IBX

Possible Chamber Experiments

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IBX (25-50 ns final pulse)

New challenge for final transport is to focus whole pulse onto target – integrated experiment includes time-dependent energy and current variations due to ramping/drift compression

[not just "DC" slice as in NTX and past experiments]

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	ARIES-IFE (2002) Possible option: but tighter constraints on vacuum and beam emittance	ARIES-IFE (2001) Option: uses 1-10 Torr *2 beams*	ARIES-IFE (2001) 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) ARIES-IFE (2002) Possible option: but tighter constraints on vacuum and beam emittance	ARIES-IFE (2001) Option: uses 1-10 Torr *2 beams*	PROMETHEUS-H (1992) ARIES-IFE (2001) 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) ARIES-IFE (2002) Main-line approach: uses pre-formed plasma and 1 mTorr for 3 meters *~50-200 beams*	ARIES-IFE (2002) Option: uses 1-10 Torr *2 beams*	ARIES-IFE (2002) Option: uses 1-100 mTorr ~2-100 beams

Several quantities scale with the line charge density λ

Beam potential:	$\varphi_0 = qI_p/(\beta c) = \lambda$
Electric field at beam edge:	$E_0 = 2\varphi_0/r_b = 2\lambda/r_b$
Current (electric):	$I_e = \lambda\beta c$
Magnetic field at beam edge:	$B_0 = 2I_e/(cr_b) = 2\lambda\beta/r_b$
Time scale for electron motion:	$\tau = 2R/(\beta_e c)$ where $(1/2)m_e\beta_e^2c^2 = e\varphi_0$, so $\tau \sim \lambda^{-1/2}$
Beam density:	$n_b = \lambda/(\pi r_b^2 qe)$
Beam plasma frequency:	$\omega_{bi} = [4\pi n_b qe^2/(AM_p)]^{1/2} \sim \lambda^{1/2}$
Beam cyclotron frequency:	$\omega_{ci} = qB/(AM_p c) \sim \lambda$

Example: FFSE, $\lambda \approx 8\times10^{-4}$ μC/m, $e\varphi_0 \approx 8$ eV, $E_0 \approx 16$ V/cm (for $r_b = 1$ cm)

Driver, $\lambda \approx 80$ μC/m, $e\varphi_0 \approx 0.8$ MeV, $E_0 \approx 1.6$ MV/cm (for $r_b = 1$ cm)

Electron motion, non-local ionization, beam pinching, ω_{bi}, ω_{ci}, etc., increase with λ

Need to study science issues as λ increases toward driver scale

A Series of Scaled Experiments at LBNL will address science issues of HIF

Concept: keep perveance K at driver-scale, and progressively increase λ

FFSE (Final Focus Scaled Experiment) *electron neutralization* — **Completed**

160 keV Cs^+, 95 - 400 μA, $K = 1\text{-}4 \times 10^{-5}$, $\lambda = 2\text{-}8 \times 10^{-4}$ μC/m

NTX (Neutralized Transport Experiment) *neutralized ballistic transport* — **Being set up**

400 keV K^+, 75 mA, $K \approx 10^{-3}$, $\lambda \approx 0.05$ μC/m

HCX (High Current Experiment) *quadrupole transport in accelerator* — **Underway**

1.8 MeV K^+, 0.8 A $K \approx 10^{-3}$, $\lambda \approx 0.2$ μC/m

IBX (Integrated Beam Experiment) *first integrated system/bunching* — **Proposed**

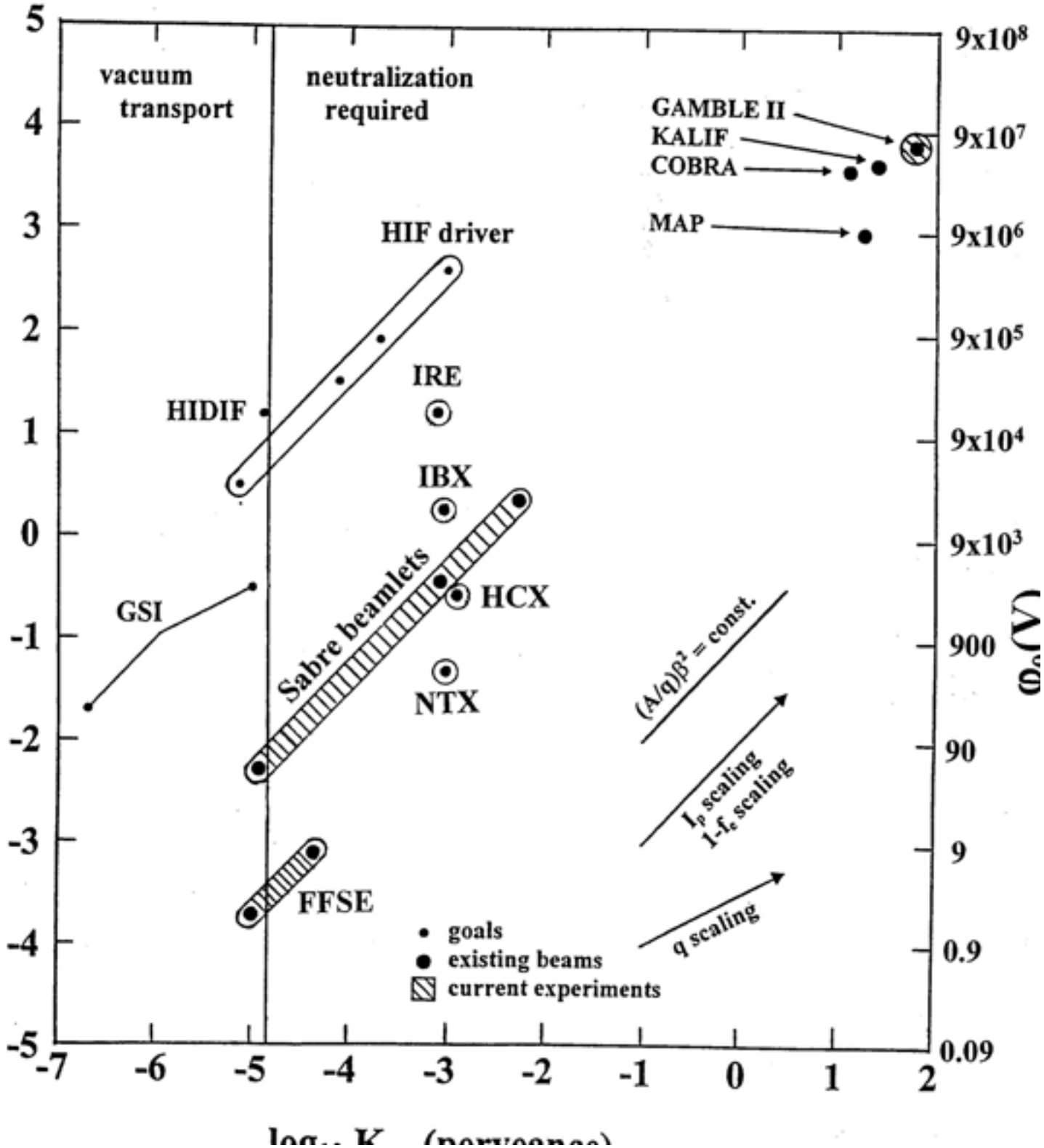
10-20 MeV K^+, 10 A (final) $K \approx 10^{-3}$, $\lambda_{final} \approx 1\text{-}2$ μC/m

IRE (Integrated Research Experiment) *integrated system/heat matter* — **Future**

200 MeV K^+, 500A (final) $K \approx 7.5 \times 10^{-4}$, $\lambda_{final} \approx 17$ μC/m

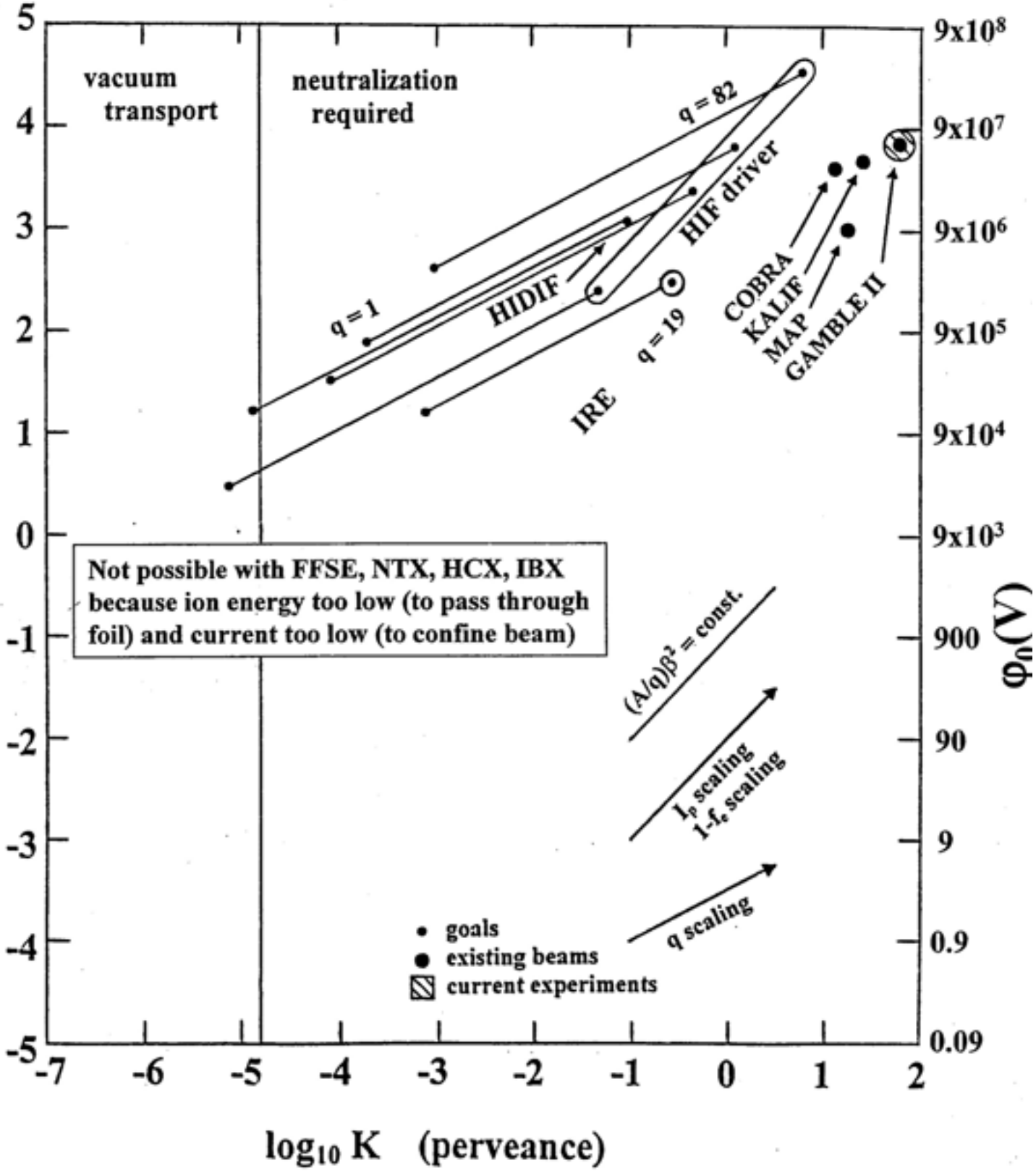
Parameter space for neutralized transport

q = 1

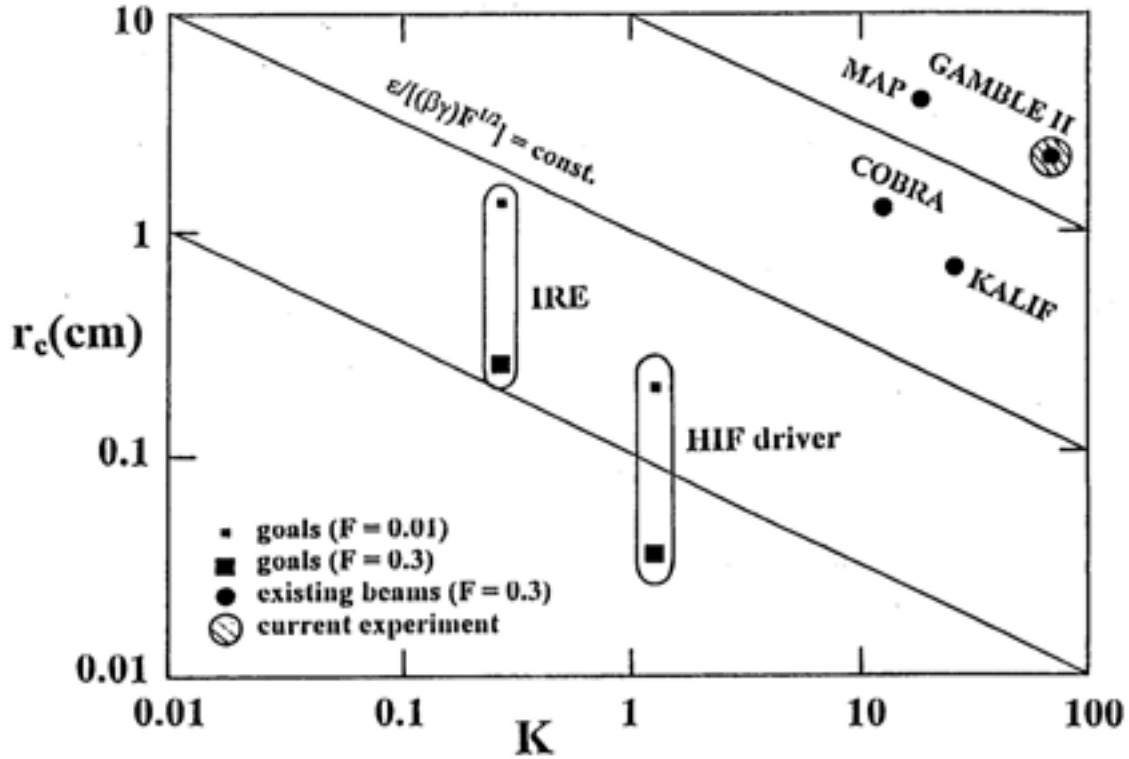


Parameter space for channel-like transport

q ~ Z (~ fully stripped)



Small equilibrium beam radius for channel-like transport requires high current (high K) and small emittance (ε)



$$r_c = [\varepsilon/(\beta\gamma)]\,[FK]^{-1/2}$$

ε = unnormalized emittance
$F = I_c / (qI_p)$ for channel
$F = I_{net} / (qI_p)$ for self-pinched
K = perveance

Currents ≥ 1 kA needed to study pinch modes

Channel transport issues for IRE

(1) demonstration of efficient channel transport with a heavy ion beam over a sizeable distance at small radius
- (pre-IRE) understand minimum radius limit due to channel heating
- (pre-IRE) understand high voltage channel drive
- hydro expansion of channel
- long distance transport ($L > \lambda_\beta$)

(2) capture/combining of multiple beams

(3) radial beam profile at target

(4) instabilities (esp., filamentation)

Self-pinched transport issues for IRE

(1) demonstration of efficient self-pinched transport with a heavy ion beam over a sizeable distance at small radius

- hydro expansion
- beam front erosion
- aiming of beam in chamber
- long distance transport ($L > \lambda_\beta$)
- (for mini-focus) wall guiding (halo, bends, image currents)

(2) beam interaction/overlap near target

(3) radial beam profile at target

(4) instabilities (esp., filamentation)

IBX Chamber Experiments

(1) Focus voltage-ramped/drift-compressed beam onto target

(2) Neutralized ballistic focus (Isp simulations look good for NTX)
- (verify that there are no new problems at the higher λ of IBX)
- plasma plug
- neutral gas
- ionization from photons from target

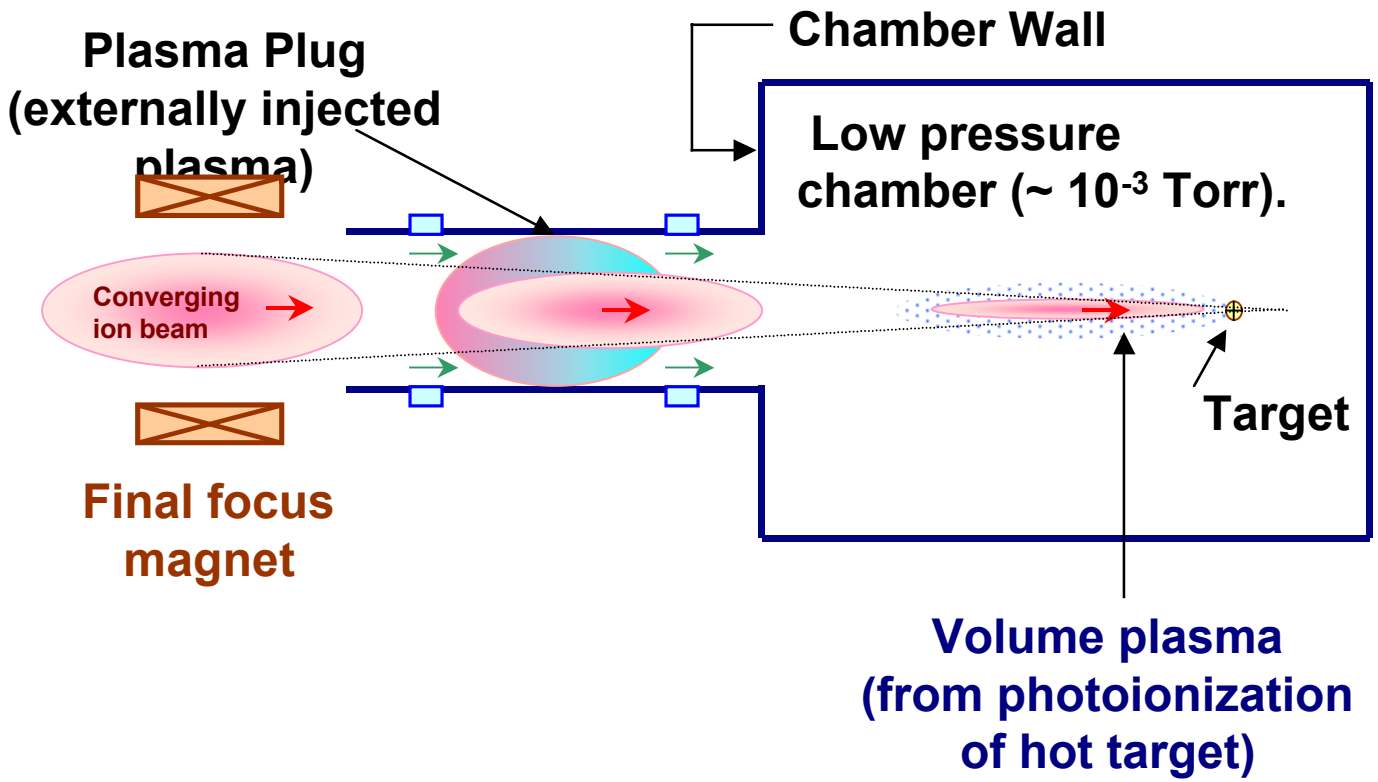
(3) Effects of wall materials and varying distances to beam (including stability)
- effects of ΔR in metal boundaries
- effects of boundaries modeling liquid jets, vortices, slabs, etc.
- effects of various boundary materials (dielectrics, Flibe, Flibe on metal, etc.)

(4) Effects of aerosols
- first study for ARIES

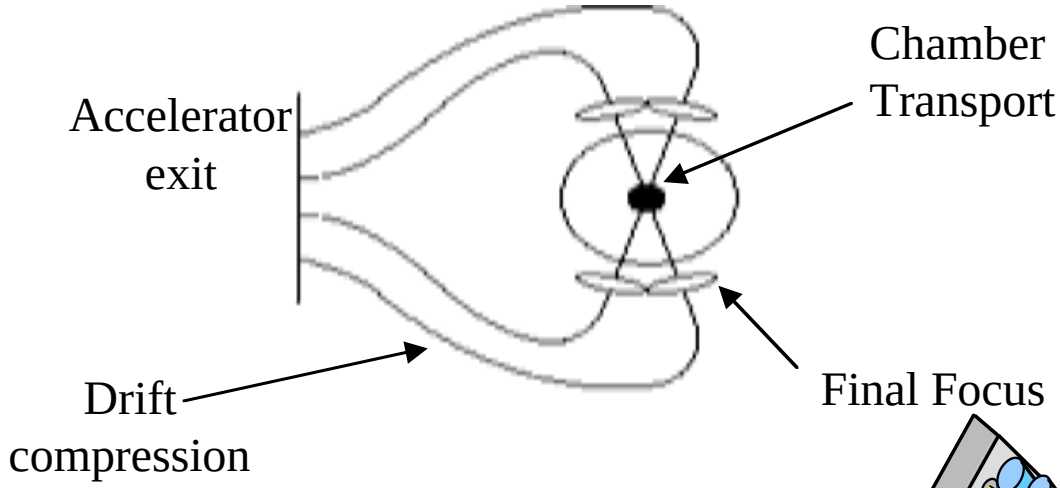
(5) Possible modeling of multiple beam effects
- use solid tapered metallic rods (with/without current) to model neighboring beams

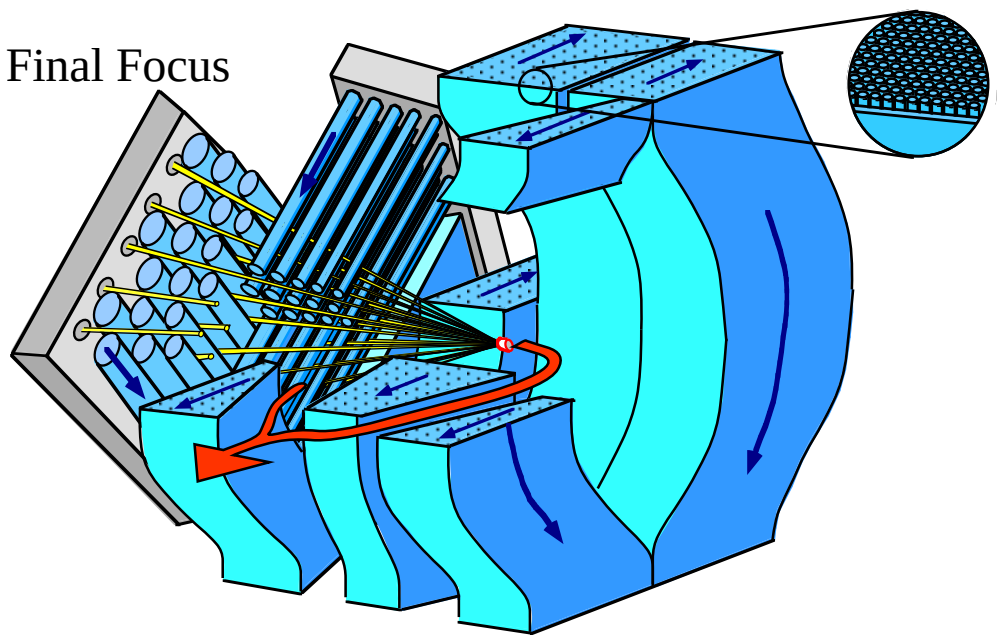
(6) Effects associated with ramping/drift compression
- effects of voltage errors in ramping voltages

Neutralized Ballistic Transport



Neutralized ballistic transport with thick liquid walls is mainline approach for HIF





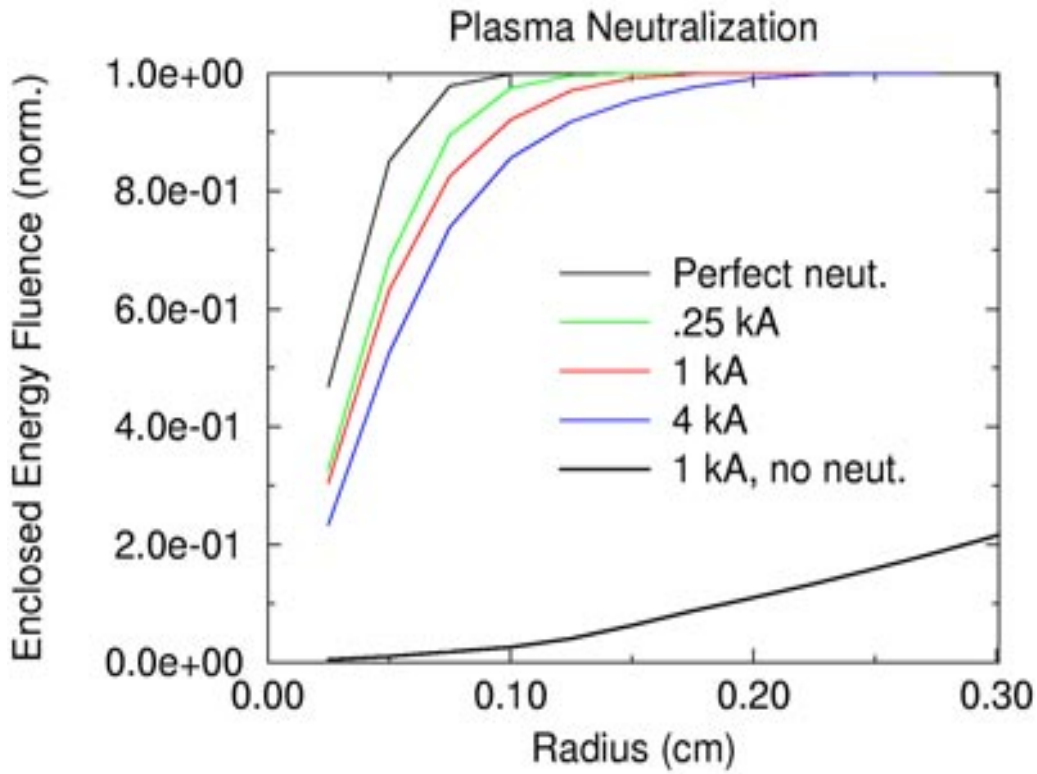
Multiple beams converge onto one side of target, and Flibe jets for thick liquid wall chamber

(Per Peterson HIF2002 Invited Talk)

Driver Scale Simulations for 3 meter transport show neutralization with plasma near injection produces small spot

plasma plug (13 cm) + vacuum + wall emission

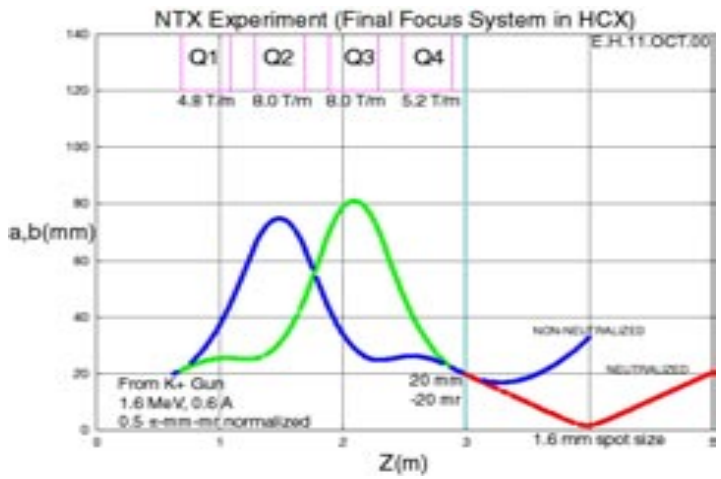
beam spot < 1 mm for all currents



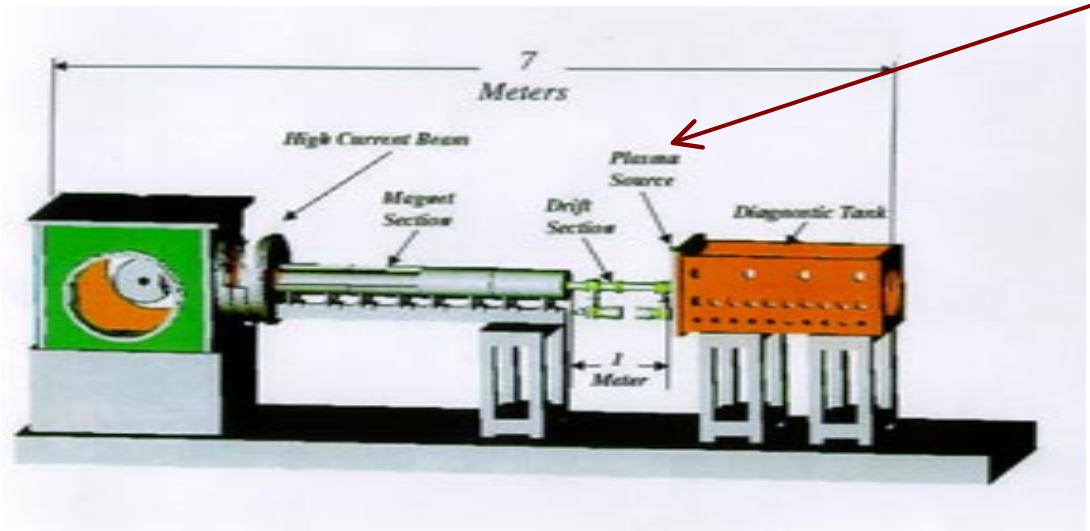
NTX (Neutralized Transport Experiment) will study ballistic focus with plasma neutralization

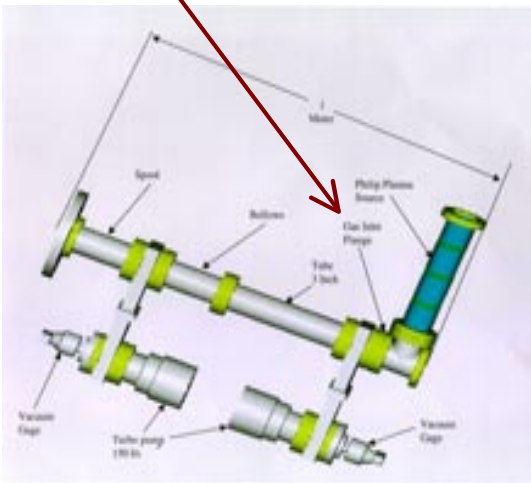
New source/optics in existing 400 kV injector allows low aberrations and small focal spots after neutralization, for a range of perveance

→large plasma neutralization effect



The plasma source will allow control of both spatial plasma gradient as well as a range of plasma to beam density ratios, background gas, controlled and variable





Aerosol Effects

(1) ∂E/∂x — find aerosol limit for 10% energy loss

(2) Scattering — assume emittance dominated spot
find limit for 10% increase in spot area (5% in radius

(3) Stripping — find limit for onset

(4) Charged droplets — charging processes
role of ion beam in charging
max ϕ that droplet can attain
simple deflection due to E

(5) Micro-breakdown — fine mist, beam E leads to breakdown
beam induced ionization of aerosol
net B
pinches

(6) Plasma-like effects of "charged aerosol" — Debye-like effects
dusty plasma effects
plasma waves, etc.

…

Examples of $n_{aerosol} r^3$ for all three cases

Recall: $n_{aerosol}\, r^3 = [3/(4\pi)]\, n_{equivalent} / n_{liquid}$

Use: $n_{liquid} = 10^{22}\ cm^{-3}$

Then:

$n_{aerosol}\, r^3 = 1.0 \times 10^{-3}$ for $\partial E/\partial x$ limit for q = +10

$n_{aerosol} r^3 = 0.25 \times 10^{-6}$ for scattering limit for q = +10

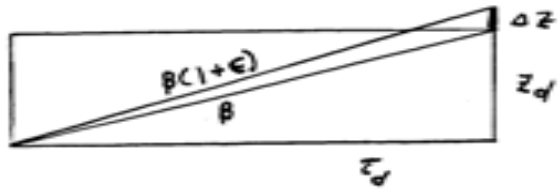
$n_{aerosol} r^3 = 0.86 \times 10^{-9}$ for stripping

Worst case is for stripping

Example (use $n_{aerosol}\, r^3 = 1 \times 10^{-9}$):

$n_{aerosol}$ (cm^{-3})	r (micron)
10^{12}	0.001
10^{9}	0.01
10^{6}	0.1
10^{3}	1
1	10

VOLTAGE ACCURACY FOR DRIFT COMPRESSION



$$z_d = \beta c \tau_d$$
$$z_d^* = \beta(1+\epsilon) c \tau_d$$
$$\Delta z = \epsilon \beta c \tau_d = \epsilon z_d$$

$$\boxed{\begin{aligned} \epsilon_\beta &= \frac{\Delta z}{z_d} \\ \epsilon_\epsilon &= 2\epsilon_\beta \end{aligned}}$$

EXAMPLE:

IBX

$\beta = 0.03$
$\Delta\tau = 50$ ns
$\Delta z = 45$ cm
$z_d = 30$ m

$\epsilon_\beta = \frac{45}{3000} = 1.5\%$

$\epsilon_\epsilon = 3\%$

DRIVER

$\beta = 0.2$
$\Delta\tau = 10$ ns
$\Delta z = 60$ cm
$z_d = 400$ m

$\epsilon_\beta = \frac{60}{40000} = 0.15\%$

$\epsilon_\epsilon = \underline{\underline{0.3\%}}$

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