Operating Manual
for Nevis LHe Electron Bubble
Chamber Cryostat

Version 4

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1. SYSTEM DESCRIPTION

This Operating Manual gives the procedures to be followed for operations of the Nevis Liquid Helium Electron Bubble Chamber System (LHe e-Bubble Chamber), with explanation of the LHe/LN\textsubscript{2} Cryostat involved. The procedures set forth here are required for the safety of the system and of the operators, as well as for the quality of the results to be obtained. All participants in the operations must study the Operating Manual and pass an exam showing that they have read and understood the version that is authorized at that time. The Log Book for the operations must indicate which version that is being followed at the time, who is in charge of the operations at any given time (chief), and who else is assisting. All significant conditions in the system and changes must be noted in the Log Book.

The LHe e-Bubble Chamber system consists of these sub-systems:

- The LHe e-Bubble Test Chamber
- The LHe/LN\textsubscript{2} Cryostat
- The LHe Dewar and LN\textsubscript{2} Dewar
- The Helium gas bottle and control
- The vacuum pumping stations and pumping lines
- The pressure gauges, vacuum gauges and flow meter
- The temperature sensors and heaters
- The high and low voltage (cable and feedthrough) sub-systems
- The electrode structures and radioactive sources
- The electronic readout system
- The optical measurement sub-systems
- The safety subsystems (oxygen monitor, relief valves, etc.)

The objective of this project is to study, design and develop a new electron-bubble particle detector, using cryogenic liquid as the detecting medium, for the detection of low-energy particle tracks, such as neutrinos from the Sun, accelerator facilities and nuclear reactors. The test device will also be used for research on new detectors for the next generation of colliding-beam facilities, at a later time. The purpose of this system is to find the parameters that allow the high spatial resolution on track segments better than 30~50 microns and allow the determination of the feasibility of constructing a modest-size tracking chamber that in turn would lead to a study for a large detector for neutrinos and other applications.

The reasons of selection of Liquid Helium (or Neon) as working medium are as follows

- The negative charge charier in liquid helium is not a free electron, but an electron localized in a vacuum-filled bubble of diameter 1~2 nm, “e-Bubble”, which are free to move through the liquid helium under an external electrical field at a constant drift speed proportional to the electrical field. The information derived from a plane furnished with an array of charged detectors allows a three dimensional image of the track to be formed.
- The mobility of the electron bubble in an electrical field is about $10^{-2} \sim 10^{-3} \text{cm}^2/\text{(Vs)}$ in liquid helium, and the natural drift velocity of these bubbles in a practical drift field is about $1\text{cm/s}\sim 1\text{m/s}$. This gives naturally a range of readout cycle times long enough to minimize the cost and complexity of the electronics required.
• The long drift time allows to make maximal use of multiplexing of the readout to transform the huge amount of data inherent in three-dimensional imaging of a large volume with high resolution into a relatively small number of output signal lines each carrying a high rate of data flow.

• E-Bubble has several resonant absorption lines in the infrared, could be used for imaging.

• The thermal diffusion of the individual e-Bubble decreased at low temperature. This is in contrast to the case of free electron charge carriers in noble liquids, where the electron temperature is much higher than the ambient temperature, resulting in a serious limitation on the drift distance allowed for a given spatial resolution. This implies that one can achieve better performance at liquid helium temperatures.

• The requirement of high spatial and energy resolution is easily met by working in low-density detecting medium, with minimum diffusion. Helium has low density and requires more volume for a given mass but has the advantage of spreading out the signal in space, leading to measurable track lengths for very low energy particles.

• Liquid helium is of high purity, with essentially no other substances with an appreciable solubility in such low temperature liquid and consequently no risk of capture of the electrons, even with a long drift path. This means there is also no source of radioactive decay in the body of liquid helium.

• Helium has a radiation length of about seven meters; this combined with high spatial resolution, allows magnetic measurement of sign and momentum with a very modest magnetic field, as low as 0.1T.

• The liquid-vapor interface holds electrons for a time depending on temperature and electrical field, and can be used for optical gating of signals. Electrons trapped in the bubbles can be released from this trap either by photo-ionization by a visible or infrared light pulse, or thermally into the vapor phase, where it proceeds to drift with the normal mobility of the gas (the mobility is of $10^2$-$10^3 \text{ cm}^2/\text{Vs}$). The threshold for this process corresponds to relatively low photon energy, on the order of 1eV for liquid helium.

In summary, the physical properties of the electron state in liquid helium are uniquely well suited for high spatial and energy resolution, good performance at very low energies, in a very large volume with the lowest possible background rates, for the detection of low-energy particle tracks. These promise important benefits for the measurement of neutrinos form the Sun and accelerator facilities in a wide of energies.

The LHe e-Bubble Chamber system primarily consists of the LHe e-Bubble Test Chamber and the LHe/LN$_2$ Cryostat, as shown in Figure 1. The LHe/LN$_2$ Cryostat provides a 4.2K environment, which contains the LHe Test Chamber and provides the helium vapor cooling (2.2~4.2K) to the Test Chamber. The LHe/LN$_2$ Cryostat mainly includes the vacuum chamber, the liquid helium service vessel and the liquid nitrogen service vessel, which are disassembled to get access to the e-Bubble Test Chamber.

Two radiation heat shields (80K and 4.2K) are thermally attached to the liquid nitrogen and the liquid helium service vessels, respectively. The cryostat has two optical windows at the sides and one at the bottom of the vacuum chamber and each heat shield. The volumes are about 45 liters for LHe vessel and 41 liters for LN$_2$ vessel. The minimum interval between LHe and LN$_2$ refills is about 3 days. The overall dimensions of the e-Bubble chamber are shown in Figure 1 and Figure 2.

The Test Chamber is a double walled LHe vessel and its inner volume is about 1.5 liters. Two copper cooling loops for the helium vapor-cooling circuits are welded on the flanges of the Test Chamber. A needle valve in the Cryostat is used to supply and control the flow rate in the helium vapor-cooling circuits. The Test Chamber is designed to stand an internal pressure of 10bar. All relief devices for the Cryostat and Test Chamber are located at the top flange of the LHe/LN$_2$ Cryostat.
The Test Chamber contains a plastic frame with high voltage poles (10kV). There are 10 high voltage cables (10kV each with negligible current) inserted from the bottom flange of the Test Chamber. Each SS conductor wire is electrically insulated by Teflon coating sleeve of 3mm in outside diameter. There are four low voltage ports on the top flange of the Test Chamber.

1. **LHe service vessel** (LHe volume: 45 liters)
2. **4K heat shield** (Demountable connection and good thermal contact with LHe vessel)
3. **LN\textsubscript{2} service vessel** (LN\textsubscript{2} volume: 41 liters)
4. **77K heat shield** (Demountable connection and good thermal contact with LN\textsubscript{2} vessel)
5. **Needle valve**
   The needle valve is used to control the helium flow rate of the helium vapor-cooling circuit. The helium from the LHe service vessel, controlled by the needle valve, flows into the annular space of the test chamber. At the warm end of the cooling tubing the helium gas is pumped out. The pumping tube to the Test Chamber has a VCR fitting connection and its diameter is 3/8 inch. The size of the cooling tube on the Test Chamber is 1/4 inch in diameter. The pumping rate should be capable to keep the temperature of helium in the annular space of the Test Chamber between 2.2K and 4.2K.
6. **Windows** (Spectrosil WF, attached with the 4K heat shield, 80K heat shield, and vacuum chamber)
7. **Vacuum chamber** (Demountable flange connected at the lower half section)
8. **Ports**
   8.1 **Access ports on the top flange**
      a. Nitrogen fill and vent ports (quantity: 3)
      b. Helium vessel fill and vent ports with 4 psi pressure relief valve (2)
      c. Central tube fill/vent port with 30 psi pressure relief, compound pressure gauge and ball valve (1)
      d. Vapor cooling circuit pumping port with 4 psi pressure relief valve (2)
      e. High voltage feedthrough ports (5)
      f. 19 pin electrical feedthrough port (1) with 4 psi pressure relief valve
      g. 8 pin electrical feedthrough port (1)
      h. LHe liquid level meter ports (1)
      i. Helium needle valve operator (1)
      j. Evacuation valve with NW-25 flange with compound pressure/vacuum gauge and ball valve (1)
      k. Helium vessel pumping port with NW-25 flange
   8.2 **Access ports on the sides of the vacuum chamber**
      A. 19 pin electrical feedthrough ports for temperature sensor (3)
      B. Low voltage feedthrough ports (4)
9. **High voltage cable and feed-through**
   There are 10 high voltage cables (10 kV for each with negligible current) from the bottom flange of the Test Chamber, which need thermal interception at 4.2K and 77K levels. Each conductor wire is electrically insulated by Teflon coating sleeve of 3 mm in outside diameter. The high voltage cable will be provided to the vendor for pre-installation along the outer surfaces of the LHe vessel and LN\textsubscript{2} vessel. The feedthrough ports at the top flange of the Cryostat should use the Conflate flange connections with reference diameter of 2.75 inches.
10. **Low voltage cable and feed-through**
    There are 4 low voltage feedthrough ports (4x8 pins) on the side of the vacuum chamber, see Figure 1. The ports use the Conflate flange connections with reference diameter of 1.33 inches.
Figure 1 Schematic diagram of liquid helium e-Bubble chamber cryostat
Figure 2 Schematic diagram and photo of liquid helium e-Bubble chamber
2. SAFETY SUMMARY

The aim of the safety regulations is to prevent accidents. The most important concern is proper training, so that everyone who is involved in operating the equipment knows what each element of the equipment is and how it works, and what the hazards are and how they can be avoided. This includes knowing the rules that are in place. Always avoid short cuts that save time and effect at the cost of increased risk.

Another element of the safety strategy is to have a physical design that avoids hazards. For example, all high voltage connections should be enclosed so that they are inaccessible, pressure relief systems are provided, etc. We avoid the use of flammable or toxic substances and limit the amount of radioactive materials to within the controlled limit.

- Never work alone
- Training. Everyone touching the equipment must have passed the training for the equipment. This operating manual must be studied by each potential operator. A test on it must be passed before an operator is qualified. Operators must be qualified for the current version. If there are substantial changes, a new version will be released, and all operators must re-qualify
- Consensus. If there is a disagreement within the operating team on safety, the work must stop, and a group of responsible Nevis physicists should consider the concern before continuing
- Log Book. There will be a Log Book for operating the e-Bubble Test Chamber System. An operating session must start with the Chief Operator signing in, writing the name of the necessary second operator, and recording the date. All significant operating steps should be entered in the Log Book
- All significant conditions in the system and changes must be noted in the Log Book
- Do not temper with any pressure relief
- Exercise caution when handling nitrogen and liquid helium. Wear insulating gloves and avoid splashing liquid on clothing
- Do not exert any lateral forces on the Dewar tails as misalignment of the tails and possible thermal shorts may result
3. PUMPING SYSTEMS

- **Figure 3:** Top flange arrangements of liquid helium cryostat
- **Figure 4:** Flow diagram of cryostat and its liquid filling lines (LHe, LN$_2$ Dewar and Gas helium bottle)
- **Figure 5:** Flow panel of cryostat and its vacuum pumping lines

- **Turbo-pump:** Turbo-Molecular Pumping Station (PFIEFFER VACUUM TSU071) with a vacuum valve (NW-40) and two vacuum gauges (Ionization and Convect)

- **Mechanical pump:** Mechanical Rotary Vane Pump (ALCATEL 2021SD) with a vacuum valve (NW-25), a vacuum gauge (Thermocouple) and a compound vacuum/pressure gauge (30" Hg, 0-30 psig)

- **Control Panel:** there are four separate pumping lines with several ball manual valves mounted on the control panel. No.1 is used for LHe vessel evacuation, No.2 is used for the central tube evacuation, No.3 and No.4 are used for the two vapor cooling circuit pumping ports. They can be operated separately or work together depending on experimental requirements

- **Flexible coupling and Copper loops:** with NW-25 flange ports at its two ends

Figure 3 Top flange arrangements of liquid helium cryostat
4. OPERATING PROCEDURES

(STEP 1) BEFORE START

- Make sure all valves (vacuum, ball, globe) except ball vale 16 on the LHe Dewar closed and all relief valves installed on the LHe Dewar, LN₂ Dewar, Pumping port and Cryostat
- Do not open any valves if there is a below 0 pressure being shown on the pressure gauge on the LHe Dewar and LN₂ Dewar. This would allow air to rush into the Dewar and form an ice plug
- Be sure to wear safety glasses and insulated gloves in handling of liquid helium and nitrogen

(STEP 2) EVACUATION OF LHe/LN₂ CRYOSTAT VACUUM JACKET

- Connect the turbo-pump to the evacuation port (I) extending from the Cryostat
- Open vacuum valve 101, plug in the turbo-pump, evacuate the flexible coupling for seconds
- Open evacuation valve 103, evacuate the cryostat vacuum jacket until the pressure at the pump drops to 1×10⁻⁵ torr or less (it is recommended to evacuate the system overnight before operating)
- Close firmly evacuation valve 103
- Unplug the turbo-pump and close vacuum valve 101
- Re-evacuation is required when cryogen hold times begin to decrease or condensation becomes noticeable on the lower vacuum jacket during operation
- Do not introduce cryogen into the chamber with the evacuation valve open. This may cause cryopumping of vacuum pump oils into the cryostat vacuum Jacket

(STEP 3) PUMP/PURGE CENTRAL TUBE AND e-BUBBLE CHAMBER

- Connect the helium gas transfer line to the port of needle valve 11 on the gHe bottle
- Connect the other end of the helium gas transfer line to the connector of ball valve 9
- With the cryostat at room temperature, open ball valve 1 on the control panel, this connect the mechanical pump to the central tube vent port (e)
- Plug in mechanical pump, evacuate pumping line for seconds
- Open ball valve 7 and ball valve 9, evacuate the central tube, e-Bubble chamber and helium gas transfer line until pressure drops to below 1 torr
- Close ball valve 7 and 1, and unplug the mechanical pump
- Open globe valves 13 and set regulator valve 12 at 15 psi
- Open needle valve 11 and ball valve 9, break the vacuum back with helium gas from gHe bottle
- After 30 seconds, close ball valve 9, the central tube is now pressurized (15 psi)
- Open ball valve 8, release helium gas out of central tube, be sure the pressure is slightly higher than the atmosphere pressure (check the pressure gauge on the top of central tube)
- Close ball valve 8
- Repeat the above pump and purge procedures 2~3 times as central tube and e-Bubble chamber filled with pressurized pure helium gas (15 psi)
- Close ball valve 7, 8 and 9
- Close globe valves 13, regulator valve 12 and needle valve 11
- Disconnect and remove the helium gas transfer line from the connector of ball valve 9
- Keep the helium gas transfer line on the port of needle valve 11 of the gHe bottle
(STEP 4) PUMP/PURGE LHe VESSEL

- Connect the helium gas transfer line to the connector of ball valve 10
- Open ball valve 2 on the control panel, this connects the mechanical pump to the LHe vessel pumping port (m)
- Plug in mechanical pump, evacuate pumping line for seconds
- Open ball valve 104 and 10, evacuate helium gas transfer line and LHe vessel for several minutes to remove any air or moisture
- Open the helium needle valve (k), evacuate the path through the needle valve, capillary tube and cooling circuit loops
- Close ball valves 104 and 2, and unplug the mechanical pump
- Open globe valves 13 and set regulator valve 12 (on the gHe bottle) at 4 psi
- Open needle valve 11, break the vacuum back with helium gas from gHe bottle
- After 30 seconds, close the helium needle valve (k)
- Close ball valve 10, LHe vessel is now pressurized (4 psi)
- Close globe valves 13, regulator valve 12 and needle valve 11
- Keep the helium gas transfer line on the connector of ball valve 10
- Never evacuate the LHe vessel unless the cryostat vacuum jacket has been previously evacuated, collapse of the LHe vessel wall may occur
- Be sure to seal all helium fill/vent ports on the LHe vessel after removing the vacuum pump, to prevent air and moisture from entering the vessel

(STEP 5) PRECOOLING LHe VESSEL WITH LN

- Connect a Teflon transfer hose to connector 19 on the LN Dewar
- Insert the other end of the Teflon transfer hose though the helium fill port (c1) into LHe vessel until it reaches the bottom
- Open globe valve 20 on the LN Dewar, this valve can be adjusted to obtain the proper liquid flow rate
- Open the helium vent port (c2), Liquid nitrogen will be transferred into the LHe vessel directly from the pressurized LN Dewar, while venting out through the helium vent port (c2)
- During this cool down, open occasionally the helium needle valve (k) approximately one turn, let liquid nitrogen entering the needle valve, capillary tube, and cooling circuit loops. This procedure also prevents the needle valve from freezing shut as it is being cooled along with the rest of the LHe vessel
- Check temperature sensors (T1 and T3)
- Approximately 4~5 liters of liquid nitrogen is sufficient to precool LHe vessel
- When the liquid nitrogen transfer is complete, close globe valve 20 on the LN Dewar
- Remove the Teflon transfer hose from helium fill port (c1) on the LHe vessel
- Seal helium fill/vent ports (c1 and c2) to prevent air and moisture from entering LHe vessel, while venting though the relief valves installed on them
- Keep the Teflon transfer hose on the connector 19 of the LN Dewar

(STEP 6) LIQUID NITROGEN FILLING TO LN VESSEL

- Insert the Teflon transfer hose though one of the Nitrogen fill/vent tubes (a) into LN Dewar until it reaches the bottom
- Open globe valve 20 on the LN Dewar, this valve can be adjusted to obtain the proper liquid flow rate
• **Liquid nitrogen** will be transferred into the **LN\(_2\) vessel** directly from the pressurized **LN\(_2\) Dewar**, while venting through the other **Nitrogen fill/vent tubes (a)**
• Check temperature sensors (T10 and T11)
• Approximately 40~45 liters of LN\(_2\) is needed for this cool-down and fill
• When the **liquid nitrogen** transfer is complete, close **globe valve 20** on the **LN\(_2\) Dewar**
• Remove the **Teflon transfer hose** from **Nitrogen fill/vent tubes (a)** on the **LN\(_2\) vessel**
• Remove the **Teflon transfer hose** from connector 19 on **LN\(_2\) Dewar**

**(STEP 7) REMOVE LN\(_2\) FROM LHe VESSEL**
• Check temperature sensors (T1, T3, T4, T5 and T6), allow **liquid nitrogen** to completely cool **LHe vessel** and e-Bubble chamber to liquid nitrogen temperature (several hours)
• Insert a **Teflon tube** though the **helium fill port (c1)** into **LHe vessel** until it reaches the bottom
• Open **globe valves 13** and set **regulator valve 12** (on the gHe bottle) at 4 psi
• Open **needle valve 11** and **ball valve 10**
• Admit warm gas helium from **gHe bottle** into the **LHe vessel** by over-pressuring it
• All vent ports or pressure relief valves should be sealed to allow pressurization (4 psi)
• Liquid helium will start flowing out of this tube once the **LHe vessel** is pressurized
• Continue this process for about 5 minutes after it appears that no LN\(_2\) is flowing out off this **Teflon tube**
• Note that solid nitrogen has a very large heat capacity (an order of magnitude greater than copper), so even an inch left at bottom of the vessel will require large amounts of liquid helium to cool them to 4.2K
• During this process, check temperature sensor T1 until it is higher than 100K
• Remove the **Teflon tube** out off the **LHe vessel** and seal the **helium fill port (c1)**
• Close **ball valve 10**
• Close **globe valves 13, regulator valve 12** and **needle valve 11**
• Keep the **helium gas transfer line** on the **connector** of **ball valve 10**
• Keep the **helium gas transfer line** on the port of **needle valve 11** of the **gHe bottle**

**(STEP 8) PUMP/PURGE LHe VESSEL**
• Open **ball valve 2** on the control panel, this connects the **mechanical pump** to the **LHe vessel pumping port (m)**
• Plug in **mechanical pump**, evacuate **pumping line** for seconds
• Open **ball valve 104**, evacuate the **LHe vessel** for several minutes to remove final traces of LN\(_2\)
• Open **helium needle valve (k)**, evacuate the path through the **needle valve, capillary tube** and **cooling circuit loops**
• Once the pressure reached a minimum, close **ball valve 104** and **2**
• Unplug the **mechanical pump**
• Open **globe valves 13** and set **regulator valve 12** (on the gHe bottle) at 4 psi
• Open **needle valve 11** and **ball valve 10**, break the vacuum back with helium gas from **gHe bottle**
• After 30 seconds, close **ball valve 10**, **LHe vessel** is now pressurized
• Repeat the above pump and purge procedures 2~3 times as the **LHe vessel** and **cooling circuit loops** filled with pressurized pure helium gas (4 psi)
• Close **globe valves 13, regulator valve 12** and **needle valve 11**
• Remove the **helium gas transfer line** from the **connector** of **ball valve 10**
**STEP 9) LIQUID HELIUM FILLING TO LHe VESSEL**

- Before beginning to transfer liquid helium, be sure that the **LHe vacuum jacketed transfer line** has been properly evacuated. Periodic re-evacuation of the transfer line is necessary for efficient LHe.
- Purge the **LHe transfer line** with gaseous helium.
- Insert quickly the **LHe transfer line** to the bottom of the **LHe vessel** through the **helium fill port (c1)**.
- Close **ball valve 16** on the **LHe Dewar**.
- Remove the plug of **quick connector 14** on the **LHe Dewar**, place the end of the **LHe transfer line** into **quick connector 14** and insert it until it touches **fill valve 15** on the **LHe Dewar**.
- Open **fill valve 15** and insert the **LHe transfer line** to the bottom of the **LHe Dewar**, tighten **quick connector 14**.
- Open the **helium vent port (c2)**.
- The boil-off caused by the warm **LHe transfer line** being inserted into the **LHe Dewar** will cause immediate pressure rise and transfer **liquid helium** into the **LHe vessel**.
- Check temperature sensors **(T1 and T3)**.
- Set the initial transfer rate of **liquid helium** at a very slow rate guaranteed not to accumulate any liquid helium in the **LHe vessel** until the temperature T3 at bottom of 4K-heat shield is cooled below 20K.
- This slow transfer makes more efficient use of the enthalpy of the liquid helium as it cools the **LHe vessel** and the attached **radiation shield**.
- During the liquid helium transfer, plug in the **mechanical pump**.
- Open **ball valve 6,5 and 4** on the control panel, at which point the **mechanical pump** should start to "gurgle", indicating that the **helium gas** is entering the **pumping port (f)**.
- Open and close **helium needle valve (k)** several times, to clear the path through **needle valve and capillary tube** and let **liquid helium** entering **cooling circuit loops** for **e-Bubble chamber cooling**.
- Check the **flow meters** and **compound vacuum/pressure gauge** on the control panel.
- After several minutes the pump should become quiet, close **ball valve 4,5 and 6**.
- Unplug the **mechanical pump**.
- When the temperature (T3) at the bottom of the 4K-radiation heat shield gradually cooled down to approximately 9K, at which point the helium transfer rate can accelerate and the cryostat filled completely with liquid helium.
- At the final phase of **liquid helium transfer**, **helium needle valve (k)** is fully opened to allow the **liquid helium** to enter the **cooling circuit loops**.
- Check the helium level meter occasionally. The **LHe vessel** are completely filled (21” on the helium level meter) using about 50 liters of **liquid helium** for this cool down and fill.
- It is important not to keep the helium level meter on except when you need to record the level to avoid the extra heat load to the LHe vessel.

**STEP 10) AFTER LIQUID HELIUM FILLING**

- Upon completion of **LHe transfer**, the temperature (T3) at the bottom of 4K radiation heat shield stabilized at about 8.1K.
- Wait a few minutes for the helium boil-off to settle down, then remove the **LHe transfer line** until it just clears **fill valve 15**, then close **fill valve 15**.
- Open **ball valve 16** and the **LHe Dewar** is only venting from the relief valve (0.5psi).
• Remove the LHe transfer line from the helium fill port (c1), seal the helium fill/vent ports (c1 and c2) to prevent air from entering the LHe vessel, the helium vapor should now be venting out off the pressure relief valves
• Remove the line completely from the LHe Dewar, plug in quick connector 14
• The pressure relief valves are usually set to vent at a pressure of 4 psi. It maintains a positive pressure inside LHe vessel which prevents air entering the vessel, while maintaining a constant drive pressure to send liquid helium through needle valve, capillary tube into cooling circuit loops
• After the LHe transfer is complete, refill the LN2 vessel, and refill periodically thereafter

**STEP 11) LIQUID HELIUM FILLING TO e-BUBBLE CHAMBER AND CENTRAL TUBE**

• Check the pressure gauge on the top of central tube, make sure the pressure of e-Bubble chamber is higher than atmosphere pressure, otherwise back-filling it with helium gas, as listed in **STEP 3**
• Open ball valve 8, insert quickly the LHe transfer line into the central tube vent port (e)
• Close ball valve 16 on the LHe Dewar
• Remove the plug of quick connector 14 on the LHe Dewar, place the end of the LHe transfer line into quick connector 14 and insert it until it touch fill valve 15 on the LHe Dewar
• Open fill valve 15, insert LHe transfer line to the bottom of LHe Dewar, tighten quick connector 14
• The boil-off caused by the warm vacuum jacketed transfer line being inserted into the LHe Dewar will cause immediate pressure rise and transfer liquid helium into the e-Bubble chamber
• Once the e-Bubble chamber is filled with LHe, the pressure inside the central tube (e) will be gradually over-pressurizing, which prevents air from entering the central tube (e)
• After the liquid helium transfer, remove LHe transfer line until it just clears fill valve 15, then close the fill valve 15
• Remove the LHe transfer line from the central tube (c) and close ball valve 8
• Open ball valve 16 and the LHe Dewar is only venting from the ball valve 16
• Remove the LHe transfer line completely from the LHe Dewar, plug in quick connector 14
• The pressure inside e-Bubble chamber is monitored by the compound pressure/vacuum gauge and is vented out off the pressure relief valve located at the central tube (e)

**STEP 12) DURING NORMAL OPERATION**

• Check temperature sensors for the holding time of the liquid helium and liquid nitrogen
• The normal boil-off rate of the combined total liquid helium (about 45 liters), is approximately 500 cc per hour, resulting in a hold time of about 4 days, The LN2 vessel has a net capacity of about 41 liters, also lasts more than 4 days
• At end of 4th day, the temperature of 4K-heat shield start to gradually increase to above 9K, indicating that the heat load from the LHe vessel to the 4K-heat shield is slowly increasing

**STEP 13) LOWER TEMPERATURE OF E-BUBBLE CHAMBER**

• Open ball valve 4,5 and 6 on the control panel, this connects the mechanical pump to the pumping port (f) of the cooling circuit loops
• Plug in the mechanical pump, pump the cooling circuit loops to lower the pressure, thereby to decrease the temperature of e-Bubble chamber
• The pumping mass flow rate is monitored by the flow meters on the control panel
Adjust the **helium needle valve operator** (k) at the top flange of the cryostat to change the liquid helium mass flow rate entering the **cooling circuit loops** from the LHe vessel.

- When the lower temperature has been reached, close **ball valves 4, 5 and 6** on the control panel.
- Unplug the **mechanical pump**.
- The temperatures are monitored and control by temperature sensors around e-Bubble chamber.

**(STEP 14) WARM-UP**

- System warm-up consists of allowing the cryogen to boil away and the cryostat to warm to room temperature, there are two modes, one is normal warm-up and the other quick warm-up.
- After liquid helium boil away and the cryostat warm up room temperature, be sure that all ports are closed to prevent air from entering the vessel.
  - **Normal warm-up:**
    - Open the **helium fill/vent ports** (c1 and c2) on the LHe vessel.
    - Use heaters mounted at the top flange of the e-Bubble chamber to increase temperature.
    - Wait liquid helium and nitrogen boil-off and vent out of the pressure relief valves and vent ports.
  - **Quick warm-up:**
    - Open **globe valves 13** and set **regulator valve 12** at 5 psi.
    - Connect the helium gas transfer line to the evacuation port (I) extending from the cryostat.
    - Open **needle valve 11** and purge the helium gas transfer line.
    - Open **evacuation valve 103** and break vacuum back of the cryostat vacuum jacket with warm helium gas from gHe bottle.
- **Liquid withdraw:**
  - Purge the LHe transfer line with gaseous helium.
  - Insert the LHe transfer line to the bottom of the LHe vessel through helium fill port (c1).
  - Close **ball valve 16** on the LHe Dewar.
  - Remove the plug of **quick connector 14** on the LHe Dewar, place the LHe transfer line into quick connector 14 and insert it until it touch fill ball valve 15 on the LHe Dewar.
  - Open **fill valve 15** and insert the LHe transfer line to the bottom of the LHe Dewar.
  - Tighten quick connector 14, open **vent valve 17** on the LHe Dewar.
  - Liquid helium transfer from the LHe vessel will take place as the helium vapor inside the LHe vessel is vented from the vent valve 17.
  - Upon the LHe transfer is complete, at which point the temperature T1 at the bottom of LHe vessel will increase abruptly.
  - Wait a few minutes for the helium boil-off to settle down, remove the LHe transfer line until it just clears the fill valve 15, then close the fill valve 15.
  - Remove the line completely from the LHe Dewar.
  - Close the vent valve 17, open **ball valve 16** and let the LHe Dewar vent from ball valve 16.
  - Install the plug of quick connector 14.
  - Remove the LHe transfer line from helium fill port (c1).
  - Seal helium fill/vent ports (c1 and C2) to prevent air from entering the LHe vessel.