FUTURE CIRCULAR COLLIDER

SRF 400 & 800 MHz CRYOMODULES:

Design evolution and future work

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with contributions from: V. Parma, S. Gorgi Zadeh, F. Peauger, I. Karpov, M. Timmins, F. Cottenot, C. Sharp, S. Calvo, L. Delprat, A. Henriques, G. Nergiz, F. Valchkova-Georgieva.
and inputs from: N. Elias (ESS), P. Pierini (ESS), C. Maiano (ESS), D. Passarelli (FNAL), V. Roger (FNAL)

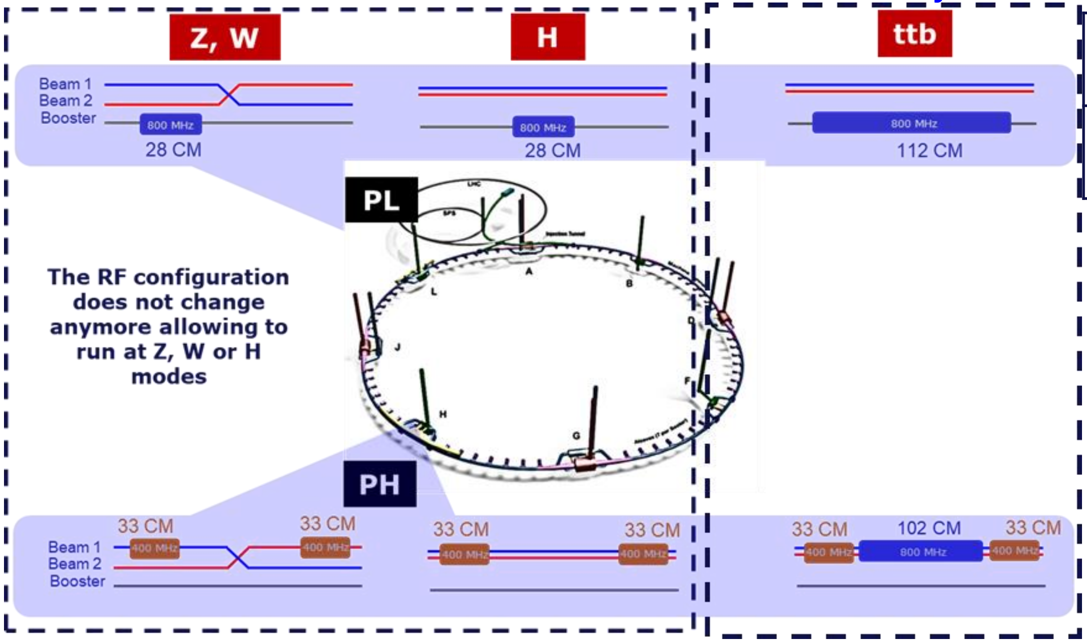
FCC week 2025, Vienna

Outline

- SRF system layout – Reverse Phase Operation (RPO) scheme
- Cryomodules specifications update:
    - 400MHz Cryomodule
        - CM general requirements
        - Heat loads budget and margins
    - 800MHz Cryomodule
        - CM general requirements
        - Heat loads budget and margins
- Current engineering work
    - 400MHz Cryomodule: Overview, cavities supporting system, cryogenic scheme, cryomodule assembly, HOMs/BLAs/Cold-Warm transitions
    - 800MHz Cryomodule: Overview, cryogenic scheme
- Helium safety and LSS access conditions
- Summary and future work

SRF system layout: Reverse Phase Operation (RPO) scheme

Booster system



The RF configuration does not change anymore allowing to run at Z, W or H modes

(O. Brunner et al.)

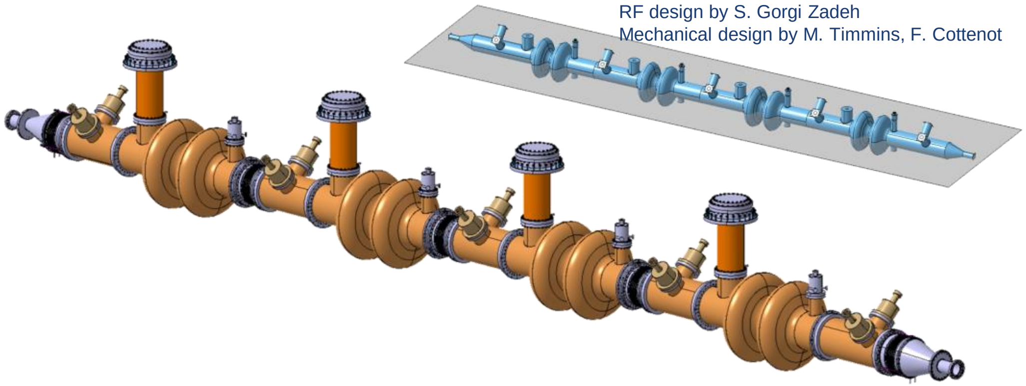
Collider system

	Cavities	**Cryomodules**
Z, W, ZH – 800MHz	112 cavities @2K RPO for Z and W working points	28 (4 cavity x CM) Installed before beginning of operation
ttbar -800MHz	448 cavities @2K	112 (4 cavity x CM) Installed in the technical stop between ZH and ttbar

	Cavities	**Cryomodules**
Z, W, ZH – 400MHz	264 cavities @4.5K RPO for the Z working point	66 (4 cavity x CM) Installed before beginning of operation
ttbar -800MHz	408 cavities @2K	102 (4 cavity x CM) Installed in the technical stop between ZH and ttbar

SRF system layout: 400 MHz cavity string and RF parameters

Collider	Z	W	ZH
	1 beam RPO	1 beam	2 beams
Total RF voltage [MV]	89	1049	2098
Beam current [mA]	1283	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		



RF design by S. Gorgi Zadeh
Mechanical design by M. Timmins, F. Cottenot

Impact on the cryomodule technical specs

Constant cavity voltage from Z to ZH:

- Higher heat loads at the Z working point (129W/cav instead of 9W/cav), higher operational cost

Same cavity and cryomodule design from Z to ZH:

- Suppression of the single-cell 400MHz design
- Reduction of the capital cost of design, R&D, production, installation, commissioning, etc.
- Higher impedance and HOM power dissipated at the Z working point (63.2 kW instead of 32.9 kW), setting the requirement in terms of HOMs extractors design for all the 66 CMs

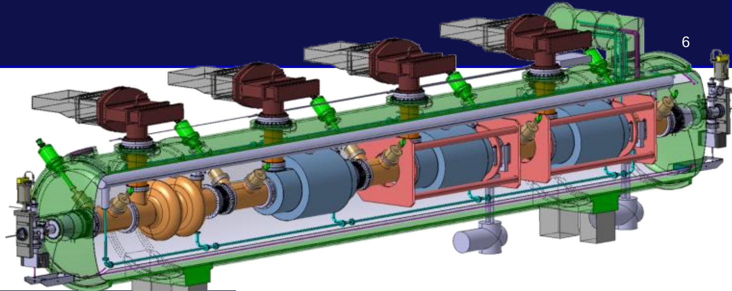
Lower RF power per cavity at the Z working point (380kW instead of 1MW):

- Possibility to reconsider a more standard FPC design and cryomodule assembly procedure (see next slides)
- Lower RF dissipation in the FPC outer conductor, constraining the diameter of the outer vessel, which could be reduced

400 MHz Cryomodule

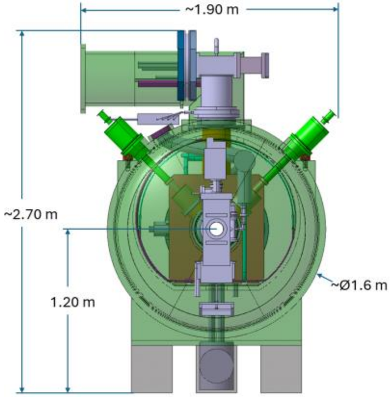
Technical specifications

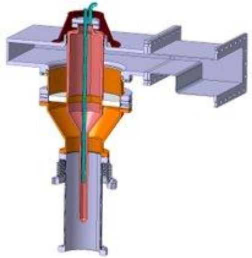
Details about the cryomodule integration in the talk of M. Timmins and F. Valchkova-Georgieva: “RF general layout and integration”



	Value	Remarks
Diameter warm beam pipe	100 mm	Possibility to change to 160mm gate valves
CM length (GV flange to GV flange)	11.24 m	No length reduction foreseen
Beam height from the floor	1200 mm	Instead of 980mm beam height in the arc – need to adjust the tunnel pavement
CM width (with jumper)	< 2 m	-
CM height from the floor	< 2.7 m	Final value TBD according to: final geom. for the FPC, waveguides, jumper and PRDs space occupations.
CM weight	12 000	-
Cavity operating temperature	4. 5 K	-
Environ. magnetic shield	≤ 5 mG	Levels of magnetic shielding TBD
Layout architecture	Fully segmented (baseline)	Choice determined by the need of having warm BLAs between cryomodules
Tunnel integration	Supported on floor	-
Tunnel inclination	0.25%	Influence on liquid levels
FPC design	Ceramic window in the waveguide (current model)	Possibility to return to a design with the ceramic window in the vacuum vessel
FPC orientation	Vertical/top	Fixed antenna
FPC cooling strategy	Active cooling with supercritical helium (DWT)	Active cooling considered as baseline for operational flexibility (HI still considered as option since the design is not finalized)
Beam line absorbers	Yes	Study ongoing, considered warm in the current design given the high heat loads expected (range of kW)
Tuning range /Tuning system	140 kHz	Engineering of a first concept for the tuning system in progress
Maximum allowable pressure	2.1 bar (a)	This value is a first assumption, validation process ongoing
Cryomodule load cases	-	TBD
Maintainability	-	Design for in situ accessibility to critical components

Mech design: M. Timmins, F. Cottenot
Drwg : FCCACSGA0002





400 MHz Cryomodule - Heat loads and margins

Evolution compared to FCC week

	Z(*)	W/H/$t\bar{t}$
	Collider	Collider
# of cryomodules	28	66
Static HL at 4.5K/CM [W]	131	131
Dynamic HL at 4.5K/cav (CM) [W]	9 (36)	129 (516)
HL to thermal shield at 50K/CM [W]	218	218
Required liquefaction capacity/CM [mg/s]	320	320

Nominal values (last year)

- Static heat loads to the cold mass: Values derived from the **experimental measurements of the LHC cryomodule** with active thermal shield correction – substituting the MTR placeholder value.
- Dynamic losses: **Power dissipation per cavity (goal values)** as indicated in the baseline, not including the contribute of the FPC, HOMs and non-superconductive parts.
- Heat loads to thermal shield: Derived with conservative assumptions and a simplified design of the CM
- Liquefaction capacity necessary for the active cooling of the FPC

	Z/W/H/$t\bar{t}$
	Collider
# of cryomodules	66
Static HL at 4.5K/CM [W]	131
Dynamic HL at 4.5K/cav (CM) [W]	129 (516)
HL to thermal shield at 50K/CM [W]	218
Required liquefaction capacity/CM [mg/s]	320

Nominal values (current - RPO)

- Finalization of the RPO scheme for the collider: the number of cryomodules required at the H working point will be installed since the beginning.
- **Higher total energy consumption** linked to the higher number of cryomodules and higher cavity voltage **at the Z working point**.

	Z/W/H/$t\bar{t}$
	Collider
# of cryomodules	66
Static HL at 4.5K/CM [W]	197
Dynamic HL at 4.5K/ CM [W]	516
HL to thermal shield at 50K/CM [W]	327
Required liquefaction capacity/CM [mg/s]	320

Margins on RF side

- **50% design uncertainty margin on the static heat loads** – due to the preliminary design maturity, for the main elements inside the cryomodule it has been assigned only a space occupation.
- **50% margin on the liquefaction capacity** – to grant flexibility on the helium flowrate.
- **Uncertainty margin on dynamic heat loads will be added.**

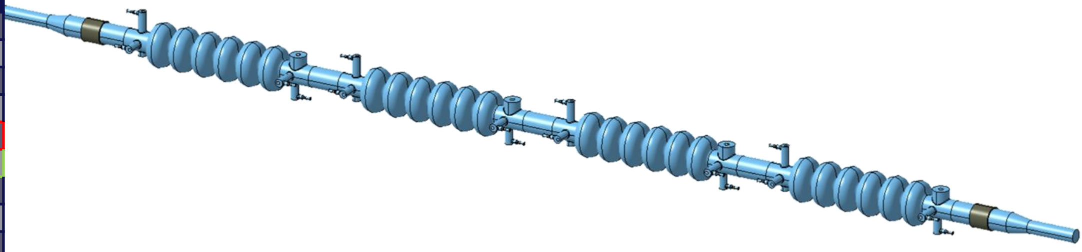
For what concerns operations**: at least 8% operational margin on the dynamic loads should be considered** – for the scenario with only **90% operational cavities** operating at higher E_{acc} with a consequent increase of **20% or more on the dynamic heat loads** (according to the Q_0/E_{acc} slope of the cavities). Provision for cavity performance degradation to be added.

SRF system layout: 800 MHz cavity string and RF parameters

Booster	Z	W	ZH
	RPO	RPO	
Total RF voltage [MV]	80	401.9	1961
Beam current [mA]	14.3	11.8	2
RF Frequency [MHz]	800.58		
Operating temp. [K]	2		
Cavity voltage [MV]	8.4	13.5	17.5
# cell/cavity	6		
Eacc [MV/m]	2.5	12	15.6
Q0	3E+10		
Max RF power [kW]	42		
Coupling QL	1E+07		
# CM (with 4 cav/CM)	28		
# cavities	112		

	ttb collider		ttb booster
	2 beams		1 beam
Total RF voltage [MV]	2098	9202	10180
Beam current [mA]	10		0.4
RF Frequency [MHz]	400.79	800.58	
Operating temp. [K]	4.5	2	
Cavity voltage [MV]	7.95	22.5	22.7
# cell/cavity	2	6	
Eacc [MV/m]	10.6	20.1	20.25
Q0	2.7E+9	3E+10	
RF power [kW]	78	195	8.8/12.6
Optimum coupling QL	4.5E+06	4.1E+06	9.4E+07/2.7E+07
# CM (with 4 cav/CM)	66	102	112
# cavities	264	408	448

RF design by S. Gorgi Zadeh
Mechanical design by M. Timmins, F. Cottenot



Impact on the cryomodule technical specs

Variable cavity voltage from Z to ZH:

- Sizing of the cryogenic capacity should account for the variation of the dynamic heat loads (impact of this variation may be negligible with respect of the constant contribute of the static heat loads – check in progress)

6-cell cavities:

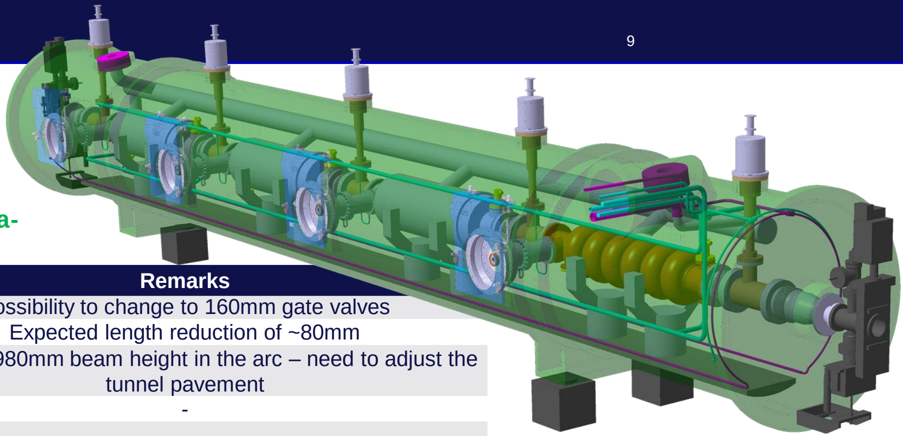
- Longer cryomodules but reduction of the number of cryomodules required for ttbar operation

Higher requirement for Eacc is 20.25 MV/m:

- Value considered for the sizing of the 800MHz cryomodule, one single design for booster and collider for all the working points

800 MHz Cryomodule

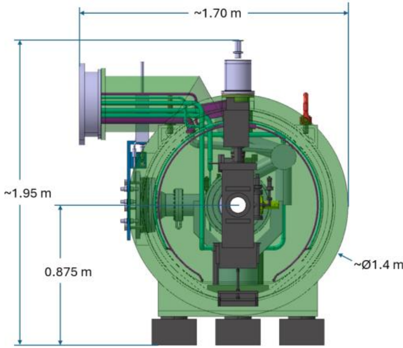
Technical specifications



Details about the cryomodule integration in the talk of M. Timmins and F. Valchkova-Georgieva: “RF general layout and integration”

	Value	Remarks
Diameter warm beam pipe	100 mm	Possibility to change to 160mm gate valves
CM length (GV flange to GV flange)	10.25 m	Expected length reduction of ~80mm
Beam height from the floor	1200 mm (collider) / 1200 + 1030mm (booster)	Instead of 980mm beam height in the arc – need to adjust the tunnel pavement
CM width (with jumper)	< 2.7 m	-
CM height from the floor	< 1.9 m	-
CM weight	10 000(?)	-
Cavity operating temperature	2 K	-
Environ. magnetic shield	≤ 5 mG	Levels of magnetic shielding TBD
Fast cooldown of cavities	>20 K/min between 40K and 4K	PIP-II reference, valueTBC
Layout architecture	Fully segmented (baseline)	Choice determined by the need of having warm BLAs between cryomodules
Tunnel integration	Supported on floor (collider) / supported on fixed pillars (booster)	-
Tunnel inclination	0.25%	Influence on liquid levels
FPC design	Ceramic window in the vacuum vessel	-
FPC orientation	Horizontal / Side	Fixed antenna. Possibility to review the orientation given the criticalities in the supporting system (ensuring RF transmission and allowing thermal contraction)
FPC cooling strategy	Active cooling with supercritical helium (DWT)	Active cooling considered as baseline for operational flexibility (HI still considered as option since the design is not finalised)
Beam line absorbers	Yes	Study ongoing, considered warm in the current design given the high heat loads expected (range of kW)
Tuning range /Tuning system	TBD (sum of manufacturing and operational compensation ranges)	TBD
Maximum allowable pressure	2.1 bar (a)	This value is a first assumption, validation process ongoing
Cryomodule load cases	-	TBD
Maintainability	-	Design for in situ accessibility to critical components

Mech design based on FermiLab PIP-II design:
M. Timmins, F. Cottenot
Drwg : FCCACSGA0003



800 MHz Cryomodule - Heat loads and margins

Evolution compared to last year

	Z(*)	W/H/$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Collider
# of cryomodules	6	14/28/150	122
Static HL at 2K/CM [W]	32		
Dynamic HL at 2K/cav (CM) [W]	0.3 (1.2)	3 (12)	23 (92)
HL to thermal shield @50K/CM [W]	103		
Required liquefaction capacity/CM [mg/s]	320		

Nominal values (last year)

- Static heat loads to the cold mass: **Baseline estimate of 8W/cav** is kept (in line with experimental values on prototypes with similar design: HB650CM of PIP-II and HB CM ESS).
- Dynamic losses: **Power dissipation per cavity (goal values)** as indicated in the baseline, not including the contribute of the FPC, HOMs and non-superconductive parts.
- Assuming 15% booster duty cycle.
- Static heat loads to thermal shield: Derived with conservative assumptions on a simplified design of the CM.
- Liquefaction capacity required for the active cooling of the FPC

	Z	W	H	$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Booster	Booster	Collider
# of cryomodules	28	28	28	112	102
Static HL at 2K/CM [W]	38.4				
Dynamic heat loads at 2K/cav (CM) – peak value [W]	3.7 (14.8)	9.7 (38.8)	14.6 (58.4)	24.1 (96.4)	26.8 (107.2)
Dynamic heat loads at 2K/cav (CM) – avg value [W]	0.7 (2.8)	1.7 (6.8)	2.4 (9.6)	4.2 (16.8)	-
HL to thermal shield @50K/CM [W]	154				
Required liq. capacity/CM [mg/s]	320				

Margins on RF (current, 6-cells/RPO)

•Static heat loads**: Baseline estimate adapted to account for the 6-cells cavities**

•Finalization of the RPO scheme for the booster: Definition of the **cavity voltage** (and dynamic heat load) **time profiles** during the cycle.

	Z	W	H	$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Booster	Booster	Collider
# of cryomodules	28	28	28	112	102
Static HL at 2K/CM [W]	56				
Dynamic heat loads at 2K	As in the table above				
HL to thermal shield @50K/CM [W]	180				
Required liq. capacity/CM [mg/s]	480				

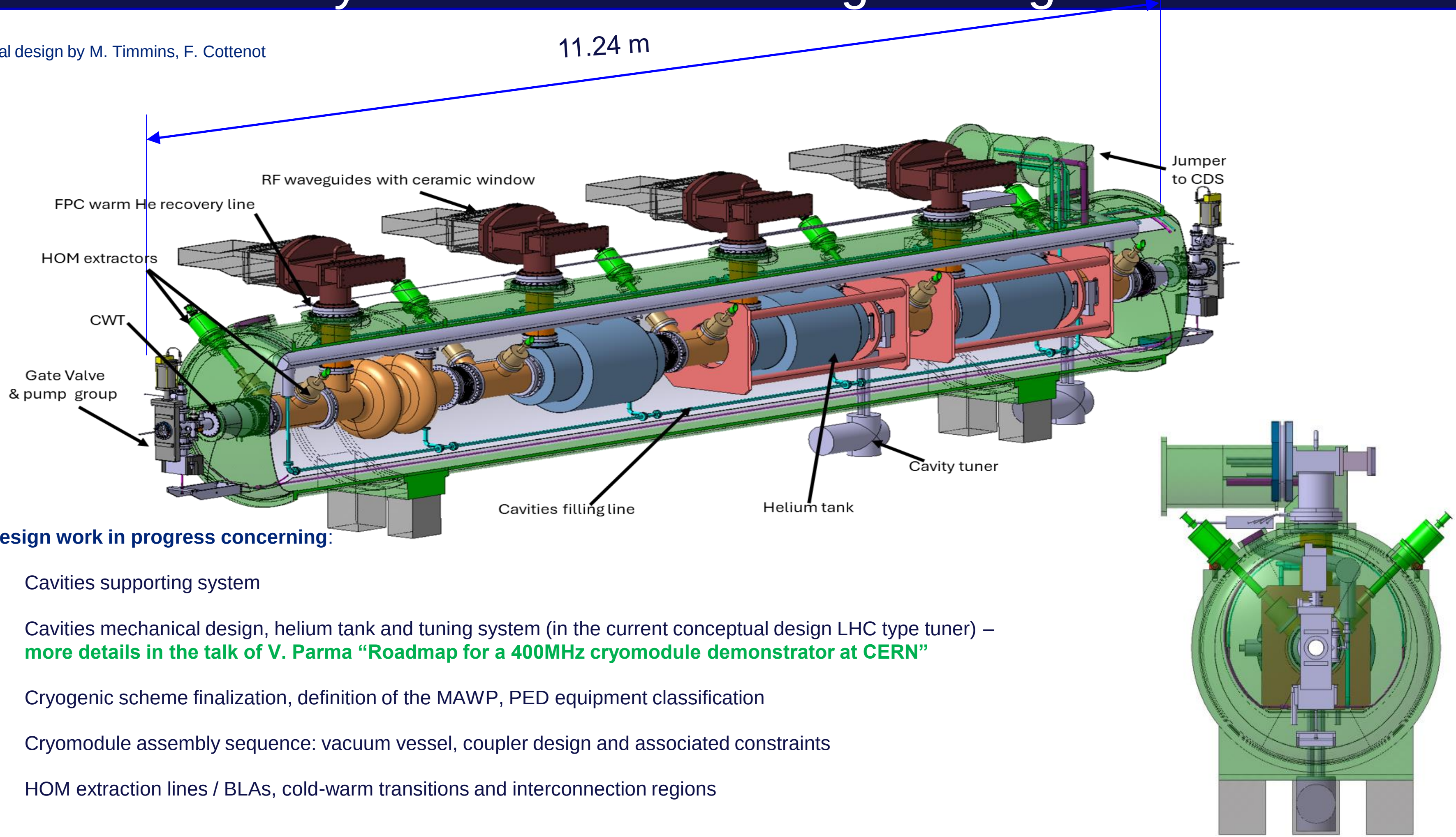
Margins on RF side

- **50% design uncertainty margin on the static heat loads** – due to the preliminary design maturity, for the main elements inside the cryomodule it has been assigned only a space occupation. The engineering work to derive the real dimensions started at the beginning of this year.
- **50% margin on the liquefaction capacity** – to grant flexibility on the helium flowrate.
- **No uncertainty margin on dynamic heat loads will be added**

For what concerns operations**: at least 8% operational margin on the dynamic loads should be considered** – same reasoning as indicated for the 400MHz cavities.

400 MHz Cryomodule: Current engineering work

Mechanical design by M. Timmins, F. Cottenot



Design work in progress concerning:

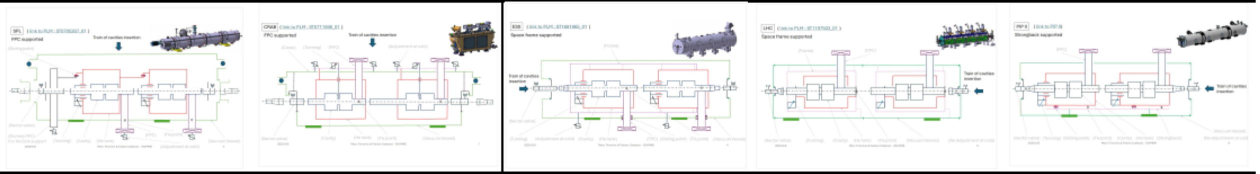
- Cavities supporting system
- Cavities mechanical design, helium tank and tuning system (in the current conceptual design LHC type tuner) – **more details in the talk of V. Parma "Roadmap for a 400MHz cryomodule demonstrator at CERN"**
- Cryogenic scheme finalization, definition of the MAWP, PED equipment classification
- Cryomodule assembly sequence: vacuum vessel, coupler design and associated constraints
- HOM extraction lines / BLAs, cold-warm transitions and interconnection regions

400 MHz Cryomodule: cavities supporting system

Design principles: **(I) Isostatic system** of constraints that would allow the **free thermal contraction of the different elements** (different than LHC hyperstatic system). **(II)** System of constraints with the **FPC as fixed point in the longitudinal direction.**

Overview of cavity supporting schemes of different Cryomodules

Comparative analysis of the supporting systems of other cryomodules: M. Timmins and F. Cottenot



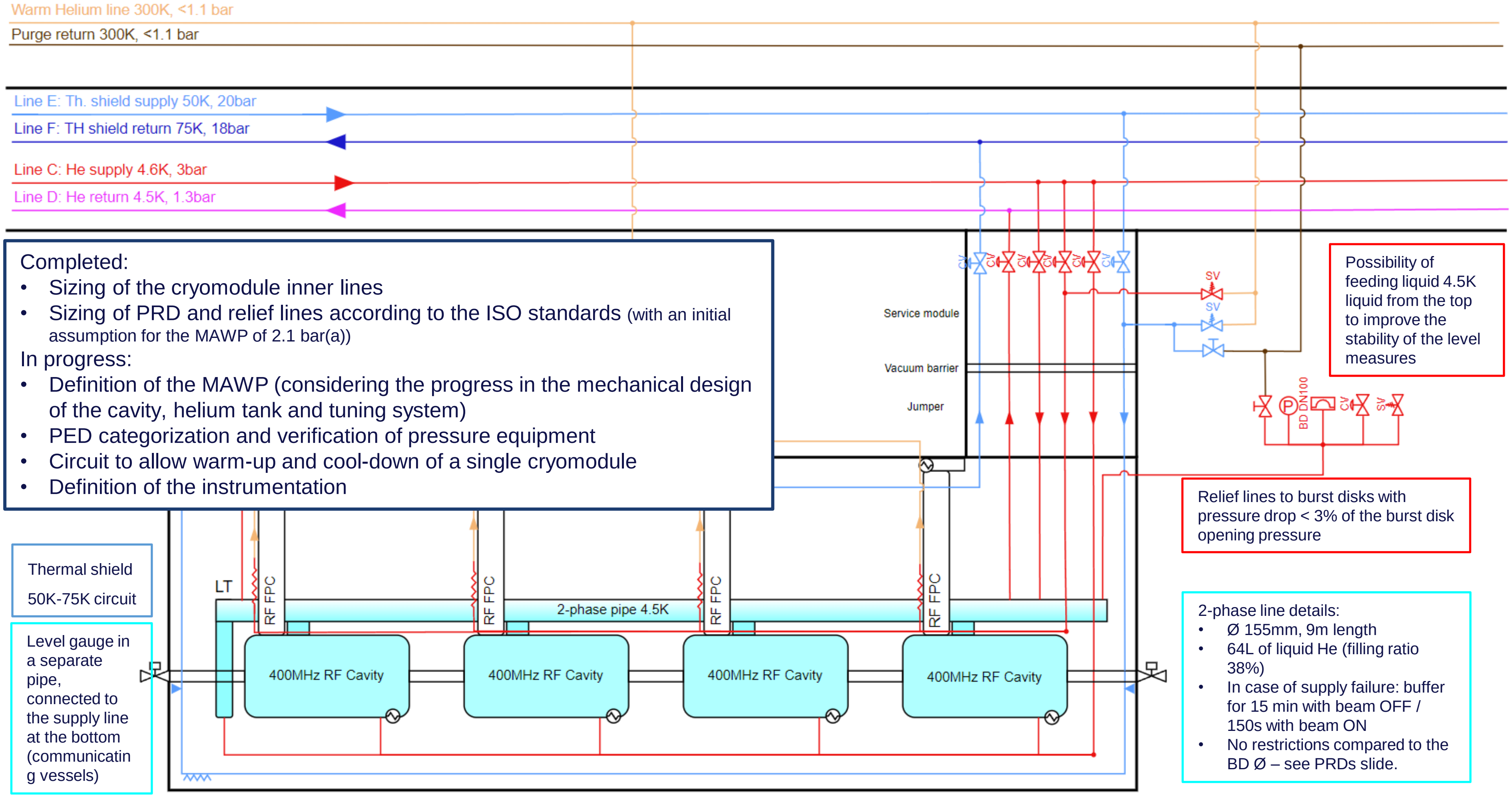
Simplicity in terms of :	SPL	CRAB	ESS	LHC	PIP II
Train of cavities assembly and alignment in cleanroom *yes = Permanent reference structure*	yes	yes	yes	no	no
FPC assembly onto cavity *yes = installation in clean room without cryostat - no = assembly outside clean room / return in clean room*	yes	yes	yes		
Train of cavities insertion into vacuum vessel *yes = Insertion from the top more compact in terme of integration & Reduce tooling needs*	yes	yes	no		
Train of cavities supporting and alignment inside vacuum vessel outside cleanroom *yes = Possibility to align the train of cavities form the outside - no = align cavities individually or difficult access*	yes	yes	yes		
Sector valves installation before cryostating *yes = installation in clean room - no = assembly outside clean room*	yes	yes	yes		
Vacuum vessel manufacturing *yes = circular shape & circular seals*	no	no	yes		
Train of cavities preserves alignment at cold *yes = no loss of alignment at cold - no = realignment required at cold*	no	no	yes		
Train of cavities alignment adjustment at cold *yes = allowed alignment at cold - no = impossible realignment at cold*	yes	yes	n/a		
Number of components *yes = less components - no more components*	yes	yes	no	no	no

SPL, CRAB and ESS concepts for cavity support show the most advantages.

Final choice needs to account for the:

- Design of the 400MHz helium tank, connection between the tank and the cavity and tuning system
- Design of the FPC and assembly constraints
- Compatibility with the HOM design (especially for the ESS design)
- Cost and standardization for the cryomodule series production in industry

400 MHz Cryomodule: cryogenic scheme



Completed:

- Sizing of the cryomodule inner lines
- Sizing of PRD and relief lines according to the ISO standards (with an initial assumption for the MAWP of 2.1 bar(a))

In progress:

- Definition of the MAWP (considering the progress in the mechanical design of the cavity, helium tank and tuning system)
- PED categorization and verification of pressure equipment
- Circuit to allow warm-up and cool-down of a single cryomodule
- Definition of the instrumentation

Possibility of feeding liquid 4.5K liquid from the top to improve the stability of the level measures

Relief lines to burst disks with pressure drop < 3% of the burst disk opening pressure

Thermal shield

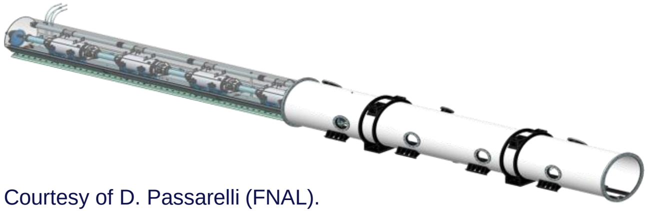
50K-75K circuit

Level gauge in a separate pipe, connected to the supply line at the bottom (communicating vessels)

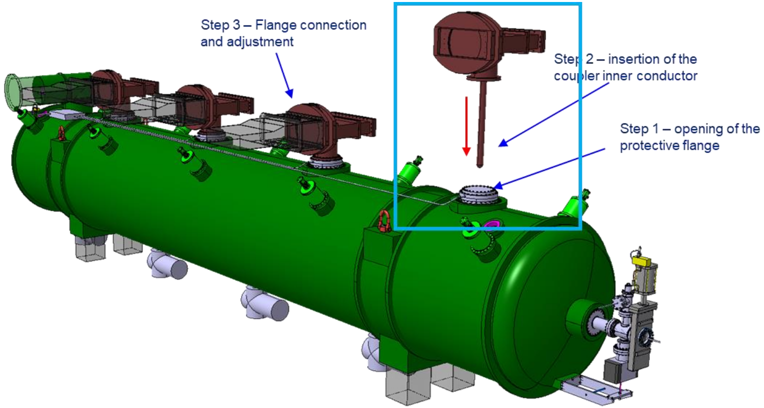
2-phase line details:

- Ø 155mm, 9m length
- 64L of liquid He (filling ratio 38%)
- In case of supply failure: buffer for 15 min with beam OFF / 150s with beam ON
- No restrictions compared to the BD Ø – see PRDs slide.

400 MHz Cryomodule: Cryomodule assembly



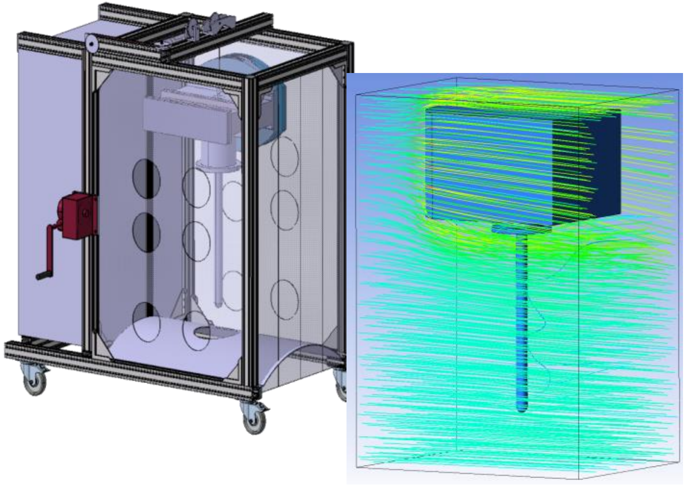
Courtesy of D. Passarelli (FNAL).
Axial insertion of the cavity string into the vacuum vessel



Steps for the FPC mounting after the cavity string insertion in the vacuum vessel

Current design principles:

- **Cylindrical vacuum vessel**:
    - Design used in machines with high numbers of cryomodules (XFEL, LCLS-II), **cost saving option**: traditional tubular products in low carbon steel
    - Axial insertion of the cavity string in the vessel **outside of the clean room, highly industrialized process**
- **FPC design with ceramic window in the waveguide** (dimensioned for 1MW of RF power at the Z working point) requiring a local cleanroom to be assembled after the insertion of the cavity string in the vacuum vessel.
- **High effort expected for the design, prototyping and validation of the local cleanroom** to avoid cavity contamination

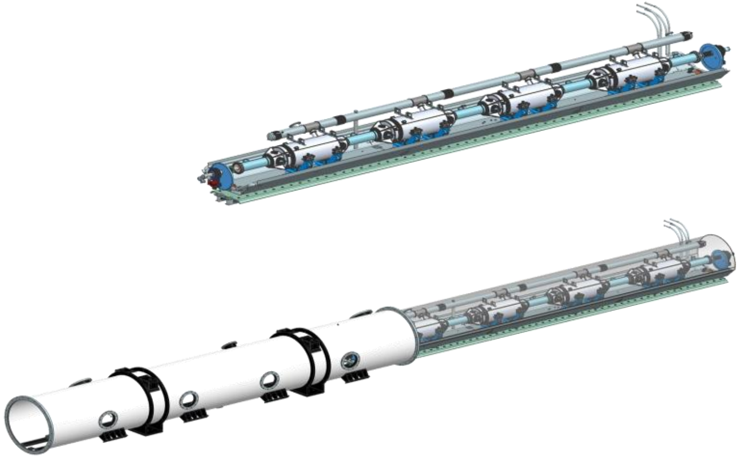


Model for the local cleanroom prototype and CFD study to assess the presence of turbulent flow

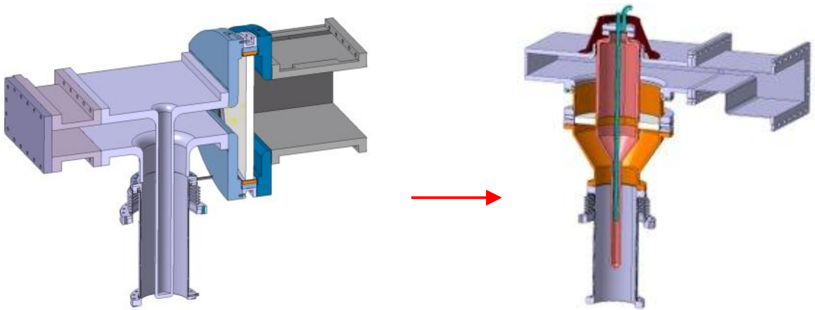
400 MHz Cryomodule: Cryomodule assembly

In RPO the RF power at the Z working point is 380 kW (operational):

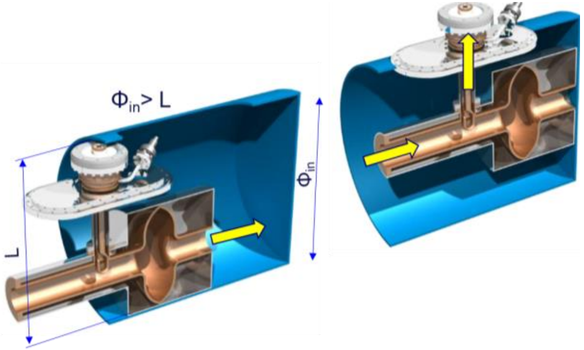
- Possibility to reconsider a **more conventional design for the FPC**, with **ceramic window in the vacuum vessel**
- Conventional assembly of the FPC in cleanroom, without exposing the cavity vacuum to potential contamination
- Axial assembly of the cavity string in the vacuum vessel
- Possibility to **reduce the length of the FPC outer conductor**, constraining the diameter of the vacuum vessel



Courtesy of D. Passarelli (FNAL)



Courtesy of S. Calvo



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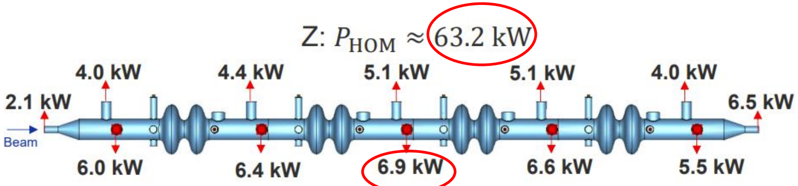
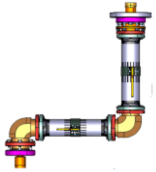
400 MHz Cryomodule: HOM extractors, BLAs and CWT

HOM extractors

- Higher HOM power extraction requirements at the Z WP with RPO, very challenging and bulky design for the extractors of all 66 cryomodules
- All the intercavity HOM extractors **will be rigid (**$P_{HOM} \cdot 6 > 1$ kW), **difficult to match routing** of rigid coaxial and **assembly/maintenance need**
- **Space reservation** in the tunnel should be considered for damping the power (complicated routing to the klystron gallery)





DQW HOM extractors, extracting 1kW in operation – **Design to be rescaled to handle up to 15 kW** (including margin)

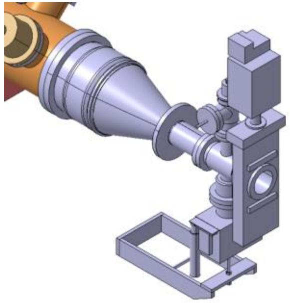
Beam line absorbers (BLAs)

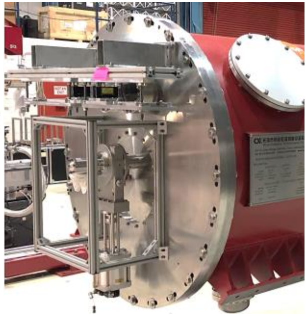
- Adaption of the cryomodule interconnection regions to **host the warm BLAs** (segmented machine layout becomes compulsory)
- Assessment of the **BLAs impact on machine reliability** (potential issues with contamination)

EIC BLA (warm – water cooled).
The HOM power is too high to be damped in the cryogenic lines (as done in XFEL)

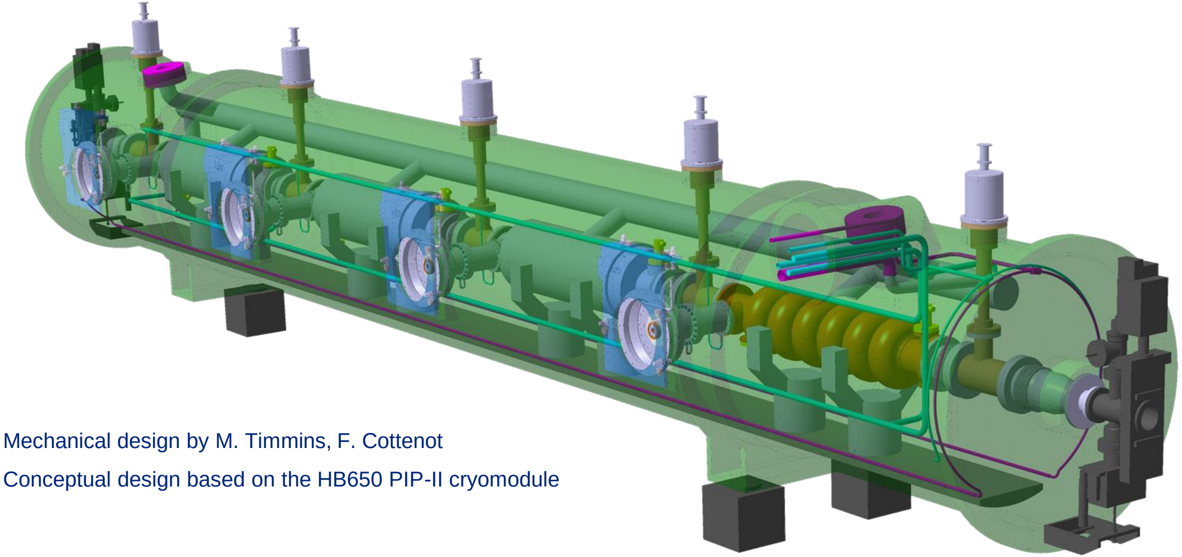
CWT, beam tapering and gate valves

- Under discussion the **possibility to reduce the beam pipe tapering angle** (larger beam pipe in the interconnection region 160mm instead of 100mm) **to reduce of 10% the HOM power** dissipated in operation at the Z working point and allow the **installation of BLA after the gate valve** – in favor of sectorization and machine availability
- Bigger gate valves (longer closing time, of 9s instead of 4s) will result in a **higher number of cryomodules contaminated in case of beam vacuum break**



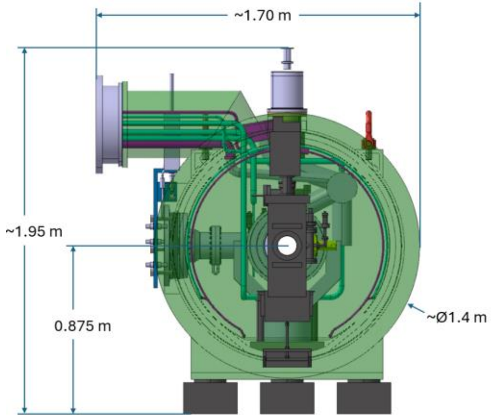


800 MHz Cryomodule: Current engineering work



Mechanical design by M. Timmins, F. Cottenot

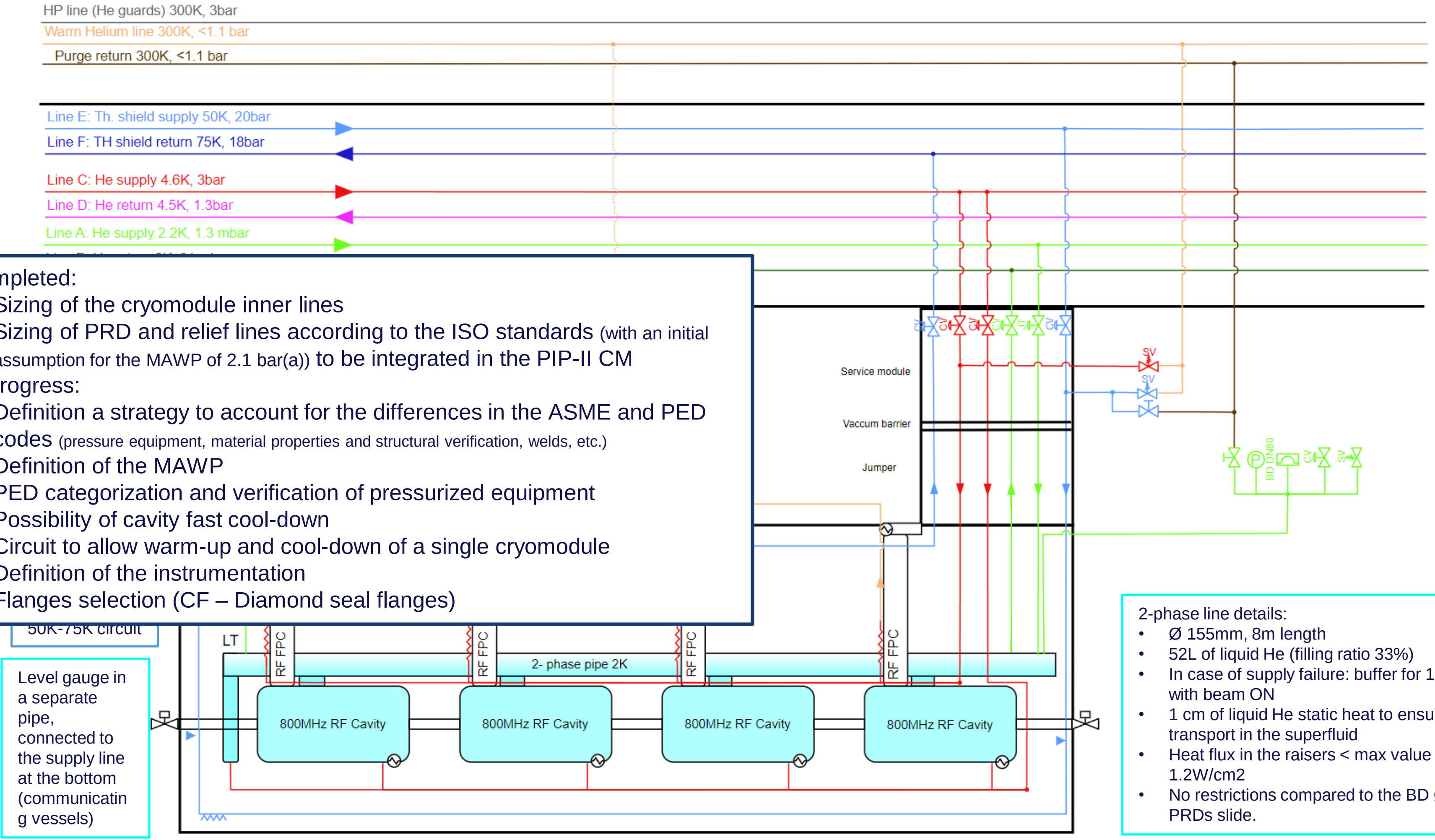
Conceptual design based on the HB650 PIP-II cryomodule



Design work in progress, in collaboration with FermiLab colleagues – **more details in the talk of M. Garlasche: “Cavity substrate development” and K. McGee: “800 MHz SRF cavity and cryomodule developments at FNAL towards FCC”**

- 1-cell 800MHz cavities fabrication for treatment and testing at FNAL
- 5-cell 800MHz (from IJCLab) cavity testing at FNAL
- Cavities mechanical design, helium tank and tuning system
- Adaptation of the PIP-II cryomodule design to integrate FCC 800MHz cavity string
- Cryogenic scheme finalization, definition of the MAWP, strategy definition to deal with the different standards for pressure equipment (ASME code vs PED code), PED category classification

800 MHz Cryomodule – Cryogenic scheme



Completed:

- Sizing of the cryomodule inner lines
- Sizing of PRD and relief lines according to the ISO standards (with an initial assumption for the MAWP of 2.1 bar(a)) to be integrated in the PIP-II CM

In progress:

- Definition a strategy to account for the differences in the ASME and PED codes (pressure equipment, material properties and structural verification, welds, etc.)
- Definition of the MAWP
- PED categorization and verification of pressurized equipment
- Possibility of cavity fast cool-down
- Circuit to allow warm-up and cool-down of a single cryomodule
- Definition of the instrumentation
- Flanges selection (CF – Diamond seal flanges)

Level gauge in a separate pipe, connected to the supply line at the bottom (communicating vessels)

2-phase line details:

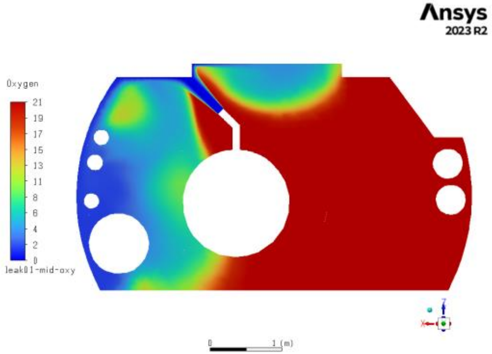
- Ø 155mm, 8m length
- 52L of liquid He (filling ratio 33%)
- In case of supply failure: buffer for 15 min with beam ON
- 1 cm of liquid He static heat to ensure heat transport in the superfluid
- Heat flux in the raisers < max value of 1.2W/cm2
- No restrictions compared to the BD Ø – see PRDs slide.

Helium safety and access to LSS

Goal: Define a safe strategy to access the SRF cryomodules for maintenance without warming up the entire LSS, to reduce the down time and improve machine availability.

Worst case scenario: Beam vacuum break

The liquid helium inventory (115kg) of the 400MHz cryomodule is entirely released in the tunnel with a flowrate of ~10 kg/s. In correspondence of the burst disk the oxygen level and the temperature drop (-200C) in 1-2 s, which is not a sufficient reaction time for a person to escape. (**see talk from G. Nergiz)**



Preliminary strategy:

- The **cryomodule interest by the maintenance work** (and the adjacent(s) one(s)) will be **warm**
- All the **cryomodules on the way** from the closest access point to the cryomodule interested by the activity need to be emptied (**no liquid He**, only cold vapor).
- Active thermal shield cooling to limit the maximum cavities temperature (40-50K) in the cryomodules not interested by the maintenance work, so that **to reduce cavity reconditioning needs.**

Work is currently ongoing to reduce the probability of beam vacuum break and/or limit the helium flowrate, assess the probability of beam vacuum break when transiting next to the cryomodules (strategy in XFEL?), define a minimum liquid inventory that could reduce the longitudinal extension of the helium spill.

Summary and future work

Summary from last FCC week 2024:

- Update of the technical specifications and heat loads for the 400MHz and 800MHz cryomodules after the approval of the RPO
- Detailed engineering design started for multiple components of the cryomodules, the definition of the FPC design will strongly help in the consolidation of the design and assembly sequence
- HOM extractors and BLAs design and integration to be address more in details
- The assembly strategy is developed in parallel with the design of the components
- Progress in the definition of the LSS access condition in collaboration with HSE, to improve the machine availability

Progress in the engineering design of the cryomodule internal components is essential before consolidating the cryomodule overall dimensions, integration and assembly aspects !

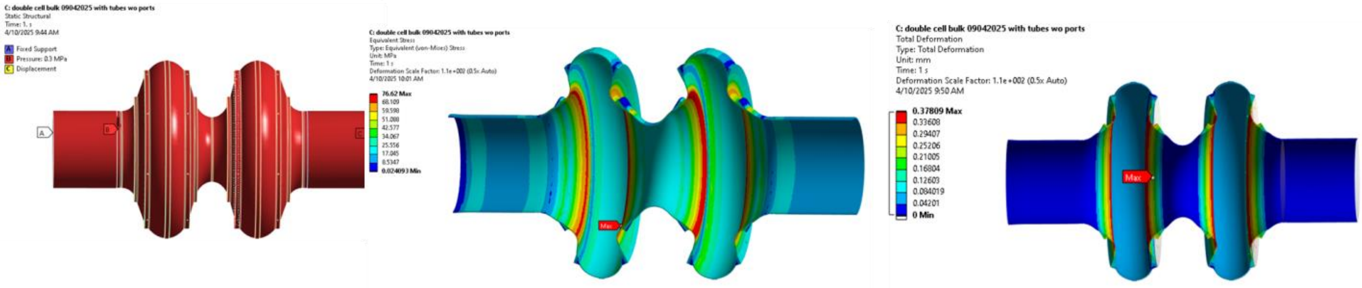
Thank you
for your attention.

Supporting slides

400 MHz Cryomodule: cavitiy, helium tank, tuning needs

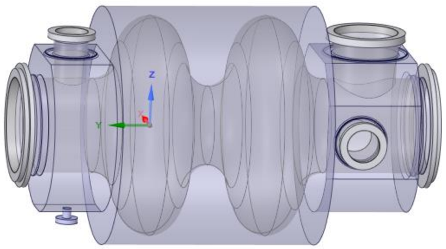
Bulk machined cavity for coating qualification

Double cell ST2419142 040425, ports removed, tubes 3.84 thickness



(K.Artoos et al.)

Simulations on stiffness with He tank, tuning forces

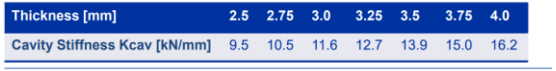


Perform simulations to determine the thickness of the cavity and the He tank. Influencing parameters:

1. Assessment for pressure
2. LFD and PS
3. Tuner

(T. Hernandez, EN-MME)

CAVITY			
Thickness [mm]	Force [KN]	Displacement [mm]	Stiffness [KN/mm]
2.5	1	0.11	9.51
2.75	1	0.09	10.63
3	1	0.08	11.77
3.25	1	0.08	12.95
3.5	1	0.07	14.15
3.75	1	0.07	15.38
4	1	0.06	16.64

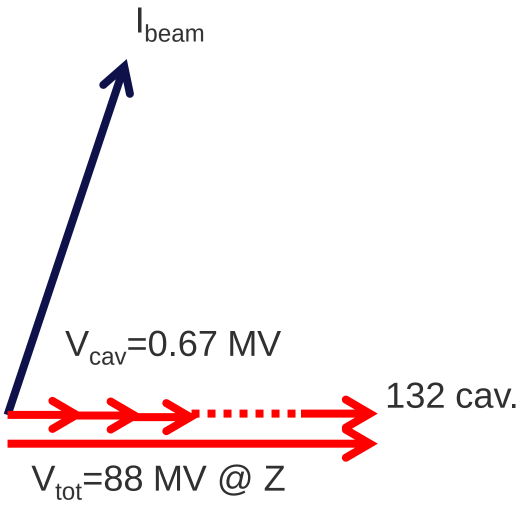


Thickness [mm]	2.5	2.75	3.0	3.25	3.5	3.75	4.0
Cavity Stiffness Kcav [kN/mm]	9.5	10.5	11.6	12.7	13.9	15.0	16.2

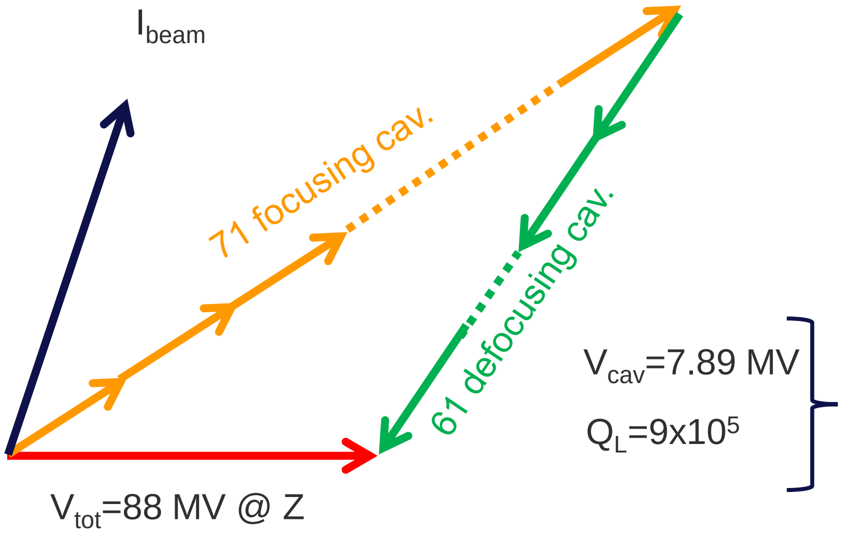
From Shahnam Gorgi Zadeh presentation

Reverse Phase Operation (RPO)

- ❑ Reverse phase operation (RPO) mode allows increasing RF cavity voltage when total RF voltage is low
- ❑ Experimentally verified with high beam loading in KEKB and baseline solution for EIC ESR
- ❑ **RPO proposed for FCCee as new baseline**
  - ▪ **at Z for collider**
  - ▪ **at Z, W, ZH(injection), ttb(injection) for booster – <u>I. Karpov, FCC Beam Optic meeting, 28 Jan 2025</u>**



Q_L=6.4x10^3
ΔF = -62 kHz



same as for W & H

(O.Brunner et al.)

Heat Load budgets 400 MHz (Pt.H)

MTR 2023

	Z
Collider	
# cell / cav	1
# CM (4 cav/CM)	28
RF voltage [MV]	1.43
Duty cycle	100%
Dynamic losses to the helium bath/cav [W]	**9**
Static losses to the helium bath/CM [W]	**32**
Static losses to the thermal shield circuit/CM [W]	-
Total W/CM at 4.5 K	**68**
Machine total to the helium bath at 4.5 K [kW]	1.904
Machine total heat load to the thermal shield [kW]	not specified

- Static: 8 W/cavity (still from CDR)
- No HL to thermal shield
- No uncertainty margins

FCC week 2024 (with margins)

	Z
Collider	
# cell / cav	1
# CM (4 cav/CM)	28
RF voltage [MV]	1.43
Duty cycle	100%
Dynamic losses to the helium bath/cav [W]	**9**
Static losses to the helium bath/CM [W]. 50% uncertainty margin	**197**
Static losses to the thermal shield circuit/CM [W]. 50% uncertainty margin	**327**
Total W/CM at 4.5 K	**233**
Machine total to the helium bath at 4.5 K [kW]	6.52
Machine total heat load to the thermal shield [kW]	9.16

- Static: rescaled from LHC CM +50% uncertainty
- HL to thermal shield added
- No HL breakdown by component (too early)

March 2025 (RPO)

	Z
Collider	
# cell / cav	**2**
# CM (4 cav/CM)	**66**
RF voltage [MV]	**7.95**
Duty cycle	100%
Dynamic losses to the helium bath/cav [W]	**128.12**
Static losses to the helium bath/CM [W]. 50% uncertainty margin	**197**
Static losses to the thermal shield circuit/CM [W]. 50% uncertainty margin	**327**
Total W/CM at 4.5 K	**709.50**
Machine total to the helium bath at 4.5 K [kW]	46.83
Machine total heat load to the thermal shield [kW]	21.58

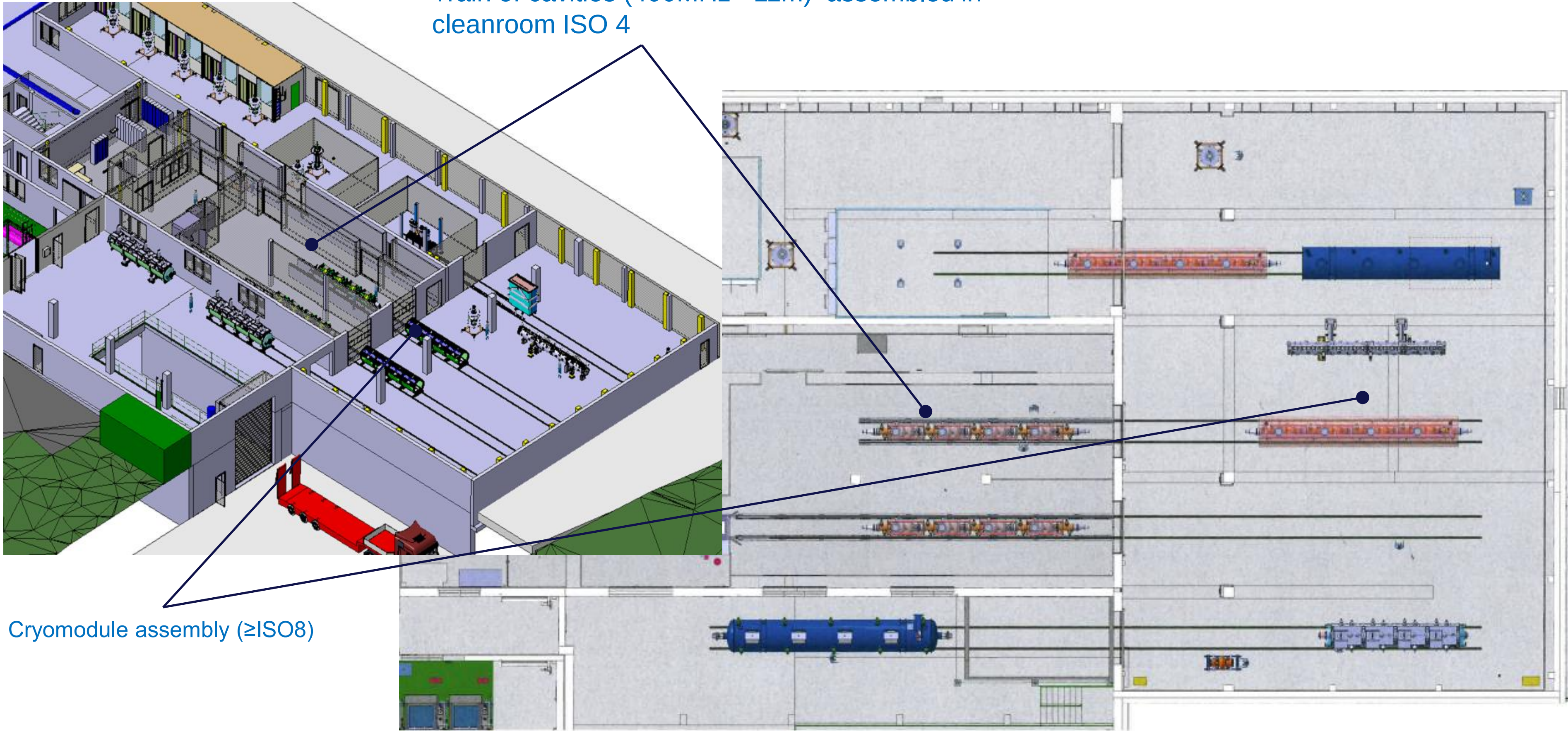
- RPO: 66 CM, RF voltage increased
- No HL breakdown by component (still too early)
- No changes on HL/CM figures (uncertainty margins)

SRF HL budgets managed via EDMS:

FCC-ee CM Heat loads budget | Document FCC-INF-SPC-0014
https://edms.cern.ch/ui/#!master/navigator/document?D:101544492:101544492:approvalAndComments (v.3)

SA18 layout and space constraints

Compatibility with SA18 layout and space/weight constraints



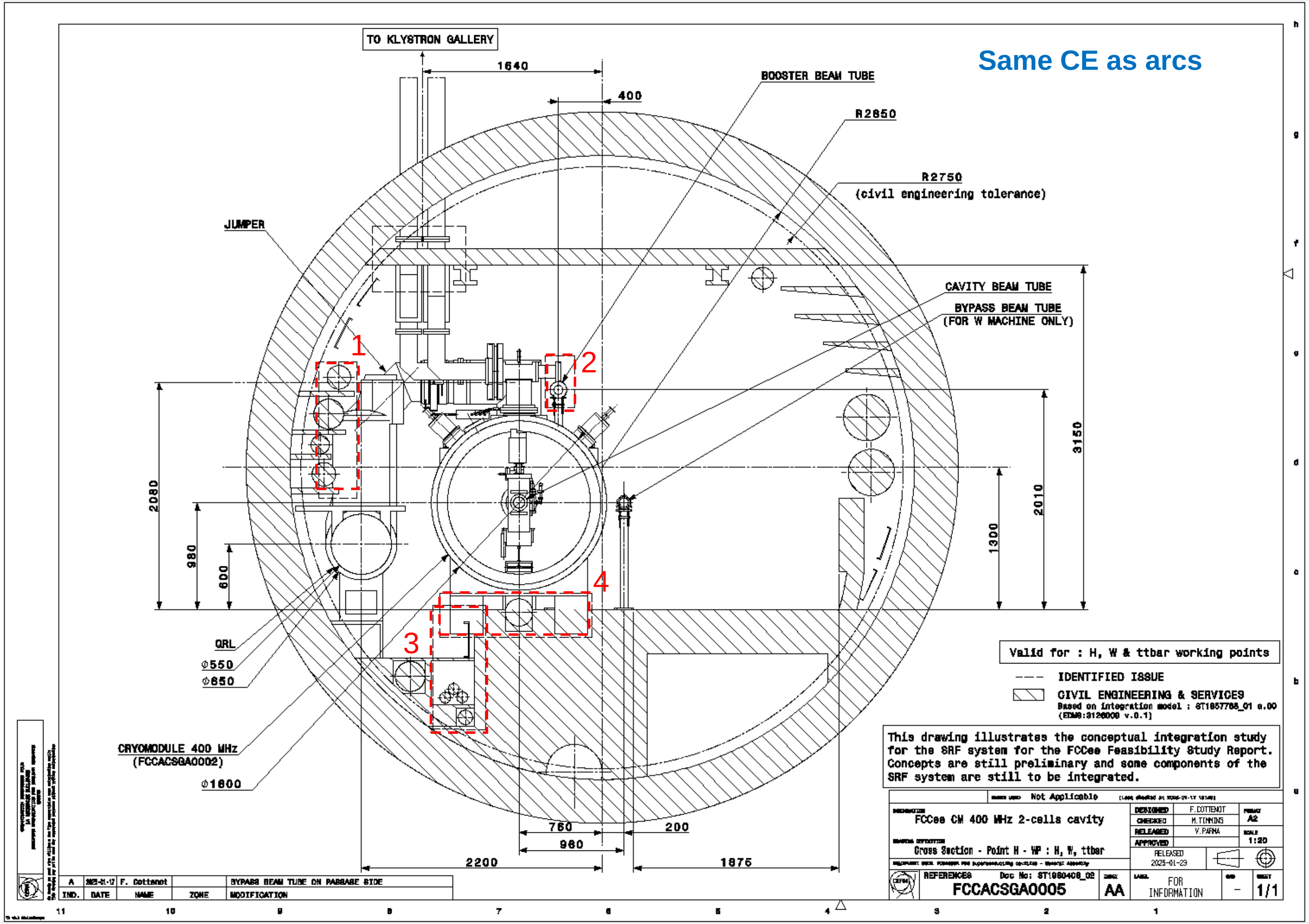
Train of cavities (400MHz ~11m) assembled in cleanroom ISO 4

Cryomodule assembly (≥ISO8)

400 MHz CM in Pt H (Collider)

Some integration issues:

1. **Interference QRL-service lines → minor, reposition lines**
2. **Interference with booster → minor, can be coped with design**
3. **CM jack in trench → relocate cables, extend floor**
4. **Beam height as arcs, CM jacks underground → sloped tunnel between arcs and Pt. H, or more compact CM size (not an option today)**



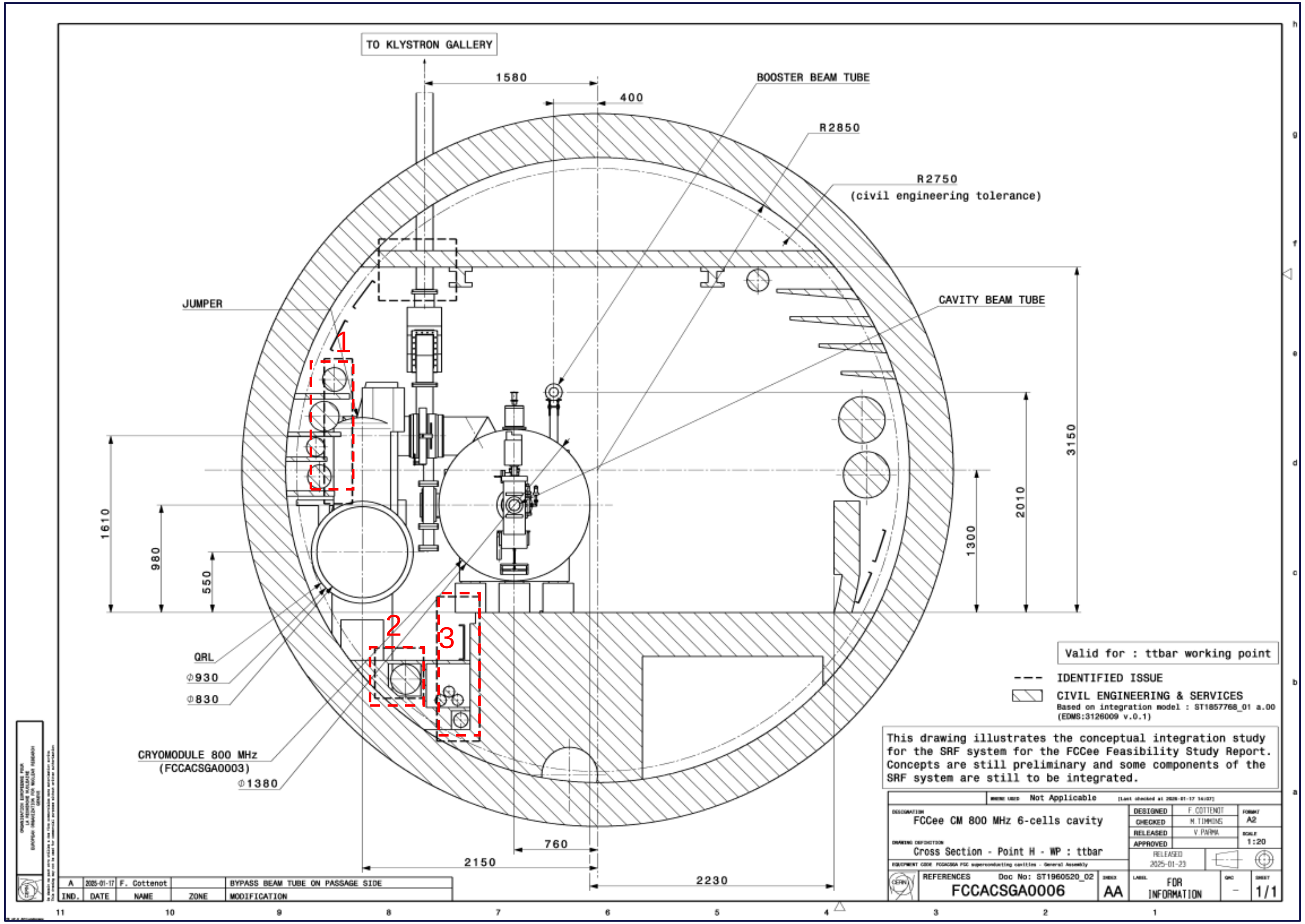
Same CE as arcs

This drawing illustrates the conceptual integration study for the SRF system for the FCCee Feasibility Study Report. Concepts are still preliminary and some components of the SRF system are still to be integrated.

800 MHz CM in Pt H (Collider)

Some integration issues:

1. **Interference QRL-service ducts → minor, reposition lines**
2. **Interference service ducts →minor, reposition lines**
3. **CM jack in trench → relocate cables, extend floor**

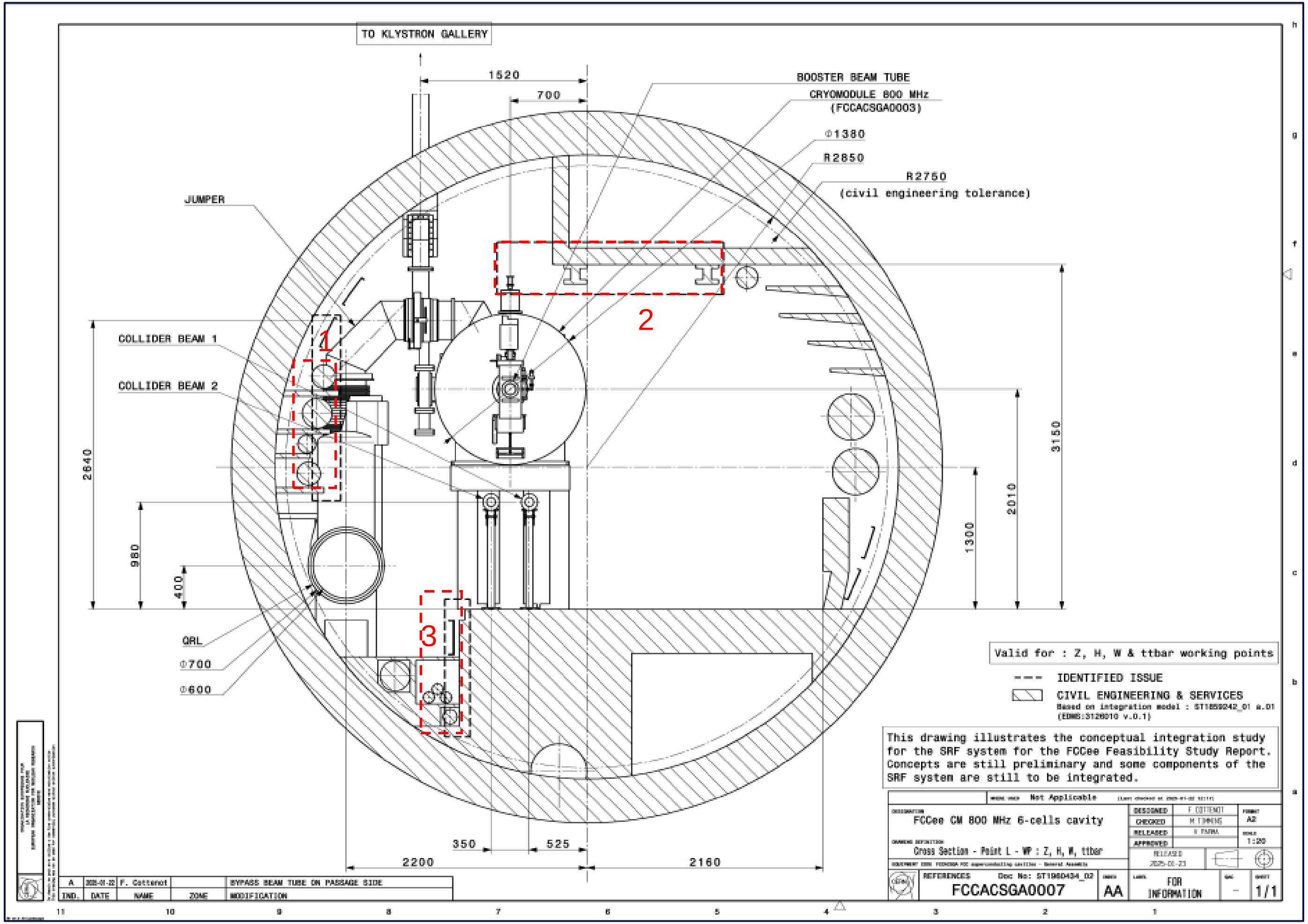


This drawing illustrates the conceptual integration study for the SRF system for the FCCee Feasibility Study Report. Concepts are still preliminary and some components of the SRF system are still to be integrated.

800 MHz CM in Pt L (Booster)

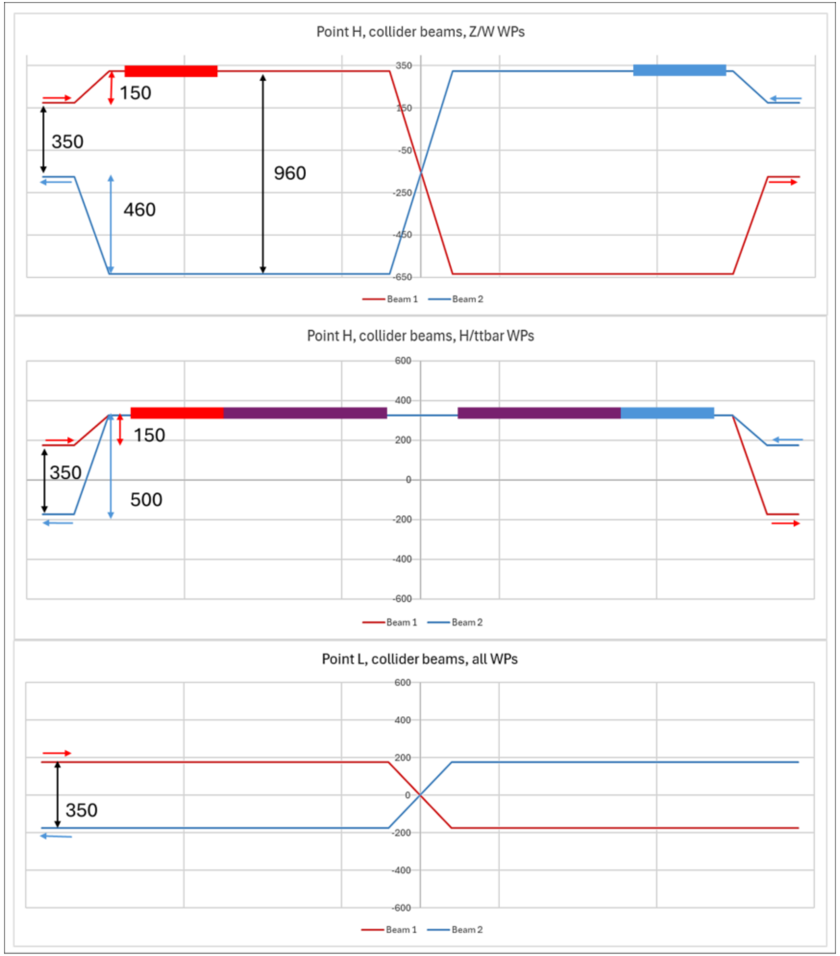
Some integration issues:

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



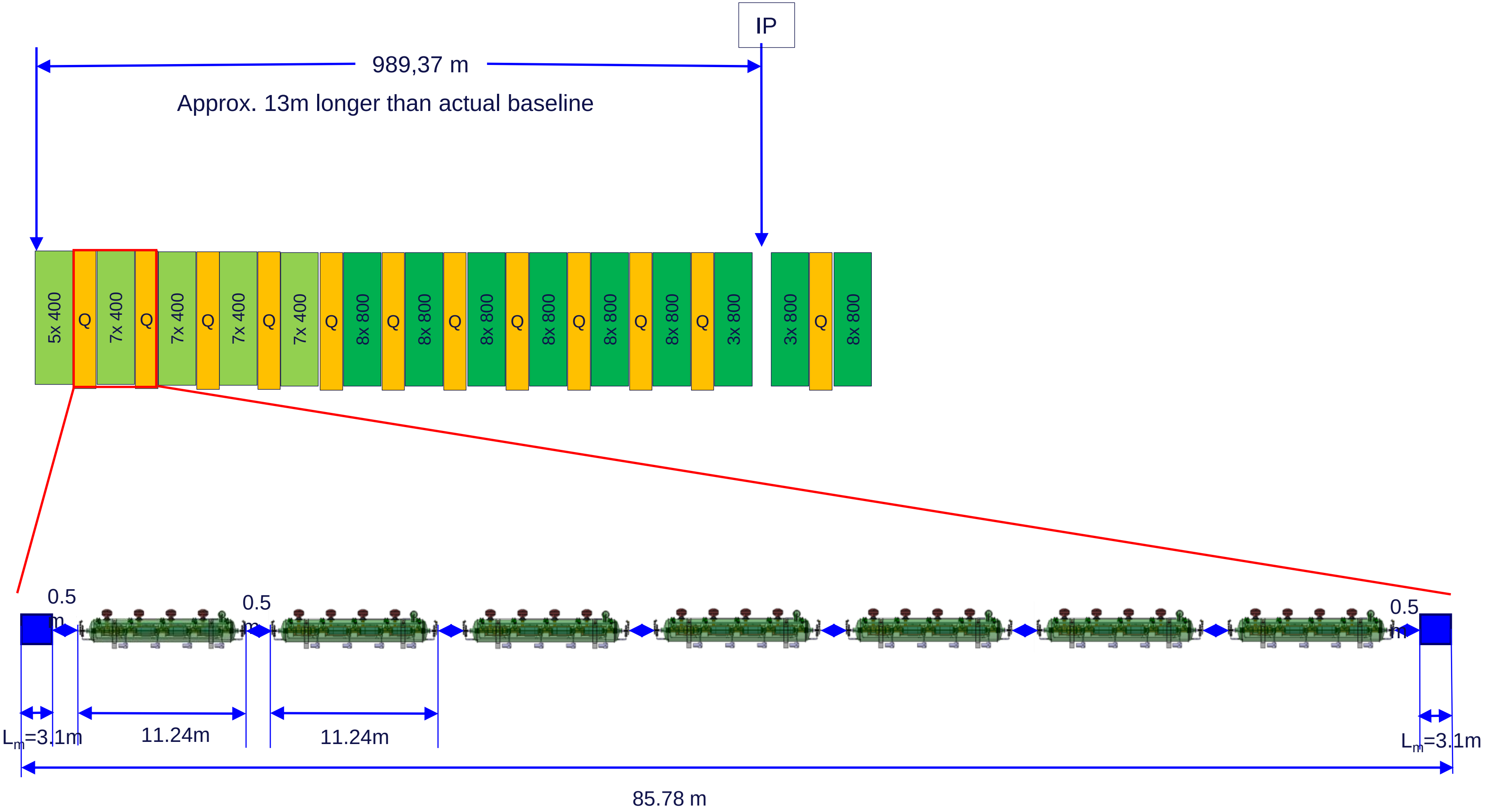
This drawing illustrates the conceptual integration study for the SRF system for the FCCee Feasibility Study Report. Concepts are still preliminary and some components of the SRF system are still to be integrated.

Beam spacings and positions wrt arcs in Pt. H and L



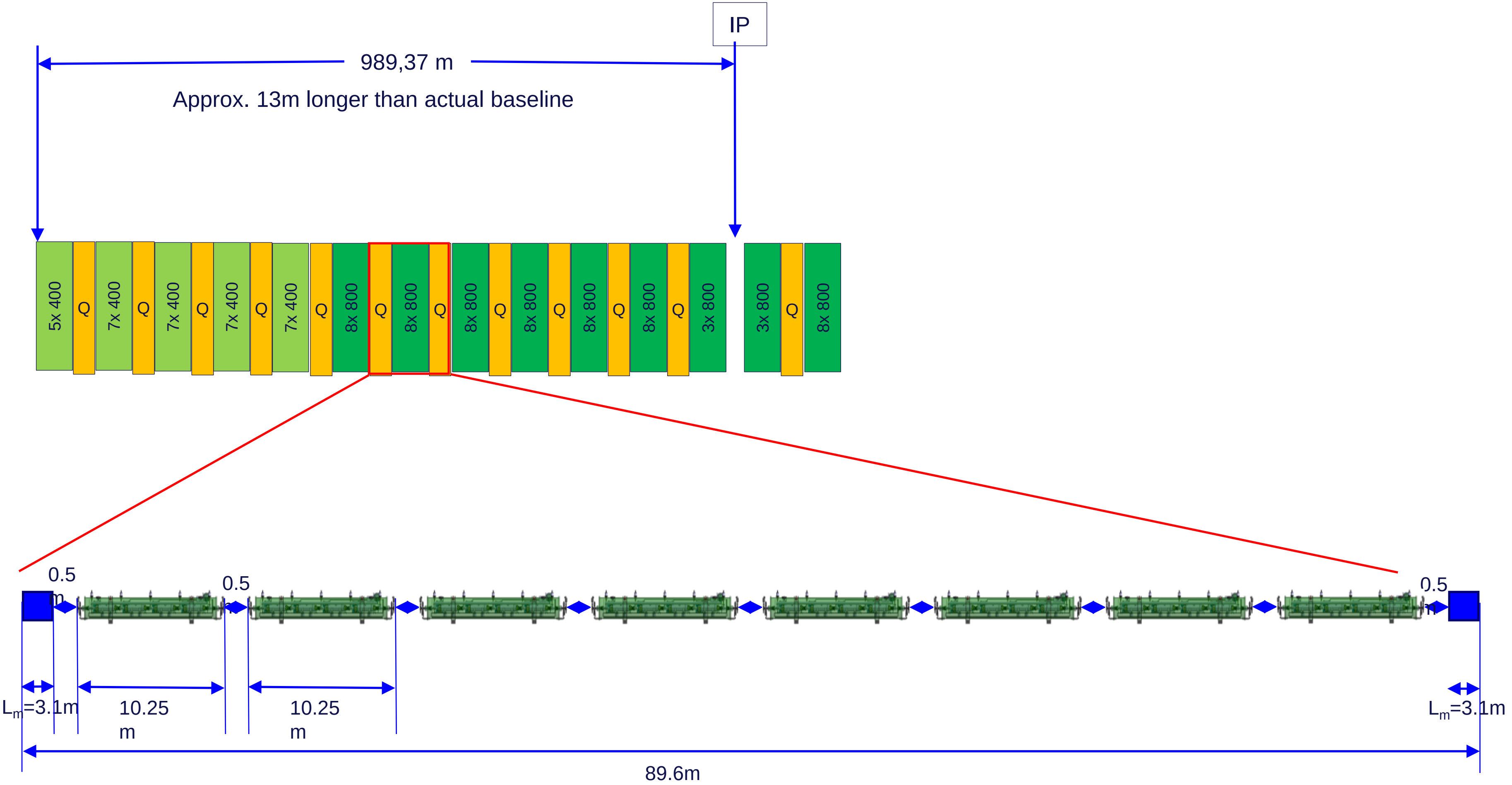
K. Canderan

Longitudinal spacing Pt.H (1/2)



K. Canderan

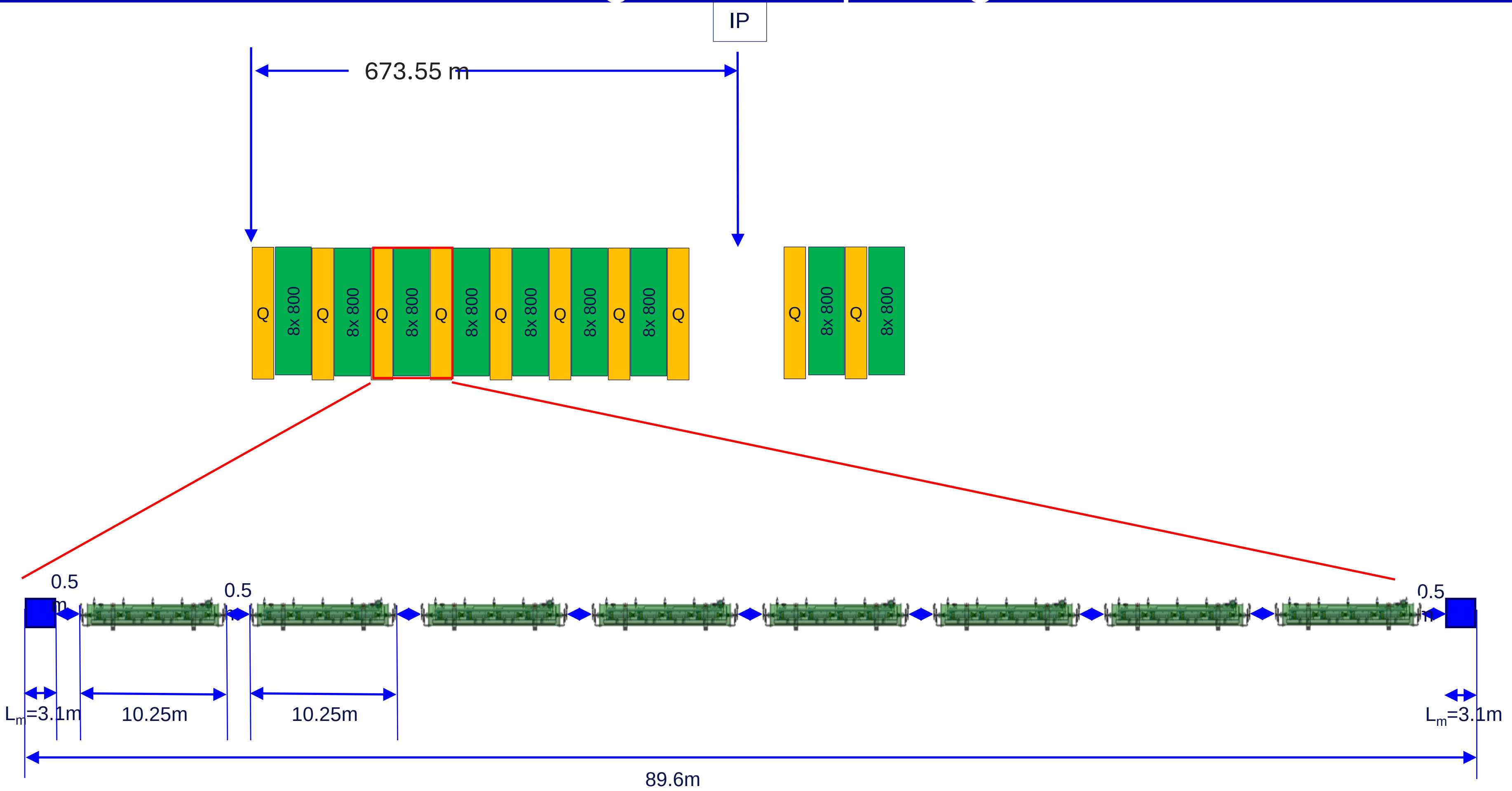
Longitudinal spacing Pt.H (2/2)



Approx. 13m longer than actual baseline

K. Canderan

Longitudinal spacing Pt.L



K. Canderan