SNS Progress Review

DTL and CCL RF Structures

James H. Billen

September 11, 2000

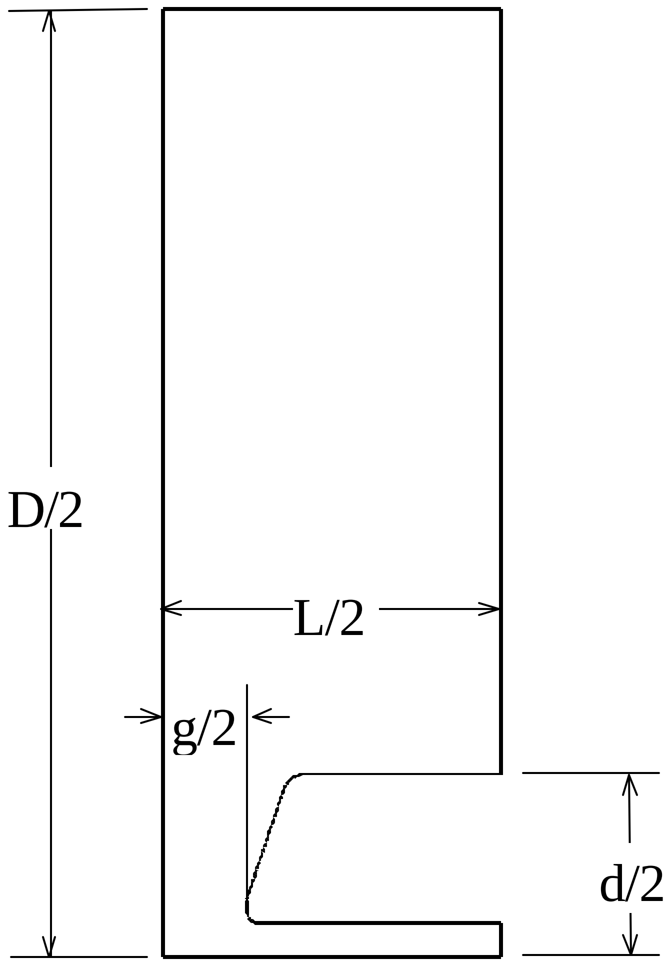
Outline

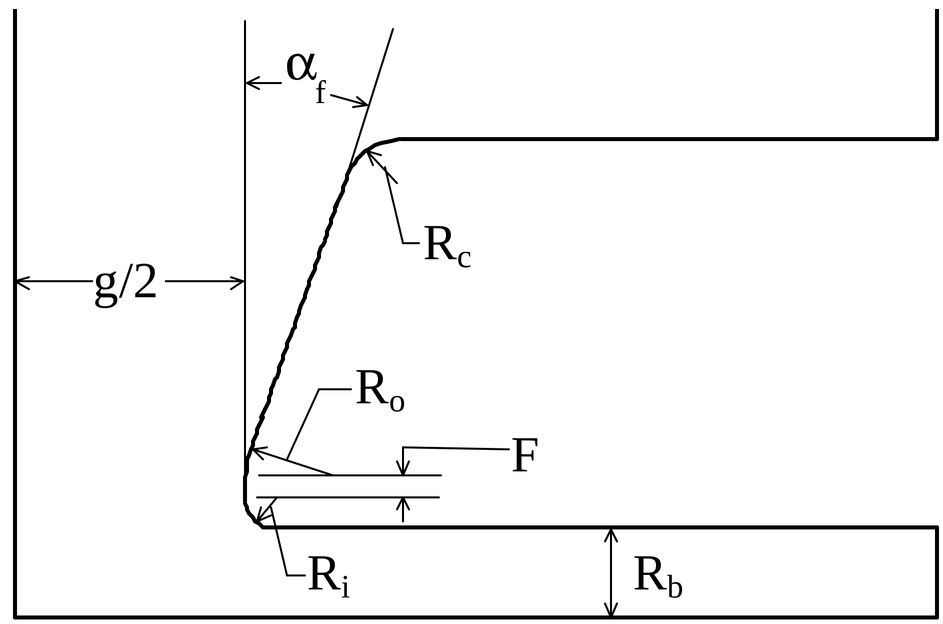
- DTL
  - Review of the design
  - Cell design procedure for the drift-tube linac
  - Frequency budget and tank radius adjustment
  - Low-power aluminum model status
- CCL
  - Review of the design
  - Cell design procedure for the drift-tube linac
  - Tuning plan
  - Low-power aluminum model status

Drift-Tube Linac (DTL) Properties

- Energy range: 2.5 MeV (β = 0.073) to 86.8 MeV (β = 0.403).
- Six tanks, each using one 402.5-MHz, 2.5-MW klystron.
- Spacing of 1 $\beta\lambda$ between tanks.
- Total Length is 36.5 m (tank 1 is 4.1 m, others are 6.1 to 6.4 m).
- Peak surface electric field is limited to 25.3 MV/m (1.3 Kilpatrick).
- Nominal accelerating field E_0 = 3.6 MV/m. (Ramped field in tanks 1, 3, and 6; peak E_0 = 3.77 MV/m at the end of tank 6.)
- Bore radius R_b = 1.25 cm.
- Average shunt impedance ZT^2 = 40 MΩ/m for all expected losses.
- FFODDO lattice (every third drift tube does not contain a quadrupole, can be used for diagnostics and steering).
- Post-coupler stabilized (places limits on drift-tube-to-wall spacing).

Geometric Parameters in a DTL Cell



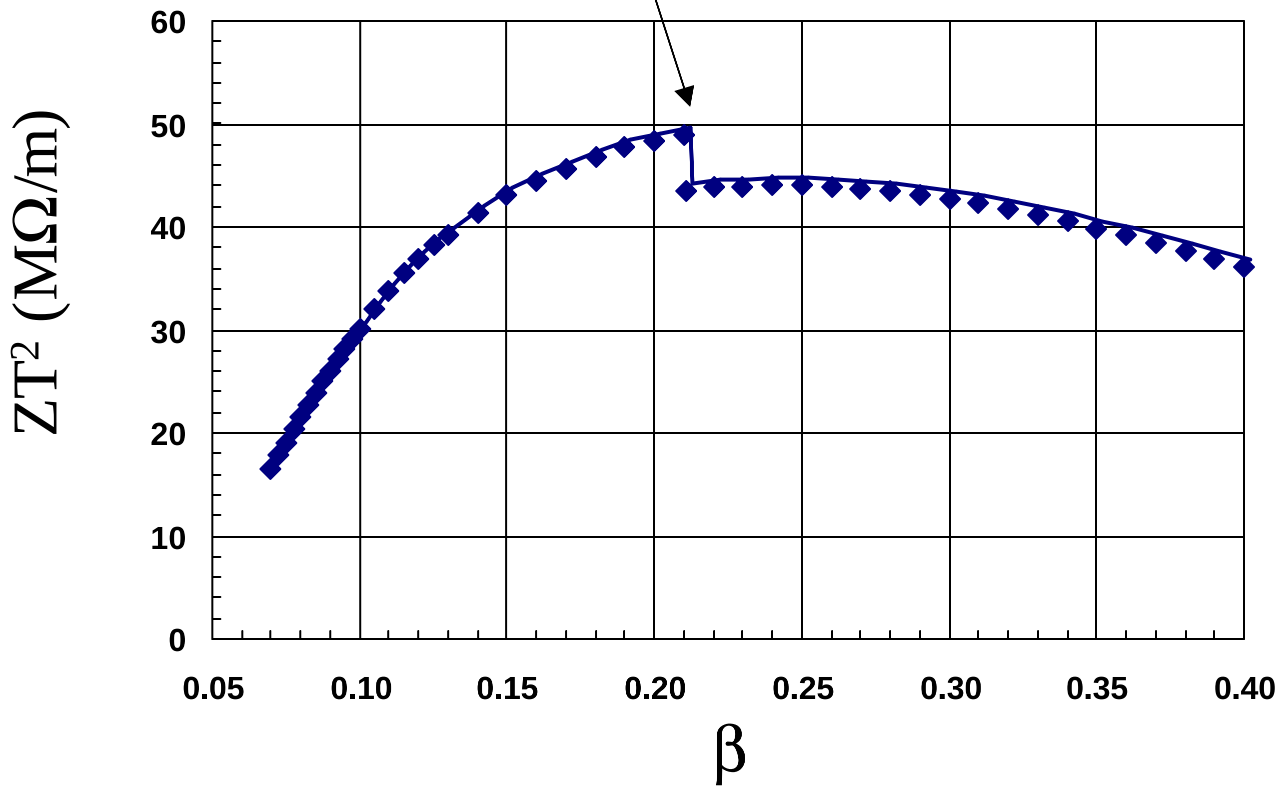


DTL Cell Design

- Certain dimensions are fixed (or limited) by design criteria:
  - Bore radius = 1.25 cm.
  - Drift-tube-to-wall distance $\approx 0.9 \times \lambda/4$.
  - Drift tubes must accommodate cooling passages and PMQs.
- Optimize the rf cavity shape for highest ZT^2 at both ends of a range of velocity β by varying a few dimensions (e.g. drift-tube diameter, face angle).
- Adjust the gap between noses for resonance at 402.5 MHz.
- Linearly interpolate cell dimensions between the optimization points.

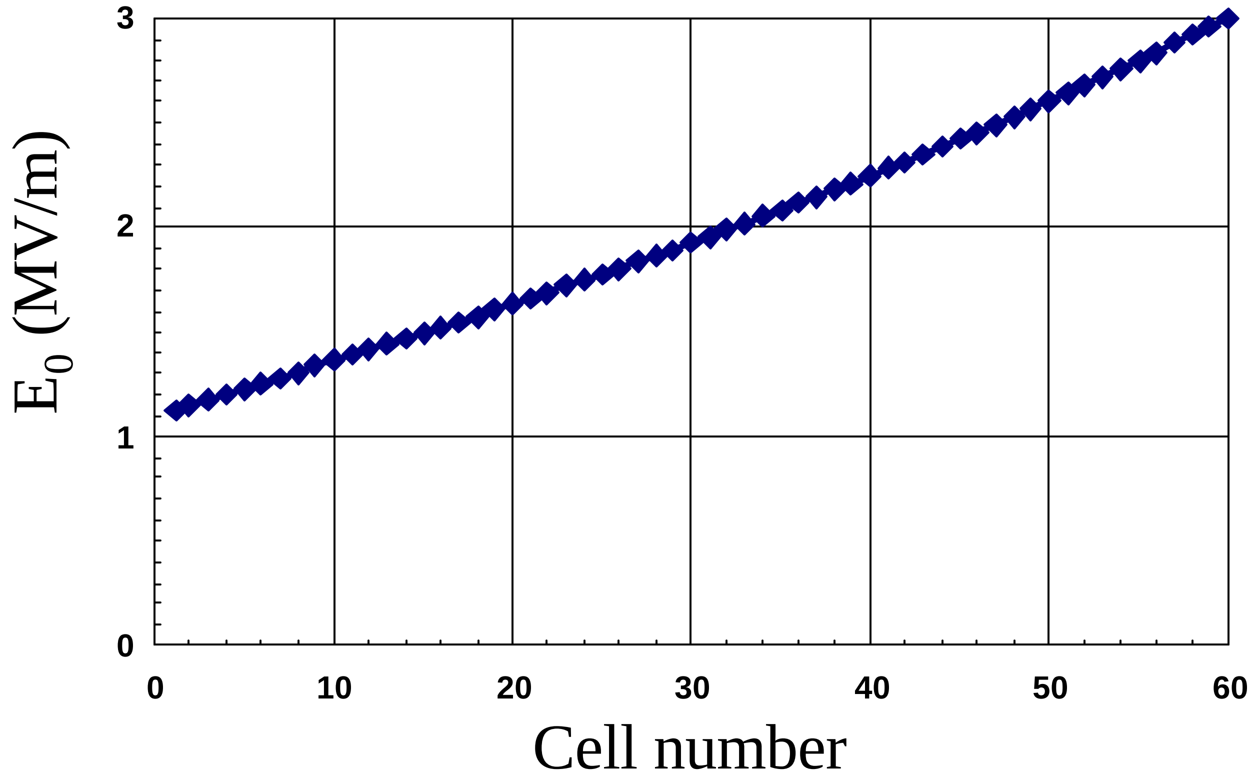
DTL Shunt Impedance

Drift tube and tank diameters increase at tank 3.



Tank 1 Design Field Distribution

Ramp is linear with β (not cell number).



Frequency Budget

- The 8 slug tuners per tank must have enough range to correct for all possible frequency errors resulting from manufacturing tolerances.
- Tank diameter is adjusted to account for known frequency shifts plus half the slug tuner range. (Full range is 2.09 MHz)
- Largest frequency errors (in kHz) for tank 1:

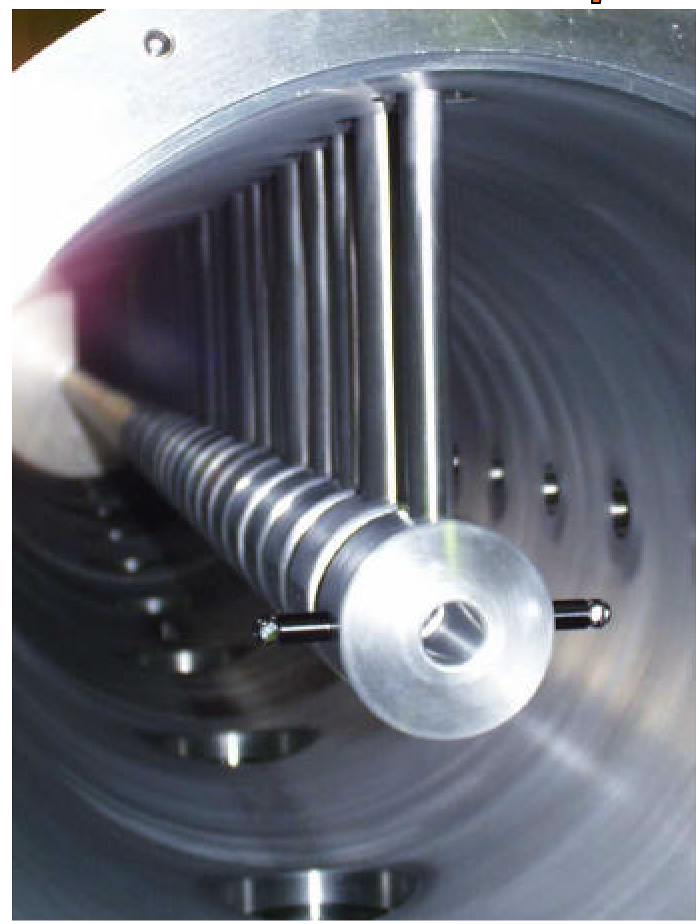
Dimension	Tolerance (mm)	Error (kHz)
Tank diameter	±0.406	±242
Drift-tube diameter	±0.076	±79
Drift-tube gap	±0.025	±448
Stem diameter	±0.355	±63
Post couplers	±0.355	±140*
Total (all with like sign)		±972

* Estimate from previous DTLs, effect comes mainly from tip-to-drift-tube spacing.

Radius Adjustment for Tank 1 Low-Power Model

- Cells were designed using Superfish with diameter D = 43 cm.
- Computed frequency shifts add up to +2.792 MHz and include:
  - Stems +1.505 MHz
  - Post couplers +0.241 MHz
  - Half of tuner range +1.046 MHz
- For the low-power model we ignore the effects of holes in the wall. High-power tanks will include corrections for pumping grills.
- Tuning rate for changes in tank radius is –11.845 MHz/cm.
- <u>Increase</u> the radius 0.2357 cm to lower the frequency.
- Adjusted tank diameter D = 43.4715 cm.

Tank 1 Low-Power Model Verifies Drift-Tube Alignment Method and RF Cavity Properties



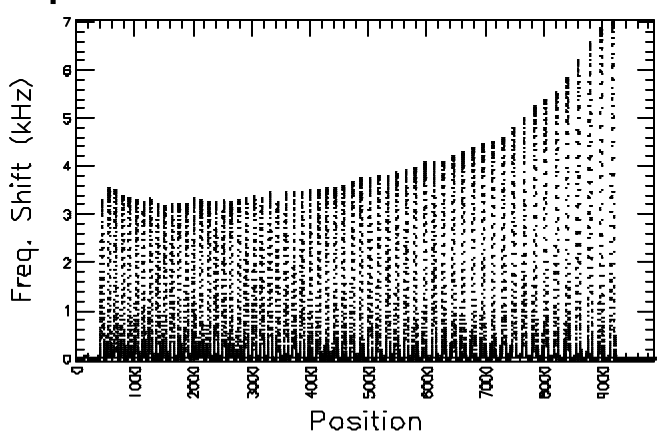
Low-Power Model Measurements

- Preliminary measurements (before fields have been stabilized):
  - Frequency range of slug tuners is ~2 MHz, as expected.
  - TM_{010} frequency is within range of the slug tuners.
  - Bead-perturbation measurements without post couplers show expected tilt sensitivity slope of ~ 820 %/MHz.
- Work in progress :
  - Tune post couplers to stabilize the field.
  - Adjust post-coupler asymmetry to fine tune the field distribution.
  - Measure the frequency effect of pumping slots.
  - Adjust the iris for desired coupling to external power supply.

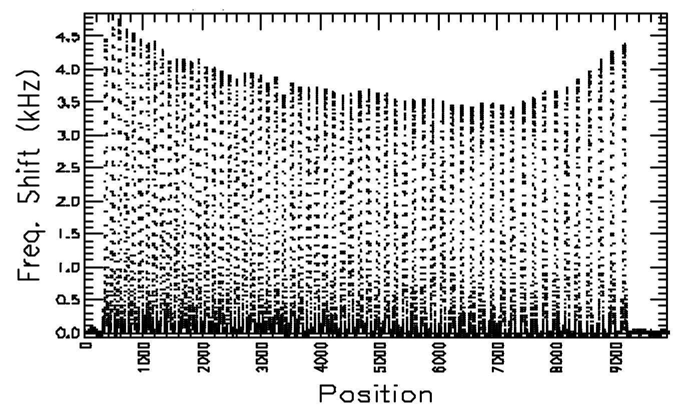
Bead-Perturbation Technique Measures the Axial Field Distribution

- Measurement data consists of frequency shifts versus longitudinal position of a metal sphere pulled through the cavity bore. (Position is inferred from time for a constant velocity bead.)
- Frequency shifts (typically a few kHz) are proportional to the square of the electric field integrated over the bead volume.

No end perturbation



50-kHz end perturbation

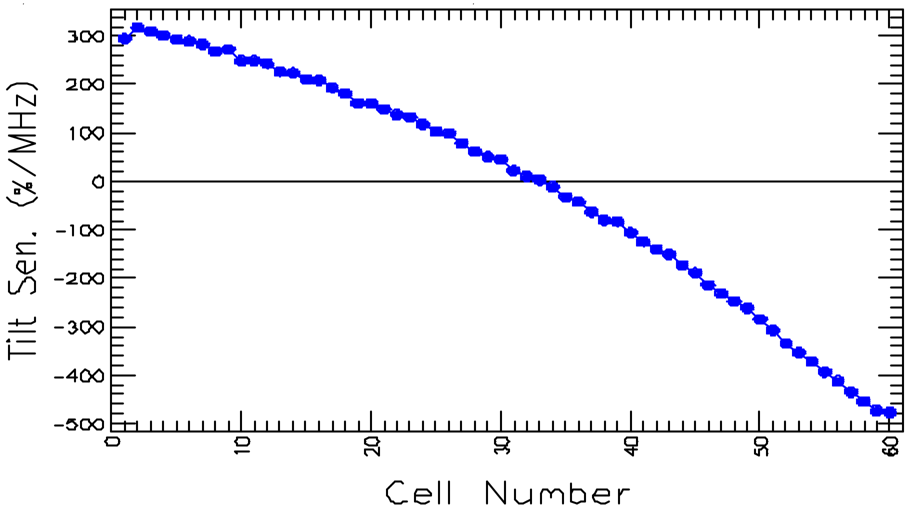


Tilt Sensitivity without post couplers shows the need for stabilization.

- Measures the stability of the fields against frequency perturbations.
- For each cell, and for equal and opposite end perturbations Δf :

$$T.S. = \frac{E_0^- - E_0^+}{\frac{1}{2}\left(E_0^- + E_0^+\right)} \times \frac{1}{\left(\Delta f^+ - \Delta f^-\right)}$$

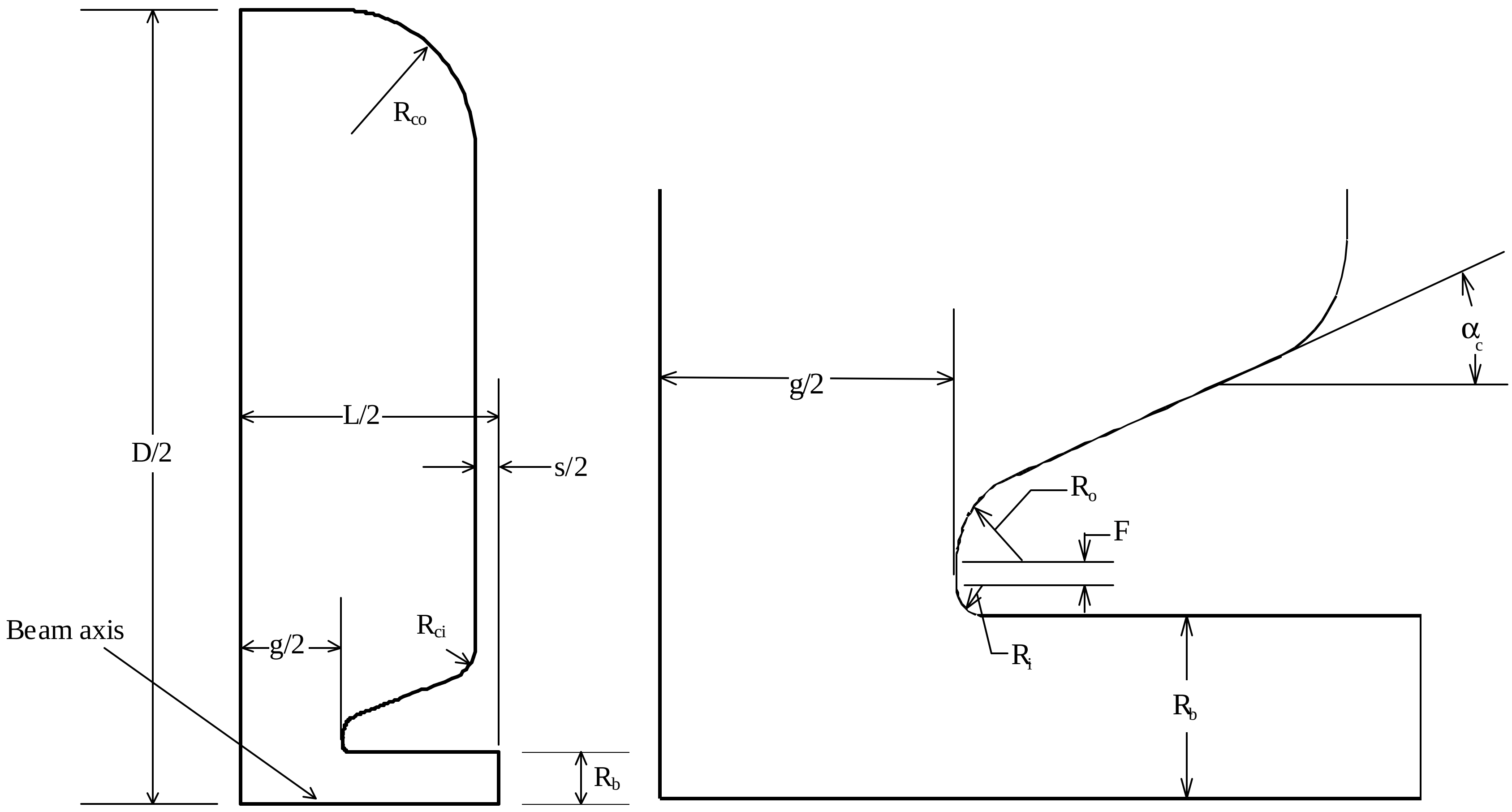
where the superscript is the sign of Δf on the low-energy end.



Coupled-Cavity Linac (CCL) Properties

- Energy range: 86.8 MeV (β = 0.403) to 185.6 MeV (β = 0.550)
- Four rf modules, each with a 805-MHz, 5-MW klystron (2 irises).
- Bridge couplers span the 2.5 $\beta\lambda$ magnet/diagnostic spaces between 8-cavity segments, 12 segments/module.
- FODO lattice with period 13 $\beta\lambda$ @ 805 MHz.
- Nominally 5% cell-to-cell coupling.
- Peak surface electric field is limited to 33.9 MV/m (1.3 Kilpatrick).
- Nominal accelerating field E_0 = 3.77 MV/m. (Field ramps up over the first 9 segments, starting from 3.06 MV/m.)
- Bore radius R_b = 1.5 cm.
- Average shunt impedance ZT^2 = 40 MΩ/m for all expected losses.

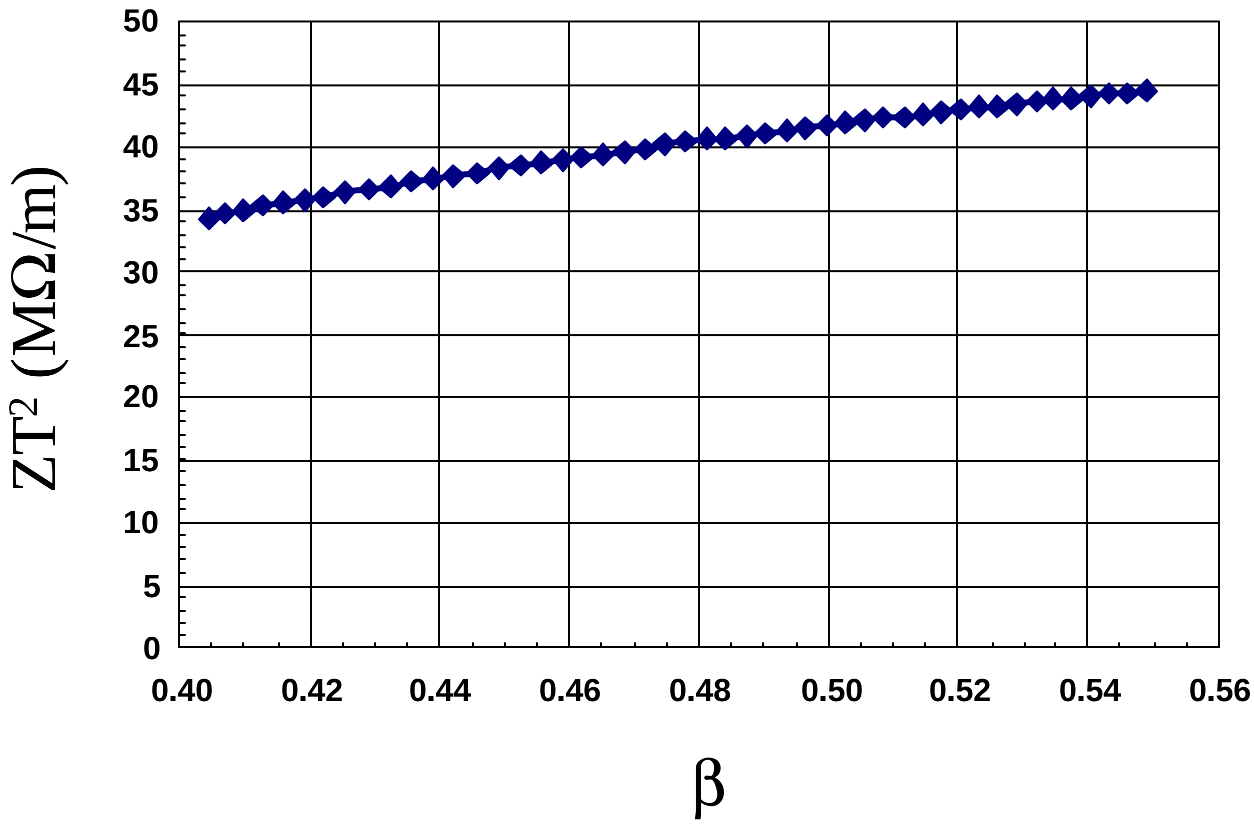
Geometric Parameters in a CCL Cavity



CCL Cell Design

- Starting point: optimize the rf cavity shape for highest ZT^2 at both ends of a range of velocity β by varying a few dimensions (e.g. nose shape, gap length, corner radii).
- Vary cavity diameter for resonance at 805 MHz.
- Some dimensions are fixed by beam-dynamics design criteria (bore radius = 1.5 cm) or cooling requirements (septum thickness = 1.0 cm).
- For ease of manufacturing, fix the cavity diameter, outer corner radius, and coupling slot dimensions over the entire CCL, using average dimensions from the optimization exercise.
- Retune each cavity by slightly adjusting the gap.

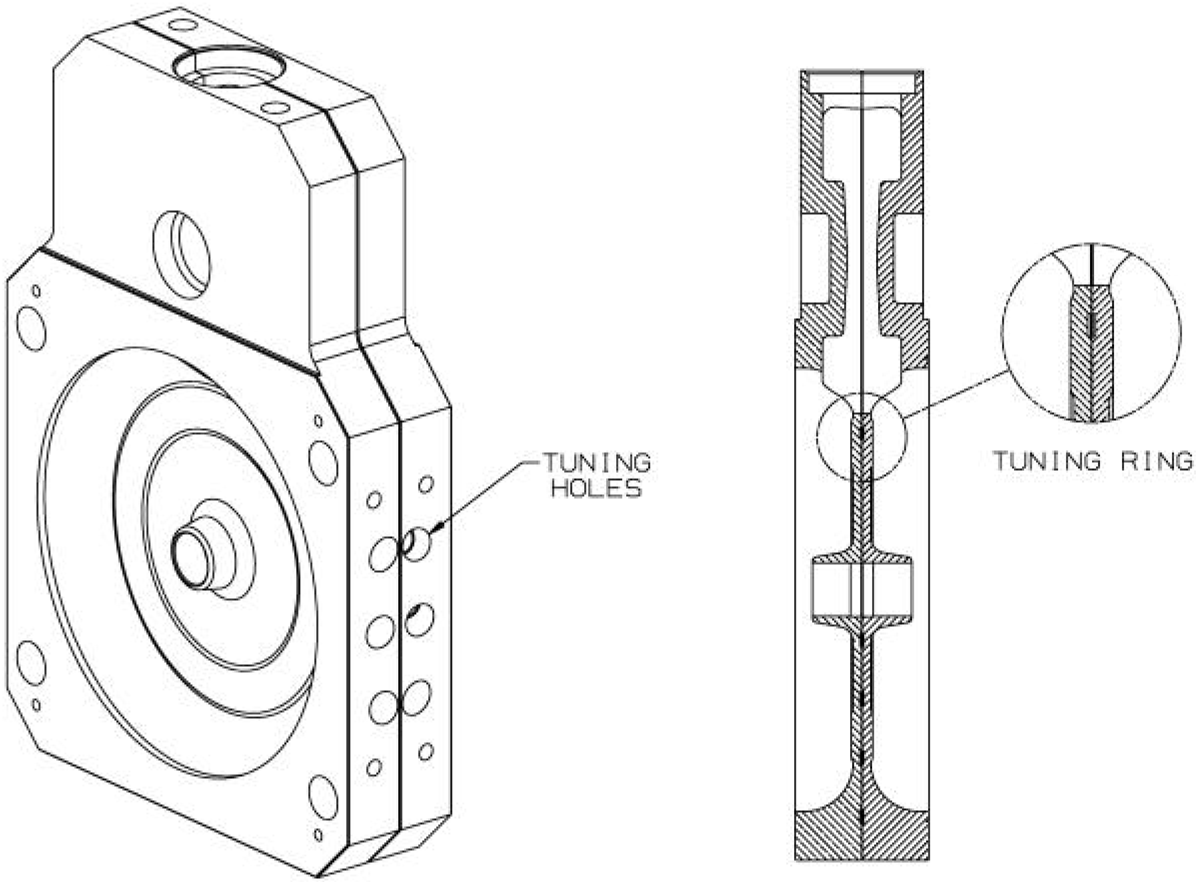
CCL Shunt Impedance



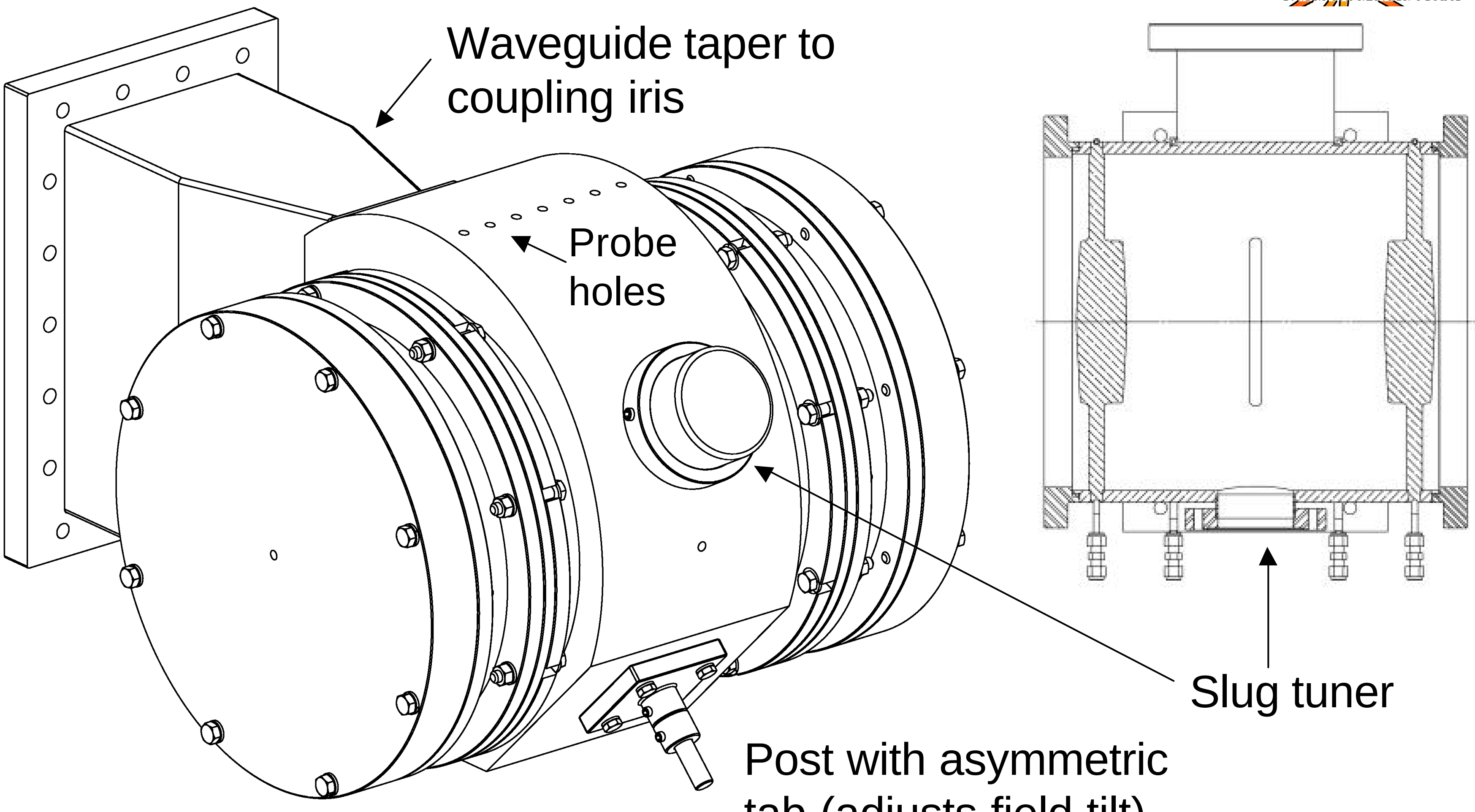
Summary of the Detailed Tuning Plan

- Goal is $f_{\pi/2} = 805.00 \pm 0.01$ MHz and closed stop band under operating conditions.
- Accelerating cavities include two features for tuning at different stages:
  - Pre-braze stack up, machining the tuning-ring has 2.5 MHz range.
  - Post-braze tuning, "dinging" tuning holes has 400-kHz range.
- Coupling cavities are tuned by squeezing or pulling apart the noses.
- Bridge-coupler tuning achieves the design field distribution using two features in the powered cell:
  - Slug tuner with ~2-MHz range.
  - Asymmetric post adjusts relative field level in adjacent segments.
- Two bridge cavities in each module include a drive iris.

Tuning Features in Half Cell Assembly



Bridge Coupler Low-Power Model
Power Cell and Two Coupling Cells

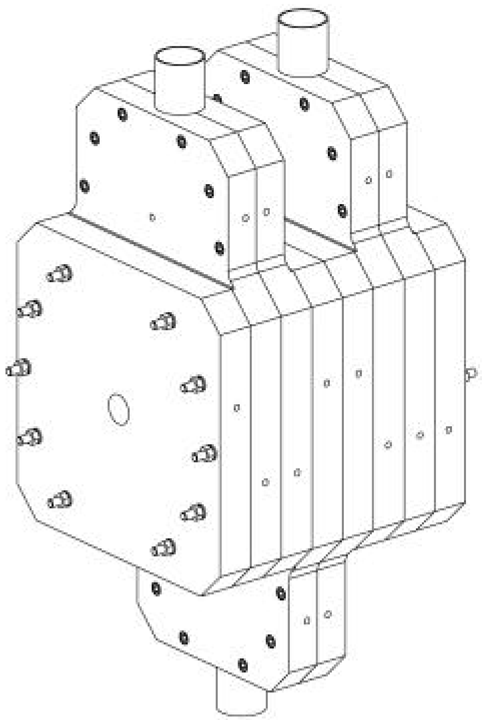


CCL Low-Power Modeling Setup at Coronado Machine in Albuquerque

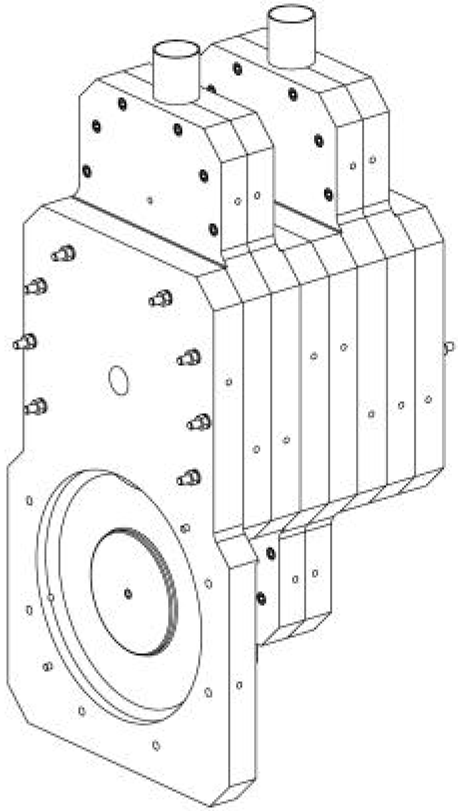
CCL Low-Power Modeling Goals

- Verify details of the tuning plan.
- Determine cavity dimensions for the hot model
- Determine target frequencies for individual cavities.
  - Because of second neighbor coupling, the $\pi/2$ mode frequency is lower than the average accelerating cell frequency.
  - The difference is ~3 MHz at $\beta = 0.4$ and ~2.5 MHz at $\beta = 0.55$.
- Compare measured coupling with code predictions.
  - 2-D model using Superfish and Gao's Slater-perturbation approach.
  - 3-D calculations using HFSS.

Low-Power Models Now Exist for First and Last Segments of the CCL



End-of-module termination



Bridge coupler termination

Activities:

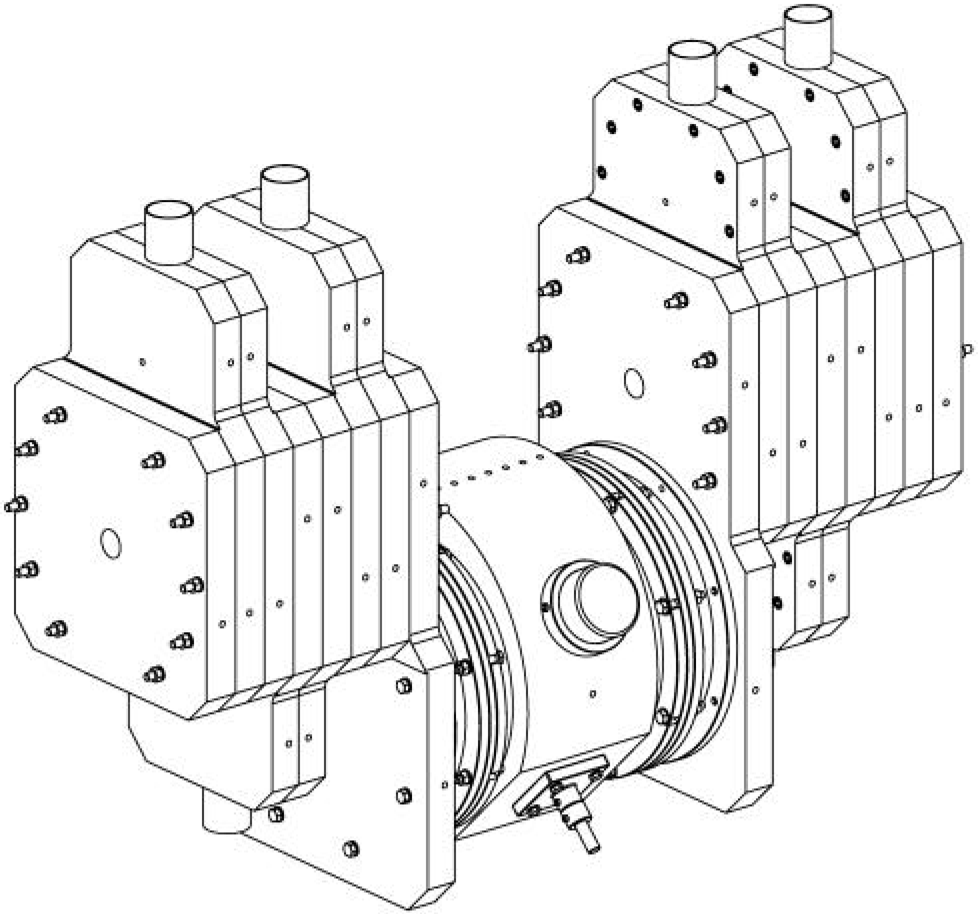
Measure the individual cavity frequencies.

Measure structure modes and fit the dispersion curve to determine coupling.

Tune the accelerating cavities to make $\pi/2$ mode frequency 805 MHz.

Tune the coupling cavities to close the stop band.

Bridge Coupler Between Two Segments



Activities:

(Segments have already been tuned at this point.)

Adjust the asymmetric post to vary the relative field level between segments.

Tune the bridge coupling cells and the center bridge cell.

Measure dispersion curve for the entire structure.

Summary

- Cavity physics design is complete for both DTL and CCL.
- The DTL low-power model has already proven to be a valuable tool for verifying the mechanical alignment method.
- Preliminary rf measurements on the DTL model agree with expectations and show that the cavity is tunable.
- Tuning of two CCL low-power models is underway.
- Frequency measurements on the CCL model cavities shows good consistency among identical parts.