



A liquid hydrogen target to fully characterize the new MEG II liquid xenon calorimeter

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ABSTRACT

The MEG II experiment aims to improve the sensitivity to $\mu^+ \rightarrow e^+ \gamma$ down to 6×10^{-14} , surpassing the 4.2×10^{-13} UL by MEG. To achieve this sensitivity the detector performances need to be assessed and monitored via dedicated calibrations. To calibrate the Liquid Xenon Calorimeter near the signal energy (52.8 MeV), photons are produced through the Charge EXchange (CEX) process $\pi^- p \rightarrow n \pi^0 (\rightarrow \gamma \gamma)$. Here we present the liquid Hydrogen target used for the CEX run 2021, during the first MEG II physics run.

1. Introduction

The Muon to Electron Gamma (MEG) experiment was designed to search for the $\mu^+ \rightarrow e^+ \gamma$ decay and completed data taking in 2013. The result achieved is the current upper limit on the branching ratio for this process: $BR < 4.2 \times 10^{-13}$ at 90% confidence level [1]. The upgraded MEG II aims to improve the sensitivity to 6×10^{-14} [2]. A sketch of the experiment is shown in Fig. 1. The key aspects of the upgrade are: a thinner and more slanted target, a pixelated Timing Counter (pTC), a new Cylindrical Drift Chamber (CDCH), the addition of a Radiative Decay Counter (RDC), a finer granularity for the Liquid Xenon Calorimeter (XEC) using MPPC, new electronics and calibration methods. The kinematic variables associated with the e^+ are measured with the spectrometer (COBRA)+CDCH+pTC). The kinematic variables (E, t, position) of the γ , expected to be monochromatic at 52.8 MeV, are measured with the XEC. This is a 1000 ℓ “c-shaped” Liquid Xe calorimeter, equipped with both PMT and SiPM [3]. The performances of this detector are central for the sensitivity of MEG II. The Charge EXchange (CEX) process $\pi^- p \rightarrow \pi^0 n$; $\pi^0 \rightarrow \gamma \gamma$ produces γ with a flat distribution in the interval [54.9, 82.9] MeV. Extremal

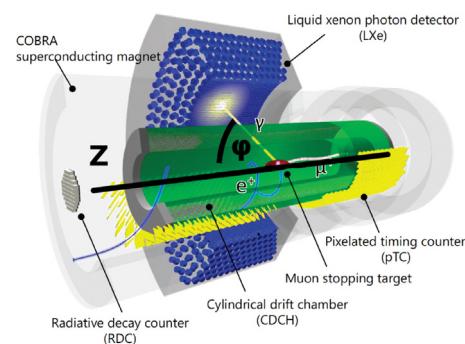


Fig. 1. A 3D schematics of the MEG II apparatus. The c-shaped LXe calorimeter is clearly visible on the left side.

values are reached for photons emitted back to back. Thus, a signal-like photon can be tagged by detecting a high-energy photon in the opposite direction. The tagging is performed with a BGO detector which can be

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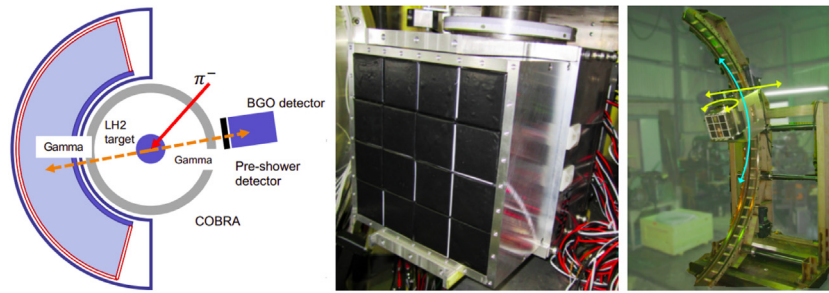


Fig. 2. A diagram of the CEX measurement, with the back to back photons configuration; A picture of the BGO detector; A picture of the BGO mover.

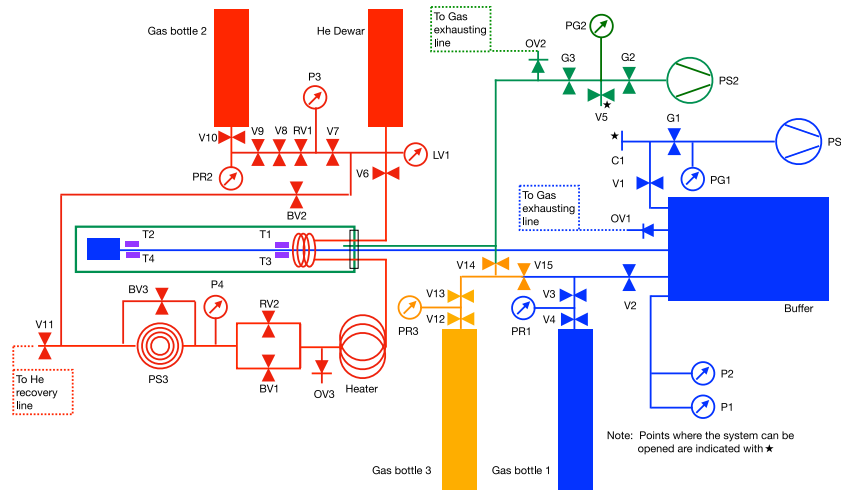


Fig. 3. Circuit of the LH2 target. To increase the readability of the scheme of the circuit, the different sub-circuits are color coded.

positioned (steps of 30 cm in \hat{z} and 16 deg in $\hat{\phi}$) opposite to specific patches of the XEC. The requirement $\Delta E/E < 1\%$ translates to $\Delta\theta_{\gamma} < 5^\circ$. A sketch of the CEX measurements, a picture of the BGO detector and its moving structure are shown in Fig. 2.

The incoming 70.6 MeV/c π^- are stopped in a cylindrical cell (60 mm diameter, 70 mm length) of 0.5 mm stainless steel containing liquid Hydrogen. This correspond to $\sim 90\%$ stopping efficiency. The Radiative Capture $\pi^- p \rightarrow n\gamma$ is a competitive process, with relative probability ≈ 0.65 [4]. The γ produced is more energetic (129 MeV) and used to control the linearity.

2. LH2 target

The hydrogen has to be kept liquid ($T < 20.39$ K at 1 atm) and in the center of the COBRA magnet, requiring a cryogenic infrastructure to be inserted for 2 m. The target consists of four sub-systems:

- A “closed volume” hydrogen circuit, in which a 1.5 bar over-pressurized 100 ℓ buffer is connected to the target cell
- A copper rod (2 m in length and 2 cm in diameter): supported and cooled at one end with liquid helium flowing in a copper coil; holding the target cell at the other.
- Vacuum Insulation for the whole system
- A slow-control based on a SCS2000 [5] controlling: temperatures, pressures, He flux and the alarm system

The buffer volume for the gaseous hydrogen, as well as all the infrastructure and services, are kept outside the magnet.

The circuit is shown in Fig. 3 and, to increase the readability, the different sub-circuits are color coded:

- Blue — Hydrogen is filled into the buffer from a cylinder, which gets then removed. The buffer itself is connected to the cell, the

exhausting line, a vacuum pump, piezoresistive pressure transmitters and a Nitrogen bottle

- Red — The liquid He flux is obtained by pressurizing a Dewar with an He bottle. The He passes around the Cu rod and through a heater before entering the He recovery line
- Green — Insulation vacuum system
- Yellow — A nitrogen bottle is used for purging the hydrogen when emptying the buffer and kept connected for safety

The operation of the target itself is partially manual and partially controlled through a LabVIEW program which, for example, controls the read-out of the various sensors and the flux of the incoming He. A module SCS2000 allows to read the various sensors. There are two key indicators used to monitor the liquefaction process and stability of the system:

- PT100 sensors: resistors have been put in thermal contact with the Cu rod at both ends (two per side for redundancy). The resistance of these elements decreases with the temperature, allowing to monitor the cooling at the Cu coil and the cell. These are going to be replaced by Lakeshore silicon diodes sensors, better suited for these temperatures.
- Hydrogen pressure: at room temperature the hydrogen is set to 1.5 bar over-pressure. When the liquefaction starts the overall pressure is reduced and can be linked to the amount of liquid Hydrogen in the cell.

3. Conclusions

The CEX reaction provides γ to characterize of the XEC. The selection is performed positioning the BGO opposite to specific patches of the LXe. An example of the correlation between the LXe and BGO energy is shown in Fig. 4.

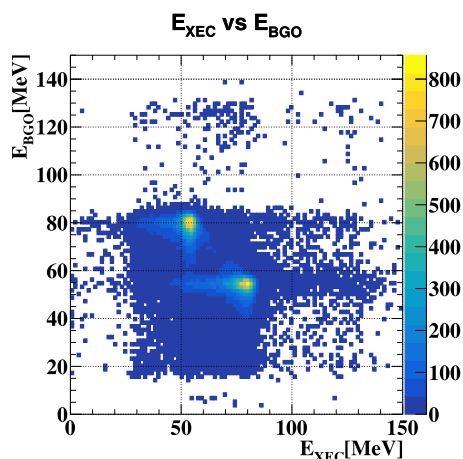


Fig. 4. An example of correlation for the photon energy in the LXe and BGO detectors. The hotspots are the back to back events.

- From the γ spectrum, the energy resolution is extracted.
- The time resolution is extracted from the time difference between the LXe and fast scintillators positioned in front of the BGO.

The whole calibration takes roughly two weeks and is done once per year. This new target satisfies the requirements for the calibration and various upgrades are already ongoing for next year's run.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. Declaration of competing interest document has not been provided; hence, we have just used the first option in the standard form, as this section is a requirement. Please confirm if this is correct.

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