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KPS

Study on Emittance Growth Caused by Nonuniform Transverse Laser Distribution in Photo-injector

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Abstract

- High qualitative electron beams are essential to the PAL-XFEL Project. In order to have high-brightness electron beams, we need beams with high peak current and low emittance. Emittance growth, therefore, is one of the important issues in beam physics. The emittance from an RF photo-injector is influenced by the transverse laser distribution. When a laser is injected onto a photocathode, a nonuniform laser makes a nonuniform electron beam distribution that affects emittance growth. The object of this study is to investigate a correlation between emittance growth and nonuniformity of transverse laser distribution using the PARMELA simulation code. Consequent emittance growth was observed as the laser distribution deviated strongly from a uniform distribution. The transverse emittance depends on the bunch charge according to nonuniformity of beam distribution. This study provides a valuable guide to estimate the effect of laser nonuniformity in this critical range of very high-brightness electron beams by a RF photocathode-injector.

Introduction

- **Object** : To produce a high-brightness electron beam from a photocathode RF gun

$$B = \frac{2I}{\varepsilon_{n,x}\varepsilon_{n,y}}$$

B : brightness

I : current

$\varepsilon_{n,x}$: normalized x-emittance

$\varepsilon_{n,y}$: normalized y-emittance

Low-emittance & High current electron gun

↓

Emittance Compensation
&
A qualitative limit

↓

Laser profile control capability

Introduction (cont'd)

- For the beam production

Laser profile control capability

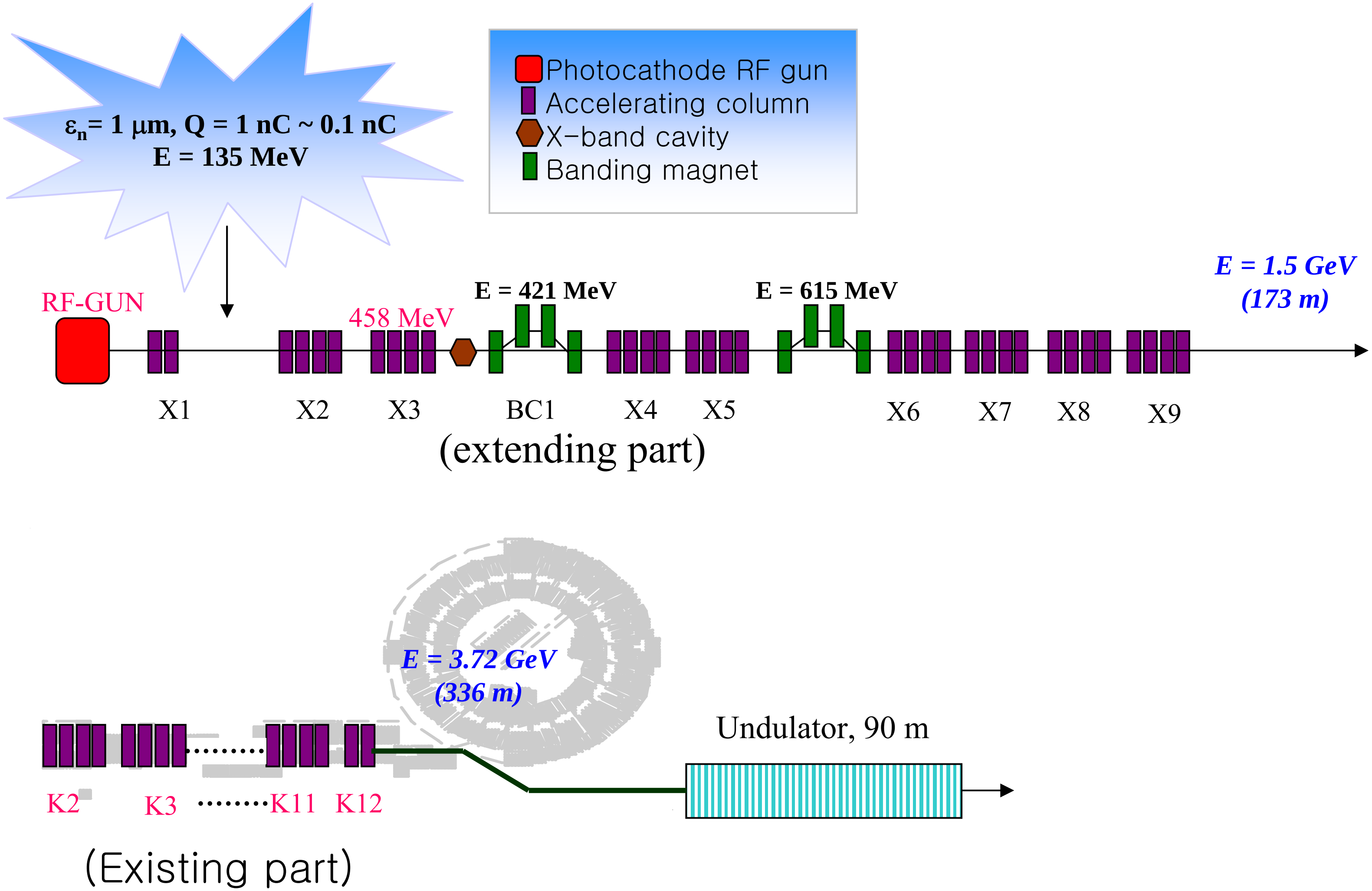
: We require both longitudinal and transverse laser distributions to be uniform.

Question

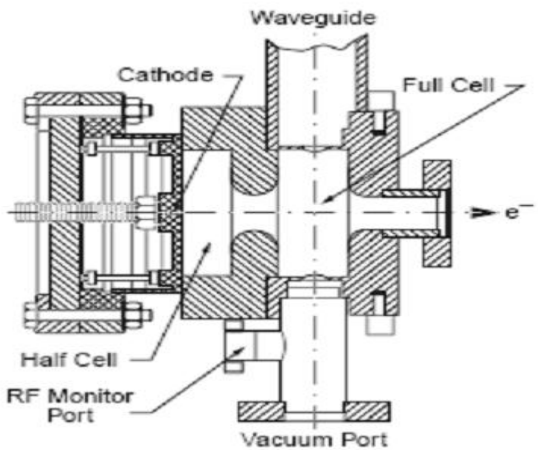
What is the beam performance
when the transverse laser beam profiles are distorted?

Emittance vs. non-uniform laser

PAL XFEL Project

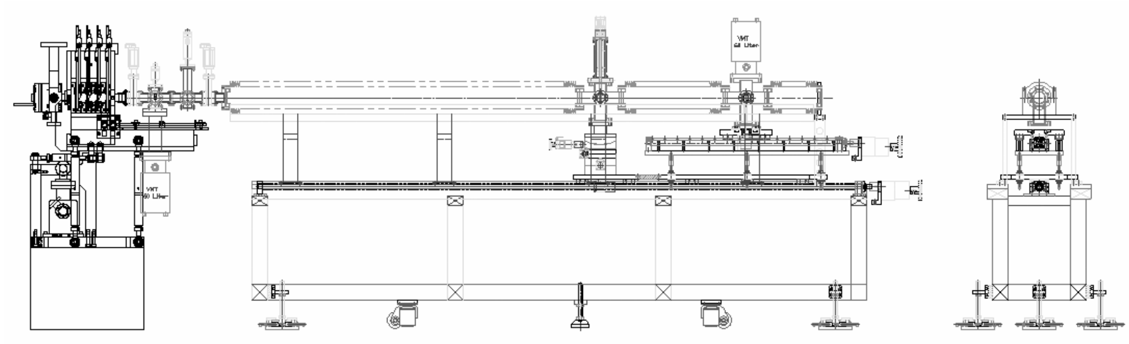


Requirement of Injector



1.6cell PC RF-gun
BNL-IV type

Beam Energy	135MeV
Charge	1 nC
Repetition Rate	30Hz
ϵ_n (Normalized RMS Emittance)	< 1 ~ 1.2 m
Energy Spread (rms)	< 0.1 %



The cross section of PC RF-gun

Theory - Emittance with non-uniform laser

In the equilibrium, electron beam → "MB" (uniform)

Any deviation → energy difference (nonstationary vs stationary beam) → ε growth

$$\frac{\varepsilon_{nf}}{\varepsilon_{ni}} = \sqrt{1 + \frac{N r_c \tilde{x}}{15\sqrt{5}\gamma_0 \varepsilon_{ni}^2} \frac{U}{W_0}}$$

ε_{ni} : initial normalized ε

ε_{nf} : final normalized ε

N : particle number in one bunch

r_c : classical electron radius

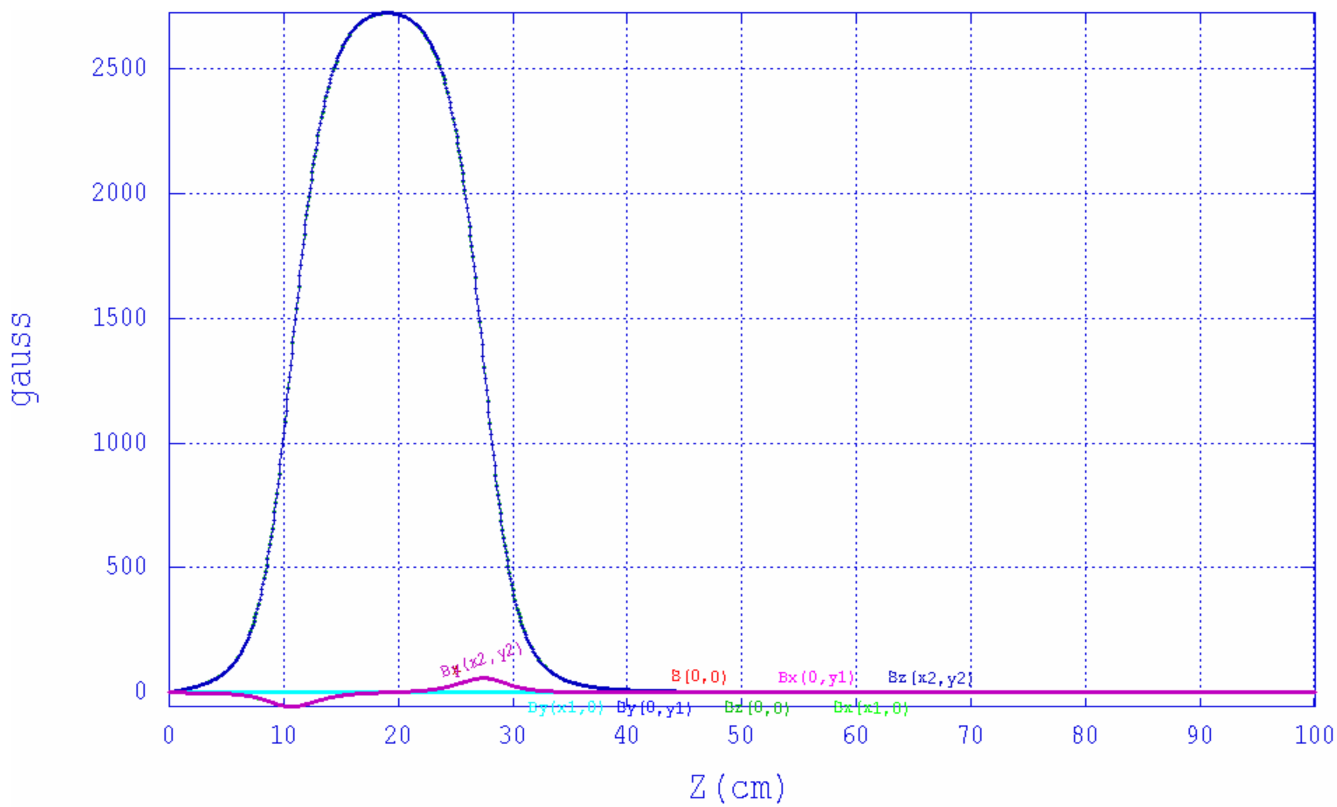
$\tilde{x}$: rms transverse dimension

$\frac{U}{W_0}$: normalized field energy difference per unit length

between nonuniform and uniform initial beam

Simulation

- Electron linac design code : PARMELA
- Using background magnetic fields from program POISSON



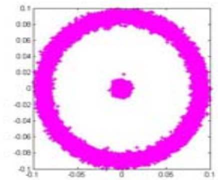
Longitudinal B-field (z-direction)

Transverse Input Beam

- Cylindrically symmetric distribution

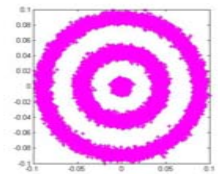
uniformity

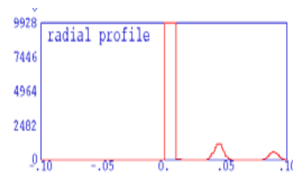
Cylindrically
Symmetrical Model I
(SM I)



39 %

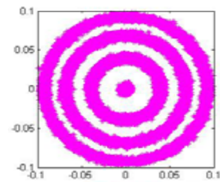
Cylindrically
Symmetrical Model II
(SM II)

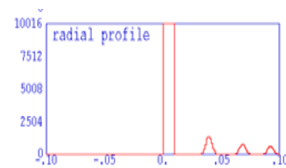




54 %

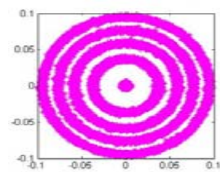
Cylindrically
Symmetrical Model III
(SM III)

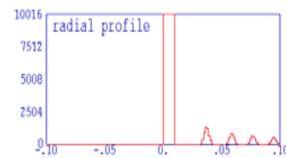




67 %

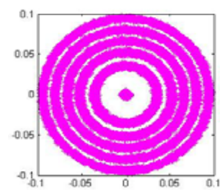
Cylindrically
Symmetrical Model IV
(SM IV)

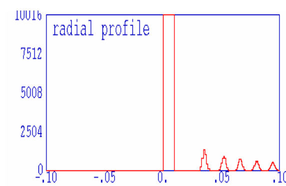




74 %

Cylindrically
Symmetrical Model IV
(SM IV)





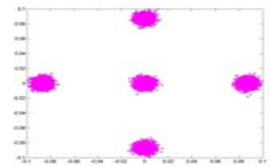
90 %

Transverse Input Beam

- Non-cylindrically symmetric distribution

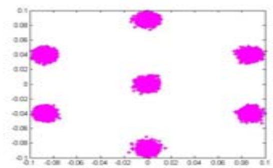
uniformity

Noncylindrically Symmetrical model I (NSM I)



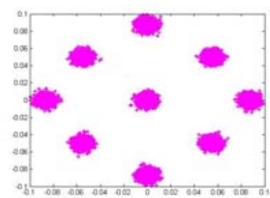
9 %

Noncylindrically Symmetrical model II (NSM II)



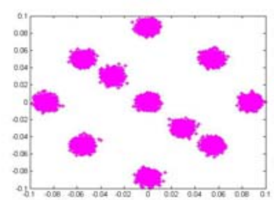
12 %

Noncylindrically Symmetrical model III (NSM III)



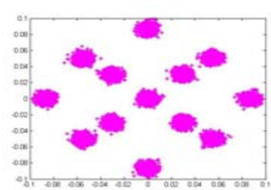
16 %

Noncylindrically Symmetrical model IV (NSM IV)



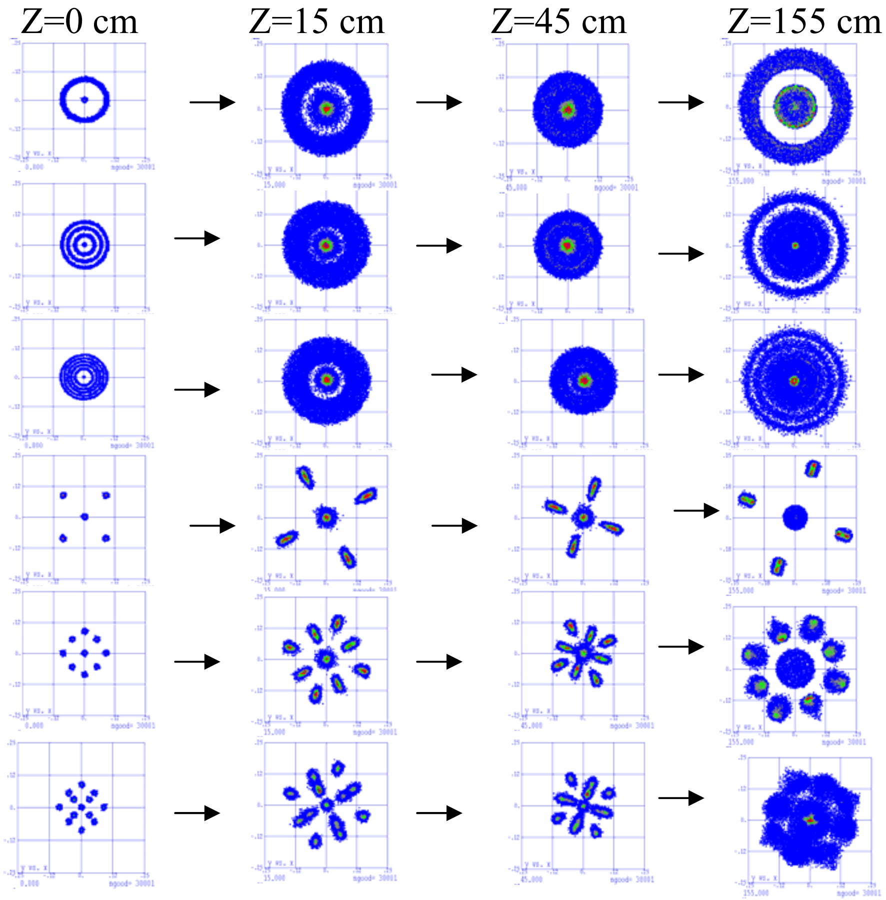
19 %

Noncylindrically Symmetrical model V (NSM V)



22 %

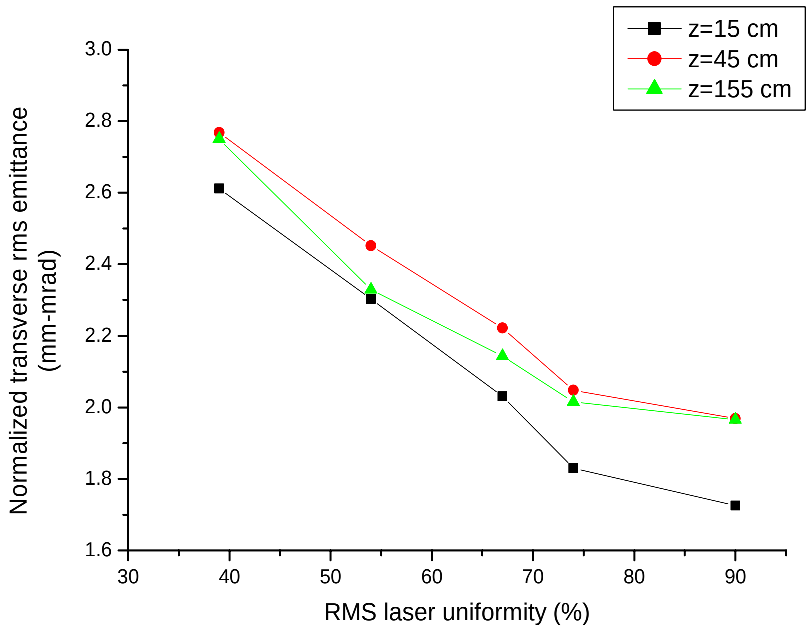
Simulation Results (1)

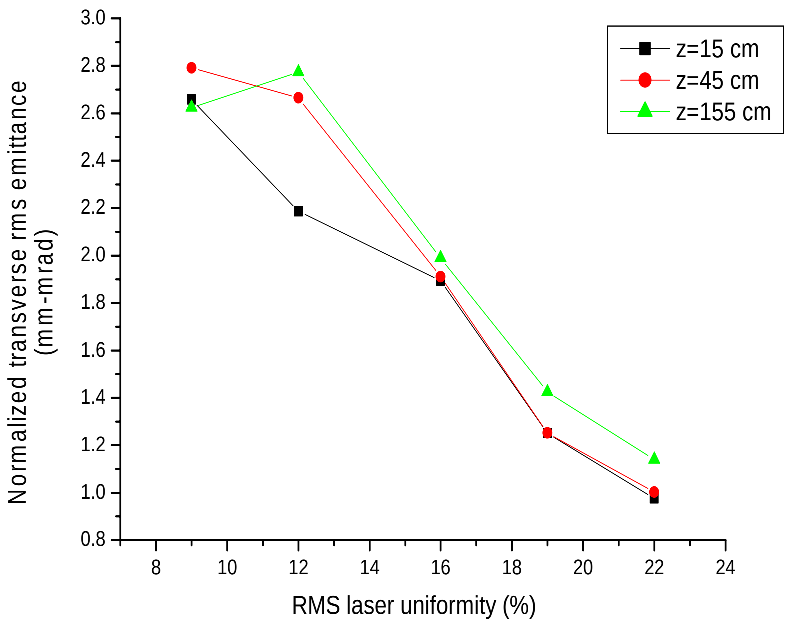


Simulation plots of the beam profiles at four different locations along the transport channel for the symmetrical and nonsymmetrical models.

Simulation Results (2)

- Emittance as a function of laser rms uniformity



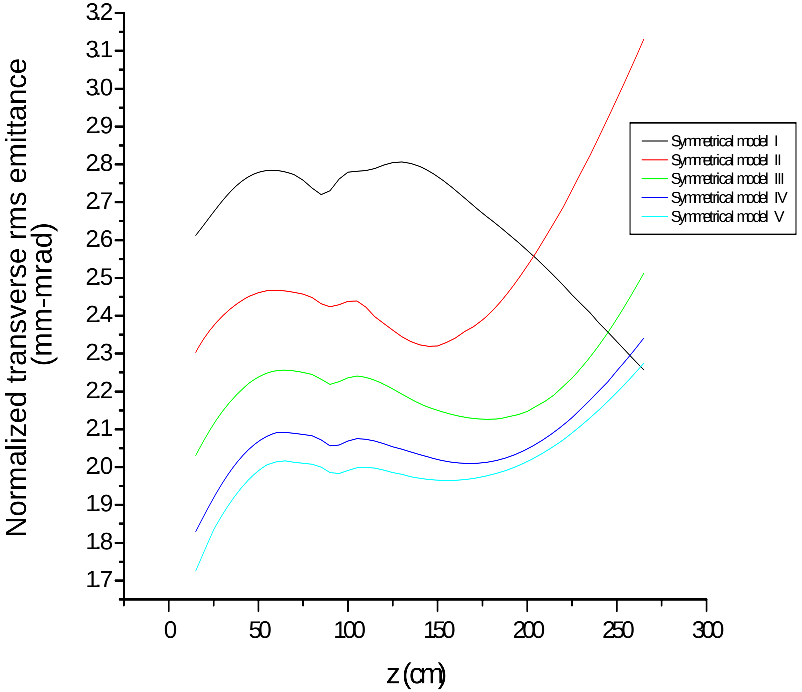


Emittance as a function of laser rms uniformity from SM I ~ V when the bunch charge is 0.1 nC

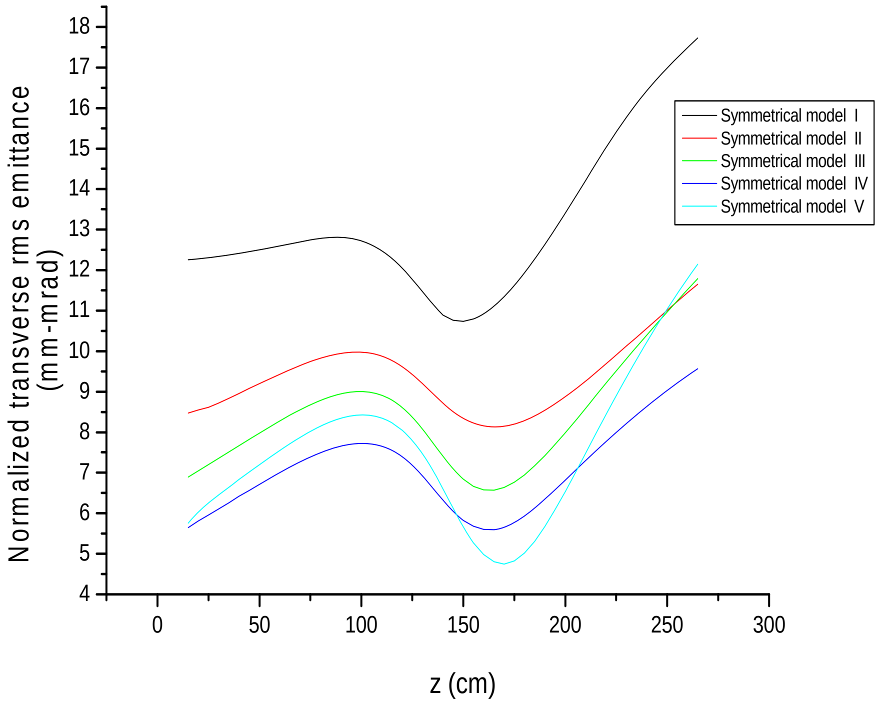
Emittance as a function of laser rms uniformity from NSM I ~ V when the bunch charge is 0.1 nC

Simulation Results (3)

- Beam emittance versus z. Each curve is for a different symmetrical distribution.



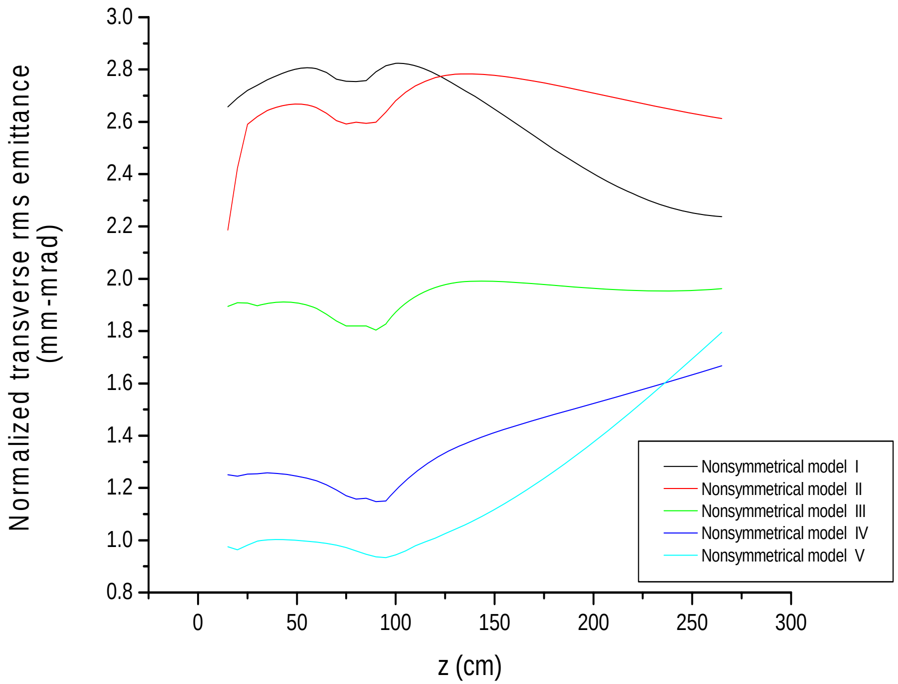
0.1 nC



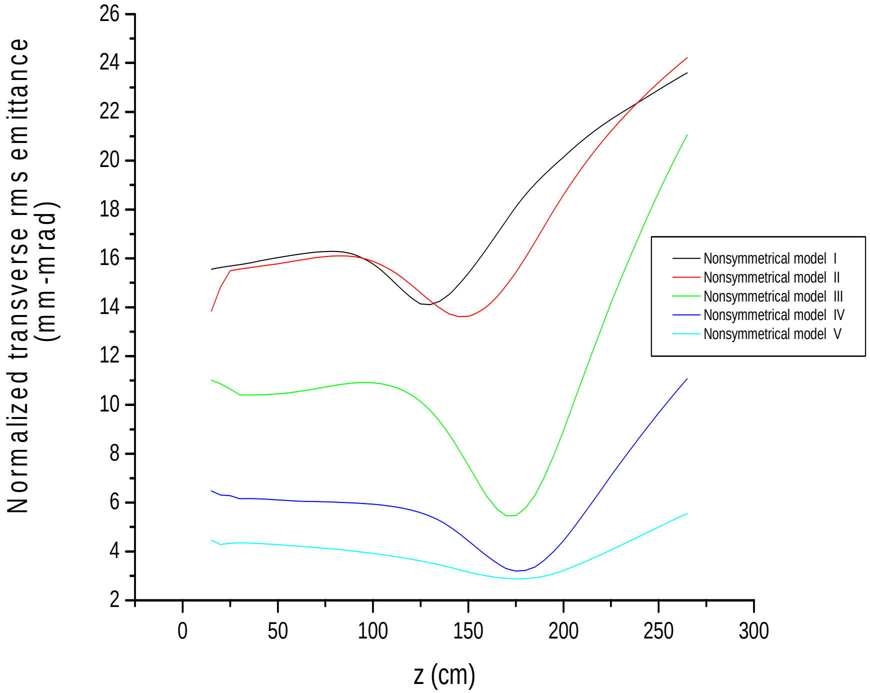
1 nC

Simulation Results (3)

- Beam emittance versus z. Each curve is for a different nonsymmetrical distribution.



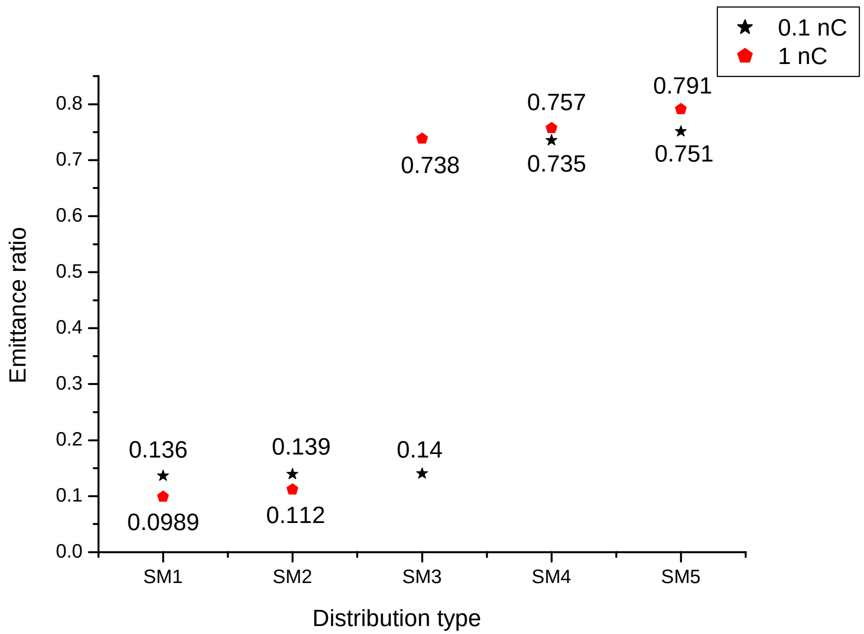
0.1 nC



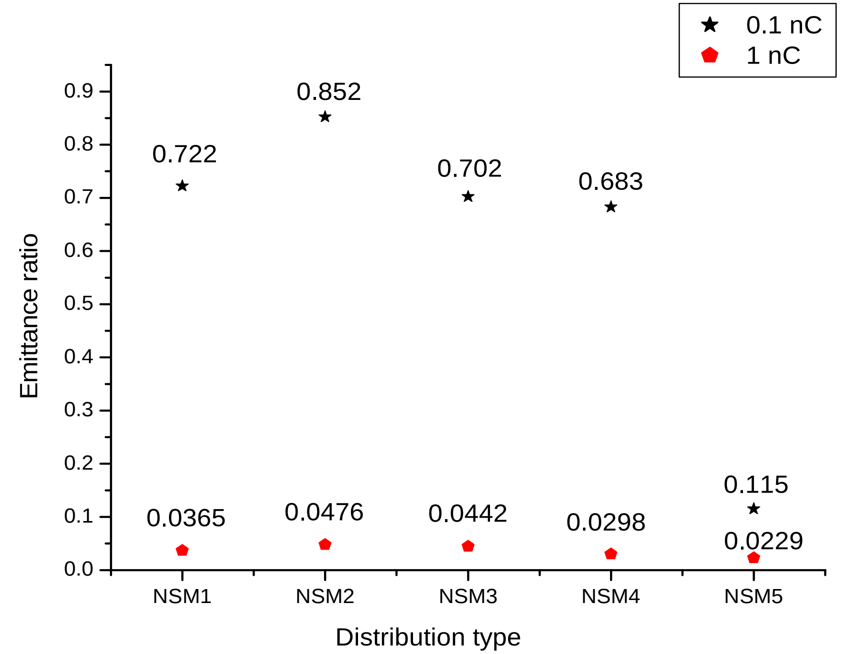
1 nC

Analytic approach

- Emittance ratio



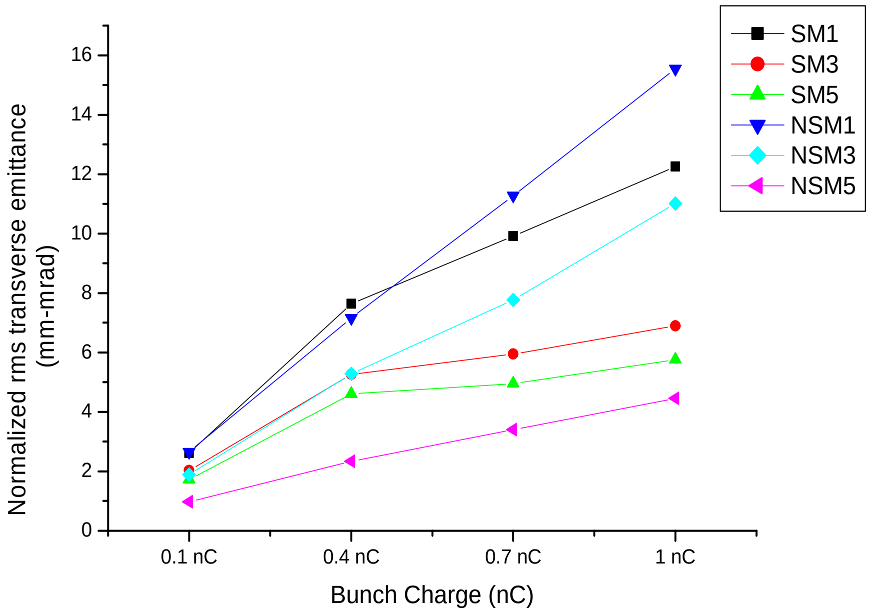
Emittance ratio versus
<u>symmetrical</u> transverse distribution type
from z=0 cm to z=15 cm.
The bunch charge is 0.1nC or 1nC



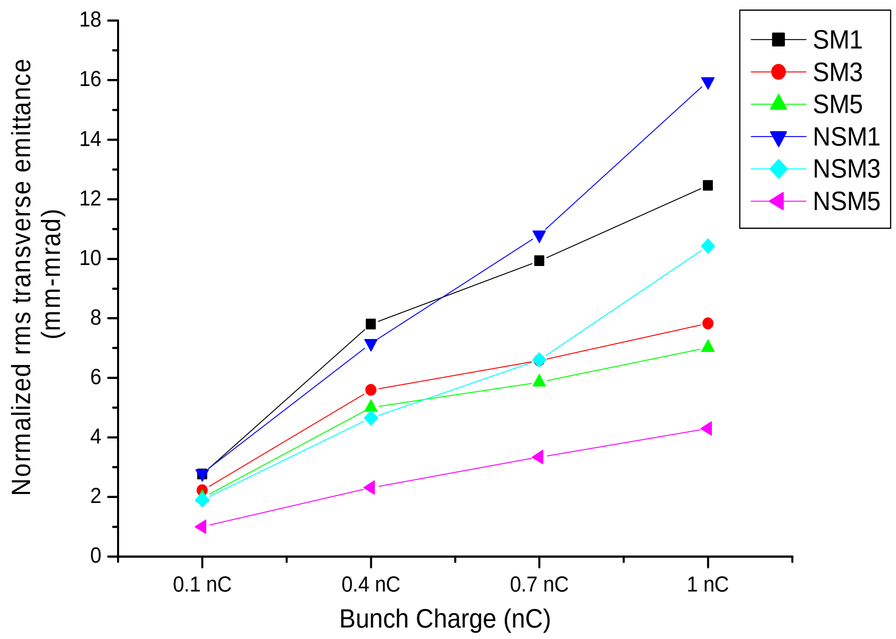
Emittance ratio versus
<u>nonsymmetrical</u> transverse distribution type
from z=0 cm to z=15 cm.
The bunch charge is 0.1nC or 1nC

Analytic approach

- Emittance as function of bunch charge



Emittance as function of bunch charge at z = 15 cm



Emittance as function of bunch charge at z = 45 cm

Conclusion

- The emittance growth is really close to the laser distribution. The emittance of symmetrical model V (SM V) is 1.725μm, the SM IV is 1.83μm, NSM III is 1.894μm, NSM IV is 1.251μm and NSM V is 0.975μm at z =155 cm. These values approach PAL-XFEL emittance expectation 1μm.

- We simulate the input distribution effect of "initial" emittance change. The emittance ratio is considered at strong scheff (space charge effect) region (z =0 cm ~15 cm)

- In both SM and NSM transverse input beams, the dependence of the emittance on the bunch charge is similar, linear with charge.

- This results can provide a valuable guide to the estimating of the effect of laser non-uniformity in this critical region of very-high brightness electron beams.