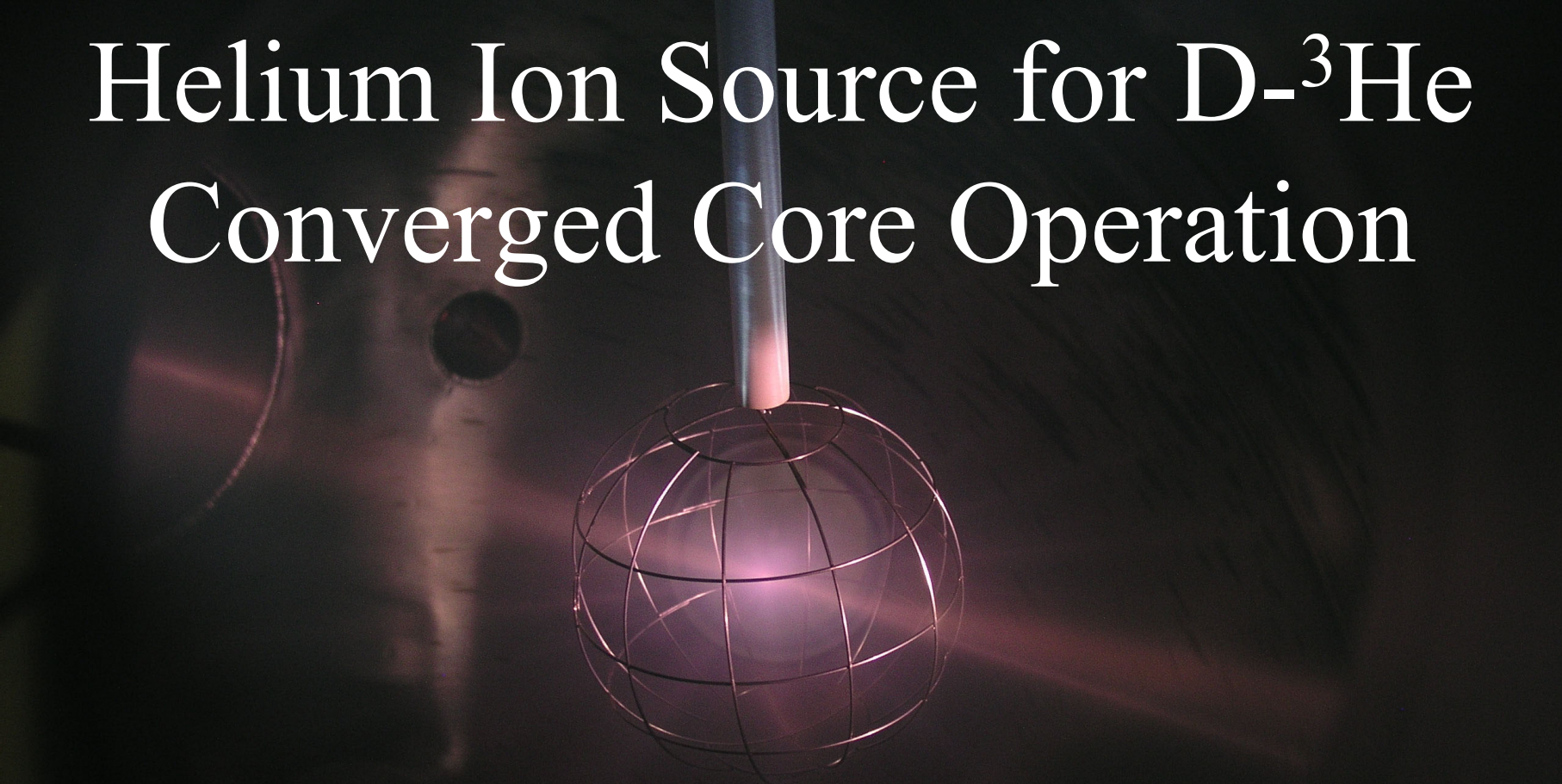
Helium Ion Source for D-^{3}He Converged Core Operation



The 6th U.S.-Japan IEC Workshop
Tokyo Institute of Technology, Oct. 20-21 2003

Greg Piefer
University of Wisconsin—Madison
Fusion Technology Institute

Talk Outline

- Need for ion source design
- Ion generation system
- Ion extraction system
- Experimental results

Research Objectives

- Generate a beam of highly ionized helium gas and inject into IEC
- Enable converged-core operation by limiting neutral gas flow

External Source Reduces Penning Ionization Difficulties

- In D-^{3}He mixtures, helium atoms lose energy by collisions with deuterium, reducing He ionization
- Ionization and injection of helium by an external source will reduce this problem

Ion Source will Enable Converged-Core Operation

- Operation in present mode requires ionization in the main IEC device
  - Ionization done by electrons streaming from hot filaments, or Paschen breakdown—both require a minimum amount of neutral gas to be in the main IEC
  - Presence of neutral gas causes collisions with ion flow and charge exchange, disrupting convergence

Ion Source will Enable Converged-Core Operation (cont)

- External ionization source has no background pressure requirement in main IEC
- Ion beam injection can be done with minimal neutral gas flow, allowing very low pressures $< 10^{-5}$ torr in the IEC device
- Low pressure will enable ion flow to converge
  - Convergence should result in very high density core
  - Convergence also results in beam-beam interactions, which increases the center-of-mass collision energy

Ion Generation System Must Create High Density Plasma

- To minimize neutral gas flow out of the generation system, ion beam must exit through small hole
- Maximum current through a hole is limited by plasma density according to Bohm criterion:

$$I_B = 0.61 * nqA\left(\frac{k_b T_e}{m_i}\right)^{\frac{1}{2}}$$

- Solving this for n, assuming a desired beam current of 60 mA through a 3 cm^2 hole, shows a source density requirement of > 10^{13} ions/cm^3

High Density Requires Helicon Plasma Generator

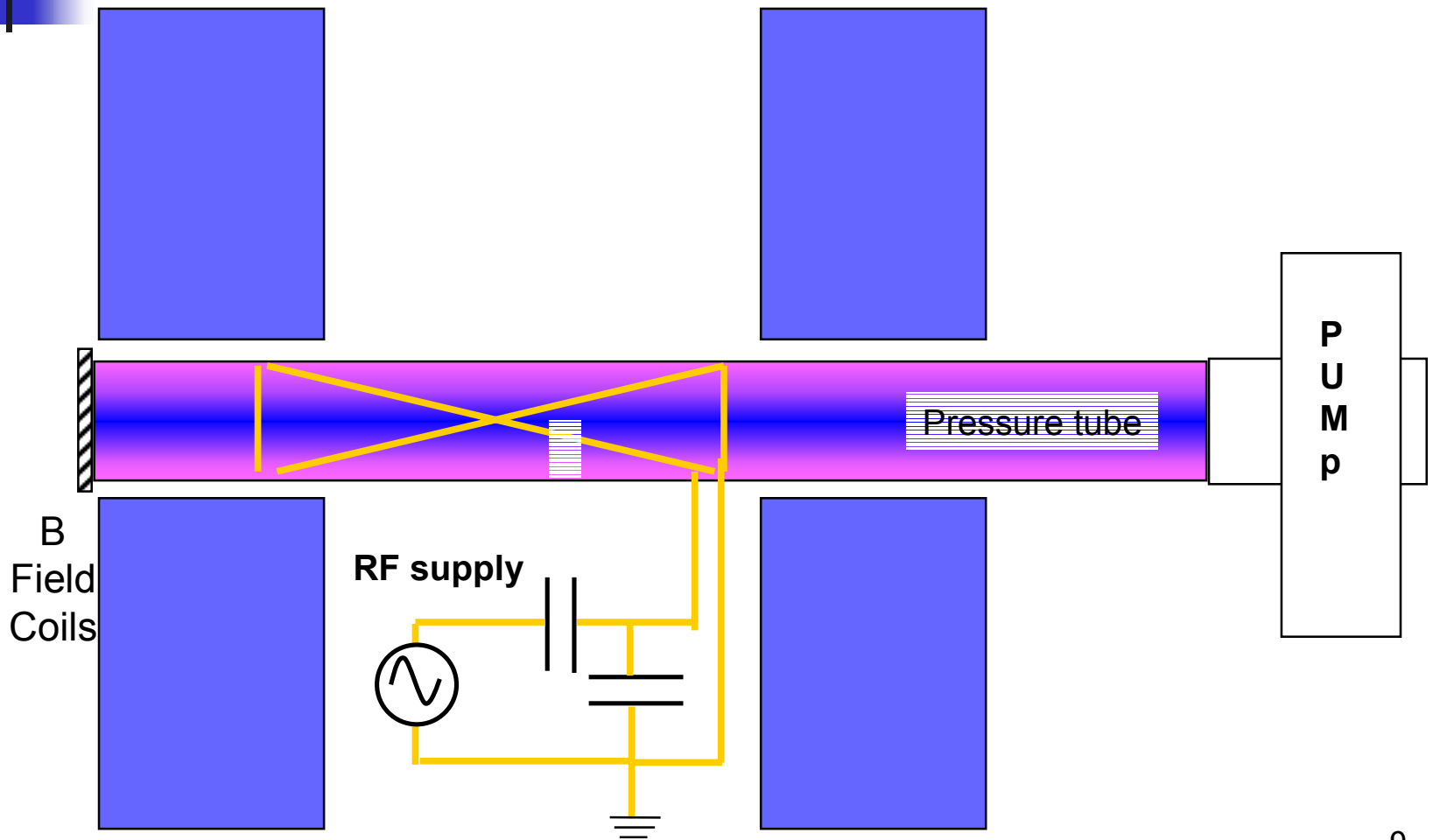
- Helicon sources work by launching helicon waves along an axial magnetic field
- Helicon wave dispersion relation:

$$\frac{\omega}{k} = \frac{3.83 B_o}{\mu_o e n a}$$

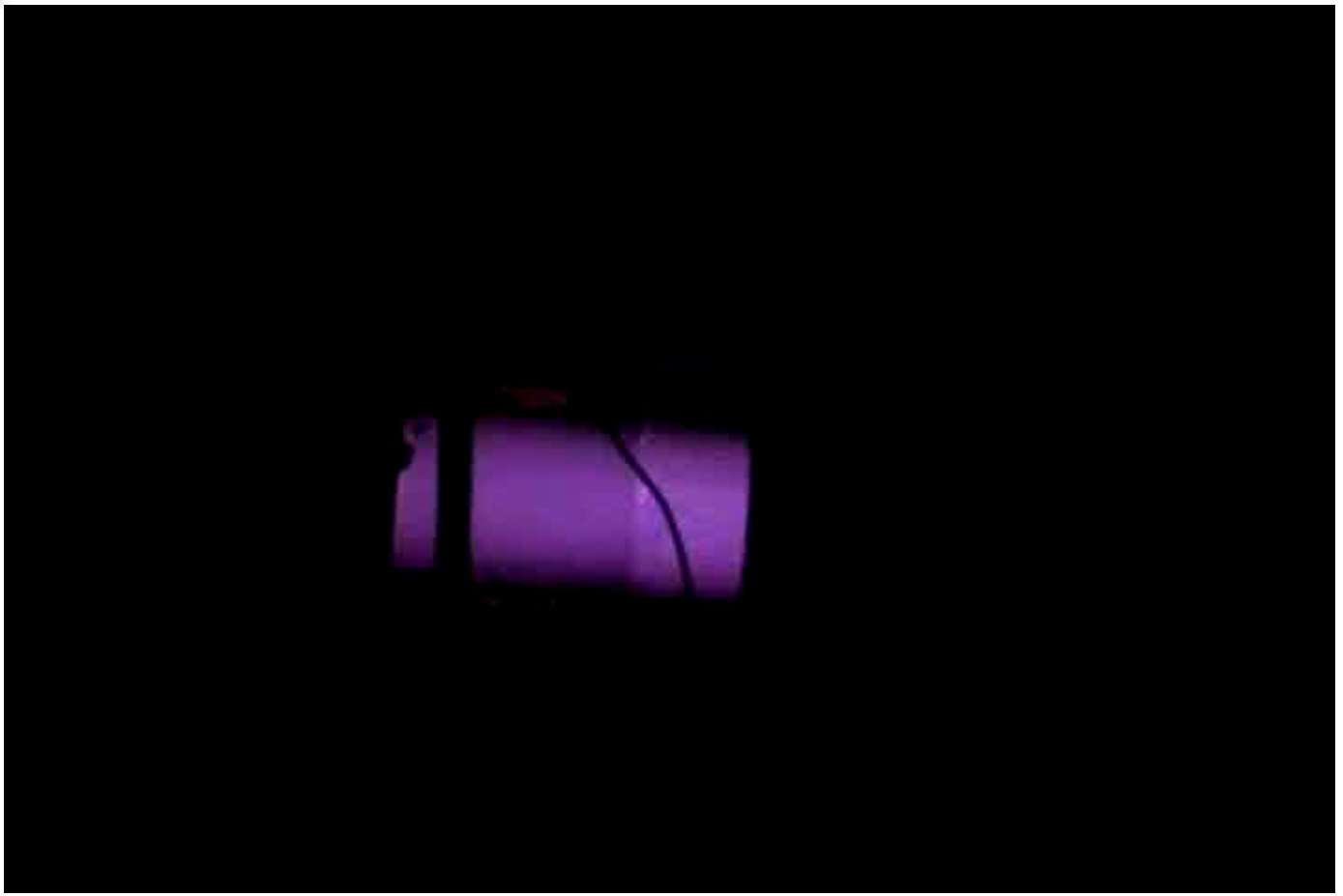
- Helicon sources have been shown to produce ~ 10^{13} ions/cm^3 in helium[1]

[1]Jacobson, V.T., "Development of VASIMR Helicon Source", 43rd annual meeting of the APS Division of Plasma Physics—Mini-Conference on Helicon Sources, 2002

Helicon Source Layout



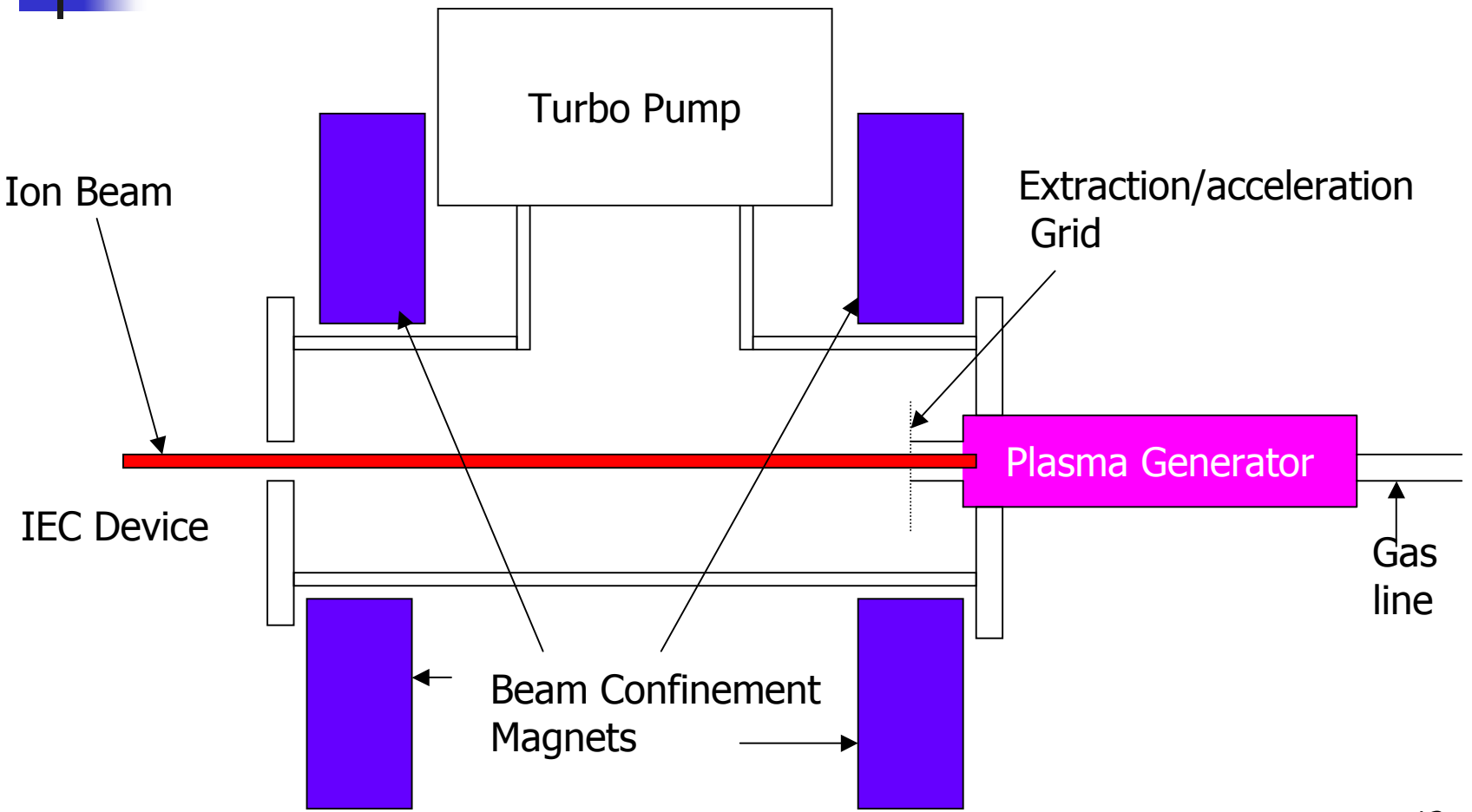
Helicon Pulse in UW Plasma Generator



Ion Extraction System Components

- Ions extracted and accelerated to several keV by extraction grid, then slowed as they approach the IEC wall
- Axial magnetic field for beam confinement
- Turbo pump for differential pumping, which removes excess neutral gas

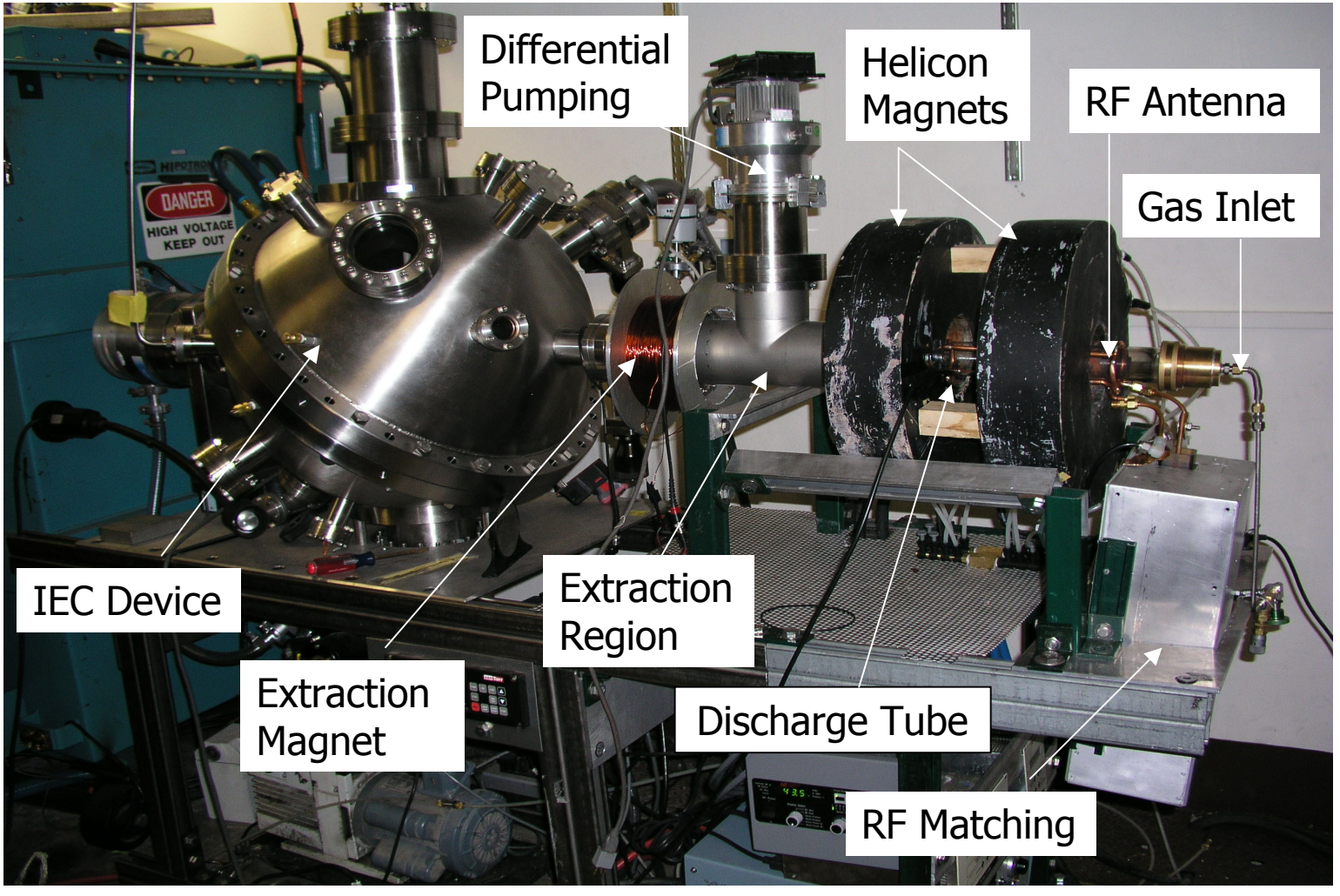
Ion Extraction System Schematic



Significant Progress Made in Ion Beam Development

- First plasma achieved in 2003
- Helicon antenna and magnets developed and constructed
  - Steady-state magnetic fields up to 2 kG
  - Steady-state RF power up to 1.4 kW
- Extraction region designed and built—first experiments to occur soon
- Differential pumping system available when extraction system comes online

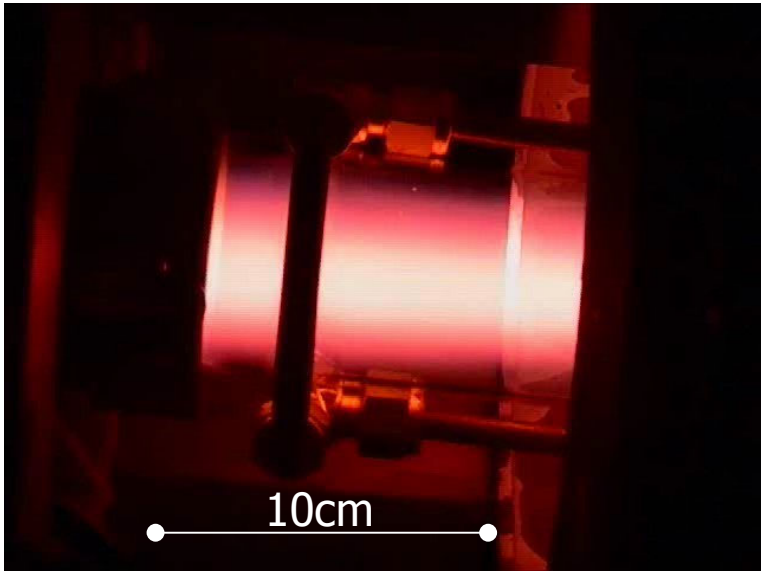
Ion Source Mated to UW IEC



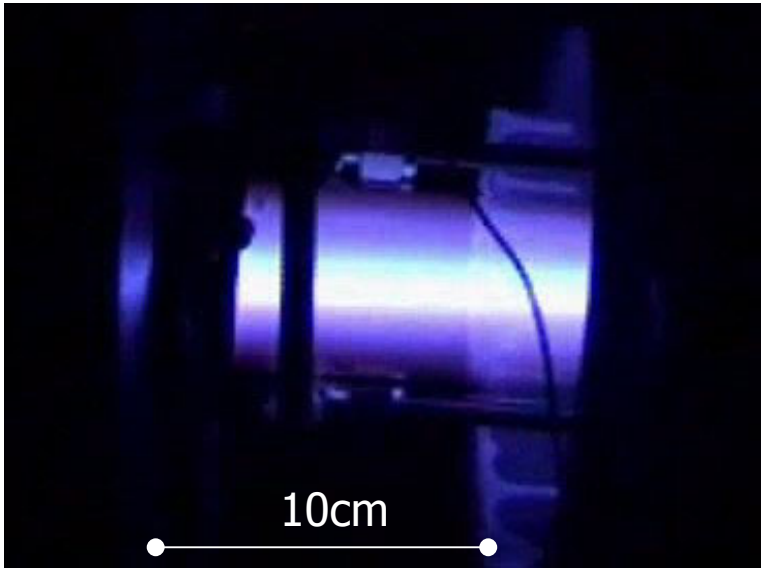
Preliminary Experimental Results are Encouraging

- High density helicon discharges established in He and Ar gases
- 2 mA helium beam pulled into IEC by cathode voltage, with no extraction system, magnetic confinement, or differential pumping at 0.2 mTorr

Helicon Discharges in UW Ion Source

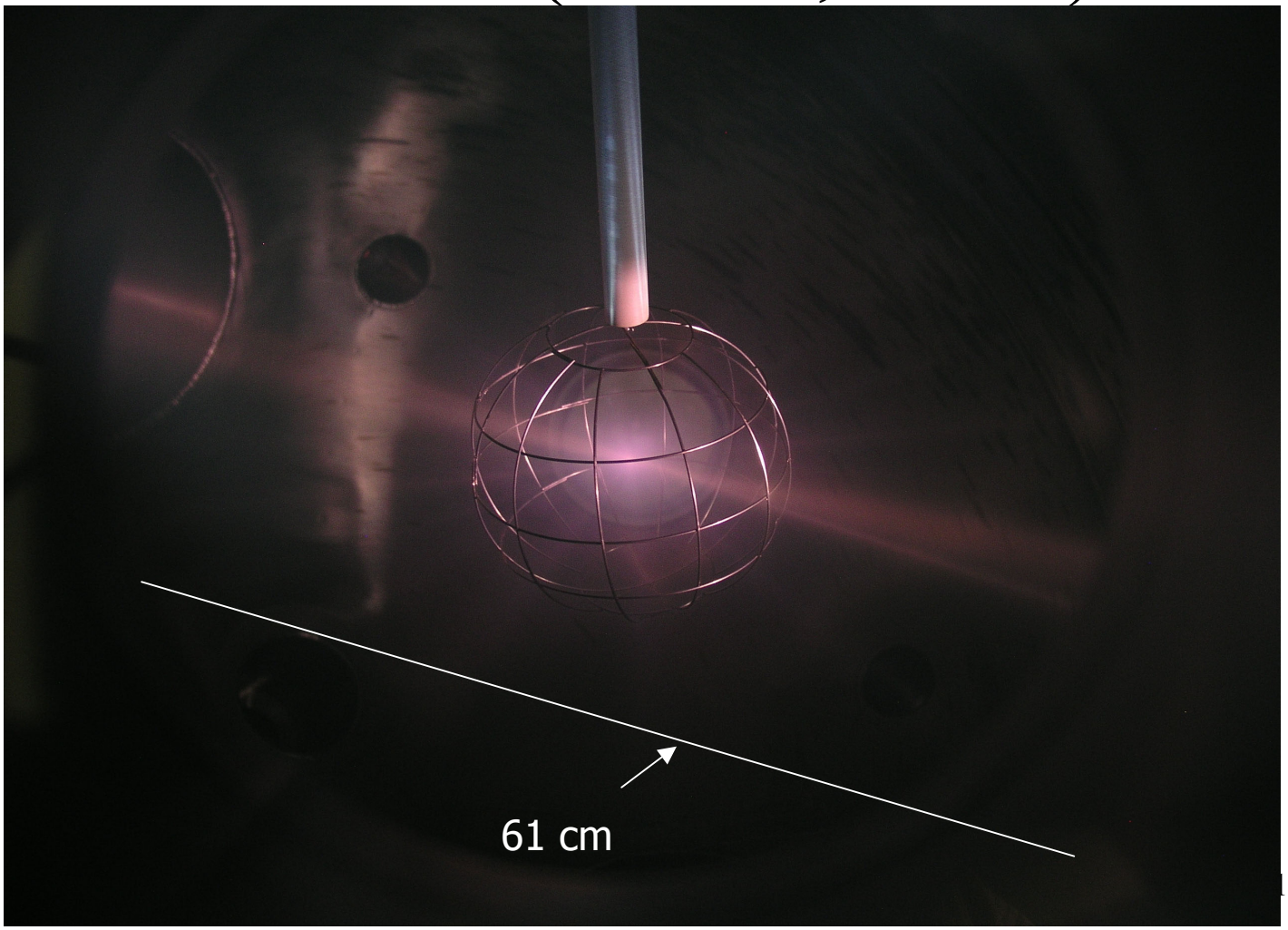


Helium



Argon

Helium Beam Discharge into UW-IEC (35 kV, 2mA)



Summary: Ion Source Will Enable Converged Core Experiments

- Helicon ion sources allow high beam currents with low neutral gas flow, allowing IEC to operate at very low pressure
- External source allows for greater He ionization fraction
- Initial experiments underway on UW helicon ion source
- Extraction and differential pumping systems to come on-line soon, enabling converged core experiments to begin