The FCCee collider and booster: study of the SRF cryogenic systems and machine architecture

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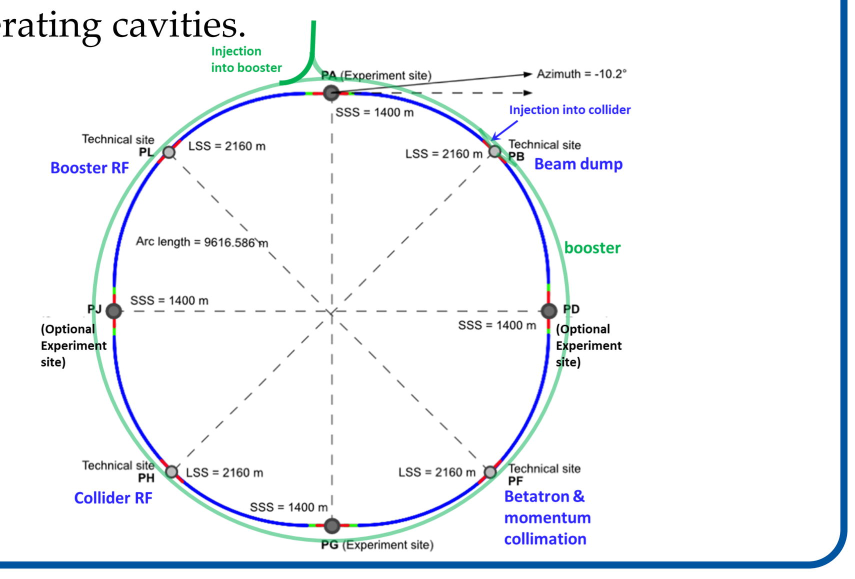
Introduction

CERN is leading an international collaboration study for the **Future Circular Collider (FCC)**, a new research infrastructure in a **91-km circular tunnel, to host the next generation of higher performance particle colliders** to extend the research currently being conducted at the LHC, and the High-Luminosity phase (HL-LHC) starting around 2040. Beams of electrons and positrons will have to be accelerated over increasing levels of energies (from 45.6 GeV to 182.5 GeV) while reducing current intensities (from 1.28 A to 5 mA) to keep the level of synchrotron radiation (SR) losses at 100 MW (50 MW per beam). The **staged increase in particle energy needs is obtained by increasing the number of cavities housed in CM**, during scheduled machine upgrades, in both the point H of the collider and point L of the booster. As a result, the layout of the **SRF system must allow accelerator hardware changes to be incremental during the scheduled machine upgrades,** without modifications to the accelerator tunnel civil engineering, technical systems and infrastructures, designed for the highest energy level since the beginning . At its highest energy layout (ttbar working point), the FCCee collider and booster will count 66 CM at 400 MHz, and 272 CM at 800 MHz, each housing four cavities, and covering a total SRF length of about 3.3 km. The total RF electrical power consumption is estimated to be almost 150 MW and the SRF system will require an unprecedented cryogenic cooling capacity in particle accelerators.

FCC layout

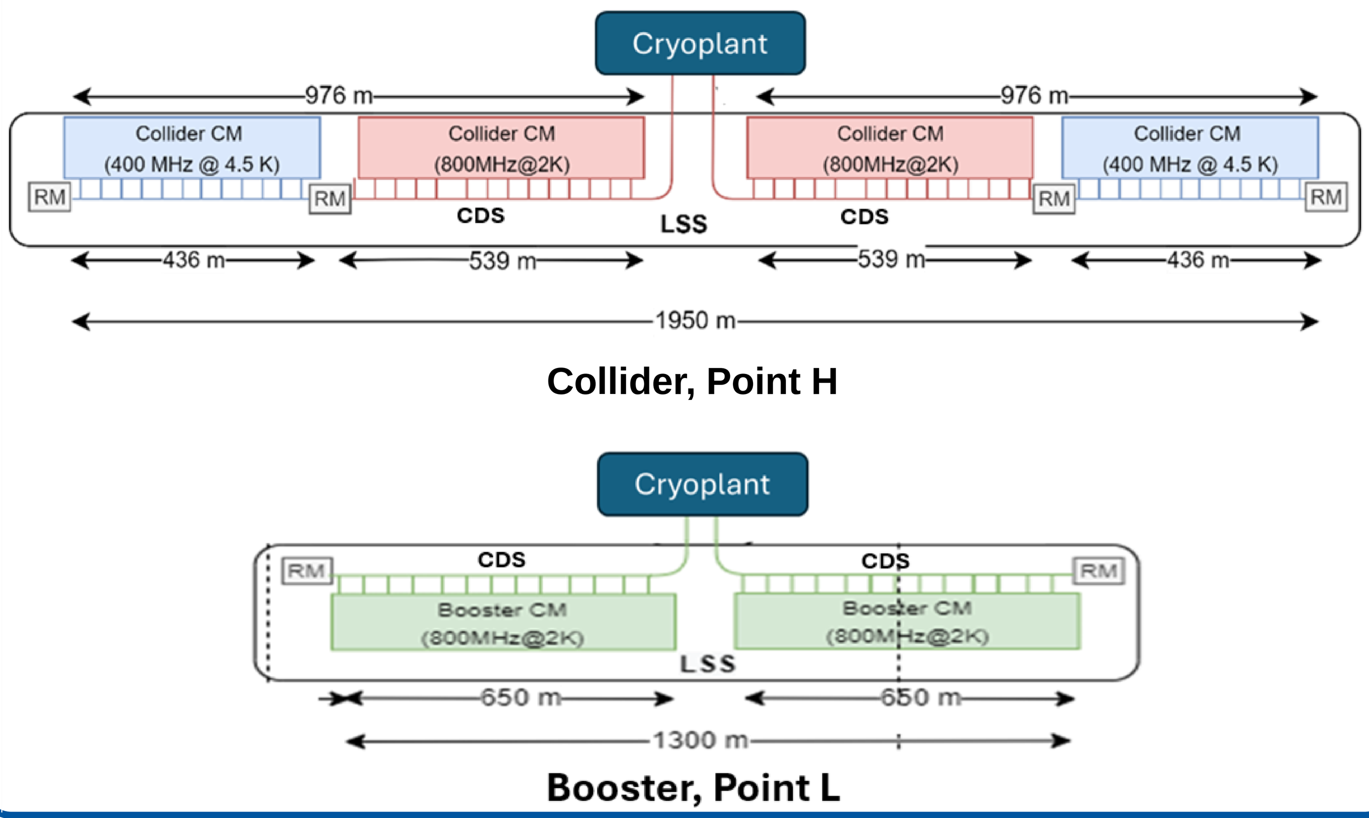
- 91km tunnel having 8 points for experiments and technical systems
- The tunnel host both the 2-beam collider ring and the booster ring
- Point H and Point L are dedicated to the SRF accelerating cavities.



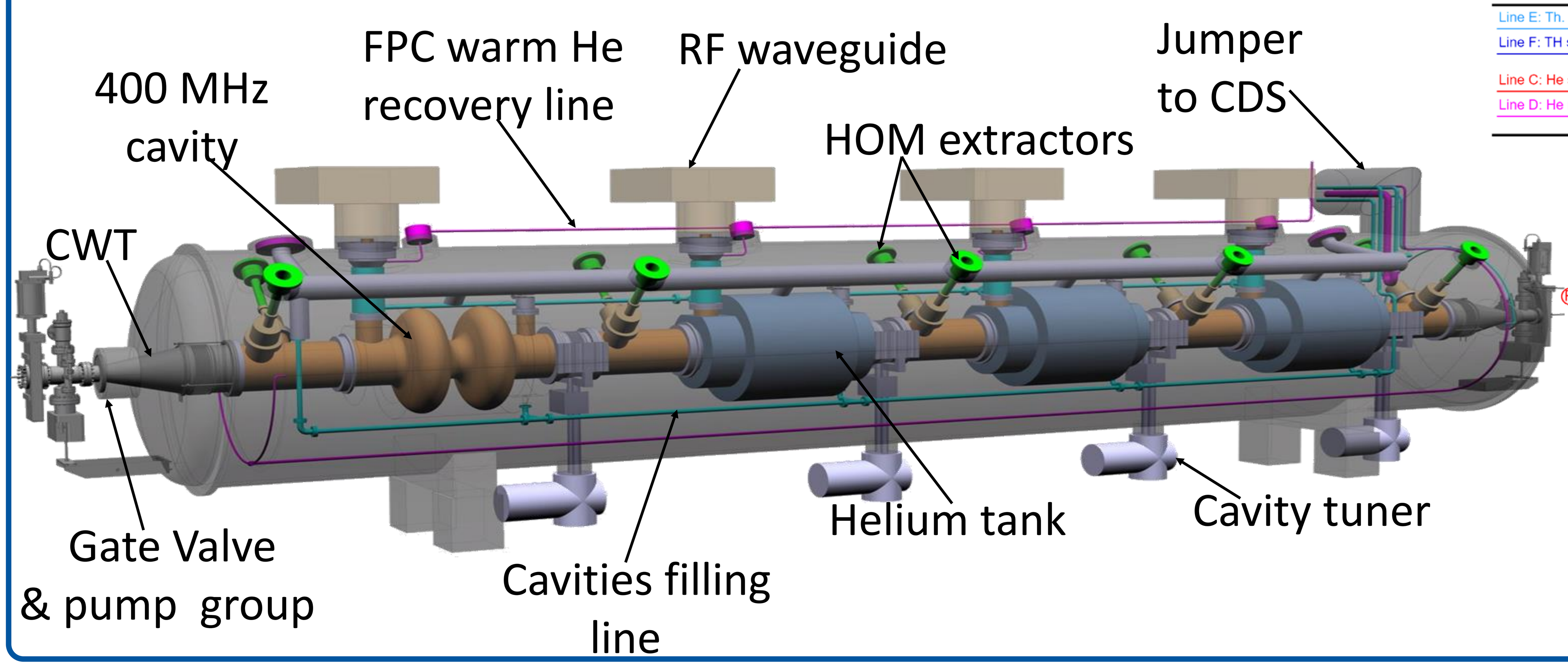
Parameters of the SRF system

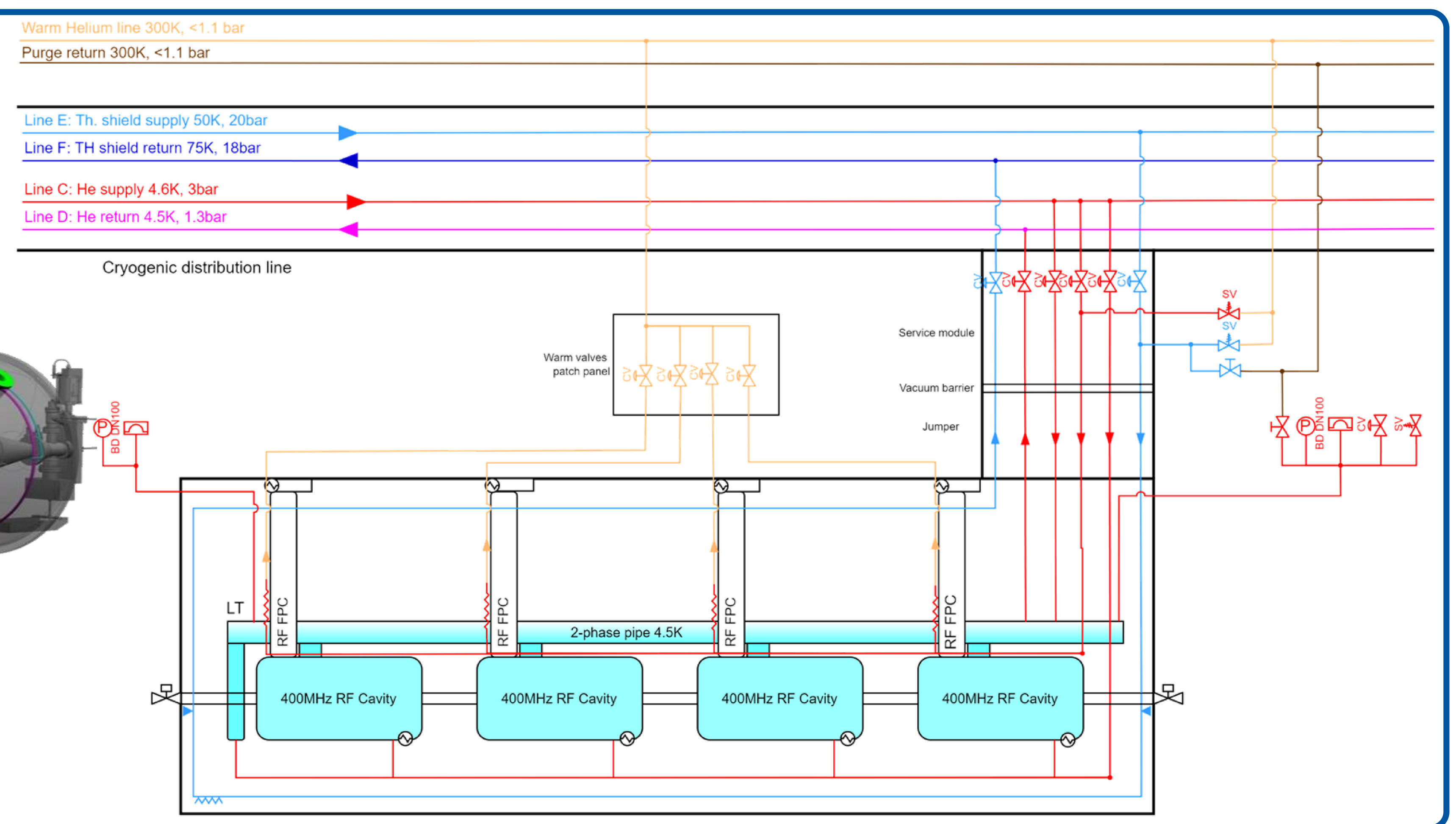
	Collider (Point H)	Collider (Point H)	Booster (Point L)
RF frequency [MHz]	400.79	801.58	801.58
Cavity type/technology	2-cell / Nb sputtered Cu	5-cell / bulk Nb	5-cell / bulk Nb
E_{acc} [MV/m]	10.6	20.1	20.1
Operating temp. [K]	4.5	2	2
Q_0	2.7E+09	3.0E+10	3.0E+10
RF power/cav. [kW]	78	163	5
Dynamic losses / cav [W]	129	23	3
#CM (with 4 cav/CM)	66	122	150

FCC cryogenic distribution system (at ttbar)

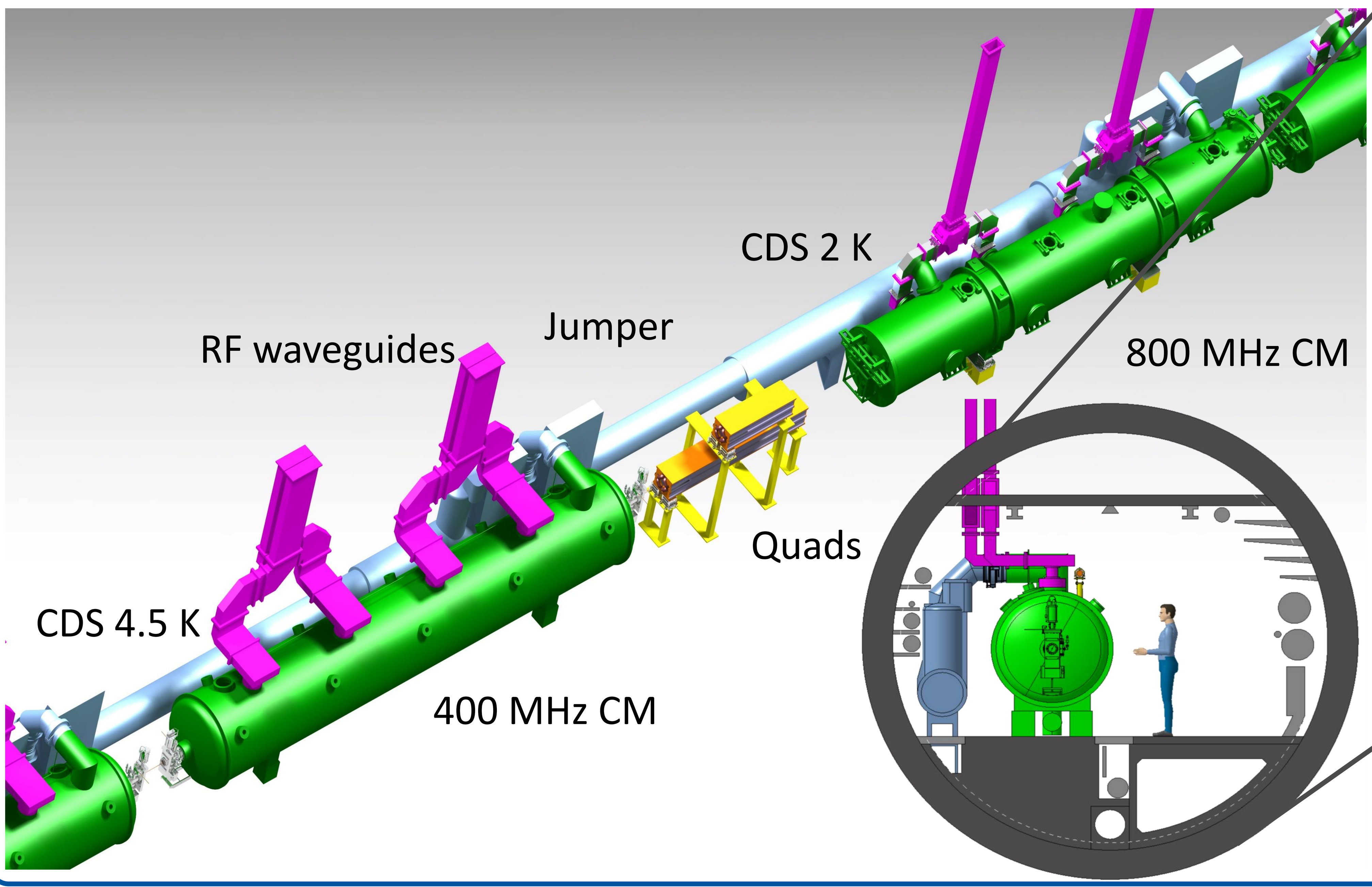


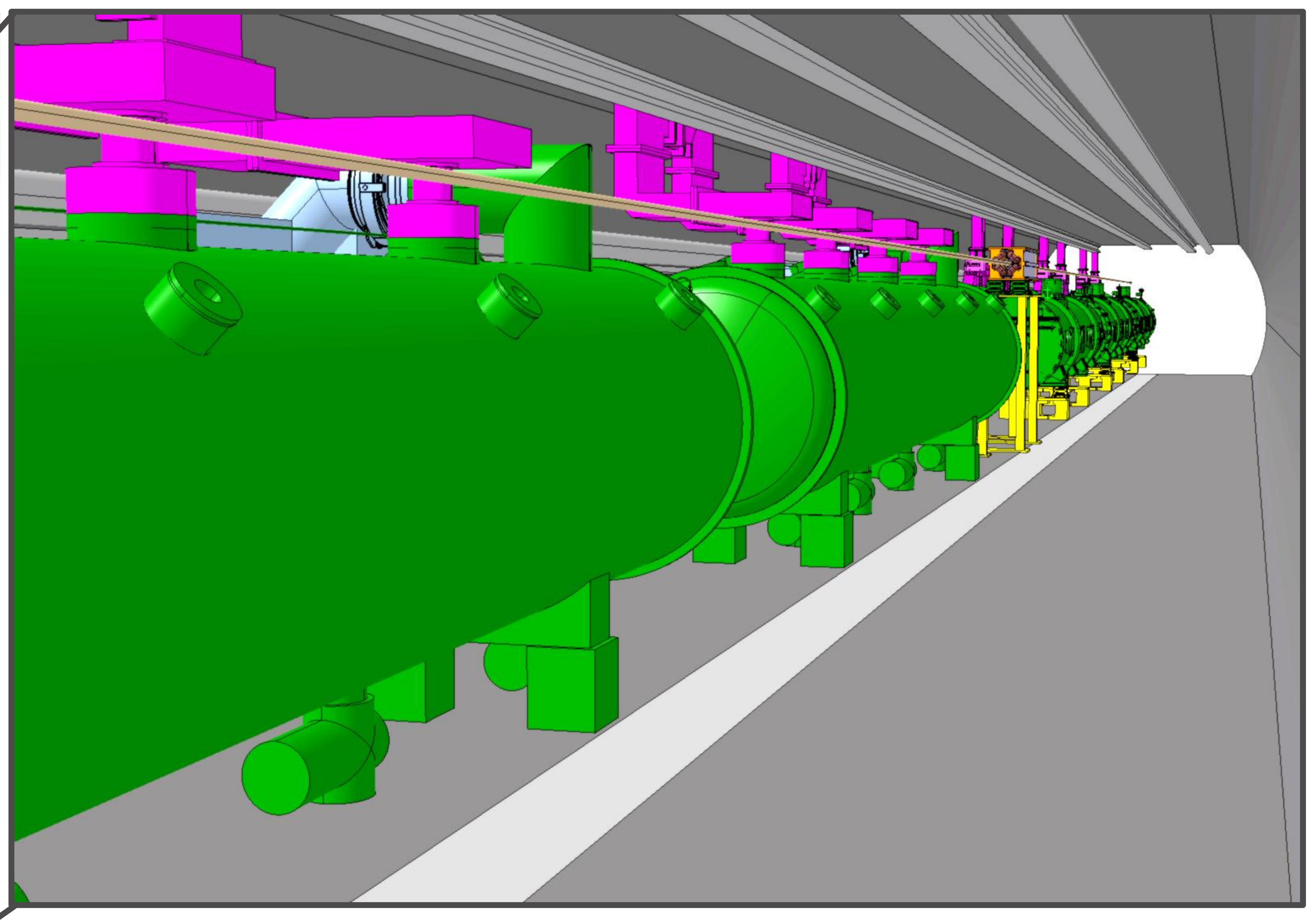
400MHz cryomodule and cryogenic scheme





Integration of the cryomodules in the tunnel in Point H





On the right, the view illustrates the CM interconnections, and the transition between the 400MHz and the 800MHz CMs, with the 4.5K and 2K CDS visible behind. On the Left, the cross section and isometric view of the 400MHz integrated in the tunnel.

Cryomodules and CDS Heat Loads (totals at ttbar, no margins)

	HL at 2K [W]	HL at 4.5K [W]	HL at 50K	Vapor cooling [g/s]
400MHz CM:				
Static	-	131	218	0.32
Dynamic	-	516		
800MHz CM:				
Static	32	-	103	0.32
Dynamic	92	-		
Total collider CM	15’128	42’702	26’954	60
Total CDS	350	1’200	6’600	-
Grand Total Collider	**15’478**	**43’902**	**33’554**	**60**
Total booster CM	6’600	-	15’450	48
Total CDS	340	-	4’600	-
Grand Total Booster	**6’940**	-	**20’050**	**48**

HL margins and installed cooling capacity

To define the installed cooling capacity the following margins must be considered. Due to the preliminary state of the design an uncertainty margin of 50% is applied on static heat loads, whereas no margin is applied to the dynamic load, assumed as qualification values.

An overcapacity factor of 1.5 is applied to define the final value of the installed cryogenic capacity, so that nominal performances can be ensure throughout the machine lifetime

$$Q_{installed} = 1.5 \times (1.5 \times Q_{static} + Q_{dynamic})$$

Summary and outlook

The architecture of the SRF systems for the **FCC is based on 400 MHz and 800 MHz cavities operating at 4.5 K and 2 K respectively and housed in standalone CMs.** Each unit can be conveniently added and connected to the warm beam lines, the CDS, and the RF power system according to energy upgrade needs. The **CDS, defined for the ttbar configuration, needs to be preinstalled in the tunnel from the very beginning of the FCC operation.** Cryogenic schemes have been defined as well as preliminary HL budgets. Future work includes the **engineering of the CM** and the **construction and test of full-scale demonstrators in the coming years.**