PROCEEDINGS OF SCIENCE

Liquid Xenon calorimetry in the MEG experiment

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The MEG experiment utilizes a novel calorimetry technique for photon detection based on scintillation in Liquid Xenon. The main features of this technique are presented. Research and development is reviewed as well, from early tests on a prototype to the set-up of the final detector. Emphasis is laid on calibration and monitoring procedures, particularly important in such a precision measurement.

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1. Introduction

MEG is a sensitive search for Lepton Flavour Violation (LFV from now on) through the decay $\mu^+ \to e^+\gamma$ ([1] for details . This search is considered as one of the most significant probe of Supersymmetry, with a predicted sensitivity (10^{-13}) to the branching ratio improved by two orders of magnitude about with respect to the current limit[2]. The impact of this measurement on Physics beyond the Standard Model has been outlined by several speakers at this Conference (see for instance [3]).

This sensitivity can be achieved thanks to unprecedented detector performances at these energies ($E_{e^+} = E_\gamma = m_\mu = 52.8$ MeV). In particular, the resolution on the photon energy and direction plays a key role in background suppression and required a lot of effort in the last years on research and development on LXe calorimetry, which was never carried out with a large volume.

2. Scintillation in Liquid Xenon

Liquid Xenon (LXe from now on), as well as other liquid rare gases, is considered as an excellent medium for radiation detectors because of its scintillating properties. Light emission by rare gases has been extensively studied for gas, liquid and solid phases for many years[4]. Fluorescence in LXe (at $\lambda = 175$ nm) results from de-excitation of the excimer state $Xe_2^* \to 2Xe{+}h\nu$) induced by ionizing radiation according to the two following schemes:

- direct excitation ($Xe^* + Xe \to Xe_2^*$);
- ionization+recombination.

It is also known that the probability of these two processes is correlated to the particle energy loss: the faster excitation mechanism is preferred in the case of heavily ionizing particles, while only the latter is involved in light emission by minimum ionizing particles. A high light yield (42000 photons/MeV, comparable to that of NaI(Tl)), combined with a fast decay component ($\tau \approx 20$ ns, 10 times as fast as NaI) is peculiar of this processes. Moreover, the excimeric emission makes noble liquids transparent to their own scintillation light, as the bound Xe_2 molecule is absent in the ground state. We are going to show that the energy resolution of LXe detectors is strongly related to the transparency of the scintillating medium.

With respect to Ar and Kr, Xe has to be preferred for calorimetry because of its high atomic number and density (which implies a shorter radiation length, $X_0 = 2.77$ cm). Moreover, it has a higher boiling temperature, which requires a lower cryogenic power.

2.1 Technique validation by a Large Prototype test

While self-absorption should be negligible, light attenuation may occur as a result of diffusion (Rayleigh scattering) and absorption by impurities. The latter is a critical issue in the case of large detectors, as it heavily affects both photo-statistics and uniformity of the energy response function. The dominant absorber in the range of interest is water vapor, whose absorption spectrum overlaps the VUV LXe fluorescence spectrum. It follows that even a 1 ppm concentration of water in LXe is sufficient to shorten the absorption length down to a few cm. This is therefore a critical issue for a large volume detector.

Research and development work was then in order to test optical properties of such a medium. A Large Prototype (LP from now on, with 100l LXe) of the final detector was built and arranged with an array of photomultipliers measuring the amount of scintillation light collected at different distances from a lattice of α-sources[5]. The transparency was shown to improve by removing the residual water by means of a purification system (see Fig.1). The absorption length eventually was $\lambda > 95$ cm at 90% C.L., with a sensitivity limited by the dimensions (50 cm) of the sample[1].

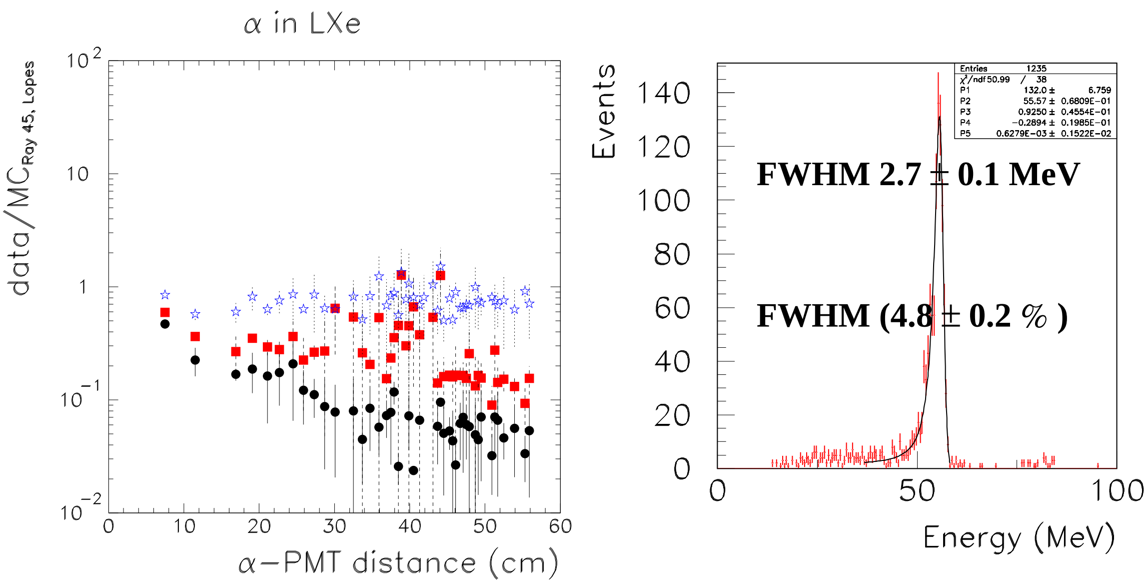

Figure 1: Left: absorption profile of LXe scintillation light in the Large Prototype of the LXe calorimeter of the MEG experiment at three different purification stages. Right: energy spectrum for 55 MeV events induced by γs from π^0 decay.

The LP was then exposed to 55 MeV γs from decays of π^0 from pion charge exchange reaction ($\pi^- p \rightarrow \pi^0 n$) on a liquid Hydrogen target, in order to test the detector response at a γ-energy close to that of $\mu \rightarrow e\gamma$ decay. The resolution turned out to 4.8% FWHM (as shown in Fig.1), dominated by escape effects on the low-energy tail (the right edge, which does not depend on these, is 1.2% wide). The timing resolution was studied as well and found to improve with photostatistics, as expected; the FWHM obtained for 55 MeV photons was 90 ps. Both values are compliant with the proposal goals.

3. The final detector

The electromagnetic calorimeter consists in a single-vessel detector containing 800 l of LXe surveyed by 850 quartz-windowed PMTs. Based on former experience on the LP, a big effort was devoted to implement new monitoring and calibration techniques. The capability of the LXe purification system to remove moisture was improved at the level of 1 ppb by the use of a dedicated, liquid-phase circulation pump.

[1]The purity of different samples used in the past might explain the contradictory results in the literature concerning LXe emission yield.

3.1 Calibration techniques

In addition to light emitters (LED, laser) and α-sources, a novel calibration method was accomplished so as to study the detector response at intermediate energies. This method makes use of a proton beam delivered by a Cockcroft–Walton generator to a dedicated target at the centre of the apparatus in order to induce radiative nuclear reactions. The possibility of tuning the proton kinetic energy up to 1 MeV, combined with the use of different target nuclei, allows us to exploit different reactions, with the energy of outcoming γs ranging from few MeVs up to ~ 20. The most commonly used target is ^{6}Li, providing 17.6 or 14.6 MeV γ-lines. Another target being used very often is ^{11}B, giving rise to an excited $^{12}C^{*}$ level which decays by emitting one 16.1 MeV γ or two cascade γs with 4.4 and 11.7 MeV. The latter is particularly important as it provides an effective tool to study the relative timing between LXe and the Timing Counter (which is used for the measurement of the positron time-of-flight, see [6]). The reconstructed energy spectra obtained from either reaction are shown in Fig.2). The width of these lines turns out to be consistent with 5% FWHM at 52.8 MeV, according to a poissonian photoelectron statistics.

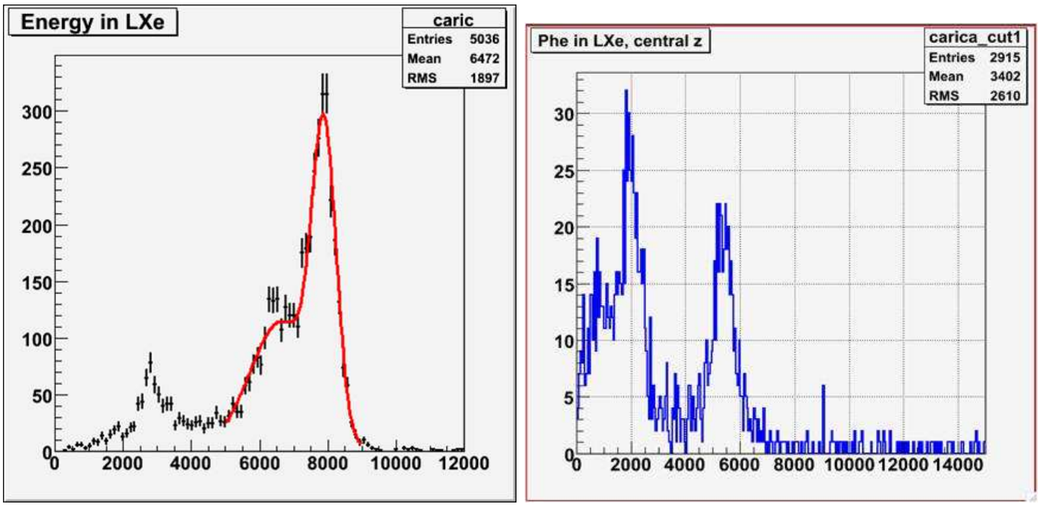

Figure 2: LXe energy spectra for γ-lines from Li(p,γ)Be (left) and B(p,γ)C (right) reactions.

3.2 Performances in 2007 engineering run and perspectives for 2008 run

The final detector has been operated since November 2007. While a good transparency ($\lambda >$ 3 m at 95% C.L.) was achieved after 1 week operation, the observed light yield in the case of γ used to be lower by 50% than expected; on the other hand, the corresponding value for α-events was in agreement with expectations (see Fig.3). An explanation of this behaviour invokes a twofold effect. First, an ionization quenching due to the presence of residual electro-negative impurities (namely O_2) which affects the ion recombination. Second, a significant N_2 contamination could give rise to non-radiative collitional losses ($Xe_2^{*}+N_2 \rightarrow 2Xe+N_2$), which is more relevant in the case of the slower ionization+recombination mechanism[7]. As a consequence of this, both energy (6.5% at 55 MeV) and timing (115 ps) resolutions appeared to be worse than those obtained with the LP. In order to restore the demanded light yield, a new impurity-removal system has been set up at the beginning of 2008 run. Main features are: the use of a O_2-getter cartridge at the outlet of

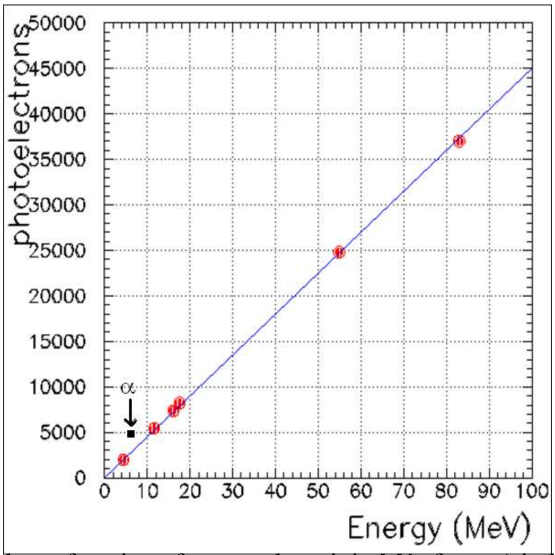

Figure 3: Light yield as a function of energy deposit in LXe for γs (circles) and αs (squares).

the liquid-phase purifier; (in parallel) restore of gas-phase circulation (as already used in the LP) through a Zr-getter; stop using inner Nitrogen cooling pipes so as to prevent leakages.

4. Conclusions

LXe scintillation is an established technique for e.m. calorimetry which exhibits excellent energy resolution and fast response, as proved by a 100 l prototype. Operation of the final detector (10 times as large than the LP) during the 2007 engineering run turned out to be affected the presence of contaminants (O_2, N_2), which reduces the light yield for γs by 50%. Standard solutions have been adopted to fix that problem, so that we are confident to be able to reach the goal resolution by the 2008 run.

References

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