Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

BIW10 14th Beam Instrumentation Workshop May 2-6, 2010

東北大学

Cherenkov Ring to Observe Longitudinal Phase Space of a Low Energy Electron Beam Extracted from RF Gun

May 4, 2010
Beam Instrumentation Workshop 2010 @ Santa-Fe, New Mexico

Hiroyuki Hama*

Beam Physics and Accelerator Science Group
Research Center for Electron Photon Science (old Laboratory of Nuclear Science)
Tohoku University
1-2-1 Mikamine, Taihaku-ku, Sendai 982-0826, Japan
-
*hama@lns.tohoku.ac.jp

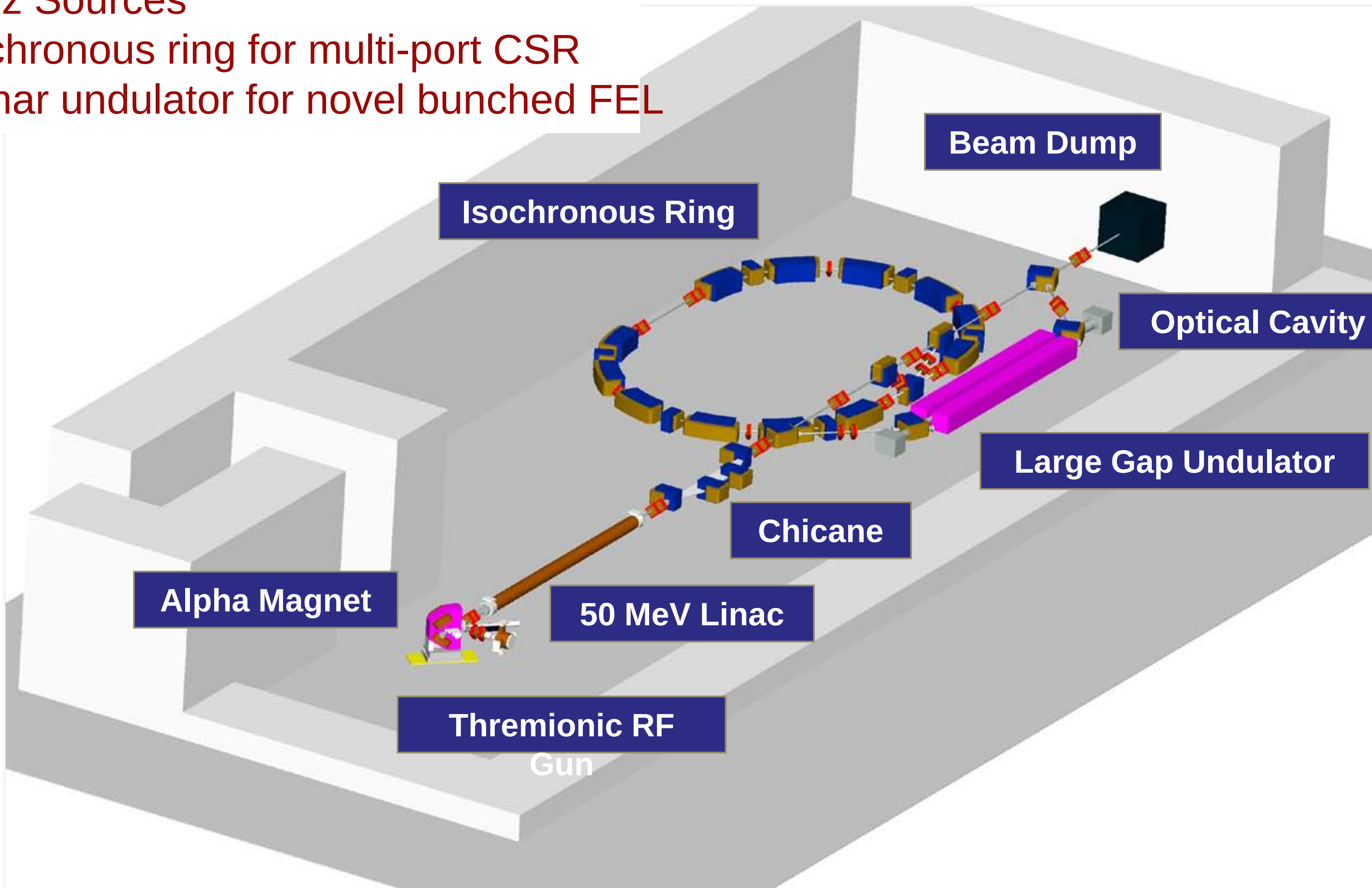
Talk Outline

1. Introduction
   - Thermionic RF Gun for Femtosecond Beam in t-ACTS @ Tohoku Univ.
   - Space Charge Effect for the Longitudinal Electron Distribution
2. Cherenkov Ring, Properties
   - Cherenkov Angle and Electron Energy
3. Linear Focal Cherenkov Ring Camera
   - Turtle-Back Mirror and Aspherical Condenser Lenses
   - Ray-trace and Discussions
4. Summary and Prospect

Introduction

t-ACTS: Test Accelerator-based Coherent THz Source

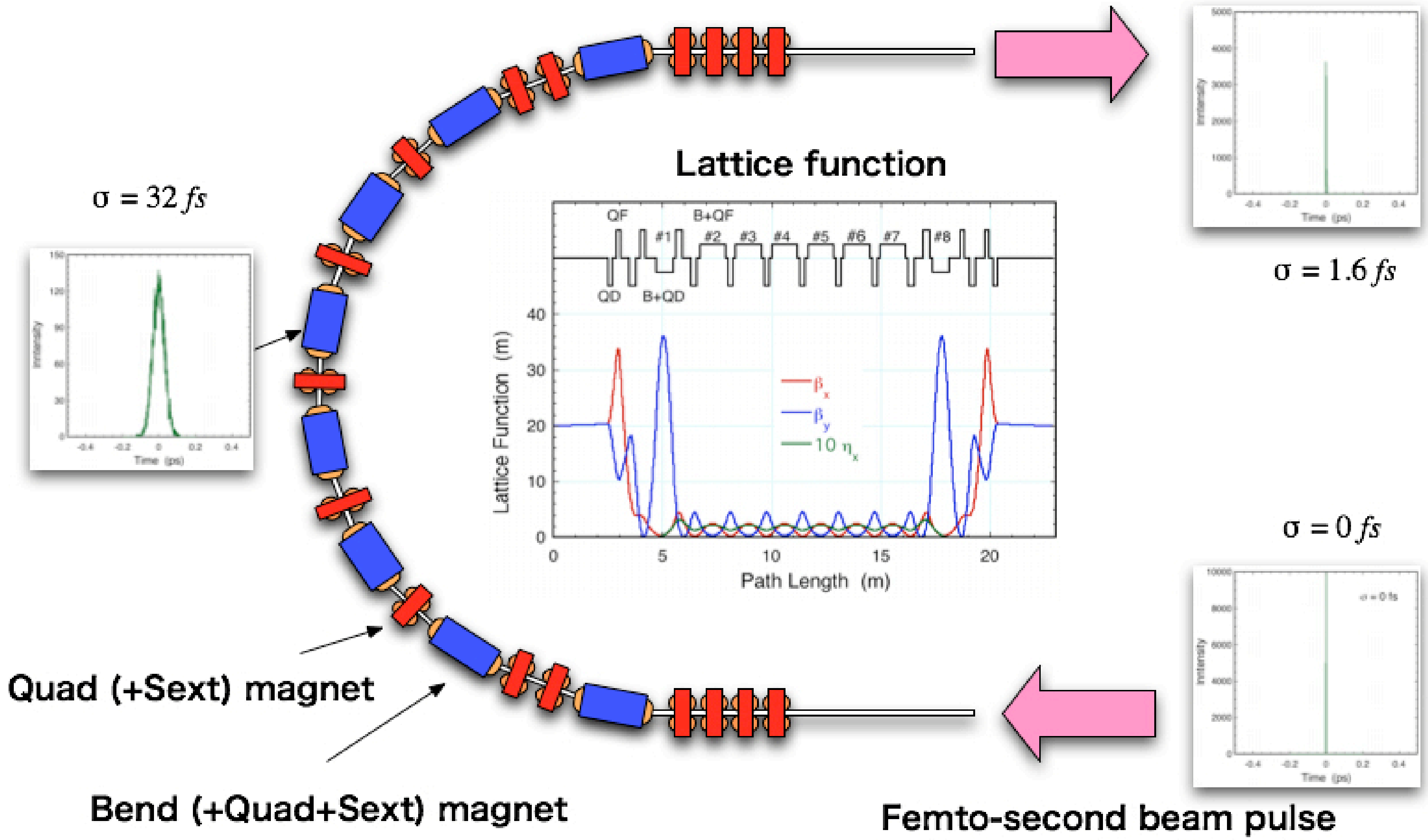
Main THz Sources
1) Isochronous ring for multi-port CSR
2) Planar undulator for novel bunched FEL



Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Complete Isochronous Ring, Source of THz-CSR

Taking the energy dispersion and the phase advance of betatron motion into account, isochronous transportation can be achieved for preservation of the short pulse.

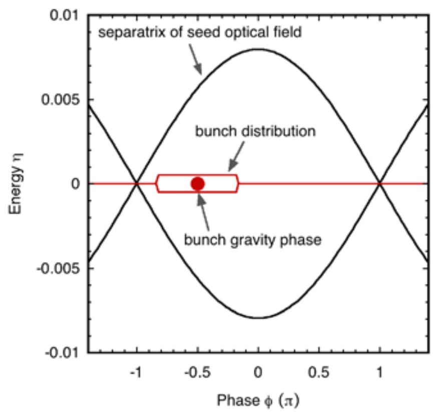


$$E = 200\,MeV, \varepsilon = 5\,nmrad(\varepsilon_n = 2\,mmmrad), \rho = 3m(2\,m : d.s.)$$

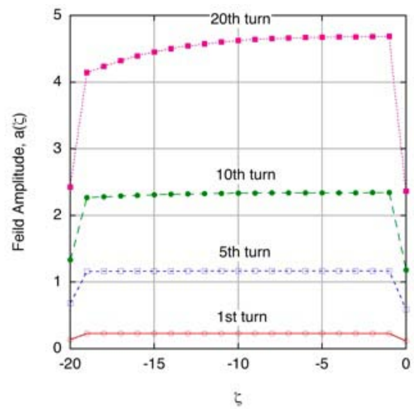
Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Oscillator Bunched-FEL

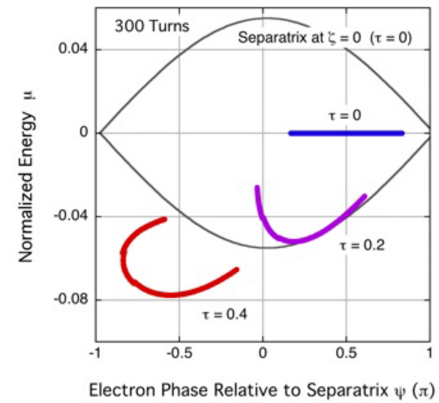
(driven by the bunch shorter than resonant wavelength)



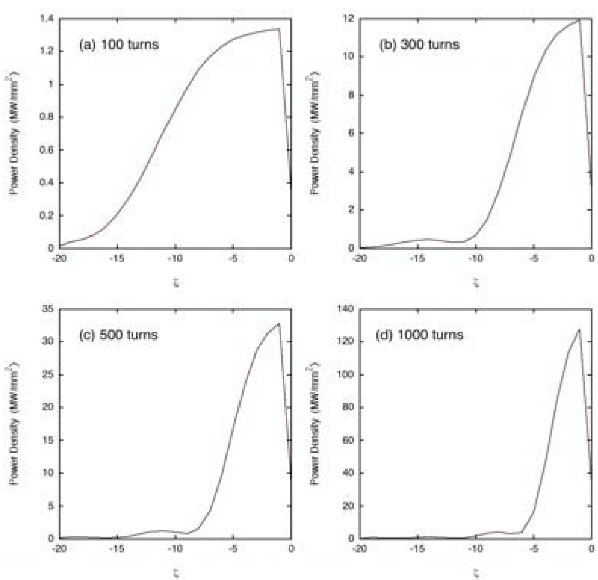
Bunch in Optical Potential



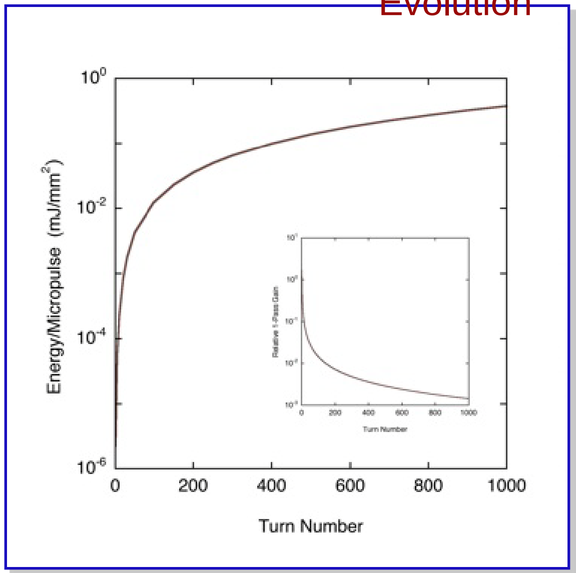
Early Stage (< 20 round-trips)
pile-up of field amplitude (CSR)



Phase Space Evolution



forward-peak temporal structure



Power Evolution (insert: one-path gain)

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Why thermionic RF gun*) toward femtosecond pulse ?

- Simple operation and apparatus because of no-laser (& cheap).
- Stable electron source !
- Lower charge micropulse, but multi-bunch and high repetition.

(Potential ability of the thermionic RF gun has not cultivated yet)

New approach for optimization of thermionic RF gun is a challenge !

Accurate evaluation of space charge effect is crucial.

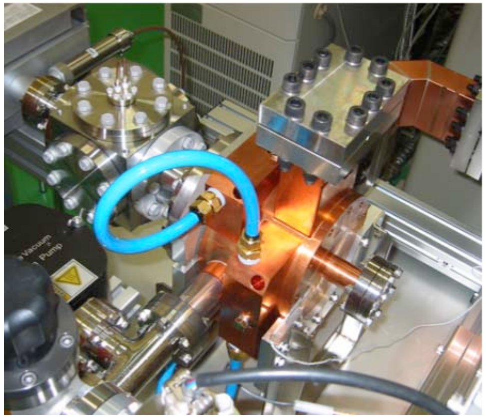
☞ experimental has to be done !

(no proper model in simulation codes for space charge)

*)Conventional

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Independently Tunable Cells (ITC) RF gun @ Tohoku Univ.

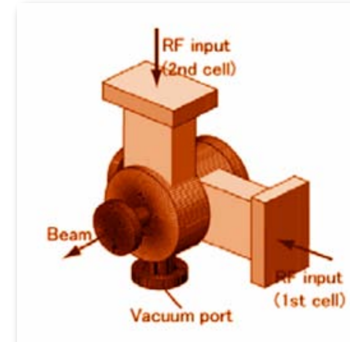


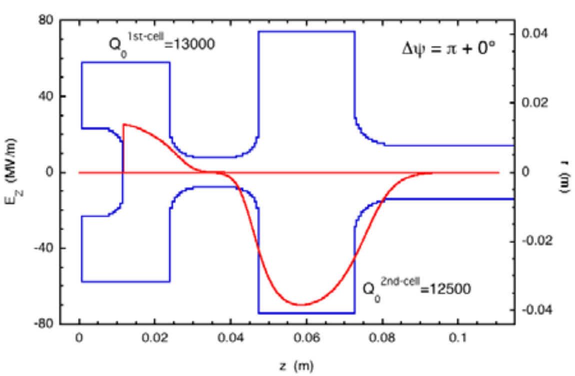
A few knobs to change phase space in general.

☞ two cells can be tuned independently

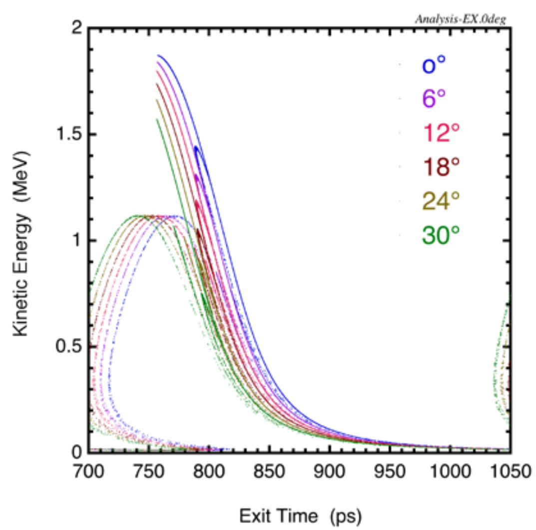
☞ <u>linearized phase space possible</u>

Preferred for bunch compression

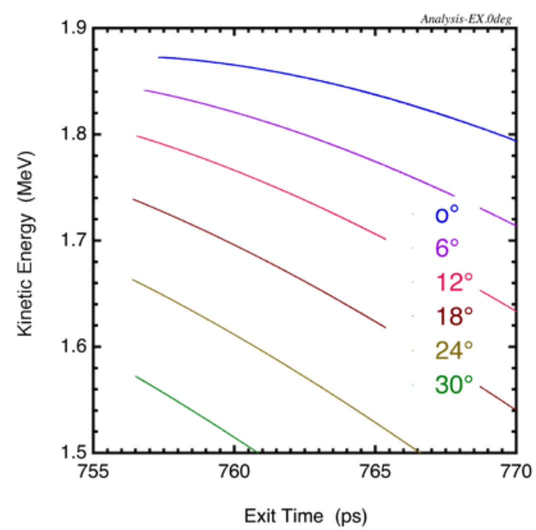




$$\psi = \phi_{cell2} - \phi_{cell1}$$



Longitudinal phase space

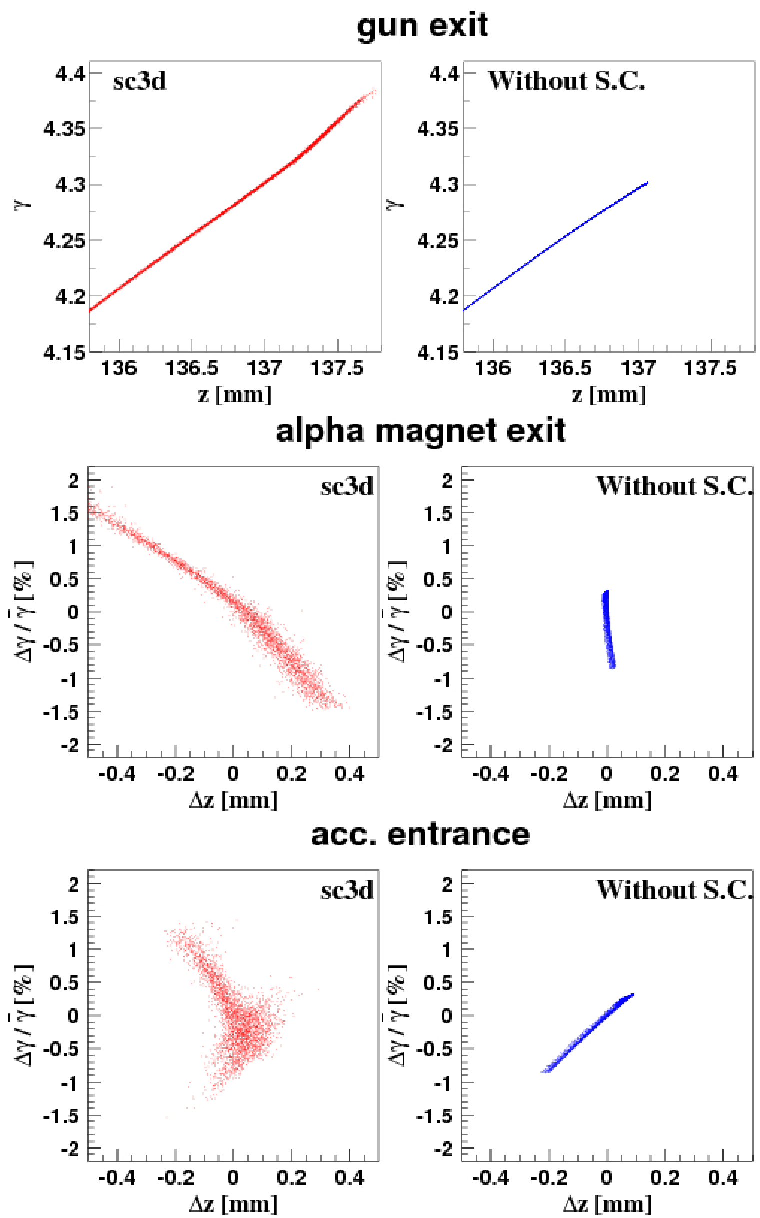


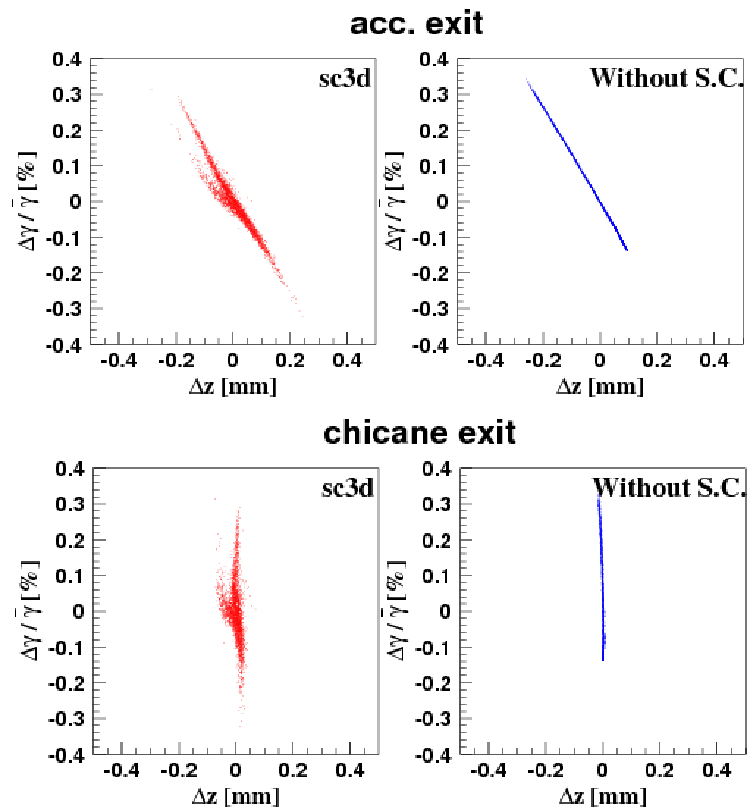
Longitudinal phase space (Expanded)

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Bunch Compression (ITC-RF gun + α-magnet + acc. + chicane)

Simulated by GPT code with “SC3D” routine for space charge evaluation





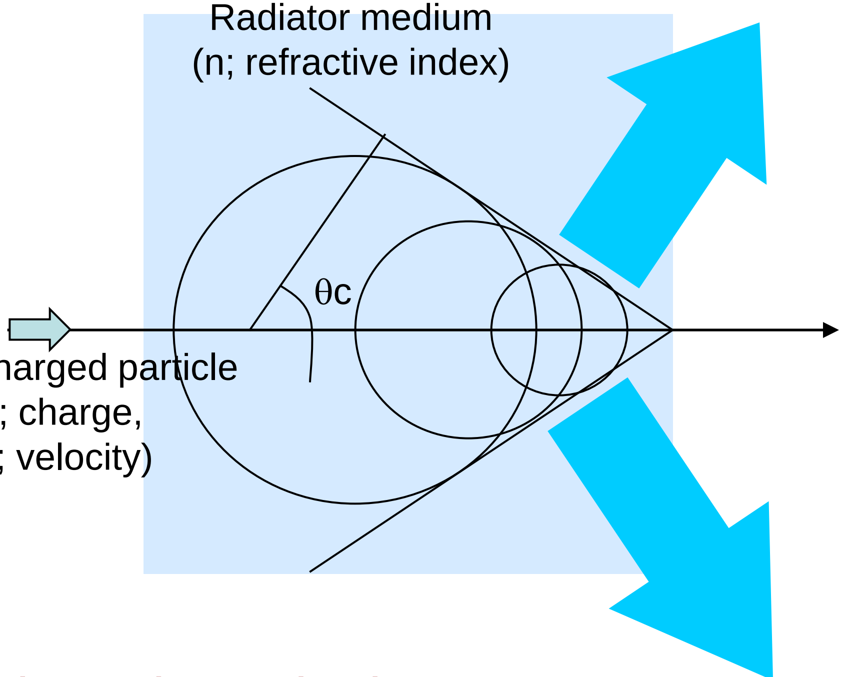
Initial particle distribution in the longitudinal phase space dominates the final bunch shape !

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

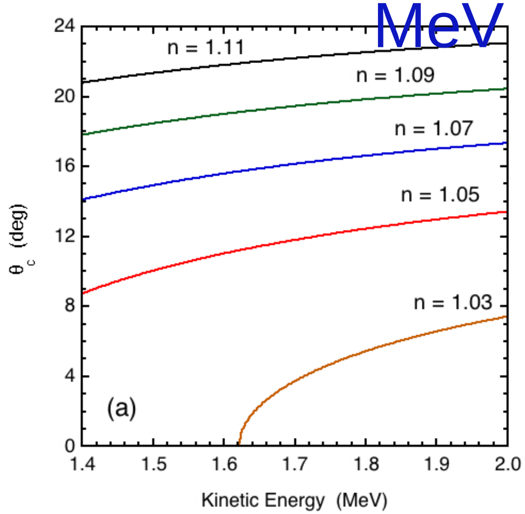
Cherenkov Ring, Properties

TOHOKU UNIVERSITY

BIW10 14th Beam Instrumentation Workshop May 2-6, 2010

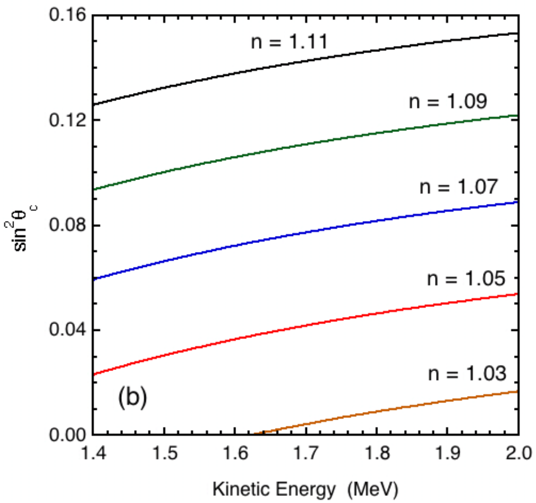


We are looking at E = 1.4 - 2 MeV



Cherenkov angle

n = 1.05 or higher



Relative photon yield

Cherenkov criteria

$$\beta > 1/n(\omega)$$

Cherenkov angle

$$\cos\theta_c = 1/n(\omega)\beta$$

Cherenkov photons

$$N = 2\pi\alpha z\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)\sin^2\theta_c$$

Silica-aerogel for radiator medium

$d\theta_c / dT$ has to be large ☞ smaller n
Large photon yield ☞ larger n

At the moment,
we have chosen n =
1.05 due to compromise

N=0.45 M photons /1 pC / 10 nm band-width @ 500 nm
from 1 mm radiator at T=1.7 MeV

Silica-aerogel

- transparent
- 1.0 < n < 1.2 (higher n is a bit dark)
- can be put into the vacuum with a flame-holder

TOHOKU UNIVERSITY

Linear Focal Cherenkov Ring (LFC) Came

14th Beam Instrumentation Workshop May 2-6, 2010

BIW10

SIMPLE CONCEPT

Electron kinetic energy

☟

Cherenkov angle

☟

Gather the photons by a special mirror

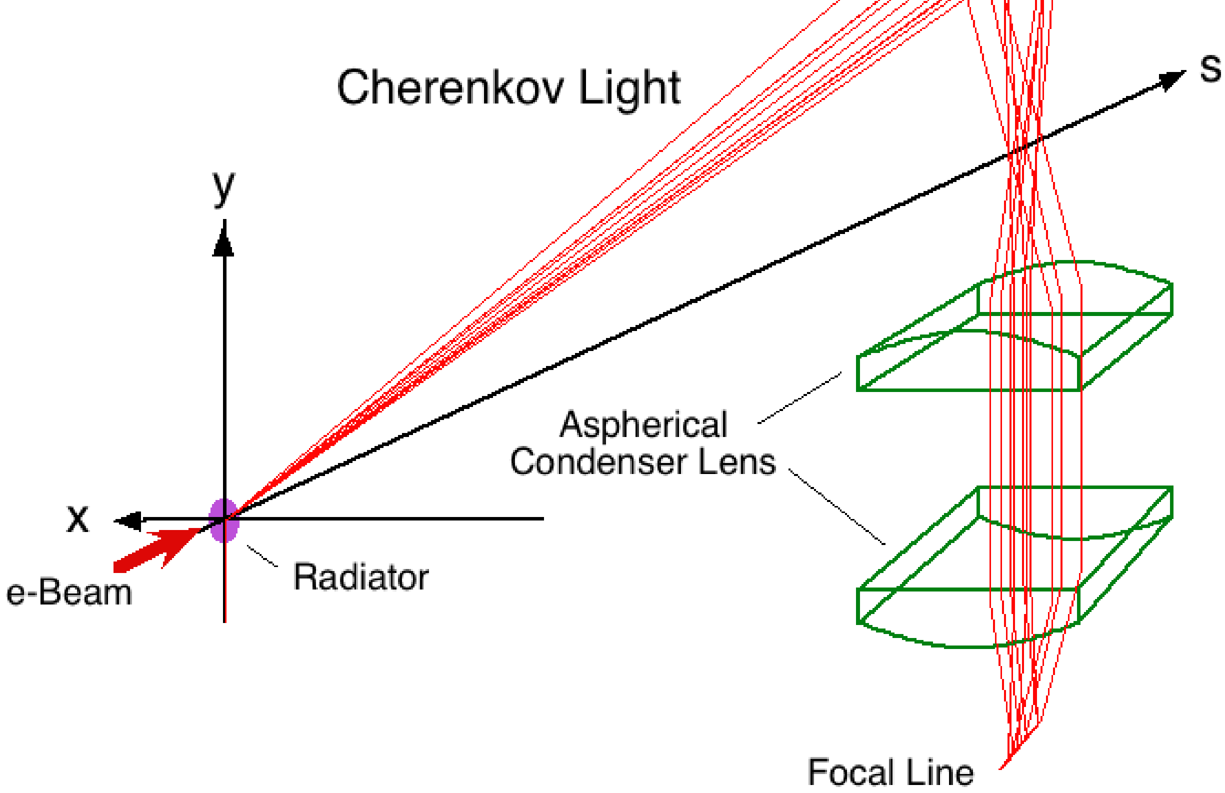
☟

Focus onto linear position (preserving time information)

1) Fast energy monitor by CMOS or other photo sensors
2) Direct phase space measurement employing a streak camera

Linear Focal Cherenkov Ring (LFC) Came

Turtle-back Mirror
s-axis: parabolic
x-axis: spherical



LFC-camera

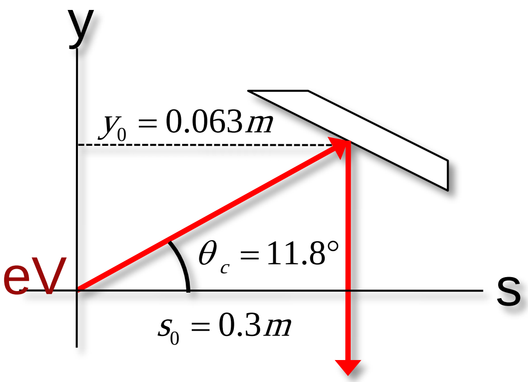
Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Optical elements of LFC-camera

Turtle-back mirror

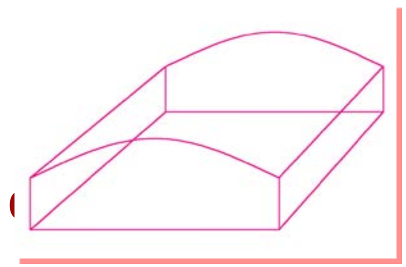
$$x^2+y^2-\left(-\frac{1}{2A}s^2+\frac{A}{2}\right)^2=0\quad\left(A\equiv\sqrt{y_0{}^2+s_0{}^2}+y_0\right)$$

Base point (0, y_0, s_0) for T = 1.7 MeV



Aspherical condenser lens

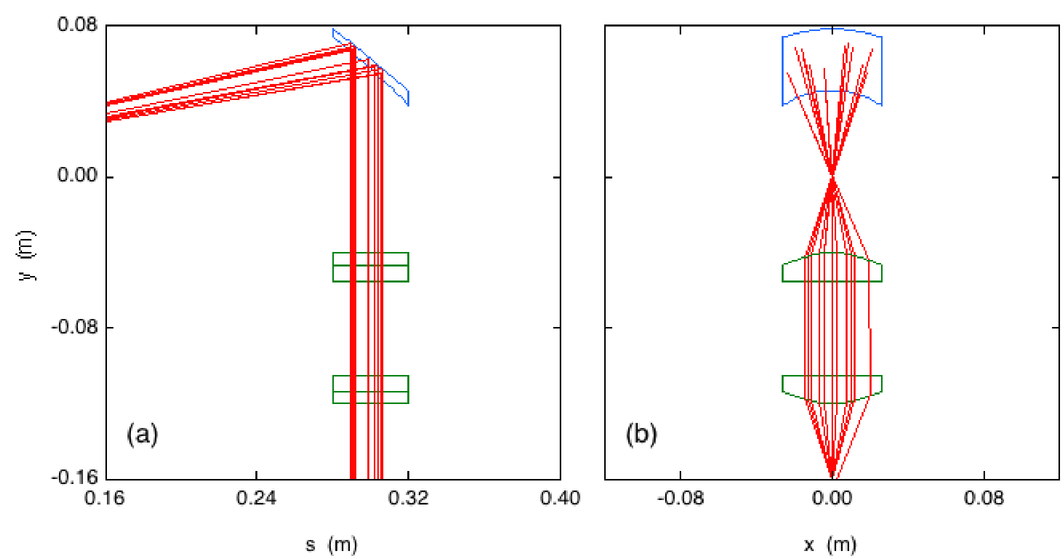
$$x^2+\left(y+gx^2\right)^2-\left(\frac{R}{\eta-1}+gx^2\right)^2=0$$



g; aspherical parameter (=23), R; base curvature radius (4

η; relative refractive index (=2)

Ray-trace calculation (point source)



Due to remaining spherical aberration, the system can cover ~ 30 deg of 2π Cherenkov ring.

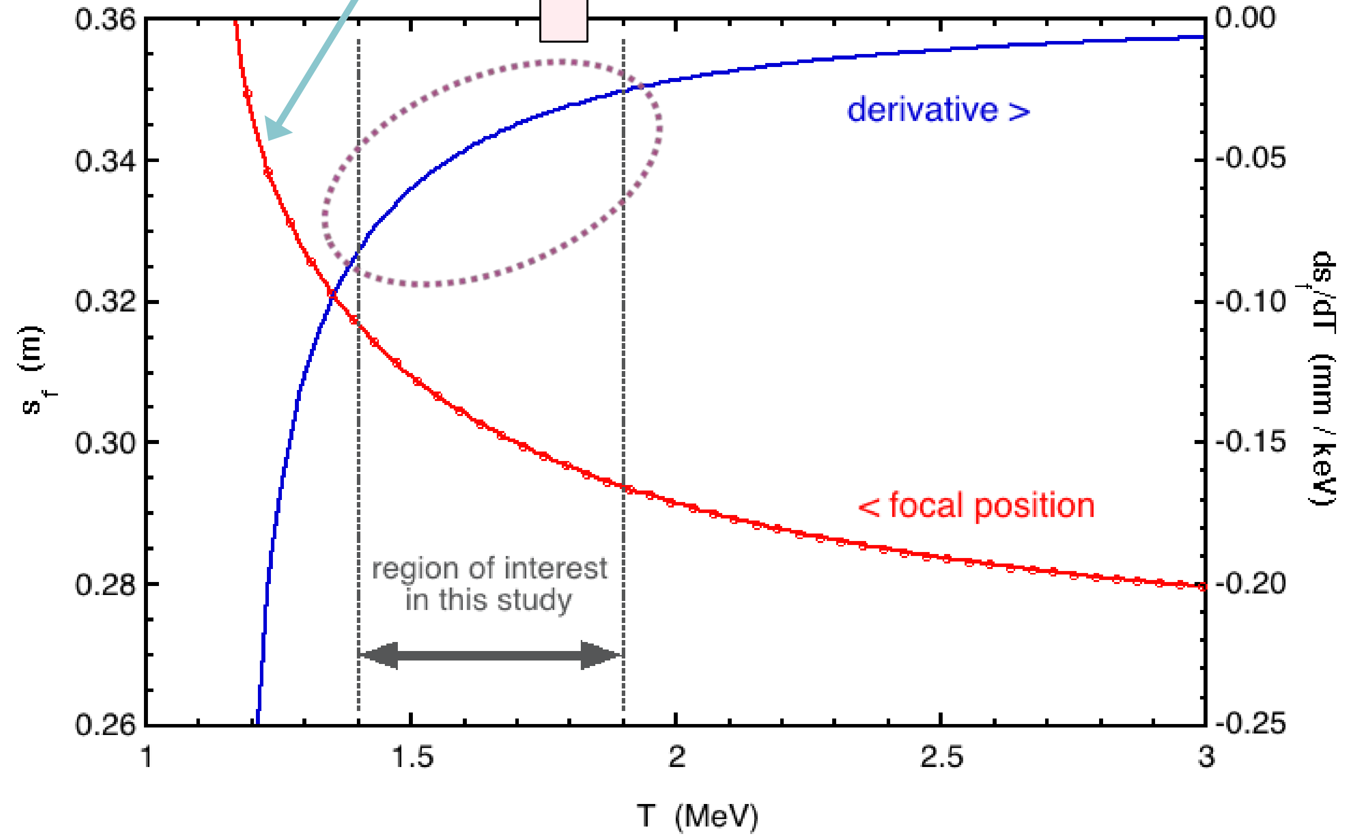
Intrinsic energy resolution of LFC-camera

Focal position vs β

$$s_f(\beta) = An\beta\left(1-\sqrt{1-\left(\frac{1}{n\beta}\right)^2}\right)$$

For this study

$$\frac{ds_f}{dT} = 0.085 \sim 0.025 \quad [mm/kev]$$

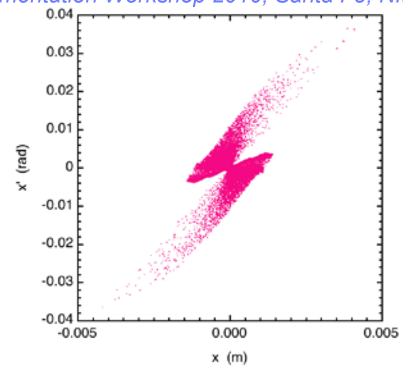


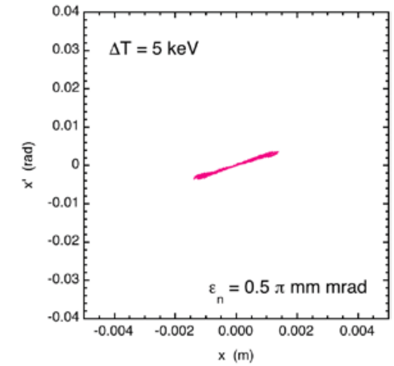
Focal position (left) and its derivative (right)

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Effect of beam emittance

transverse phase space @ gun exit



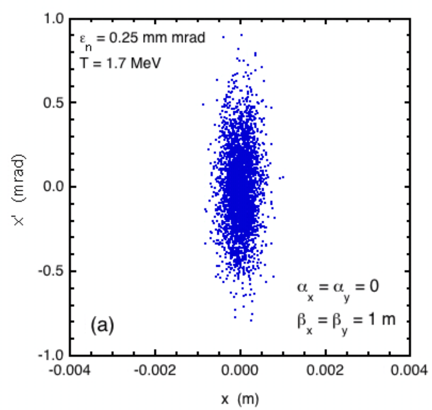


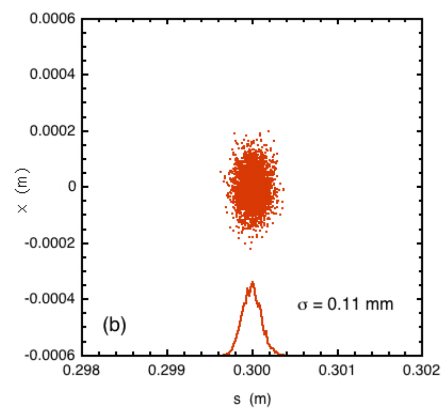
Whole beam   ΔT = 5 keV from top energy

Slice-emittane > thermal emittance (0.25 π mm mrad)

tight focus

$\beta = 1m$

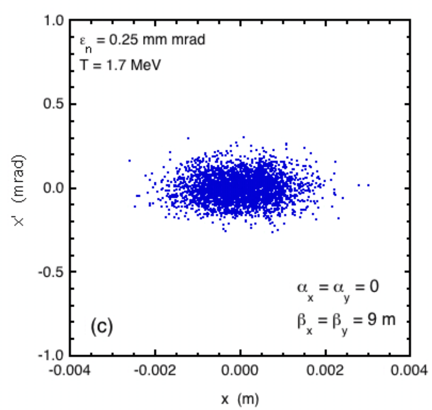


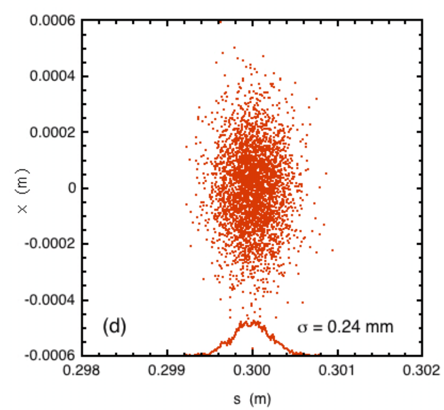


$$\sigma_s = 0.11mm$$
$$\Rightarrow \sigma_T = 3keV$$

loose focus

$\beta = 9m$





$$\sigma_s = 0.23mm$$
$$\Rightarrow \sigma_T = 6keV$$

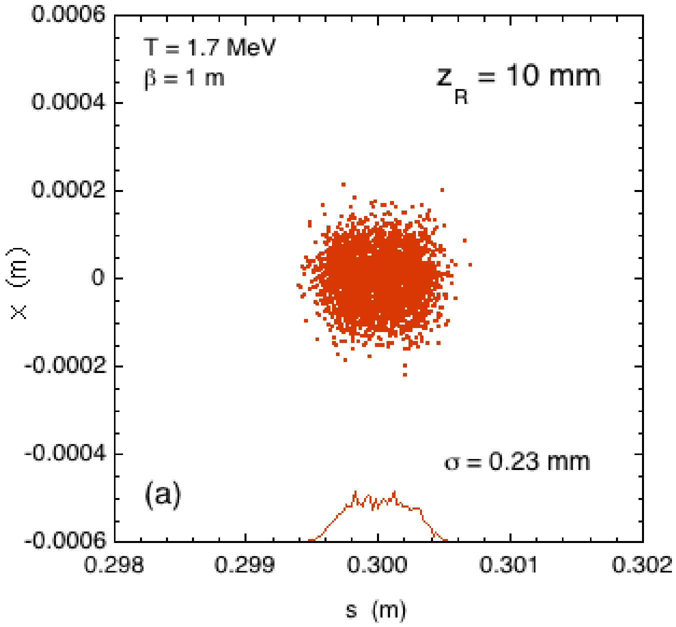
Electrons@Radiator	Lights@Focal Line

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

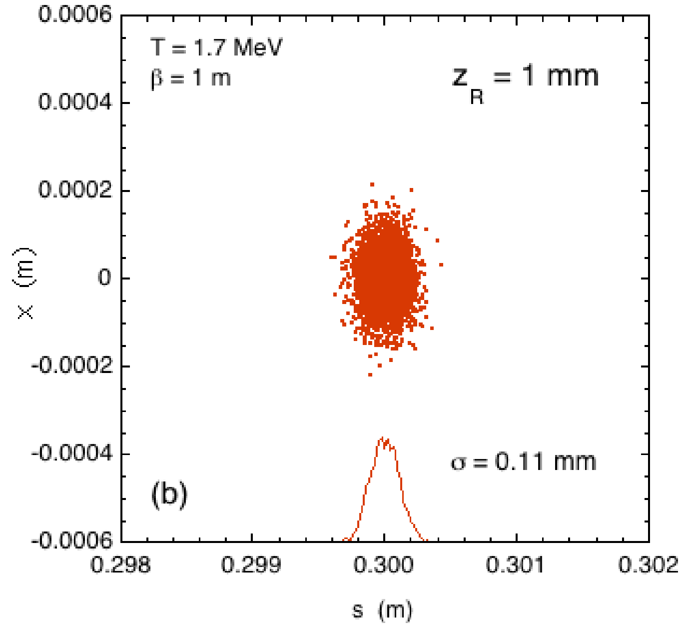
Effect of radiator thickness

tight focus on the radiator (β = 1 m)

thicker radiator (10 mm)



thinner radiator (1 mm)



$$\sigma_s = 0.23mm \Rightarrow \sigma_T = 6keV$$

$$\sigma_s = 0.11mm \Rightarrow \sigma_T = 3keV$$

Transverse beam size on the radiator is significant for the energy reso

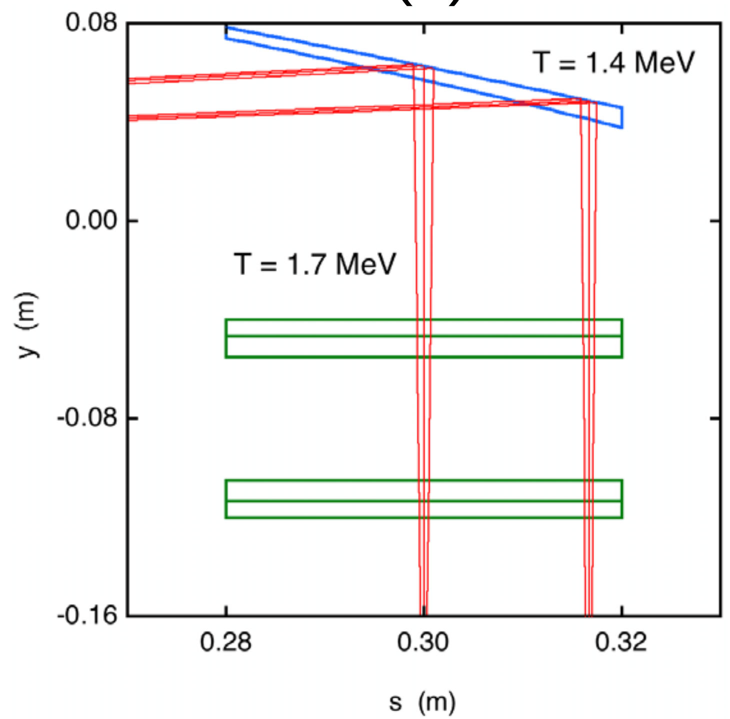
Intrinsic time resolution of LFC-camera

major contribution for path length (traveling time) deviation would be

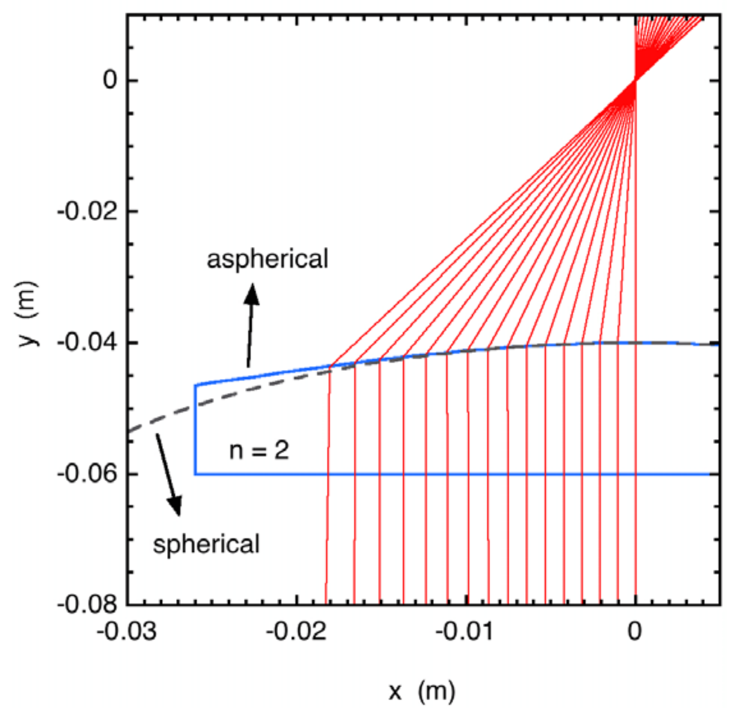
(1) Source position (2) Path position of aspherical lenses

(3) Spatial distribution of the beam on the radiator

(1)



(2)



Parabola mirror brings focus for parallel lights. (also reason for better energy resolution)

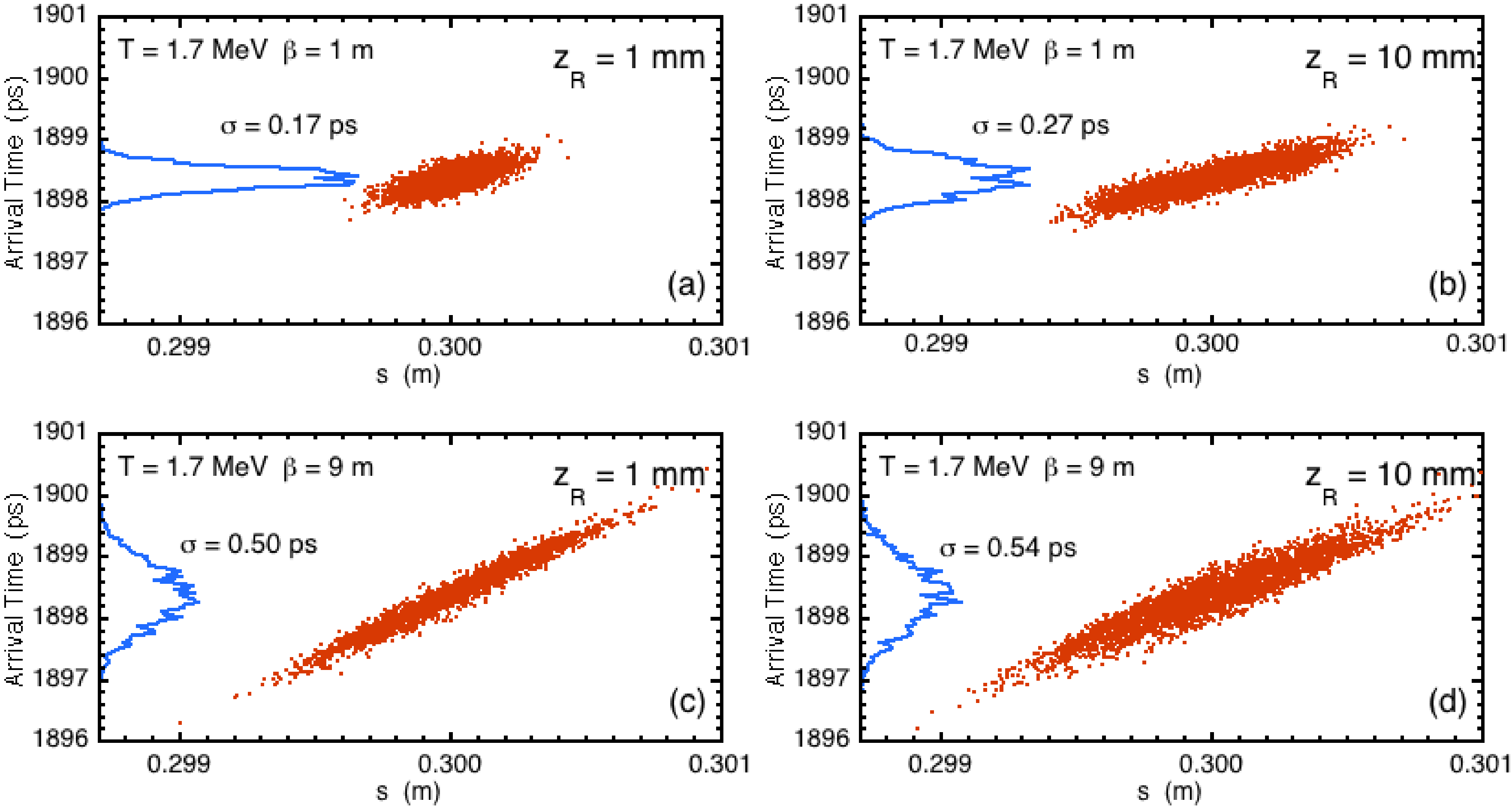
Aspherical lens suppresses path length deviation.

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Effect of beam size and radiator thickness

thinner radiator (1 mm)

thicker radiator (10 mm)



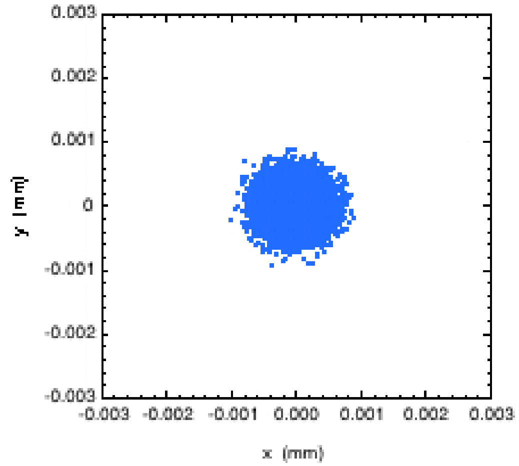
Better intrinsic time resolution (< 0.2 - 0.5 ps).
Tight focused beam secures a couple of hundreds *fs* resolution

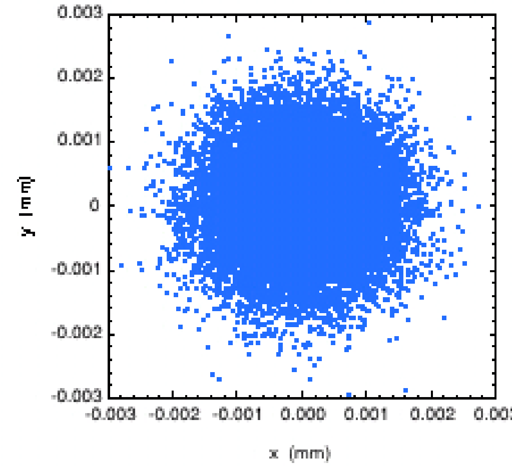
Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

What is the result ?

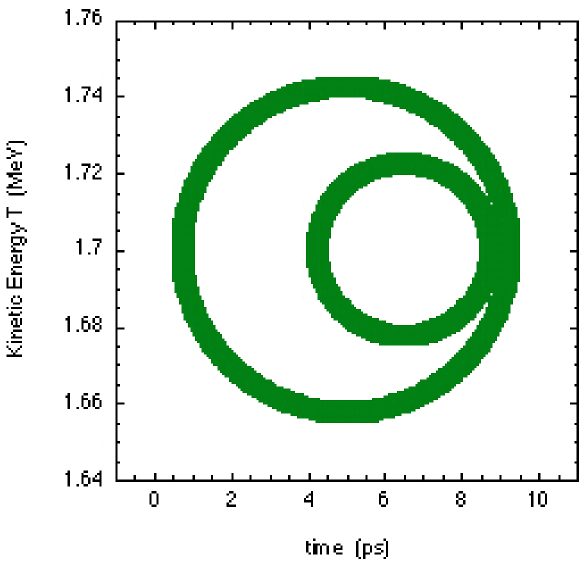
ε_n = 0.25 mm mrad
β = 1 m & 9 m
z_R = 1 mm

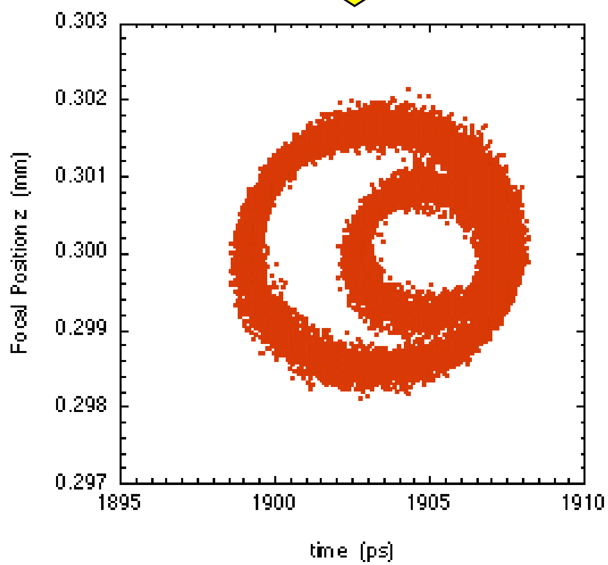
Beam spatial distribution at the radiator

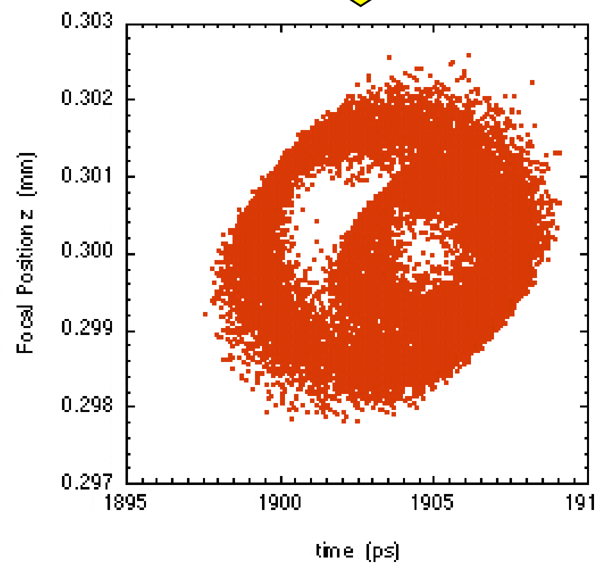




Beam distribution
in
longitudinal phase space







Observe phase space

Editor's Note: PDF version of slides from Beam Instrumentation Workshop 2010, Santa Fe, NM

Summary & Prospect

We have designed a novel system for measurement of the longitudinal phase space distribution of the relatively lower energy electrons extracted from a thermionic RF gun.

LFC (Linear Focal Cherenkov ring) –camera

- a turtle-back mirror ; confine the Cherenkov ring onto a focal line
- two aspherical condenser lenses ; optical transport

Numerical ray-trace

- intrinsic energy resolution ; less than 5 keV
- intrinsic time resolution ; less than 300 femtosecond

Transverse beam size has to be well focused on the radiator !

Radiator thickness is less significant, can be extended upto 1 cm

Continue optimization of the optical element (lens-free optics ?).

Study combined use with a streak camera.

How about higher beam energy, such as 3 or 4 MeV ?