Nika2 Training. dj

Introduction.

NIKA2 (New IRAM KID Array 2) is a dual-band camera operating with three frequency-multiplexed kilopixels arrays of Lumped Element Kinetic Inductance Detectors (LEKID) cooled at 150mK. NIKA2 is designed to observe simultaneously at wavelengths of 1.15 and 2.0 mm. In addition, it allows for polarization observations at 1.15 mm.NIKA2 is built by an international consortium, led by the Institute Neel (Grenoble, France).

NIKA2 was installed at the IRAM 30m telescope in October 2015 and after several upgrades, tests, and commissioning, NIKA2 has been offered to the astronomy community for total power observations since October 2017.

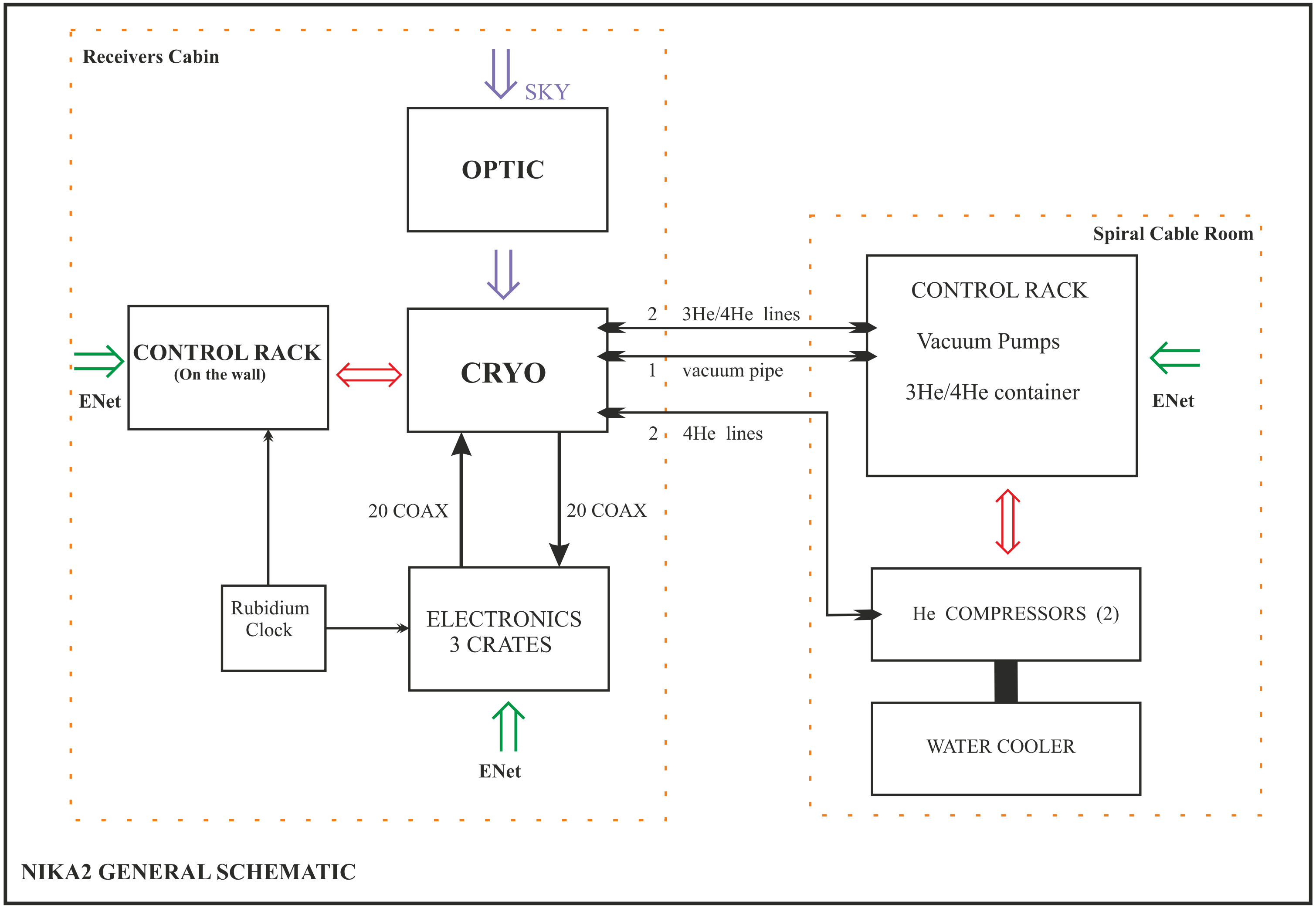
Testing and commissioning of polarimetry at 1mm is still ongoing in 2020.

Overview.

Band	Number of KIDs	Wavelength	Bandwidth	NEFD	HPBW	FoV
2mm/150 Ghz	616	2.00 mm	125-170 Ghz	8 mJy*s1/2	17.7''	6.5'
1mm/260 Ghz	2x1140	1.1 5mm	240-280 Ghz	33 mJy*s1/2	11.2''	6.5

Wavelength (mm)	2.0 mm	1.15 mm
Average KID per feed-line	255 (based on 1020 pixels)	142.5 (based on 1140 pixels)
Number of boards.	4	16
Power consumption (W)	370	1220
Tone tuning resolution (Hz)	953	953
Frequency range (Ghz)	1.3-1.8	1.9-2.4

NIKA2 GENERAL ARCHITECTURE.



NIKA2 component breakdown.

OPTICS.

Telescope focal plane is re-imaged to the KID arrays by:

* 2 mirrors M5 and curved M6 at room temperature.
* 2 curved mirrors M7 and M8 at 50K.
* A stray light baffle between 50 K(30K) and 4K.
* A HDPE lens at 1K.
* A 30 cm dichroic at 150 mK to split the beam into two bands.
* HDPE lenses and a grid polarizer to split the 1mm band into H and V polarizations (the kid arrays are able to receive both polarizations).
* Out of band frequencies are filtered by multimesh filters at all stages (30K,4K and 1K) while IR filters at 300K, 70K and 30K
*Radiation screens at 1K (still), 4-5K stages and 30K and 70K stages.

Cryostat. CLOSED CYCLE SYSTEM AND FULLY REMOTELY CONTROLLED.

* ~ 1300K g in weight including 2 pulse tubes, optical elements, radiation/magnetic screening, kids, cabling, valves and dilution fridge – thousands of parts.
* Pulse tubes (cryomech PT415) 2 stage coolers offering 1.5W @ 4.2K and 40W @ 45K each (cryomech specs.,.) and working in parallel cooling down to a bass temperature of 3K, sufficient to start the dilution process.
* cool-down time 5-6 days with an extra day 1 to 2 days for complete thermal stabilization of low thermal conducting components (lenses, filters and baffle coating).
* Dilution fridge is capable at operating at a 4K temperature input and is capable of reaching base temperatures of 150mK for the operation of the KID detectors.
* 1 month continuous cold operation possible - need more run data to confirm this statement.
* 0.1 mK RMS temperature stability in a 15 minute time period is possible.

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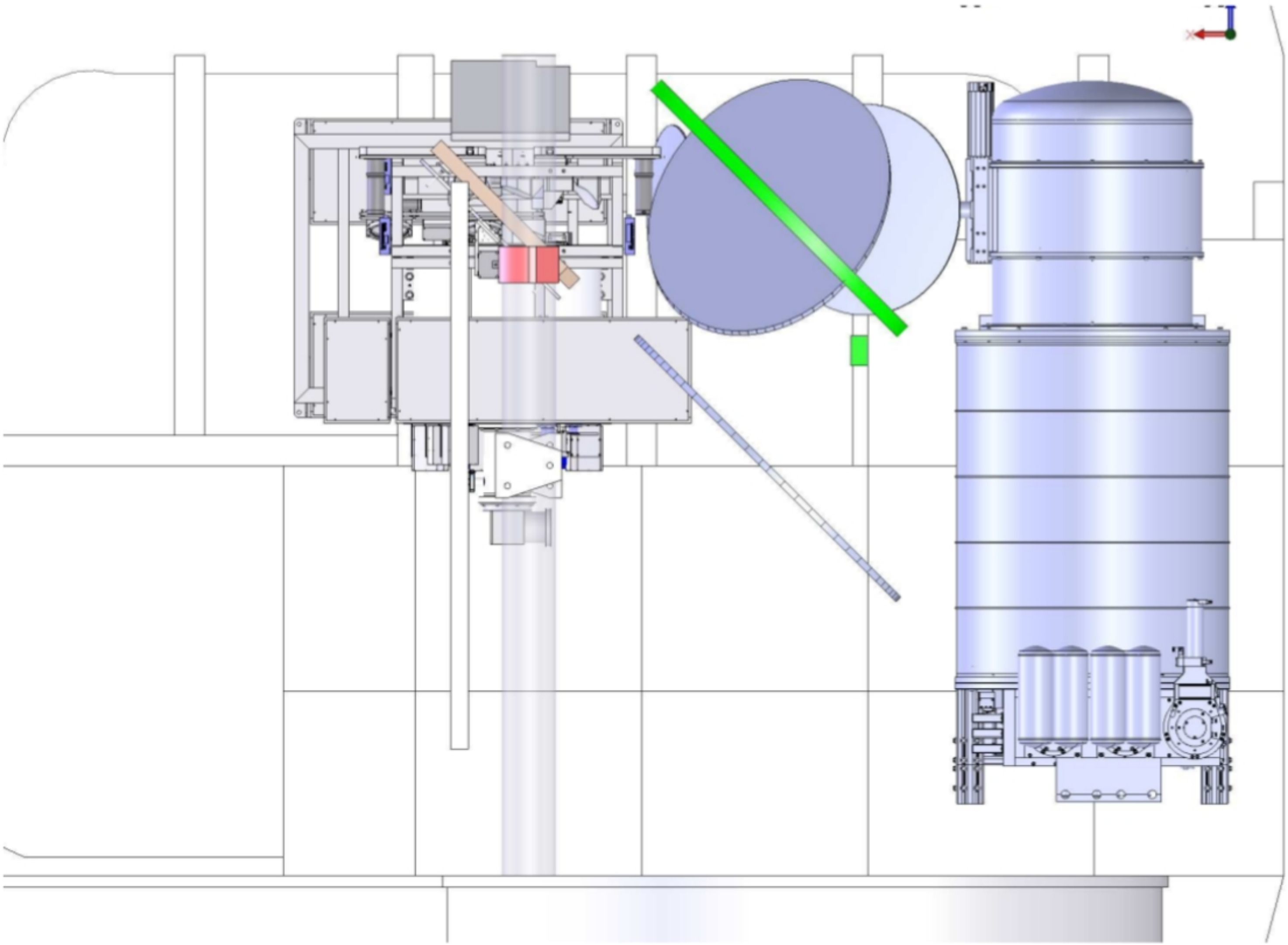
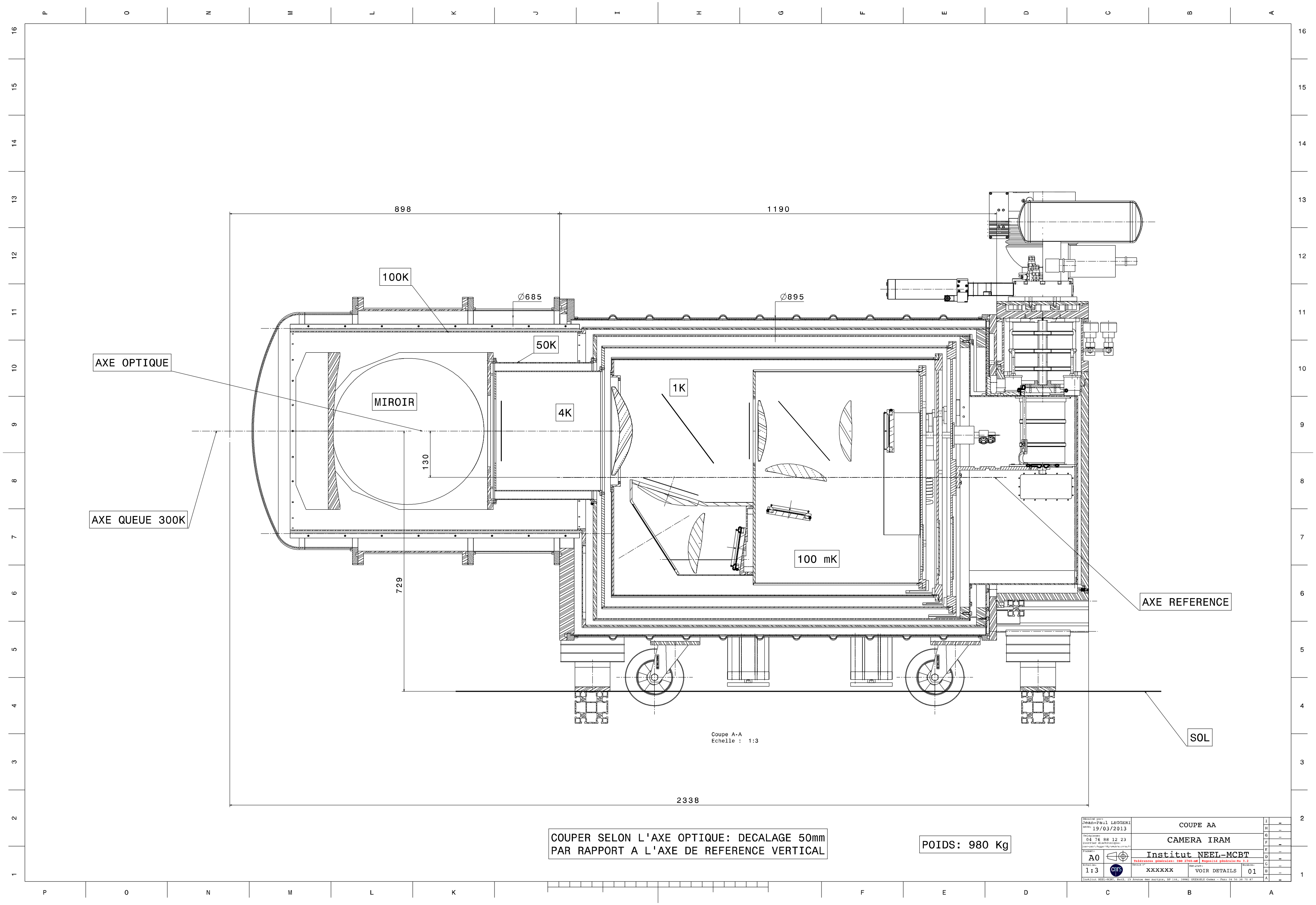
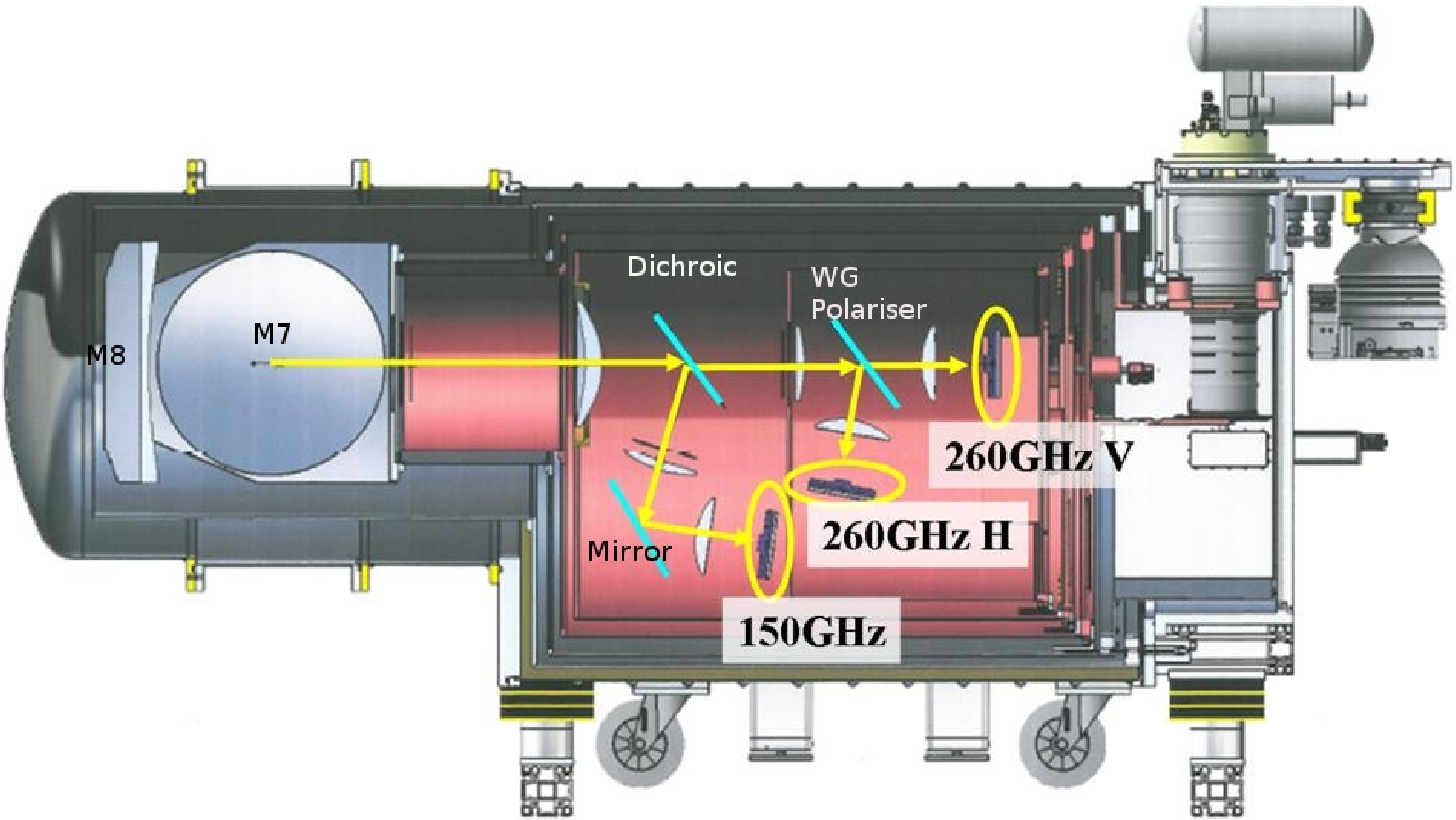
NIKA2 Top view- external optics.



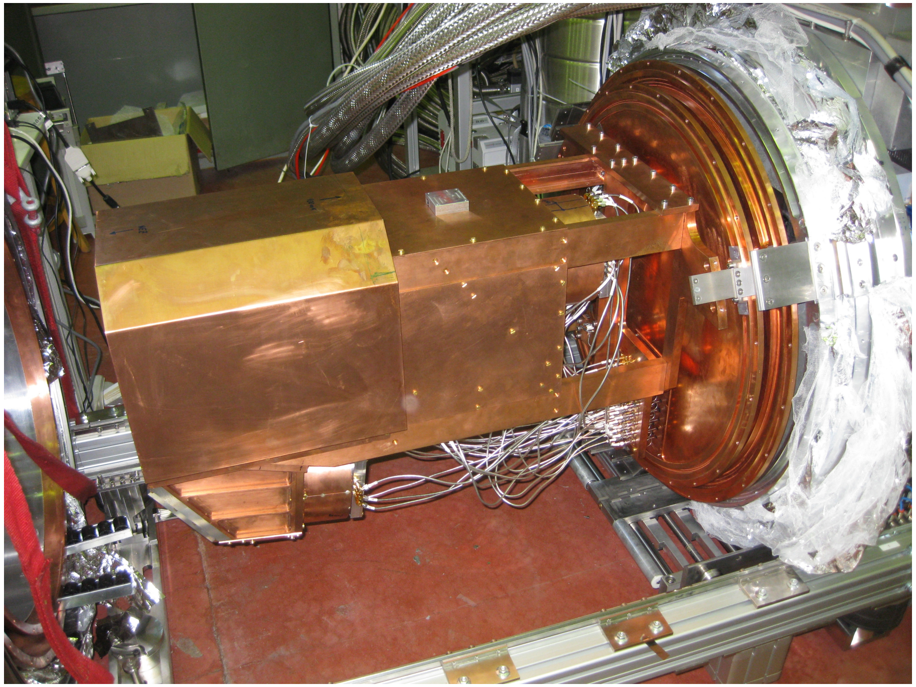
NIKA2 CRYOSTAT AND INTERNAL OPTICS.

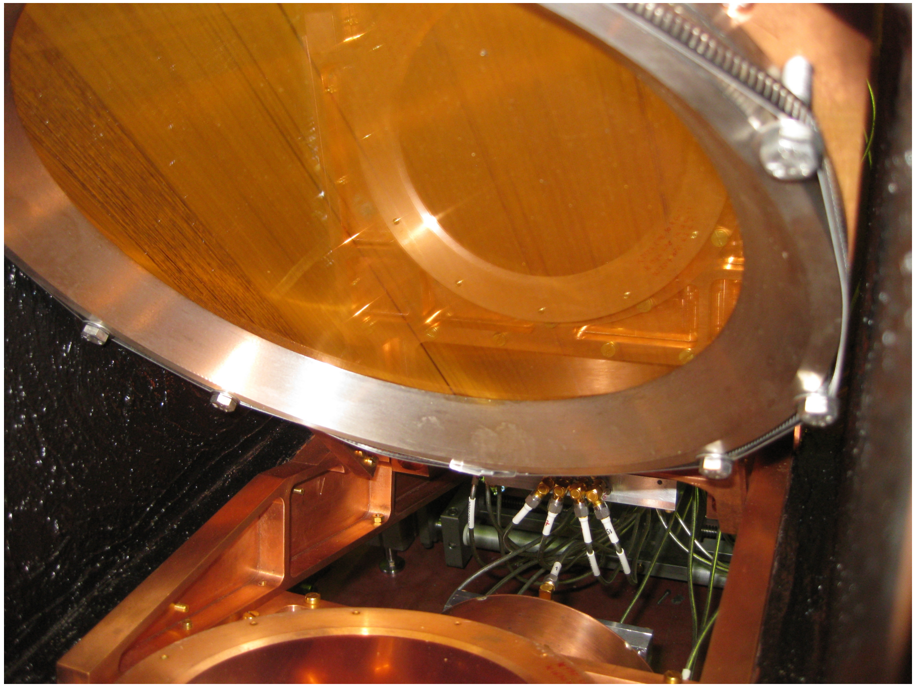


NIKA2 CRYOSTAT AND INTERNAL OPTICS.



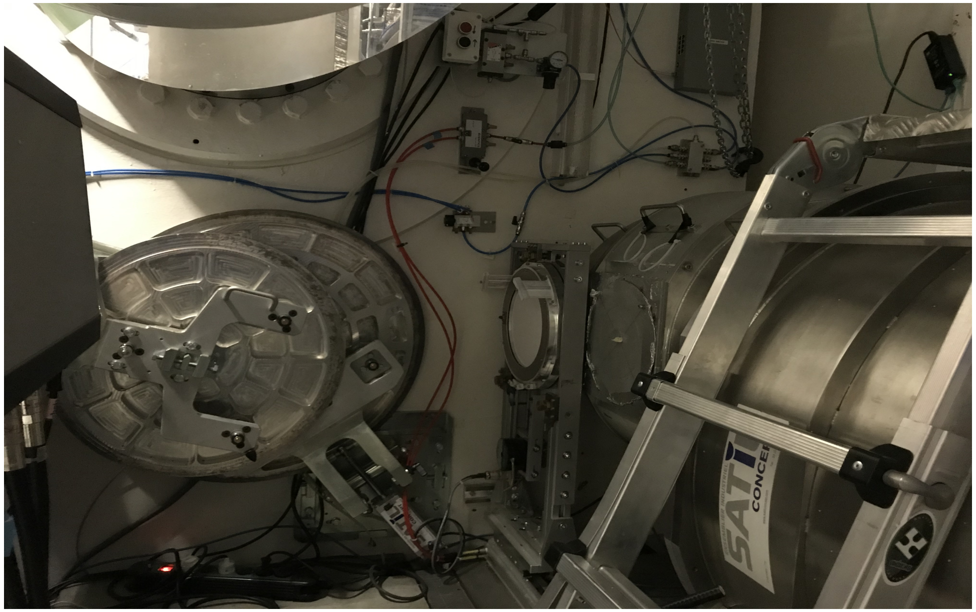
Cryostat Internal

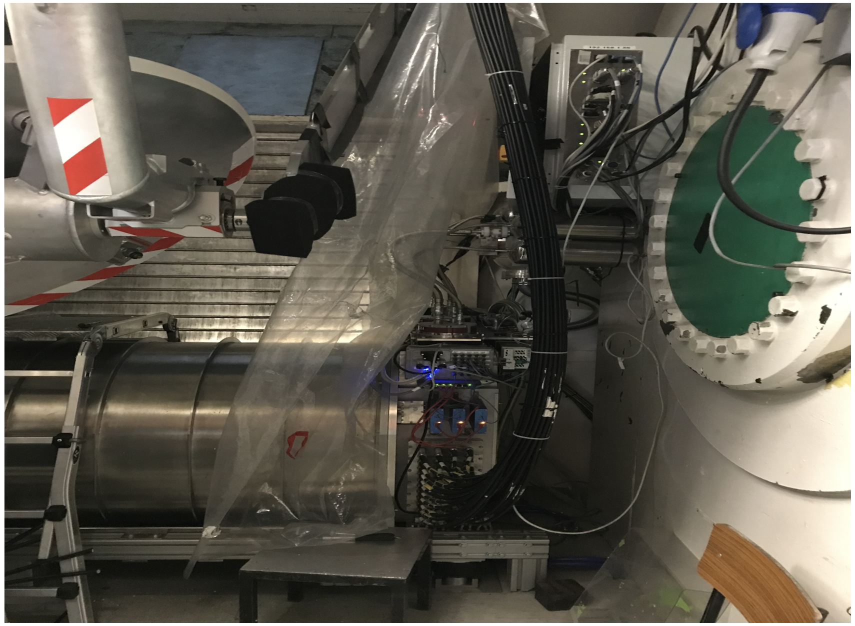


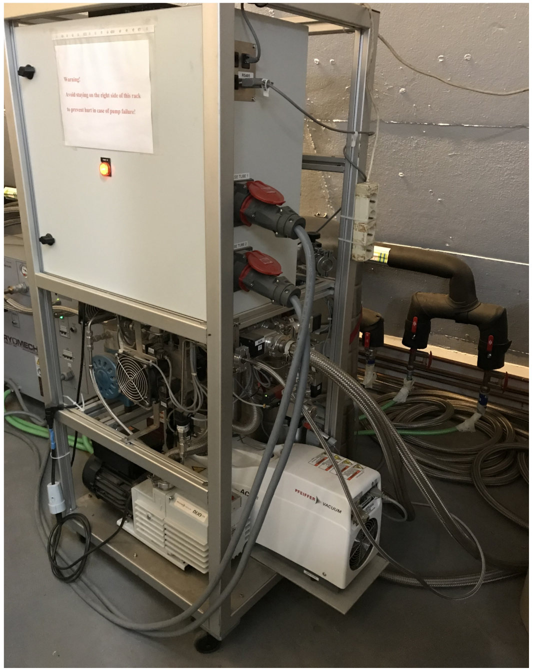


Wire grid polarizer for 1.15 mm band at 150mK

INSTRUMENT LOCATION.







Kinetic inductance detector (KID).

* A KID is a properly shaped superconducting film able to change his surface impedance in consequence of radiation absorption which translates to a change in the kinetic inductance of the cooper pair.

* In certain metals below its superconducting critical temperature,Tc, electrons bond to form Cooper pair. The breaking of these pairs lead to 2 electrons called quasi particles which coexist with the cooper pairs.

* Incident photons with energies greater than twice the superconducting energy gap will break the Cooper pairs leading to an increase in the quasi-particle density. For very thin films this increased density causes a change in the surface impedance of the material which alters the kinetic inductance associated with the kinetic energy of cooper pair.
(accelerating Cooper pairs accumulate kinetic energy which translates, electrically, into an additional inductance term named "kinetic inductance")

* Integrating the thin film into an LC resonant structure, an inductance change will shift the natural resonance frequency of the KID. The shift in resonant frequency is directly proportional to the input power

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}.$$

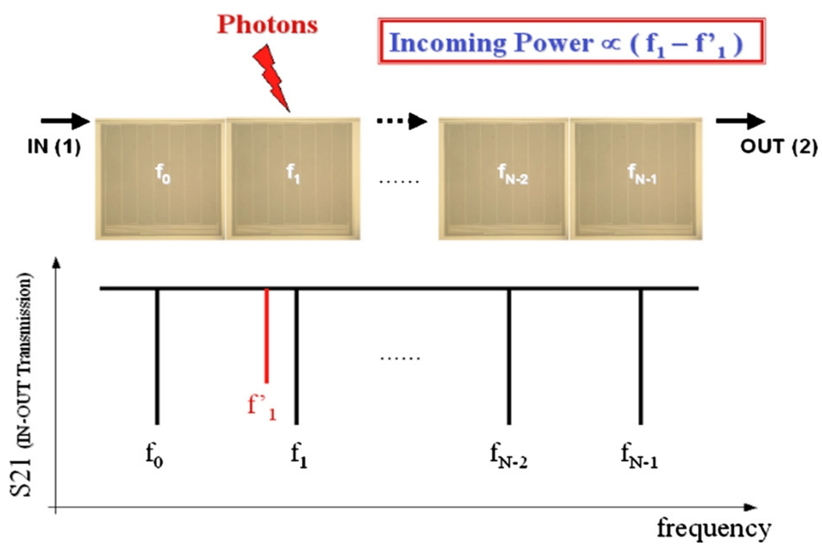
*In superconductor resonators very high quality factors Q can be obtained giving the possibility of placing thousands such resonators, tuned by design at different frequencies, on the same readout/excitation line.

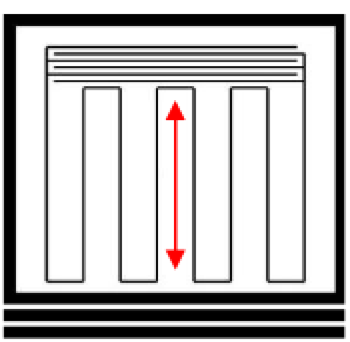
* Resonant frequency and Q of the KID depends on the the shape of the resonant section and on the the coupling area between resonator and feed-line

* NIKA 2 uses Lumped Element KID or LEKID comprising of an inductive meander section
and a interdigital capacitor. The meander exhibits little current variations along its length and can be shaped to act as a radiation absorber. By tuning the width, the geometry and the number of meandered lines, one can impedance-match the absorber to the free space impedance of the incoming wave with quantum efficiencies greater 90 %.

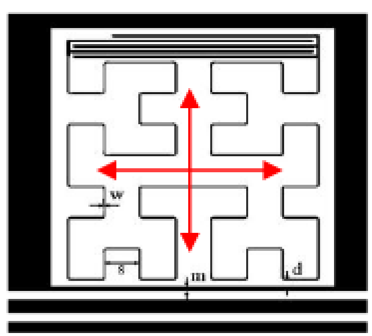
*.A Hilbert fractal geometry is used giving a device sensitive to both polarization..

Kinetic inductance detector (KID).

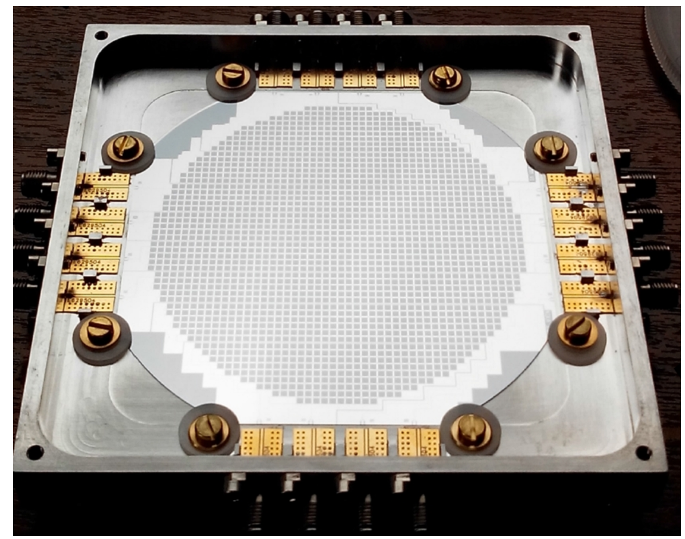




Standard LEKID



Hilbert LEKID



1020 pixel array of NIKA2

KID readout electronics.

Electronics 3 crates.

* Readout electronics: The readout comprises coaxial cables connected from 300 K to the base temperature, 20 low-noise cryogenics amplifiers (LNA) installed in the 4 K stage, and warm electronics.

* The warm electronics consists of readout boards named New Iram Kid ELectronic in Advanced Mezzanine Card format(NIKEL AMC), central, clocking and synchronisation boards (CCSB) mounted on the MicroTCA CarrierHub (MCH) and one 600 W power supply. These boards are distributed in three micro-Telecommunication Computing Architecture (MTCA) crates. In order to readout 3300 pixels, NIKA 2 is equipped with 3 crates hosting 20 boards (8X2 for arrays at 1.15 mm and 4x1 for 2 mm array).

*A NIKEL AMC board works with 6 separate Field Programmable Gate Arrays (FPGAs) each coupled to a Digital to Analog Converter; they can generate a comb of frequencies each over a 500 MHz bandwidth each set to the resonant frequency of a LEKID in a feedline. The comb is then up-converted by mixing with a local oscillator carrier at the appropriate frequency. The output line is down-converted to the base band and is acquired by an Analog to Digital Converter (ADC), and then compared to a copy of the input tones kept as a reference in order to extract the in-phase (I) and in-quadrature (Q) signal.

*Each board is capable of exciting/reading 400 KIDs over 500Mhz.

* Frequency range for 2mm band : (1.3-1.8) Ghz.
* Frequency range for 1mm band : (1.9-2.4) Ghz.

NIKA2 calibrator.

* Calibration source to uniformly illuminate all the NIKA2 detectors with a known, calibrated flux. By alternatively switching the source on and off, a small signal will be induced on the detectors. Measuring the amplitude of this effect translates a frequency shift of the detectors to the corresponding optical power received from the sky.

* In order for the source to correctly illuminate all pixels, the calibrator is mounted at the center of the secondary mirror, in the small cylinder that is present in the 'blind spot'.

* The 2mm channel is a monochromatic source at 139.5 GHz and 170.5 Ghz with circular polarization.

* The 1mm channel has two lines, at 232.5 GHz and 263.5 GHz, and is linearly polarized since the KID array accepts both polarizations.

* The signal power emitted by each channel should induce a signal on each detector of roughly 1KHz. This correspond to the signal given by a $\Delta T \sim 1K$ at 2mm, and $\Delta T \sim 0.5 - -1K$ at 1mm.

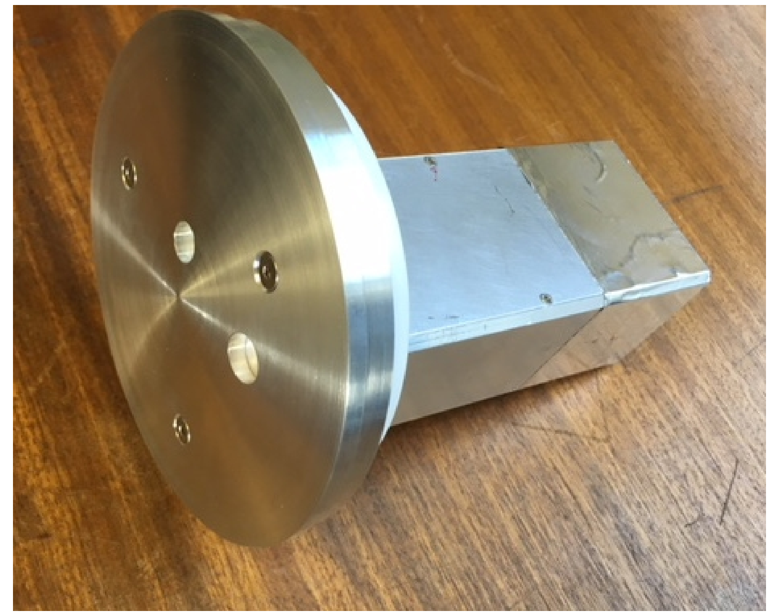
* The calibrator is connected to a control box, based on an Arduino card. The Arduino box provides an interface that is accessible via TCP on the network and allows the full remote control of the calibrator. The IP address of the Arduino is 192.168.1.70

*The program to control the calibrator is called 'CalibratorController.exe' and is available on the NIKA2 PCs '.31' and '.38'. It allows to:

• turn the power of the calibration module on or off
• control the temperature and choose the current on the heater for temperature regulation
• switch each individual calibration channel repeatedly on/off with a signal synchronized to the NIKA2 acquisition.

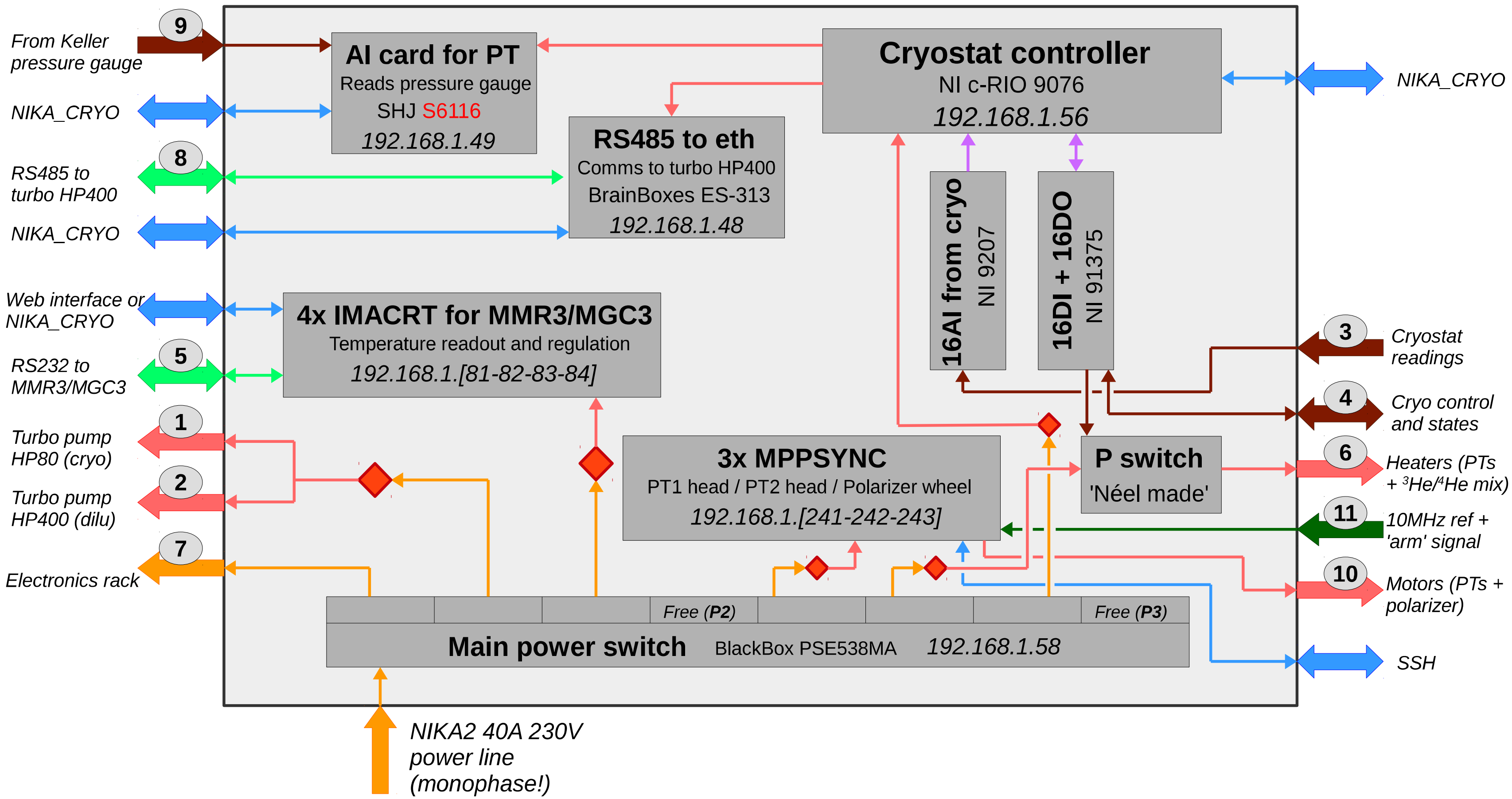
* The Arduino control box is located in the cabin near to the NIKEL readout electronics racks.

NIKA2 calibrator.

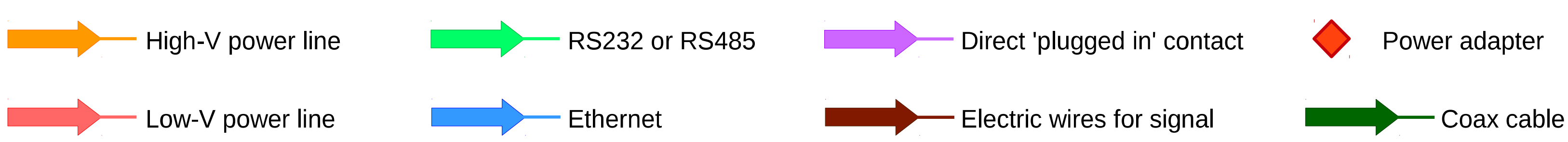


The NIKA2 calibrator module, seen from the front. The two small holes in the front cylinder are aligned to the output of the 1mm and 2mm calibrator sources. The white ring visible on the back of the cylinder is the PVC support used for thermally isolating the module.

Slide1

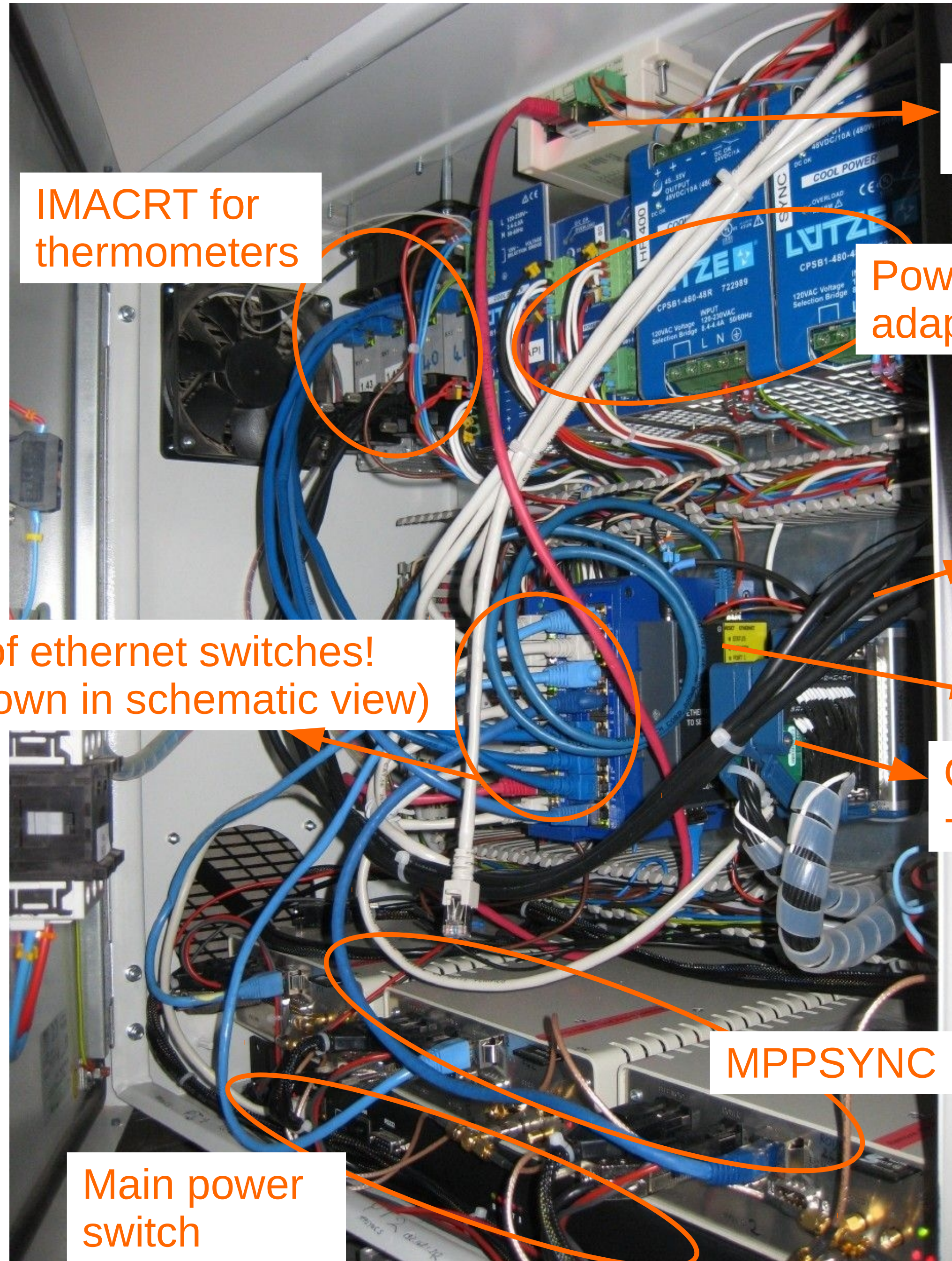


NOTES: - all Ethernet connections actually pass through a switch, so that only 1 Ethernet cable connects this box to the rest of the NIKA network!
- the numbers are used to show where each of the outputs is located on the main 'interface panel' (see page 3!)
- the wires of numbers 1, 3 and 4 actually pass through an extra 'interface' stage shown in page 4. This stage is detailed in the file called 'cablingConnectorsBoxOnCryo_updated.pdf'



slide2

Global view of cryostat electronics box



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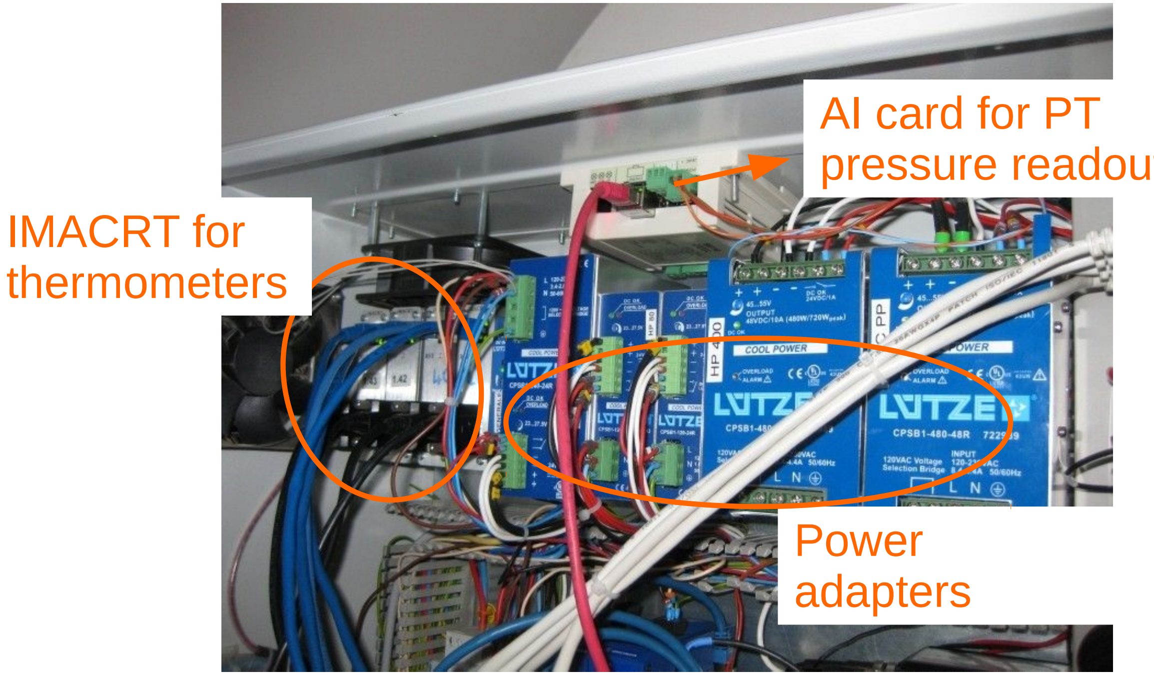
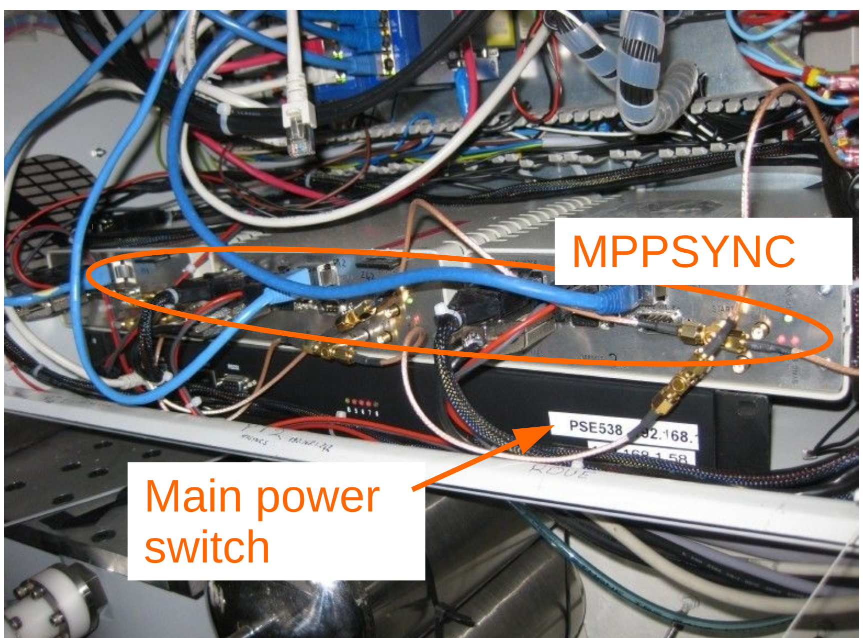
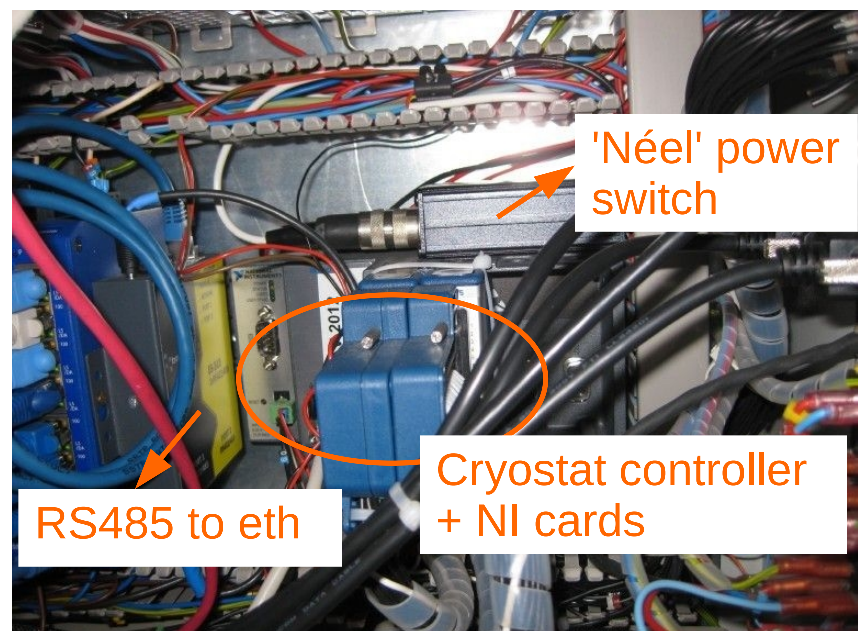


Zoomed views of cryostat electronics box





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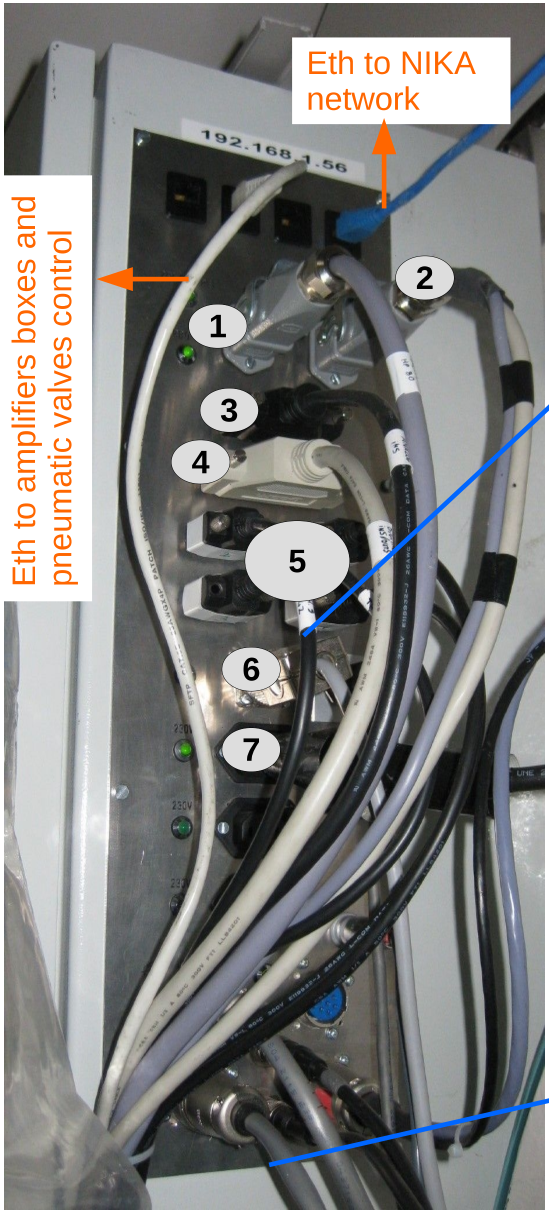
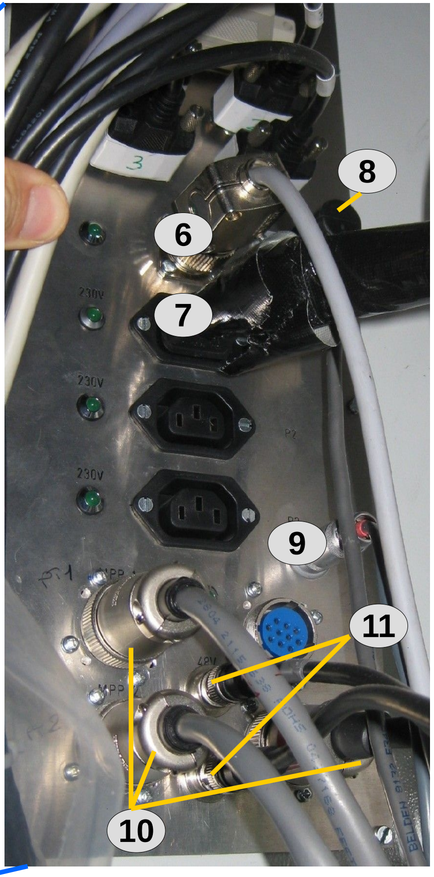
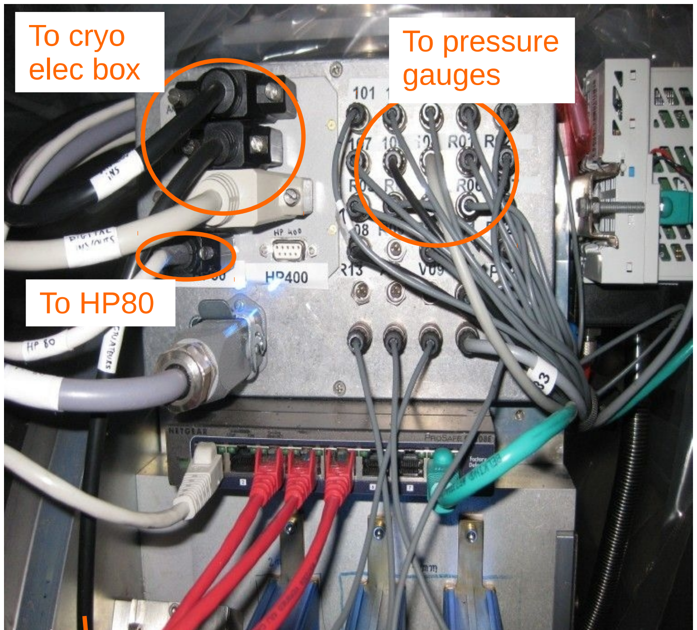


Connector panel on the cryostat electronics box

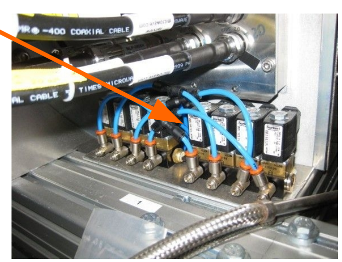


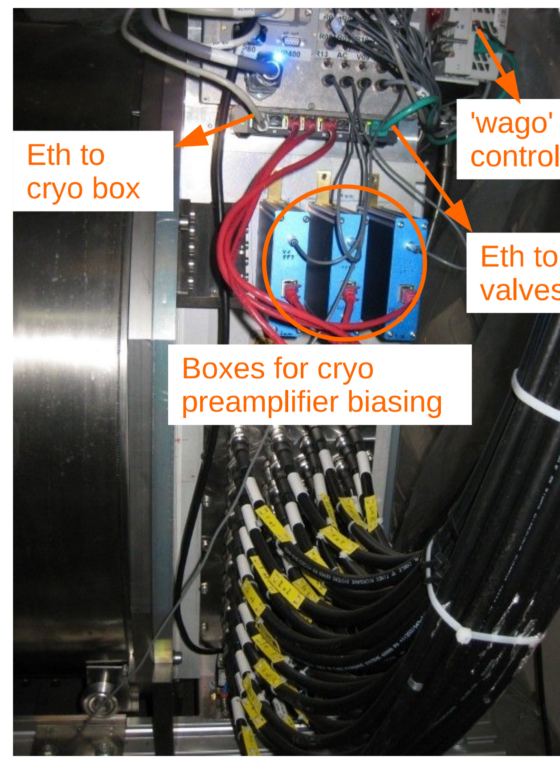
slide5

Cryostat side: main connections / components



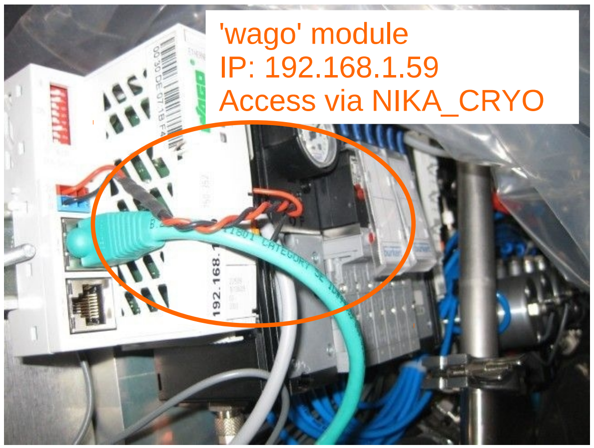
To pneumatic attenuators for cryostat inclination control

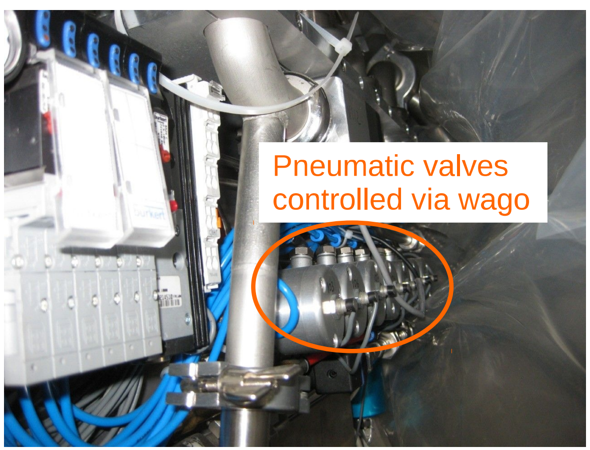


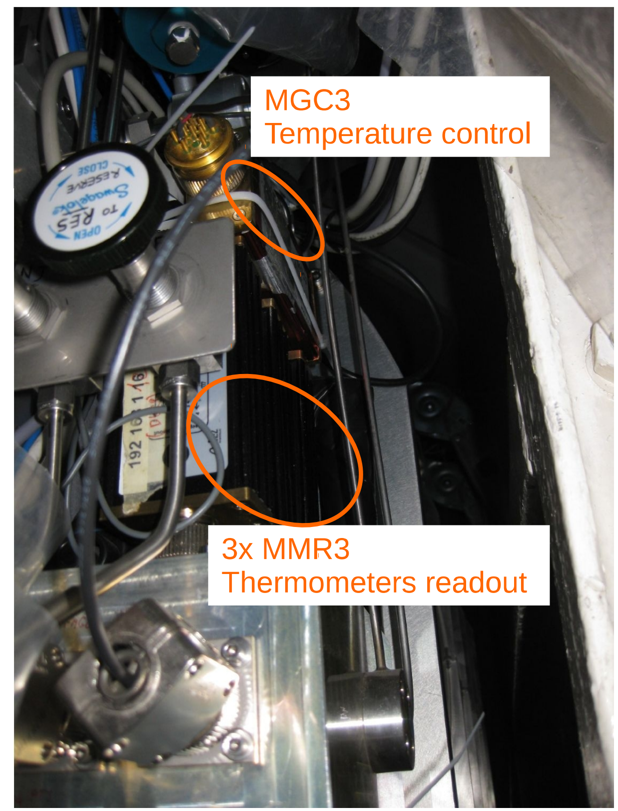


slide6

Cryostat back:
main connections /
components

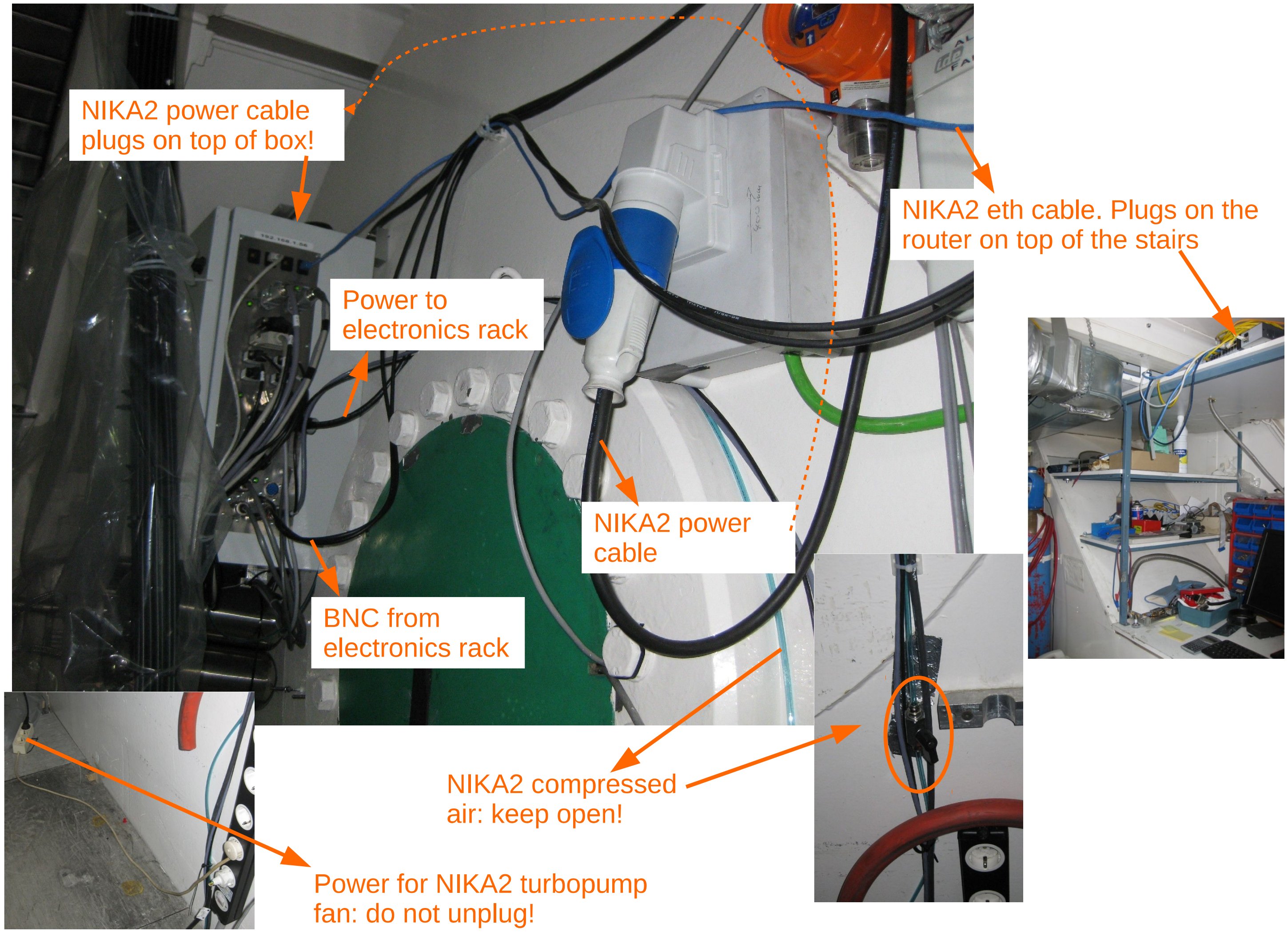




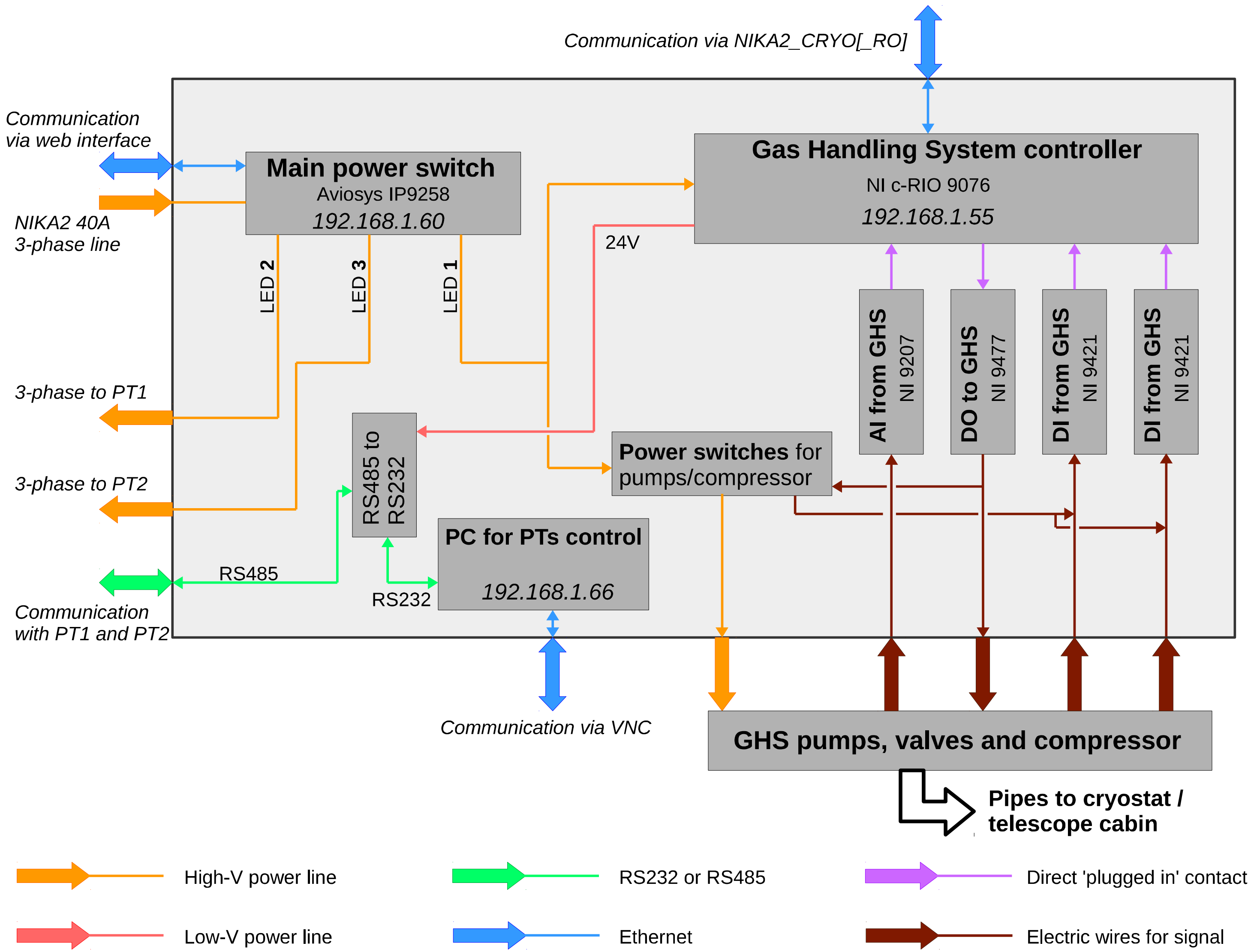


slide7

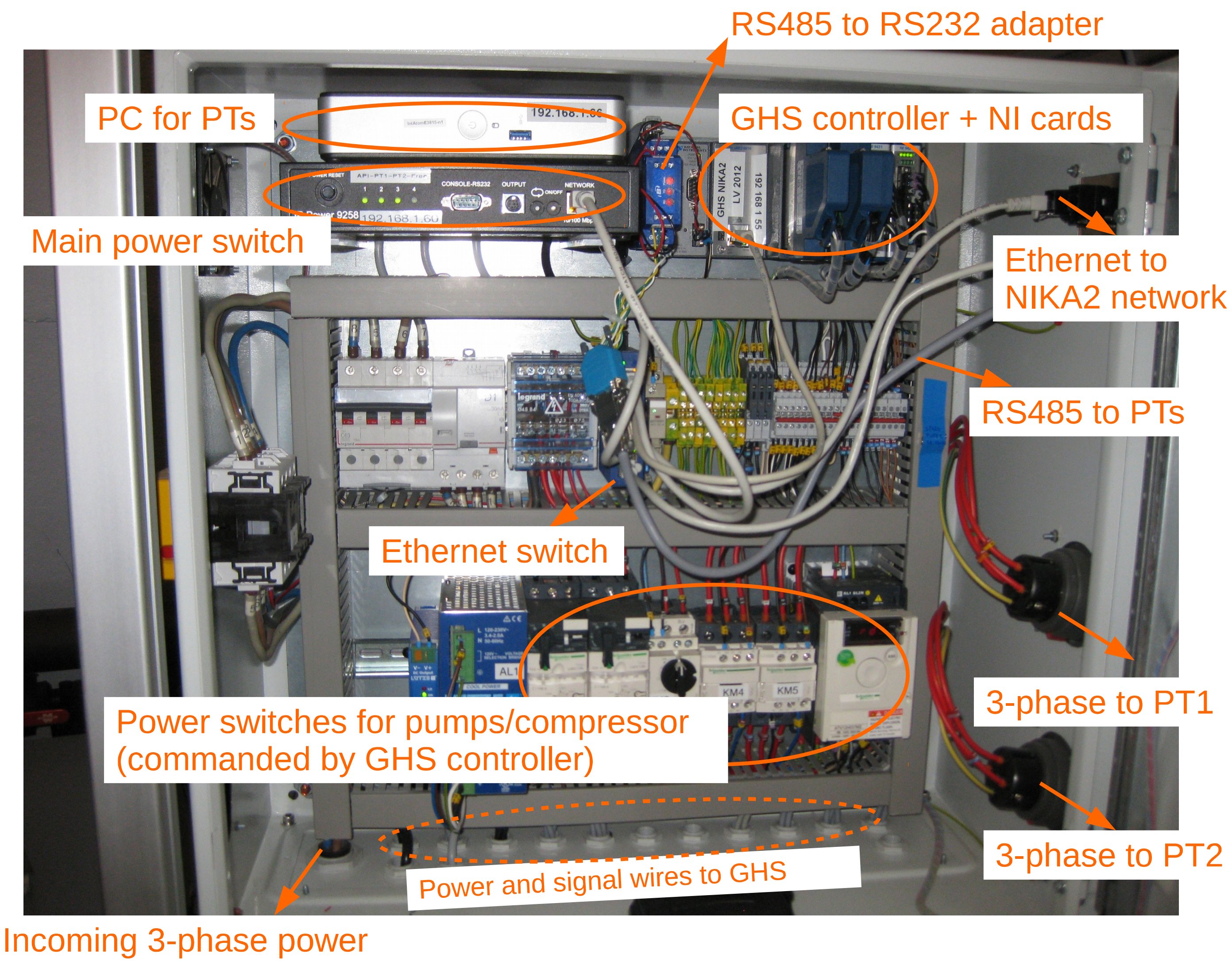
Main connections of the cryostat electronics box



Gas Handling System (GHS) Overview



GHS Electronics Location.



He4,He3 cooling.

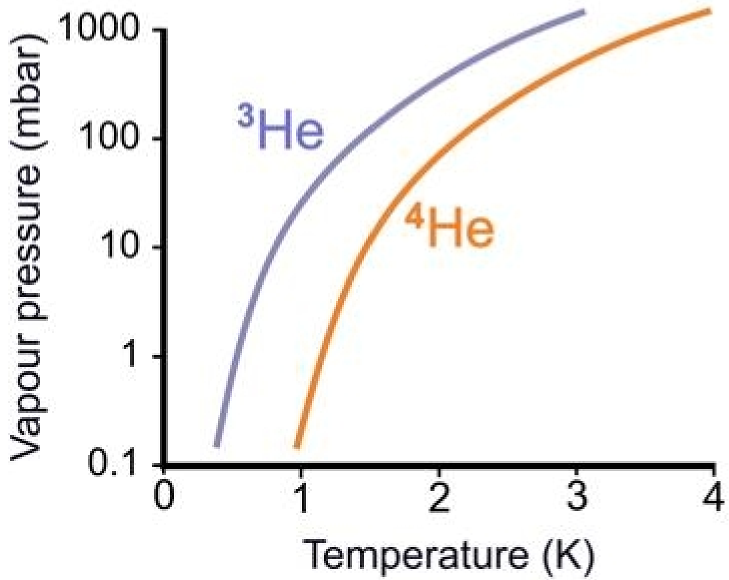
Cooling.

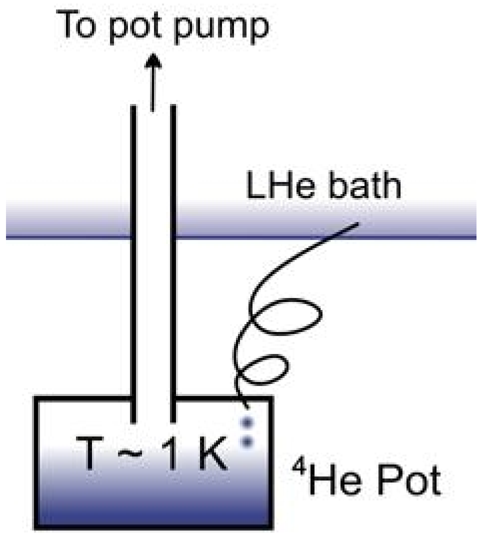
* Enthalpy of vaporization (Latent heat of vaporization (L) or heat of vaporization) is the of energy(enthalpy) that must be added to a liquid substance to transform a quantity of that substance into a gas.

* binding energy between He3 atoms weaker than He4, meaning lower L and higher vapor pressure. $P \propto \exp(-L/RT)$

* Pumping on liquid lowers vapour pressure above liquid – allowing more energetic molecules to evaporate taking heat from the remaining liquid hence cooling.

* Boiling point (at 1 atm) of He4 4.2K, He3 3.2K. Base temp He4 ~1.2K, He3 ~ 0.25K upon pumping.





He4 ,He3, mixture.

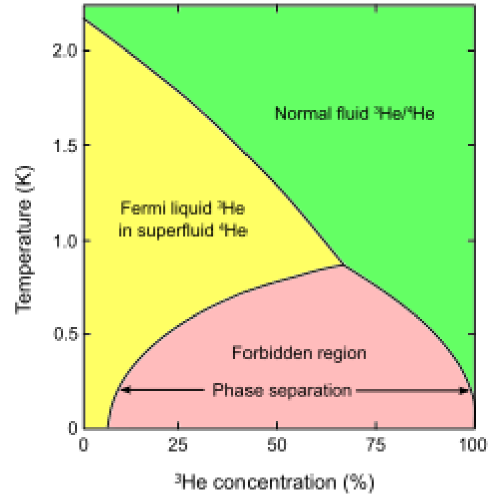
* Pure He4 obeys Boson statistics has I=0 (protons, neutrons are spin ½ particles- 2 particles have spin “up” and 2 spin “down” giving total I=0). Superfluid at 2.17K

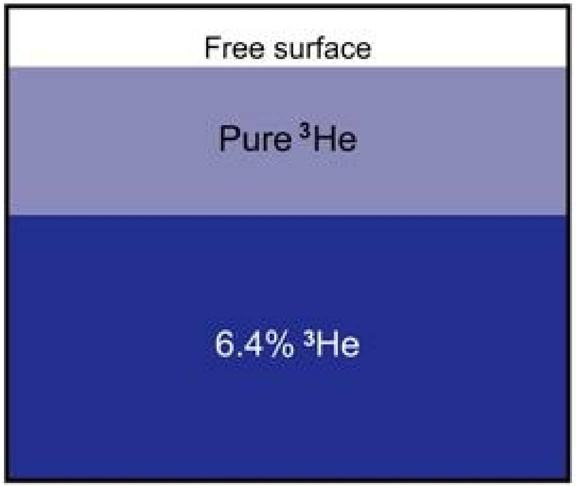
* Pure He3 bays Fermi statistics has I= ½ (1proton, 2 neutrons- 1 “up”,1 “down” and 1/2 giving total I=1/2). The enthalpy of He3 in He4 is higher than for pure He3 due He3 in He4 behaving as a Fermi gas. This is analogous to the enthalpy difference between He3 gas and He3 liquid that results in cooling power in an evaporation refrigerator

*The superfluid transition temperature of a He4 - He3 mixture depends on the He3 concentration.

* He3 phase diagram shows lambda line for He4 superfluid transition of He4 and the phase separation line of the mixtures below which they separate into a He4-rich (the ‘dilute’ phase) and a He3 -rich phase (concentrated).

* At low very low temperatures the concentrated phase is essentially pure 3 He, while the dilute phase contains about 6.6% He3 and 93.4% He4 down to temperatures approaching 0 K, in contrast to the vapor density in the evaporator case, where the number of atoms decreases exponentially with temperature. The high He3 particle density in the dilute phase is essential for He3– He4 dilution refrigeration because it permits a high He3 molar flow rate. The low density the He3 rich floats on top of the denser He4 rich liquid.

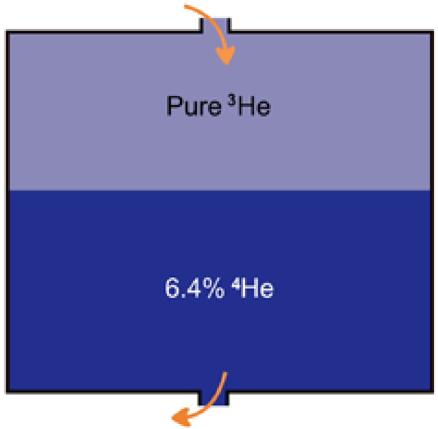




He4-He3 mixture cooling.

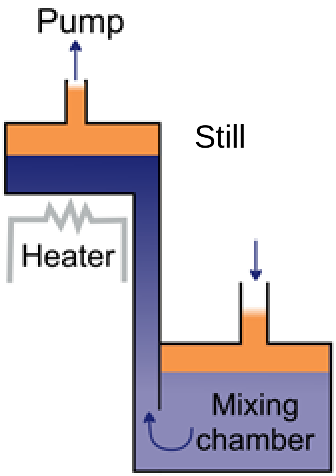
Cooling power in dilution process.

* Inside the chamber, the He3 is diluted as it flows from the concentrated phase through the phase boundary into the dilute phase. The heat necessary for the dilution is the useful cooling power of the refrigerator, as the process of moving the He3 through the phase boundary is endothermic and removes heat from the mixing chamber Environment.



* Cooling power is given by the ΔH (heat of mixing) multiplied by the He3 molar rate. At low temperatures the specific heats are proportional to T^2 giving $Q \propto n_3 T^2$, where n_3 is the molar flow rate of He3. Cooling is possible down to very low temperatures.

* Removal of the He3 from the mixer chamber is via a tube connecting to a distiller (still) at a temperature ~ 1k. Pumping on the still lowers the vapour pressure allowing gaseous He3 to be removed from the mixture in the still, He4 remains superfluid. The depletion of He3 from the mixture causes a pressure gradient in the tube causing the migrating of He3 in the diluted phase from the mixing chamber. The He3 concentration in the dilute phase of the mixing chamber will stay constant because He3 atoms are continuously crossing the phase separation line from the concentrated to the dilute phase, producing cooling due to the latent heat of mixing.



Dry dilution.

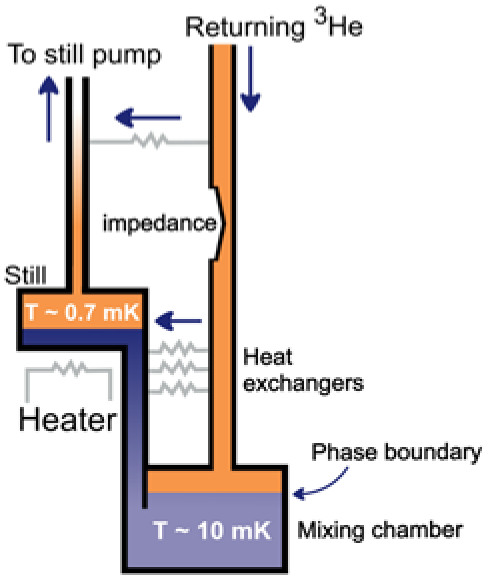
dilution cooler, Dry system as for NIKA.

* An heat exchanger located just before the impedance in the returning He 3 tube lowers the returning gas temperature by the outgoing He3 vapour from the still.

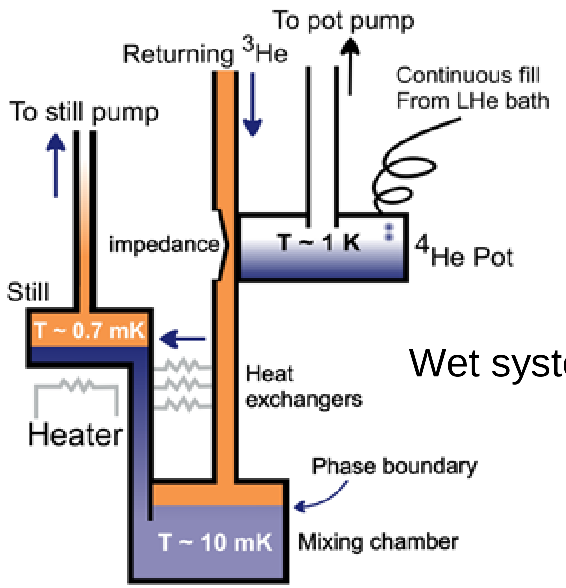
* The impedance produces a pressure difference causing JT expansion which together with the heat exchanger causes the gas to condense to a liquid. High condensing pressure is required in the gas circulating system in-order to guarantee the He3 to liquefy. A high pressure pump (compressor) is used to obtain the high pressure.

* An addition heat exchanger connected to the still causes further cooling before entering into the mixing chamber.

* In the case of a “wet” system a pumped He4 pot is used to cool the impedance.



Dry system



Wet system

Dry dilution.