Propagation of HI Beams in Chamber Metal Vapor Atmosphere

C. Olson, Sandia National Laboratories

D. Welch, D. Rose, B. Oliver, T. Genoni, and R. Clark,
Mission Research Corporation

S. Yu, Lawrence Berkeley National Laboratories

ARIES Electronic Project Meeting 10-24-01

Outline

- **ARIES - HIF propagation modes vs. chamber wall type**
- **Wetted-wall power plant studies (HIBALL HI, OSIRIS-HIB, PROMETHEUS-H)**
- **Neutralized ballistic transport (concept/issues, LSP examples)**
- **Assisted pinch transport (concept/issues, LSP examples)**
- **Self-pinched transport (concept/issues, LSP examples)**
- **ARIES - HIF propagation modes vs. chamber wall types**

ARIES-IFE Study of HIF

Transport Mode / Chamber Concept	**Ballistic Transport** *chamber holes ~ 5 cm radius* *most studied*		**Pinch Transport** *chamber holes ~ 0.5 cm radius* *higher risk, higher payoff*	
	Vacuum-ballistic *vacuum*	**Neutralized-ballistic** *plasma generators*	**Preformed channel** **("assisted pinch")** ***laser + z-discharge***	**Self-pinched** *only gas*
Dry-wall *~6 meters to wall*	**Not considered now: Requires ~500 or more beams**	**Not considered: insufficient neutral-ization for 6 meters**	**Option: uses 1-10 Torr** ***2 beams***	**Option: uses 1-100 mTorr** **~2-100 beams**
Wetted-wall *~ 4-5 meters to wall*	HIBALL (1981) **Not considered: Needs ≤ 0.1 mTorr leads to □**	OSIRIS-HIB (1992) **Possible option: but tighter constraints on vacuum and beam emittance**	**Option: uses 1-10 Torr** ***2 beams***	PROMETHEUS-H (1992) **Option: uses 1-100 mTorr** **~2-100 beams**
Thick-liquid wall *~ 3 meters to wall*	**Not considered: Needs ≤ 0.1 mTorr leads to □**	HYLIFE II (1992-now) **Main-line approach: uses pre-formed plasma and 1 mTorr for 3 meters** ***~50-200 beams***	**Option: uses 1-10 Torr** ***2 beams***	**Option: uses 1-100 mTorr** **~2-100 beams**

Wetted-Wall HIF Power Plant Studies

HIBALL HI Reactor Study (1981):

First wall: HT-9 ferritic steel

INPORT tubes: SiC with PbLi flow

Pressure: < 10^{-5} Torr Pb

Ballistic transport (in vacuum)

OSIRIS-HIB Design (1992):

First wall: three-layer carbon cloth blanket

Flibe coolant bleeding through cloth

Pressure: < 2×10^{-4} Torr

Neutralized ballistic transport with co-moving electrons

PROMETHEUS-H Reactor Design Study (1992):

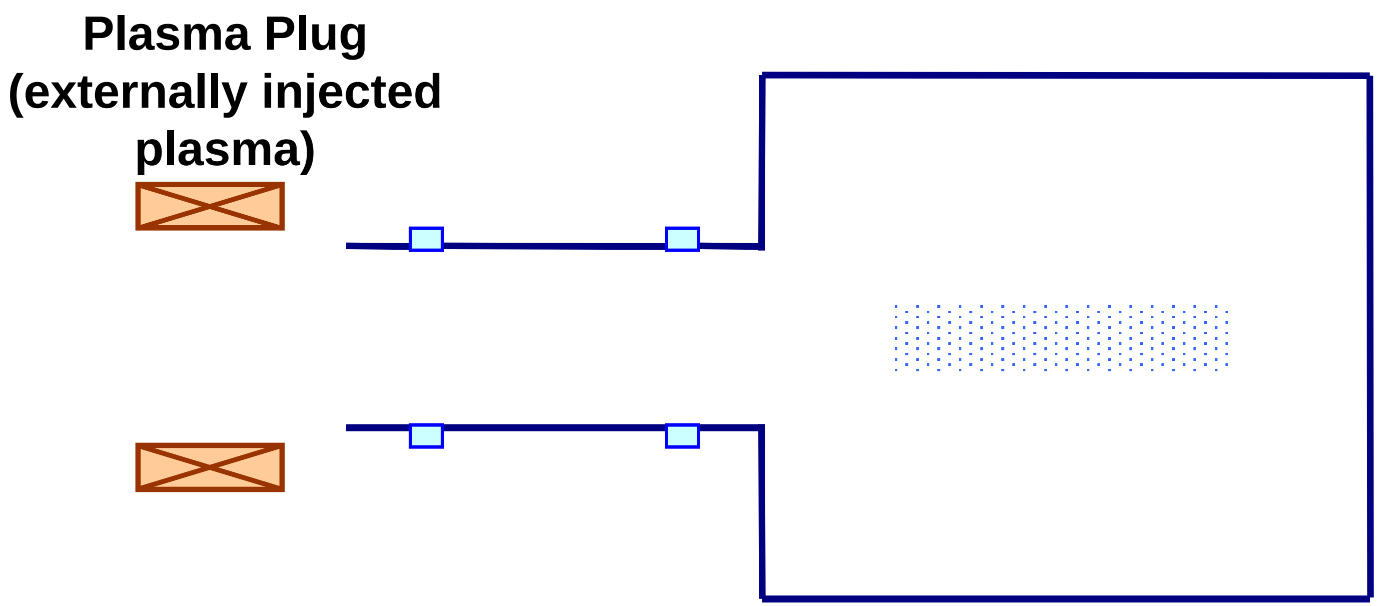
First wall: SiC porous

thin film of liquid Pb

Pressure: ~ 100 mTorr

Self-pinched transport

Neutralized Ballistic Transport

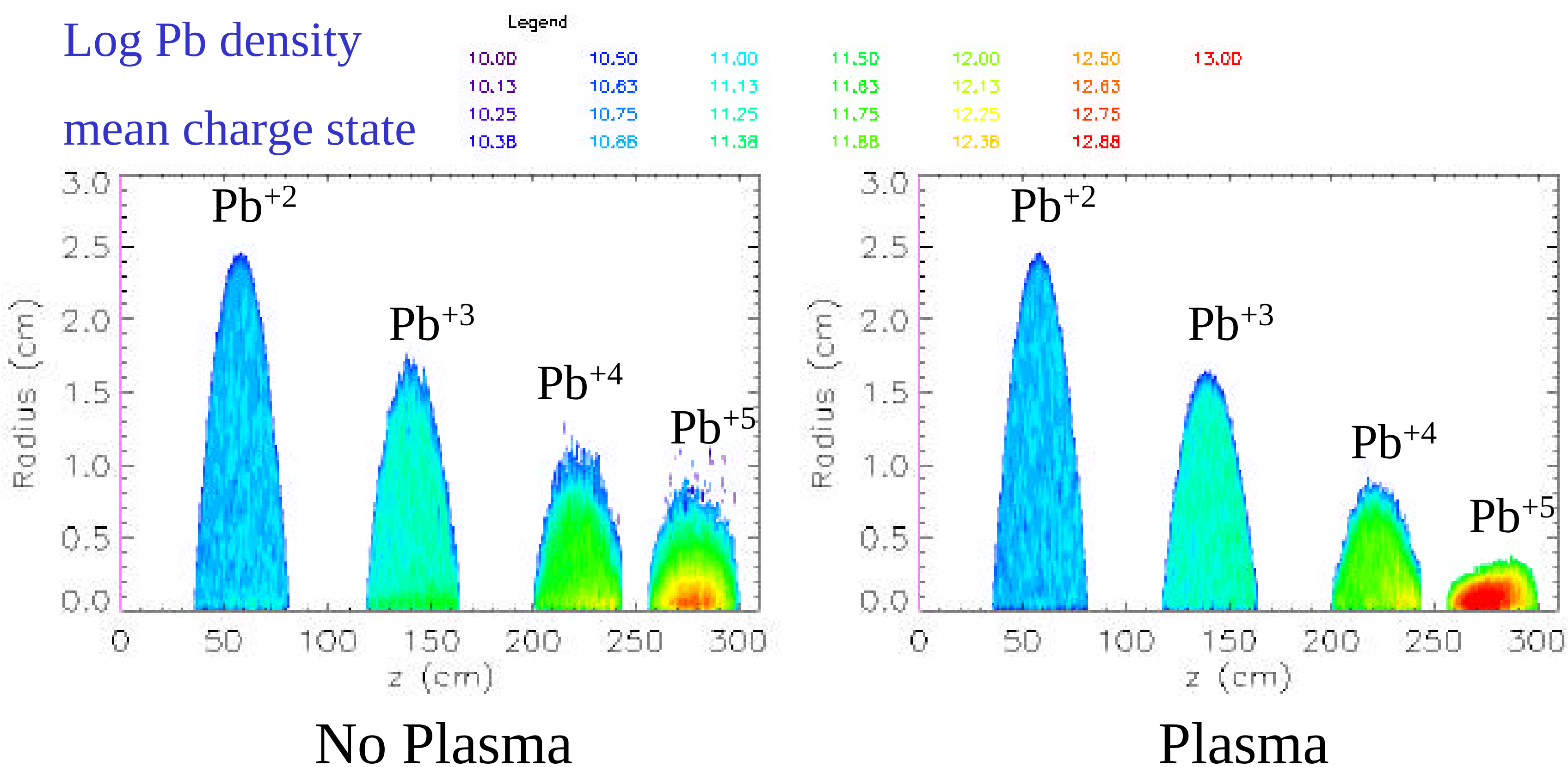


- Neutralization by: preformed plasma, gas, photoionization
- Key Issues: handling beams stripped to Z > 1, transport lengths beyond 3 meters

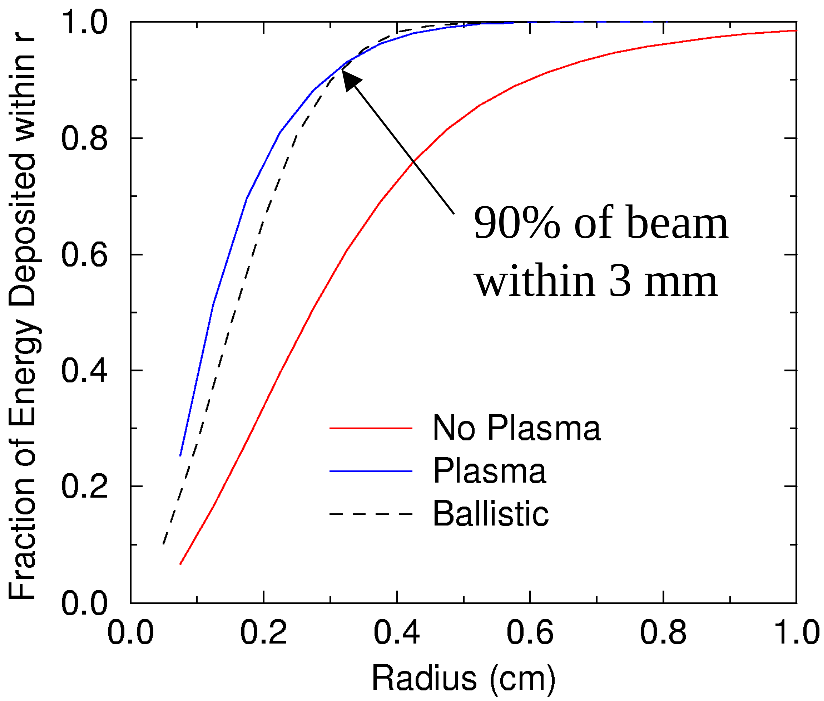
Driver Scale Beam Simulations:

Photo plasma crucial to good spot

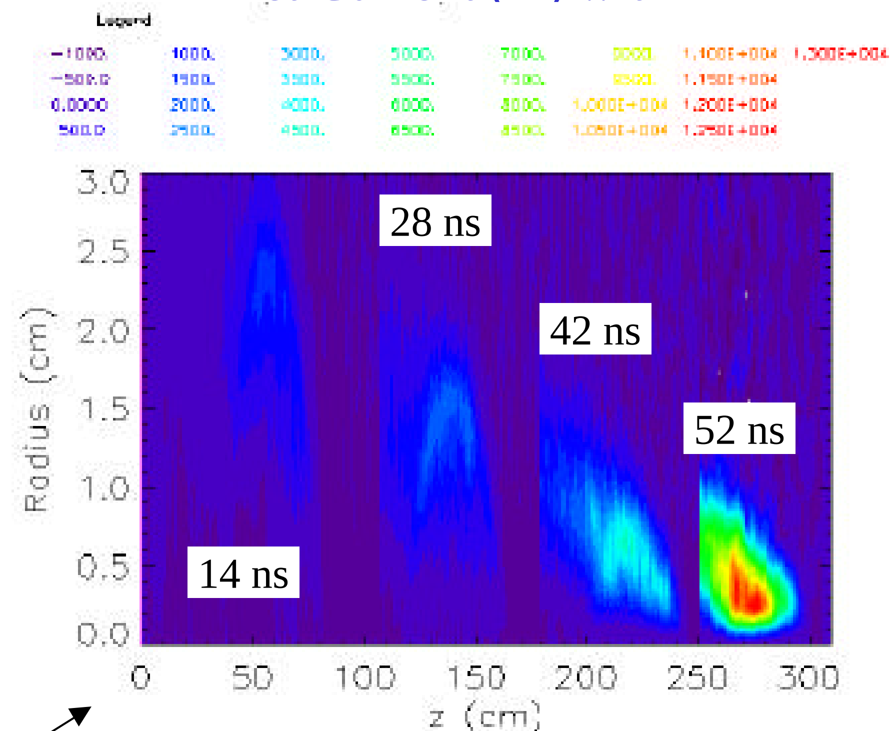
- Stripped ions deflected by un-neutralized charge at beam edge
- Plasma provides > 99% neutralization, focus at 265 cm



Plasma simulation spot slightly better than ballistic case



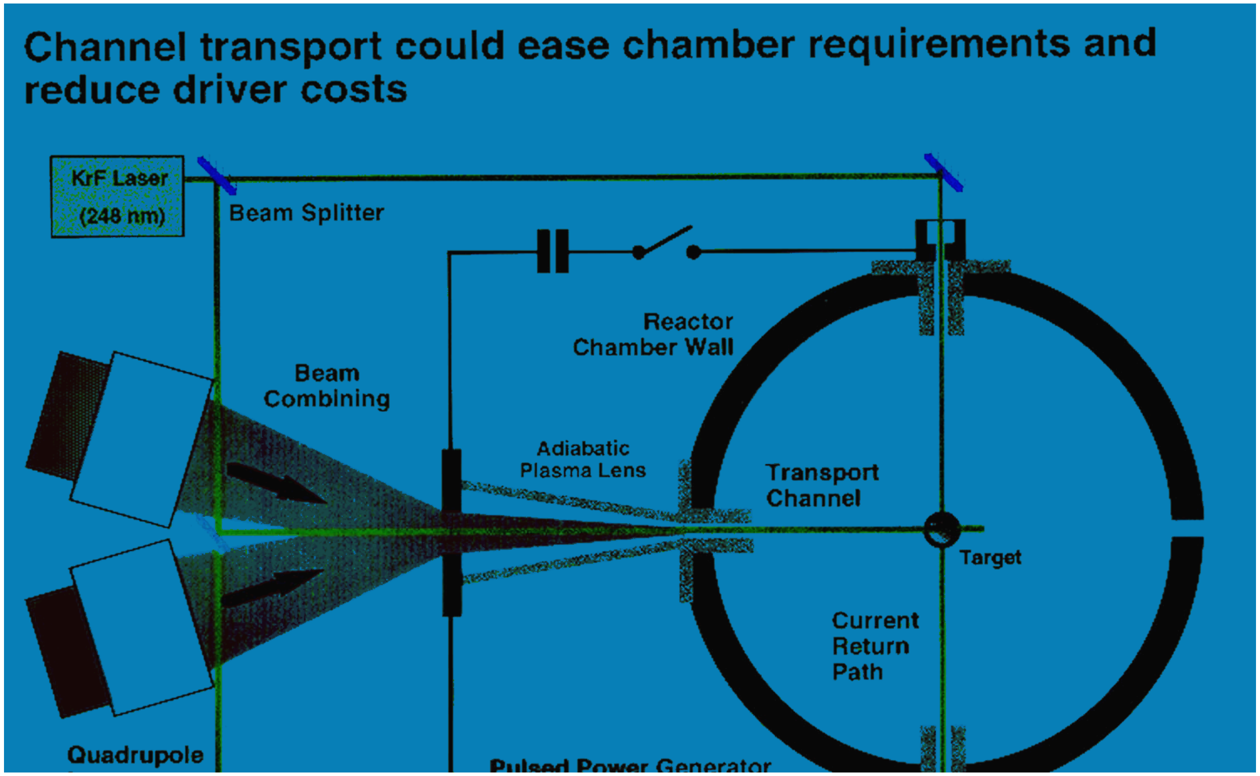
Net Current (A) within r



- Residual net current results in premature but tight focus (pinching near target)

Assisted Pinch Transport

small chamber entrance holes, eases chamber focusing requirements, and reduces accelerator costs, but requires laser and z-discharge.



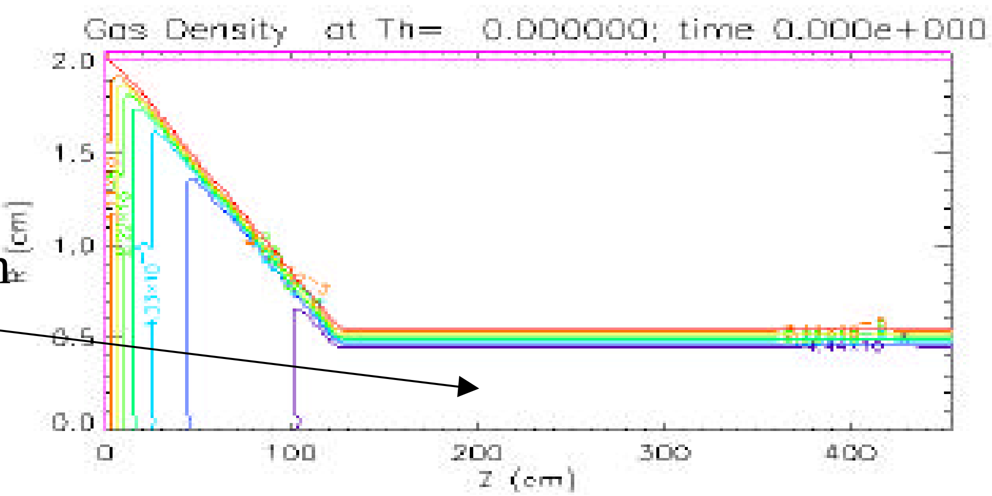
Main issues are the insulator at the chamber entrance, and beam/ channel stability (recent ARIES-IFE studies on both are favorable).

IPROP is used to model beam/plasma interaction with initial discharge conditions

- IPROP is a quasi 3D EM hybrid code
- 2 T fluid model for the plasma, PIC beam ions
- Ohm's Law, $J_e = \mathbf{F}(\quad p_e/n_e - v_i\nu_m + \mathbf{E} + \mathbf{v} \quad \mathbf{B})$
- Spitzer, e-neutral resistivity
- Ionization X-section falls as $1/Z^2$
- Moliere scattering, Bethe slowing down

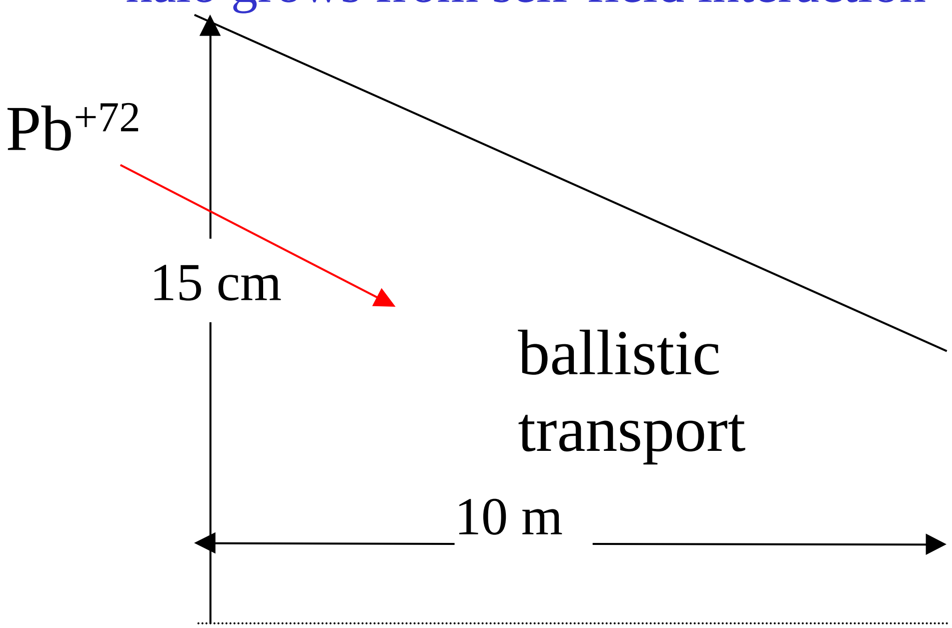
Initial Discharge Conditions

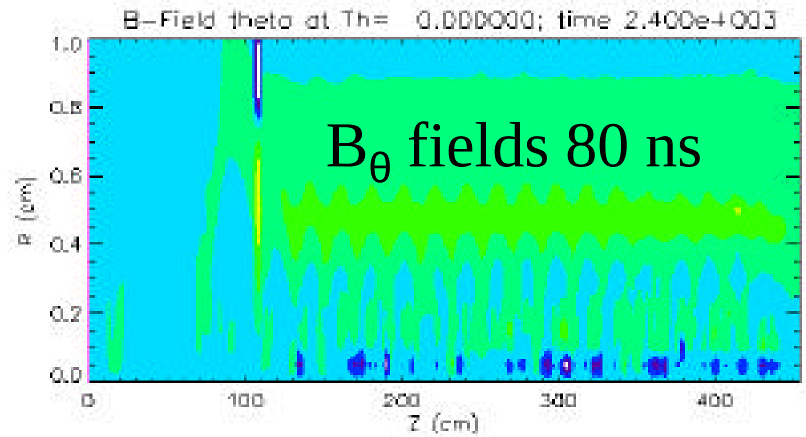
- 50-kA discharge
- 5-Torr, 3 eV ambient Xe
- 0.5 torr reduced density within discharge

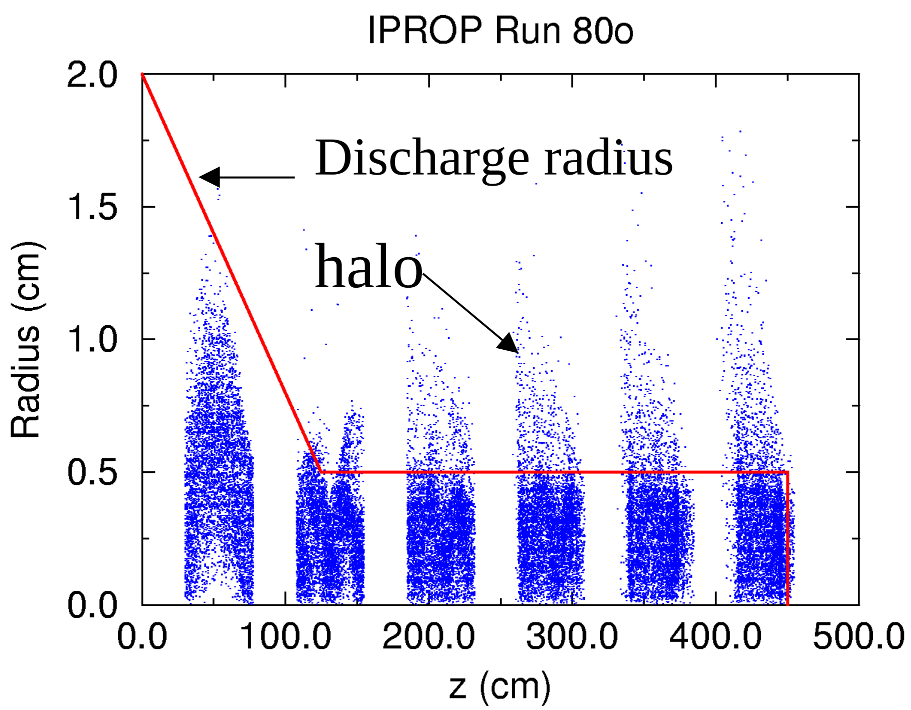


87% energy transport, 3.5-mm RMS radius calculated for APT

- 4-GeV, 6 MA Pb^{+72} ions, 1-mrad divergence
- 10-m ballistic transport to discharge
- Calculated τ_m = 5 μs limits net current growth to 30 kA over 8-ns pulse
- halo grows from self-field interaction

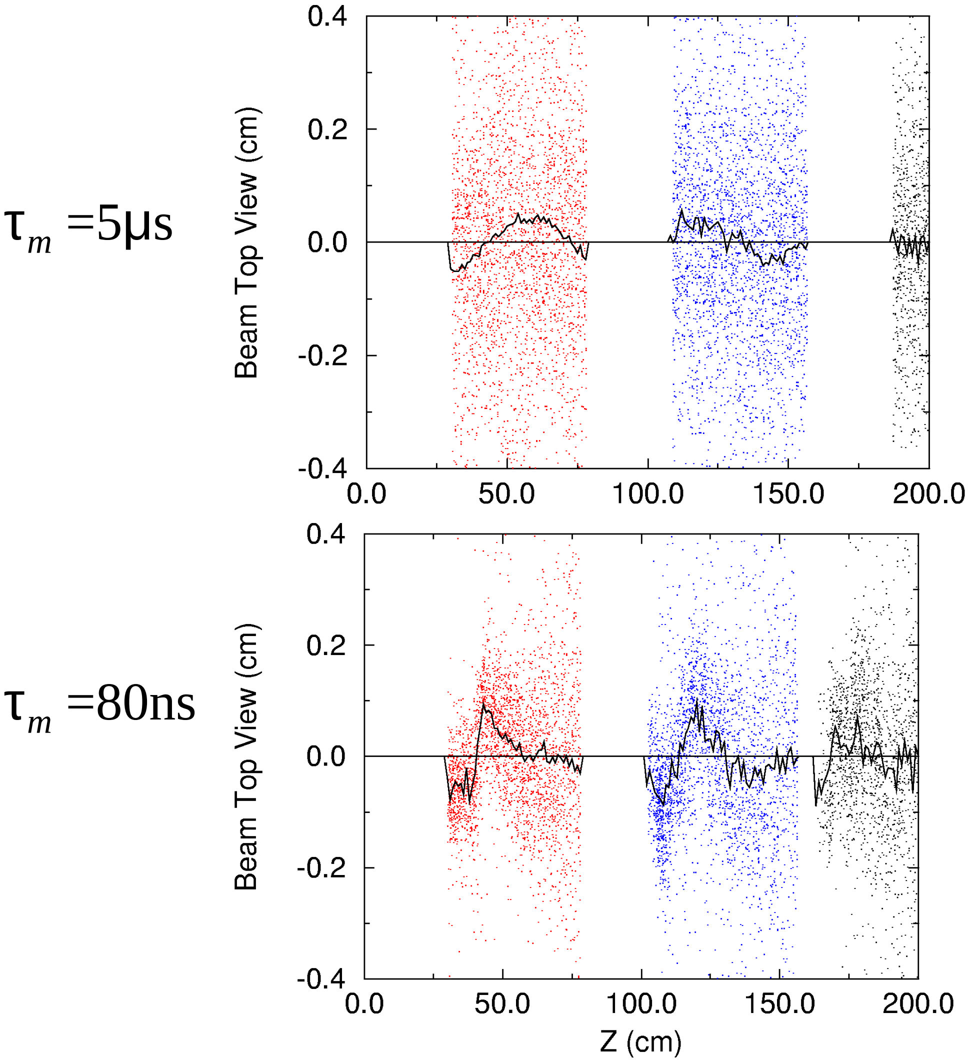






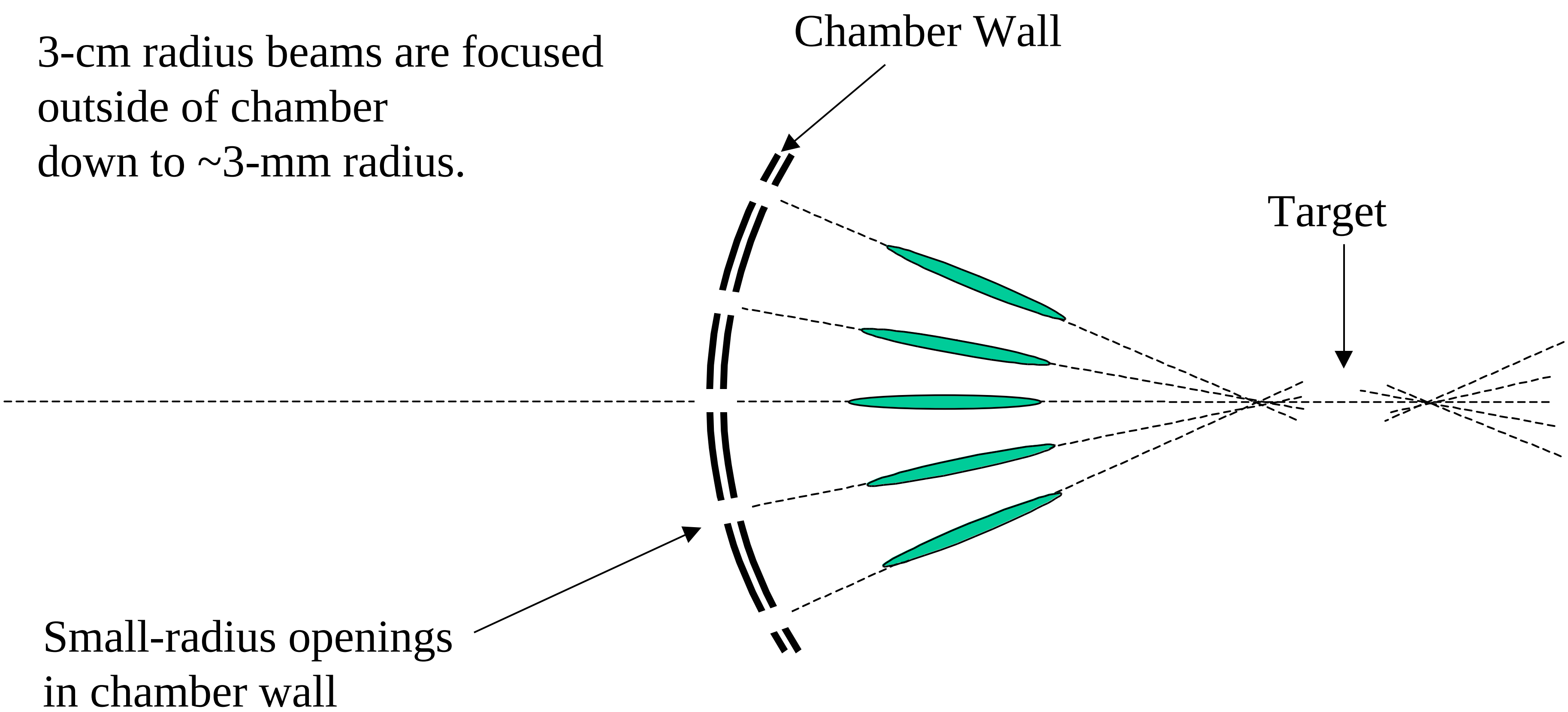
3D IPROP simulation shows negligible hose growth

- IPROP with *m=0,1* Fourier modes
- Constant, specified σ radial profile
- In both cases, offsets remain < 1 mm
- Low τ_m simulation shows much less growth than theory
  - result of betatron detuning from 300-kA net current?



Self-Pinched Transport

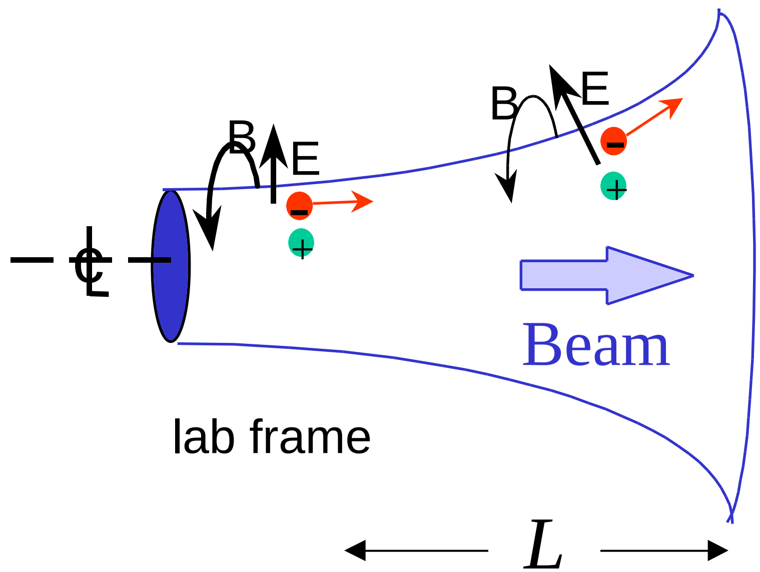
Many-beam SPT chamber mode (N > 10)



Self-pinched transport is predicted to occur at an intermediate gas pressure

- Maximum pinch force occurs when beam-impact ionizes a plasma density roughly that of the beam on time-scale of beam density rise time, L/v_b
- Optimized for normalized trumpet length: $R = L\sigma\, n_g/4Z = 1^*$
- Trumpet shape and non-local secondary ionization supply neutralization without $v_e = v_b$

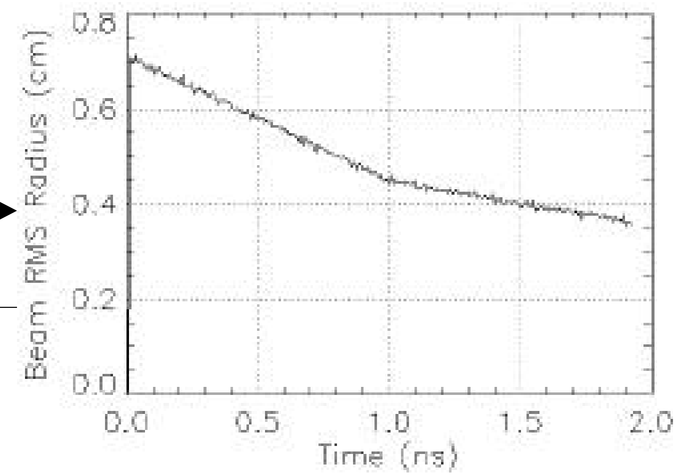
Electron orbits are mainly ExB

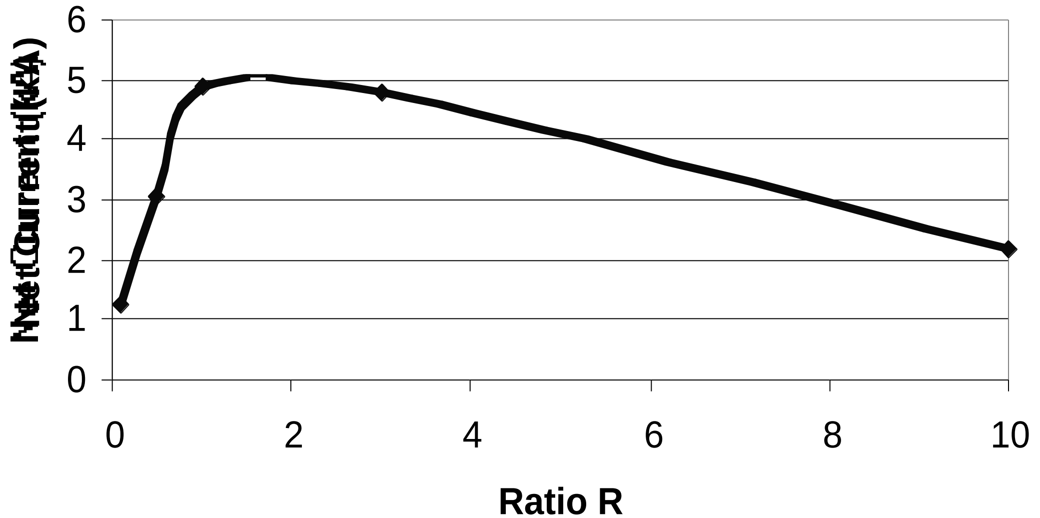


*D.R. Welch and C.L. Olson, Fus. Eng. and Des. **32-33**, 477 (1996).

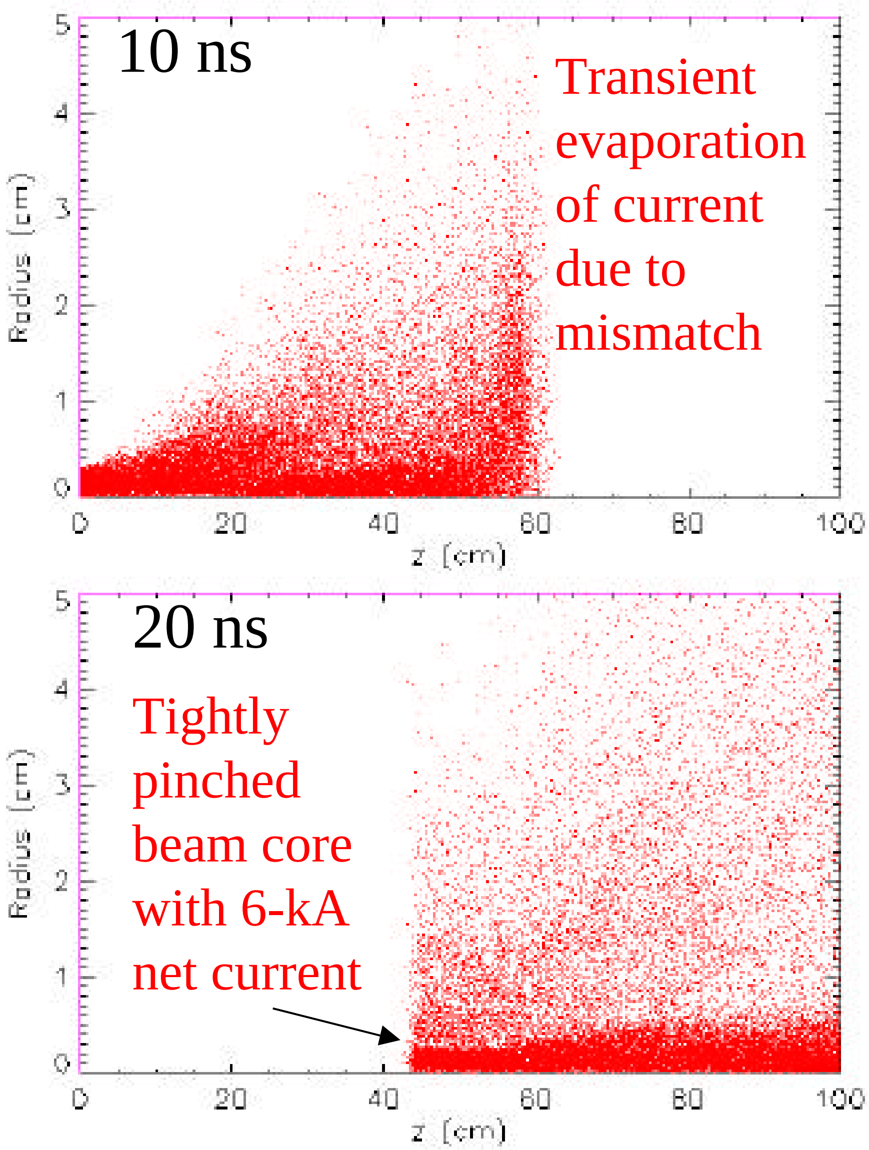
LSP calculates maximum I_{net} near normalized trumpet length of unity

- LSP simulations of 10-kA, 4-GeV Pb^{+} beam
- Beam trumpet 7 mm to 0.35 mm in 2 ns or 12 cm





1-m propagation demonstrates pinched equilibrium for R = 0.14



65-kA, 4-GeV Pb^{+65} beam

8-ns pulse

τ = 0.5 ns, 7-3.5 mm radius

50-mTorr Xe gas fill

Only 61% transport within 6 mm radius after 1-m

Tolerable ss erosion rate

10^{-3}

Transport Conclusions

- No show stoppers discovered for any of the transport schemes
- State of theory for NBT is the most mature - plasma via photo-ionization greatly improves transport for 3 m length
- APT results are sensitive to gas conductivity - present modeling calculates decay length sufficient to suppress deleterious self-field effects.
- SPT calculations have identified propagation window in 10-150 mTorr Xe - pinched equilibrium simulated. Efficiency of energy transport and 3D stability issues need to be addressed.

ARIES-IFE Study of HIF

Transport Mode / Chamber Concept	**Ballistic Transport** *chamber holes ~ 5 cm radius* *most studied*		**Pinch Transport** *chamber holes ~ 0.5 cm radius* *higher risk, higher payoff*	
	Vacuum-ballistic *vacuum*	**Neutralized-ballistic** *plasma generators*	**Preformed channel** **("assisted pinch")** *laser + z-discharge*	**Self-pinched** *only gas*
Dry-wall *~6 meters to wall*	**Not considered now: Requires ~500 or more beams**	**Not considered: insufficient neutral-ization for 6 meters**	**Option: uses 1-10 Torr** ***2 beams***	**Option: uses 1-100 mTorr** **~2-100 beams**
Wetted-wall *~ 4-5 meters to wall*	HIBALL (1981) **Not considered: Needs ≤ 0.1 mTorr leads to □**	OSIRIS-HIB (1992) **Possible option: but tighter constraints on vacuum and beam emittance**	**Option: uses 1-10 Torr** ***2 beams***	PROMETHEUS-H (1992) **Option: uses 1-100 mTorr** **~2-100 beams**
Thick-liquid wall *~ 3 meters to wall*	**Not considered: Needs ≤ 0.1 mTorr leads to □**	HYLIFE II (1992-now) **Main-line approach: uses pre-formed plasma and 1 mTorr for 3 meters** ***~50-200 beams***	**Option: uses 1-10 Torr** ***2 beams***	**Option: uses 1-100 mTorr** **~2-100 beams**