Diversion of Plasma in Beam Port with a Vertical Magnetic Field

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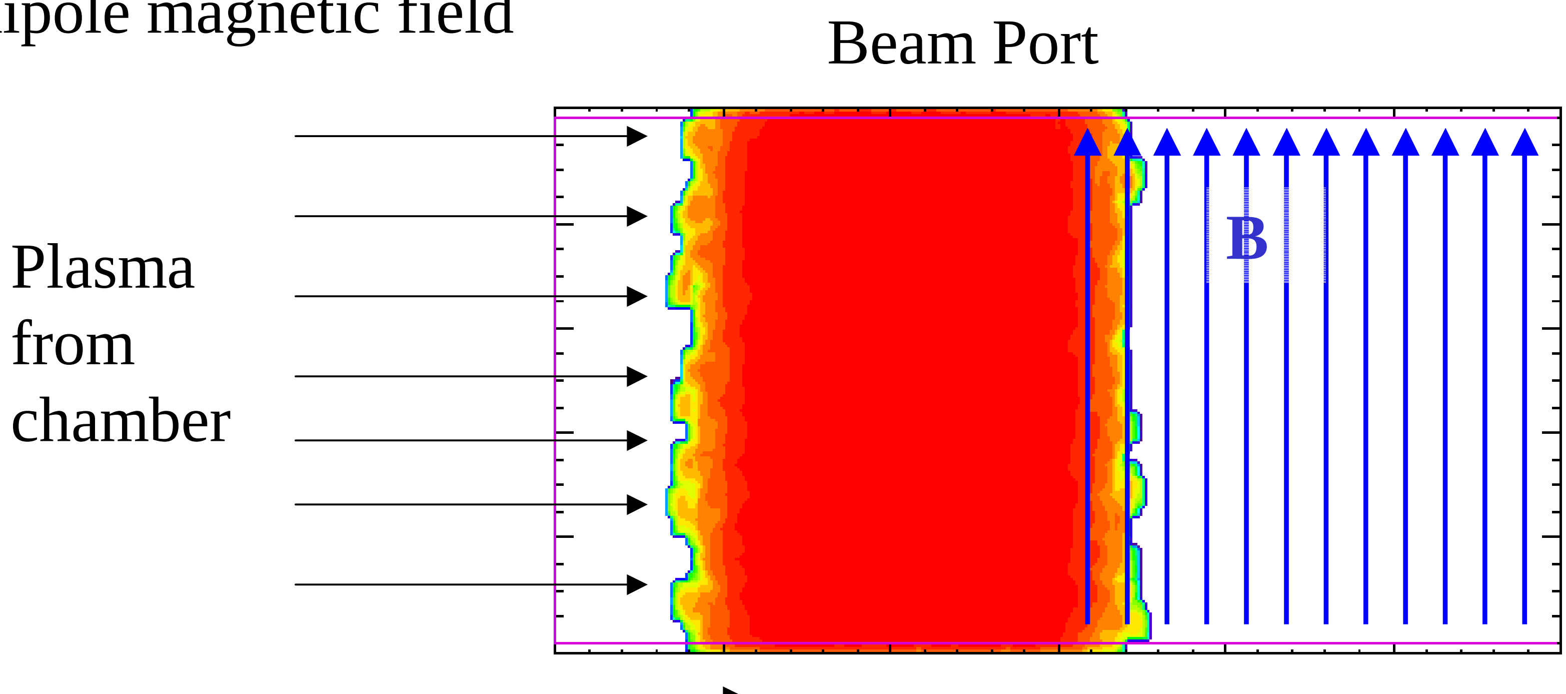
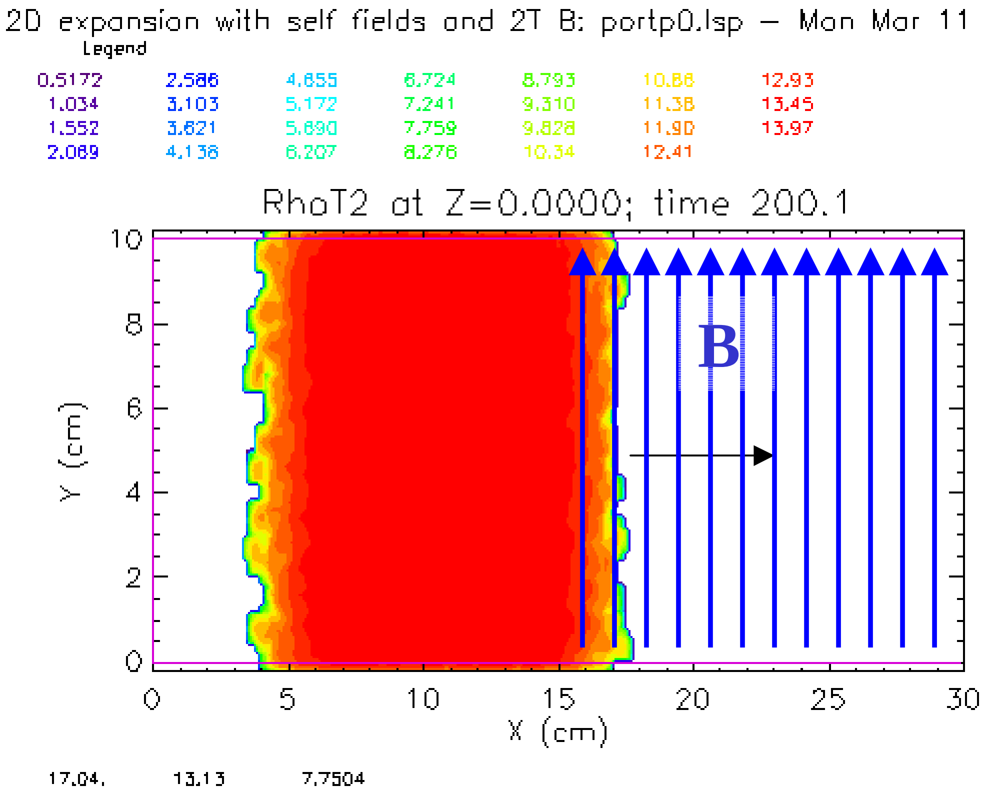
A plasma can be blown off the chamber wall and expand into the beam port

- We expect the plasma to be of order 10^{14} cm^{-3} density and 10 eV
- Neutral fraction may be quite small for these conditions
- Plasma can be diverted to port wall with a vertical or dipole magnetic field



LSP Plasma Diversion Simulation



Moving plasma blob confined by **B**

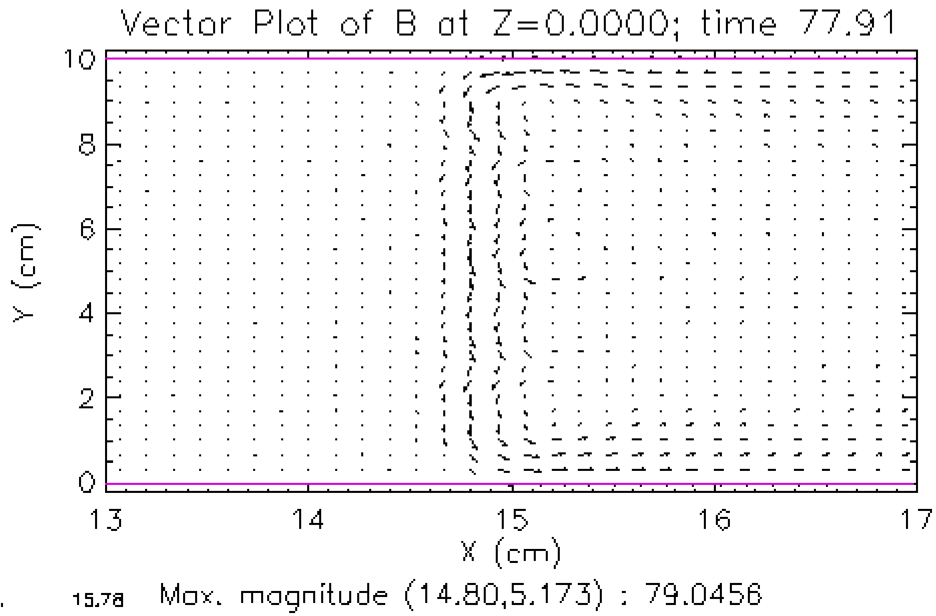
- A moving plasma blob is initialized in the x-y Cartesian simulation with a 10^{14} cm^{-3} density. The simulation box was 30-cm long and 10-cm wide. The plasma had H^{+} ions with a 10-100 eV temperature and a 3-9 cm/microsecond forward velocity. A no-field case and a case with electromagnetic fields and a 1-kG B_y field (for x > 15 cm) were simulated with Lsp.
- The B_y case shows the plasma is stopped and decays to the outer wall.

1-kG field was chosen to confine low-beta plasma

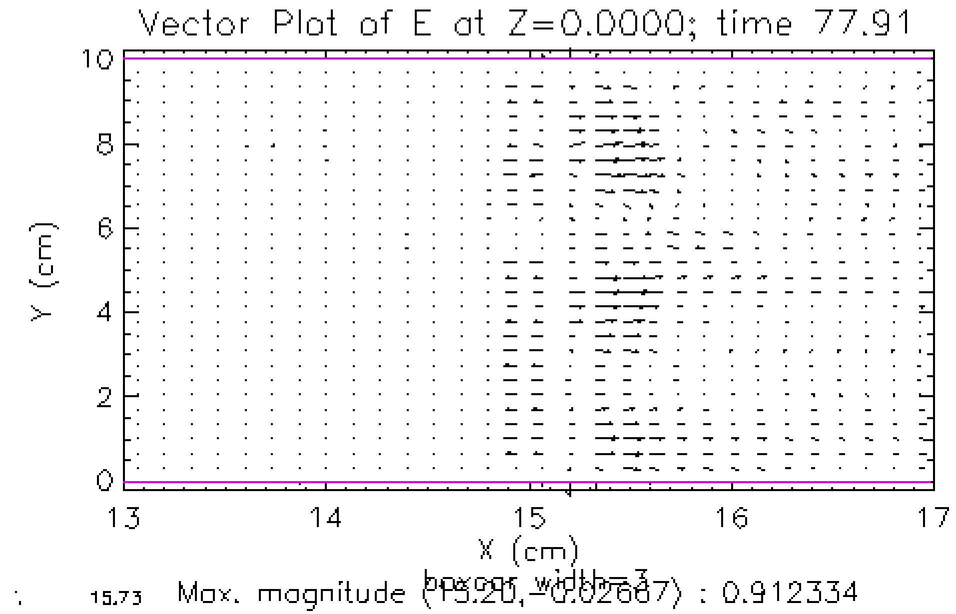
- For 10-eV, 10^{14} cm^{-3} plasma, the ratio of plasma energy to magnetic field energy
  $\beta = 8\pi nkT/B^2 = .04$
  - plasma cannot exclude magnetic field and should be confined
- Mean ion cyclotron radius $\omega_c = m_i v_i c/eB$ is roughly 3 mm for protons

2D Electromagnetic calculation run 80 ns

- Plasma ions can move a few mm
- JxB force leads to charge separation (electron motion is completely stopped)
- Plasma diamagnetic current negates 10% of applied field



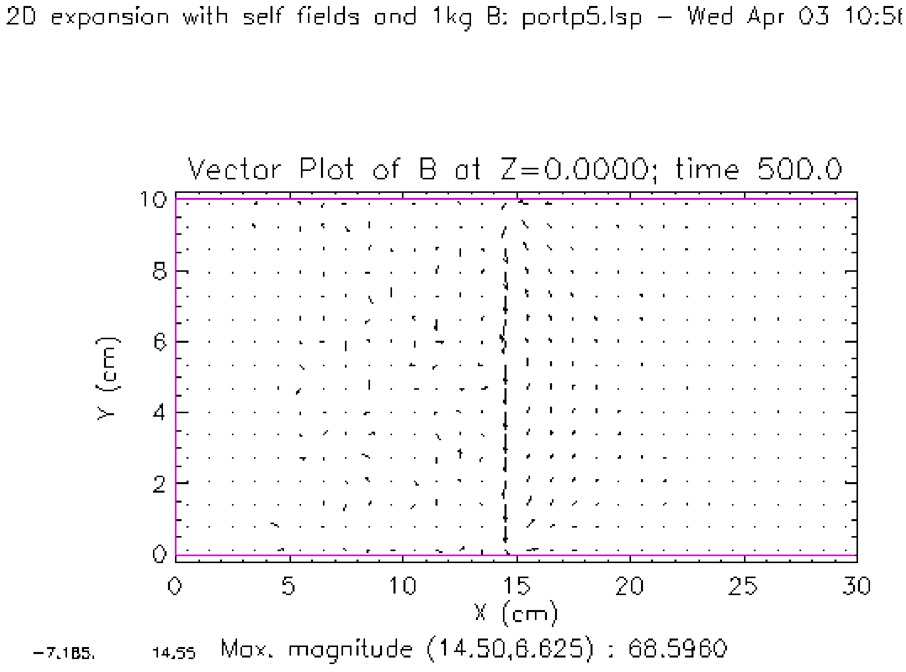
80 Gauss self B



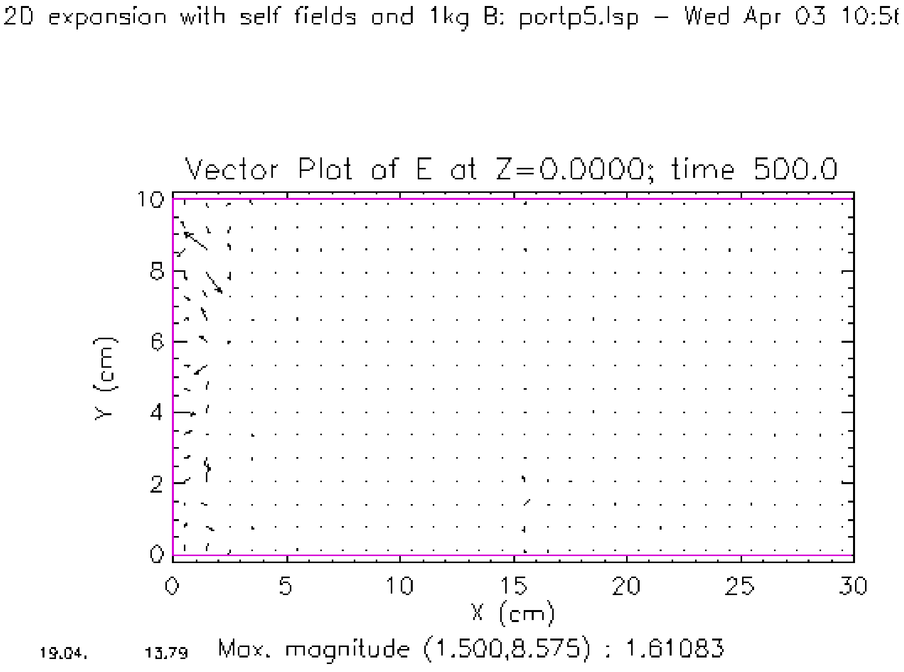
1 kV/cm self E

Self-Fields remain small after 500 ns

- Magnetic field penetration stagnates at 10% of applied field
- Small depth to penetration



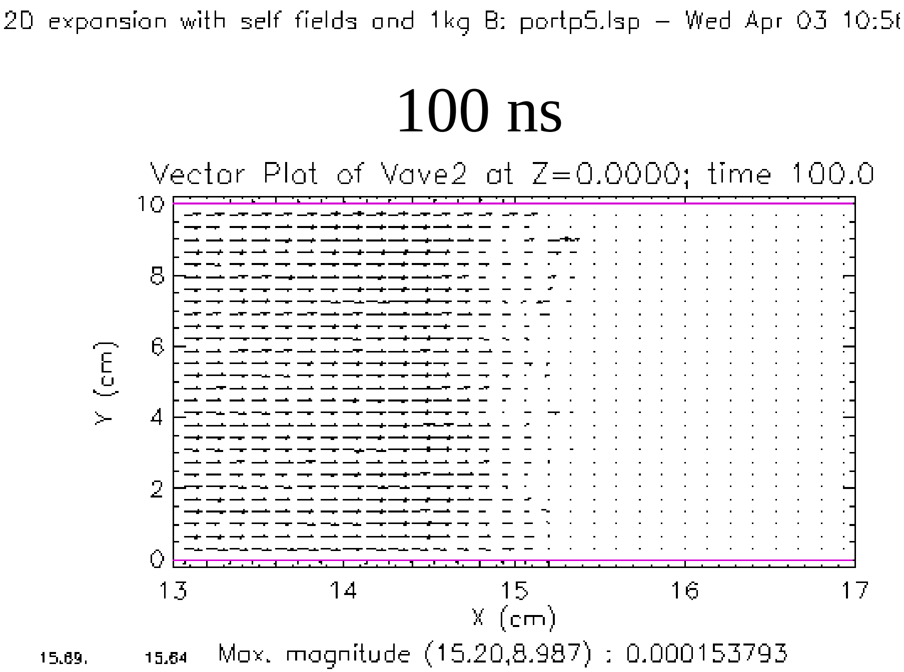
70 Gauss self B



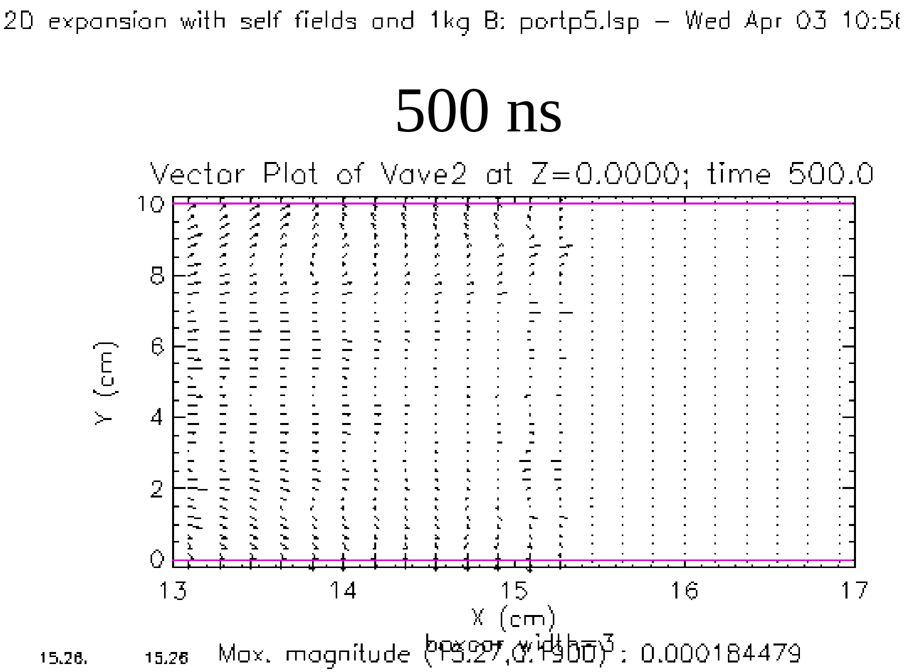
1.6 kV/cm self E

Ions are turned in space charge field

- Ion velocity stagnates at 15.4 cm, decays to wall

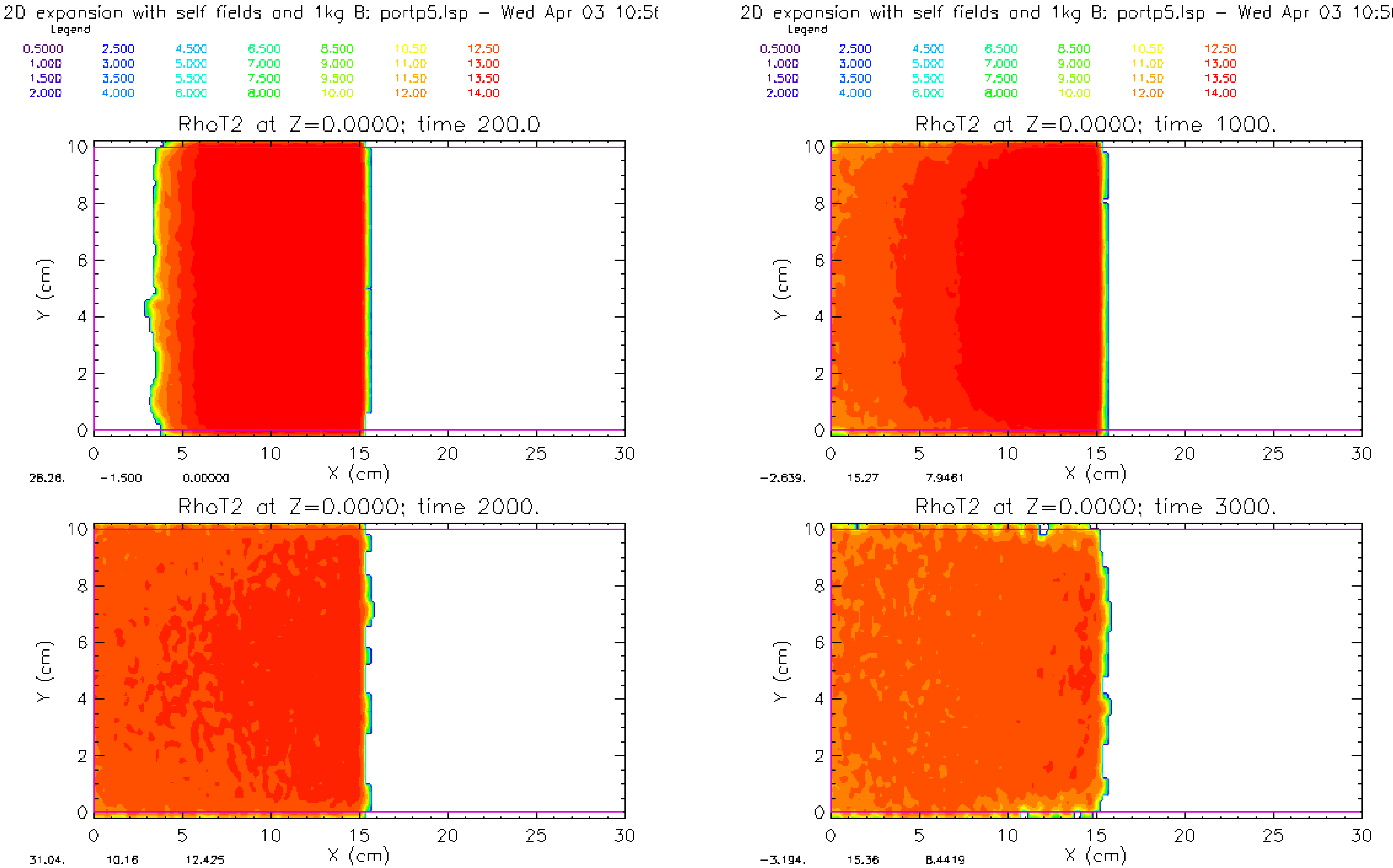


100 ns



500 ns

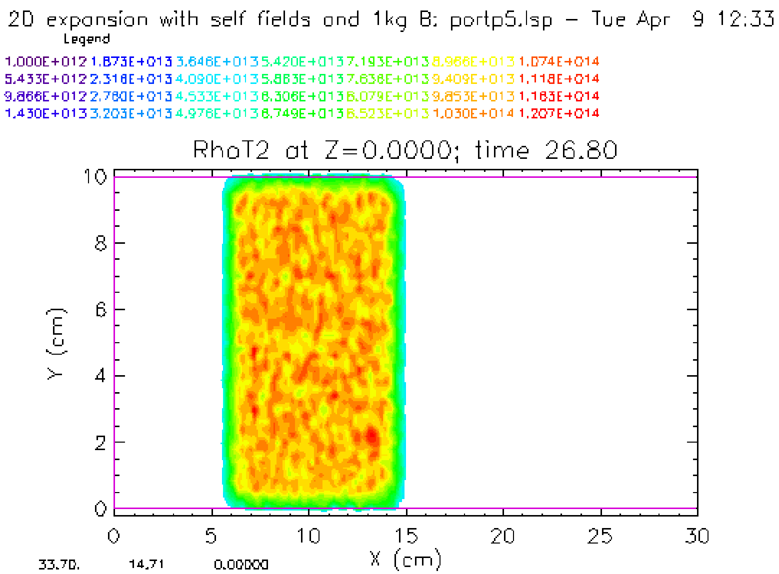
Snapshots of B_y run - plasma stagnates at roughly x = 18 cm

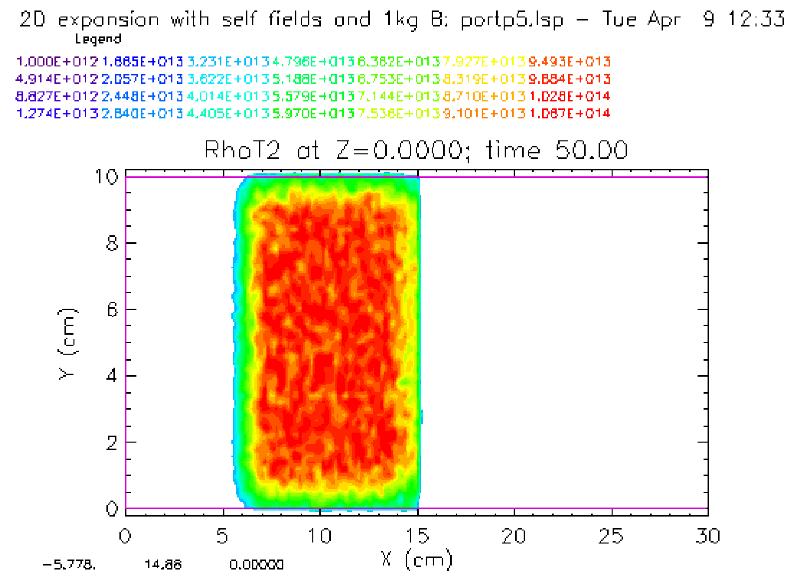


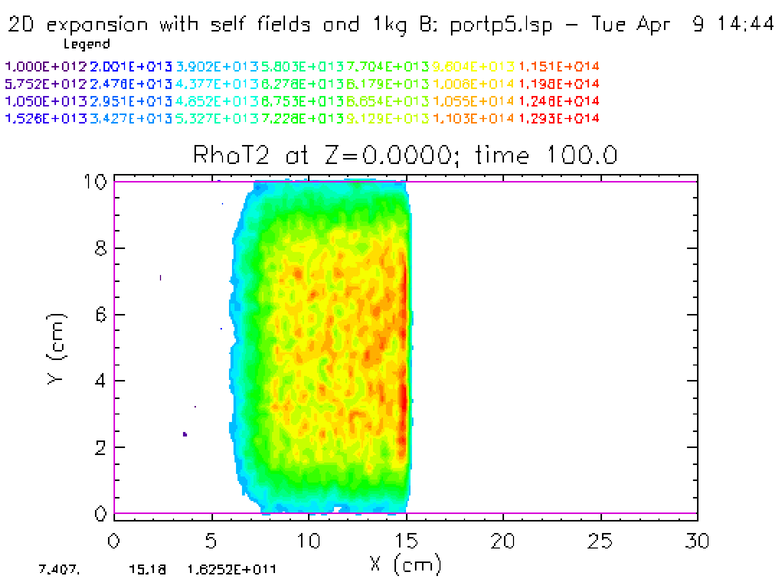
0.4 Beta Plasma Calculation

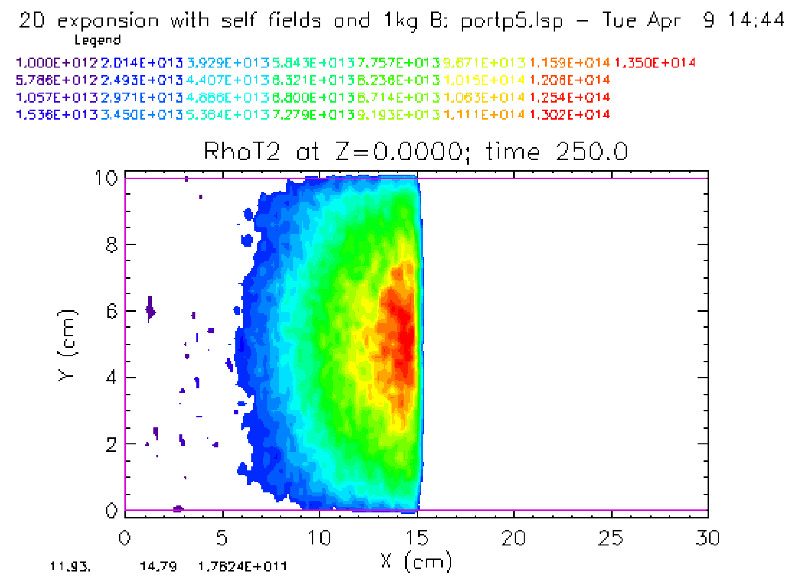
- Plasma temperature is increased to 100 eV with a 9 cm/μs forward-directed velocity
- Simulation is much faster than increasing density by 10 but keeping T fixed
- Same external magnetic field topology

100-eV plasma with v = 9 cm/μs

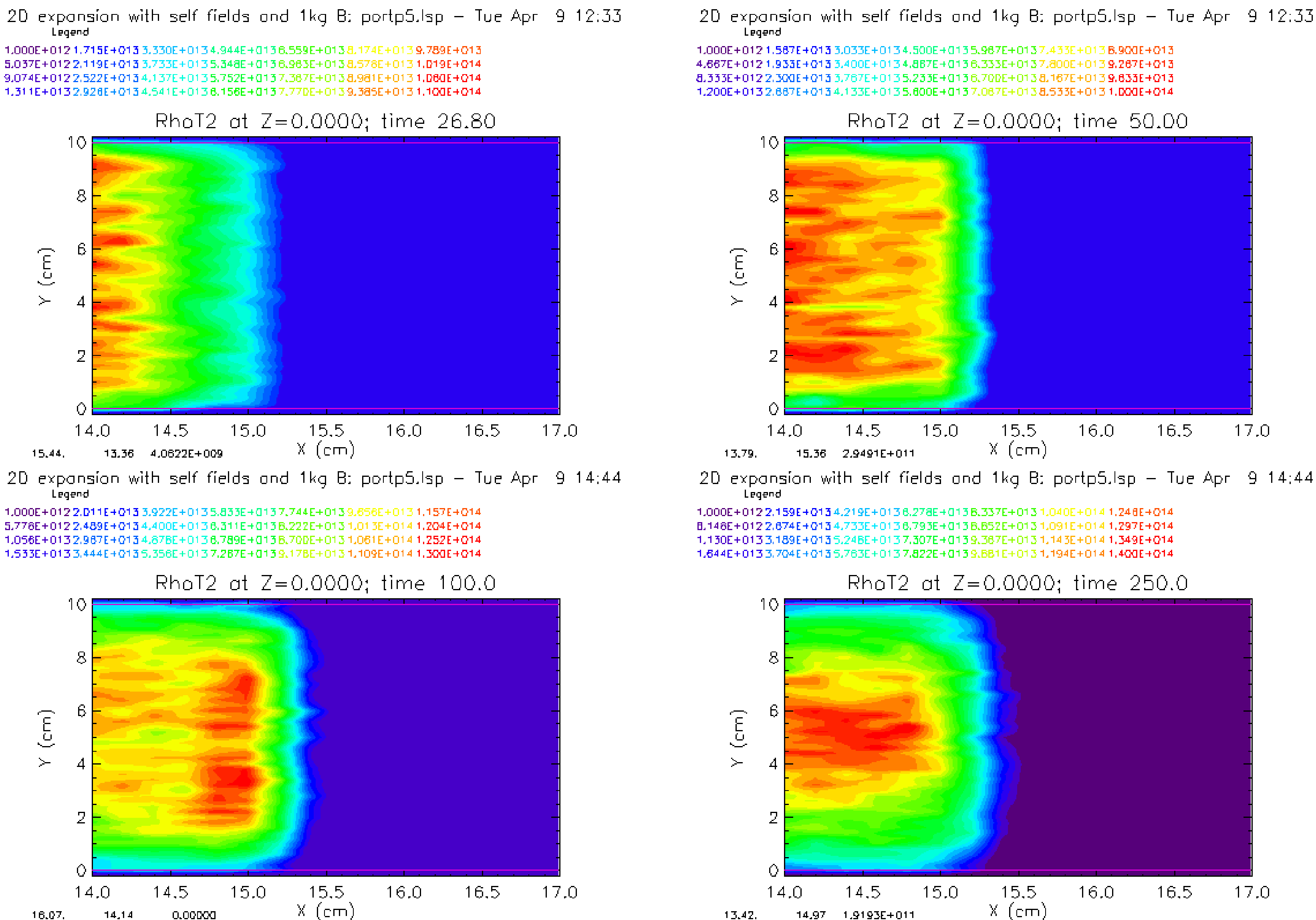




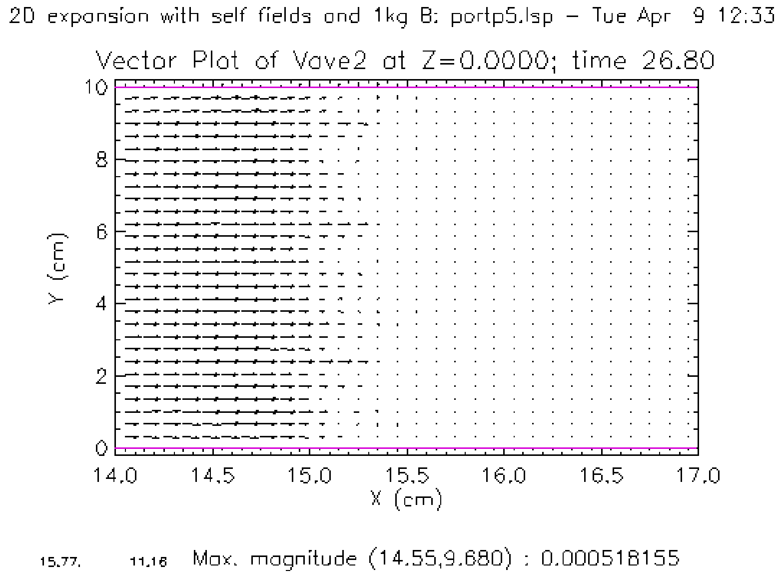


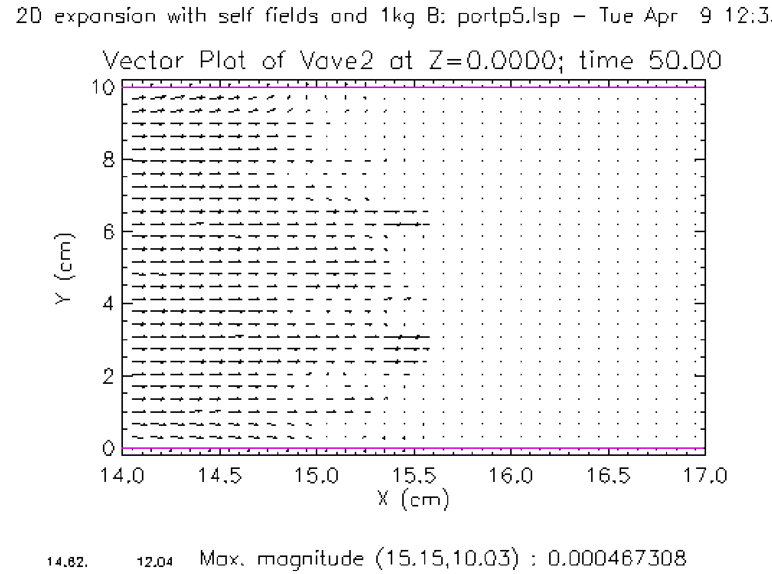


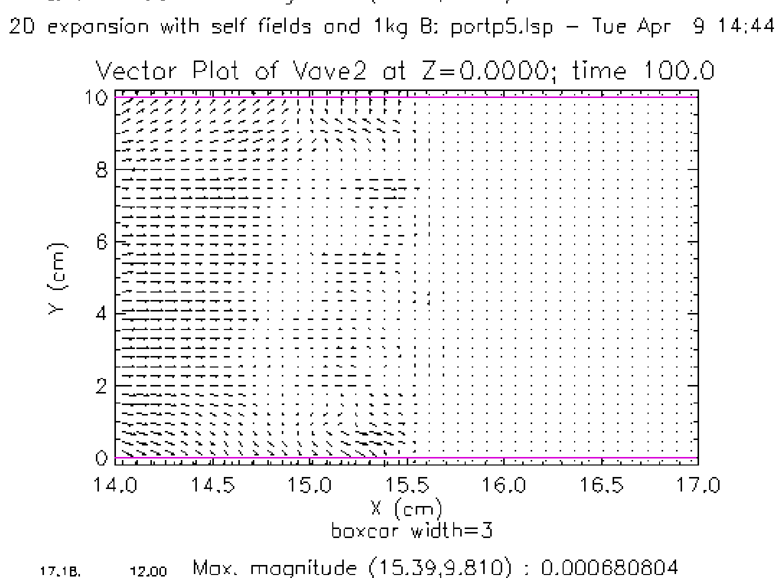
Close up of ion density shows stagnation at 15.5 cm

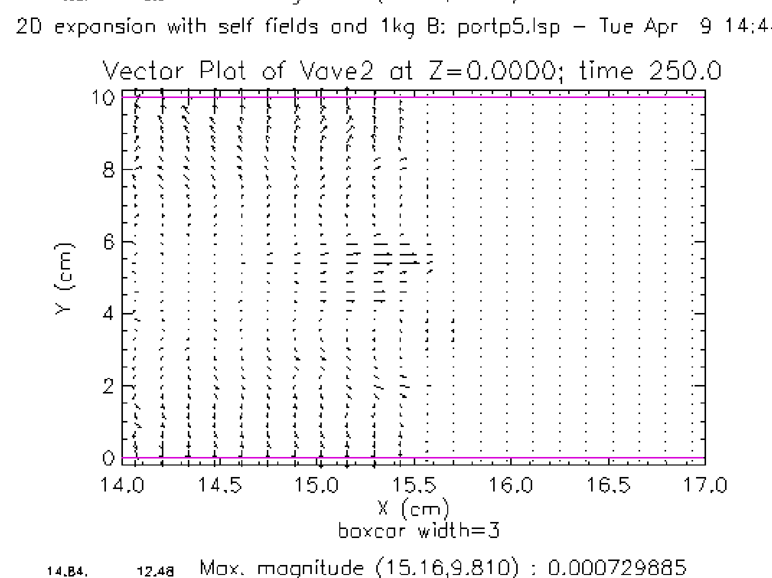


Mean ion velocity turns towards outer wall by 250 ns

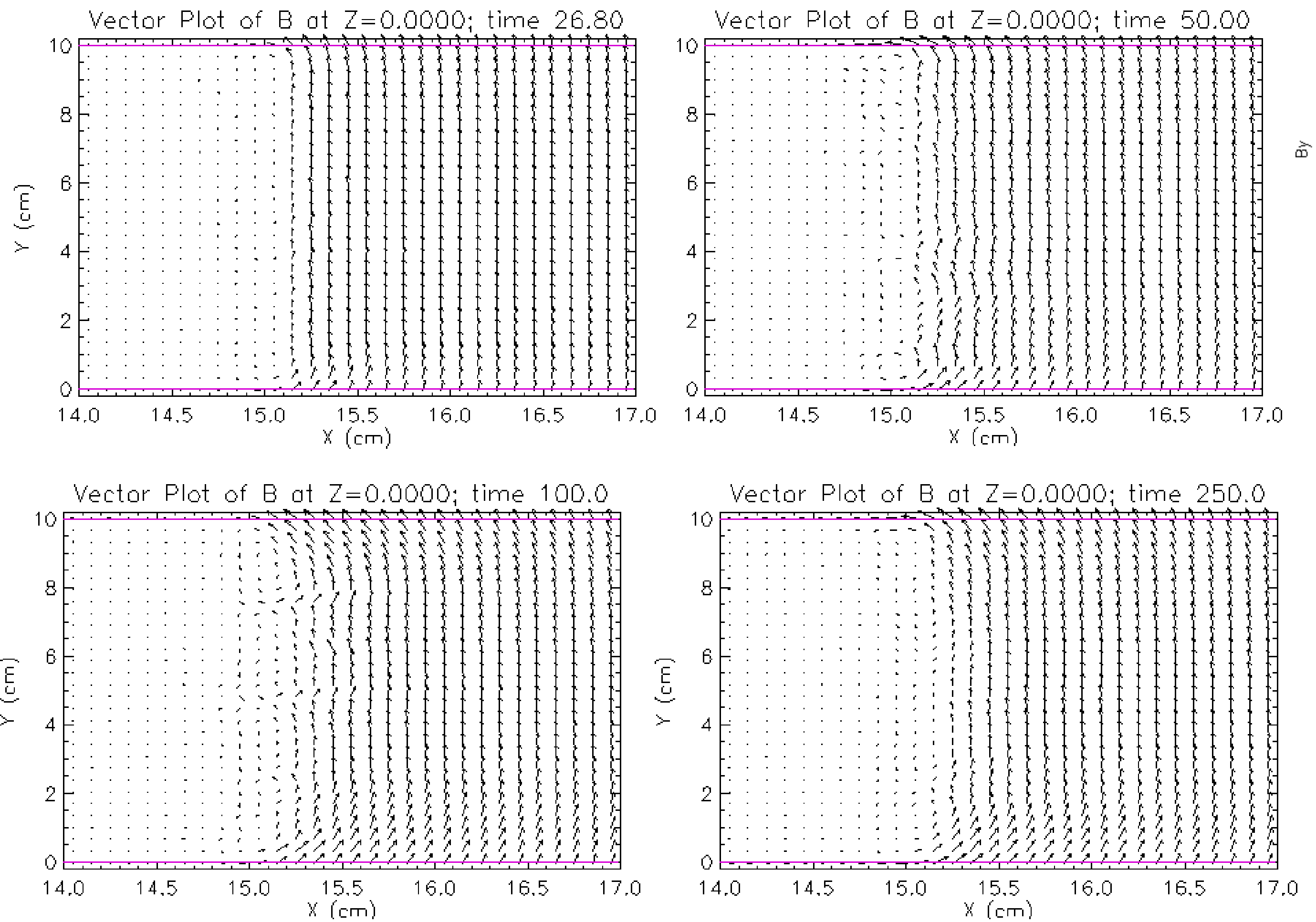


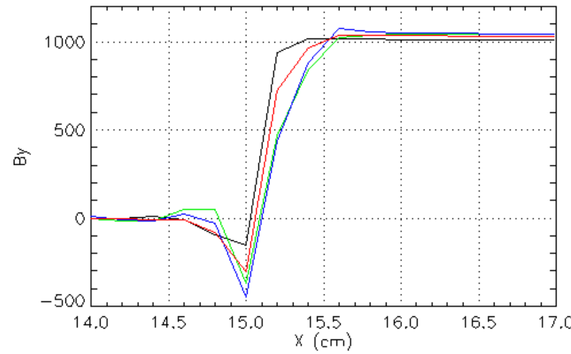






Plasma pushes fields back 5 mm before stagnating and decaying





B_y at y = 0 for t=25, 50, 100 and 250 ns

Conclusion

- 2D calculations predict expected plasmas diverted by a moderate strength magnetic field (1 kG)
- B field need extend no further than a few cm - beam deflection is small of order 10^{-5} radian
- 3D effects generally weaken confinement - may necessitate somewhat larger required magnetic fields than 2D calculations - but expect same qualitative behavior.

Effect of Pre-Neutralization and Protoionization on Transport

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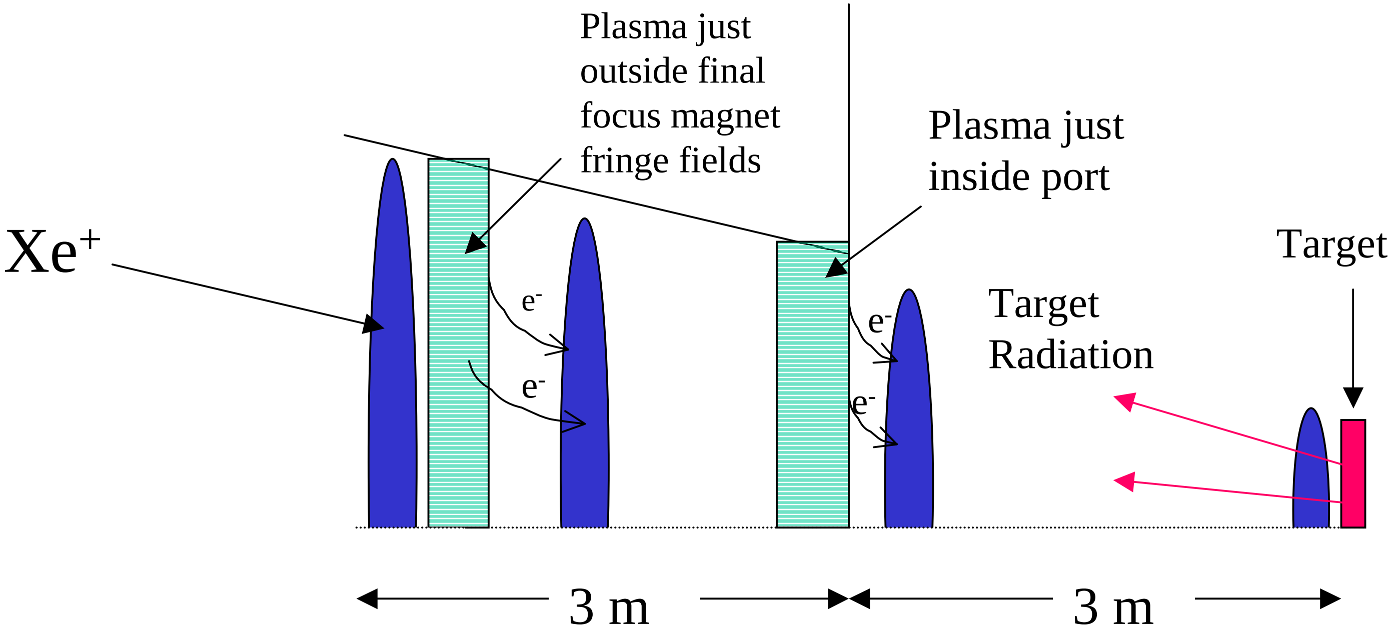
Progress on an integrated calculation for both foot and main pulse with NBT



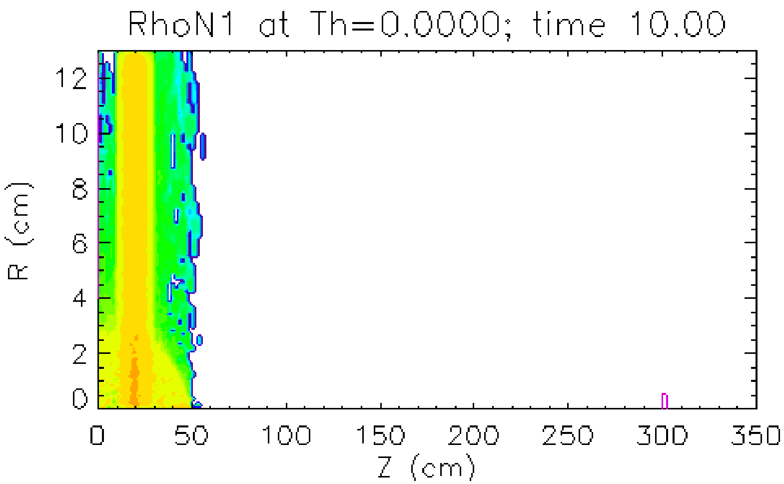
Do the benefits of a local plasma extend to the both foot and main pulses?

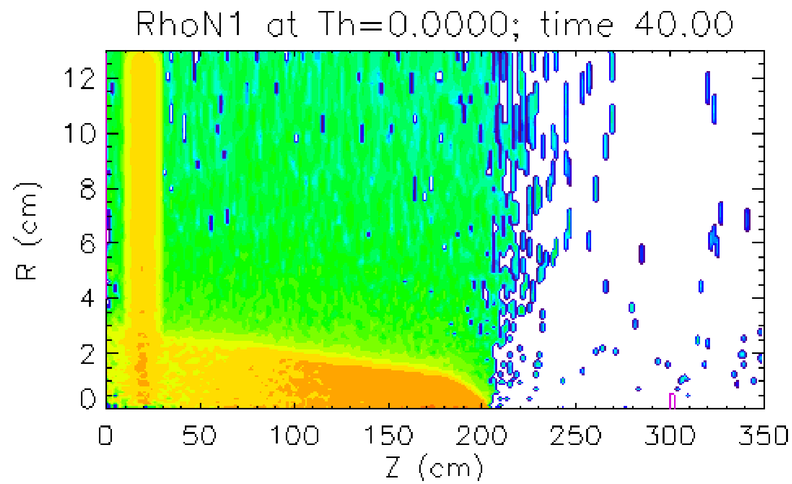
What are the effects of photo ionization and stripping?

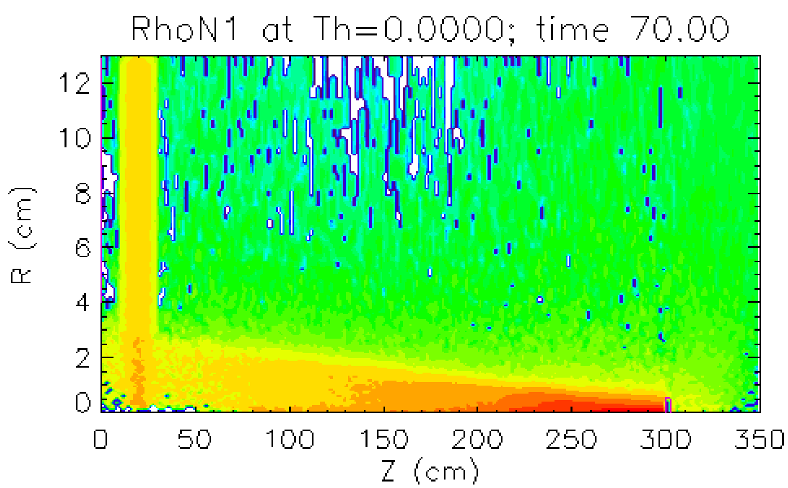
Beam/Chamber Parameters

- Foot Pulse: Pb 3 GeV, 870 A, ($K=5x10^{-5}$) 30ns
- Main Pulse Xe 2.4 GeV, 2.8 kA ($K=1.8x10^{-4}$) 8 ns
- 1.1 pi-mm-mrad normalized emittance
- 0.6 mTorr BeF_2 in chamber (ionization and stripping)
- With and without pre-neutralization by 10-cm long $2.5x10^{12}$-cm^{-3} density plasma

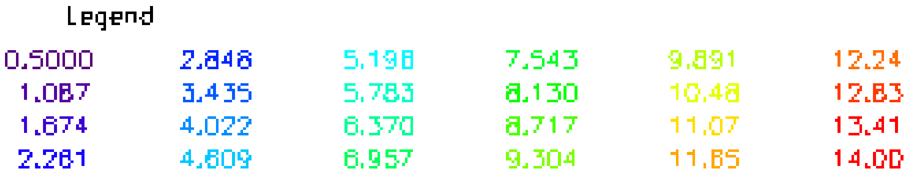
Plasma electrons are effective neutralizers even with ion stripping







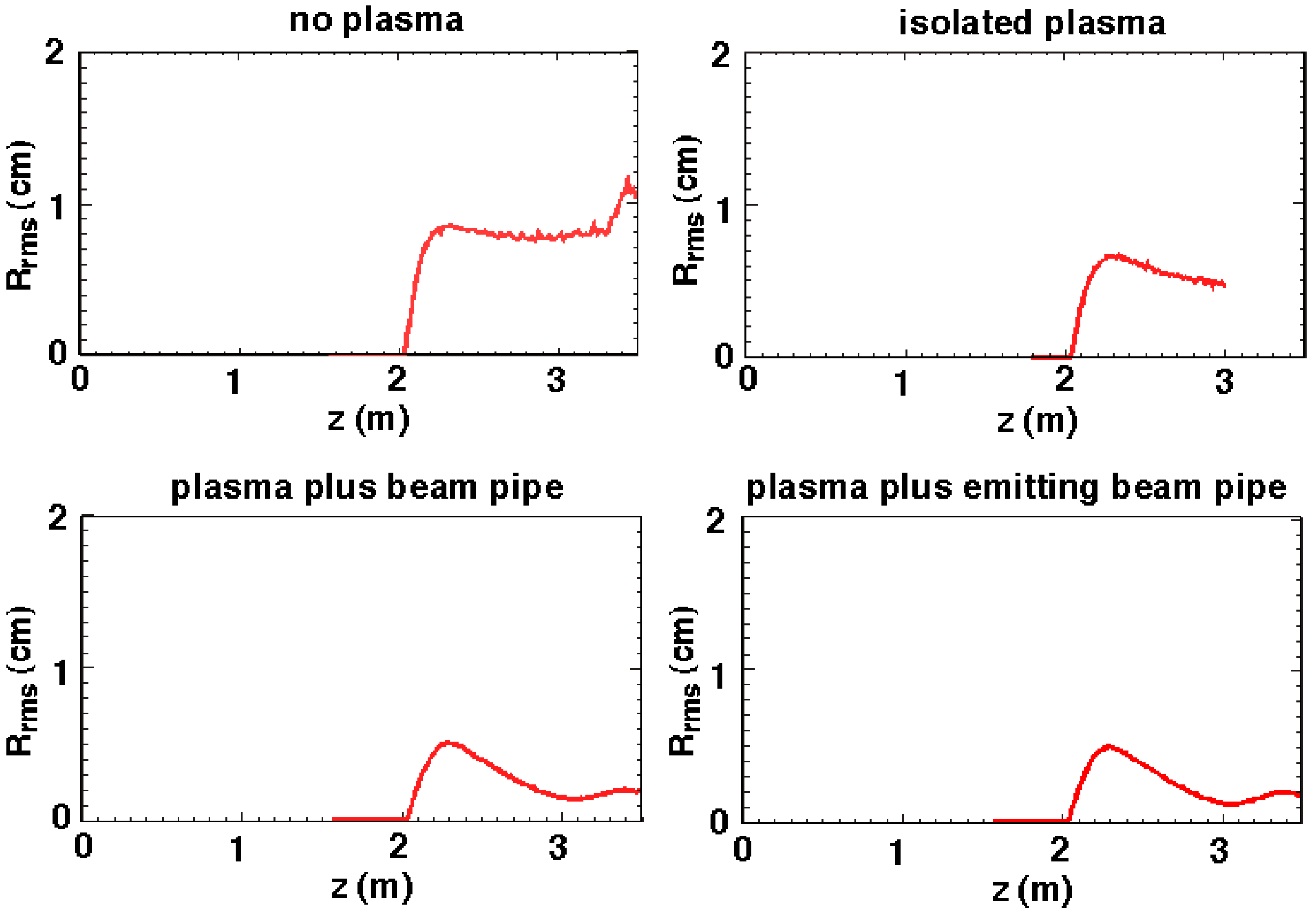
Log n_e



Plasma pre-neutralization improves transport dramatically

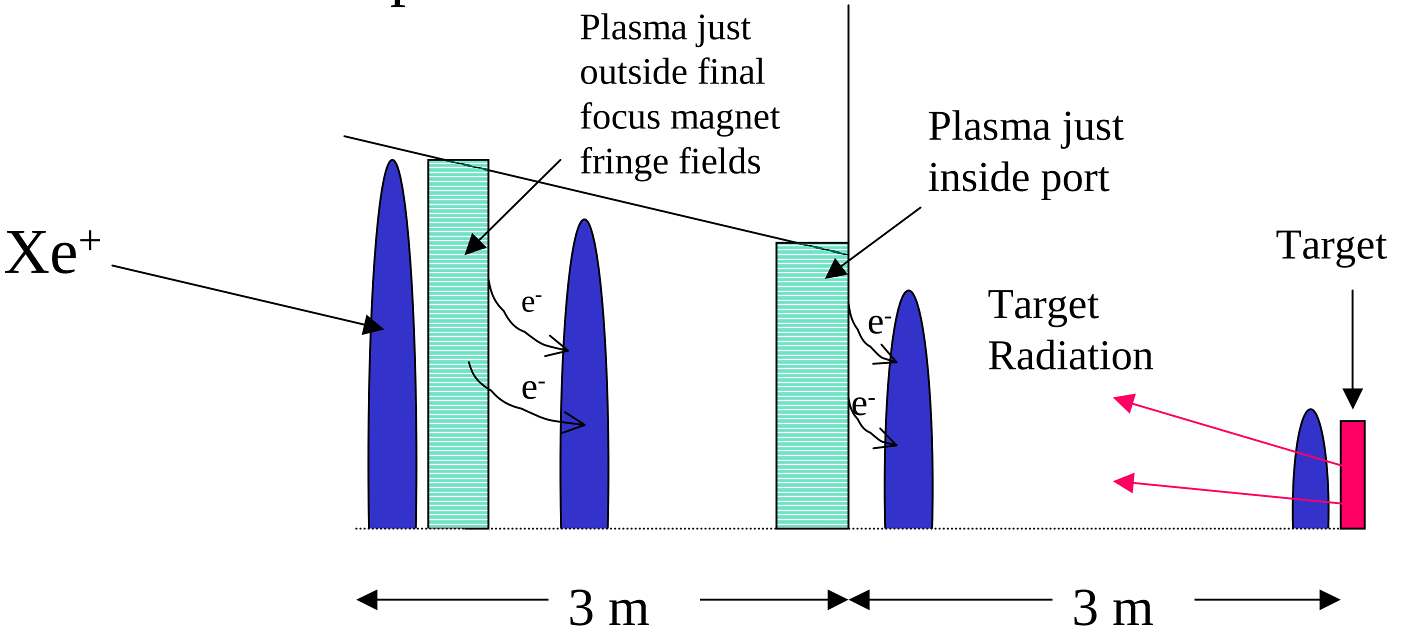
Snapshots near focus of 870-A Pb foot pulse in 7 x 10^{12} cm^{-3} BeF_2

- conducting beam pipe near plasma significantly improves neutralization
- emission from beam pipe makes small additional improvement
- effects of pre-neutralization decrease with increasing gas density



Lsp simulation with plasma pre-neutralization, photoionization

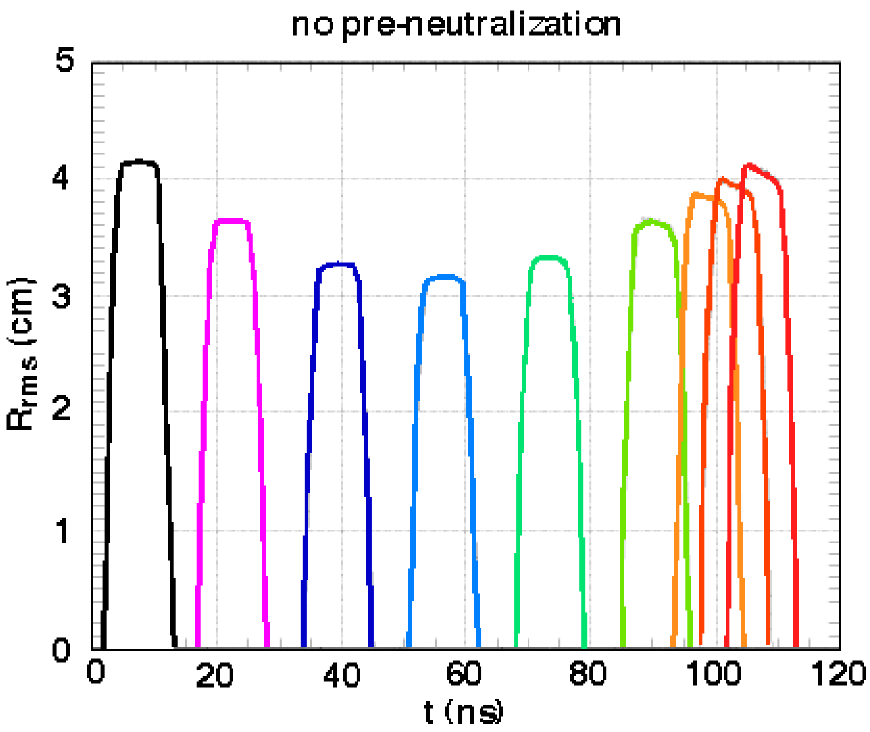
- 6-m long, 2-plasma foot (in progress) and main pulses
- impact only and including photo ionization and stripping for main pulse

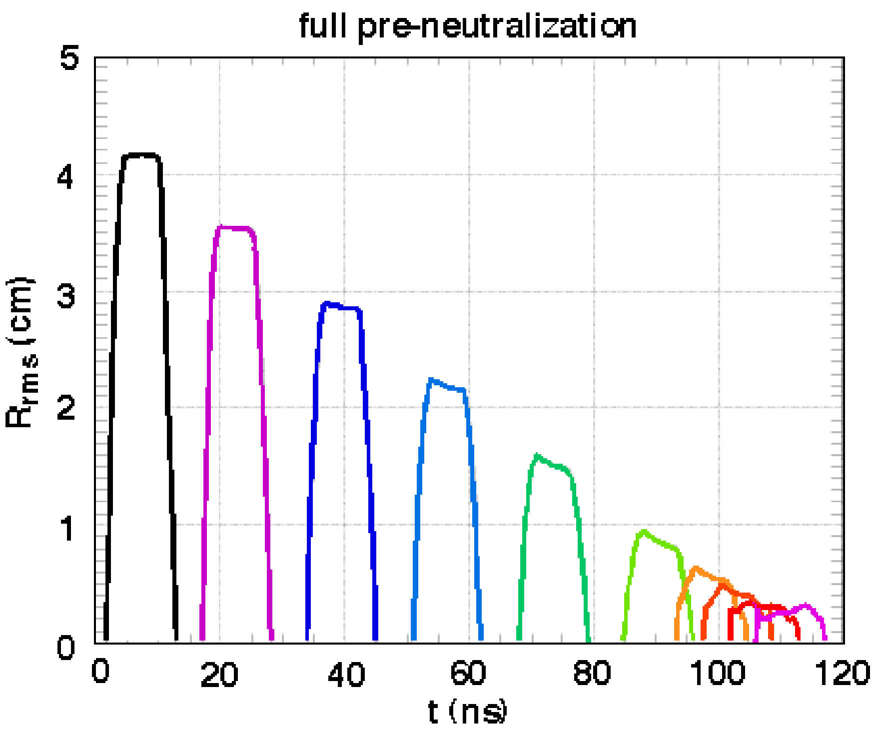


Pre-neutralization also works at higher perveance

results for "realistic" 2.8-kA Xe main pulse in 7 x 10^{12} cm^{-3} BeF_2

- **tapering 3 m emitting beam pipe with 10-cm plasma layer at each end**
- **3-m chamber after beam pipe with plausible gas-vacuum interface**
- **pre-neutralization makes dramatic improvement in transport**



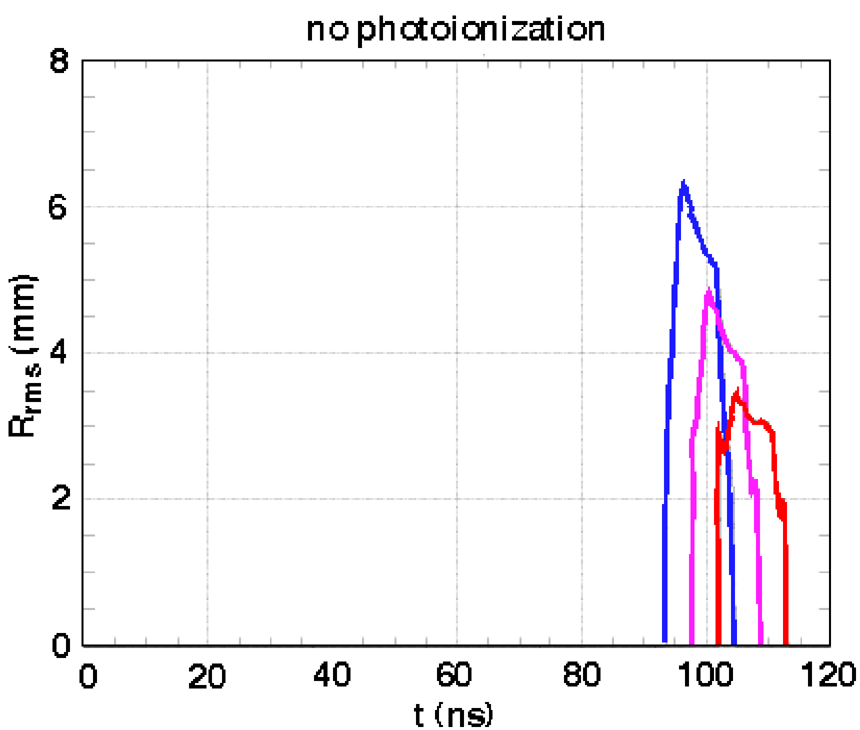


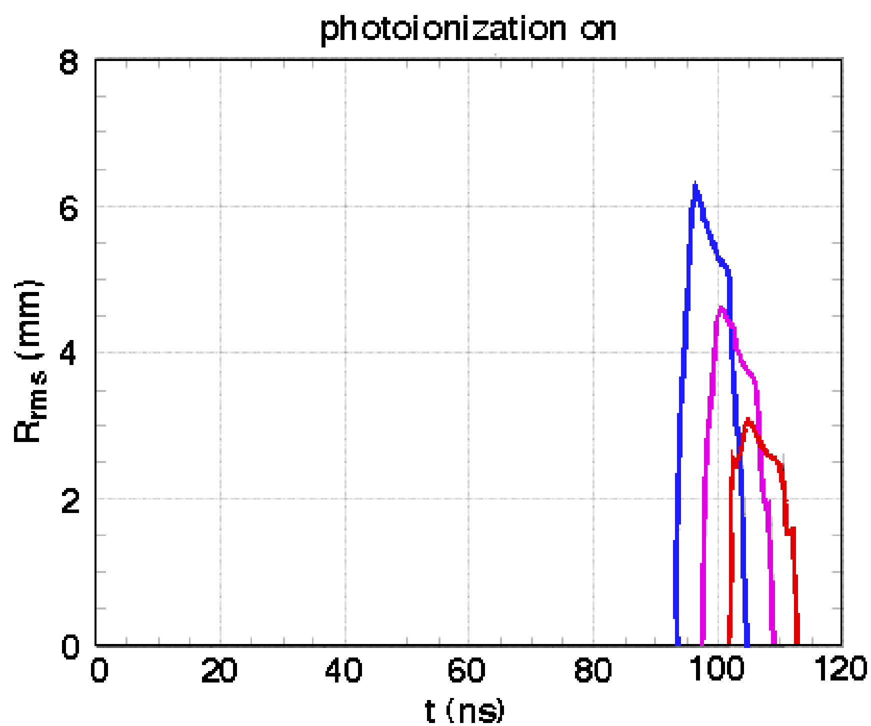
- **final 2.5 mm radius is close to value required by distributed-radiator target**

What does photoionization do?

results for “realistic” 2.8 kA Xe main pulse in 7 x 10^{12} cm^{-3} BeF_2

- **target heating by 30-ns foot pulses in other entry ports**
- **LSP currently allows only single ionization of background gas**
- **photoionization reduces focal spot by about 15%**



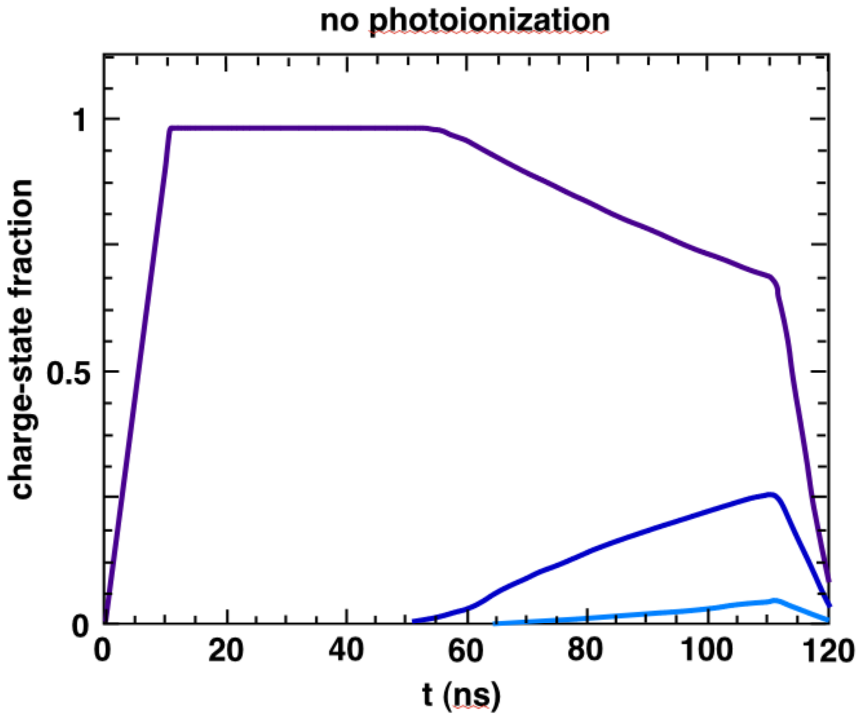


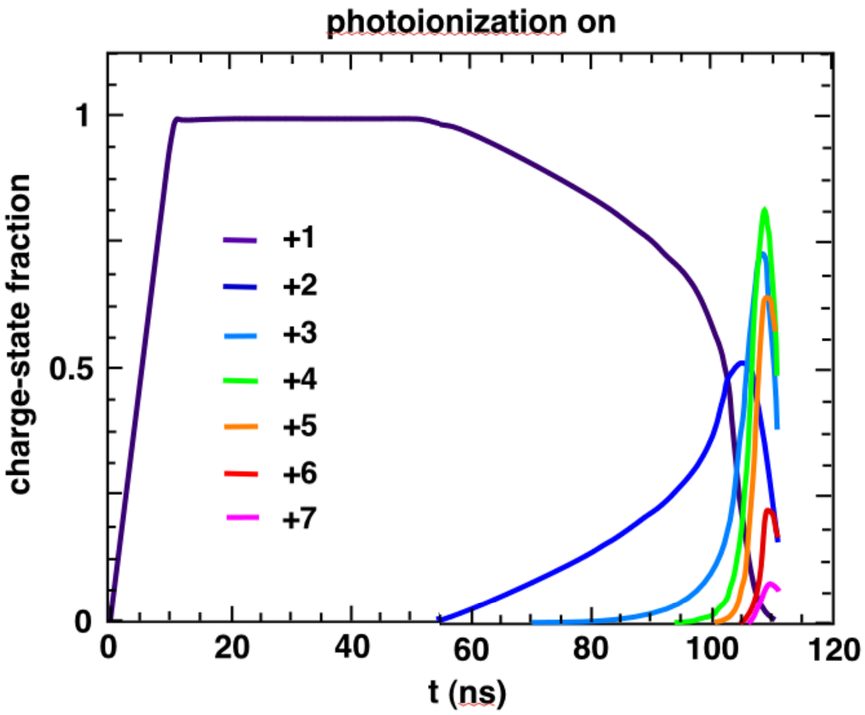
- **neutralization by photoionization plasma is offset by increased beam charge**
- **inclusion of multiple gas ionization would improve situation**

How does photoioniztion affect beam charge?

results for "realistic" 2.8 kA Xe main pulse in 7 x 10^{12} cm^{-3} BeF_2

- **time histories of beam charge states**
- **stripping artificially stopped 20 cm before target for numerical reasons**
- **photoionization significantly increases average charge state near target**



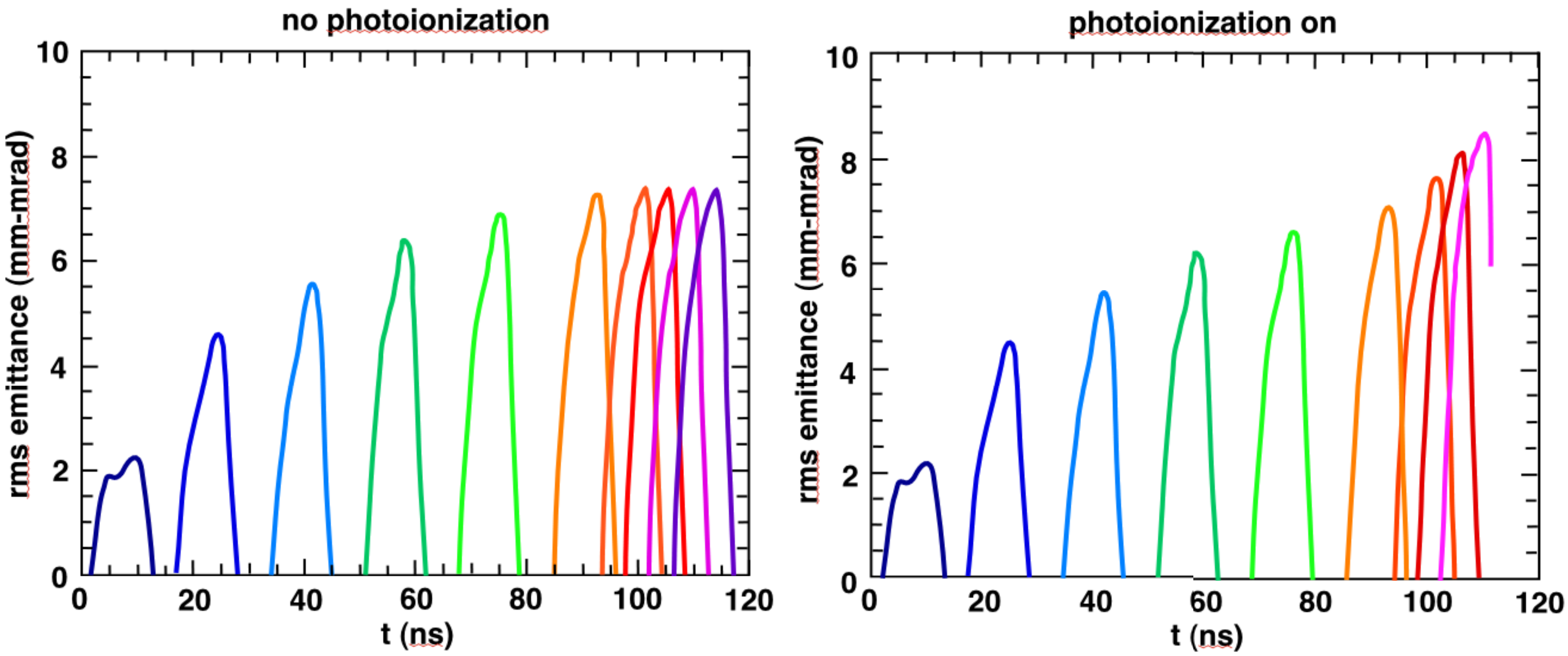


- **effect of higher charge state is limited by small distance to target**

How does photoionization affect beam emittance?

results for "realistic" 2.8 kA Xe main pulse in 7 x 10^{12} cm^{-3} BeF_2

- **time histories of beam rms emittance at select axial locations**
- **higher charge-state near target leads to 20% emittance increase**



- **effect of higher emittance is offset by better neutralization**

Conclusions

- Pre-neutralization from plasma improves chamber transport efficiency
  - Both foot and main pulses benefit
- Given pre-neutralizing plasma, lower chamber pressure helps beam transport for both foot and main pulses
- Photo ionization assists main pulse transport
  - photo stripping increases beam charge state and emittance near target, tempers the effect to a 15% spot improvement
  - inclusion of multiple gas ionization should improve spot further