Re-commissioning of 28 GHz Gyrotron

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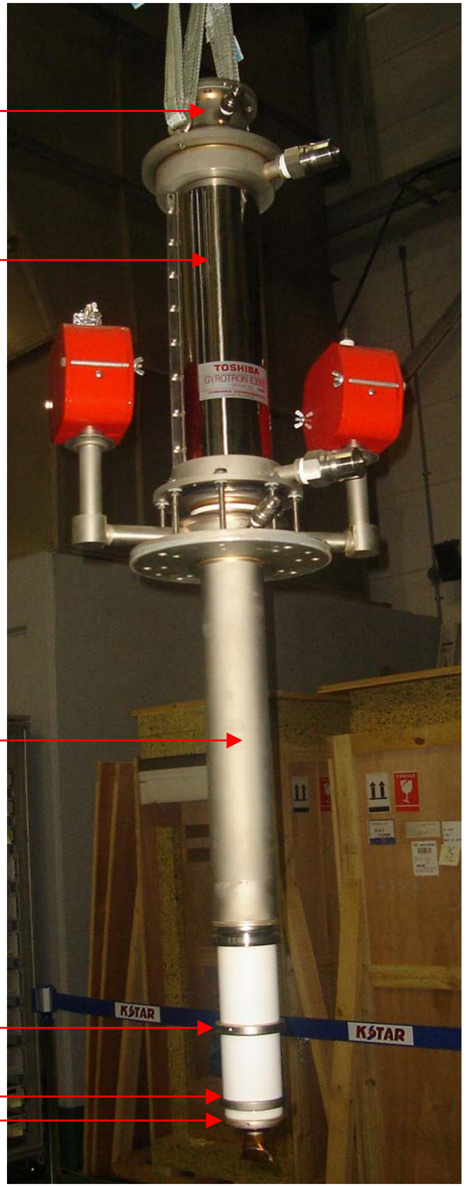
Abstract

A 28-GHz gyrotron provided by Tsukuba University is planned to be used for plasma heating in MP2 device at National Fusion Research Institute (NFRI). The gyrotron output mode is TE_{02} mode, and the maximum RF power and the pulse length are 200 kW and 75 ms, respectively. Since we are going to use the existing superconducting magnet and the power supply system at NFRI, the magnetic field profile should be readjusted to the optimum operations. In this paper, we present the study on the magnetic fields by the NFRI magnet and beam dynamics using the simulation codes. We also describe the development plan for the 28 GHz gyrotron system.

* This work is supported by NFRI.

28 GHz gyrotron (Toshiba #26022)

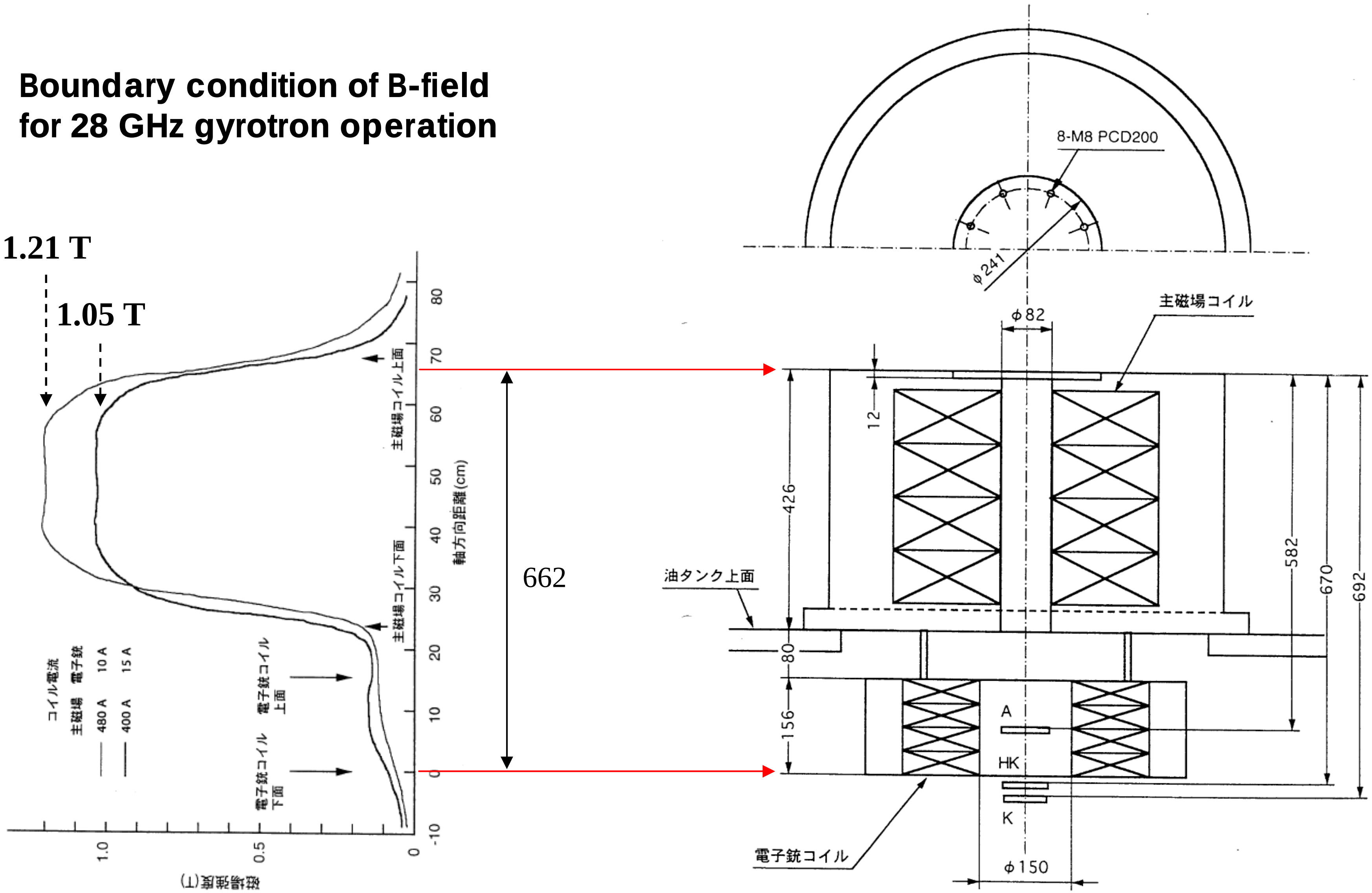


Specification of 28 GHz gyrotron

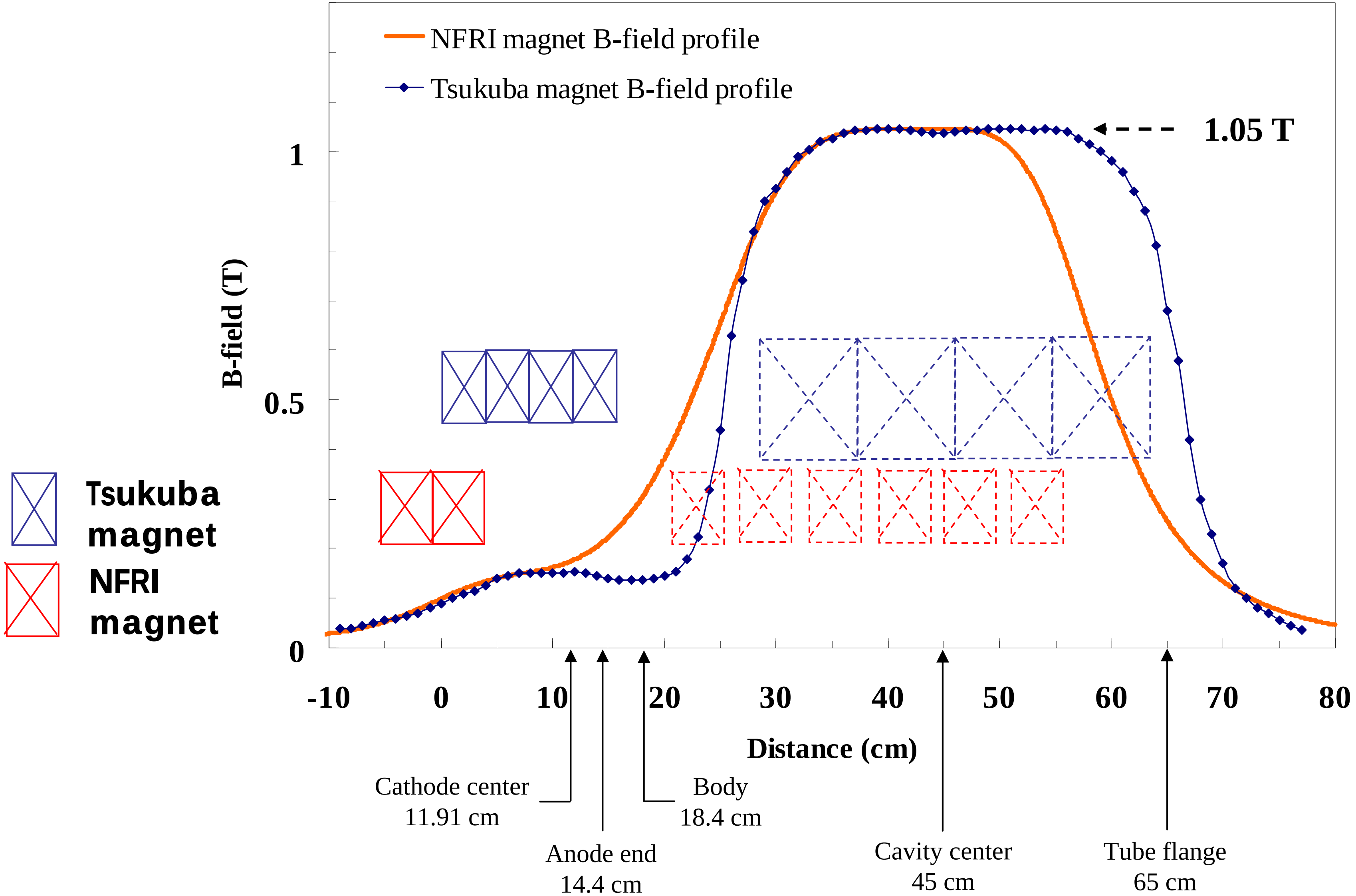
Parameter	Maximum	Nominal data	unit
Beam voltage	90	75	kV
Beam current	9	8	A
Anode voltage	35	28.8	kV
Heater voltage	13	7.8	Vdc
Heater current	9	5.8	Adc
Cavity magnetic flux density	1.35	1.1	T
Cathode magnetic flux density	0.17	0.11	T
Output power(TE_{02} mode)	211	205	kW
Efficiency		34.2	%
Pulse width	75	1	ms
Duty factor	0.005	0.002	

Tsukuba magnet system

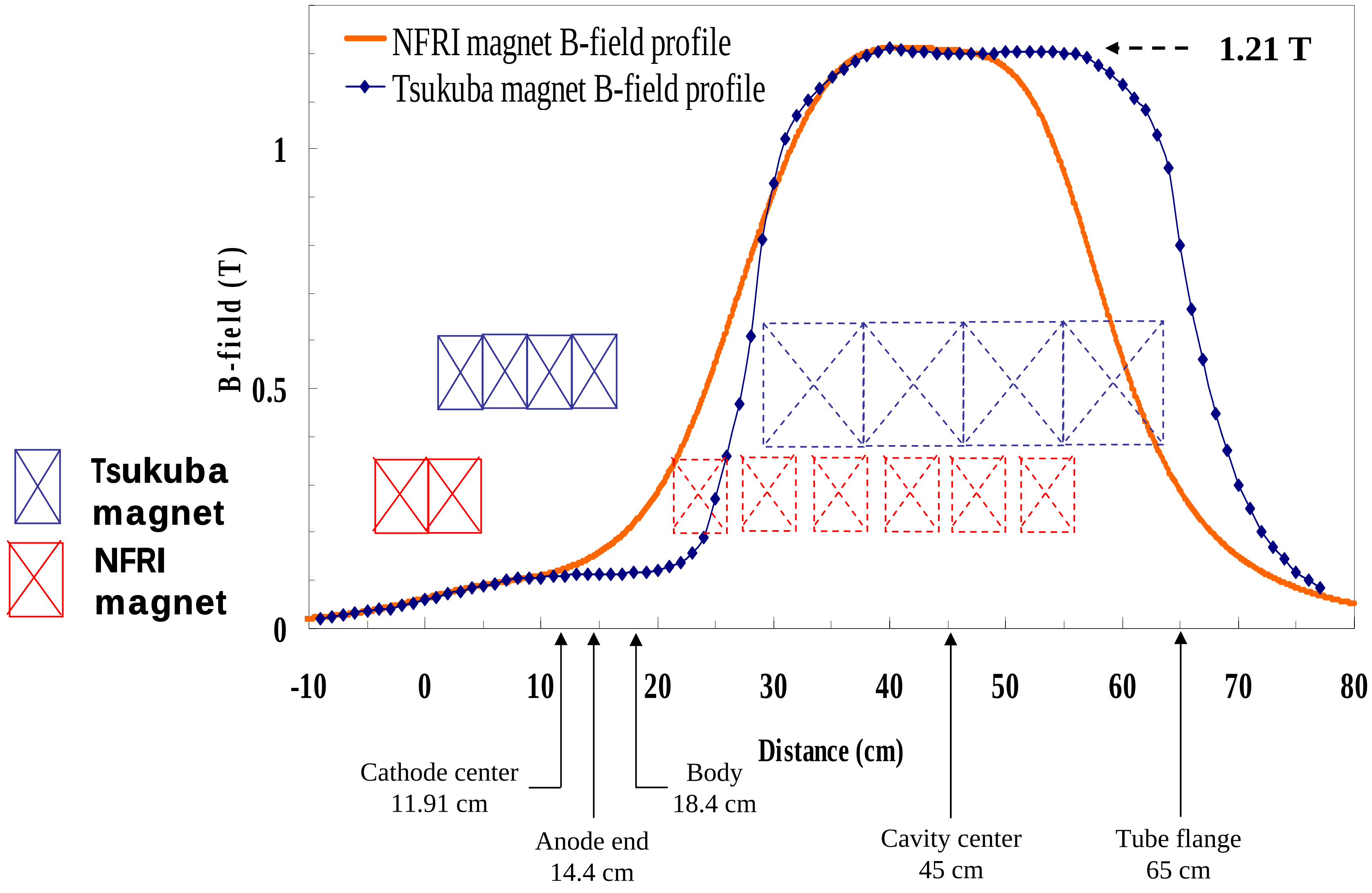
Boundary condition of B-field for 28 GHz gyrotron operation



Comparison of B-field profile at 1.05 T



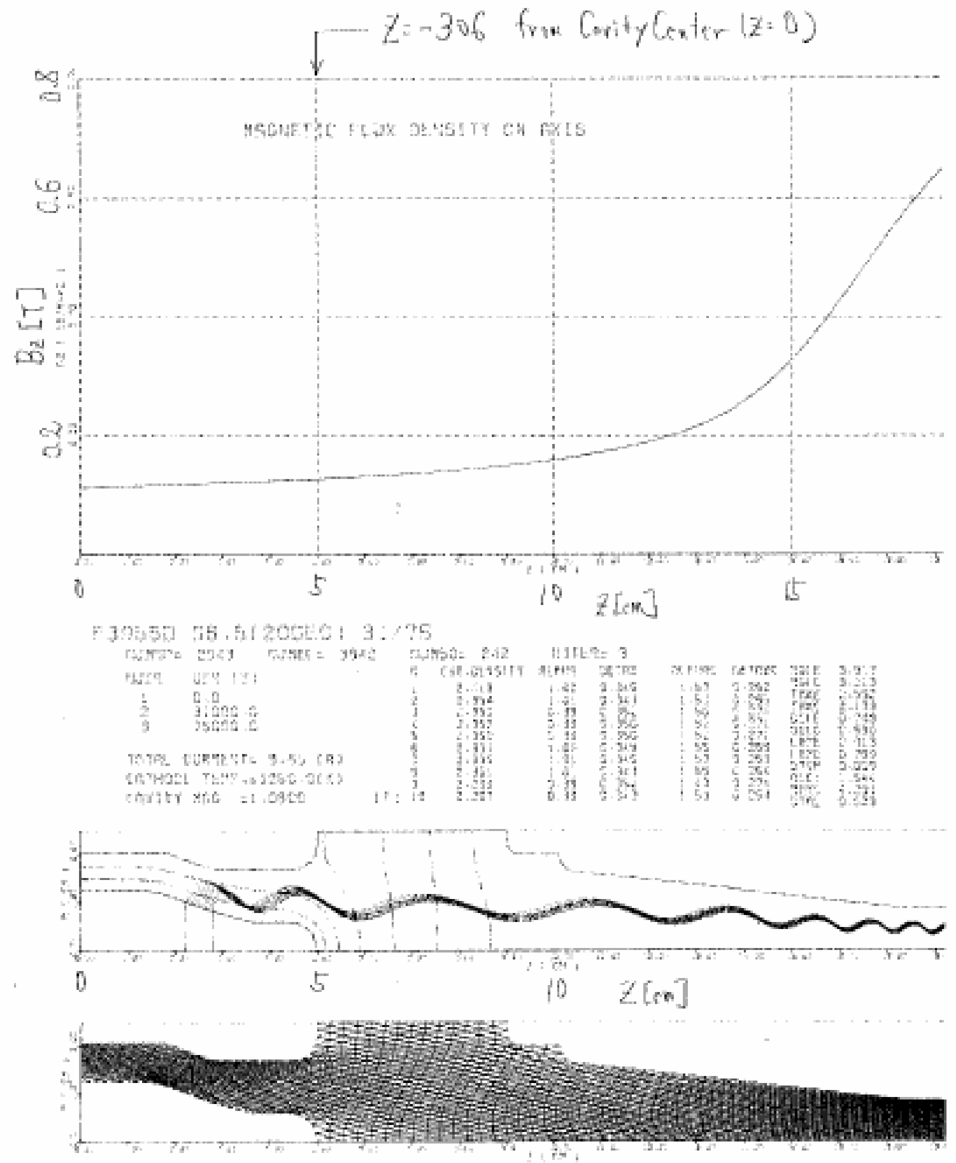
Comparison of B-field profile at 1.21 T



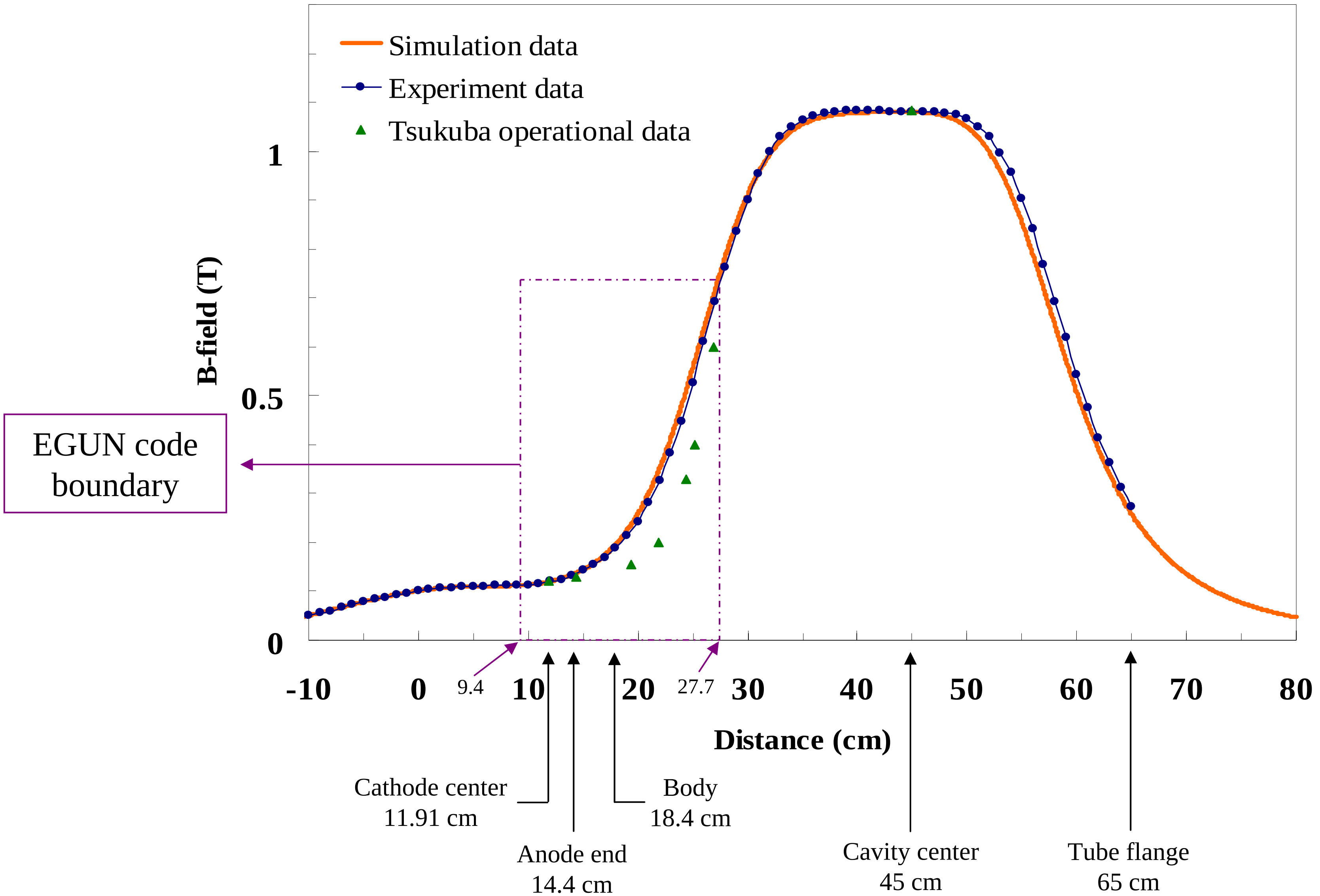
Actual operation data

B-field at cathode center(11.91 cm) = 0.12 T

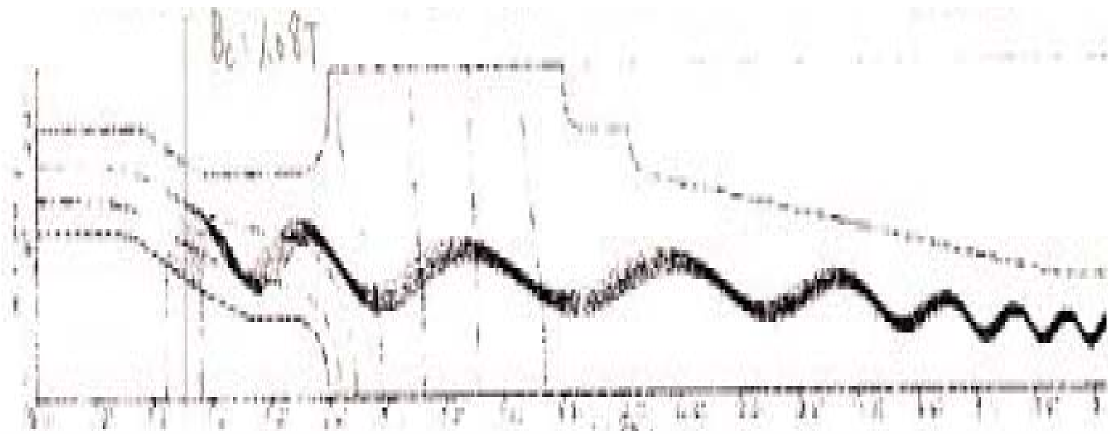
B-field at cavity center(45 cm) = 1.08 T



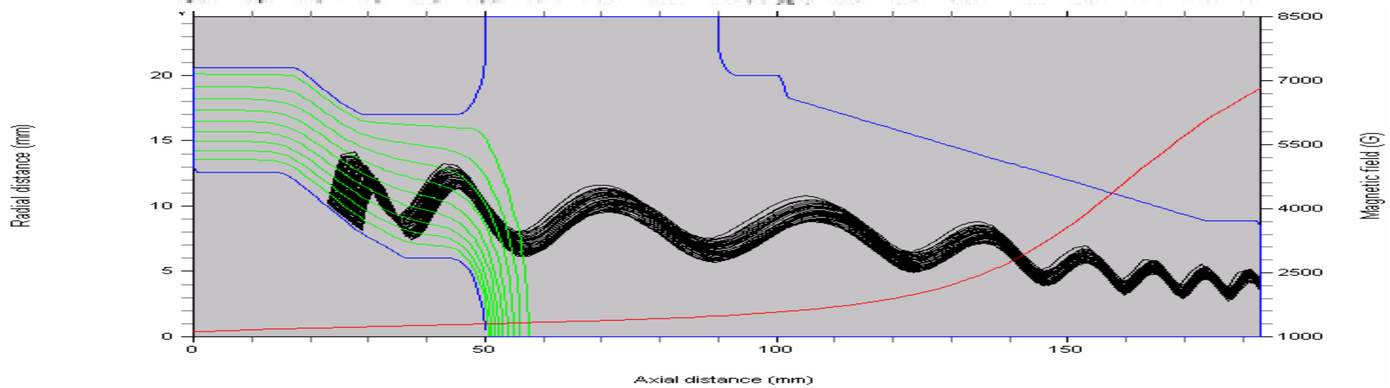
NFRI magnet B-field profile for 28 GHz gyrotron



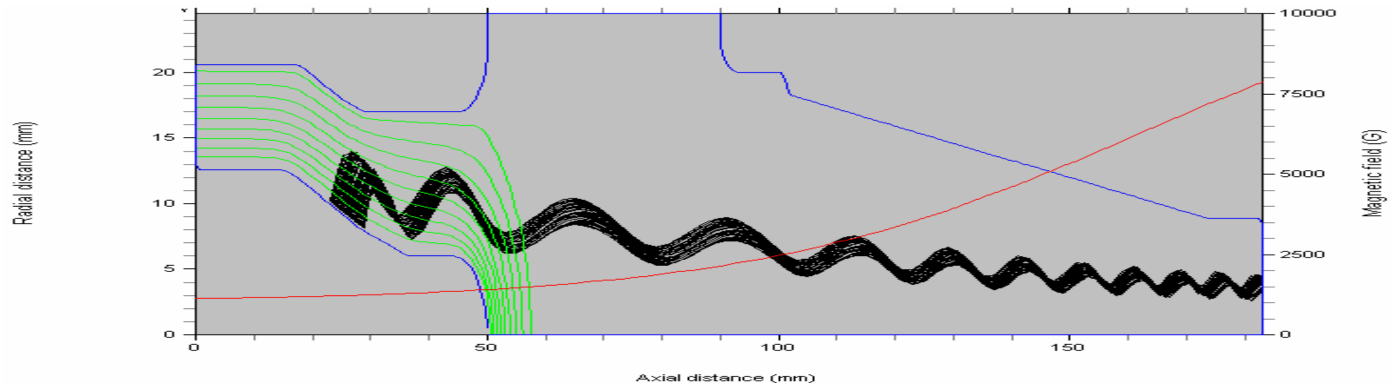
Comparison of E-beam trajectories by EGUN code



Under Tsukuba magnet B-field profile



Under Revival Tsukuba magnet B-field profile



Under NFRI magnet B-field profile

Beam data comparison

	Tsukuba data	NFRI simulation data	unit
Emittance	497	2610	pi-mm-mrad
Normalized emittance	278	1460	pi-mm-mrad
$<\gamma>$	1.1459	1.1459	
Energy	74.5454	74.5391	keV
Gamma difference	0.02	0.03	%
Voltage difference	0.17	0.27	%
$<r>$	3.957	4.145	mm
$< \beta_z >$	0.3799	0.4012	
$< \beta_t >$	0.3066	0.2776	
$<\beta_t>/<\beta_z>$	0.8070	0.6919	
Average pitch factor, $<\beta_t/\beta_z>$	0.8073	0.6936	

Operation theory

28 GHz corresponds to a wavelength of 10.71mm.

For operation in the $TE_{n,m}$ mode, the cavity radius is related to λ by $R_0 = x'_{n,m}\lambda / 2\pi$

where $x'_{n,m}$ is the mth root of $J'_n(x)$.

Cavity radius : $R_0 = 11.96\,mm$ (TE_{02} mode, 28 GHz)

For operation at the first harmonic the optimum beam radius is given by

Beam radius : $R_e = x_{n\pm1,i} R_o / x_{n,m}\ (i = 1\,or\,2)$

In general, the corotating mode (with the lower sign) is chosen, since this provides better coupling of the beam to the RF field.

Beam radius : $R_e = \dfrac{1.8412}{7.0156} \times 11.96\,mm \cong 3.14\,mm$

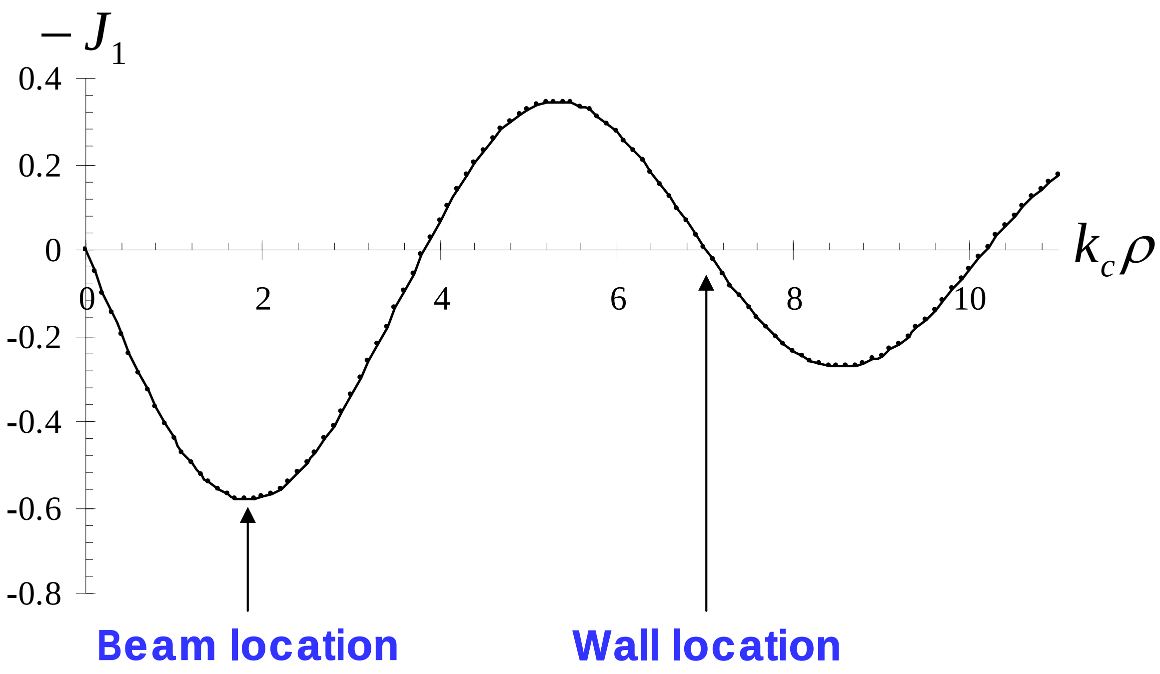
Operation theory

TE_{02} mode in circular waveguide

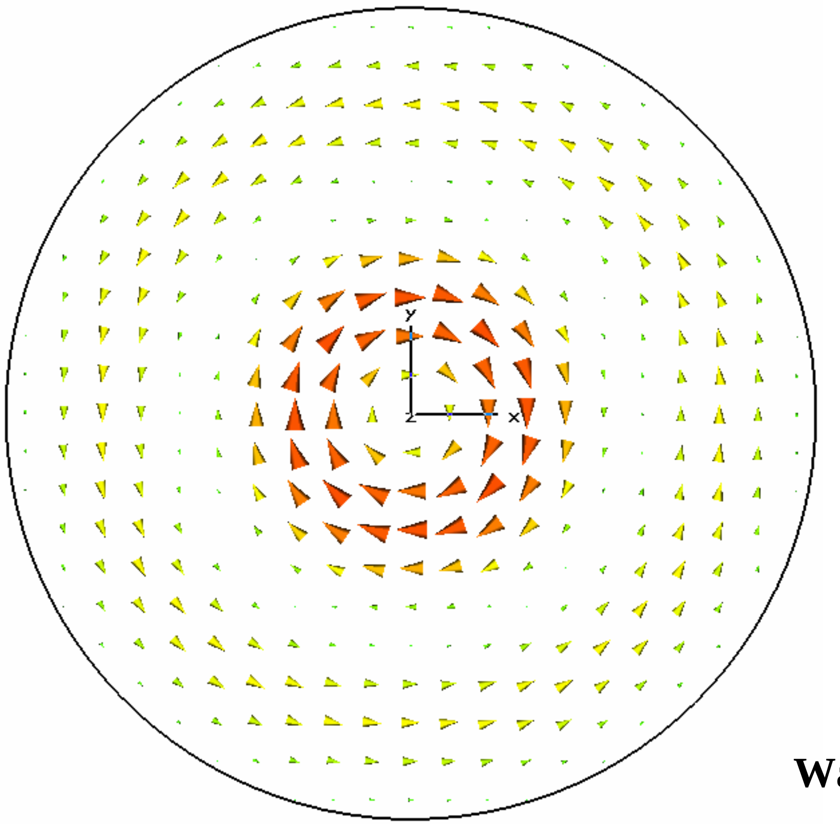
$e^{-jk_z z}$ propagation bas been assumed. ($\because k_c^2 = k^2 - k_z^2$)

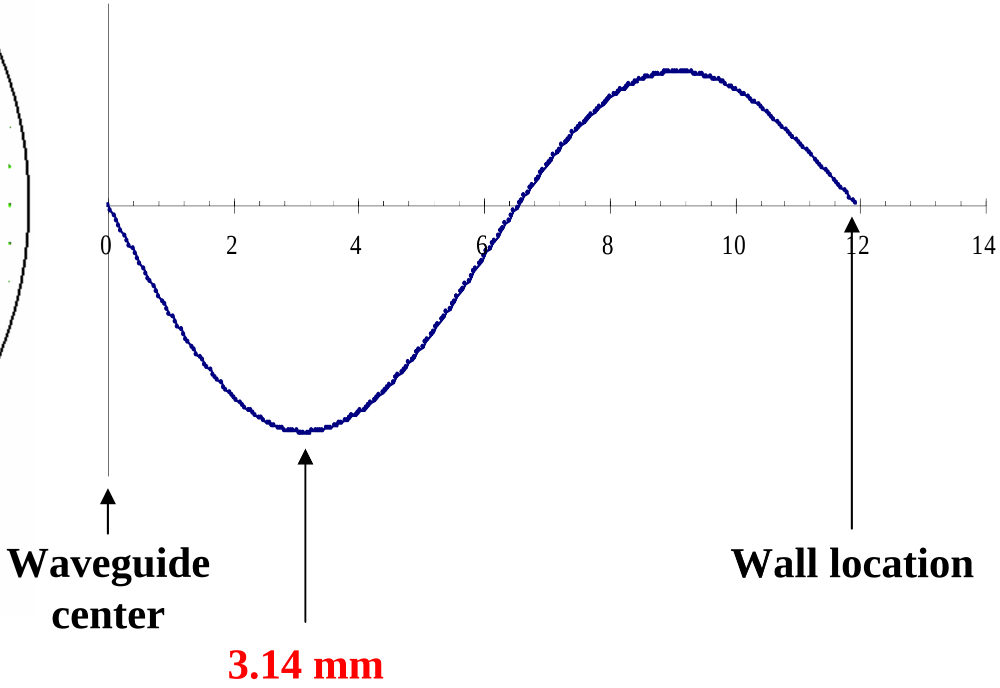
$$E_\rho(\rho, \phi, z) = 0$$

$$E_\phi(\rho, \phi, z) \sim J_0'(k_c\rho) = -J_1(k_c\rho)$$



Operation theory

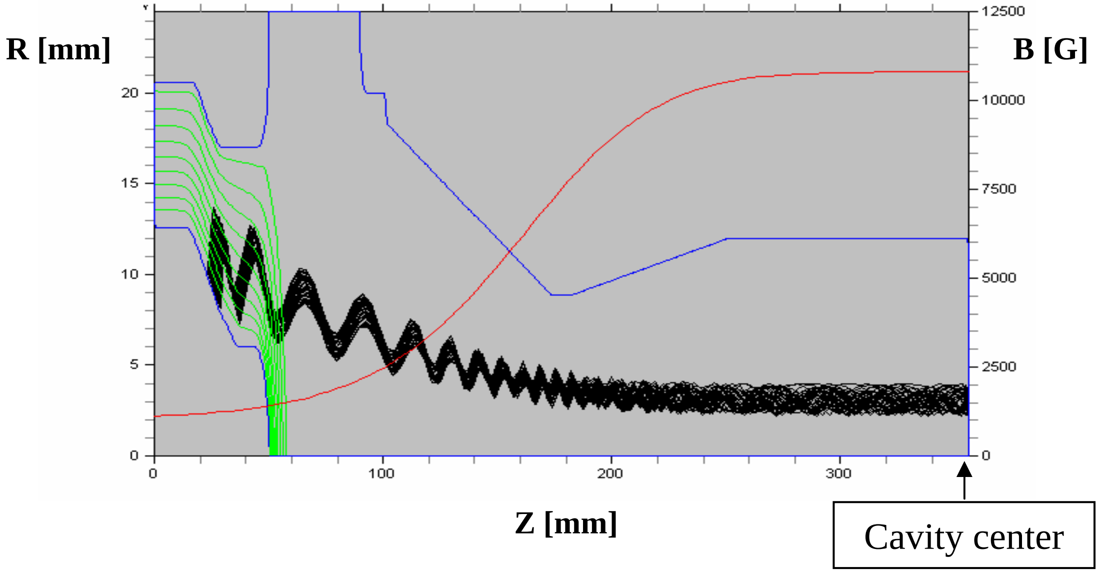


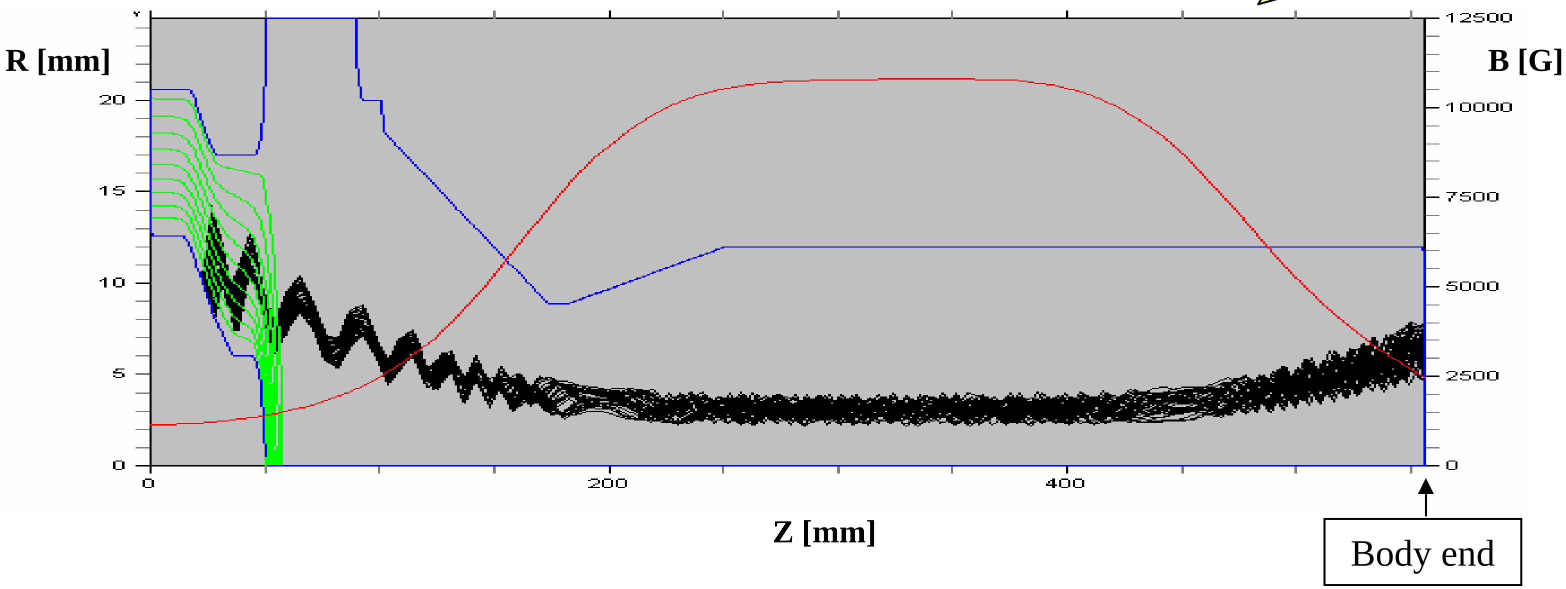


TE_{02} mode MWS simulation result

x-axis versus E-field (arb. amplitude)

E-beam trajectories under NFRI magnet B-field





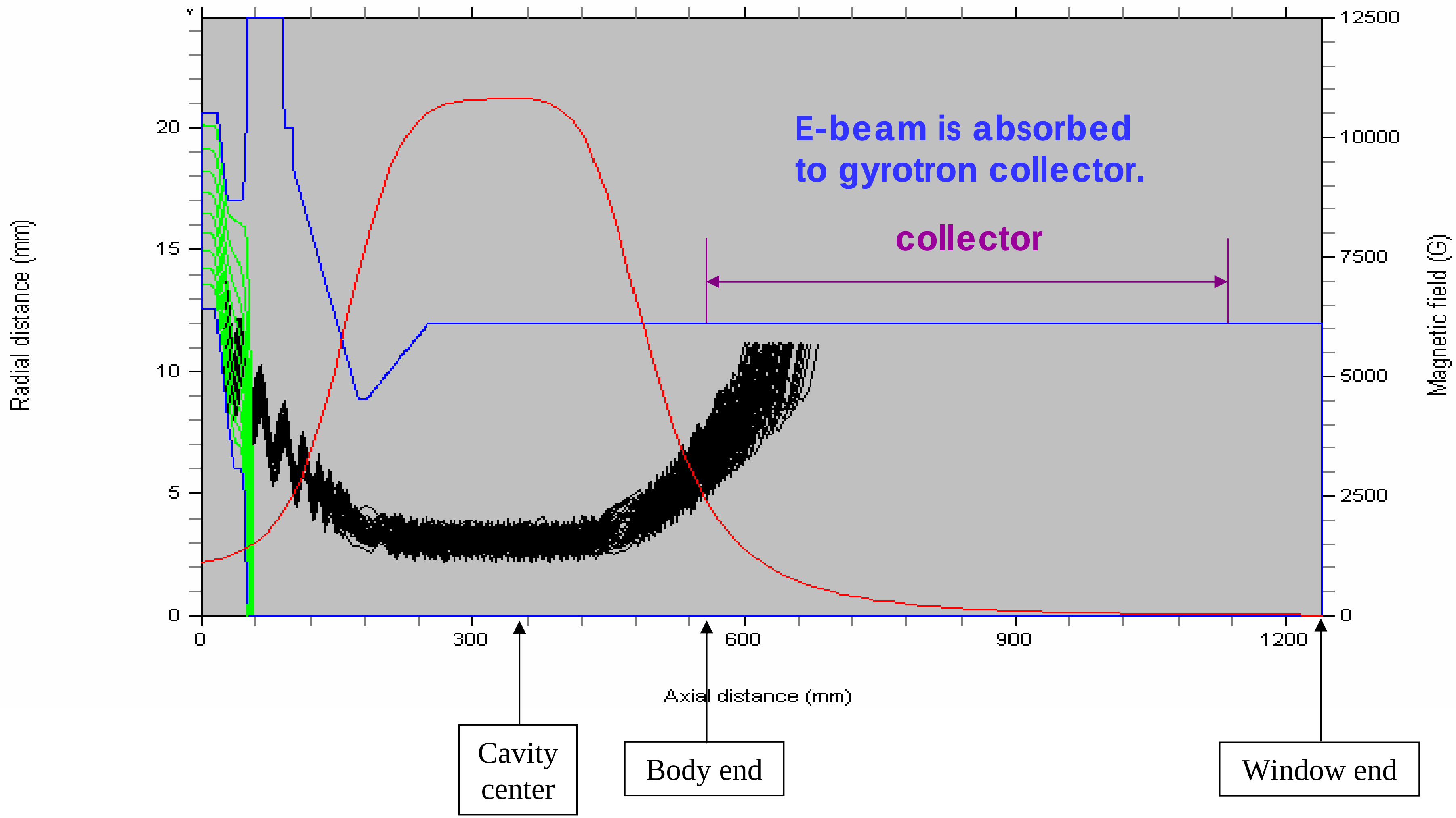
E-beam does not collide with gyrotron body.

Beam data under NFRI magnet B-field

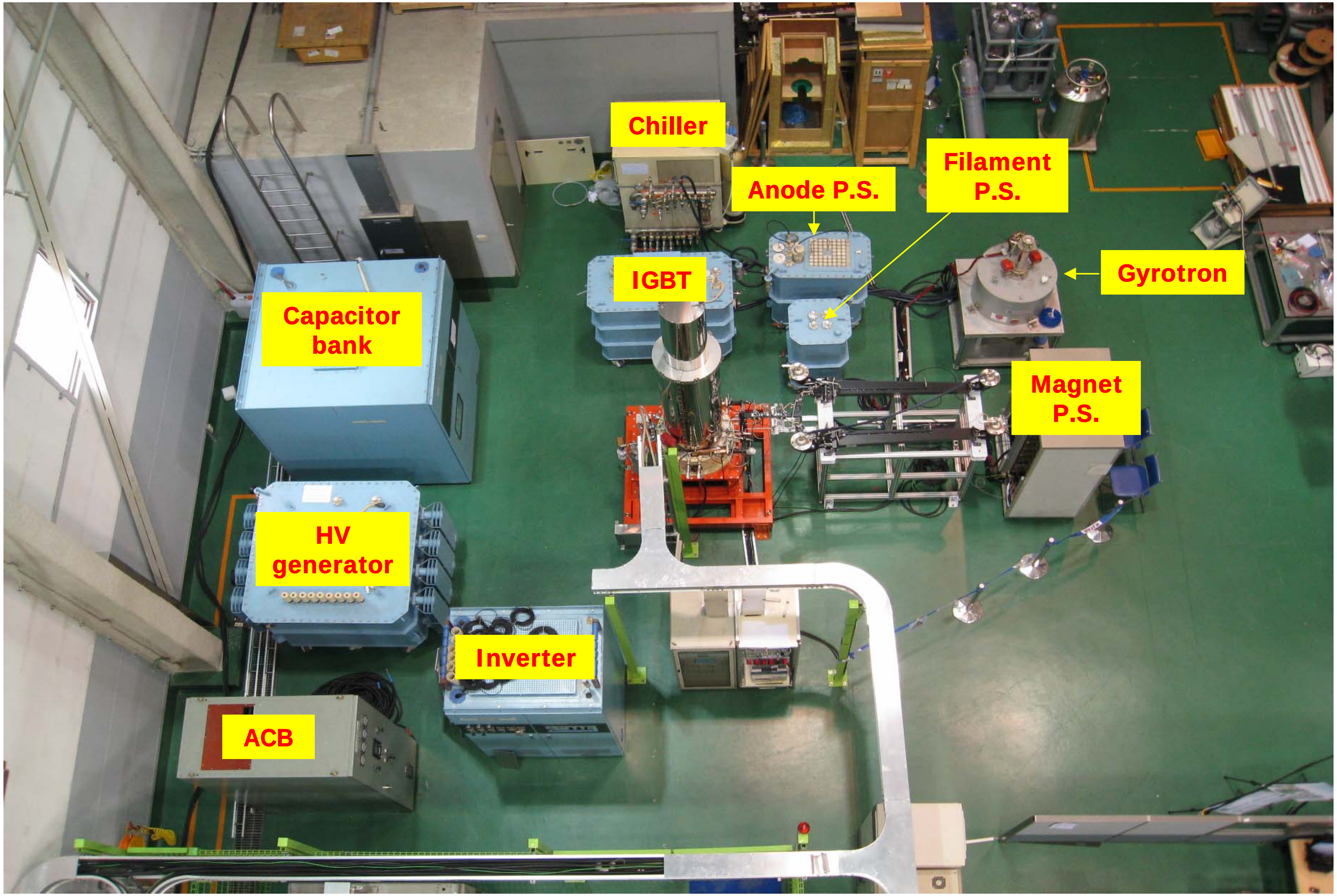
	Cavity center	Body end	unit
Emittance	3550	2810	pi-mm-mrad
Normalized emittance	1980	1580	pi-mm-mrad
$<\gamma>$	1.1450	1.1462	
Energy	74.0878	74.6981	keV
Gamma difference	0.07	0.07	%
Voltage difference	0.52	0.54	%
$<r>$	3.096	6.358	mm
$< \beta_z >$	0.3622	0.4641	
$< \beta_t >$	0.3249	0.1520	
$<\beta_t>/<\beta_z>$	0.8971	0.3276	
Average pitch factor, $<\beta_t/\beta_z>$	0.9004	0.3280	

Beam radius r=3.096 mm by e-gun simulation is similar r=3.14 mm calculated by operation theory.

E-beam trajectories under NFRI magnet B-field



Power supply for 28 GHz gyrotron (Repairing)



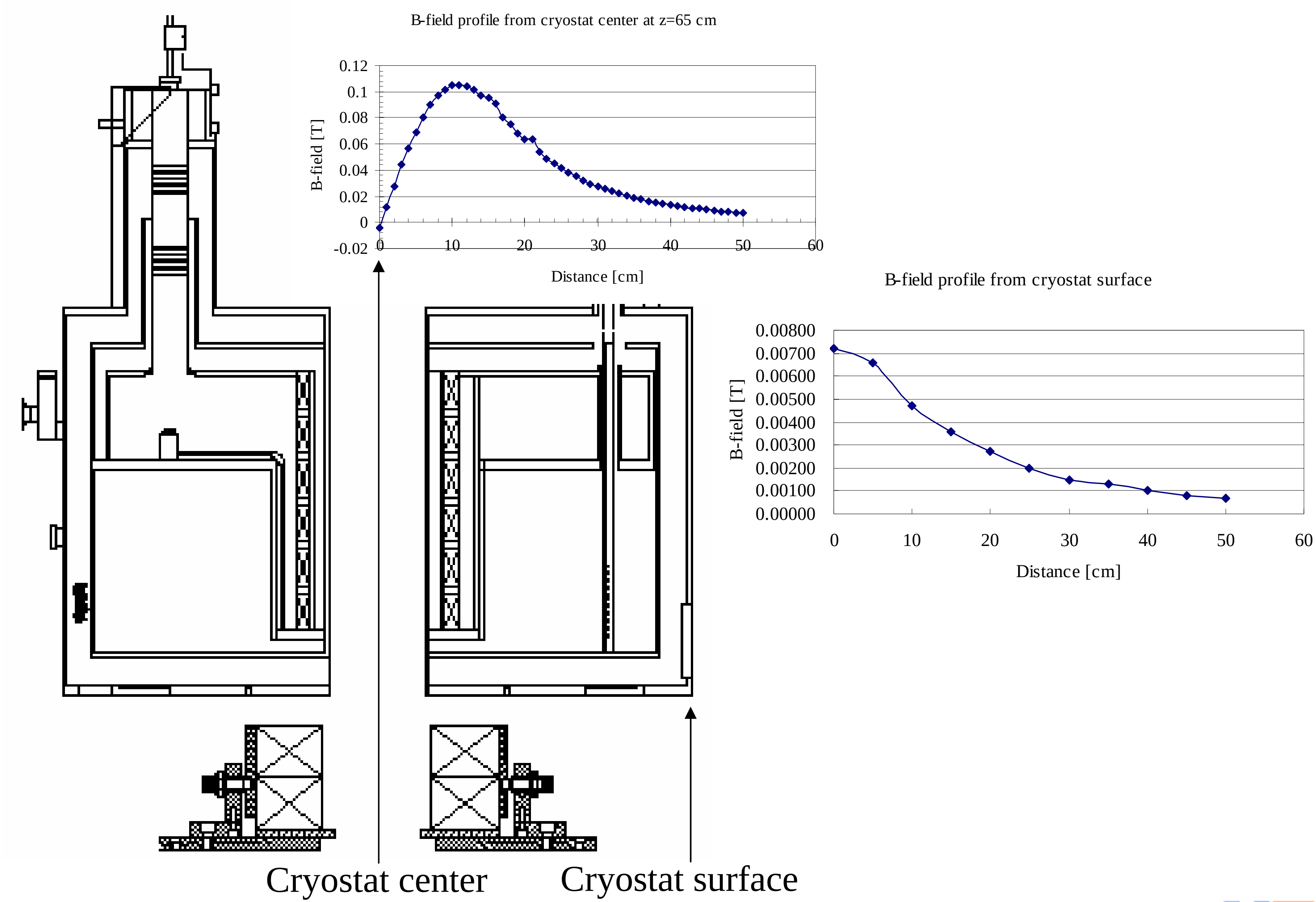
28 GHz RF components (Shipping from Tsukuba univ.)

Item	Size	Quantity
Mode filter	62.6 mm ID	1 EA
Mode filter	37 mm ID	1 EA
TE02-mode directional coupler	37 mm ID	1 EA
Waveguide arc detector with SF6 gas port	62.6 mm ID	1 EA
TE02-mode dummy load	37 mm ID	1 EA
TE02-mode Vlasov antenna	37 mm ID	1 EA
Tapered waveguide	62.6 mm to 37 mm	1 EA
Flexible tube	62.6 mm ID	2 EA
Straight waveguide	37 mm ID	1 EA
Straight waveguide	62.6 mm ID	2 EA
Bellows	62.6 mm ID	1 EA
Waveguide with SF6 gas port	62.6 mm ID	1 EA

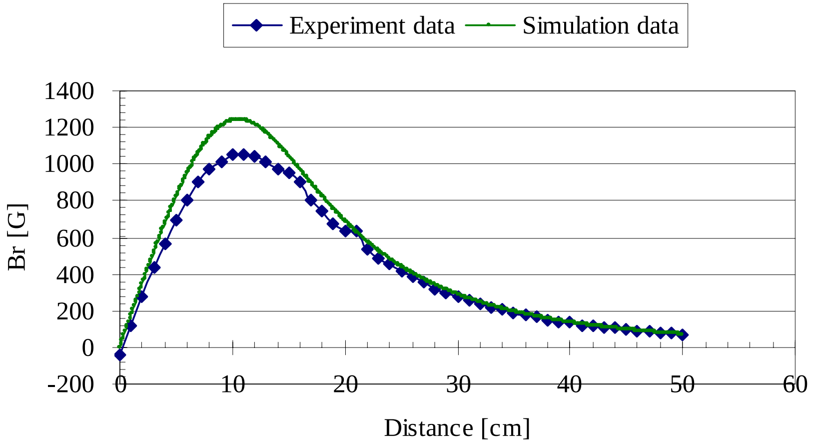
Summary

1. The development of 28 GHz gyrotron system was promoted at National Fusion Research Institute (NFRI).
2. We obtained the required B-field: 1.08 T at cavity center and 0.12 T at cathode center using NFRI magnet system.
3. By E-gun simulation, the e-beam trajectory shows the possibility to operate 28 GHz gyrotron under NFRI magnet B-field profile.
4. These results are also fit to 28 GHz, TE_{02} mode gyrotron operational theory.
5. We are now preparing power supply and RF waveguide components.
6. 28 GHz gyrotron is capable to generate the beam(200 kW, 75 ms) at NFRI system.

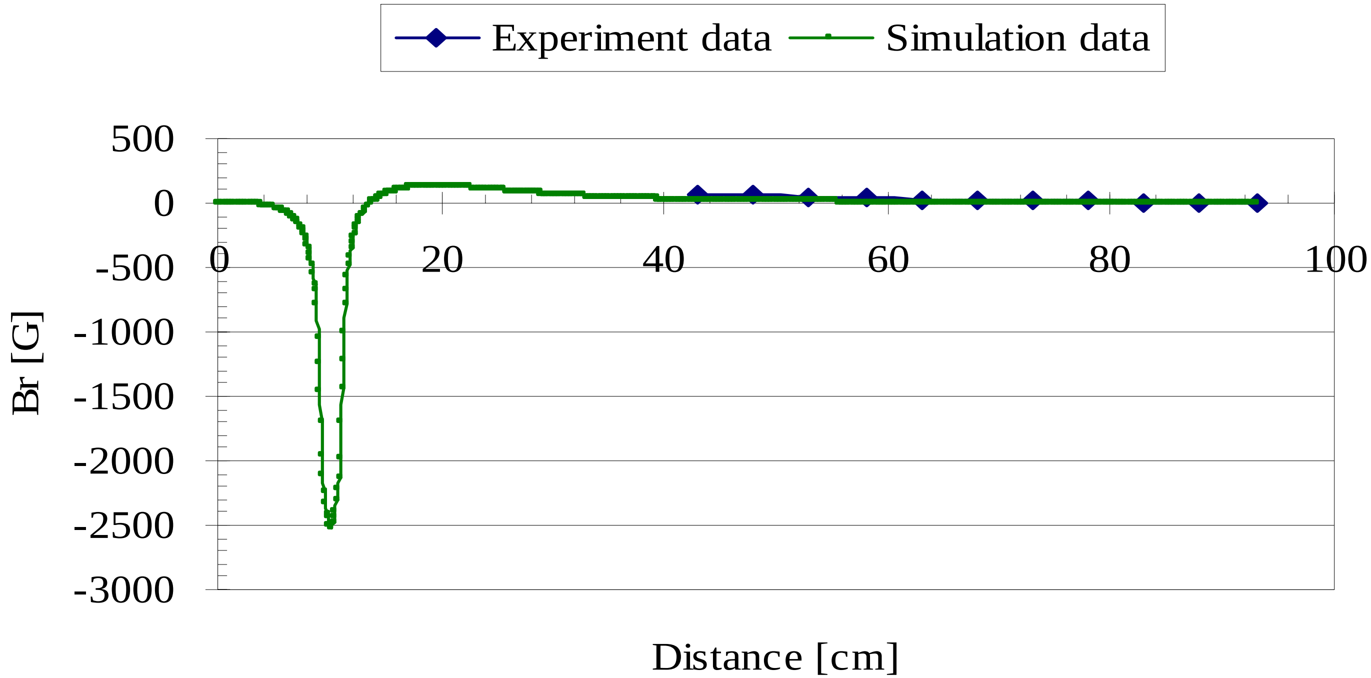
B_r field measurement result



B_r field measurement result



B_r field at z=65 cm (Magnet top)



B_r field at z=45 cm (Cavity center)