Cool-down & warm-up of XFEL linac

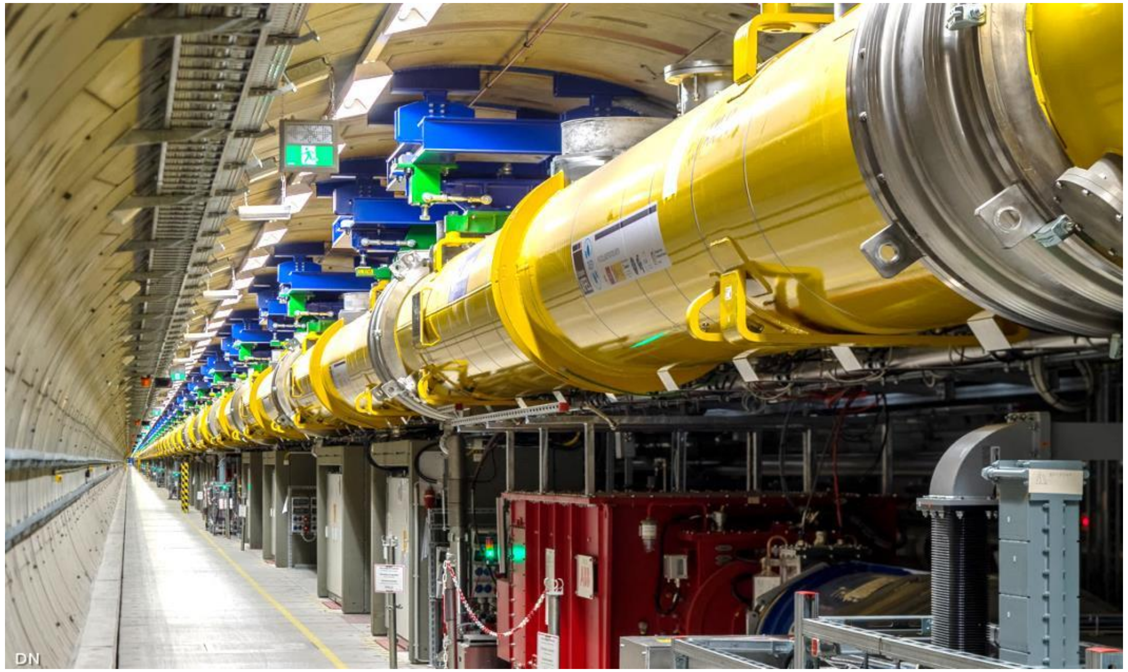
Tobias Schnautz
MKS

Hamburg, 19.06.2025

Overview

- XFEL project: General information
- XFEL cryogenic system
- Cool-down / Warm-up:
  - General information
  - Procedure
  - Risk handling
- Summary

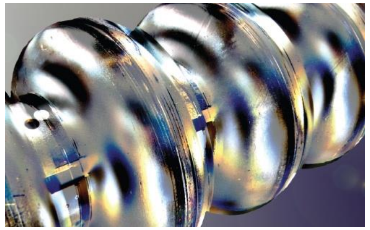
General information about the XFEL project



- XFEL-Linac
  - Length of accelerator: 1500m
  - Accelerator modules: 96
  - Max. electron energy: 17.5GeV
  - Start of beam operation: January, 2017
  - Start of user runs: September, 2017
  - Three SASE undulators
    ► serving 7 experimental stations
    ► cover 300eV to 30keV photon energies

XFEL cryogenic system:

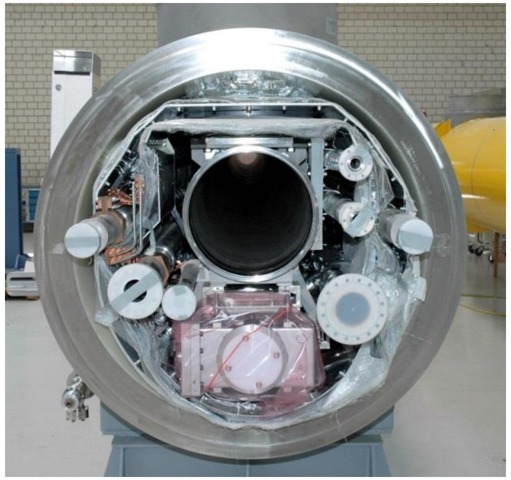
- 671 control valves
- 2647 temperature sensors
- 800 pressure sensors
- 212 flow sensors
- > 100 level sensors



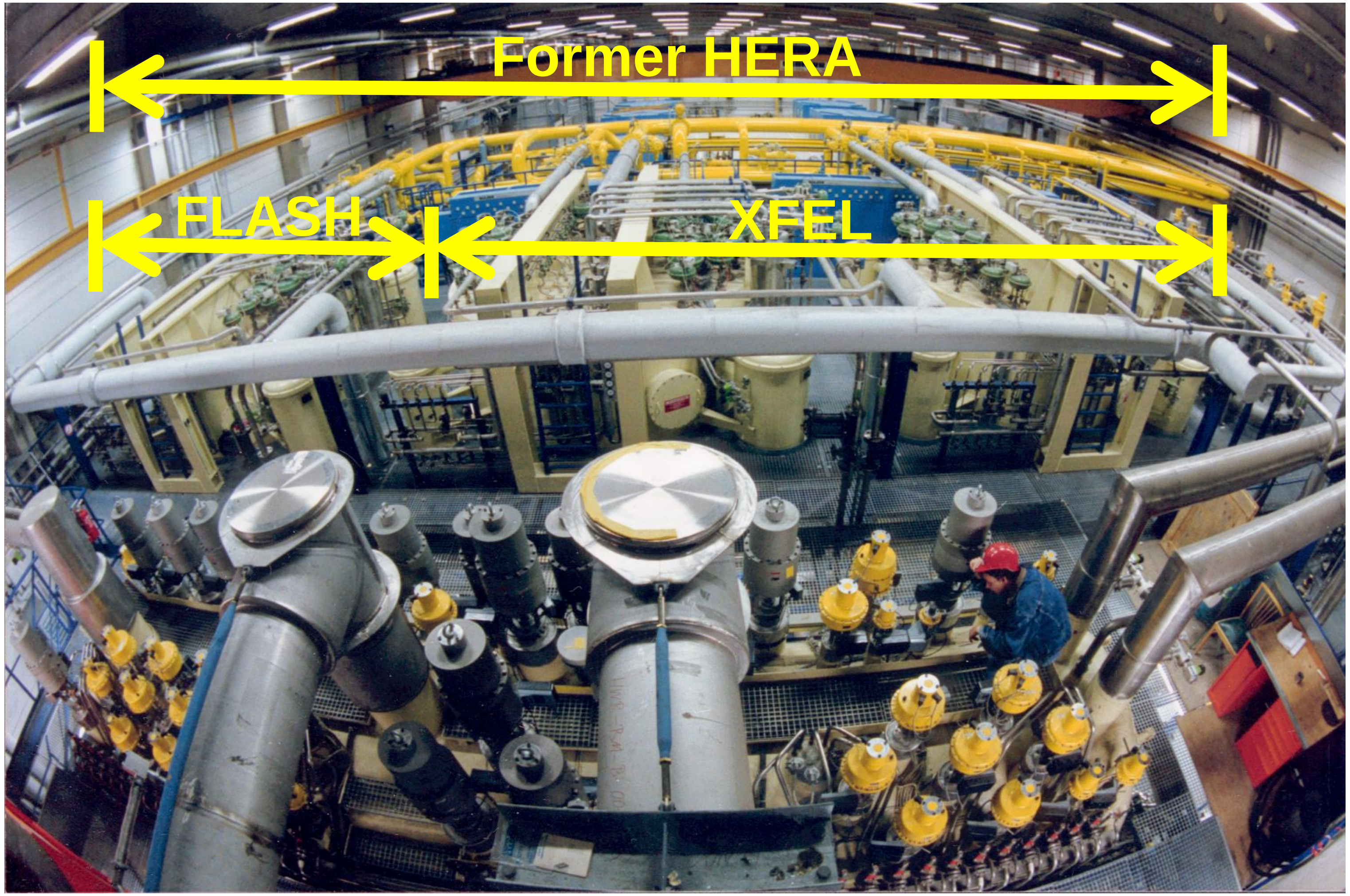
General information about the XFEL project

- **XFEL-Cryomodules**
  - **Cavities: 8 superconducting 9-cell 1.3GHz cavities per cryomodule (a total of 768 cavities)**
  - **Cavity cooling: Helium II bath at 2.0K (5/8K and 40/80K thermal shields)**

8 SC cavities + 1 SC quadrupole = cryomodule (12m)



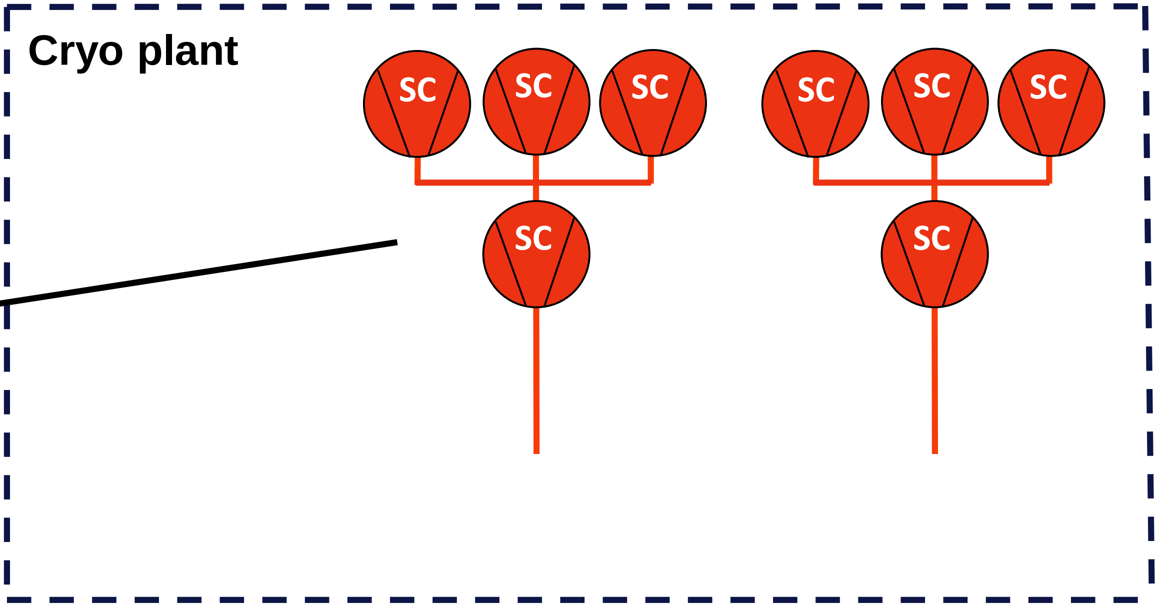
Overview of the XFEL cryogenic system



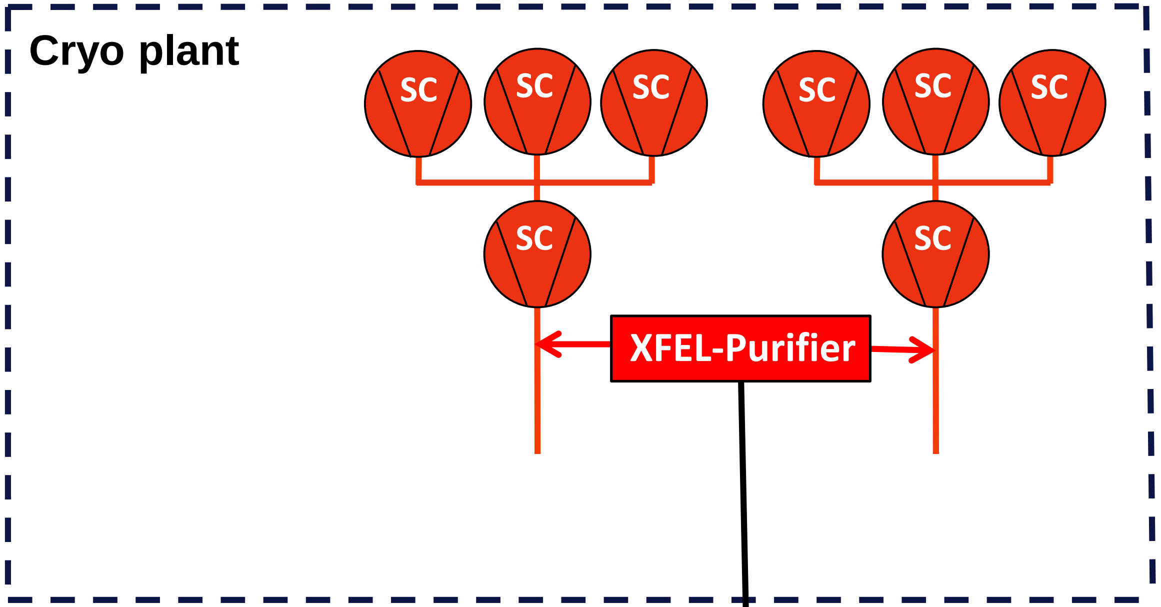
Overview of the XFEL cryogenic system

Vendor

LINDE



Overview of the XFEL cryogenic system



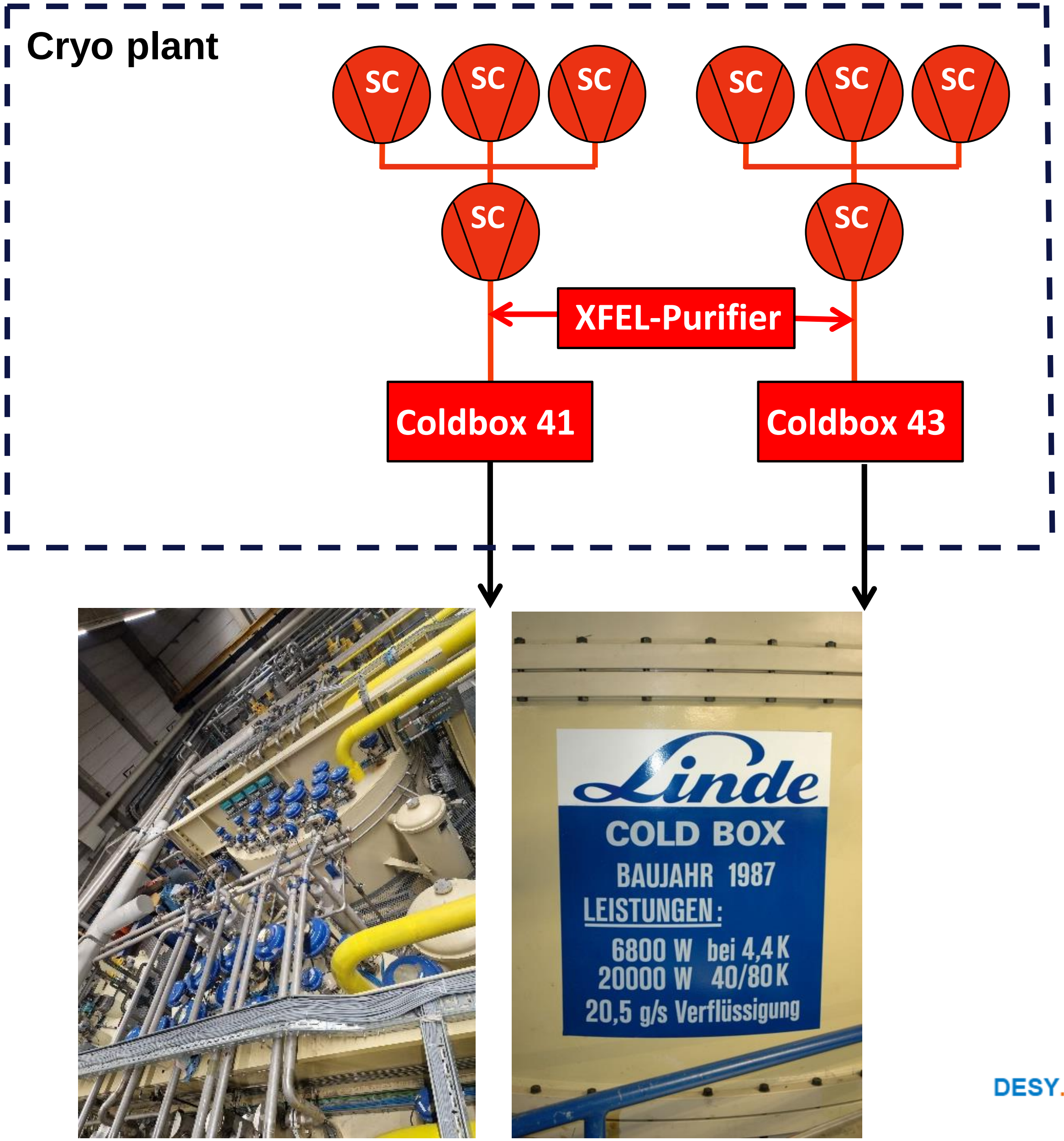
Vendor

LINDE

Overview of the XFEL cryogenic system

Vendor

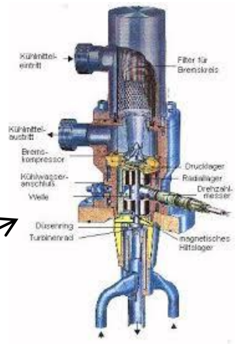
LINDE



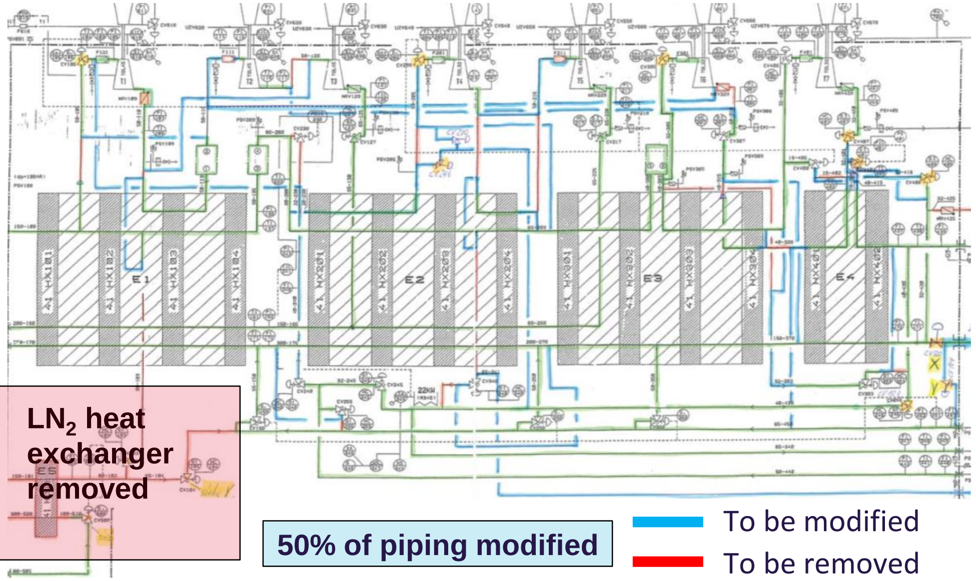
Overview of the XFEL cryogenic system

Vendor

LINDE



Re-arrangement of expansion turbines



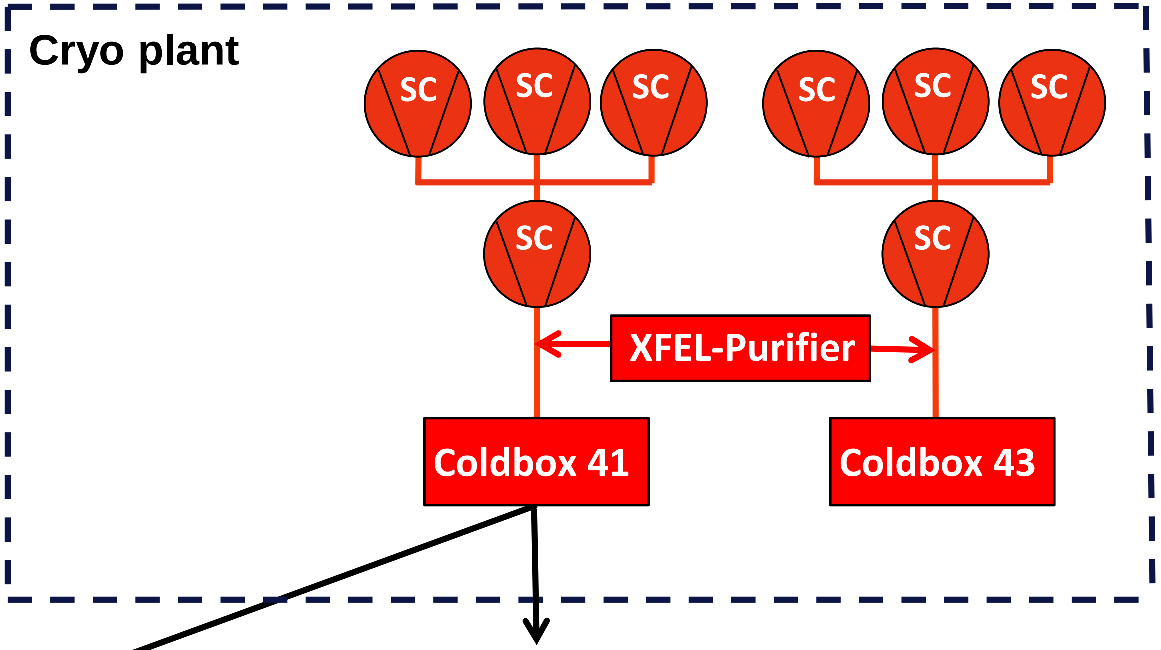
LN_2 heat exchanger removed

50% of piping modified

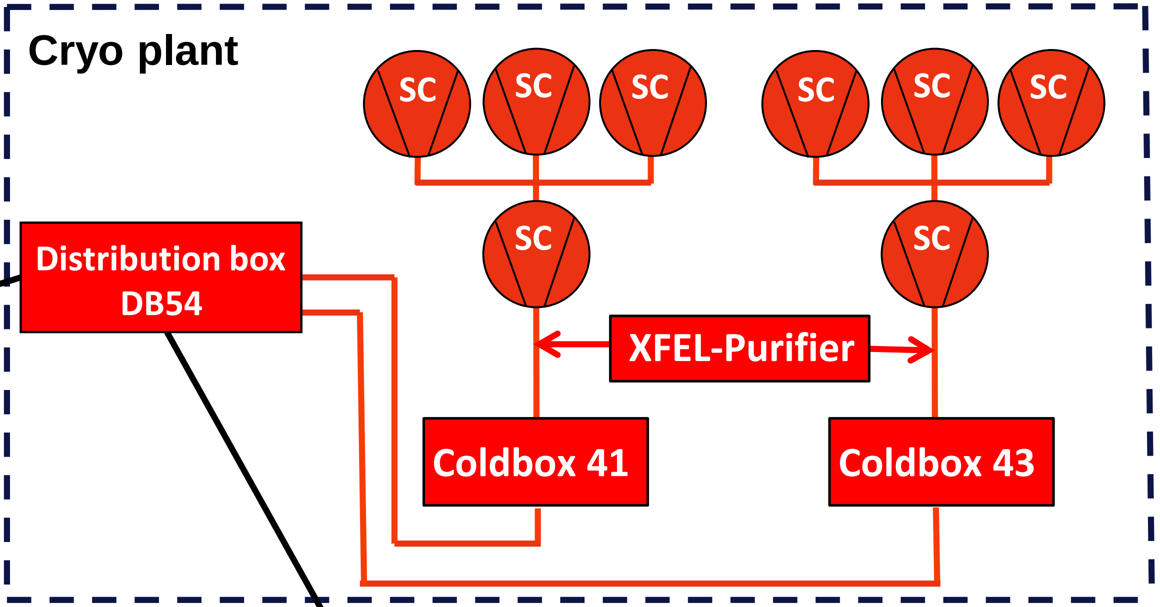
To be modified

To be removed

No changes

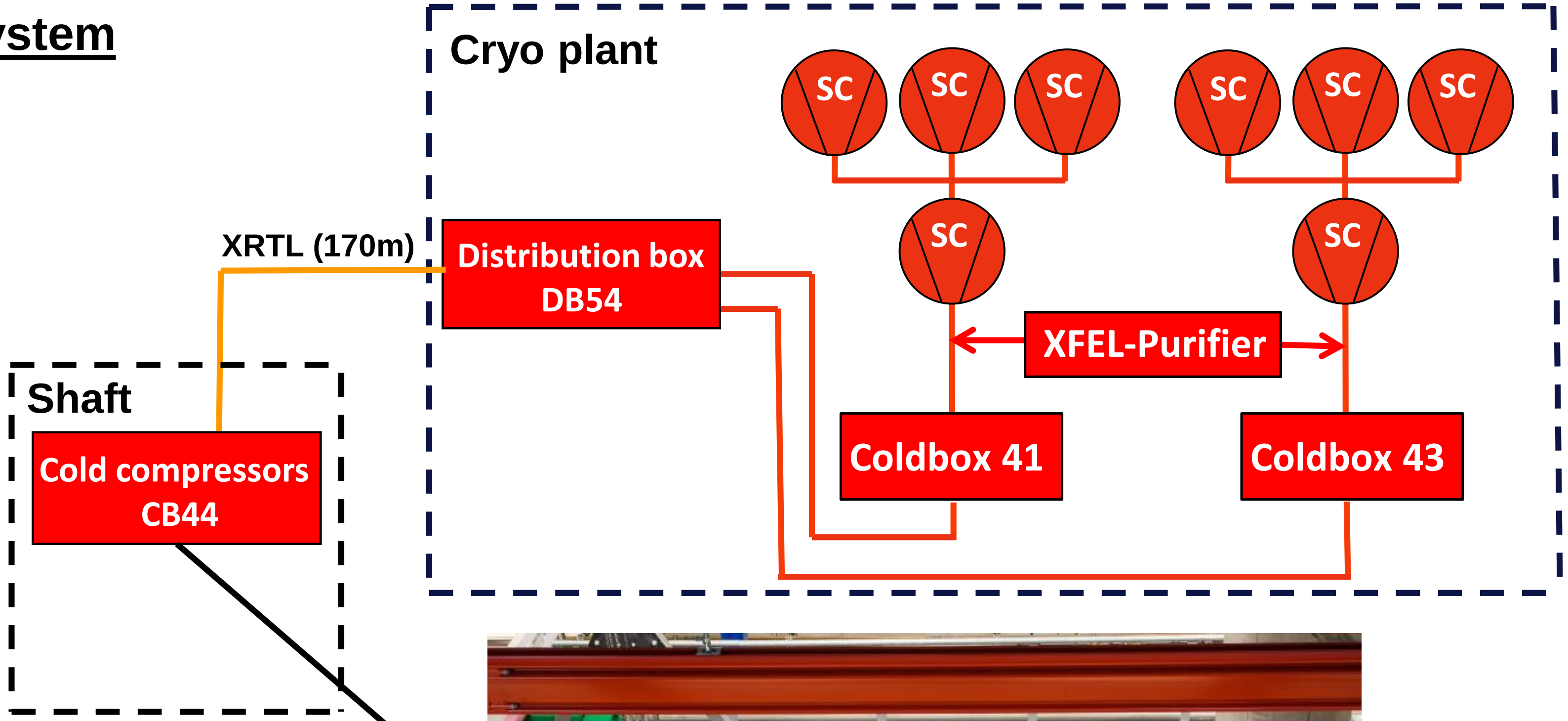


Overview of the XFEL cryogenic system



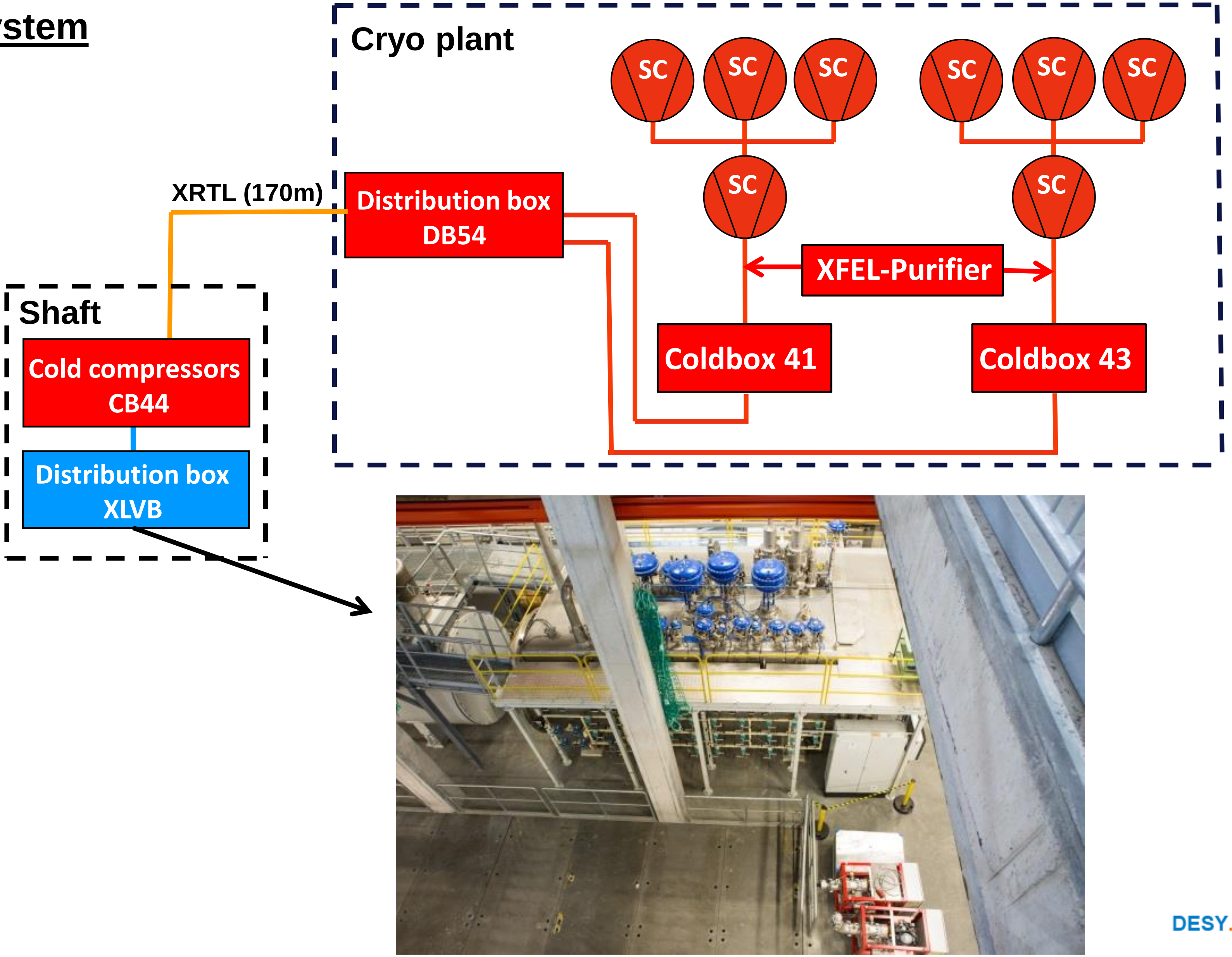
Overview of the XFEL cryogenic system

Vendor
LINDE
DEMACO

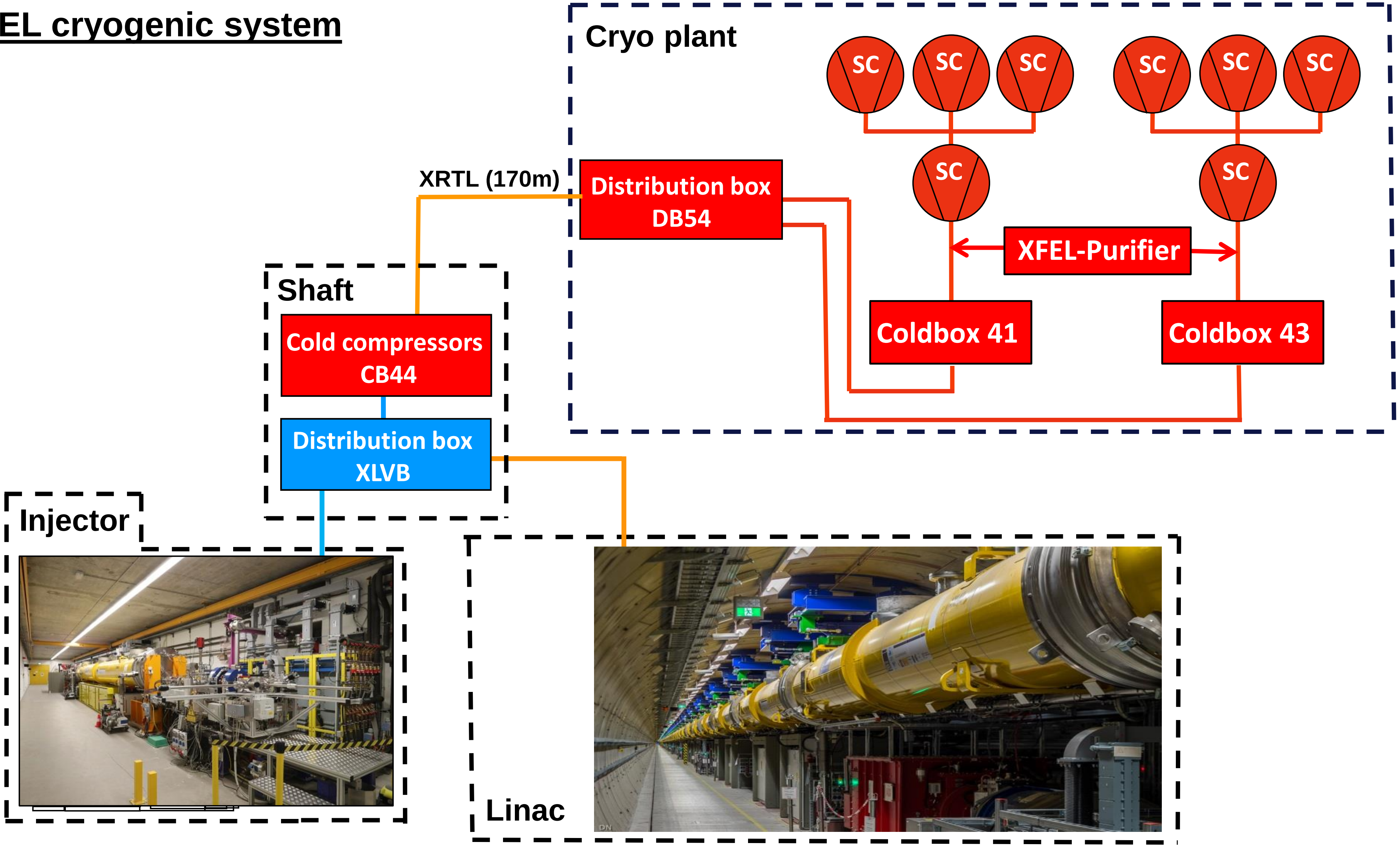


Overview of the XFEL cryogenic system

Vendor
LINDE
DEMACO
Contribution
BINP



Overview of the XFEL cryogenic system



Vendor

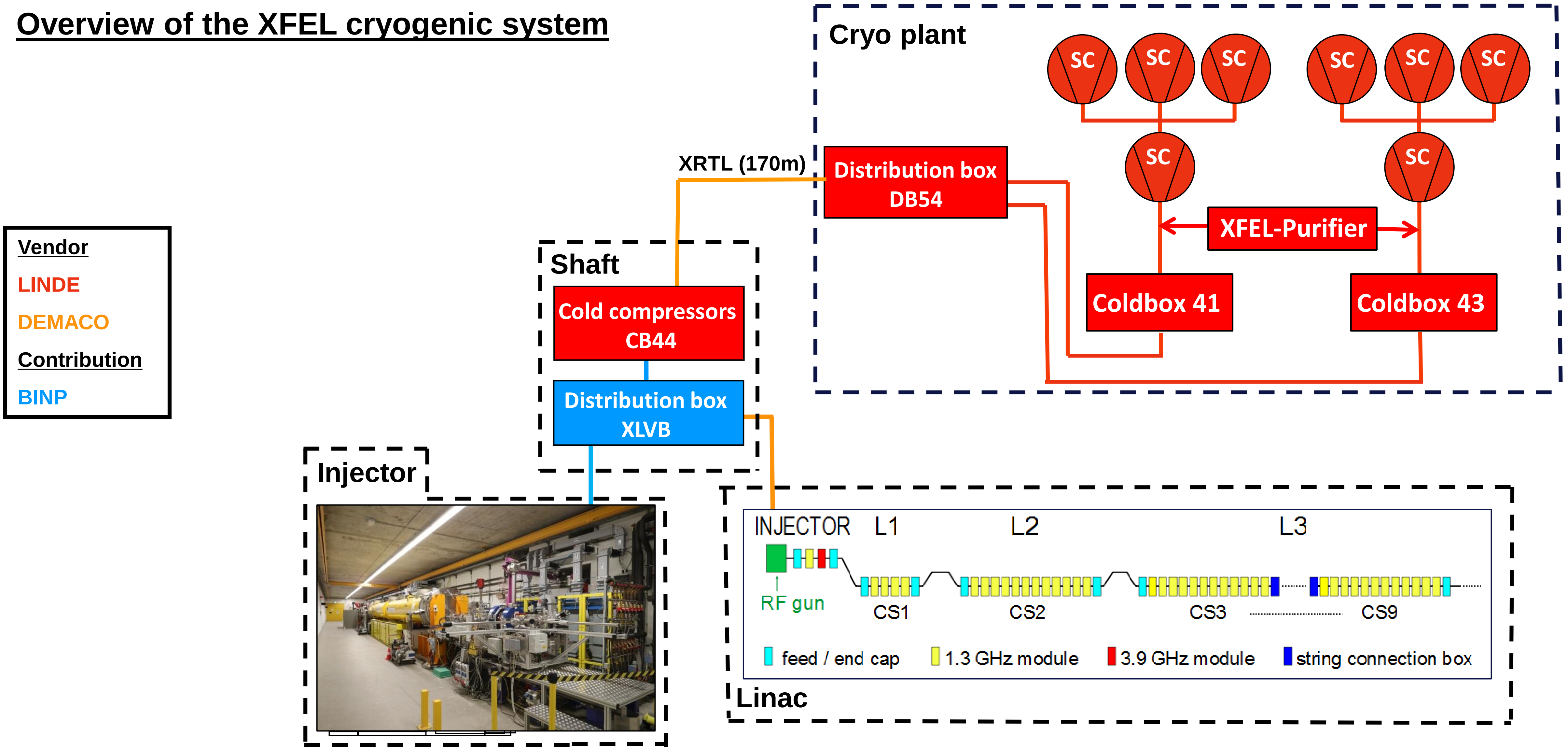
LINDE

DEMACO

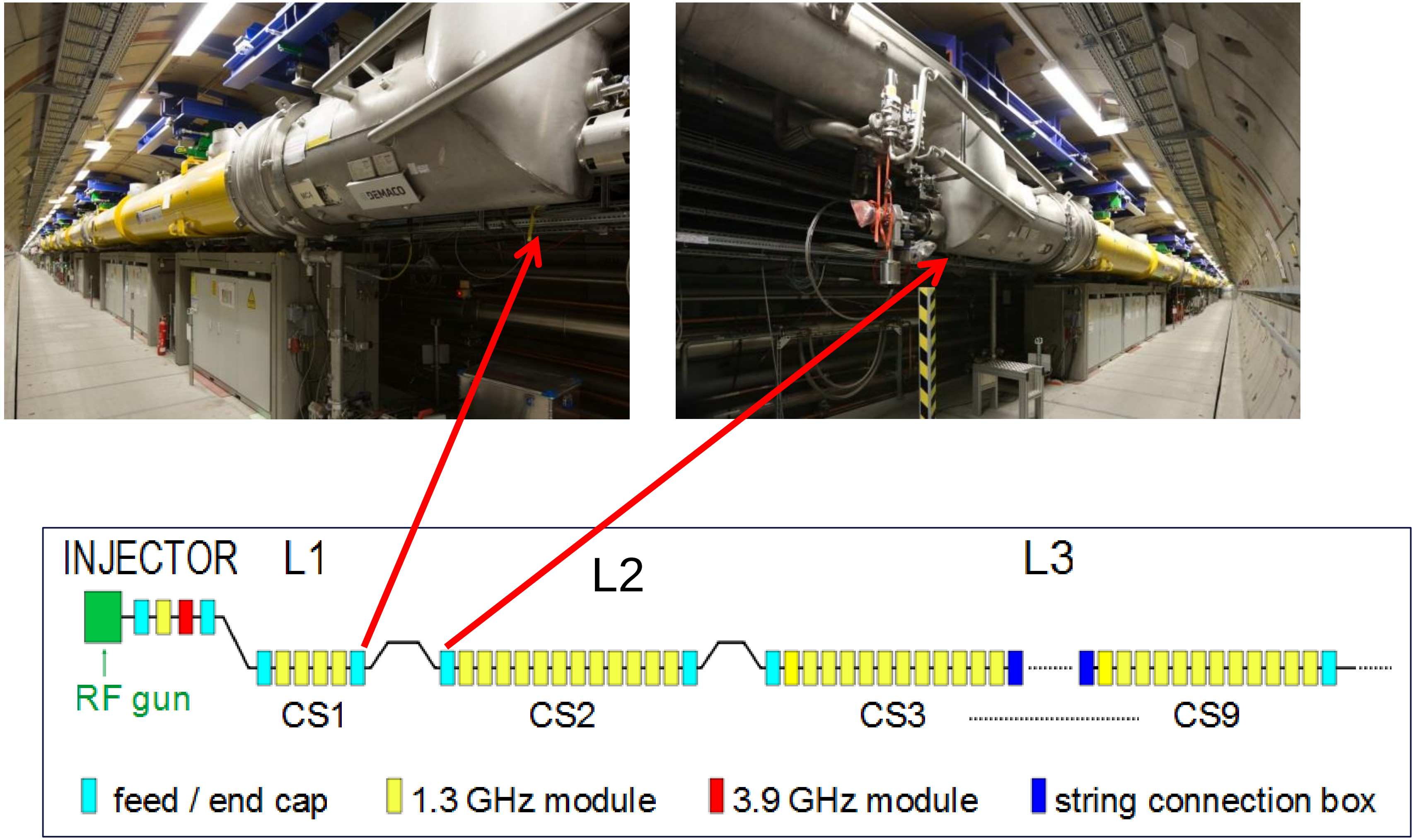
Contribution

BINP

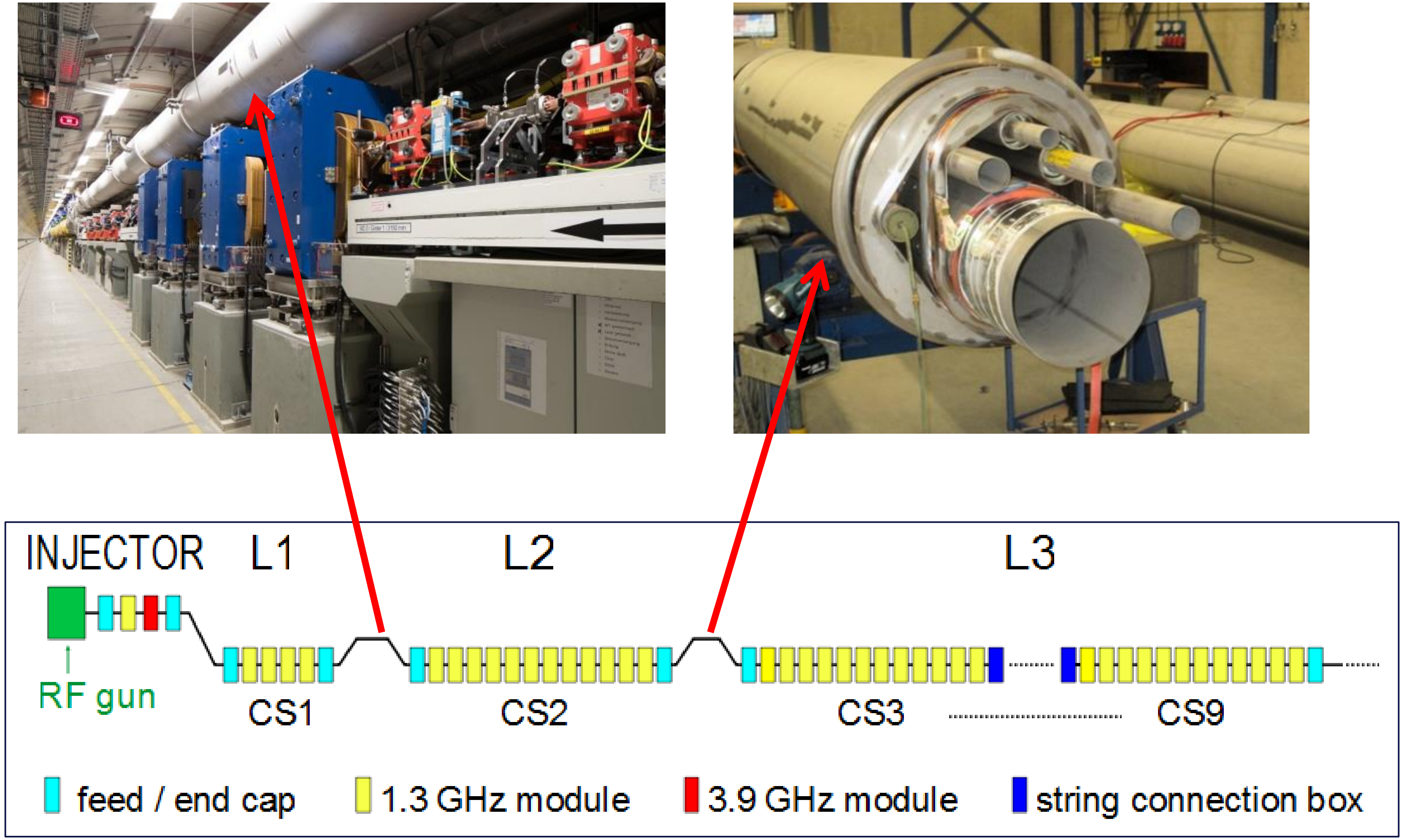
Overview of the XFEL cryogenic system



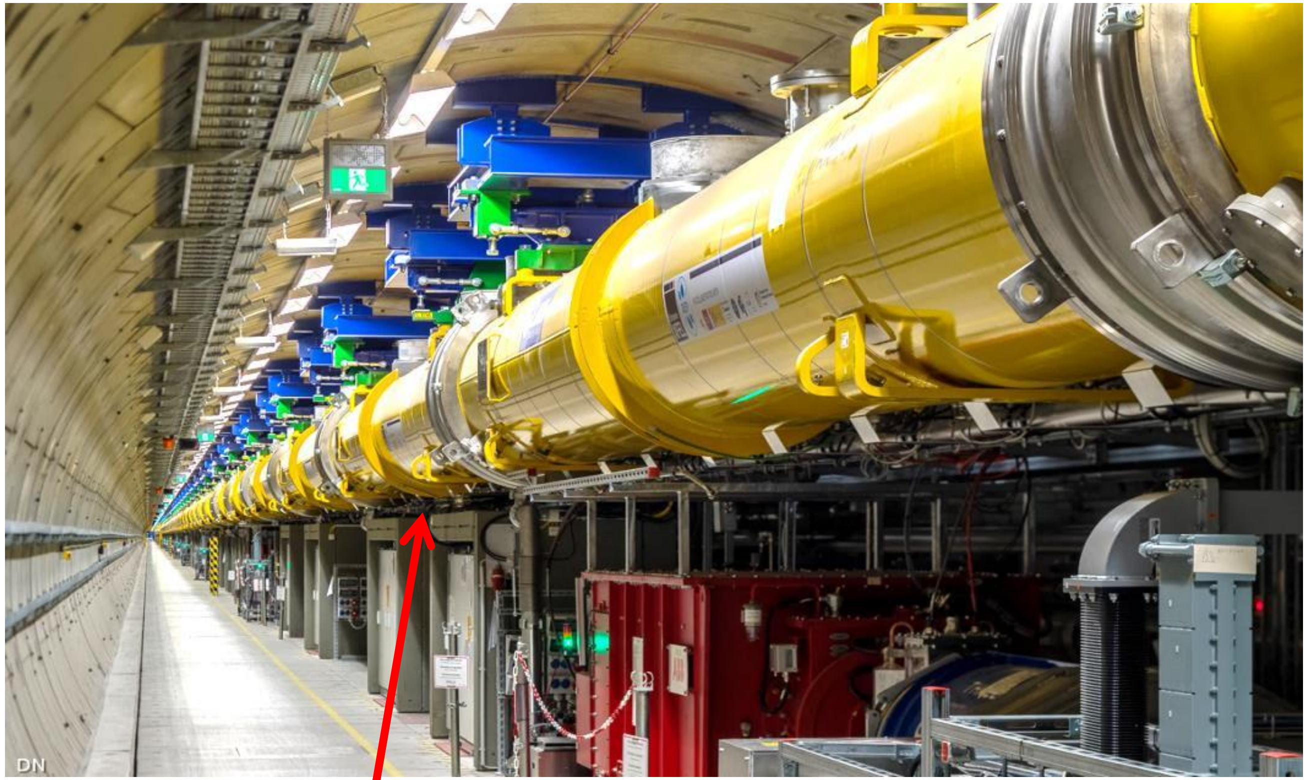
Overview of the XFEL cryogenic system



Overview of the XFEL cryogenic system

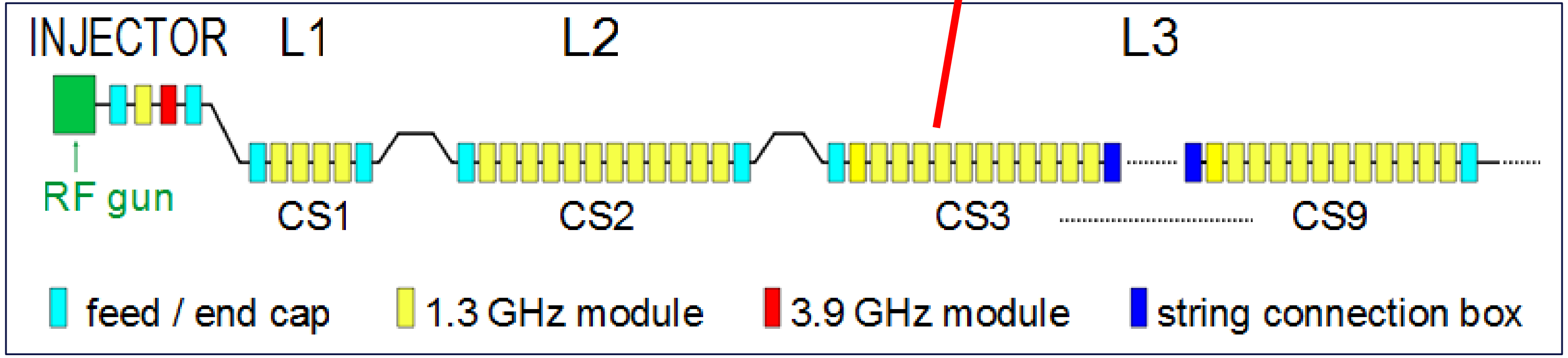


Overview of the XFEL cryogenic system

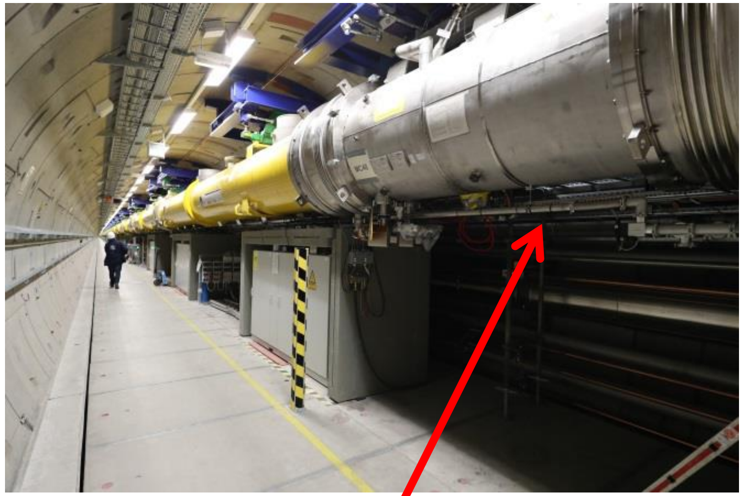


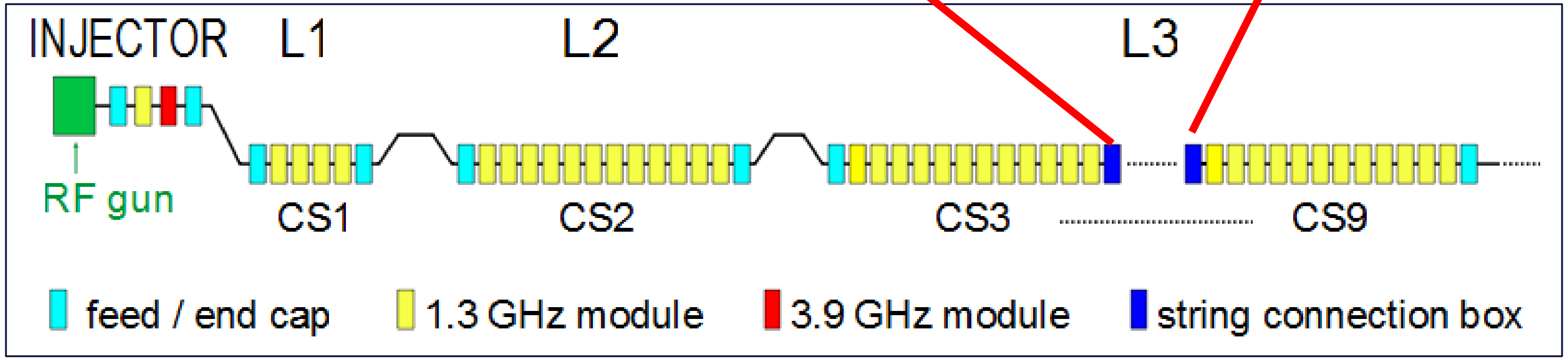
Cryo Strings CS1-9:

12 cryomodules (most of them)

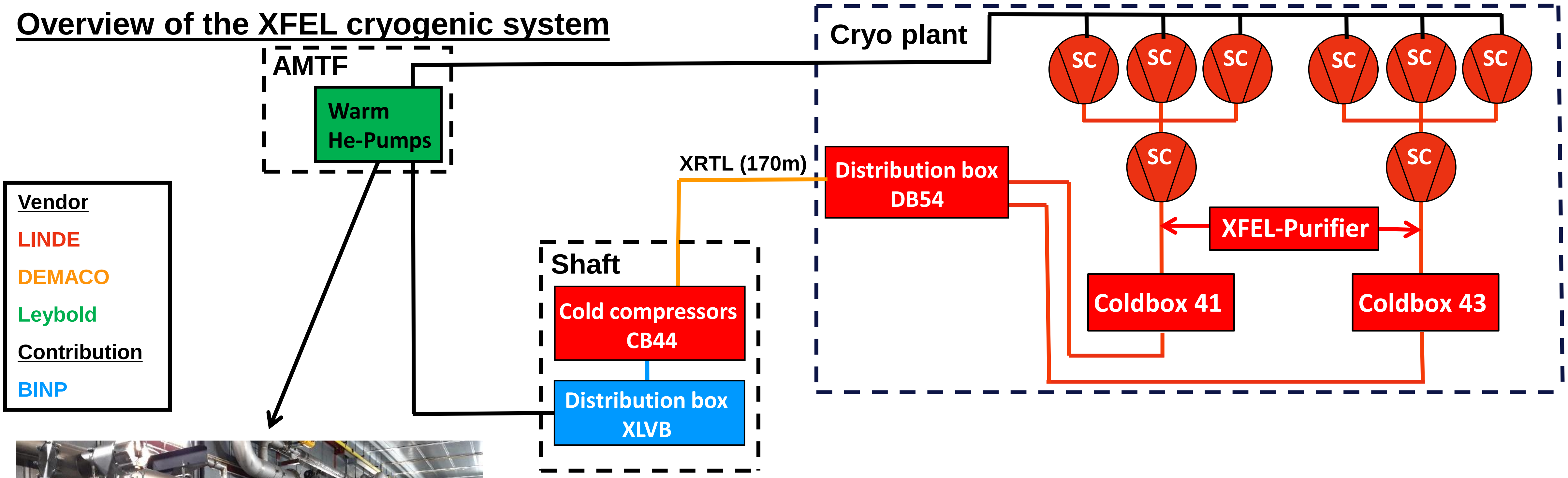


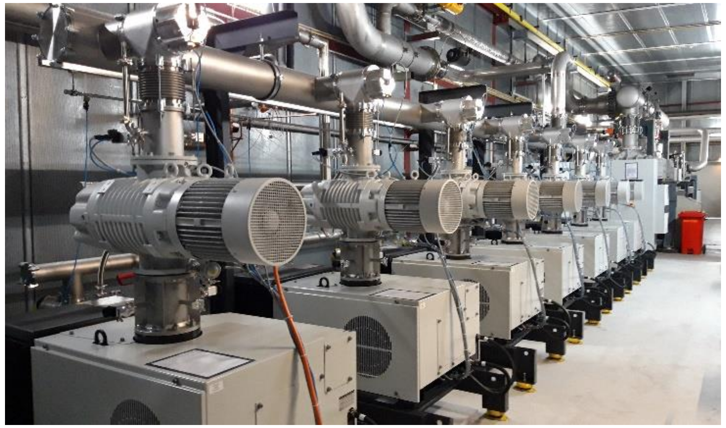
Overview of the XFEL cryogenic system





Overview of the XFEL cryogenic system



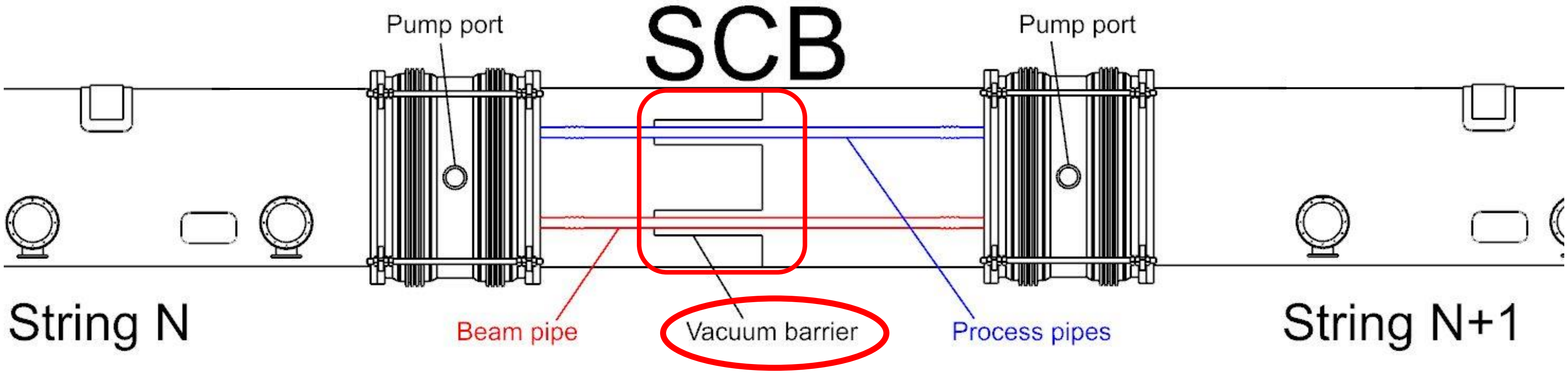


Warm He-Pumps (AMTF):

- **Backup for cold compressors CB44**
- **Limited capacity: no beam operation possible**
- **Important component for XFEL**

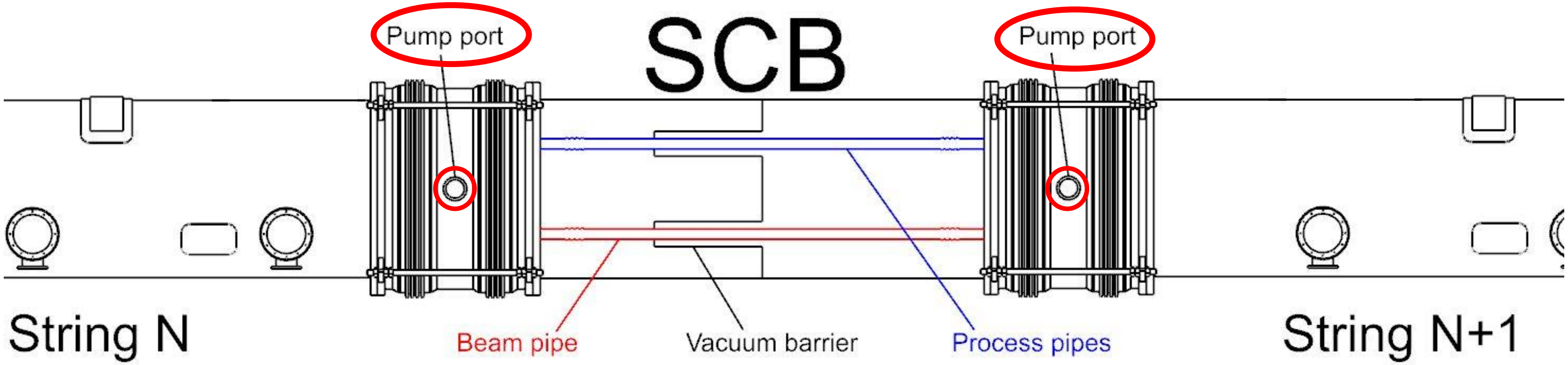
XFEL cryogenic system: Linac

- **Vacuum**
  - Each cryomodule string (CS) has its own Iso-vacuum
    - ► Iso-vaccum of two cryomodule strings (CS) is separated by a vacuum barrier



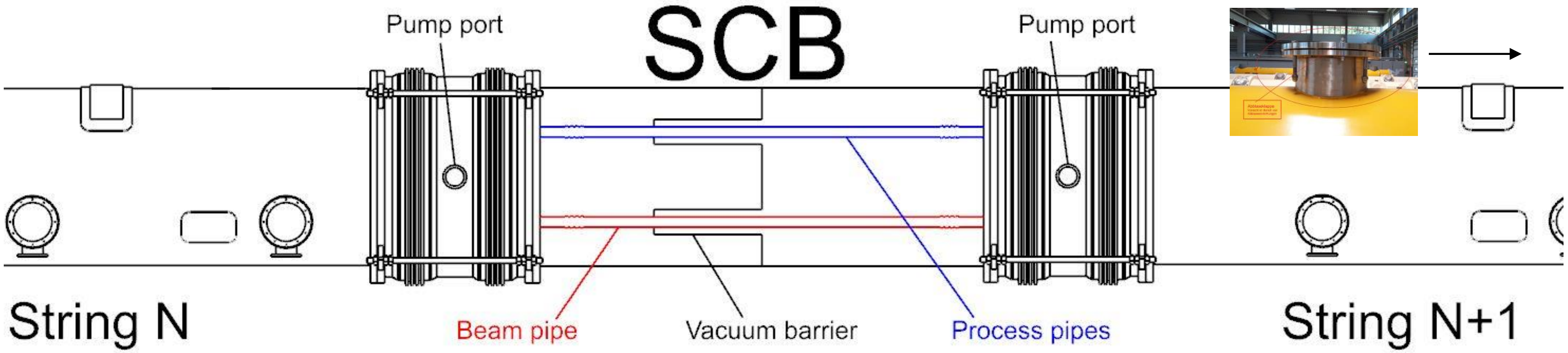
XFEL cryogenic system: Linac

- **Vacuum**
  - Each cryomodule string (CS) has its own Iso-vacuum
    - ► Iso-vaccum of two cryomodule strings (CS) is separated by a vacuum barrier
  - Each cryomodule string has two pump ports, equipped with vacuum pumps



Vacuum

- Each cryomodule string (CS) has its own Iso-vacuum
  - ► Iso-vaccum of two cryomodule strings (CS) is separated by a vacuum barrier
- Each cryomodule string has two pump ports, equipped with vacuum pumps
- Each cryomodule (CM) within a string has one vacuum safety flap to protect vacuum barriers



XFEL warm-up: General information

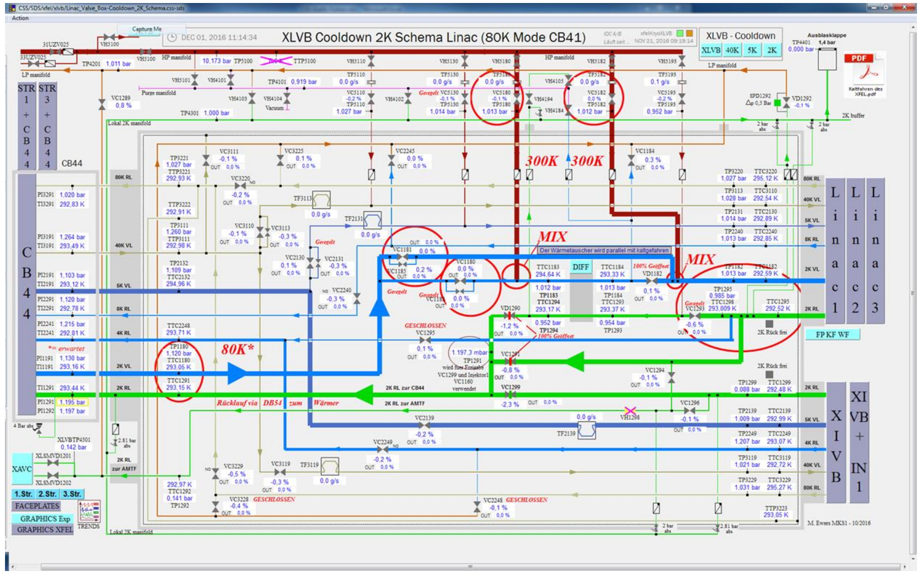
- **What is to be expected during warm-up of XFEL linac**
  - (Most likely) **nothing spectactular**, as…

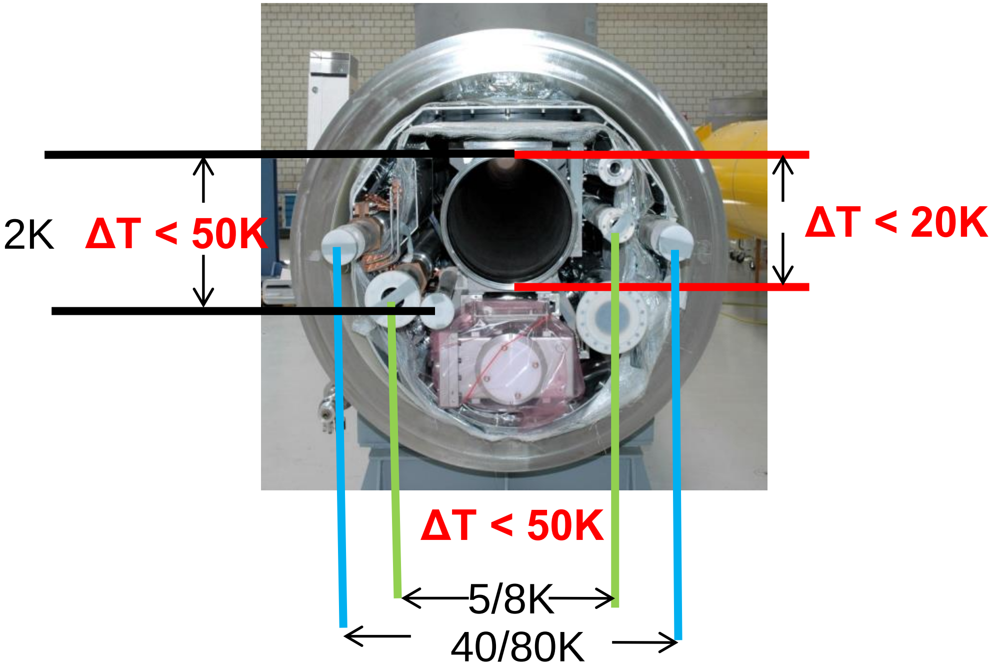
XFEL warm-up: General information

- **What is to be expected during warm-up of XFEL linac**
  - (Most likely) **nothing spectactular**, as…
    - ► Cryo operators are well trained

XFEL warm up: General information

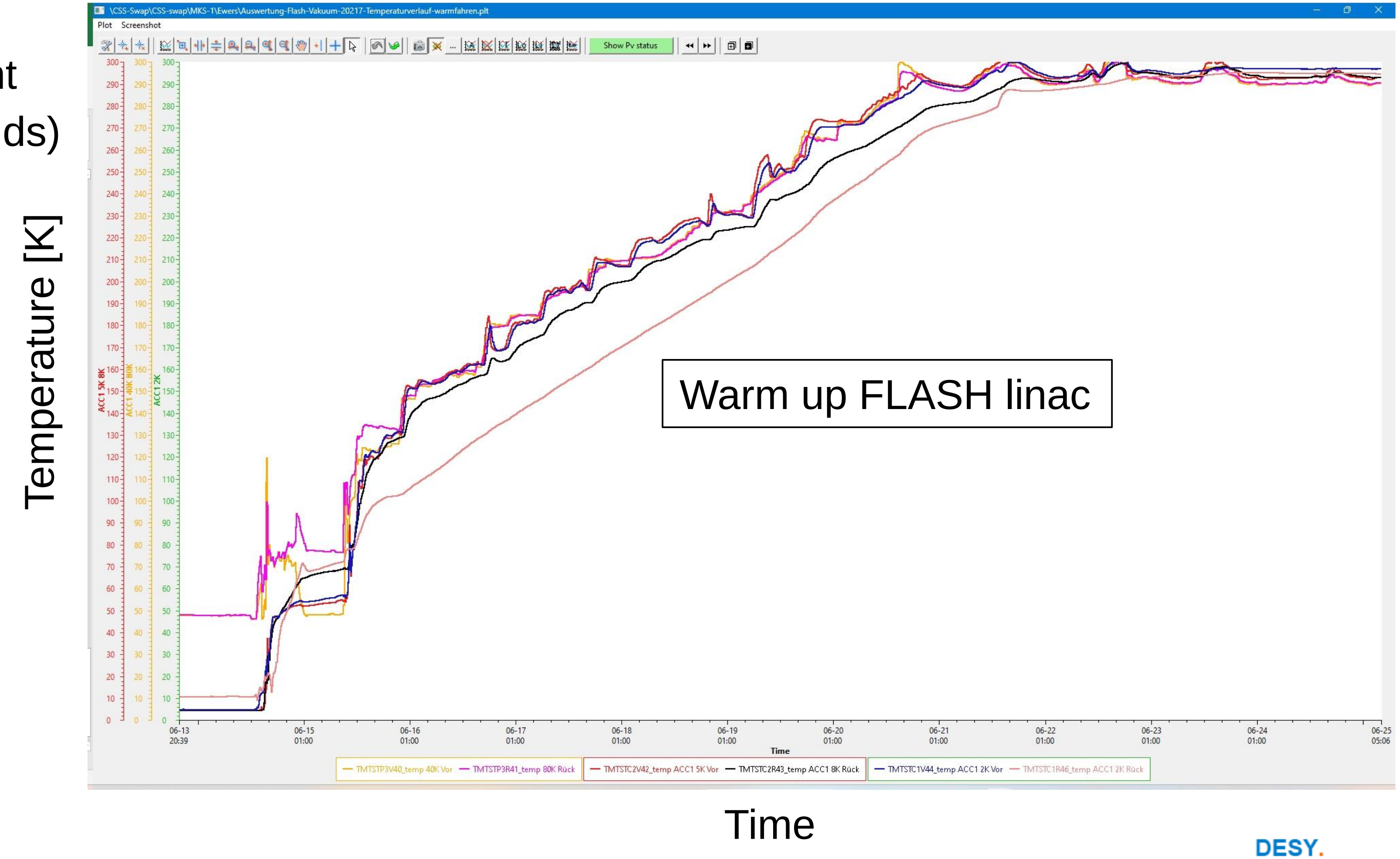
- **What is to be expected during warm up of XFEL linac**
  - (Most likely) **nothing spectactular**, as…
    - ▶ Cryo operators are well trained
      - Warm-up instruction document





XFEL warm-up: General information

- **What is to be expected during warm up of XFEL linac**
  - (Most likely) **nothing spectactular**, as…
    - ► Cryo operators are well trained
      - Warm-up instruction document
      - Experience (FLASH, test-stands)



XFEL warm-up: General information

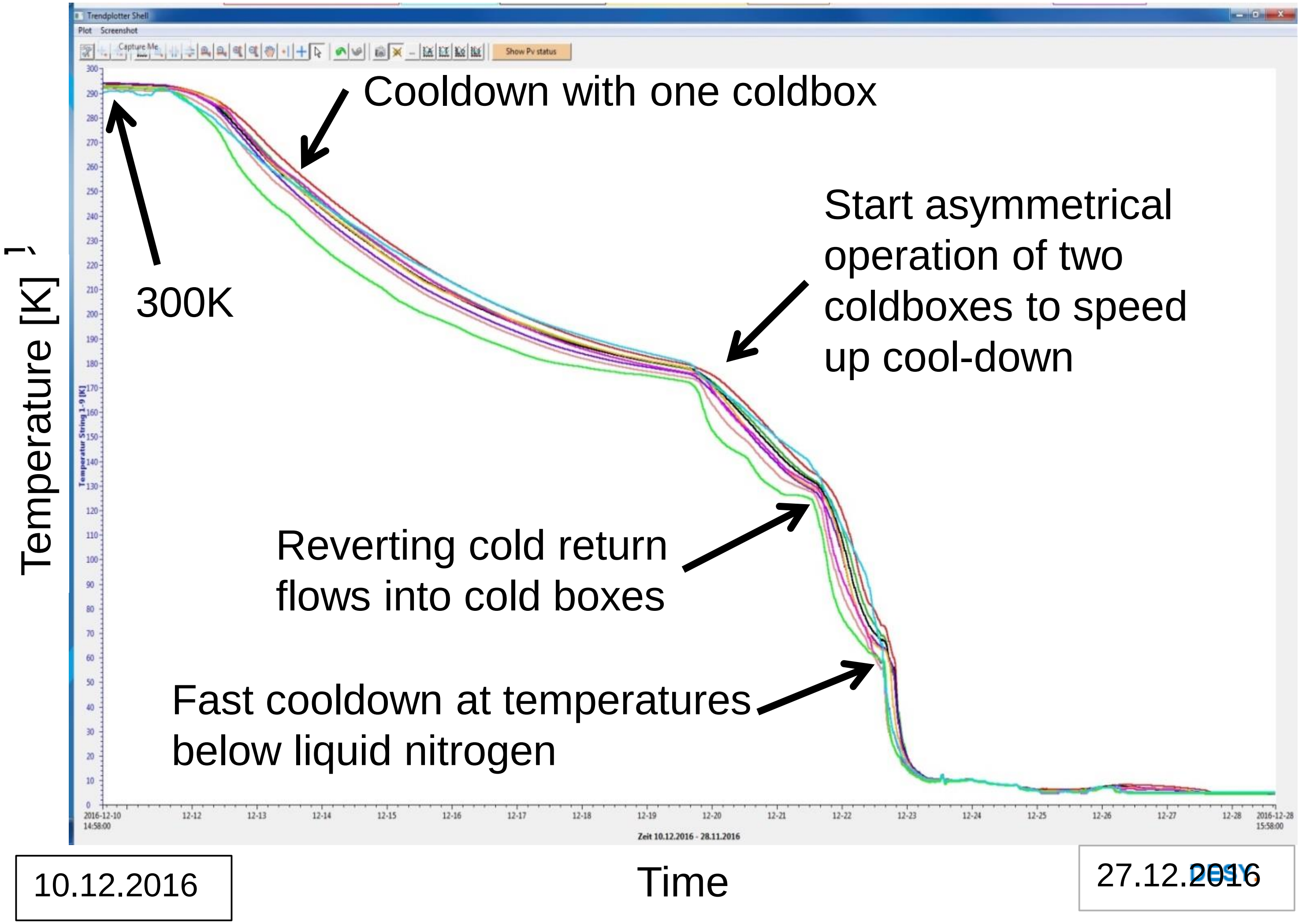
What is to be expected during warm up of XFEL linac

- (Most likely) **nothing spectactular**, as…
  - ► Cryo operators are well trained
    - Warm-up instruction document
    - Experience (FLASH, test-stands)
  - ► XFEL cryomodules have been thermally cycled on test-stand (AMTF) without problems
    - Design / manufacturing failures would have been „visible“

XFEL warm-up: General information

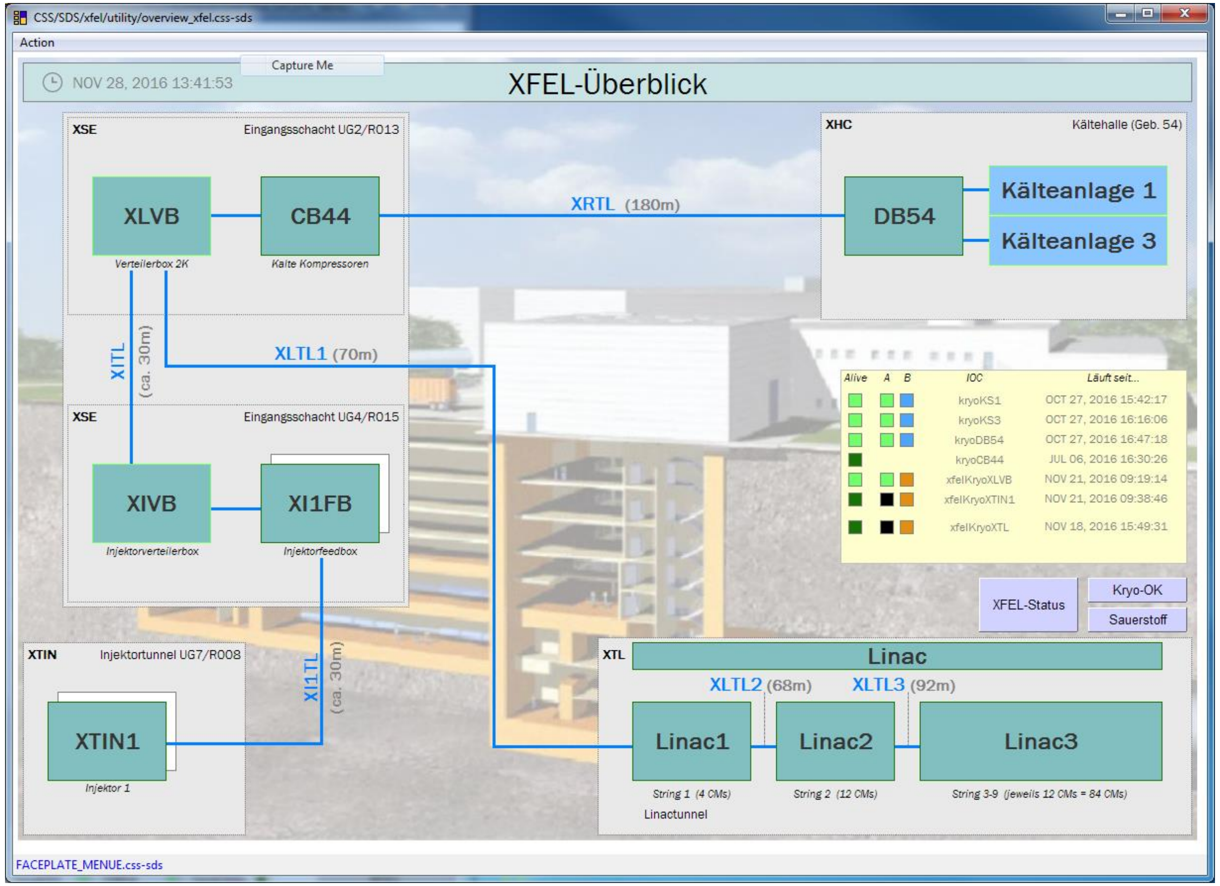
- **What is to be expected during warm up of XFEL linac**
  - (Most likely) **nothing spectactular**, as…
    - ► Cryo operators are well trained
      - Warm-up instruction document
      - Experience (FLASH, test-stands)
    - ► XFEL cryomodules have been thermally cycled on test-stand (AMT without problems
      - Design / manufacturing failures would have been „visible“
- **<u>First cooldown of XFEL Linac (300K - 4K)</u>**
  - Main goal: 4K in 2016
  - First cooldown was very smooth
  - First cooldown of XFEL linac was successful and in time!

Cool-down XFEL linac



XFEL warm-up: Procedure

- **Warm-up instruction document**
  - Overview of main components of XFEL cryogenic system

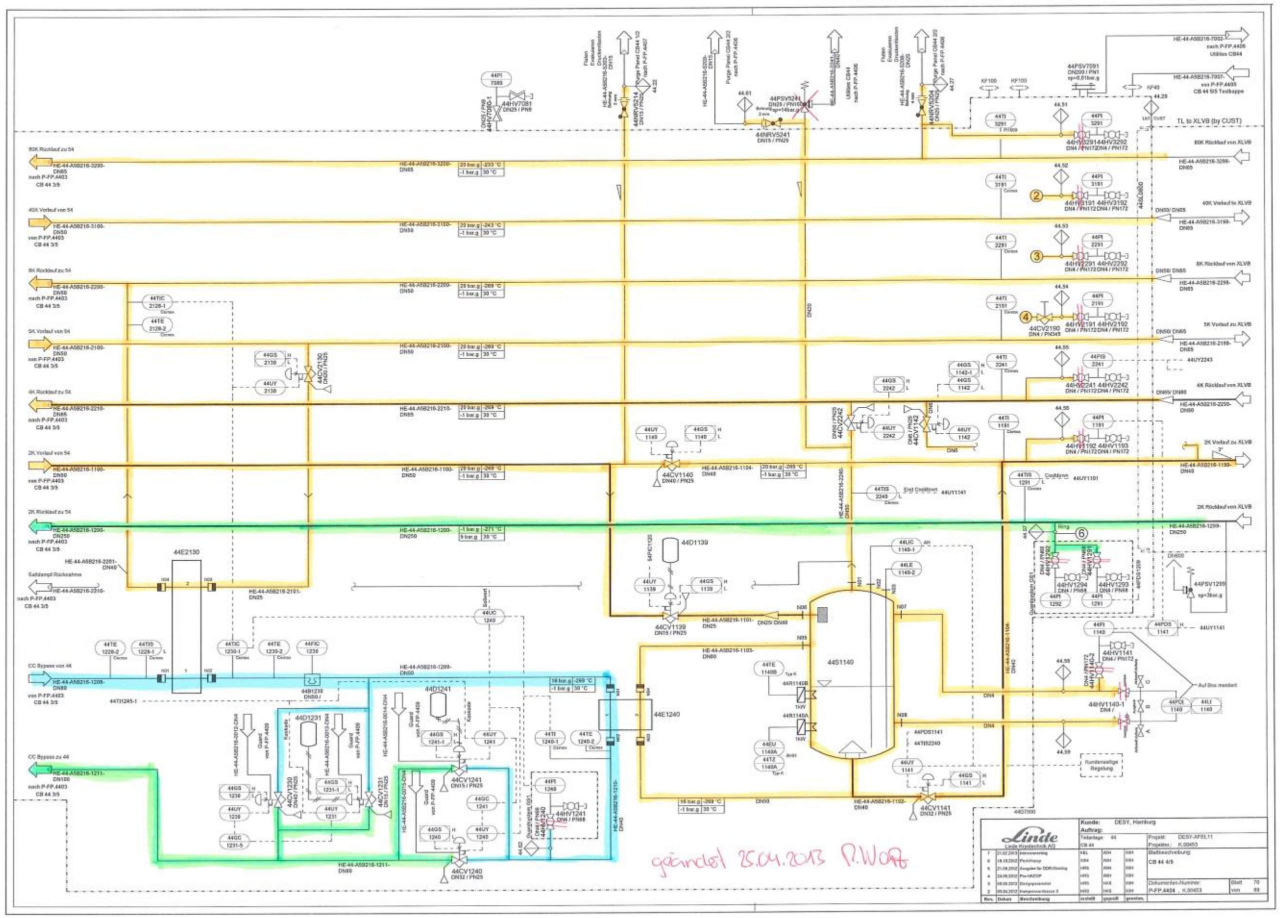


XFEL warm-up: Procedure

- **Warm-up instruction document**
  - Overview of main components of XFEL cryogenic system
  - Max. allowable working pressures

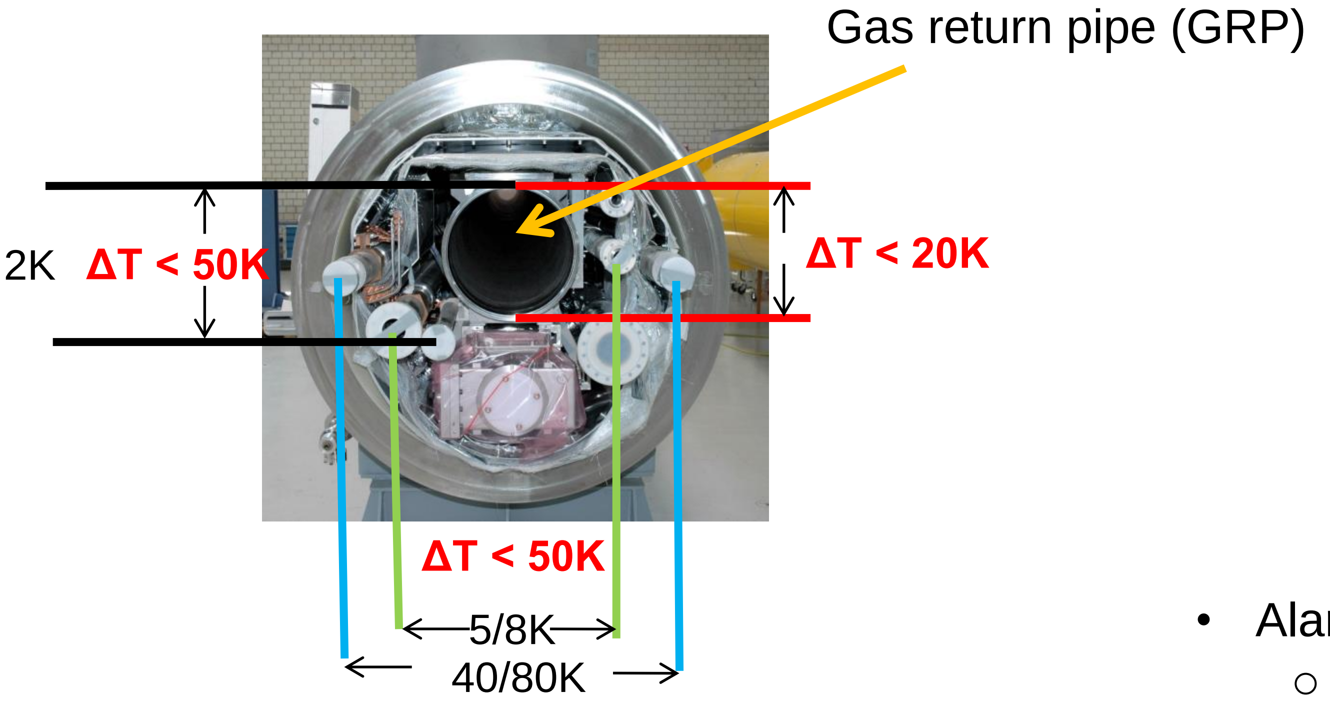
3 Pressure Data

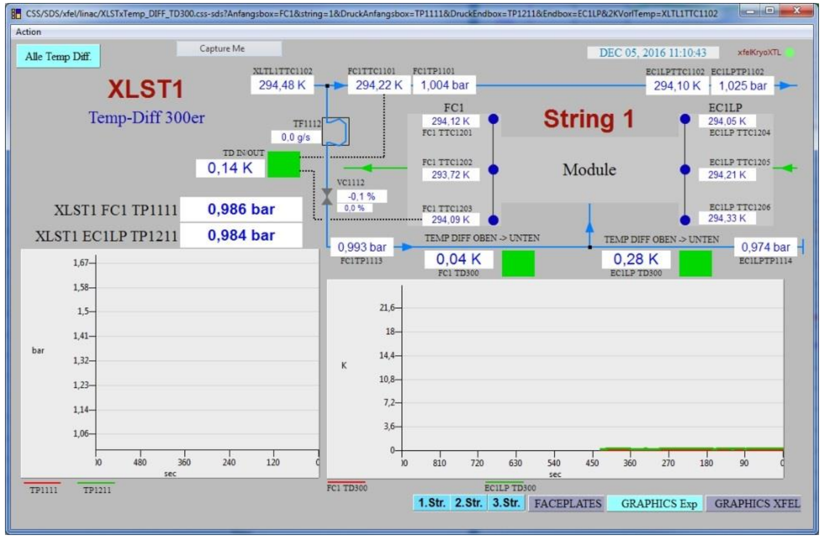
Colour code	Design pressure	Pneum. pressure test 1.1 x design pressure	Leakage test 1 x design pressure	Remarks
(yellow)	20 bar(g)	22 bar(g)	20 bar(g)	PED
(blue)	16 bar(g)	17.6 bar(g)	16 bar(g)	PED
(green)	4 bar(g)	4.4 bar(g)	4 bar(g)	PED
				no pressure and leak test
X	-	-	-	Equipment to be **removed** for pressure and leakage test
II	-	-	-	Equipment to be **closed** for pressure and leakage test

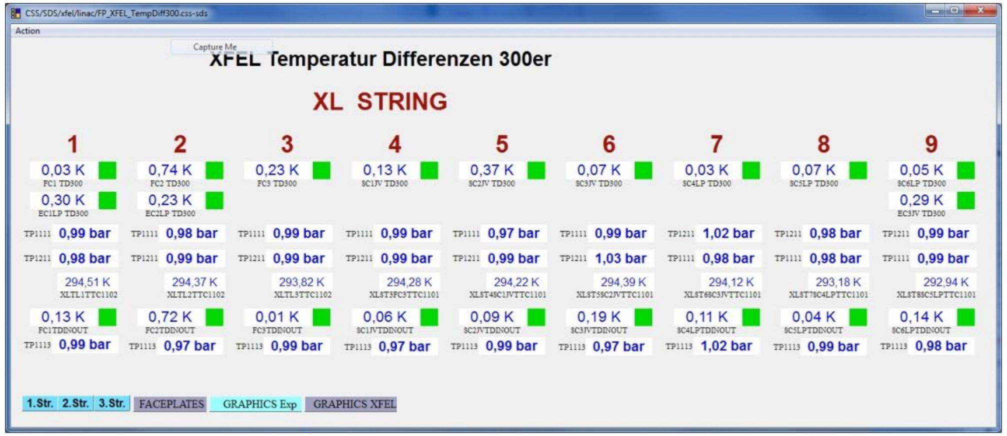


XFEL warm-up: Procedure

- **Warm-up instruction document**
  - Overview of main components of XFEL cryogenic system
  - Max. allowable working pressures
  - Max. allowable temperature gradients





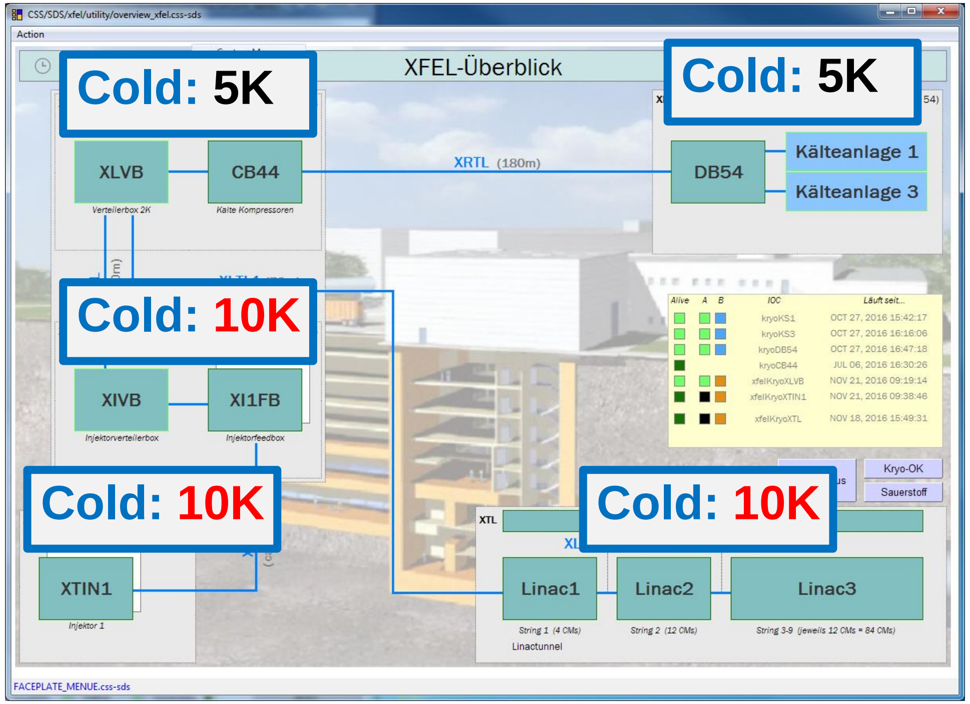


- Alarm values for different components
  - High values (e.g. 15K for GRP vertical)
  - Highhigh values (e.g. 20K for GRP vertical)

XFEL warm-up: Procedure

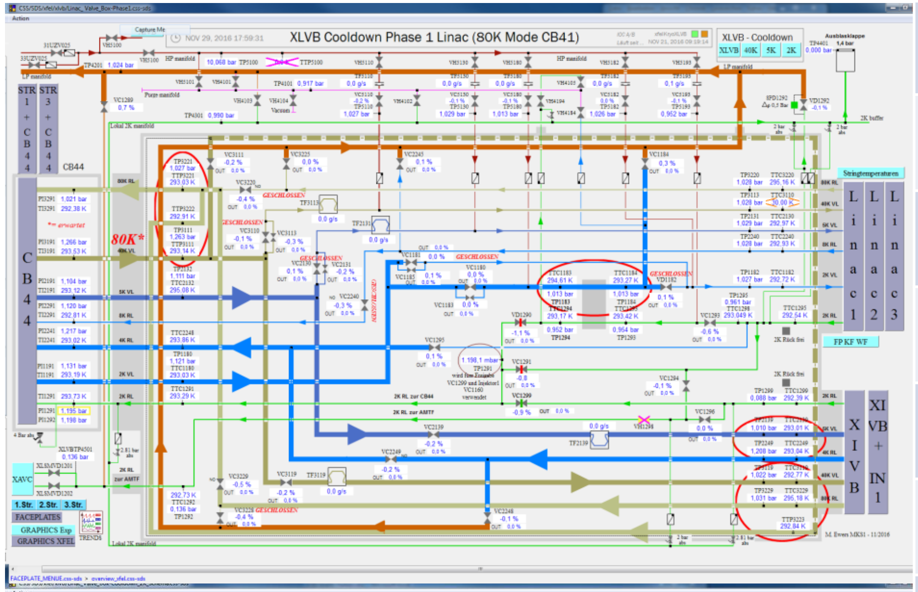
- **Warm-up instruction document**
  - Overview of main components of XFEL cryogenic system
  - Max. allowable working pressures
  - Max. allowable temperature gradients
  - Different phases of warm-up
    - ► Phase 0: Stop CC operation
    - ► Phase 1: Evaporation of liquid helium (static heat load)
    - ► Phase 2: Cold gas flow of 10K
    - ► Phase 3: Conversion of coldbox to 80K mode
    - ► Phase 4: Cold gas flow of approx. 50K (below triple point of nitrogen: 63K)
    - ► Phase 5: Adjustment of flat ramp from 50K- 80K (to slowly reach/pass through 63K)
    - ► Phase 6: Adjustment of ramp (dT=50K) for warm up 80K – 300K
    - ► Phase 7: Warm gas flow of 300K

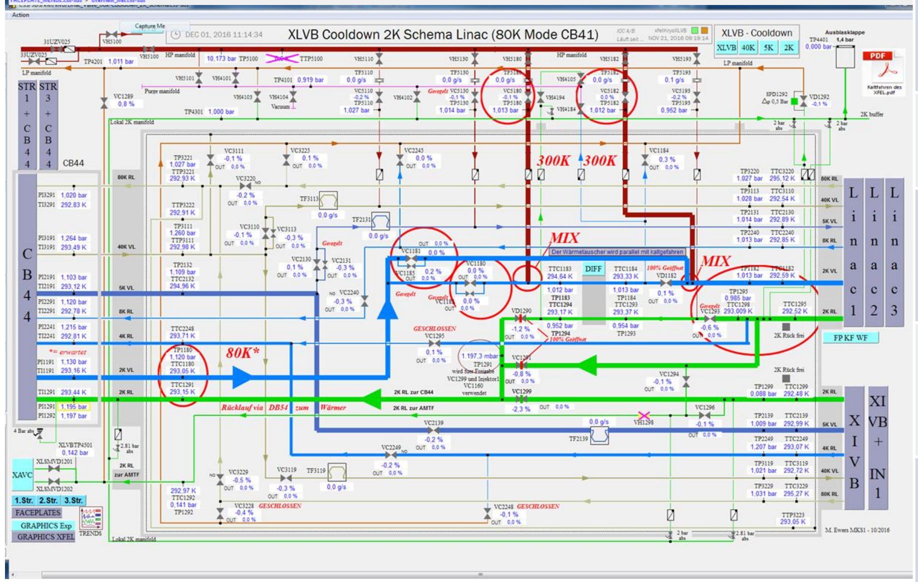
Phase 2



XFEL warm-up: Procedure

- **Warm-up instruction document**
  - Overview of main components of XFEL cryogenic
  - Max. allowable working pressures
  - Max. allowable temperature gradients
  - Different phases of warm-up
    - ▶ Phase 0
    - ▶ Phase 1
    - ▶ Phase 2
    - ▶ …
- For all phases
  - Color code on "P&ID"
    - ▶ Relevant valves, sensors, etc.
  - Plausibility check of values (flows, pressures, temperatures)
  - Inspection rounds for identification of failures/defects/damage, etc.





40K supply

80K return

5K supply

4K return

8K return

2K supply

2K return

20K return

LP manifold

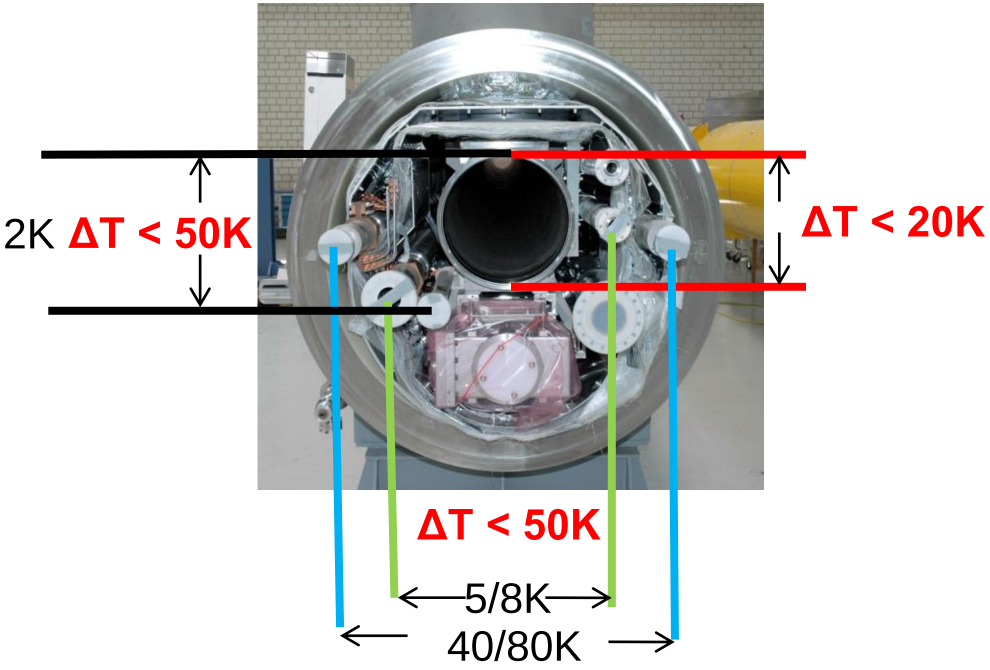
HP manifold

Purge manifold

XFEL warm-up: Risk handling / provisions

XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**



Exceeding ΔT = 50K means thermal stress which can damage a cryomodule

XFEL warm-up: Risk handling / provisions

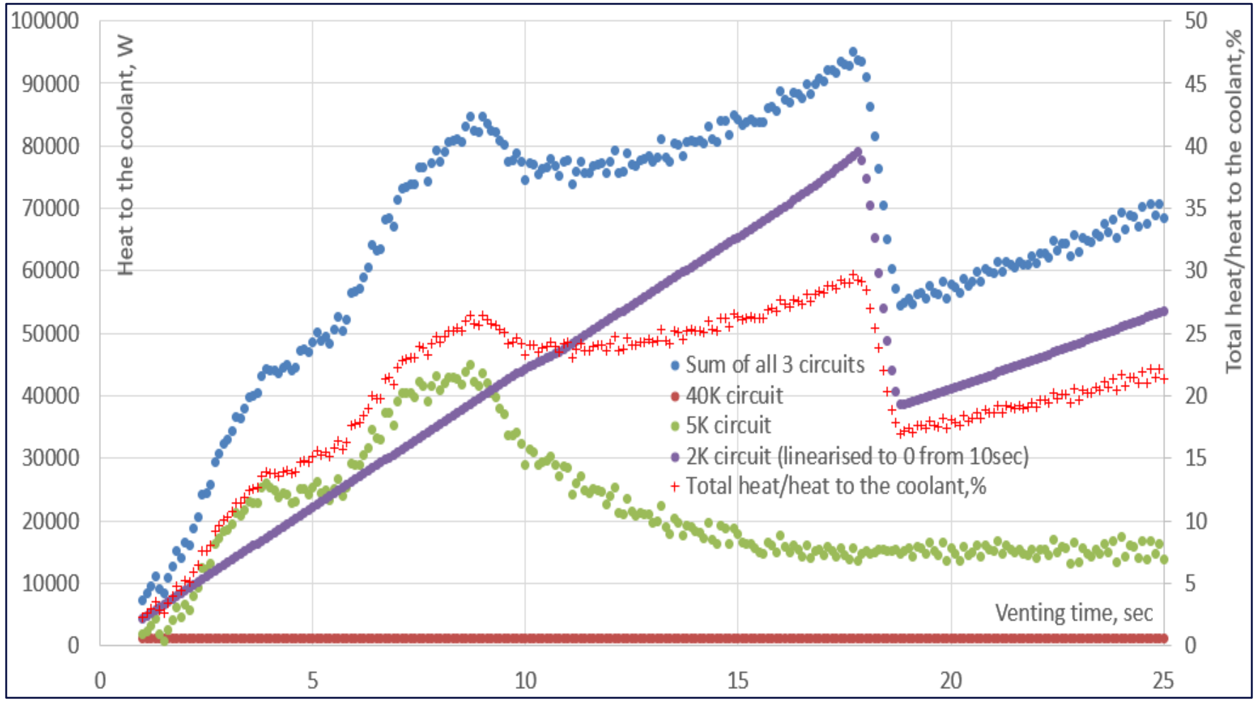
- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of He process pipes (& shields)

XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding $\Delta T < 50K$ at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of He process pipes (& shields)

XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of different temperature levels
    - ► >90% of infiltrated air is deposited on 2K and 5-8K level



XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of different temperature levels
    - ► >90% of infiltrated air is deposited on 2K and 5-8K level
    - ► Dimension of deposited air is unknown (8 years of cold operation)

XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of different temperature levels
    - ► >90% of infiltrated air is deposited on 2K and 5-8K level
    - ► Dimension of deposited air is unknown (8 years of cold operation)
  - **What will happen at triple point of nitrogen (63K)?**

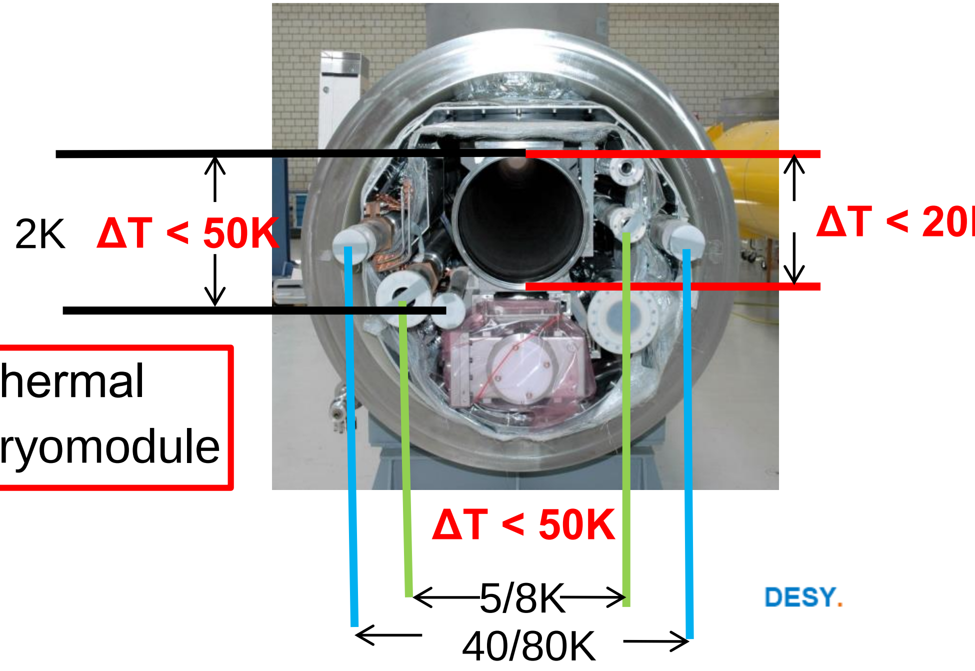
XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of different temperature levels
    - ► >90% of infiltrated air is deposited on 2K and 5-8K level
    - ► Dimension of deposited air is unknown (8 years of cold operation)
  - **What will happen at triple point of nitrogen (63K)?**
    - ► Deposited air will evaporate
    - ► Vacuum gets worse
    - ► Temperature gradient of helium in piping system might increase

XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
  - Leaks: Air in the Iso-vacuum will deposit on cold surfaces of different temperature levels
    - ► >90% of infiltrated air is deposited on 2K and 5-8K level
    - ► Dimension of deposited air is unknown (8 years of cold operation)
  - **What will happen at triple point of nitrogen (63K)?**
    - ► Deposited air will evaporate
    - ► Vacuum gets worse
    - ► Temperature/pressure of helium in piping system might increase spontaneously
  - **Main question: Can a temperature gradient ΔT > 50K occur?**
    - ► How can this be avoided?

Exceeding ΔT = 50K means thermal stress which can damage a cryomodule



XFEL warm-up: Risk handling / provisions

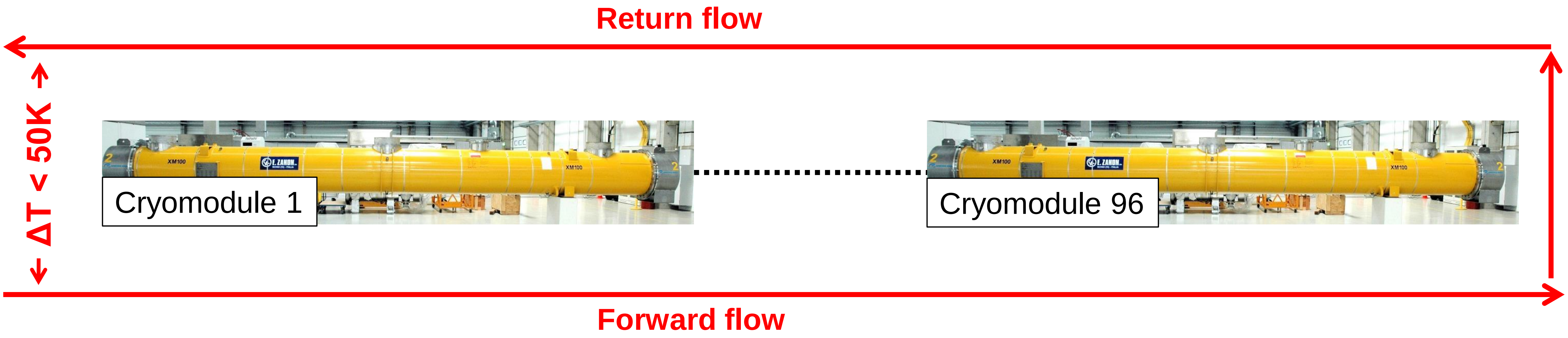
- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - **Warm-up procedure**: Warm up with margin in temperature gradient
    - ► Design: ΔT < 50K for a single pipe in cryomodule

Return flow: ΔT < 50K

Forward flow: ΔT < 50K

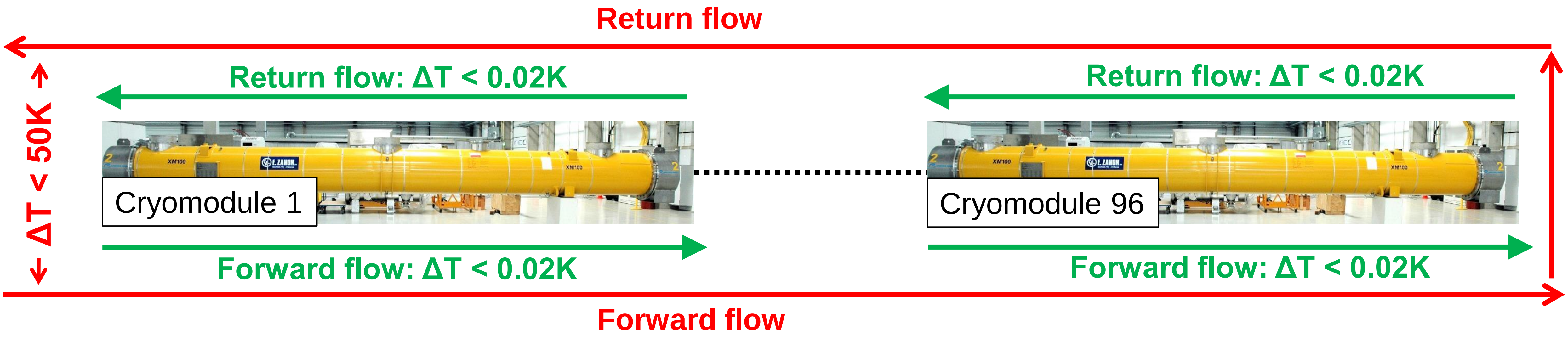
XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - **Warm-up procedure**: Warm up with margin in temperature gradient
    - ► Design: ΔT < 50K for a single pipe in cryomodule
    - ► During warm-up: ΔT = 50K along the whole linac (forward & return)



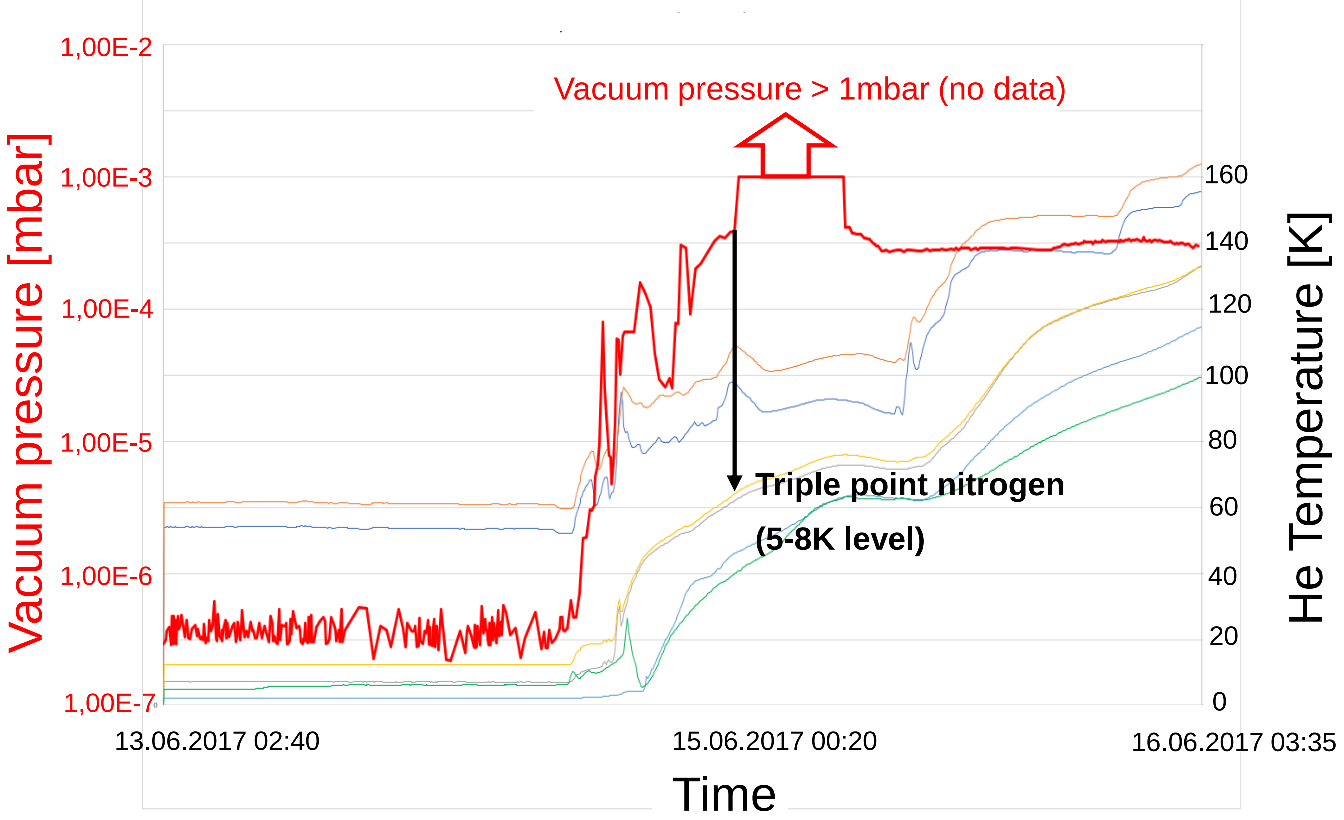
XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - **Warm-up procedure**: Warm-up with margin in temperature gradient
    - ► Design: ΔT < 50K for a single pipe in cryomodule
    - ► During warm up: ΔT < 50K along the whole linac (forward & return)
    - ► → ΔT = 0.02K is adjusted for a single pipe in cryomodule → margin of ~50K for single cryomodule!



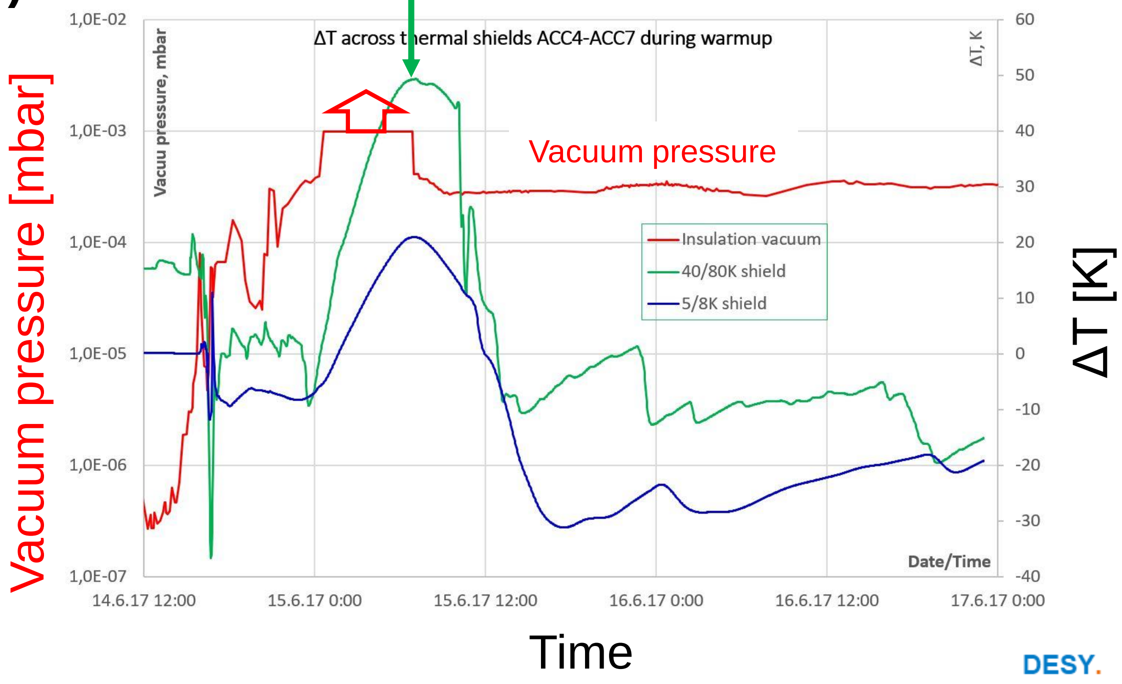
XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - Warm-up procedure: Warm up with margin in temperature gradient
  - **Experience**: Warm-up of FLASH linac **after 4 years of cold operation** (no problems)
    - ► Vacuum pressure reached > 1 mbar without critical impact on temperature rise



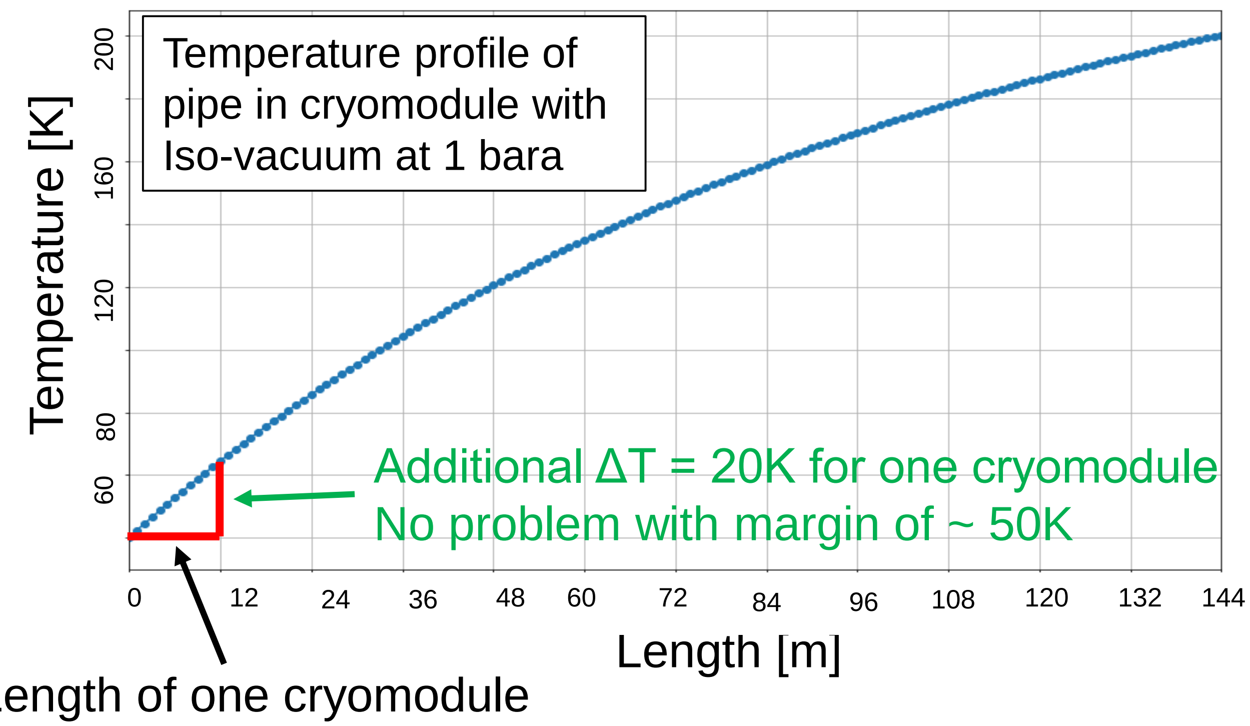
XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - Warm up procedure: Warm-up with margin in temperature gradient
  - Experience: Warm-up of FLASH linac **after 4 years of cold operation** (no problems)
    - ► Vacuum pressure reached > 1 mbar without critical impact on temperature rise
    - ► Max. ΔT along 4 cryomodules: ΔT = 50K
    - ► **→ For a single cryomodule: ΔT = 6K (not critical)**



XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - Warm-up procedure: Warm up with margin in temperature gradient
  - Experience: Warm-up of FLASH linac after 4 years of cold operation (no problems)
  - Calculations: **Worst case scenario with Iso-vacuum at 1000mbar** (no problems)
  - ► **ΔT for one cryomodule: ΔT = 20K (not critical)**



XFEL warm-up: Risk handling / provisions

- **Risk: Exceeding ΔT < 50K at triple point of nitrogen (63K)**
- **Provisions:**
  - Warm-up procedure: Warm up with margin in temperature gradient
  - Experience: Warm-up of FLASH linac after 4 years of cold operation (no problems)
  - Calculations: Scenario with Iso-vacuum at 1000 mbar (no problems)
    ► ΔT of 20K to neigbouring cryomodule

- **Conclusion: With ΔT = 50K along the linac - No reasonable scenario during warm-up, where critical temperature gradients for a cryomodule will be exceeded**

XFEL warm-up: Risk handling / provisions

- **Risk: Losing helium (operational problems, cryoplant shutdown, etc.)**

XFEL warm-up: Risk handling / provisions

- **Risk: Losing helium (operational problems, cryoplant shutdown, etc.)**
- **Provisions:**
  - **Warm up procedure**: Evaporation of liquid helium (phase 1)

XFEL warm-up: Risk handling / provisions

- **Risk: Losing helium (operational problems, cryoplant shutdown, etc.)**
- **Provisions:**
  - Warm up procedure: Evaporation of liquid helium (phase 1)
  - **Warm-up procedure**: Reduced helium pressure to 5bara (in most of circuits)

XFEL warm-up: Risk handling / provisions

- **Risk: Losing helium (operational problems, cryoplant shutdown, etc.)**
- **Provisions:**
  - Warm-up procedure: Evaporation of liquid helium (phase 1)
  - Warm-up procedure: Reduce helium pressure to 5 bara (in most circuits)
  - → **Helium inventory**: Reduction of helium inventory **in linac** from 3562kg to 139kg
    ► Released helium will be stored in storage tanks

Beam operation		**Warm up**
40/80K circuit: 135kg	→	40/80K circuit: 33kg
5/8K circuit: 900kg		5/8K circuit: 26kg
2K circuit: 2527kg		2K circuit: 80kg
Total: 3562kg		**Total: 139kg**

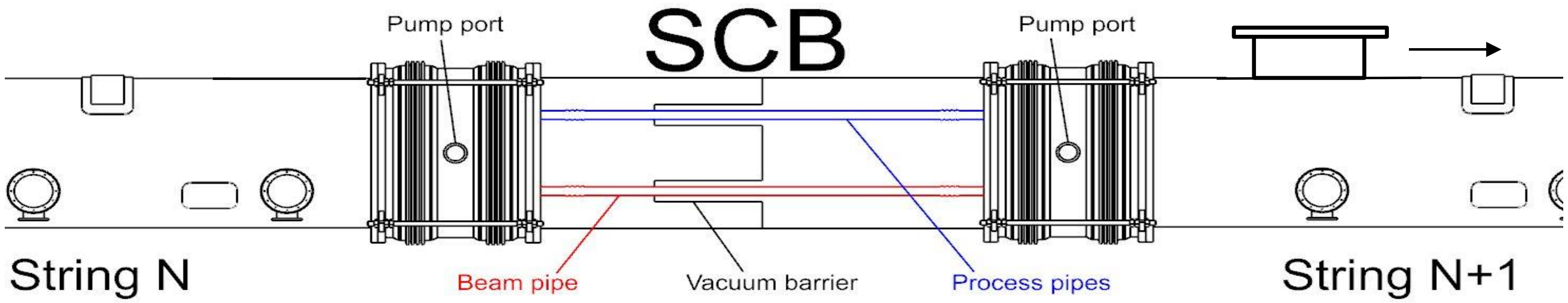
XFEL warm-up: Risk handling / provisions

- **Risk: Loosing helium (operational problems, cryoplant shutdown, etc.)**
- **Provisions:**
  - Warm-up procedure: Evaporation of liquid helium (phase 1)
  - Warm-up procedure: Reduce helium pressure to 5 bara (in most circuits)
  - → Helium inventory: Reduction of helium inventory in linac from 3562kg to 139kg

    ► Released helium will be stored in storage tanks
- **Conclusion: Following the warm-up procedure, only a minor risk of losing helium remains**

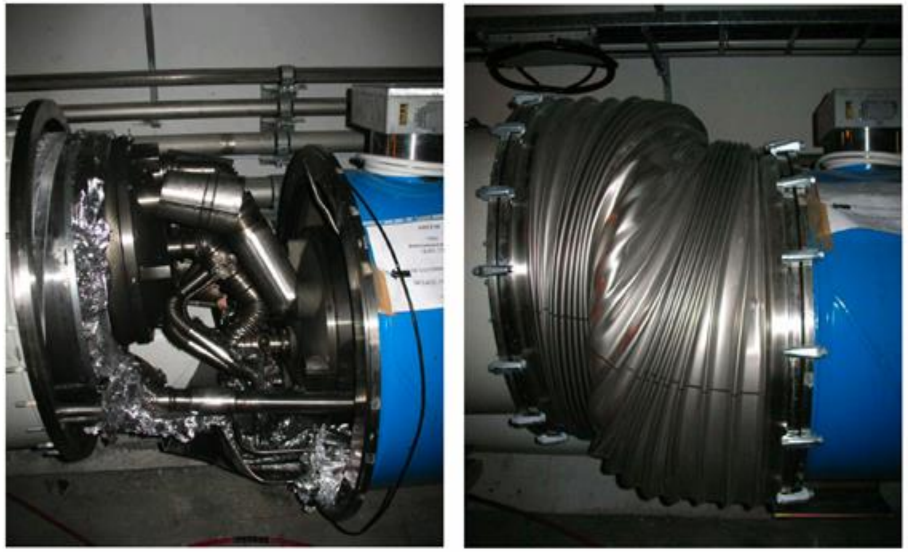
XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**

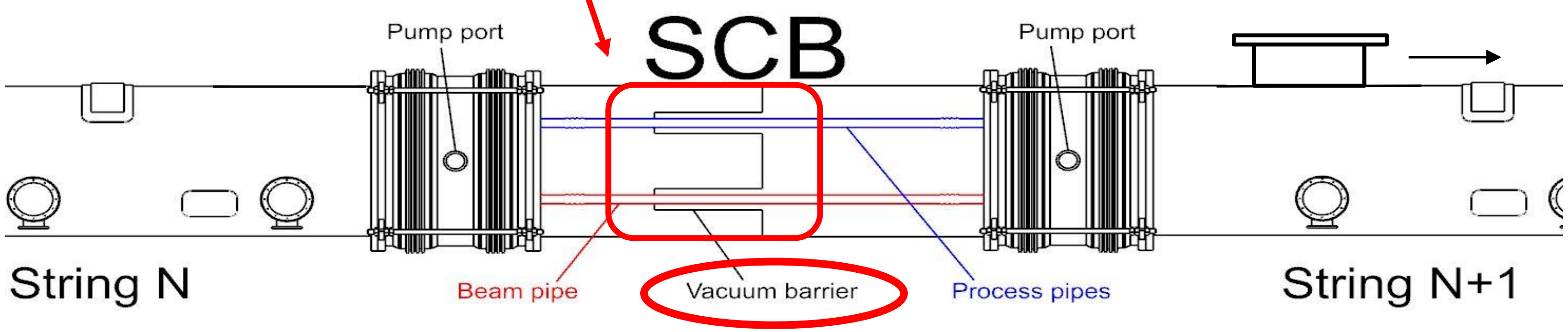


XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier

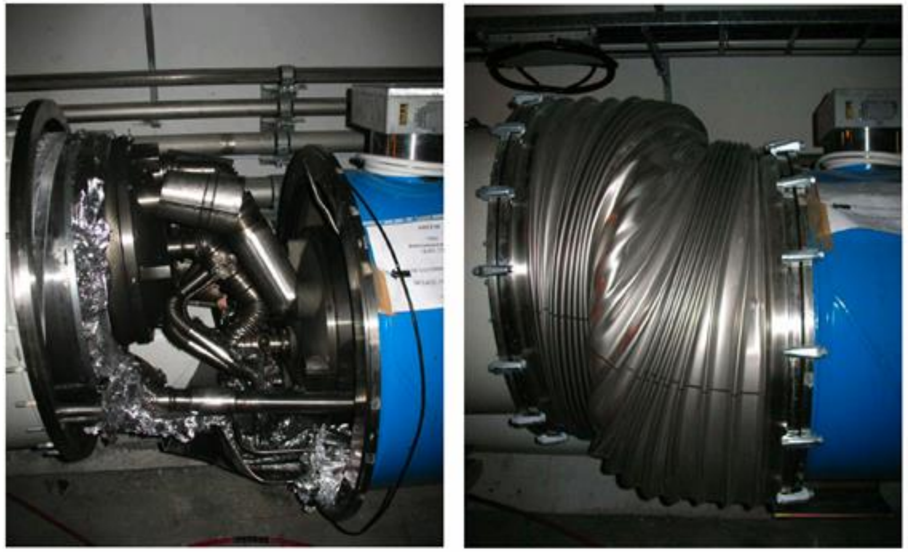


CERN

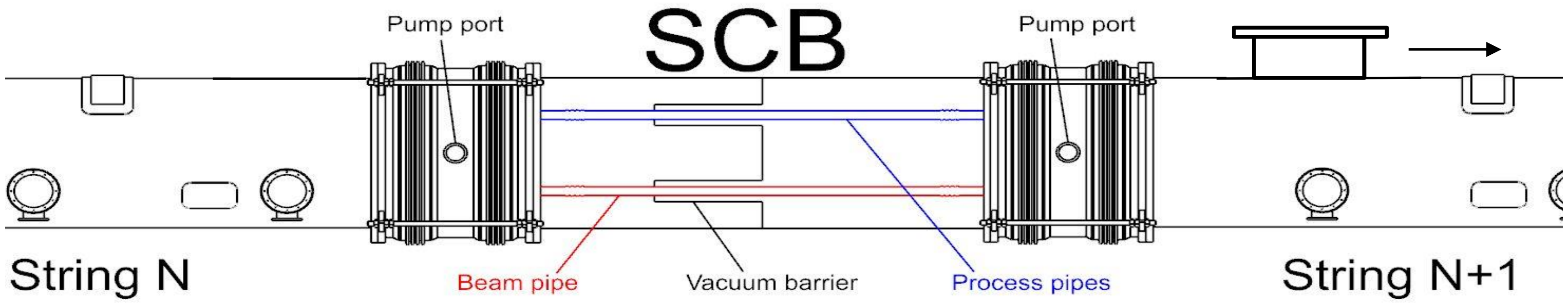


XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
  - ► Load on vacuum barrier too high: serious damage

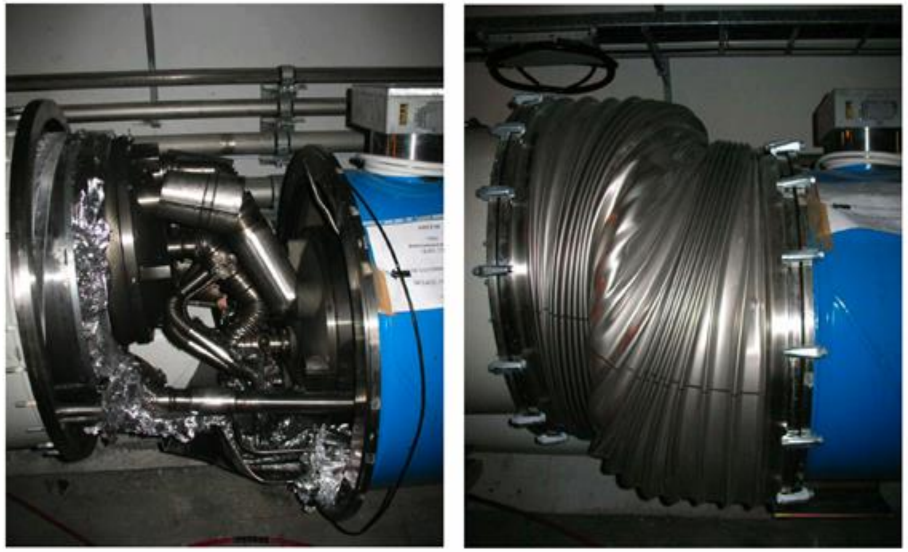


CERN

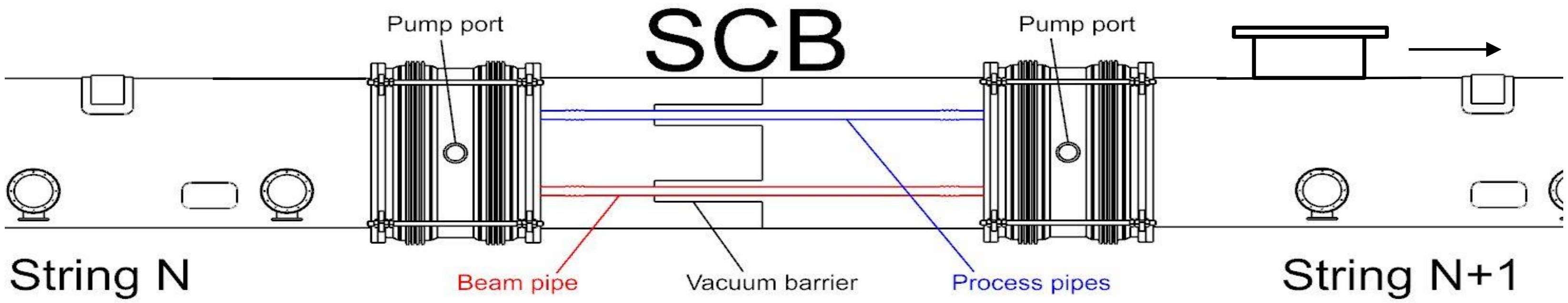


XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar

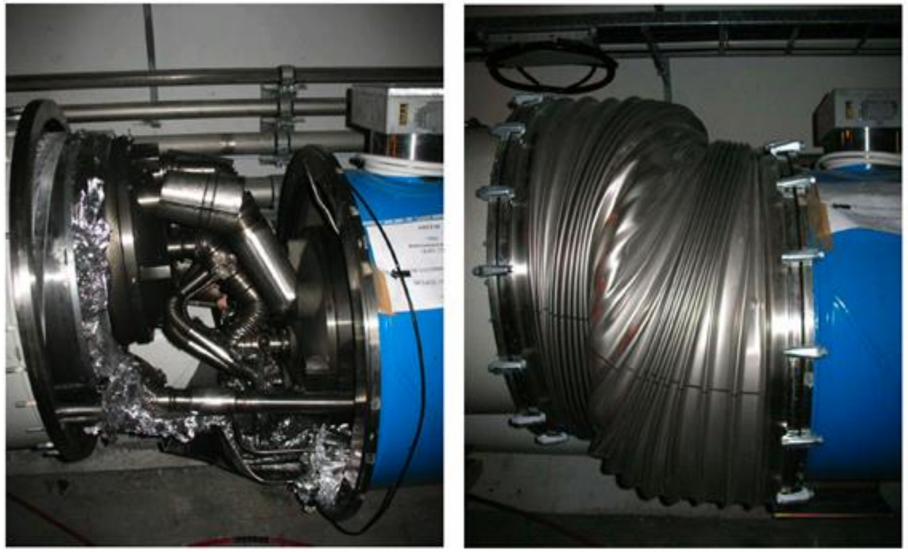


CERN



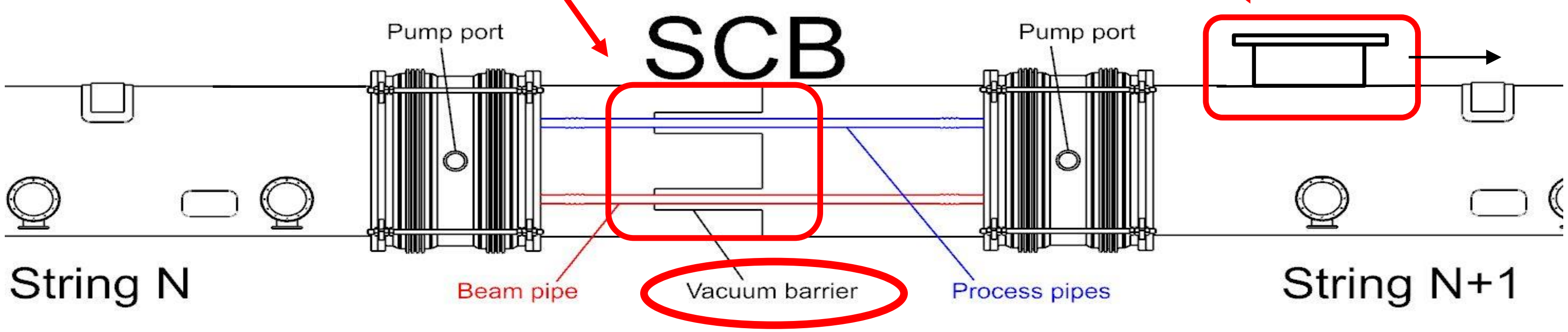
XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar



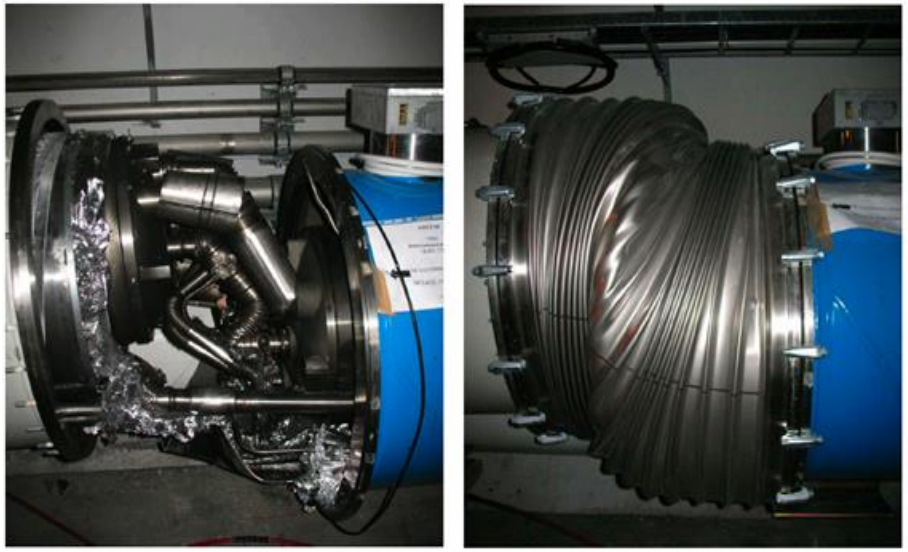
CERN

- **Provisions**:
  - **Linac design**: Vacuum barrier of CS is protected by safety flap (@ 1bara) → cold helium is released in tunnel



XFEL warm-up: Risk handling / provisions

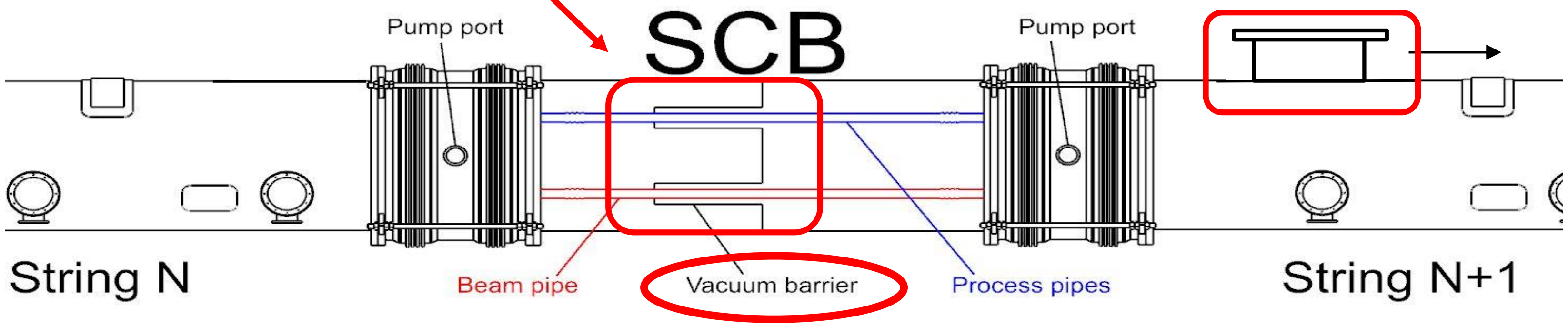
- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar



CERN

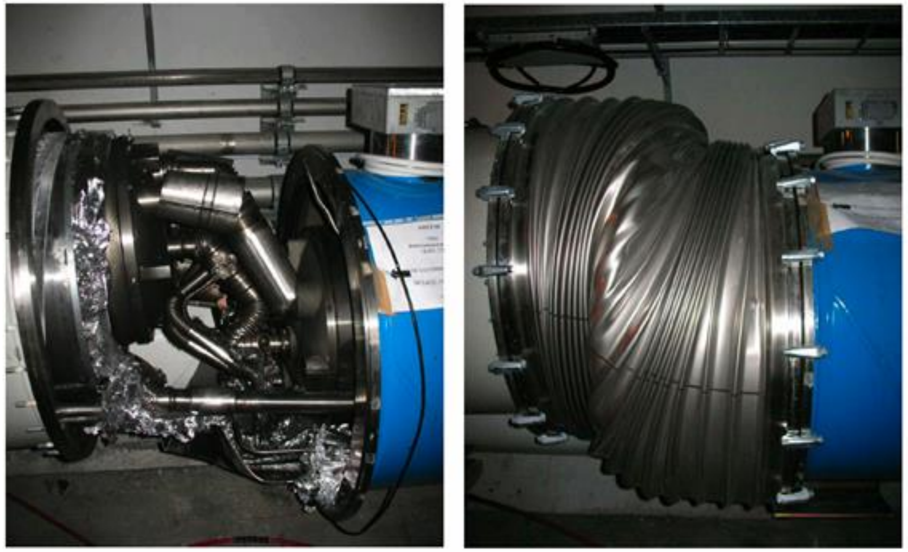
- **Provisions**:
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1bara) → cold helium is released in tunnel

    Linac design: Vacuum barriers are designed for 2 bar



XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar

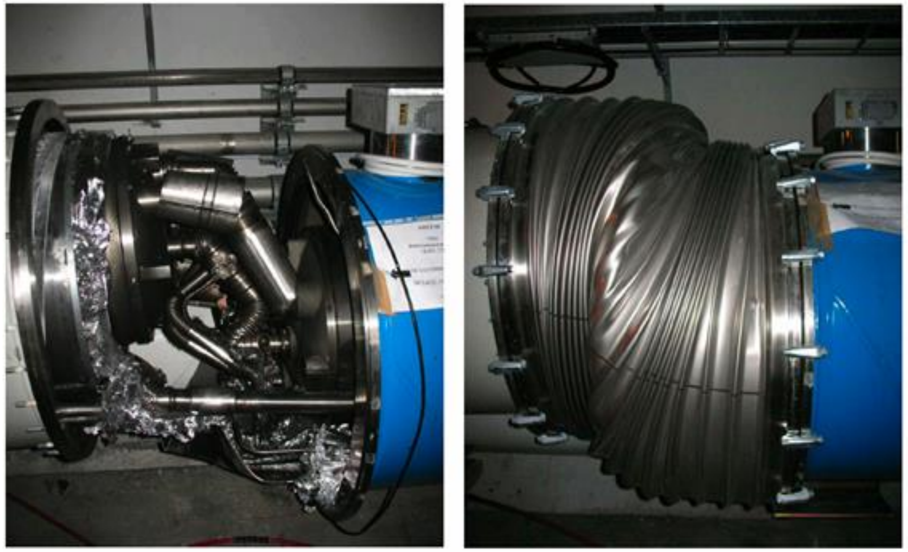


CERN

- **Provisions:**
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1 bara) → cold helium is released in tunnel
  - **Linac design**: Vacuum barriers are designed for 2 bar
    - ► No danger for vacuum barrier if Iso-vacuum of cryo string is vented

XFEL warm-up: Risk handling / provisions

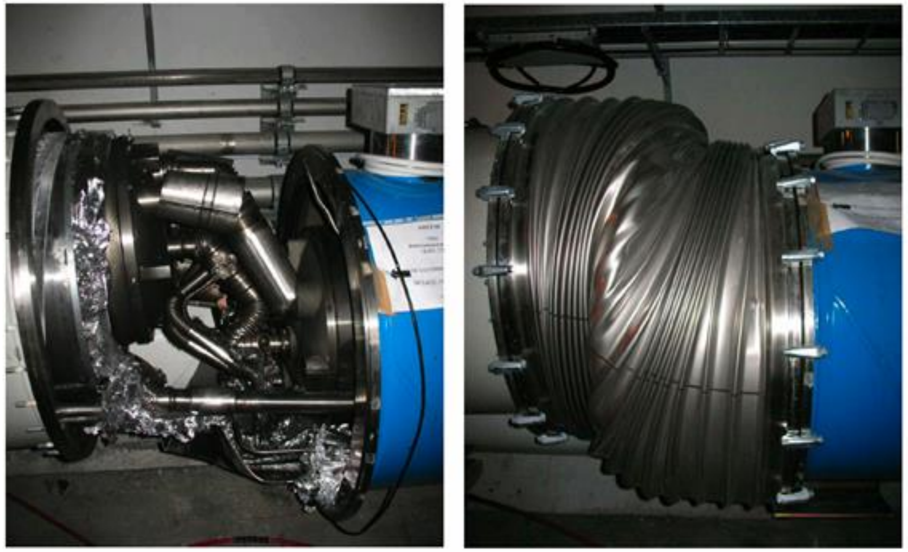
- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    ► → Load on vacuum barrier > 1 bar



CERN

- **Provisions:**
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1 bara) → cold helium is released in tunnel
    Linac design: Vacuum barriers are designed for 2 bar
    ► No danger for vacuum barrier if cryo string is vented

XFEL warm-up: Risk handling / provisions



CERN

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flooded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar
- **Provisions:**
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1 bara) → cold helium is released in tunnel
    Linac design: Vacuum barriers are designed for 2 bar
  - **Warm up procedure**: Vacuum spaces of strings might be connected during warm up
    - ► Probably no helium would enter the tunnel (no need for safety flap to open)

XFEL warm-up: Risk handling / provisions

- **Risk: Process pipe rupture within cryomodule**

  Very unlikely

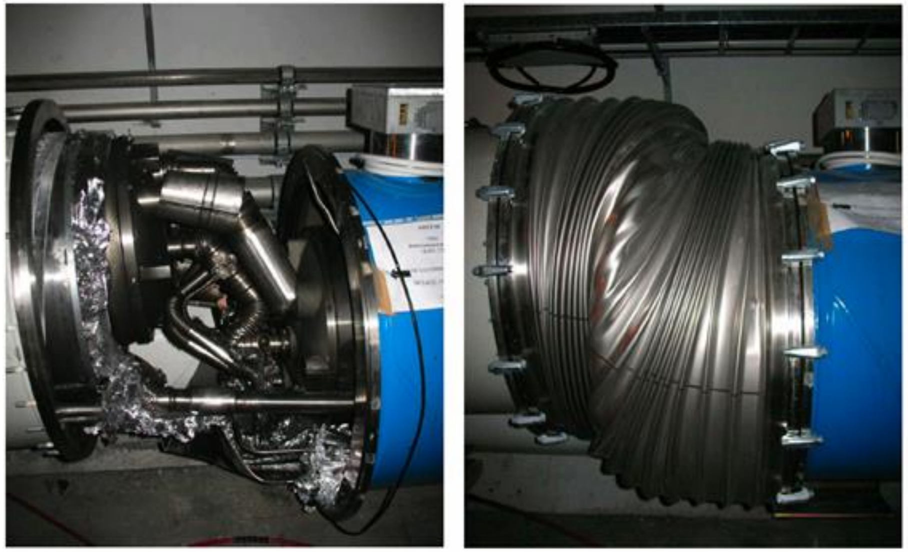
  - → High load on vacuum barrier

    ► Load on vacuum barrier too high: serious damage

  - XFEL during warm-up:

    ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar

    ► → Load on vacuum barrier > 1 bar



CERN

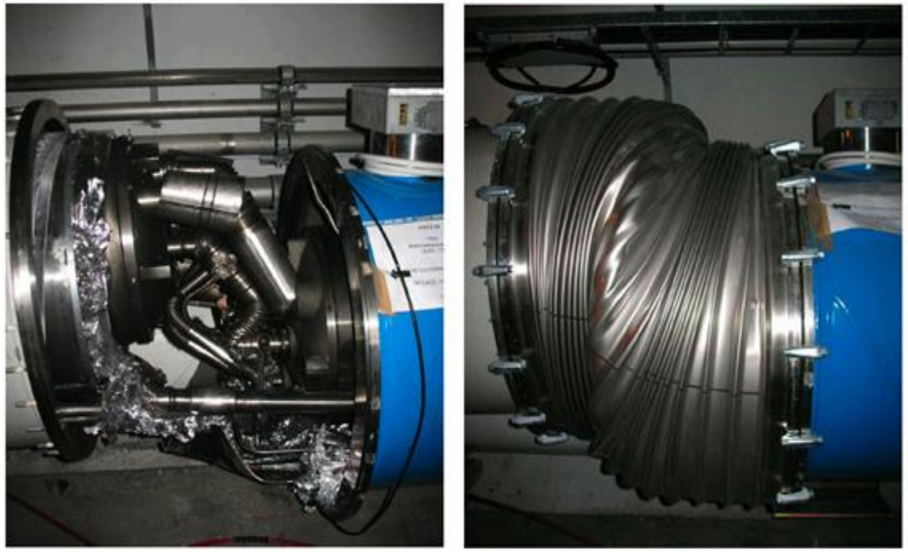
- **Provisions**:
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1 bara) → cold helium is released in tunnel

    Linac design: Vacuum barriers are designed for 2 bar
  - **Warm up procedure**: Vacuum spaces of strings might be connected during warm up

    ► Probably no helium would enter the tunnel (no need for safety flap to open)

    Might not be necessary

XFEL warm-up: Risk handling / provisions



CERN

- **Risk: Process pipe rupture within cryomodule**
  - Pressure rise in vacuum space (flouded with cold helium)
  - → High load on vacuum barrier
    - ► Load on vacuum barrier too high: serious damage
  - XFEL during warm-up:
    - ► Pipe rupture would pressurize Iso-vacuum of a cryo string > 1 bar
    - ► → Load on vacuum barrier > 1 bar
- **Provisions:**
  - Linac design: Vacuum barrier of CS is protected by safety flap (@ 1 bara) → cold helium is released in tunnel
  - Linac design: Vacuum barriers are designed for 2 bar
  - Warm up procedure: Vacuum spaces of strings might be connected during warm up
- **Conclusion: An incident like at CERN seems not to be possible**

XFEL warm up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**

XFEL warm up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**
  - So far NO LEAKS are known in the system
    - ► All modules were tested under operational conditions in test stand
    - ► No indications of leaks during cool-down
    - ► Note: Leaks are difficult to detect under cold conditions

XFEL warm up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**
  - So far NO LEAKS are known in the system
    - ► All modules were tested under operational conditions in test stand (no problems)
    - ► No indications of leaks during cool down
    - ► Note: Leaks are difficult to detect under cold conditions

- **Provision: Preparation for detection of leaks and possible additions of pump stations where needed**
  - Beam vacuum
    - ► Beam vacuum of cryo strings will be sealed by gate valves
    - ► Additional turbo pumps and leak detectors are prepared for quick reaction in case of suspicious behaviour

XFEL warm-up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**
  - So far NO LEAKS are known in the system
    - ► All modules were tested under operational conditions in test stand (no problems)
    - ► No indications of leaks during-cool down
    - ► Note: Leaks are difficult to detect under cold conditions

- **Provision: Preparation for detection of leaks and possible additions of pump stations where needed**
  - Beam vacuum
    - ► Beam vacuum of cryo strings will be sealed by gate valves
    - ► Additional turbo pumps and leak detectors are prepared for quick reaction in case of suspicious behaviour
  - Isolation vacuum
    - ► High volume pump stations are prepared, will be brought to tunnel before warm up starts and connected to vacuum sections

XFEL warm up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**
  - So far NO LEAKS are known in the system
    - ► All modules were tested under operational conditions in test stand (no problems)
    - ► No indications of leaks during cool down
    - ► Note: Leaks are difficult to detect under cold conditions

- **Provision: Preparation for detection of leaks and possible additions of pump stations where needed**
  - Beam vacuum
    - ► Beam vacuum of cryo strings will be sealed by gate valves
    - ► Additional turbo pumps and leak detectors are prepared for quick reaction in case of suspicious behaviour
  - Isolation vacuum
    - ► High volume pump stations are prepared, will be brought to tunnel before warm up starts and connected to vacuum sectors
  - Data logging during warm-up is key
    - ► Data analysis important to quickly react to potential problems

XFEL warm-up: Risk handling / provisions

- **Risk: Contamination of beam vacuum due to leaks developing during warm-up**
  - So far NO LEAKS are known in the system
    - ► All modules were tested under operational conditions in test stand (no problems)
    - ► No indications of leaks during cool down
    - ► Note: Leaks are difficult to detect under cold conditions

- **Provision: Preparation for detection of leaks and possible additions of pump stations where needed**
  - Beam vacuum
    - ► Beam vacuum of cryo strings will be sealed by gate valves
    - ► Additional turbo pumps and leak detectors are prepared for quick reaction in case of suspicious behaviour
  - Isolation vacuum
    - ► High volume pump stations are prepared, will be brought to tunnel before warm up starts and connected to vacuum sectors
  - Data logging during warm up is key
    - ► Data analysis important to quickly react to potential problems
- **Conclusion: Vacuum values will be monitored and analyzed. No reason to be concerned.**

Summary

- **The XFEL linac will be warmed up for the first time**
  - There is always a risk but the system is designed for dynamic procedures, and…
    - ► Procedures are well prepared
    - ► The cryogenic design is safe
    - ► We have longterm and adequate experience
    - ► …
  - **(Most likely) nothing spectactular will happen but having a warm XFEL linac!**

Thank you!