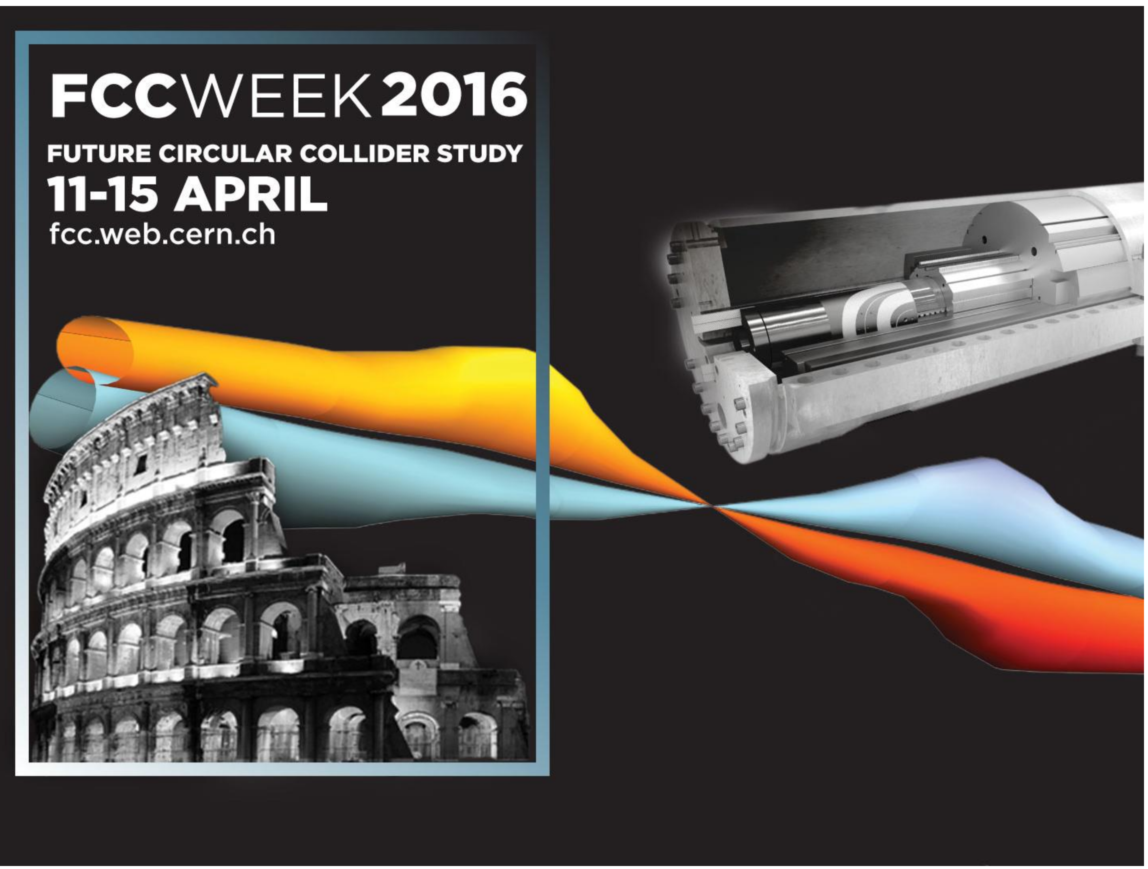
FCC Week 2016, Roma

Cryogenics overview



Laurent Tavian,
CERN, ATS-DO

On behalf of the FCC cryogenics study collaboration

14 April 2016

Content

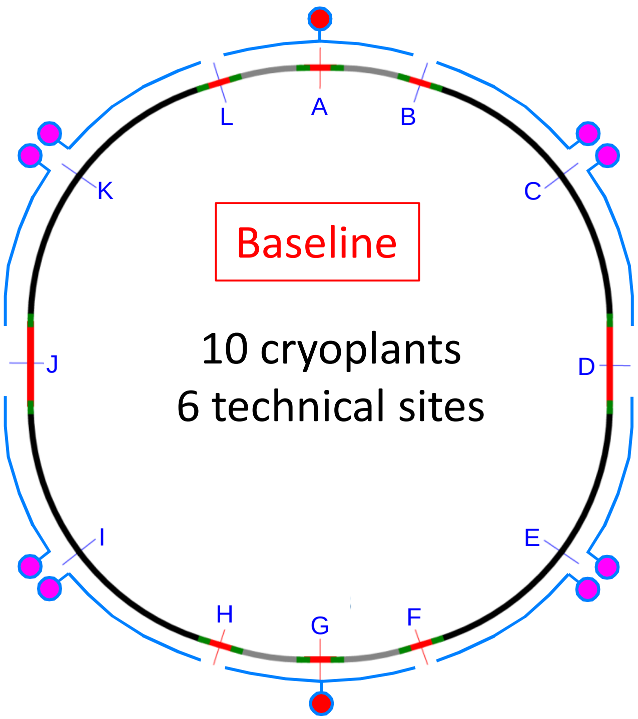
- Introduction: FCC cryogenic study organization
- FCC-hh cryogenics overview
- FCC-ee cryogenics overview
- Conclusion

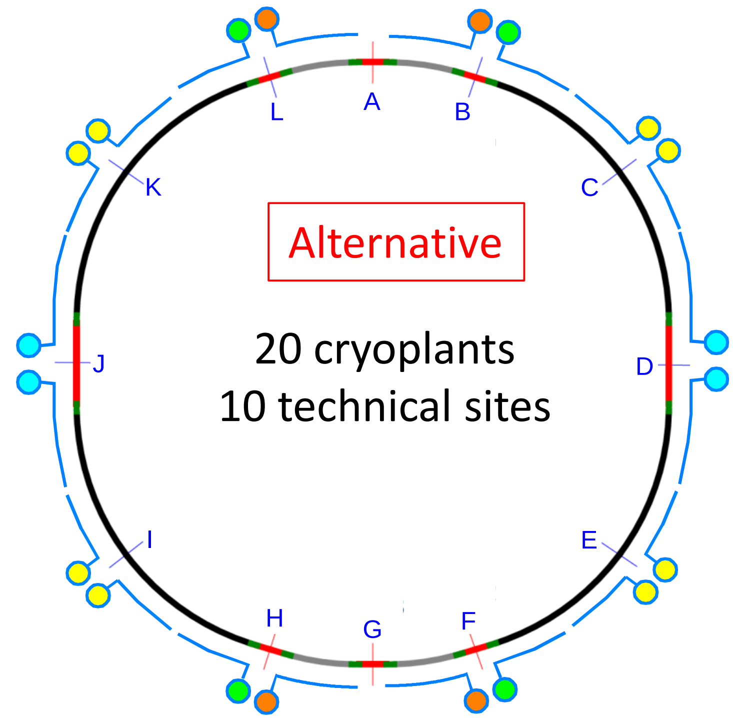
FCC cryogenics studies

- **FCC Cryogenics Studies**
  - **Cryoplants** (~50-100 kW @ 4.5 K including 10 kW @ 1.8 K)
    - **Ne-He cycle for refrigeration above 40 K** — TU-Dresden
      - MoU and addendum signed
      - New addendum under discussion
    - **Innovative He cycle** — CEA Grenoble
      - MoU signed
      - Addendum 1 signed
      - Addendum 2 signed*
  - **Cooling scheme and cryo-distribution** — PhD student, C. Kotnig
    - In steady-state
  - **Specific studies (CD, WU, Transients…)** — Fellow, H. Correia Rodrigues
    - In steady-state
  - **Design pressure impact on heat inleaks** — Wroclaw-TU
    - MoU signed
    - Addendum signed*

*: New w/r to Washington

FCC-hh (100 km) cryogenic layout





Cryoplant	40-60 K [kW]	1.9 K [kW]	40-300 K [g/s]
	592	11	85
	616	12	85

Without operational margin !

Cryoplant	40-60 K [kW]	1.9 K [kW]	40-300 K [g/s]
	296	5.7	43
	325	6.2	43
	293	5.6	43
	331	6.4	43

FCC-hh refrigeration capacity

Temperature level	Cooling circuit	Capacity / Sector	Dynamic range
40-60 K	Beam screen	530 kW	~6
	Thermal shield	90 kW	
40-300 K	Current lead	85 g/s	~2
1.9 K (4.2 K ?)	Cold-mass	12 kW	~3

- Large cooling capacity required above 40 K → new for particle accelerators
- Large dynamic range required above 40 K (factor ~6) → new for particle accelerators
→ Special effort to develop an efficient and flexible 300-40 K refrigeration cycle (see contributions of TU Dresden and CEA Grenoble/SBT).

- Large cooling capacity at 1.9 K (factor 5 w/r to LHC)
→ Special effort to develop large and efficient 1.8-K refrigeration cycle (see contributions of CEA Grenoble/SBT).

FCC-hh cryoplant architecture

300-40 K cryoplant

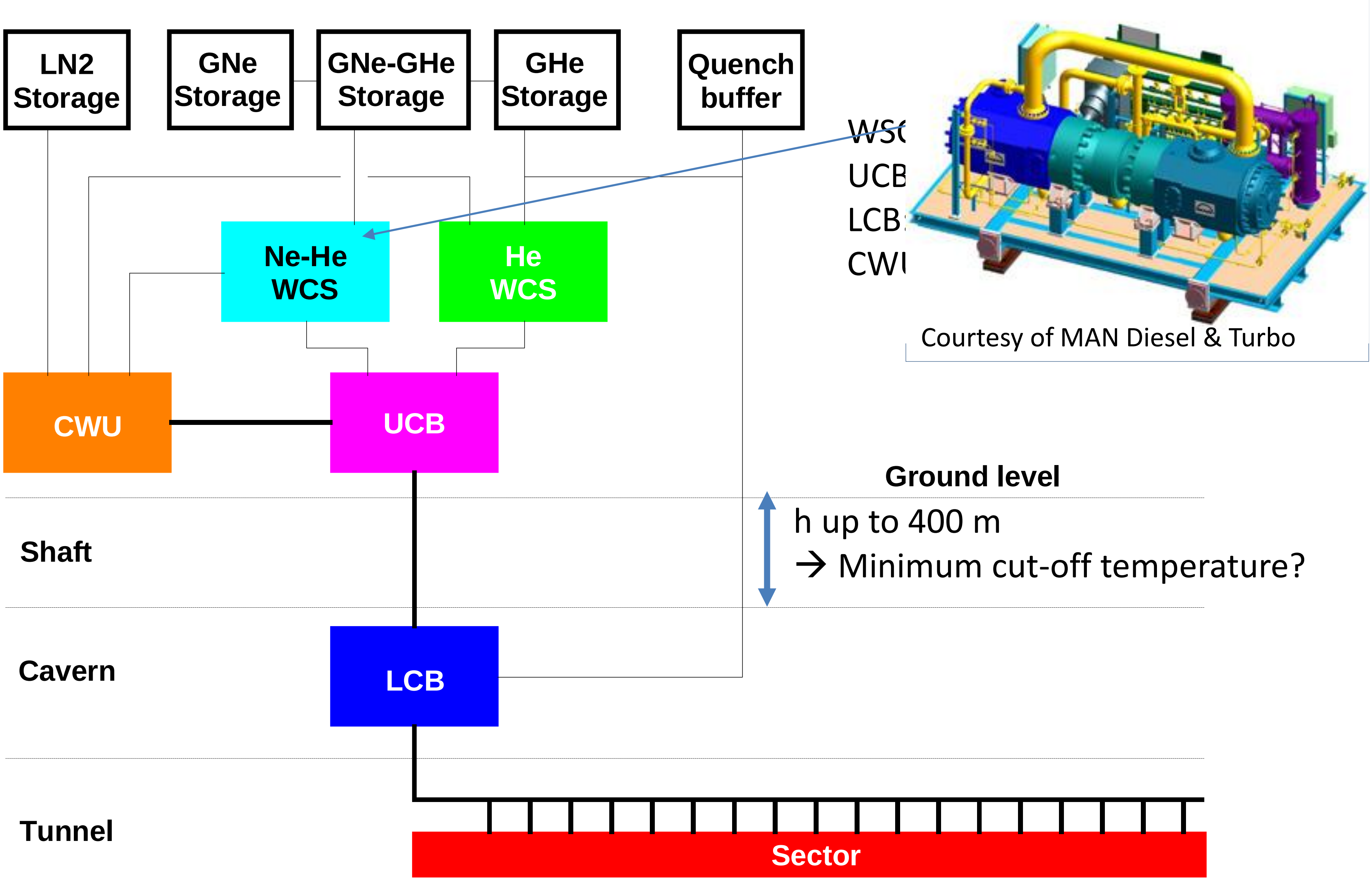
- Beam screen (40-60 K)
- Thermal shield (40-60 K)
- Current leads (40-300 K)
- Precooling of 1.9 K cryoplant

1.9 K cryoplant

- SC magnet cold mass

Contributions of TU Dresden and CEA/SBT

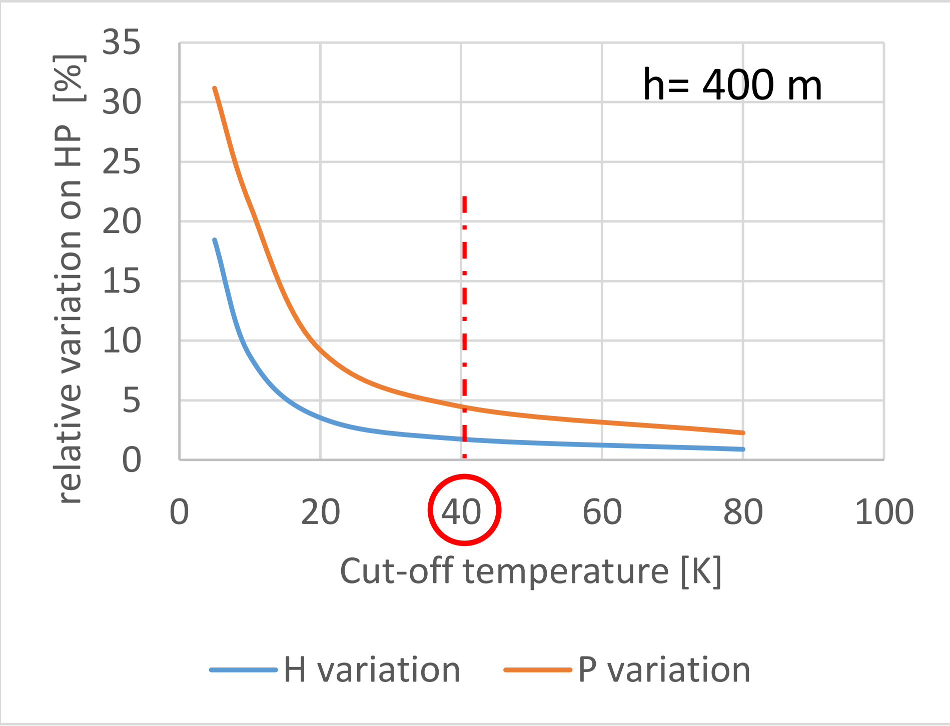
Cryogenics architecture

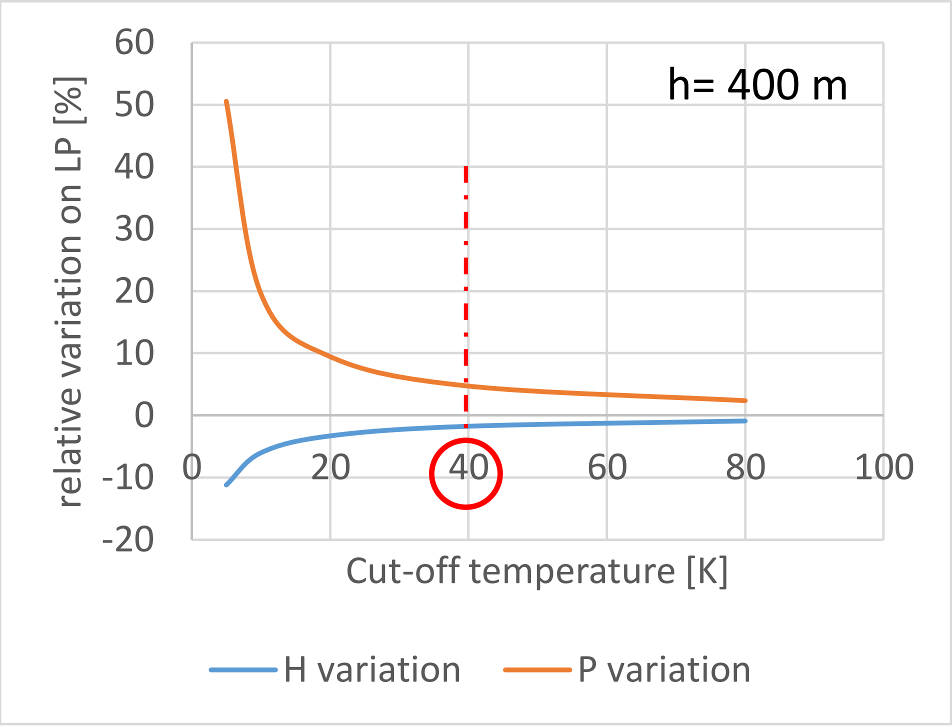


Courtesy of MAN Diesel & Turbo

Cut-off temperature

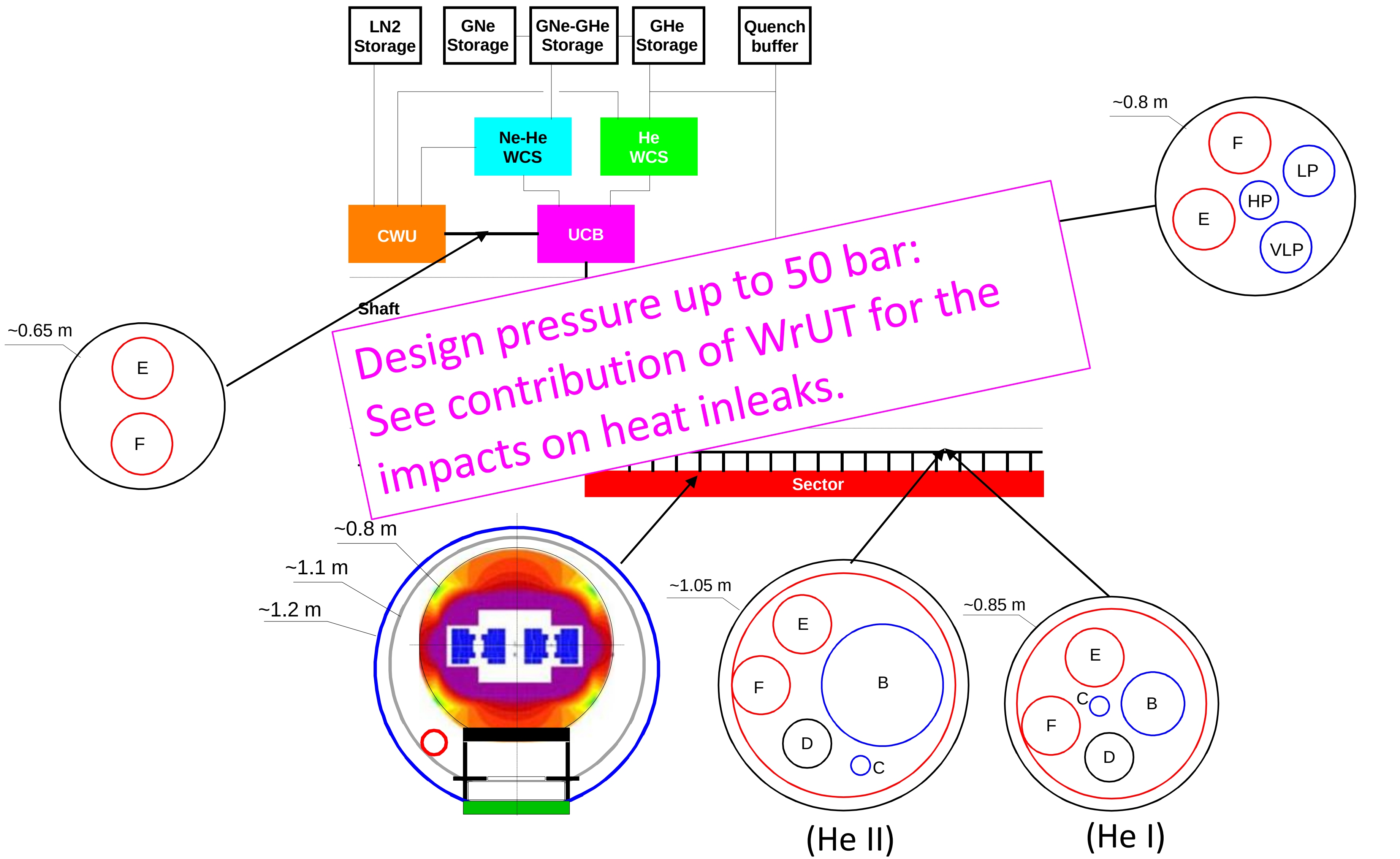
Shaft elevation (h) impacts the hydrostatic head (ρ.g.h) and the enthalpy (g.h) variations:
The relative variation strongly depends on the operating temperature.





40 K is a good compromise compatible with a Nelium cycle producing the refrigeration capacity down to 40 K and which has to be located at the surface for limiting the Neon inventory (cost).

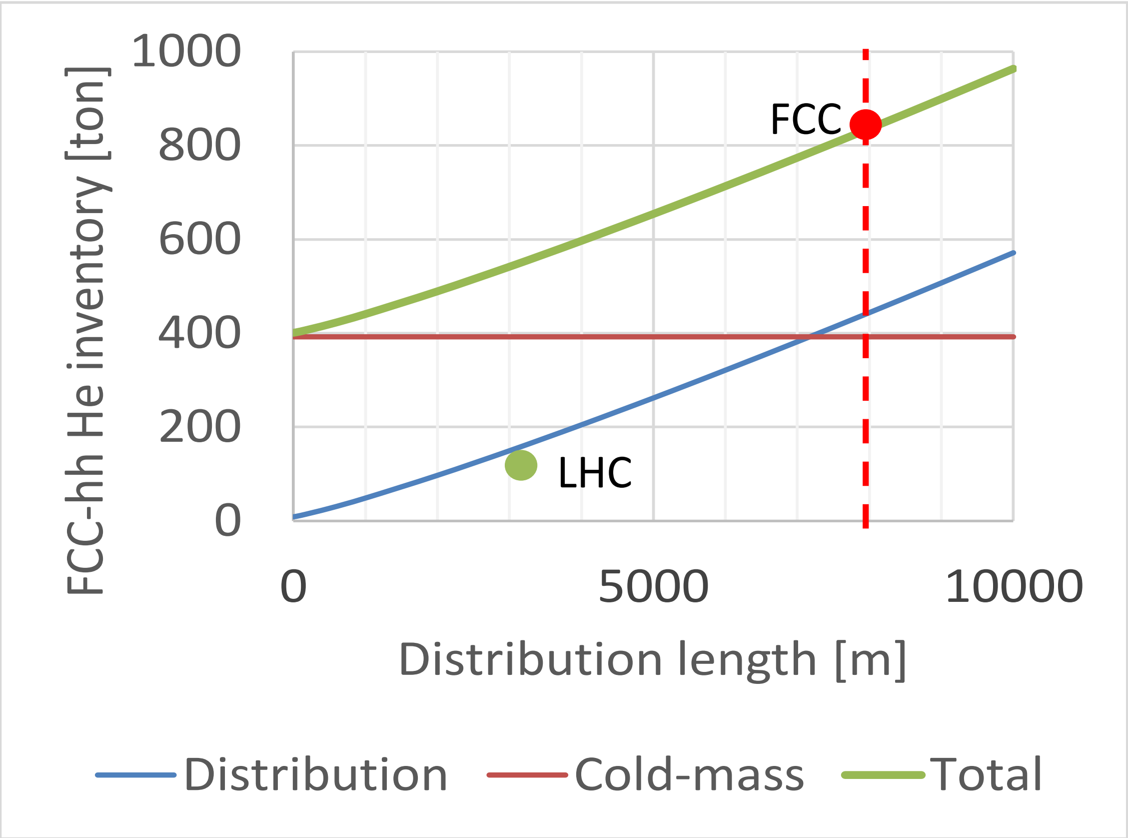
FCC-hh Cryo-distribution

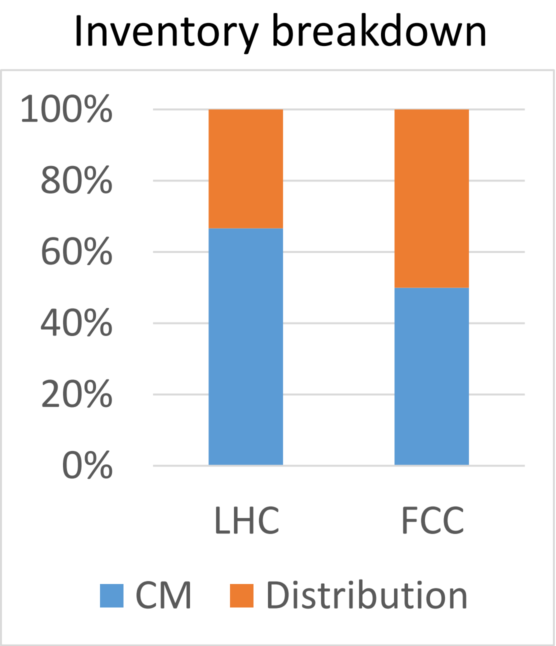


Design pressure up to 50 bar:
See contribution of WrUT for the impacts on heat inleaks.

FCC-hh He inventory

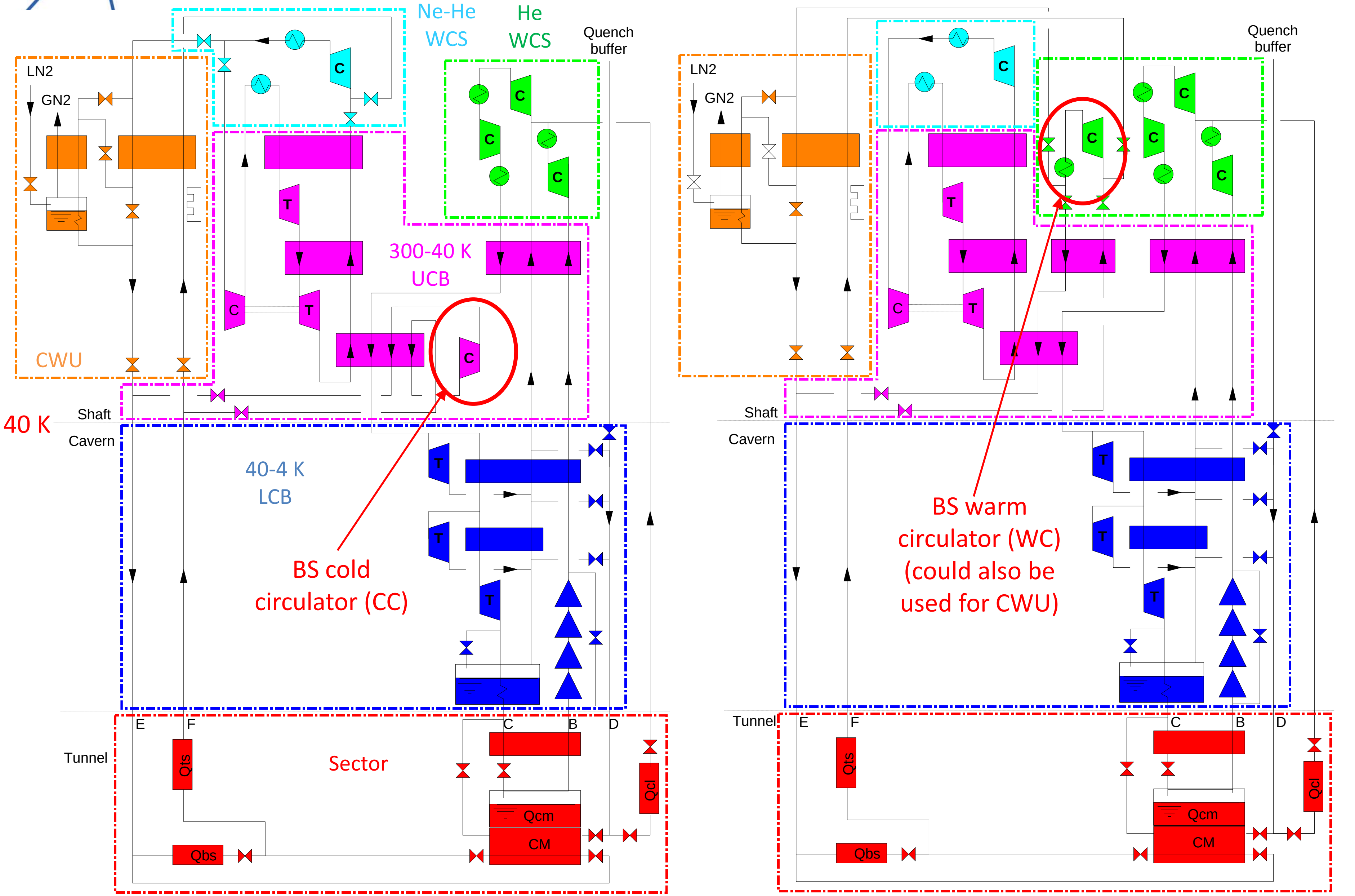
Cold mass He inventory : 33 l/m (scaled from LHC)
Distribution inventory dominated by the beam-screen supply and return headers



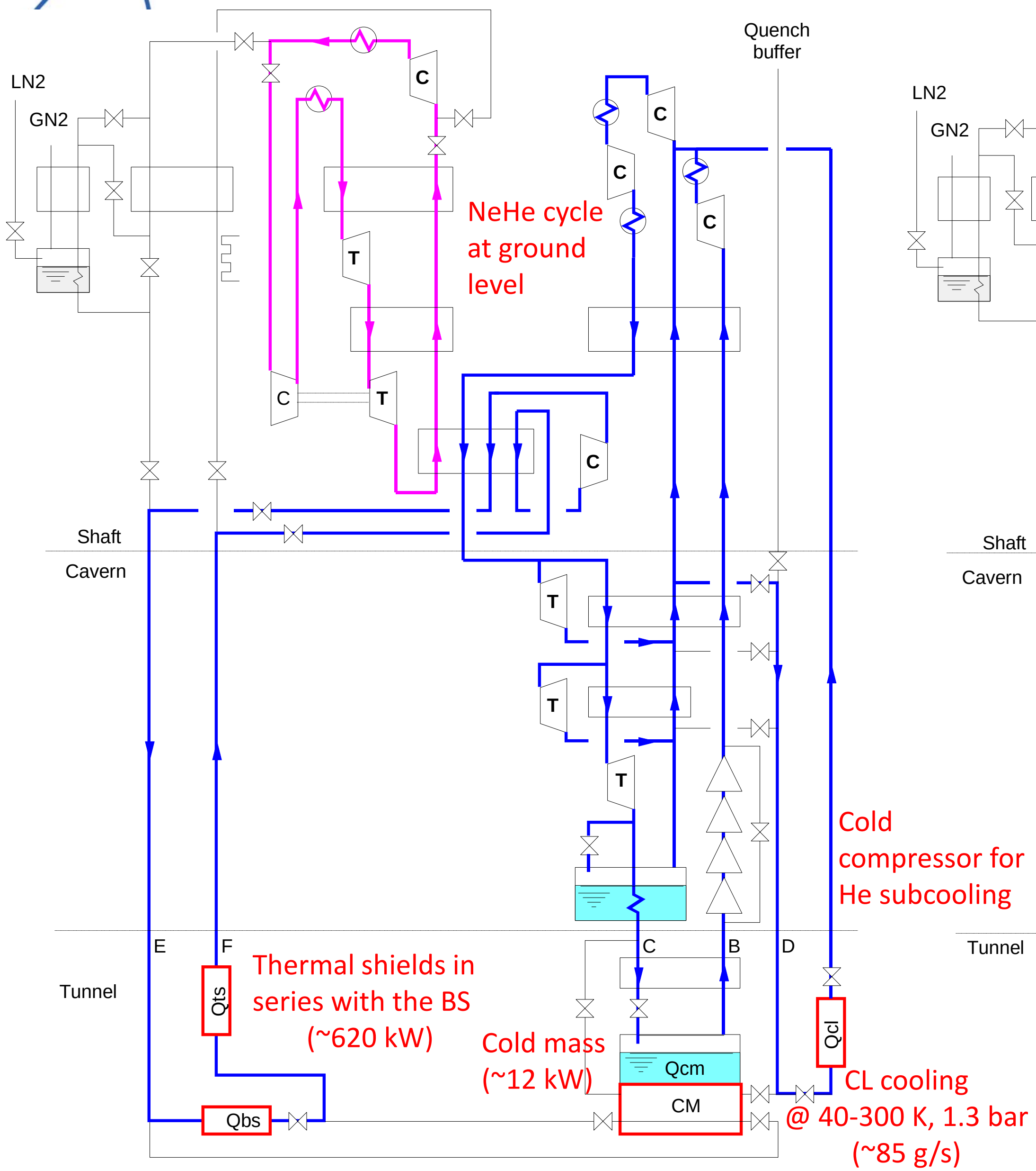


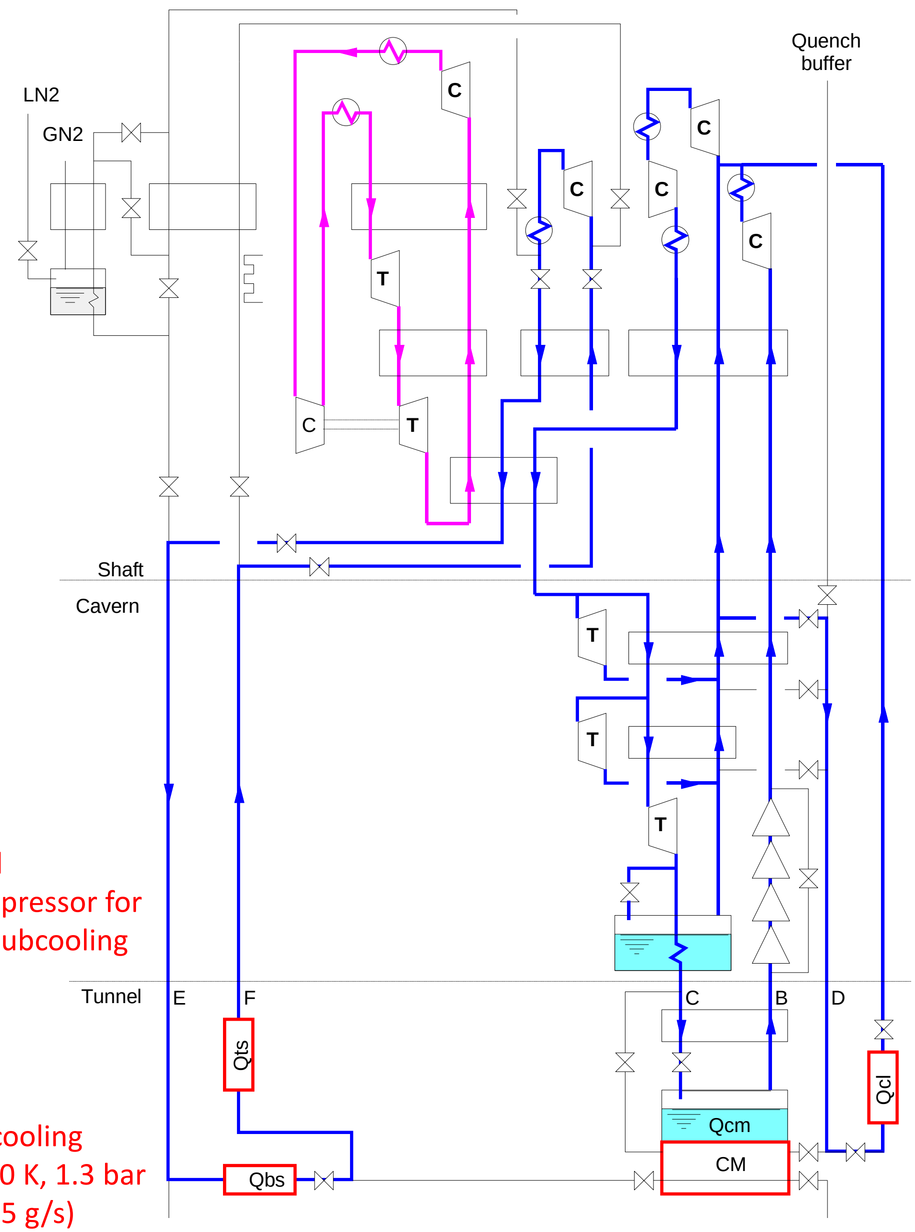
FCC He inventory: ~800 t ! (~6 LHC He inventory)

Process flow diagram



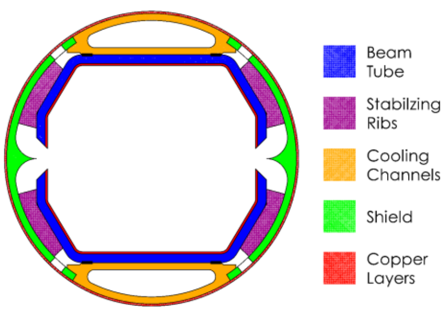
Nominal operation

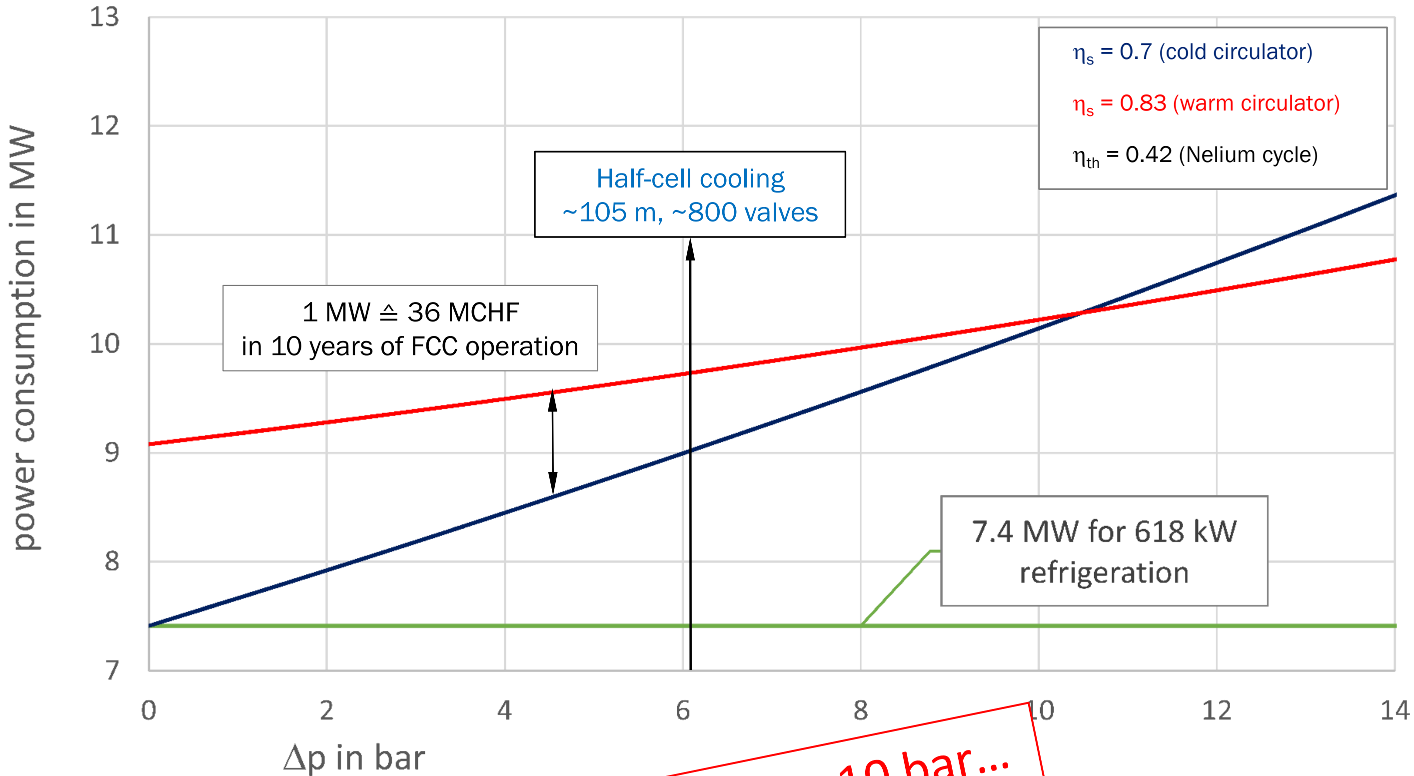


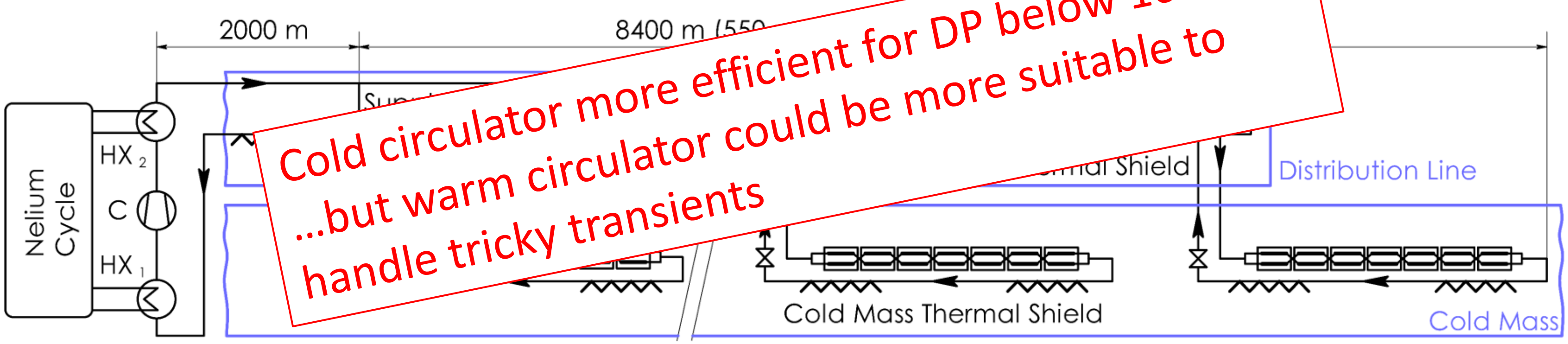


Power consumption vs beam-screen pressure drop

C. Kötnig
S. Klöppel

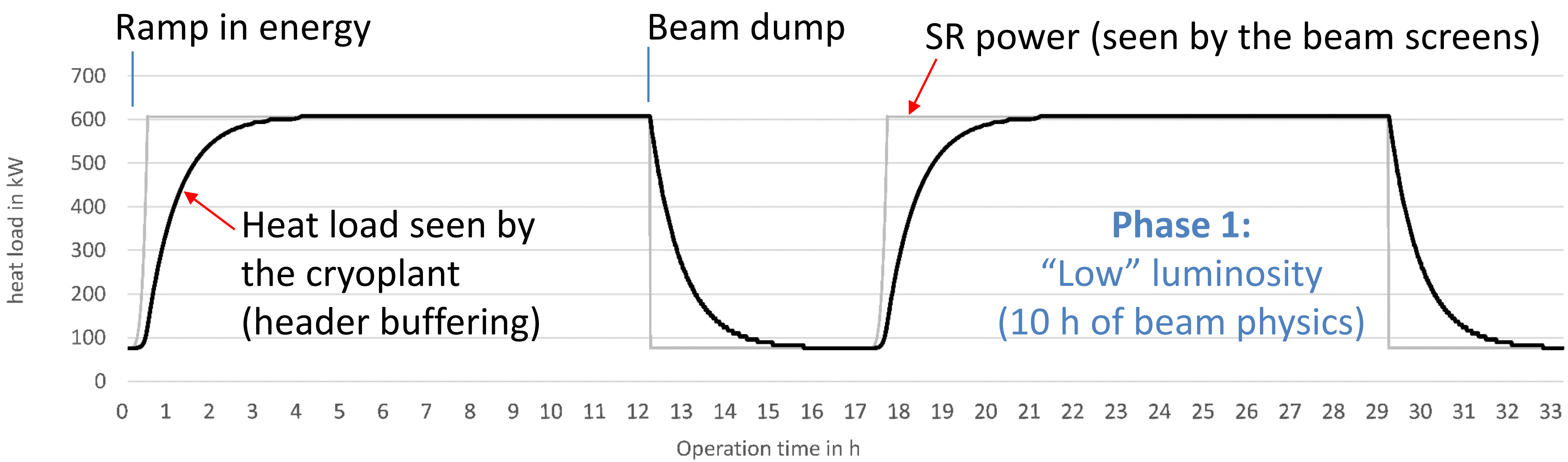


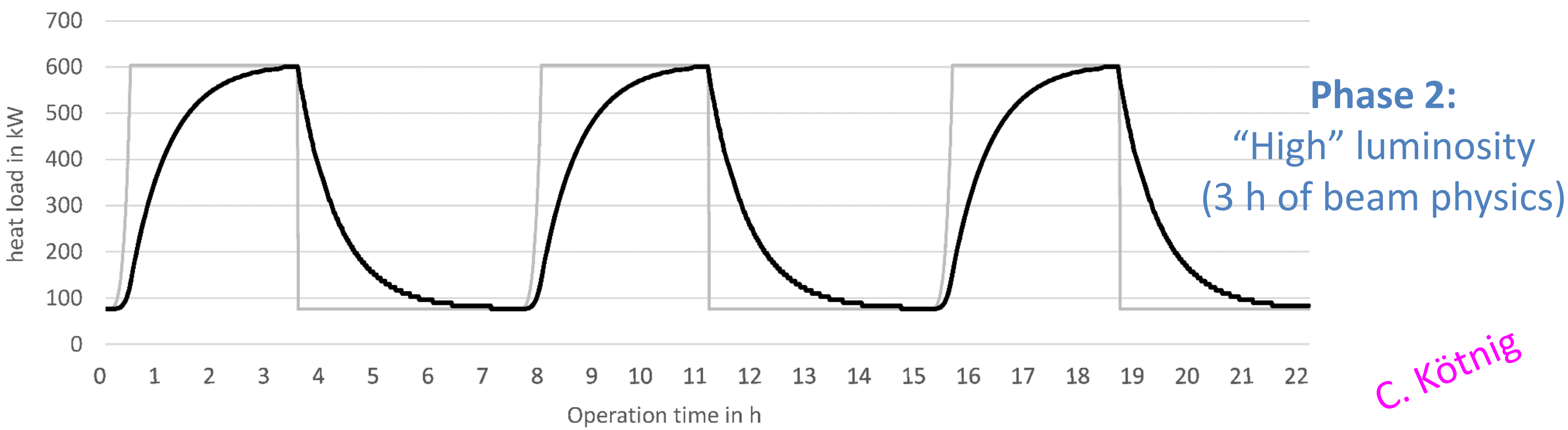




Cold circulator more efficient for DP below 10 bar…
…but warm circulator could be more suitable to handle tricky transients

Beam-screen transient

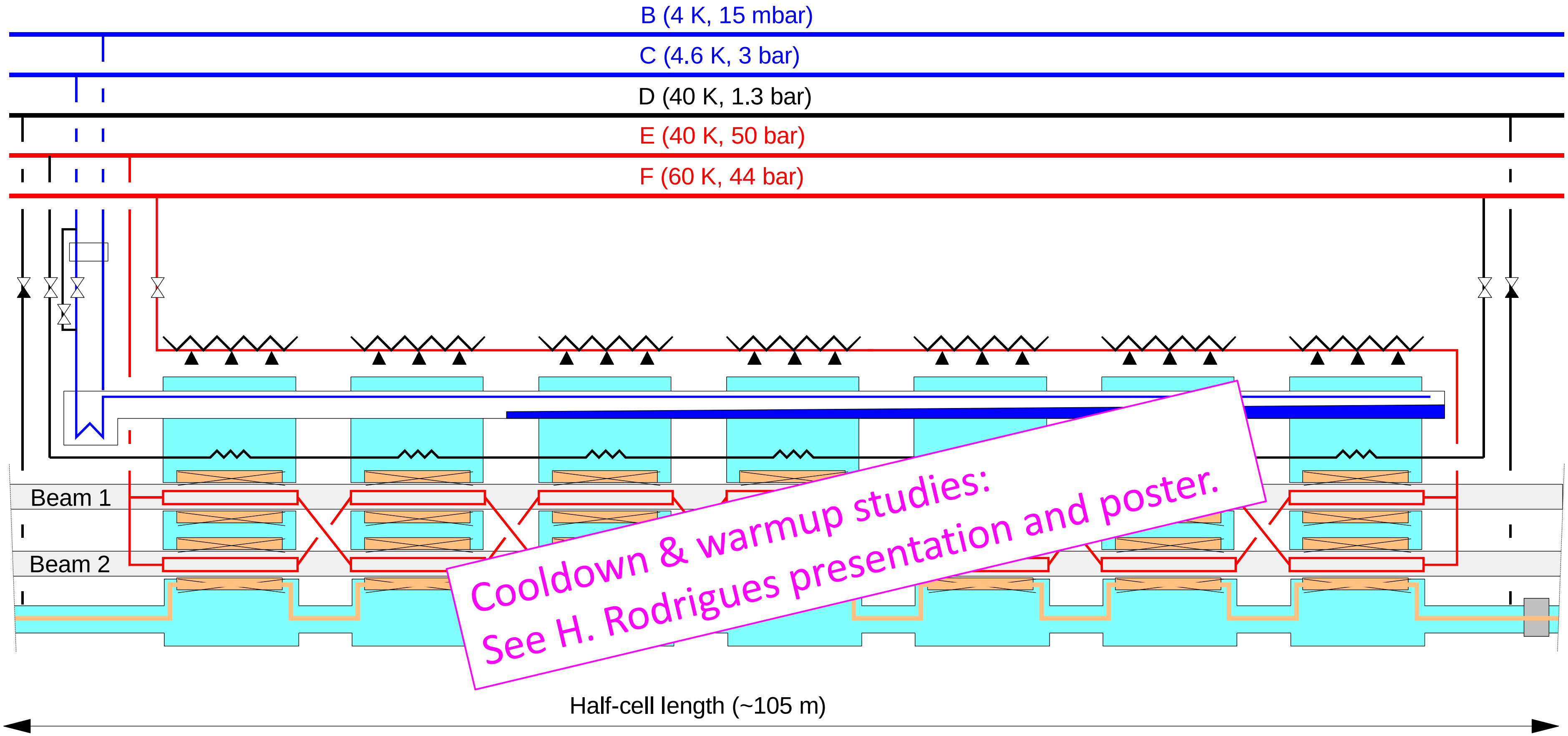




C. Kötnig

Half-cell cooling loop (Superfluid)

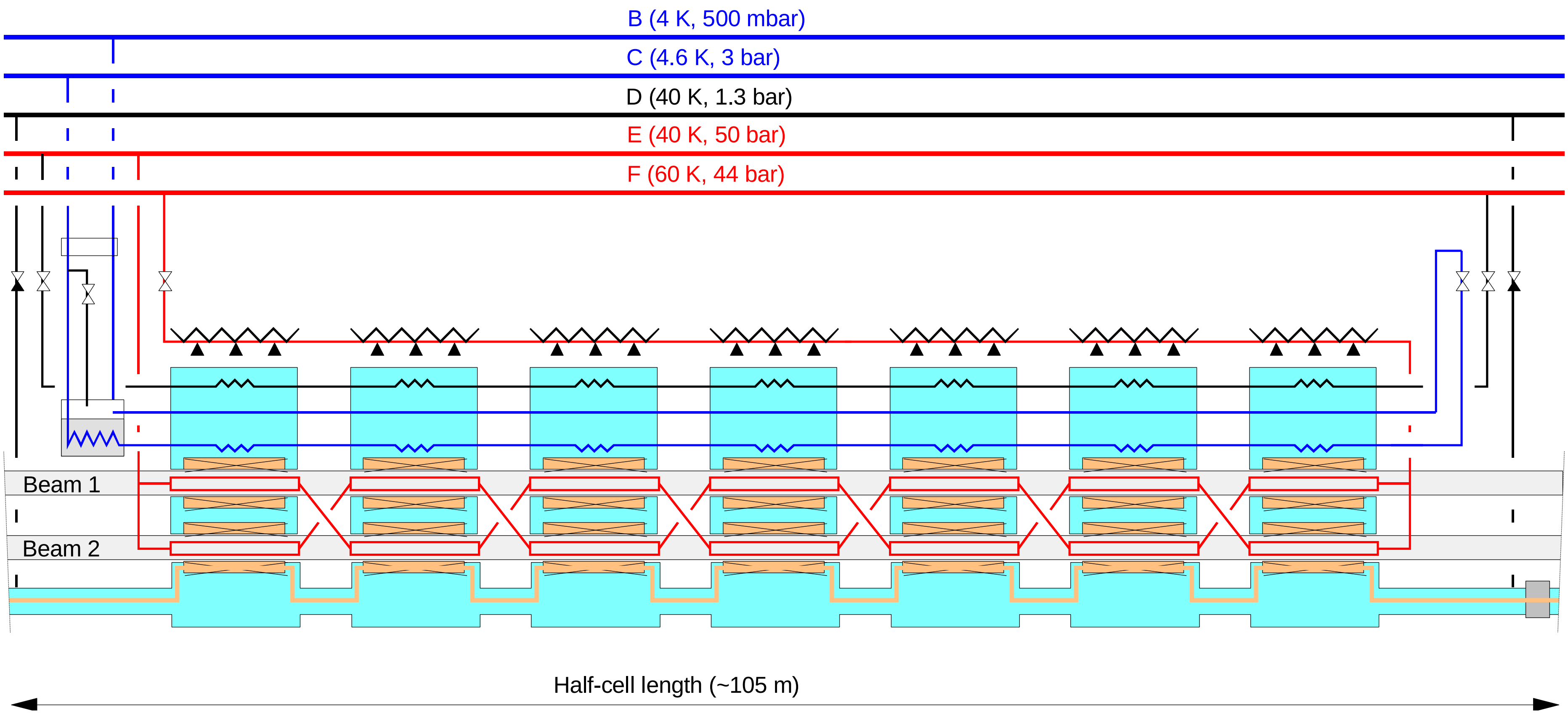
Superfluid He cooling "à la LHC"



- Separate circuit for indirect cool-down and warm-up (no impact on the CM design pressure)
- Bayonet heat exchanger for Liquid-liquid LHe II
- Thermal shield and heat intercepts on the return headers
- Safety/quench valve spacing : ~100 m (to be validated → ~40 MJ per magnets)
- Cold quench buffer (Header D) at 40 K (to be validated (LHC @ 20 K))

Half-cell cooling loop (SHe)

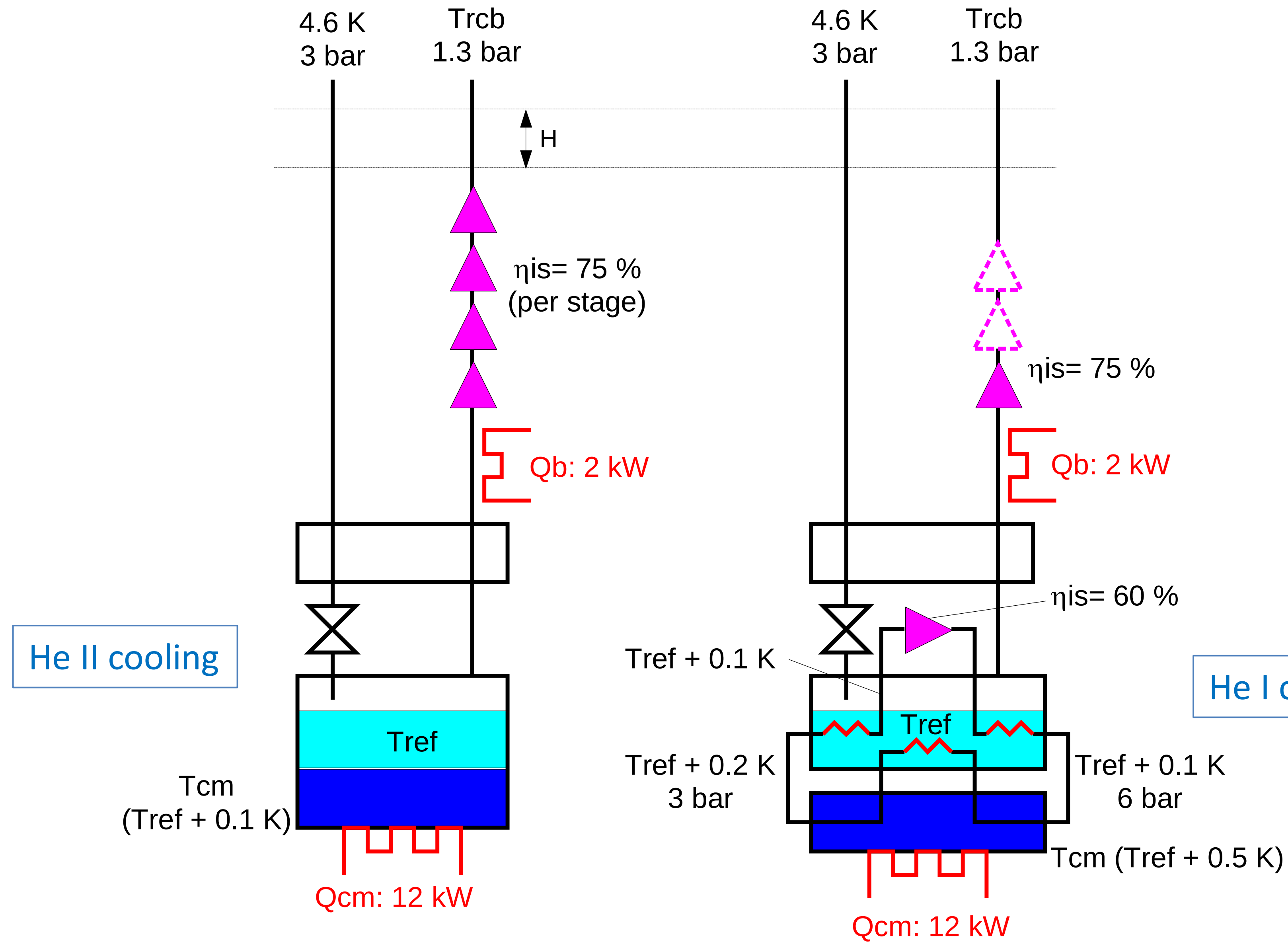
Normal He cooling "à la HERA"



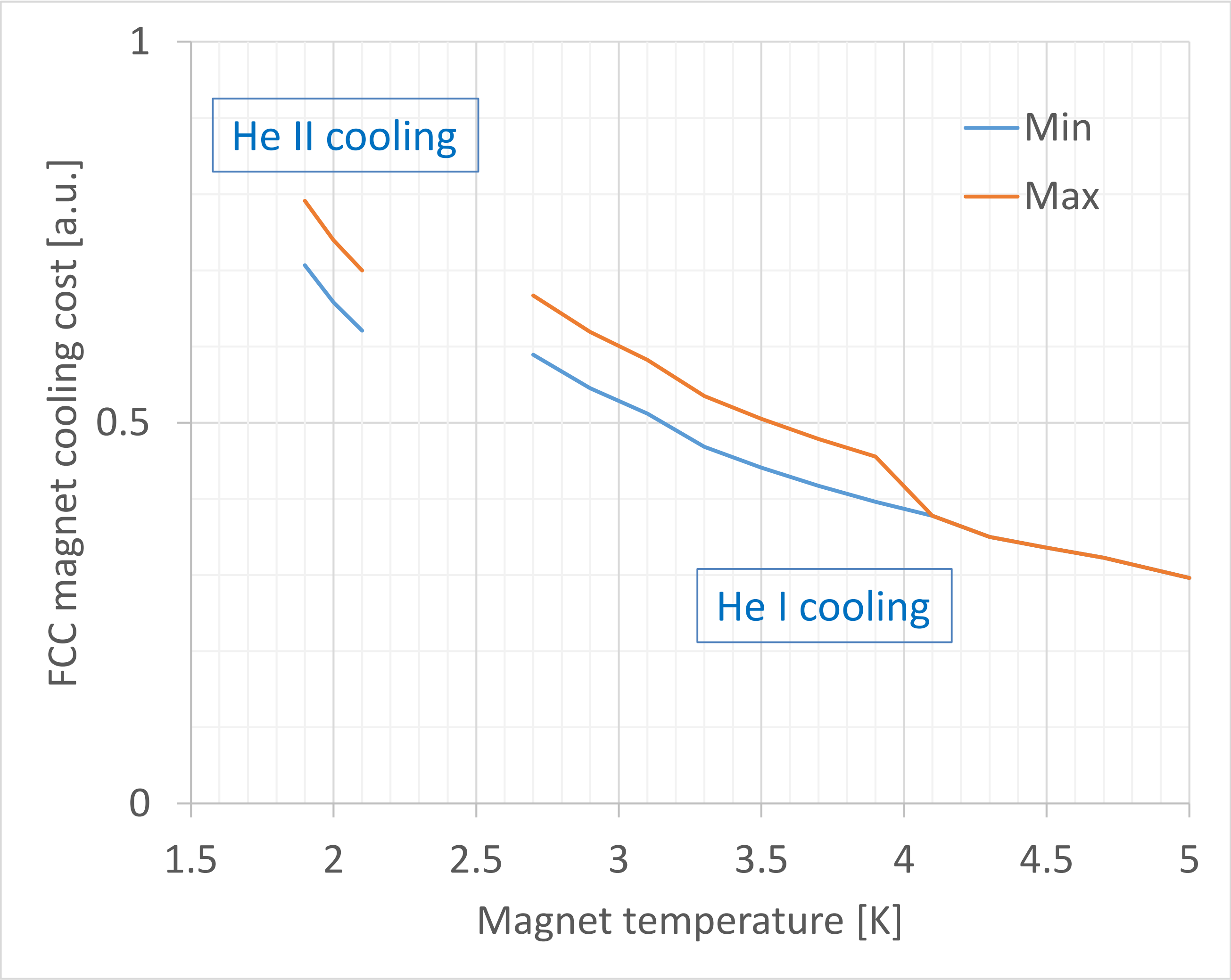
Cooling of magnet cold-masses with supercritical helium (SHe) at high heat load (1.5 W/m) :

→ See C. Kötnig poster

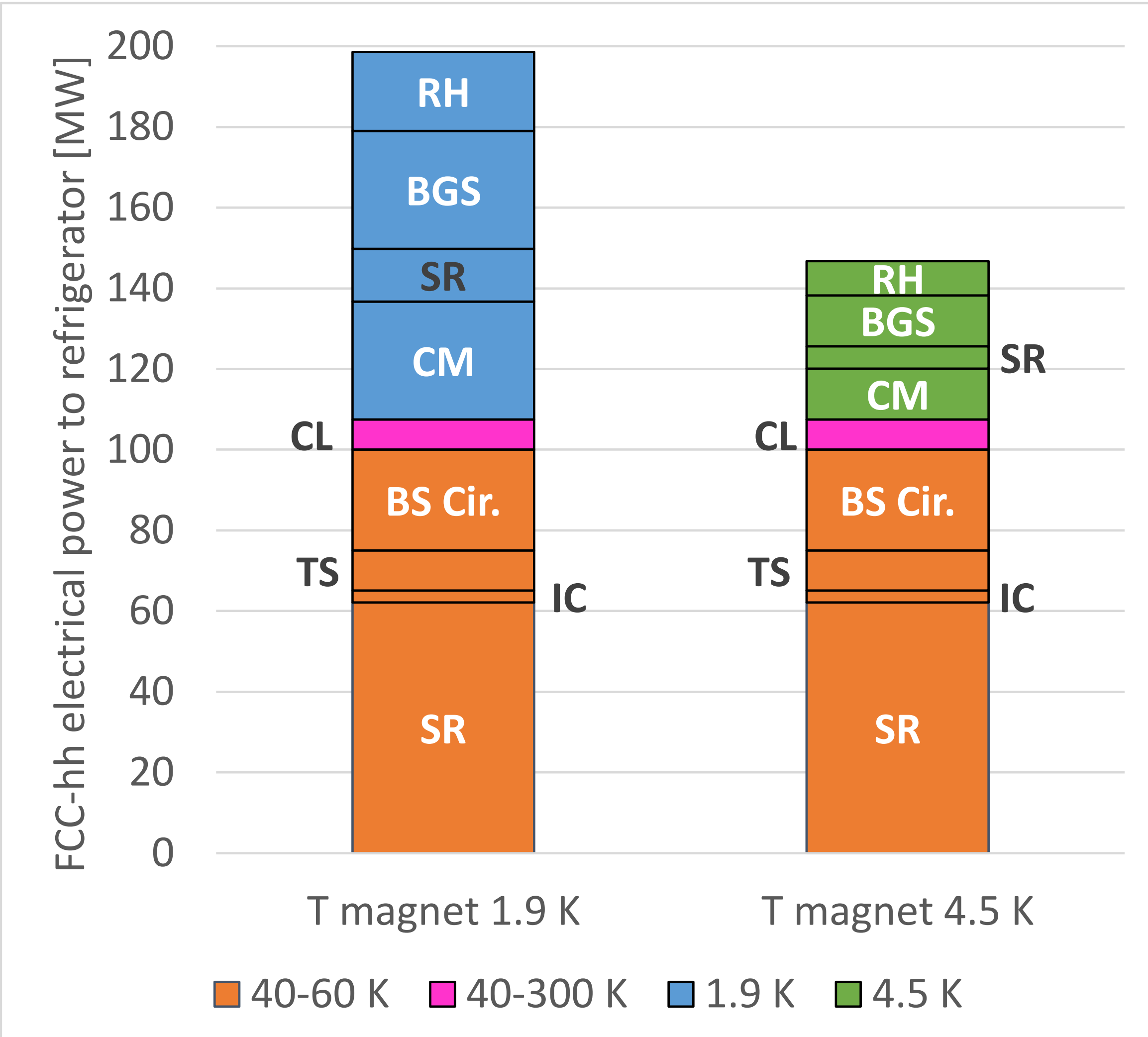
Magnet cooling: He II vs He I cooling



Magnet cooling cost including 10 years of operation



FCC-hh electrical consumption



RH: resistive heating
BGS: beam-gas scattering
CM: cold mass heat-inleaks
CL: current lead
BS cir.: Beam screen circulator
TS: thermal shield
IC: image current
SR: synchrotron radiation

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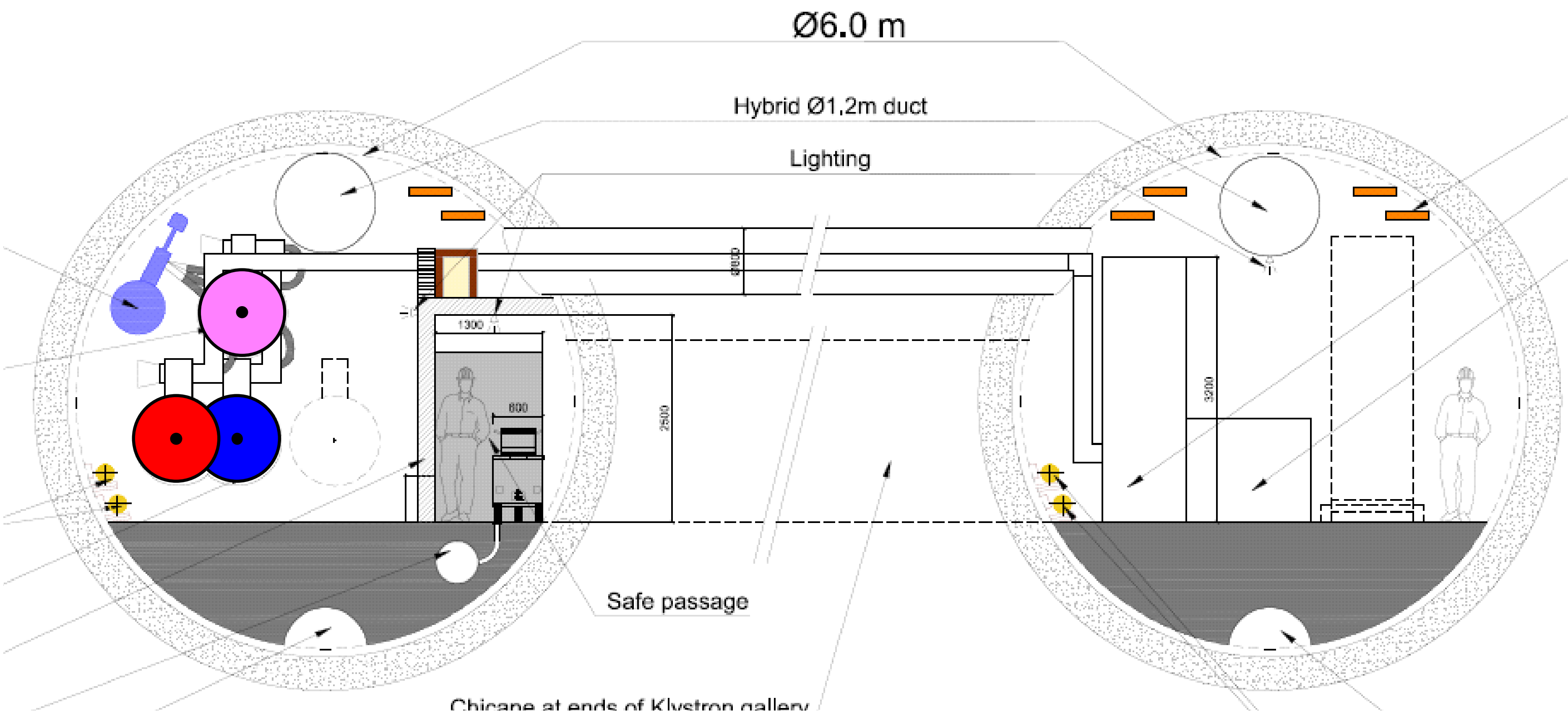
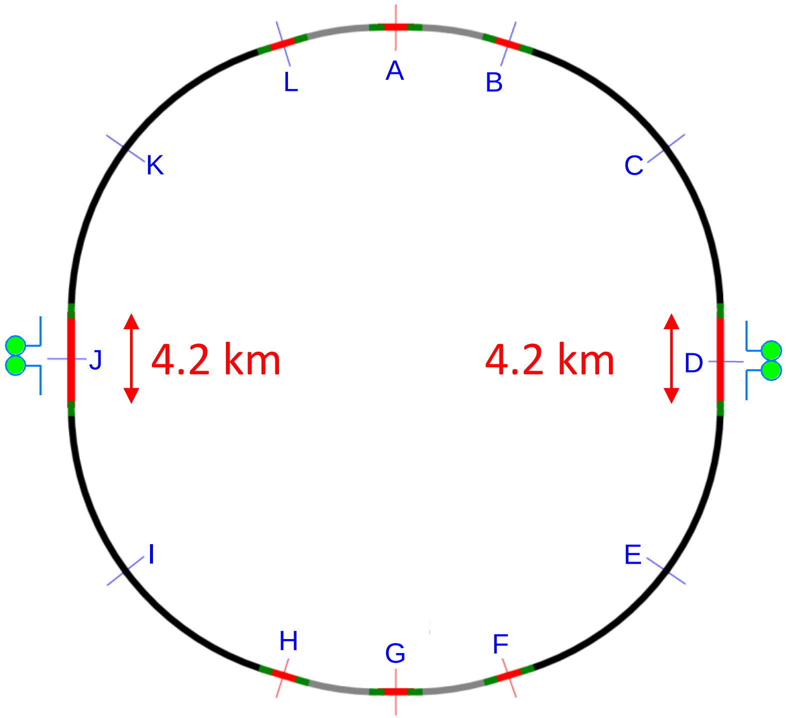
FCC-ee RF straight section



2 main-ring and 1 booster-ring RF module strings

FCC-ee cryogenic capacity (2 main + 1 booster rings)



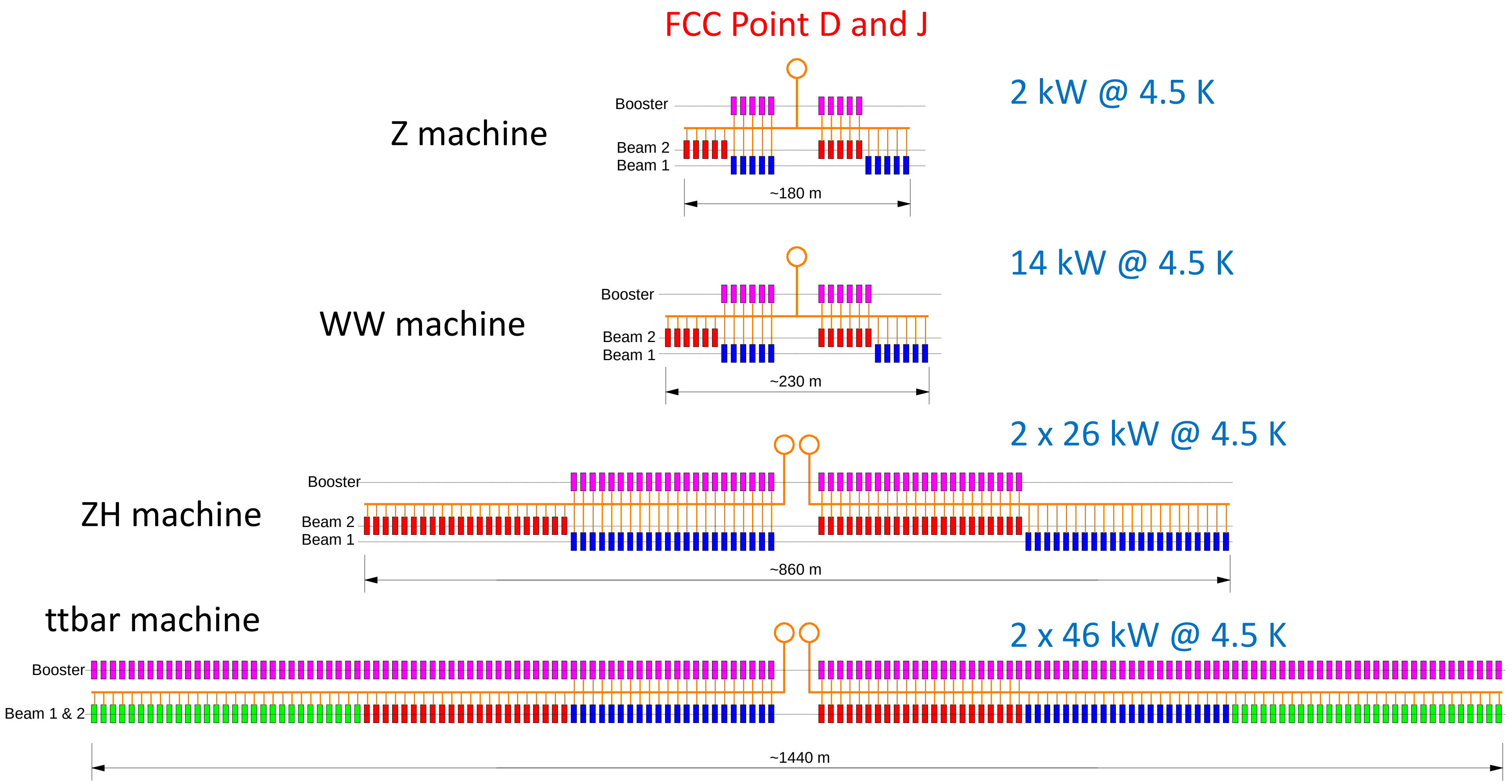
Basic input:

- RF-cavity modules installed in the extended straight sections (ESS at Points J and D)
- Baseline: 1-2 cells, 400 MHz RF cavities @ 4.5 K with Q0= 3.1 E9
- Qstat: 5 W/m (main rings and booster ring)
- Qdyn for booster ring: 10 % of one main ring

Machine	Q stat [kW]	Q dyn [kW]	Qtot [kW]	Cryoplant #	Cryoplant size [kW@4.5 K]
Z	2.9	0.5	3.4	2	1.7
WW	3.7	24	27	2	14
ZH	14	88	102	4	26
ttbar	31	154	185	4 (8)	46* (23)

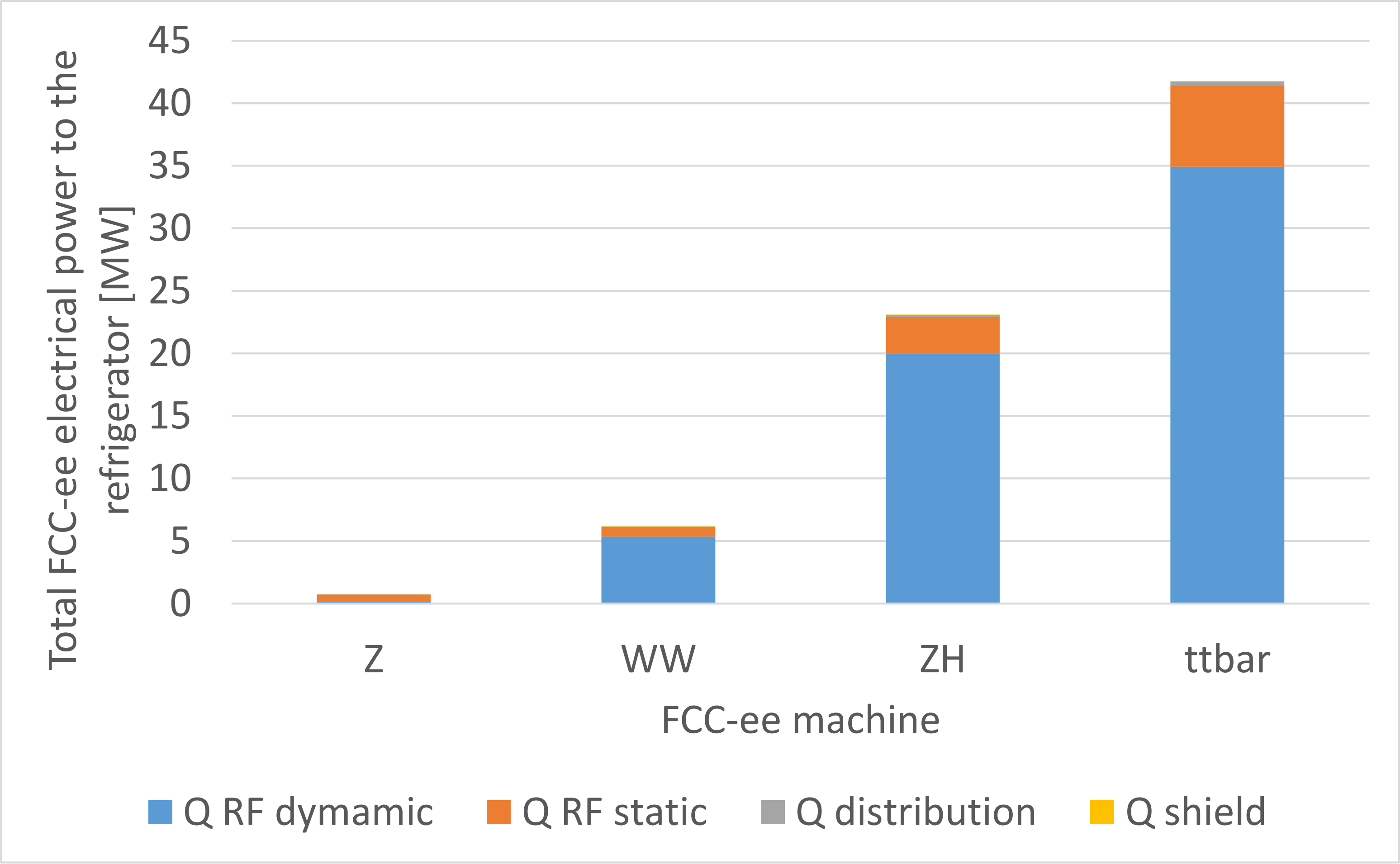
*: Outside State-of-the-Art

FCC-ee: Cryogenic layout

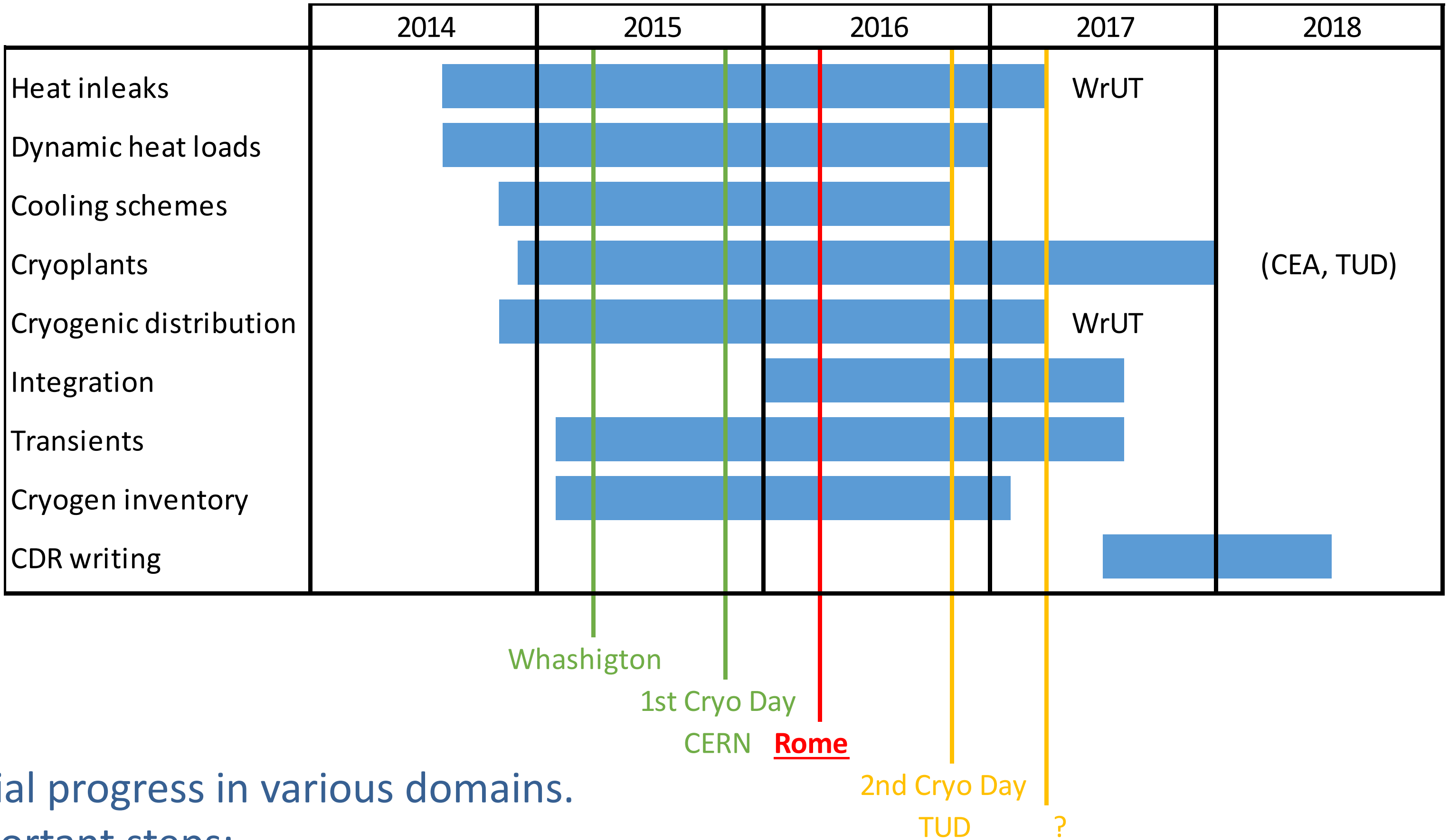


~ 10 m-long cryo-modules with cold-warm transitions

FCC-ee: Cryogenics electrical consumption



Conclusion: schedule



Substantial progress in various domains.

Next important steps:

- Cryoplant studies by industrial partners (Air Liquide & Linde)
- Beam-screen transient → local and global controls strategy
- Quench discharge and recovery (impact on CM design pressure and # of quench valves)
- Distribution system (heat in-leaks, INVAR option)
- Freezing of magnet operating temperature