Simulation for Intense L-band Electron Accelerator*

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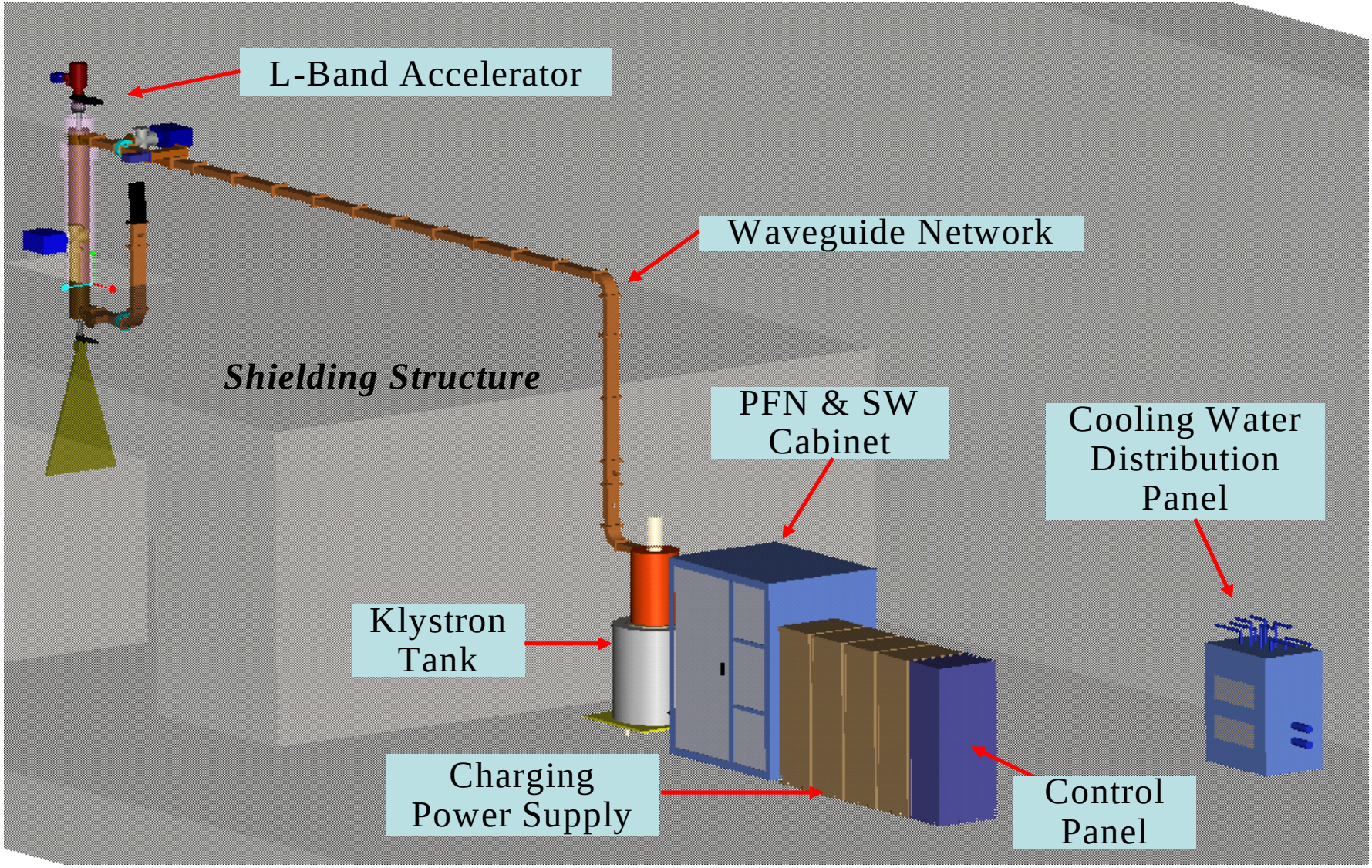
- L-band traveling-wave electron linac
- Irradiation applications
- 10 MeV and average 30 kW
- Single klystron (pulsed 25 MW)
- Single accelerating column
- Vertical mount

System Layout



Accelerator Parameters

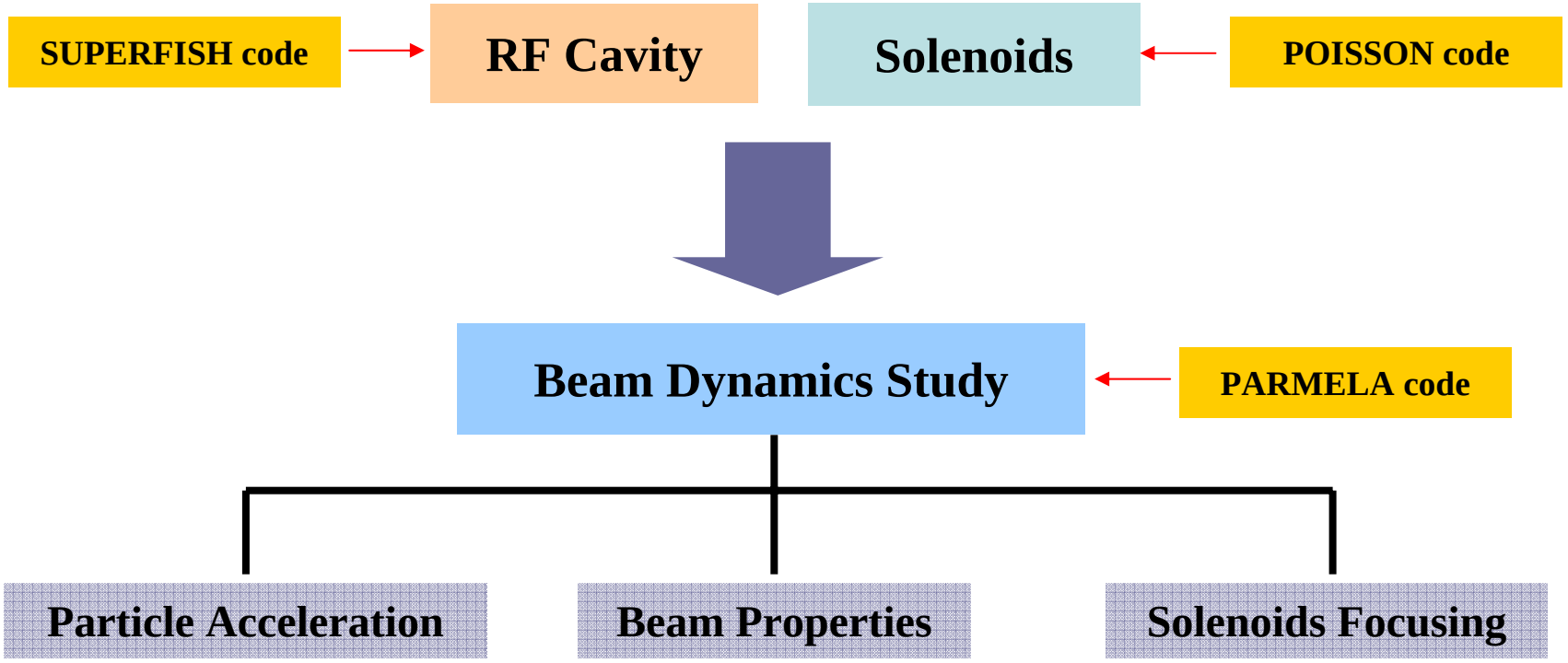
RF System Parameter	
Operating Frequency	1.3 GHz
Pulsed RF Power	25 MW
Pulse Length	7 μs
Repetition Rate	350 Hz
Average RF Power	60 kW

E-gun Parameter	
High Voltage	80 kV
Pulsed Beam Current	1.6 A
Pulse Length	6 μs
Repetition Rate	350 Hz

Beam Parameter	
Beam Energy	10 MeV
Pulsed Beam Current	1.45 A
Beam Transmission Rate	91%
Averaged Beam Power	31.4 kW

Accelerating Structure Parameter	
Type of Structure	Constant-impedance
Shape of Cell	Disk-loaded
Operating Mode	2π/3 mode
RF Filling Time	0.8 μs
Operating Temperature	40˚C ± 1˚C
Averaged Accelerating Gradients	4.2 MV/m
Beam Loading Factor	- 4.7 MeV/A
Temperature Shift Factor	- 2.3 MeV/˚C

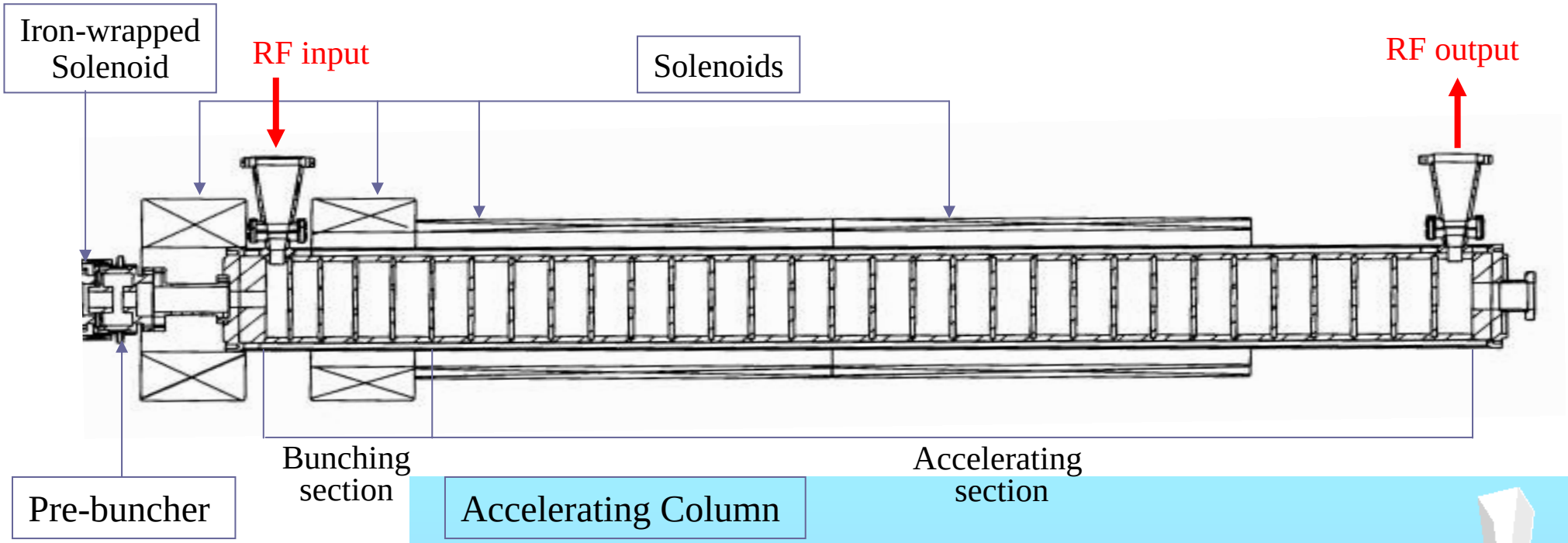
Outline



- Energy gain with accelerating fields
- Beam loading effect
- Temperature tolerance

- Phase spectrum
- Energy-phase diagram
- Emittance

- Beam envelope with focusing magnetic fields



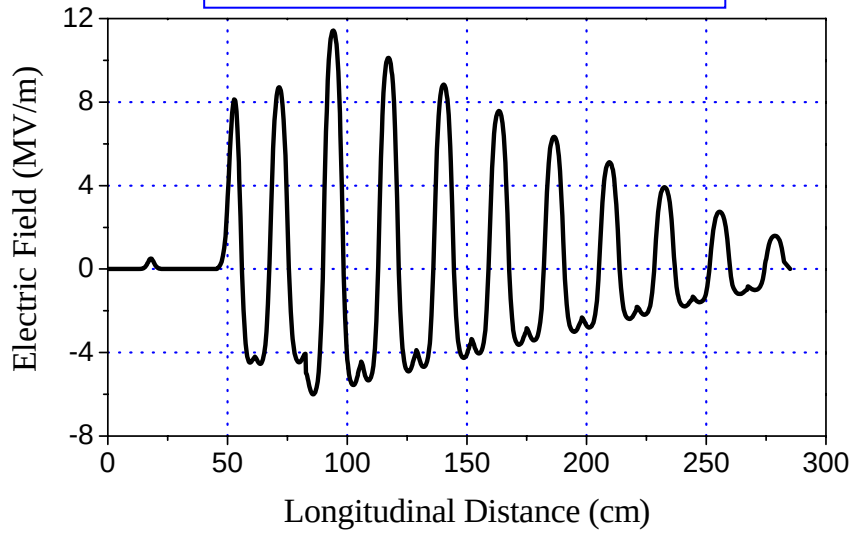
- Re-entrant shape
- Modulating voltage is 20 kV.

Accelerating Column

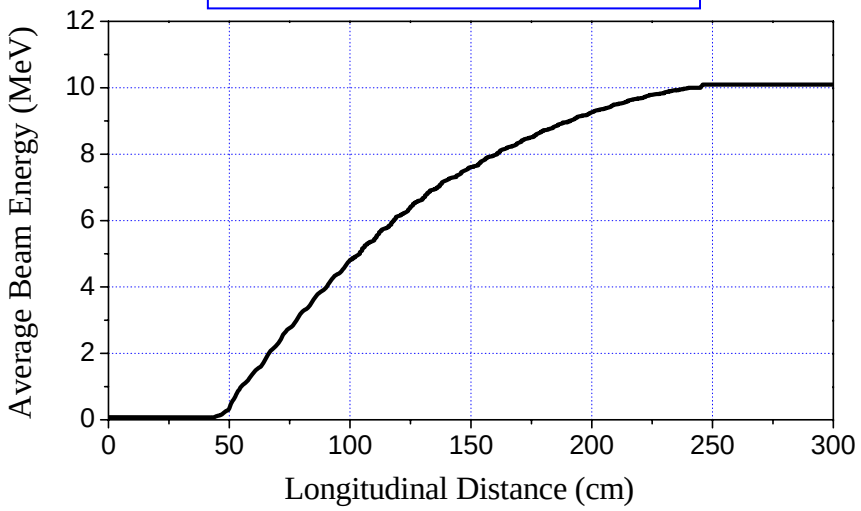
Cavity	Phase velocity / Speed of light	Attenuation Coefficient (Nep/m)
1st buncher	0.65	0.0538
2nd buncher	0.75	0.0489
3rd buncher	0.88	0.0442
4th buncher	0.92	0.0431
5th buncher	0.98	0.0415
Normal	1.00	0.0623

Accelerating Fields and Energy Gain

Longitudinal Electric Fields



Beam Energy Distribution



- Longitudinal electric field

$$E(z) = E_0 \exp(-\alpha z)\sin\phi - \underbrace{Ir_s(1-\exp(-\alpha z))}_{\text{Beam loading term}}$$

r_s : shunt impedance,
α : attenuation coefficient
P_0 : input RF power
ϕ : phase of the accelerating field.

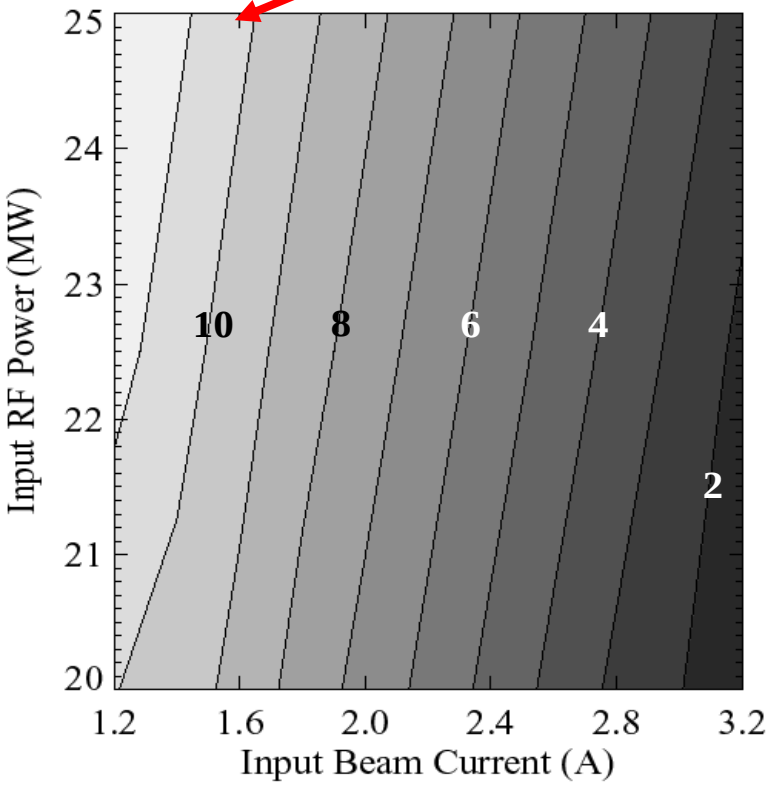
$$E_0 = \sqrt{2\alpha P_0 r_s}$$

- Fully beam-loaded condition.

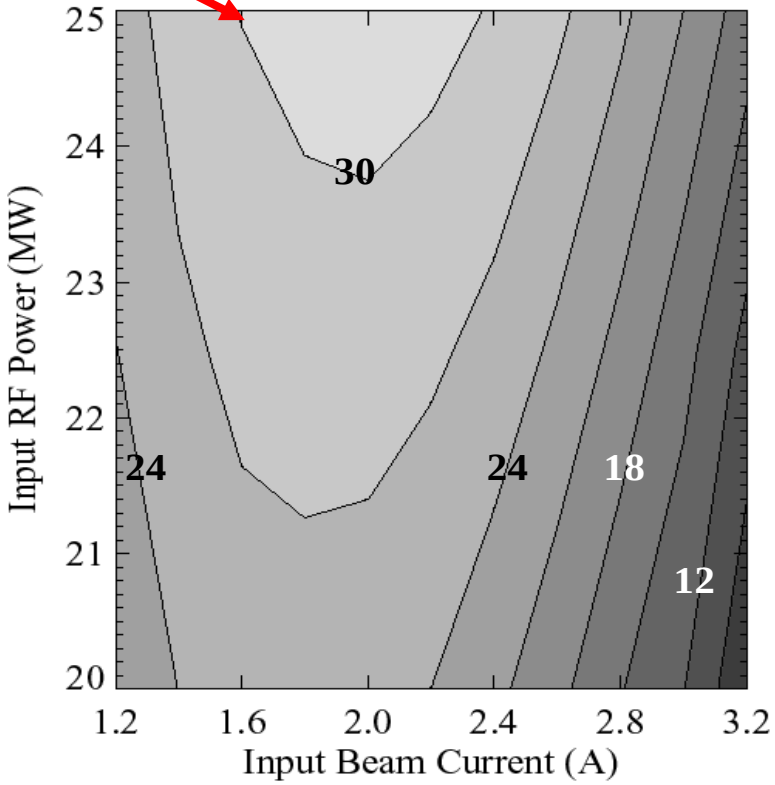
- The increase of beam energy is reduced as the beam passes through the column.

Beam Loading Effect

Nominal operating condition



Output Beam Energy (MeV)



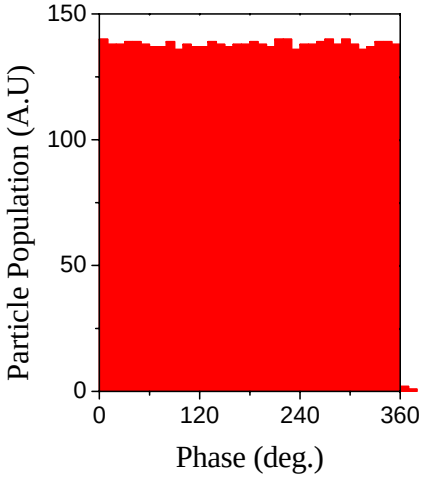
Average Output Beam Power (kW)

• Beam Loading Factor: - 4.7 MeV/A

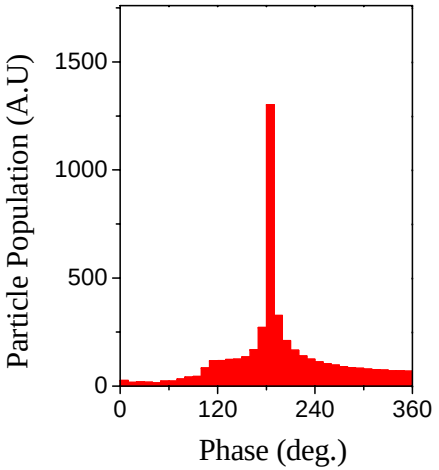
Beam Bunching

- Biased by pulsed E-gun
- Initial energy: 80 keV

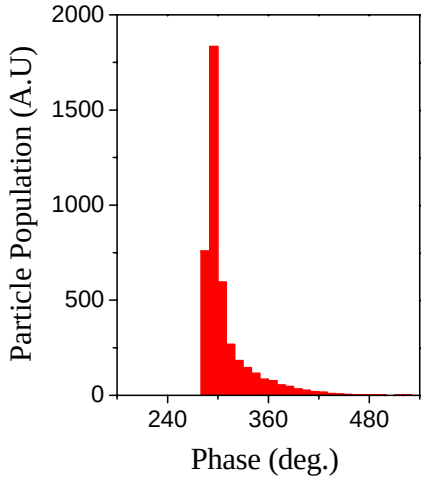
End of E-gun



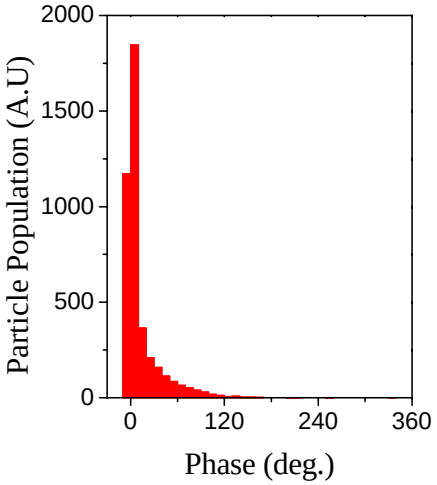
Entrance of Accelerating Column



- Bunched by pre-buncher
- Modulating voltage: 20 kV
- Drift length: 32.5 cm



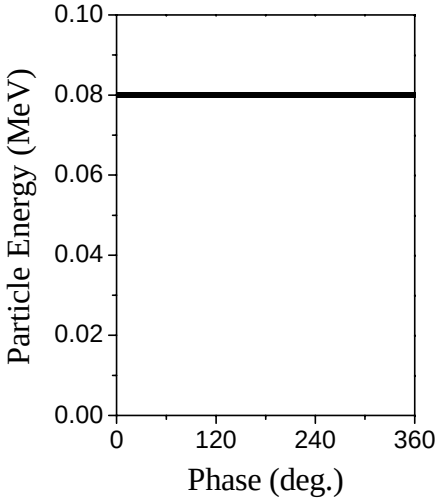
End of Bunching Section



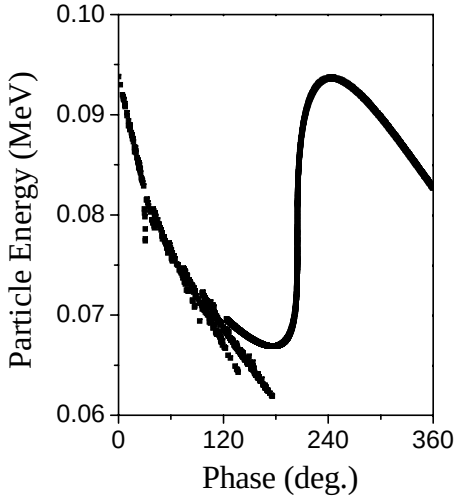
End of Accelerating Column

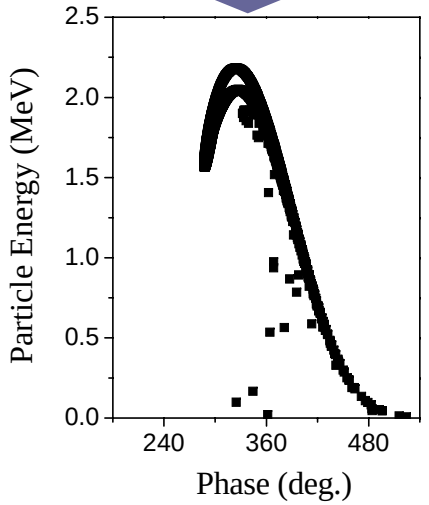
Longitudinal Beam Properties

End of E-gun

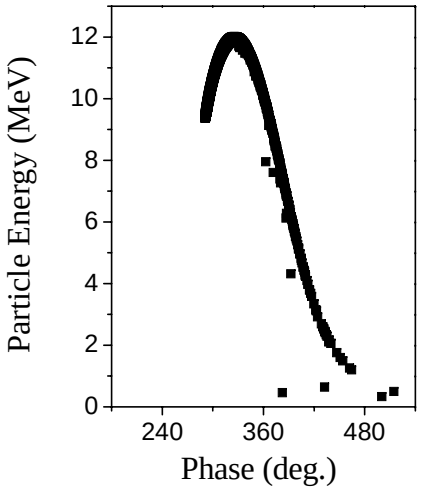


Entrance of Accelerating Column





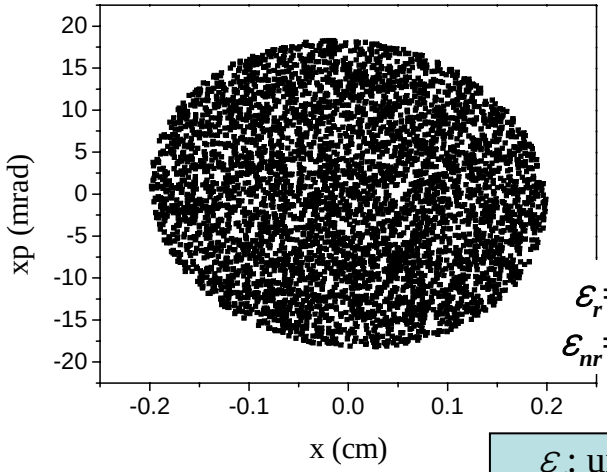
End of Bunching Section



End of Accelerating Column

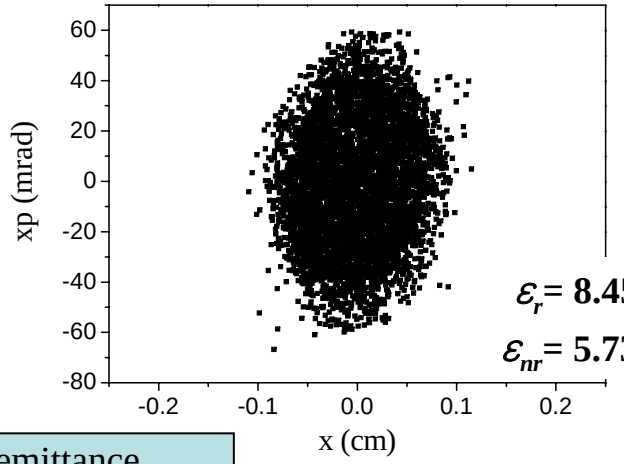
Transverse Beam Properties

End of E-gun



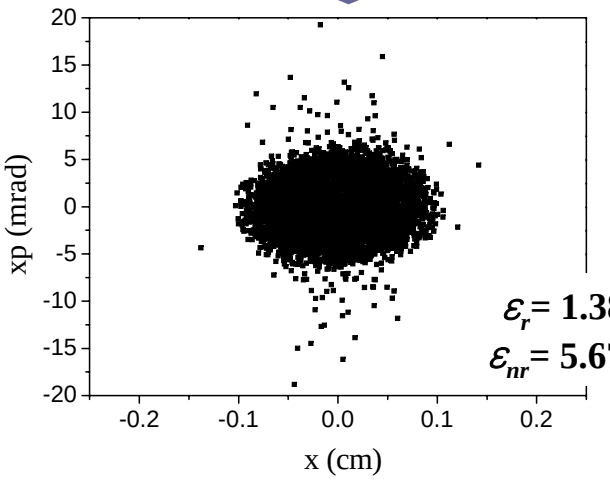
ε_r= 9.05 mm·mrad
ε_{nr}= 5.26 mm·mrad

Entrance of Accelerating Column



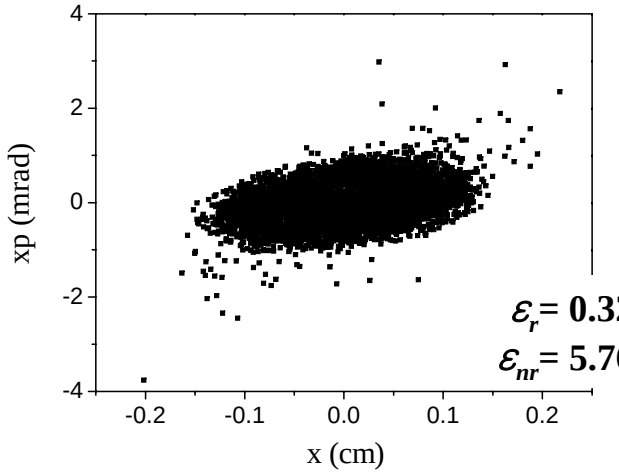
ε_r= 8.45 mm·mrad
ε_{nr}= 5.73 mm·mrad

ε_r: unnormalized RMS emittance
ε_{nr}: normalized RMS emittance



ε_r= 1.38 mm·mrad
ε_{nr}= 5.67 mm·mrad

End of Bunching Section

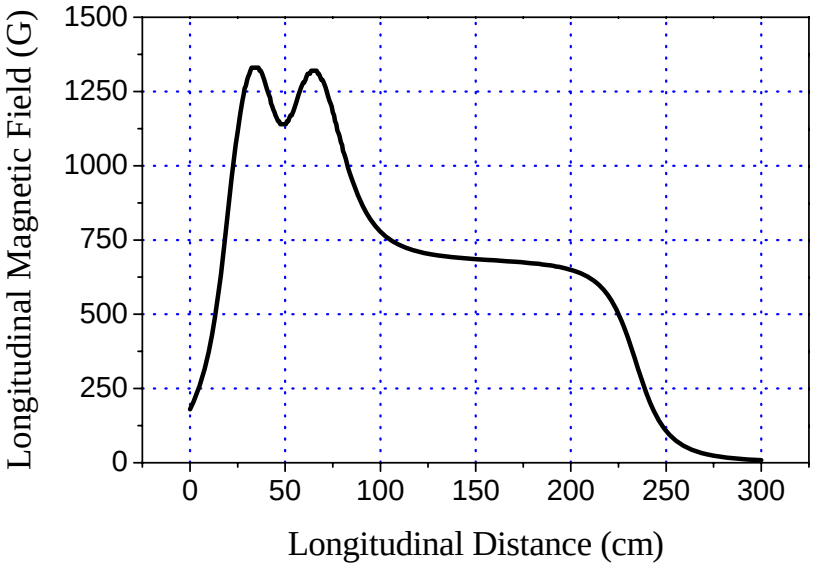


ε_r= 0.32 mm·mrad
ε_{nr}= 5.76 cm·mrad

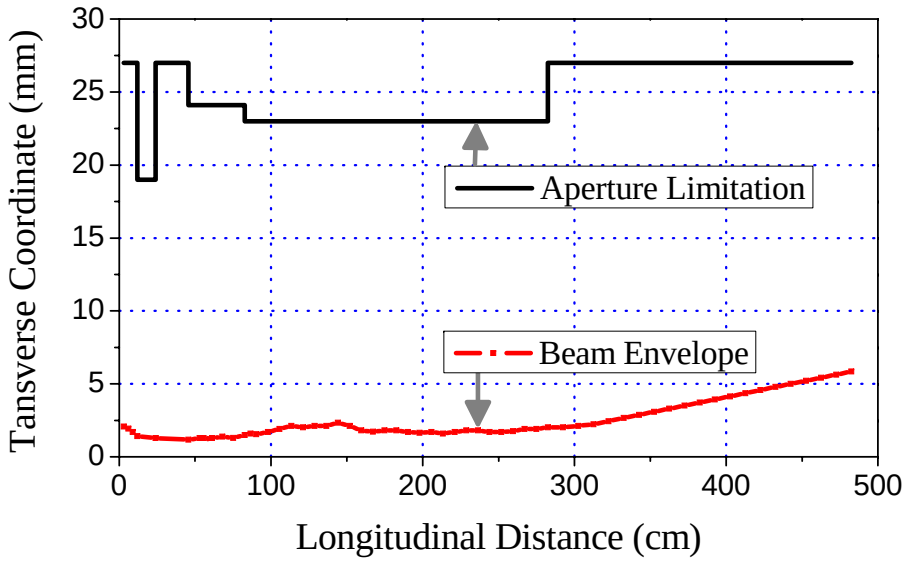
End of Accelerating Column

Focusing Solenoids

Focusing Magnetic Fields



Beam Envelope and Aperture Limitation



- Beam transmission rate: 91%
- Most of beam loss occurred at the entrance of accelerating column.

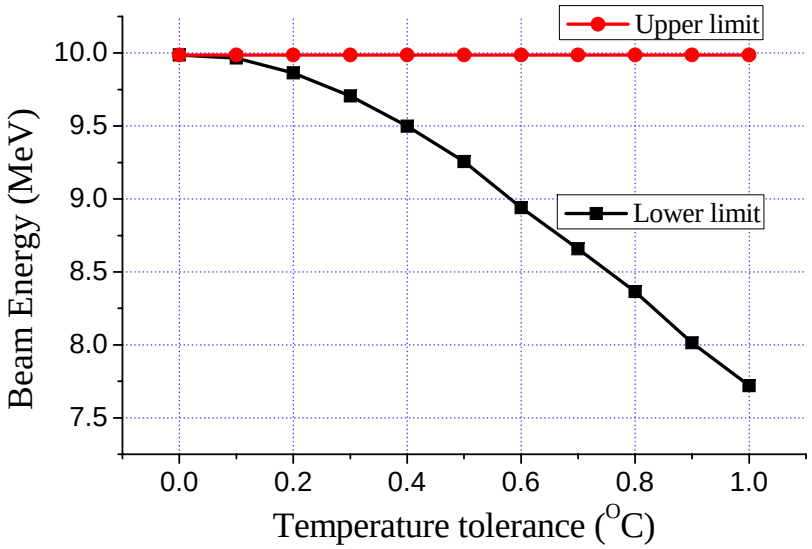
Temperature Tolerance

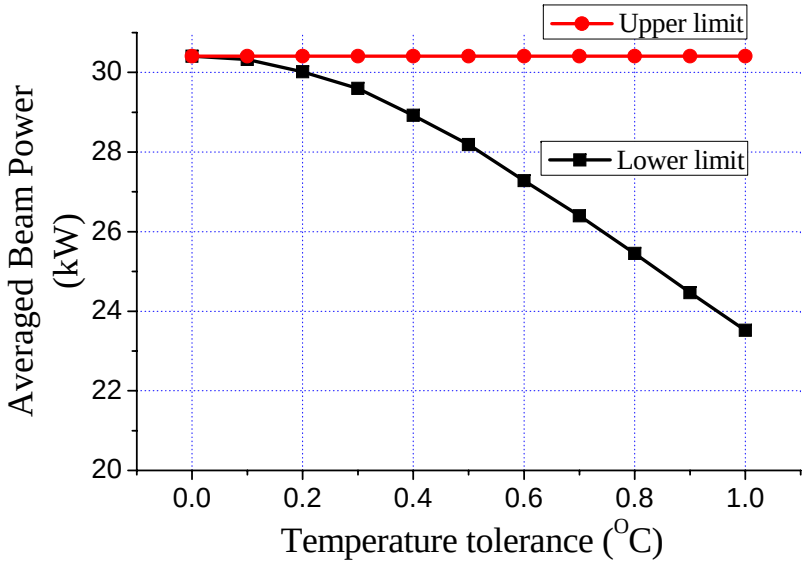
Temperature Changes

⇨ Resonant Frequency Shift

⇨ $|E(\omega)|^2 \propto \dfrac{1}{(\omega-\omega_0)^2+(\omega_0/2Q)^2}$

ω_0 : Resonance frequency
ω : Operating frequency
Q : Quality factor





$\Delta P/P \cong \Delta E/E \leq 23\%,$

under $\Delta T = \pm 1^{\circ}C$

* Upper limit: The temperature of every cavity is 40 °C.
* Lower limit: The temperature of every cavity is shifted by the temperature tolerance from 40 °C.

Summary

- 10-MeV electron beams with 30 kW.
  - Input power: 25 MW with duty factor of 2.1×10^{-3}
  - Optimized input current: 1.6 A (Beam loading factor = −4.7 MeV/A)

- Beam properties
  - Bunch length and emittance: Acceptable for irradiation applications.

- Focusing issue
  - Beam envelope: small enough for the safe beam transmission

- Temperature tolerance
  - Temperature tolerance is determined as ±1°C.
  - Beam energy is reduced with −2.3 MeV/°C