Recent RF Simulation Studies of PXIE RFQ.

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Outline

Project X

Mechanical solid model verification:

- Low frequency and distorted fields in Module 1 (input matcher).
- Output cutback retuning.
- Verification of separate modules.
- Impact of vane tip modulation.

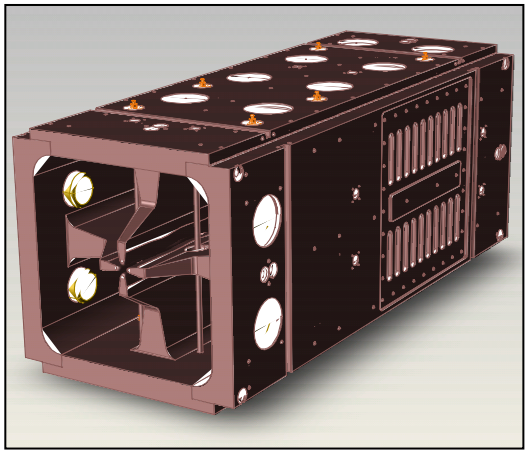
Multipacting simulations:

- MP in SNS RFQ
- MP in PXIE RFQ

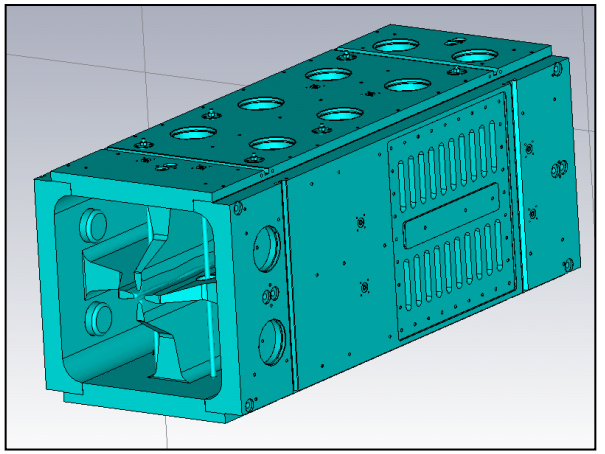
On the end-wall design:

- End-wall deformation.
- End-wall heating.
- Increased beam aperture in the input end-wall.

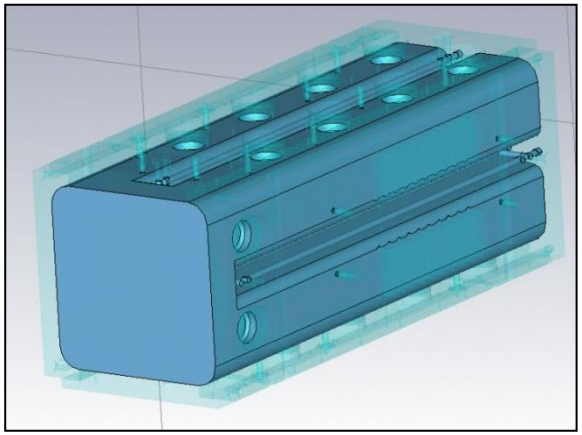
Import the solid models into CST



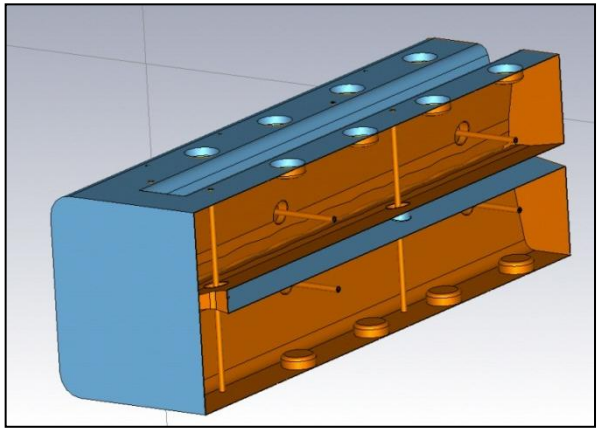
1) Mechanical solid model of RFQ module



2) Mechanical solid model of RFQ module imported into CST MWS



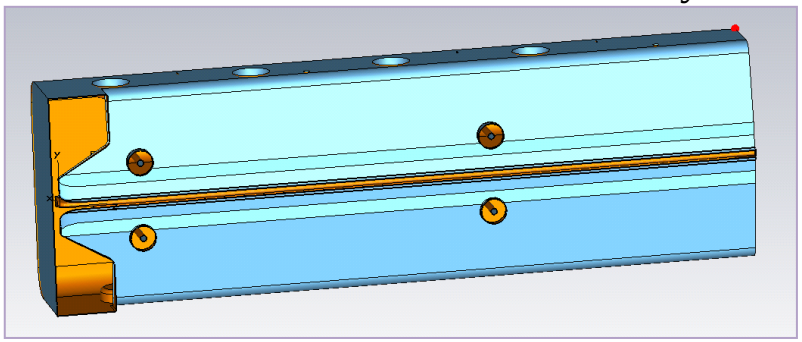
3) The model is filled up with “vacuum” to create so called RF volume.



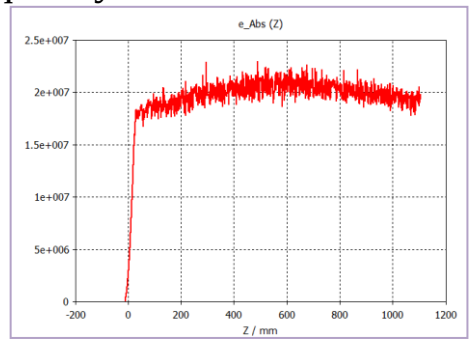
4) All metal parts of the model and external features are removed, only RF volume is left.

Correction of Module 1

The problem has been detected by Andrew Lambert (LBNL): the mechanical model of PXIE Module 1 converted to RF model demonstrated very low frequency and distorted field distribution.

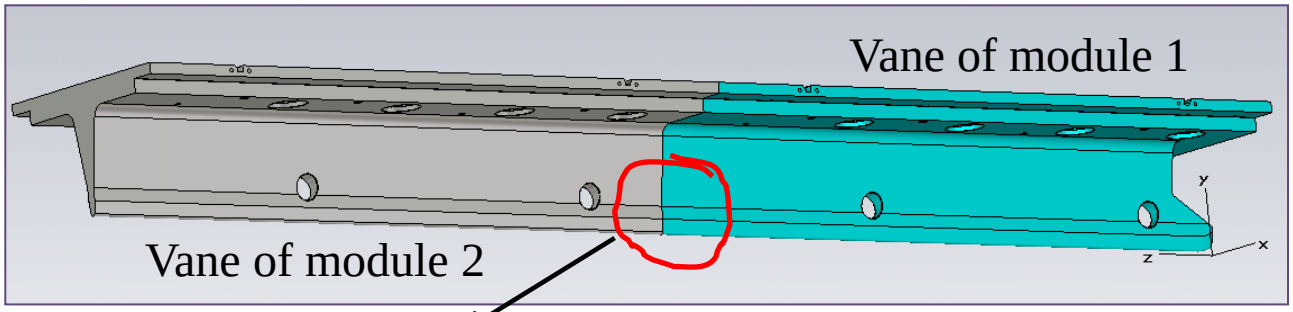


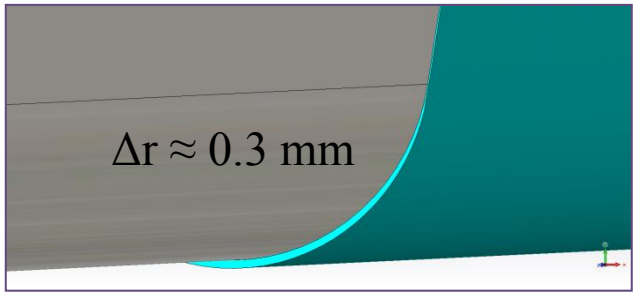
Module 1 with input matcher



Field distribution

Before correction:
Frequency 159.98 MHz
Field bump ≈ 12%



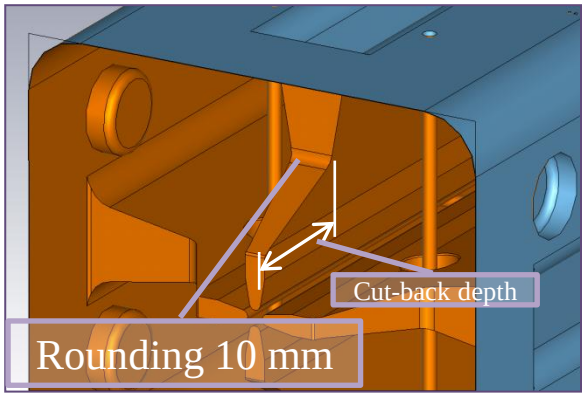


This deviation of mean aperture radius from nominal value has been found in Module 1 and corrected. After correction nominal frequency and flat field distribution restored.

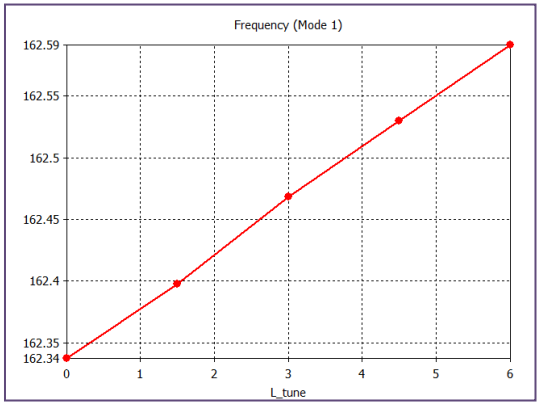
Output cut-back retuning

Project X

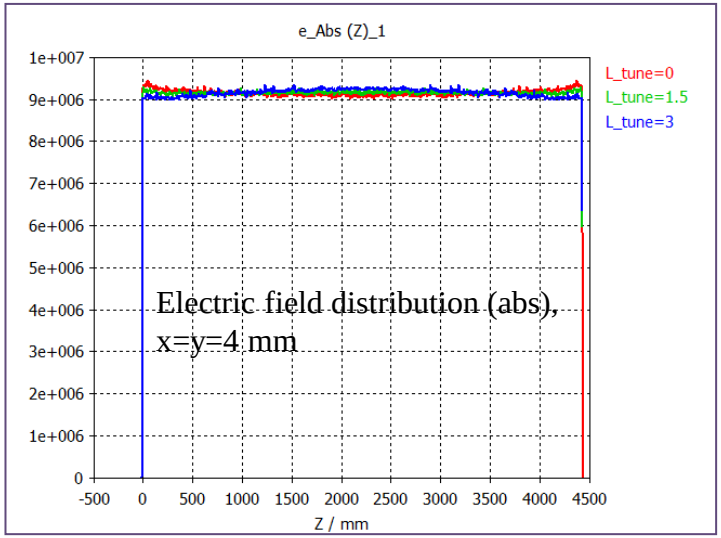
It was found that in original RF models the output cut-backs has been tuned with rounding 30 mm instead of the final value of 10 mm. The re-tuning has been performed with full length RFQ with two OUTPUT terminations, since longer structure is more sensitive to termination detuning.

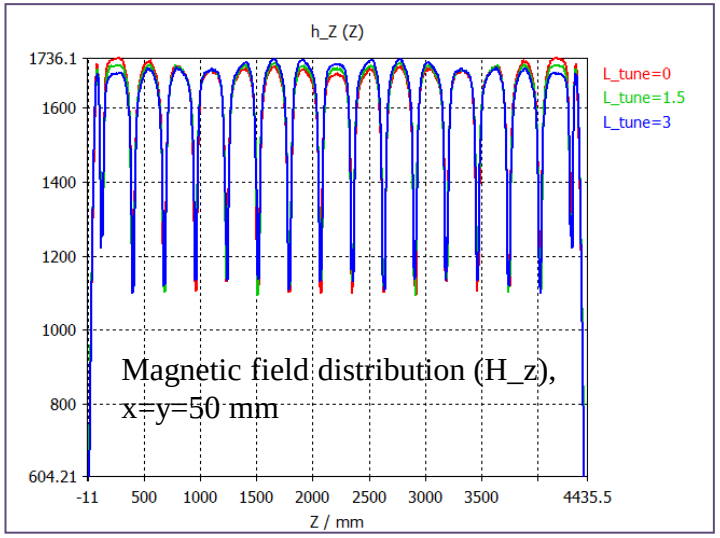


Output termination. The rounding in question is shown.



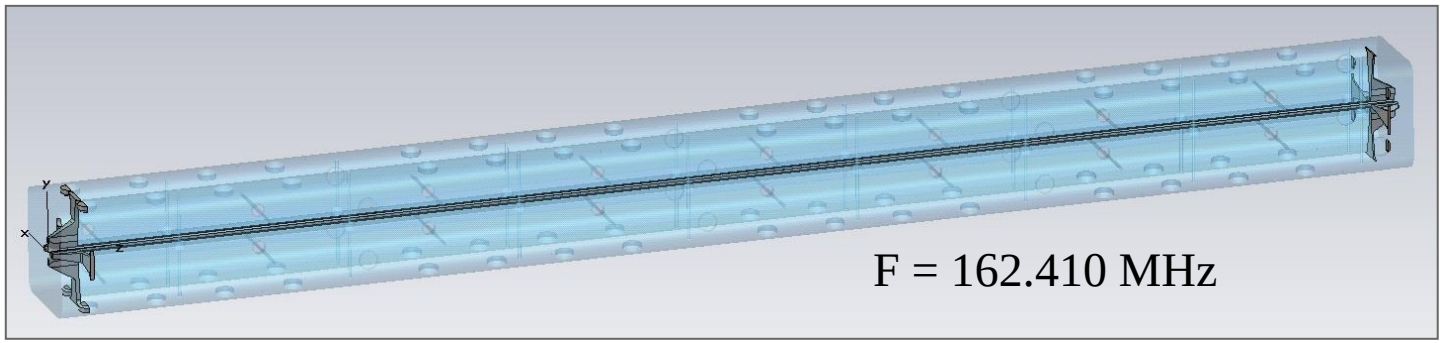
Operating frequency vs change in cut-back depth (decreasing)

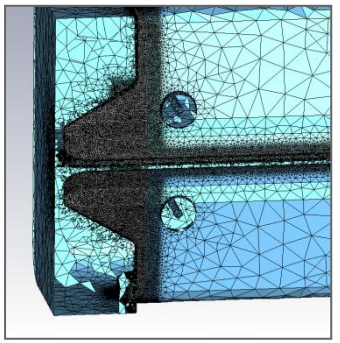




To restore field flatness the output cut-back depth should be decreased by 1.5 mm.
So, finally:
Depth of input cut-back is 82.5 mm (unchanged).
Depth of output cutback decreased from 75.9 mm to 74.4 mm.

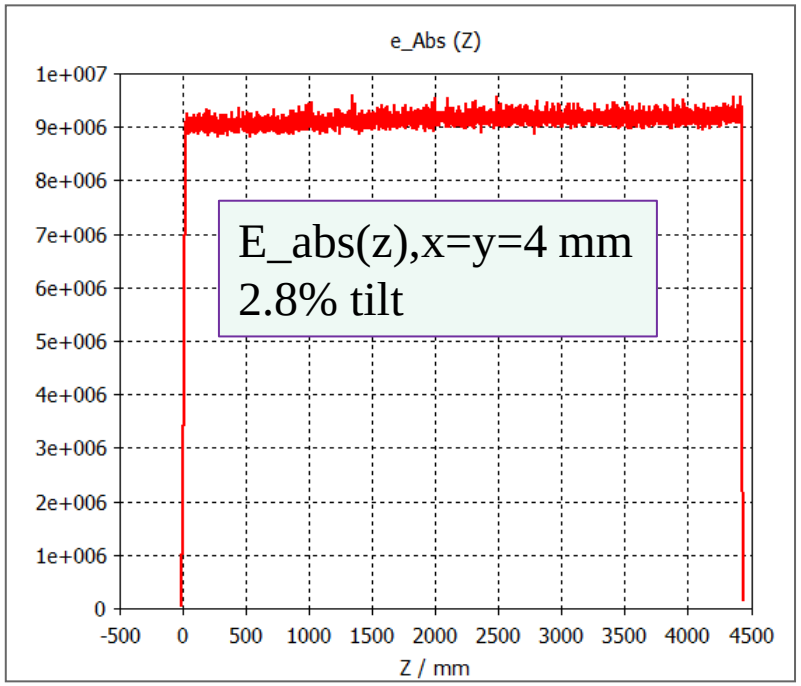
Complete model (flat tips)

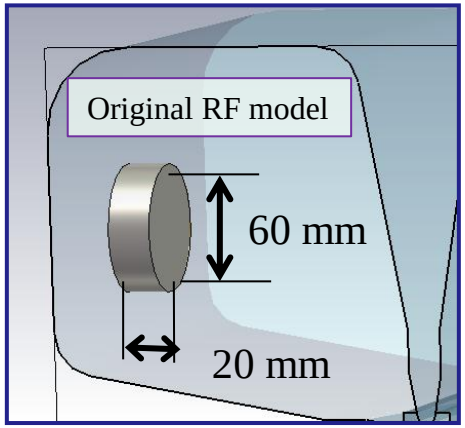


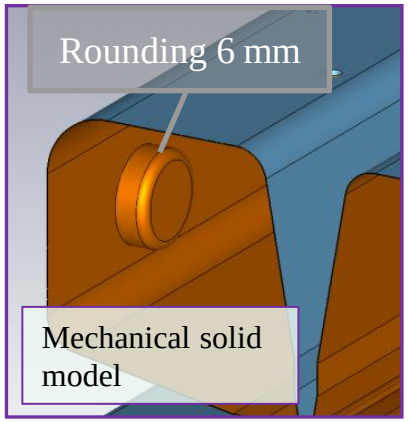


PXIE RFQ full length model. The vane tips and the cut-backs are described as separate solids to enhance local mesh in critical areas.

Mesh in the input cut-back area



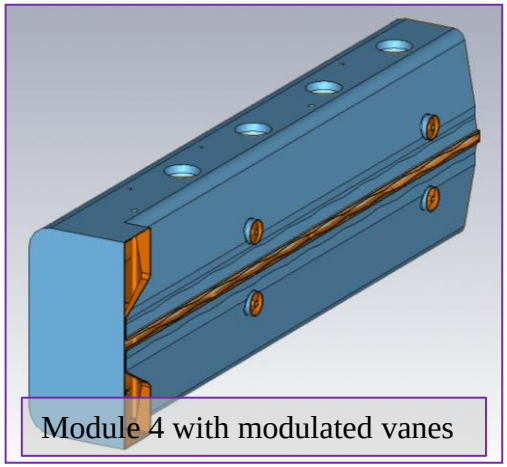




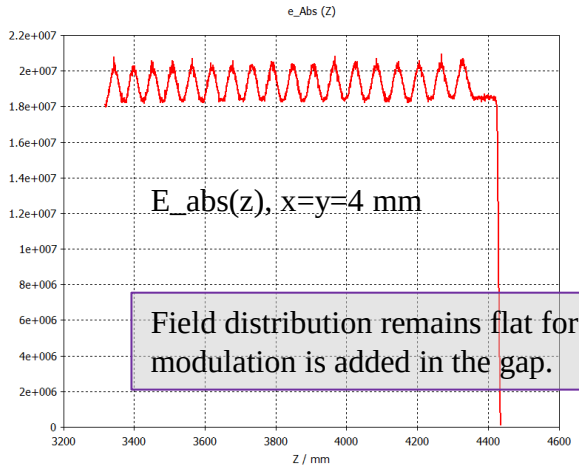
The operating frequency is lower than that of original RF design because of:
- Slug tuner rounding (-56 kHz)
- Difference between CST 2011 and CST 2012 (≈ -20 kHz)

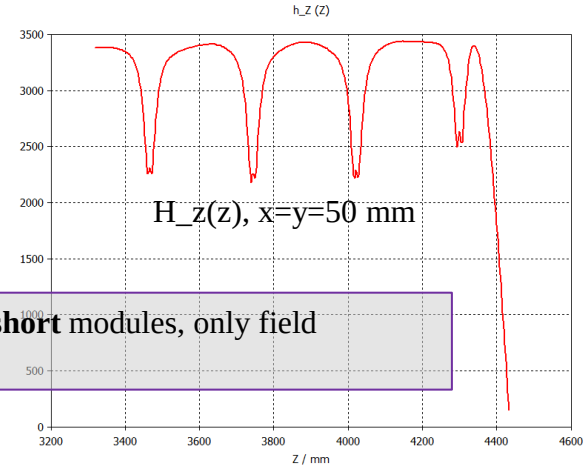
Impact of vane modulation

In general vane modulation increase local frequency. However, in PXIE design this increase is compensated by variable aperture radius. In fact, the mean aperture radius is not constant, but it slightly decreases from input to output, and that compensates increasing modulation. This compensation is not exact and the overall impact of vane modulation is lower local frequency compare to the original design with flat vane tips.



Module 4 with modulated vanes





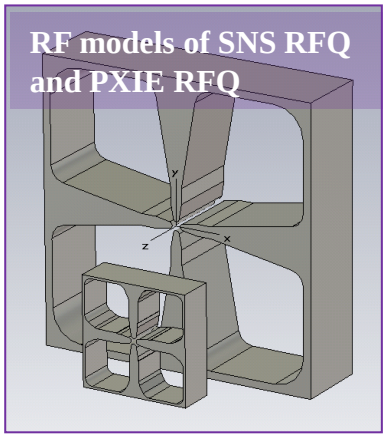
Field distribution remains flat for **short** modules, only field modulation is added in the gap.

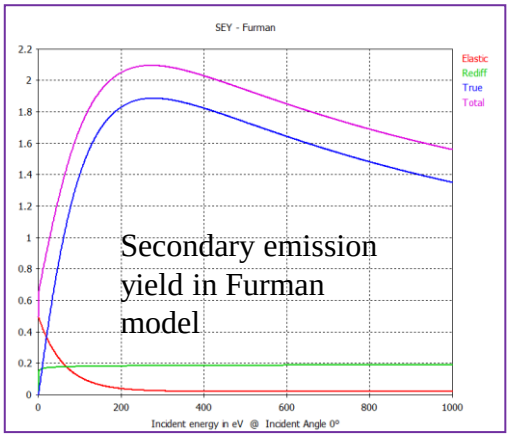
Module number	Separate modules with flat vanes	Half-length RFQ	Separate modules with modulated vanes
	Freq., MHz	Freq., MHz	Freq., MHz
Module 1	162.424	162.422	162.398
Module 2	No result		162.261
Module 3	162.393	162.352	162.205
Module 4	162.319		162.203

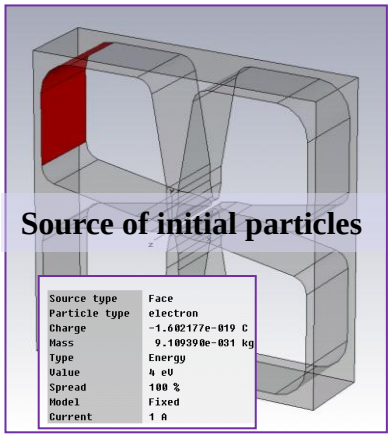
Multipacting in PXIE RFQ

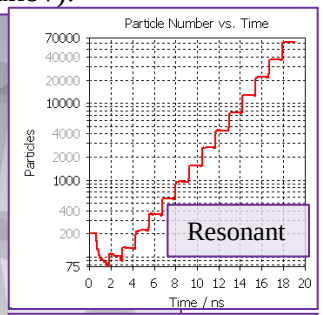
Project X

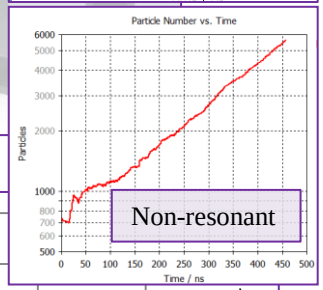
Multipacting study in PXIE RFQ power coupler indicated the signs of multipacting in the main body of RFQ (S.Kazakov).



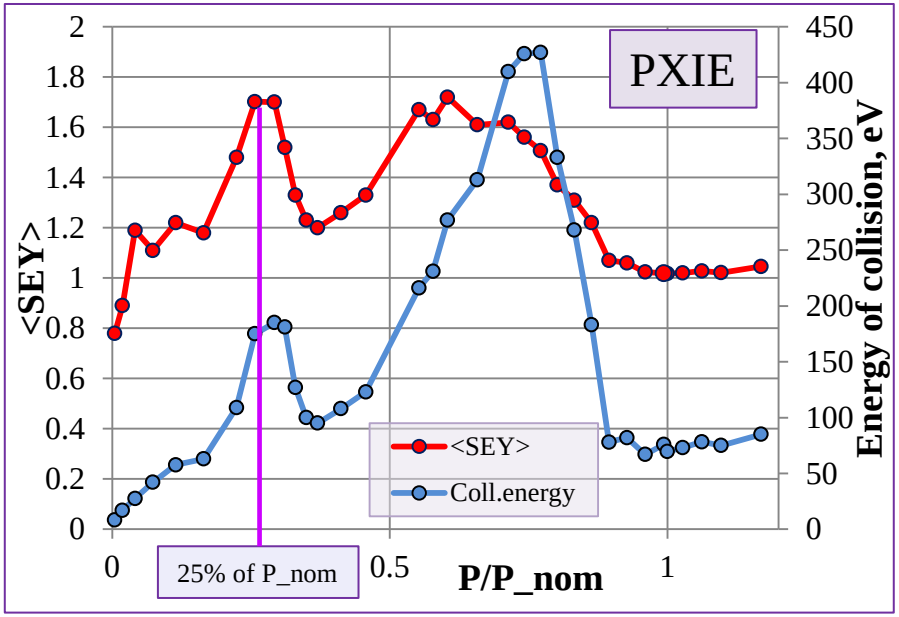


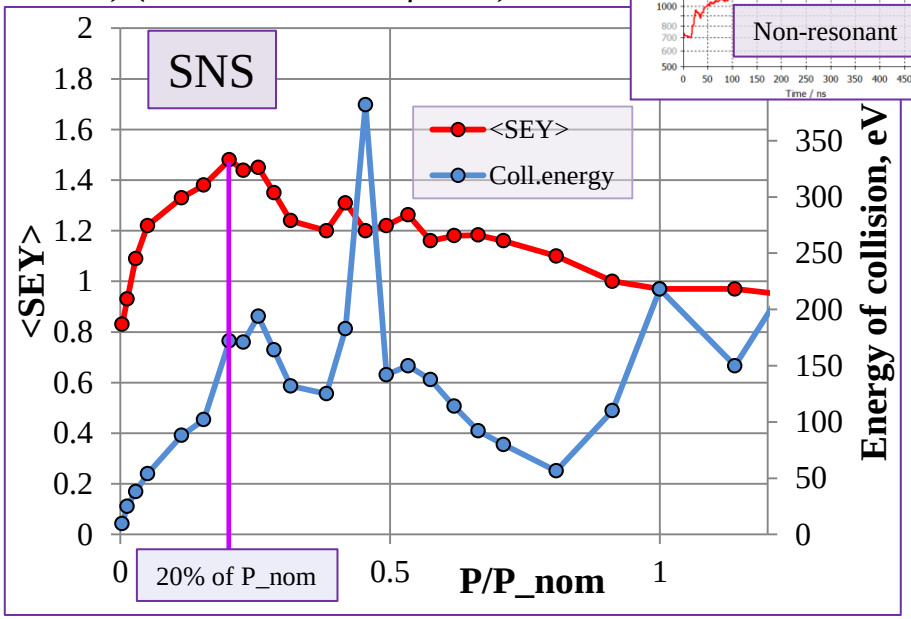






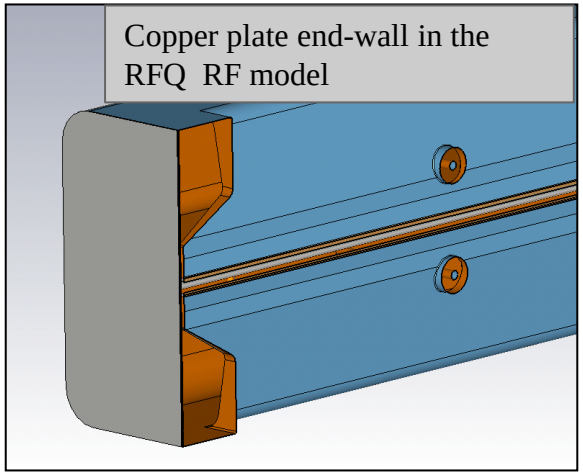
<SEY>=(Total_Number_Of_Secondaries)/(Total_Number_Of_Hits)

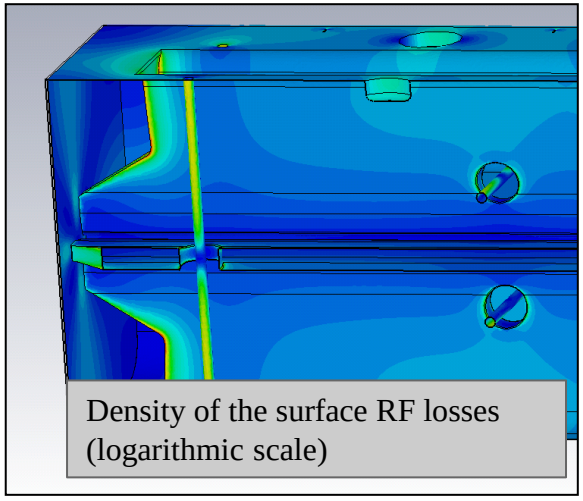


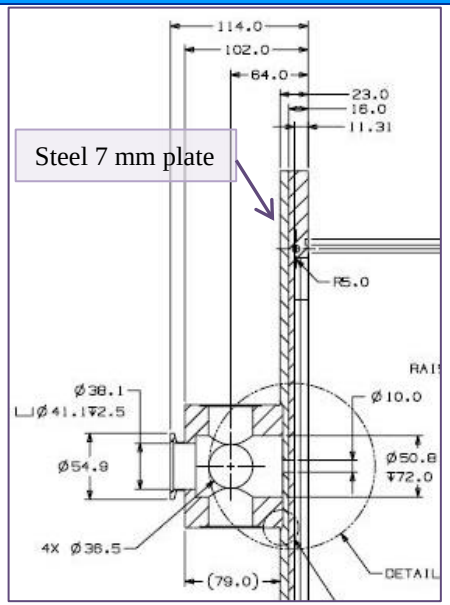


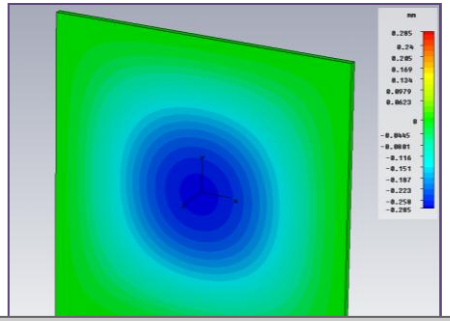
End-wall deformation and heating.

Project X

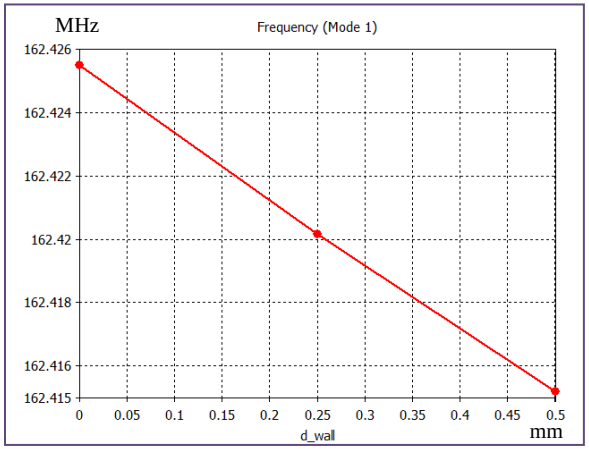




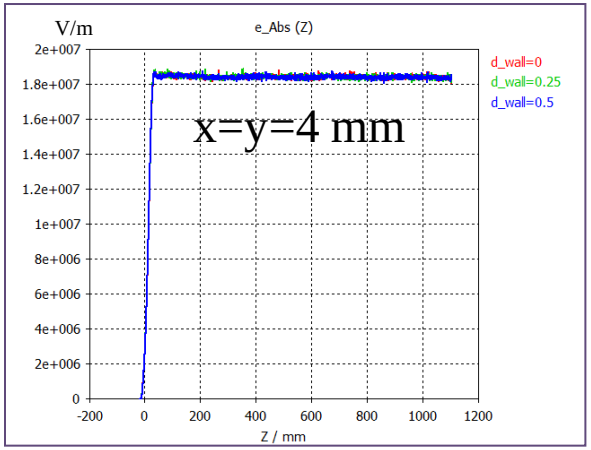




End-wall displacement due to atmospheric pressure. For end-wall enforced with steel plate 7 mm thick maximum displacement is 0.3 mm.



Frequency vs input end-wall displacement.

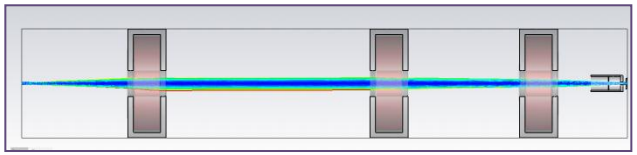


Field distribution vs input end-wall displacement.

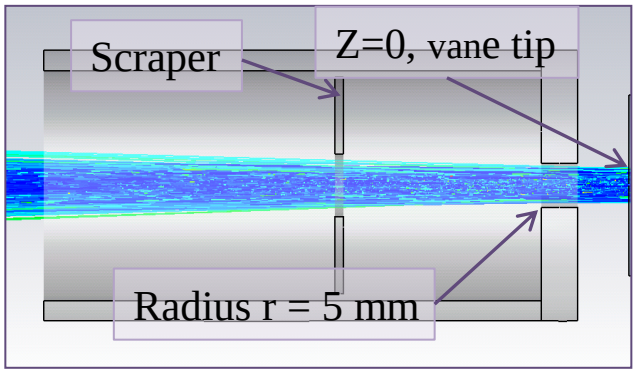
DC power losses (heat)
Input end-wall – 246 W
Output end-wall – 360 W

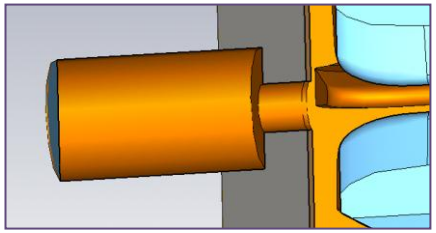
Increased input beam aperture

Project X

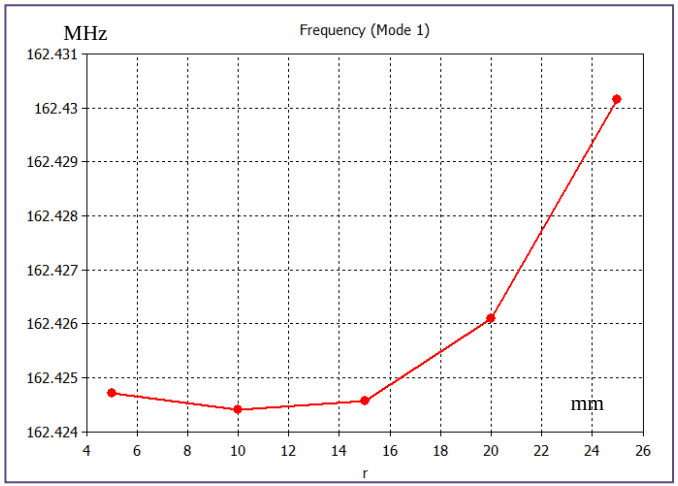


Beam in LEBT. CST PS simulations. “Smooth” variant.



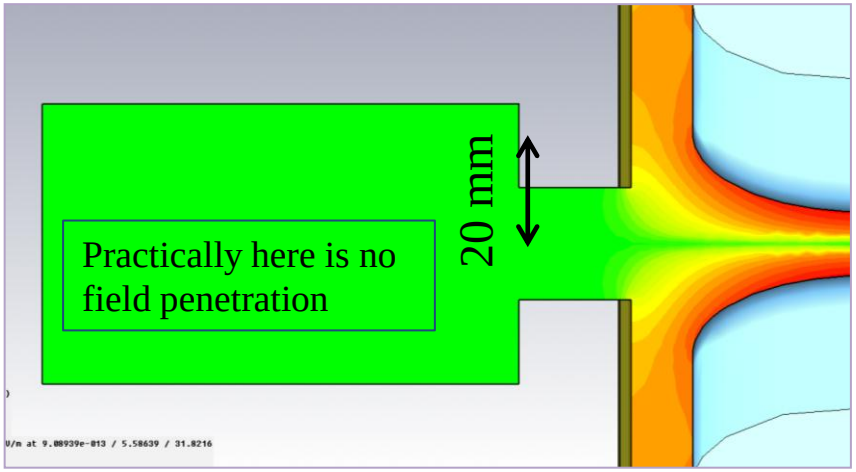


RF model of LEBT-RFQ interface

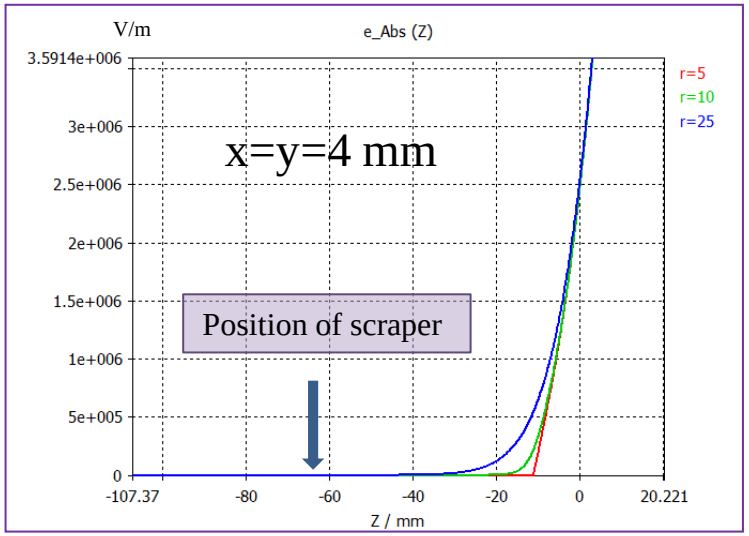


Frequency vs beam aperture radius

Beam matching is possible without losses, but margins are too tight.



E field distribution. Logarithmic scale.



Field distribution vs beam aperture radius

Conclusion

- The geometrical discrepancies between mechanical models and original RF design were removed.
- The output cut-back depth was retuned (-1.5 mm, from 75.9 mm to 74.4 mm).
- The frequency of complete RFQ model based on the mechanical one is lower than originally designed because of difference between CST versions (≈ -25 kHz) and the tuner roundings that was not taken into account (- 56 kHz).
- The vane modulations noticeably decrease frequency of modules. Frequency decrease is different in different modules, and this can lead to field flatness distortion in a full length structure . **This effect should be verified and addressed.** Preliminary we can consider overall frequency correction by RFQ transverse size H (dF/dH = 1.04 MHz/mm) and field tuning by slug tuners.
- Both SNS and PXIE RFQs don't have dynamic conditions for multipacting at nominal level of power.
- Both RFQs have MP barrier that starts at very low power and has maximum at 20-25% of operating level.
- SNS RFQ doesn't have MP beyond this first barrier.
- PXIE RFQ has second MP barrier. It shouldn't be a problem after RF conditioning at first MP barrier – copper will be cleaner and SEY will be low.
- In general PXIE RFQ seems to be more susceptible to multipacting.
- Generally low fields at the end-walls of RFQs provide relatively low RF losses on the walls and low sensitivity to the mechanical details in the area.
- RF losses are 246 W in the input end-wall and 360 W in the output end-wall (higher because it's closer to the vanes and surface fields are higher)
- End-wall deformations due to the atmospheric pressure cause small frequency shift and absolutely no field distortion (nice feature for fine frequency tuning). For 30 kHz frequency shift limit a steel plate of 5-6 mm would be OK to enforce input end-wall, and 7-8 mm would be OK for output end-wall
- Input beam aperture diameter can be increased up to 50 mm with negligible frequency shift of 10 kHz. Practically there is no field penetration through the beam aperture.