GSI/CERN superFRS kick-off meeting 3-4.07.2019

Cryogenic system for testing the FAIR sFRS magnets

A. Perin, G. Rolando, T. Barbe, B. D'Hulster, T. Dupont, L. Stewart

CERN TE-CRG

July 4th , 2019

https://indico.cern.ch/event/828084/timetable/#20190704.detailed

Outline

The cryogenic infrastructure

- Hardware
- Control system
- Status

Towards operation

GSI-FAIR Super-FRS magnet tests at CERN

In the framework of a collaboration agreement between CERN and GSI, **57 Super-FRS magnets will be tested at CERN at 4.5 K**: 48 multiplets and 9 dipoles.

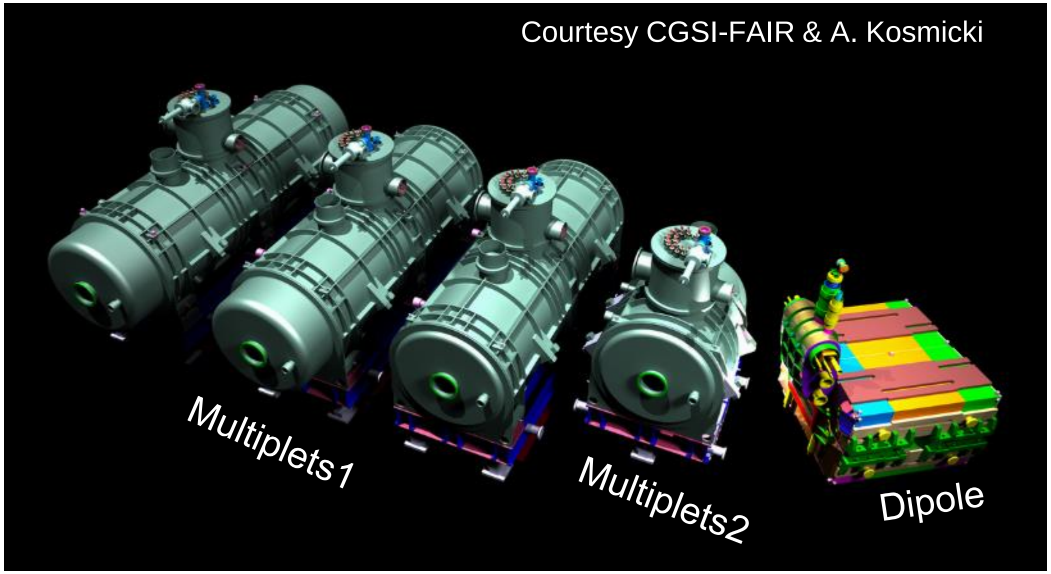
Mass up to **70 tons** and dimensions up to **5 m** high

The test sequence is planned to last about **42 days for each magnet**.

The required test rate **is 21 magnets / year**

The super-FRS magnet tests are the main driver for the architecture of the new test facility

Type	#	Total mass	Cold mass
		[kg]	[kg]
dipole	24	50’000	2’000
multiplet 1	24	70’000	45’000
multiplet 2	9	25’000	20’000



See also:
A. Perin et al. CEC 2015, Mat. Sci. Eng. **101** p. 012185
J.H. Derking et al. CEC 2015, Mat. Sci. Eng. **101** p. 012104

Overview of the cryogenic system

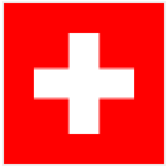
<u>Located in 2 buildings:</u>
B279: compression stations
B180: 1400 m^2 for cryogenics and tests

<u>The facility can accommodate devices:</u>
- Up to **55 tons, 7 m** high max
- Up to **89 tons, 5 m** high max

Dimensioning parameters for performing the test sequence for a multiplet 1 (heaviest magnet)

Test Phase	Requirement
Cool-down 293 K – 90 K	5.6 kW cooling power, 21.4 g/s at 10 bar
Cool-down 90 K – 4.5 K	6.2 m^3 of saturated LHe at 4.5 K
Filling of magnet with LHe	1.7 m^3 of saturated LHe at 4.5 K
Cold tests heat loads	30 W static at 4.5 K + 35 W dynamic during10 minutes 160 W at 60 K – 70 K (screen) 1.6 g/s at 4.5 K – 300 K (liquefaction load)
Warm-up 90 K – 293 K	5.4 kW heating, 20 g/s at 10 bar

Procurement



Helium refrigerator

Linde Kryotechnik

Cryo distribution

Kriosystem

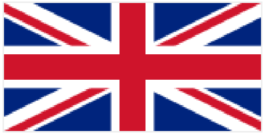
Compression station refrigerator

Mayekawa Italy SRL

9 major contracts
in 7 member states

LHe dewar: *Cryoworld BV*

LN_2 distribution: *Demaco Holland BV*



Cool down / warm up unit

AS Scientific Products

LN_2 storage tank

Cryocan

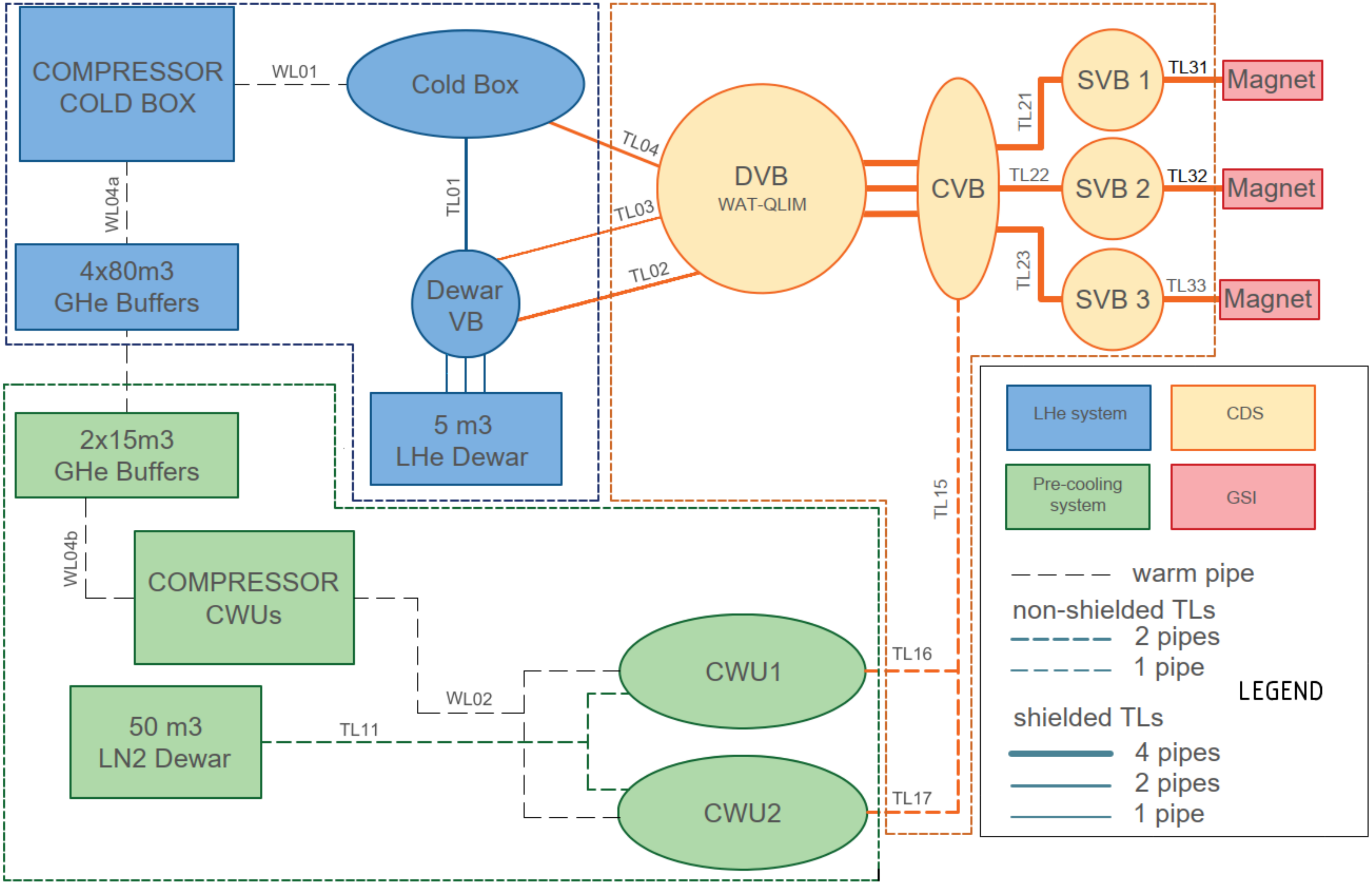
Cryogenic valves: *Flowserve*

Warm control valves: *Stohr Armaturen*

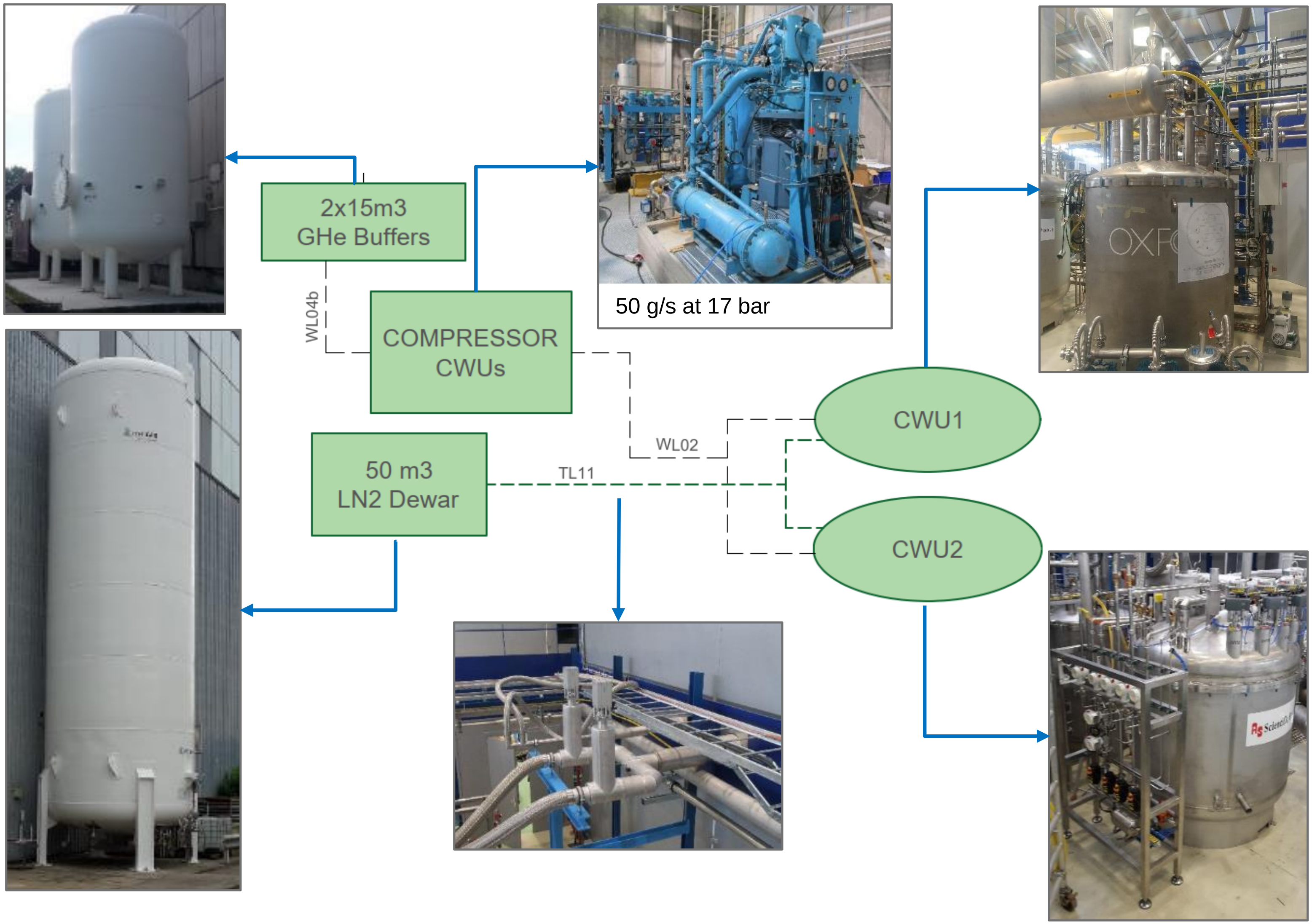
Infrastructure overview

Current status of the cryogenic test facility in B180

B180 test facility – 3 Main sub-systems



The pre-cooling system



Precooling & warming up system

Purpose cool-down / warm up units:

- precool devices to 80 K;
- warm up devices from 4.5 K to room temperature.

50 g/s GHe circulation at 10 bar

15 kW cooling capacity with ΔT of 50 K (LN_2)

15 kW heating capacity

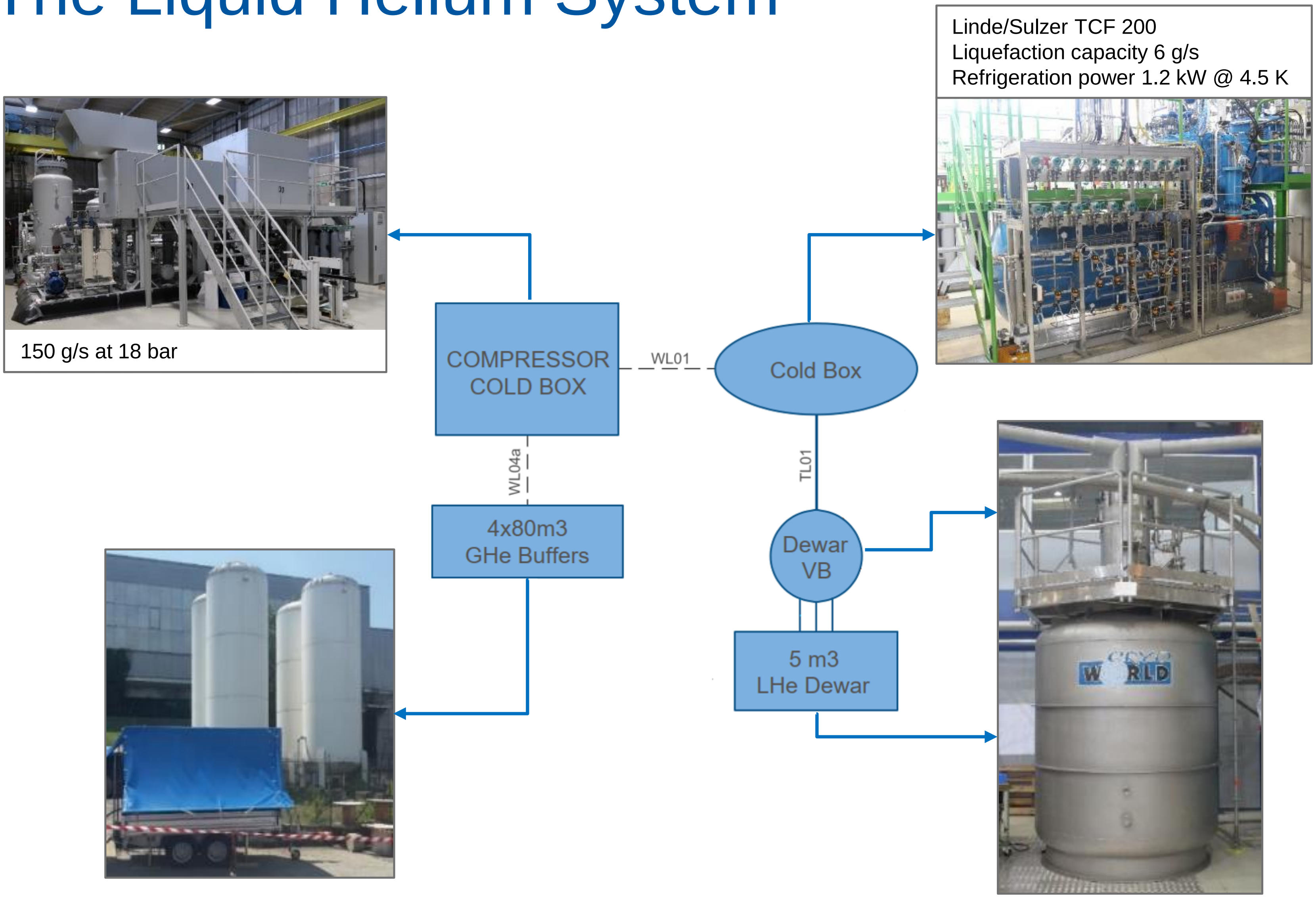
Includes 80 K adsorber to remove gas impurities

CWU1

CWU2

50 m^3 LN_2 storage tank

The Liquid Helium System



Helium refrigerator

An existing **Sulzer TCF200** helium refrigerator of 1979 was fully refurbished by *Linde Kryotechnik* in 2016.

Brayton cycle with **two** turbines in series. **Third** turbine for boosting performance.

<u>Original performance:</u> 1.2 kW refrigeration or 5.6 g/s liquefaction with 1.0 kW shield between 60 – 90 K.

<u>Main refurbishment work included:</u>

- Adding a GHe return to 300 K;
- New purge and instrumentation rack;
- New cooling water distribution panel and turbine bearing gas supply panel;
- New turbine coolers;
- Maintaining all cryogenic valves;
- Repairing thermometers;
- Repainting the box.


Helium refrigerator before refurbishment


Helium refrigerator after refurbishment

Helium refrigerator compression station

A new compression station from *Mayekawa Italy S.R.L.* is used for driving the helium refrigerator.

<u>Main components:</u>

- Two stage compound screw compressor;
- One 3.3 kV AC electrical motor;
- Oil separation system with oil separator, 3 coalescing filters and a charcoal adsorber.

<u>Design performance:</u>

Supply pressure: 18.7 bar

Suction pressure: 0.9 bar

GHe flow rate: 160 g/s

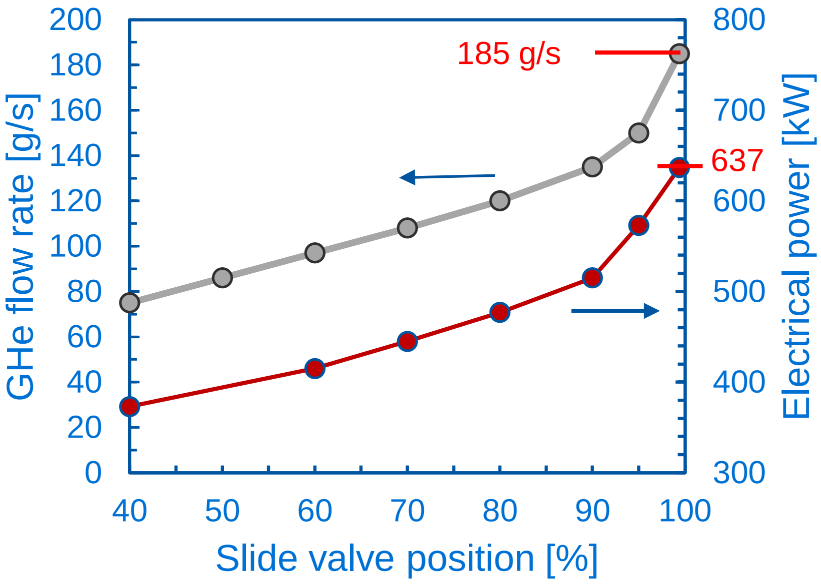
Electrical power: 706 kW

Helium refrigerator compression station

Helium refrigerator oil separation system

Helium refrigerator: commissioning results

Helium refrigerator compression station



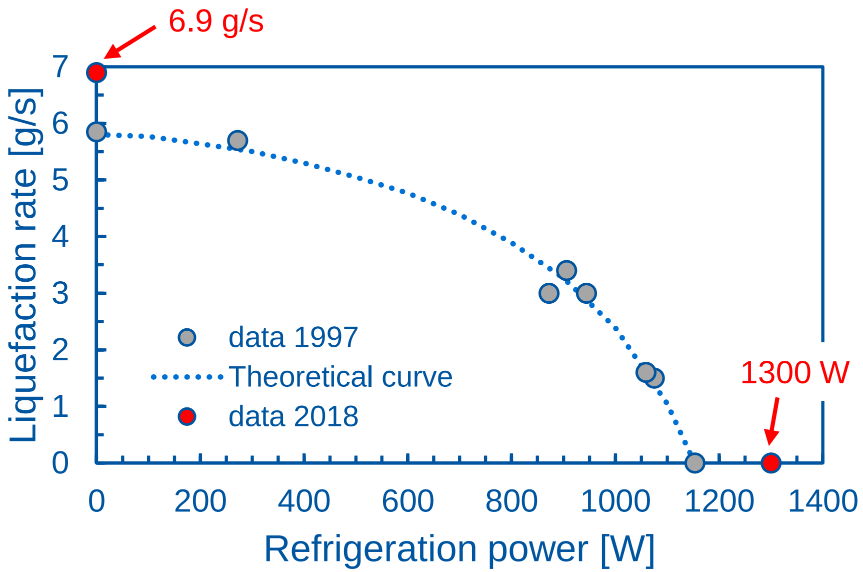
Supply pressure: 17.2 bar

Suction pressure: 1.0 bar

Max flow rate: 185 g/s

Electrical power: 637 kW

Helium refrigerator



Supply pressure: 17.2 bar

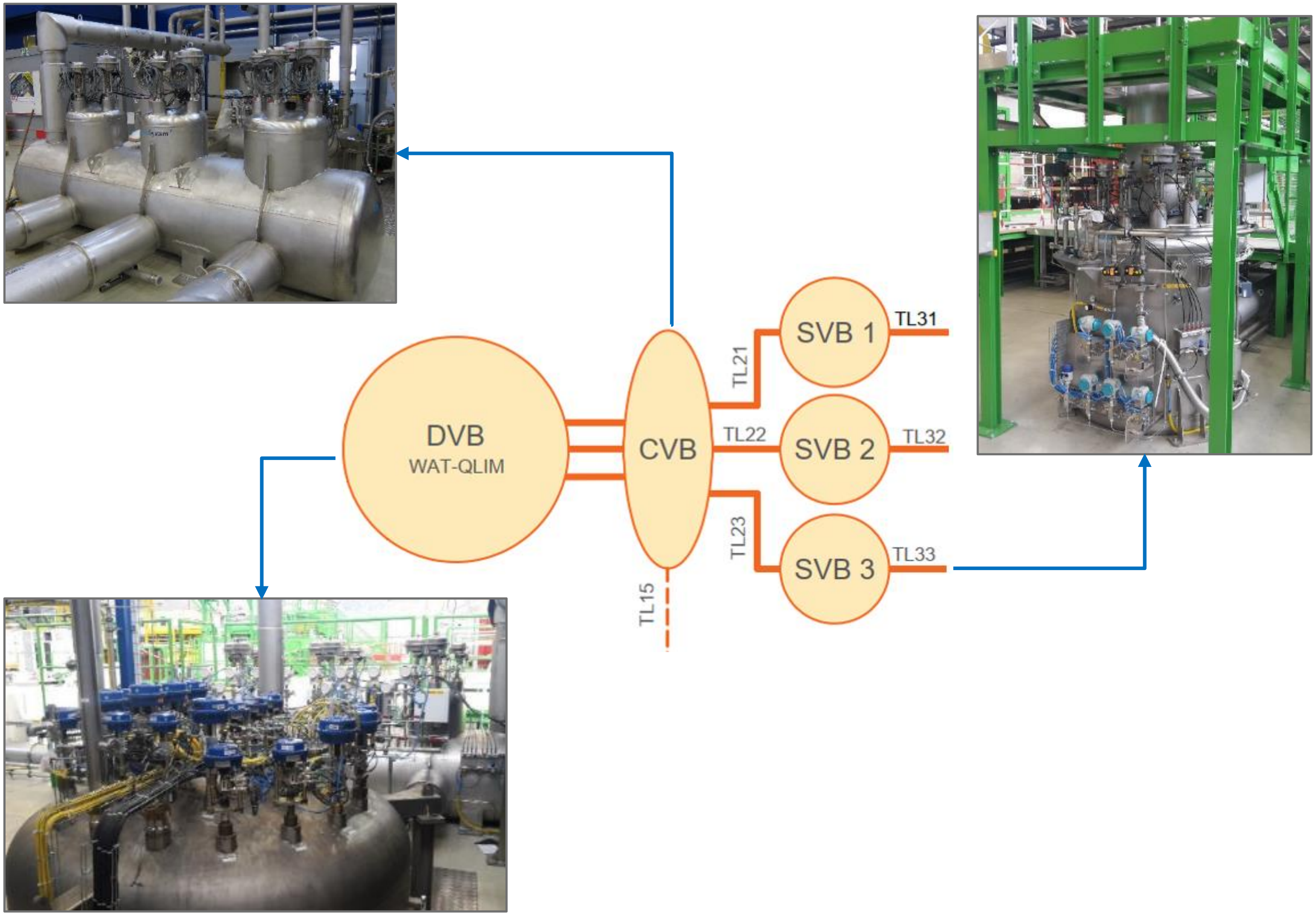
Suction pressure: 1.0 bar

Refrigeration power: 1300 W @ 160 g/s

Liquefaction power: 6.9 g/s @ 125 g/s
(205 liters/hour)

No shield cooling

Cryogenic distribution system

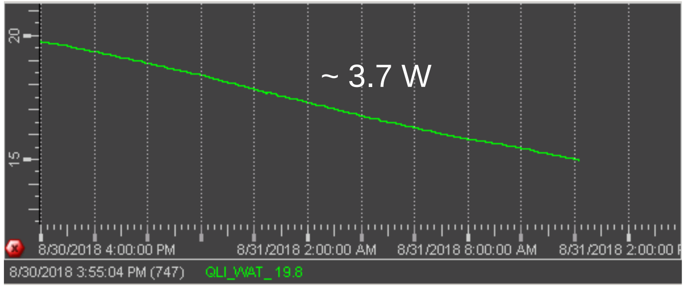


The cryogenic distribution system

5 m^3 LHe dewar delivered by *Cryoworld BV*

Preliminary measured evaporation rate:

~2.6% / day of total capacity or 3.7 W



LHe dewar installation

Cryo distribution installation

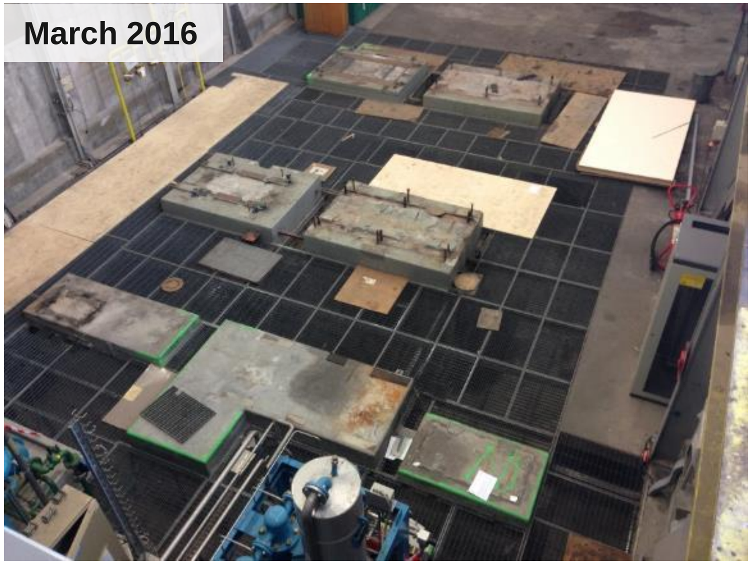
Cryodistribution delivered by *Kriosystem*

First cool down in autumn 2017 to test:

- Mechanical integrity
- Leaks
- Vacuum jacket temperature

No major non-conformities found.

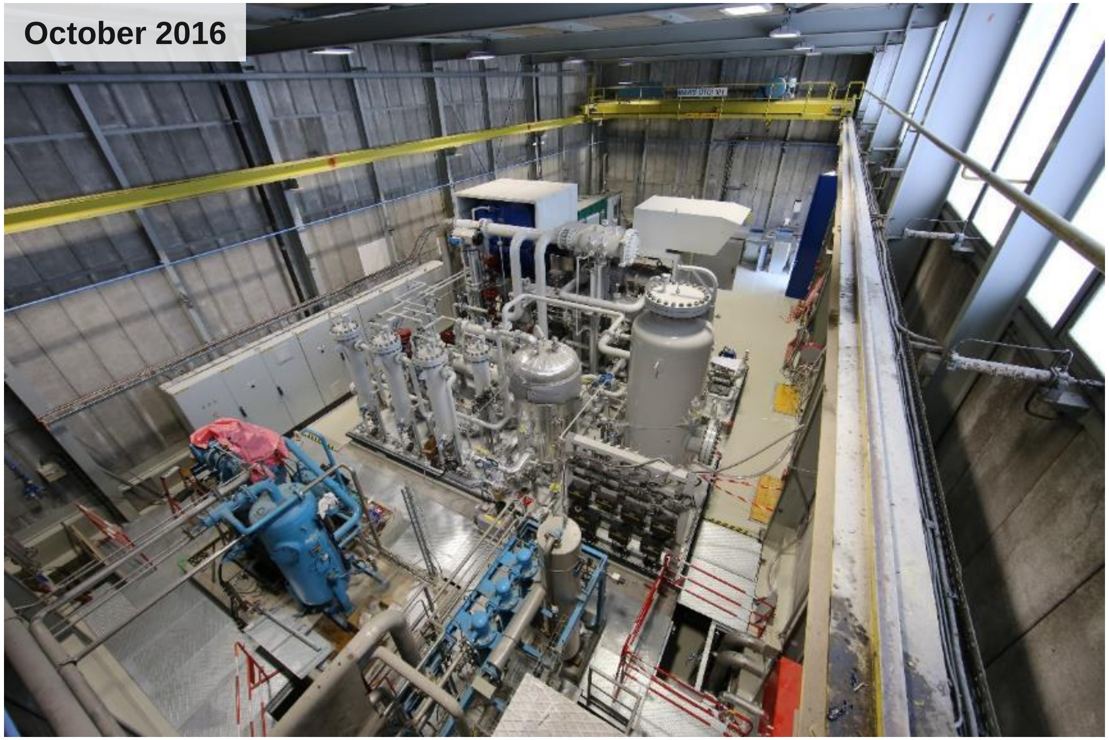
Compression station building 279: overview


March 2016


May 2016

Compression building B279 was built in 1971.

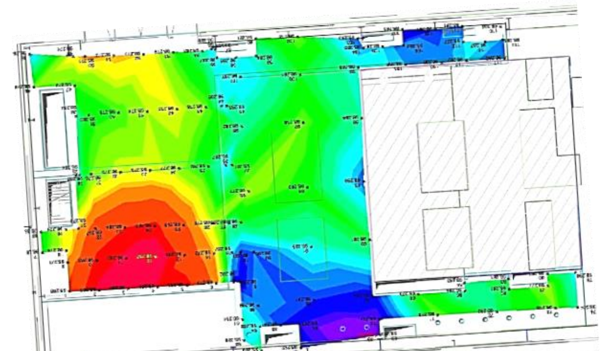
The building is fully renovated to fulfil current standards with respect to safety and environmental aspects.


October 2016

B279: oil spillage measures

Oil spillage measures taken to:

- collect the total amount of oil (2000 L)
- prevent leakage outside the building (through cracks, drainages etc.)

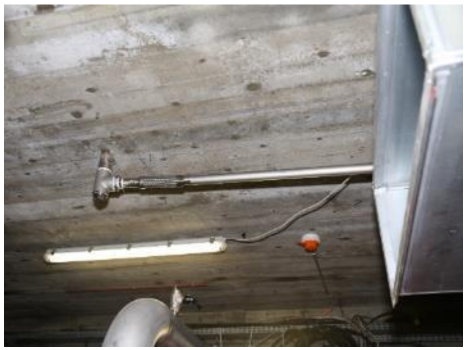


Mapping floor level

Resign on floor

Profiles at corners

Steps at doors and openings



Collector pipe at lowest point of floor

Gutters

Retention tank 1: 1900 L

Retention tank 2: 1900 L

B279: noise measures

Noise **outside** the building needs to stay **below 60 dB(A)** due to proximity of offices.

A study determining the noise damping coefficients showed that we need **below 90 dB(A) inside** the building.

Noise sources:

Helium refrigerator compression station: 98 dB(A)

CWU compression station: 88 dB(A)

Noise study

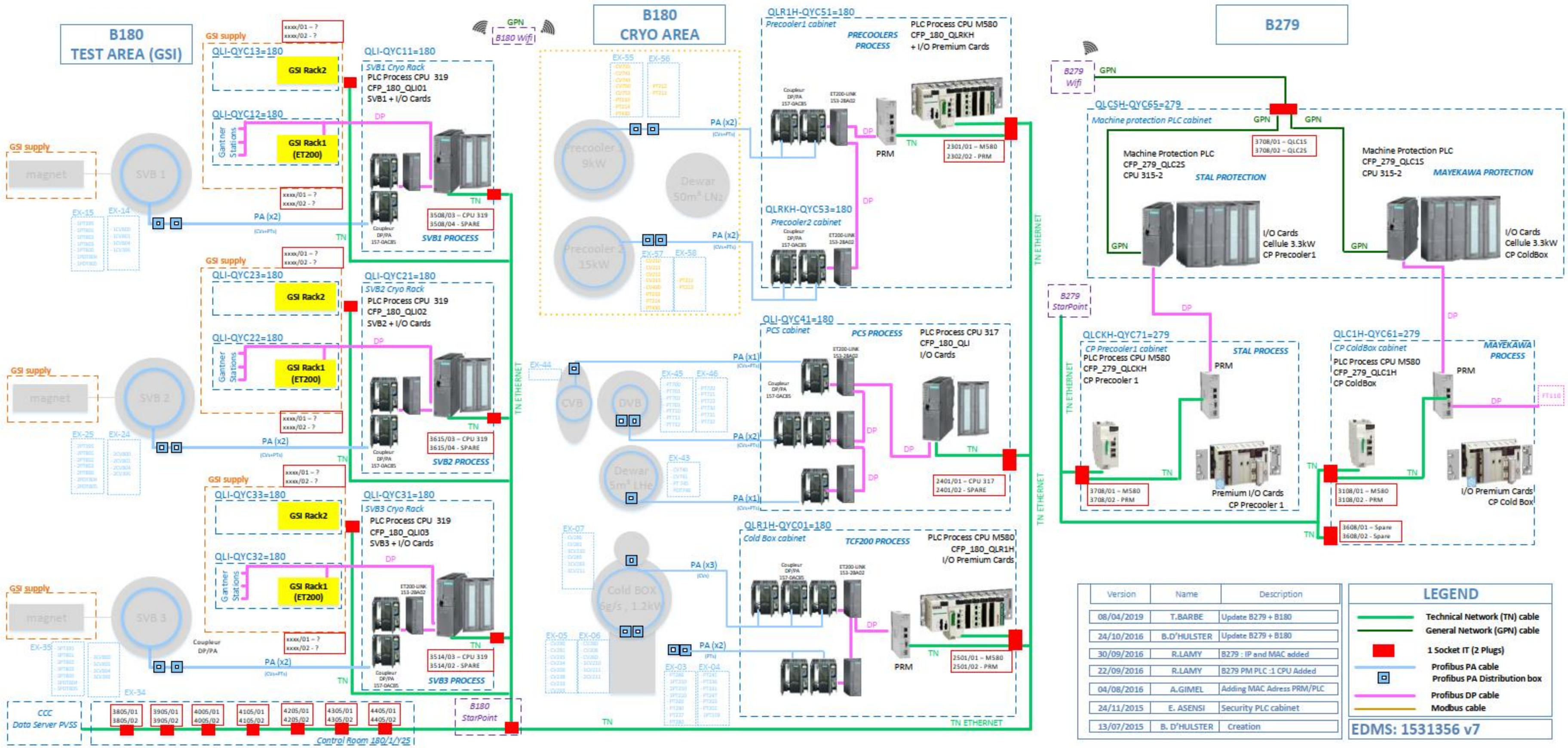
Two options:

1) Isolating the building -> complex and costly
2) Noise hood around compressor stages helium refrigerator compression station

Option 2 selected. Noise hood reduces noise to 90 dB(A) at 1 m of compression station.

Noise hood

Controls: PLC Architecture



Version	Name	Description
08/04/2019	T.BARBE	Update B279 + B180
24/10/2016	B.D'HULSTER	Update B279 + B180
30/09/2016	R.LAMY	B279 : IP and MAC added
22/09/2016	R.LAMY	B279 PM PLC :1 CPU Added
04/08/2016	A.GIMEL	Adding MAC Adress PRM/PLC
24/11/2015	E. ASENSI	Security PLC cabinet
13/07/2015	B. D'HULSTER	Creation

LEGEND

- Technical Network (TN) cable
- General Network (GPN) cable
- 1 Socket IT (2 Plugs)
- Profibus PA cable
- Profibus PA Distribution box
- Profibus DP cable
- Modbus cable

EDMS: 1531356 v7

Controls: PLC Architecture

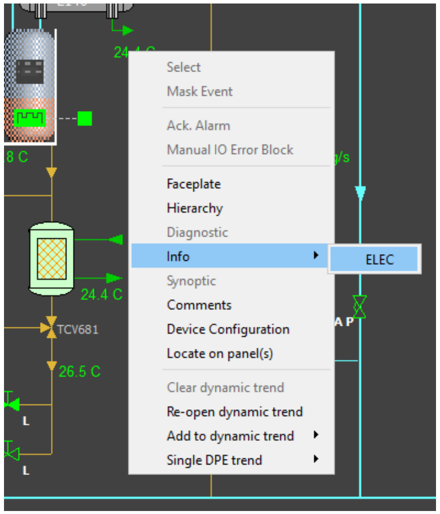
10 PLCs
~ 3000 used I/O
~ 7000 used Unicos object

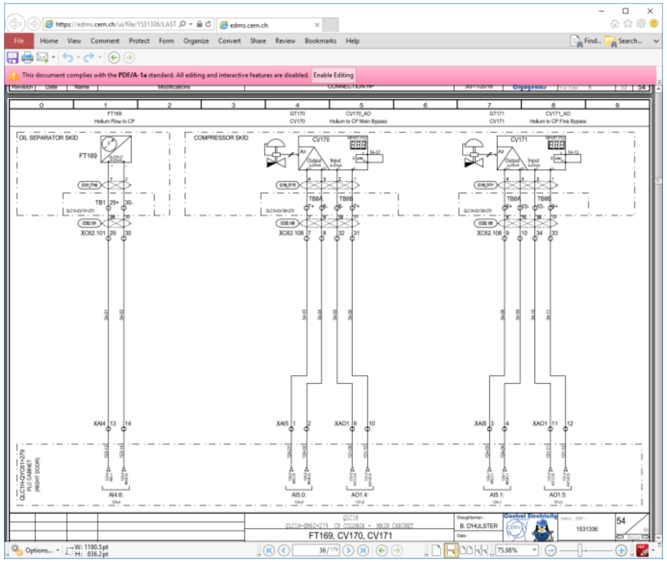
Programmed and tested by TE-CRG-CE

	Area	Installation	Name	PLC Type	Dev. Tools	UNICOS Version
Test Facilities	FAIR	QLC1H (CP for CB)	CFP-279-QLC1H	M580	UNITY V11.1	CPC6 1.10
Test Facilities	FAIR	QLCKH (CP for Preco1&2)	CFP-279-QLCKH	M580	UNITY V11.1	CPC6 1.10
Test Facilities	FAIR	Protection for QLC1H	CFP-279-QLC1S	CPU315	STEP7	Not unicos
Test Facilities	FAIR	Protection for QLCKH	CFP-279-QLC2S	CPU315	STEP7	Not unicos
Test Facilities	FAIR	QLR1H (CB)	CFP-180-QLR1H	M580	UNITY V11.1	CPC6 1.8
Test Facilities	FAIR	QLRKH (Preco1&2)	CFP-180-QLR2H	M580	UNITY V11.1	CPC6 1.10
Test Facilities	FAIR	QLI (PCS)	CFP-180-QLI	CPU317	STEP7	CPC6 1.10
Test Facilities	FAIR	QLI01 (SVB01)	CFP-180-QLI01	CPU319	STEP7	CPC6 1.10
Test Facilities	FAIR	QLI02 (SVB02)	CFP-180-QLI02	CPU319	STEP7	CPC6 1.10
Test Facilities	FAIR	QLI03 (SVB03)	CFP-180-QLI03	CPU319	STEP7	CPC6 1.10

Controls: supervision and data logging

- Data archived using standard LHC logging
  - ~8000 signals already available
- Alarm using LHC laser system for operator call
- Logic Specification and electrical diagram linked in WinCC OA through EDMS





Electrical & cabling Architecture

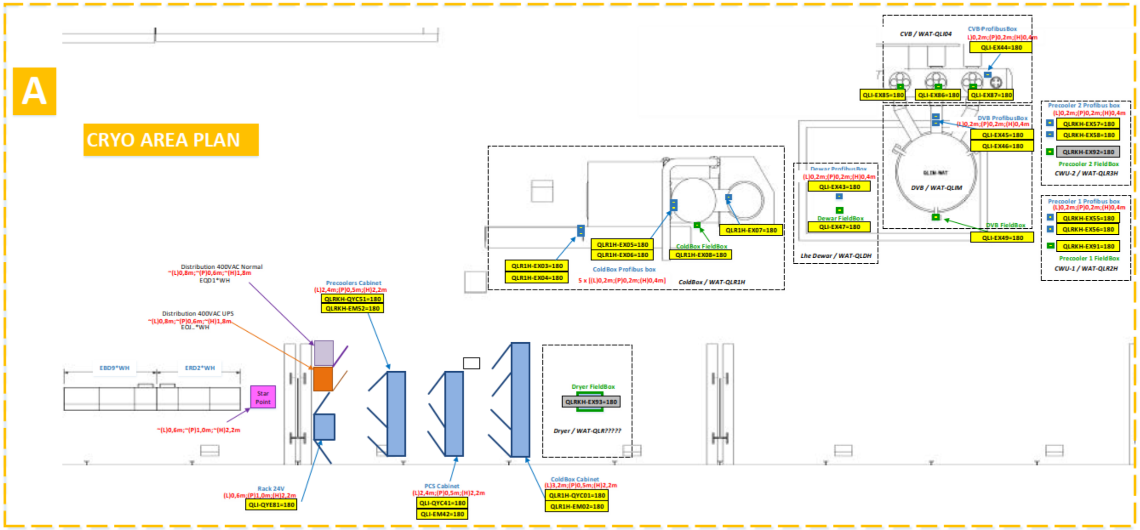
List of racks/cabinets/field boxes B180-Cryogenics

V. Inglese, B. D'Hulster, S. Knoops — EDMS 1490820

Building	Installation	n	Rack name	Description	PLC name	Ethernet (TN): Number of sockets (1 socket = 2 plugs)	Rack type parameters: Type	Type description	Width	Height	Depth
279	CP	1	QLC1H-QYC61=279	Compressor CB - PLC	CFP_279_QLC1H	1	cabinet	ELDON	800	2200	500
279	CP	2	QLC1H-EM62=279	Compressor CB - Main electrical cabinet			cabinet	ELDON	2400	2200	500
279	CP	3	QLC1H-EM63=279	Compressor CB - Purge cabinet - OPTIONAL							
279	CP	4	QLC1H-EX64=279	Compressor CB - Field Box - OPTIONAL							
279	CP	5	QLC1H-EX66=279	Compressor CB - Field Box - OPTIONAL							
180 - Outside N	CP	6	QLC1H-EX67=180	Compressor CB - Field Box Buffers bat180			fieldbox	ELDON	600	500	210
279	CP	7	QLC1H-EX101=279	Compressor CB - Field Box JB01 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	470	300	180
279	CP	8	QLC1H-EX102=279	Compressor CB - Field Box JB02 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	9	QLC1H-EX103=279	Compressor CB - Field Box JB03 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	10	QLC1H-EX104=279	Compressor CB - Field Box JB04 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	11	QLC1H-EX105=279	Compressor CB - Field Box JB05 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	12	QLC1H-EX106=279	Compressor CB - Field Box JB06 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	13	QLC1H-EX107=279	Compressor CB - Field Box JB07 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	470	300	180
279	CP	14	QLC1H-EX108=279	Compressor CB - Field Box JB08 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	470	300	180
279	CP	15	QLC1H-EX109=279	Compressor CB - Field Box JB09 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	16	QLC1H-EX110=279	Compressor CB - Field Box JB10 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	147	110
279	CP	17	QLC1H-EX111=279	Compressor CB - Field Box JB11 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	300	230	180
279	CP	18	QLC1H-EX112=279	Compressor CB - Field Box JB12 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	170	160	110
279	CP	19	QLC1H-EX113=279	Compressor CB - Field Box JB13 (Mayekawa)			fieldbox	MAYEKAWA / CORTEM	254	245	180
279	CP	20	QLCSH-QYC65=279	Protection Machine PLC for all compressors	CFP_279_QLCSH	1	cabinet	ELDON	1600	2200	500
279	CP	21	QLCKH-QYC71=279	Compressor Precooler 1 - PLC	CFP_279_QLCKH	1	cabinet	ELDON	800	2200	500
279	CP	22	QLCKH-EM72=279	Compressor Precooler 1 - Main electrical cabinet			cabinet	ELDON	1600	2200	500
279	CP	23	QLCKH-EM73=279	Compressor Precooler 1 - Purge cabinet - OPTIONAL							
279	CP	24	QLCKH-EX74=279	Compressor Precooler 1 - Field Box SKID CP - OPTIONAL							
279 - Outside E	CP	25	QLCKH-EX78=279	Compressor Precooler 1 - Field Box Buffers bat279			Fieldbox	ELDON	500	400	210
279	CP	26	QLCKH-EX79=279	Compressor Precooler 1 - Field Box DESHUILAGE - OPTIONAL							
279	CP	27	QLCKH-QYC75=279	Compressor Precooler 2 - PLC - OPTIONAL							
279	CP	28	QLCKH-EM76=279	Compressor Precooler 2 - Main electrical cabinet - OPTIONAL							
279	CP	29	QLCKH-EM77=279	Compressor Precooler 2 - Purge cabinet - OPTIONAL							
279	Infra	30	QLI-QYE82=279	24VDC distribution (for B279)	-		rack 19"		600	2200	900
180	CB	31	QLR1H-QYC01=180	ColdBox - PLC	CFP_180_QLR1H	1	cabinet	ELDON	800	2200	500
180	CB	32	QLR1H-EM02=180	ColdBox - Main electrical cabinet			cabinet	ELDON	2400	2200	500
180	CB	33	QLR1H-EX03=180	ColdBox - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	CB	34	QLR1H-EX04=180	ColdBox - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	CB	35	QLR1H-EX05=180	ColdBox - Profibus PA Box 3			Fieldbox PA	SIEMENS	360	120	83
180	CB	36	QLR1H-EX06=180	ColdBox - Profibus PA Box 4			Fieldbox PA	SIEMENS	360	120	83
180	CB	37	QLR1H-EX07=181	ColdBox - Profibus PA Box 5			Fieldbox PA	SIEMENS	360	120	83
180	CB	38	QLR1H-EX08=180	ColdBox - FieldBox			Fieldbox		180	100	80
180	Precooler	39	QLRKH-QYC51=180	Precooler1 - PLC	CFP_180_QLRKH	1	cabinet	ELDON	800	2200	500
180	Precooler	40	QLRKH-EM52=180	Precooler1 - Main electrical cabinet		0	cabinet	ELDON	1600	2200	500
180	Precooler	41	QLRKH-EX55=180	Precooler1 - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	Precooler	42	QLRKH-EX56=180	Precooler1 - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	Precooler	43	QLRKH-EX91=180	Precooler1 - FieldBox PR1			Fieldbox	ELDON	600	500	250
180	Precooler	44	QLRKH-EX93=180	Precooler1 - FieldBox DRYER - OPTIONAL							
180	Precooler	45	QLRKH-QYC53=180	Precooler2 - PLC - OPTIONAL							
180	Precooler	46	QLRKH-EM54=180	Precooler2 - Main electrical cabinet - OPTIONAL							
180	Precooler	47	QLRKH-EX57=180	Precooler2 - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	Precooler	48	QLRKH-EX58=180	Precooler2 - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	Precooler	49	QLRKH-EX92=180	Precooler2 - FieldBox PURGE PUMP Precooler			Fieldbox	SCHNEIDER	400	600	200
180 - Outside S	Precooler	50	QLDN-EX94=180	Precooler - LN2 TANK - FieldBox			Fieldbox	SCHNEIDER	400	300	150
180 - Outside S	Precooler	51	QLDN-EX59=180	Precooler - LN2 TANK - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	Infra	52	QLI-QYE81=180	24VDC distribution (for B180)			rack 19"	MAG CERN	600	2200	900
180	PCS	53	QLI-QYC41=180	PCS - PLC	CFP_180_QLI	1	cabinet	ELDON	800	2200	500
180	PCS	54	QLI-EM42=180	PCS - Main electrical cabinet			cabinet	ELDON	1600	2200	500
180	PCS	55	QLI-EX43=180	PCS - DEWAR Lhe - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	PCS	56	QLI-EX44=180	PCS - CVB - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	PCS	57	QLI-EX45=180	PCS - DVB - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	PCS	58	QLI-EX46=180	PCS - DVB - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	PCS	59	QLI-EX47=180	PCS - DEWAR Lhe - FieldBox			Fieldbox	ELDON	300	300	210
180	PCS	60	QLI-EX85=180	PCS - CVB - FieldBox n1			Fieldbox	ELDON	300	300	210
180	PCS	61	QLI-EX86=180	PCS - CVB - FieldBox n2			Fieldbox	ELDON	300	300	210
180	PCS	62	QLI-EX87=180	PCS - CVB - FieldBox n3			Fieldbox	ELDON	300	300	210
180	PCS	63	QLI-EX49=180	PCS - DVB - FieldBox			Fieldbox	ELDON	500	400	210
180	SVB	64	QLI-QYC11=180	Cryo Rack SVB1	CFP_180_QLI01	1	rack 19"	MAG CERN	600	2200	900
180	SVB	65	QLI-QYC12=180	GSI Rack SVB1	-	1		GSI /			
180	SVB	66	QLI-QYC13=180	GSI Rack SVB1	-	1		GSI /			
180	SVB	67	QLI-EX14=180	SVB1 - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	SVB	68	QLI-EX15=180	SVB1 - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	SVB	69	QLI-EX16=180	SVB1 - FieldBox			Fieldbox	ELDON	300	300	210
180	SVB	70	QLI-QYC21=180	Cryo Rack SVB2	CFP_180_QLI02	1	rack 19"	MAG CERN	600	2200	900
180	SVB	71	QLI-QYC22=180	GSI Rack SVB2	-	1		GSI /			
180	SVB	72	QLI-QYC23=180	GSI Rack SVB2	-	1		GSI /			
180	SVB	73	QLI-EX24=180	SVB2 - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	SVB	74	QLI-EX25=180	SVB2 - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	SVB	75	QLI-EX26=180	SVB2 - FieldBox			Fieldbox	ELDON	300	300	210
180	SVB	76	QLI-QYC31=180	Cryo Rack SVB3	CFP_180_QLI03	1	rack 19"	MAG CERN	600	2200	900
180	SVB	77	QLI-QYC32=180	GSI Rack SVB3	-	1		GSI /			
180	SVB	78	QLI-QYC33=180	GSI Rack SVB3	-	1		GSI /			
180	SVB	79	QLI-EX34=180	SVB3 - Profibus PA Box 1			Fieldbox PA	SIEMENS	360	120	83
180	SVB	80	QLI-EX35=180	SVB3 - Profibus PA Box 2			Fieldbox PA	SIEMENS	360	120	83
180	SVB	81	QLI-EX36=180	SVB3 - FieldBox			Fieldbox	ELDON	300	300	210
180	Control room	-	-	-	-	5	-	-	-	-	-
					Total	20					

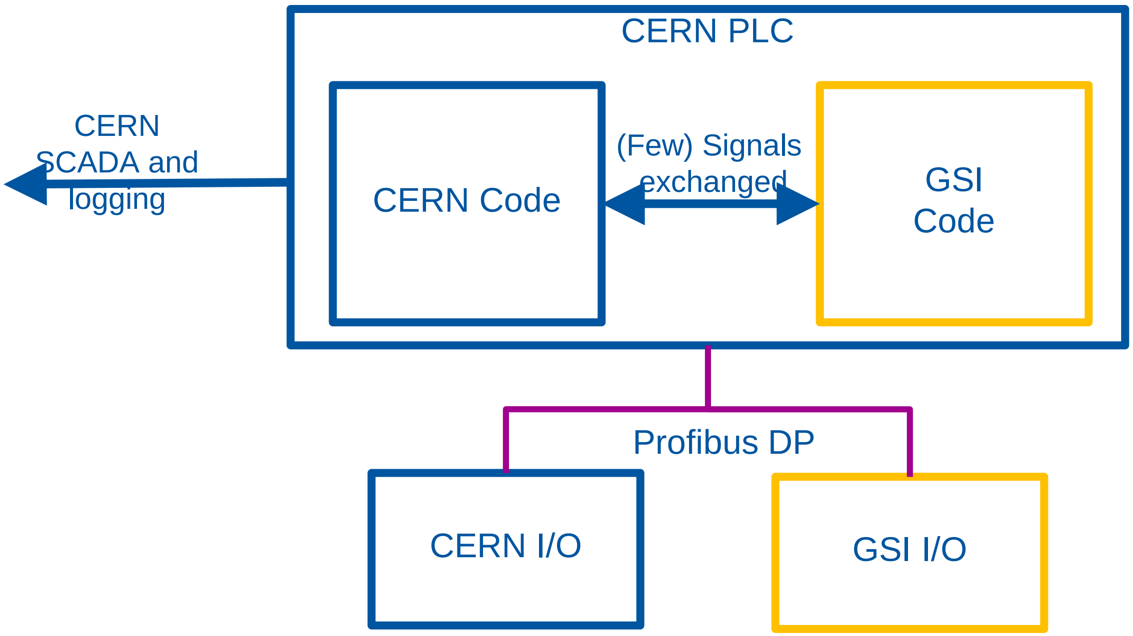
16 cabinets / racks
47 field boxes

Designed - built - installed by TE-CRG-CE



Controls: commissioning

- Cryogenic control system was commissioned over a 2 years period and is now ready
- GSI software for magnet monitoring and protection is integrated in CERN control system

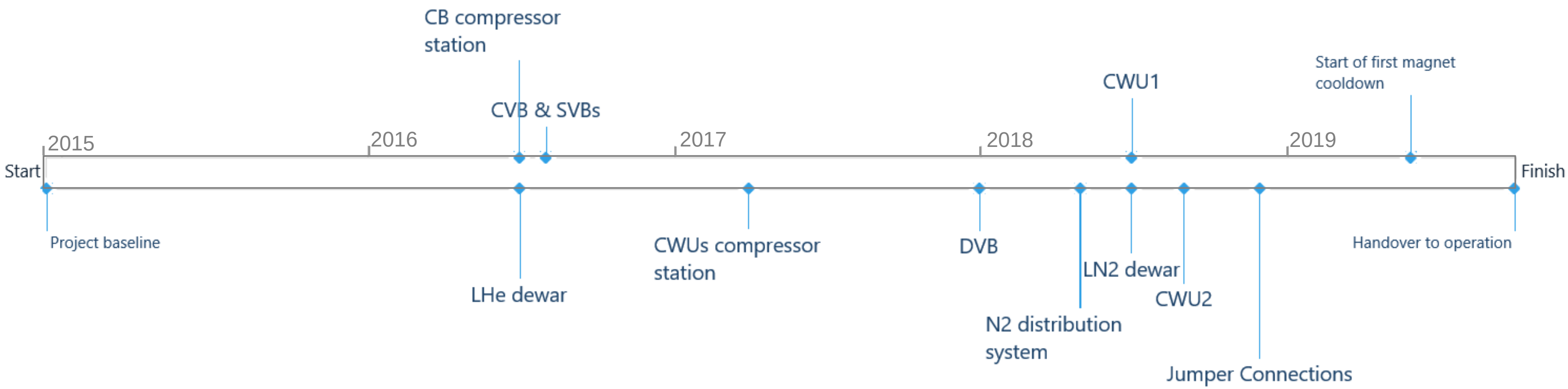


Main Project timeline

The orders for the cold box compressor and for the liquid helium system were placed in 2015.

All main components of the cryogenic infrastructure were installed between June 2016 and August 2018.

As the delivery of the magnets was delayed, the project schedule was revised at the end of 2016 and the planned resources were allocated to other projects.



<u>The cryogenic system required for testing the 1st super-FRS magnet was ready at the end of April 2019.</u>

<u>All systems will be in configuration for series test by autumn 2019.</u>

Roadmap to handover to operation

Documentation

- Review of P&IDs and instrumentation list: **CDS completed,** LHe & pre-cooling system ongoing
- Project and equipment documentation: **stored in EDMS**
- Electrical schemes: **stored in EDMS**
- Control specifications: **stored in EDMS,** CWU2 and pre-cooler re-generation circuit will be validate following equipment commissioning

Main steps (baseline)

- Joint (project and operation teams) commissioning of the cryogenic infrastructure with the magnet is scheduled for May – September 2019.
- Responsibilities defined in document EDMS 2156999 for the commissioning period.
- Finalization of consolidations and non conformities will be completed by the end of September 2019
- Handover to operation will take place at the end of September 2019 following a complete thermal cycle of the 1st magnet.

Towards the nominal operation of the cryoplant at B180 / West Area Testing Facility

Team

- CRG Operation link person: Thierry Dupont
- The team in charge of Operation of WAT cryogenics is:
  - From CERN industrial service contract S176 Cryogenics M&O
  - Same team as cryogenic testing facility at SM18
  - Already involved in the commissioning and testing
- Organization
  - Operates locally and/or remotely during working days
  - Ensure stand-by duty service to put installation in safe mode in case of event during nights and week-ends
- Formal hand over to the operation team: target date October 1st 2019

Provided Services

- Operation & Maintenance budget is based on number of running hours in planned operation windows:
  - 2019 = 5’000h
  - 2020 = 7’000h
- Usual preventive maintenance of the cryoplant is included
- Management of Liquid Nitrogen Logistics
- Success factors :
  - Achieve availability target above 95% Cryo-OK in the operation windows, for instance SM18 availability was 99.8% in 2018
  - Ensure helium losses are traced and continuously reduced

www.cern.ch

Remaining tasks on equipment for series tests

Pre-cooler regeneration system

- System to be completed
- Not required for first magnet cool down

Consolidation of the N2 exhaust system

- Experience during commissioning has shown that the exhaust system creates a visible condensation plume that could be disturbing due to the proximity of the road. This effect is particularly visible with cold weather
- A 15 kW heater will be installed at the exhaust to avoid cold gas outlet.
- Commissioning with first magnet will be done with the existing system.
- Consolidation planned for June – July 2019