Bunching Beam Dynamics in Final Stage of Heavy Ion Fusion Driver

T. Kikuchi, M. Nakajima, and K. Horioka
Energy Sciences, Tokyo Institute of Technology (TIT)

International Workshop on Recent Progress of Induction Accelerators
(RPIA2002), October 29-31, 2002, Tsukuba, Japan

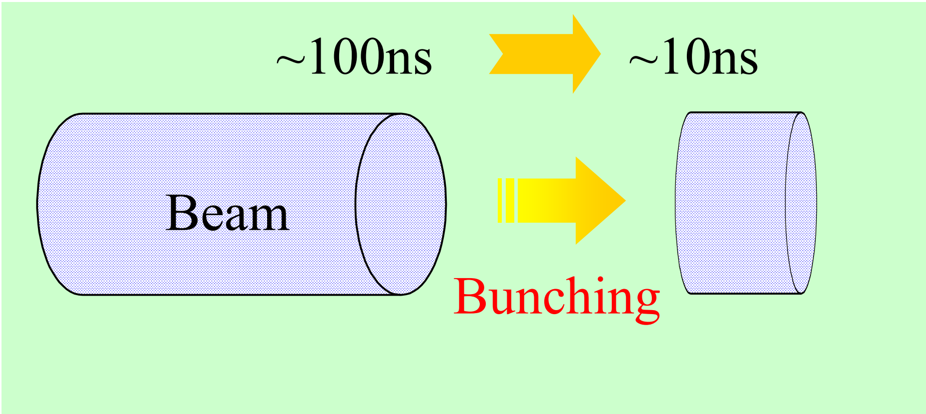
Background & Purpose

Tokyo Institute of Technology

● Heavy Ion Inertial Fusion : HIF

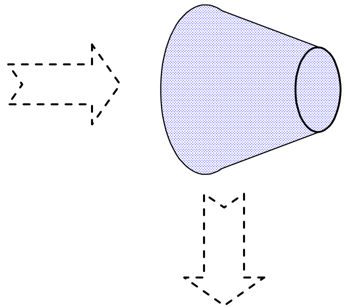
Intense Heavy Ion Beam (~10GeV ~10ns ~100kA)
Generation & Transport are required for effective implosion.

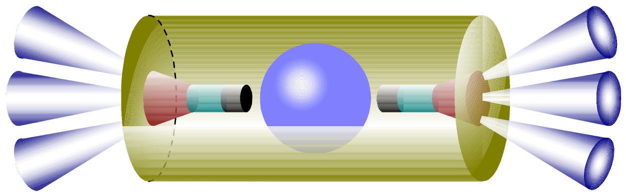
Accelerated Heavy Ion Beam ▶ Final Beam Bunching



▶ Induction Linear Accelerator

Focusing



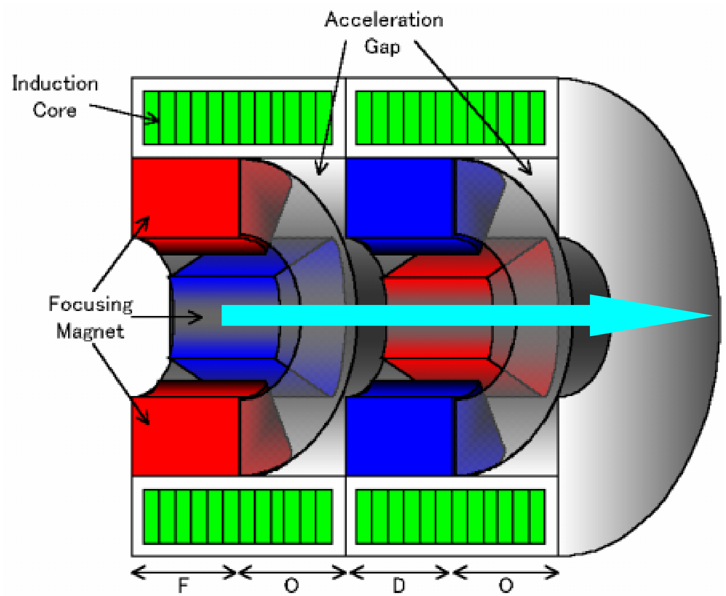


Beam Irradiation for Implosion

Heavy Ion Beam Bunching by Induction LINAC

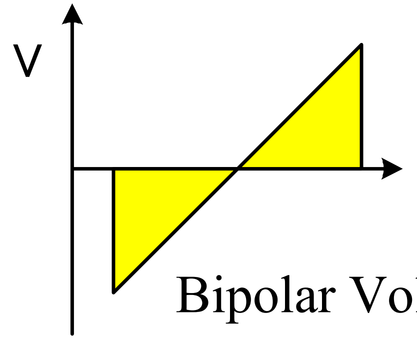
Tokyo Institute of Technology

Apply Bunching Voltage at each Gap



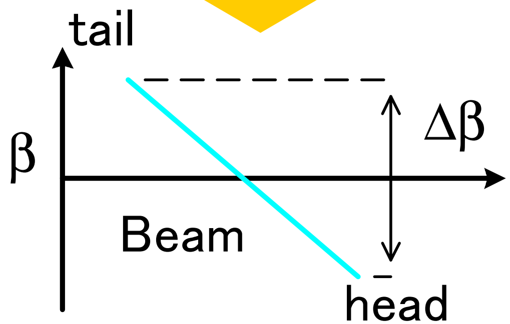
Induction buncher consists of periodic lattice, acceleration gaps & FODO quadrupole.

● for beam bunching



Bipolar Voltage Waveform

apply to beam



Beam head is decelerated
Beam tail is accelerated
by

Head & tail velocities are modulated.
Δβ/β indicates Velocity Tilt.

Beam bunch becomes short during transport.

Beam Parameters

Tokyo Institute of Technology

Ion Species	Pb^{1+} (207.2 amu)
Ion Number	2.5×10^{15}
Total Charge	0.4mC
Pulse Duration	250ns ⇒ 10ns
Total Beam Current	1.6kA ⇒ 40kA
Beam Number	4
Current per Beam	400A ⇒ 10kA
Particle Energy	10GeV ($\beta \sim 0.31$)
Longitudinal Beam Length	23m ⇒ 0.9m

Parameters in final stage of HIF driver system

Bunch Compression Ratio = 25

by J.J. Barnard, *et al.*, Physics of Fluid B 5, 2698 (1993).

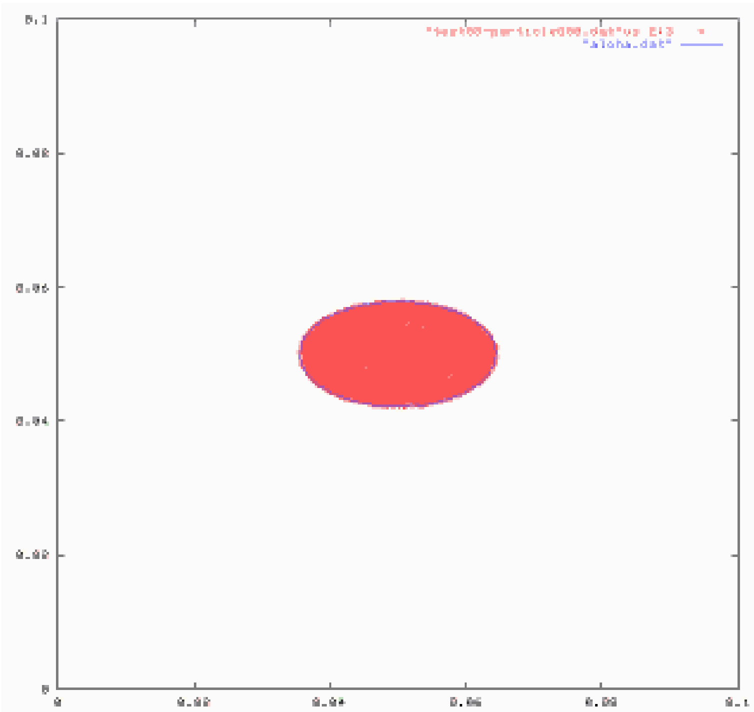
Beam Transport by PIC Simulation

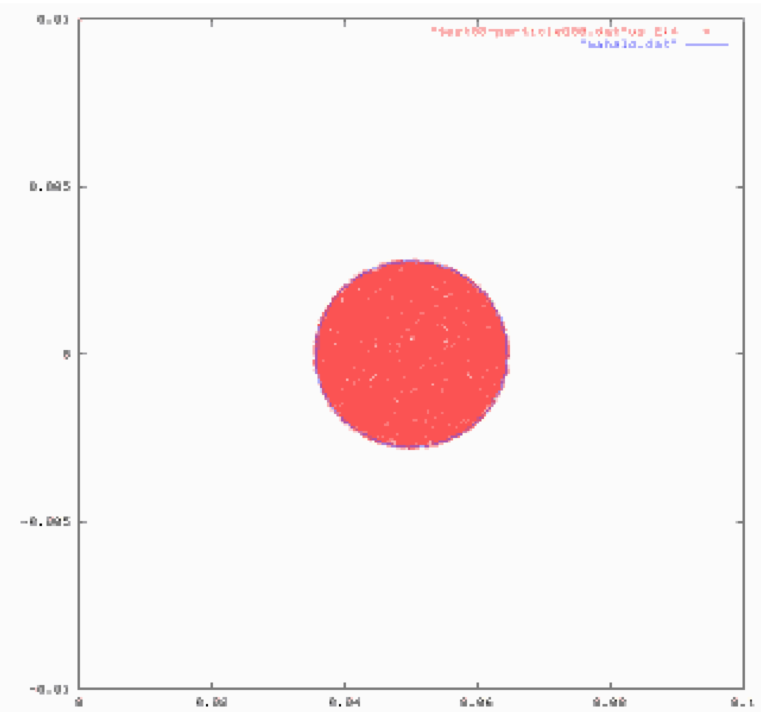
Tokyo Institute of Technology

x-y Real Map

x-x’ Phase Map

y [cm]





dx/ds [mrad]

x [cm]

x [cm]

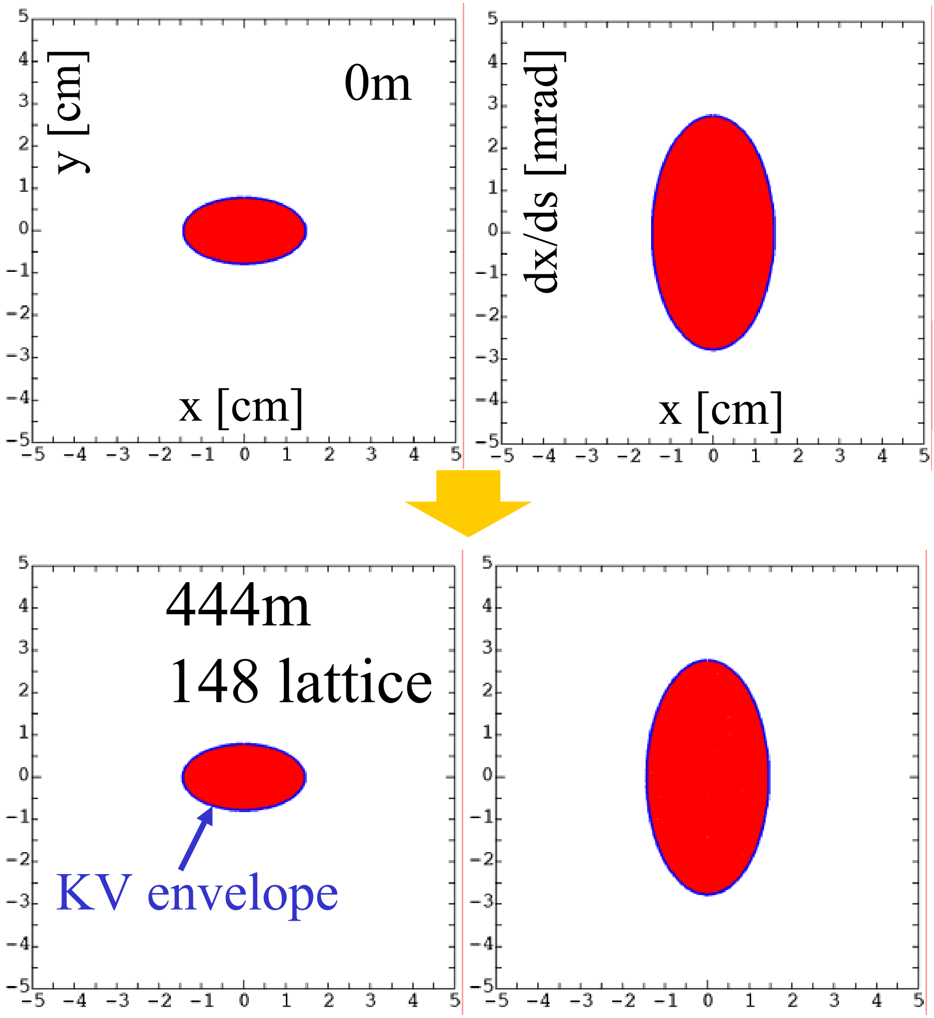
Beam Transport in FODO Lattice

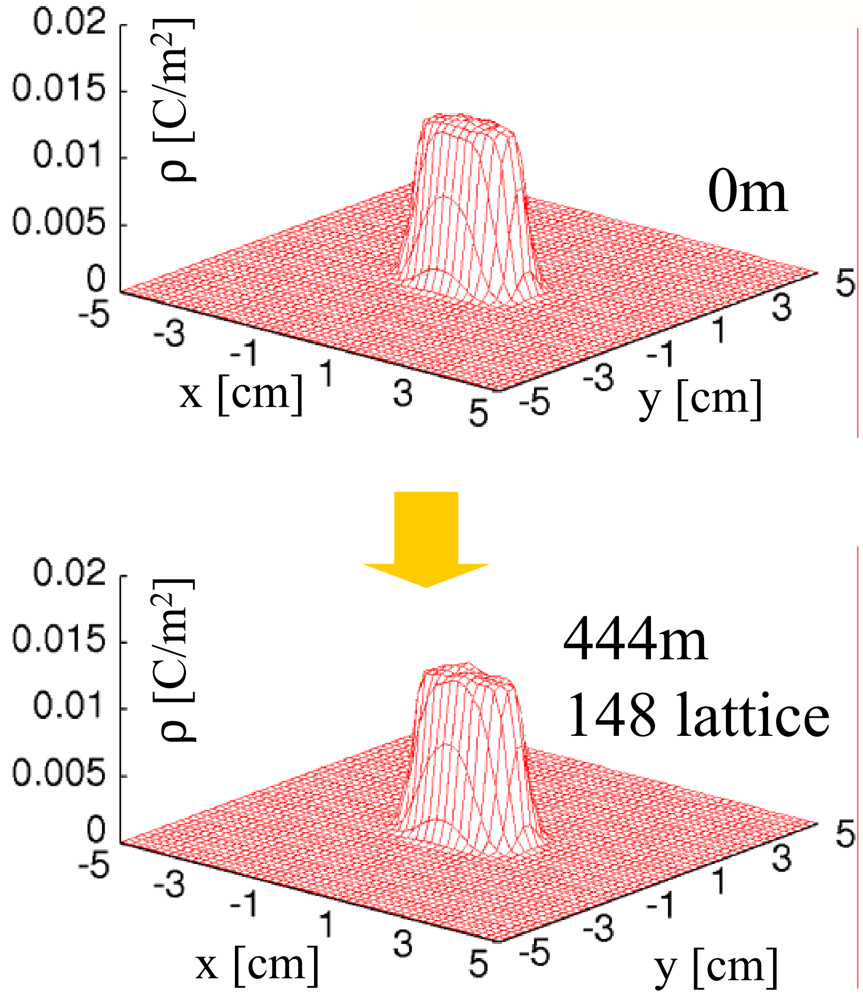
without compression

Beam Transport by PIC Simulation

Tokyo Institute of Technology

Particle Maps





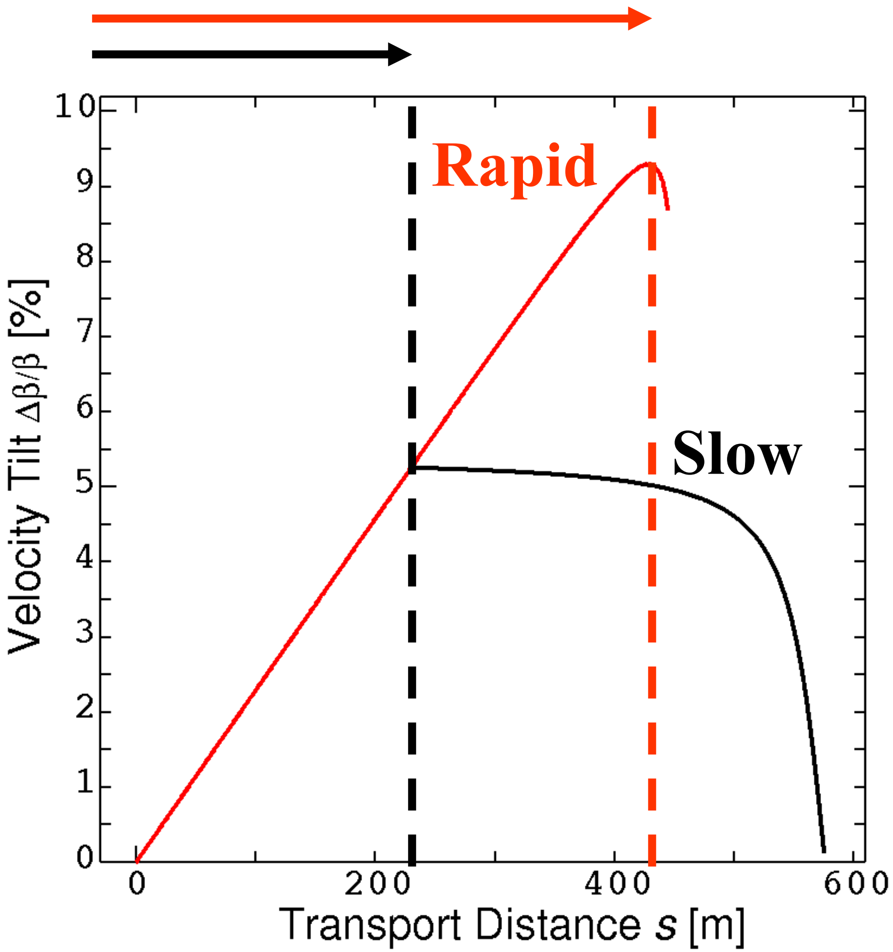
Charge Distribution

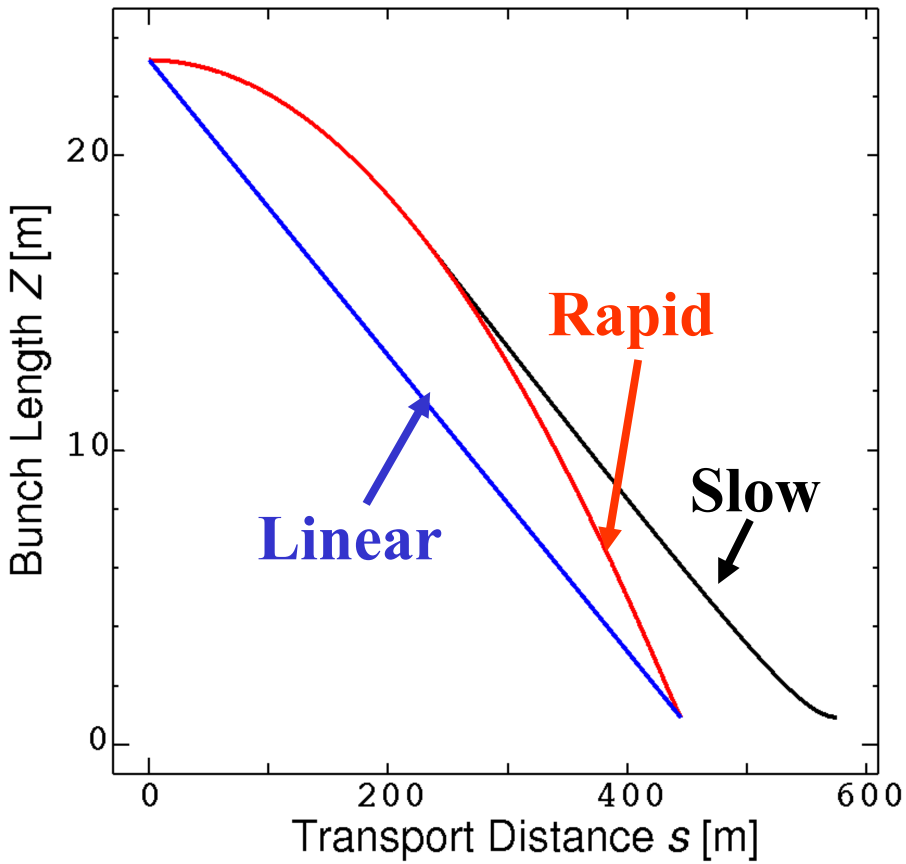
Estimation for Beam Compression Effect

Tokyo Institute of Technology

Induction Buncher

from Longitudinal Envelope Calculation





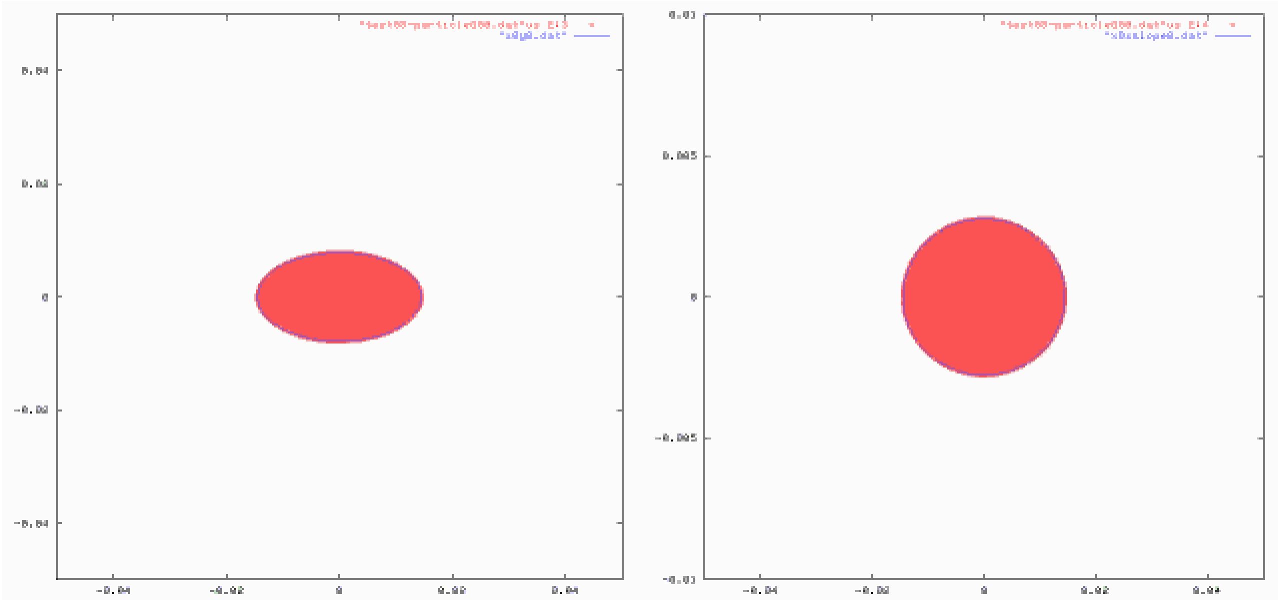
We calculate about 3 compression schedules

Estimation for Beam Compression Effect

Tokyo Institute of Technology

x-y Real Map　　　x-x' Phase Map

y [cm]

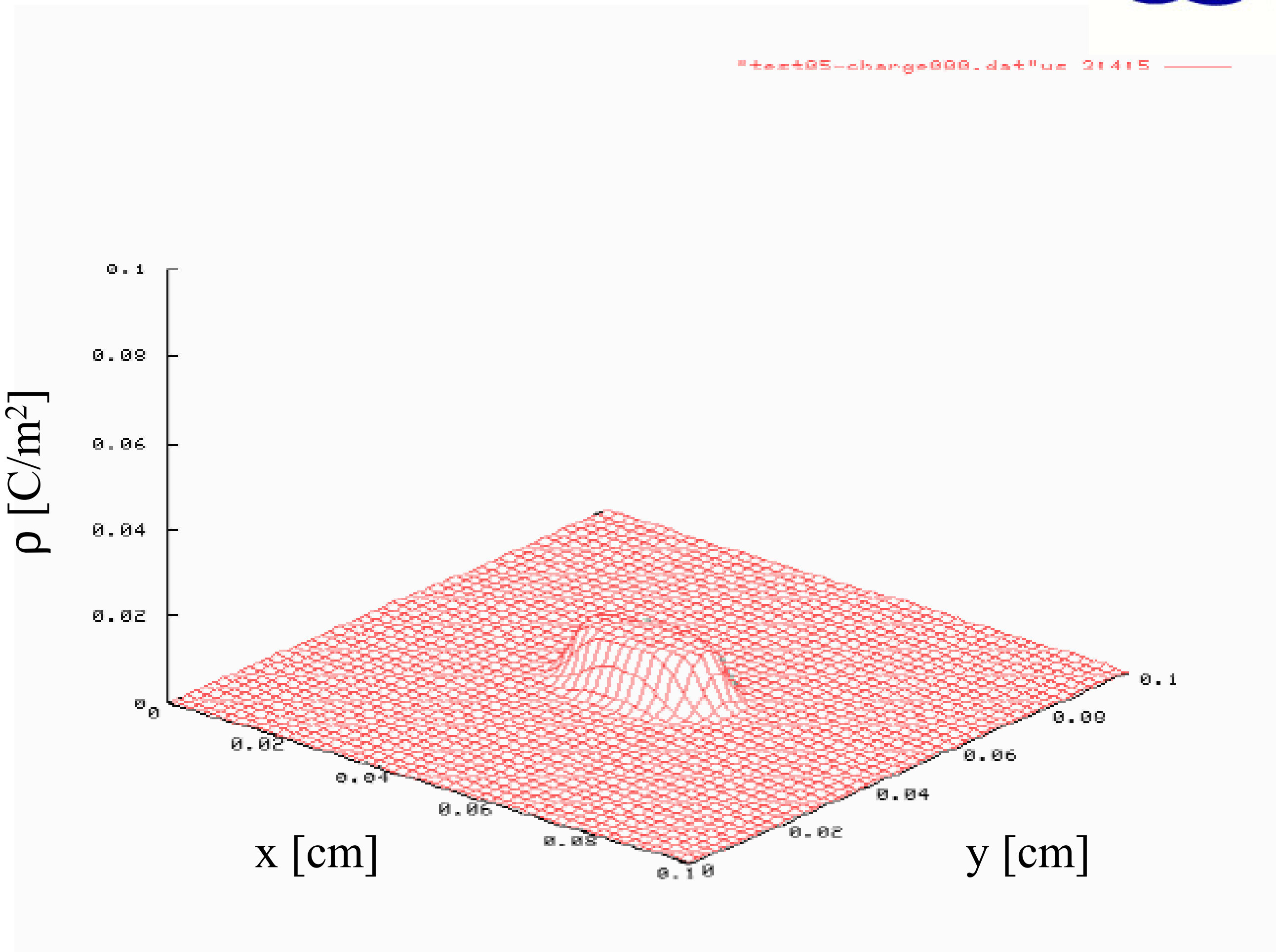


dx/ds [mrad]

x [cm]　　　x [cm]

Beam Transport in FODO Lattice
with linear compression schedule

Estimation for Beam Compression Effect

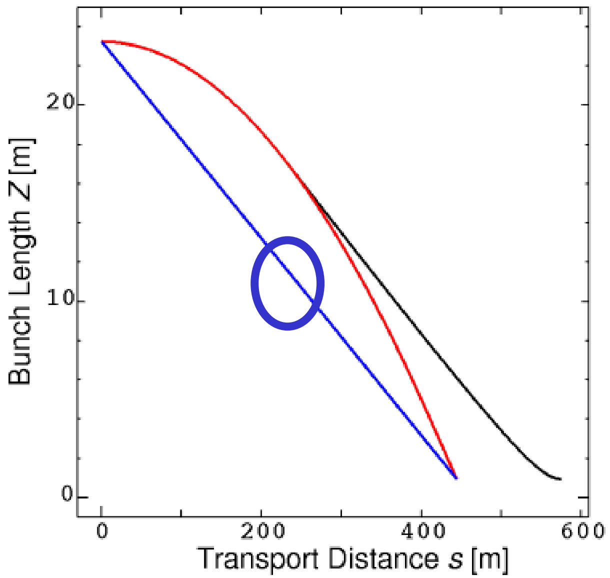


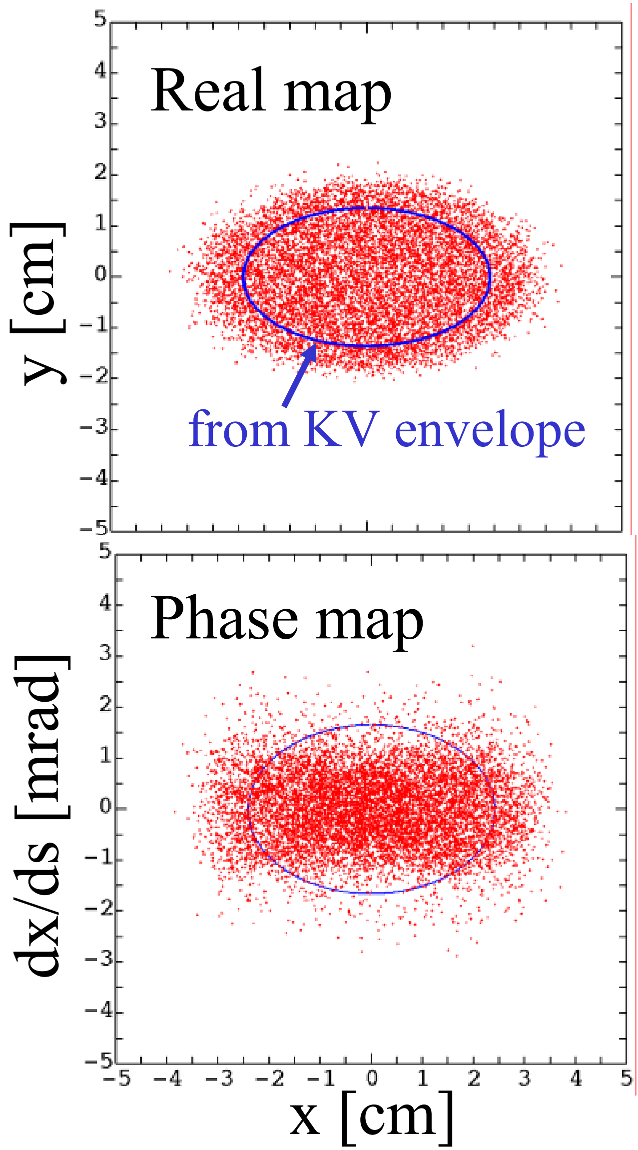
Charge Distribution Change in x-y space
with linear compression schedule

Linear Compression Schedule

Tokyo Institute of Technology

at stagnation point
444m,148 lattice

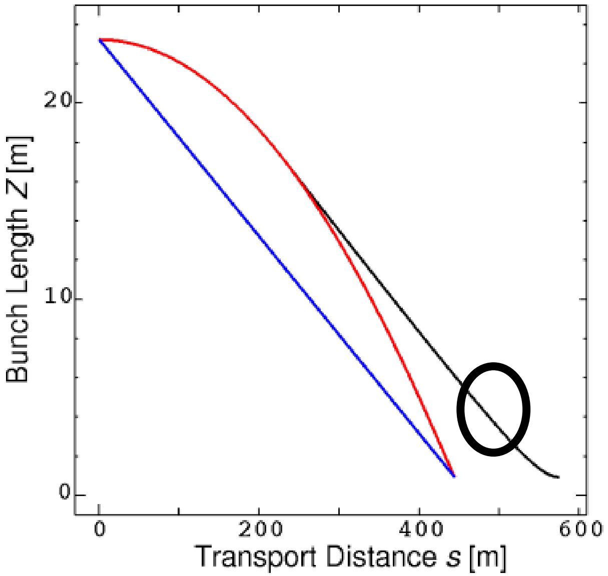


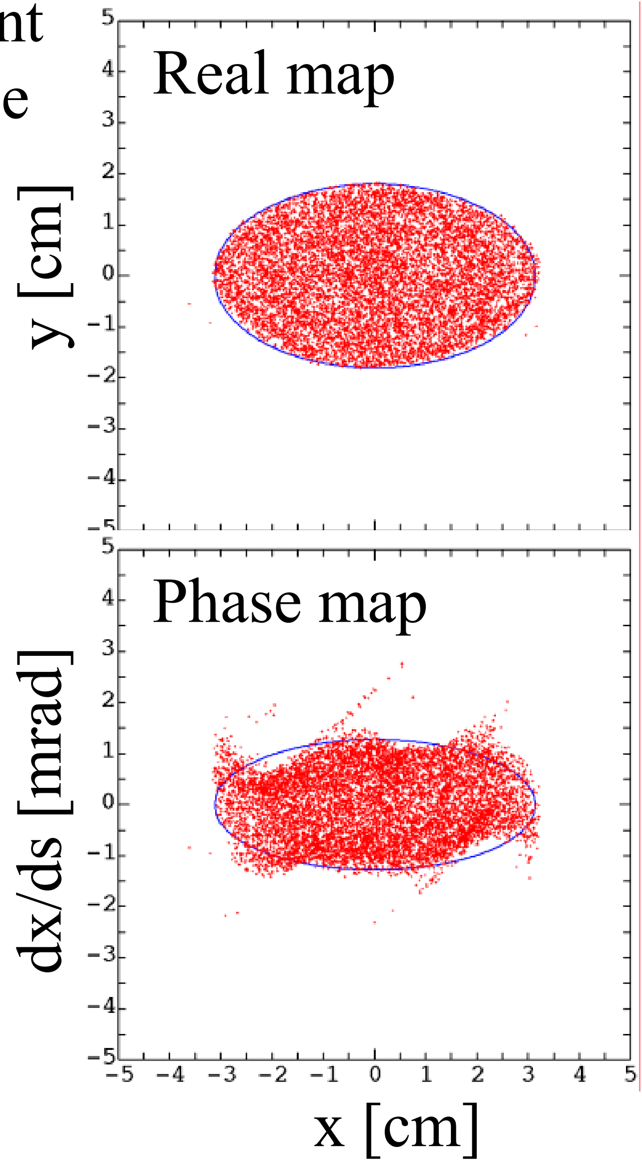


▶ Emittance dilution
due to Resonance effect (σ = 60deg)

Slow Compression Schedule

at stagnation point
573m, 191 lattice



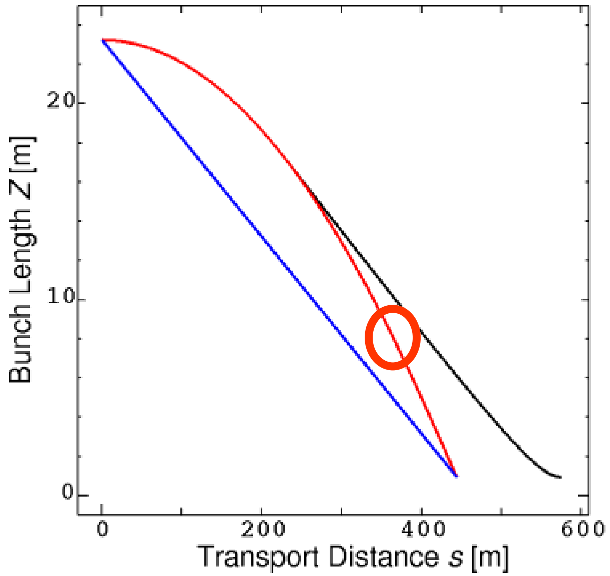


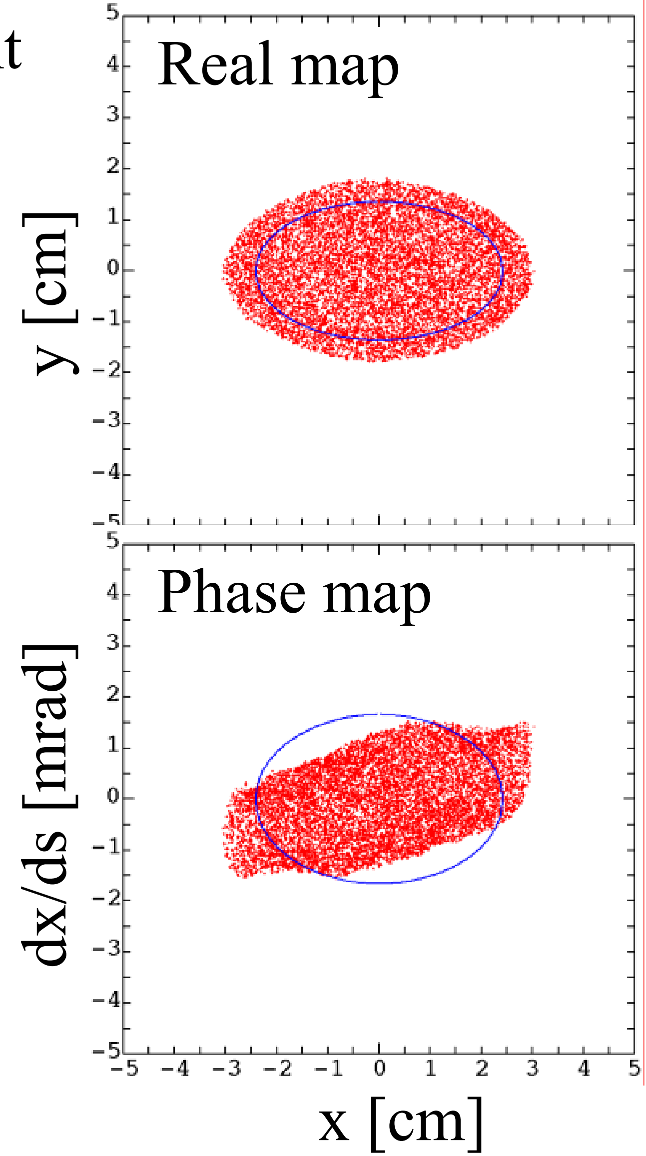
- Emittance dilution smaller than linear case

Rapid Compression Schedule

Tokyo Institute of Technology

at stagnation point
444m,148 lattice





Phase maps and Emittance Dilutions are changed by Compression schedules

Mesh Size & Debye Length

Intense ion beams, *non-neutral plasmas*, will show collective phenomena.

▶ in *Usual* Plasma Simulations,

$$H / \lambda_D = 0.23^*$$

H : Spatial Mesh Size ($H=\Delta x=\Delta y$)
λ_D : Debye Length

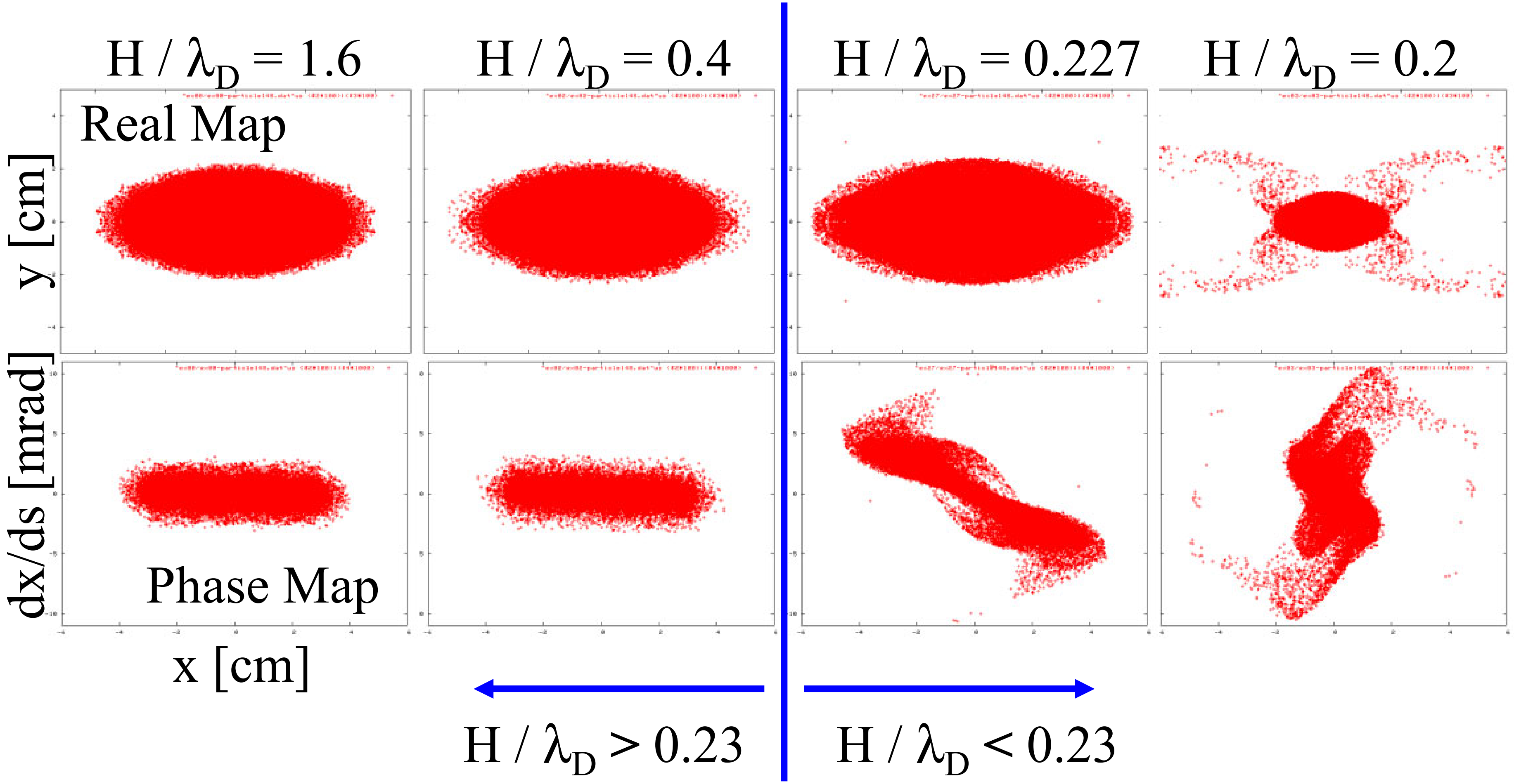
We try to calculate with changes of PIC mesh size H.

*R.W. Hockney and J.W. Eastwood, *Computer Simulation using Particles* (McGraw-Hill, New York, 1981).

Calculations with H / λ_D Changes

Tokyo Institute of Technology

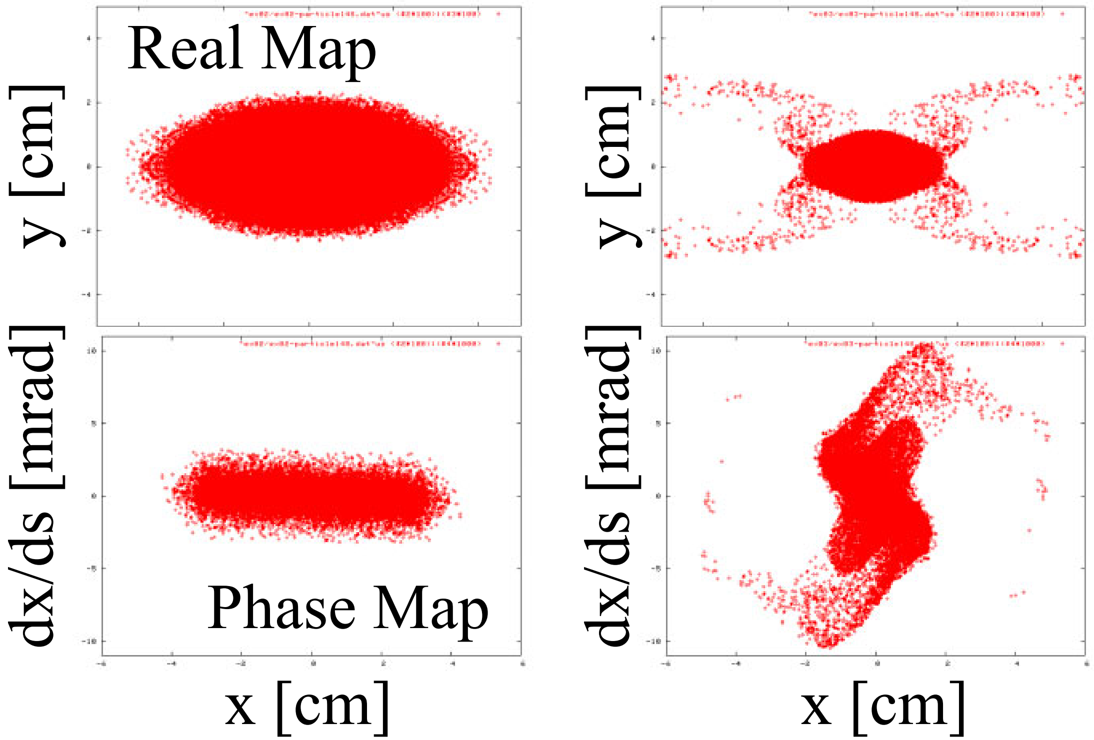
at 444m, 148 lattice, just x25 compression



Calculation results are quite different in H / λ_D < 0.23 or not

Negative Feedback of Particle Loss

$H / \lambda_D = 0.4$ $H / \lambda_D = 0.2$



$N_f / N_i = 1$ $\underline{N_f / N_i = 0.7}$

N_f : Final super particle number
N_i : Initial super particle number

Particle Loss causes mismatch increase

↓

Large mismatch increases beam radius

↓

Large beam radius causes beam loss

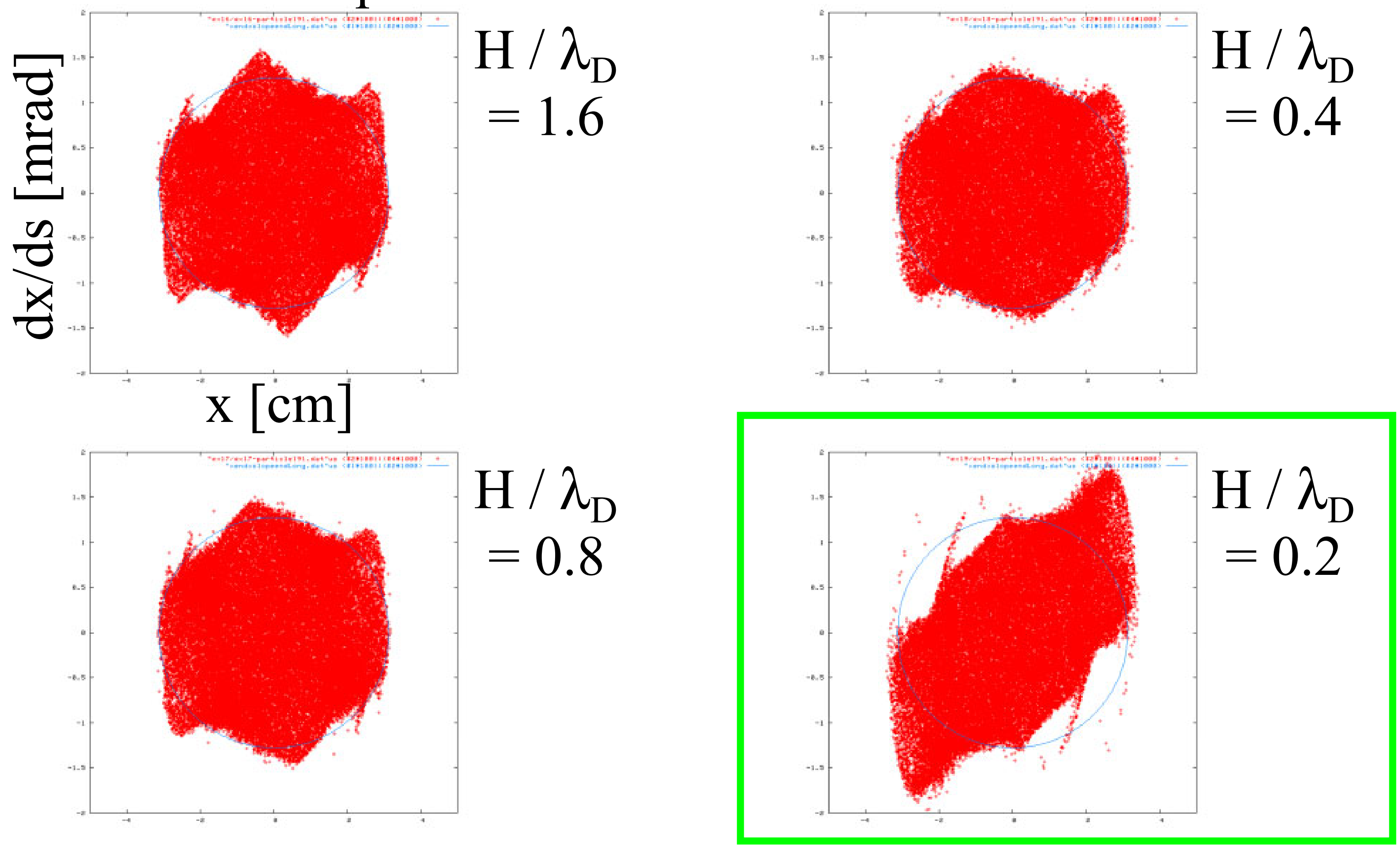
Seed of particle loss is Resonance & Plasma Oscillation

Calculations with H / λ_D Changes

Tokyo Institute of Technology

in case of slow compression schedule

Phase Map



No particle loss, but phase map is clearly different at $H/\lambda_D < 0.23$.

Summary

Tokyo Institute of Technology

- Emittance dilution depends on compression schedules in intense ion beam bunching

- In high-current beams, collective behavior is important

  ► resonance effects induced plasma oscillations important issue for emittance dilution in Final Beam Bunching