Multiple charge state ion beam acceleration with an RFQ LINAC

Jun Tamura[1, 2, 3],

Toshiyuki Hattori[1], Noriyosu Hayashizaki[1], Takuya Ishibashi[1], Taku Ito[1], Takeshi Kanesue[4], Hirotsugu Kashiwagi[5], Masahiro Okamura[3]

[1]Tokyo Institute of Technology

[2]RIKEN

[3]Brookhaven National Laboratory

[4]Kyushu University

[5]Japan Atomic Energy Agency

Outline

Space chare dominated beam dynamics in an RFQ linac

Numerical simulation

Multiple charge state ion beam acceleration in an RFQ linac

Contents

1. Introduction

Heavy ion sources → High current beam
Highly ionized particles

Desired ions with different charge state ions

Some accelerator systems
Multi charge beam injected simultaneously into RFQ linac

Example
1. Direct Plasma Injection Scheme (Laser Ion Source + RFQ Linac)
2. EBIS based RHIC injector at BNL

Aim

Effects from these different charge state ions cannot be neglected

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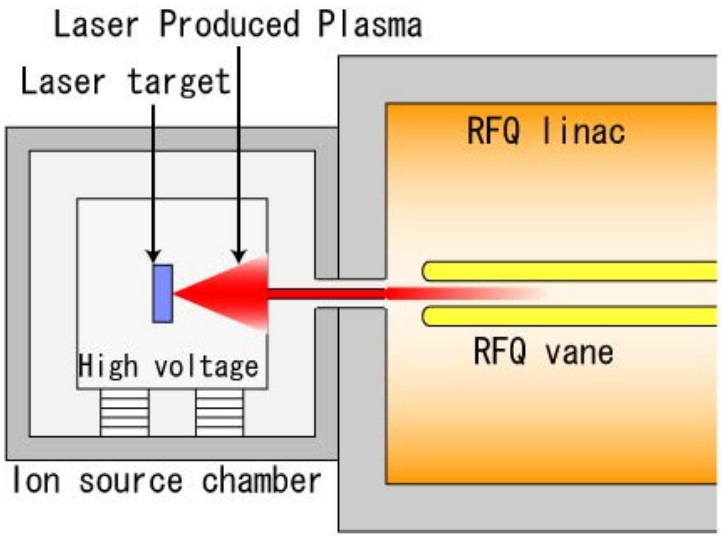
Numerical Simulation (Particle-Mesh method)

2. Direct Plasma Injection Scheme

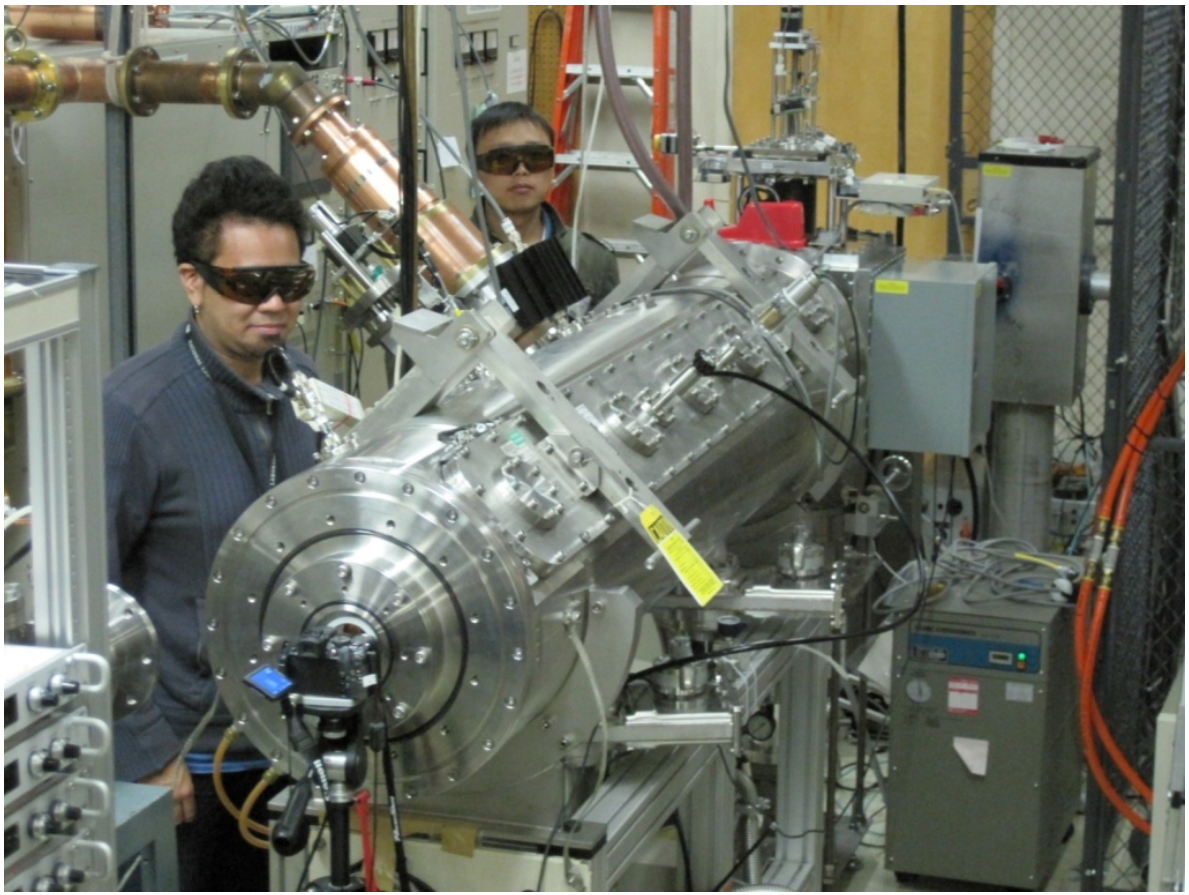
Combination of laser ion source and RFQ linac
No LEBT

High-intensity heavy ion beam acceleration with low cost



1. Pulsed laser is focused on the laser target.
2. Generated laser plasma expand with initial drift velocity.
3. Designed ions are extracted at the RFQ entrance with high voltage applied to the cage inside the ion source chamber

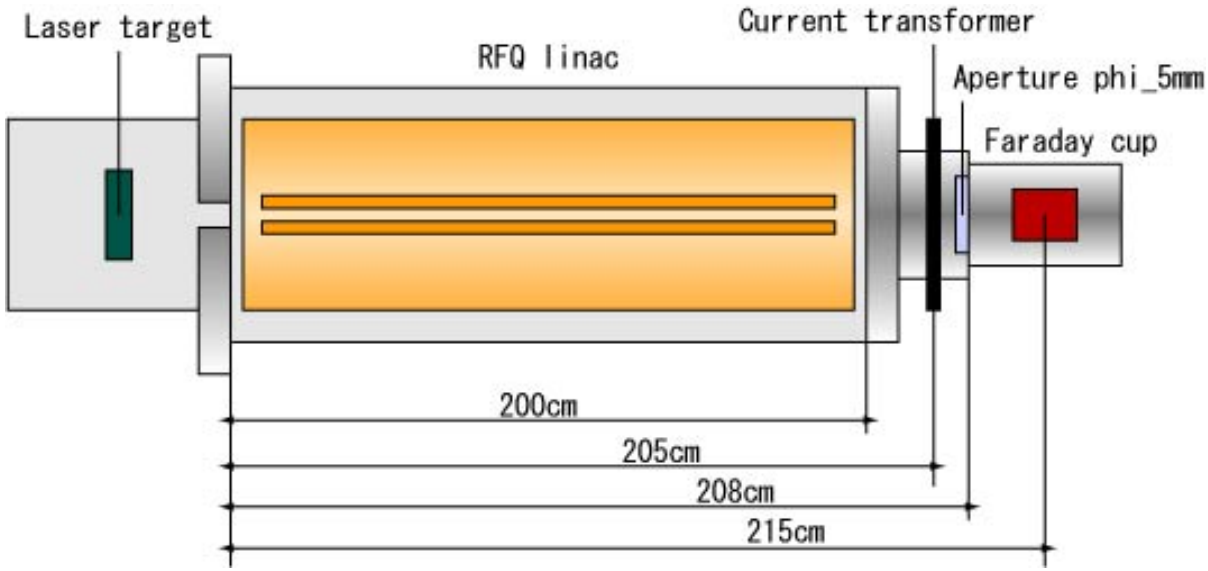
RFQ linac for laser ion source at Brookhaven

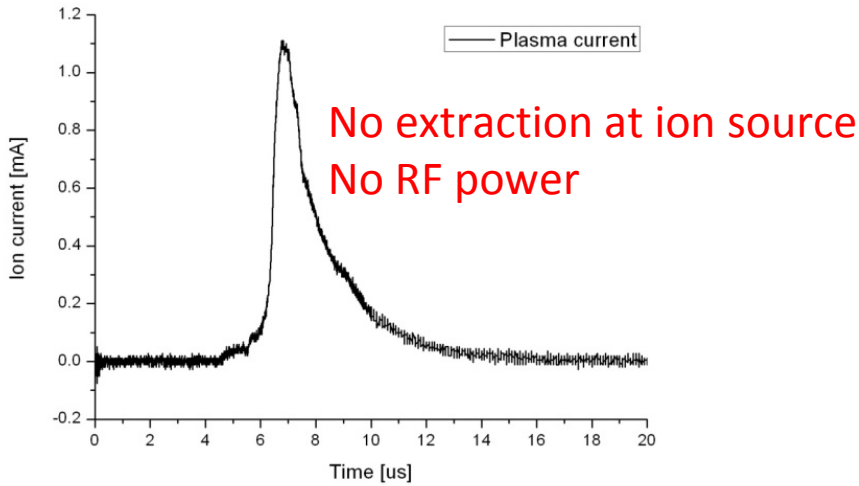


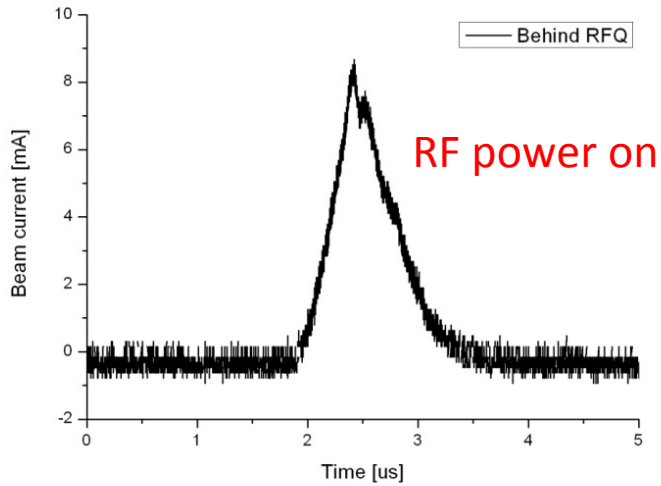
Nd:YAG Laser
Wavelength : 1064 nm
Energy per pulse : 2300 mJ
Pulse duration : 4-8 ns
Beam diameter : 17 mm
Divergence : 0.5 mrad

RFQ Linac
F Frequency : 100 MHz
Energy in : 20 keV/u
Energy out : 100 keV/u
Charge-to-Mass : 1/3
Cell number : 118
Length : 2 m

Ion current from laser plasma and beam current after RFQ



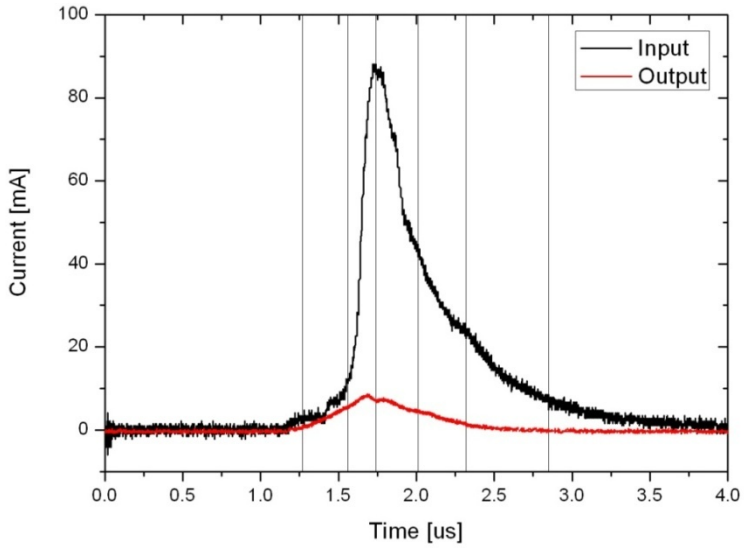




Laser plasma current after 215cm drift
Measured with Faraday cup

Beam current after the RFQ
Measured with current transformer

Transverse transmission



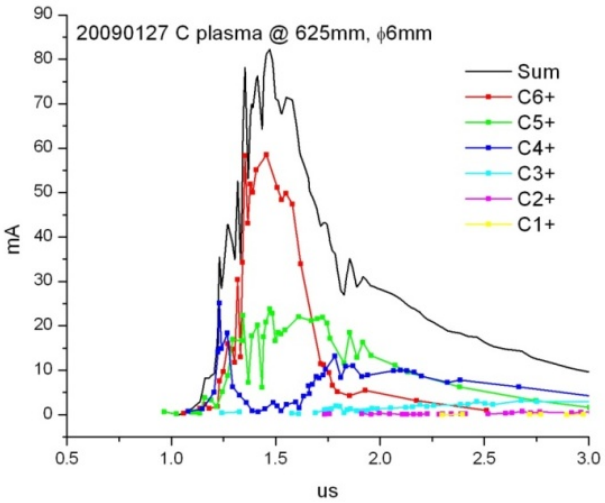
Ion current 215cm far from the target

Current density decrease with L^{-3}

Ion current at 62.5cm from the target

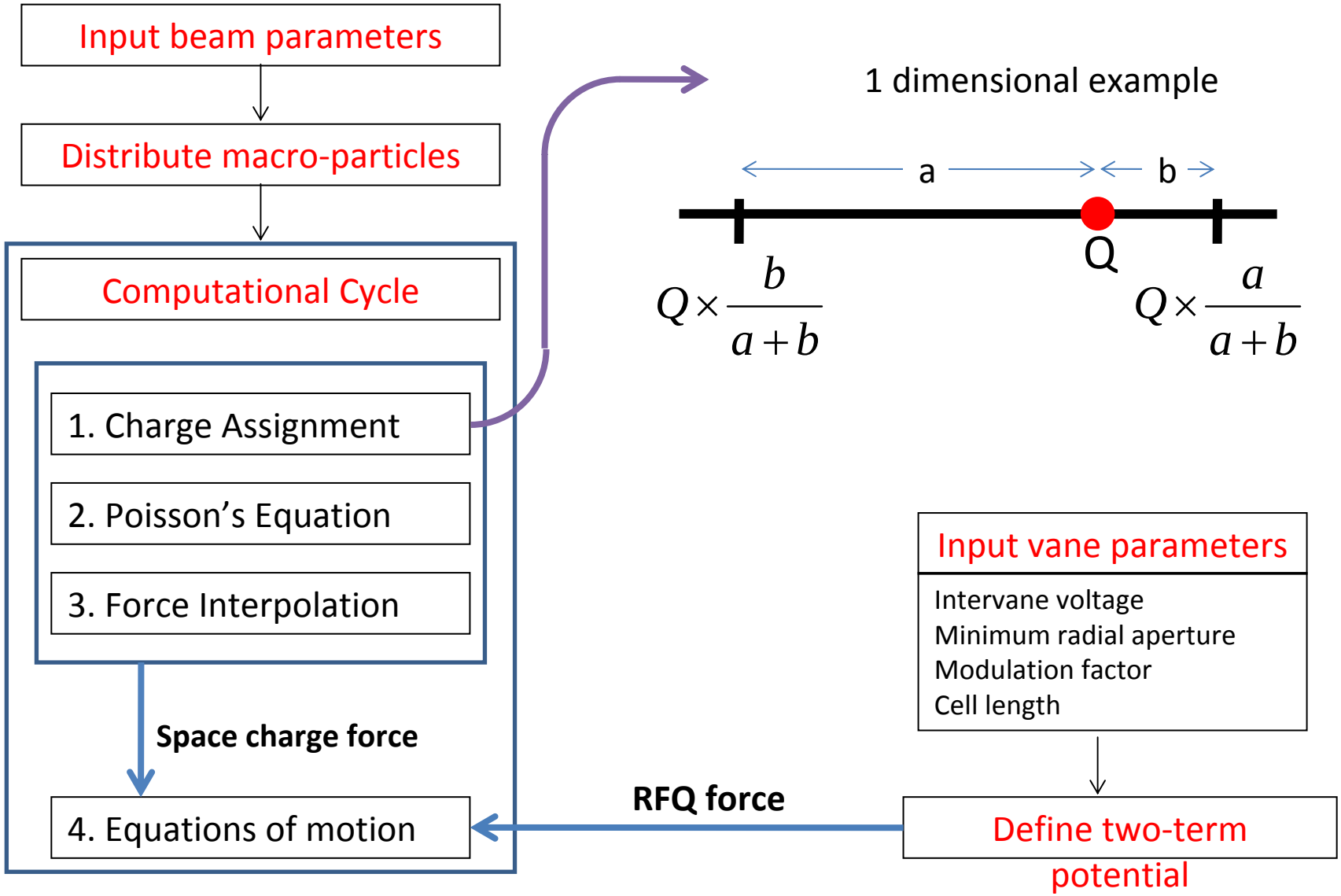
Transverse transmission is about 10 %

Charge distribution measured with electrostatic analyzer

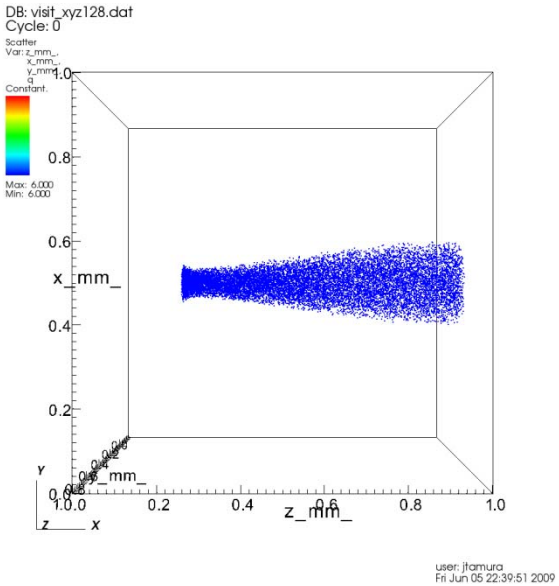


This charge state distribution vs. time is used for the simulation of the output beam pulse.

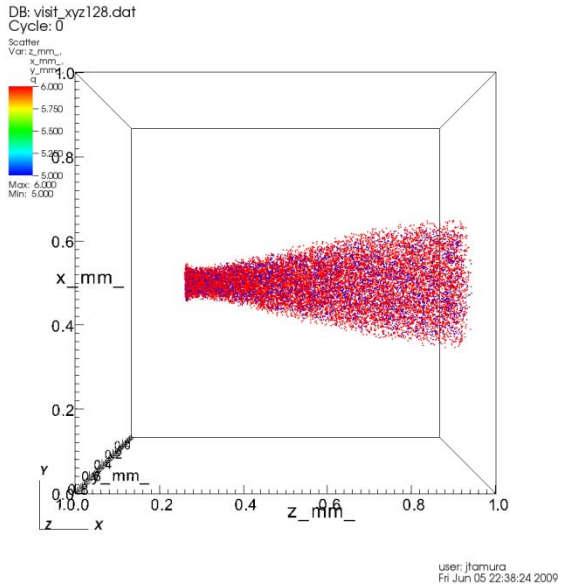
Particle-Mesh method



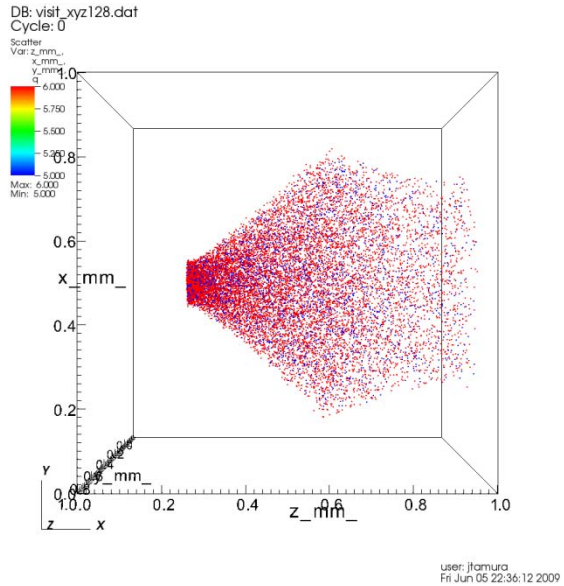
Simulation at different times in the pulse



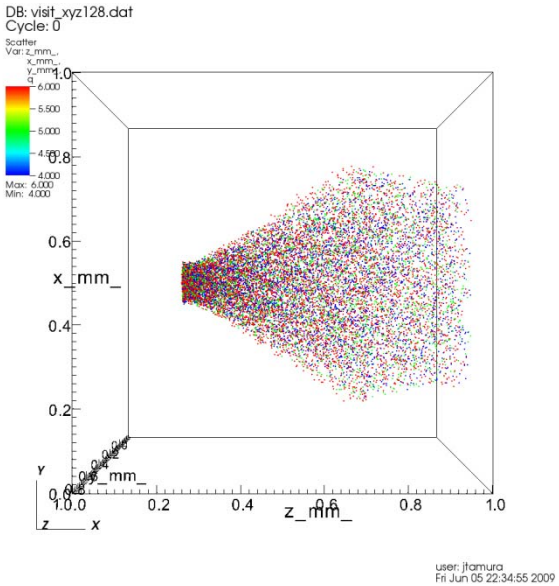
15.0keV (at 1.27us), 5mA



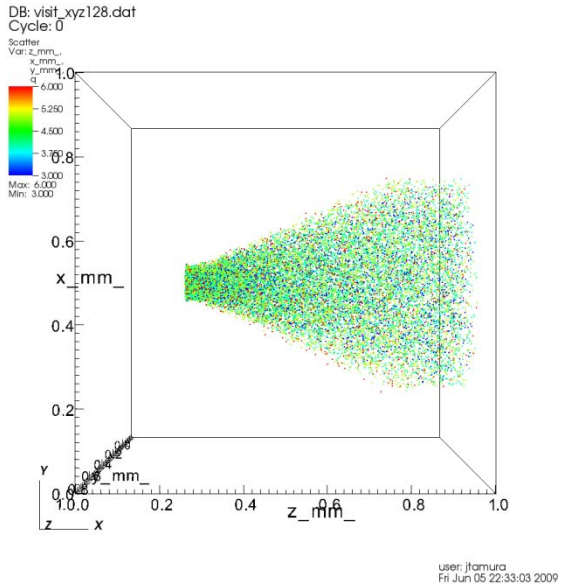
10.0keV (at 1.56us), 10mA



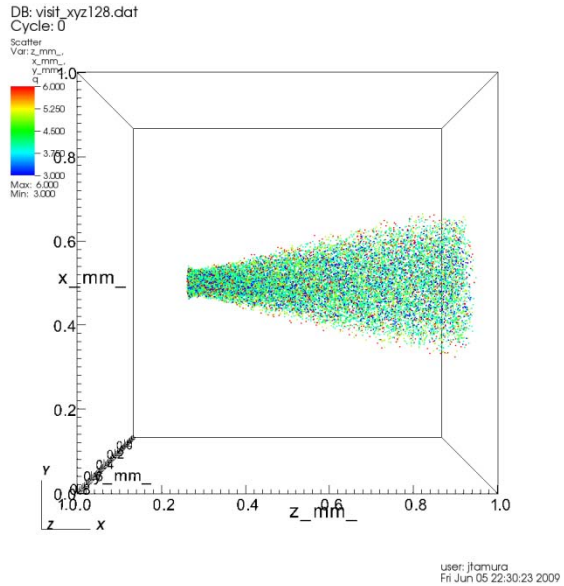
8.0keV (at 1.74us), 80mA



6.0keV (at 2.01us), 40mA

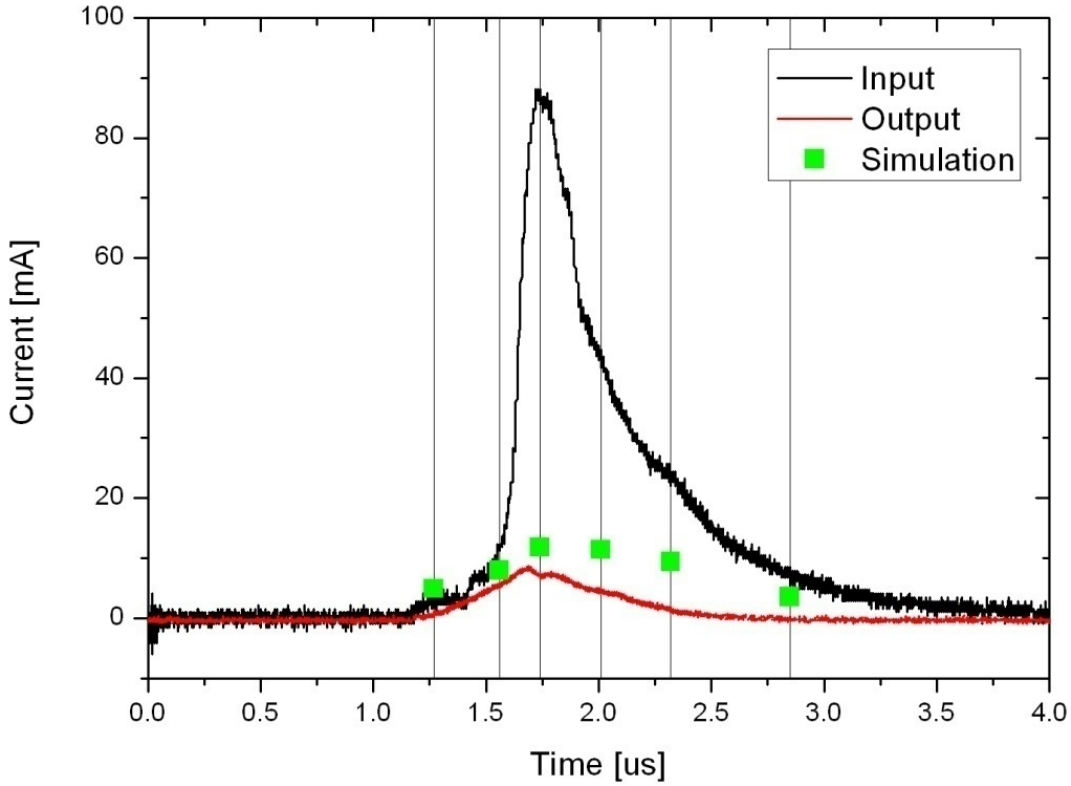


4.5keV (at 2.32us), 20mA



3.0keV (at 2.85us), 4mA

Simulation result



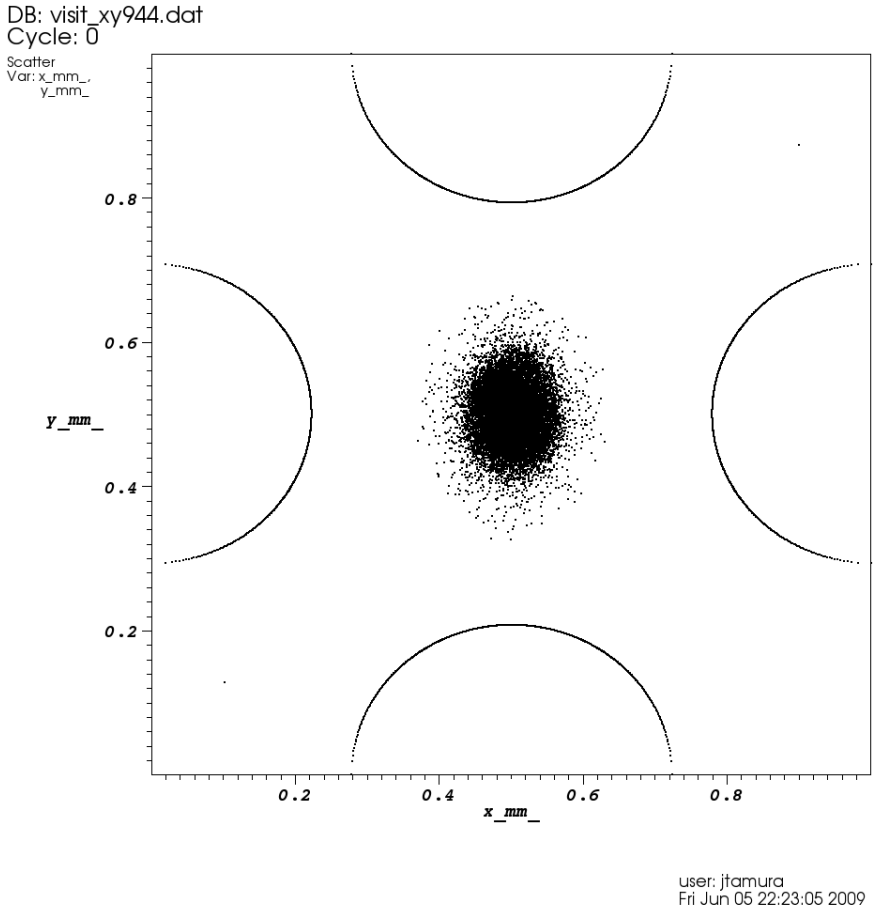
Good agreement at the beginning of the pulse

At the end of the pulse → More consideration about RM section of RFQ

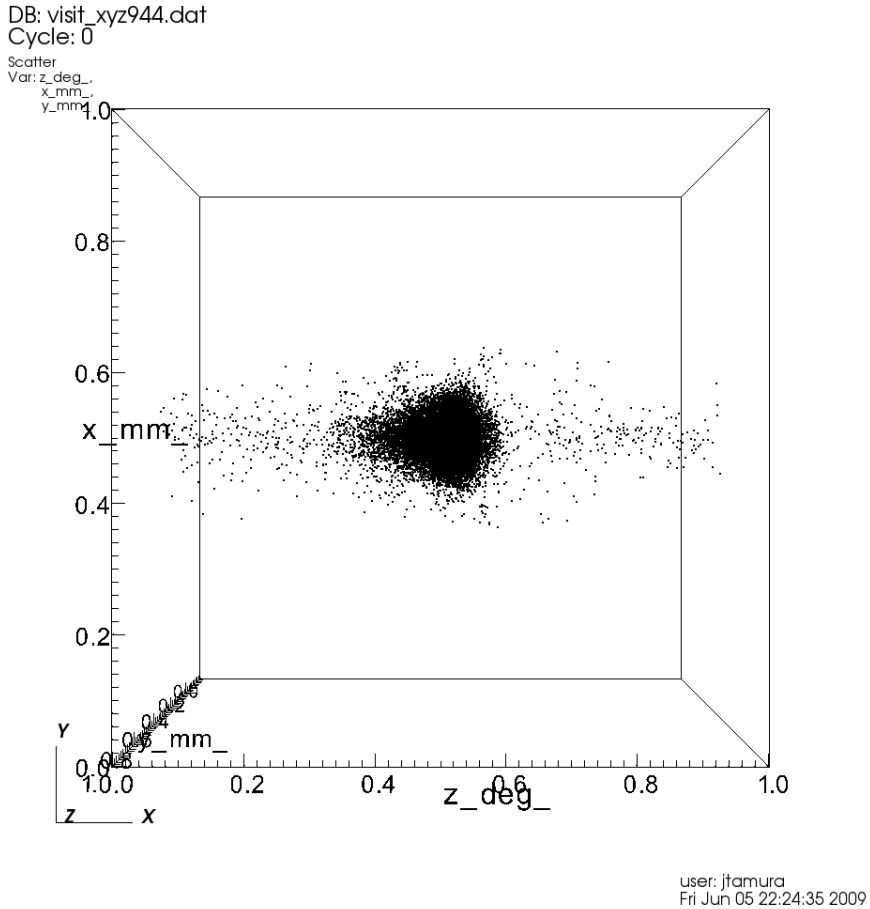
Charge distribution → Longitudinal transmission (accelerated or un-accelerated)

2. Single charge beam acceleration with an RFQ linac

12mA, C5+ acceleration
Designed injection energy (20keV/u) and intervane voltage (96kV)



X - Y plane

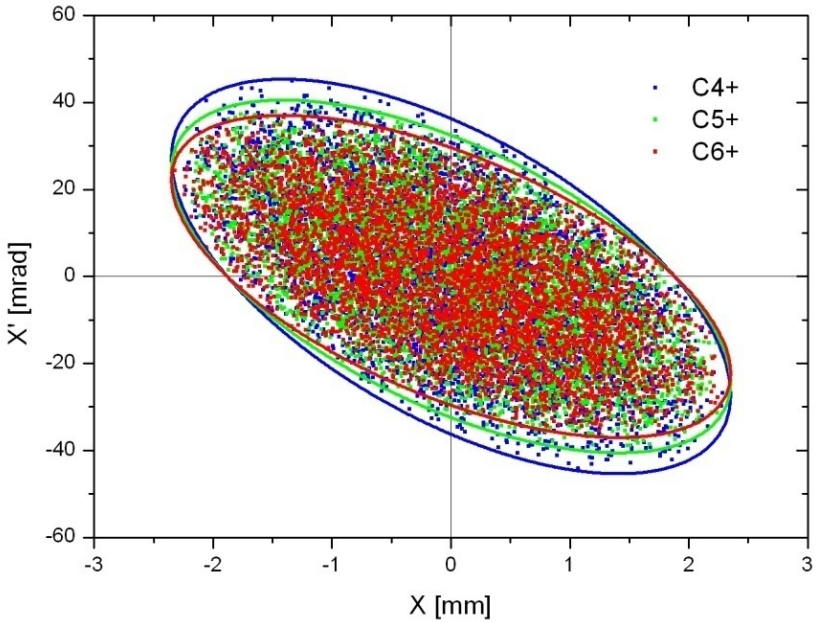


Z-X-Y space

3. Multi charge beam acceleration with an RFQ linac

Parameters for simulation

Frequency = 100.0 MHz
Time step : dt = 0.625 ns (1 RF cycle divided by 16)
1 macro-particle represent about 1000 particles.
Calculation box : 2cm * 2cm * beta*lambda (mesh : 80 * 80 * 160)
Inter-vane voltage : 96kV (for C5+ acceleration)
Elimit = 250.0 keV
944 time steps for 118 cells



Initial distribution on horizontal phase plane

Normalized emittance : 0.5 pi mm mrad

Under the same extraction voltage

⇓

Different injection energy

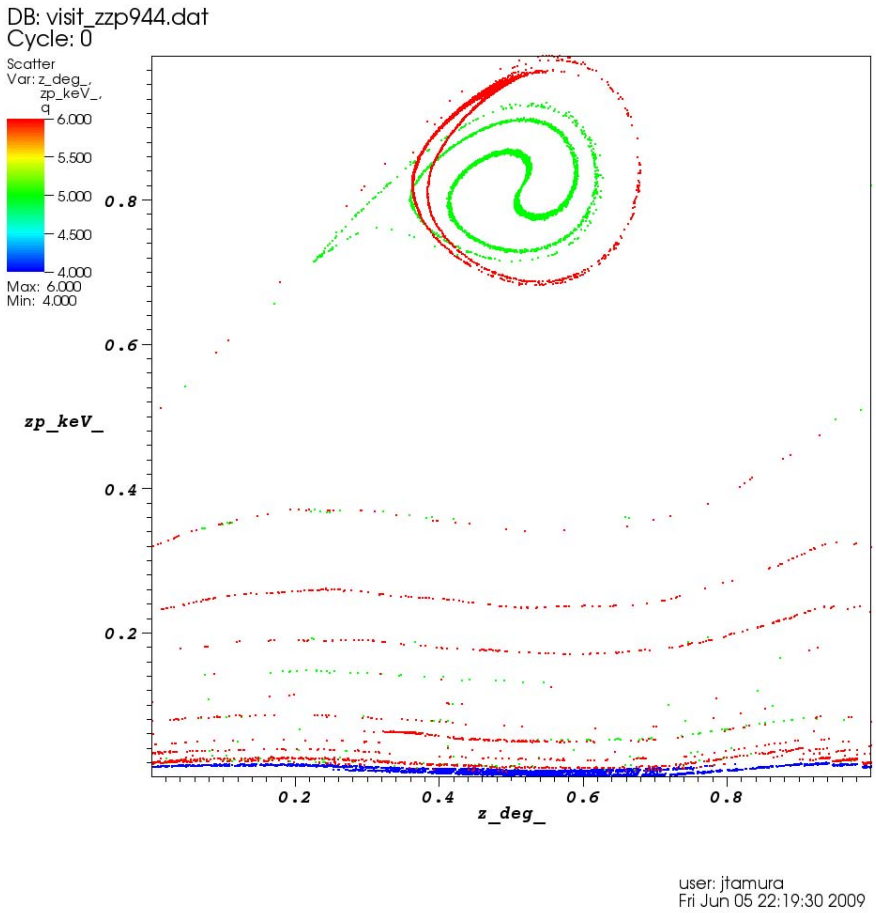
C4+ : 16 keV/u
C5+ : 20 keV/u ⇐ **designed ion**
C6+ : 24 keV/u

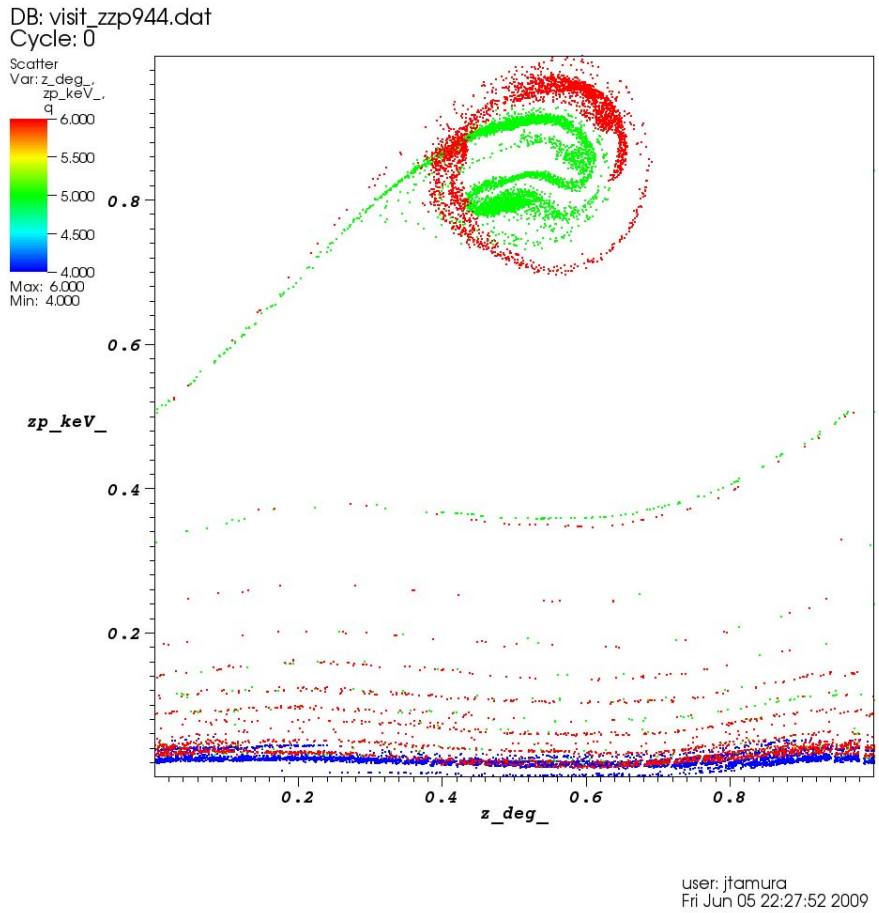
Particle motions on longitudinal phase space

C4+, R-loss : 00.0 %, L-loss : 100 %
C5+, R-loss : 00.0 %, L-loss : 4.04 %
C6+, R-loss : 00.0 %, L-loss : 32.0%

C4+ : Blue
C5+ : Green
C6+ : Red

C4+, R-loss : 00.0 %, L-loss : 100 %
C5+, R-loss : 00.0 %, L-loss : 7.95 %
C6+, R-loss : 0.02 %, L-loss : 46.2 %



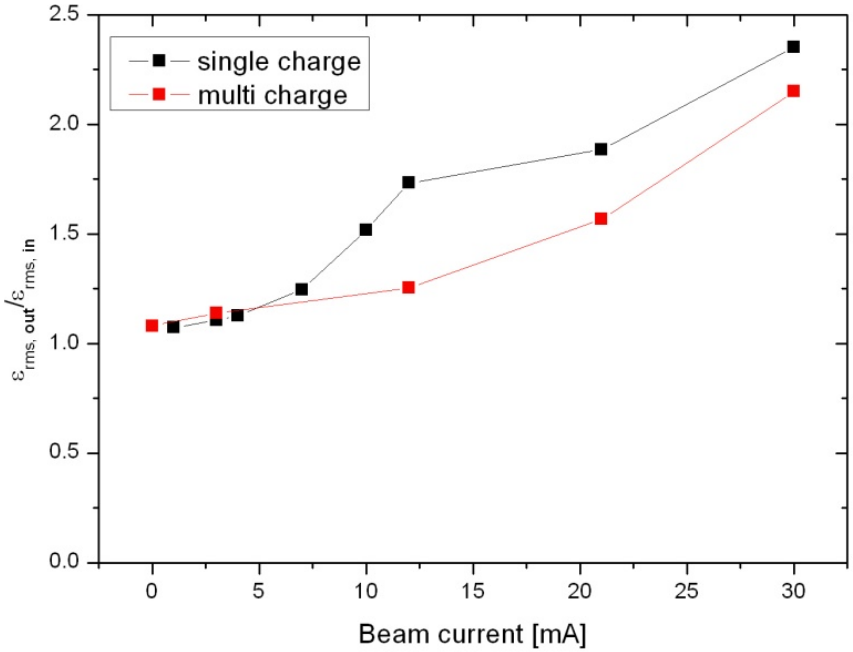


Without space charge

With space charge (total current of 12mA)

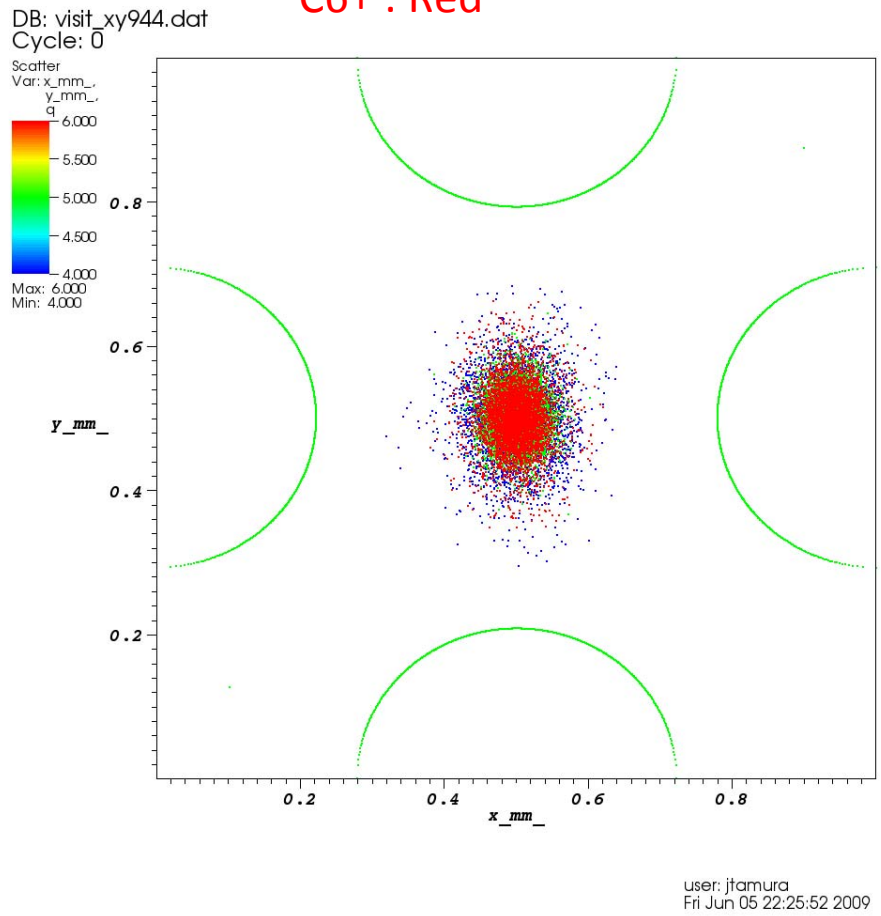
Particle motions in transverse phase plane

Transverse emittance growth
Vs.
Total beam current



Single charge > Multi charge

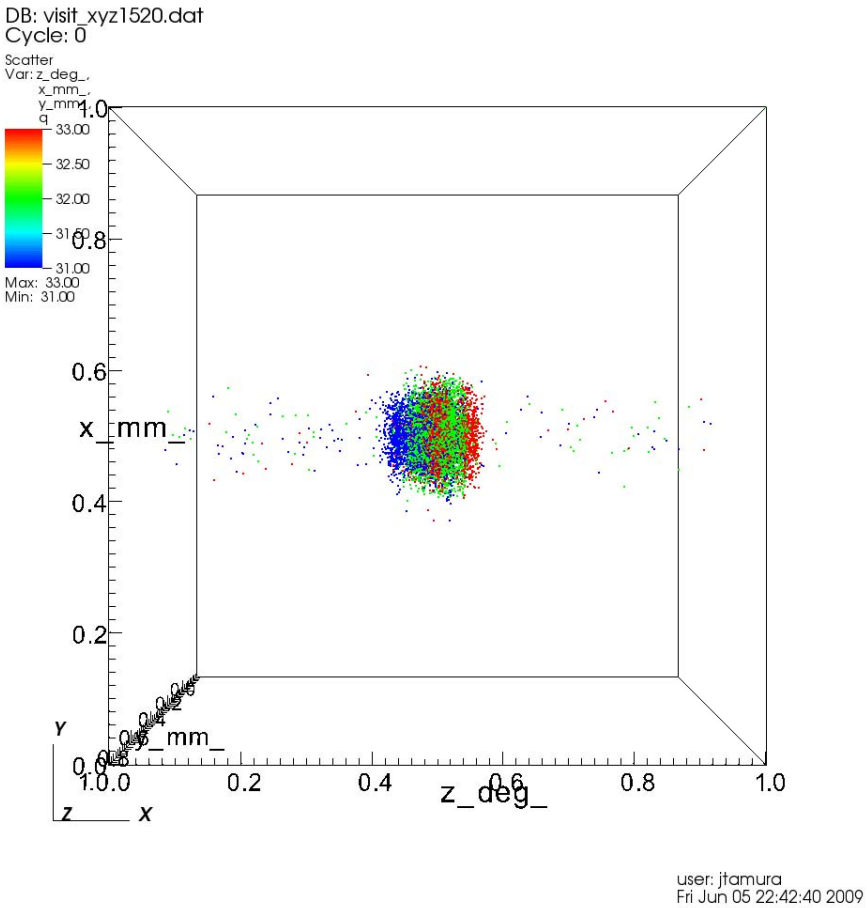
C4+ : Blue
C5+ : Green
C6+ : Red



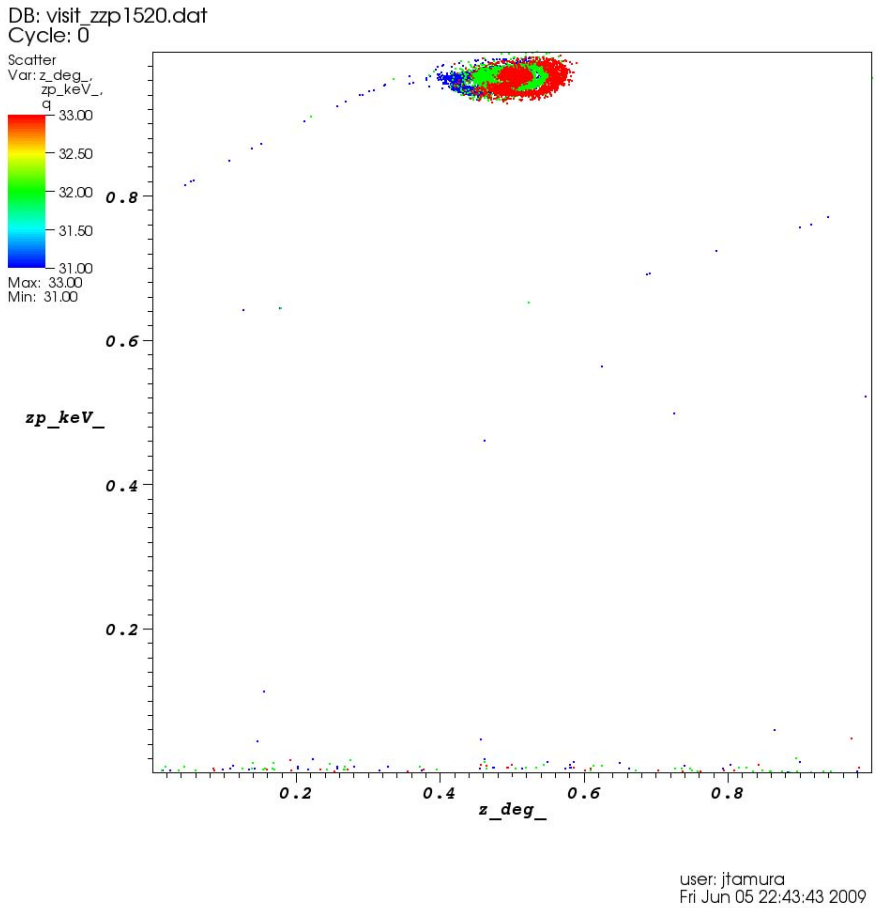
X-Y plane

Au31+, Au32+, Au33+ Acceleration with new EBIS-RFQ

These ions have close charge-to-mass ratio



Z-X-Y space



Longitudinal phase space

Summary

1. Numerical simulation for multiple charge state ion beam acceleration in an RFQ linac

2. Transverse emittance growth with single charge beam and multi charge beam

3. Beam acceleration example for Direct Plasma Injection Scheme

4. Beam acceleration example for EBIS-RFQ for RHIC injector at BNL

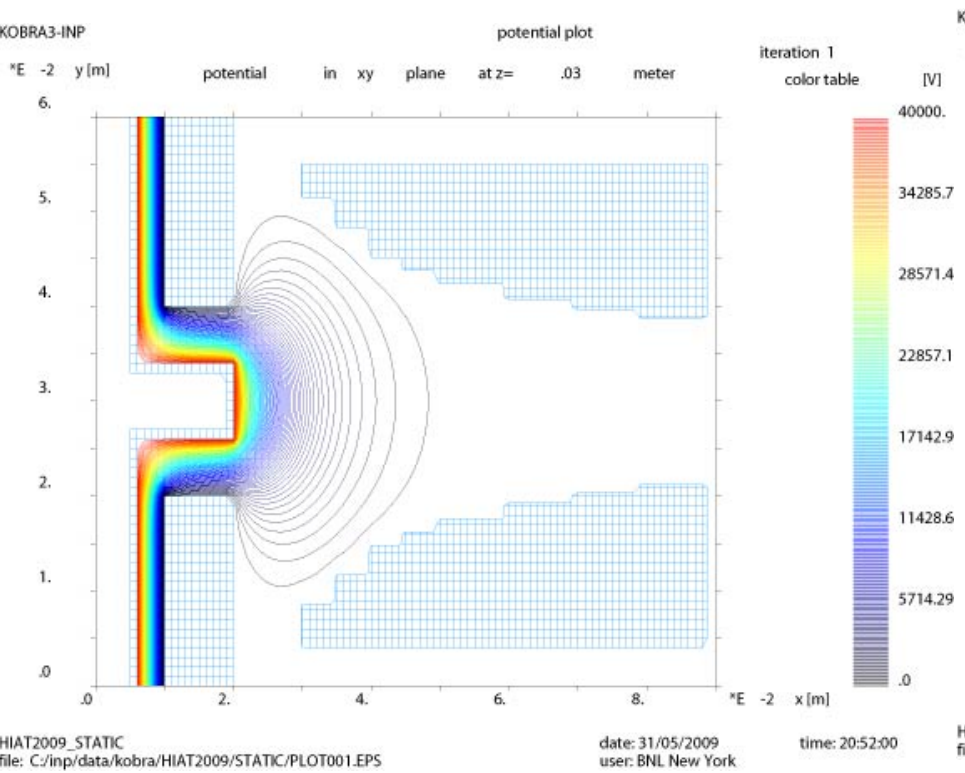
5. Importance of multi charge effect to designed particle

Thanks for your attention

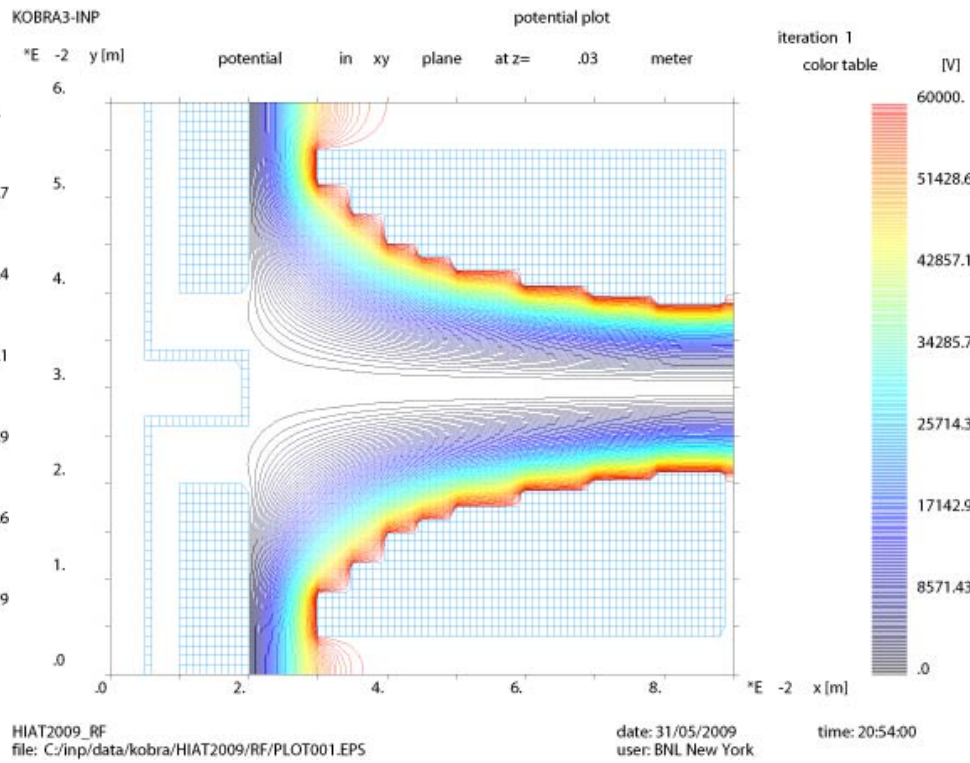
Electric field potential at RFQ entrance section

The most characteristic part of Direct Injection Scheme

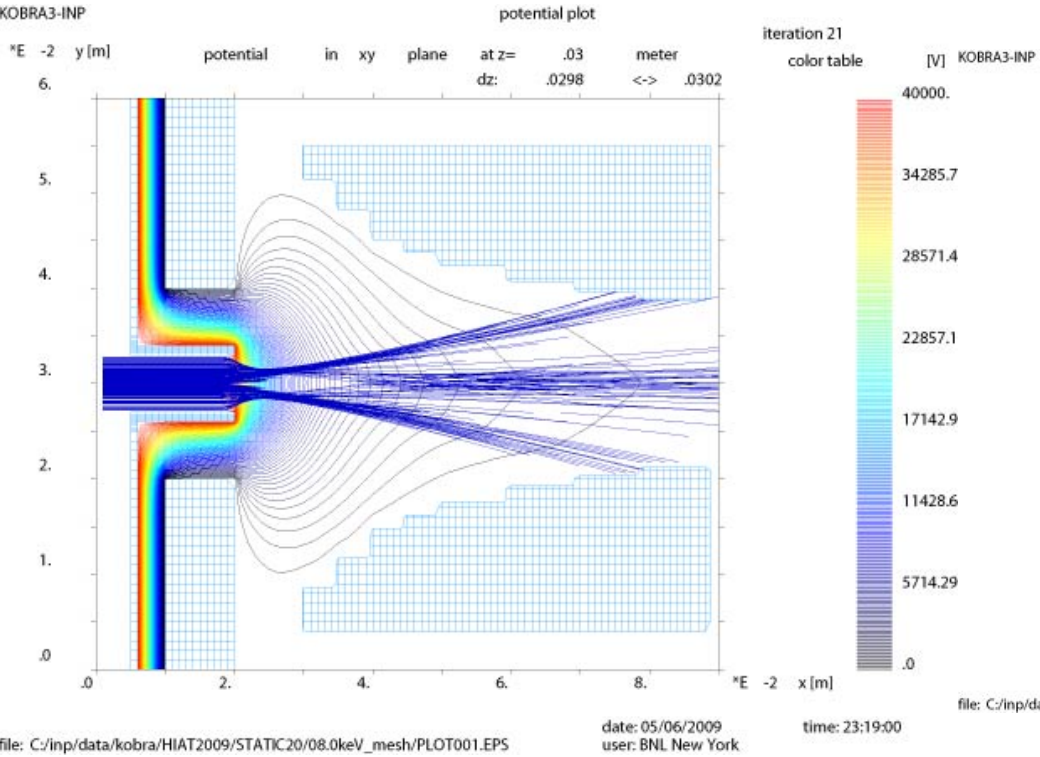
External electric field from static and RF obtained separately by using KOBRA3-INP

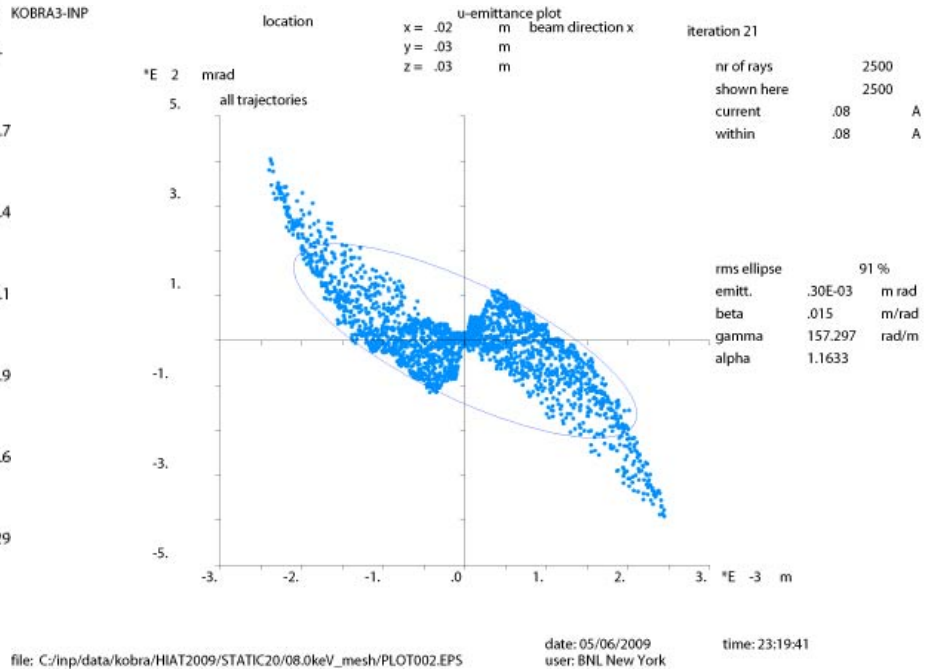


STATIC



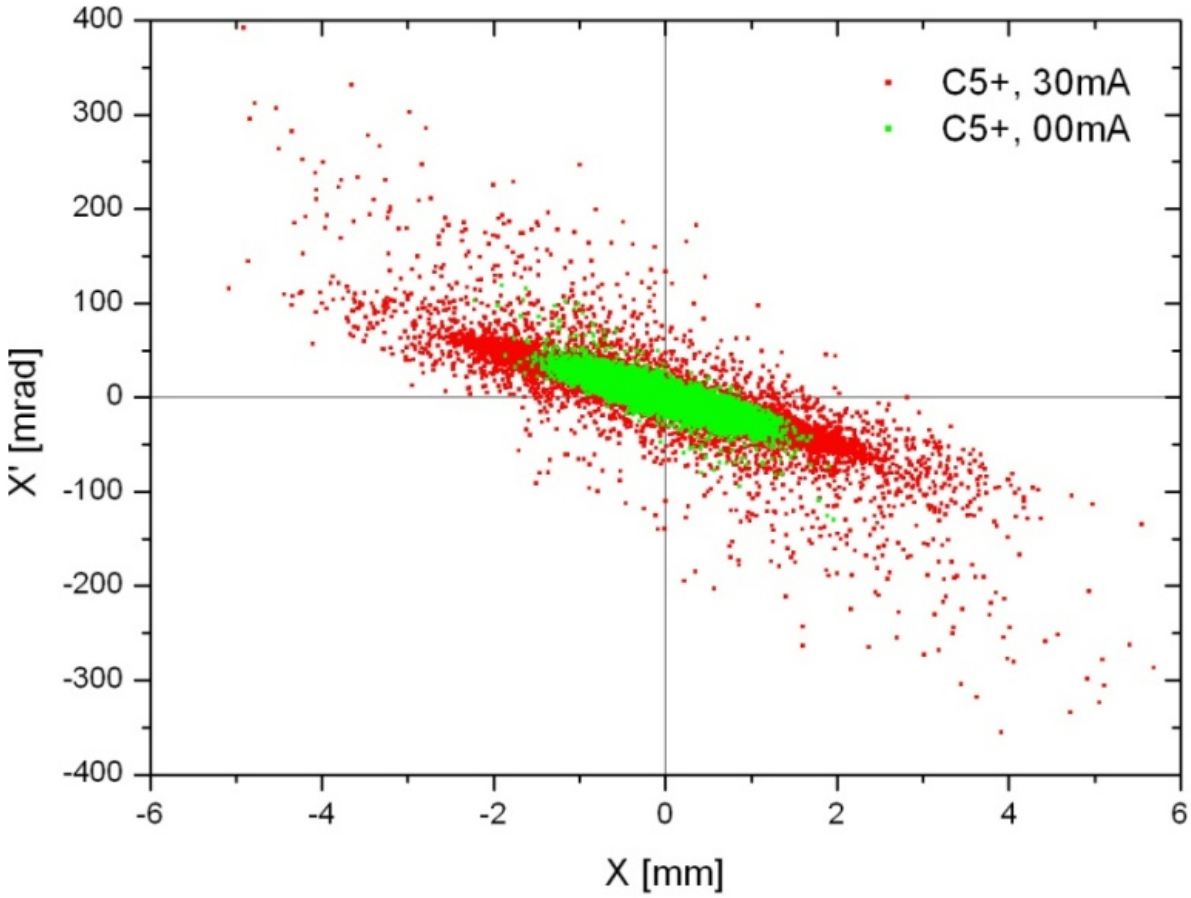
RF


KOBRA3-INP
potential plot
*E -2 y [m]
potential in xy plane at z= .03 meter
dz: .0298 <-> .0302
6.
5.
4.
3.
2.
1.
.0
.0
2.
4.
6.
8.
*E -2 x [m]
iteration 21
color table [V] KOBRA3-INP
40000.
34285.7
28571.4
22857.1
17142.9
11428.6
5714.29
.0
file: C:/inp/data/kobra/HIAT2009/STATIC20/08.0keV_mesh/PLOT001.EPS
date: 05/06/2009
user: BNL New York
time: 23:19:00


location
u-emittance plot
x = .02 m beam direction x
y = .03 m
z = .03 m
iteration 21
*E 2 mrad
all trajectories
5.
3.
1.
-1.
-3.
-5.
-3.
-2.
-1.
.0
1.
2.
3.
*E -3 m
nr of rays 2500
shown here 2500
current .08 A
within .08 A
rms ellipse 91 %
emitt. .30E-03 m rad
beta .015 m/rad
gamma 157.297 rad/m
alpha 1.1633
file: C:/inp/data/kobra/HIAT2009/STATIC20/08.0keV_mesh/PLOT002.EPS
date: 05/06/2009
user: BNL New York
time: 23:19:41

C4+
Initial energy : 16.0 keV/u
Alpha : 0.750
Beta : 0.0648 mm/mrad
Emit : 85.310 pi mm mrad
C5+
Initial energy : 20.0 keV/u
Alpha : 0.750
Beta : 0.0725 mm/mrad
Emit : 76.301 pi mm mrad
C6+
Initial energy : 24.0 keV/u
Alpha : 0.750
Beta : 0.0794 mm/mrad
Emit : 69.658 pi mm mrad

RFQ output emittance with and without space charge



Horizontal phase space at 117.5 cell