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SRF SYSTEM INTEGRATION:

Cryomodule technical specifications and design of the 400MHz

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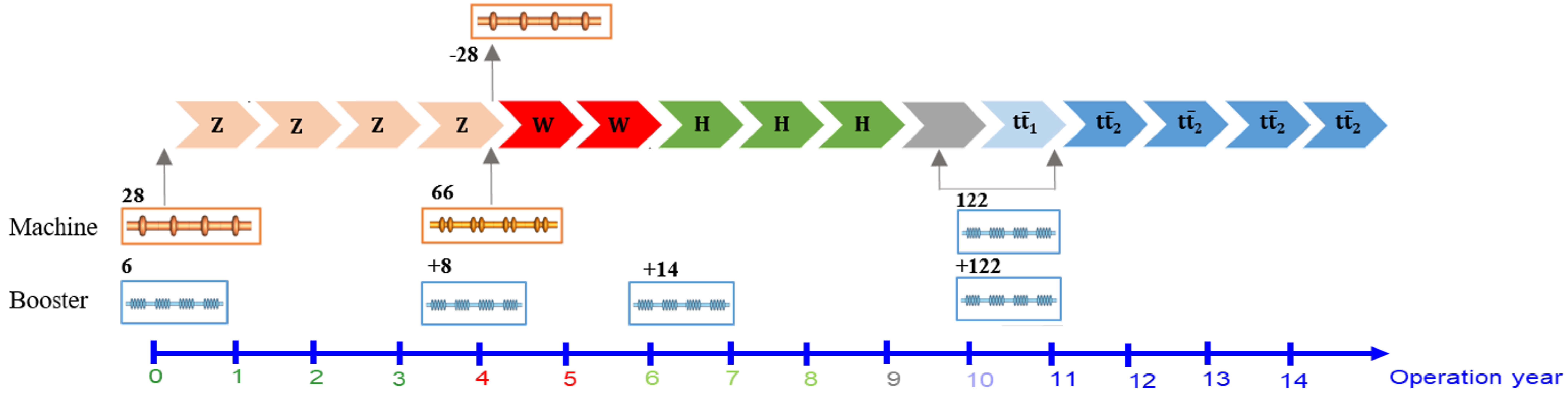
and inputs from: N. Elias (ESS), P. Pierini (ESS), D. Passarelli (FNAL), V. Roger (FNAL)

FCC week 2024, San Francisco

Outline

- RF system layout
- Cavity strings 400MHz and 800MHz
- Cryomodules specifications:
    - 400MHz Cryomodule
        - CM general requirements
        - Heat loads budget and margins
        - Cryogenic scheme
    - 800MHz Cryomodule
        - CM general requirements
        - Heat loads budget and margins
        - Cryogenic scheme
    - Helium safety and PRDs
- Design details of the 400MHz CM
    - Overall dimensions
    - Iterations on FPC geometry and cooling strategy
- Summary and future work

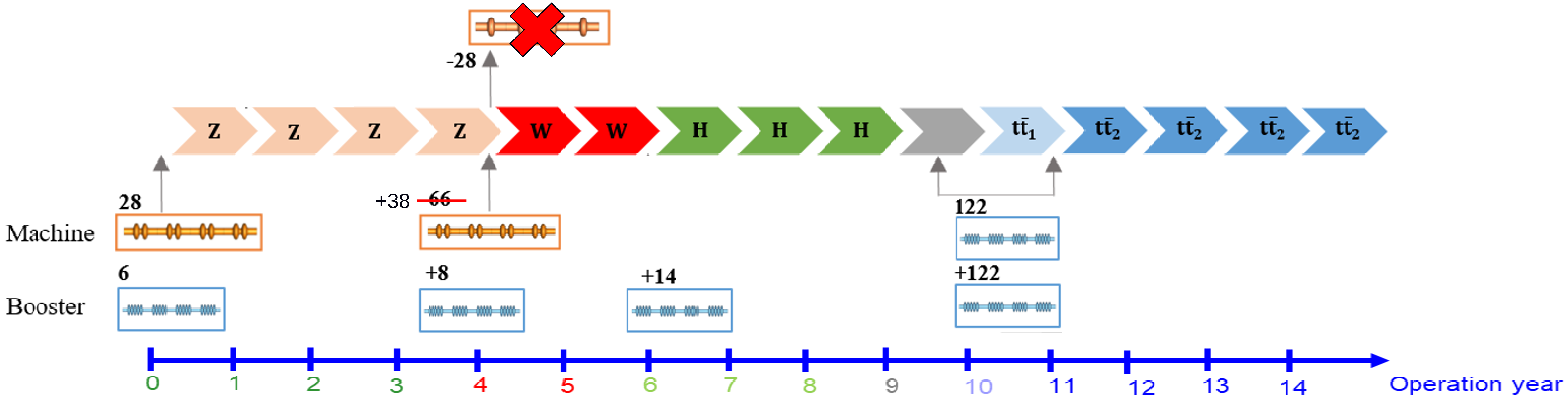
RF system layout - Baseline

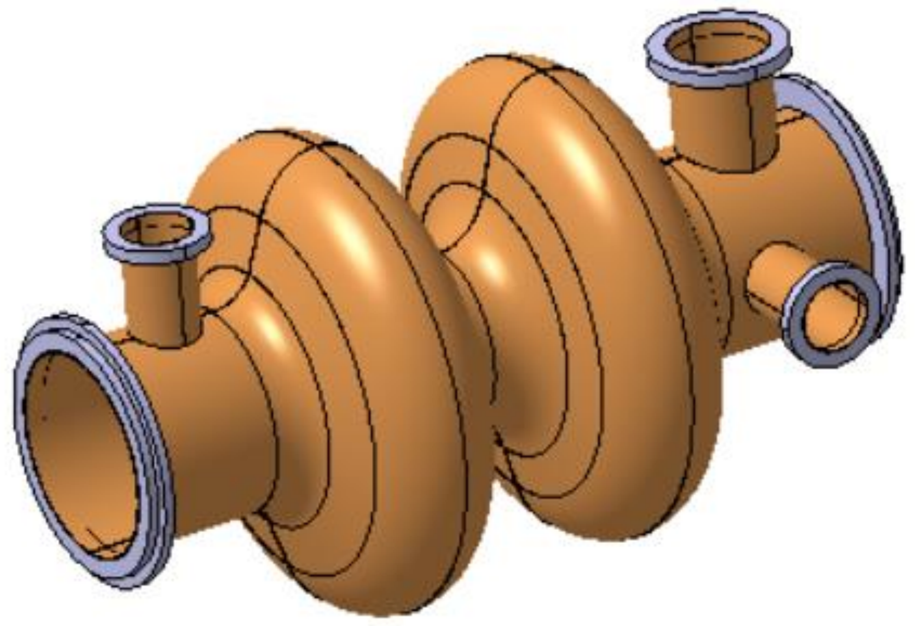


Physics schedule – number and type of cryomodules to be installed:

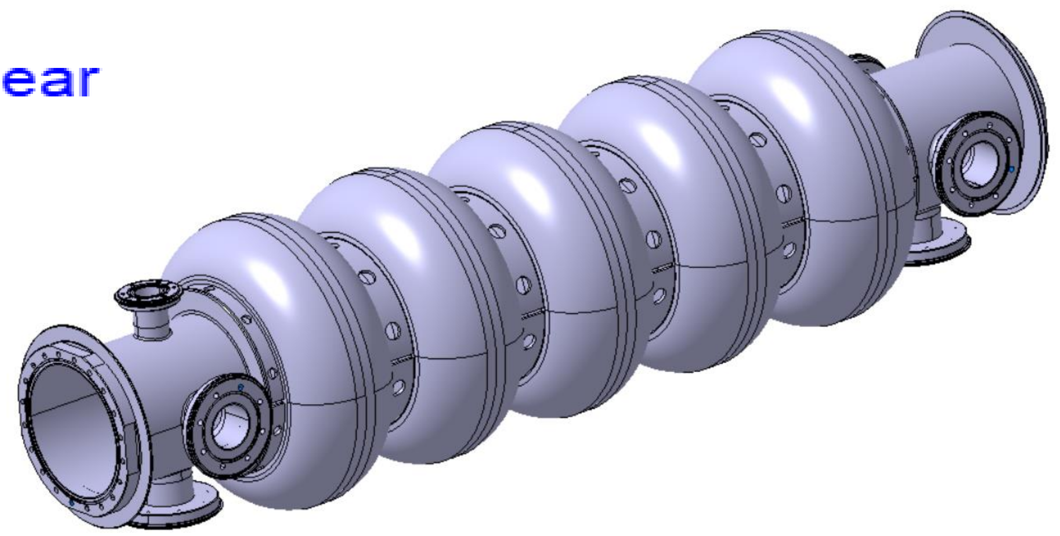
- 400MHz single-cell (Nb/Cu): 28 CM @4.5K, removed after the Z working point
- 400MHz two-cell (Nb/Cu): 66 CM @4.5K
- 800MHz five-cell (bulk Nb): 272 CM @2K, 122 CM for the collider and 150 CM for the booster.

RF system layout – 400MHz 2-cells option





RF design: S. Gorgi Zadeh
3D model: M. Timmins



RF design: S. Gorgi Zadeh
3D model: M. Chiodini

Physics schedule – number and type of cryomodules to be installed:

- 400MHz two-cell (Nb/Cu): 28 CM @4.5K, removed after the Z working point
- 400MHz two-cell (Nb/Cu): 38 CM @4.5K
- 800MHz five-cell (bulk Nb): 272 CM @2K, 122 CM for the collider and 150 CM for the booster(**).

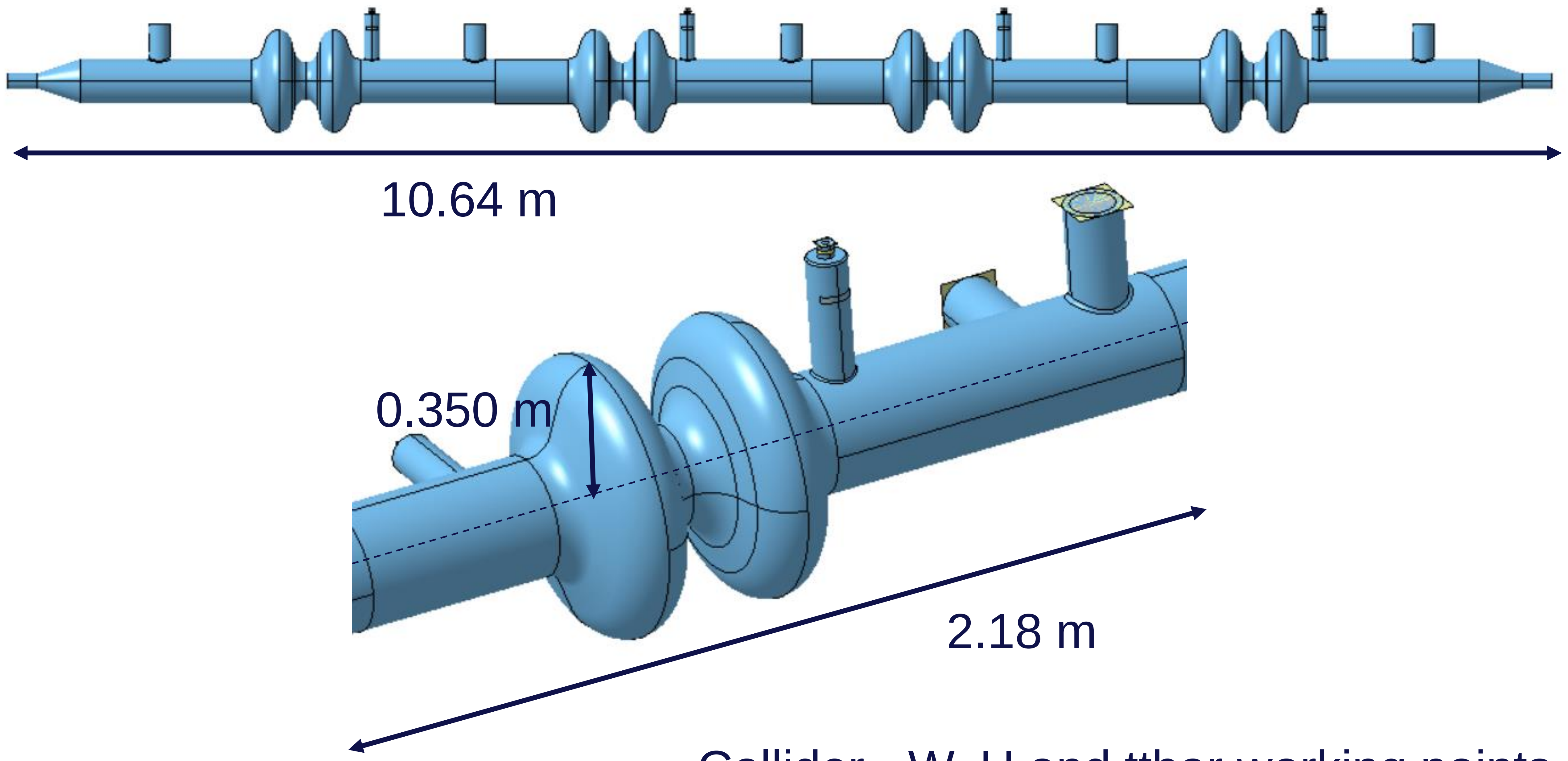
Cryomodule design focused on the integration of the 400MHz two-cell cavities, and the 800MHz five-cell cavities.
(**) Potential reduction of the # CM, according to the new RF parameters for the booster RF voltage

Cavity string 400MHz

2 cell cavities / 4 cavities per CM

	W / H / $t\bar{t}$	
	Collider (2 beams)	
# cell / cav	2	
RF Frequency [MHz]	400.79	
#cav/CM	4	
Eacc [MV/m]	10.63	
Vcavity [MV]	7.95	
# CM	66	
T operation [K]	4.5	
Nominal dynamic losses/cav [W]	129 (*)	
stat losses/cav [W]	Defined in the CM specs	
Q0	2.70E+09	
Max FPC power/cav [kW]	388	
HOM power [kW]	15.4 / 6.4 / 3	
Intercavity spacing	2023 2.04m	2024 2.18m
Cavity string length	2023 10.1	2024 10.64

(*) Dynamic losses linked to the nominal values of Q0 and E_{acc} . This value represents only the power dissipated by the cavity. The heat loads from power coupler and HOMs are not included.



Collider - W, H and ttbar working points

RF design: S. Gorgi Zadeh

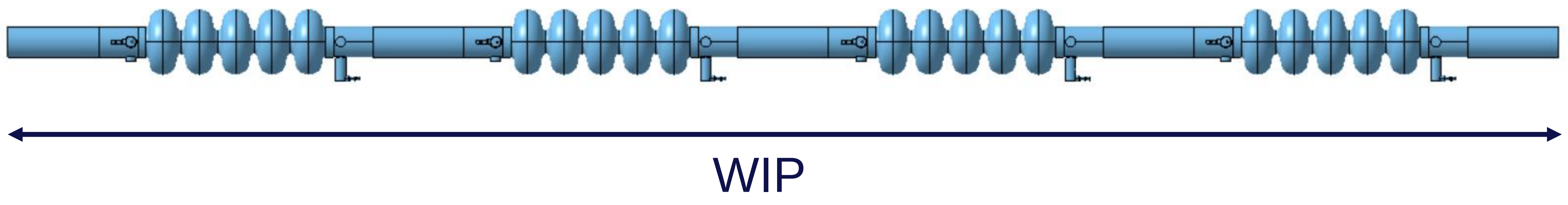
Longer intercavity spacing compared to the geometry presented at the FCC week 2023

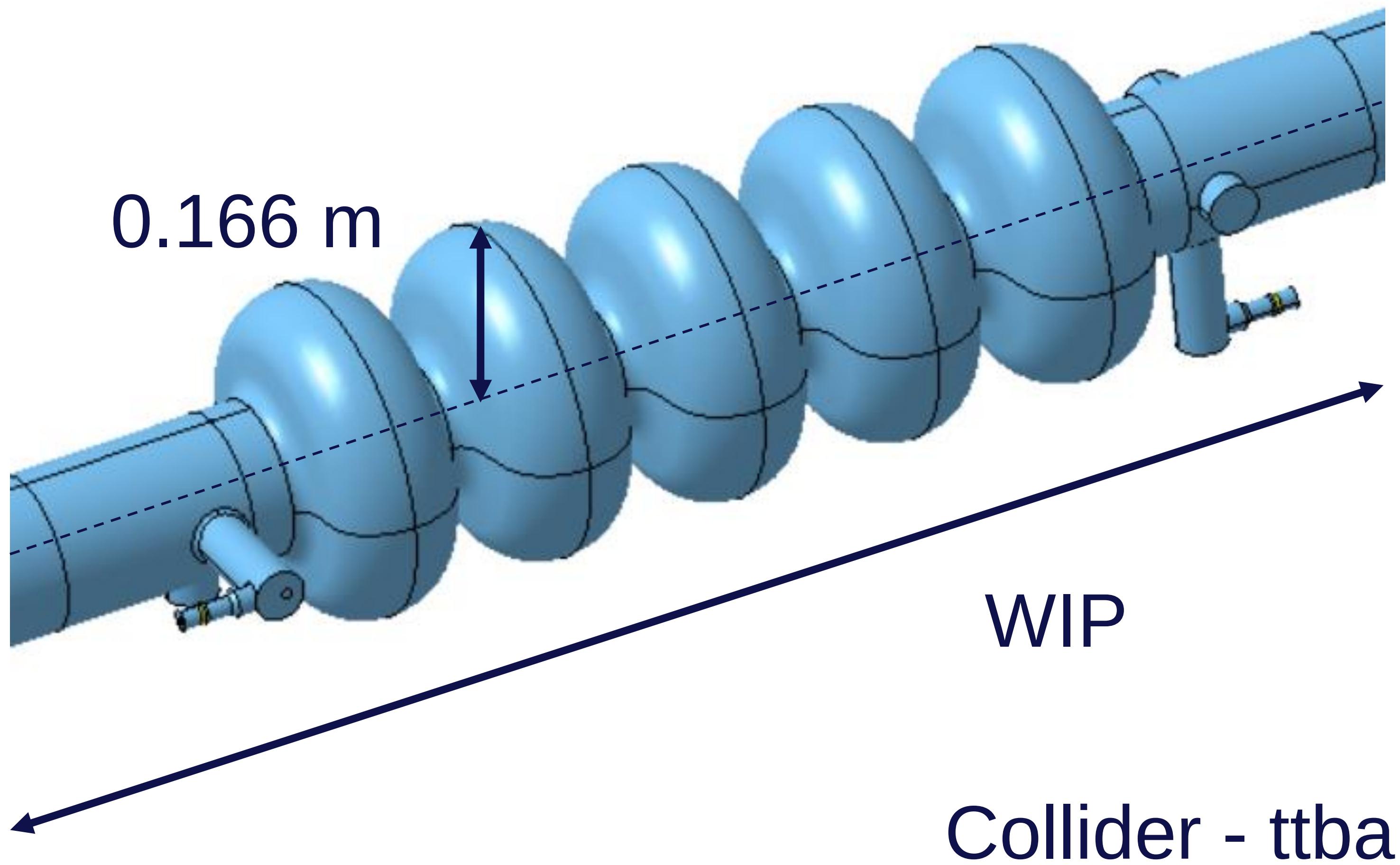
Cavity string 800MHz

5 cell cavities / 4 cavities per CM

	$t\bar{t}$	Z / W / H / $t\bar{t}$
	Collider (2 beams)	Booster (2 beams)
# cell / cav	5	5
RF Frequency [MHz]	801.58	801.58
#cav/CM	4	4
Eacc [MV/m]	20.60	20.05
Vcavity [MV]	19.26	5.83 / 18.75 / 18.75 / 19.17
# CM	122	150
T operation [K]	2	2
Nominal dynamic losses/cav [W]	23 (*)	3 (*)
stat losses/cav [W]	Defined in the CM specs	
Q0	3.00E+10	3.00E+10
Max FPC power/cav [kW]	163	208 (15% duty cycle)
HOM power [kW]	2.98	TBD
Intercavity spacing	2023 1.67	2024 WIP
Cavity string length	2023 6.68	2024 WIP

(*) Dynamic losses linked to the nominal values of Q0 and E_{acc} . This value represents only the power dissipated by the cavity. The heat loads from power coupler and HOMs are not included.





Collider - ttbar working point
Booster – all working points

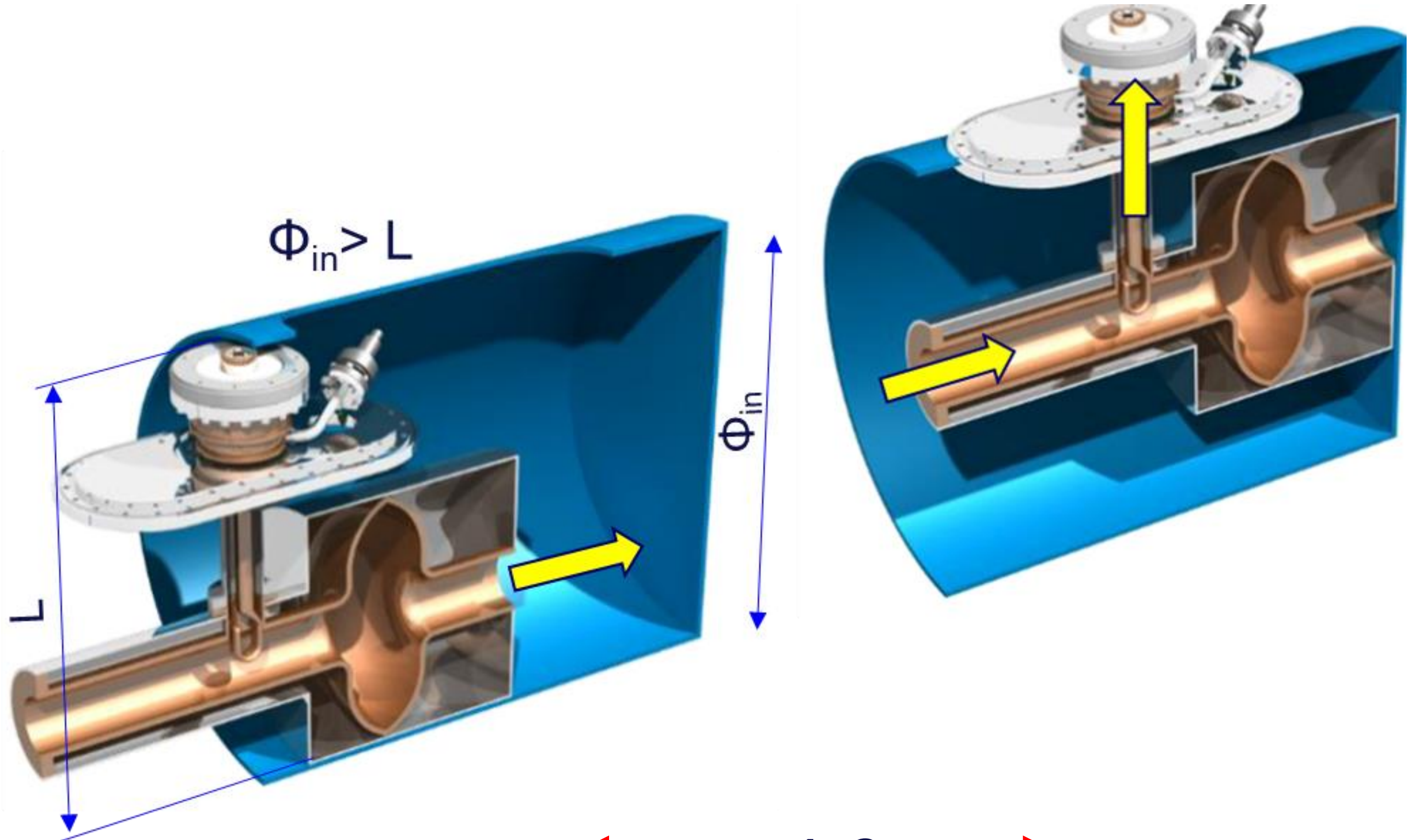
RF design: S. Gorgi Zadeh

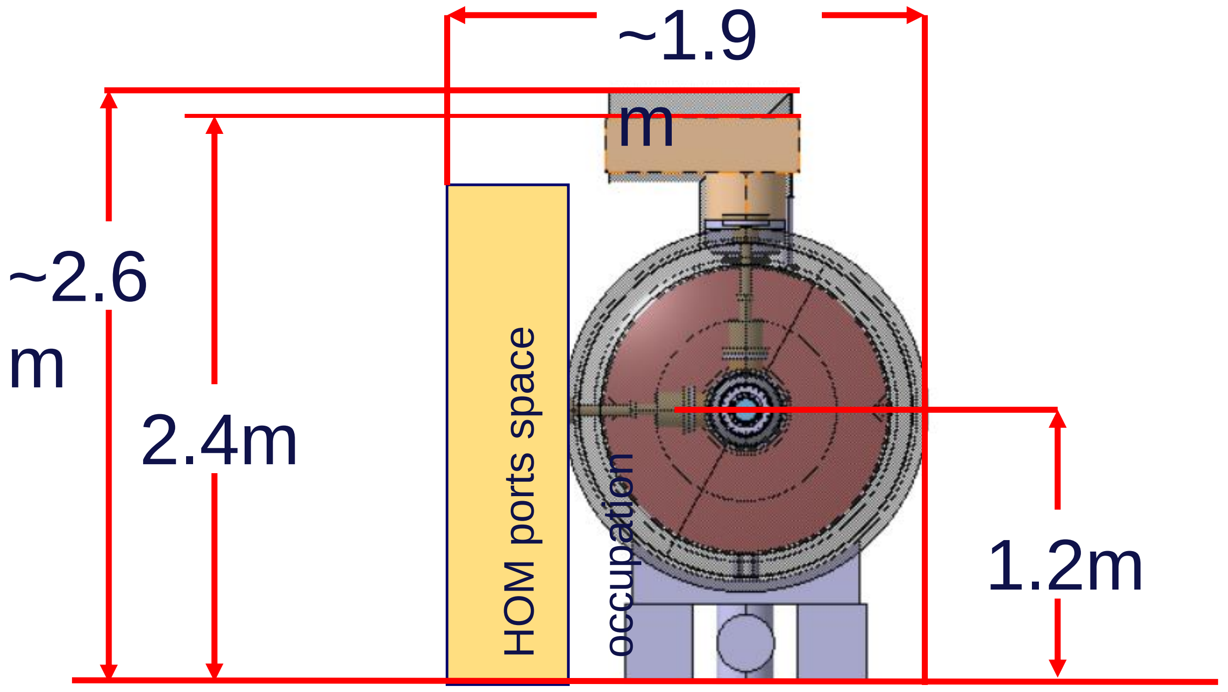
Different requirements to be addressed with the same cryomodule design

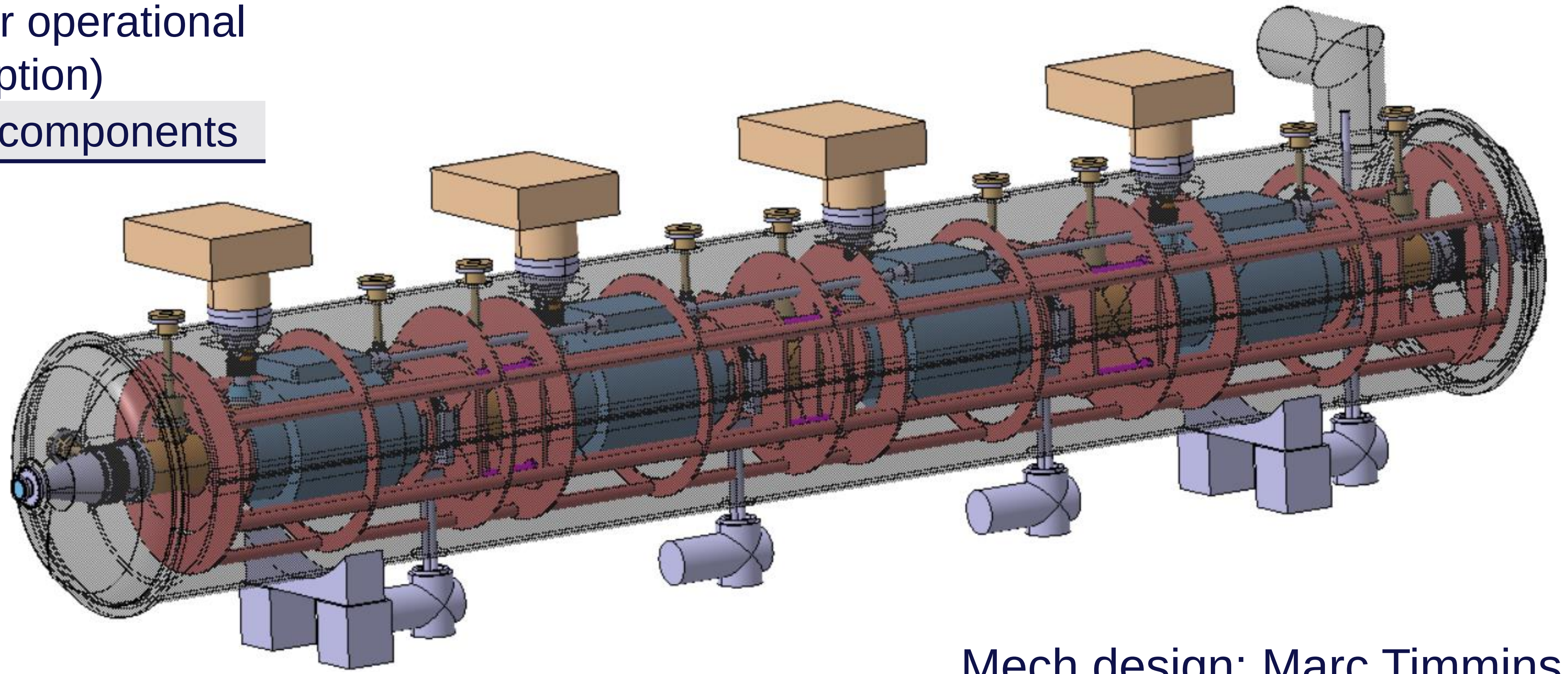
400 MHz Cryomodule

General requirements

	Value	Remarks
Ø Warm beam pipe	50 mm	Possibility to change to 75mm under discussion.
CM length (GV flange to GV flange)	11.24 m	
Beam height from the floor	1200 mm	New proposed value. Present baseline 980mm.
CM width	~ 1.9 m	Final value TBD according to: final geom. and cooling method for the FPC, lifting lugs and HOMs outlets.
CM height	~ 2.6 m	Final value TBD according to: final geom. and cooling method for the FPC, waveguides, jumper and PRDs space occupations.
Cavity operating temperature	4.5 K	
Environ. magnetic shield	≤ 5 mG	Levels of magnetic shielding TBD
Layout architecture	Fully segmented (baseline)	Proposal under discussion: continuous insulation vacuum with external cryogenic distribution line
Tunnel integration	Supported on floor	
Tunnel inclination	0.25%	Influence on liquid levels
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)
Maintainability		Design for in situ accessibility to critical components







Mech design: Marc Timmins

400 MHz Cryomodule

Heat loads and margins

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

Nominal values

- Static heat loads to the cold mass: Derived from experimentally measured values of LHC cryomodule (with active thermal shield correction)
- Dynamic losses: Power dissipation per cavity indicated in the baseline
- 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	Collider
Static HL at 4.5K/CM [W]	197	197
Dynamic HL at 4.5K/CM [W]	43.2	236.4
HL to thermal shield at 50K/CM [W]	327	327
Required liquefaction capacity/CM [mg/s]	480	480

Margins on RF side

- **50% margin on the static heat loads** – due to the preliminary design maturity
- **8% operational margin on the dynamic loads** – for the scenario with only **90% operational cavities** operating at higher E_{acc} with a consequent increase of **20% on the dynamic heat load.**
- **50% margin on the liquefaction capacity** – to grant flexibility on the helium flowrate.

	Z(*)	W/H/$t\bar{t}$
	Collider	Collider
# CM	28	66
Static HL at 4.5K [kW]	5.5	13
Dynamic HL at 4.5K [kW]	1.1	36.7
Total HL at 4.5K [kW]	6.1	49.7
HL to thermal shield at 50K [kW]	9.2	21.6
Required liquefaction capacity [g/s]	13.5	32

Machine total HL

- Static heat loads at 4.5K: sum of the contributes of all the CM
- Dynamic heat loads at 4.5K: sum of 90% of the total number of cavities
- Heat loads to the thermal shield at 50K: sum of the contributes of all the CM

400 MHz Cryomodule – Cryogenic scheme

DISCLAIMER: Preliminary scheme, instrumentation is missing.
Exhaust helium release in the tunnel/recovery line under discussion.

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

Thermal shield

50K-75K circuit

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

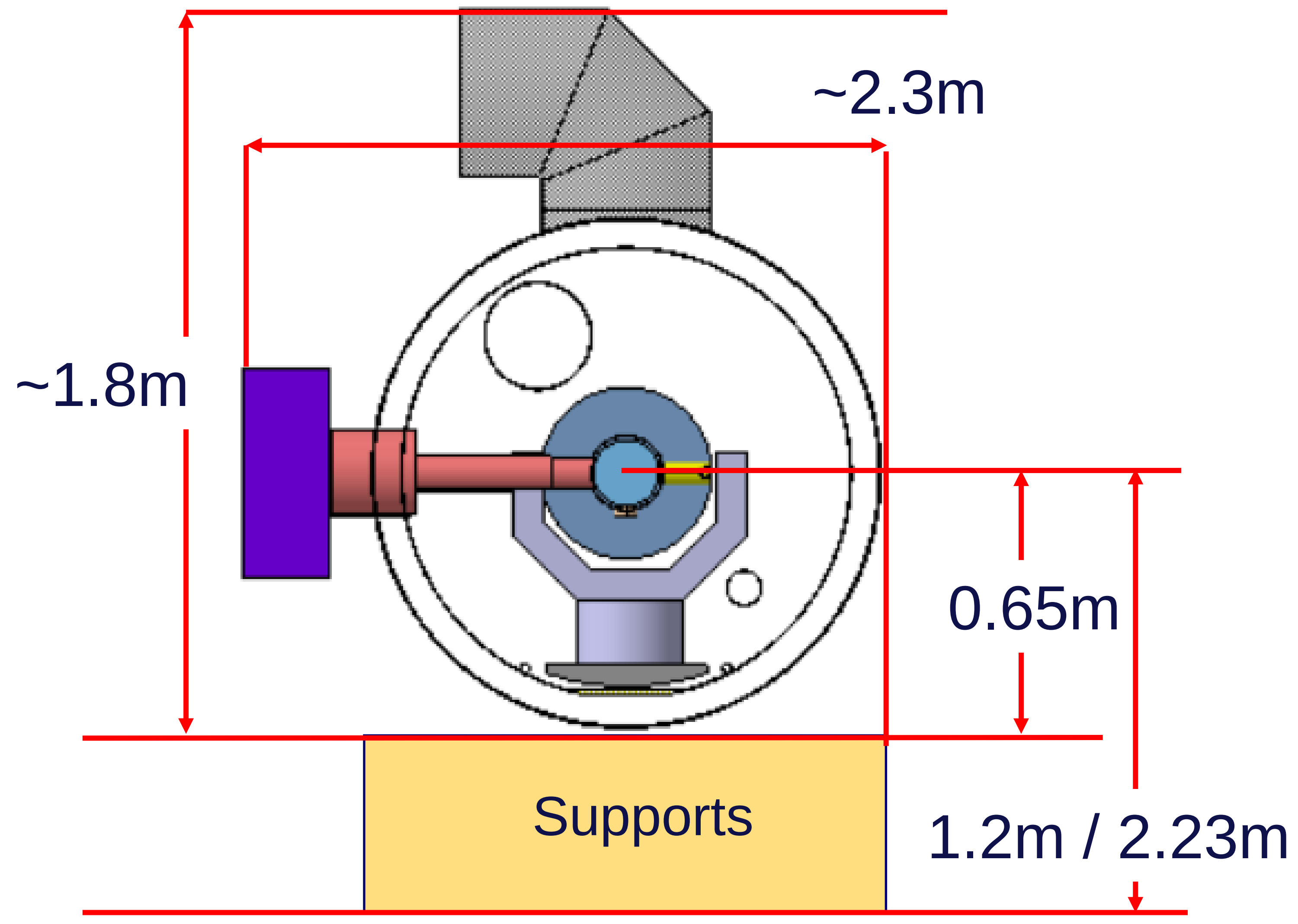
2-phase line details:

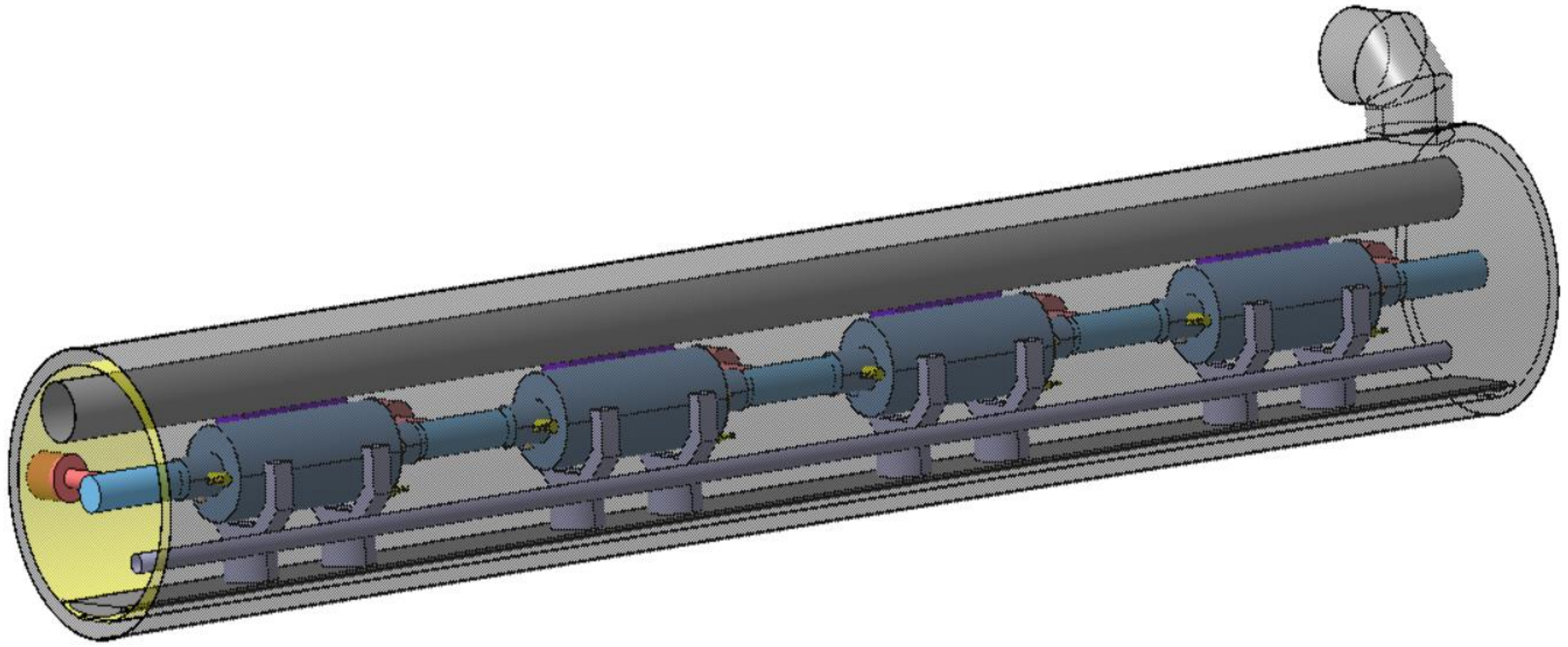
- Ø 155mm, 7m length
- 64L of liquid He (filling ratio 48%)
- In case of supply failure: buffer for 15 min with beam OFF / 150s with beam ON
- No restrictions compared to the BD Ø – see PRDs slide.

800 MHz Cryomodule

General requirements

	Value	Remarks
Beam pipe size (Ø after tapering)	50 mm	Possibility to change to 75mm under discussion
CM length (GV flange to GV flange)	WIP	
Beam height from the floor	1200 mm (collider) / 1200 + 1030mm (booster)	New proposed value. Present baseline 980mm (collider) / 980 + 1030mm (booster).
CM width	~ 2.6 m	Final value TBD according to: final geom. and cooling method for the FPC, waveguides, lifting lugs and HOMs outlets.
CM height	~ 1.8 m	Final value TBD according to: final geom. and cooling method for the FPC, jumper and PRDs space occupations.
Cavity operating temperature	2 K	
Environ. magnetic shield	≤ 5 mG	Levels of magnetic shielding TBD
“Fast” CD of cavities	> 2-3 K/min across 9.2K	PIP-II reference, valueTBC
Layout architecture	Fully segmented (baseline)	Proposal: continuous insulation vacuum with integrated cryogenic line
Tunnel integration	Supported on floor (collider) / supported on fixed pillars (booster)	
Tunnel inclination	0.25%	Influence on liquid levels
FPC orientation	Horizontal / Side	Fixed antenna. Horizontal position so the same CM can fit in the collider and booster position
FPC cooling strategy	Active cooling with supercritical helium (DWT)	Active cooling considered as baseline for operational flexibility (HI still considered as option)
Maintainability		Design for in situ accessibility to critical components





Conceptual design based on the FermiLab PIP-II design: Marc Timmins

Detailed mechanical design: refer to the talk from Donato Passarelli

800 MHz Cryomodule

Heat loads and margins

	Z(*)	W/H/$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Collider
Static HL at 2K/CM [W]	32	32	32
Dynamic HL at 2K/CM [W]	1.2	12	92
HL to thermal shield @50K/CM [W]	103	103	103
Required liquefaction capacity/CM [mg/s]	320	320	320

Nominal values

- 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 elliptical HB CM of ESS).
- Dynamic losses: Power dissipation per cavity indicated in the baseline.
- 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	Collider
Static HL at 2K/CM [W]	48	48	48
Dynamic heat loads at 2K/CM [W]	1.44	14.4	14.4
HL to thermal shield @50K/CM [W]	154	154	154
Required liquefaction capacity/CM [mg/s]	480	480	480

Margins on RF side

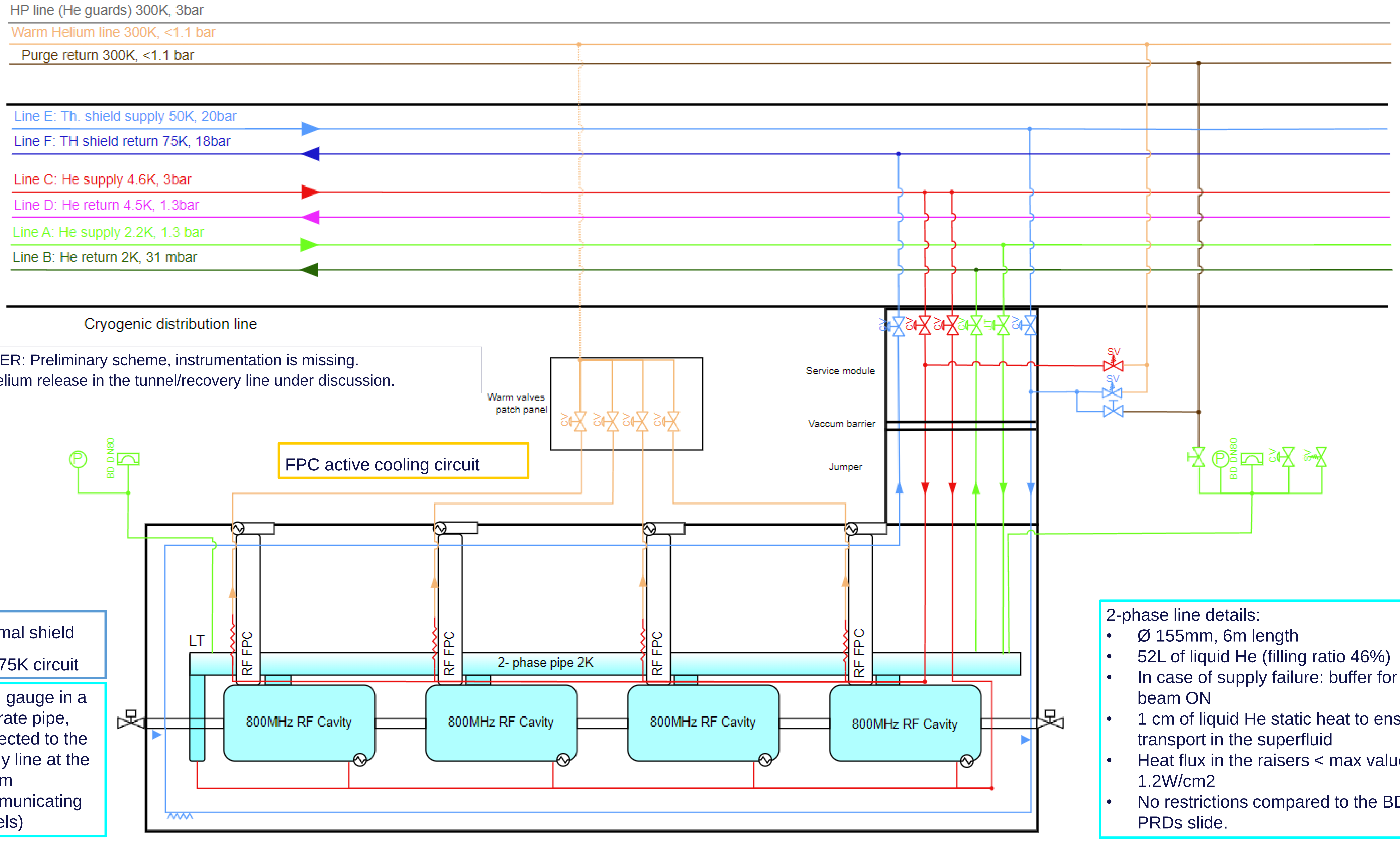
- **50% margin on the static heat loads** – due to the preliminary design maturity.
- **8% operational margin on the dynamic loads** – for the scenario with only **90% operational cavities** operating at higher Eacc with a consequent increase of **20% on the dynamic heat load.**
- **50% margin on the liquefaction capacity** – to grant flexibility on the helium flowrate.

	Z(*)	W	H	$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Booster	Booster	Collider
# CM	6	14	28	150	122
Static HL at 2K [kW]	0.3	0.7	1.4	7.2	5.9
Dynamic HL at 2K [kW]	0.007	0.17	0.34	1.8	11.2
Total HL at 2K [kW]	0.3	0.9	1.7	9.2	18.8
HL to thermal shield at 50K [kW]	1	2.2	4.4	23.1	18.8
Required liquefaction capacity [g/s]	3	7	14	72	59

Machine total HL

- Static heat loads at 2K: sum of the contributes of all the CM
- Dynamic heat loads at 2K: sum of 90% of the total number of cavities
- Heat loads to the thermal shield at 50K: sum of the contributes of all the CM

800 MHz Cryomodule – Cryogenic scheme



DISCLAIMER: Preliminary scheme, instrumentation is missing.
Exhaust helium release in the tunnel/recovery line under discussion.

FPC active cooling circuit

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, 6m length
- 52L of liquid He (filling ratio 46%)
- 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 PRDs

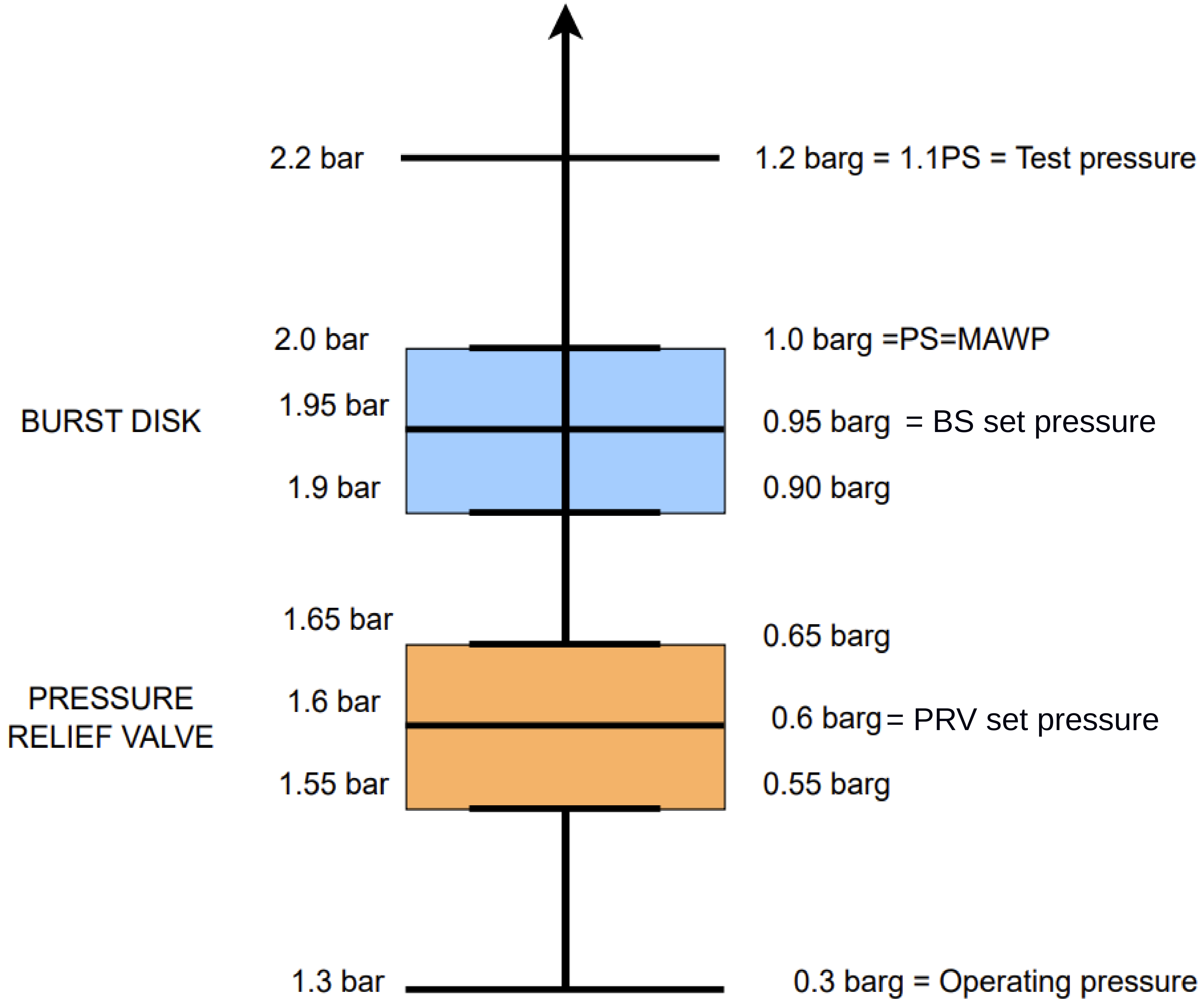
Risk case scenarios FCC cryomodules:

1. Machine subjected to a **power cut**. In the helium tanks of all the cryomodules, the pressure raises since the static loads cause helium boil-off in. This is a **non-nominal operating condition,** not an emergency scenario. The limited mass flow will be dealt with a CV/SV which ensure leak-tight reclosing, **the mass flow is intended to be recovered.**

2. **Insulation vacuum break**. Rupture of the vacuum vessel with atmospheric air venting and condensing on cold surfaces. At this stage it is considered that the cold surfaces are fully protected with MLI. Thus, a heat transfer rate of **0.6 W/cm2** has been taken to calculate the heat load causing helium boil-off in the helium tank. (Dimensioning of the vacuum vessel relief plates TBD).

3. **Beam vacuum break**. Rapture of the beam pipe causing atmospheric air leak and condensation inside the cavities. In this case the heat flux exchange considered is **4 W/cm2**, given the condensation in the cavities internal surfaces where there is no insulation/protection.

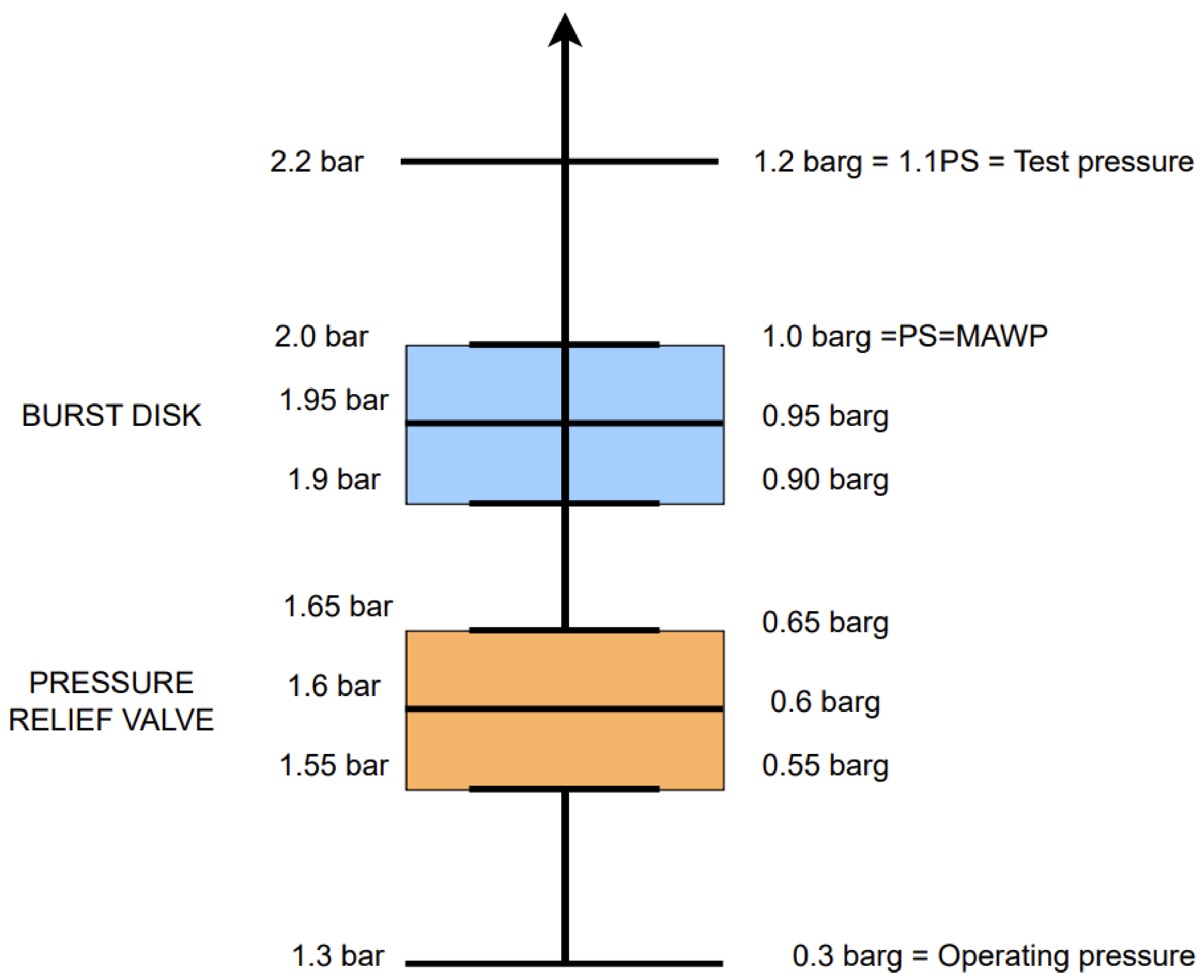
Worst case scenario to cover – used for the definition of the discharge area of the PRDs



The MAWP / PS is an initial assumption, based on similar designs (LHC and ESS), no structural analysis has been performed on the actual design of the FCC cavities.

Helium safety and PRDs

CM/ Case	Risk Situation	Heat load	Mass flow	T	Pressure reached (bar)	Discharge diameter	Comments
400MHz – Risk case scenario 3	Beam vacuum break (100 mm aperture)	380 kW	**19.57 Kg/s**	4.99K	~ 1.95 bara	**$Ø_{min}$= 130.5mm** **1 x BD DN150** **or** **2 x BD DN100** (each one taking half of the flow rate)	HL calculated considering the wet surface of the cavities (9.5m^2) without protection (4 W/cm^2). Exceptional case. Mitigation measures are needed to contain the probability of this event (e.g. orifice limiting bellows protections, no mech. work with liquid inventory).
800MHz – Risk case scenario 3	Beam vacuum break (100 mm aperture)	195 kW	**10.3 Kg/s**	4.99K	~ 1.95 bara	**$Ø_{min}$= 95mm** **1 x BD DN125** **or** **2 x BD DN80** (each one taking half of the flow rate)	HL calculated considering the wet surface of the cavities (4.96m^2) without protection (4 W/cm^2). Mitigation measures are needed to contain the probability of this event (e.g. orifice limiting bellows protections, no mech. work with liquid inventory).



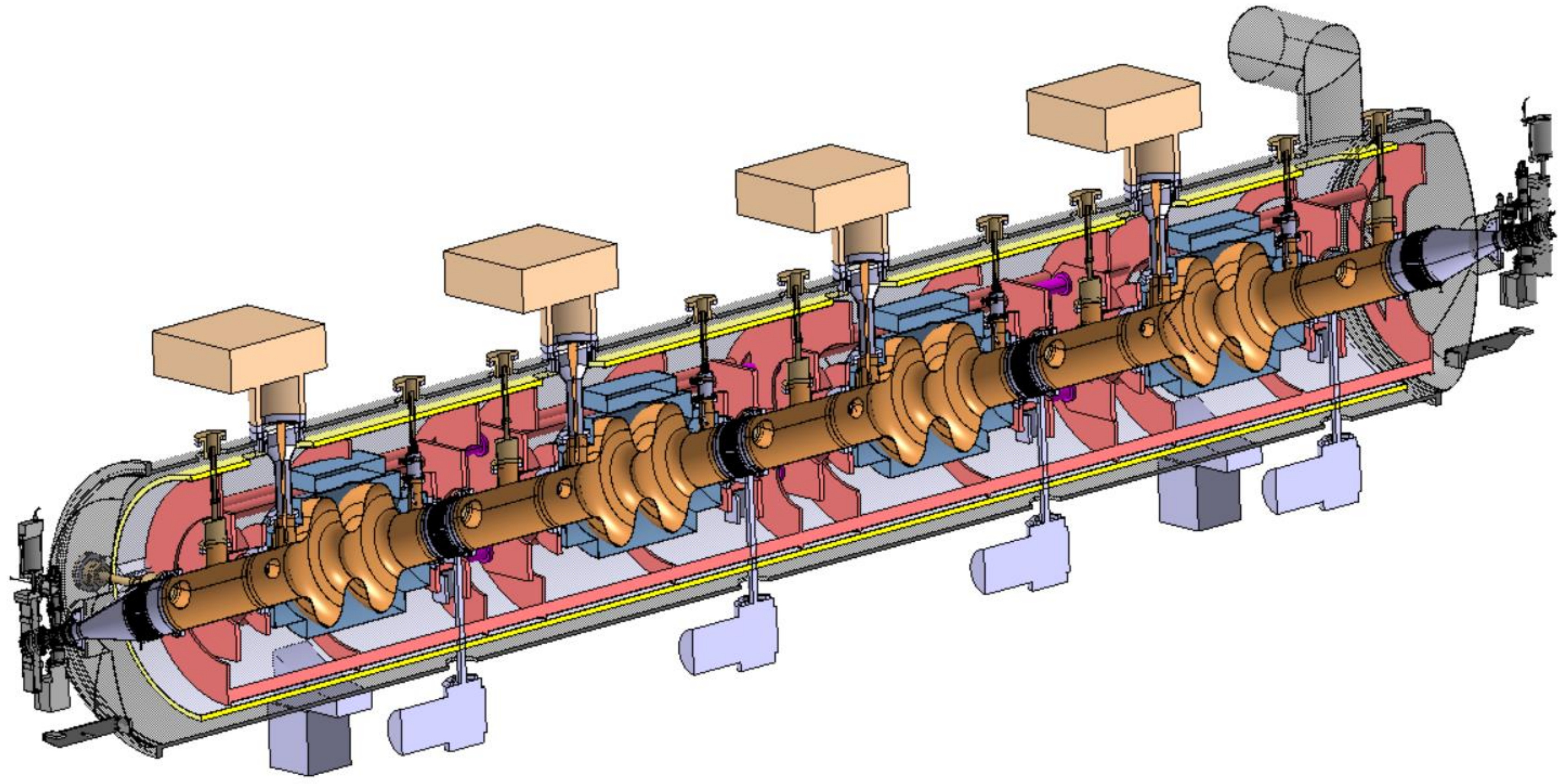
The BDs size sets the minimum value for the diameter of the 2-phase pipe and the raisers – to avoid restrictions along the path of the pressurized vapor.

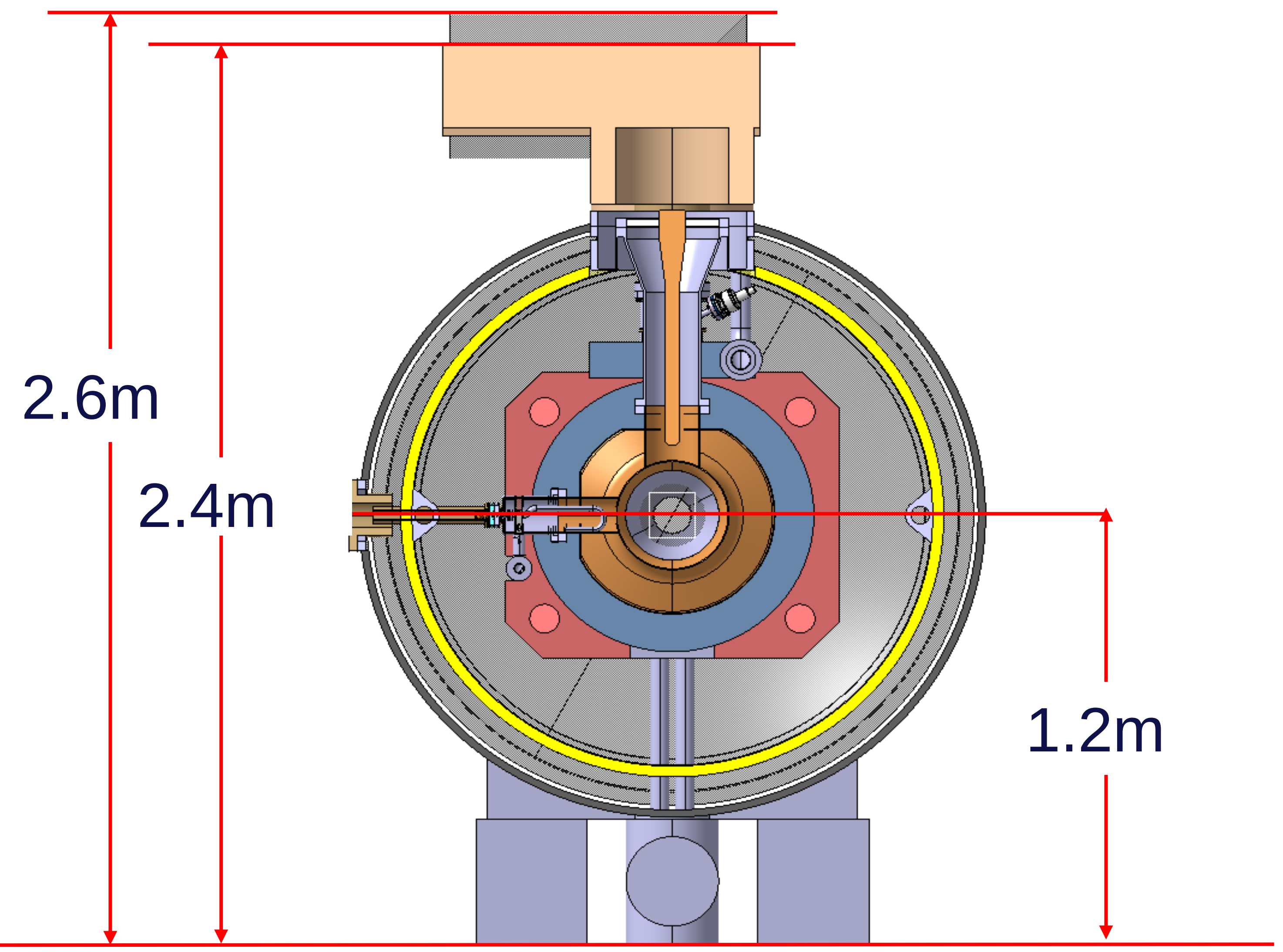
3%: Maximum pressure drop considered from the helium tank to the BDs.

Required discharge area calculated according to the standards EN ISO 13648-3, EN ISO 4126-6 and EN ISO 4126-7

Design details of the 400MHz CM

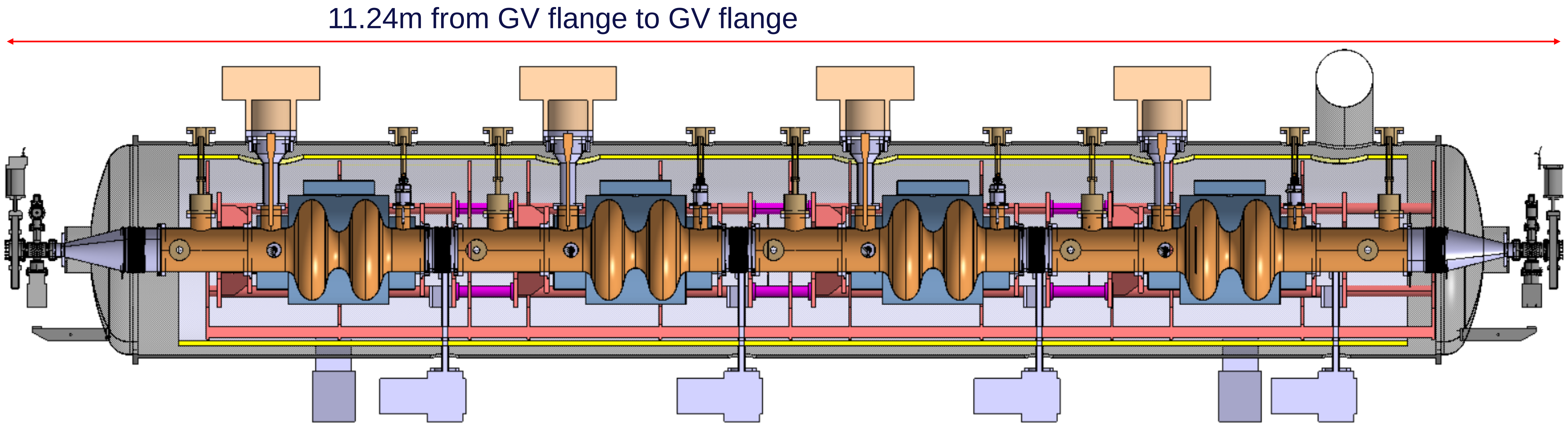
Overall dimensions





Key design concepts:

- Actively cooled thermal shield at 50K
- HOMs connectors:
    - Flexible coax if P_{HOM} x 6 <1kW
    - Rigid coax if P_{HOM} x 6 >1kW
- Tie-rods supports
- LHC type tuner with motor outside
- Accessibility to waveguide and HOM ports
- Simplification of the helium tank shape (compared to LHC) and introduction of the 2-phase line instead of the vapor boxes (not illustrated).
- Helium inventory of 116 kg – preliminary conservative estimate.



Mech design: Marc Timmins

FPC geometry and cooling strategy

GOAL :

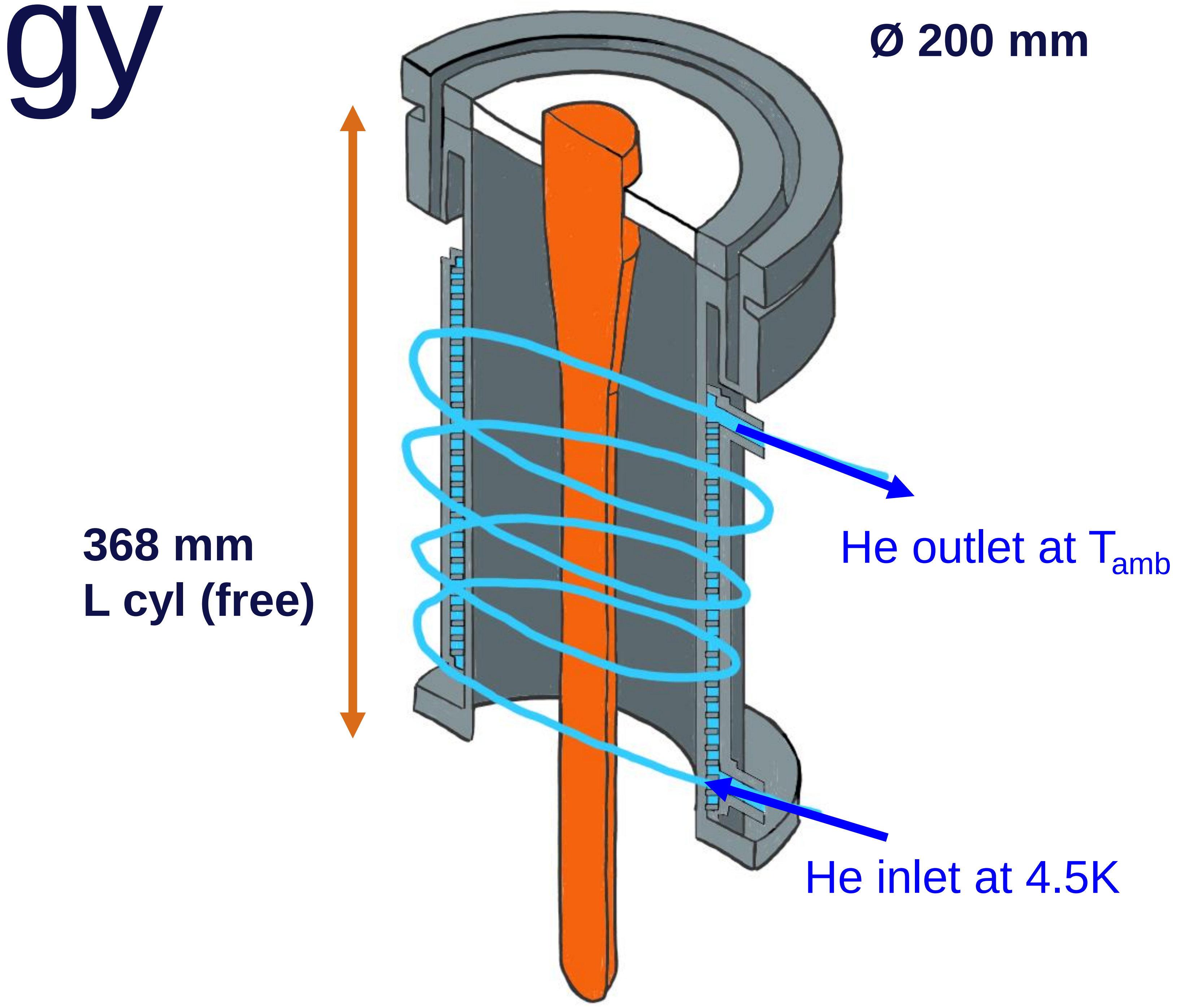
1. Minimize the static and dynamic heat loads of the FPC (not yet accounted in the FCC MTR) throughout:
   - the machine working points (Z,W,H,ttbar) → P_{cav} : 900 kW (Z) – 400 kW (W and H) continuous
   - The RF operating conditions (nominal, beam transient, coupler conditioning) → variable EM field → variable RF dissipation in the FPC outer conductor.
2. Provide the inputs for the integration of the FPC in the cryomodule, and the cryogenic scheme

CONSTRAINTS :

- RF design of the inner and outer conductor
- RF power input and operating conditions

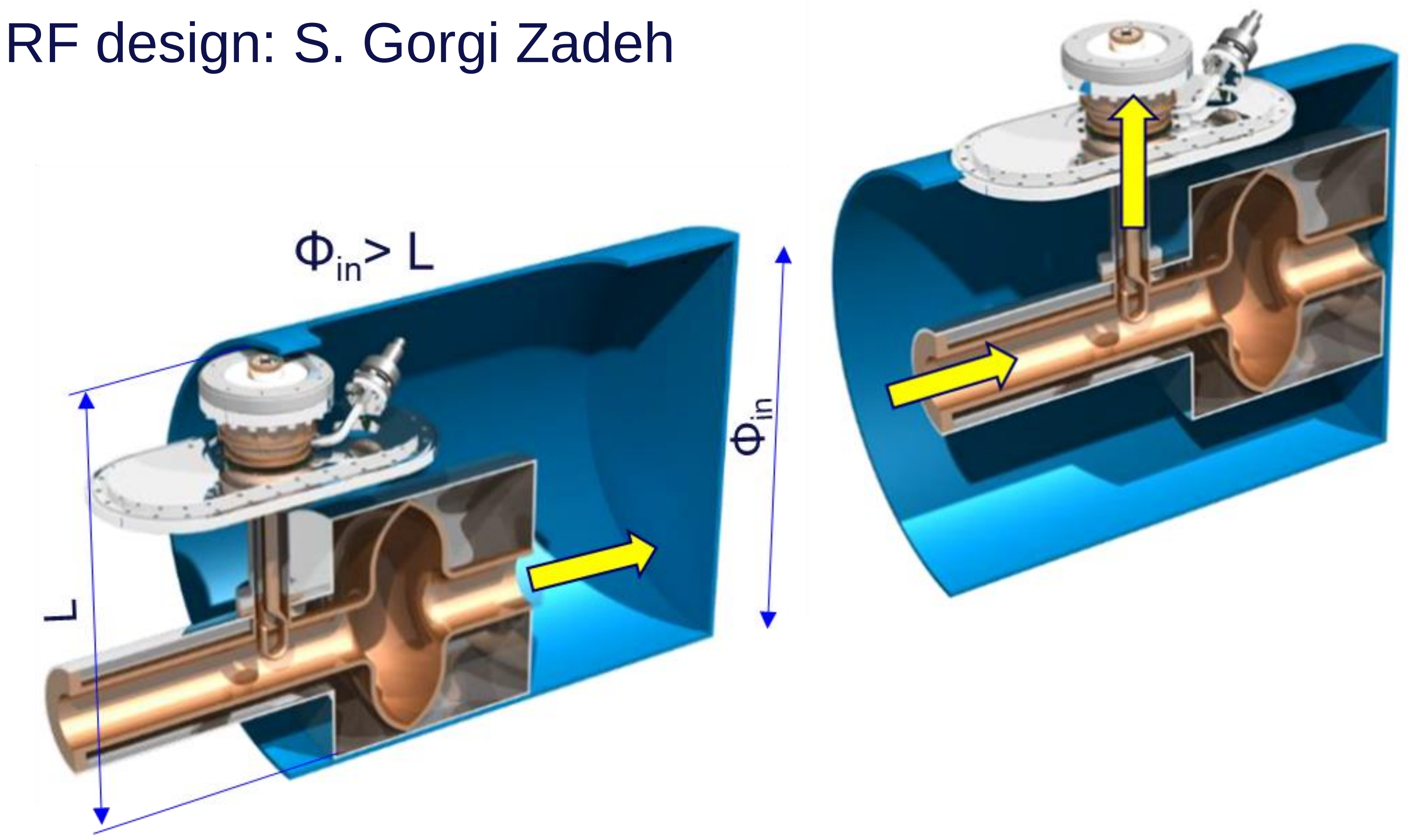
FREE PARAMETERS :

- Outer conductor cooling strategy
- Length of the cylindrical part.



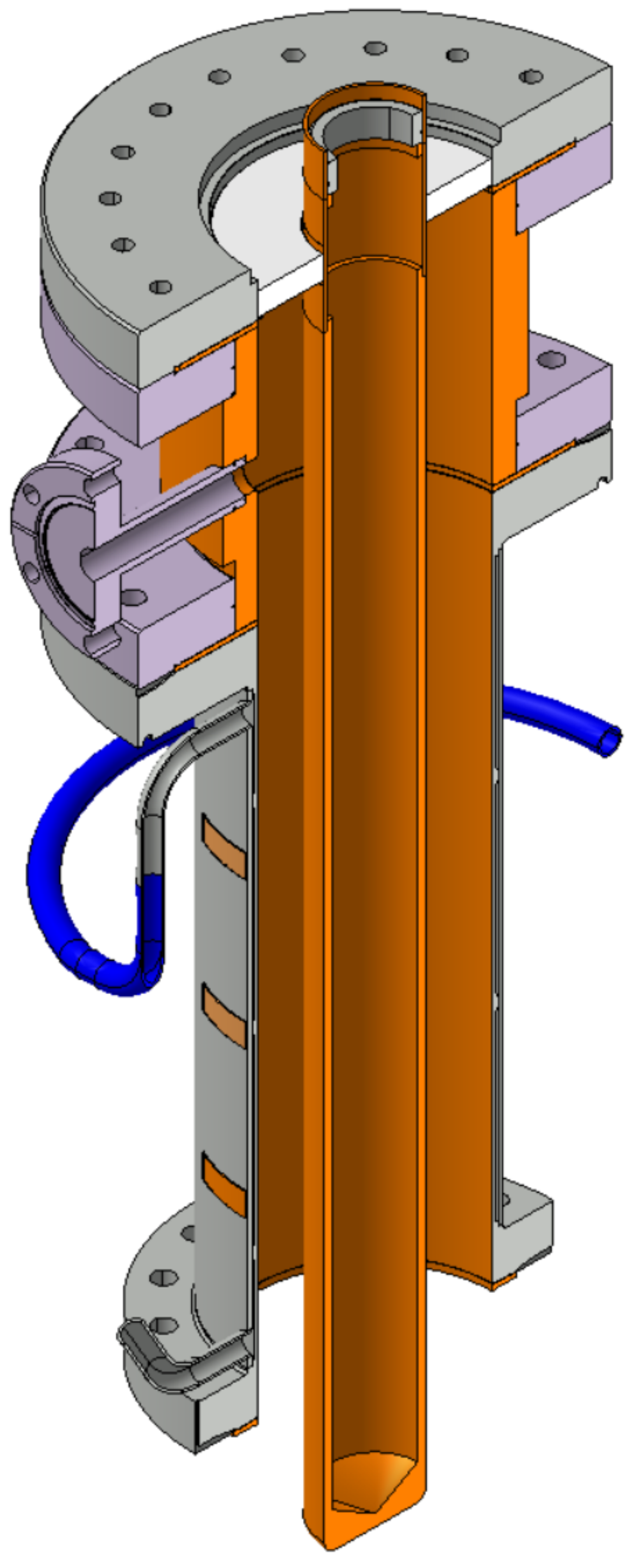
FPC baseline design to deliver 900kW – 400kW of RF power to the 400 MHz 2-cell cavities.

RF design: S. Gorgi Zadeh

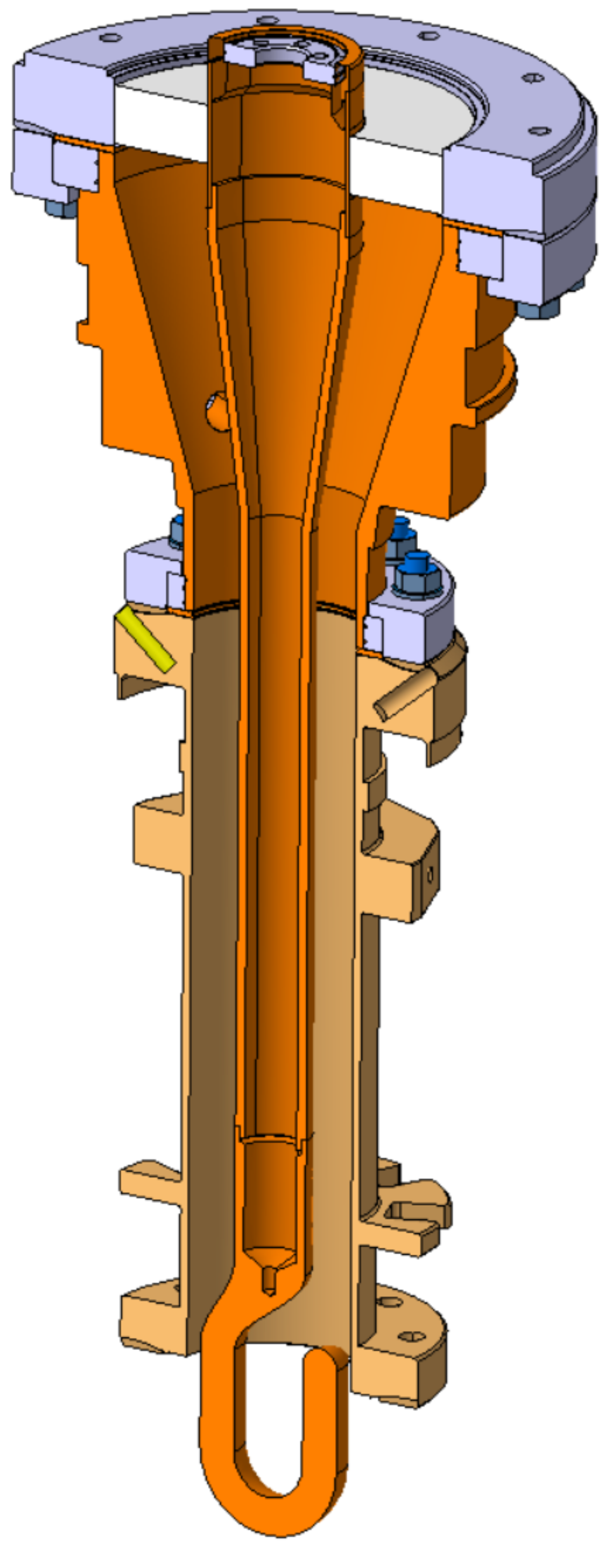


Alternative cooling strategies

	Active cooling with supercritical helium	**Fixed T heat interception**
Thermodynamic efficiency (Cryogenic cost)	Strategy exploits the high sensible heat of the helium vapor, from 4.5K to T_{amb}.	The cost of the heat loads released to the different temperature levels is compared with the cost of the helium vapor refrigeration.
CAPEX	Potentially lower. Requires liquefaction capacity to be added to the cryogenic plant.	Requires additional cryogenic lines and valves in the service module.
Flexibility	Flexible cooling capacity changing the helium mass flow for the multiple operating condition (no need of electric heaters for low heat load scenarios).	None.
Operational complexity	To be assessed (heaters, control, mass flow regulation).	Low – passive heat extraction.
Reliability	To be assessed.	High.
Machines	LHC, ESS, SPL	Crab cavities, XFEL, PIP-II



SPL coupler design: Active vapor cooling



Crab cavities coupler design : Heat Intercepts

RF inputs and preliminary conclusions

High variability of the operating conditions

The RF power dissipated in the outer conductor is calculated as

$$P_{RF} = \frac{1}{2} R_{wall}(T) \int_0^{2\pi} \int_0^{L} H(x,\theta,t)^2 \, dx d\theta$$

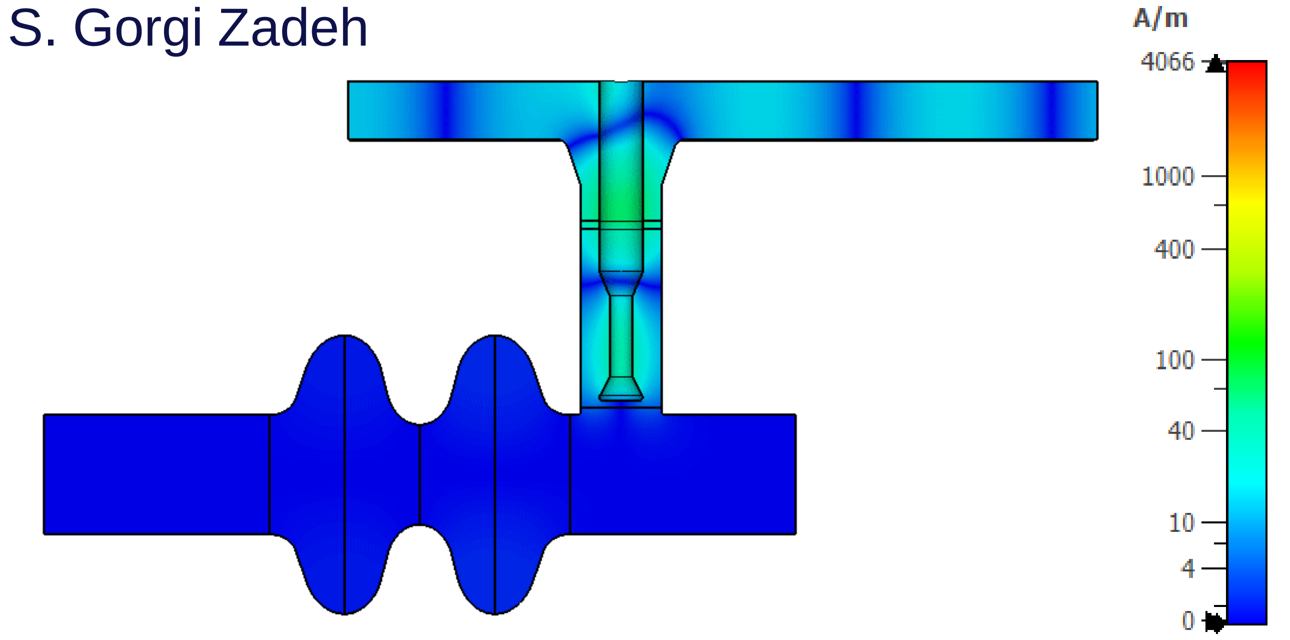
$$= \frac{1}{2} R_{wall}(T) \cdot \pi D \int_0^{L} |H(x)|^2 \, dx$$

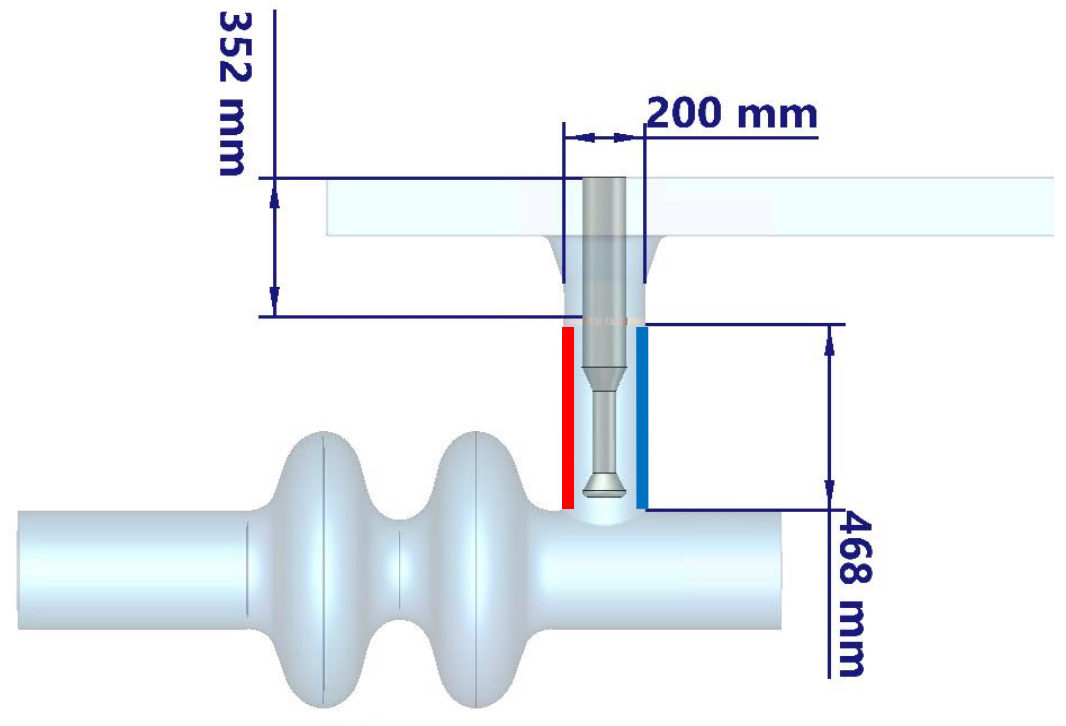
with $H(x,\theta)$ from RF simulations.

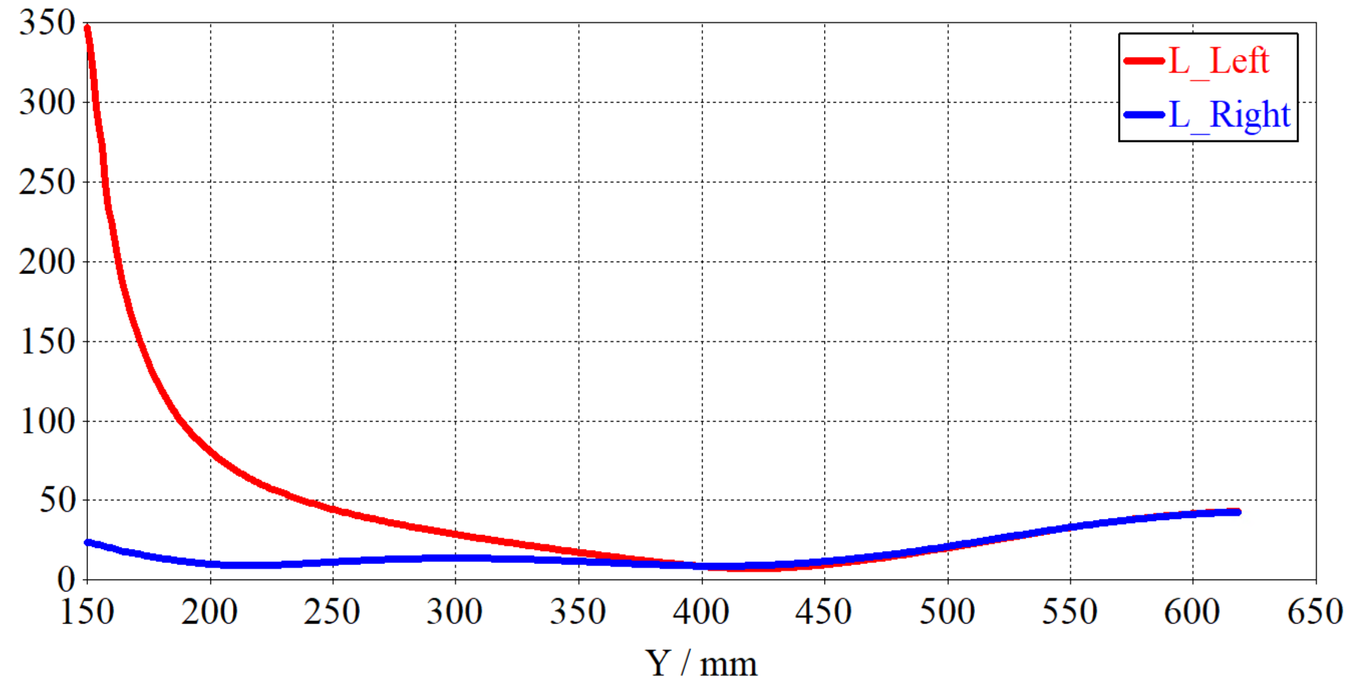
The magnetic field is multiplied by:

- **1** : **Nominal operation**, almost no reflected power for a synchrotron machine. Duration: **10 months per year.**
- **1.5** : **Off nominal operation**: beam transients of operation in half detuning. Duration: **several minutes to 10 months per year.**
- **2** **Coupler conditioning**: full reflection mode, 4 x RF power dissipation. Duration: **several weeks.**

S. Gorgi Zadeh







- Values to be scaled with the energy stored in the cavity at the different working points
- This H field values are representative of the W/H WP
- This coupler geometry and antenna position are not acceptable for the Z WP

Preliminary conclusions:

- The **active cooling strategy** allows to **change the flowrate** – and the energy consumptions – according to the **RF operating conditions**.
- Additional fluid dynamic studies of the DWT required to ensure **optimal heat transfer with variable He flowrates**.
- This choice would impact the final geometry of the FPC outer conductor and the final constraint on the **diameter of the vacuum vessel.**
- At system level, the selected cooling strategy will determine the **cryogenic scheme** and distribution lines

Summary and future work

Updates:

- Progress in the definition of the technical specifications for the 400MHz and 800MHz cryomodule.
- Definition of a heat loads budget and margins for the cryogenic system.
- Definition of a preliminary cryogenic scheme.
- Assessment of the risk case scenario leading to helium overpressure in the tank and calculation of the required discharge area of the PRDs.
- Updates on the 800MHz design – refer to the talk from Donato Passarelli.

Future work:

- Finalization of the conceptual design
- Definition of the **tuning system**
- **Engineering design** of the **helium tank** in relation to the cavity tuning

Thank you for your attention.

Supporting slides

400 MHz Cryomodule

Heat loads budget – Cryomodule nominal values

Z(*) Preliminary values.

	Z(*)	**W/H/$t\bar{t}$**
	Collider	Collider
#cav/CM	4	4
T operation [K]	4.5	4.5
Dynamic losses at 4.5K/cav [W]	9	129
Static losses at 4.5K / CM [W]	131	131
Dynamic losses at 4.5K/CM [W]	36	516
Losses to the thermal shield at 50K/CM	218	218

Static losses to the helium bath

- Value for the entire cryomodule instead of W/cav.
- Nominal value from the **experimental measures of the LHC cryomodule -** radiative heat load to the cold masses **corrected** to account for the presence of an **actively cooled thermal shield in the FCC CM** (150W – 19W = 131W).

Dynamic losses:

- **Nominal value** in W/cav kept **from baseline.**

Losses to the thermal shield

- Derived with conservative assumptions and a simplified design of the cryomodule.

	Z(*)	**W/H/$t\bar{t}$**
	Collider	Collider
Required liquefaction capacity /CM [mg/s]	320	320

With active cooling as baseline for the FPC, the cryogenic plants must include liquefaction capacity.

800 MHz Cryomodule

Heat loads budget – Cryomodule nominal requirements

	Z(*)	W/H/$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Collider
#cav/CM	4	4	4
T operation [K]	2	2	4.5
Dynamic lossess at 2K/cav [W]	0.3	3	23
Static losses at 2K/ CM [W]	32	32	32
Dynamic losses at 2K/ CM [W]	1.2	12	92
Static losses to the thermal shield @50K/CM (50%margin)	103	103	103

Static losses to the helium bath

- Value for the entire cryomodule based on the MTR estimate of 8 of W/cav.
- In line with experimental values from prototypes of HB650 (PIP-II) and elliptical HB (ESS), both design candidates from the 800 MHz CM

Dynamic losses:

- **Value** in W/cav kept **from the baseline**

Losses to the thermal shield

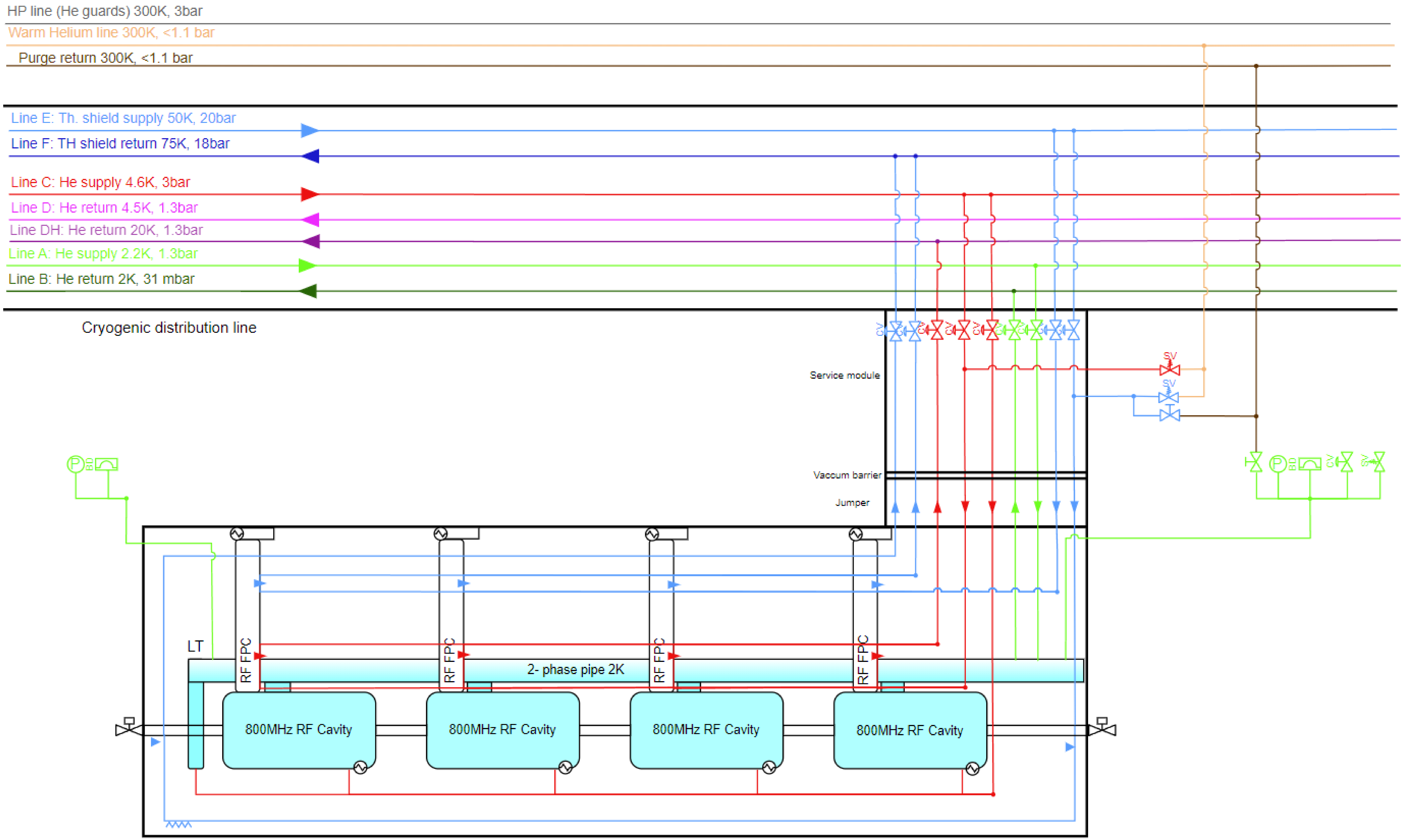
- Derived with conservative assumptions and a simplified design of the cryomodule.

	Z	W/H/$t\bar{t}$	$t\bar{t}$
	Booster	Booster	Collider
Required liquefaction capacity/CM [mg/s] – lead from the collider need	320	320	320

With active cooling as baseline for the FPC, the cryogenic plants must include liquefaction capacity.

400 MHz Cryomodule – P&ID (Heat intercepts for the FPC cooling)

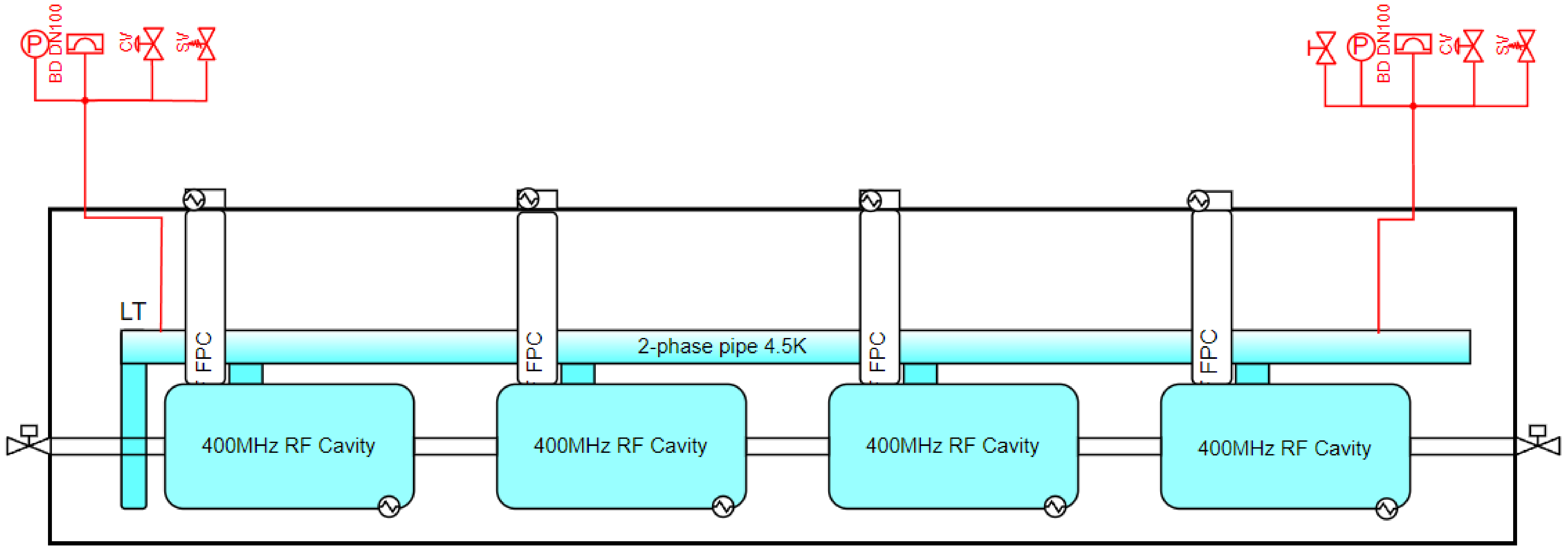
800 MHz Cryomodule – P&ID (Heat intercepts for the FPC cooling)



Helium inventory calculation

Geometrical parameters – 400MHz

Wet surface of four cavity, inside the helium tank.	9.44	m2		
External surface of one helium tank.	3.21	m2		
Helium inventory per helium tank	0.223	m3	223	L
Volume liquid helium 2-phase pipe Buffer for 15 minutes, beam OFF	**0.064**	**m3**	**64.65**	**L**
Diameter double phase pipe	**0.155**	**m**		
Volume double phase pipe	0.13	m3	132	L
Filling ratio	**48.9%**			
Wet surface of the double phase pipe	1.68	m2		
Diameter of the raisers	**0.155**	**m**		
Wet surface of the raisers (4)	0.097	m2		
Volume of the raisers (4)	0.0037	m3	3.7	L
Total wet surface	**14.62**	**m2**		
Total volume - Helium inventory L	1.027	m3	1027	L
Liquid helium inventory	0.96	m3	960	L
He vapor inventory	0.067	m3	67	L
Helium inventory kg x CM	**115.701**	**kg**		

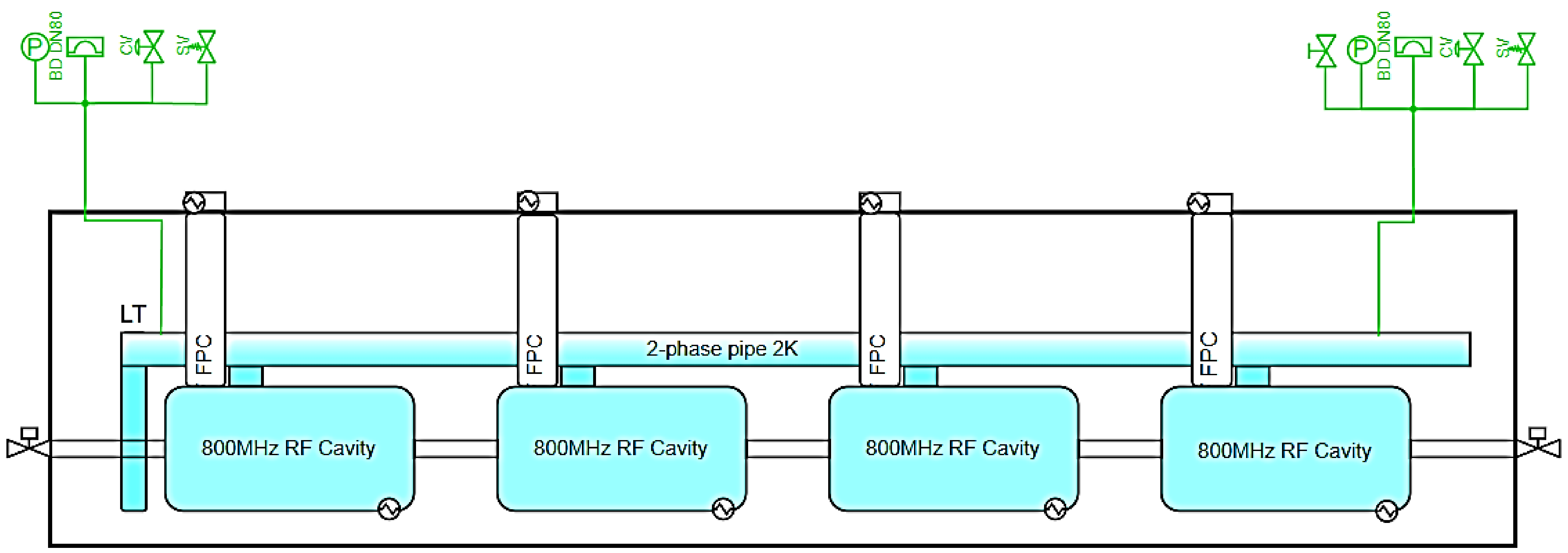


Design guidelines:

- Liquid helium in the 2-phase = Buffer for 15min with beam OFF
- ØBD = Ømin 2-phase
- 50% max filling ratio
- Ø raisers = Ø 2-phase

Geometrical parameters – 800MHz

Wet surface of four cavity, inside the helium tank.	4.96	m2		
External surface of one helium tank.	1.77	m2		
Helium inventory per helium tank	0.08	m3	80	L
Volume liquid helium 2-phase pipe Buffer for 15 minutes, beam ON + 1cm of static height	**0.052**	**m3**	**52**	**L**
Diameter double phase pipe	**0.155**	**m**		
Volume double phase pipe	0.11	m3	113	L
Filling ratio	**46.5%**			
Wet surface of the double phase pipe	1.68	m2		
Diameter of the raisers	**0.140**	**m**		
Wet surface of the raisers (4)	0.097	m2		
Volume of the raisers (4)	0.0037	m3	3.7	L
Total wet surface	**8.59**	**m2**		
Total volume - Helium inventory L	0.436	m3	437	L
Liquid helium inventory	0.37	m3	376	L
He vapor inventory	0.06	m3	60	L
Helium inventory kg x CM	**54.87**	**kg**		

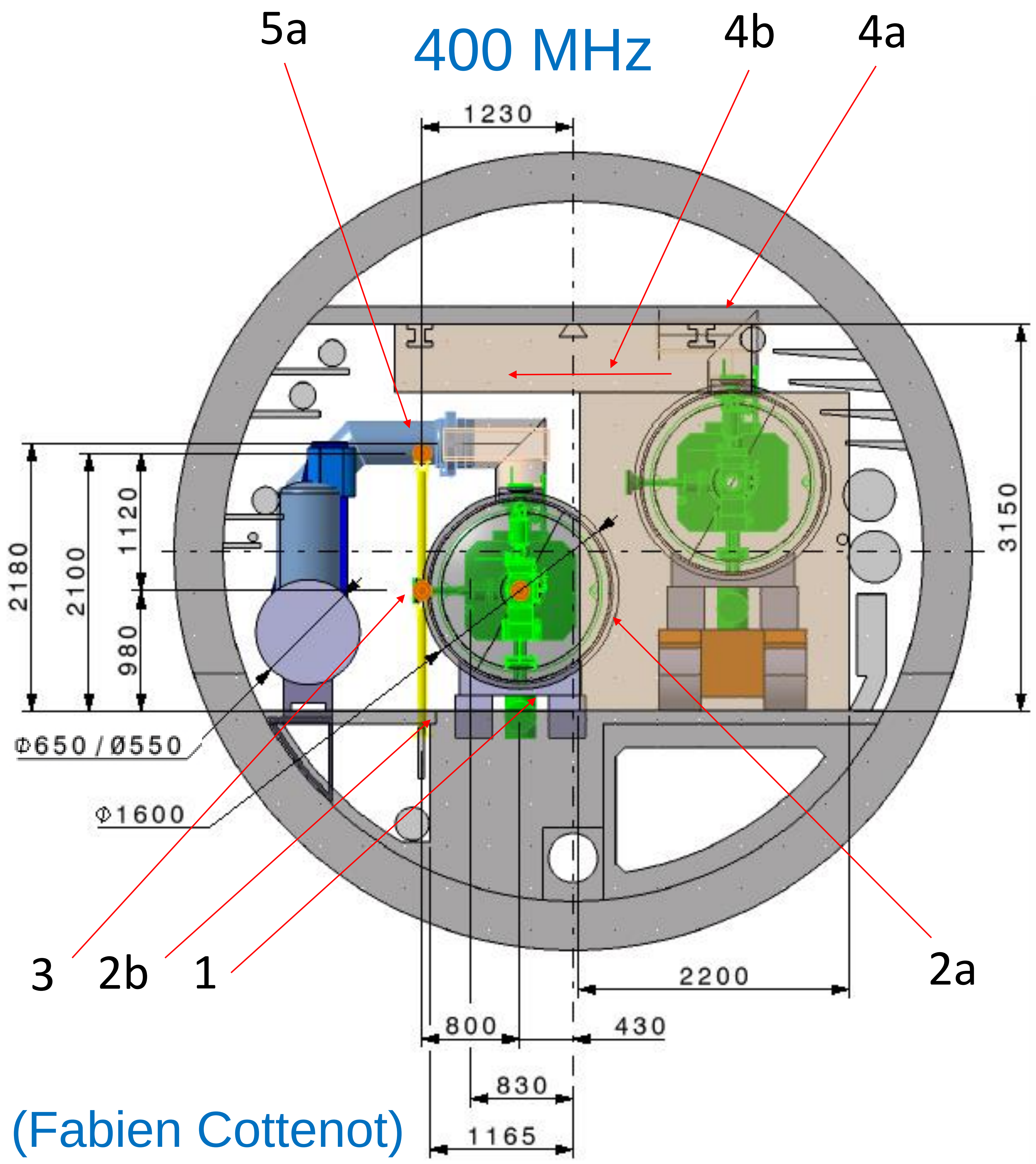


Design guidelines:

- Liquid helium in the 2-phase =
  - Buffer for 15min with beam ON
  - Liquid to ensure 1cm of liquid height on top of the raisers
- ØBD = Ømin 2-phase
- 50% max filling ratio
- Ø raisers to ensure a max heat flux of 1.2W/cm2 in the superfluid helium

Point H _ 400 MHz

Current Integration with new models



(Fabien Cottenot)

Point H: Z, W

Collider

Interferences:

1 : CM/floor
▶ Height 980 to 1200

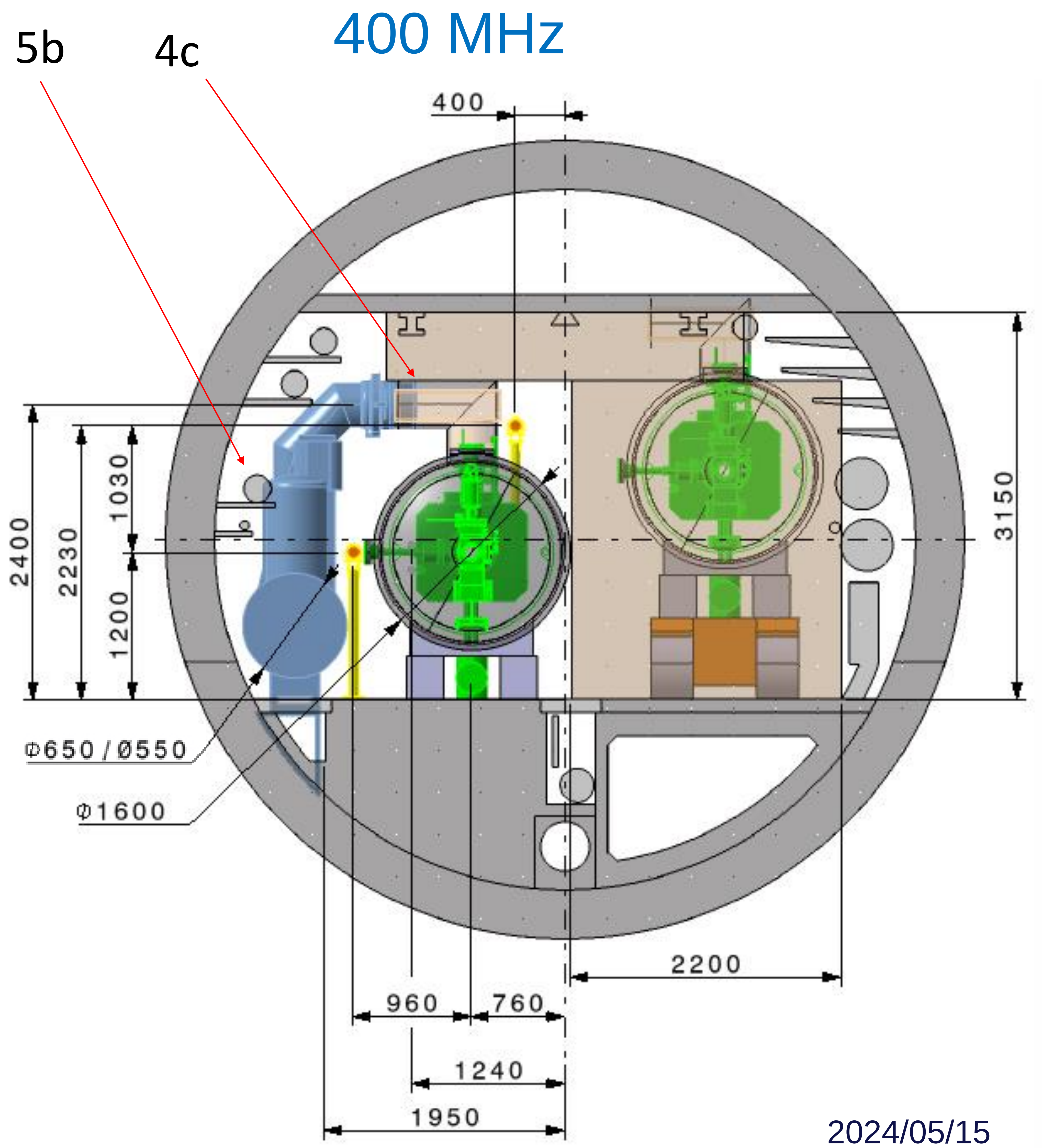
2a: CM/Transport zone
▶ Distance beam2 : 430 to 760
2b: CM/floor support
▶ Distance 1165 to 1950

3: Circulating Beam / CM
▶ Distance beam1/2 : 800 to 960

4a : CM transport / Robot space
▶ To be studied
4b : CM installation / Robot
▶ To be studied
4c : CM in position / Robot
▶ To be studied

5a: Cryo line Jumper / Booster
▶ Moved to the other side
5b: QRL Jumper / Service
▶ To be studied

Modification proposal



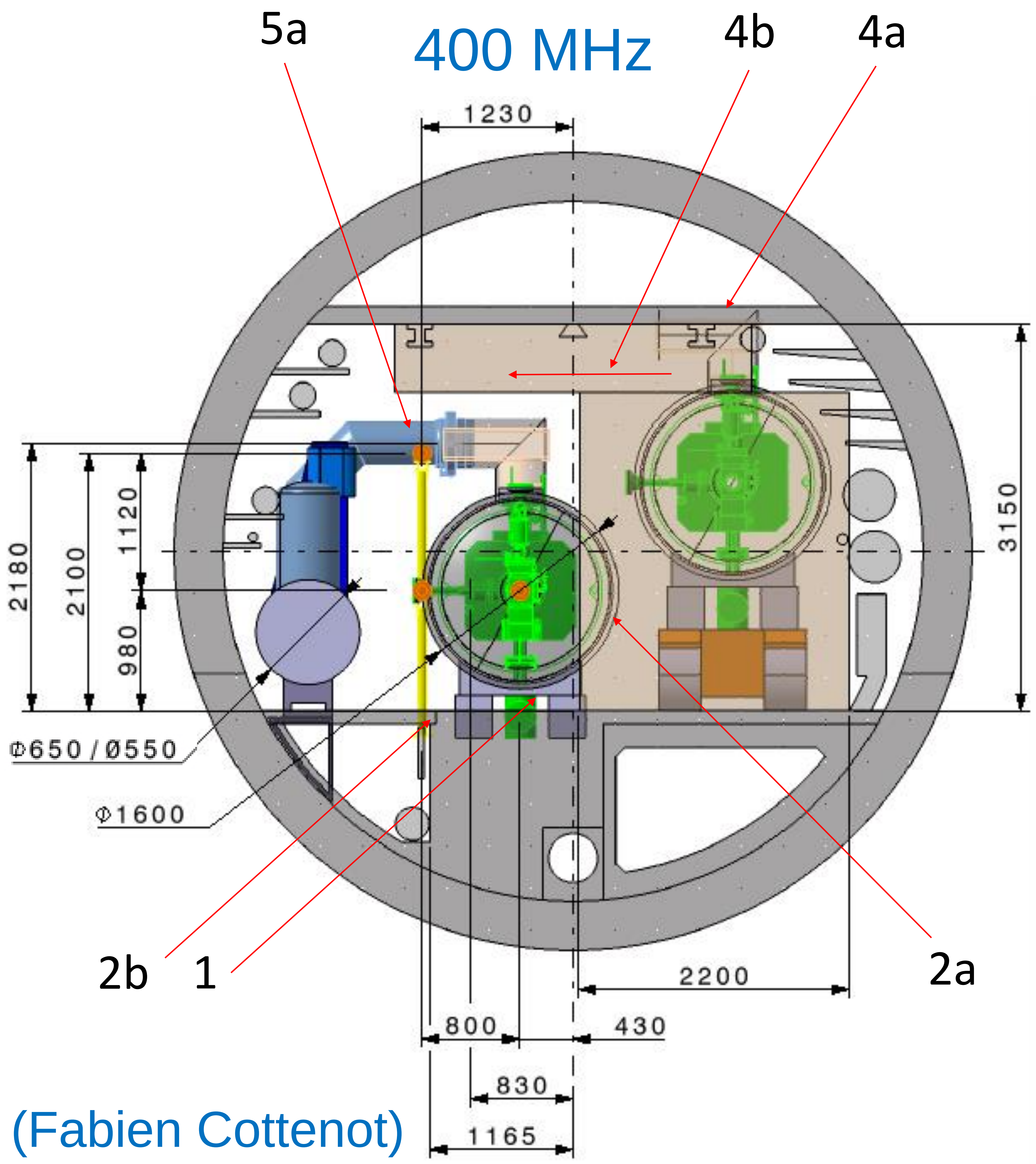
FCC

Point H _ 400 MHz

Point H: H, ttbar

Collider

Current Integration with new models



(Fabien Cottenot)

Interferences:

1 : CM/floor

▶ Height 980 to 1200

2a: CM/Transport zone

▶ Distance beam2 : 430 to 760

2b: CM/floor support

▶ Distance 1165 to 1950

4a : CM transport / Robot space

▶ To be studied

4b : CM installation / Robot

▶ To be studied

4c : CM in position / Robot

▶ To be studied

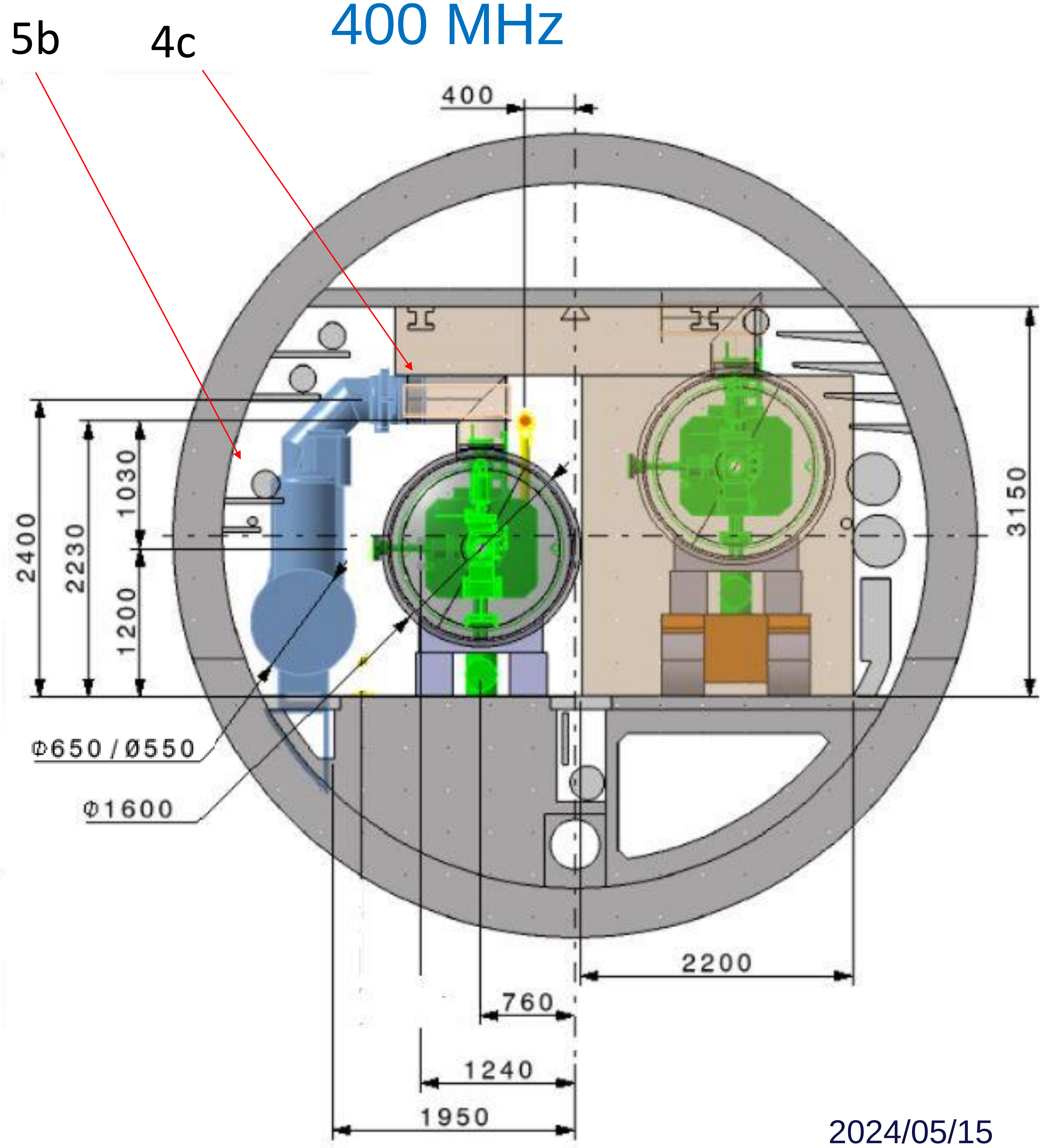
5a: Cryo line Jumper / Booster

▶ Moved to the other side

5b: QRL Jumper / Service

▶ To be studied

Modification proposal



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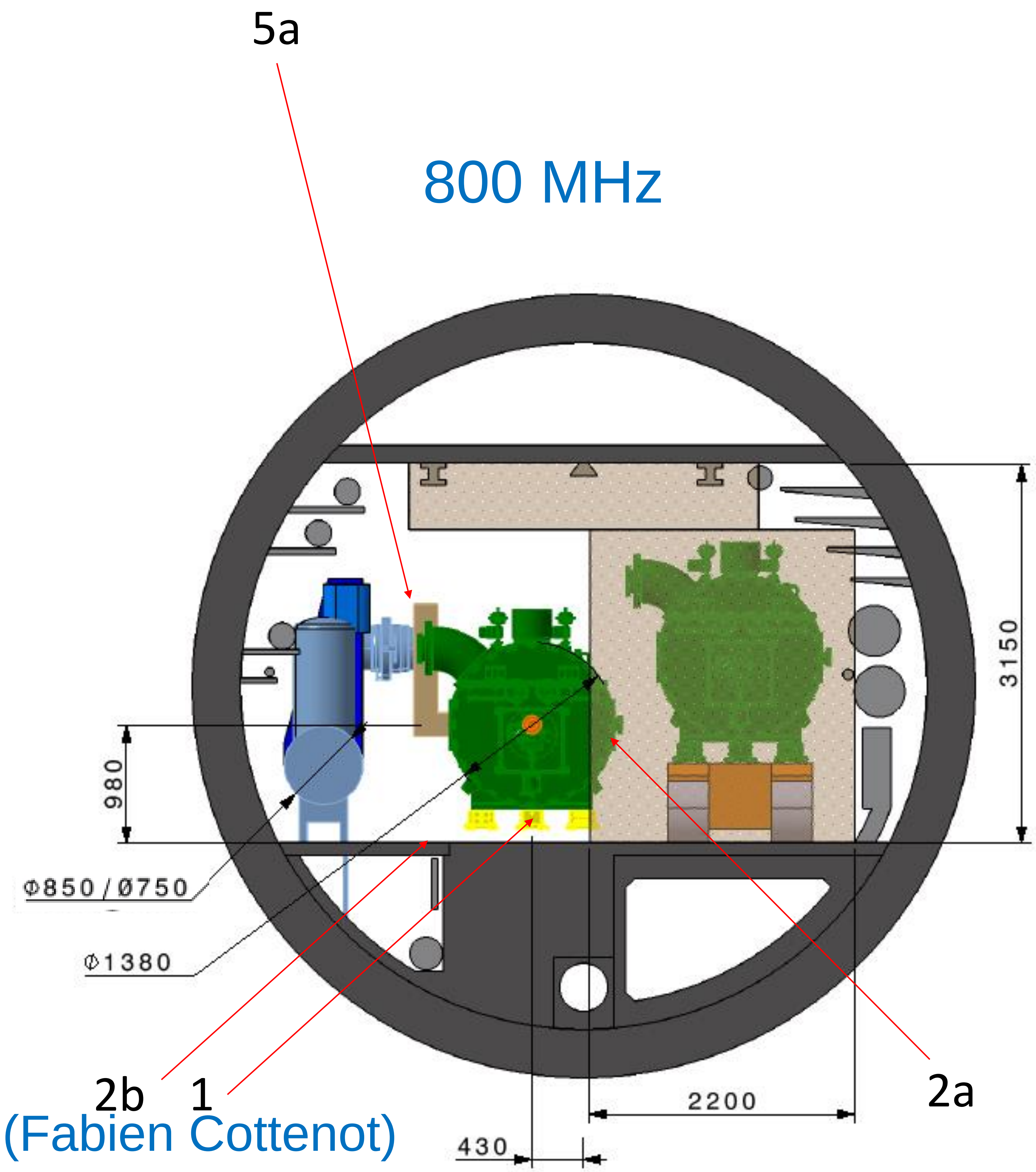
Point H _ 800 MHz

Current Integration with new models



(Fabien Cottenot)

Point H: ttbar

Collider

Interferences:

1 : CM/floor (for 400 MHz)

▶ Height 980 to 1200

2a: CM/Transport

▶ Distance beam2 : 430 to 760

2b: CM/floor (for 400 MHz)

▶ Distance 1165 to 1950

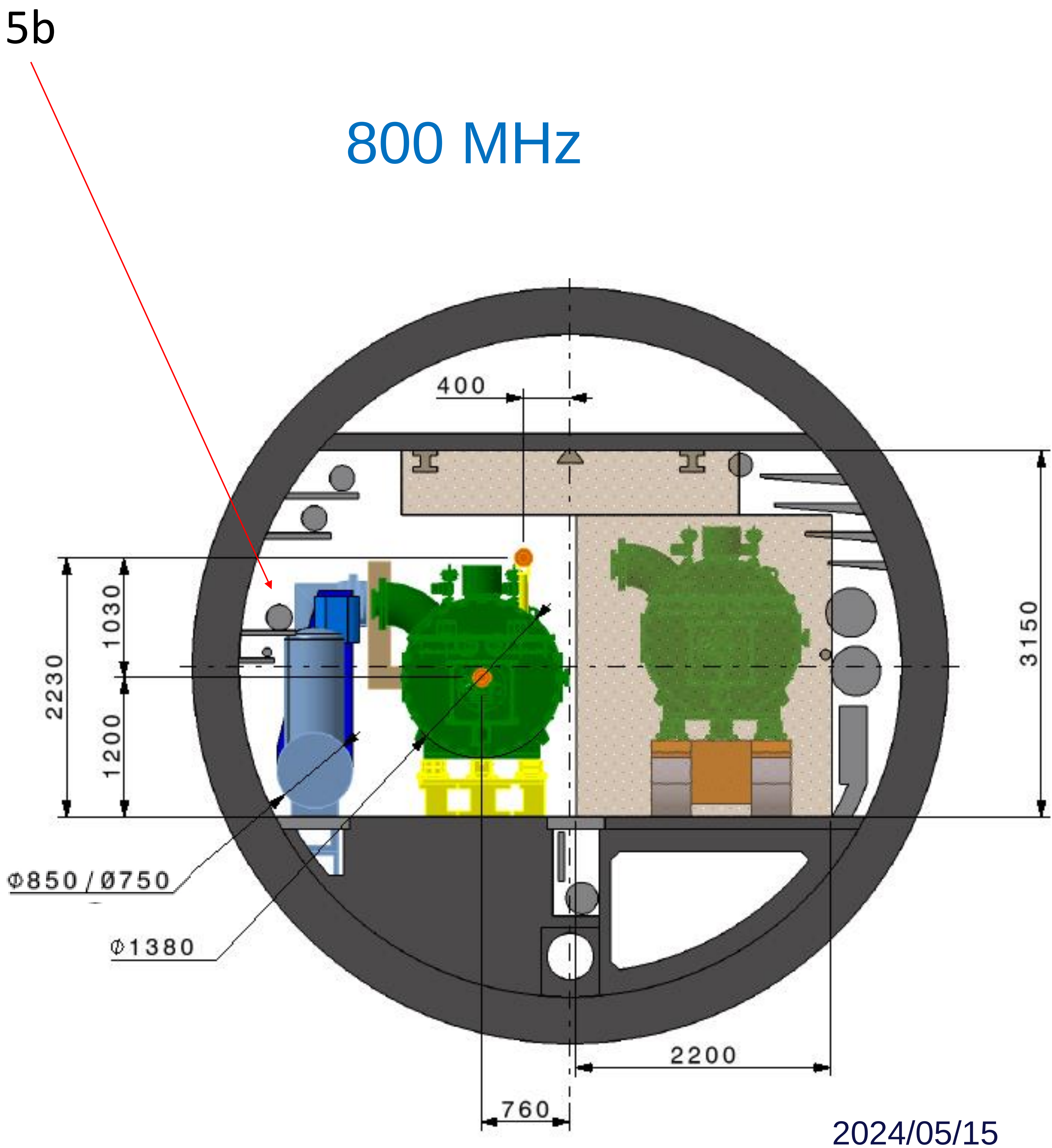
5a: QRL Jumper / Booster

▶ Moved to the other side

5b: QRL Jumper / Service

▶ To be studied

Modification proposal



2024/05/15

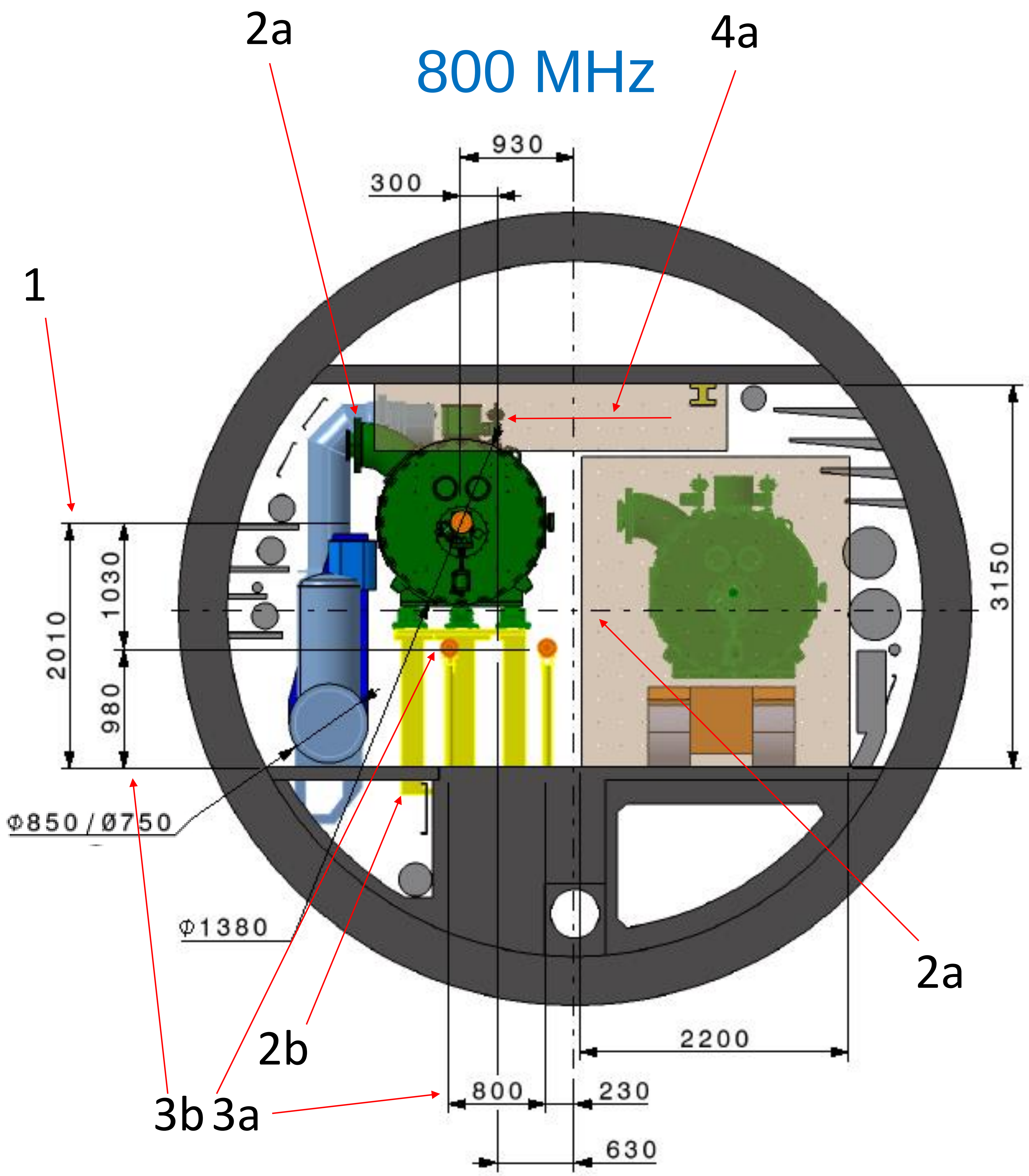
Point L _ 800 MHz

Current Integration with new models

Point L: Z...ttbar

Booster

Modification proposal



Interferences:

1 : CM/floor

▶ Height 2010 to 2230

2a: CM/QRL Jumper

2b: CM/floor not supported

▶ Distance booster : 930 to 700

3a: Circulating Beam / CM support

▶ Distance beam1/2 : 800 to 350

3b: Beam height

▶ Height beam1/2 : 980 to 1200

4a : CM installation / Robot

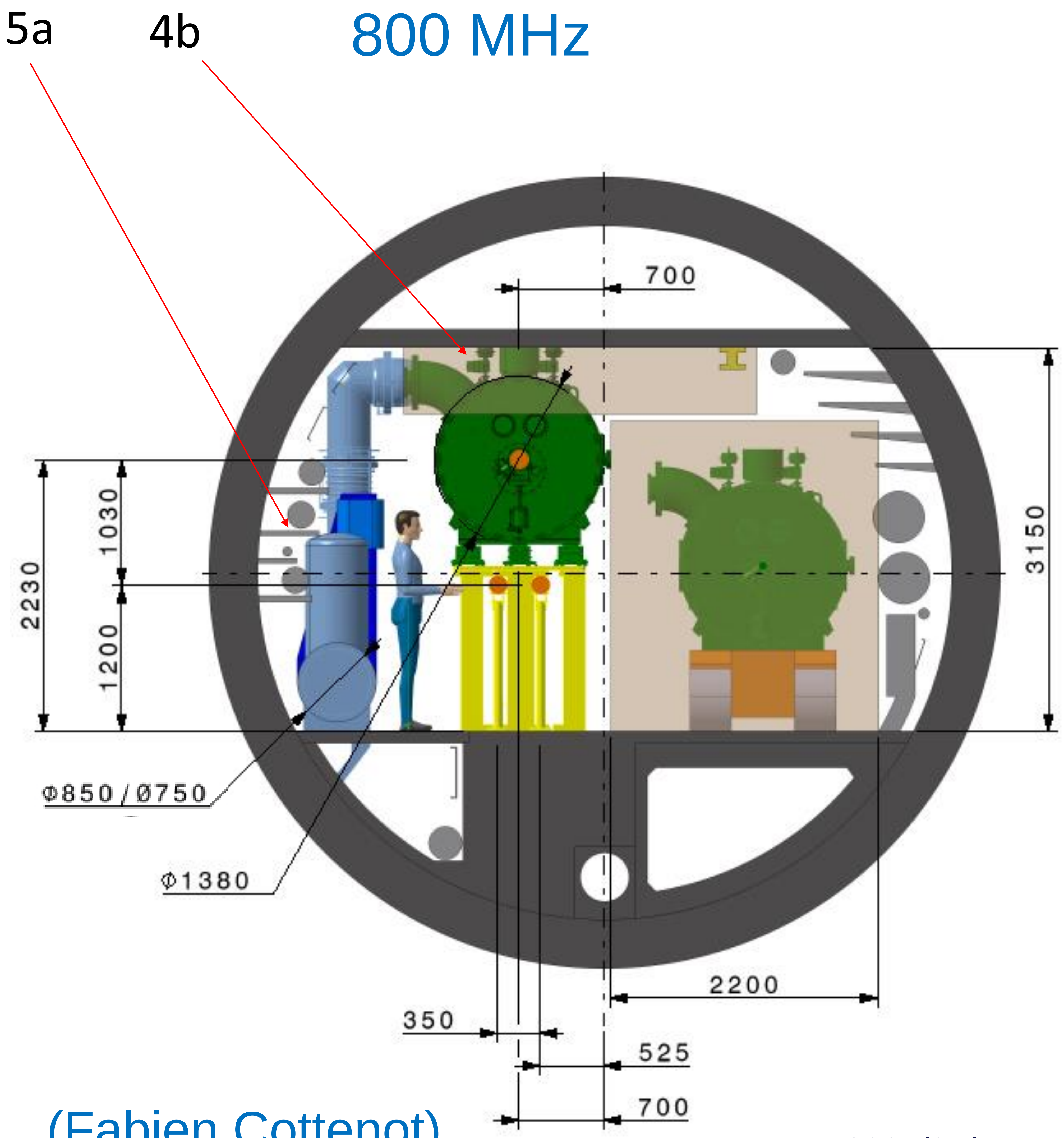
▶ To be studied

4b : CM in position / Robot

▶ To be studied

5a: QRL Jumper / Service

▶ To be studied



(Fabien Cottenot)

2024/05/15