



Status and first results of XFEL cryogenics

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..presenting the work of many colleagues, institutes and contractors



**HELMHOLTZ
| ASSOCIATION**

- XFEL & XFEL cryogenic system overview
- Requirements for XFEL refrigerator
- Modifications of HERA cryo plant -> XFEL refrigerator
- 2K cold compressor system
- Refrigerator commissioning & acceptance tests
- Cold compressor open issues
- XFEL injector cryogenic operation – first operation experience
- XFEL installation status & future of cryo operation

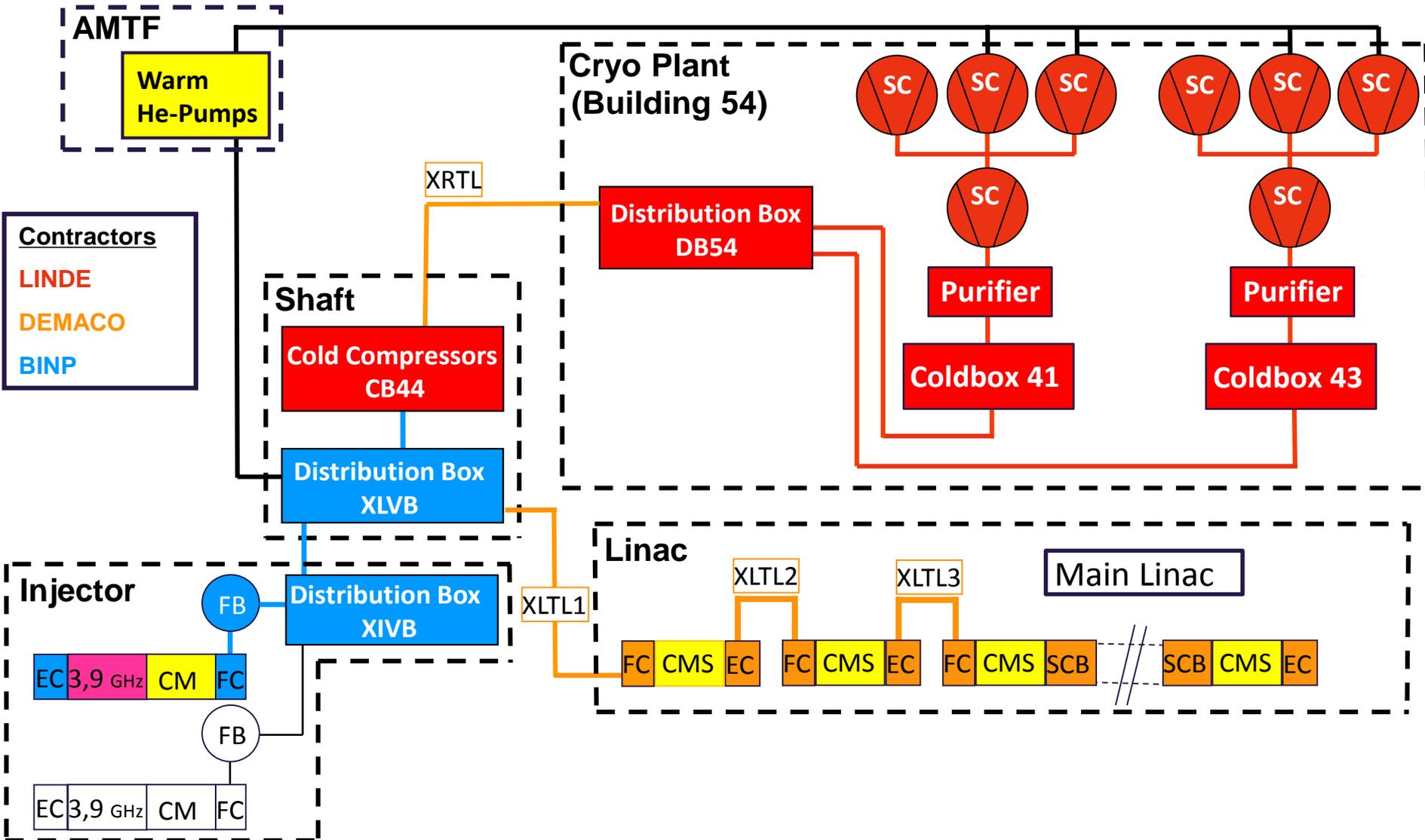
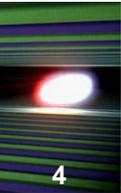
General information about XFEL - project

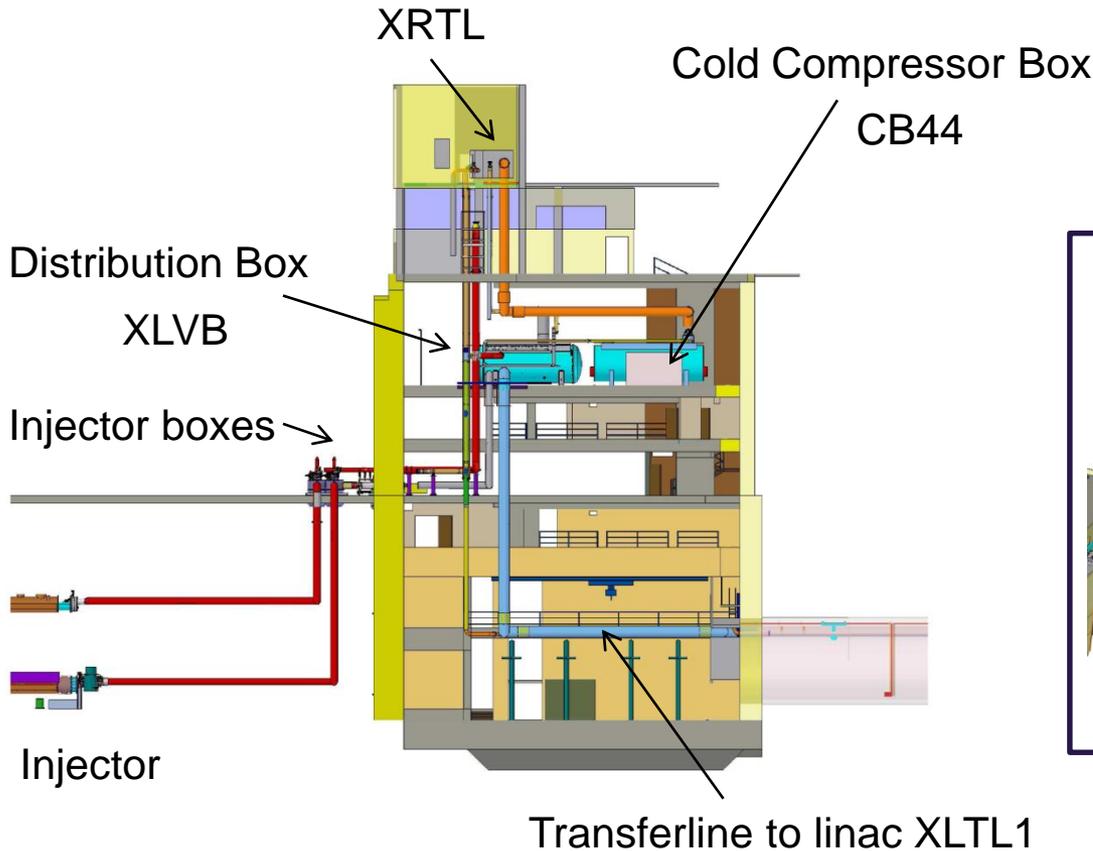
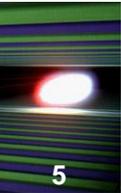


Key figures:

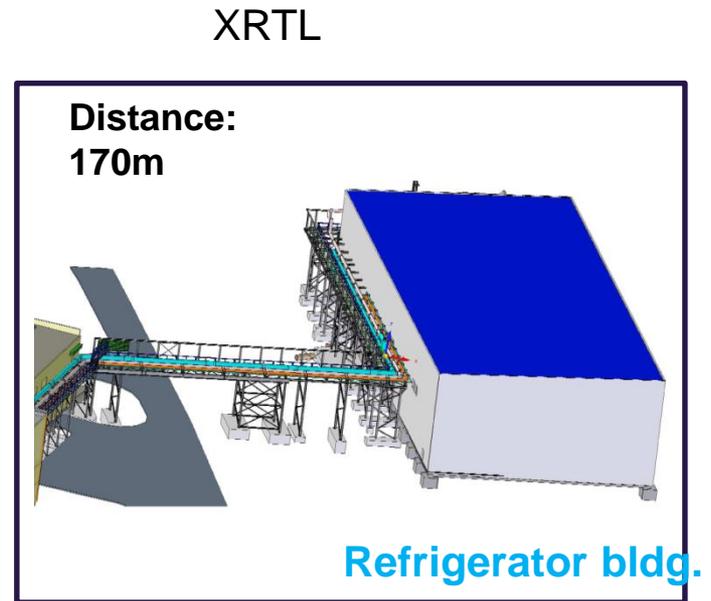
- Length of accelerator: 1500m
- Length of facility: 3400m
- Accelerator modules : 100
- Max. electron energy: 17,5 GeV
- Max. wavelength: 0,5nm
- Start of operation: 2016

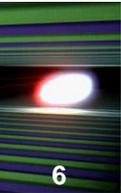






XFEL XSE shaft bldg.





Contributions from Budker Institute for Nuclear Physics (BINP), Novosibirsk, Russia



XFEL Injector valve boxes XIVB & FB



XFEL Injector transfer lines, feed- & end caps

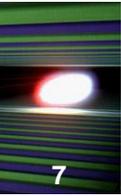


Distribution valve box XLVB

**All equipment delivered,
installed and in use
already (XFEL injector)**

(XLVB warm gas tubing will be modified)





XRTL

DeMaCo Netherlands supplied:

Transfer-lines: XRTL; XLTL1..3

String-Connection-Boxes 1-6

Feed-Caps 1-3

End-Caps 1-3

all equipment delivered & installed(*)



XLTL1



Feed-Cap 1 at DeMaCo / in XFEL tunnel

(*) XLTL1 not yet connected to XLVB by intention

Requirements on XFEL refrigerating plant (17.5 GeV)

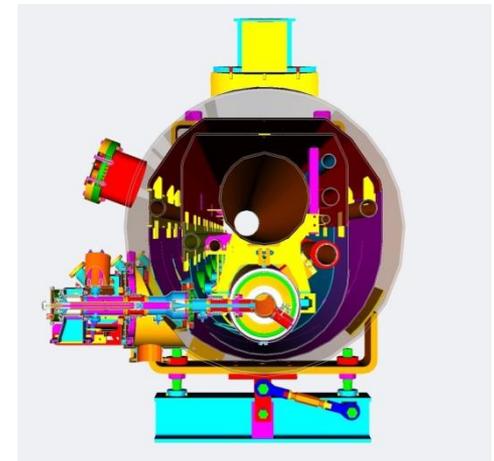
- **2K: 1.9 kW (incl. 30% overcapacity)**
- **5/8K: 3.6 kW (incl. 50% overcapacity)**
- **40/80K: 24 kW (incl. 50% overcapacity)**
- **Operation: 24 h/d, 7 d/week**
- **Run periods of 2-3 years without scheduled break**
- **Refrigerator availability > 99%**
- **Cold Compressor suction pressure stability < 1%**

„TESLA-Technology“



1.3 GHz superconducting cavities

XFEL cryomodule = 8 cavities + 1 sc quad



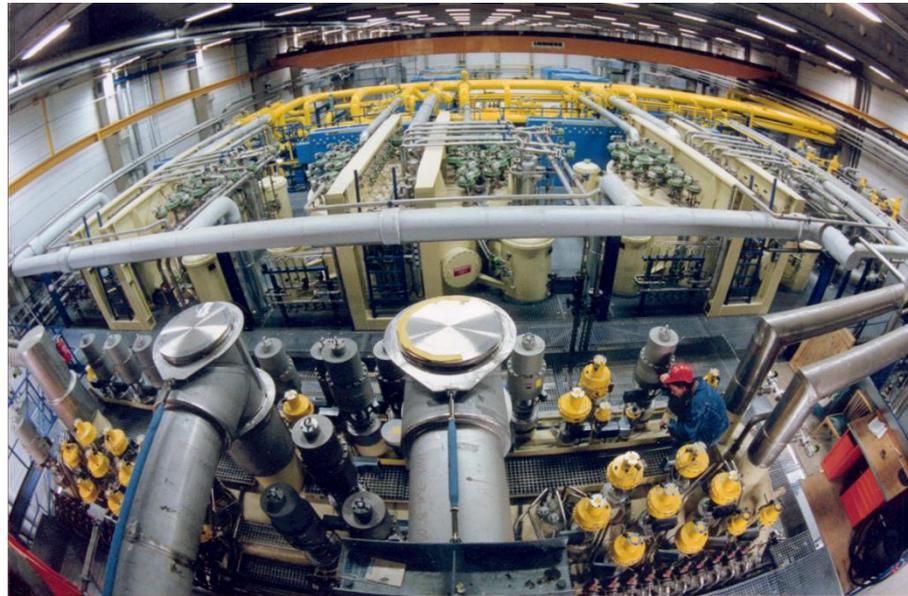
Industrial Study (LINDEKRYOTECHNIK,2006) and its Results:

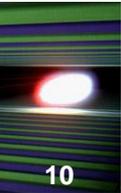
2 HERA refrigerators (subplants) + 2K system (cold compressors) could be modified to XFEL-refrigerator

Use of existing HERA helium refrigerator = cheapest solution

-> reason to realize this solution

LINDEKRYOTECHNIK (LKT) contractor for XFEL refrigerator





‘One Cold-Box’ Option ???

Circuit	Load [W] sum	Load [W] Only HeII bath	Mass flow[g/s] supply	Mass flow[g/s] return	Pressure [bar] supply	Pressure [bar] return	Temp [K] supply	Temp [K] Return
2K	2457	2307	115	143	1.2	<= 0.024	<=4.407	<=3.87
5-8 K	4150		170	142	5.5	5.44	5	8.2
40-80K	30000		142	142	18	17	40	80

Table 1: Specification of the main parameters of the XFEL-Refrigerator. The parameters are handed over at the transfer line of the CB44 to the distribution box XLVB. The split 2K-box approach is assumed. It is also assumed that the JT-heat exchanger is part of the XLVB. The loads include 50% over-capacity, compared to the calculated and predicted loads for the XFEL-linac. (The heat loads of the main transfer line between DB54 and CB44 are included in the parameters of Table 1-Table 3. The performance of this transfer line, which is not in the responsibility of the contractor, shall be considered as described in section 8.3.)

Circuit	Load [W] sum	Load [W] Only HeII bath	Mass flow[g/s] supply	Mass flow[g/s] return
2K	559-1896	49-1746	29-85	30-96
5-8 K	1812-3593		69-141	68-130
40-80K	10377-23923		49-114	49-114

Table 2: Operating conditions with respect to section 1.2.3 (17.5 GeV linac, two pulsed injectors) Here the ranges from the lowest possible calculated static loads (only one injector) to the maximum design dynamic+static load conditions (two pulsed injectors, including 50% over-capacity for the 5/8K and 40/80K circuits and 30% overcapacity for the 2K circuit.) are considered.

DESY 17.5 GeV specification

2K: 1.46 (+30% = 1,9) kW

5K-8K: 2.4 (+50% = 3.6) kW

40K-80K: 16.0 (+50% =24) kW

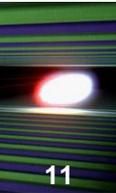
LKT prognosis for one coldbox:

2K: 2.01 kW

5K-8K: 3.03 kW

40K-80K: 20.17 kW

➔ **Hope: operating 17.5 GeV Linac with one refrigerator (CB) should be possible and would save primary energy costs**



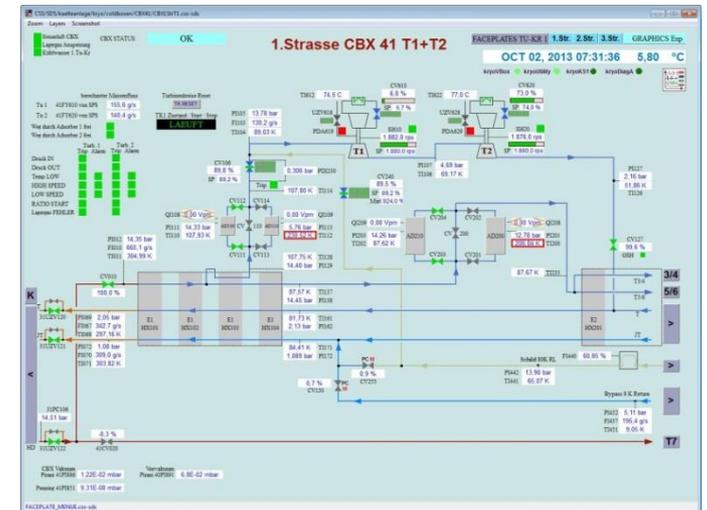
■ Modifications

- 50% of all piping were modified
- LN2 precooling heatexchanger was removed
- Turbines were re-arranged and equipped with optimised flow parts



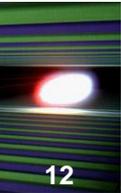
■ At least some items remained

- Platefin heatexchangers
- 80K and 20K Adsorber
- Cryogenic valves (shaft, stem and some plugs)
- 17 years of operational experience → automated procedures migrated into plc

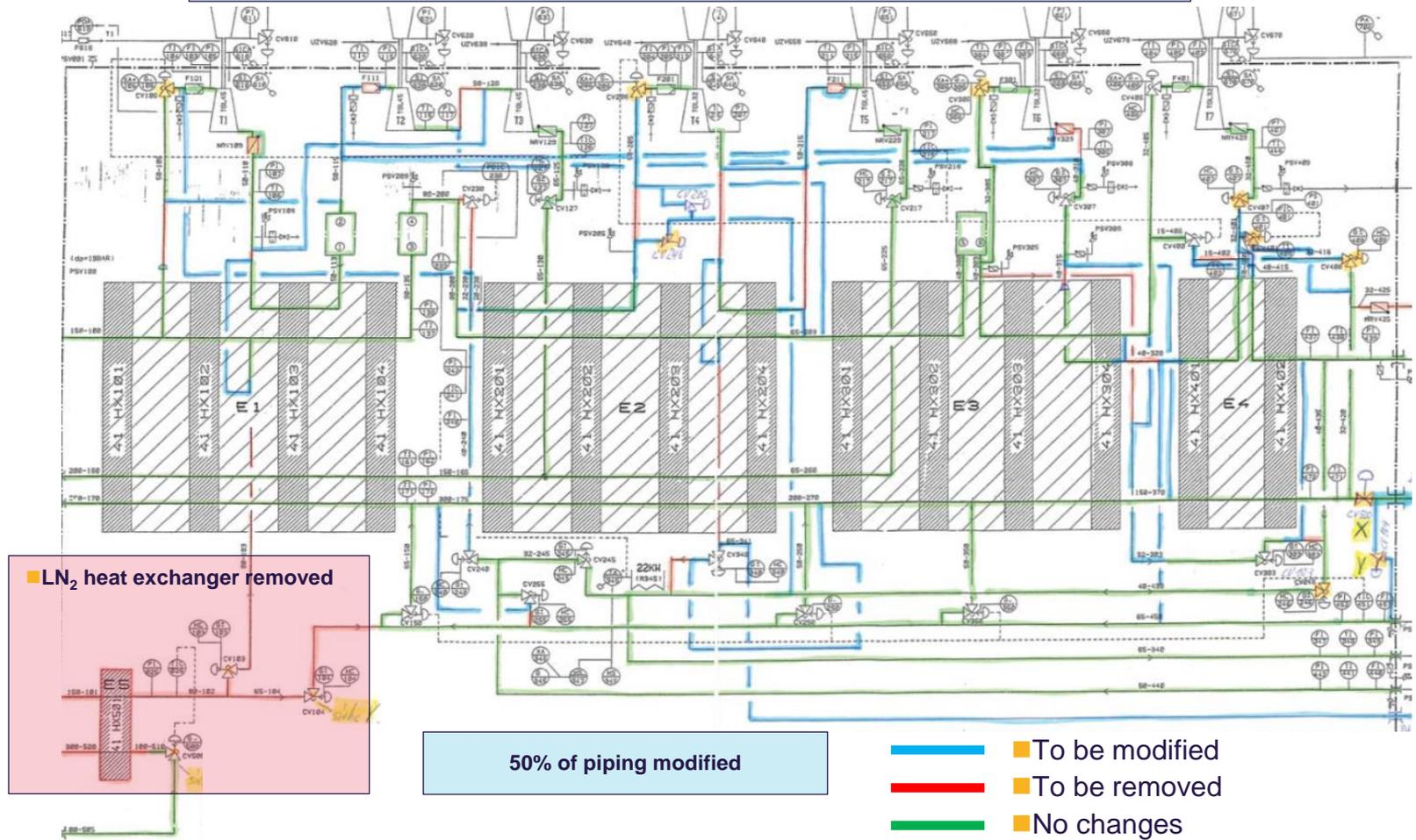


HERA Refrigerating Plant → XFEL Refrigerating Plant

Overhauling, modifications, extensions



■ Re-arrangement of turbine strings



■ LN₂ heat exchanger removed

50% of piping modified

- ■ To be modified
- ■ To be removed
- ■ No changes

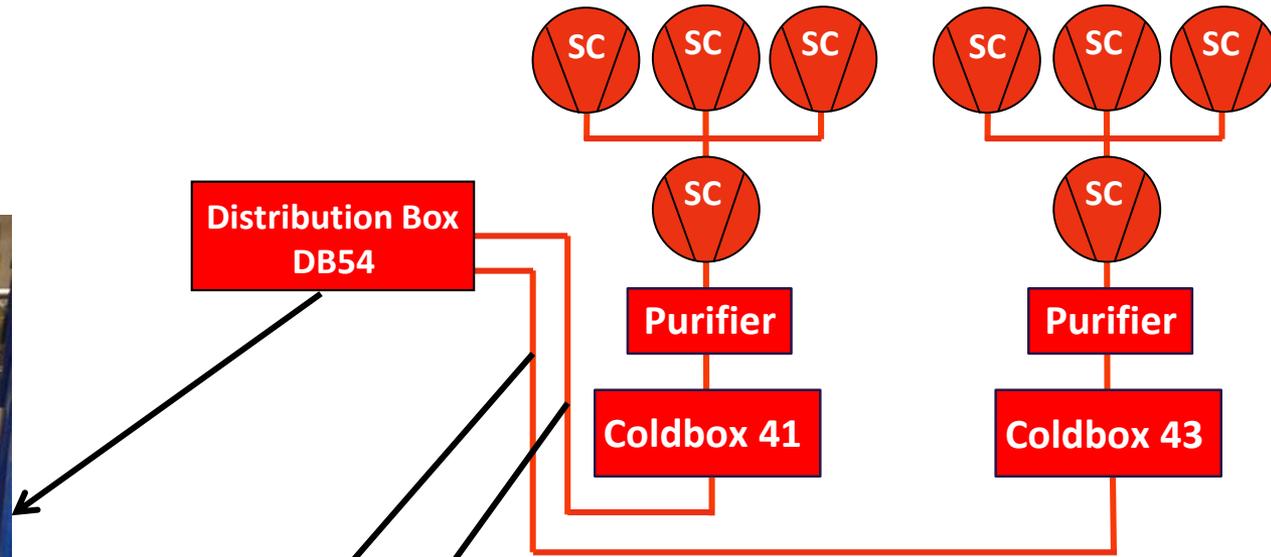
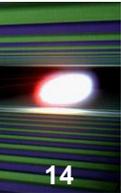
■ Main Objective

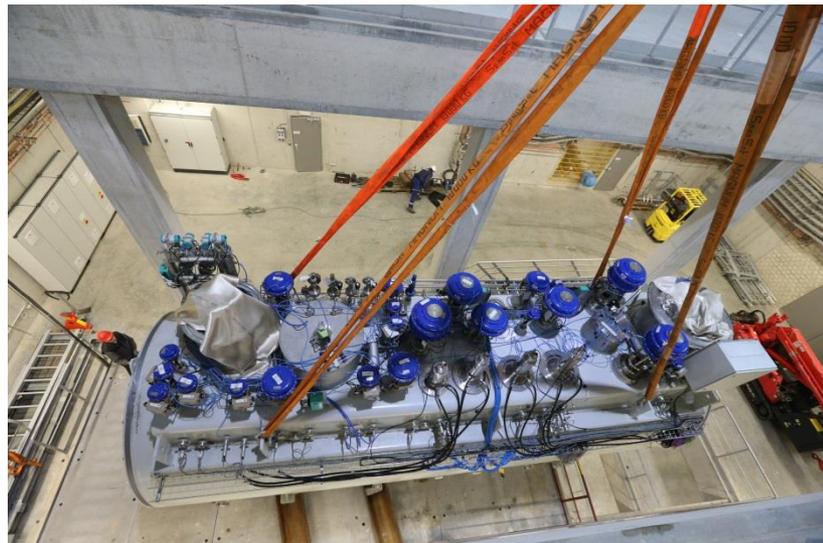
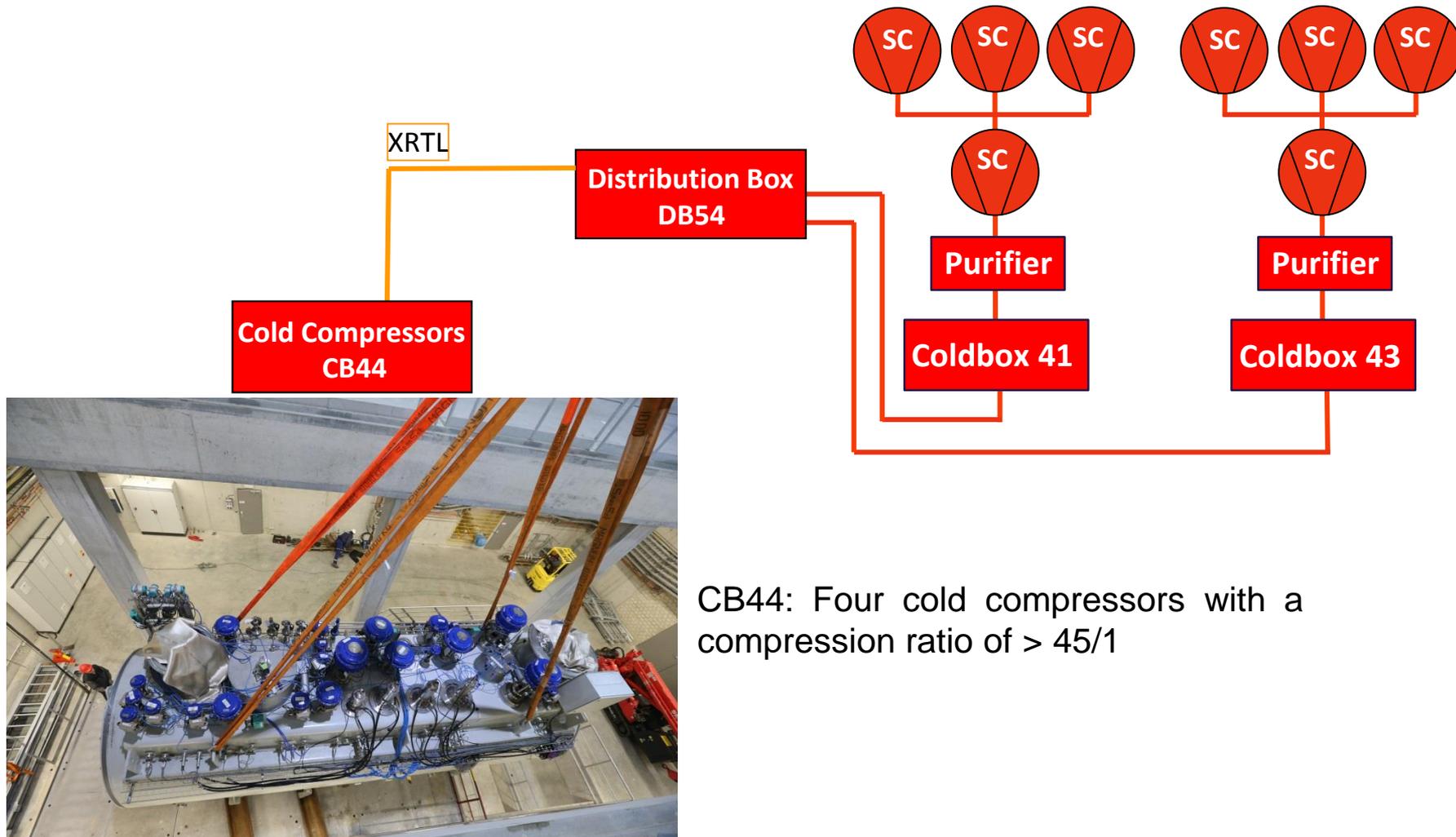
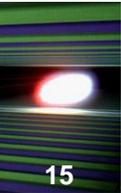
- To ensure «a sufficient helium-supply of the XFEL-linac for at least 15 years of continuous operation» [from T. Schnautz, B. Petersen «Specification of the XFEL-Refrigerator»]

■ Some numbers about overhauling:

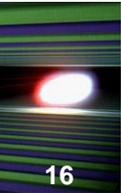
- Adsorbent replacement at 4 dryers
- Revision of 9 screw compressor blocks
- Calibration of 178 safety valves
- New sealings at 1292 manual valves
- Painting of all equipment overhauled
- Pressure & leak test







CB44: Four cold compressors with a compression ratio of $> 45/1$



■ Cold Compressor Box CB44

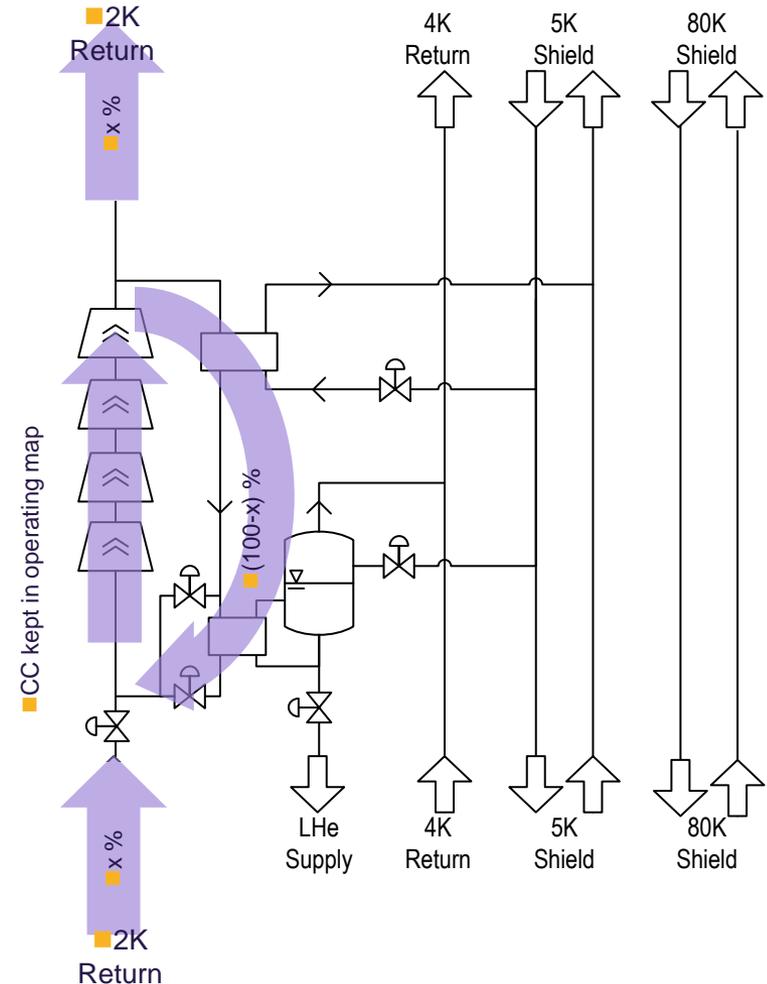
- 4 cold compressors, total compression ratio = 1/45.8
- Full flow re-cooling bypass
- Startup & pumpdown independent from «experiment side»
- Re-connection to sub-atmospheric linac (demonstrated for injector)
- Operational robustness due to high internal turndown ratio

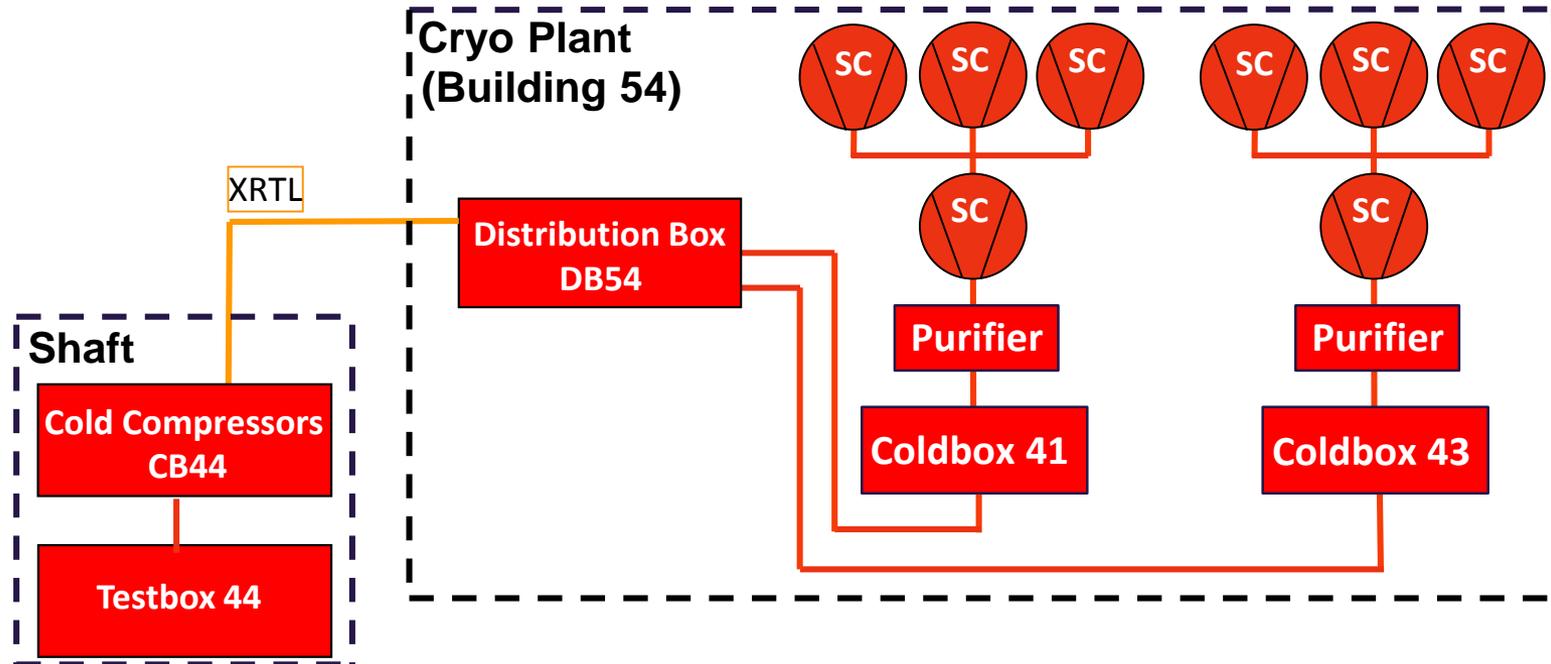


Remark:

internal bypass is a great help for operation -

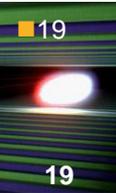
but it is no energy saver !





Performance tests:

1. Single coldbox operation: CB41 or CB43 with cold compressors (CB44)
2. Parallel coldbox operation: CB41 and CB43 with cold compressors (CB44)

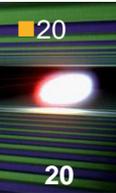


- Parallel CB operation demonstrated
- Capacity tests for single & parallel CB operation
- Specified capacities exceeded for parallel CB operation
- Single CB operation -> seems to be sufficient for XFEL linac operation
- ,mixed-cycle' operation of CCs demonstrated (25% dynamic range)

	CC mass flow [g/s]	CC inlet pressure [mbar]	CC discharge pressure [mbar]	5-8K [kW]	40-80K [kW]
XFEL spec (no margin)	74	24	1100	2.4	16
Single ColdBox CB41	99.6	22.9	1100	2.74	18.14
Single Coldbox CB43	102.7	21.8	1100	2.78	18.06
Single Coldbox operation CB43 CCs Part Load ,mixed-cycle'	75	23.3	815	3.15	20
Parallel-operation measured (at design spec)	106.6	23.2	1100	4	26.7

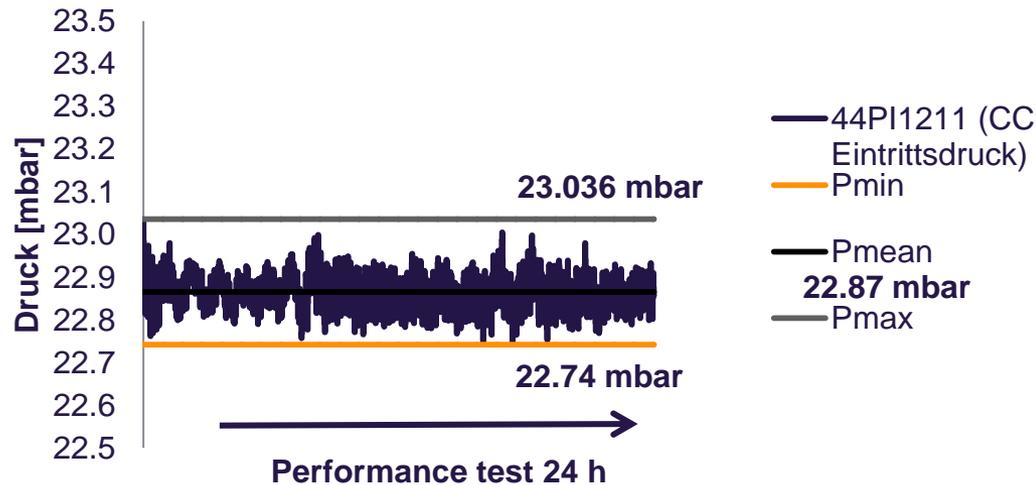
Capacity shifted from 2K to 5K



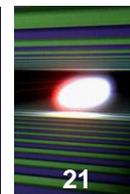


- 2K operation pressure stability better +/- 1% demonstrated

CC Inlet Pressure



Plot from single cold box operation of CB41

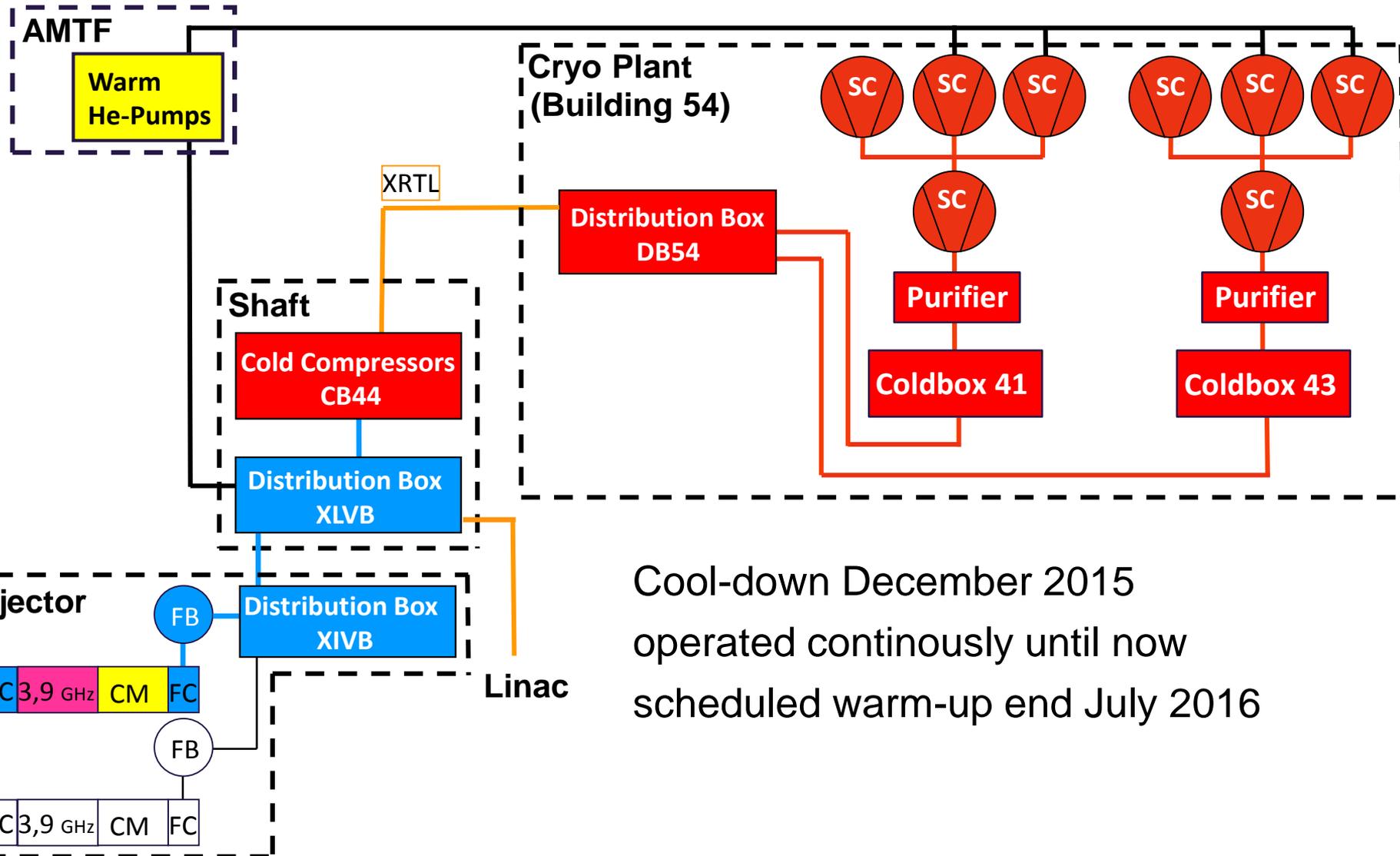
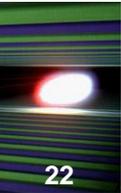


... we are in quite good shape – but there are some problems to be solved:

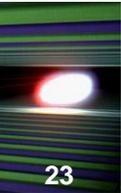
- Bearing failures at cold compressors (ceramic bearings)

Cold compressor stage	Current Pressure ratio [mbar]	Bearing failures	Expected lifetime [h] Scheduled / expectation	Observed very preliminary [h]
CC-stage 1 (44CC1211)	26 / 118	No failures	16000 / 16000	open
CC-stage 2 (44CC1212)	118 / 330	4	16000/30000	286
CC-stage 3 (44CC1213)	330 / 815	4	16000/32000	288
CC-stage 4 (44CC1214)	815 / 1090	1	16000/41000	open

- LINDEKRYOTECHNIK started root cause analysis
- General analysis is conducted: frequency spectra monitoring, general review of loads ..etc.etc.
- Some construction changes are already implemented
- Test bench will be installed
- 800h continuous operation to be demonstrated
- ...list of open issues after final acceptance



Cool-down December 2015
operated continuously until now
scheduled warm-up end July 2016

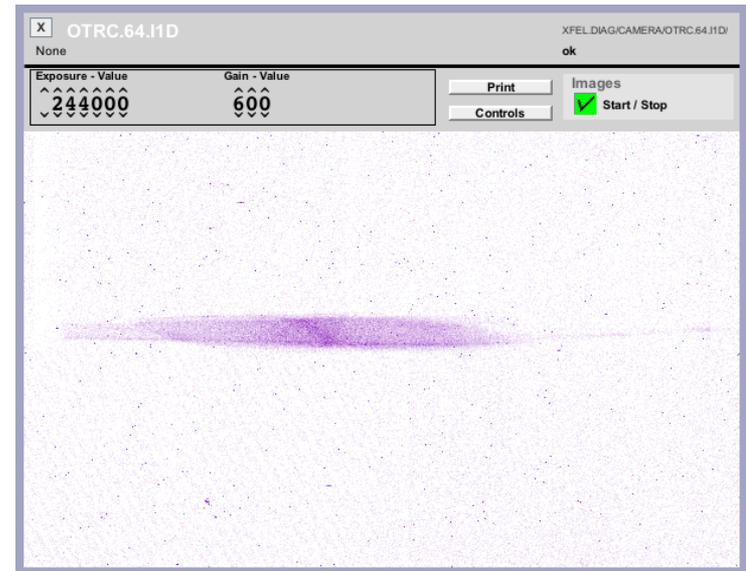
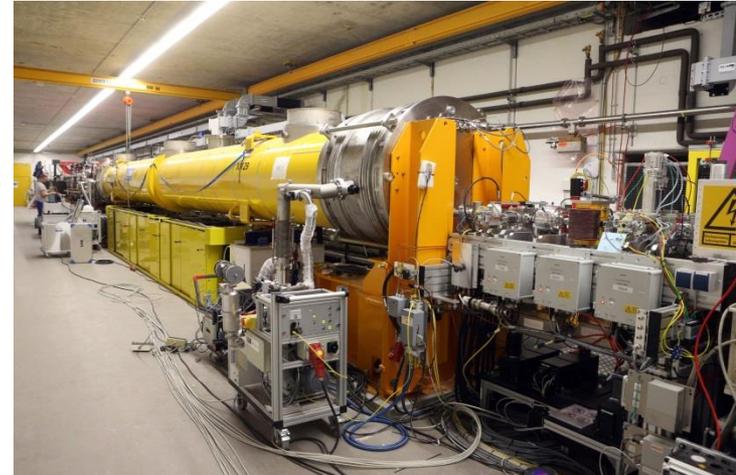


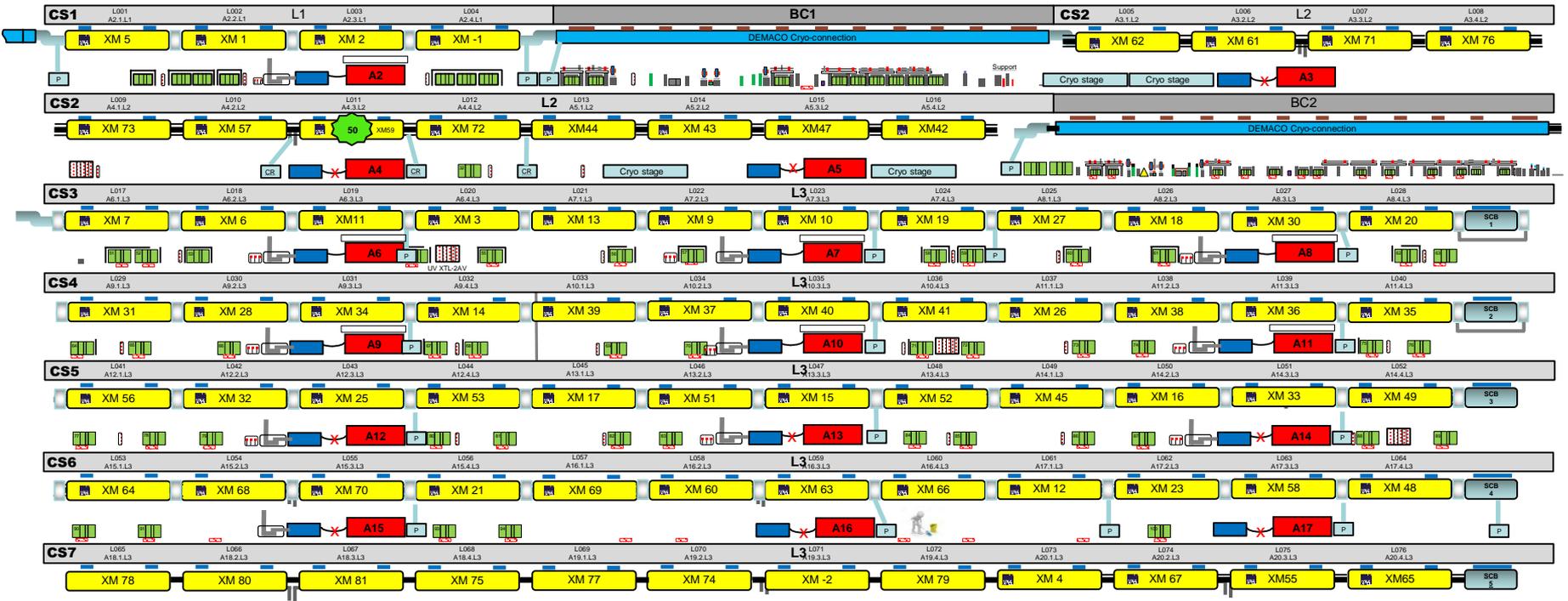
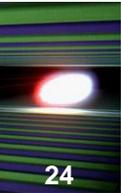
XFEL Injector in operation since December 2015

First beam 2 weeks after cool down – before Christmas !!

Status June 2016:

XFEL design emittance demonstrated





Status 03.06.2016

76 Modules installed

+ 8 in preparation now

1 RF-Station ready

6 RF-Stations under commissioning

9 RF-Station in preparation

- XFEL cryo system: installation completed (99%)
- Refrigerator capacities: specification exceeded
- 2K CC operation: main features demonstrated
- 2K CC issues: bearings – problems to be solved
- Continuous operation of XFEL injector demonstrated

- **Future plans:**
- **Cryomodule installation completed/ tunnel closed 9/2016**
- **XFEL linac cool down: procedures will start October 4, 2016, 8:00h**
- **First beam in XFEL linac before Christmas 2016**

- **Thank you for yor attention !**