A Proposal for a TESLA Accelerator Module Test Facility

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Abstract
The Tera-eV Energy Superconducting Linear Accelerator (TESLA), a 32 km long superconducting linear electron/positron collider of 500 GeV (upgradeable to 800 GeV) centre of mass energy, presently in the planning phase at DESY, will consist of about 21000 superconducting RF-9-cell cavities of pure Niobium, cooled in a 2.0 K helium bath. The cavities will be assembled in groups of 12 in about 16-17 m long cryostats (cryomodules). Among other things, the cryomodules will be equipped with thermal shields at 40/80 K and 5-8 K temperature levels respectively.
Before their installation in the TESLA tunnel, the accelerator cryomodules have to be qualified after the assembly in random tests. The qualification includes the check of the general mechanical dimensions and the measurement of the cryogenic performance of all systems, in particular, the performance of the cavities.
In addition, all about 21000 single cavities have to be tested before the assembly in the cryomodules at a rate of about 24 per day.
The paper presents the layout of the test facility and, in particular, the layout of the helium distribution system and the test benches.

1.Introduction

Before their installation in the TESLA tunnel, the about 1800 accelerator cryomodules have to be qualified. The qualification includes the check of the general mechanical dimensions and the measurement of the cryogenic performance of all systems, in particular, the performance of the cavities. At the start of the cryomodule series production the tests will cover 100% of the cryomodules, in order to check and adjust the fabrication. As soon as the non-acceptance rate will decrease below a value in the order of 1%, only about 25% of the cryomodules will be tested.
These random tests can be applied with low risk for the commissioning of the accelerator, because all main single components, like cavities and quadrupoles, will be tested to an extent of 100% before the assembly of the cryomodules. In addition and in contrast to the operation of superconducting high energy physics storage rings like HERA and LHC, the low performance of single cryomodules can be tolerated for the operation of the linac to some extent.
For the time being, the performance of single superconducting RF-cavities can only be monitored by cryogenic tests. Industrial studies /1/ have shown that the effort, needed for the cryogenic tests of single cavities pays, as soon as the failure rate of the single cavities exceeds 1.2 %. Also the overall accelerating gradient of the linear accelerator can be improved in the range of more than 10% by sorting of the cavities according to their performance /1/. For the fabrication of the TESLA cryomodules more than 21 000 single cavities have to be tested at a rate of about 24 cavities per day.

In addition, about 800 packages of superconducting magnets (quadrupoles and steering dipoles) have to be tested in vertical dewars at an average rate of one quadrupole per day.
In general, with the exception of the tests of prototypes, the tests will aim only at quality insurance. For the cavities as well as for the cryomodules the test results from the test facility will be used as a fast feedback into the series production in order to avoid failures and to increase the performance.

2. Definition of the Test Programmes

2.1 Test Programme for the Vertical Tests of Single Cavities and Quadrupoles

The maximum accelerating field and the corresponding unloaded quality factor Q_o of each single cavity will be measured at a temperature of 2K in a bath cryostat. To increase the throughput of the vertical tests stands, eight cavities are assembled at one cryostat insert. Each cavity will be equipped with a fixed coupler antenna ($Q_{ext} = 1 \times 10^{10}$) and a pick up probe ($Q_{ext} = 1 \times 10^{13}$). The cavities will be locked in the accelerator mode. The accelerator field will be increased to the maximum value in steps. At each step the cavities will be powered for 20 s in cw-operation mode /2/. According to estimates of the test schedule, about 20 hours are needed for one complete test run for eight cavities, including the assembly and disassembly of the insert to the cryostat and the cool down and warm up procedures (see table 1).

Table 1: Schedule for the test of eight cavities in one vertical dewar
The indicated numbers correspond to the 4.5 K liquefaction load (g/s)

Time / h	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Assembly																				
Pump & Purge,leak checks																				
Cool down 300K->4.5 K						50	50													
Cryostat filling								50	50											
pump down 4.5K->2K										20	20									
measurement 2 cavities												8								
measurement 2 cavities													8							
measurement 2 cavities														8						
measurement 2 cavities															8					
warm up 2k -> 300K																				
Dis-assembly																				

The inserts will be assembled at the cavity preparation site and delivered to the test facility. Cavities, which will have passed the tests successfully, will be sent to the cryomodule manufacturer. Cavities with low performance will be fed back into the preparation procedures.
The superconducting performance of the magnet packages will also be tested in the bath cryostats. In particular the current performance will be monitored. Two magnet packages will be tested at a time in one cryostat.

2.2 Test Programme for the Accelerator Module Test Benches

The cryogenic performance tests include the integral leak check of all vacuum systems and cryogenic process tubes, the test of the instrumentation, measurements of the static heat loads and of the maximum accelerating field of the cavities and the corresponding unloaded quality factor Q_o. The quality factor will be monitored by means of cryogenic measurements of the dynamic heat load. The cryogenic measurement of the Q_o-value has been demonstrated as well in the horizontal cryostat (CHECHIA) / 3/ as for the cryomodules of the linear accelerator of the TTF. During the performance tests of the cavities, also the x-ray radiation and the related dark currents will be measured by means of two ionisation chambers at each test bench and dark current monitors at both ends of the beam tube of the cryomodules, respectively.

The pre-conditioned RF-couplers will be further conditioned. The RF-phase will be adjusted in the order of +/- 20 degrees. There will be also the possibility to process the cavities.

The instrumentation of superconducting magnet packages will also be tested.

About 170 cryomodules will be equipped with cryogenic valves, temperature sensors, flow sensors and liquid level indicators (string interconnection equipment). Also this instrumentation will be tested on the test benches.

Table 2: Schedule for the test of one cryomodule containing a magnet package
The indicated numbers correspond to estimated test hours.

days	1	2	3	4	5	6	7	8	9
Test Bench									
connections	24								
iso-vacuum		24	24						
tube leak checks				8					
beam-vacuum		24	24						
coupler pumping/heating		24	12						
coupler processing				24	24				
cavity processing							20		
cool down					24	24			
tuner tests						4			
dynamic losses							4		
static losses						24	4		
magnetl tests							4		
warm up								24	
disconnections									24

According to estimates of the test schedule (see table 2), about eight to nine days are needed for the complete test of one accelerator cryomodule, including the mechanical assembly and disassembly on the test bench. To fulfil this schedule, it is assumed that the pre-conditioned RF main couplers will be pumped and heated before the installation on the test bench.

3. Layout of the Accelerator Module Test Facility

3.1 Hall Layout

From the given test rates and the estimates of the test schedules it follows that 6 test benches for cryomodules and at least 3 vertical dewars have to be installed in the module test facility.

The number of test benches includes an overcapacity of about 20% for the test of 25% of the modules. In order to increase the efficiency of the vertical tests, 6 vertical dewars are foreseen.

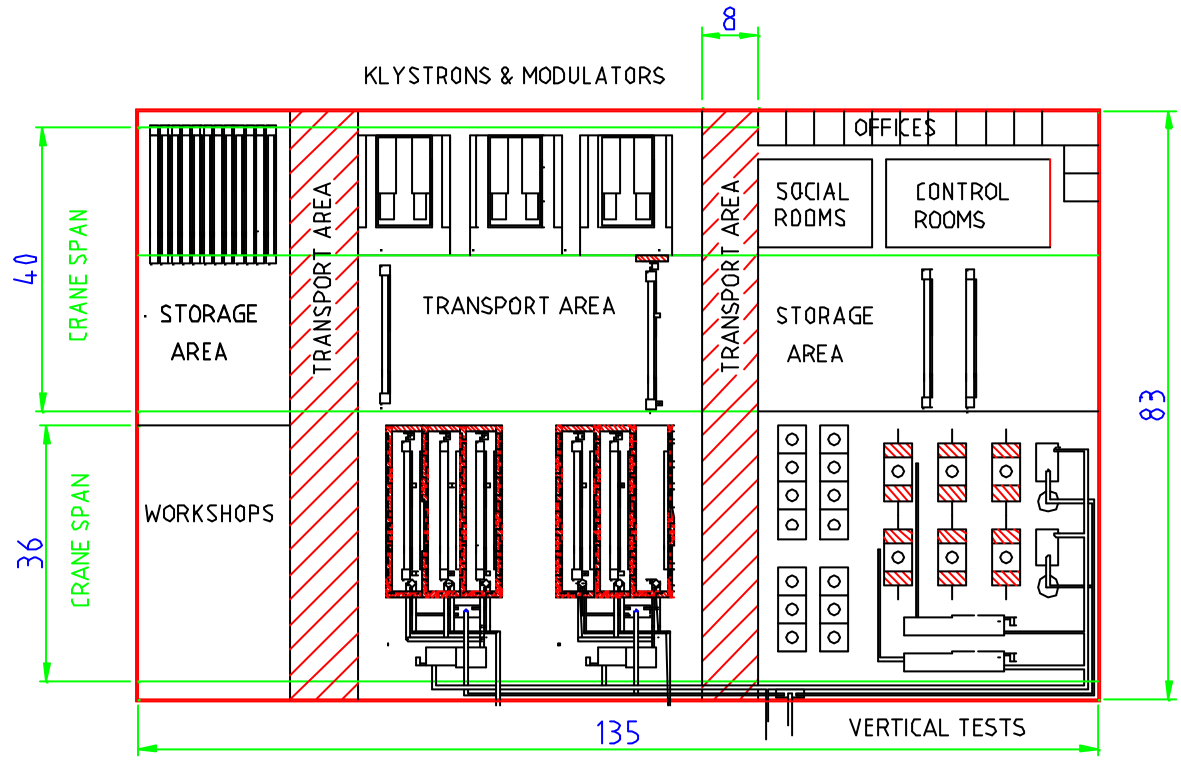

Fig.1: Ground Plan of the Accelerator Module Test Facility

The overcapacities will compensate for shut down periods, maintenance and repairs. In addition, depending on the detected failure rates, capacities for the repetition of tests have to be foreseen.

Beside the test areas there will be areas for the intermediate storage of cryomodules and cavity test inserts, a test area for 'warm' measurements of cryomodules, transport areas, infra structure areas and workshops. Also control rooms, offices and social rooms have to be provided. The test hall will have an overall size of 135m x 85m ground area and a height of about 12m. Two parallel hall cranes, each with a capacity of 20 000 kg, a span of 36m or 40 m respectively, and a hook height of 9m will be installed (see fig. 1).

There will be under floor channels leading from the cryogenic and RF supply equipment to the test benches and to the test dewars in order to take all supply tubes and cables.

Each individual module test bench has to be surrounded by a concrete shielding of 0.8 m thickness. A roof shielding of 0.8 m thickness in order to establish radiation safety in all parts of the test hall will cover the test benches. There will be an inner space of 23m x 4.4m x 2.5m for one test bench. Three test benches will be grouped together as a block.

The front door of each test bench together with a module support structure can be moved horizontally on railways into the transport area. For the installation of a cryomodule on a test bench, the cryomodule will be moved by the hall crane from the storage area to the front of one test bench and will be installed on the support structure. After installation, the support structure will be moved back into the shielding of the test bench. During the installations inside the shielding, the front door can be shifted relatively to the support and will stay open.

The vertical dewars will be inserted into the ground and covered by movable concrete shielding blocks of 1.2 m thickness. The cryostat inserts will be moved from the storage area into the cryostats by use of the hall crane.

3.2 Cryogenic Systems

For the continuous operation of the test hall, cooling capacities of about 10 KW at 40/80K, 1.0 KW at 4.5K and 0.6 KW at 2.0K are needed. In order to reduce the effort of the helium distribution system, only the 40/80K and 4.5K circuits will be branched to the test benches and the test dewars. At the cryomodule test benches as well at the vertical cryostats the 2K liquid helium will be supplied by the isenthalpic expansion of the 4.5K helium, which will be sub cooled to 2.2K before the expansion by means of counter flow heat exchangers. The average 2K heat loads will be small in comparison to the capacity of the cold compressors of a TESLA refrigerator plant, and these loads will always vary. Therefore distributed warm compressor systems will be used to lower the vapour pressure of the helium baths to 31 mbar /4/. As a result, a helium liquefaction rate of about 50 g/s has to be supplied on average from the helium plant. Peak liquefaction rates will be buffered by means of two 10 m^3 liquid helium storage reservoirs.

The cryogenic system of the test facility will be designed in a modular structure (see fig.2 and the component flow schemes in the appendix). The test facility can by connected to any helium refrigerator plant, which can supply the capacities mentioned, in particular to the HERA refrigerator or TESLA refrigerator on the DESY site.

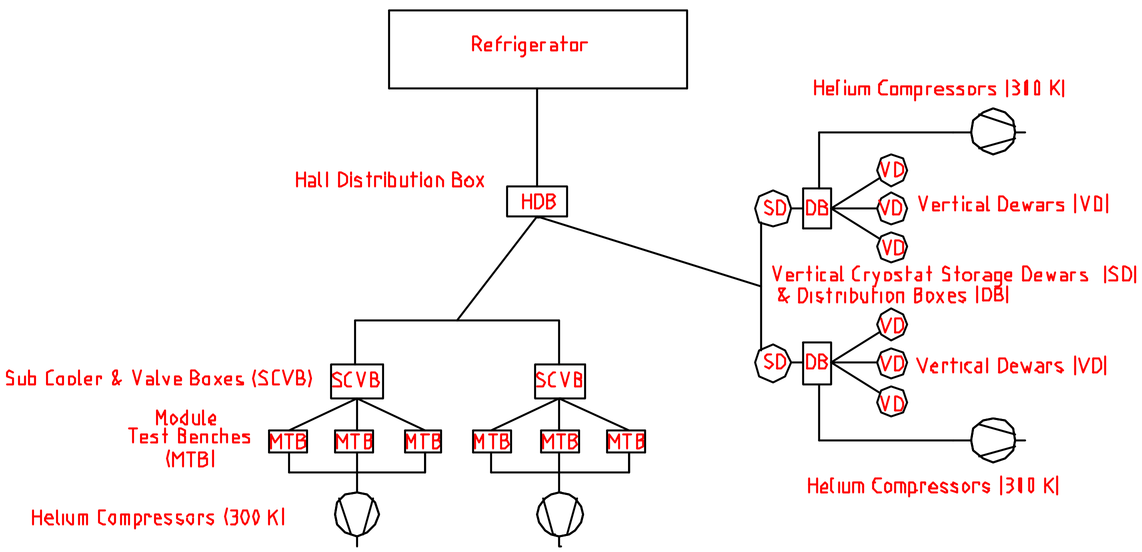

Fig 2.: Block diagram of the cryogenic system
Flow schemes of the different components
can be found in the appendix.

3.2.1 Cryomodule Test Benches

The cryogenic supply of the test benches is divided into two 'layers', in order to operate the test benches independently from each other, to avoid air condensation on cryogenic valves during the exchange and installation of modules, and to reduce the consequences of leaky valves. One layer are the feed boxes of each test bench, the other layer are the sub cooler & valve boxes, to which a group of three feed boxes will be connected (see fig.2).

In order to supply the cryogenic 40/80K and 4.5K shield circuits as well as the 2K circuit, each cryomodule test bench has to be equipped with a feedbox, including a feed cap and an end cap. The feed box will be fixed inside the shielding of the test bench and will contain cryogenic valves for each supply and return tube, a small 4.5 K sub cooler and an 2K counter flow heat exchanger. The 4.5K sub cooler of the feedbox is used to stabilize the supply temperatures of the 4.5K and 2K circuits. All safety vent lines and relief valves are connected to the feed box. The feed cap, which is attached to the feedbox will contain all connection flanges to the cryomodule. The end cap will be fixed to the module support structure and will contain only the short circuits of all cryogenic tubes and a 2K liquid reservoir. The position of each end cap can be adjusted easily to the different length of cryomodules.

Each cryogenic supply tube in the feedbox is equipped with a Venturi flow meter. As well in the feed cap as in the end cap all supply and return tubes are equipped with redundant thermometers. Redundant liquid level indicators and pressure sensors are installed in the 2K reservoir of the end cap. The pressure of all cryogenic circuits will be monitored.

The cryogenic layout of a test bench is almost identical to the TTF/FEL-cryomodule test bench, which has been described in more detail / 5/. The flow scheme of one module test bench is shown in the appendix fig. A.1.

Each group of three feed boxes will be supplied via tranfer lines from one sub cooler & valve box (see appendix fig. A.2). The connecting transfer lines consist of 4.5 K supply, 4.5 K return, 40K supply and 80 K return tubes. The sub cooler & valve box contains one 4.5K sub cooler and cryogenic valves for all process tubes of the different transfer line branches and all corresponding warm up and cool down tubes and valves connected to the tranfer lines. The sub cooler has to compensate the heat losses of the transfer lines, leading from the refrigerator to the test benches.

As a result of the combination of feed boxes and sub cooler & valve boxes all cryogenic supply and return tubes are separated by two cryogenic valves in series from the test bench.

The sub cooler & valve boxes will be supplied from the test hall distribution box (see fig.2 and fig. A.6 in the appendix).

The 2K vapour return tubes of three test bench feed boxes are connected to one 300K helium compressor unit (see fig. A.7). In the exhaust of the compressor unit the pumped mass flow can be measured by warm gas flow meters. By means of these flow meters, the heat load of the 2K circuit can be monitored with a resolution in the order of +/- 0.1 W at a constant liquid helium level in the 2K liquid reservoirs of the end caps.

3.2.2 Vertical Test Cryostats

As for the supply of the module test benches also for the vertical dewars two 'layers' of valves in the dewars and in distribution boxes will be installed (see fig.2). The design of the vertical dewars can be scaled from the vertical test dewars of the TTF / 4// 6/ (see fig. 3 and fig. A.3). The vertical dewars will consist of a 2.2m^3 liquid helium volume, cryogenic valves and a 2K counterflow heat exchanger, installed in the vacuum jacket. Three dewars will be connected to one distribution box respectively (see fig. A.4). The distribution boxes will contain all warm up and cool down connections and valves. One 10 m^3 liquid storage dewar will be connected to each distribution box respectively, in order to buffer the loads for the refrigerator (see A.5). The storage dewars will be supplied from the test hall distribution box and will also be used as sub coolers.

The 2K vapour return tubes of the vertical dewars will be connected to warm helium compressor units.

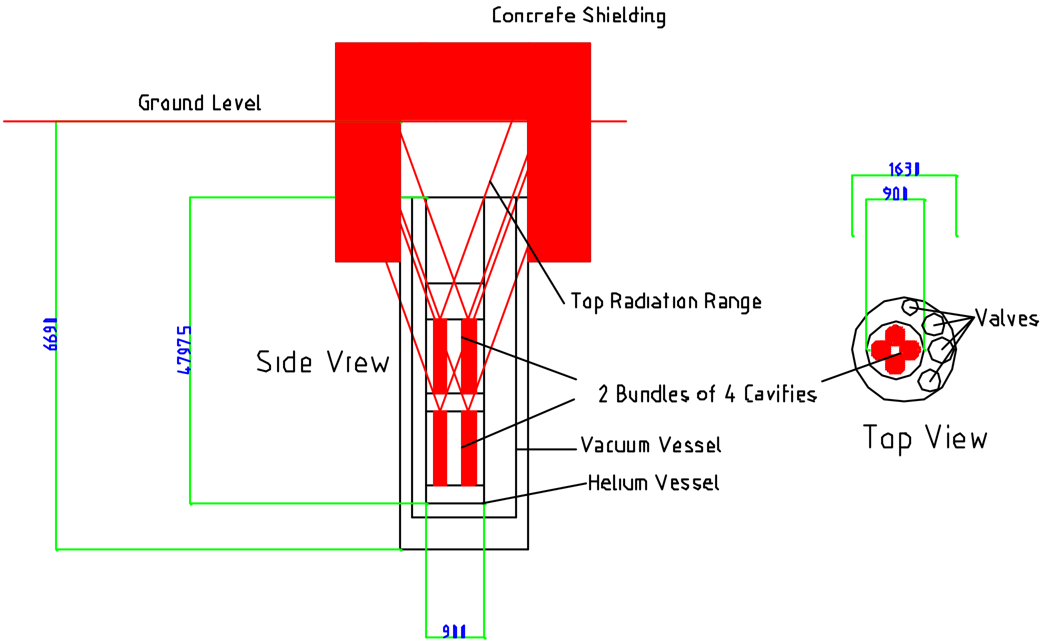

Fig. 3: The overall size of a vertical test dewar containing 2 bundles of 4 cavities.

3.2.3 Warm Helium Compressor Units

Warm helium compressor units will be used as well for the module test benches as for the vertical test dewars to lower the helium vapour pressure to about 31 mbar. The compressor units will consist of three stages of roots blowers and one stage of rotary vane pumps, similar to the compressor units, which are in use in the TTF for already more than 30 000 h of operation /4 /.

Table 3: Specification of the helium compressor units
(See the flow schemes in the appendix fig. A.7 and fig. A.8)

	Number of Units	Inlet Pressure (bar)	Exhaust Pressure (bar)	Mass Flow (g/s)
Module Test Benches	2	0.01	1.05 – 1.3	5
Vertical Test Dewars	2	0.01	1.05 – 1.3	10

The specification for the compressor units is shown in table 3. The specifications include the pump capacities, which are needed for the cool down of the helium liquid from about 4.5K to 2K.
In the compressor units for the module test benches with lower mass flow capacities, one roots blower in the first stage and one rotary vane pump in the 4^{th} stage can be left out (see fig. A.7).

3.3 RF Systems

According to the test schedule of the cryomodules , up to 4 test benches have to be supplied with RF power in parallel and independently from each other at a time for the conditioning of the couplers and the dynamic measurements of the cavities. It is supposed that all couplers of one cryomodule will be conditioned in parallel.

In order to avoid time consuming installations of the RF equipment in between the test benches and to obtain redundancy, one 10 MW klystron and modulator set will be related to each test bench, including a fixed RF distribution system.

3.4 Vacuum Systems

3.4.1 Insulation Vacuum

For the insulation vacuum of the cryogenic systems standard turbo molecular pump units are foreseen. Each cryomodule test bench will get its individual turbo molecular pump unit. The other cryogenic equipment will be connected to a net of pump stands according to the experience of the HERA and TTF insulation vacuum systems.

3.4.2 Main Coupler Vacuum

The main RF couplers of one cryomodule will be equipped with one pumping tube connected to the pumps without individual valves. There will be only one manual valve at the pumping tube. The set of pumps and pumping tube will stay at each individual cryomodule from the assembly, during the tests until the installation in the TESLA tunnel.

3.4.3 Cavity Vacuum

During the tests on the module test benches, one turbo pump unit will be connected to the cavity vacuum.

One getter pump will be connected to the coupled vacuum system of the eight cavities of each vertical dewar insert. In addition there will be oil free turbo molecular pump units at the vertical dewars as a back up.

3..5 Controls

For the time being it is assumed that there will be different sub control systems for the RF- ,vacuum- and cryogenic systems, which have to be integrated by an industrial visualization and data management system. In general, standard industrial components have to be used as far as possible. The transfer of data between the different systems and the data management will be mandatory for the operation of the test facility.

3.6 Infrastructure

The installation of the test facility will require 4.5 MW of electrical primary power, 2.7 MW equivalent of water cooling capacity and about 500 m^3 /h of instrument air. About 0.7 MW of heat will be dissipated into the air of the test hall. (The operation of the related TESLA or HERA refrigerator is not included in these numbers).

Acknowledgments
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Appendix

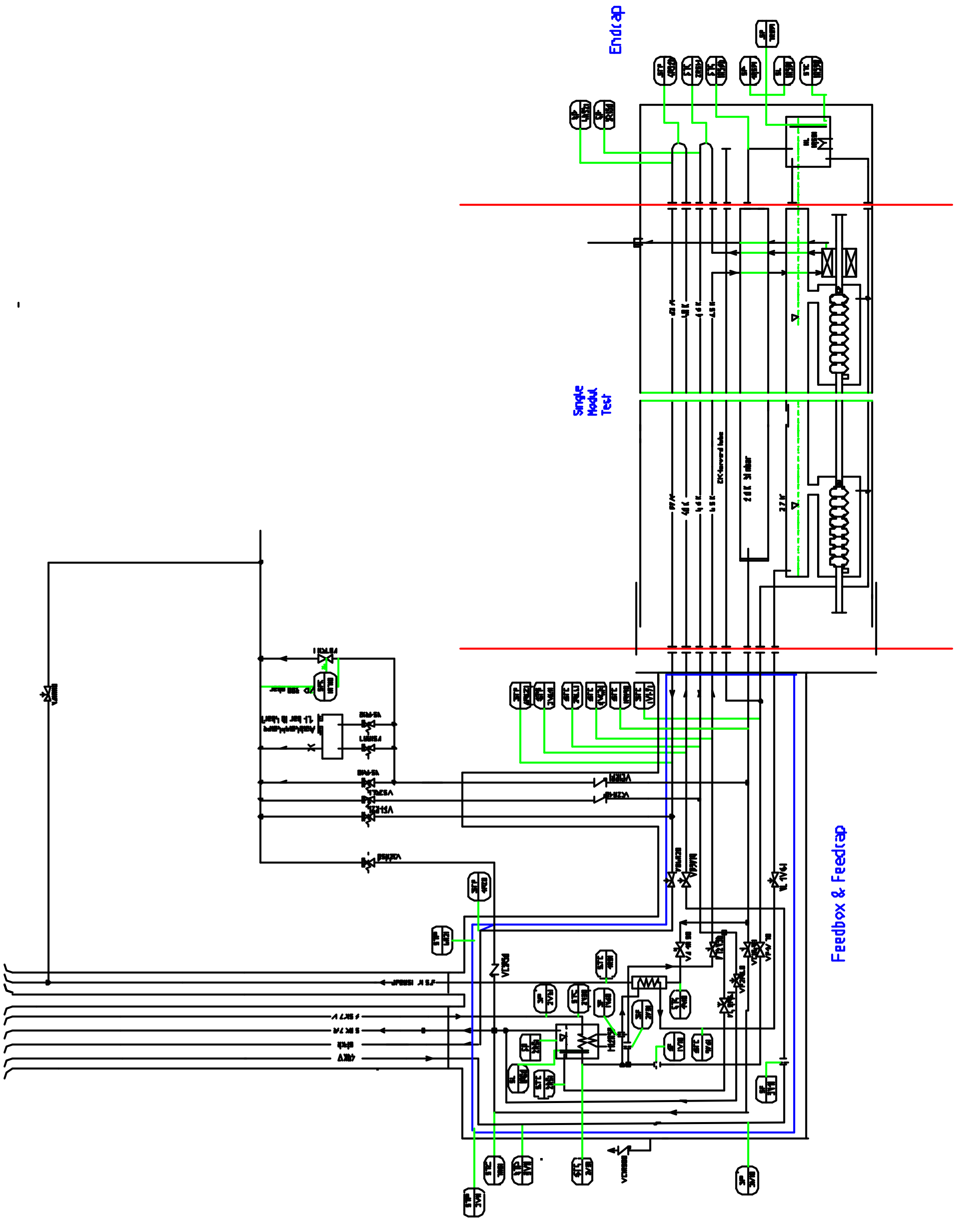

Figure A.1 : Cryogenic flow scheme of one module test bench.
Six of these test benches will be installed in the test hall

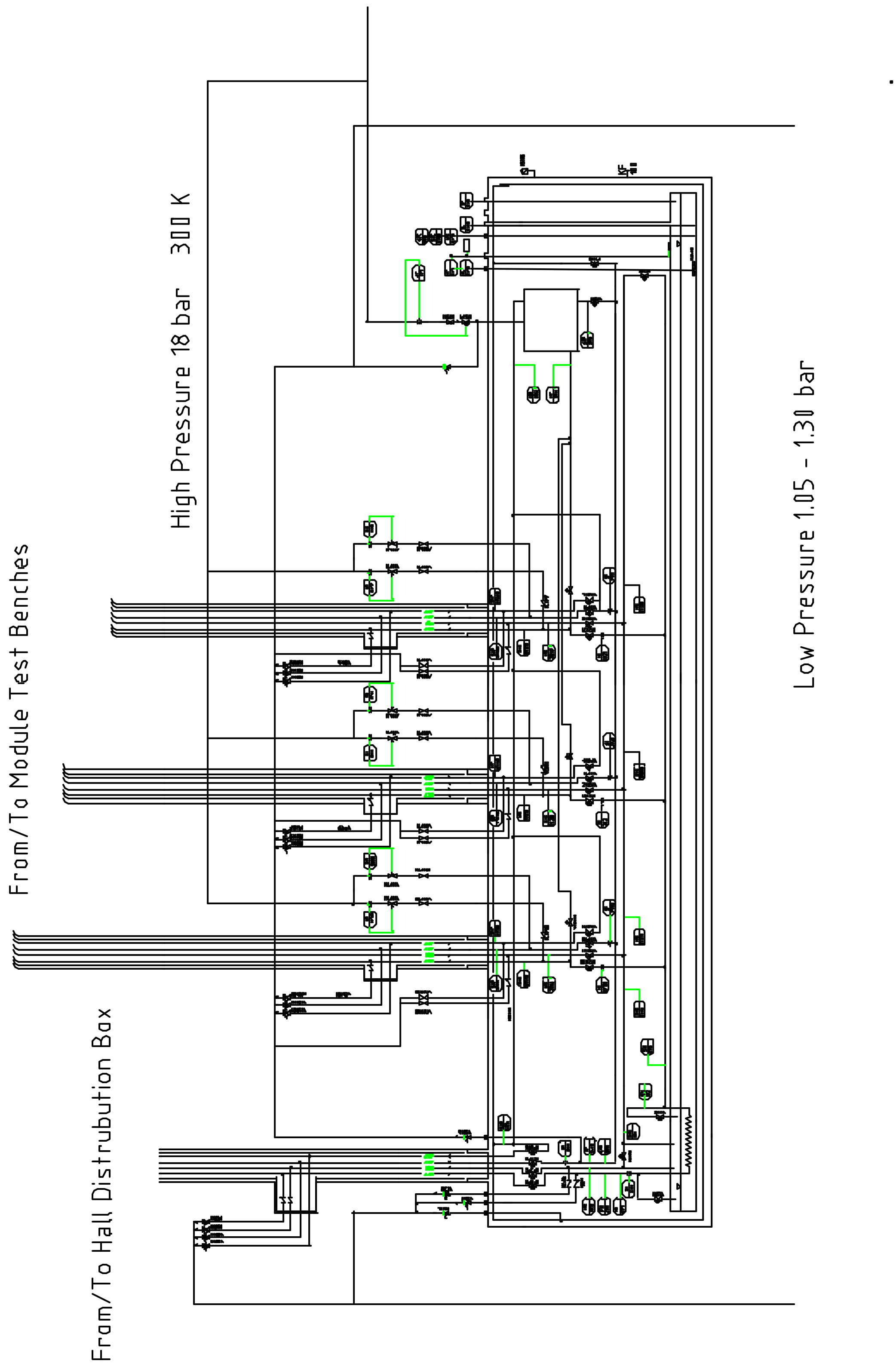

Figure A.2 : Cryogenic flow scheme of one sub cooler & valve box.
Two of these boxes will be installed in the test hall.

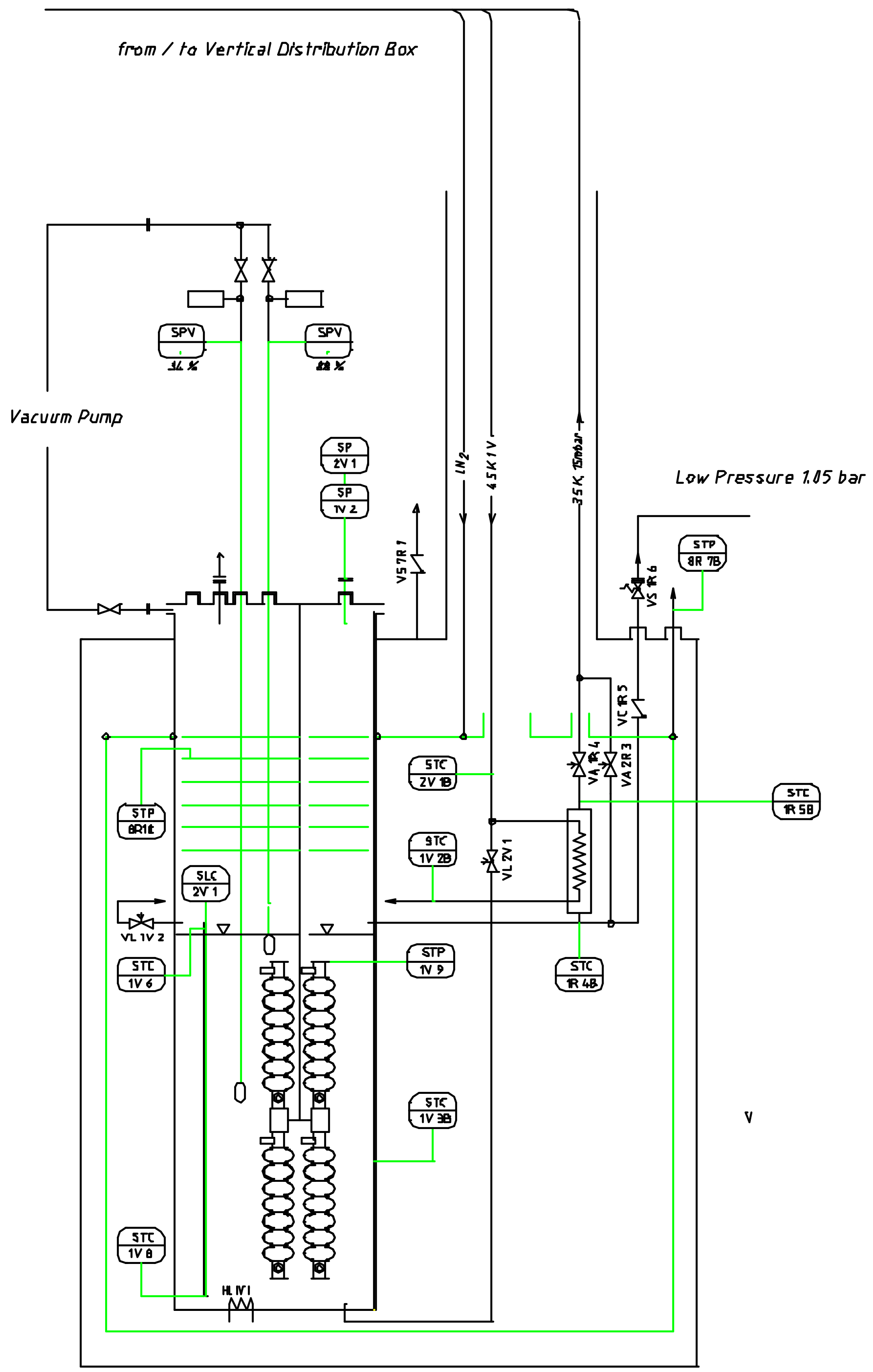

Figure A.3 : Cryogenic flow scheme of one vertical test dewar.
Six of these vertical dewars will be installed in the test hall.

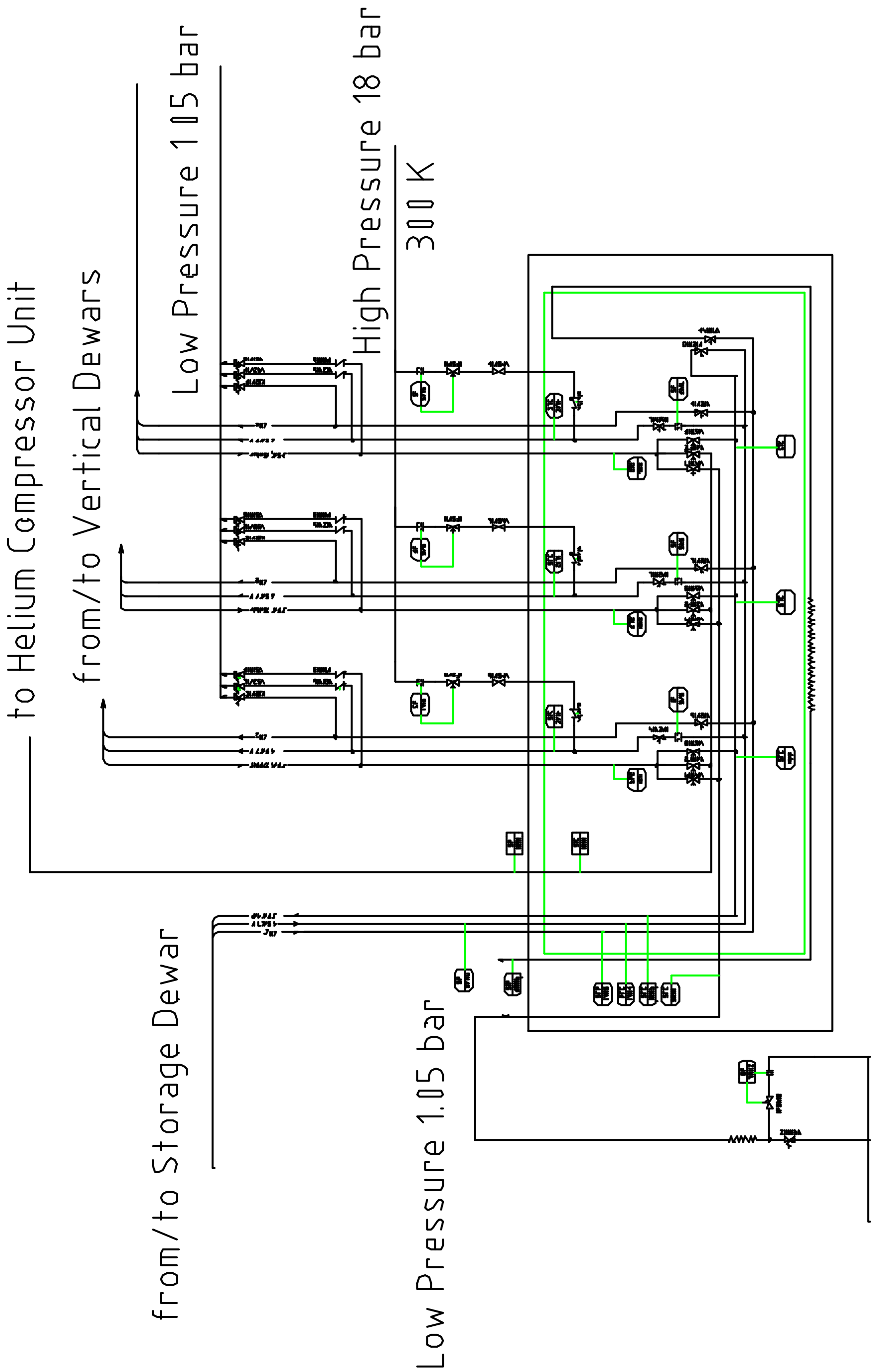

Figure A.4 : Cryogenic flow scheme of one vertical dewar distribution box.
Two of these boxes will be installed in the test hall.

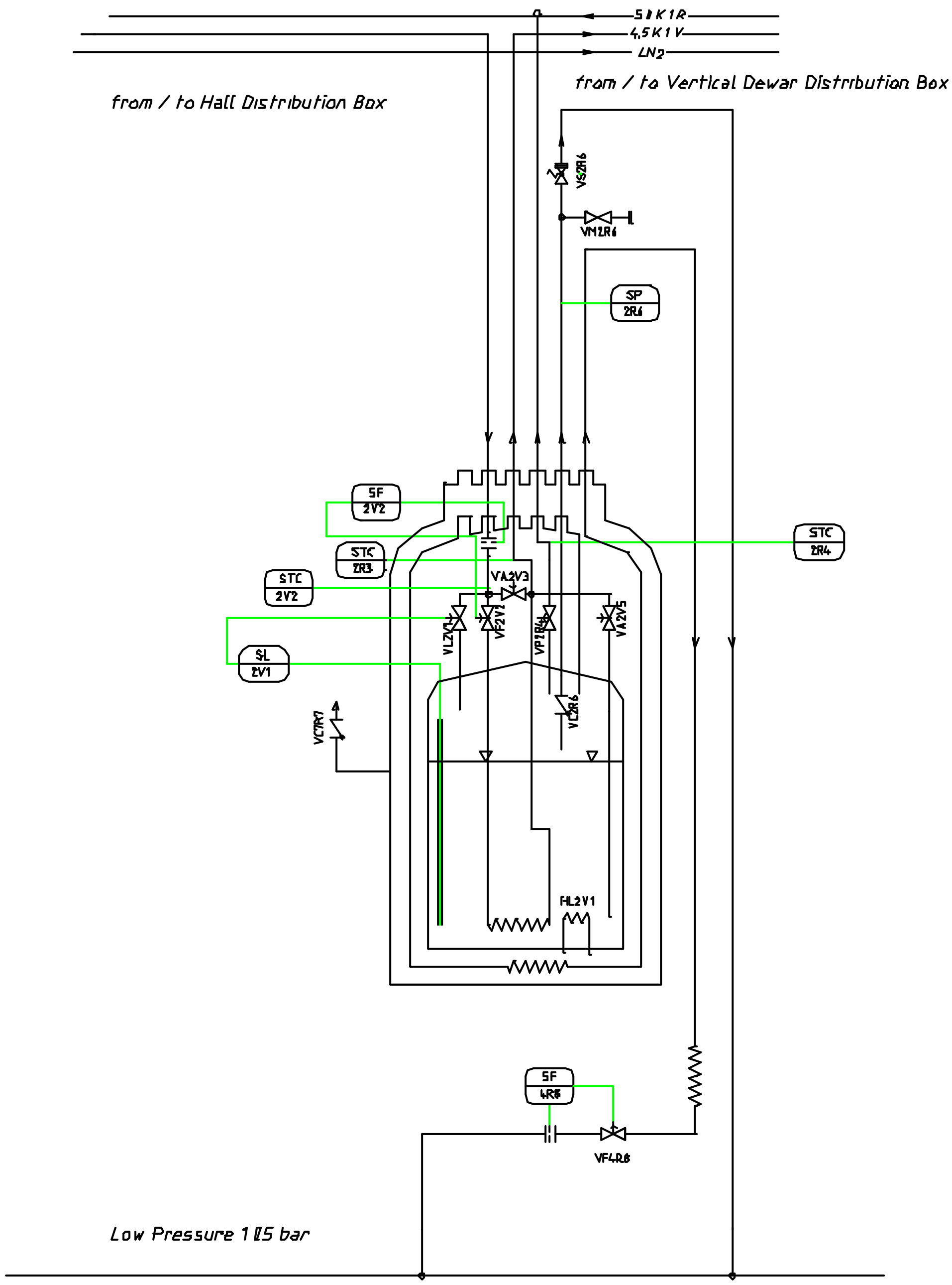

Figure A.5 : Cryogenic flow scheme of one vertical cryostat storage dewar
Two of these storage dewars will be installed in the test hall.

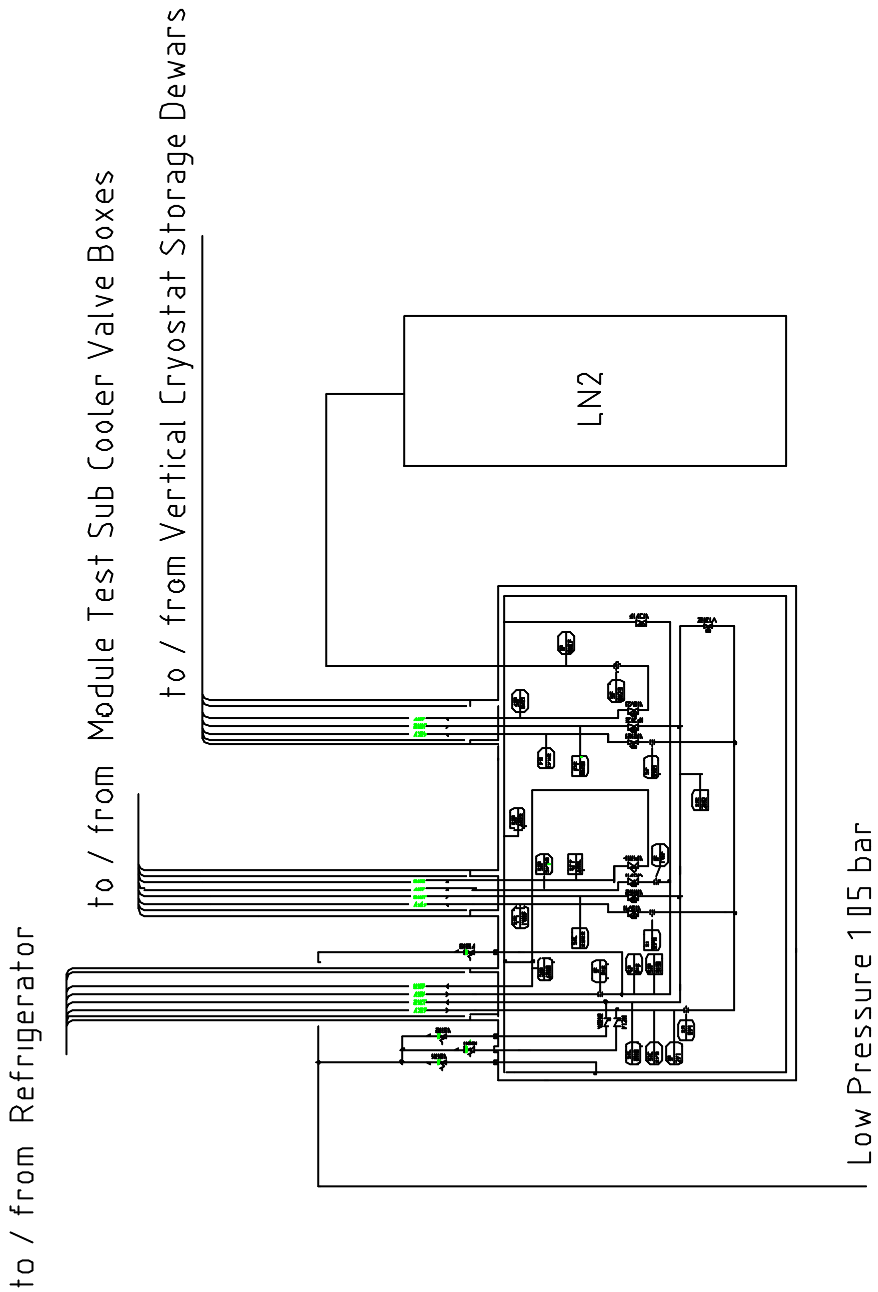

Figure A.6 : Cryogenic flow scheme of the hall distribution box. The thermal shields of the vertical dewars and the vertical dewar helium distribution systems will be LN2-cooled.

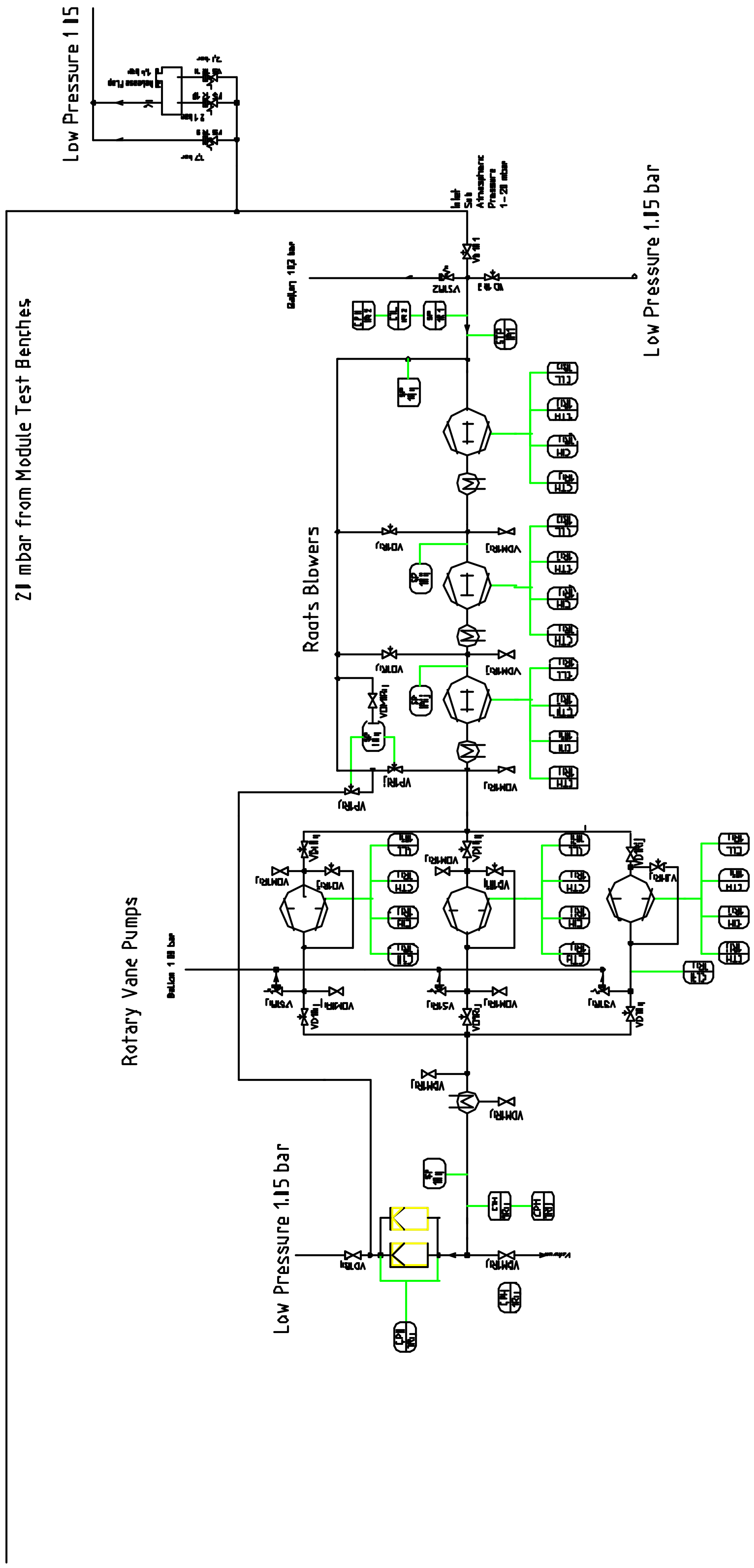

Figure A.7 : Gas flow scheme of one helium compressor unit for the supply of three module test benches. Two of these compressor units will be installed in the test hall.

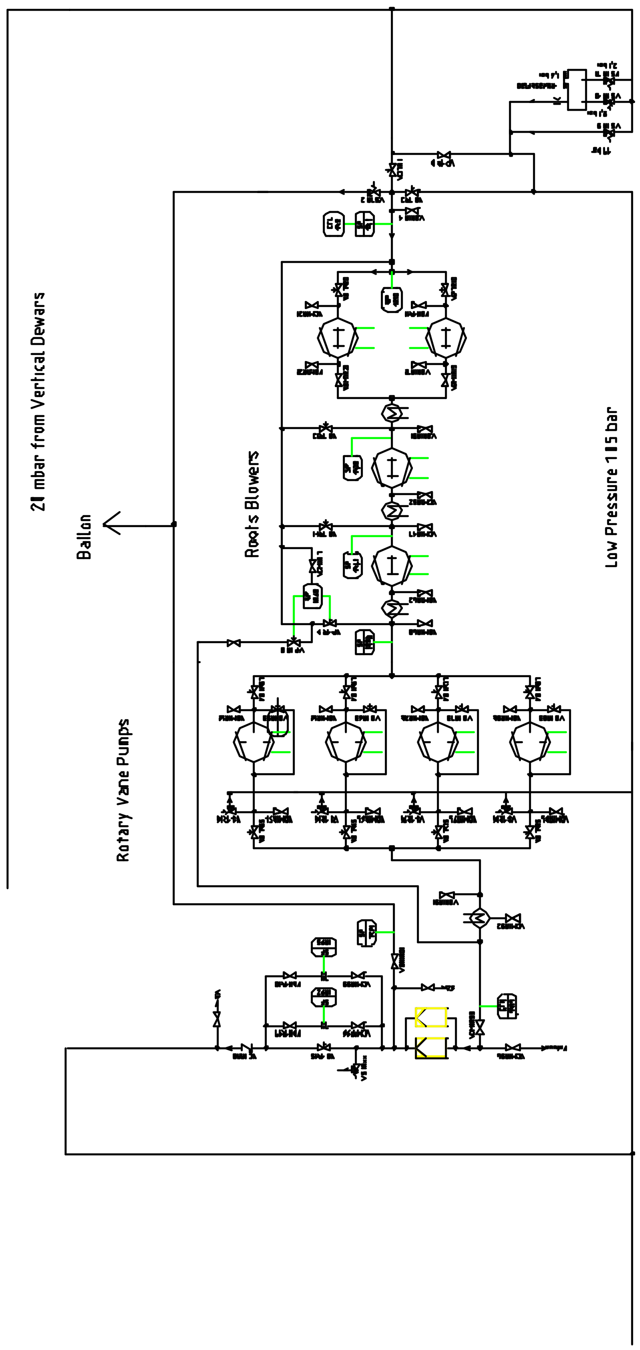

Figure A.8: Gas flow scheme of one helium compressor unit for the supply of three vertical test dewars. Two of these units will be installed in the test hall.