Image Charge Effect on Emittance Reduction Phenomenon in Electron Gun

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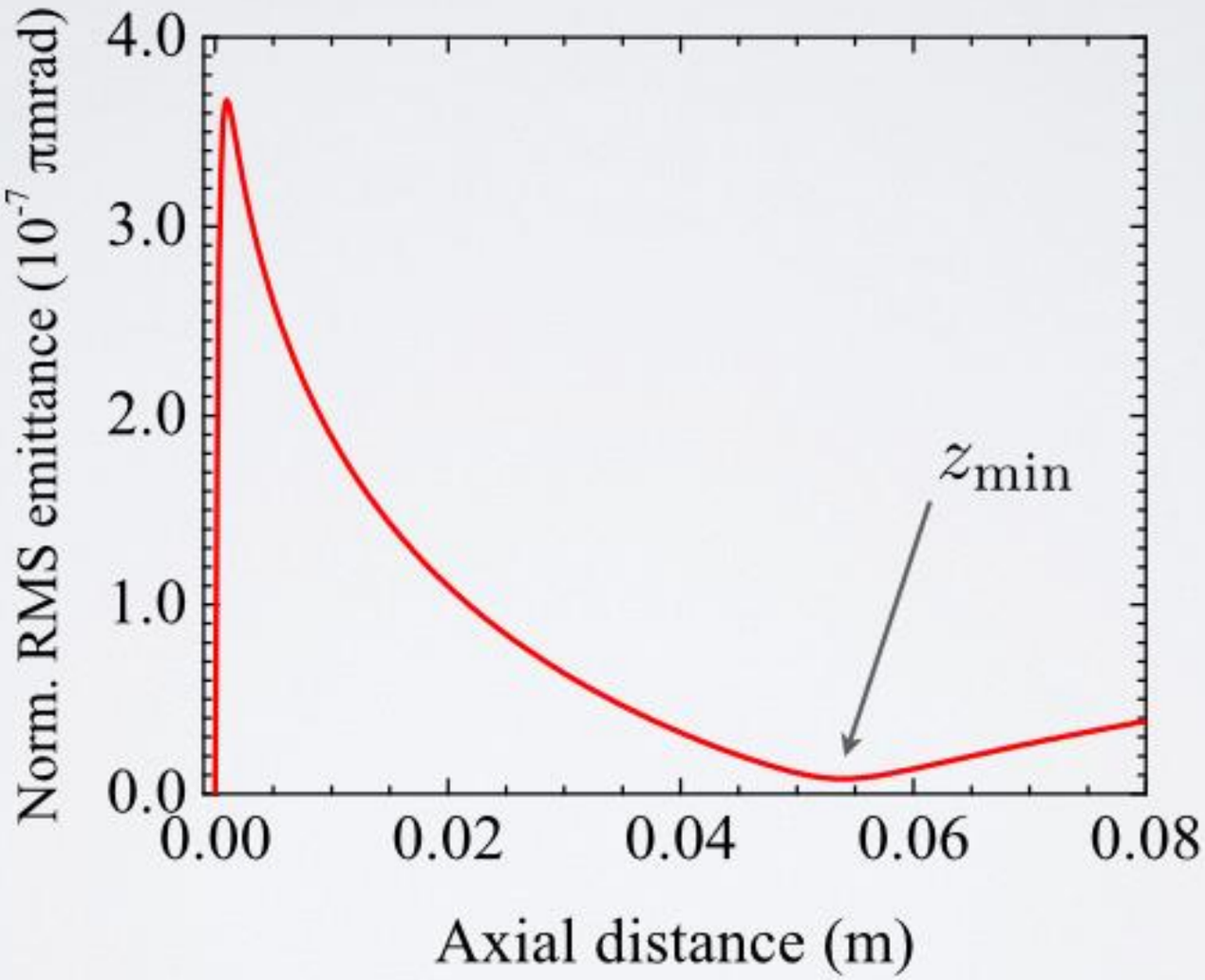
Outline

- Background
- Purpose
- Emittance reduction at vicinity of cathode
- Simulation results
- Summary

Emittance reduction phenomenon

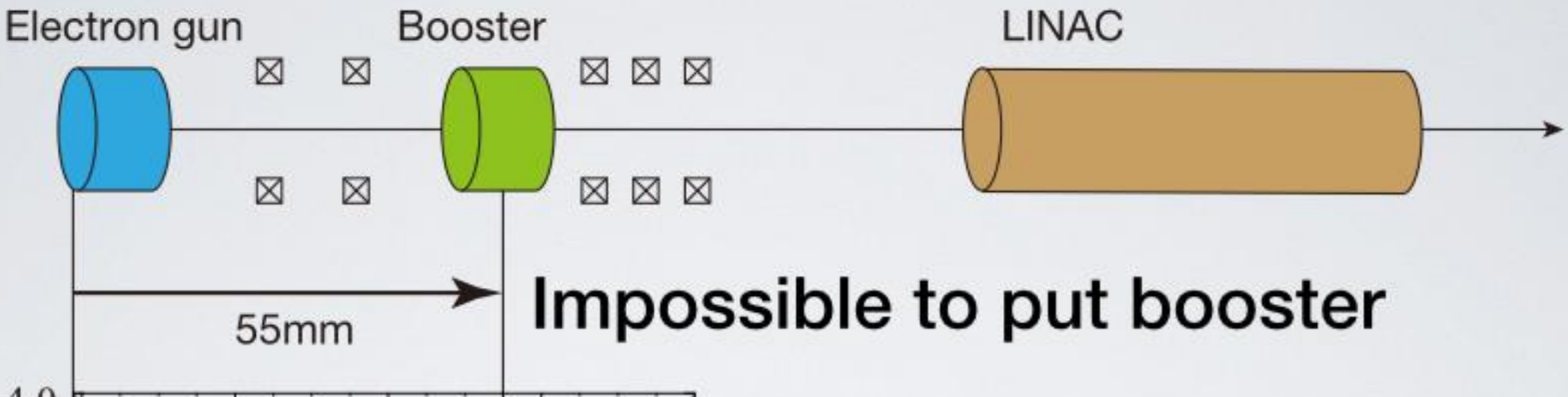
- Low emittance beam - required
- Emittance reduction phenomena was observed in simulation[1].

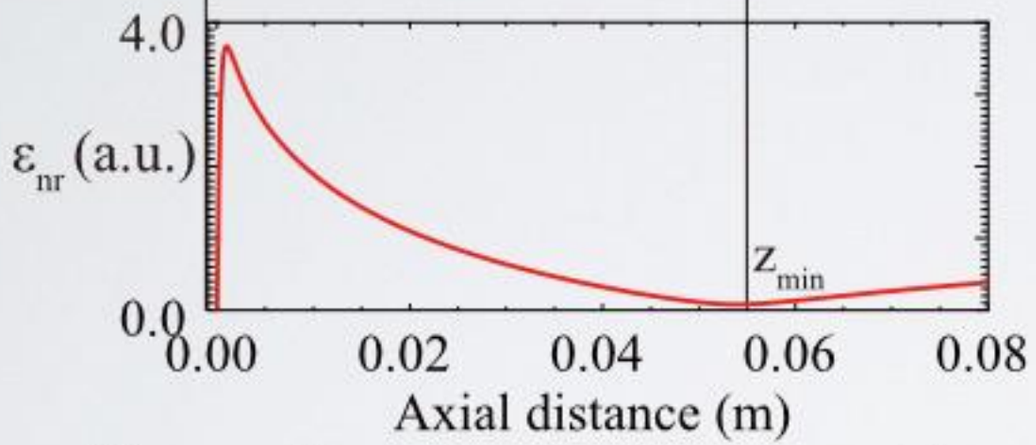


- Minimum emittance is much smaller

[1] K. Kasamsook,et al. ,Proceedings of FEL,THPPH042(2006).

Purpose





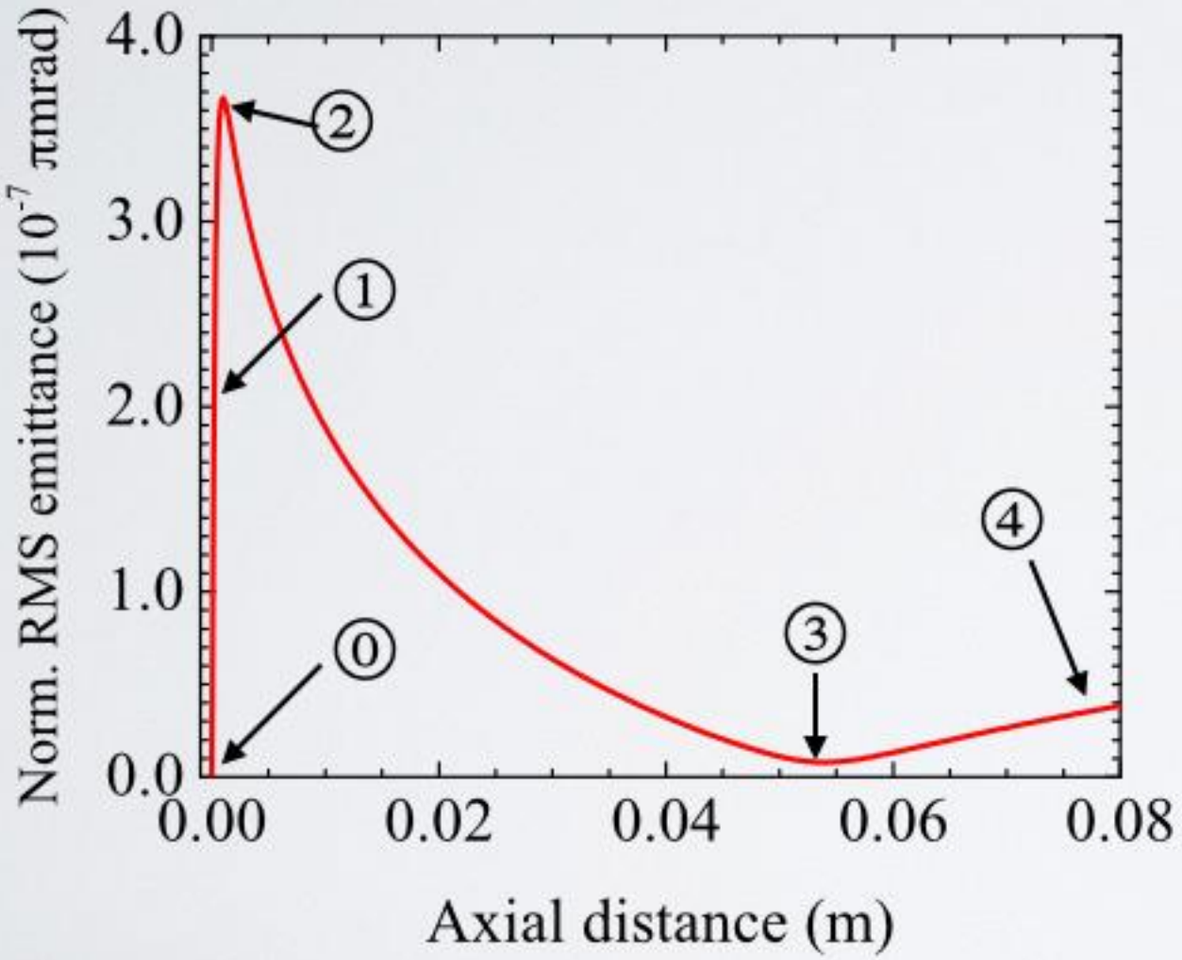
- Boosting technique makes emittance conserved.
- Position of minimum emittance, z_{min} ,depends on electron gun parameters such as initial current density, accelerating gradient. [2]
- If we could control z_{min}, we can take advantage of this phenomena

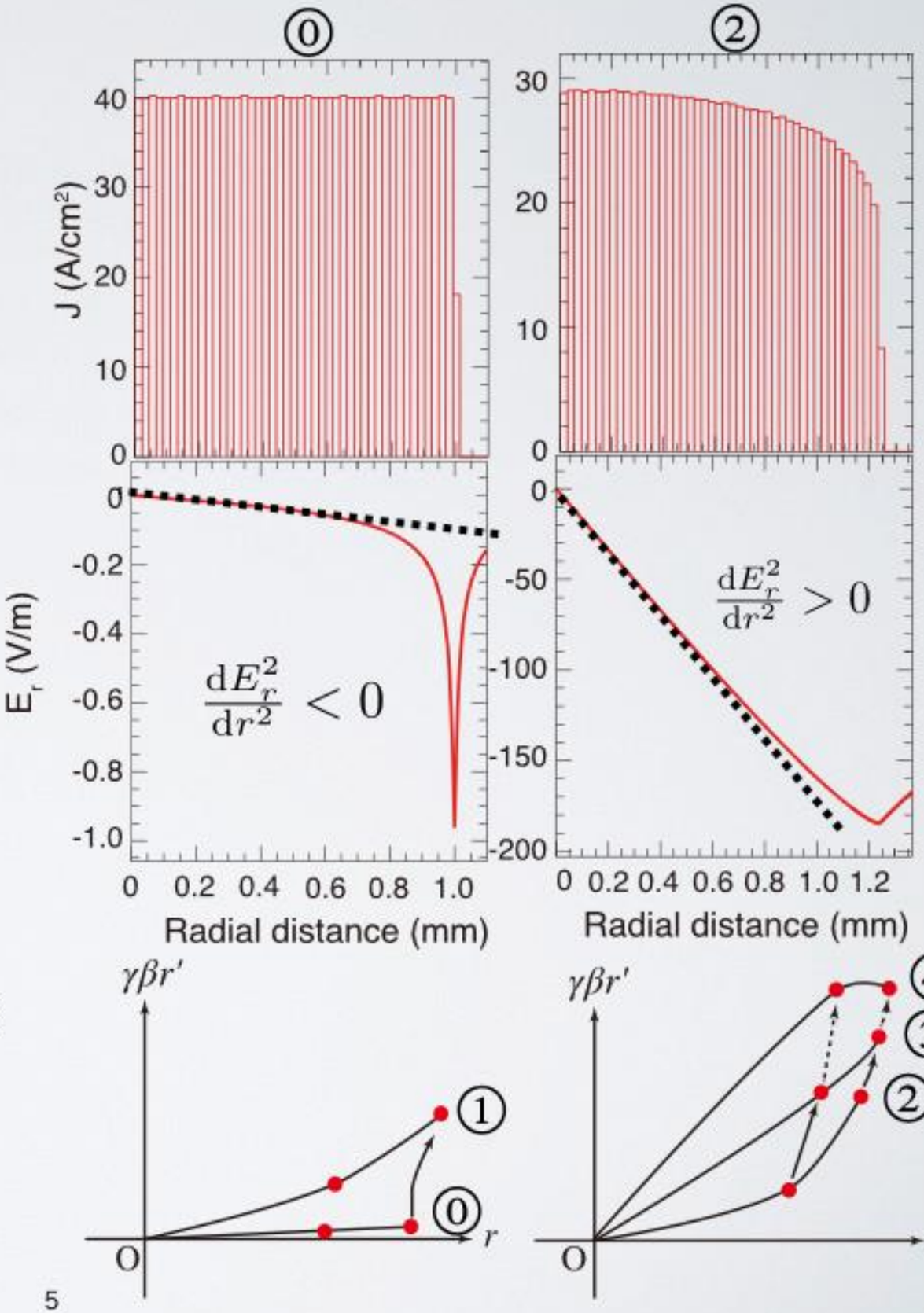
Clarify dependence of z_{min} on electron gun parameters

[2]A. Mizuno, et al. Nucl. Instr. and Methods. Phys. A 774,51-59 (2015)

Mechanism of emittance reduction

- Principle of emittance reduction has already been described[2].





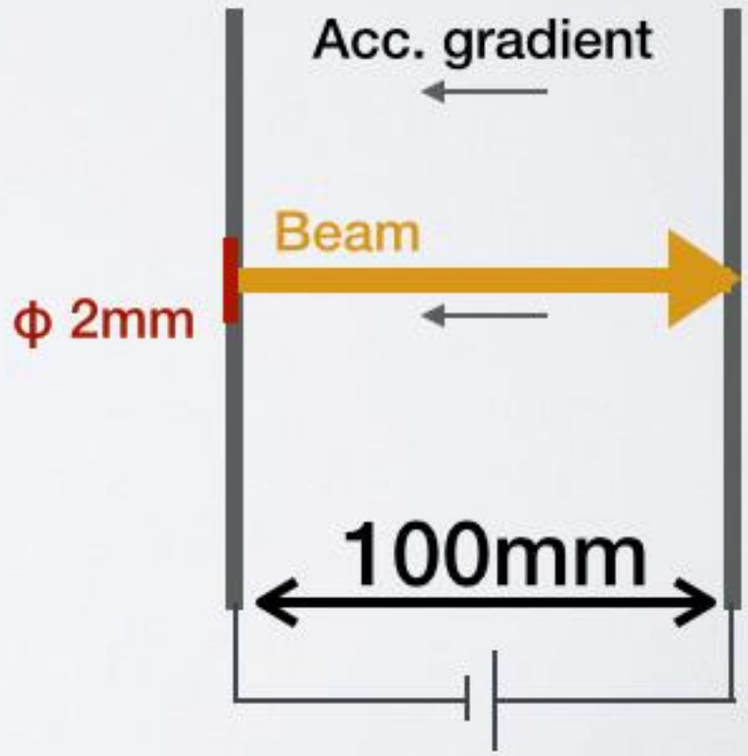
[2]A. Mizuno, et al. Nucl. Instr. and Methods. Phys. A 774,51-59 (2015)

Method of numerical simulation

- We used KUAD2 code[3]
  - ✓ 2D axial-symmetric
  - ✓ Time-independent
- Numerical simulation with following assumption
  - ✓ DC continuous beam
  - ✓ Thermal emittance is negligible.
  - ✓ Uniform current density profile
  - ✓ Homogeneous accelerating gradient
  - ✓ No external magnetic field
  - ✓ With space charge effect
- Normalized RMS r-emittance

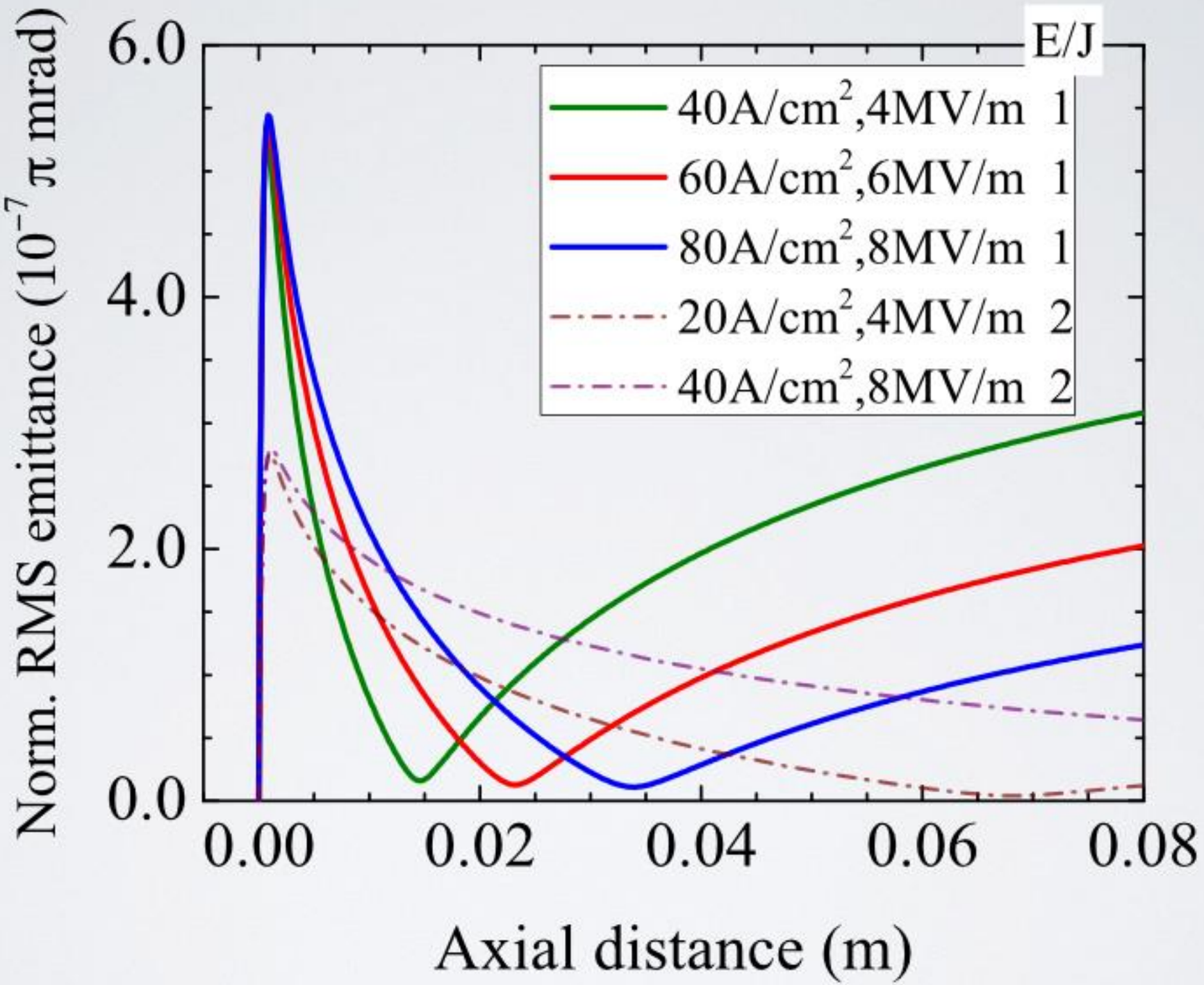
$$\varepsilon_{\mathrm{rms},r,n} = \sqrt{\langle r^2 \rangle \langle (\gamma\beta r')^2 \rangle - \langle r\gamma\beta r' \rangle^2}$$

- We changed accelerating gradient and initial current density.



[3] K. Masuda: Ph.D Thesis, Dept. of Engineering, Kyoto Univ. (1998)

Emittance evolution



- Same maximum emittance but different emittance evolution

Simulation results of z_{min}[mm] in ideal DC gun

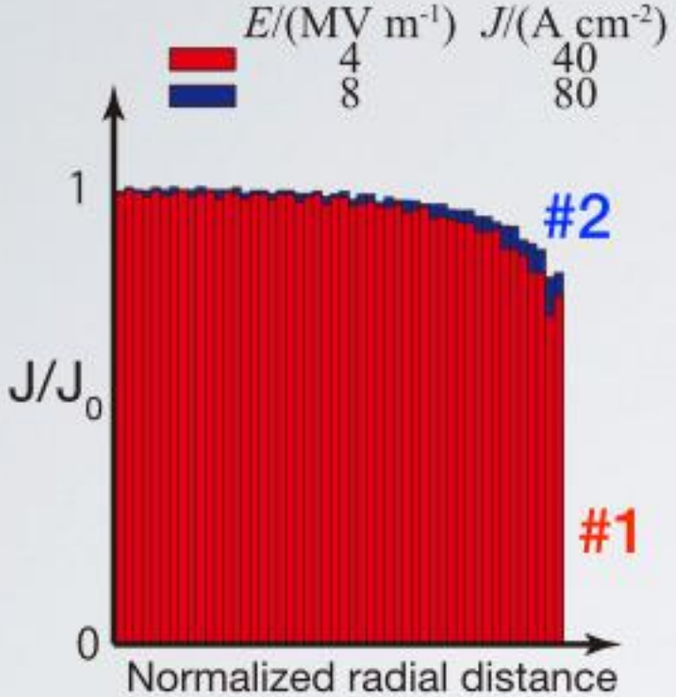
J \ E	2	4	6	8	10	60
20		66	263	449	631	
40		14	53	209	362	
60			22	64	210	Increase
80			12	32	82	
100	Space charge Limit			19	43	

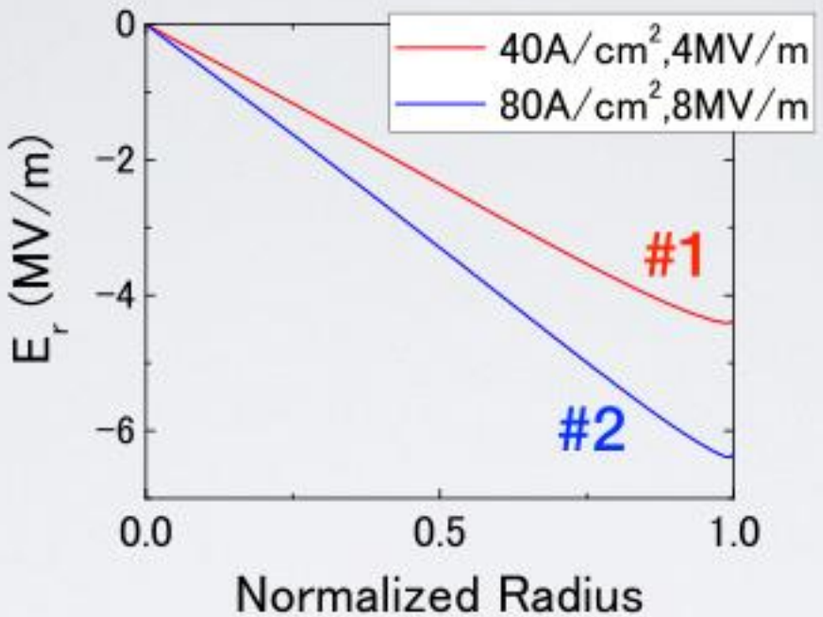
MV m^{-1}

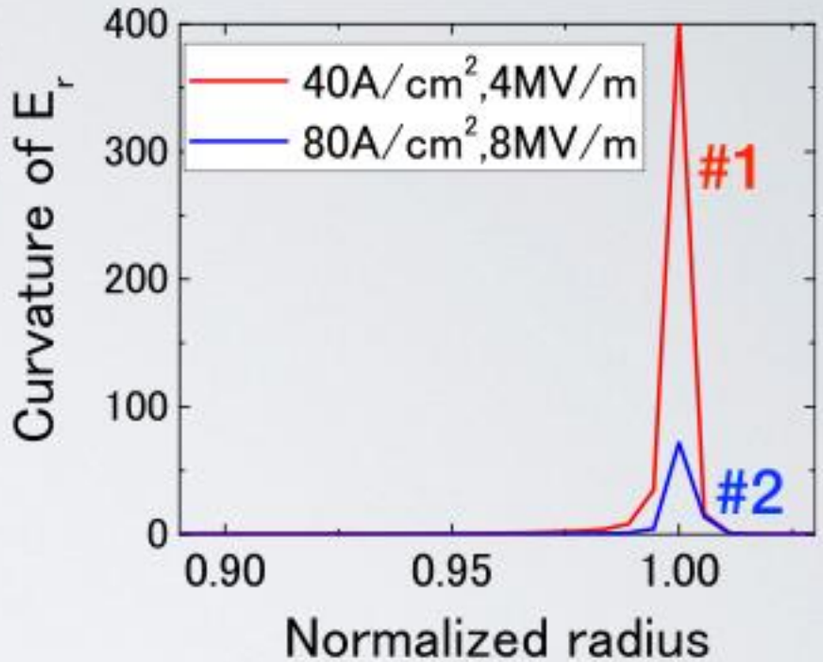
A cm^{-2}

< 0.1πmm-mrad

What determines z_{min}?







	E(MV/m)	J(A/cm²)	r(mm) at z=1mm	z_{min}
#1	4	40	1.087	14mm
#2	8	80	1.055	32mm

- #1 of current density profile is less uniform than #2 of that.
- Er induced by charge profile compensate phase-space curvature.
- If curvature of Er is greater, driving force for compensation also increase.

Less nonlinear J ⟶ Small driving force ⟶ more distant z_{min}

Normalized perveance

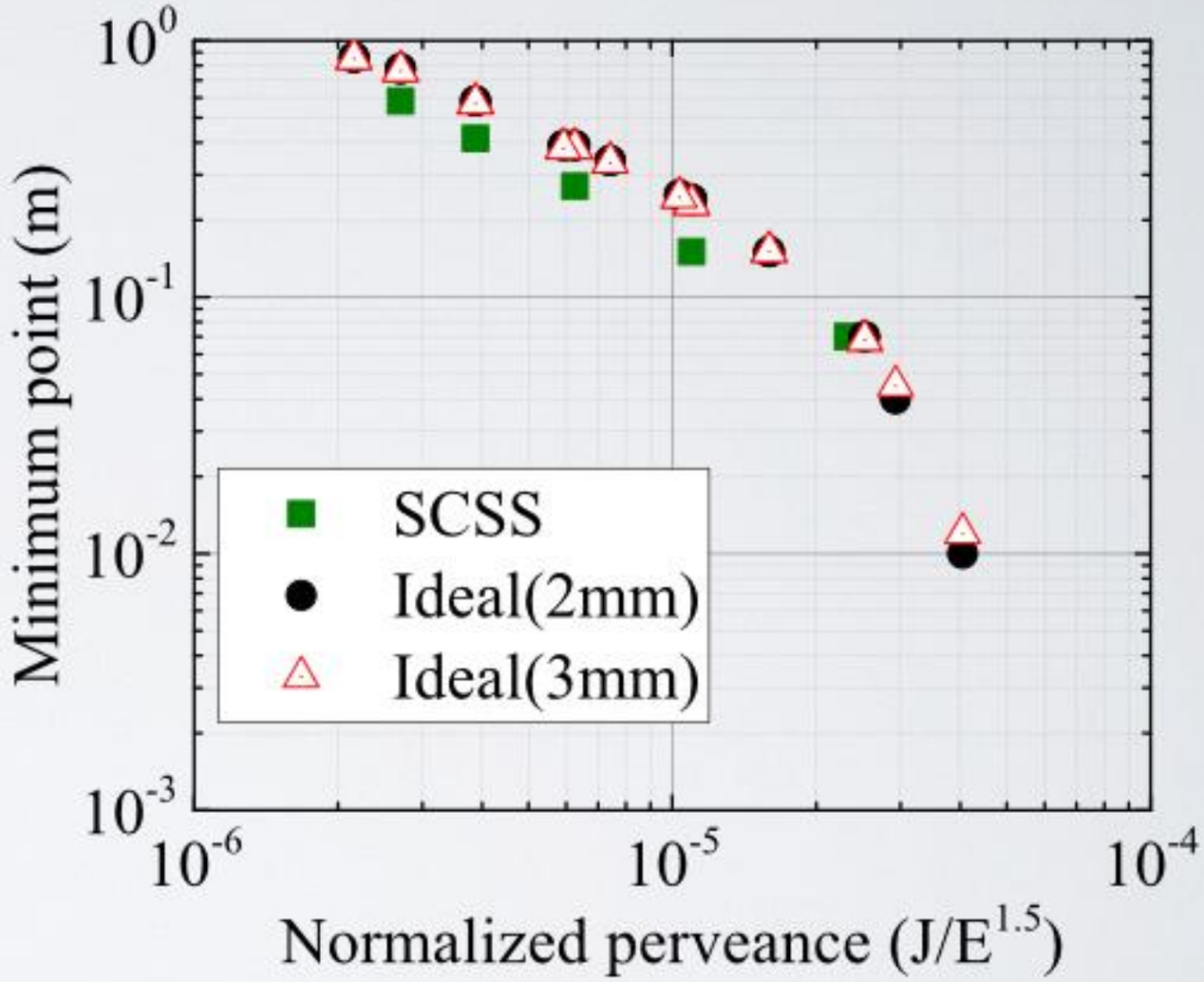
- Nonlinearity of current density ← space charge effect.
- Perveance is an indicator that shows space charge limit.

- We define normalized perveance

$$P_n = \frac{J_{\mathrm{init}}}{(E_{z,\mathrm{z}=0})^{\frac{3}{2}}}$$

- We also did simulation using SCSS gun geometry-SACLA

- z_{min} depends on normalized perveance



- This correlation is also verified by simulation using a real SCSS gun case.

Summary

- We studied emittance evolution by numerical simulation.
- Normalized perveance is an important factor for z_{min}
- Minimum emittance position depends on quantity of space charge effect at cathode
- Small difference of current density profile makes large difference of z_{min}

Acknowledgment

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