FCC_ee RF system: update – MARCH ‘22

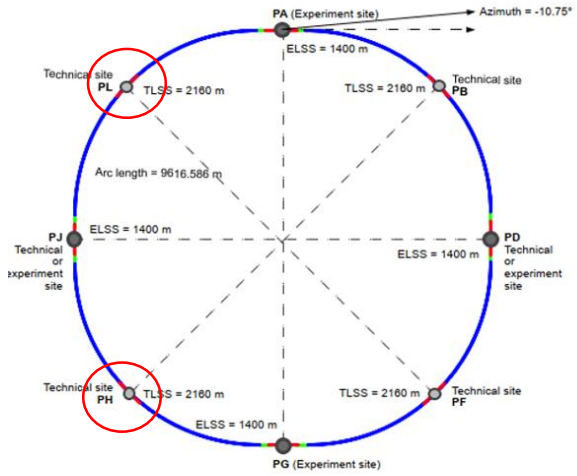
Goals:

- implement the recent updates (parameters, layout,)
- study the replacement of the 4_cells cavities by 2_cells cavities at 400MHz
- revisit the booster choices
- validate and document an updated baseline version
- update the integration and installation strategy
- list the main objectives of phase 2, including a viable timeline

F. Peauger, V. Parma, O Brunner

FCC_ee: recent updates

	Energy (GeV)	I (A)	RF voltage (GV)
Z	45.6	1.4	0.120
W	80	135	1
H	120	26.7	2.48
ttbar	182.5	5	11.67



TIWG 29/09/2021

- The RF voltages have recently been updated -> increased by ~ 20% compared to the CDR reference values
- Energy saw tooth issues considerations favor the following RF systems distribution:
  - Point L: Z, W, H
  - Point H: ttbar
- It seems logical that the booster for Z, W and H shall be installed at point L, the complement for ttbar at point H

FCC_ee: the scenarios

Baseline (CDR)

1 cell ELL_400 (Nb/Cu)

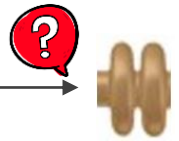
4 cells ELL_400 (Nb/Cu)

5 cells ELL_800 (bulk Nb)

Z

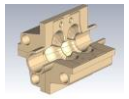
W, H

ttbar complement



2 cells

SWELL_600



2 cells SWELL_600 (Nb/Cu)

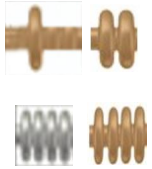
4 cells ELL_600 (bulk Nb or Nb/Cu)

Z, W, H

ttbar complement

→ Full demonstration – phase 3

ELL_600



1-2 cells ELL_600 (Nb/Cu)

4 cells ELL_600 (bulk Nb or Nb/Cu)

Z, W, H

ttbar complement

⛔ All scenarios -> strong impact on Z (and W) Ibeam

⛔ Mix 1_ and 2_ cells -> large impact on timeline

- The baseline is solid but needs to be optimized
- The SWELL validation is a long process –> no decision before end of phase 3 (test with beam)
- For now, Ell_600 MHz is no longer considered

FCC_ee CDR table update – solid, but not optimal

	Z		W		H		ttbar			
	per beam	booster	per beam	booster	per beam	booster	2beams	booster	2beams	booster
Frequency [MHz]	400						400		800	
RF voltage [MV]	**120**	**140?**	**1.0**	**1.0?**	**2.48**	**2.48?**	**4.96**	**2.48?**	**6.71**	**9.19**
Eacc [MV/m]	5.7	10	10	10	10	10	10	10	25	25
# cell / cav	1	4	4	4	4	4	4	4	**5**	**5**
Vcavity [MV]	2.14	12	15	15	15	15	15	15.6	23.44	23.44
#cells	56	48	272	272	672	672	1344	672	1320	1960
# cavities	56	12	68	68	168	168	336	168	264	392
# CM	14	3	17	17	42	42	84	42	66	98
T operation [K]	4.5						2			
dyn losses/cav [W]	18.5	210	210	210	228	228	228	228	65	65
stat losses/cav [W]	8									
Qext	60k									
Detuning (kHz)	-9.78									
Pcav [kW]	~950		~950		~300		~150		~150	

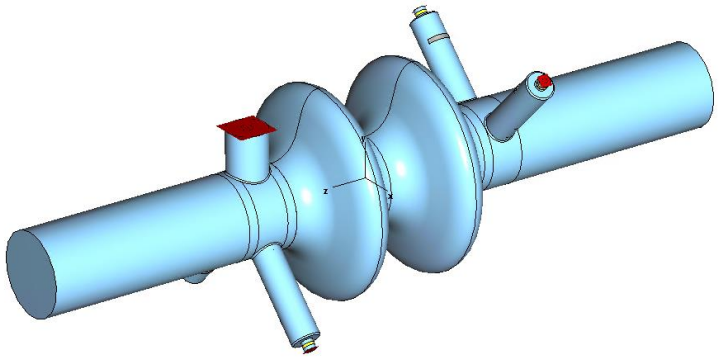
RF system per beam

RF system common for both beams

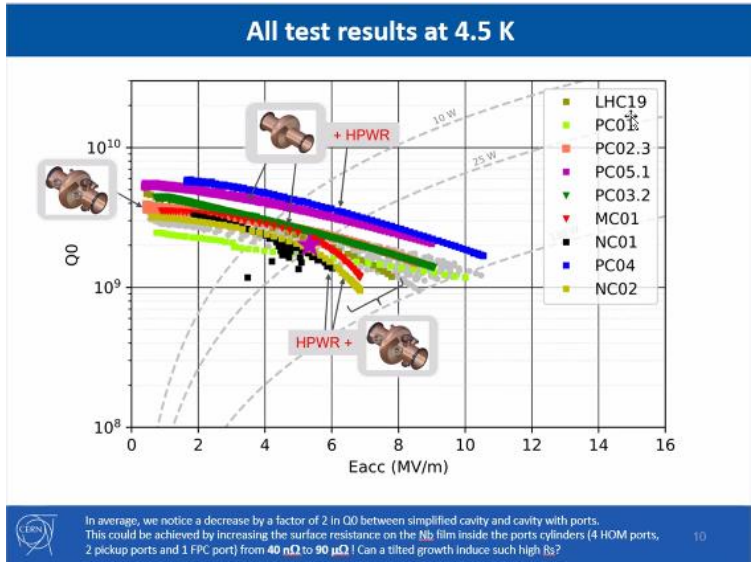
- **400 MHz 4_cells cavities are:**
  - Technically extremely challenging (big infrastructures for surface preparation, coating, prone to ponderomotive oscillations)
  - Limiting the W performances (limited by HOMs)
  - Not optimum for a common RF system for both beams for the H

FCC_ee: proposed baseline changes

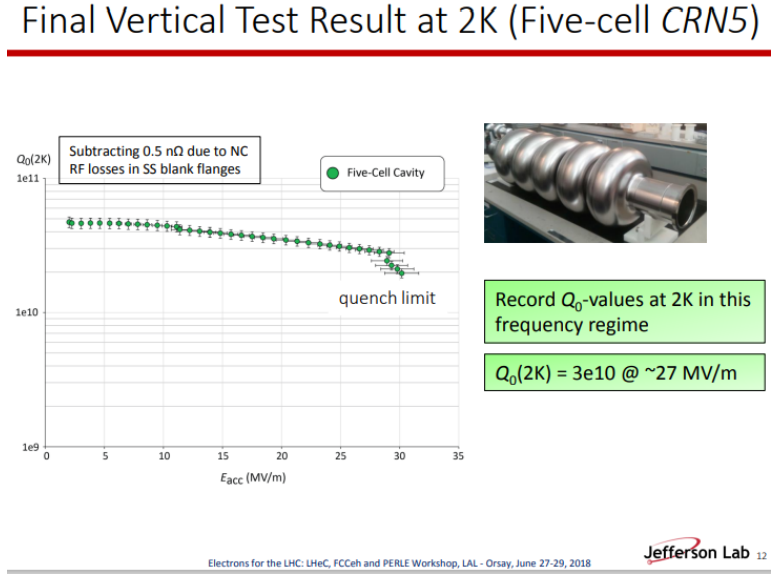
- Replace 4_cells cavities by 2_cells cavities at 400 MHz -> relaxed beam – cavity interactions
- 400 MHz: Consider E_{acc} = 10 MV/m (2_cells cavities), Q_o = 3.E9, 4.5K (eventually 12 MV/m Q_o = 2.E9) – see below
- 800 MHz: Increase E_{acc} from 20 MV/m to 25 MV/m for the bulk Nb 800 MHz system (less conservative but still realistic)
- Booster (Z): consider 400 MHz 2_cells, 4.5K, as the beam current is important (~140mA)
- Booster (W, H, ttbar): consider 800 MHz, 5_cells, 2K, acceleration performances considerations



Sosoho-Abasi Udongwo , Univ. of Rostock



Franck Peauger, TTC meeting 2020



Franck Marhauser, 2018

FCC_ee - CDR best alternative – 2_cells option (400MHz)

	Z		W		H		ttbar			
	per beam	booster	per beam	booster	2 beams	booster	2 beams	booster	2 beams	booster
Frequency [MHz]	400	400	400	800	400	800	400	800	800	800
RF voltage [MV]	120	140	1000	1000	2480	2480	2480	2480	9190	9190
Eacc [MV/m]	5.72	11.67	11.91	24.26	11.99	25.45	11.99	25.45	25.02	25.02
# cell / cav	1	2	2	5	2	5	2	5	5	5
Vcavity [MV]	2.14	8.75	8.93	22.73	8.99	23.85	8.99	23.85	23.44	23.44
#cells	56	32	224	220	552	520	552	520	1960	1960
# cavities	56	16	112	44	276	104	276	104	392	392
# CM	14	4	28	11	69	26	69	26	98	98
T operation [K]	4.5	4.5	4.5	2	4.5	2	4.5	2	2	2
Pcav [kW]	962	337	440	112	357	95	~150	18	~150	3

RF system per beam

RF system common for both beams

- RF system per beam only for Z and W -> common for H and ttbar (~confirmed by Ivan)
- Booster 800 MHz for W, H, ttbar -> 2K required at point L (NEW)
- RF power:
  - ~1 MW only for Z (fixed FPC, TS klystron)
  - Moderate RF power for W, H, ttbar -> relaxed FPC challenges, use half height wave guides (400 MHz)

	Z		W		H		ttbar			
	per beam	booster	per beam	booster	2 beams	booster	2 beams	booster	2 beams	booster
Frequency [MHz]	400	400	400	800	400	800	400	800	800	800
RF voltage [MV]	120	140	1000	1000	2480	2480	2480	2480	9190	9190
Eacc [MV/m]	5.72	11.67	11.91	24.26	11.99	25.45	11.99	25.45	25.02	25.02
# cell / cav	1	2	2	5	2	5	2	5	5	5
Vcavity [MV]	2.14	8.75	8.93	22.73	8.99	23.85	8.99	23.85	23.44	23.44
#cells	56	32	224	220	552	520	552	520	1960	1960
# cavities	56	16	112	44	276	104	276	104	392	392
# CM	14	4	28	11	69	26	69	26	98	98
T operation [K]	4.5	4.5	4.5	2	4.5	2	4.5	2	2	2
dyn losses/cav [W]	19	167	174	50	176	55	176	55	53	53
stat losses/cav [W]	8	8	8	8	8	8	8	8	8	8
Qext	6.0E+04	1.5E+06	1.2E+06	8.9E+06	1.5E+06	1.2E+07		6.2E+07		4.2E+08
Detuning [kHz]	9.777	0.470	0.430	0.115	0.121	0.031	0.034	0.006	0.089	0.009
Pcav [kW]	962	337	440	112	357	95		18		3
rhob [m]	9935	9935	9935	9935	9935	9935	9935	9935	9935	9935
Energy [GeV]	45.6	45.6	80.0	80.0	120.0	120.0		120.0	182.5	182.5
energy loss [MV]	38.50	38.50	364.70	364.70	1846.31	1846.31		1846.31		997.09
cos phi	0.32	0.27	0.36	0.36	0.74	0.74		0.74		0.11
Beam current [A]	1.400	0.140	0.135	0.014	0.053	0.005	0.010	0.001	0.010	0.001
Lacc [m]	0.375	0.749	0.749	0.937	0.749	0.937	0.749	0.937	0.937	0.937
#cav/CM	4	4	4	4	4	4	4	4	4	4
R/Q [ohm]	79	152.8	152.8	521	153	521	153	521	521	521
G [ohm]	196.20	196.34	196.34	273.20	196.34	273.20	196.34	273.20	273.20	273.20
Q0	3.0E+09	3.0E+09	3.0E+09	2.0E+10	3.0E+09	2.0E+10	3.0E+09	2.0E+10	2.0E+10	2.0E+10
Ep/Eacc	1.90	2.05	2.05	2.00	2.05	2.00	2.05	2.00	2.00	2.00
Bp/Eacc	4.10	6.39	6.39	4.20	6.39	4.20	6.39	4.20	4.20	4.20
Ep [MV/m]	10.86	23.93	24.42	48.52	24.58	50.91	24.58	50.91	50.05	50.05
Bp [mT]	23.44	74.60	76.12	101.89	76.61	106.90	76.61	106.90	105.10	105.10
Cavity design	UROS1	C3794	C3794	UROS5	C3794	UROS5	C3794	UROS5	UROS5	UROS5

CDR vs NEW baseline proposal

		Z		W		H		ttbar				
		machine	booster	machine	booster	machine	booster	machine	booster	machine	booster	
CDR	#CM (total)	28	3	34	17	84	42	84	42	66	98	->372 CM
NEW	#CM (total)	28	4	56	11	69	26	69	26	98	98	->390 CM

Point L

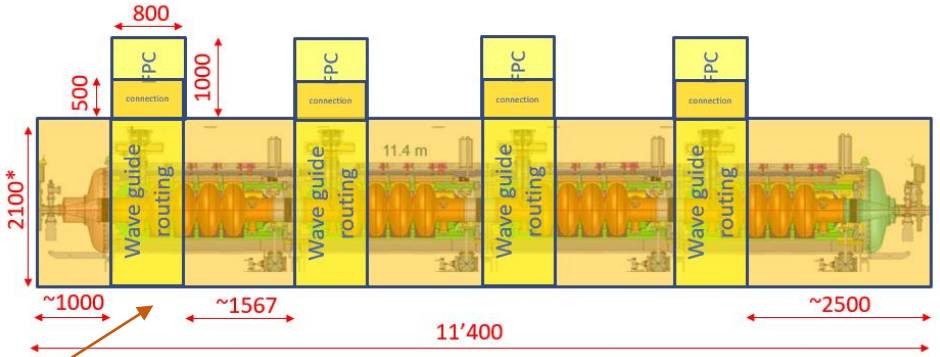
Point H

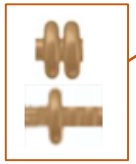
- Z machine remains THE challenging machine
- NEW proposal:
  - similar total number of cavities, with reduced complexity
  - Less critical beam cavity (HOMs) for W and H
  - Reduced RF power requirements & better re-usage of existing HW – split or combined RF distribution systems
  - Allows half height waveguides for W , H, ttbar -> more compact RF power and distribution systems
  - Relaxes the FPC parameters: high power fixed coupler for Z, medium power movable FPC for W, H, ttbar (for high gradient)

Cryomodules types

400 MHz Cryomodule

Longitudinal space occupation

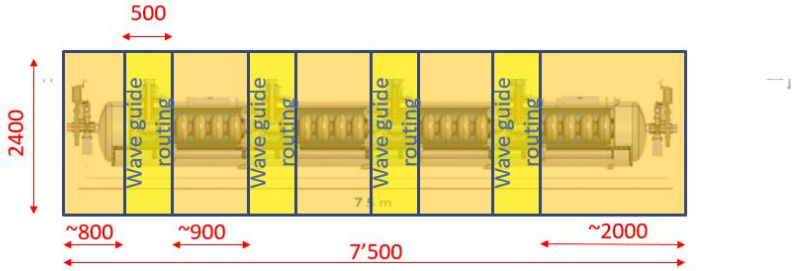




800 MHz CM (based on SPL design, bottom RF coupler)

Longitudinal space occupation

- Cryomodule, FPC, WG space envelopes (does not include WG routing to ceiling)



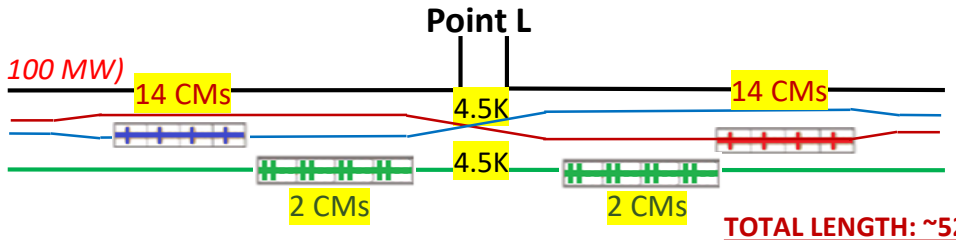
V.Parma/E. Montesinos

- Consider only 2 types of CM
- Same CM design for 1_cells (Z) and 2_cells (W, H) 400 MHz systems – distance between WG must remain constant
- The use of half-height WG may allow to reduce the number of WG holes – to be studied in details

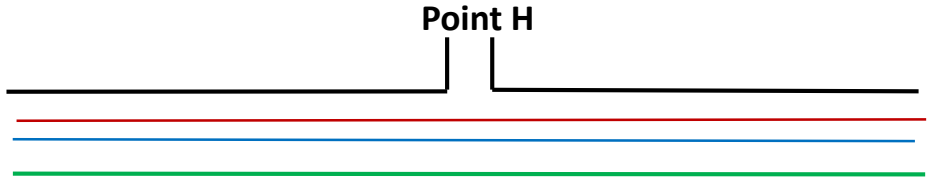
Integration – option 1 (point H for ttbar complement only)

Z machine *(0.12 GV, 100 MW)*

400MHz Beam 1
400MHz Beam 2
Booster



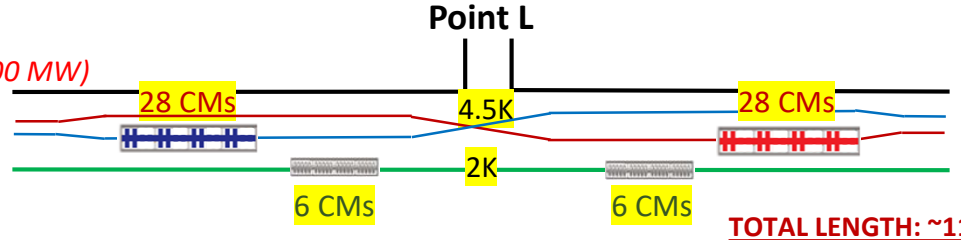
TOTAL LENGTH: ~522 m (tbc)



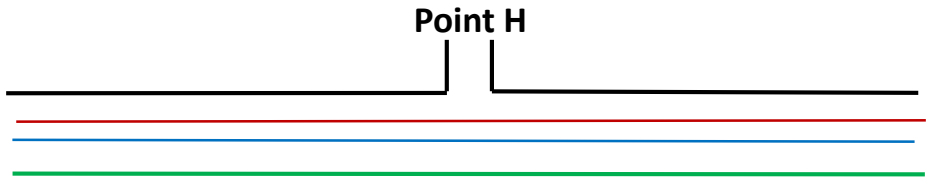
TOTAL LENGTH: ~0 m (tbc)

W machine *(1 GV, 100 MW)*

400MHz Beam 1
800MHz Beam 2
Booster



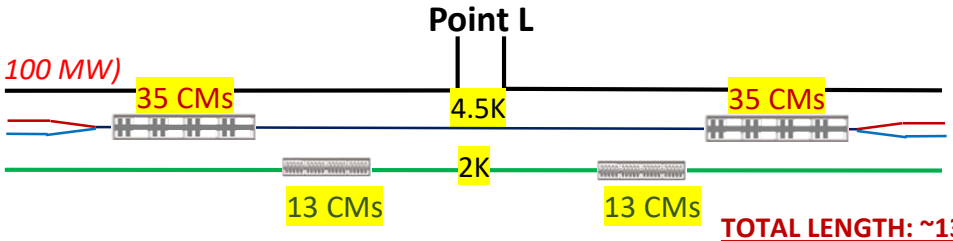
TOTAL LENGTH: ~1120 m (tbc)



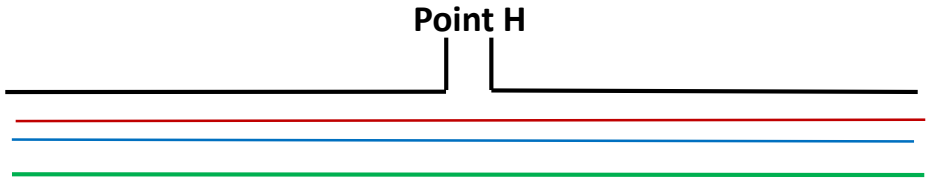
TOTAL LENGTH: ~0 m (tbc)

H machine *(2.48 GV, 100 MW)*

400MHz Beam 1
800MHz Beam 2
Booster



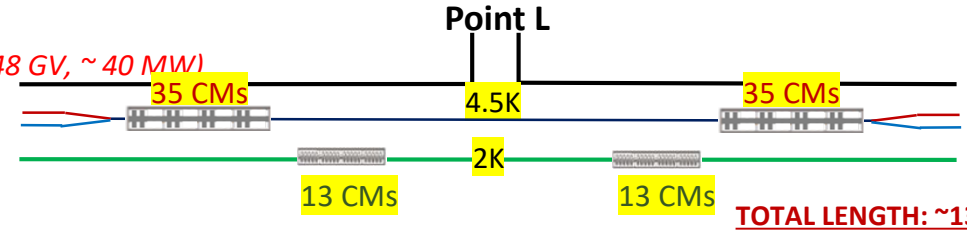
TOTAL LENGTH: ~1370 m (tbc)



TOTAL LENGTH: ~0 m (tbc)

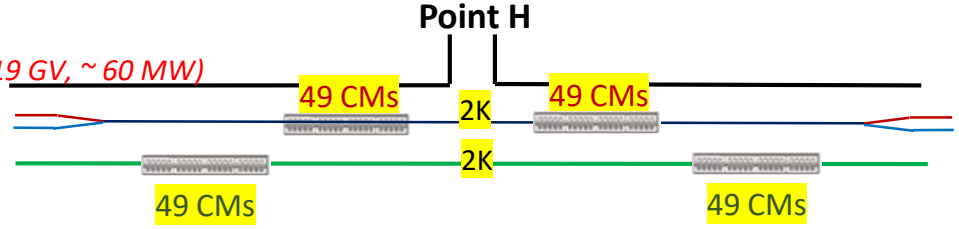
ttbar machine *(2.48 GV, ~ 40 MW)*

400MHz Beam 1
800MHz Beam 2
Booster



TOTAL LENGTH: ~1370 m (tbc)

(9.19 GV, ~ 60 MW)



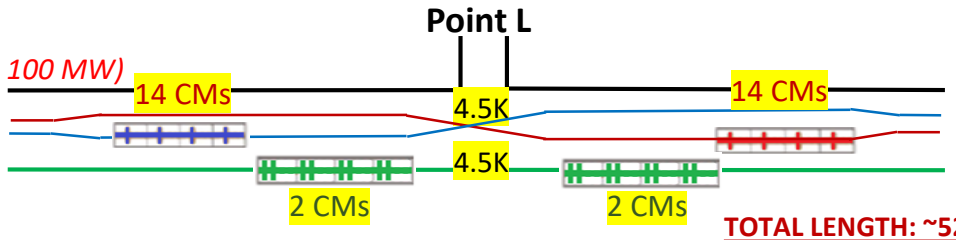
TOTAL LENGTH: ~1727 m (tbc)

Integration – option 2 (2K at point H only)

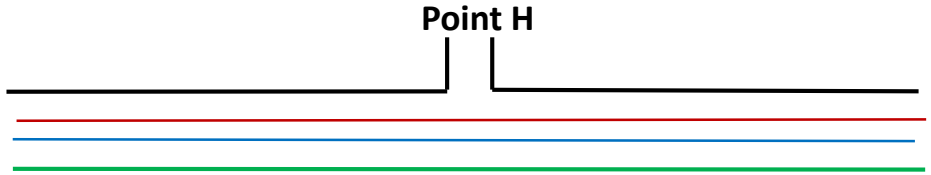
Z machine *(0.12 GV, 100 MW)*

400MHz
400MHz

Beam 1
Beam 2
Booster



TOTAL LENGTH: ~522 m (tbc)

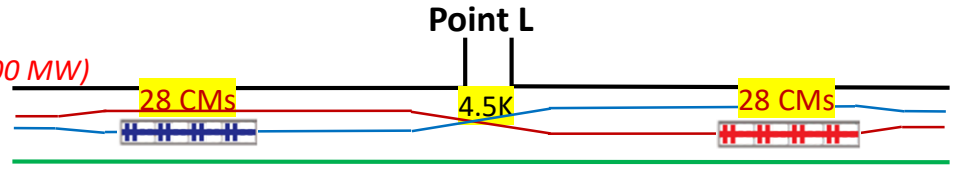


TOTAL LENGTH: ~0 m (tbc)

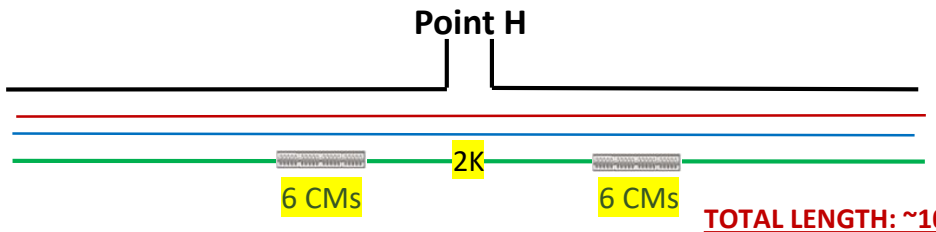
W machine *(1 GV, 100 MW)*

400MHz
800MHz

Beam 1
Beam 2
Booster



TOTAL LENGTH: ~913 m (tbc)

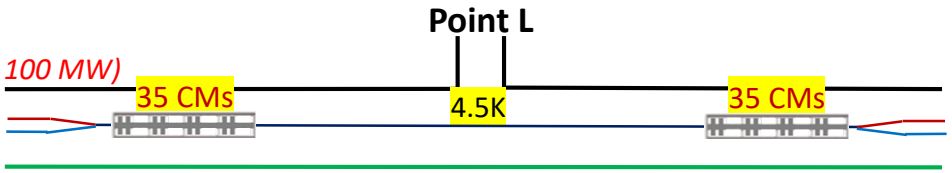


TOTAL LENGTH: ~106 m (tbc)

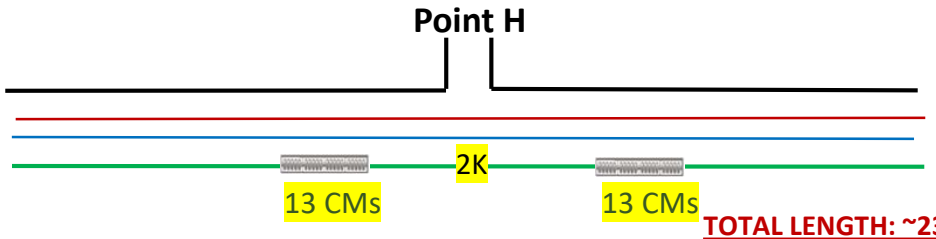
H machine *(2.48 GV, 100 MW)*

400MHz
800MHz

Beam 1
Beam 2
Booster



TOTAL LENGTH: ~1141 m (tbc)

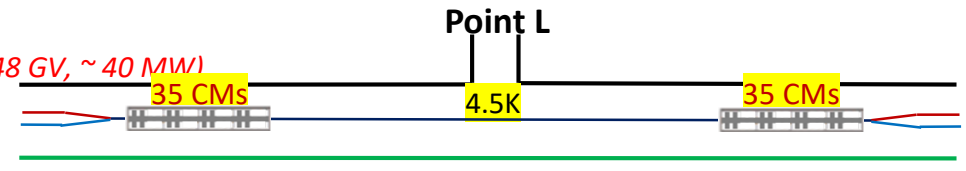


TOTAL LENGTH: ~230 m (tbc)

ttbar machine *(2.48 GV, ~ 40 MW)*

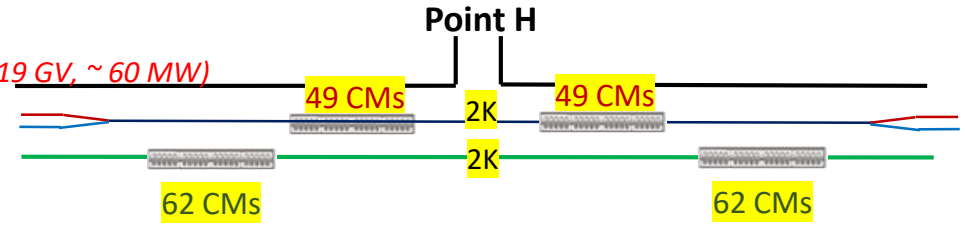
400MHz
800MHz

Beam 1
Beam 2
Booster



TOTAL LENGTH: ~1141 m (tbc)

(9.19 GV, ~ 60 MW)



TOTAL LENGTH: ~1955 m (tbc)

FCC_ee main challenges for phase 2 – in priority order

- Cavity Studies & Beam Dynamics
  - complete baseline and SWELL_600 studies (beam cavities interactions, HOM power extraction)
  - define optimum overall scenarios (machine, booster and injector)
- ELL_400 MHz (1_cell): demonstrate > 10-12 MV/m
  - continue the Ell_1.3 GHz program (Q0 > 10^{10} at > 20 MV/m, 2 K). Qualify & optimize substrate fabrication
  - qualify & optimize large substrate fabrication, preparation and coating – large series
- SWELL
  - SWELL_1.3 GHz: demonstrate competitive E_{acc} qualify prep, coating, mechanical design, assembly and RF test procedures
  - SWELL_600 MHz: demonstrate concept: RF & mechanical design, multipactor, vacuum, assembly, cooling, tuning -> engineering studies
  - Mid2023: review and decision on SWELL_600 MHz prototype
- FPC:
  - develop, build and test new generation of couplers for LHC cavities @ 400 MHz, ~500 kW CW (document design consideration for fixed 1 MW FPC)
  - develop, build and test couplers for high gradient cavities
  - develop, build and test couplers for SWELL -> construction during phase 3
- TS HE klystron:
  - finalize full RF design of 400 MHz, 1.2 MW, 80% tube -> investigate fabrication possibilities (THALES) plus testing possibilities (e.g. CEA Saclay)
- WOW:
  - qualify & optimize surface preparation & coating on complex shapes (incl. dev of related simulation tools)
- CTD:
  - Study and design full concept, including cooling schemes -> for construction during phase 3

Program timeline