Fluctuation Measurements on the Madison Symmetric Torus with a Heavy Ion Beam Probe

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Abstract

Measurements of electron density fluctuations $\tilde{n}_e$ and potential fluctuations $\tilde{\Phi}$ on the Madison Symmetric Torus (MST) reversed field pinch (RFP) are undertaken with a newly installed 200keV Heavy Ion beam Probe (HIBP) system. Initial fluctuation signals observed are closely coupled to low frequency MHD activities. Electrostatic fluctuation induced particle transport can be addressed by simultaneous measurements on $\tilde{n}_e$ and $\tilde{\Phi}_e$. Langmuir probes have been used on MST to measure this kind of transport at low plasma current level and at the edge of the plasma. By changing the beam energy and beam injection conditions, the MST-HIBP can provide localized fluctuation measurements at almost all radii for a broad range of plasma parameters, and thus enrich our understanding of turbulent transport in reversed field pinch plasmas. Current working issues include isolating electrostatic fluctuation signals from those caused by magnetic fluctuations, increasing the ion beam intensity to increase signal-to-noise ratios, and looking for the best operational regime (sample volume locations, plasma parameters, etc.) for this diagnostic.

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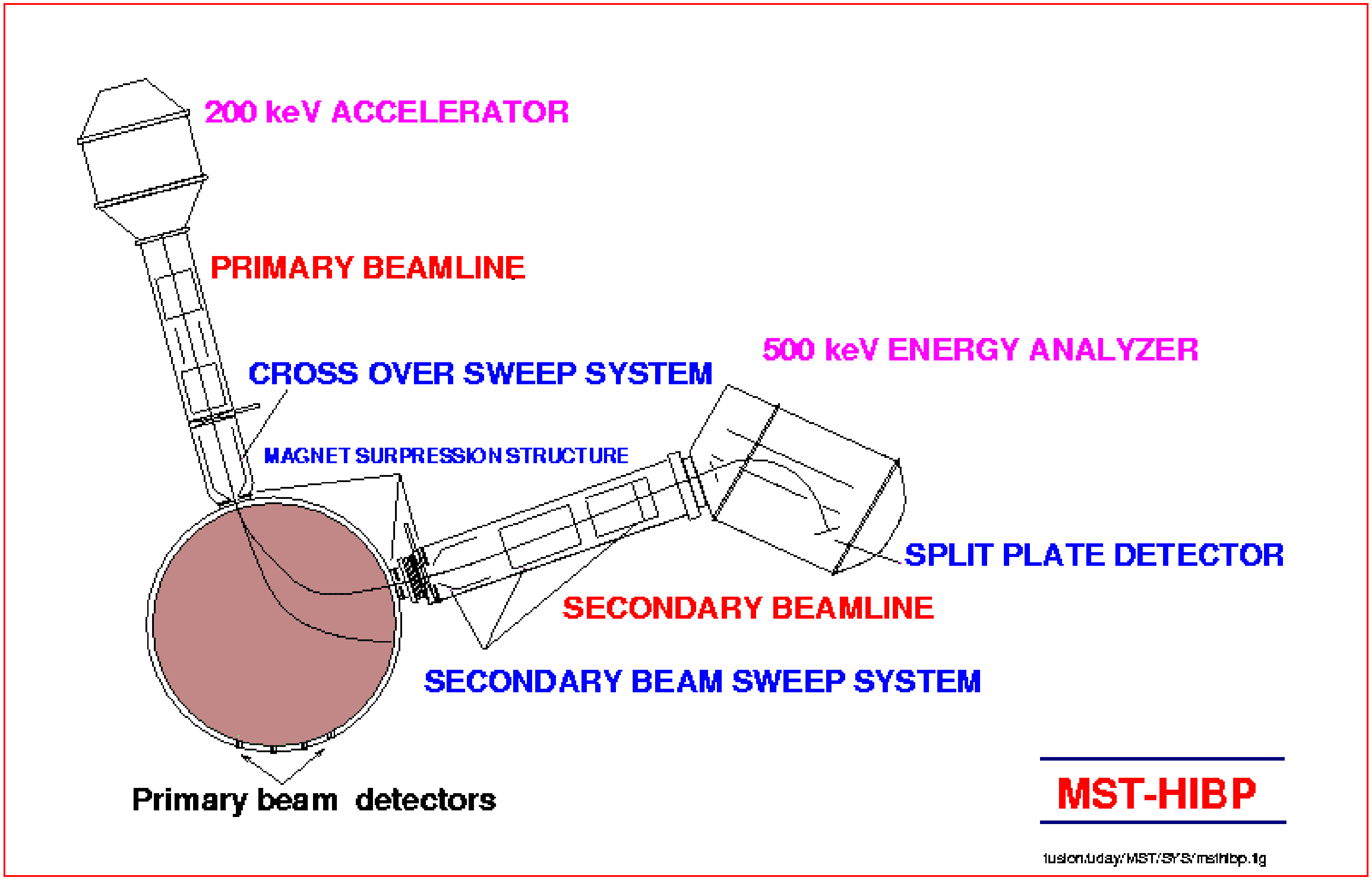
Introduction

- Anomalous particle and energy transport is one of the major obstacles for the RFP as well as for other magnetic configurations
- Various fluctuations have been recognized to be responsible for the anomalous transport
- Heavy ion beam probes (HIBP) have been used on a host of magnetically confined machines to measure electrostatic potential Φ, electrostatic potential fluctuations $\tilde{\Phi}_e$, electron density n_e, density fluctuations $\tilde{n}_e$, magnetic vector potential A, electron temperature $\tilde{T}_e$, and magnetic vector potential fluctuations $\tilde{A}$
- A 200 keV heavy ion beam probe system has been installed on MST to measure the equilibrium potential profile $\Phi(r)$, electrostatic potential fluctuations $\tilde{\Phi}_e$, electron density fluctuations $\tilde{n}_e$, magnetic field fluctuations, and fluctuation induced transport
- A major difference between this system and previous ones is a newly designed, complex sweep plate system used on both primary and secondary beamlines to give a radial scan of the plasma.
- This poster will focus on measurement of electron density fluctuations $\tilde{n}_e$ and potential fluctuations $\tilde{\Phi}$ at the core (r/a ~ 0.5) region of the MST plasma.

Principle of Fluctuation Measurements



How Does a Heavy ion Beam Probe Work? (Please see posters by ***Demers*** and ***Shah*** next to this)

- ***Potential*** Φ_{sv} at the sample volume is obtained by looking at the energy of the secondary ions on the detector plates: $$\Phi_{sv} = \frac{W_d - W_i}{q_s - q_p}$$

W_d: beam energy at the detector; W_i: initial beam energy; q_s: secondary ion charge; q_p: primary ion charge

- ***Potential fluctuation*** $\tilde{\Phi}_{sv}$ at the sample volume is obtained by looking at the fluctuations of the ratio between *up* and *down* signals on the detector plates:

$$\tilde{\Phi}_{sv} = \frac{q_s}{q_s - q_p} V_A F(\theta)\Delta\left(\frac{i_U - i_L}{i_U + i_L}\right)$$

Where V_A is the analyzer voltage; $F(\theta)$ is geometric factor of the analyzer; i_U and i_L are currents on the upper and lower detector plates, $\Delta\left(\frac{i_U - i_L}{i_U + i_L}\right)$ is the fluctuation in the difference current to sum current ratio

- ***Density fluctuation*** $\tilde{n}_e$ level at the measurement volume is obtained from the fluctuations of the signal magnitude at the detector plates:

$$\frac{\tilde{i}_s}{< i_s >} = \frac{i_s - < i_s >}{< i_s >} = \frac{\tilde{n}_e}{< n_e >}$$

Where i_s is the secondary signals; n_e is the electron density at the sample volume; <…> denotes average values

- ***Electrostatic fluctuations induced particle transport*** Γ_E^f is given by

$$\Gamma_E^f = \frac{< \tilde{E}_\perp \tilde{n}_e >}{B}$$

Where $\tilde{E}_\perp$ is the fluctuating electric field perpendicular to the equilibrium magnetic field B

- ***Wave number*** ***(average*** k***)*** is derived from simultaneously measurements of the nearby 2 or 3 sample volumes. The fluctuating electric field $\tilde{E}$ is derived from $\tilde{E} = -ik\tilde{\phi}$, where k is calculated from the phase shift between two signals from nearby sample volumes: $\bar{k} = \frac{\Delta_p}{d}$

- ***Magnetic vector potential fluctuation*** $\tilde{A}_{\zeta sv}$ at the sample volume is proportional to the fluctuation of the beam position at the detector plates

$$\tilde{y}_d = \frac{eR_d R_{sv} \tilde{A}_{\zeta sv}}{M} \int_{t_{sv}}^{t_d} \frac{dt}{R^2} - \frac{eR_d}{M} \int_{t_0}^{t_{sv}} \frac{\tilde{A}_\zeta}{R} dt - \frac{2eR_d}{M} \int_{t_{sv}}^{t_d} \frac{\tilde{A}_\zeta}{R} dt$$

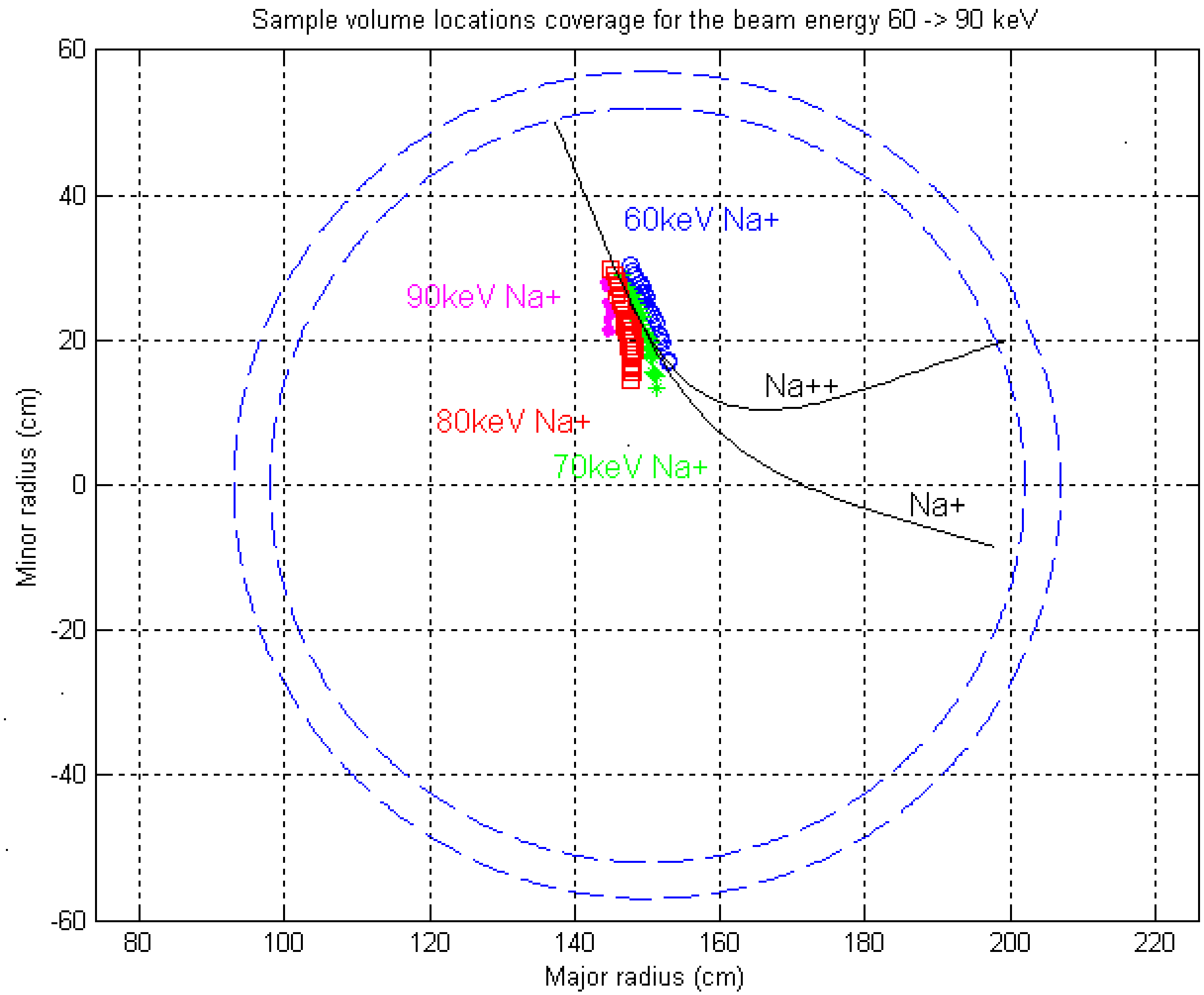
Where $\tilde{A}_{\zeta sv}$ is the magnetic vector potential fluctuations; M is the ion mass; R_d is the detector position in MST coordinate; R_{sv} is the sample position; t_0, t_{sv}, t_d are the times when the ion beam reaches the injection point, the sample volume, and the detector plate.

Motivations and Advantages of the MST-HIBP

- **To measure electrostatic fluctuation induced transport**
  - Anomalous transport >> classical transport
- **To help to identify the cause of $\tilde{E}$ and its role**
  - Tearing modes, interchange modes, drift modes, …
- **To help to develop methods of reducing fluctuation levels and increase confinement**
  - To flatten current profile, pressure profile, temperature profile, …
- **To help to study MHD dynamo in the plasma core region**
  - Electromotive force caused by $< \tilde{v} \times \tilde{B} >$
- **To help to improve modeling of the magnetic field**
  - Heavy ion beam probe is a very sensitive diagnostics to the core magnetic field distribution
- **To help to understand turbulence in the RFPs**
  - Signal processing & data transforms to show time and frequency features
- **To provide localized and unperturbed measurements**
  - At almost all radii for a broad range of plasma conditions
- **To develop HIBP technique on the RFP machines**
  - First time use of HIBP on a RFP

Ray Tracing and Diagnostic Coverage

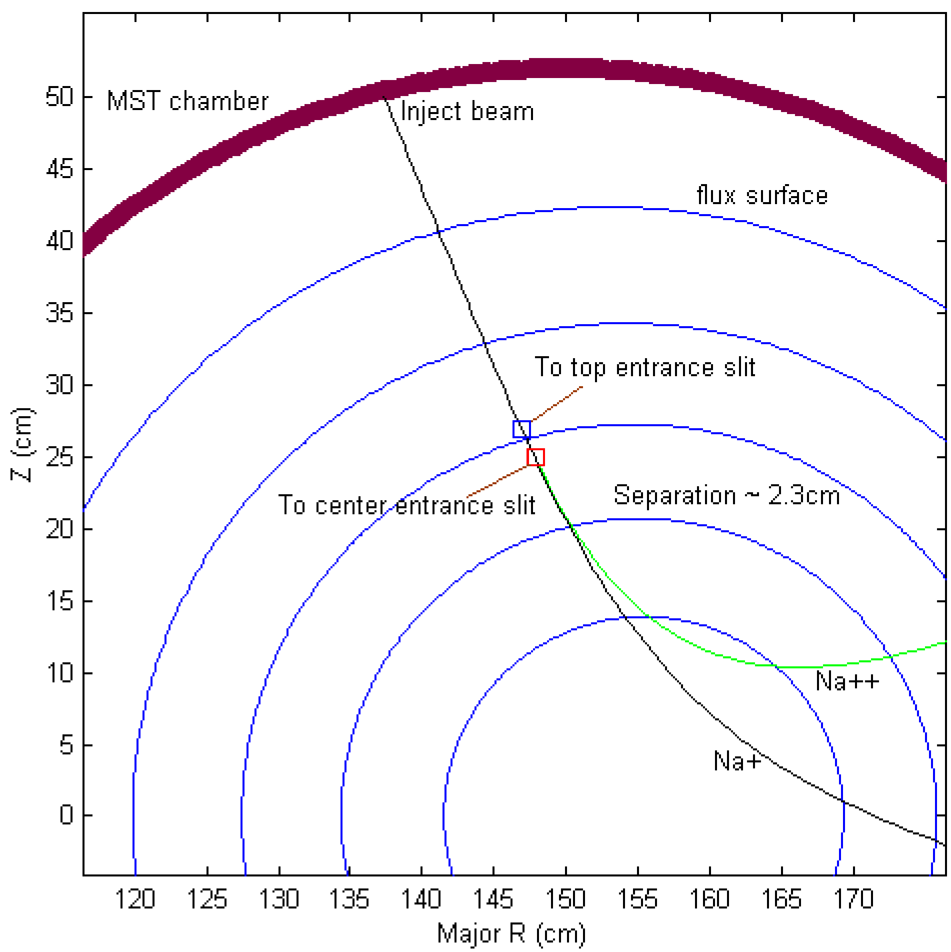
- The diagnostic coverage of the MST-HIBP has been studied by changing the beam energy and beam injection conditions
- The magnetic field used here was generated from MSTFIT (Jay Anderson)



Sample Volume Locations and Alignment

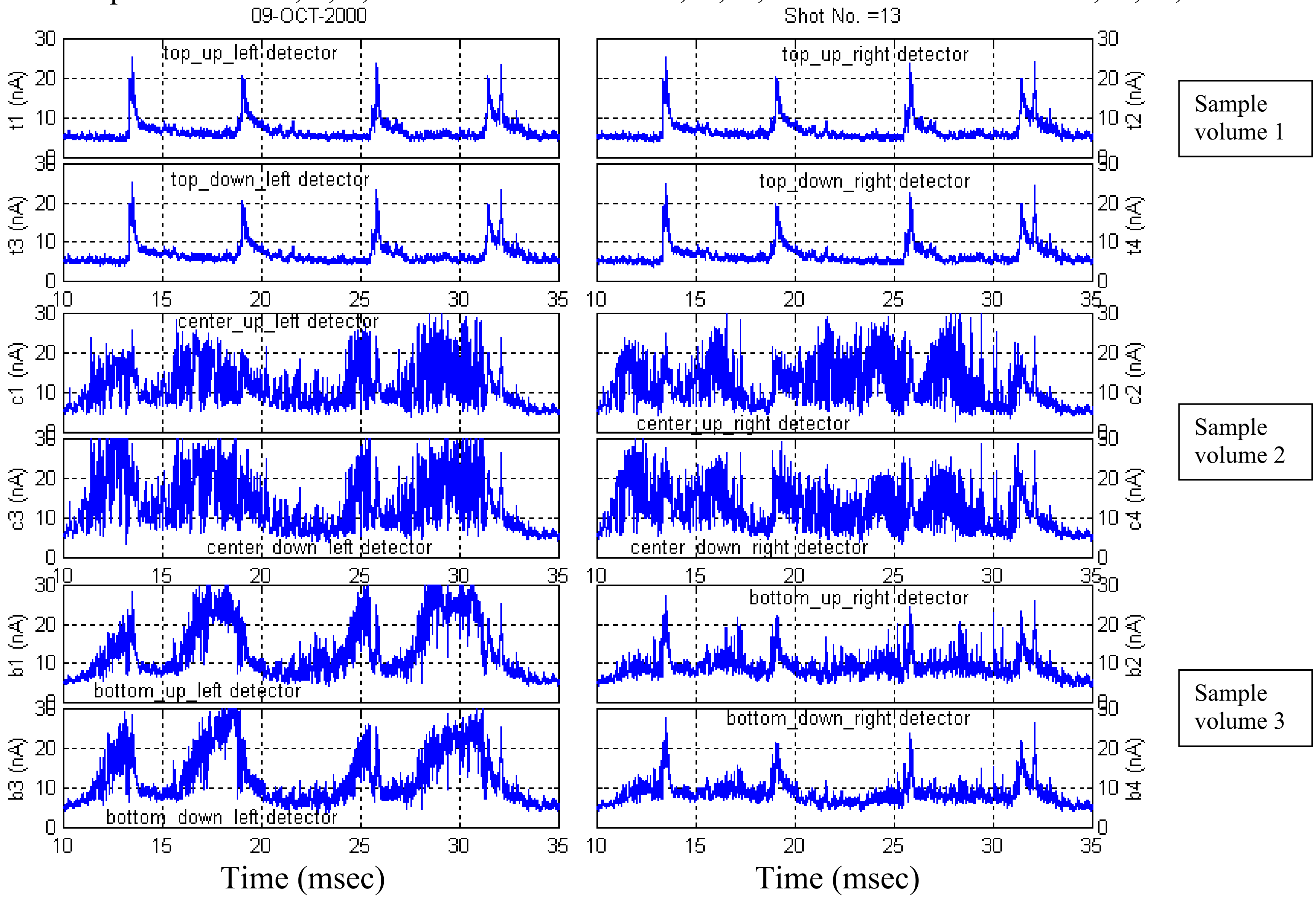
- Sample volumes are located at r/a ~ 0.5
- Secondary ions to the top entrance slit will be detected on the bottom detectors, while those to the center entrance slit will be detected on the center detectors. Top detectors were not used.
- Separation between two sample volumes is about 2.3cm, mainly in the radial direction

Sample volume locations for the center & bottom detectors. Shot 13, 10/09/2000



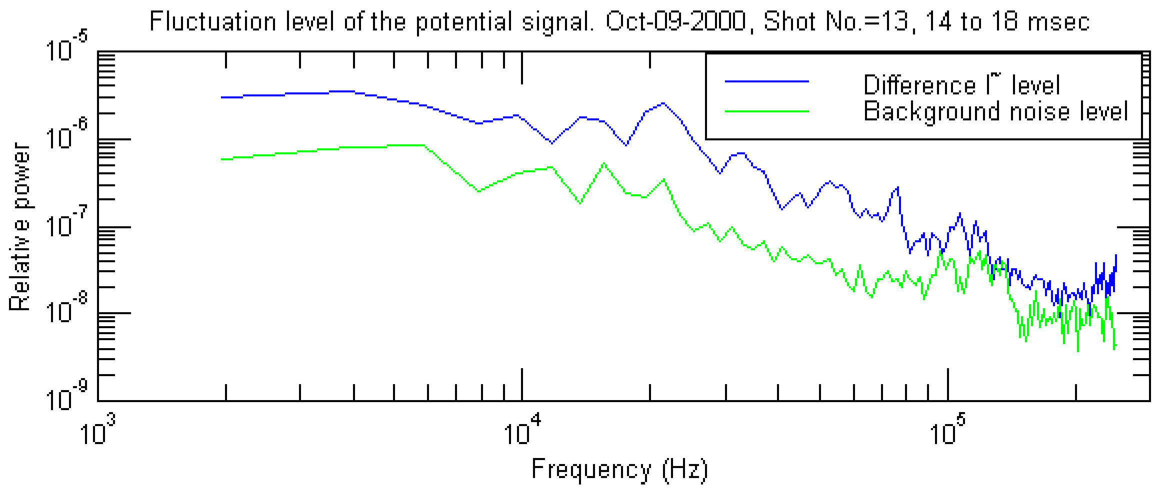
Typical Fluctuating Signals on the Detectors

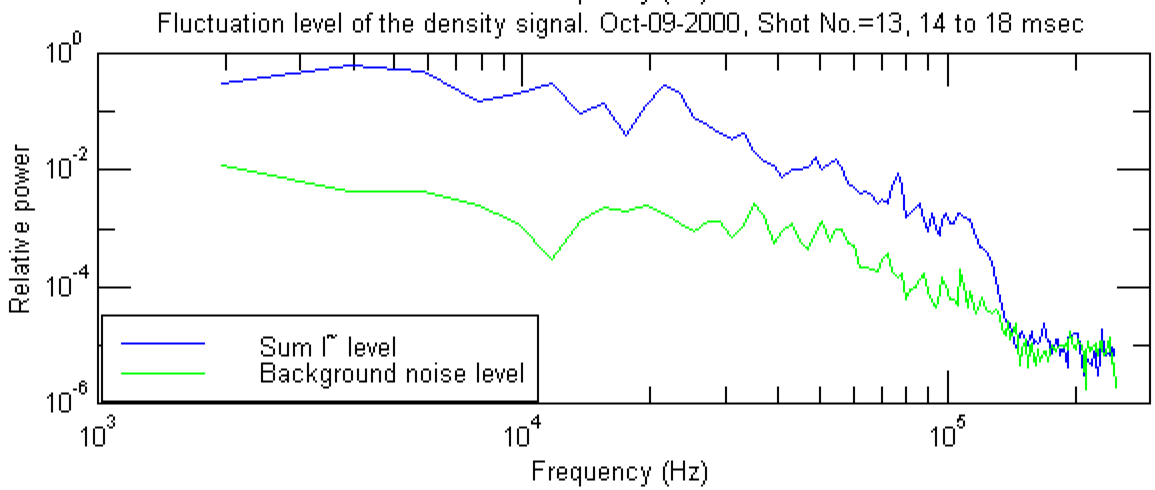
- Top detectors: t1,t2,t3,t4. Center detectors: c1,c2,c3,c4. Bottom detectors: b1,b2,b3,b4



Spectrum of the Detected Signals at $r / a \cup 0.5$

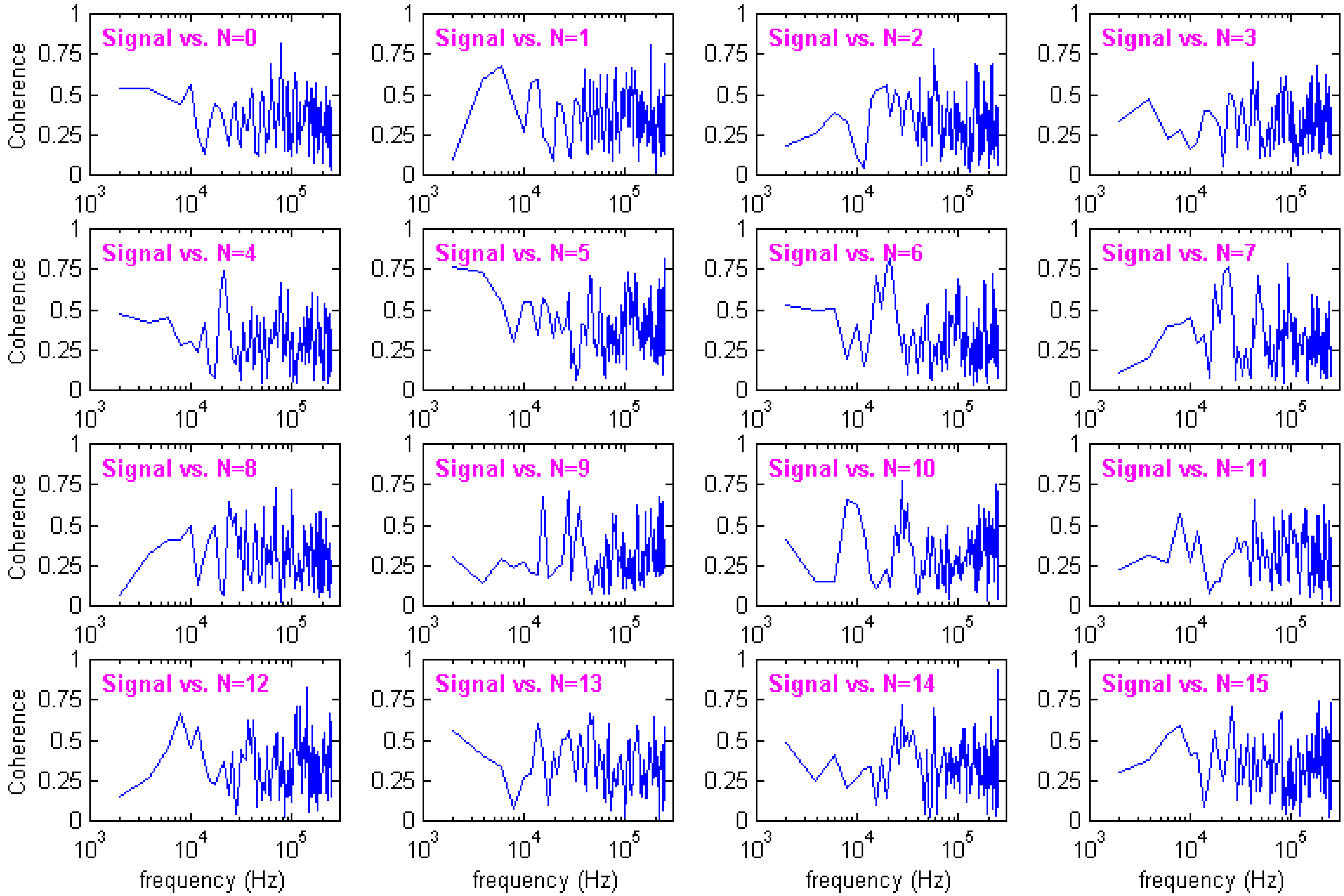
- A peak at around 20kHz is clearly seen from the power spectrum plots
- Noise levels are also plotted for comparisons





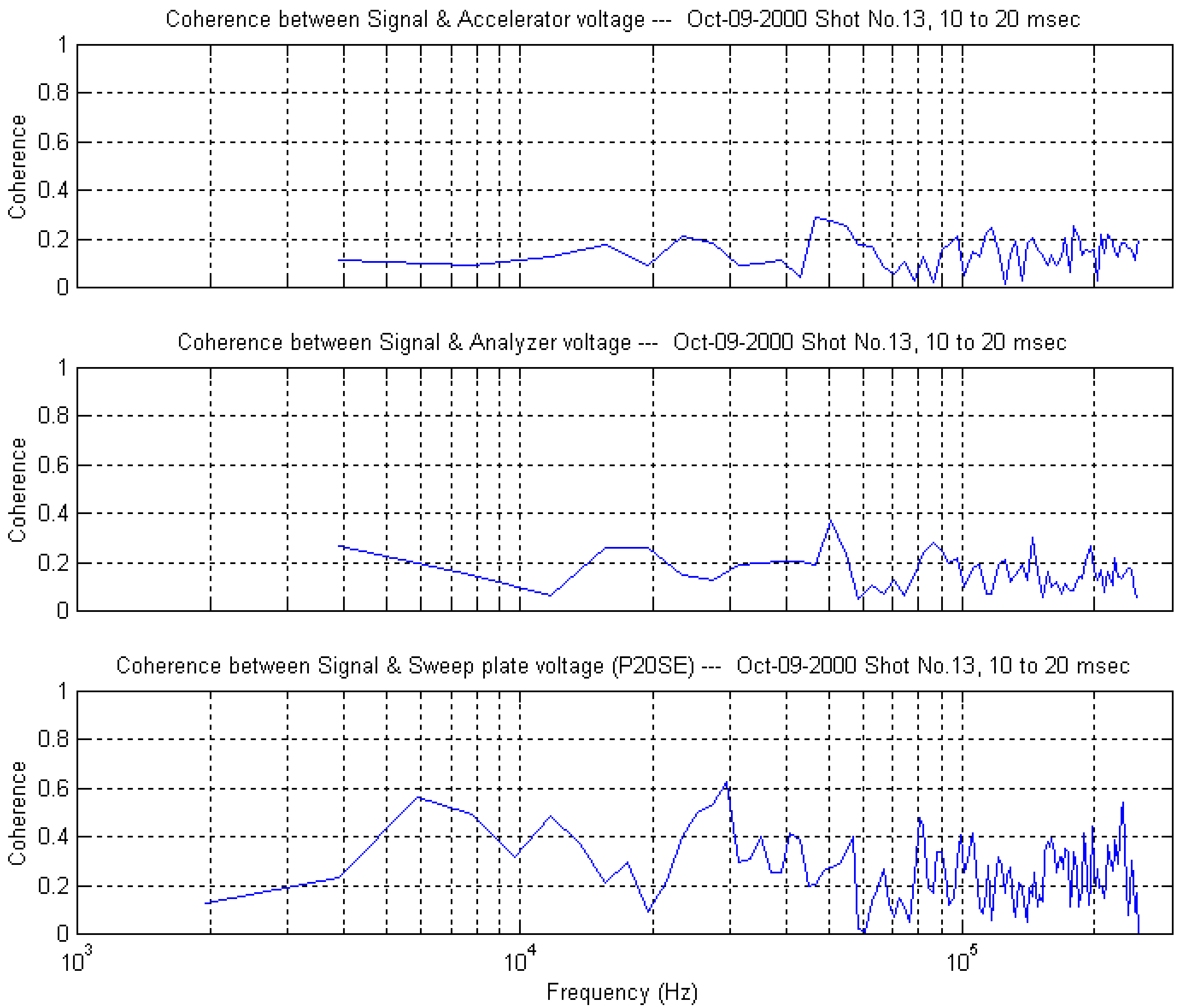
Coupling Between the Detected Signals with Toroidal Modes

- The density signals are seen closely related to the core n=6,7 toroidal modes around 20kHz
- Below 10kHz, the signal also shows a relative high coherence with almost all the modes



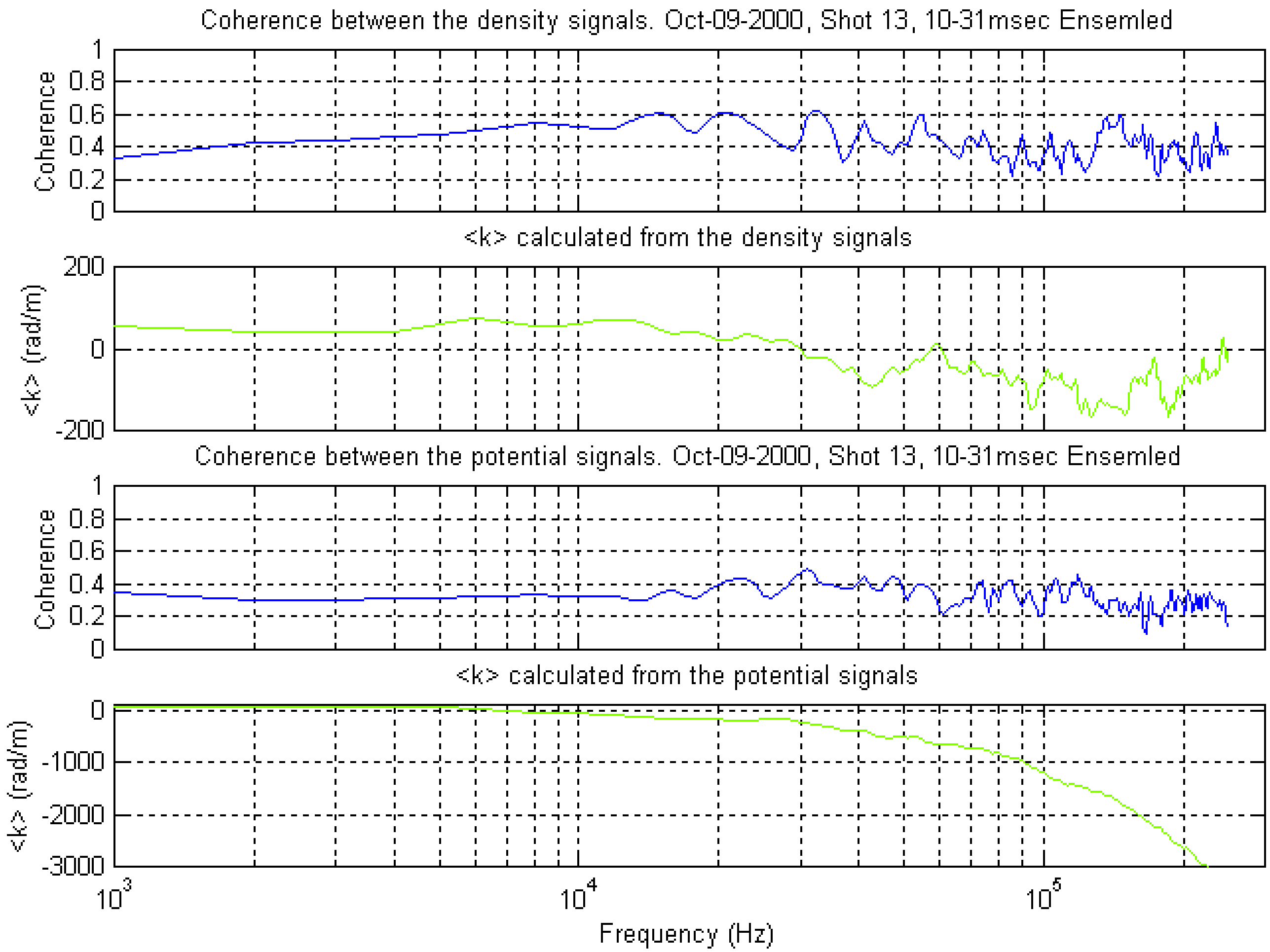
Signal Contamination by the Power Supplies

- As the diagnostic ion beam is driven and steered by the high voltage power supplies, the detected signal could be contaminated by these power supplies.
- Coherences between the secondary signal and different driven power supplies can be calculated to shown the influences of the fluctuations from power supplies' outputs on the signals:
  - Detected signal is not correlated with the accelerator power supply's output when the signal power is sufficient high. (Although at ~20kHz, both have a peak)
  - Detected signal is weakly correlated with the analyzer power supply's output (coherence ~ 0.4) at ~40kHz (which is the power supply's switching frequency) when the signal intensity is low
  - Detected signal is correlated with the 20kV sweep plate power supply's output that is closest to the plasma in the primary beam line. This may be caused by the plate's UV/Plasma loading effect, which we've been dealing with since beginning.
- Issues of signal contamination by the power supplies need to be paid more attention in the future in order to get meaningful result. This includes carefully layout of all the signal/power cables to reject any suspect noise pickups.


Coherence between Signal & Accelerator voltage --- Oct-09-2000 Shot No.13, 10 to 20 msec
Coherence between Signal & Analyzer voltage --- Oct-09-2000 Shot No.13, 10 to 20 msec
Coherence between Signal & Sweep plate voltage (P20SE) --- Oct-09-2000 Shot No.13, 10 to 20 msec
Coherence
1
0.8
0.6
0.4
0.2
0
10^3
10^4
10^5
Frequency (Hz)

Initial Wave Number Calculations

- The average wave number <k> was calculated from the two points measurement
- Separation between two sample volumes is $\Delta \sim 2.3$cm
- The <k> calculated here could subject to big error because of low coherence between the signals. More reliable number can be calculated once we have more data to ensemble
- Coherence between the density signals is higher than that of the potential signals



Fluctuation Measurements From Langmuir Probes

- Langmuir probes have been used to measure the electrostatic potential fluctuations and electron density fluctuations at the MST plasma edge ($r/a > 0.9$) for standard, PPCD (pulse poloidal current drive), and plasma biasing cases (by Ching-Shih Chiang) at low plasma current level (~200kA discharge)
- At the plasma edge, electrostatic fluctuations are responsible for the particle transport, but not for the energy transport
- Both electrostatic fluctuations and electron density fluctuations are greatly reduced at the edge with PPCD and plasma biasing
- Plasma biasing can reduce edge particle transport flux by a factor of three, while PPCD doesn't impact the edge particle flux very much except at the very edge ($r/a > 0.96$)
- Direct comparison between the beam probe measurements and Langmuir probes could be difficult, as they are dealing with different plasma regions and operation conditions
- HIBP is a complementary diagnostic of Langmuir probes

Initial Results and Conclusions

- For the first time, a heavy ion beam probe system is used to measure potential fluctuations $\tilde{\Phi}$ and electron density fluctuations $\tilde{n}_e$ in the core of the MST reversed field pinch. Secondary signals have been systematically measured since May 2000
- Fluctuating signals have been seen on the detector plates
- Most recent signals were measured in the core region where r/a ~ 0.5
- Initial signal analysis show that the detected signals are closely correlated to the n = 6,7 toroidal core (tearing) modes at around 20kHz. They also show relative high coherence with almost all the modes at even lower frequency range (<10 kHz). Whether these fluctuations are related to the electrostatic modes or magnetic modes needs to be further studied
- Efforts have been done to improve the signal/noise ratio and to find optimum operation regime. A broad range of plasma and beam conditions have been tested and beam signals detected
- Relatively high intensity signals that enable us to analyze the fluctuation levels have been recorded recently with a newly installed ion gun (see Demers' poster next to this)
- Signals from the secondary ion beam have been used to improve MSTFIT, the magnetic field modeling, which in turn improves the accuracy of our heavy ion beam trajectory calculations
- Signal contaminations from the power supplies that are applied all through the diagnostic system may exist and affect our fluctuation measurements

Future Work

- Continue to increase signal/noise ratio to improve the fluctuation measurements
- Address noise rejection issue, such as noises from power supplies
- Isolate electrostatic fluctuations from those of electromagnetic fluctuations
- Study electrostatic fluctuation induced particle flux
- Process data with high resolution spectral analysis (wavelet, etc)
- Study the possibility of fluctuation measurements for the improved plasma confinement cases
- Help to improve the magnetic field modeling with improved trajectory calculations and improved secondary ion beam measurement
- Help to address the causes of the electrostatic fluctuations