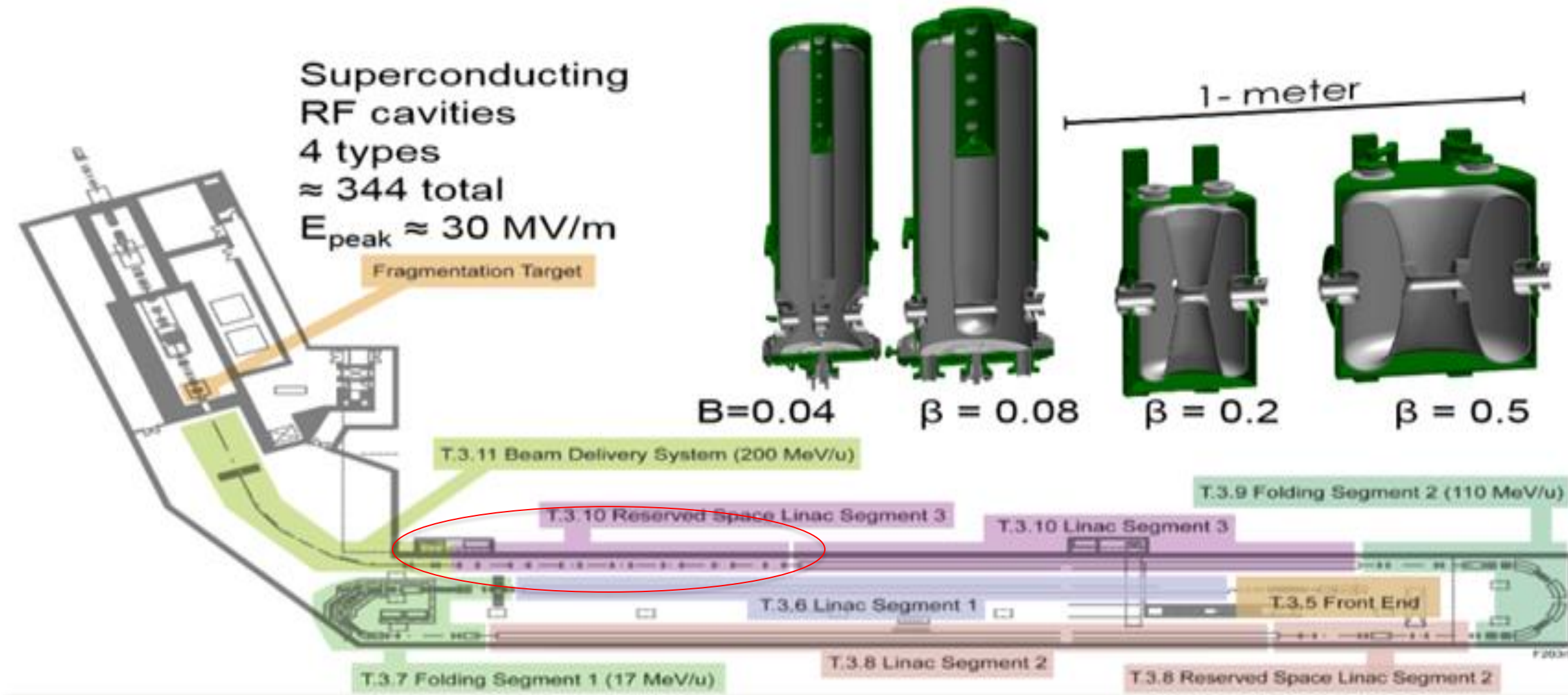


Optimizing Cavity Choice for FRIB Energy Upgrade Plan

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Motivation

FRIB has an energy upgrade plan up to ≥ 400 MeV/u for uranium and already prepared a vacant space of approximately 74 meters in the design stage and cryogenic capacity that accommodates for the energy upgrade plan. This upgrade requires an optimized linac design and challenging technology improvement.

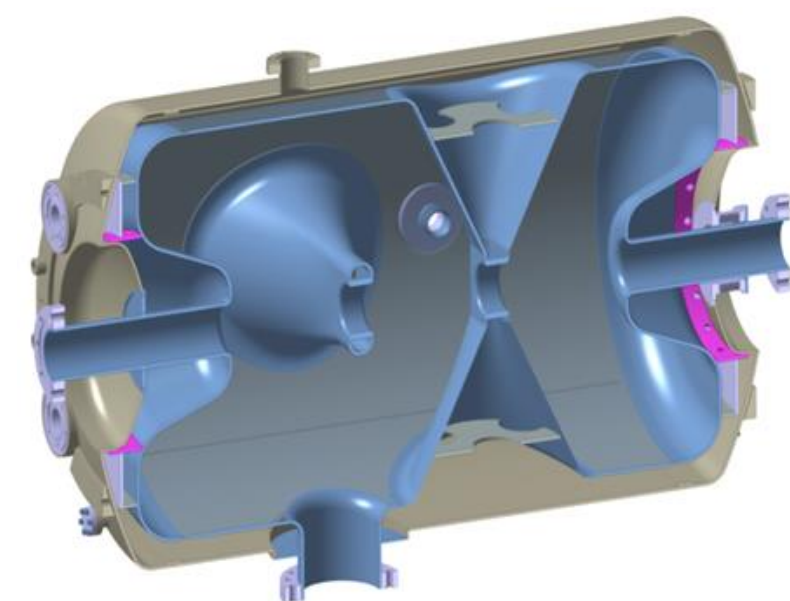


Possible cavity classes for FRIB energy upgrade

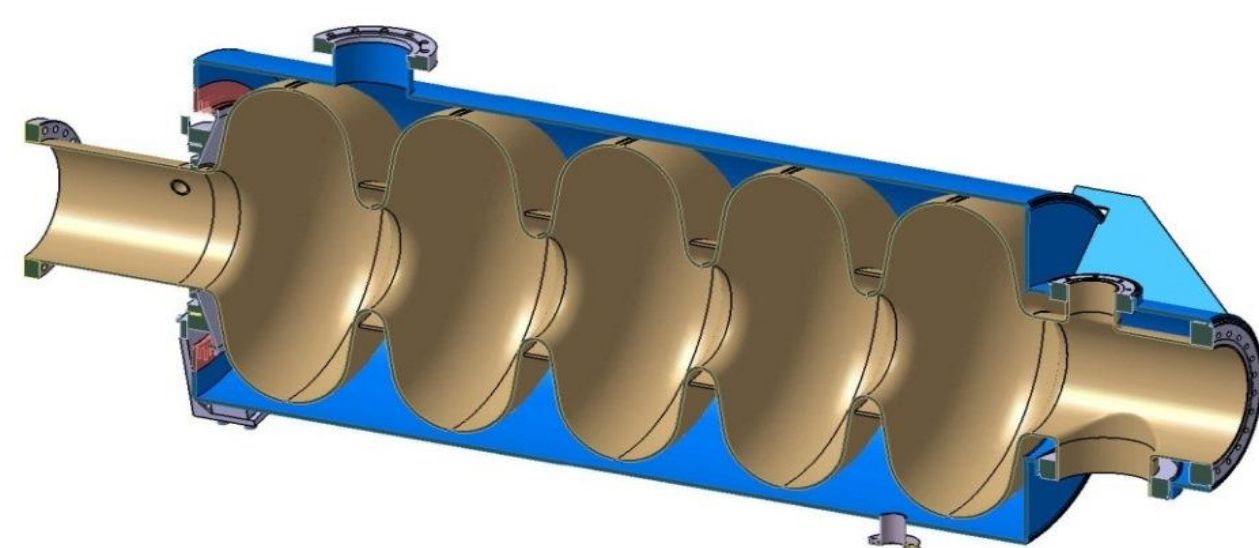
- FRIB beta = 0.53 Half Wave Resonator (HWR)
No R&D is needed in this case. FRIB already uses the 0.53 HWR. Eight 0.53 HWR cryomodules will be utilized for the upgrade.



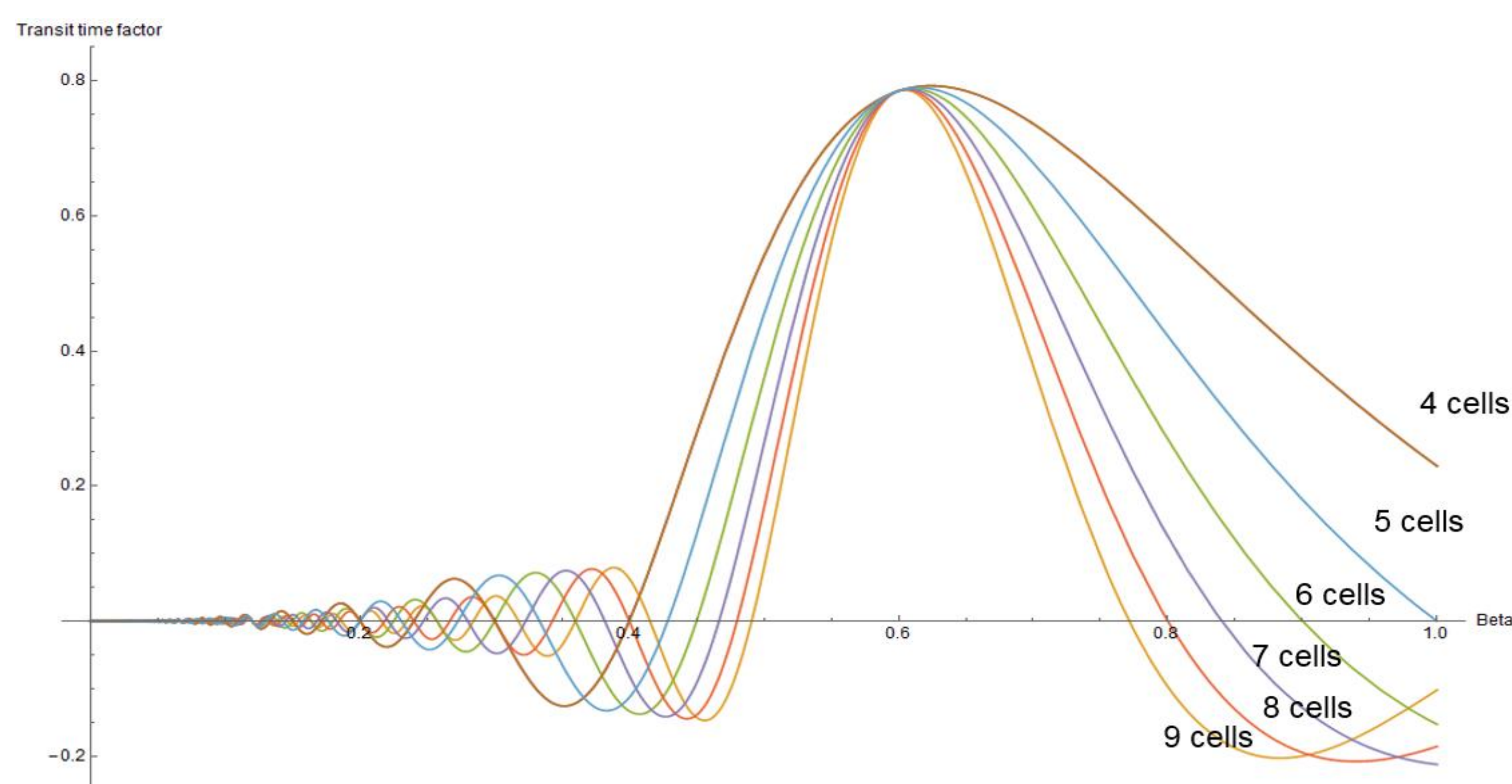
- Spoke cavity
Due to the complexity of spoke cavity shape, it is not considered as a potential cavity choice for FRIB energy upgrade.



- Elliptical cavity
Elliptical cavity is a potential choice for FRIB energy upgrade plan. It has many benefits that will be presented in this poster.



The dependence of transit time factor on number of cavity cells



From the figure above in a multi-species linac such as FRIB less number of cells increase velocity acceptance.

Choice of operating frequency

Possible frequency choices are multiple of the base frequency which is 80.5 MHz.

- Higher operating frequency is advantageous due to:
 - Surface resistance is proportional to f^2 , i.e. R_{BCS} can be minimized via doping technology which reduces cavity cryogenics heat load significantly.
 - Cavity surface area is proportional to $1/f^2$, i.e. the higher frequency the smaller cavity becomes. That reduces cavity cryogenic heat load, reduces cryogenic components size in the cryomodule and reduces cost.
 - Higher frequency minimizes the reduction in cavity performance due to small surface defects at the optimized temperature.

Acceptance for potential operating frequencies is calculated

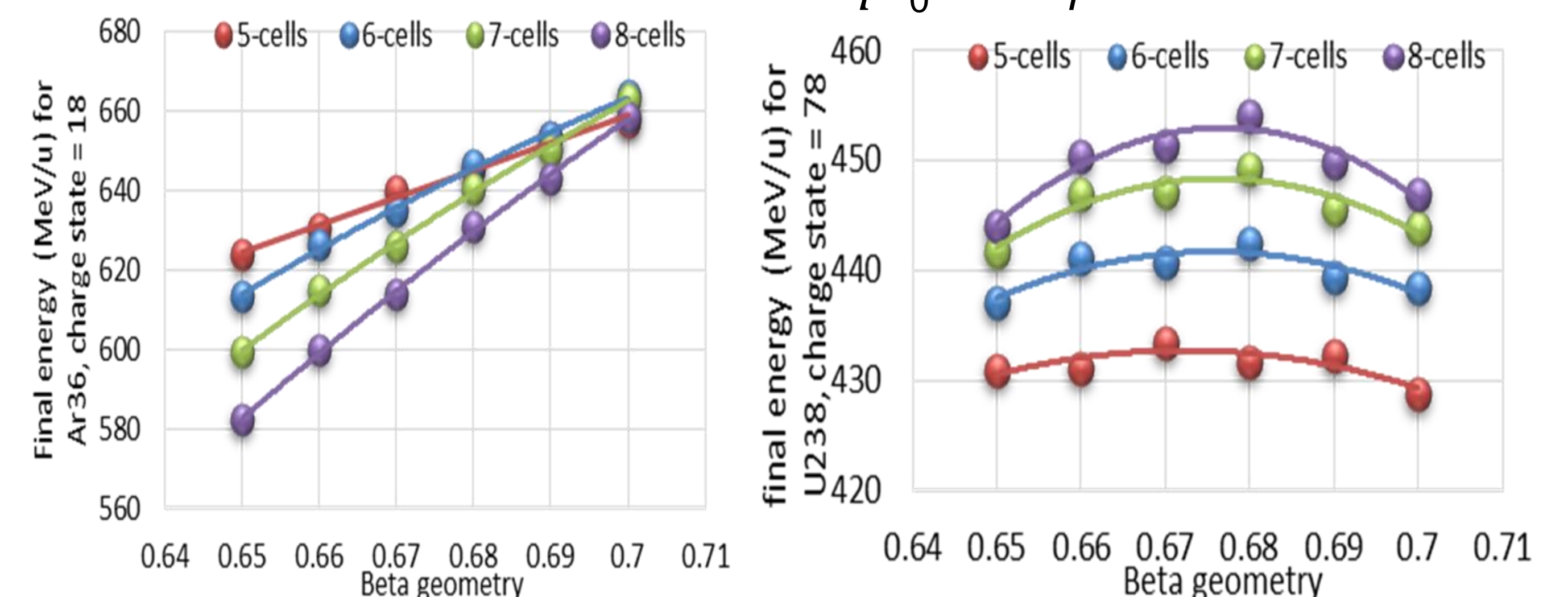
Cavity type	f	N	V_c	w_{max}	$\Delta\Phi$	Initial
	MHz	gaps	MV	MeV	ns	$\pi \cdot \Delta\Phi \cdot w_{max}$
HWR	322	2	4.93	25.45	0.22	5.65
Elliptical	644	8	21.51	28.80	0.11	3.20
Elliptical	805	8	17.73	23.39	0.088	2.06
Elliptical	966	8	15.21	19.77	0.073	1.45
Elliptical	1288	8	11.73	15.04	0.06	0.83
Elliptical	1288	11	16.13	13.91	0.06	0.77

- Analytically acceptance for all candidate frequencies is sufficient so far, For FRIB baseline, the longitudinal acceptance at the segment 2 is about 0.140π -ns-MeV/u and the beam emittance with errors including 99.99% of 1.6 million tracked particles of multi-charge-state Uranium is about 0.08π -ns-MeV/u.

Choice of beta geometry (beta optimum)

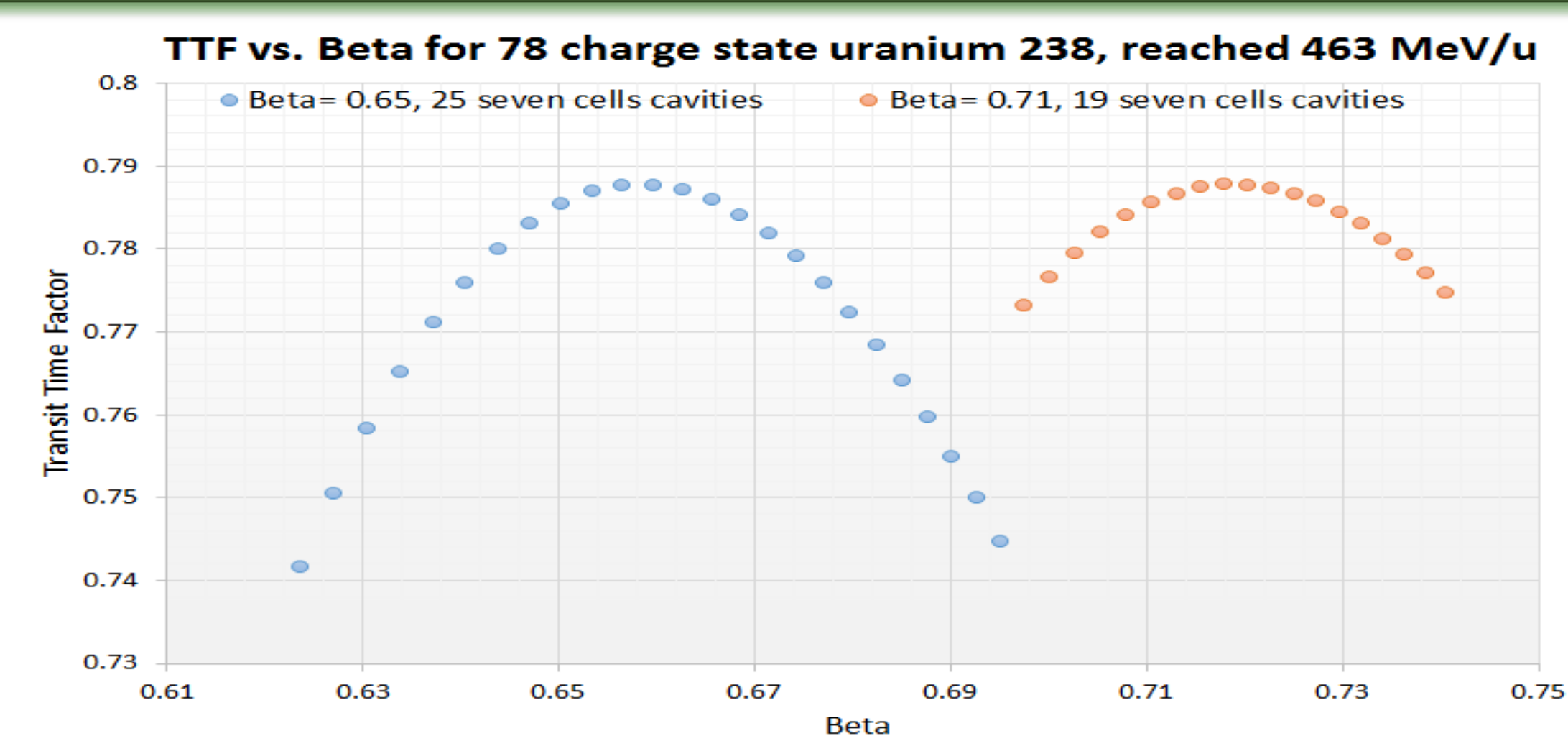
- Light ion case such as Argon 36 with $q=18$, we obtain ΔE = Final energy at β_g 0.70 - Final energy at β_g 0.68 = 658 – 631 MeV/u = 27 MeV/u see figure on the left.
- Heavy ion case such as Uranium 238 with $q=78$, we obtain ΔE = Final energy at β_g 0.68 - Final energy at β_g 0.70 = 454 – 447 MeV/u = 7 MeV/u see figure on the right.

$$\Delta w = qE_0 l T \cos \varphi$$



Conclusion: Beta geometry = 0.70 is a good choice for both light and heavy ions.

Combination of betas option



The optimized beta geometries configuration is $\beta_g = 0.65$ and $\beta_g = 0.71$ for 644 MHz. In this configuration we obtain the final energy of a 463 MeV/u for ^{238}U , $q = 78$. Whereas, for utilizing one beta geometry = 0.68 at 644 MHz the final energy is a 455 MeV/u for ^{238}U , $q = 78$. We can conclude that since the difference in final energies between linac with one beta scheme is not significant compared with two betas scheme. Moreover, two betas linac require more work than one beta linac. Therefore, one beta geometry linac is given the preference.

Cryomodule layout options

Due to the limitation in FRIB tunnel entrance which limits the cryomodule length so that it doesn't exceed the hatch length, which is 6.7 meters.

Conclusion

It can be concluded that beta geometry = 0.70 is a good choice for both light and heavy ions. From final energy point of view, operating frequency = 644 MHz provides maximum energy for both heavy and light ions. However, the final energy difference between 644 MHz and 1288 MHz is not significant. Moreover, operating with higher frequencies is advantageous. It reduces material use, improves Q_0 , reduces cryomodule components size, and reduces cavity heat load. To determine whether or not the acceptance is sufficient beam dynamics simulations are required.