High Luminosity LHC

Overall plans for Cryogenics for HL-LHC

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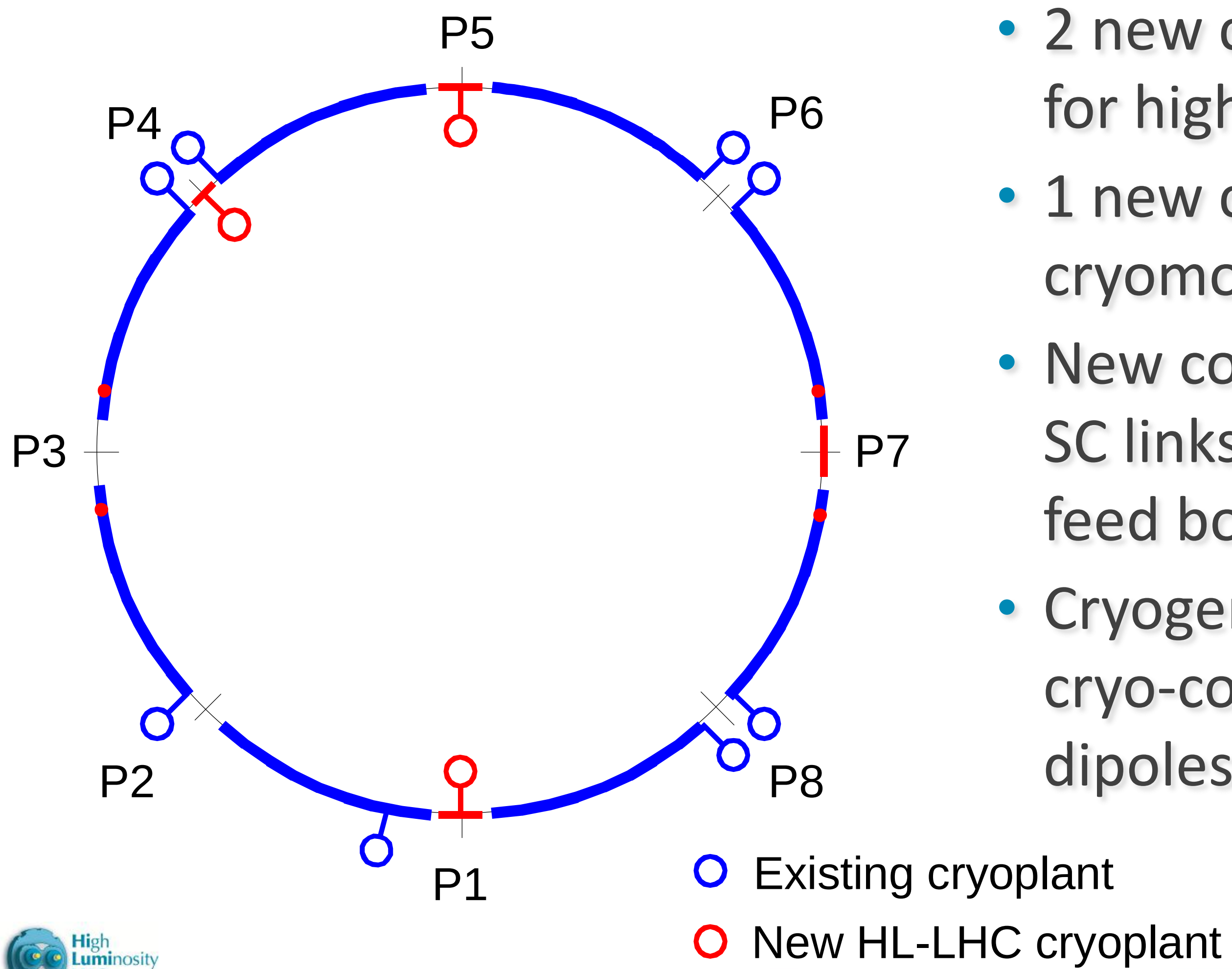
- Overall HL-LHC layout
- Cryogenic layout proposals at:
  - Point 1 and Point 5
  - Point 4
  - Point 7
- Local and global cryo-limitation in Sectors
- Specific studies and tests
- Schedule and conclusion

Overall HL-LHC layout



- HL-LHC cryo-upgrade:
  - 2 new cryoplants at P1 and P5 for high luminosity insertions
  - 1 new cryoplant at P4 for SRF cryomodules
  - New cooling circuits at P7 for SC links and deported current feed boxes
  - Cryogenic design support for cryo-collimators and 11 T dipoles at P3 and P7

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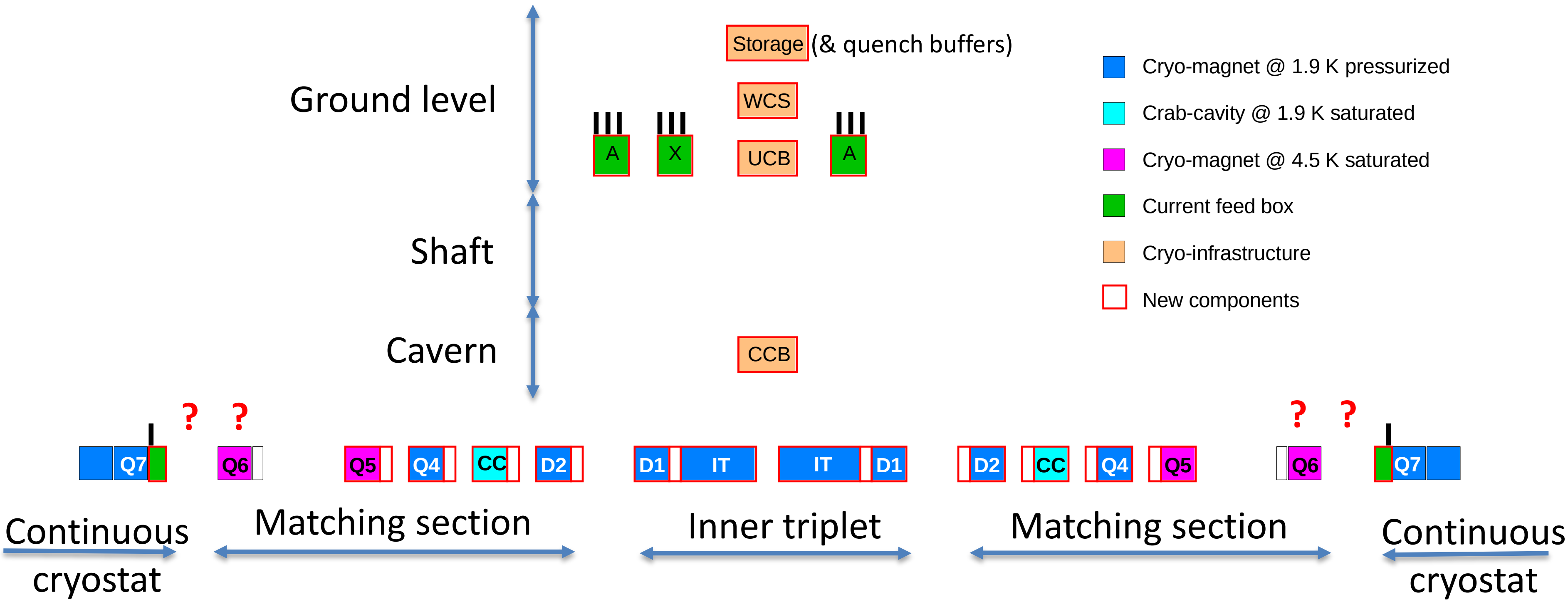
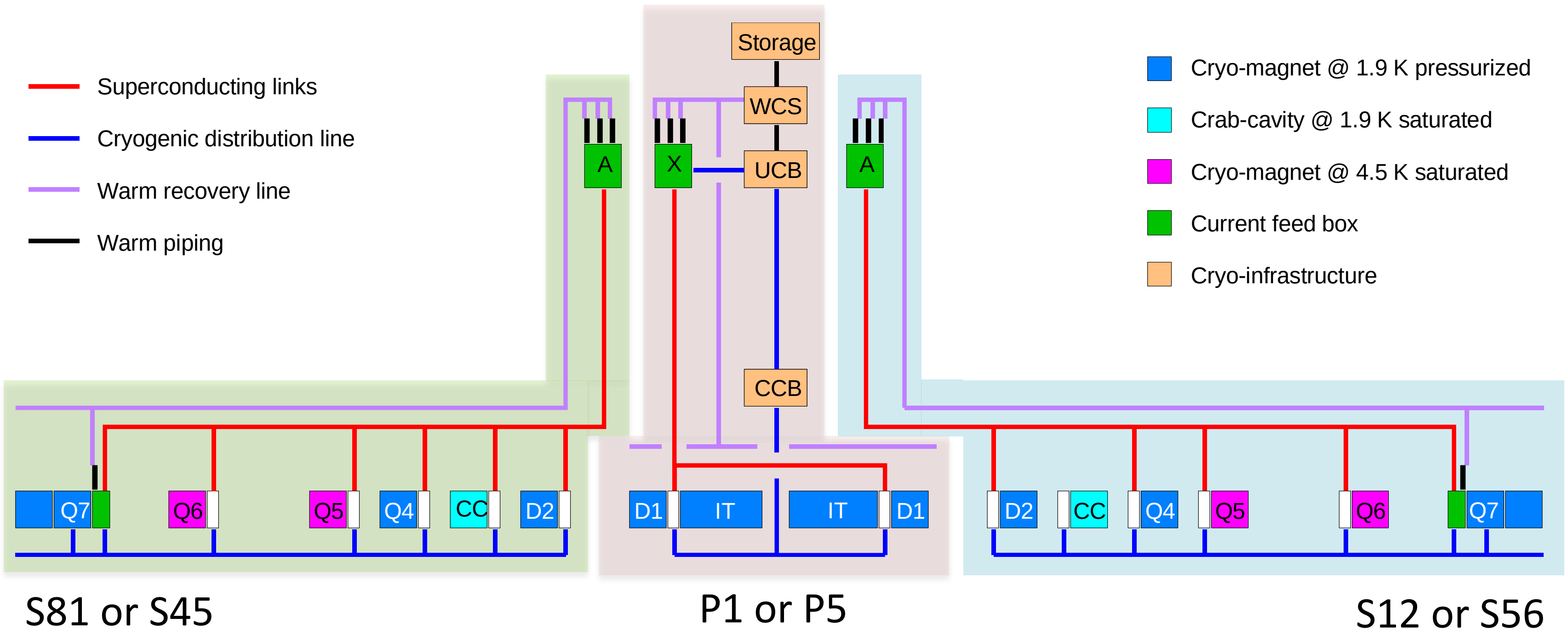
Main components at Point 1 and 5



?: what about new Q6 and additional Q7+?

P1 & P5 layout 1: Matching section cooled with sector cryoplants



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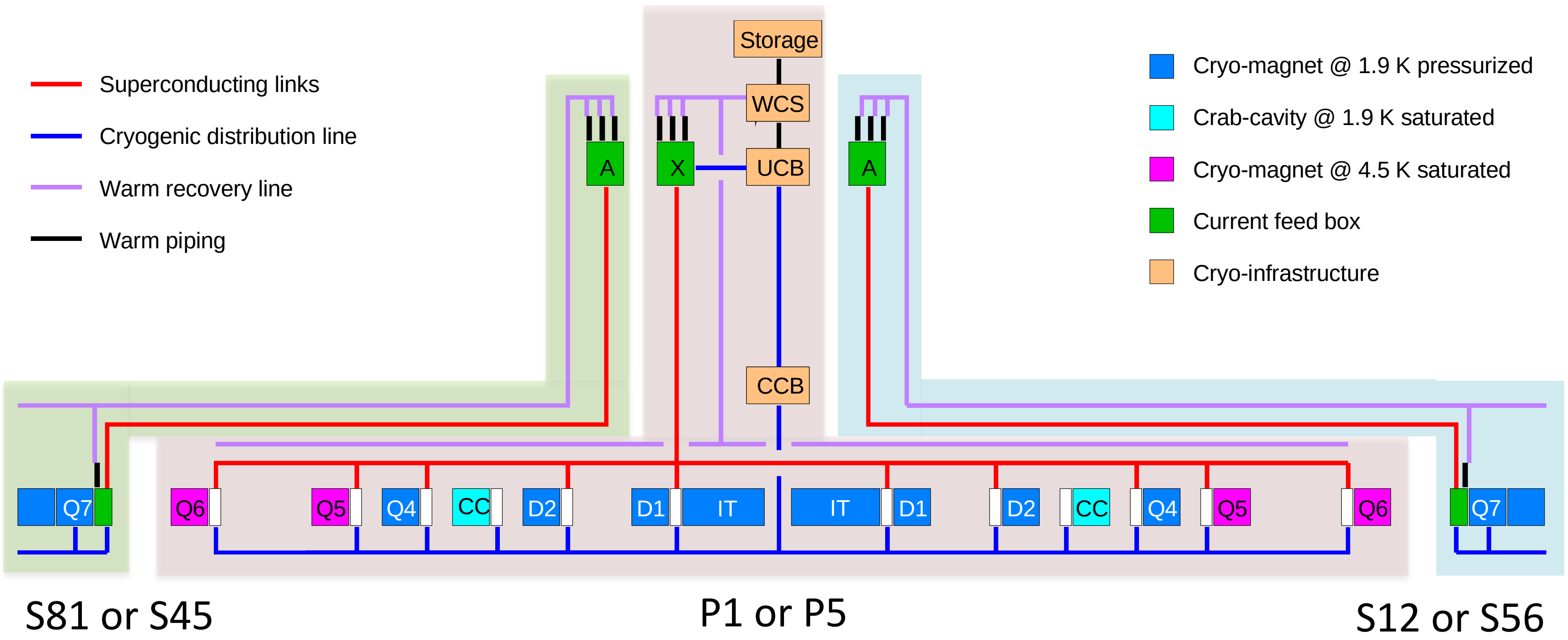
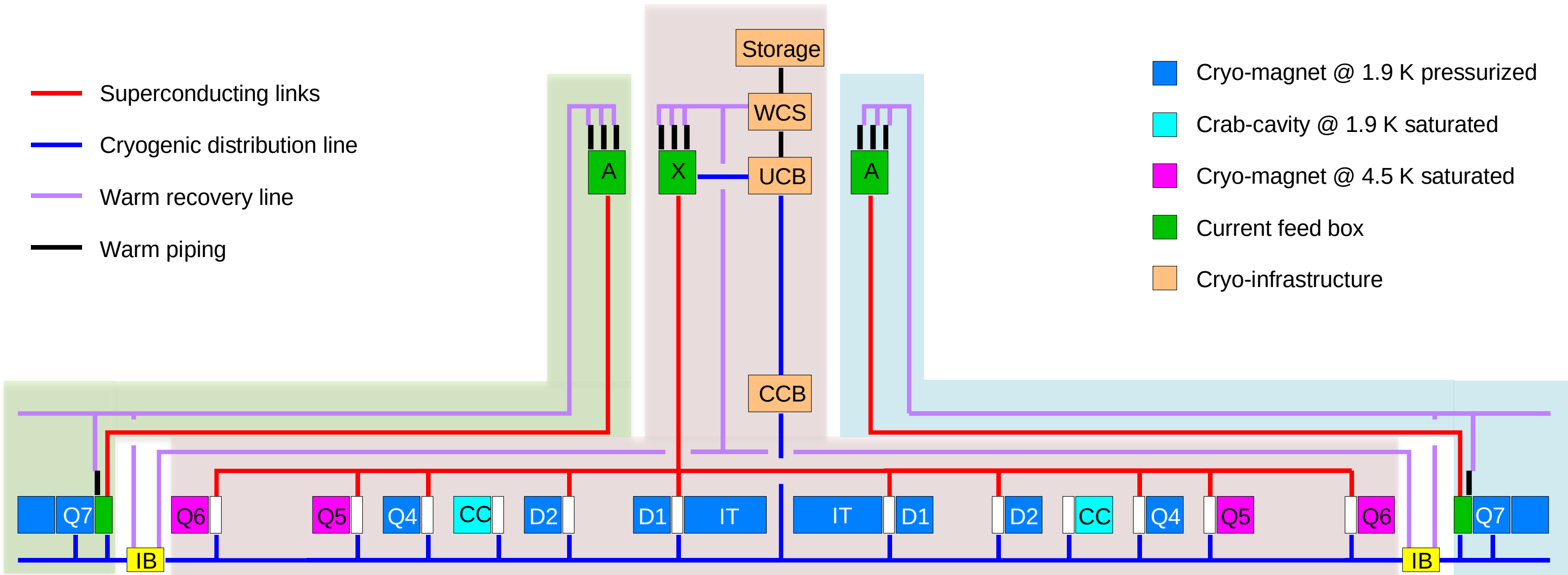
P1 & P5 layout 2: Matching section cooled with inner triplet cryoplants



Comparison of layouts at P1 and P5

	Advantage	Drawback
Layout 1: MS with sector	Corresponds to the CtC baseline (minor modification on the existing QRL, i.e. only new jumper extensions foreseen)… Better sharing of high current circuits within SC links.	…but reuse of existing QRL if the new MS layout largely differ from the existing one (operating temperature and/or new equipment (D2, CC, Q4, Q5, Q6? Q7+?…)) → could be also expensive and space consuming… …and maybe not feasible! i.e MS will need a new compound transfer line (8-10 MCHF tbc)
Layout 2: MS wit IT	Optimisation of the distribution and space with respect to the HL-LHC need. Allow the upgrade of “A” boxes during LS2 Complete sectorization of MS + IT allowing mechanical intervention without warm-up of the two adjacent sectors (but interconnection, if any, must be designed accordingly)	Increase of the CtC (~1 km of compound transfer line with ~20 service modules) → additional cost (8-10 MCHF tbc) Increase of number of high current circuits in the “X” SC link

Interconnection for partial redundancy



Present redundancy baseline w/o interconnection (IB) in between cryoplants !

"Partial" redundancy:
- cold standby during technical and Xmas stops
- low beam-intensity operation in case of major breakdown on the new cryoplant (full nominal redundancy not possible)
- what about redundancy with detector cryogenics ?

Cost increase

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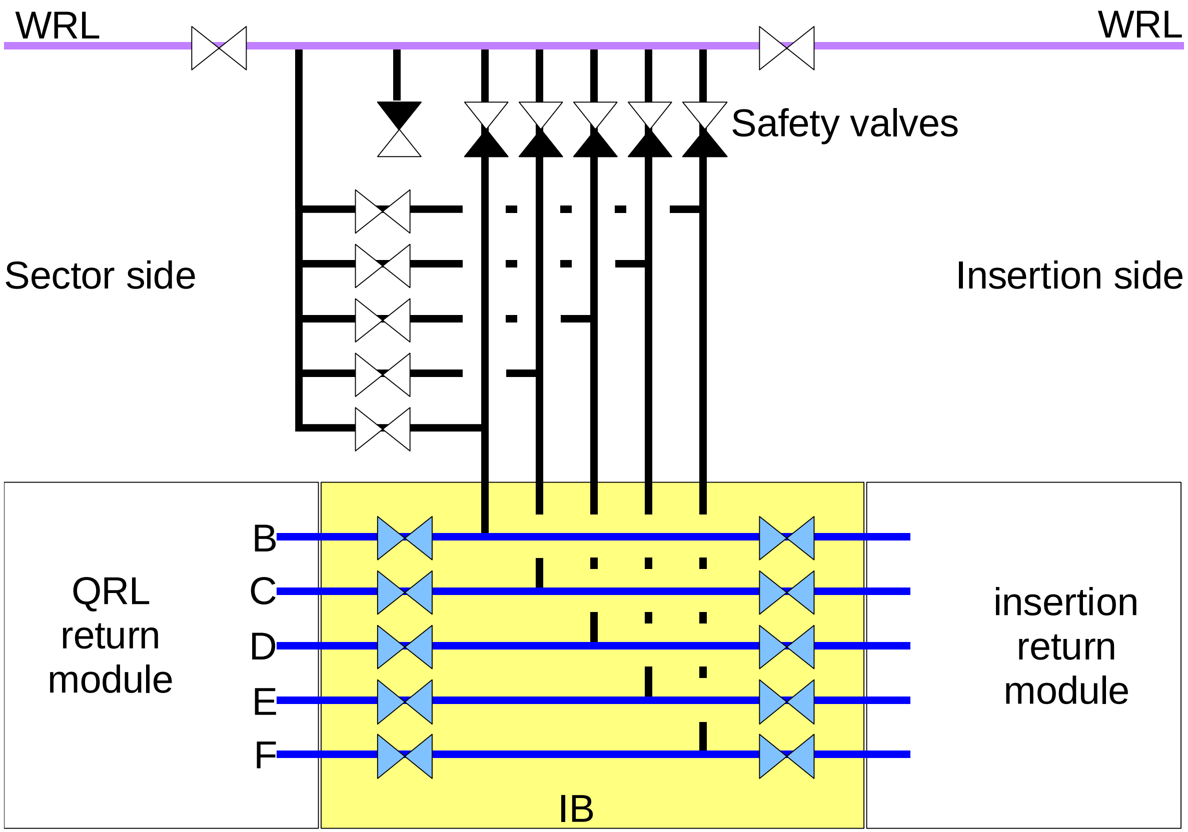
Interconnection box (IB)

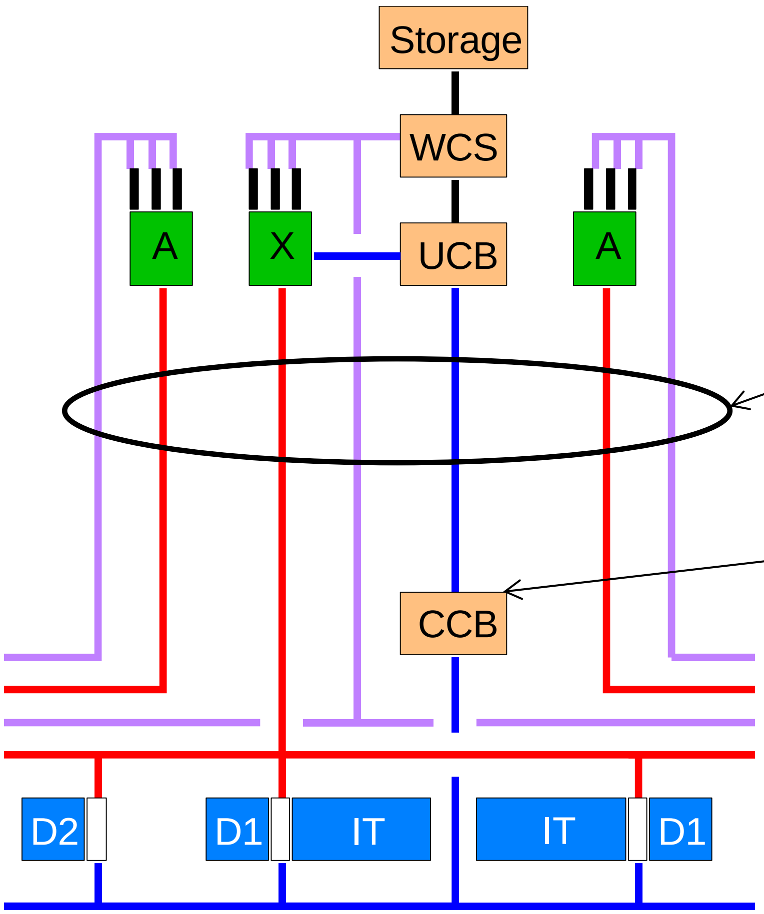


Up to 10 cryogenic valves to be integrated in the tunnel (space ?)

→ Volume in between valves used as controlled volume for safe cryo-consignation

→ Valve DNs depend on the level of needed redundancy

Space requirement in caverns and shafts

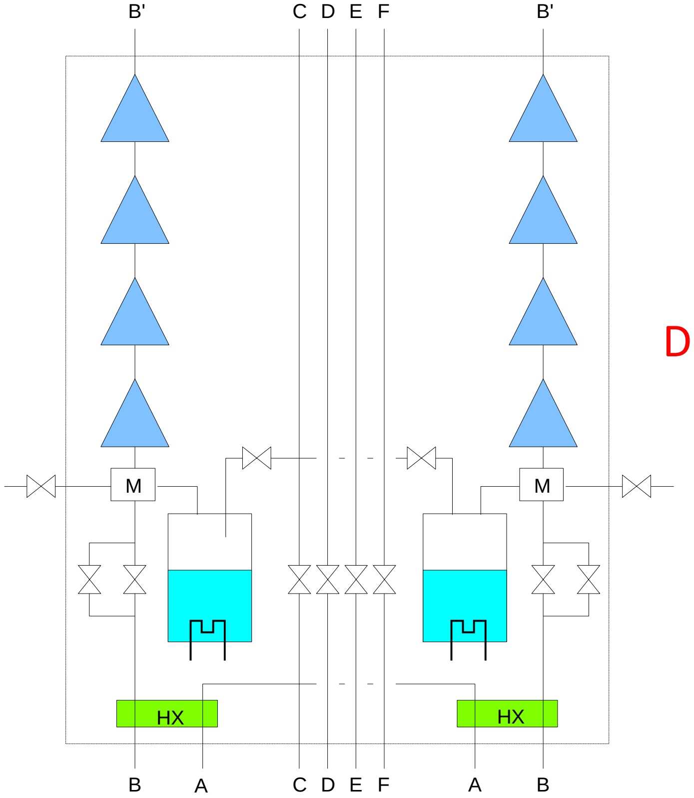


Shaft requirement→ In addition to the
3 SC links:
- 1 compound cryoline (~DN500)
- 3 warm recovery lines (~DN100-150)

Cavern requirement:
- 1 cold compressor box

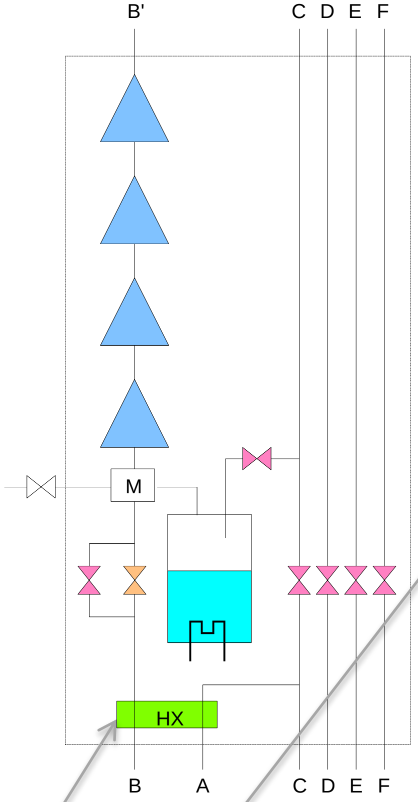
Minimum CCB requirement in cavern

Double CC train

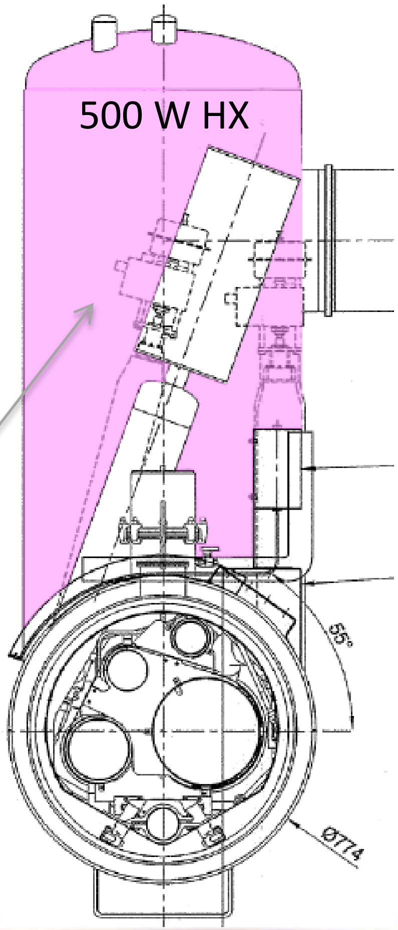


Depending of the total cooling capacity and operating temperature

Single CC train

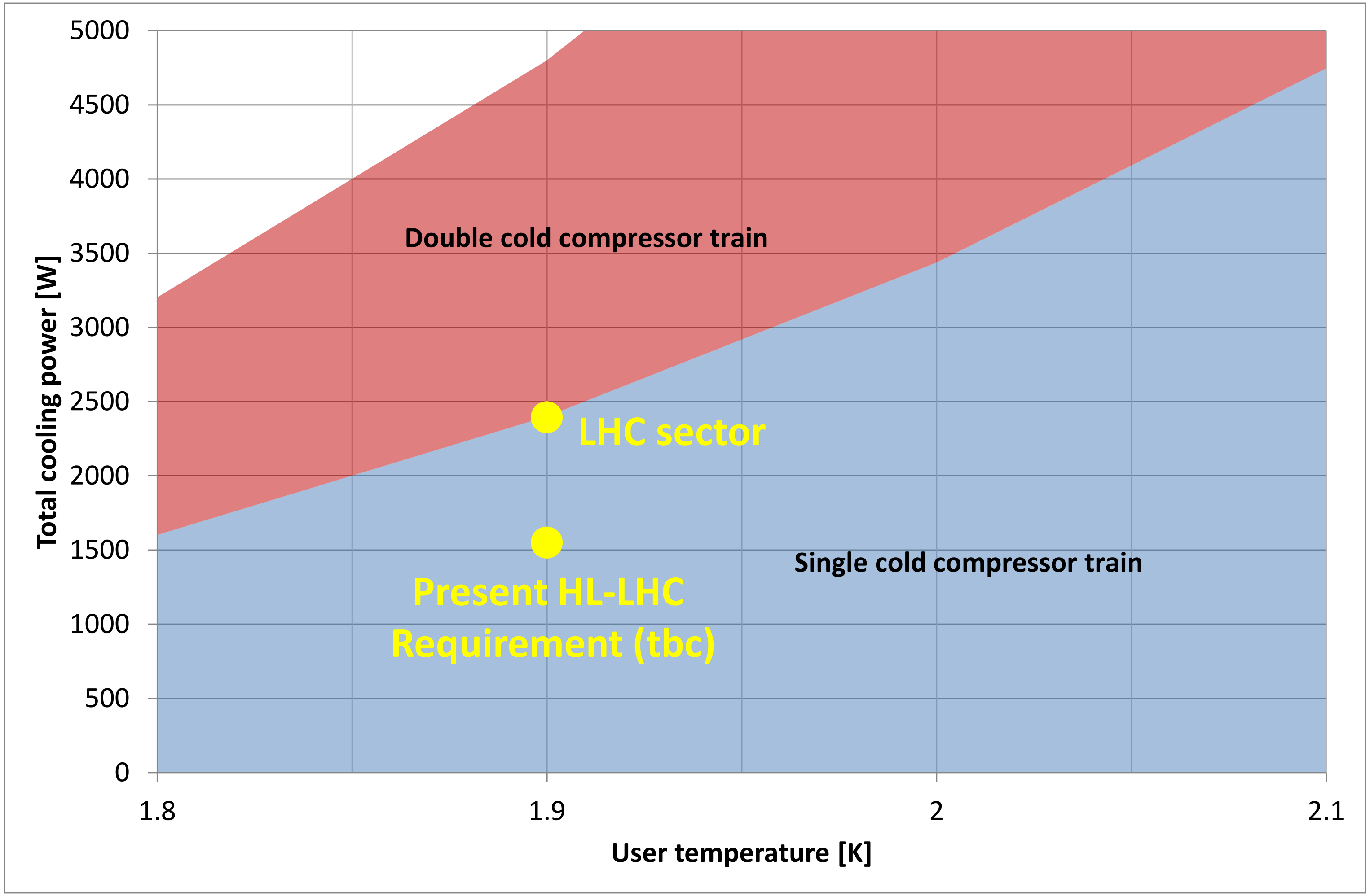


Best for cavern integration

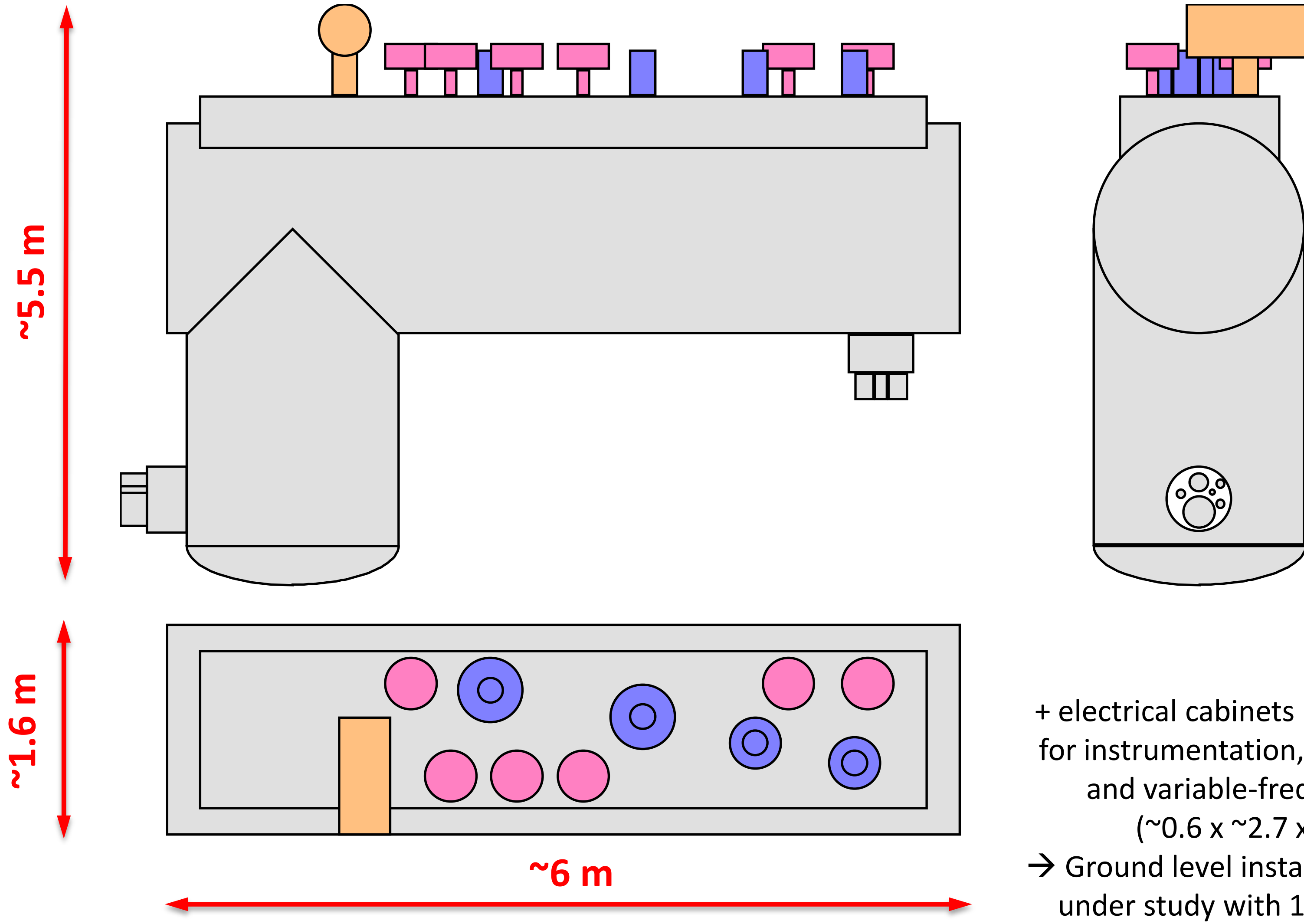


Global or distributed ?
(500 W max size for distributed HX !)

Number of cold compressor trains



Minimum size of cold compressor box (CCB)



+ electrical cabinets in protected area for instrumentation, AMB controllers and variable-frequency drives ($\sim 0.6 \times \sim 2.7 \times \sim 2.2\ m^3$)

→ Ground level installation of cabinets under study with 150 m of cabling (today: 25 m max)

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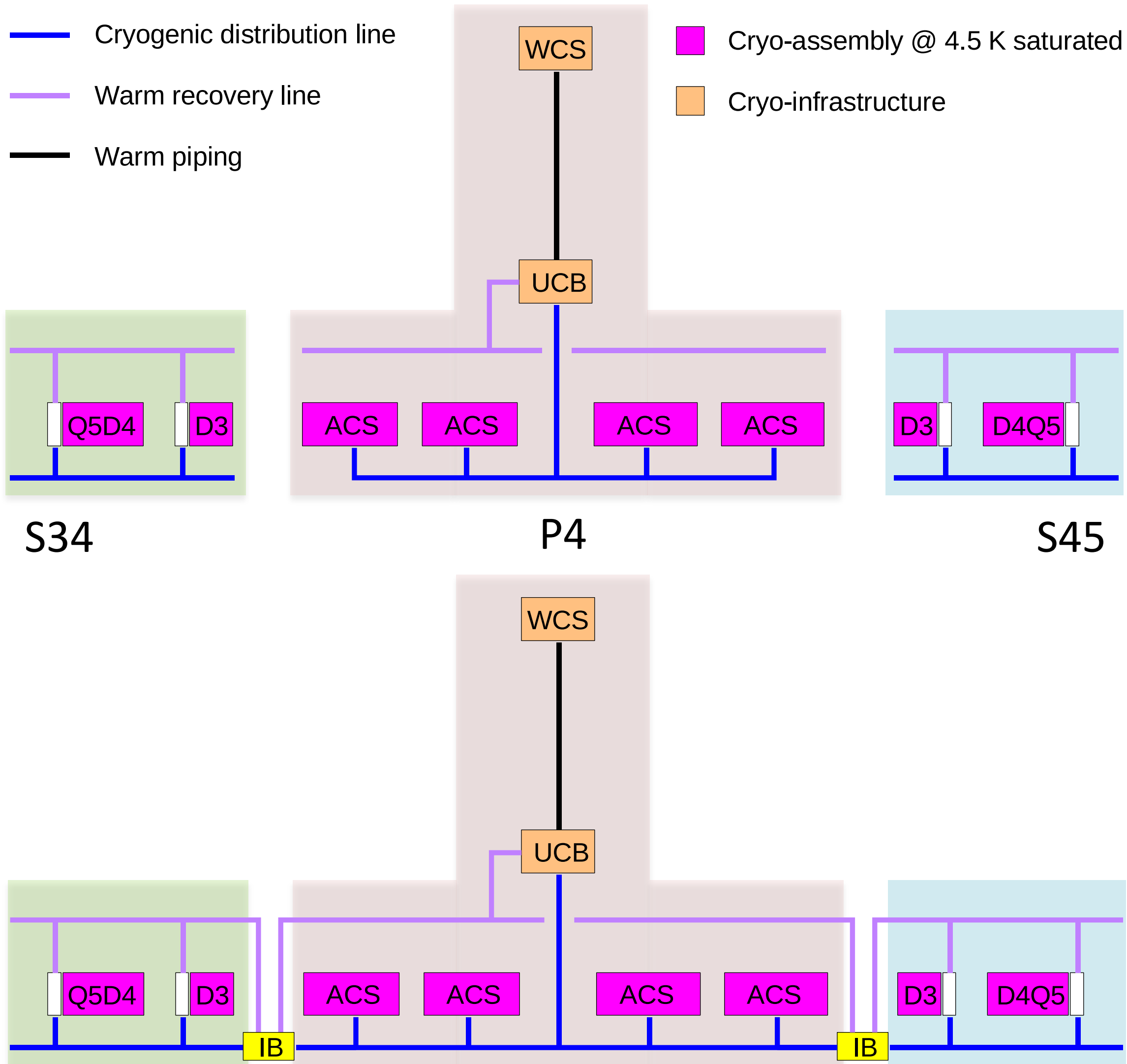
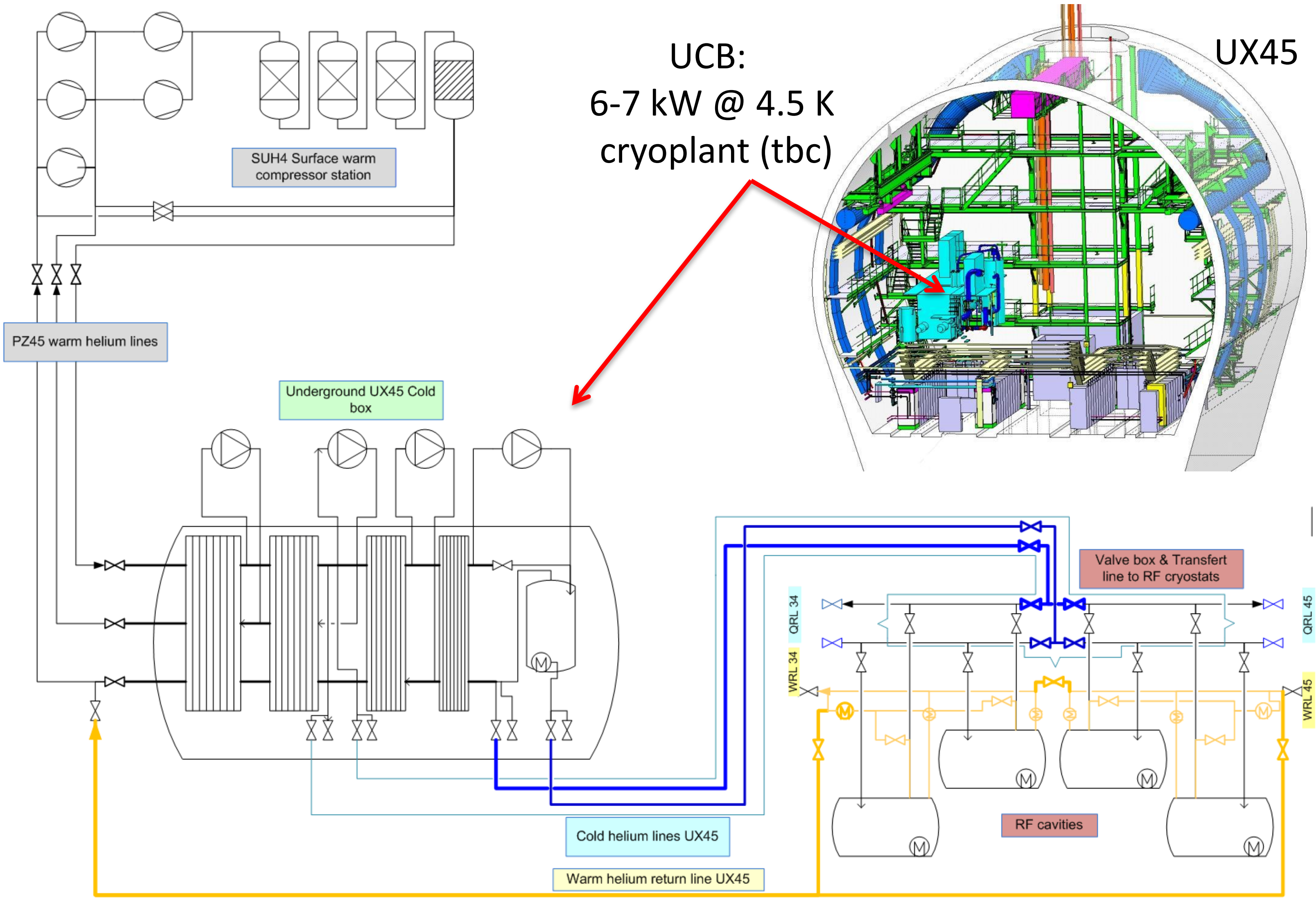
P4 Layout: new cryogenics for SRF module



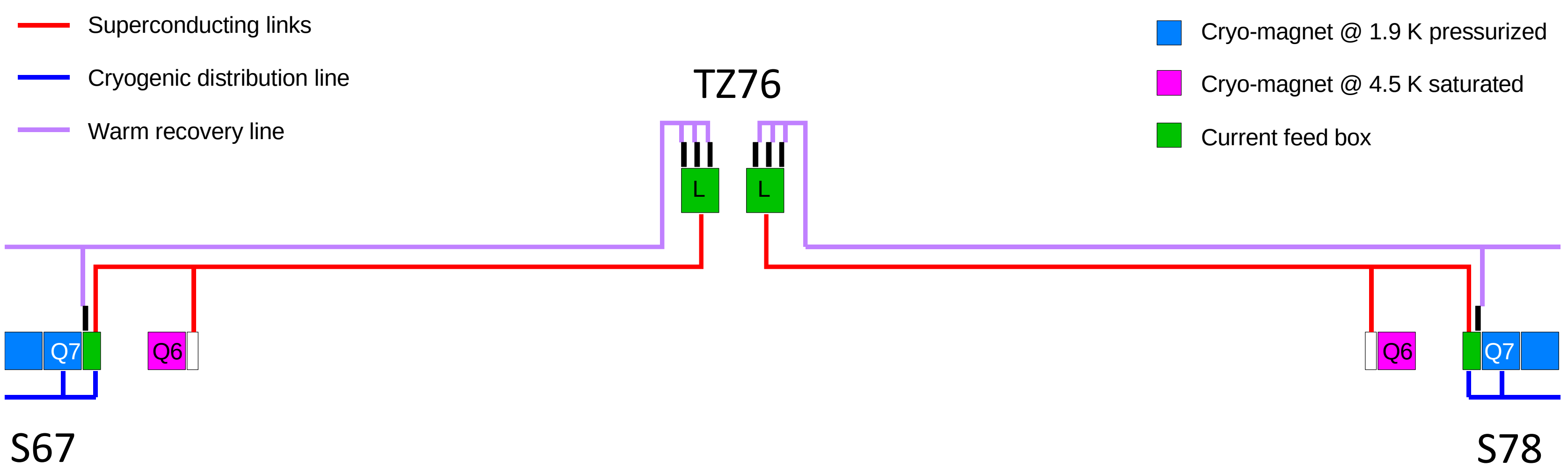
With interconnection for partial redundancy (Accepted as baseline)

P4 cryogenic process & flow diagram



P7 Layout: Deported current feed boxes

- New cooling circuits for SC links and deported current feed boxes
  - Extension of the warm recovery lines to the TZ76
  - Cryogenic design of new SC links and current feed boxes.



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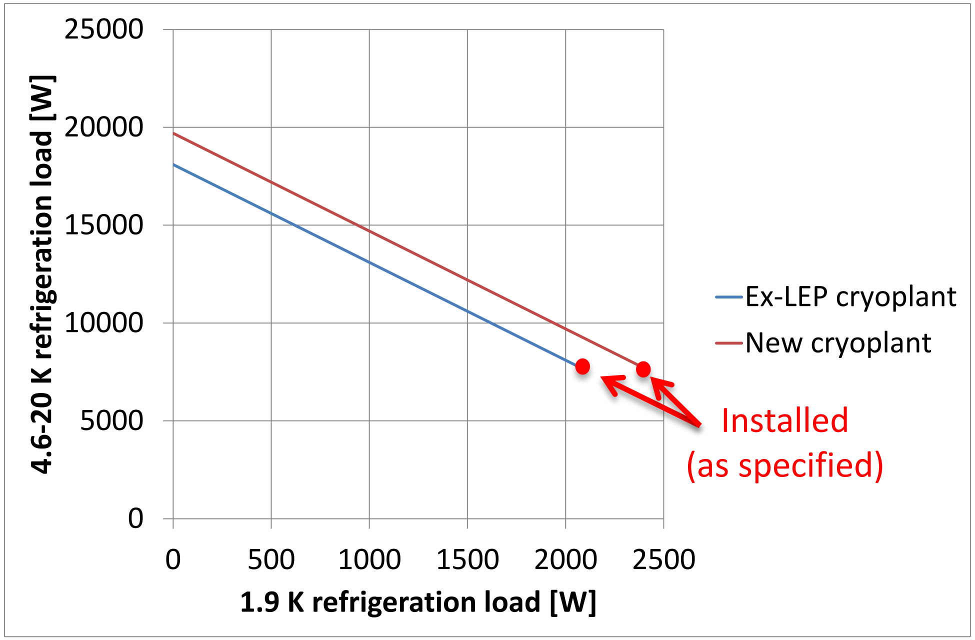
Sector heat loads: local limitation

- Synchrotron radiation → $Qsr = Qsr_{nom} \cdot \left(\frac{E}{E_{nom}}\right)^4 \cdot \frac{Nb}{Nb_{nom}} \cdot \frac{nb}{nb_{nom}}$
- Image current → $Qic = Qic_{nom} \cdot \left(\frac{Nb}{Nb_{nom}}\right)^2 \cdot \frac{nb}{nb_{nom}} \cdot \left(\frac{0.60 \cdot E + 2.80}{E_{nom}}\right)^{0.5} \cdot \left(\frac{\sigma}{\sigma_{nom}}\right)^p$
- Beam gas scattering → $Qbgs = Qbgs_{nom} \cdot \frac{Nb}{Nb_{nom}} \cdot \frac{nb}{nb_{nom}}$
- Resistive heating → $Qrh = Qrh_{nom} \cdot \left(\frac{E}{E_{nom}}\right)^2$

	LHC nominal	LH-LHC 25ns	LH-LHC 50ns
Nb	1.15E+11	2.2E+11	3.5E+11
nb	2808	2808	1404
bunch length [m]	7.50E-02	7.50E-02	7.50E-02

		Qs [W]	Qsr [W]	Qic [W]	Qbgs [W]	Qrh [W]	Total [W]	Locally installed [W]	Local margin (e.g. for e-cloud) [W]	Local margin (e.g. for e-cloud) [W/m per aperture]
Half-cell beam-screens @ 4.6-20 K	Nominal	7.5	18	19	0	0	44	255	211	**2.0**
	HL-LHC 25 ns	7.5	34	70	0	0	112	255	143	**1.3**
	HL-LHC 50 ns	7.5	27	89	0	0	123	255	132	**1.2**
Cell cold-masses @ 1.9 K	Nominal	18	0.11	0.12	5.1	11	34	90	56	**0.26**
	HL-LHC 25 ns	18	0.20	0.42	9.8	11	39	90	51	**0.24**
	HL-LHC 50 ns	18	0.16	0.53	7.8	11	37	90	53	**0.25**

Sector heat loads: global limitation



Load transfer from 1.9 K to 4.6-20 K refrigeration

~1 W/m per aperture available for e-cloud
→ ~20 % lower than local limitation (OK !)

		Total* [W]	Globally installed [W]	Global margin w/o load transfer [W]	Global margin w/o load transfer [W/m per aper.]	Global margin with load transfer [W]	Global margin with load transfer [W/m per aper.]
Sector beam-screens @ 4.6-20 K	Nominal	2597	7600	5003	**0.87**	10630	**1.8**
	HL-LHC 25 ns	6296	7600	1304	**0.23**	6243	**1.1**
	HL-LHC 50 ns	6951	7600	649	**0.11**	5850	**1.0**
Sector cold-masses @ 1.9 K	Nominal	975	2100	1125	**0.19**	0	0
	HL-LHC 25 ns	1112	2100	988	**0.17**	0	0
	HL-LHC 50 ns	1060	2100	1040	**0.18**	0	0

*: 54 half-cells + 1 LL inner triplet + 1 SC link

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Specific cryogenic studies and tests (or what differ from LHC design ?)

- Cooling circuits for large heat deposition:
  - on 1.9 K cold masses up to 10 W/m
    → heat extraction from SC cables and quench energy margin
    → Generic heat flow in magnet cross section
  - on beam-screens up to 13-20 W/m (image current effect ?)
- Cooling of HTS SC links and current feed boxes
- Cooling and pressure relief of crab-cavities
- Validation tests on SC link, crab-cavities, magnets, beam screens…
- Reactivation of the Heat Load Working Group
- Quench containment and recovery (cold buffering ?)
- Large-length cable (150 m) for cold-compressor controls and drives
- Large capacity (750-1500 W) sub-cooling heat exchangers
- Larger turndown capacity factor on 1.8 K refrigeration cycle: up to 10?

From users to cryogenic infrastructure

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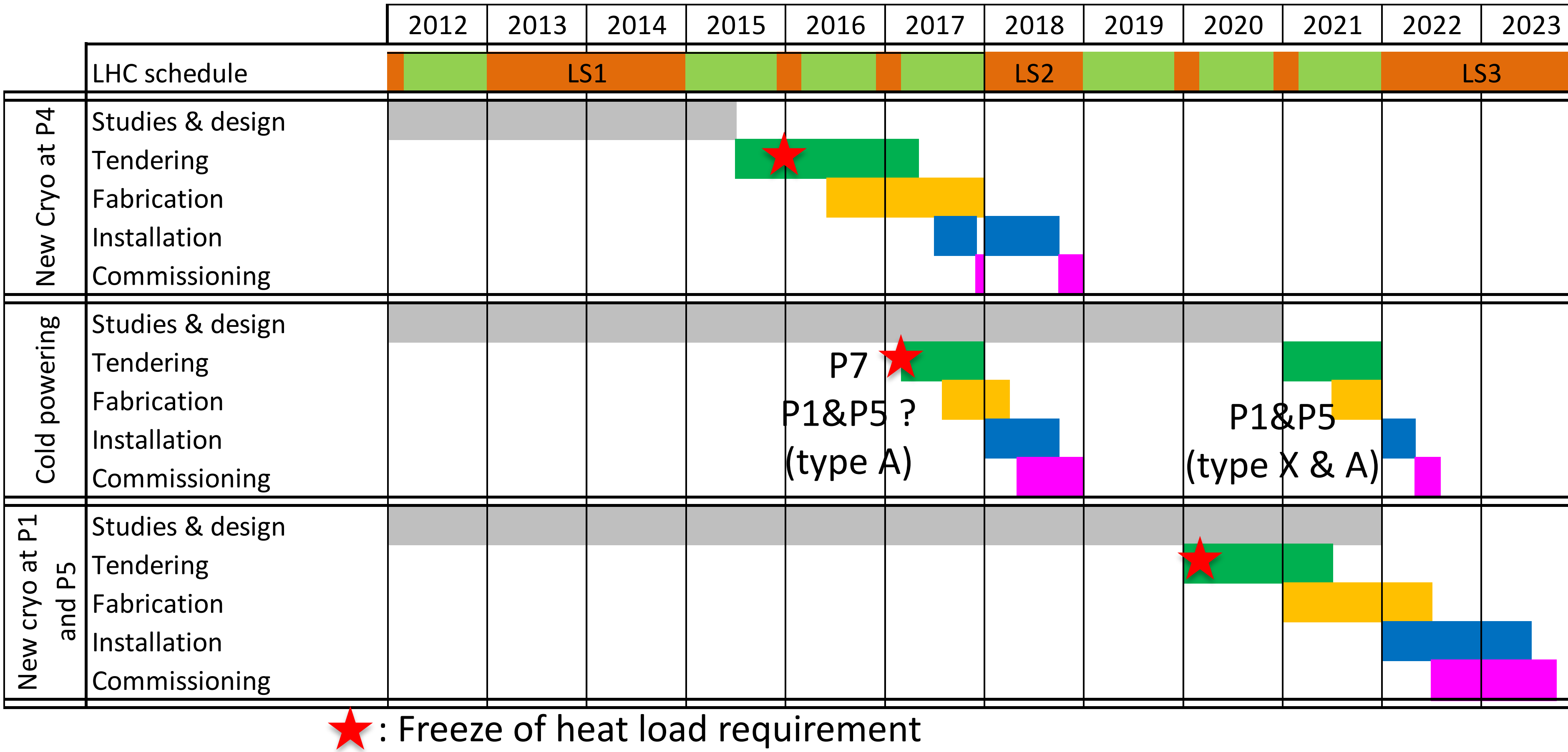
Schedule



2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
LHC schedule
LS1
LS2
LS3
New Cryo at P4
Studies & design
Tendering
Fabrication
Installation
Commissioning
Cold powering
Studies & design
Tendering
Fabrication
Installation
Commissioning
P7
P1&P5 ?
(type A)
P1&P5
(type X & A)
New cryo at P1 and P5
Studies & design
Tendering
Fabrication
Installation
Commissioning
: Freeze of heat load requirement

Conclusion

- Several HL-LHC cryogenic layouts have been presented with alternatives for cooling sectorization and redundancy → additional study needed for final decision
- Preliminary heat load estimate is defined :
  → local and global limitation for sector cryogenics are compatible with the proposed HL-LHC beam parameter.
  → the HLWG to refine and follow the heat load inventory have to be reactivated.
- Specific cryogenic studies and tests are defined → some of them have already started
- Integration study of new underground equipment must be done to validate:
  → the possible reuse of part of the existing distribution system (QRL)
  → the underground space availability for the cold compressor boxes at P1 and P5

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