RF Measurements and Tuning of the 750 MHz RFQ for Medical Applications

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CERN

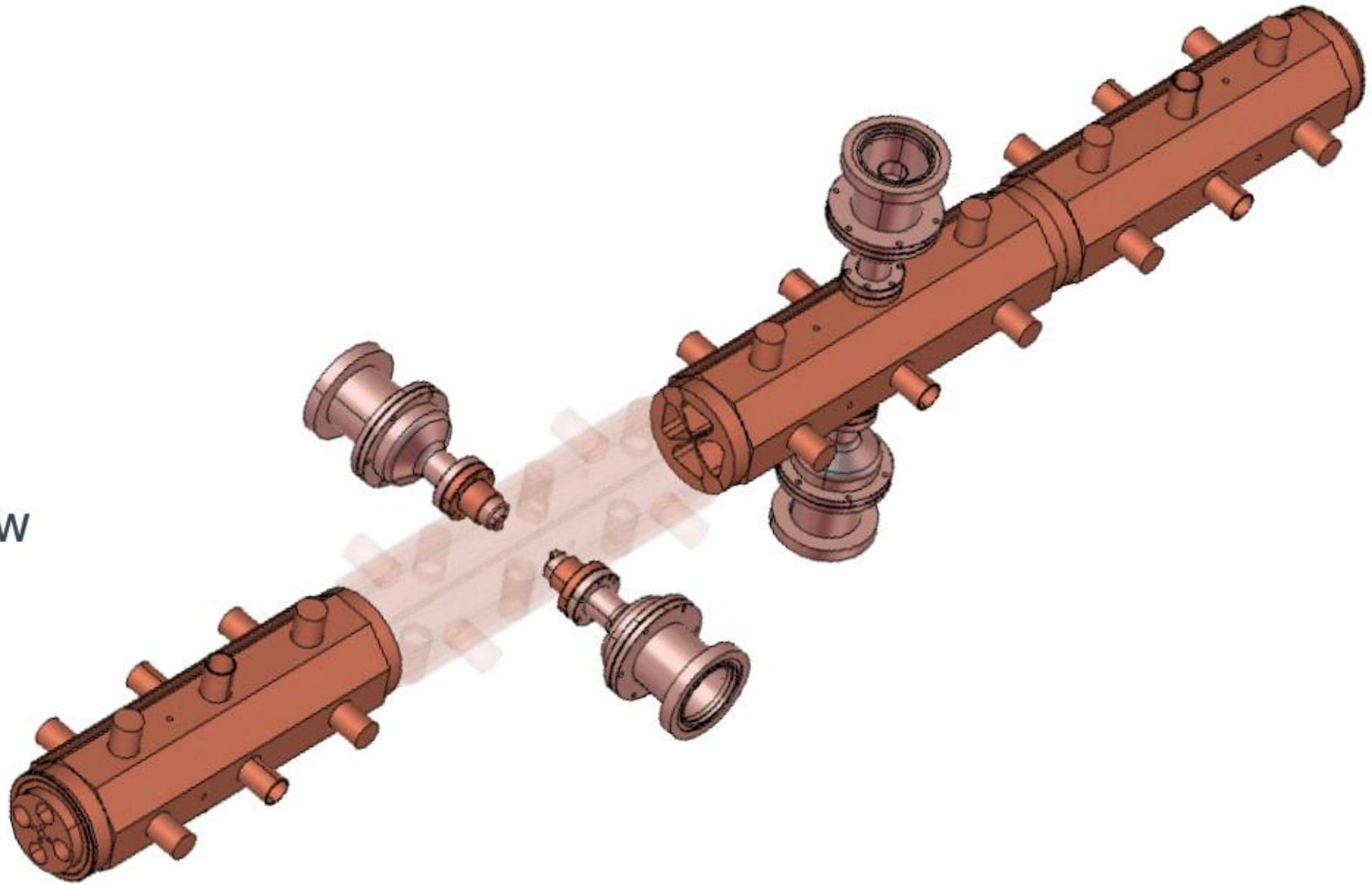
9.3.2018

Outline

- RF measurement setup
- Mechanical tuner design
- Bead-pull measurement
- Single module and full assembly measurenents
- Field flatness tuning
- RF frequency tuning
- Tuner cutting
- Final frequency, field and Q-factor measurements

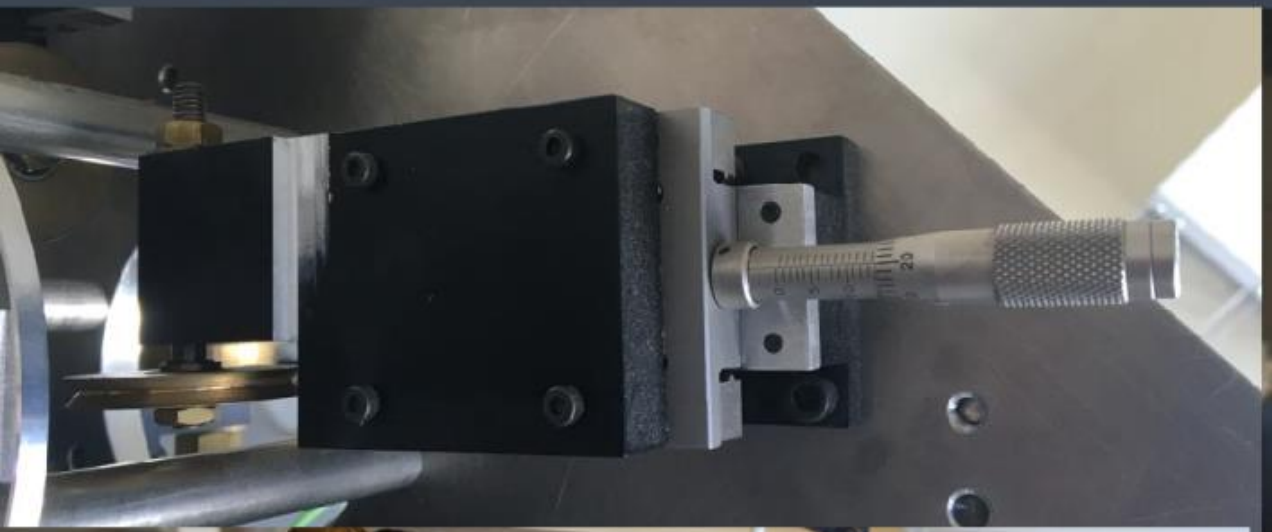
750 MHz RFQ

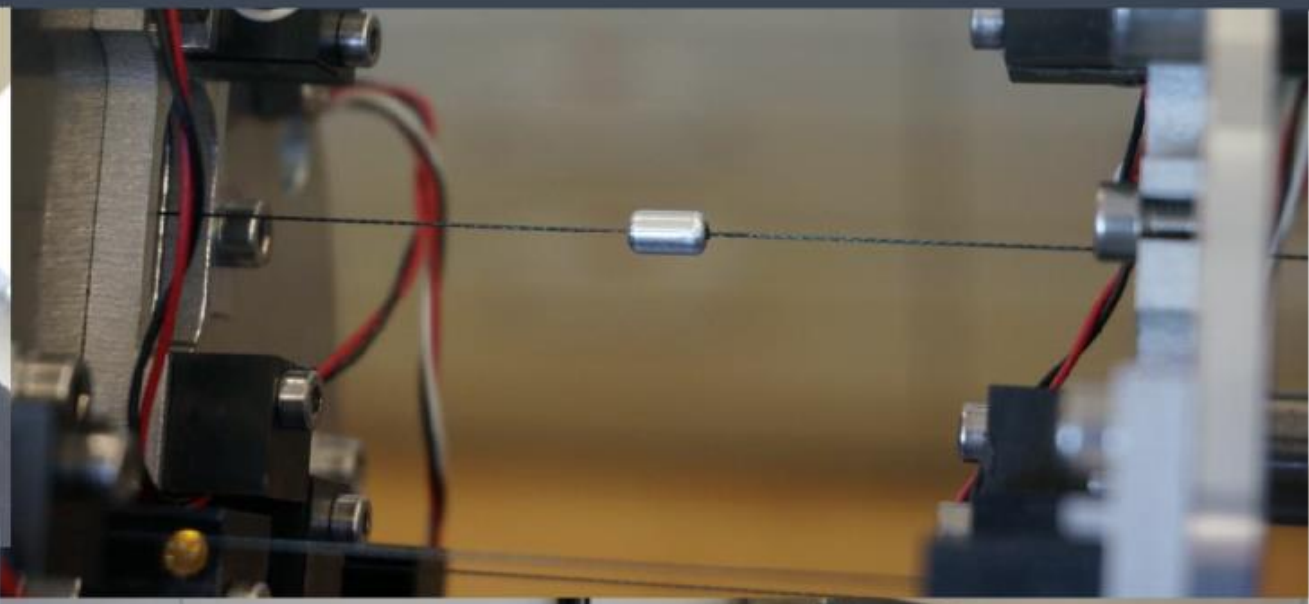
Frequency	750 MHz
Input Energy	40 keV
Output Energy	5 MeV
Length	2 m
Diameter	0.134 m
# Modules	4
# Tuners	32
Power Supply IOT	4 x 100 kW
# Power Couplers	4
# Pickup Antennas	16

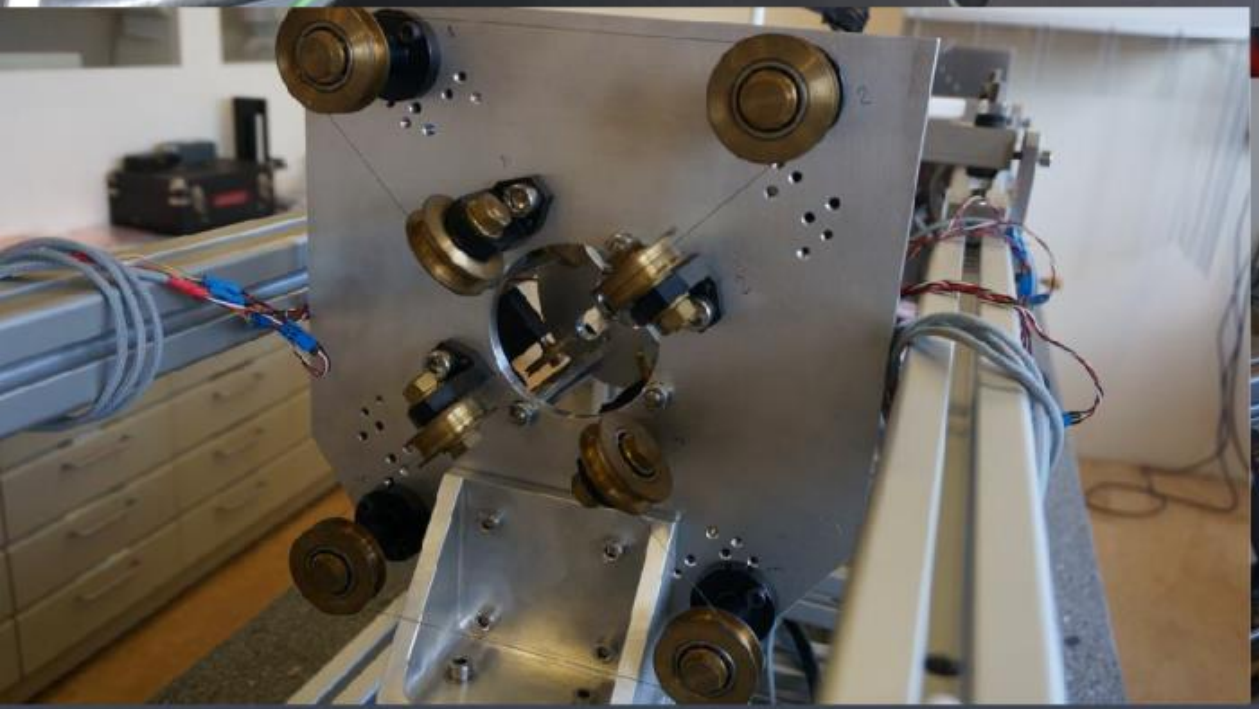


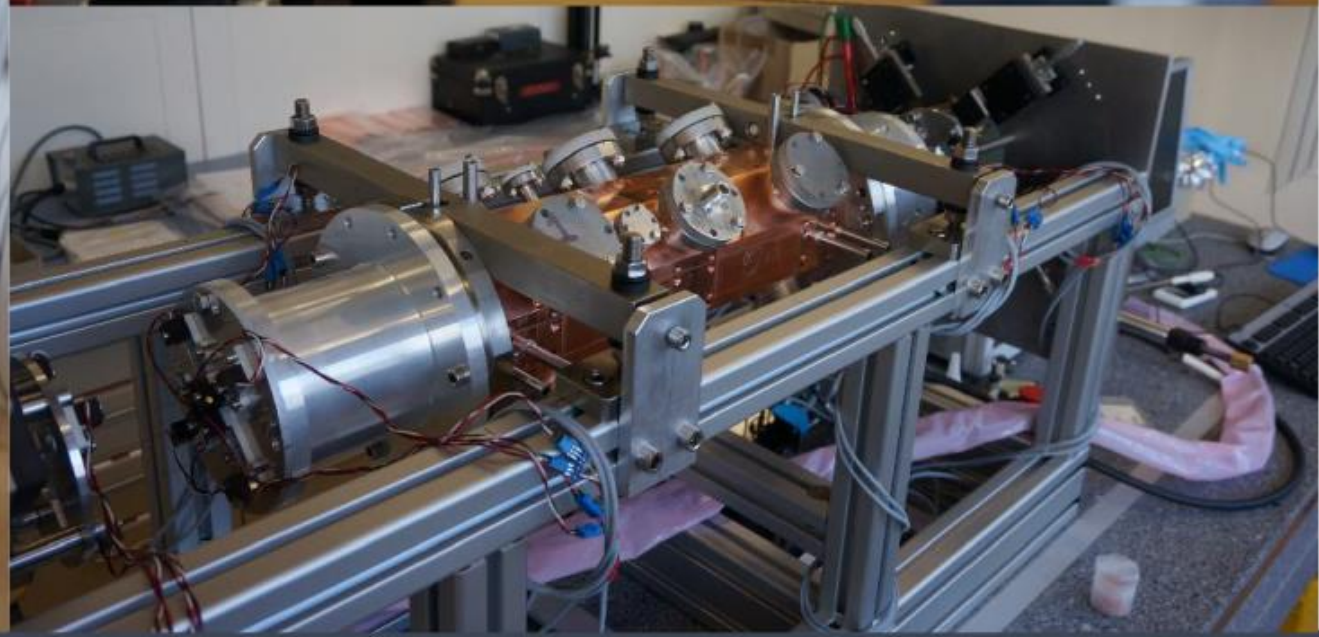
Bead Pull System

Bead Pull System

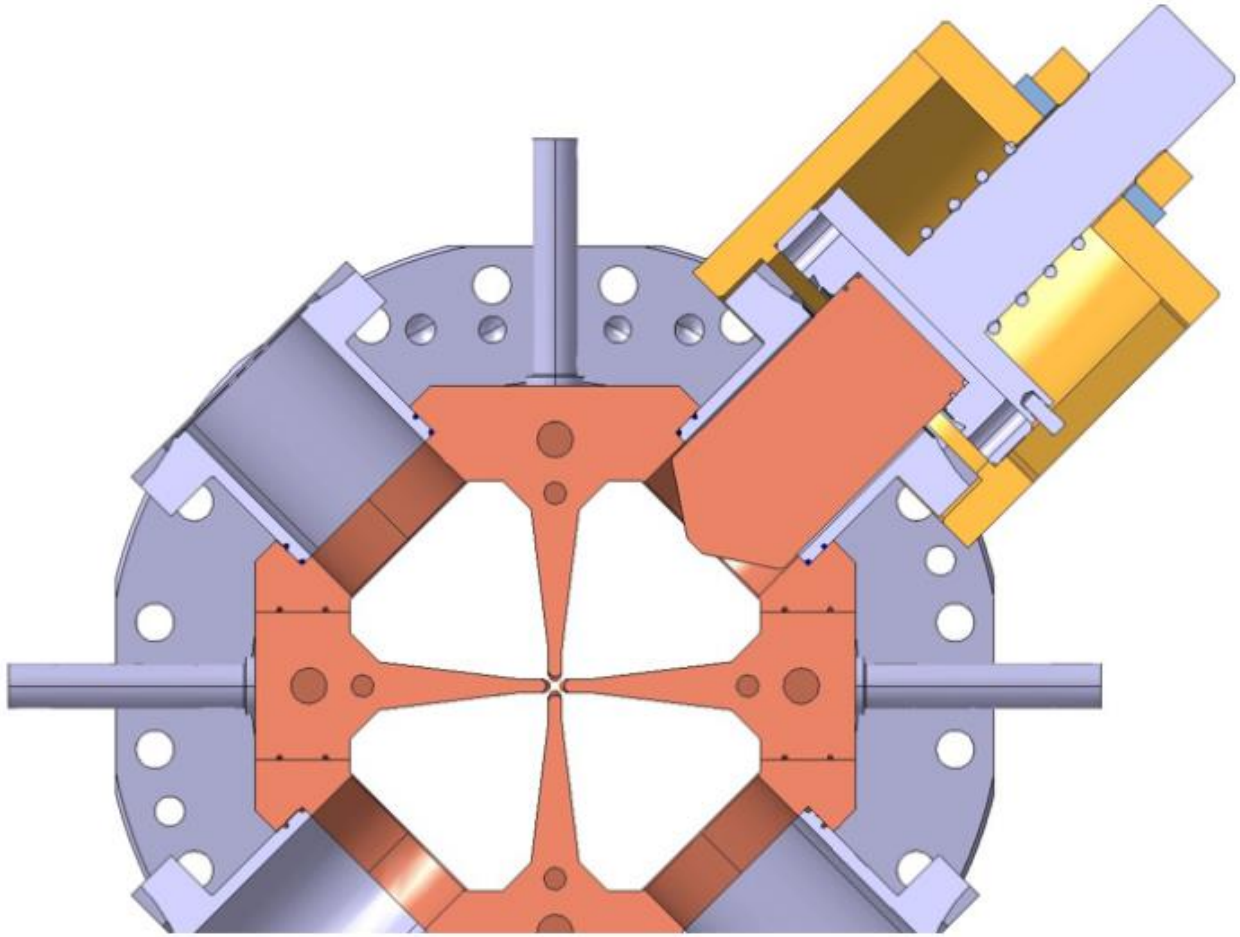


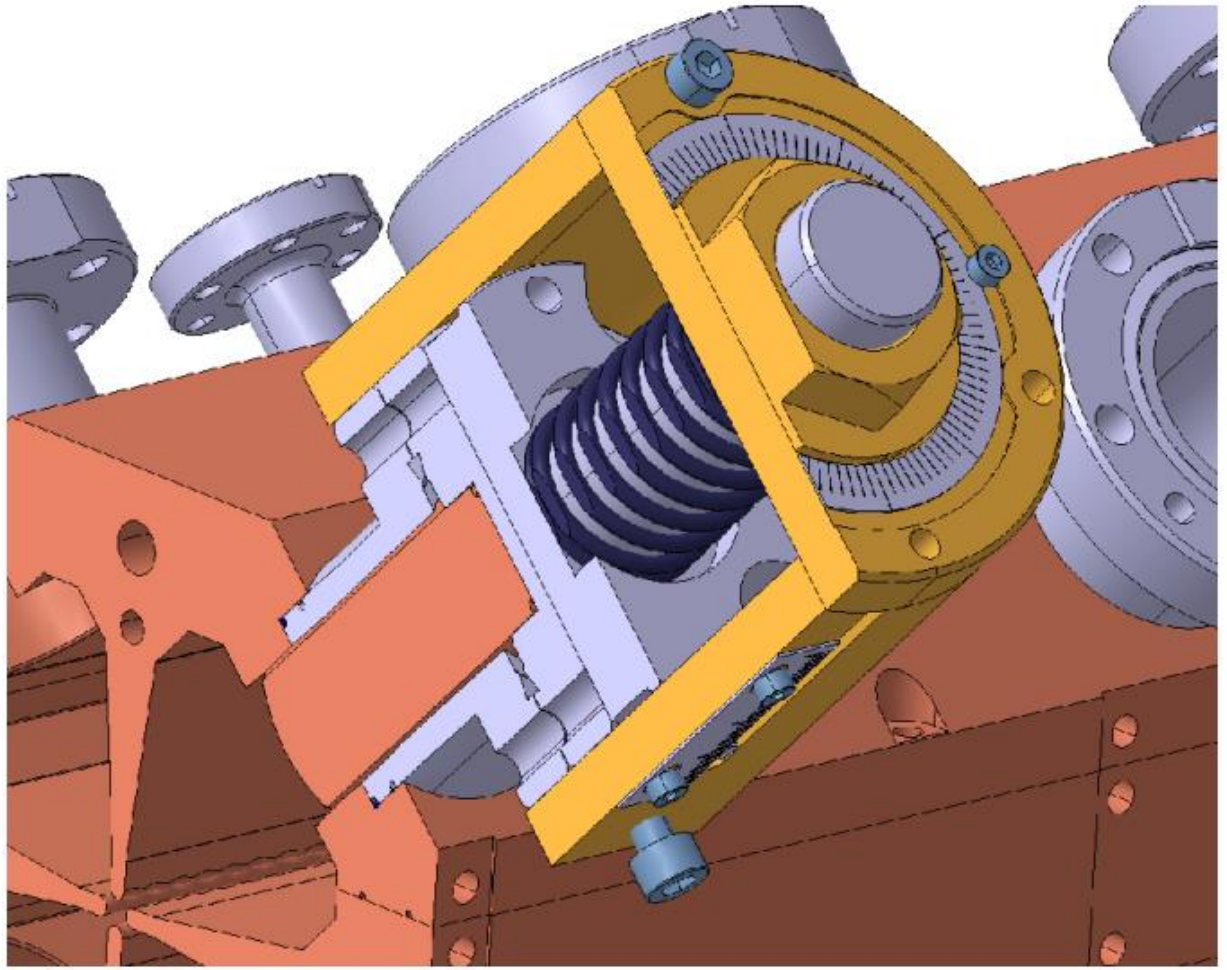




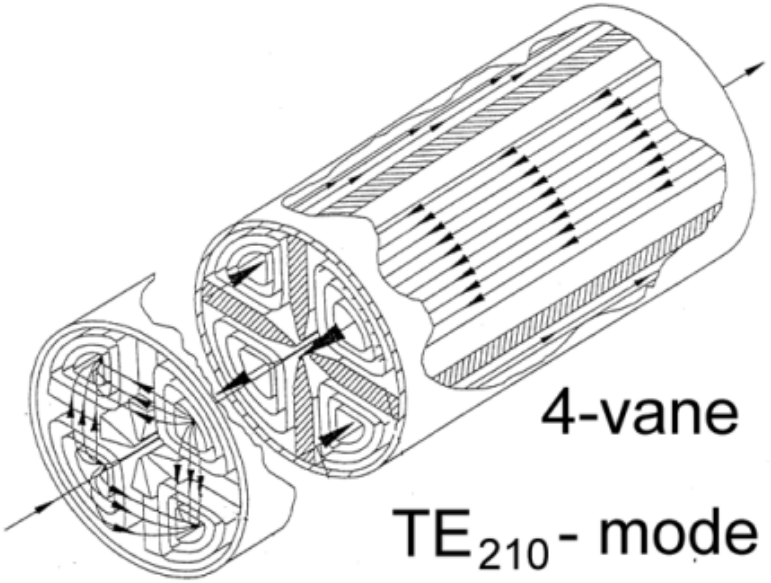


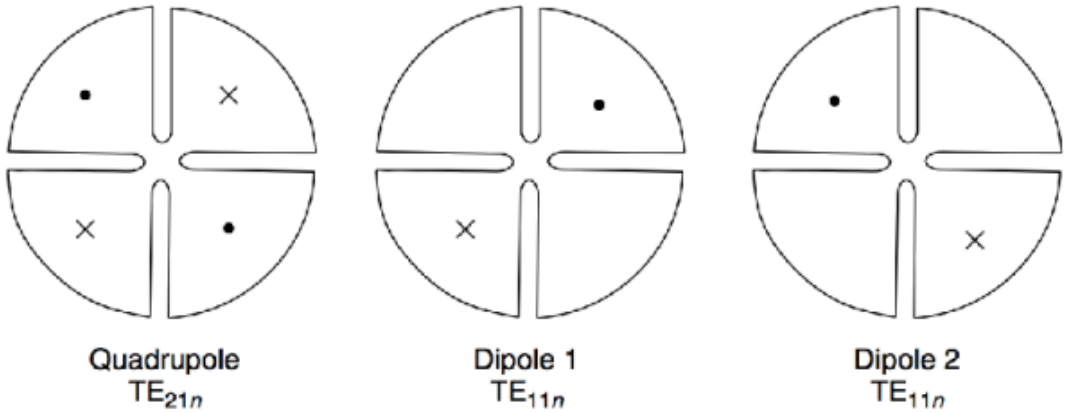
Tuner Tooling





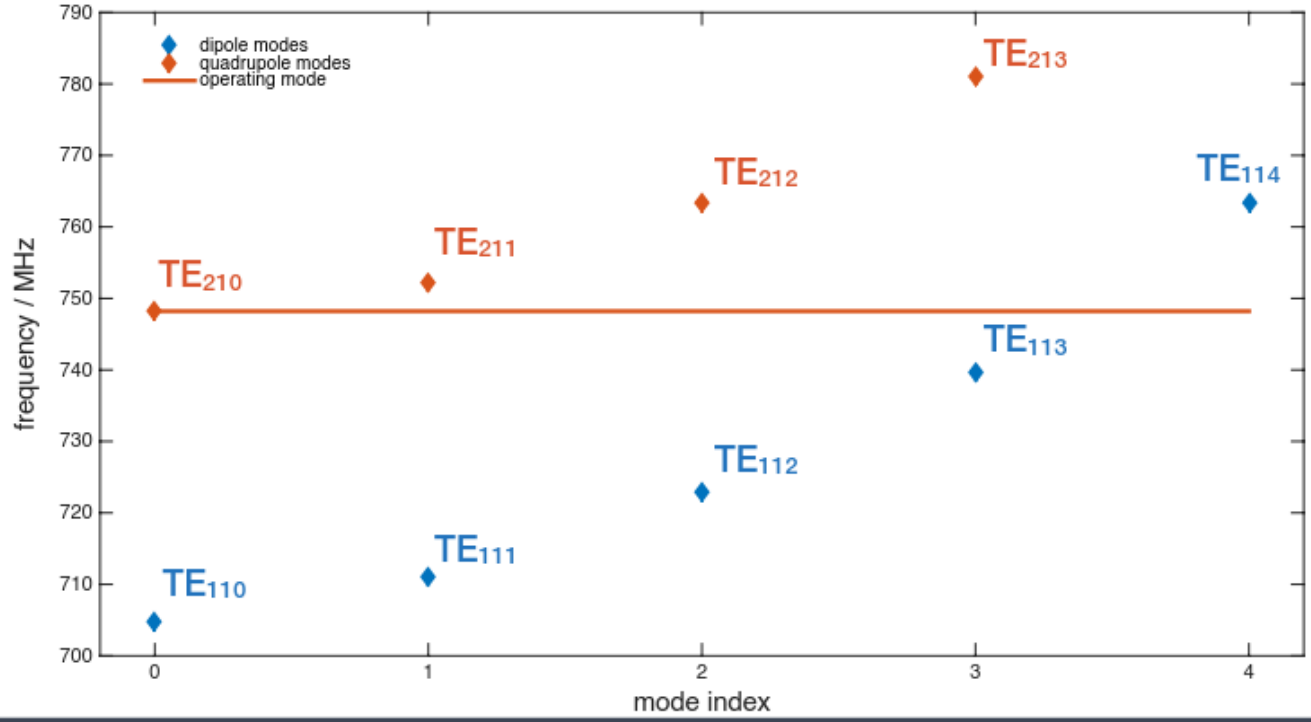
4-vane RFQ



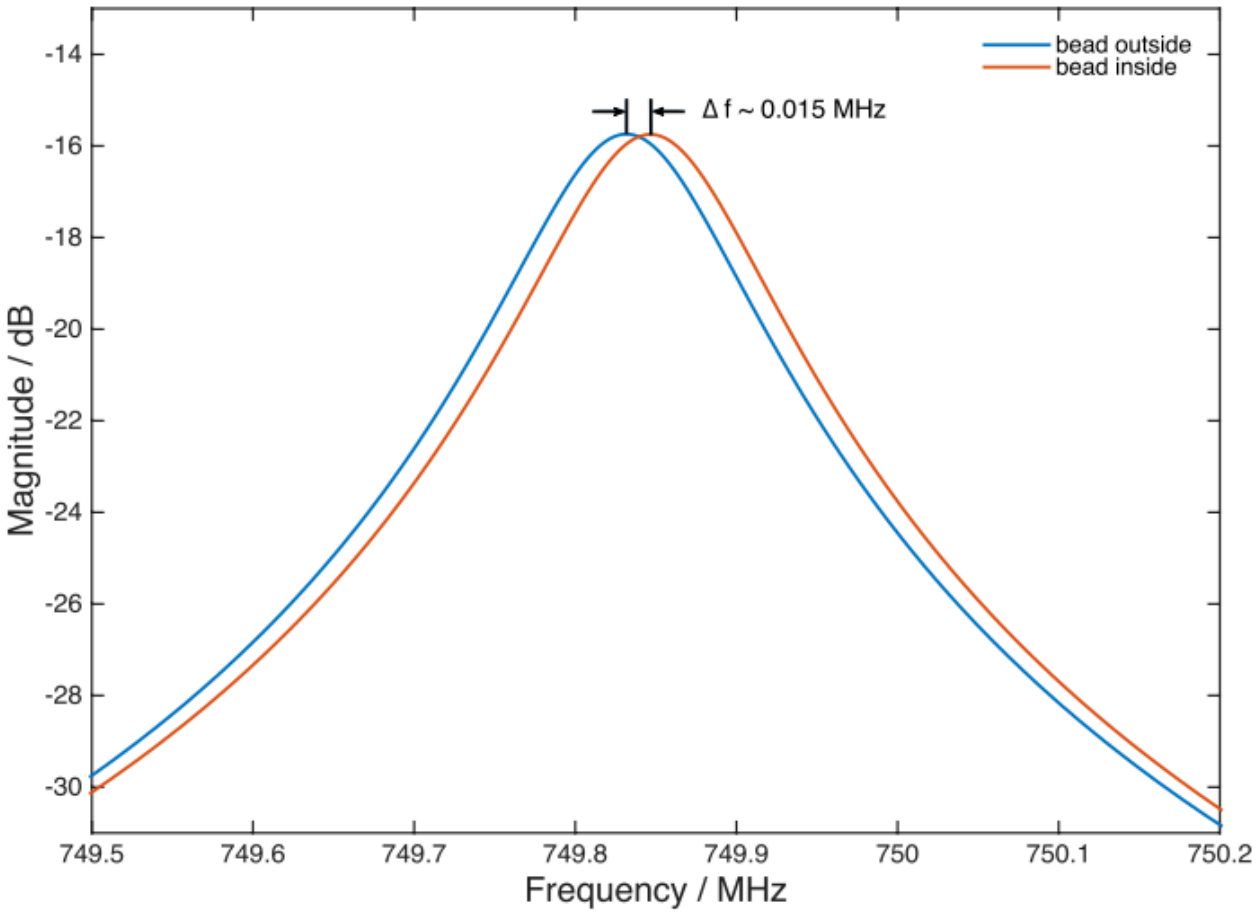


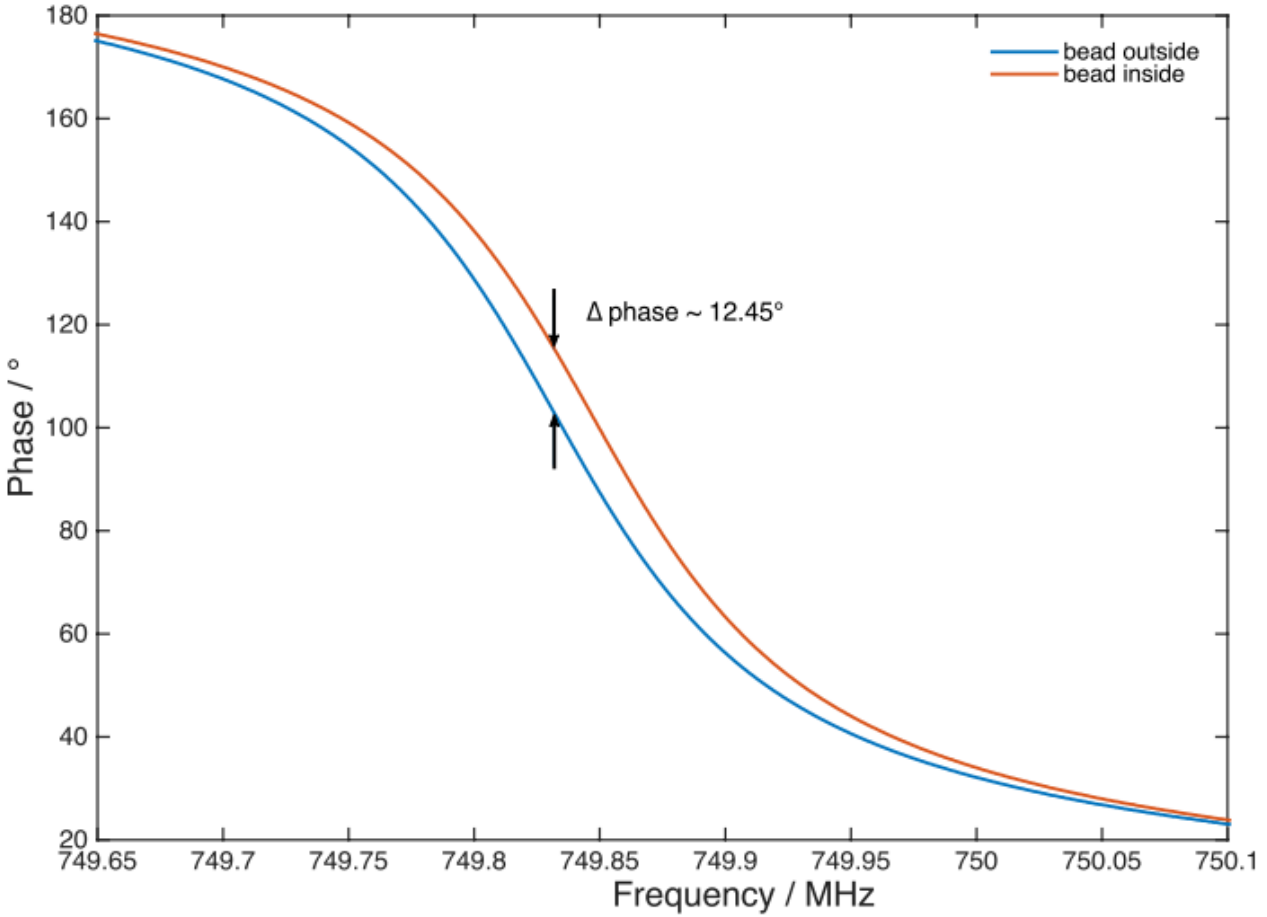
$$Q = (q1 - q2 + q3 - q4) / 4$$
$$Ds = (q1 + q3) / 2$$
$$Dt = (q2 + q4) / 2$$

$$Ds = Dt = 0$$



Bead Pull Measurements

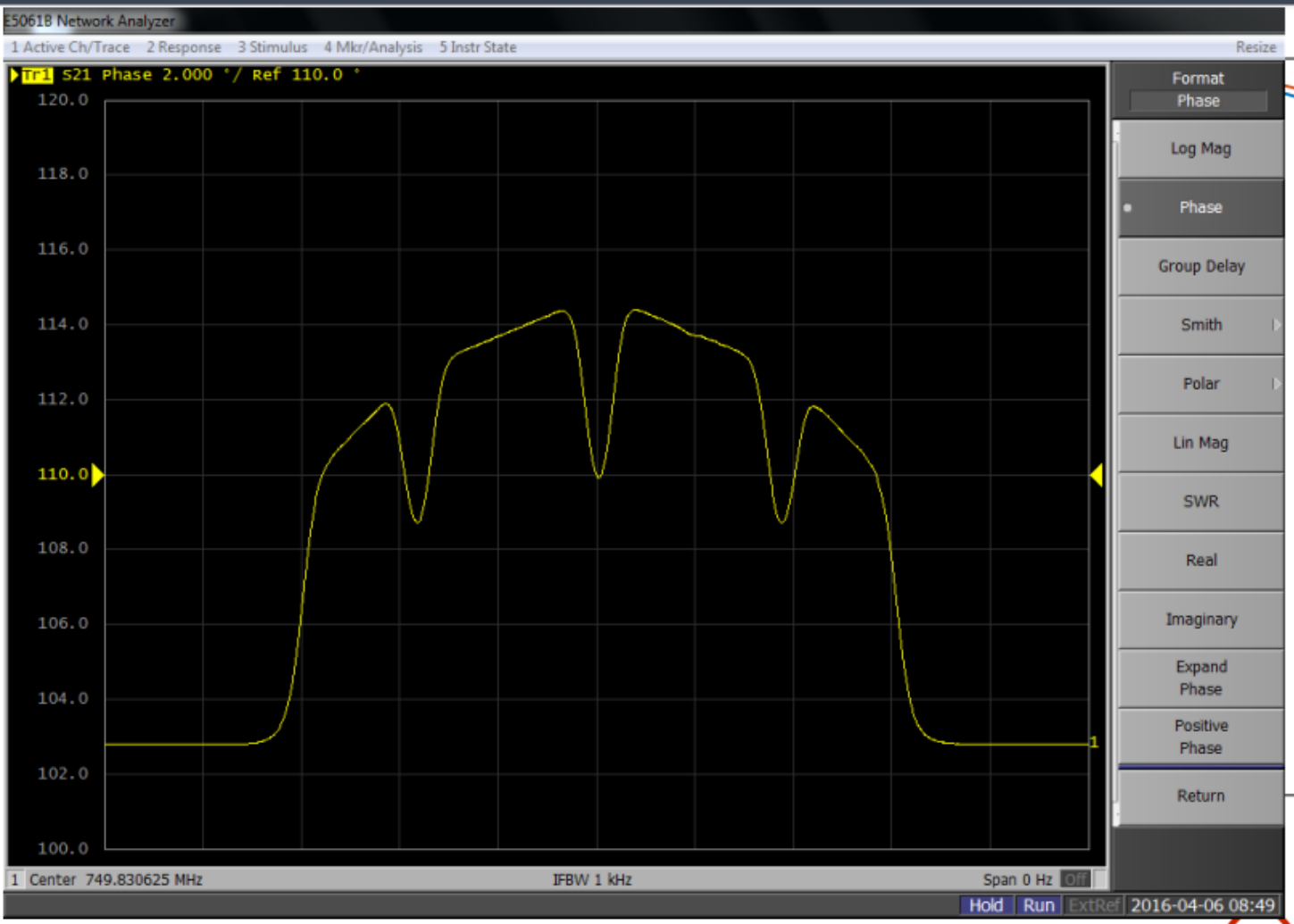


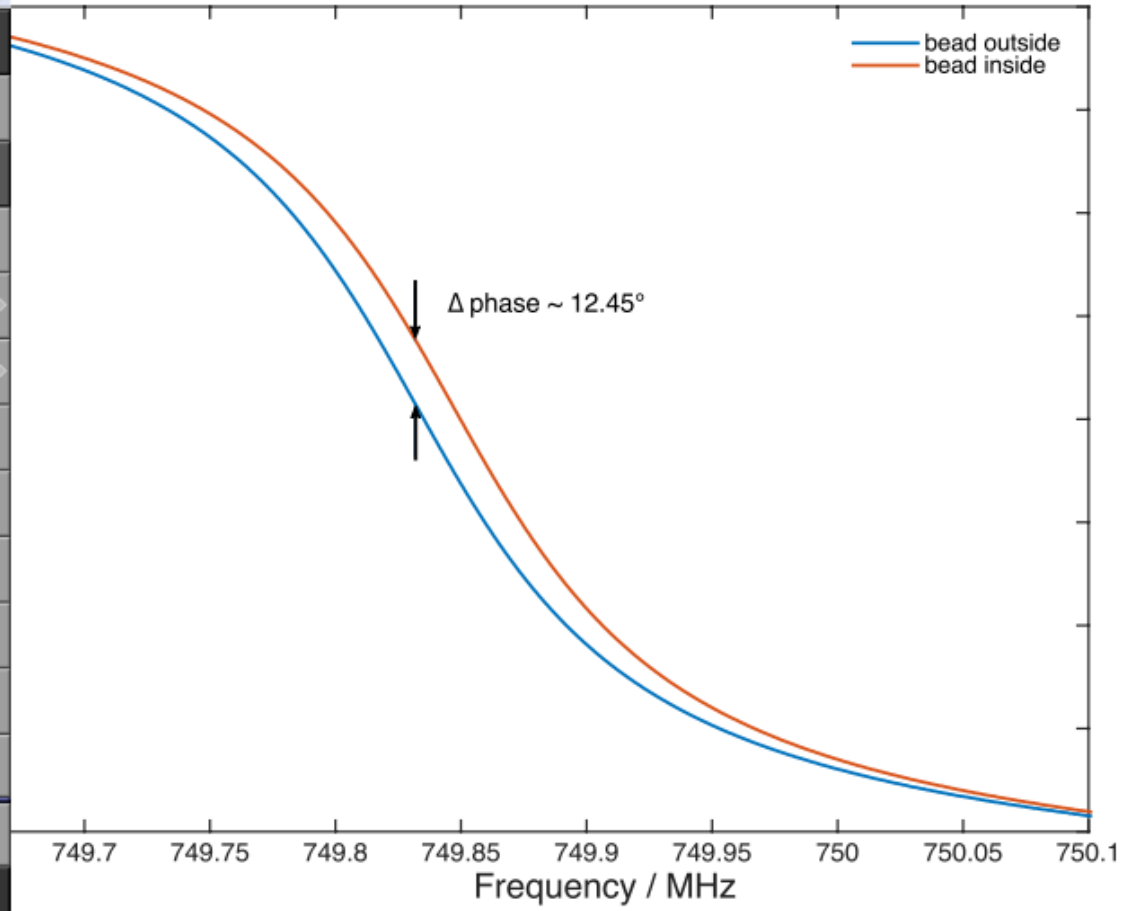


$$\frac{\Delta W}{W} = \frac{\Delta \omega}{\omega} = \frac{\Delta \phi}{\phi}$$

$$\frac{\Delta f}{f_0} = -\frac{\pi \cdot r^3}{W_0}\left[\frac{\epsilon_r - 1}{\epsilon_r + 2} \cdot \epsilon_0 E^2 + \frac{\mu_r - 1}{\mu_r + 2} \cdot \mu_0 H^2\right]$$

Bead Pull Measurements





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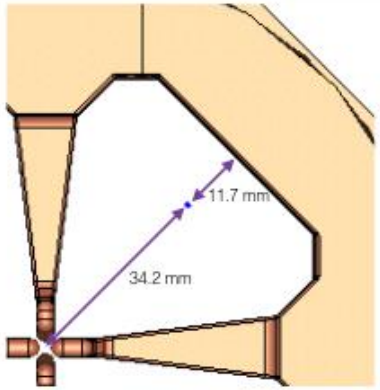
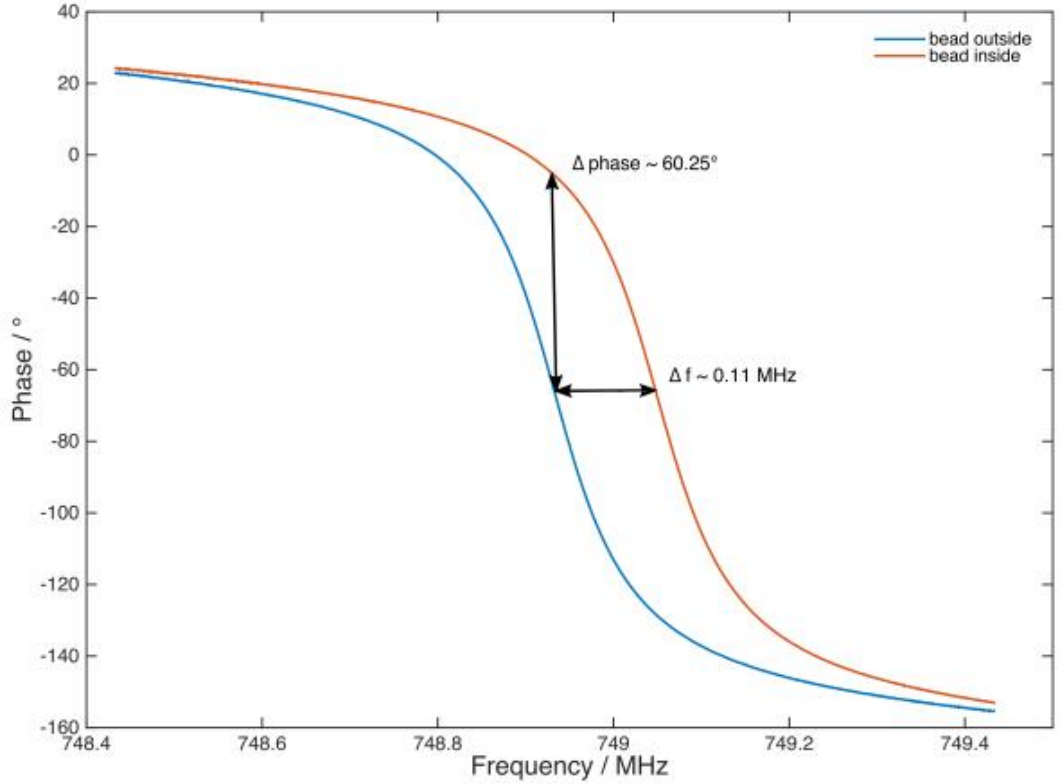
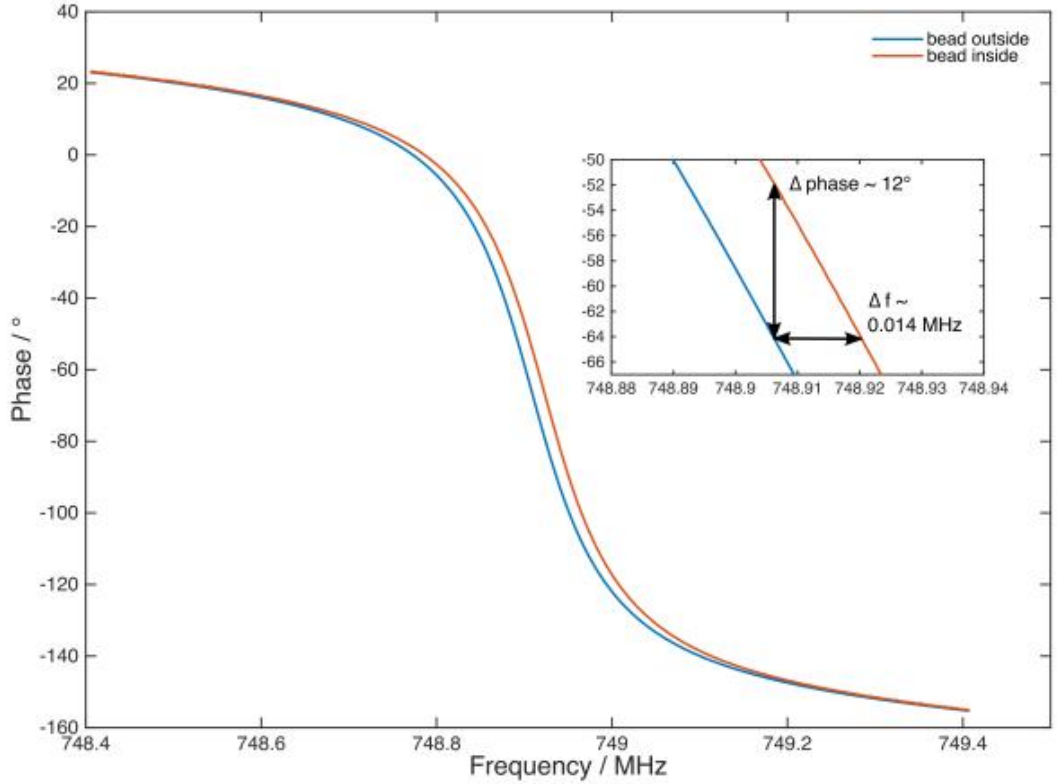
Bead Size and Phase Shift

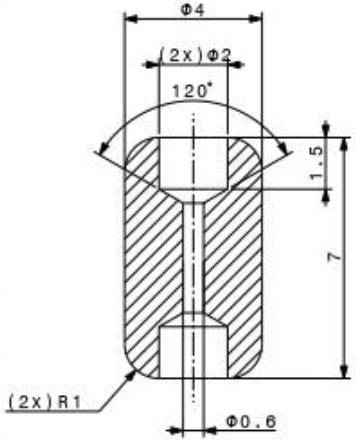


titanium bead
⌀ 8 mm
length 16 mm

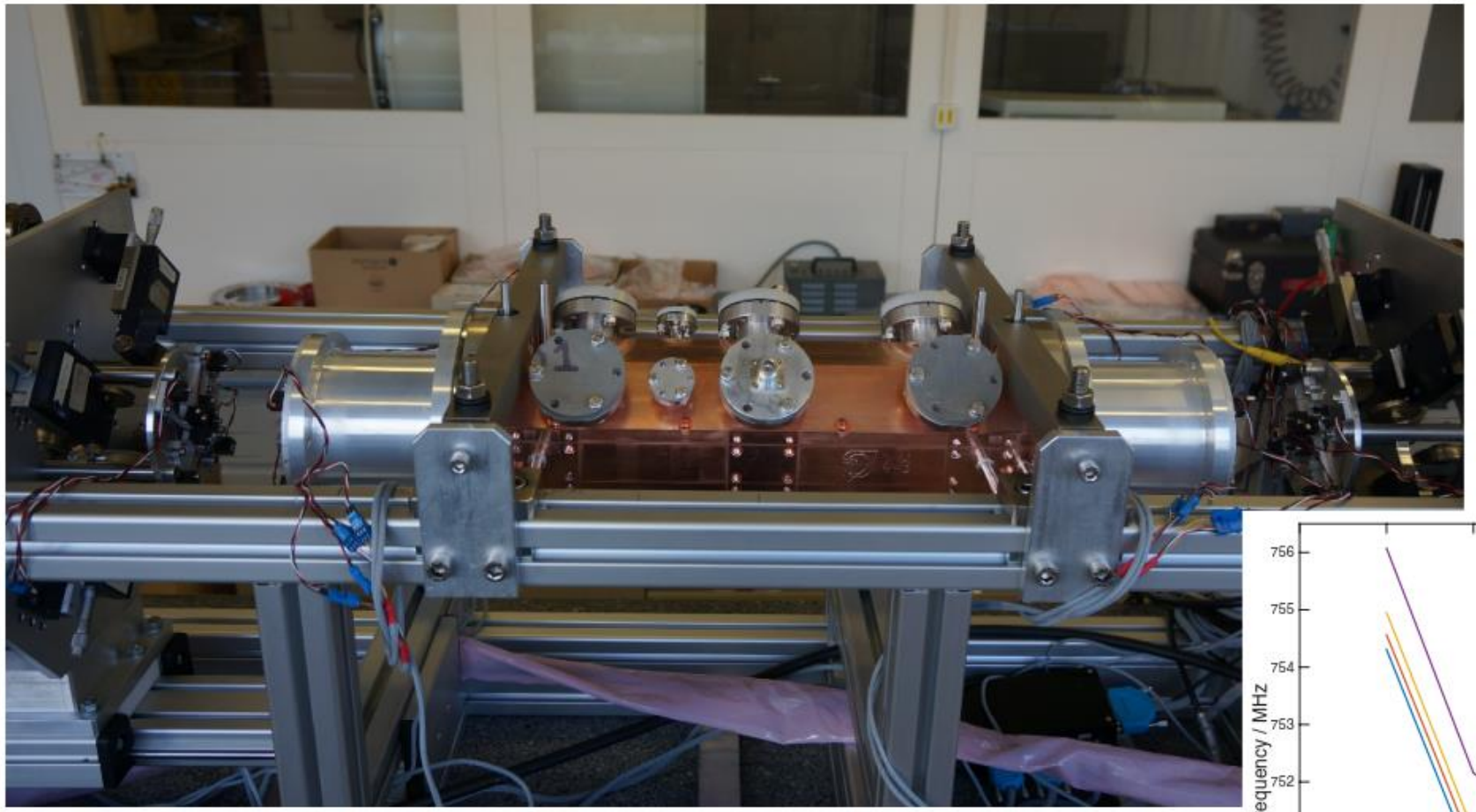
aluminum bead
⌀ 4 mm
length 7 mm

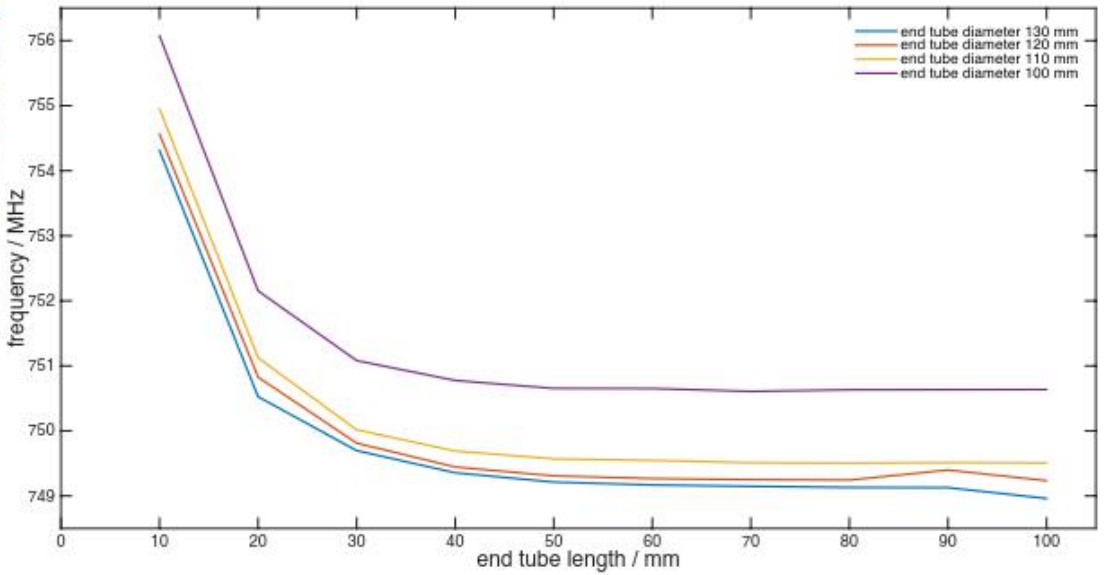






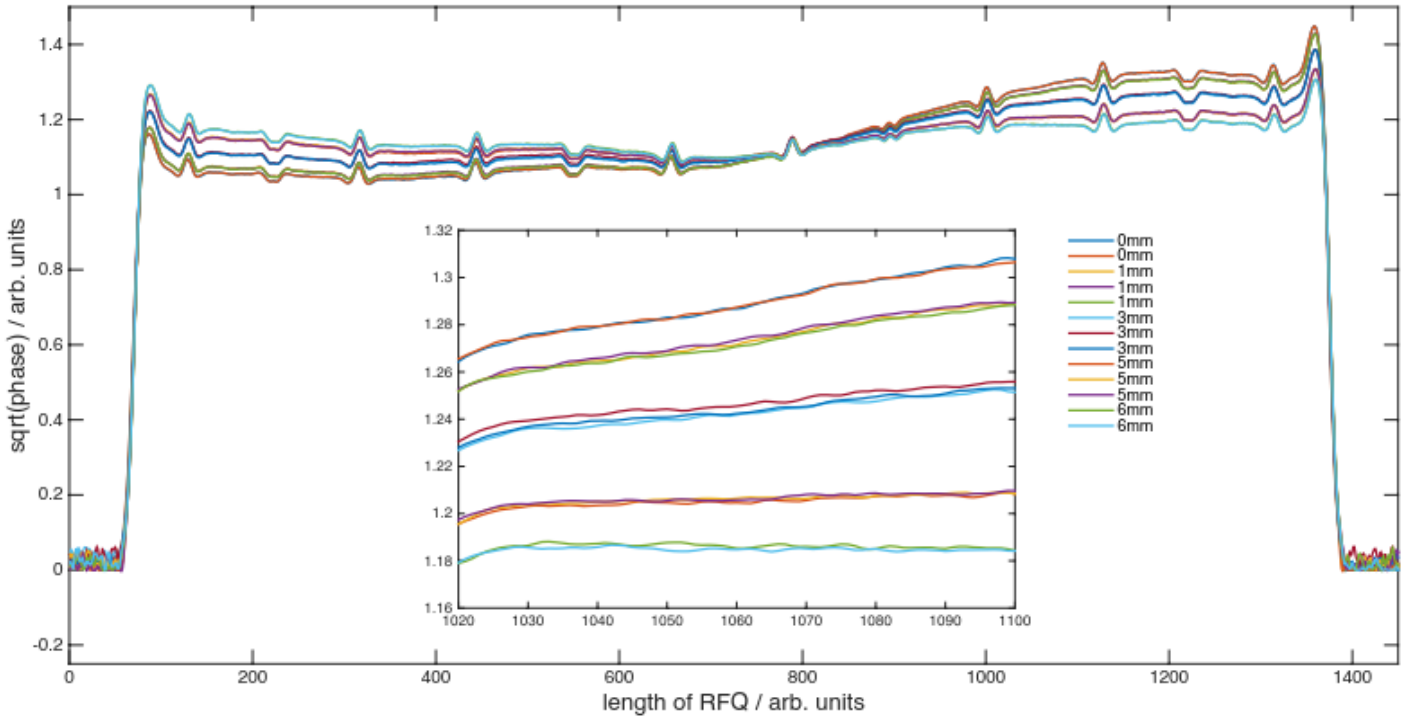
Single Module Measurements





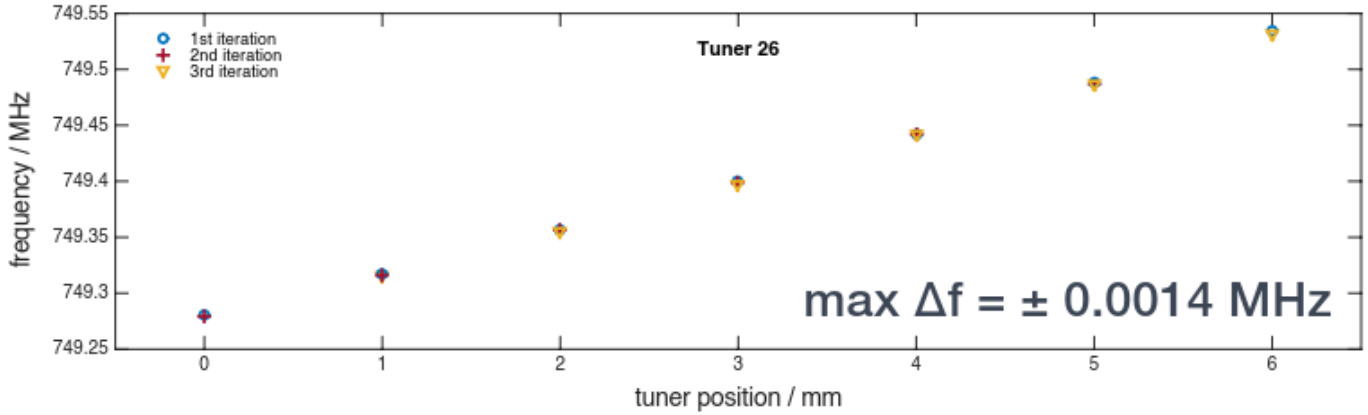
Full Assembly

Reproducibility Measurements

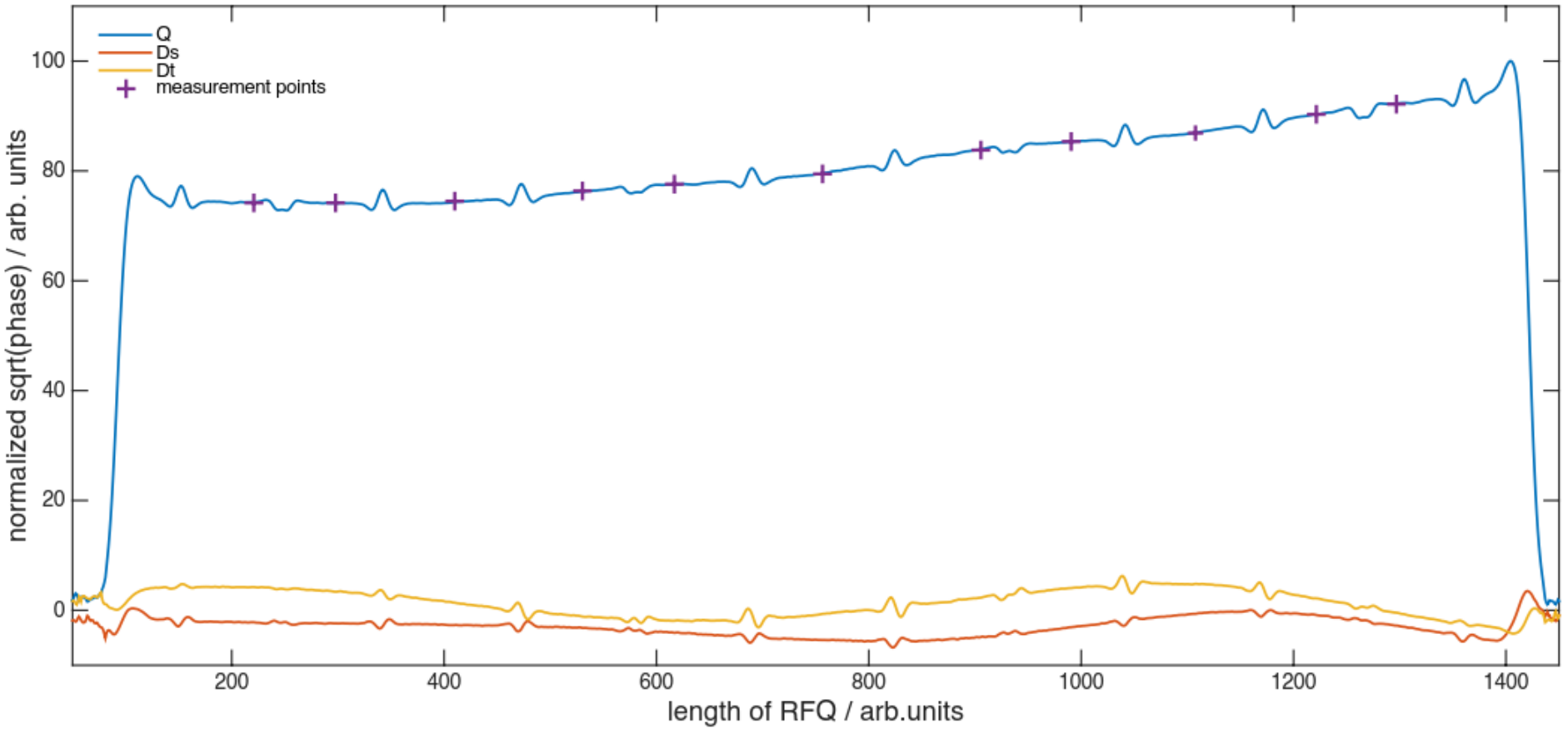


T 26

max Δφ = ± 0.025°



Field Tuning

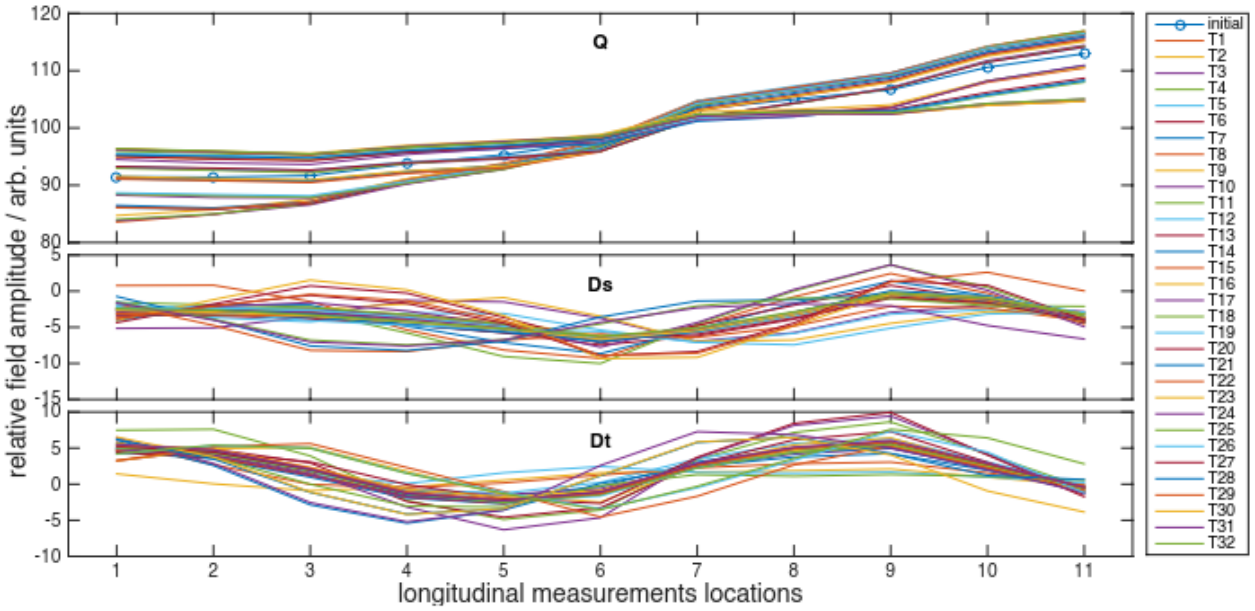


Component	Initial
Q	±10.8 %
Ds	±3.0 %
Dt	±3.6 %

Tuning Algorithm

$$
\begin{aligned}
Q &= (q_1 - q_2 + q_3 - q_4)/4 &&= const. \\
Ds &= (q_1 - q_3)/2 &&= 0 \\
Dt &= (q_2 - q_4)/2 &&= 0
\end{aligned}
$$

$$
\begin{bmatrix} 100 - V_1 \\ \vdots \\ 100 - V_{11} \\ 0 - V_{12} \\ \vdots \\ 0 - V_{22} \\ 0 - V_{23} \\ \vdots \\ 0 - V_{33} \end{bmatrix} = \begin{bmatrix} \frac{\partial Q_1}{\partial T_1} & \frac{\partial Q_1}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Q_1}{\partial T_{32}} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Q_{11}}{\partial T_1} & \frac{\partial Q_{11}}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Q_{11}}{\partial T_{32}} \\ \frac{\partial Ds_1}{\partial T_1} & \frac{\partial Ds_1}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Ds_1}{\partial T_{32}} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Ds_{11}}{\partial T_1} & \frac{\partial Ds_{11}}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Ds_{11}}{\partial T_{32}} \\ \frac{\partial Dt_1}{\partial T_1} & \frac{\partial Dt_1}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Dt_1}{\partial T_{32}} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Dt_{11}}{\partial T_1} & \frac{\partial Dt_{11}}{\partial T_2} & \cdots & \cdots & \cdots & \frac{\partial Dt_{11}}{\partial T_{32}} \end{bmatrix} \cdot \begin{bmatrix} T_1 - 0 \\ T_2 - 0 \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ T_{32} - 0 \end{bmatrix}
$$

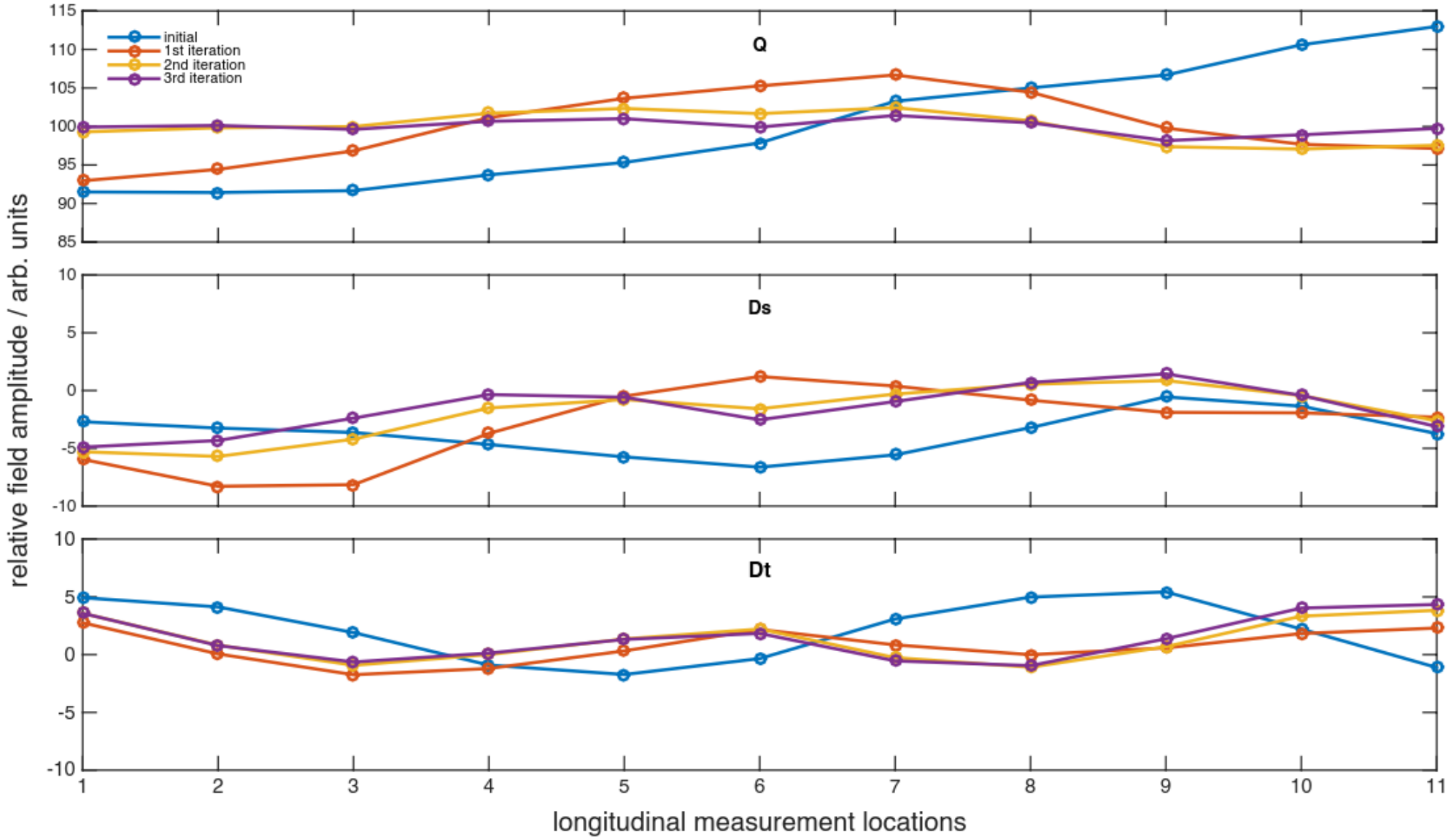


$$
\vec{V} = \mathbf{M} \cdot \vec{T}
$$

$$
\Downarrow
$$

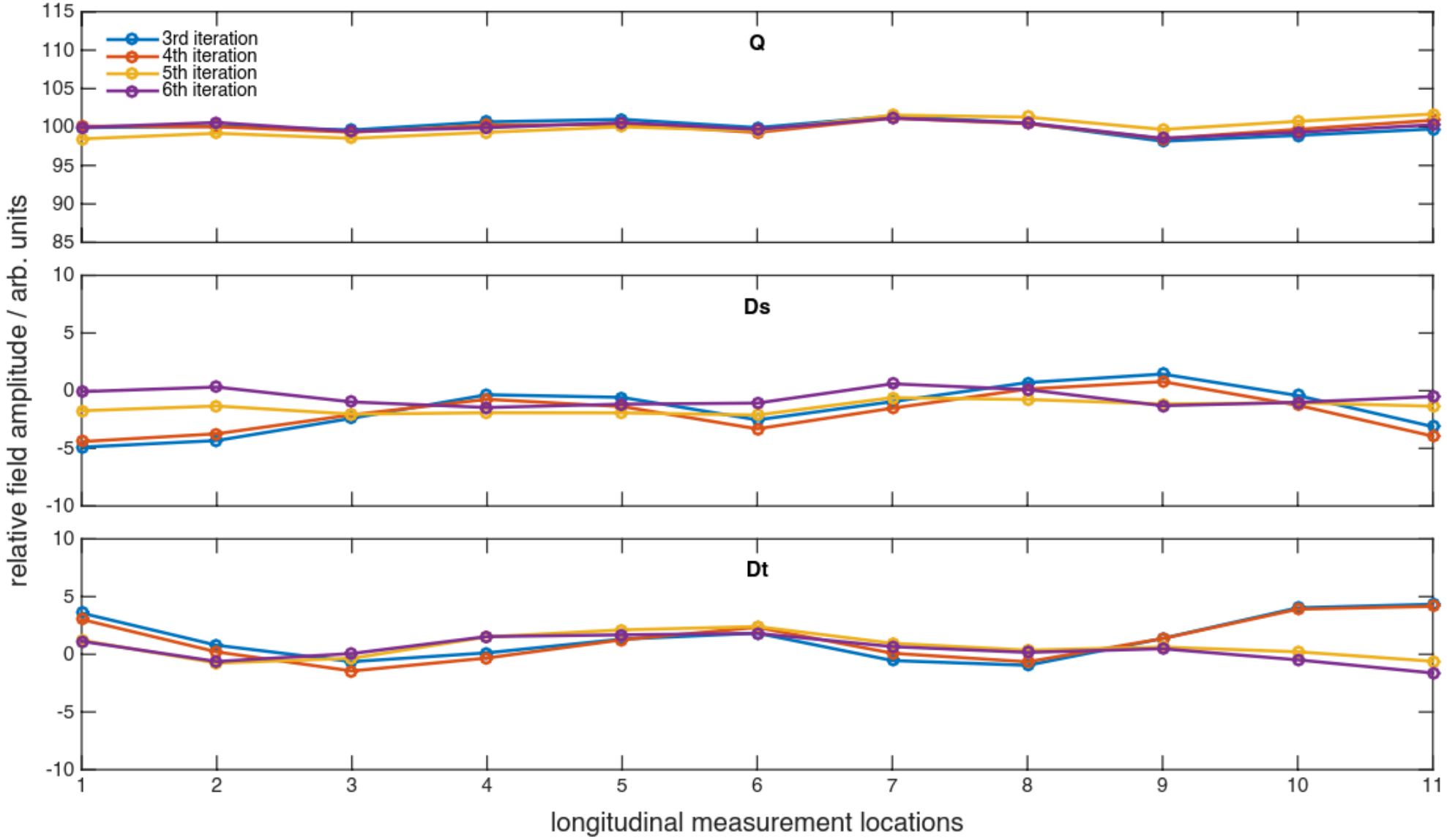
$$
\vec{T} = \mathbf{M^{-1}} \cdot \vec{V}
$$

Field Tuning

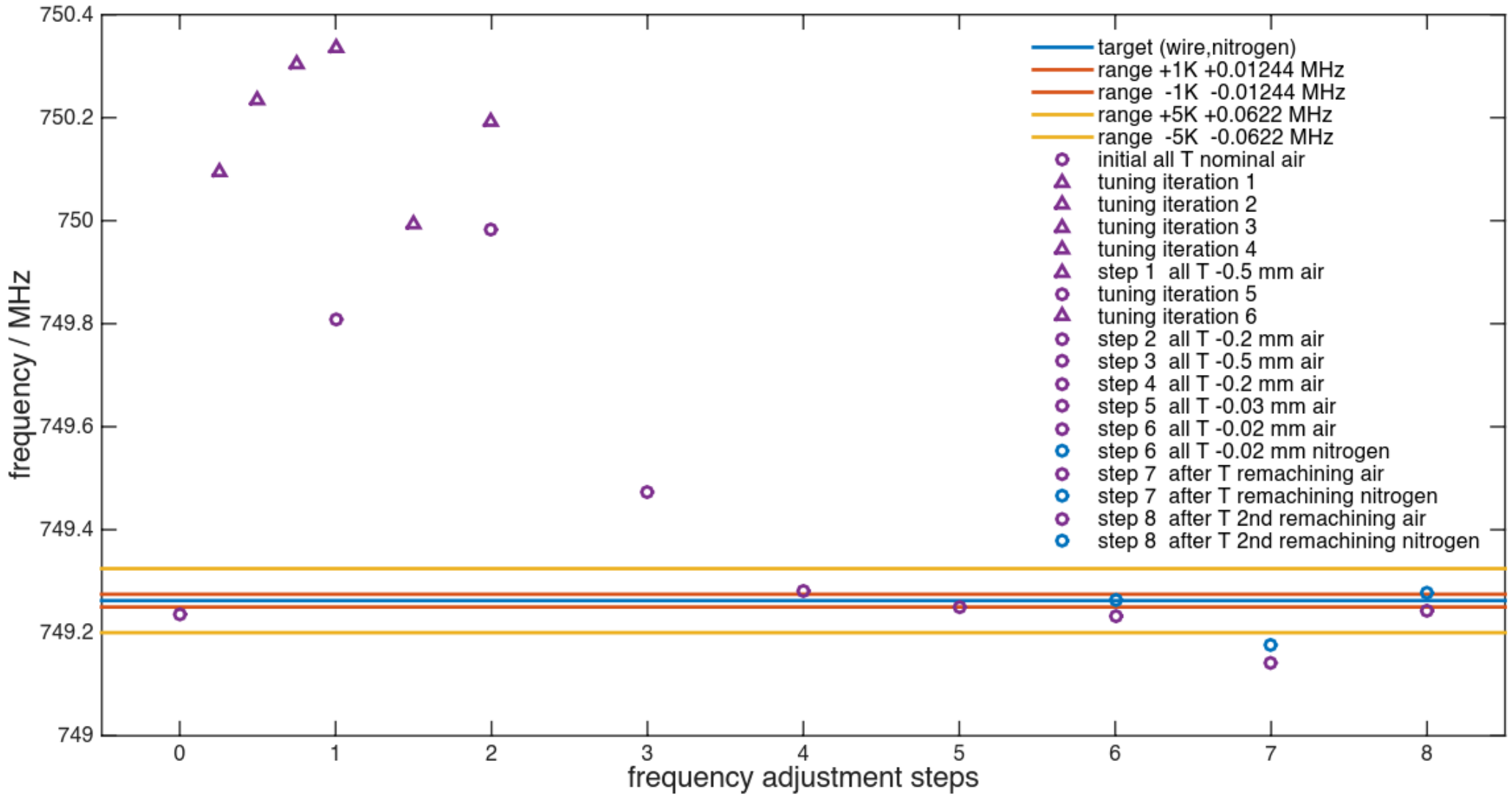


Field Tuning

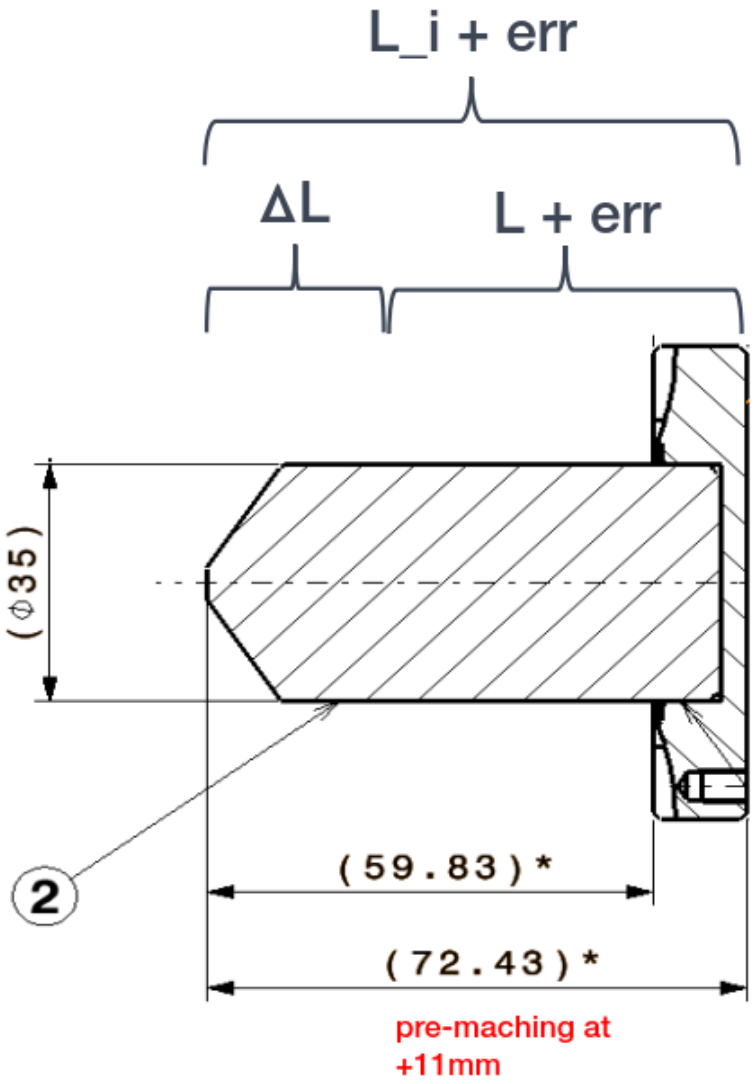
Component	6th iteration
Q	±1.32 %
Ds	±1.03 %
Dt	±1.72 %

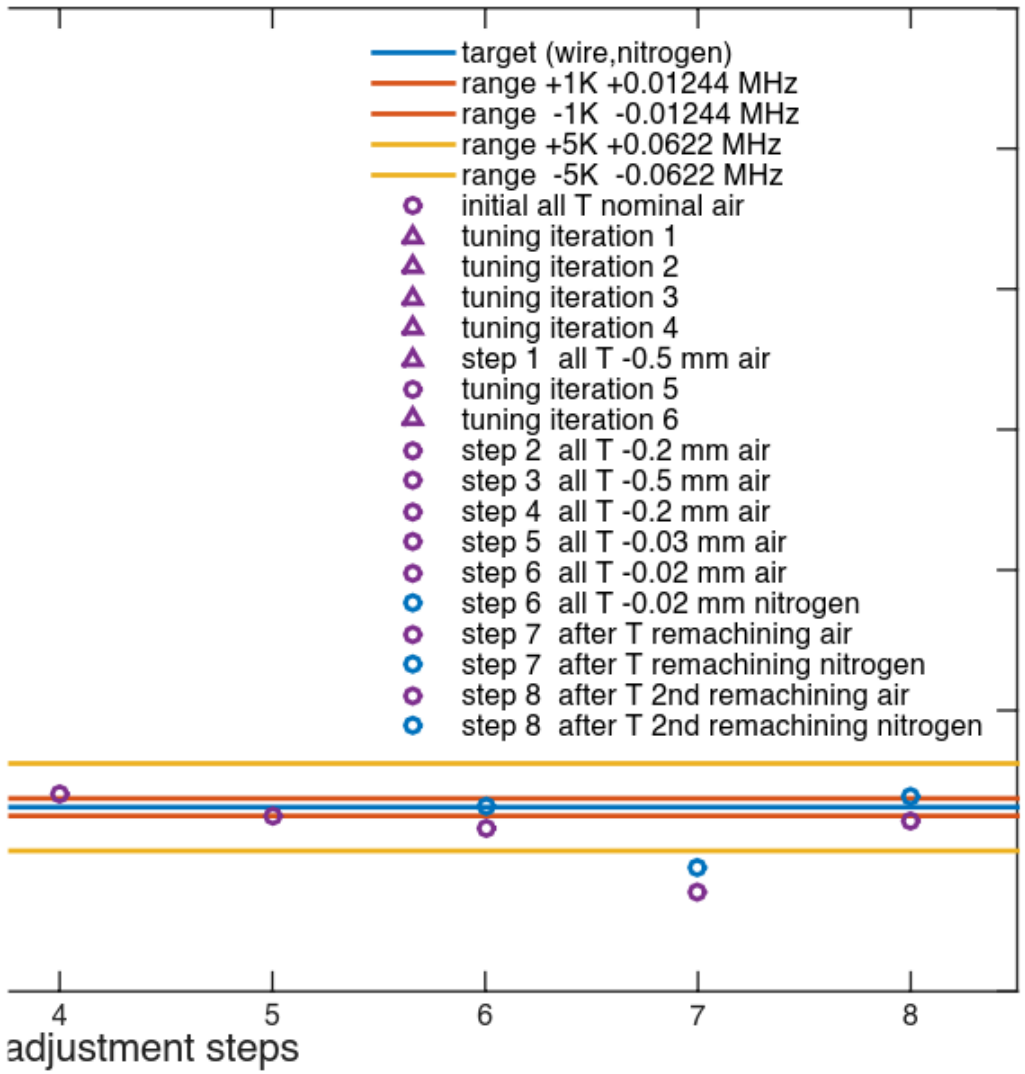


Frequency Tuning

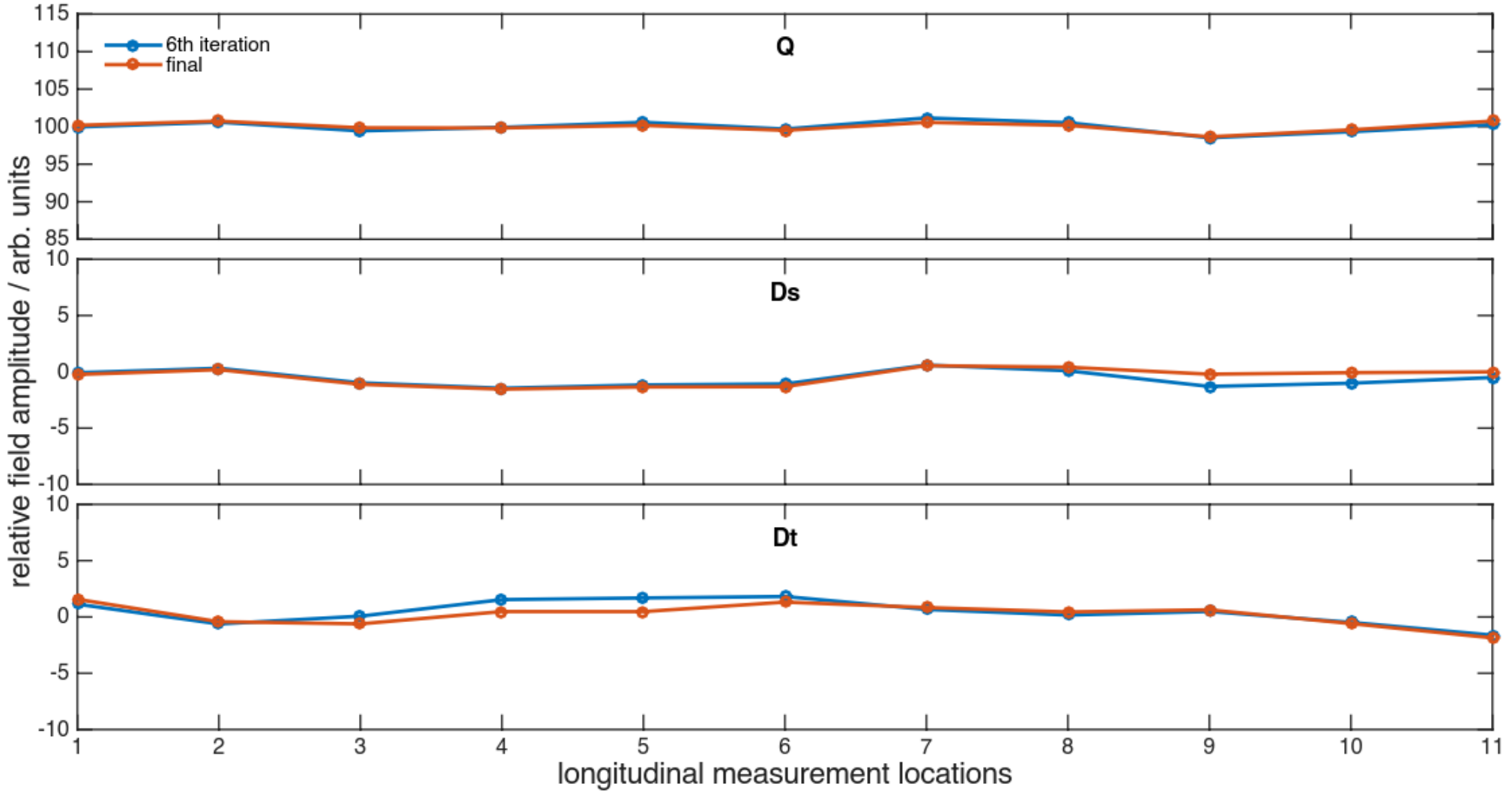


Frequency Tuning





Final Field Distribution



Component	Final Errors
Q	±1.04 %
Ds	±1.04 %
Dt	±1.71 %

Q Values

$Q^*_{0_i}$, $Q^*_{L_i}$ and Q_{ext_i}

$$Q_{ext_i} = \left(\frac{1}{Q^*_{L_i}} - \frac{1}{Q^*_{0_i}} \right)^{-1}$$

from measurements

$$Q_{ext} = \left(\frac{1}{Q_{ext_1}} + \frac{1}{Q_{ext_2}} + \frac{1}{Q_{ext_3}} + \frac{1}{Q_{ext_4}} \right)^{-1}$$

$$Q_{0_i} = \left(\frac{1}{Q^*_{L_i}} - \frac{1}{Q_{ext}} \right)^{-1}$$

Component	Design	Measurement
Q_{0_1}	6440	6492
Q_{0_2}		6492
Q_{0_3}		6355
Q_{0_4}		6944
Q_{ext_1}	21900	26060
Q_{ext_2}		27878
Q_{ext_3}		27878
Q_{ext_4}		21410
Q_0	6440	6570
Q_{ext}	5475	6377
Coupling β	1.18	1.03