New Heating Techniques and Applications and CEE's

Oak Ridge National Laboratory

DOE Peer Review of RF Technology Program
Oak Ridge, TN
May 9, 2000

Heating Modes Under Investigation

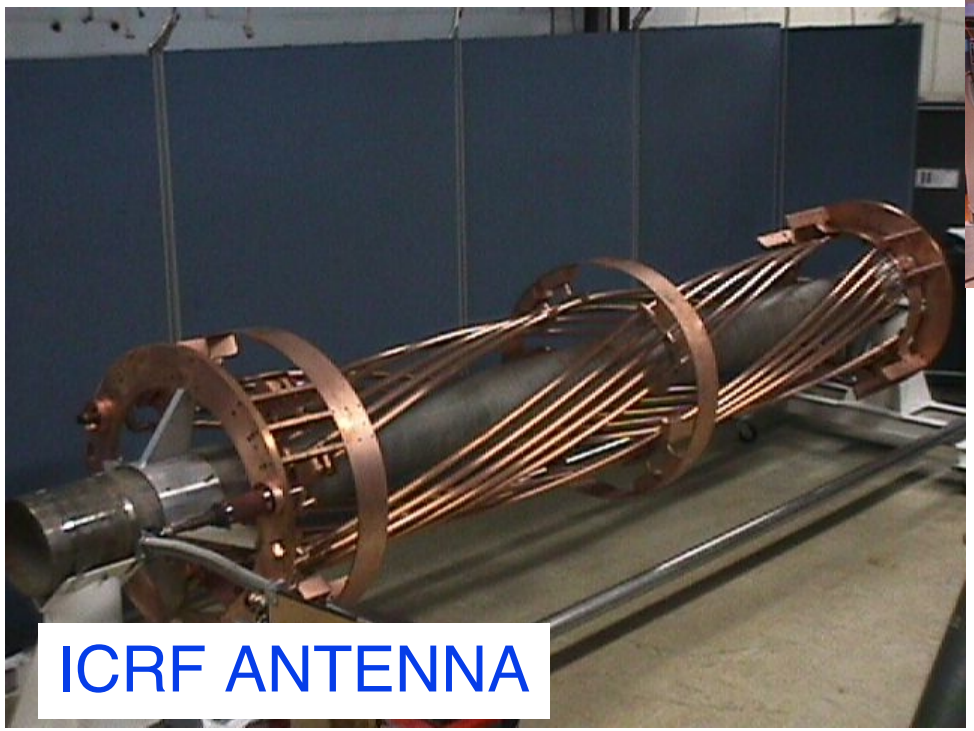
- ICRF
- IBW
- ECH
- EBW
- LH
- Helicons

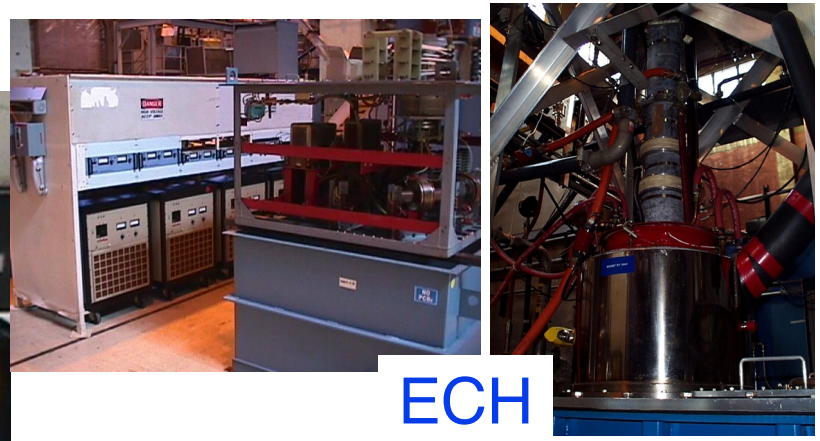
Experiments & Proposals

- Fusion
  - –NSTX- HHFW, ECH, EBW
  - –MST (U. Wisc.) EBW, LH
  - –NCSX (proposed)- HHFW, ECH
  - –QOS(proposed)- ICRF, ECH, EBW
  - –VTX- IBW
  - –ET- HHFW, IBW; Folded Waveguide
  - –FTU/IGNITOR- ICRF; folded waveguide

- Non-fusion
  - –NASA- plasma propulsion- Helicons & ICRF
  - –Isotope separation- ICRF & ECH
  - –Semiconductor processing- ICP

Isotope separation ICRF & ECH





ECH and EBW

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ECH and EBW

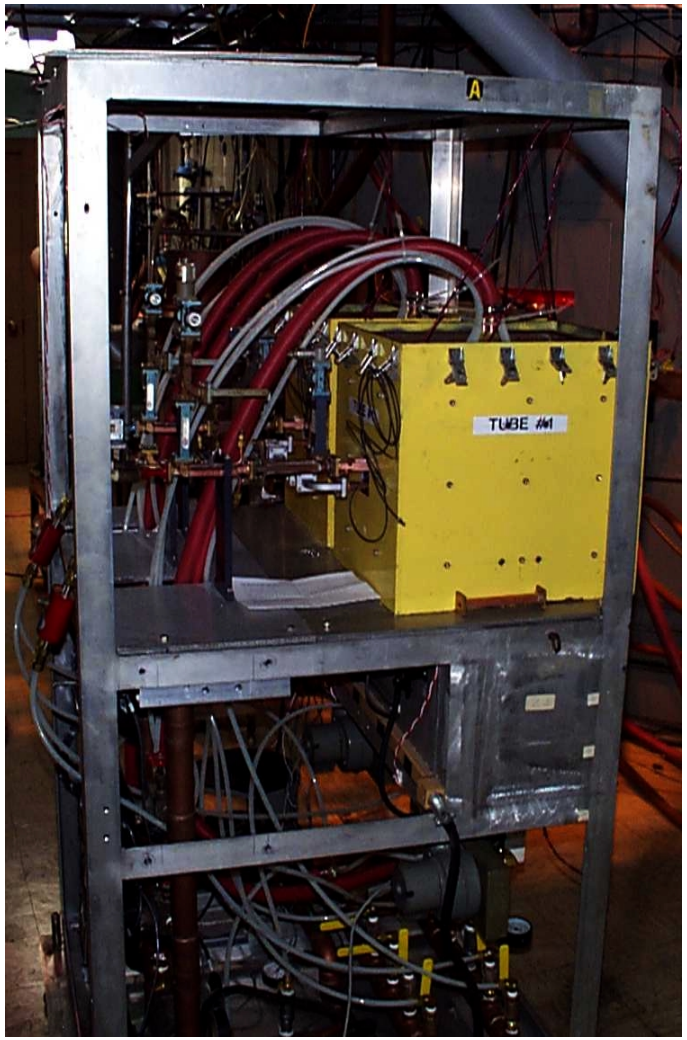
- Motivation
  - Plasma initiation
  - Plasma heating; localized & bulk
  - Plasma startup assistance
  - Current drive
- Applications & recent development work
  - NSTX
  - MST
  - DIII-D

NSTX

- ECH Pre-ionization
  - Developed and installed 30 kW 18 GHz system for PPPL
  - System operational and appears useful for routinely initiating plasma

- High power ECH Startup and EBW system (proposed)
  - 28 GHz hardware available up to ~ 1.2 MW
  - Conceptual design and cost estimates complete

18 GHz ECH-PI Equipment

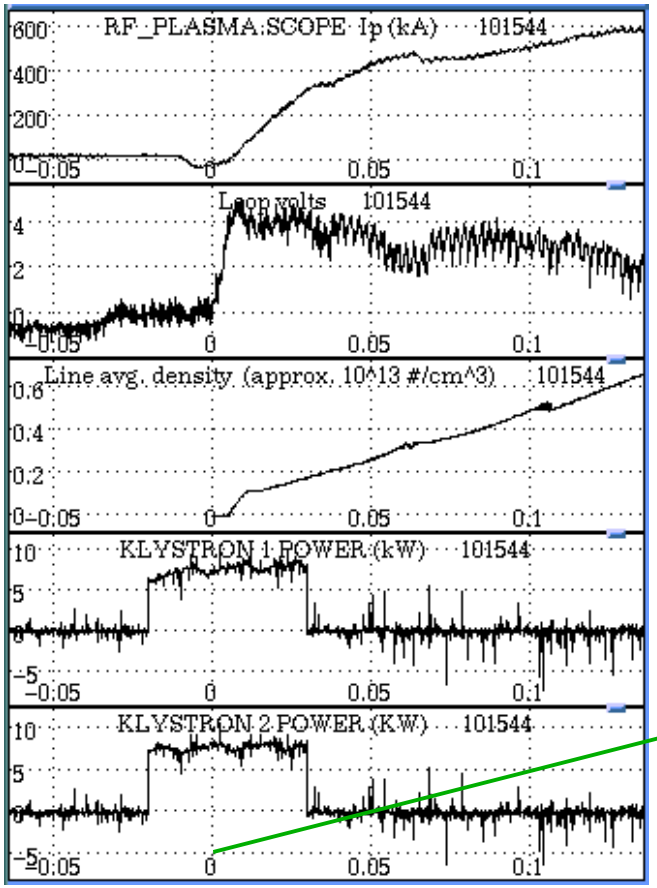


18 GHz klystrons

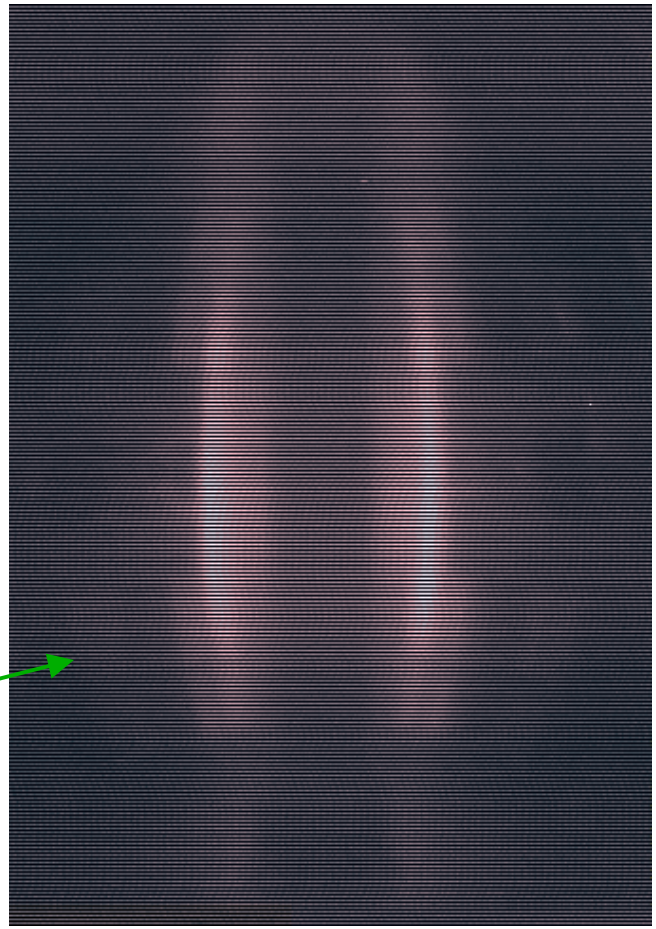
Dual waveguide launcher

ECH Preionization in NSTX generates good startup plasma

Applying ~15 kW of 18 GHz ECH power produces plasma breakdown, allows plasma current initiation with low startup loop voltage



50-ms ECH pulse from 2 klystrons

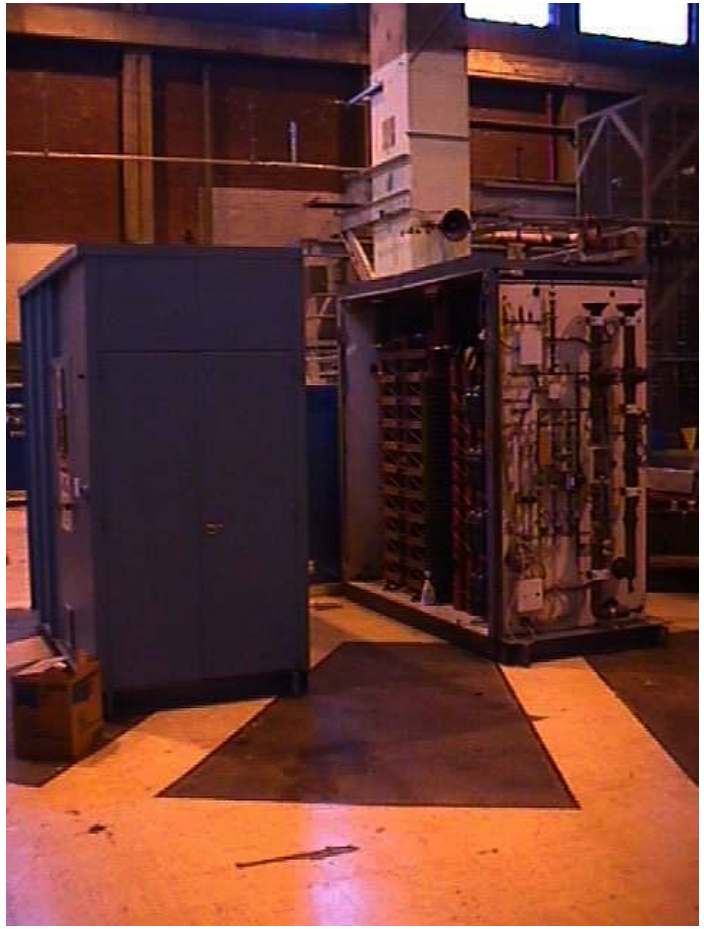


Picture at t ≈ 0 ms showing ECH plasma

High Power ECH on NSTX

- Several missions
  - Startup assist
  - Non-inductive startup
  - Current profile, temperature profile control
- Low field imposes low density limit for ECH
  - EBW heating proposed
- High power 28 GHz ECH hardware available at ORNL
  - System proposed
  - Quite feasible
  - Relatively low cost due to use of existing infrastructure and hardware
  - Conceptual design in progress
- Proposal for NSTX funding in place
  - FY2001 current schedule to begin activity

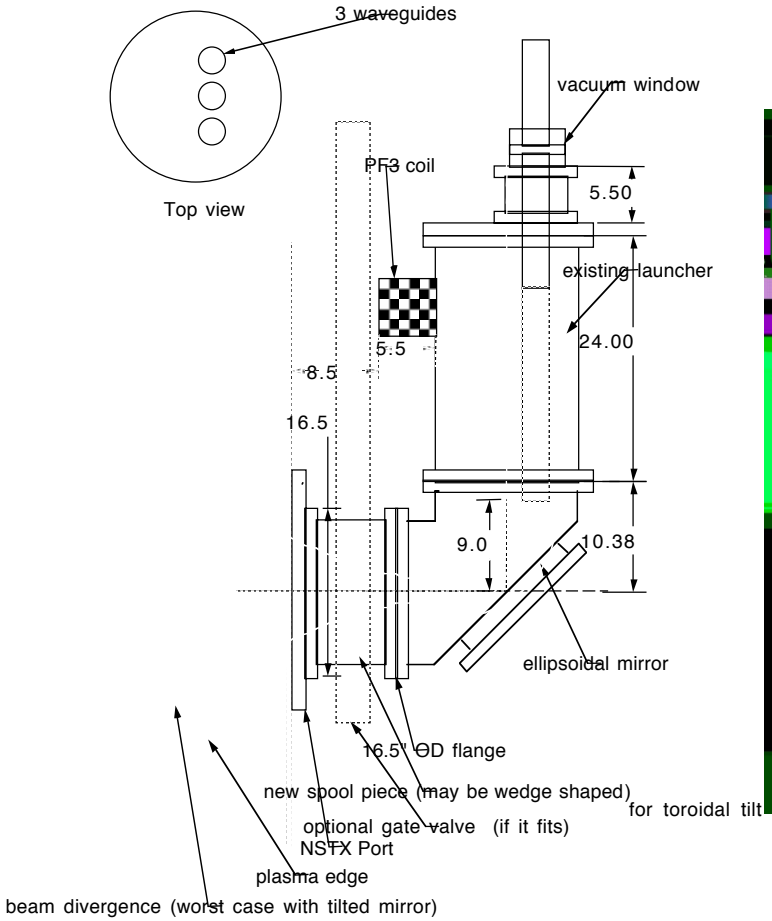
28 GHz ECH Hardware at ORNL



EBW Development

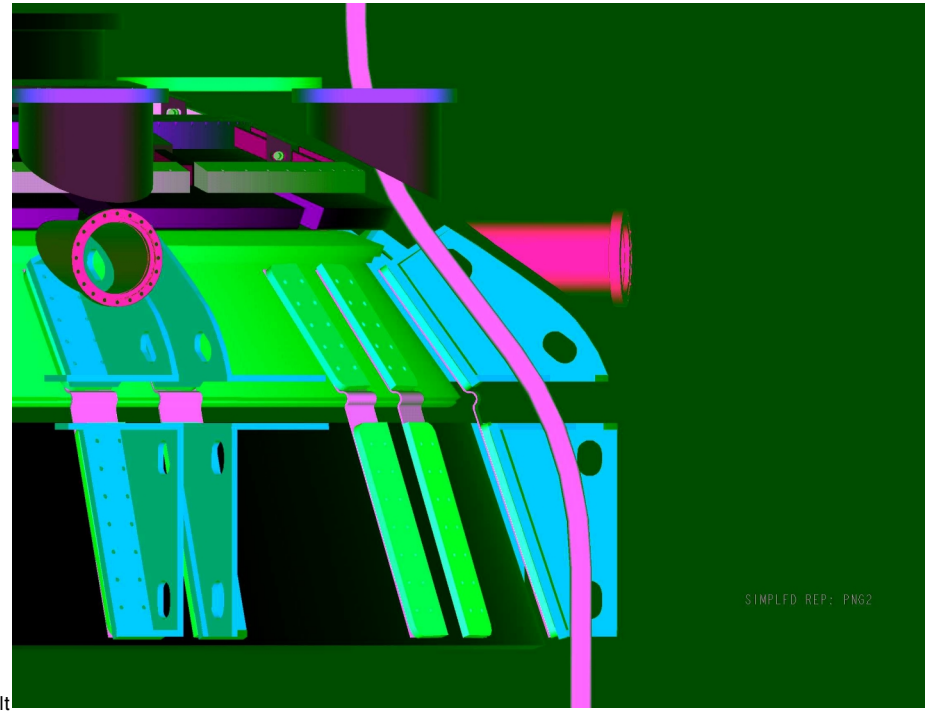
- Electron Bernstein wave heating and current drive offers a very exciting new capability for low field, overdense plasma heating
- Coupling efficiency critically dependent on mode conversion/tunneling process
  - Density profile and fluctuation levels are important
  - Launch beam control critical
- Some demonstrations have been successful on W7AS
- Two coupling modes analyzed O-X-EBW; X-EBW
- High quality beam launch required
  - Polarization control
  - Narrow beam focused near critical edge layer
  - Experimental beam pointing control
  - Low frequency makes this more difficult
- EBW coupling study planned on NSTX using 18 GHz system (X-EBW)
- O-X-EBW coupling study needed- likely on MST due to delays at NSTX

Two possible launcher schemes



Proposed 28 GHz multiple beam ECH launcher

TSB 2/2000



Curved waveguide through top port
(In-vacuo mirror not shown)

D-IIID

Gyrotron control systems development (Wally Baity)

HVDC Power supply work (Glen Barber)

MST

EBW Development work (proposed)

Launcher design participation

Experimental work- study coupling

Power system development

EBW Launcher development proposed through VLT

Proposed EBW launcher development

Participation through a workshop

NSTX and MST tests

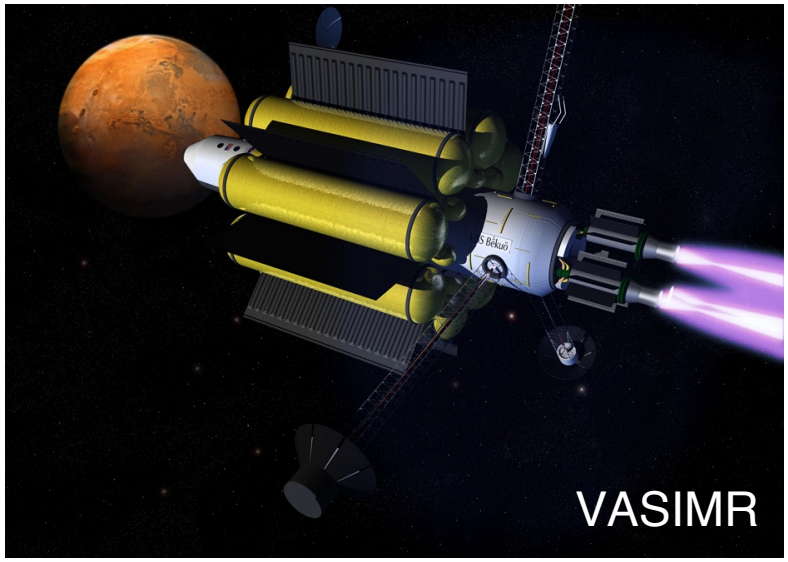
High density plasma sources

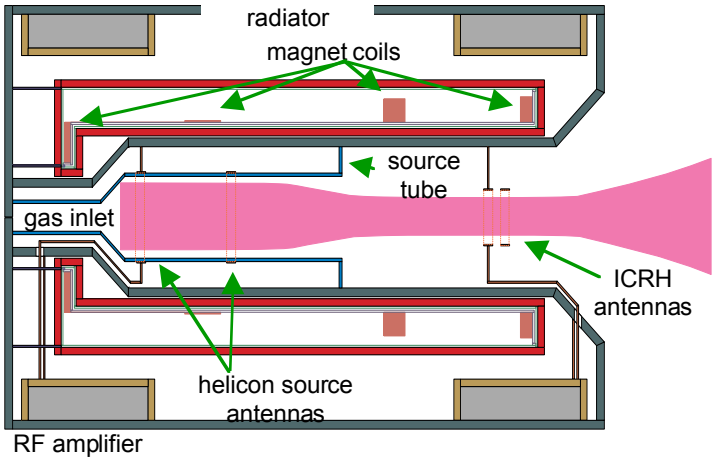
ORNL has developed a high density - low temperature hydrogen helicon plasma source producing densities up to ~ 10^{19} m^{-3}

Work begun on DOE outreach funds, for development of high density RFTF plasma source, later funded by NASA for use as plasma source for VASIMR (Variable Specific Impulse Rocket) concept

Other applications include

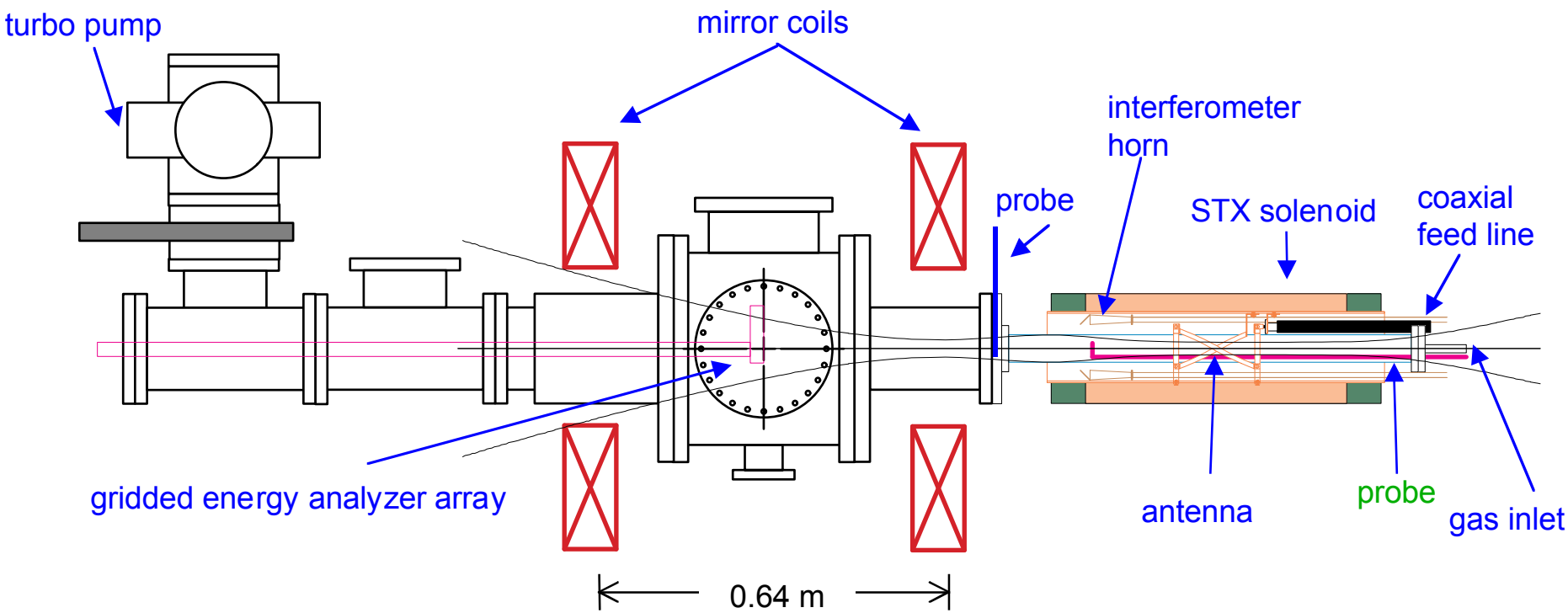
- **Plasma source for CEEs**
  - **First stellarator attempt on SHEILA heliac, good performance with Ar, were not able to obtain high density H plasma with helicon antenna**
- **Investigation of single species ICRH at the fundamental frequency**
- **Materials, RF/edge plasma, high voltage tests**
- **Increasing LH loading by creating localized plasma in front of grill**



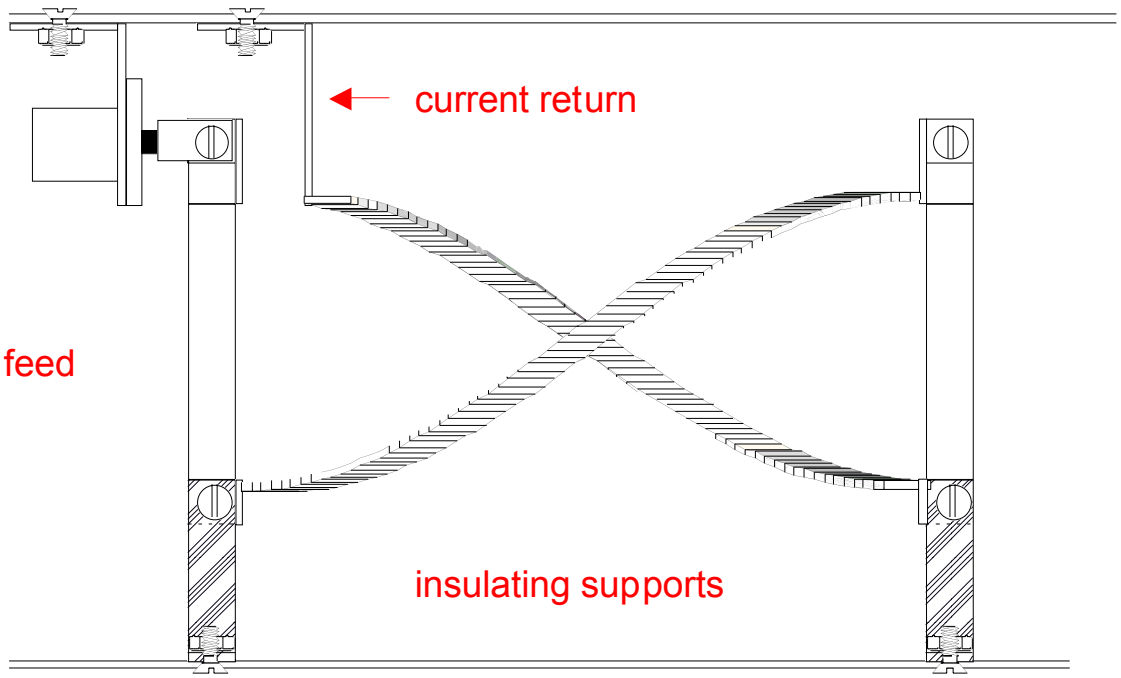


RTD concept

Mini-RFTF with STX solenoid



Multi-configuration antenna for Mini-RFTF Helicon Source



ground plane -fits inside solenoid magnet bore

Can be quickly modified to give several antenna configurations:

- Helical
- Nagoya type III
- Double half-turn
- Phased dual double half-turns

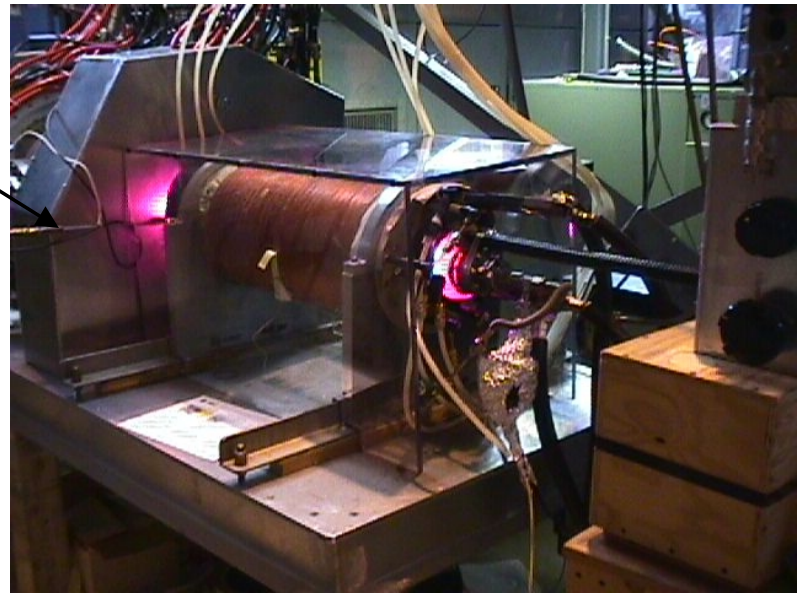
Antenna length and spacing easily modified

Outer ground-plane provides current return path

Hydrogen plasma operation

SIDE VIEW

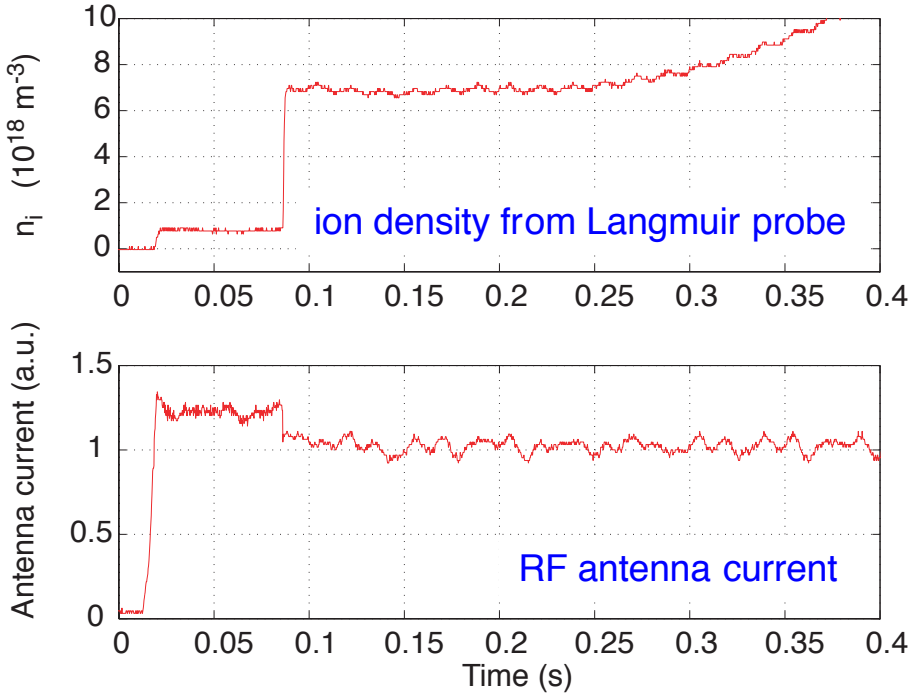
Langmuir probe



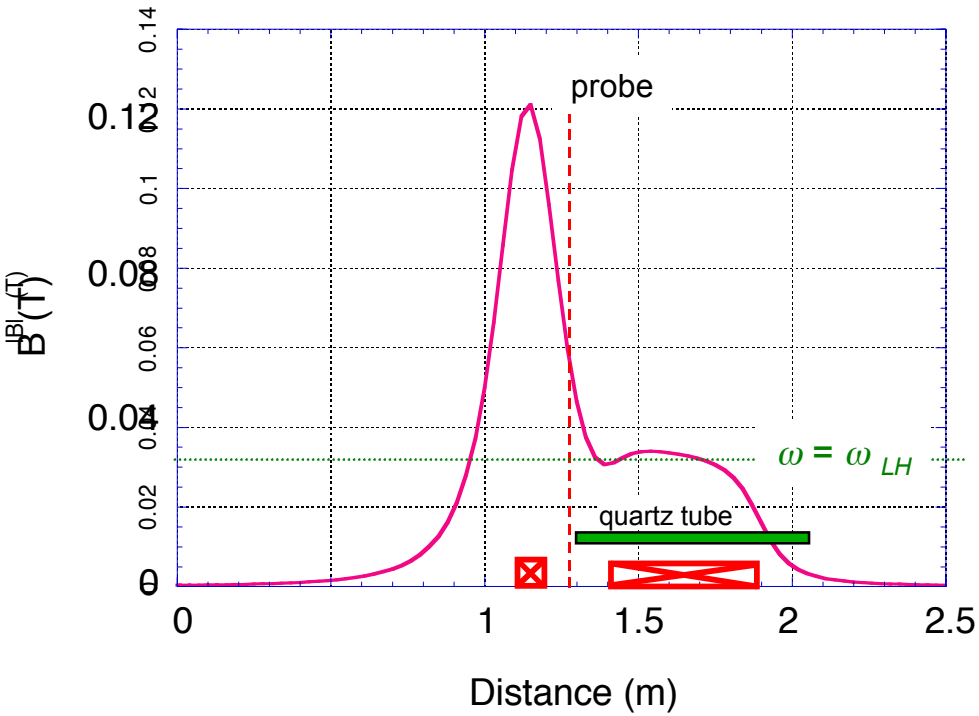
EXHAUST END VIEW

Plasma densities ≥ 7×10^{18} m^{-3} have been achieved for hydrogen plasmas

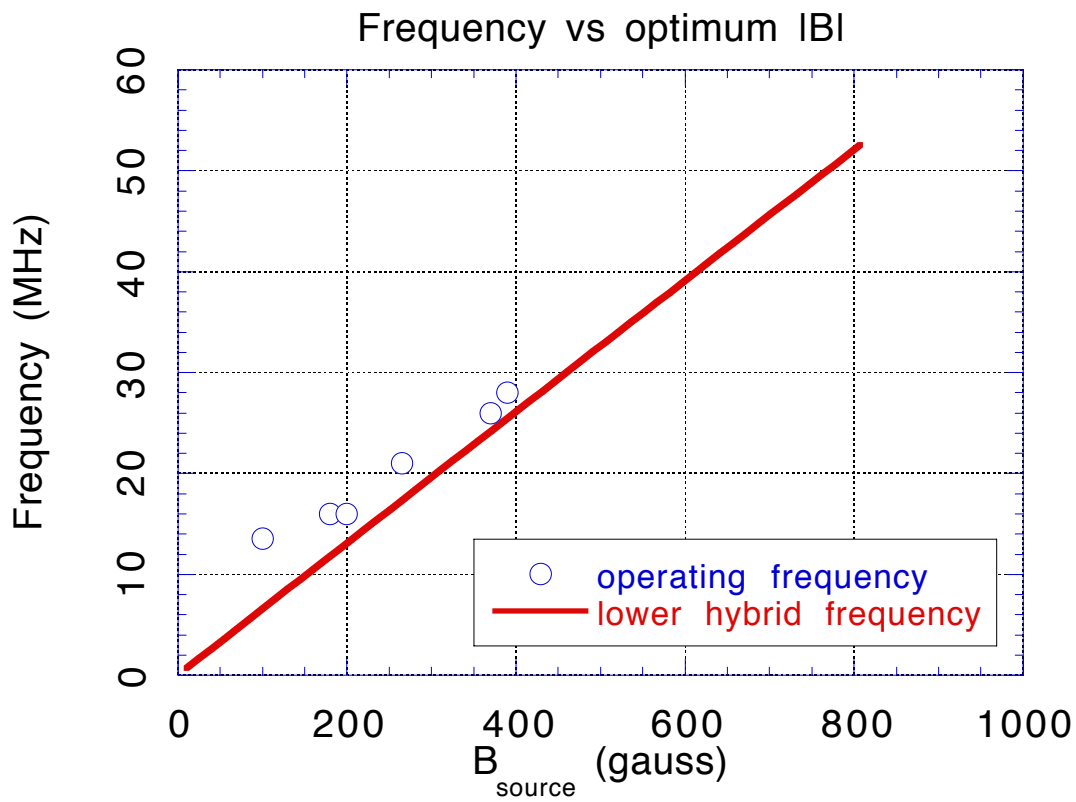
Ion density and and antenna current



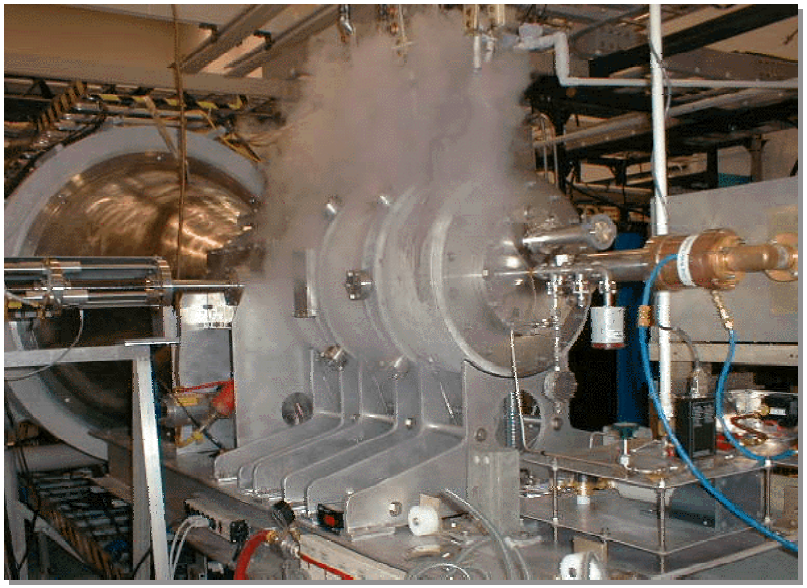
IBI profile for operation at 21 MHz

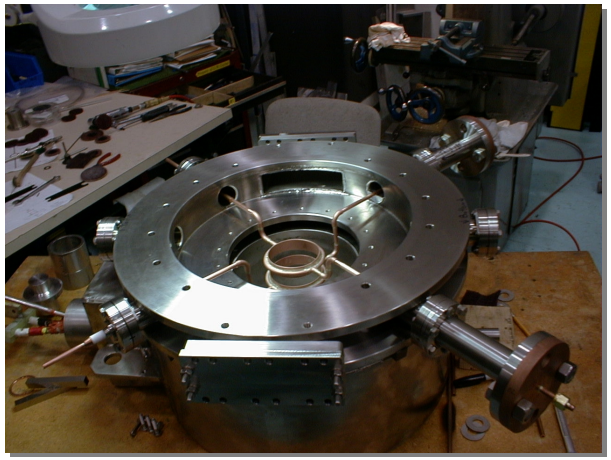


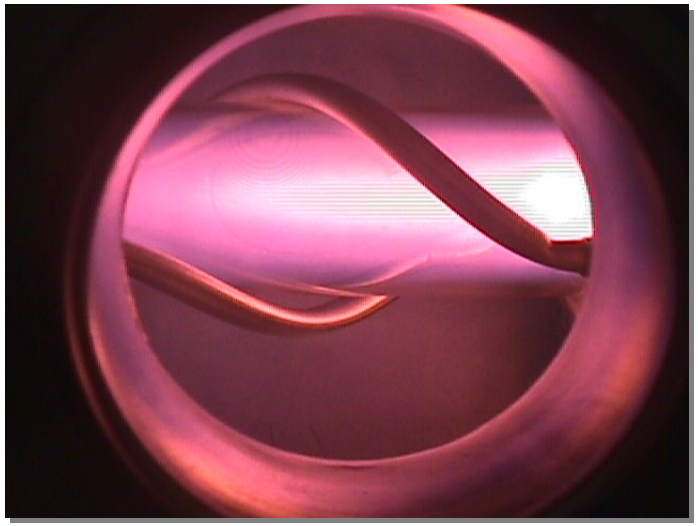
H plasma: Highest density achieved over a range of frequencies for |*B*| such that ω_{RF} is slightly greater than ω_{LH}



VX-10 Device at the Advanced Space Propulsion Laboratory

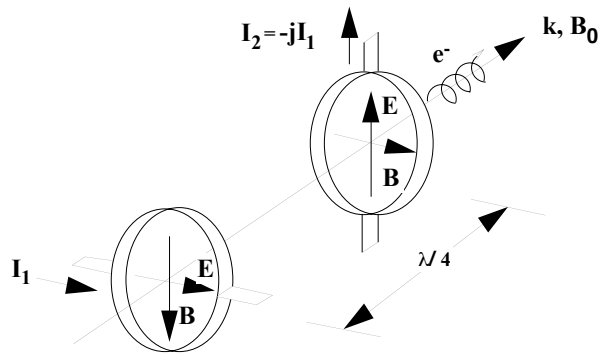




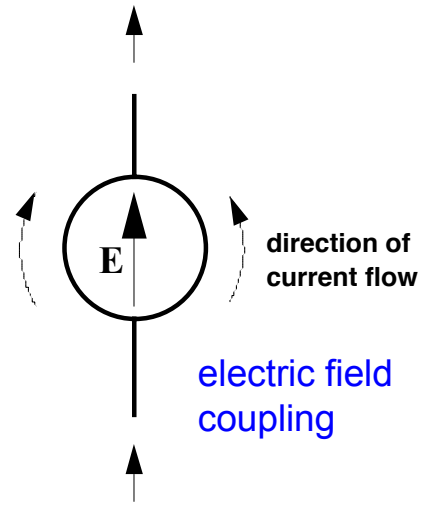


Dual half-turn antennas can couple effectively to helicon modes

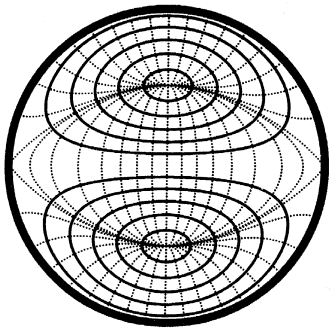
- Phased antennas such as dual half-turn types can be used to launch helicon waves for plasma production, pre-ionization, etc
- Can also launch reverse polarized wave for beach heating
- Single species fundamental ion heating with “helicon” polarization possible if l=2 static magnetic field component is added



Phased dual half-turn array



electric field coupling



Helicon m=+1 mode H andE profiles

D. G. Miljak and F. F. Chen, Plasma Sources Sci. Technol. 7, (1998) p. 61.

Single species mode conversion scenario

Solenoid coil produces z directed magnetic field

Current through boron nitride coated rod on axis of source tube produces l=2 transform through ϕ directed B field

Separate antennas are used for plasma production and ion heating

Ion temperatures measured with existing energy analyzer array, RF b-dot probes used to investigate m=-1 to m=+1 mode conversion

Example scenario:

- plasma production frequency = 13.56 MHz
- ion heating frequency = 310 kHz
- B_z = 195 gauss produced by solenoid (40 A on STX coil)
- B_ϕ = 60 gauss at r = 2.5 cm produced by center rod (~740 A)