Beam dynamics studies of H- beam chopping in a LEBT for PXIE

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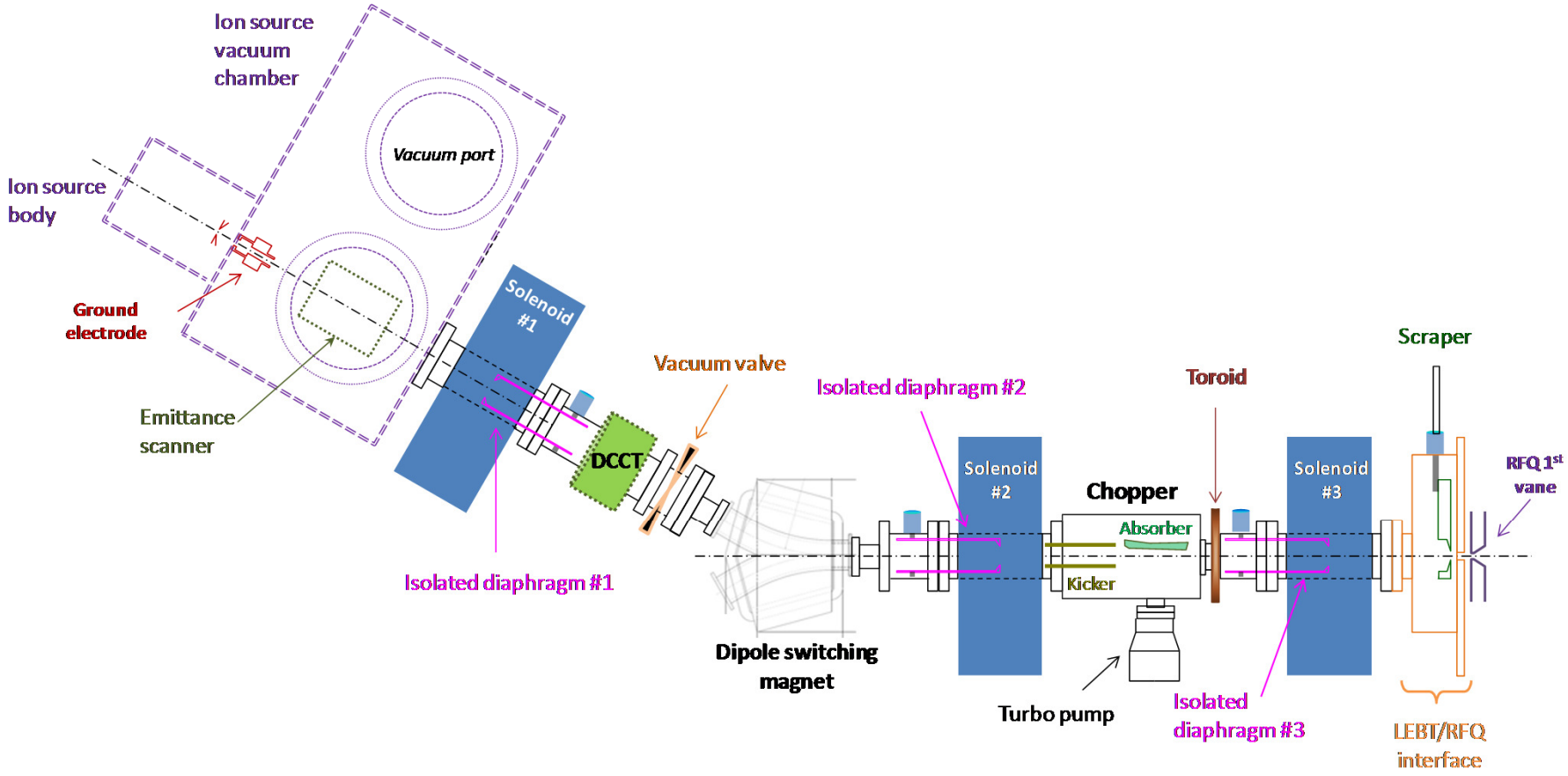
PXIE LEBT Conceptual Design (3-solenoid Design)

Length of the LEBT ~ 2.75m

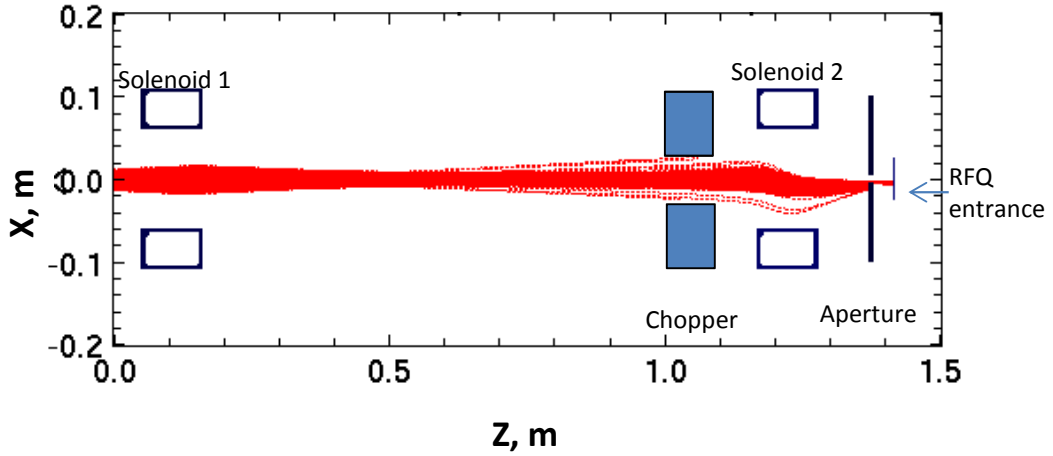


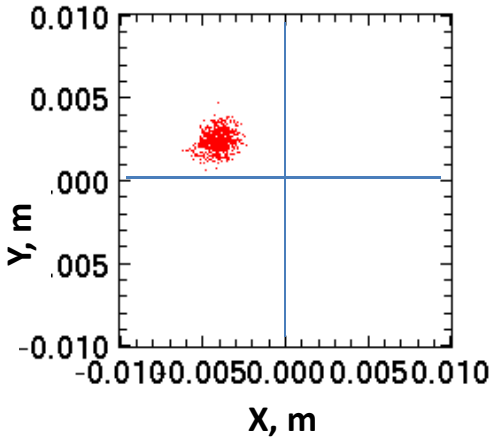
PXIE LEBT Optics

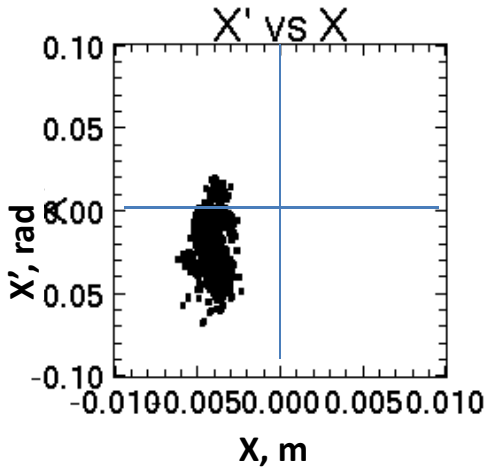
- LEBT beam dynamics has been simulated using various codes
  - Trace 3D
  - Astra
  - TLAT
  - WARP 3D
- All results have good agreement.

I = 10mA
E_k = 30keV
Deflecting voltage: ± 650 V
with *90% space charge* neutralization throughout the LEBT

WARP simulation:
snapshot of particle distribution at x-z

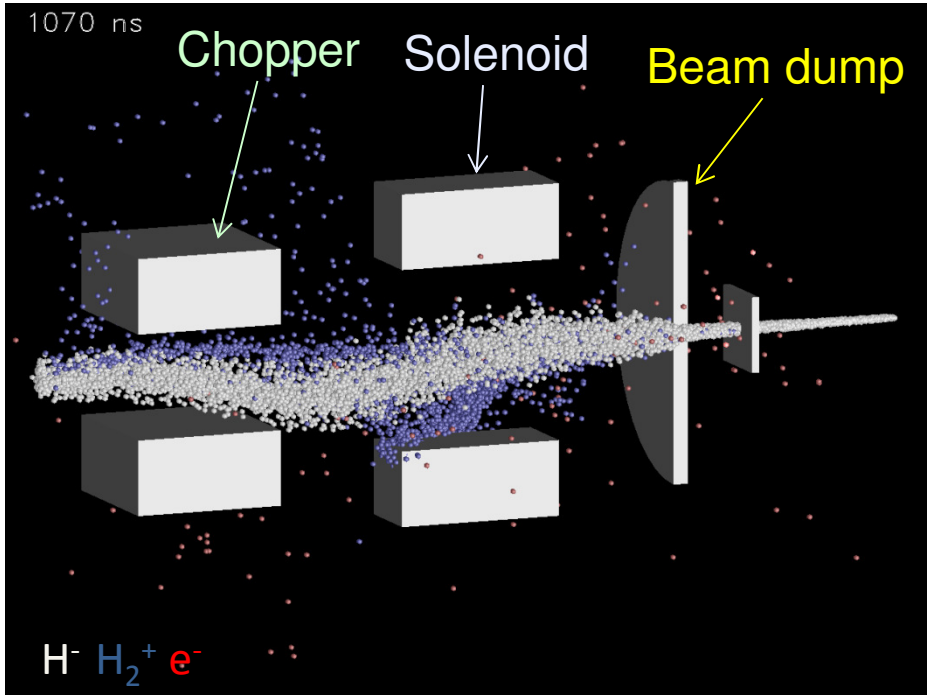






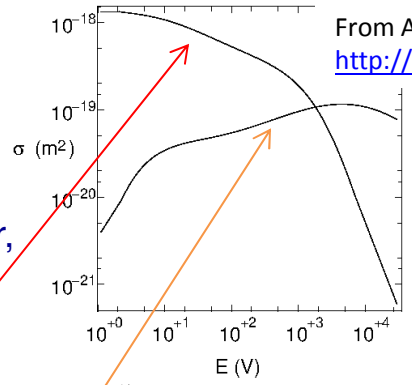
LEBT and Chopper Beam Dynamics Simulation

- Partial space charge neutralization will be lost along the beam in the chopper and maybe through the second solenoid.
  - Typical space charge neutralization time ~ 50 μsec at 10^{-6} Torr.
- Beam dynamics study is crucial to investigate the time-dependence of the space charge neutralization in the segment after the chopper
  - Beam stability
  - Emittance growth
- Time-dependent simulation of LEBT chopper using WARP 3D
  - Chopper + solenoids
  - Simulations performed with particle interactions

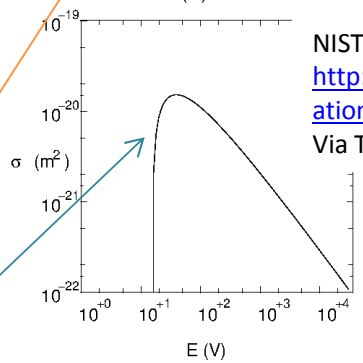


Simulation Including Particle Interactions with Background Gas

- **WARP 3D is a particle-in-cell code, developed to achieve end-to-end 3D self-consistent time-dependent simulations of beam.**
  - ✓ acceleration, focusing and compression along accelerator,
  - ✓ Particle loss at walls, interaction with desorbed gas and electrons, halo
  - ✓ neutralization from plasma in chamber.
- **WARP 3D being further developed to support PXIE**
- **Includes multiple interactions**
  - Charge exchange $H^- + H \rightarrow H + H^-$
  - Ionization $e^- + H \rightarrow H^+ + 2\ e^-$
  - Detachment $H^- + H \rightarrow 2\ H + e^-$
  - Detachment $H^- + H_2 \rightarrow H + H_2 + e^-$
  - Ionization $e^- + H_2 \rightarrow H_2^+ + 2e^-$
  - Ionization $H^- + H_2 \rightarrow H^- + H_2^+ + e^-$

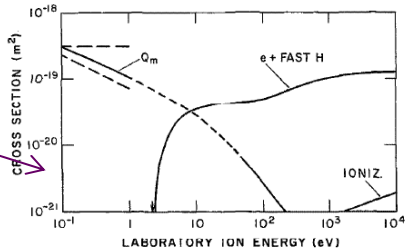


From Aladdin cross section database
http://www-cfadc.phy.ornl.gov/home.html

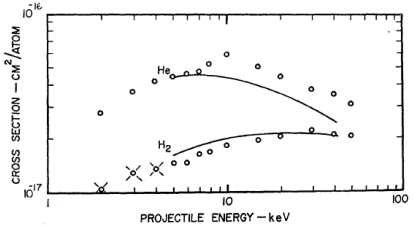


NIST Electron impact cross sections
http://physics.nist.gov/PhysRefData/Ionization/Xsection.html
Via TxPhysics library

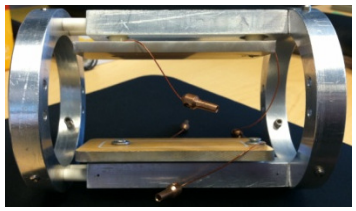
A. V. Phelps, J. Phys. Chem. Ref. Data, 19, 653(1990).



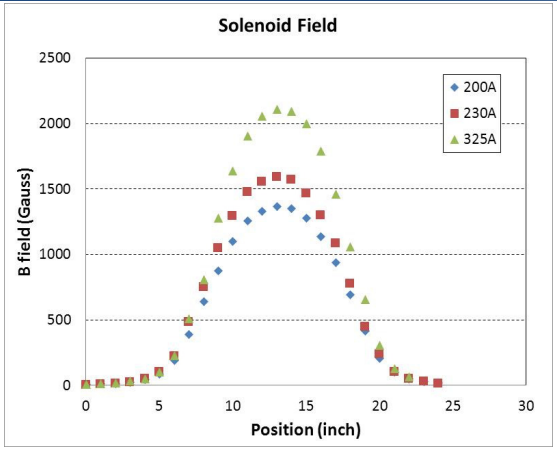
J. F. Williams, Phys. Rev., 154, 9(1967).



Chopper Simulation Benchmark Experiment Setup

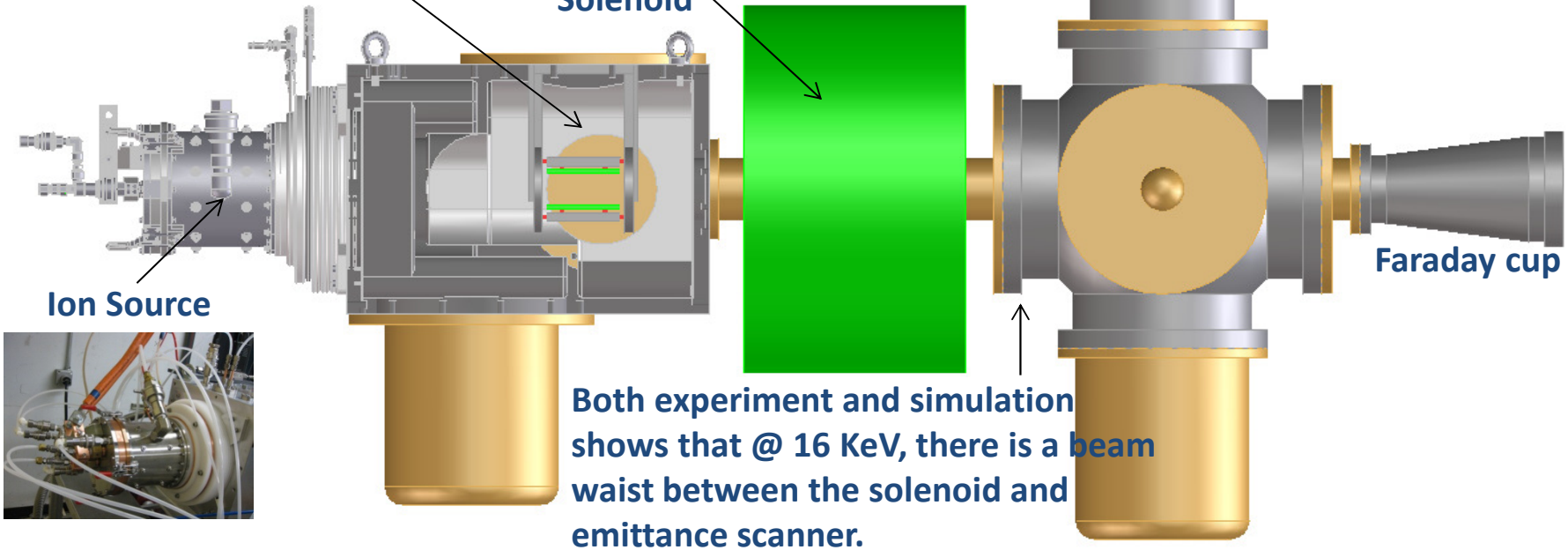


Chopper



Emittance scanner

Solenoid



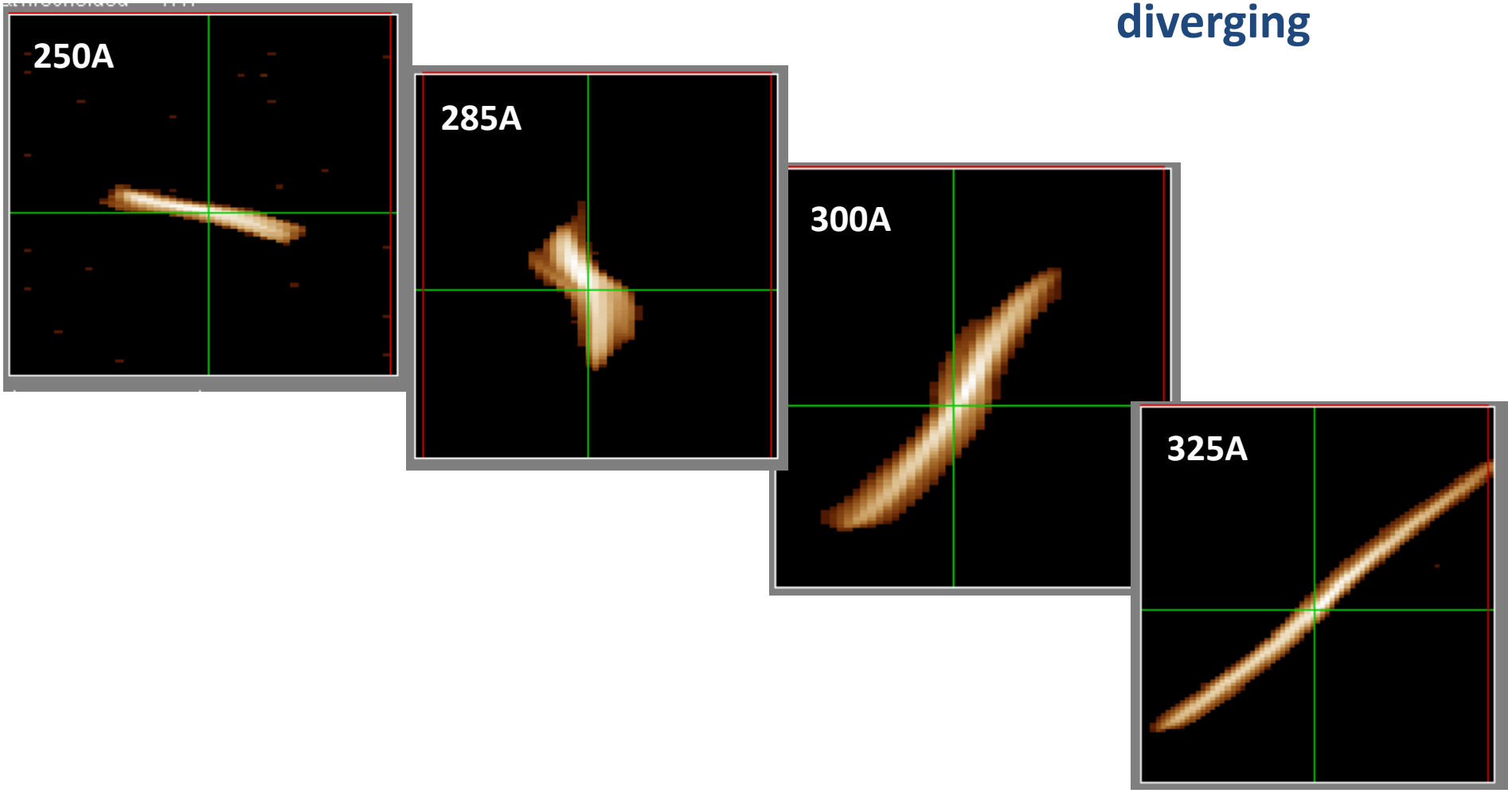
Faraday cup

Ion Source

Both experiment and simulation shows that @ 16 KeV, there is a beam waist between the solenoid and emittance scanner.

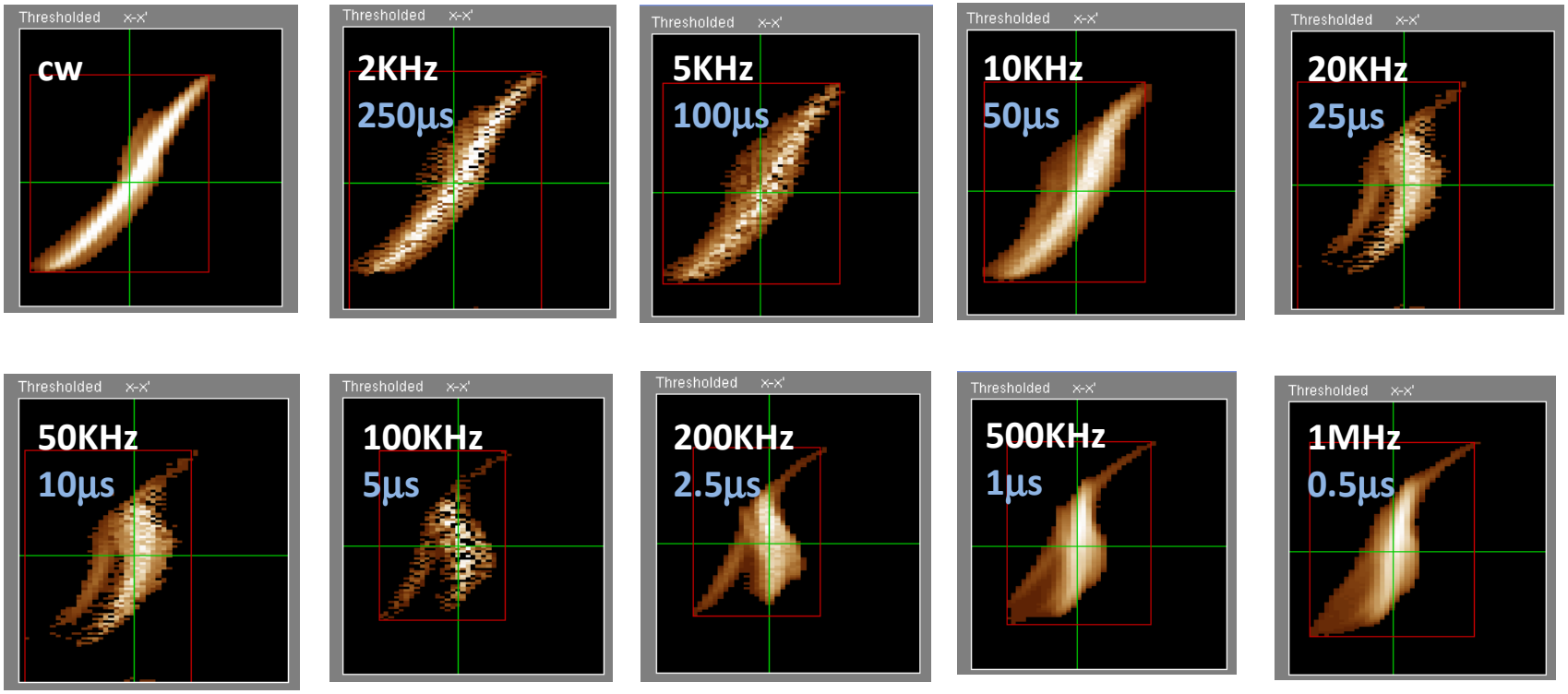
Experiments Indicate Over-focused Beam

Stronger solenoid field → **Beam is more diverging**



16 KeV, 3 mA H- Beam pulsed @ 50% duty factor

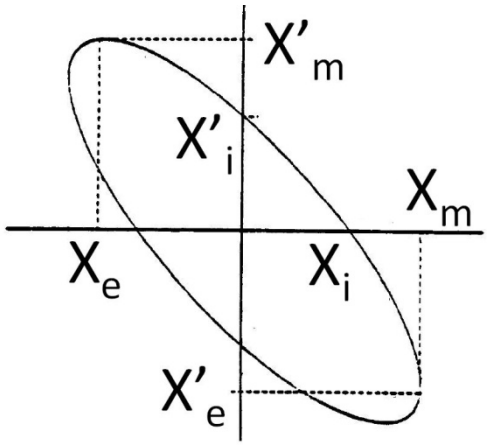
Pulse width → **shorter**



Higher repetition rate → Less space charge neutralization

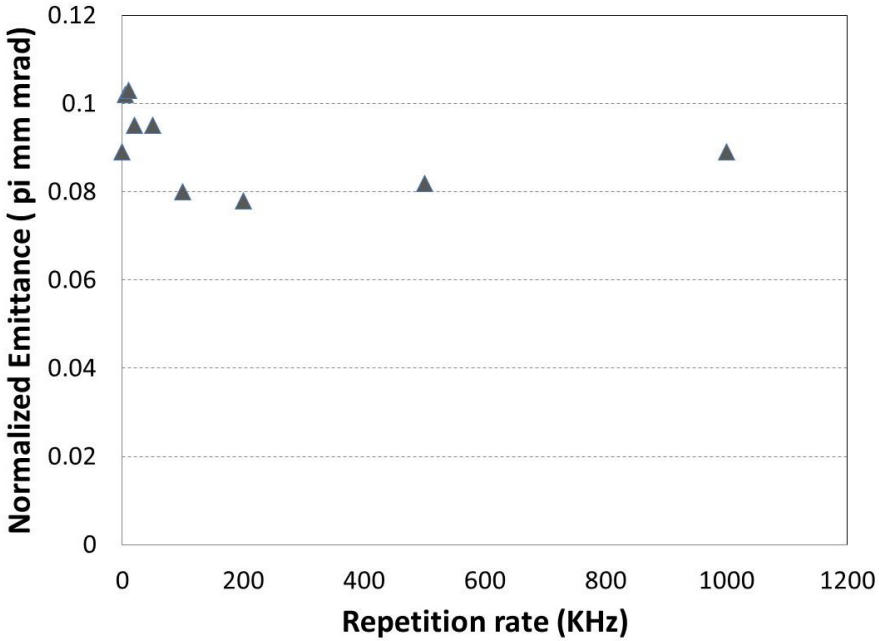
Beam waist moves downstream

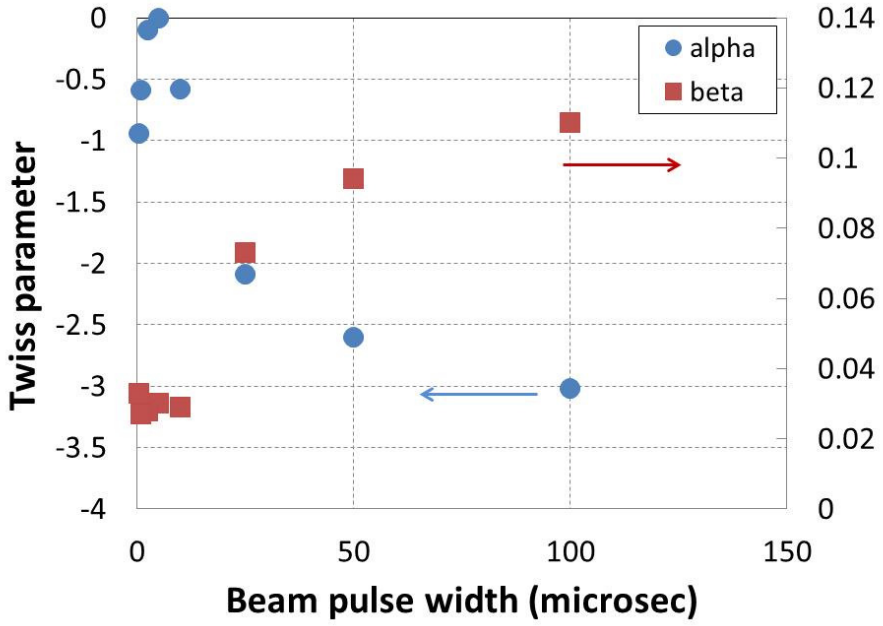
Emittance and Twiss parameters vs. Rep Rate



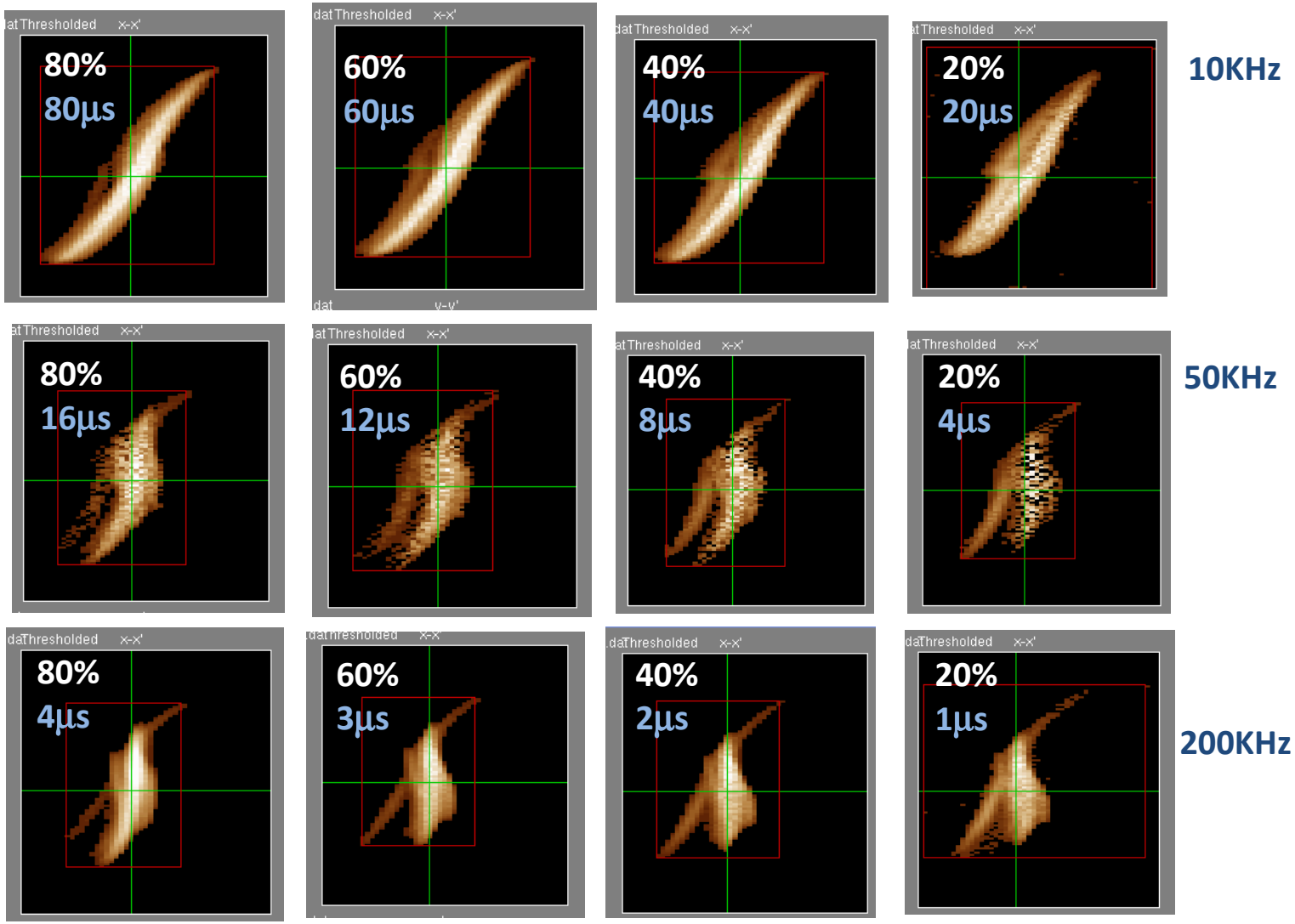
$$\alpha = -\frac{x_e}{x_i} = -\frac{x'_e}{x'_i}$$

$$x_m = \sqrt{\beta\varepsilon}$$

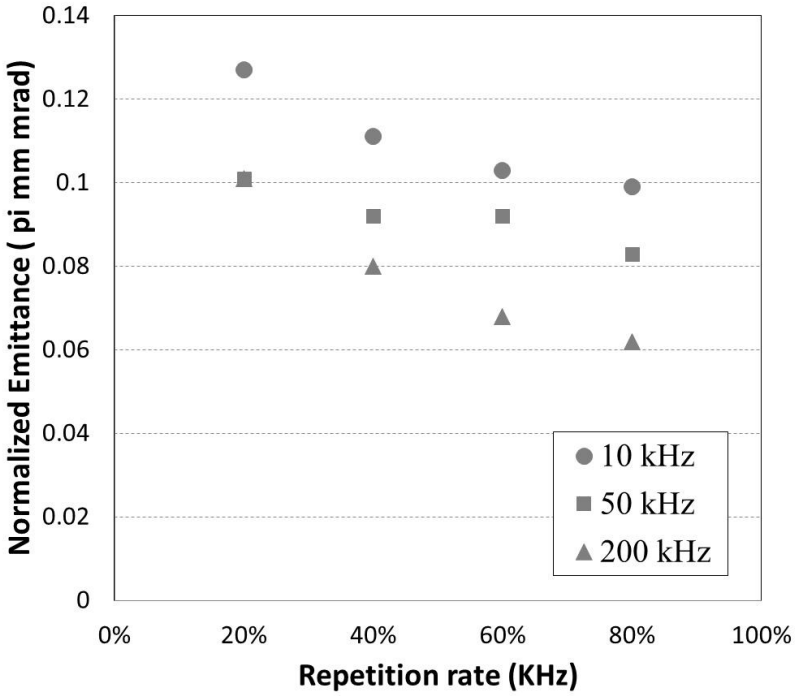


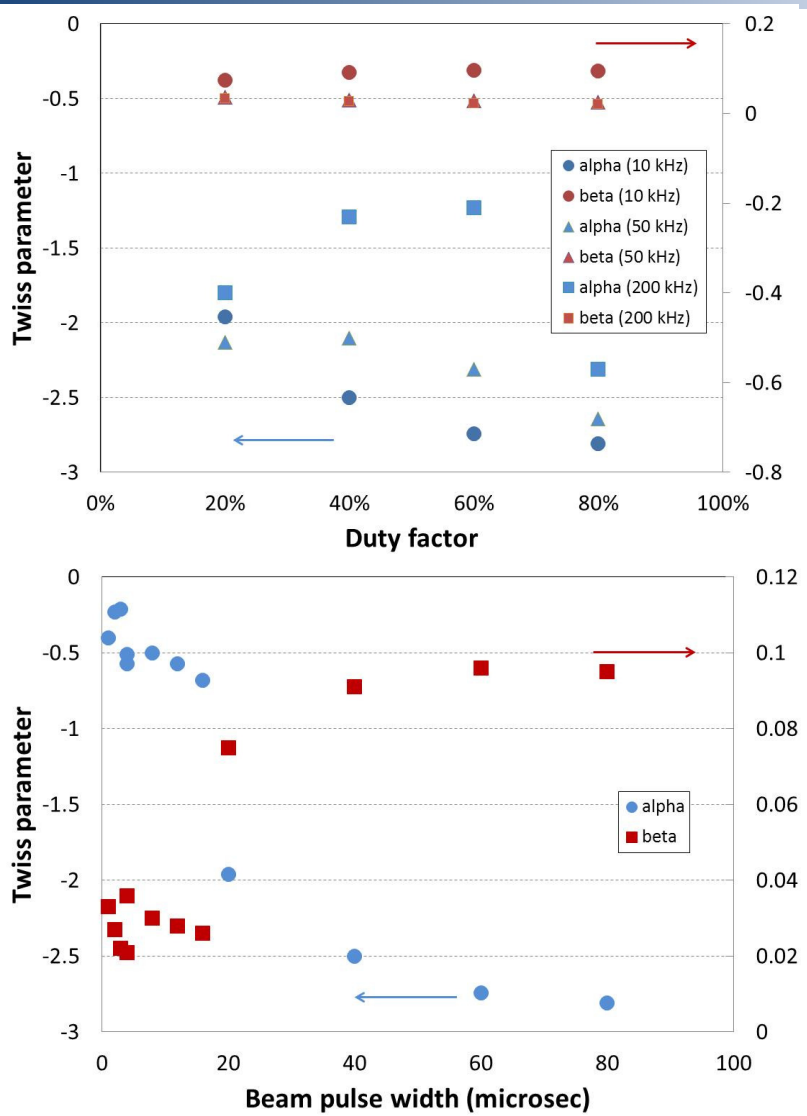


Effect of Pulse Duty factor

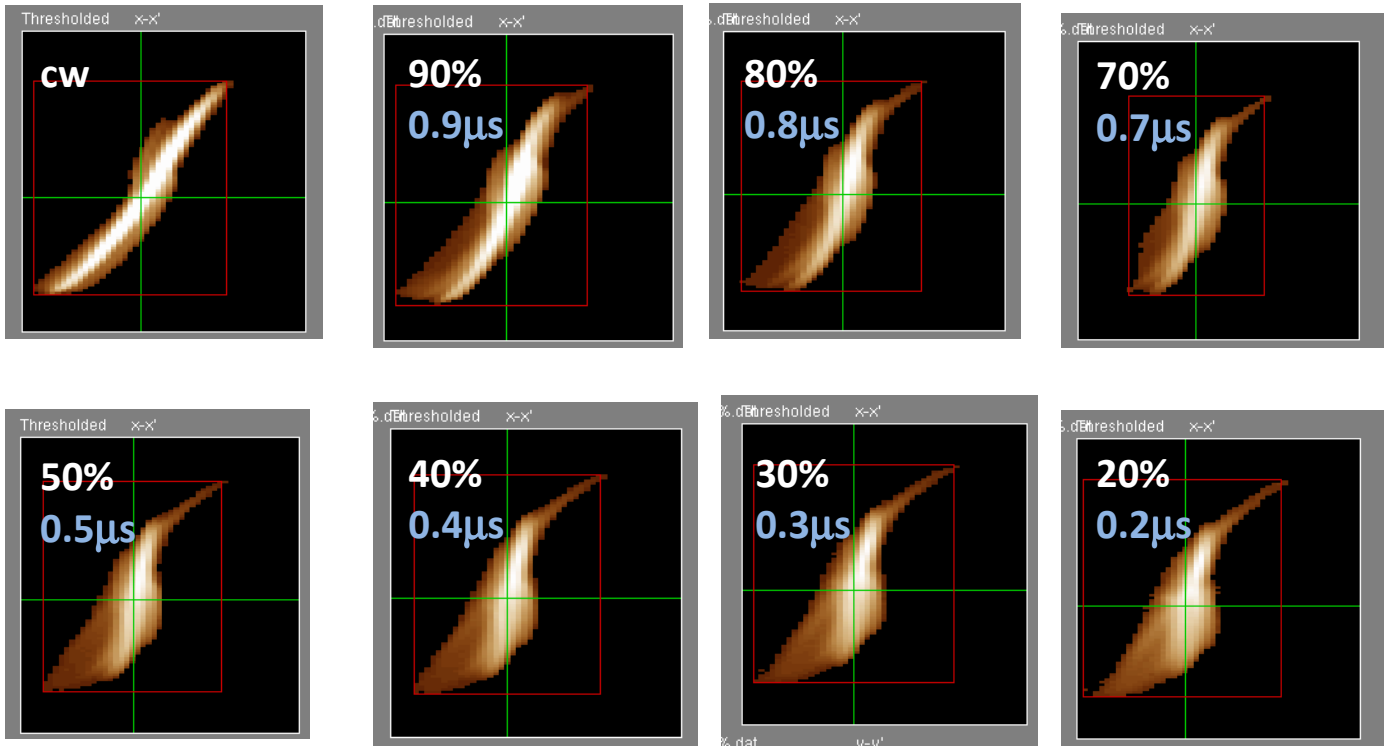


Emittance and Twiss parameters vs. Pulse Duty Factor

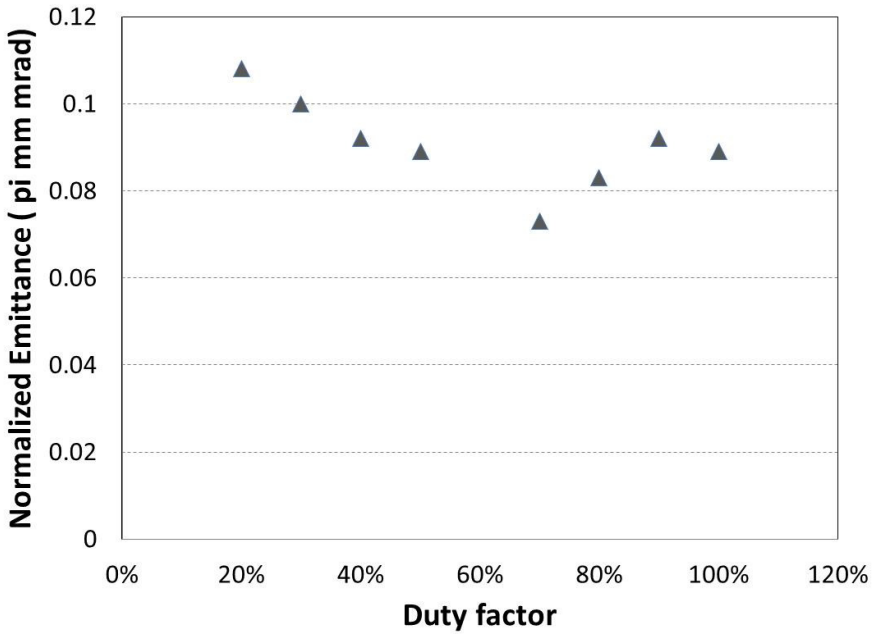


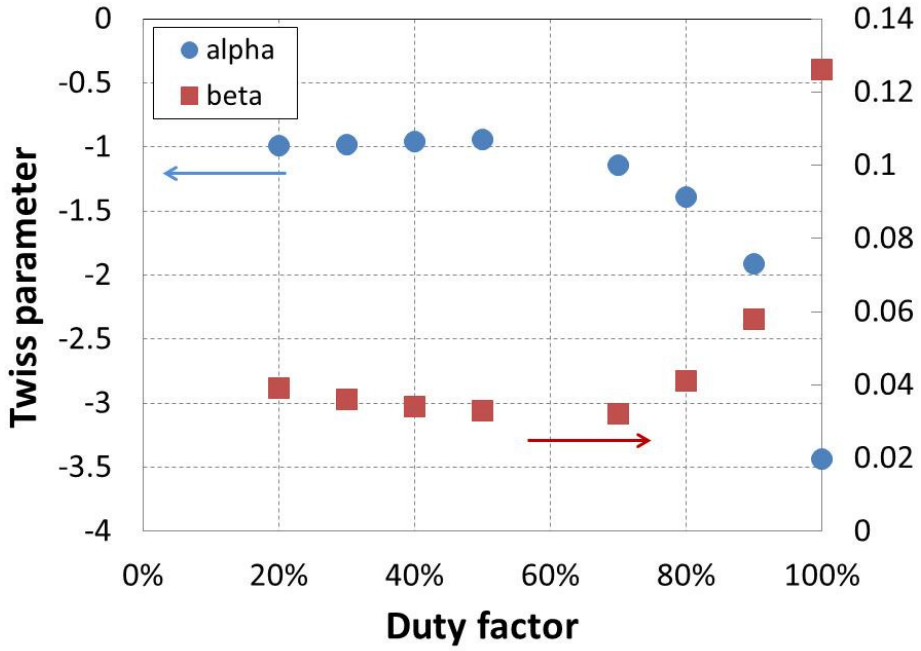


16 KeV, 3 mA H- Beam pulsed @ 1 MHz

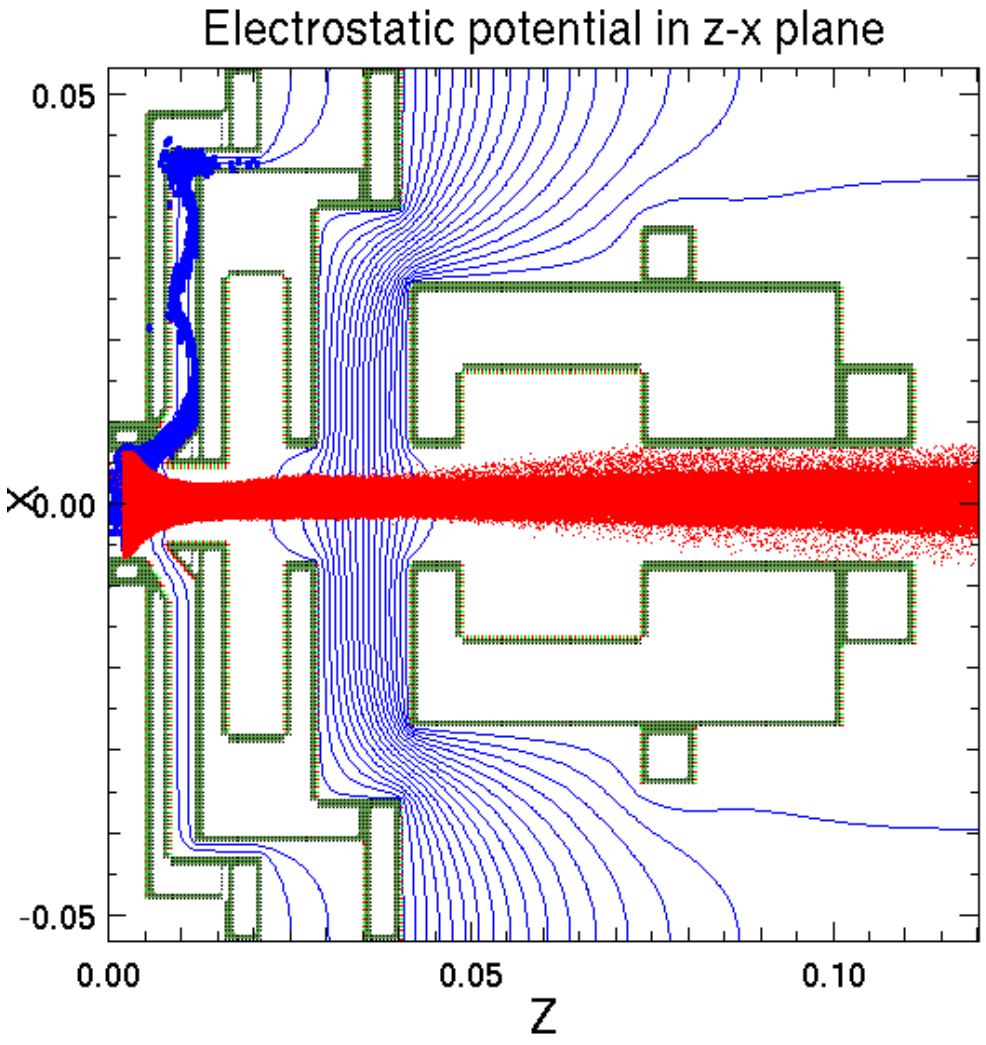


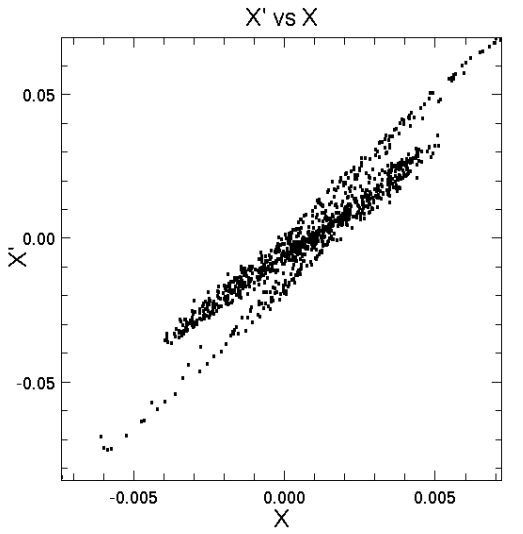
Emittance and Twiss parameters @1MHz

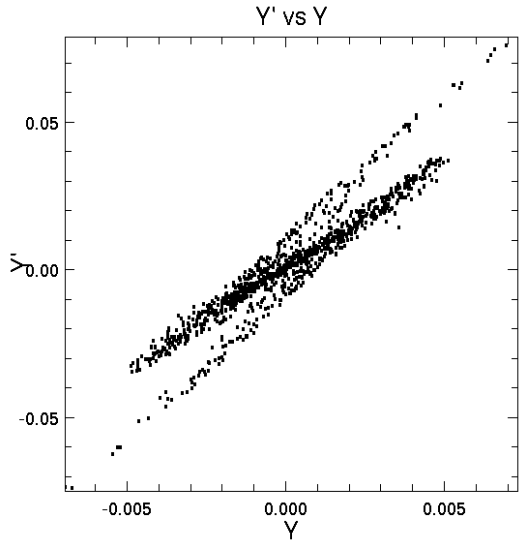




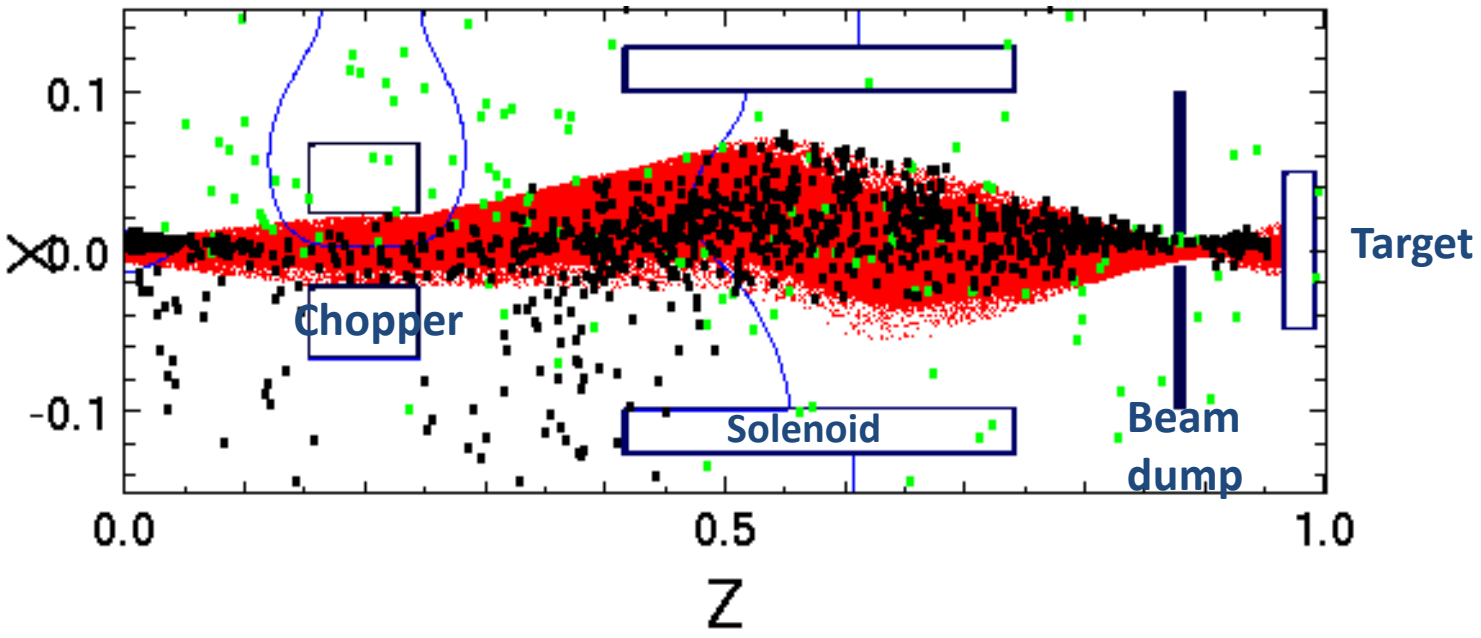
WARP Simulation of H- Beam Extraction (@ 16kV, 3 mA)







WARP Simulation of Chopper + Solenoid (Work in progress)

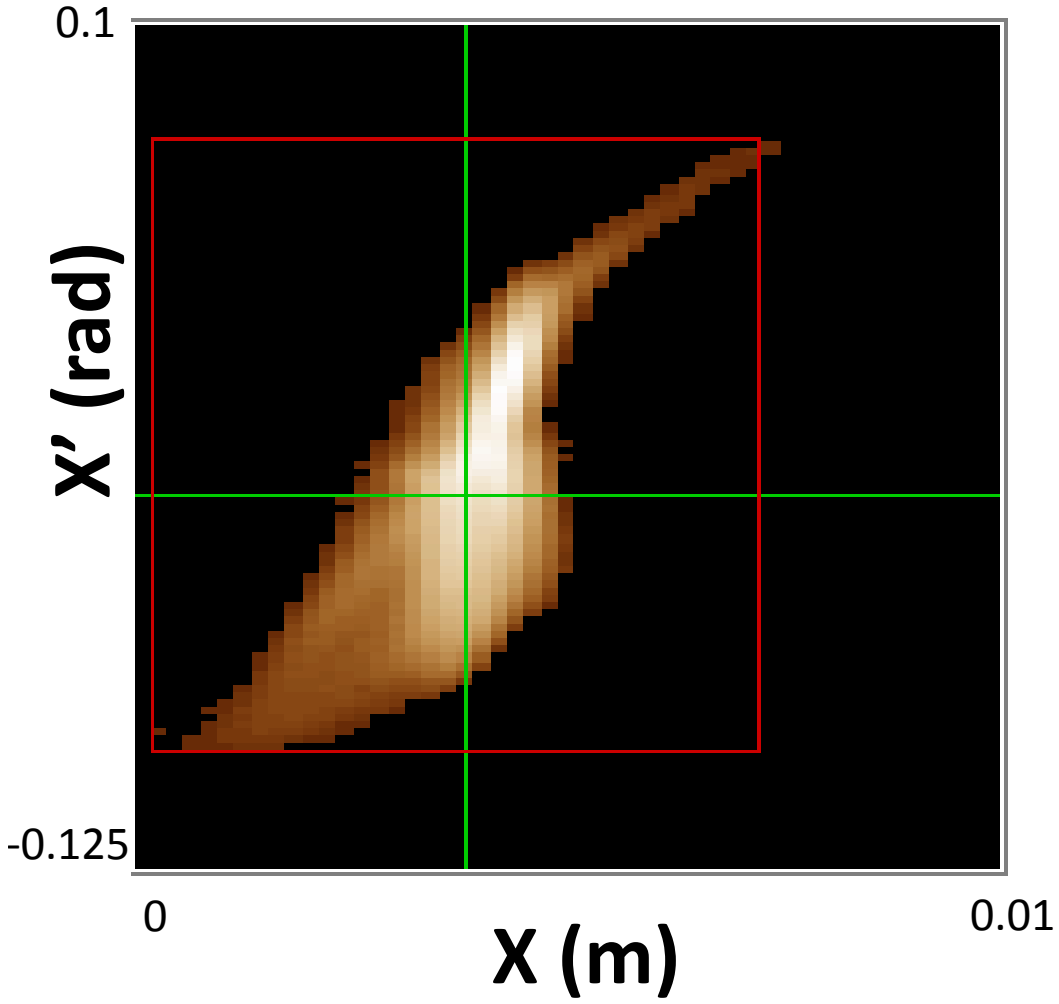


- H^-
- Electron
- H_2^+

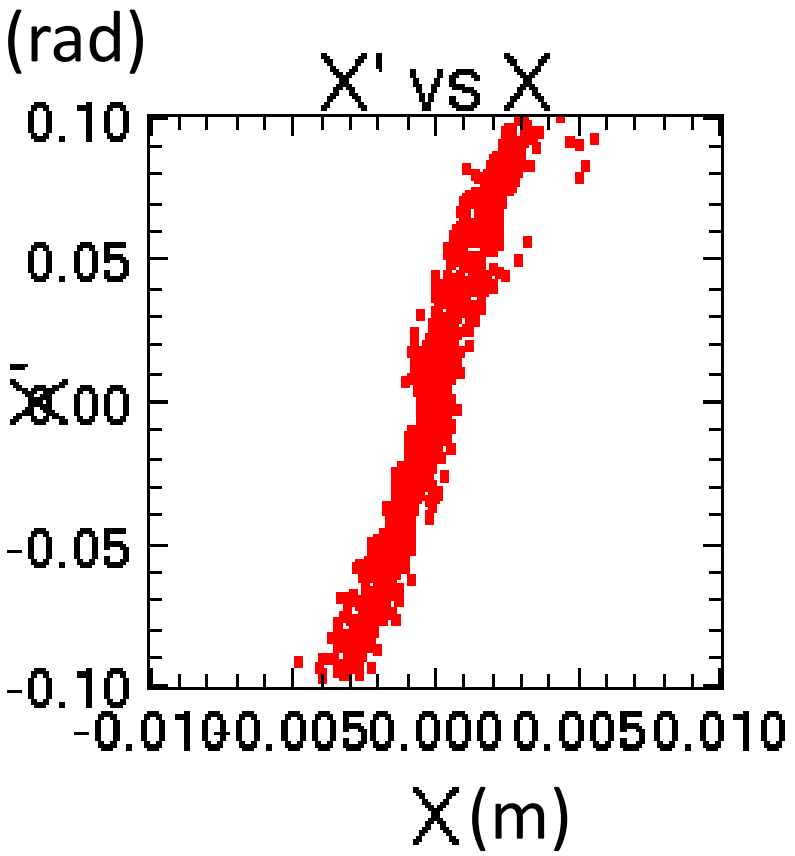
- Use the beam ensemble simulated by WARP

16 KeV, 3 mA H- Beam (pulsed @ 1 MHz 20%)

Experiment

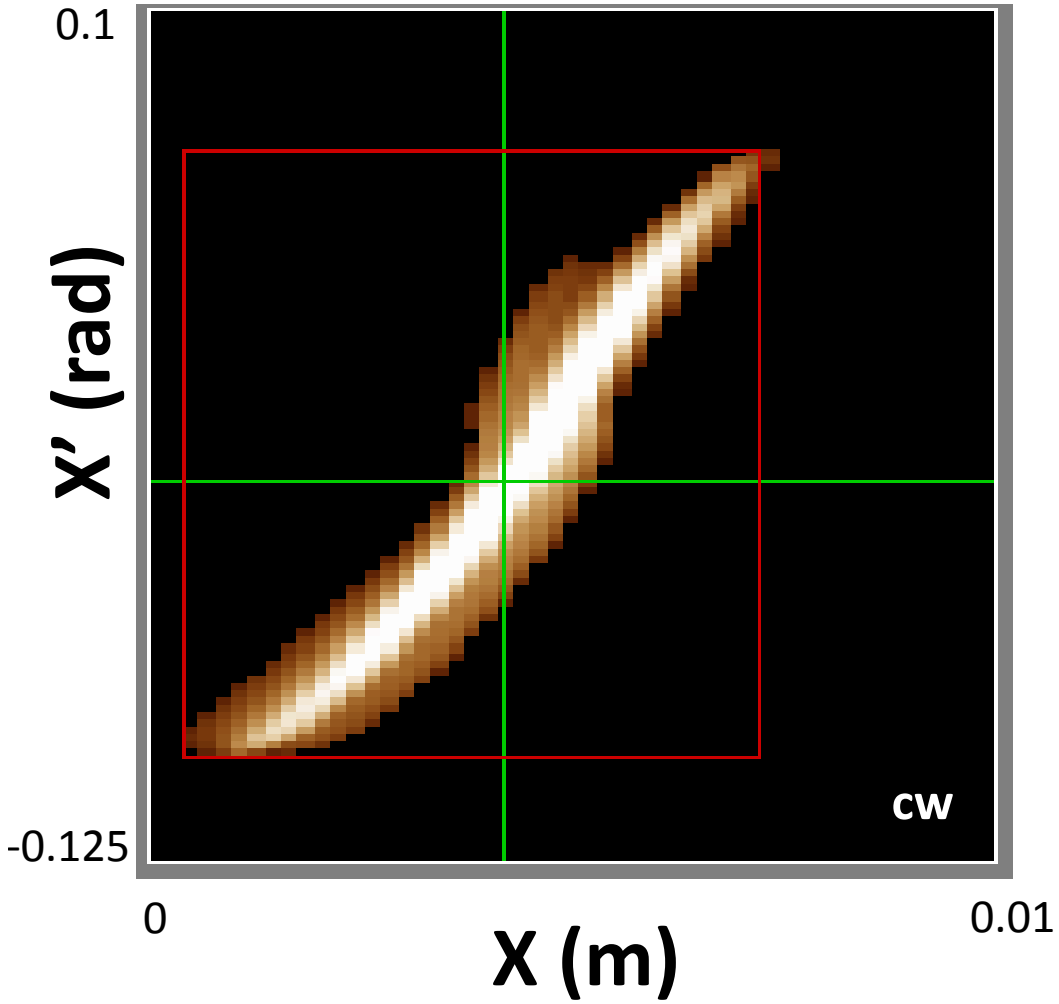


WARP Simulation

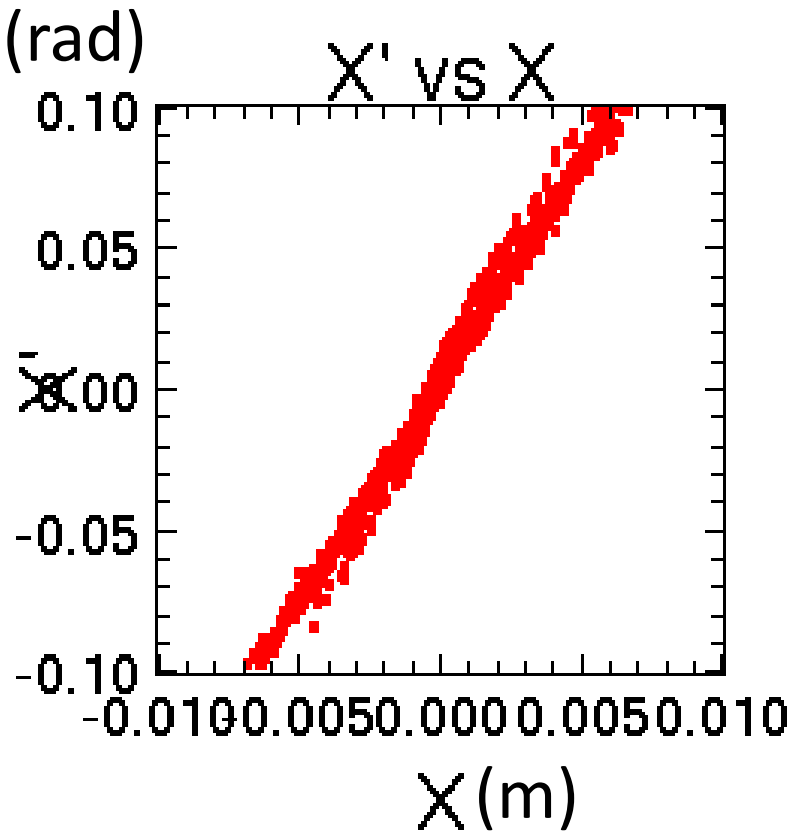


16 KeV, 3 mA H- Beam (CW)

Experiment

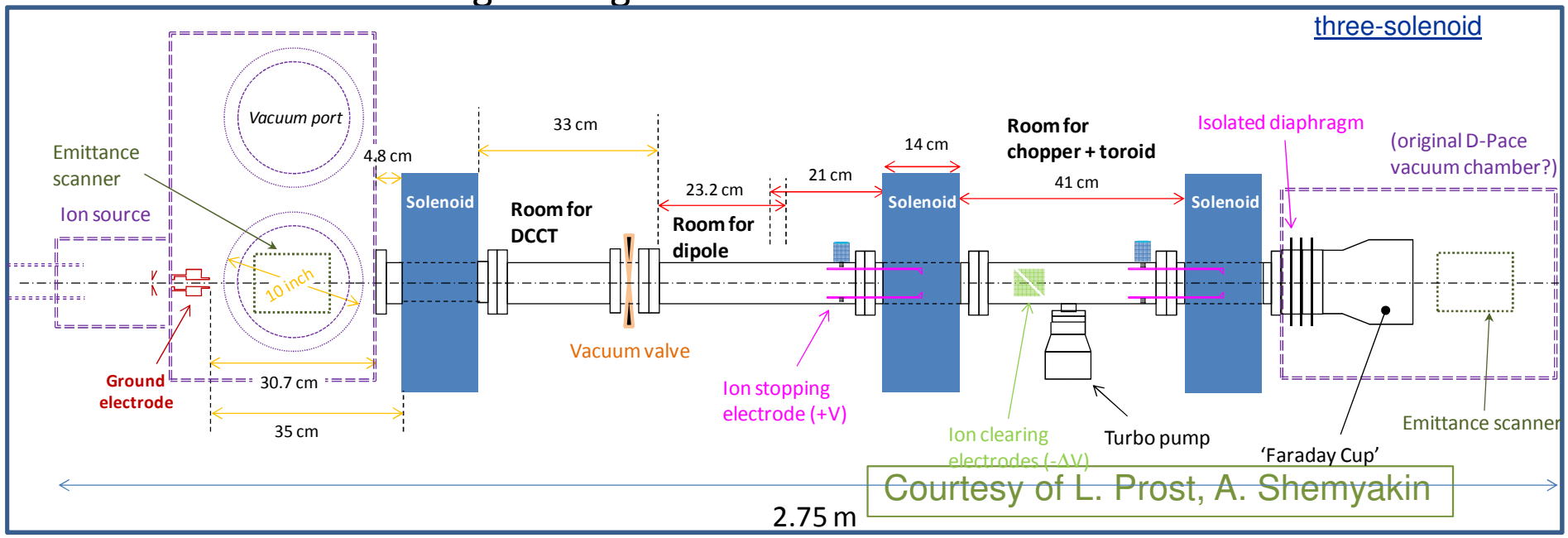


WARP Simulation



Future Plan

- WARP 3D simulation
  - Continue simulations of 3 mA, 16 keV H- beam dynamics in a chopper and solenoid as in the benchmark experiment
  - Emittance and twiss parameter vs. pulse repetition rate
  - Comparison between simulation and experimental results
- Time-dependent simulation of three-solenoid LEBTs including particle interactions with background gas.



Summary

- Time-dependent WARP 3D simulations of particle interactions, such as electron detachment, charge exchange, H- ionizations etc. in the LEBT are still ongoing.
- Both experimental and preliminary simulation results showed that, from the chopper to the entrance of RFQ, emittance increases.
- Chopper simulation benchmark experiment has been performed at various pulse duty factor and repetition rate.
- WARP 3D simulations in progress for benchmarking.