On PXIE RFQ tuning.

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Outline

Project X

Complete RFQ models with vane tip modulation:

- Separate modules with vane tip modulation.
- Check on the gaps between modules.
- Complete RFQ with vane tip modulation.

Field flatness tuning:

- Initial field distribution in the RFQ
- Tuner sensitivity per module
- Field distributions in the tuned RFQ

Bead pull consideration:

- General
- Radial position of the bead
- Shape, size and material of the bead
- Accuracy of bead alignment

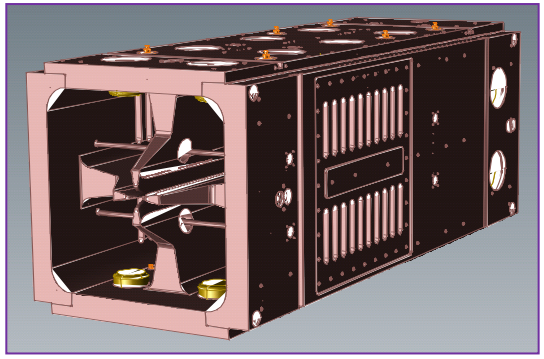
Final table of frequencies

Frequency in MHz

Module	MWS, flat tips	MWS, modulated tips, run 1	MWS, modulated tips, run 2*	COMSOL, modulated tips
1	162.424	162.398	162.408	162.403
2	-	162.261	162.294	162.289
3	162.393	162.205	162.241	162.235
4	162.319	162.203	162.209	162.202
Full model	162.41		162.311	162.260

Mean F = 162.285 MHz

run 2* - denser mesh



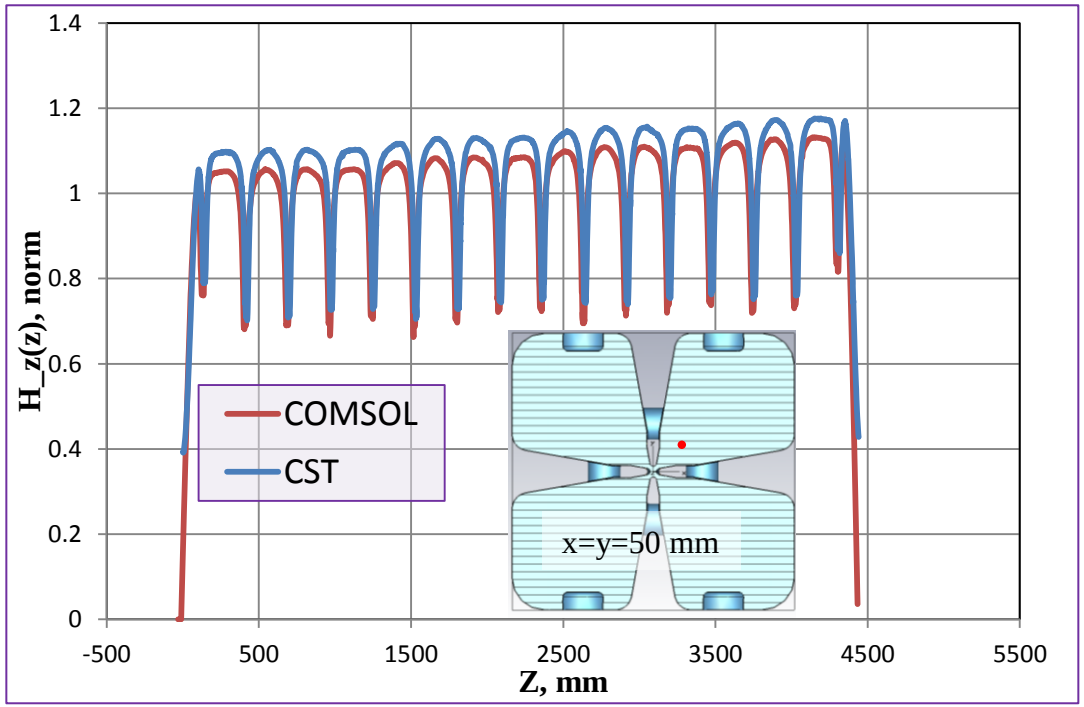
CAD model of Module 1

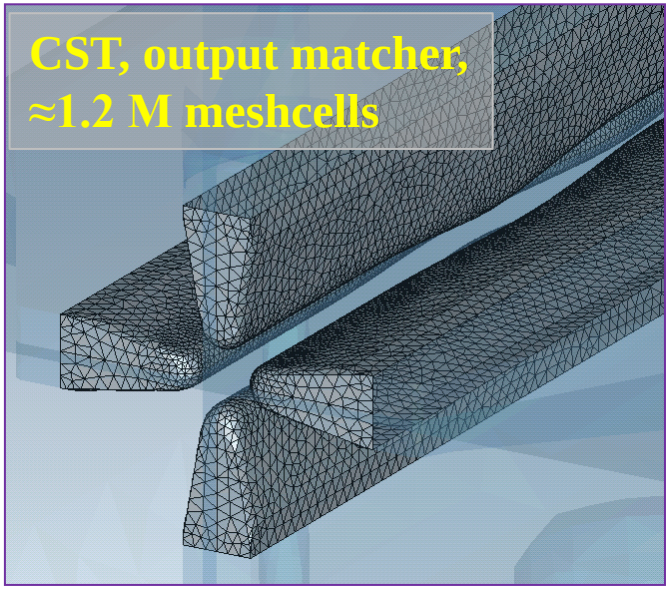
Final set of simulations have performed with CST and COMSOL. Equivalent RF models for the codes were constructed using the original CAD models (date stamp on the models is 01/23/2013). In the final simulations the model construction and meshing were improved for CST. The meshing for COMSOL is rather tricky, but results in a very good mesh. Very fast solver and high quality mesh makes COMSOL a very effective tool

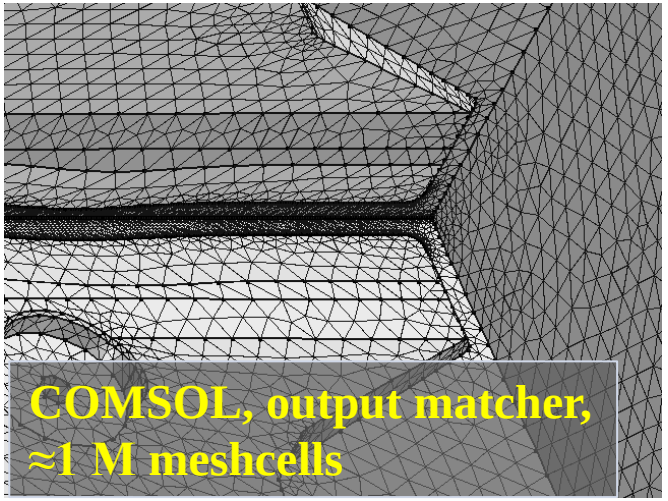
The final simulations confirmed the decrease of frequency of modules and lower frequency of full length RFQ model.

Tilt of field distribution in the full RFQ

Project X

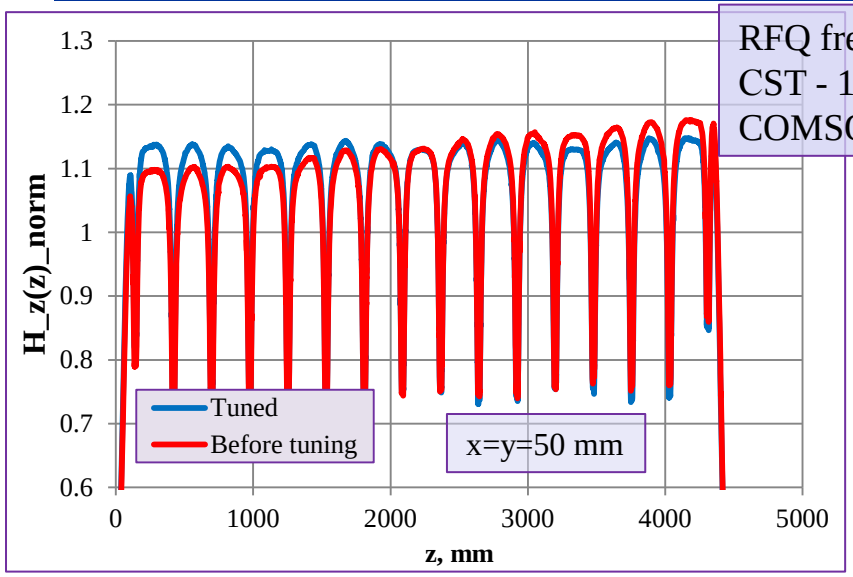




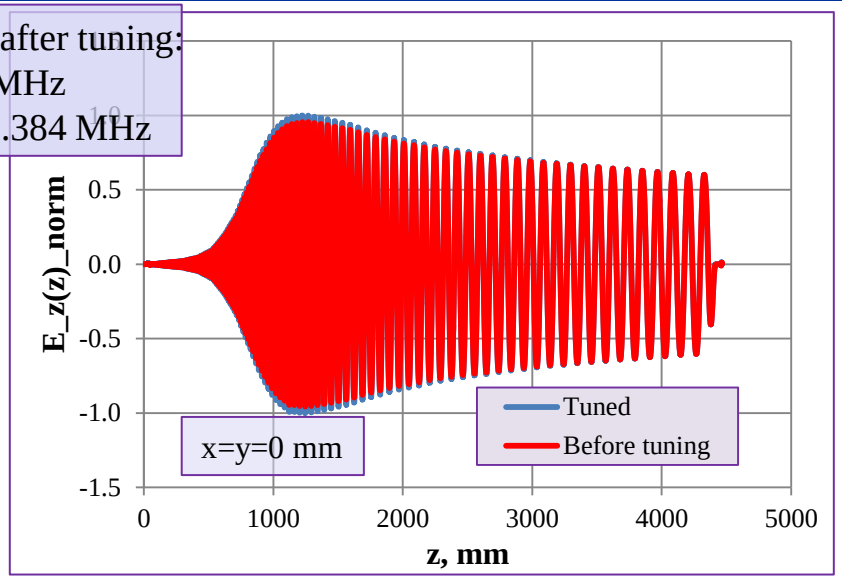


The field distribution in full length RFQ has linear tilt ≈ 7%. CST and COMSOL results are in very good agreement. The normalization factor is slightly different for the curves to show the similarity of fine details. The model with 0.5 mm gap between the modules was simulated, but nothing extraordinary was revealed.

Field flatness tuning



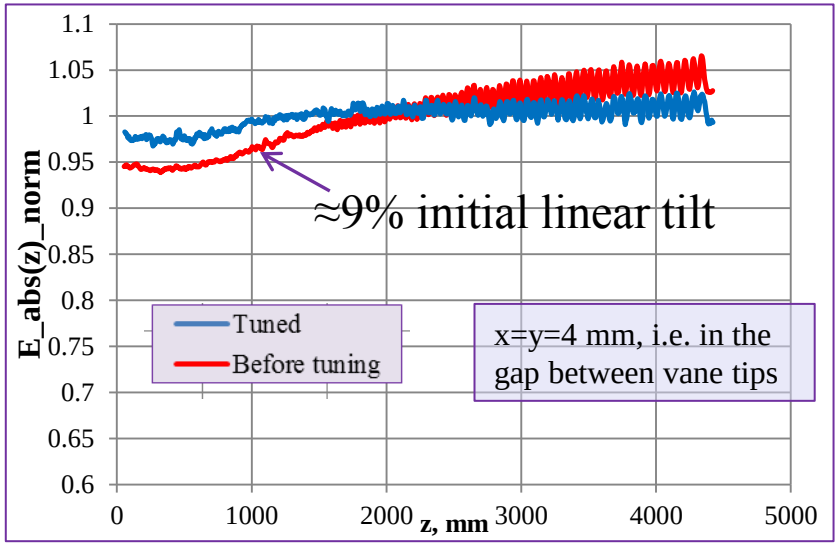
RFQ frequency after tuning:
CST - 162.433 MHz
COMSOL - 162.384 MHz



A tuning coefficient for the output module is 77.43 kHz/mm, which means that the move of ALL tuners by 1 mm change frequency of the module by 77.43 kHz.
Assuming that the coefficient is the same for all modules, the correction of tuner lengths to tune each module to 162.4 MHz was:

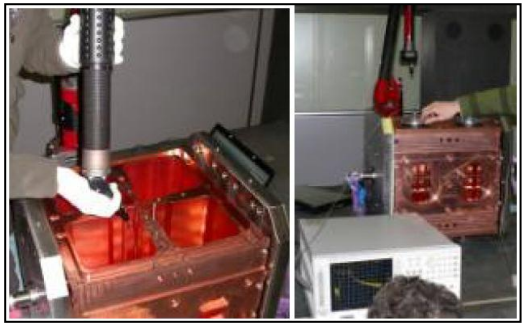
Module 1 – 0 mm
Module 2 – 1.4 mm
Module 3 – 2.05 mm
Module 4 – 2.47 mm

Proper frequencies of the modules practically restored field flatness. Though the electric field distribution between vane tips has sag in the Module 1.



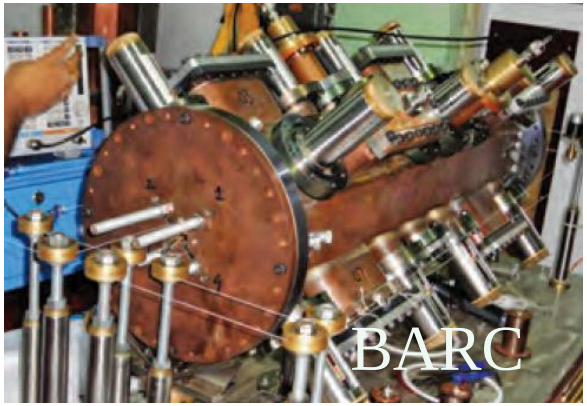
General on bead pull

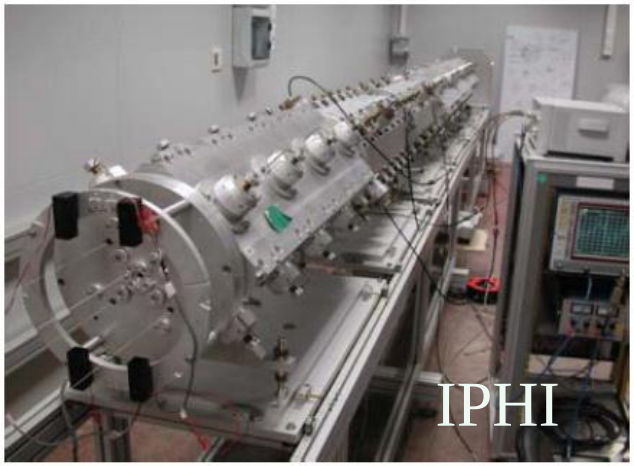
Goal: Verification of separate modules after manufacturing.

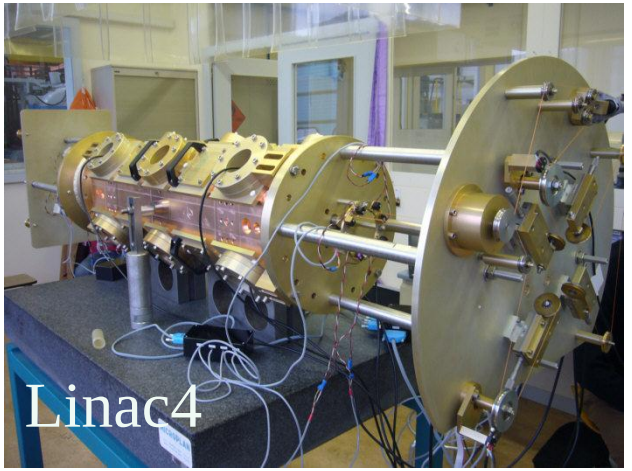


Mechanical and RF measurements of IFMIF RFQ module. IFMIF didn't specify what RF measure-ments they did, but it seems that it was only frequency measurements.

- Temporary end plates (LBNL)
- Bead pull system – LBNL?
- Four strings – symmetry
- One string - simplicity
- Bead diameter, position, material (required frequency shift 1-2 kHz)
- PISLs (dummy?), no tuners and loops
- No PISLs, tuners and loops
- Bead alignment accuracy







Radial position of bead

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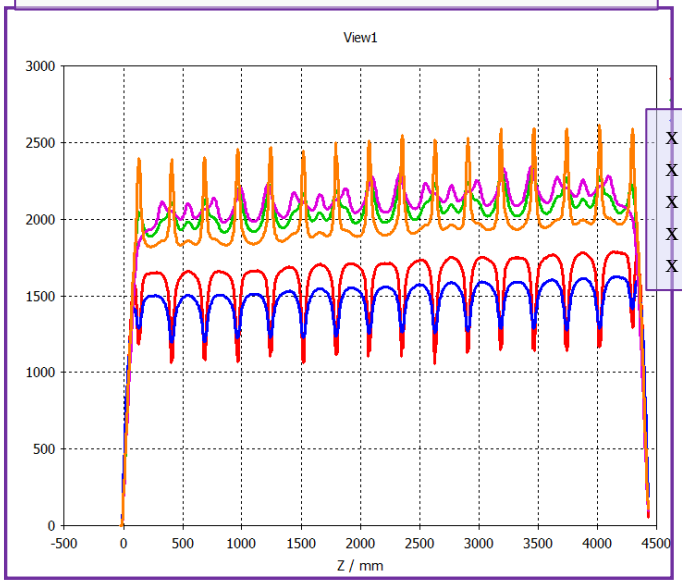
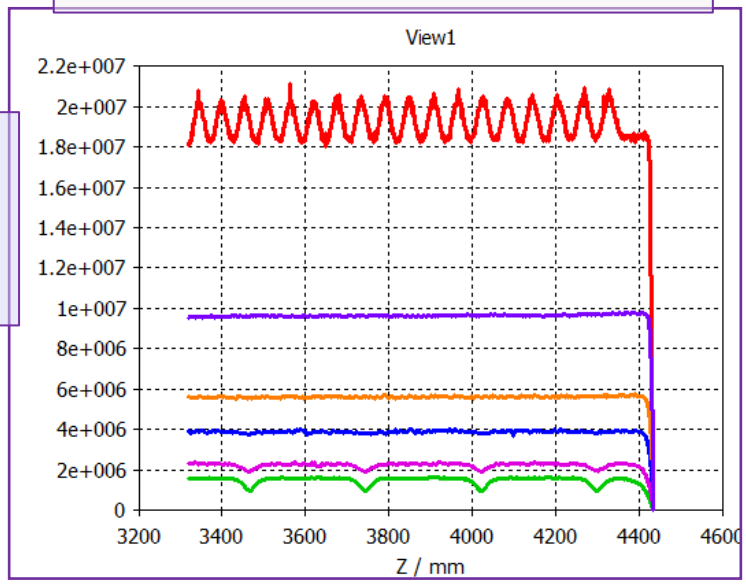
Distribution of H_z in PXIE RFQ at different distance from axis.

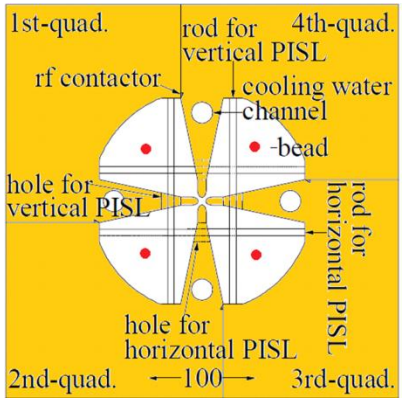


x = y = 150 mm
x = y = 105 mm
x = y = 80 mm
x = y = 50 mm
x = y = 35 mm

x = y = 4 mm
x = y = 10 mm
x = y = 15 mm
x = y = 20 mm
x = y = 30 mm
x = y = 40 mm

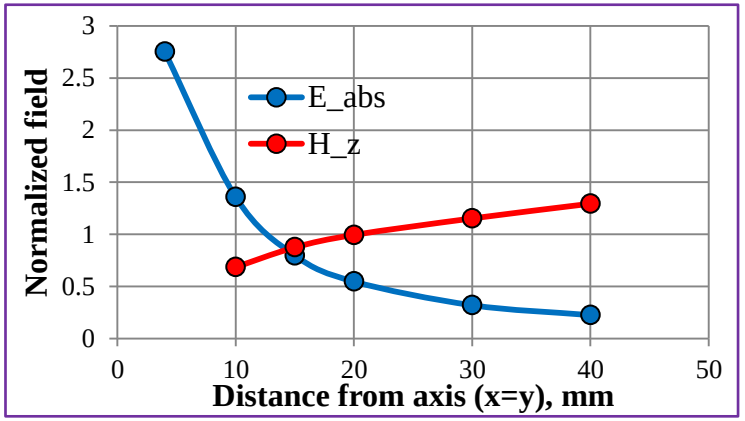
Distribution of E_abs in the PXIE RFQ module 4 at different distance from axis.



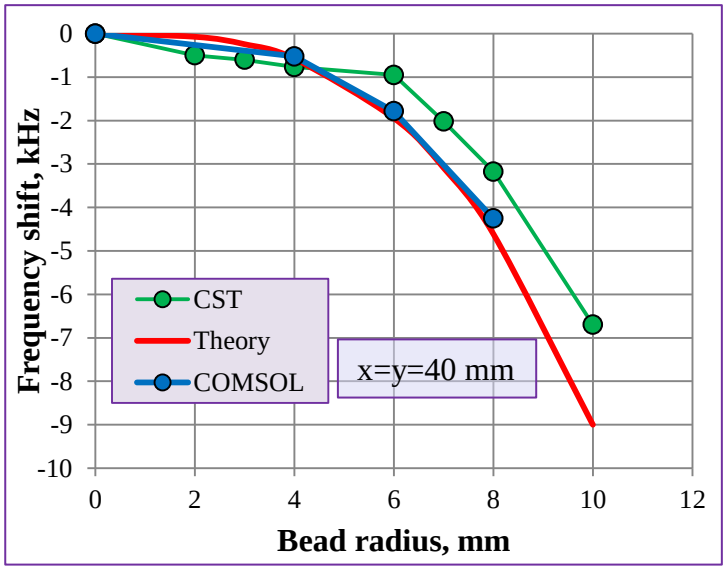


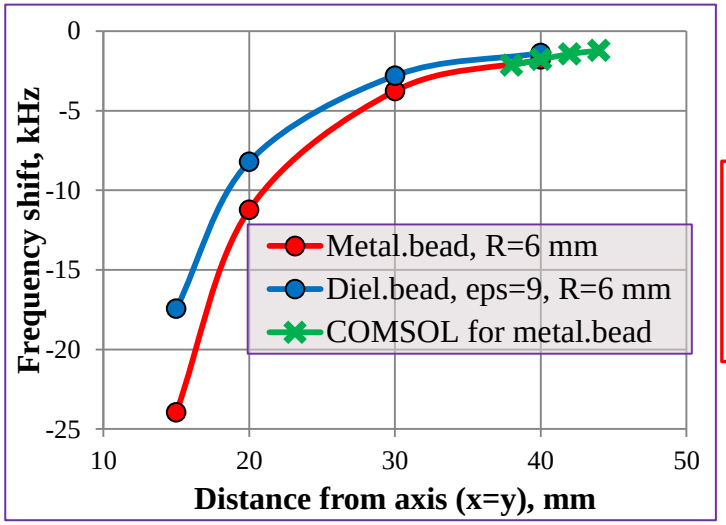
Beads position in JPARC bead pull measurements

We decided to work in area between axis and PISLs, where both magnetic and electric field distributions are smooth.



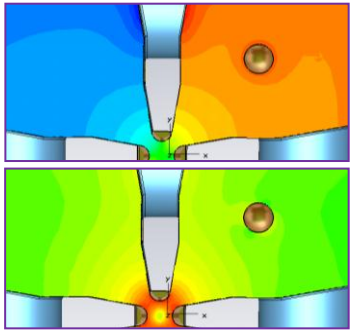
Size, material





Application of Slater theorem

$$\frac{\Delta\omega_0}{\omega_0} \approx \frac{\int_{\Delta V}(\mu|\mathbf{H}|^2 - \varepsilon|\mathbf{E}|^2)dV}{\int_{V}(\mu|\mathbf{H}|^2 + \varepsilon|\mathbf{E}|^2)dV} = \frac{\int_{\Delta V}(\mu|\mathbf{H}|^2 - \varepsilon|\mathbf{E}|^2)dV}{W_{total}}$$



For a dielectric sphere with radius *r*

$$\frac{\Delta\omega_0}{\omega_0} = -\frac{\pi r^3}{W_{total}}\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\varepsilon_0 E^2$$

For diamagnetic metal with radius *r*

$$\frac{\Delta\omega_0}{\omega_0} = -\frac{\pi r^3}{W_{total}}\left(\varepsilon_0 E^2 - \mu_0 \frac{H^2}{2}\right)$$

We chose R=6 mm
Material (options):
Sapphire bead, eps=9
Hollow aluminum sphere

ε_o is the permittivity of free space
ε_r is the relative permittivity of the sphere
μ_0 is the permeability of free space

Contribution of magnetic field for metal bead at x=y=40 mm is 6-7% relatively to total frequency shift

Field distortion and bead alignment

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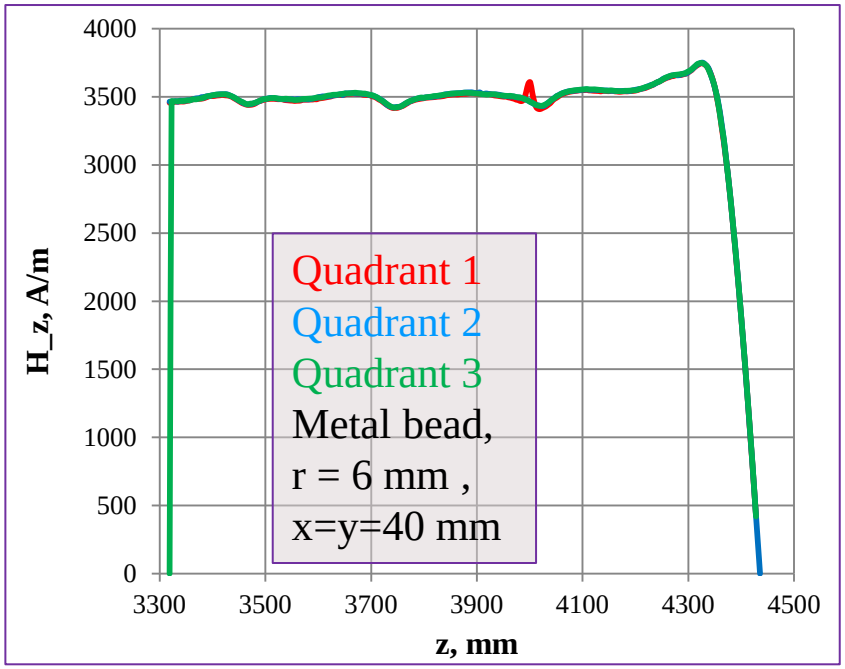
With PISLs – no distortion observed for any bead at any position. The module is very short and stabilized in transverse plane.



Without PISLs no distortion for the frequency shift of 2 kHz. Notice almost smooth field distribution.
For max frequency shift of 20 kHz no result yet, but no big distortion is expected either.

Neighboring modes in a single module are very far from each other:
163.5 MHz - dipole
167.8 MHz - quadrupole
212.5 MHz - dipole

Distance from axis , mm	40	15
Alignment sensitivity, % of field/mm	1.6	8.1
Alignment accuracy for ±1%, mm	±0.63	±0.12

Conclusion

- There is a tilt of field distribution in the full length PXIE RFQ model due to the vane tip modulation.
- The frequency of the modules can be pre-tuned before final assembly. The pre-tuning eliminates the tilt almost completely.
- The area between axis and PISLs is more preferable for bead pull since it has more smooth field.
- The material of bead does not matter much. Both metal and dielectric can deliver required frequency shift.
- The bead radius 6 mm and bead position at 30 mm from axis seems to be acceptable compromise between max frequency shift and alignment accuracy.
- Since the modules are short it looks like bead pull measurements without PISLs and with a single string are possible.