Twenty years of cryogenic operation of the FLASH superconducting linac

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Summary

Twenty years of cryogenic operation of the FLASH superconducting linac

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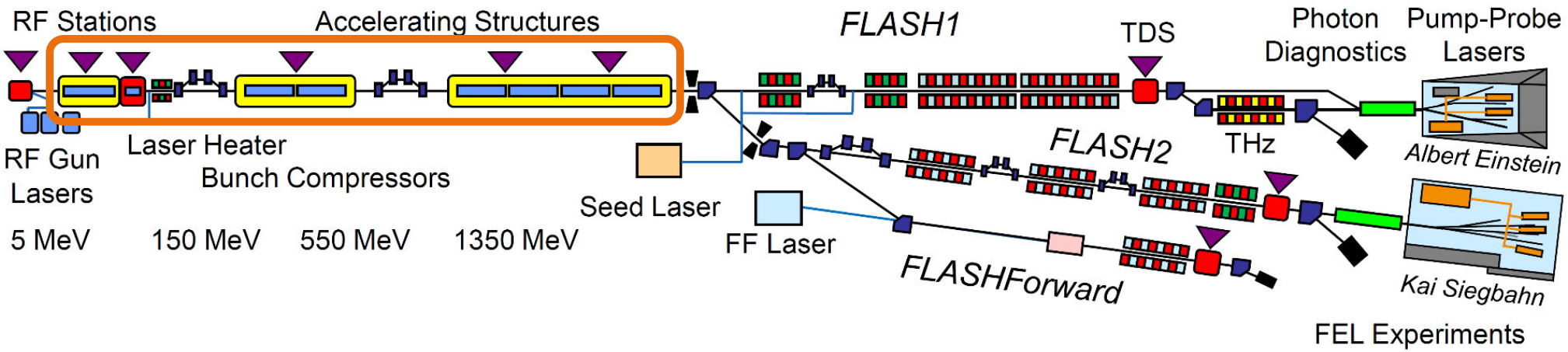
The FLASH SC linac and its cryogenic distribution

The FLASH facility

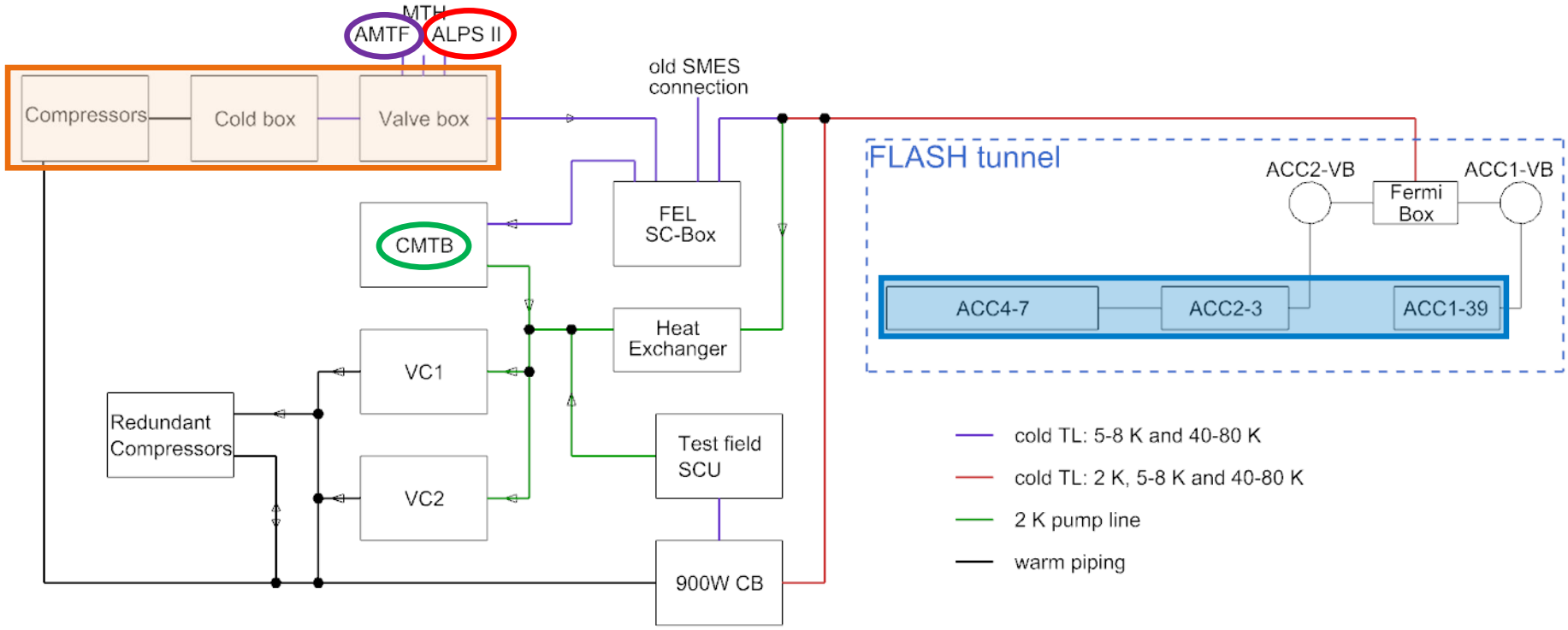
Status in 2023



FLASH cryogenic supply

In 2023

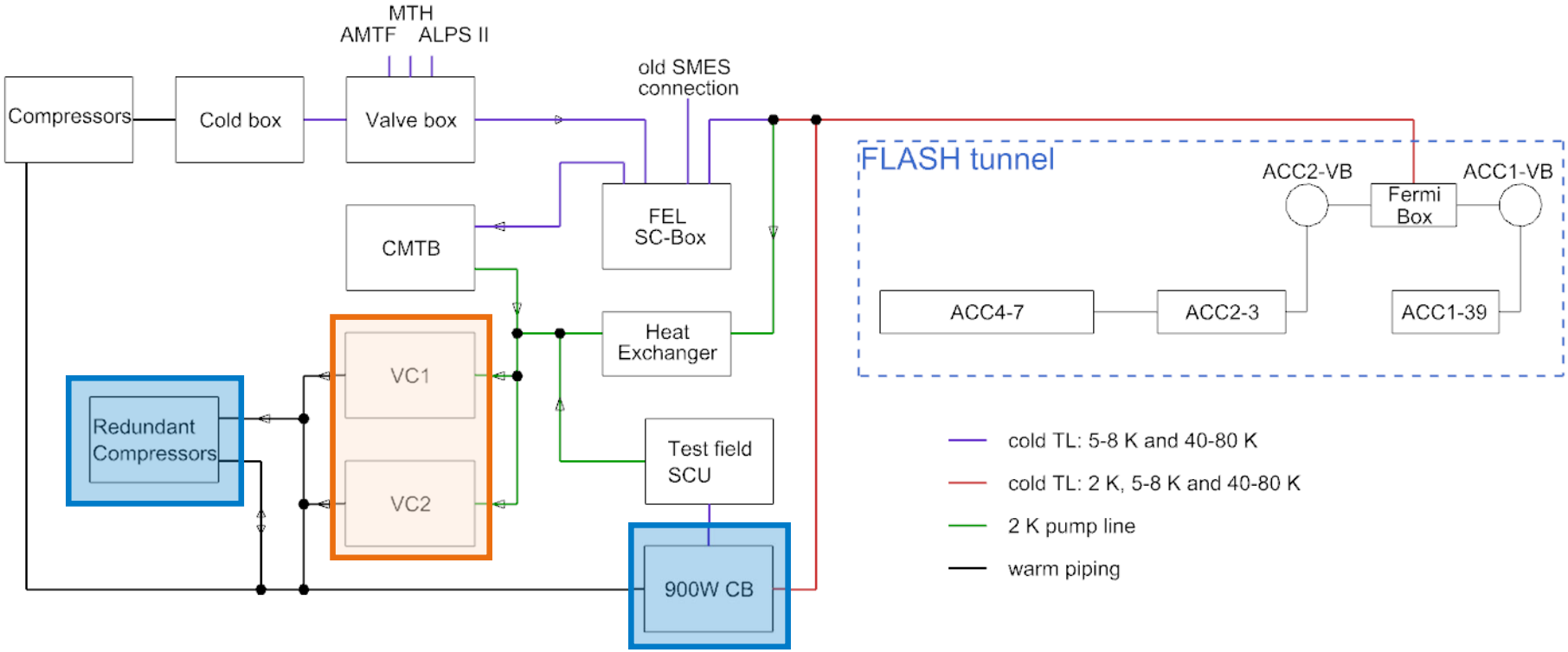
- One 3.9 GHz and seven 1.3 GHz **SC cryomodules**
- Cooled by one **former HERA cryoplant,** shared with CMTB (2006), AMTF (2010), ALPS II (2021)



FLASH cryogenic supply

In 2023

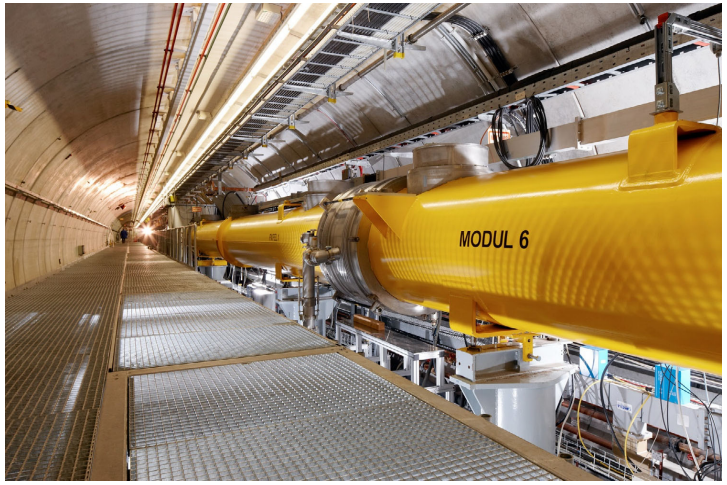
- Two parallel **warm compressors** for 2 K operation, shared with CMTB and the SCU test field (starting 2023)
- **Redundant** cryoplant and compressors available (not used in the last 15 years)

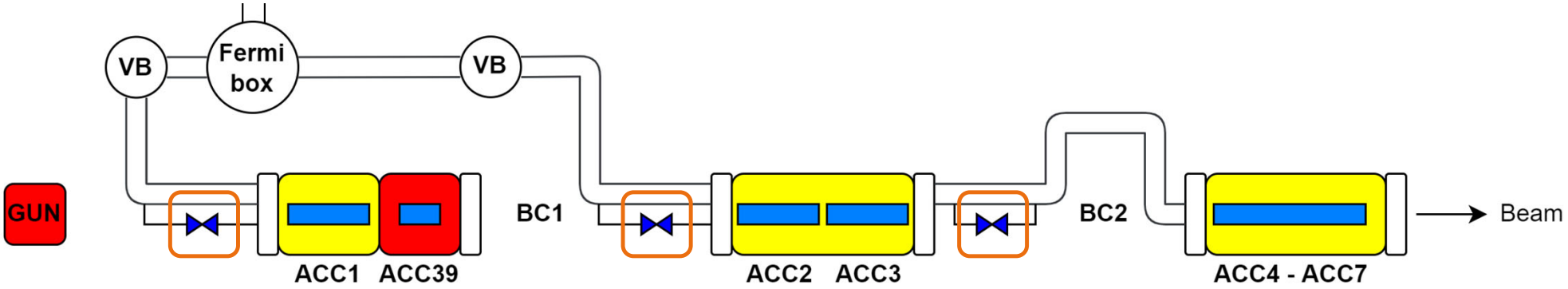


FLASH cryogenic at the linac

2023

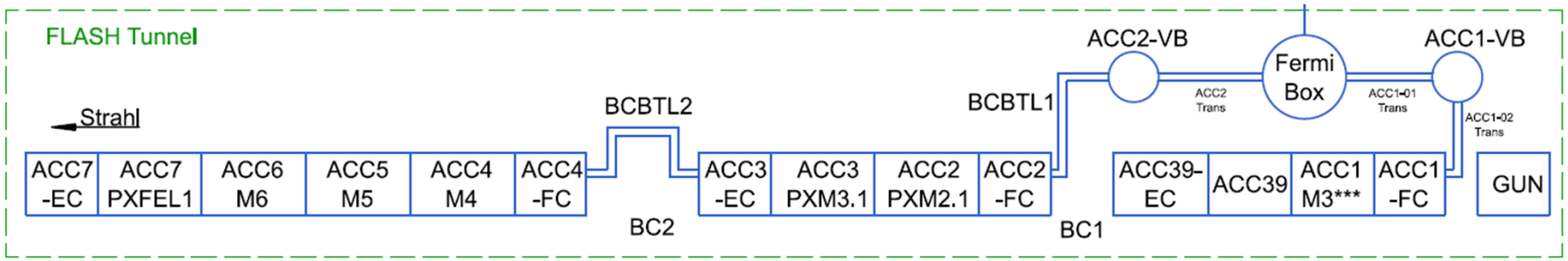
- Helium (40-80K, 5-8K) from cryoplant distributed to two branches at the Fermi-box
- 4K helium pre-cooled in the 2K heat exchanger at the Fermi-box
- Three **Joule-Thompson valves** distribute liquid helium to the three linac sections



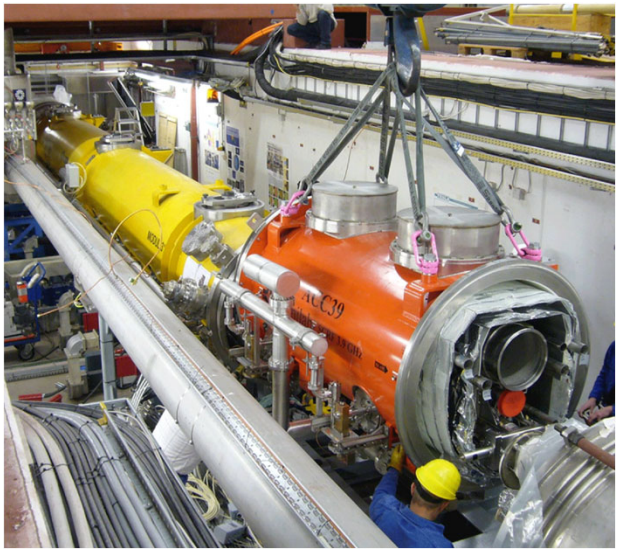


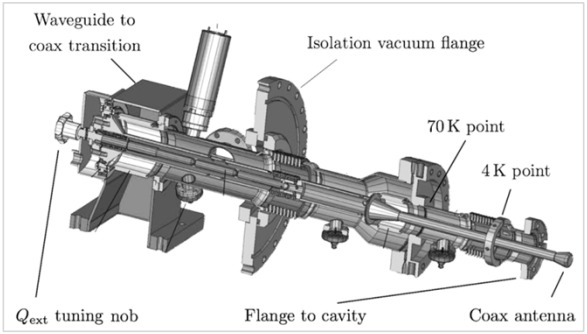
The FLASH cryomodules

In 2023



Position	Module S/N	Module type	First installation	Coupler type
ACC39	-	3.9 GHz	2009	3.9 GHz
ACC1	3***	TTF type II	2009	TTF III
ACC2	PXM2.1	XFEL prototype	2022	TTF III
ACC3	PXM3.1	XFEL prototype	2022	E-XFEL
ACC4	4	TTF type III	2003	TTF II
ACC5	5	TTF type III	2003	TTF III
ACC6	6	TTF type III	2007	TTF III
ACC7	PXFEL1	XFEL prototype	2009	TTF III

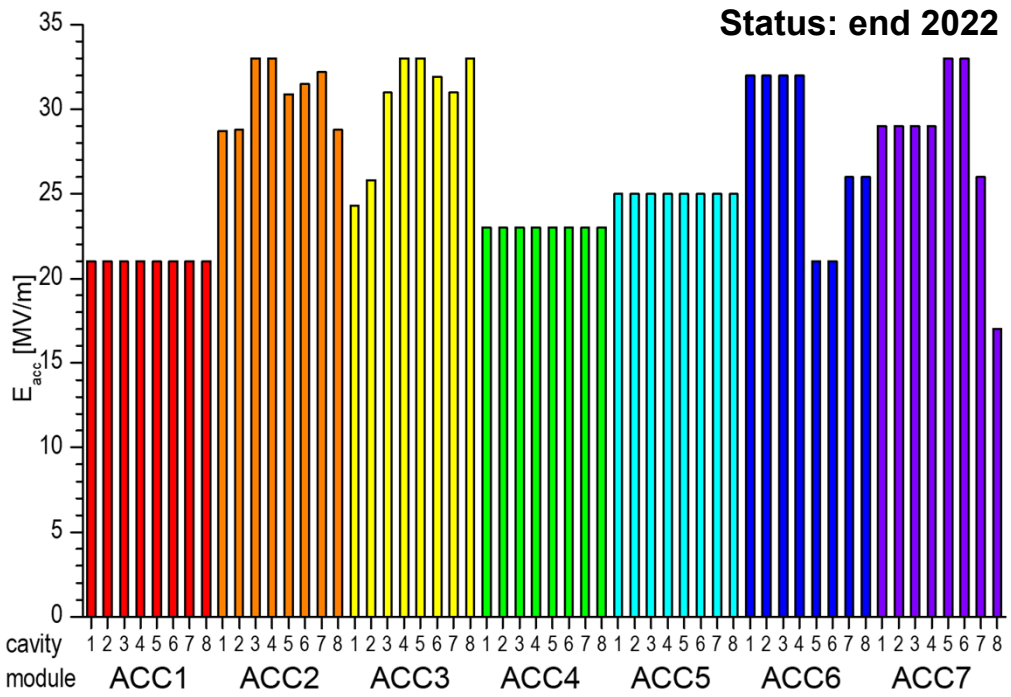




FLASH cryomodule operation

Summary of cavity performances

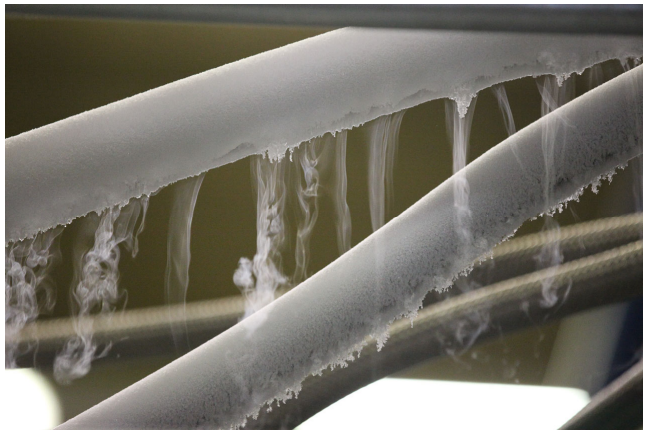
- Upgraded waveguides allow adaptation to cavity performances (optimization ongoing)
- Performance in average 84% of the expectation from vertical tests
- No gradient degradation during operation at FLASH

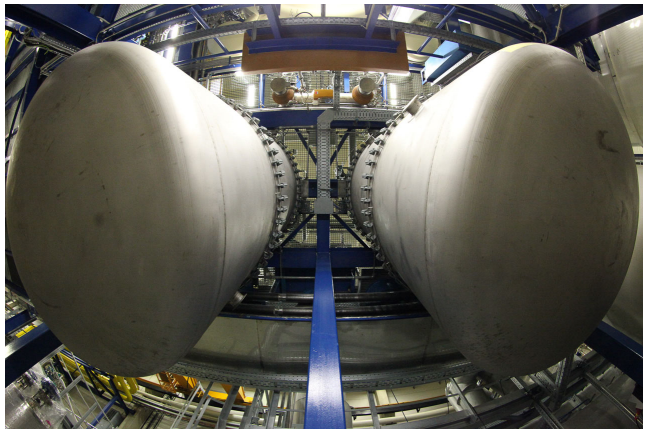
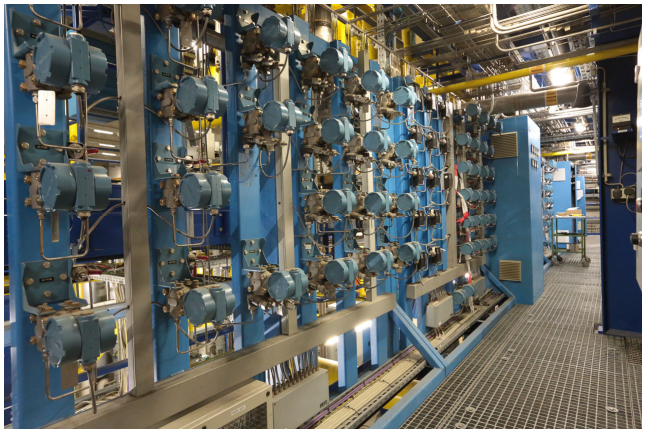


The FLASH cryoplant

FLASH cryoplant

Some impressions

FLASH cryoplant

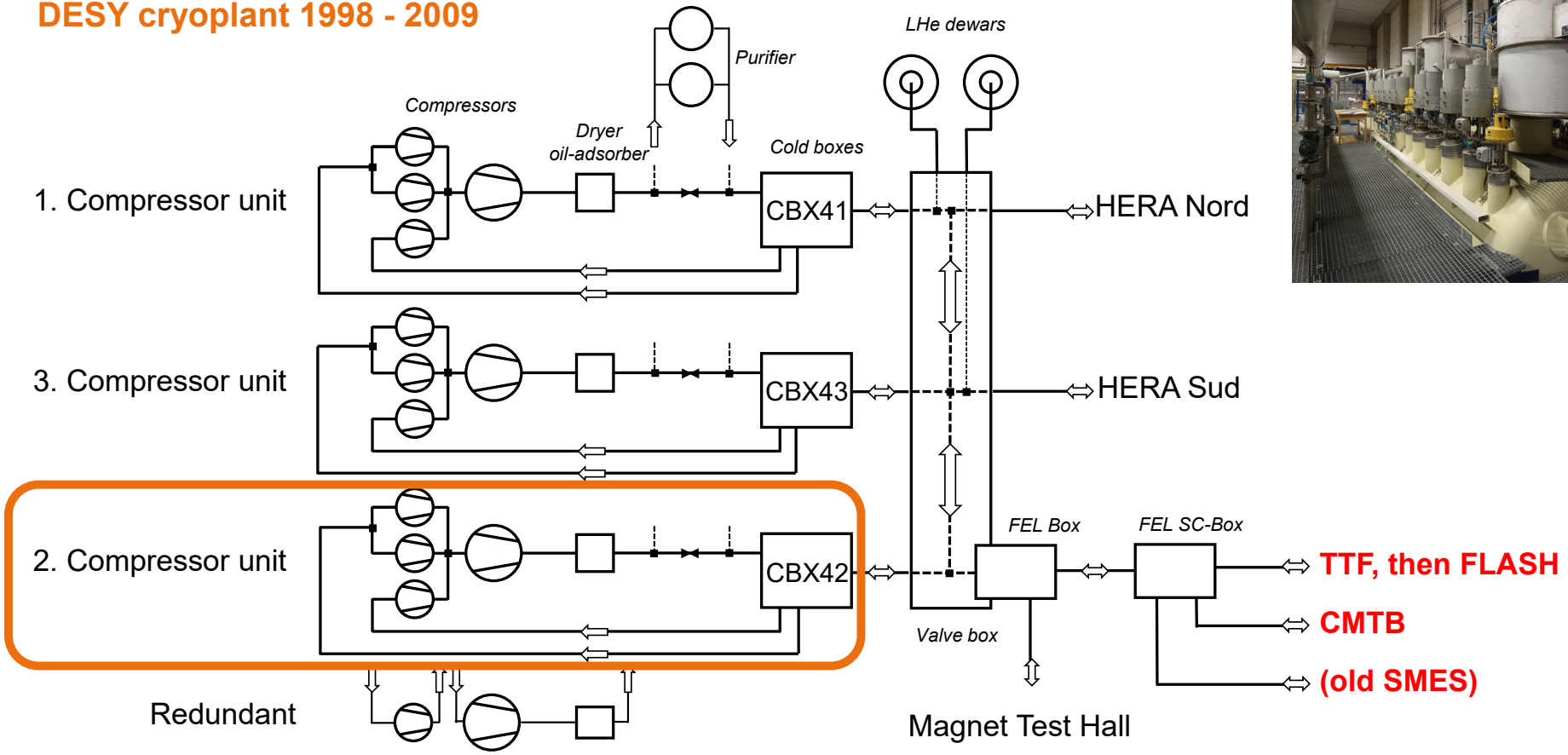
Main parameters

- The FLASH cryogenic plant, some numbers:
  - compressor power: 1.5 MW low pressure compressors, 1.7 MW high pressure compressors
  - Maximum flow: 1000 g/s at 18 bar
  - Cooling power: 20 kW at 40/80 K
    6.8 kW at 4.4 K
    20 g/s liquefying power

- Cryo capacity distributed among users
  - Parallel operation of FLASH, AMTF, CMTB, ALPSII demonstrated in 2023
    - Possible limitations during cool down and warm up of single test stands

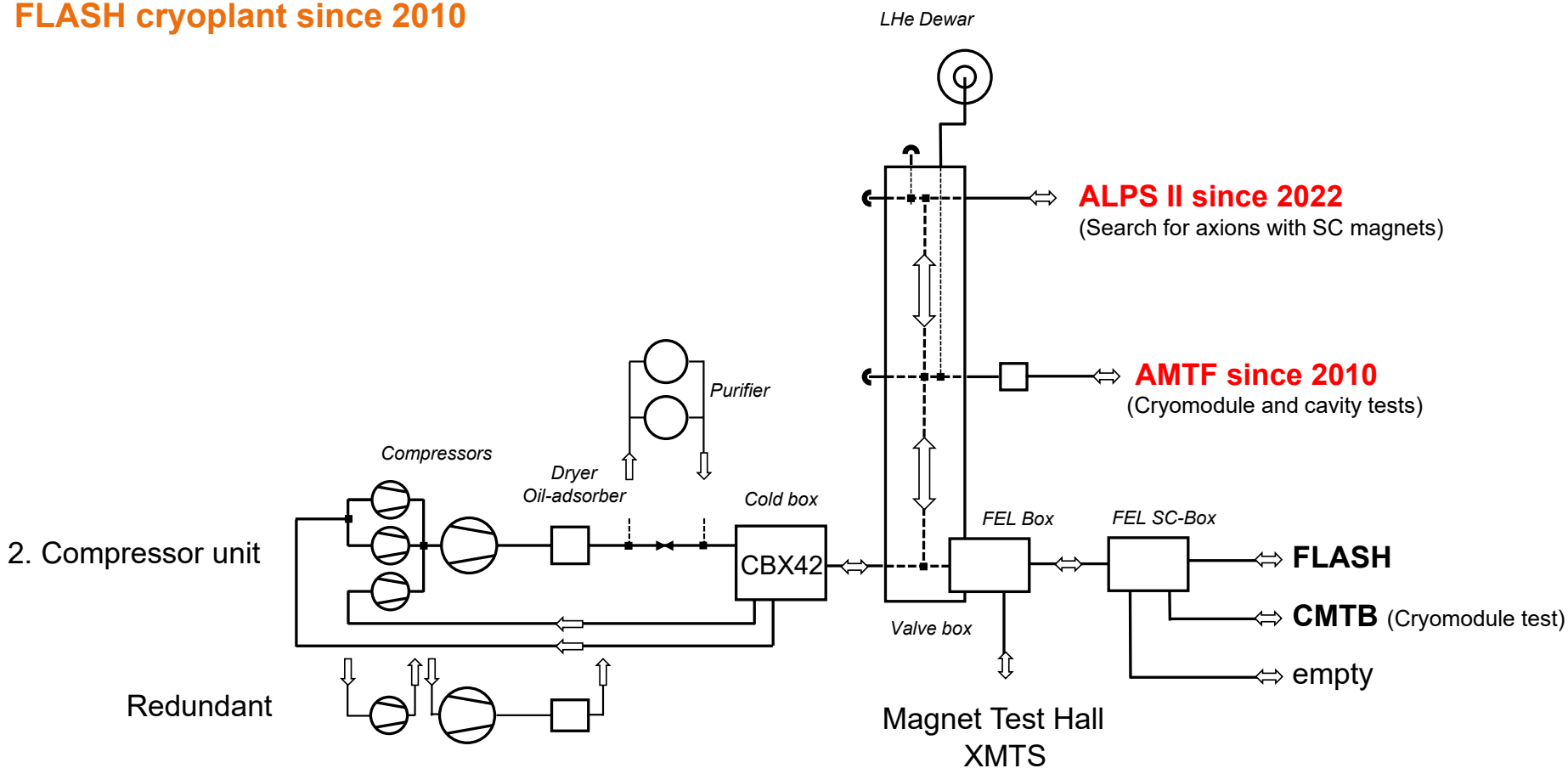
The FLASH cryoplant 1998 - 2023

DESY cryoplant 1998 - 2009



The FLASH cryoplant 1998 - 2023

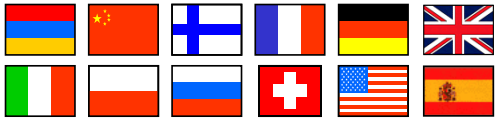
FLASH cryoplant since 2010



Evolution of the FLASH cold linac

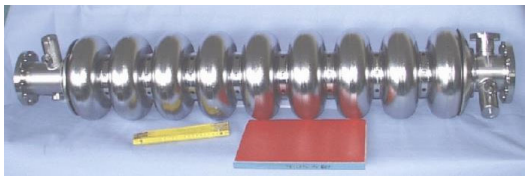
From TTF (TESLA Test Facility) to FLASH

1996



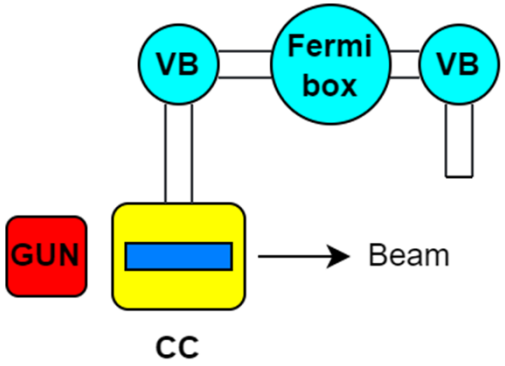
The TESLA collaboration

- Common effort of almost all laboratories using SC cavities (53 partners from 12 countries) to:
  - Increase cavity gradient from 5 to 25 MV/m
  - Reduce costs



TESLA Test Facility

- First beam tests with gun only in 1996
- First cryomodule installed 1996 with one cavity
- First test with CC and beam in 1997



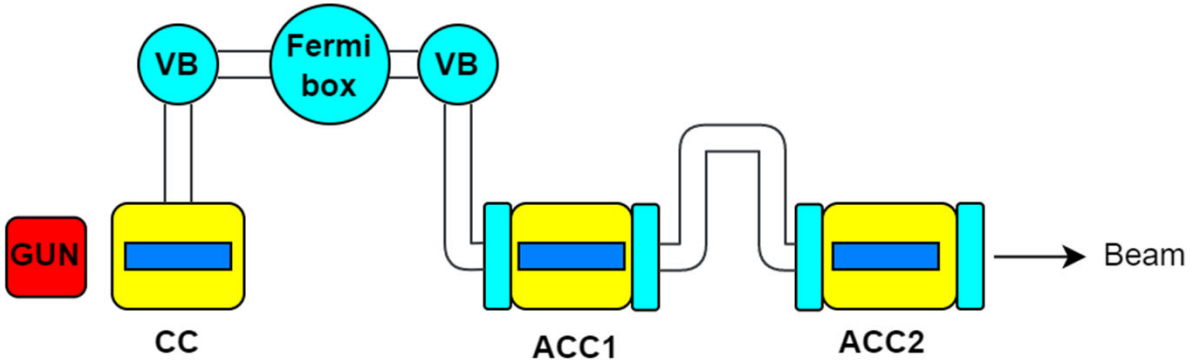
From TTF to FLASH

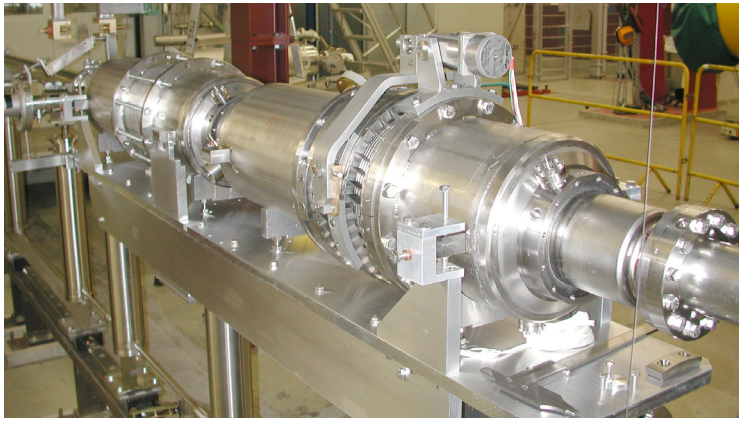
1997-2002

- First TTF type cryomodules (each with eight cavities) at position ACC1 / ACC2
- First bunch compressor, first undulator

  → **February 2000: first lasing with a SASE FEL at a VUV wavelength of 109 nm worldwide**

- In 2002: test of the Super-Structure module at ACC1, first blade tuner





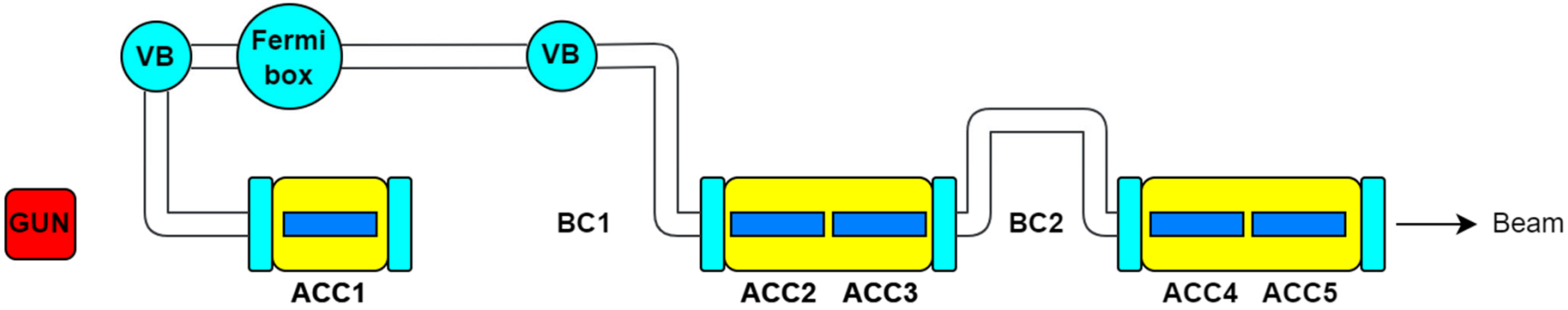
Super-Structure: 2x7-cell structures

From TTF to FLASH

2003-2005

- Refurbished (M3*) and new cryomodules M4, M5 (TTF type III modules, basis for XFEL, LCLSII, Shine, …)
- Second bunch compressor with transfer line BCBTL2
- New injector area (ACC1 moved, Module Super-Structure, ½ BCBTL1, VBs ACC1 and CC removed)

→ FLASH becomes an FEL user facility (SASE 13 nm in 4/2006)



FLASH

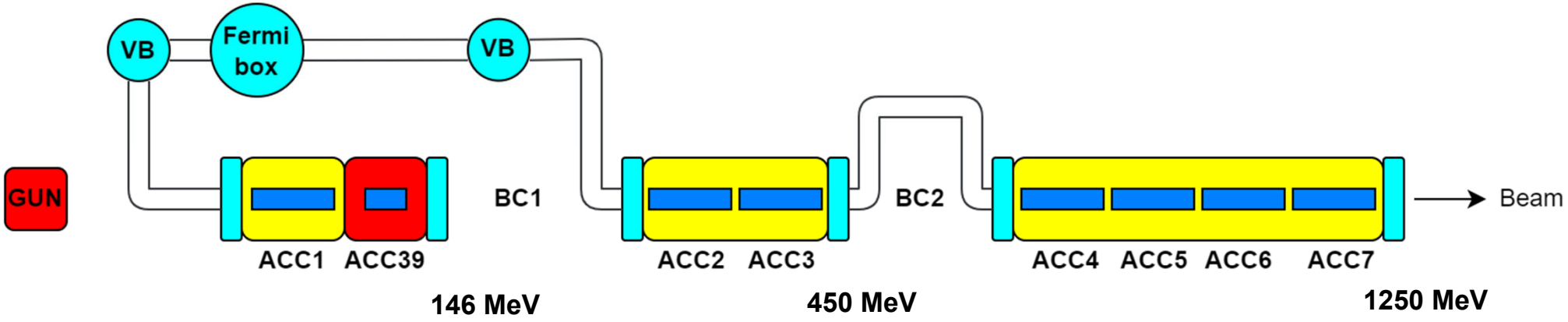
2007 and 2009 shutdowns

2007 shutdown

- Repair ACC5, replace ACC3, install ACC6
- 5 Hz, 1 to 800 bunches, 1 MHz, 500 kHz, …
  SASE: 6.5 nm

2009 shutdown

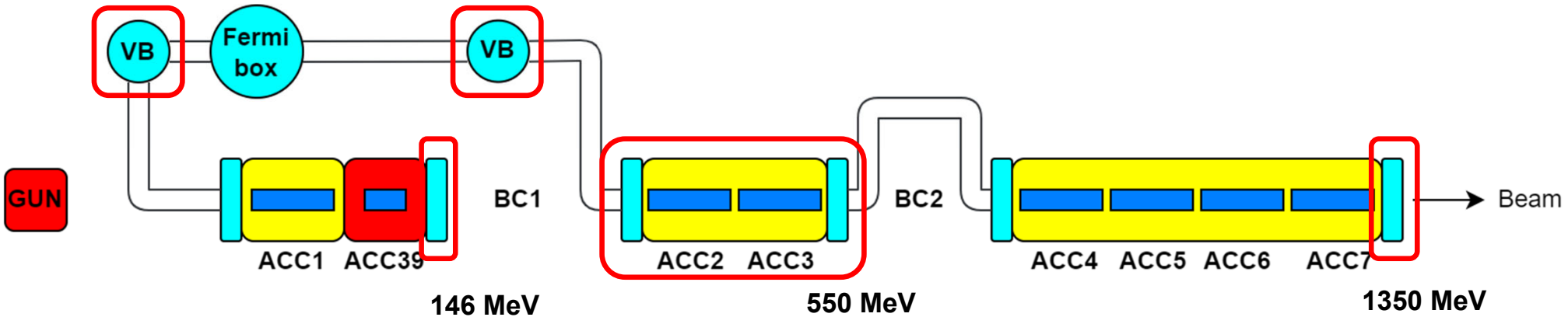
- Replace ACC1, install ACC39 and ACC7
- 10 Hz, 1 to 800 bunches, 1 MHz, 500 kHz, …
  SASE: 47 – 4.1 nm



FLASH

2022 shutdown

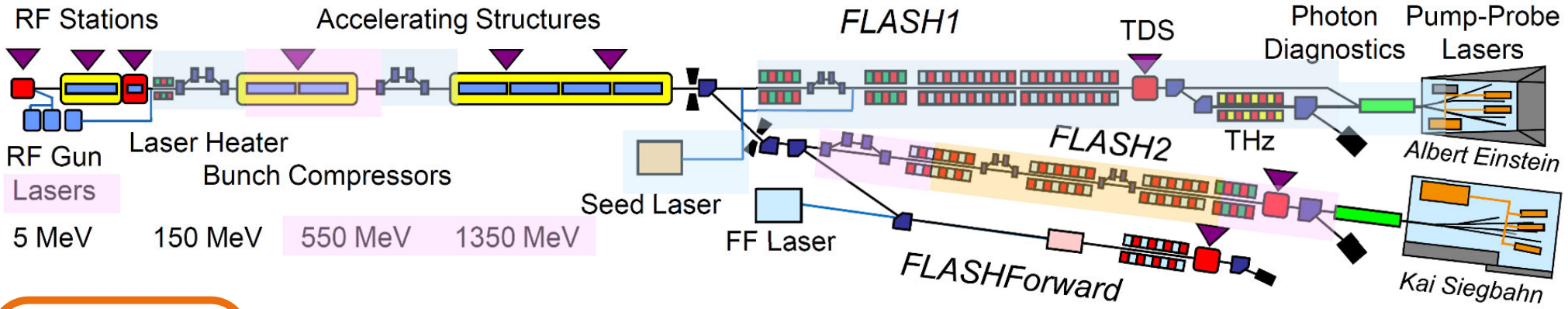
- Energy upgrade: PXM2.1 and PXM3.1 installed at ACC2-3 (1250 → 1350 MeV)



The 2022 shutdown

FLASH2020+

Towards an extraordinary XUV- and soft X-ray facility



Phase 0
Energy upgrade
3rd BC (FLASH2)
TDS (FLASH2)
Injector Laser
Afterburner FLASH2

Phase 1
Variable gap undulators (FLASH1)
Pump-probe laser (FLASH1)

Laser heater in 1st BC
New 2nd bunch compressor (BC)

Phase 1+
High rep.rate seeding (FLASH1)
Photon diagnostics (FLASH1)

Phase 2
New variable gap undulators + chicanes
for new lasing concepts (FLASH2)

- More details: see talk **TUIAA02**, M. Vogt: “FLASH 2020+ Upgrade Project”

Motivation and challenges

For the SC linac

- **Scope of the shutdown** for the SC linac: **energy upgrade 1250 → 1350 MeV**

  See poster MOPMB082

  - replace ACC2-ACC3 with 2 XFEL prototype cryomodules

    → new cryogenic connections ACC2-FC and ACC3-EC

    → new and modified valves

- **Challenge**: incomplete documentation of older components would fail regulatory requirements → **operating pressure reduced to <0.5 bar** for all pressurized components in the linac

  → test performed at FLASH before final OK

  → bigger (or more) relief valves needed, with pneumatic loading system to be independent from back pressure and have a higher reclosing pressure

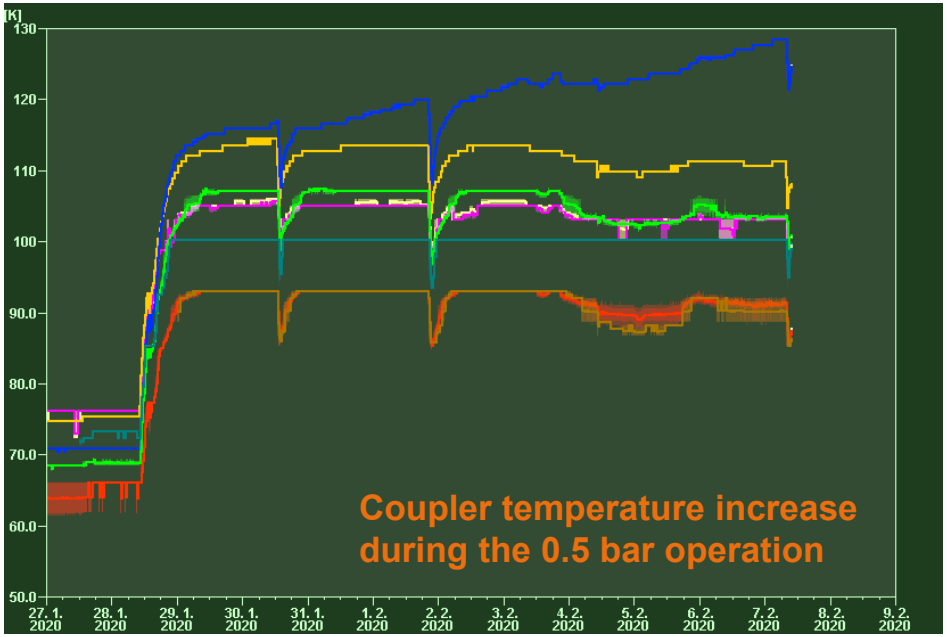
  → new venting test of a XFEL cryomodule

0.5 bar (375 Torr) operation preliminary tests

To verify feasibility

- Two tests performed:
  - Operation at 0.5 bar for 3 days with AMTF operation in parallel (incl. WU/CD)
  - Warm up and cool down test with the 0.5 bar limit → new 5K valve to speed up cool down

- Conclusions:
  - Operation within the new pressure possible
  - Temperature increase at the 40/80 K thermal shield and couplers observed, but temperature stabilised at higher T
  - Impact of RF, beam and magnet operation not critical
  - Impact of dynamic operations in AMTF / CMTB in parallel not critical



Venting test

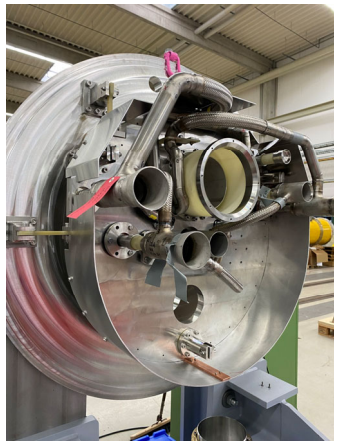
XM-3 at CMTB

- Cryomodule in cold and stable state, all supply valves closed → open isolation vacuum pump port at the cryomodule
- From pressure rise in the piping we calculate the heat flux to the single circuit (parameter needed to size the relief components)
- Further consequence: size of pump ports reduced from DN100 to DN80

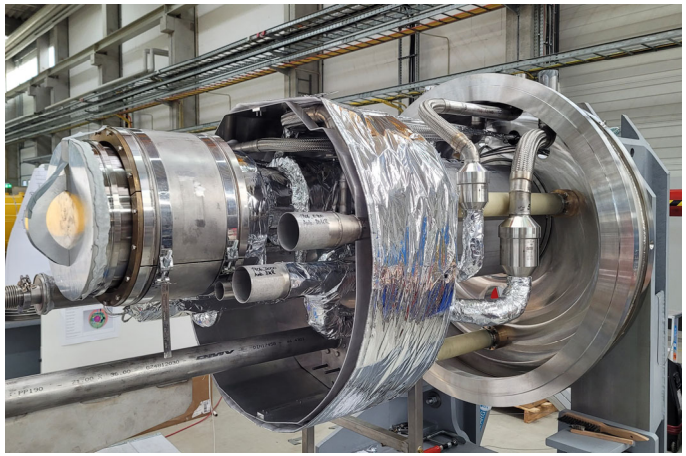
(Further details to be published soon)

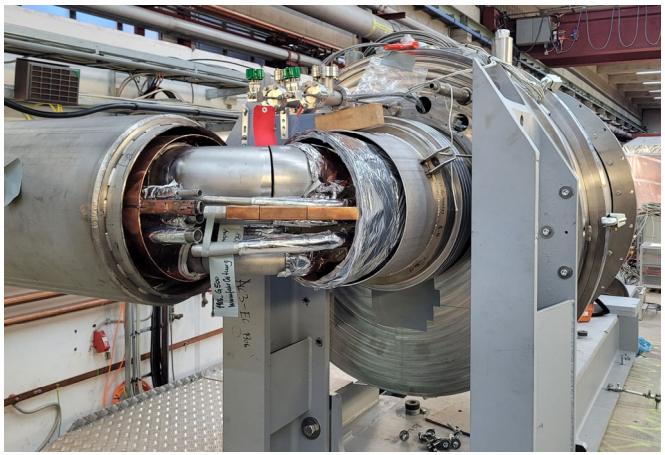
Overview of the cryogenic activities

Some impressions





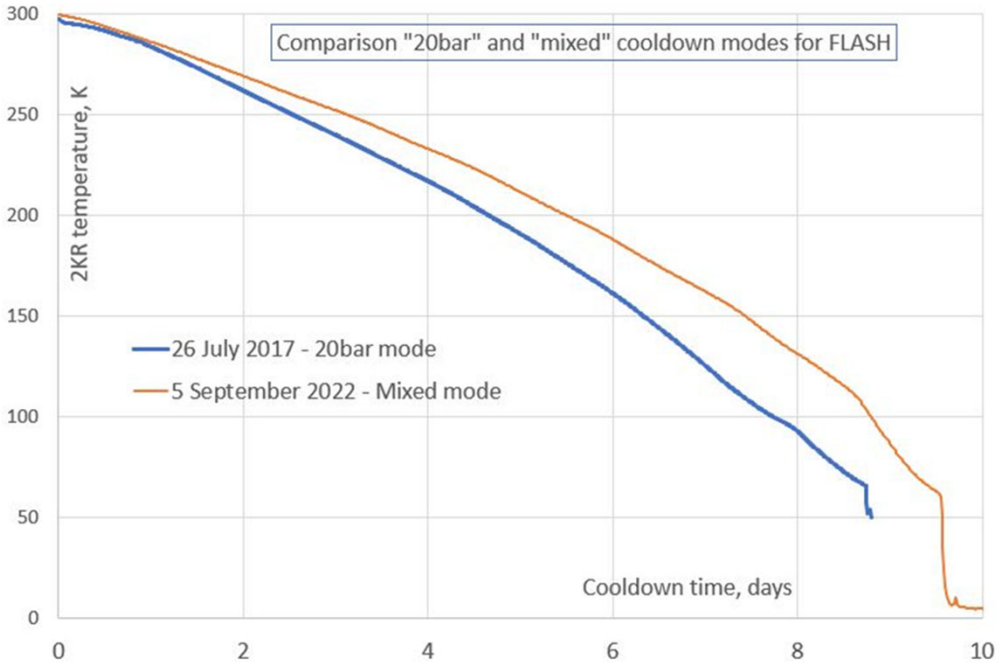


Operation overview

Cooling cycles and cool down with new configuration

One valve added after CD test

- Since 2002, FLASH has seen 9 cool-downs and 8 warm-ups
- Average cool-down/warm-up time (to 4 K): ~10 days each
- Expected a slightly longer cool down with 0.5 bar operation, but no substantial difference in cool down duration observed
  - Some issues with mixing warm gas and cold gas in the 4 K forward line → more practice needed!
  - FEL sub-cooler box in 2017 already cold, in 2022 cooldown together with FLASH



One year of 0.5 bar operation

First “impressions”

- The system is more sensitive to disturbances
  - A faster reaction time is needed
- It is easier to loose precious (!) helium in case of outages (relief valves open at 0.5 bar)
- Recovery after an outage takes longer, more caution needed to avoid opening relief valves
- The system is more sensitive to changes in parallel systems (AMTF / ALPS II / CMTB)
  - More caution needed during parallel operation and transient operations

Static heat loads

2K and 40/80K static heat loads

- Calculated during operation as flow × delta enthalpy
  - Enthalpy for the 2K evaporated helium: constant temp 2K, and pressure 31 mbar (23 Torr)
- Average 2K static heat load 30 W, 40/80 K static heat load ~1 kW
- No reliable data for the 5/8 K circuit (liquid in the pipes, no known quality)

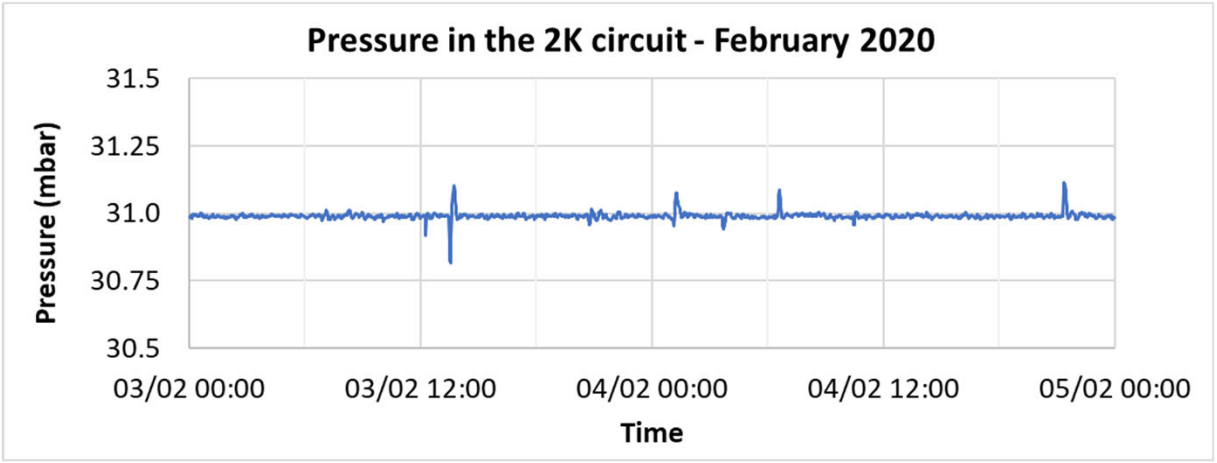
40/80 K static heat loads				
Time	*RF energy (GeV)*	*P (bar)*	*Flow (g/s)*	*Heat load (W)*
12/2018	0	11.8	15.4	796
12/2019	0	12.3	24.8	799
12/2020	0	12.8	16.8	888
12/2022	0	1.4	4.9	889
04/2023	0	1.4	8.9	1111

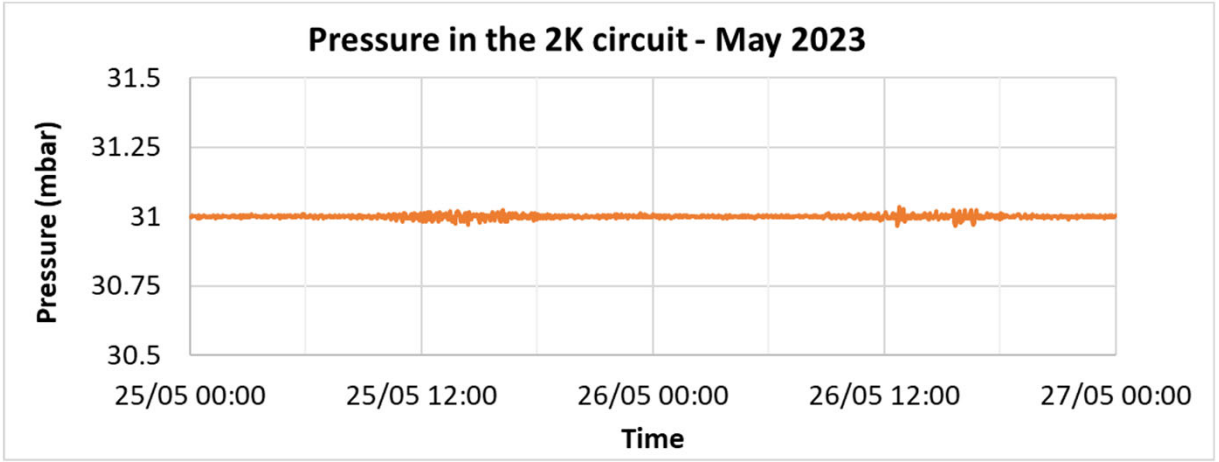
2 K static heat loads			
Time	*RF energy (GeV)*	*P (bar)*	*Heat load (W)*
12/2018	0	1.6	23
12/2019	0	1.6	35
12/2020	0	1.6	26
12/2022	0	1.4	28
04/2023	0	1.4	33

Pressure stability

Now and then

- Average pressure stability better than 0.1 mbar (75 mTorr)
- Values not affected by 0.5 bar operation

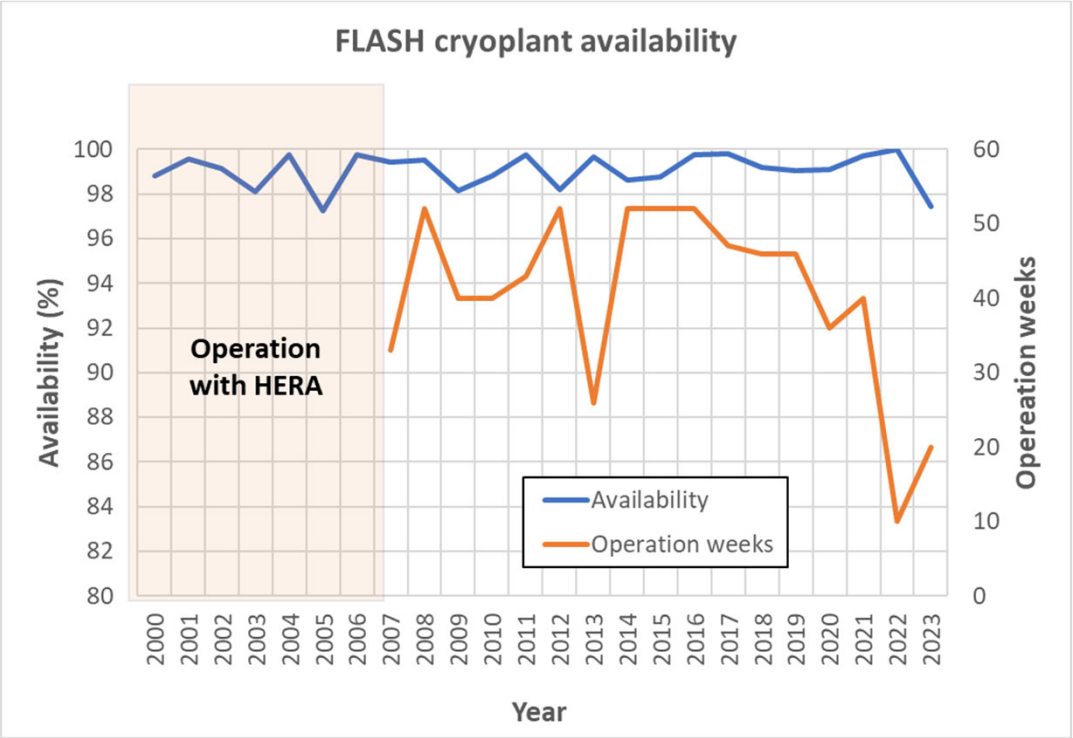




Cryoplant availability

Since 2000

- Average availability during operation 99%
  - includes HERA till 04.2007
  - Longer shutdowns not included
- Does not correspond to cryo-downtime of FLASH
  - does not include machine set-up time
- Typical sources of downtime:
  - Power supply
  - Cooling water
  - Compressors



Conclusions

Conclusions

From TTF to FLASH2020+

FLASH linac

- FLASH is an FEL user facility since 2005
- The FLASH linac is in continuous development
- The linac has been a test bench for many accelerator components that are now considered “standard” and is the basis for XFEL modules (and LCLS II, Shine, …):
  - TTF-like cavities and couplers
  - Tuning systems
  - HOM couplers, BPMs, magnetic shielding, …

Outlook

- Major shutdown of the warm section starts in summer 2024
  - The cold linac will be warmed up, no work on the cold linac expected

Thanks

to all the colleagues who helped for this presentation

AND

to all the colleagues who made FLASH possible (the list is too long for this page)

And thank you
for your attention!

Contact

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