“Measurement of core potential and density fluctuations on MST with a heavy ion beam probe”

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ABSTRACT

The core profiles (r/a = 0.3~0.7) of the electrostatic potential fluctuations and electron density fluctuations have bee n measured for the first time in the MST reversed field pinch with a heavy ion beam probe (HIBP). Traditional fluctuation measurements with Langmuir probes have been limited to the edge plasma region (r/a > 0.8) at low current. The HIBP has been used to ex tend the MST measurements to the core region of the plasma and cover broader range of plasma parameters. The measured $\tilde{\phi}$ is ~30-40Vrms ($e\tilde{\phi}/T_e$ ~ 10-15%) for standard 380kA discharges, while $\tilde{n}/n$ ~ 10-15%. The measured power spectra of both $\tilde{\phi}$ and $\tilde{n}/n$ show a peak at the tearing mode frequency. Broadband fluctuations (>30kHz) are also found at frequencies higher than the core resonant tearing modes and their rela tionship is studied with bi - spectral analysis. Simultaneous measurements have been made at two sample locations, thus allowing us to estimate electrostatic fluctuations induced transport. The 2 sample volumes are nearly radial aligned and therefore do not provide information about k_θ. Correlation between the measured core $\tilde{\phi}$ from the HIBP and edge $\tilde{\phi}$ from a Langmuir probe (TLP) will also be discussed.

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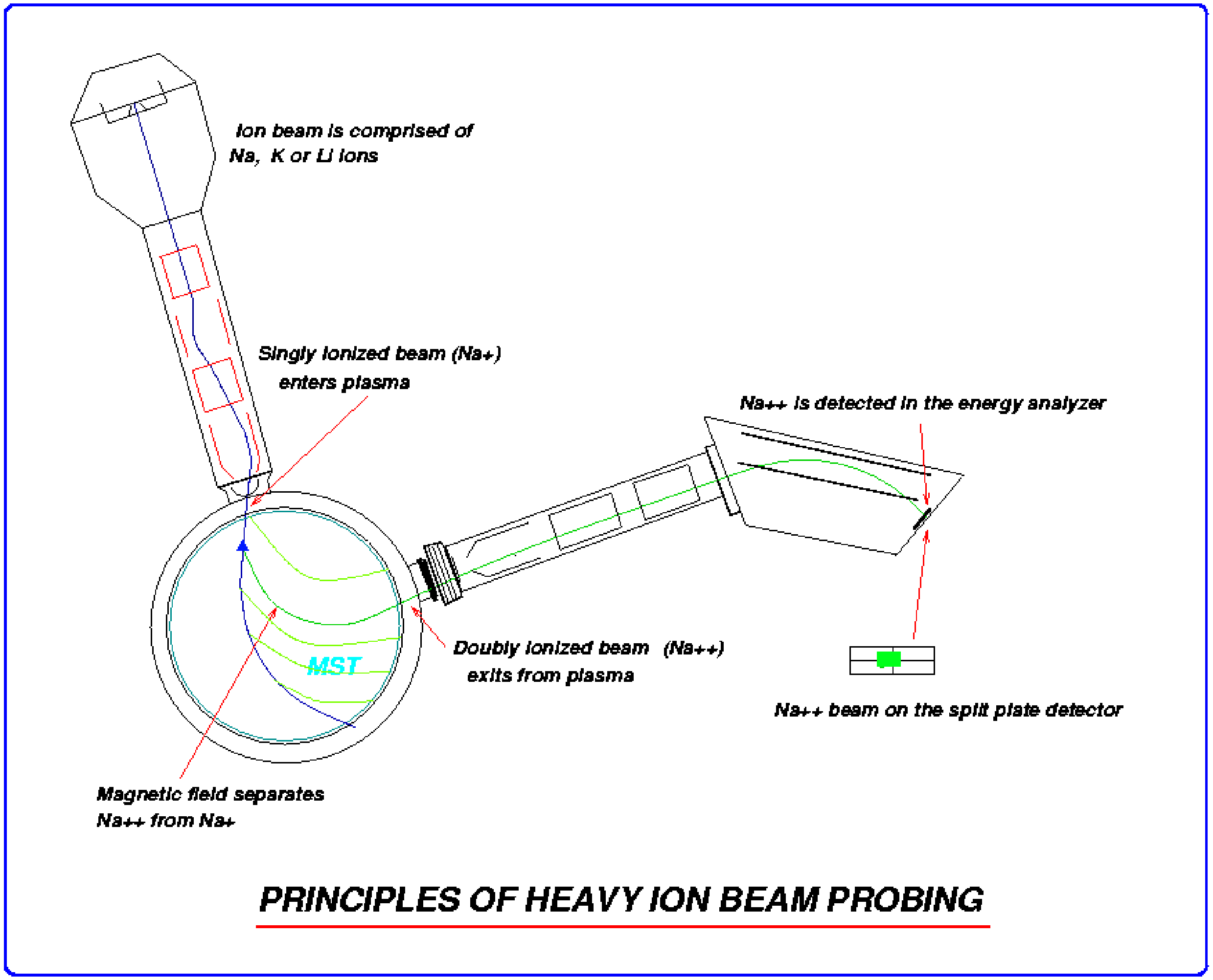
PRINCIPLES OF BEAM PROBING

- Singly charged ions are injected into a magnetically confined plasma
- Doubly charged ions generated by electron impact ionizations are separated from the singly charged ions by the magnetic field: $r_L = \frac{Mv}{qB}$
- The secondary ions are detected and analyzed outside the plasma



HIBP MEASURES ϕ, $\tilde{\phi}$, $\tilde{n}/n$, ETC.

- Plasma potential:

  ϕ = secondary ion energy – primary ion energy

- Potential fluctuations:

  $\tilde{\phi}$ = fluctuations in the secondary ion energy

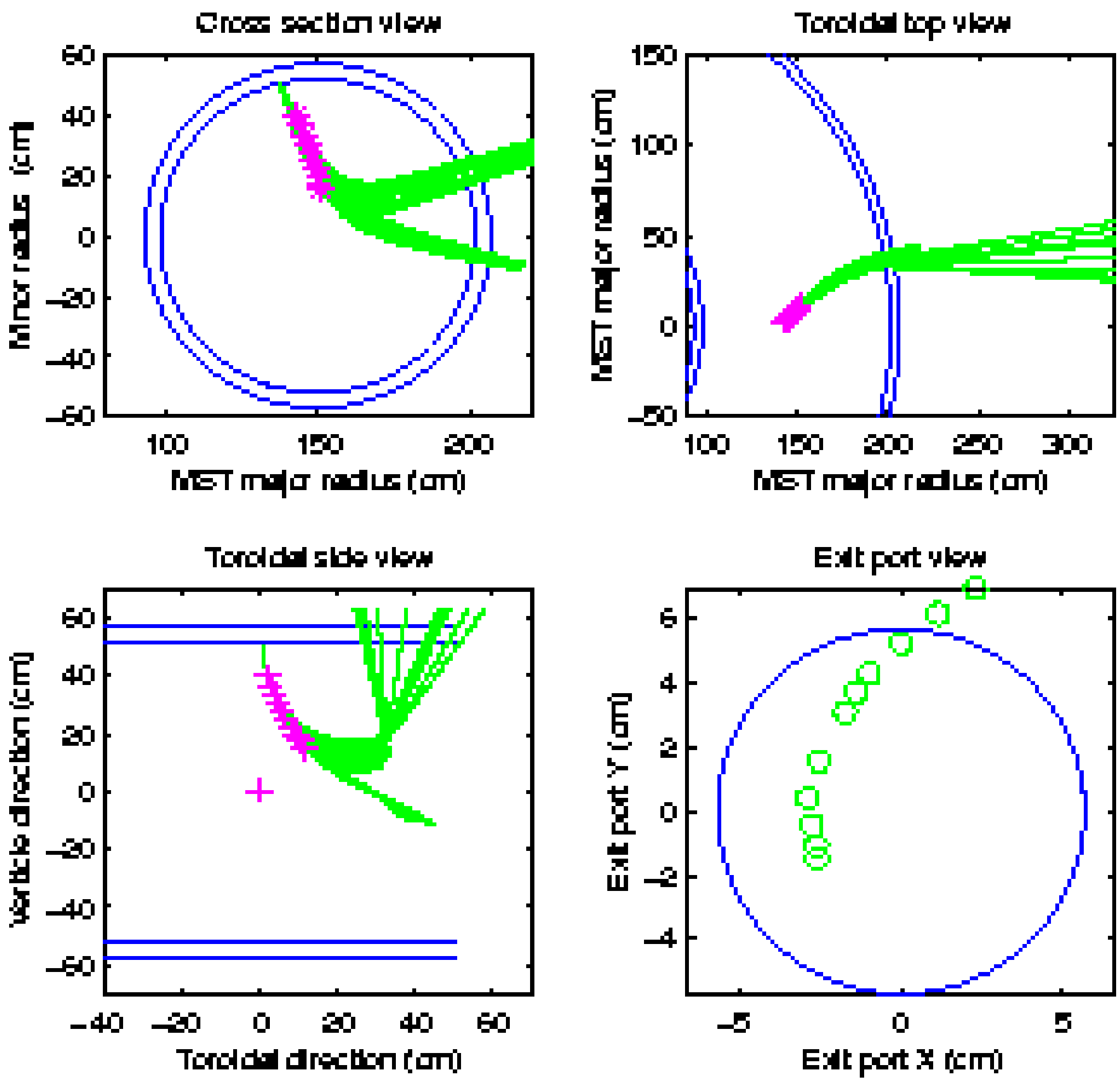
- Density fluctuations:

  $\tilde{n}_e \propto$ fluctuations in the secondary signal intensities

- Magnetic field and/or fluctuations:

  $B_p \propto$ toroidal motions of the secondary ion beam

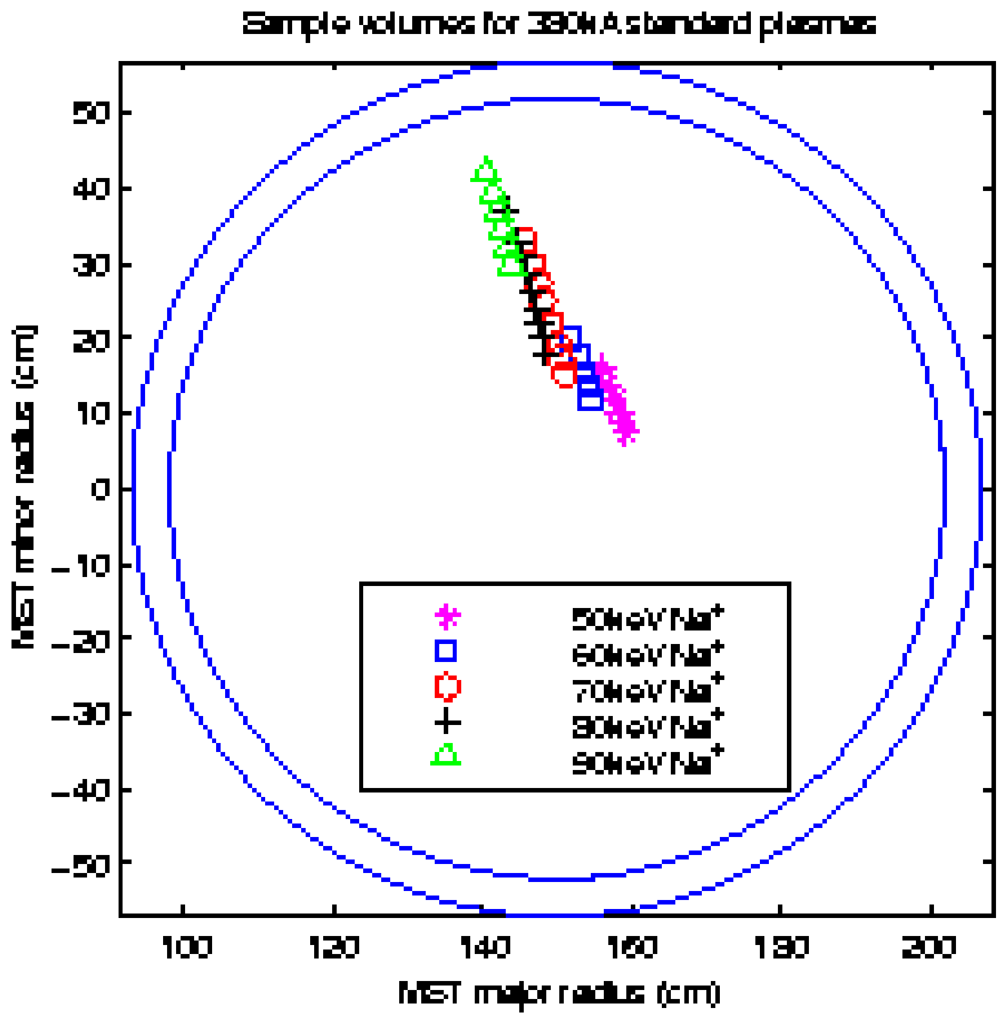
RADIAL SCAN BY CHANGING BEAM ENERGIES & INJECTION ANGLES



CORE AREA HAS BEEN MEASURED

- Present system set-up allows measurements from

  r/a ~ 0.2 to 0.8 for standard plasmas



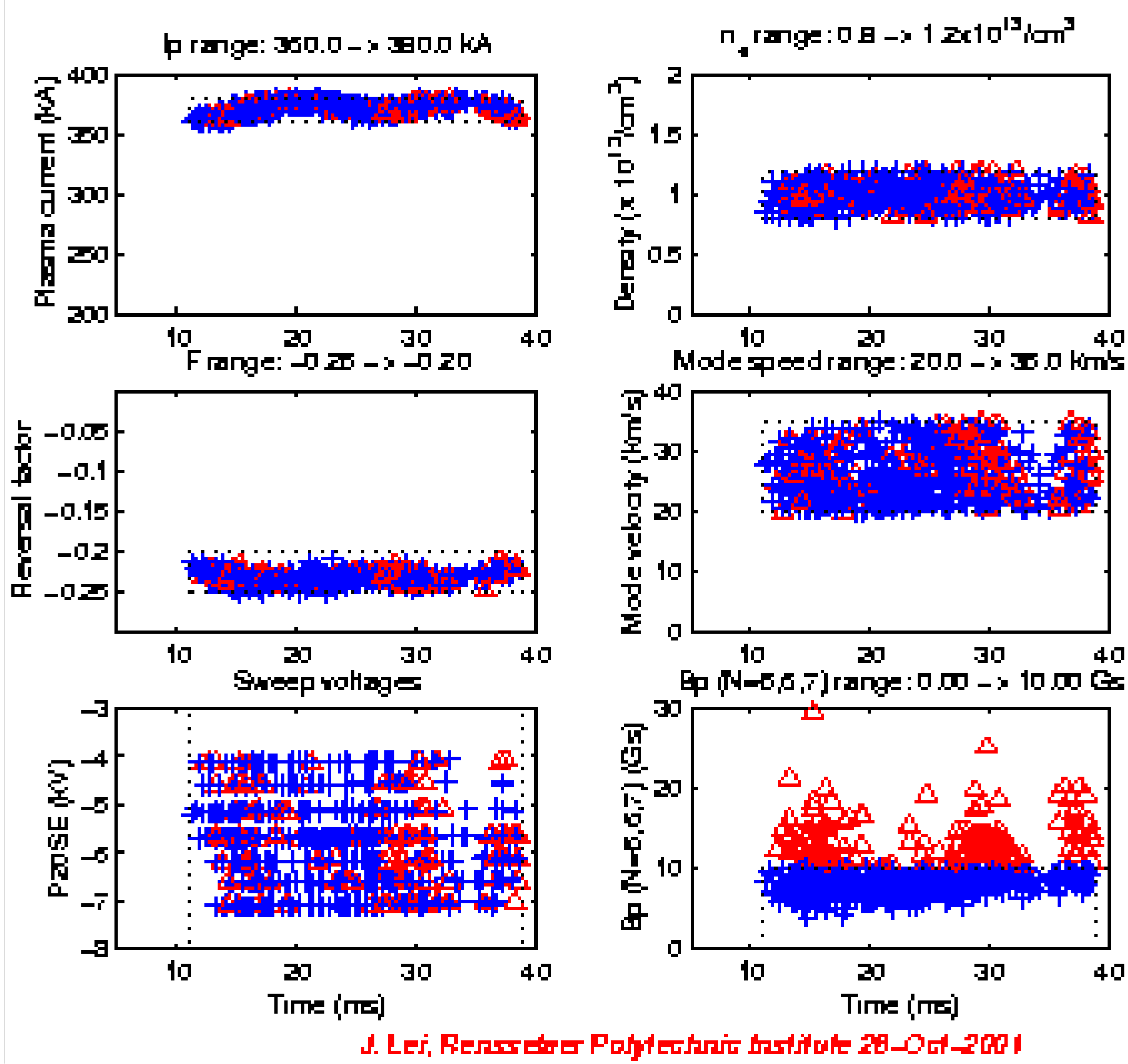
FLUCTUATION DATA ARE ANALYZED WITH ENSEMBLE AVERAGING

- Large ensemble are generated for similar plasma conditions

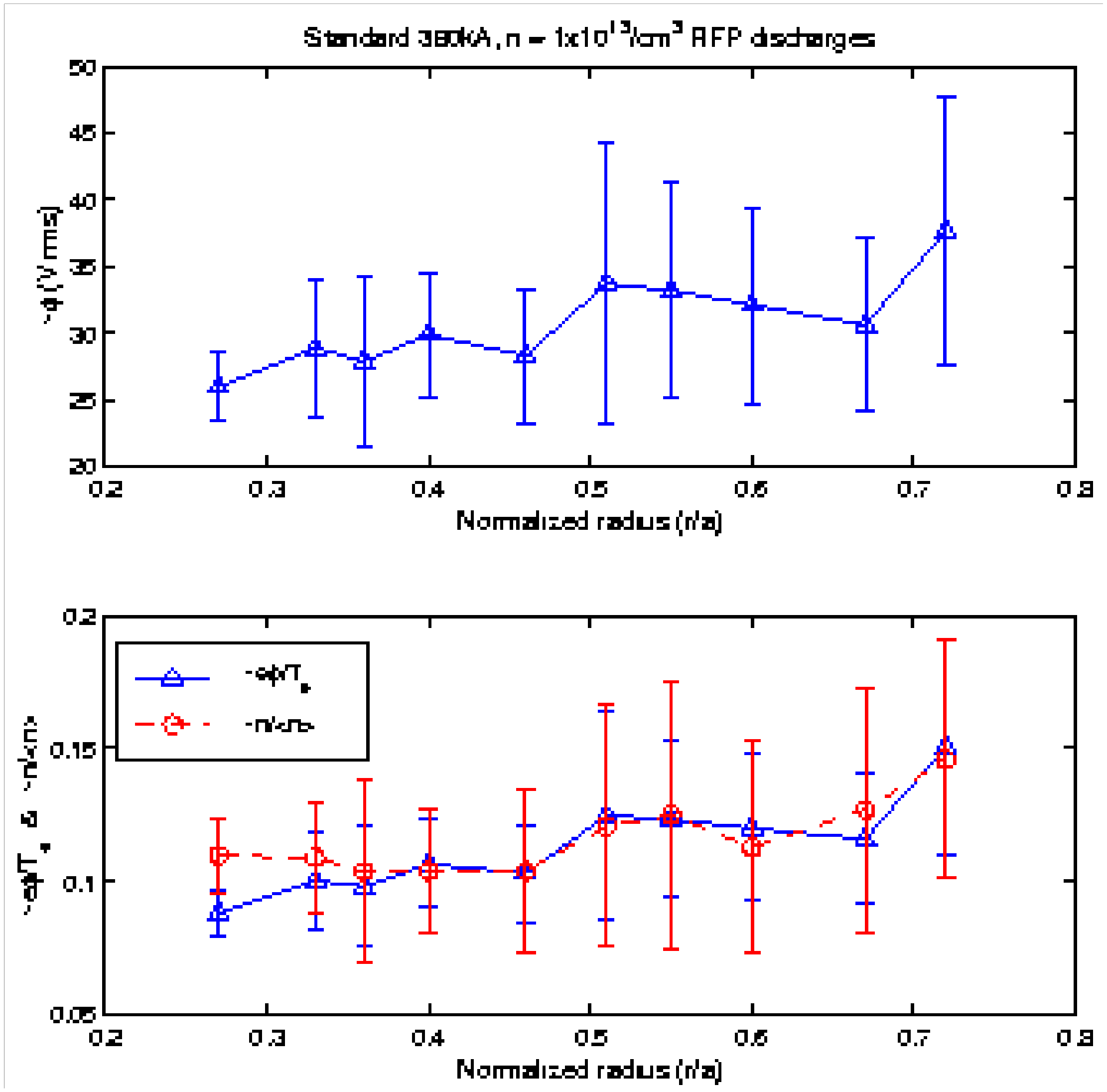
- Fluctuations characteristics are averaged over ensembles to reduce statistic noise and to increase S/N ratio

- Typical window size of a realization is 0.5ms

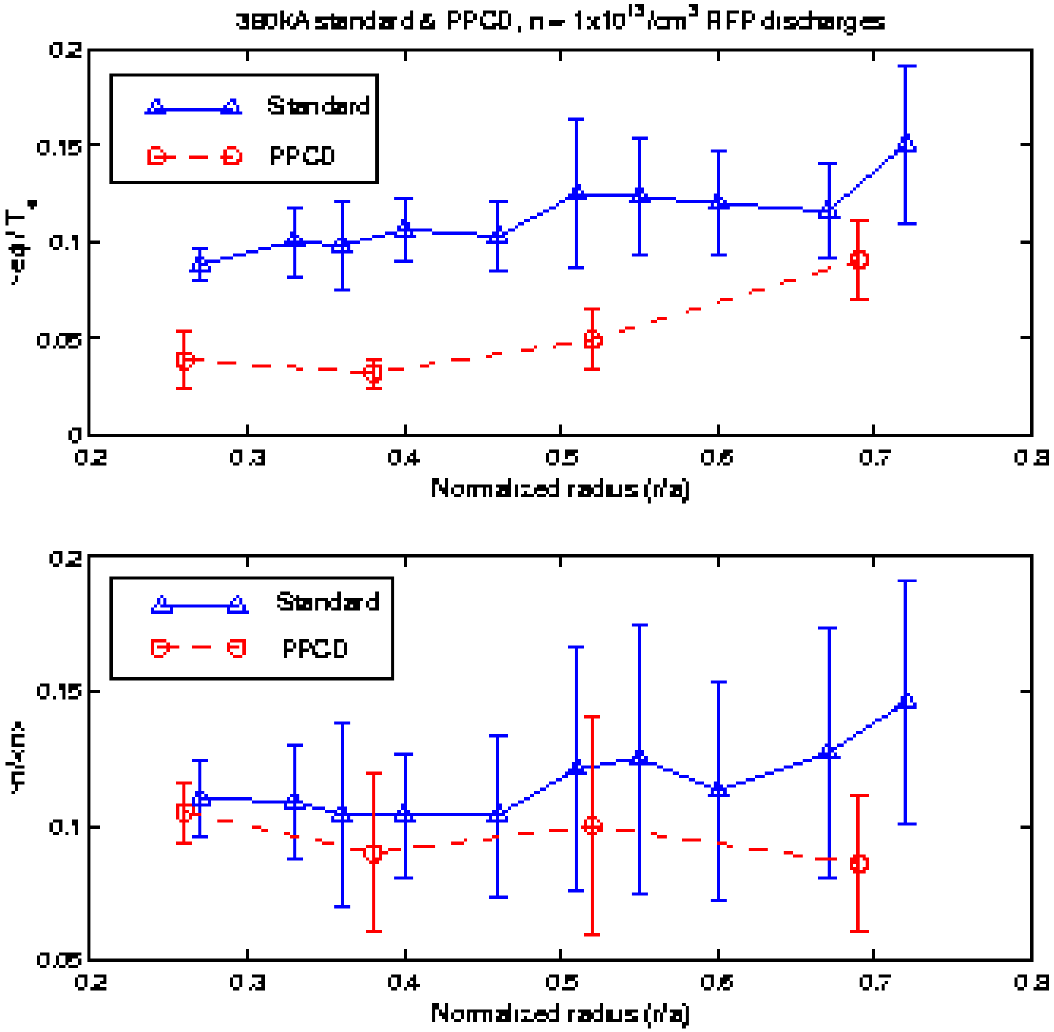
- Realizations are taken away from sawteeth



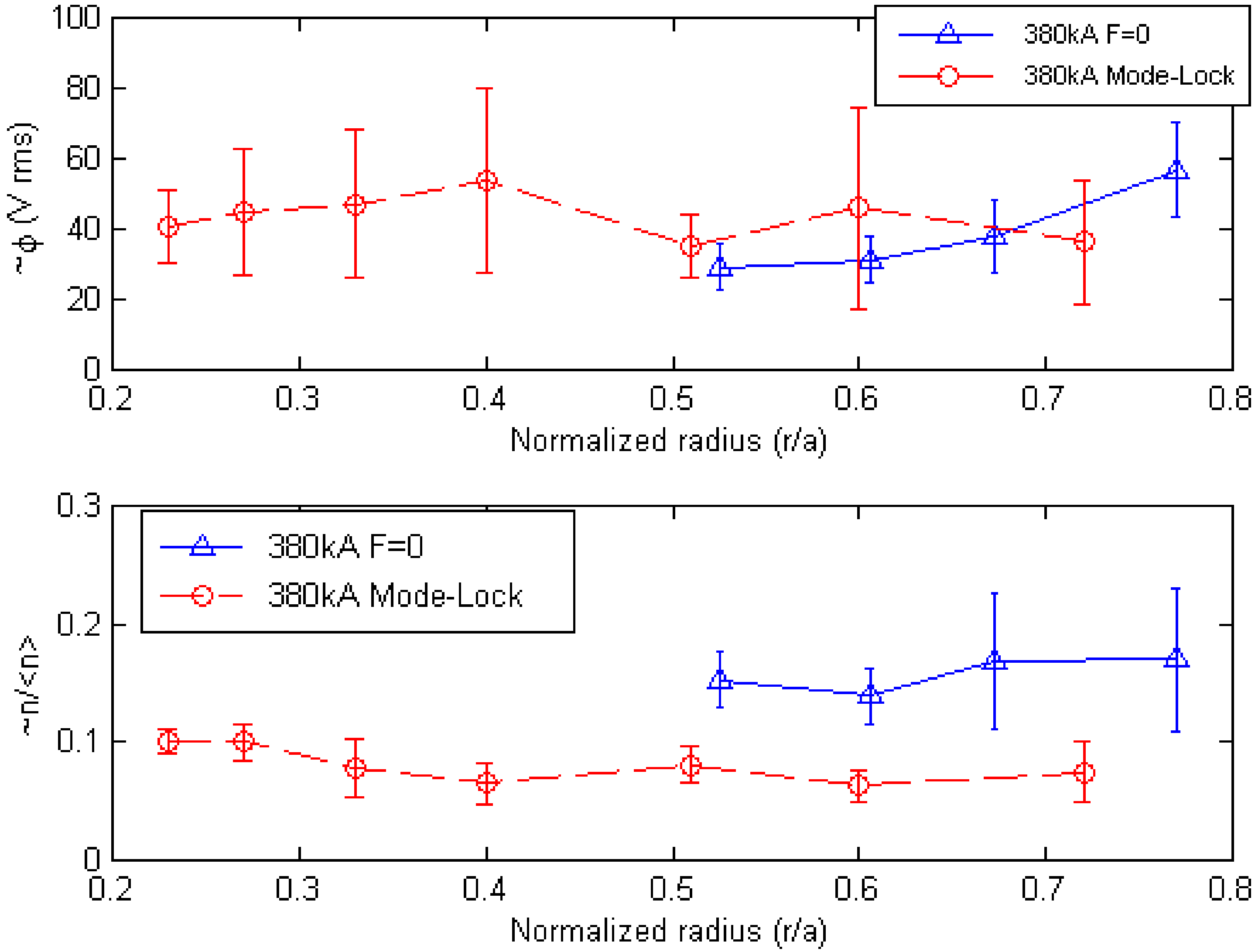
BOLTZMANN RELATION IS FOUND IN STANDARD DISCHARGES



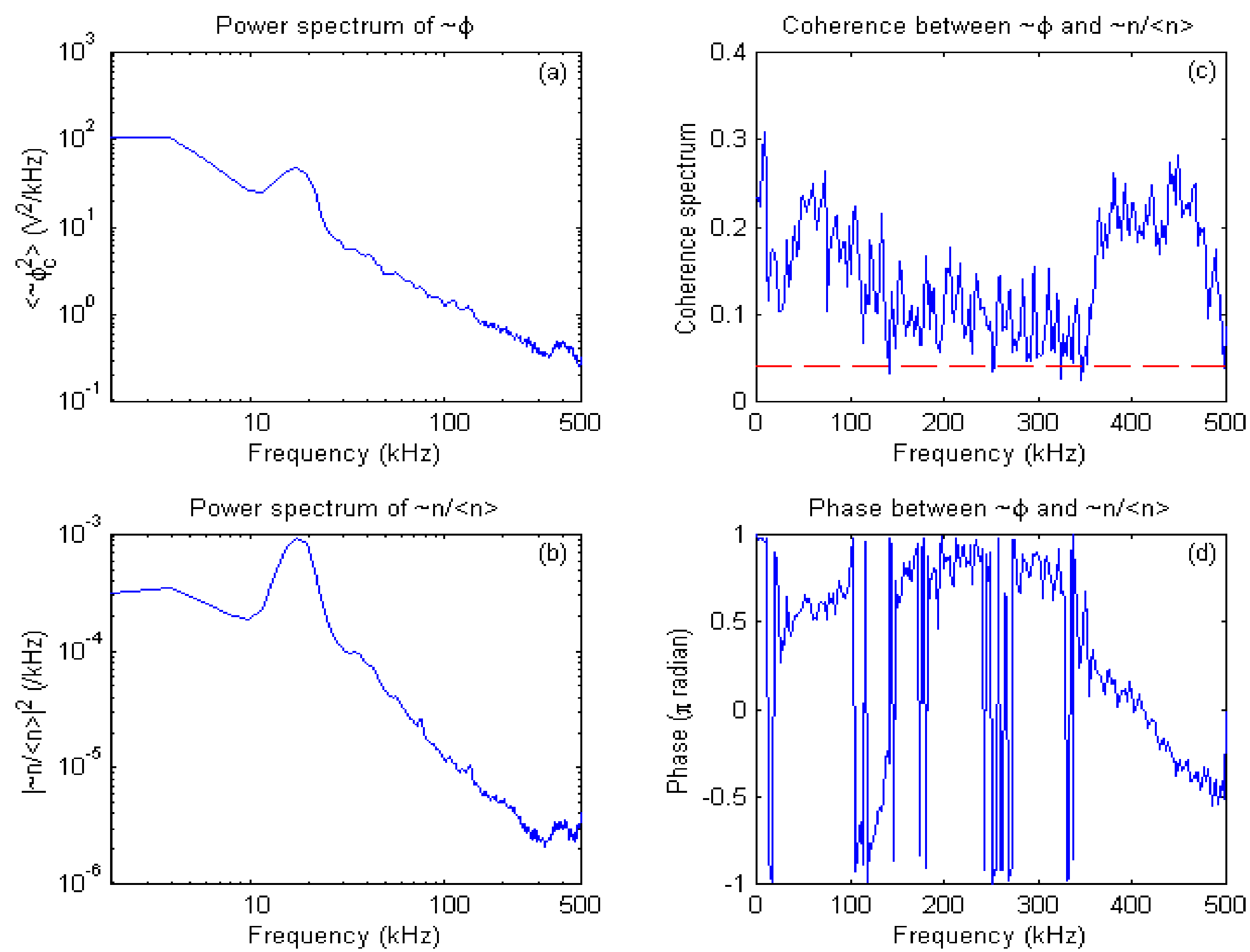
FLUCTUATIONS ARE REDUCED IN PPCD DISCHARGES



FLUCTUATIONS IN NON-REVERSAL & MODE-LOCKING DISCHARGES



LOW FREQUENCIES DOMINATE THE CORE FLUCTUATIONS



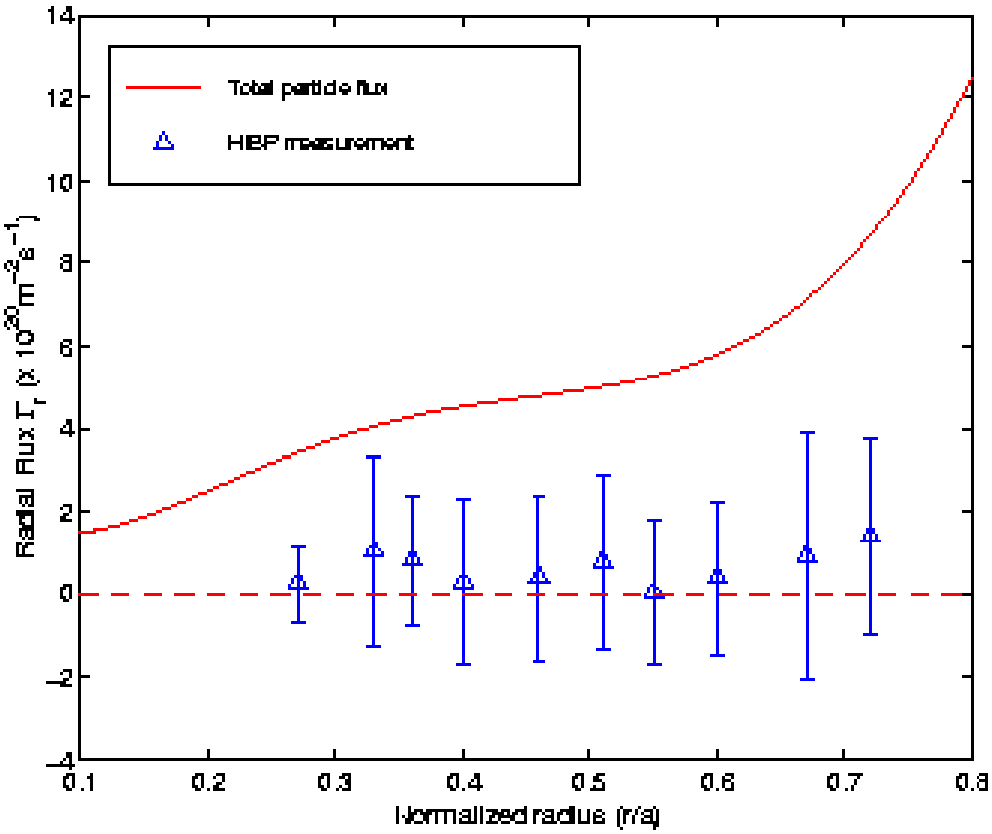
FLUCTUATIONS INDUCED PARTICLE TRANSPORT IS SMALL

- Electrostatic fluctuations induced radial particle transport is:

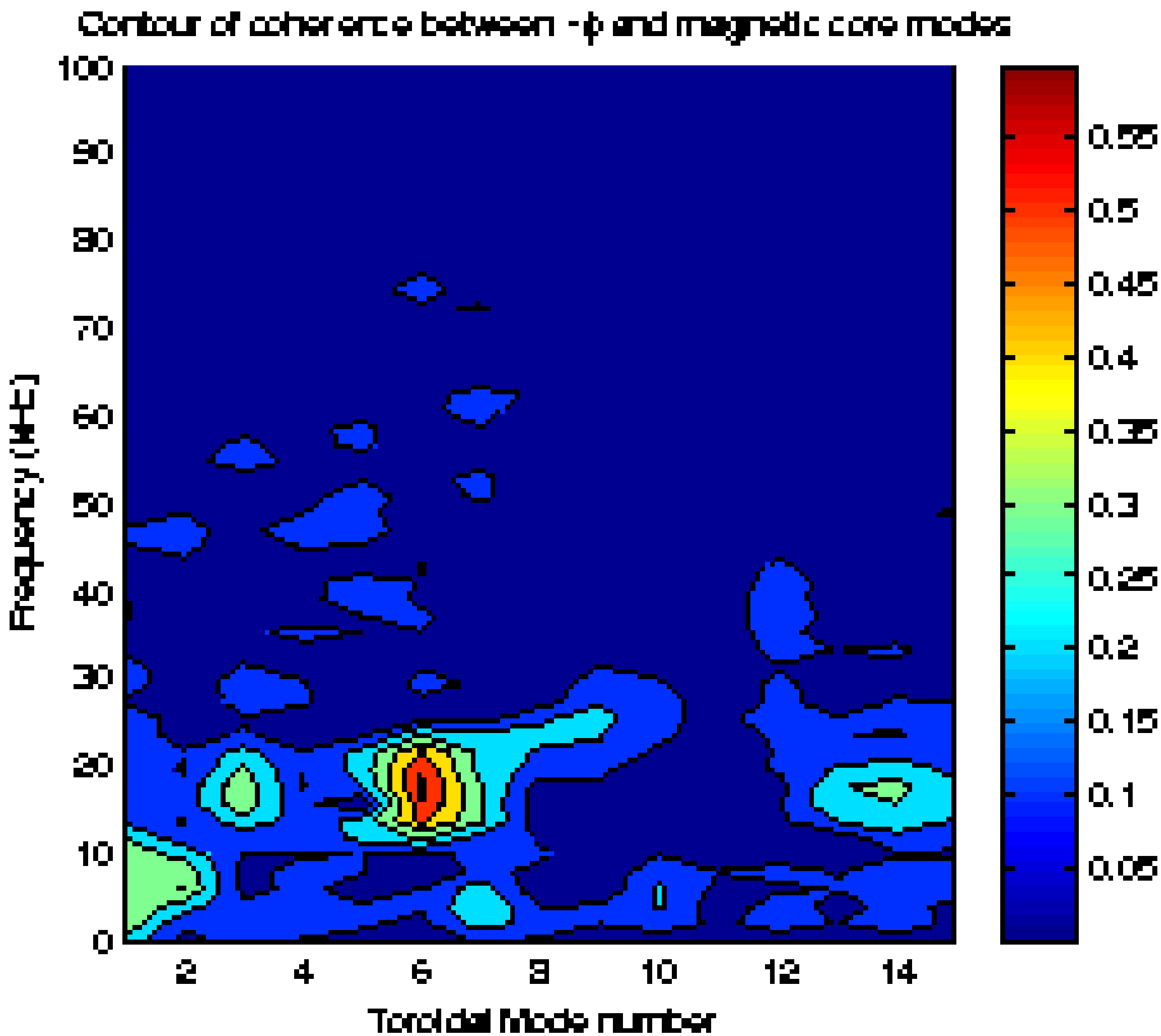
$$\Gamma_r^E = \langle \tilde{n}\tilde{V}_{Er} \rangle = \frac{\langle \tilde{n}(\vec{E}\times\vec{B})_r \rangle}{B^2} = \frac{i(\bar{k}_\theta B_\phi - \bar{k}_\phi B_\theta)\langle \tilde{n}\tilde{\phi} \rangle}{B^2} = \frac{-(\bar{k}_\theta B_\phi - \bar{k}_\phi B_\theta)|P_{n\phi}|\sin\theta_{n\phi}}{B^2}$$

where $P_{n\phi}$, $\theta_{n\phi}$ are the cross-power and phase between $\tilde{\phi}$ and $\tilde{n}$

- If using the dominant MHD modes to infer the wave number k, Γ_r is calculated to be small



FLUCTUATIONS ARE CORRELATED WITH (M/N = 1/6) MAGNETIC MODE

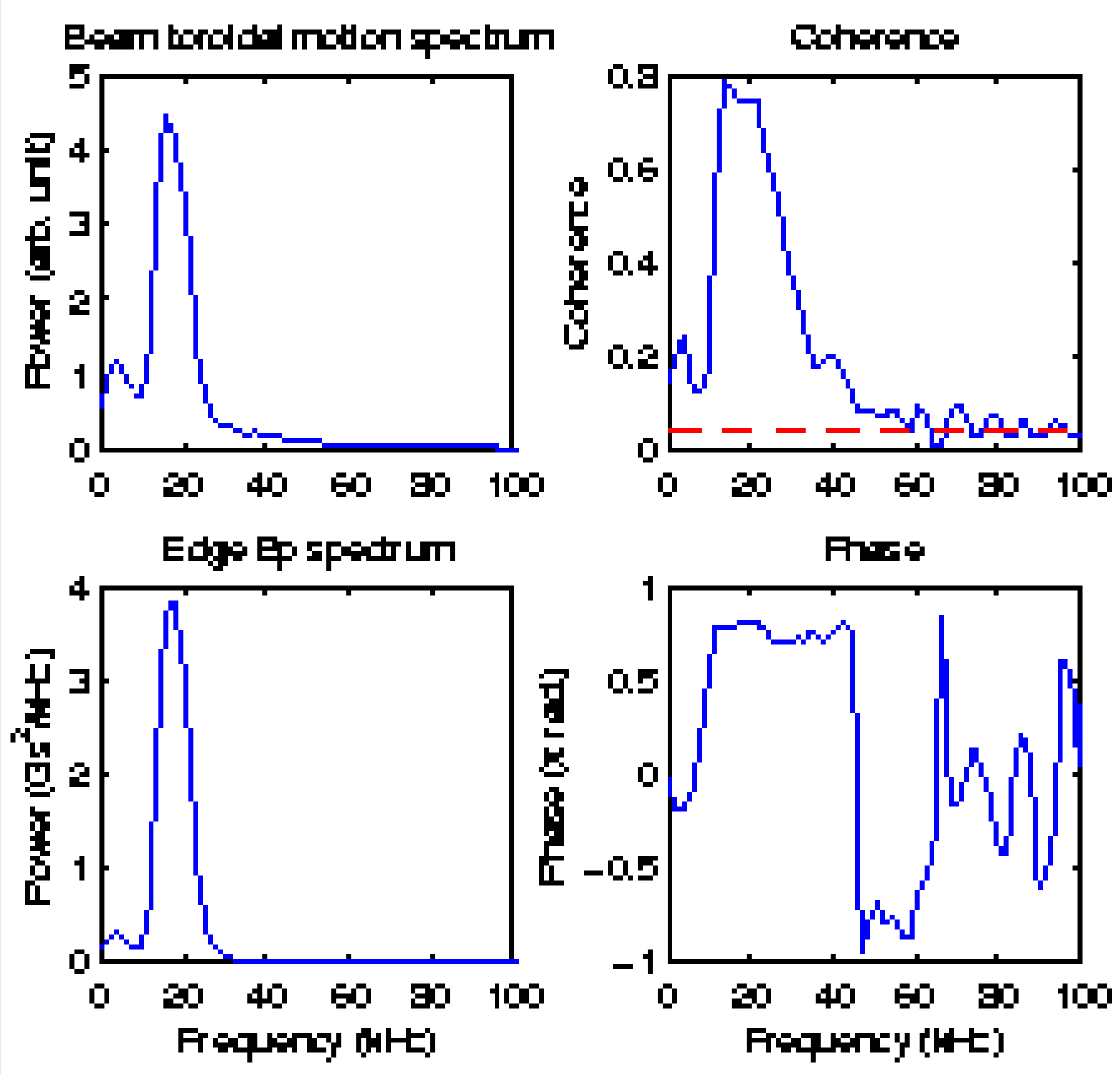


MST-HIBP MAY DIAGNOSE THE LOCALIZED MAGNETIC FIELDS

- ***Toroidal*** motion of the secondary beam is related to the local ***poloidal*** magnetic field at the sample location

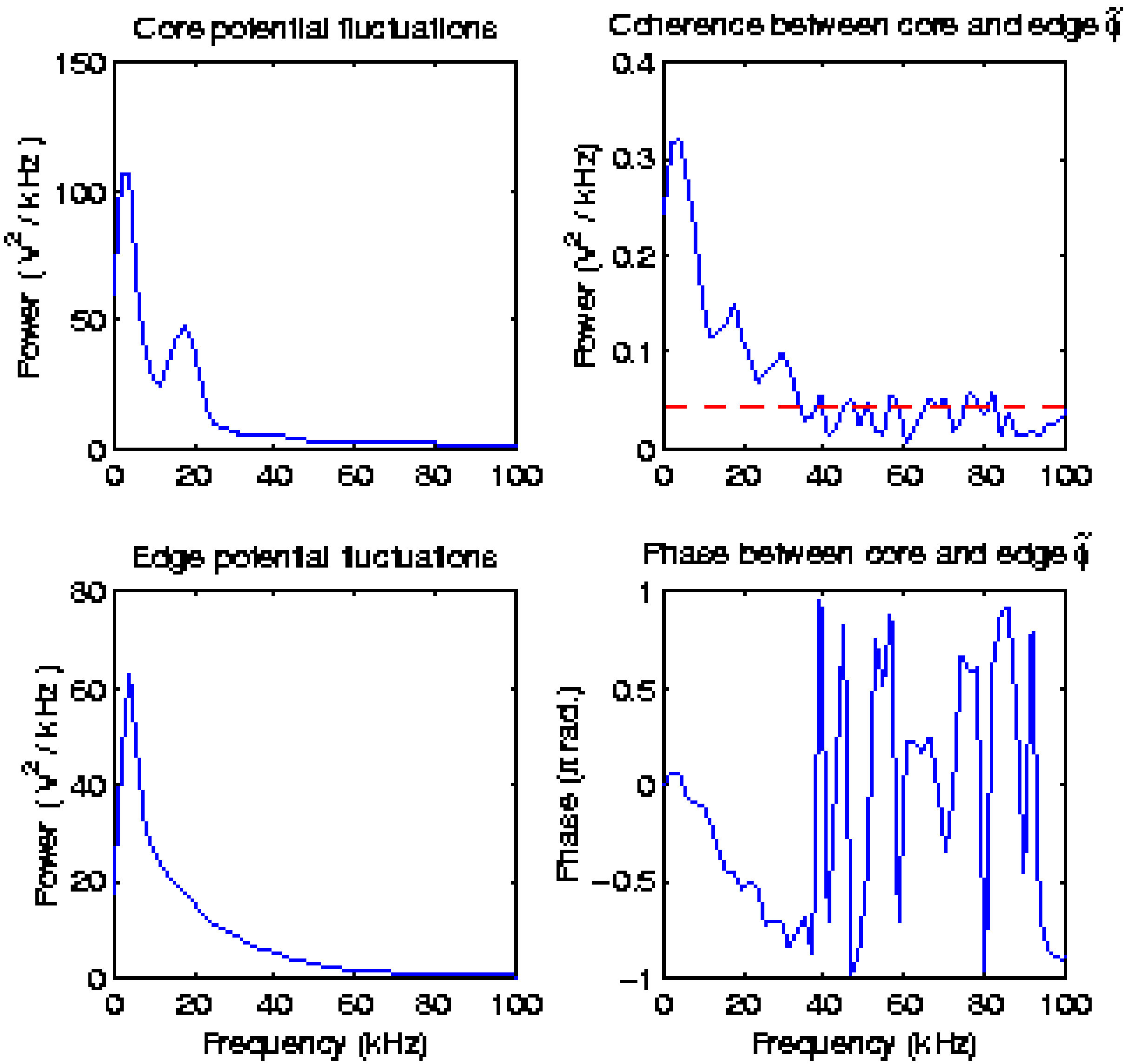
$$y_d \propto B_p \Rightarrow \tilde{y}_d \propto \tilde{B}_p$$

- ***Phase = 0*** if the poloidal separation (~ 140 deg.) of the two measurements is corrected



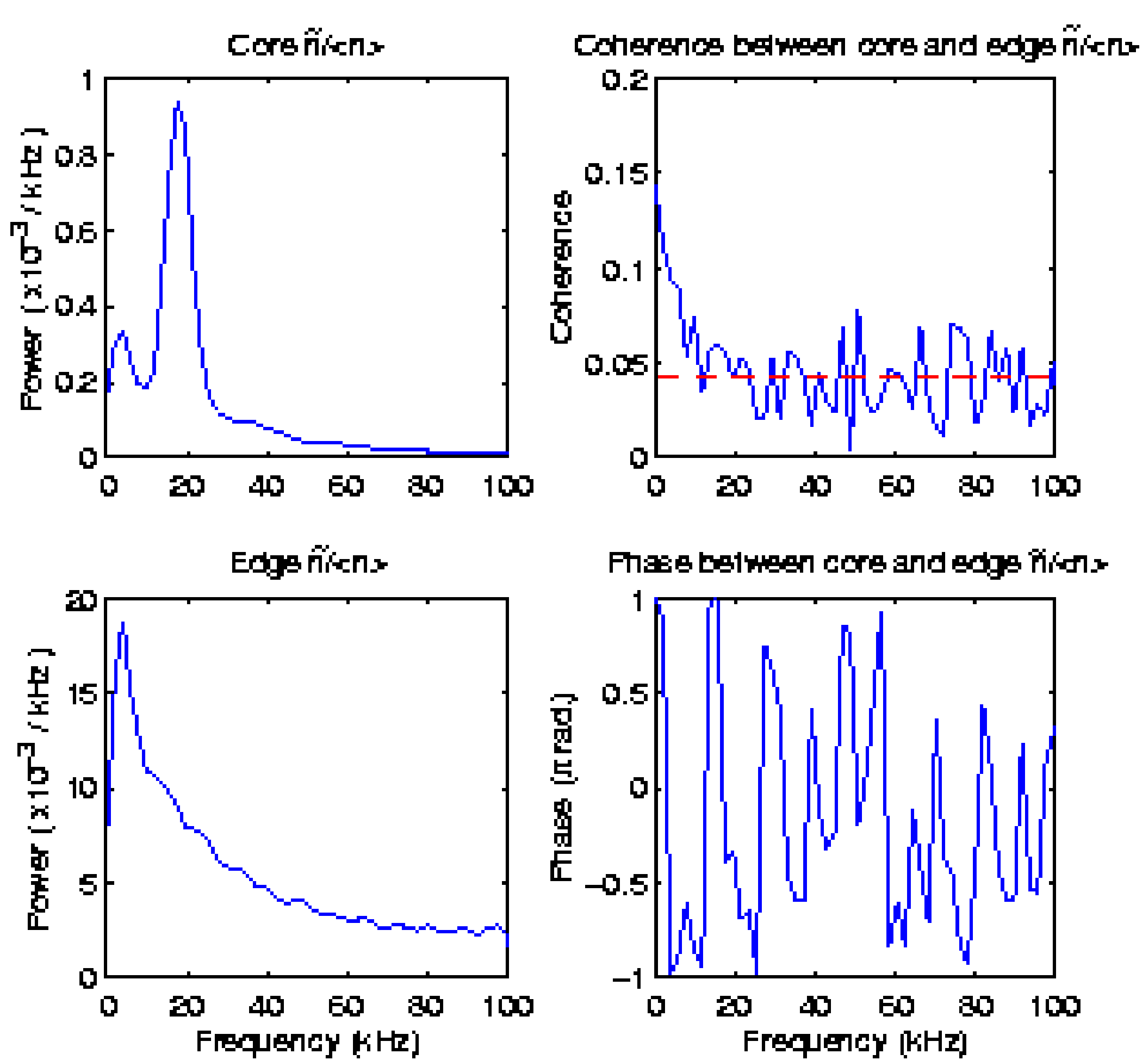
CORE & EDGE POTENTIAL FLUCTUATIONS ARE CORRELATED

- Edge $\tilde{\phi}$ has been measured by a Langmuir probe at (45P, 222T, r/a=0.96)
- Edge electric fields are important for the core potentials
- A *time delay ~13us* is found between the edge and core potential fluctuations



CORE & EDGE DENSITY FLUCTUATIONS ARE UN-CORRELATED

- No significant coherence found between the core and edge $\tilde{n}$ over the whole spectrum (except perhaps at very low frequencies)
- Measurements suggest that $\tilde{n}$ is more localized
- Edge $\tilde{n}$ ~ 60%



CORE $\tilde{E}_r$ IS UN-CORRELATED WITH MINORITY ION FLOW VELOCITIES

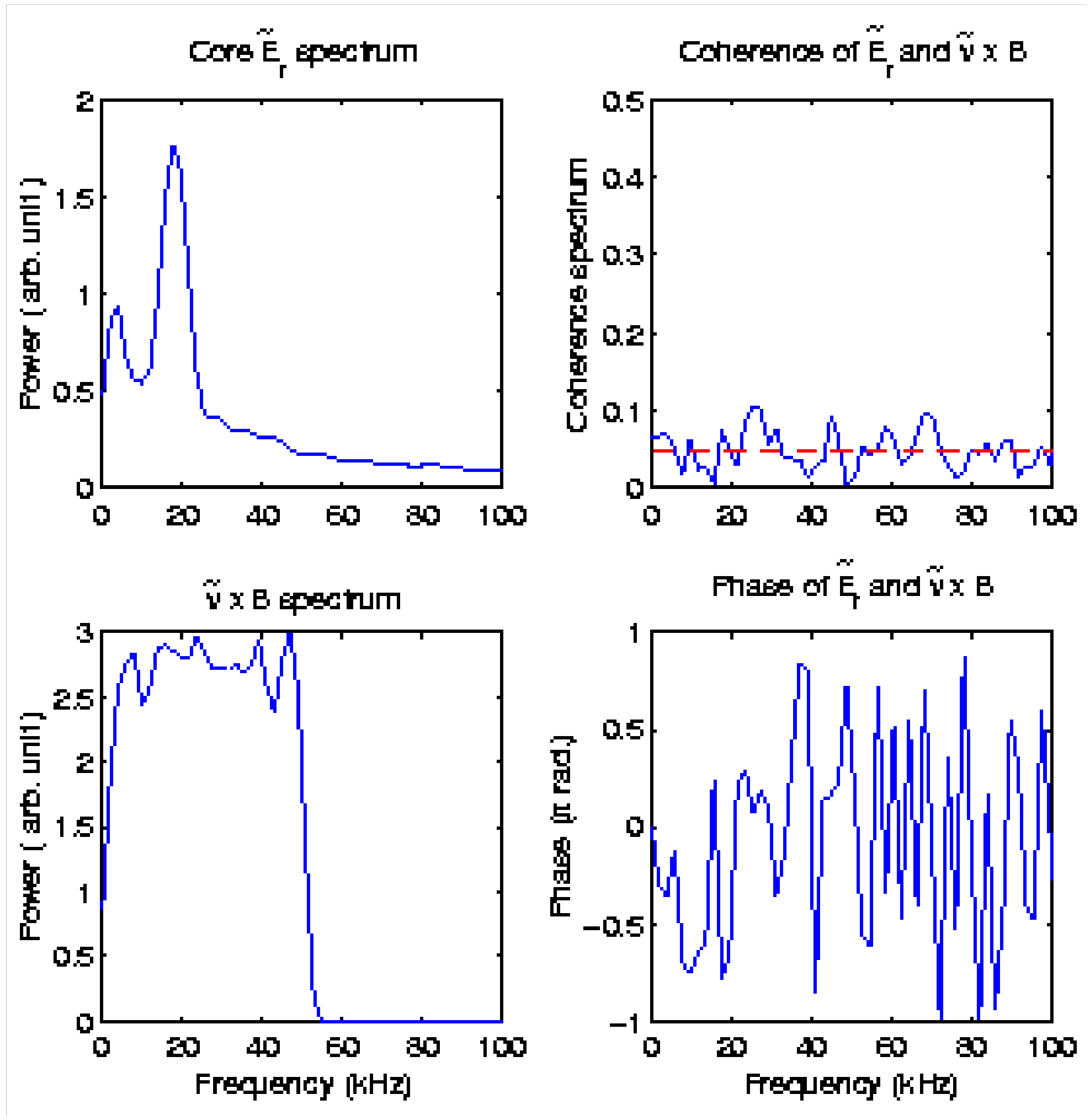
- IDS (Ion Dynamic Spectrometers) measures the core toroidal and poloidal impurity ion flows

- Fluctuating MHD radial electric field from v x B

$$\tilde{E}_r^{MHD} = \tilde{v}_\phi B_\theta - \tilde{v}_\theta B_\phi$$

- $\tilde{E}_r^{HIBP}$ has found to be un-correlated to $\tilde{E}_r^{MHD}$

- At 380kA, IDS may not work well

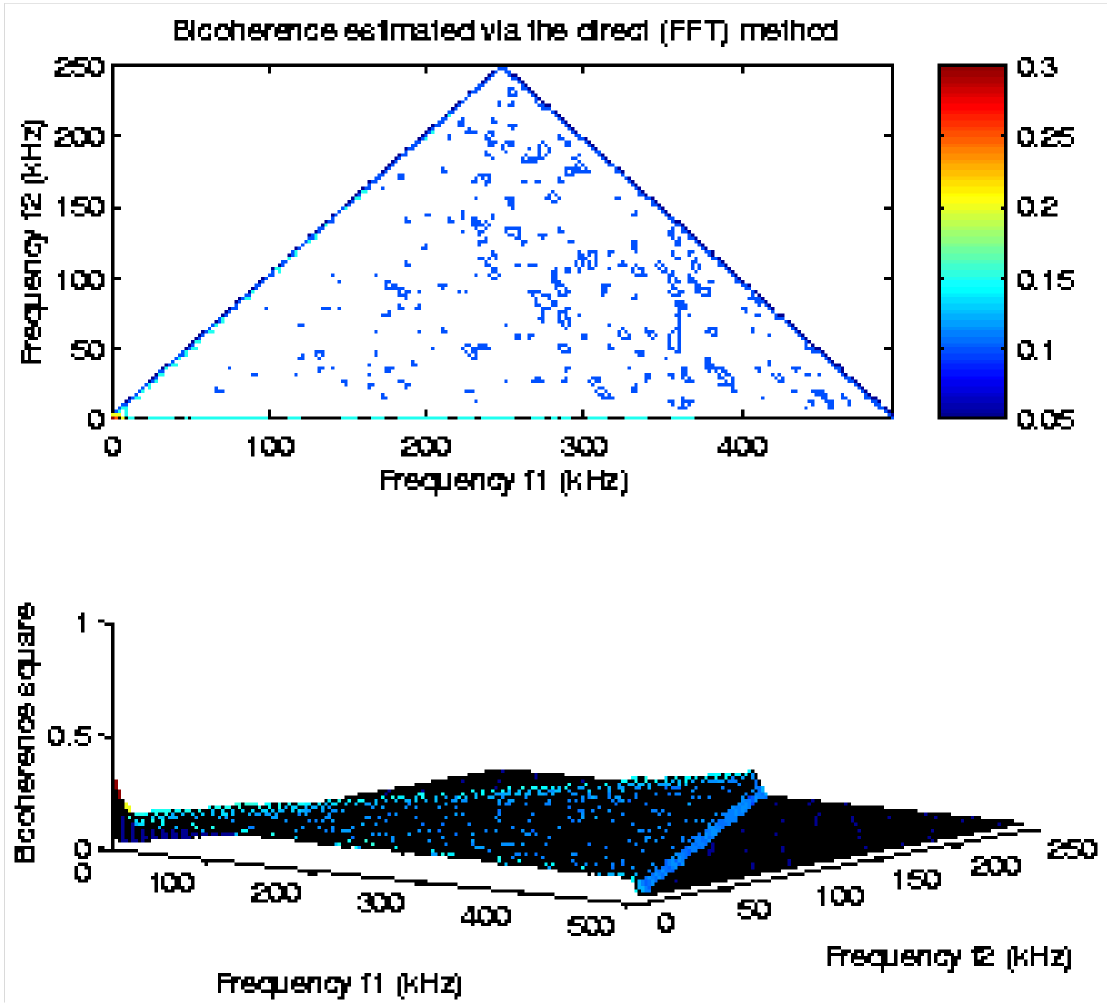


WAVE-WAVE COUPLING IS SMALL FROM BI-SPECTRAL ANALYSIS

- *Bi-coherence* gives a measurement of non-linear coupling between two different frequencies or wave numbers:

$$b(f_1,f_2)=\frac{\left|\left\langle X(f_1+f_2)X^*(f_1)X^*(f_2)\right\rangle\right|}{\sqrt{\left\langle\left|X(f_1)X(f_2)\right|^2\right\rangle\left\langle\left|X(f_1+f_2)\right|^2\right\rangle}}$$

- Both core and edge potential fluctuations have small non-linear coupling among different components

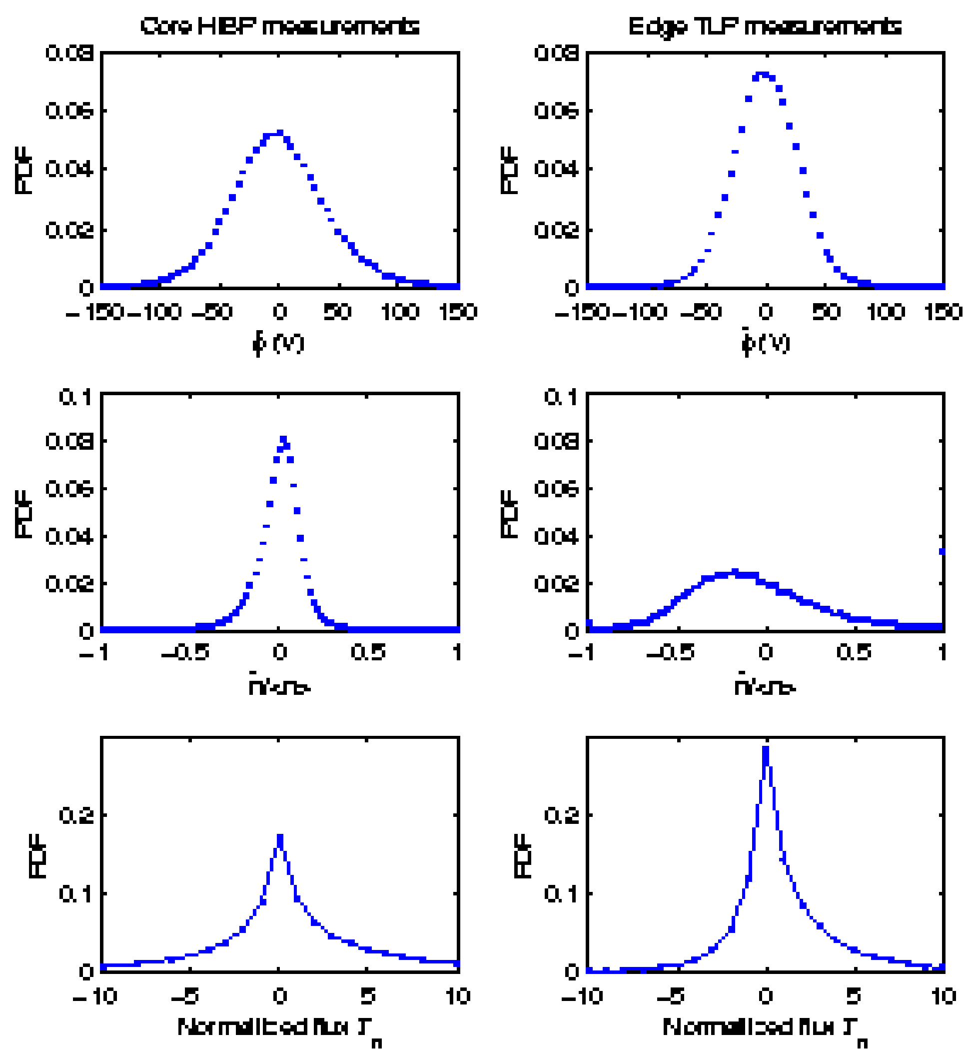


PROBABILITY DENSITY FUNCTIONS ARE GAUSSIAN LIKE

- The probability of a measured signal x that has values larger than a certain quantity x_0 is:

$$P\{x > x_0\} = \int_{x_0}^{\infty} p(x)\,dx$$

where p(x) is called the probability density function (PDF) of the signal x



PATH (TRAJECTORY) ATTENUATION EFFECTS ARE SMALL

- Attenuations along the ion trajectories can affect the $\tilde{n}/n$ measurements

- HIBP secondary signal is

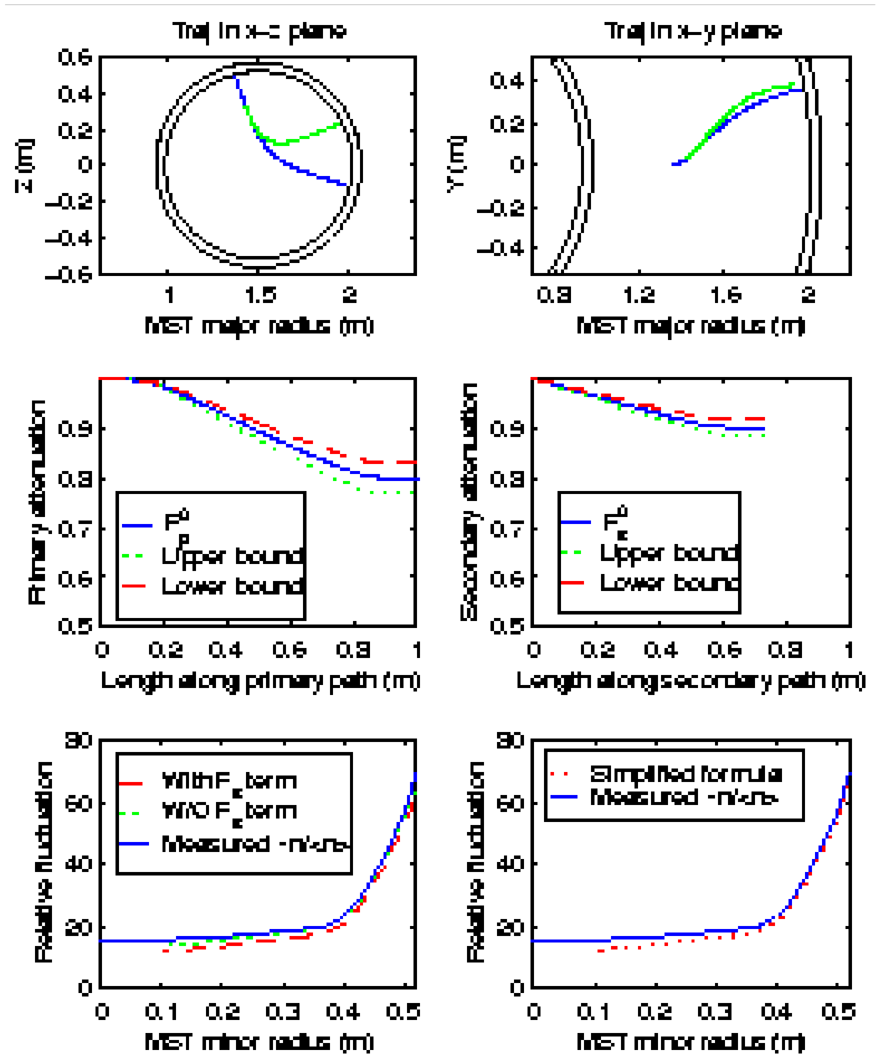
$$I_{sec}(d) = 2I_0 F_p(0,i) F_s(i,d) \sigma_{12}(i) l_{sv}(i) n_e(i)$$

$$F_p(0,i) = \exp\left(-\int_0^i \sigma_{12}(r) n_e(r) dr\right)$$

$$F_s(i,d) = \exp\left(-\int_i^d \sigma_{23}(r) n_e(r) dr\right)$$

- Numerical simulations have shown that the path effects are small

- Local $\tilde{n}$ power dominates the measured $\tilde{n}$ fluctuation power



MEASURED DENSITY FLUCTUATIONS ARE NOT SENSITIVE TO ELECTRON TEMPERATURE FLUCTUATIONS

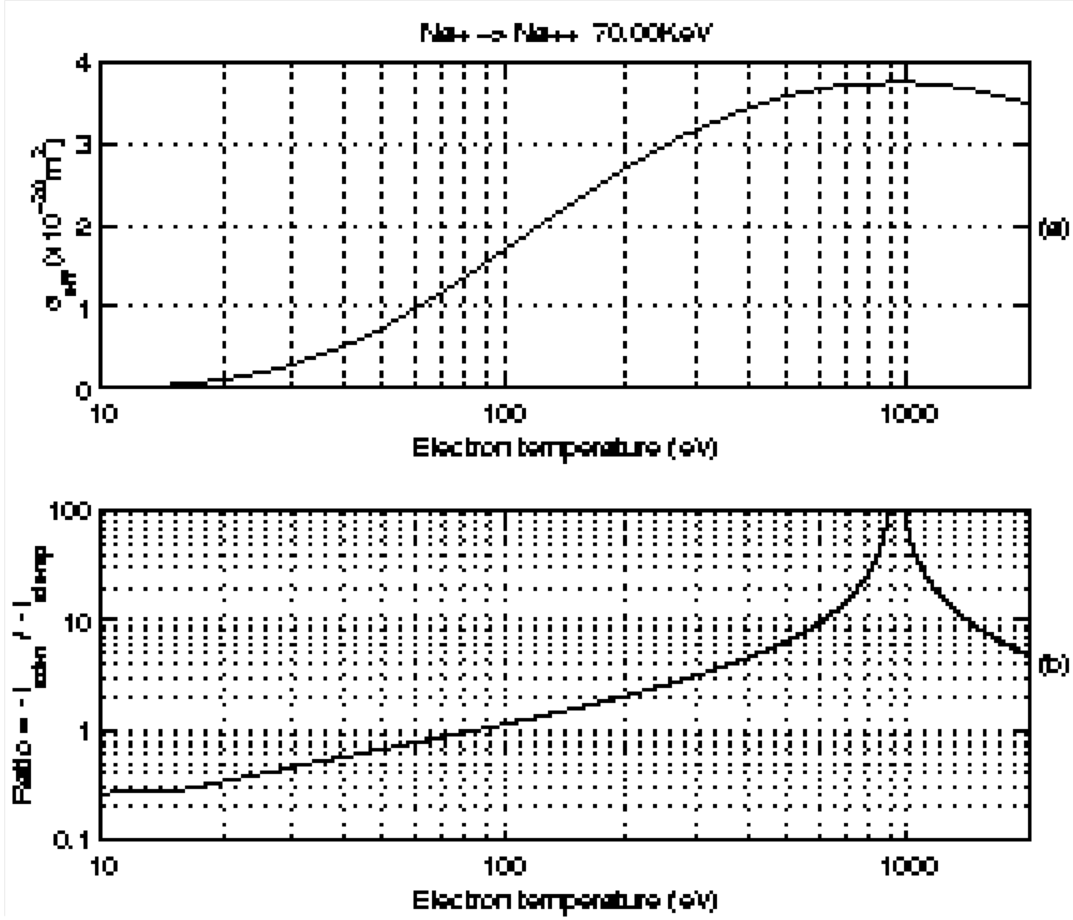
- Fluctuation signals:

$$\tilde{I}_s = \tilde{I}_{s\_den} + \tilde{I}_{s\_temp} \propto \tilde{n}\sigma + n\tilde{\sigma}$$

- Relative importance:

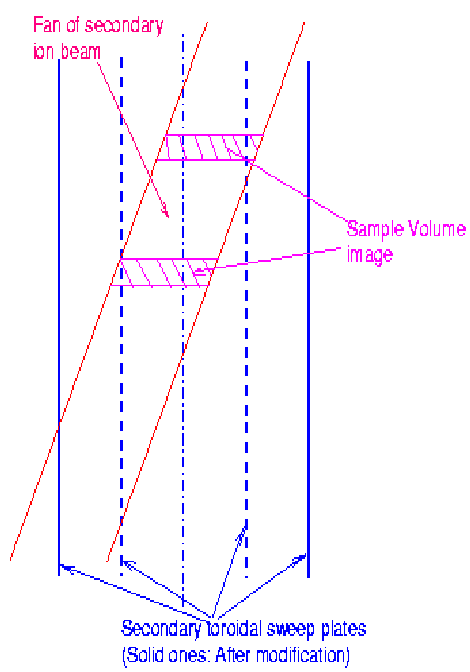
$$\frac{\tilde{I}_{s\_den}}{\tilde{I}_{s\_temp}} = \frac{\tilde{n}/n}{\tilde{T}_e/T_e} \bullet \frac{\sigma}{T_e}\left(\frac{\partial\sigma}{\partial T_e}\right)^{-1}$$

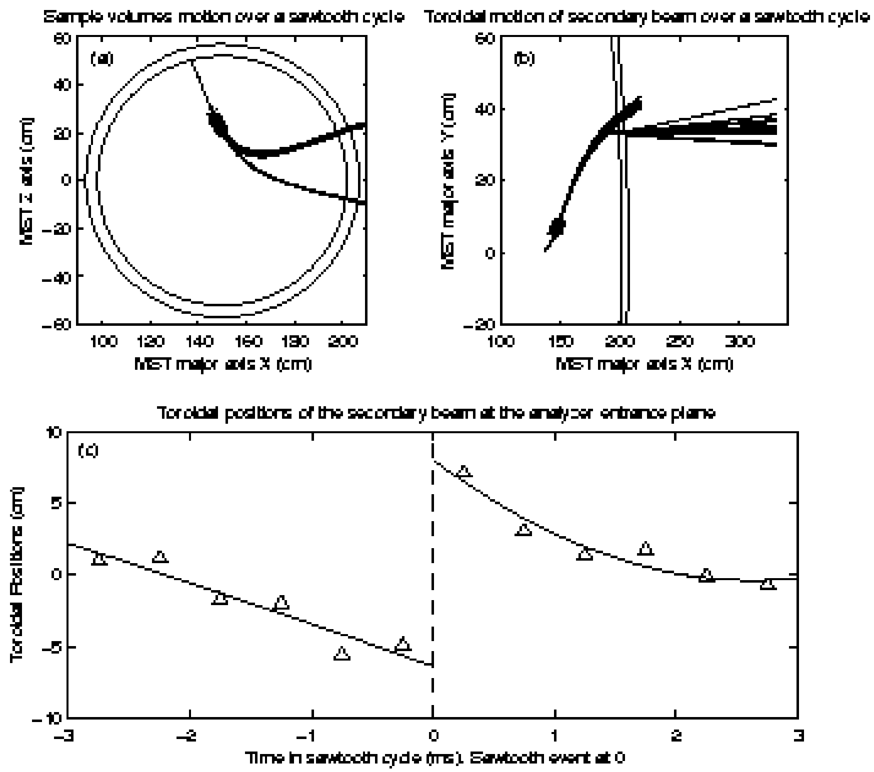
- Numerical simulation results shown that $\tilde{n}$ measurements are not sensitive to $\tilde{T}_e$



SCRAPE-OFF EFFECTS MAY EXIST

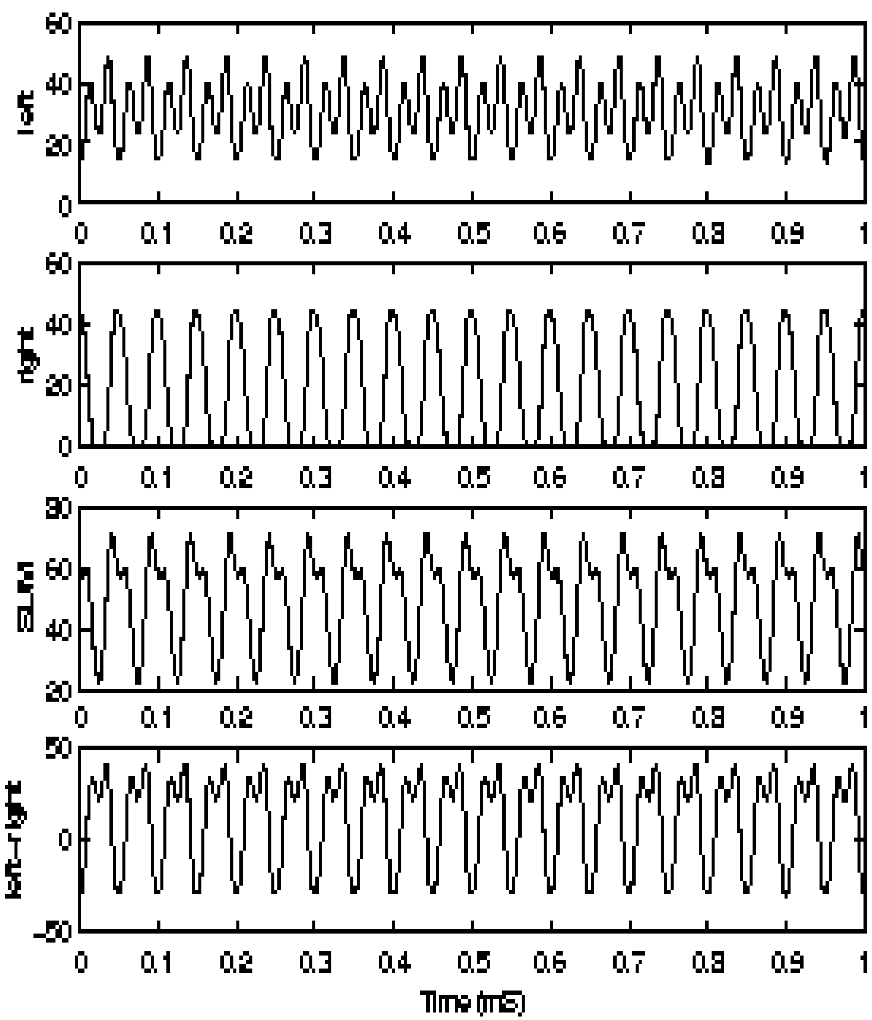
- Large $\tilde{B}_p$ in MST cause the secondary beam to fluctuate toroidally
- Scrape-off affects $\tilde{n}/n$ measurements, but not $\tilde{\phi}$
- Scrape-off effects have been reduced by sweep plates modification
- Feedback control to further reduce the scrape-off effects



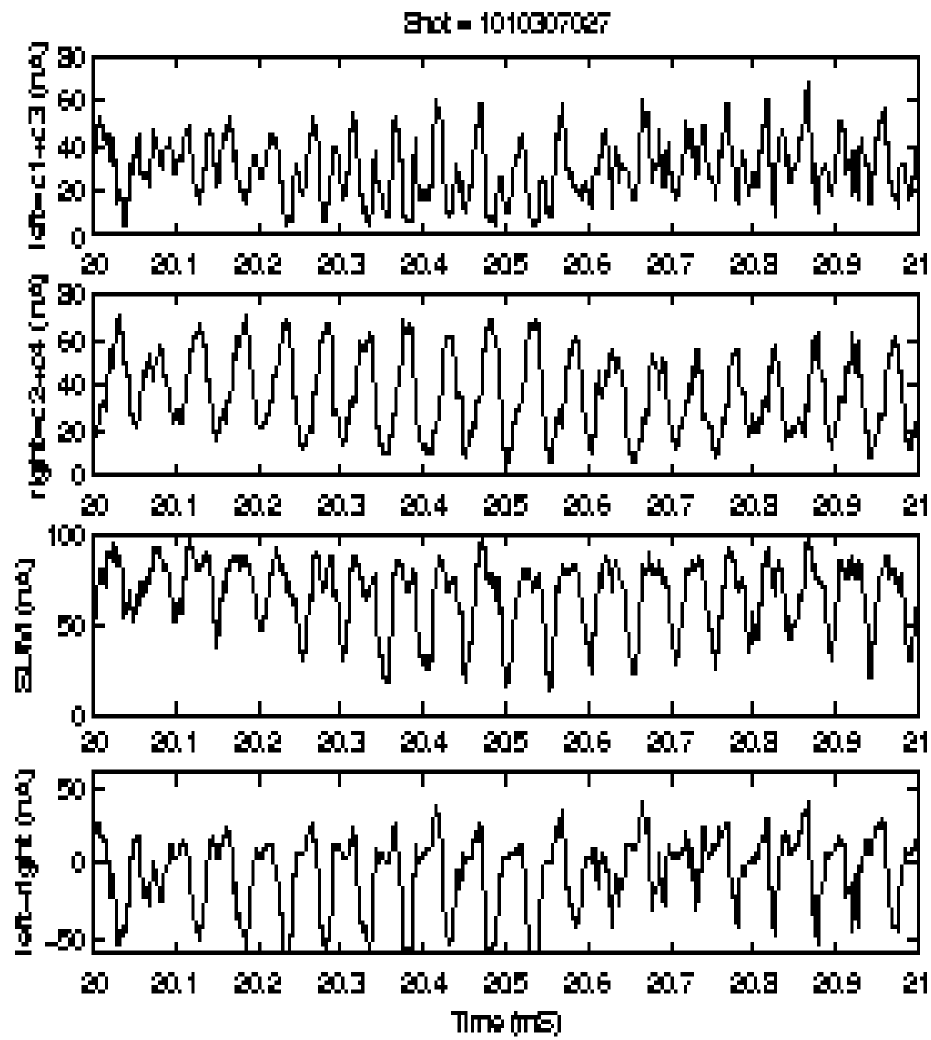


SCRAPE-OFF EFFECTS HAVE BEEN SIMULATED

Simulated scrape-off effects



An example of real signals



SUMMARY

- For the first time, plasma potential and electron density fluctuations are simultaneously measured in the core of the MST RFP
- $e\tilde{\phi}/T_e$ is significantly reduced in PPCD plasmas
- For the first time, electrostatic fluctuations induced particle transport is measured small in the core of the MST RFP
- Both $\tilde{\phi}$ and $\tilde{n}/n$ are correlated with the core resonant MHD modes
- Core $\tilde{\phi}$ is found related to the edge $\tilde{\phi}$, while $\tilde{n}/n$ is more localized

FUTURE WORK

- Expand the application of the MST-HIBP to more discharge types
- Expand the fluctuation measurements to the edge and center of MST
- Investigate the core $\tilde{B}_p$ measurements
- Increase the signal level by improving the ion optics
- Modify the poloidal sweep plates in the secondary beamline to improve the diagnostic coverage
- Apply feedback control to avoid the scrape-off effects
- Improve the primary beam measurements