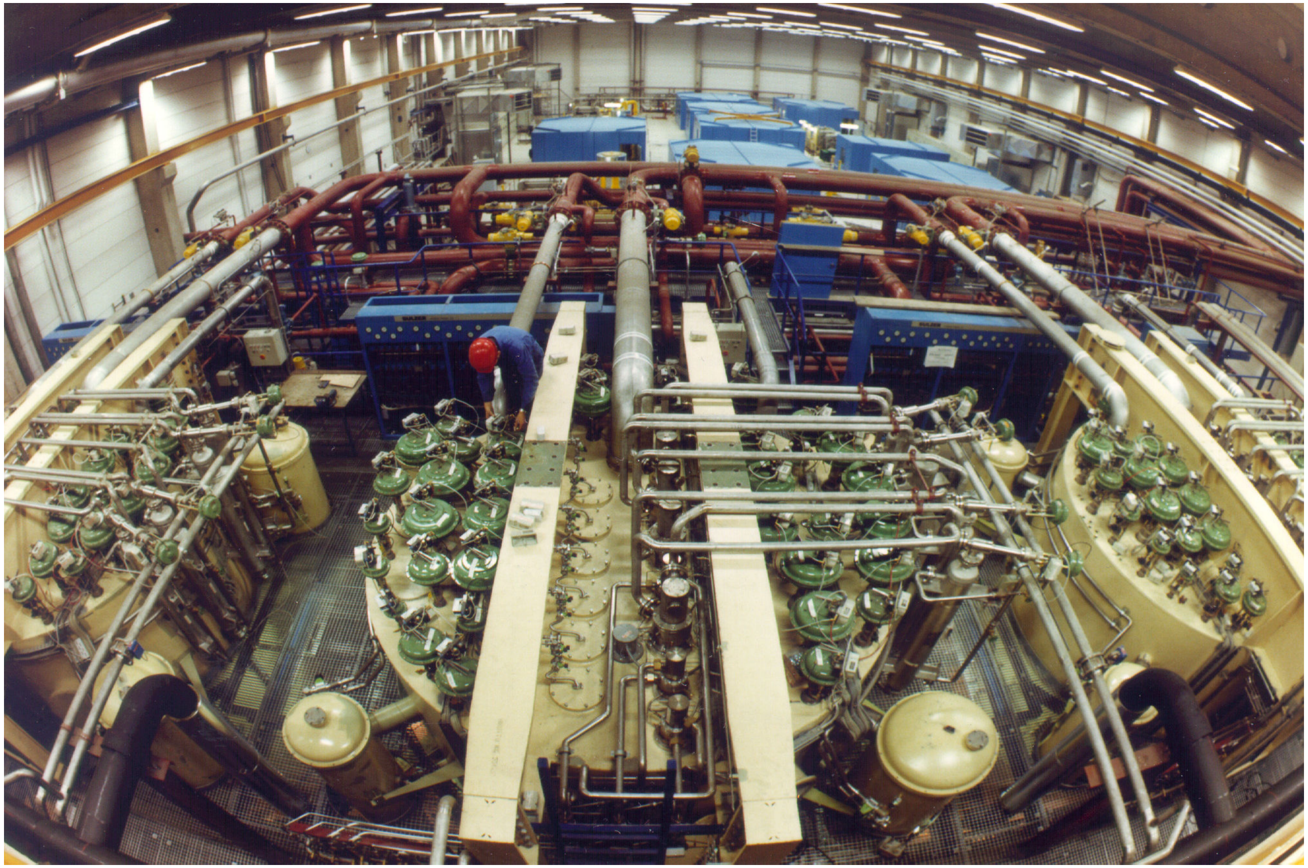
XFEL Cryogenic System

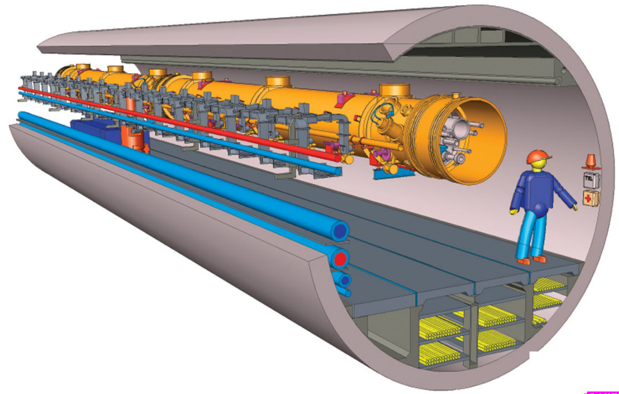
Layout, operation modes, incident scenarios & safety measures

Bernd Petersen DESY MKS, XFEL WP 13



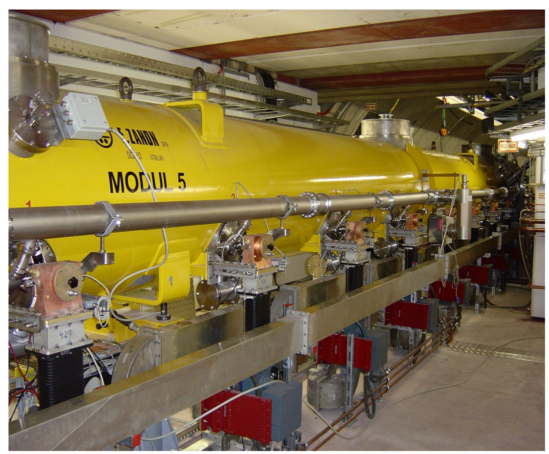
XFEL-cryogenic tasks

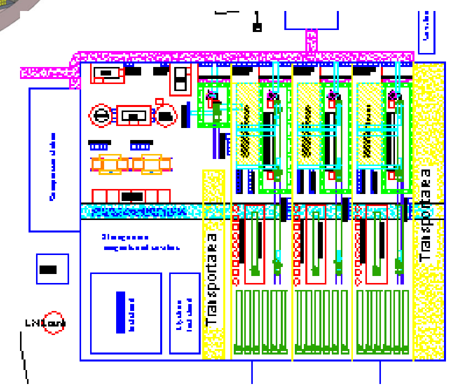
Consumers:

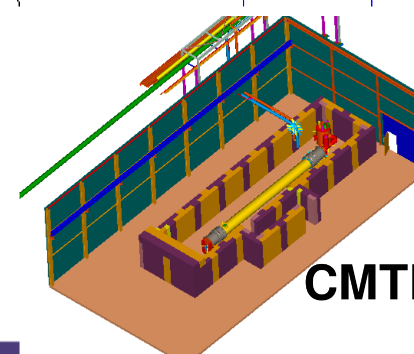


- **XFEL-Accelerator (incl. Injectors)**

- **Accelerator-Module-Test-Facility**







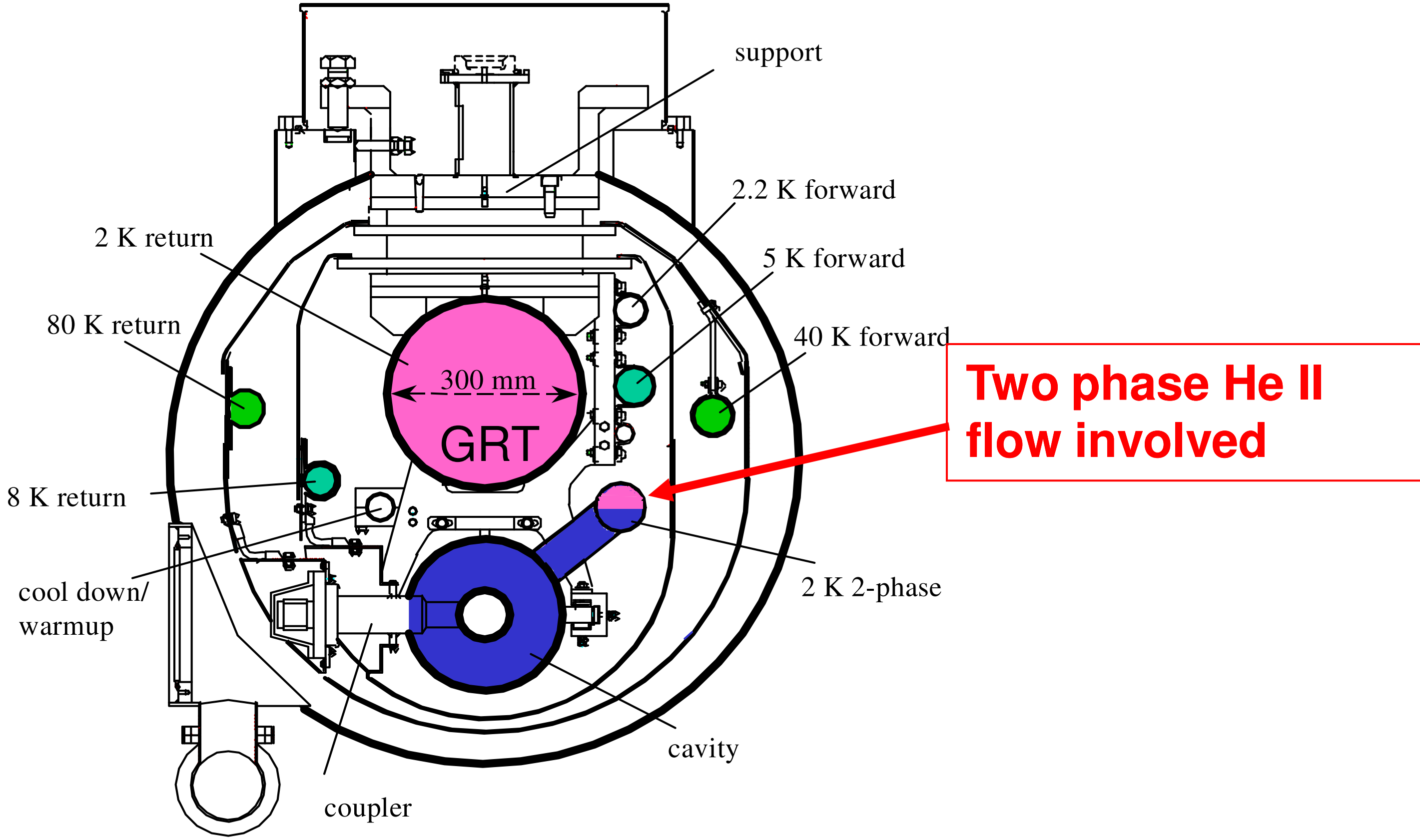
CMTB

FLASH-Linac

Operation continued
in parallel
to XFEL-Linac

Layout of XFEL-linac cryogenic: Helium II bath cooling

About 800 1.3 GHz sc cavities will be cooled in a 2K Helium II bath



XFEL-Linac-Cryogenic tasks (NEW start)

- **816** sc Nb 1.3-GHz 9-cell cavities have to be cooled in a Helium II bath at 2K , Qo= 10**10, 23.6 MV/m, 10 Hz
- 40 3.9 GHz cavities (in 2 cryomodules)
- **92** 1,3 GHz cryomodules in RF operation
- **8** cryomodules in 'cold stand-by'
- 2 ‚Cryo-Bypass-Transfer-Lines' (BCBTL) at warm Bunch-Compressor sektions
- 2 independent injectors (1 cryomodule each)

Operating conditions of XFEL Linac-Cryogenic

Continous operation of the refrigerator

24 h per day / 7 days per week

Operation periods of 2 – 3 years without scheduled break of cold helium supply

Avialability > 99%

(without 'utilities' and process control)

Alternative concept of XFEL-Cryogenic

Simplified flow scheme

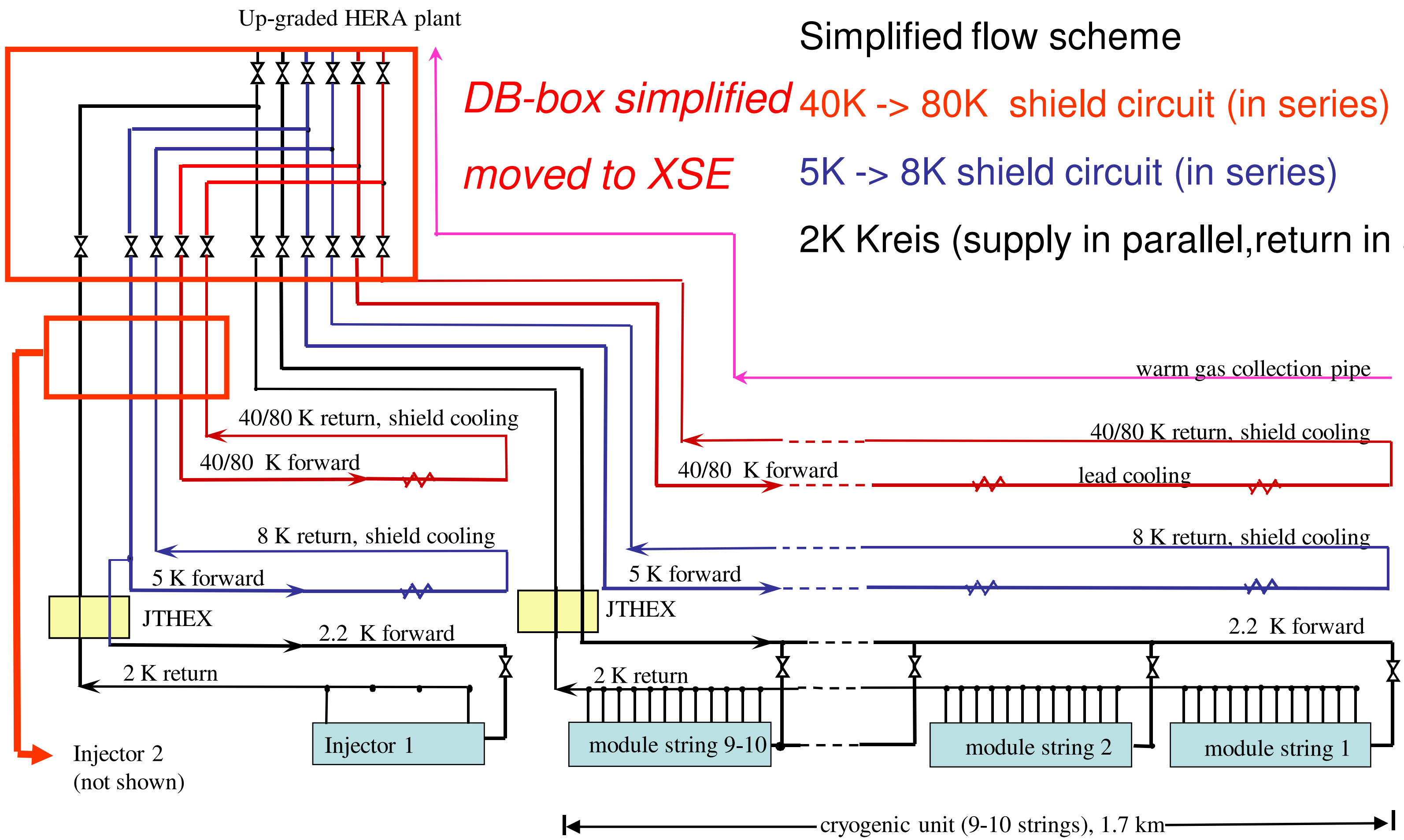
DB-box simplified

moved to XSE

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

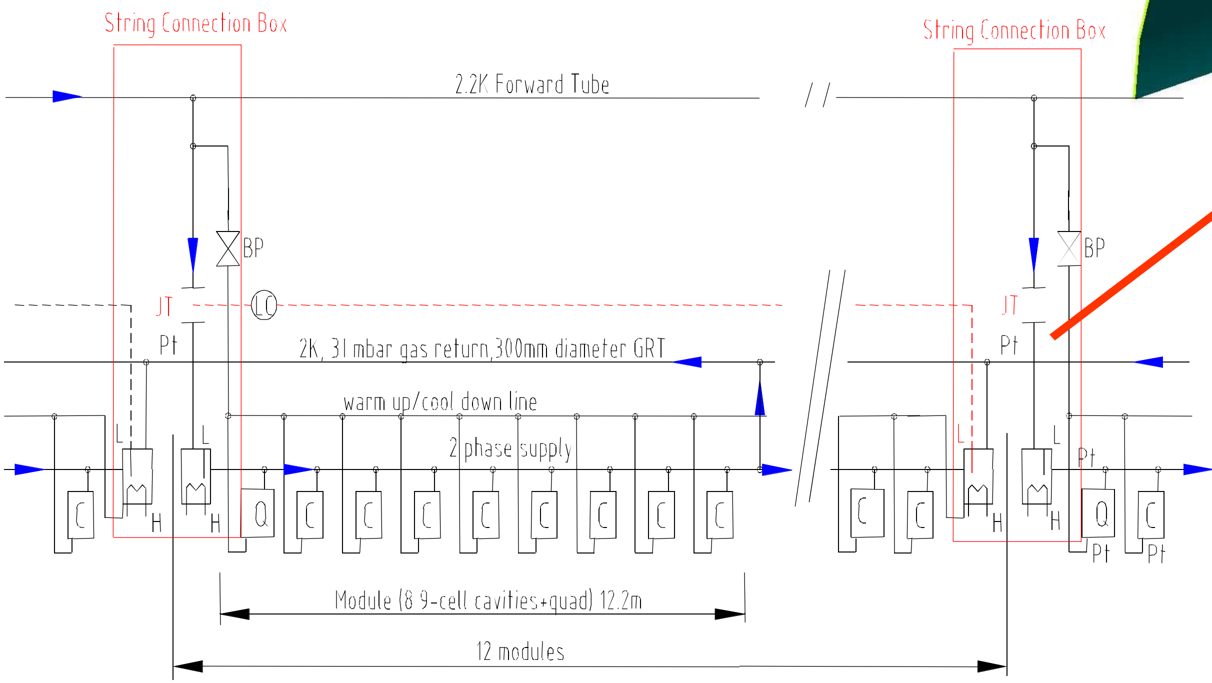
5K -> 8K shield circuit (in series)

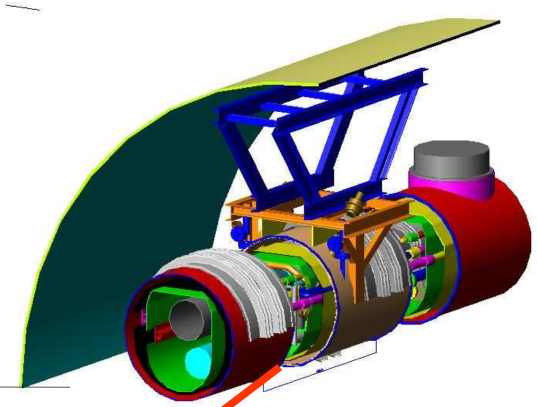
2K Kreis (supply in parallel,return in series)



Linac cryogenic ‚string‘

Cryogenic units of 12 cryomodules = ‚strings‘



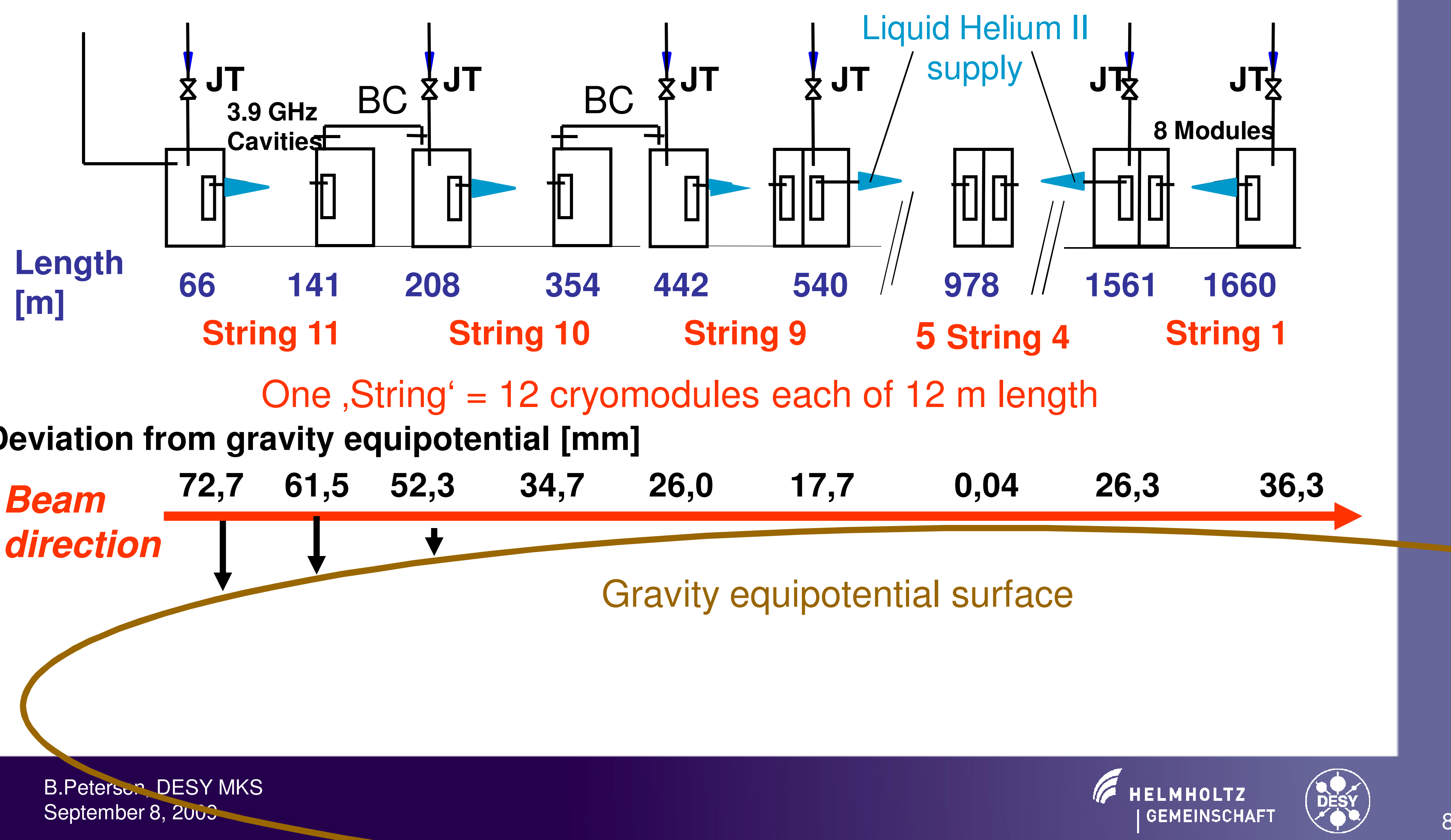


String **C**onnection **B**oxes

contain all cryogenic instrumentation

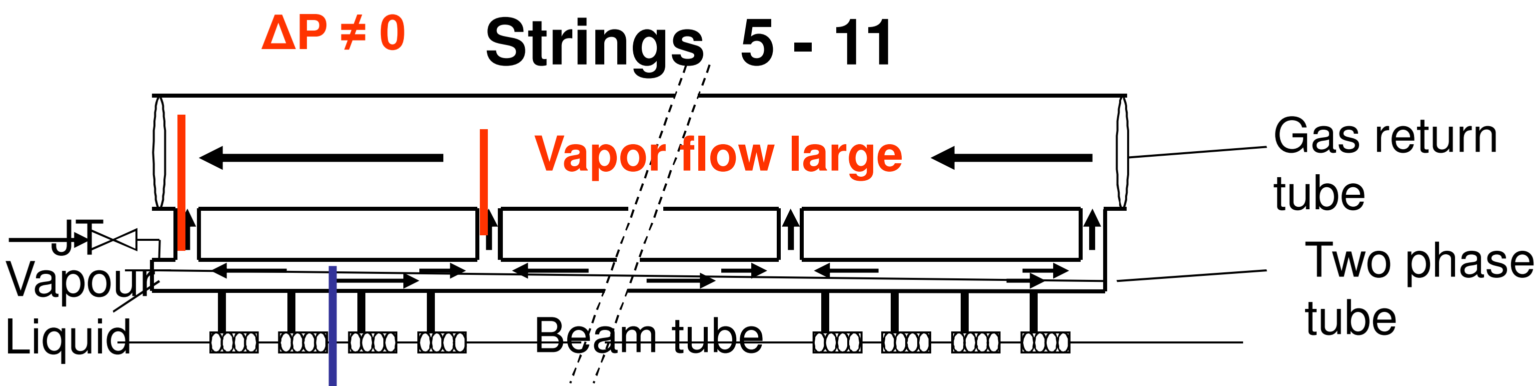
Disadvantage: 2-phase flow affected by gravitational forces

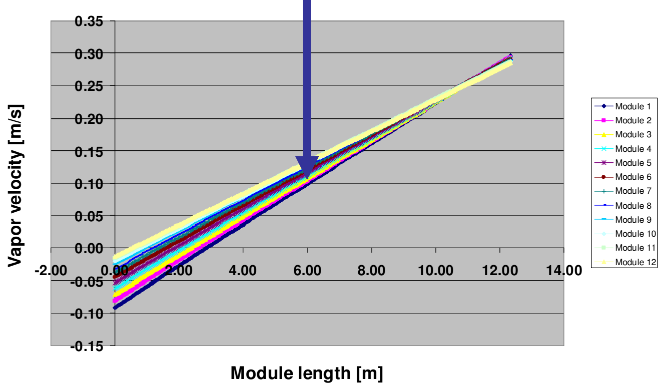
Laser-straight XFEL-linac



Disadvantage:
Complex 2-phase flow conditions

Example: Situation at the start of the XFEL-linac (refrigerator side)





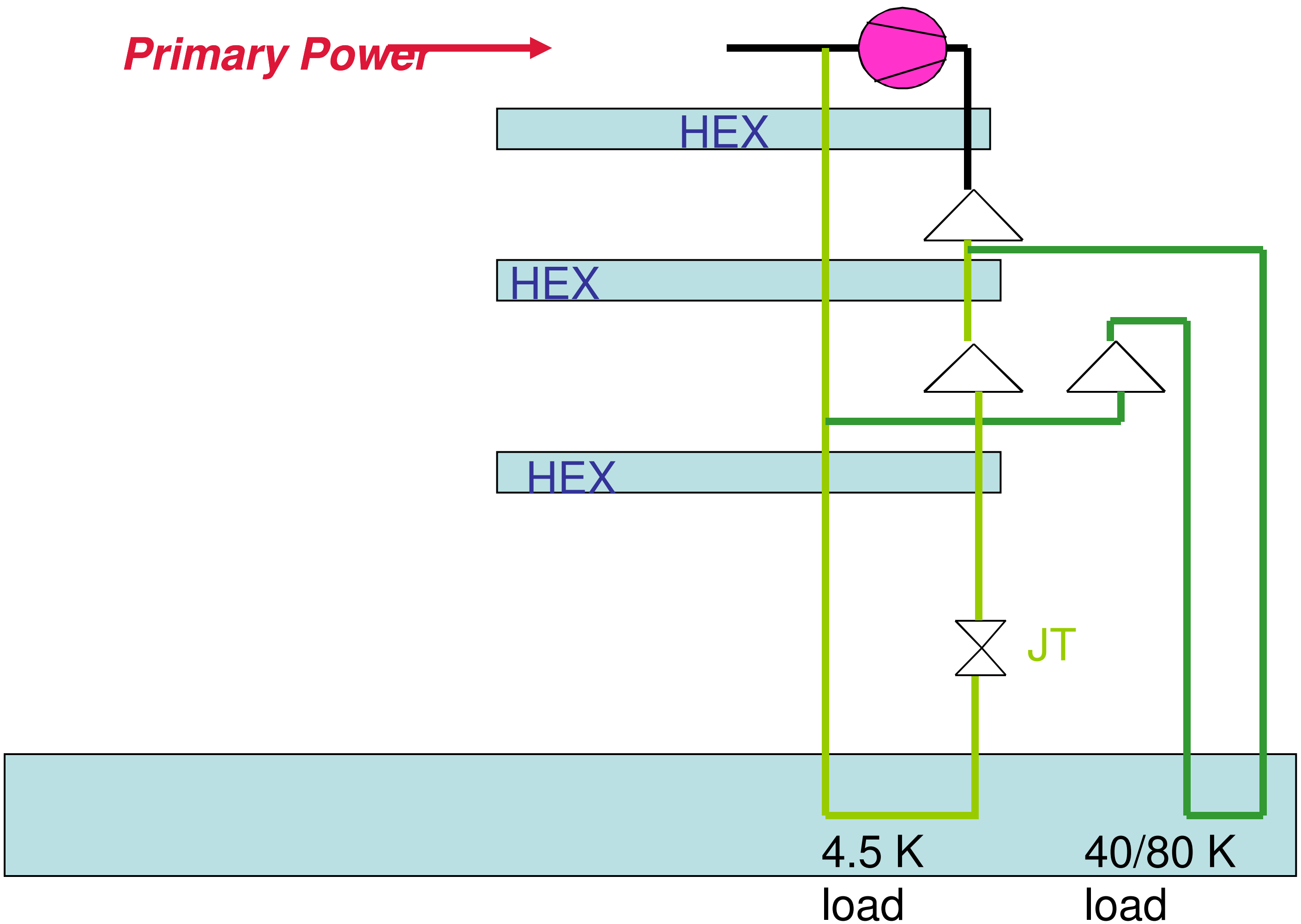
Vapor flow velocity in 2-phase tube

String 10

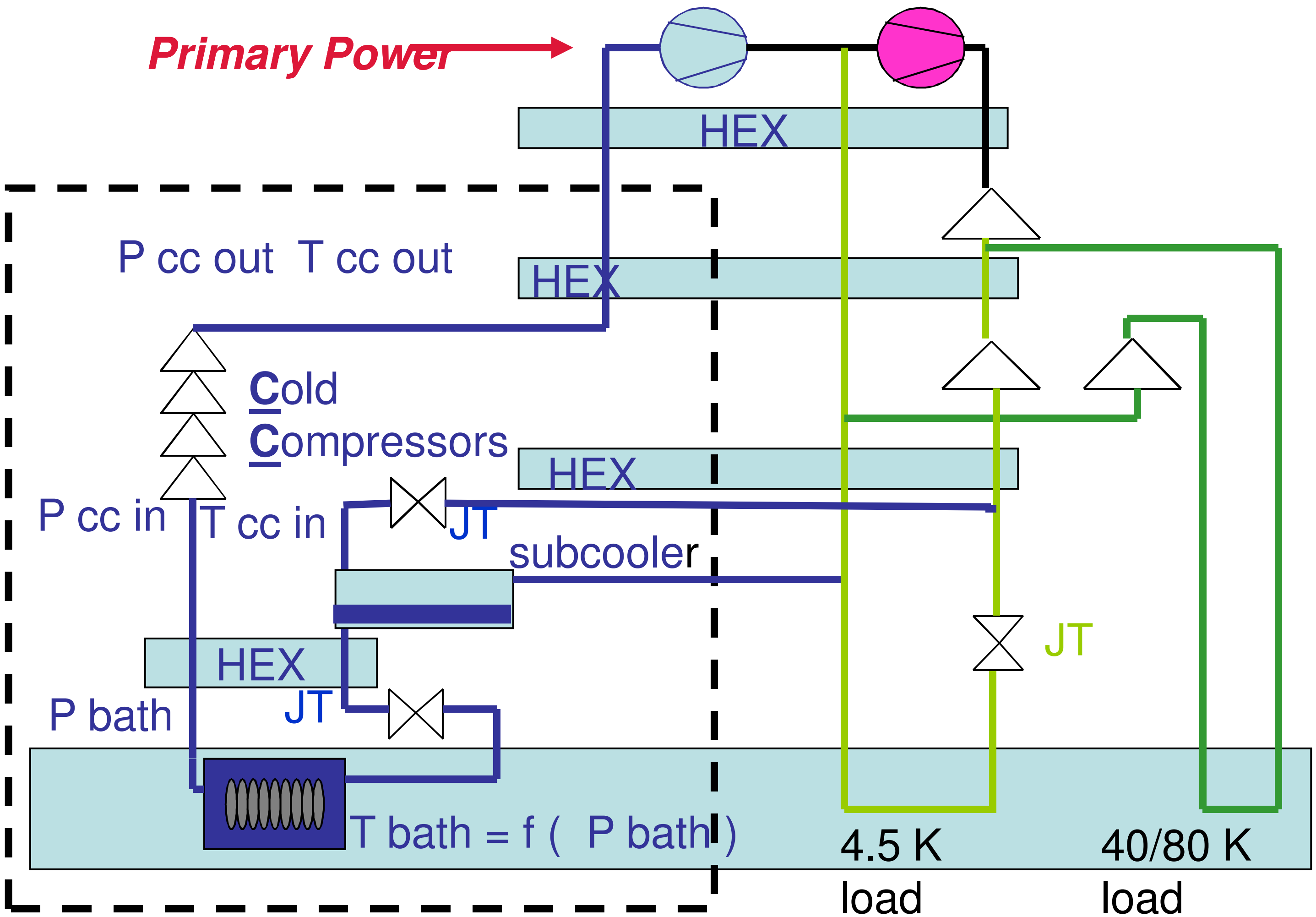
TDR Heat loads of XFEL-Linac (20 GeV, 10 Hz)

source	2 K Static W	2 K dynamic W	5-8 K Static W	5-8 K dynamic W	40-80 K Static W	40-80 K Dynamic W
Mainlinac cryomodules	154	879	1281	625	8233	4457
3.9 GHz cryomodules	3	43	19	11	126	55
Mainlinac distribution	322		472		2279	
Injector cryomodules	3	17	22	12	142	86
Injector distribution	212		208		1807	
Sum	694	939	2002	648	12587	4598
Design Sum	1041	1409	3003	972	18880	6897
End sum		2450		3975		25777

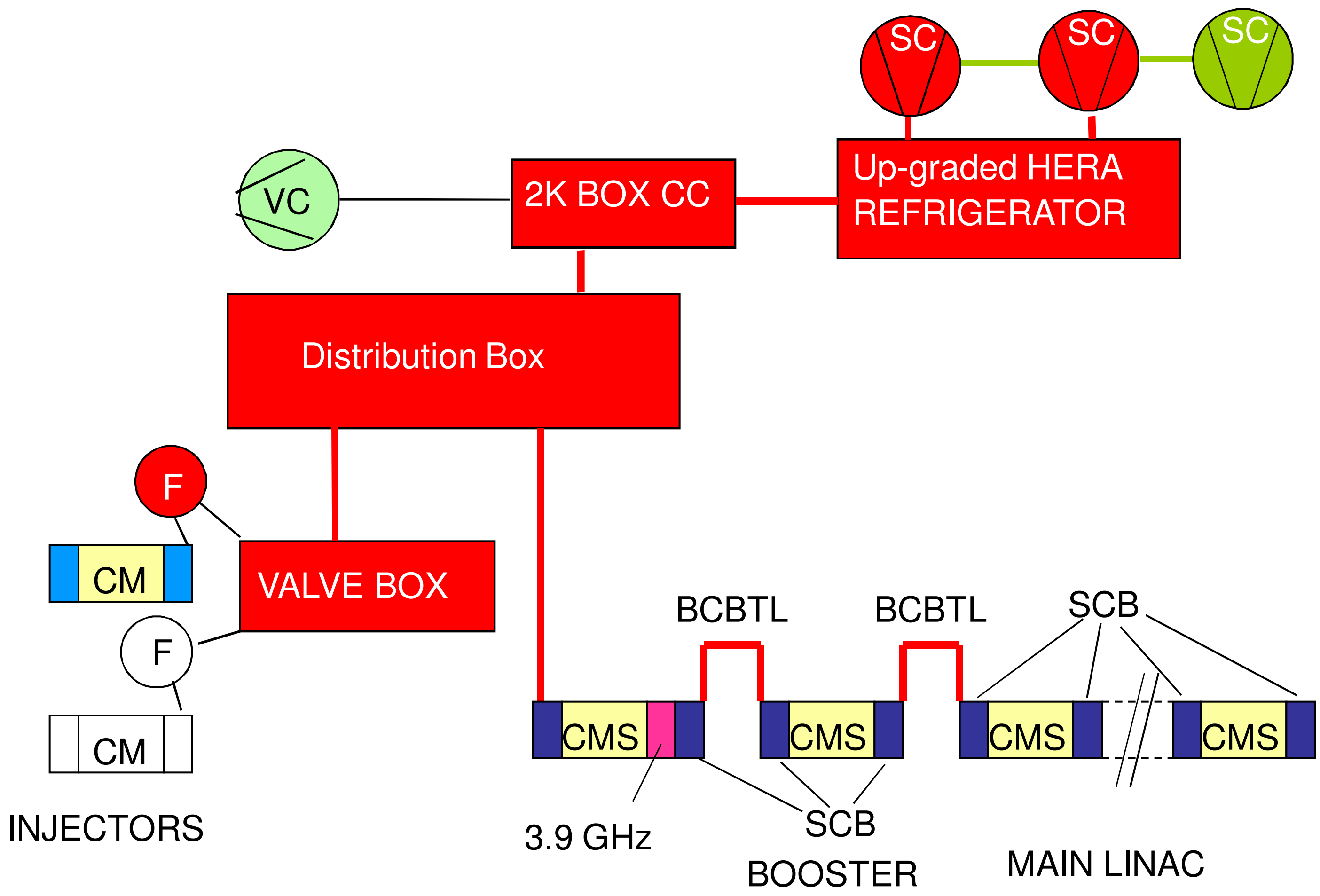
4.5K refrigerator scheme (simplified)



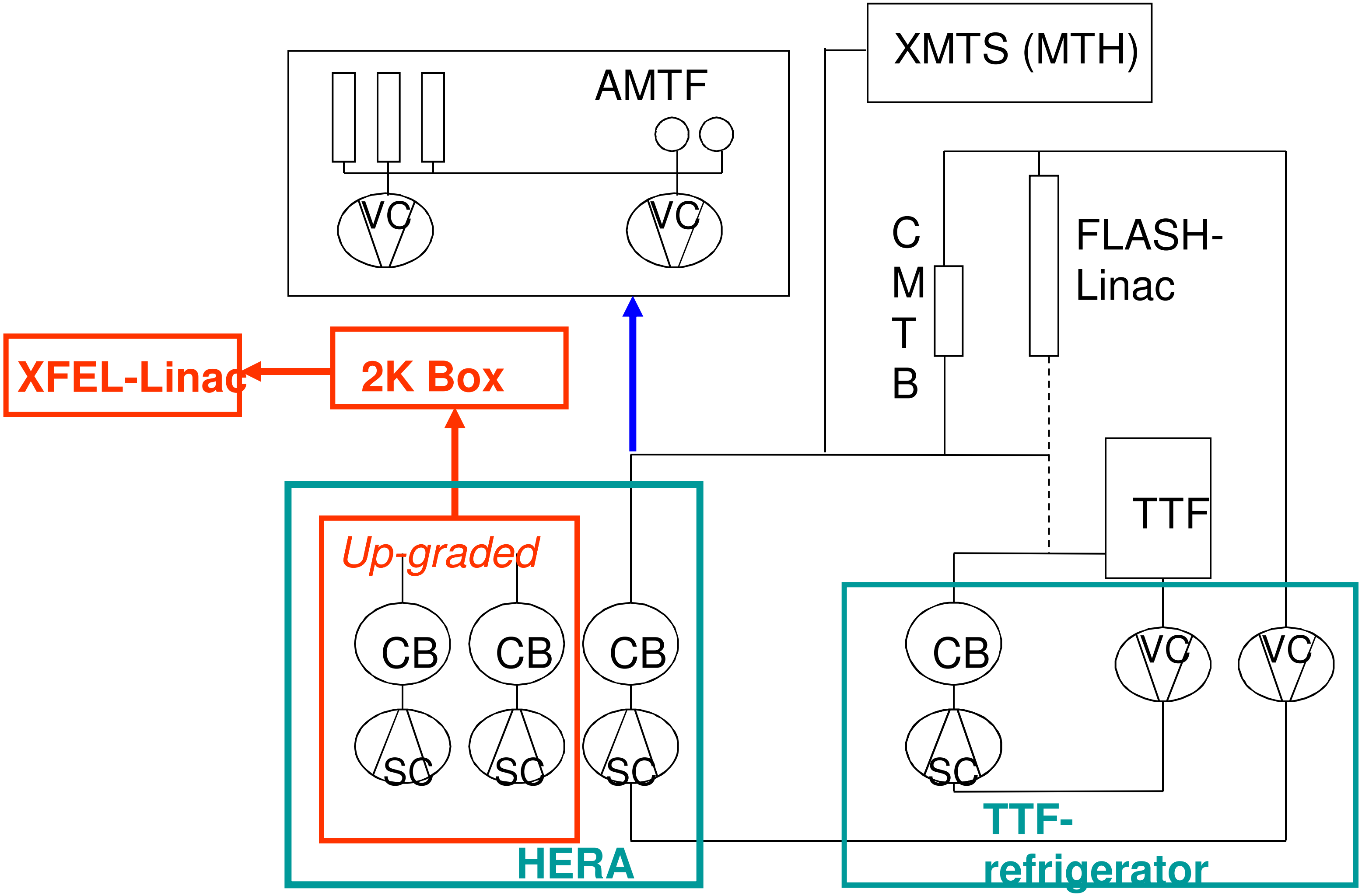
2K Cooling Scheme (simplified)



Alternative concept of XFEL-cryogenic

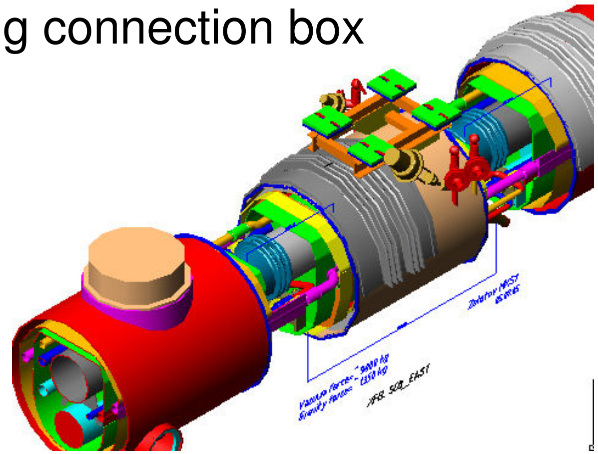


Alternative: up-grade of HERA-plant for XFEL

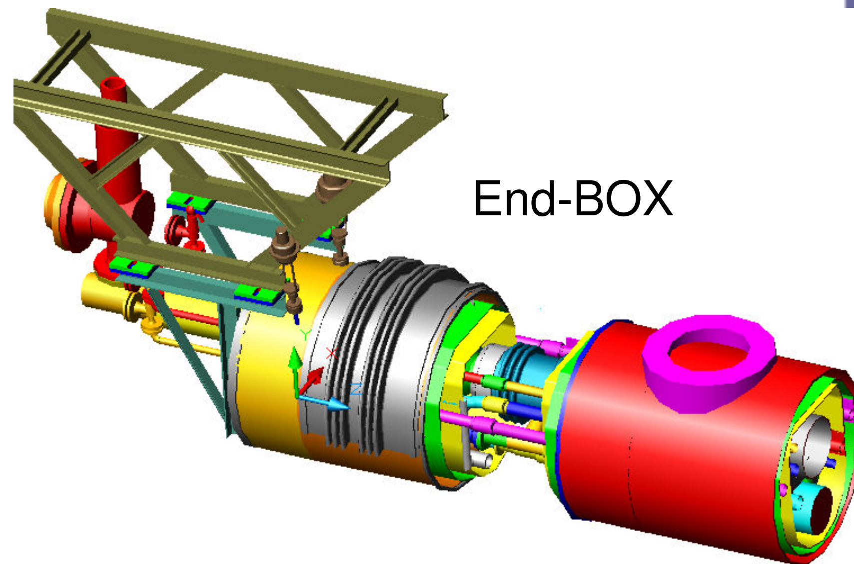


Linac cryogenic components

‚regular‘ string connection box



End-BOX



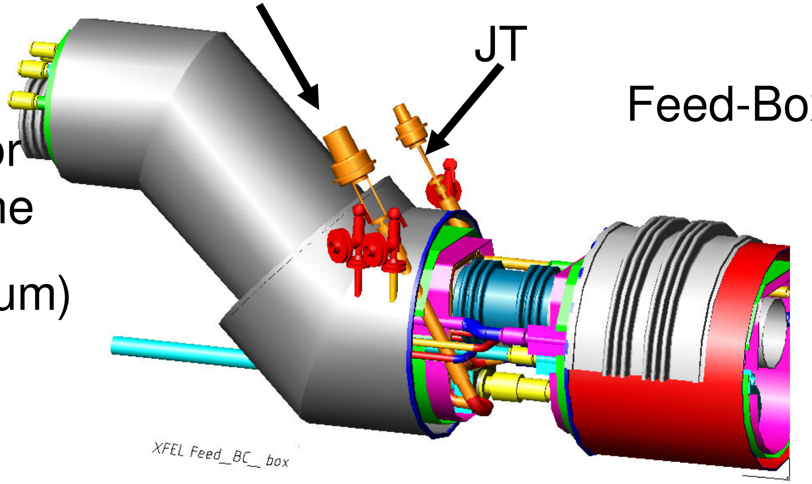
Cool-down/warm-up

JT

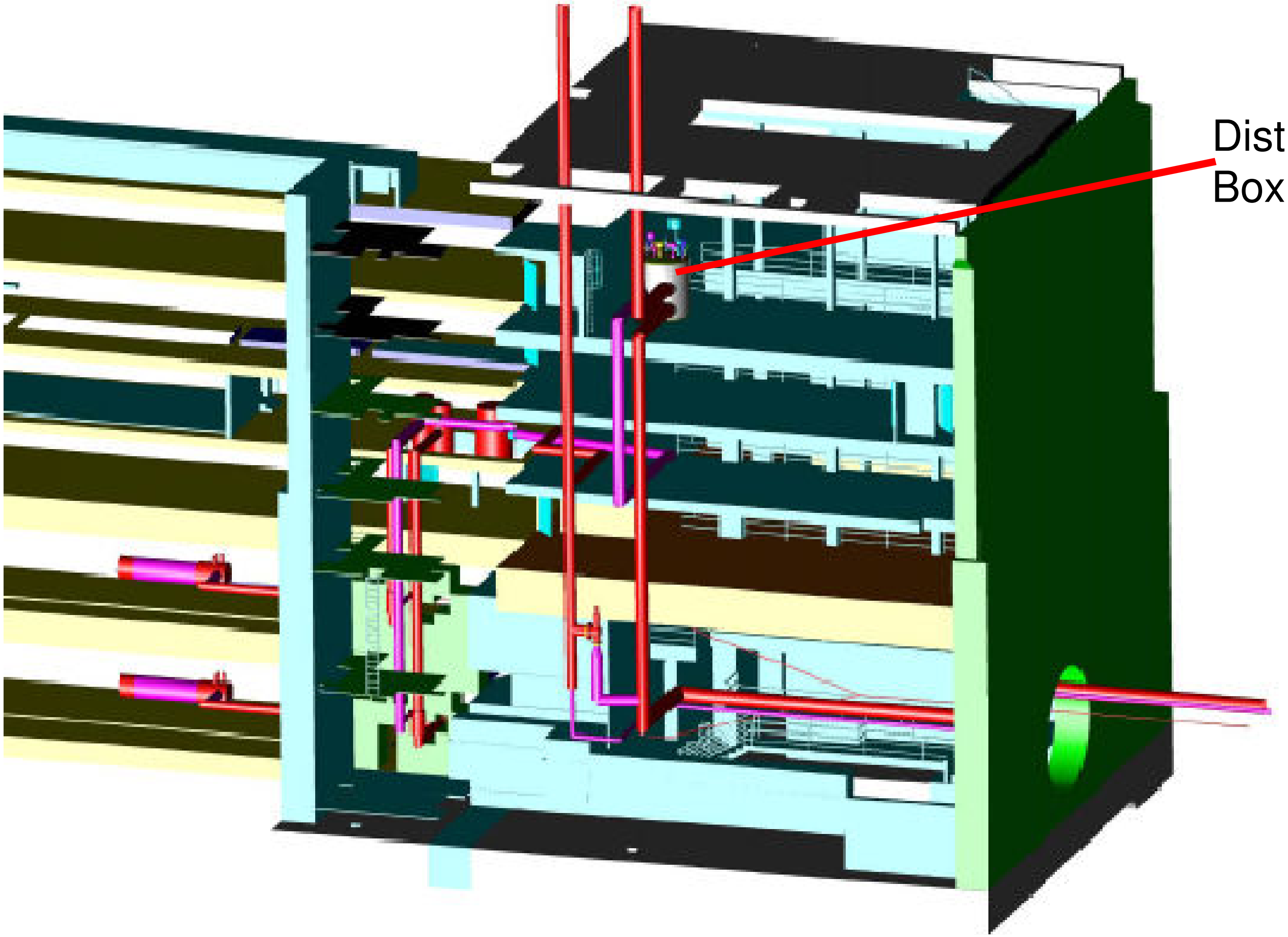
Feed-Box

Bunch Compressor
Bypass Transferline

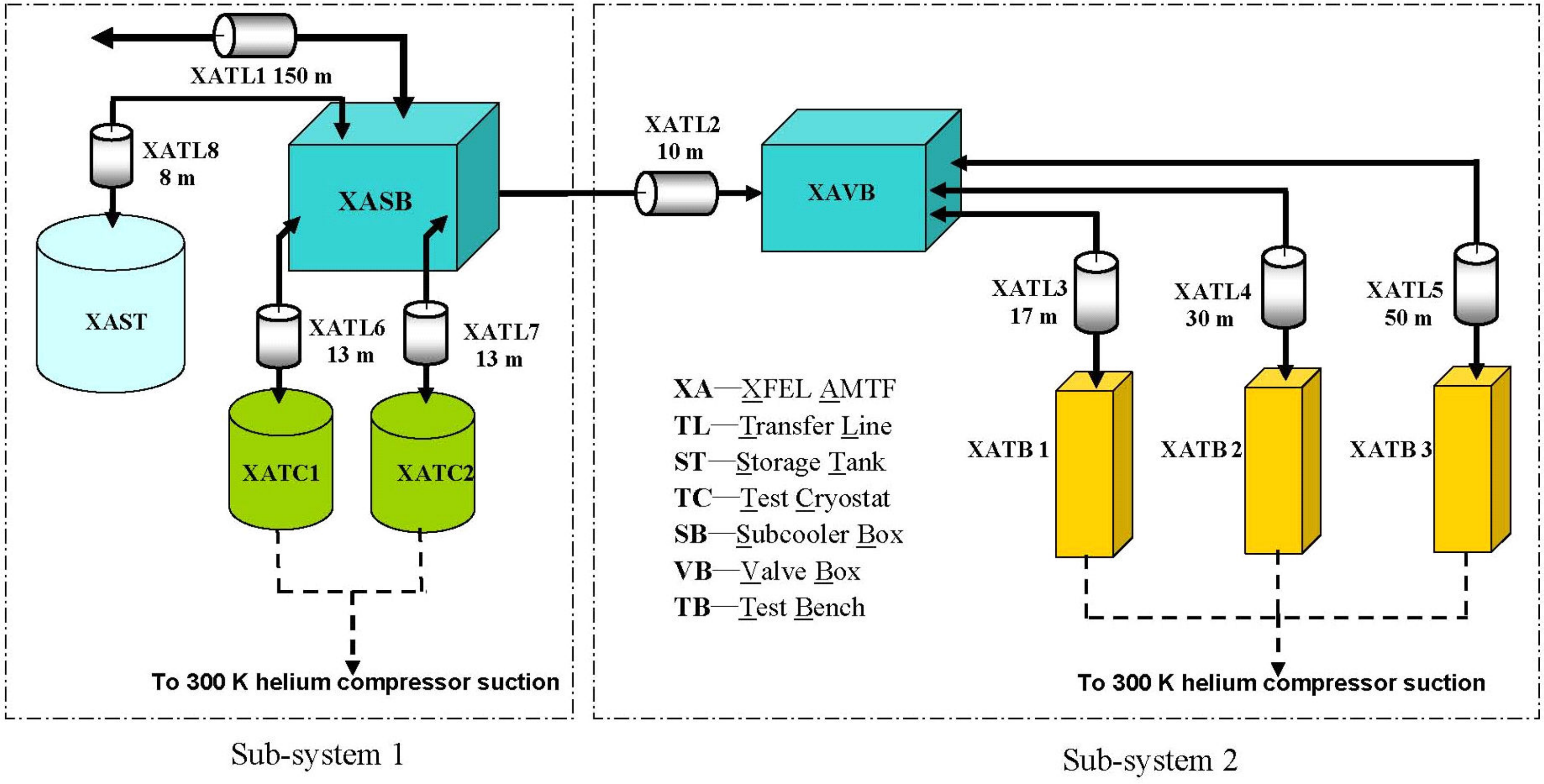
(only 1-phase helium)



Cryogenic installations in XSE



AMTF -Cryogenics



Incident Scenarios & Safety Measures

- **moderate loss of insulation vacuum caused by helium leak -> CMTBM3***
- catastrophic loss of insulation vacuum caused by helium leak (LHC event)-> **MCI**
- **catastrophic loss of insulation vacuum caused by ambient air -> CMTB/M3***
- **moderate loss of cavity/beam vacuum caused by helium leak -> CMTB/M3***
- catastrophic loss of cavity/beam vacuum caused by helium leak (cavity rupture)
- **catastrophic loss of cavity/beam vacuum caused by ambient air –> CMTB/M3***
- **moderate loss of coupler vacuum by ambient air -> CMTB/M3* (with N2)**
- catastrophic loss of coupler vacuum by ambient air

Included in CMTB/M3* test program:

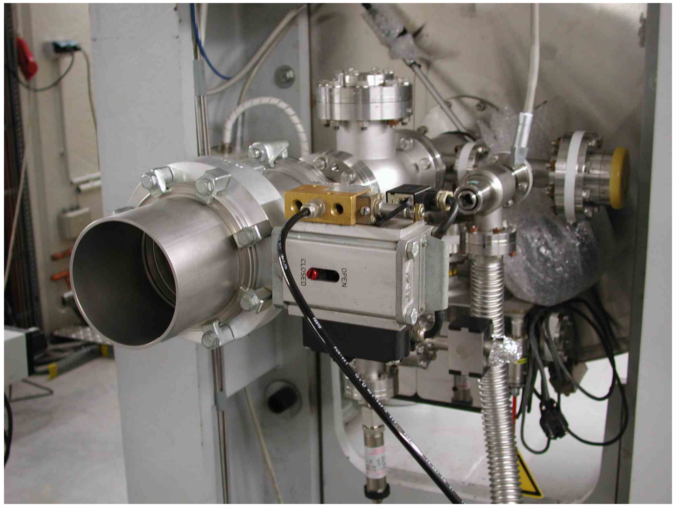
- frequent check of cryogenic performance following venting tests
- check of RF cavity performance following venting tests

‚catastrophic venting‘ means : largest reasonable venting cross-section
DN 100 pump port for insulating vacuum, beam tube dia for beam tube vacuum

Venting system coupler-cavity-and iso-vacuum

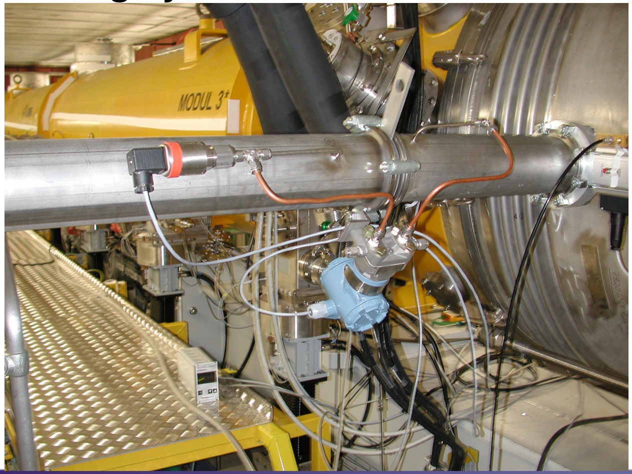
Courtesy of
Kay Jensch

**Venting system
beam-pipe-vac DN 100**



Venting system coupler-vac DN 100

Venting system Iso.-vac DN 100



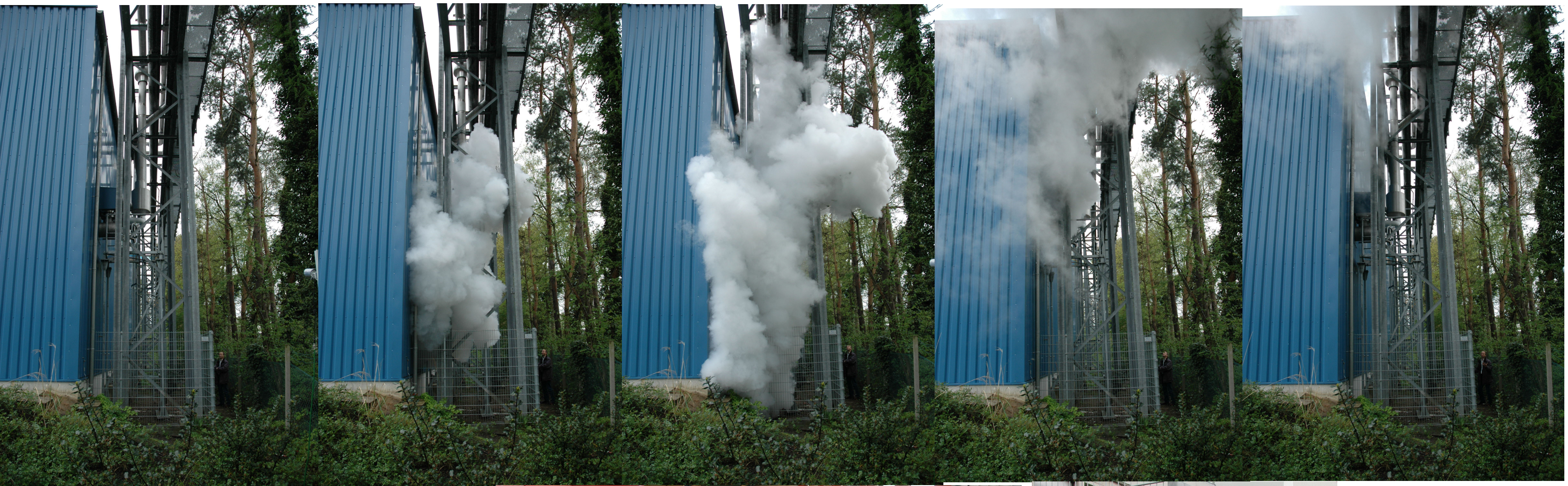
The cryogenic safety valves of the CMTB

All safety valves have an outflow coefficient of at least α = 0.7.

(*) The valve was blocked in closed position during tests 2 -5.

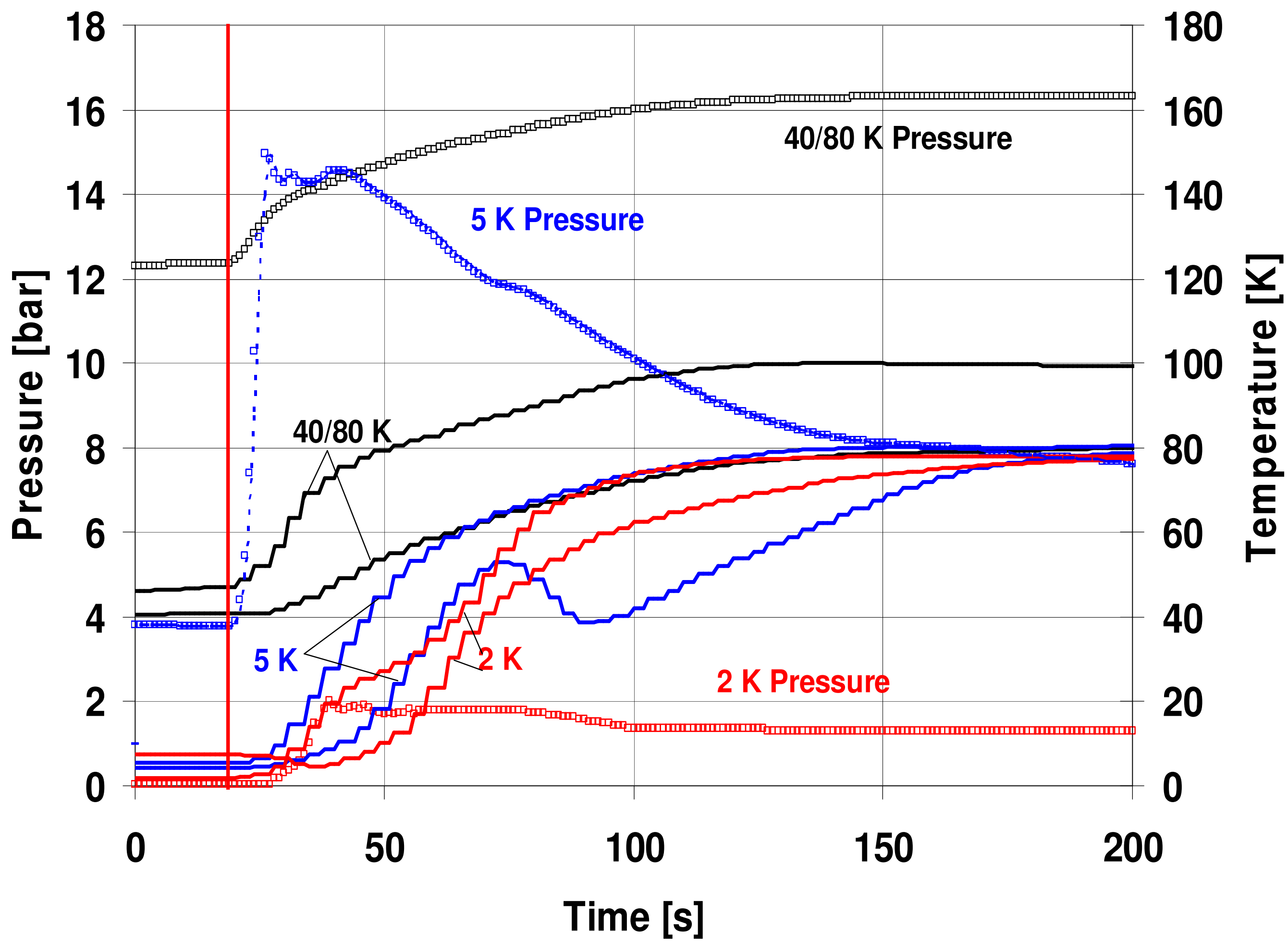
Circuit	40/80 K supply	40/80 K return	5 K supply	5 K return	2 K (*) return	2 K return
Set pressure	20bar abs	20 bar abs	20 bar abs	13 bar abs	1.4 bar abs	1.7 bar abs
Size	20/40 DN	20/40 DN	20/40 DN	50/80 DN	50/80 DN	150/250 DN
Design Pressure	20bar abs	20 bar abs	20 bar abs	20 bar abs	4 bar abs	4bar abs

Helium release outside CMTB during M3* Crash Tests

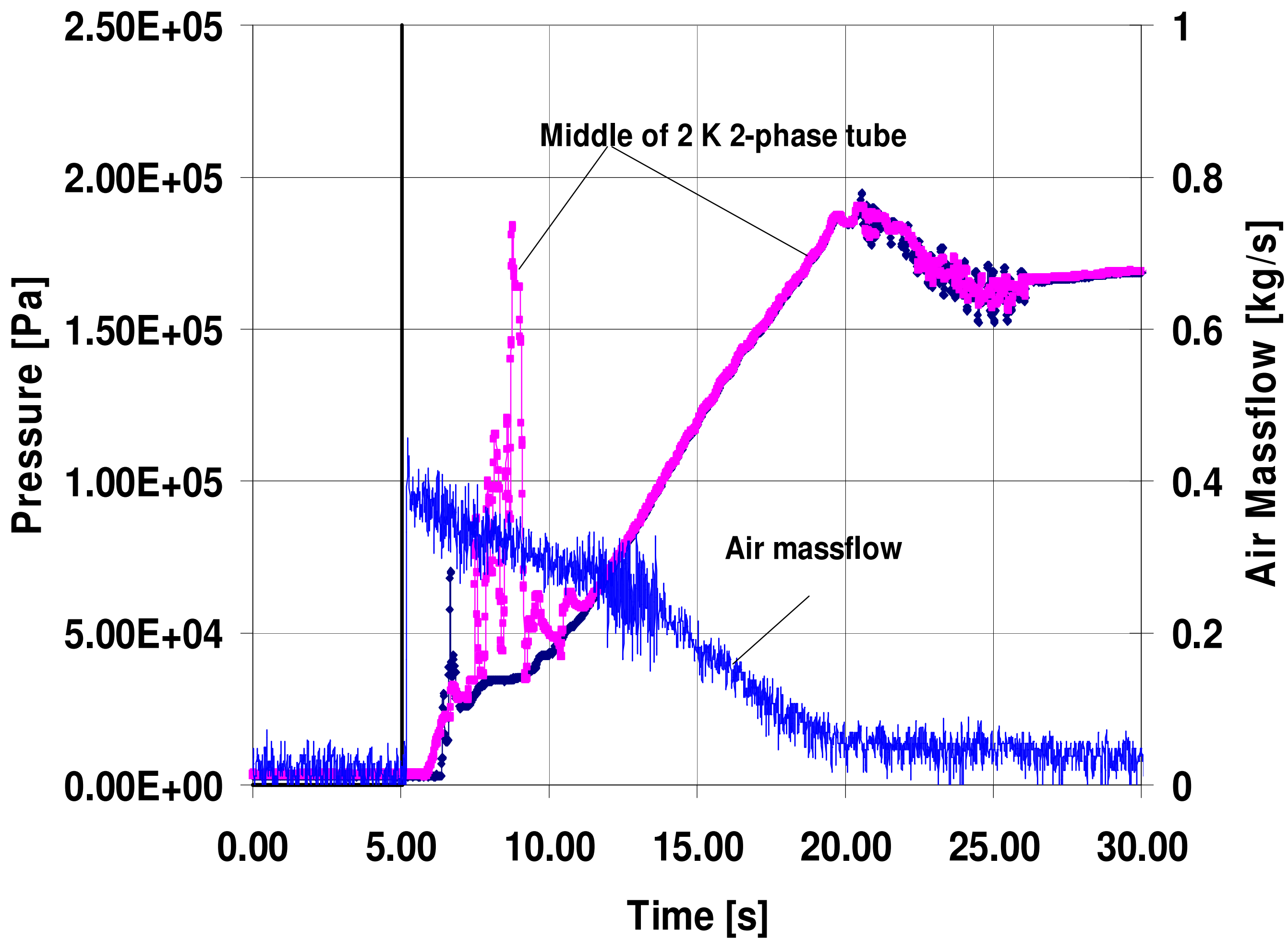


FLASH has similar installations outside Hall 3 !

Insulation vacuum venting ‚2K‘=2K start cond. (1&2)

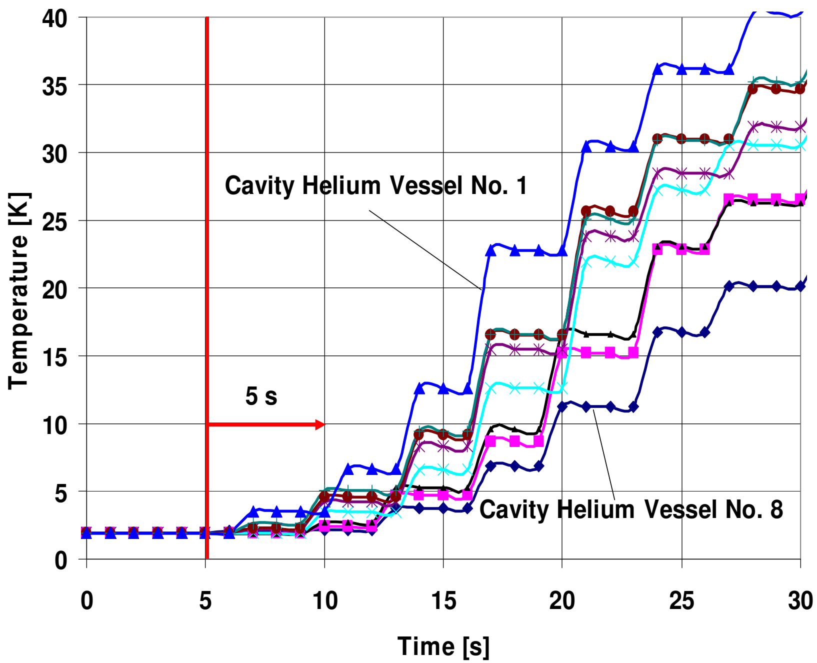


Cavity/beam vacuum venting ‚2K‘=2K (3)

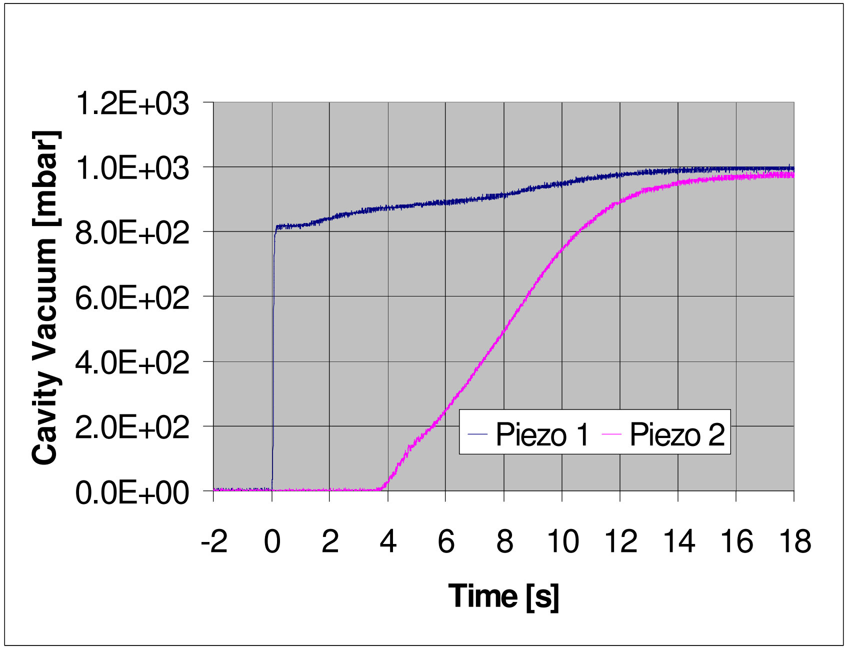


Cavity/beam vacuum venting ‚2K'=2K (3)

Cavity helium vessel temperatures



Beam vacuum pressures at both ends of the cryomodule



Courtesy D.Hoppe

Air needs 4 sec to pass the length of a cryomodule !

Estimated average heat transfer densities

The heat transfer to helium can be estimated for the different cooling circuits of the cryomodule , if the state change of the internal energy is estimated from the pressure rise to the peak value, the measured temperature changes during venting and the surfaces of the involved cooling circuits.These estimates are quite uncertain (in the order of +/- 50%), because the temperature distribution in the Helium is very inhomogeneous. For the cavity vacuum venting tests, the heat transfer can be calculated more precisely from the invading air flow (+/-10%.)

Area	Test1 [KW/ m^2]	Test 2 [KW/ m^2]	Test 3 [KW/ m^2]	Test 4 [KW/ m^2]	Test 5 [KW/ m^2] 4.5 K	Test3/ Air [KW/ m^2]	Test4/ Air [KW/ m^2]
Ref. literature	6.0	6.0	40	40	6.0	40	40
2 K	**3.3**	**4.0**	**23**	**14.4**	**6.5**	**14.2**	**14.2**
5 K	**1.6**	**2.3**	**-**	**-**	**1.3**	-	-
40/80 K	**0.05**	**0.15**	**-**	**-**	**0.1**	-	-

Safety Measures (1)

The XFEL-Cryogenic safety valves will be sized according to the results of our CMTB module 3* ‚crash-tests‘

2K Circuit: 2 DN150 SV at both ends of the linac

5K/8K; 2.2K : safety valves at each string connection box venting into a closed DN200 header

40/80 K : safety valves at both ends of the linac

MCI-Maximum Credible Incident

Is the complete disruption of one/all process tubes ***credible*** ?

We do not expect any arc like in LHC and the XFEL stored energies are orders of magnitude lower

But

Process tubes might be disrupted by mechanical events

The consequences (‚collateral damages') could be much serious in case of the XFEL because of the installation at the ceiling of the tunnel

-> Our colleagues at WUT,Poland will supply a detailed analysis for the MCI and for the Helium release.

Safety Measures (2) (under consideration)

Place relief device close to module interconnection to lower longitudinal flow resistance

Reduce radial flow resistance by holes of about DN300 in thermal shields at the interconnections (prepare MLI accordingly)

Increase relief device dia
to DN300(MCI,20 kg/s)

Tunnel supports at the vacuum barriers of the XTL cryo boxes have to take forces corresponding to a difference pressure across the barriers of 2.25 bar (1.5 bar +50%margin, about 22 to)

Tunnel supports of individual modules have to take longitudinal forces corresponding to the strength of the module ports (in the order of 4 to ?)

Design effort (ZM;MEA) is needed for the review of the complete mechanical strength of the string assembly

Safety Measures (3)

Safety flaps (up to DN300) installed on the vacuum vessel of each cryomodule