Test Stand Development at ORNL

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Plasma Facing Components 2011 Meeting

Oak Ridge National Laboratory

Oak Ridge, Tennessee

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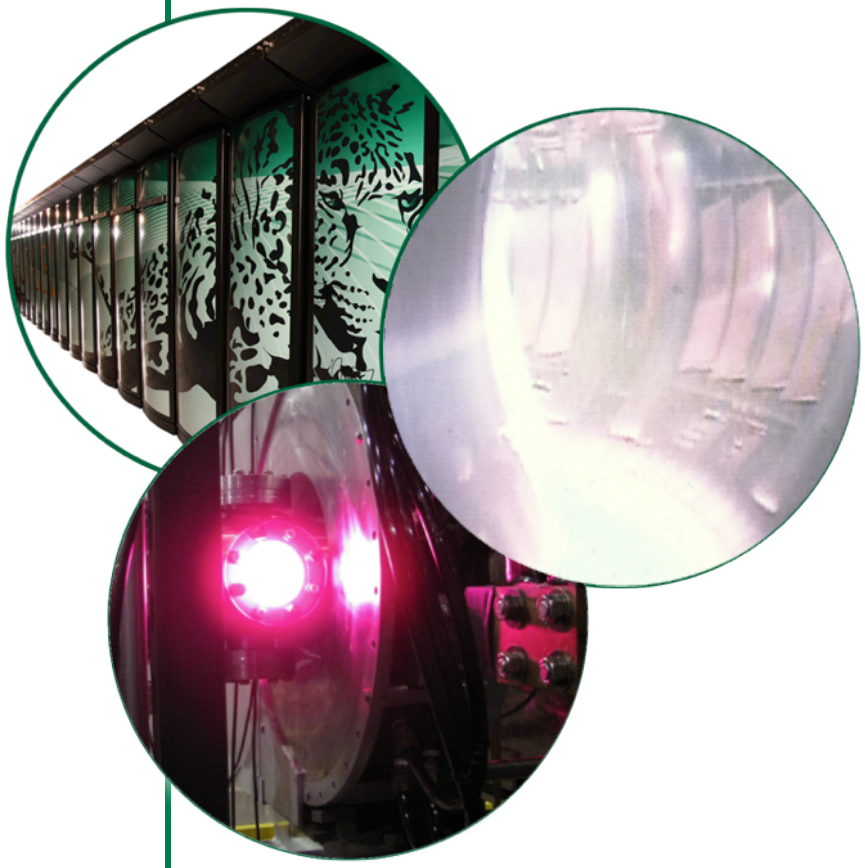

U.S. DEPARTMENT OF ENERGY

Fusion Energy Division
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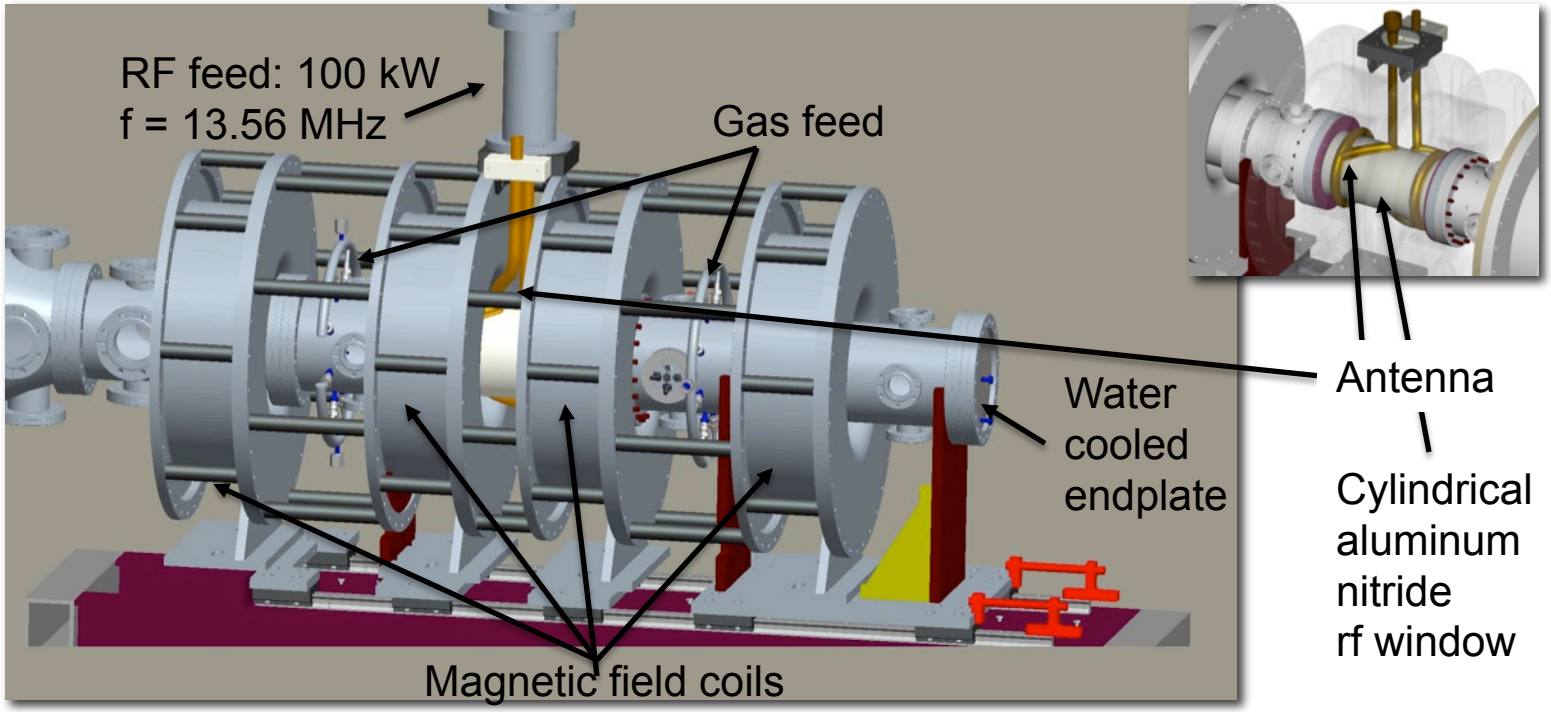
Introduction

- Research is now being conducted at ORNL on a fully rf-based intense plasma source having the following features:
  - Electrodeless
    - inherently steady state
    - low maintenance requirements
    - lack of metallic electrodes and relatively low heat flux in plasma production region minimizes impurity generation
  - Combination of helicon plasma generator with additional electron and ion cyclotron heating allows a wide range of plasma parameters to be produced at the target, without the need for biasing, and with possible high power fluxes up to 20 MW/m^2 with particle fluxes (in the production/heating region) > 10^{23} $m^{-2}s^{-1}$
- A 15 cm diameter, high |B|, high particle flux helicon source has produced plasma densities $n_e > 4 \times 10^{19}$ m^{-3}, and operated at sufficient density (> 10^{19} m^{-3}) with |B| ~ 0.5 T in the plasma production region, to produce required particle flux at source for a PMTS
- Operation of an ECH experiment for investigation of overdense heating (whistler and EBW) in a linear geometry has begun
- Modeling in support of this work is underway using the versions of the Genray (ray tracing) and SOLPS (neutrals and plasma transport) codes modified for use in a linear geometry, as well as the EMS-2D (rf propagation and power deposition) code

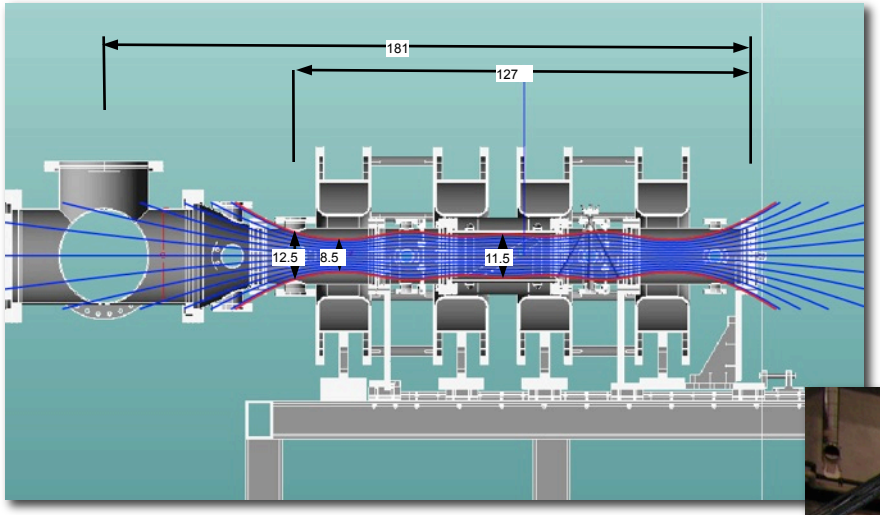
The ORNL high-field helicon plasma source

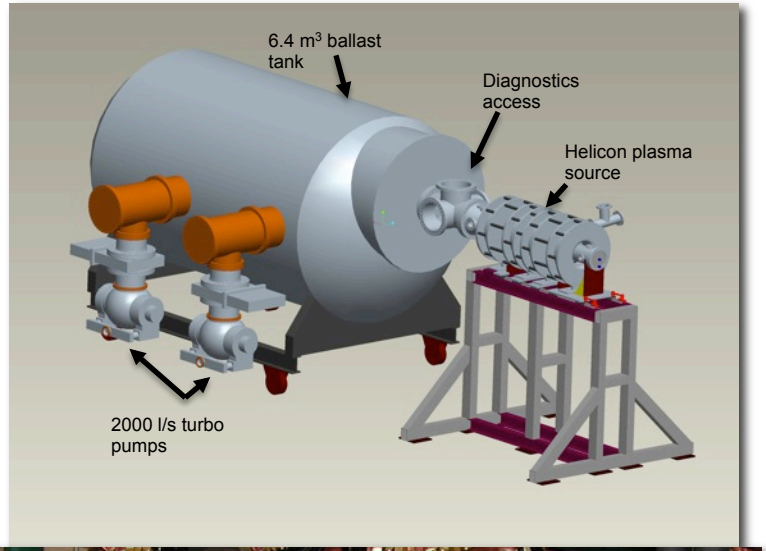


- 15 cm diameter electrodeless light-ion (H, D, He) plasma source
- EBT magnet coils – can produce 1.6 T maximum CW magnetic field strength
  - Produce uniform field underneath antenna for optimum rf coupling to plasma
  - Create downstream peak in magnetic field found experimentally to produce increased plasma production with hydrogen
- Water cooled half-turn helical antenna operated in air – designed for 100 kW operation, presently limited to ~ 30 kW due to currently available rf power
- Aluminum nitride rf window (high thermal conductivity)

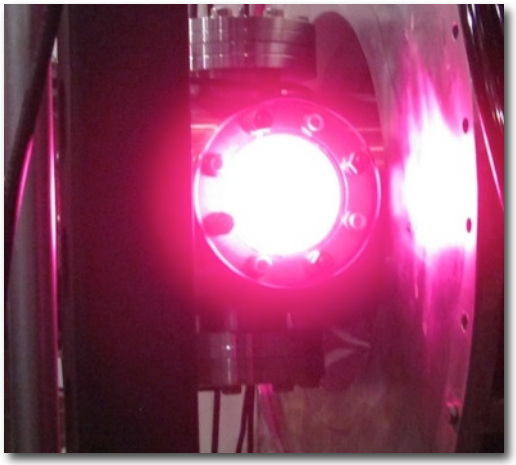
Helicon Views

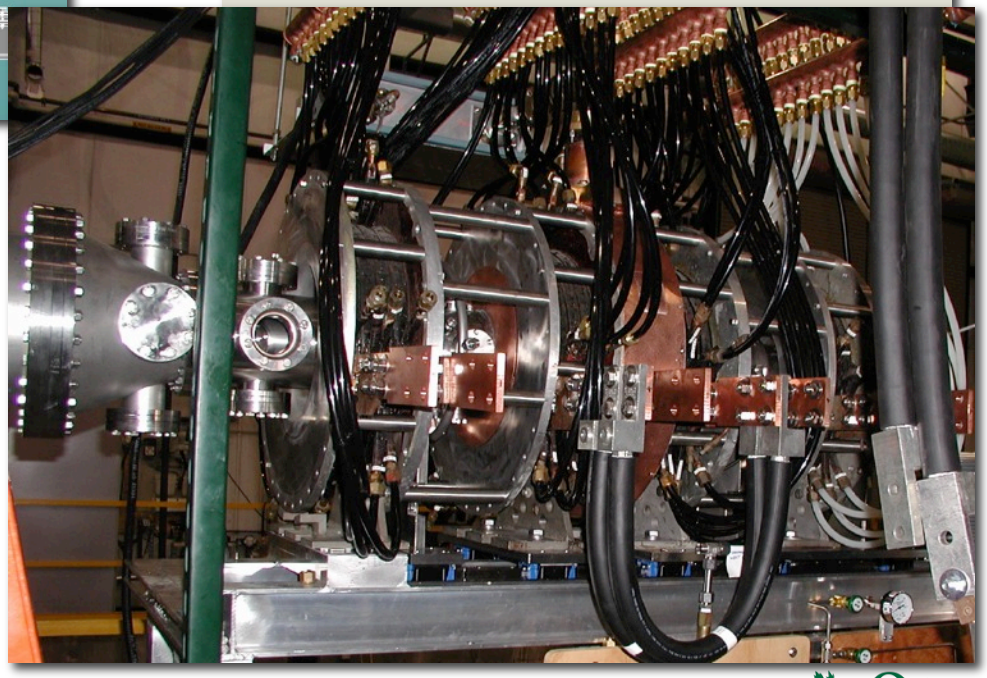
Dimensions (cm)





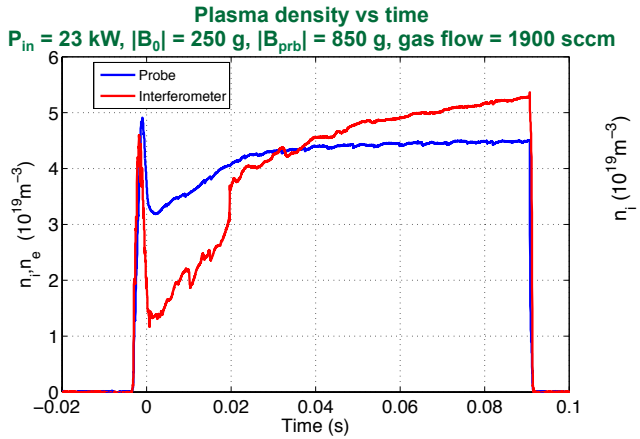
High-density H plasma operation





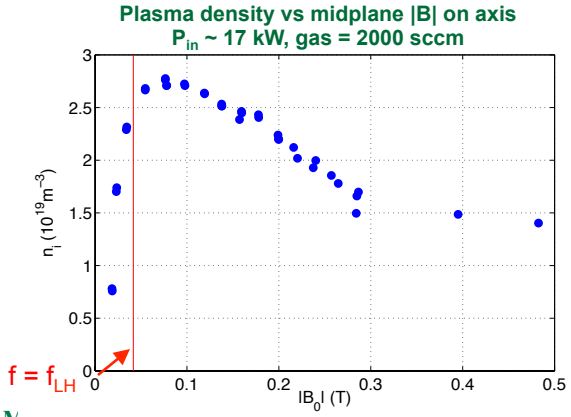
He operation: high density and |B| have been achieved

- Plasma densities > 4 X 10^{19} m^{-3} have been measured both by Langmuir probe and interferometer

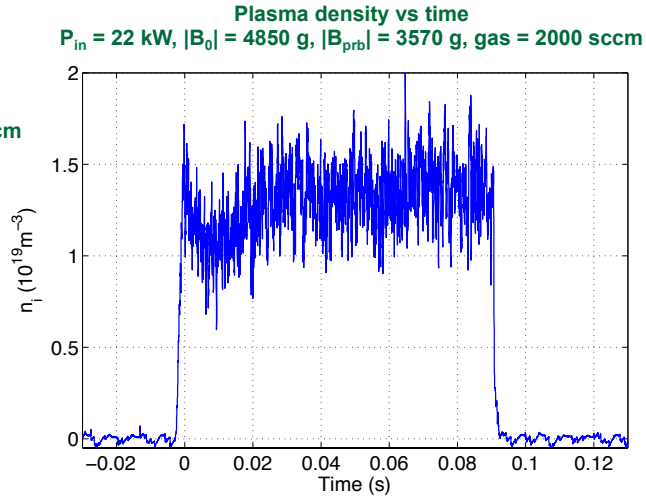


Probe: $I_{sat\ l}$ = 0.6 n_i e v a T_e (est) = 6 eV
Intererferometer: chord length = 3. 8 cm

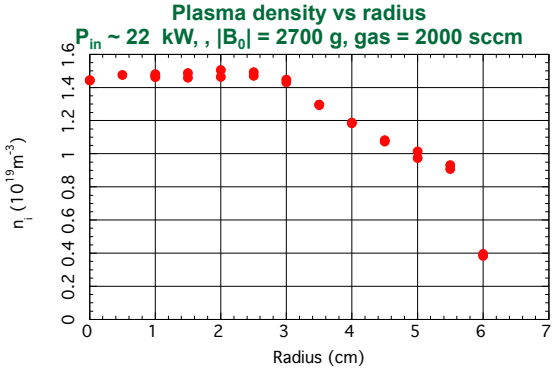
- Maximum density vs |B| under antenna with constant mirror ratio



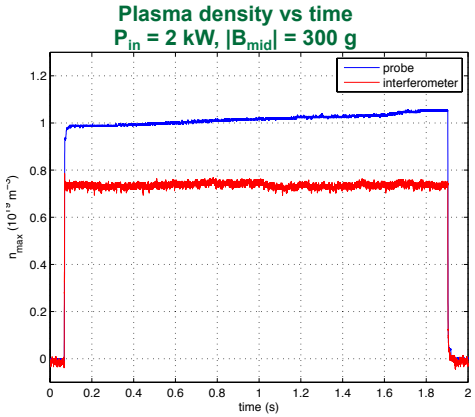
- High density achieved with |B| ~ 0.5 T at antenna



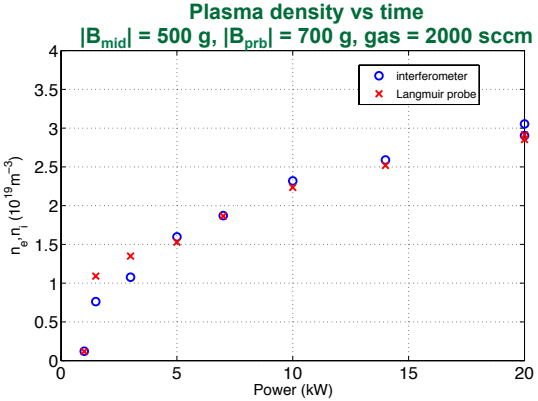
- Broad plasma profile observed with high field operation



- 2s pulses achieved w/high density plasma (symmetric coil operation)



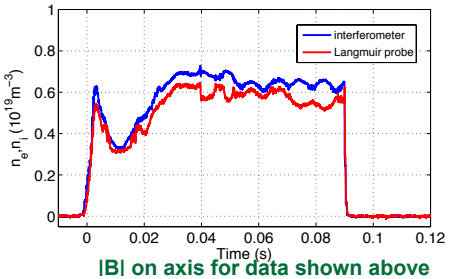
- Density scaling w/power (symmetric coil operation)



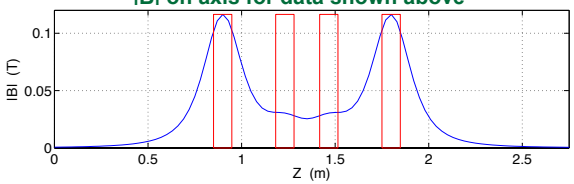
High density hydrogen and deuterium operation has also been achieved

- Plasma density > 6 X 10^{18} m^{-3} has been achieved with symmetric coil operation with hydrogen

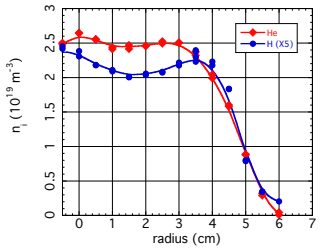
Plasma density vs time, H
P_{in} ~ 20 kW, gas ~ 1000 sccm



|B| on axis for data shown above

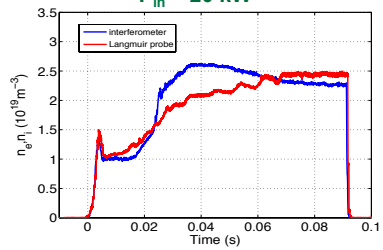


Radial density profile for symmetric operation

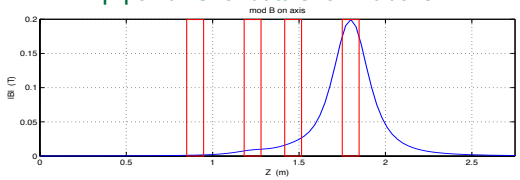


- Highest plasma density with H (and D) observed with 3 – coil operation

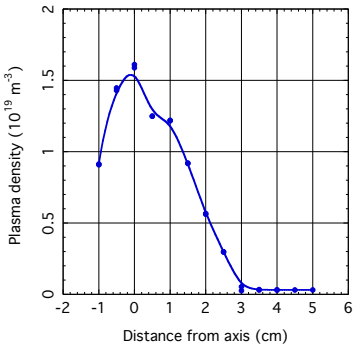
Plasma density vs time, H
P_{in} ~ 20 kW



|B| on axis for data shown above

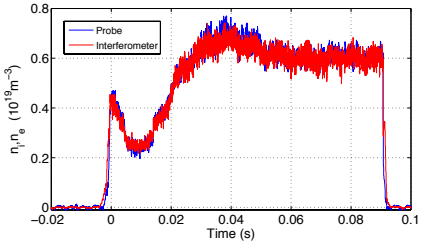


Radial profile with first coil turned off



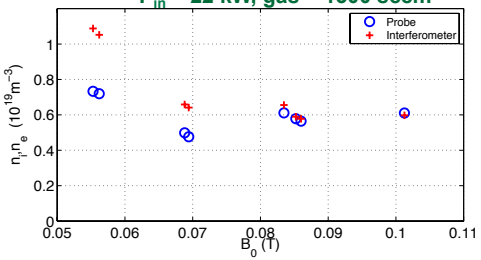
- Approximately same density at 3 X higher |B| achieved with deuterium (symmetric coil operation)

Plasma density vs time
P_{in} ~ 22 kW, $|B_0|$ = 1020 gas = 1300 sccm



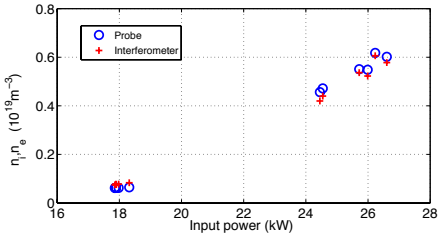
- Density dependence on $|B_0|$, deuterium, symmetric-coil operation

P_{in} ~ 22 kW, gas = 1300 sccm



- Density dependence on power, deuterium, symmetric-coil operation

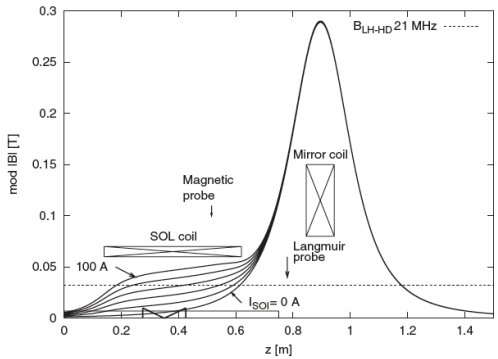
$|B_0|$ ~ 1000 g, gas = 1300 sccm



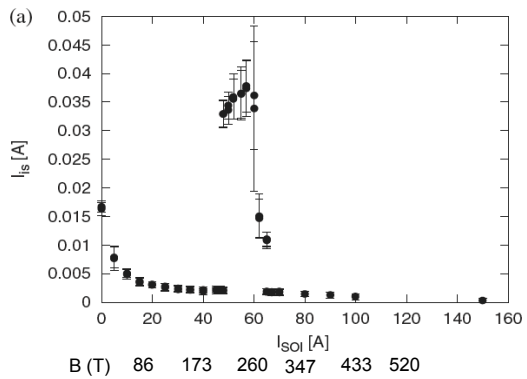
Higher power may increase range of magnetic fields at which high density can be achieved with H,D

- Limited range of operation seen on mini-RFTF at low power density

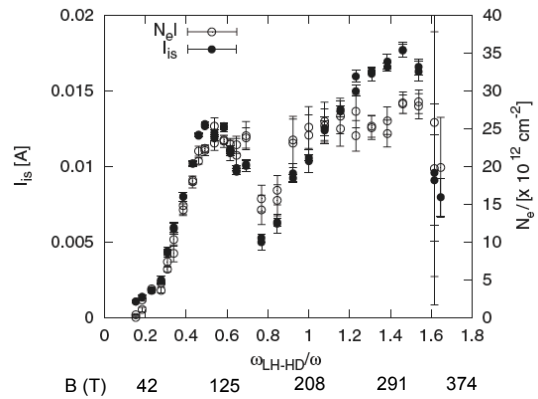
Magnetic field profiles



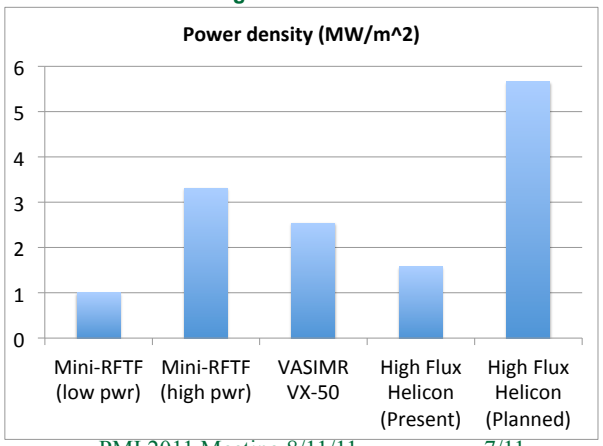
Ion saturation current, low power, H operation



Ion saturation current, high power, H operation

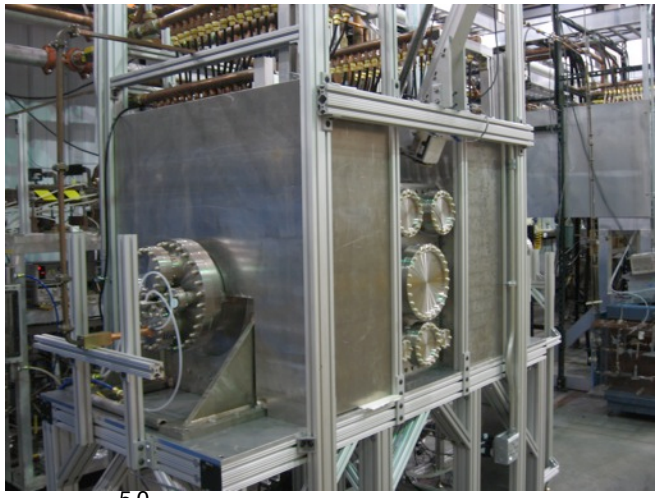


Comparison of power densities: Mini-RFTF, VASIMR VX-50 and High Flux Helicon

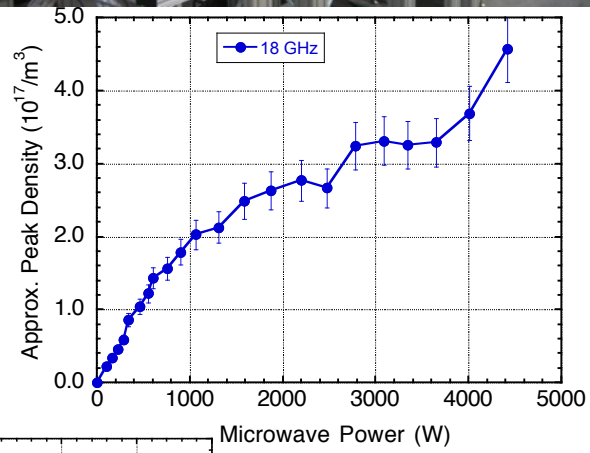


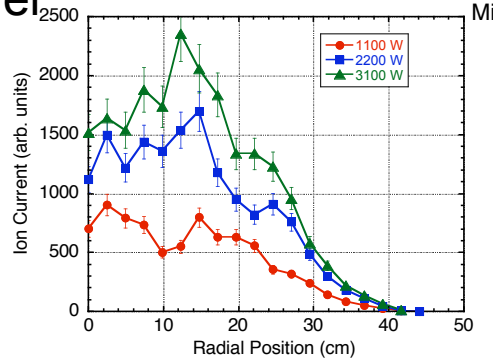
Y. Mori et al., Plasma Sources. Sci Technol **13** (2004) 424.

Successful microwave plasma production at high fields has been demonstrated



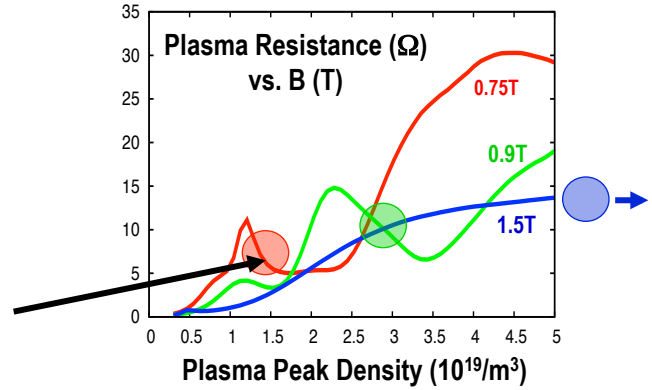
- Plasma formation has been successful at 18 GHz with high magnetic fields (~0.9 Tesla peak)
  - High-field launch whistler wave coupler concept works
  - A peak density of > $4 \times 10^{17}/m^3$ has been observed with an electron temperature of 6-8 eV (Te higher than helicon plasma)
  - Our goal of producing a density of ~$1 \times 10^{18}/m^3$ for over-dense whistler/EBW heating at 6 GHz is within reach
  - Higher 18 GHz microwave power (>10kW) should be available soon with a higher-voltage power supply (testing week of 8/15/11)
- Heating experiments at 6 GHz are schedule for August/September





Pressure = 3×10^{-4} Torr

Modeling efforts are underway

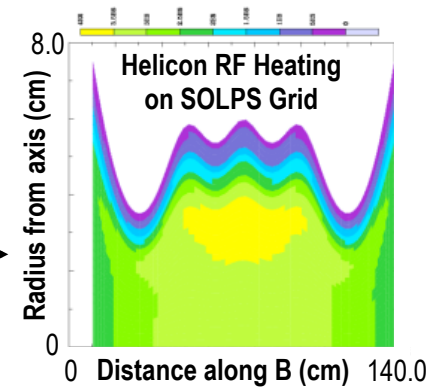


EMS-2D – Helicon RF plasma heating

- Accounts for B, n, profiles, geometry, antenna, heating
- Benchmarks well with various Helicon measurements
- Determines design and stable Helicon operating parameters

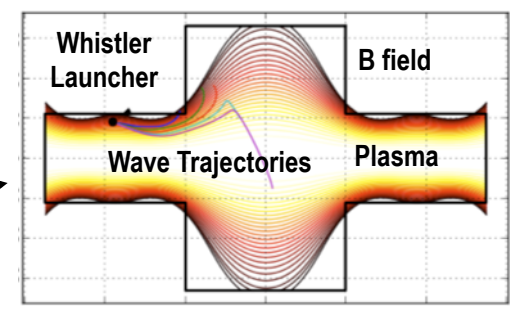
SOLPS – plasma-neutrals-wall transport and interactions

- Accounts for B, wall, and pump geometries; plasma n, Ti, Te; atoms, molecules, ionization, recombination, wall reflection, desorption, pumping, etc.
- Benchmarked and applied to tokamak edge-divertor plasmas
- Adapted to model linear Helicon, PhIX, PMTS with RF heating
- Determines fueling-pumping configuration producing optimal plasma/ neutral radial/axial density profiles for RF heating



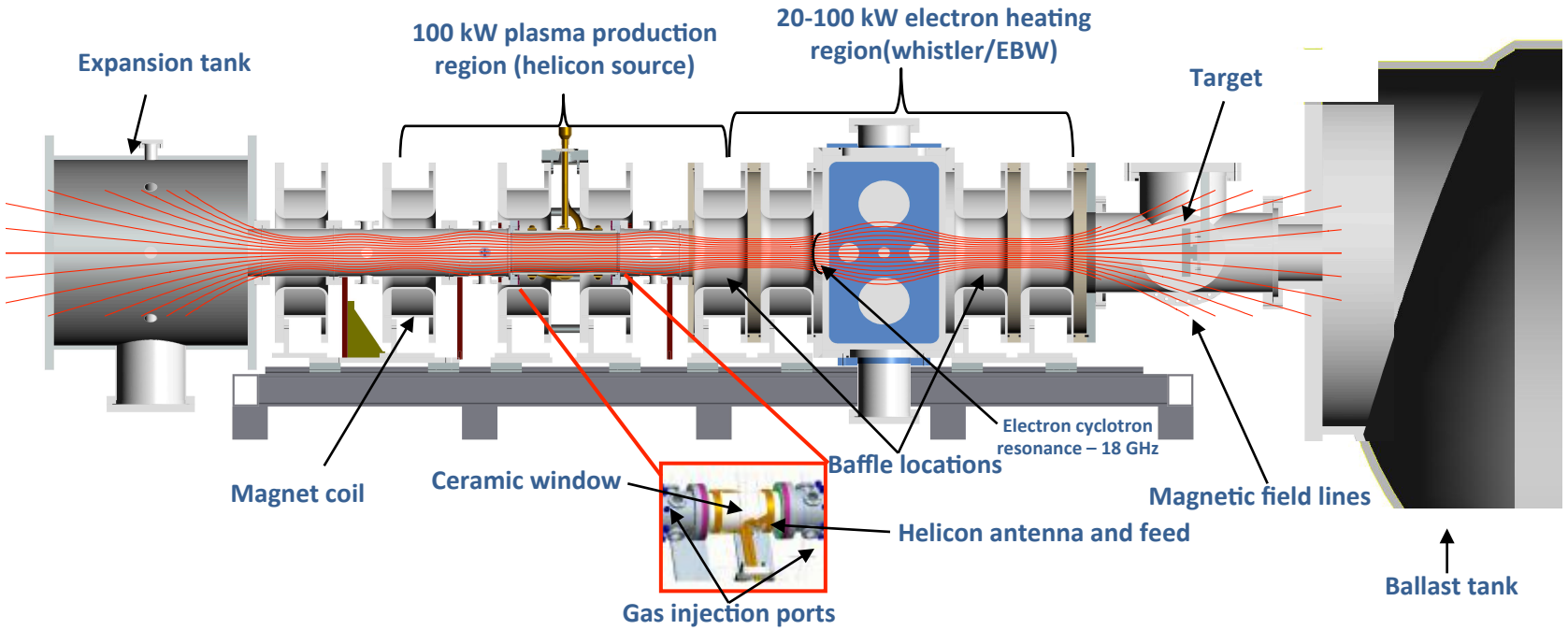
GENRAY – whistler and EBW ray tracing and plasma heating

- Accounts for B, n, profiles, geometry, launcher, elec. Heating
- Benchmarked and applied to toroidal experiments
- Modified to use Cartesian framework for linear devices
- Determines launcher configuration and heating efficiency



Next Step: Produce combined Physics Integration Experiment (PhIX) to explore electron heating of a helicon-produced plasma

- PhIX integrates two existing experiments to explore outstanding issues in the development of an intense RF plasma source
- RF helicon is efficient particle generator – produces plasma densities up to 3 X 10^{19} m^{-3}
- High-field launch "whistler" or Electron Bernstein Wave (EBW) heating increases energy of plasma stream



Conclusions

- Experiments on a high power, high flux helicon device have produced the following achievements
  - Operation with antenna in air at power levels up to 30 kW
  - High plasma densities (> 4 X 10^{19} m^{-3} He, 2.6 X 10^{19} m^{-3} H,D)
  - High B operation (n_e~ 1.5 X 10^{19} m^{-3} @ $|B_0|$ = 0.5 T (He), n_e~ 0.6 X 10^{19} m^{-3} @ $|B_0|$ = 0.1 T (D)
- Additional experiments planned at higher power levels up to 100 kW – should produce higher densities and allow operation at higher |B| with H and D
- Experiments have begun on a whistler/EBW heating experiment. Power supply problems have limited densities achieved to-date to below cutoff
- Genray and SOLPS/B2-Eirene have been adapted to linear geometry, modeling with these codes and the EMS-2D rf code are underway
- Beginning next FY, the helicon and whistler/EBW experiments will be combined to produce the PhISX device dedicated to an examination of overdense electron heating of a helicon-produced plasma

ICRF power has been efficiently coupled to a helicon produced D plasma in VASIMR VX-50 experiment

- Deuterium, 230 sccm, 20 kW helicon + 20 kW ICH slow wave heating
- Single pass damping
- Average ion energy increased by 200 eV
- ICH heating efficiency ~ 80%

VASIMR VX-50

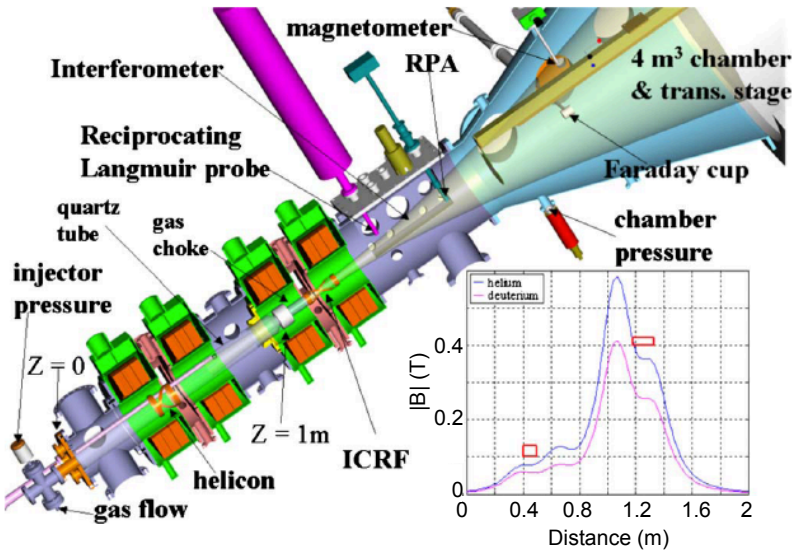


FIG. 2. (Color online) Engineering drawing of the VX-50, showing the major systems and the location of the diagnostic instruments. The RPA used to obtain most of the data in this paper was located, as shown at $z=1.7$ m.

Ion energy distributions for different ICH power levels

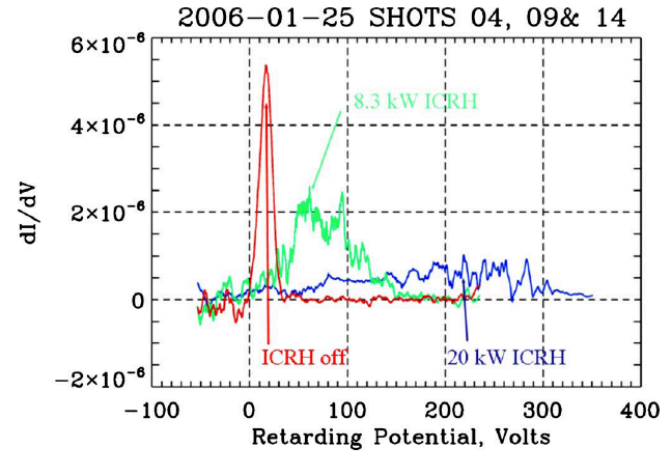
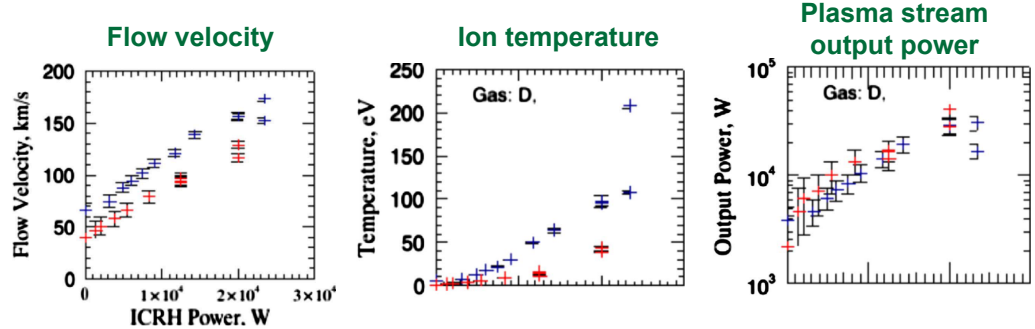


FIG. 28. (Color online) Comparison of ion energy distributions for 0, 8.3, and 20 kW of ICH power in deuterium plasma, input flow rate 0.625 mg/s, and 20 kW helicon power.



E. A. Bering III et al., "Observations of single-pass ion cyclotron heating in a trans-sonic flowing plasma" Phys. Plasmas **17**, (2010), 043509"