Fitting RF/Waveguides Into 6D Channels

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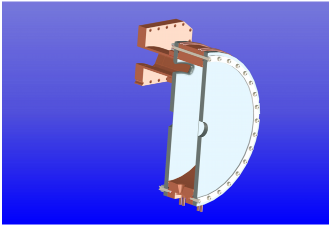
1. Introduction

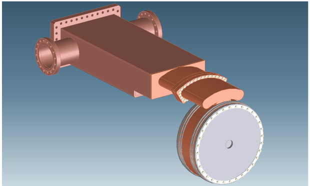
MuCool has experience squeezing RF hardware into small magnet bores.

HPRF cavity in Lab G solenoid. Coaxial input coupler and vacuum lines are also shown.

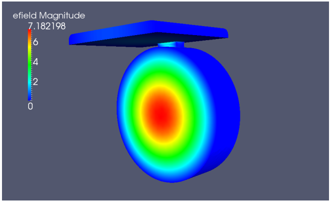
The modular cavity is the most recent example of this.



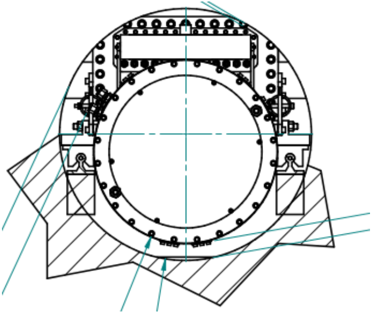
(1) Insufficiently modular.



(2) Too complicated.

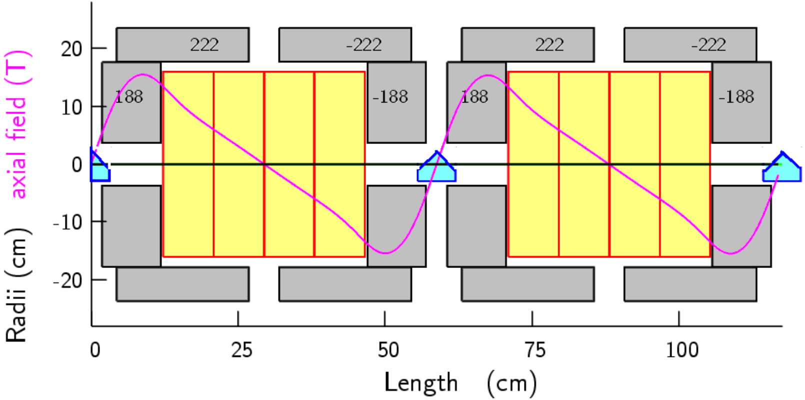


(3) Getting warmer.



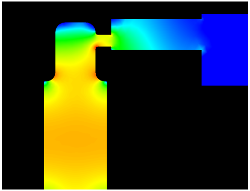
(4) ∼1 year to final design!

How can this experience inform the 6D design effort?

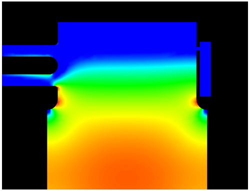


2. Design Considerations for the Modular Cavity

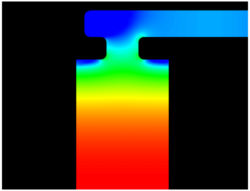
Longitudinal vs. radial coupling



805 MHz pillbox



All Seasons

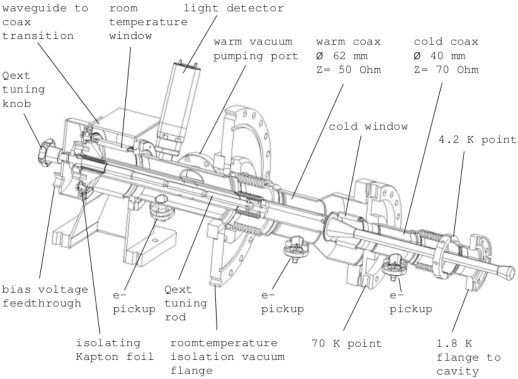


Modular

- Longitudinal coupling (as in pillbox, ASC cavities) leads to off-axis field enhancement. Multipacting, dark current issues!
- Muons, Inc. designs notwithstanding, longitudinal coupling is difficult to implement in a "real" multi-cell cooling channel.

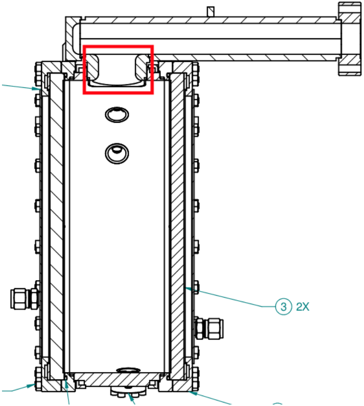
Coaxial vs. waveguide power couplers

- 201 MHz cavities use coaxial power couplers. 201 MHz waveguides are huge!
- Waveguide couplers are much easier to design & build for 650 MHz cavities.



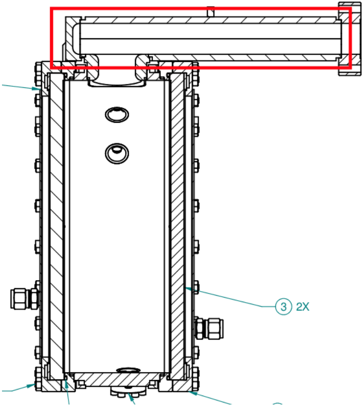
TTF-3 FPC design: nontrivial!

Design drivers: “neck” height



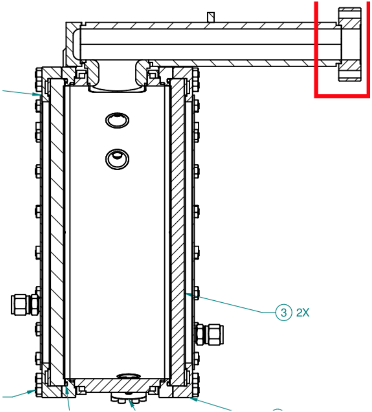
Coupling iris must be long enough to allow coolant line clearance.

Design drivers: coupling waveguide height



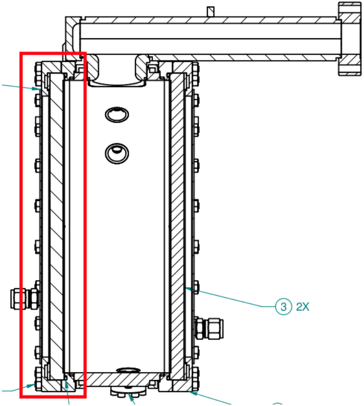
Coupling waveguide is as tall as possible to minimize MP.

Design drivers: coupling waveguide height



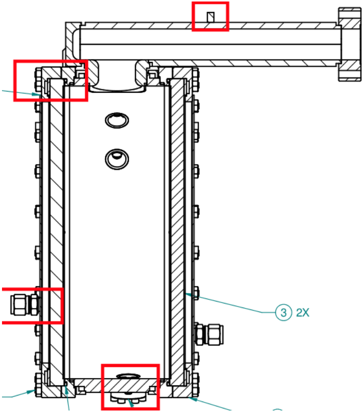
Flange design was nontrivial. Having a flange close to the cavity body makes fabrication much easier.

Design drivers: Beryllium wall thickness



Be walls are 8 mm thick to support cavity vacuum. This is about as thin as you'd want to go for *exterior* Be walls. More on this later.

Design drivers: Allowance for peripheral hardware



Don't forget hardware for RF pickups; coolant fluid; mechanical support; vacuum integrity.

3. 650 MHz Cavity “Sketch”

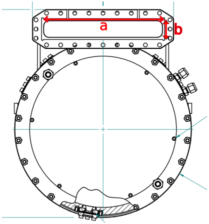
Some constants & cavity parameters

- $f = 650$ MHz
- 30 MV/m
- $R = \frac{2.405c}{2\pi f} = 0.1765$ m
- $\beta = 0.85$ **(Is this correct for end-stage cooling?)**
- $R_s(\mathrm{Cu}) = 6.3\ \mathrm{m}\Omega$
- $R_s(\mathrm{Be}) = 9.8\ \mathrm{m}\Omega$
- All calculations are for TM_{01} mode only.
- **Assume $T = 77$ K (i.e. liquid nitrogen temperature).**
- Calculations are for an ideal Cu pillbox with flat Be walls.

Figures of merit, etc. at 30 MV/m

- Given $\beta = 0.85$, the transit time factor is 0.787. Then the phase advance per cavity is $\mathbf{114}^\circ$. This is not something simple like $\pi/2$, so *each cell must be driven independently.*
- Stored energy $U \approx 15$ J.
- Peak power $P \approx 2.5$ MW. (This is another argument against a coaxial coupler.)
- $Q_0 \approx 25000$
- $R/Q \approx 190\ \Omega$
- Cavity voltage $V_c = dE_0 T \approx 3.4$ MV

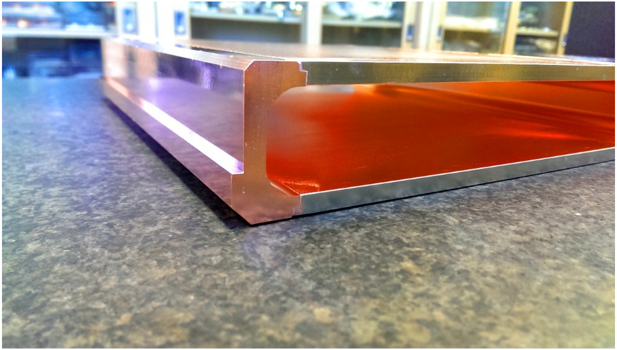
What about waveguides?



- For $f = 650$ MHz, $a \approx 270$ mm.
- Recall that RF peak power $P \approx 2.5$ MW.
- The cross-sectional area A of the waveguide is set by power requirements. Specifically, the breakdown E-field in an air-filled WG $E_{\mathrm{wg}} \approx 3$ MV/m. Then

$$A = \frac{4P\eta_0}{\sqrt{1 - (\omega_c/\omega)^2} E_{\mathrm{wg}}^2} \approx 4 \mathrm{~cm}^2 \longrightarrow b \geq 1.5 \mathrm{~mm}$$

Actual, physical waveguide dimensions

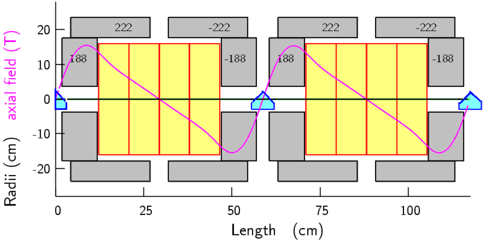


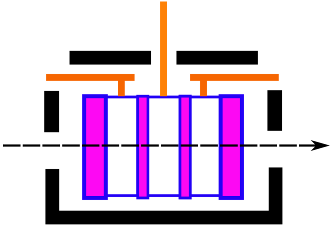
Narrow waveguide for the modular cavity.

- $a \approx 270$ mm and $b \approx 1.5$ mm.
- WG walls are 6.35 mm (1/4") thick for modular cavity.
- Realistic width ≈ 290 mm.
- Realistic height ≈ 15 mm.
- These numbers may change as we study multipacting.

Actual, physical cavity dimensions

- *Outer* Be plates must be 8 mm thick to resist vacuum pressure. (Unless the cavity & magnet share vacuum?) Plates between cells may be thinner.
- Using the modular cavity as a template, the outer radius of one 650 MHz cell is ≈ 200 mm. (The Cu ring is ∼ 15 mm thick.)
- From Bob's sketch, a cell looks 35 cm long. This is probably too short even for 3 cavities. A 3-cell cavity is ∼ 450 mm long.





Caveat lector and conclusions

We have some rough dimensions for the 650 MHz cavity. These dimensions have some tenuous connection to reality. They are almost sure to change depending on (a) RF optimization; (b) multipacting and field emission analysis; (c) design changes; (d) what we learn when trying to actually build one of these mega-magnets.

Furthermore, you now have some rough dimensions and scaling laws to play with. It should be easy (though perhaps not lightning-quick) to generate iterations of this design based on new cooling and magnet ideas.

Alternative frequencies, β's

For further calculations with different values, we can easily perform more calculations. This could be done over email exchanges or via a technical note.

β	0.6	0.85	1.0
L (m)	0.103	0.146	0.171

650 MHz cell, $R = 0.177$ m

β	0.6	0.85	1.0
L (m)	0.083	0.118	0.138

805 MHz cell, $R = 0.143$ m