Cryogenics for Large Accelerators

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Outline:

- Present and Future 2K accelerators
- Accelerator Module Test Facility (AMTF)

Accelerators at 2K

Accelerator	Heat load @ 2K	Eq. Refriger. Power @ 4.5K
CEBAF	2*4.2kW	2*18 kW
LHC	8*2.4kW	8*18 kW
SNS	≈ 2.4 kW	≈ 11 kW
FRIB	≈ 4 kW	18 kW
XFEL/DESY	≈ 2.4 kW	≈ 11 kW
LCLS-II	2*4.6 kW	2*18 kW
ESS	≈ 3 kW	≈ 10 kW
ILC	14-28(?) *2.4 kW	
RHIC		≈ 14 kW
FAIR/GSI		6+18 kW (?)

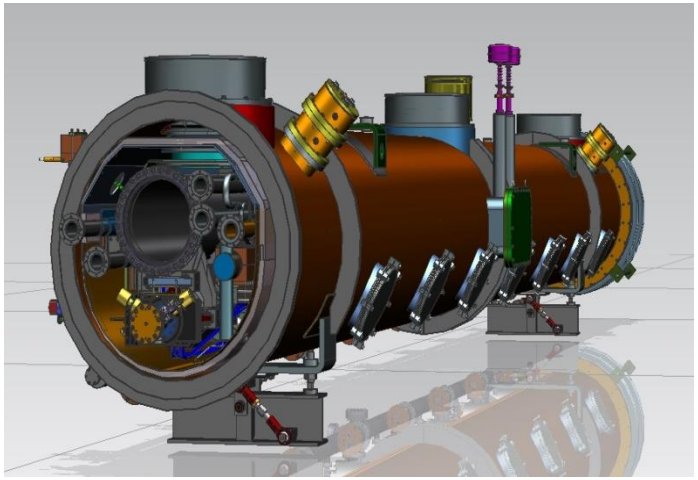
There is quite substantial number of accelerators working at 2K level!

The number of accelerators with sc cavities is growing!

The large cryogenic system & refrigerators are required!

Note 1: for XFEL, it could be possible to cover 2K heat load with one 9kW@4.5K refrigerator (this will be cross-checked)
Note 2: some refrigerators require also non-negligible 4.5K refrigeration load (e.g. FRIB, Cornell's ERL) or 4.5K liquefaction load (e.g. SNS, FRIB, LCLS-II, ESS)

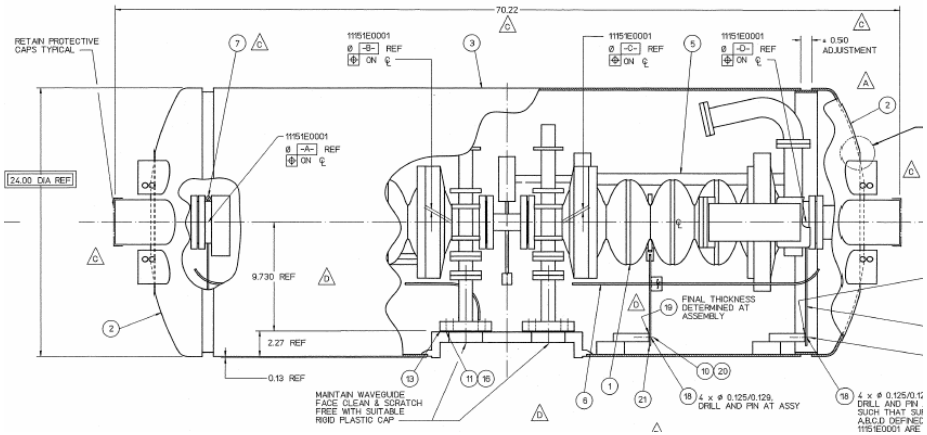
Accelerators with s.c. cavities at 2K: cross-sectional view



LCLS-II

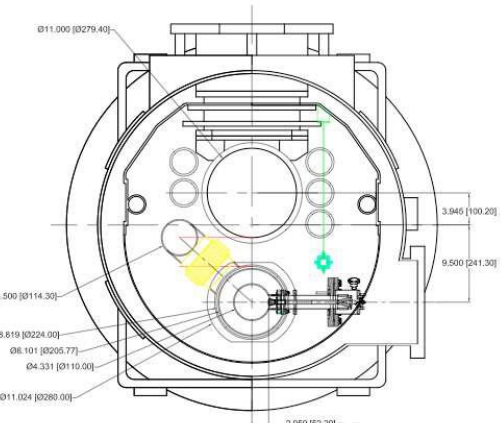
CEBAF, C-100

SNS, ESS



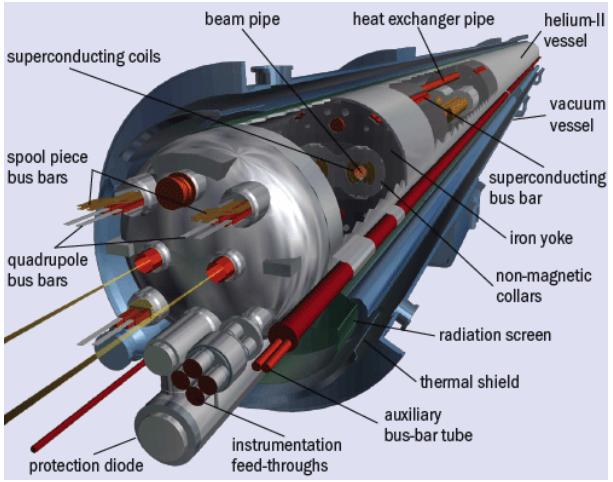
CEBAF, old cryomodule

FLASH, XFEL, ILC

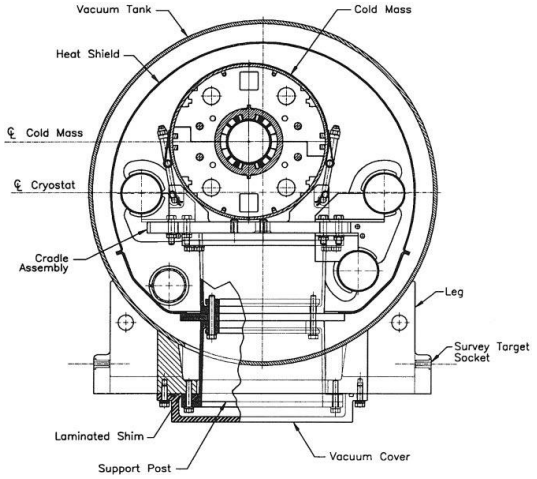


Cornell ERL

Accelerators with s.c. magnets at 2 or 4K: cross-sectional view

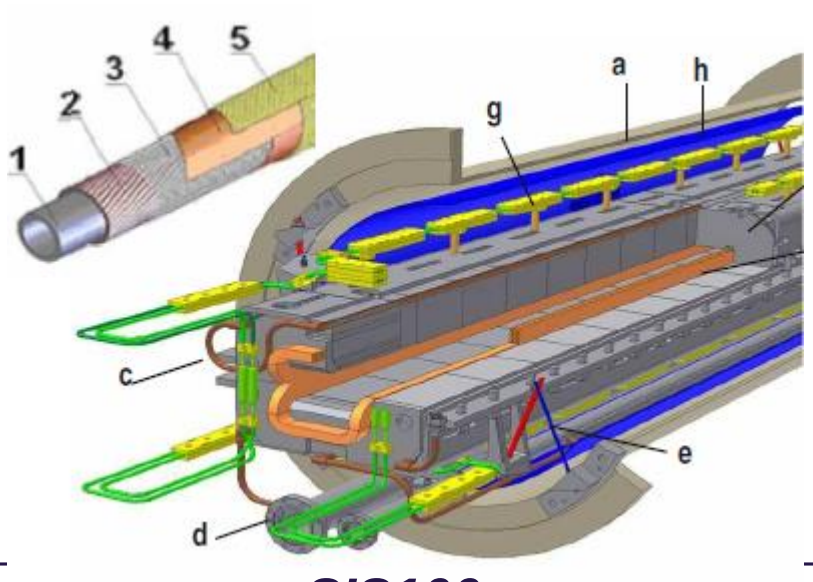


LHC



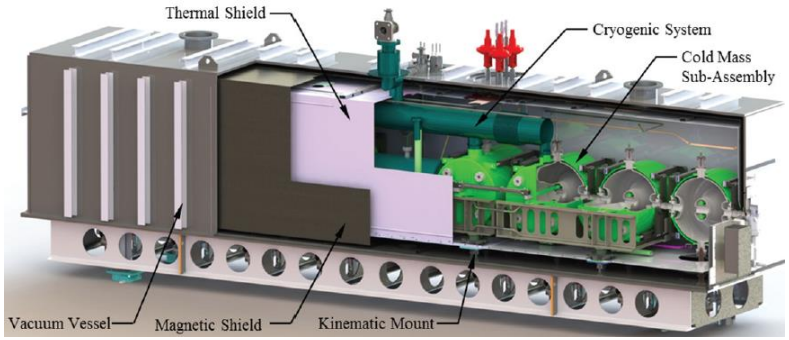
RHIC

SIS300

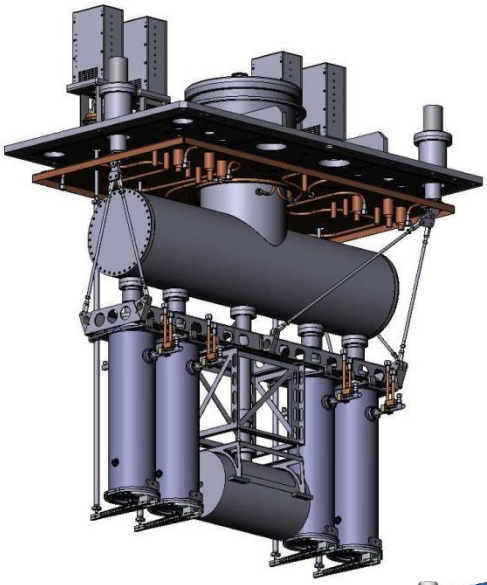


SIS100

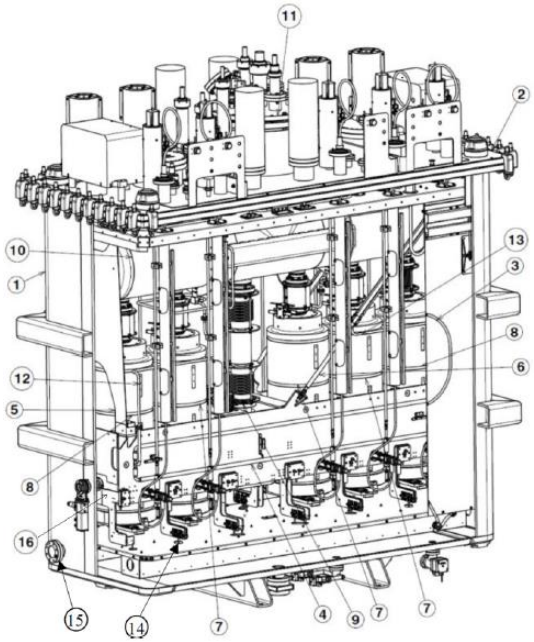
Accelerators with s.c. cavities at 2 or 4K for heavy ions: cross-sectional view



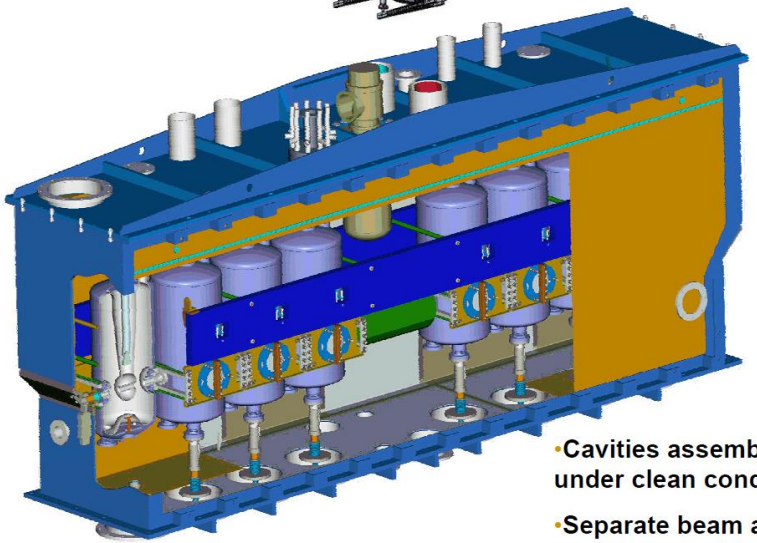
FRIB, Michigan



ISAC-II/ARIEL, TRIUMF



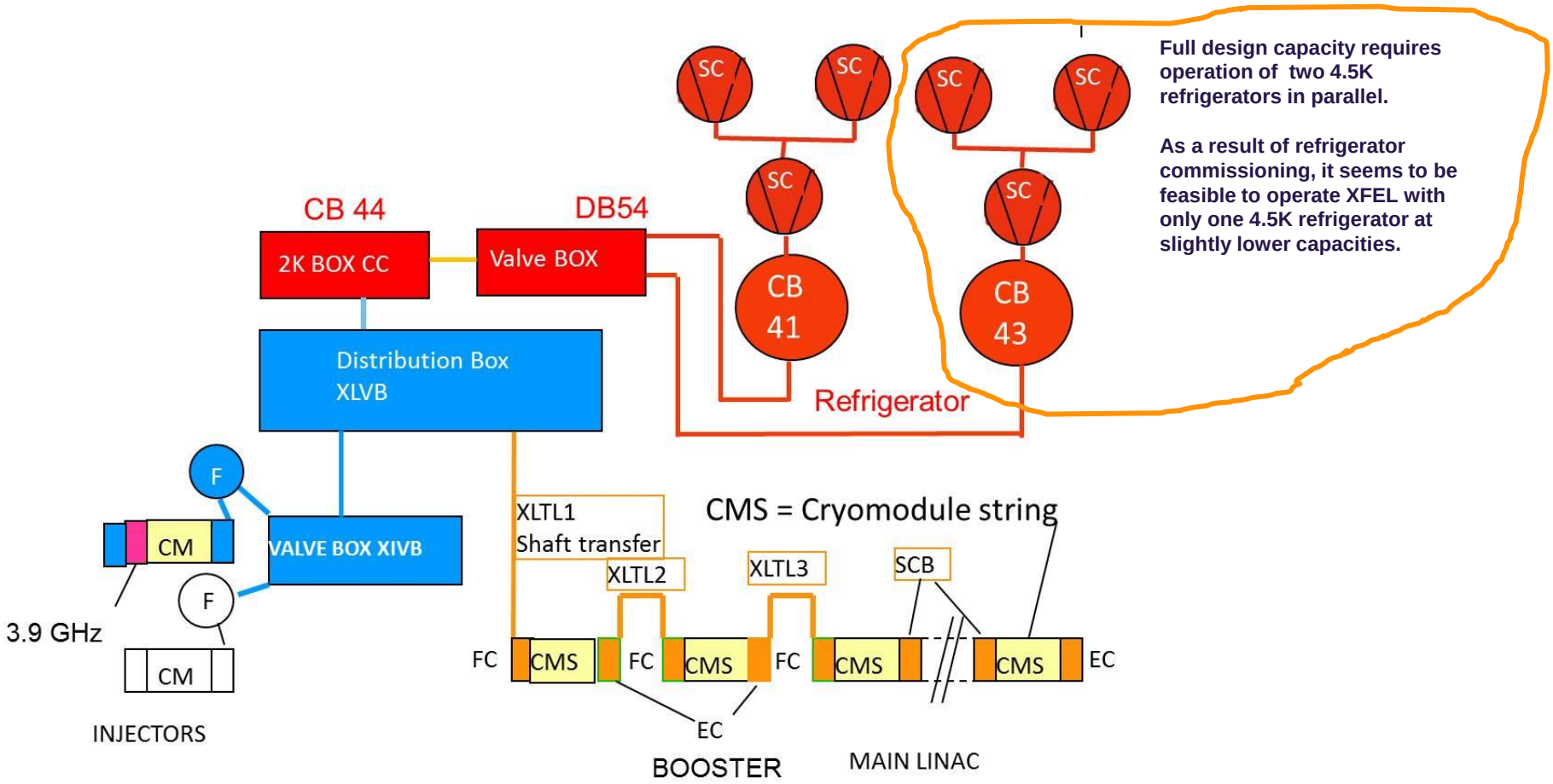
HIE-ISOLDE, CERN



- Cavities assembled under clean conditions
- Separate beam and insulating vacuums

Rare Isotope Accelerator, Argonne

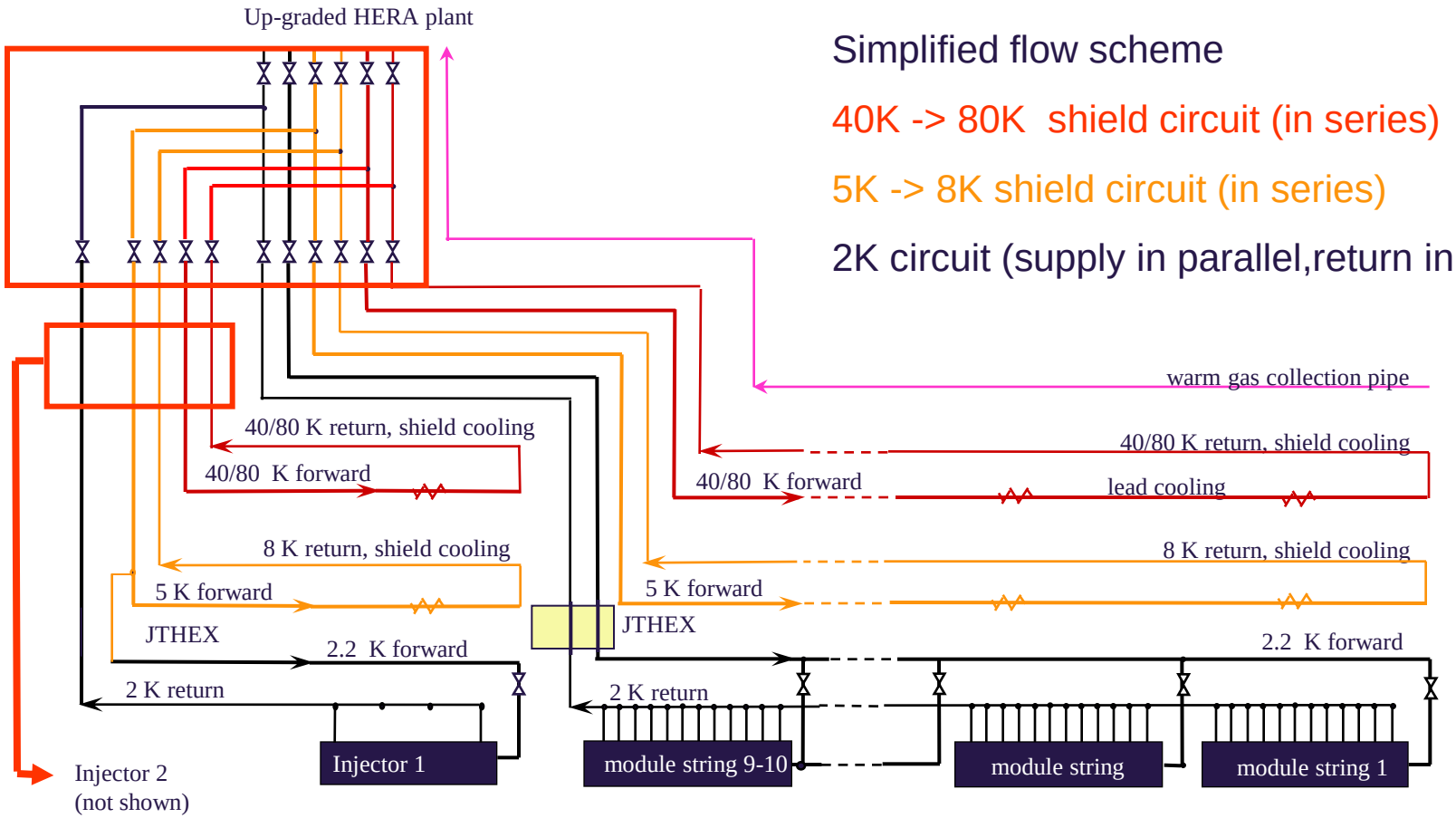
XFEL-cryogenic system -overview



Full design capacity requires operation of two 4.5K refrigerators in parallel.

As a result of refrigerator commissioning, it seems to be feasible to operate XFEL with only one 4.5K refrigerator at slightly lower capacities.

Simplified flow diagram of XFEL accelerator



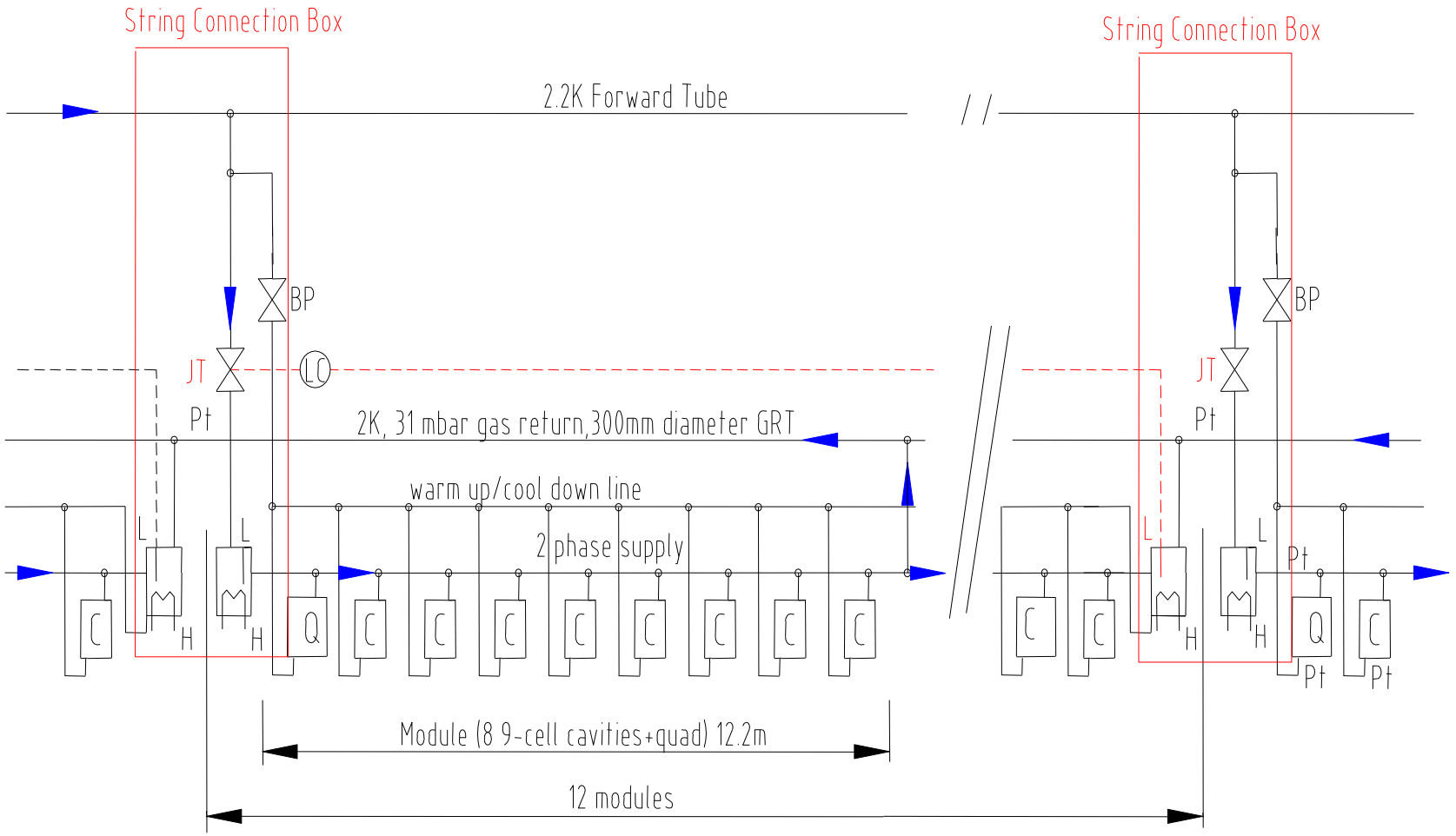
Simplified flow scheme

40K -> 80K shield circuit (in series)

5K -> 8K shield circuit (in series)

2K circuit (supply in parallel,return in series)

Simplified flow diagram of cryomodule string



Note: String connection box contains all cryogenic instrumentation

AMTF: purpose & objectives (TDR)

- Complete cold performance tests of all XFEL cryomodules before tunnel installation (RF measurements, vacuum check, cryo-losses)

  103 cryomodules, rate: 1cryomodule/week

- Cold RF tests of all XFEL superconducting cavities before cryomodule assembly

  824 cavities, rate: 6 cavities/week

- Cold tests of all superconducting magnet packages before cryomodule assembly

  103 magnets, rate: 1magnet/week

AMTF Hall – Cavities and Cryomodules

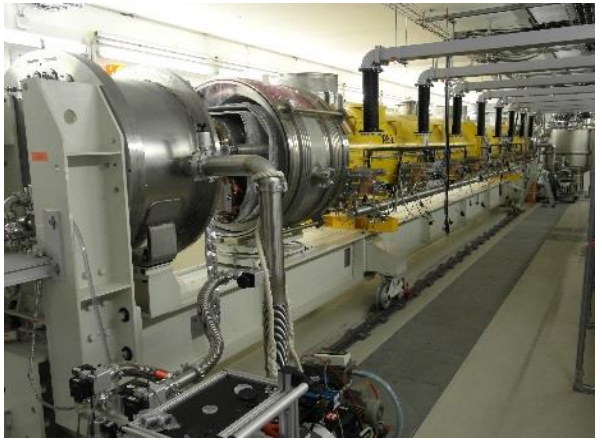
- Vertical Cryostat

- Radiation protection shielding

- Cavity preparation area

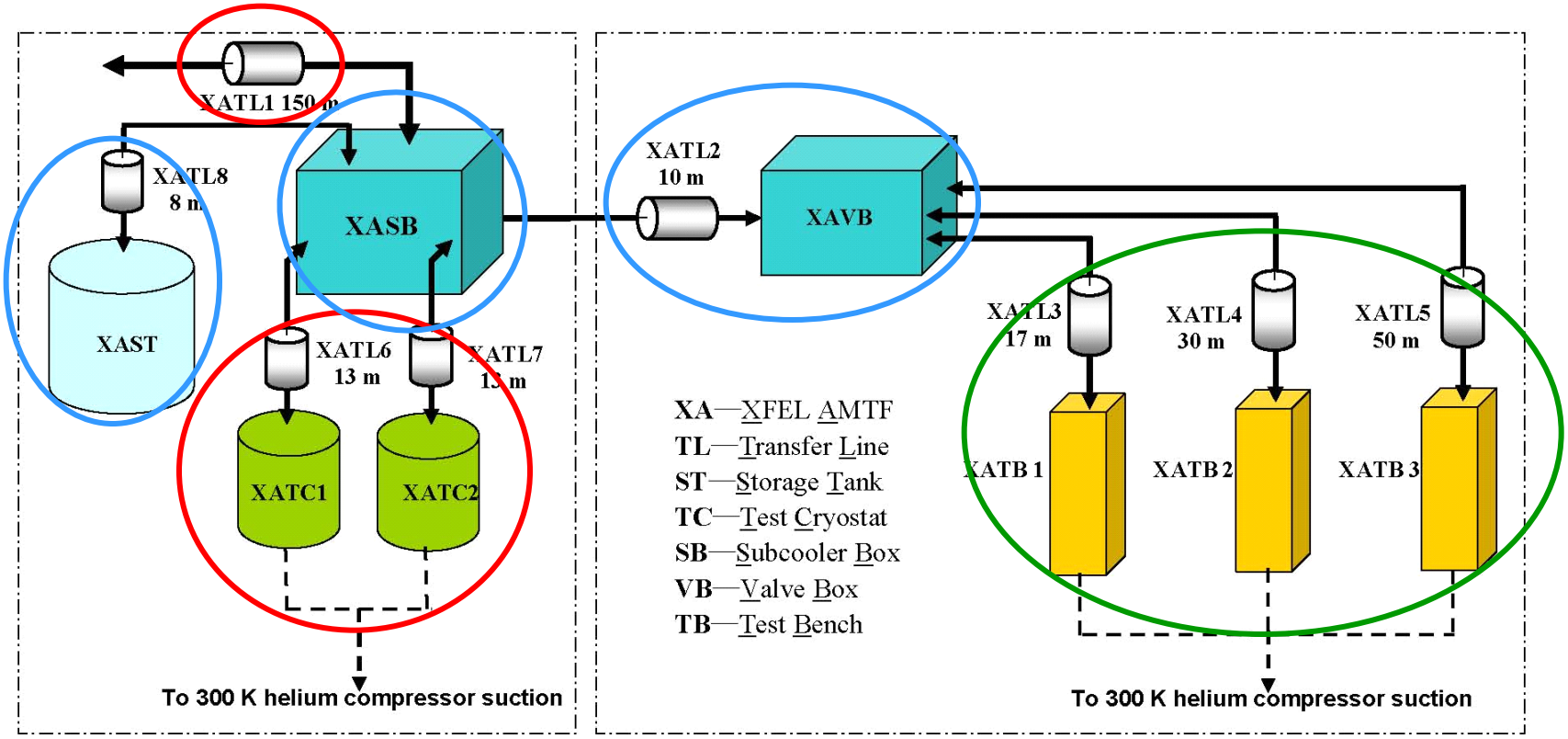
- Unloading of the cryomodule after transport

- Cryomodule preparation area



- XATB – module inside radiation protection shielding

AMTF – cryogenics contributions



Sub-system 1

Sub-system 2

Red = Wroclaw University of Technology+Kriosystem, Poland (in-kind)

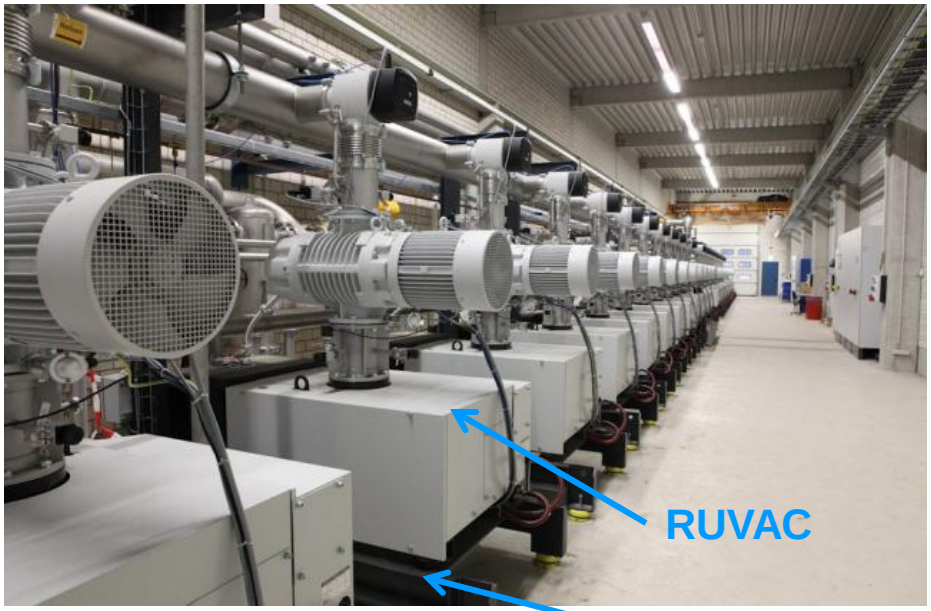
Blue = DESY MKS acting for XFEL company (no in-kind!)

-> DeMaCo, Netherlands

Green= Budker Institute of Nuclear Physics, Russia (in-kind)

Helium compressors (DESY in-kind)

Manufacturer: Oerlikon Leybold



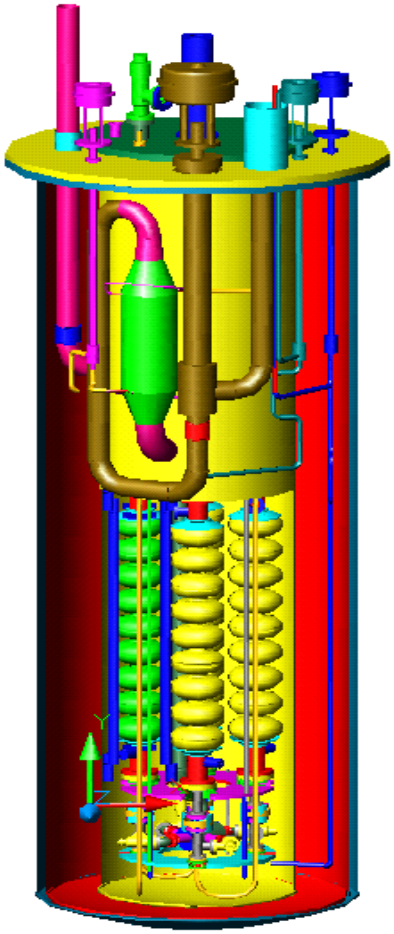
2 sets of compressors for 2K operation at AMTF (2 x 20 g/s helium at 20 mbar)

1 set = 12 x parallel pump stations (WS 2001 RUVAC roots vacuum pump + SOGEVAC SV750B rotary vane vacuum pump)

– simple, modular, redundant

In average: about 8000 h operation (status June 2015)

AMTF Vertical Cryostats



SPEC DESY

April 2009

Design & Construction

WUT&Kriosystem

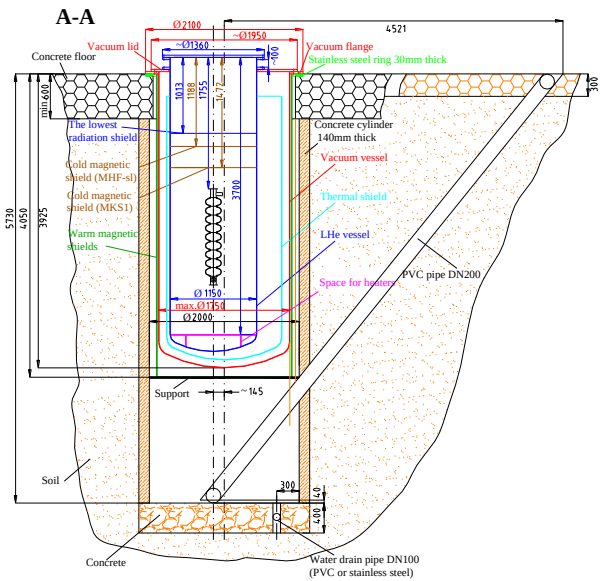
Delivery & installation:

July 2012 – April 2013

Cavity Frame Design:

DESY FLA

6 inserts for AMTF



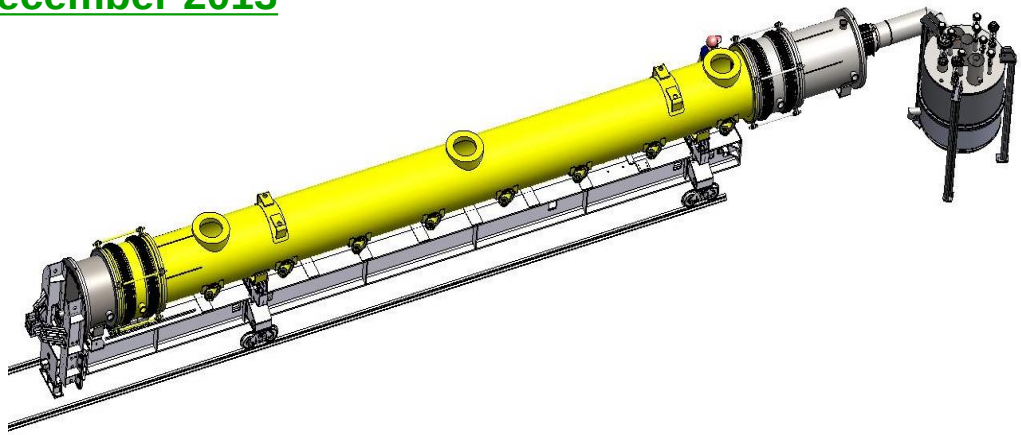
Courtesy of J.Schaffran

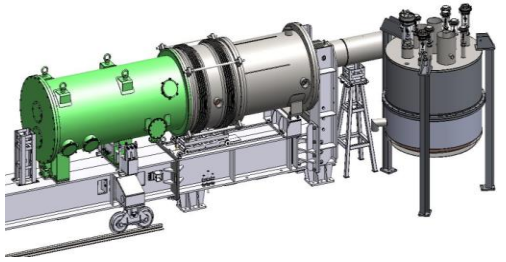
AMTF:3 cryomodule test stands & cryostat adapters

Spec DESY (February 2010) Design, Construction, Installation: BINP

First test stand delivered & installed May 2013 (cold commissioning July 2013)

Cold commissioning of 3rd test stand December 2013





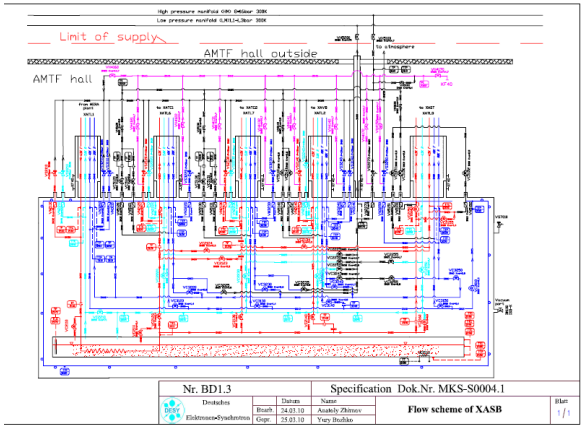
2 cryostat adapters for the test of single dressed cavities at AMTF

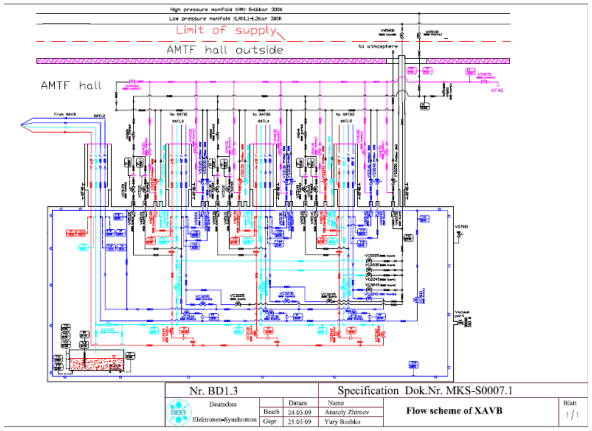
XASB, XAVB, XAST

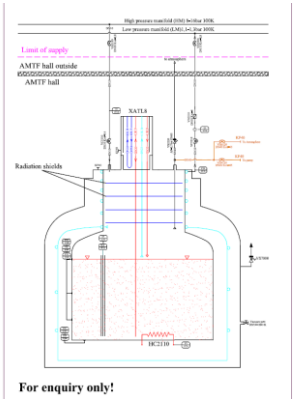
DESY is acting for XFEL company

Manufacturer: DeMaCO

Wessington Cryogenics Ltd, UK







Sub-Cooler Box XASB

Valve Box XAVB

L Helium Dewar XAST

Cryogenic operation of AMTF

- Supplied by HERA helium refrigerator.
- 33 g/s of LHe and cooling capacities of about 3 kW at 40/80K, 0.5 kW at 4.5K.
- Modular structure - independent operation of test stands from each other.
- Buffering of extra liquefaction in 10000 ltr liquid helium storage dewar (XAST).
- Missing of air condensation on cryogenic valves during exchange of modules or cavities.
- Capacity limits – return gas peak, screw compressor capacity during cool down/warm-up, 2 dynamic procedures in parallel.

Cool down and Warm up

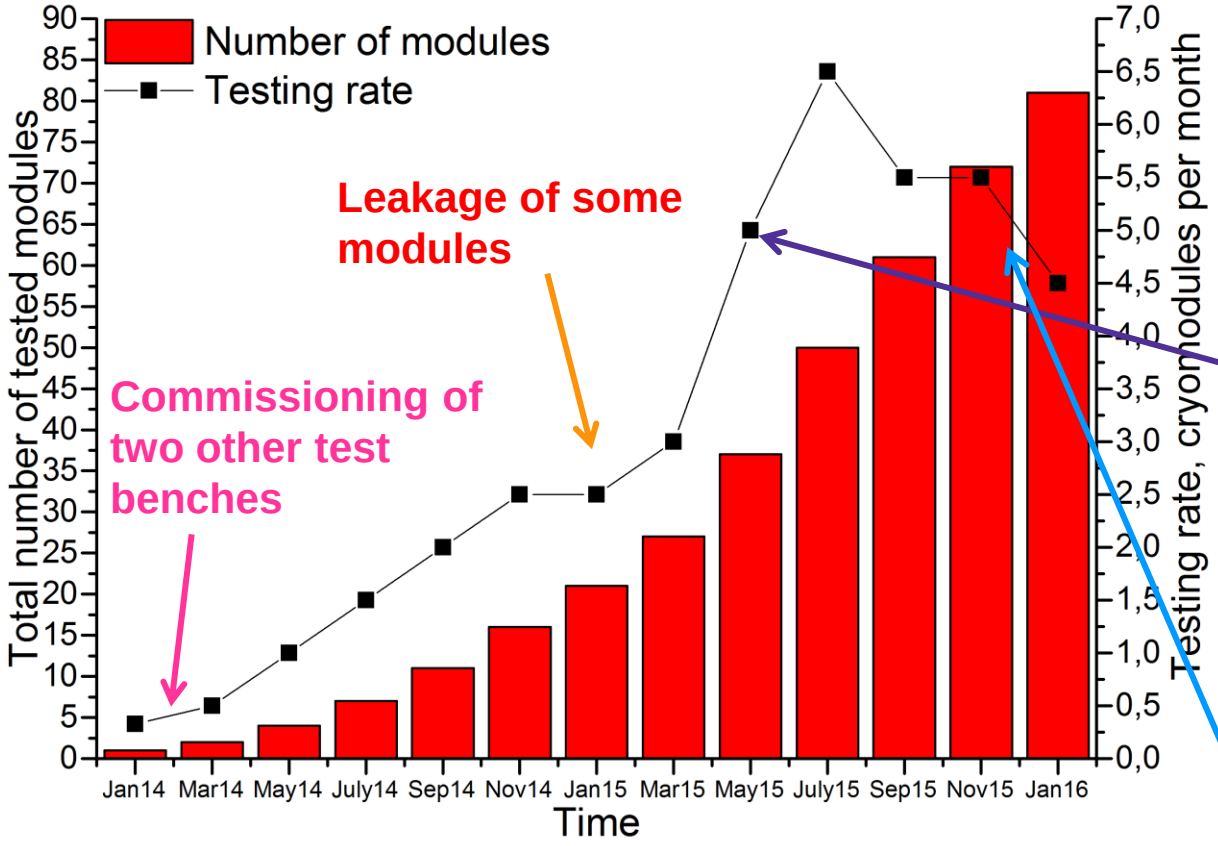
XATC1, XATC2

- Manual pump and purge
- Cool-down to 4K, liquid helium transfer and warm-up in automatic mode
- Manual pump-down to 2K

XATB1, XATB2, XATB3

- Manual pump and purge
- Mainly automatically warm-up,
- Cool-down partially in automatic mode

Summary of preliminary results (status Feb. 2016)



All superconducting magnets are tested!

In total, >1200 Cavity tests were performed on vertical cryostats.

Specified test rate of accelerator modules is reached !

Total heat load (static+dynamic) in line with budget.

Testing rate is slightly reduced due to lower cryomodule delivery rate

Near all results above XFEL specification:

- accelerating gradient 23.6 MV/m
- cavity quality factor $Q_0 = 10^{10}$ at 23.6 MV/m

Some preliminary conclusions

- Deliveries & installation of XATCs,XASB,XAVB,XATL were “just-in-time“ for start-up of cavity production
- Deliveries & installation of XATBs were “just-in-time“ for start-up of cryomodule production
- No dedicated debugging of cryo-supply and other systems
- XATCs design capacities demonstrated
- Complexity of XATBs commissioning underestimated
- General effort for installation & commissioning underestimated
- 1 cryomodule test/week is reached (further ramping-up rate is under investigation)
- So far: in budget and almost “in time“ (not “on schedule“)

Thank you for your attention !