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

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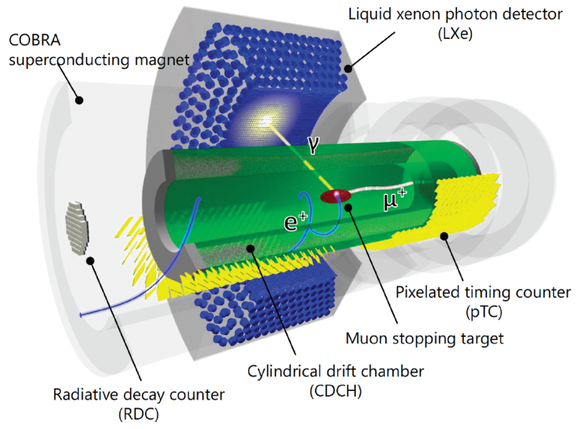
The MEG II Experiment

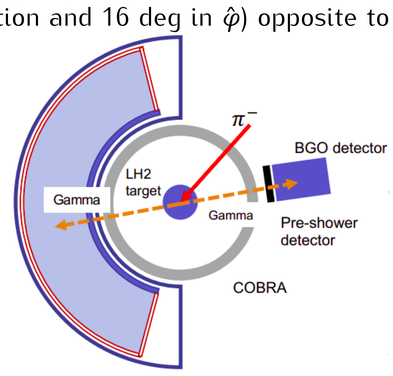
The Muon to E Gamma (MEG) experiment was designed to search for $\mu^+ \to e^+ + \gamma$ decay and completed data taking in 2013. The result achieved is the most stringent limit on this process, reaching a sensitivity of 4.2×10^{-13} [1]. MEG II aims to improve this astonishing result [2]. In the last years the apparatus underwent a number of upgrades: a thinner and more inclined target, a pixelated Timing Counter, a new (Cylindrical) Drift Chamber and many more.

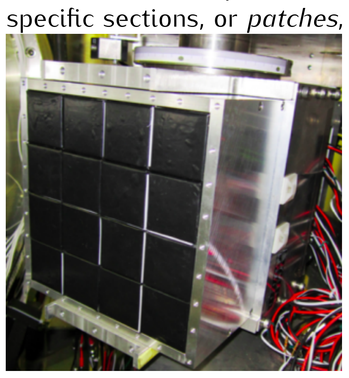
The experiment relies on the detection and precise measurement of the monochromatic γ coming from the decay and expected at 52.8 MeV. The sub-system dedicated is the 'c-shaped' Liquid Xe calorimeter, its calibration is then central for the sensitivity of the upgraded MEG II experiment. Energy, time and position resolution have to be measured and monitored for the complete analysis.



CEX calibration

To calibrate the MEG II LXe calorimeter photons of the appropriate energy are required. Using the Charge EXchange process $\pi^- + p \to \pi^0 + n$; $\pi^0 \to \gamma + \gamma$ at rest we obtain γ with a flat distribution in the interval $54.9 < E_\gamma < 82.9$ MeV. This interval is extremely interesting because starts close to the energy expected for the signal. If we want to select the lower energy γ entering the calorimeter we just need to detect the high energy γ emitted in the opposite direction. The tagging is performed with a BGO detector which can be positioned (steps of 30 cm along the $\hat{z}$ direction and 16 deg in $\hat{\varphi}$) opposite to specific sections, or *patches*, of the LXe calorimeter.





The LH2 target

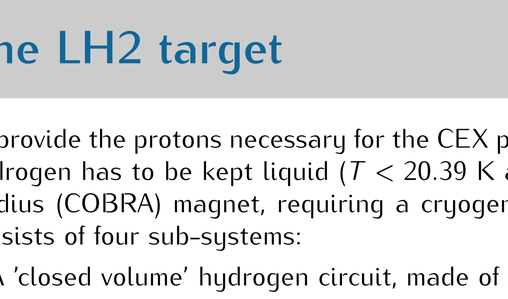
To provide the protons necessary for the CEX process a Liquid Hydrogen Target was developed. The hydrogen has to be kept liquid ($T < 20.39$ K at 1 atm) and in the centre of the COnstant Bending RAdius (COBRA) magnet, requiring a cryogenic infrastructure to be inserted for 2 m. The target consists of four sub-systems:

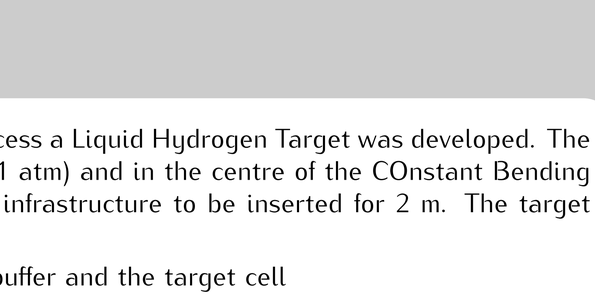
- A 'closed volume' hydrogen circuit, made of a buffer and the target cell
- A copper cold finger cooled fluxing liquid helium in a copper coil
- Vacuum Insulation
- A slow-control system based on the SCS2000

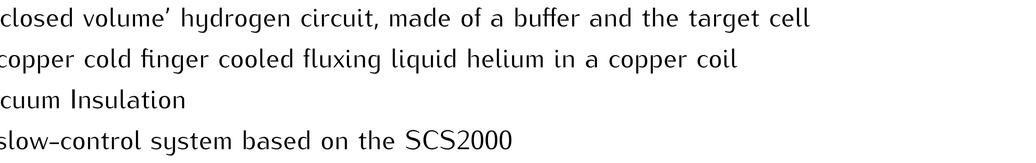
The buffer volume for the gaseous hydrogen, as well as all the infrastructure and services, are kept outside the magnet.

Working principle

The inserted section is an aluminium cylinder evacuated for thermal insulation. Inside, a copper rod is held suspended and cooled with liquid helium from the end outside the magnet. A small container is attached to the inserted end: here the hydrogen will liquefy. Cooling from the opposite end the Cu cold finger makes so the liquefaction starts later but creates a thermal buffer to increase the stability of the temperature of the cell (e.g. in case of some variations of the He flux).

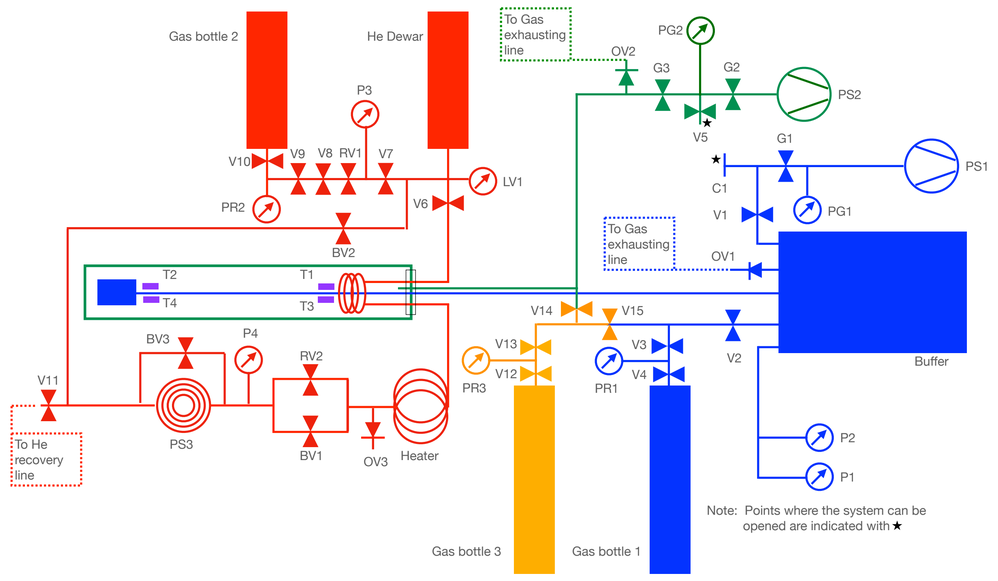






The LH2 target's circuit

Functionality and safety are key in the development of such an apparatus, more so when working with highly flammable substances. In this regard, the interplay between the MEG II collaboration and the PSI expertise helped preventing both major and minor dangers to arise. The resulting circuit has a series of safety measures (like over pressure valves and connections to the recovery lines) but is straightforward enough to allow a run-shifter to intervene if necessary. The procedures for the correct operation have been ironed out with the security committee and are well documented.



To increase the readability of the scheme of the circuit, the different sub-circuits are color coded:

- Blue - The hydrogen's buffer is filled with a bottle which is then removed. The buffer itself is connected to the cell, the exhausting line, a vacuum pump and piezoresistive pressure transmitters.
- Red - The liquid He flux is obtained pressurising a Dewar with an He bottle. The He passes around the Cu rod and through a heater. At this point it is collected in the recovery line.
- Green - The vacuum system is needed for thermal insulation and quite straightforward.
- Yellow - A nitrogen bottle is used for purging the hydrogen when emptying the buffer.

Indicators and control

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

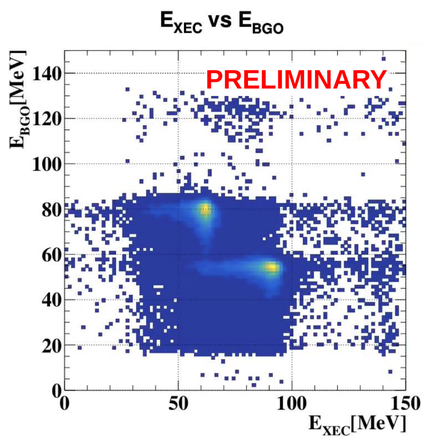
- PT100 sensors: resistor have been put in thermal contact with the Cu rod at both ends (two on each side for redundancy). The resistance of these elements decreases with the temperature, allowing to monitor the cooling new the Cu coil and the cell for liquid hydrogen. Starting at $\approx 107\ \Omega$ at room temperature, the resistance decrease until liquefaction starts, at around $\approx 2.5\ \Omega$. These are going to be replaced by Lakeshore 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 due to the change in volume. Knowing the volumes is possible to link the pressure measurement to the fraction of backer already filled.

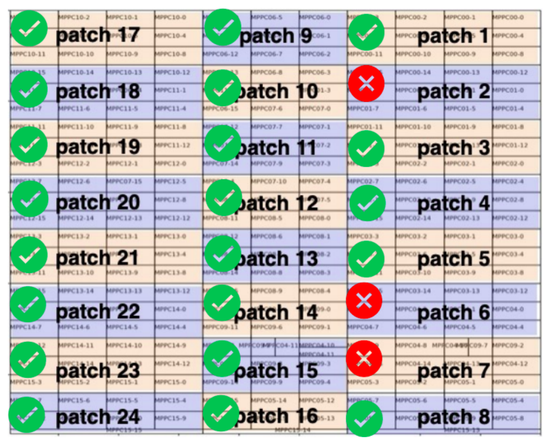
LXe resolutions

The LH2 target provides back to back γ events to measure the resolution of the LXe. The events are selected using the BGO, positioned in front of specific patches of the LXe

- The energy resolution is extracted from the spectrum after applying the necessary cuts. An example of the correlation between the LXe and BGO energy is here shown.
- The time resolution is measure taking the difference of the LXe and the 'pre-shower' time

With this new target (only partially tested) and a tight schedule we manage to collect data on 21/24 patches. The analysis is still in progress and therefore the values for the resolutions are not shown.





References

1. **Baldini, A. M. and others**, *Search for the lepton flavour violating decay $\mu^+ \to e^+\gamma$ with the full dataset of the MEG experiment*, Eur. Phys. J. C 76, 8, 434 (2016)
2. **Baldini, A. M. and others**, *The design of the MEG II experiment*, Eur. Phys. J. C 78, 5, 380 (2018)