Emittance Compensation in a Superconducting RF Photoinjector

USPAS
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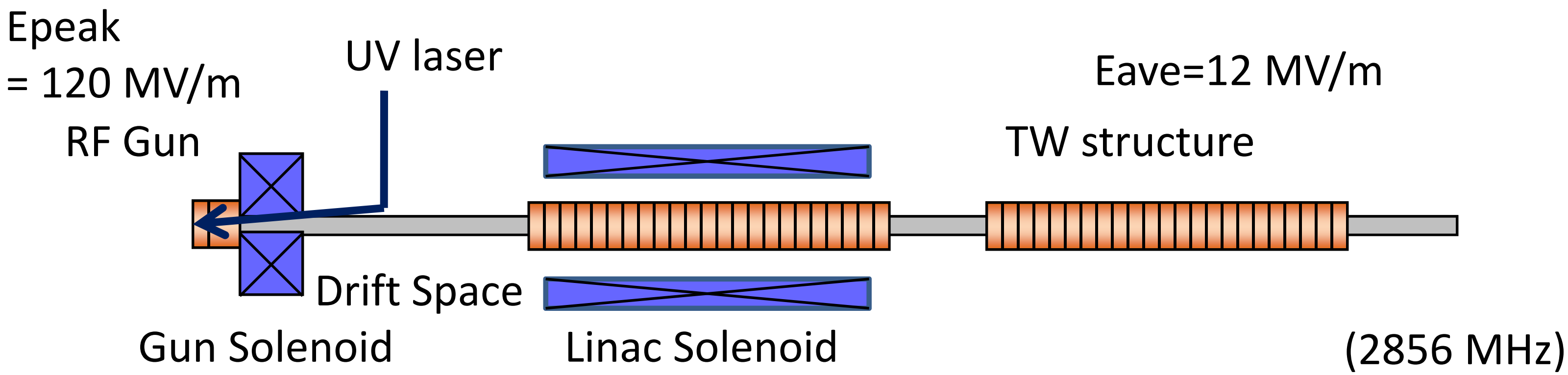
Outline

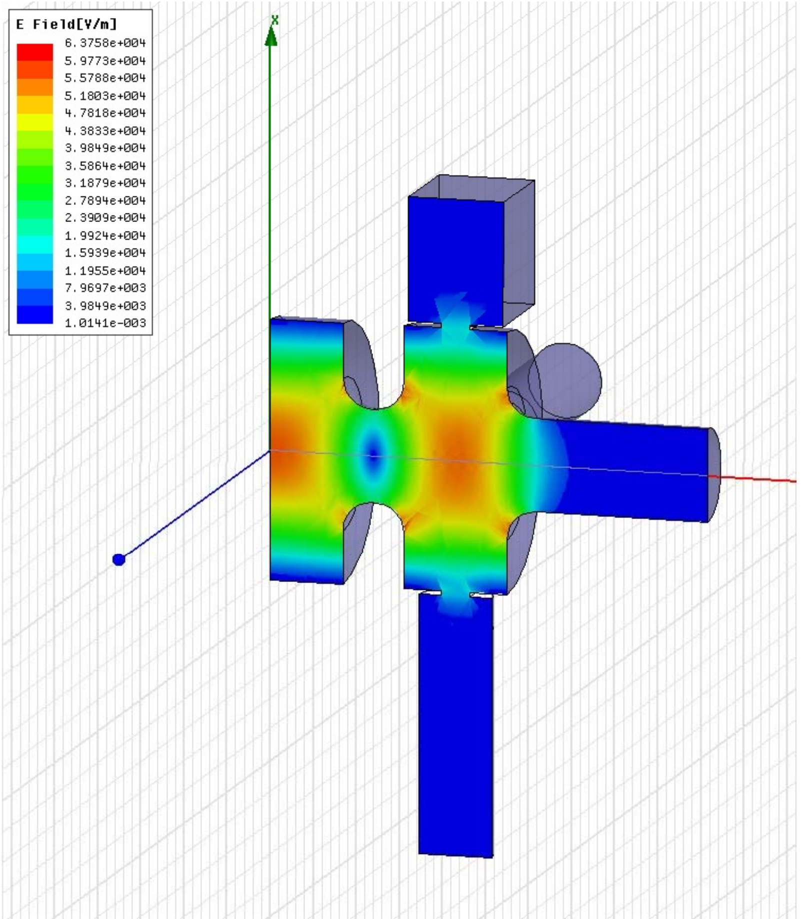
- Overview of the photoinjector.
- What is the emittance?
- Emittance compensation.
- Magnetic RF field focusing.

Normal Counducting Photoinjector

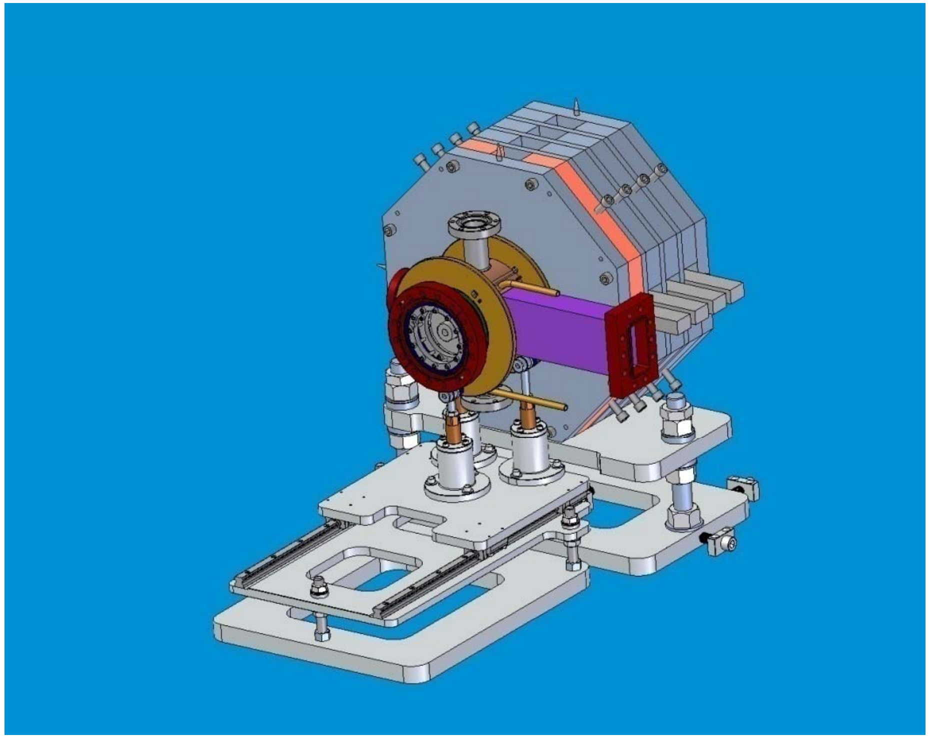


- Photoelectrons are produced by illuminating the cathode by the 10-ps-long laser pulse with 1mm of the spot size for 1nC operation.
- The beam is 5 MeV after the gun.
- The gun solenoid and linac solenoid are used for the emittance compensation as well as focusing.
- The drift space between the gun and the first linac is important for the emittance compensation.

Photocathode RF Gun

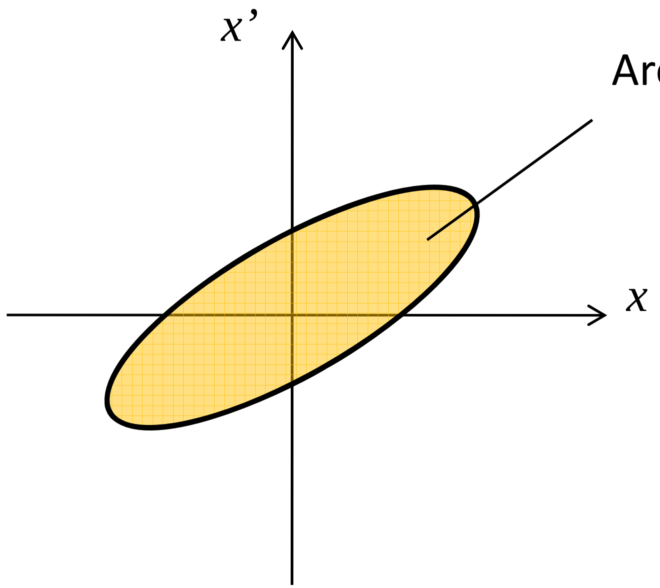


1.6-cell cavity



Gun and Solenoid

What is the emittance?



rms emittance

- Unnormalized emittance

$$\epsilon = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

- Normalized emittance

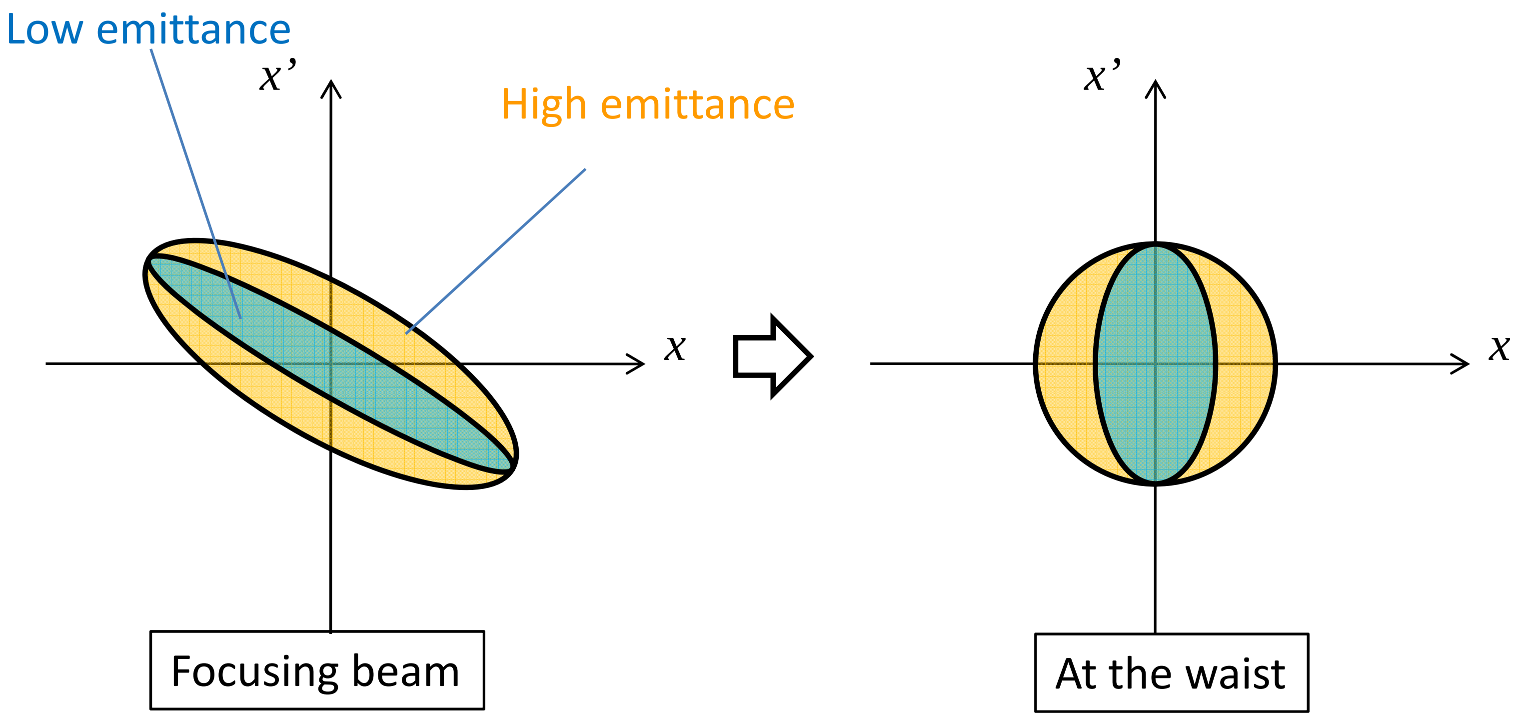
$$\epsilon_n = \langle\beta\gamma\rangle\epsilon \approx \frac{1}{mc}\sqrt{\langle x^2\rangle\langle p_x^2\rangle - \langle xp_x\rangle^2}$$

Independent of the beam energy.

- Rms emittance: ->
- 90% emittance: covers 90% of the particles.
- 100% emittance covers all of the particles.

The emittance conserves during the beam transportation. (Leouville's Theorem)

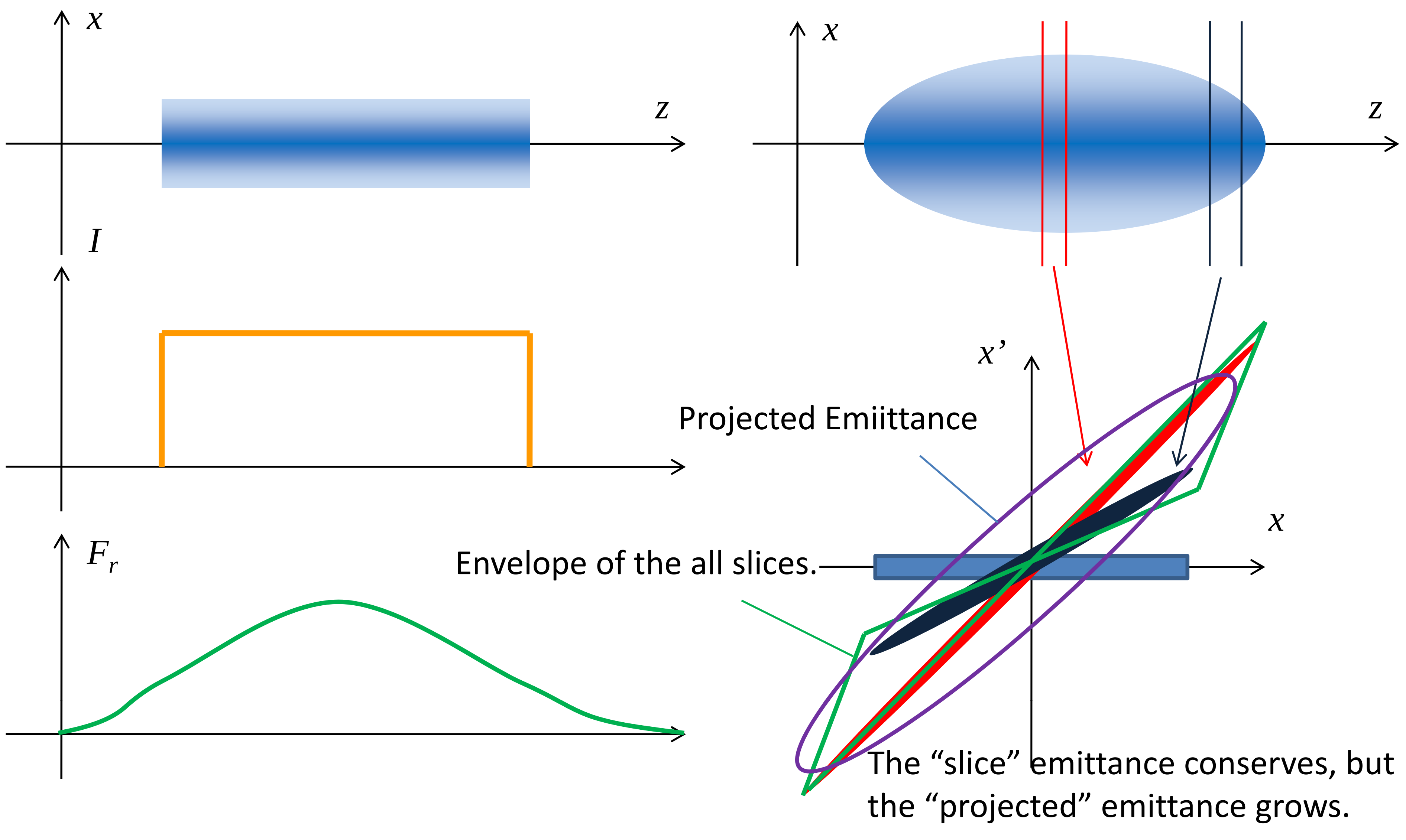
Focusing the Low Emittance Beam



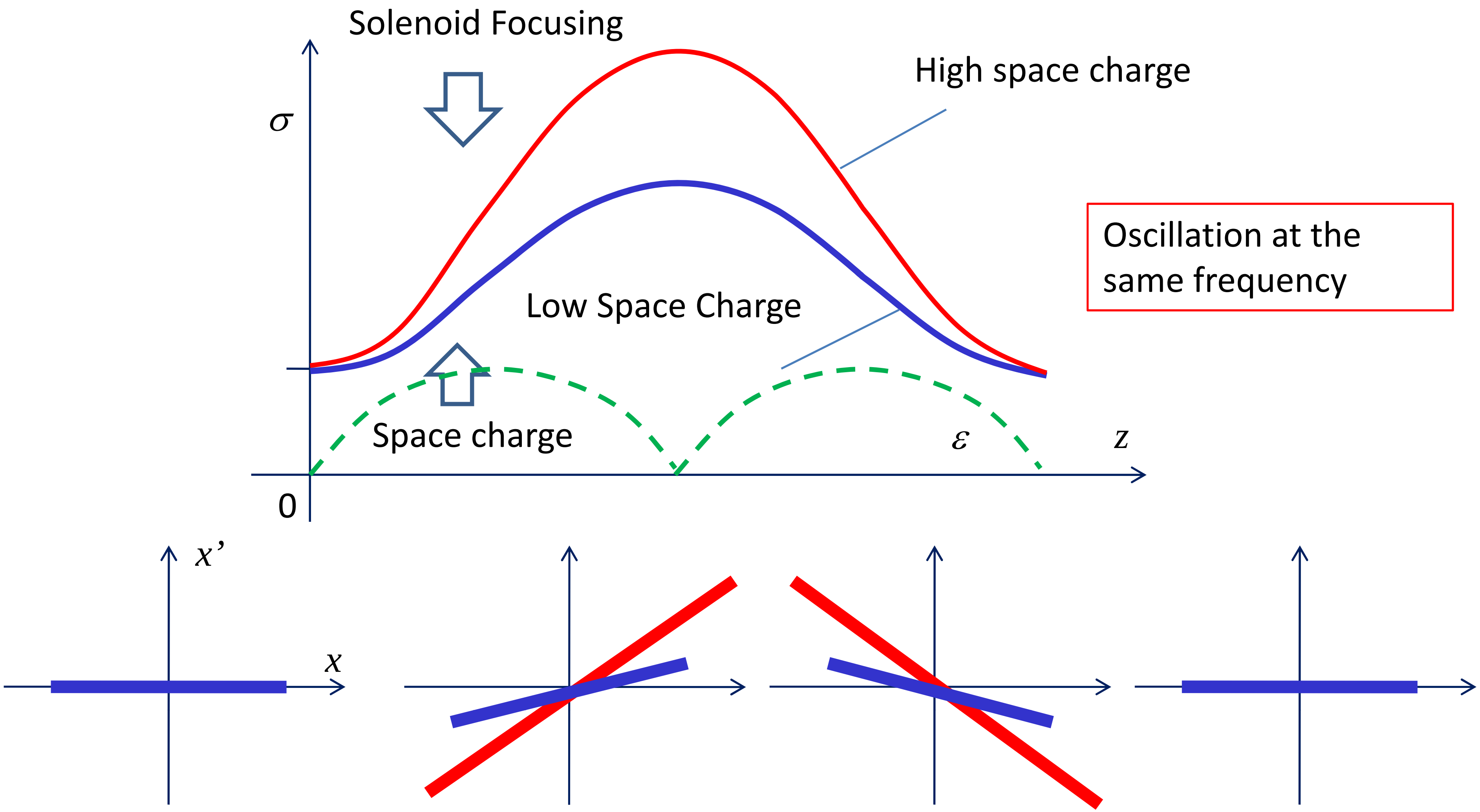
A low emittance beam can make a small waist.

a low eimittance beam = a high brightness beam.

The Emittance Growth in the RF Gun

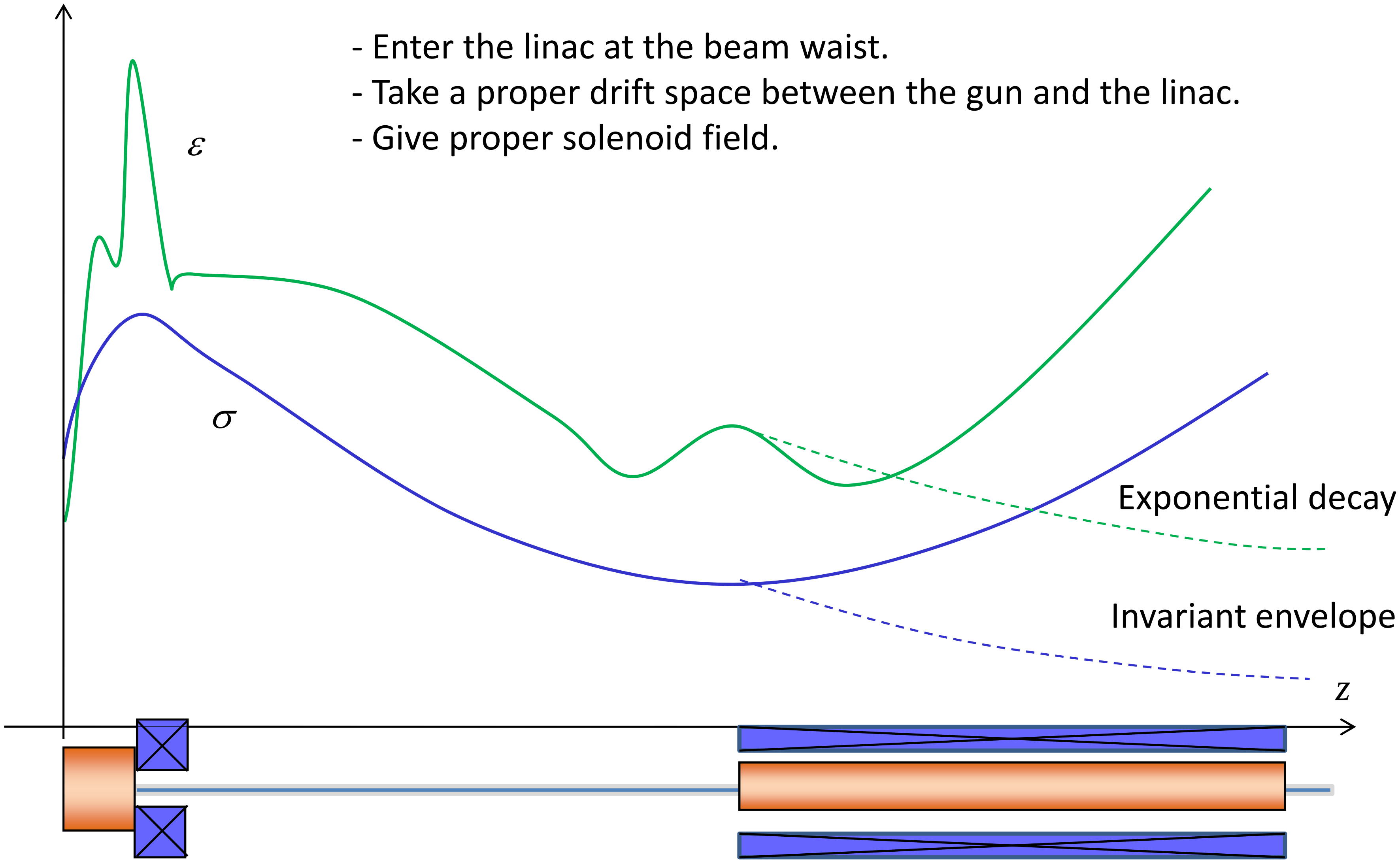


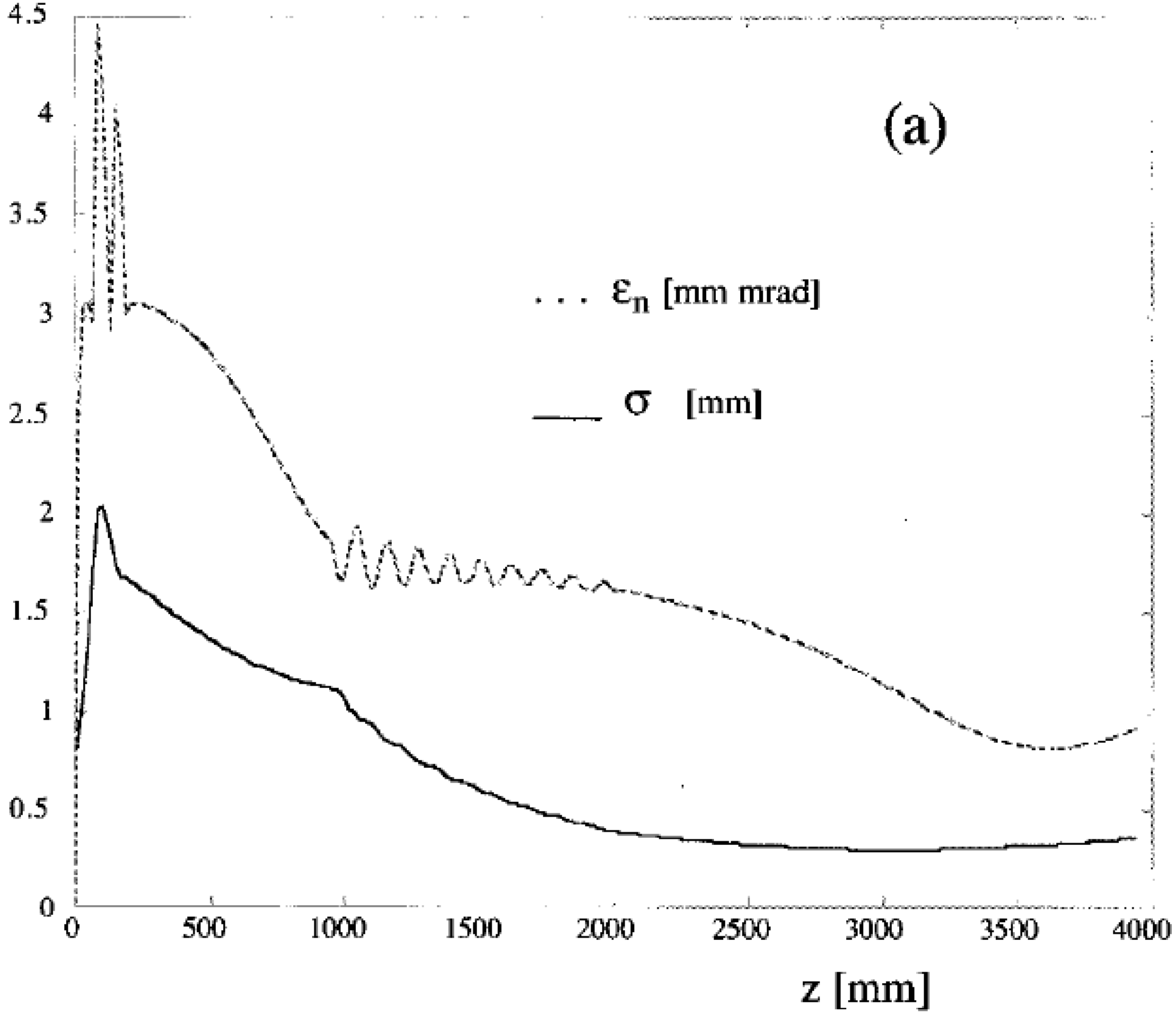
Concept of the Emittance Compensation



Invariant Envelope

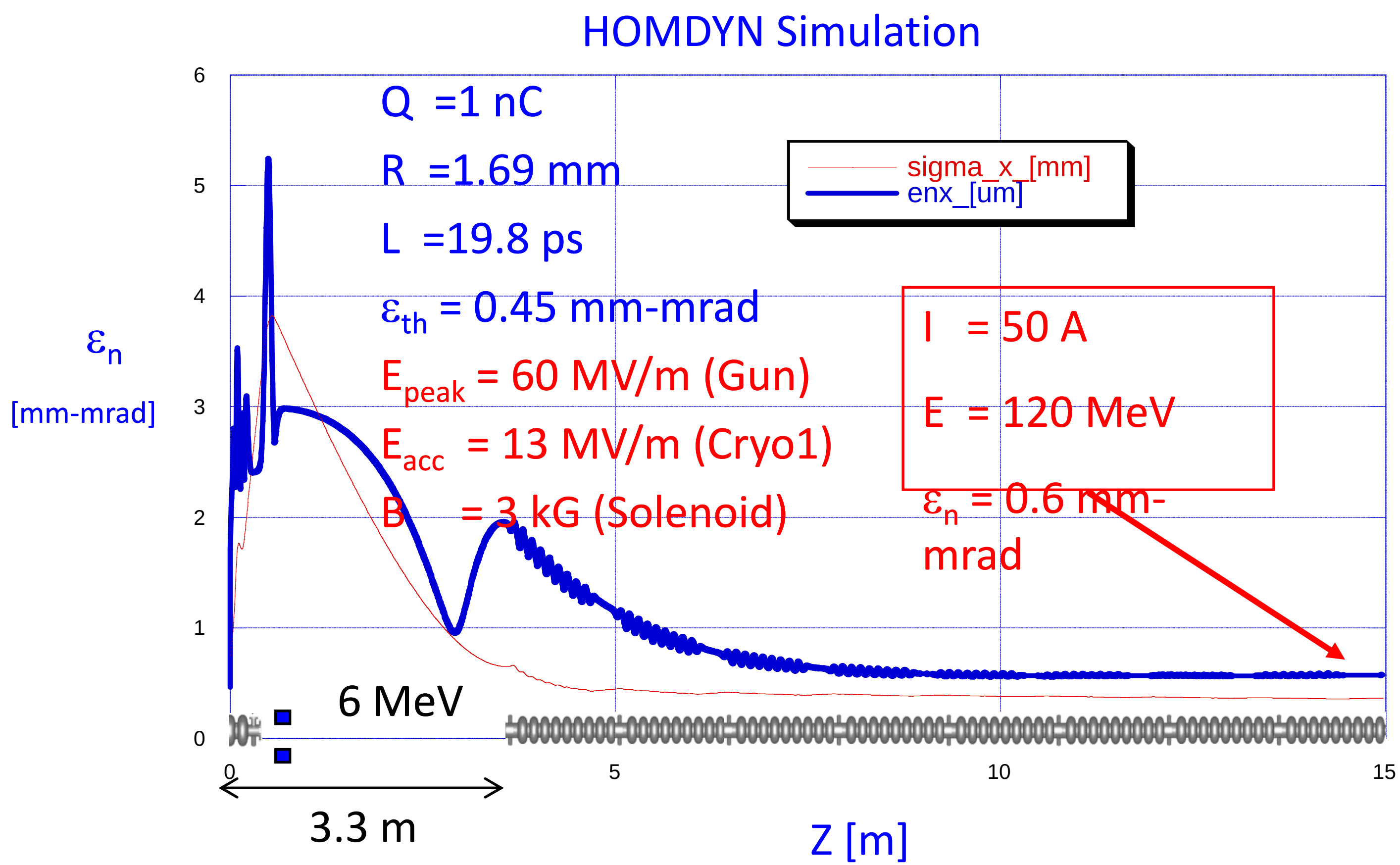
- Enter the linac at the beam waist.
- Take a proper drift space between the gun and the linac.
- Give proper solenoid field.





L. Serafini et al., “Envelope analysis of intense relativistic quasilaminar beams in rf photoinjectors: a theory of emittance compensation”, Phys. Rev. E 55, 6 (1977) 7565

Super Conducting Photoinjector



M. Ferrario et al., Meeting on " Superconducting RF Gun Simulations" EUROFEL Work Package 5, 2.-3. June 2005 at BESSY

A standing wave structure has focusing force in its nature. ⇨ Solenoids around the linacs can be omitted.

How to make a solenoid field near a super conducting gun?

For the emittance compensation, Bpeak~0.3 T is required.

Magnetic field trap.

⇩

- Put away from the cryomodule.
- Turn on only when SC state is formed.
- Magnetic RF focusing.

Focus by the Magnetic RF Field

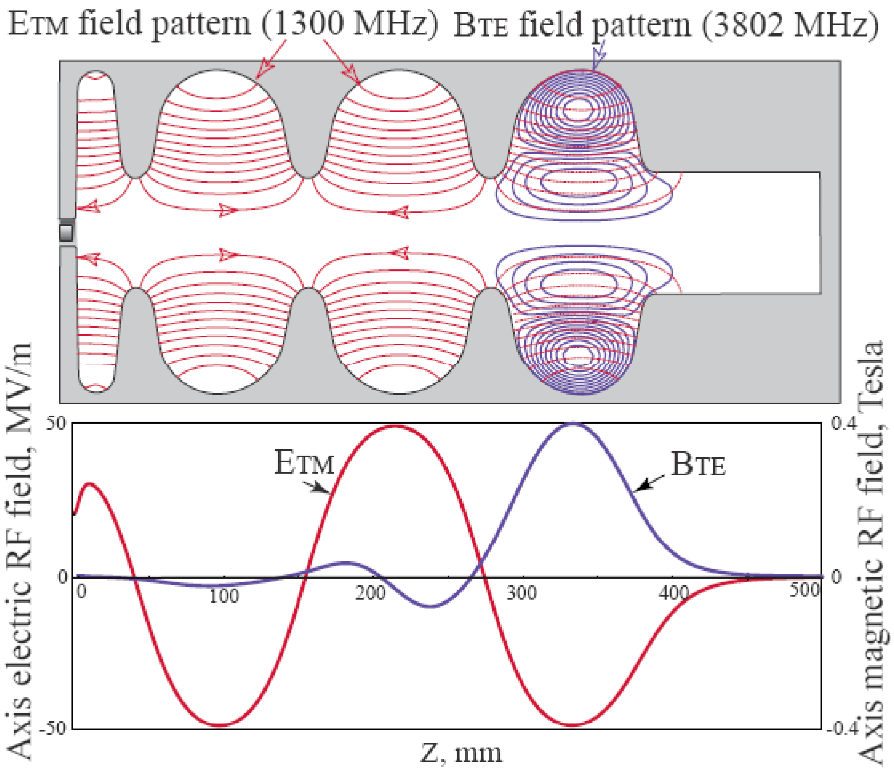


Figure 2: a) RF field pattern of E_{TM010} 1300 MHz and B_{TE021} 3802 MHz. b) Axis fields of the RF modes.(Color picture)

Other modes will not be excited.

RF which makes focusing mode will be provided separately.

⇩

Can control the field strength.

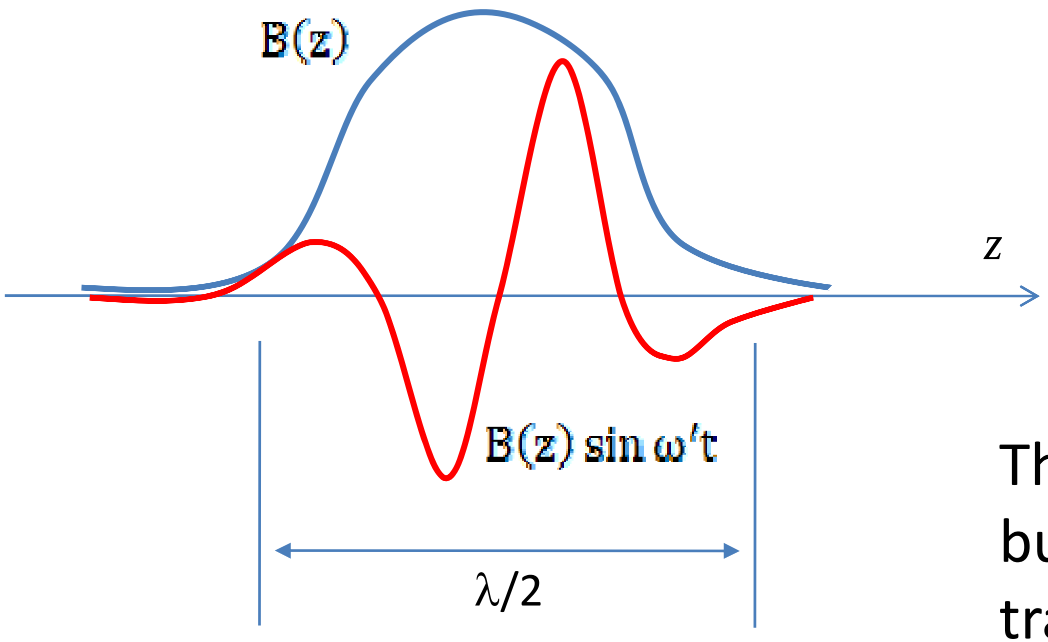
Peak field of TE021 locates different place where Peak of TM010 mode exists.

⇩

Peak magnetic field does not increase so much.

D. Janssen and V. Volkov, "Emittance Compensation in a Superconducting Photoelectron Gun by a Magnetic RF Field", EPA04, 330 (2004)

Frequency Mismatch



$$F_{sol} \propto |B_z|^2$$

The beam will be focused, but the emittance and the trajectory will fractuate.

Emittance Oscillation

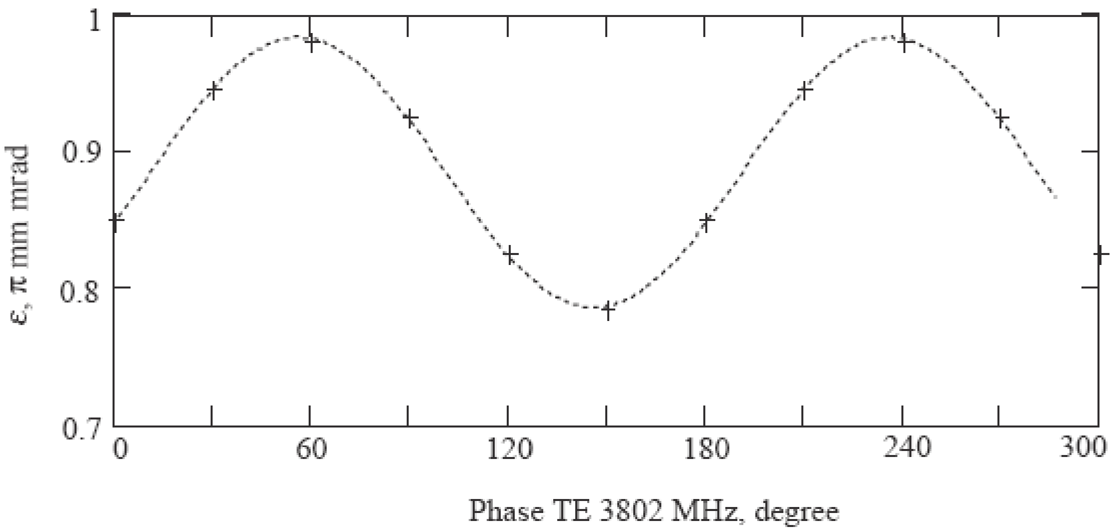


Figure 6: Transverse emittance variation vs. RF phase of TE_{021} mode (φ_{TE}), fitted by a sinus function.

D. Janssen and V. Volkov, “Emittance Compensation in a Superconducting Photoelectron Gun by a Magnetic RF Field”, EPA04, 330 (2004)

TE021 in the Second Cell

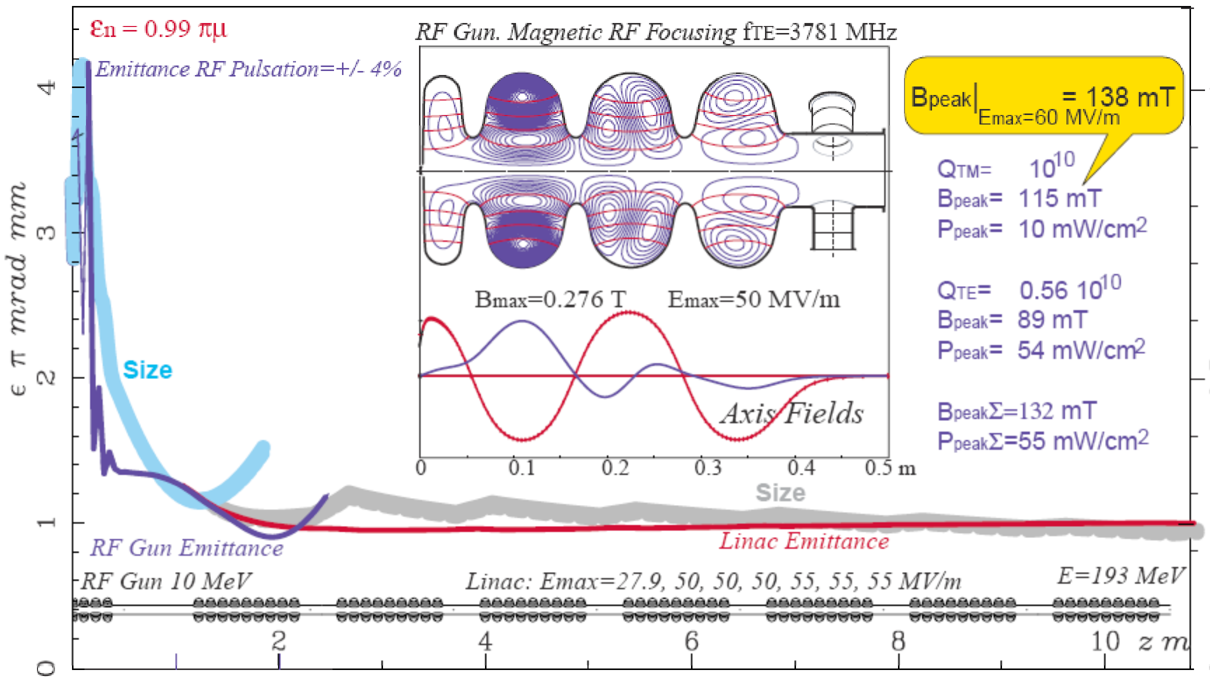


Figure 3: Transverse normalized emittance and rms beam size of bunches in a superconducting 3.5 cell photo cathode RF gun and a linac with TESLA cavities. Fig. 1 shows the RF focusing.

The RF gun beam is here matched to the linac, i.e. the beam waist and the location of the emittance minimum are expanded due to the acceleration up to the end of the linac.

05 Beam Dynamics and Electromagnetic Fields D02 Non-linear Dynamics - Resonances, Tracking, Higher Order

Volkov et al., “Superconducting RF gun cavities for large bunch charges”, PAC’07 (007) 24150

Beam energy is low. ⟹ Focusing field can be low.

Separated Cell

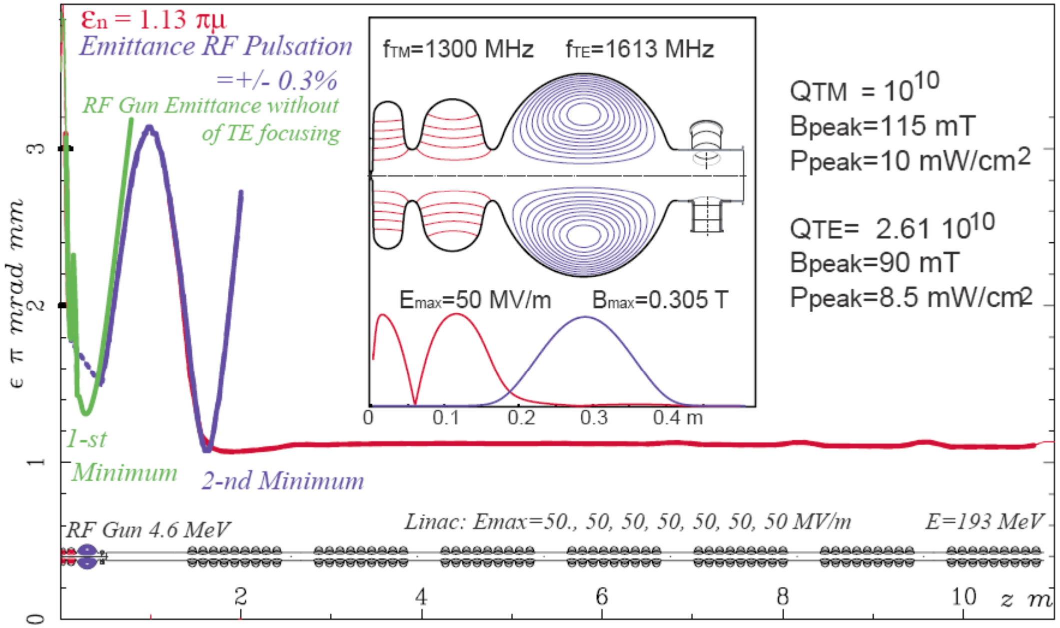


Figure 4: Transverse normalized emittance of bunches in a super-conducting 1.5 cell photo cathode RF gun and in a linac with TESLA cavities. The electric RF focusing is shown in fig. 1. The RF power feed for the TM mode has to be made from the side of the cathode assembly. The RF peak power density at the surface for the TE mode (P_{peak}) is close to the TM mode peak density.

$L' = \lambda'/2$

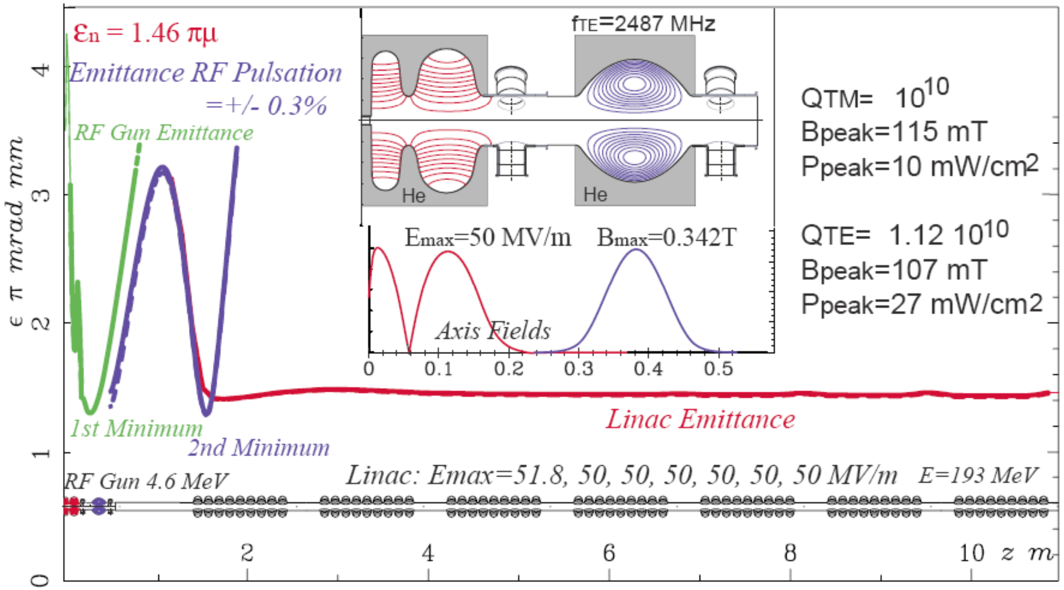


Figure 5: Transverse normalized emittance of bunches in a super-conducting 1.5 cell RF gun and in a linac with TESLA cavities.

In both cases with separate RF focusing two emittance minimums appear at the axis. The RF gun beams are matched with the linac, i.e. the RF gun beam waist and the location of the emittance minimum are expanded up to the end of the linac.

Volkov et al., “Superconducting RF gun cavities for large bunch charges”, PAC’07 (007) 24150

Summary

- The emittance compensation is required for obtaining low emittance beams in photoinjectors.

- In the normal conducting photoinjector, the solenoids right after the gun and around the first linac are used.

- In the superconducting photoinjector, the external magnetic field should be avoided.

- The magnetic RF focusing fed by an independent power source at different frequency may be a good solution.