HIF-IRE Driver Description

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Four Induction Linac Based IRE Scenarios have been Examined Since 1996

- IRE objectives are evolving: NIF + IRE sufficient for ETF decision

  Source-to-target multiple beam physics

  Technology integration and cost validation

  User Facility: High Energy density plasma science and Ion specific target physics
- Criteria for focusability
- Accelerator parameters

Focusability Factors

Occupied Transverse phase space

Occupied Longitudinal phase space

Neutralization; look at the dimensionless measure of space charge <u>Perveance</u> (Q)

$$Q = \frac{2ZeI}{(\beta\gamma)^3 Mc^3 4\pi\varepsilon_0} \approx \frac{2Z^2 I_0}{(\beta\gamma)^3 (31x10^6 Amp) M_{amu}}$$

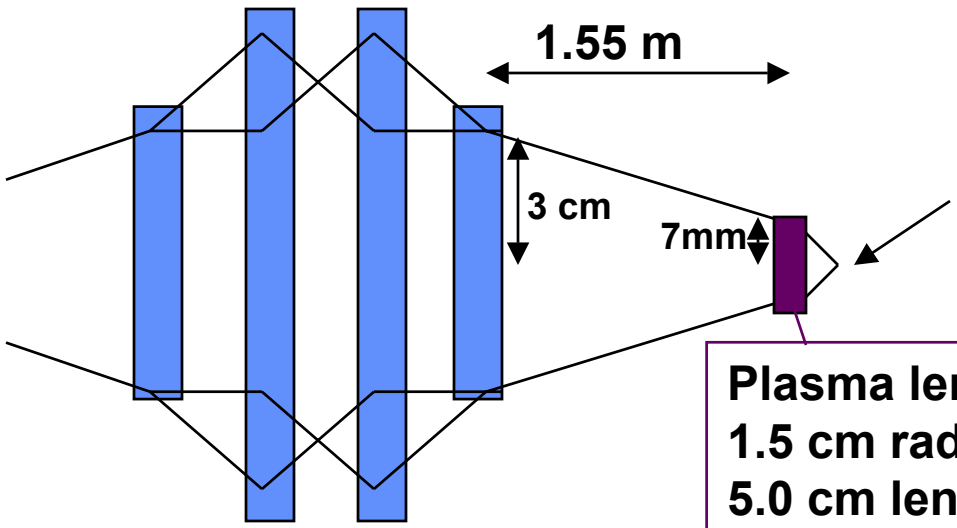
IRE	Q	Required Neutralization	Spot Temperature
100 MeV K^+	10^{-2}	99.9%	———
200 MeV K^+	10^{-3}	99%	100eV for a=2.0mm
400 MeV K^+	10^{-4}	90%	150eV for a=1.0mm
800 MeV R_b^+	$6x10^{-5}$	50%	200+eV for a=1.0mm
	$3x10^{-5}$	0%	

Major Parameters of Four IRE Linacs

Name	HTE Update	IRE 200	IRE 400	IRE 800
Total Energy	30kJ	30kJ	30kJ	250kJ
Final Kinetic Energy	100MeV	200MeV	400MeV	800MeV
Ion	K^+ (39amu)	K^+	K^+	R_b^+ (85amu)
Number of Beams	84/21	32	32	32
Injector Energy	1.6MeV	1.6MeV	1.6MeV	1.6MeV
Pulse Duration at Injection	4.5 μs	6.7 μs	3.3 μs	23 μs
Pulse Duration End of Linac	.4 μs	.2 μs	.2 μs	.2 μs
Initial Gradient	125kV/m	43kV/m	95kV/m	15kV/m
Peak Gradient	500kV/m	1200kV/m	1600kV/m	2000kV/m
Quadrupole Type	Electrostatic/ Pulsed Magnetic	Superconducting	Superconducting	Superconducting
Linac Length	240m	305m	338m	730m
Total Volt Seconds*	100V-s	90 V-s	107V-s	271V-s

* DARHT has $\approx$ 50 V-s

A "double focus" (quads+plasma lens may be used to reduce spot size to ~0.5 mm)



Radius at final focus ~0.5 mm

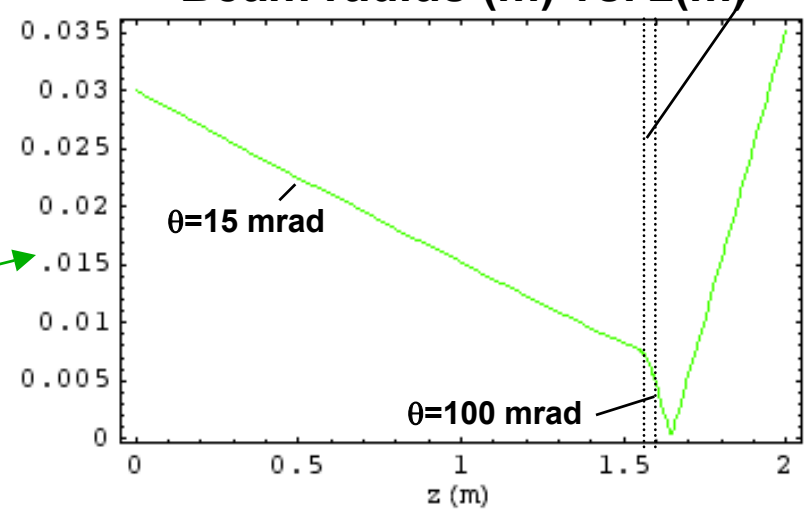
Plasma lens
1.5 cm radius
5.0 cm length
400 kA

Possible alternative: focus to the null of a high field magnetic cusp

Plasma lens

Conventional final focus using quadrupoles

Beam radius (m) vs. z(m)



Envelope plot for T=450 MeV Xe^{+}
Unneutralized perveance = 10^{-3}
99.5% neutralized
Stripped at plasma lens to Xe^{+26}
Normalized emittance =4 mm-mrad

An IRE Accelerator that Matches the 1/4 Scale Target will have 1/4 Range and 1/4 Spot Radius of a Distributed Radiator Target Foot Beam

Xe^{+1} (A=131) at 450 MeV
Total pulse energy = 45 kJ
Pulse duration = 6.25 ns

13 beams required to reduce final perveance to below 10^{-3}
16 beams required for symmetry
64 beams increases cost modestly but reduces perveance to 2×10^{-4} if needed

•Total HIF-IRE •Project Costs	•With today's •technology/ costs (TPC)	•Projected cost with ~$30-50 M R&D to improve technology/ component costs	•Final beam perveance
•64 beams	•$820 M	•$280 M	•2×10^{-4}
•16 beams	•$675 M	•$230 M	•8×10^{-4}

NTX will test focusing over this range of final beam perveances

Induction Module Impedance May be Designed to Match the Beam Load

To minimize reflected power set

$$Z = Z_{matched} \equiv \frac{\Delta V}{I_b}$$

ΔV **= gap voltage**

I_b **= beam current**

Z **= low frequency module impedance**

$(\upsilon \leq 10 MH_z)$**, primarily from drive circuitry and cores**

example:

ΔV **= 500 kV**

I_b **= 112 beams x 100A = 11.2 kA**

$Z_{matched}$ **=** $\frac{500x10^3}{11.2x10^3}$ **= 44.6 Ohms**

Low frequency Z **will vary along the linac**

Crude Model: Inefficiency is Due to Impedance Mismatch and Core Losses

$$\eta \approx \frac{4 Z_d I_b / \Delta V}{\left(1 + Z_d \left(I_b + I_c\right) / \Delta V\right)^2}$$

Z_d = Drive circuit impedance

I_c = Core current

In a driver $I_b >> I_c$ most of linac

$$\eta \approx \begin{cases} 1.0 & Z_d I_b = \Delta V \\ .64 & Z_d I_b = \Delta V / 4 \end{cases}$$

Assumes: reflected power is lost

core losses negligible

reactive components of Z small

no ballast resistors

Z_d is resistive (low υ)

For <u>beam</u> <u>stability</u> we may use $Z < Z_{matched}$

The Resistive Component of Module Impedance Drives a Longitudinal Bunching Instability

Head-to-tail growth rate $\propto$ resistive Z

Capacitive part of Z is stabilizing

Inductive part of Z is destabilizing

Module resonances are at high frequency $\left(\upsilon \geq 10^8 H_z\right)$; they are stabilized by momentum spread and longitudinal beam field

current bunches $SI_b \propto \exp(-i\omega t - i\Omega Z)$

dispersion relation $\Omega^2 = -i\omega \dfrac{eI_b}{M\upsilon^3} Z(\omega)$

typical e-fold distance $\approx 100m$

Low frequency mode is controlled with feed forward circuitry

IRE could be a test bed

Multiple Beam Experiment