Beamline Design Issues

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Beamline design requirements

(1) allow the ion beam to enter the chamber

(2) provide electron neutralization of the beam space charge

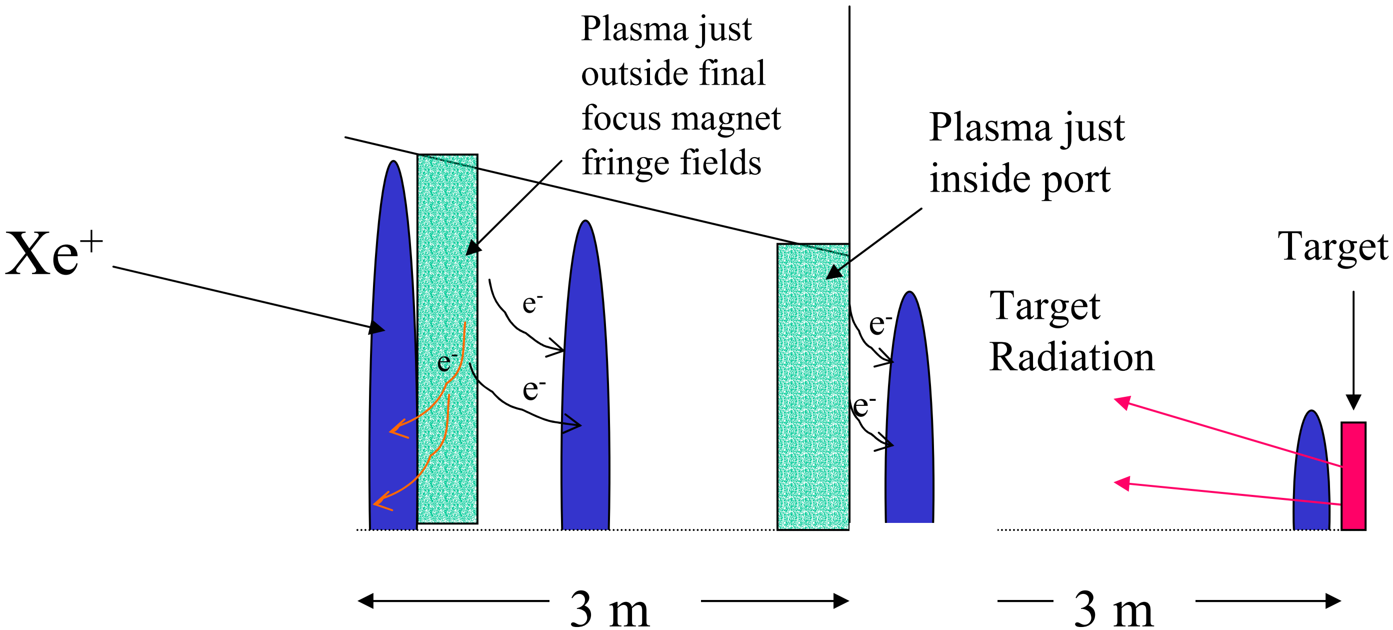
- provided by 2 plasma plugs of 10^{12} cm^{-3} density (Lsp sim)

(3) inhibit rapid upstream motion of electrons

(4) provide protection from chamber plasmas and gas expanding upstream after the fusion explosion

- initial plasma plug increases in density to 10^{15} ionizing neutral gas (analytic calc), dipole magnet diverts plasma to wall (Lsp sim)

High perveance HIF beams can be neutralized with a localized plasma



- After final focus magnets, beams must drift roughly 6 meters and strike a < 3 mm target radiator
- Localized plasma or "plasma plug" can provide significant neutralization

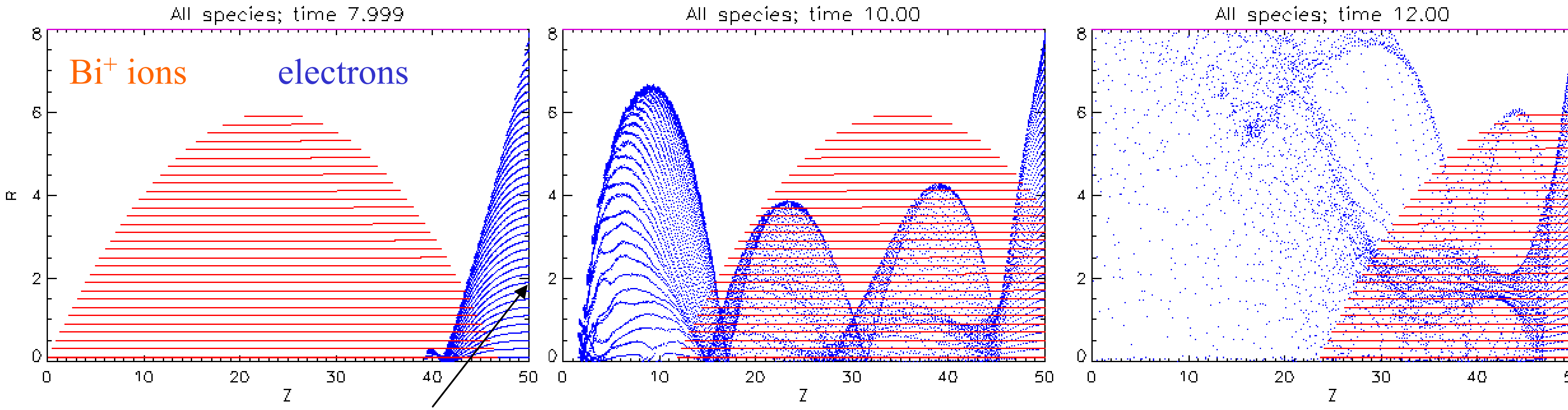
Problem - Emittance growth has been calculated in Lsp simulations of NBT with a plasma plug

- Plasma plug electrons are attracted by the beam space charge, downstream and upstream
  - If electrons are not uniform in density, the resulting anharmonic electrostatic potential increases the beam emittance before reaching plasma
  - For large currents, unacceptably large spot sizes have been calculated
- Here, we focus on the upstream interaction of the ion beam with plasma electrons
- Solution is consistent with NBT beam port design

Lsp model for beam-plasma plug *upstream* interaction

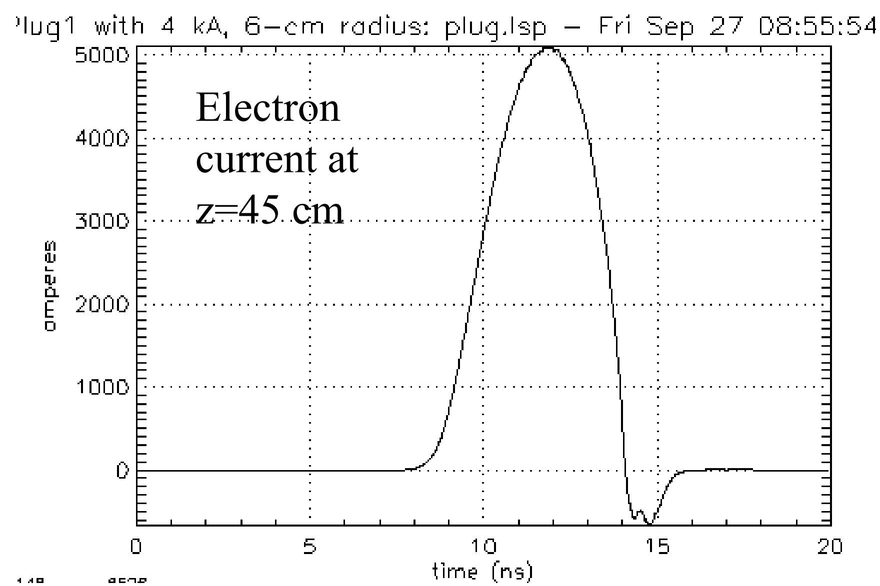
- Simulations are two and three dimensional
- Beam is injected through open boundary on left: .25-4 kA current, 4 GeV Bi^+
- Electrons are Child-Langmuir emitted from grounded plane on right
- CL electrons react like electrons from a dense plasma plug without the need to resolve plasma parameters (simulations are fast)

Plasma electrons are pulled into unneutralized beam as beam approaches plasma plug



Plasma electron emission at z =50 cm

- 4-kA Bi^+ beam (initially cold)
- plasma electrons are modeled at CL emission from z=50 metal wall
- 5-kA electron current flows back
- For k=1.5x10^{-4}, growth is 1.5 pi-mm-mrad
- electrons stream back non-uniformly and oscillate



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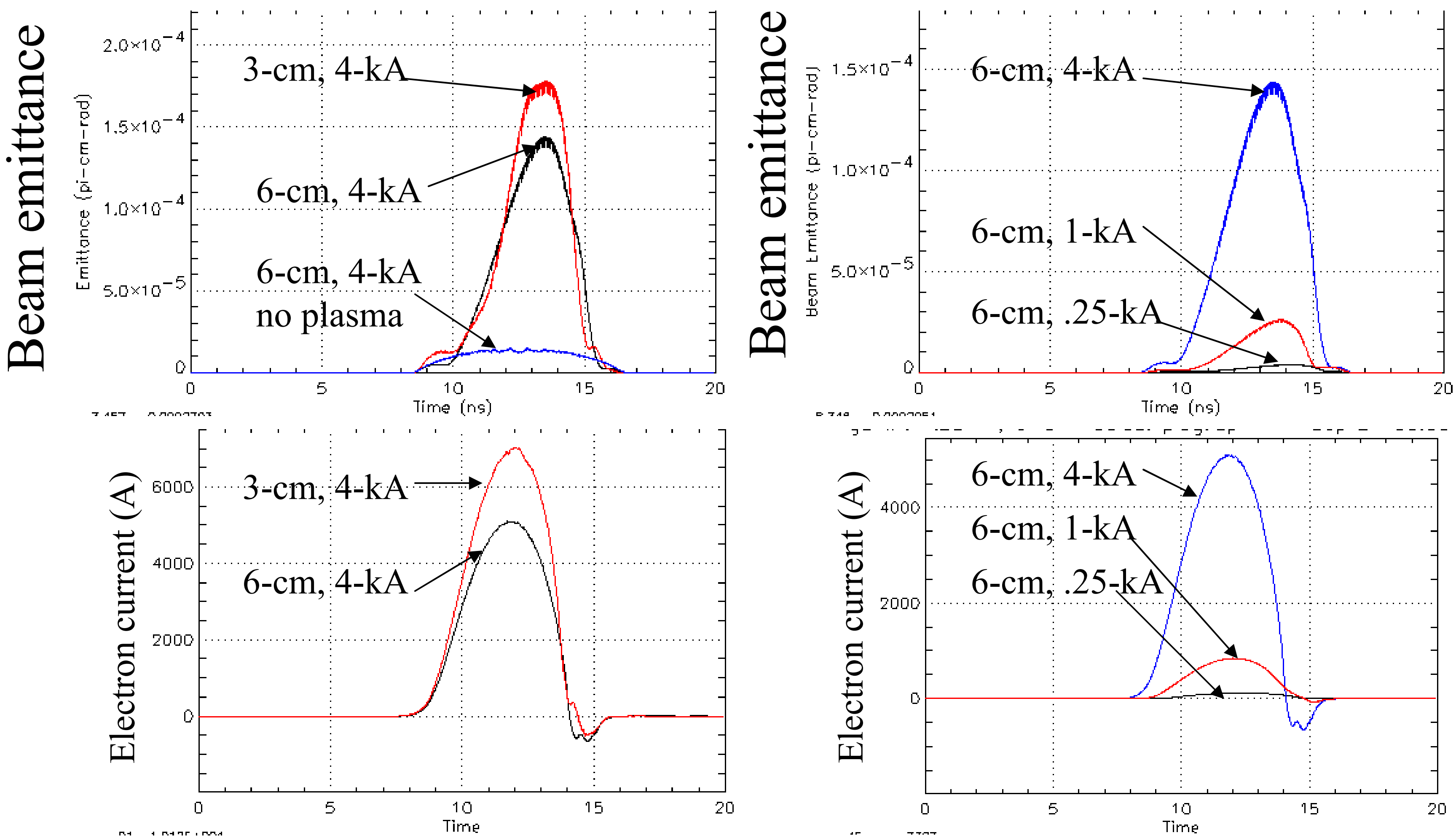
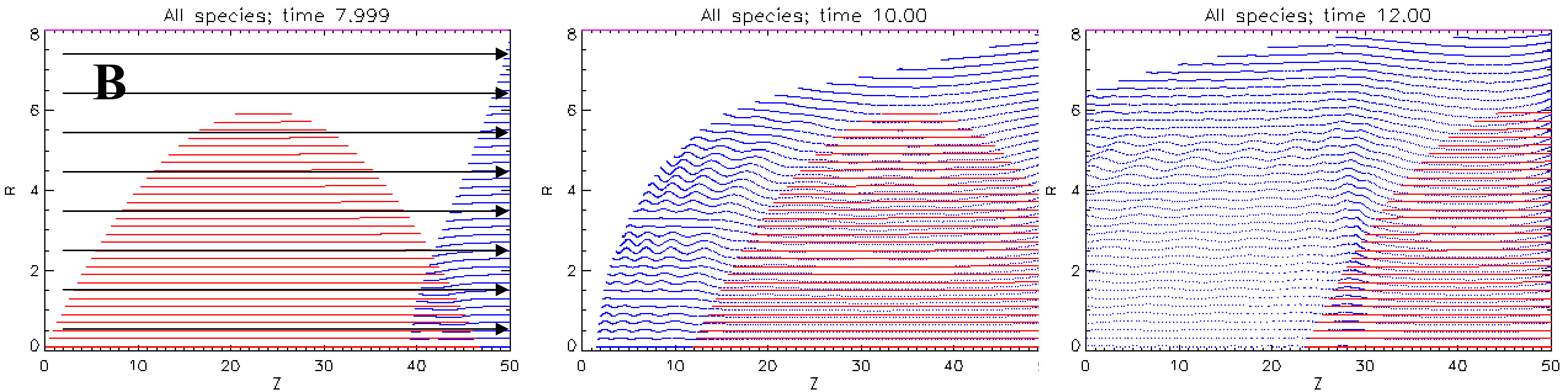


- Emittance growth (at z = 50 cm) scales with current, higher for smaller radius beam
- electron current (at z=45 cm) grows faster than linear with beam current

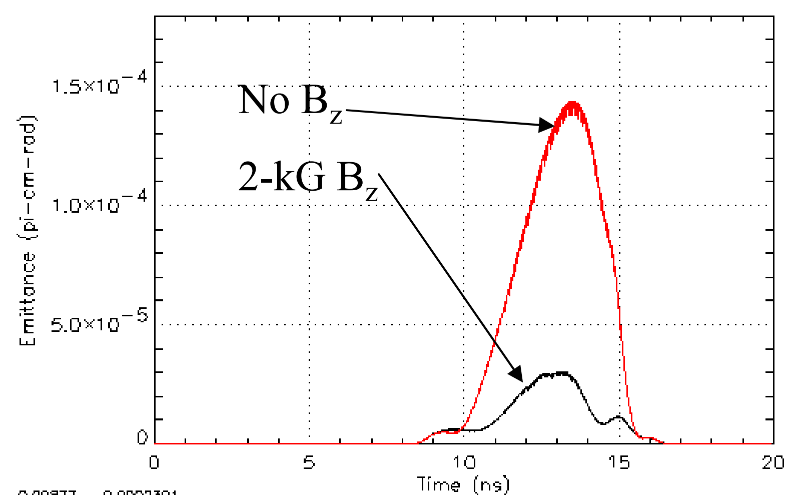
We now attempt to suppress upstream motion of electrons with applied magnetic fields in two geometries

- Solenoidal field (B_z)
- Dipole Field (B_y)

2-kG solenoidal field removes most of the emittance growth

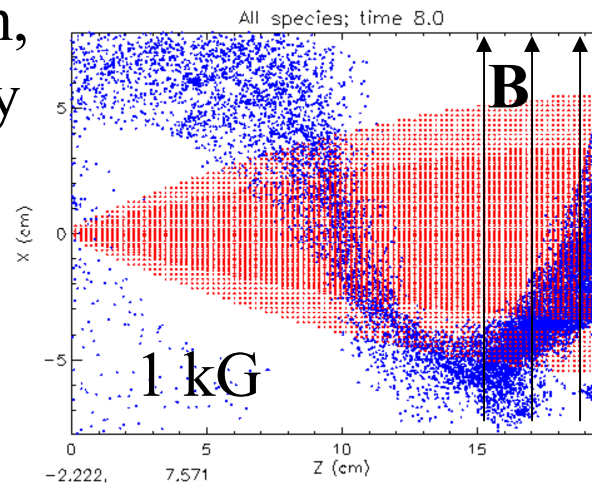


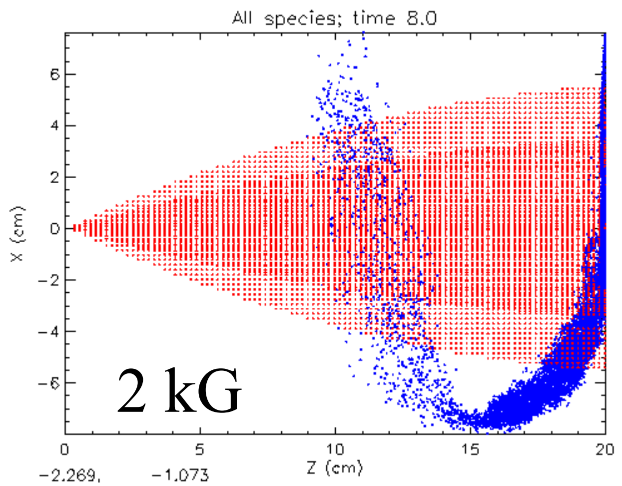
- Electrons stream in uniformly, nearly harmonic forces, little emittance growth
- B field would have to extend the length of beam 50-150 cm, plasma flow into field complicated

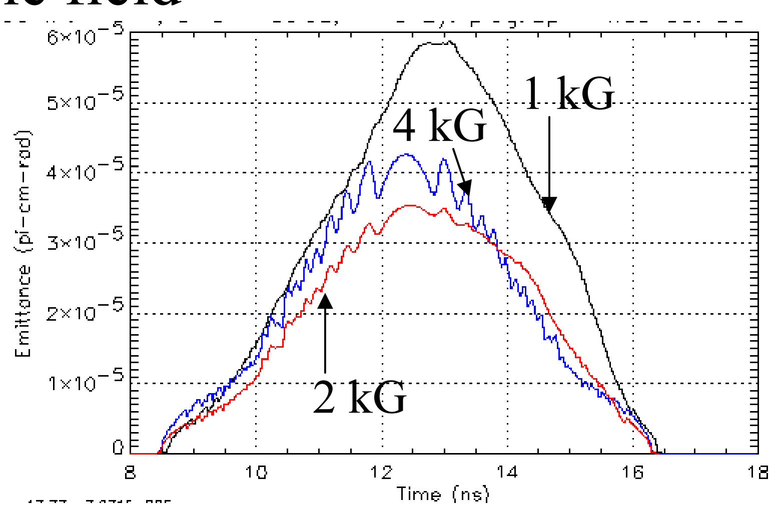


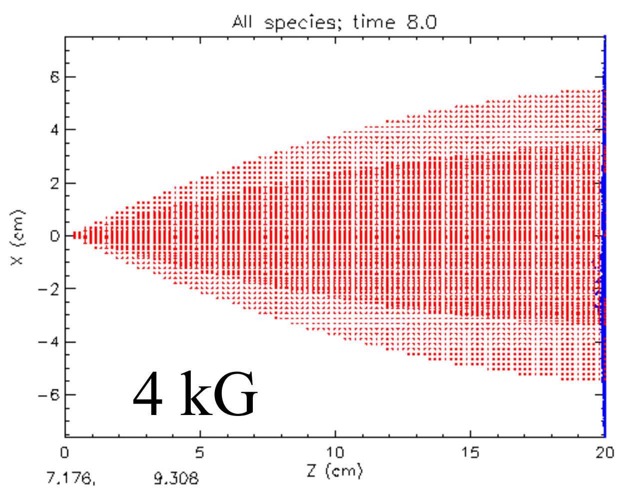
Dipole field >2 kG, only 5-cm long, suppresses backstreaming in 3d Lsp sims

- Electrons eventually ExB drift into beam, drift time slowed by increasing B
- Some emittance growth is due to beam steering in dipole field





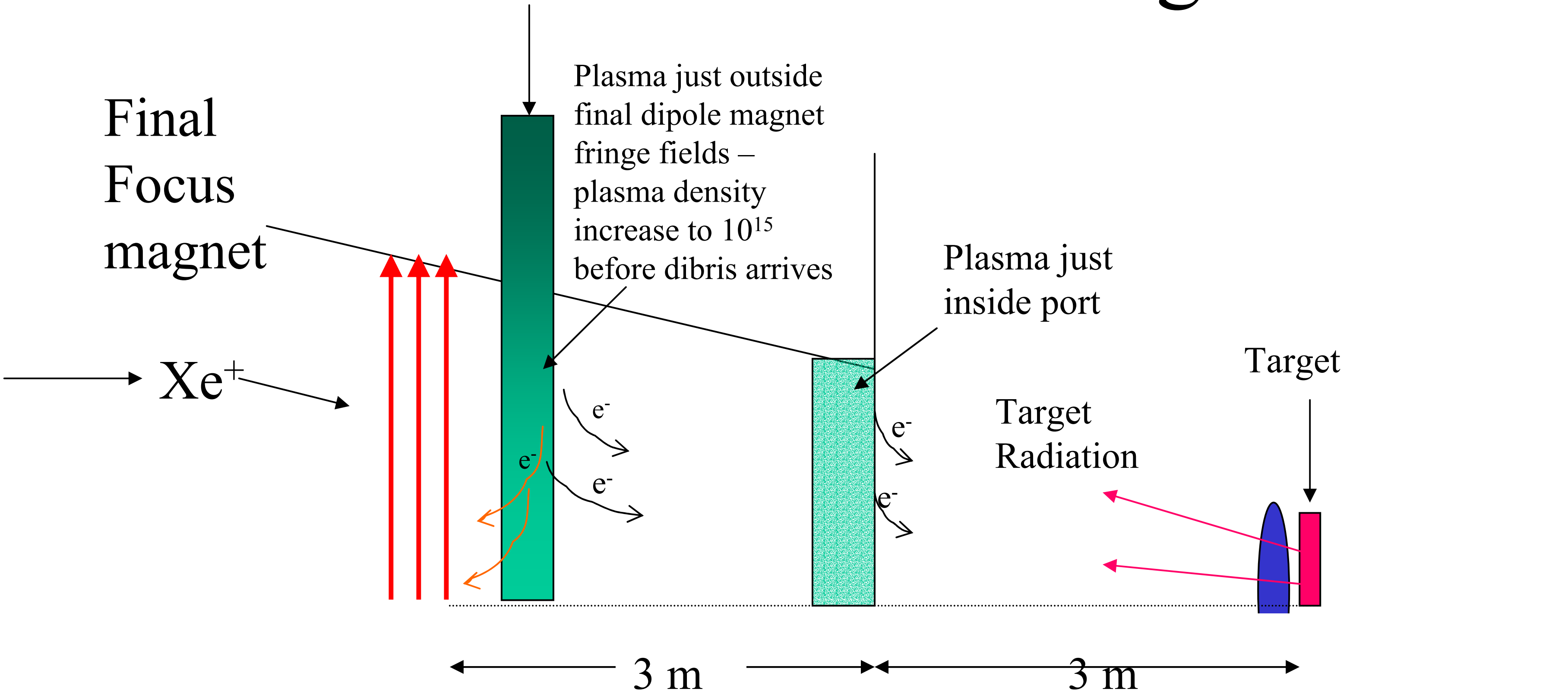




Beam plasma plug interaction can increase emittance for high K

- effect scales with current
- electron EM fields are non-uniform creating anharmonic potential, emittance growth
- solenoidal field of order a kGauss can force electrons to be uniform and greatly reduce emittance growth
- dipole magnetic field can suppress upstream motion of the beam, no plasma-B field interaction

Dipole magnet is consistent with current beamline design



- Dipole magnet and upstream plasma plug both have dual roles
  - 2 kG field suppress both electron and chamber plasma upstream motion
  - Initial plasma plug density ramps from 10^{12} to 10^{15} to both neutralize ion beam and ionize neutrals

Conclusions

- Unacceptable emittance growth calculated for high-current beams entering plasma plug
- Electron motion can be suppressed with a dipole magnetic field just upstream of plasma
- 1-2 kG dipole magnetic field is consistent with current beamline design, verified in 3D Lsp simulations