Design of GRETA Cooling Systems

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Abstract **The Gamma-Ray Energy Tracking Array (GRETA) is a full 4π gamma-ray tracking detector capable of reconstructing the energy and three-dimensional position of gamma-ray interactions within a compact sphere of high-purity germanium crystals. GRETA will be key instrument for the Facility for Rare Isotope Beams (FRIB) with its unprecedented combination of full solid-angle coverage and high efficiency, good background rejection, and excellent energy and position resolution, and will advance the rare-isotope science at the FRIB. The GRETA Detector Array Sphere will have the capacity to accommodate a total of 30 Germanium Quad Detector Modules (QDM). The 30 QDMs are to be cooled and maintained below 100 K using liquid nitrogen (LN) at all times while the array is in normal operation, and will require regular filling of a LN Dewar on each module.The LN dewar is connected to a common cooling plate to which the detectors are attached. The Dewar is designed to allow the Quad Module to be operated in any orientation with a LN holding time of no less than 12 hours when the detector module is fully powered. An automated LN cooling and refilling system is required to supply LN to the 30 Quad Modules and ensure them maintained below 100 K. Each of the GRETA Quad Modules houses a total of 148 pre-amplifier units within the module, and with the high power consumption of each pre-amplifier, active cooling of the pre-amplifier compartment is required. In addition to the pre-amplifiers, each Quad Module will have 4 digitizer modules attached to it, which generate heat and require cooling as well. The cooling system for GRETA electronics not only removes excess heat, but also provides the required gain stabilization of the electronics systems. A closed-loop liquid (Glycol) cooling system will provide the required temperature stability and dissipate power generated heat. This paper presents design of the LN cooling system for GRETA QDMs and the closed-loop liquid cooling system for GRETA electronics including techincal requirments, design schemes, analyses of heat loads and process parameters, operation modes and so on.**

Introduction to GRETA

- **GRETA:** Gamma Ray Energy Tracking Array, a premier full 4π coverage of γ-ray tracking detector, a key instrument at FRIB capable of reconstructing the energy and three-dimensional position of γ-ray interactions within a compact sphere of high-purity germanium crystals (HPGe).
- **GRETA Cooling Systems:**
  - **Liquid nitrogen (LN) cooling system** for a total of 30 HPGe Quad Detector Modules (QDM) on two Hemispheres
  - **Closed-loop liquid (Glycol) cooling system** for Electronics (Digitizer Modules and Pre-Amplifiers) to instrument all 30 QDMs

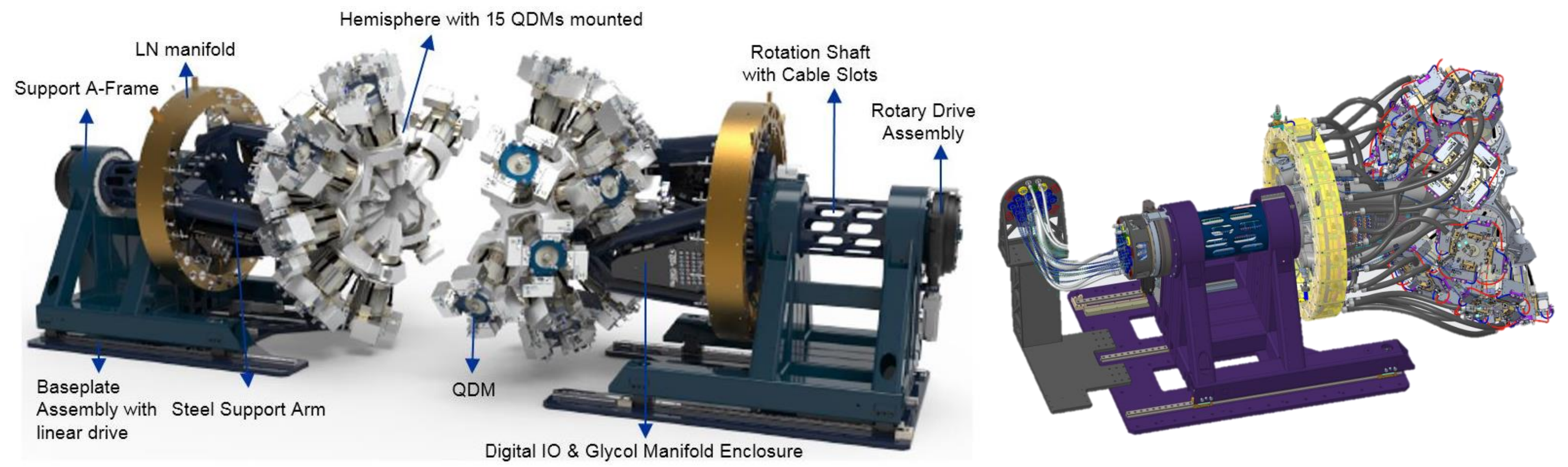


Fig.1 GRETA system with 30 Quad Detector Modules mounted on two Hemispheres

- **Technical requirements to Detector LN cooling system:**
  - The GRETA 30 HPGe detectors must be cooled and maintained below 100 K (goal is <95 K) using liquid nitrogen (LN) at all times while the array is in normal operation, and require regular filling of the detector Dewar on each module. The detector Dewar with a capacity of 3.5 liter is designed to allow the Quad Detector Module (QDM) to be operated in any orientation with a LN holding time of no less than 12 hours when the QDM is fully powered.
  - An automated LN cooling/filling system is required to supply LN to all the 30 QDMs at preset time intervals to keep the detector Dewars non-empty. It will provide fill time and temperature logs for all Quad Modules for each fill cycle. It should minimize condensation in the vicinity of the QDM due to the proximity of electrical components and signal/power cables.

- **Technical Requirements to Electronics Closed-loop liquid cooling system**
  - Each of the GRETA QDMs houses a total of 148 preamp units and 4 Digitizer Modules (DMs). The pre-amplifiers per QDM generate about 75 watts of power during operation. One Digitizer Module generate about 50 watts of power, and four DMs per QDM produce total 200 W excess heat. The four DMs on each QDM are cooled in series. Based on electronics operation and performance (gain stability) requirements, the Pre-amplifiers and DMs must be maintained at the temperature within a range of 4-35 ºC and the temperature stability within ±2ºC.
  - The liquid cooling system will serve the main function of dissipating excess heat generated by electronics components to maintain a controlled temperature environment so as to ensure gain stability of the electronics systems. The liquid flow can be automated shut-off in the event of specific error conditions. The cooling system must not introduce vibrations to the QDMs that could result in deterioration in the energy resolution performance.

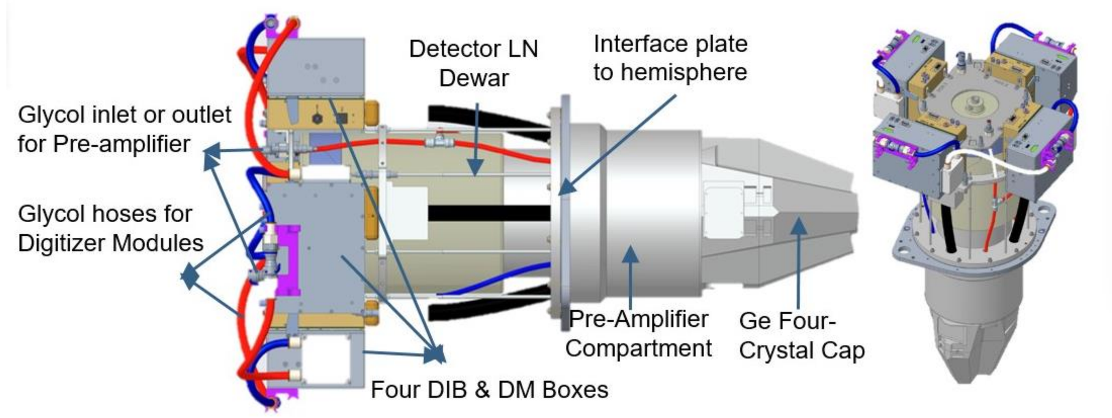
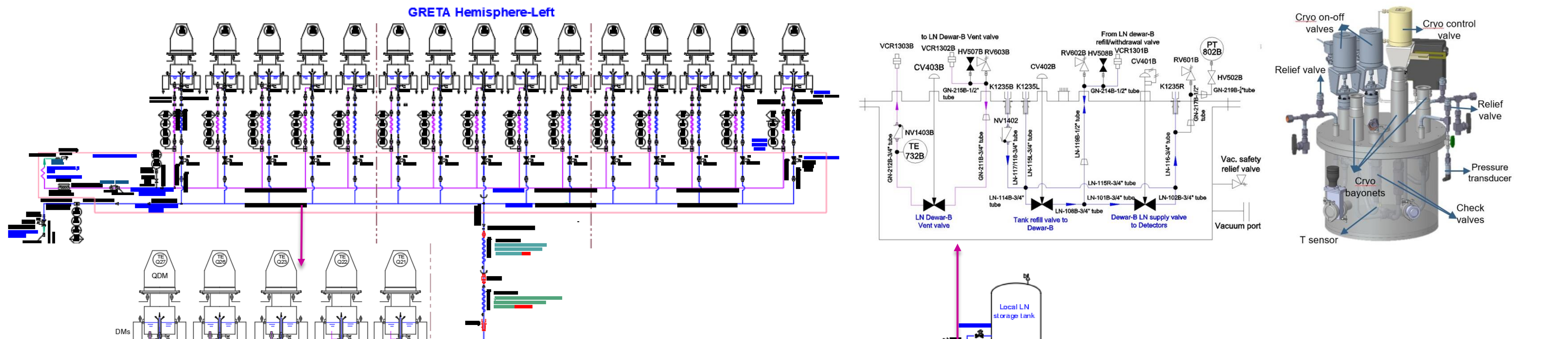


Figure 2. Side views of the GRETA Quad Detector Module

Quad Detector Module LN2 Cooling Test Platform

Design of GRETA LN Cooling System

- The whole LN cooling system consists of two identical sub-systems respectively to cool the 30 QDMs positioned on corresponding two hemispheres (Left and Right).
- Each sub-system consists of a main LN supply dewar (Dewar-L/R), a LN distribution valve box (LN DVB-L/R), an integrated LN fill-GN vent manifold with solenoid-actuated detector refill valves and manifold precool vent valves, vacuum-jacketed (VJ) transfer lines between LN DVB and the manifold, foam-insulated hoses transferring LN from the manifold to the QDMs, LN fill bayonets equipped with Cryo elec-insulators, pressure safety relief valves, and instruments such as resistive temperature sensors and pressure transducers.
- One backup LN supply dewar (Dewar-B) with an associated distribution valve box (LN DVB-B) is used to supply LN to the QDMs in case that any of the two main LN2 supply dewars fails.
- A Cryofab LN swivel fitting is assembled at the interface between the main vacuum-jacketed line routing from the LN DVB to the entrance of the rotation shaft of the support frame and the 1/2" VJ flexible line going through the shaft to the manifold. The swivel fitting is employed to realize the rotation of the 1/2" VJ flexible line together with the manifold and the hemisphere.



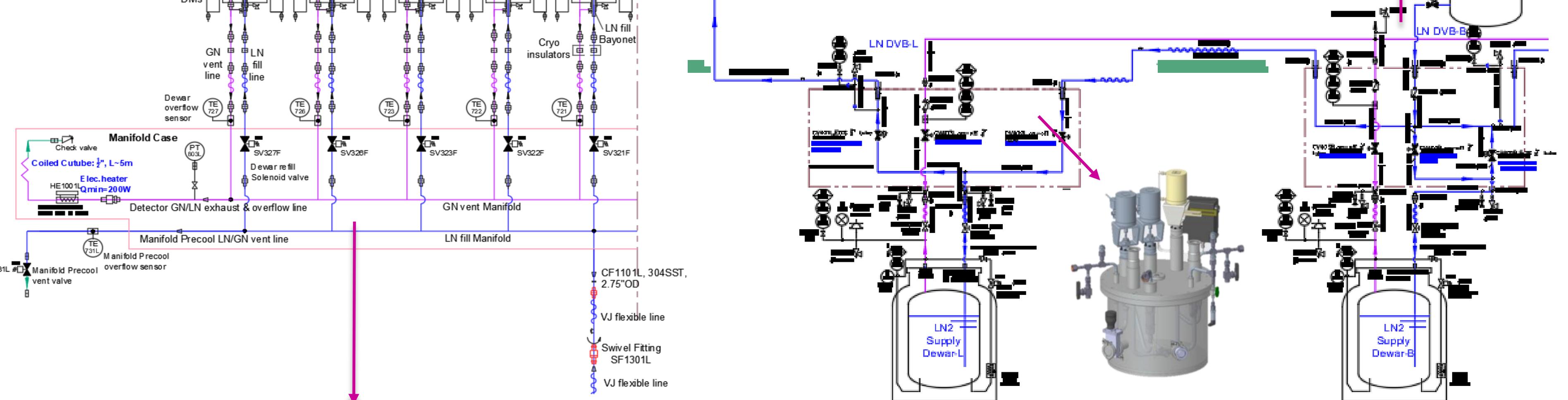


Figure 3. Flow diagram of GRETA LN cooling system (one hemisphere)

Backup LN dewar

- **Operating modes** including cool down, detector normal operation, detector fill cycle, supply dewar fill cycle, warm up and so on.
- **Detector normal operation**: no LN flows through the system, and the LN system is kept at room temperature except for the GN exhaust line enclosed in the LN manifold case. The LN contained in the 3.5L Dewar on each QDM keeps it working at < 100 K.
- **Detector fill cycle:**
  - **Pre-cooling** the insulated LN transfer line from LN supply dewar to LN fill manifold and the fill manifolds itself, until liquid is sensed by precool overflow sensor located downstream of the precool vent valve.
  - After the fill manifold get cold, individual Detector refill valves to the detectors open and allow LN to enter the Detector Dewars. Exhaust gas or overflowing LN flows through exhaust hoses to manifold case, passing through Detector overflow sensors that are used to sense when the Detector Dewars are full.
  - **The LN refill to the QDMs is executed group-by-group in series**. The 15 detector modules on one hemisphere will be divided into 3 groups and are filled group by group. The first 5 detector modules are filled at the same time. The first 5 detector refill valves are opened and then each valve is closed when liquid is sensed at the detector overflow. As soon as one valve is closed, another is opened until the end of the cycle.
  - The LN supply dewars will be refilled by the local LN storage tank following the detector refill cycle.
- The LN filling interval will be set every 8 hrs. The fill time for a detector dewar is to be between 5~10 mins according to the GRETINA operation. The LN cooling system will supply LN at a flow rate of 1.5 ~ 3 l/min from the supply dewar to LN manifold. The total LN2 consumption for the QDMs on one hemisphere and its cooling system is between 75~85 liter plus precool usage ~50 ltr at every 8 hrs.
- During Detector LN fill cycle, the calculated pressure drop along the LN transfer system is around ~10.0 psi, and so the working pressure of the LN2 supply dewar is set at about 10~15 psi in order to ensure the pressure of the LN entering the QDM dewar is lower than 0.4 kg/cm2 (maximum allowable pressure in the detector dewar).
- The operating pressure of the LN2 supply dewar can be regulated between 10~35 psi.

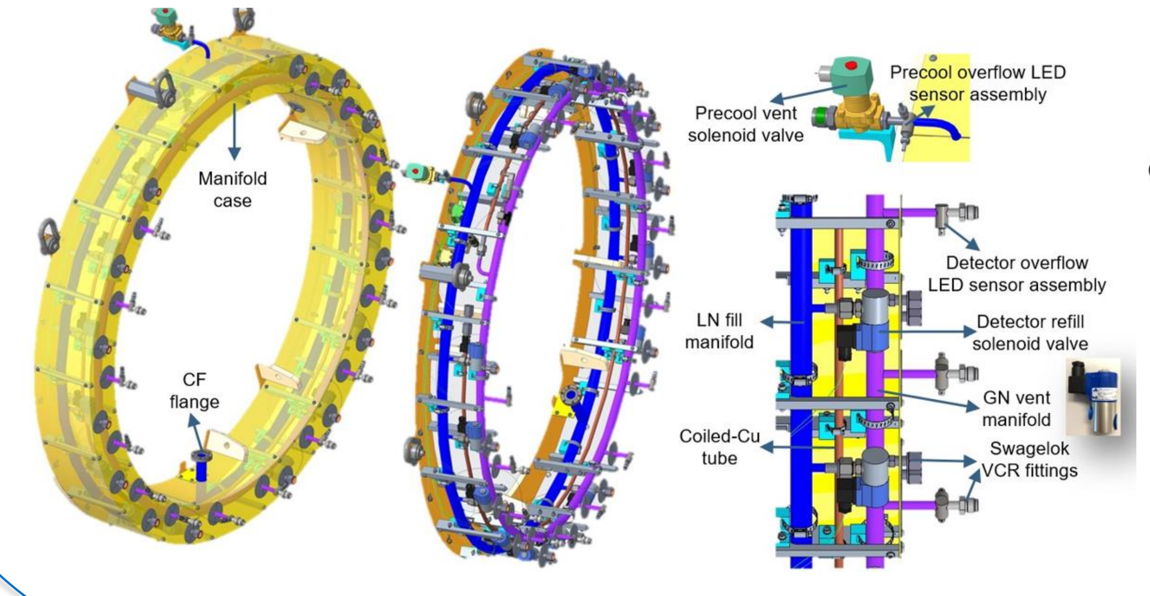


Figure 5. 3D models of LN fill and GN vent manifolds

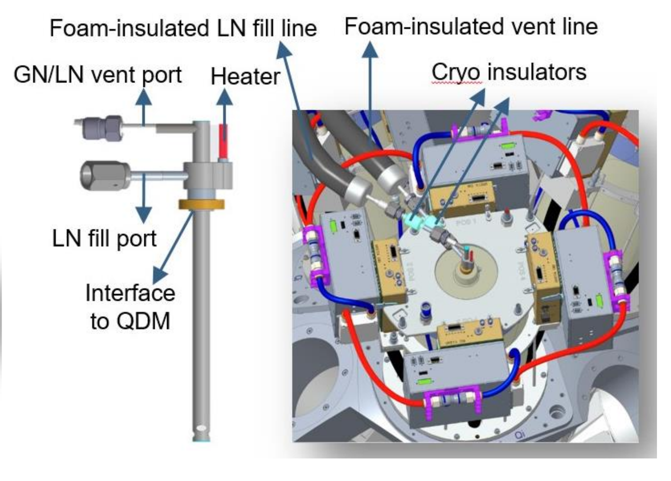
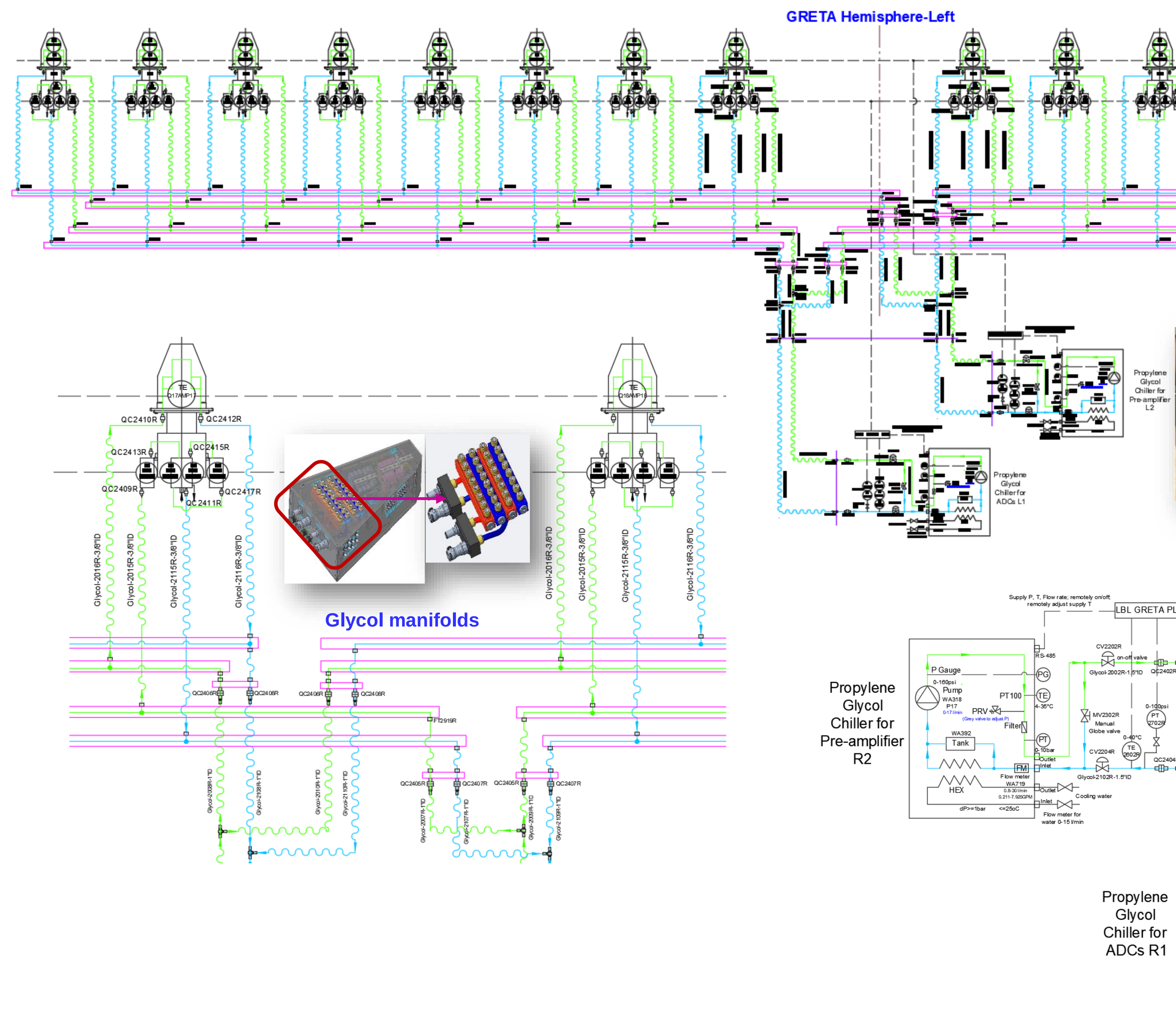


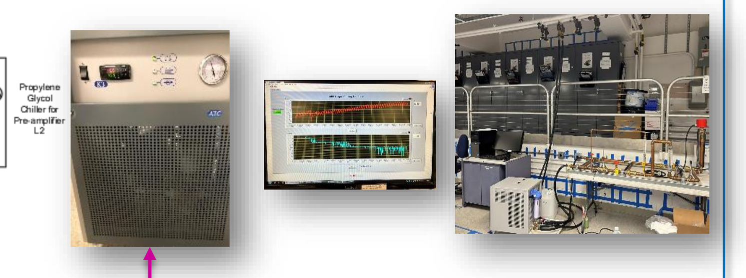
Figure 6. LN fill bayonets

Design of Closed-loop Liquid Cooling System

- The GRETA closed loop liquid cooling system is divided into two identical independent sub-systems to serve all the 30 detector electronics on two hemisphere, similar as the LN cooling system.
- Each sub-system is further divided into two separate cooling circuits for the preamplifier compartments and Digitizer Modules on one hemisphere.
- In order to maintain the same temperature on each QDM electronics as possible, parallel cooling flow circuits are used.
- The four closed-loop cooling circuits consist of a dedicated re-circulating chiller unit which cools the circulating coolant (pure propylene glycol), Glycol supply and return distribution manifolds, and the associated hardware including tubing, hoses, valves, double-end quick-disconnect couplings, tube fittings, and instruments.
- 8 closed-loop manifolds on a hemisphere, 2 supply and 2 return manifolds for the Pre-amplifier housing, and 2-supply and 2-return manifolds for the DMs.



Glycol manifolds



Glycol Chiller Test Platform

Conclusion and Future Work

- Design of the cooling systems are being completed except the LN transfer lines routing from supply dewars to manifolds.
- Approx. 95% of components were procured and delivered to LBL, and key components such as LN/GN manifolds, LN DVBs, LN fill bayonets are in fabrication and progressing well.
- The GRETA Cooling Systems are on track to deliver all hardware at the schedule time for System Assembly to start.

Glycol Chillers

- The 4 ATC chillers are water-cooled and compatible with pure propylene glycol. The coolant is maintained at a working temperature adjustable in the range of 4ºC to 35ºC, with a temperature stability of ±0.1ºC.
- The required cooling capacity is determined respectively by the excess heats generated by electronics, with a capacity of 1.75 kW for Pre-amplifiers and 3.2 kW for DMs.
- The ATC chillers are low vibration and low noise (e.g. turbine pump units) in order to maintain a smooth flow and minimize potential for vibration which may be transferred to the Quad Detector Modules.