The Madison Symmetric Torus - Heavy Ion Beam Probe

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ABSTRACT

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The Madison Symmetric Torus (MST)-Heavy Ion Beam Probe (HIBP) is operational and acquiring data. The signal-to-noise ratio of acquired data is sufficient during portions of most plasma discharges, but prohibitively low during sawtooth crashes. Obtaining data during saw teeth and improving all measurements requires increased ion current and lower analyzer noise; detected noise is due primarily to UV. Another challenge is an incompletely defined equilibrium and fluctuating magnetic field. The fields play a significant role in determining ion trajectories and are thus crucial to all measurements. Detection of secondary signal for sets of plasma conditions may be used to refine predicted equilibrium fields by iteratively comparing elements of calculated beam trajectories with estimates from modeling codes. Measurements also show what appears to be beam modulation due to magnetic modes. Correlation of these measurements with those made by coils at the wall will help to extend the knowledge of fluctuating fields within a reversed field pinch (RFP). Broadband magnetic fluctuations are much larger on MST than those encountered in previous HIBP applications. We thus have an excellent opportunity to develop the HIBP as a magnetic diagnostic and provide information on the equilibrium and fluctuating magnetic fields, which is of significant interest to the RFP community.

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A GENERAL DESCRIPTION OF HEAVY ION BEAM PROBING

- A heavy ion beam probe accelerates a beam of mono-energetic, singly charged ions into a magnetically confined plasma
- A fraction of the injected ions undergo electron impact ionization and emerge from the plasma as doubly charged ions
- The plasmas confining magnetic field separates the doubly charged ions from the singly charged ions; the radii of the ions is given by $r_L=Mv/qB$, where M is the mass of the ion, q is the charge of the ion, and B and v are the magnitude of the magnetic field and particle velocity vectors.
- The secondary particles are detected and analyzed outside the plasma within a parallel plate electrostatic analyzer
- Measurements that are commonly made include the plasma potential, and potential and density fluctuations
- The measurements are localized to the ionization location of the secondary ions within the plasma.

SPECIFICATIONS OF THE MST HEAVY ION BEAM PROBE

ACCELERATOR

- The accelerator column is a 200 keV Van De Graaff type column
- It is air insulated during operation at voltages < 150 kV, SF_6 insulated > 150kV

ANALYZER

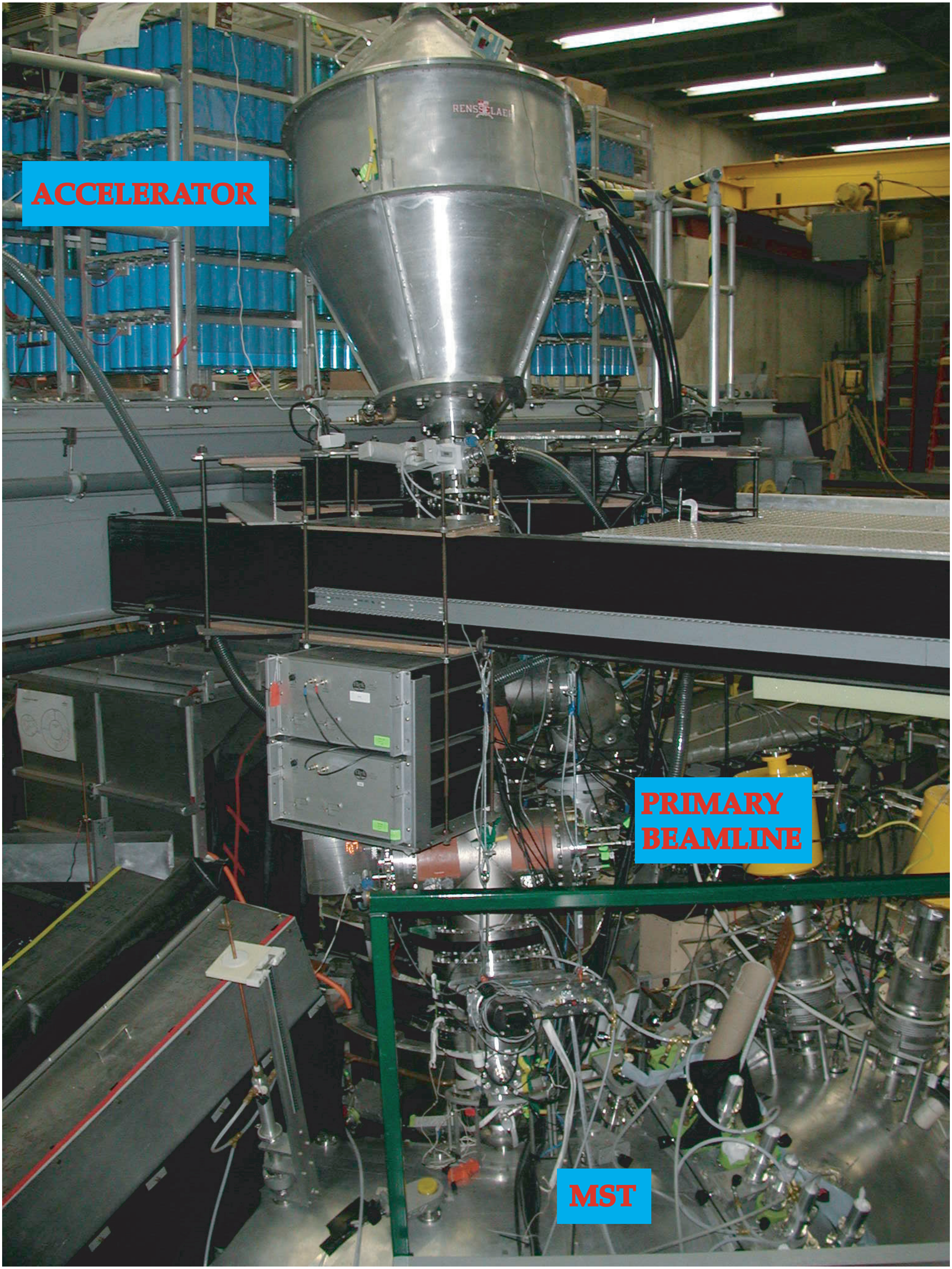
- The analyzer is a 100kV electrostatic Proca-Green type parallel plate
- It electrostatically deflects and detects secondary ions within a well characterized electric field region
- The analyzer houses three sets of split plate ion beam detectors. Each detector set is comprised of four detector plates

INJECTION AND DETECTION BEAMLINES

- The injection or primary beamline houses four pairs of electrostatic plates used to steer the singly charged ion beam into the plasma at various entrance angles
- The detection or secondary beamline houses three pairs of electrostatic plates used to steer the doubly charged ion beam into the analyzer

PROBING ION BEAM

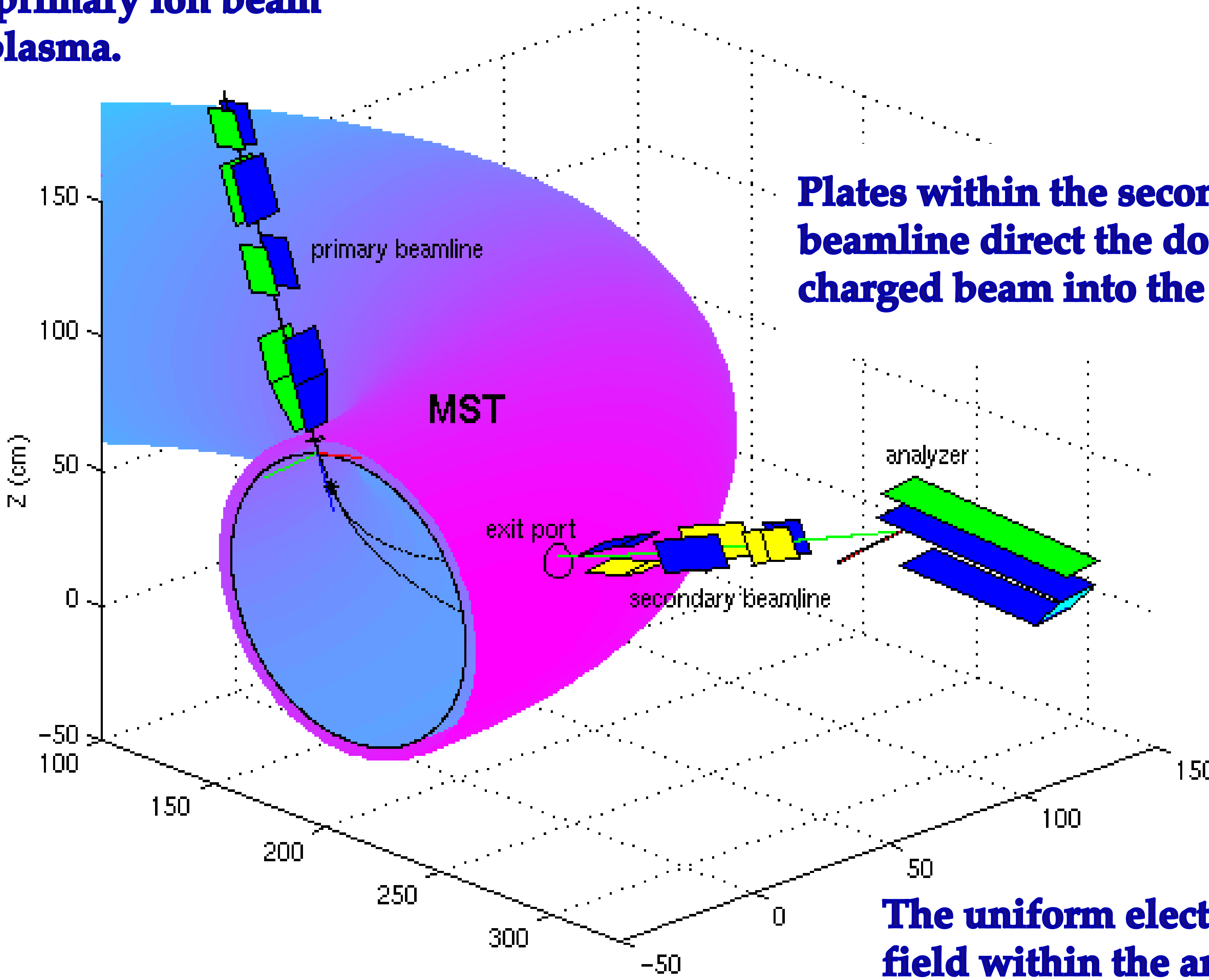
- The primary ion beam is made-up of singly charged sodium ions
- The FWHM of the beam approximately 1m below the ion gun is .5-1cm


ACCELERATOR
RENSSELAER
PRIMARY
BEAMLINE
MST


HIGH VOLTAGE DIVIDERS AND
HIGH VOLTAGE MULTIPLYING STACKS

Electrostatic plates within the primary beamline steer the primary ion beam into the plasma.

Plates within the secondary beamline direct the doubly charged beam into the analyzer.



The uniform electrostatic field within the analyzer deflects the beam onto the detectors.

SUCCESS!
THE FIRST MST-HIBP SECONDARY ION SIGNALS WERE DETECTED ON MAY 11,2000

- The Rensselaer Polytechnic Institute Heavy Ion Beam Probe is installed and acquiring data on the Madison Symmetric Torus.

- Despite a complicated and undiagnosed magnetic topology, the Heavy Ion Beam Probe has successfully acquired signal.

- This is the first such successful application of a Heavy Ion Beam Diagnostic to a Reversed Field Pinch Device.

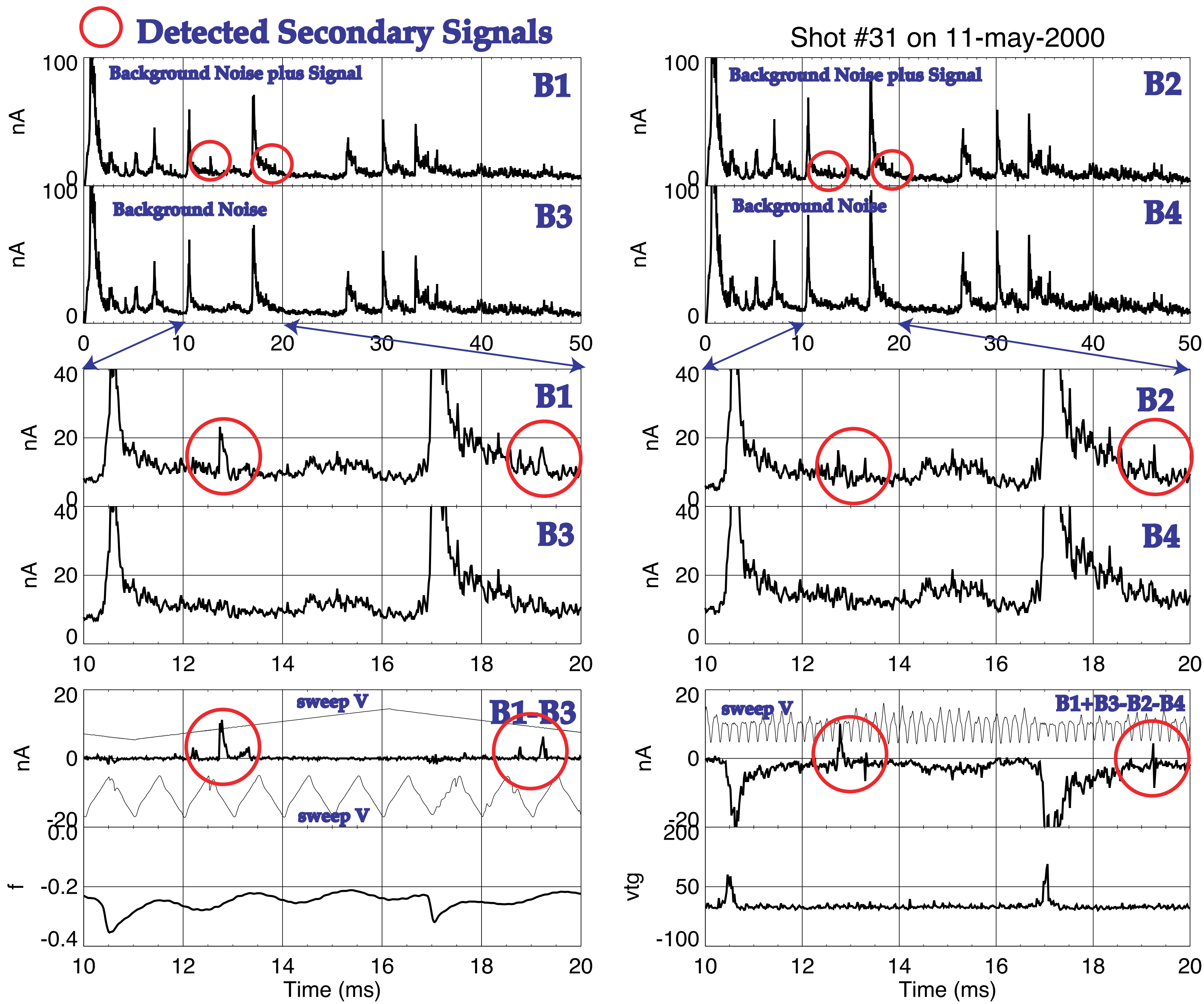
- Measurements of core potential, and core potential and density fluctuations are possible.

- The measurements will cover a substantial radial extent of the plasma cross section.

- These measurements will permit radial potential profile mapping and radial particle flux estimates (see posters 1.110 and 1.111).

RECENT EXPERIMENTAL PROGRESS

- The first secondary signals were detected on May 11, 2000
- The baseline operational regime of the HIBP on MST has since been mapped-out. We have explored the operational regime by varying the probing ion beam energy -W_b, plasma current - I_p, plasma density - n_e, and the reversal parameter - f
- Ion gun optics have been upgraded to increase the level of injected primary ion beam current, detected secondary ion signal levels, and signal/noise ratios
- Trajectories of detected secondary ions are being used to supplement and improve the MST B-Field modeling code (see poster 1.110)
- First measurements of the internal plasma potential of MST have been made during discharges in the range of 350-380kA (see poster 1.110)
- Fluctuation measurements have also been made with the HIBP (see poster 1.111)



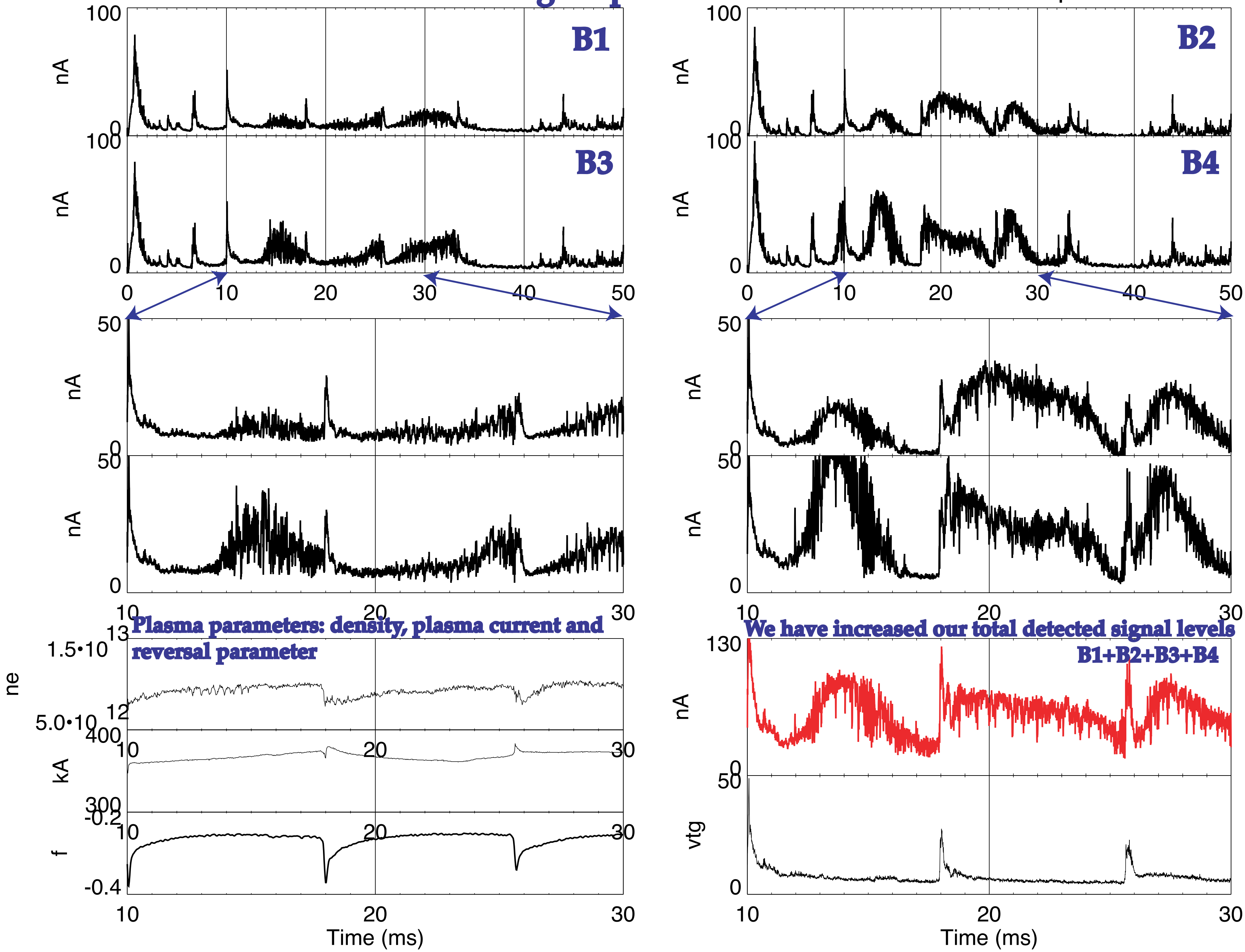
Detected Secondary Signals
Shot #31 on 11-may-2000
Background Noise plus Signal
B1
B2
Background Noise
B3
B4
nA
100
0
10
20
30
40
50
B1
B2
B3
B4
12
14
16
18
sweep V
B1-B3
B1+B3-B2-B4
f
0.0
-0.2
-0.4
vtg
200
50
-100
Time (ms)

SIGNIFICANT IMPROVEMENTS HAVE BEEN MADE IN DETECTED SECONDARY SIGNAL LEVELS

- We have increased our detected secondary signal level by a factor of 10.

Signals From One Detector Set, Comprised of Four Detectors
Each Trace is a Combination of Signal plus Noise

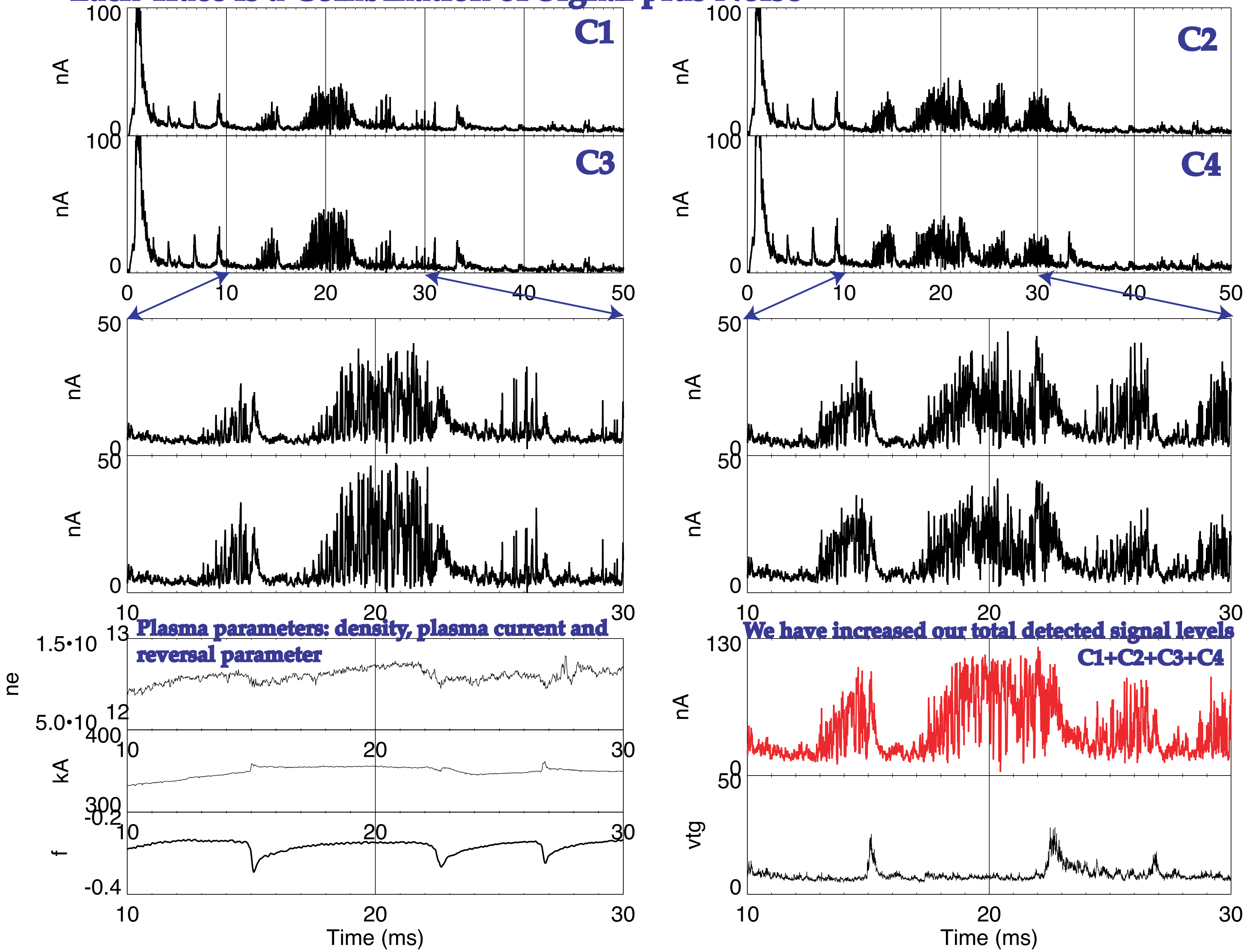
Shot #70 on 30-sep-2000



Signals From One Detector Set, Comprised of Four Detectors

Each Trace is a Combination of Signal plus Noise

Shot #76 on 4-oct-2000



THE SIGNALS ON THE DETECTORS EXHIBIT SOME BASIC FEATURES

NOISE

- The background noise on the detectors is a combination of UV induced, electronic pick-up, and digitizer noise.
- The largest noise source is UV radiation from the plasma.
- This UV-radiation, emitted from the plasma region, streams up the secondary beamline, reflects within the analyzer and lands on the detector plates causing secondary electron emission.
- In addition, large amplitude noise spikes are present on the detectors during sawteeth. This noise is presumably due to increased UV flux during the sawtooth crash.

FLUCTUATIONS

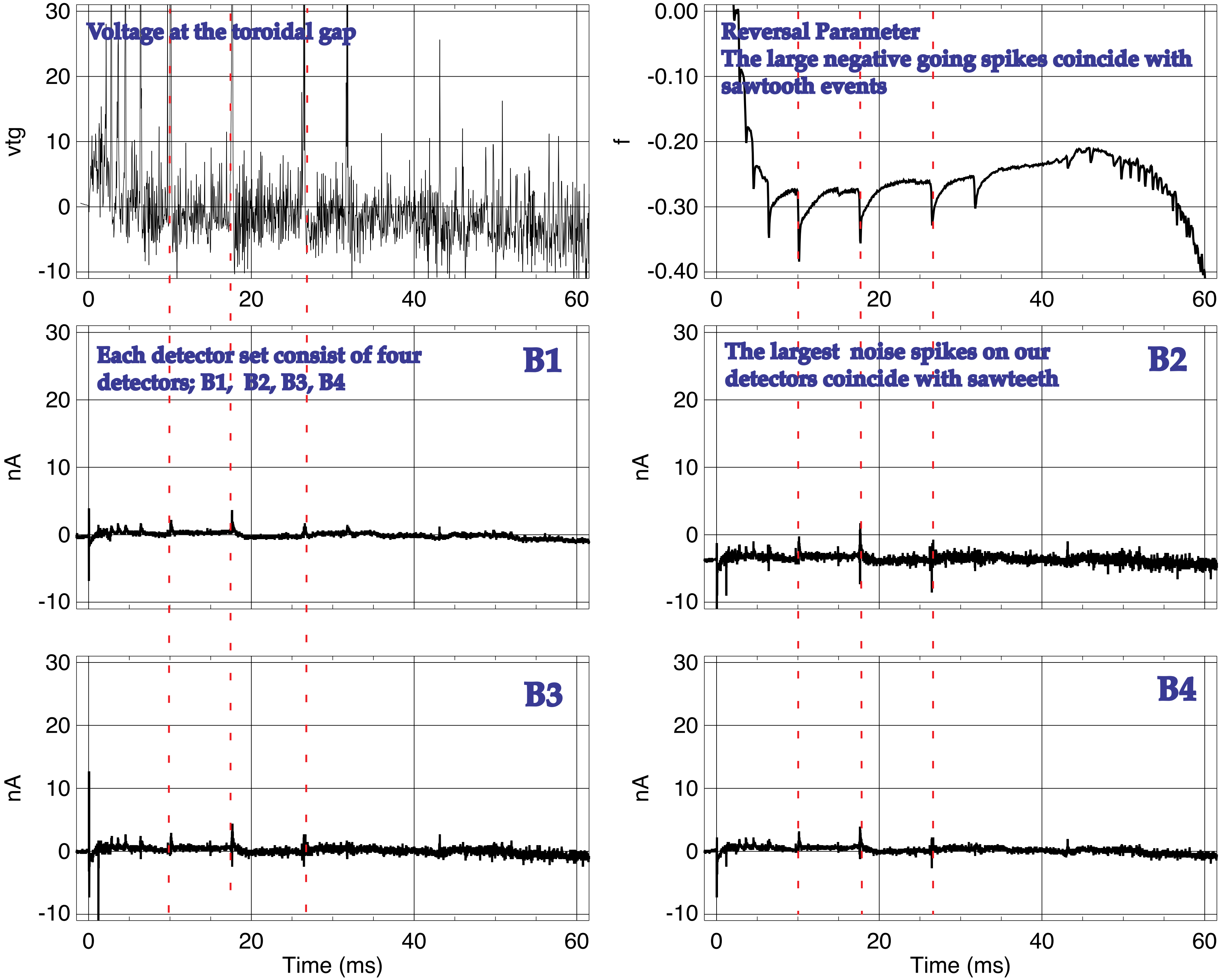
- The detected secondary signals exhibit a broad range of fluctuation amplitudes and frequencies.
- The fluctuations are a combination of desired fluctuations such as density and potential, as well as undesirable fluctuations such as voltage fluctuations on the steering plate power supplies due to plasma radiated UV.

AMPLITUDE VARIATIONS

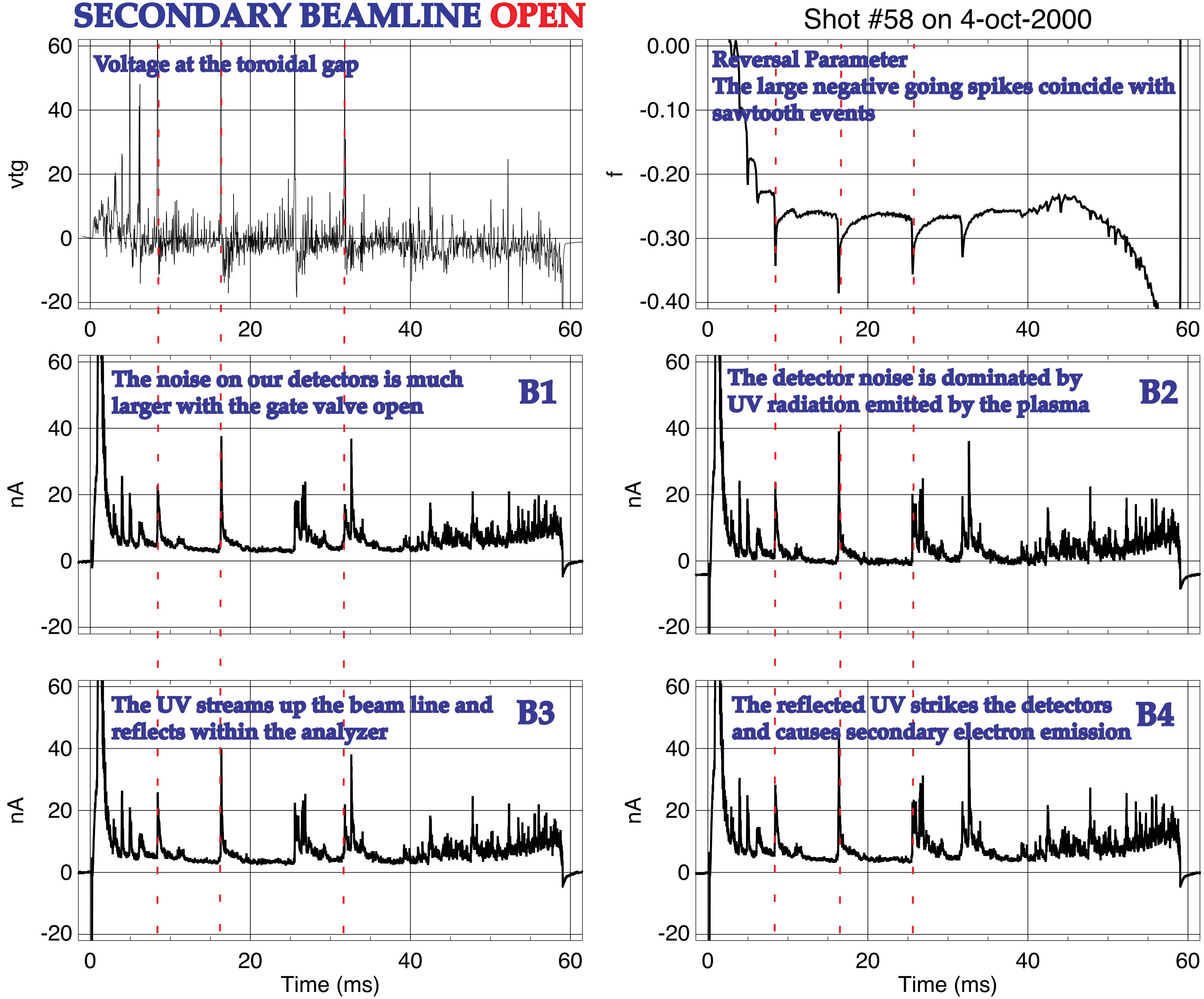
- The amplitude of the detected secondary signal varies with time.
- The variation is likely due to MHD activity within the plasma. This activity alters the ion beam trajectories within the plasma.

NOISE ON DETECTORS WITH GATE VALVE TO SECONDARY BEAMLINE CLOSED

Shot #19 on 4-oct-2000

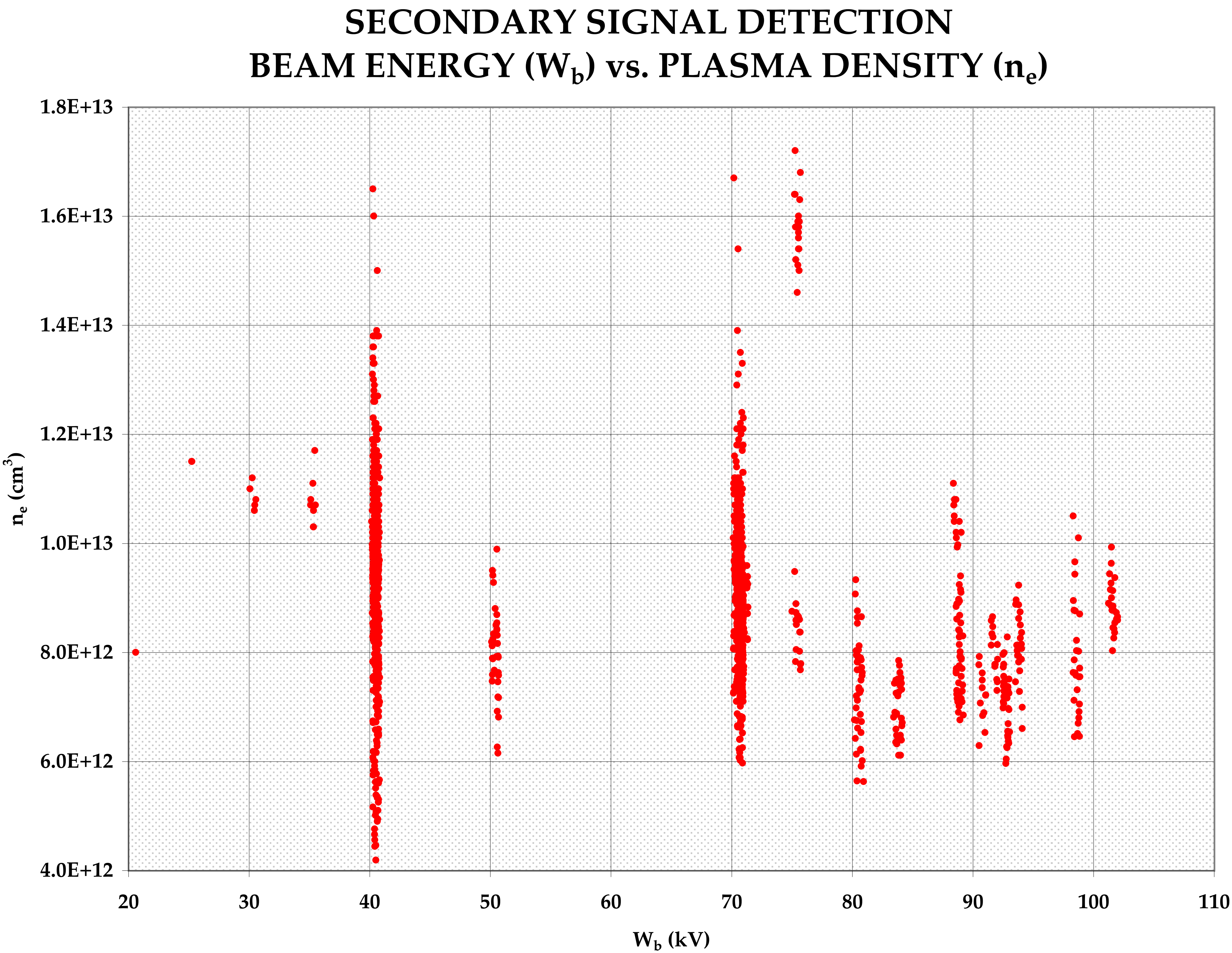


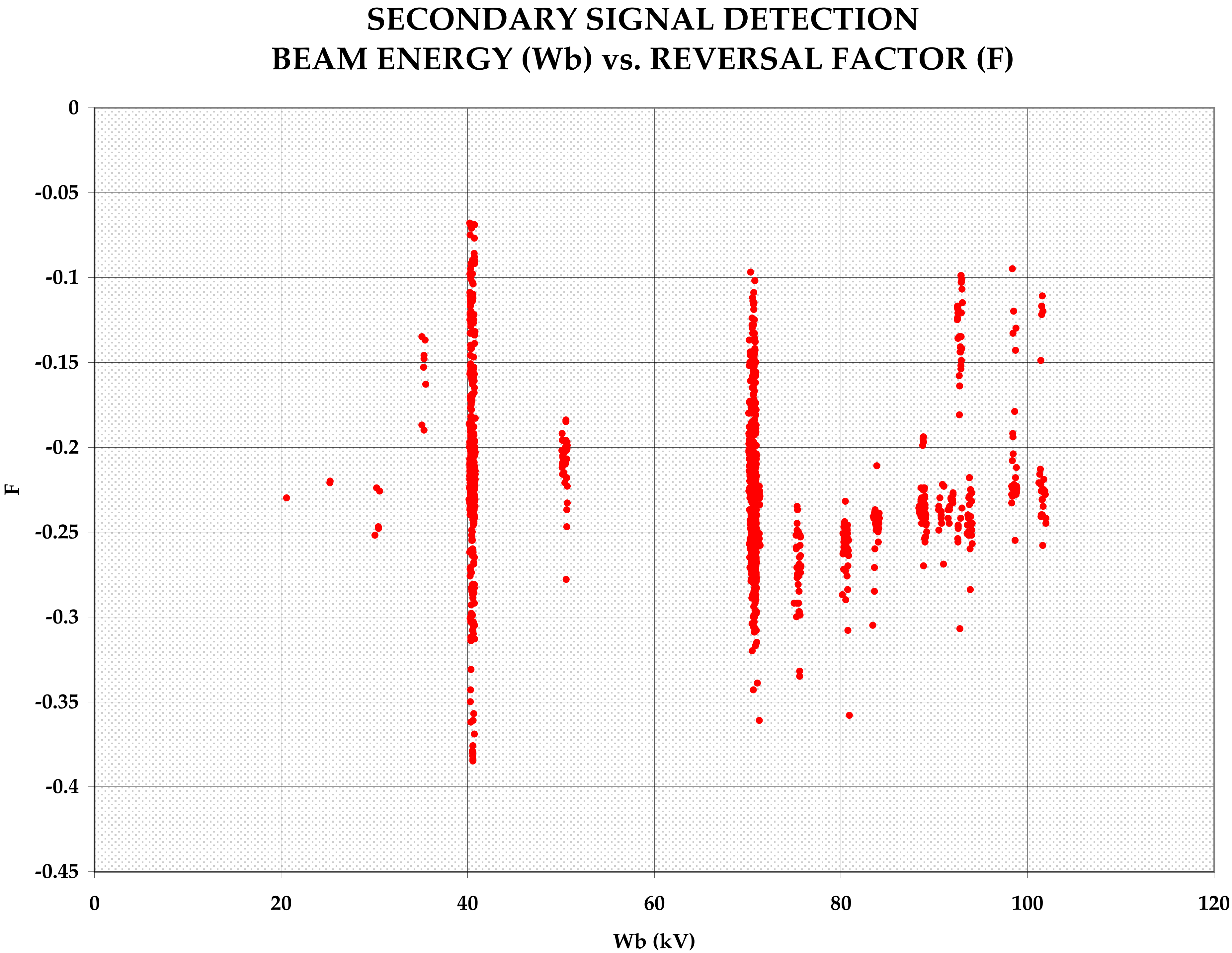
NOISE ON DETECTORS WITH GATE VALVE TO SECONDARY BEAMLINE OPEN



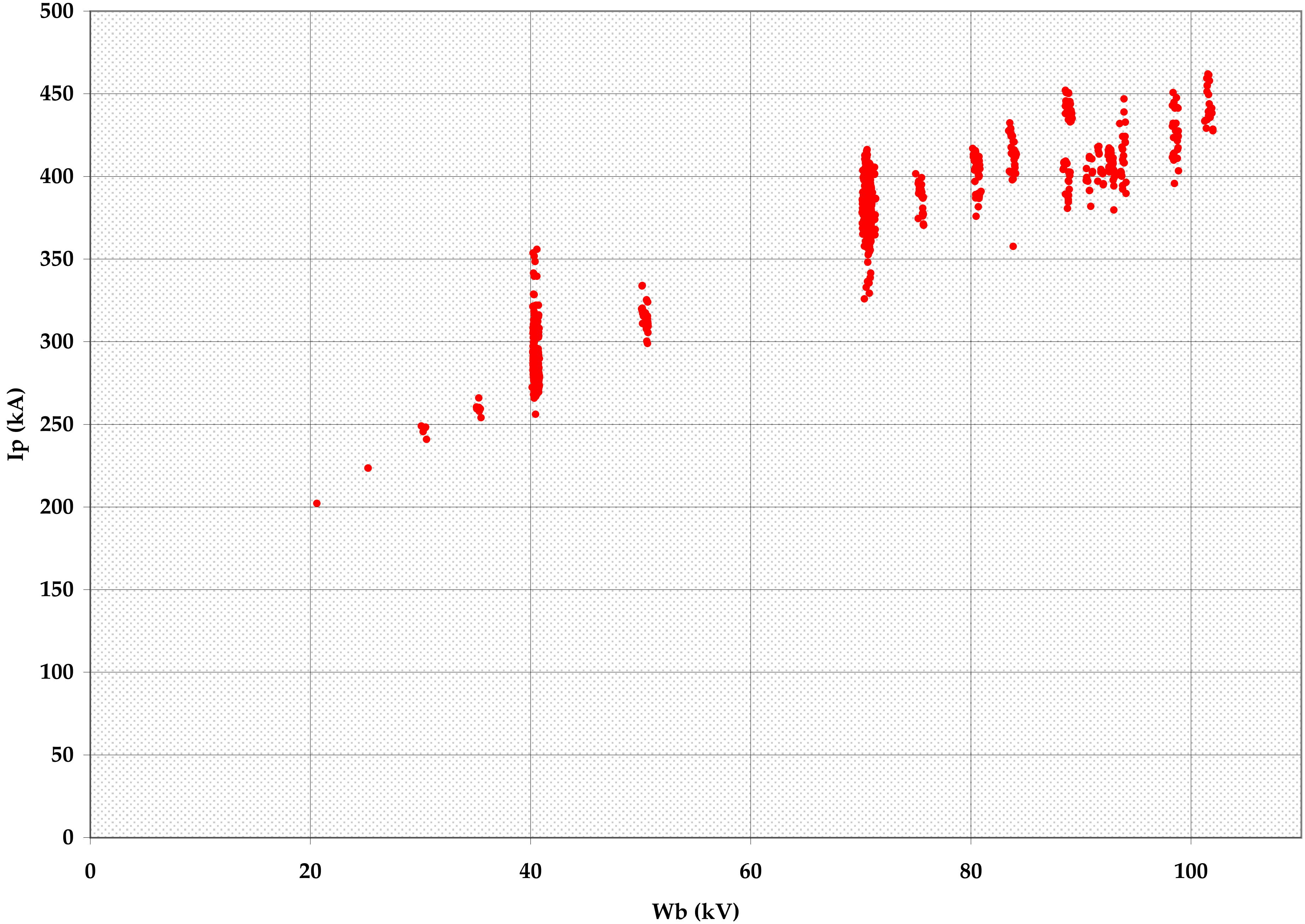
THE FOLLOWING ILLUSTRATE THE RANGE OF MST PLASMA CONDITIONS DURING WHICH SECONDARY SIGNALS HAVE BEEN DETECTED

- Each red point on the plots indicate a condition during which secondary ion signals were detected in standard MST plasmas.
- The upper and lower limits of reversal parameter - f, plasma density - n_e, and plasma current - I_p, are imposed by the common MST operational regime and not limits of the HIBP diagnostic.
- These scans are not meant to be exhaustive, but rather illustrate the broad range of plasma condition during which the HIBP is operational.


SECONDARY SIGNAL DETECTION
BEAM ENERGY (W_b) vs. PLASMA DENSITY (n_e)
n_e (cm^3)
1.8E+13
1.6E+13
1.4E+13
1.2E+13
1.0E+13
8.0E+12
6.0E+12
4.0E+12
20
30
40
50
60
70
80
90
100
110
W_b (kV)


SECONDARY SIGNAL DETECTION
BEAM ENERGY (Wb) vs. REVERSAL FACTOR (F)
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.35
-0.4
-0.45
F
0
20
40
60
80
100
120
Wb (kV)

SECONDARY SIGNAL DETECTION
BEAM ENERGY (Wb) vs. PLASMA CURRENT (Ip)



FUTURE WORK

- Efforts will continue to increase the level of injected primary ion beam current. The noise on the detectors necessitates higher signal to noise levels for measurement accuracy.

- Modifications to the primary beamline radial sweep plate driving power supply is necessary to accurately and consistently steer the primary ion beam into the plasma during each shot. This power supply is operable, but it's steer voltage is inconsistent due to UV loading of the sweep plates by the plasma.

- To detect a larger fraction of secondary ions emerging from the plasma at the secondary port, we will modify or supplement the pair of radial steering plates within the secondary beamline. This pair of plates is presently inoperable due to UV loading from the plasma.

- We will acquire measurements from additional locations within the plasma.

- We will continue with data analysis; separating the plasma physics from the instrumental effects.

- Exploration of RFP plasma physics issues using a HIBP is now possible.