Design issues of Project X LEBT and RFQ

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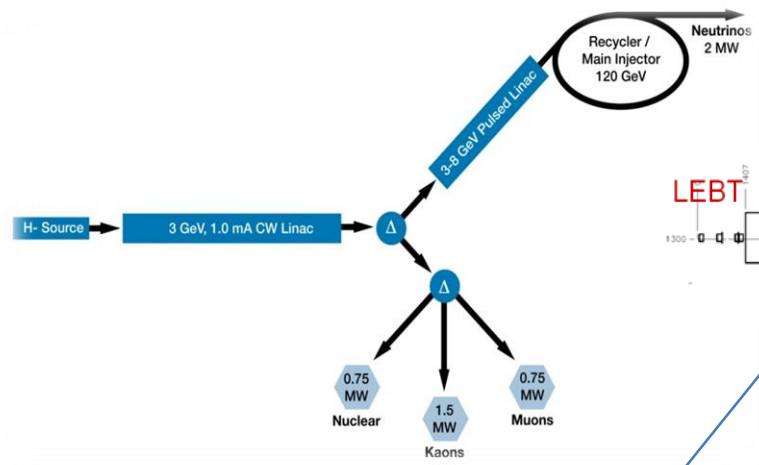
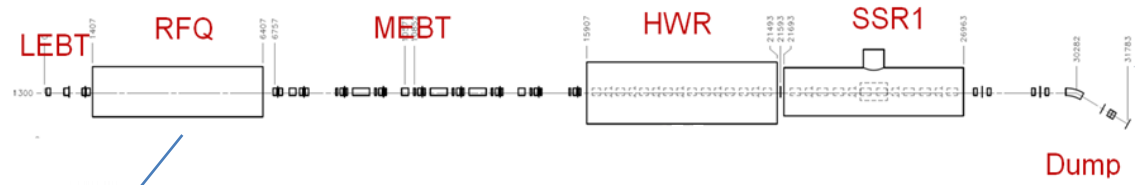
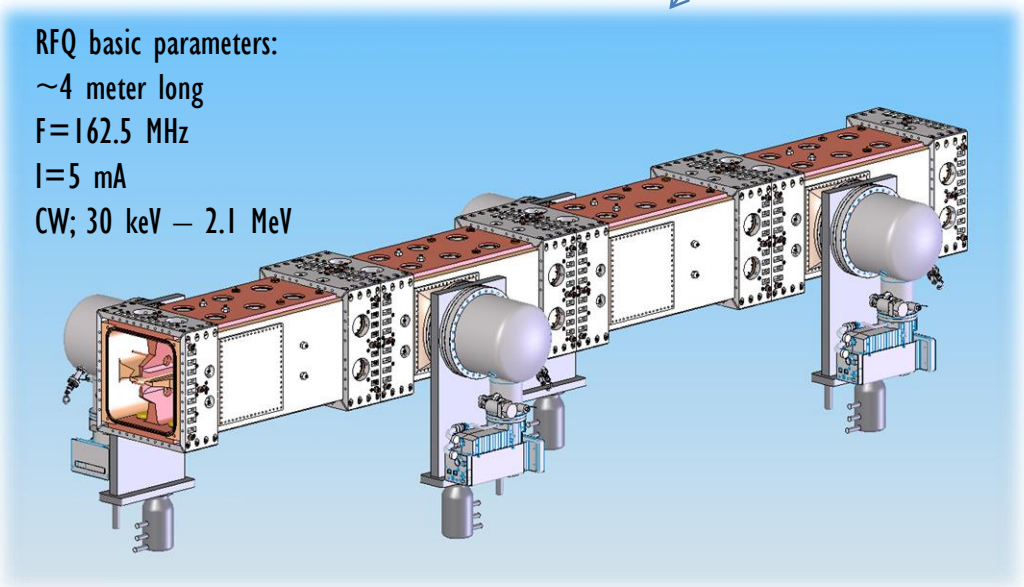
LAYOUT OF PROJECT X AND PXIE

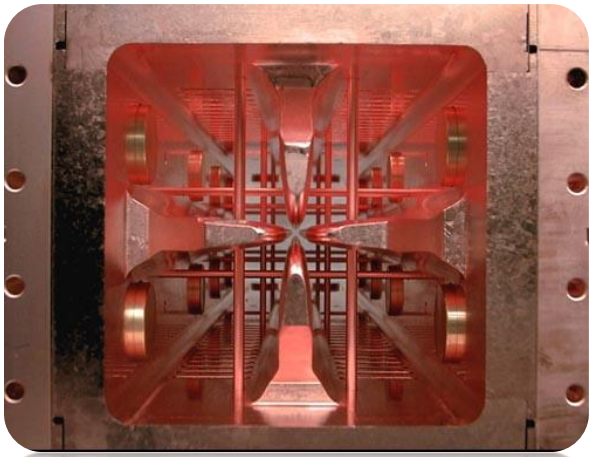




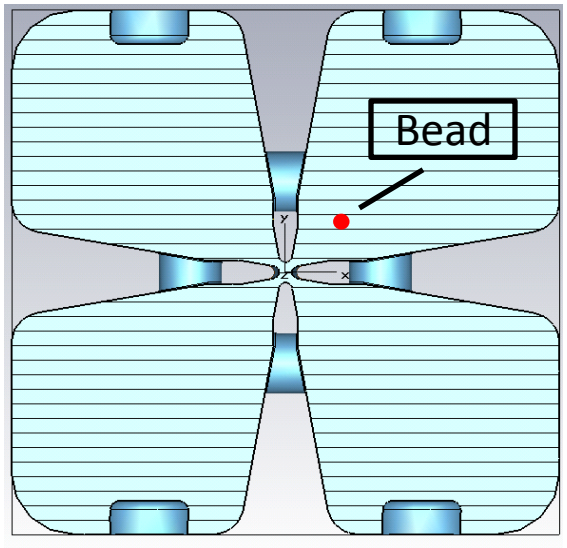
RFQ basic parameters:
~4 meter long
F=162.5 MHz
I=5 mA
CW; 30 keV – 2.1 MeV



SNS RFQ,
similar design



Simulations of “Bead-pull” method in RFQ



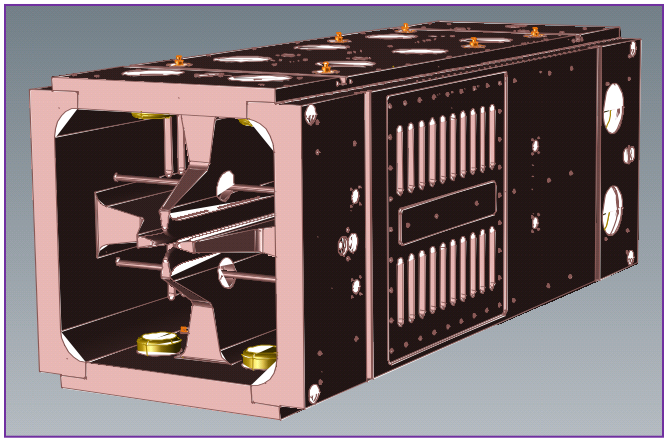
RFQ cross section

Task: Define size, material and transverse position of bead (sphere) to obtain required frequency shift.

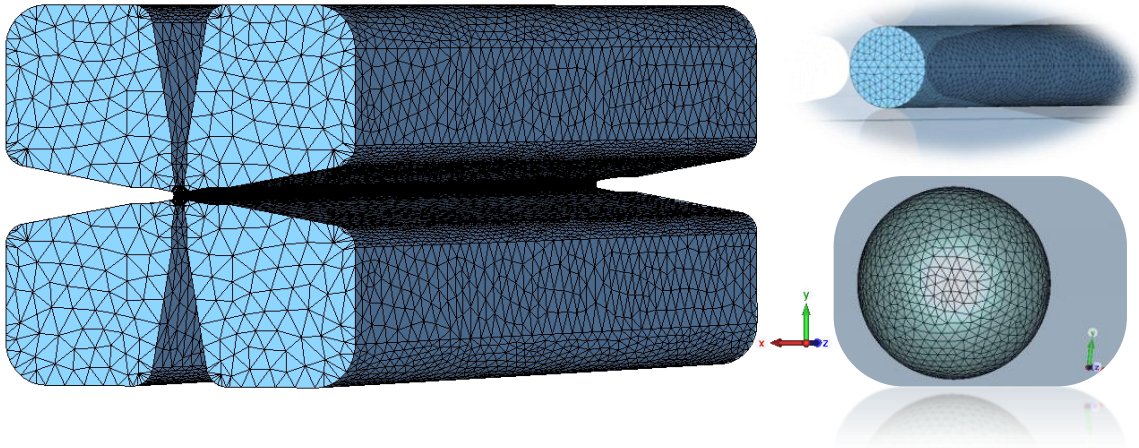
What has been used and done:

- Basics of bead pull: Slater theorem -> $\Delta F \sim E^2$
- CST MWS used for simulations.
- Two materials: dielectric (ε=10.5) and metal(PEC).
- Bead transverse position x =y changed from 0 to 30 cm.
- Radius of bead was changed from R=2.5 to R=6 in each position.

Vacuum “bead” <--> material bead – trick to keep mesh unchanged.

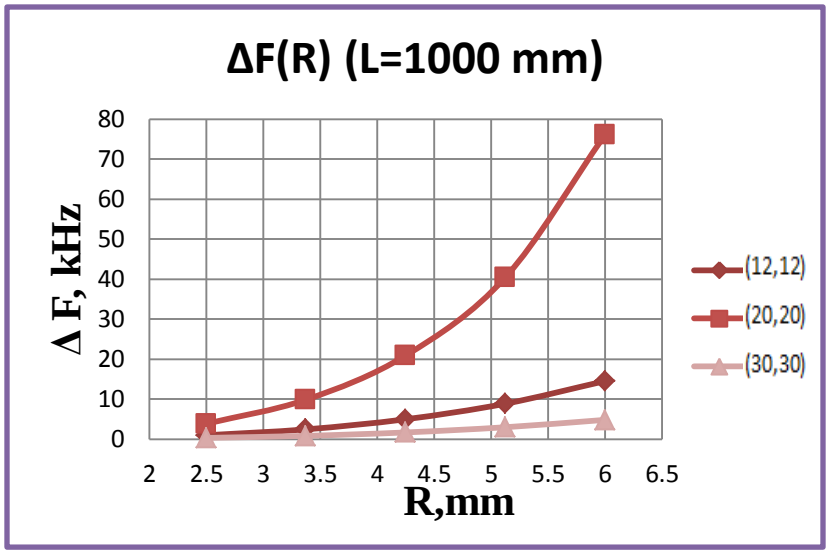


Module 1 of RFQ

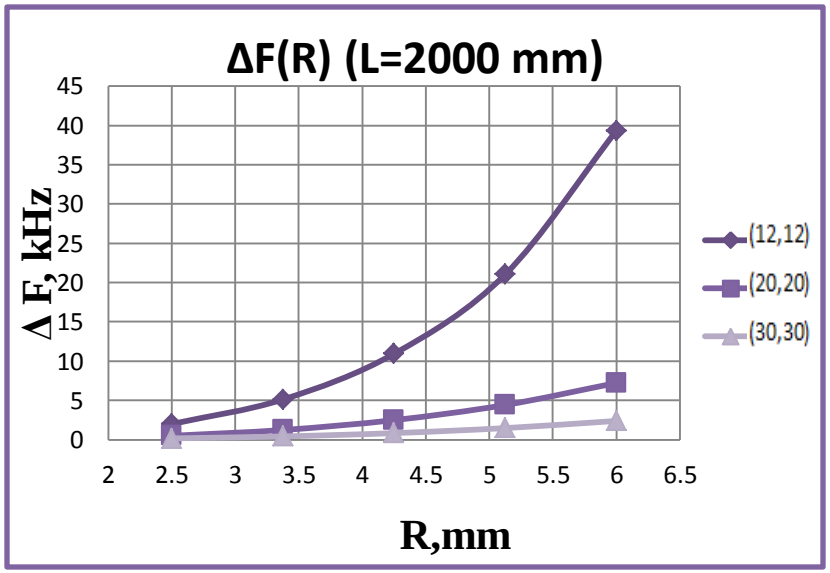


Results for dielectric bead

Bead radius R, mm	Delta F, kHz		
	(X,Y)=(12,12)	(X,Y)=(20,20)	(X,Y)=(30,30)
2.5	3.87	1	0.345
3.375	9.88	2.475	0.8525
4.25	20.91	5.0025	1.705
5.125	40.4125	8.88	3.005
6	76.055	14.5325	4.8475

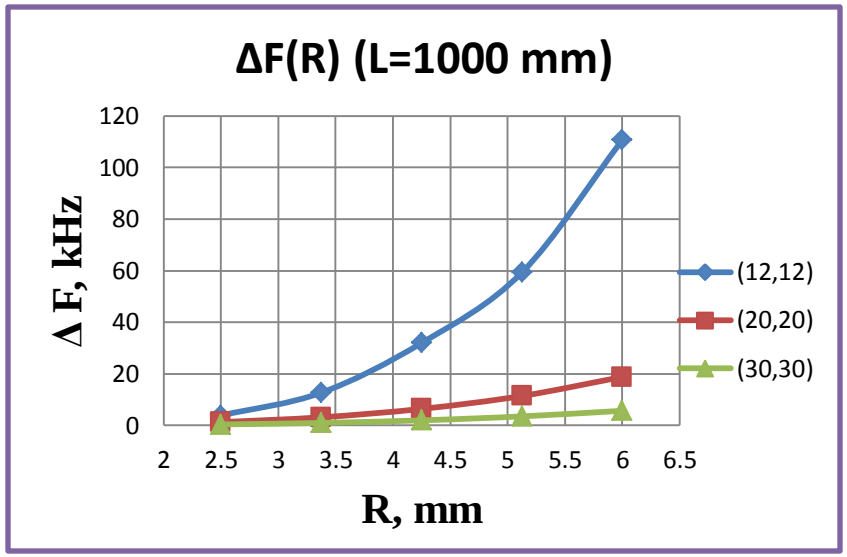


Bead radius R, mm	Delta F, kHz		
	(X,Y)=(12,12)	(X,Y)=(20,20)	(X,Y)=(30,30)
2.5	1.995	0.5	0.17
3.375	5.1175	1.2375	0.42
4.25	10.9325	2.495	0.84
5.125	21.035	4.4175	1.48
6	39.34	7.2225	2.3925

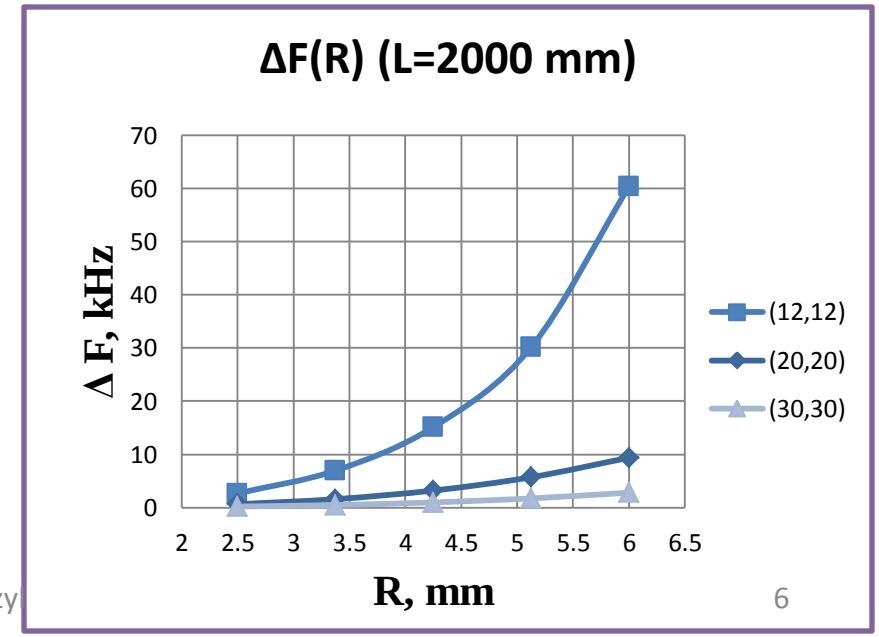


Results for metal bead

Bead radius R, mm	ΔF, kHz		
	(X,Y)=(12,12)	(X,Y)=(20,20)	(X,Y)=(30,30)
2.5	3.876	1.2825	0.405
3.375	12.725	3.175	0.9975
4.25	31.995	6.4325	2
5.125	59.325	11.4425	3.525
R5=6	110.65	18.81	5.695

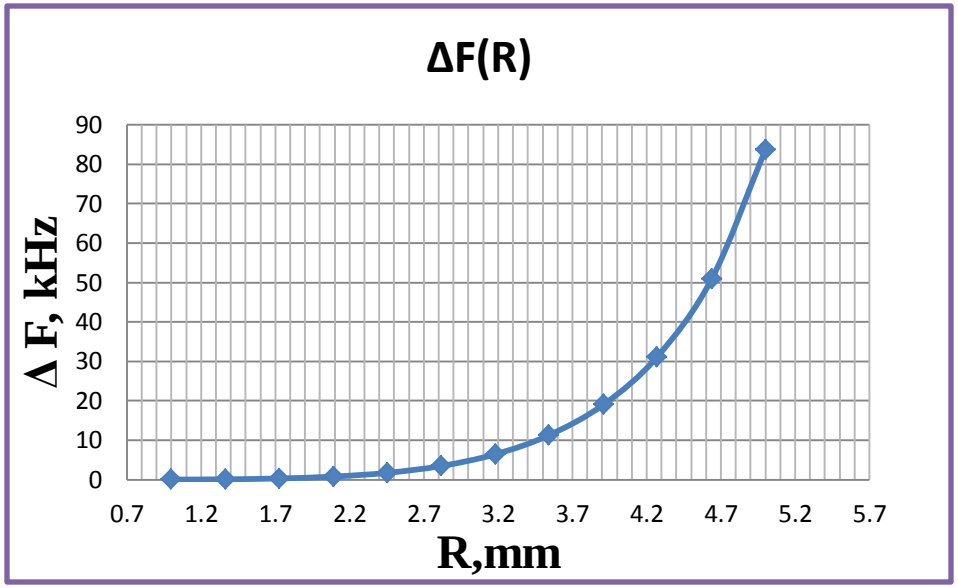


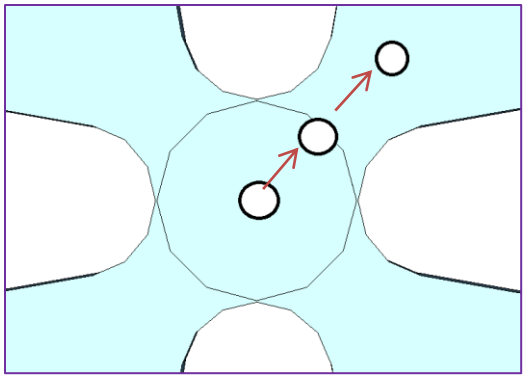
Bead radius R, mm	ΔF, kHz		
	(X,Y)=(12,12)	(X,Y)=(20,20)	(X,Y)=(30,30)
2.5	2.6775	0.6425	0.2
3.375	6.96	1.595	0.4925
4.25	15.125	3.2175	0.9875
5.125	30.14	5.7125	1.7375
6	60.3425	9.385	2.8125



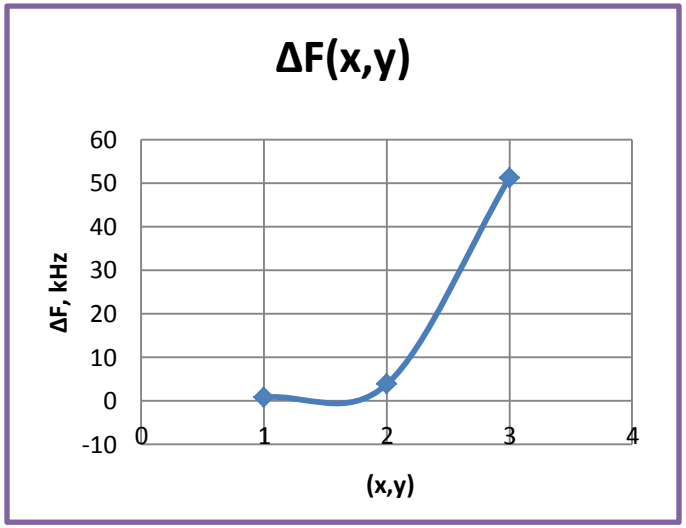
Dielectric bead in the center of RFQ

Bead radius R, mm	ΔF, kHz
1.0000	0.02
1.3642	0.09
1.7285	0.3
2.0927	0.78
2.4536	1.72
2.8179	3.46
3.1821	6.44
3.5397	11.22
3.9106	19.05
4.2715	31.16
4.6391	50.95
5.0000	83.69



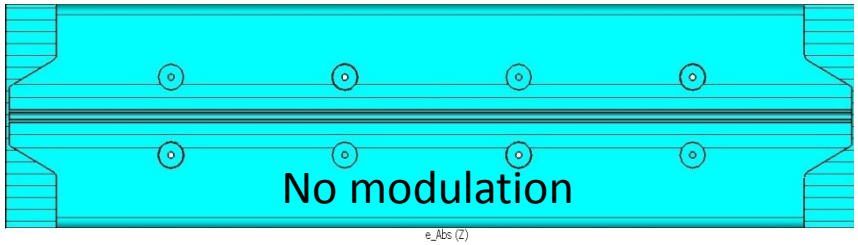


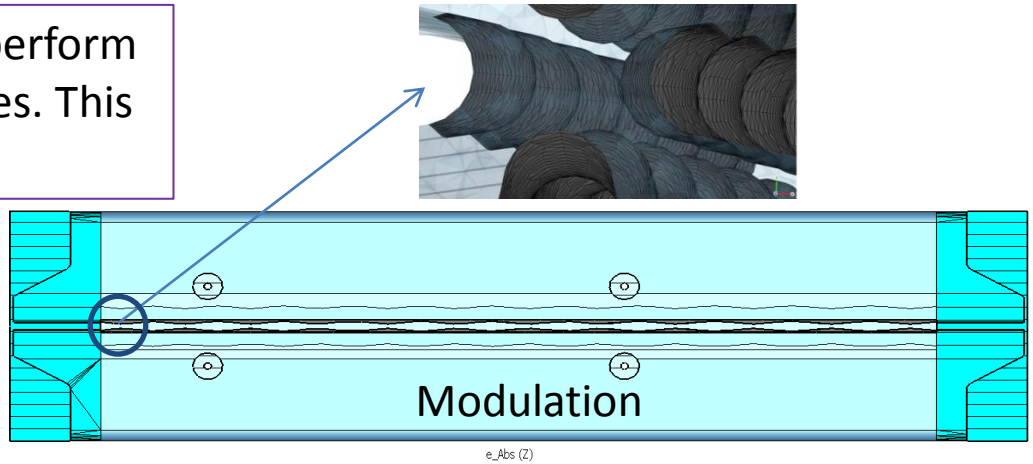
#	Bead position (X,Y), mm	ΔF, kHz
1	0,0	0.78
2	2,2	3.8
3	4,4	51.2

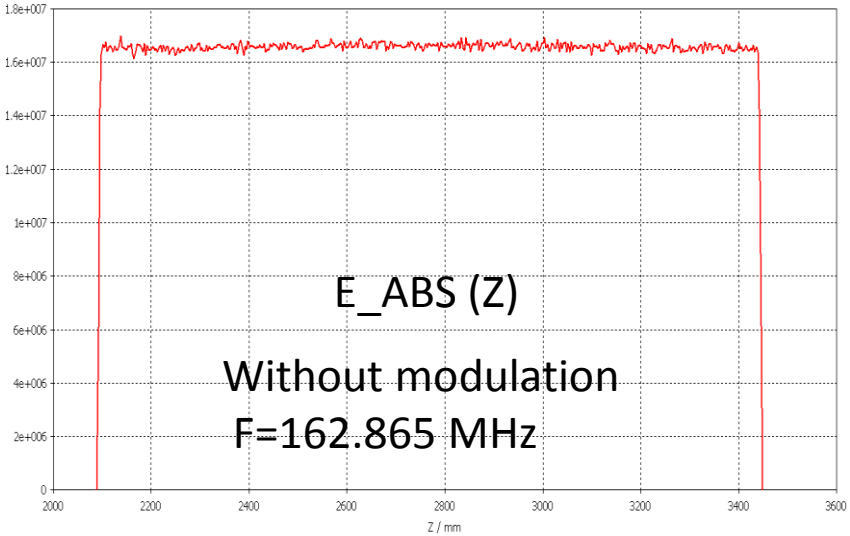


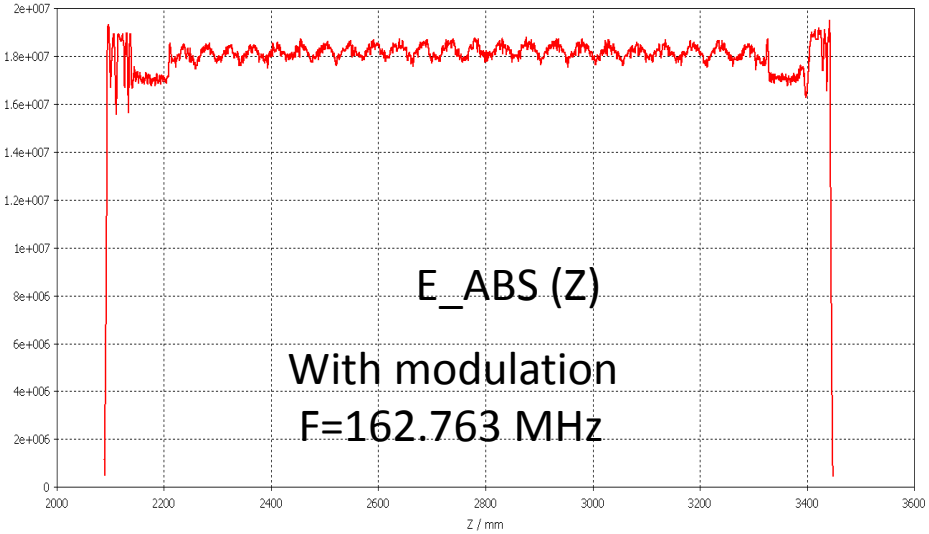
Simulations of RFQ model with temporary end walls

The temporary end walls are designed to perform RF measurements on separate RFQ modules. This simulation is a verification of their design.



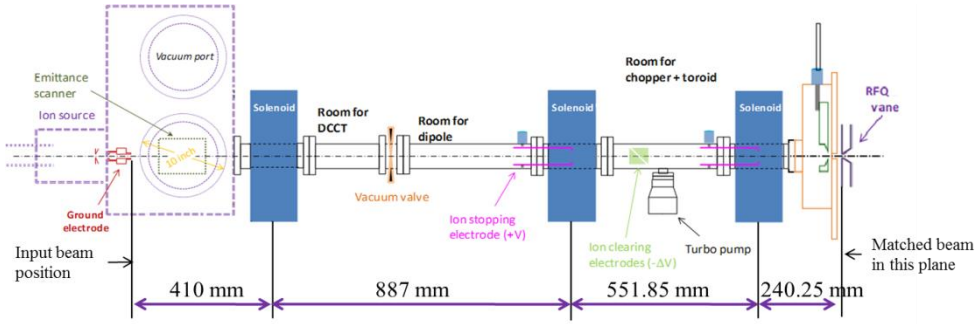


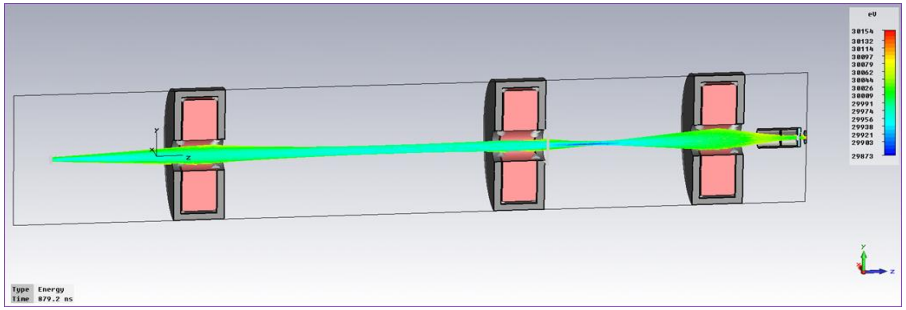




Frequency shift due to the modulation ΔF=101 kHz

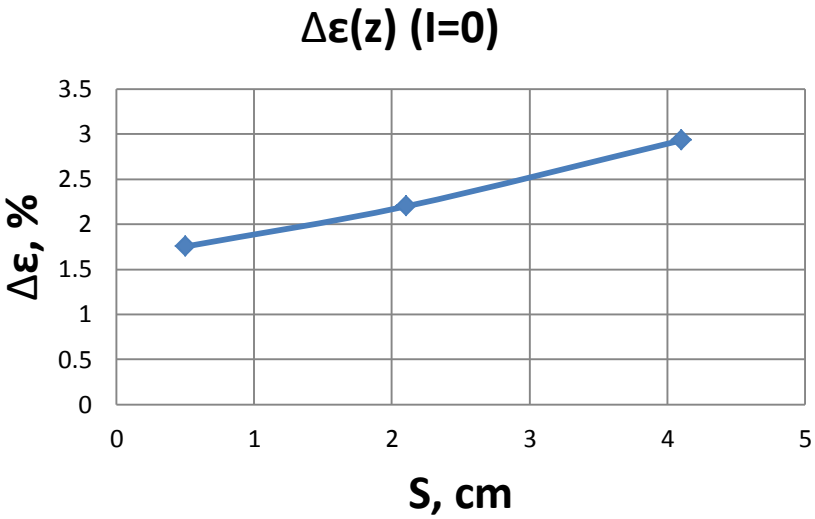
Beam dynamics in LEBT





Emittance growth as a function of distance S between ion source and solenoid.

S, cm	Δε_norm, %
0.5024	1.753468
2.1024	2.198377
4.1024	2.93117

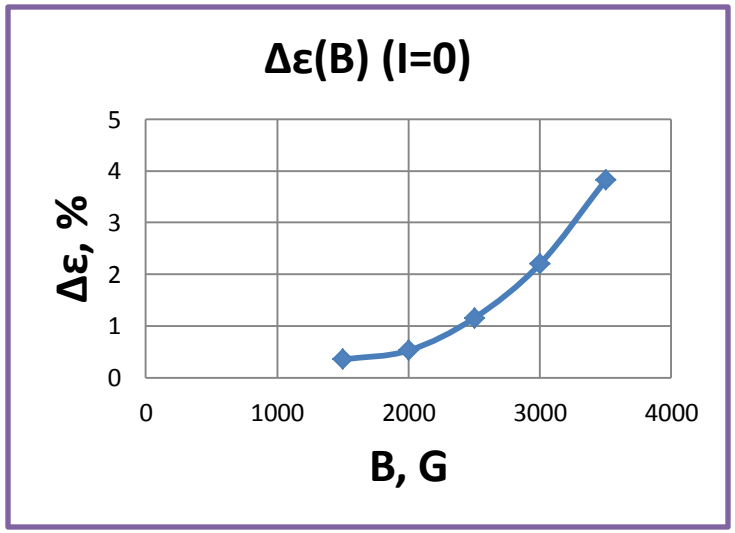


Initial normalized RMS emittance
$\varepsilon = 0.03821\ \pi$ cm·mrad

Beam dynamics in LEBT

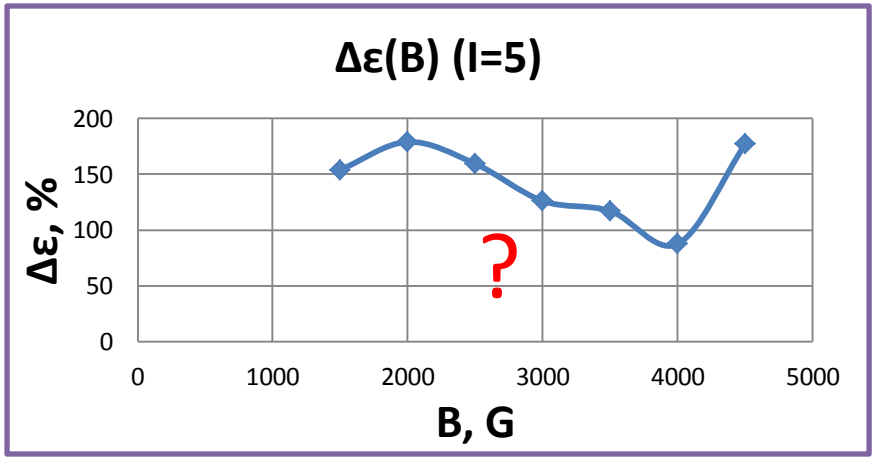
Emittance growth as a function of focusing strength , I =0

B, G	Δε_norm, %
1500	0.35123
2000	0.523423
2500	1.151531
3000	2.198377
3500	3.820989



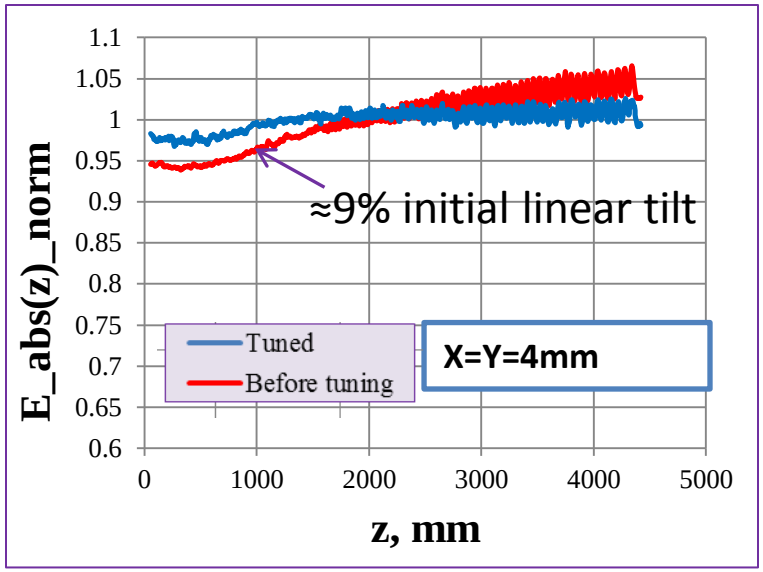
Emittance growth as a function of focusing strength , I = 5 mA

B, G	Δε_norm, %
1500	153.7556
2000	178.8014
2500	159.2515
3000	125.988
3500	117.0113
4000	87.62104
4500	176.8385



Evaluation of matched beam at the entrance of RFQ with the “real” fields.

Field distribution in RFQ

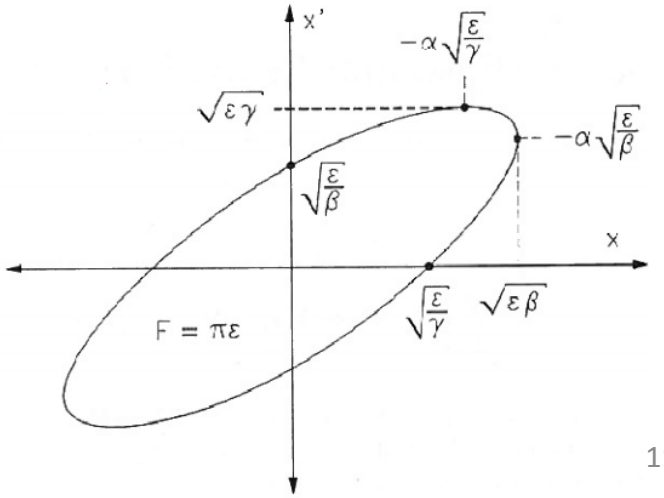


Goal:
Match input 5 mA beam , i.e. find input beam Twiss parameters that provide output beam with minimum losses and minimal emittance growth

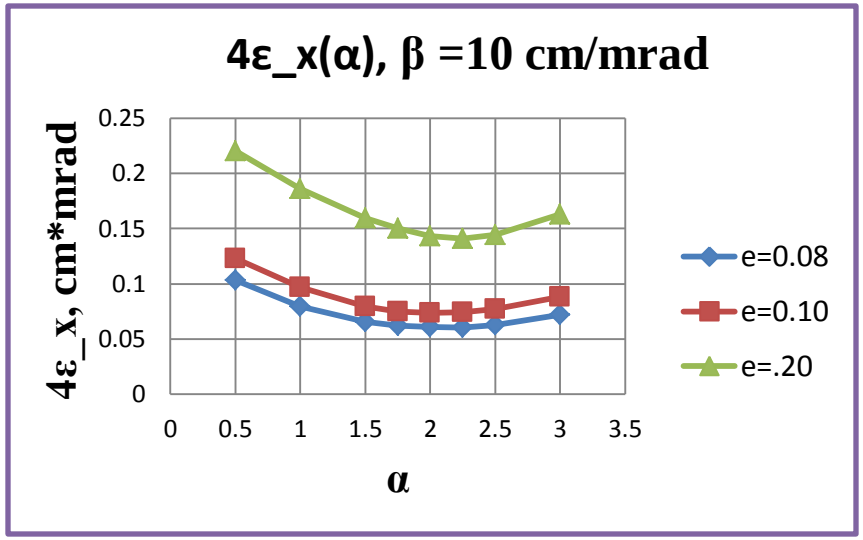
1. Three input RMS normalized emittances were considered: 6ε=0.08; 0.10; 0.20 in cm·mrad,
2. Two series of parameter sweep: α is variable, β is constant and vice versa)
3. Best input beam parameters found.

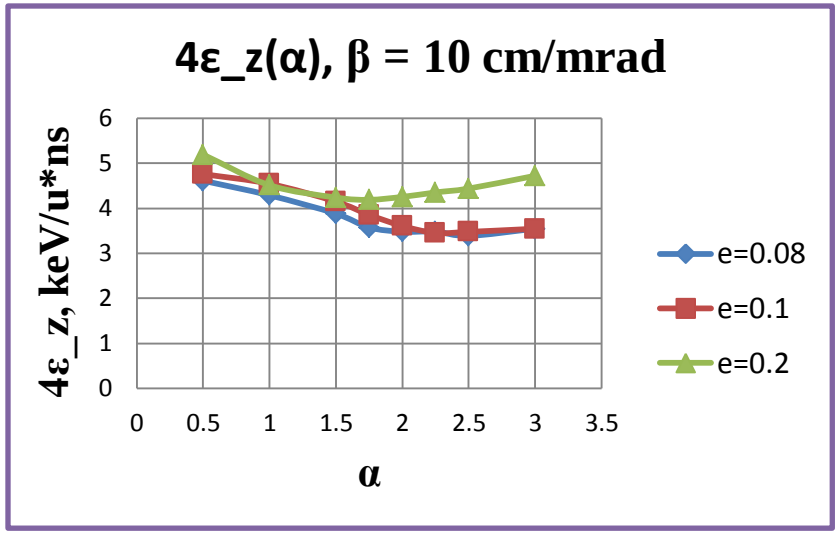
Emittance basics:

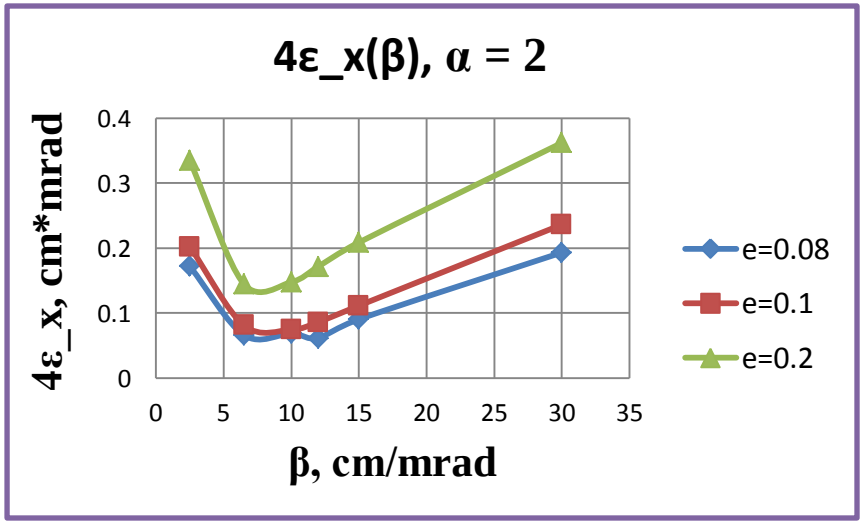
1. $\epsilon = \gamma x^2 + 2\alpha x x' + \beta x'^2$
2. β, α, γ are the Twiss parameters, β describes the size of the beam, α describes incline, ε = area in x. x’ plane occupied by beam particles divided by π and $\gamma = \frac{1+\alpha^2}{\beta}$
3. x and x' are the position and angle of the particle respectively

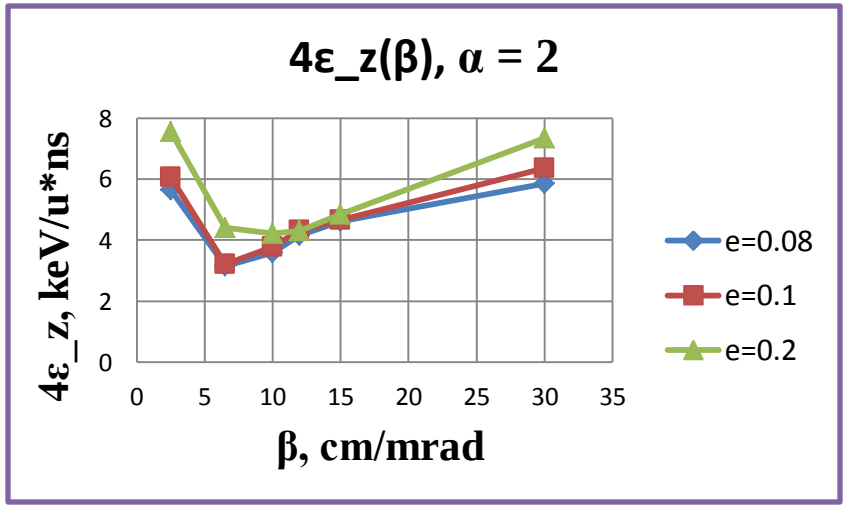


Evaluation of matched beam at the entrance of RFQ with the “real” fields.



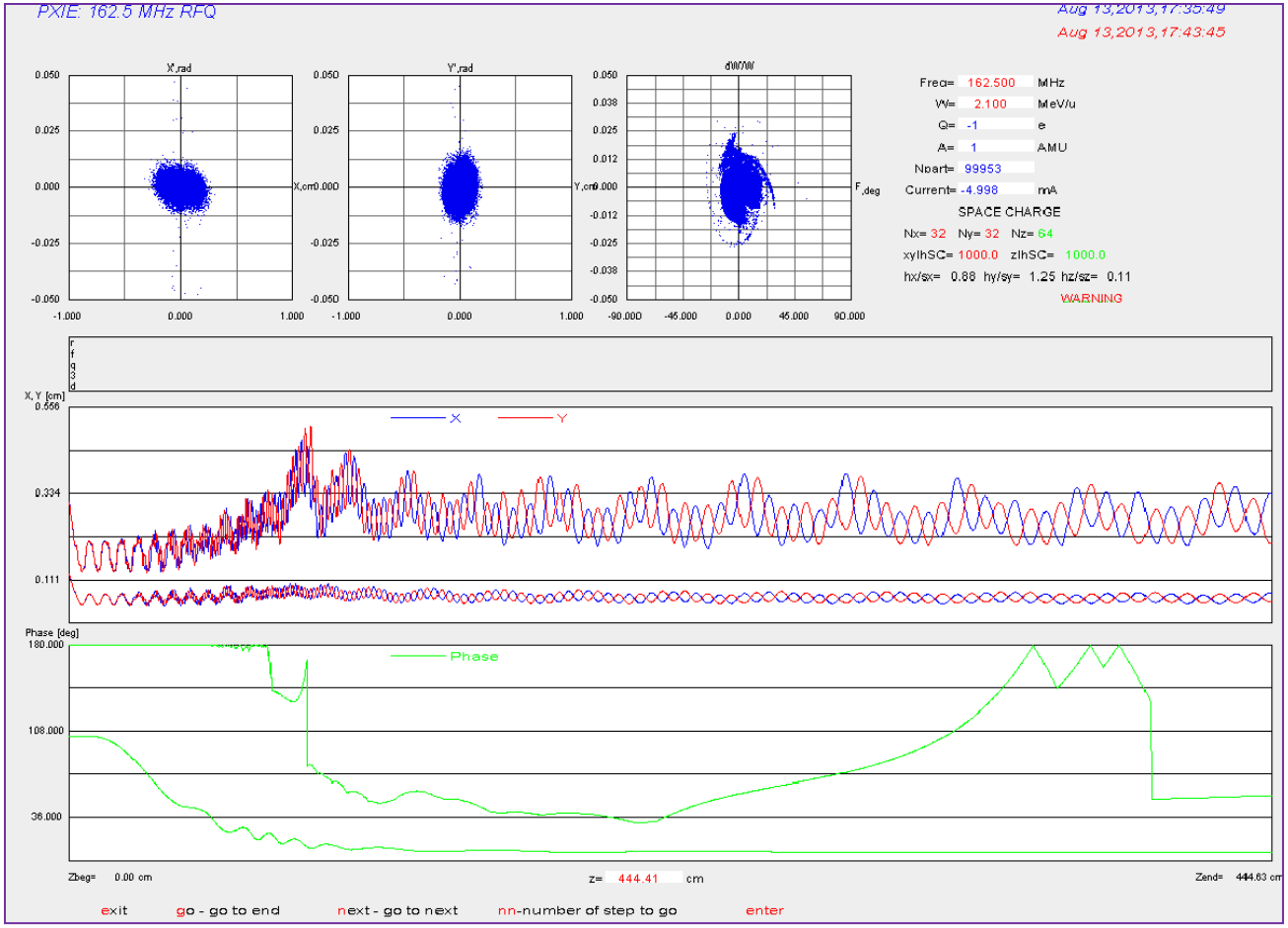






Evaluation of matched beam at the entrance of RFQ with the “real” fields.

TRACK output



Matched input beam Twiss parameters are:
α=2; β=9.5 mm/rad,

For initial RMS normalized emittance
6ε = 0.08 cm·mrad
the output beam has
α_x = 0.11403;
β_x= 0.02764 mm/rad
α_y = -0.19399;
β_y= 0.01337 mm/rad
and transverse emittance growth of 15 %
Practically no losses in RFQ.

Conclusion

- Bead-pull measurements in RFQ were simulated, the tables for choice of bead size, material and position were developed
- Simulations of RFQ model verified the temporary end walls design.
- Transverse emittance growth study has been performed. In general the results are as expected, but some of them still must be understood.
- Evaluation of matched beam at the entrance of RFQ with the “real” fields is done successfully with the use of TRACK . Matched input beam parameters were found for three input emittances , which covers expected range of emittance growth in LEBT.