Design Study on 8 MeV Standing-wave Accelerating Structure

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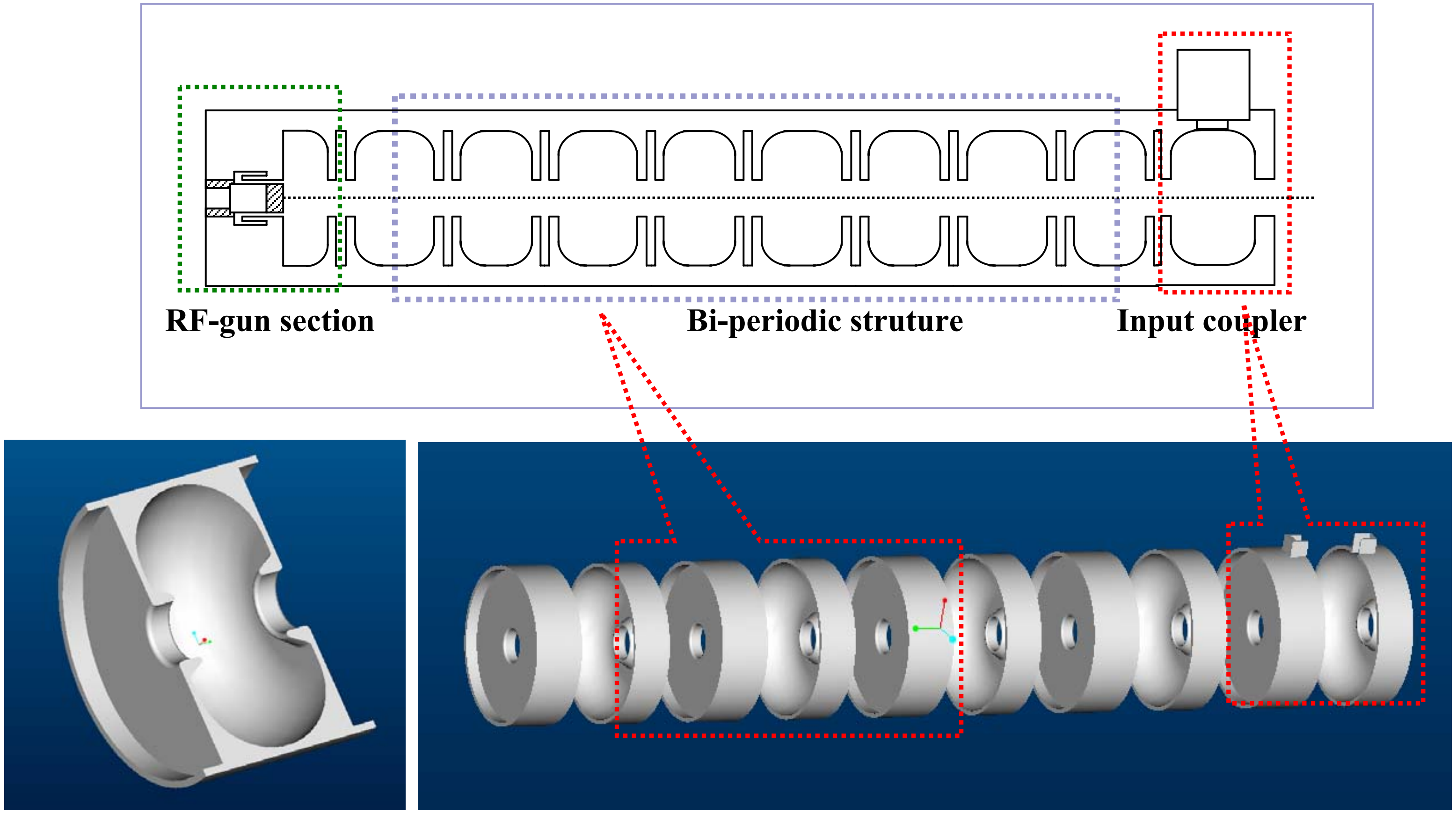
Abstract

We designed a compact size standing wave accelerating structure. The design parameters for a 8 MeV, on-axis coupled, SW accelerating section with the π/2 mode were selected in use of an RF source of 1.5 MW C-band (5 GHz). SUPERFISH and PARMELA codes are used for the accelerating structure, and HFSS program is also used for the RF input coupler. The SW accelerating section is 495 mm long with 3 bunch cavities and 15 accelerating cavities.

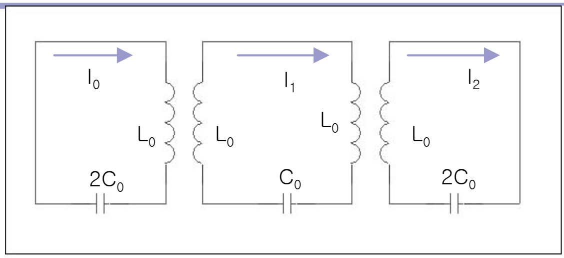
Introduction

- **Recently The design of linear accelerating structure is standingwave type instead travelingwave type.**
- **C-band RF frequency for linear accelerator have several important merits**
  - **Accelerator size could be smaller due to small radius of accelerating column**
  - **Higher beam energy with fixed RF power could be ejected, because shunt impedance depends on frequency**
- **Accelerator column is periodic structure on-axis coupled cavity where RF mode is $\pi/2$**
  - **In this mode sensitivity is smallest among other modes because of the widest frequency bend width.**

Accelerating Structure



π/2 mode in periodic structure



$$x_0\left(1-\frac{\omega_0^2}{\Omega^2}\right)+x_1 k=0$$

$$x_1\left(1-\frac{\omega_0^2}{\Omega^2}\right)+(x_0+x_2)\frac{k}{2}=0$$

$$x_2\left(1-\frac{\omega_0^2}{\Omega^2}\right)+x_1 k=0$$

$$LX_q=\frac{1}{\Omega_q^2}X_q$$

$$L=\begin{pmatrix} 1/\omega_0^2 & k/\omega_0^2 & 0 \\ k/2\omega_0^2 & 1/\omega_0^2 & k/2\omega_0^2 \\ 0 & k/\omega_0^2 & 1/\omega_0^2 \end{pmatrix} \qquad X_q=\begin{pmatrix} x_0 \\ x_1 \\ x_2 \end{pmatrix}$$

q=0 → zero mode $\qquad \Omega_0=\frac{\omega_0}{\sqrt{1+k}} \qquad x_0=\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$

q=1 → π/2 mode $\qquad \Omega_1=\omega_0 \qquad x_1=\begin{pmatrix} 1 \\ 0 \\ -1 \end{pmatrix}$

q=2 → π mode $\qquad \Omega_2=\frac{\omega_0}{\sqrt{1-k}} \qquad x_2=\begin{pmatrix} 1 \\ -1 \\ 1 \end{pmatrix}$

Perturbation theory by the effects of frequency errors of the individual oscillators.

$$\Delta X_q=\sum_{r\neq q} a_{qr}X_r \qquad a_{qr}=\frac{X_q P X_r}{1/\Omega_r^2-1/\Omega_q^2} \qquad X_{q,n}=Ae^{j\phi}\cos\frac{\pi qn}{N}e^{j\Omega_q t}$$

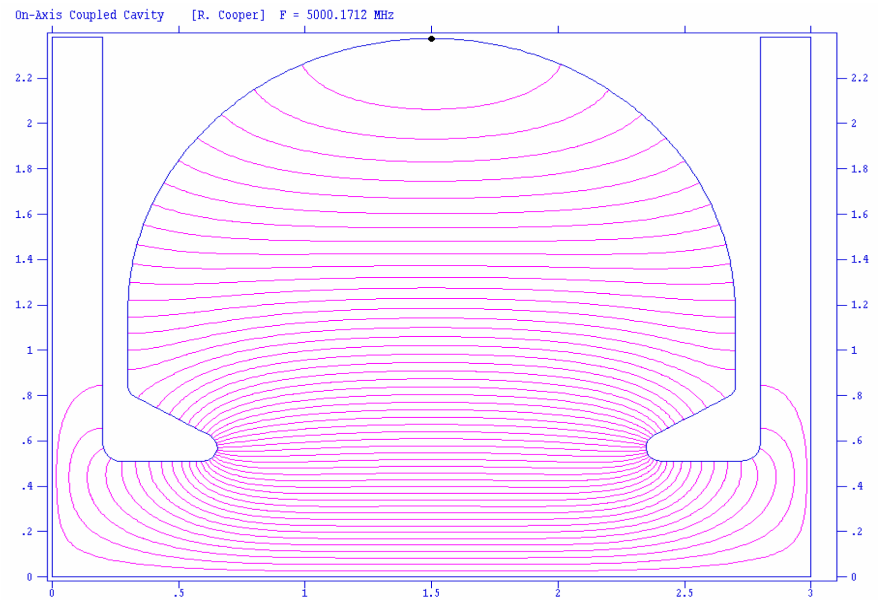
$$p=\begin{pmatrix} -\left(2\delta\omega_0/\omega_0^3\right) & -k\left(2\delta\omega_0/\omega_0^3\right) & 0 \\ -k\left(2\delta\omega_1/\omega_0^3\right)/2 & -\left(2\delta\omega_0/\omega_0^3\right) & -k\left(2\delta\omega_1/\omega_0^3\right)/2 \\ 0 & k\left(2\delta\omega_0/\omega_0^3\right) & \left(2\delta\omega_0/\omega_0^3\right) \end{pmatrix}$$

$$\Omega_0=\frac{\omega_0}{\sqrt{1+k}}\sqrt{1-\frac{\delta\omega_1}{\omega_0}} \qquad X_0=\begin{pmatrix} 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}-4\frac{\delta\omega_0}{\omega_0}\right) \\ 1-\frac{1+k}{2k}\frac{\delta\omega_1}{\omega_0} \\ 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}+4\frac{\delta\omega_0}{\omega_0}\right) \end{pmatrix}$$

$$\Omega_1=\frac{\omega_0}{\sqrt{1+k}}\sqrt{1-\frac{\delta\omega_1}{\omega_0}} \qquad X_1=\begin{pmatrix} 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}-4\frac{\delta\omega_0}{\omega_0}\right) \\ 1-\frac{1+k}{2k}\frac{\delta\omega_1}{\omega_0} \\ 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}+4\frac{\delta\omega_0}{\omega_0}\right) \end{pmatrix}$$

$$\Omega_2=\frac{\omega_0}{\sqrt{1+k}}\sqrt{1-\frac{\delta\omega_1}{\omega_0}} \qquad X_2=\begin{pmatrix} 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}-4\frac{\delta\omega_0}{\omega_0}\right) \\ 1-\frac{1+k}{2k}\frac{\delta\omega_1}{\omega_0} \\ 1+\frac{1+k}{2k}\left(\frac{\delta\omega_1}{\omega_0}+4\frac{\delta\omega_0}{\omega_0}\right) \end{pmatrix}$$

On-axis Coupled cavity



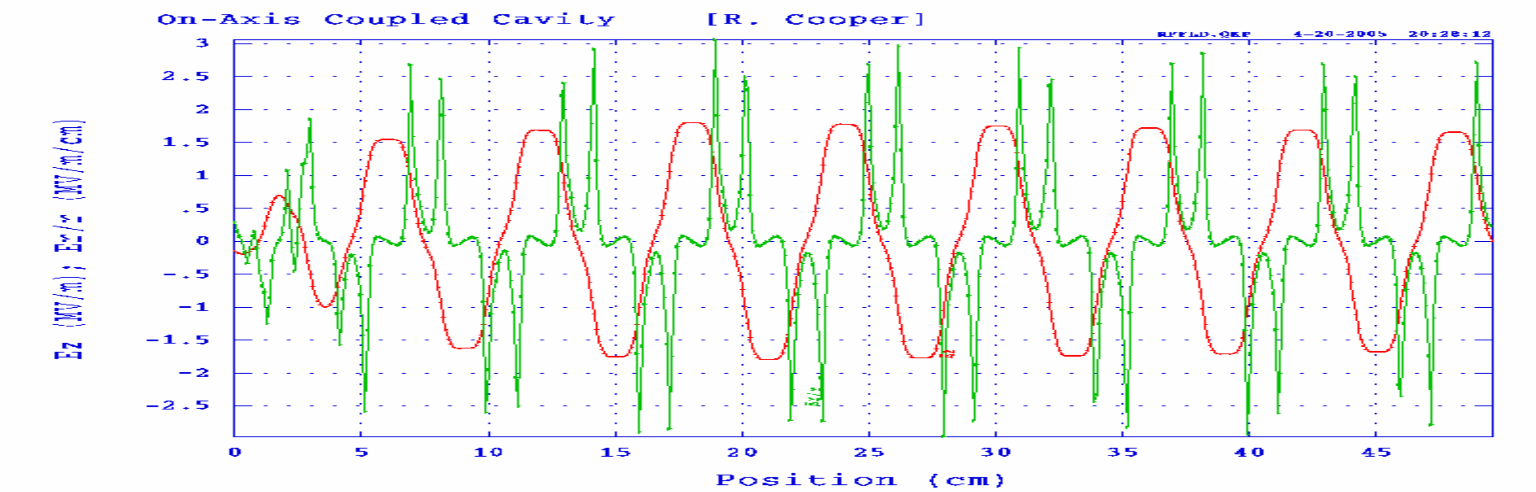
- There is strong E-field In accelerating cell to accelerate electron beam

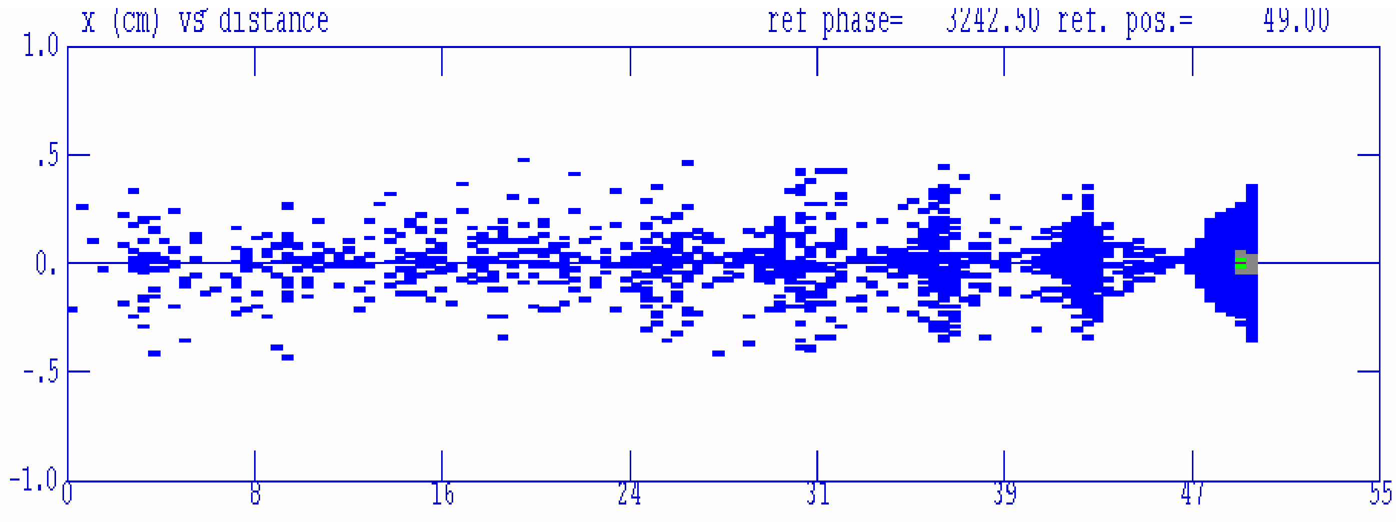
- In coupling cell there isn't E-field but Strong B-field for the RF coupling

- Radius of coupling cell is different because RF field should be distributed evenly when the length of linac structure is increased.

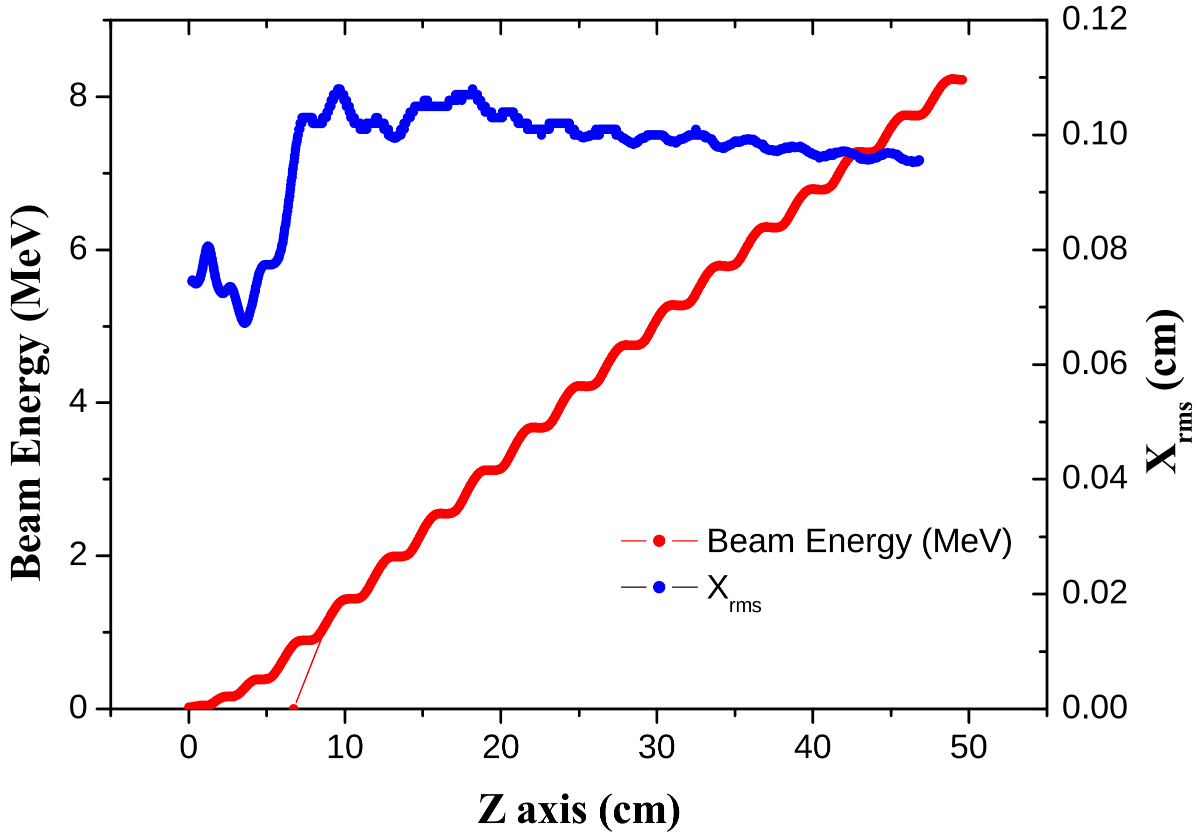
Resonant Frequency	5.000 GHz
Shunt Impedance	149.5 MΩ/m
Transit time factor	0.81
Q-factor	12842
The length of the Accelerating cell	48 mm
Radius of the the Accelerating Cell	23.7mm
Radius of coupling cell	24.1mm
The length of Coupling cell	4 mm

π/2 mode field and beam

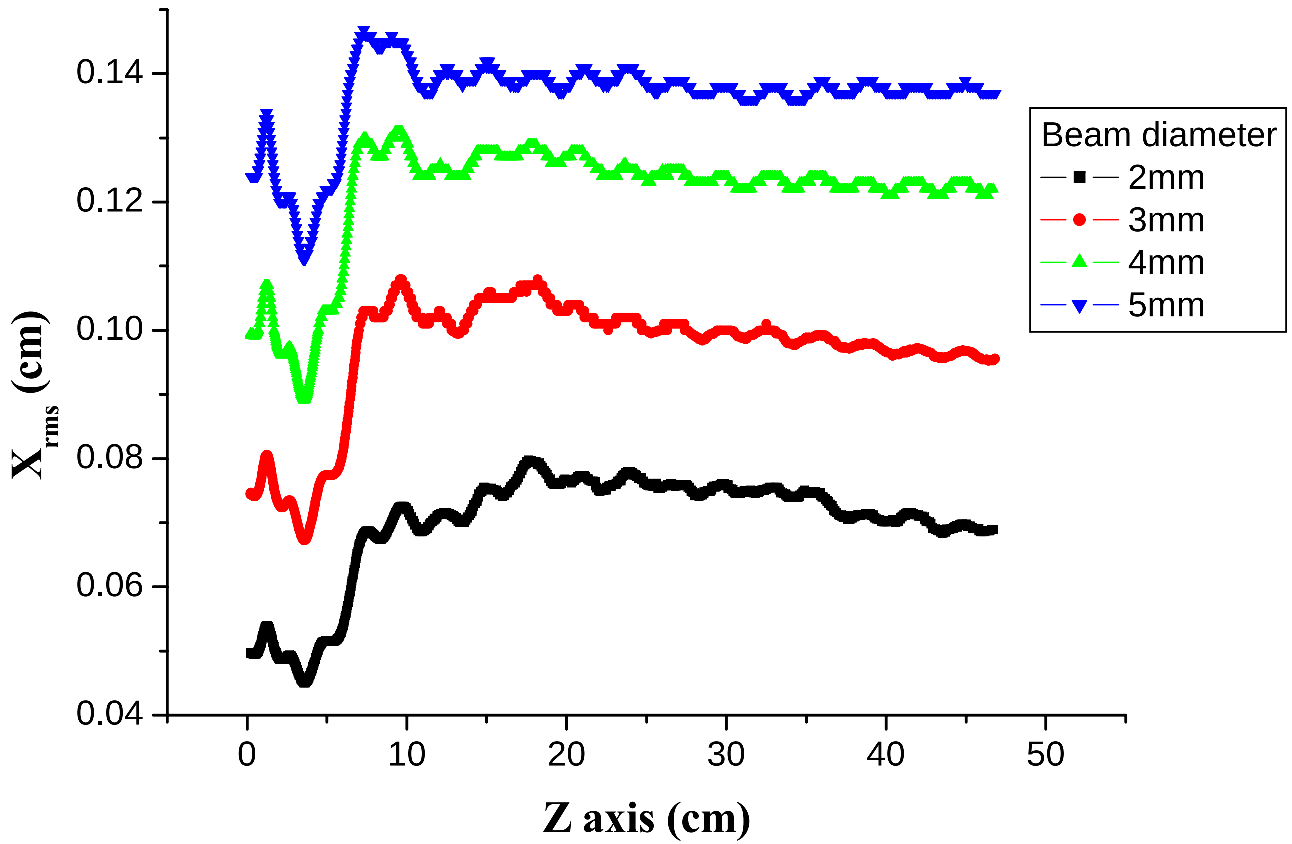




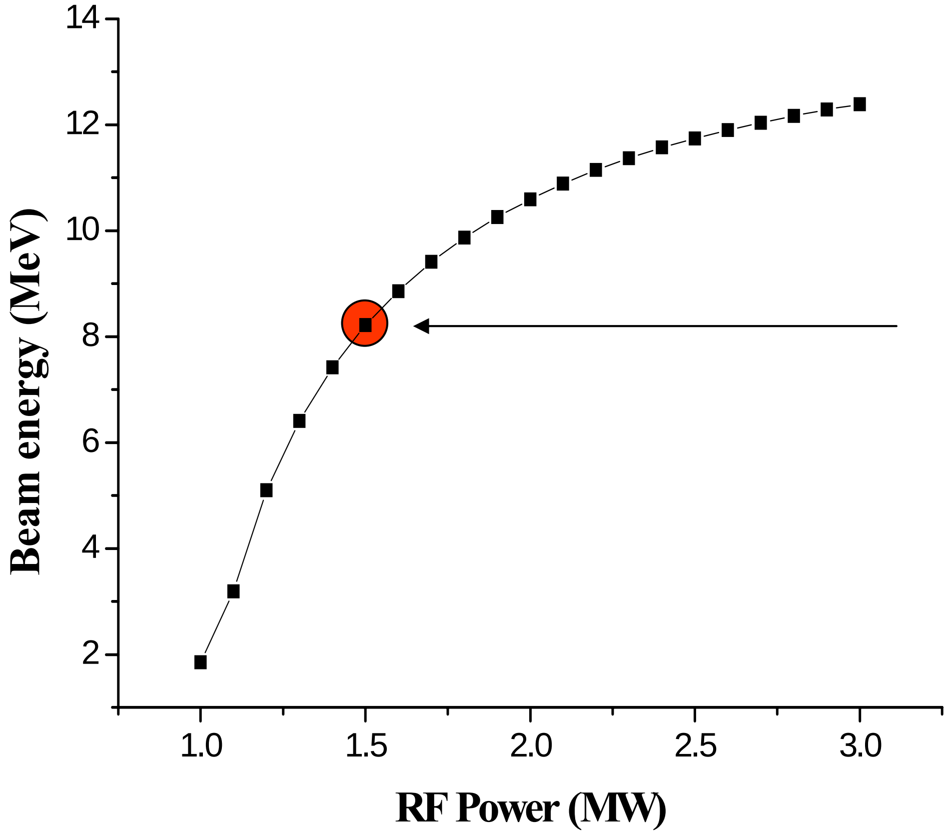
0.55 m Linac with 1.5MW Power

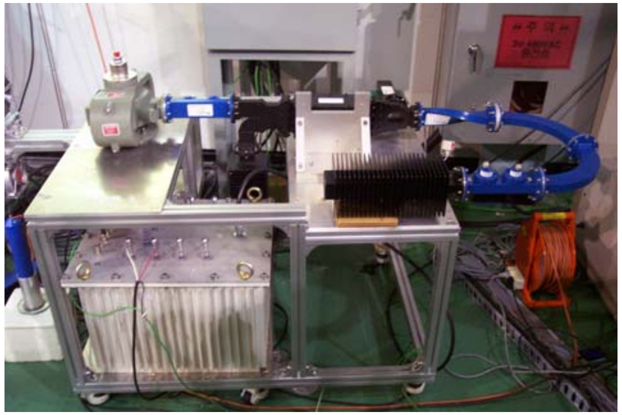


Beam size according to the cathode size



0.55 m Linac with increasing Power

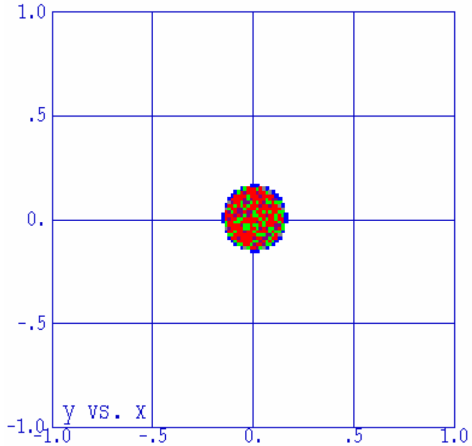




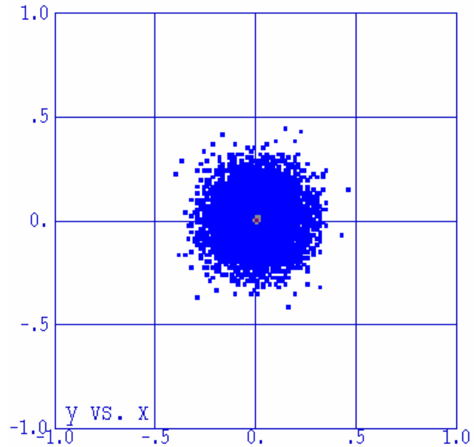
1.5 MW pulsed magnetron system

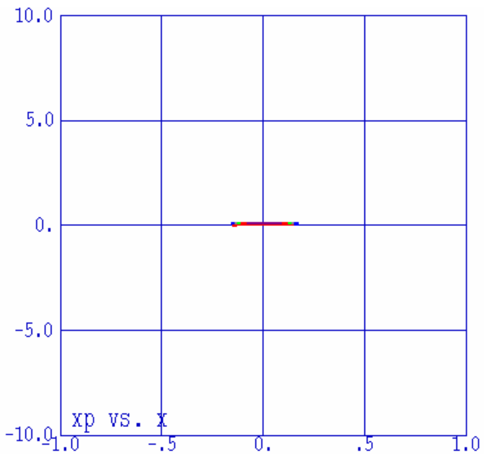
Beam profile at input and output

Initial beam

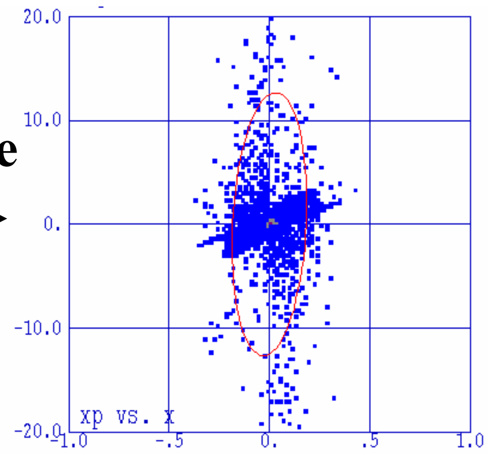


Beam size





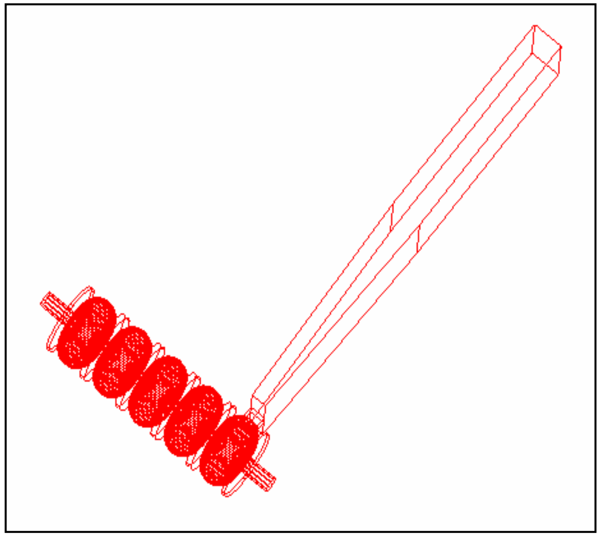
Emittance



Final beam

- **Beam transmission ratio : 80 %**

Design of Input coupler



- The coupled cavity is at the end of the linac connected with the rectangular waveguide (WR187) through which RF is transmitted into the standingwave linac.
- The aperture between the cavity of the input coupler and waveguide is determined to make magnetic coupling
- We are designing coupler for S11 to be below –25 dB at 5.000GHz.

System Characteristics

Beam energy	**8.3 MeV**
RF frequency	**5.000 MHz**
Input RF power	**1.5 MW**
Beam current	**20mA**
Beam power	110 kW
Pulse width	**4 μsec**
Beam diameter	4 mm
Structure type	**On-axis coupled caivty**
The number of cell	**18**
Average field	13.5 MV/m
Shunt Impedance	149 MΩ/m
Quality factor	12800

Conclusion

- **We have designed a C-band (5 GHz) standingwave accelerator for operating 8 MeV electron beams with 1.5 MW pulsed magnetron(CPI SFD 369).**
- **The designed Standingwave accelerator structure has 15 regular cavities and the total length is 49.55 cm.**
- **Dimensions of DC-gun and buncher dimension are specially designed for the best beam matching.**
- **Cold model fabrication is planed for the low power RF test.**