LN2 continuous Flow Cryostats, a compact vibration free cooling system for single to multiple detector systems

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ABSTRACT

In comparison to mechanical cryo-coolers, liquid nitrogen cooling has the double advantage to be free of vibration and to remain not affected by power failure.

The paper reports about a very compact cryostat using a continuous circulation of liquid nitrogen which is provided from an external storage tank. Since years, this cryostat is intensively used on the ESO VLT to cool either optical or Infra Red detectors.

After an introduction presenting the principle, the paper reports the performance of the cryostat recorded over many years of utilization. We also present a few additional developments which allow the use of the cryostat for more exotic applications such that Nasmyth rotating instruments or extremely stable radial velocity spectrograph. With the construction of MUSE, a new era has started for this cryostat. The large multi IFU instrument requires 24 cryostats. The last chapter of the paper describes this futurist system which is close to completion.

Keywords: Cryostat, liquid nitrogen, CCD detector

1. INTRODUCTION

This project started in 1988 in preparation of the VLT instrument program. At this time most of the optical detectors (mostly CCD detectors were cooled using bath cryostats. These cryostats were dimensioned in order to guaranty a full day of operation without rush for the morning refilling. This led, generally to use the commercial Dewars from Infrared Laboratory which were significantly larger than the detector housing. The primary idea from this project was to develop a nitrogen cryostat which did not need daily refilling and being nevertheless significantly smaller than the previous ones. Two main solutions were investigated either a small bath cryostat with an automatic refilling of a cryostat using a continuous circulation of nitrogen. The continuous flow solution was selected: Having no volume of LN2 offers a number of advantages which will be developed in more detail in the document.

2. DESIGN, DESCRIPTION

2.1 Basic principle

Figure 1 shows the schematic of the Continuous Flow Cryostat. The CFC includes 3 heat exchangers: i) the cold plate (8), ii) the radiation shield (7) and iii) the warm heat exchanger (9). The over pressure produced by the natural evaporation of the liquid nitrogen in the supply tank (1) is used to circulate the coolant toward the cryostat via a vacuum insulated line (6). The coolant is then circulating in the cold plate (8), which directly cools the chip carrier. The coolant continues via a second annular heat exchanger (7), which surrounds the first one, acts as radiation shield and cools the radiation shield of the detector housing. Before leaving the cryostat, the gas turns in a third heat exchanger (9) where it is warmed up close to ambient temperature in order to avoid any risk of condensation along the exhaust pipe. A PID control loop is used to controller the temperature of the cold plate by action on a small electro-magnetic valve (11) which leaves coolant the possibility to circulate in the tubing. A manual adjustable bypass valve ensures a permanent coolant flow such that it can keep the detector a few Kelvin above the operation temperature. This is especially useful in case of power failure as it prevents a complete warm-up of the detector. A second control loop is used to control the temperature of the gas in the warm heat exchanger.

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In order to keep a good vacuum over a long period of time the cryostat is also fitted with a small sorption pump (small basked filled with active charcoal). A third control loop is required to control the temperature of this pump, which need periodically (~ every 2 years) to be heat-up for regeneration.

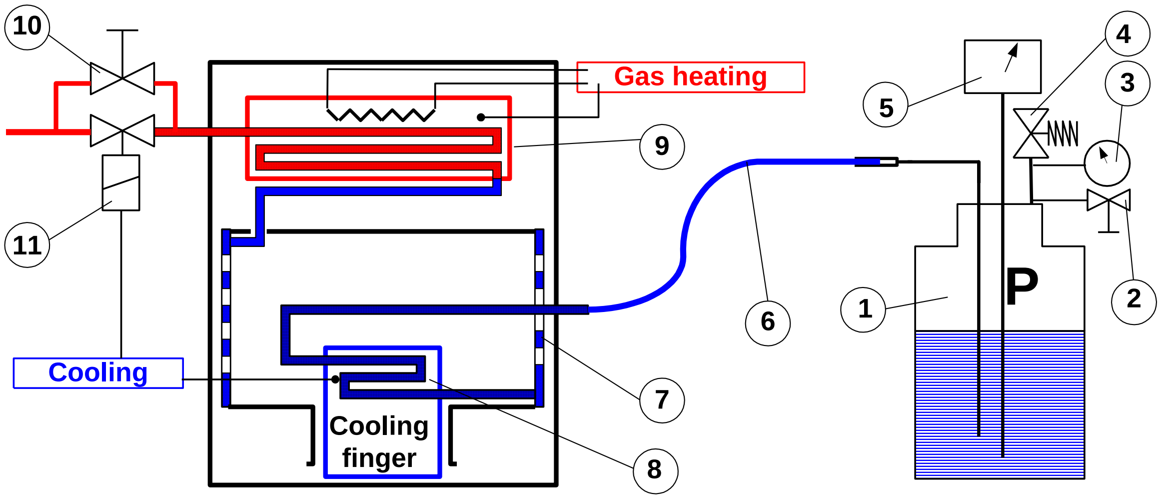

Figure 1: Continuous Flow Cryostat principle1 LN2 storage tank, 2. De-pressurization valve, 3. Manometer, 4. Over-pressure valve, 5. Liquid nitrogen level gauge, 6. Vacuum insulated transfer line, 7. Radiation shield heat exchanger, 8. Cooling heat exchanger, 9. Gas heater, 10. Bypass valve, 11. Regulation valve

2.2 Design, realisation

The first choice was to scarify the security against some flexibility offered by dismountable joints. This selection has been based on the long positive experience gained with the double cutting ring connectors from Swagelock. These connections have been proven to be extremely reliable even at cryogenic temperatures providing the various components are coated with 5 to 10 µm of silver. All components are made from stainless steel, with exception of the main heat exchanger which for thermal reason is manufactured out of copper. Figure 2 shows a cut through the cryostat on which it is possible to identify most of the component described before.

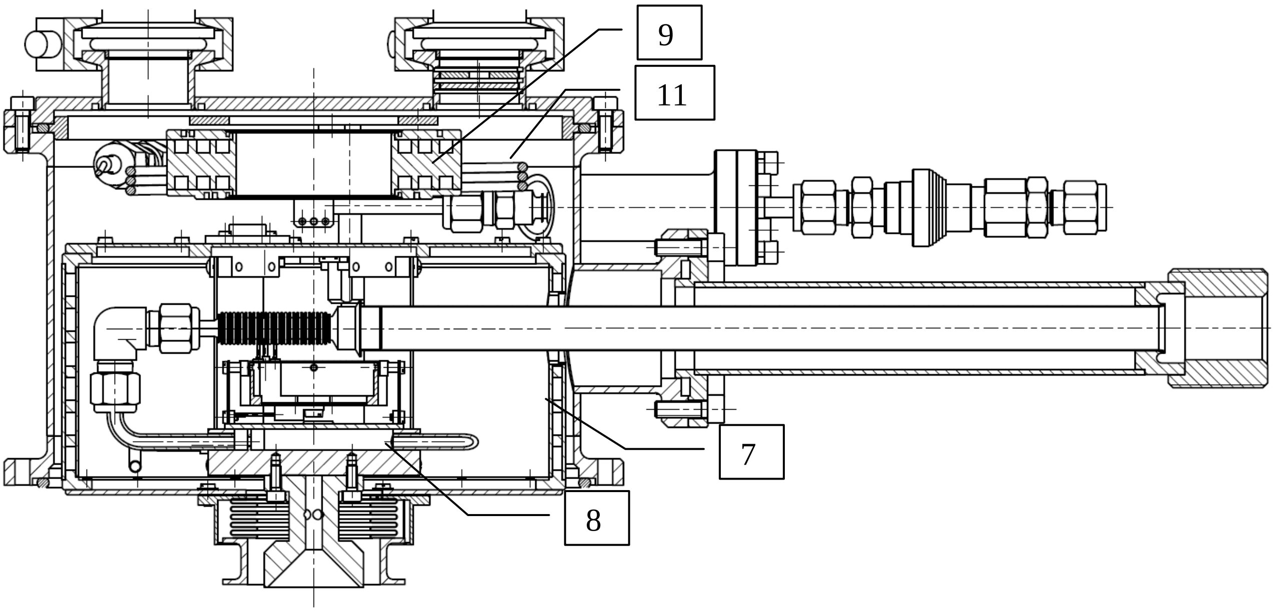

Figure 2: Continuous Flow Cryostat design

2.3 Operation, performance

The system offers a certain flexibility regarding the operating temperature. Generally CCD detectors are operated around 140 K. There is a thermal gap of some 70K between the temperature of the coolant and the final temperature of the sample. This gap can either i) be mainly build in the thermal link between the cryostat heat exchanger and chip carrier or ii) partly to equally distributed. This leads in the first configuration to a heat exchanger operated around 77K and in the second solution a heat exchanger operated around 100K. From a point of view purely thermal, the cryostat would clearly perform better close to the liquid nitrogen temperature. At such temperature we would fully benefit from the enthalpy. In practice due to the dominating heat lost in the line, the cryostat operates better at a temperature slightly higher than the one of the phase transfer of LN2. Figure 3 shows the consumption of nitrogen measure on this cryostat fitted with a small 8 cm^2 CCD detector.

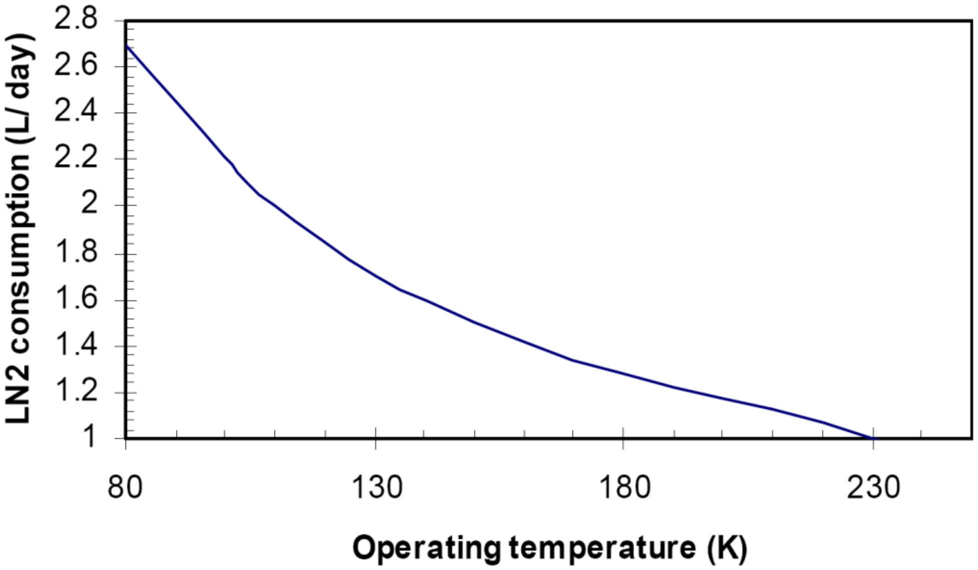

Figure 3: Nitrogen consumption

After more than ten years of experience we have a well consolidated figure of the real performance. Considering the two ESO observatories and the detector test laboratories a total of more than 15 cryostats are permanently operated with a very low rate of failure. Originally designed to cool optical detectors the cryostat has also been used successfully for Infra Red applications (NACO IRWFS). In such case a lowest temperature of 83 K can be reached.

The small tube (ref. 11 on figure 2) which ensures the connection between the gas heater and the shield heat exchanger remain one of the most important sources of problem. This tube which has a restricted cross section in order to minimize the thermal load tends to clog while not enough care is taken to the cleanliness of the supply tanks.

3. APPLICATIONS

The original idea was to develop a compact and vibration free cryostat, which does not require daily human intervention. For these characteristics, this cryostat has been selected to equip a number of the ESO instruments. The following chapter gives a short description of the most interesting applications.

3.1 High resolution spectrographs

This is certainly the most obvious application for this cryostat. A high resolution spectrograph can only perform optimally if it is in a stable environment. Every human intervention is a source of un-stability. It is also hardly conceivable to use a mechanical cooler in a thermally stabilized environment.

Among the high resolution spectrograph UVES (Ultra violet and Visible Echelle Spectrograph) with a spectral resolution over 100 000 is one of the most sensitive to any sorts of disturbances. For this reason the instrument is enclosed in a thermal enclosure. The two detectors are cooled using Continuous Flow Cryostats. A special feed-through is used to penetrate the feeding line into the thermal enclosure. This feed-through includes the nitrogen vacuum insulated line, the vacuum line and the gas out let. In this particular case in addition to the de-location of all human interventions, one other significant advantage of this system is the constant weight. The cryostats are, as usual directly supported by the camera which are mounted themselves on a tilting mechanism in order to select the spectral range. Due to the very high accuracy required the stability of the spectrum would certainly be affected by any change of gravitational load. This reason was sufficient to fully disqualify the use of a bath cryostat.

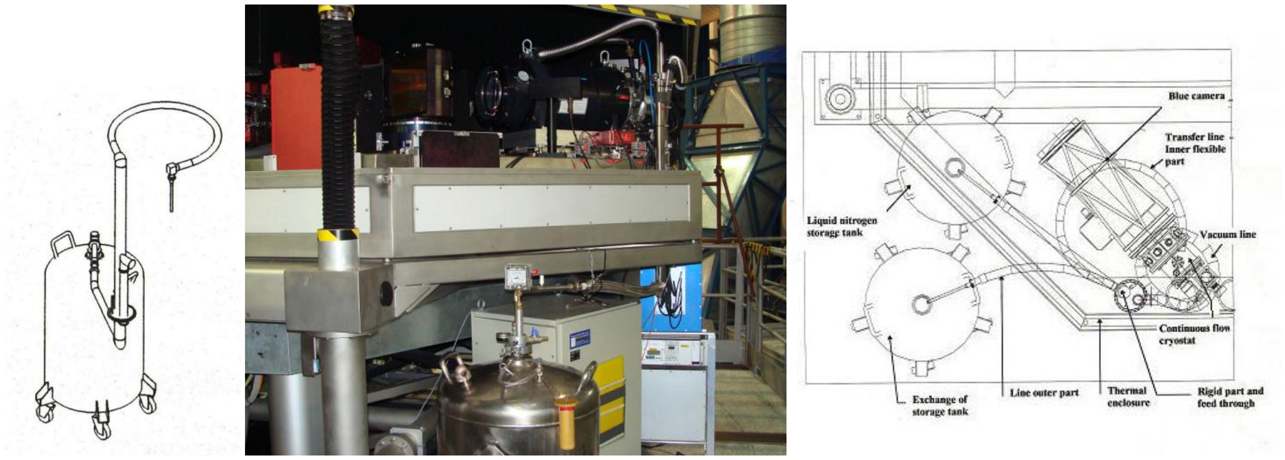

Figure 4: UVES arrangement

3.2 Nasmyth rotating instruments

If, for reason of vibration, one excludes the use of mechanical coolers, the cooling detectors on a rotating instrument become a problematic issue. Because a bath cryostat can only be filed up to the middle it needs always to be twice as big as necessary. The continuous flow system is an attractive solution, providing a can be found to supply the nitrogen. A long line routed through the cable wrap is a poor alternative. Such a line, with at least 10 meters length, would have a strong impact on the nitrogen consumption. A double wall vacuum insulated line would also require a rather long curvature radius. This would impose a re-design of the present standard cable wrap which houses only cable, cooling tube and Helium gas lines. Finally a rotating feed-through has been build. The design is based on a thermal insulated bayonet joint (known also under the name of Johnston fitting).

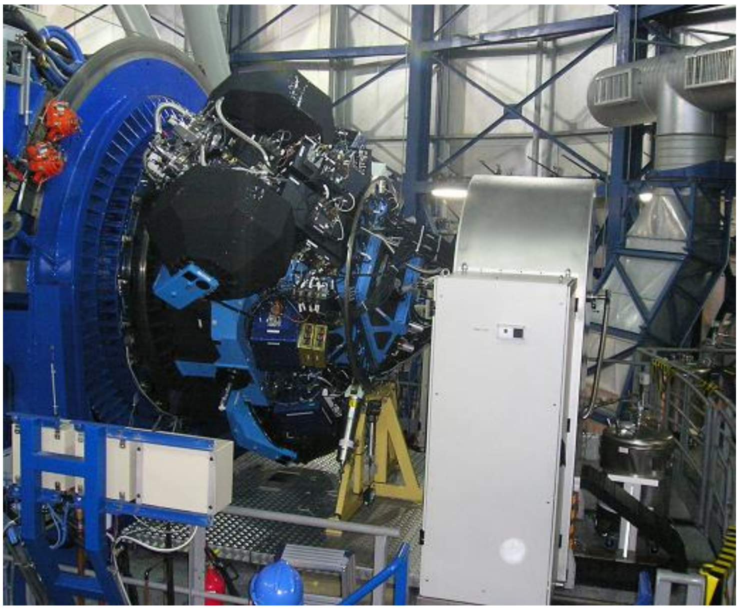

Figure 5: VIMOS (Visible Imager and Multi-object spectrograph)

This new development open the way to the application of Continuous flow Cryostats on rotating instruments. Up to now three instruments are operated with this mode: NACO with two cryostats, VIMOS with 4 CCD cryostats (see figure 5) and the REM camera at La Silla with one cryostat

3.3 Multiple detector system

MUSE, one of the second generation instruments for the VLT is a large 3D spectrograph. MUSE combines 24 spectrographs in order to be able to probe a field of view as large as possible. Each spectrograph is equipped with 4000 x 4000 pixel detectors — the largest detectors used at ESO. Right at the start of the project various alternatives have been envisaged to cool this battery of detectors. After careful comparison with a few other designs, the continuous flow system appears to be the safest solution for this instrument. Despite the complexity of the “tubing” and the somehow high operational cost this system can guaranty a very smooth and reliable operation.

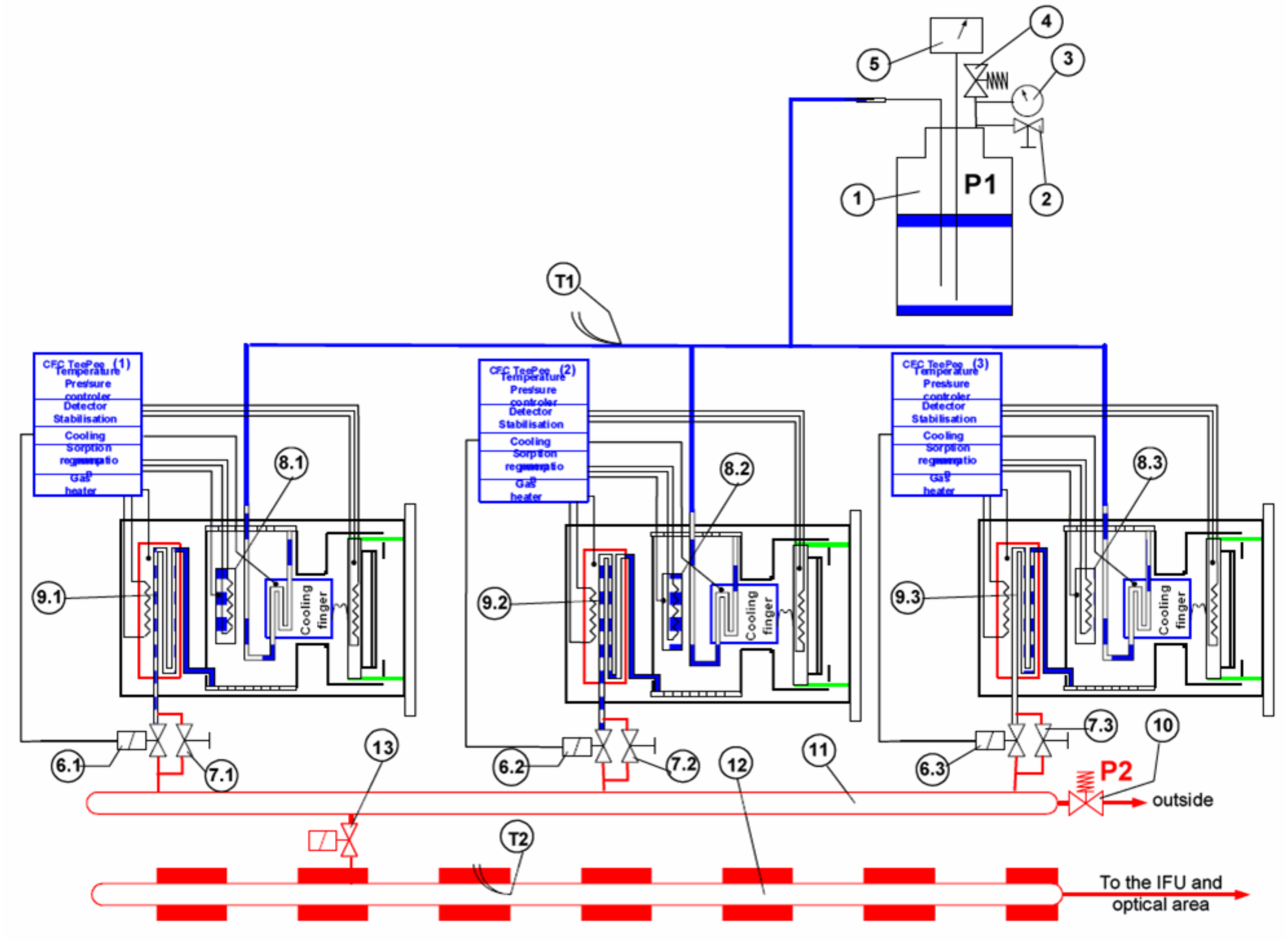

Figure 6: Schematic view of multiple cryostat system

Figure 6 shows a schematic overview of such a multiplexed system. For the specific case of MUSE, which hosts some very sensitive image slicers, a specific feature has been implemented to use the cryostat exhaust gas as protective atmosphere inside the instrument enclosure. The gas which leaves the cryostats is collected in the exhaust container (**11**). An over pressure valve (**10**) is used to stabilize the pressure (**P2** = 0.1 bar) in this container. When the instrument is used in a small laboratory, it is very important to direct the gas leaving the safety valve to the outside to prevent any dangerous situations. The gas from the container has a second way to escape: it can leave to a second container which is fitted with thermal exchanger plate in order to be permanently at room temperature. This passive temperature stabilization container (**12**) will supply clean nitrogen gas at room temperature to the optical area in order to avoid any contamination or degradation of the optics. A temperature sensor (**T2**) is installed in every gas exchange container. It will measure the temperature of the gas and in case the temperature is lower than a limit temperature it will not allow the gas anymore to circulate in the IFU. The valves (**13**) will be closed.

In this complex system a few additional features have been implemented to increase the reliability. An example is the additional temperature sensor (**T1**) is used to monitor the temperature of the outer skin of the LN2 transfer line. In case this temperature drops below a certain critical point, the system will give a warning which can be used to plan a vacuum regeneration of the line.

Figure 7 shows a view of the VCS (Vacuum Cryogenic System) of MUSE during the assembly test phase in the ESO laboratory. The first test has proven the feasibility of running 12 cryostats on a single distribution line. The distribution line has been designed with a special internal geometry to ensure a homogeneous distribution of the coolant independently to the position of the cryostats.

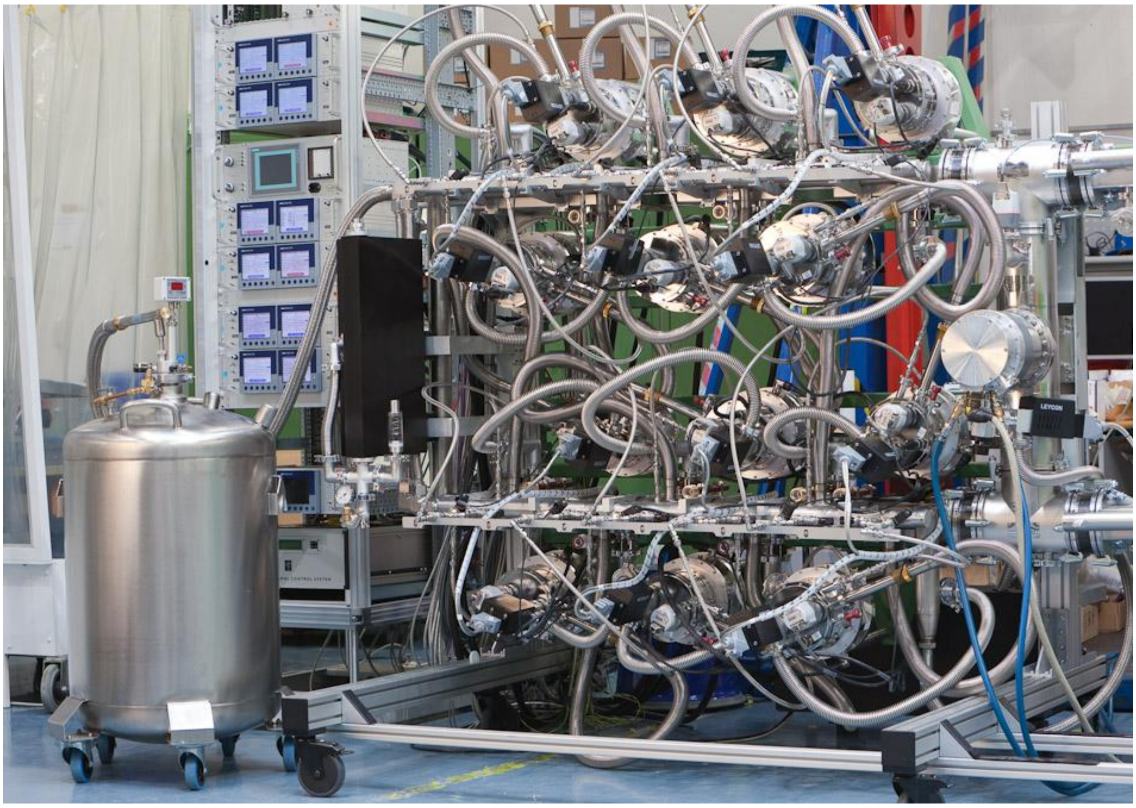

Figure 7: MUSE Vacuum Cryogenic System

Actually, after the first basic verification, the system test is progressing with the performance testing. Safety and reliability of the vacuum and cryogenic combined system will also be verified before connecting cryostat with real detectors. Today we can already confirm that most of the main goals have been reached.

The vacuum system is performing well. The complete evacuation of 12 cryostats from atmospheric pressure down to a pressure where cool down can start without any danger of contamination is carried out within less than 3 hours; (requirement $t < 5$ hours)

The cool-down of the 12 cryostats runs also very smoothly, it takes less than within 3 hours to have the 12 detectors stabilized at operating temperature; (requirements: $t < 5$ hours)

Running the CCD at the ideal operating temperature of 163K a standard supply tank has a total hold time of around 40 hours; (requirements: $t > 30$ hours)

This first test shows that in case of serious problem the complete detectors system can recover normal operation within less than 1 day.

4. AKNOWLEDGEMENTS

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