# Project-X RFQ. EM design issues.

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**May 11, 2011**

# Talk Outline

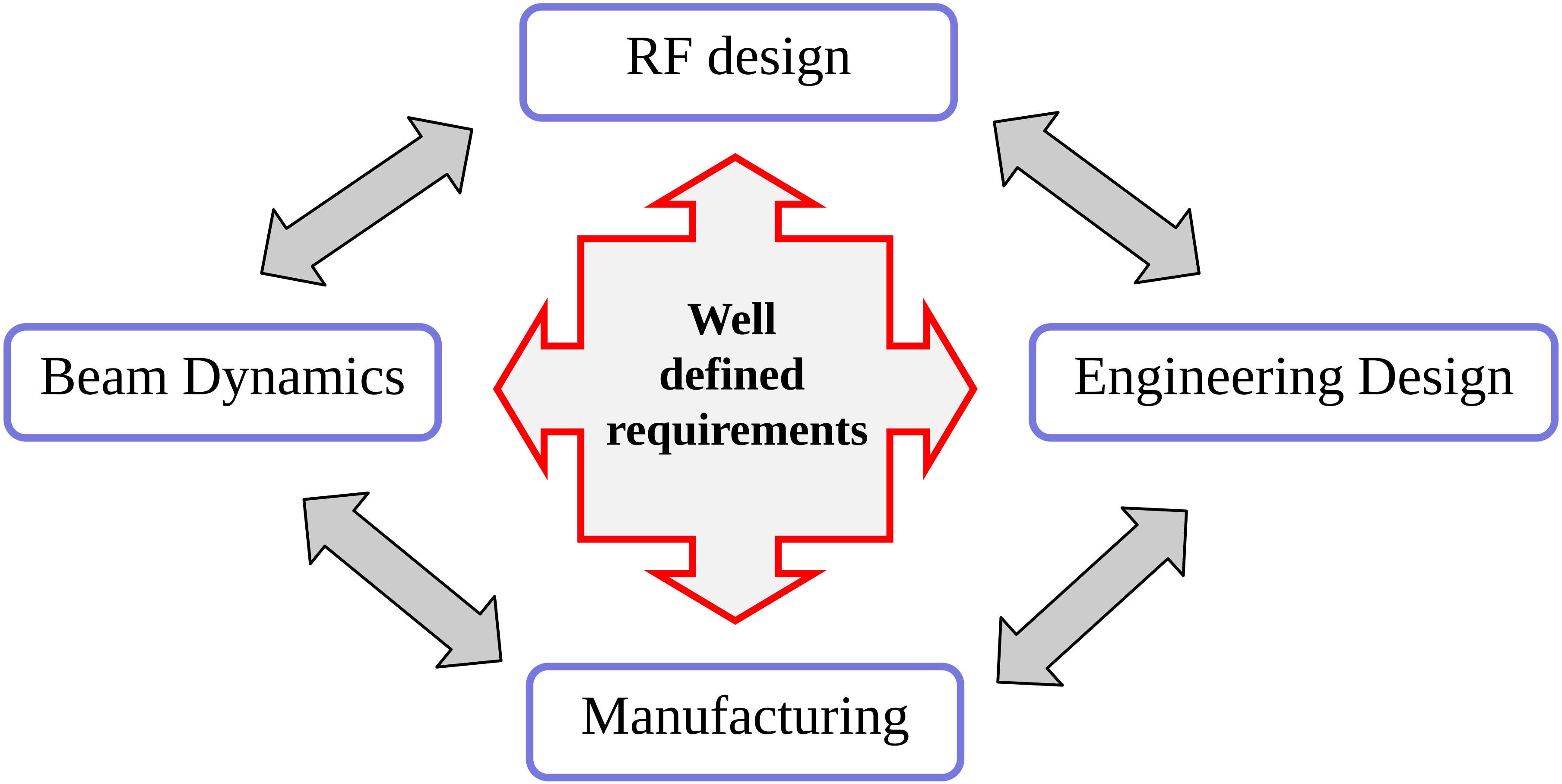
Project X

- General on RFQ design
- Cross-section, tip shape, vane shape
- Input-output terminations
- Field stability - Optimal length, end rode tuners, windows, resonant coupling , PISL
- Segmentation for brazing
- Modulation, segments of different cross-section
- Beam dynamic – RF field vs EM field
- Cooling: vanes, undercuts, body
- Couplers and tuners
- Vacuum ports

} Not this time

Project X

## RFQ Design: An Interactive & Iterative Procedure that takes years for original design



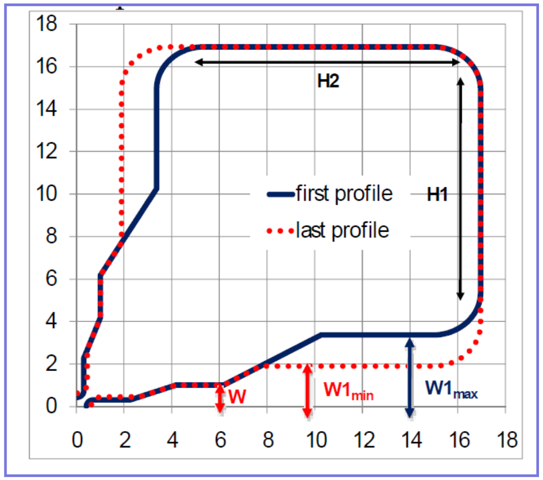
# Cross-section

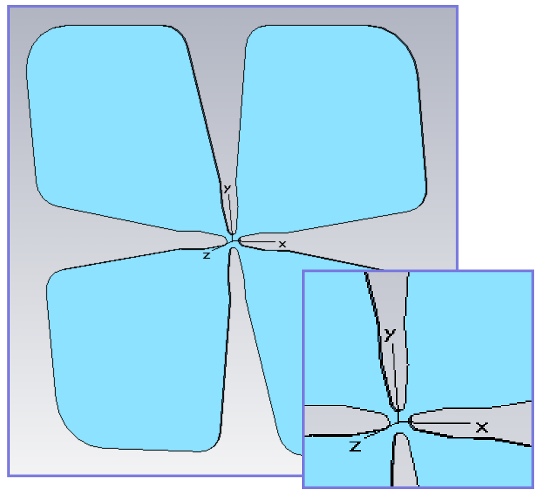
Project X

IFMIF
R0 = 4.1/7.1 mm, r0/R0 = 0.75
25.6 MV/m, 79/132 kV

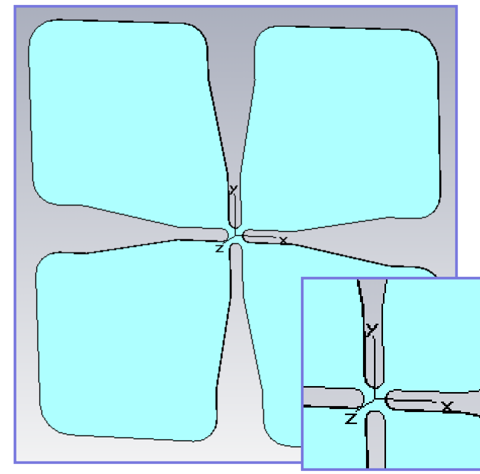
LBNL, 2.1 Mev
R0=5.21 mm, r0/R0 = 0.75
16.4 MV/m, 68 kV

Kolomiets, 2.5 MeV
R0=6.0 mm, r0/R0 = 0.9
17.9 MV/m, 85 kV

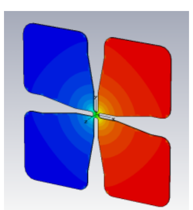


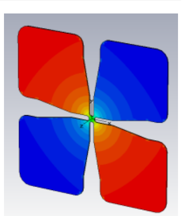

D:157.7 MHz
Q:162.6 MHz




D: 157.2 MHz,
Q: 162.2 MHz



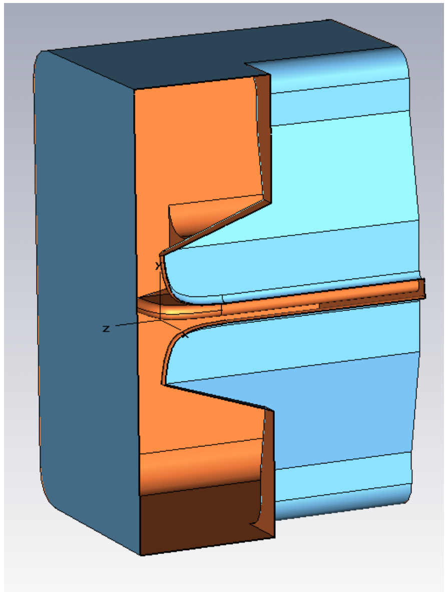
Hz, dipole



Hz, quadrupole

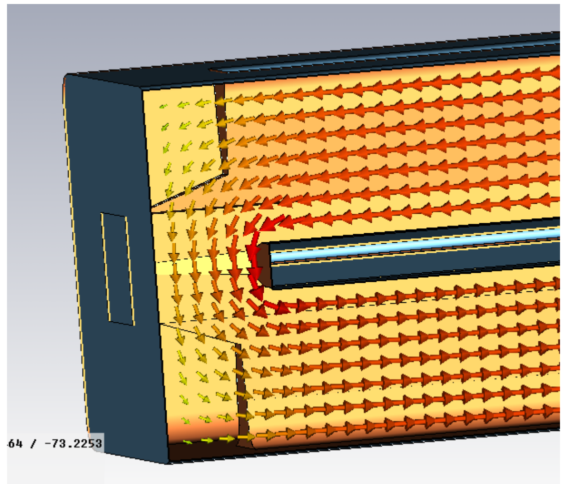
- vane tip shape –> a simple one
- vane shape –> thickness for rigidity and cooling, flat area for tuning
- vacuum stiffness ??

# End terminations

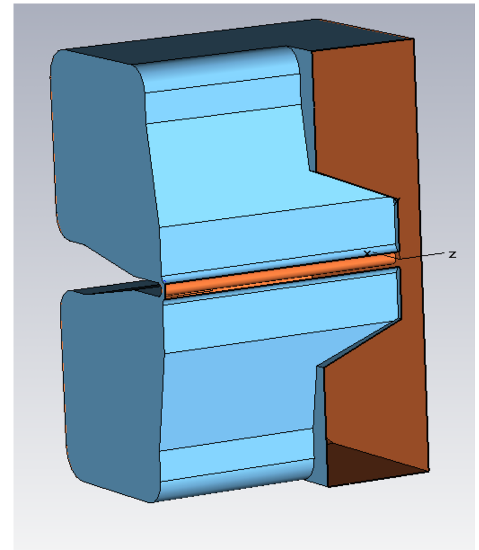


Input matcher

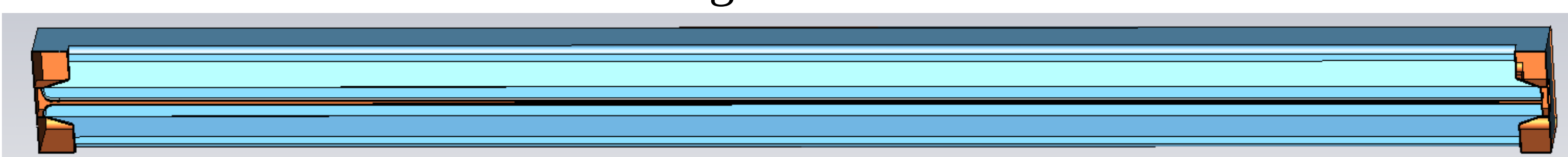
Magnetic flux return



Regular central part.
Vane length 4565 mm



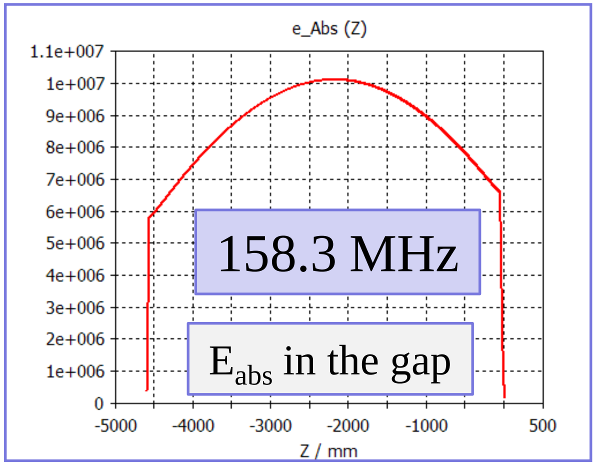
Output termination (matcher)



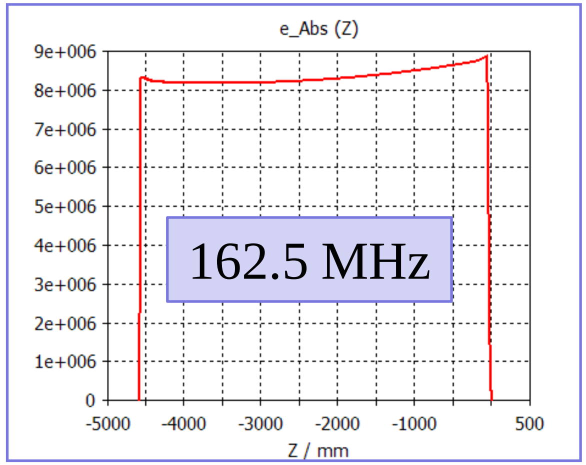
End terminations must be tuned to provide proper operating frequency and operating field distribution

# End terminations. Tuning

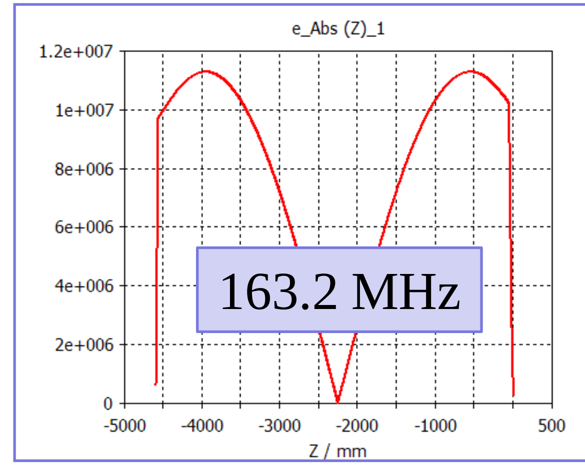
The end terminations can be tuned for a single mode only. Therefore all non-operating modes are distorted. For example, the input matcher has local frequency174 MHz for dipole mode. .



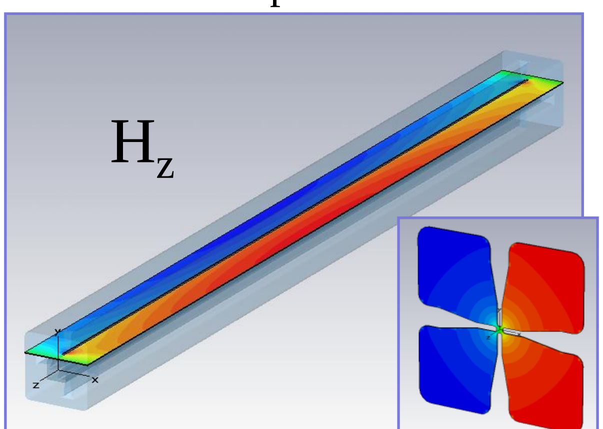

1st dipole.

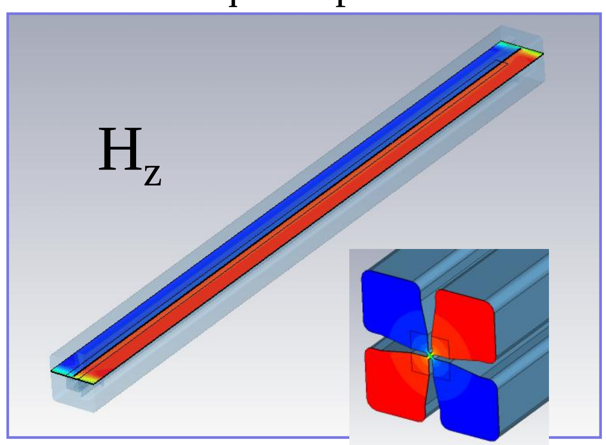


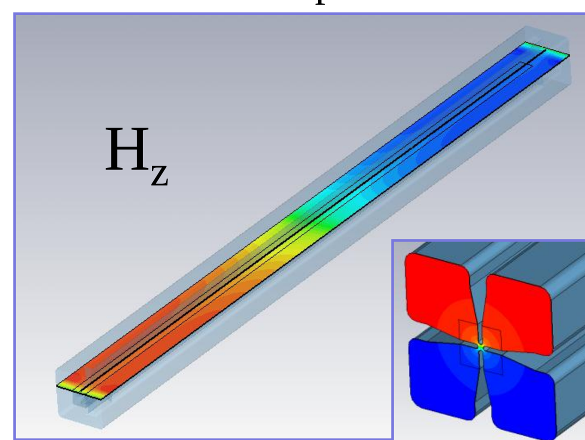

1st quadrupole.




2nd dipole.



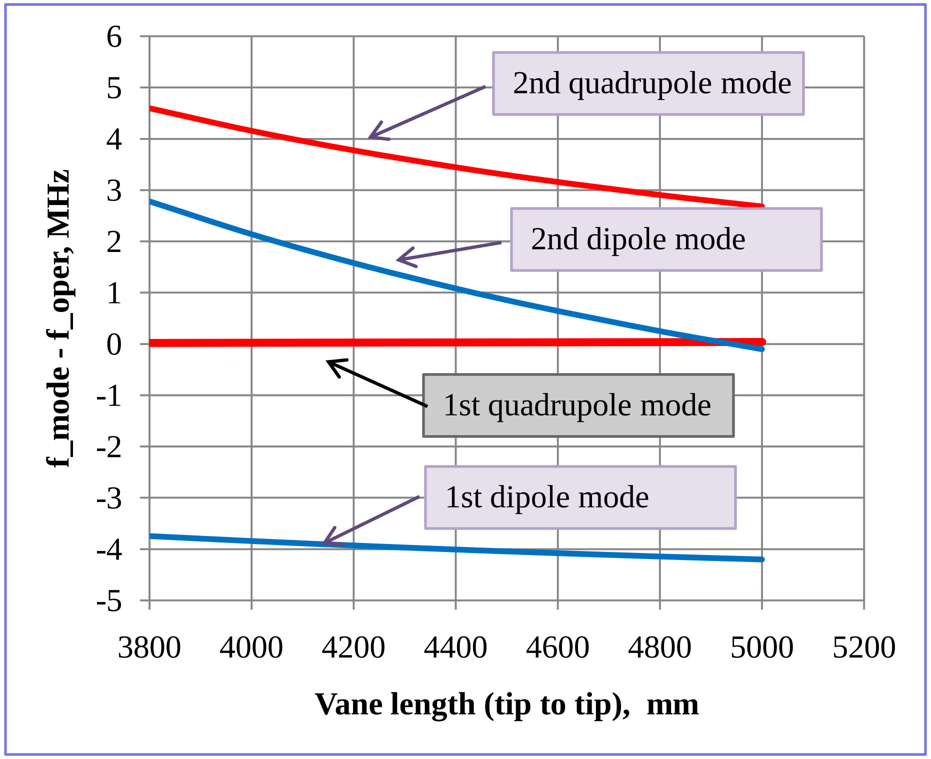



# Field stability. Optimal length.

Project X

Mode separation vs vane length
(Simulations for Kolomiets's variant)

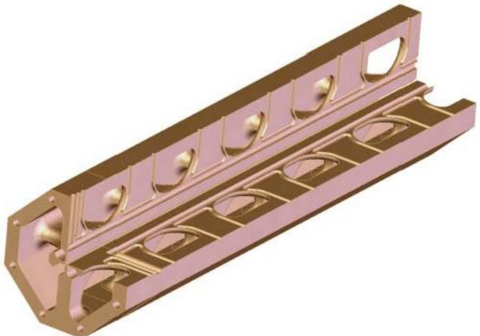



Depending on the length of the RFQ, one of the non-operating modes may be too close to the operating one. Small perturbations can cause these modes to mix with the $TE_{210}$ mode and distort the field. So, the key requirement for field distribution stability is sufficient frequency separation between modes.

For given coupling between the quadrants (gap distance) and the end terminations the optimal vane length seems to be ≈ 3600 mm (Staples 2.1 MeV – 4040 mm, Kolomiets – 4572 mm).

Also there are techniques to reduce the effect of the non-operating modes: vane coupling rings, stabilizing loops, end plate dipole tuners, resonant coupling of RFQ segments, window coupling.

# Field stability. Window coupling. *Project X*



Vanes with windows, "four ladder" cavity

Traditional vane (HINS RFQ)

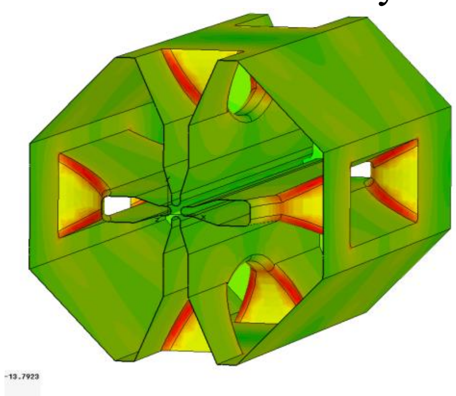
"Four ladder" structure

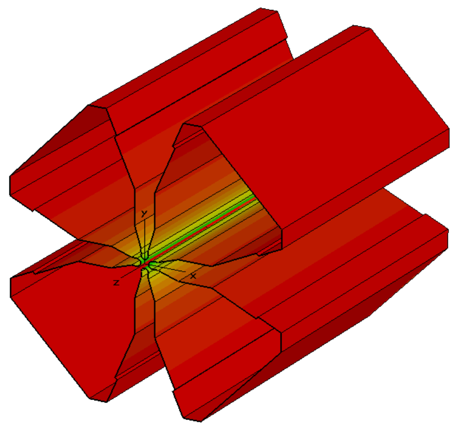
<u>Pros</u>:

- No problem with dipole modes, high azimuthal stability.
- Smaller transverse dimensions

<u>Cons:</u>

- Less effective than traditional
- Non-uniform RF losses, "hot" spots in very inconvenient places.



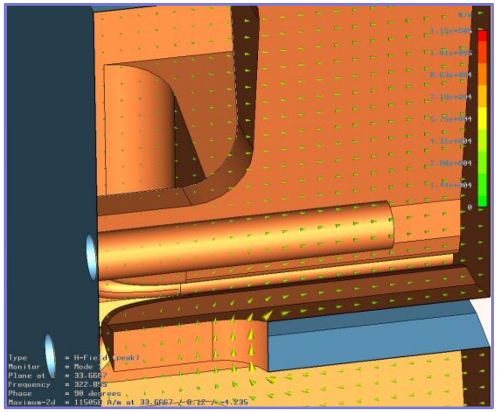
Surface magnetic field distribution

$H_{max}$ = 15640 A/m
P = 202 kW

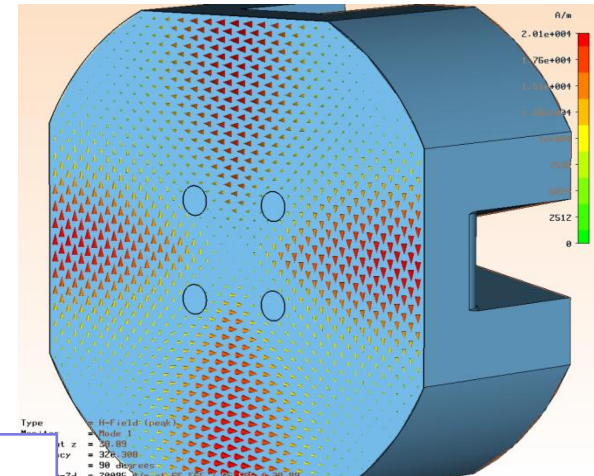
$H_{max}$=2954 A/m
P = 141 kW

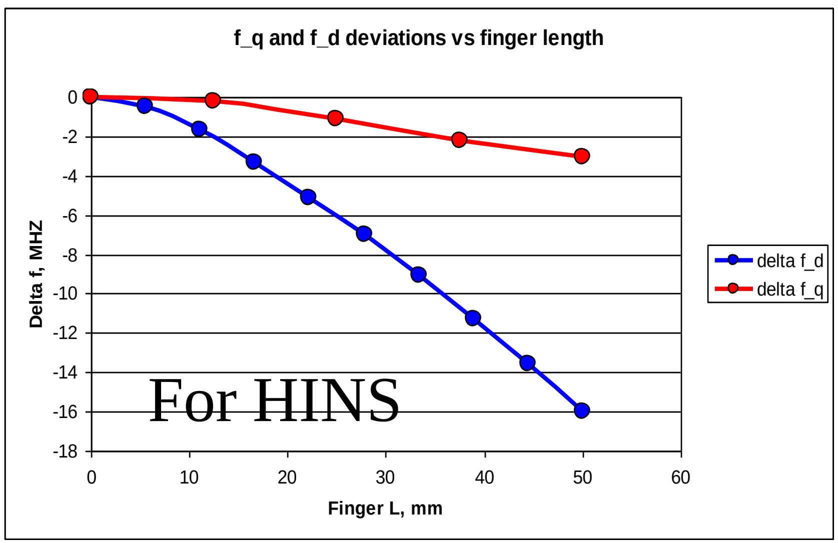
F = 162.5 MHz
V = 85 kV
L = 4.5 m (without ends)

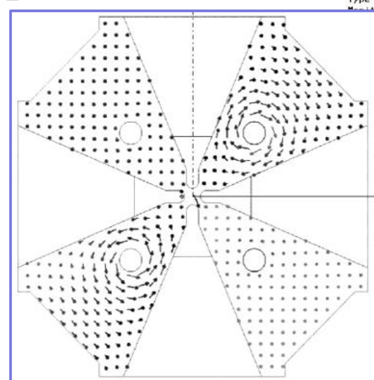
# Field stability. End plate tuners.

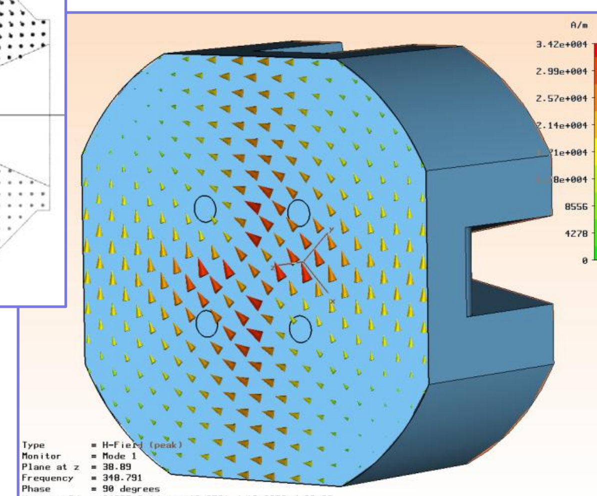


At certain distance from axis they almost do not affect the quadrupole modes. But their coaxial mode couple with the dipole modes, thus lowering the dipole band.



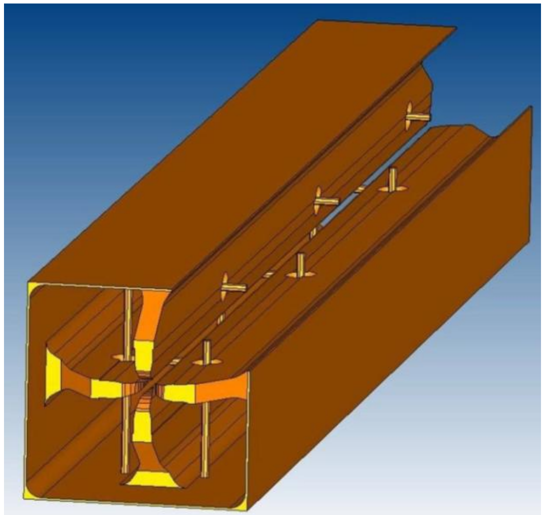





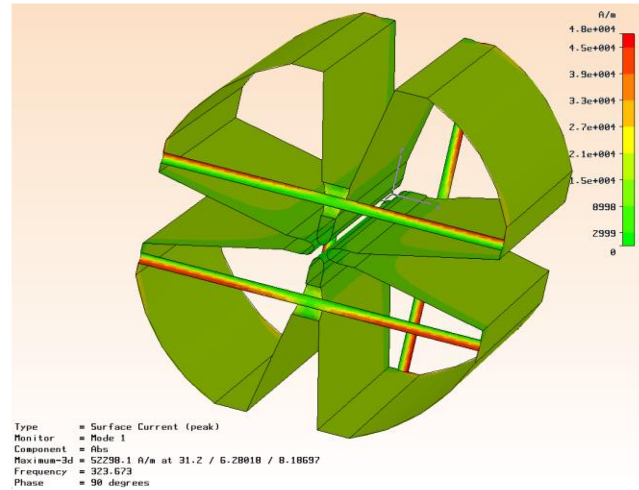

For PrX RFQ the expected vane length is 3600-4800 mm. So, these tuners are useless for us.

# Field stability. PISLs.

Pi mode stabilizing loops – extremely effective for dipole suppression



SNS RFQ




J-PARC

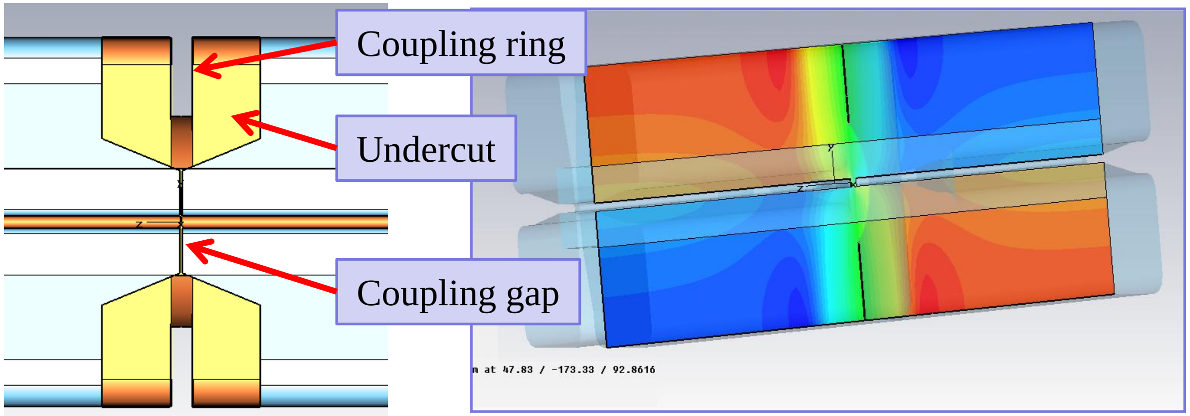
| | | |
|---|---|---|
| SuperFish (without PISL) | f_SF(MHz) & Q_SF | 333.827 & 11276 |
| MAFIA_STD (without PISL) | f_MFS(MHz) & Q_MFS | 330.675 & 10812 |
| MAFIA_PISL | f_MFP(MHz) & Q_MFP | 320.782 & 10264 |

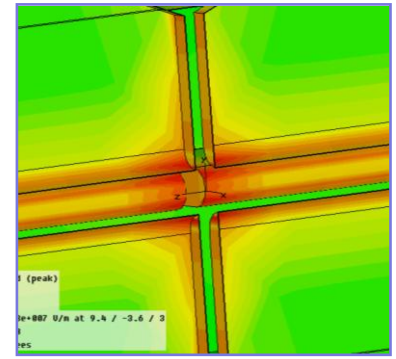
These numbers for J-PARC RFQ are suspicious for me

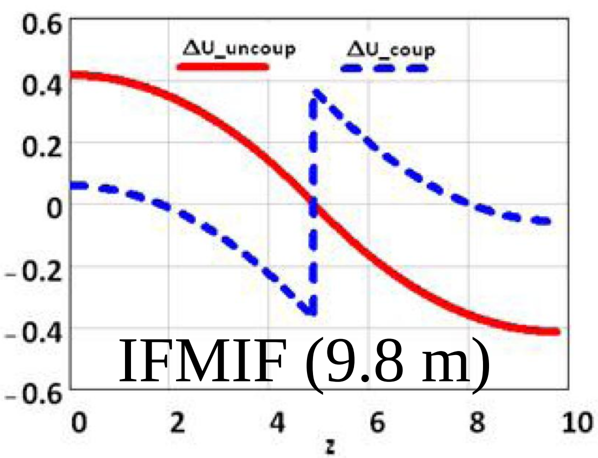
<u>Concerns:</u>

- Mechanical problems – RF, water and vacuum sealing
- Heating and cooling problems.

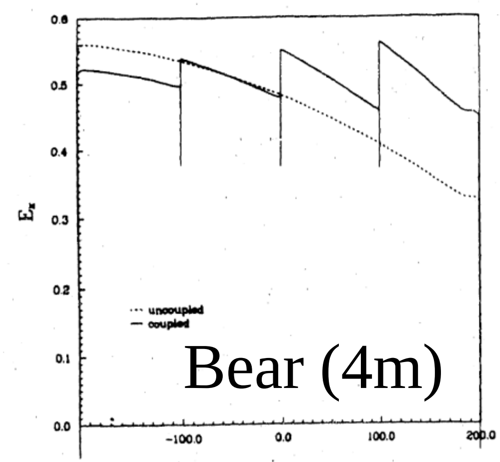
# Field stability. Coupling cells.






Comparison of the voltage (IFMIF) and the field in the gap (Bear) distribution for coupled and uncoupled structures with the same perturbation at one end.




So, no advantages with one coupling cell?

# Segmentation.

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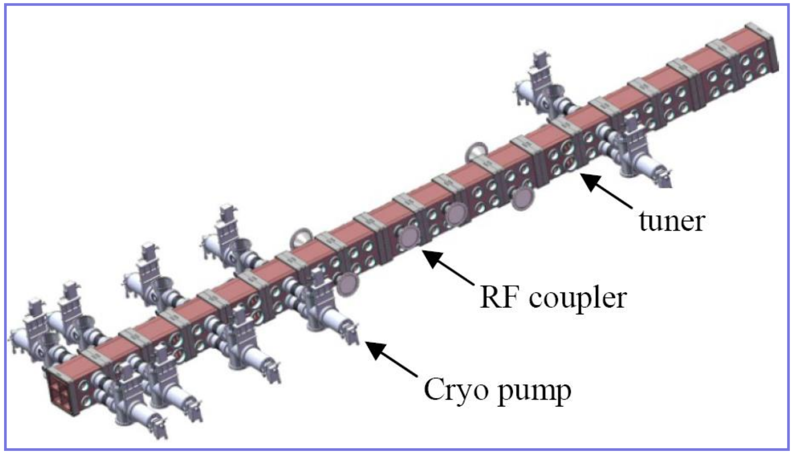
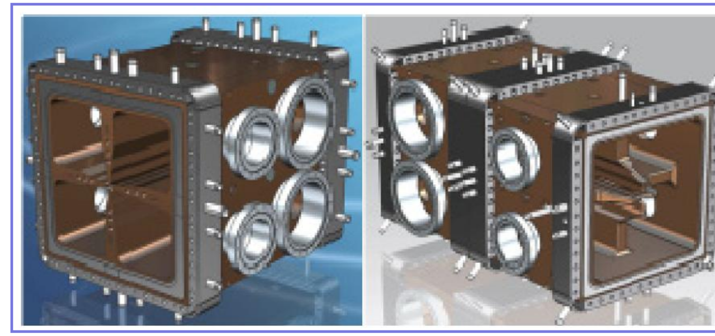
IFMIF: interesting example



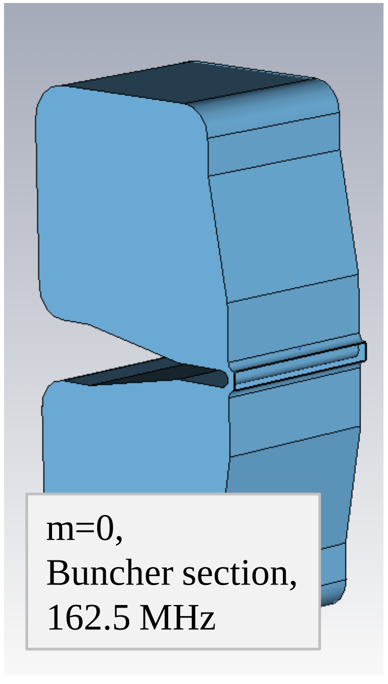
Total length – 9.8 m, overall transversal dimensions - 430x430 mm, 18 flanged modules, length of one module – 543.35 mm.
No coupling cells, PISLs, VCRs, vane windows, dipole end plate tuners.

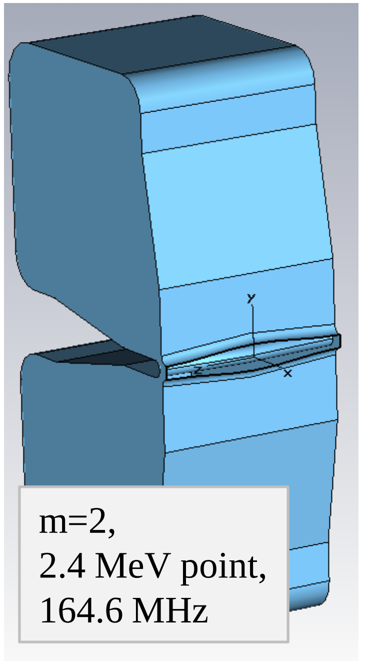
The flange must de-couple mechanical, vacuum and RF connection and provide proper alignment. It is a complicated part.

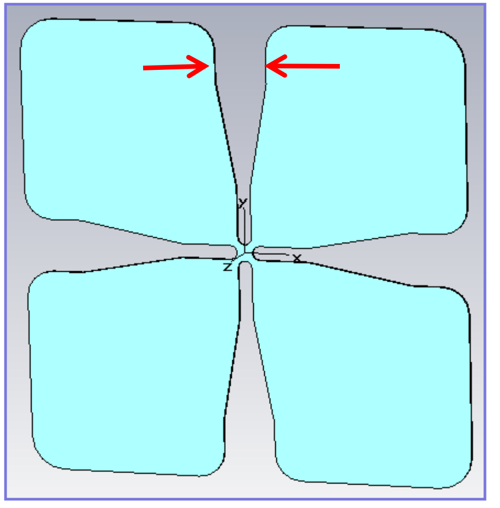
# Individual tuning of segments

*Project X*

We found that the local frequency of operating mode depends on modulation. The variation of local frequency leads to field distribution variation.



In case of short segments, the local frequency of each segment can be tuned individually. The usage of tuning elements and power losses can be reduced.

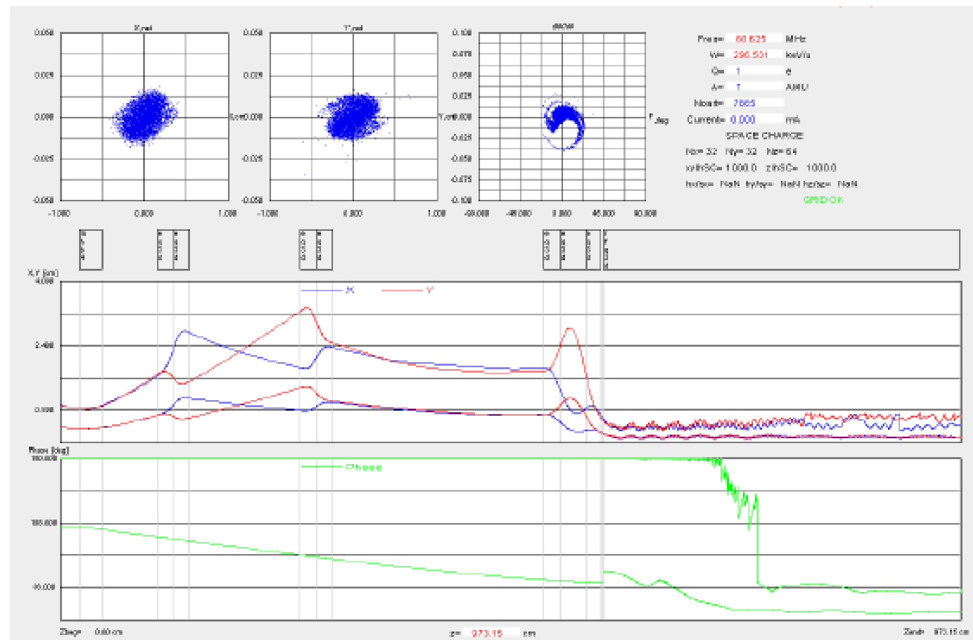
# RF field vs EM field

Project X

RFQ design and tracking codes use electrostatic fields.

Ostroumov: The Full 3D field distribution was exported from MW-Studio into TRACK as a **single cavity.**

| Quantity | EM-Studio Cell by Cell | MW-Studio Full RFQ |
|---|---|---|
| W-output (keV/u) | 296.5 | 296.5 |
| Transmission (%) | 83 % | 79% |
| Long. RMS π deg.keV/u | 18.6 | 22.4 |
| Trans. RMS π mm.mrad | 0.215 | 0.22 |
| Output Beam | Symmetric | Almost symmetric |



The lower transmission and the larger longitudinal emittance may be due to the lower precision of the RF fields. We can use cell-by-cell RF simulation with very high precision to verify the electrostatic approach.

# Conclusion

- **Keep looking…**