

High-Intensity Beam simulation for IFMIF / like Accelerator

Seok Ho Moon & Moses Chung

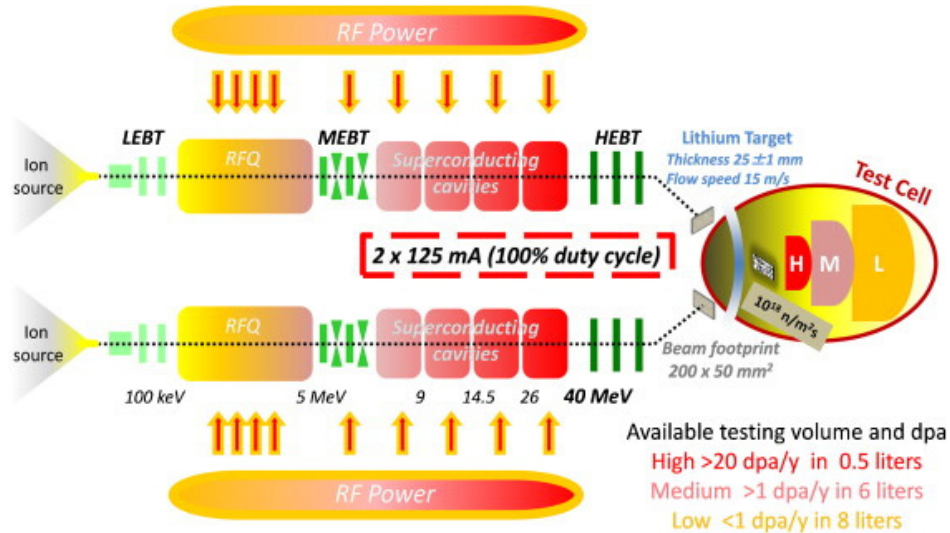
2018. 06. 21 Thursday

Intense Beam and Accelerator Laboratory
Ulsan National Institute of Science and Technology

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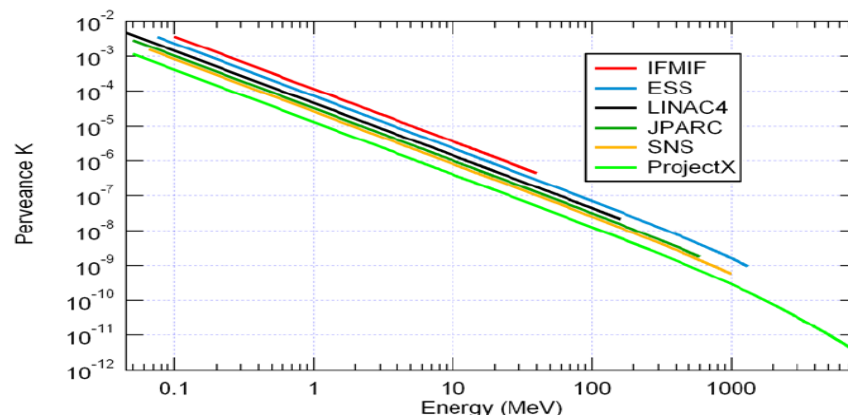
- Introduction
- Low Energy Beam Transport (LEBT)
- Medium Energy Beam Transport (MEBT)
- Summary & Future plan

IFMIF



Particle Type : D^+
Beam Current : 125mA
Operation Type : CW

IFMIF/EVEDA, 2018, What is IFMIF, [http://www.ifmif.org/?page_id=6], Accessed May 24, 2018



Phu Anh Phi Nghiem et al, The IFMIF – EVEDA challenges in beam dynamics and their treatment (2011)

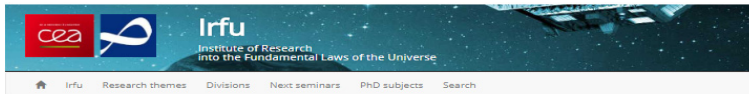
$$\text{Perveance } K = \frac{I}{I_0} \cdot \frac{2}{\beta^3 \gamma^3} \cdot (1 - \gamma^2 f_e)$$

f_e : neutralization factor

TRACEWIN & WARP

< TRACEWIN >

Developer: Researchers of CEA

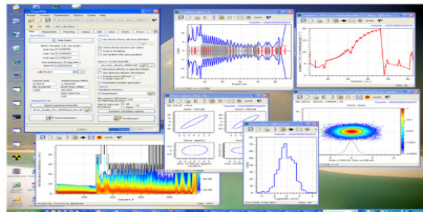


TraceWin rapid explanation

TraceWin is used for linear and non linear calculations for 2D or 3D ions or electrons beams. It permits fast beam envelop computations or/and can be used as a GUI for Toutatis and Partran (macroparticle transport in linacs). The code is capable to match the beam to a channel. The different elements of a linac can be tuned (EM fields amplitude, length, phase for cavity) to obtain phase advance law or to set the beam size or Twiss parameters at different locations. Multiparticle transport can be executed transparently compared to envelope computations, this allows to easily study the impact of non linear effects. It is possible to plot most of relevant value about linac structure or beam. Zoom, hardcopy, save on disk, scale change, copy-paste tools are available. Sensitivity to element errors in a linac can be studied by using a Monte Carlo approach. A huge number of cases can be simulated remotely via a home made client/server architecture. A heterogeneous array of machines can be used.

Main features:

- A wide range elements including RFQ with Toutatis module.
- 1D, 2D, 3D static and dynamic fields map (with superposition capability).
- envelope and macro-particle tracking simulations.
- start-to-end simulations from source to target.
- transport of two beams in the same structure.
- gas stripping and scattering analysis.
- automatic transverse and longitudinal beam tuning.
- correction procedure based on diagnostics.
- static and dynamic error simulations for all elements.
- simulations with large number of particles for large scale computations (Monte Carlo) based on a client/server architecture.
- statistic analysis including beam loss location.
- GUI and various help tools.
- Windows/Linux/MACOS versions.
- reference code for IMFIF, LINAC4, SPIRAL2, EUROTRANS, EURISOL and SPL projects.
- successful comparison with experiments at the UNILAC (GSI).



Contact: Didier URIOT
didier.uriot@cea.fr

<http://irfu.cea.fr/dacm/en/logiciels/index.php>

Second order momentum / Macroparticle

< WARP >

Developer: D.Grote, J.L.Vay,
A.Friedman, S.Lund

Warp

Navigation

Home

The Team
Example simulation scripts
Warp at Bitbucket
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How To's

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Running Warp
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Lattice
Diagnostics and Plots
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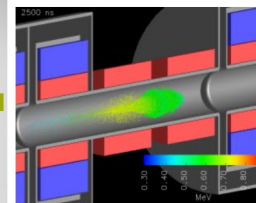


Fig. X-Z projection of an inductively focused/accelerated short-pulse beam in the NDCX-II accelerator. Solenoid and induction cell elements are shown and beam particles are color coded by axial kinetic energy (D.P. Grote, 2010).

Overview

Warp is an extensively developed open-source particle-in-cell Python package designed for simulation of plasmas and high current particle beams in a range of applications. The name "Warp" stems from the code's ability to simulate Warped (bent) Cartesian meshes. This bent-mesh capability allows the code to efficiently simulate space-charge effects in bent accelerator lattices (resolution can be placed where needed) associated with rings and beam transfer lines with dipole bends.

Warp has a broad variety of integrated physics models and extensive diagnostics -- most of which work in multiple dimensions to allow examination of modeling idealizations within a common framework.

History

Warp was first developed by Alex Friedman in the 1980s at LLNL following a Livermore Lab model of steerable compiled code modules linked to an interpreter. The Warp code has been continuously and extensively extended by David Grote (LLNL/LBNL) from the late 1980s to the present with key contributions from others in the [Warp team](#) to achieve it's present highly developed state.

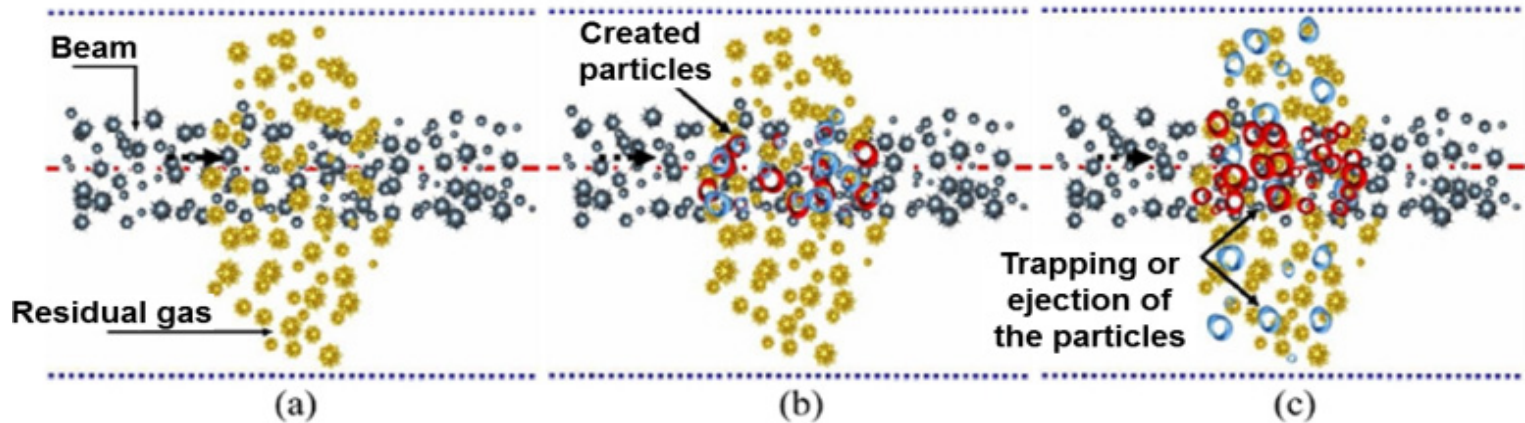
<http://warp.lbl.gov/home>

Full PIC

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SCC(Space Charge Compensation)

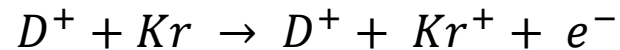


Nicolas, Chauvin. Space-Charge effect.(2014):12

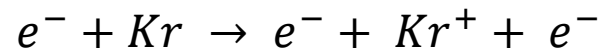
Neutralization time: $\tau_n = \frac{1}{n_g \sigma_i v_b}$

Atomic Processes

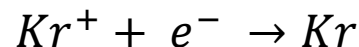
1. Ionization by beam



2. Ionization by electron

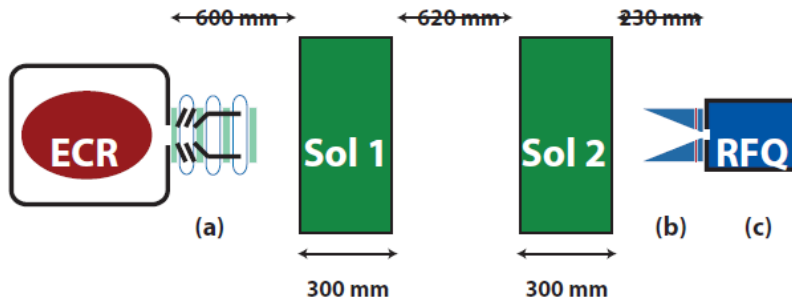


3. Recombination



Schematic of LEBT & Parameter

Schematic of IFMIF LEBT



Nicolas, Chauvin et al. Final Design of the IFMIF-EVEDA Low Energy Beam Transport Line. PAC (2009): 1-2

Lattice parameter

Value

Beam Pipe Radius

80mm

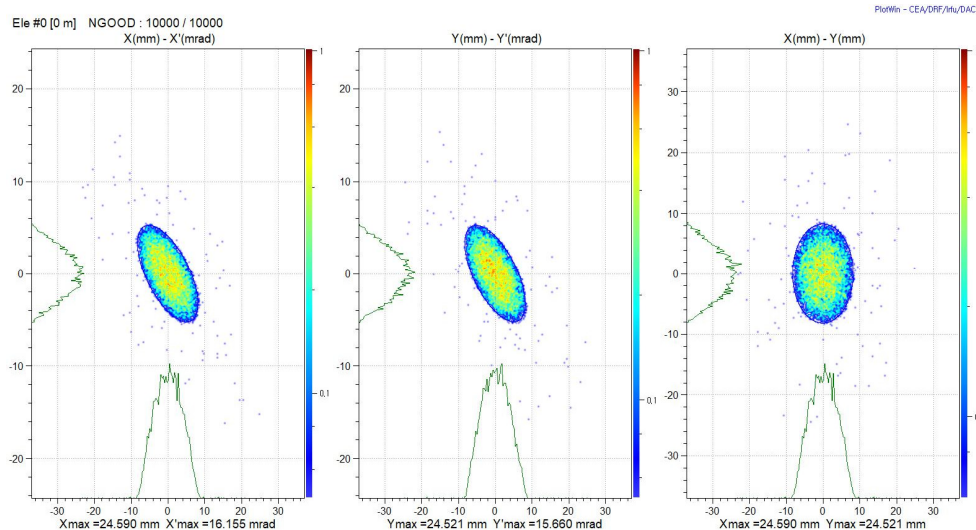
Cone Radius

35mm, 12mm

B-field of Solenoid

Sol1:0.37T
Sol2:0.47T

Initial Beam Parameter



Beam Parameter

Initial Value

Particle Type

D^+

Beam Current

125mA

Initial Energy

100keV

Emittance

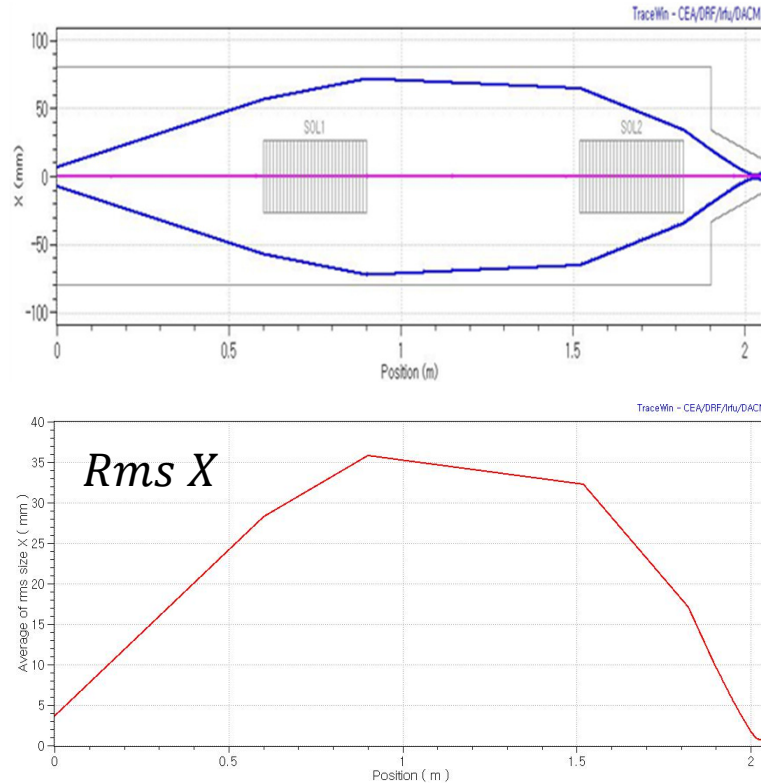
$0.064 \pi \cdot \text{mm} \cdot \text{mrad}$

Twiss Parameter

$\alpha = 0.8, \beta = 2.0$

Without SCC

TRACEWIN



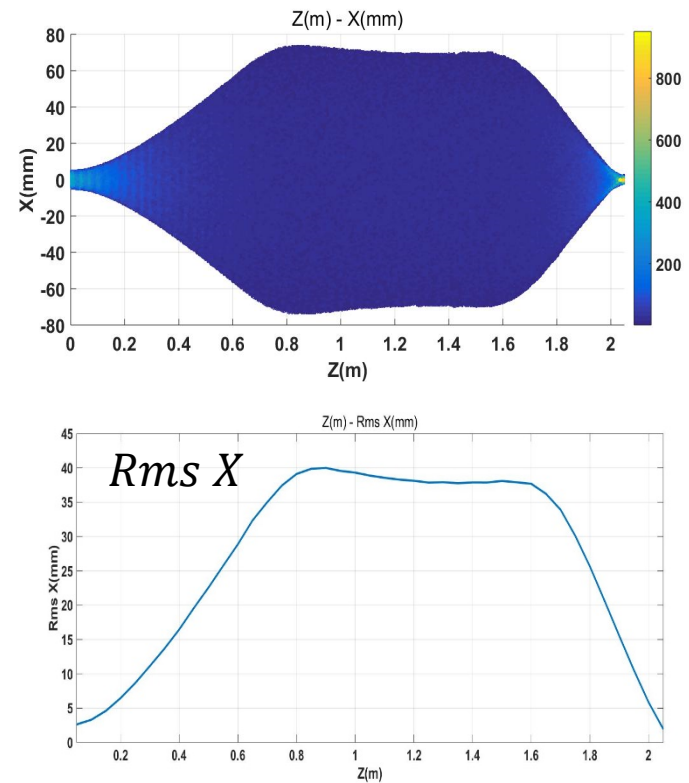
At exit

$$\varepsilon_{n,rms\,x} = 0.2796\pi. mm. mrad$$

$$\varepsilon_{n,rms\,y} = 0.2794\pi. mm. mrad$$

$$\text{Target value: } \varepsilon_{n,rms} = 0.233\pi. mm. mrad$$

WARP



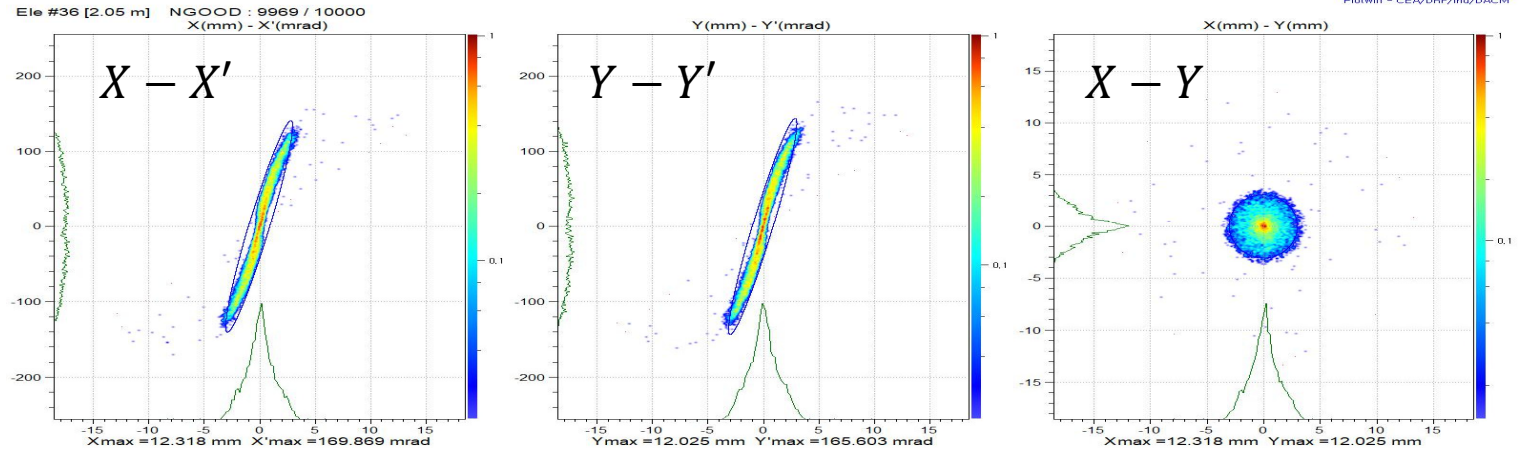
At exit

$$\varepsilon_{n,rms\,x} = 0.3697\pi. mm. mrad$$

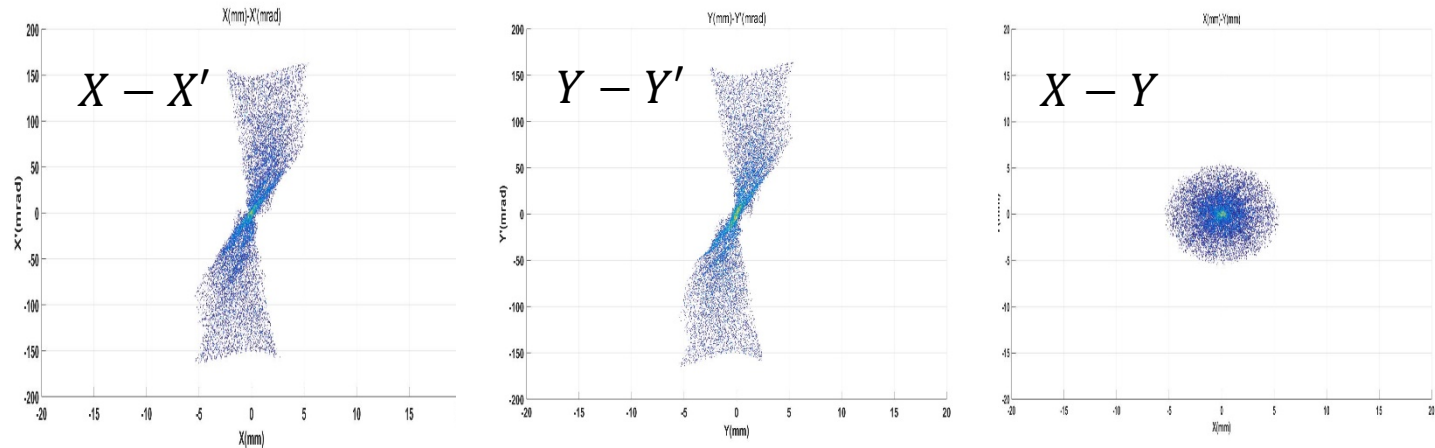
$$\varepsilon_{n,rms\,y} = 0.3778\pi. mm. mrad$$

Without SCC

TRACEWIN

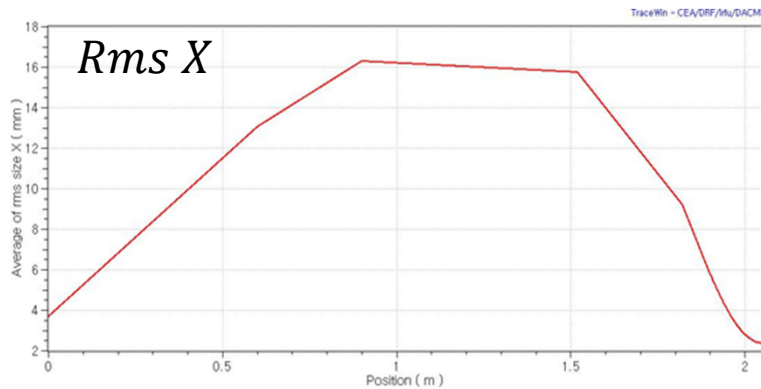
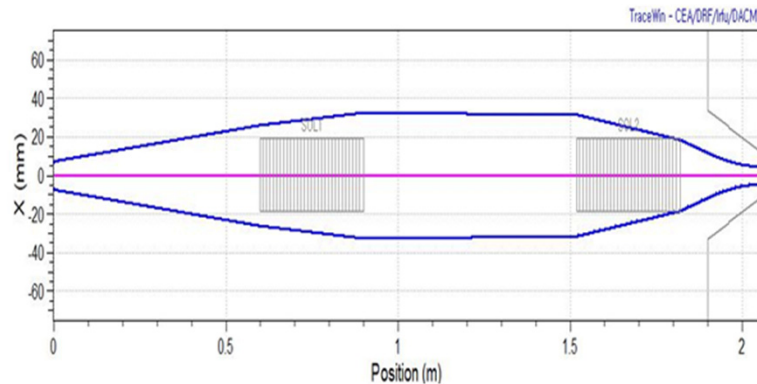


WARP



With SCC

TRACEWIN



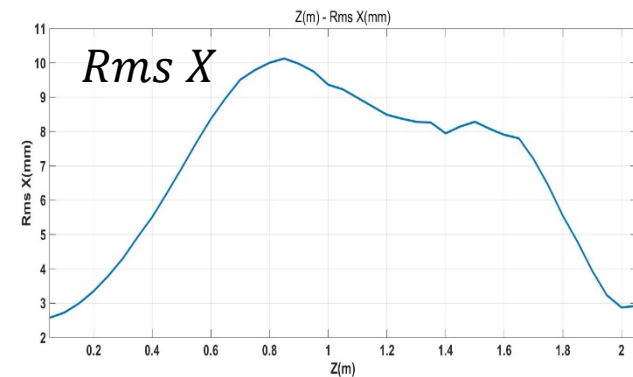
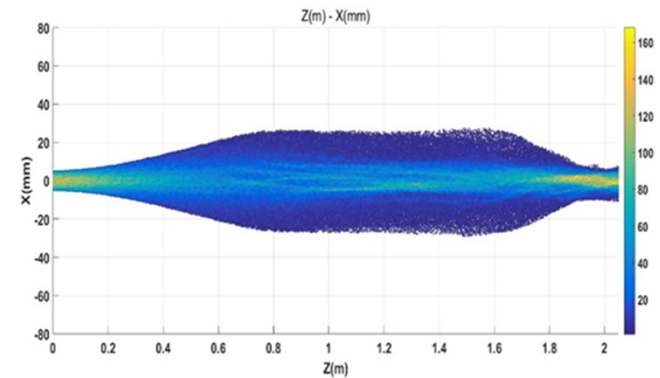
At exit

$$\varepsilon_{n,rms x} = 0.1228\pi. mm. mrad$$

$$\varepsilon_{n,rms y} = 0.1189\pi. mm. mrad$$

$$\text{Target value: } \varepsilon_{n,rms} = 0.233\pi. mm. mrad$$

WARP



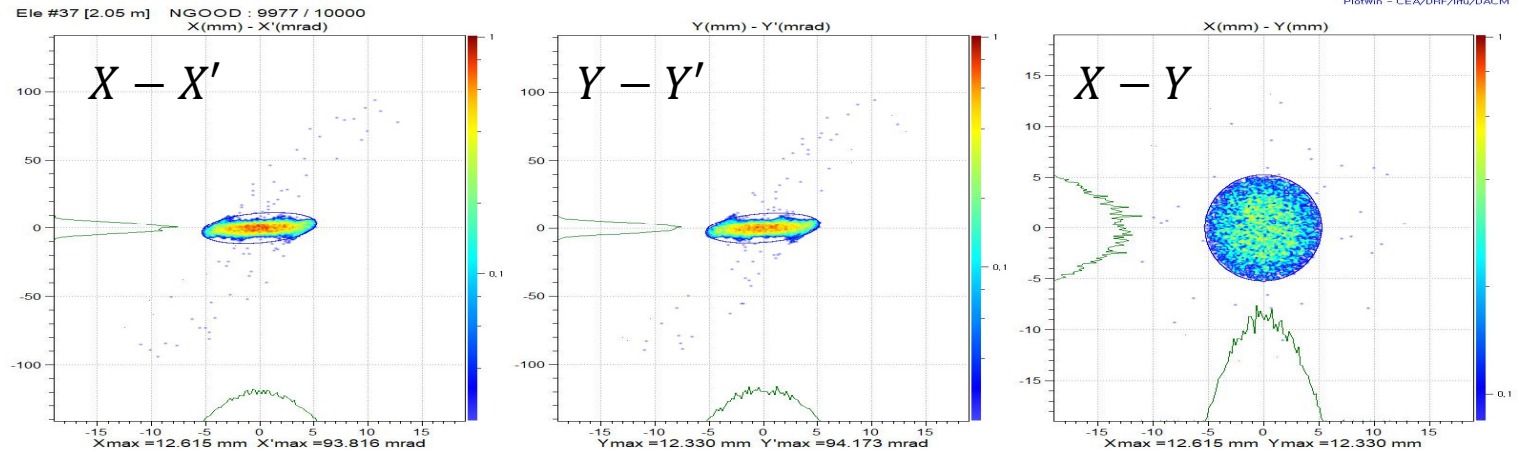
At exit

$$\varepsilon_{n,rms x} = 0.1763\pi. mm. mrad$$

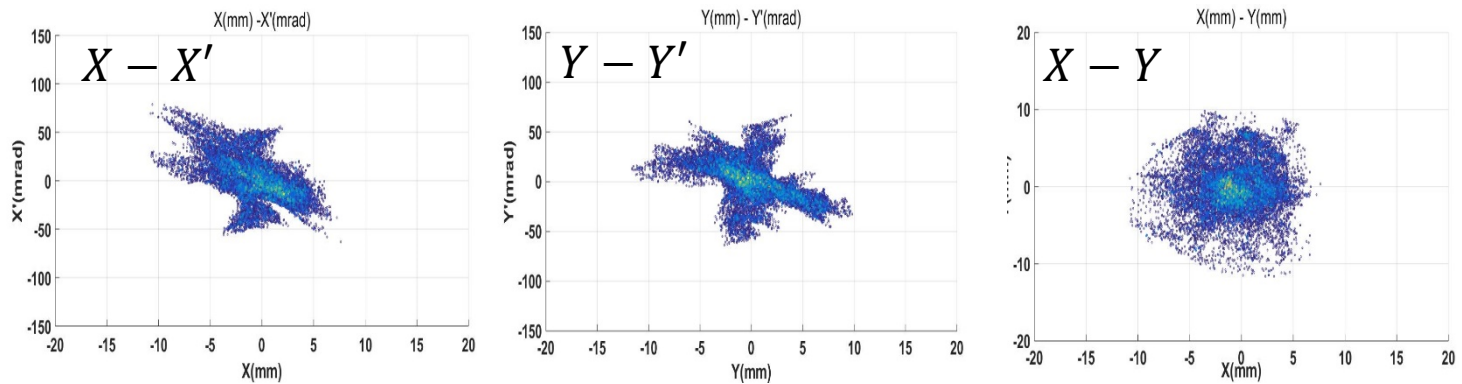
$$\varepsilon_{n,rms y} = 0.1957\pi. mm. mrad$$

With SCC

TRACEWIN

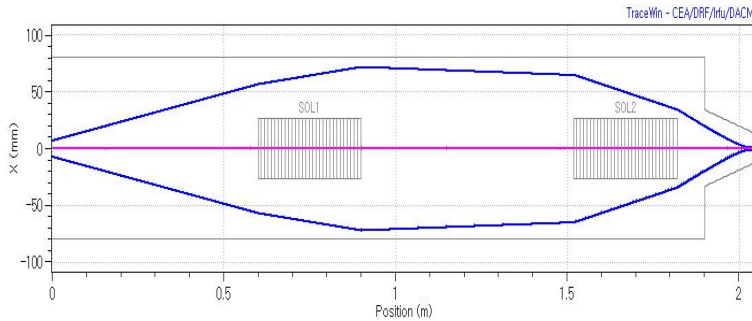


WARP



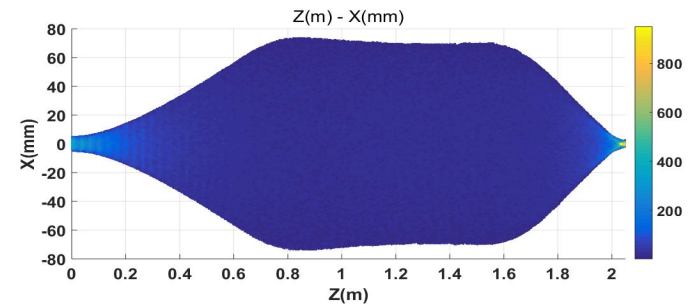
Result Comparison

Without SCC



$$\varepsilon_{n,rms\,x} = 0.2796\pi. mm. mrad$$

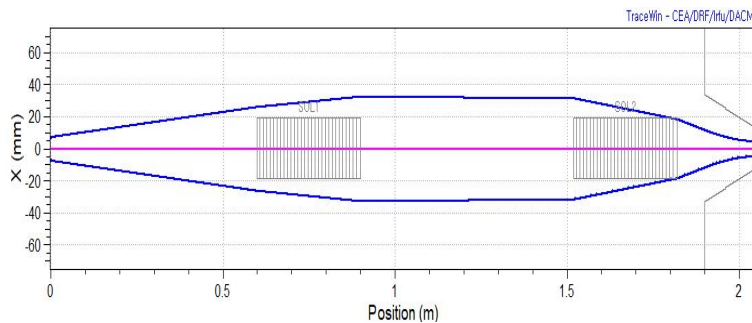
$$\varepsilon_{n,rms\,y} = 0.2794\pi. mm. mrad$$



$$\varepsilon_{n,rms\,x} = 0.3697\pi. mm. mrad$$

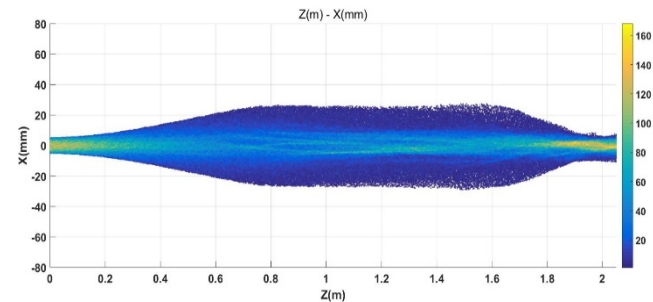
$$\varepsilon_{n,rms\,y} = 0.3778\pi. mm. mrad$$

With SCC



$$\varepsilon_{n,rms\,x} = 0.1228\pi. mm. mrad$$

$$\varepsilon_{n,rms\,y} = 0.1189\pi. mm. mrad$$



$$\varepsilon_{n,rms\,x} = 0.1763\pi. mm. mrad$$

$$\varepsilon_{n,rms\,y} = 0.1957\pi. mm. mrad$$

Target value: $\varepsilon_{n,rms} = 0.233\pi. mm. mrad$

Instability Issue

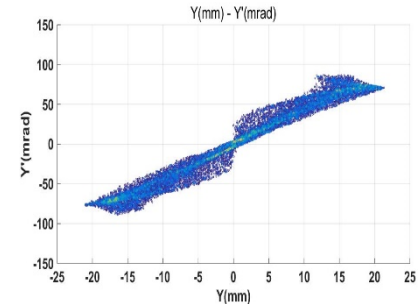
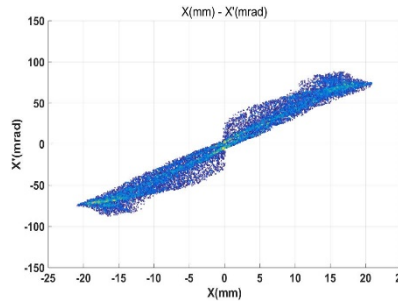
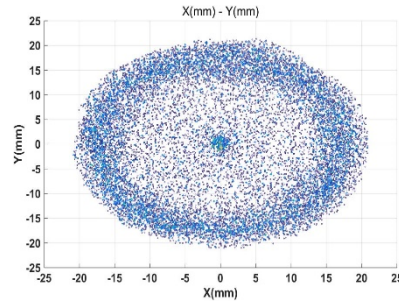
Two stream instability: $F(k, \omega) = \frac{\omega_{pe}^2}{\omega^2} + \frac{\omega_{pi}^2}{(\omega - kv_0)^2}$ (unstable when $F(k, \omega) > 1$)

$X - Y$

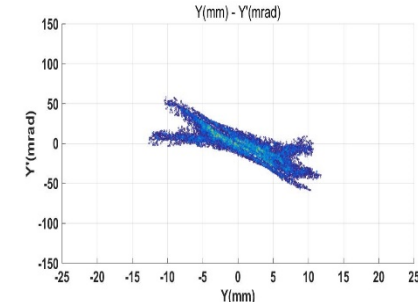
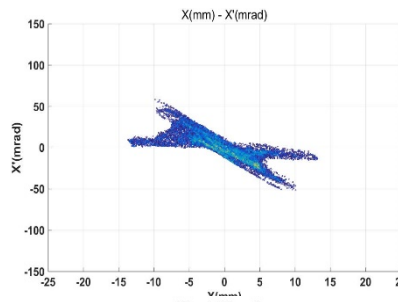
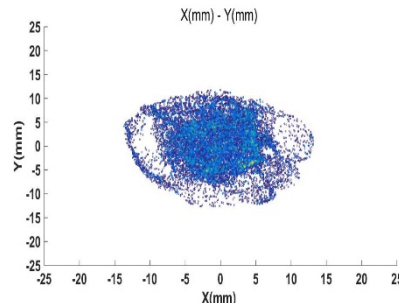
$X - X'$

$Y - Y'$

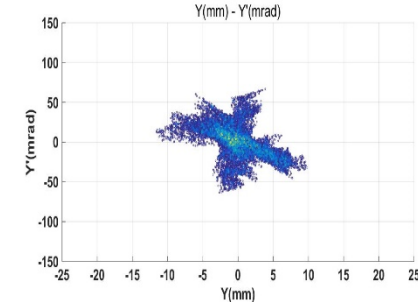
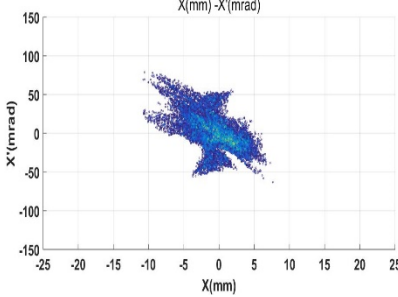
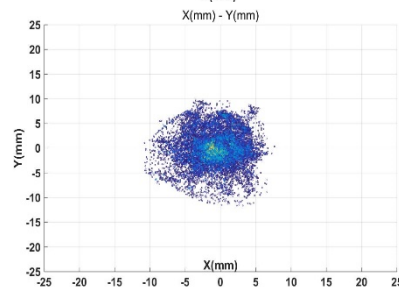
$2\mu s$



$4\mu s$



$6\mu s$

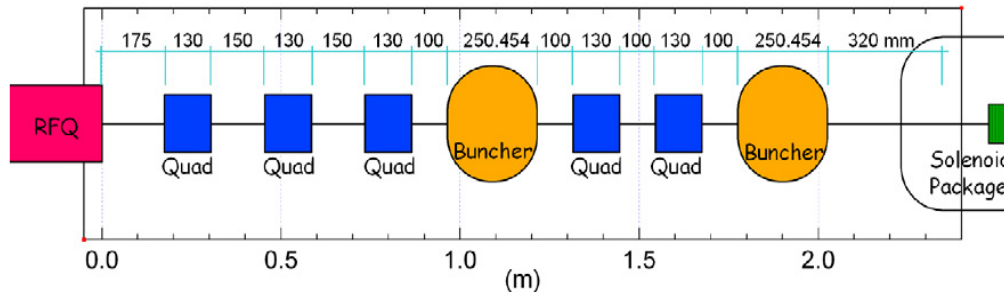


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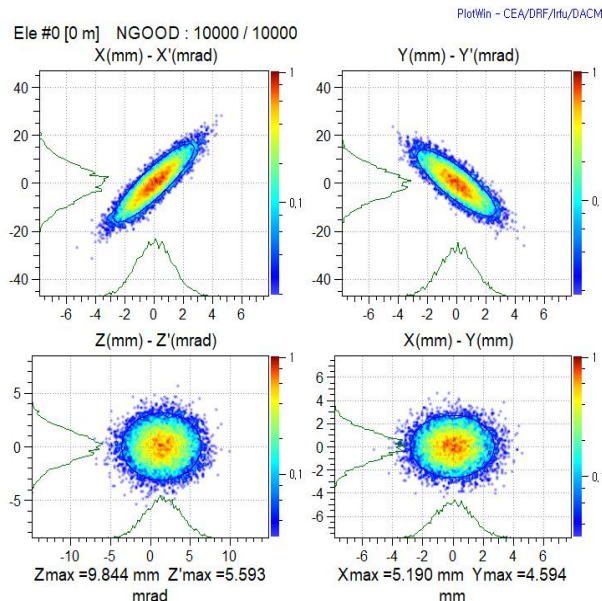
Schematic of MEBT & Parameter

Schematic of IFMIF MEBT



I. Podadera et al. The Medium Energy Beam Transport Line(MEBT) of IFMIF/EVEDA Lipac. IPAC (2011): 1-2

Initial Beam Parameter



Lattice Parameter

Value

Gradient of
Quadrupole

Quad1,2,3:25T/m
Quad4: 20.5T/m
Quad5: 20T/m

Buncher Frequency

175MHz

Maximum $E_0 LT$

350kV

Beam Parameter

Initial Value

Particle Type

D^+

Beam Peak Current

125mA

Initial Energy

4.98MeV

Longitudinal Emittance

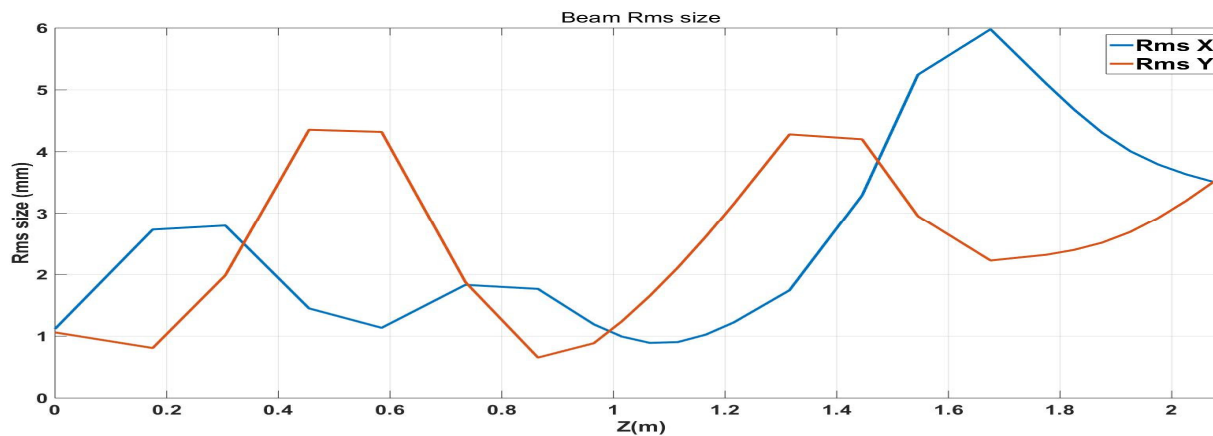
$0.3 \pi. mm. mrad$

Twiss Parameter

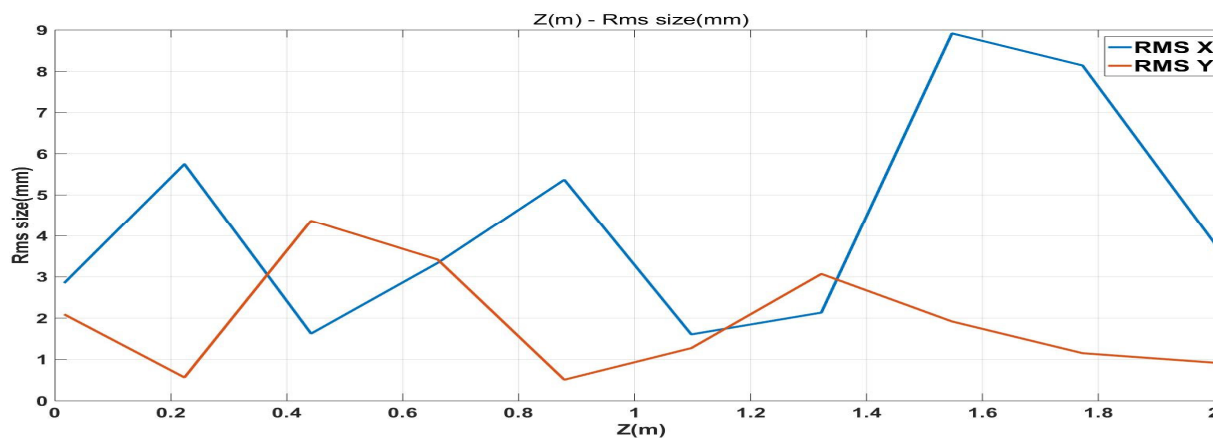
$\alpha_x = -1.95, \beta_x = 0.37$
 $\alpha_y = 1.5, \beta_y = 0.355$

Simulation Result

TRACEWIN



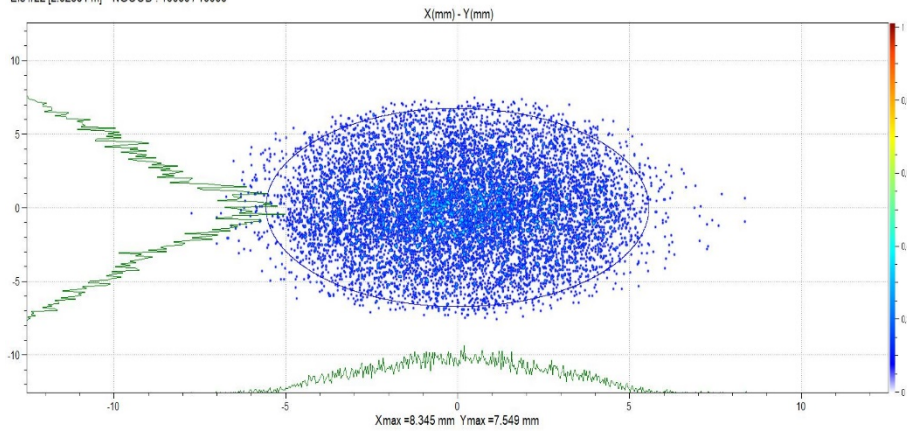
WARP



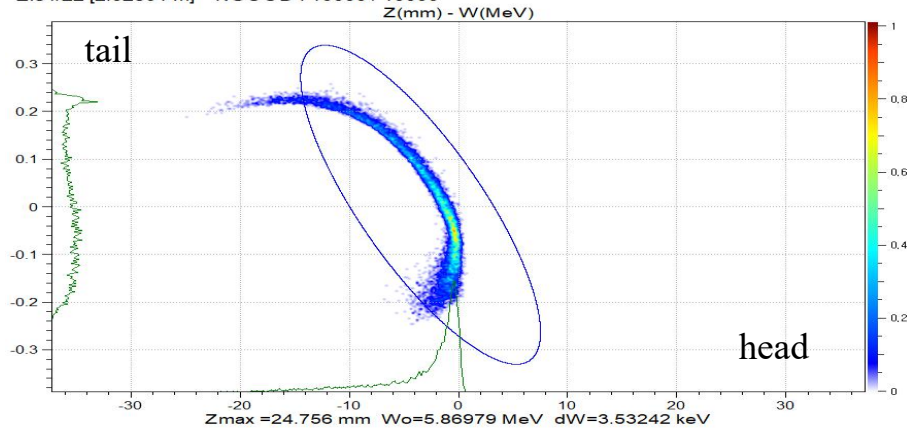
Simulation Result

TRACEWIN

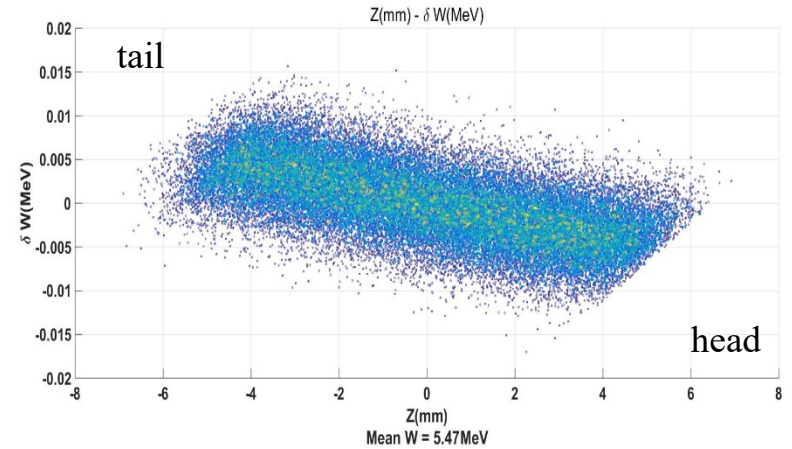
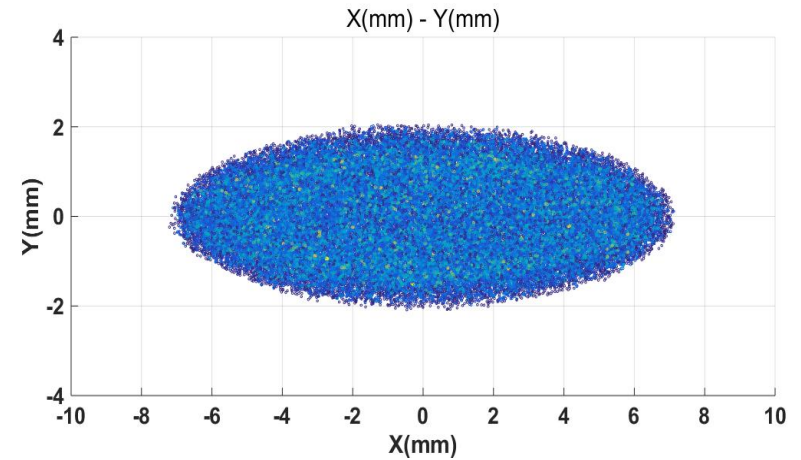
Ele #22 [2.02591 m] NGOOD : 10000 / 10000



Ele #22 [2.02591 m] NGOOD : 10000 / 10000



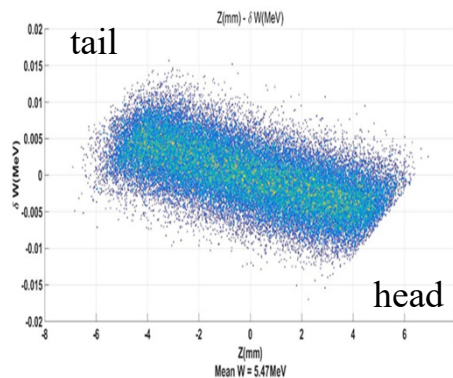
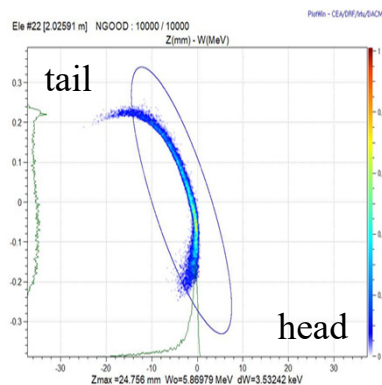
WARP



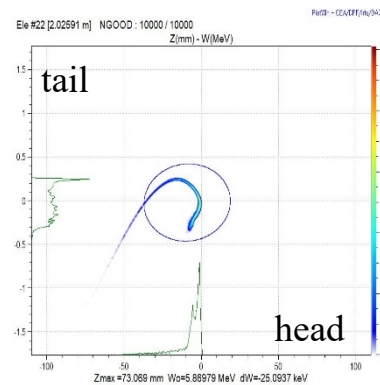
Peak Current Issue

Longitudinal space charge: $F_Z = -\frac{q^2 g}{4\pi\epsilon_0 \gamma^2} \frac{d\lambda}{dz}$ (γ : kinematic factor, $g: 1 + \ln\left(\frac{b}{a}\right)$)

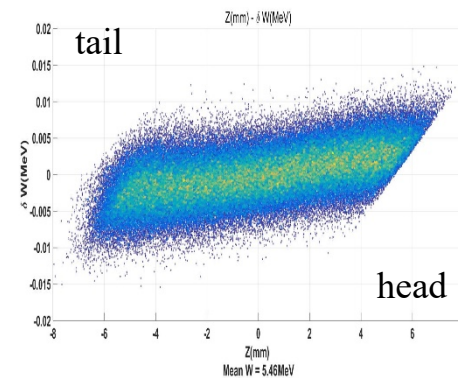
125mA



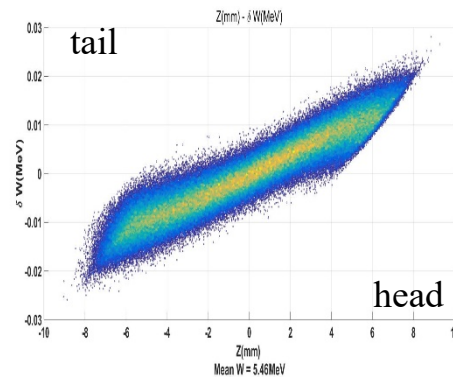
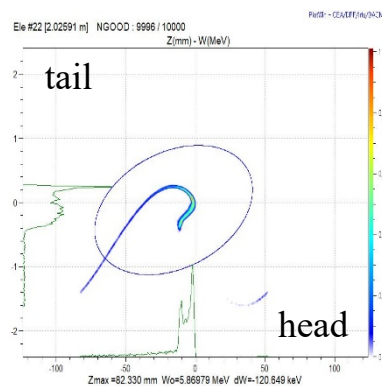
375mA



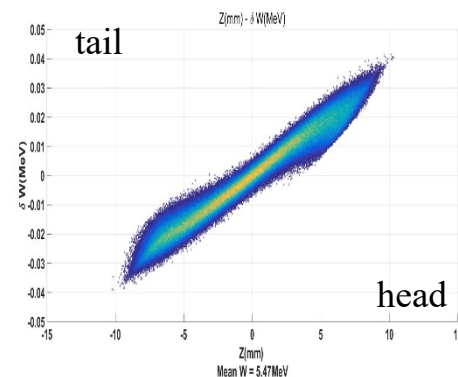
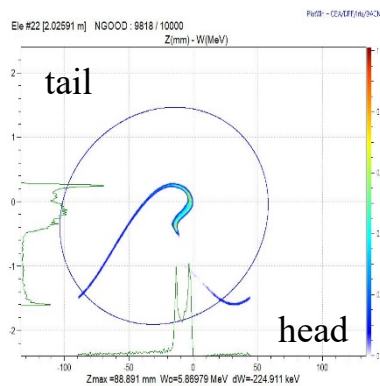
Left: TRACEWIN, Right: WARP



625mA



875mA



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Future Plan & Summary

- SCC (Space – Charge – Compensation) is essential for achieving required emittance.
- Instability in LEBT, WARP simulation for MEBT will be optimized.
- RFQ,HWR(SRF) simulation can't be done in warp simulation. Therefore RFQ,HWR(SRF) simulation will be done by TRACEWIN, IMPACT – Z. Results from those two simulation codes will be cross checked.

Thank you!

Seok Ho Moon, Moses Chung

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