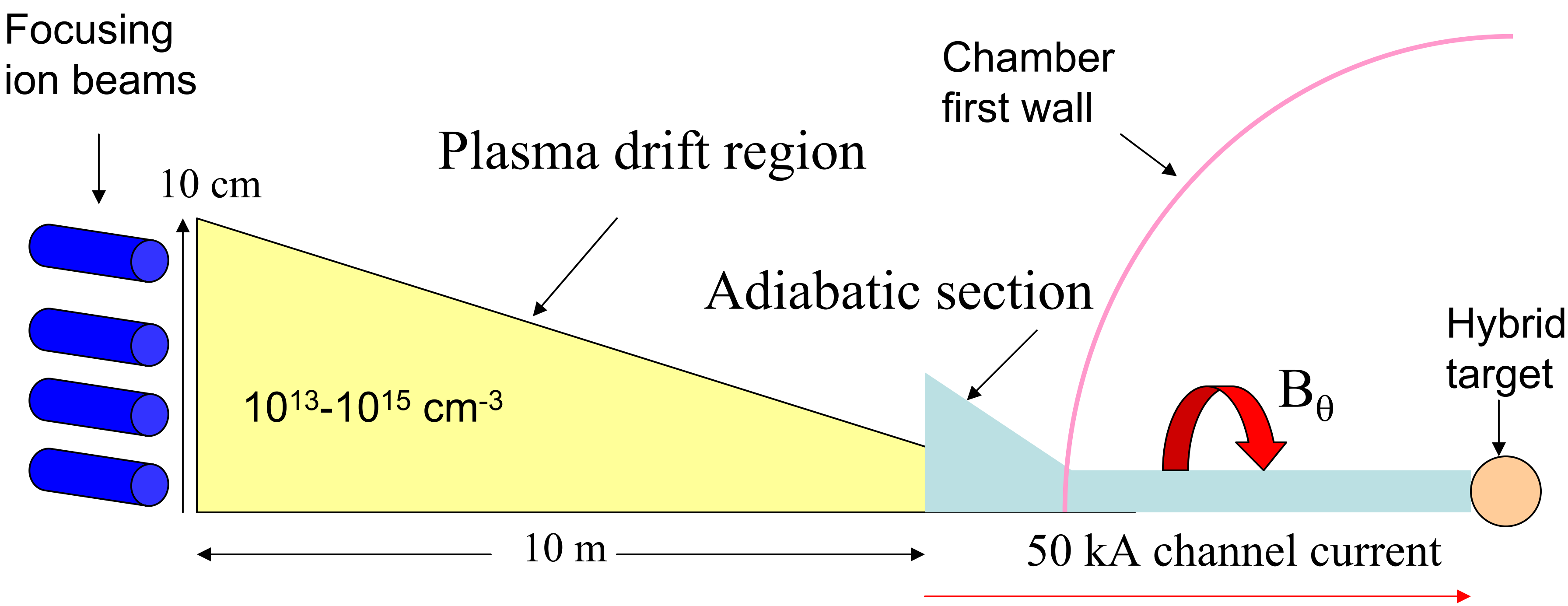
Simulations of Neutralized Drift Compression

D. R. Welch, D. V. Rose
Mission Research Corporation
Albuquerque, NM 87110
S. S. Yu
Lawrence Berkeley National Laboratory
Berkeley, CA
C. L. Olson
Sandia National Laboratories
Albuquerque, NM

Presented at the ARIES Project meeting
At Georgia Tech, September 4, 2003

Beams drift, combine and possibly compress in plasma drift region

- 10-80 beams per side
- Combined beams must focus to a 1-cm spot at the adiabatic discharge channel to couple to hybrid target (0.5-cm radiator - D. A. Callahan, M. C. Herrmann, M. Tabak, Laser and Particle Beams, **20**, 405-410 (2002).)



Goal is determine transport characteristics and stability regimes of compressing/combining beams in neutralizing plasma

Topics

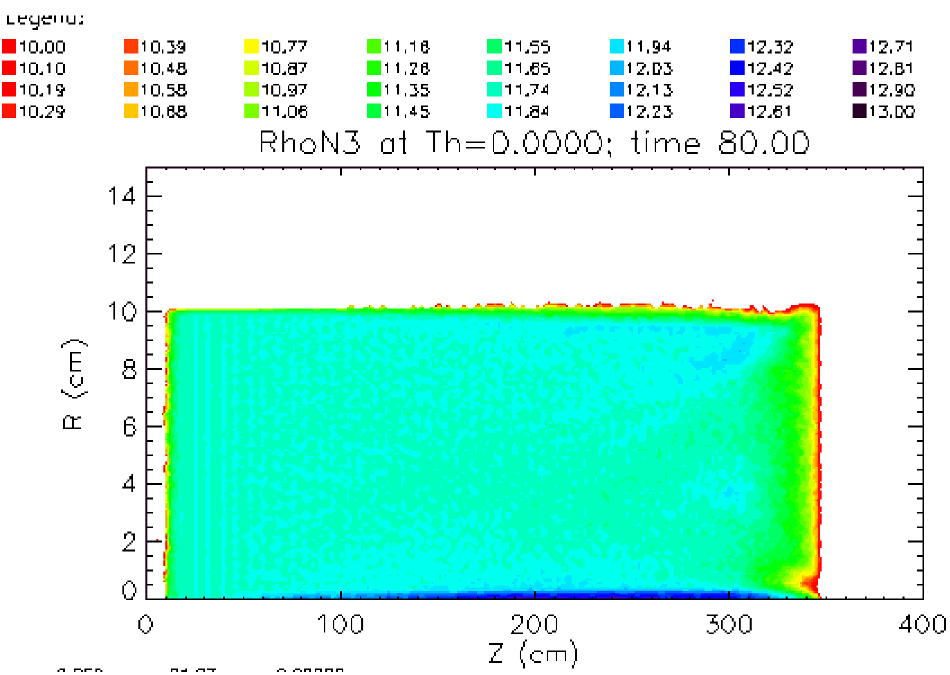
- Plasma-neutralized drift transport in a solenoidal field for a driver beam
  - Search for optimal transport conditions
- Extreme neutralized drift compression (NDC) with IBX parameters for HEDP applications
  - Compress in neutralizing volumetric plasma
  - Need to compress ½ J beam to 0.2 ns (to avoid target disassembly) and 1 mm radius for 10^{11} J/m^3 energy density

What solendoid/plasma conditions yield best beam transport?

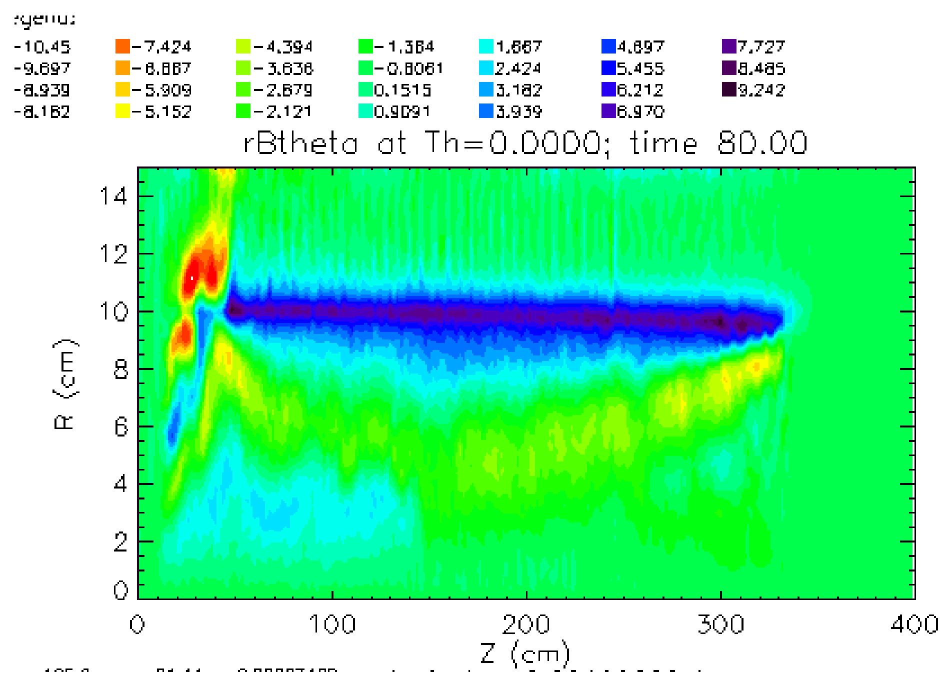
- For near term laboratory experiments, residual net currents are not a problem – $n_p >> n_b$ is sufficient
- For a driver, we need to worry about minimizing both electrostatic and magnetic self fields
- Examine problem with simulations of driver beam injected into ***preformed*** plasma with solenoidal field (no compression)

6-7 kA net currents calculated for beam without applied B_z

- 150 kA, 200 MeV Ne^+ beam, normal injection with 10-cm sharp-edged radius, 15-cm tube filled with 10^{12} cm^{-3} plasma – finer resolution, more 6x more particles
- *6-kA net current* predicted by laminar flow theory



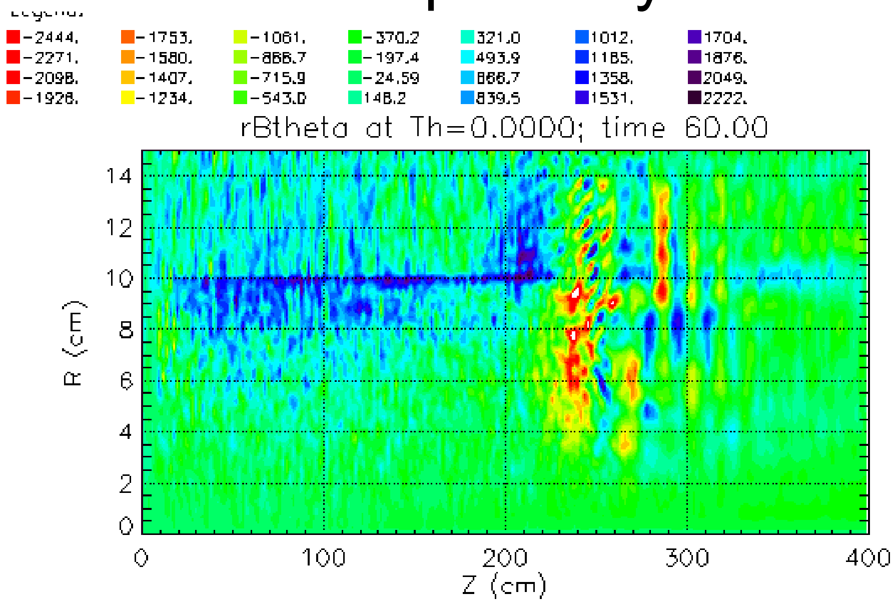
Beam density at 80 ns



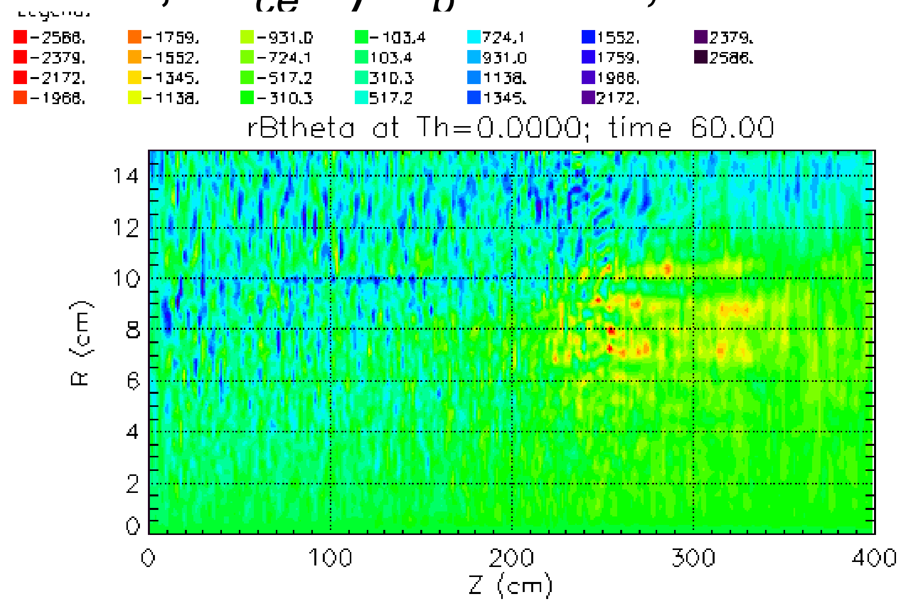
Net current with radius R at 80 ns

Net currents decrease with increasing B_z and skin depth to cyclotron radius*

- 150 kA, 200 MeV Ne^+ beam, normal injection with 10-cm sharp-edged radius
- Net current is 1.5 kA for 2 kG fields, 0.7 kA for 8 kG
- Here skin depth to cyclotron radius, $\omega_{ce} / \beta\omega_p = 4.33, 18$



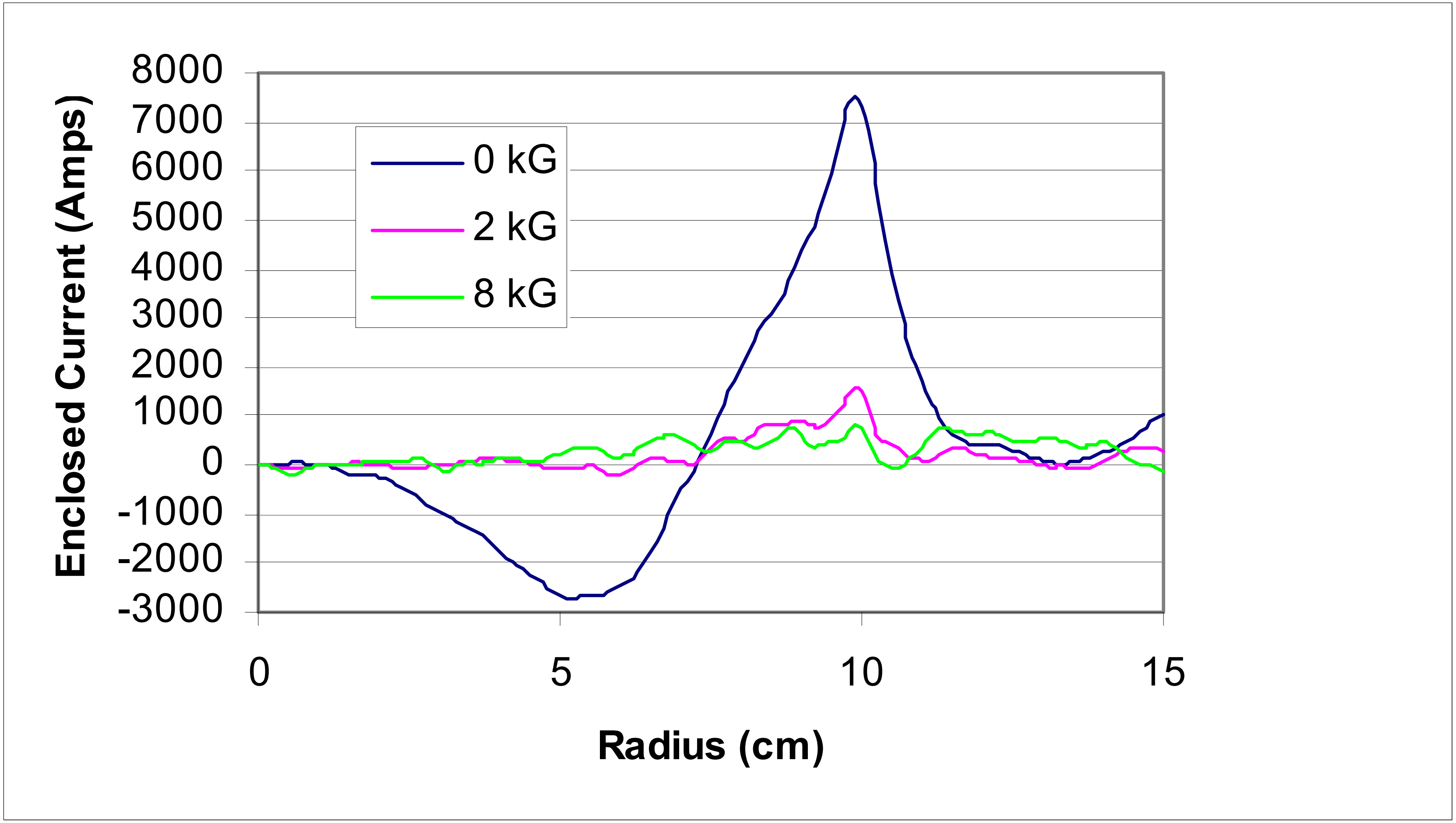
Net current with radius R at 60 ns for 2 kG B_z



Net current with radius R at 60 ns for 8 kG B_z

* Consistent with model of I. Kagonovich, PPPL

Net Current scaling with B_z

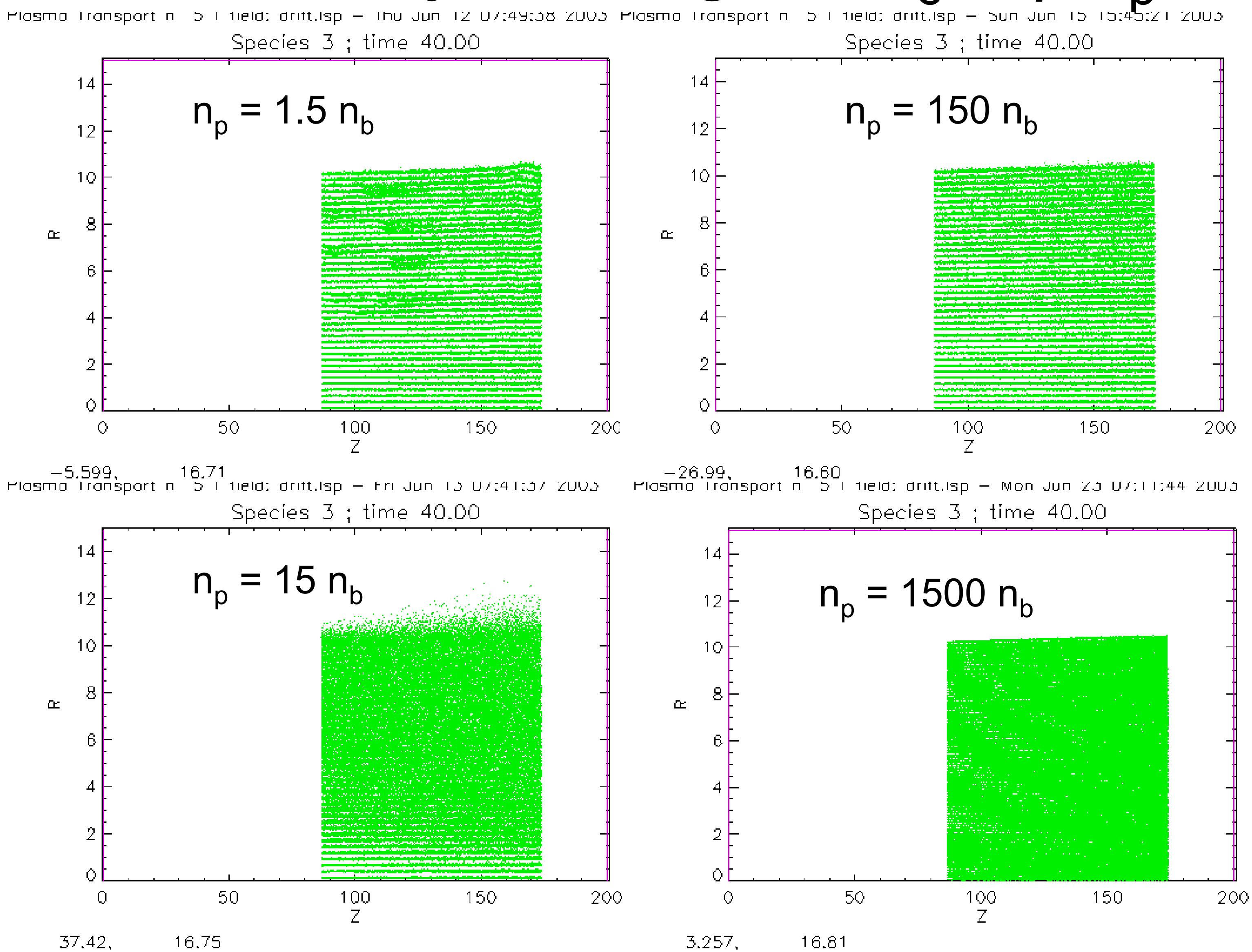


- Averaged over 5 cm about z=150 cm at 60 ns

Matched rotating ion beam case

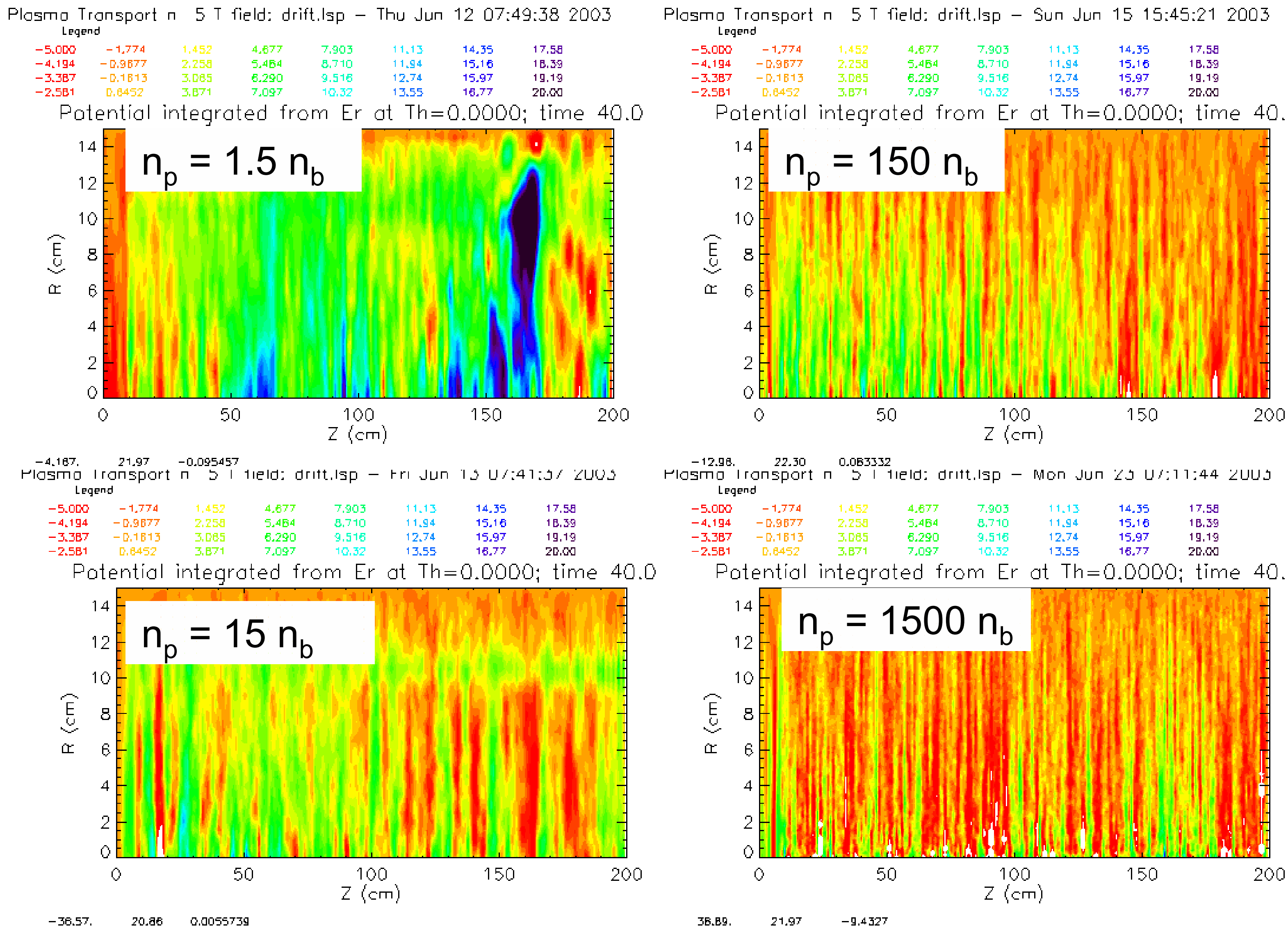
- 2.7 kA, 200 MeV, 10 cm Ne^+ ion beam (cold)
- Ne rotation matched with 5 T solenoidal field
- Transport for 2 meters in 15-cm drift tube with electron emission from outer wall
- $2x10^{10}$- $2x10^{13}$ cm^{-3} uniform 3-eV plasma density
- LSP explicit simulation – electron cyclotron and plasma frequencies resolved
- Beam density $n_b = 1.3x10^{10}$ cm^{-3}
- 4 simulations with $\omega_c = 8.8x10^{11}$ s^{-1}
  - $\omega_p = 0.01, 0.03, 0.1, 0.3\ \omega_c$
  - $n_p = 1.5, 15, 150, 1500\ n_b$

Beam transport improves with plasma density as long as $\omega_c > \beta\omega_p$



t=40 ns

ES potential drops with plasma density



40 ns

Potential drops to noise level for 1500 density ratio

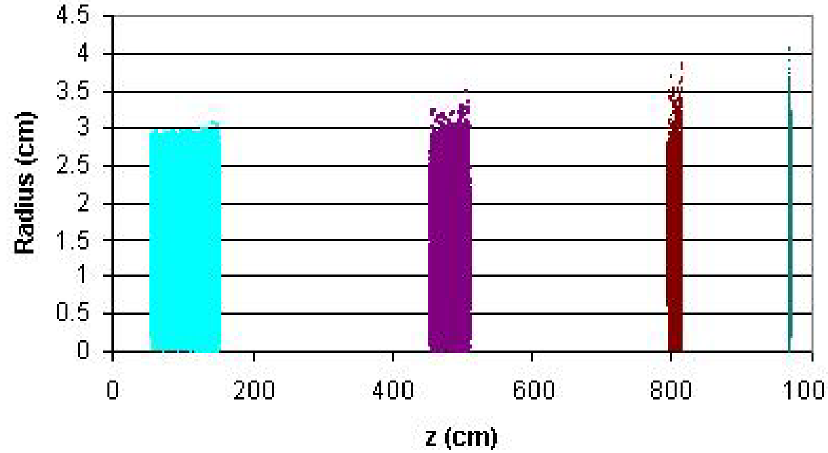
Transport is most ballistic with large plasma density and applied solenoidal field

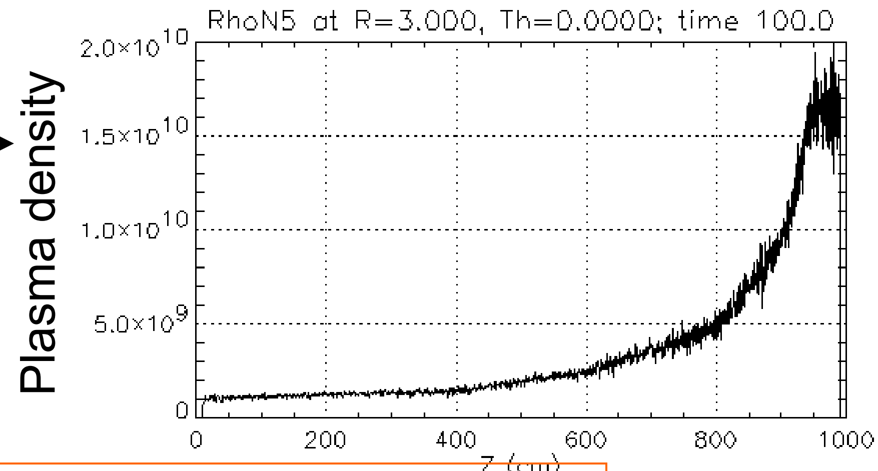
- $n_p >> n_b$ and $\omega_c > \beta\omega_p$ produces best transport
- Residual electrostatic potential small for $n_p >> n_b$
- Azimuthal self magnetic field small for $\omega_c > \beta\omega_p$ *

* Also consistent with model of I. Kagonovich, PPPL

IBX Neutralized Drift Compression

- 6 MeV, 0.35 A K^+ beam (.32 J, 10^{-4} perveance)
- 1 pi-mm-mrad emittance
- Beam profile
  - uniform 3-cm outer radius with 50 ns rise and fall in density ($1.4\text{x}10^8$ cm^{-3} density)
- Velocity tilt 0.017-0.019*c* in **200 ns pulse**
  - Focus at z = 980 cm
- 10-m drift length, 20-m focal length
- No beam energy error at injection
- Plasma density initialization
  - Increasing 10^9 – $1.75\text{x}10^{10}$ cm^{-3} →
- 2D Lsp simulations
  - Electromagnetic, explicit particles
  - Outer wall SCL electron emission
  - 2.5-mm, < .1 ns resolution
  - Double precision



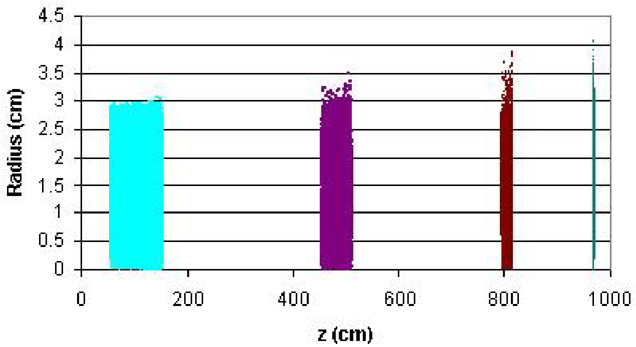


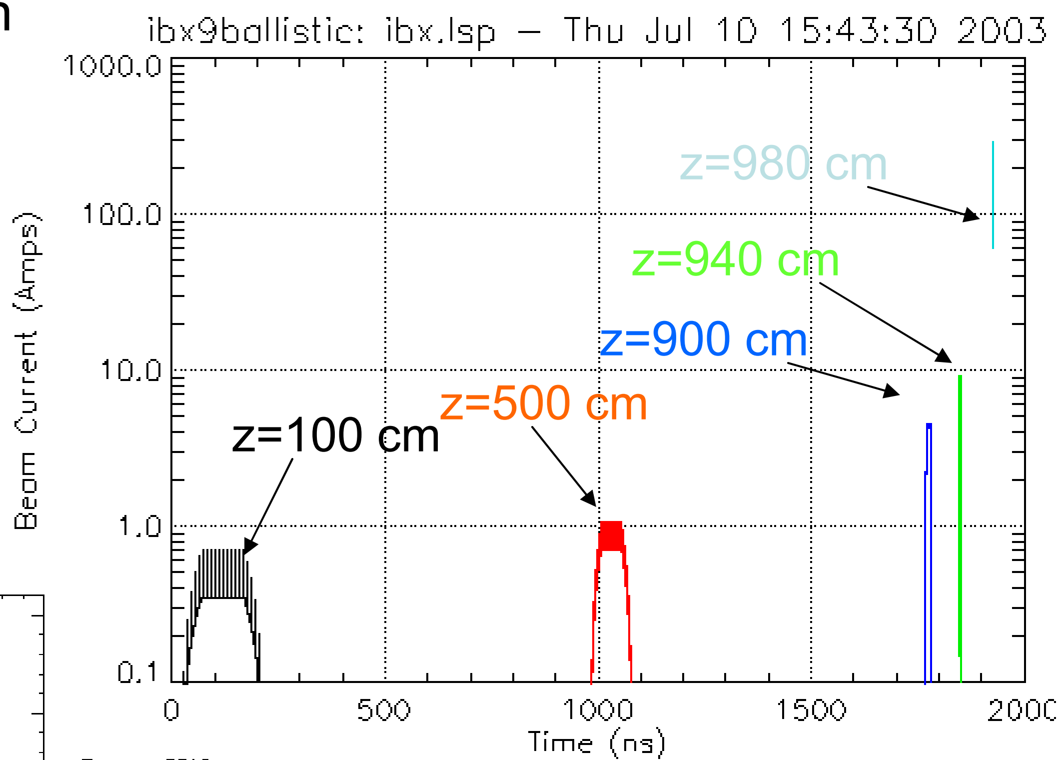
Requires factor of 1000 axial compression

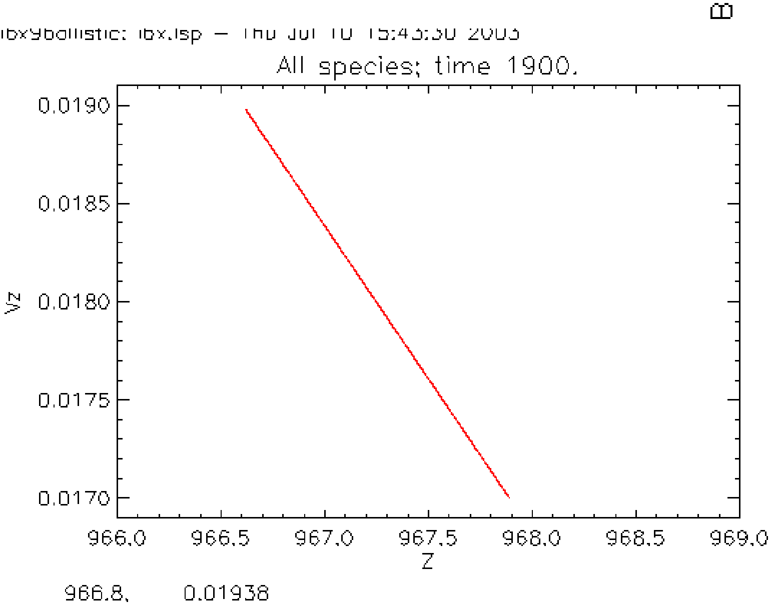
No guide solenoidal magnetic field

Ballistic beam compresses to 300 Amps – 1000 compression

- Constant radius beam, 50-ns rise/fall, 980-cm compression length
- Limited by resolution



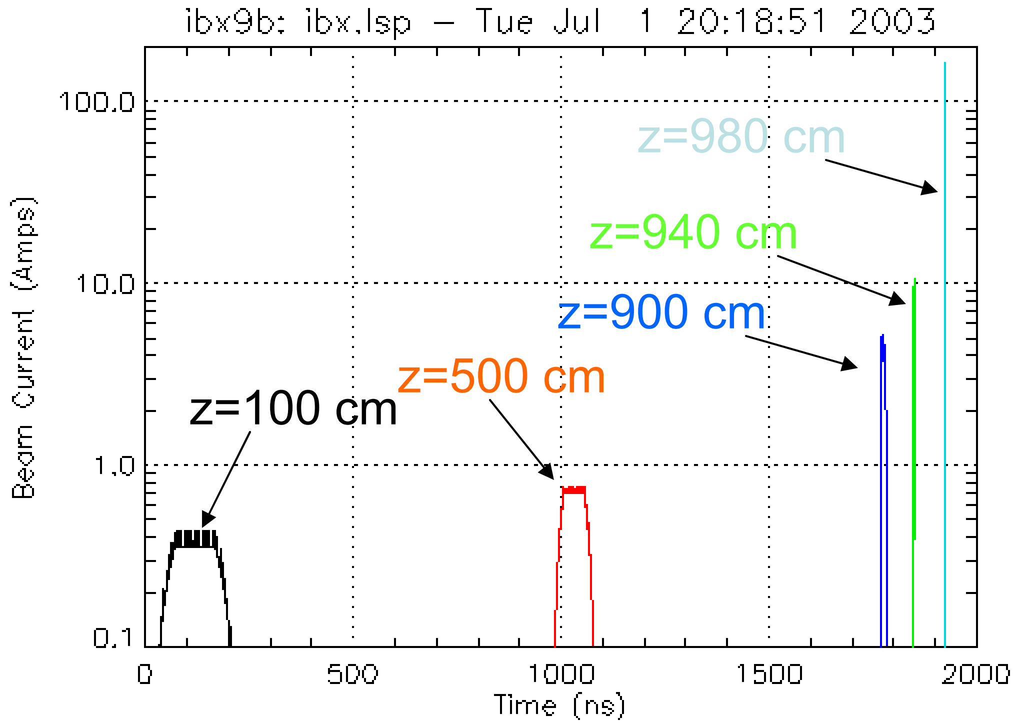


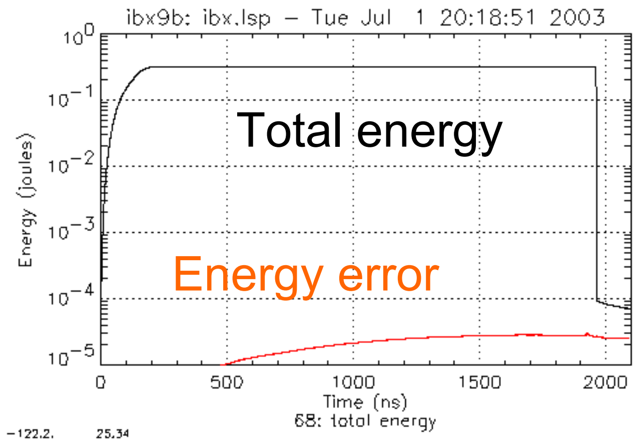


Longitudinal phase space still cold just before focus

Full Lsp simulation calculates compressed to 200 A

- **Including self EM fields, plasma effects**

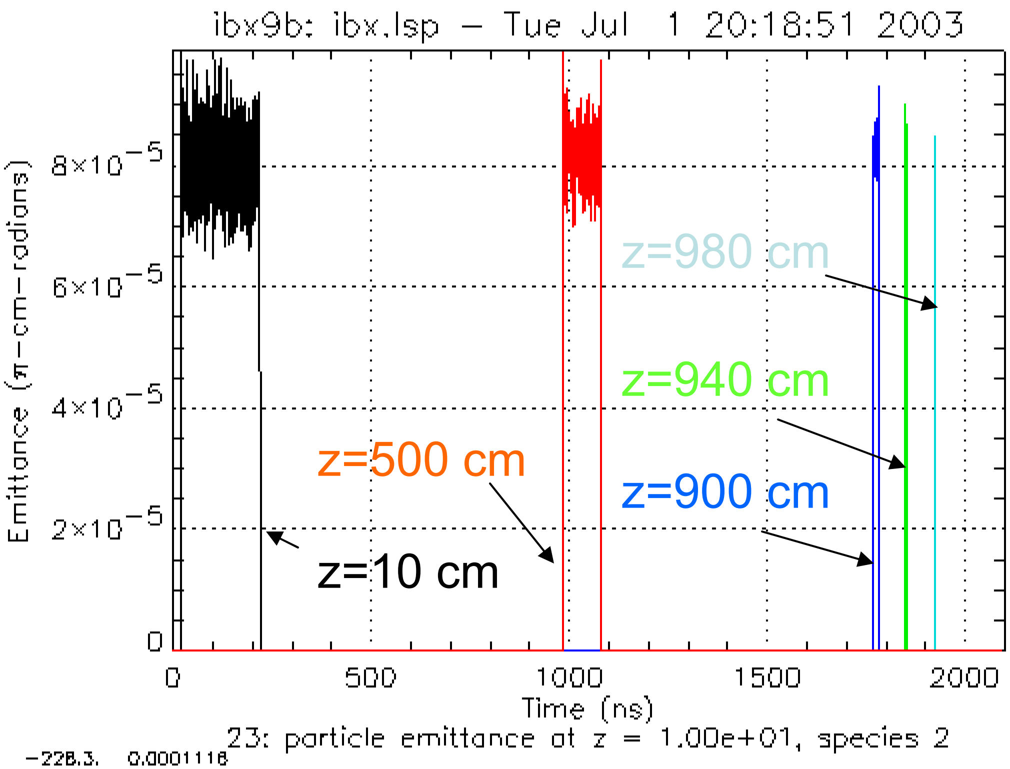




Small numerical energy error

No significant growth in emittance

- Current loss to wall 0.04%

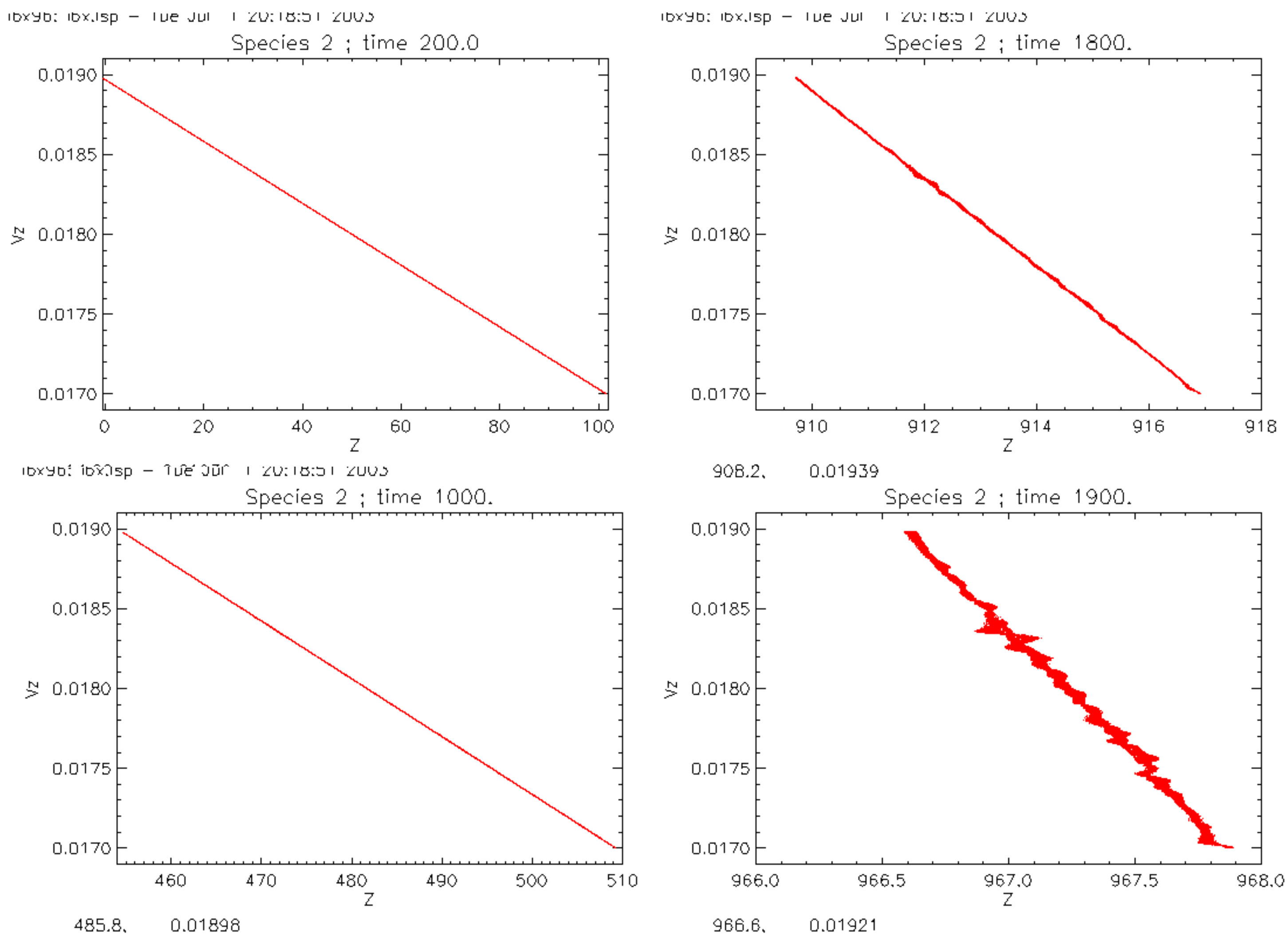


probes at different axial positions

Therefore, focusing still possible <u>after</u> compression.

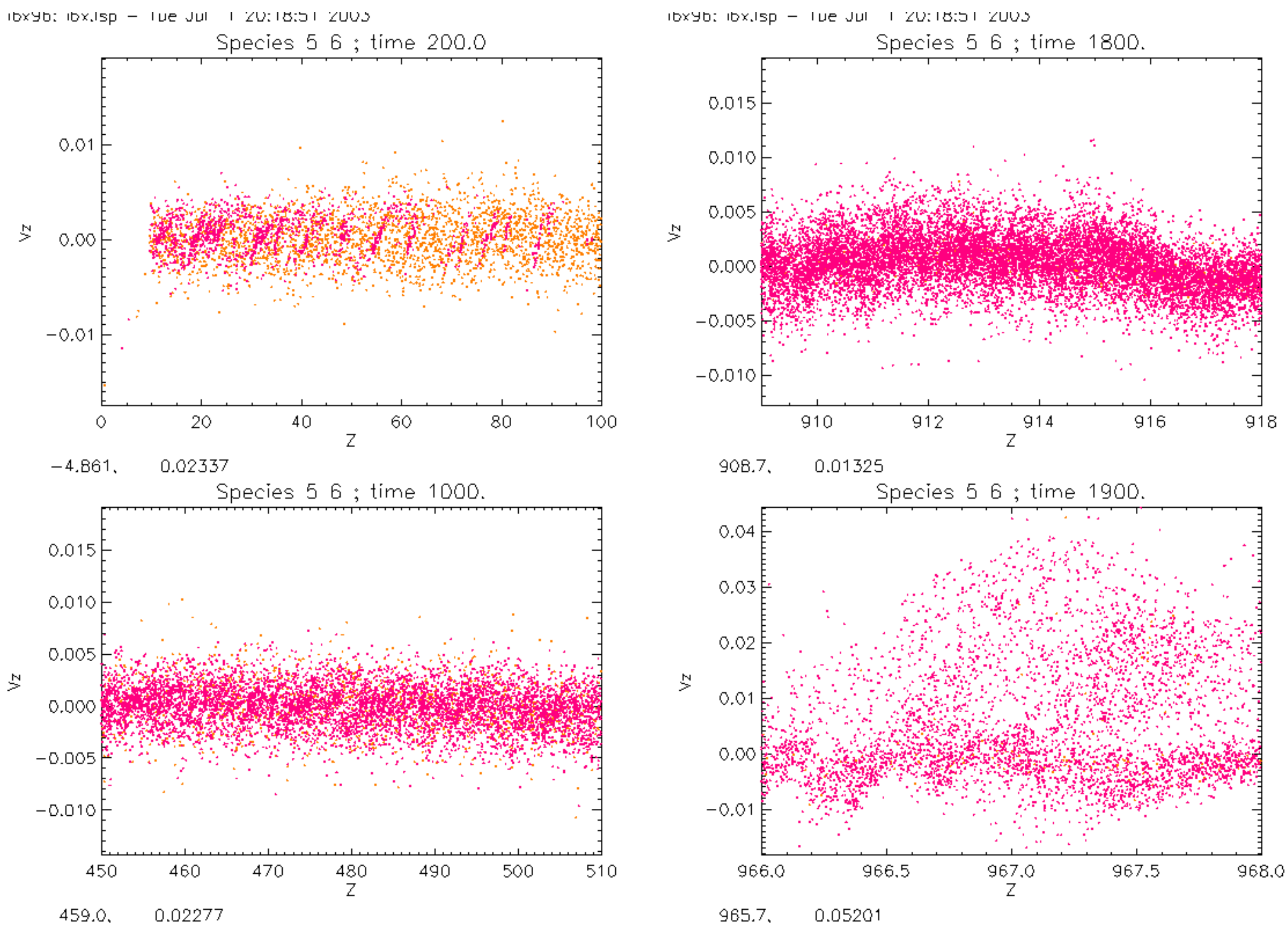
Small growth in longitudinal energy spread

- Constant radius profile, increasing plasma density
- Wiggles in energy seen beyond 1800 ns - 2 stream or numerical?



Electron oscillation evident

- Weak 2-stream instability?
  - wavelength consistent $\lambda = 2\,\pi\,\beta\,(c\,\omega_p)^{-1/2} \approx 6$ mm
- Does beam compression reduce instability?



Simulations show robust drift compression in a neutralizing plasma

- IBX parameters were simulated with a velocity tilt to compress to 0 pulse length in 980 cm
- Beam compresses by nearly 600 in full sim
- No calculated transverse emittance growth
  - Beam can still be focused radially!
- Weak beam-electron two-stream instability
- Simulations of NDC with NTX parameters are underway

Reasonable beam compression ratios limited only by accuracy of velocity tilt!