Modeling of Assisted and Self-Pinch Transport

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Pinched transport for several chamber concepts being studied.

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*	
	<u>Vacuum-ballistic</u> *vacuum*	**<u>Neutralized-ballistic</u>** *plasma generators*	**<u>Preformed channel</u>** **("assisted pinch")** *laser + z-discharge*	**<u>Self-pinched</u>** *only gas*
<u>Dry-wall</u> *~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
<u>Wetted-wall</u> *~ 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
<u>Thick-liquid wall</u> *~ 3 meters to wall*	Not considered: Needs ≤ 0.1 mTorr leads to 〉	HYLIFE II (1992-now) <u>Main-line approach</u>: 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

Assisted pinch transport (APT) and self-pinched transport (SPT) reduce chamber focus requirements and reduce driver costs

Common Benefits

- Small chamber entrance holes means easier protection of final focus optics, etc.
- Possibility of fewer chamber entrance holes (APT, N=2, SPT, N=2-100) simplifies chamber design physics and engineering

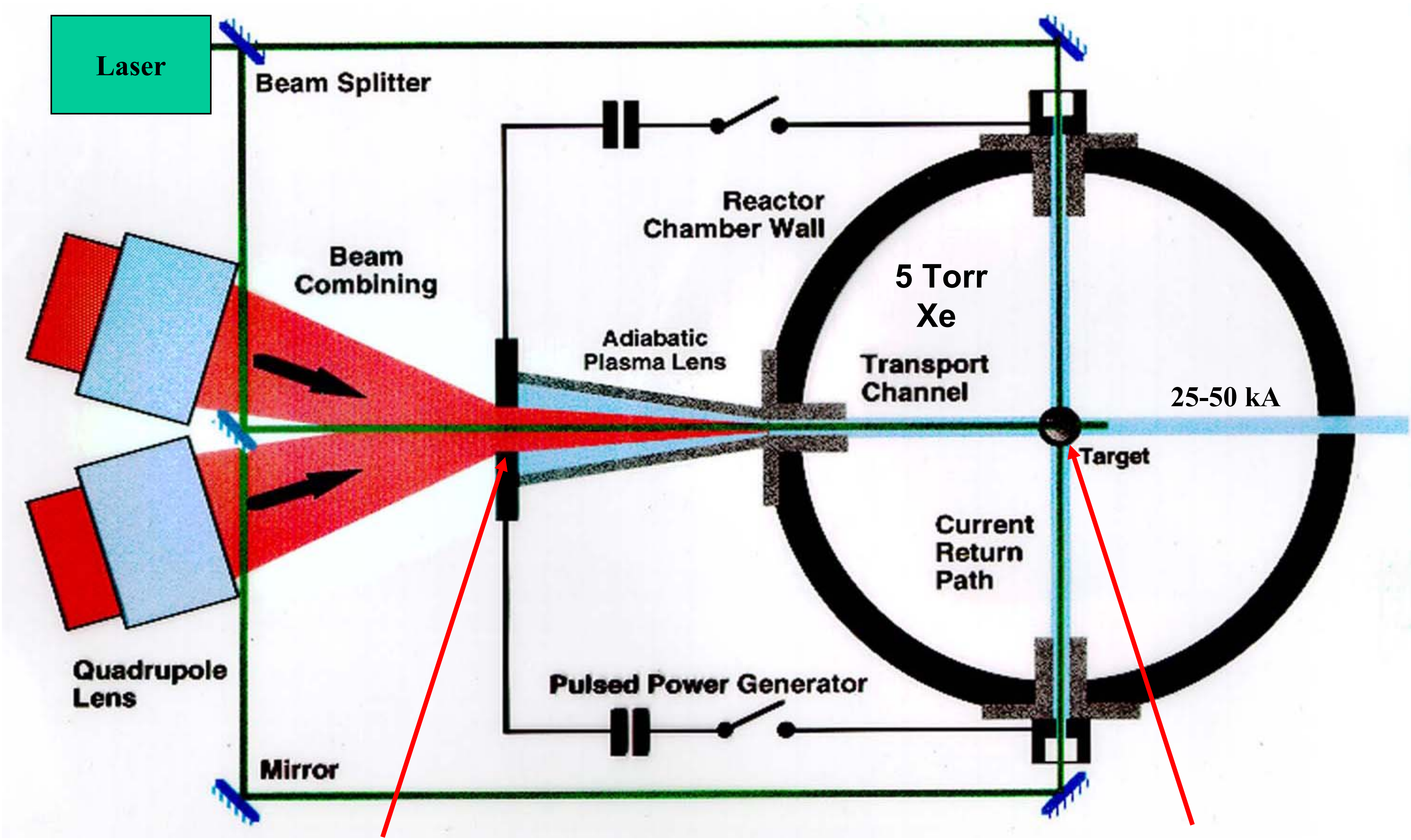
APT Issues

- Pointing and tracking needs to be addressed.
- Requires “hybrid” target design.

SPT Issues

- Beam head erosion, beam evaporation reduce energy transport efficiency
- Beam steering needs to be addressed (pointing and tracking)
- Beam-beam interaction near target (for larger numbers of beams)

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



IPROP simulation starts

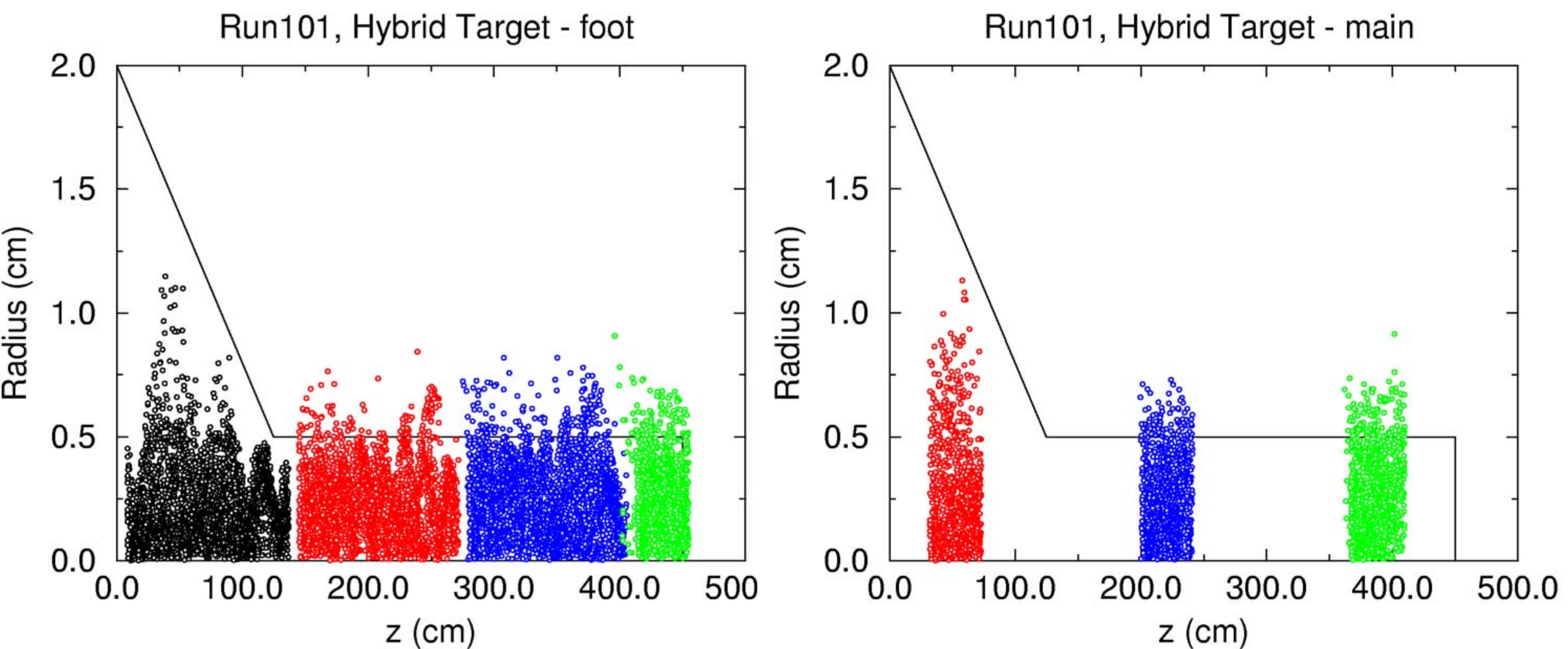
Hybrid Target

APT Coupling of foot and main pulses to D. Callahan's Hybrid Target

- 125-ns long IPROP simulation
- Discharge parameters
  - 5-Torr ambient, 0.5-Torr channel Xe
  - 25-50-kA discharge
- Beam parameters (1 side) - 3.45 MJ
  - 3.0-GeV, 12.5-kA, 25-ns Pb foot pulse
  - 4.5-GeV, 66.5-kA, 8-ns Pb main pulse
  - Xe beam was also simulated
  - 1-2 milliradian divergence
- Hybrid Target has 5-mm radiator

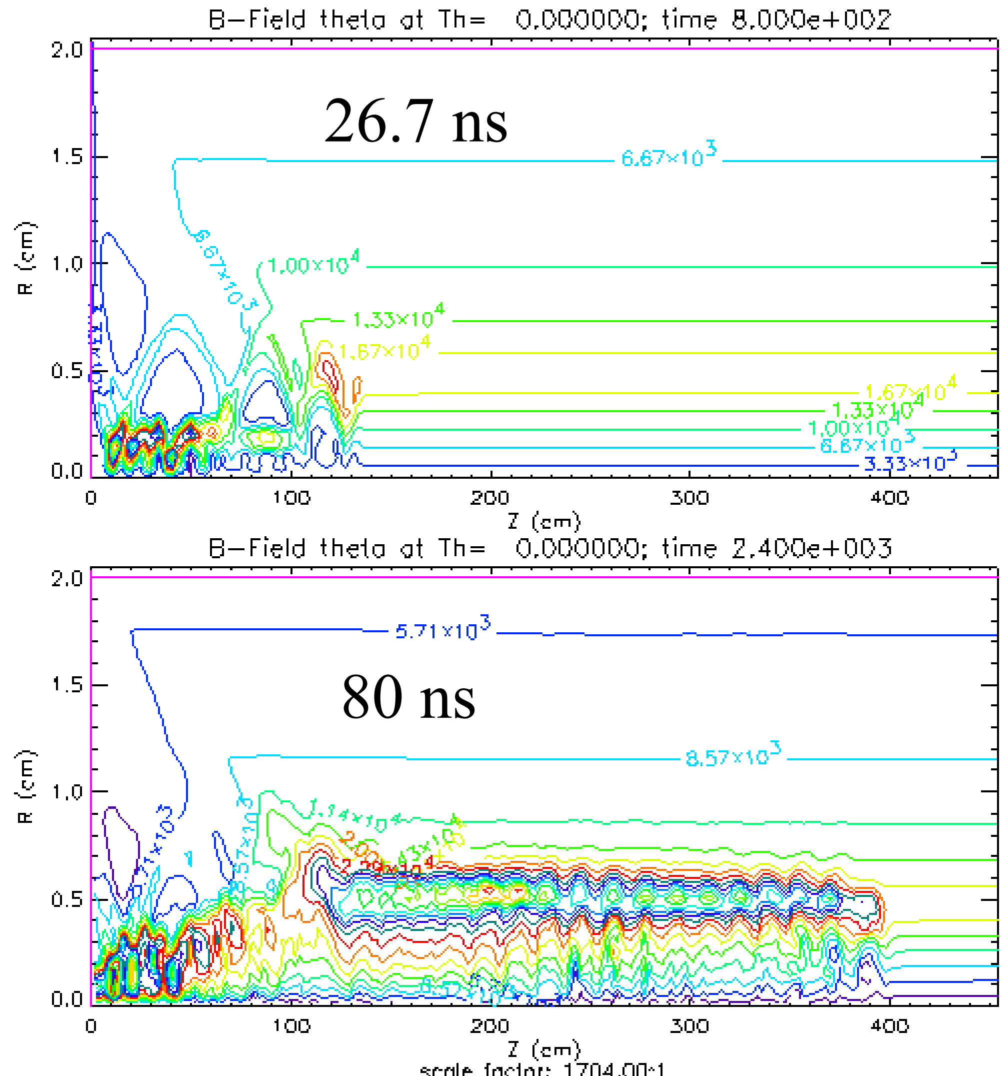
Two distinct beams have also been simulated - halo is weaker

- Peak electrical current is lower than previous sims: 4.8 MA vs. 6 MA, energy is 4.5 GeV vs. 4 GeV
- Foot and main pulses well focused
- Nose of main pulse must "catch" tail of foot pulse



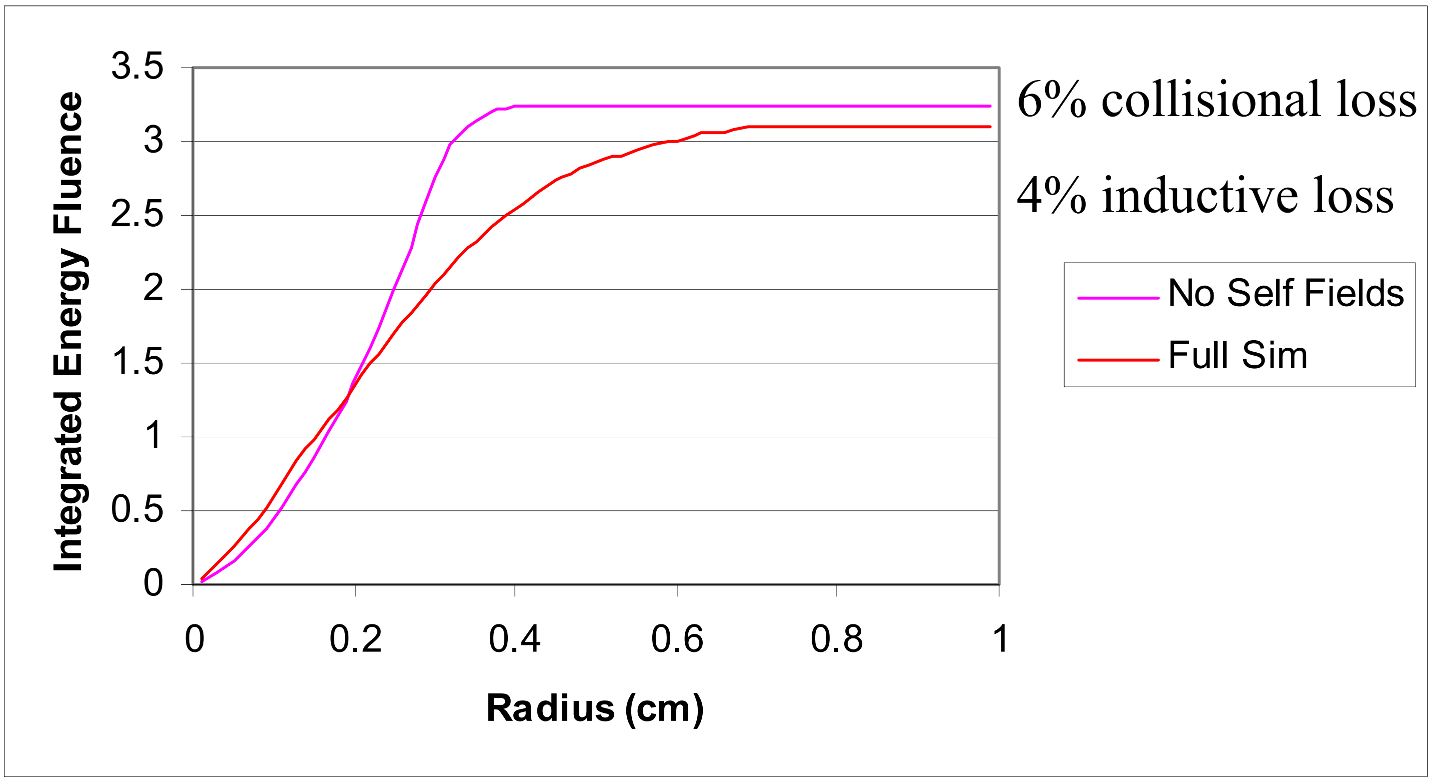
Self fields of order those of 50-kA discharge

- Self fields reach 45 kG, highly rippled by 80 ns
- Some enhanced confinement?
- Beam interacts with ripple and a halo forms



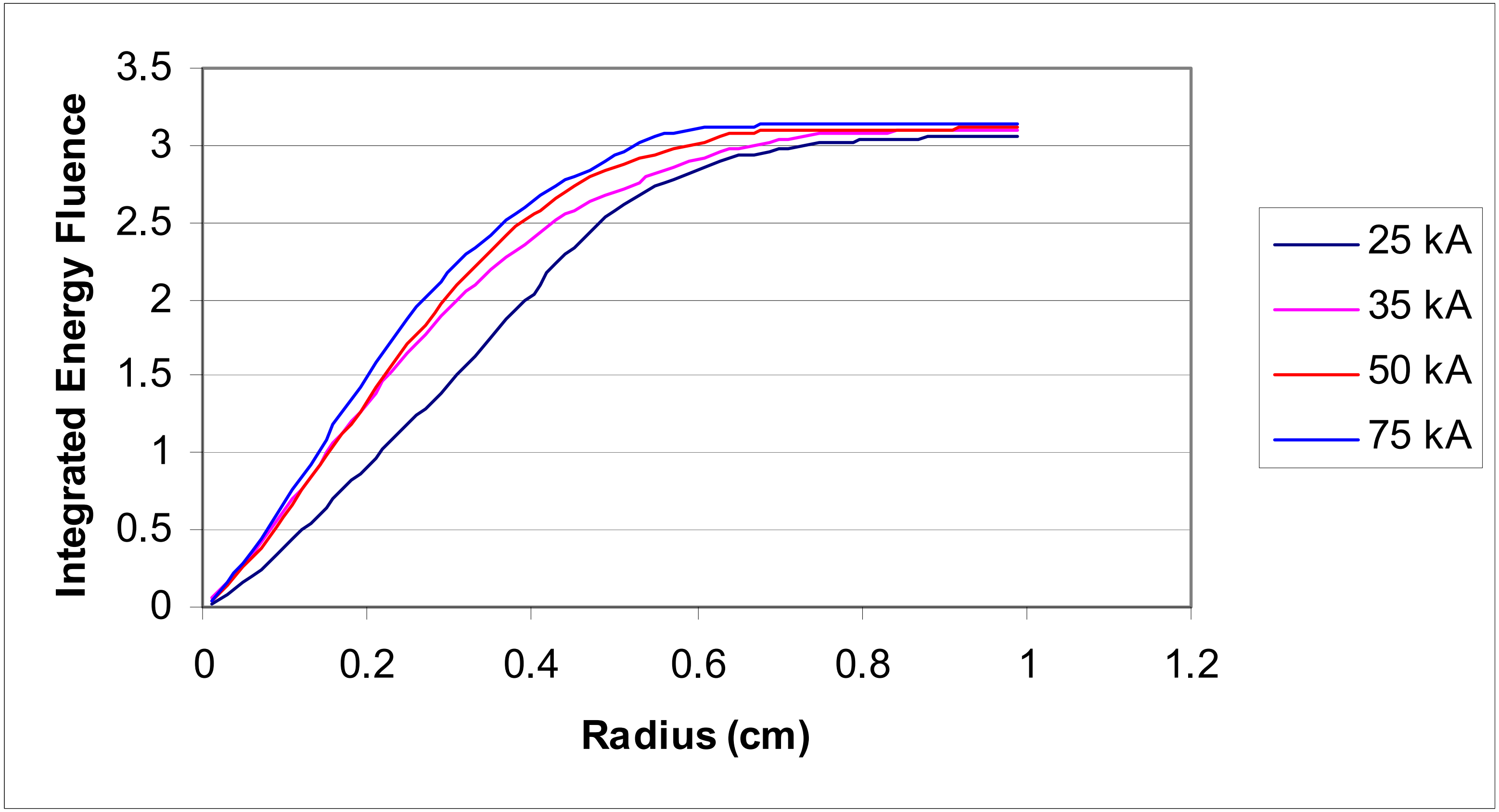
85% energy efficiency within 5 mm for nominal beam/discharge

- Energy transport within given Radius
- Ideal case (no self fields) yields 94% efficiency



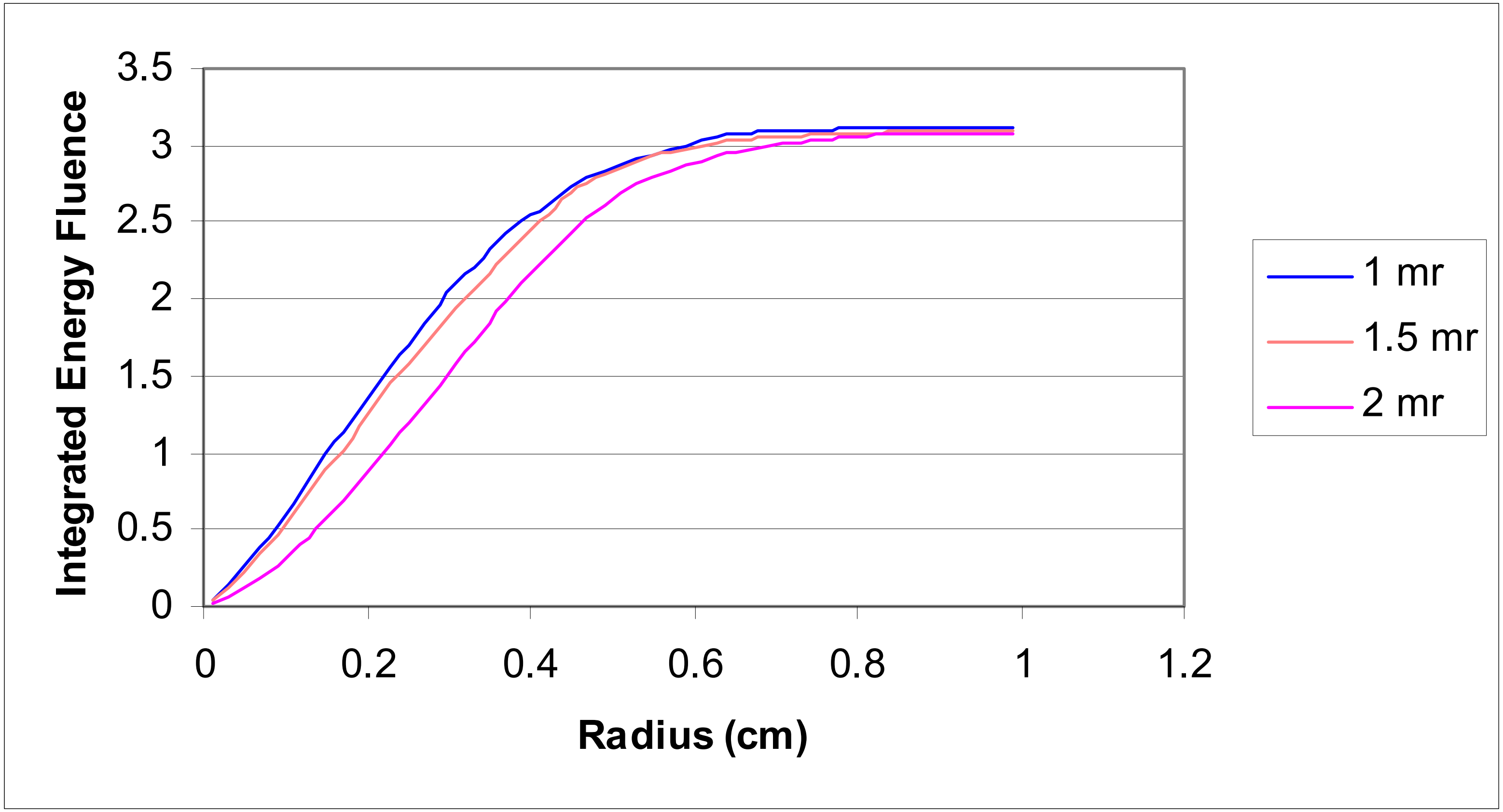
Efficiency falls for currents below 50 kA

- 75 kA discharge yields best transport within 0.5 cm
- Efficiency falls with decreasing currents from 87% to 80%



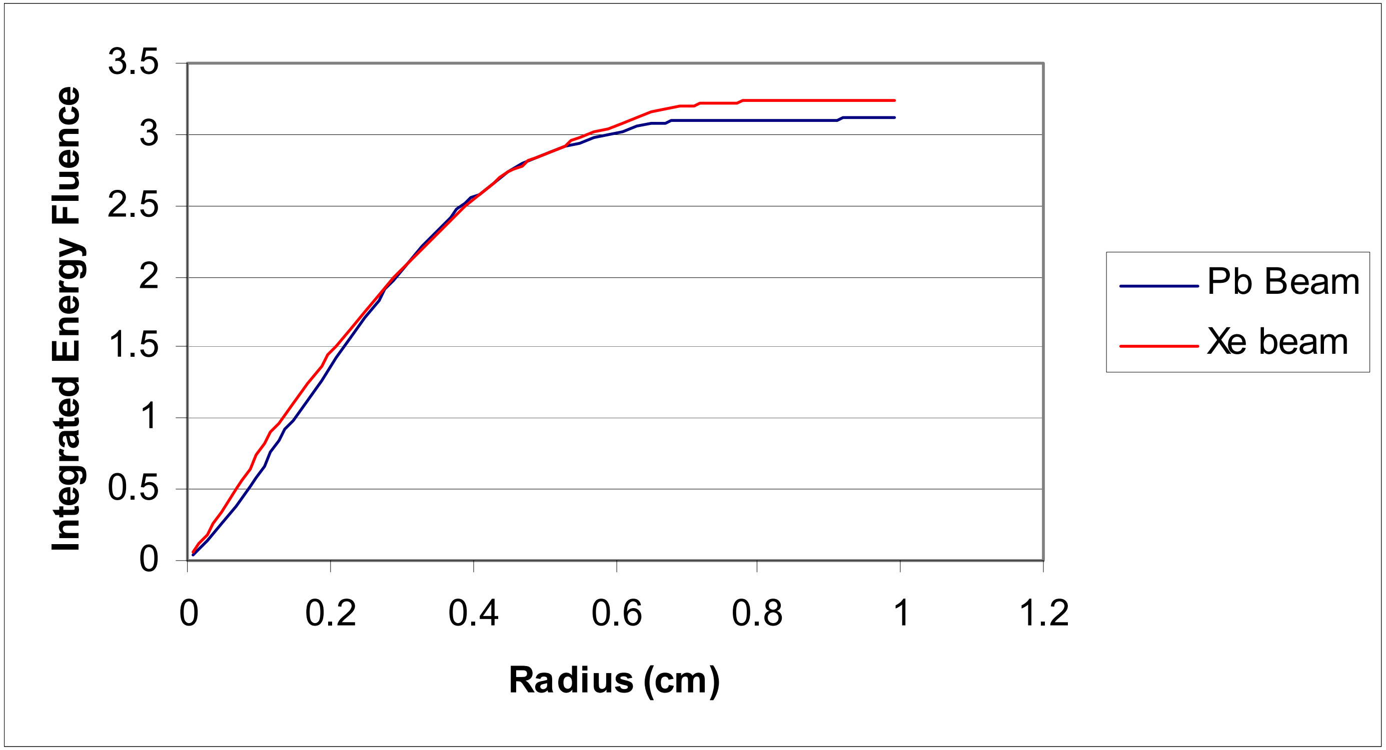
Efficiency falls slowly with beam divergence

- < 1.5 milliradian is adequate for 50 kA discharge defines minimum beam emittance



Transport insensitive to beam ion

- Xe^{+44}, scaled to deliver same energy on target
  - 1.8-GeV foot and 2.4-GeV main pulse
  - Similar stripped electrical current and charge to mass ratio
- roughly 85% transport for both within 5 mm radius
- 50-kA discharge

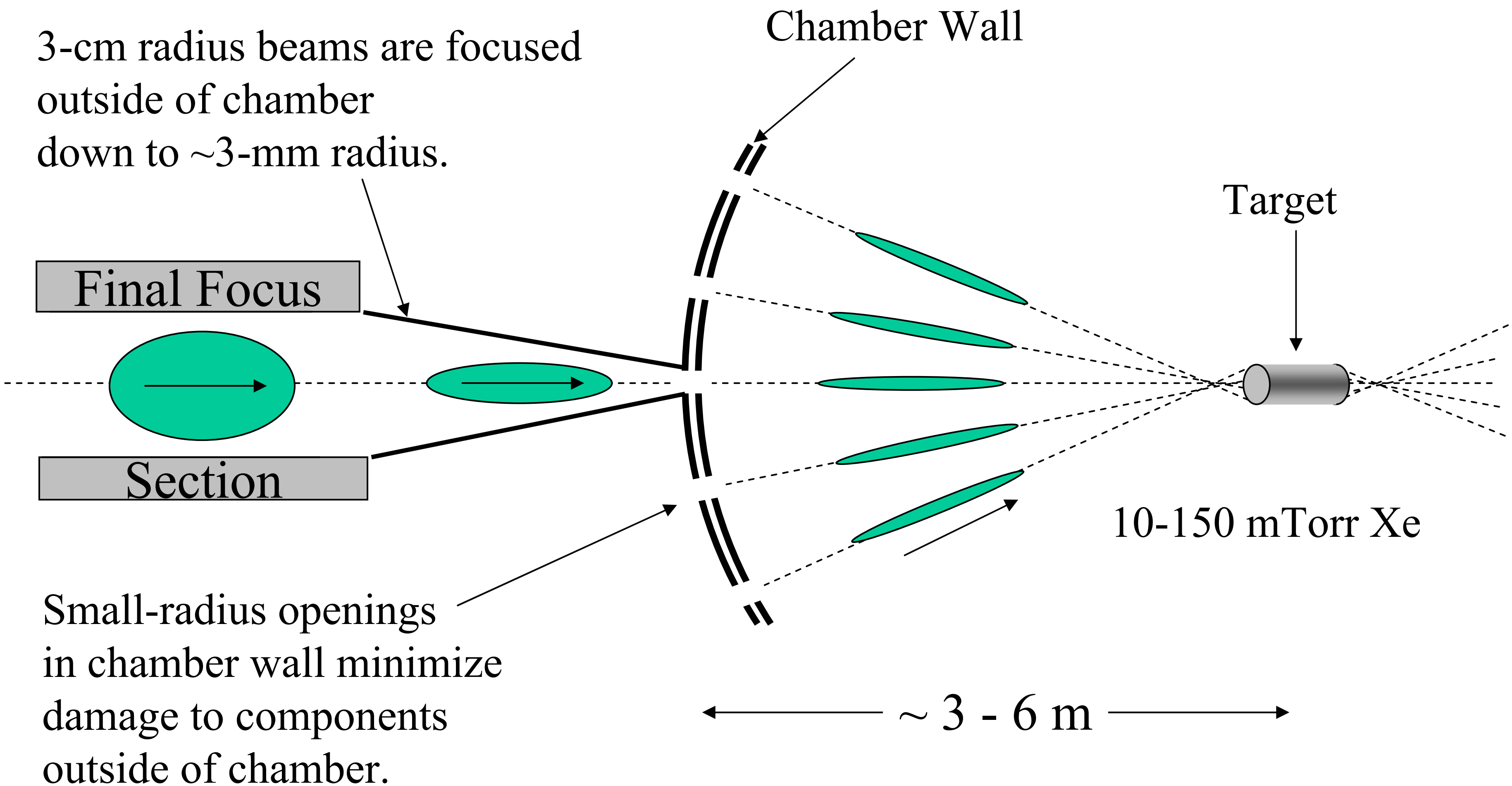


Conclusions: APT

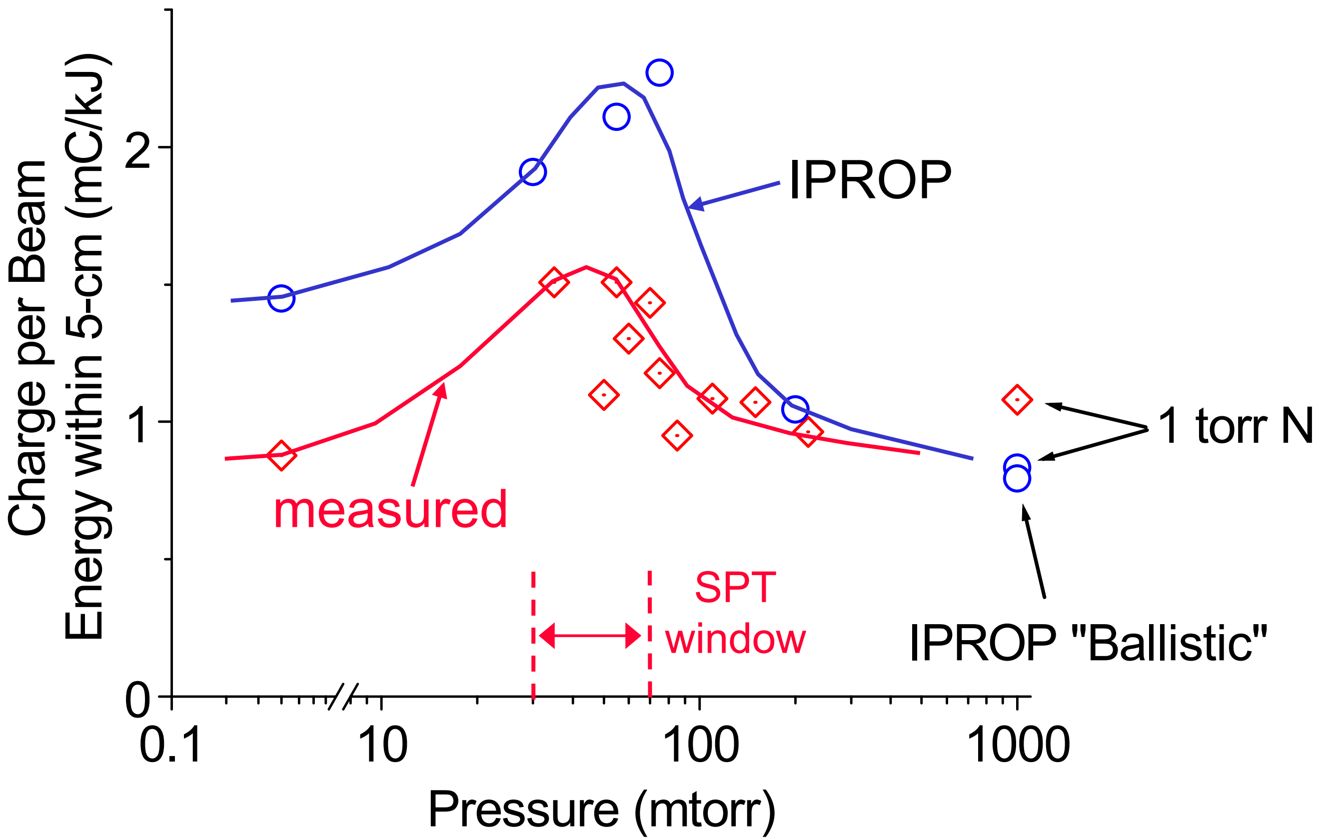
- APT scheme efficiently couples HIF beam to the Hybrid Target - 85% efficiency
- Efficiency falls rapidly for channel currents < 35 kA
- Transport degrades for beam divergence (<1.5 milliradians)
- Scheme is insensitive to ion species

Self-pinched chamber transport scheme

Charge and partial current neutralization provided by impact ionization of highly stripped ion beam in 10's mTorr gas



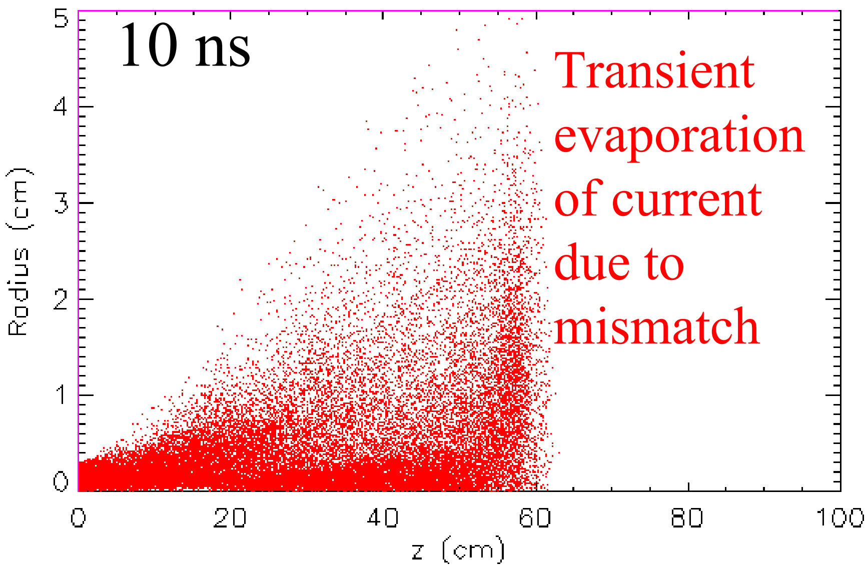
Comparison of measured [with Li(Cu) nuclear activation] and predicted proton charge collected on a 5-cm-radius target at 50 cm into the transport region shows the same SPT pressure window.*

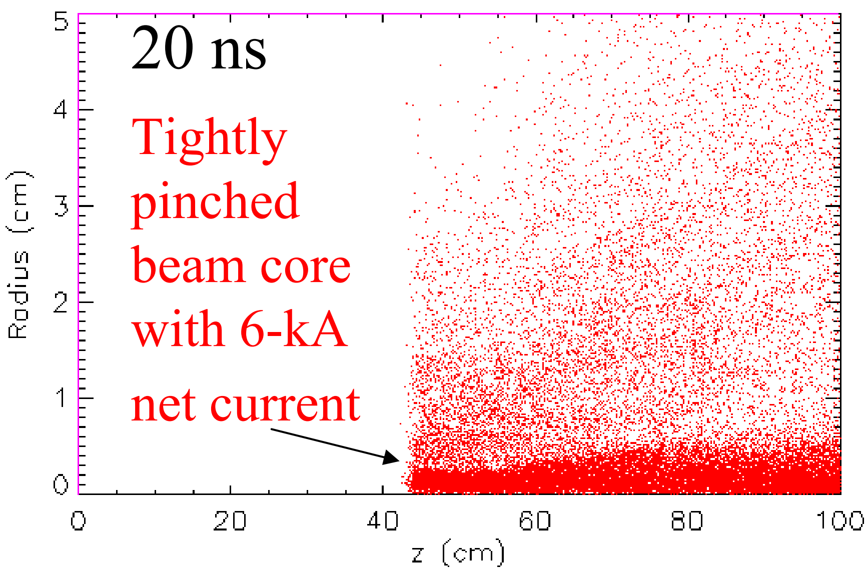


Results from SPT experiment on Gamble II at NRL

[*P. F. Ottinger, *et al*., Phys. of Plasmas **7**, 346 (2000)]

1-m propagation demonstrates pinched equilibrium





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

8-ns pulse

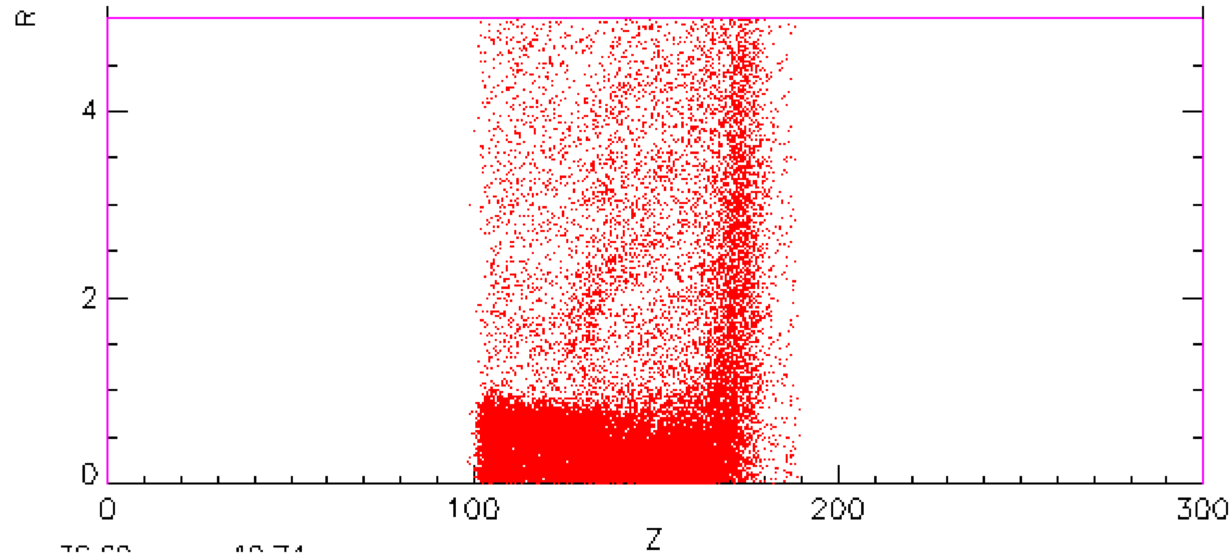
τ = 0.5 ns, 7-3.5 mm radius

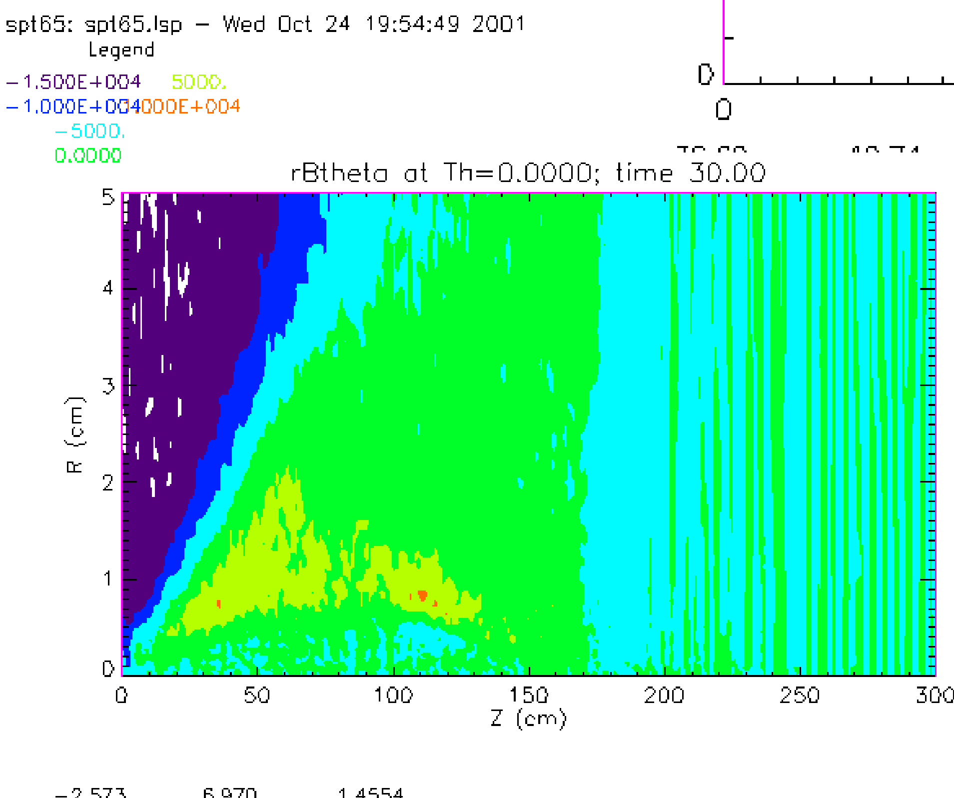
50-mTorr Xe gas fill

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

Tolerable steady-state erosion rate ~ 10^{-3}

At 65 mtorr, beam develops an equilibrium half-current radius of 0.5 cm



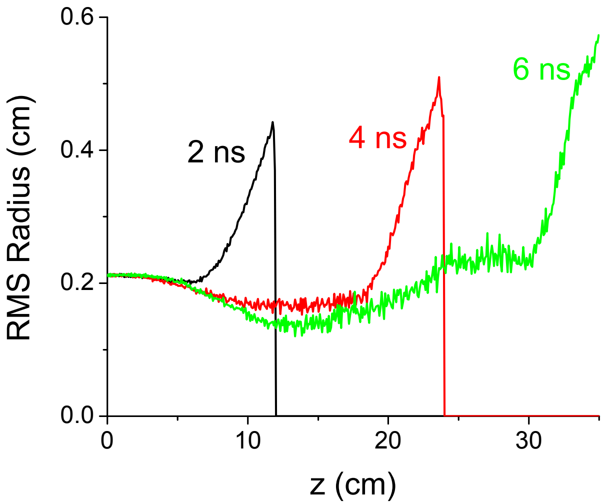


~5 kA of net current

"Equilibrium" studies…

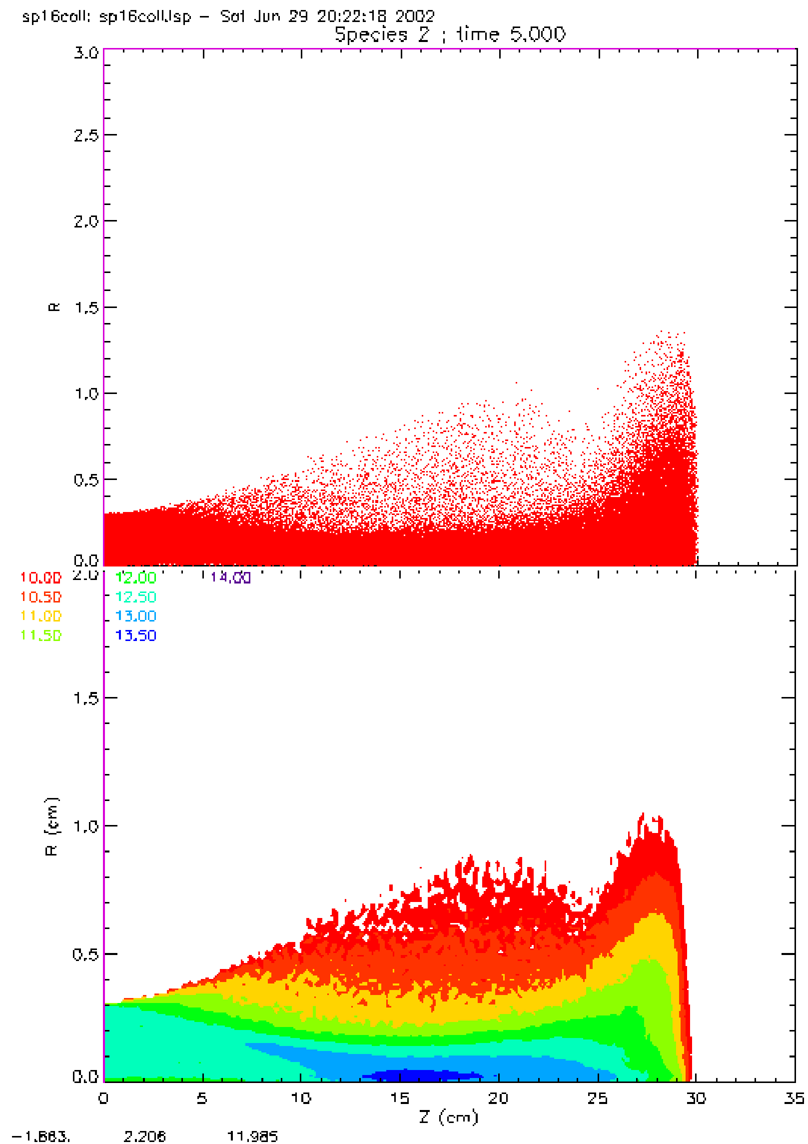
- Examine plasma electron and plasma ion evolution in the presence of a rigid beam (no beam dynamics)
- Equilibrium simulations use an "infinitely" massive beam ion with the same charge state (+65) and ionization cross-sections as previous runs
- Radial ion velocities found to be consistent with channel hydro limits.

Simulations with finite-mass beam ions (Pb^{+65}) and radial temperature profiles suggest less evaporative losses.



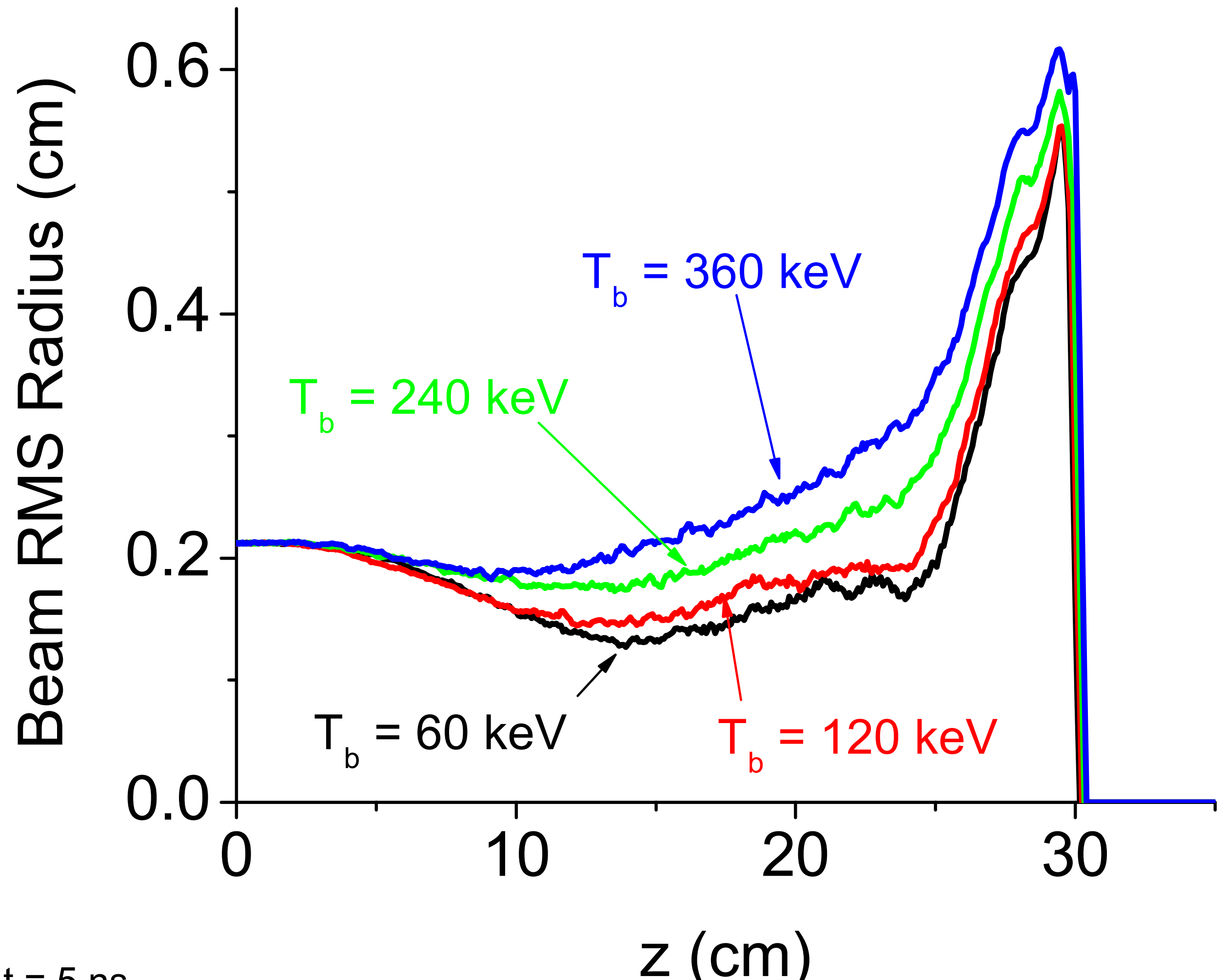
Beam Particle Positions @ 5 ns

Beam Density (LOG) @ 5 ns



$T_{b\text{-}perp}$ = 12 keV

Scans in T_b carried out to look for optimal beam matching conditions.



t = 5 ns

Status: SPT

- Self-pinched transport is an attractive chamber propagation scheme; small entrance holes in the chamber wall, no hardware (sacrificial structures) in chamber.
- LSP simulations have identified a propagation window in 10-150 mTorr Xe.
- We continue to work towards understanding the beam transport equilibrium and improve transport efficiency:
  - Multiple plasma ion stripping examined
  - Radial temperature profiles for the beam examined
  - Trumpet length and beam temperature being examined for optimal matching
- Equilibrium studies being carried out to study plasma ion distributions and their coupling to the beam transport.
- Efficiency of energy transport is presently being studied.
  - Simulations so far have shown evaporation at early stages of transport can result in up to 30% losses.
  - Steady-state erosion rates are predicted to be small.

Farrokh's Three Questions:

- Wrap up? A journal paper is being prepared on the APT work. One important remaining question is "how small a 50 kA channel can be made?" The SPT studies are more computationally challenging and need more work (and more computer time) to optimize the transport efficiency over several meters. A journal paper is envisioned in the next year (depending on funding).
- Impact on ARIES IFE studies? Both transport modes have significant impact on the final focus and chamber designs, with possibly high leverage in facility cost.
- Experiments?
  - APT: To date, channel formation studies have been carried out (SNL, LBNL, GSI), but only microAmp heavy ion beams have been used on free-standing channels (GSI). Wall stabilized channels have been formed (NRL) and intense light ion beams (100 kA) have been transported (2.5 cm diam.). High current heavy ion beam experiments need to be carried out (IRE class driver, minimum).
  - SPT: Experiments (NRL) using light ion beams injected into low pressure gas (He) have been carried out, but optimal injection conditions were not delivered. New experiments are on pulsed power facilities (with further diode development) are feasible and necessary for continued evaluation of this transport scheme. Heavy ion beams of sufficient intensity will likely require costly new facilities (IRE?)