

INTEGRATION OF RF POINTS FOR FCC-EE

F. Valchkova-Georgieva and Marc Timmins

With contribution from : V. Parma, S. Gorgi Zadeh, F. Peauger, I. Karpov, F. Cottenot, C. Sharp, S. Calvo, L. Delprat
And inputs from: D. Passarelli (FNAL), V. Roger (FNAL) and CERN technical infrastructure working group
FCC week 2025, Vienna

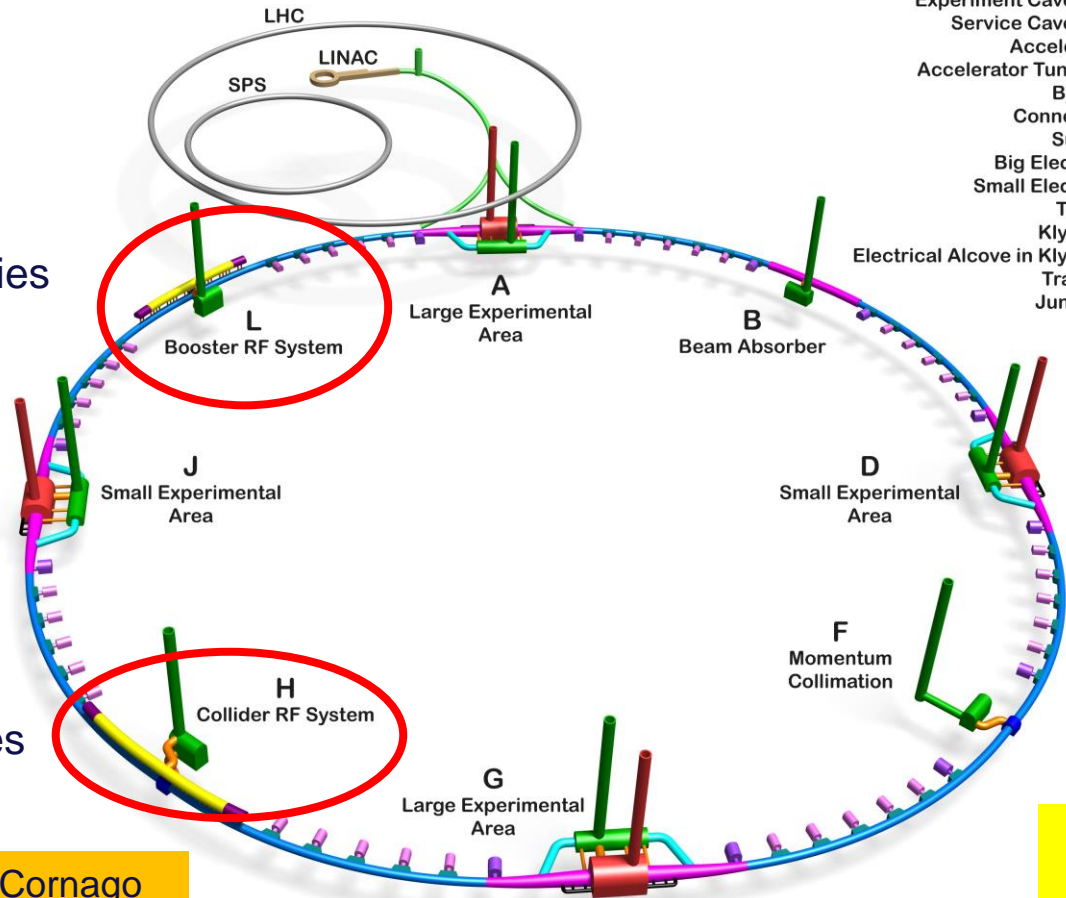
Outline

1. CM design and assumptions for feasibility study
2. CM Integrations in Pts H and L
3. Optimizations as part of the pre -TDR phase
4. Underground structure integration for Pt H and L
5. Next steps
6. Virtual visit

FCC-ee Underground Structure Overview

Booster
800 MHz cavities

Collider
400 & 800 MHz cavities



- Experiment Cavern and Shaft
- Service Cavern and Shaft
- Accelerator Tunnel
- Accelerator Tunnel Widening
- Bypass Tunnel
- Connection Tunnel
- Survey Gallery
- Big Electrical Alcove
- Small Electrical Alcove
- Transport Bay
- Klystron Gallery
- Electrical Alcove in Klystron Gallery
- Transfer Tunnel
- Junction Cavern

Only schematic,
and not to scale.

Courtesy A. Navascues Cornago

1. Base line parameters for feasibility study

Collider

Collider	Z	W	ZH
	1 beam RPO	1 beam	2 beams
Total RF voltage [MV]	89	1049	2098
Beam current [mA]	1292	135	2 x 26.8
RF Frequency [MHz]		400.79	
Operating temp. [K]		4.5	
Cavity voltage [MV]		7.95	
# cell/cavity		2	
Eacc [MV/m]		10.6	
Q0		2.70E+09	
RF power [kW]		380	
Optimum coupling QL		9.2E+05	
# CM (with 4 cav/CM)		66	
# cavities		264	

	ttb collider	
	2 beams	
Total RF voltage [MV]	2098	9202
Beam current [mA]	10	
RF Frequency [MHz]	400.79	800.58
Operating temp. [K]	4.5	2
Cavity voltage [MV]	7.95	22.5
# cell/cavity	2	6
Eacc [MV/m]	10.6	20.1
Q0	2.7E+9	3E+10
RF power [kW]	78	195
Optimum coupling QL	4.5E+06	4.1E+06
# CM (with 4 cav/CM)	66	102
# cavities	264	408



RPO (same cavities and CM for Z, W, ZH)

- 400 MHz 2 cell cavity for all working points. (Pt H. 66)
- 800 MHz 6 cell cavity (Pt L. 102)

Booster

Booster	Z	W	ZH
	RPO	RPO	
Total RF voltage [MV]	80	401.9	1961
Beam current [mA]	16.2	6.2	2
RF Frequency [MHz]		801.58	
Operating temp. [K]		2	
Cavity voltage at extraction [MV]	5.6	13.5	17.5
# cell/cavity		6	
Eacc [MV/m]	4.9	12	15.6
Q0		3E+10	
Max RF power [kW]		42	
Coupling QL		1E+07	
# CM (with 4 cav/CM)		28	
# cavities		112	

	ttb booster	
	1 beam	
Total RF voltage [MV]	10180	
Beam current [mA]	0.4	
RF Frequency [MHz]	800.58	
Operating temp. [K]	2	
Cavity voltage [MV]	22.8	
# cell/cavity	6	
Eacc [MV/m]	20.3	
Q0	3E+10	
RF power [kW]	8.9/12.7	
Optimum coupling QL	9.2E+07/2.7E+07	
# CM (with 4 cav/CM)	112	
# cavities	448	



Same physical Cryomodule

- 800 MHz 6 cell cavity (Pt L. 112)



Further details in K. Canderan's presentation "SRF 400 & 800 MHz cryomodules: Design evolution and future work"

1 - CM design and assumptions for feasibility study

800 MHz cavities strongly inspired from PIP-II

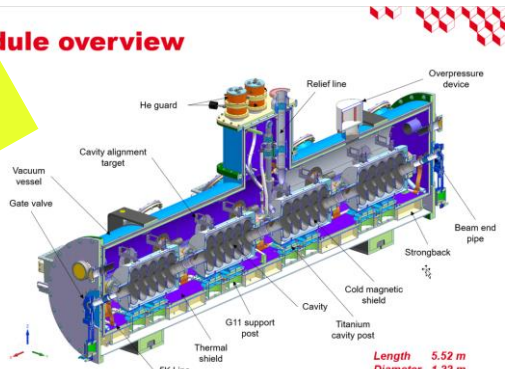
400 MHz cavities strongly inspired from LHC

LB650 Cryomodule overview

Provided by

- 4 cavities
-
-
- Super (HX)
- Cryogenic valves and bayonets
- Over pressure device for the insulation vacuum.
- Instrumentation and instrumentation flanges
- 3 Helium Guards
- 4 Viewports

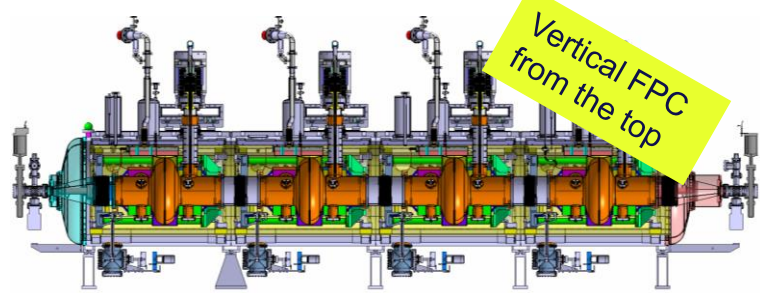
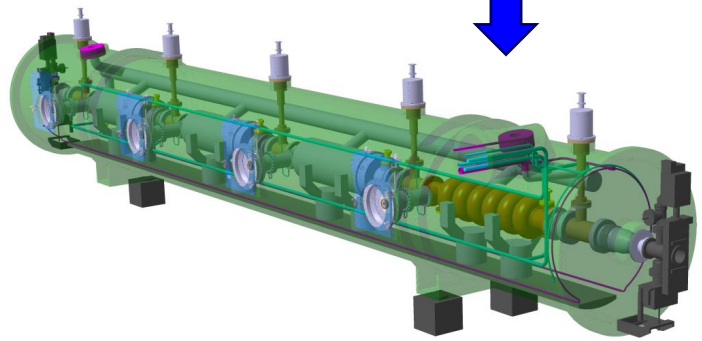
Horizontal FPC from the side



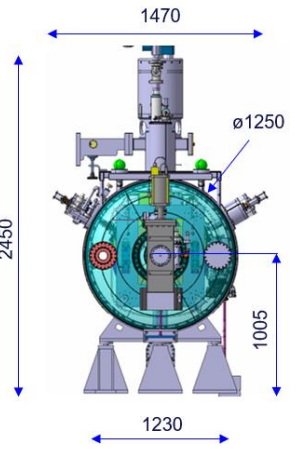
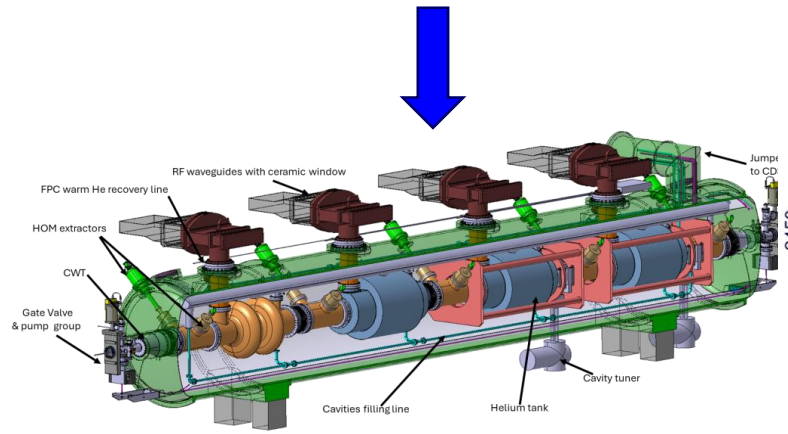
Length 5.52 m
 Diameter 1.22 m
 Height 2.24 m*
 Weight 7.5T

*Distance between cryomodule feet and the Helium guards

Courtesy Fermilab. (D. Passarelli)



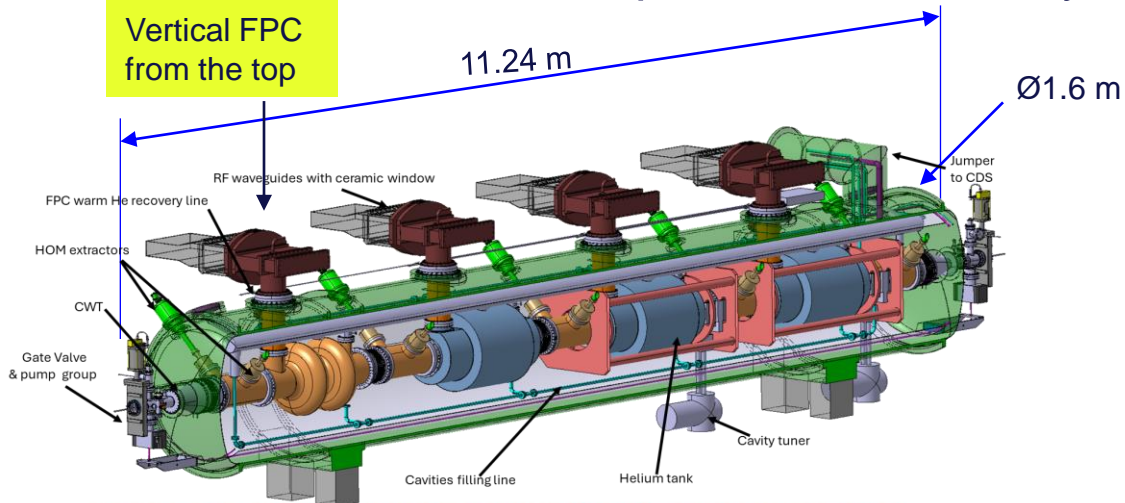
Vertical FPC from the top



New powers (RPO) for FPC, HOM and tappers not taken into account in the design.

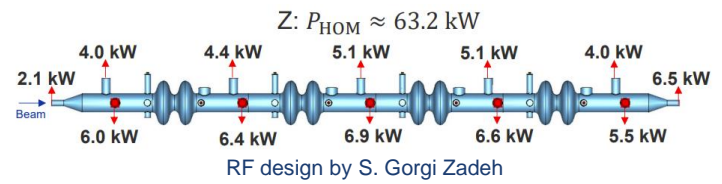
1 - CM design and assumptions for feasibility study

Vertical FPC from the top

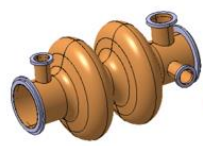


Superconducting elliptical cavity

- 400 MHz, 2-cell
- 1.5 m. long
- Electropolished and seamless RF surface
- Niobium thin film with HiPIMS

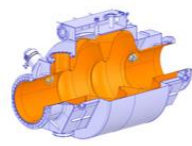


Items to be designed, built and qualified (non exhaustive list!)



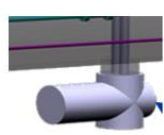
Cavity Nb sputtered

New design



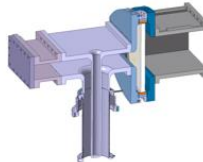
He tank (LHC design shown)/cavity assy

LHC design



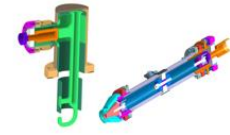
Tuning system

LHC design



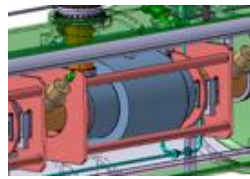
FPC (with WG windows)

New design



HOMs, RF extraction lines (LHC/CRab designs shown)

LHC/CRAB design (no longer representative)

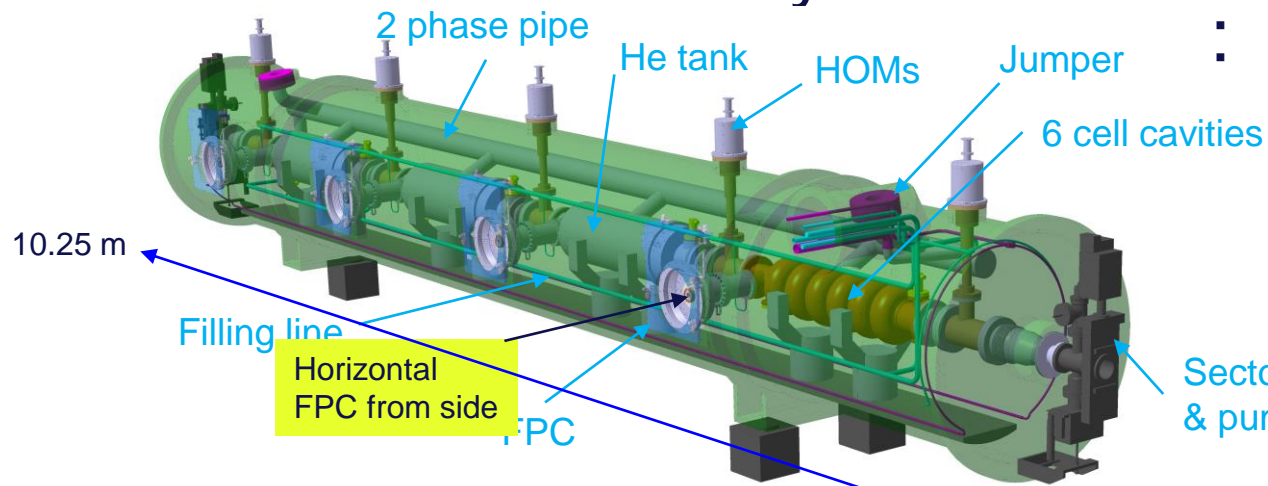


LHC supporting structure and insertion scheme

Further details in K. Canderan's presentation "SRF 400 & 800 MHz cryomodules: Design evolution and future work"

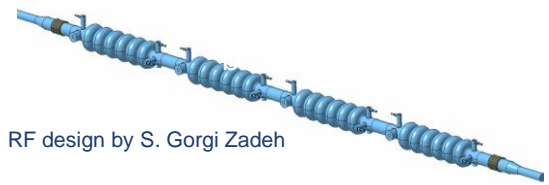
1 - CM design and assumptions for feasibility study

FCC 800 MHz cavity



Superconducting elliptical cavity

- 800 MHz, 6-cell
- 1.5 m. long
- Bulk Niobium with electropolished and doped RF surface (mid T baked)



RF design by S. Gorgi Zadeh

Sector valves & pumping



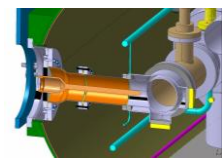
New CERN design

He tank

Tuner

PIPII design

PIPII design

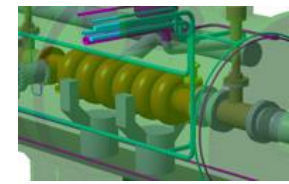


New CERN design

FPC



HOMs, RF extraction lines (LHC/CRAB designs shown) LHC/CRAB design

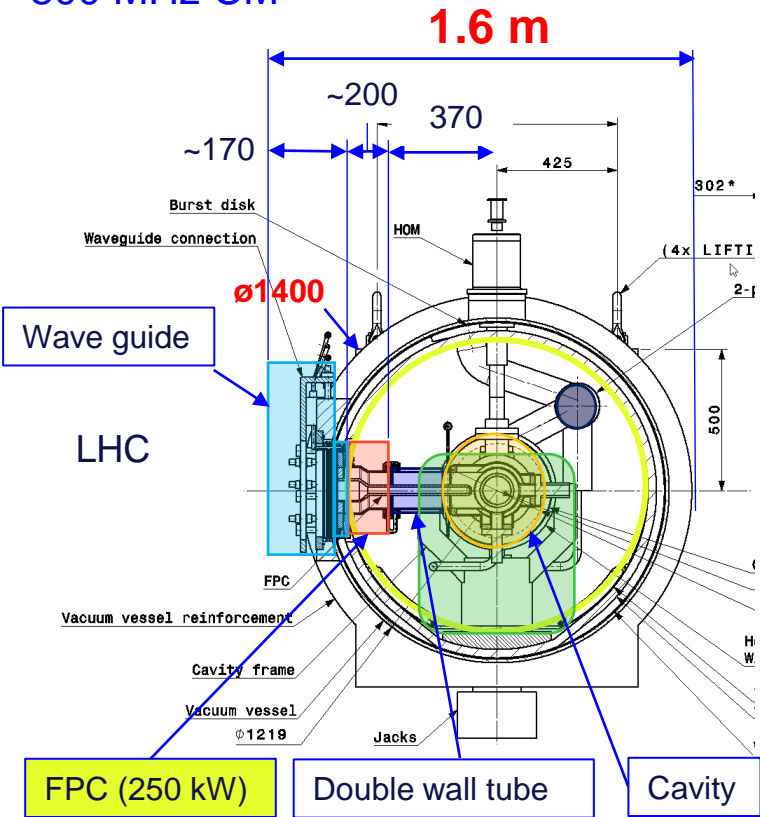


Same supporting structure and insertion scheme

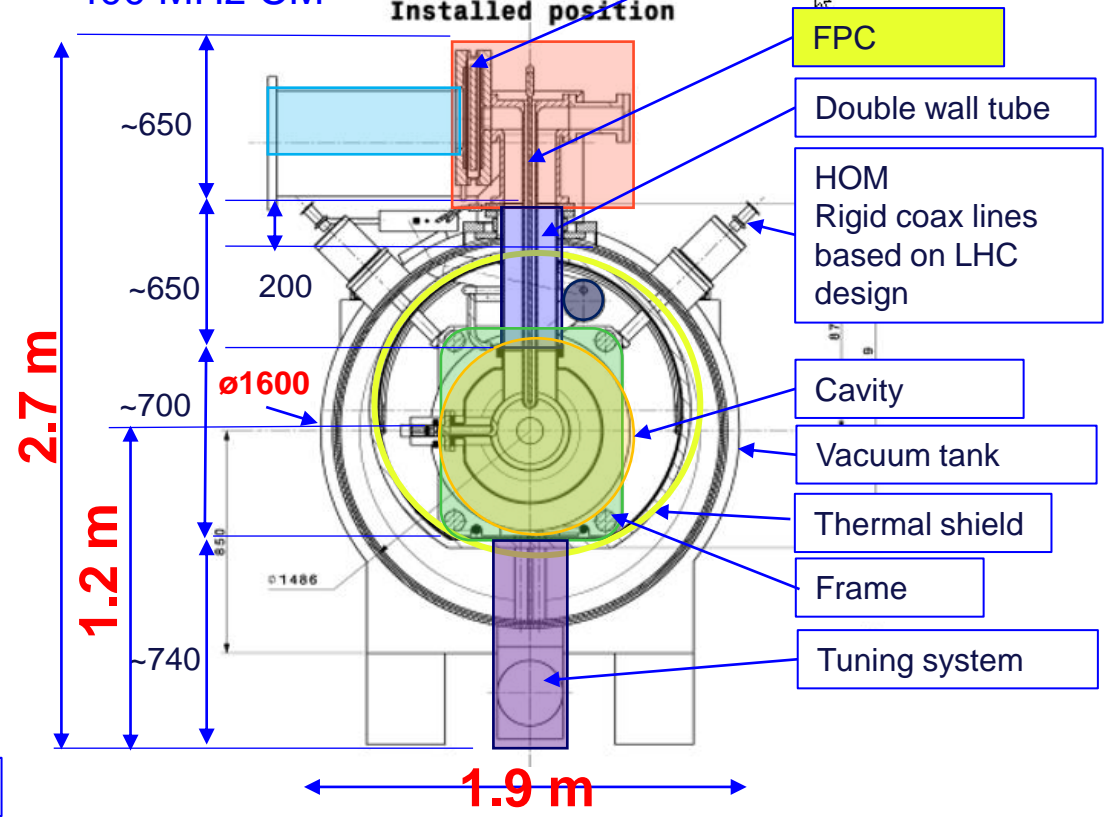
Further details in K. Canderan's presentation "SRF 400 & 800 MHz cryomodules: Design evolution and future work"

Driving dimensions

800 MHz CM



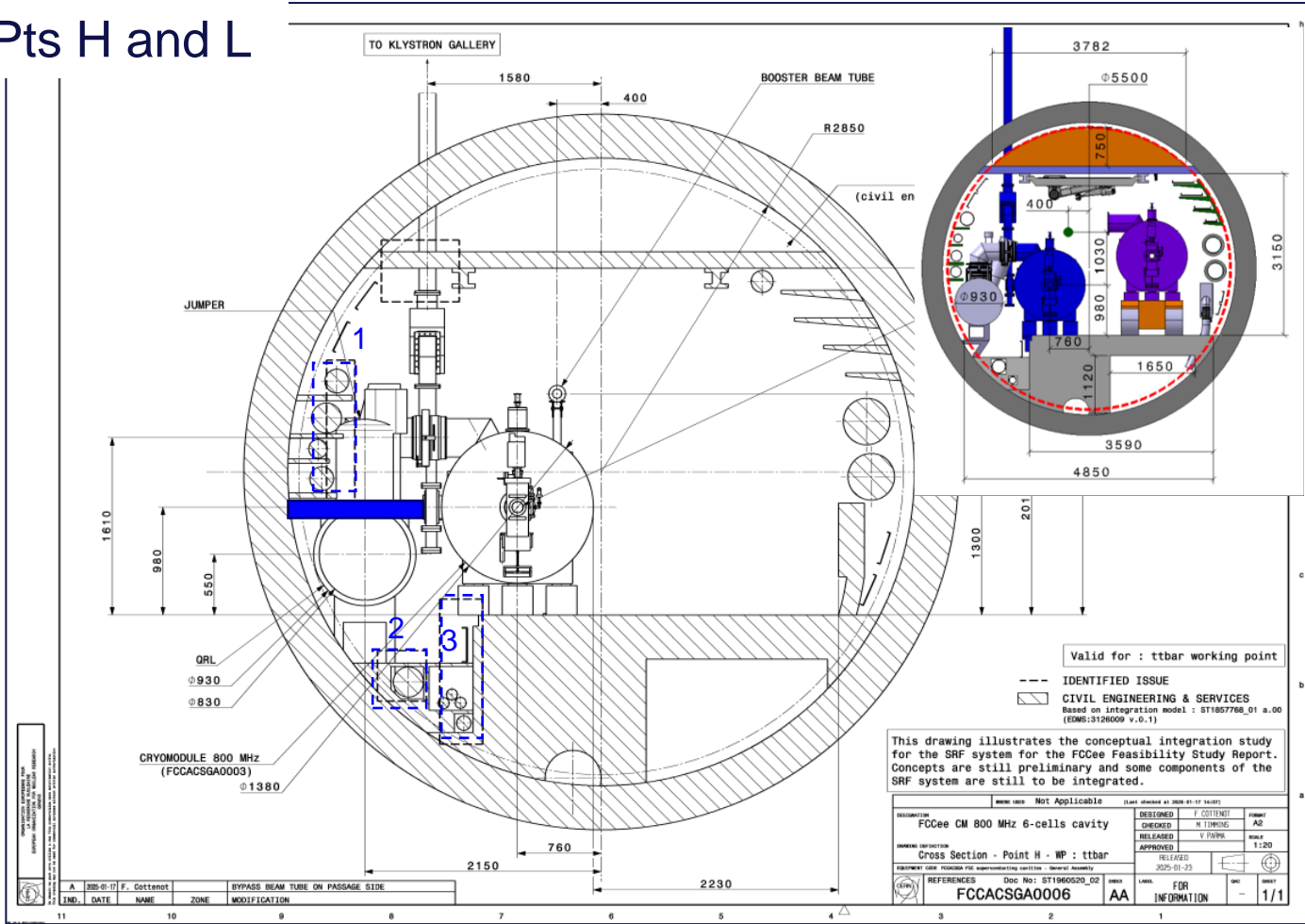
400 MHz CM



2 - Integrations in Pts H and L

Some integration issues:

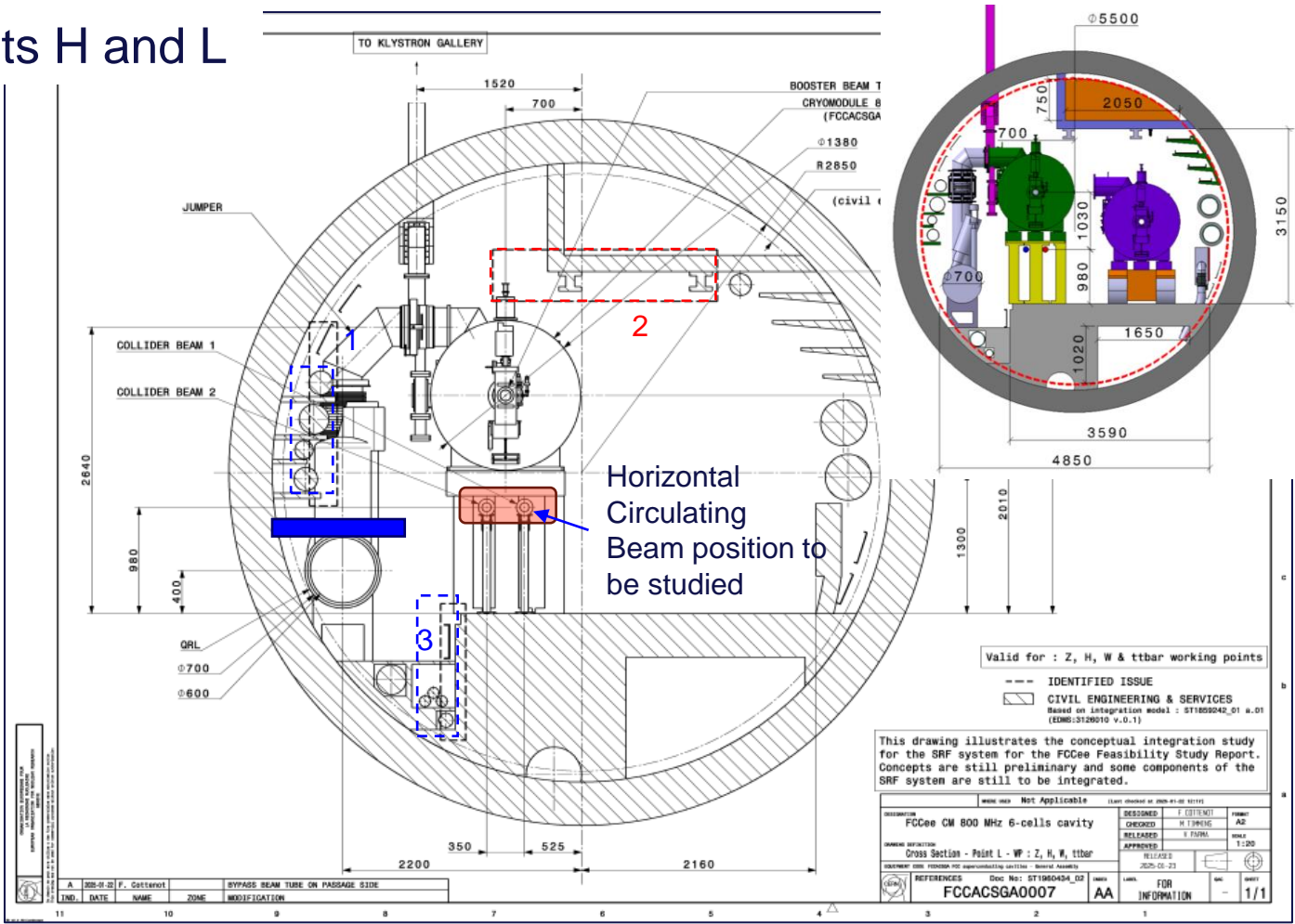
1. Interference QRL-service ducts → minor, reposition lines (already integrated in feasibility study)
2. Interference service ducts → minor, reposition lines (already integrated in feasibility study)
3. CM jack in trench → minor, relocate cables, extend floor (coming soon)



2 - Integrations in Pts H and L

Some integration issues:

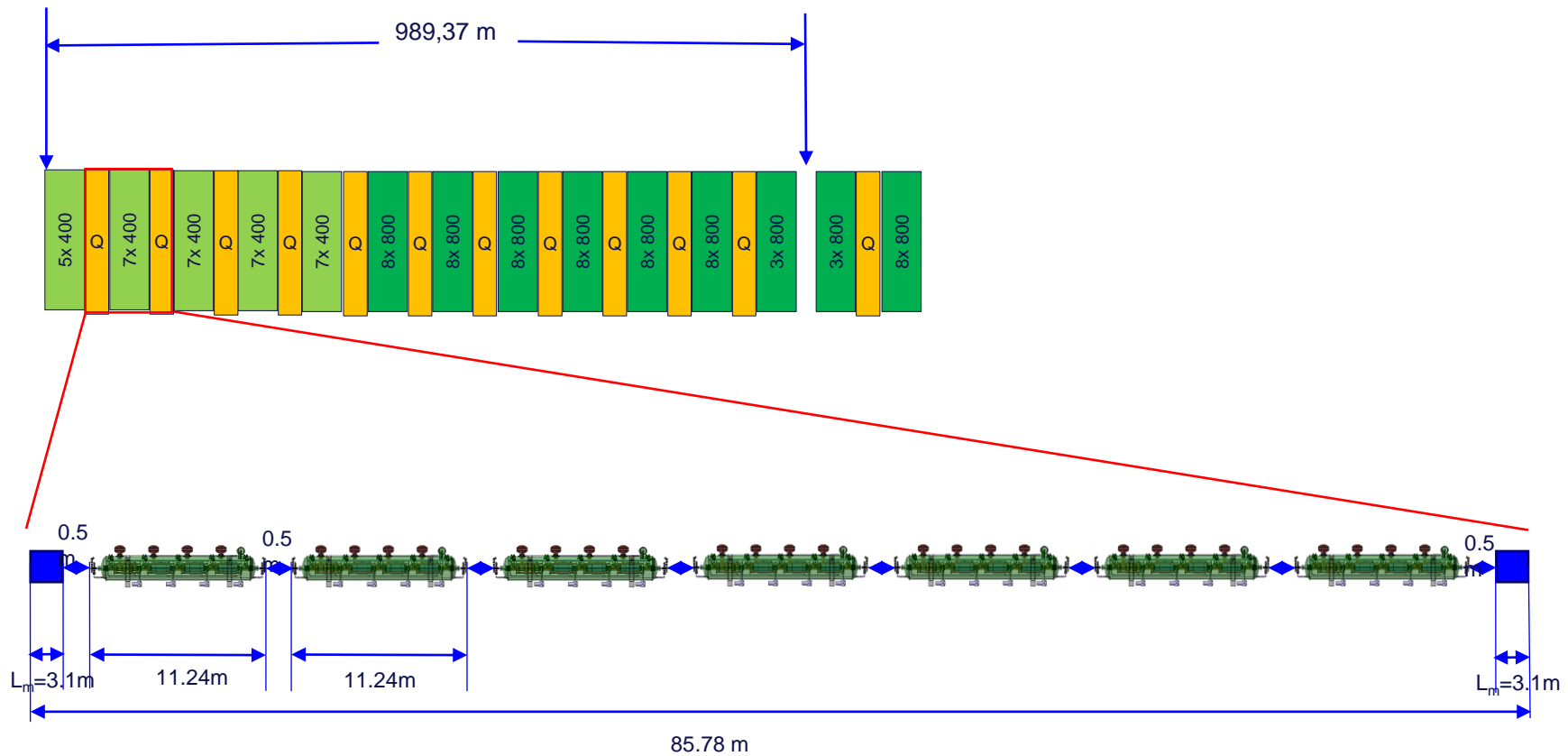
- 1. Interference QRL-service ducts → minor, reposition lines (already integrated in feasibility study)
- 2. Installation potential interference with ceiling → installation to be studied
- 3. CM jack in trench → relocate cables, extend floor (already integrated in feasibility study)



DESIGNED		CHECKED		APPROVED	
RELEASED		DATE		SCALE	
REFERENCES		Doc No: ST1960434_02		FOR INFORMATION	
FCCACSGA0007		AA		1/1	

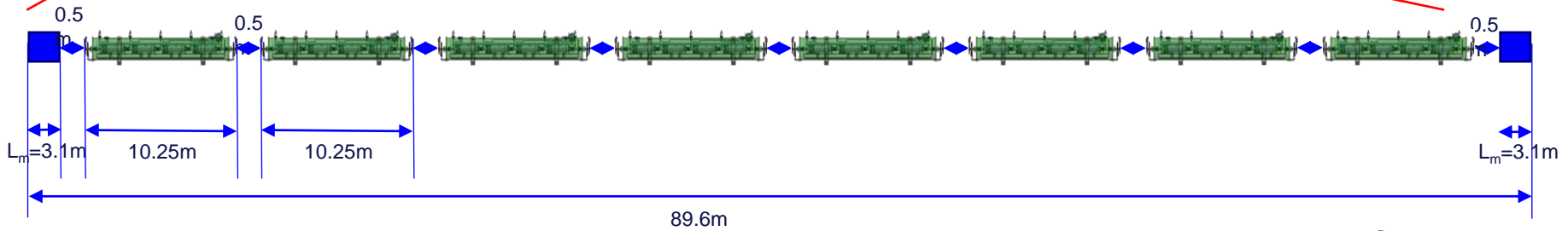
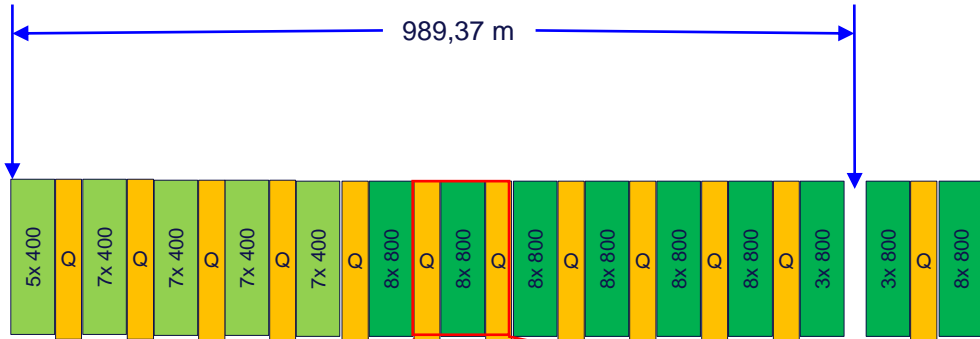
2 - Integrations in Pts H and L

IP

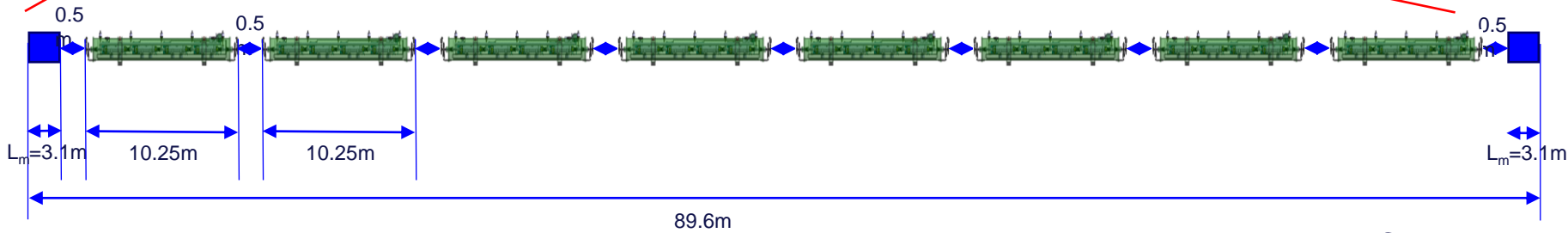
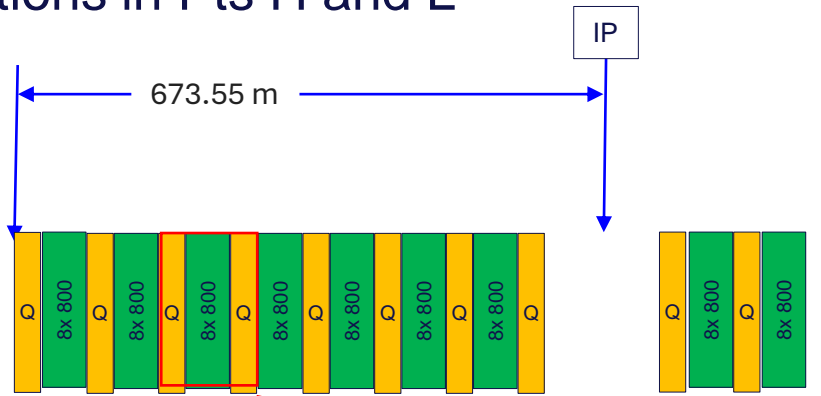


2 - Integrations in Pts H and L

IP



2 - Integrations in Pts H and L



2 - Integrations in Pts H and L

Pt H

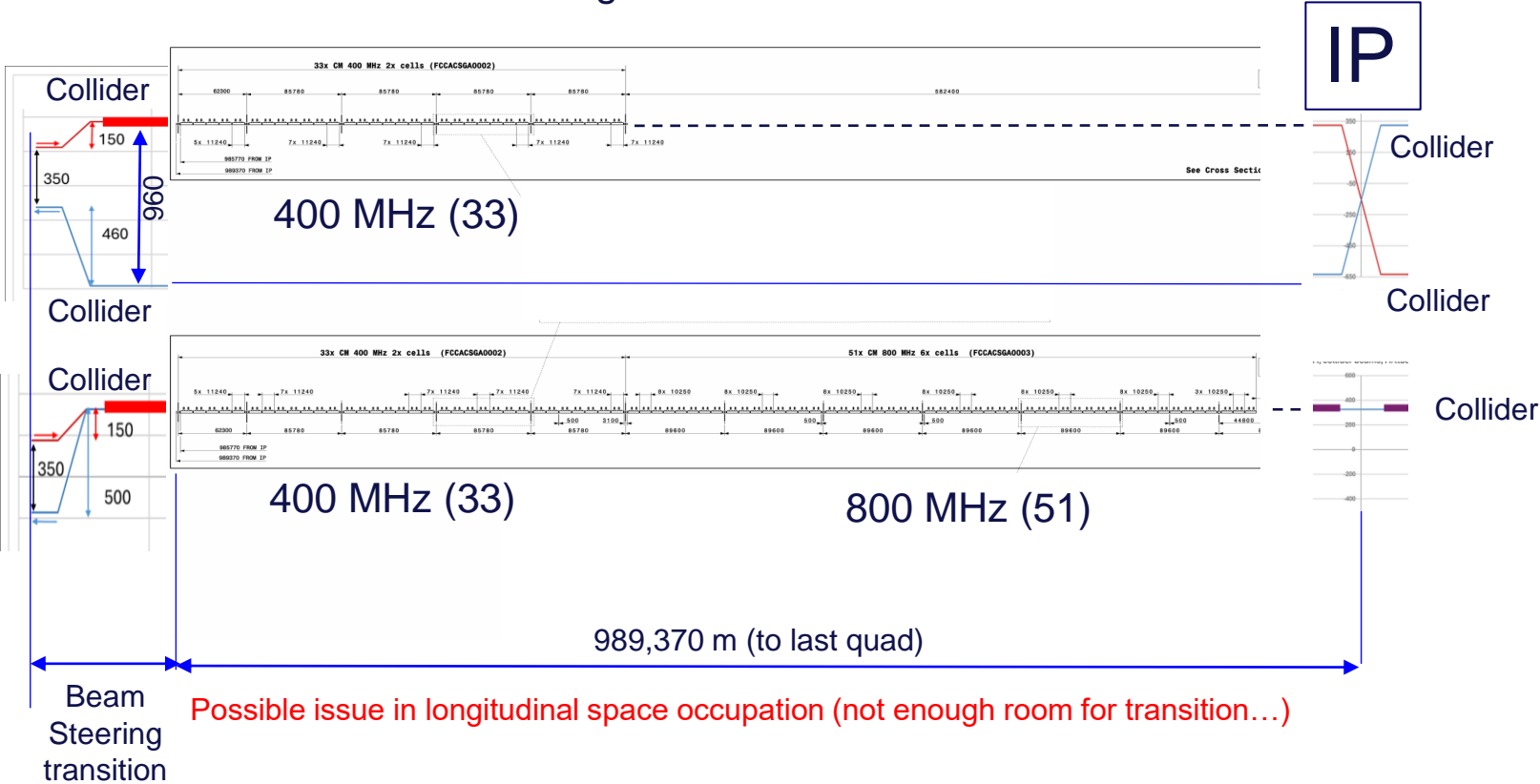
CM installed for Z/W don't move

Ref drawing: FCCACSGA0008

Z / W

ARCS

H / ttbar



IP

Collider

Collider

Collider

Possible issue in longitudinal space occupation (not enough room for transition...)

2 - Integrations in Pts H and L

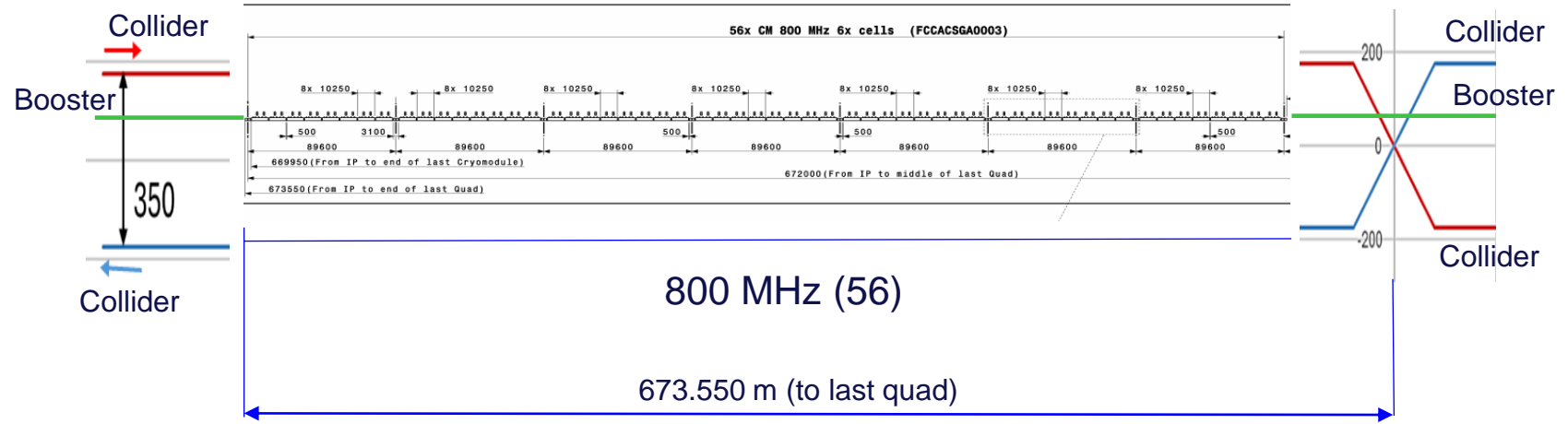
(Z / W / H) / ttbar

Pt L

Ref drawing: FCCACSGA0010

IP

ARCS

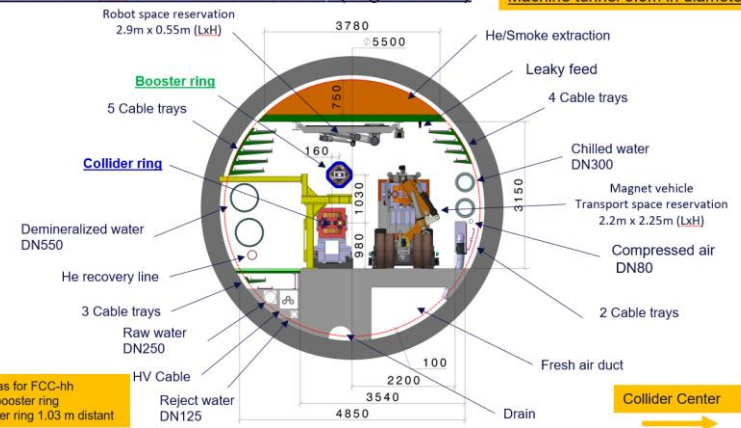


1 - CM design and assumptions for feasibility study

Machine tunnel 5.5m in diameter

Integration of FCC-ee machine elements (regular arc)

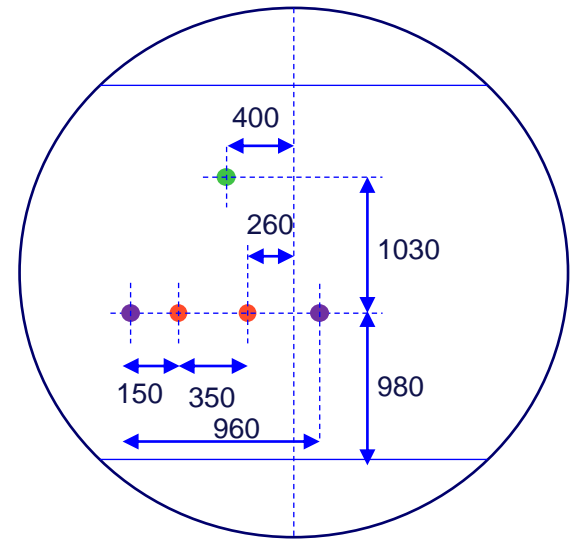
Machine tunnel 5.5m in diameter



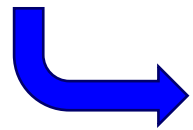
Main cross section as for FCC-hh
 Main ring below of booster ring
 Main ring and booster ring 1.03 m distant

- B1-B2 collider Arc position
- B1 CM: collider inlet CM
- B2 CB: collider circulating beam
- B3: Booster

Transversal Beam positions in Pt H (Z, W)



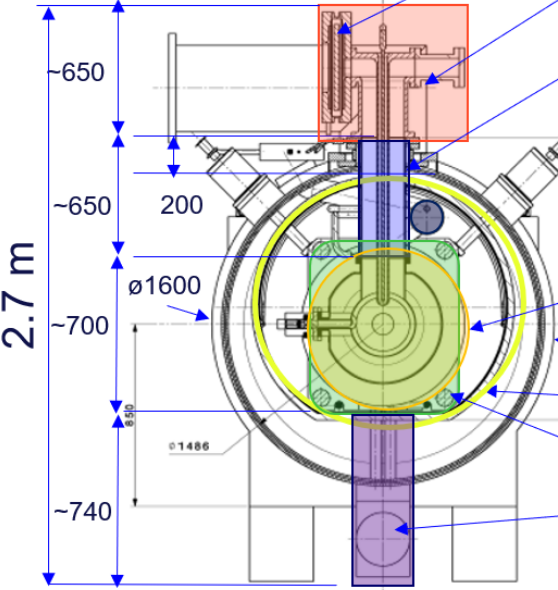
Collider Center



3 – Optimization in pre-TDR phase

Work in progress pre-TDR (SRF R&D-D project V. Parma)

400 MHz CM
More bulky



- FPC ceramic window for high power
- FPC
- Double wall tube
- HOM Rigid coax lines based on LHC design
- Cavity
- Vacuum tank
- Thermal shield
- Frame
- Tuning system

Possible new compact design (ceramic window in coupler (Lower power 500 kW peak)

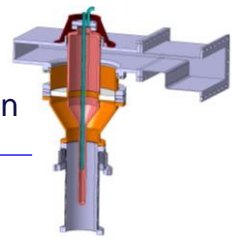
Possible optimization of length (reduced dynamic loads)

HOM optimization length (challenging seen the higher power in RPO.

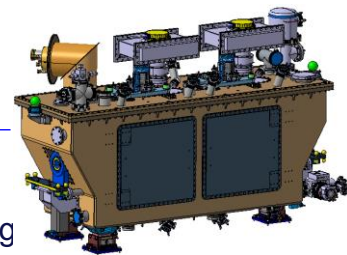
Vacuum tank shape and insertion scheme are currently being studied)

Exploring the feasibility of designing a tuning system that does not require a frame

Investigation alternative locations and more compact tuning system



FPC new design S. Calvo



Crab cavity CM T. Capelli

FCC-ee Underground Structure point H

PLM References: https://plm.cern.ch/p/CAD/number:ST1857768_01:AA.04

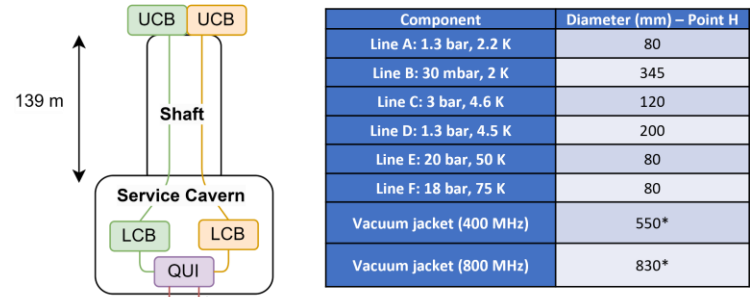
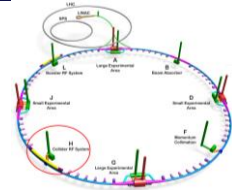
EDMS References: <https://edms.cern.ch/document/3126009/1.0>

[Feasibility Report](#)

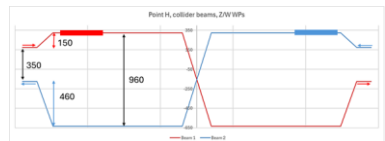
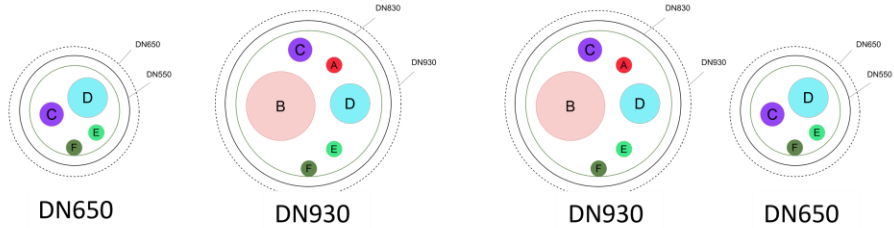
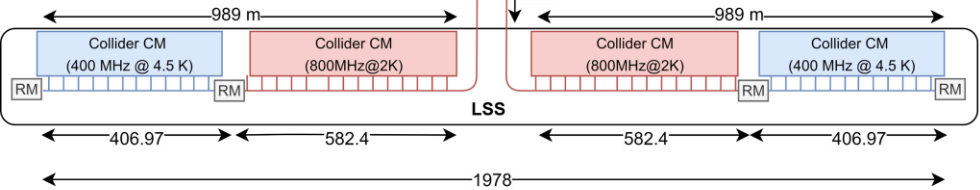
FCC-ee RF/Cryogenic Layout point H

Courtesy Cryo team

TLSS length: 2032 m



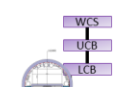
* +100 mm for bellows and flanges



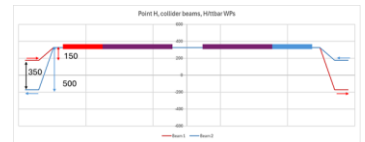
Z,W and H machine



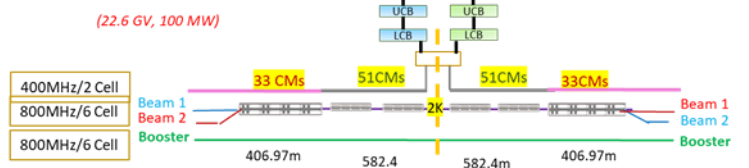
Access Point H



The RF configuration does not change anymore allowing the run at Z, W or H operation



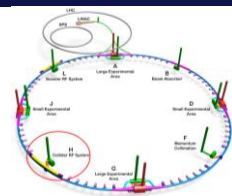
tbar machine



Midpoint RF section TOTAL RF LENGTH: 1978,75 m

- 2K Booster CMs near to cryoplants then 4.5K Collider CMs

FCC-ee RF Machine tunnel & Klystron Gallery cross section (z,w machine)



Feasibility Report

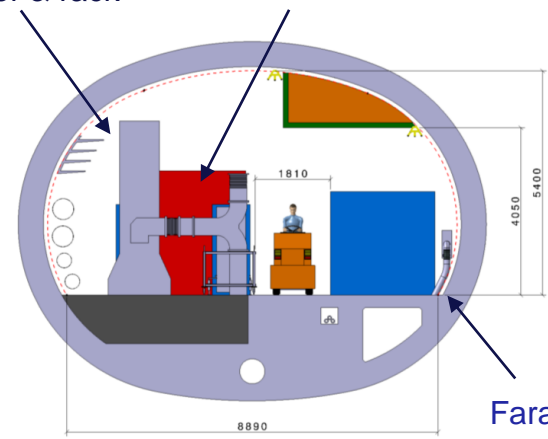
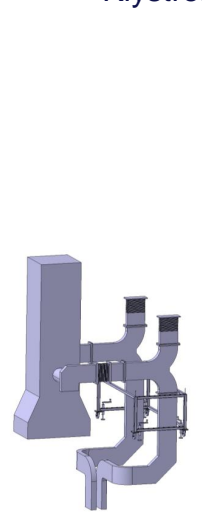
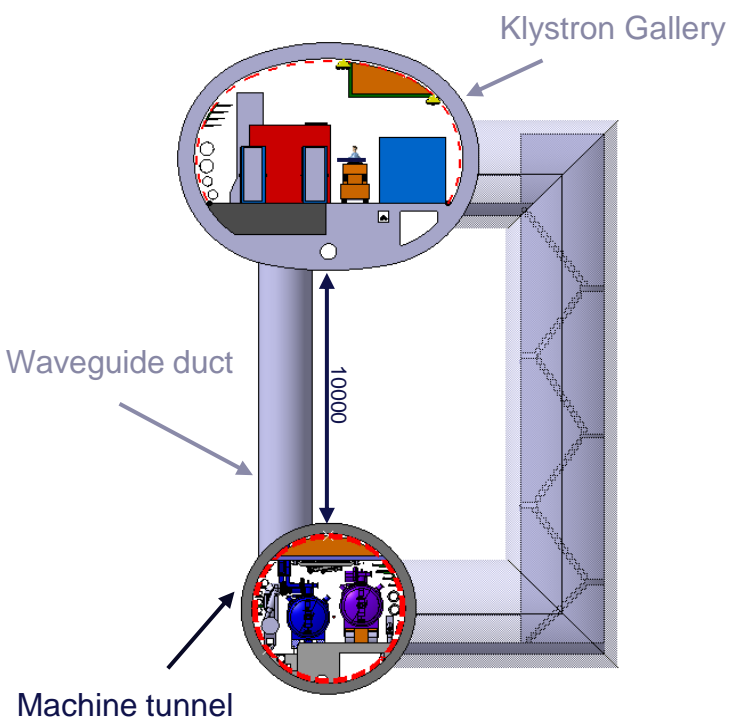
400 MHz cryomodules (ø 1.6 m x 11.24 m), half RF LSS

- 33 e⁺e⁻ CM (406.97 m)
- 66 klystrons

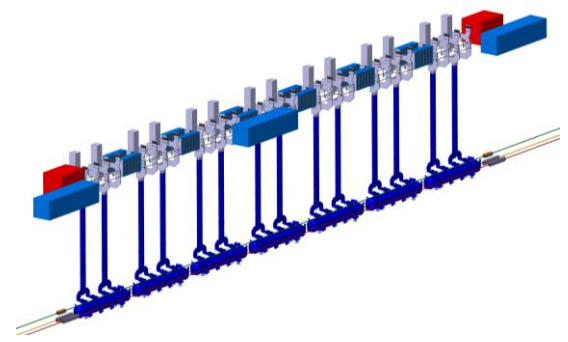
Klystron, circulator & rack

HV Bunker

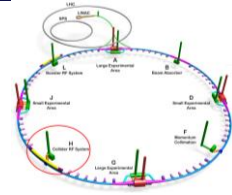
Faraday cage



Collider Center



FCC-ee RF Machine tunnel & Klystron Gallery cross section (tbar machine)



800 MHz cryomodules (ø 1.38 m x 10.25 m), half RF LSS

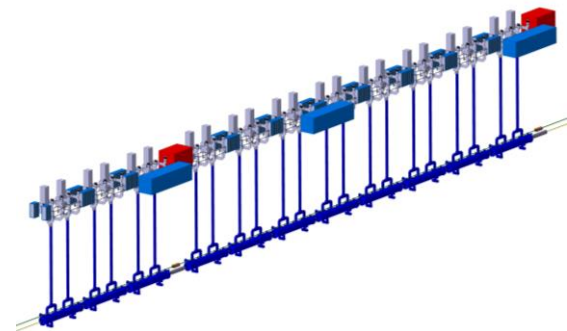
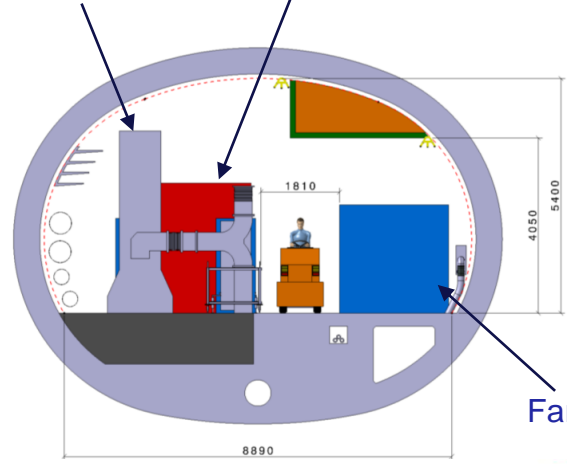
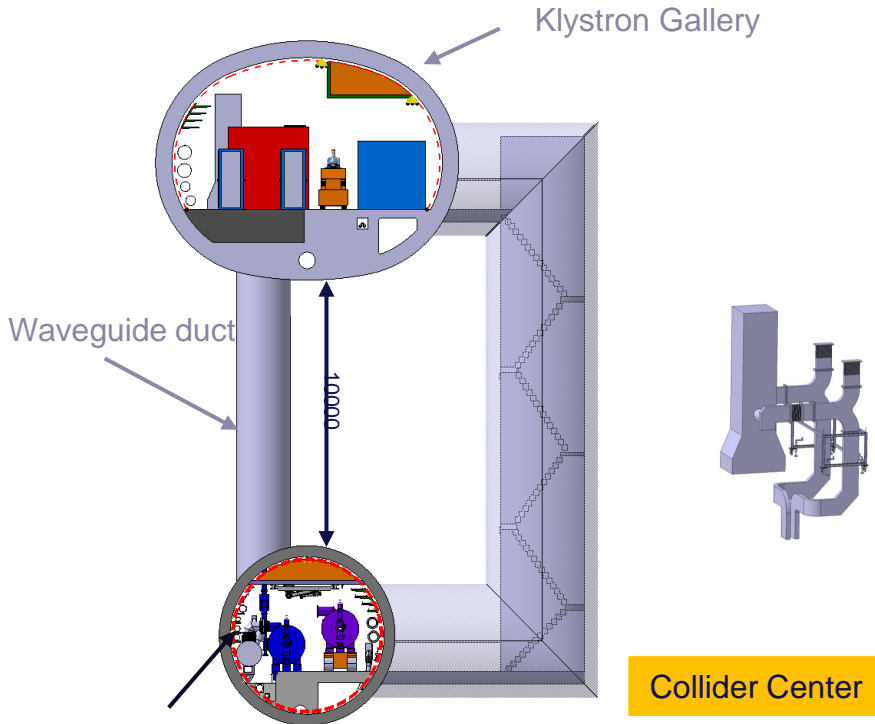
- 51 e^+e^- CM (582.4 m)
- 102 klystrons

Feasibility Report

Klystron, circulator & rack

HV Bunker

Faraday cage

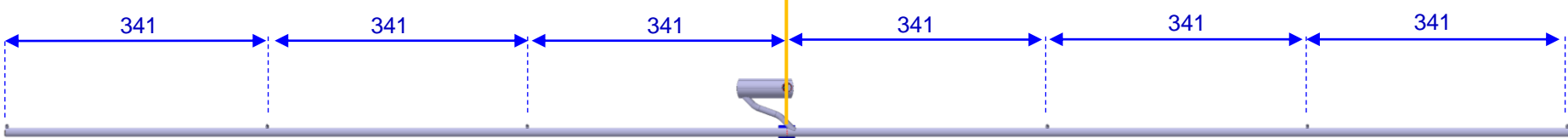
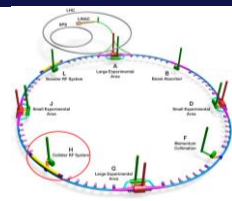


FCC-ee Underground Structure study Point H

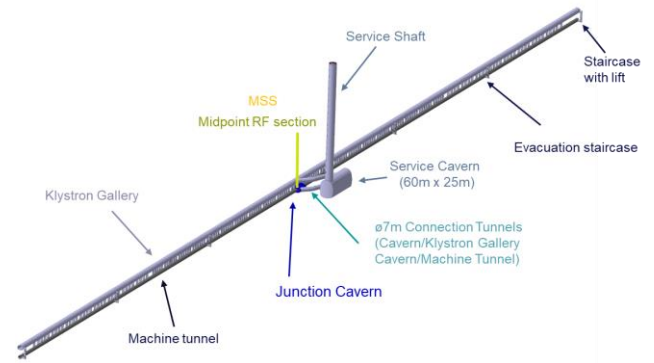
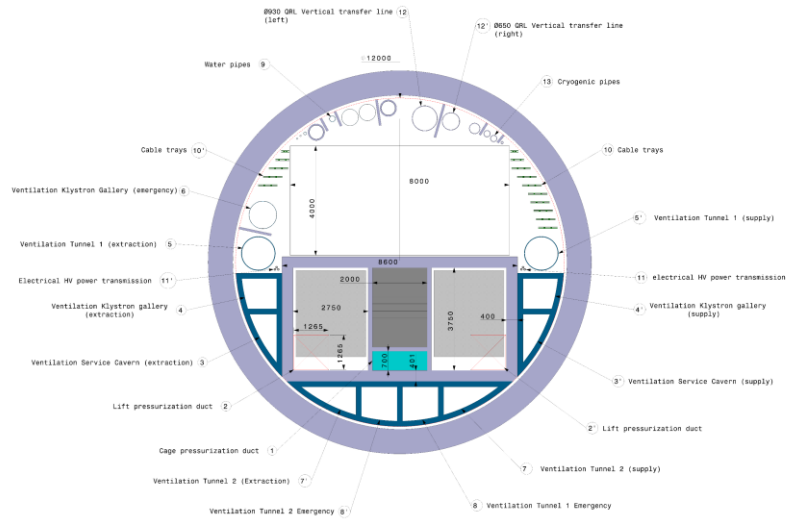
Feasibility Report

Collider Center

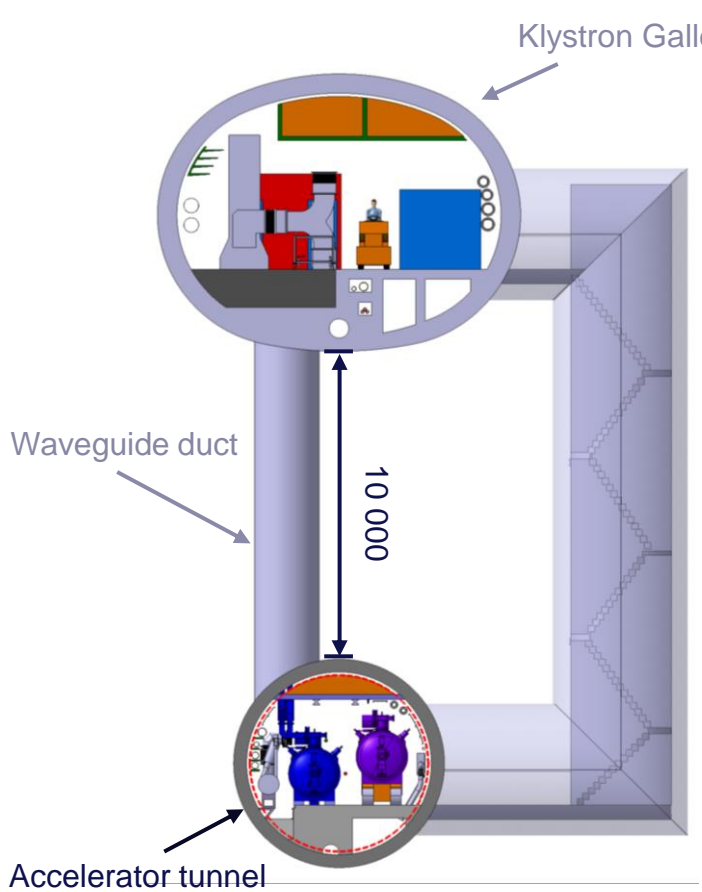
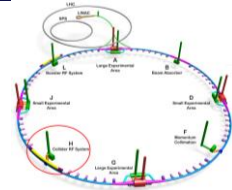
MSS
Midpoint RF section



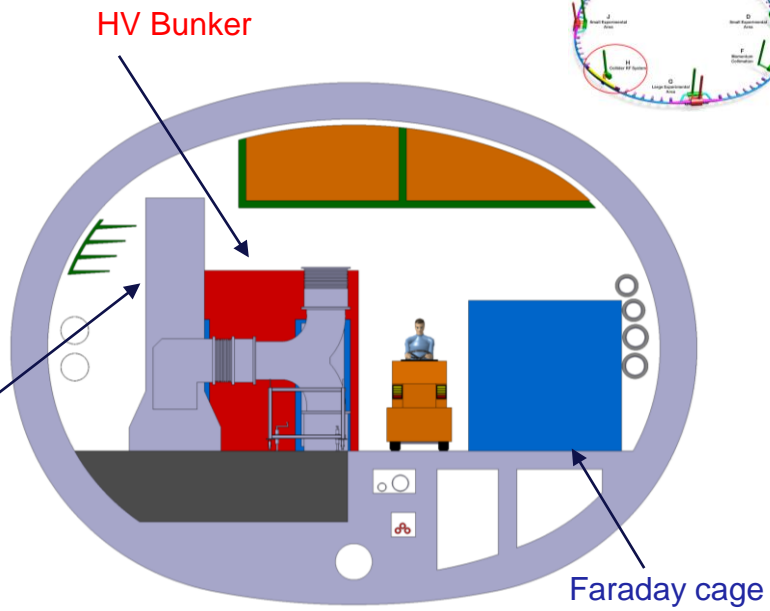
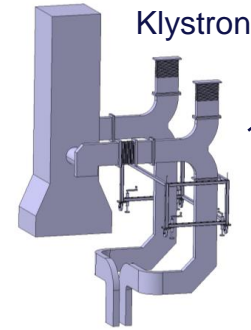
Service Shaft



FCC-ee RF Machine tunnel & Klystron Gallery cross section (z,w machine)



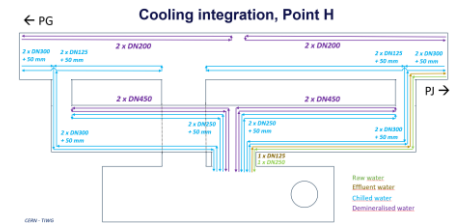
Pre-TDR Study



Collider Center



Please follow Inigo Martin Melero's presentation "Ventilation update"



FCC-ee Underground Structure point L

PLM References: https://plm.cern.ch/p/CAD/number:ST1859242_01:AA.05

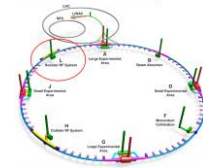
EDMS References: <https://edms.cern.ch/document/3126010/1.0>

[Feasibility Report](#)

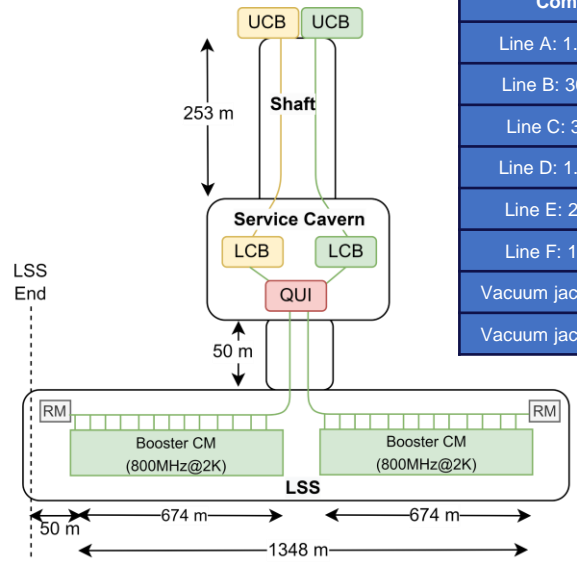
FCC-ee RF/Cryogenic Layout point L

Courtesy Cryo team

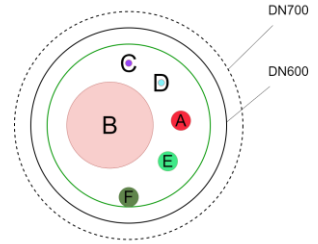
TLSS length: 2032 m



Component	Diameter (mm) – Point L
Line A: 1.3 bar, 2.2 K	60
Line B: 30 mbar, 2 K	265
Line C: 3 bar, 4.6 K	20
Line D: 1.3 bar, 4.5 K	20
Line E: 20 bar, 50 K	60
Line F: 18 bar, 75 K	60
Vacuum jacket (400 MHz)	-
Vacuum jacket (800 MHz)	600*



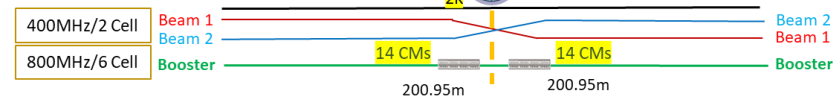
*+100 mm for bellows and flanges



The RF configuration does not change anymore allowing the run at Z, W or H operation

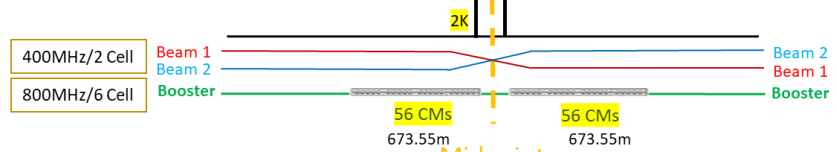
Z,W and H machine

(2.1 GV, 5 MW)



ttbar machine

(11.3 GV, 5 MW)

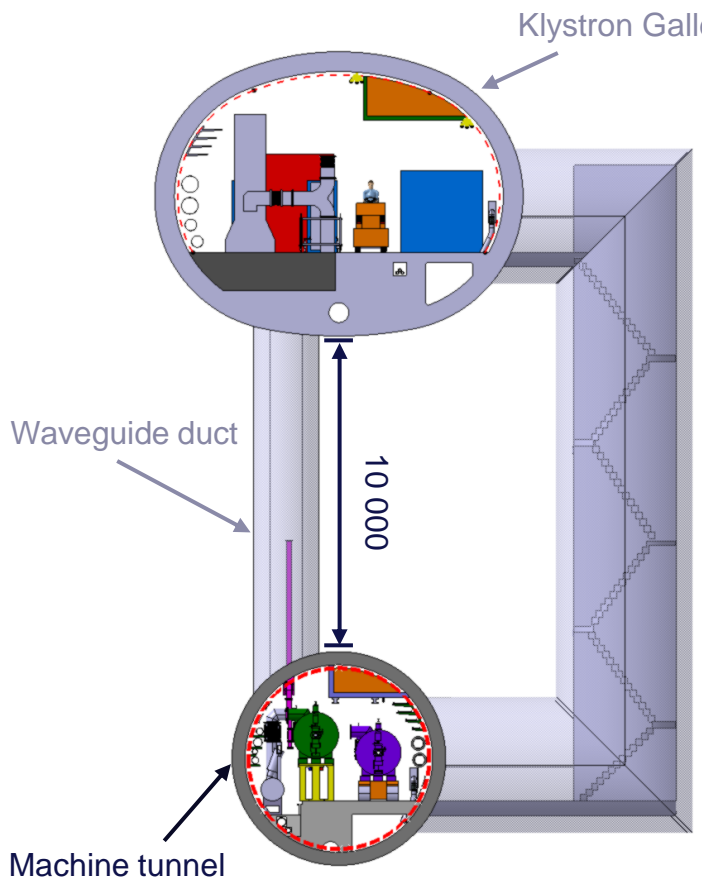
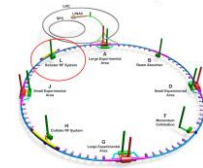


Midpoint RF section

TOTAL RF LENGTH: 1347.1m

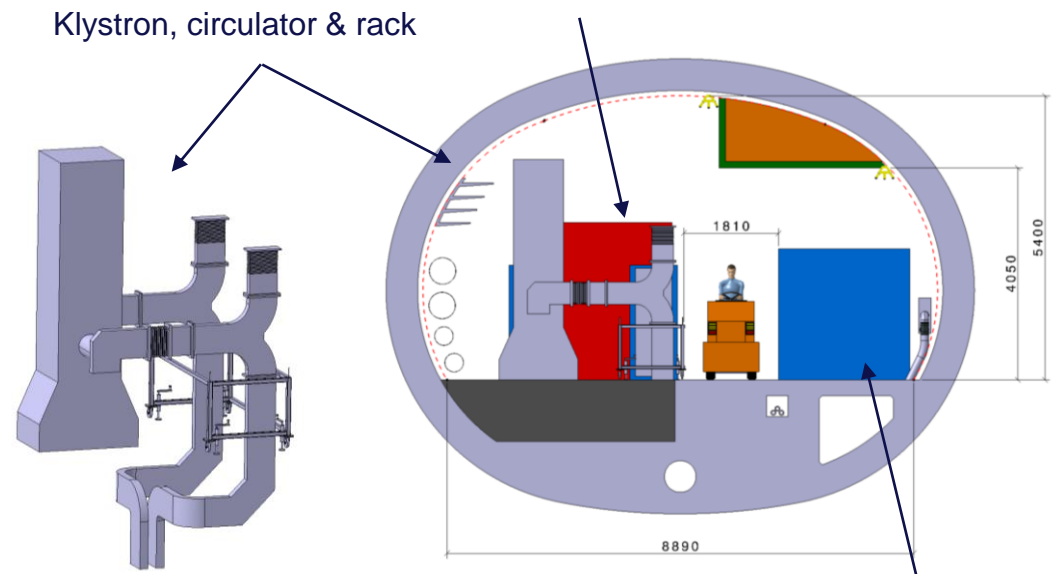
- 2K Booster CMs near to cryoplants

FCC-ee RF Machine tunnel & Klystron Gallery cross section (tbar machine)



Feasibility Report

HV Bunker



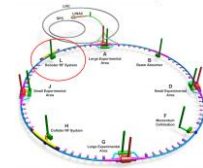
Faraday cage

Klystron longitudinal

Collider Center

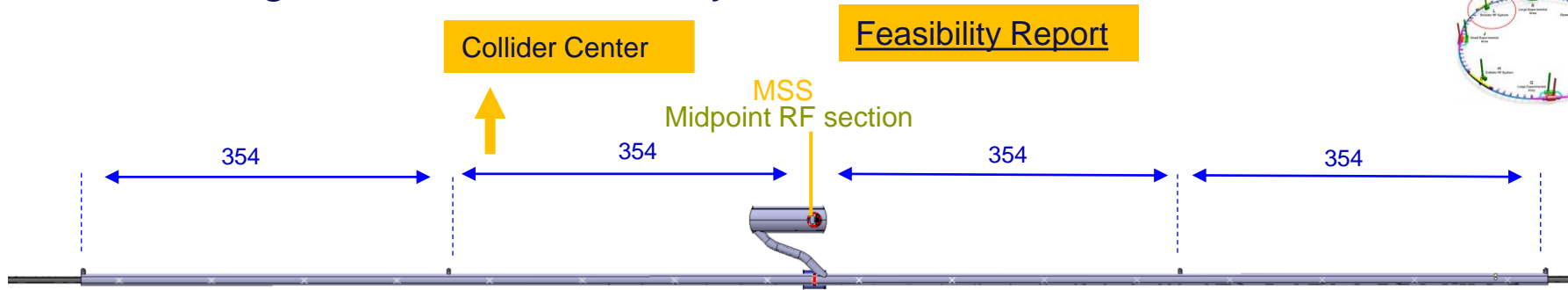


FCC-ee Underground Structure study Point L

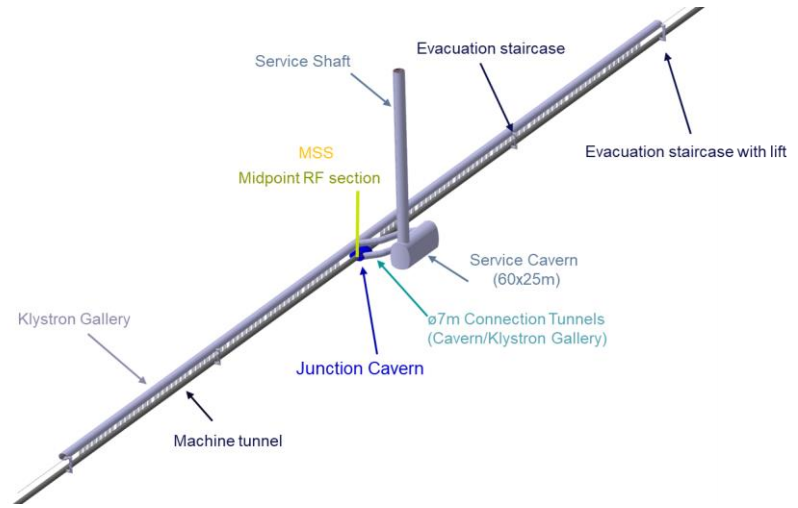
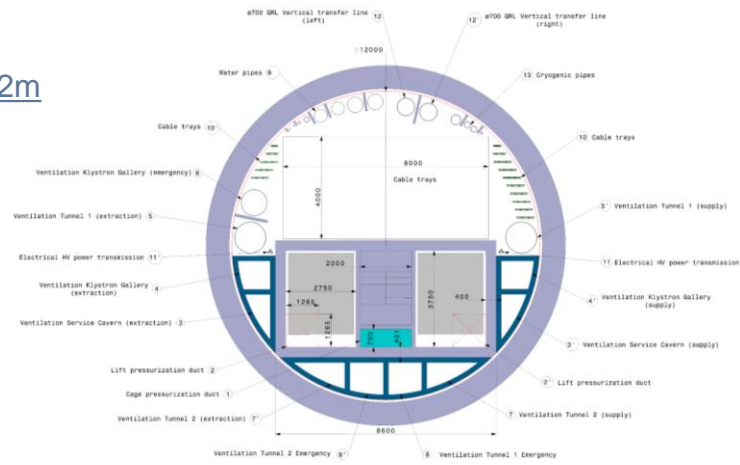


Collider Center

Feasibility Report



Service Shaft ϕ 12m



Conclusion

- For Collider Z, W, H and ttbar machine all 400MHz Cryomodules will be housed at point H.
 - For Collider ttbar machine 800MHz Cryomodules will be housed at point H.
 - For Booster Z, W, H and ttbar machine all 800MHz Cryomodules will be housed at point L .
- The integration study is still at a conceptual level and needs to be regularly updated with the evolution of the design of the CMs, the cryogenic lines, and other machine elements. The layout of the klystron galleries will further evolve with the technical design of all services.
- RF feedback based on SRF R&D project during pre-TDR phase (structured process to manage configurations).

I would like to acknowledge the FCC
Technical Infrastructure Coordination team
and the FCC Accelerator Technology team
for their input and support in the
integration studies.

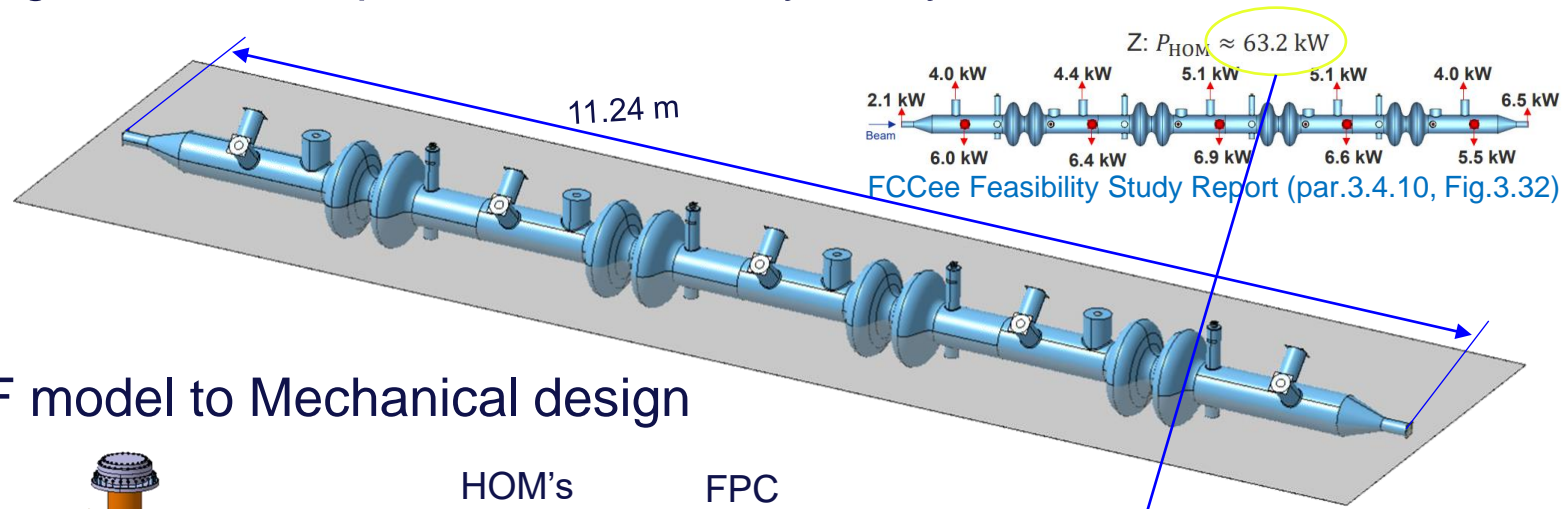


Thank you
for your attention.

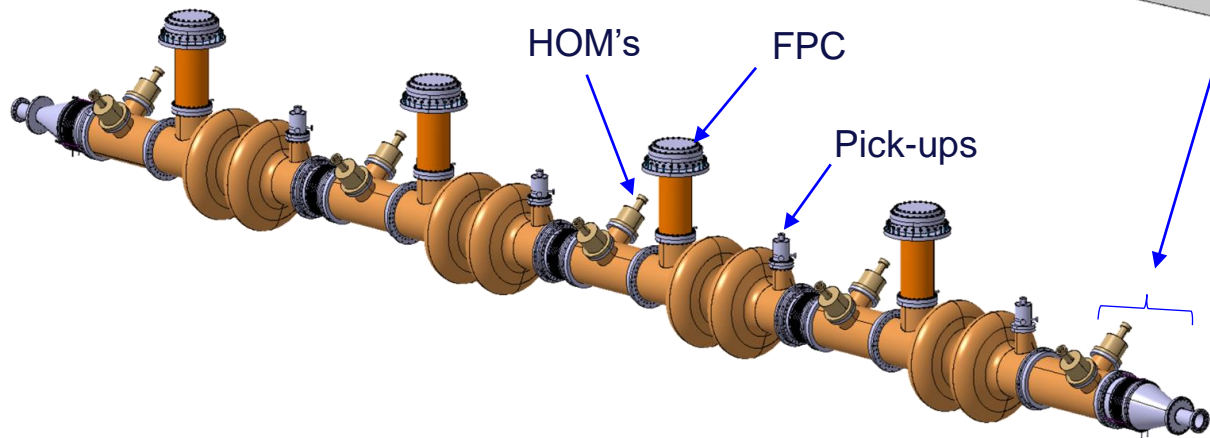


Back-up slides

1 - CM design and assumptions for feasibility study



From RF model to Mechanical design



New power hasn't been taken into account in the design of HOMs tappers

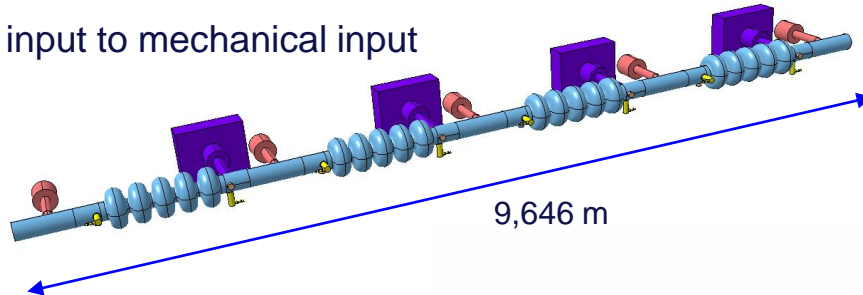
1 - CM design and assumptions for feasibility study

FCC 800 MHz cavity

Superconducting elliptical cavity

- 800 MHz, 6-cell
- 1.5 m. long
- Bulk Niobium with electropolished and doped RF surface (mid T baked)

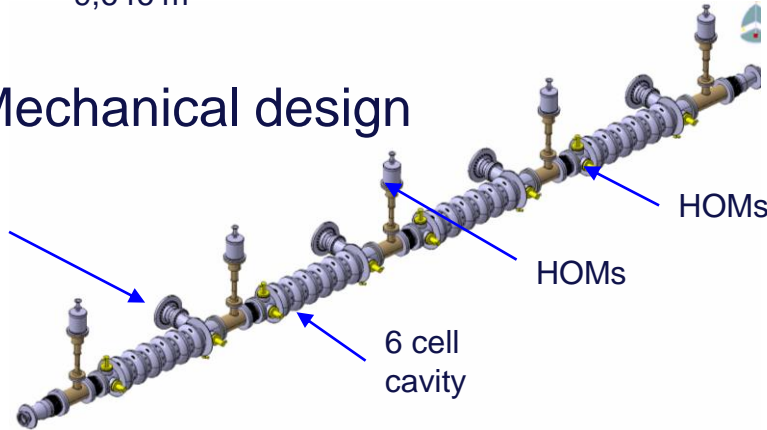
From RF input to mechanical input



9,646 m

From RF model to Mechanical design

FPC on the side

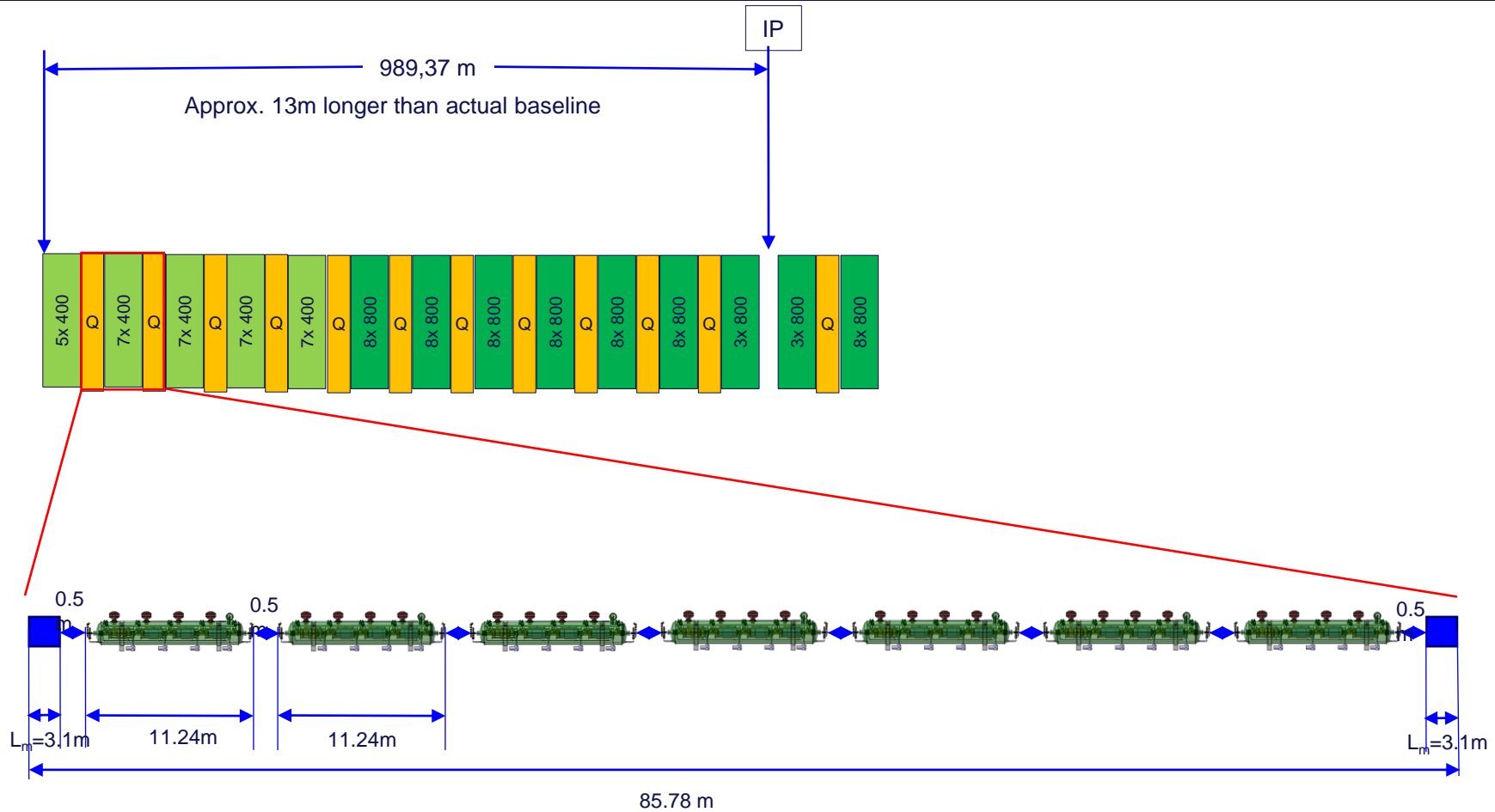


HOMs

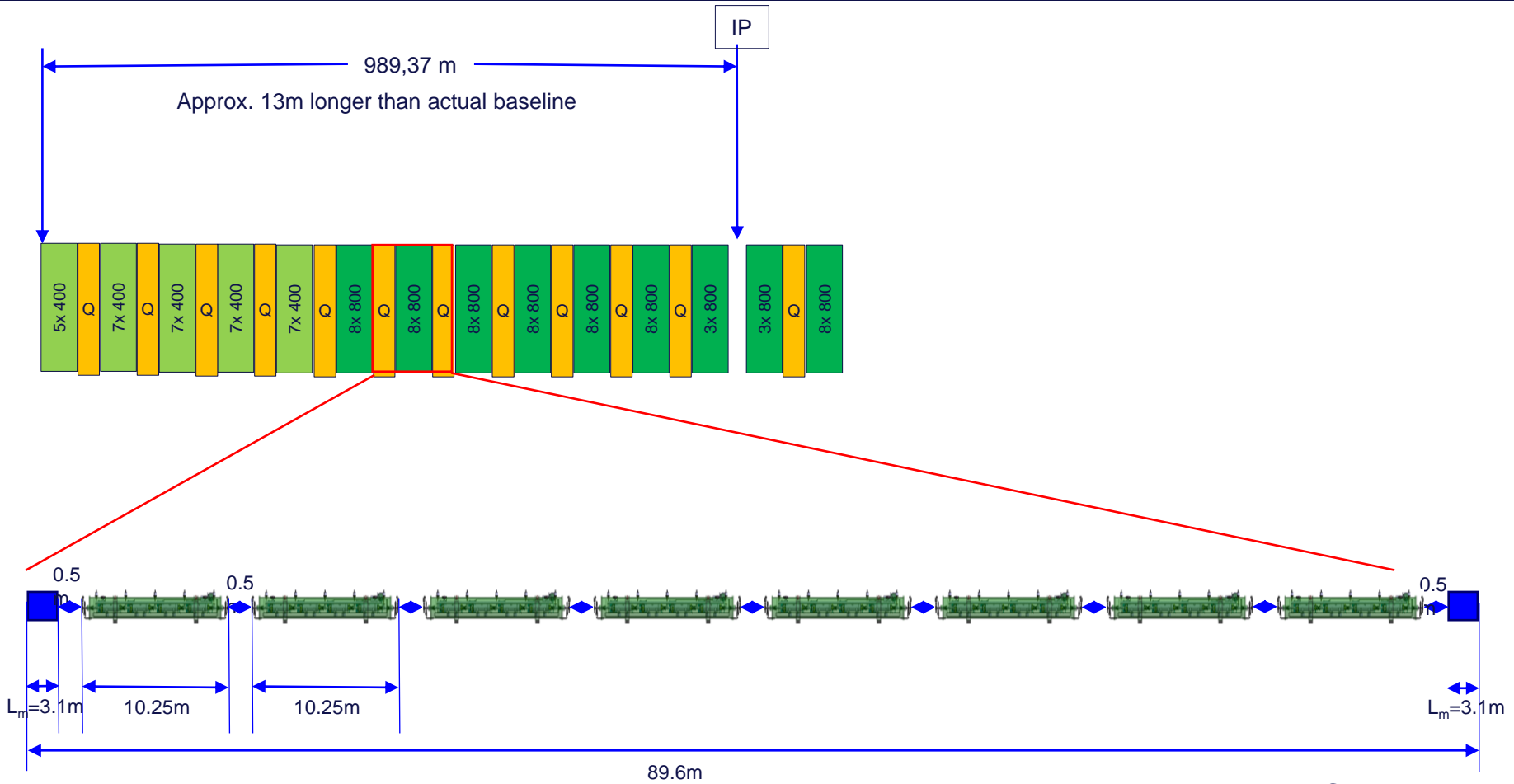
HOMs

6 cell cavity

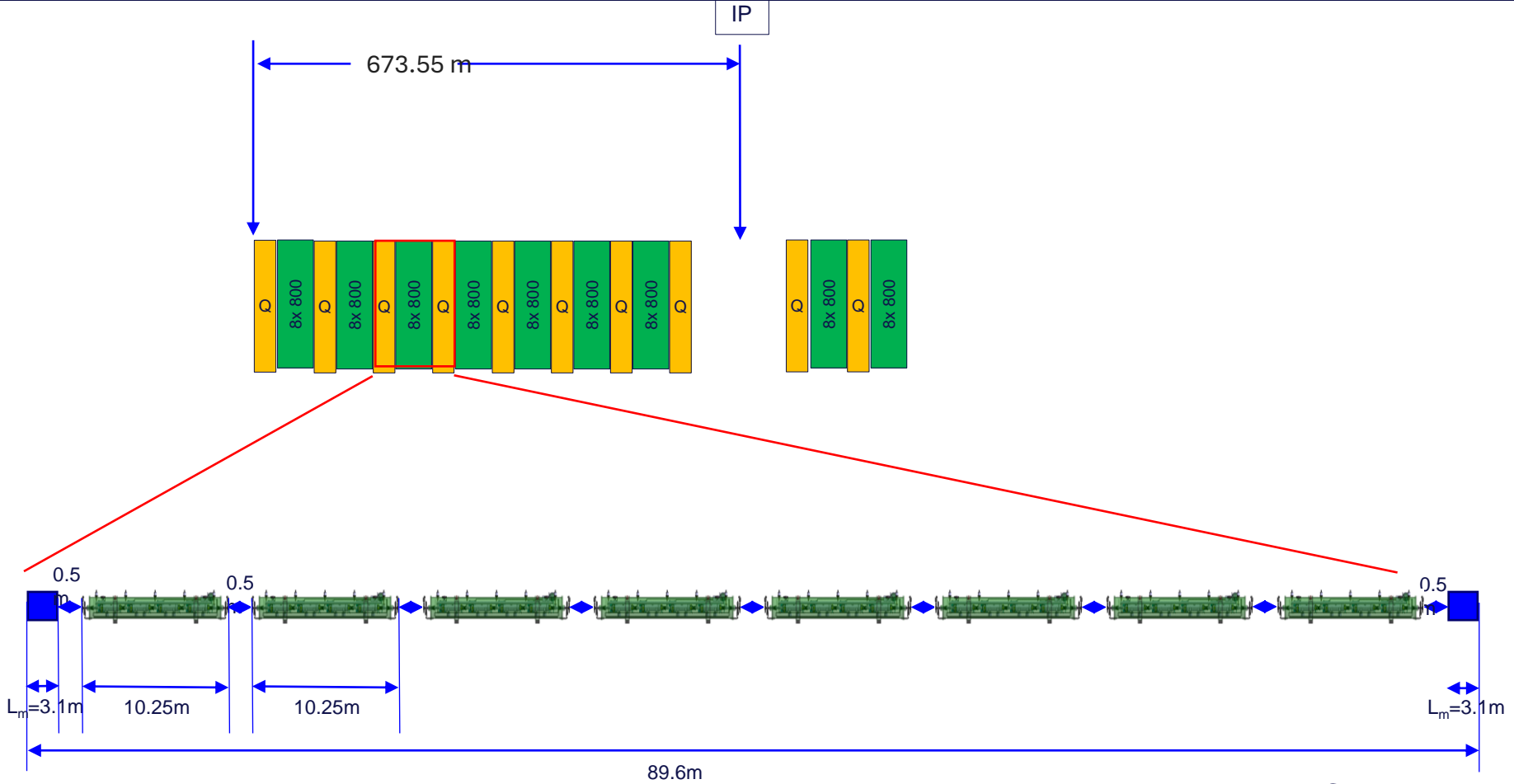
Longitudinal spacing Pt.H (1/2)



Longitudinal spacing Pt.H (2/2)



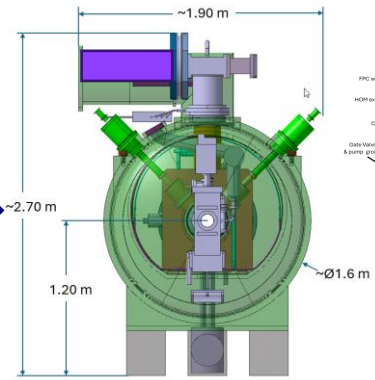
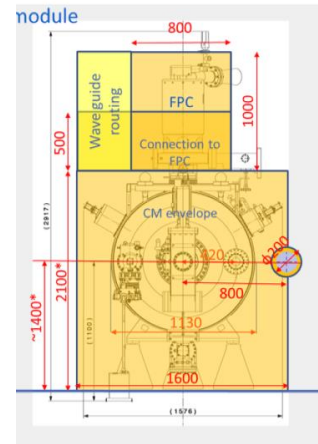
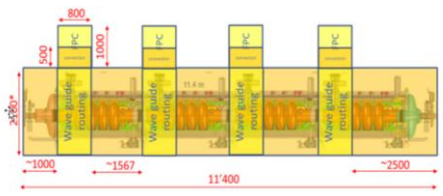
Longitudinal spacing Pt.L



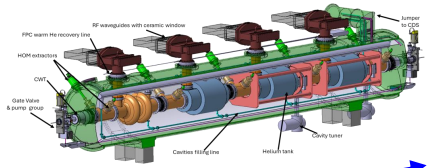
1 - CM design and assumptions for feasibility study

FCC week 2022

400 MHz CM based on LHC design



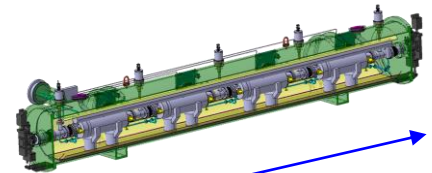
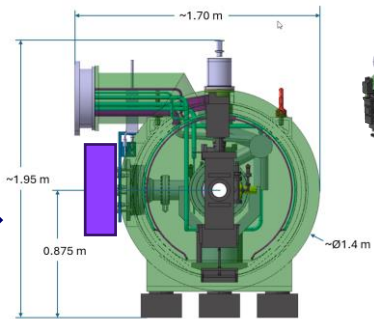
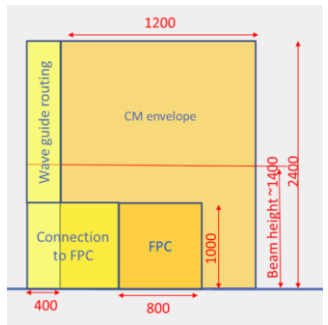
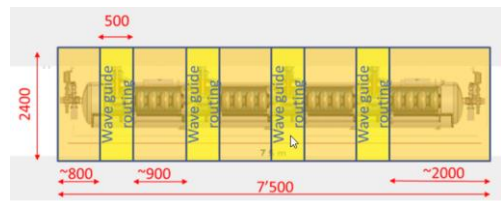
FCC week 2025



11.240 m

Drawing ref: FCCACSGA0002

800 MHz CM based on SPL design



10.250 m

Drawing ref: FCCACSGA0003