

High-Intensity Beam simulation for IFMIF / like Accelerator

Seok Ho Moon & Moses Chung

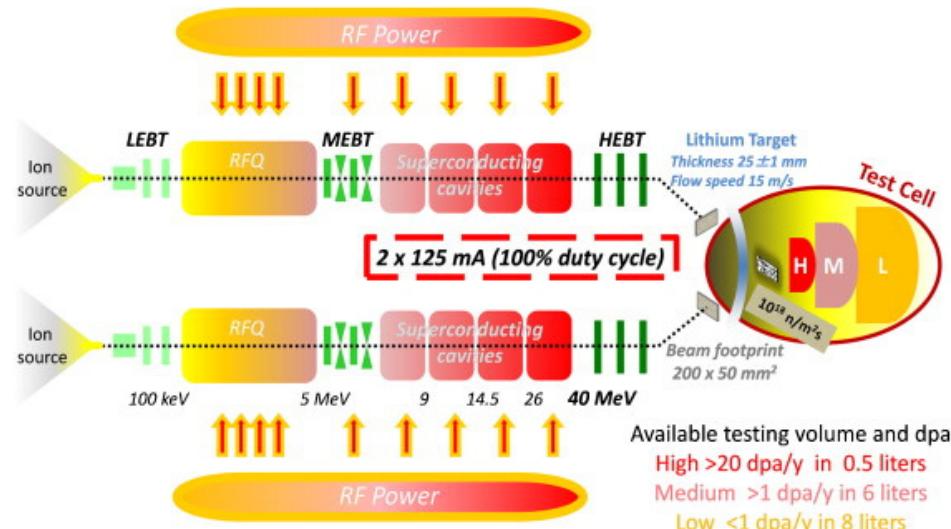
2018. 06. 21 Thursday

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

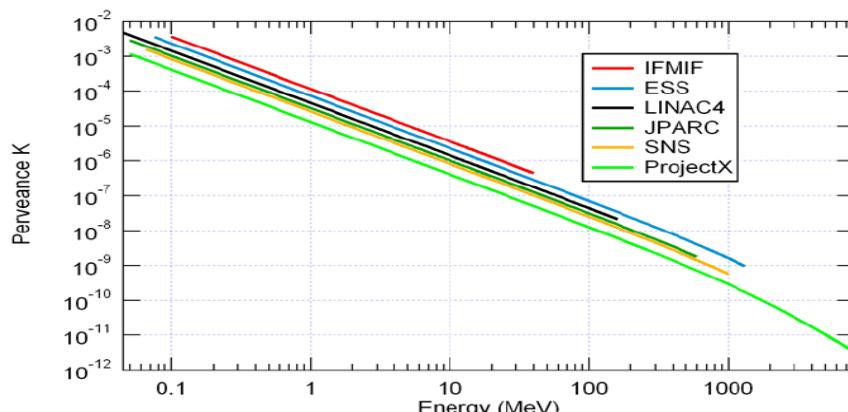
Contents

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

IFMIF



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)

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

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

f_e : neutralization factor

TRACEWIN & WARP

- - - < TRACEWIN > - - -

Developer: Researchers of CEA



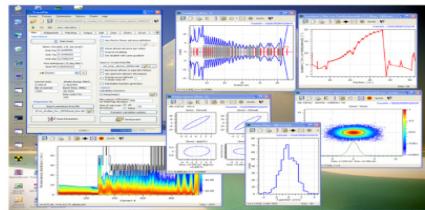
TraceWin rapid explanation

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 G4 Beam Transport and Partran (macroparticle transport) in linacs. The code is capable to model different components of a linac. Beam parameters 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 Tousaints module,
- 1D, 2D, 3D static and dynamic fields map (with superposition capability),
- 1D, 2D and 3D macroparticle transport calculations,
- start-to-end simulation from source to target;
- transport of two beams in the same structure;
- gas stripping and scattering analysis,
- emittance, transverse and longitudinal beam tuning,
- correction procedure for beam 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 and MACOS versions,
- reference code for IPMIF, 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
- Browse Warp source
- Publications and Documentation
- Training
- Sitemap

How To's

- Installation
- Running Warp
- Warp Units and Variables
- Particles
- Field Solvers
- Lattice
- Diagnostics and Plots
- Particle Data to and from a Grid
- Saving/Retrieving Data
- Parametric Scans
- User notes

Home

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 its present highly developed state.

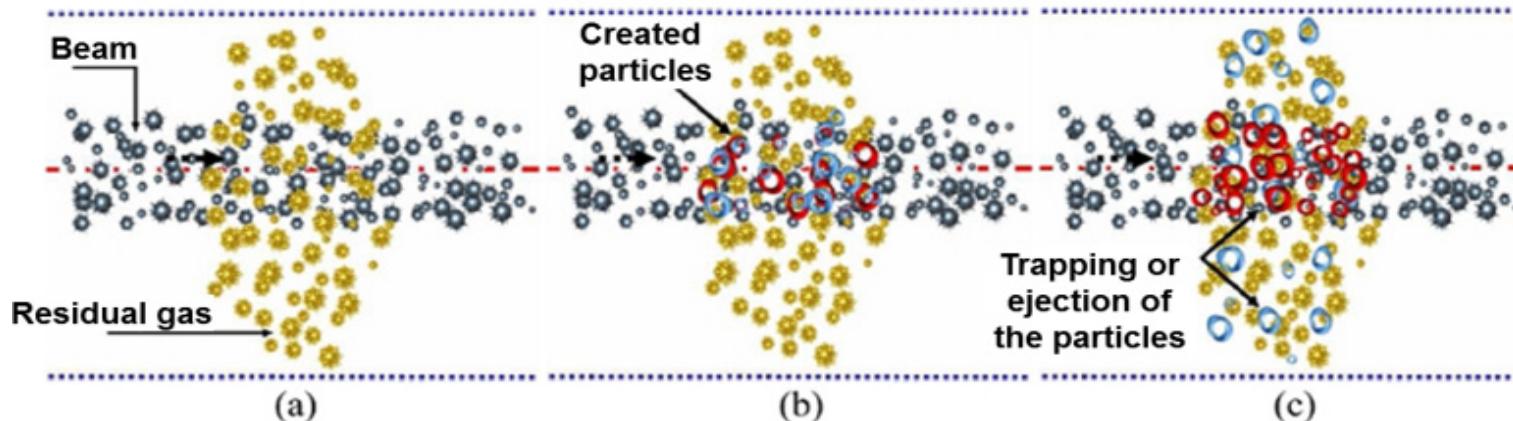
<http://warp.lbl.gov/home>

Full PIC

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SCC(Space Charge Compensation)



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

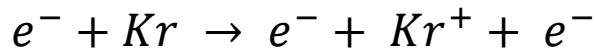
Nicolas, Chauvin. Space-Charge effect.(2014):12

Atomic Processes

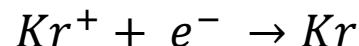
1. Ionization by beam



2. Ionization by electron

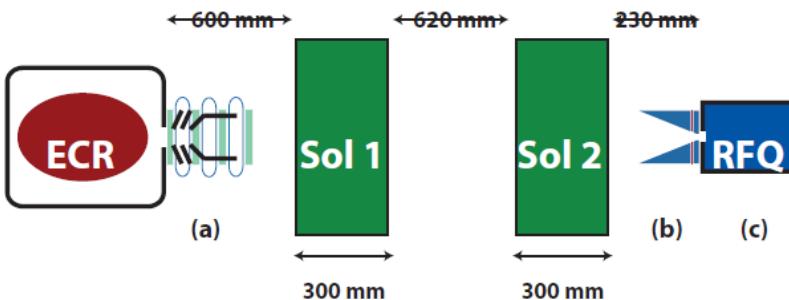


3. Recombination



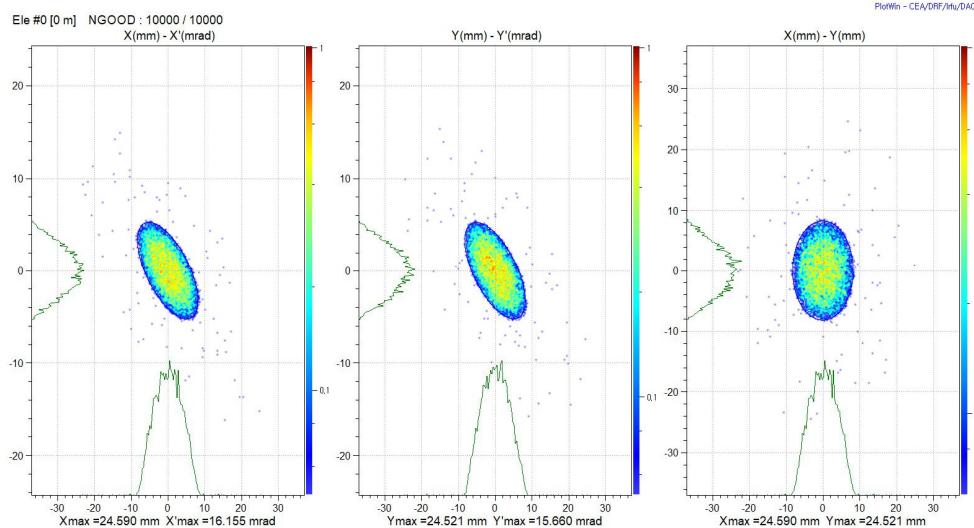
Schematic of LEBT & Parameter

Schematic of IFMIF LEBT



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

Initial Beam Parameter

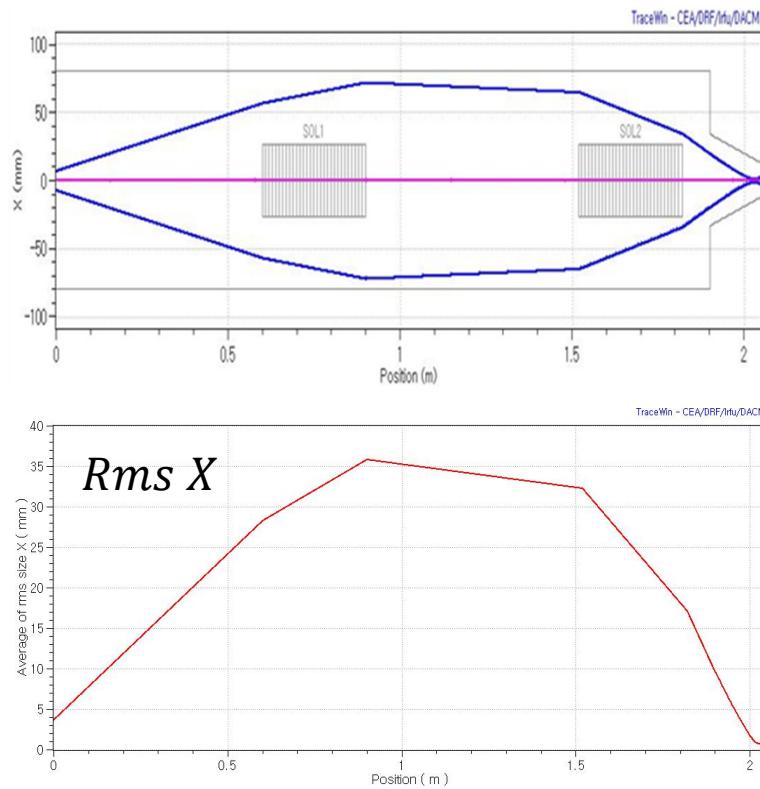


Lattice parameter	Value
Beam Pipe Radius	80mm
Cone Radius	35mm, 12mm
B-field of Solenoid	Sol1:0.37T Sol2:0.47T

Beam Parameter	Initial Value
Particle Type	D^+
Beam Current	125mA
Initial Energy	100keV
Emittance	$0.064 \pi. mm. mrad$
Twiss Parameter	$\alpha = 0.8, \beta = 2.0$

Without SCC

TRACEWIN

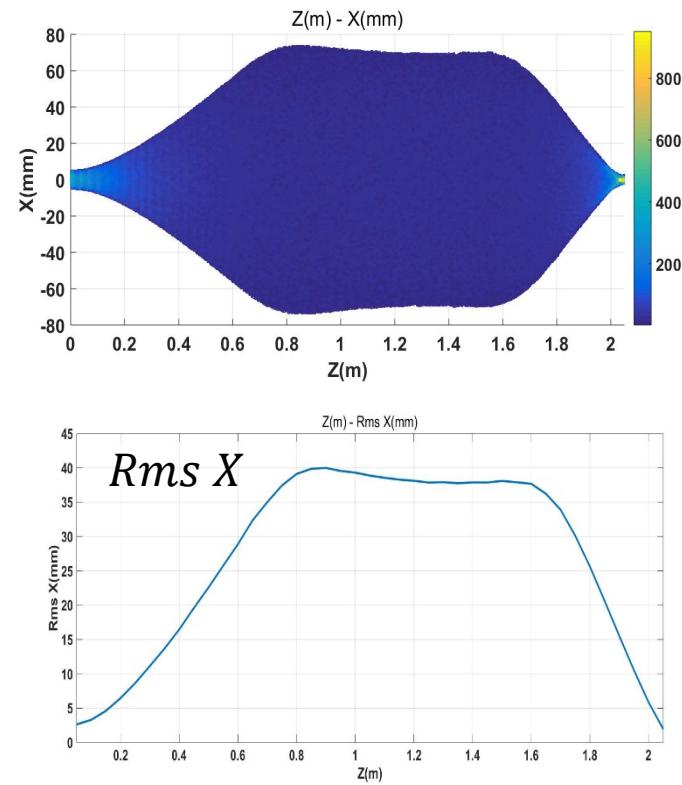


At exit

$$\begin{aligned}\varepsilon_{n,rms\,x} &= 0.2796\pi.\text{mm. mrad} \\ \varepsilon_{n,rms\,y} &= 0.2794\pi.\text{mm. mrad}\end{aligned}$$

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

WARP

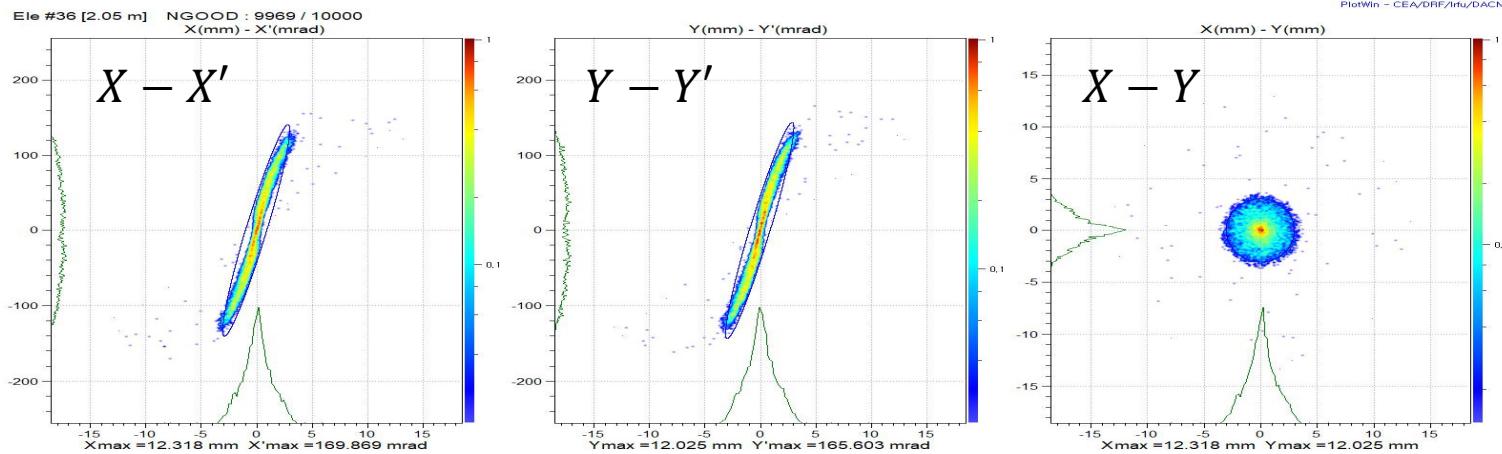


At exit

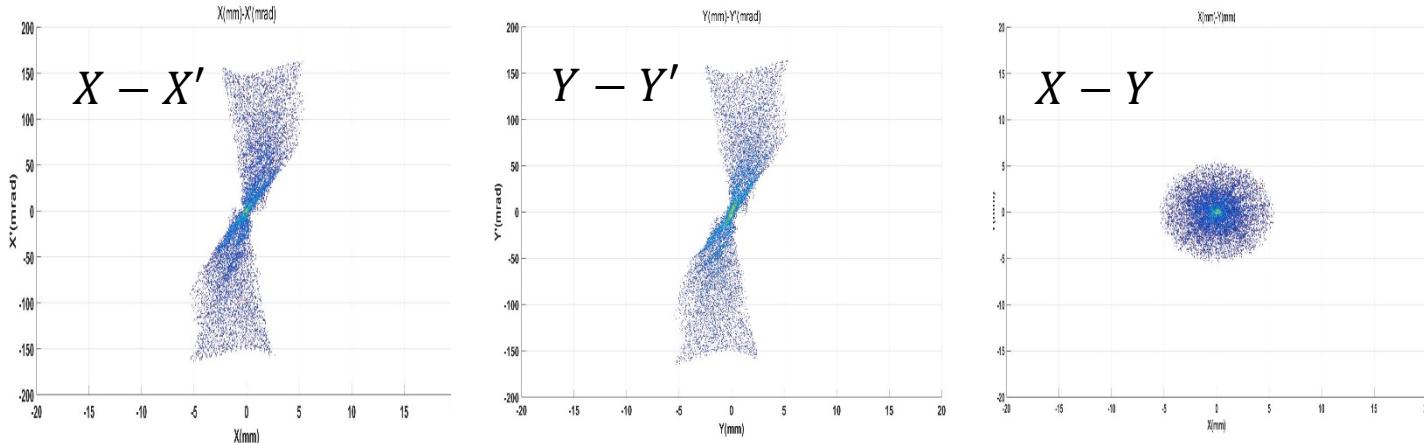
$$\begin{aligned}\varepsilon_{n,rms\,x} &= 0.3697\pi.\text{mm. mrad} \\ \varepsilon_{n,rms\,y} &= 0.3778\pi.\text{mm. mrad}\end{aligned}$$

Without SCC

TRACEWIN

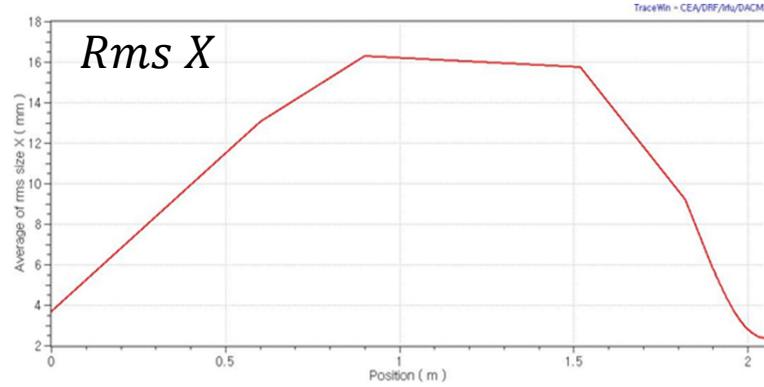
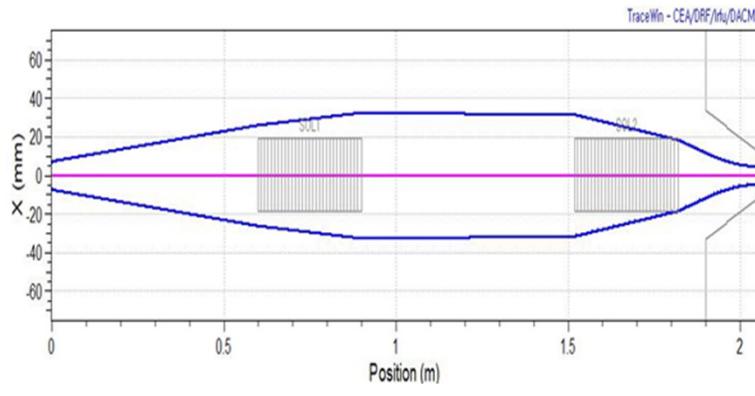


WARP



With SCC

TRACEWIN

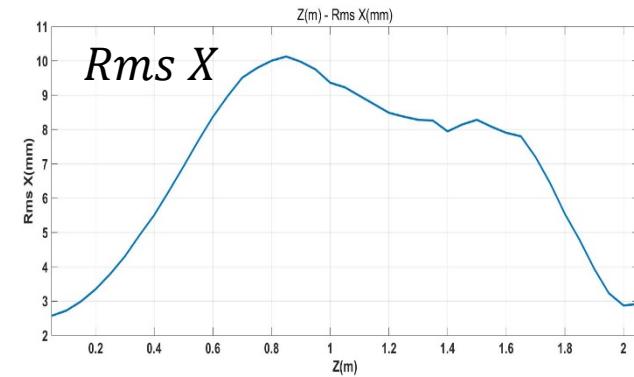
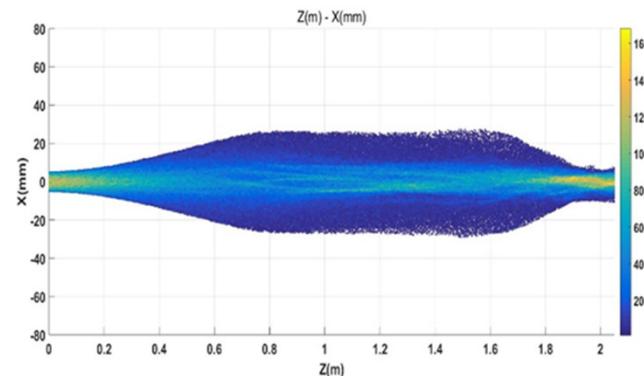


At exit

$$\begin{aligned}\varepsilon_{n,rms\,x} &= 0.1228\pi.\,mm.\,mrad \\ \varepsilon_{n,rms\,y} &= 0.1189\pi.\,mm.\,mrad\end{aligned}$$

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

WARP

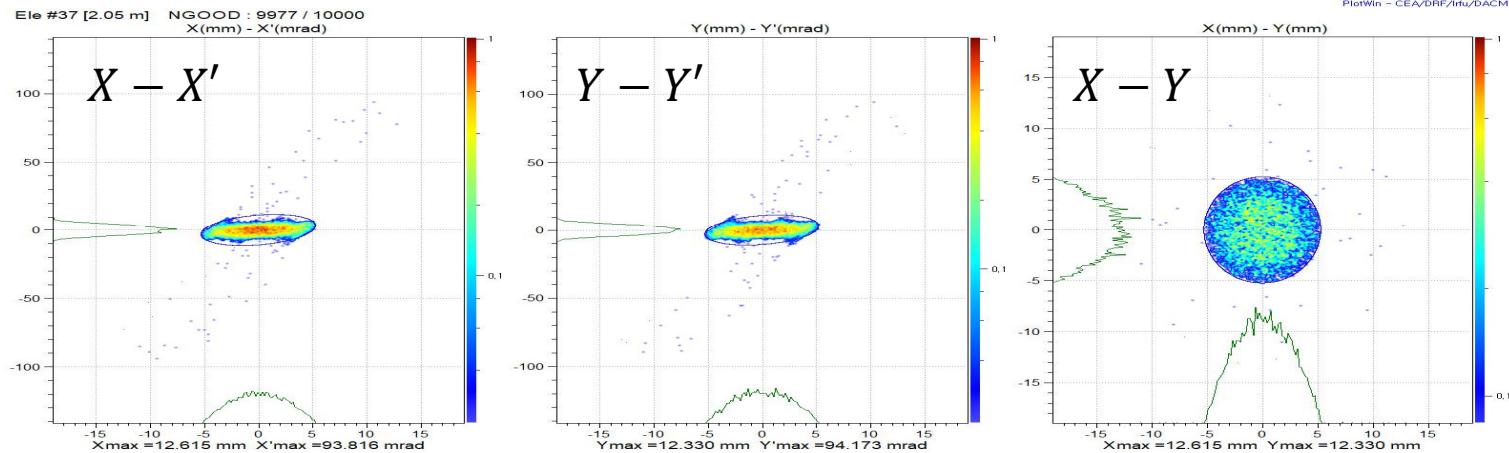


At exit

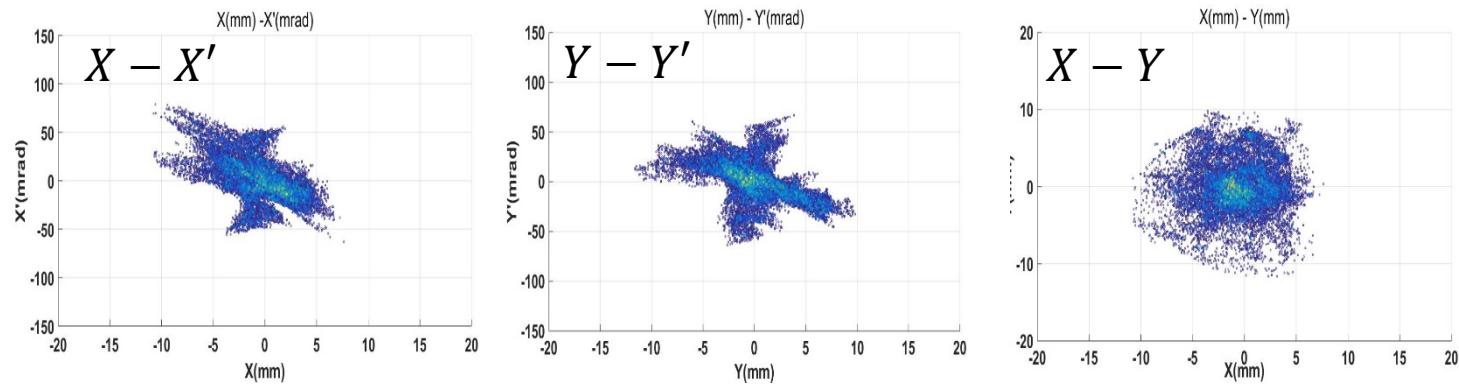
$$\begin{aligned}\varepsilon_{n,rms\,x} &= 0.1763\pi.\,mm.\,mrad \\ \varepsilon_{n,rms\,y} &= 0.1957\pi.\,mm.\,mrad\end{aligned}$$

With SCC

TRACEWIN

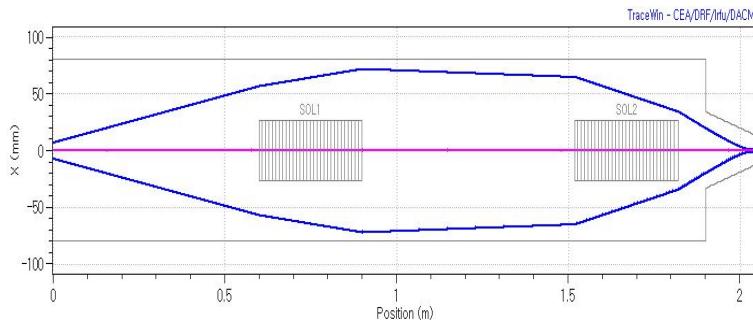


WARP



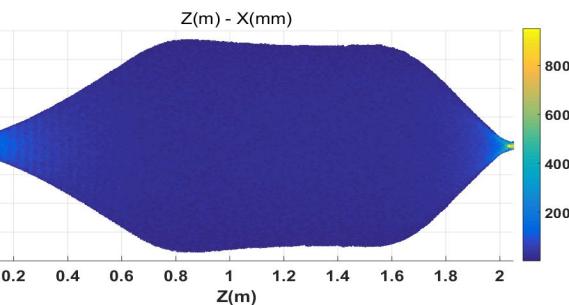
Result Comparison

Without SCC



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

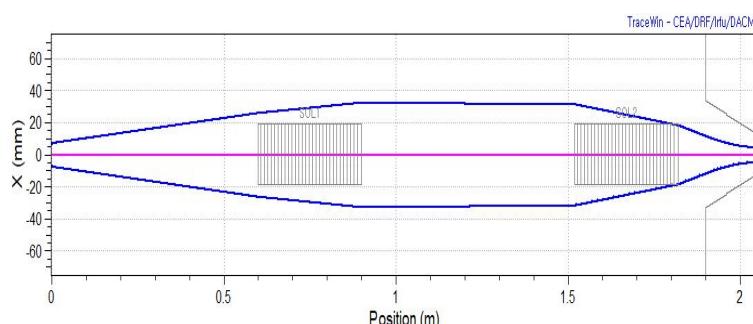
$$\varepsilon_{n,rms} y = 0.2794\pi \cdot mm \cdot mrad$$



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

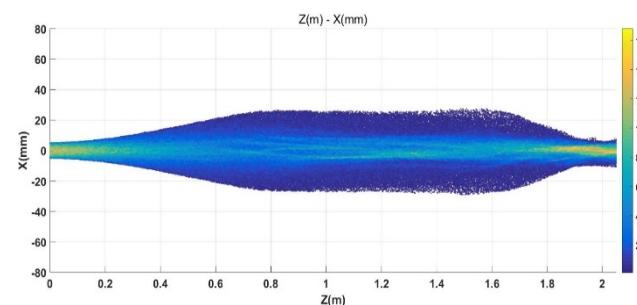
$$\varepsilon_{n,rms} y = 0.3778\pi \cdot mm \cdot mrad$$

With SCC



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

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



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

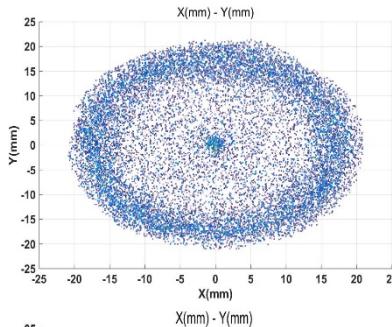
$$\varepsilon_{n,rms} y = 0.1957\pi \cdot mm \cdot mrad$$

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

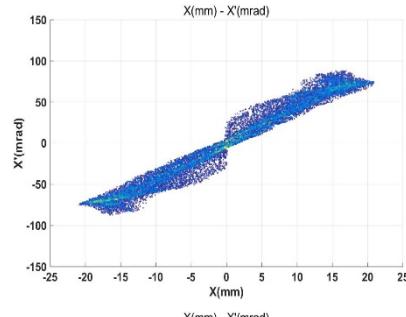
Instability Issue

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

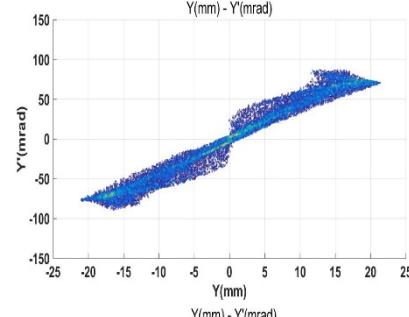
$X - Y$



$X - X'$



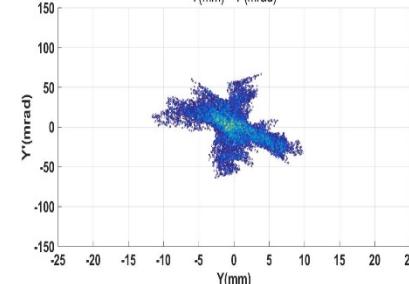
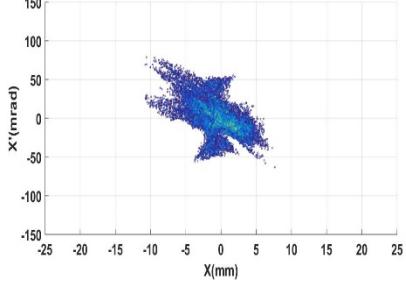
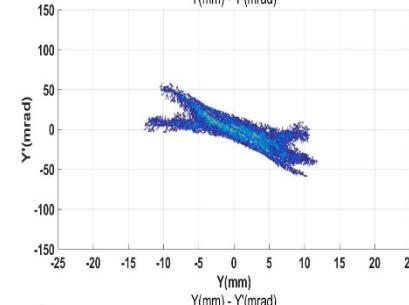
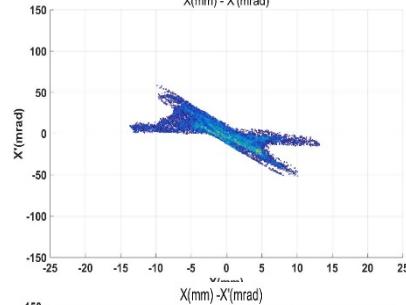
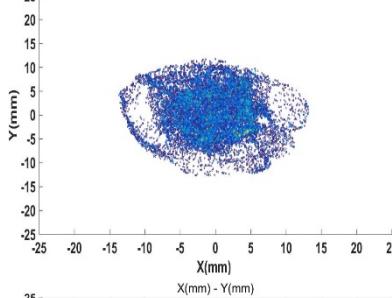
$Y - Y'$



2 μ s

4 μ s

6 μ s

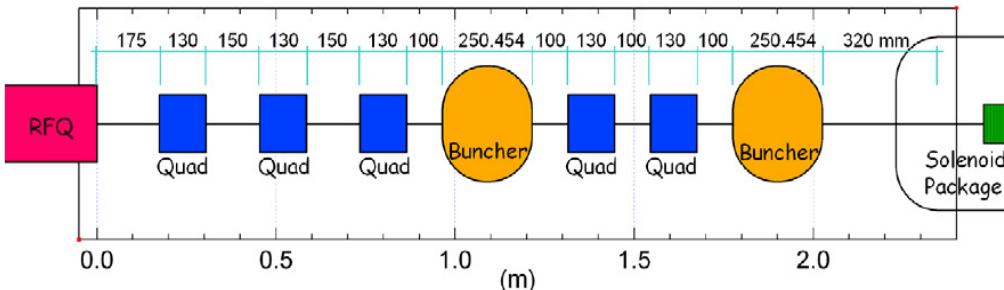


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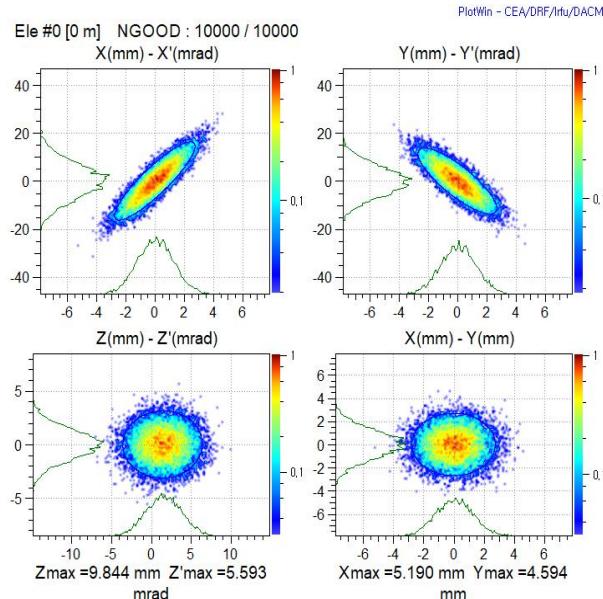
Schematic of MEBT & Parameter

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

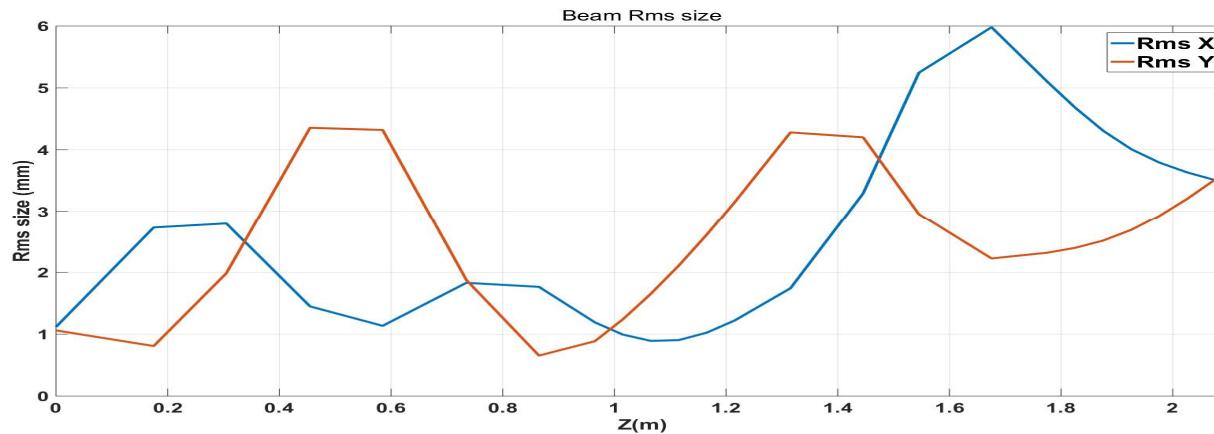


Lattice Parameter	Value
Gradient of Quadrupole	Quad1,2,3:25T/m Quad4: 20.5T/m Quad5: 20T/m
Buncher Frequency	175MHz
Maximum $E_0 LT$	350kV

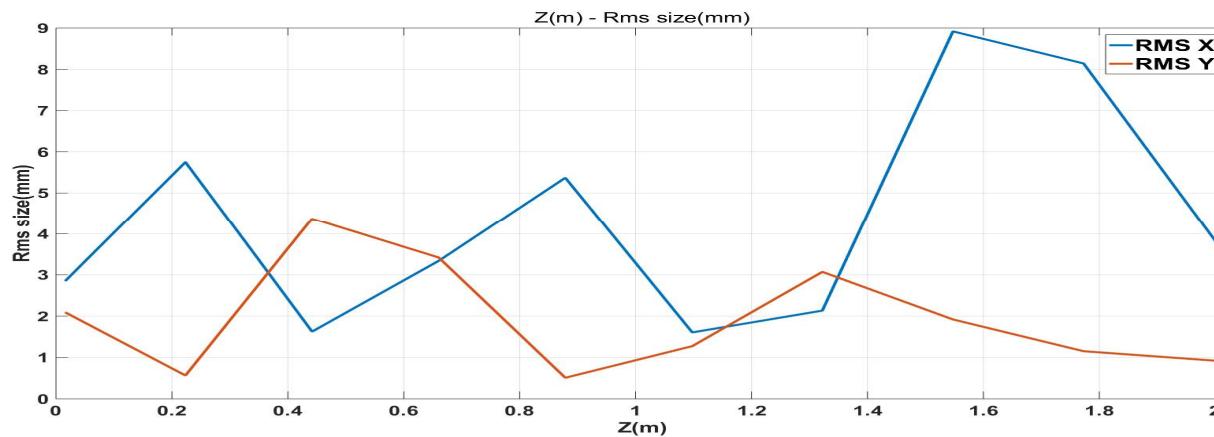
Beam Parameter	Initial Value
Particle Type	D^+
Beam Peak Current	125mA
Initial Energy	4.98MeV
Longitudinal Emittance	$0.3 \pi. mm. mrad$
Twiss Parameter	$\alpha_x = -1.95, \beta_x = 0.37$ $\alpha_y = 1.5, \beta_y = 0.355$

Simulation Result

TRACEWIN



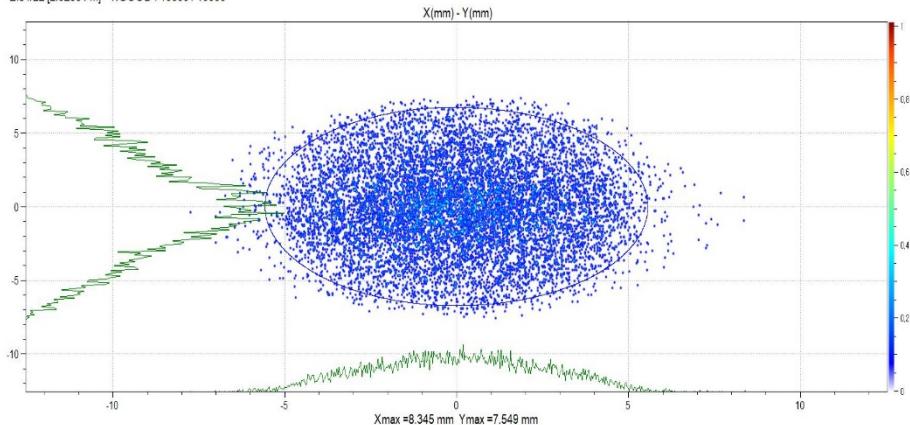
WARP



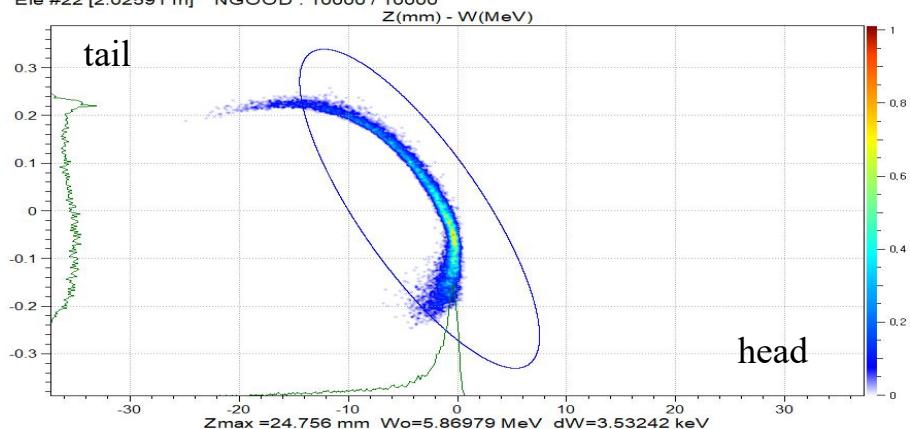
Simulation Result

TRACEWIN

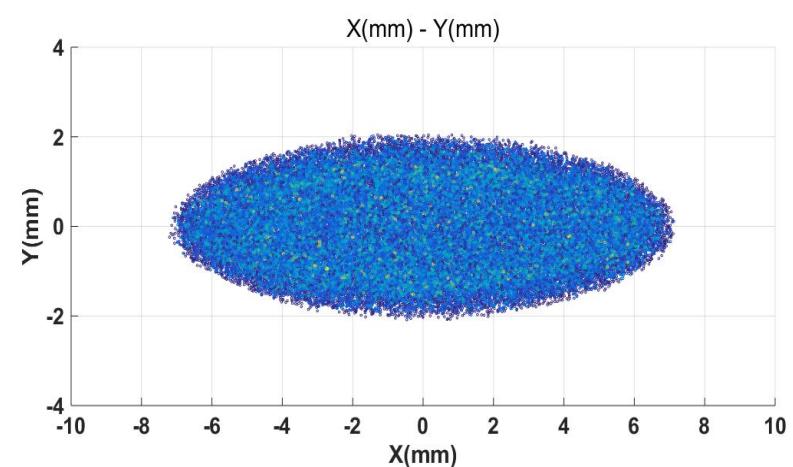
Ele #22 [2.02591 m] NGOOD : 10000 / 10000



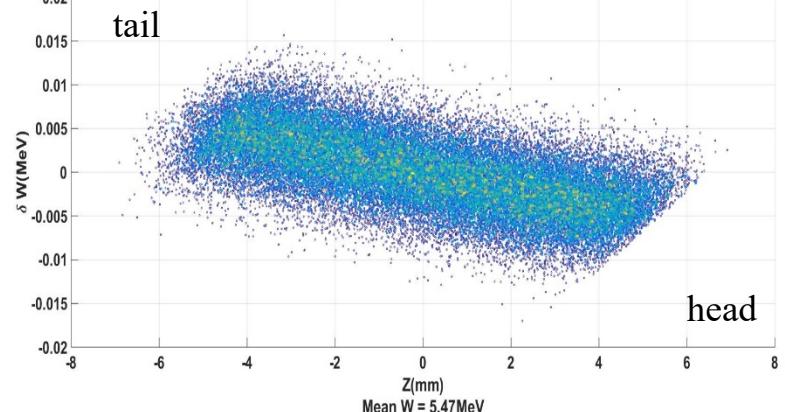
Ele #22 [2.02591 m] NGOOD : 10000 / 10000



WARP



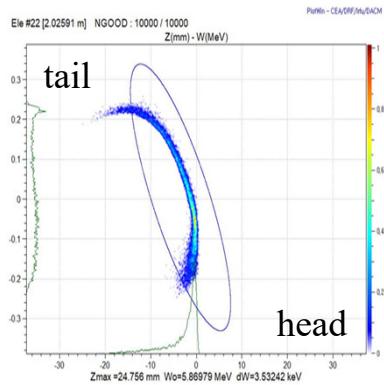
Z(mm) - δ W(MeV)



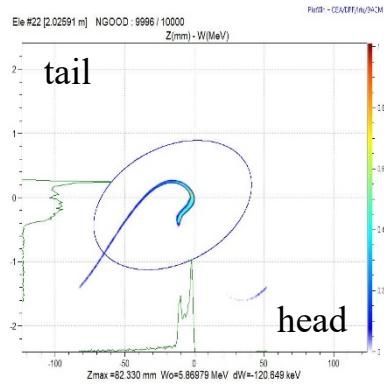
Peak Current Issue

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

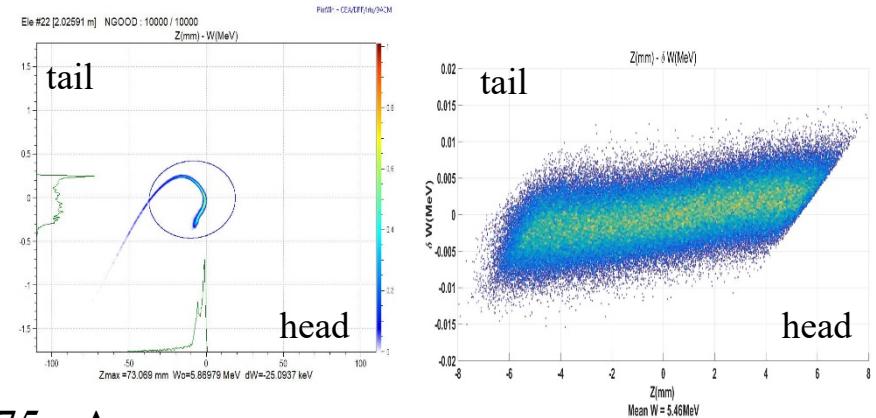
125mA



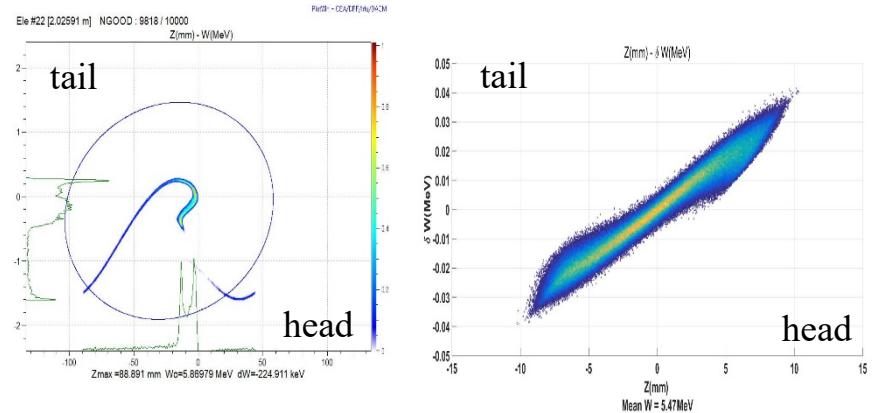
625mA



375mA



875mA



Left: TRACEWIN, Right: WARP

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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!

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