

Diversion of Plasma in Beam Port with a Vertical Magnetic Field

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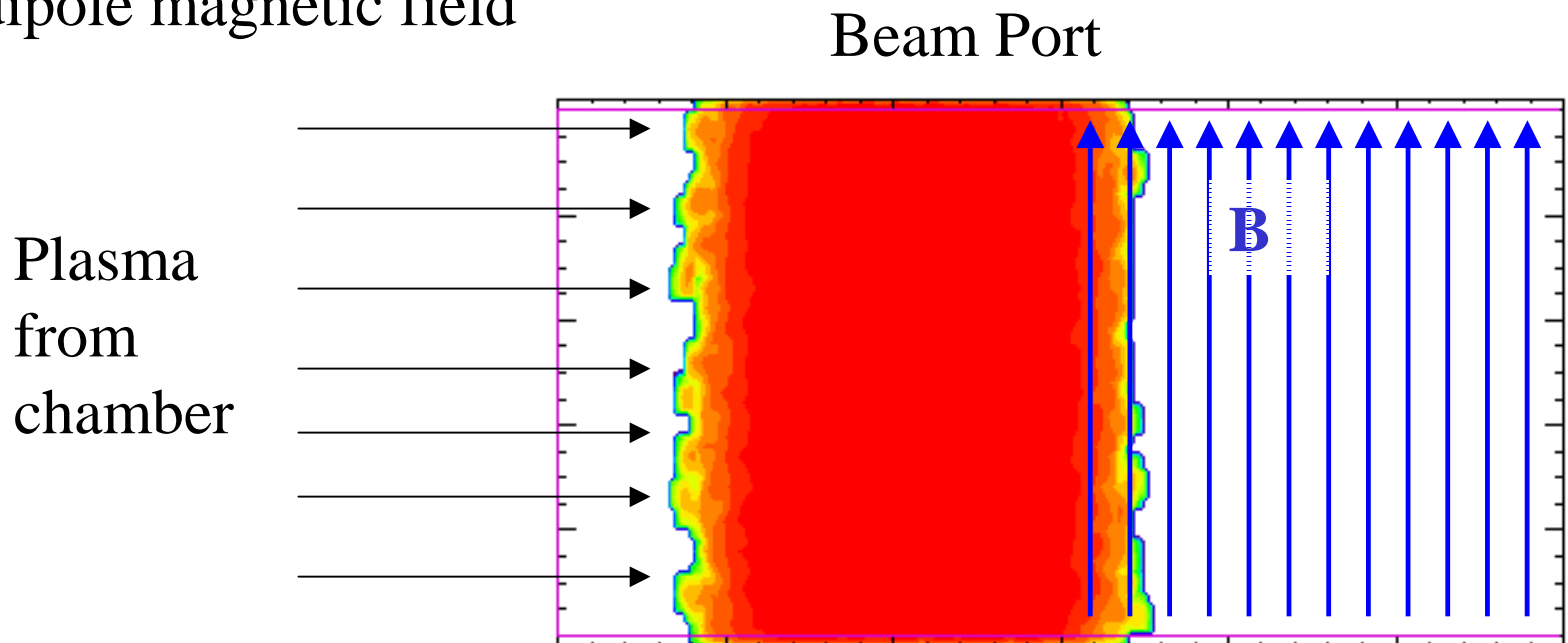
Presented at the ARIES Project Meeting

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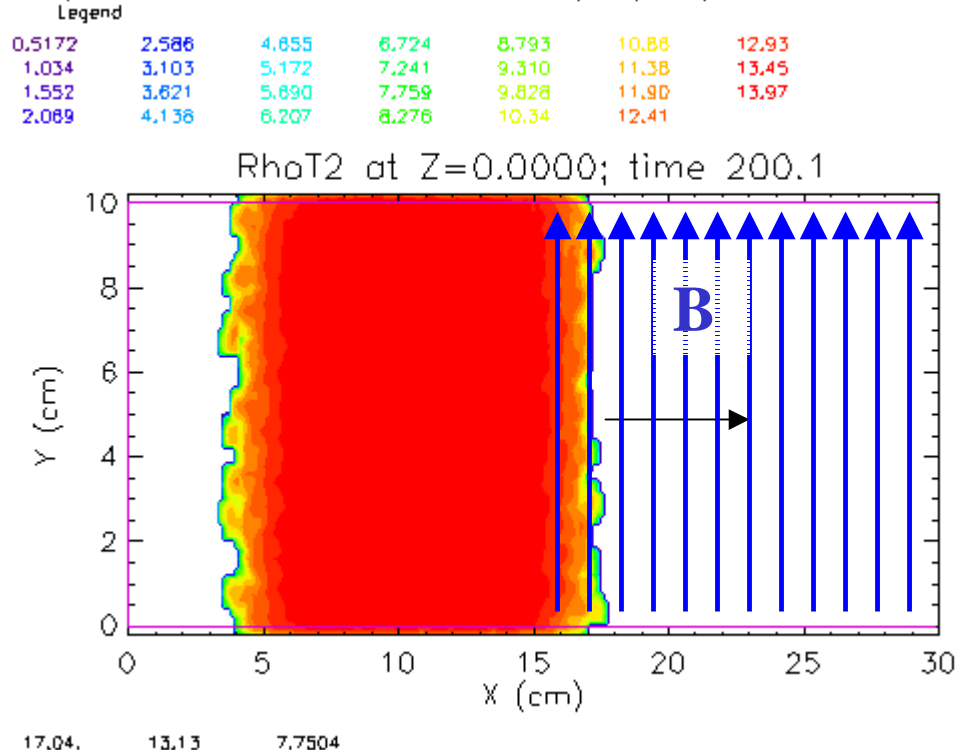
A plasma can be blown off the chamber wall and expand into the beam port

- 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

2D expansion with self fields and 2T B: portp0.lsp – Mon Mar 11 09:02



Moving plasma
blob confined by **B**

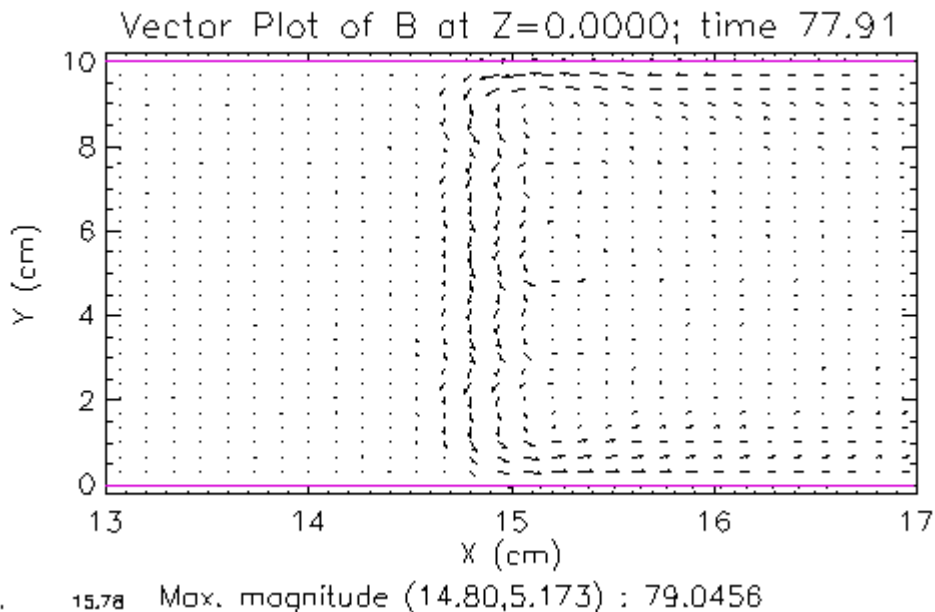
- A moving plasma blob is initialized in the x-y Cartesian simulation with a 10^{14} cm^{-3} density. The simulation box was 30-cm long and 10-cm wide. The plasma had H^+ ions with a 10-100 eV temperature and a 3-9 cm/microsecond forward velocity. A no-field case and a case with electromagnetic fields 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

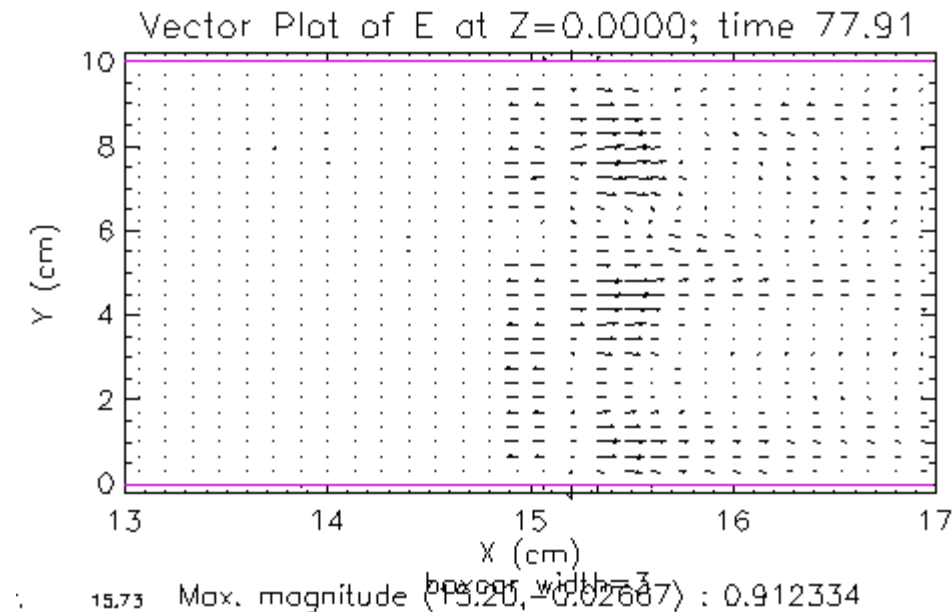
- For 10-eV, 10^{14} cm⁻³ plasma, the ratio of plasma energy to magnetic field energy
$$\beta = 8\pi nkT/B^2 = .04$$
 - plasma cannot exclude magnetic field and should be confined
- Mean ion cyclotron radius $\omega_c = m_i v_i c / eB$ is roughly 3 mm for protons

2D Electromagnetic calculation run 80 ns

- Plasma ions can move a few mm
- $\mathbf{J} \times \mathbf{B}$ force leads to charge separation (electron motion is completely stopped)
- Plasma diamagnetic current negates 10% of applied field



80 Gauss self B



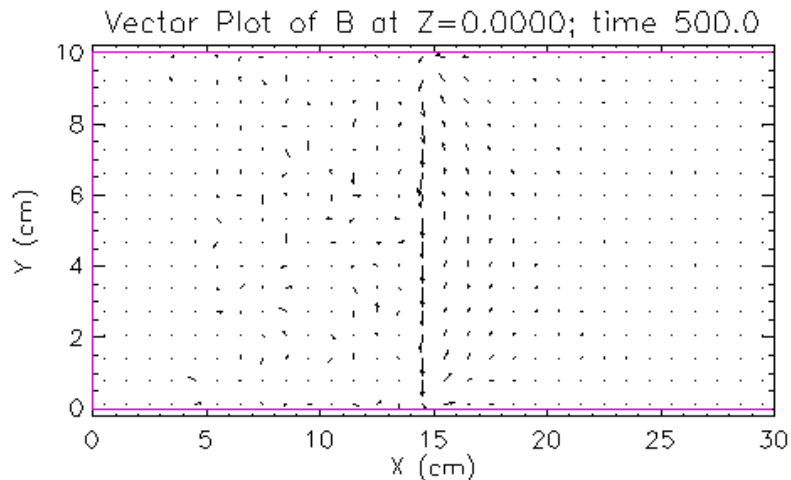
1 kV/cm self E

Self-Fields remain small after 500 ns

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

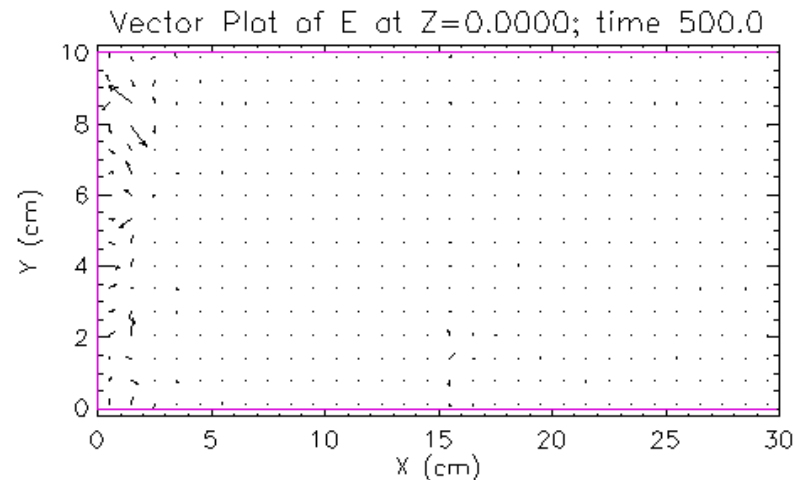
2D expansion with self fields and 1kg B: portp5.lsp – Wed Apr 03 10:5t

2D expansion with self fields and 1kg B: portp5.lsp – Wed Apr 03 10:5t



-7.185. 14.55 Max. magnitude (14.50,8.625) : 68.5960

70 Gauss self B



19.04. 13.79 Max. magnitude (1.500,8.575) : 1.61083

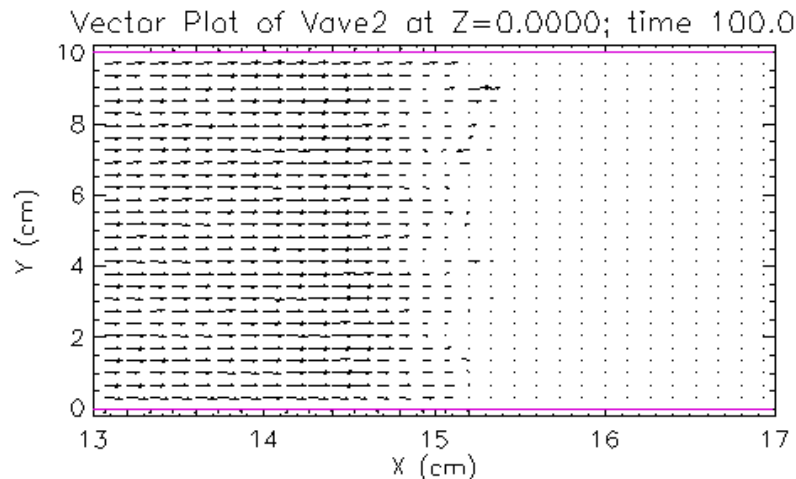
1.6 kV/cm self E

Ions are turned in space charge field

- Ion velocity stagnates at 15.4 cm, decays to wall

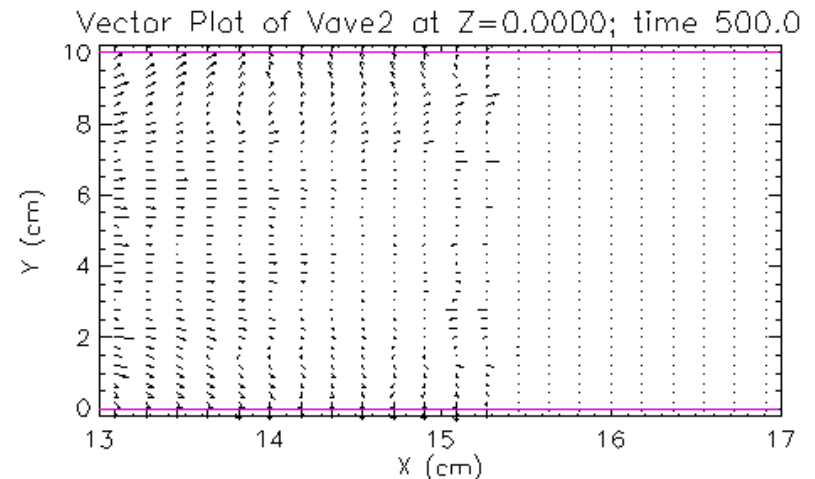
2D expansion with self fields and 1kg B: portp5.lsp – Wed Apr 03 10:56 2D expansion with self fields and 1kg B: portp5.lsp – Wed Apr 03 10:56

100 ns



15.89. 15.64 Max. magnitude (15.20,8.987) : 0.000153793

500 ns

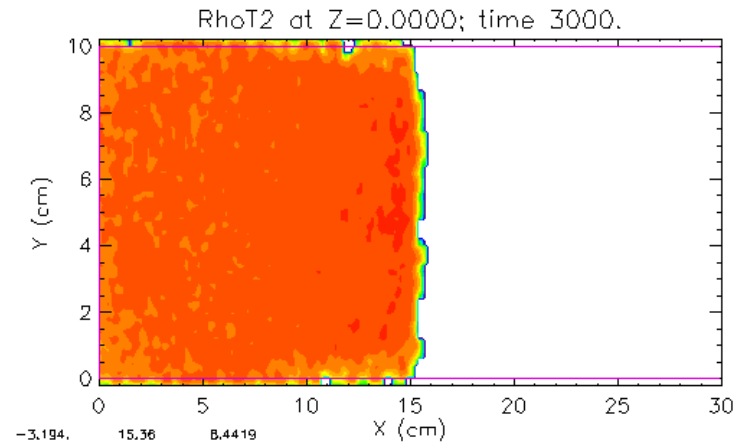
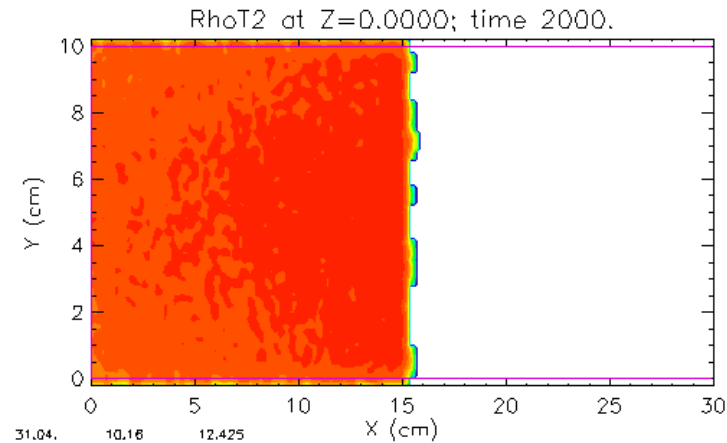
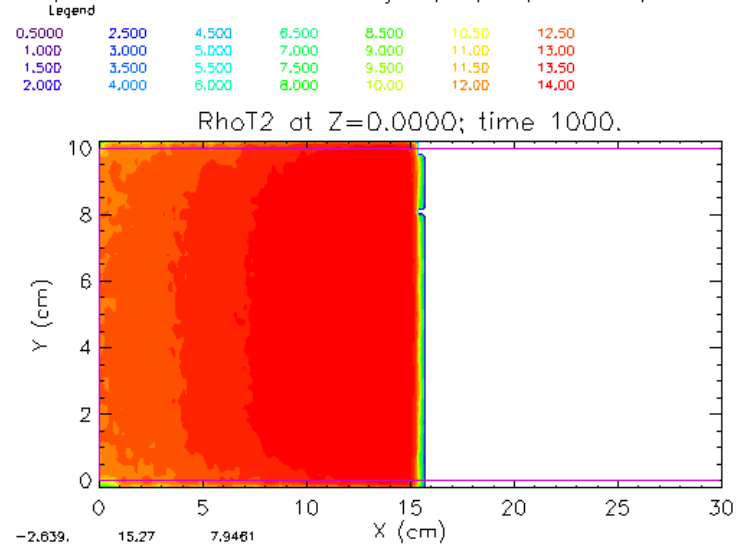
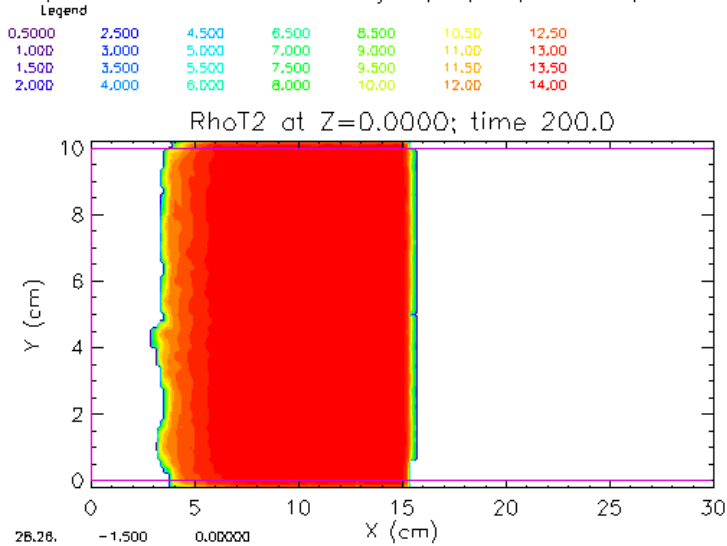


15.28. 15.28 Max. magnitude (15.27,0.1900) : 0.000184479

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

2D expansion with self fields and 1kg B: portp5.lsp - Wed Apr 03 10:56

2D expansion with self fields and 1kg B: portp5.lsp - Wed Apr 03 10:56



0.4 Beta Plasma Calculation

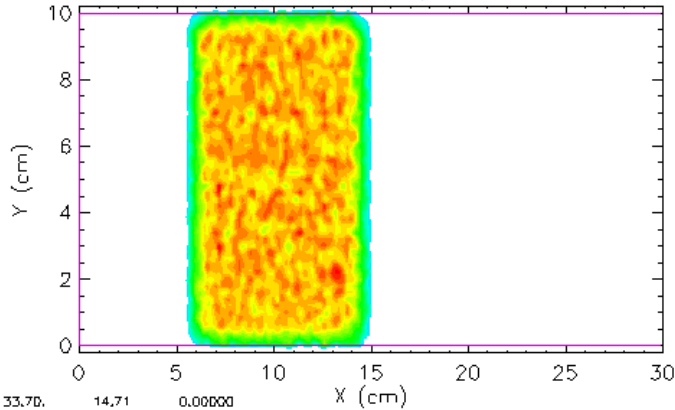
- Plasma temperature is increased to 100 eV with a 9 cm/ μ s forward-directed velocity
- Simulation is much faster than increasing density by 10 but keeping T fixed
- Same external magnetic field topology

100-eV plasma with $v = 9 \text{ cm}/\mu\text{s}$

2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

Legend
 1.000E+012 1.873E+013 3.646E+013 5.420E+013 7.193E+013 8.966E+013 1.074E+014
 5.433E+012 2.318E+013 4.090E+013 5.863E+013 7.638E+013 9.409E+013 1.118E+014
 9.866E+012 2.780E+013 4.533E+013 6.306E+013 8.079E+013 9.853E+013 1.163E+014
 1.430E+013 3.203E+013 4.970E+013 6.749E+013 8.523E+013 1.030E+014 1.207E+014

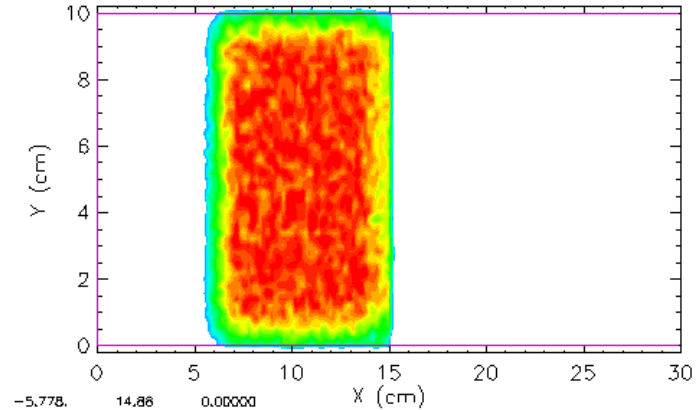
RhoT2 at Z=0.0000; time 26.80



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

Legend
 1.000E+012 1.865E+013 3.231E+013 4.796E+013 6.362E+013 7.927E+013 9.493E+013
 4.914E+012 2.057E+013 3.622E+013 5.188E+013 6.753E+013 8.319E+013 9.884E+013
 8.827E+012 2.448E+013 4.014E+013 5.579E+013 7.144E+013 8.710E+013 1.028E+014
 1.274E+013 2.840E+013 4.405E+013 5.970E+013 7.538E+013 9.101E+013 1.067E+014

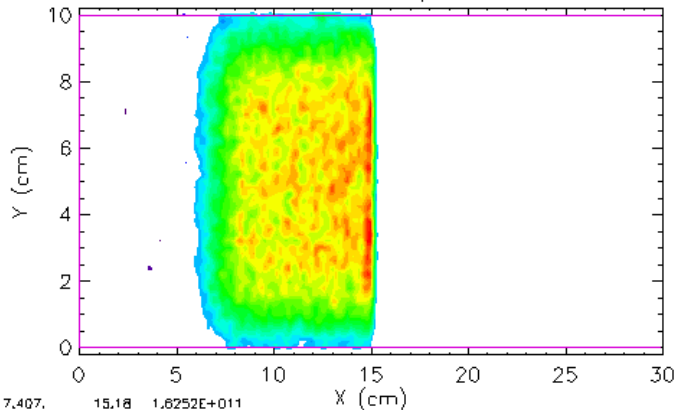
RhoT2 at Z=0.0000; time 50.00



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44

Legend
 1.000E+012 2.001E+013 3.902E+013 5.803E+013 7.704E+013 9.604E+013 1.151E+014
 5.752E+012 2.476E+013 4.377E+013 6.278E+013 8.179E+013 1.008E+014 1.198E+014
 1.050E+013 2.951E+013 4.852E+013 6.753E+013 8.654E+013 1.055E+014 1.248E+014
 1.528E+013 3.427E+013 5.327E+013 7.228E+013 9.129E+013 1.103E+014 1.293E+014

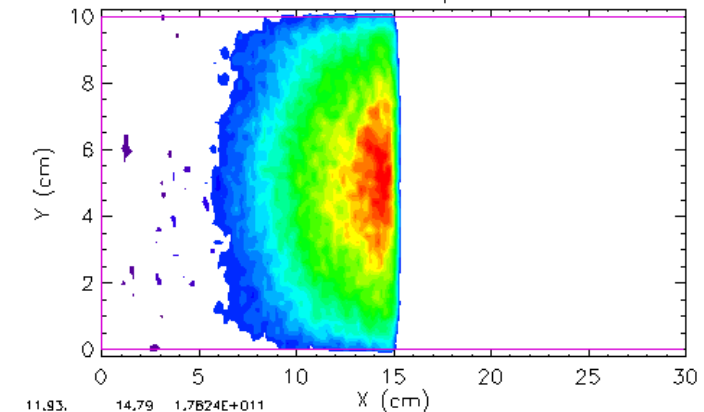
RhoT2 at Z=0.0000; time 100.0



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44

Legend
 1.000E+012 2.014E+013 3.929E+013 5.843E+013 7.757E+013 9.671E+013 1.159E+014 1.350E+014
 5.786E+012 2.493E+013 4.407E+013 6.321E+013 8.238E+013 1.015E+014 1.208E+014
 1.057E+013 2.971E+013 4.886E+013 6.800E+013 8.714E+013 1.063E+014 1.254E+014
 1.536E+013 3.450E+013 5.364E+013 7.279E+013 9.193E+013 1.111E+014 1.302E+014

RhoT2 at Z=0.0000; time 250.0

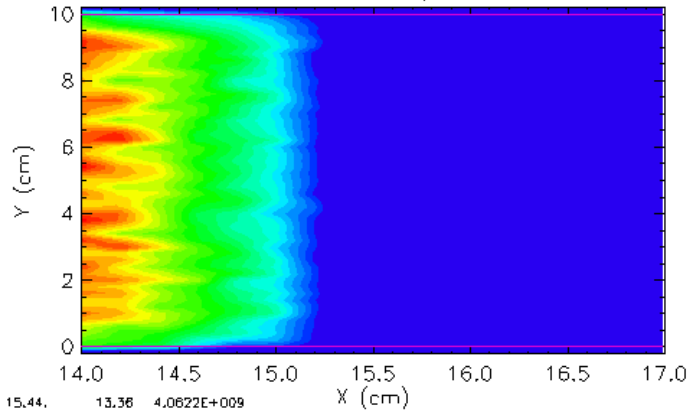


Close up of ion density shows stagnation at 15.5 cm

2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

Legend
 1.000E+012 1.715E+013 3.330E+013 4.944E+013 6.559E+013 8.174E+013 9.789E+013
 5.037E+012 2.119E+013 3.733E+013 5.348E+013 6.963E+013 8.578E+013 1.019E+014
 9.074E+012 2.522E+013 4.137E+013 5.752E+013 7.367E+013 8.981E+013 1.060E+014
 1.311E+013 2.926E+013 4.541E+013 6.156E+013 7.770E+013 9.385E+013 1.100E+014

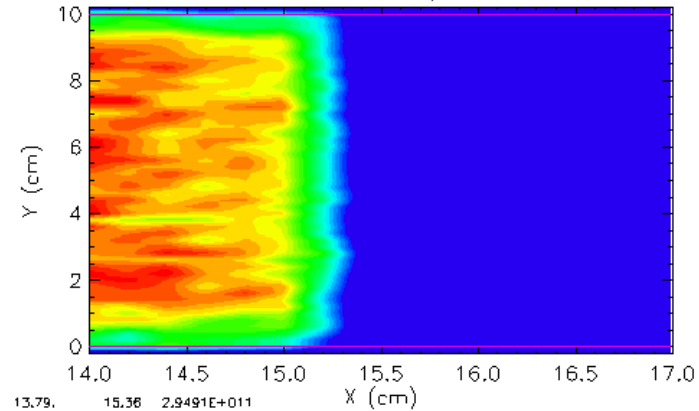
RhoT2 at Z=0.0000; time 26.80



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

Legend
 1.000E+012 1.587E+013 3.033E+013 4.500E+013 5.967E+013 7.433E+013 8.900E+013
 4.687E+012 1.933E+013 3.400E+013 4.867E+013 6.333E+013 7.800E+013 9.267E+013
 8.333E+012 2.300E+013 3.767E+013 5.233E+013 6.700E+013 8.167E+013 9.633E+013
 1.200E+013 2.667E+013 4.133E+013 5.600E+013 7.067E+013 8.533E+013 1.000E+014

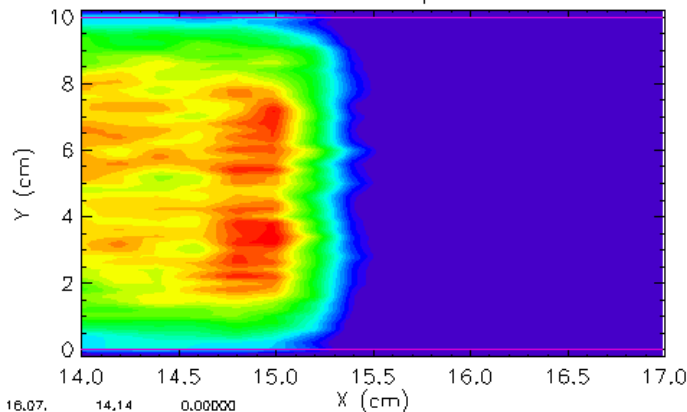
RhoT2 at Z=0.0000; time 50.00



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44

Legend
 1.000E+012 2.011E+013 3.922E+013 5.833E+013 7.744E+013 9.656E+013 1.157E+014
 5.778E+012 2.489E+013 4.400E+013 6.311E+013 8.222E+013 1.013E+014 1.204E+014
 1.058E+013 2.987E+013 4.878E+013 6.789E+013 8.700E+013 1.061E+014 1.252E+014
 1.533E+013 3.444E+013 5.356E+013 7.267E+013 9.178E+013 1.109E+014 1.300E+014

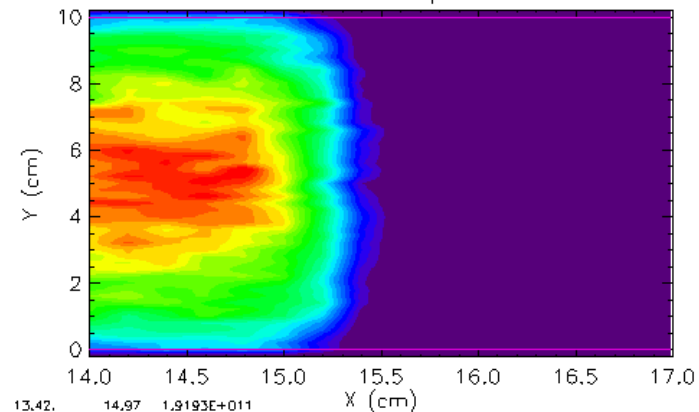
RhoT2 at Z=0.0000; time 100.0



2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44

Legend
 1.000E+012 2.159E+013 4.219E+013 6.278E+013 8.337E+013 1.040E+014 1.248E+014
 8.148E+012 2.674E+013 4.733E+013 6.793E+013 8.852E+013 1.091E+014 1.297E+014
 1.130E+013 3.189E+013 5.248E+013 7.307E+013 9.367E+013 1.143E+014 1.349E+014
 1.644E+013 3.704E+013 5.763E+013 7.822E+013 9.881E+013 1.194E+014 1.400E+014

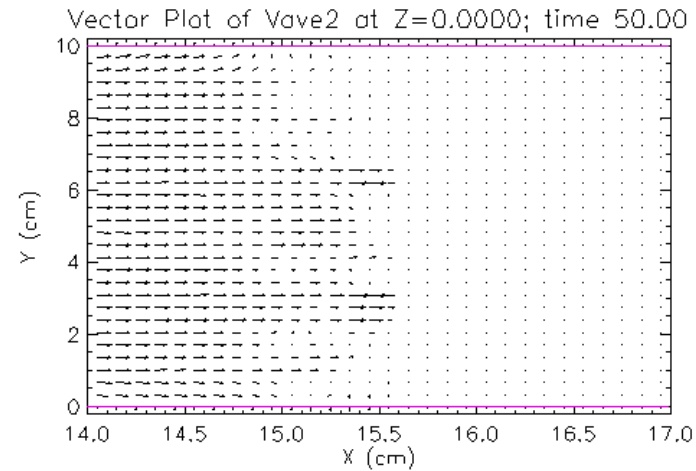
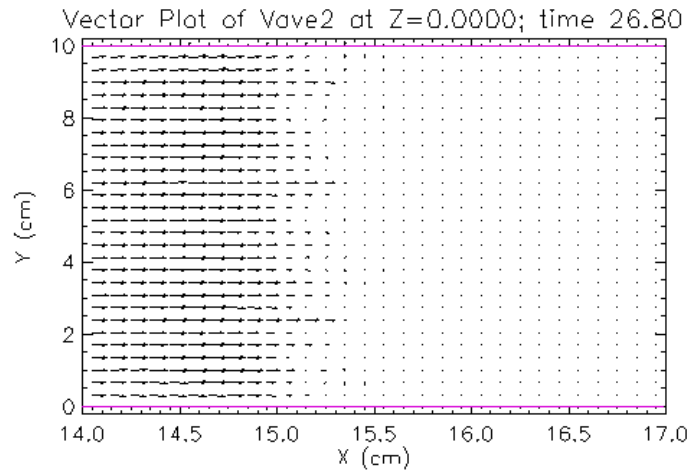
RhoT2 at Z=0.0000; time 250.0



Mean ion velocity turns towards outer wall by 250 ns

2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 12:33

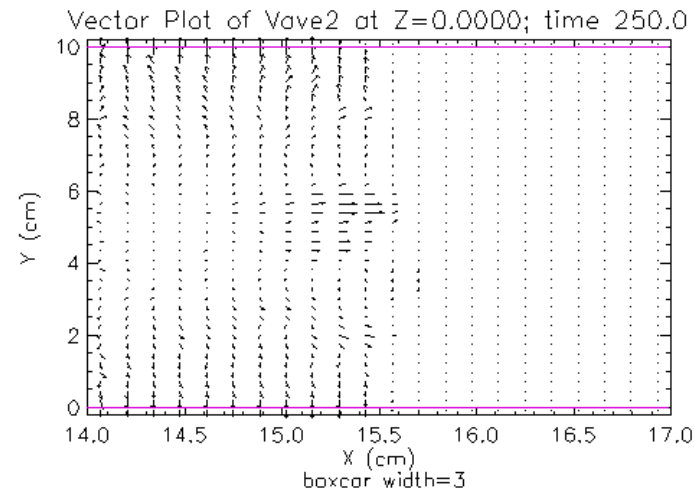
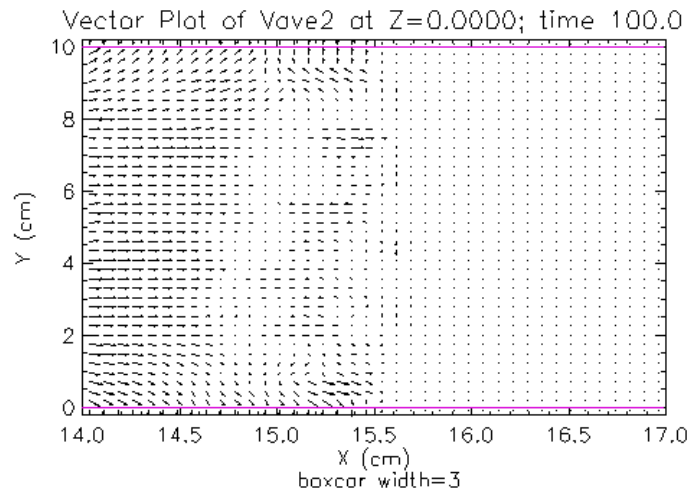


15.77, 11.16 Max. magnitude (14.55,9.680) : 0.000518155

14.82, 12.04 Max. magnitude (15.15,10.03) : 0.000467308

2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44

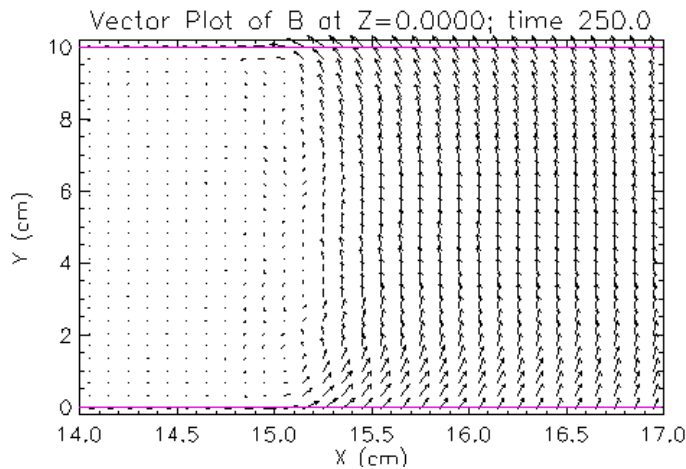
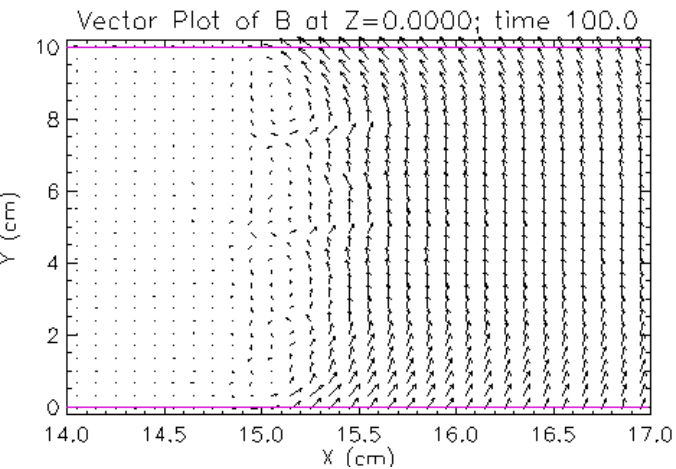
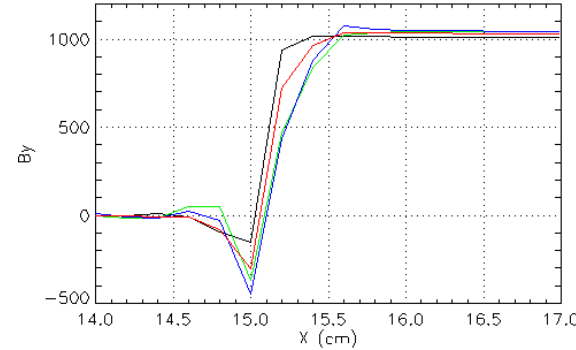
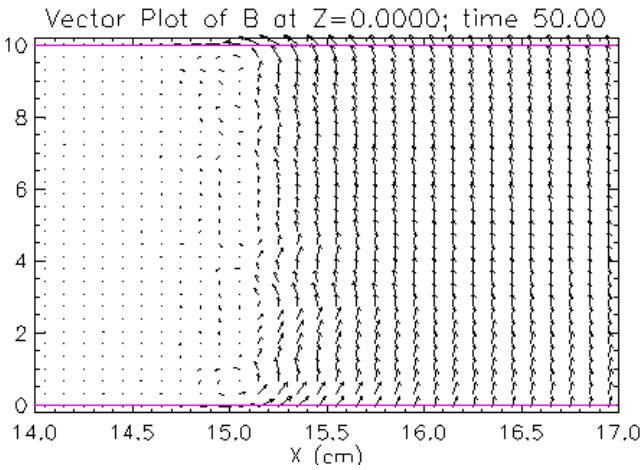
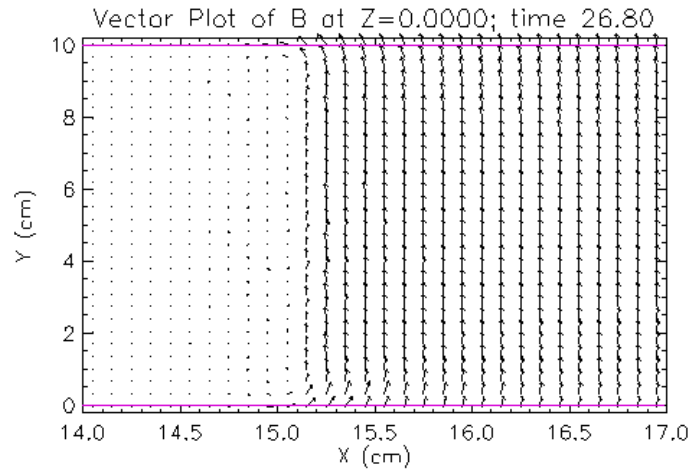
2D expansion with self fields and 1kg B: portp5.lsp – Tue Apr 9 14:44



17.18, 12.00 Max. magnitude (15.39,9.810) : 0.000680804

14.84, 12.48 Max. magnitude (15.16,9.810) : 0.000729885

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

W. Sharp and S. S. Yu

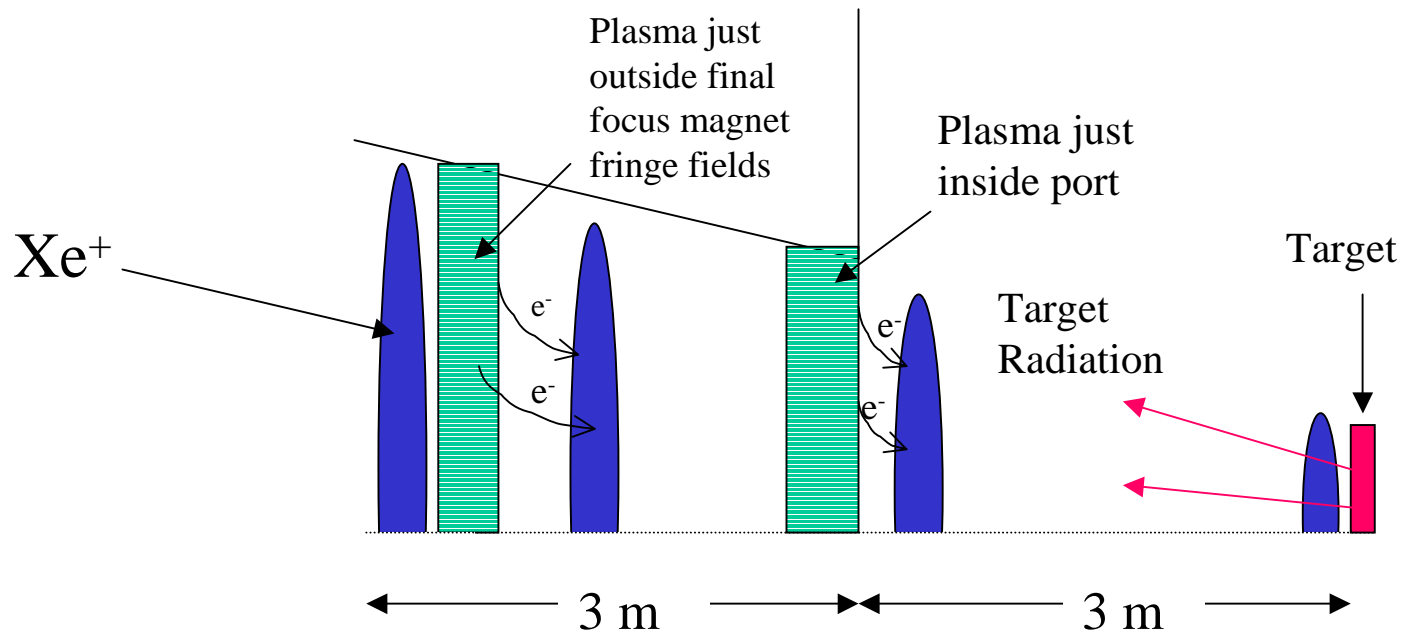
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Progress on an integrated calculation for both foot and main pulse with NBT



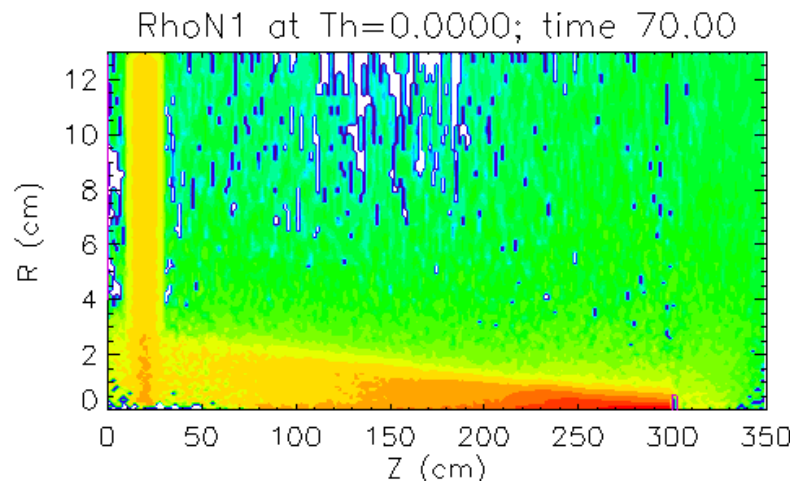
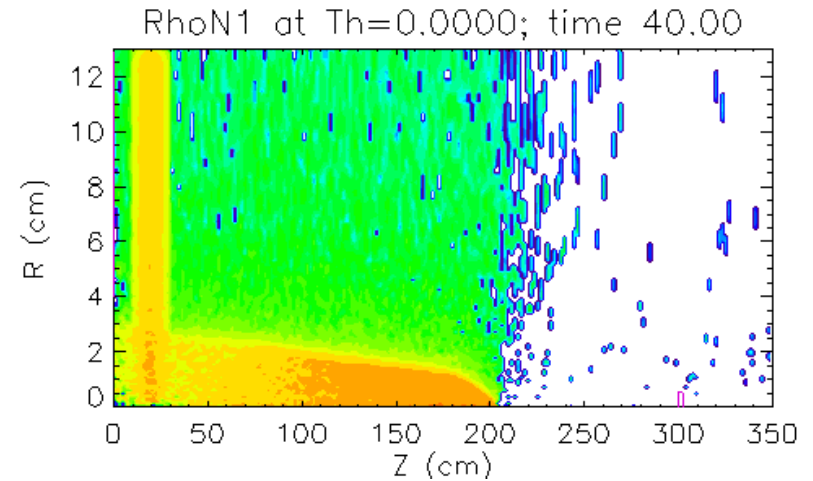
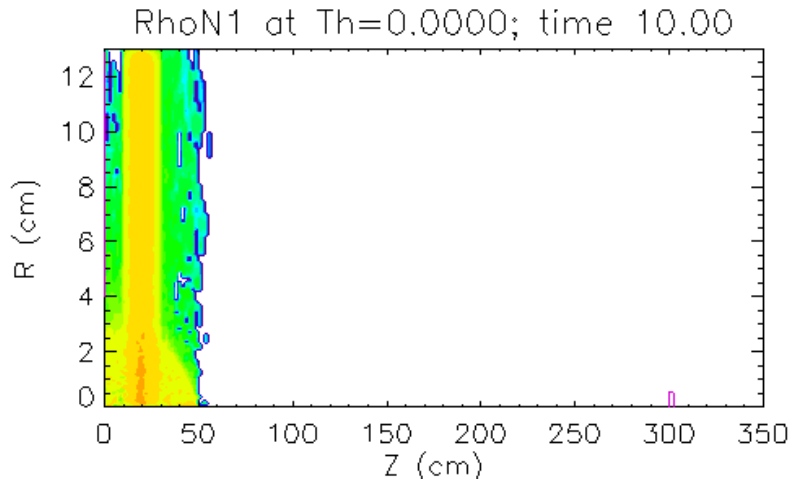
Do the benefits of a local plasma extend to the both foot and main pulses?

What are the effects of photo ionization and stripping?

Beam/Chamber Parameters

- Foot Pulse: Pb 3 GeV, 870 A, ($K=5 \times 10^{-5}$) 30ns
- Main Pulse Xe 2.4 GeV, 2.8 kA ($K=1.8 \times 10^{-4}$) 8 ns
- 1.1 pi-mm-mrad normalized emittance
- 0.6 mTorr BeF₂ in chamber (ionization and stripping)
- With and without pre-neutralization by 10-cm long 2.5×10^{12} -cm⁻³ density plasma

Plasma electrons are effective neutralizers even with ion stripping



Log n_e

Legend

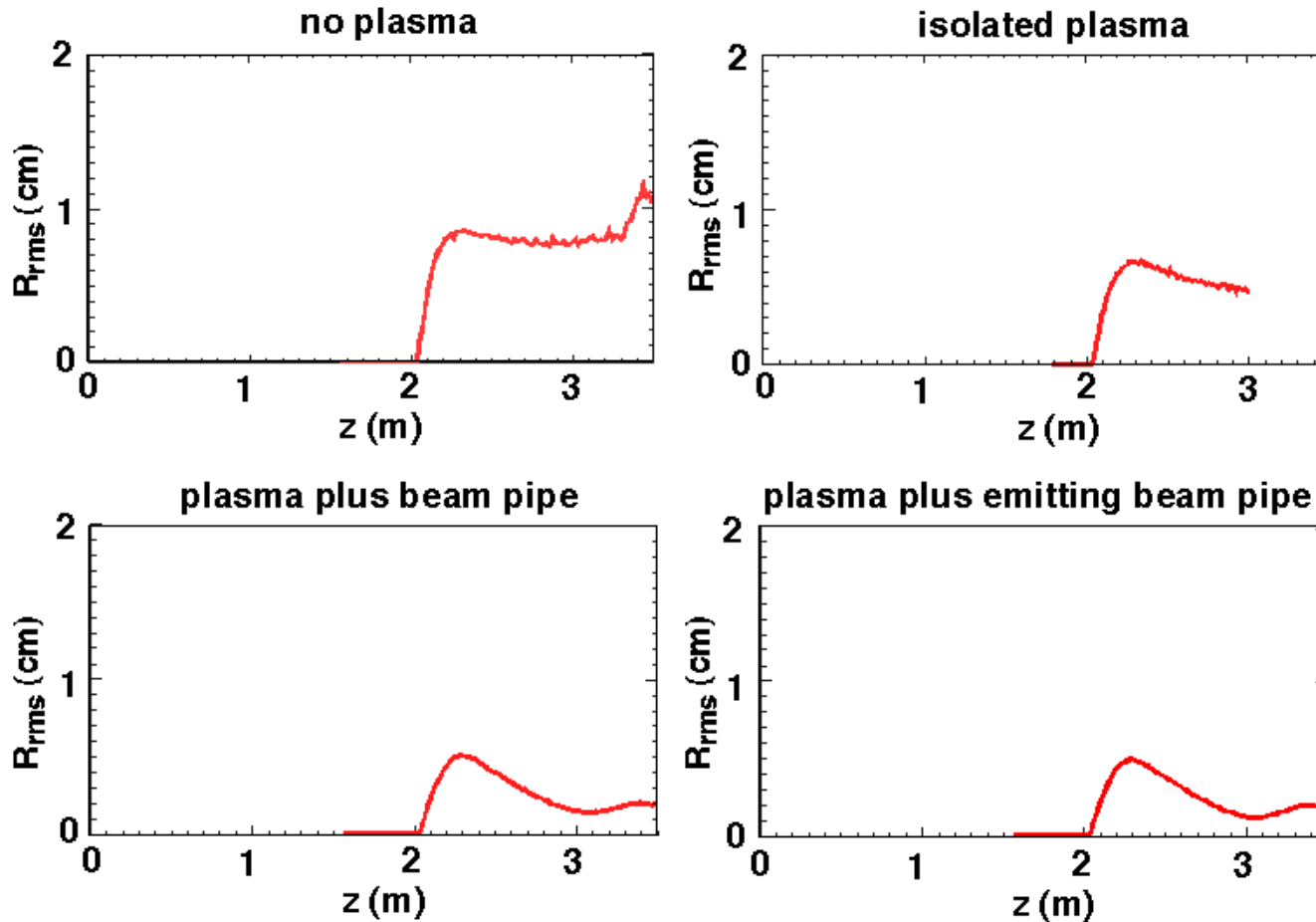
0.5000	2.848	5.198	7.543	9.891	12.24
1.087	3.435	5.783	8.130	10.48	12.83
1.674	4.022	6.370	8.717	11.07	13.41
2.261	4.609	6.957	9.304	11.65	14.00

Plasma pre-neutralization improves transport dramatically



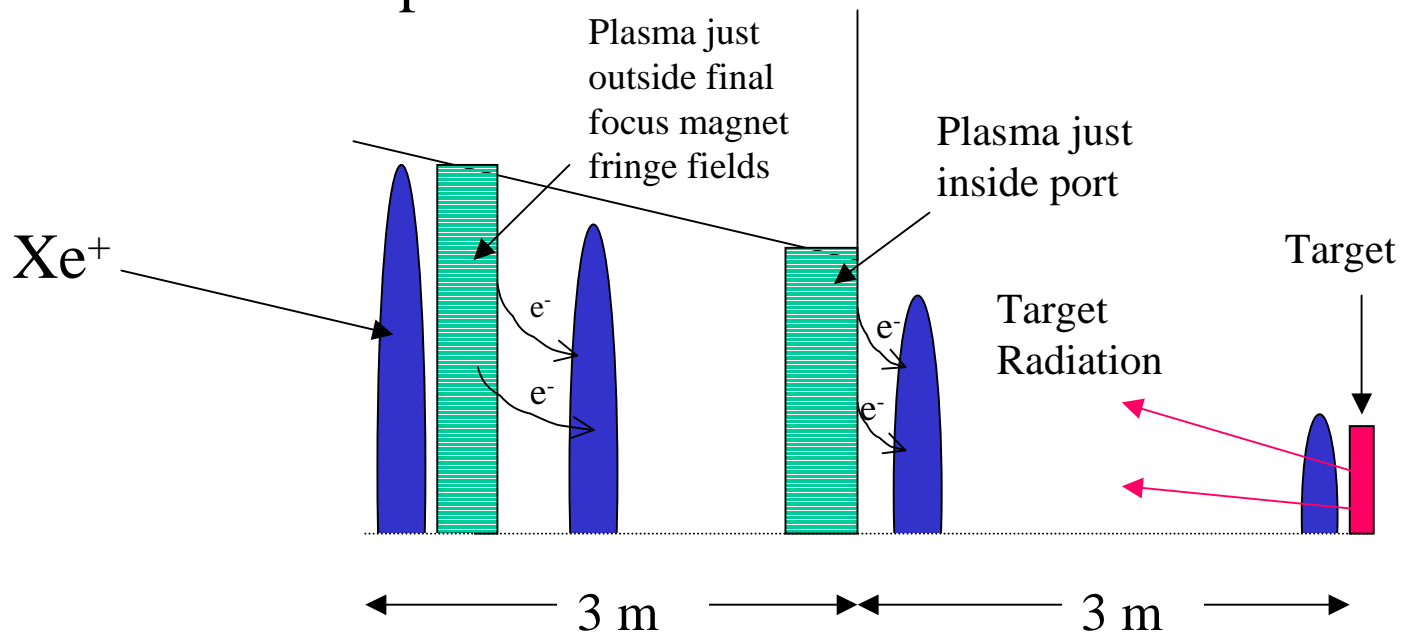
Snapshots near focus of 870-A Pb foot pulse in $7 \times 10^{12} \text{ cm}^{-3} \text{ BeF}_2$

- 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

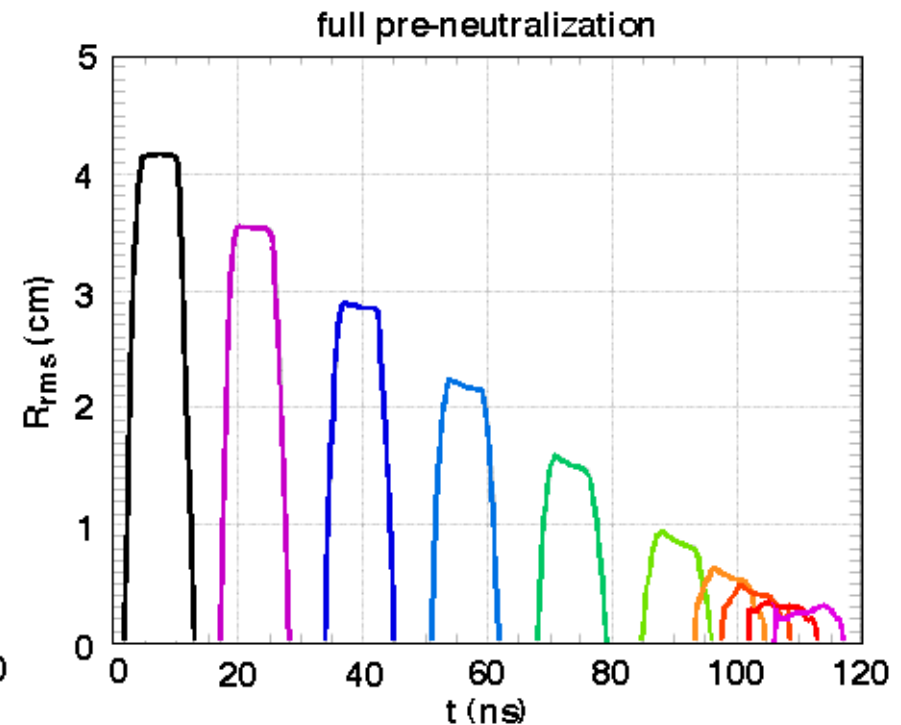
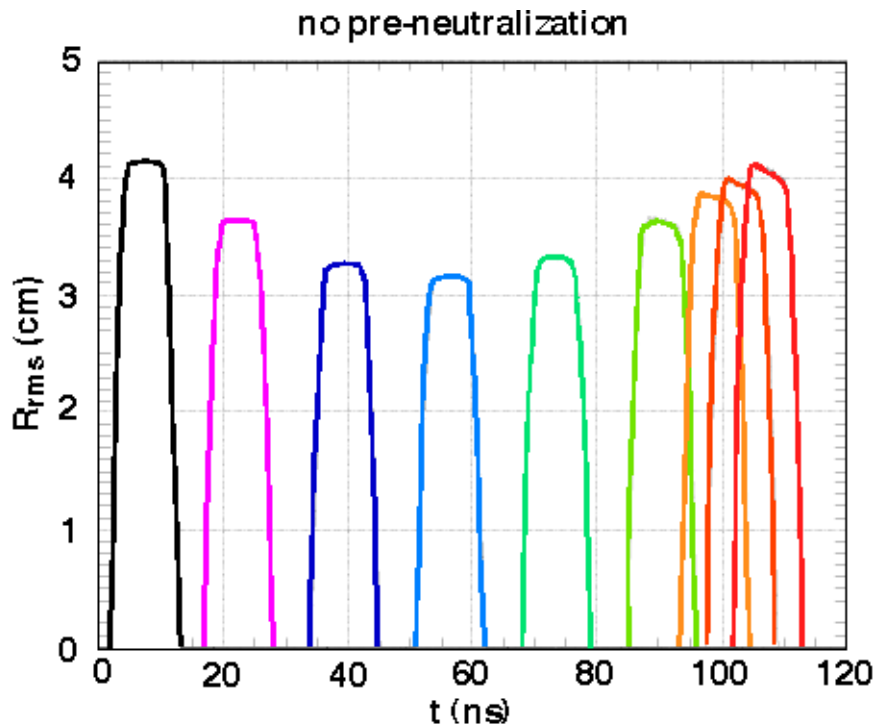


Pre-neutralization also works at higher perveance



results for “realistic” 2.8-kA Xe main pulse in $7 \times 10^{12} \text{ cm}^{-3} \text{ BeF}_2$

- 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



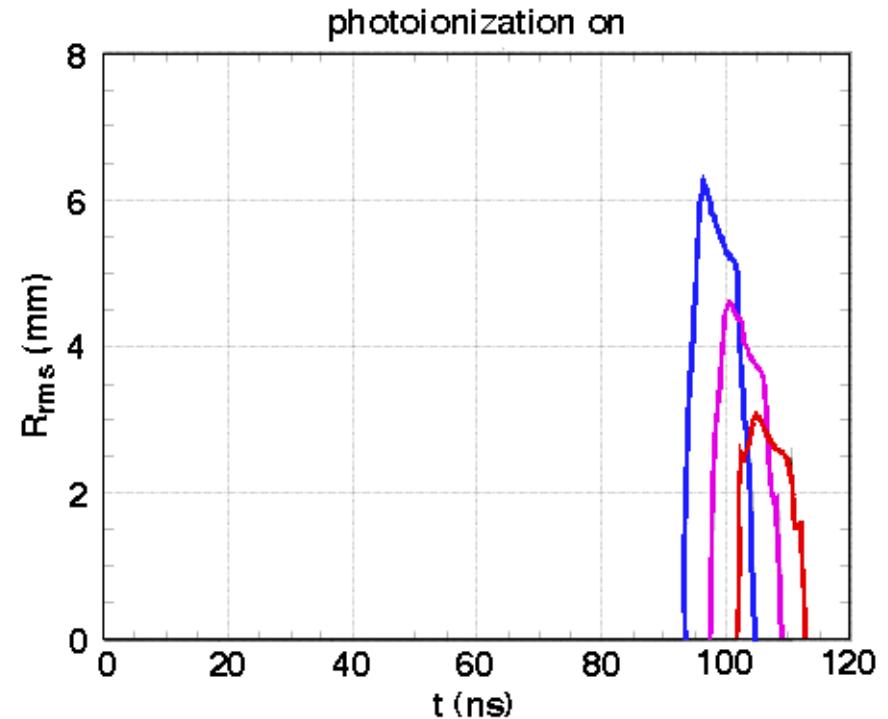
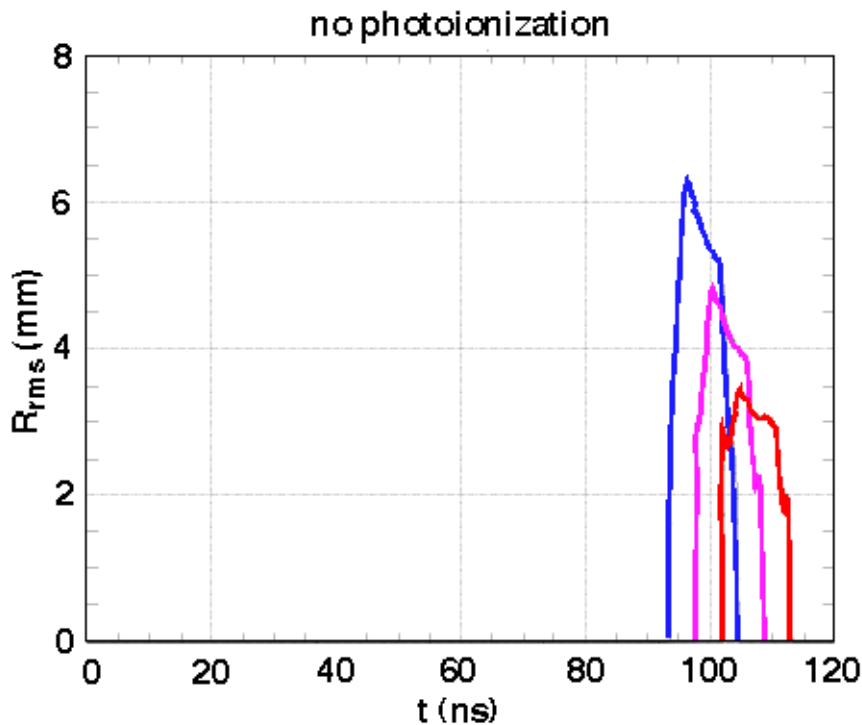
- final 2.5 mm radius is close to value required by distributed-radiator target

What does photoionization do?



results for “realistic” 2.8 kA Xe main pulse in $7 \times 10^{12} \text{ cm}^{-3} \text{ BeF}_2$

- 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%



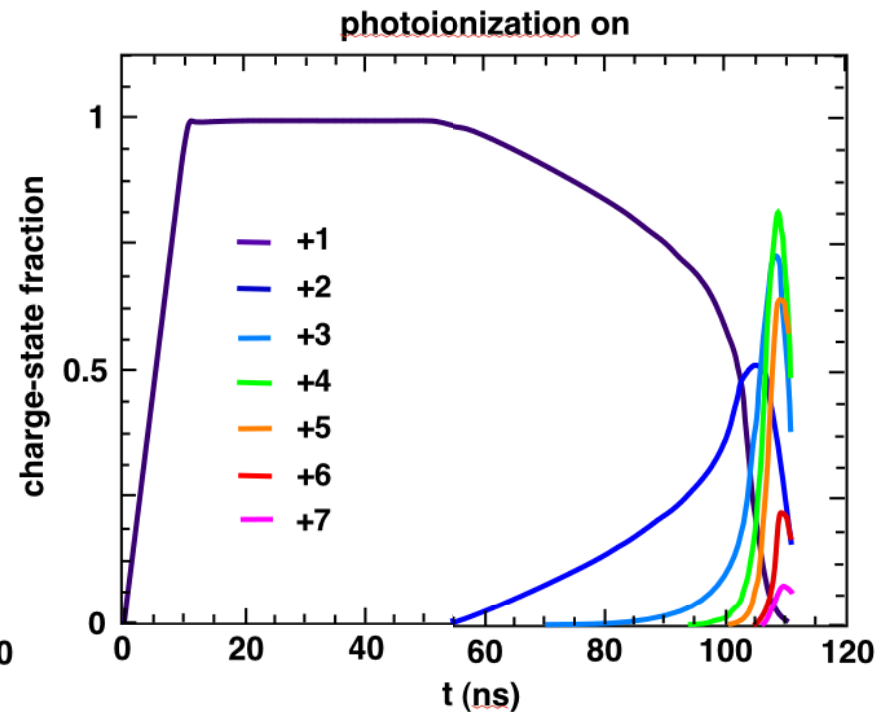
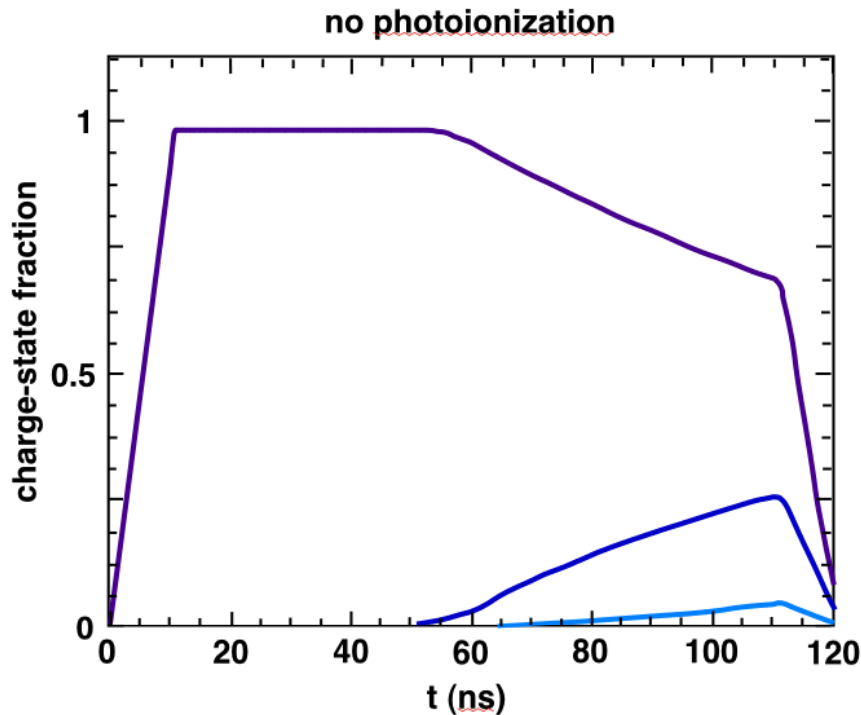
- neutralization by photoionization plasma is offset by increased beam charge
- inclusion of multiple gas ionization would improve situation

How does photoionization affect beam charge?



results for “realistic” 2.8 kA Xe main pulse in $7 \times 10^{12} \text{ cm}^{-3} \text{ BeF}_2$

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



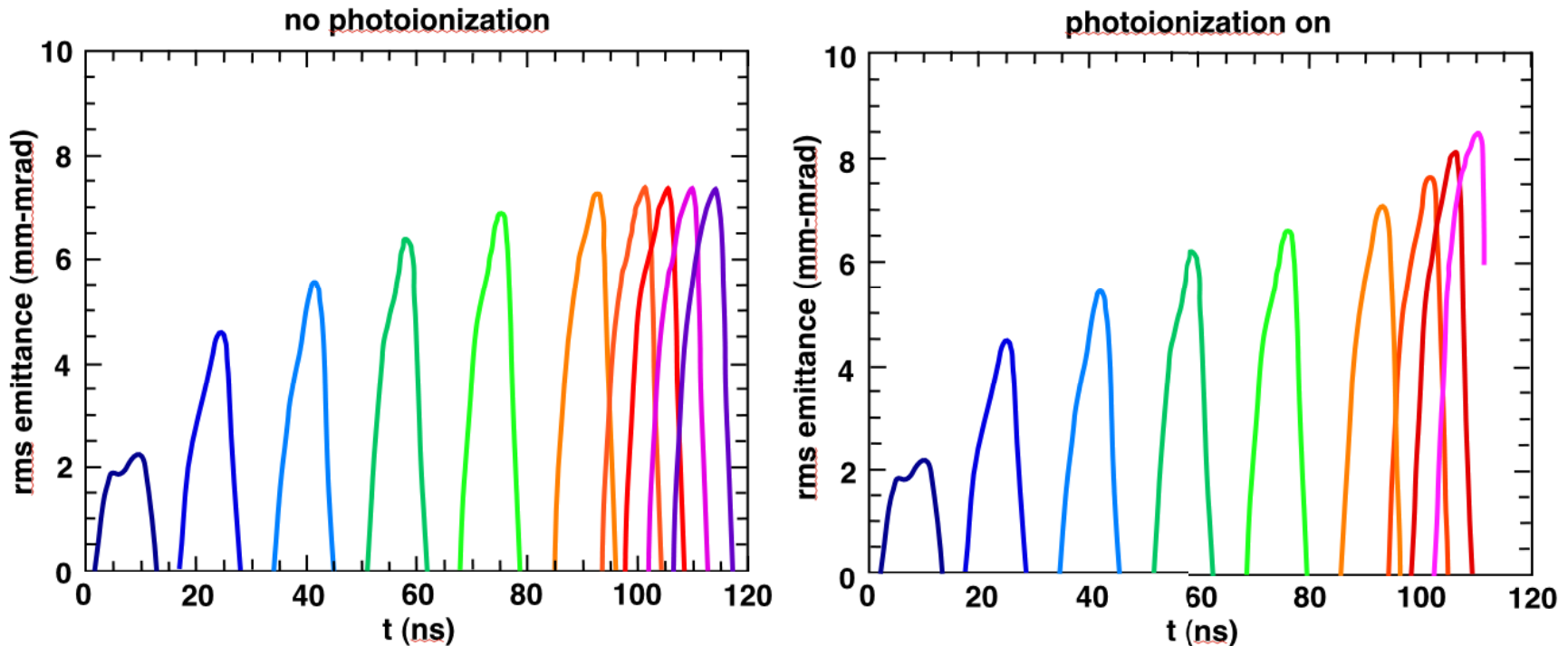
- effect of higher charge state is limited by small distance to target

How does photoionization affect beam emittance?



results for “realistic” 2.8 kA Xe main pulse in $7 \times 10^{12} \text{ cm}^{-3} \text{ BeF}_2$

- 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