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Tests of the Spoke Cavity RF Source and Cryomodules in Uppsala

ESS TDR Contribution

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1 Introduction

Uppsala University is currently creating the FREIA laboratory to serve as a Facility for Research Instrumentation and Accelerator Development [1]. The construction of the 1000 m^2 FREIA laboratory hall will be terminated in July 2013. The location of the hall at the Ångström laboratory in Uppsala is shown in Figure 1. The hall will have separate areas for three RF test bunkers, for RF power generation equipment, for a helium liquefier and cryogenic storage facility, for a vertical cryostat, for equipment mounting, for a control room, for a small workshop, for equipment storage and for offices (located at a mezzanine) and contain general laboratory infrastructure like power and fluid distribution systems. A sketch of the inside of the hall is shown in Figure 2. A helium cryogenic facility and a general purpose test cryostat will be delivered in December 2013 and commissioned by May 2014. The bunkers will be built up during 2013 using iron loaded concrete blocks.

The first project for which the FREIA Laboratory will be used is the development and prototyping of the RF system for the ESS superconducting spoke cavities to be followed by the high power testing of the first prototype ESS spoke cryomodule. In a first phase the functionality of the tetrode based RF power system will be demonstrated in tests in which one power system is used to power a single spoke cavity. In a second phase the prototype spoke cryomodule containing two superconducting spoke cavities will be tested at high power, requiring the simultaneous operation of two complete RF systems. The plan is that later, during the ESS construction phase, FREIA will be used for the acceptance testing of the series of spoke cryomodules before their installation into the accelerator.

The first RF power source with control and distribution equipment is scheduled to arrive before December 2013. The RF source will first be commissioned and tested using a water cooled load. The first prototype spoke cavity is expected to arrive in May 2014. It will be installed in the horizontal test cryostat and tested with a RF source during the second half or 2014. The prototype spoke cryomodule is scheduled to arrive in mid 2015. It will be tested at high power during the second half of 2015 and the first half of 2016. Thereafter FREIA can be used for acceptance testing of the series spoke cryomodules as they get delivered from the production line.

Below are given technical descriptions of the three major components required for the ESS test program in Uppsala; the RF equipment, the cryogenics and the test stand infrastructure.

2 RF Equipment

Reliable development of an energy efficient and resource effective RF system requires test of the individual components and the complete RF system in a realistic environment. Thus an RF test facility is required with which the different concepts, topologies and elements of the RF system can be investigated in an in-depth test program. The RF test facility requires a complete RF system consisting of a LLRF system, high power RF amplifier, RF distribution system and spoke cavity as shown in Figure 3. The LLRF system generates the low power RF signal and adjusts the individual amplitude and phase to the spoke cavities. The LLRF

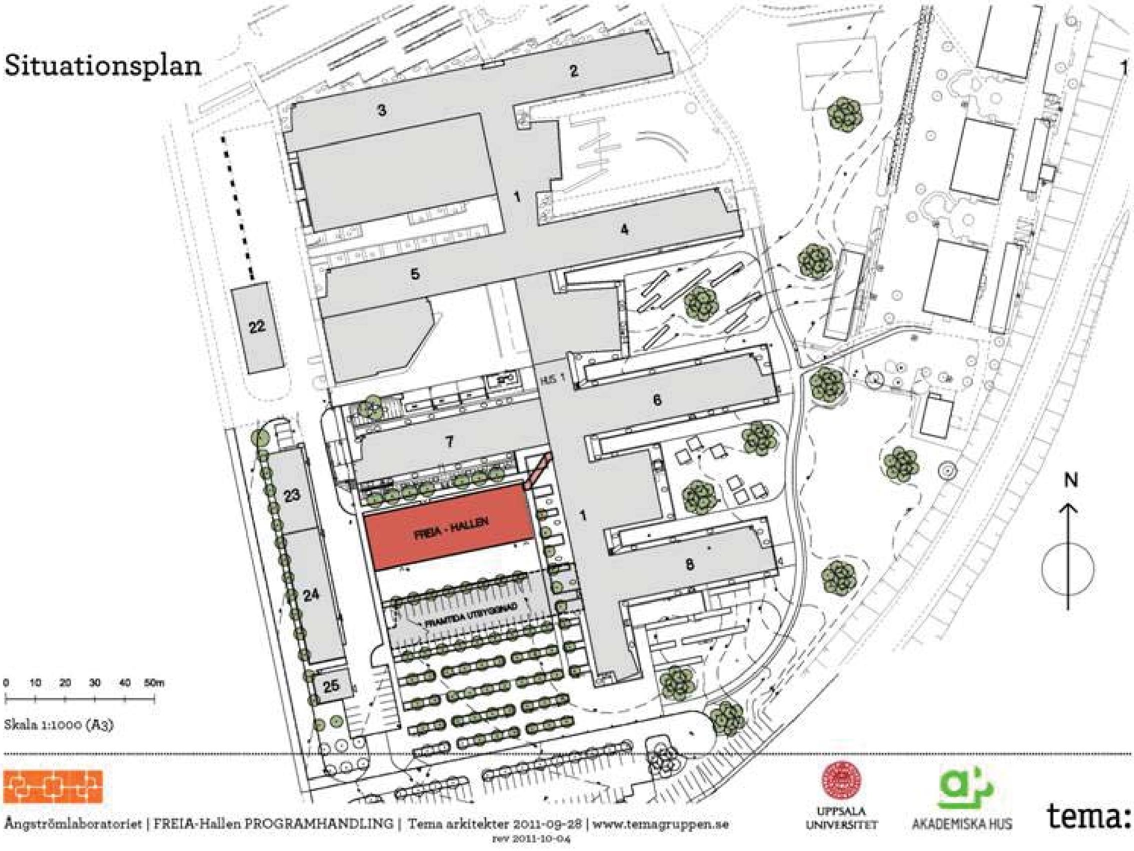

Figure 1: Location of the FREIA hall next to the Ångström Laboratory.

also measures the field in the cavities and tunes the cavity frequency to adjust for so-called Lorenz force detuning caused when the high power RF pulse starts filling the cavity volume.

The spoke cavities requires an RF power of 350 kW at 352.21 MHz with 3.5 ms pulse length and 14 Hz repetition rate. Tetrode type vacuum tubes are used as the high power RF amplifiers in combination with solid state pre-amplifiers. The layout of the proposed RF sources is described in detail in chapter 4 section RF systems subsection Spokes. For commissioning and initial testing of the high power amplifiers they will be connected to a water cooled RF load. Thereafter they will be connected to the superconducting spoke cavities.

Prototype and acceptence testing of the spoke cryomodules requires addition of a second RF power amplifier and distribution chain. This will make it possible to power both cavities in a cryomodule simultaneously. The second chain will be based on and improved from the first chain.

3 Cryogenics

The cryogenic facility includes a helium liquefier, liquid and gas helium storage, liquid helium distribution valve box, impure helium gas recovery system and a liquid nitrogen distribution

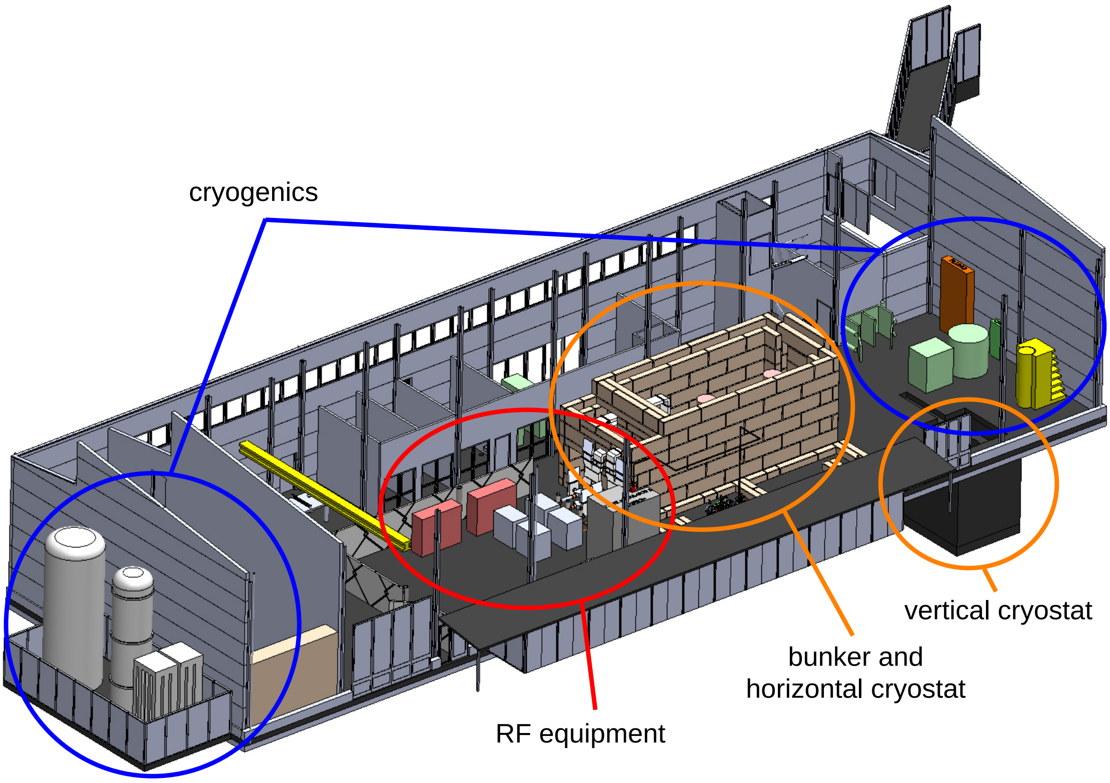

Figure 2: Interior layout of the FREIA hall.

system. The capacity of the cryogenic facility is designed to provide 30 W cooling power at 2 K to a superconducting cavity or other device in the cryostat. The layout of the facility is shown in figure 4. The helium liquefier provides a 2-phase mixture of gas liquid helium at 4.4 K, 1.3 bar at the output of its cold box into a liquid helium storage dewar. From this dewar the liquid helium is distributed to external users and cryostats connected to the distribution valve box. The temperature of the liquid helium can be decreased additionally in the 2 K cold box of the cryostat to cool superconducting cavities. A sub-atmospheric pumping system is used to decrease the helium pressure as required to keep the liquid bath temperature at 2 K.

The helium liquefier plant consists of a 4 K cold box, a helium cycle compressor (13 bar output pressure) as well as high and medium pressure helium gas storage. An oil removal system to clean the helium gas leaving the compressor, a high pressure gas distribution panel and automatic control system are included but not shown in figure 4. In addition a liquid nitrogen storage tank and distribution system is used for pre-cooling of the liquefier cold box in order to increase its liquefaction capacity. Liquid nitrogen will also be used for the thermal shield cooling of the test cryostat.

The combination of storage dewar and distribution valve box provides the possibility to deliver liquid helium both to the test cryostat as other users. This ensures upgrade possibilities to add other test cryostats as well as the filling of liquid helium transport dewars for external experiments. The large volume storage dewar can serve as a buffer supply of liquid helium when the required liquid helium flow exceeds the flow directly from the liquefier. This makes it possible to run experiments in the test cryostat with a required cooling power

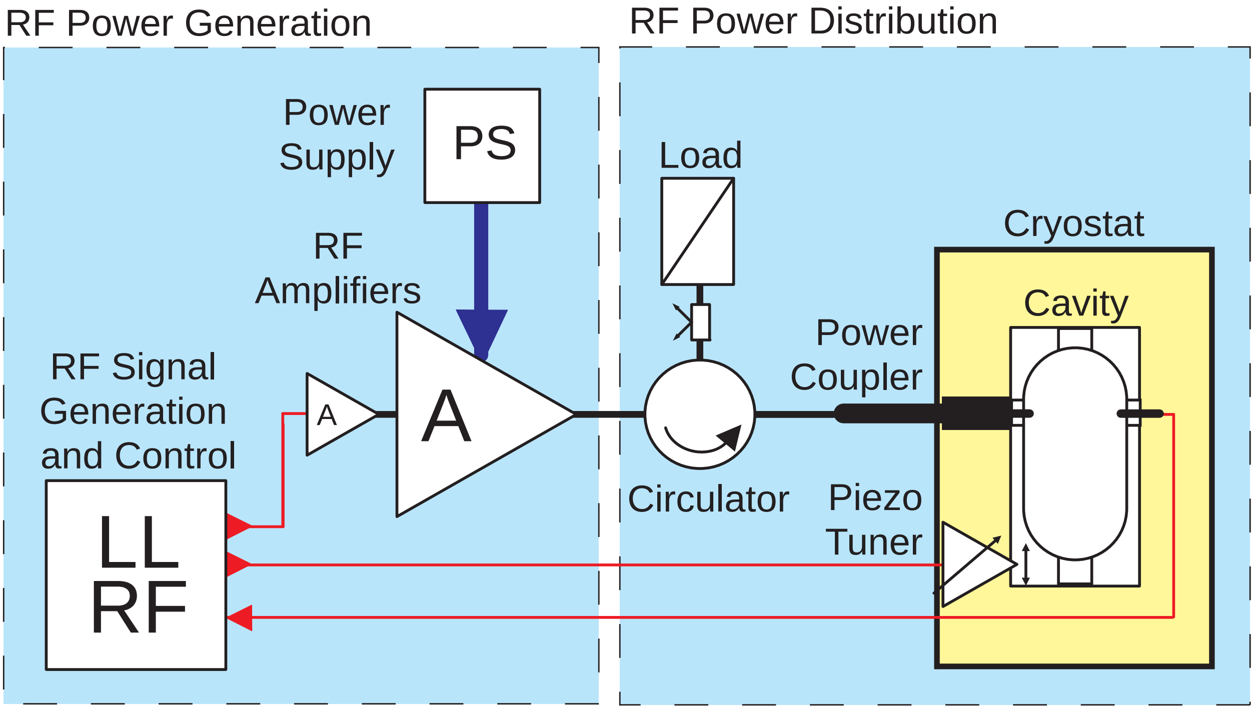

Figure 3: Possible configuration option of RF equipment to power a superconducting spoke cavity.

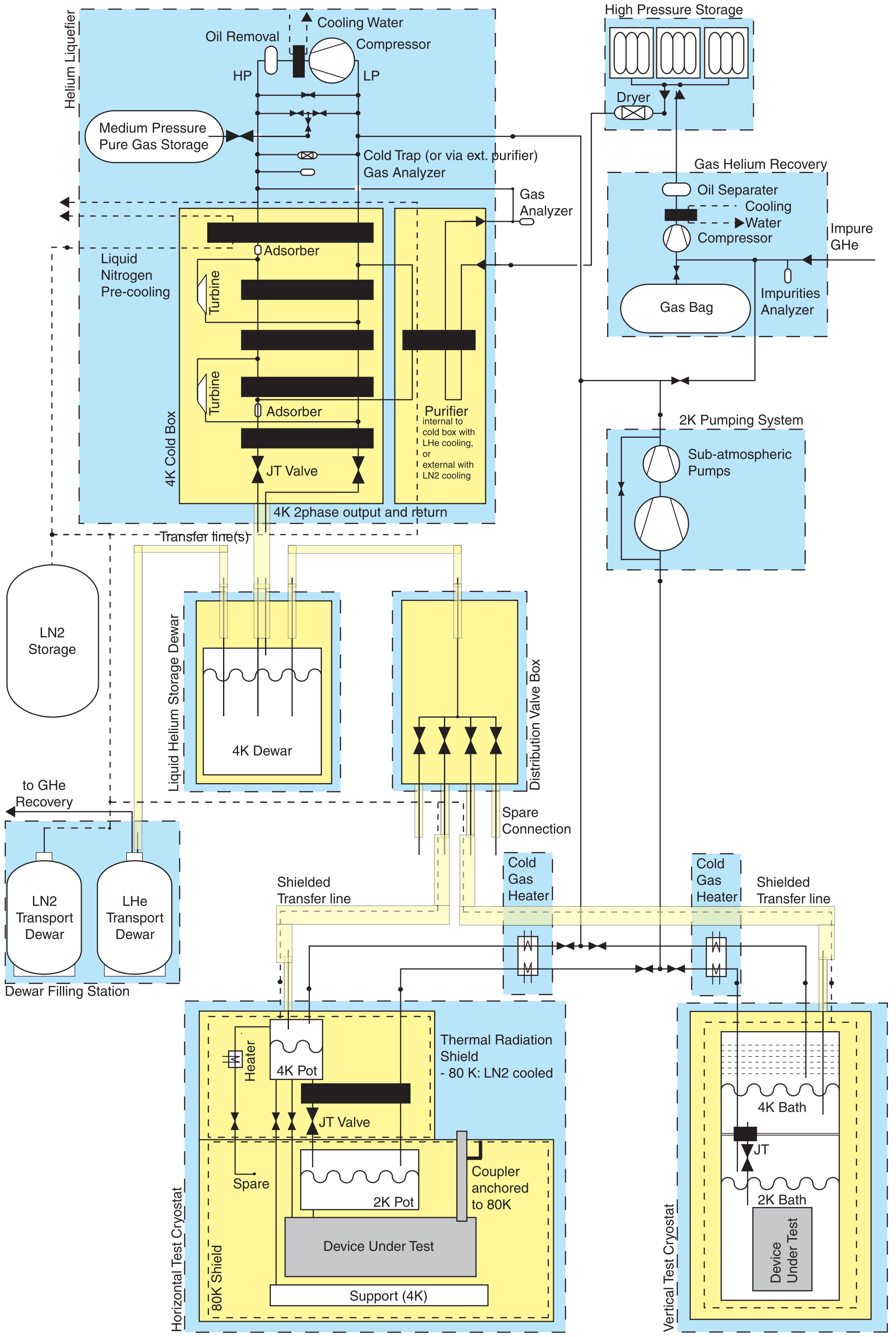

Figure 4: Layout of the cryogenic facility including horizontal and vertical test cryostats.

exceeding the liquefier power, as well as enhancing the filling speed for transport dewars.

The liquid helium used by external users returns as impure gas through the helium recovery system. We foresee that the experiments of all main external users are connected to this recovery system in order to recycle the helium and minimize losses. The recovery system consists of an ambient heater for cold gas recovered from the users, a low pressure gas bag and a small compressor. In addition a gas purifier is required to ensure removal of all contamination from the recovered helium gas. The same gas purifier system is also used during start-up of the helium liquefier plant to clean the helium gas inside the closed cycle of liquefier and test cryostat.

The 2 K liquid helium flow is created inside the test cryostat. To provide 30 W cooling power requires a 1.5 g/s 2 K liquid helium flow. Including losses and accounting for gas helium in the 2-phase flow, we estimate that this requires a 2 times larger 2-phase flow from the 2 K cold box and a 1.5 times larger 2-phase flow from the 4 K liquefier cold box. The required liquefaction capacity is therefore 4.6 g/s at 4.4 K which is equivalent to 140 l/h. The actual liquefier capacity will be in the order of 120 l/h. The 2000 l volume of the liquid helium storage dewar serves as buffer to provide the additional required flow during full dynamic thermal load operation in the test cryostat (i.e. with full RF power on two spoke cavities). The storage dewar is refilled during intermediate breaks when with only static thermal load in the test cryostat.

4 Test Stand Infrastructure

The test stand infrastructure consists of a versatile horizontal cryostat and a concrete bunker for radiation protection purposes. Initially the test stand will contain a single 2 K type cryostat with a horizontal vacuum tank. The cryostat will have a direct connection to the cryogenic facility and a vacuum pumping system. The facility will be designed such that other cryostats, with either horizontal or vertical vacuum tanks, can be added later on.

The design of the initial test cryostat will, with small improvements, be adopted from the CHECHIA cryostat at DESY, CryHoLab at CEA Saclay and the BESSY HoBiCaT facility [2, 3, 4, 5]. These cryostats have been designed for horizontal testing of superconducting cavities at temperatures between 1.8 and 4.2 K with help of an integrated cryogenic feedbox. The thermal radiation shield is typically cooled with liquid nitrogen. The HoBiCaT cryostat is shown in figure 5. This cryostat has an internal volume that is sufficiently large for the installation of two superconducing cavities. It has doors at both ends to allow easy access to the interior volume of 1.1 m diameter by 3.5 m length. The cavities slide into the cryostat on a rolling table. Power couplers can penetrate the vacuum vessel through feedthroughs on the side. Diagnostic ports are provided for additional instrumentation.

The FREIA cryostat is installed inside a bunker with 80 cm thick walls of iron ore concrete (4.0 kg/dm^3), a common Swedish alternative to barite concrete. The bunker will have an internal volume 4 m wide by 9.6 m long and 4.8 m high. This will enable simultaneous installation of both the horizontal test cryostat and the prototype spoke cryomodule.

During the ESS construction phase the FREIA facility is available for test of the complete spoke cryomodules. Testing of the prototype spoke cryomodule has already prepared the facility for the acceptance testing: RF systems have been extensively tested, staff is familiar with installation and testing of a spoke cryomodule. The bunker is designed such that a cryomodule can be installed simultaneous with the horizontal cryostat leaving the possibility open to continue tests on RF systems or a cavity. Cryomodules can enter the FREIA hall through the access door and work space between bunker and cryogenic plant. The bunker wall on that side can be opened to install the cryomodule.

References

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[2] P. Clay et al., *Cryogenic and Electrical Test Cryostat for Instrumented Superconducting RF Cavities (CHECHIA)*, Adv. Cryo. Eng. Mat. **42** (1997) Proceedings of the CEC/ICMC 1995 conference, Columbus. DESY internal report TESLA 95-21 (1995) p.80.

[3] H. Saugnac et al., *Cryogenic Installation Status of the "CRYHOLAB" Test Facility* Proceedings of the SRF 2001 conference, Tsukuba (2001) p.632, PZ007.

[4] H. Saugnac et al., *CryHoLab, A Horizontal Cavity Test Facility: New Results and Development*, Proceedings of the SRF 2003 conference, DESY (2003) p.168, MOP46.

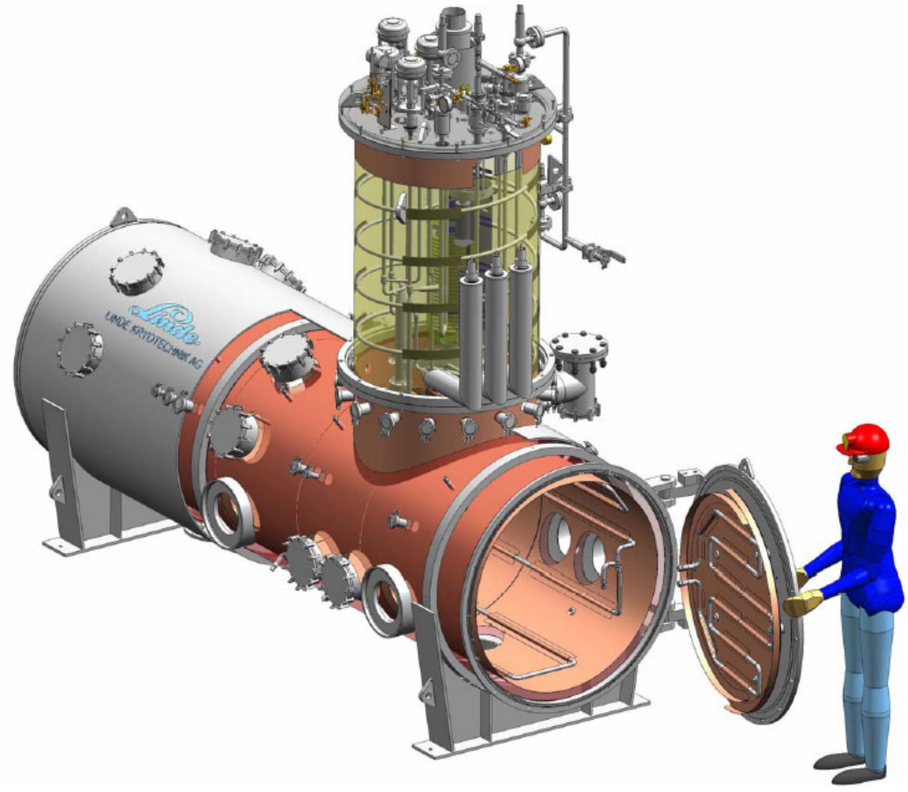

Figure 5: Layout of the HoBiCaT cryostat [5]. The vertical feedbox includes a liquid helium reservoir and 2 K cold box.

[5] J. Knobloch et al., *HoBiCaT – A Test Facility for Superconducting RF Systems*, Proceedings of the SRF 2003 conference, DESY (2003) p.173, MOP48.