Initial operation of the ORNL high flux helicon plasma source for PMI research

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U.S. DEPARTMENT OF ENERGY

Fusion Energy Division
OAK RIDGE NATIONAL LABORATORY

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Outline

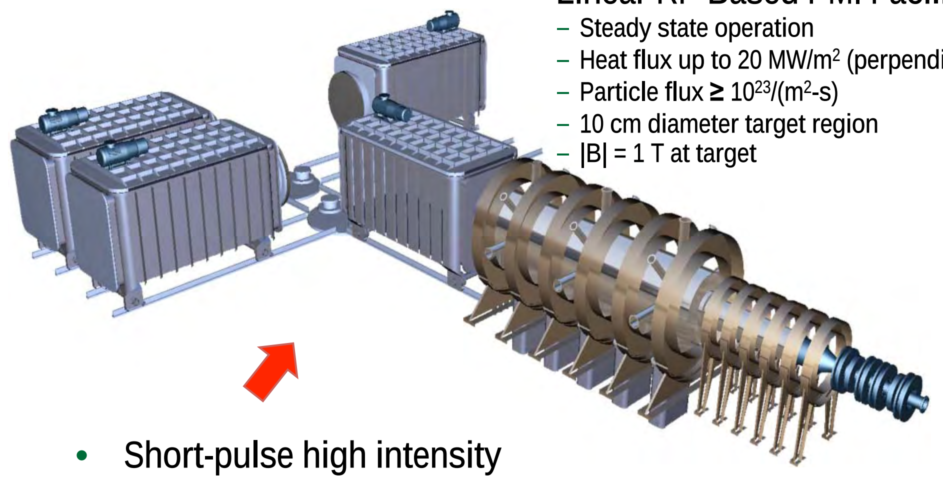
- Introduction: A Plasma Materials Interactions Test Facility (PMTF) based on a high intensity rf plasma source
- High intensity RF plasma source concept
- ORNL high particle flux helicon source
  - Design
  - Initial test results
  - Future work

Introduction

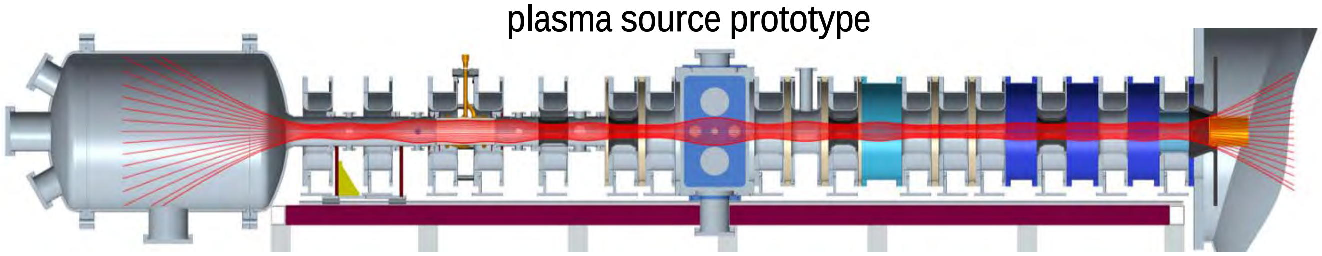
- Linear plasma facilities are a valuable adjunct to tokamaks for the study of Plasma Materials Interface (PMI) phenomena of interest for ITER and DEMO
- Advantages include
  - Cost effectiveness
  - Easy access for diagnostics and samples
  - Well controlled plasma parameters – ability to focus on specific mechanisms and processes
  - Long pulse (> 100 s, or CW)
  - Long pulse and high temperature issues can be addressed in the near term
  - Possibility for testing materials not easily handled in most tokamaks (e.g., Be, materials with neutron damage)
- Ultimate goal: develop PMI linear facility based on a high performance, flexible rf plasma source
  - Electrodeless
    - lack of metallic electrodes in plasma production and heating region minimizes contamination of samples by impurities
  - Low maintenance, intrinsically CW
  - Combination of helicon plasma generator with additional EC and IC heating provides wide range of possible source parameters, with H plasmas, without biasing
    - $n_e = 0.1 – 3 \times 10^{19}\ m^{-3}$
    - $T_e = 3 – 50$ eV
    - $T_i = 1 – 200$ eV
  - Low power and pumping requirements ($P_{rf} \leq 0.5$ MW, $\geq$ 50% ionization efficiency)

Development stages

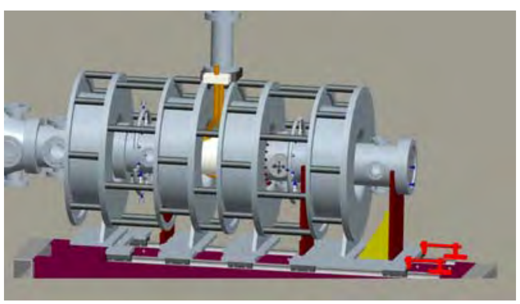
- Linear RF-Based PMI Facility
  - Steady state operation
  - Heat flux up to 20 MW/m^2 (perpendicular)
  - Particle flux ≥ 10^{23}/(m^2-s)
  - 10 cm diameter target region
  - |B| = 1 T at target



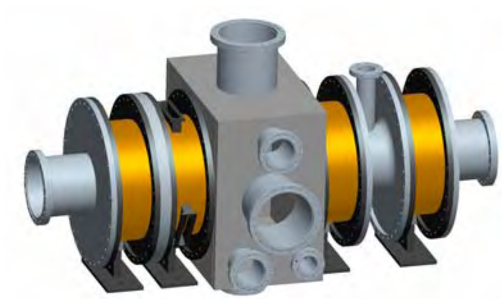
- Short-pulse high intensity plasma source prototype



- Helicon rf particle generator

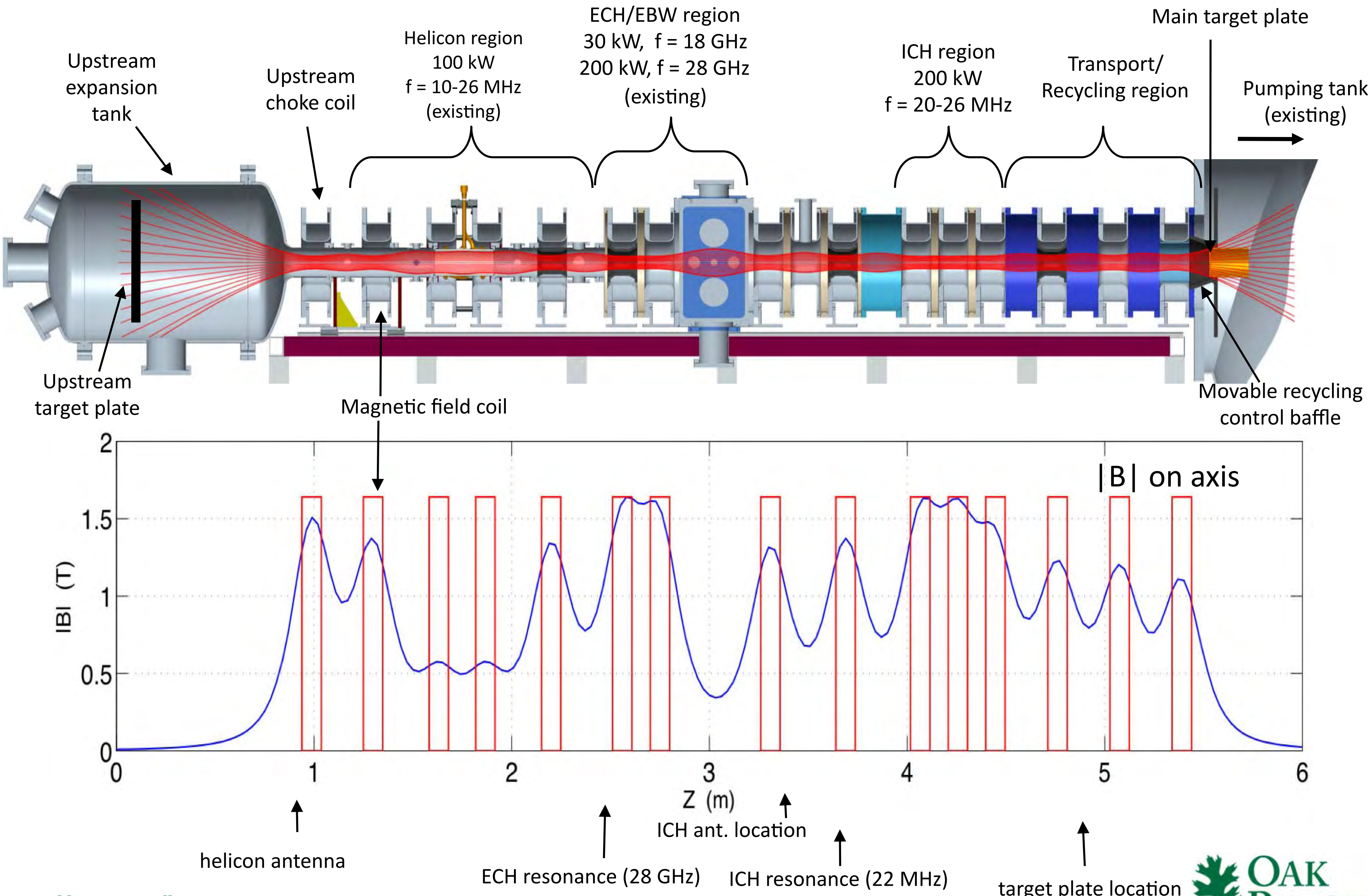


- Linear ECH/EBW test stand



- Presently operating
- Internally funded (ORNL LDRD)

Prototype PMTF linear device



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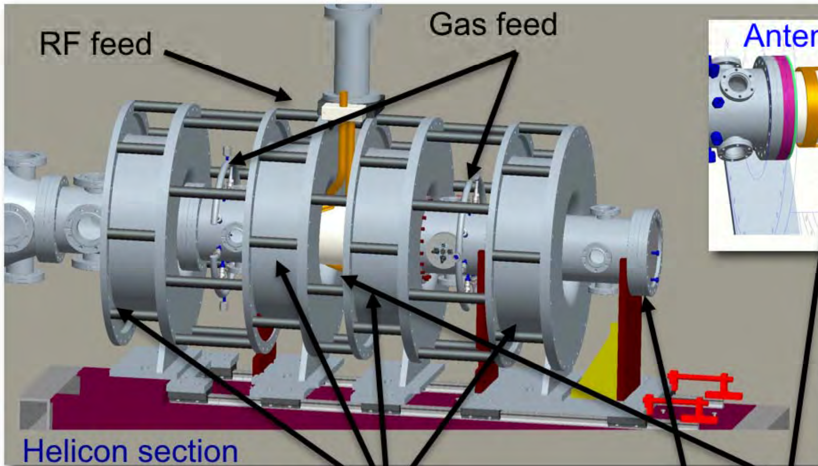
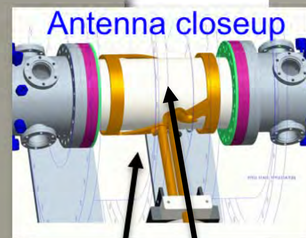
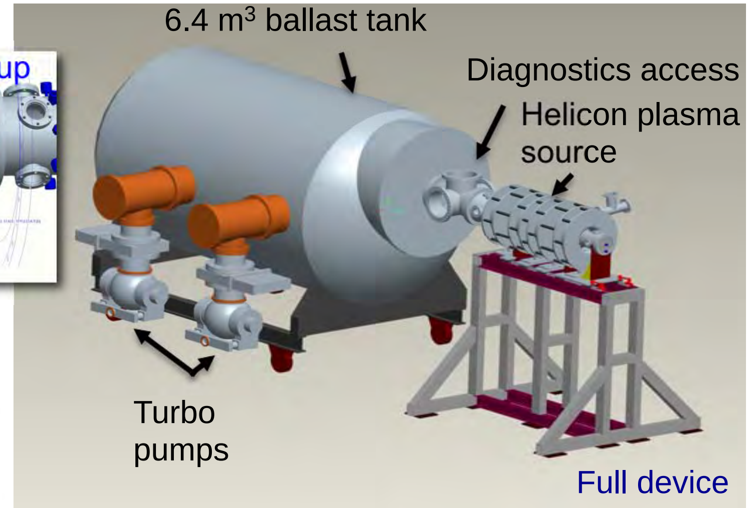
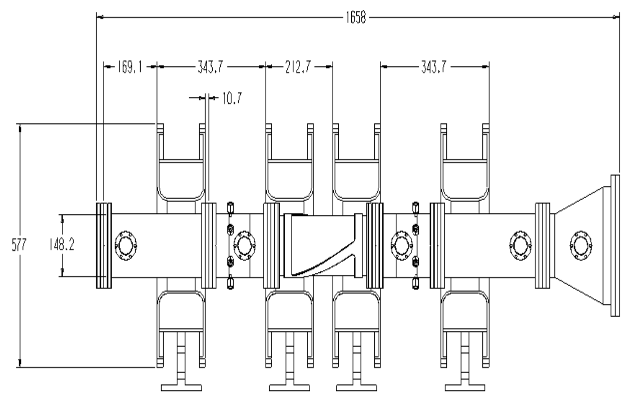
The ORNL high-field helicon plasma source



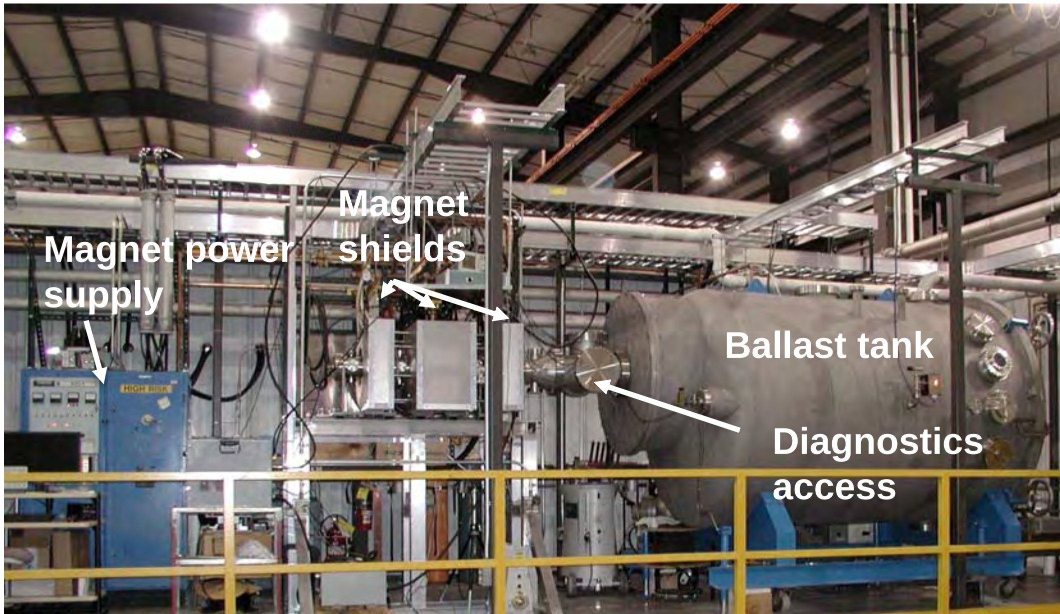






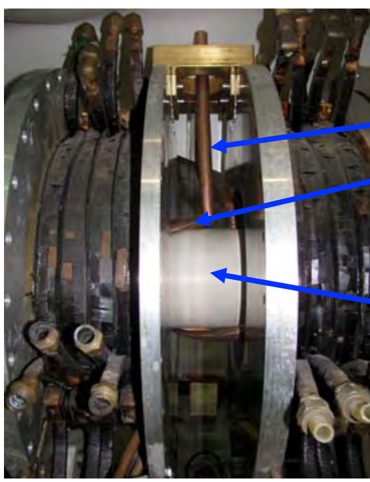
- Built and operated using LDRD funds, and utilizing previously available hardware including magnets, ballast tank, and vacuum pumps
- 15 cm diameter electrodeless light-ion (H, D, He) plasma source
- Magnet coils can produce 1.6 T maximum CW magnetic field
- Water cooled half-turn helical antenna operated in air
- High thermal conductivity aluminum nitride rf window allows high power flux with external antenna
- Main goals: Confirm high particle flux hydrogen plasma production at |B|~ 0.5 T in plasma production region, Measure heat flux at vacuum window for use in designing later steady state source

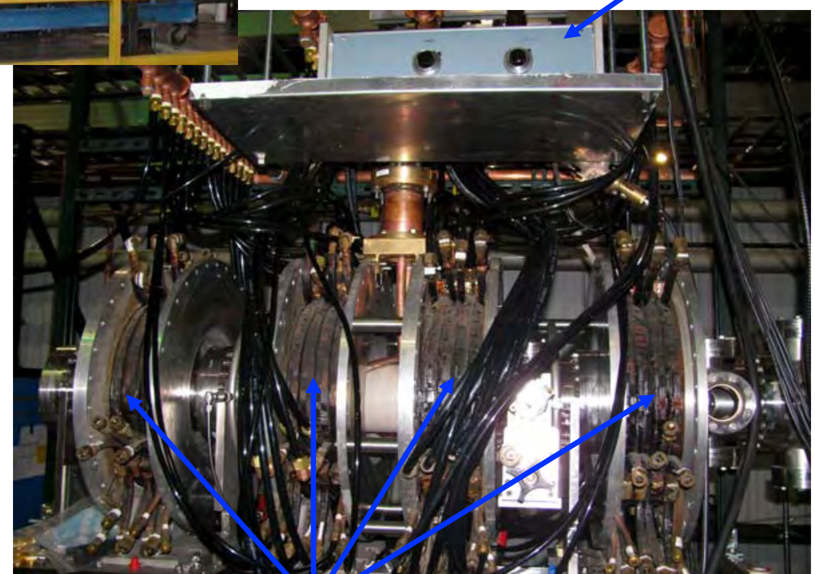
Helicon source and ballast tank



View of opposite side of ballast tank

Helicon section aluminum nitride window, and coils

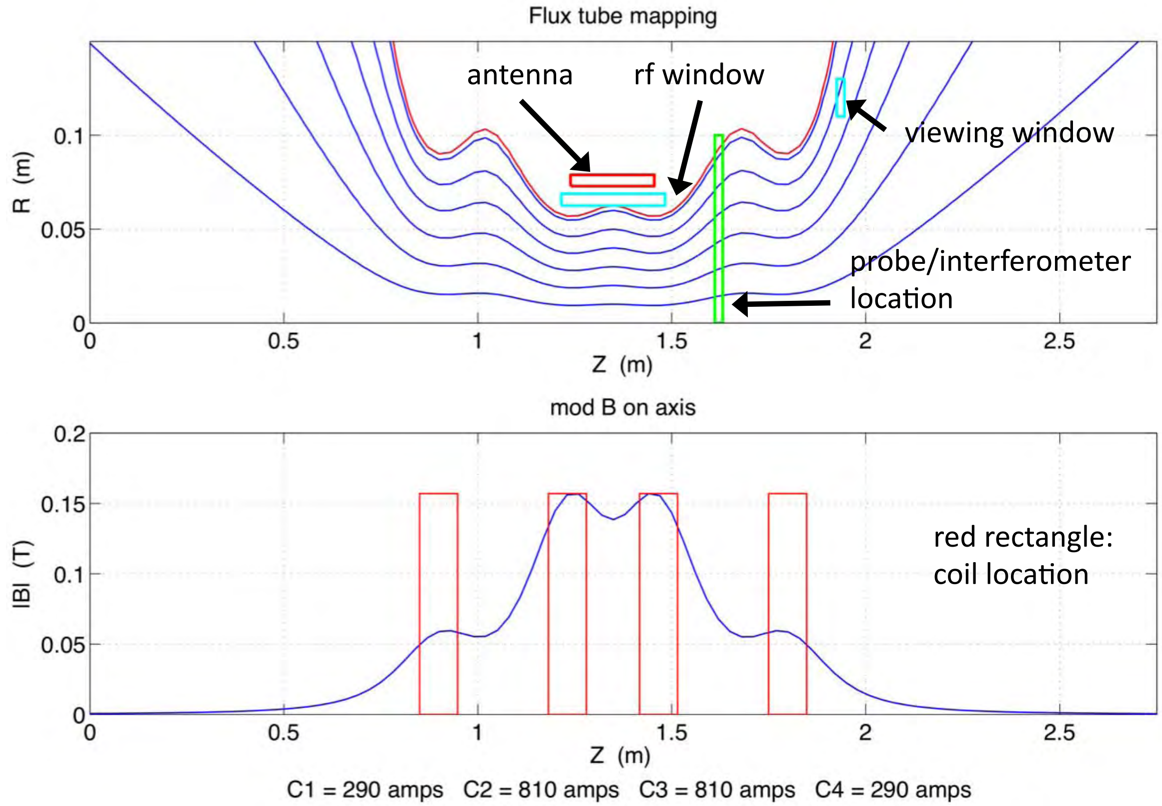




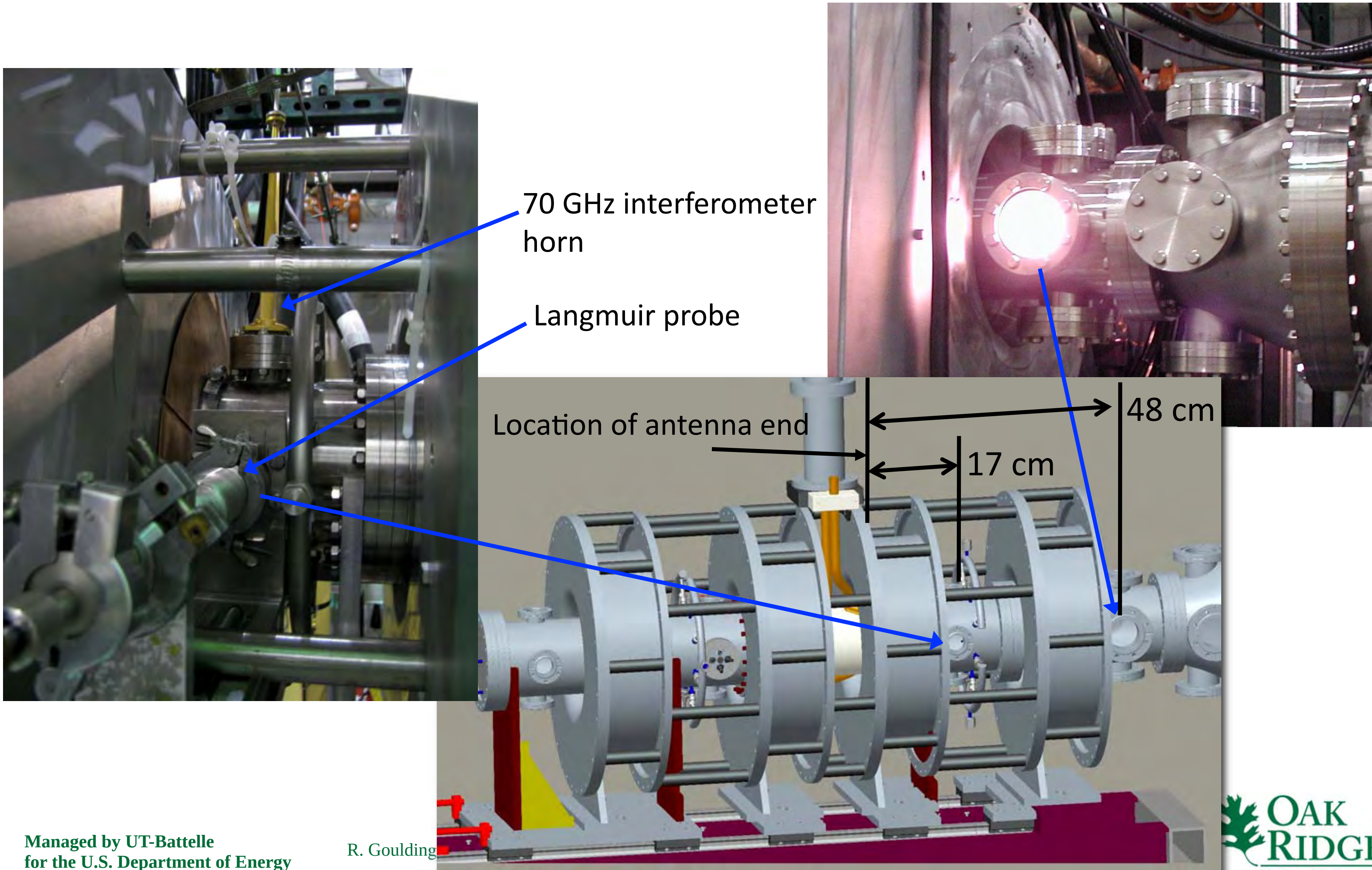
Initial operation: operating parameters

- Gas: He
- Tank pressure: 10 mTorr
- Inner coil currents – 710 A
- |B| under helicon antenna ~ 0.14 T
- Frequency: 13.56 MHz
- Forward power: 2 kW
- Pulse length: ≤ 2 s

Magnetic field flux tubes and field strength on axis

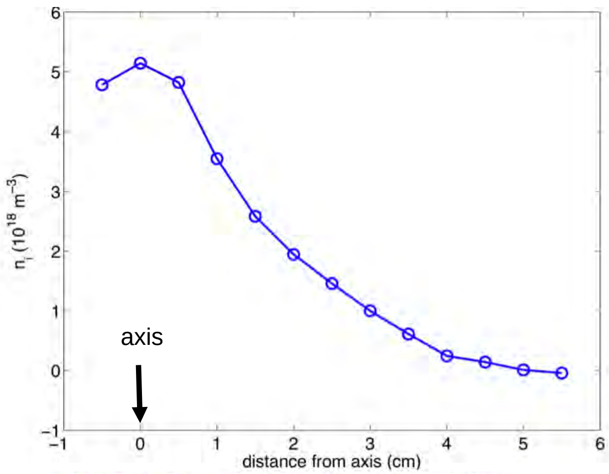


Location of density measurements and view from downstream port



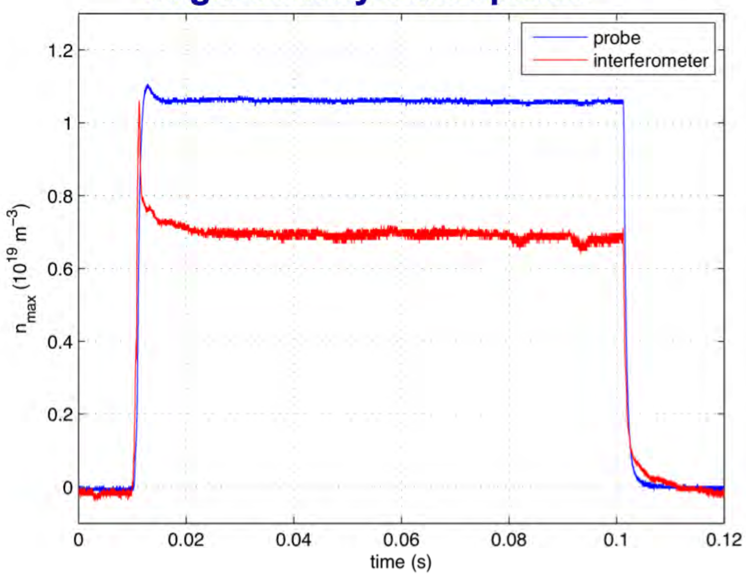
Initial results: 2 s high n_i pulses with He

Radial density profile from Langmuir probe $I_{sat\ i}$ measurements

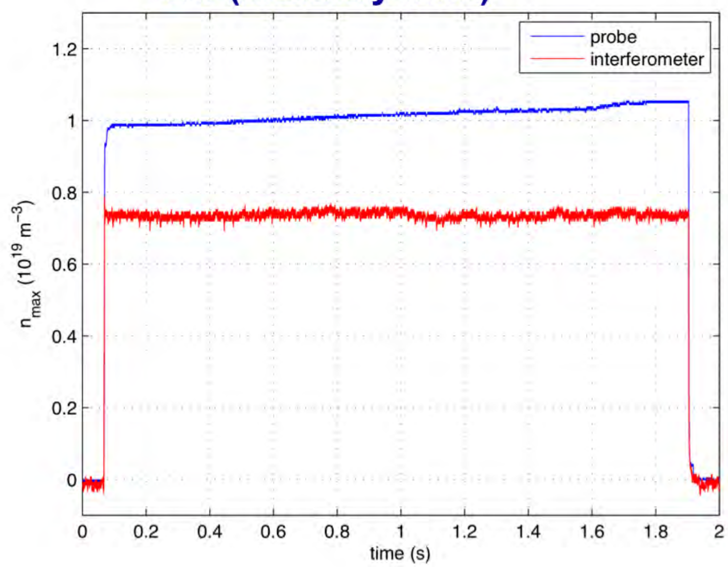


- Radial profile determined with Langmuir probe, used to determine interferometer chord length (= 3.6 cm)
- Peak density from interferometer: ~7.5 X 10^{18} m^{-3}
- Peak density from Langmuir probe calculated using standard formula for cross sectional area of cylindrical probe sheath in magnetic field, similar to interferometer result
- Power limited to 2 kW – faulty tube in 100 kW amplifier now being replaced

High density short pulse

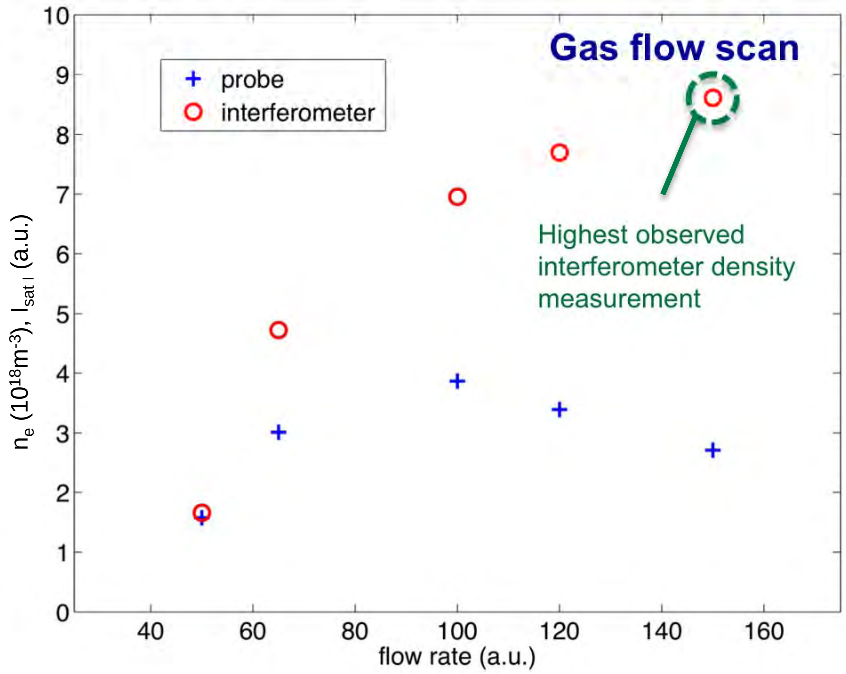


2 s (arbitrary limit)

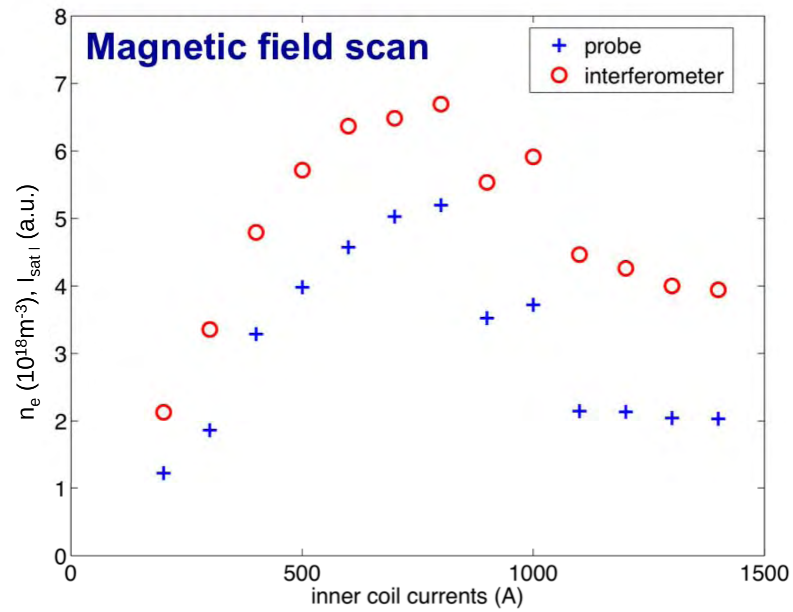


Gas flow and magnetic field scans

- Plasma density (circles) and ion saturation current (crosses, $\propto n_i T_e^{1/2}$) as function of gas flow. Ion saturation current drops at high flow rate due to reduction in T_e
- Maximum density from interferometer ~ 8.8 X 10^{18} m^{-3}



- Plasma density vs. inner coil currents, with ratio to outer coil current held constant
- Peaks at I_{inner} ~ 800 A, |B| = 0.14 T at antenna
- Appears to show eigenmode behavior similar to that observed in previous small helicon experiment. Expected to be 2nd order radial eigenmode, suggesting operation possible at |B| ~ 0.6 T near helicon antenna for hydrogen plasma density of 3 X $10^{19}m^{-3}$,

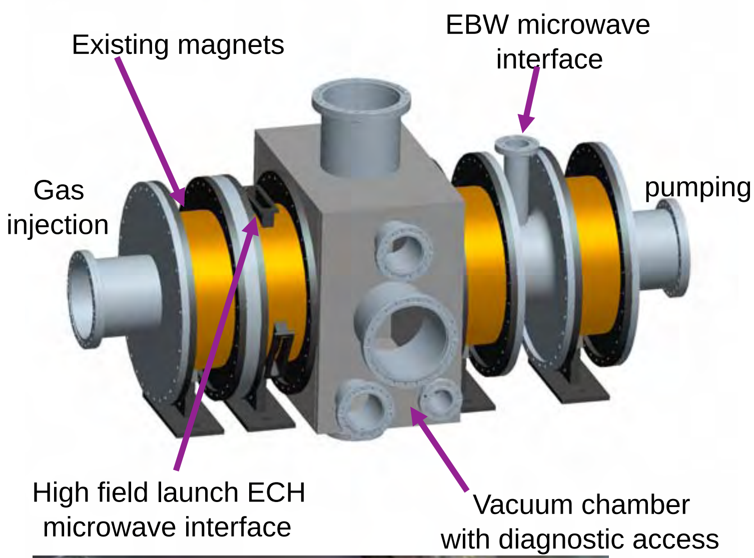


Future Work

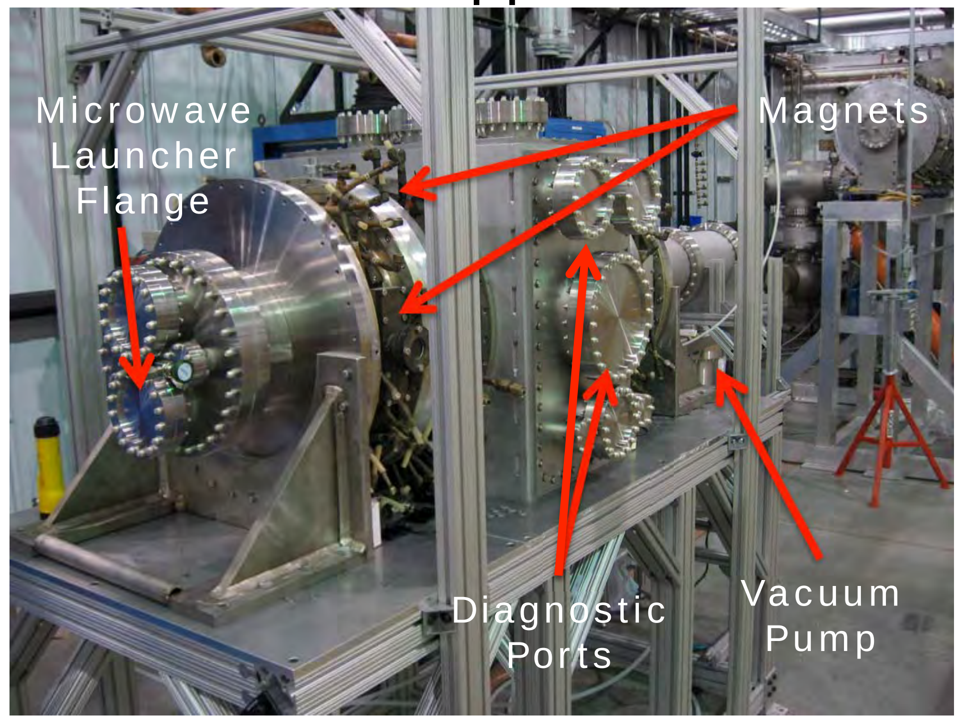
- Operate with increased input power, up to 100 kW
  - Install spare tube in 100 kW amplifier and finish troubleshooting
  - May temporarily use 10 kW amplifier
- Measure and maximize output flux with H, He
  - Vary power, gas flow and distribution, magnetic field strength and mirror ratio
- Measure impurity levels
- Measure heat deposition profiles on ceramic rf window
- Install target plate and conduct initial materials tests (details TBD)

A related device for exploring ECH heating in a linear, high density configuration is also operating
(Planned near-term operation at 18 GHz, power up to 30 kW)

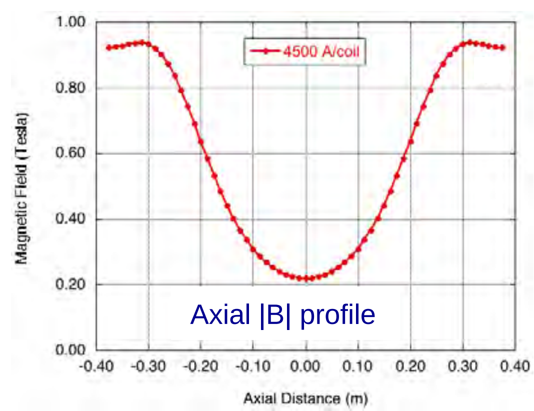
Conceptual Apparatus

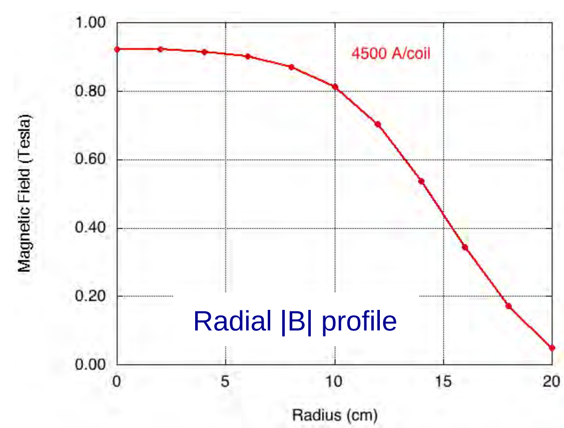


Actual Apparatus



Initial plasma operation (2.45 GHz)





Summary

- A high particle flux light-ion helicon plasma source has been constructed as the first step towards the development of a linear plasma-materials interface test facility utilizing rf plasma production and heating
- The ultimate facility will produce particle fluxes > $10^{23}/m^2$-s, and power fluxes > 10 MW/m^2 over a 10 cm diameter target with total rf input power < 500 kW
- During initial operation with He, the device has produced a maximum plasma density approaching $10^{19}/m^3$ with an input power of only 2 kW, and |B| in the production region = 0.14 T
- Simple scaling using the dispersion relation for the helicon wave suggests that it should be possible to operate at |B| in the target range > 0.5 T with hydrogen plasma at a density of ~3 X $10^{19}/m^3$
- Experiments using increased rf power will begin shortly
- An initial materials testing program using the device will be developed
- A separate device for exploration of high density ECH heating, compatible with later combined use, has also begun operation