Development of the Motional Stark Effect with Laser Induced Fluorescence (MSE-LIF) Diagnostic

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Presented at the 43^{rd} Annual APS Division of Plasma Physics Meeting

October 29 - November 2, 2001

Long Beach, CA

ABSTRACT

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The motional Stark effect diagnostic has been highly successful in measuring the q-profile and radial electric fields in large tokamaks. As previously implemented, MSE is not feasible for lower magnetic field devices. The MSE-LIF diagnostic removes this limitation. The addition of the laser extends the measurement capabilities to magnetic fields as low as 0.1 Tesla. The inclusion of a diagnostic neutral beam allows the diagnostic to be used on machines that lack large heating beams. It also allows a device with a heating beam to gain an extra MSE measurement, which will enable determination of radial electric fields with previously unattainable accuracy. The wavelength-referenced laser allows measurement of the magnetic field magnitude. From this, the paramag-

netic and diamagnetic contributions to the total field can be determined, and the plasma pressure profile can be reconstructed based on the MSE-LIF measurement. Current profiles may be reconstructed from MSE-LIF data, using the pitch angle profiles and equilibrium reconstruction codes. This poster will describe the progress to date of the development of the MSE-LIF technique.

MSE Background

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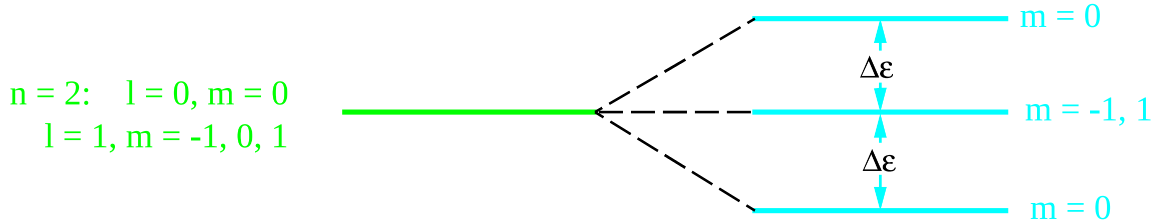
The Stark Effect: Applied electric field removes energy degeneracy of atomic states of same n, different l:



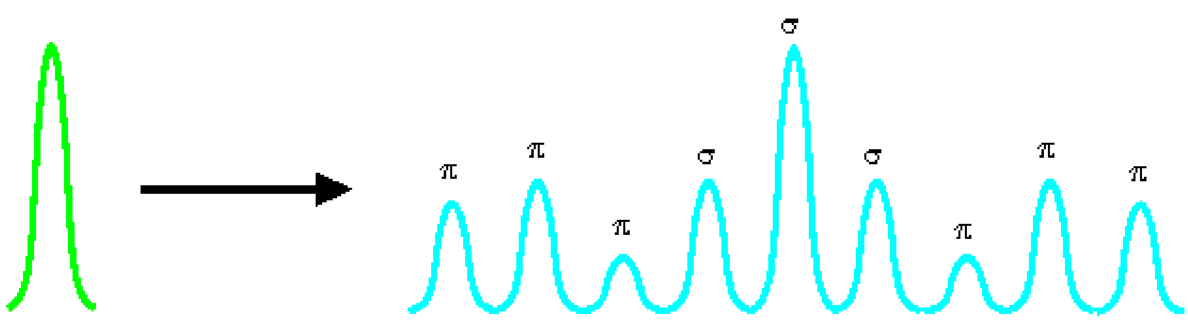
Use perturbation theory for degenerate levels to find a linear shift in hydrogen:

n = 2:

New eigenstates: $\frac{1}{\sqrt{2}}(\Psi_{200} - \Psi_{210}),\ \Psi_{21\pm1},\ \frac{1}{\sqrt{2}}(\Psi_{200} + \Psi_{210})$

Energy split: $\Delta\epsilon = 3ea_0E$

Splitting of energy levels causes splitting of spectral lines:



Polarization Effects

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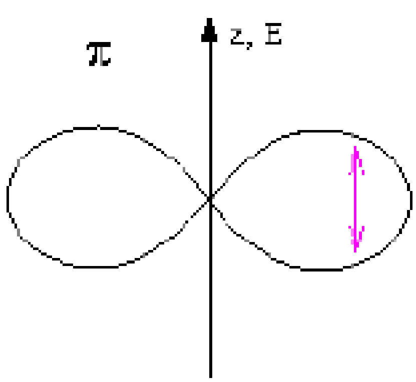
Transition rate proportional to square of transition dipole moment:

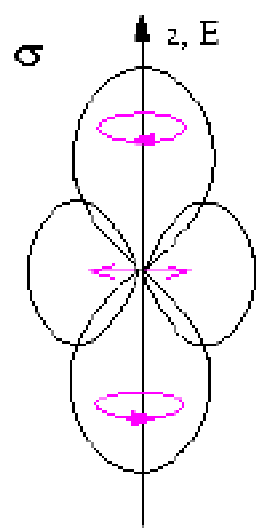
$$-e\langle\Psi_{nlm_l}\mid\vec{r}\mid\Psi_{n'l'm_l'}\rangle$$

Angular distribution and polarization of emitted radiation given as for electric dipole oscillating at $\omega = \Delta\epsilon/\hbar$

$\Delta m = 0$ transition (π): Dipole moment of form P$\hat{z}$: radiation is linearly polarized parallel to $\vec{E}$

$\Delta m = \pm 1$ transition (σ): Dipole moment of form $\sqrt{\frac{1}{2}}(\hat{x} \pm i\hat{y})$ rotating in xy plane: transverse view gives linear polarization perpendicular to $\vec{E}$





Determination of $\vec{B}$, $\vec{E}_r$

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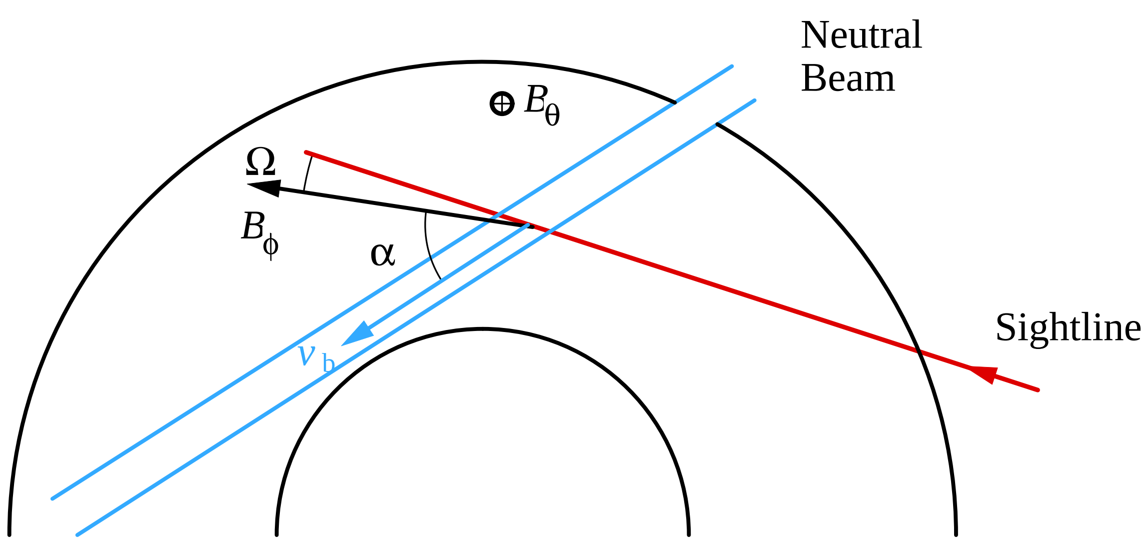
Inject beam of neutral hydrogen into magnetized plasma: emission from beam is split, polarized due to Stark effect from Lorentz electric field:

$$\vec{E} = \vec{v_b} \times \vec{B}$$

Polarimetry measurements give pitch angle of $\vec{B}$ field. Two measurements allow determination of radial electric field

$$\tan(\gamma_m) = \frac{v_b B_\theta \cos(\alpha + \Omega) + E_r \cos(\Omega)}{v_b B_\phi \sin(\alpha)}$$



Limitation of MSE-CIF at Low Field

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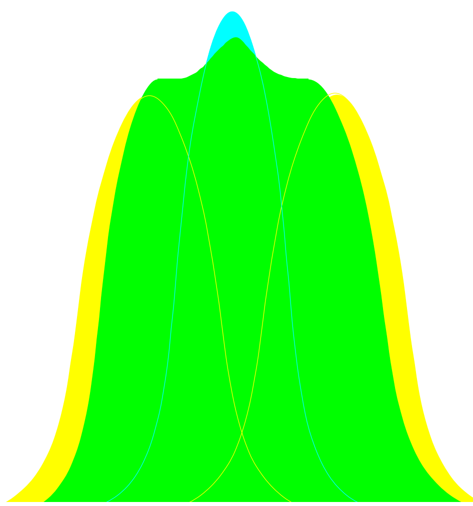
Previously implemented MSE-CIF technique used to measure q profile and radial electric field: viable only for magnetic fields > 0.75 T.

Limitation: Measured spectral linewidth of Stark shifted emission greater than separation at low field.



Polarization information is lost due to overlap: Low polarization fraction $\Longrightarrow$ low signal-to-noise.

Solution: Laser Scanning

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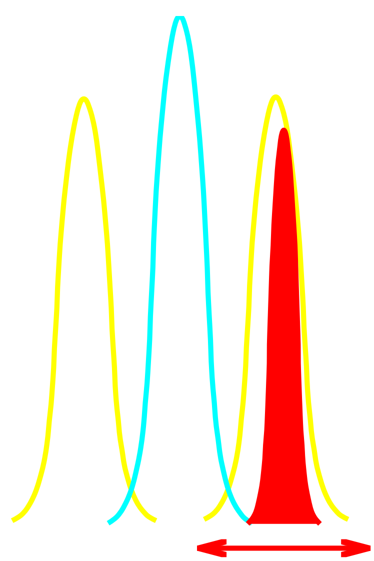
A major source of line broadening: geometrical broadening in collection optics. Defeat this by using narrow linewidth laser to excite transition:



Now limited by beam parallel Doppler broadening: can get down to fields of 0.1 T.

MSE-LIF Signal-to-Noise

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MSE design parameters	LIF	CIF
Lens Dia. (cm)	20	3×20
Beam area image(cm)	2×3	10×3
Fibers per channel (1 mm)	24	61
Improvement factors relative to TFTR		
optics-fibers étendue	11.1	5.4
beam width	0.13	1
PEM/polarizer efficiency	3.7	1
LIF enhancement	2.5	1
High Q.E. APD	3	3
species mix	0.5	1
current density	0.15	1
Polarization fraction	1.4	.16
Total improvement factor	2.6	2.6

- Relative to TFTR (5 ms time resolution and 0.1° pitch angle uncertainty).

Proposed MSE-LIF Setup

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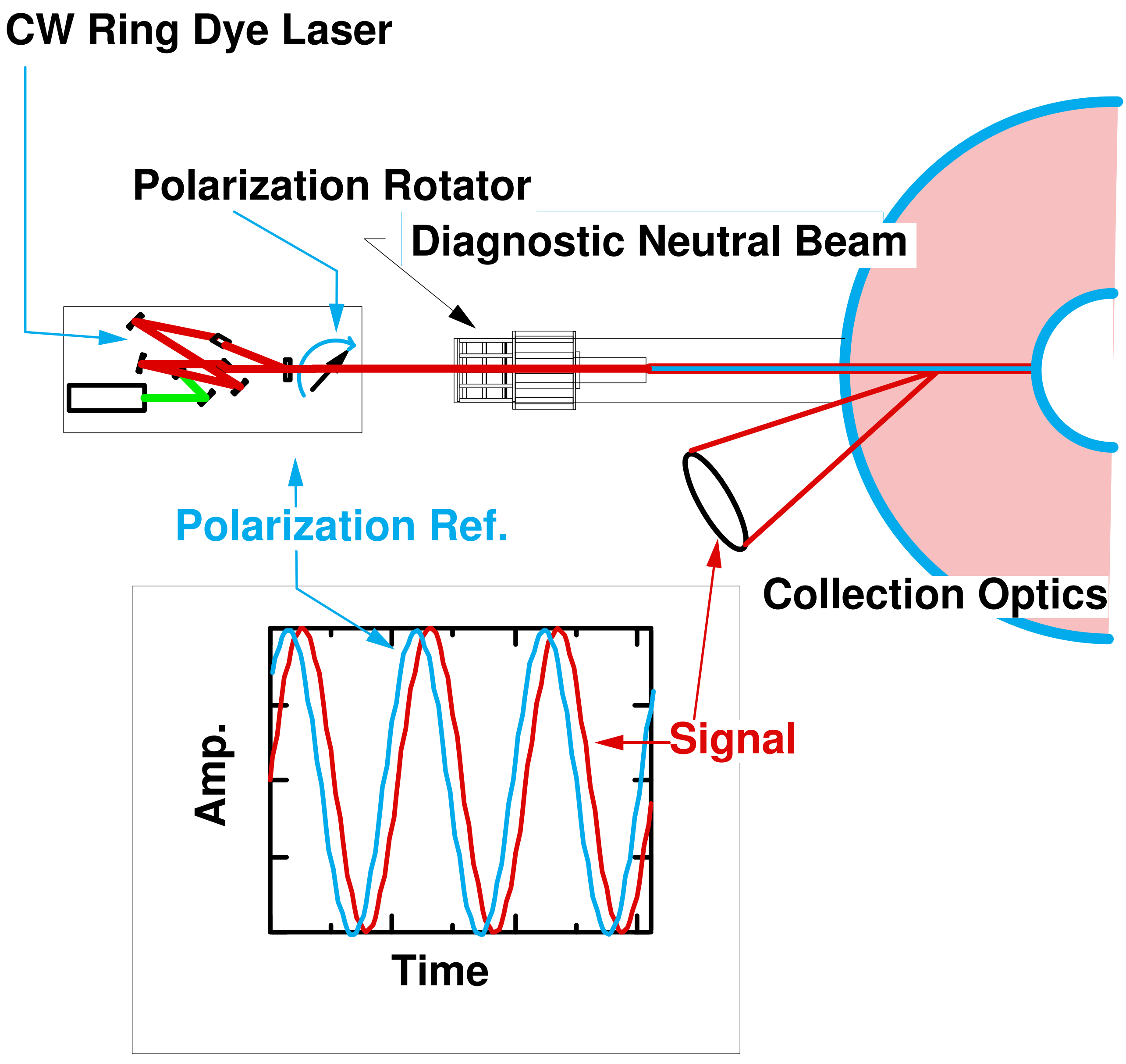

Diagnostic Capabilities

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- **Magnetic Field Magnitude and Direction:**

  Direct Measurement with MSE-LIF

- **Pressure Profiles:**

  Reconstruct using MSE-LIF measured $\vec{B}$ and equilibrium codes:

  $p + B^2/2\mu_0 = const.$

- **Current Profiles:**

  Reconstruct using measured $\vec{B}$, determined p: $\vec{\nabla} p = \vec{j} \times \vec{B}$

- **Radial Electric Fields:**

  Separate effect of radial electric fields using two independent MSE measurements - Planned for NSTX with CIF system, see poster # 32 in this session.

Relevant Physics Issues

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- **Magnetic Field and Pitch Angle:**
  - **q(R) for MHD stability**
  - **Measure magnetic fluctuations?**
- **Pressure Profile:**
  - **Study pressure gradient driven instabilities**
  - **Use as feedback for real-time control**
  - **Determine non-thermal ion/electron populations: study heating mechanisms**
- **Current Profile:**
  - **Evaluate current drive mechanisms**
  - **Study current driven instabilities**
- **Radial Electric Field:**
  - **Effect on turbulence suppression**
  - **Reversed shear & enhanced confinement**

Diagnostic Development at PPPL

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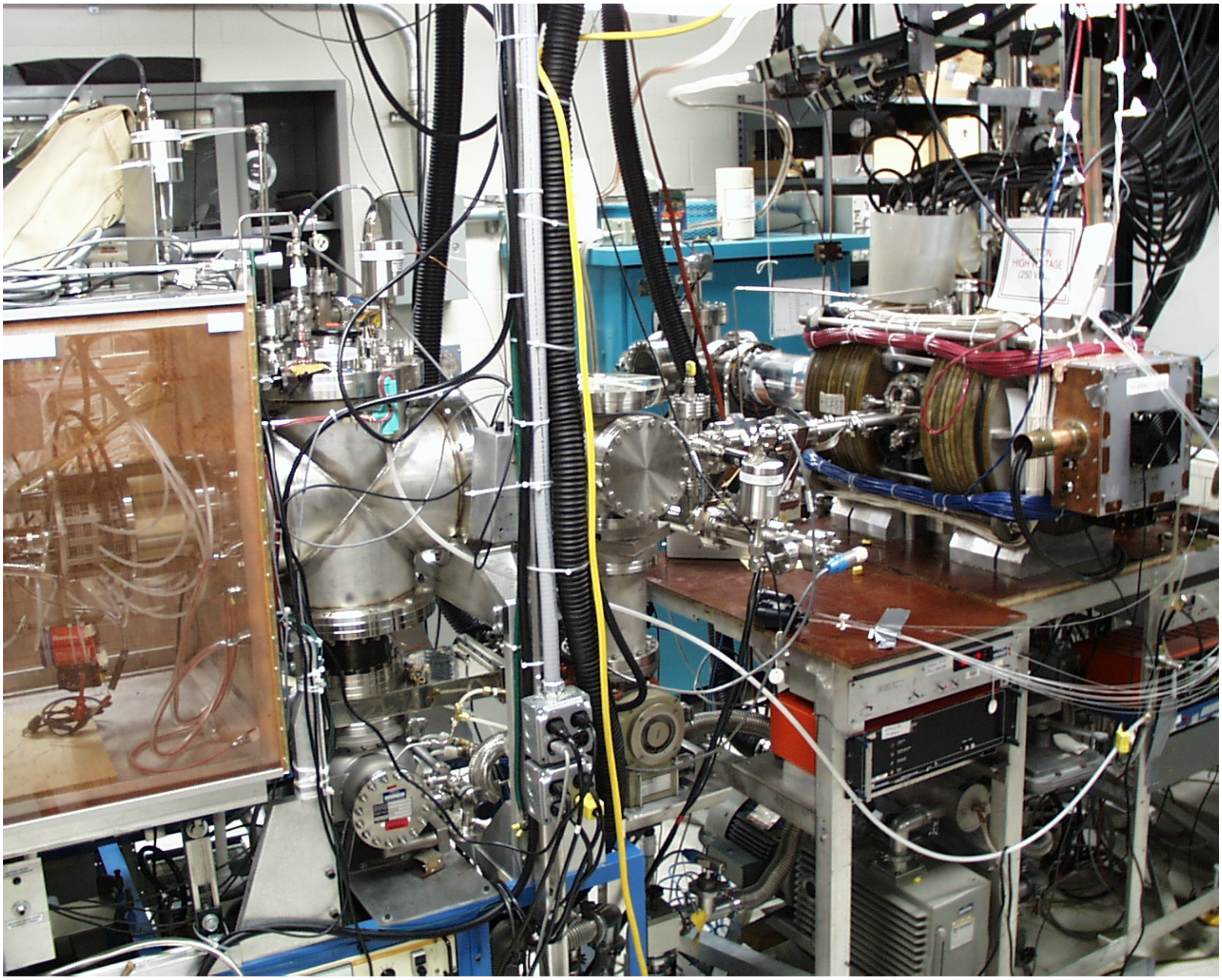

Facility and equipment for development of MSE-LIF assembled at PPPL. Includes:

- **Diagnostic neutral beam**
- **CW ring dye laser**
- **Helicon plasma source**

Diagnostic Neutral Beam

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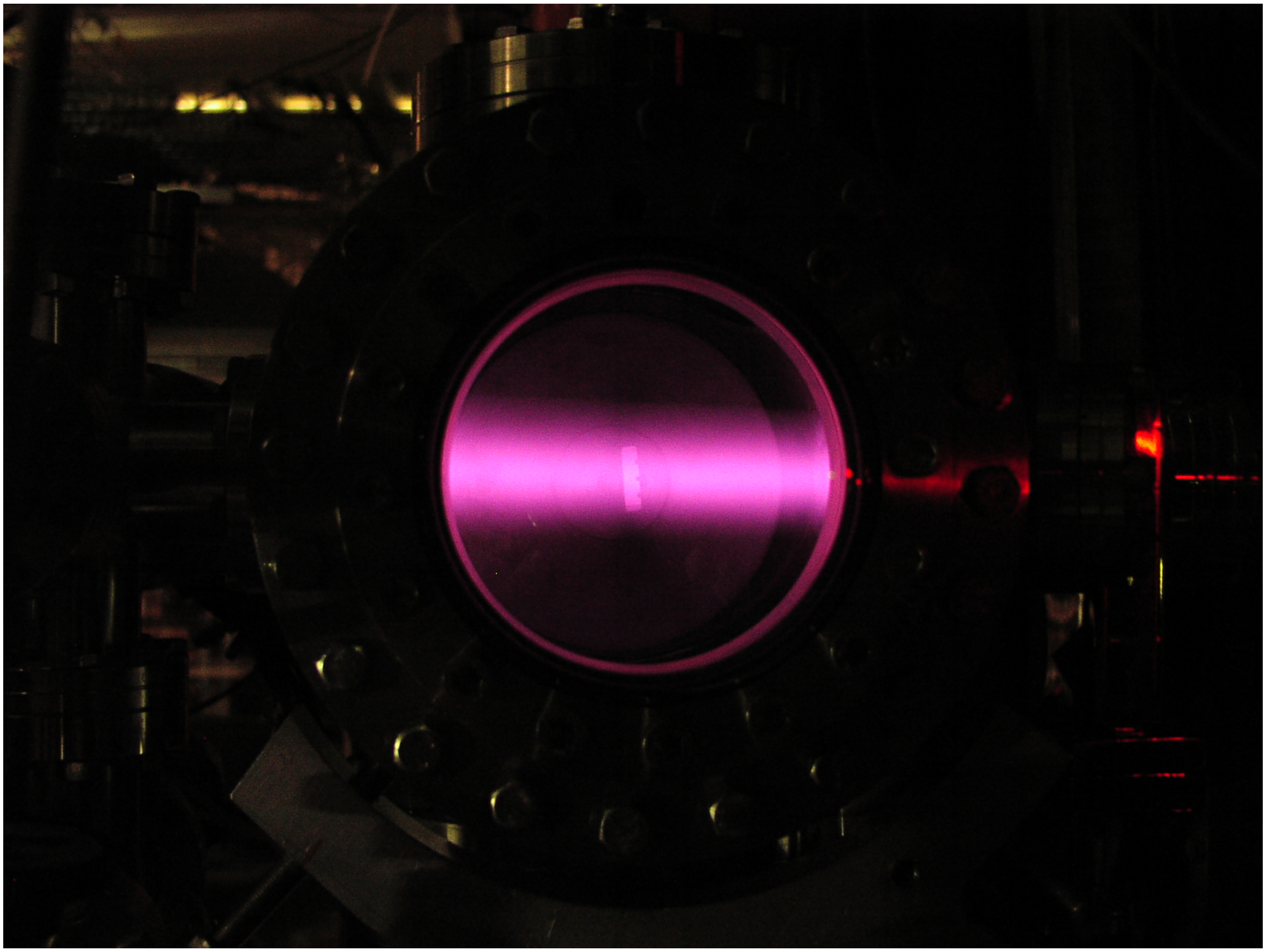

- **Hydrogen**
- **RF plasma source: 2.9 MHz, 3 kW, steady state**
- **Ring cusp magnetic field**
- **5 turn water-cooled copper coil antenna**

Diagnostic Neutral Beam

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- Operates up to 40 kV, 30 mA
- Faraday probe for intensity profile measurements
- Spectroscopic measurement of species fraction
- Improvements to voltage stability: RF filter, Line noise filter
- Further Development:
  - Further reduce voltage ripple for narrower linewidth, improved LIF signal to noise ratio - 2001
  - Improve full energy fraction: modification of source (magnets, antenna coating) - 2001/02
  - New power supply for voltage stability - late 2001/ early 2002
  - Develop voltage sweep capability to allow measurement of $\vec{B}$ field magnitude- 2002

Neutral Beam: Intensity Profile

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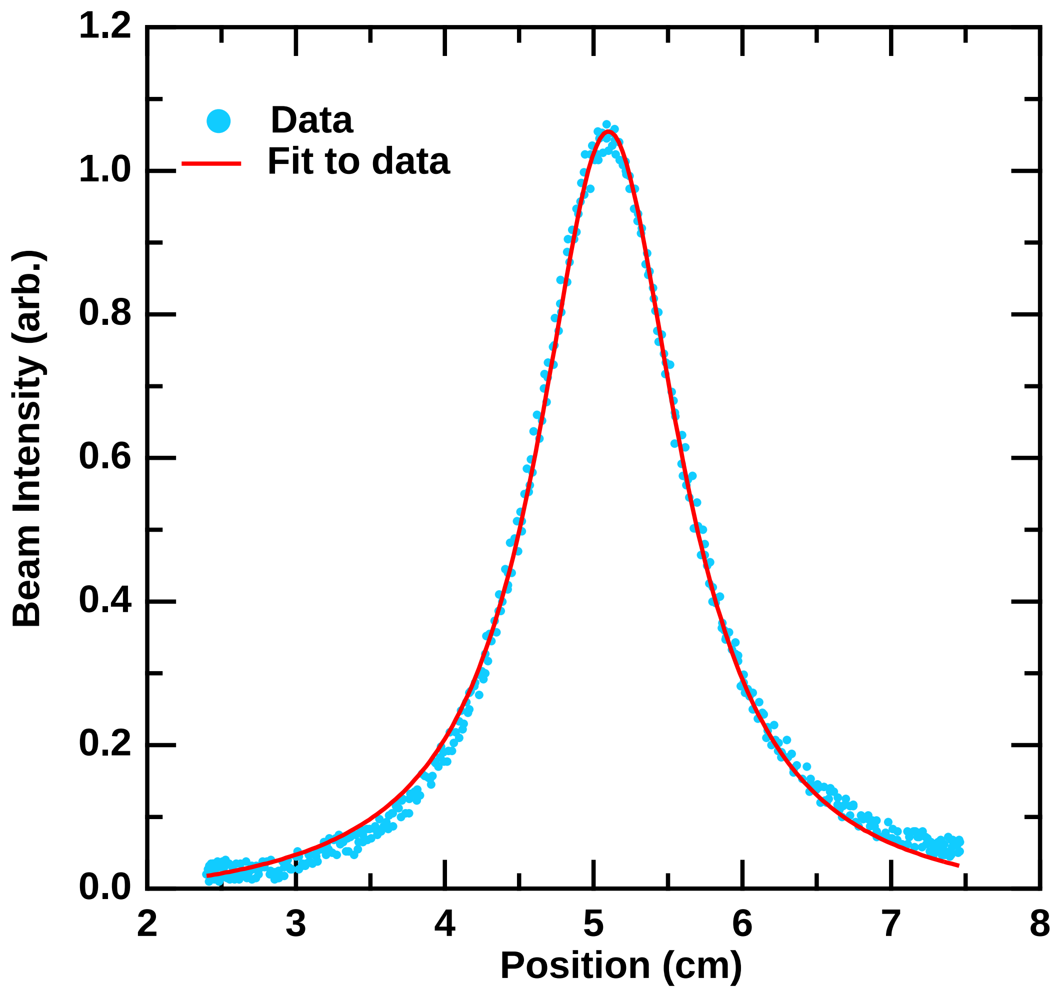

- **Fit to Faraday probe data shows good agreement with Lorentzian profie.**

- **Beam divergence: 0.11° - 0.22°**

Neutral Beam: Energy Spectrum

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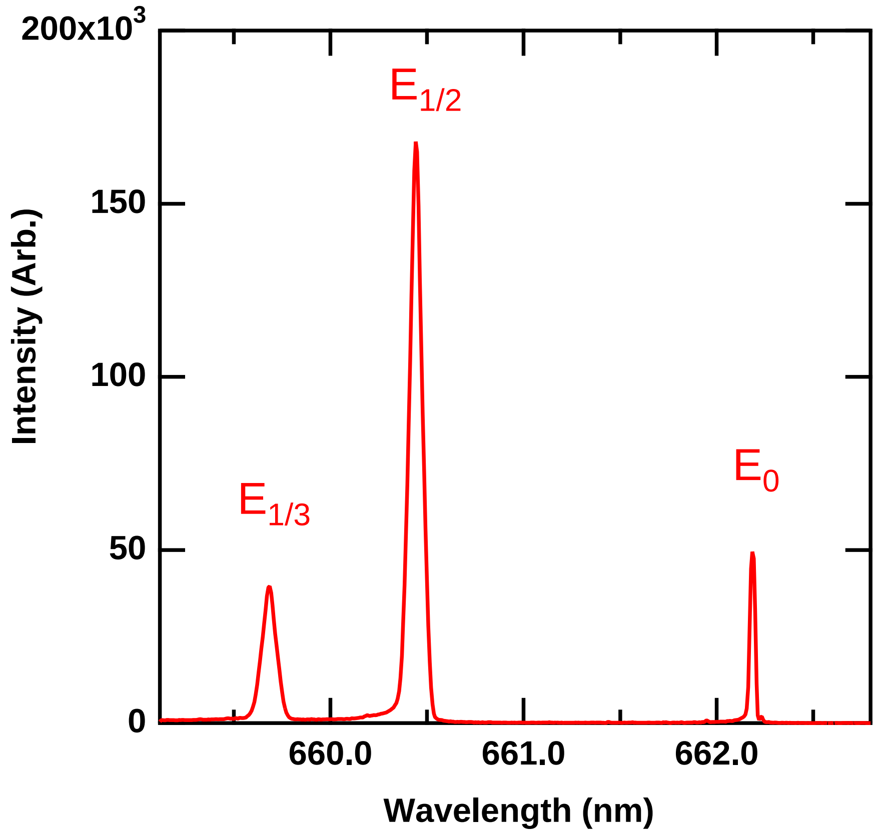

- **Some H ions are accelerated as molecules: H_2^+, H_3^+. These collisionally dissociate in neutralization cell, join beam as neutral H atoms with 1/2 and 1/3 of full energy.**

- **Spectroscopic measurements, including corrections for dependence of interaction cross sections on species and energy, show 16% full energy, 71% half energy, and 13% third energy for the above data at 38 keV.**

CW Ring Dye Laser

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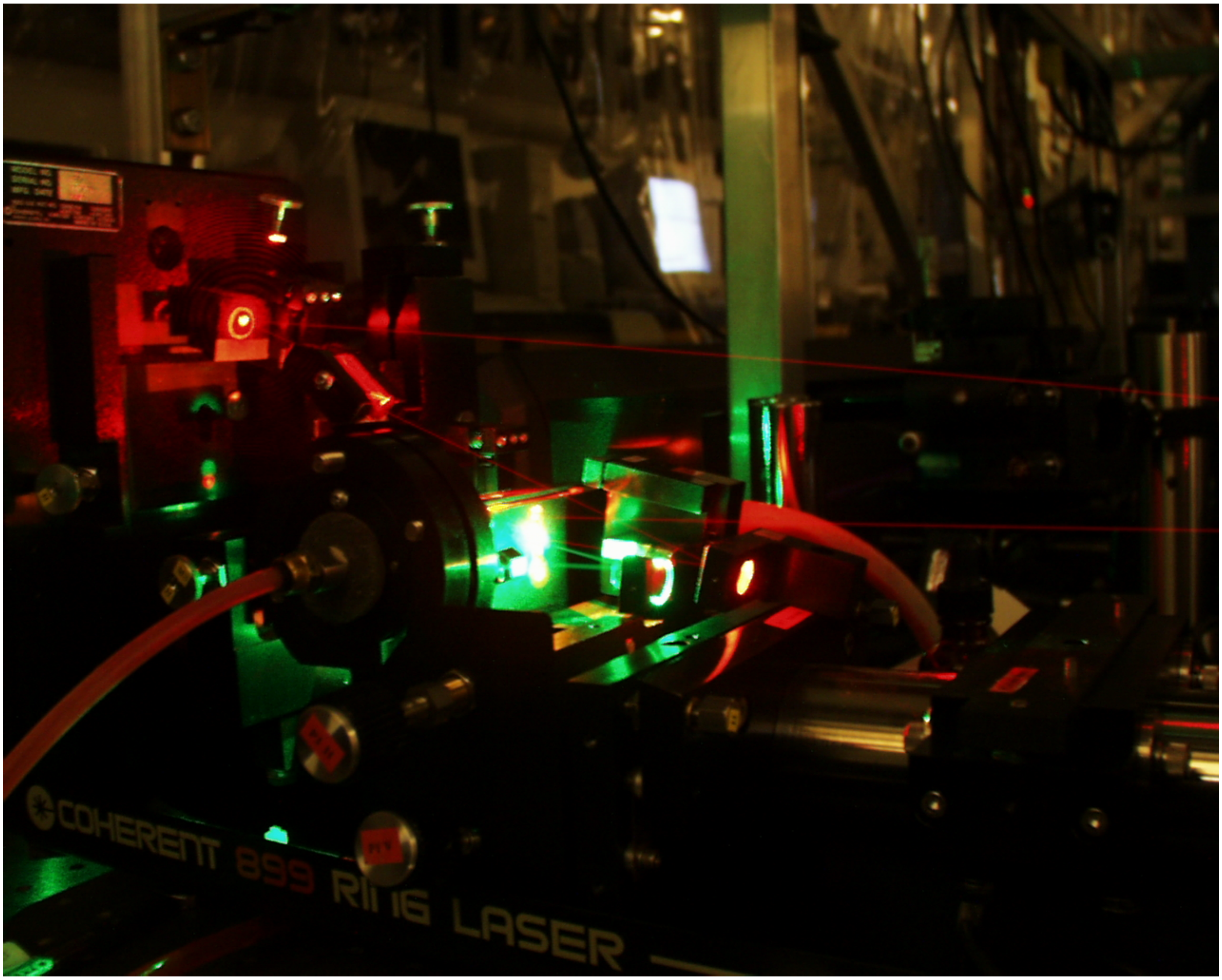

- Coherent 899-05 CW ring dye laser
- Argon ion pump laser: 7.5 W, 514.5 nm
- Exciton DCM dye, EPH solvent - good lifetime
- $\sim$ 1 W broadband, $\sim$ 600 mW single frequency at $\sim$ 650 nm

CW Ring Dye Laser

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- $<$ 70 MHz linewidth
- 30 GHz scanning capability
- Coupled to beam through fiber
- Further Development:
  - New dye jet for greater output power, improved linewidth - late 2001
  - Frequency stabilization - 2002
  - Optional Upgrades: Increase scan width to match Stark spectrum, modify for rapid scanning - 2002

Helicon Plasma Source

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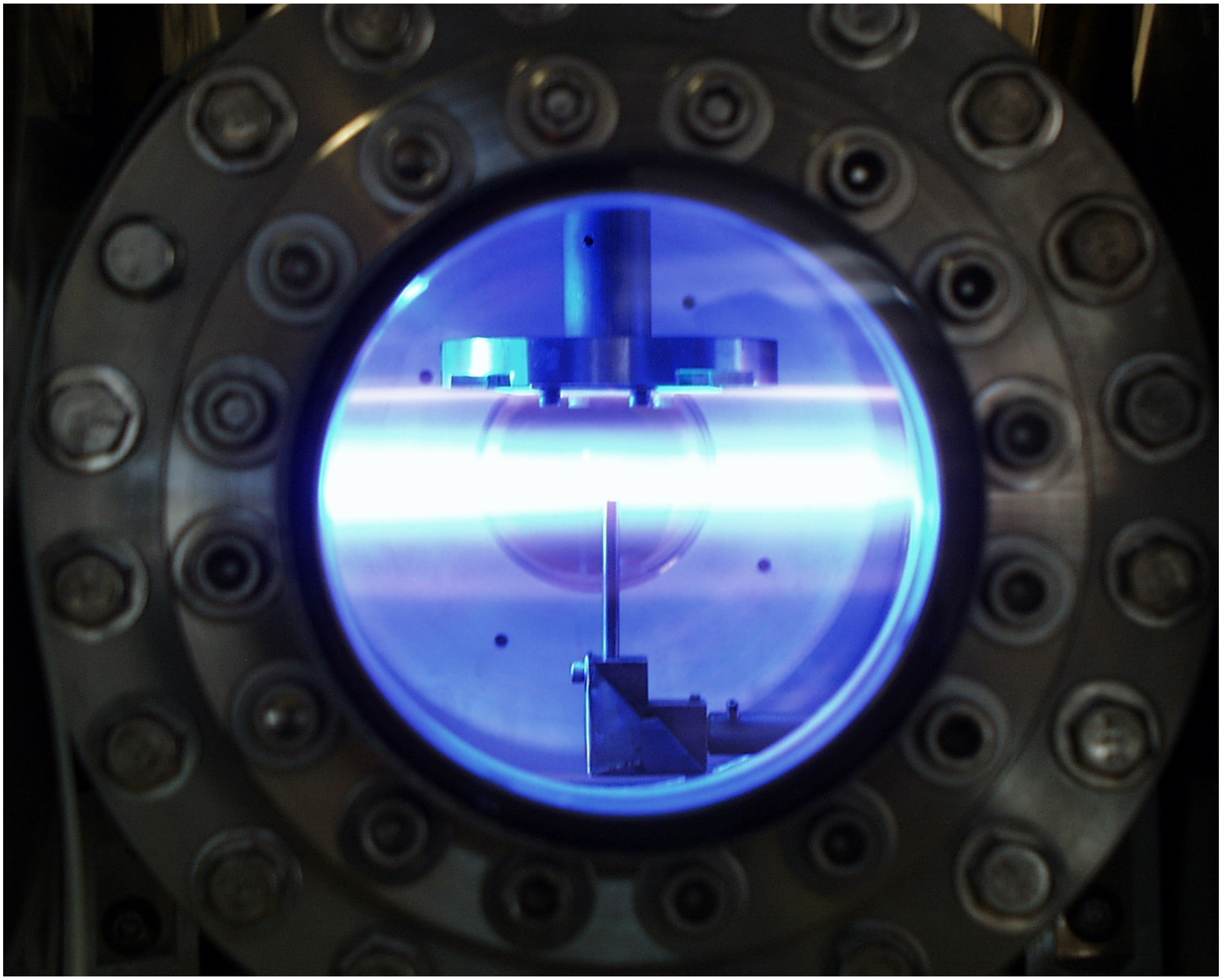

- View of plasma through horizontal port.
- Steady-state plasma used for diagnostic development and magnetic nozzle experiment (MNX).

Helicon Plasma Source

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- **Nova Photonics, Inc., in collaboration with PPPL, has assembled a steady state helicon plasma source on MNX.**
- **Plasma source using RF helicon wave.**
- **RF at 27 MHz and $\leq$ 1 kW.**
- $B \leq 0.35$ **T.**
- $n_e \sim 10^{19}$ m^{-3}.
- **Electron temperature and density profile from Langmuir probe.**
- **Electron temperature is 4-5 eV.**
- **Ion temperature, from LIF measurements, is about 0.5 eV.**

First LIF From Neutral Beam: Setup

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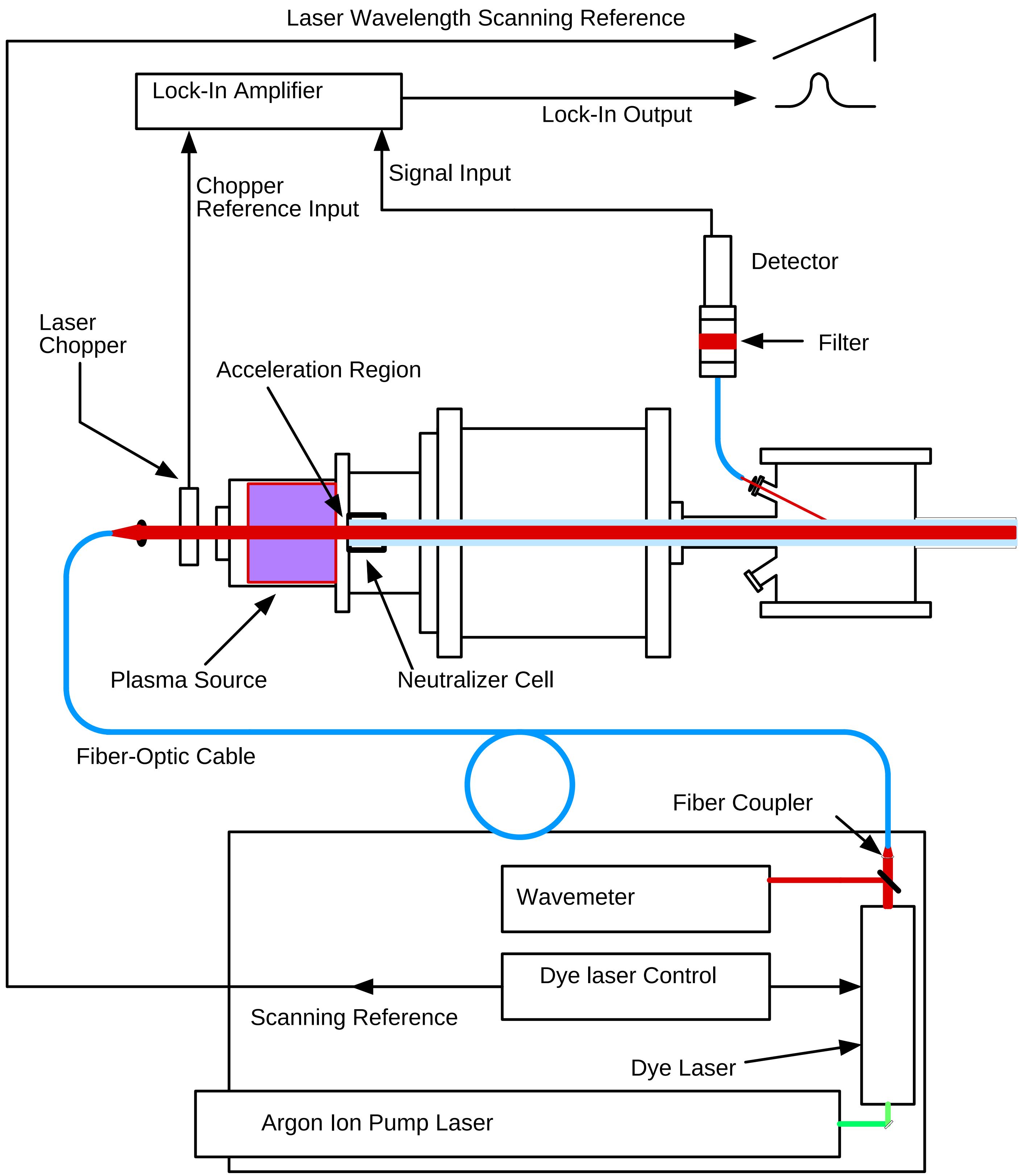

First LIF From Neutral Beam: Data

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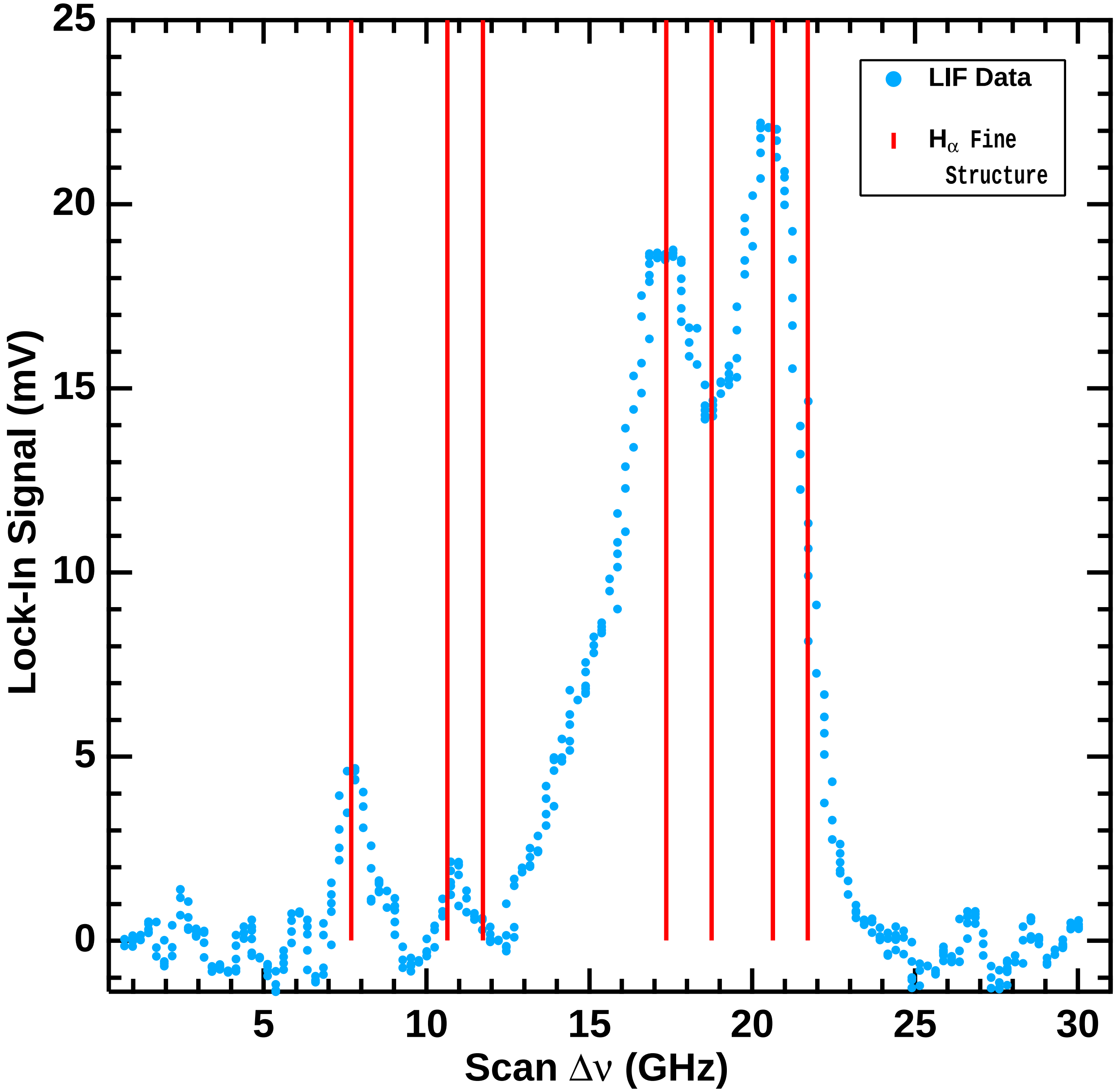

- Data consistent with observation of H_α fine structure
- $\sim$ 4 GHz linewidth believed to be due to ripple on beam acceleration power supply voltage

Future Plans

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- **Improve signal to noise of LIF by reducing voltage ripple, improving species fraction- 2001**
- **Perform measurements on applied magnetic fields in neutral gas, plasma - early 2002**
- **Demonstrate ability to measure $\vec{B}$ magnitude, direction and possibly fluctuations in helicon source plasma. - 2002**
- **Install diagnostic on NSTX - late 2002**
- **Shakedown & calibrate - 2002/03**
- **First NSTX data - 2003**

Physics Topics on NSTX

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- ST MHD stability
  - Fast ion effects
  - Current/q profile
- Pressure profile
  - Reconstruction and control
  - $\vec{\nabla} p$ instabilities
  - Non-thermal ion population: heating mechanisms
  - Trapped energetic ions: TAE modes
- Current drive: HHFW, CHI, EBW, bootstrap
- Radial electric field measurements
  - Turbulence suppression: $\vec{E} \times \vec{B}$ shear
  - Enhanced confinement modes