Neutralized Drift Compression

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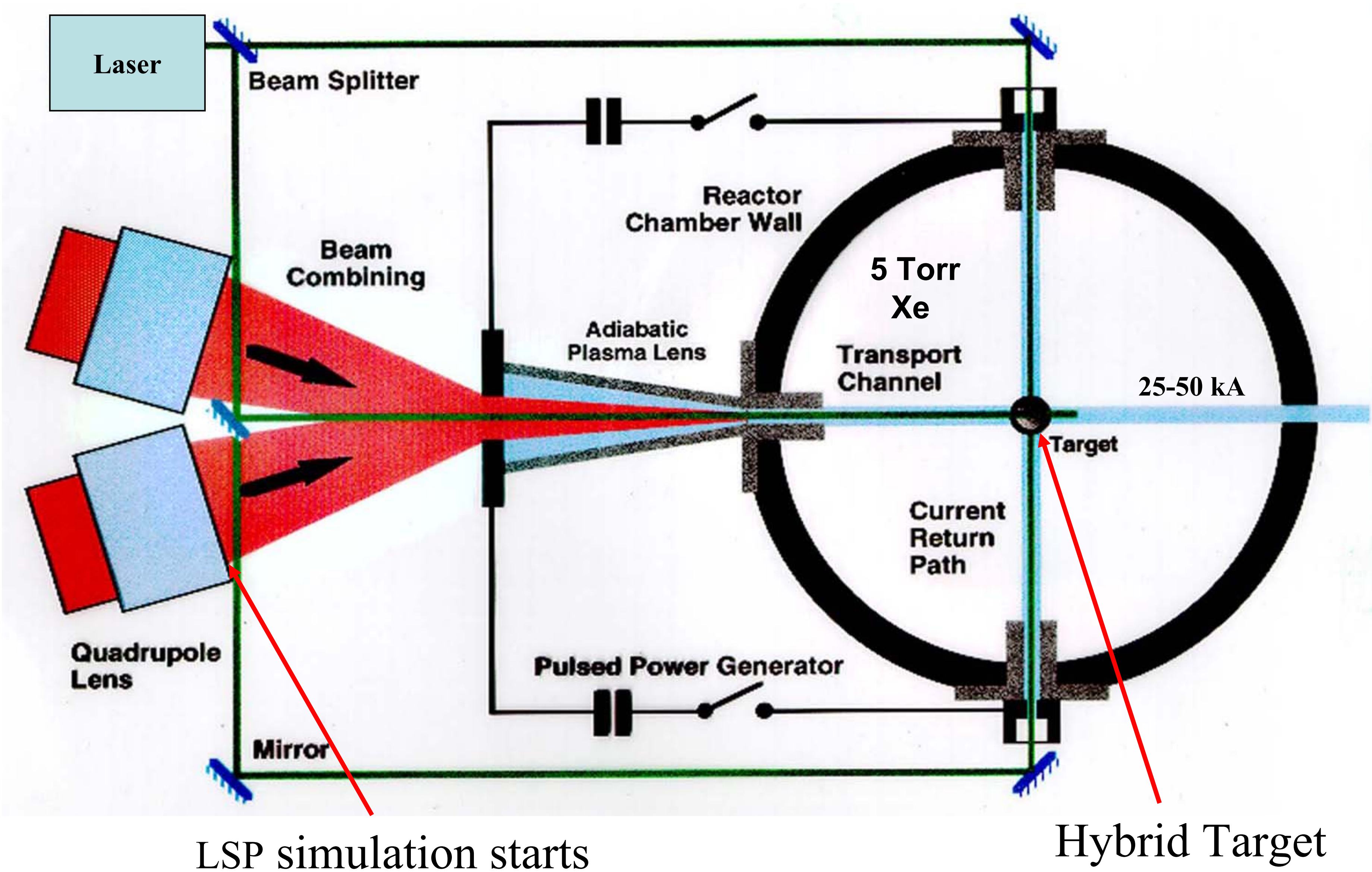
Beams must combine in all HIF transport scenarios

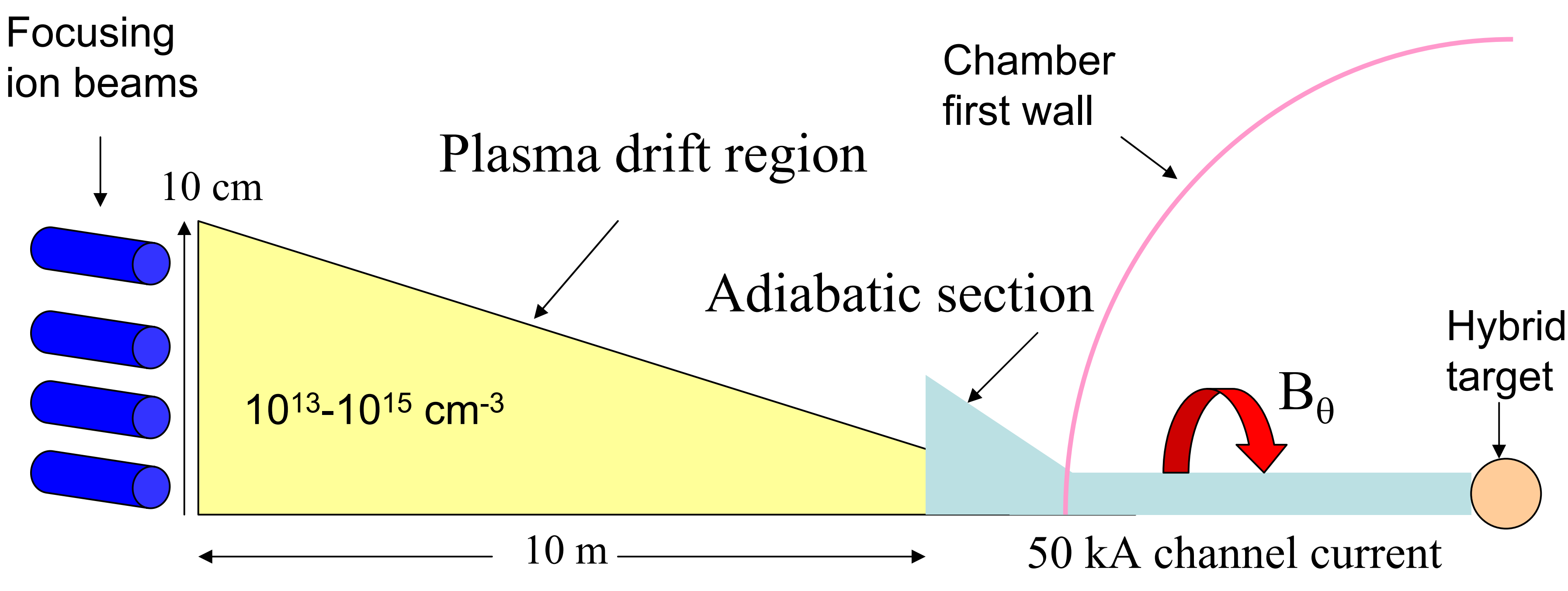
- For mainline Neutralized Ballistic Transport (NBT), the beams combine right at the target within a 2-3 mm radius
- For Assisted Pinched Transport (APT) and Self Pinched Transport, the beams combine at the Adiabatic Discharge Channel within a 1-cm radius
- 10-100’s m neutralized drift compression envisioned for modular solenoidal transport

Assisted Pinched Transport can reduce chamber focus requirements and reduce driver costs - Back up to NBT



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

Final focusing limits beam velocity tilt for compression to a few %

- For reasonable length simualtions, we use large tilts and shorter drift lengths
- 2D calculations examine the two extremes in beam current
  - low current and longer drift length (30 m)
  - high-current but shorter drift length (10 m)
- 3D calculations look at high current beam combining
- A beam frame calculations would greatly speed these calculations

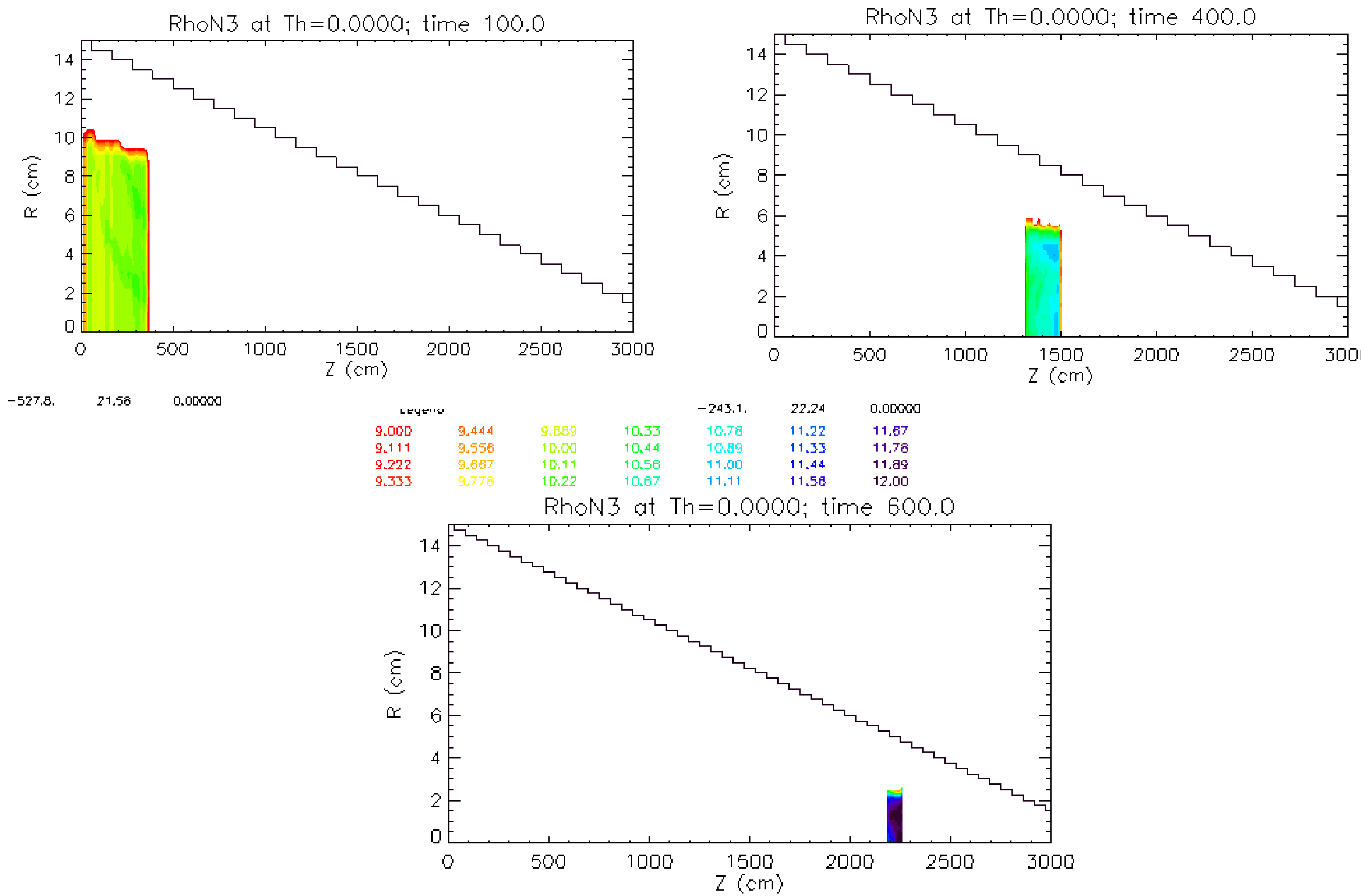
2D LSP Low-Current Parameters

- Ne^+ ions
    - 100 ns pulse length at injection
    - 2 kA current, rising to 12 kA after 600 ns transport
    - 210 MeV Ne^+ 2.5×10^{-3} perveance
    - injected in r=10 cm radius with 4 π-mm-mrad emittance
    - v tilt: beta = .125-.145 in 100 ns (20 ns pulse after 600 ns drift)
- Uniform plasma fill of 4×10^{12} cm^{-3} density in conical drift tube
- LSP* used in direct-implicit mode
    - Constraints on simulation timesteps and cell sizes are greatly relaxed
    - Scattering and stripping is ignored

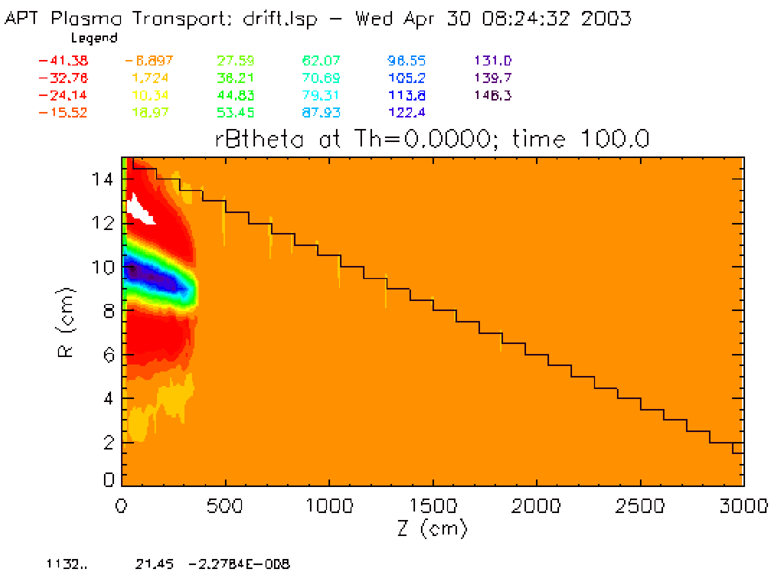
* T. P. Hughes, S. S. Yu, and R. E. Clark, Phys. Rev. ST-AB **2**, 110401 (1999); D. R. Welch, D. V. Rose, B. V. Oliver, and R. E. Clark, Nucl. Instrum. Meth. Phys. Res. A **464**, 134 (2001).

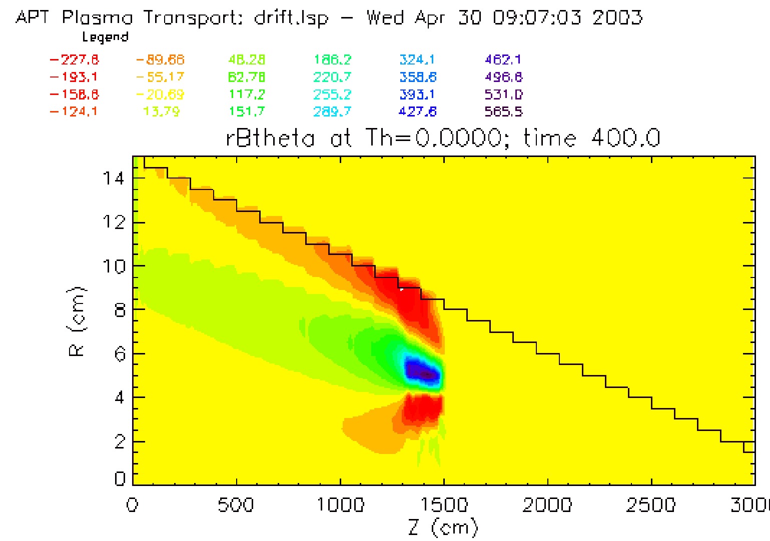
Simulation shows good transport

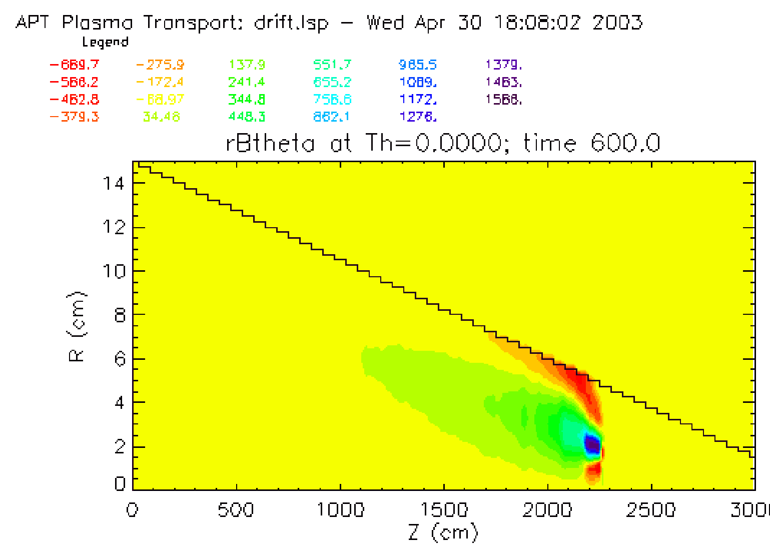
- Resolution becomes coarse for the beam at >600 ns
- Beam density begins lose sharp edge



Net currents increase with distance







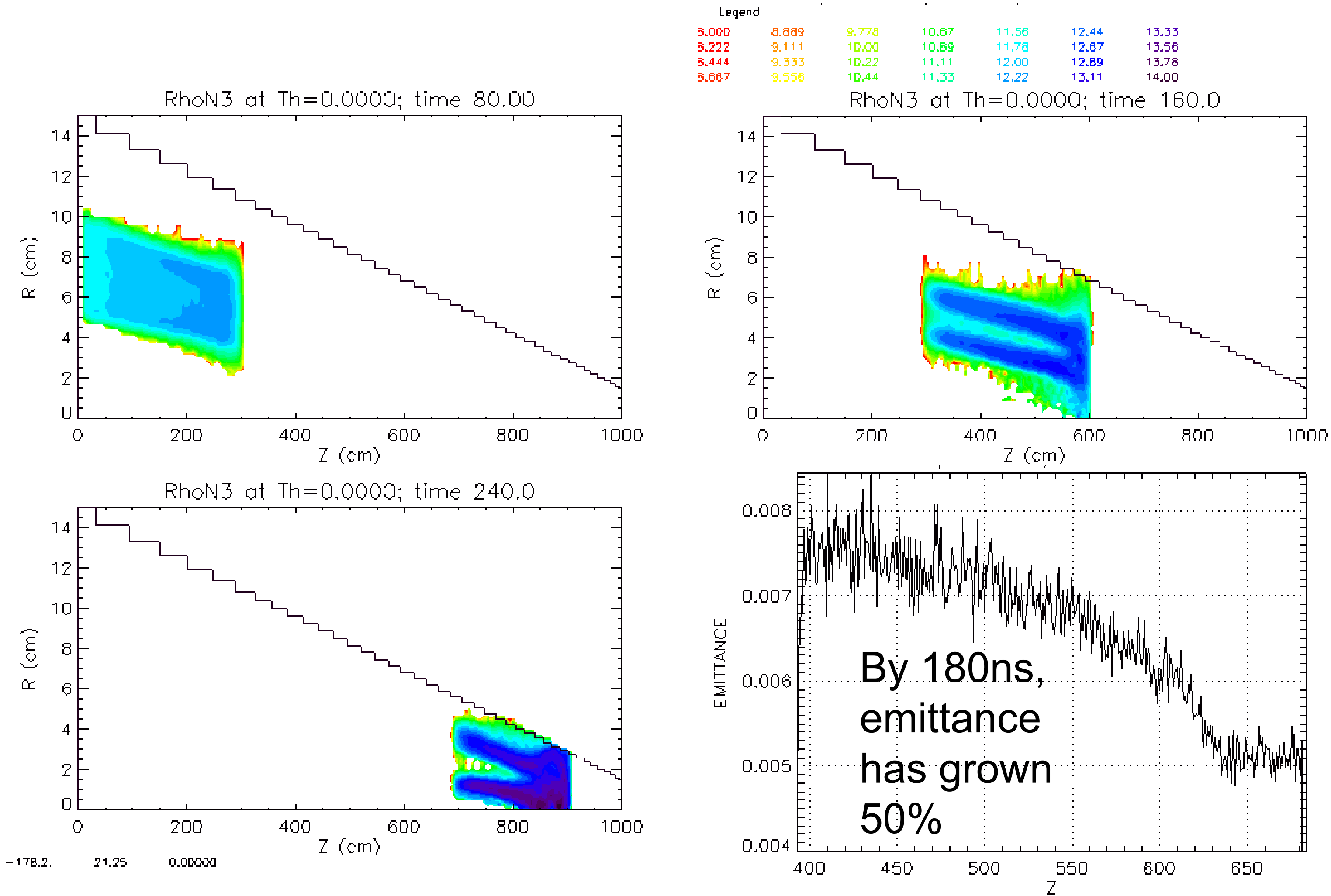
- Simple theory predicts 100 amp net current for 2 kA beam 1% of plasma density
- Beam emittance roughly doubles to 8 π-mm-mrad by 600 ns
- No surprises

2D LSP High-Current Parameters

- Used several ions Ne^+, K^+, Xe^+, Pb^+
- Uniform plasma fill with density roughly that of beam peak
- Solenoidal field 0-4 kG (uniform over simulation region)
- For Ne^+:
  - 100 ns pulse length at injection
  - 150 kA current (combining 10 beams of 15 kA)
  - 210 MeV Ne^+ 0.1 perveance (3 MJ total energy)
  - injected in r=5-10 cm annulus
  - v tilt: beta = .125-.165 in 100 ns (8 ns pulse after 14.5 m drift)
- Scaling of heavier mass ion simulation
  - Same velocity, m x more energy, 1/m x less current
  - Beam emittance was decreased with mass

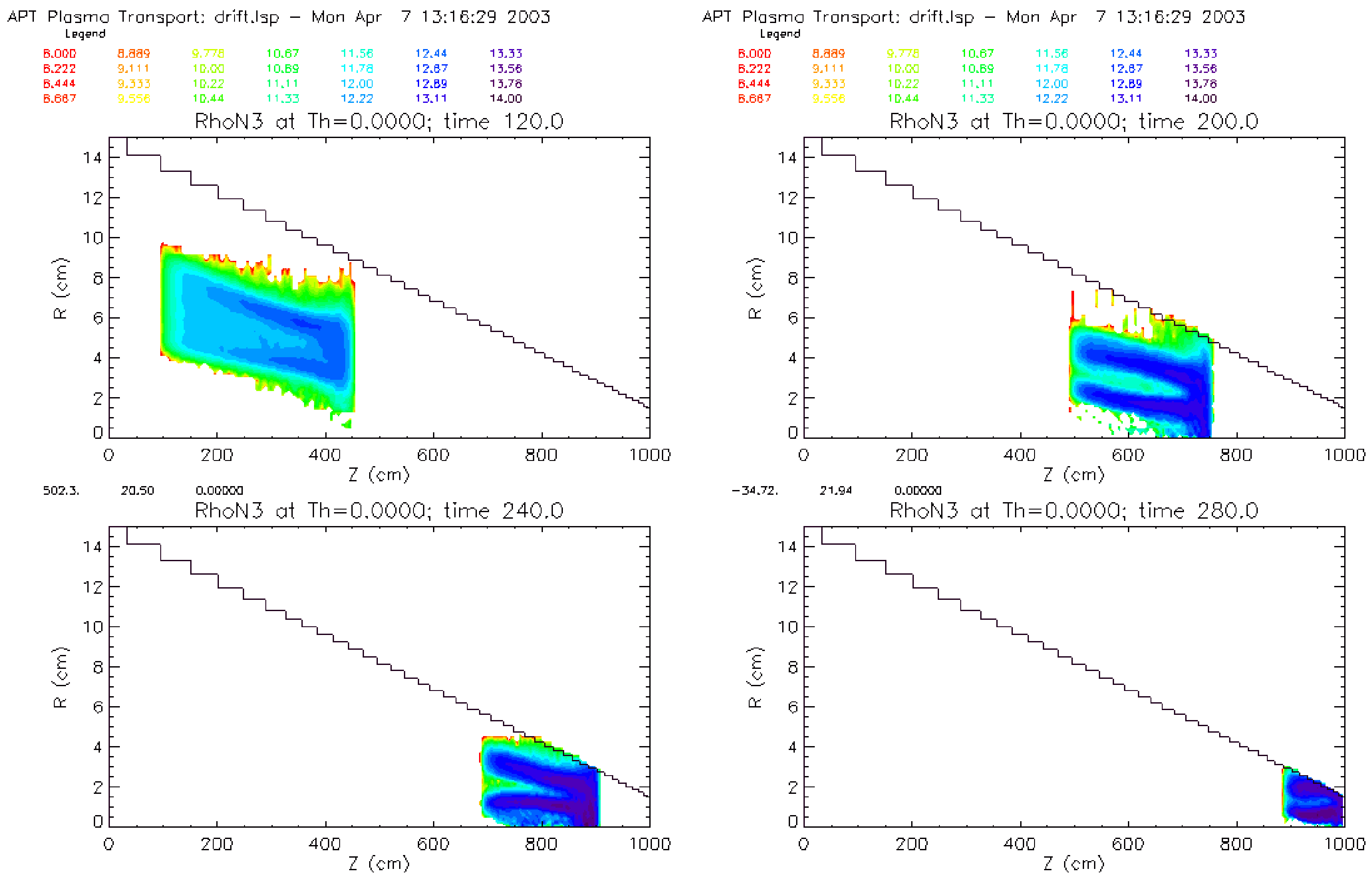
10 x 15 kA Ne^+ beams without B_z

- Ensemble given a 50-π-mm-mrad emittance (2 cm ballistic spot)
- Uniform 4×10^{14} cm^{-3} plasma density
- Charge neutralization is excellent – 99.99% neutralized at 160 ns
- Beam magnetically filaments radially, emittance increases 75-π-mm-mrad

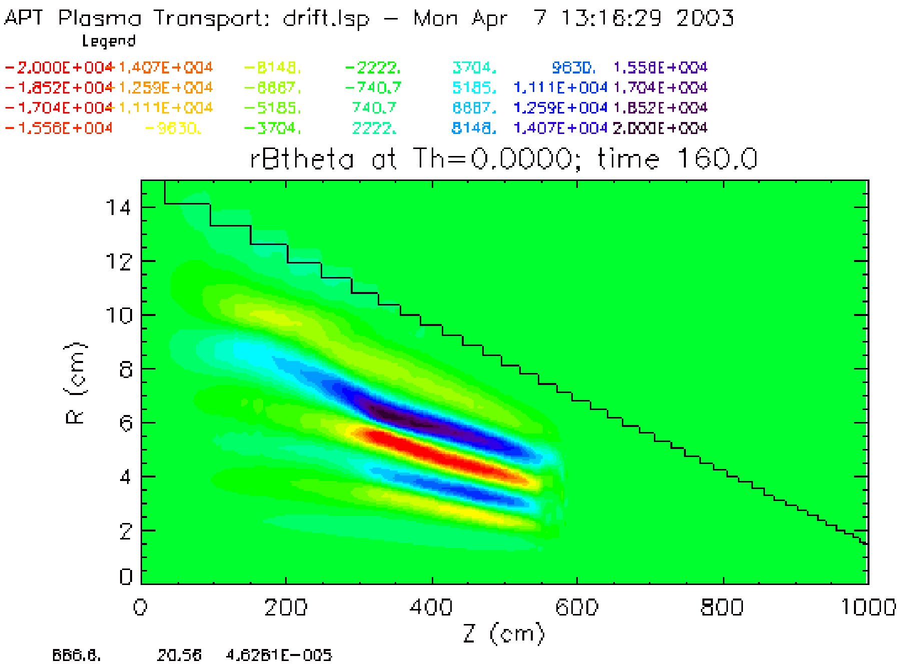


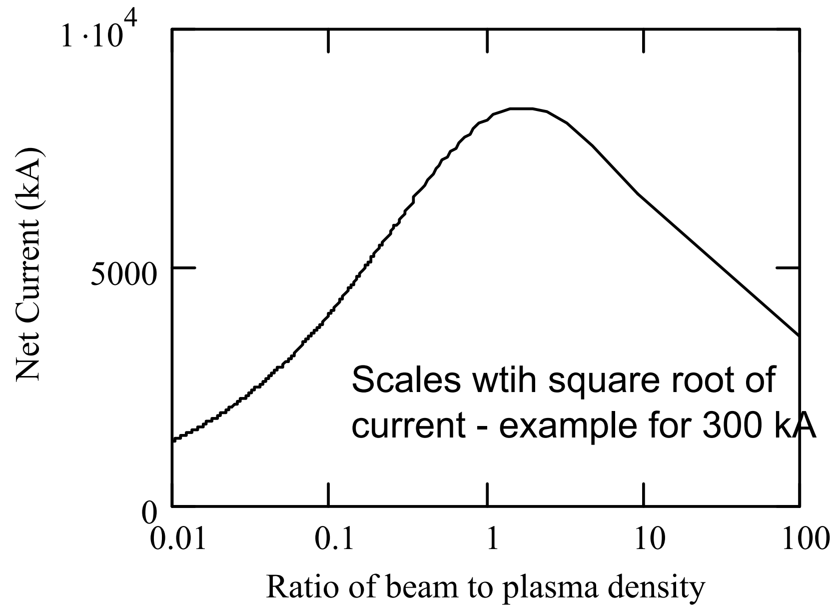
10 x 15 kA Ne^+ beams with B_z=1kG

- Filamentation is reduced slightly with applied field
- Beam density from 120-280 ns



Significant net current at beam edges produce annulii



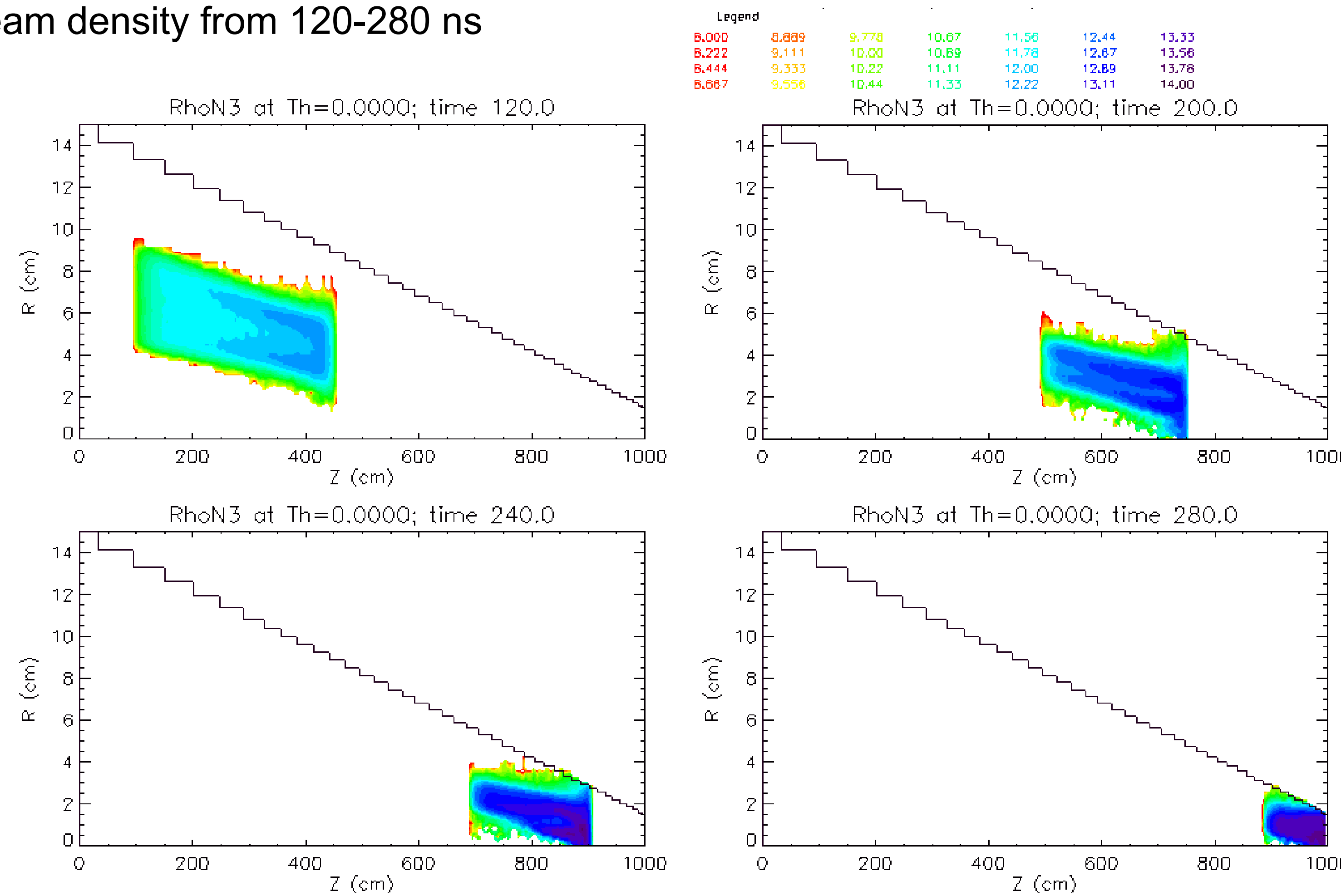


- No applied B field case
- Roughly 10-20 kA net currents (Amps) force concentric beam annulii to form - consistent with theory - D. R. Welch. D. V. Rose, B. V. Oliver, T. C. Genoni, R. E. Clark, C. L. Olson and S. S. Yu, Phys. Plasmas **9**, 2344 (2002).

Lower perveance beams should be less susceptible

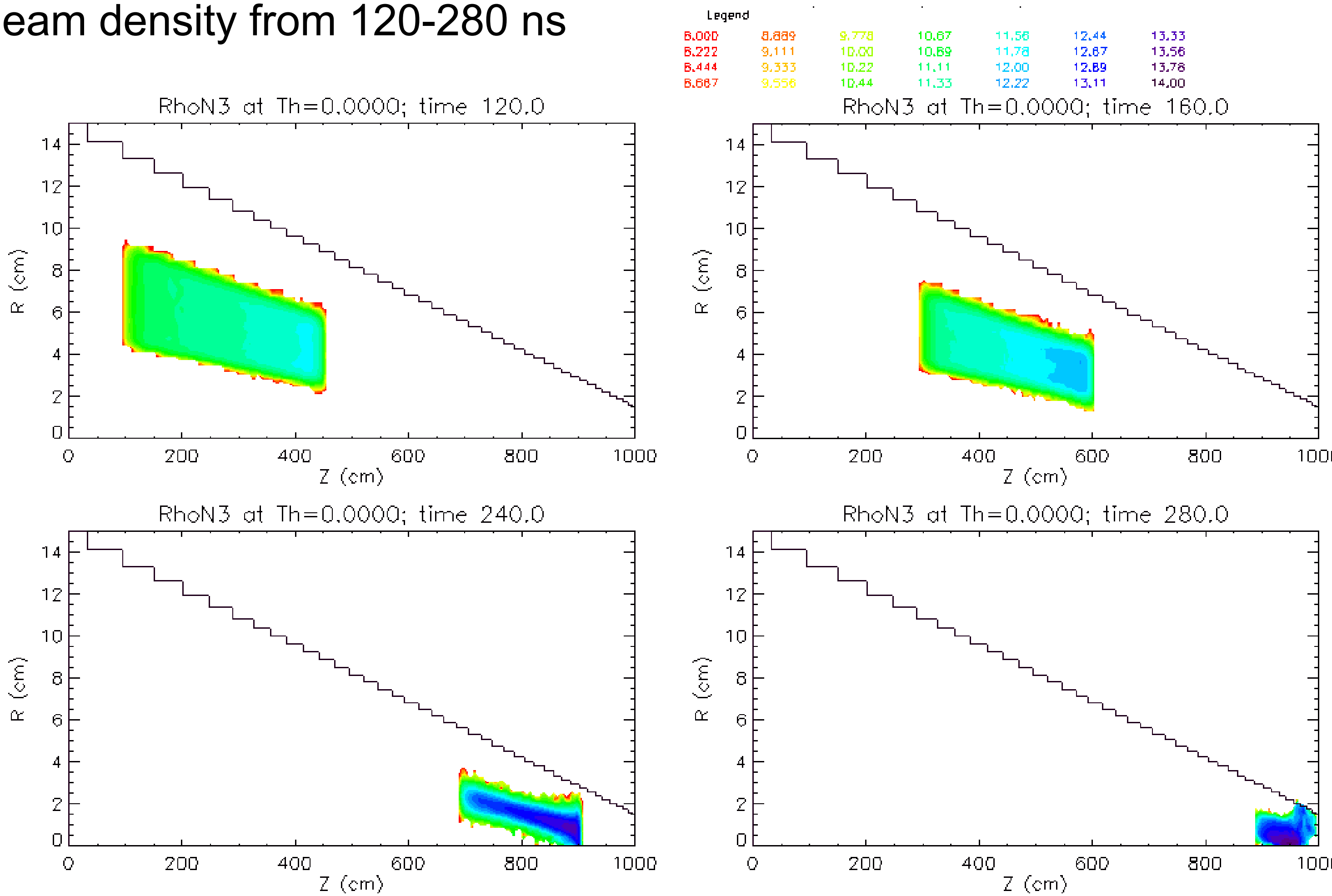
10 x 7.5 kA K^+ beams show improved transport

- 32-π-mm-mrad beam emittance for a 1.4 cm ballistic spot (K = 0.025)
- 2×10^{14} cm^{-3} plasma density
- K filametation looks tolerable, emittance grows to 42 π-mm-mrad
- Beam density from 120-280 ns



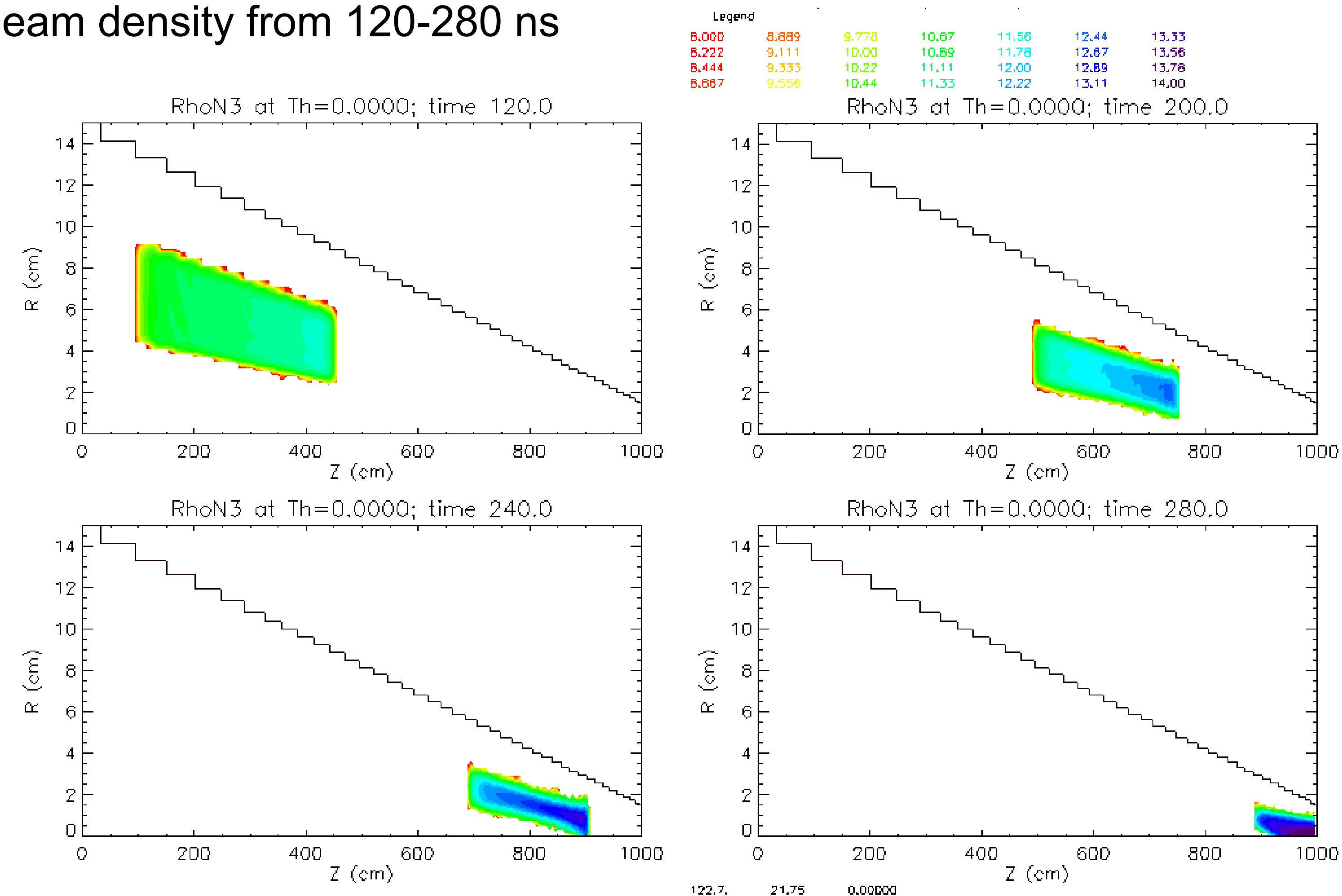
10 x 2.3 kA Xe^+ beams

- Beam emittance 13 π-mm-mrad for a 0.6 cm ballistic spot, grows to 17.5
  - $K = 2.4\times10^{-3}$
- 6×10^{13} cm^{-3} plasma density
- Coupling to adiabatic discharge channel looks feasible
- Beam density from 120-280 ns



10 x 1.45 kA Pb^+ beams

- Beam emittance 9.5 π-mm-mrad for a 0.4-cm ballistic spot, grows to 10.7
  - K = 9.2×10^{-4}
- 4×10^{13} cm^{-3} plasma density
- Stiffer beam shows little filamentation, excellent spot
- Beam density from 120-280 ns

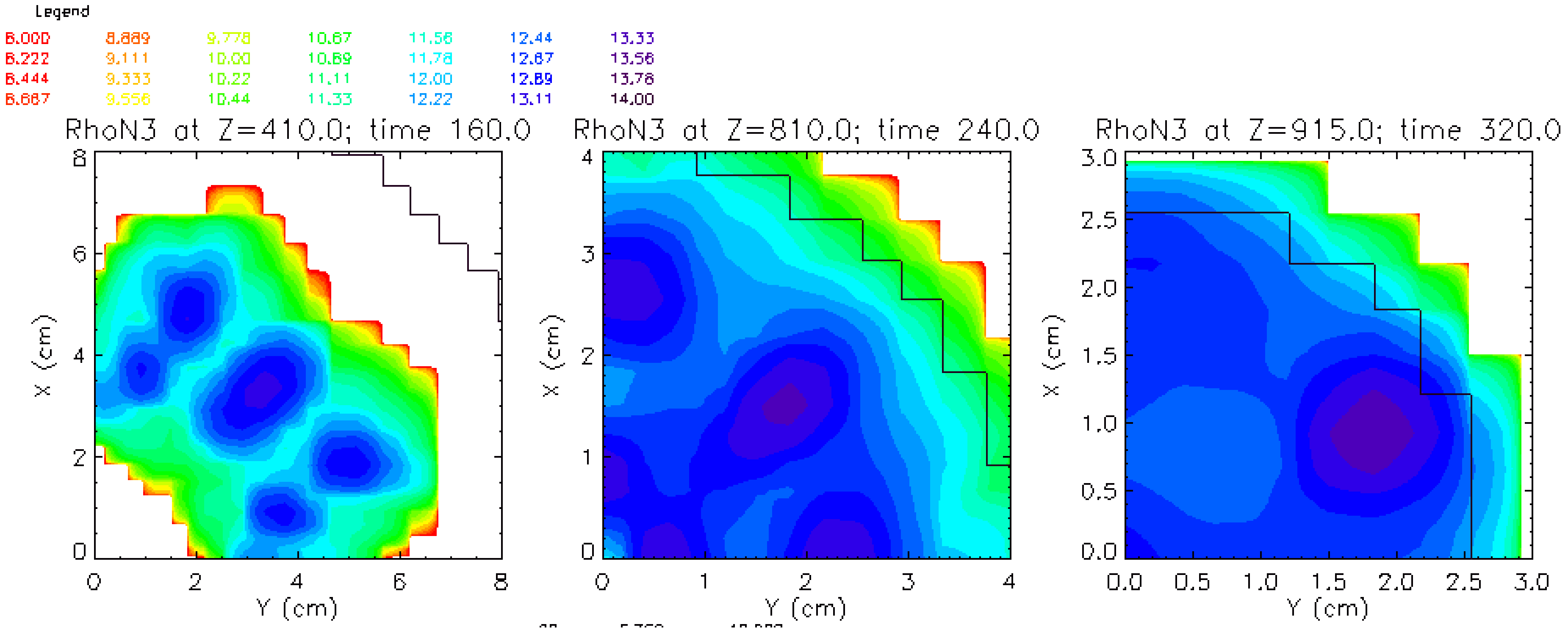


3D Lsp simulations with ¼ volume

- Direct-Implicit cartesian electromagnetic simulations
- Symmetry boundaries at y=0 and x=0
- 2 uniform density ion beams of 3-cm radii with edges just touching (slightly asymmetric in azimuth) – models 8 beams in full volume

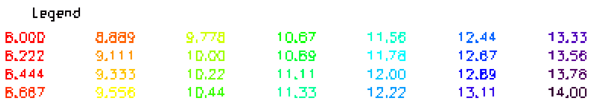
Combined Ne^+ beam filament

- 4×10^{14} cm^{-3} plasma density
- 5 π-mrad-mm emittance
- Combined beam emittance grows to 86 π-mrad-mm
- Filaments wash out near focus (z > 800 cm)



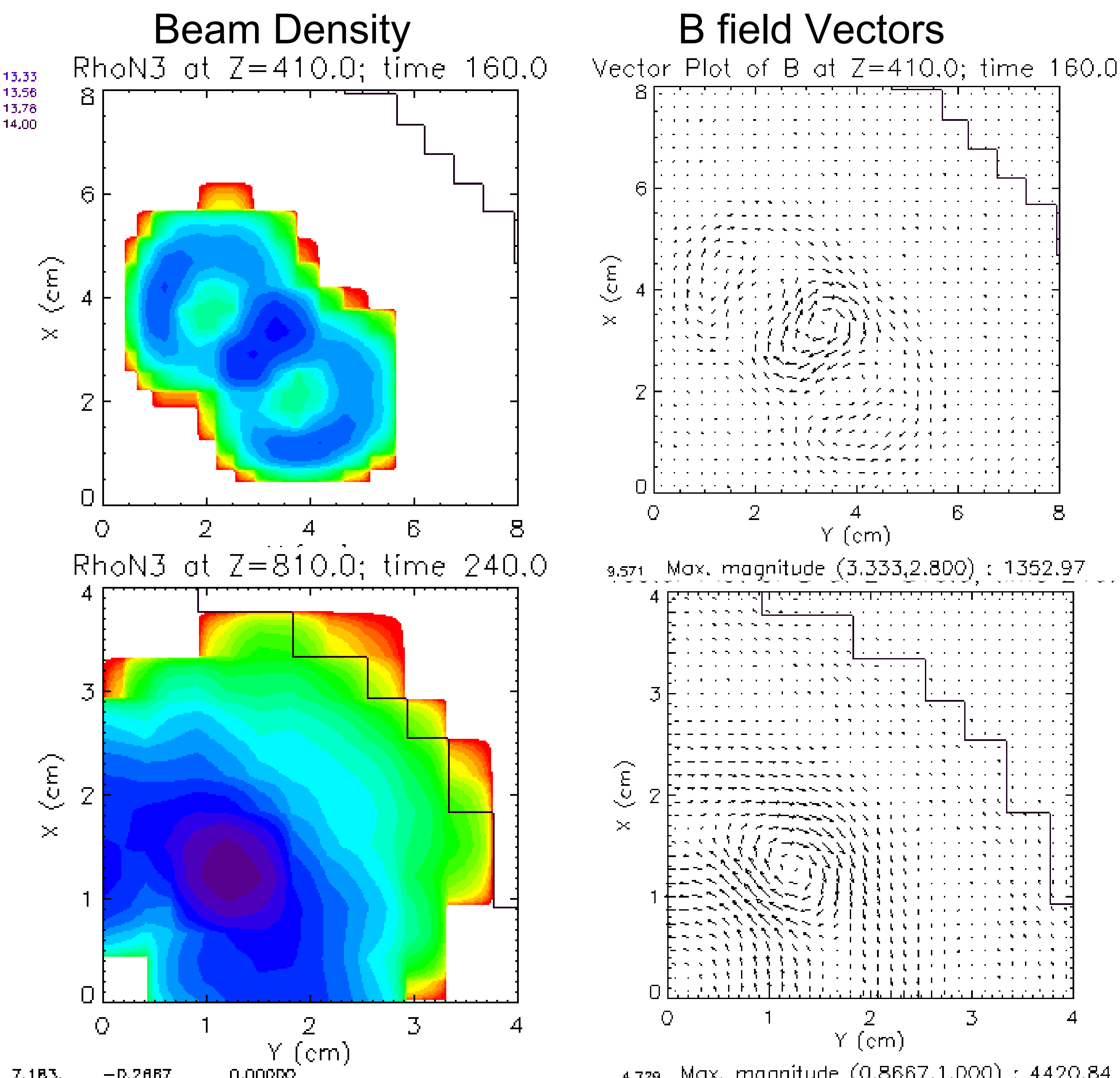
Beam density z=410 cm at 160 ns z=810 cm at 240 ns z=915 cm at 320 ns

K^+ beams show 2d and 3d filamentation



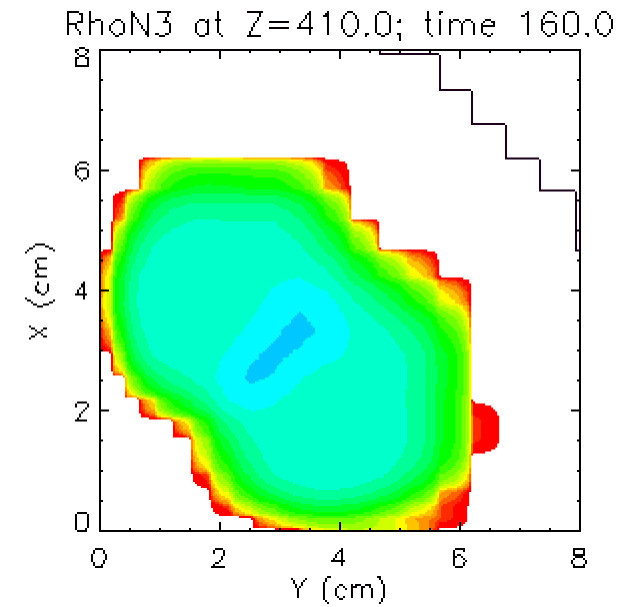
- 2×10^{14} cm^{-3} plasma
- Beamlets have 3 π-mrad-mm emittance
- 4.4 kG self B fields by 240 ns
- Combined beam emittance grows to 15 π-mrad-mm

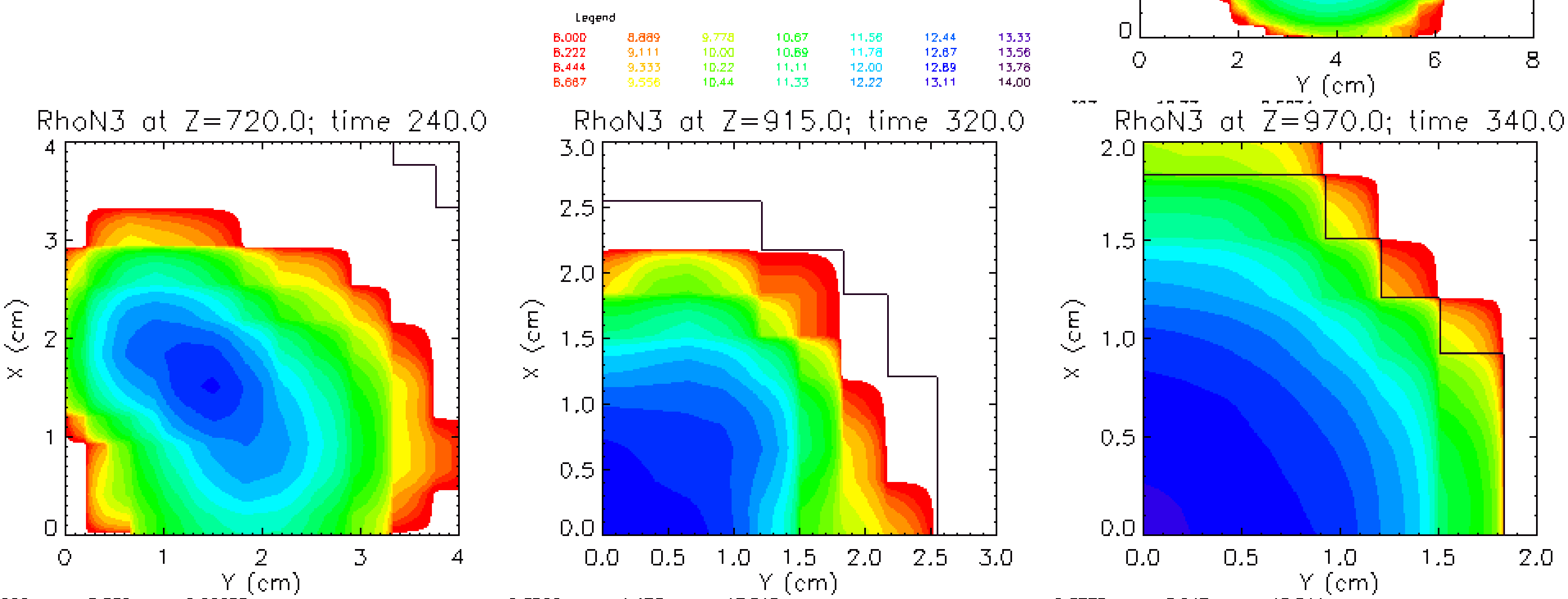
Beamlets first radially filament, then the combined beams show m=8 azimuthal mode structure



Xe beams combine quiescently

- Symmetry boundaries at y=0 and x=0
- 2 Xe^+ beams of 3-cm radii
- 1.7 π-mrad-mm emittance
- 6×10^{13} cm^{-3} plasma density
- Combined beams reach desired 1-cm spot at 1000 cm
- Combined emittance grows to 15 π-mrad-mm

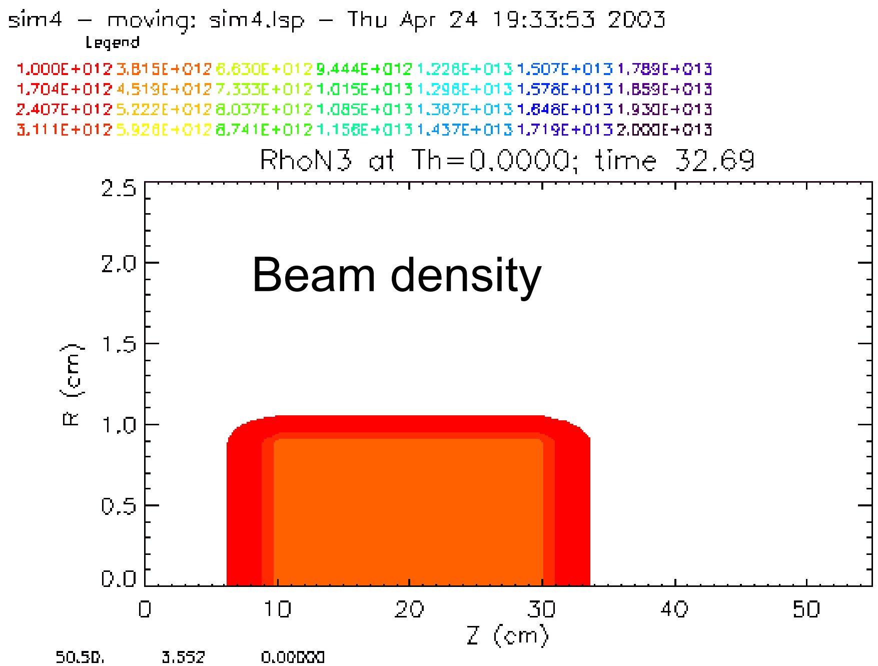


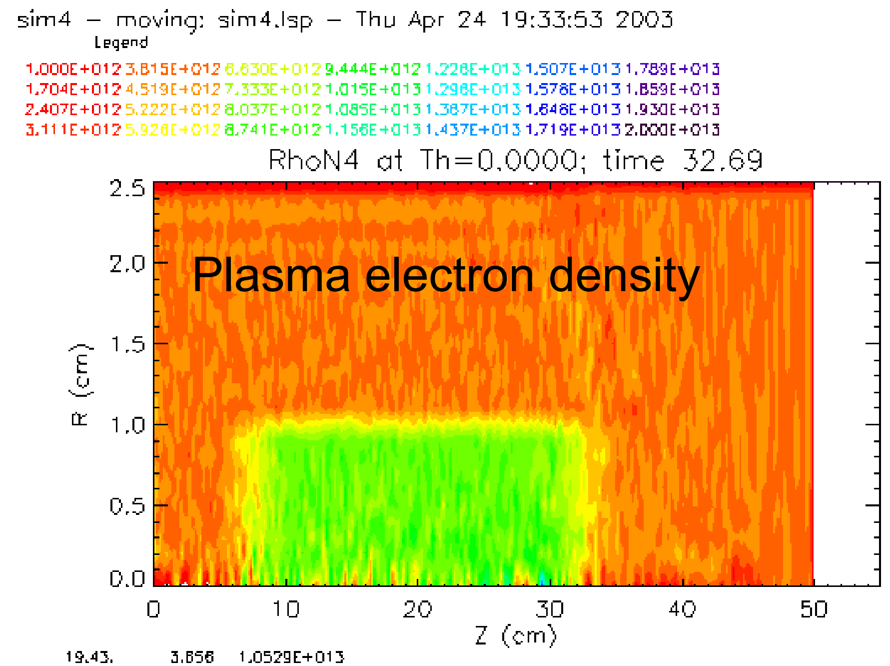


Beam frame option under development for LSP should allow longer transport simulations

- 1-cm, 10-kA beam in a 4 x10^{12} cm^{-3} plasma example propagated 32 ns in the beam frame

Mesh velocity, 0.2 *c* →





Neutralized Drift Compression Summary

- Larger mass ions (eg. Xe^{+},Pb^{+}) exhibit good transport
  - should couple to APT transport channels
- "Low-current" drift compression of Ne^{+} over 25 meters shows good transport with 6x compression
- Filamentation heats high perveance (low mass) ion beams to higher beam temperatures and larger spots
- Solenoidal field reduces filamentation – needs further study
- First look at neutralized drift compression for modular solenoidal transport encouraging