DEVELOPMENT of LONG PULSE mm-WAVE SOURCE
Trieste, 3-6 June, 2013

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GOALS

- 1. Design and fabrication of 1 MW, 300 GHz Long Pulse RF Source
- 2. Design and fabrication of Short RF Und. Structure
- 3. Performing cold and hot tests for both devices
- 4. Design, fabrication and test of the RF UNDULATOR

Why RF UNDULATOR

Drawbacks of Static Undulators

1. Cannot control the polarization
2. Cannot change the undulator period
3. Vulnerable to X-ray radiation
4. High cost

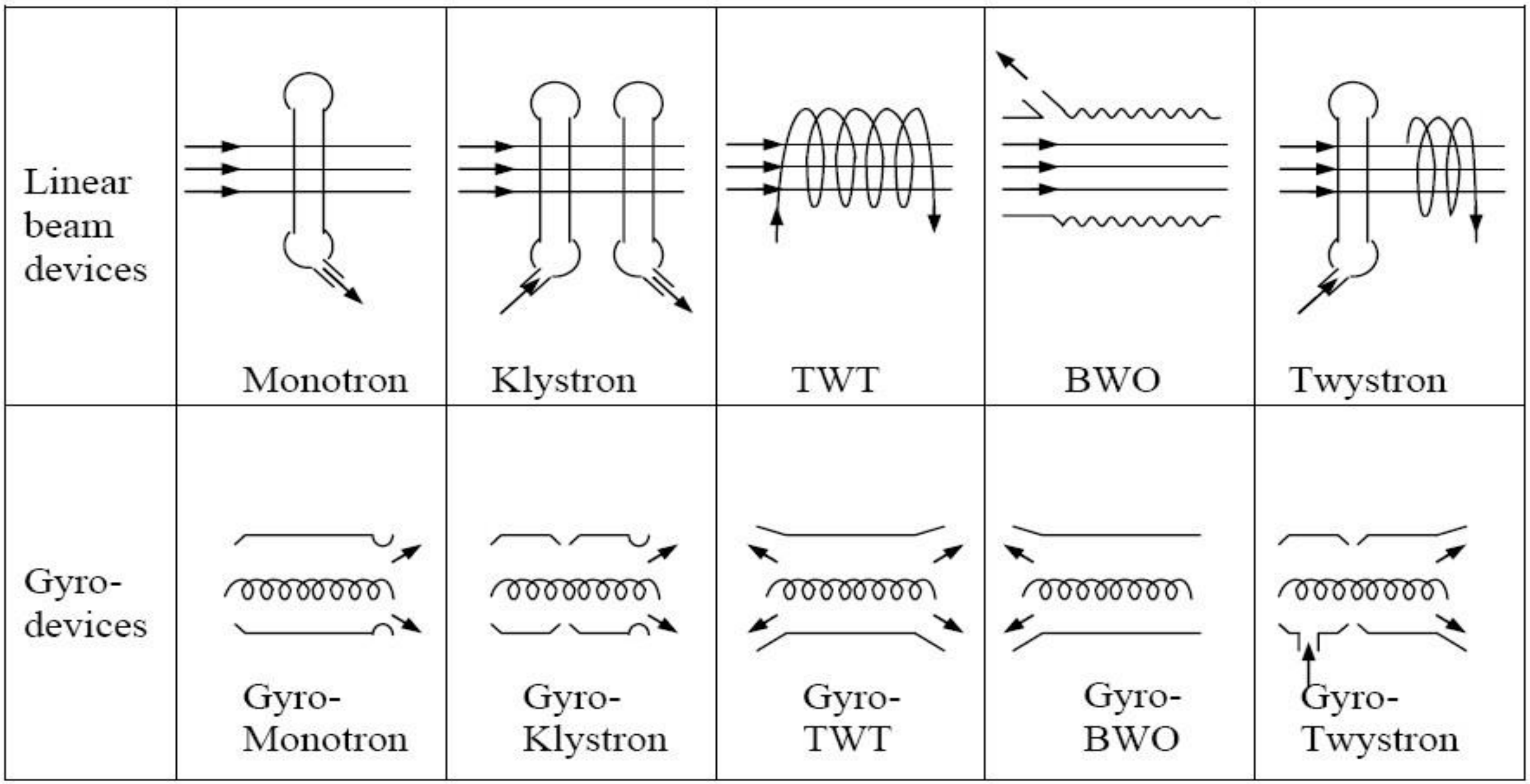
Advantages of RF undulators

1. Easy polarization control
2. Short undilator periods and large gaps.
3. Cheap in comparison with the Permanent Magnet Undulators

Drawbacks of RF Undulators

1. Realization of High-Power RF Sources with stable amplitude and phase
2. Complicate design and fabrication

Different RF sources



High-Frequency, Low&Mid Power, Long-Pulse Sources

-Gyroklystron – 94 GHz, 10KW average power

-Gyro-TWT – from 60 to 90 GHz, several KW RF Power

Both devices operate as amplifiers

-Klystron – 100-500 KW, ms range, at 6-8 GHz

-Mid-Power, Long-Pulse, High-Efficiency Gyrotron for FUSION – 1 MW, 1s to 1h pulse, cylindrical, qusioptical and coaxial cavity

-Low-Power, High-Efficiency Cyclotron Autoresonance Maser – from 100-400GHz, 1MW, @several ms. To operates as an amplifier and an oscillator, as well, PROJECT!!

High-Power, Low-Frequency, Short-Pulse Sources

High-Power, Low-Frequency, Short-Pulse sources

-Klystron (amplifier)– up to 11 GHz, 50 MW, high efficiency

-Gyroklystron (amplifier) – 17GHz, 10 MW
34 GHz, several MW, projects

-Magnicon (amplifier)– 11 GHz , 50 MW, high efficiency,

-Free electron laser- 17 GHz, 20 MW, 10-15% efficiency

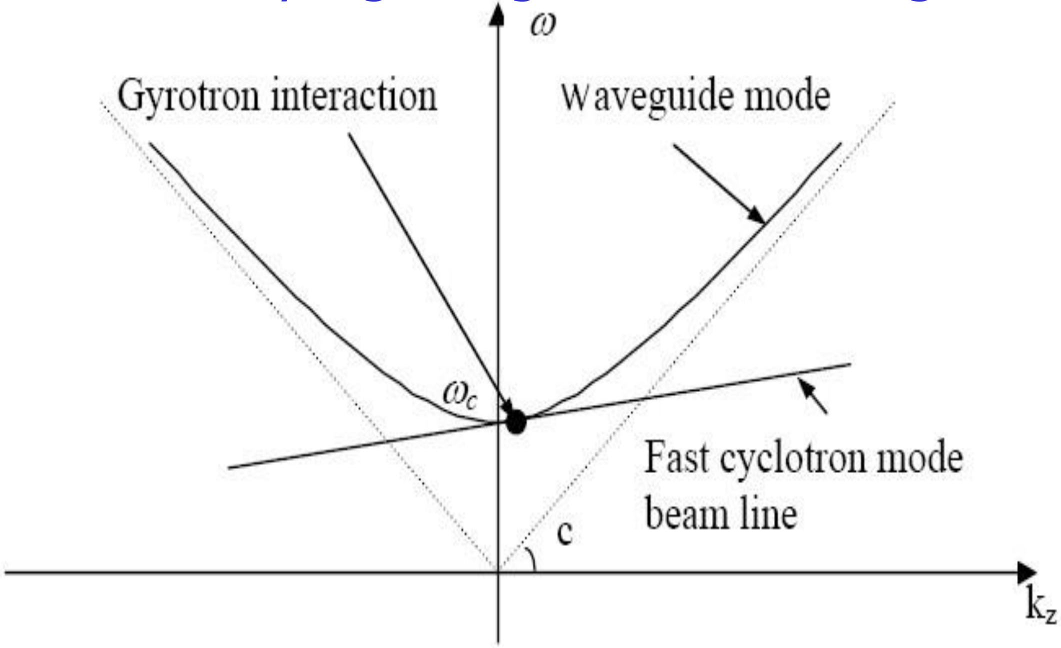
-High-power, Short-Pulse, Low efficiency Gyrotron oscillator(6-8% eff.), 50 MW

-High-Power, Cyclotron Autoresonance Maser(<10%)

10-50GHz, tens of Megawatts, Low efficiency osc.& ampl..

CRM - Gyrotron

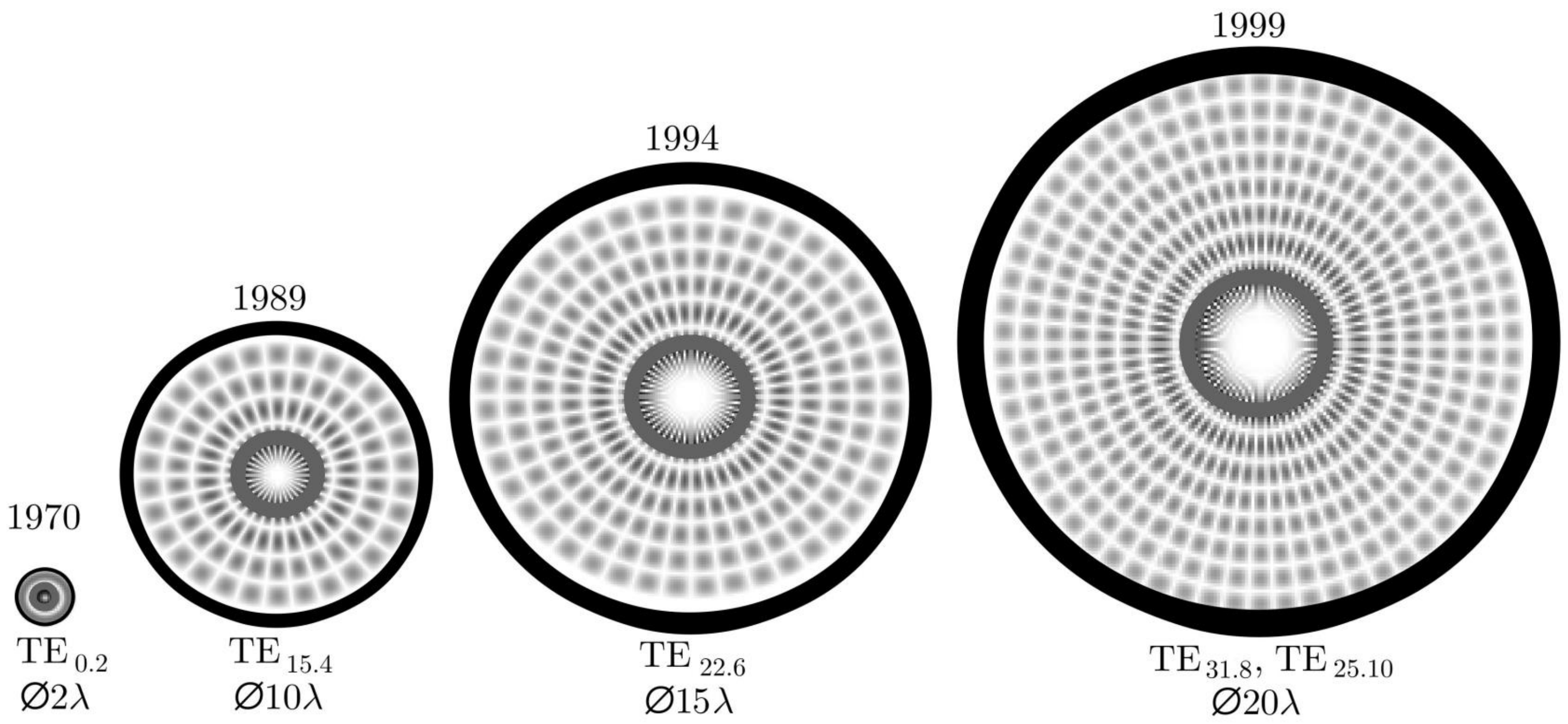
Operates at cyclotron frequency near cutoff
High efficiency at nonrelativistic beam energy - 60-100KeV
Tolerant to poor beam quality and support high current – 40-80 Amps
Needs very high magnetic field for high frequency -28GHz/T



$$\omega = s\Omega_c + k_z v_z$$

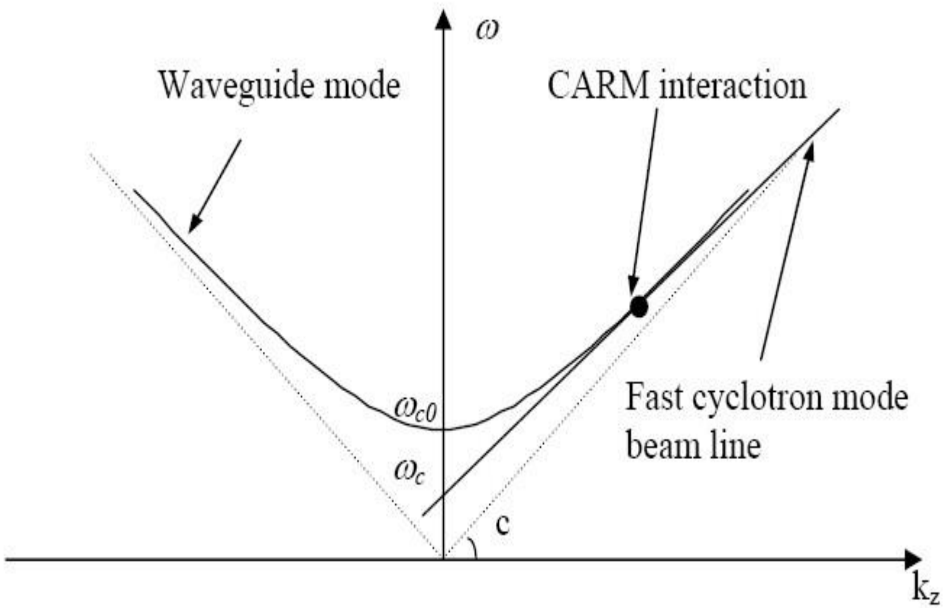
$$\Omega_c \equiv \frac{q_e B_0}{m_e \gamma}$$

Gyrotron Modes



CRM - Cyclotron Autoresonance Maser

Operates far from cutoff which reduces the fields at cavity walls
High frequency at low magnetic field
High efficiency due to the compensation from the Doppler term
Needs high beam quality



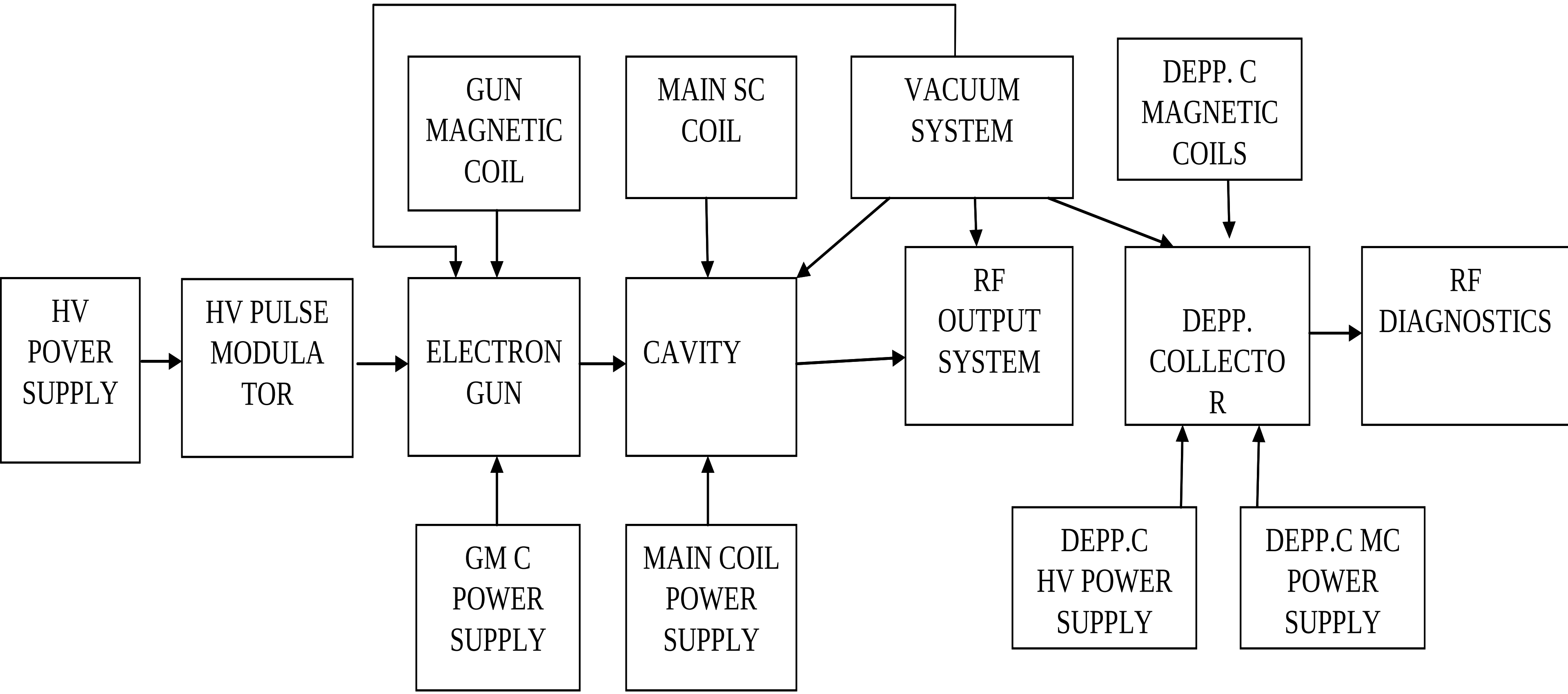
$$\omega = s\Omega_c + k_z v_z$$

$$\omega \approx \frac{s\Omega_{c0}}{\gamma(1-\beta_z\beta_\phi)}.$$

Difficulties to develop CARM

- 1) the difficulty in making mode-selective high-*kz* cavities (quasioptical or Bragg reflector cavities required)
- 2) the requirement for a very low axial velocity spread (e.g., $\Delta pz/pz < 1\%$), moderate *a* (<1) beam, since the high-*kz* interaction increases the sensitivity to axial velocity spread
- 3) the stability of gyrotron and gyro-BWO modes (if waveguide cavities are used)
- 4) the limited experimental track record, mostly short-pulse oscillators with efficiency 5–10%.
- A new experimental program to explore the capabilities of a CARM driven by an advanced low-velocity-spread MIG could test the ability of CARMs to compete with gyrotrons and gyroklystrons.

Project Assembly



Time schedule

[green]	Design
[red]	Assembling
[blue]	Buying materials and components
[yellow]	In house development
[orange]	Cold Test
[violet]	Testing, commissioning

QUARTER / ACTIVITY	I	II	III	IV	V	VI	VII	VIII
GUN	[green]	[green]	[red]	[red]	[violet]			
CAVITY		[green]	[green]	[red]	[red]	[orange]		
MAGNETIC FIELD	[blue]	[blue]	[blue]	[violet]				
MODULATOR 20 ns	[yellow]	[yellow]	[yellow]	[yellow]	[violet]			
MODULATOR 1-10 microsec				[blue]	[blue]	[violet]		
DEPRESSED COLLECTOR		[green]	[green]	[red]	[red]	[violet]	[violet]	
ASSEMBLING				[red]	[red]	[red]	[violet]	
RUNNING							[violet]	[violet]

Main Project Parameters of the E. Gun

Anode-cathode distance$(D_a-D_g)/2$	200mm
Magnetic field along the cavity	5-7 T
Pitch ratio $\alpha= v_{\gamma}/v_{ll}$	<0.5
Axial and transverse velocity spread	<0.1÷0.3 %
Cathode potential	500÷700 kV
Electric field at the cathode surface(E_c)	<10kV/mm

$$\beta_{\perp} \approx \frac{1}{\gamma c} f_m^{1/2} \frac{E_G \cos(\phi_{eB})}{B_{zG}}$$

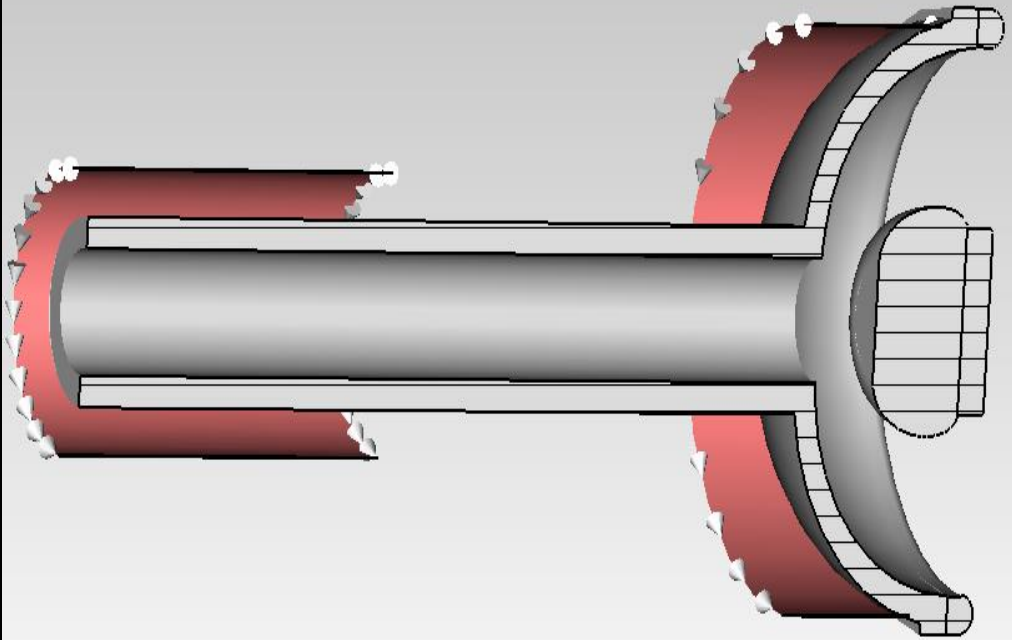
$$\alpha = \frac{\beta_{\perp}}{(1-\gamma^{-2}-\beta_{\perp}^2)^{1/2}}$$

$$\eta \approx \frac{(1-\beta_{\|_0}/\beta_{ph})}{N\ (1-\gamma_0^{-1})(1-\beta_{ph}^{-2})} \approx 20 \div 30\%$$

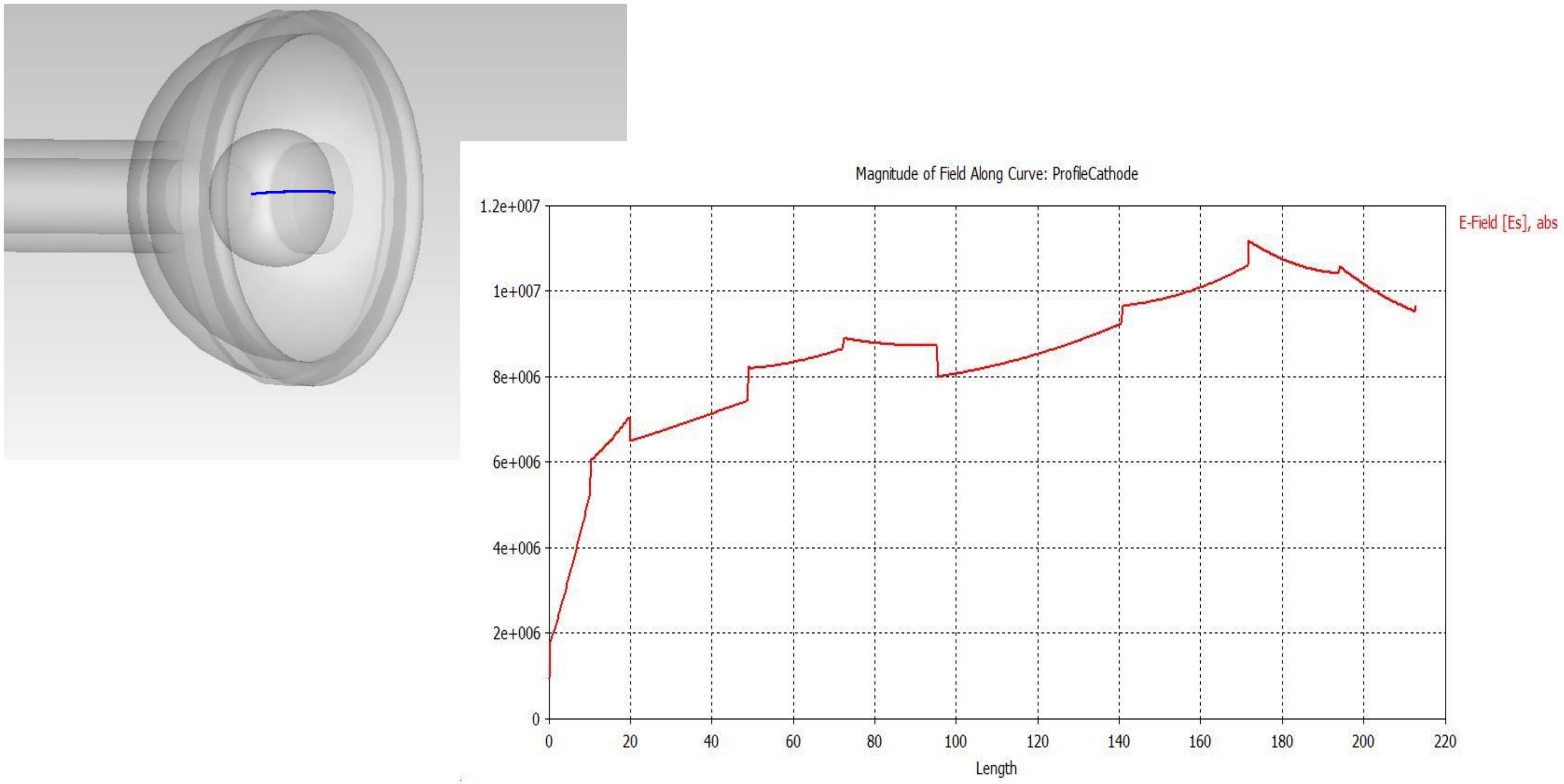
$$f_m = \frac{B_{zC}}{B_{zG}}$$

Electron Gun for Non-Adiabatic Electrostatic and Adiabatic Magnetic Pumping

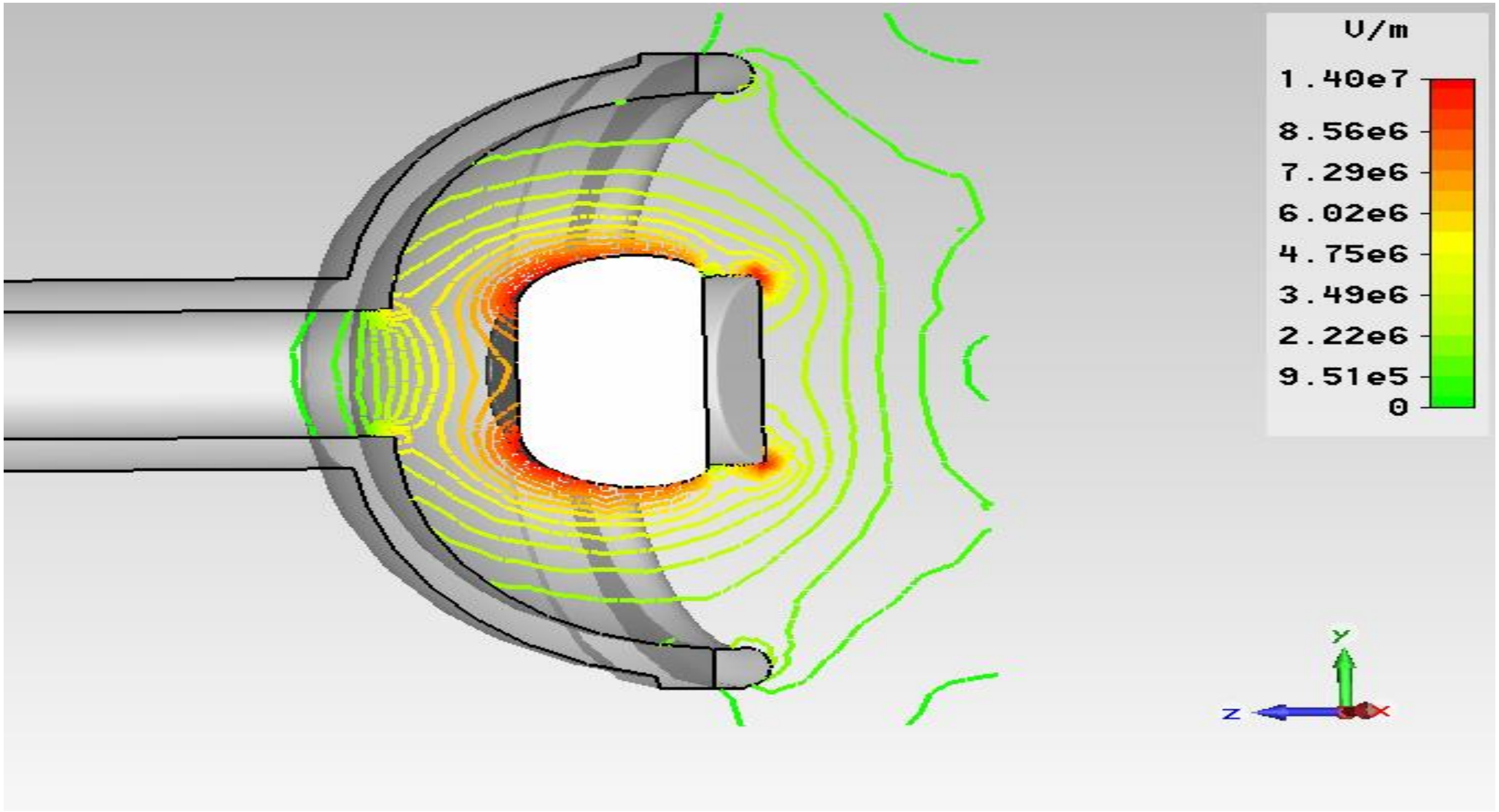
Anode-cathode distance	234 mm
Gun Radius	405 mm
Magnetic field along the cavity	5-7 T
Gun B-field	0.1 T
Distance - Main Coil-Gun Coil	770 mm
Cathode potential	5-700 kV
Main coil Radius	177 mm
Emitter ring radius	40 mm
Emitter ring thickness	1 mm



Surface Electric Field Along the Blue Line

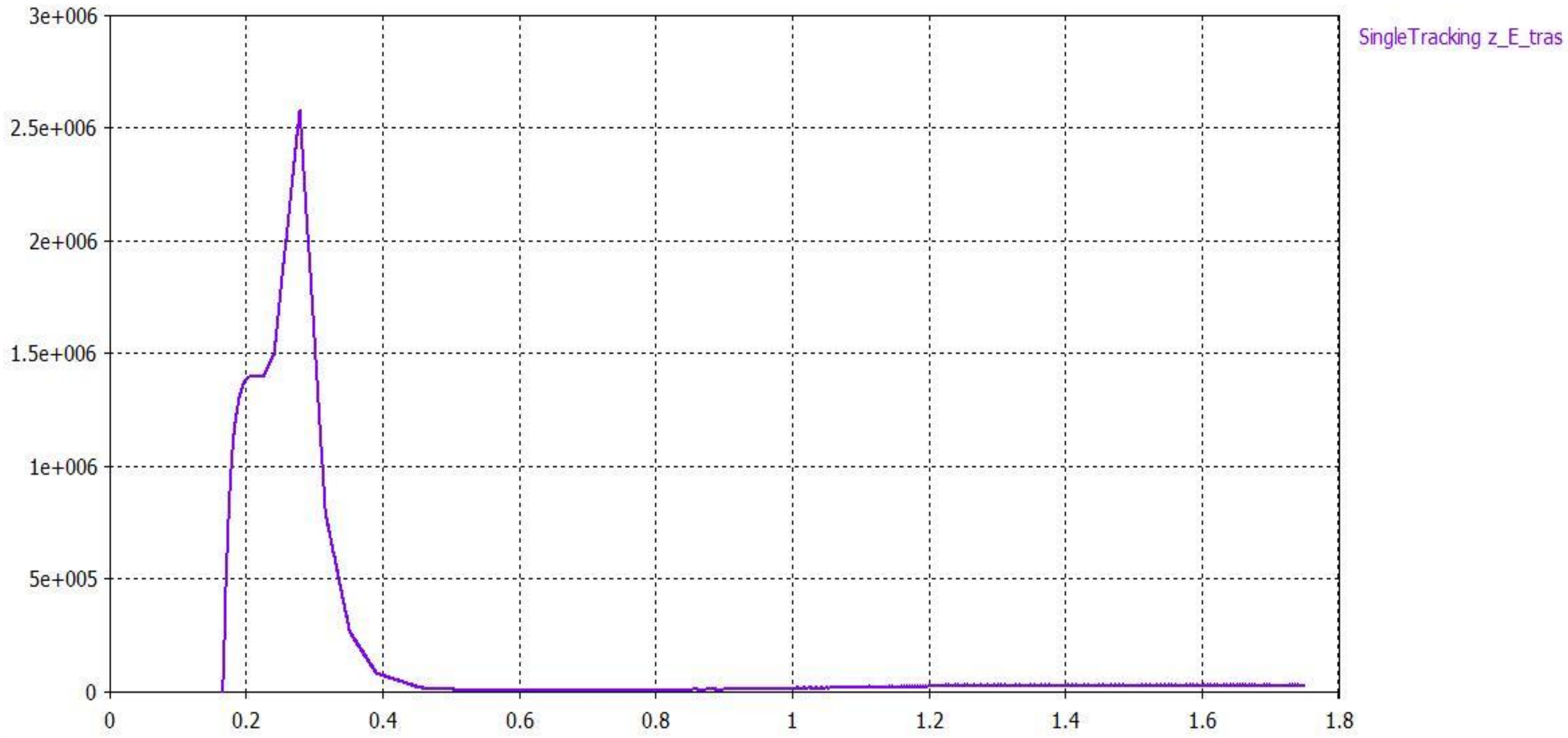


2D Electric Field Map

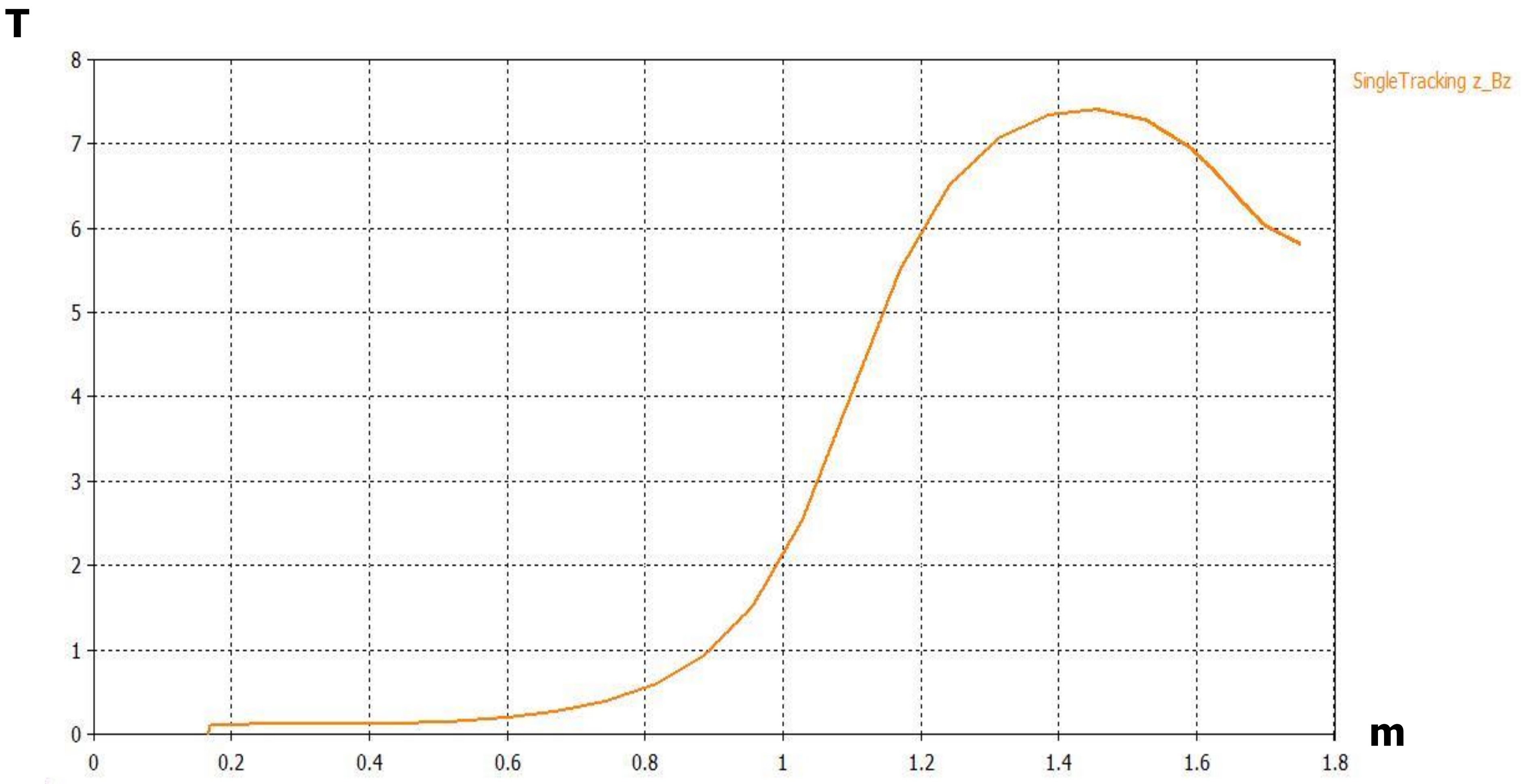


Transversal Electric Field

$V_{\perp}$ = E/B Important for Beam Pumping

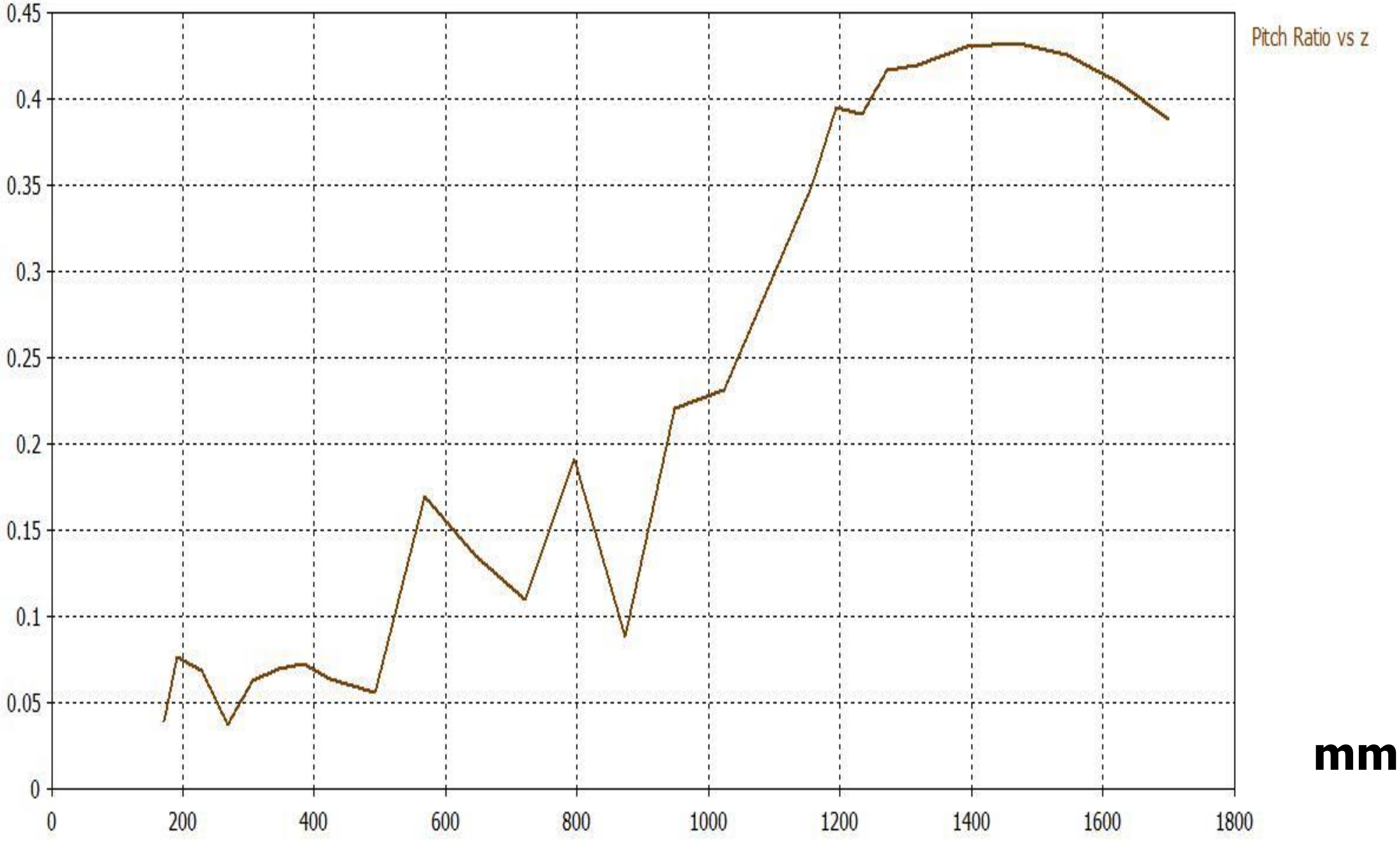


B-Field along Z



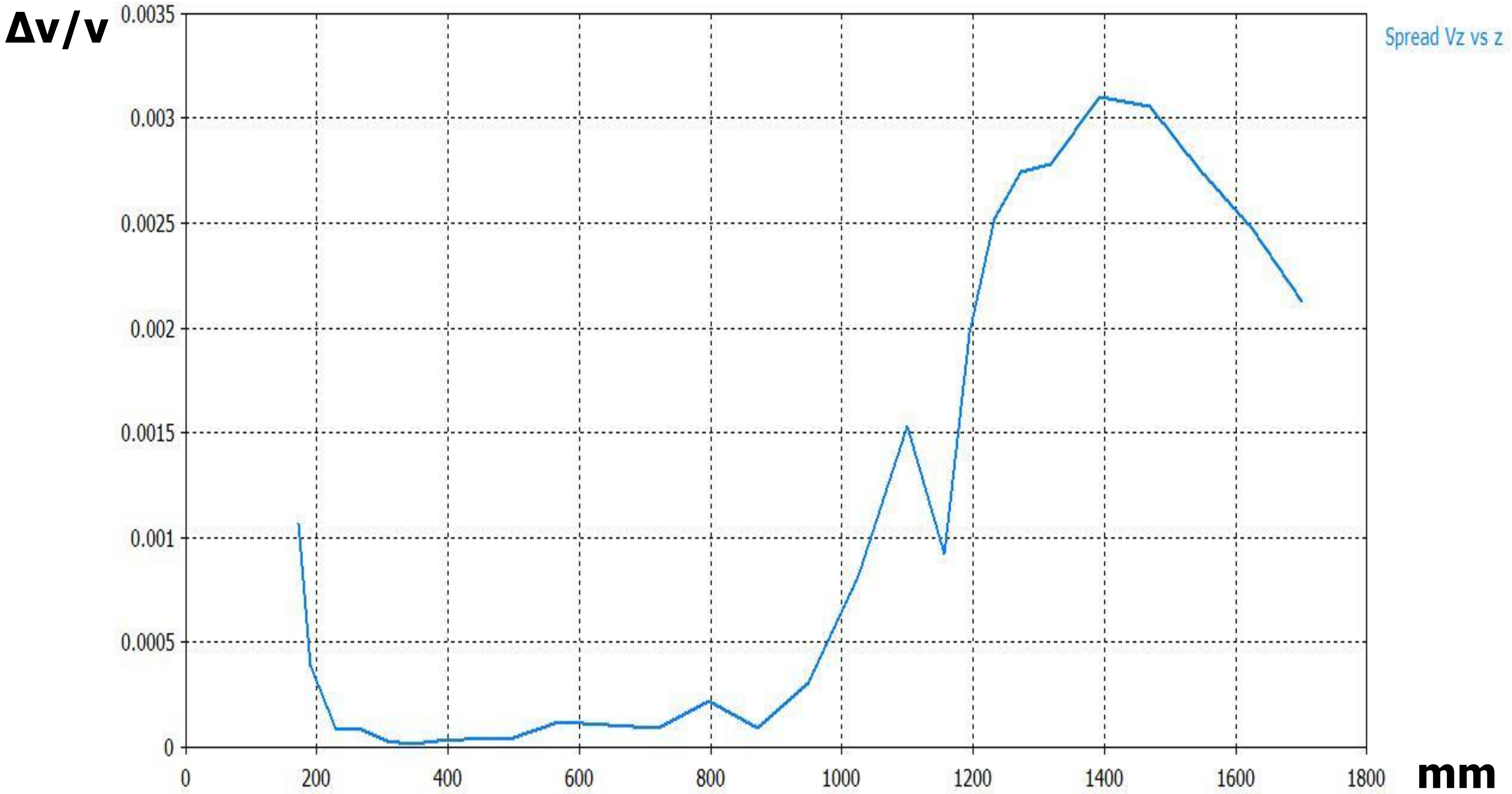
Pitch Ratio along Z

$\alpha = V_{\perp} / V_z$

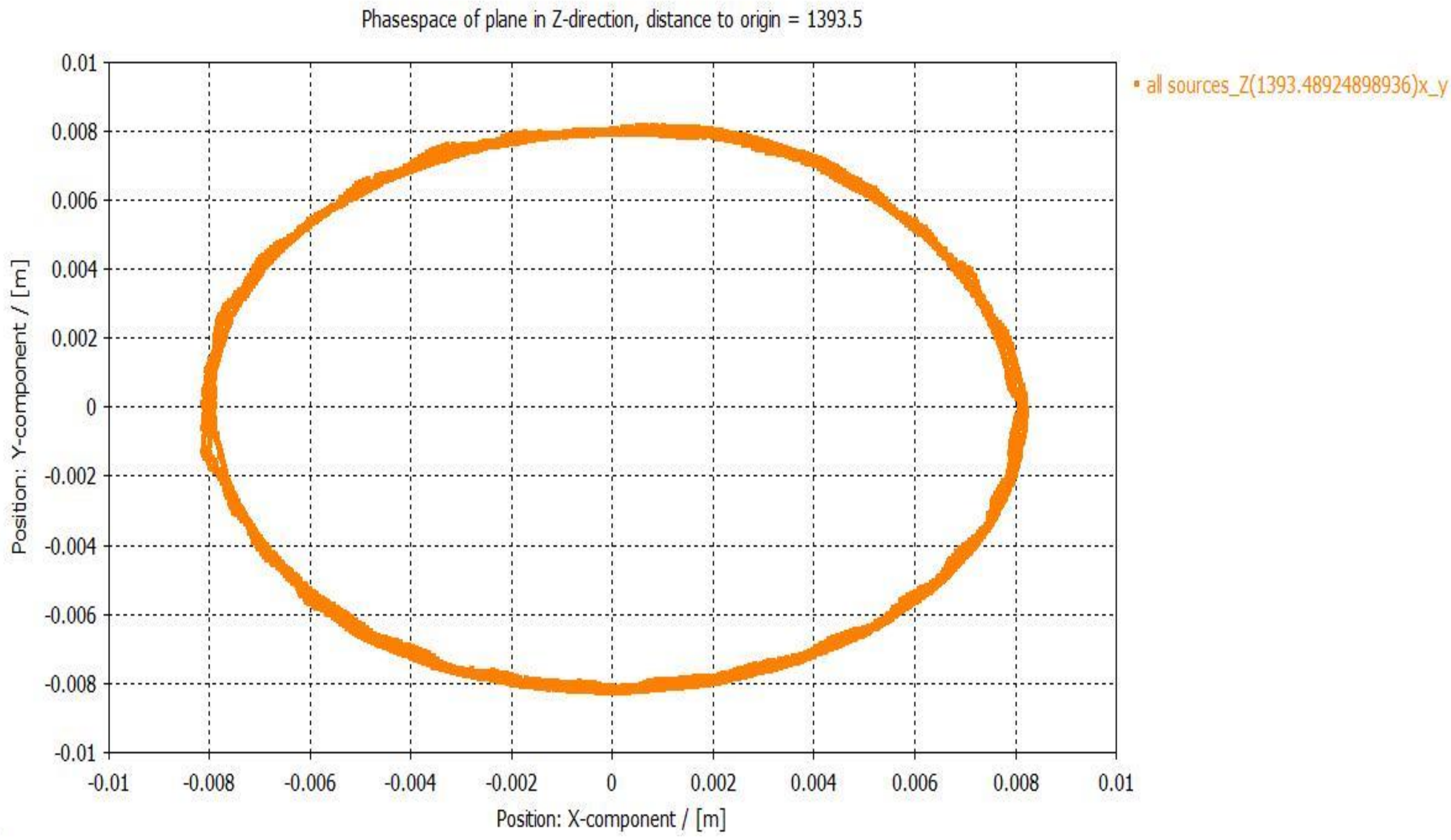


mm

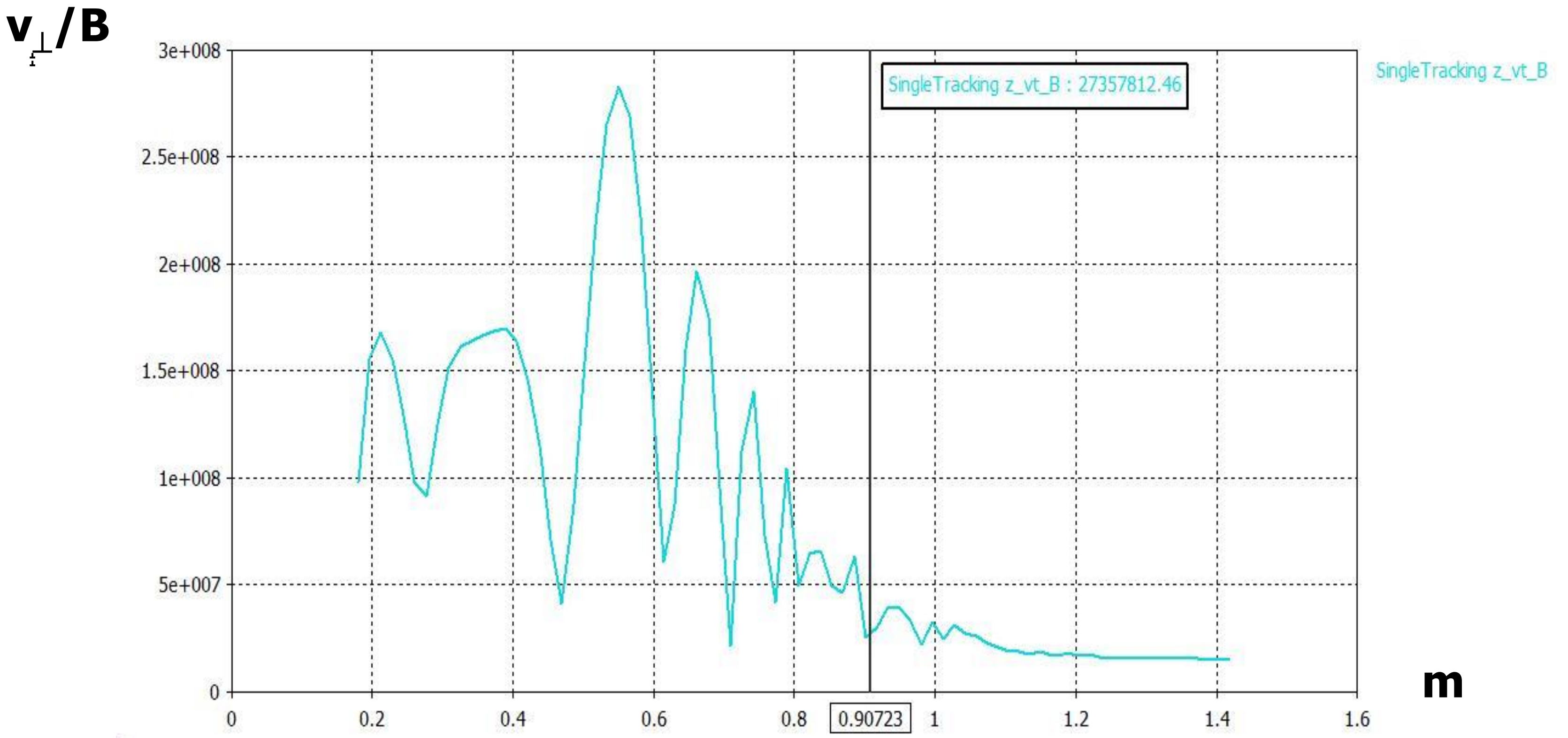
Longitudinal Velocity Spread



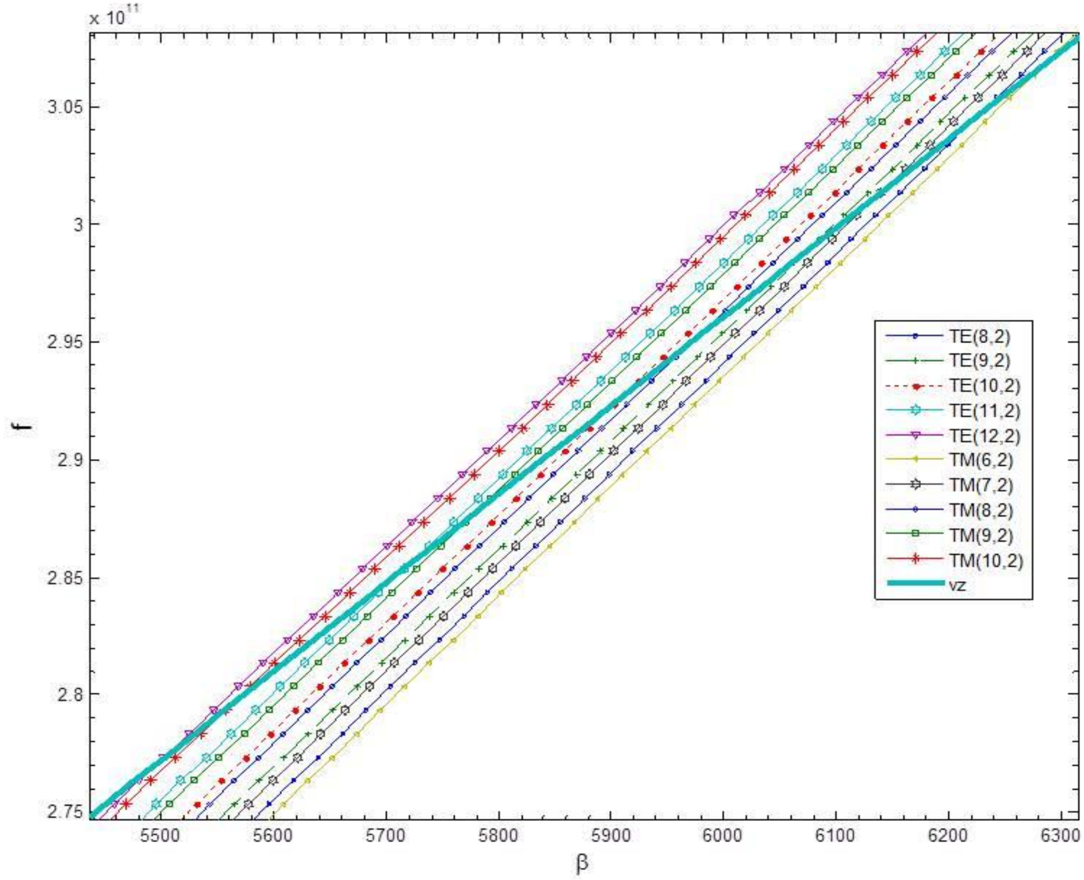
Phase-Space Picture in Z 1393mm

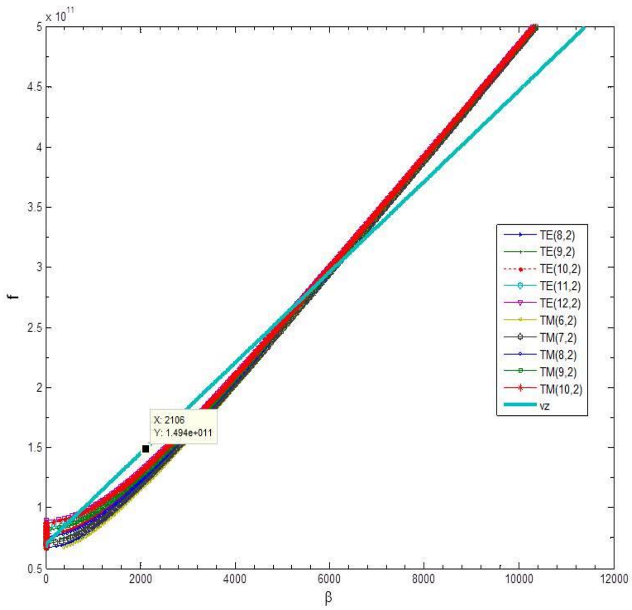


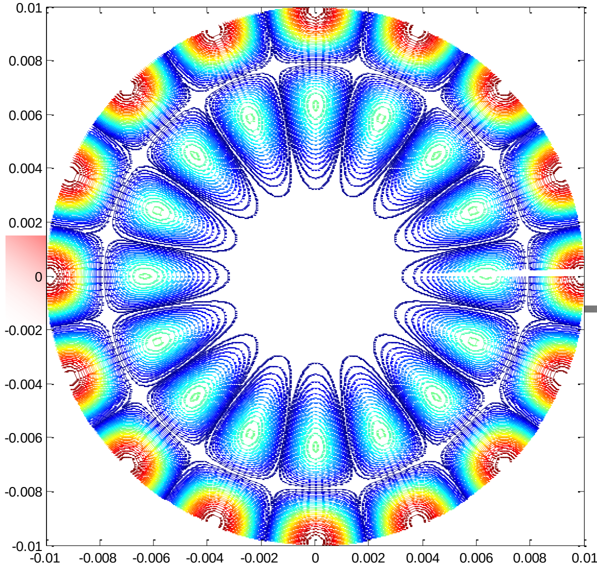
Adiabatic Beam Compression Along z



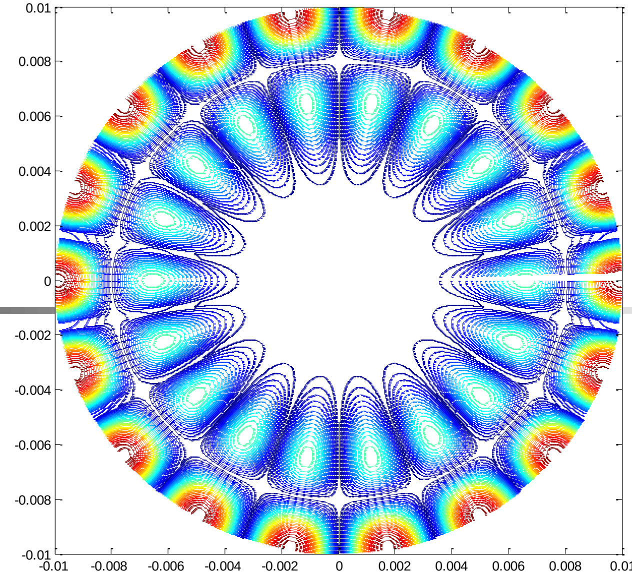
Brillouin Diagram



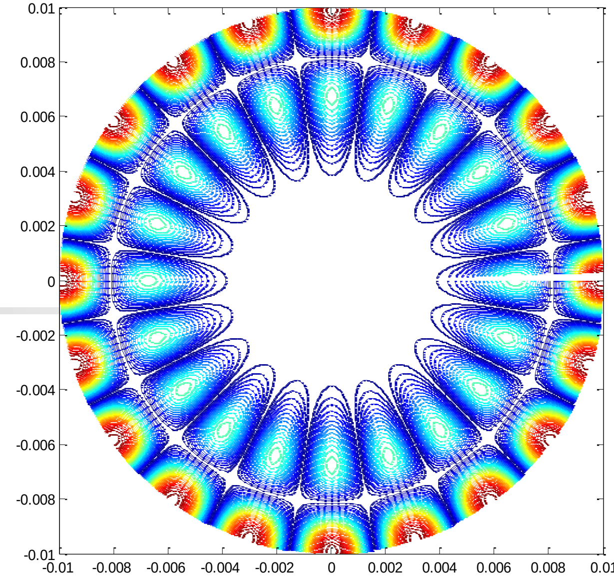




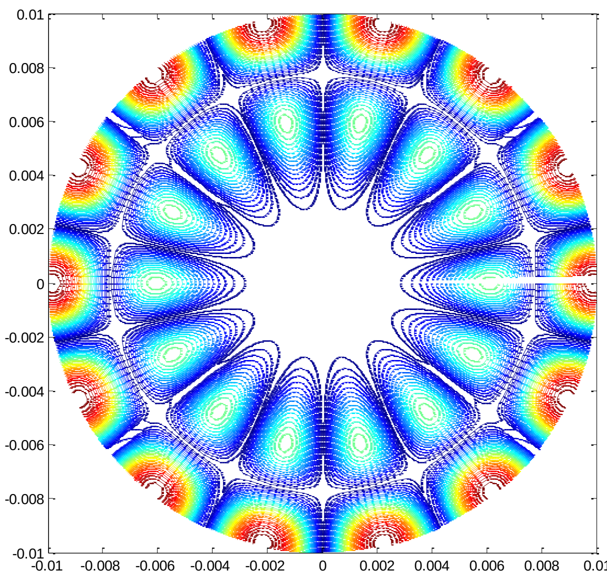
$TM_{8,2}$



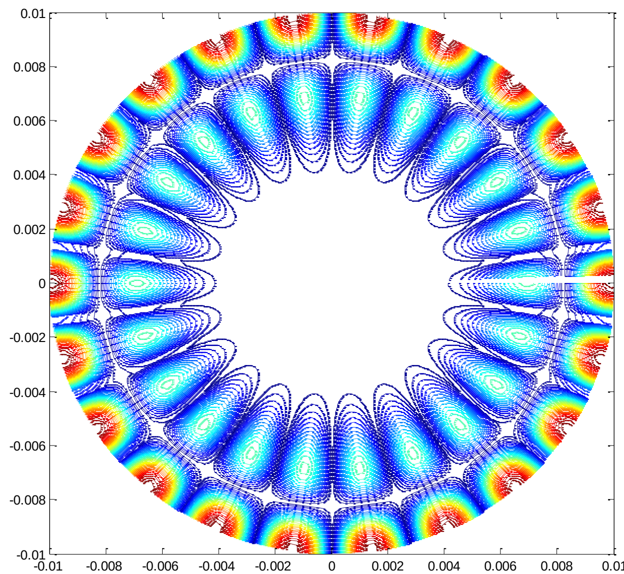
$TM_{9,2}$



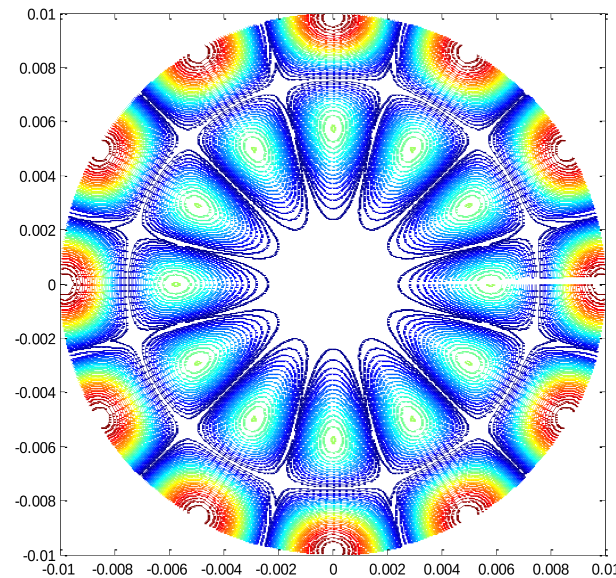
$TM_{10,2}$



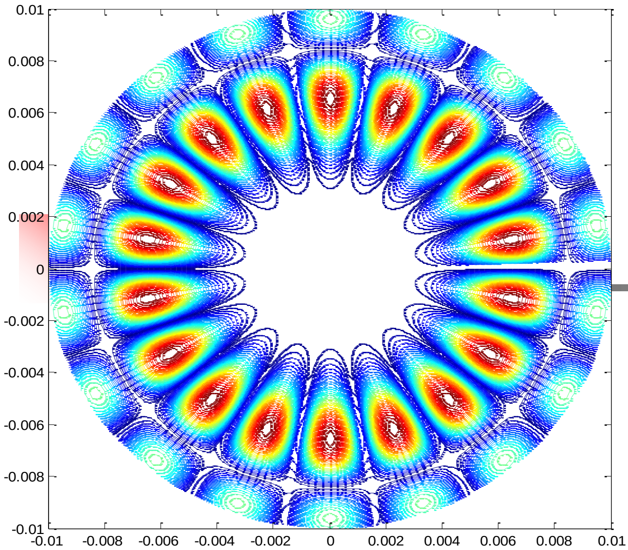
$TM_{7,2}$



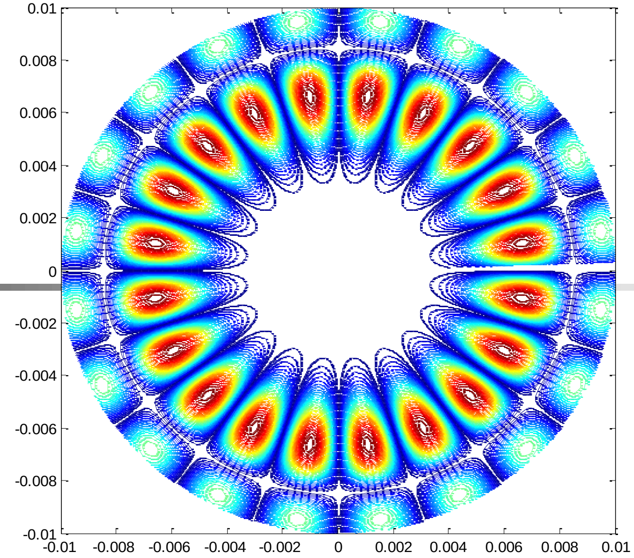
$TM_{10,2}$



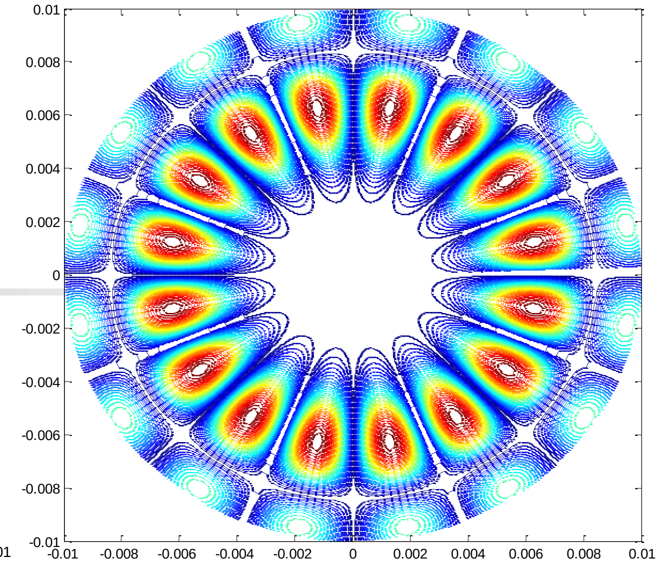
$TM_{6,2}$



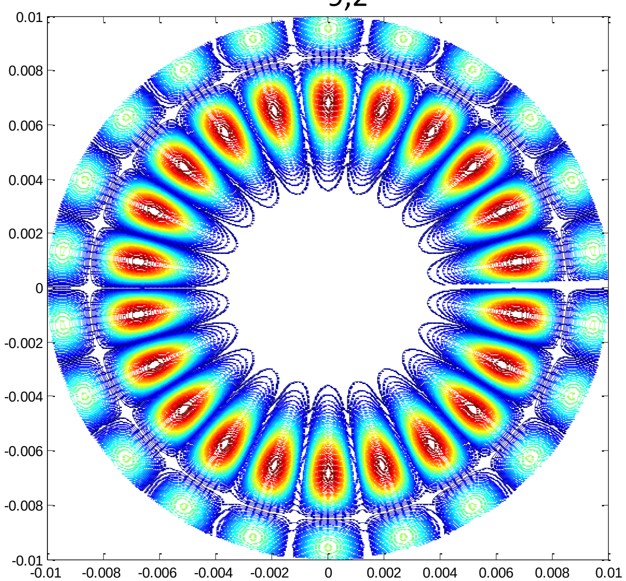
$TE_{9,2}$



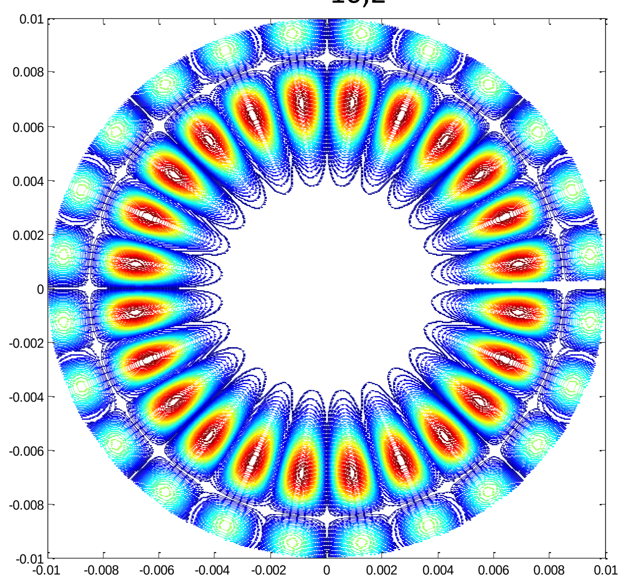
$TE_{10,2}$



$TE_{8,2}$

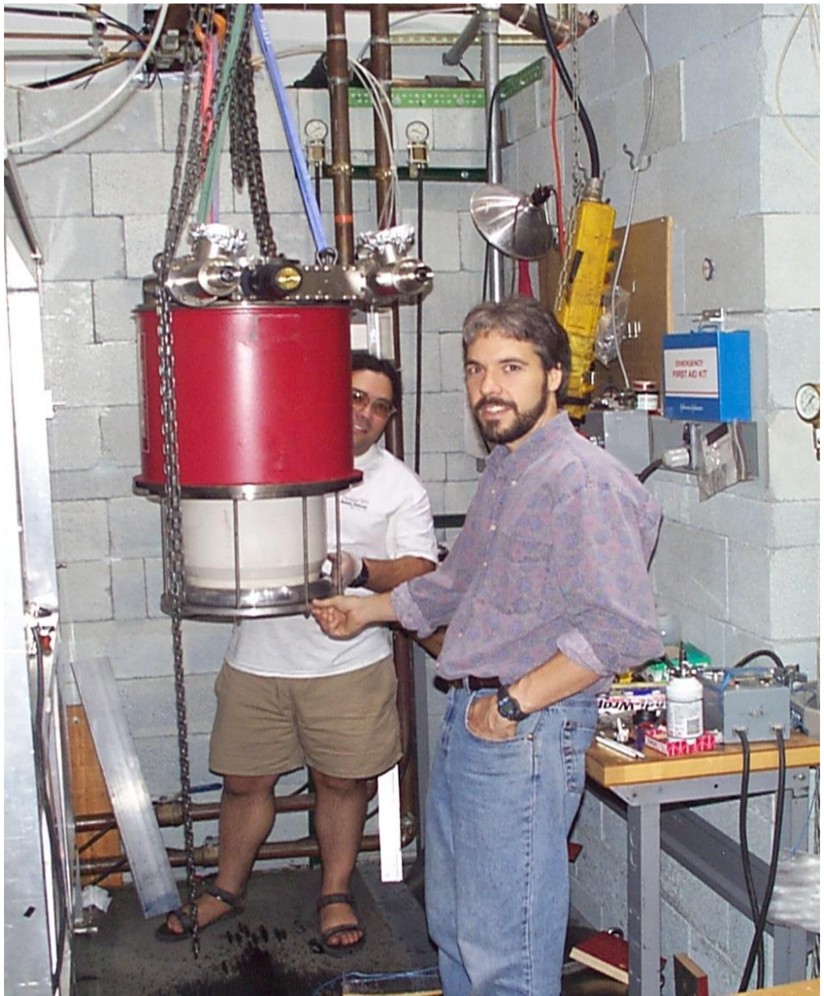


$TE_{11,2}$

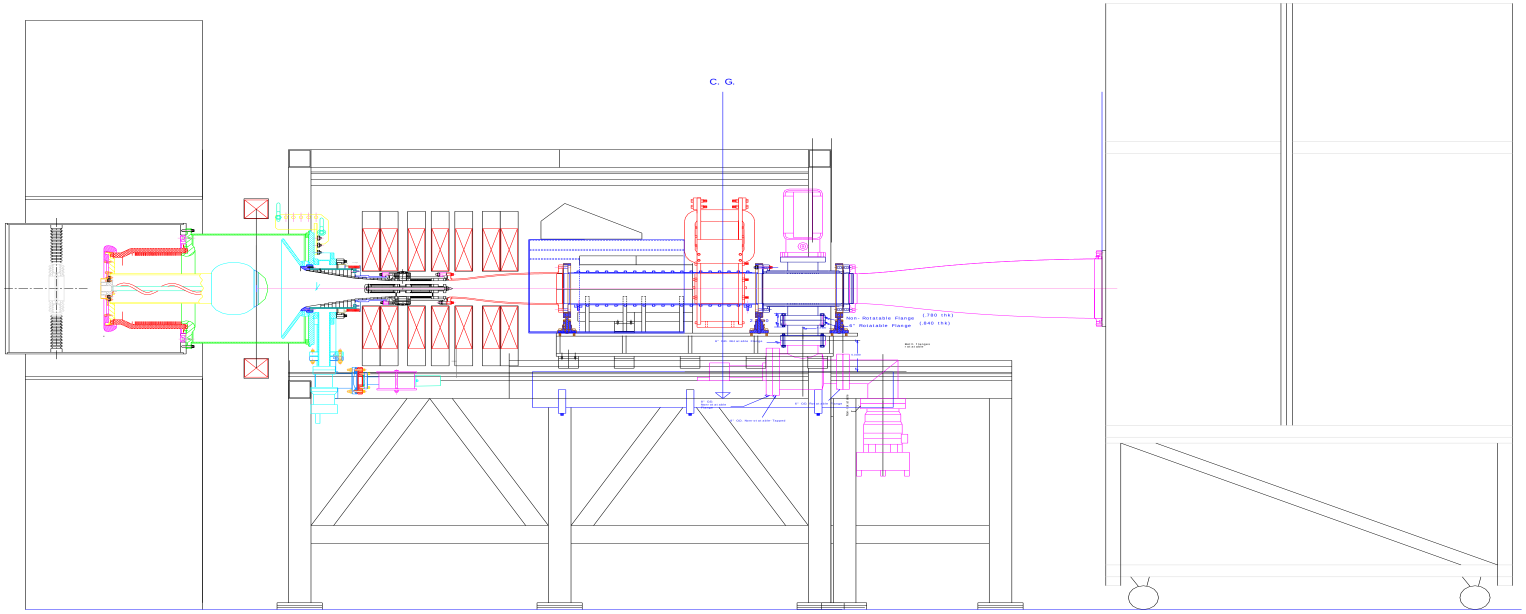


$TE_{12,2}$

Maryland Gyroklystron Gun 500kV 1000A 4μs rep.rate 10Hz

The Experiment Might Look Like This



3 m long, 1,5 m high (excluding the anechoic chamber)

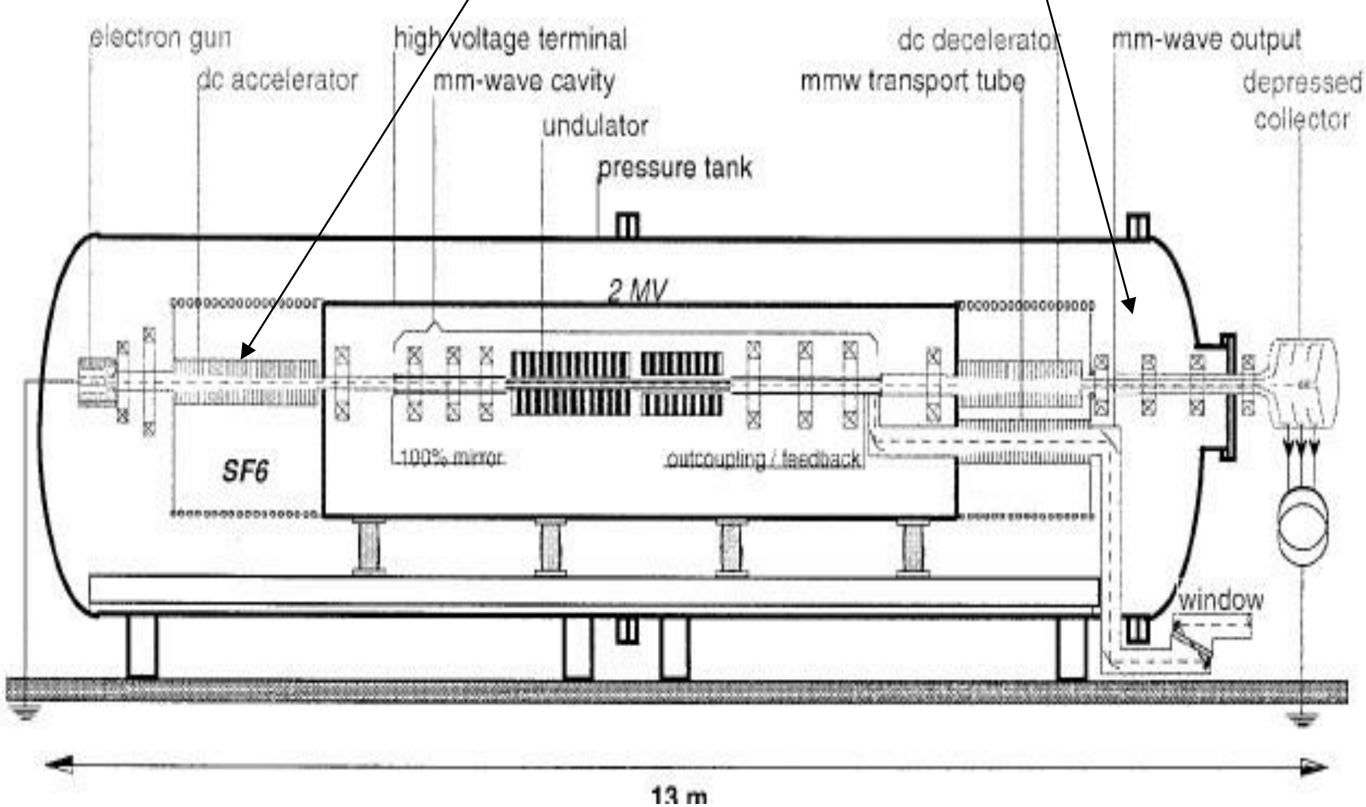
FOM-Instituut voor Plasmafysica "Rijnhuizen" FEM(Free Electron Maser) >200GHz

FOM FEM Project

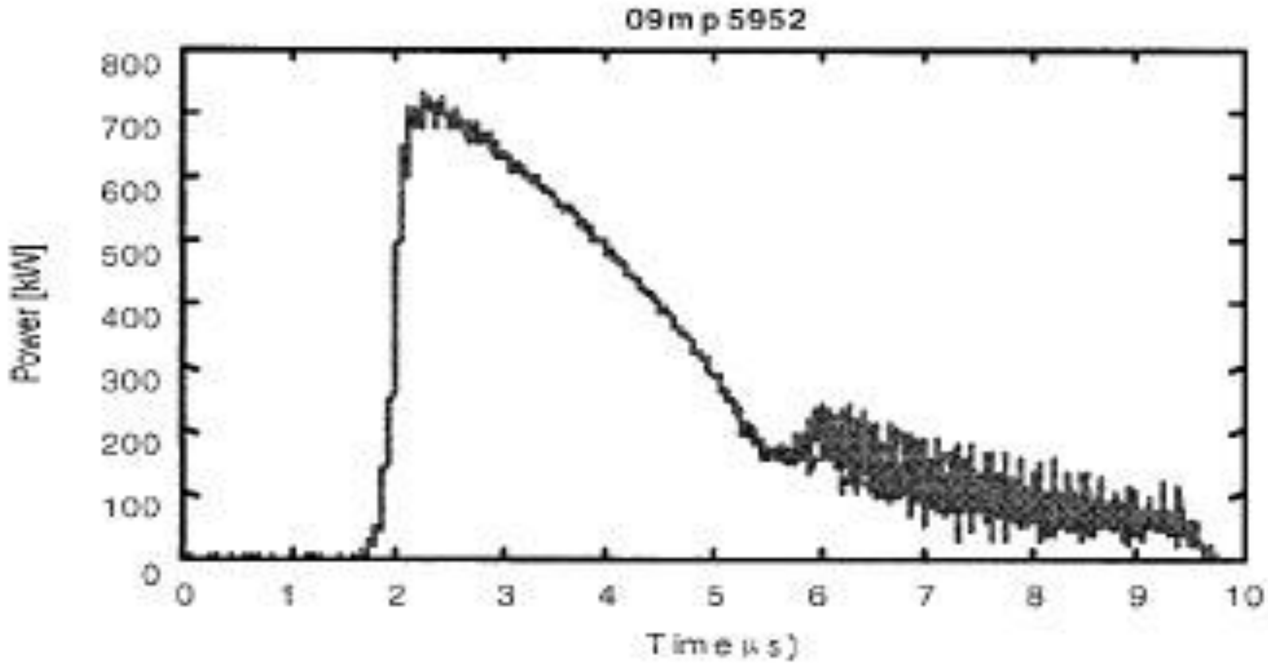
f 160÷260 GHz,
P 1 MW
T 2 s

Electrostatic accelerator 2MeV

To increase the efficiency a 99,99% beam recovery is needed



RESULTS



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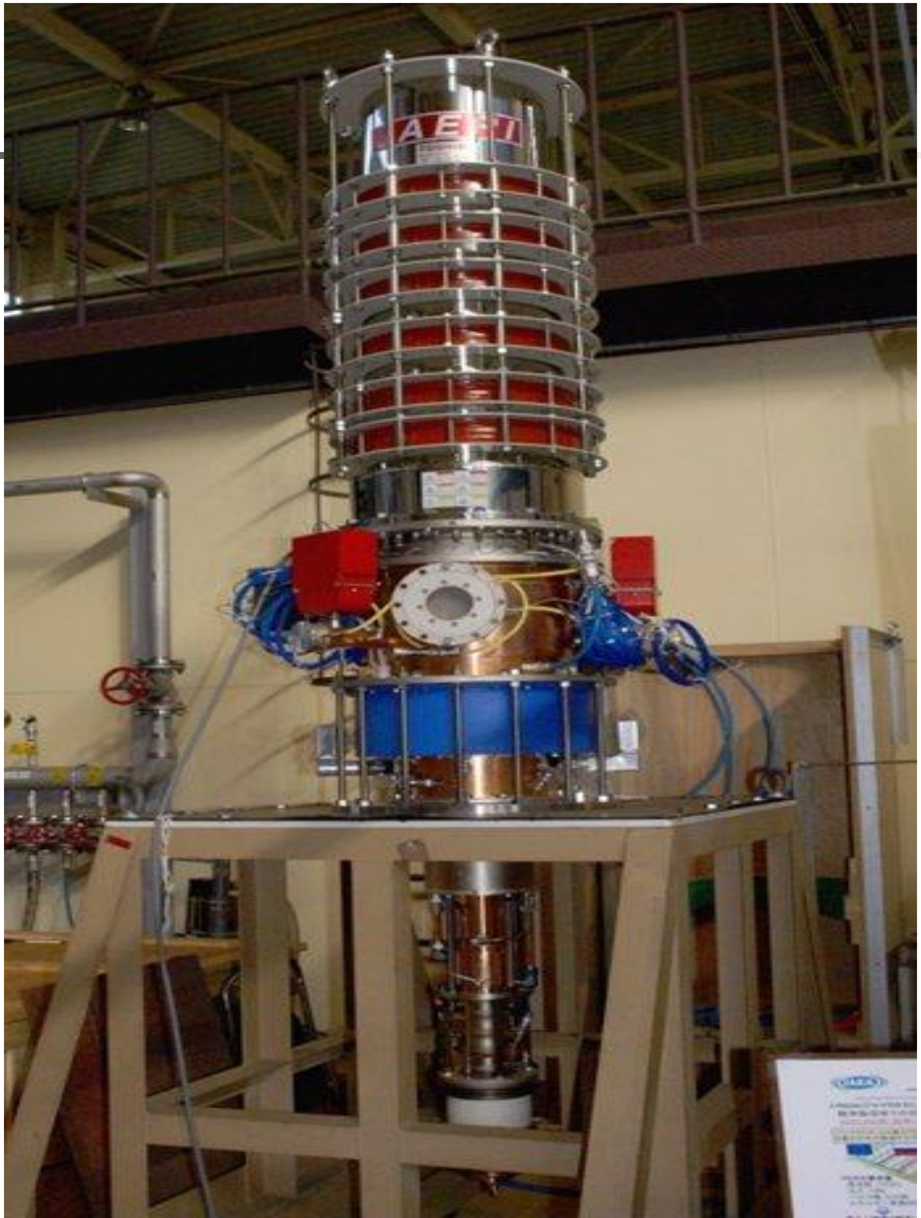
First mm-Wave Generation in the FOM Free Electron Maser

Toon (A.) G. A. Verhoeven, Waldo A. Bongers, Vladimir L. Bratman, Malcolm Caplan, Gregory G. Denisov, Cees A. J. van der Geer, Piet Manintveld, Alex J. Poelman, Jeroen Plomp, Andrej V. Savilov, Paul H. M. Smeets, Ab B. Sterk, and Wim H. Urbanus

ITER 1 MW, 170 GHz, 1h, Gyrotron



Costs for Design and Assembling

MAJORE COMPONENTS	
COMPONENTS	**COST**
HIGH VOLTAGE MODULATOR	500-1000KE
SUPPERCONDUCTING MAGNET	300KE
ELECTRON GUN	500KE
HIGH VOLTAGE POWER SUPPLY	50 KE

HOME DESIGNED COMPONENTS	
COMPONENTS	COST
ELECTRON GUN	200-300KE
GUN COIL	10 KE
CAVITY	200KE
RF OUTPUT SYSTEM	500KE
DEPRESSED COLLECTOR	300-500KE
SOFWARE CODES	200KE

Costs for Buying components and parts

COMPONENTS TO BUY	
COMPONENTS	COST
HIGH VOLTAGE POWER SUPPLY	50 KE
SUPPERCONDUCTING MAGNET	300 KE
ELECTRON GUN	200-300KE
POWER SUPPLIES FOR MAGNETS	300 KE
VACUUM SYSTEM	500KE
RF COMPONENTS AND DIAGNOSTICS	500-700KE
SOFWARE TOOLS	200KE

FLEXIBLE **COMPONENTS**	
COMPONENTS	COST
HIGH VOLTAGE MODULATOR	500-1000KE
HIGH VOLTAGE POWER SUPPLY	50 KE