Tests of PMTs for Future Dark Matter Detectors

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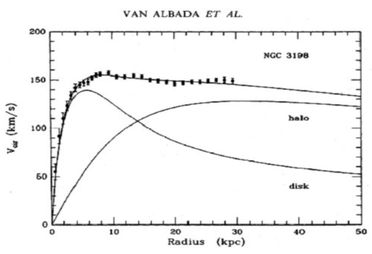
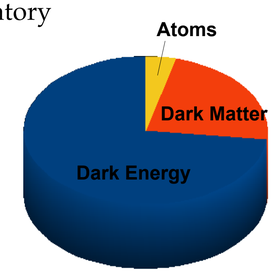
Dark Matter

- Many hints on the existence of dark matter from astronomy and cosmology
- Dark matter is believed to make up for 23% of the universe, while only 4% are made from normal matter. The other 73% are dark energy
- Dark matter does not interact electromagnetically, hence the name
- One possible dark matter candidate is the weakly interacting massive particle (WIMP)
- Many experiments try to directly detect dark matter in the laboratory



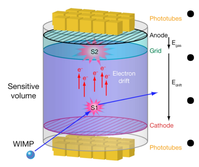
Van Albada et al., Distribution of dark matter in the spiral galaxy NGC 3198,(1985)ApJ295-305V

X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.



Future LXe Dark Matter Detectors

Detection Principle



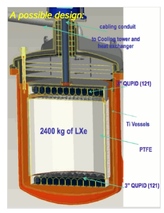
- Two-phase xenon TPC
- WIMPs scatter off xenon nuclei
- Primary scintillation light (S1)
- Charge is drifted towards surface
- Secondary scintillation light (S2) in gas phase
- 3d position reconstruction from drift time

PMT Requirements

- Performance in LXe (~ -100 °C, up to 5 bar)
- Sensitivity to xenon scintillation light (178 nm)
- Low radioactive background
- Low noise
- Single photon detection

XENON1T

- The successor of XENON100 will use 1t of LXe as target
- Construction will start end of 2011

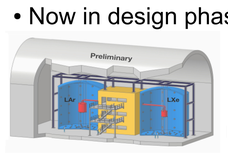


http://www.physik.uzh.ch/groups/groupbaudis/xenon/

DARWIN

Dark Matter WIMP Search with Noble Liquids

- A multi-ton detector using LXe and/or LAr
- Now in design phase



http://darwin.physik.uzh.ch/

Hamamatsu R11410-MOD

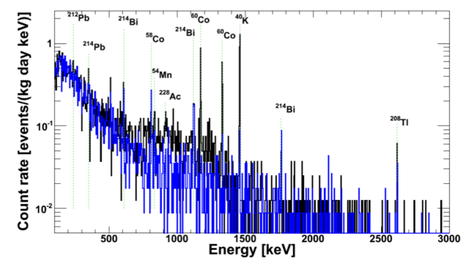
- The Hamamatsu R11410 PMT has been specifically designed for the operation in liquid xenon
- Can be operated down to -110 °C
- Special bialkali photocathode for improved operations at low temperatures
- Quartz window ensures sensitivity to xenon scintillation light at 178 nm
- High quantum efficiency

Size of photocathode	3 inch
Photocathode material	Bialkali LT
Number of dynodes	12
Operating temperature	-110 to 50 °C
Light range	160 to 650 nm
Quantum efficiency	~ 26 % at 175 nm
Maximum voltage	1750 V
Recommended voltage	1500 V

Screening Results

- The R11410-MOD PMT has been screened with Gator, a high purity germanium detector used for material screening for the XENON experiment (arXiv:1103.2125v1)
- Lower overall radioactivity than for the R8520 PMT currently used in XENON100, especially for ^{40}K

"Material Screening and Selection for XENON100", accepted for publication in Astroparticle Physics, arXiv:1103.5831



Isotope	Per PMT	Per Photocathode Area	R8520 (XENON100)
^{228}Ra	< 3.8 mBq	< 0.09 mBq/cm^2	< 0.11 mBq/cm^2
^{228}Th	< 2.6 mBq	< 0.06 mBq/cm^2	< 0.07 mBq/cm^2
^{238}U	< 95 mBq	< 2.09 mBq/cm^2	< 2.33 mBq/cm^2
^{226}Ra	< 2.4 mBq	< 0.06 mBq/cm^2	< 0.06 mBq/cm^2
^{235}U	< 4.3 mBq	< 0.10 mBq/cm^2	< 0.11 mBq/cm^2
^{40}K	13 ± 4 mBq	0.29 ± 0.09 mBq/cm^2	2.17 ± 0.31 mBq/cm^2
^{137}Cs	< 1.3 mBq	< 0.03 mBq/cm^2	< 0.02 mBq/cm^2
^{60}Co	3.5 ± 6 mBq	0.08 ± 0.13 mBq/cm^2	0.10 0 ± 0.01 mBq/cm^2

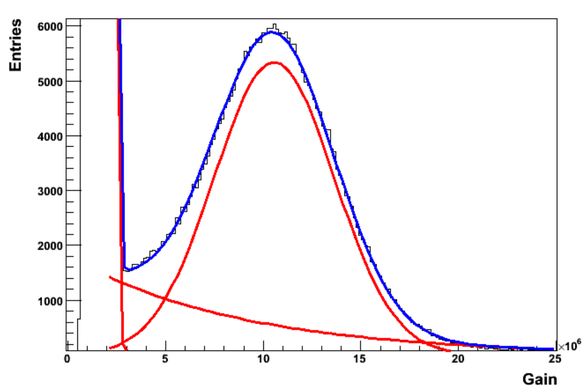
PMT Performance

Test Setup

- R11410-MOD PMTs have been tested at University of Zurich
- Tests have been conducted in a black box at room
- temperature and at LXe temperature in a small single phase liquid xenon chamber
- Single photoelectron emission has been stimulated by using blue LED light
- For linearity tests, various radioactive sources have been used together with the liquid xenon as scintillator and a NaI scintillator for the black box tests

Single Photoelectron Spectrum

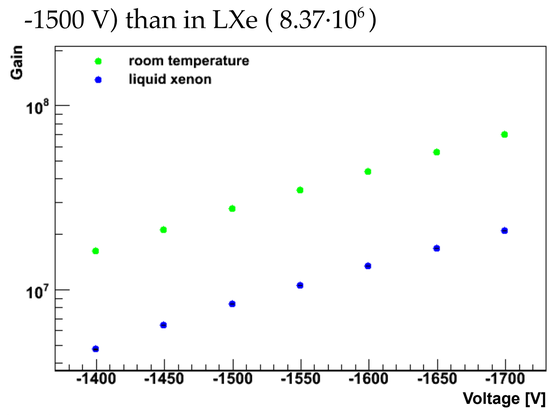
- SPE spectra have been measured at different voltages both at room temperature and in liquid xenon
- The signal peak in the spectrum can be described very well by a gaussian plus and additional exponential component (under investigation, maybe afterpulsing?)
- The PMT shows very good SPE resolution both at room temperature and in liquid xenon (resolution on signal peak ~30%, peak-to-valley ratio up to 3.8)



SPE spectrum of PMT ZK5629 at -1500V at room temperature

Gain

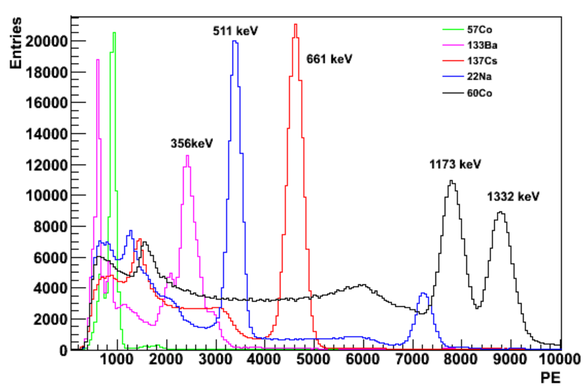
- The gain has been determined from the fit to the signal peak in the SPE spectra
- The gain is higher at room temperature ($2.77 \cdot 10^7$ at -1500 V) than in LXe ($8.37 \cdot 10^6$)

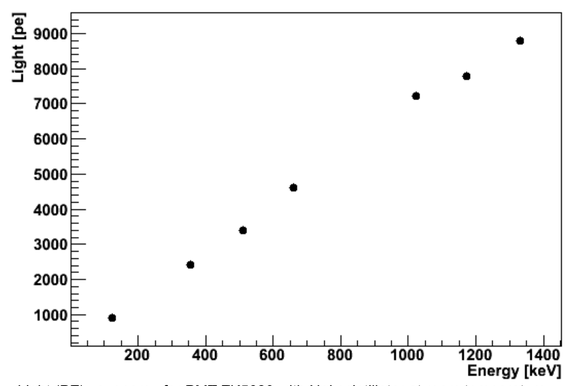


Gain of PMT ZK4988 at room temperature and in LXe

Linearity of the Base

- Various sources have been used with a NaI scintillator
- Plotting the peak position in photoelectrons against the energy, the linearity of the PMT can be determined
- The PMT shows good linearity in the tested range of up to 9000 photoelectrons





Light (PE) vs. energy for PMT ZK5629 with NaI scintillator at room temperature