# Low Frequency Gyrotron Development for Electron Bernstein Wave Experiments at NSTX

M.A. Shapiro, R.J. Temkin, E. Choi, J.R. Sirigiri
MIT Plasma Science and Fusion Center

G. Taylor
Princeton Plasma Physics Laboratory

K. Felch, P. Borchard, S. Cauffman, T.S. Chu
Communications and Power Industries

# ABSTRACT



EBW plasma heating is attractive for application on high density, low magnetic field machines, such as NSTX. Low frequency gyrotrons (15-28 GHz) at 1 MW power levels are needed for this application. A 28 GHz, 1 MW, 5 s pulsed gyrotron tube is under design at CPI and MIT for NSTX. The design is based on previous, successful CPI gyrotron development at higher frequencies.

# MOTIVATION



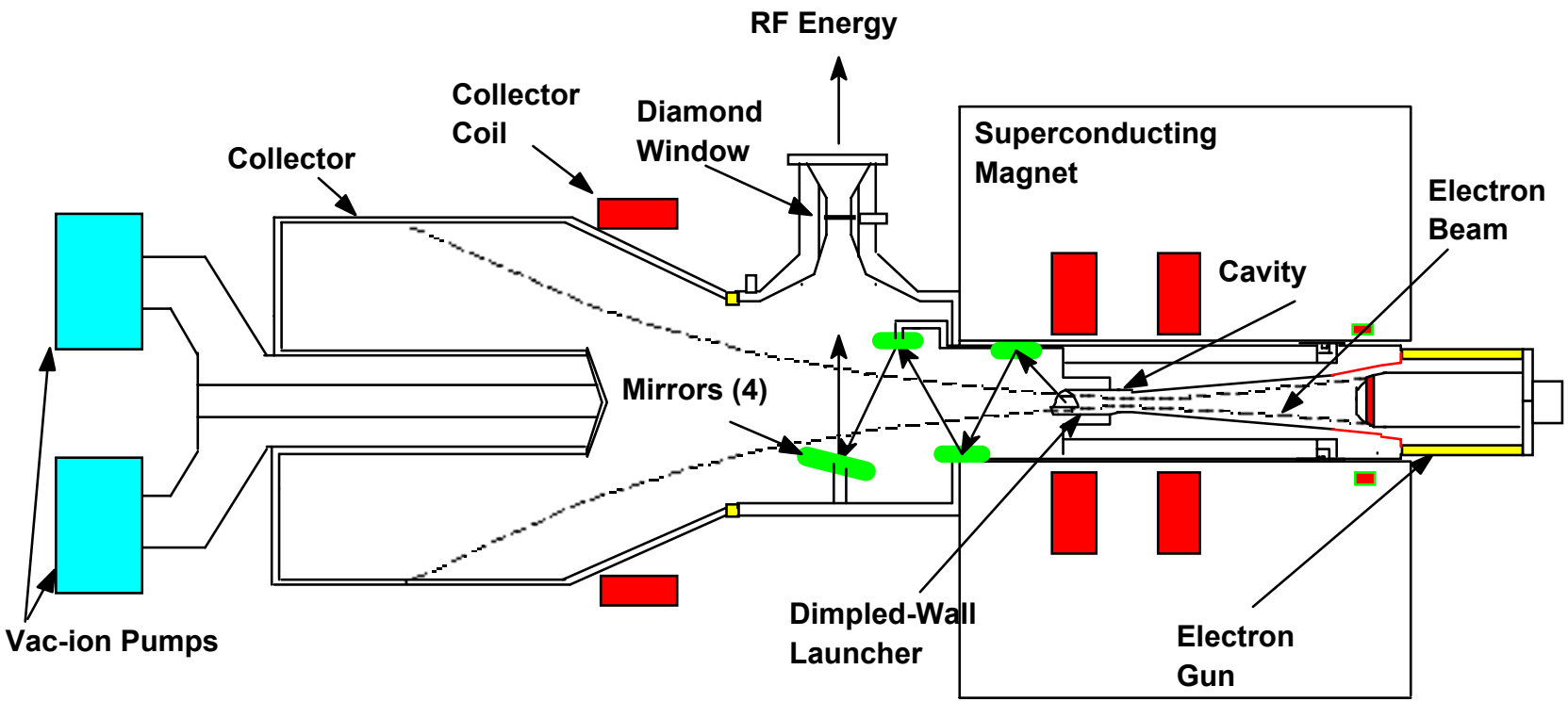
- High power (about 1 MW) CW microwave sources in frequency range 14-28 GHz are needed for EBW heating and current drive at NSTX
- 200 kW, 28 GHz gyrotrons manufactured at Varian (now CPI) in 1980s
- 1 MW CW 28 GHz gyrotron under design (MIT and CPI)

# Gyrotron components

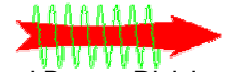
- Magnetron injection electron gun
- Microwave cavity
- Collector for electron beam
  - Depressed collector to increase efficiency
- Mode converter of operating mode to Gaussian beam
- Output window
- Tube installed in superconducting magnet
  - Additional magnets for gun and collector

# Gyrotron Schematic





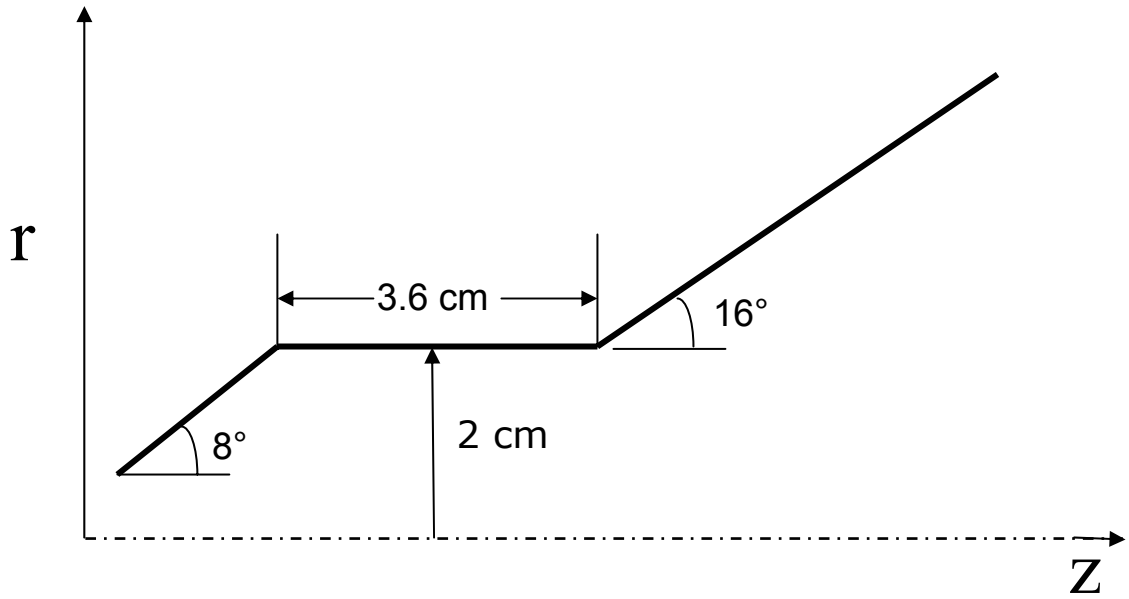
# Design Parameters




- Mode $TE_{62}$
- Frequency 28 GHz
- Magnetic field 1.06 T
- Beam current 40 A
- Beam voltage 70 kV
- Anode voltage 50 kV
- Body voltage 20 kV
- Beam radius 1.09 cm
- Beam pitch factor $\alpha$ 1.5
- Cathode radius 4 cm
- Cavity length 3.6 cm
- Cavity radius $R_c$ 2.00 cm
- Diffraction Q factor 340
- Efficiency without depressed collector 39 %
- Efficiency with depressed collector > 50 %
- Power 1.1 MW

# Geometry of the cavity

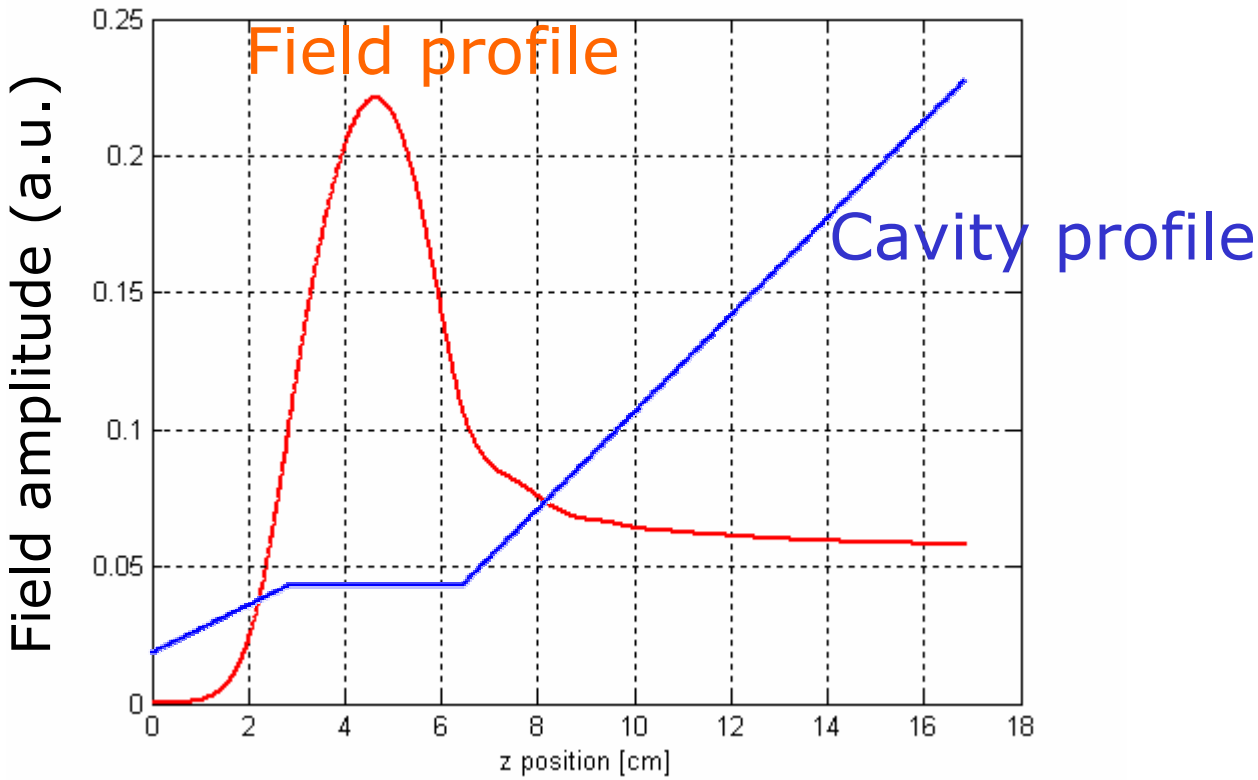





Design parameters:
V = 70 kV
I = 40 A
Alpha = 1.5
Rcav = 2 cm
F = 28.18 GHz
mu = 6.52
Q = 337

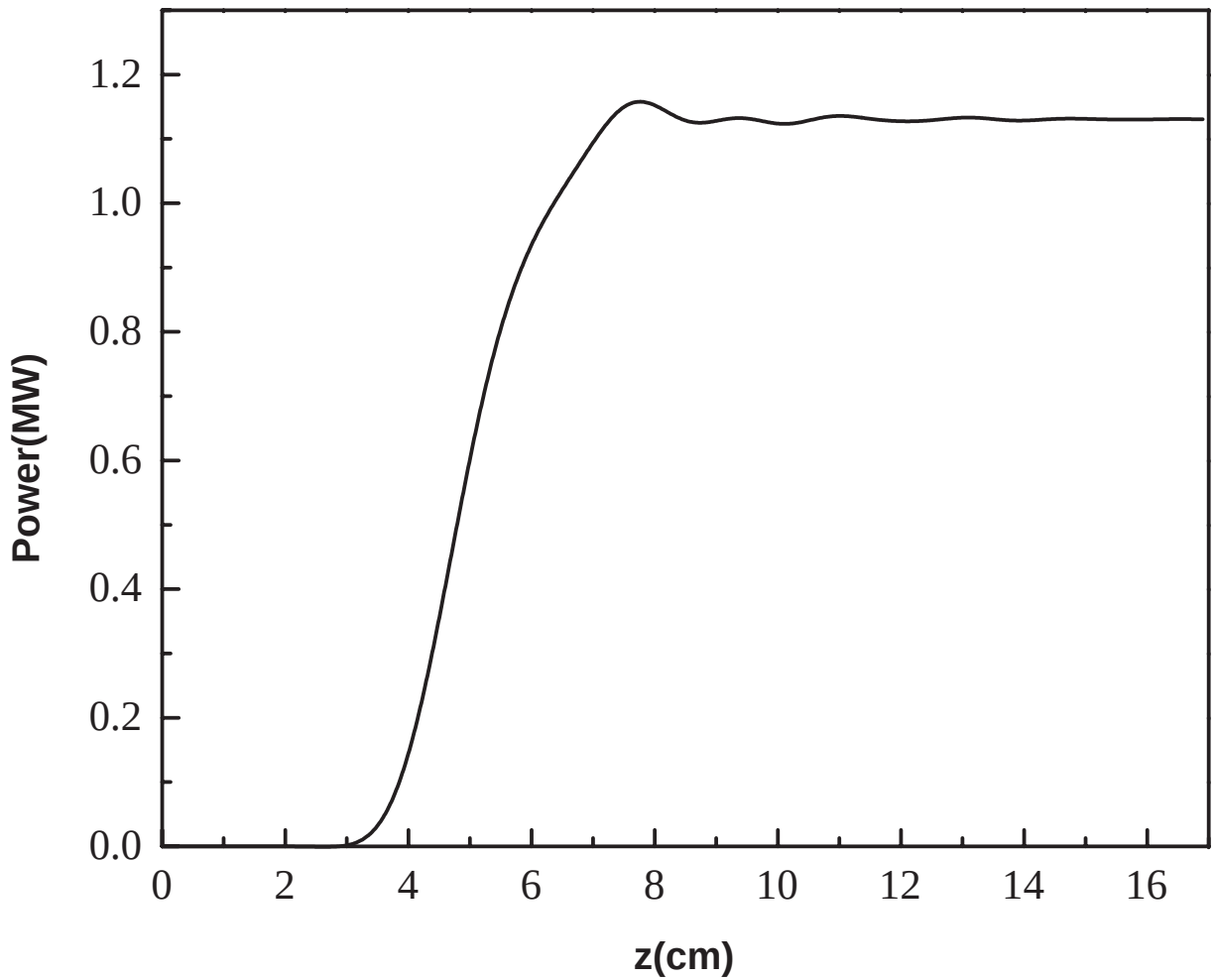
# MAGY simulation result





# MAGY simulation result



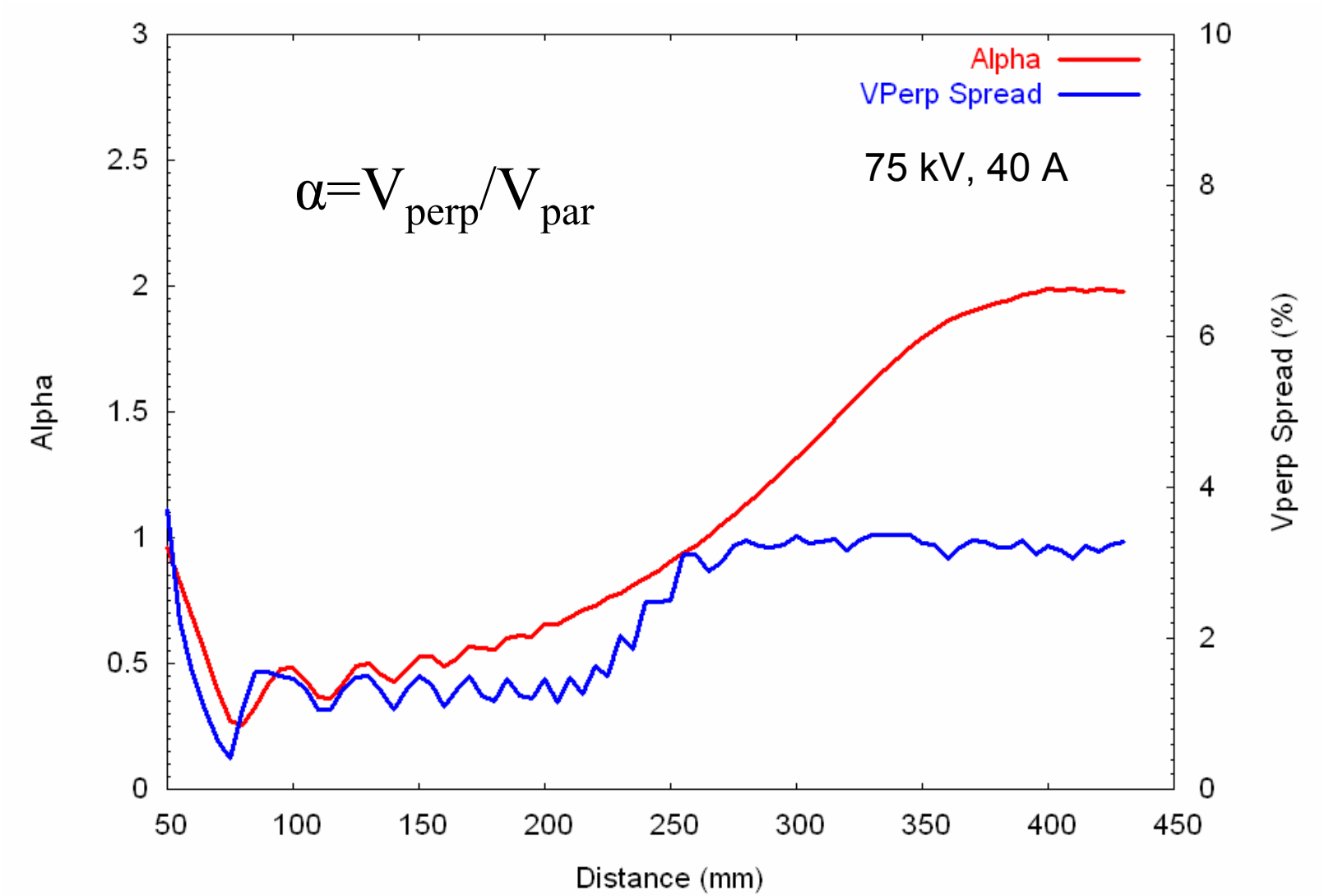



V=70 kV
I=40 A
B = 10.6 KG
P = 1.1 MW
Efficiency = 39 %

Time domain simulation code MAGY developed at Univ. MD and NRL:
M. Botton et al. IEEE Trans. PS, Vol. 26, 882 (1998)

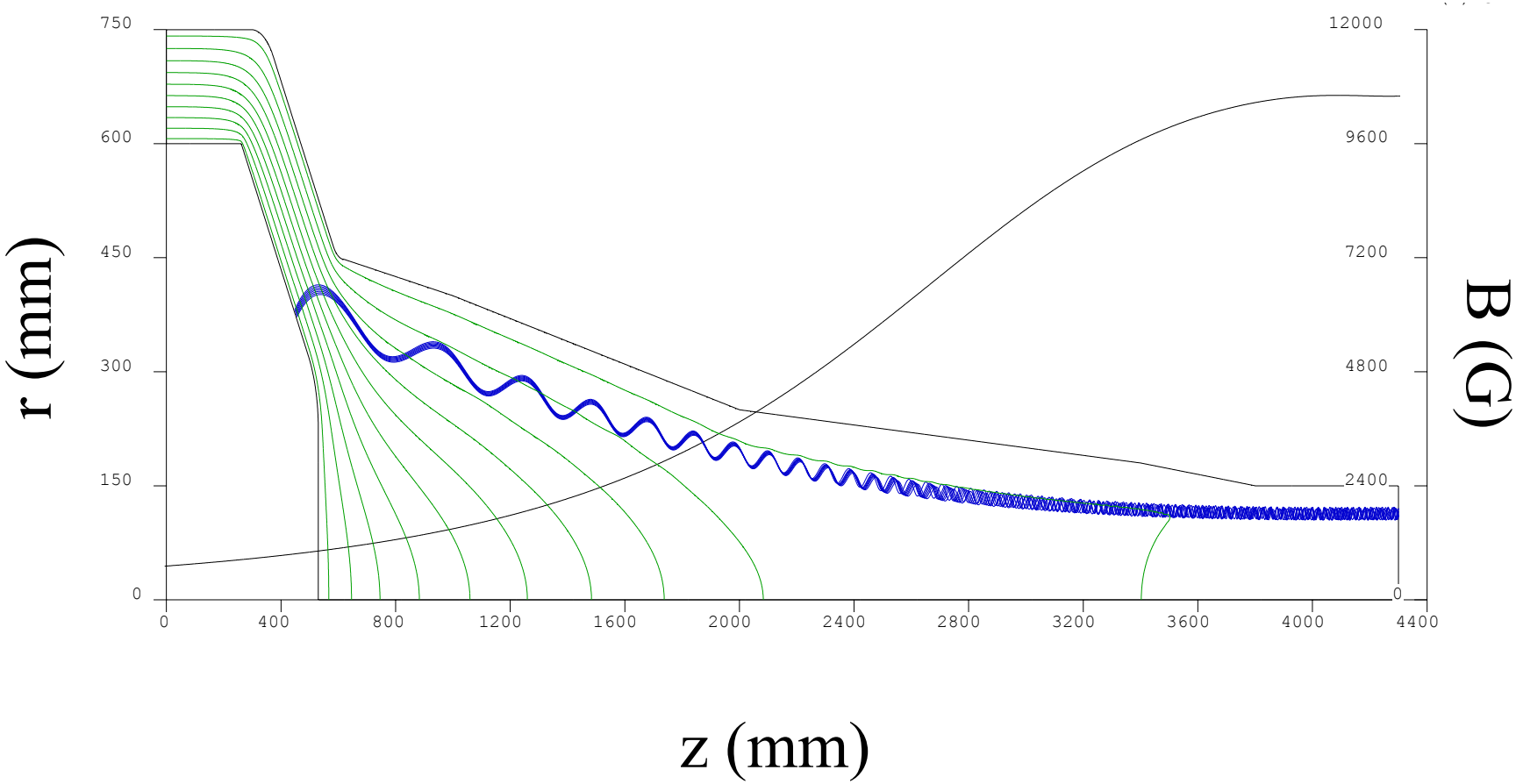
# EGUN results: alpha and velocity spread

Waves and Beams Division



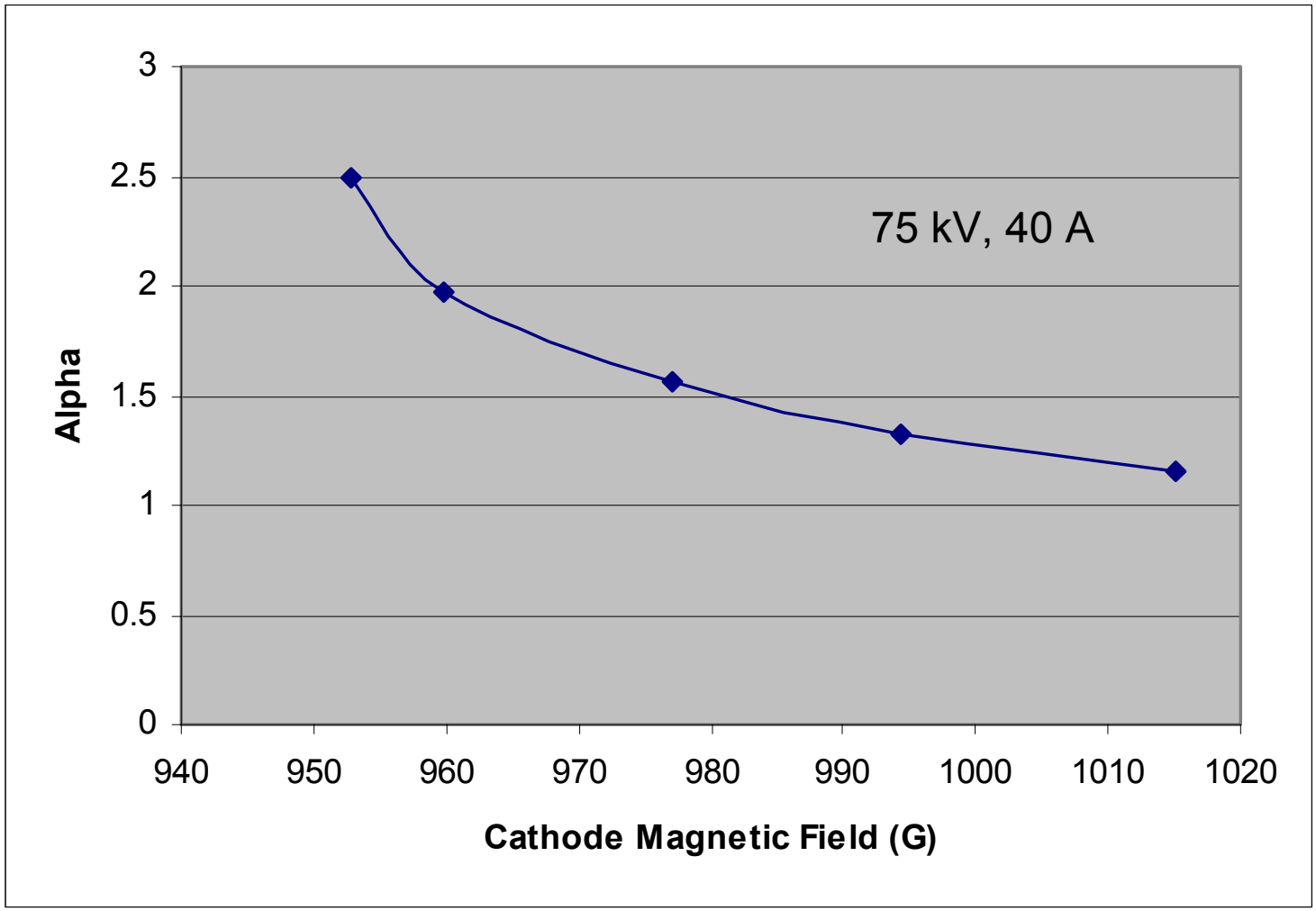
# EGUN results: Electron trajectories

Waves and Beams Division



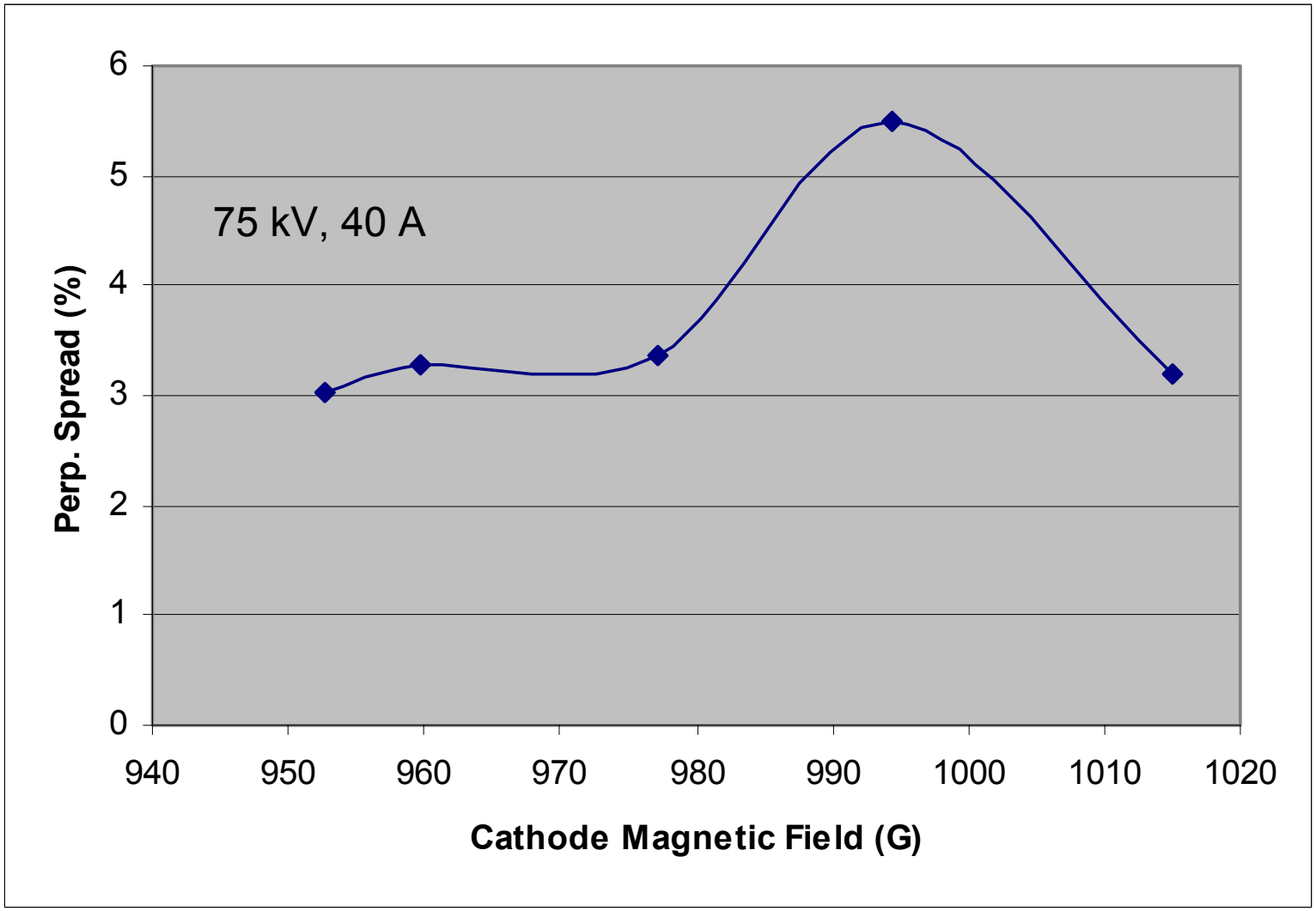
# EGUN results: Alpha vs. Cathode magnetic field





# EGUN results: Velocity spread vs. Cathode B

Waves and Beams Division



# CONCLUSIONS



- 1 MW, 28 GHz CW gyrotron designed
- 70 kV, 40 A beam from MIG used
- Results of simulations are promising
  - Efficiency of 39 % w/o depressed collector, >50 % with depressed collector
  - High velocity ratio (alpha up to 1.8)
  - Low velocity spread (3% perp. spread)
- Conceptual design is complete. Design looks promising. Industry (CPI) could proceed with fabrication if the tube is needed.

# FUTURE WORK



- Next step would be detailed engineering design at CPI.
- Final design study is needed for the internal mode converter.
- Prototype tube would be made by industry (CPI).