Preliminary Design of a LH2 Target Cooling System at LBL

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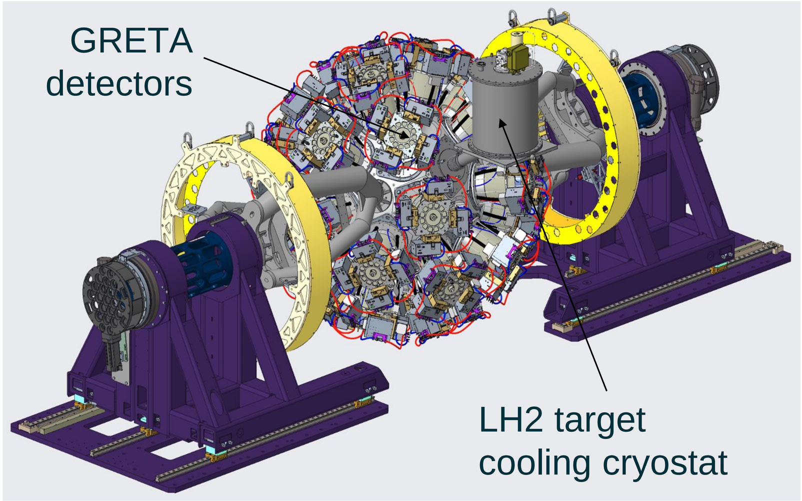
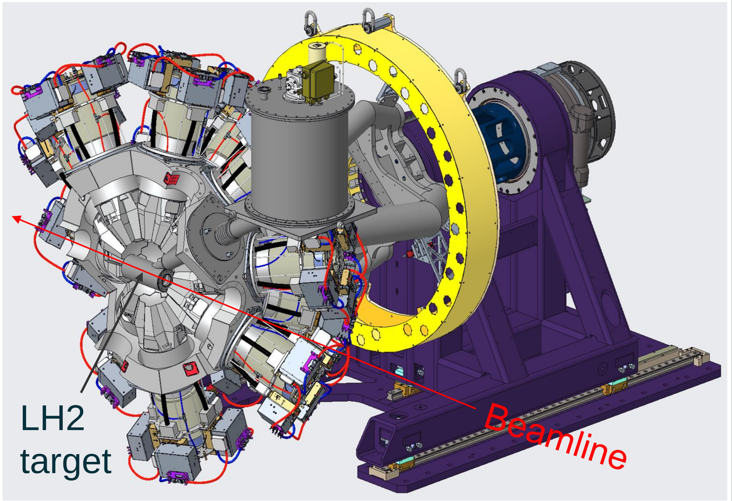
Abstract

In order to study nuclear structure at the limits of stability through a program of targeted measurements at the Facility for Rare Isotope Beams (FRIB), a thick liquid hydrogen target and vertex-tracking detector system specifically optimized to be coupled to the Gamma-Ray Energy Tracking Array (GRETA) for fast-beam measurements at FRIB is under development. The LH2 target cell and windows will be made of thin Mylar. The target thickness is 50~150 mm with an effective diameter of 50-60 mm. A cryocooler-based hydrogen cooling system is under design to cool down the target, liquefy GH2, deliver and maintain LH2 in the target. The cooling system primarily consists of a cryocooler-cooled cryostat, a GH2 and GN2 storage and handling subsystem including safety devices, as well as an instrument rack and PLC control system. The H2 is liquefied at 20 K in the cryostat by a two-stage GM cryocooler. The LH2 flows into the target through a gravity-driven thermo-syphon cooling circuit. The vaporized H2 is re-liquefied in the condenser attached to the second stage of the cold head. A 30-40 K thermal radiation shield is mounted on the first stage of the cold head to protect the 20K cold mass from 300K radiation. The safety design of the H2 cooling system has been carefully considered. This paper presents the preliminary design of the LH2 target cooling system.

Background

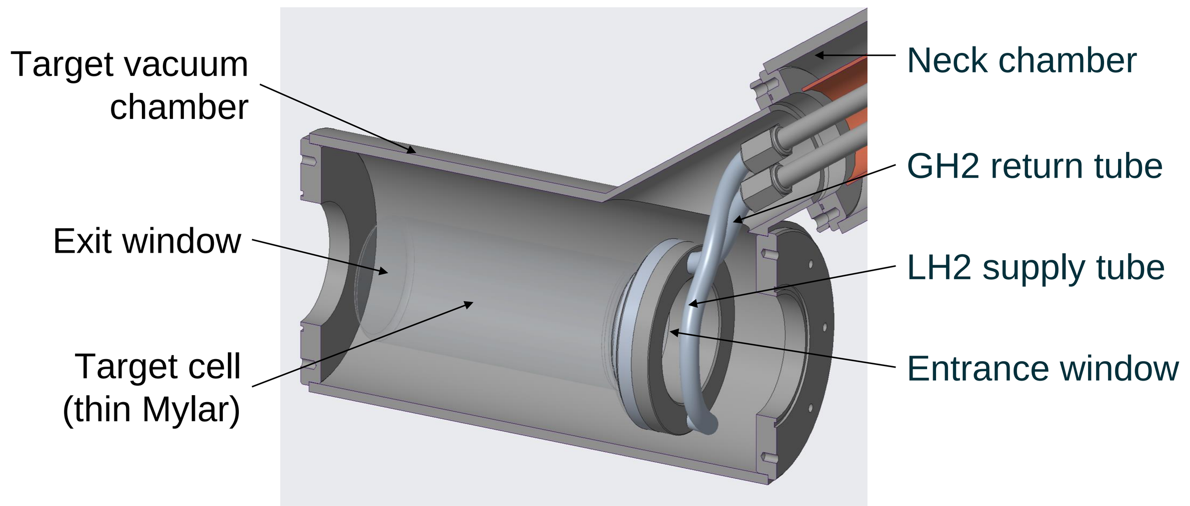
- To study nuclear structure at the limits of stability through a program of targeted measurements at the FRIB, a specifically optimized thick LH2 target and vertex-tracking detector system to be coupled to the GRETA for fast-beam measurements at FRIB is under development.
- The LH2 target cell and vertex-tracking detector system will be geometrically optimized to fit inside the GRETA array's spherical target region and provide maximal efficiency for the detection of emitted protons (Note: tracking detector is not shown).





LH2 Target Cell

- The target cell under design takes the approach adopted by the MINOS and PRESPEC systems.
- The target cell made of thin Maylar (of order 100um) is composed of two parts: an entrance window and an exit window, both glued on a stainless steel holder, which has connections to LH2 supply and GH2 return. Two aluminum rings are placed around the Mylar envelope on the stainless steel part. By contraction at low temperature, the rings strengthen the pasting against the internal pressure efforts, which could reach a maximum pressure of 1.5 bara.
- The target cell will be supported by the LH2 target cooling cryostat. Its center will be aligned with both the center of the GRETA sphere and the center of the beamline through an adjustable support system of the cooling cryostat.

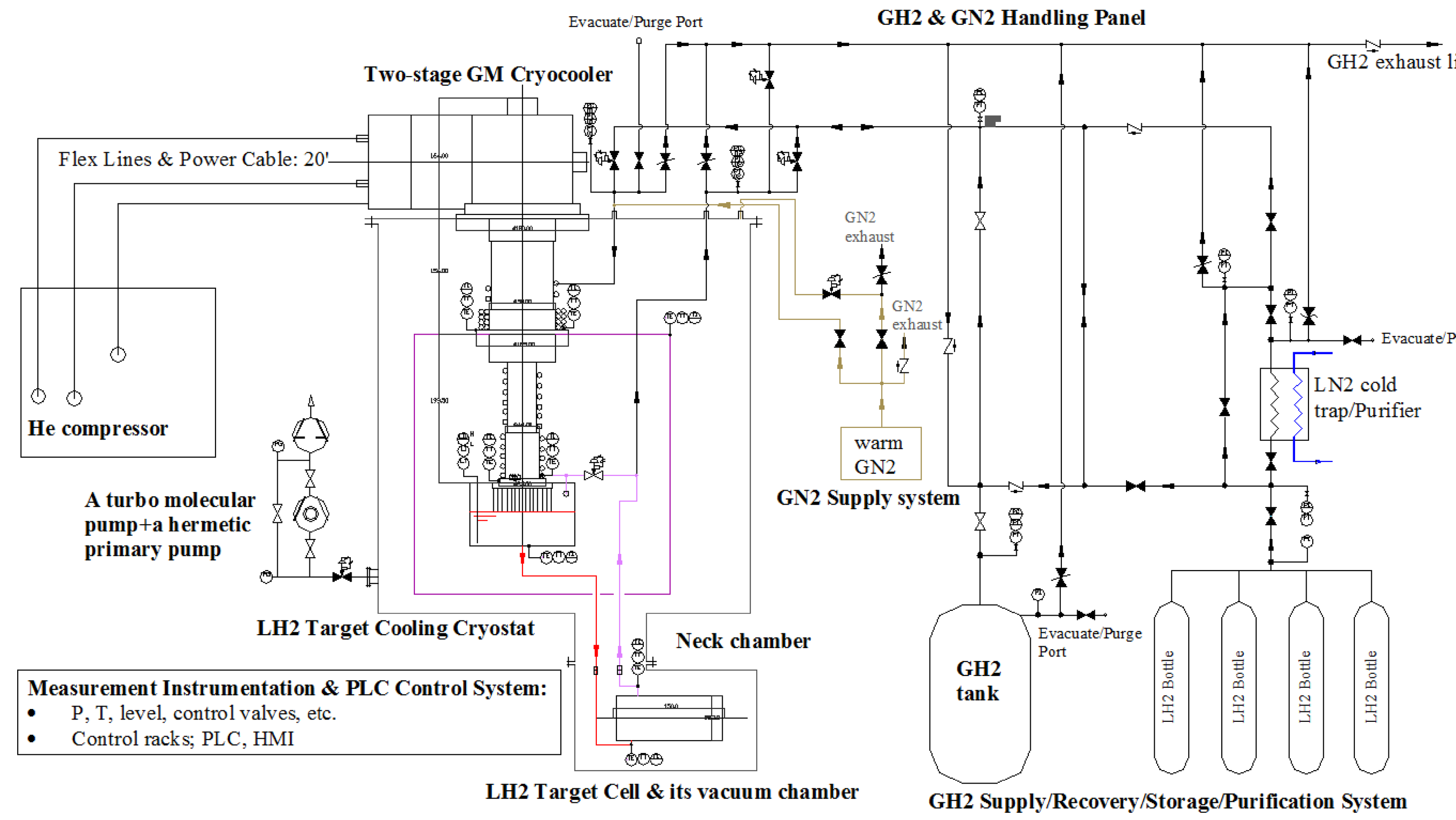


Target Cell Parameters	
Effective diameter (window, mm)	~52
Cell thickness (mm)	50~150
Max. Cell volume (ml)	~350
Operation pressure (bara)	1.05
Operation Temperature (K)	20.49

Reference: A. Obertelli et al., Eur. Phys. J. A (2014) 50: 8

LH2 Target Cooling System

- **Cooling scheme:** Cryocooler-based Hydrogen liquefier system + Zero-evaporation gravity-driven thermo-syphon flow circuit for target cell cooling



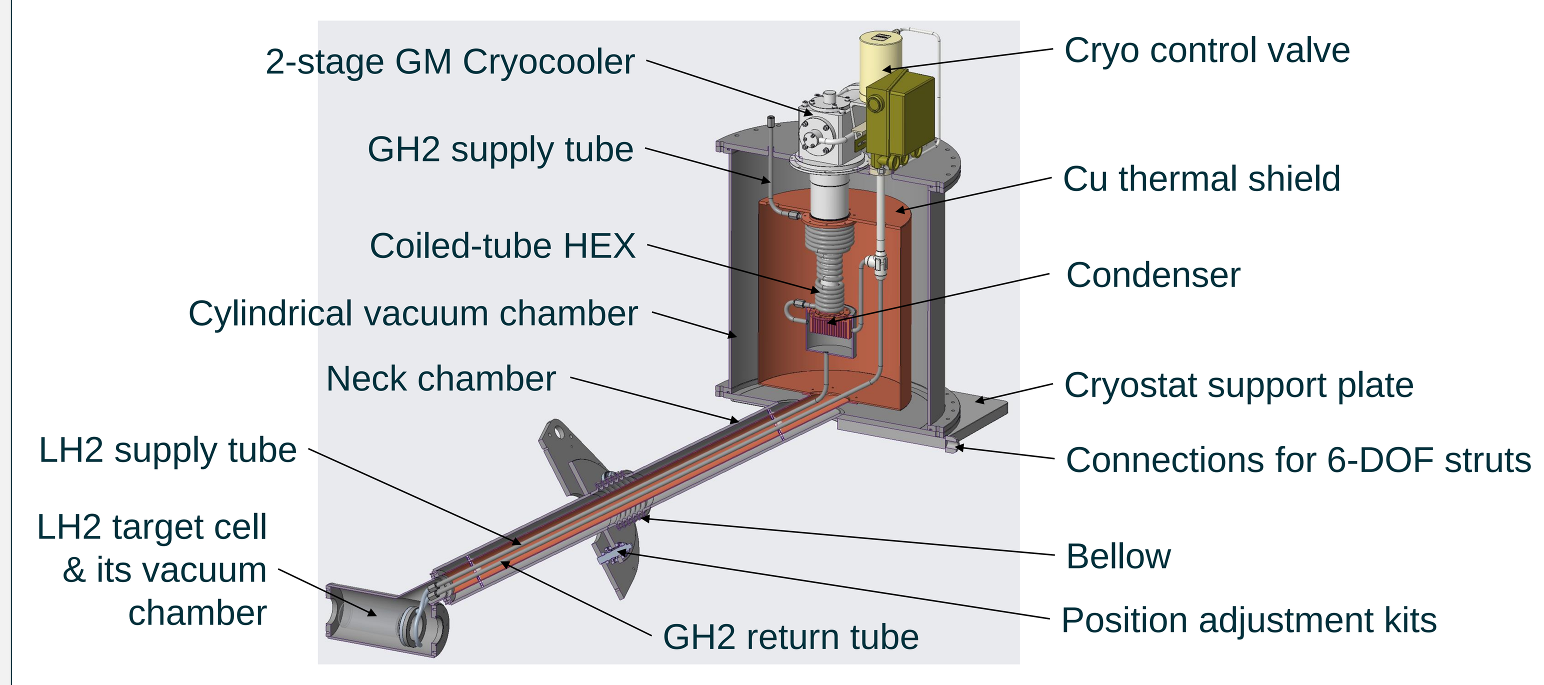
Operation Modes

- **Cool down & Liquefaction mode**: to cool down the system, liquefy GH2, and fill the target with LH2.
- **Physics operation mode (Exploitation mode)**: target cell is full of LH2 and used for experiments.
- **Empty the target for background measurement**: to allow emptying the target in a few minutes. By closing the cryo-valve, the thermosiphon process stops, and LH2 held in the target flows back to the condenser and stays there due to the lower pressure (3–5 mbar). The "empty target" is only filled with cold hydrogen vapor.
- **Stop & Warm-up mode**: to warm up the target, recover hydrogen to the storage tank, and secure the cryostat by introducing N2 or He gas. Finally, GN2 or GHe is introduced into the hydrogen circuit and the target cell at 1.1 bara to ensure a safe installation and to avoid the presence of hydrogen in the system.
- **Failure or Emergency Handling modes**: to safely recover or exhaust hydrogen, such as blockage in the hydrogen cooling circuit, target cell damage caused by solidified hydrogen, loss of vacuum in the cryostat chamber, rupture of the target cell, etc.

Safety Considerations

- The LH2 target cooling system design will ensure compliance with all safety regulations regarding the use of flammable liquids/gases. Handling hydrogen presents risks of explosion, so the system has been designed to be fail-safe and constitutes a totally closed loop with two levels of containment (cryostat vacuum vessel 300~400 ltr and storage tank ~850 ltr), and relief valves are always connected to the target to release safely the hydrogen.
- The basic concepts for the safe handling of flammable material are to eliminate oxygen and prevent exposure to any spark or energy source that could cause ignition: Avoid losing hydrogen gas to the uncontrolled area; The whole cooling system will be maintained just above atmospheric pressure to ensure no chance of oxygen entering the system; No valves that could accidentally open directly to air; All sensors and valves will be spark-proof and leak-proof; The pumps used in the system are leak-proof (hermetic).
- Avoiding over-pressure accident
  - The target cell and all other components will be thoroughly pressure-tested at both room and liquid nitrogen temperatures before use in the system, including bursting tests for cell windows.
  - Provide appropriate confined space for condensed gas to expand: emergency protection in the event of an accidental rupture of the target cell will be ensured by the secondary containment of the cryostat vacuum vessel in which the cell operates.
- Minimizing the amount of hydrogen in the system
  - The amount of LH2 in the target is ~350 liters. The target is connected to a ~850 liters storage tank via check or relief valves. The total hydrogen in the system is estimated at ~1200 liters for a 150mm target. At the end of operation, the full volume of hydrogen is transferred to the storage tank.

LH2 Target Cooling Cryostat



- The hydrogen is liquefied in the cooling cryostat using a two-stage cryocooler with a power of at least 10 W at 20K.
- The vaporized hydrogen is re-liquefied in the condenser attached to the second stage of the cold head and falls by gravity into the target through its cooling circuit.
- A thermal radiation shield at ~30K is mounted on the first stage of the cold head, which protects all cold parts at 20K from the 300K radiation.
- A turbo molecular pump in combination with a hermetic primary pump will be used to achieve a good vacuum in the cryostat.
- The cooling cryostat will be installed adjacent to the GRETA sphere. Due to the limited available space around the GRETA detectors, the challenge for the target cooling cryostat design is its installation position and the appropriate support and alignment approach of the target cell associated with it.
- Two options for the cryostat installation are under consideration:
  - ✔ Option 1, on the top of the GRETA sphere: the cryostat can be directly supported by the sphere assuming the sphere can withstand its weight, which makes alignment easier, but it may interfere with the detectors around the LH2 target.
  - ✔ Option 2, on the side of the GRETA sphere (as shown above): easily avoids interference with the detectors around the LH2 target but requires additional support near the beamline, which may lead to another interference and complicated alignment.
- For Option 2
  - The cooling cryostat vacuum chamber is composed of a main cylindrical vacuum chamber and a neck chamber. The neck chamber is divided into two parts connected using a bellow. The lower section of the neck chamber will be mounted on the sphere by replacing the specified GRETA detector and can be fine-adjusted by the position adjustment kits. The main chamber will be supported by 6-DOF struts connected to an additional support frame.
  - The neck chamber will be inserted into the center of the GRETA sphere at an angle of approximately 32° to the beamline. This design avoids interference with detectors around the LH2 target.
  - The target cell will be supported by its vacuum chamber, which is connected to the lower section of the neck chamber, and therefore its position is fixed to the GRETA sphere.

Conclusion

An LH2 target cell and a vertex-tracking detector system will be geometrically optimized to fit inside the GRETA array's spherical target region and expected to operate at FRIB. The liquid hydrogen target and its cooling system are under preliminary design at LBL. The target cell takes the approach adopted by the MINOS and PRESPEC systems. The challenge for the target cooling cryostat design is its installation position and the appropriate support and alignment approach of the target cell associated with it due to the limited available space around the GRETA detector. There are a couple of options under consideration.

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