Design of Intense Electron Linac by L-band Traveling-waves

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Abstract

- We designed an intense electron linac for industrial irradiation applications using L-band traveling-waves. It is capable to produce 10 MeV electron beams of 30 kW. The accelerator uses the 2π/3 mode with a constant-impedance, disk-loaded structure. The operating energy is limited to prevent unwanted neutron production. On the other hand, the current is limited by the beam loading effect for the given structure. We determined the optimum operating parameters by adjusting the duty factor, which was again governed by the available high-power pulsed klystron. With the SPERFISH code, we designed the accelerating and bunching cavities, and also we obtained the beam dynamics by the PAMELA code. For the cooling system design, we used the ANSYS code. In this paper, we present design details of an intense traveling-wave linac of 10 MeV, 30 kW by a 1.3 GHz, 25 MW pulsed klystron with the duty factor of 2.1x 10-3.

Accelerator Parameters

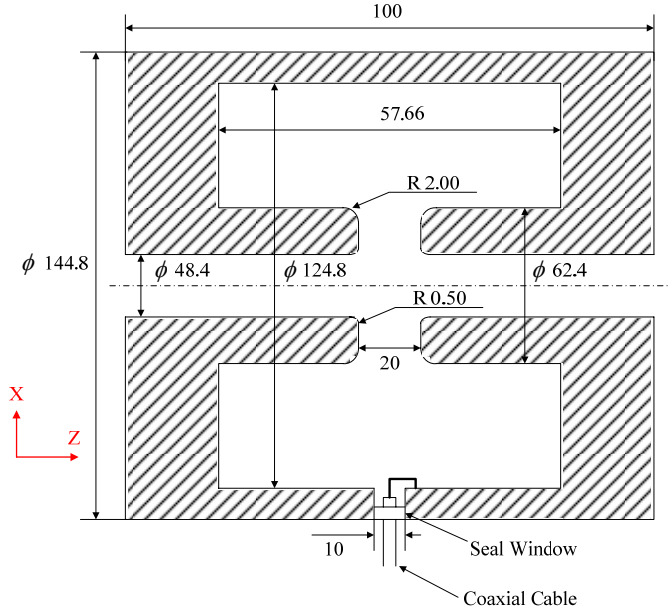
Beam Parameters	
Beam Species	Electron
Beam Energy	10.1 MeV
Pulse Beam Current	1.45 A
Beam Pulse Length	6μs
Repetition Rate	350Hz
Transmission rate	95%
Beam duty factor	$2.1 * 10^{-3}$
E0	11.5 MV/m
No load energy	17.0 MeV
Beam loading factor	-6.1 MeV/A
Output beam	16.9 MeV @ 1 mA
	14.5 MeV @ 0.5 A

E-Gun Parameters	
High Voltage	80kV
Pulse Beam Current	1.52A
Pulse Length	6μs
Repetition Rate	350Hz

RF Parameters	
Operating Frequency	1300MHz
Pulse Length	7μs
Repetition Rate	350Hz
RF duty factor	$2.38 * 10^{-3}$
Klystron Input Power	25MW

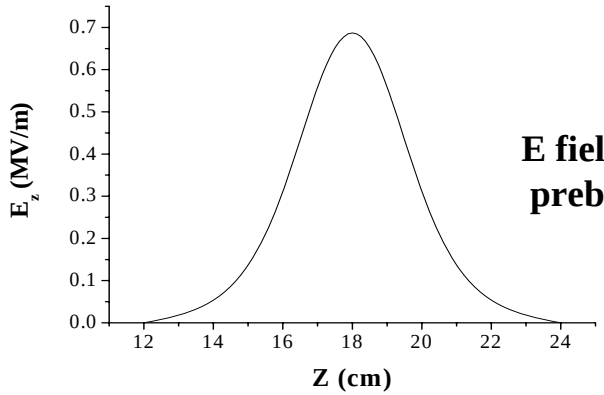
Design of Prebuncher

- The prebuncher is a re-entrant type, standing–wave cavity machined from stainless steel.
- Due to the lower Q-value of stainless steel, it is used to minimize the effects of the temperature, mechanical distortions and beam loading in the cavity.
- The velocity modulation introduced by the prebuncher causes 63 % of the electrons to be bunched within a 70˚ interval in the 24.2 cm drift space.

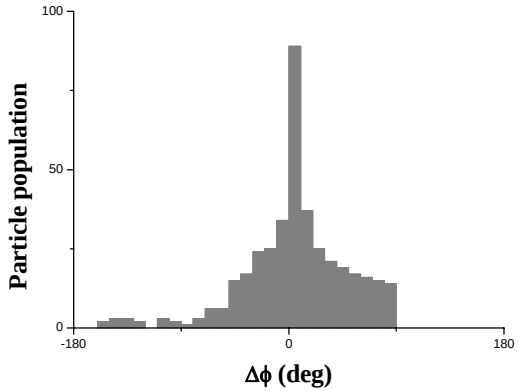


Parameters of the prebuncher

Resonant Frequency	**1,300 MHz**
No load Q	
Power	**10 kW**



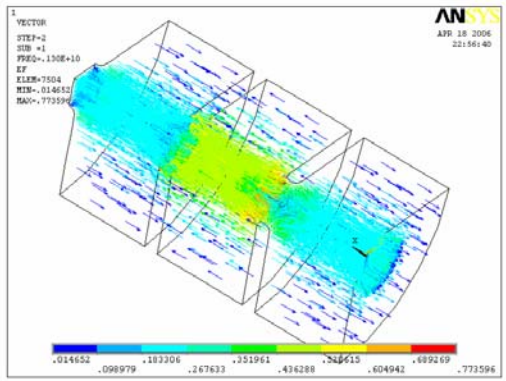
E field in the prebuncher



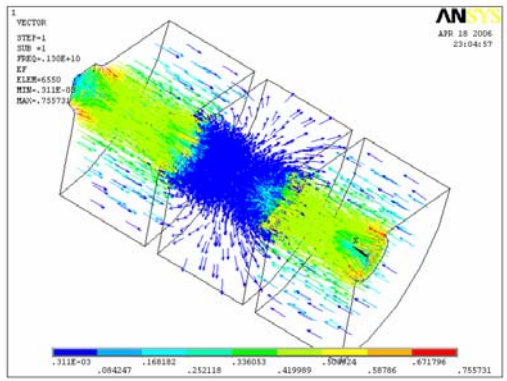
Velocity modulation

Design of buncher and accelerating section

- **Main accelerator is traveling wave, constant impedance structure.**
- **Buncher cells have identical iris diameter. But their axial distances are different from each other since each cell has different phase velocity.**
- **RF power is feed through the input coupler in the 1st buncher cell.**
- **Operating mode: 2π/3 mode with traveling-wave**
- **The electrons leave the accelerator within a phase interval of 20°.**
- **The accelerating sections have a cylindrical symmetry except coupler cavities with its matching iris aperture**
- **Fully beam loading condition : To have good energy transfer and energy gain**

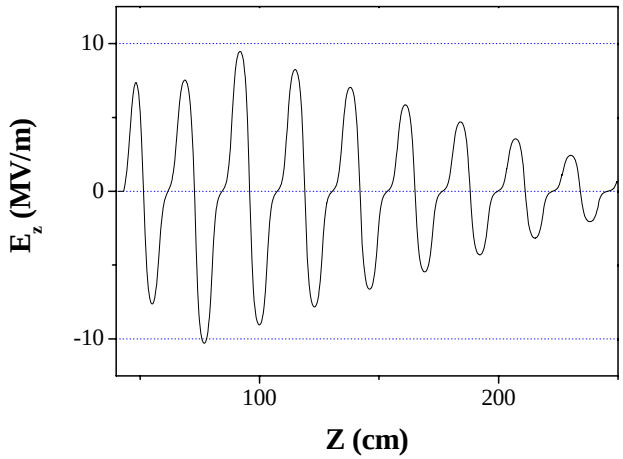


(a) Cosine solution



(a) Sine solution

E field Solution in the accelerator cavities



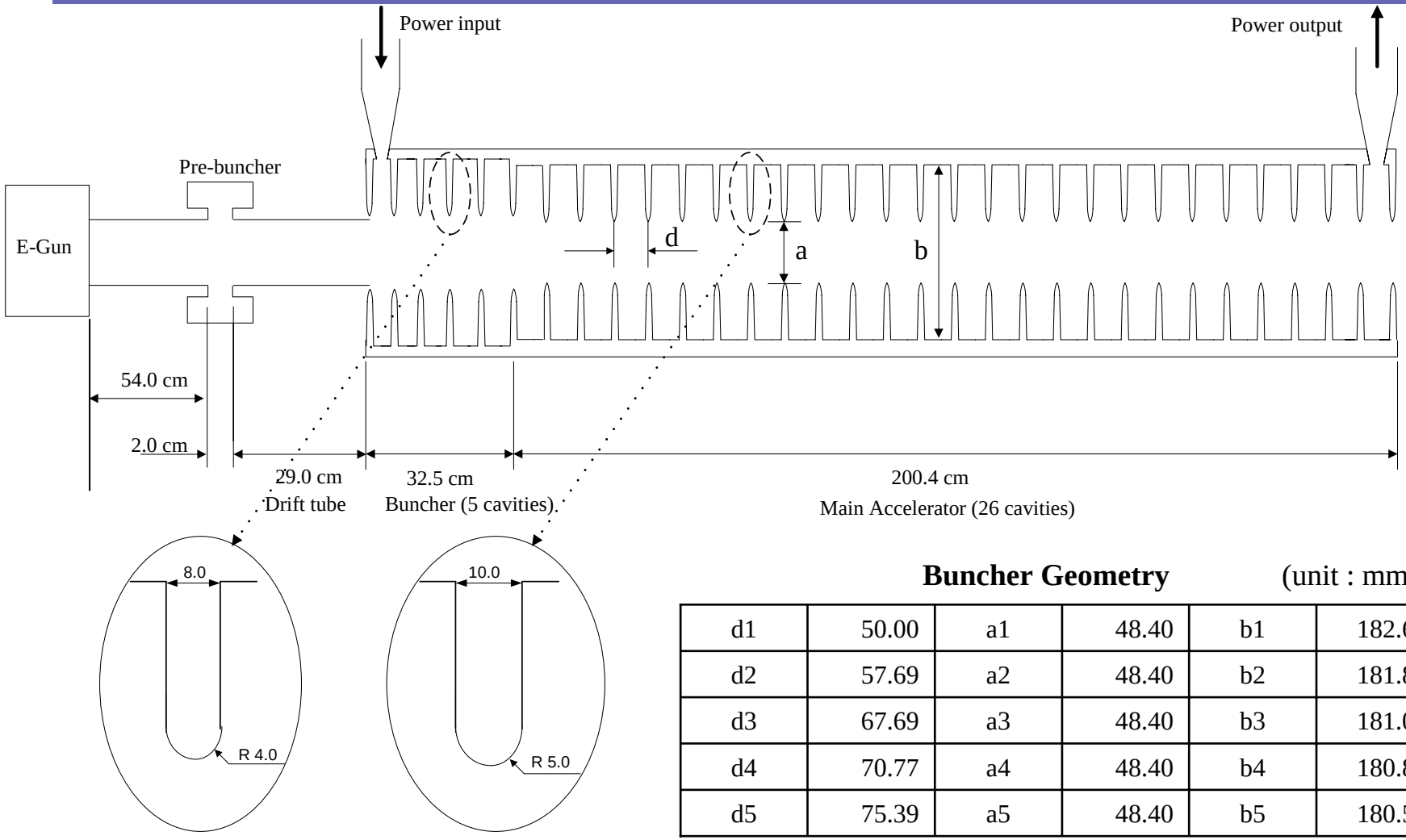
E field in the accelerator cavities

Cavity Design

Cavity Design Parameters					
	Shunt impedance (MΩ/m)	**Attenuation Coefficient (nep/m)**	**Quality factor**	**Group velocity (v_g/c)**	**Cell type**
1st buncher	18.76	0.053835	14898.24	0.016974	β = 0.65
2nd buncher	25.04	0.048907	16672.32	0.016696	β = 0.75
3rd buncher	33.03	0.044227	18711.36	0.0164505	β = 0.88
4th buncher	35.49	0.043056	19287.36	0.016393	β = 0.92
5th buncher	38.87	0.041497	20108.16	0.016315	β = 0.98
Accelerating cavity	43.08	0.062314	20335.68	0.010743	β = 1.00

Type of Structure	Constant Impedance
Number of Cells	31 (5 (B) + 26 (A))
Length	232.9cm (32.5cm(B) + 200.4cm(A))
Operating Mode	2π/3
Filling Time	0.81 μs

Schematics of Accelerating Structure



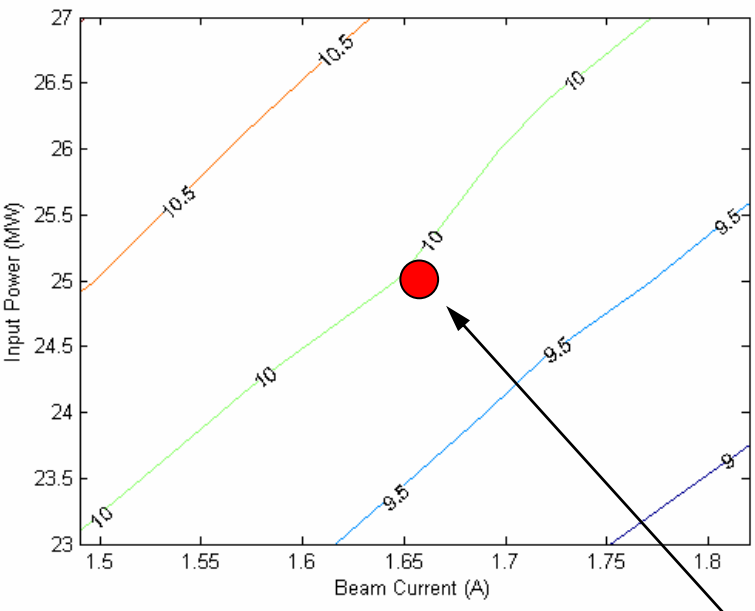
Buncher Geometry (unit : mm)

d1	50.00	a1	48.40	b1	182.69
d2	57.69	a2	48.40	b2	181.88
d3	67.69	a3	48.40	b3	181.07
d4	70.77	a4	48.40	b4	180.87
d5	75.39	a5	48.40	b5	180.59

Main Accelerator Geometry (All cavities have same values.)

d	76.87	a	43.00	b	179.55

Characteristics of Output Beam under Operating Conditions



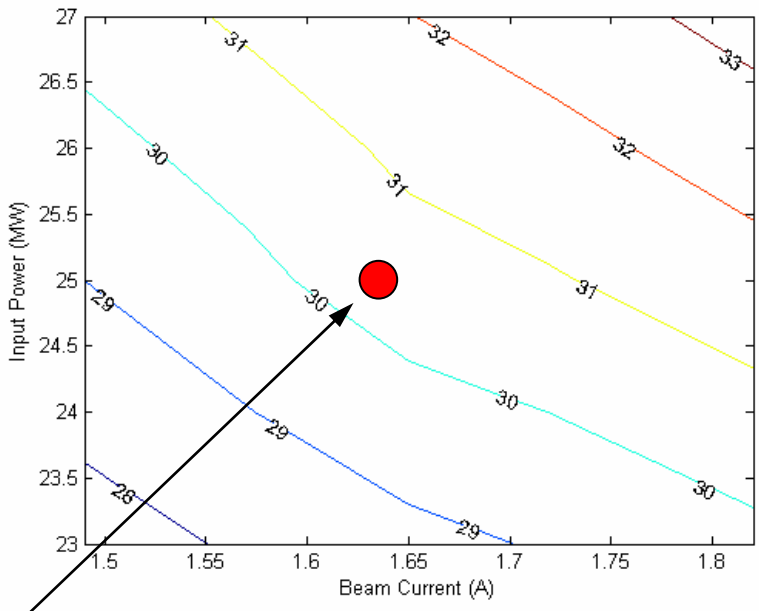


Fig1 **Working point (design)** **Fig2**

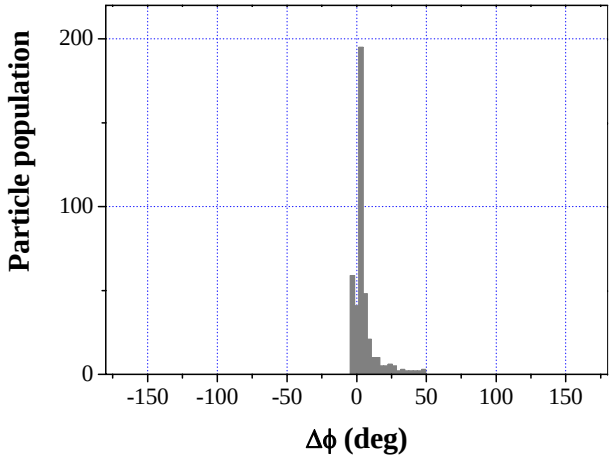
Fig1. Output beam energy contour under variations of input RF power and input beam current (unit: MeV)

Fig2. Output beam power contour under variations of input RF power and input beam current (unit: kW)

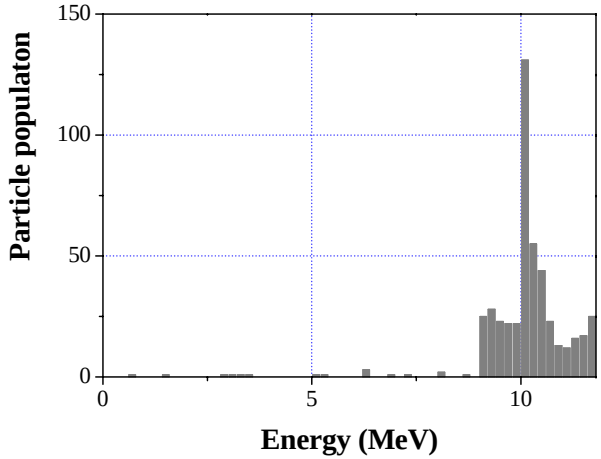
Beam Dynamics

- **Nominal input condition: Input beam current = 1.52 A, Input RF power = 25MW.**
- **Output Beam : 10.1 MeV (ave), 1.45 A (ave), 30.5 kW (ave)**

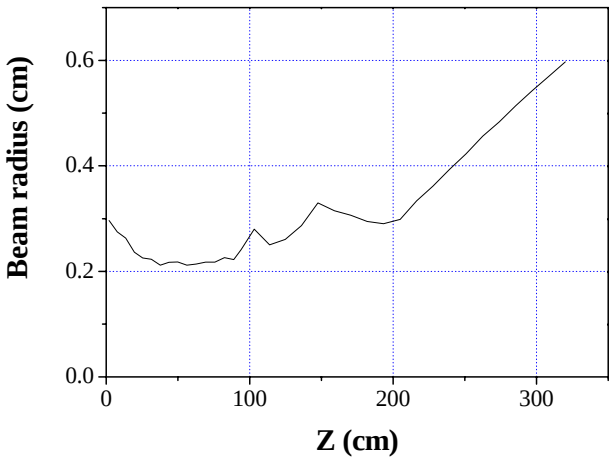
Phase spectrum at Exit of the accelerator



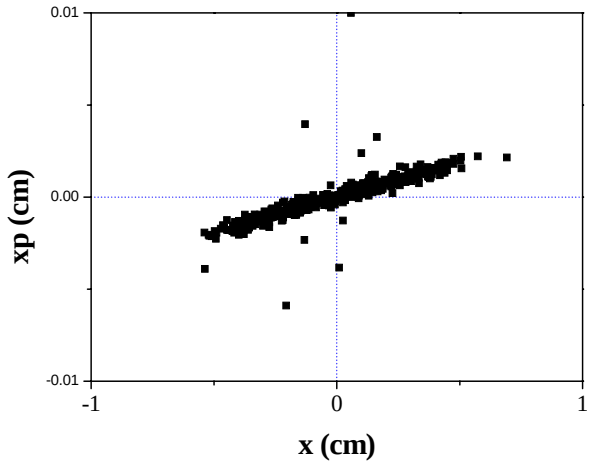
Energy spectrum at Exit of the accelerator



Beam envelope

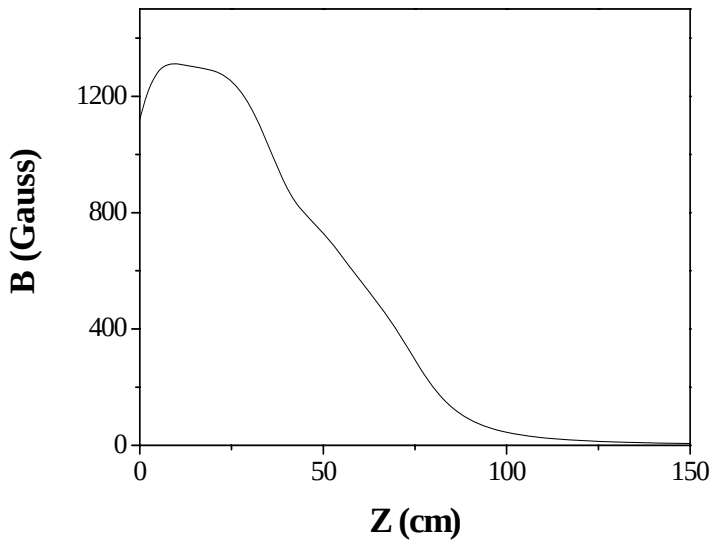


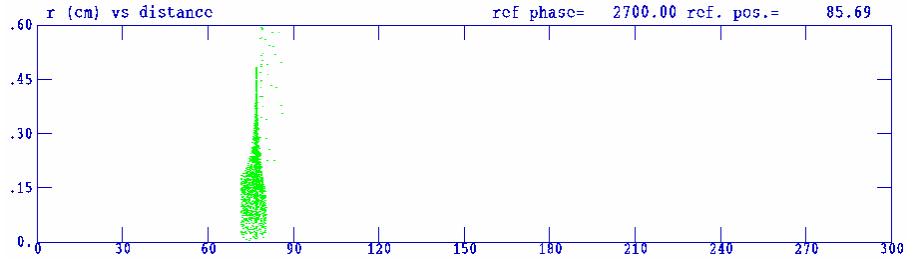
Phase space at the exit of the accelerator



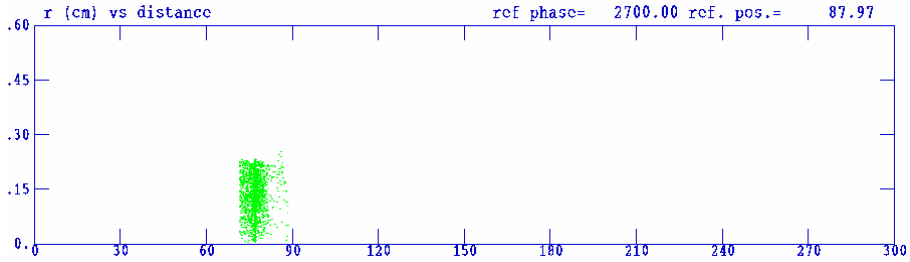
Focusing Solenoids

- There are four coils located between the electron gun and the last buncher section.
- The first coil is encased by iron to reduce the stray field to the electron gun.
- Maximum field strength is 1.3 kG at the low energy end.
- Beam envelope is significantly focused and beam transmission rate is improved





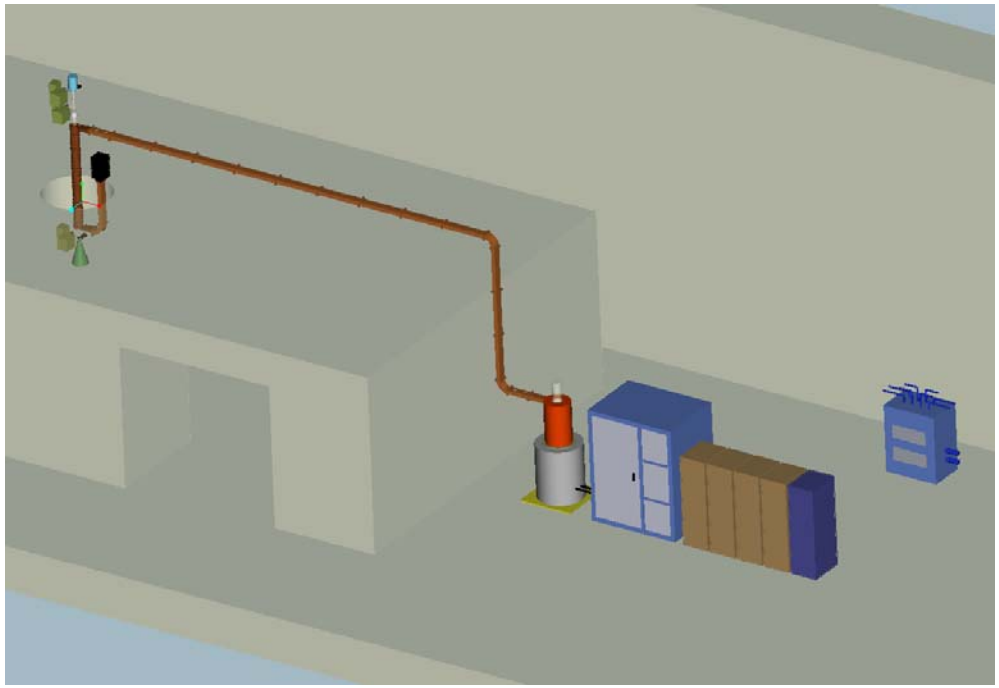
Without Focusing solenoid,
Transmission rate : 69 %

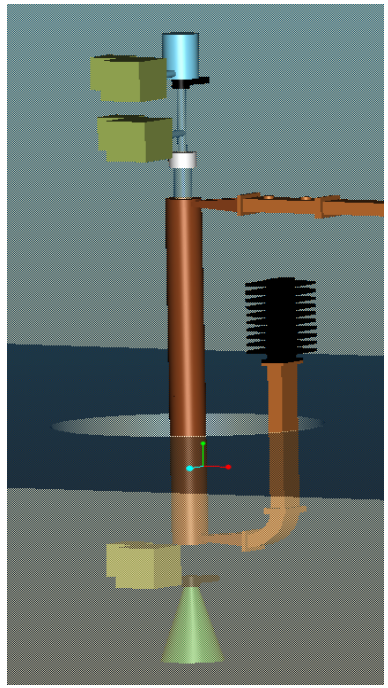


With Focusing solenoid,
Transmission rate : 95 %

RF System

- RF Source : 30 MW(peak), 60 kW(ave) klystron (Thales)
- Waveguide system
  - The waveguide network system consists of straight sections, E-plane bends, directional coupler, power load.
  - There are branch W/G network for the prebuncher system.





Conclusion

- We have given a design for the an intense electron linac for industrial irradiation applications using L-band traveling-waves.
- The accelerator system consisting a prebuncher and 5 buncher cavities and 36 accelerating cavities has been simulated by using PARMELA.
- Design goal is to produce 10 MeV electron beams of 30 kW and the results are satisfactory.
- Since the average beam current is rather high, accelerator design takes beam loading effect into consideration.
- By using focusing solenoid the beam envelope is smoothly focused and has a radius of 4.4 mm at the entrance of buncher section and 5.2 mm at the entrance of accelerating section.