (delayed) scintillation signal (proportional to ionization)

- ☐ 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.**

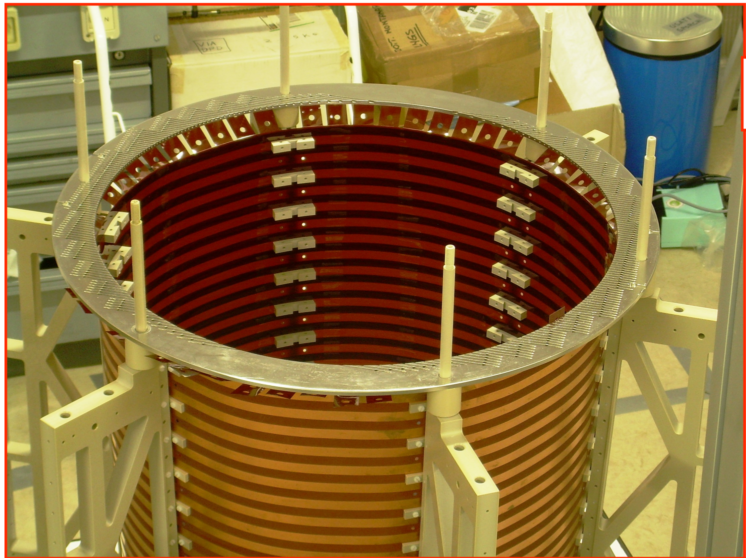


The 100 liters detector

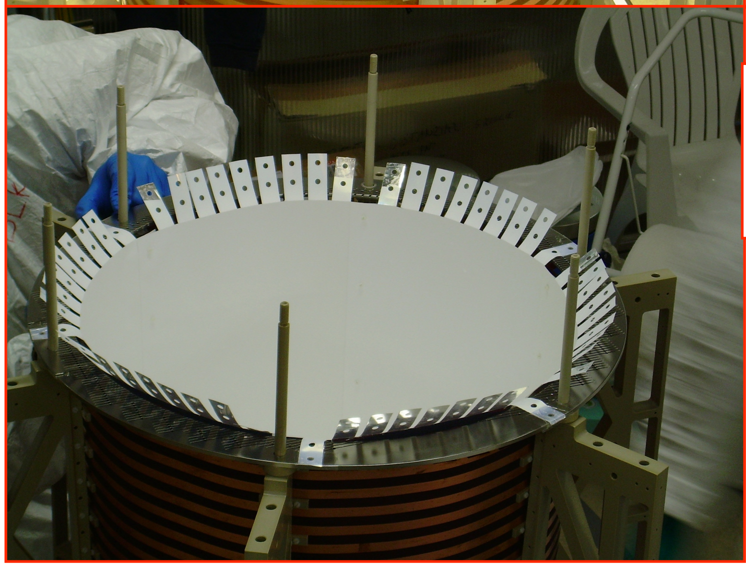
- Sensitive volume = 100 liters (140 kg).
  - ➥ 3-D event localization by means of:
    - Drift time recording (vertical axis);
    - Centroid of PM's secondary signal amplitudes (horizontal plane).
- 4π active VETO system:
  - ➥ tags and measures the neutron-induced background with an ID-factor ≈ 99.99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



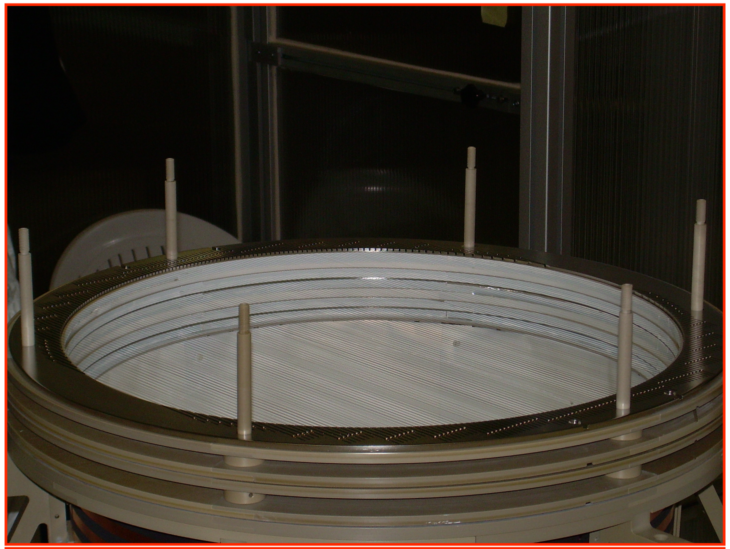
Inner Detector Assembly (Jun, 2008)



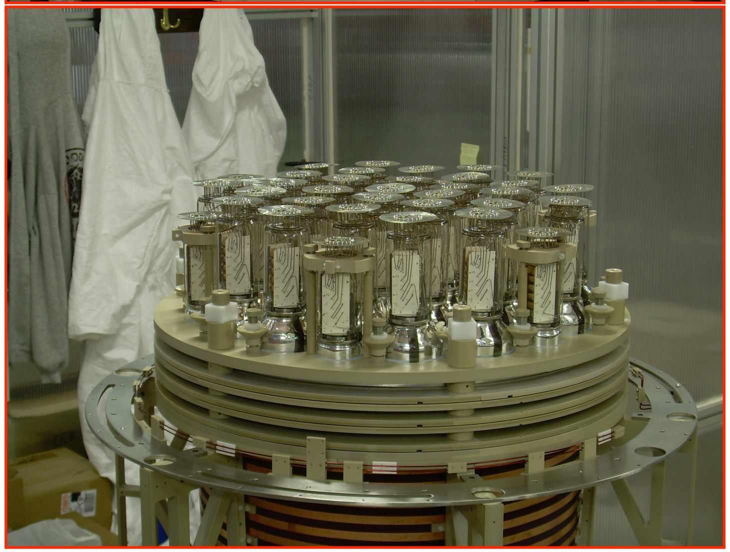
Race Tracks



Reflector +
Wavelength
Shifter

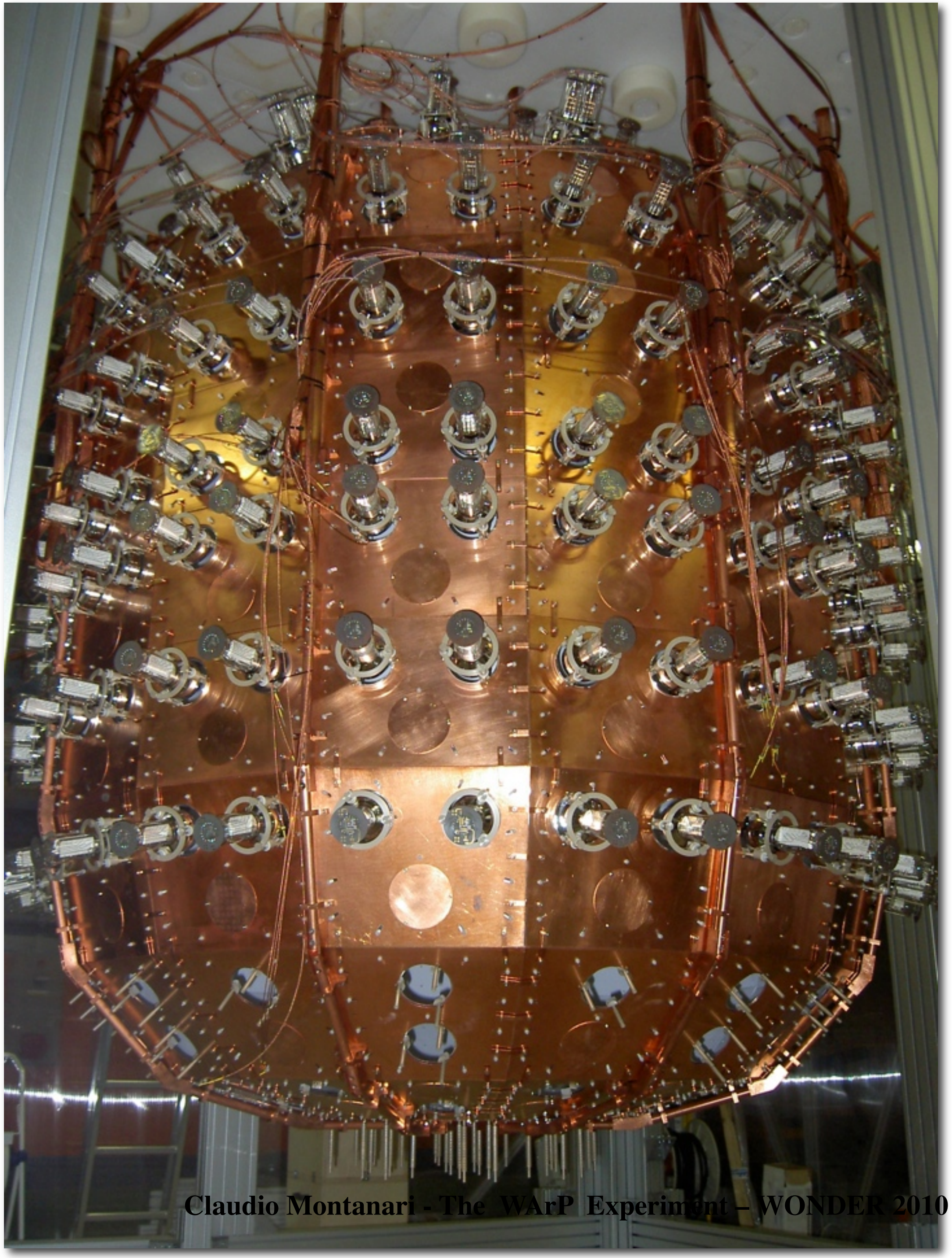


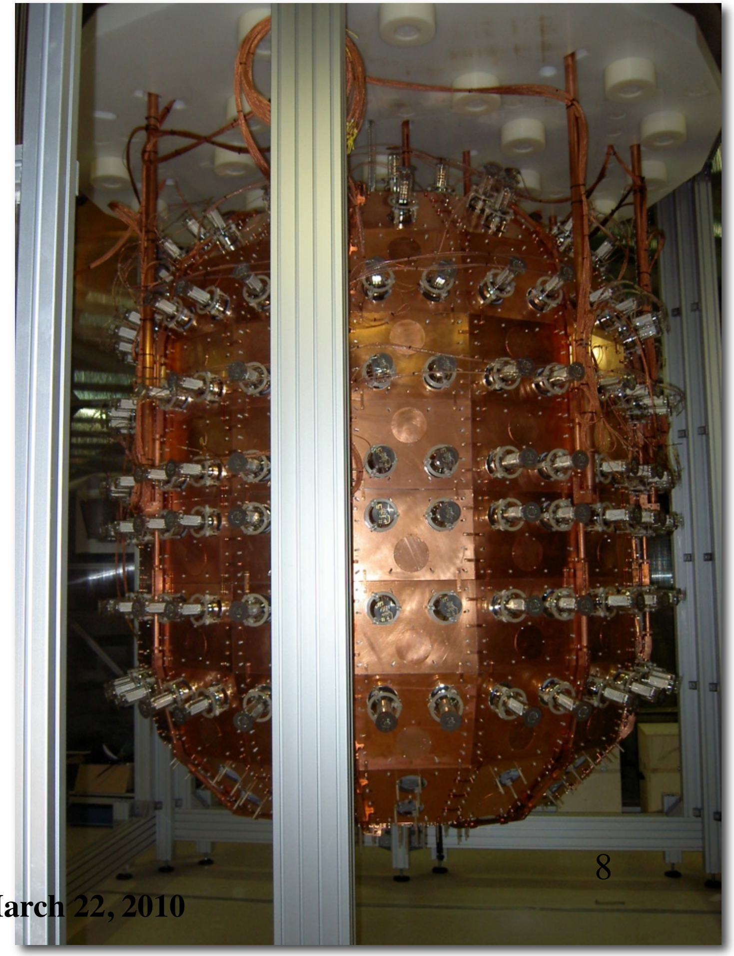
Grids



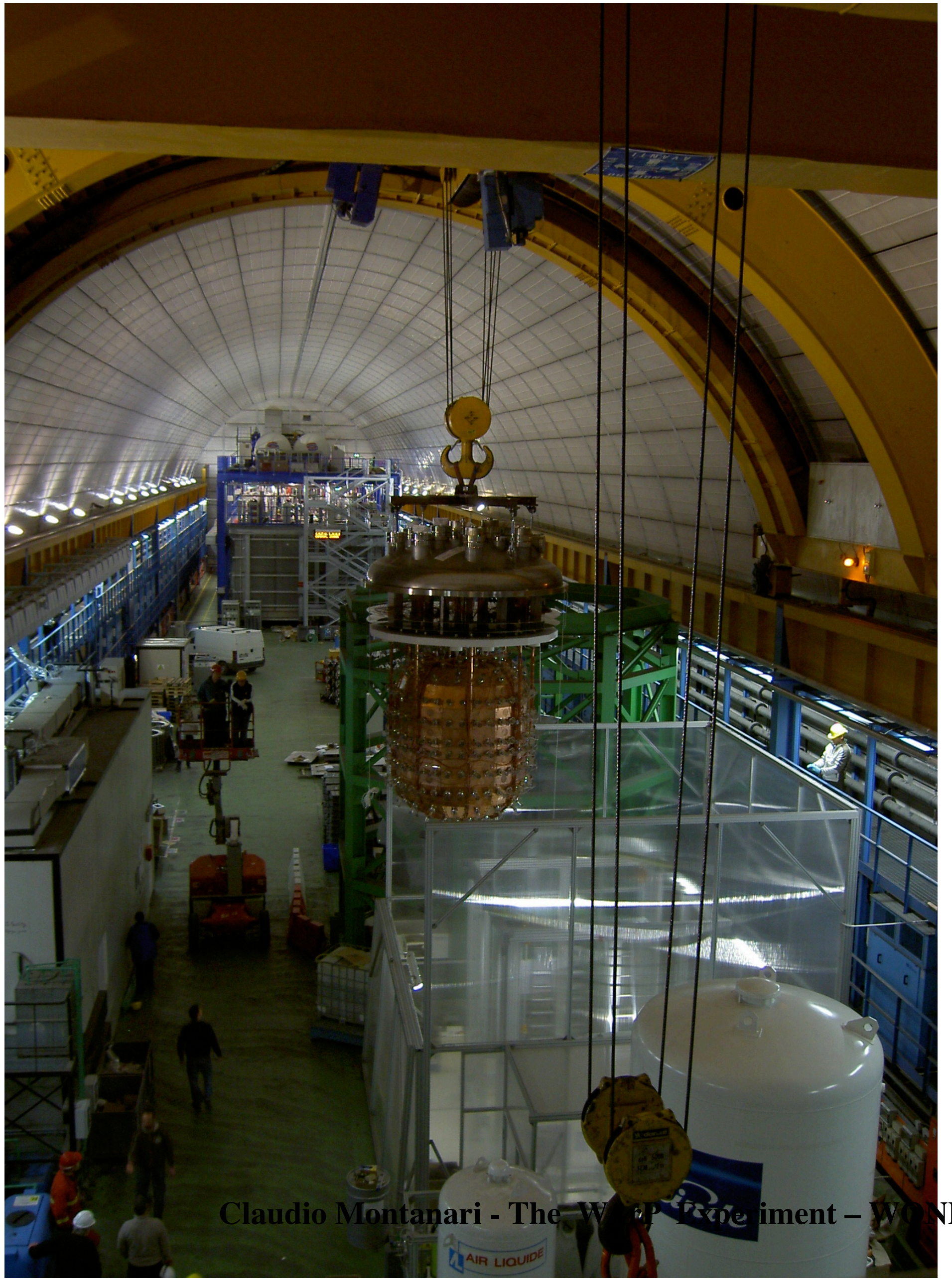
Phototubes

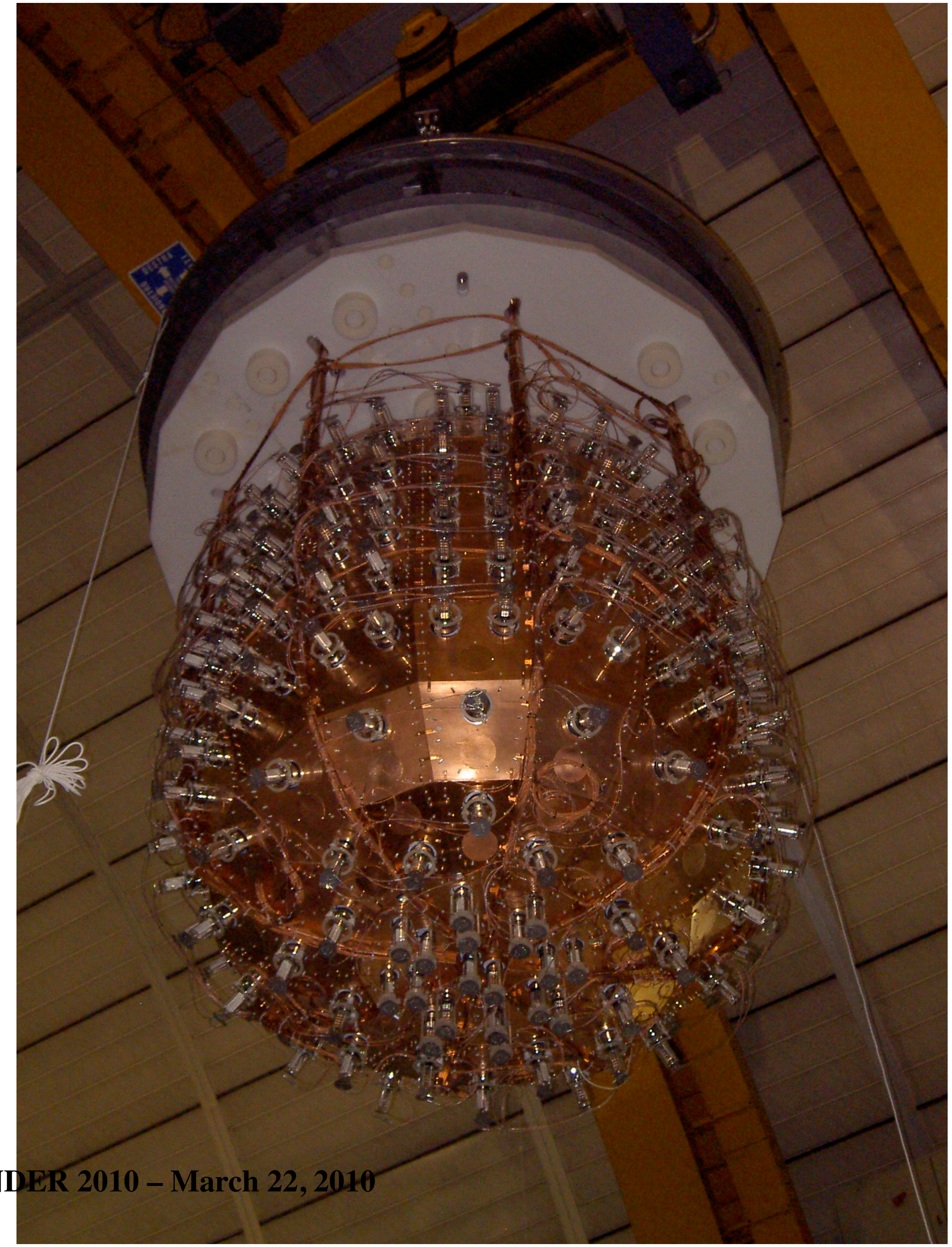
Active Shield Assembly (Nov., 2008)





Installation in the main cryostat (December 17th 2008)

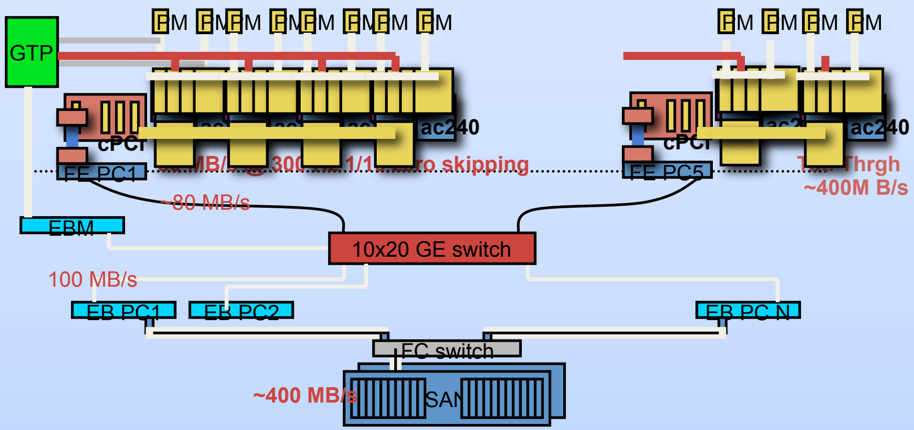




R/O Electronics

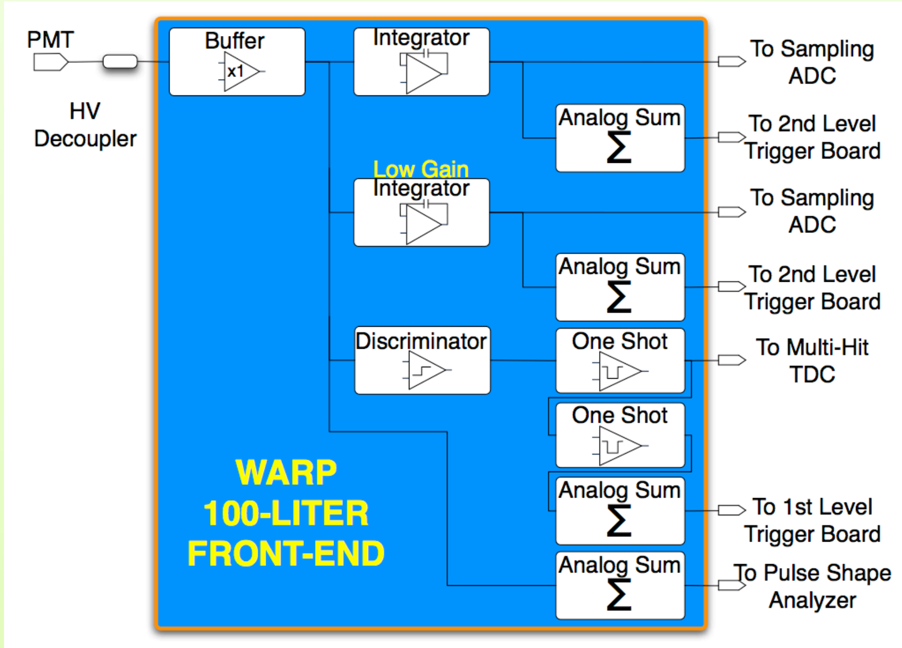
INNER DETECTOR

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.



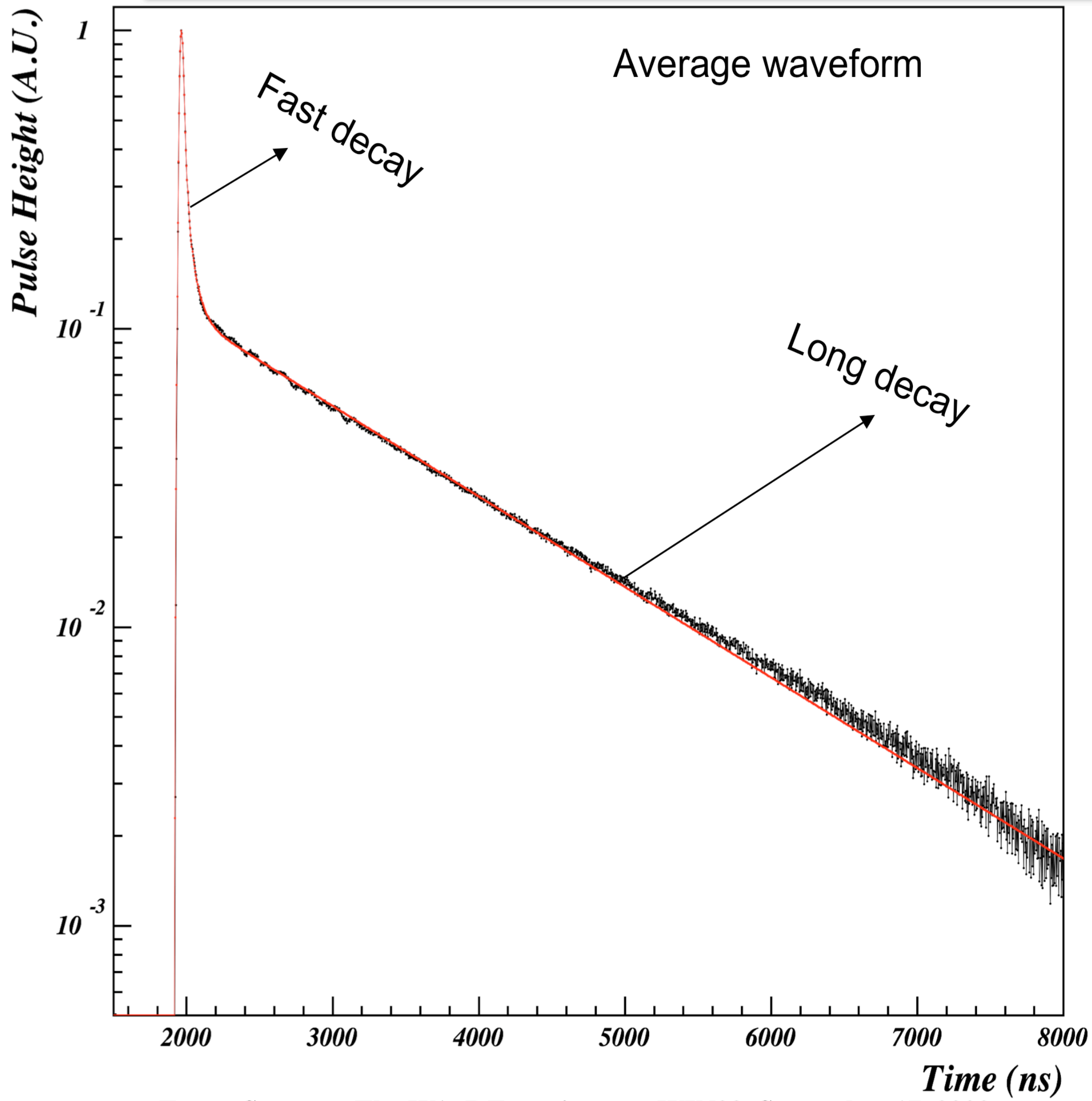
WArP-100 Technical Run

- On May 5th, 2009 (the day after LNGS restart, after the earthquake), WArP-100 commissioning (cooling + filling) was started.
- Initial Vacuum level (by pumping): 2÷6 x 10^{-6} mbar.
- Cooling: by "low quality" LAr circulation detector cooling down to ~ 200 K has been achieved in ~ 2 days.
- Final Vacuum level (by cryo-pumping): 1÷ 2 x 10^{-6} mbar.
- Filling:
  - "good quality" LAr (equiv. 5.5 GAr grade) further purified by in line H_2O and O_2 double stage filter.
  - internal material cooling down to ~ 100 K (~ 3 days).
  - GAr recirculation/reliquifaction ON.
  - LAr level rise up to nominal: ~ 3 days.
  - Filling completed on May 13th.
- All photomultipliers slowly put in operation:
  - 335 out of 337 PMTs correctly working.
  - Started DAQ at no field on the inner detector: debugging of Electronics (noises) and DAQ issues.

WArP-100 Technical Run (cont.)

- When the drift field has been turned on, a discharge at 60 kV on the HV cable connecting it to the inner chamber cathode broke the HV injection system.
  - After the detector partial disassembly, in October 2009, we found that the cable insulation was broken in several points and that discharge was occurring on a point placed few centimeters above the liquid level.
  - After investigations, we concluded that these mechanical cracks were due to internal stresses induced by a high temperature thermal treatment of the cable that was done (without notice) as part of the feed-through fabrication procedure (for Epoxy resin outgassing).
- A problem on the light yield in the inner detector was also found:
  - Light yield lower than expected:
    - 1.6 phel./keV measured from 39Ar β spectrum
    - > 2.5 ph.el./keV expected from measurements on 2.3 liters prototype and Montecarlo extrapolation.
  - The problem was not due to Argon contamination or to water sticking on the wavelength shifter layer.
  - After inspection of the many reflector/waveshifter samples that were produced together with the 100 liters components we found that different production batches of the wavelength shifter (TPB) provided conversion efficiencies that were varying by large factors (up to 2) even though that the chemical titles were exactly the same for all the batches.

LAr contamination (N_2 and O_2)



waveform fit (two exp. components).

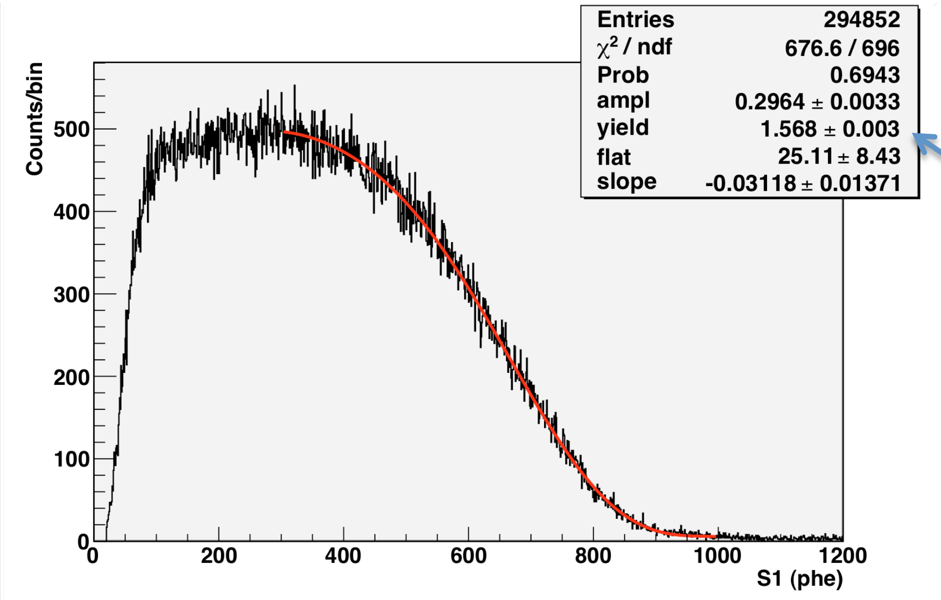
τ_{long} → indication of LAr purity:

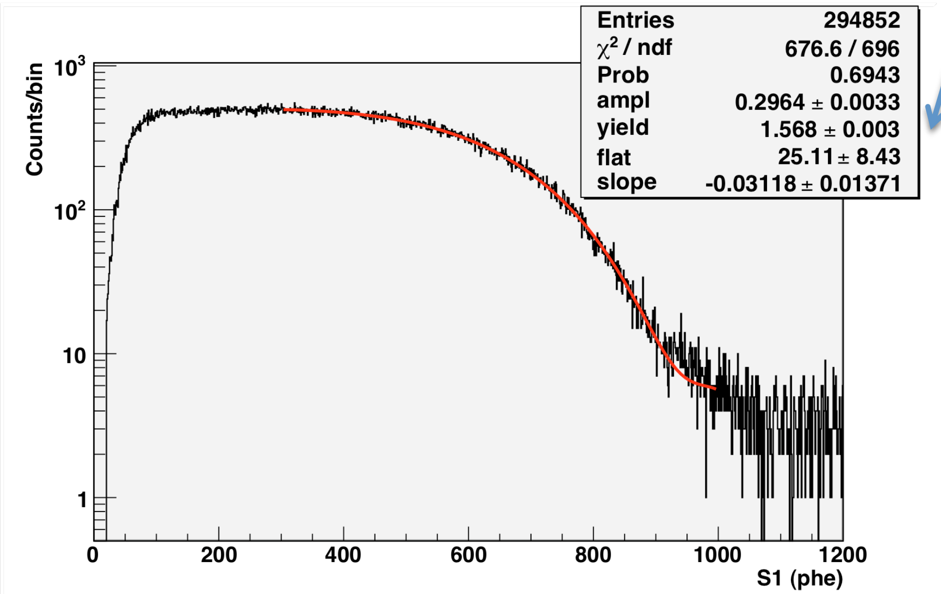
τ_{long}(fit) ≈ 1.3 µsec

⇓

good LAr purity (after three months of recirculation)

Light yield measurement from 39Ar decay

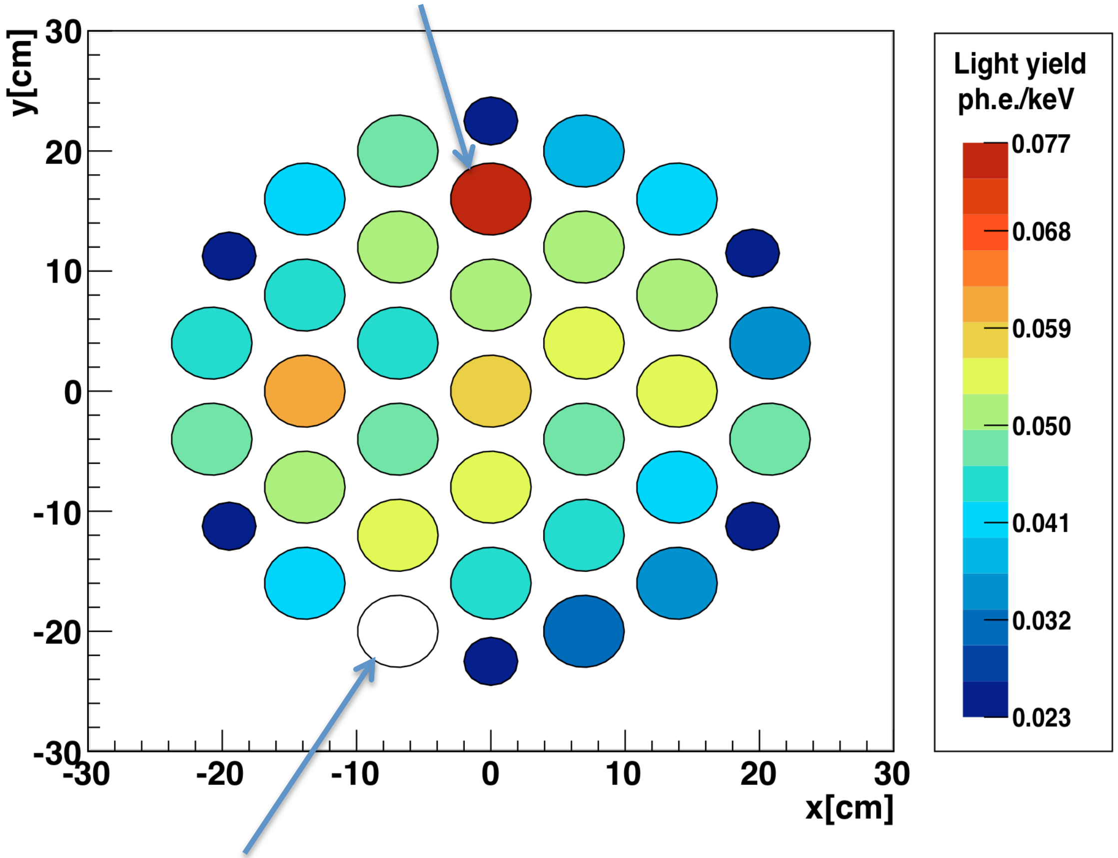




Measured Light yield
From 39Ar beta decay
Spectrum ~ 1.6 ph.el. / keV

Light Collection Uniformity

Best PMT (QE > 30%)

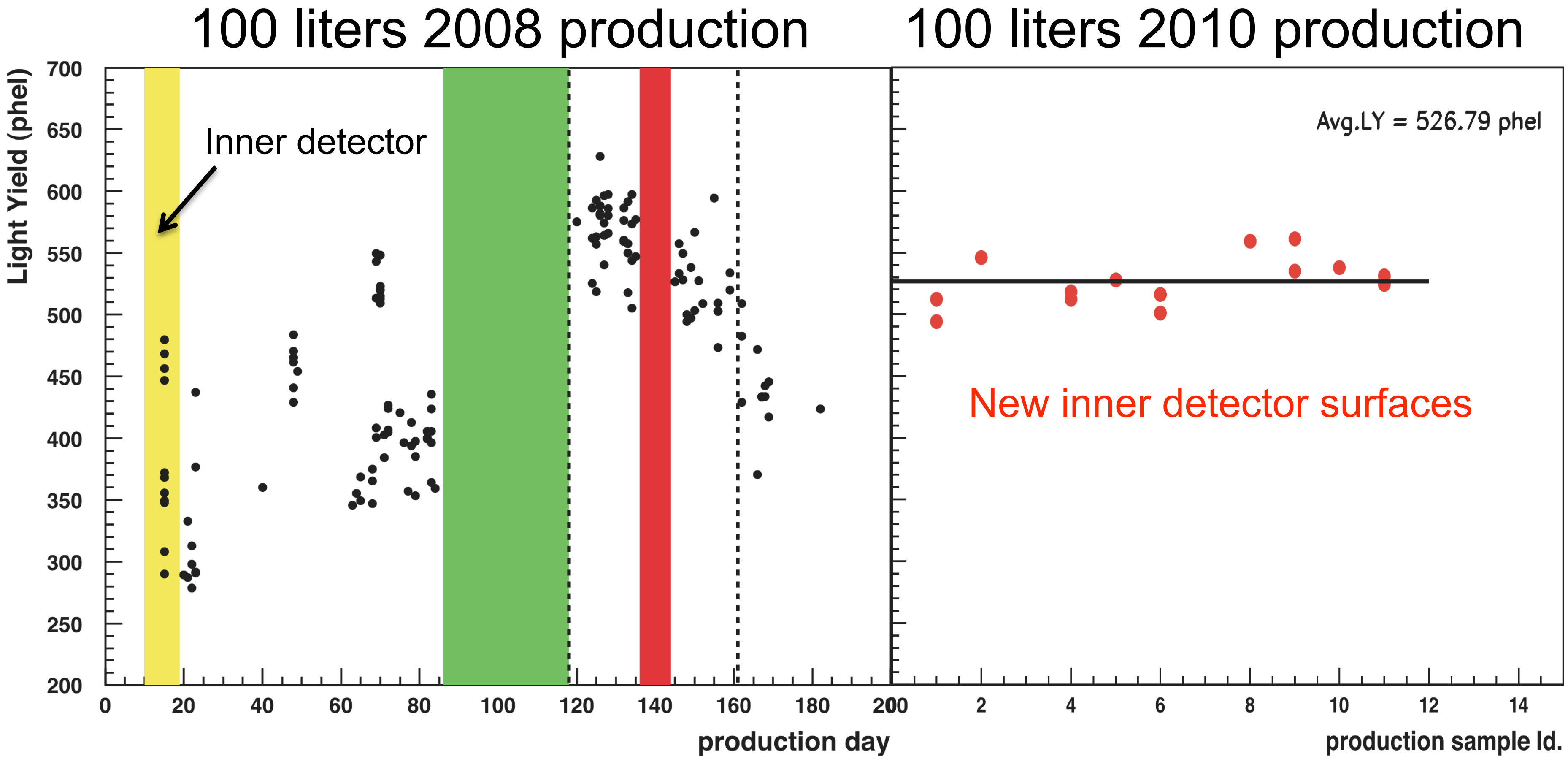


Low gain PMT (not used)

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

Wavelength shifter performance

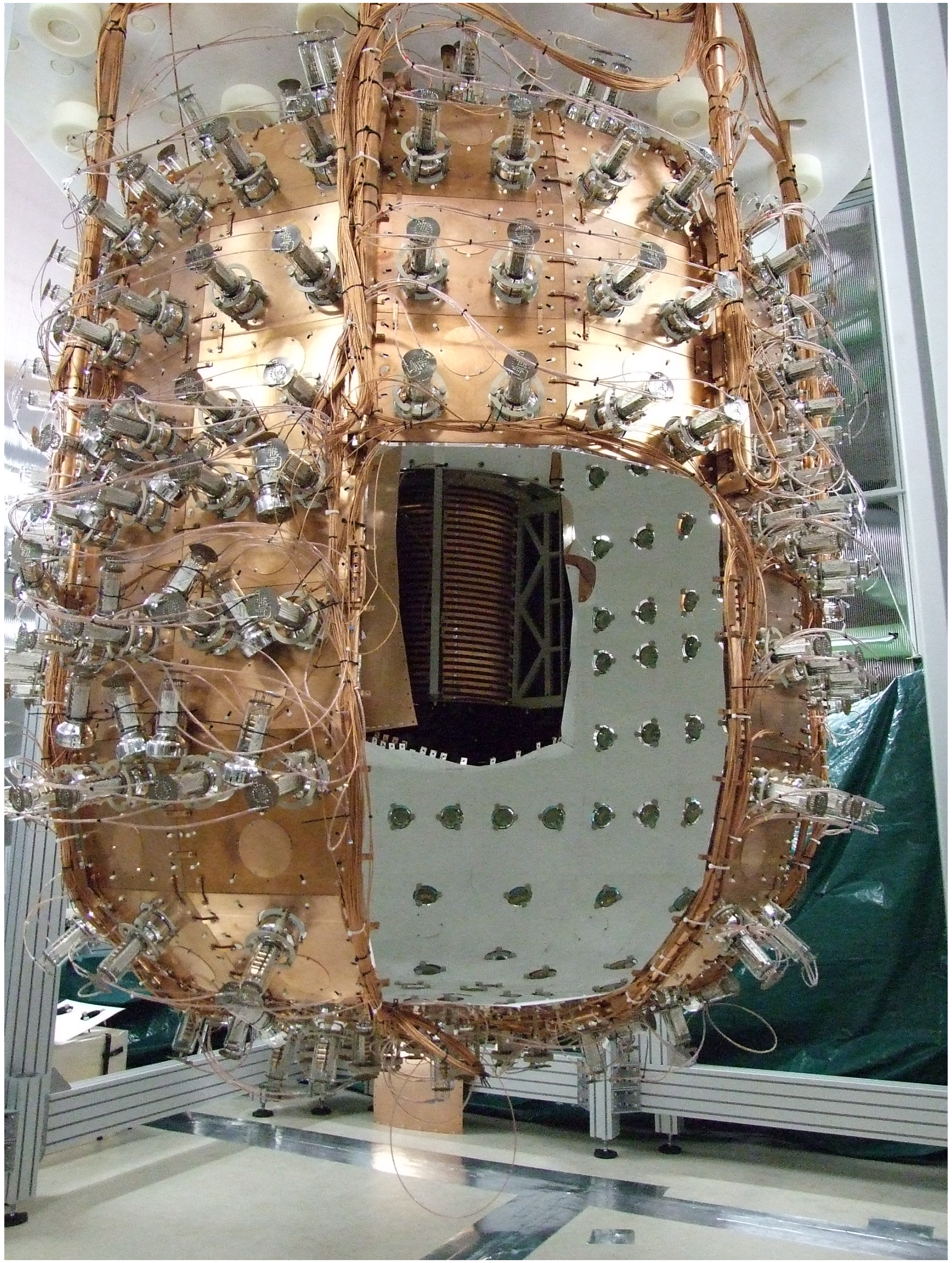
Different production batches of the wavelength shifter show very different light conversion efficiencies. The exact reason is still under investigation.



Two, freshly made, TPB batches have been acquired in 2009. The one with better performance has been used to produce a new set of surfaces for the 100 liters inner detector. The measured light yield of 2010 production samples is about 35% larger than the one of 2008 production.

100 liters intervention for the second run

- In October 2009 the 100 liters detector was brought back in the assembly clean room.
- It was then partially dismounted to allow for:
  - The replacement of the broken high voltage cable and feedthrough with a completely new, severely tested, solution;
  - The substitution of the internal surfaces of the inner detector with the ones with higher light conversion efficiency.
  - Other minor issues have been cured in the meantime.



WArP-100 Second Run

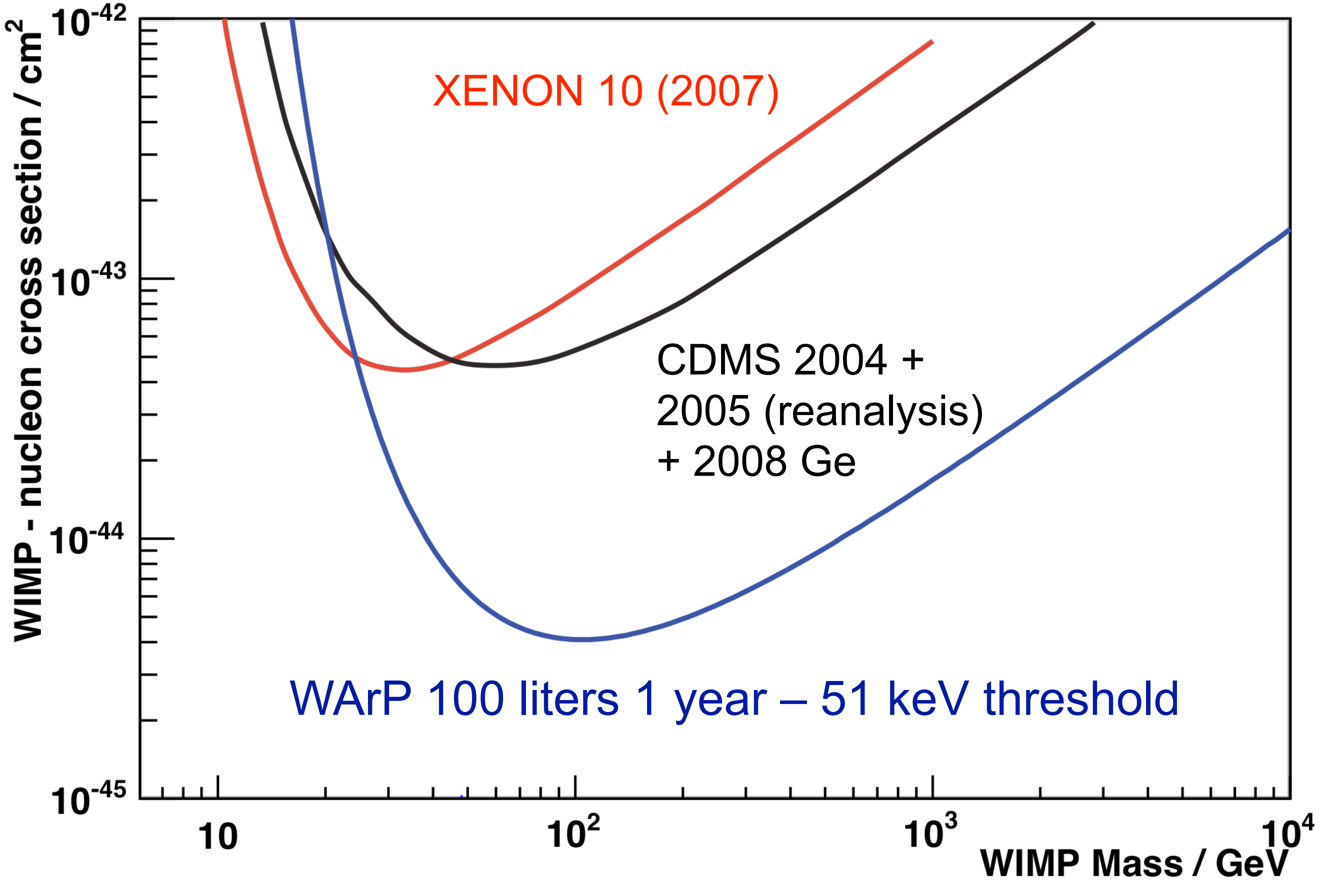
- All the re-assembly operations of the 100 liters detector, including the production of the new set of surfaces for the inner detector (to minimize the exposure to the atmosphere and ambient light), have been performed between the end of January and the beginning of February 2010.
- The detector has been moved back into the main cryostat on February 5th, 2010; vacuum pumping started the same day.
- After about one month of pumping, the vacuum level reached about the same value obtained in the 2009 run ($\approx 10^{-5}$ mbar). Again, the residual pressure was dominated by water outgassing from the detector materials (mainly plastics of the cables and of the internal polyethylene shield).
- The 6th of March, 2010 we started the cooling (under vacuum) of the detector by means of liquid argon circulating in a cooling serpentine placed inside the vacuum insulation of the main cryostat. During the cooling the residual pressure went down to about 10^{-6} mbar, as expected.
- Filling of the main cryostat started on March 9, 2010, when the temperature in the inner detector dropped below 250K (temperatures in the internal shield were already in the range of 150K or less).
- Also in this case filling was performed with high quality commercial liquid Argon (5.8 grade) that was further purified by a custom made, in line, H_2O and O_2 pre-filter.
- The detector filling was completed on March 16, 2010.

WArP-100 second filling

WArP-100 Second Run – Ongoing activities

- As a first action we wanted to test the High Voltage system for the drift.
  - The day after the completion of the detector filling, the drift field in the inner chamber has been turned on. We raised the voltage on the chamber cathode to -45 kV (the voltage required to run the chamber at 500 V/cm). No problems have been detected: both the applied voltage and the absorbed current were stable; no detectable noise was induced on the PMTs signal cables.
- At the moment the voltage on all the PMTs is being raised with a slow, carefully tested, procedure. PMTs should reach the nominal operating conditions before the end of March 2010.
- Measurements of the detector performance (light yield, uniformity, Lar purity, etc.) will then take the following few weeks.
- We therefore expect to start in May 2010 a set of energy calibrations.
- A run for WIMP search will then be started for a duration of several months, until the limit sensitivity will be reached.

WArP-100 Sensitivity



With the 100 liters working at the nominal performance we will be able to extend the sensitivity for WIMP searches by more than an order of magnitude with respect to the present best limits.

WArP Main Extrapolation Data

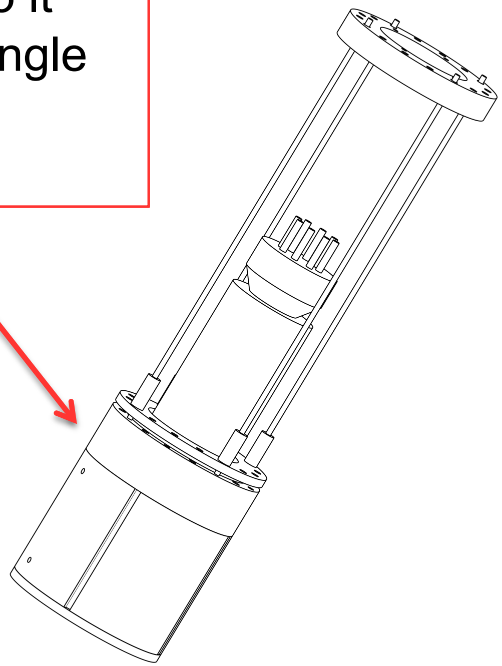
Electrons total light yield @ no field		1.7(pessimistic)		phe / keVe	
Electrons (20-60 keV) reduction @ 1 kV / cm		0.67			
Electrons total light yield @ 1 kV / cm		1.14		phe / keVe	
Electron energy	30	40	50	60	keV
Fast component fraction (electrons)	0.35	0.32	0.30	0.29	
Fast component for electrons @ 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 @ σ(p) = 10^-42 cm^2	0.058	0.042	0.031	0.021	ev/kg/day
Rate for 100 kg WArP @σ(p) = 10^-44 cm^2	21.2	15.4	11.3	7.5	ev/year
Rate [illegible] in 100 kg WArP @ 20keVe [illegible] E < 40keVe		1.1 E 08			ev/year
Rate for 1 ton WArP @σ(p) = 10^-45 cm^2	21.2	15.4	11.3	7.5	ev/year

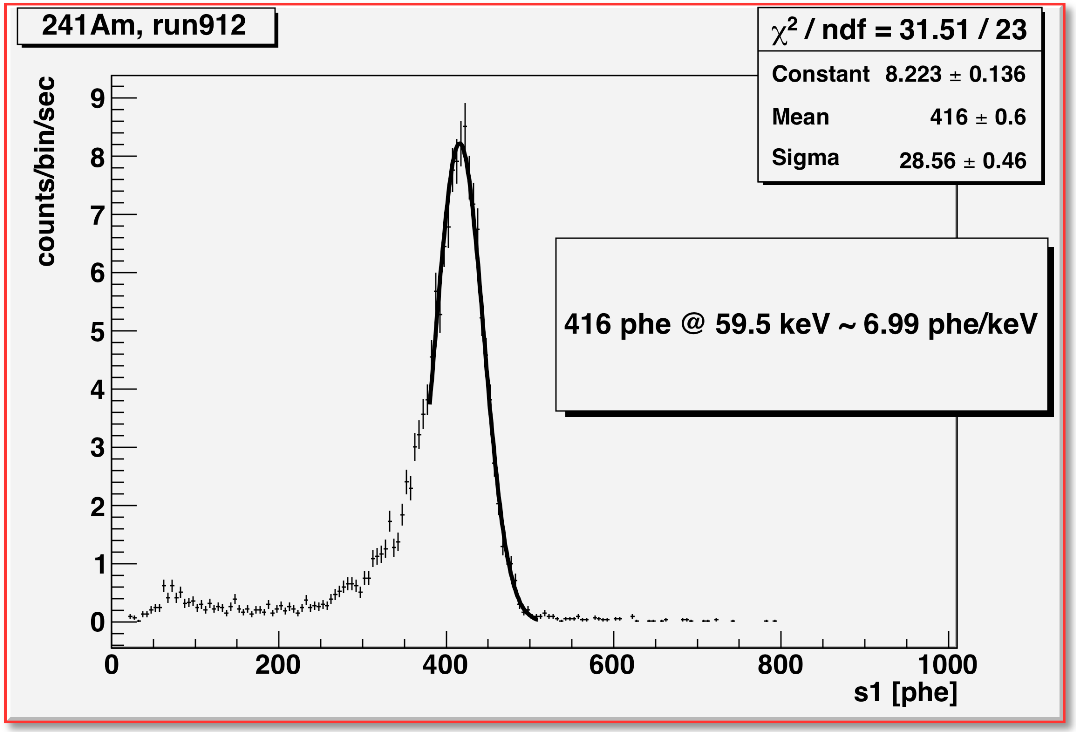
WArP-100 Upgrade

- Within the WArP R&D activities a new generation of high Quantum Efficiency PMTs, working at LAr temperature, from Hamamatsu, have been tested. First results have shown very good performance yielding a light collection of the order of 7 photoelectrons/keV, with a photocathode coverage similar to the one of the 100 liters inner detector and working in single phase mode.
- Additional tests are being carried on for long term stability, and other technical issues. A final test is planned, during 2010, with the 2.3 liters prototype.
- A set of 40 of this new generation PMTs is being procured 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 camber is also being considered.
- This upgrade will take place at the end of the present 100 liters run, and should bring the light yield in the range of 6 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.

Test of high QE new generation PMTs

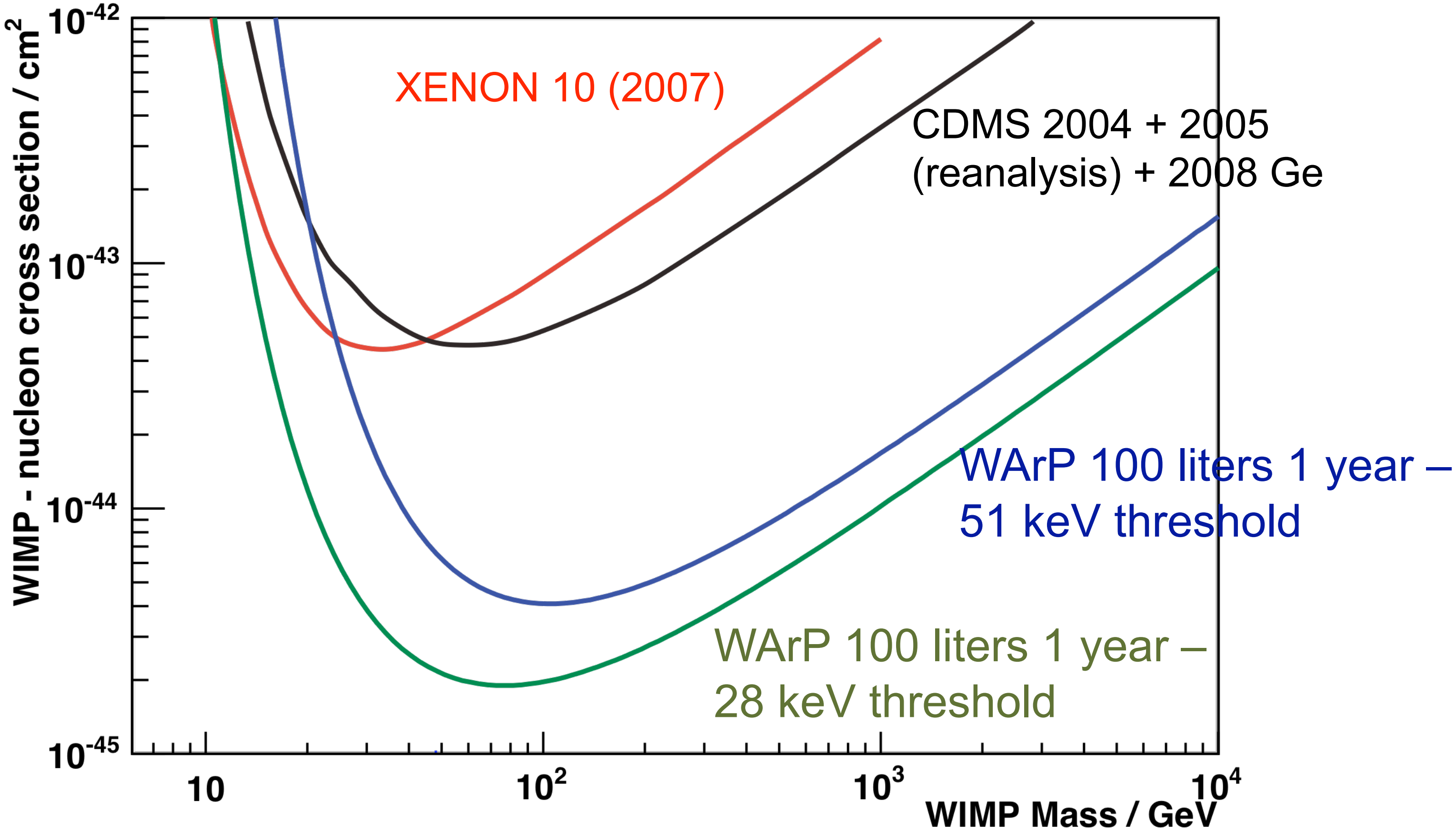
Small test chamber (0.75 lt Lar volume) read by a single 3" PMT (photocathode coverage ≈ 11%)





Results from 241Am calibration: 59.5 keV line → ≈ 7 phel./keV

WArP-100 Upgraded Sensitivity



With the 100 liters, upgraded with last generation PMTs, the sensitivity could extend to the region just above 10^{-45} cm^2 for the WIMP nucleon spin independent cross-section

Conclusions

- In the summer of 2009 WArP-100 was operated for the first time.
- The 100 liters detector has undergone a technical run that lasted about three months (until August 11). Main calibration and debugging procedures have been performed. Two problems have been detected on the high voltage system for the drift and on the light collection efficiency.
- The detector has therefore been emptied and warmed out. It was then taken back into the assembly clean room and partially dismounted.
- A replacement solution for the HV system has been identified, built, severely tested and implemented.
- All the internal surfaces of the inner detector have been replaced with higher performance ones.
- The detector has been then re-commissioned (vacuum, cooling, filling) during February and March 2010.
- The detector is presently coming back to operation; the HV system has already been tested without problems.
- An extended physics run is expected for the next several months.
- A significant detector upgrade will be then implemented.