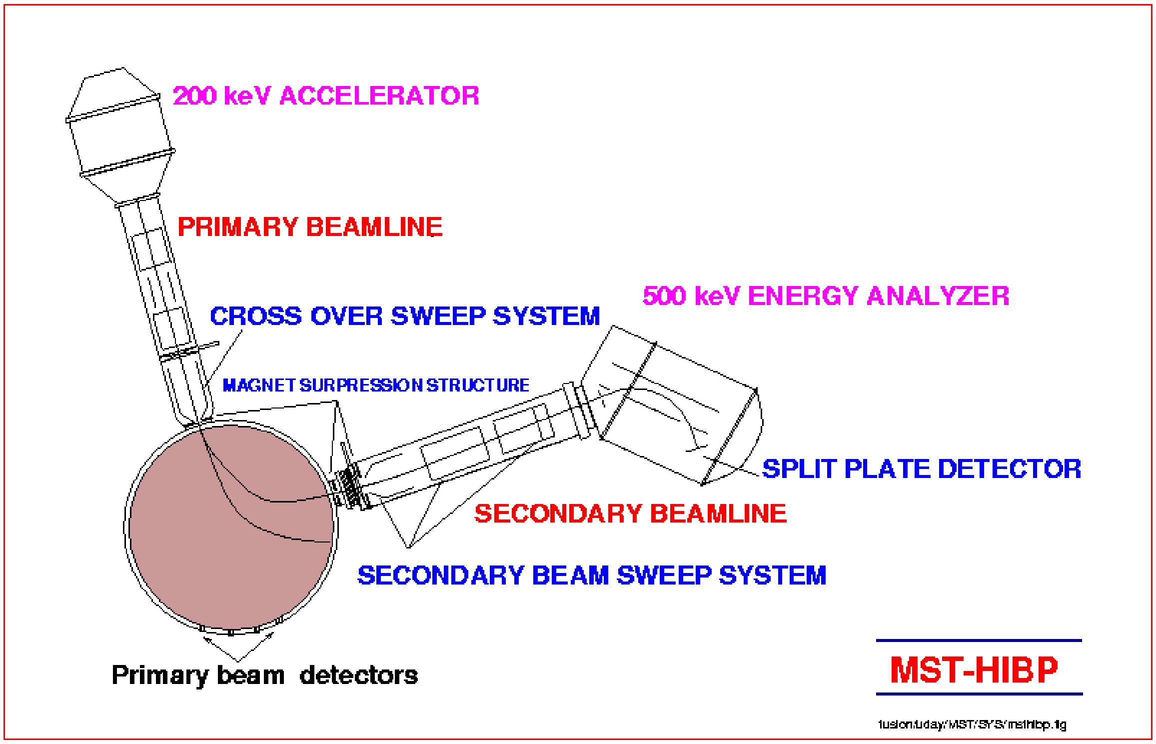
Poster Presented at ICOPS2000
5-9 June, 2000, New Orleans, LA

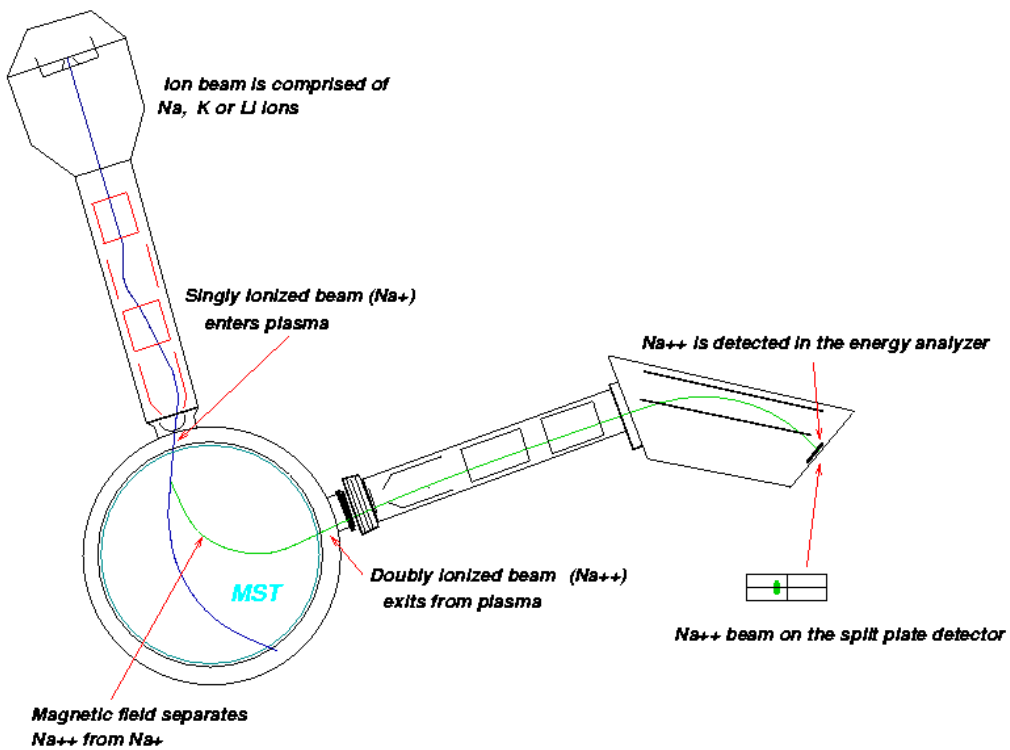
Heavy Ion Beam Probe Development

K. A. Connor, T. P. Crowley, D. R. Demers, S. J. Howard, J. Lei,
J. G. Schatz, P. M. Schoch, U. Shah, J. Si
Rensselaer Polytechnic Institute, Troy, NY

ABSTRACT

Heavy ion beam probe diagnostic (HIBP)systems are presently in operation on the Madison Symmetric Torus (MST) at Wisconsin and on a helicon plasma experiment at Rensselaer. In addition, HIBP systems have been proposed for other experiments, including the Levitated Dipole Experiment (LDX) at MIT/Columbia and the National Spherical Torus Experiment (NSTX) at Princeton. The MST system is based on the old ATF/ISX and TEXT systems and incorporates some new capabilities to accommodate the small ports and high plasma and ultra-violet fluxes. In particular, a cross-over sweep system is used in both the primary and secondary beamlines to provide broad radial coverage and a series of apertures containing permanent magnet structures have been added to permit the many electrostatic field structures to hold voltages and fields. Results of diagnostic alignment and calibration experiments will be presented along with recent progress on potential and fluctuation measurements. We are conducting experiments with the ultimate goal of developing a non-perturbing diagnostic technique for measuring RF field and density fluctuations in fusion plasmas. In order to develop this technique, a helicon plasma with a heavy ion beam probe (HIBP) diagnostic is being constructed. The helicon plasma has a magnetic field of up to 1.5 kG produced by a set of circular coils. A 1 kW, 13.56 MHz RF generator will be used to drive helicon waves in the plasma. Diagnostic apparatus utilizes a 60 keV HIBP diagnostic beam and detector that were previously used on the Tokamak de Varenne. The detection electronics is being modified to operate at higher frequencies. Present status of the experiment as well as key issues in extending HIBP measurements to higher frequencies will be discussed. The HIBP proposed for LDX, based on the old EBT/TARA system, is intended to study convective cells in a simple magnetic dipole field, similar to that found in planetary magnetospheres. Both potential structures and the impact of flows around them as observed in fluctuation measurements can be characterized with such a system. An HIBP system has also been proposed for NSTX, based on the 500kV TEXT HIBP. There is presently no plan for the 2 MeV TEXT Upgrade system.

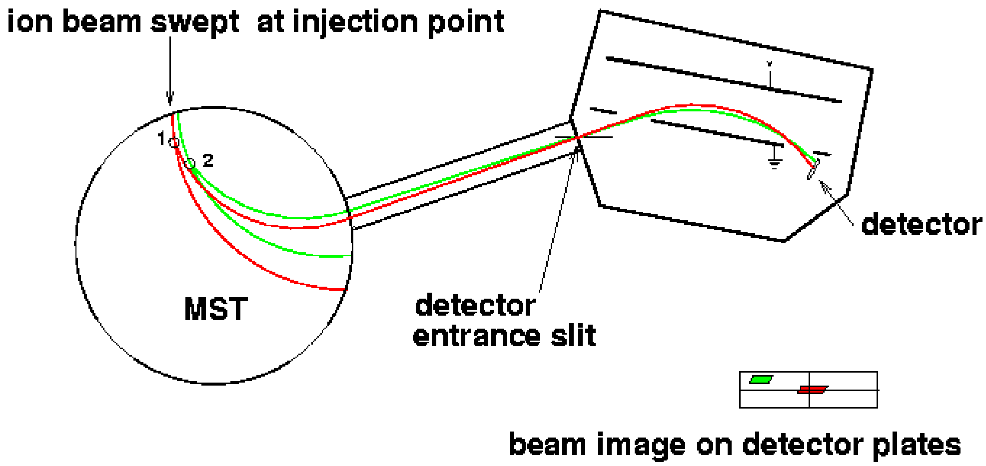

200 keV ACCELERATOR
PRIMARY BEAMLINE
CROSS OVER SWEEP SYSTEM
MAGNET SURPRESSION STRUCTURE
500 keV ENERGY ANALYZER
SPLIT PLATE DETECTOR
SECONDARY BEAMLINE
SECONDARY BEAM SWEEP SYSTEM
Primary beam detectors
MST-HIBP
fusion/uday/MST/SYS/msthibp.fig



PRINCIPLES OF HEAVY ION BEAM PROBING

fusion/uday/Thesis/principles.fig

ILLUSTRATION OF MEASUREMENT OF POTENTIAL



MEASUREMENT DEVELOPMENT

Plasma space potential and fluctuation measurements are obtained from

$$\Phi = \frac{W_d - W_i}{q_s - q_p} \qquad \& \qquad \tilde{\Phi} = \frac{q_s}{q_s - q_p} V_a F(q_i) \Delta((i_u - i_l)/(i_l + i_u))$$

W_d **= energy of secondary beam,** W_i **= primary ion beam energy**
q_s **= charge of secondary beam,** q_p **= charge of primary beam**
F **= analyzer geometric factor,** V_a **= analyzer voltage**
i_u **&** i_l **= detected current on upper and lower detector plates**

For a successful measurement we need to be able to do the following:

- **resolve signal on top and bottom detector plates**
- **resolve sample volume locations**
- **computer control sweep plates so that ion beam can be swept in any arbitrary fashion**
- **change beam energy and plasma current for optimum plasma coverage**

- **At present**
  - **we have been able to resolve signal on top and bottom plates for limited conditions**

INITIAL OPERATIONAL RESULTS

- **HIBP secondary ion signal was detected for a 70 keV primary ion beam**
- **Secondary beam current is between 5-15 nA**
- **Signal reveals that ion beam trajectory is very sensitive to magnetic fluctuations – MST plasma is dominated by magnetic fluctuations and sawteeth activity which affect the ion beam trajectory. This sensitivity is encouraging for developing MST-HIBP as a magnetic diagnostic on RFPs.**
- **Comparison between theory and experiment reveals that a correction of roughly 10-15% in MST magnetic field was required for ion beam to enter HIBP detectors**
- **Sample volume are located at r/a ~ 0.4-0.6**
- **Both primary and secondary beamline sweeps were used for signal detection (signal can now be detected without sweeps as well)**

FURTHER DISCUSSION

- **Immediate plans**
  are to measure space potential and potential fluctuation in the core of MST

- **Improve understanding of MST magnetics**
  use information from HIBP data to modify the magnetic model and recalculate trajectories – i.e. a self consistent approach

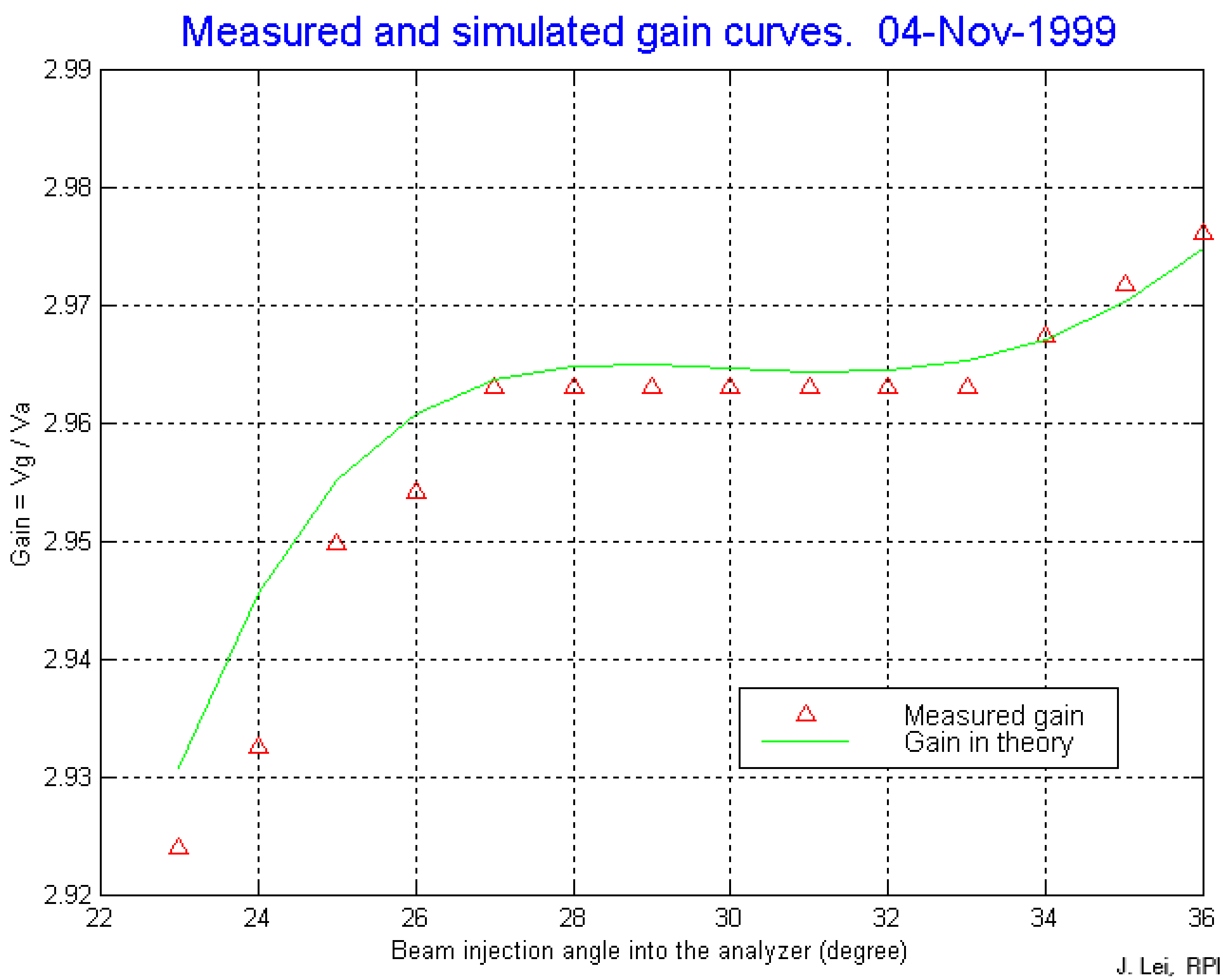
- **Resolve sample volume locations in MST to within 2 cm in the plasma**

- **Develop computer control sweep plates**
  By using a gpib controllable arbitrary waveform generator the ion trajectory can be programmed to extend present cross sectional coverage of plasma during a single discharge. This feature will also greatly aid ability to make fluctuation measurements.

- **Explore the range of plasma currents and ion beam energy combination for HIBP operation**

ENERGY ANALYZER

- Important parameter for the measurement of space potential is the gain of the analyzer
- The gain is defined as the ratio of the accelerator voltage to the analyzer voltage for a singly ionized beam
- The analyzer has been calibrated both at RPI and on MST. The result is very close to the theoretical gain



ALIGNMENT AND CALIBRATION

- **The primary beamline has been aligned to enable the ion beam to be injected into the MST even without sweeps**.

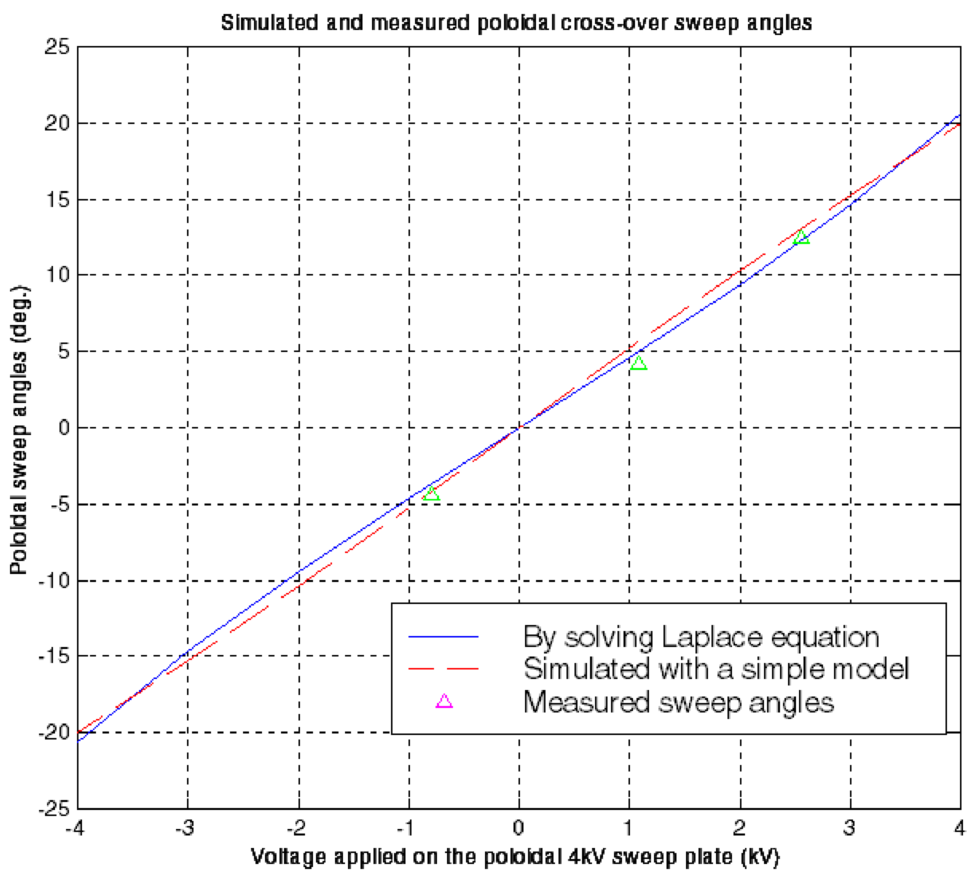
  - The alignment is implemented by using sweep plates themselves and a shutter plate at the end of the beamline.
  - The alignment needs to be checked each time after changing the ion source for the present configuration.

- **Calibration of the sweep plates is essential for HIBP measurement in order to locate the sample volumes. Two methods are used:**

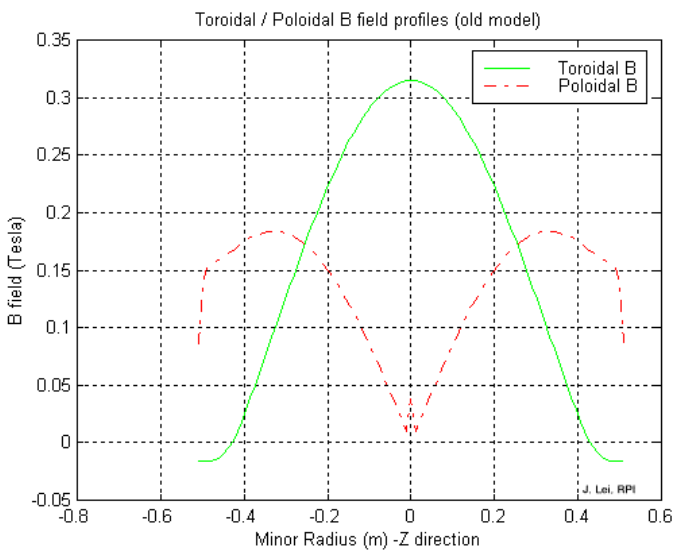
1. **Numerical method:**
   - Sweep angles can be calculated from running trajectories in the sweep system by solving a 2D Laplace problem
   - For the secondary sweep plates, only numerical methods can be used
2. **In situ calibration: (primary sweep plates only)**
   - By using a set of detecting wires at the end of the primary beamline
   - By using 'scrape off' on the 4 pairs of sweep plates in the primary beamline
   - By using the primary beam detectors

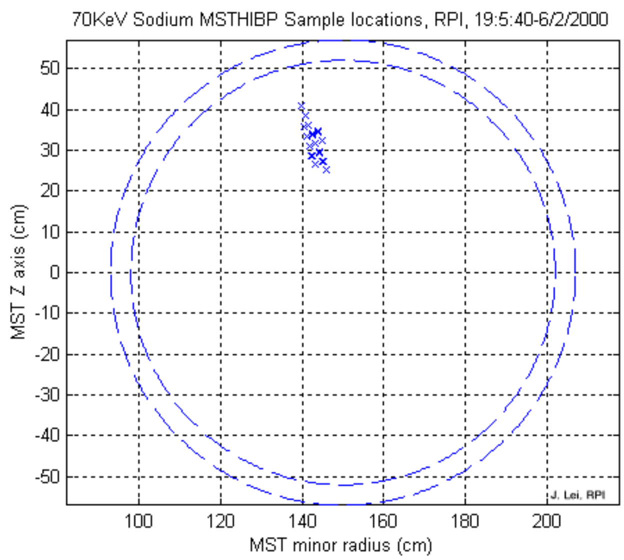
Single pin, multi-pin, cross-rod and rotary rod detectors have been placed at the bottom of the MST chamber opposite to the beam injection port

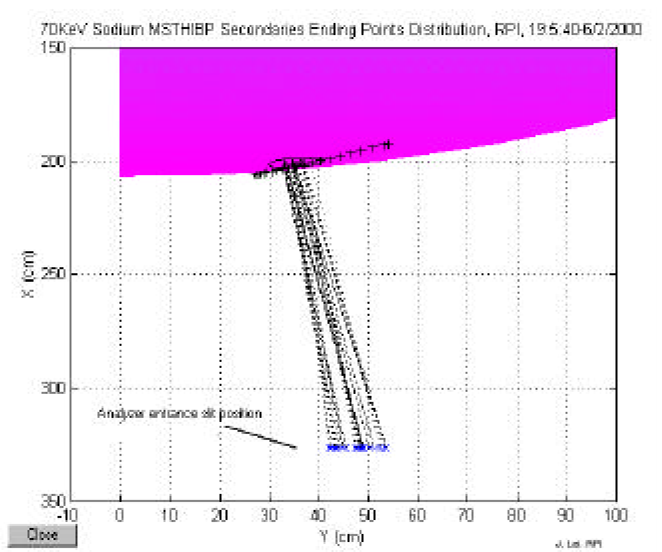
- Shown in the figure are the simulated sweep angles of the primary cross-over poloidal sweep plates, as well as the measured angles with the primary beam detectors. The results show that the sweep system designed is operational, and the measured angles fit our designed model quite well

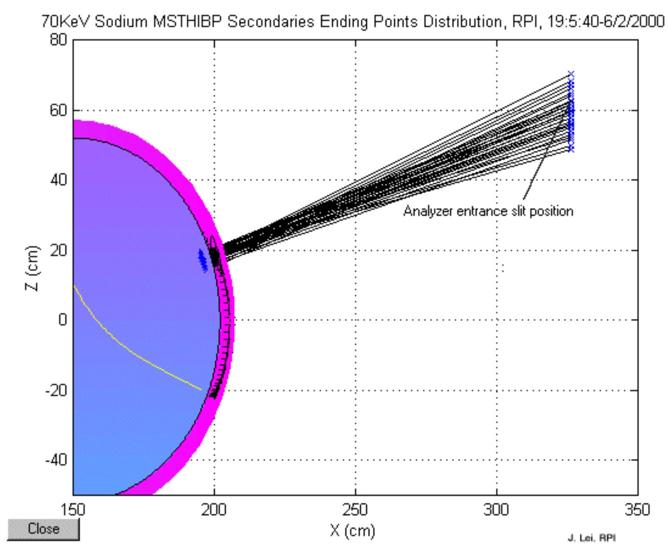


Magnetic field profiles, sample locations, and secondary trajectories calculated from the old field model

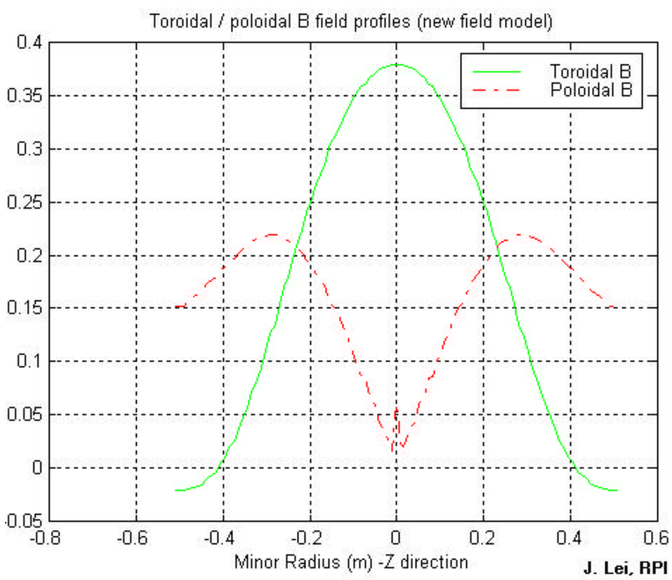


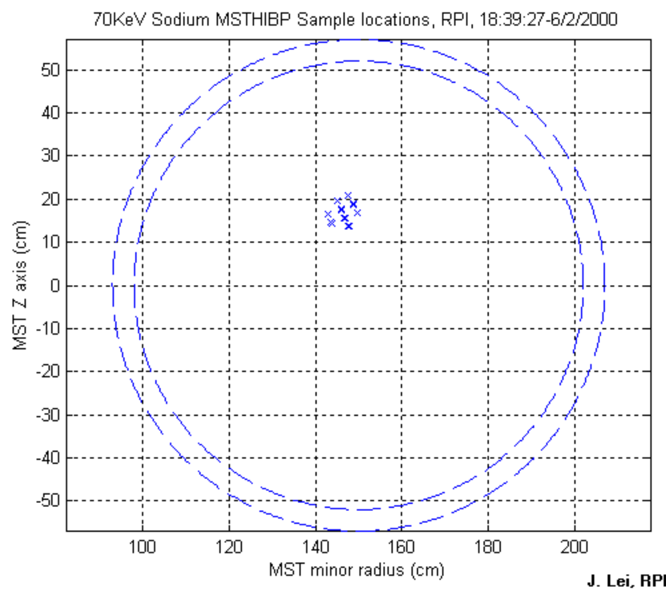


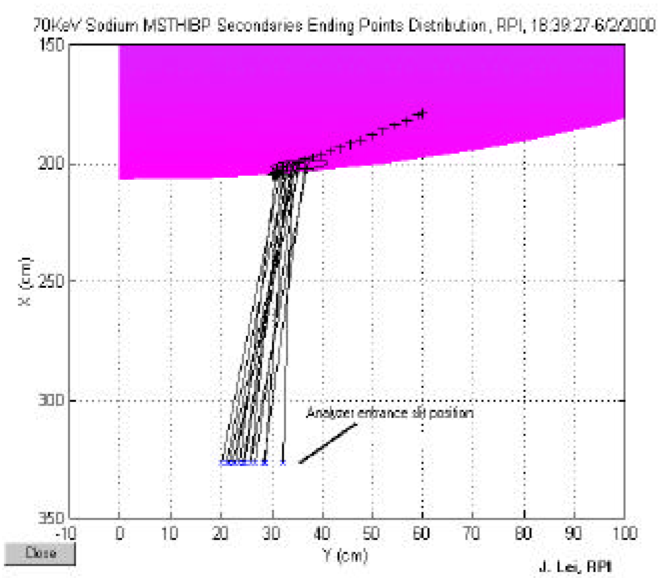


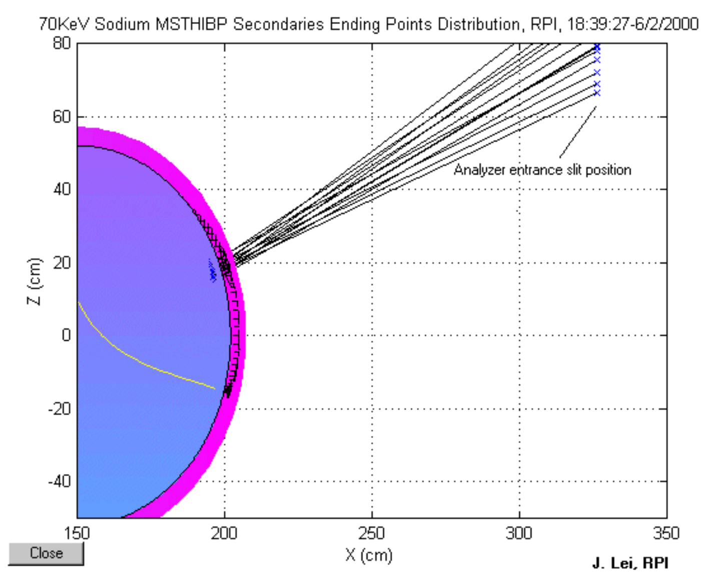


Magnetic field profiles, secondary trajectories and sample volumes from the new field model

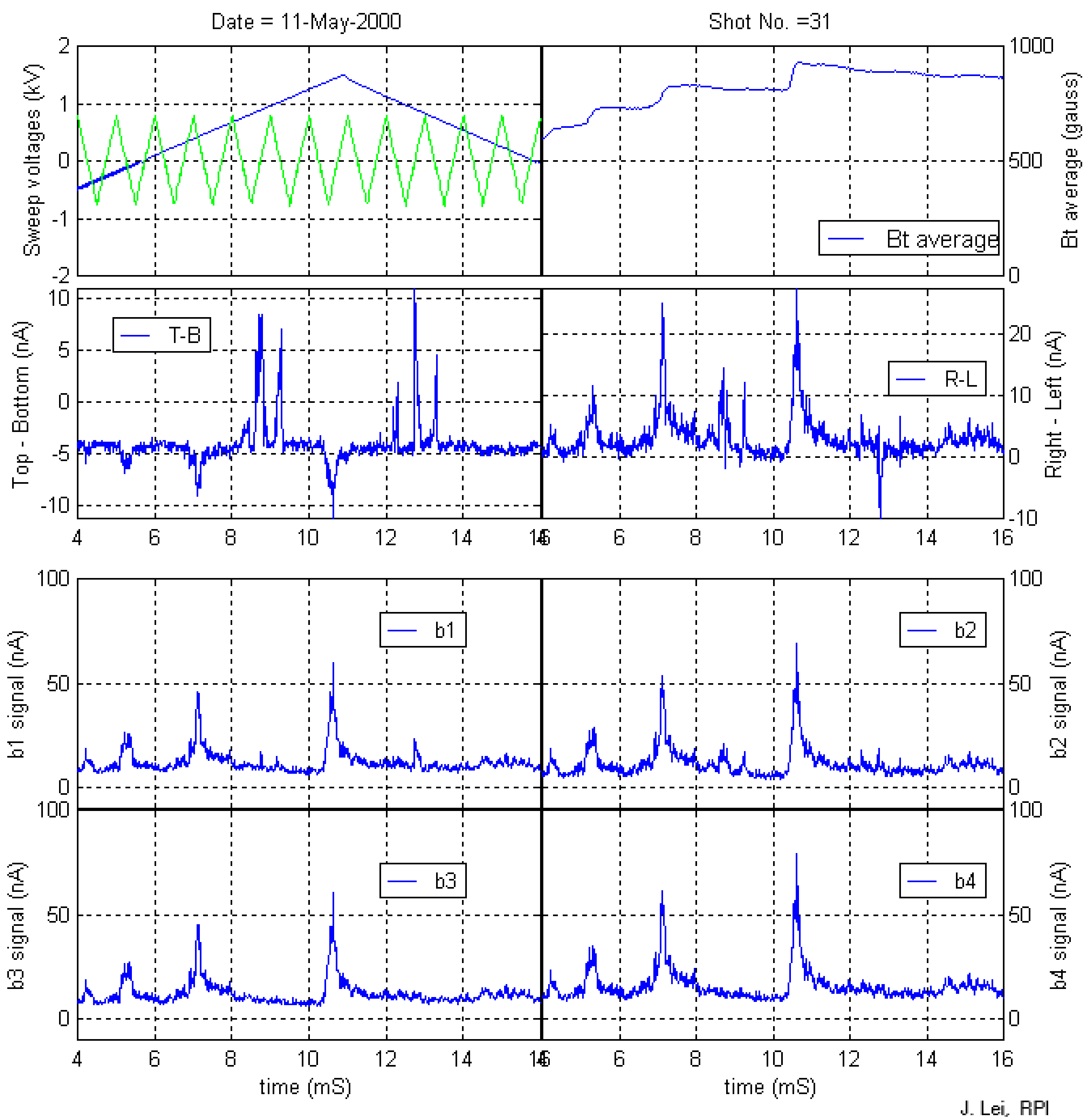




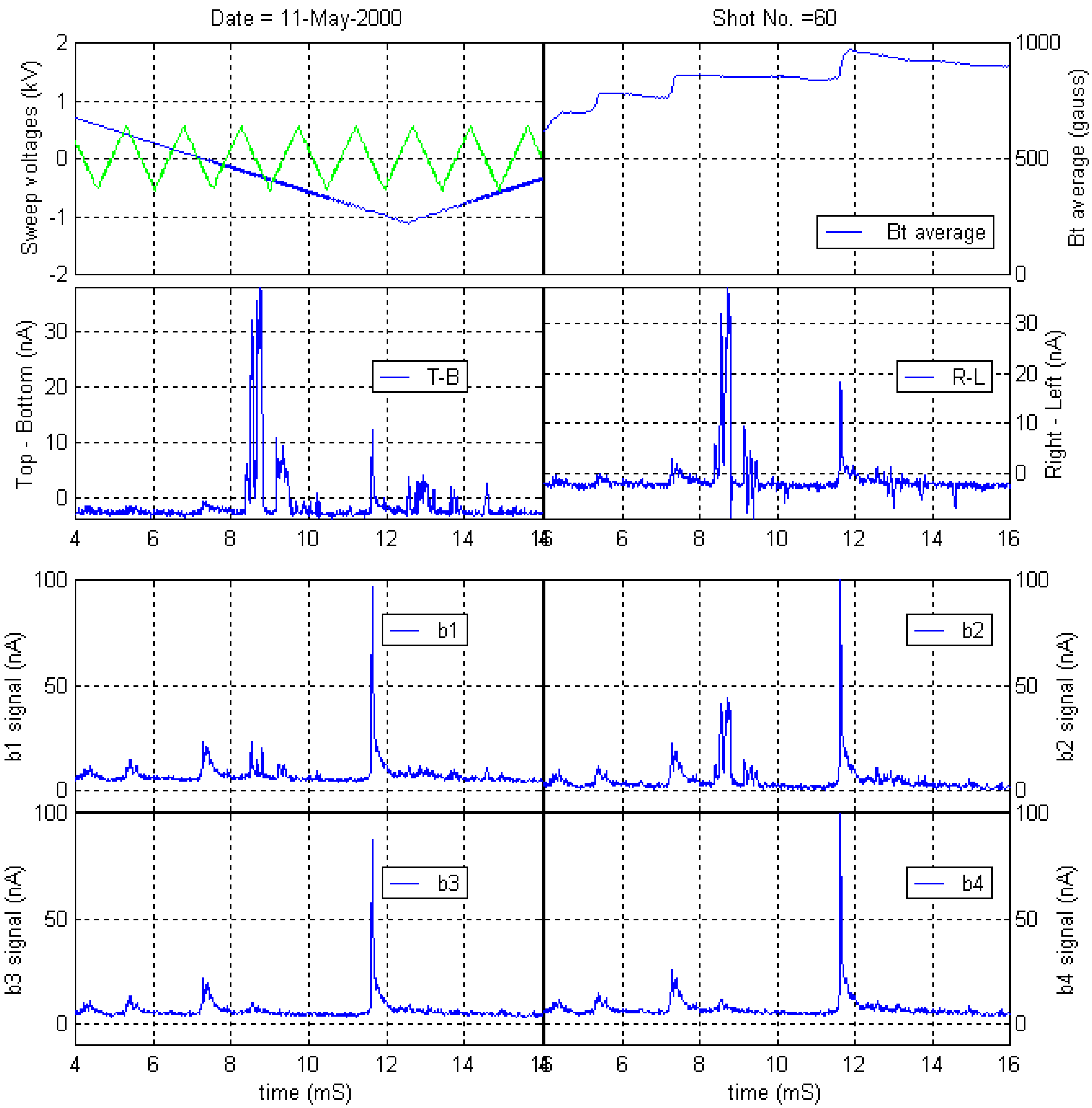




Raw data of the first secondary signals



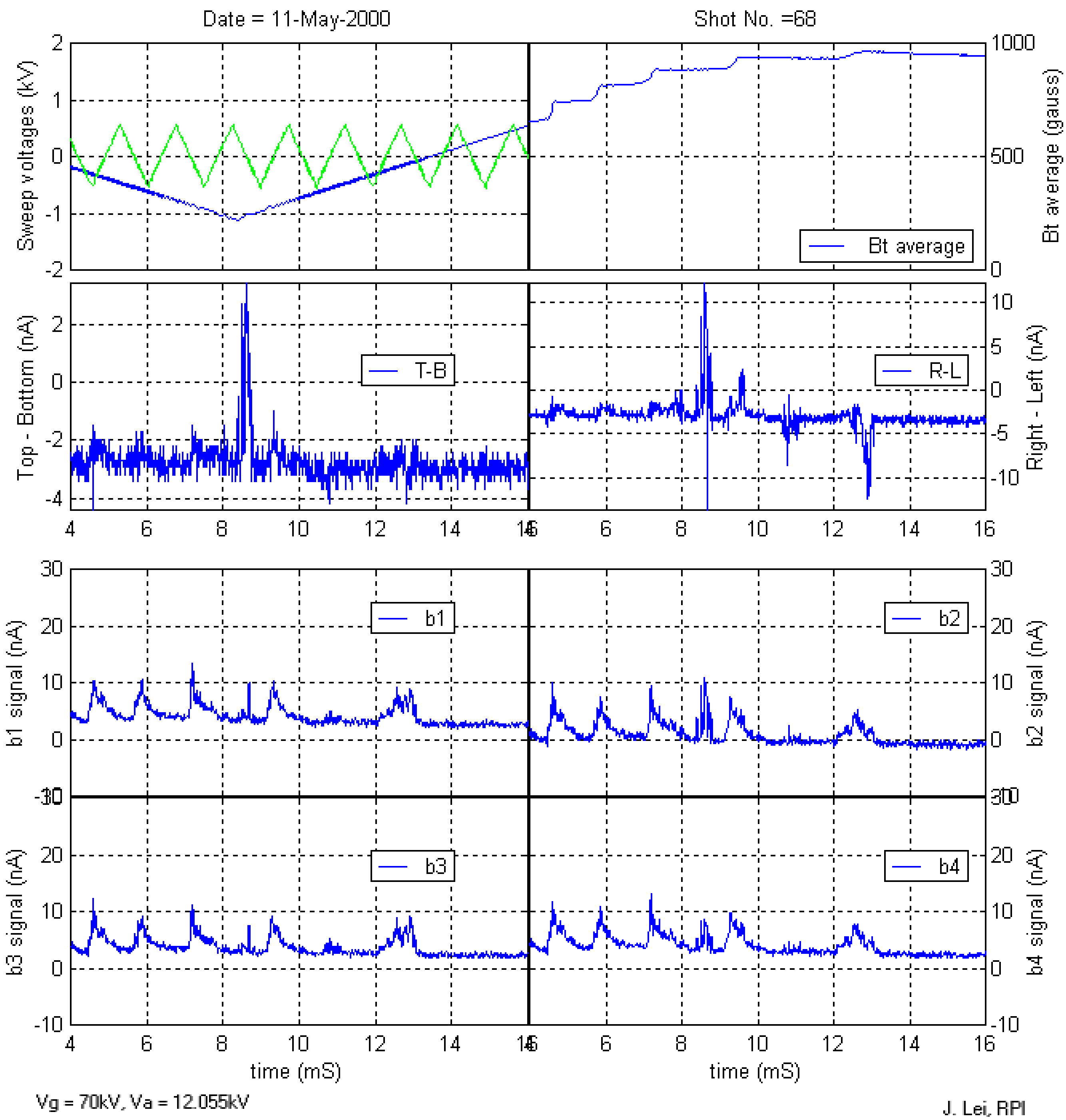
More secondary signals seen



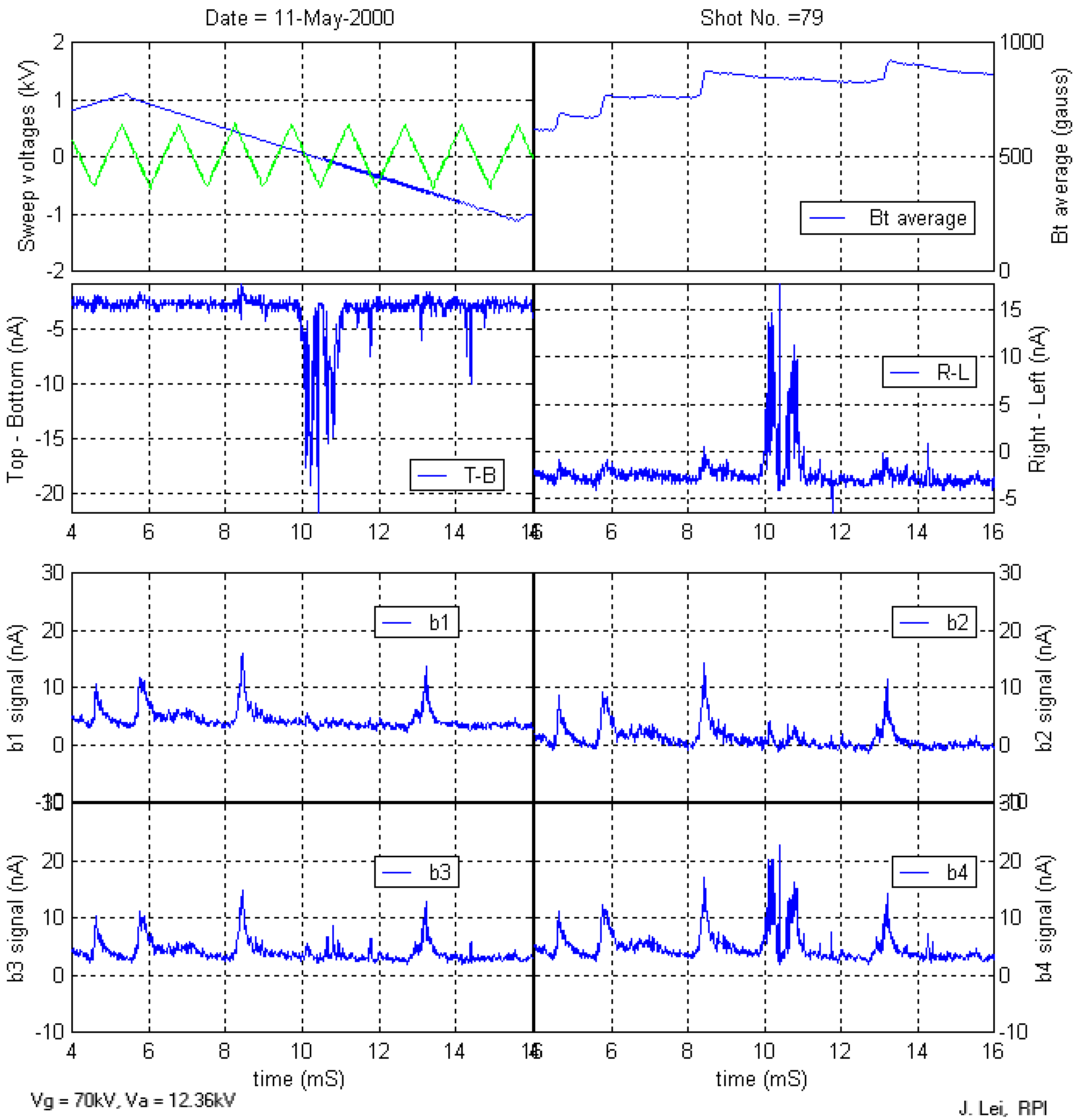
J. Lei, RPI

Potential at the sample volume can be estimated by balancing up-down signals

- Adjust analyzer voltage to balance up-down signals
- Secondary ion beam energy was estimated from this raw data
- Plasma potential at the sample position was very roughly 1.4 – 1.6 kV

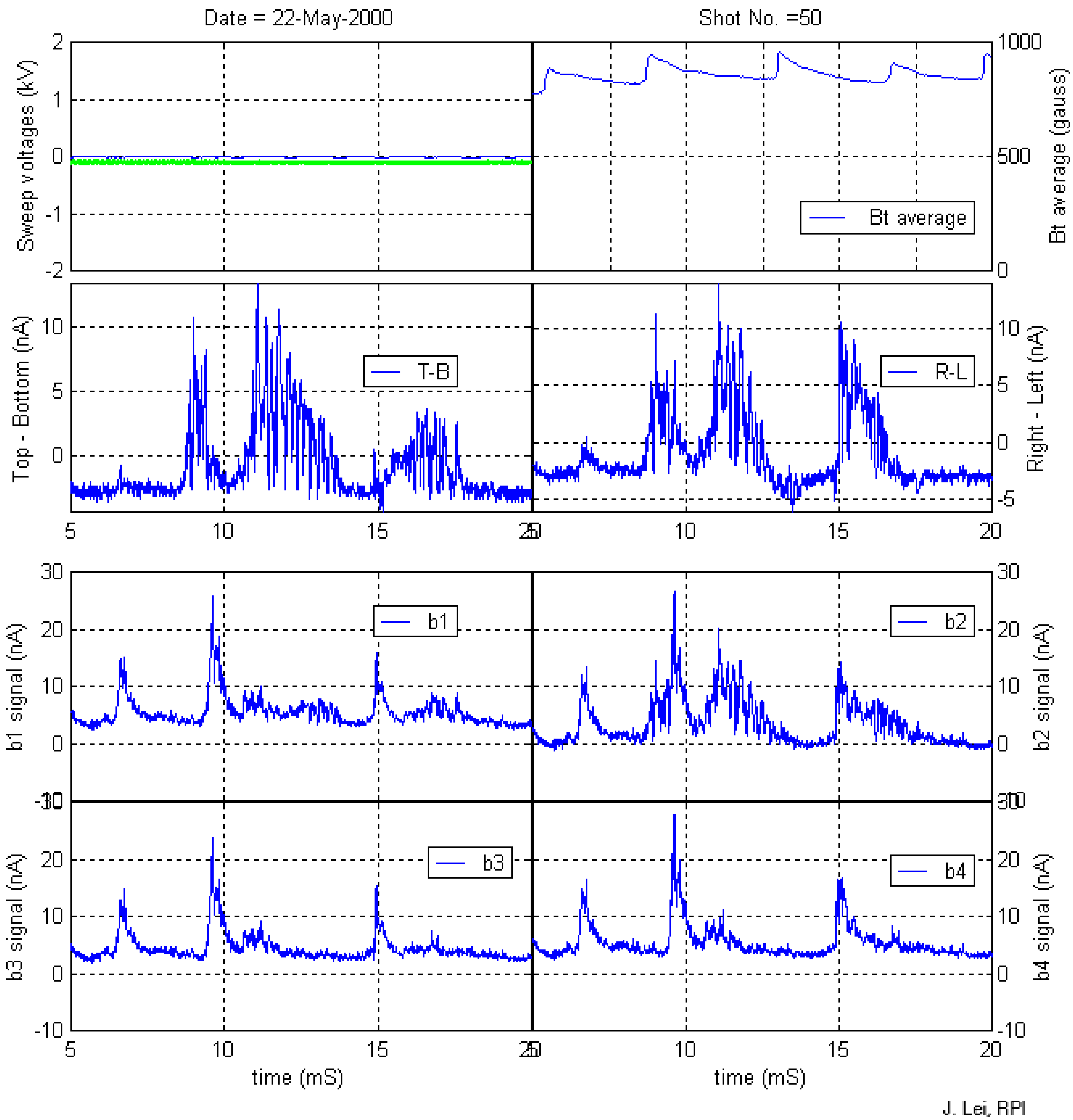


Most of secondary signals sitting on the bottom plates by increasing analyzer voltage Va



Fluctuations in the secondary signals were observed

- **There was no sweep actions in this shot**
- **Fluctuations of the secondary signals may mainly due to the fluctuations of the magentic field**



Helicon – HIBP Experiment

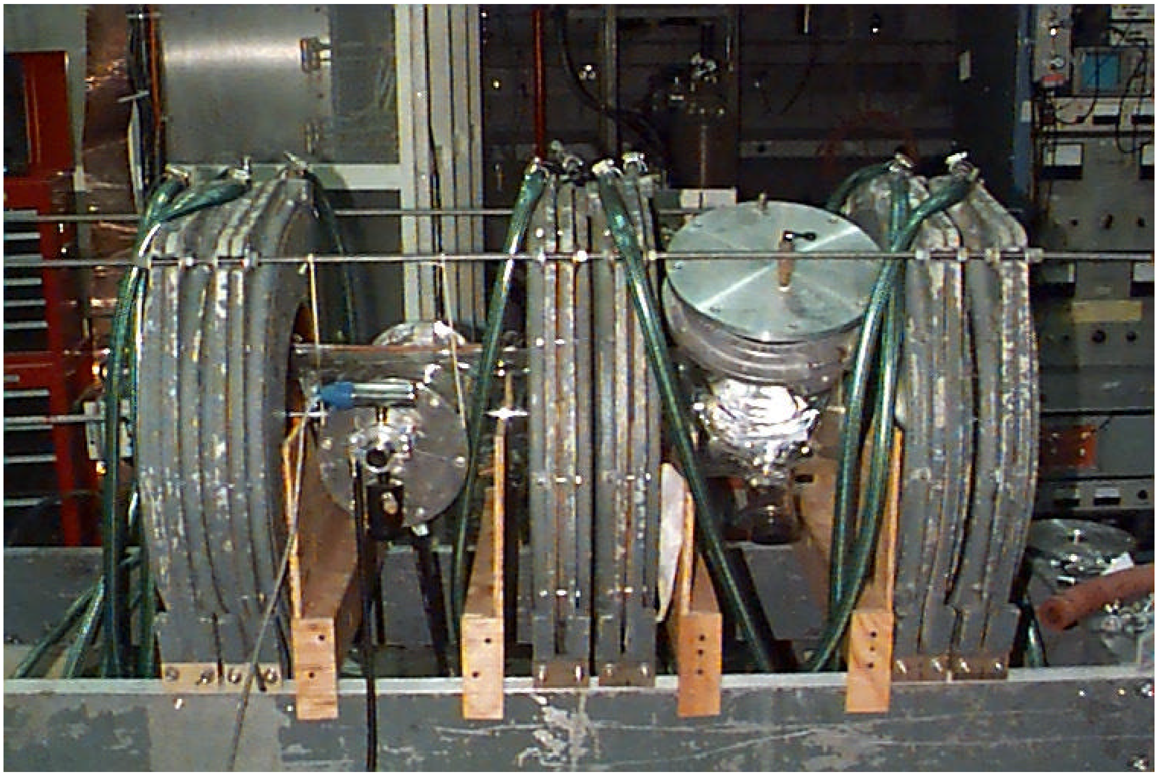
Detection of RF Perturbations Using an Ion Beam Diagnostic

To demonstrate that the techniques developed for heavy ion beam probe diagnostics (HIBP) can be used to measure radio frequency (RF) fluctuations in plasmas is the goal of our project, which is underway at Plasma Dynamics Laboratory at Rensselaer Polytechnic Institute. We hope to measure fluctuations in plasma density and magnetic and electric fields. This will provide a direct measurement of the electric and magnetic fields in the plasma during ICRF heating and thereby improve understanding of heating deposition and wave physics. In addition, the field and the density measurements will be used to determine the plasma reaction to the heating experiments. It is expected that the density measurements will be easiest to interpret, while the electric field measurement will be the most difficult to interpret.

The experimental plan is to do a series of measurements in a helicon plasma at the Plasma Dynamics Laboratory at Rensselaer Polytechnic Institute. The helicon plasma was chosen because its high density (of order 10^{19} /m^3) will produce a larger HIBP signal than can be obtained from other small plasmas.

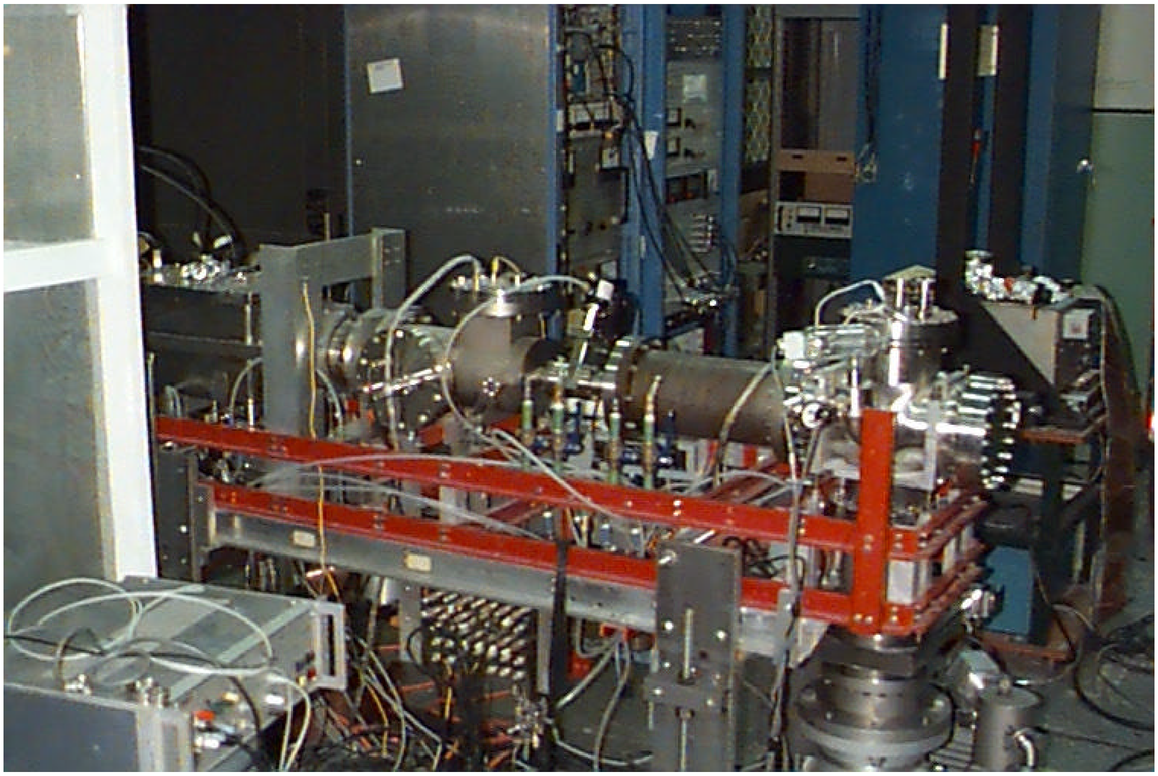
A listing of the main items on which we have done are listed below.

1. Construction of the helicon plasma device including chamber vacuum vessel RF heating supply and antenna magnetic field coils, and preliminary vacuum pumping system
2. Installation and testing of primary beam line including all power supplies sweep systems preliminary beam detectors
3. Modification of detector electronics to operate at frequencies up to15 MHz
4. Calculation of final trajectories for system.
5. Conceptual design of primary and secondary beam lines complete detailed design begun.
6. Initial measurements of magnetic field fluctuations using a Mirnov coil



Helicon plasma device

We have assembled the helicon plasma hardware (which is shown abpve) and produced plasmas. The plasma is formed in a glass vacuum chamber. The main axis of the chamber is aligned with a solenoid magnetic field produced by 6 magnetic field coils. The plasma is excited by an RF antenna that is a modification of the type used in Boswell's experiments [1].]. The vacuum is formed in a 6" (15 cm) diameter tube that is approximately 90 cm long. Several 4" ports and a 6 " port are on the chamber. The ion beam will pass through a 4" and 6" port. The antenna is located downstream from the beam line at the moment, although can be changed. The magnetic field coils are copper, water cooled pancake coils. The 1kG design field was chosen because it represents the upper range of helicon experiments reported in the literature. The RF power source is a 500 Watt, 13.56 MHz generator which has an adjustable internal matching network.

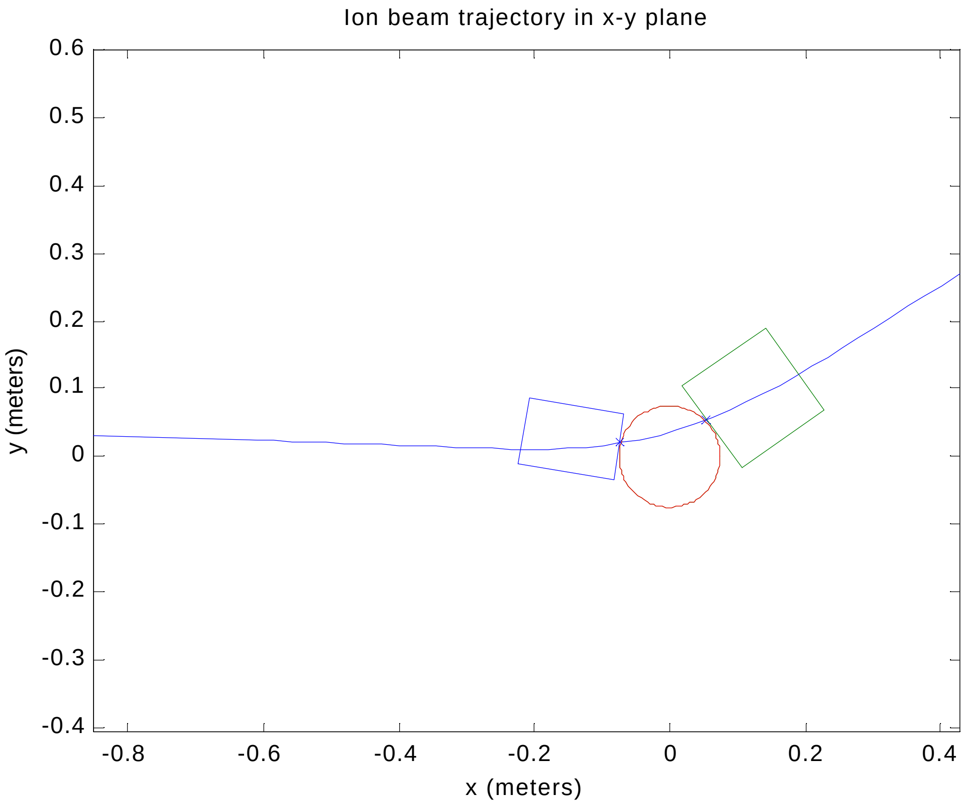


Primary and Secondary Beamlines and Energy Analyzer

InterScience, Inc. has loaned RPI equipment that was used with the TdeV neutral beam diagnostic including primary and secondary beamlines and an energy analyzer. As shown above, the TdeV primary beamline has been set-up in the lab. The neutralizer required for the TdeV experiments has been removed. Cesium beams have been produced and detected using grid and plate detectors. The initial experiments will use a simple plate detector mounted on the output flange. These experiments will be used to determine the feasibility of measuring density and magnetic field fluctuations. Later on, a second set of experiments using a more traditional HIBP energy analyzer as a detector is planned. This detector will also be able to measure electric field effects on the probing ions. It will also be less sensitive to UV noise from the plasma.

Detection Electronics

We have used a current to voltage amplifier design to measure 0-500 kHz fluctuations in several previous experiments. By reducing the gain and changing some components, a very similar design is capable of operation at RF frequencies. The modified circuit has been tested up to 15 MHz and worked well. In addition to this amplifier modification, the proposal listed the option of a beam sweeping technique to make RF measurements. Although we still need to examine noise levels and other issues regarding the detection electronics, progress has been encouraging enough that we are not presently planning on using the beam sweeping technique.



Trajectory Calculations

Trajectory calculations have been completed for the fields produced by our magnetic coils and with the constraints imposed by the plasma vacuum chamber. We have determined that 16->29 KeV Li ions can be used to probe a plasma with 1 kG magnetic field on axis. The beam probe energy scales as B^2/M where B is the magnetic field strength and M is the probe ion mass. We have options of operating with different sources(such as molecular hydrogen ions) or at different fields and different energies. Trajectory calculations of the sample volume size indicate that typical dimensions will be of order 1 cm or less. Magnetic field fluctuation measurements A National Undergraduate Fusion Fellow worked in our laboratory last summer. As part of this work, a magnetic coil was designed, calibrated, and used to measure the magnetic field fluctuations at the RF frequency. The coil will be used in later experiments to compare the coil measurements with HIBP measurements.

Vacuum Chamber Design & Future Work

The most important outstanding item is the construction of the transition vacuum chambers between the beam lines and the plasma. In addition, beam line support structures are being designed and constructed. Key components that will be done in the near term are data acquisition, vacuum control, and completion of the detector electronics.

[1] R.W. Boswell and F.F. Chen, “Helicons - The Early Years”, IEEE Trans. on Plasma Sci. 25, 1229-1244 (1997).