FUTURE
CIRCULAR
COLLIDER

# THE FCC-EE SRF SYSTEM: MACHINE LAYOUTS AND INTEGRATION UPDATE

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On behalf of the FCCee SRF team

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and D.Passarelli, V. Roger, FNAL

# Cavities and Cryomodules



Unchanged wrt FCC week 2023

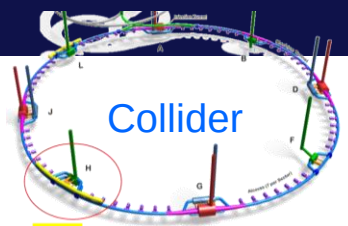
- 366 CM (3 types), 1’464 SRF cavities (4 cavities/CM, present assumption):
  - 400 MHz single-cell (Nb/Cu), 4.5 K: 28 CM, 112 cavities (removed after Z)

  - 400 MHz two-cell (Nb/Cu), 4.5 K: 66 CM, 264 cavities

  - 800 MHz five-cell (bulk Nb), 2 K: 272 CM, 1’088 cavities

- By machine:
  - Collider (ttbar): 188 CM (264 cavities 400 MHz, 488 cavities 800 MHz)
  - Booster (ttbar): 150 CM (600 cavities 800 MHz)

TLSS length: 2032 m




Access Point H

Z machine
(0.24 GV, 100 MW)
400MHz/1 Cell
800MHz/2 Cell
WCS
LCB
14 CMs
14 CMs
Beam 1
Beam 2
4.5K
Beam 2
Beam 1
Booster
2K
Booster
180m
184m

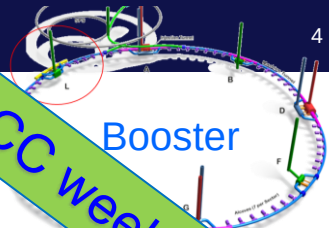
W machine
(2.1 GV, 100 MW)
400MHz/2 Cell
800MHz/5 Cell
WCS
UCB
LCB
33 CMs
33 CMs
Beam 1
Beam 2
4.5K
Beam 2
Beam 1
Booster
2K
Booster
435,9m
435,9m

H machine
(4.2 GV, 100 MW)
400MHz/2 Cell
800MHz/5 Cell
WCS
UCB
LCB
33 CMs
32 CMs
Beam 1
Beam 2
4.5K
Beam 1
Beam 2
Booster
2K
Booster
435,9m
435,9m

ttbar machine
(22.6 GV, 100 MW)
400MHz/2 Cell
800MHz/5 Cell
800MHz/5 Cell
WCS
WCS
UCB
UCB
LCB
LCB
33 CMs
61CMs
61CMs
32CMs
Beam 1
Beam 2
2K
Beam 1
Beam 2
Booster
2K
Booster
435,9m
539,2m
539,2m
435,9m

TOTAL RF LENGTH: 1950,2 m

TLSS length: 2032 m




FCC week 2023

Access point L

IP

Z machine
(0.14 GV, 5 MW)
400MHz/1 Cell
800MHz/2 Cell
WCS
LCB
2K
1016 m
Beam 1
Beam 2
6 CMs
Booster
48,9m

W machine
(1.05 GV, 5 MW)
400MHz/2 Cell
800MHz/5 Cell
WCS
UCB
LCB
2K
Beam 1
Beam 2
14 CMs
Booster
Beam 2
Beam 1
Booster
120,7m

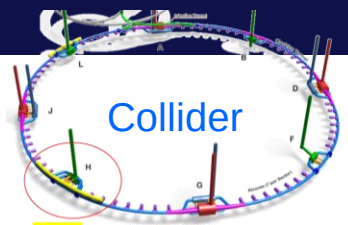
H machine
(2.1 GV, 5 MW)
400MHz/2 Cell
800MHz/5 Cell
WCS
UCB
LCB
2K
Beam 1
Beam 2
27 CMs
Booster
Beam 1
Beam 2
Booster
232.,8m

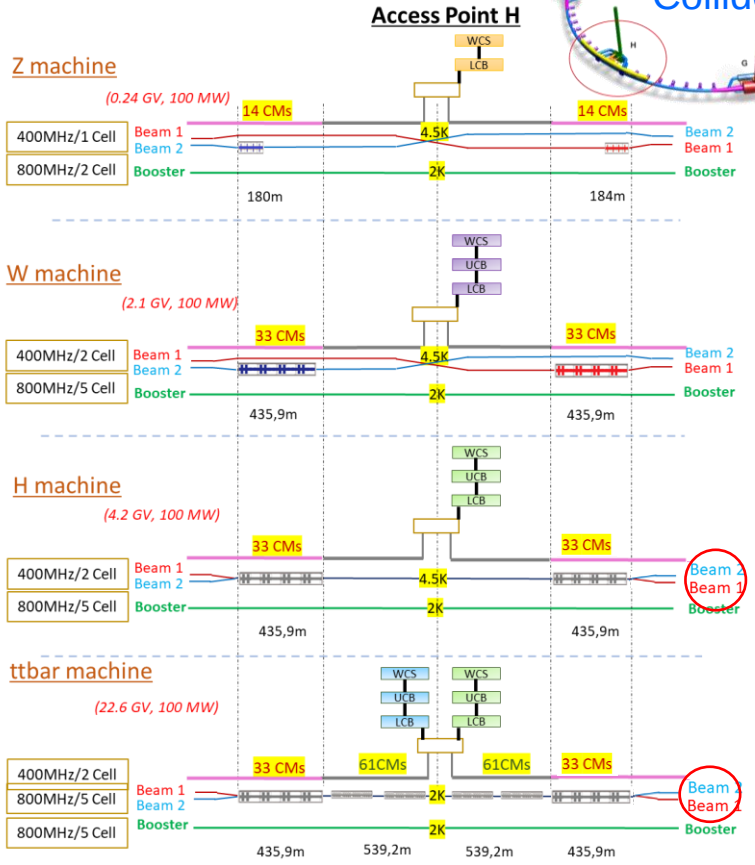
ttbar machine
(11.3 GV, 5 MW)
800MHz/5 Cell
800MHz/5 Cell
WCS
UCB
LCB
2K
Beam 1
Beam 2
Booster
75 CMs
75 CMs
Beam 1
Beam 2
Booster
648.5m
648.5m

Midpoint RF section

TOTAL RF LENGTH: 1297m

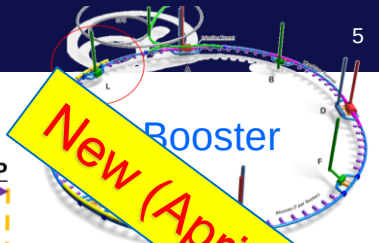
## TLSS length: 2032 m



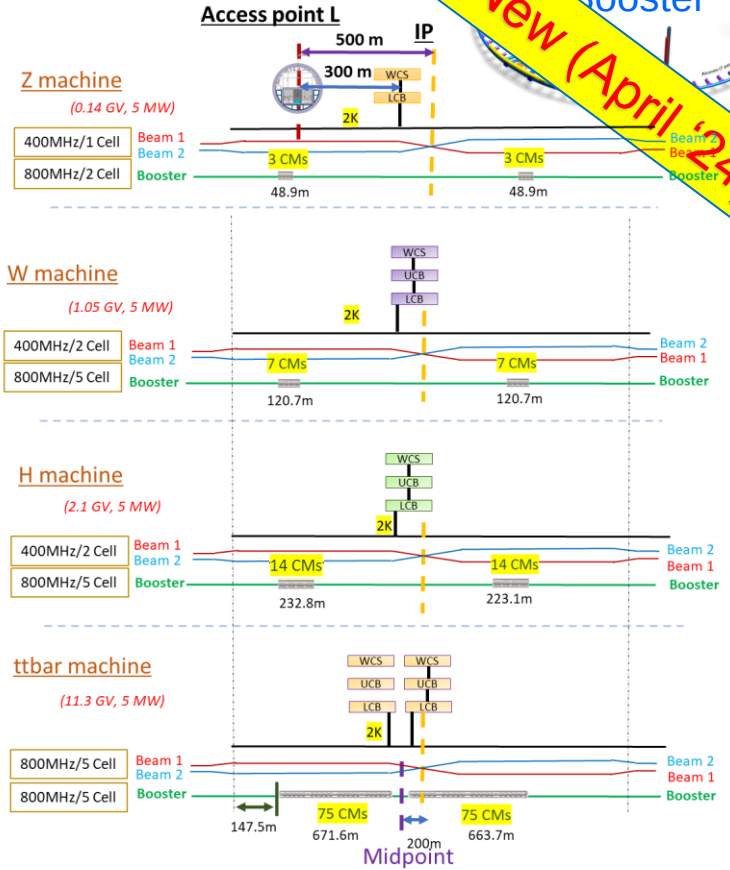




**TOTAL RF LENGTH: 1950,2 m**

## TLSS length: 2032 m




New (April '24)

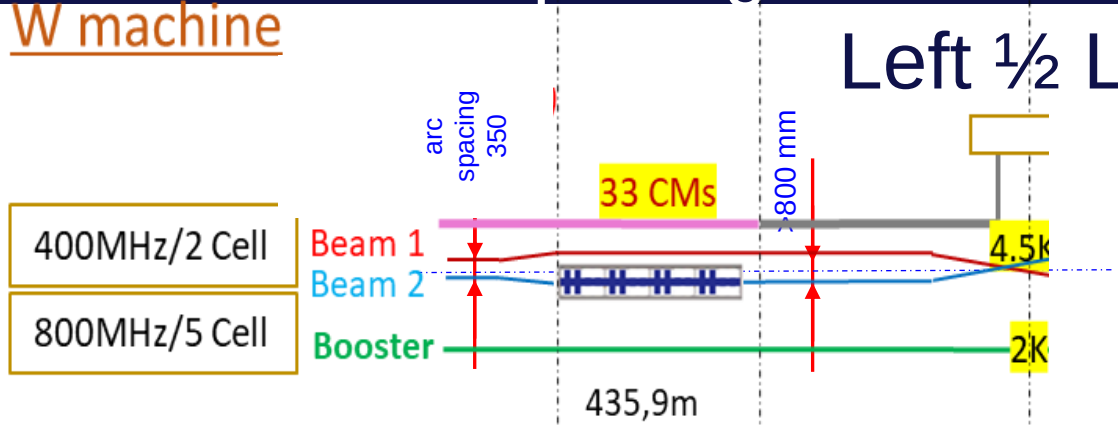



**TOTAL RF LENGTH: 1335.3m**

# Beam lines spacing from W to H



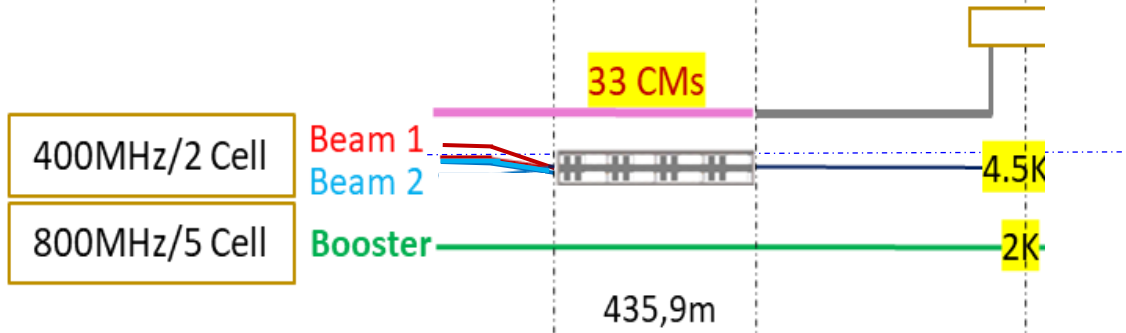
## W machine




Z and W:

- Beam spacing increase (CM width)
- Separation/recombination dipoles
- Beam 1 and 2 orbits identical

## H machine



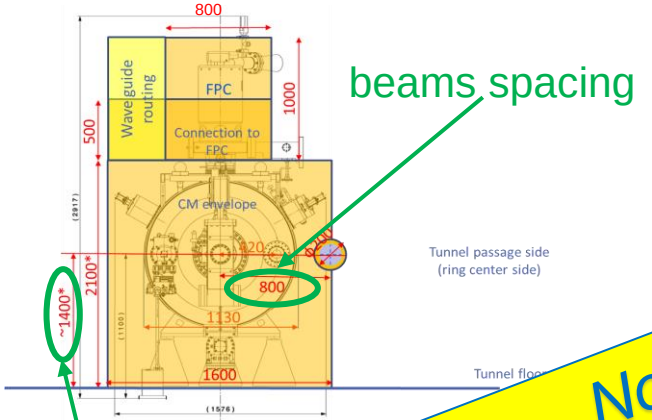

From W to H, ttbar

- CM kept in position
- 2 to 1 beam line recombination
- Beam 1 stronger deflection than Beam 2
- Orbits equalized by beam-crossing on other 1/2 LSS

# CM space occupation for integration study (since 2022)

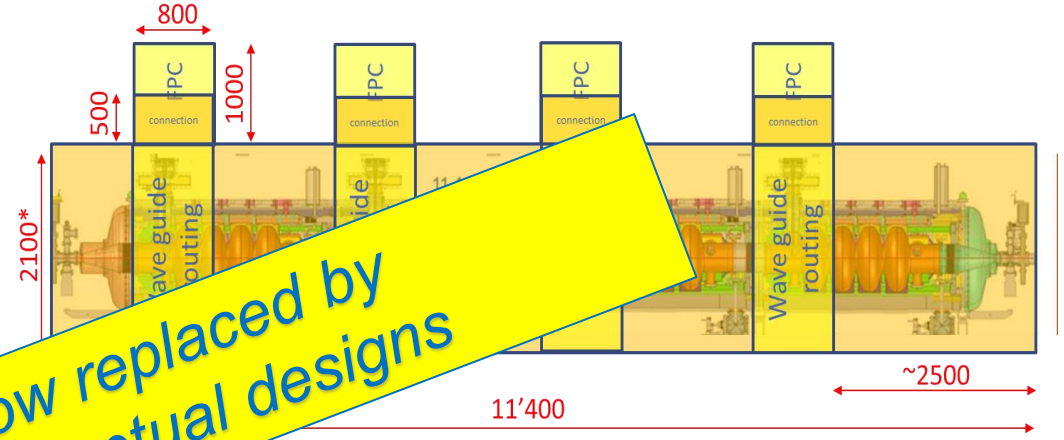


## 400 MHz Cryomodule (based on LEP, 4-cell cavities)




beams spacing

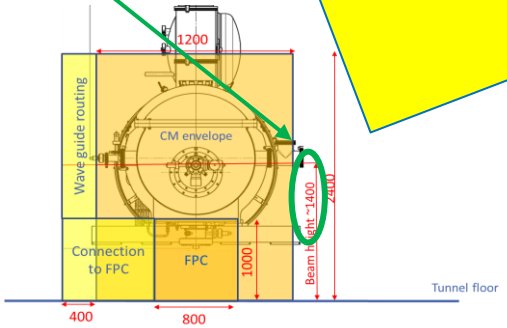
beam heights

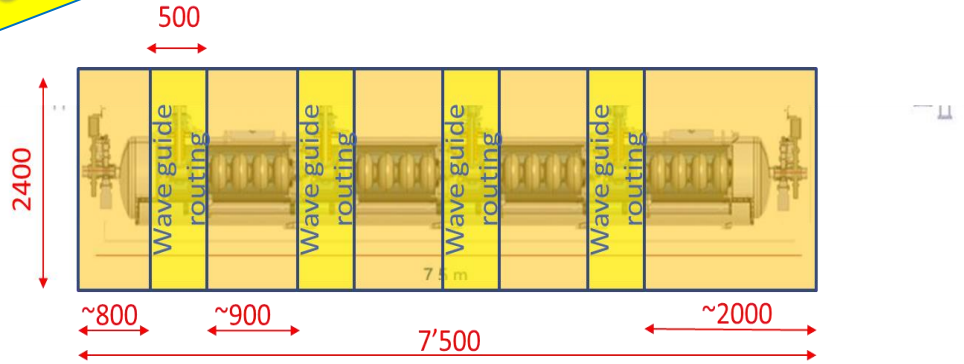



* Beam height could be ~1000mm, but increased to 1400 due to 80

Now replaced by Conceptual designs

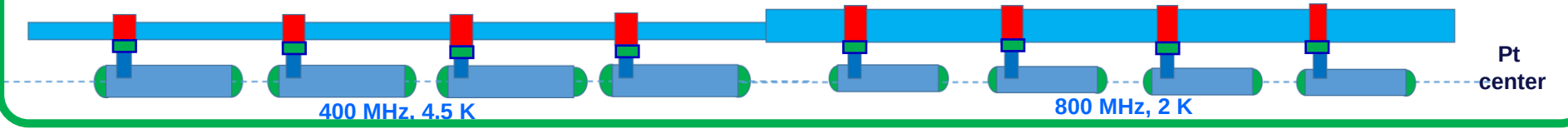
## ...dule (based on SPL, 704 MHz)



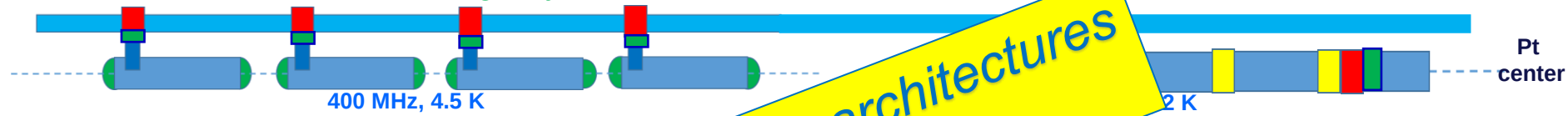



# Collider architecture options (top view, ½ LSS, quads not shown)

- **A1** (baseline): fully segmented with separate cryo line




- **AC2**: 800 MHz cont. with integr. cryo lines




- **AC3**: 400 MHz cont. vac. with cryo li… …g. cryo lines.


- **AC4**: 400 MHz a… …cont. with integrated cryo lines;


Alternative continuous architectures not covered in this talk

End Cap module | CM interconnection | Service Module | Vac.Barr. | Jumper

*(quads not shown)*

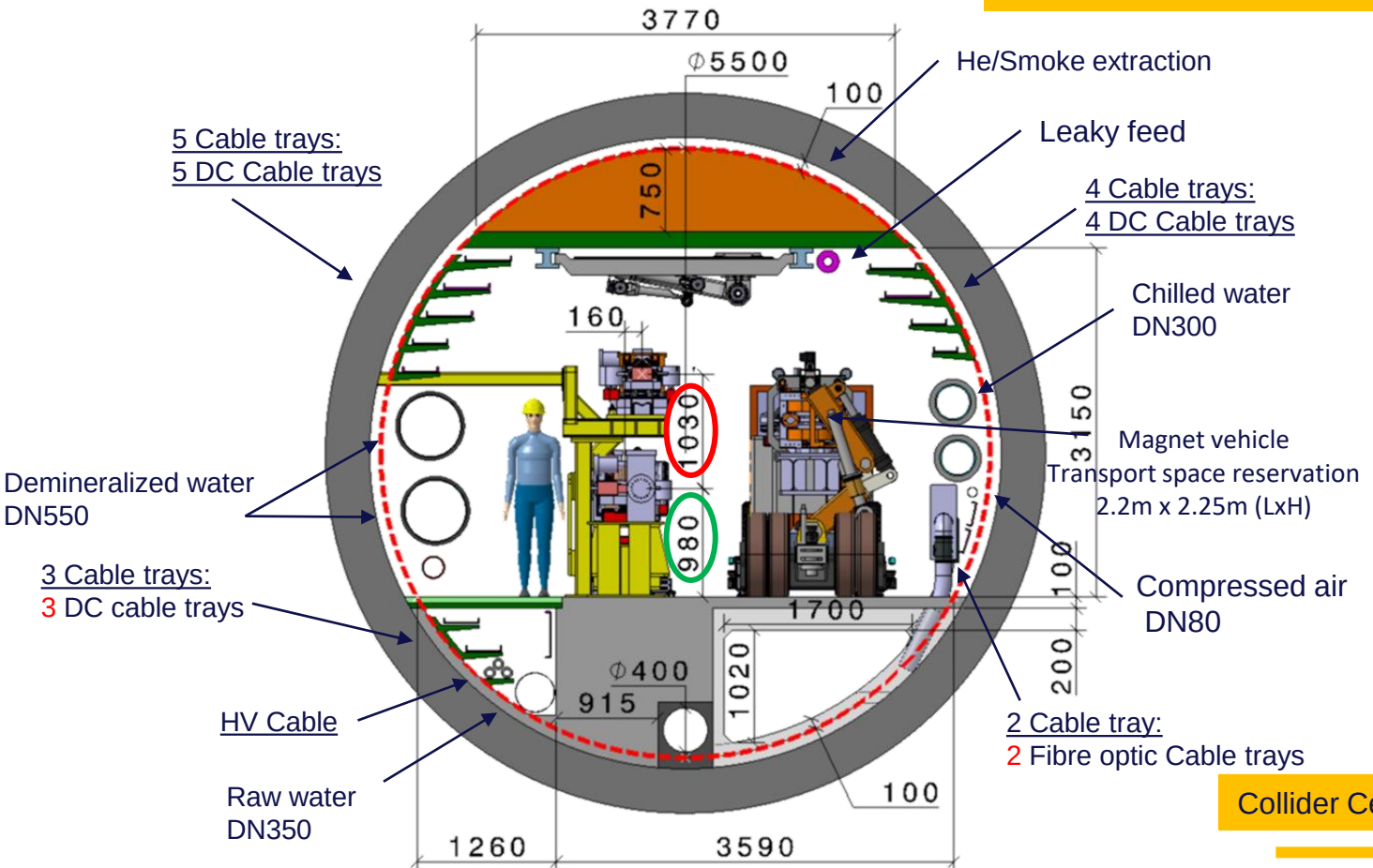
# New assumptions for integration study



- **X section integration in Pts H and L:**
  - New CM conceptual designs:
    - ✓ 400 MHz: modified design of LHC CM (see K.Canderan's talk)
    - ✓ 800 MHz: FNAL conceptual design based on PIP-II (see D. Passarelli's talk)
  - New cryo line/Service modules integration models:
    - ✓ Based on new cryo schemes (K.Canderan's talk) and based on LHC Crabs design
  - Find common X-section integration features with arcs:
    - ✓ New beam heights proposal
    - ✓ New beam spacings proposal
- **Longitudinal integration for Point H (Point L in progress):**
  - New CM/quads segmentation proposal with quad spacings in LSS
    - ✓ New interconnects space between CMs and with quads
  - New klystron/power bunkers spacing proposed in klystron gallery
  - New FPC/wave guide configurations (compatible with H to W…ttbar staging)

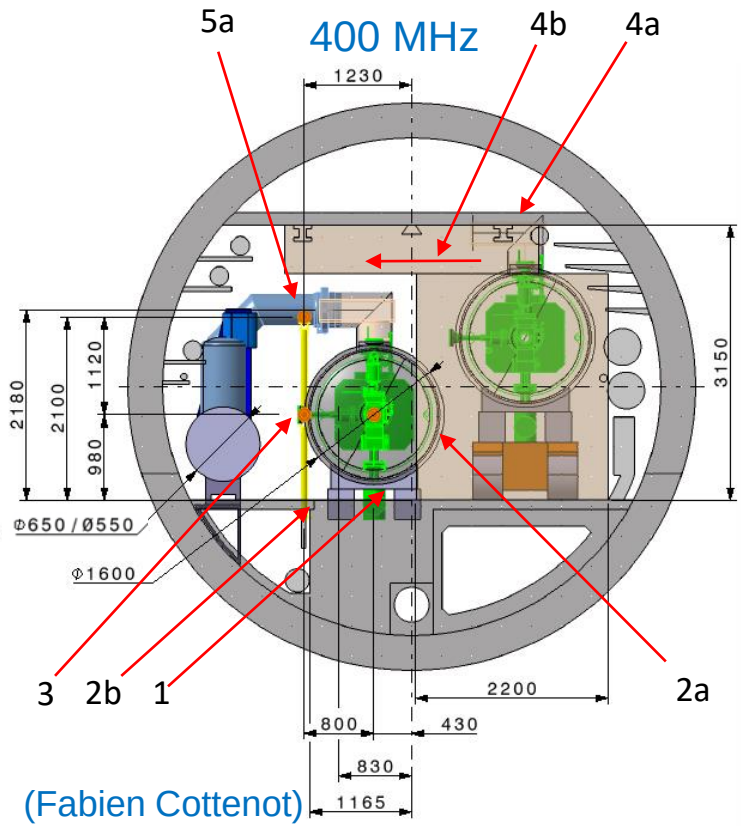
# Integration of FCC-ee machine elements (regular arc)

Machine tunnel 5.5m in diameter



# Point H _ 400 MHz

## Current Integration with new models




(Fabien Cottenot)

## Point H: Z, W

### Collider

Interferences:

1 : CM/floor
▶Height 980 to 1200

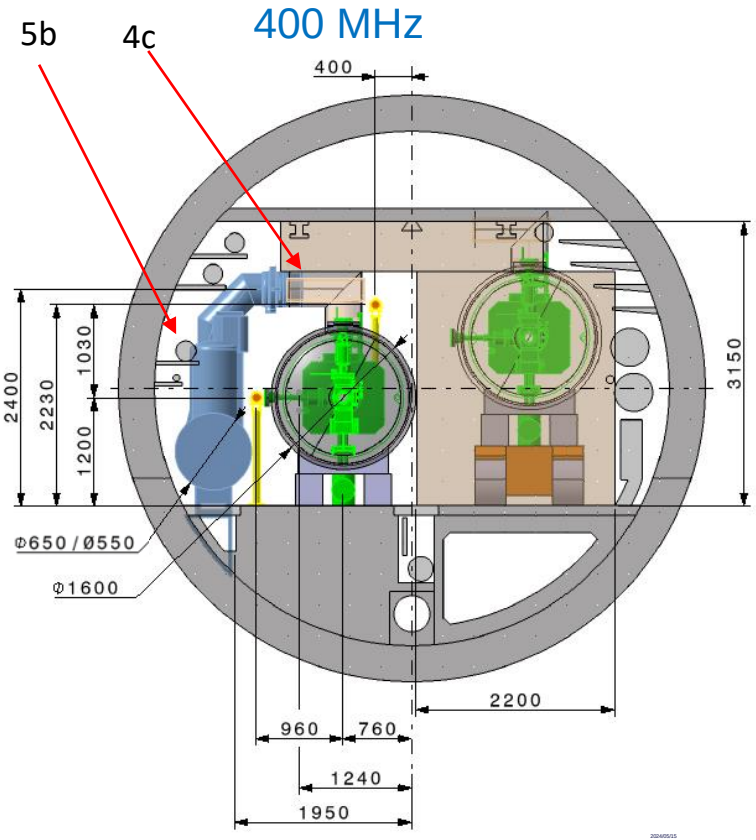
2a: CM/Transport zone
▶Distance beam2 : 430 to 760
2b: CM/floor support
▶Distance 1165 to 1950

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

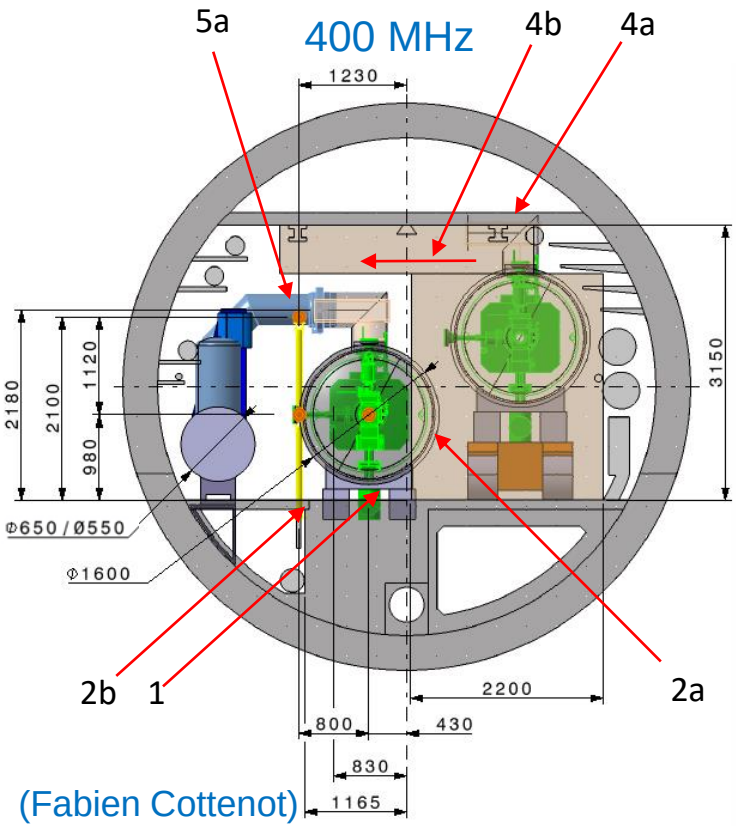
5a: Cryo line Jumper / Booster
▶Moved to the other side
5b: QRL Jumper / Service
▶To be studied

## Modification proposal



# Point H _ 400 MHz

## Current Integration with new models




(Fabien Cottenot)

## Point H: H, ttbar

### Collider

Interferences:

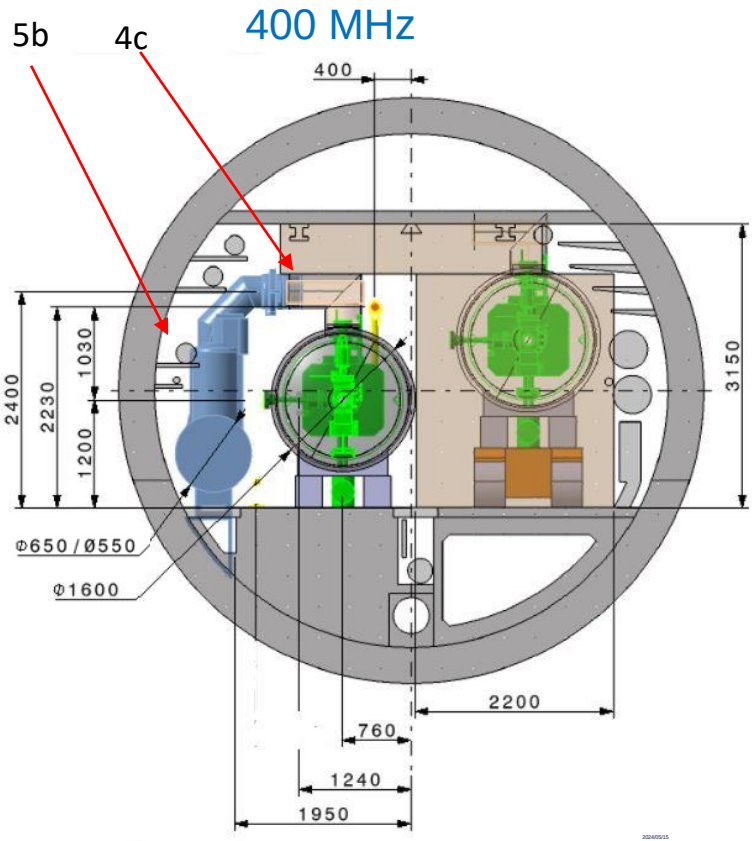
1 : CM/floor
▶ Height 980 to 1200

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

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

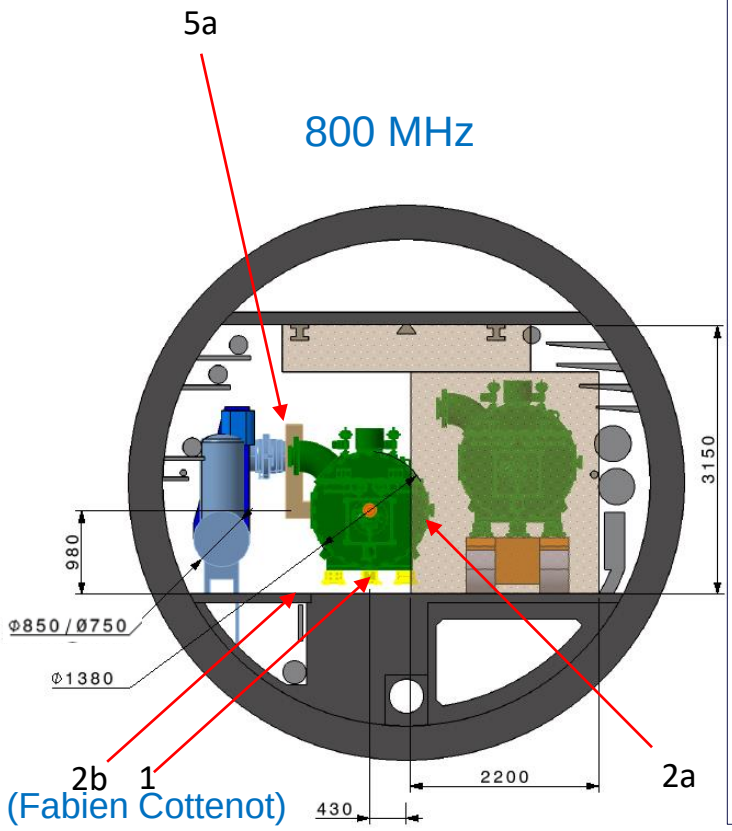


# Point H _ 800 MHz

## Point H: ttbar

Collider

### Current Integration with new models




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

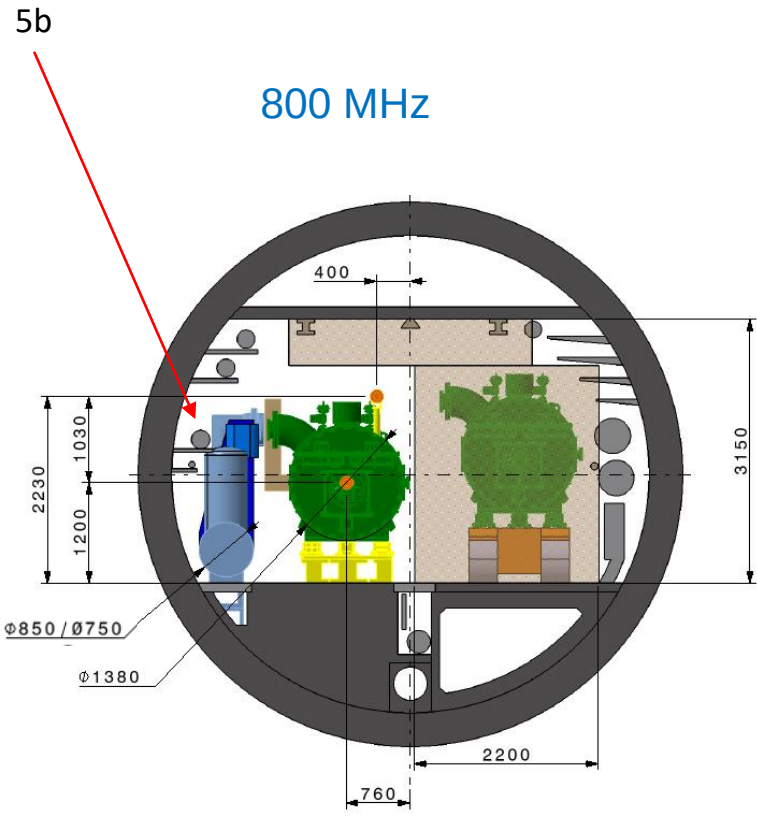
5a: QRL Jumper / Booster

▶ Moved to the other side

5b: QRL Jumper / Service

▶ To be studied

### Modification proposal



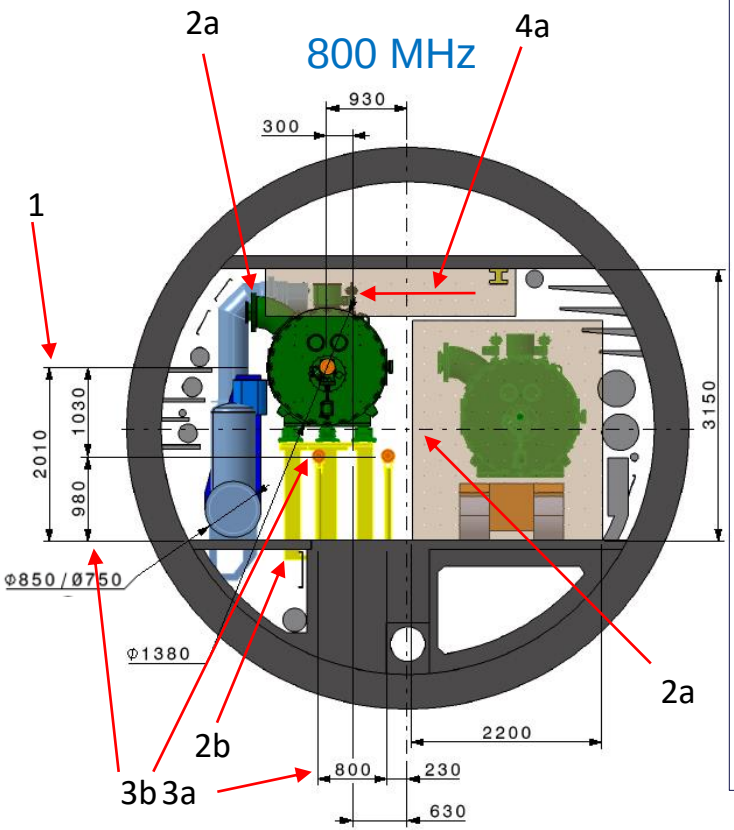

(Fabien Cottenot)

# Point L _ 800 MHz

## Point L: Z to ttbar

Booster

### Current Integration with new models




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

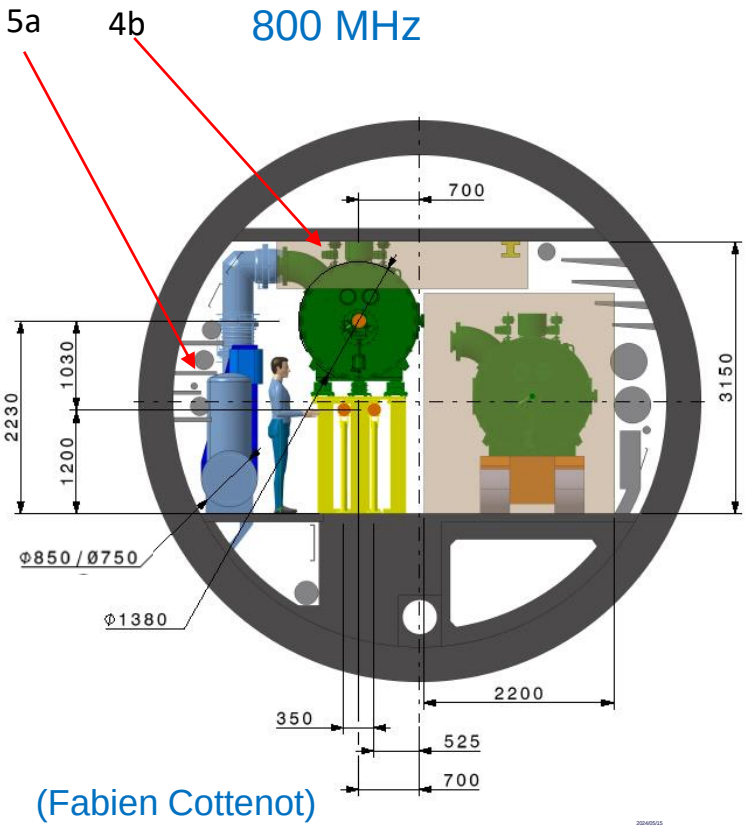
4b : CM in position / Robot

►To be studied

5a: QRL Jumper / Service

►To be studied

### Modification proposal

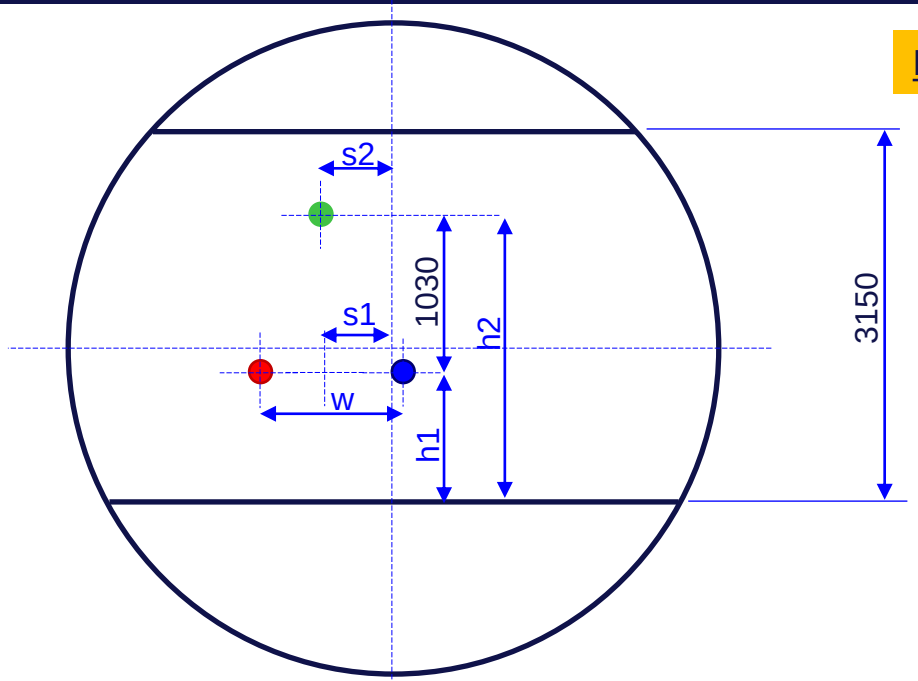



(Fabien Cottenot)

# Arcs, Points H and L: new proposed beam positions in tunnel



Machine tunnel 5.5m in diameter

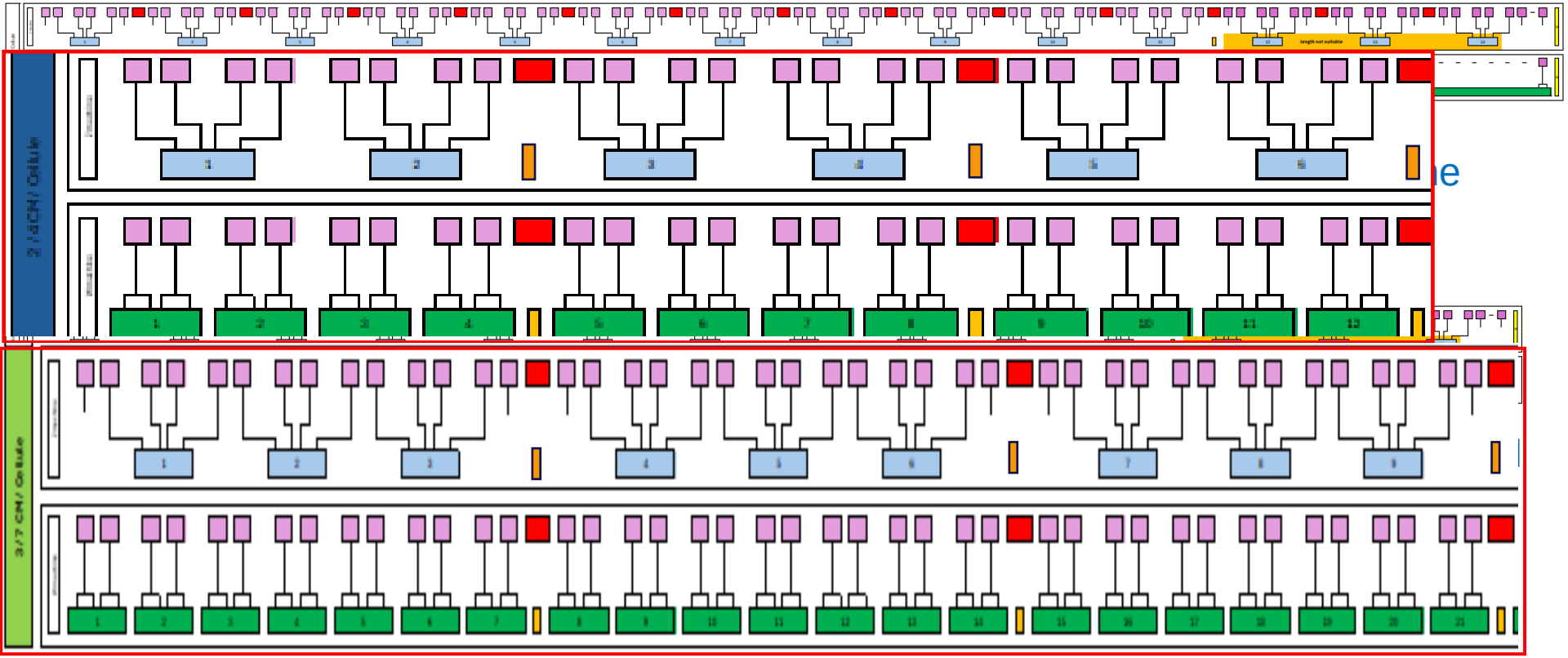



Collider Center

| | Arcs | | Point H (Collider) | | Point L (Booster) | |
|---|---|---|---|---|---|---|
| | Present value | New proposed | Present value | New proposed | Present value | New proposed |
| w | 350 | 350 | 800 | 960 | 350 | 350 |
| h1 | 980 | 1200 | 980 | 1200 | 980 | 1200 |
| h2 | 1030 | 2230 | 1030 | 2230 | 1030 | 2230 |
| s1 | 551 | 551 | NA | 1240 | NA | 700 |
| s2 | 391 | 391 | NA | 400 | NA | 700 |

# Longitudinal spacing: klystrons/bunkers and quads

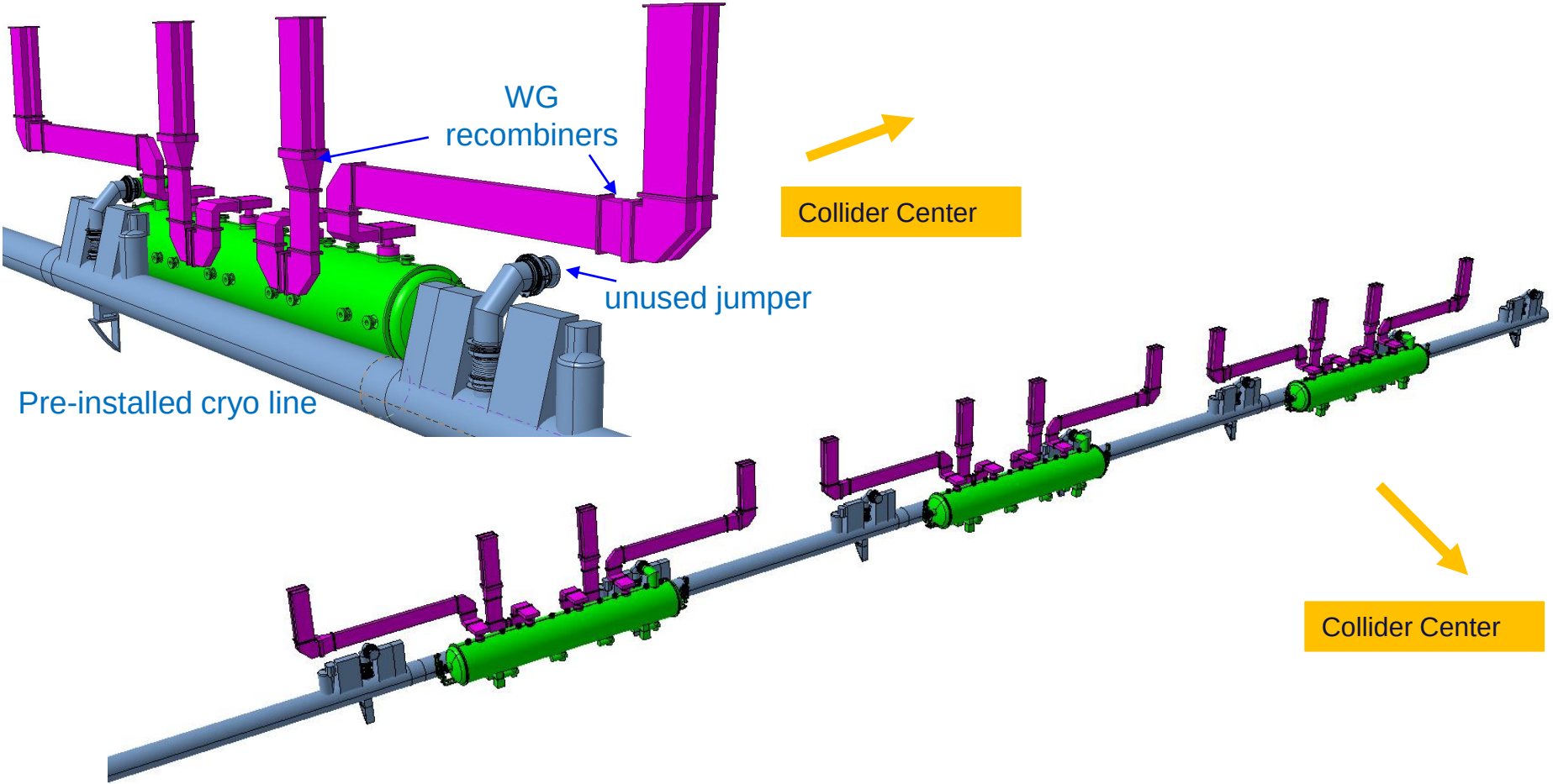





(Fabien Cottenot)

# Z machine, 400 MHz

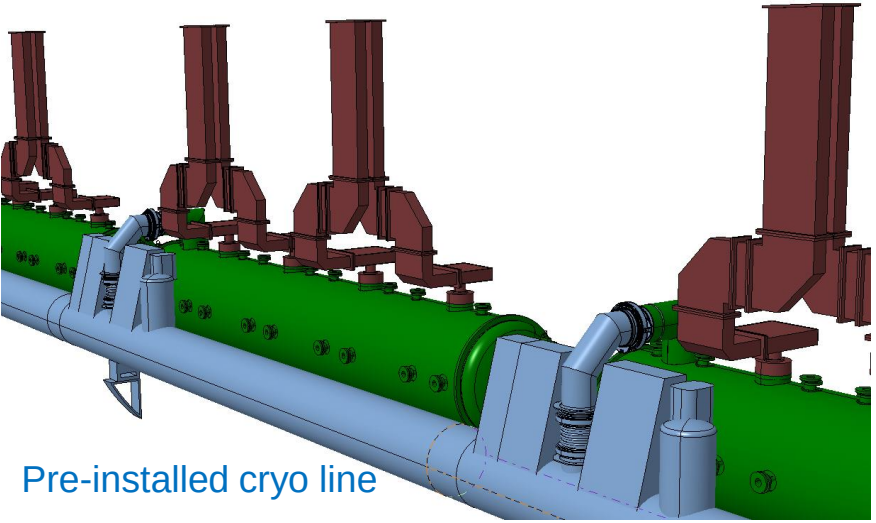





(Fabien Cottenot)

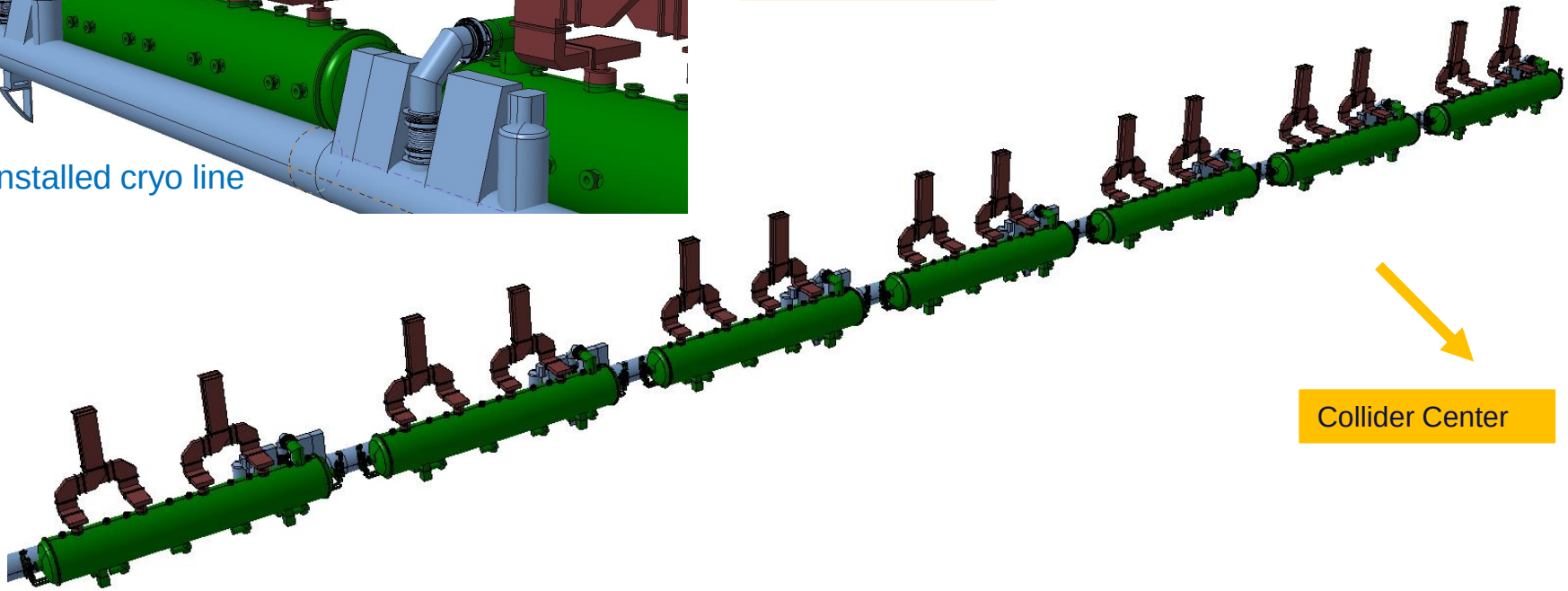
# W machine, 400 MHz





Pre-installed cryo line

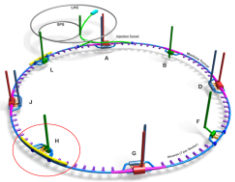
Collider Center



Collider Center

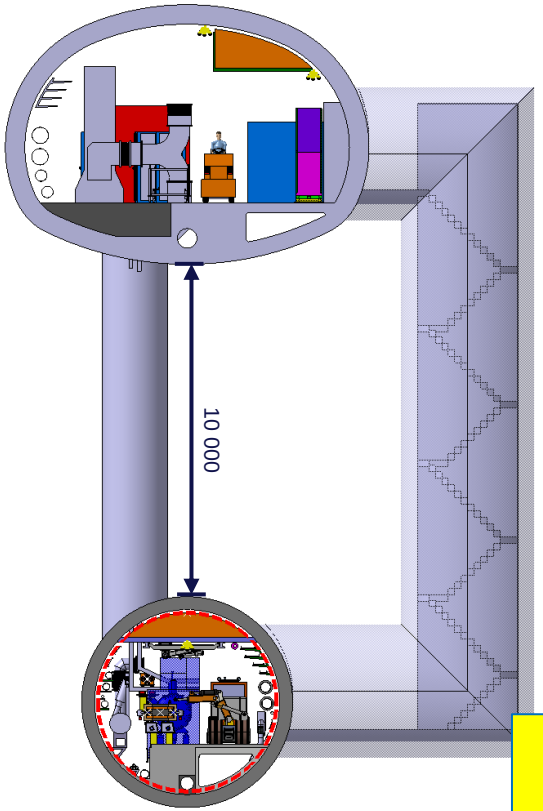
(Fabien Cottenot)

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



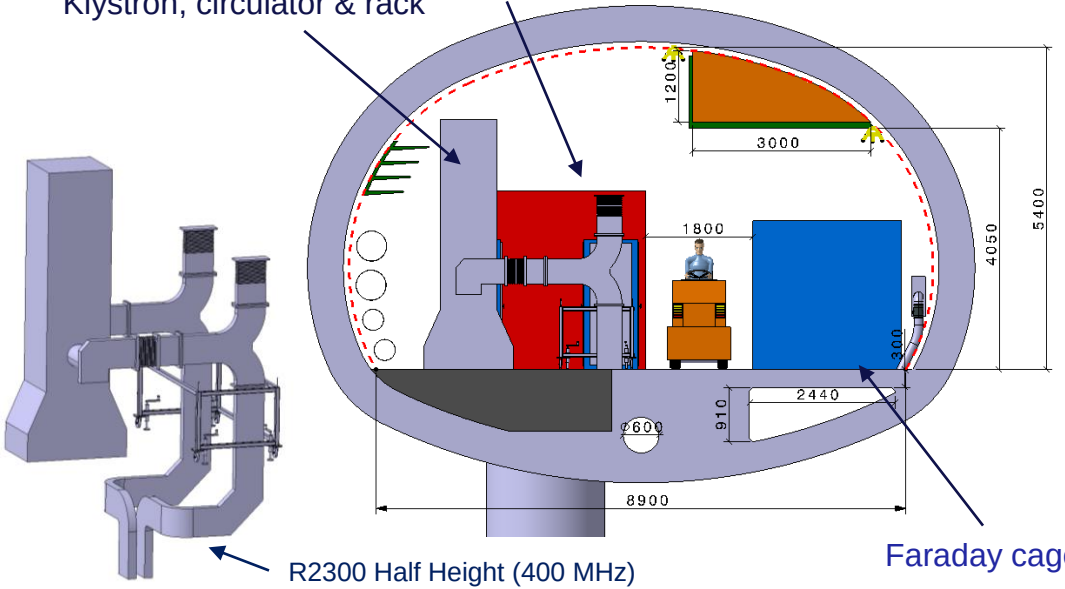
1 MW 400 MHz klystrons can be used for:

- Z: re-combine 2 WG to 1 cavity
- W and ZH: power 2 cavities




HV Bunker

Klystron, circulator & rack




R2300 Half Height (400 MHz)

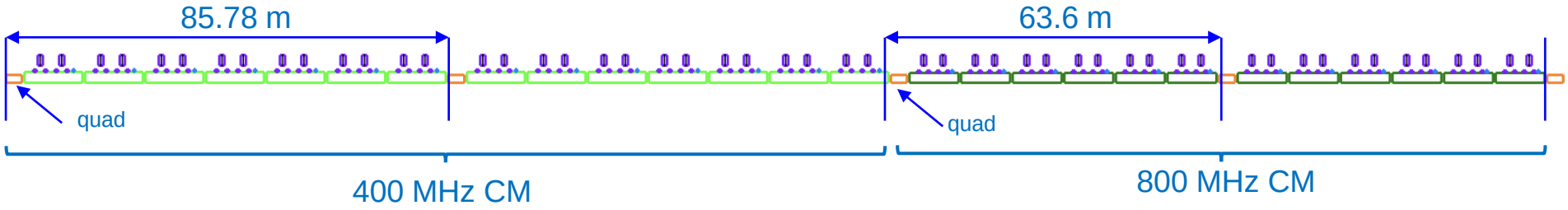
Faraday cage

*Klystron Gallery integration to be reviewed for larger HV bunkers*

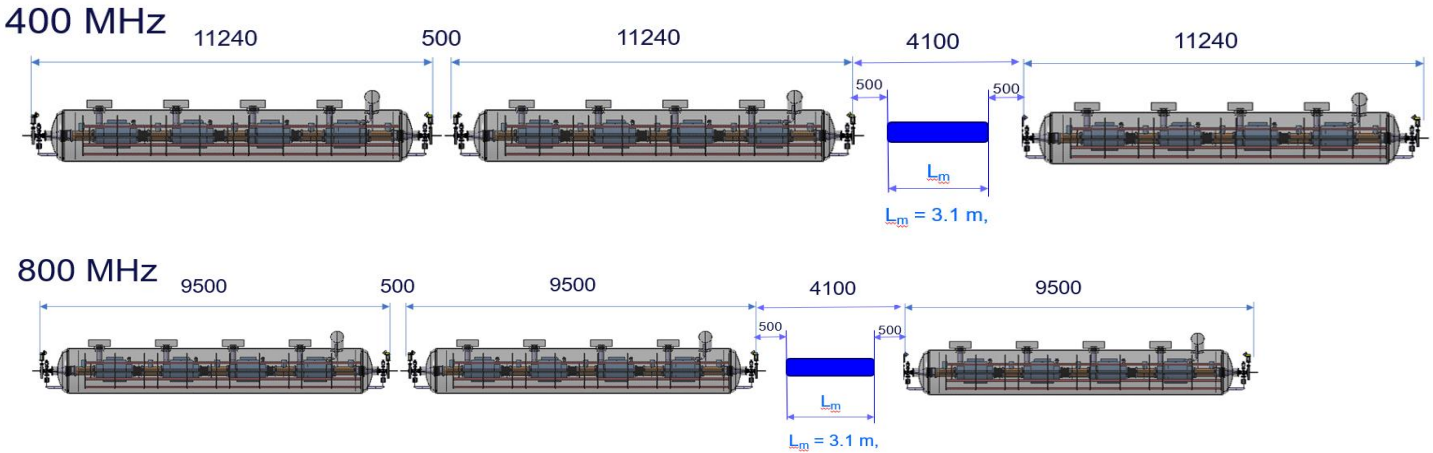
Collider Center

# CM/quads segmentation proposal (Collider)






- Quads spacing increased from 52m to 85.78m (400MHz) and 63.6m (800 MHz)
- Interconnects between CMs and to quads (CM and quads lenghts not final). No BLA included.
  - Next optics simulations and quads strengths by Katsunobu O. and Jeremie B.



# Summary



- SRF system architecture with segmented CMs and cryoline consolidated (continuous remains alternative, needing further work)

- Integration study in good progress (started in April ‘24, delivery by end ‘24)

- New CM conceptual designs now, building blocks for integration study

- Collider and Booster: 5.5 m tunnel cross-section integration tight but feasible but with some changes to resolve interferences:
  - ✓ Proposing new beam position heights and spacings (see table)
  - ✓ Remaining issues can be easily tackled

- Collider: new longitudinal integration scheme for CMs, quads, WG routing, klystrons:
  - ✓ Now compatible with Z to W transition (CMs remain in place)
  - ✓ RF bunkers: powering from 8 to 14 klystrons, size to be increased
  - ✓ New optics to validate scheme and define quad specs

# Next steps



- ✓ Complete cross-section integration (including installation handling, maintenance accessibility)
- ✓ Continue Collider longitudinal integration
- ✓ Start Booster longitudinal integration
- ✓ Start klystron gallery integration study

# Thank you for your attention !