Time-Dependent Phase-Space Measurements of the Longitudinally Compressing Beam in NDCX-I

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Accelerator and Fusion Research Division

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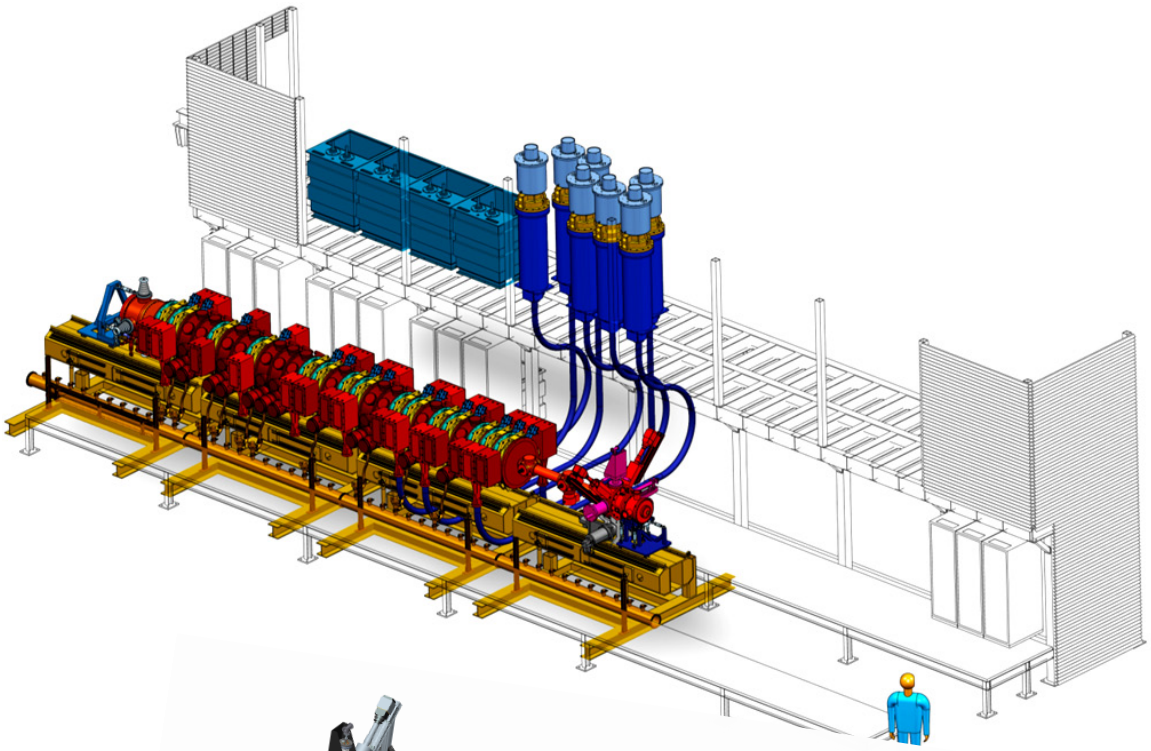
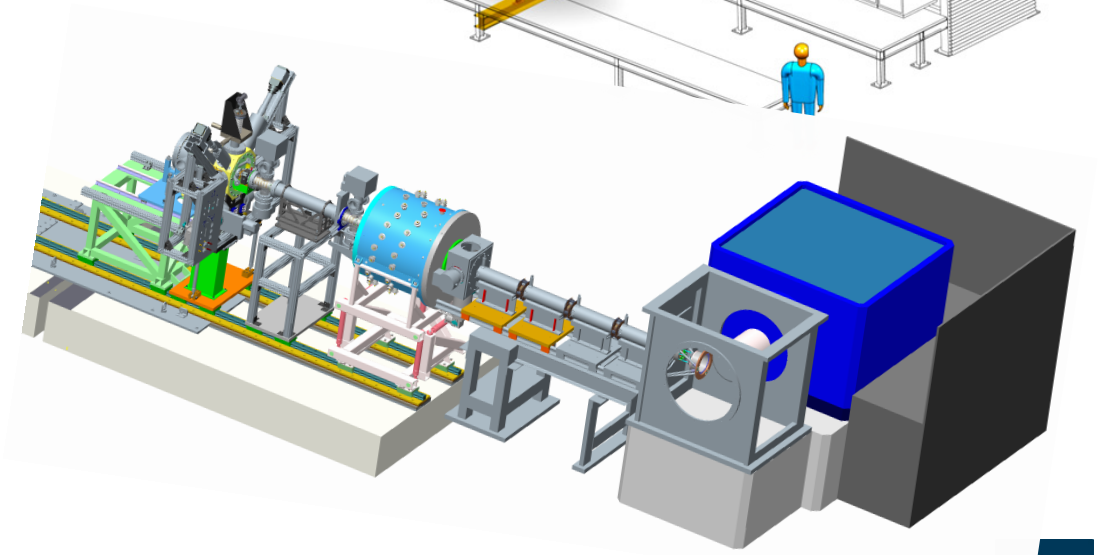
Berkeley, CA USA

NDCX – Increased fluence with neutralized drift compression



NDCX-II
1.2MeV Li^+
50nC 0.5ns
0.7mm spot

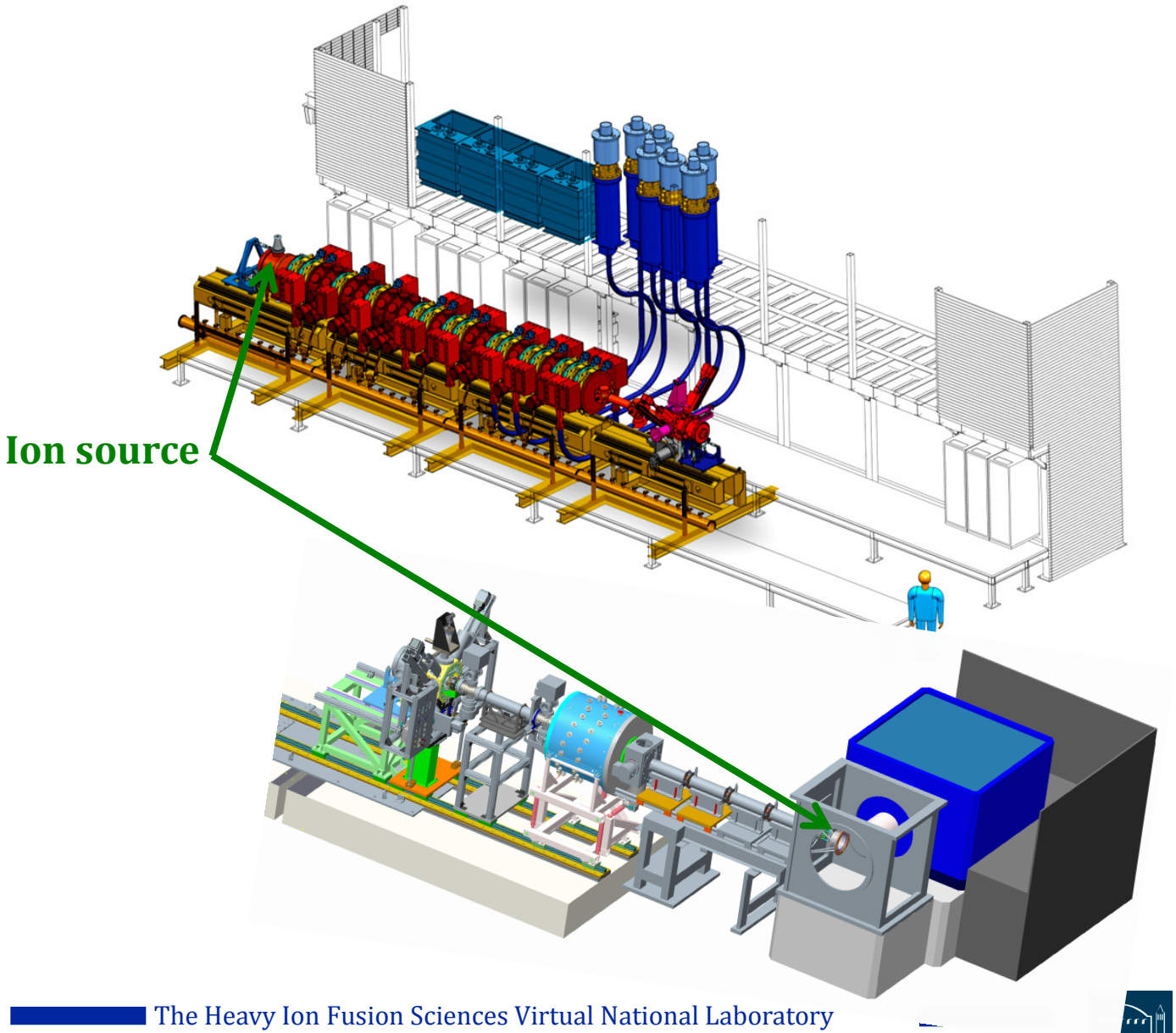
Online 2012



NDCX-I
300kV K^+
15nC ~2ns
2mm spot

Online 2009

NDCX – Increased fluence with neutralized drift compression



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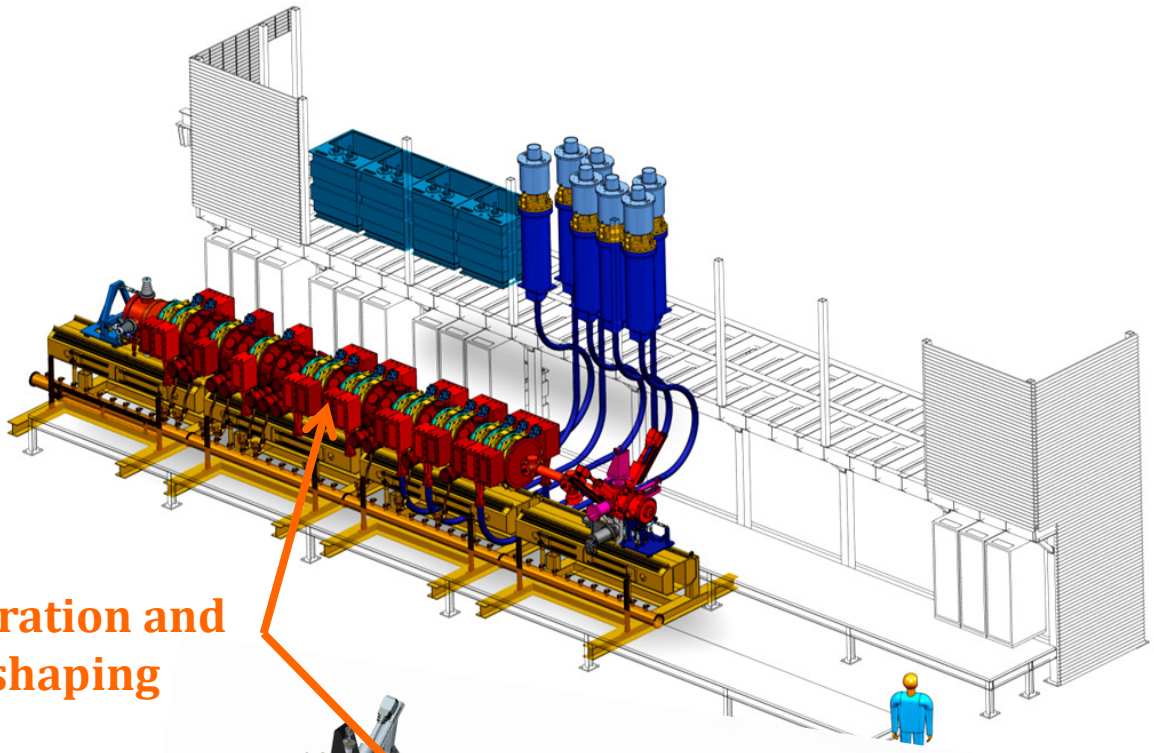
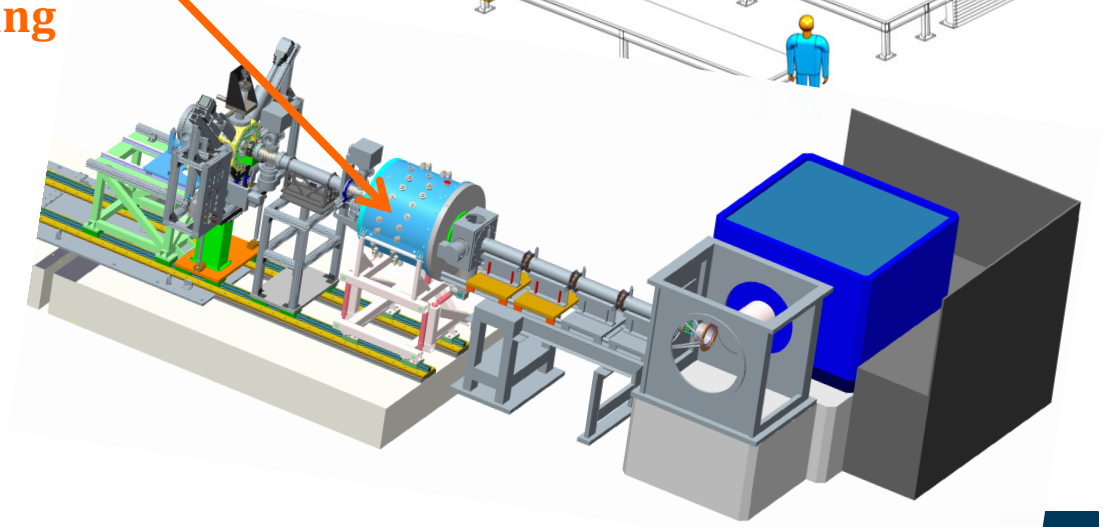


Acceleration and pulse shaping



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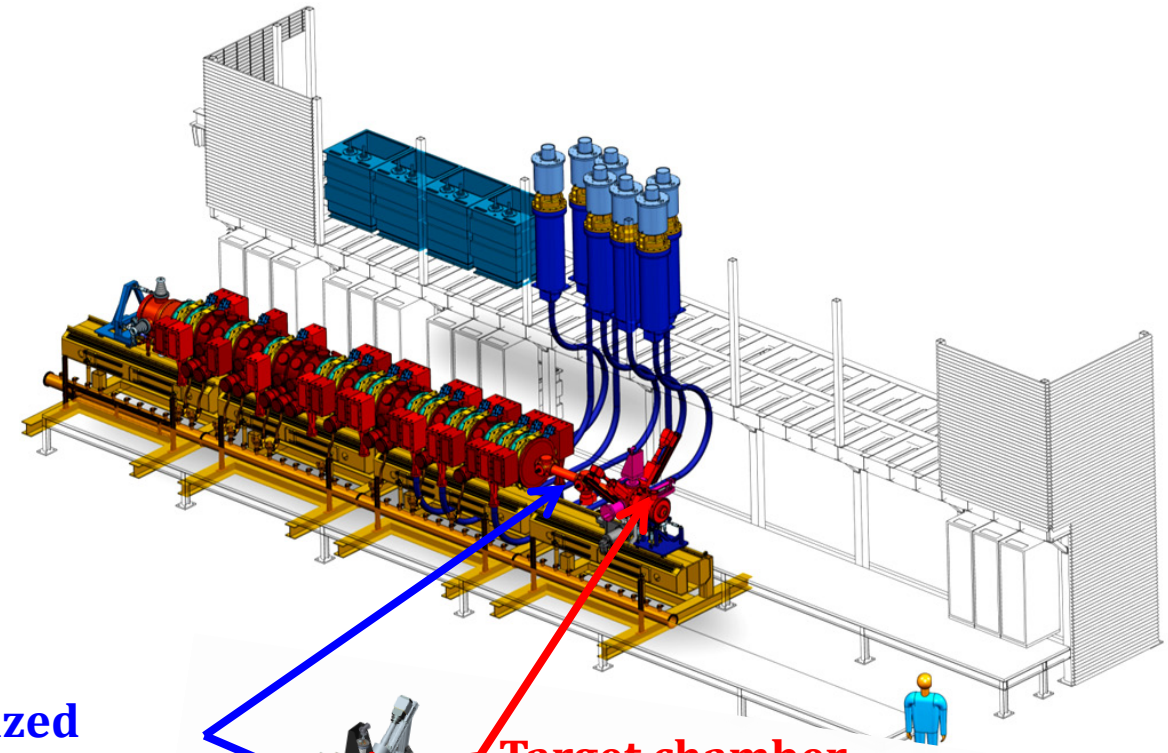
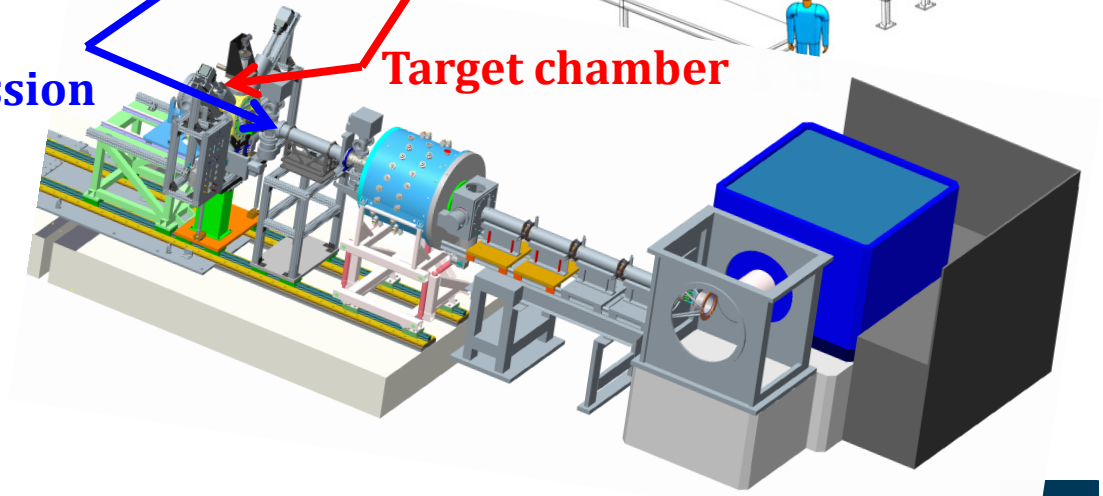


Neutralized drift compression

Target chamber



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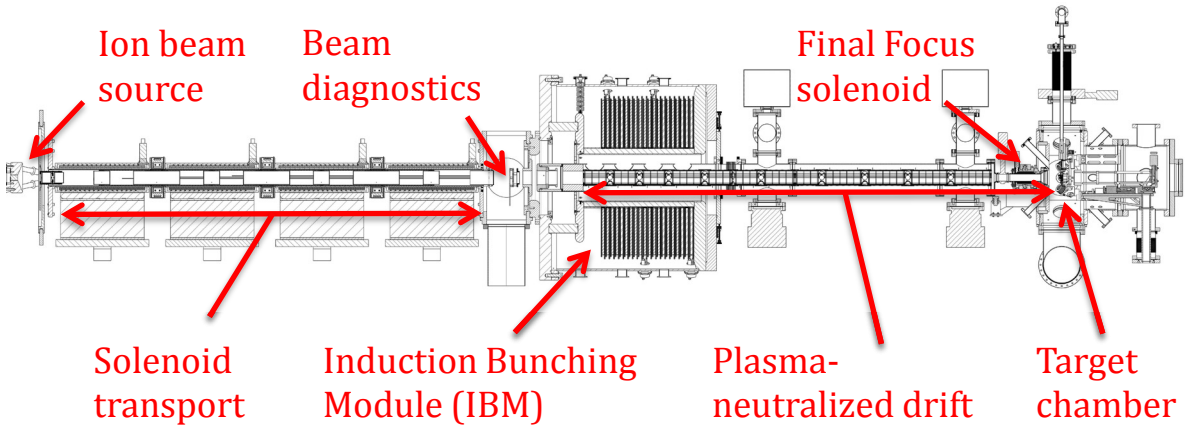
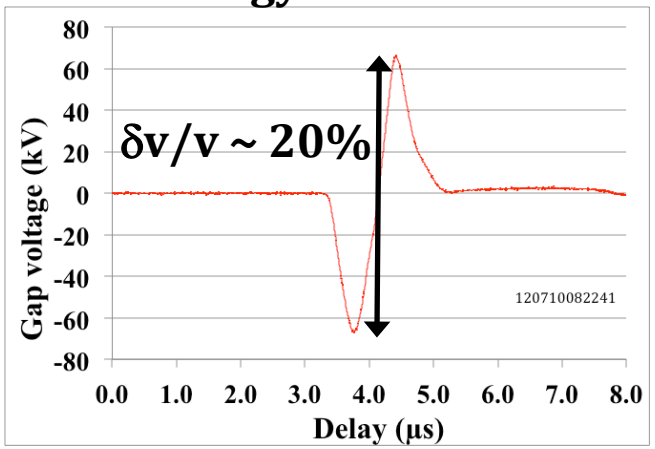
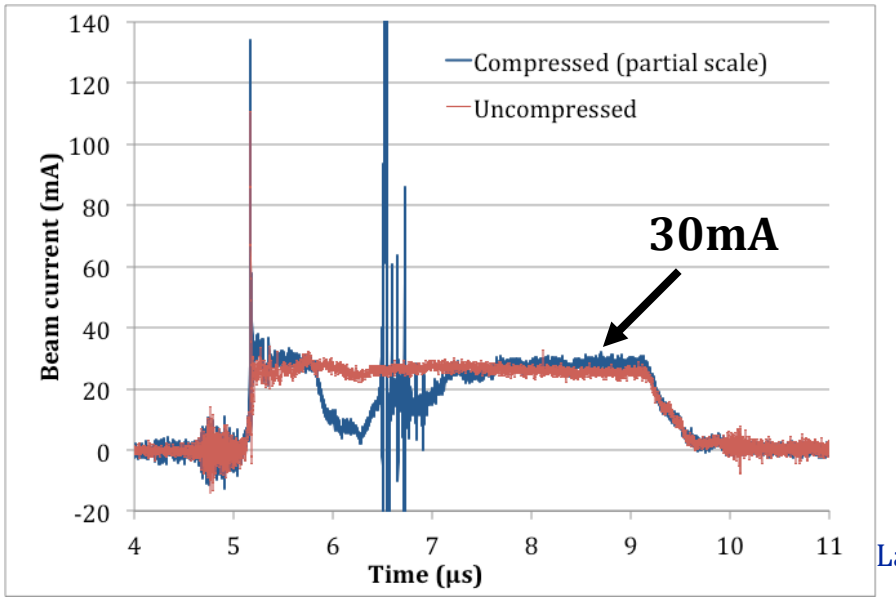
NDCX-I Experiment – Longitudinal compression



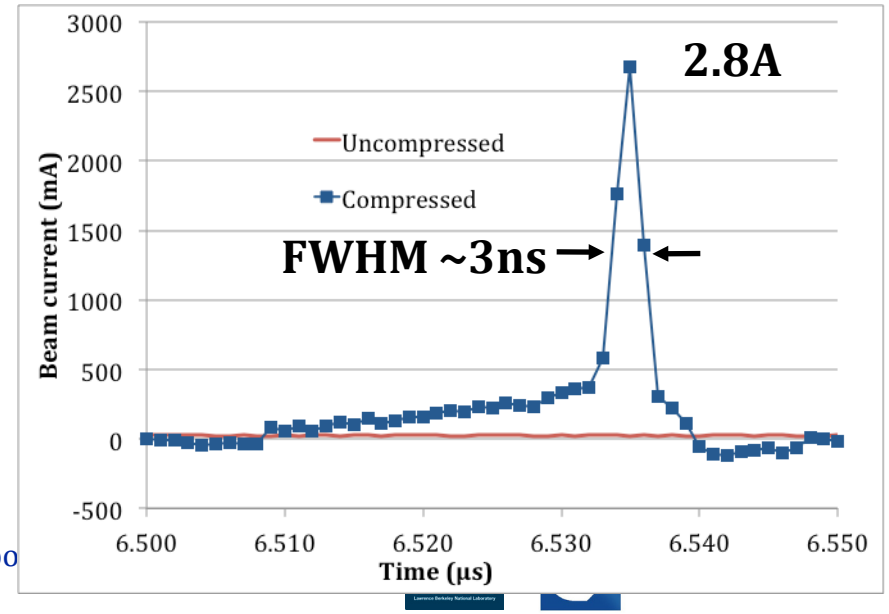
Energy modulation



Peak current ~2.8A
Uncompressed current ~30mA

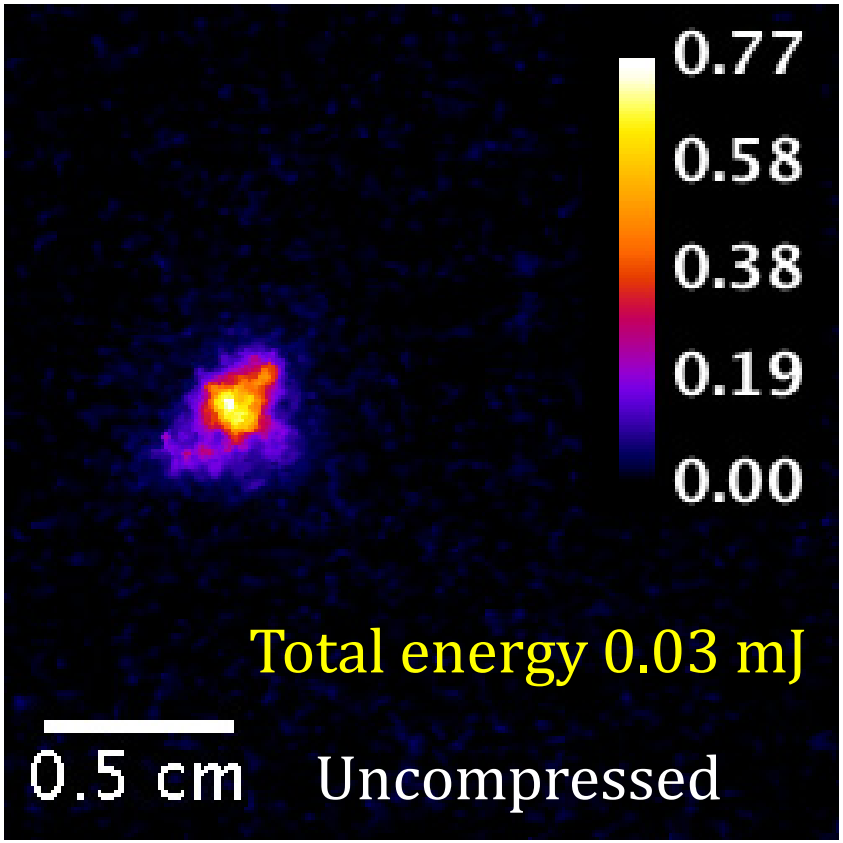


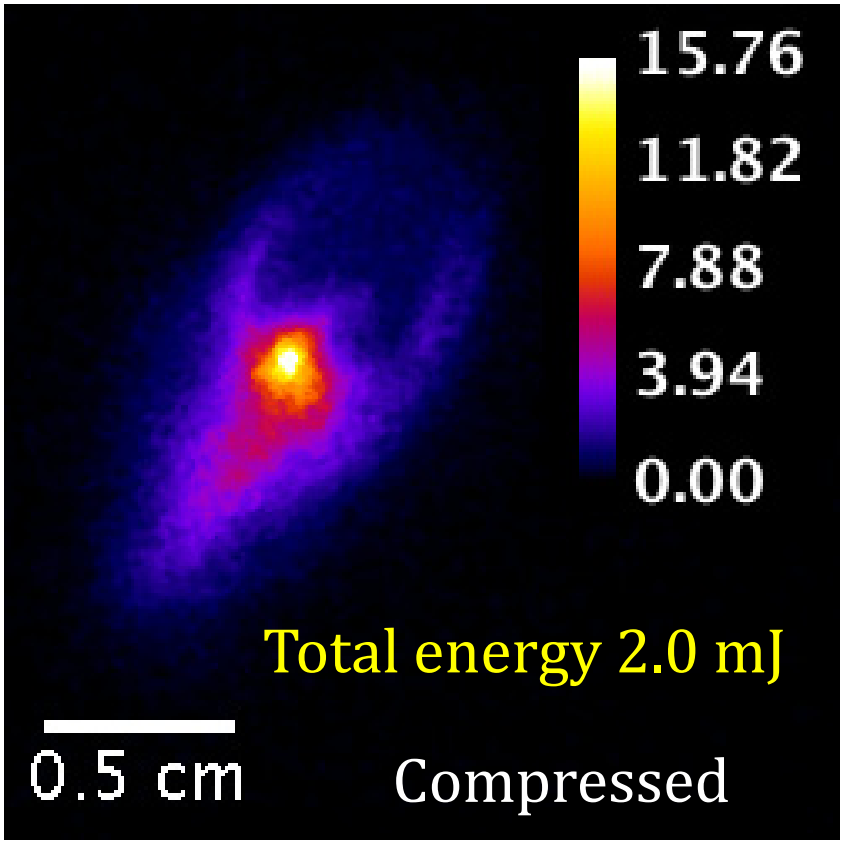
Compression Ratio >90



Aberrations at the target plane reduce beam fluence

Beam fluences (mJ/cm^2) averaged over 3.5ns gate window





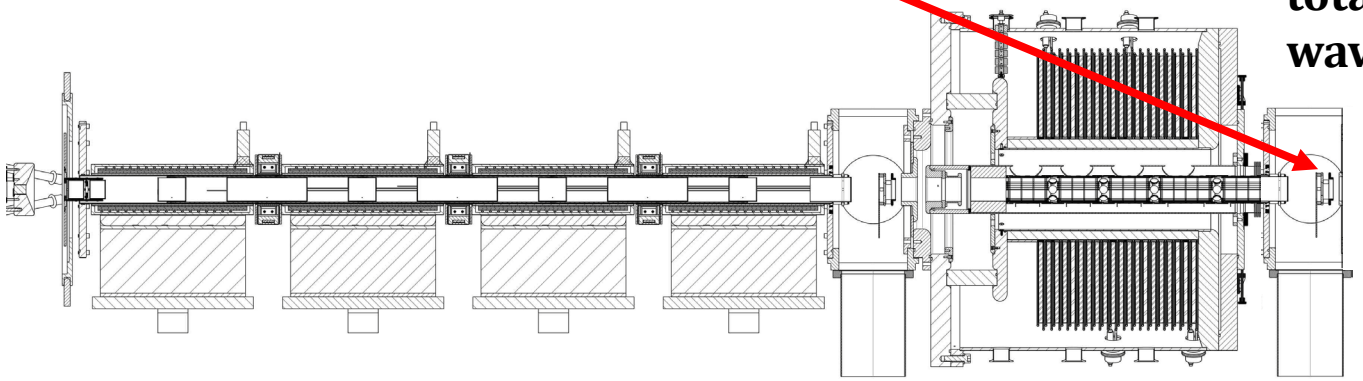
Chromatic aberrations: 'Circle of least confusion' r_c ~ 5mm

Peak fluence ratio ~20X while the peak current ratio ~90X

Measuring the modulated beam phase space

The NDCX-I neutralized drift beamline was split and beam diagnostics added.

'Deep' Faraday cups measure total current waveform.



'Box 1' **'Box 2'**

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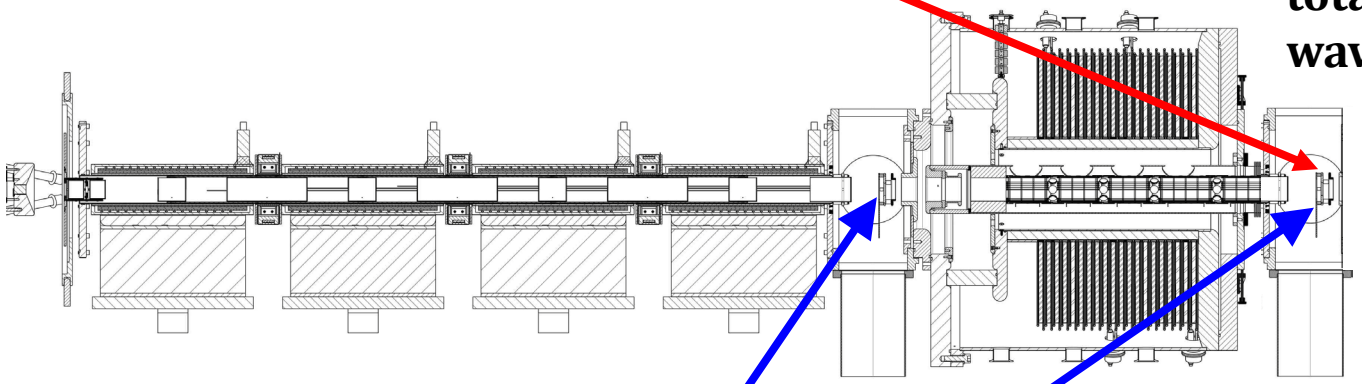
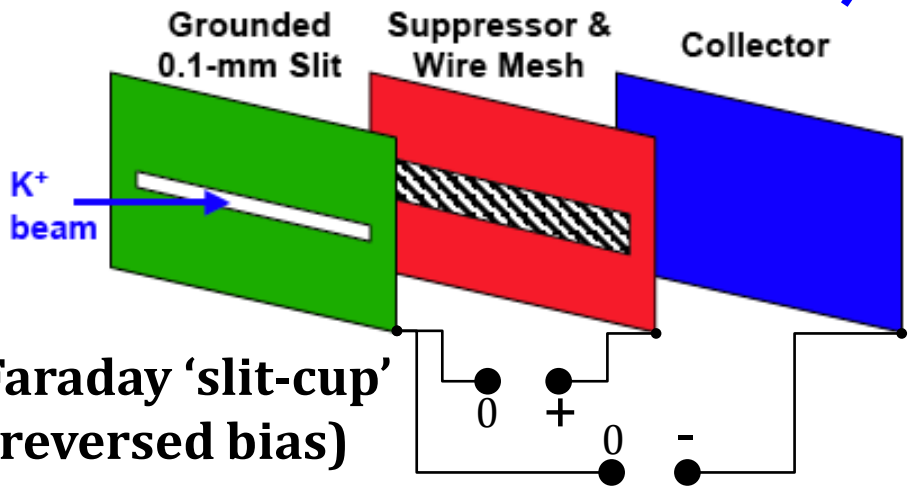


'Box 1'

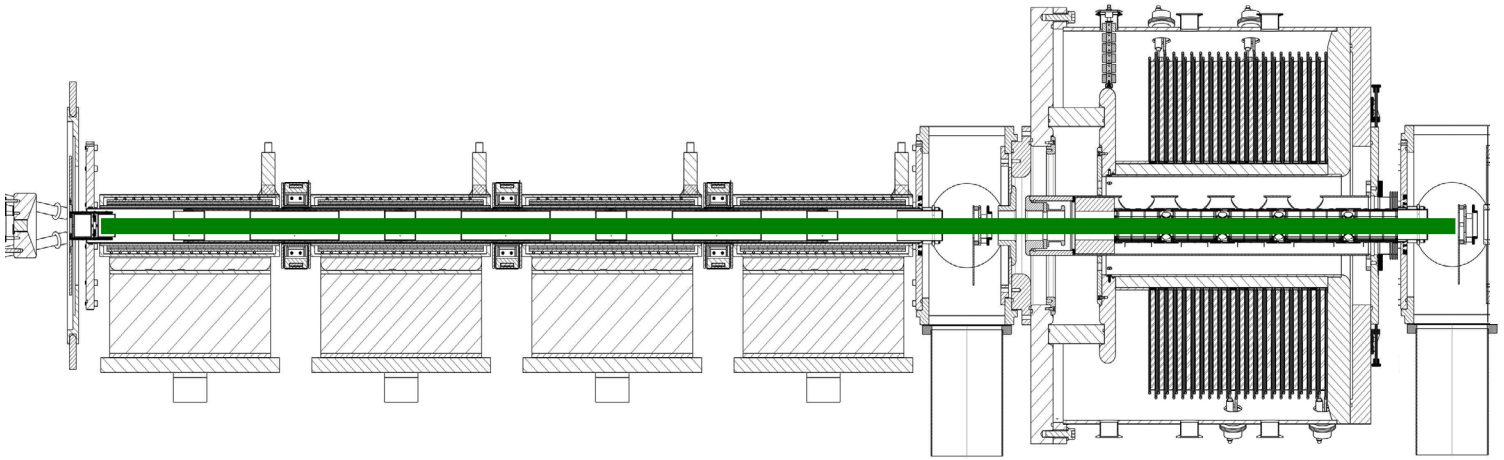
'Box 2'



Faraday 'slit-cup' (reversed bias)

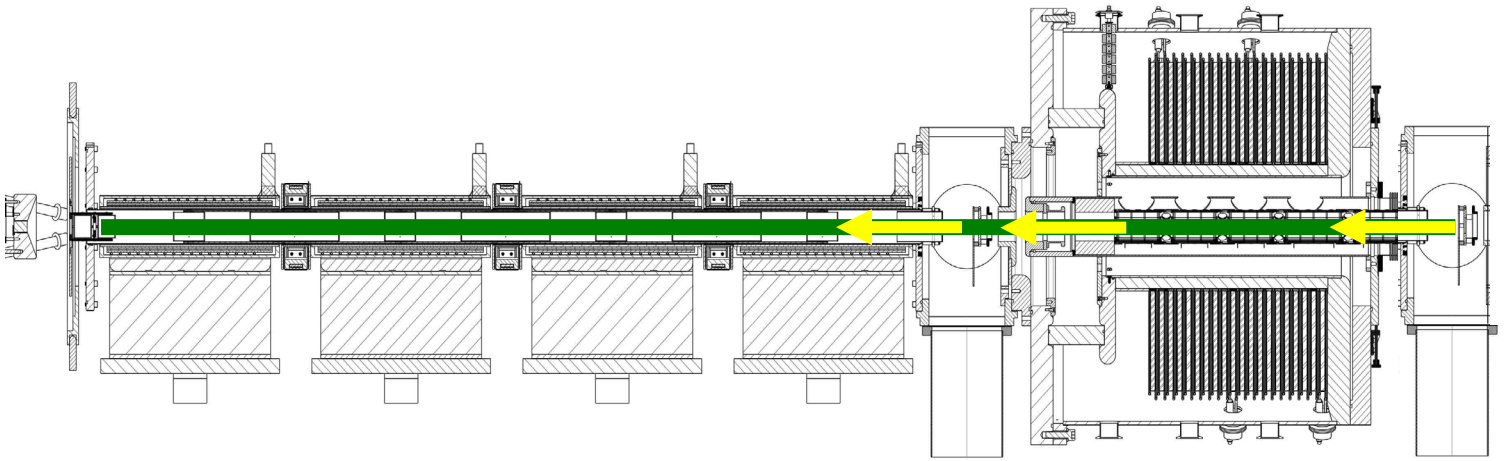
Horizontal and vertical slits and Faraday slit-cups provide time-resolved phase space density.

Controlling backstreaming electron flows



Controlling backstreaming electron flows

Electrons from the plasma and secondary emission can counter-propagate in the beam potential, disrupting beam transport tunes.



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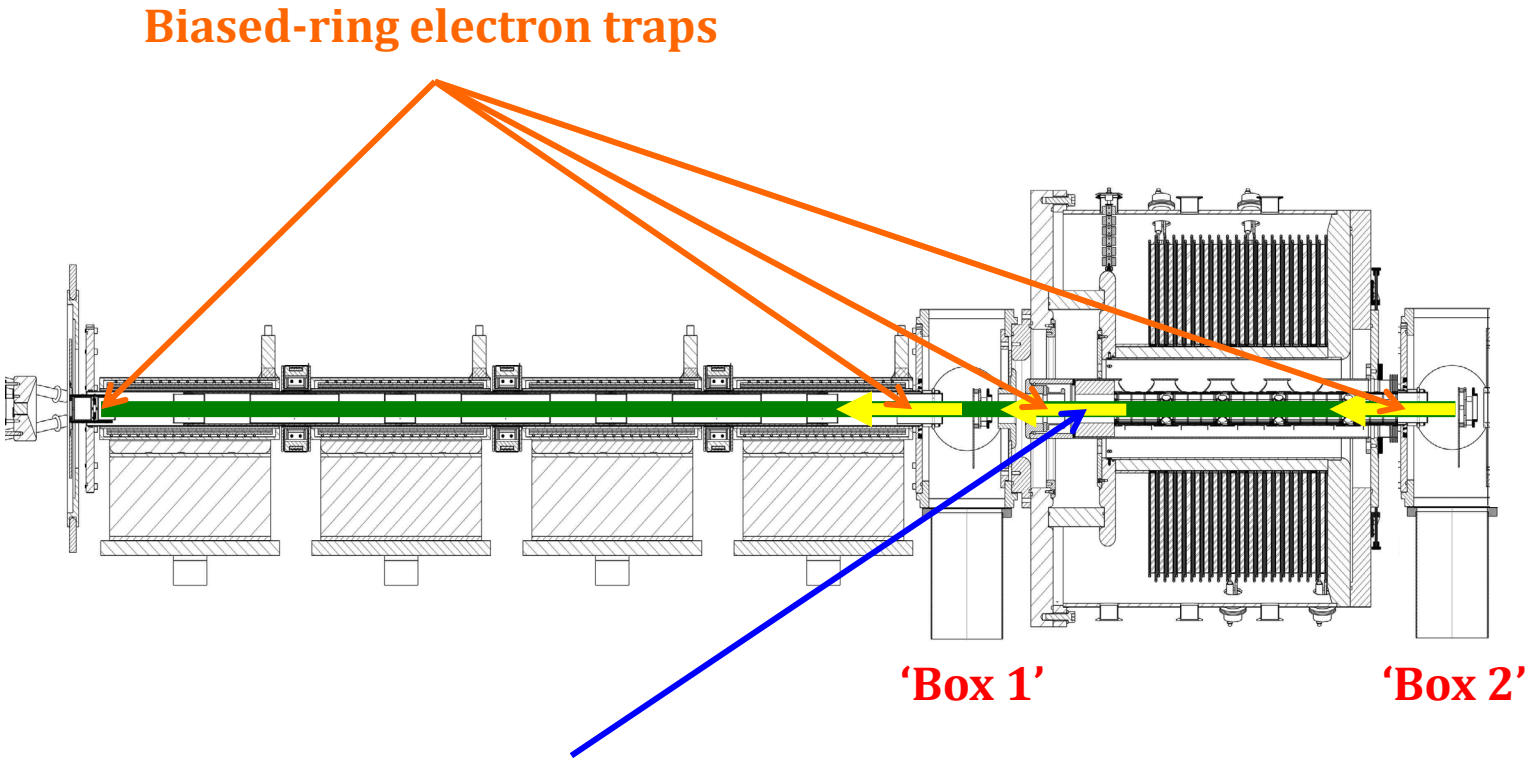
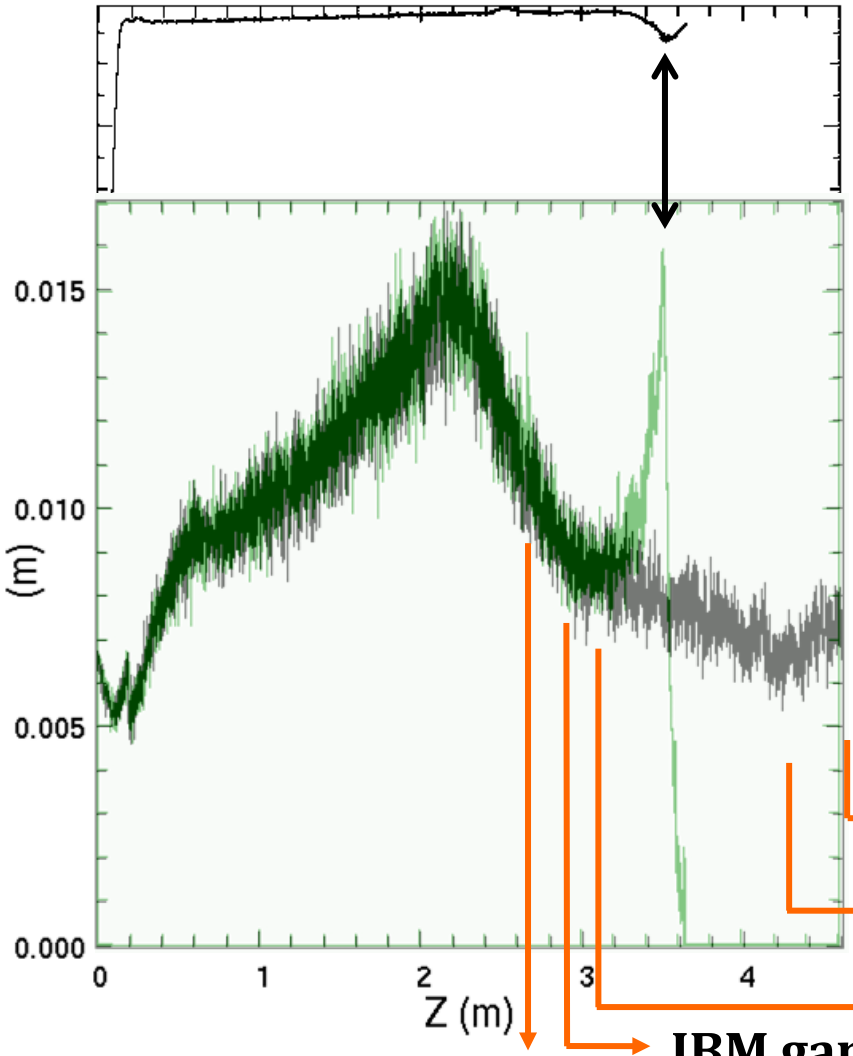


WARP model predictions of gap focusing and beam transport



Beam head

Unmodulated beam

Box 2

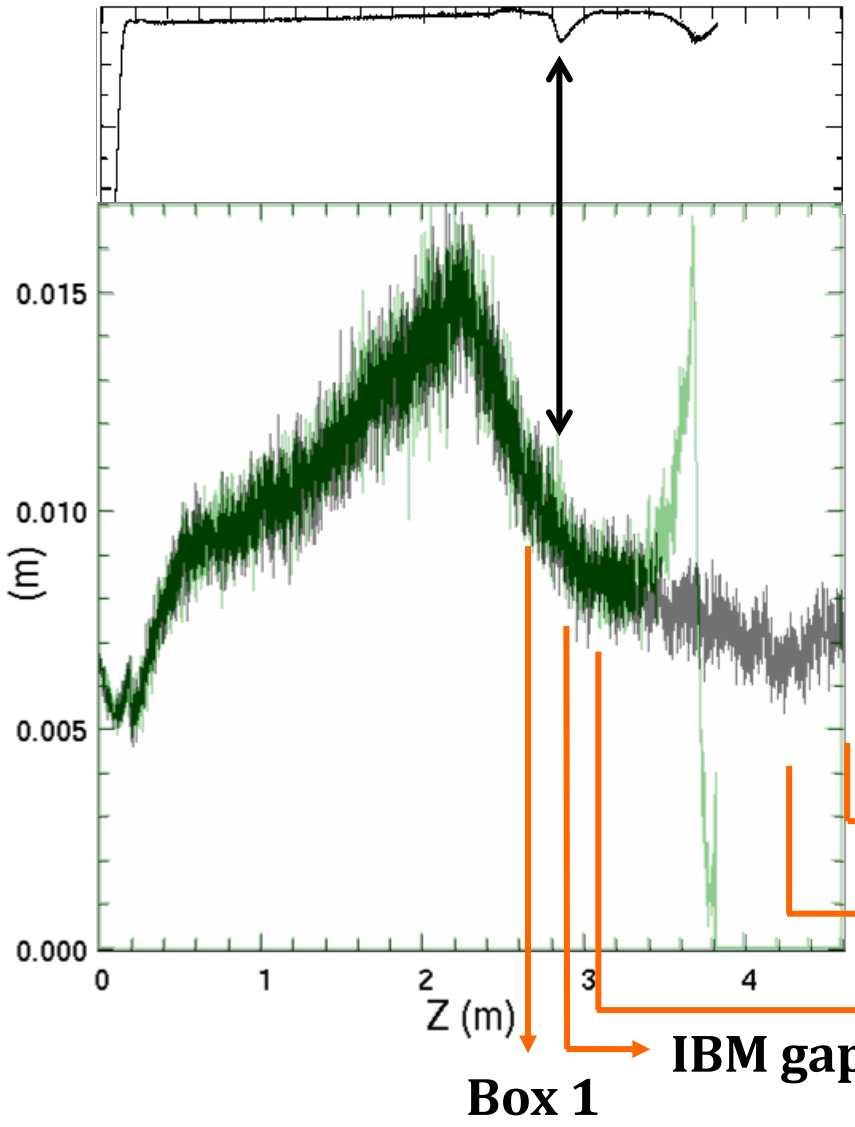
Plasma exit

Plasma entrance

IBM gap

Box 1

WARP model predictions of gap focusing and beam transport



Beam modulation beginning

Unmodulated beam

Box 2

Plasma exit

Plasma entrance

IBM gap

Box 1

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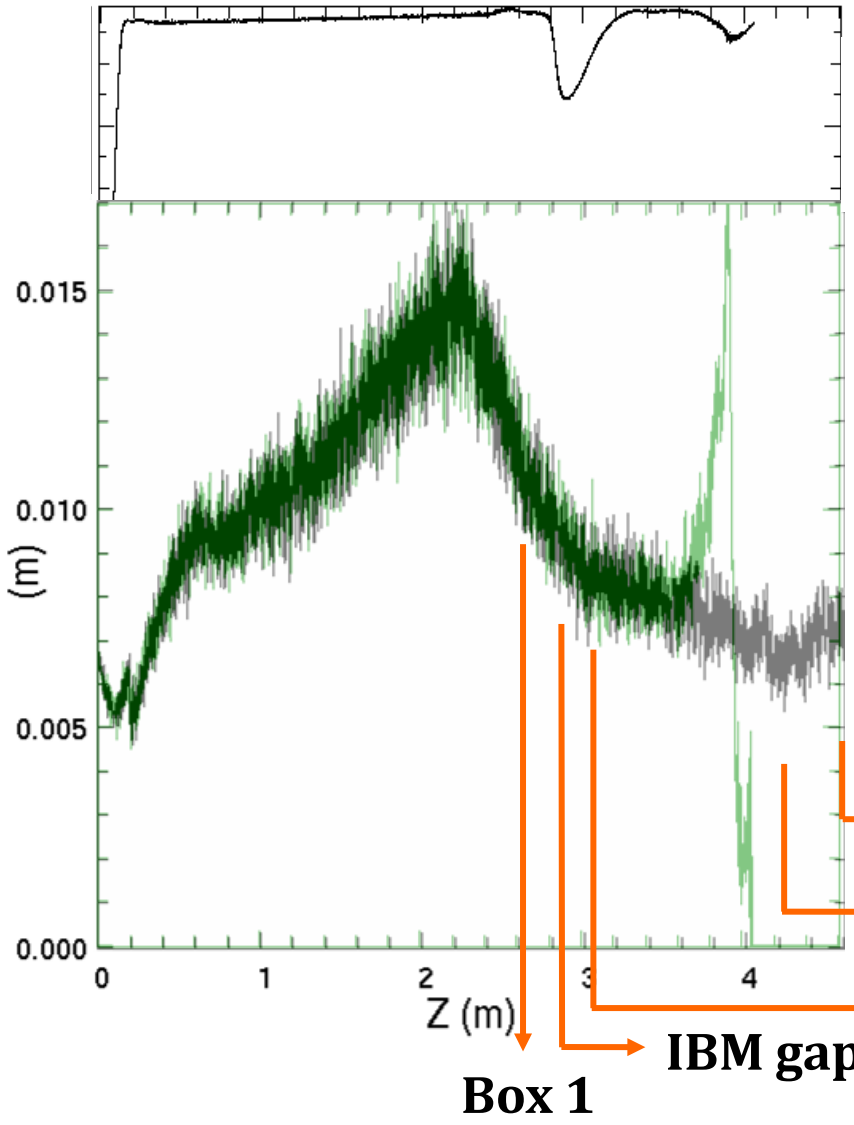

De-acceleration phase

Unmodulated beam

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Plasma exit

Plasma entrance

IBM gap

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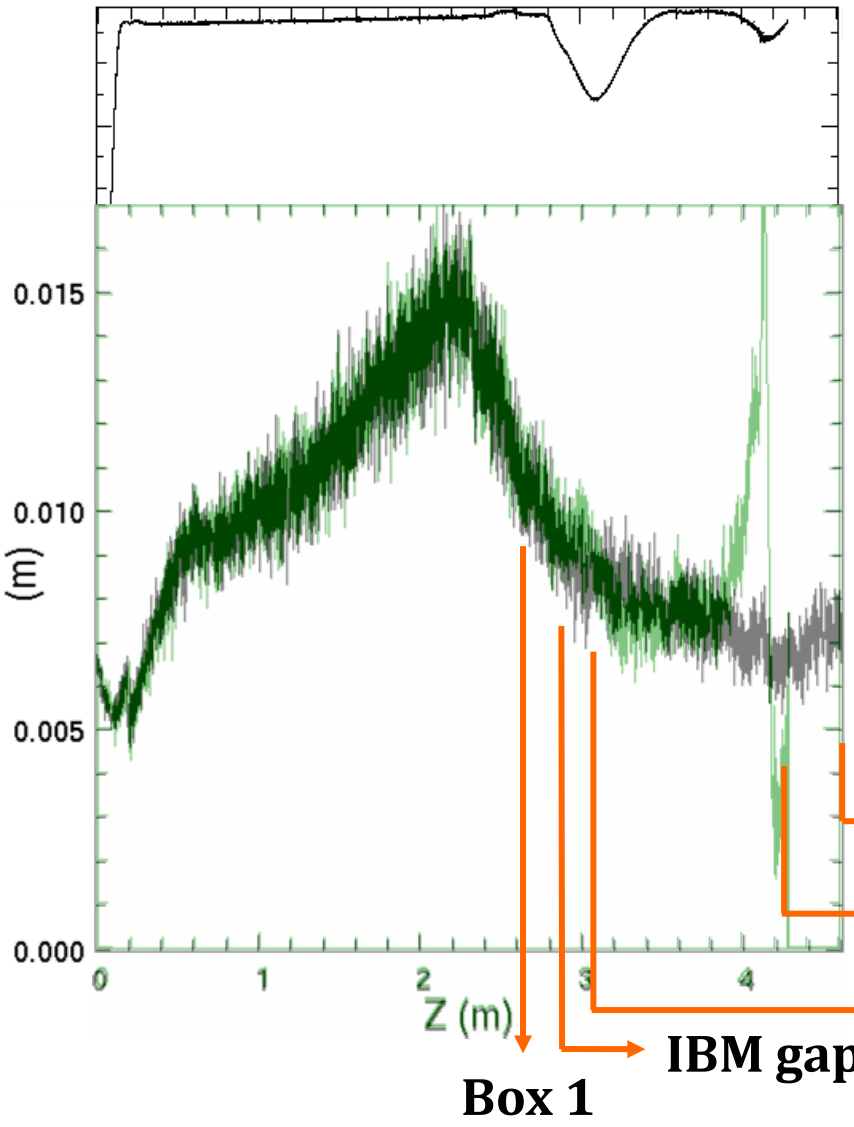
WARP model predictions of gap focusing and beam transport



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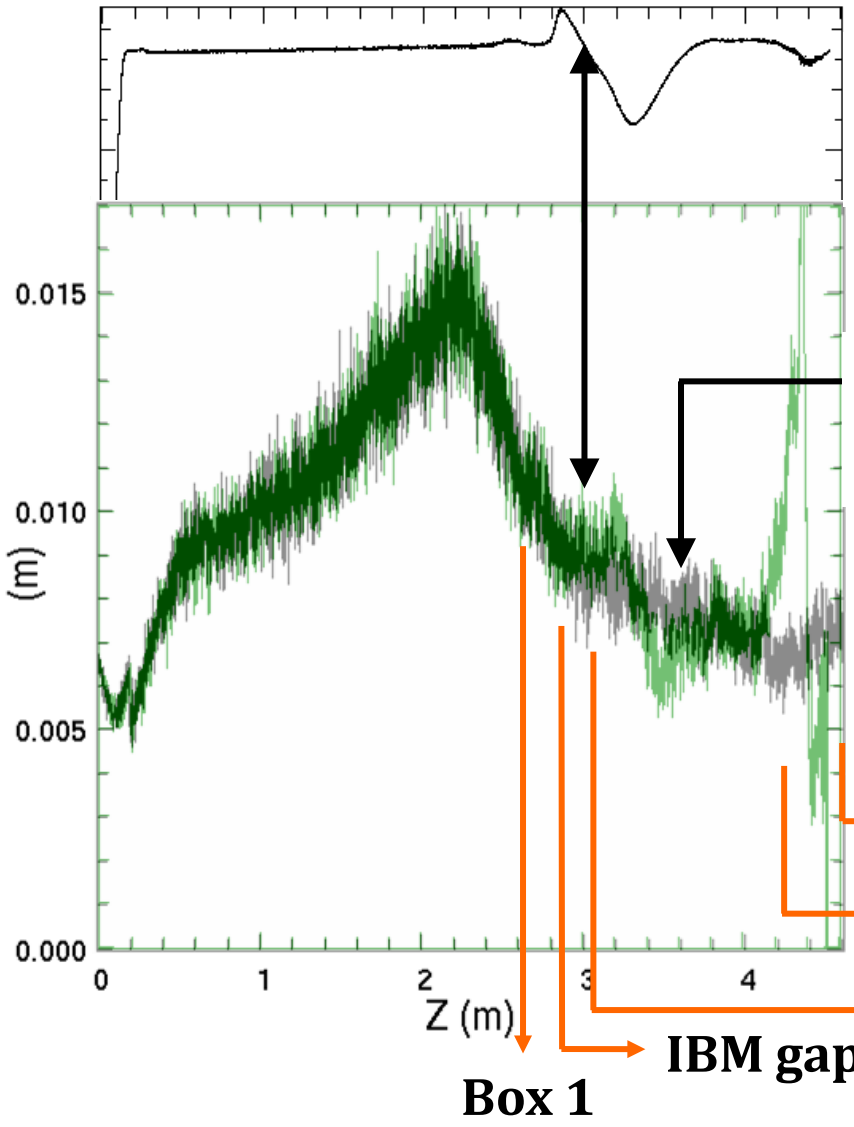

Zero-crossing
Maximum dV/dt

Focusing variation
from waveform

Unmodulated beam

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Plasma exit

Plasma entrance

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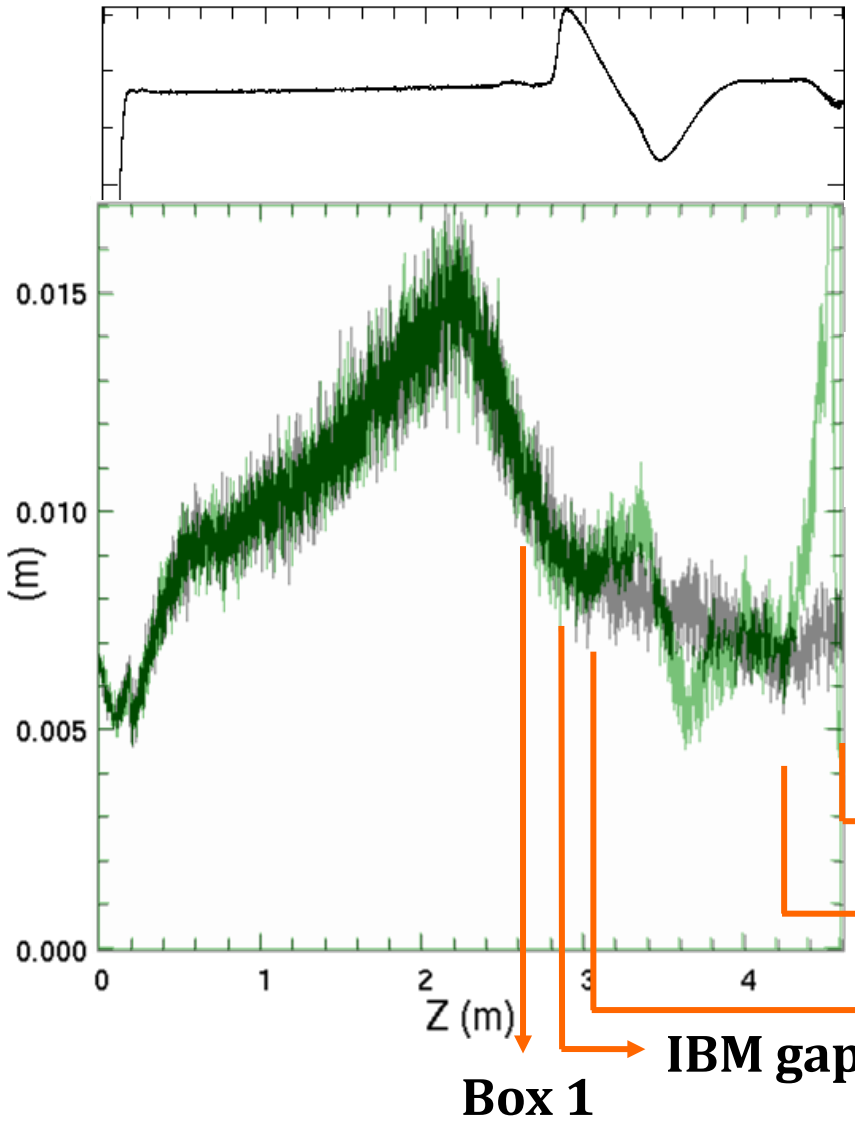

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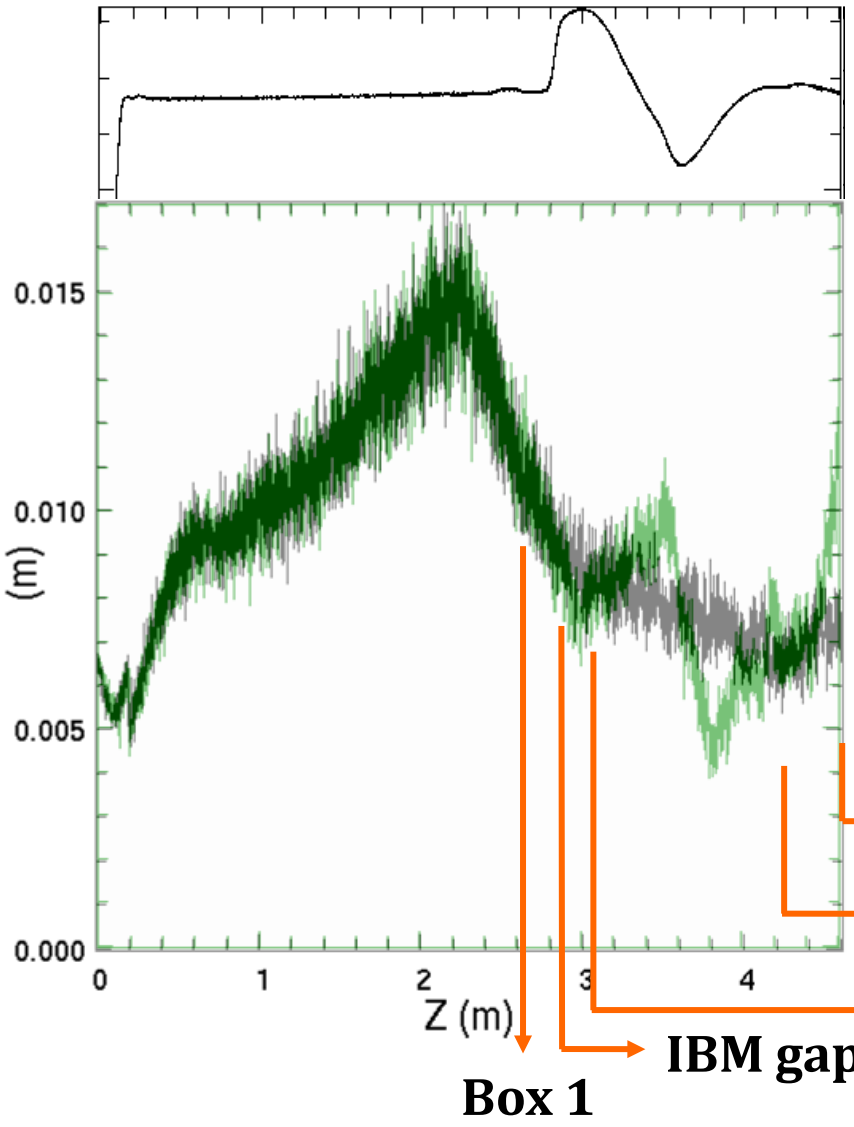

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Maximum dV/dt

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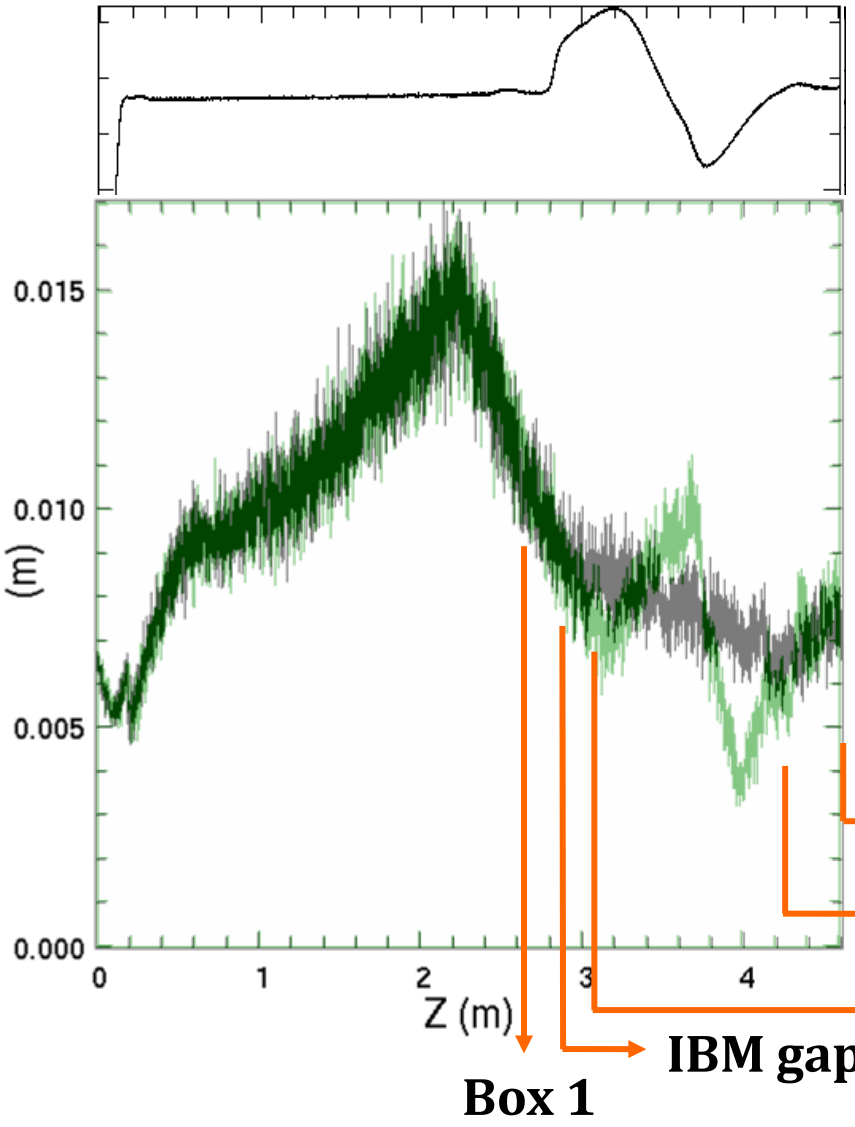

Zero-crossing
Maximum dV/dt

Focusing variation
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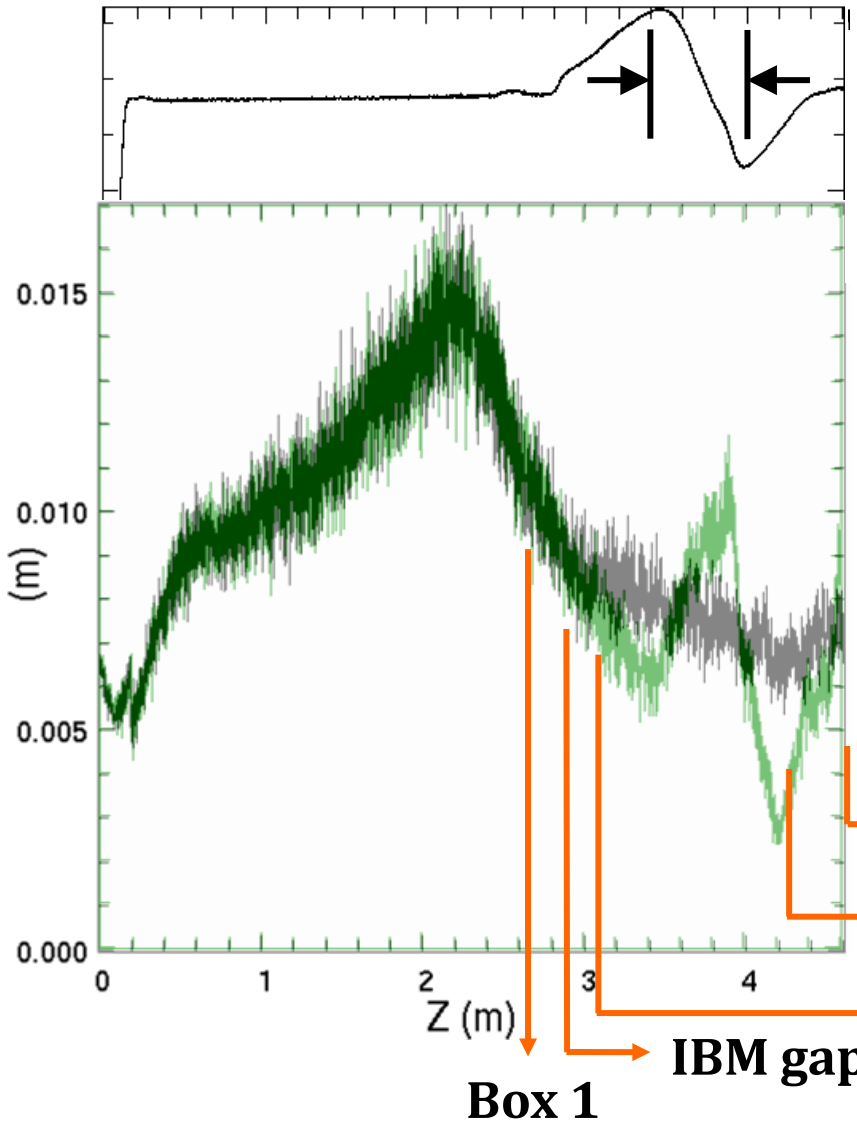

Compressing pulse

Focusing variation from waveform

Unmodulated beam

Box 2

Plasma exit

Plasma entrance

IBM gap

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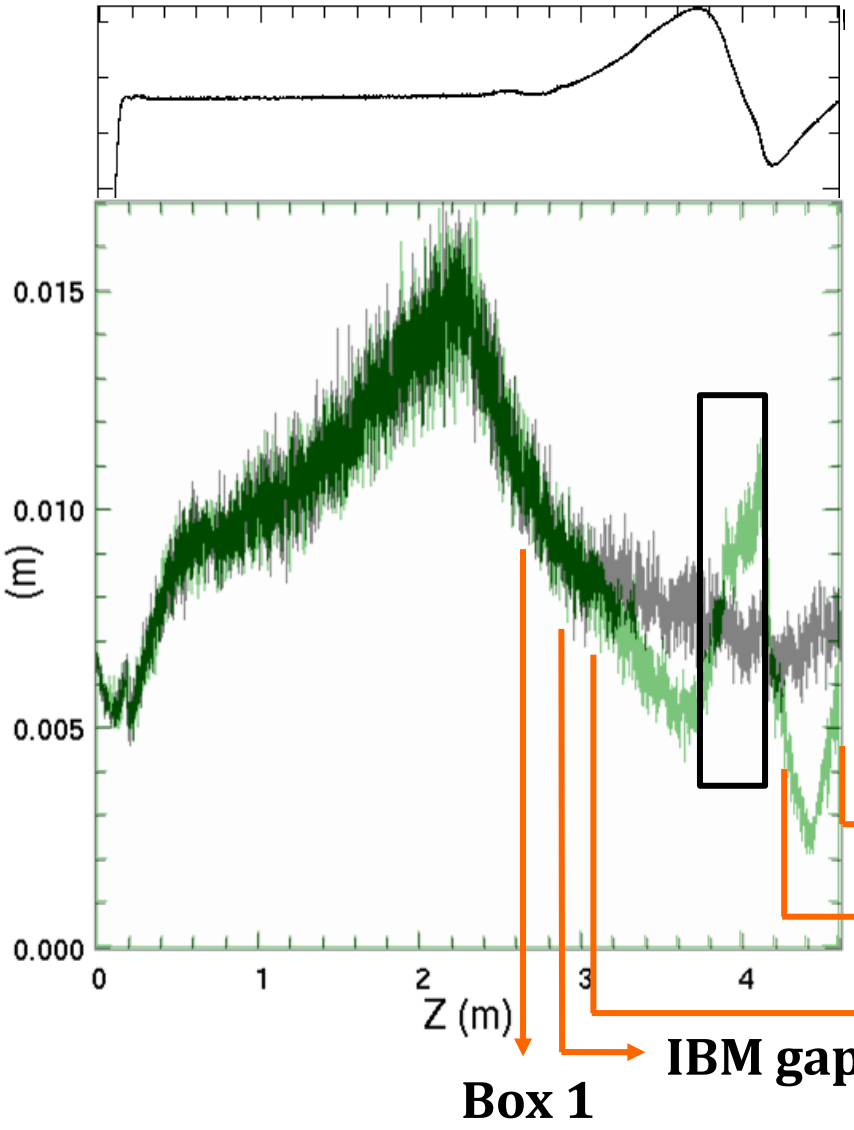
WARP model predictions of gap focusing and beam transport



Beam modulation produces time-varying envelope variations

Unmodulated beam

Box 2

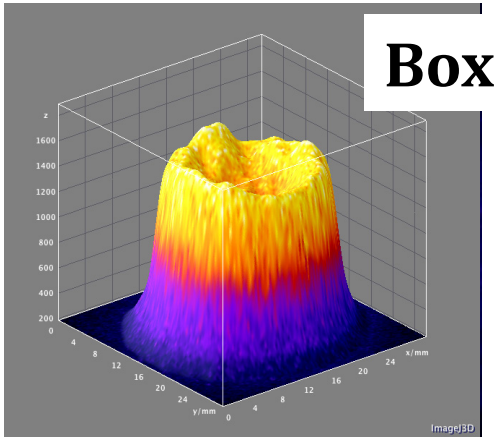
Plasma exit

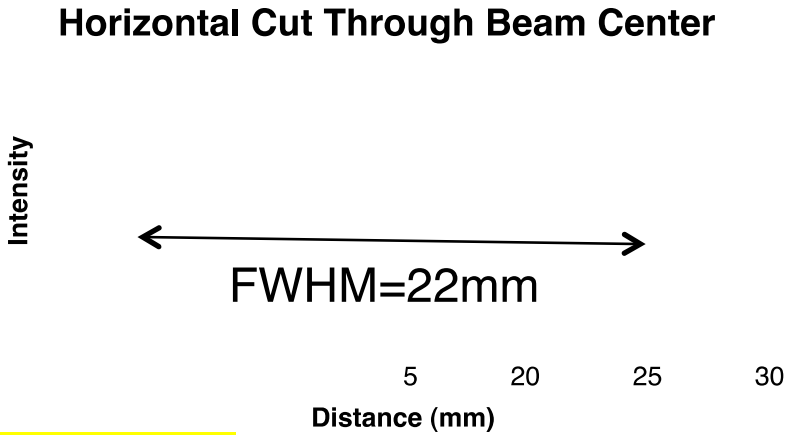
Plasma entrance

IBM gap

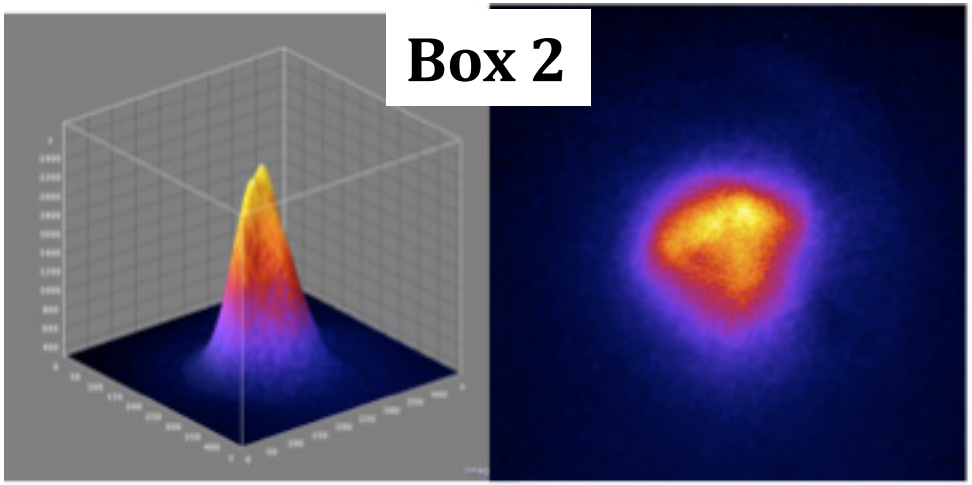
Box 1

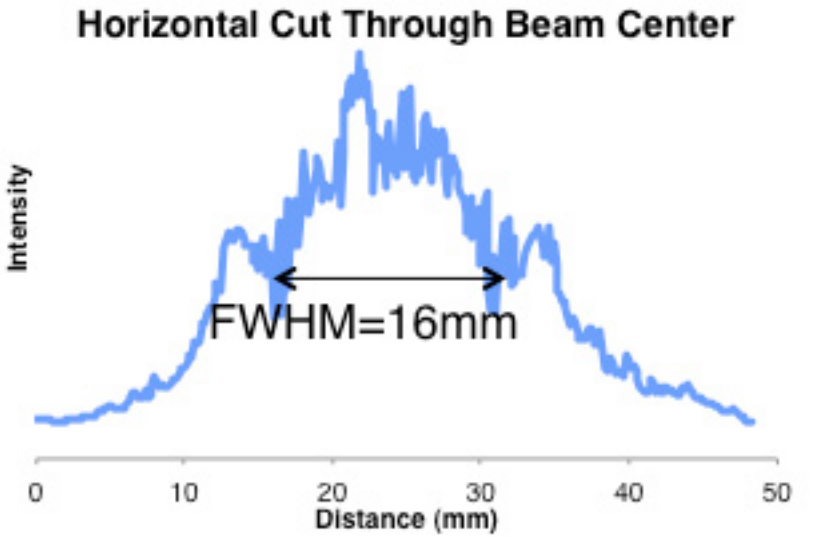
Unmodulated beam profiles exhibit considerable structure





Experimentally measured beam profiles (500 ns gate)



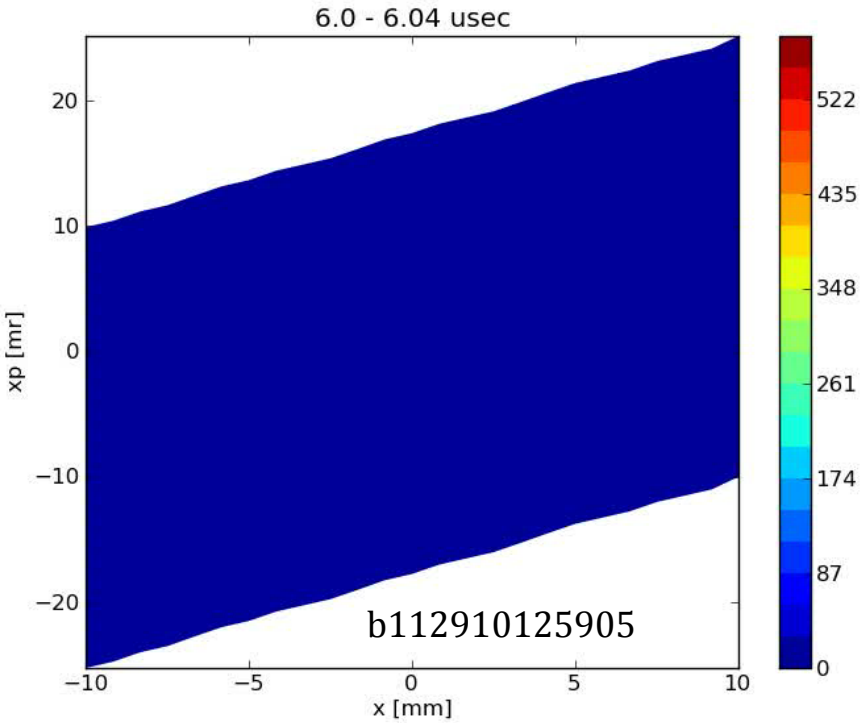


Quantitative agreement between theory and experiment in RMS spot size.

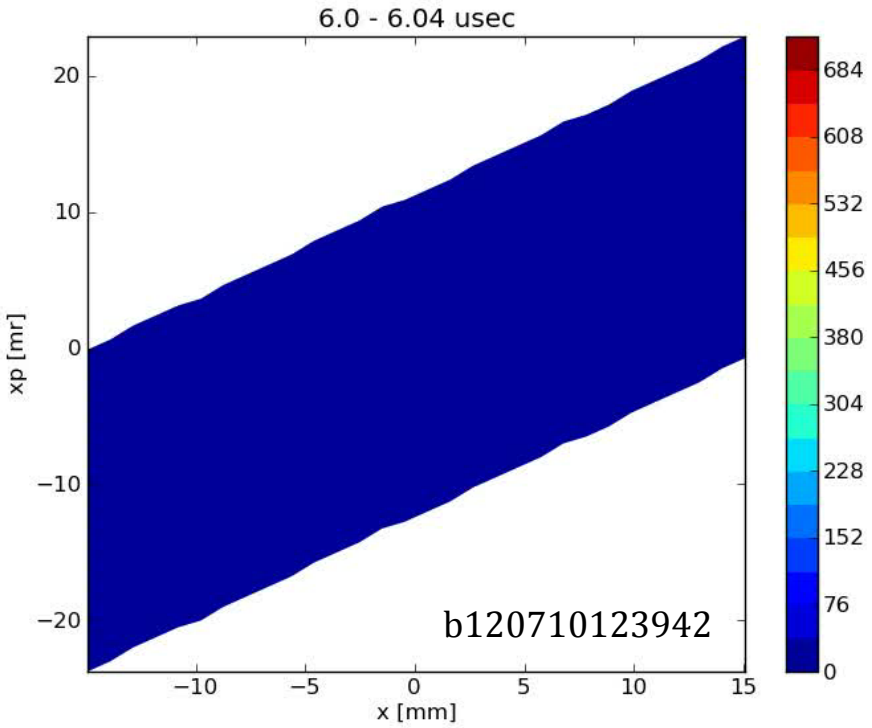
Measured phase space evolution

16 µsec animation. Modulated portion ~1.5 µsec

Unmodulated



Modulated



n.b.: A slight difference in horizontal and vertical scales exists.

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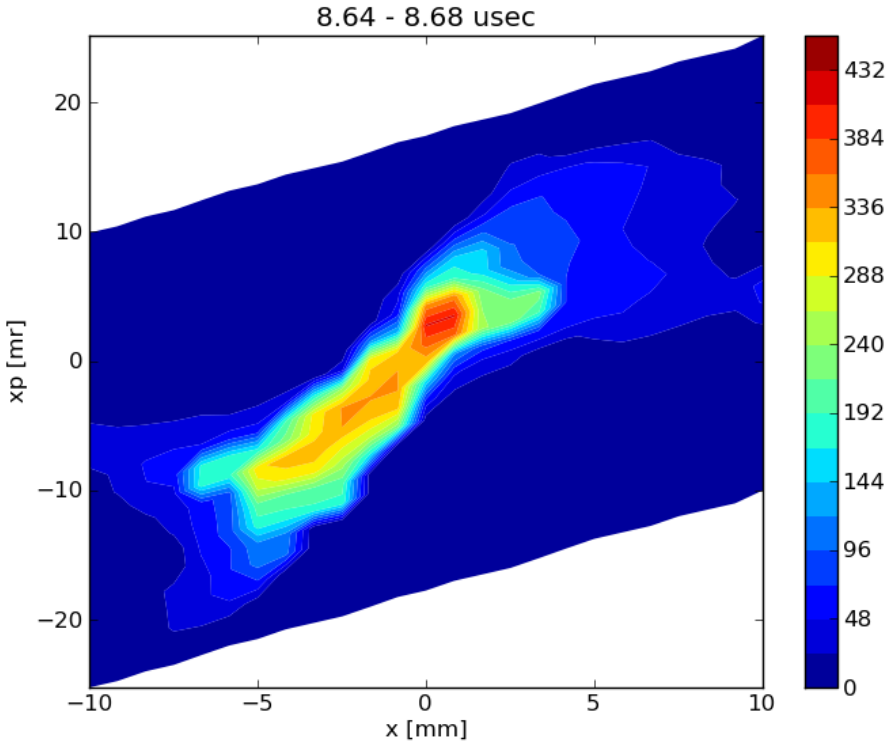
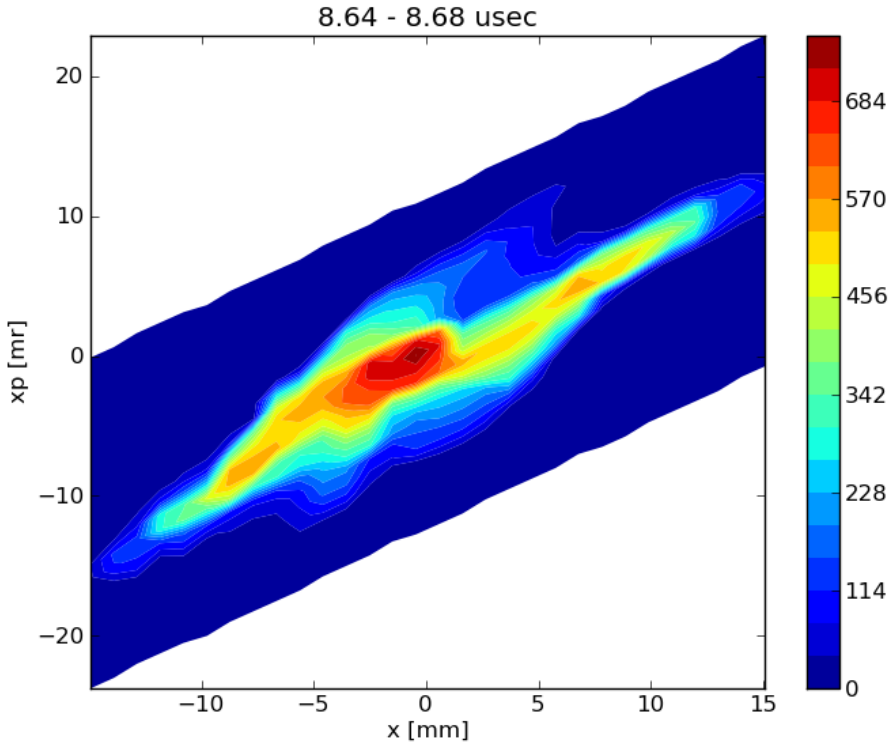
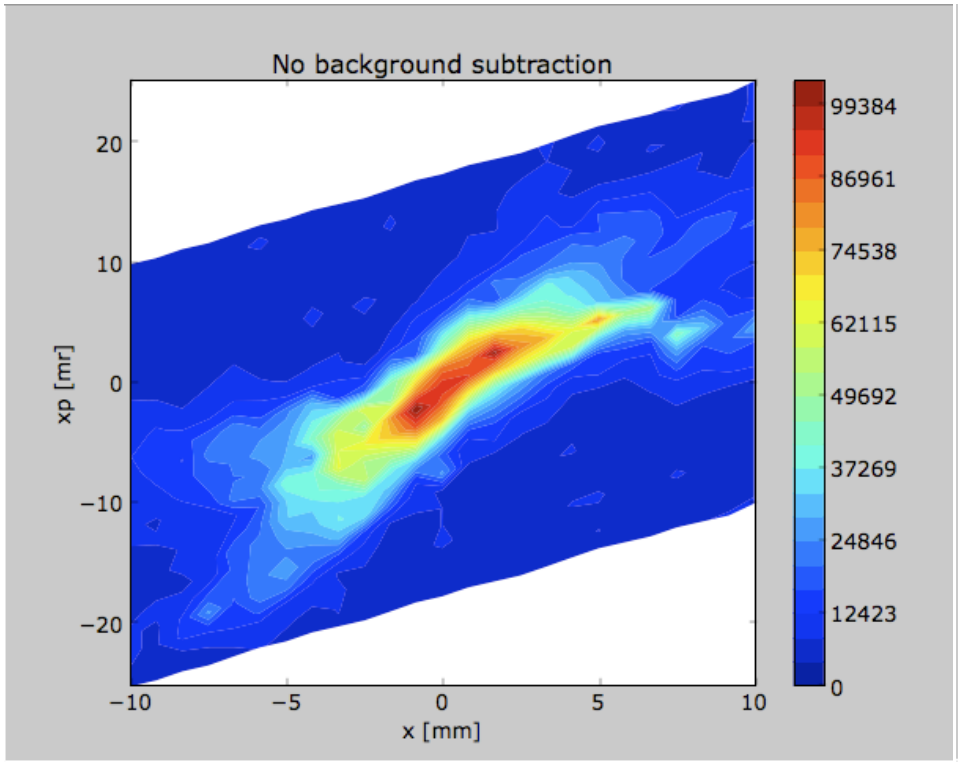


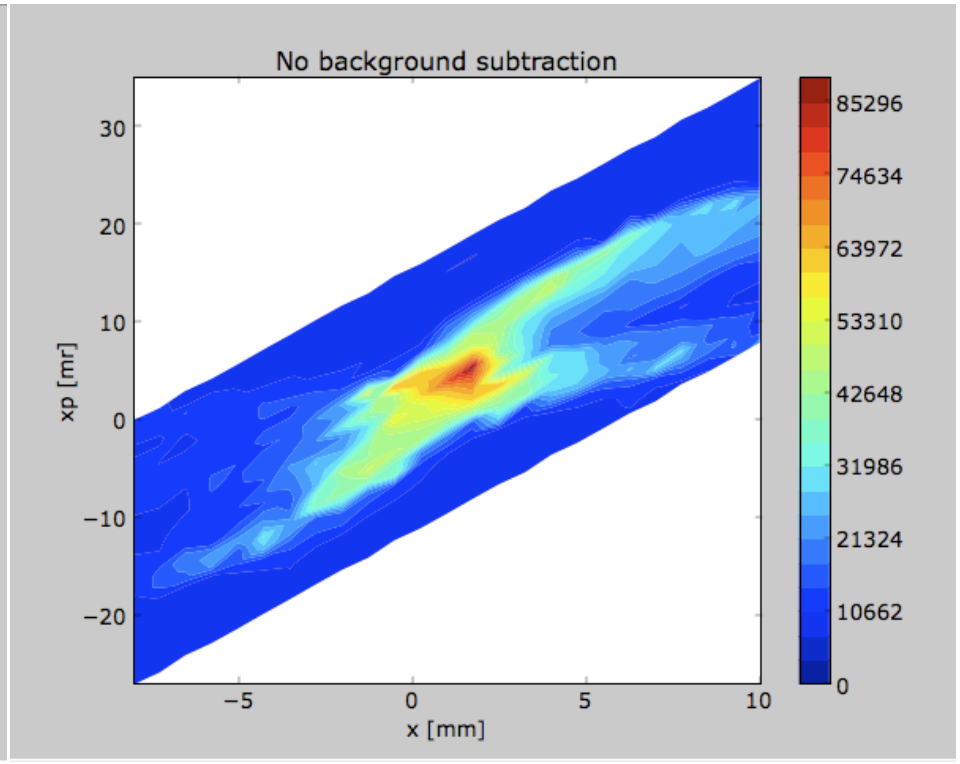
Modulated



n.b.: A slight difference in horizontal and vertical scales exists.

Box 2 phase space measurements reveal bifurcated phase space

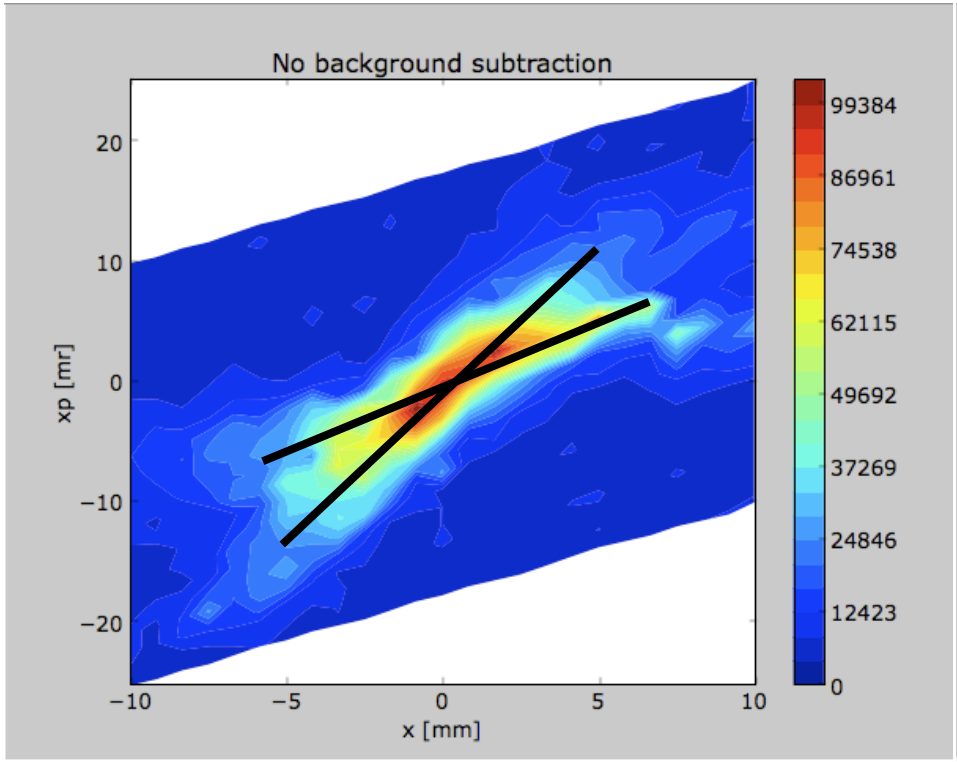


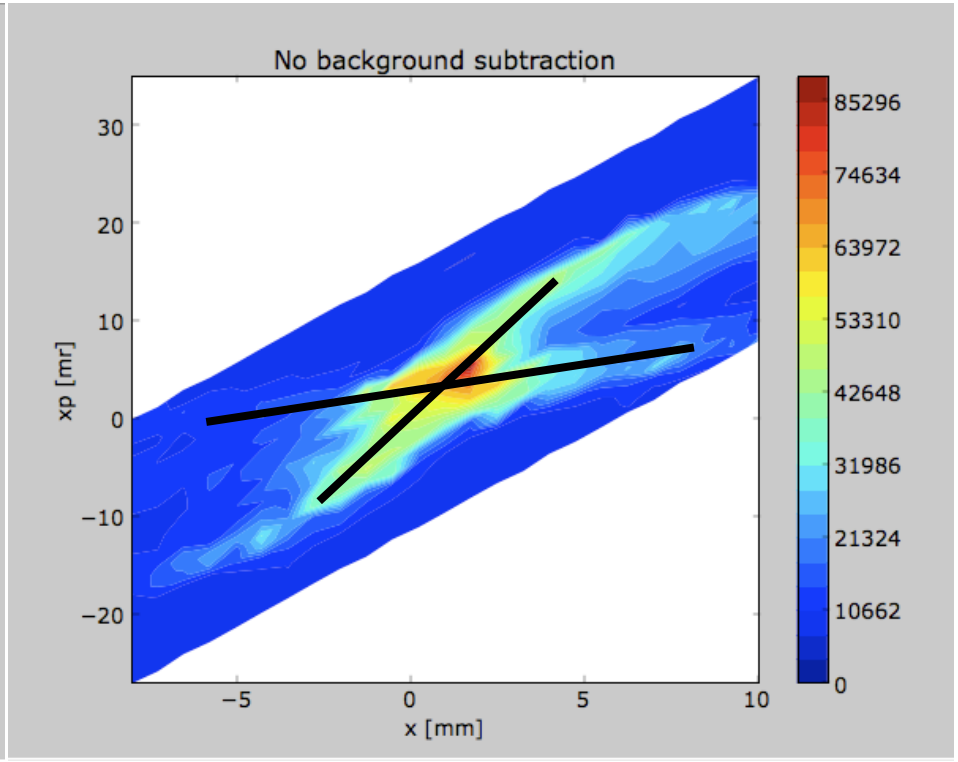


Horizontal **Unmodulated Beam** **Vertical**

Box 2 phase space measurements reveal bifurcated phase space

Two populations present from beam head and along entire pulse.

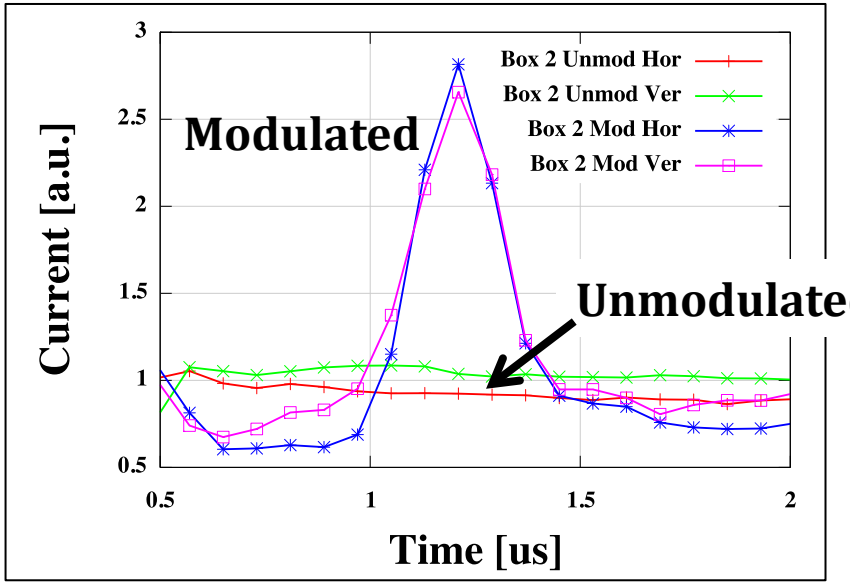


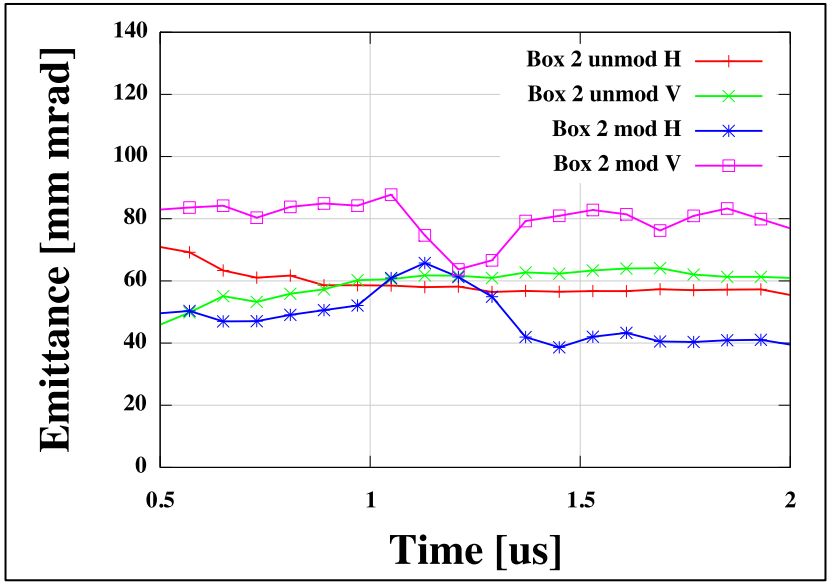


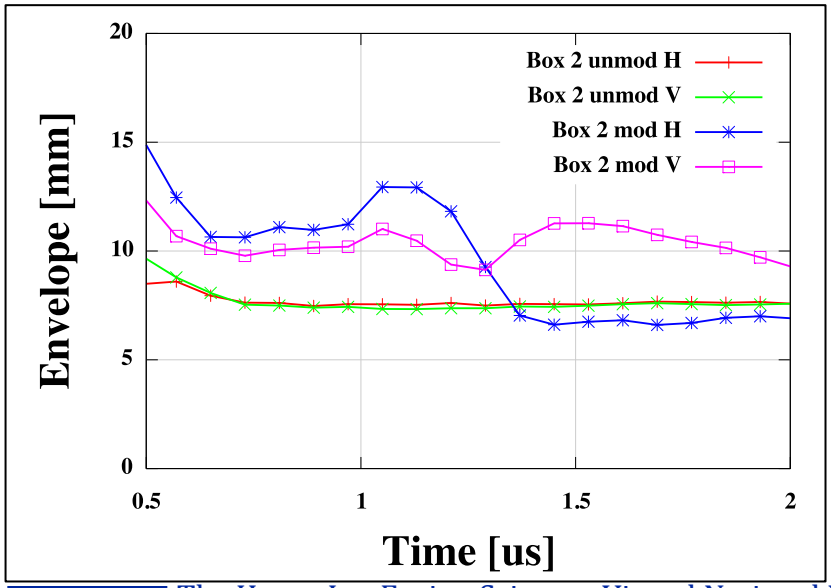
Horizontal **Unmodulated Beam** **Vertical**

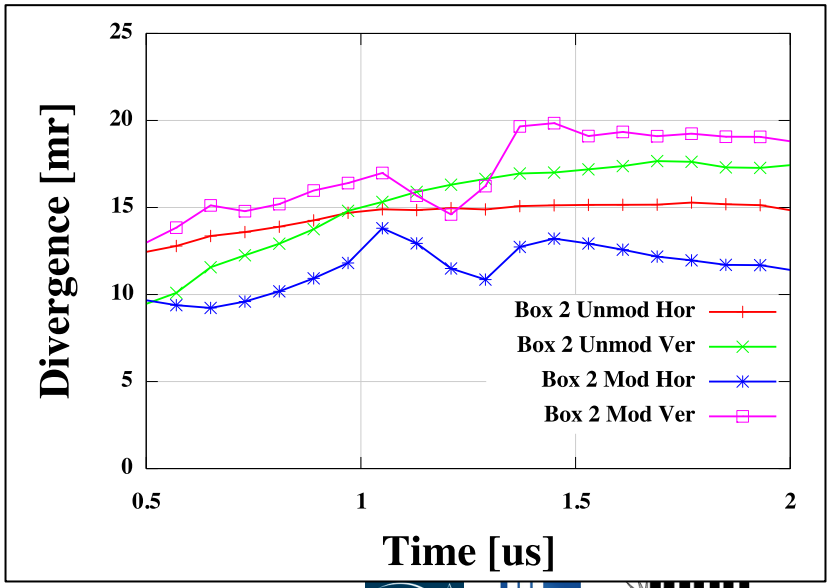
Bifurcation also appears in slit-scintillator phase space measurements. Complicates analysis of beam-gap dynamics and transport.

Time Resolved Variations in Beam Parameters









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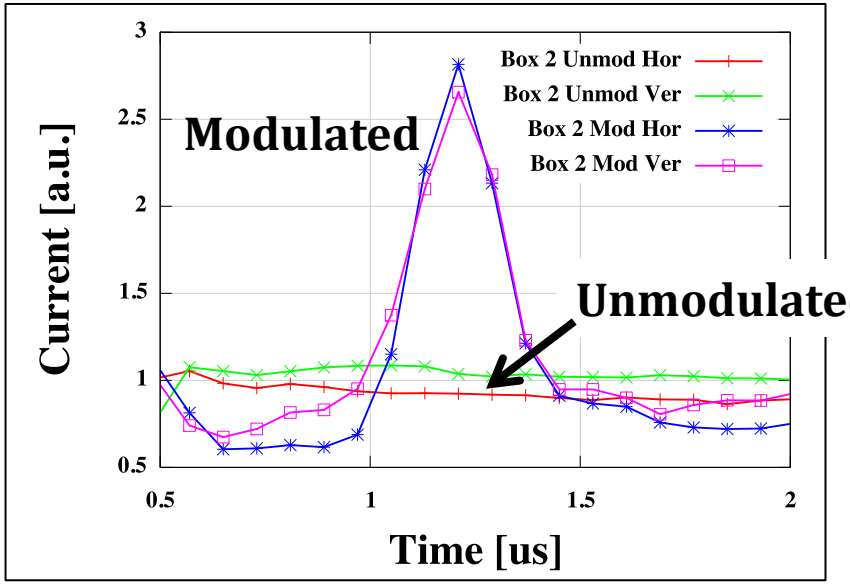
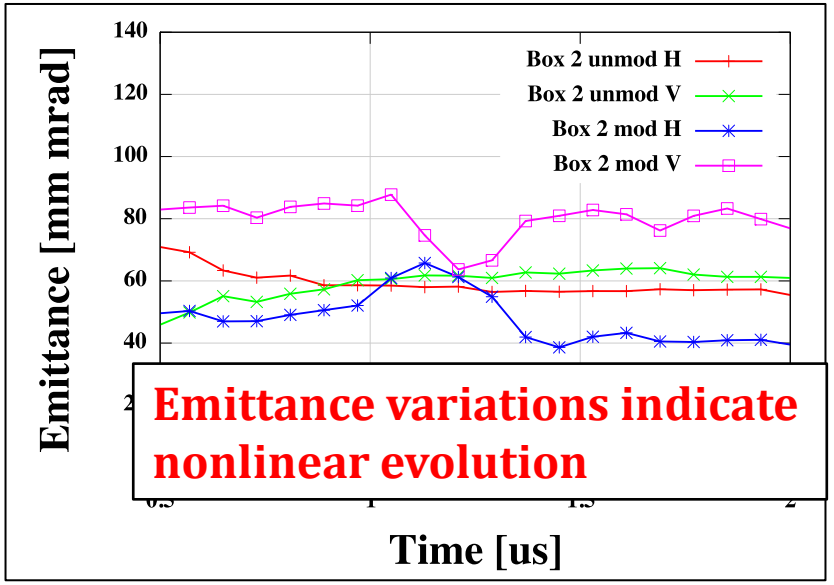
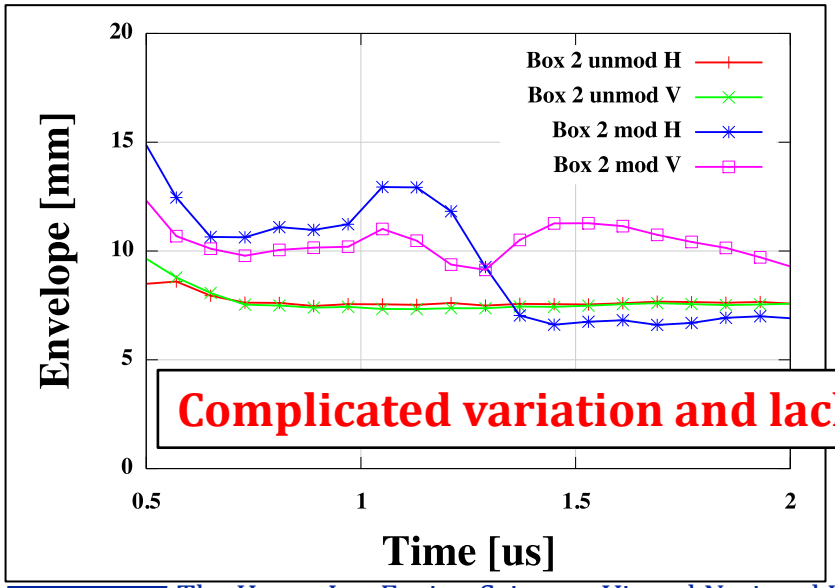
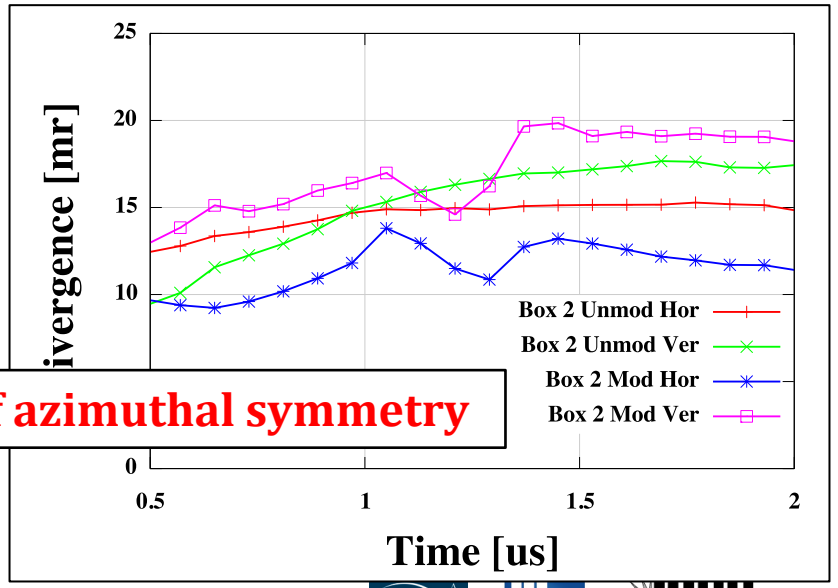




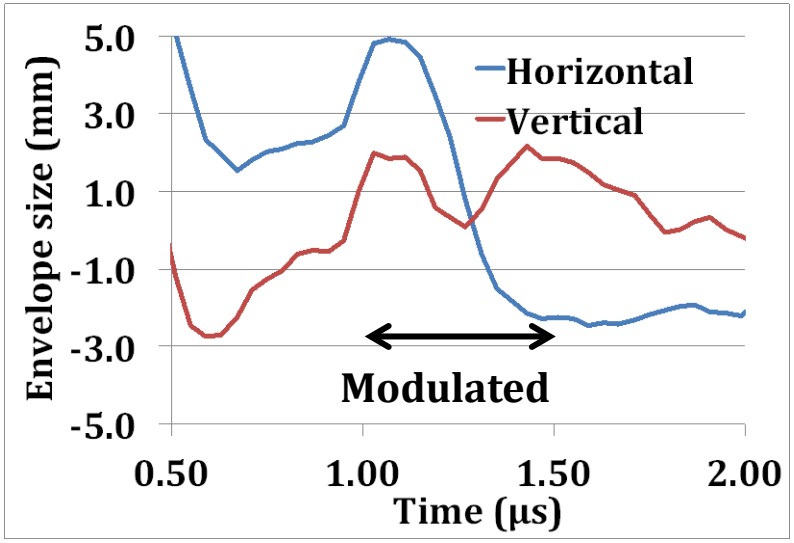
Emittance variations indicate nonlinear evolution

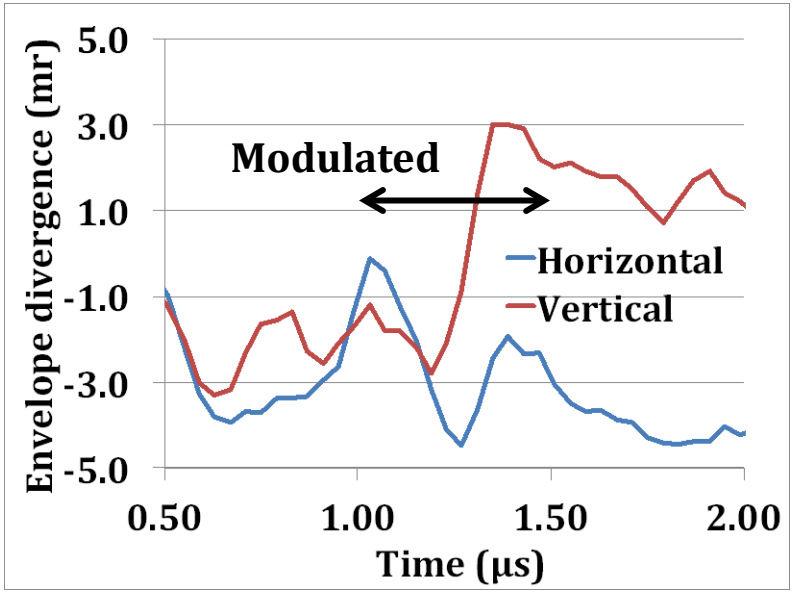




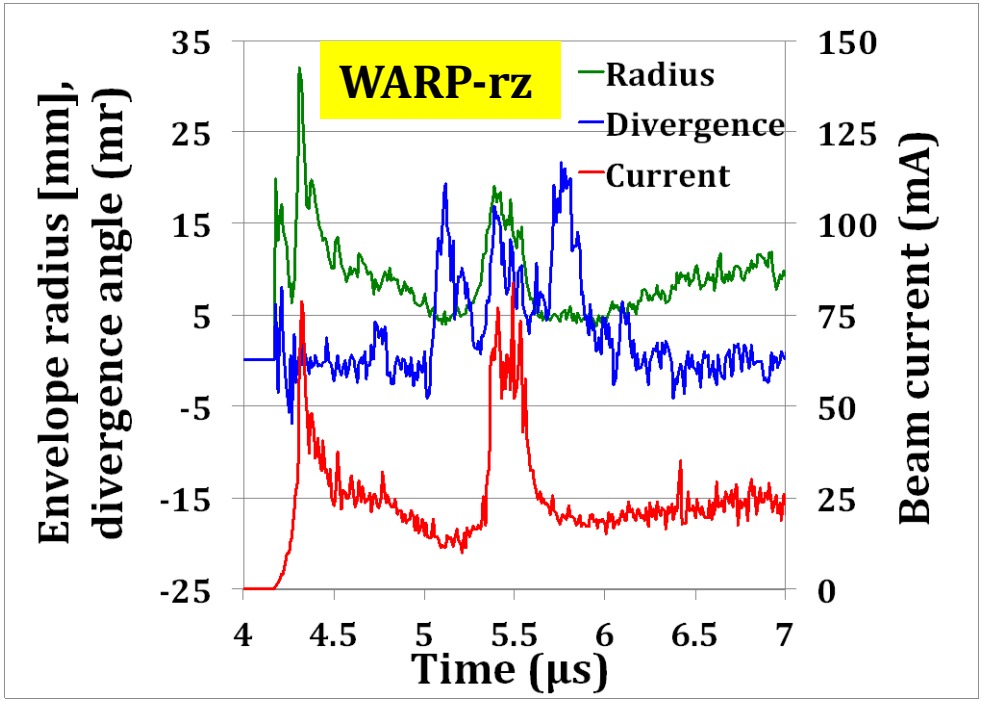
Complicated variation and lack of azimuthal symmetry

Modulated beam comparison with axisymmetric WARP model





Differences between modulated and unmodulated beam parameters



WARP replicates linear optics behavior

- **No nonlinearities**
- **No emittance variation**

Summary

Improving target beam fluence in heavy ion beam neutralized drift compression geometries may require compensation of time-varying focusing elements.

We have made a series of time-resolved measurements of the beam parameters and phase space density of an intense, velocity-modulated ion beam transported through a plasma-neutralized channel.

Measurements indicate significant deviations from linear behavior in axisymmetric transport channels.

Possible mechanisms for variation from linear behavior may include:

- **3D density perturbations in the space charge dominated beam,**
- **Coupling to weak magnetic dipole chicanes,**
- **Nonlinear beam-plasma interaction,**
- **Electron trap biasing resulting in backstreaming electron flows.**

Upcoming studies will examine these mechanisms.