Initial Measurements of Electrostatic Fluctuations and Edge Transport in Local Helicity Injection Plasmas

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PEGASUS Toroidal Experiment

Layout Slide (Include for Posters)

12:1 scale Panel size: 8’ x 4’

US Legal
8.5 x 14”

US Letter
8.5 x 11”

Motivation and Experimental Conditions

Local Helicity Injection Provides Robust Non-Solenoidal Startup on the Pegasus ST

Several Motivations to Understand Turbulence Dynamics in LHI

Modest Performance LHI Discharge Used for Probe Measurements

Probe Perturbation to Plasma Performance is Minimal

Triple Probe Diagnostic and Validation Measurements

Two Triple Langmuir Probes Deployed to Measure Electrostatic Fluctuations

Probe Measurements Have High SNR Over Bandwidth

n_e and T_e Obtained from Solution of Triple Probe Equations

Initial Probe Profile Measurements Made in LHI

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100kA Discharge Used Exhibits “MHD Transition”

Fluctuation Amplitudes Decrease Toward Plasma Core

Radial n_e Turbulence Profiles Show Change in Dynamics Around MHD Transition

High Bandwidth Measurements Reveal Spectral Content Above 400 kHz Cutoff

700 kHz Peak in High Bandwidth Spectra Also Observed in Magnetics

Direction of Electrostatic Measurements at High-β

Correlation of Electrostatic Fluctuations Indicates Weak Coupling Between Probes

Divertor LHI Provides Access to β_t~1

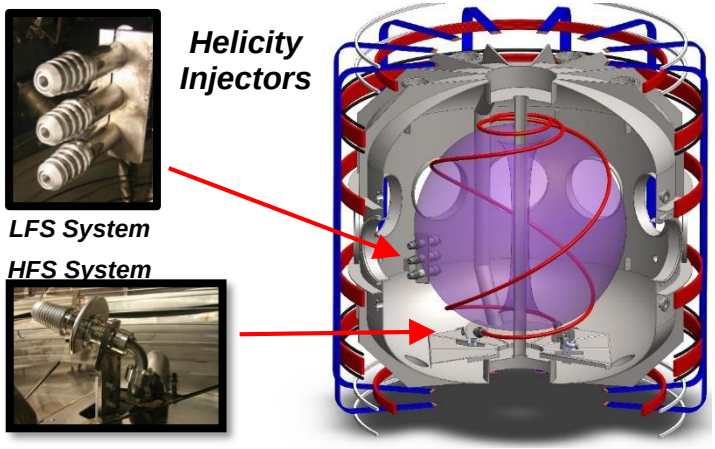
Unique Feature of High- β_t LHI Plasmas: Sustained min |B| Region

Conclusions and Future Work

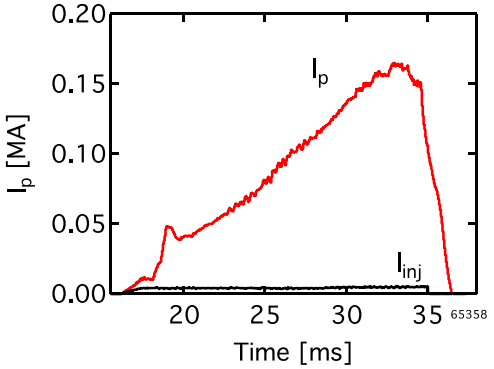
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Motivation and Experimental Conditions

Local Helicity Injection (LHI) Provides Robust Non-Solenoidal Startup on the PEGASUS ST



$I_p \leq 0.18$ MA via LHI ($I_{inj} = 5$ kA)



- Edge current extracted from injectors
- Relaxation to tokamak-like state via helicity-conserving instabilities
- Used routinely for startup on Pegasus
- Plasmas created are of appropriate conditions for probe measurements

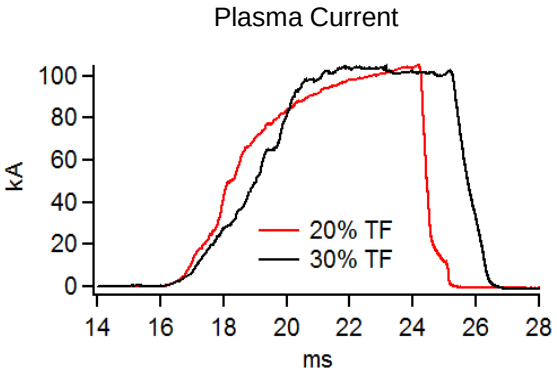
Plasma Parameters		Injector Parameters	
I_p	≤ 0.23 MA	$\sum I_{inj}$	≤ 14 kA
τ_{shot}	≤ 0.025 s	I_{inj}	≤ 4 kA
B_T	0.15 T	V_{inj}	≤ 2.5 kV
A	1.15–1.3	N_{inj}	≤ 4
R	0.2–0.45 m	A_{inj}	= 2-4 cm^2
a	≤ 0.4 m	I_{arc}	≤ 4 kA
κ	1.4–3.7	V_{arc}	≤ 0.5 kV

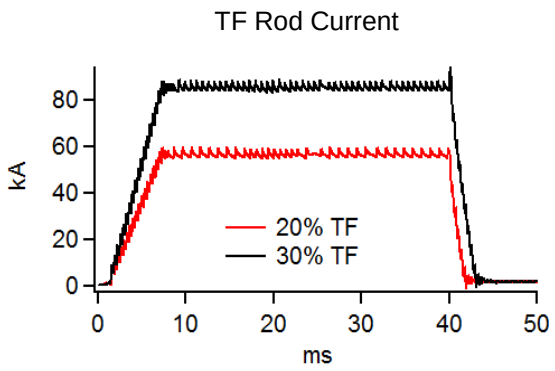
Several Motivations to Understand Turbulence Dynamics in LHI

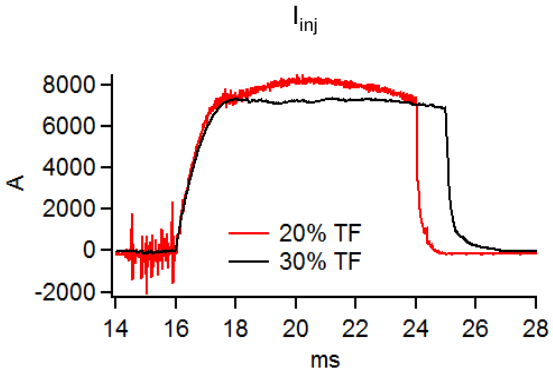
- Diagnostic Development
  - Base level understanding of electrostatic turbulence beneficial for design of future $\tilde{E}$, $\tilde{B}$ diagnostics
- Understanding Dynamics of LHI Current Drive
  - Electrostatic fluctuations in the presence of strong magnetic reconnection
- Minimum $|B|$ Configuration
  - Potential of reduction of turbulence and improved fast particle confinement

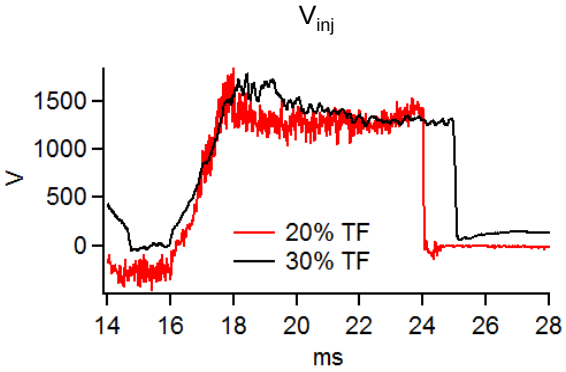
Modest Performance LHI Discharges Used for Probe Measurements

- Discharges chosen to ensure survival of probes
  - Also less vulnerable to perturbations from probes
- 100kA max I_p at 20% and 30% toroidal field
  - 30% case used for high bandwidth measurements
- I_{inj} = 7kA; V_{inj} = 1300V



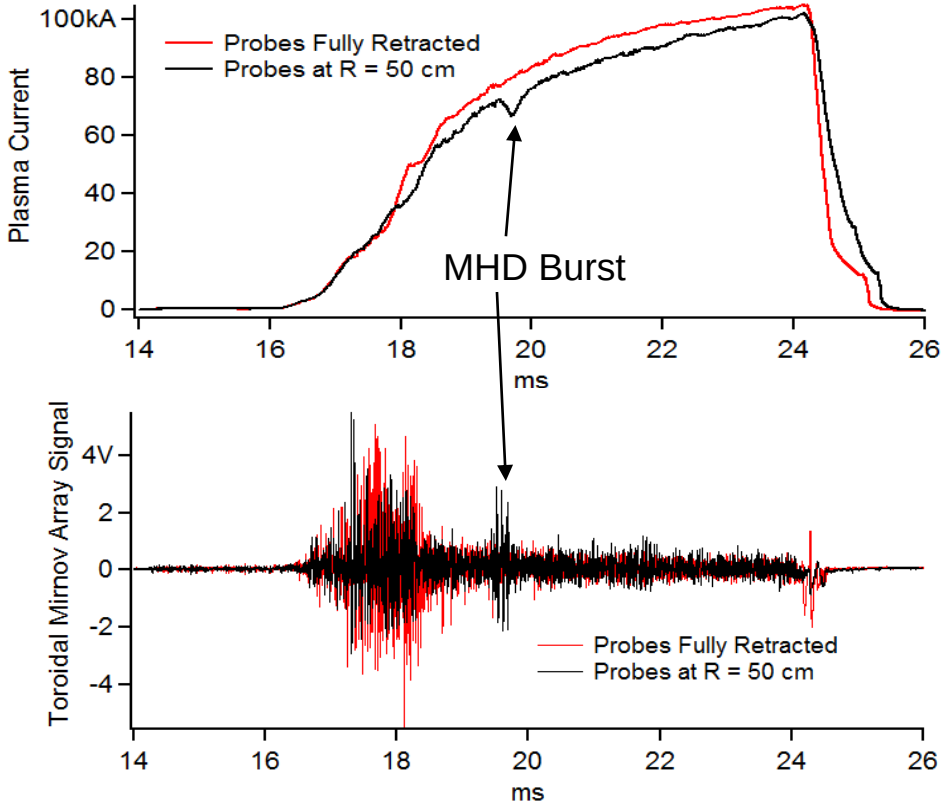






Probe Perturbation to Plasma Performance is Minimal

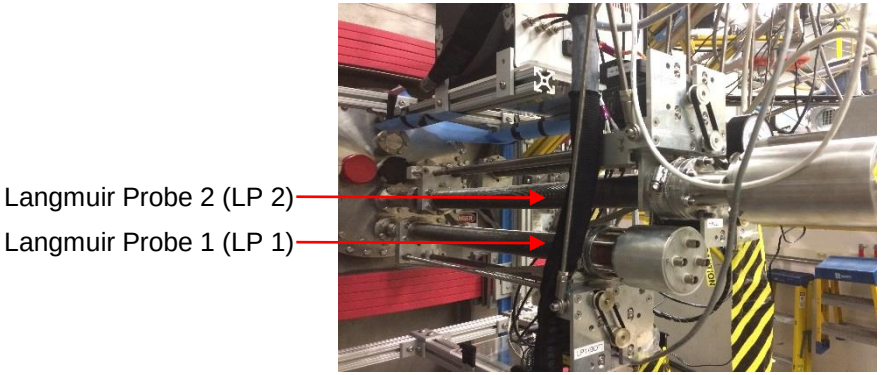
- Change in $I_p \leq 5\%$ from target discharge
- MHD bursts observed in some probe shots
  - Probe measurements before and after burst are unaffected



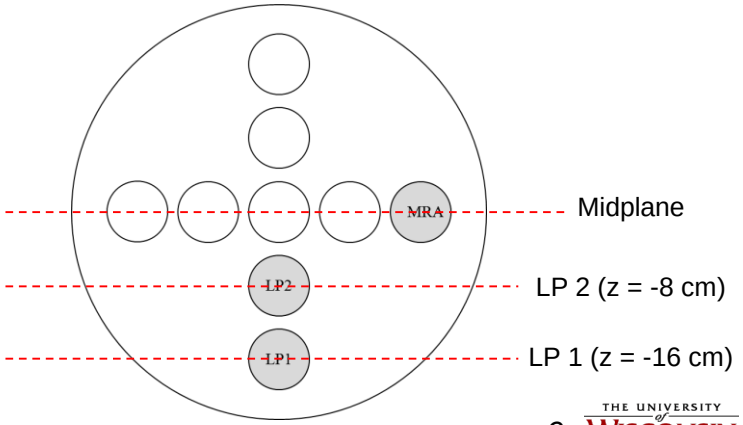
Triple Probe Diagnostic and Initial Measurements

Two Triple Langmuir Probes to Measure Electrostatic Fluctuations

- Probes separated vertically by 8 cm
  - LP1 located at 16 cm below midplane
  - LP2 located at 8 cm below midplane
- Probe tips separated by 3 mm
- Radial scanning capability
  - Range from R = 90cm to R = 45cm
  - Driven by ethernet-controlled stepper motors

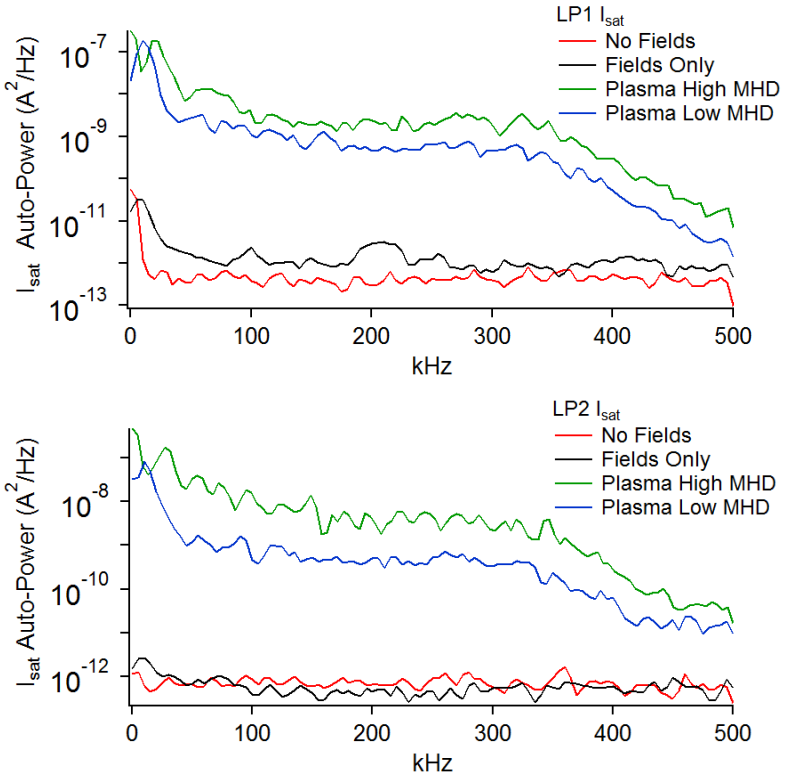


Port 8 Layout



Probe Measurements Have High SNR Over Bandwidth

- 135 V bias applied between high and low probe tips
- Probe data processed through 400 kHz anti-aliasing; digitized at 1MHz
- 30 dB signal/noise up to 300 kHz for raw measurements



n_e and T_e Obtained From Solution of Triple Probe Equations

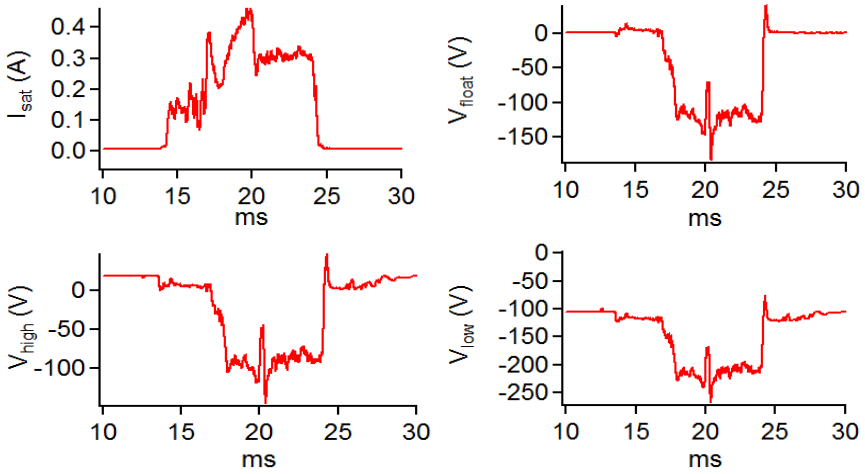
- Triple Probes measure $I_{s,i}(t)$, $V_f(t)$, $V_h(t)$, $V_l(t)$

- $n_e(t)$ and $T_e(t)$ result from numerical solution of the triple probe equation:

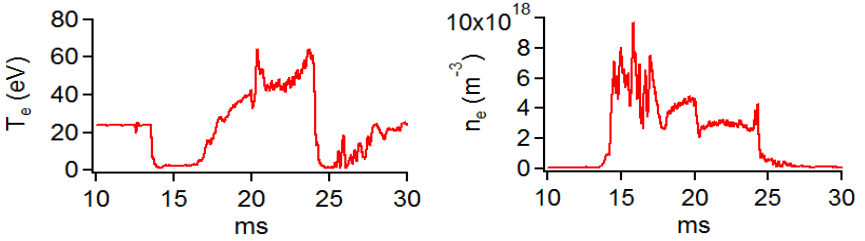
$$2\exp\left(-\frac{e(V_h - V_f)}{k_B T_e}\right) = 1 + \exp\left(-\frac{e(V_h - V_l)}{k_B T_e}\right)$$

- And:

$$n_e = \frac{I_{s,i}}{0.61 e A_p \sqrt{\frac{k_B T_e}{M_i}}}$$



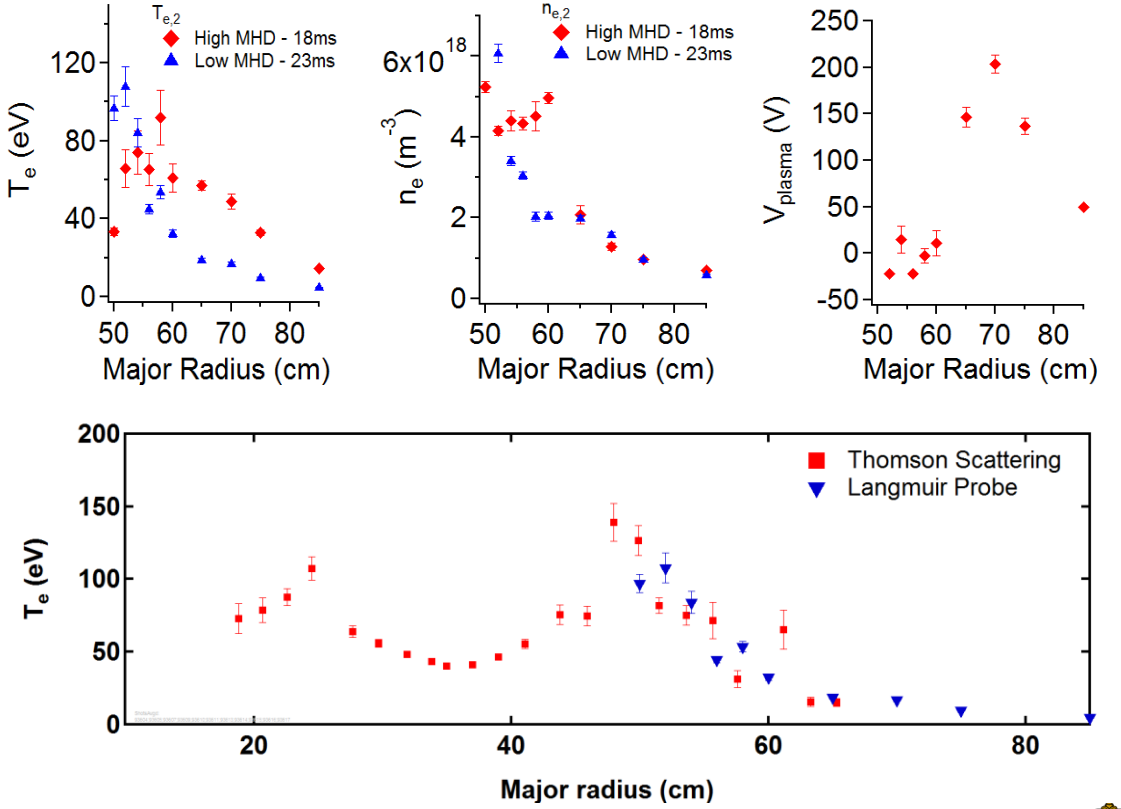
$I_{s,i}(t)$, $V_f(t)$, $V_h(t)$, $V_l(t)$ raw measurements



$T_e(t)$ and $n_e(t)$ calculated from raw measurements

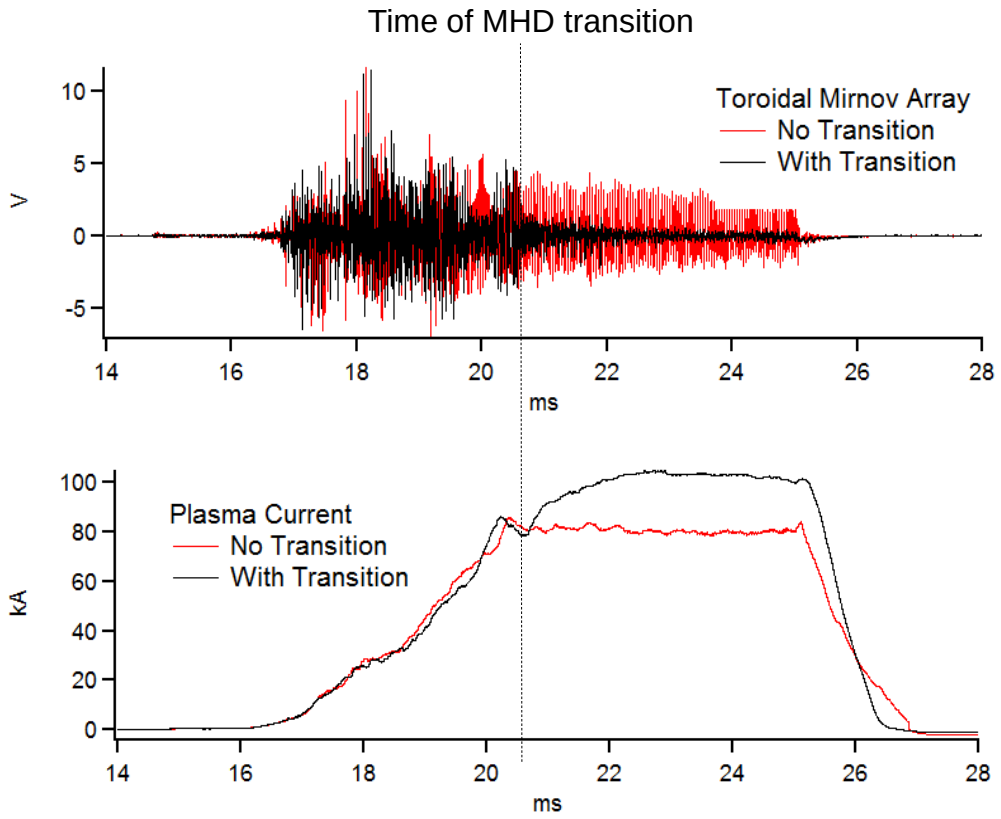
Initial Probe Measurement Profiles Made in LHI

- Temperature profiles show increased peaking in the edge after the MHD transition
- Temperature profiles agree well with Thomson measurements
- Radial profile of V_{plasma} indicates strong localized E-field at plasma edge



Electrostatic Fluctuation Behavior in LHI Plasmas

100 kA Discharge Used Exhibits “MHD Transition”



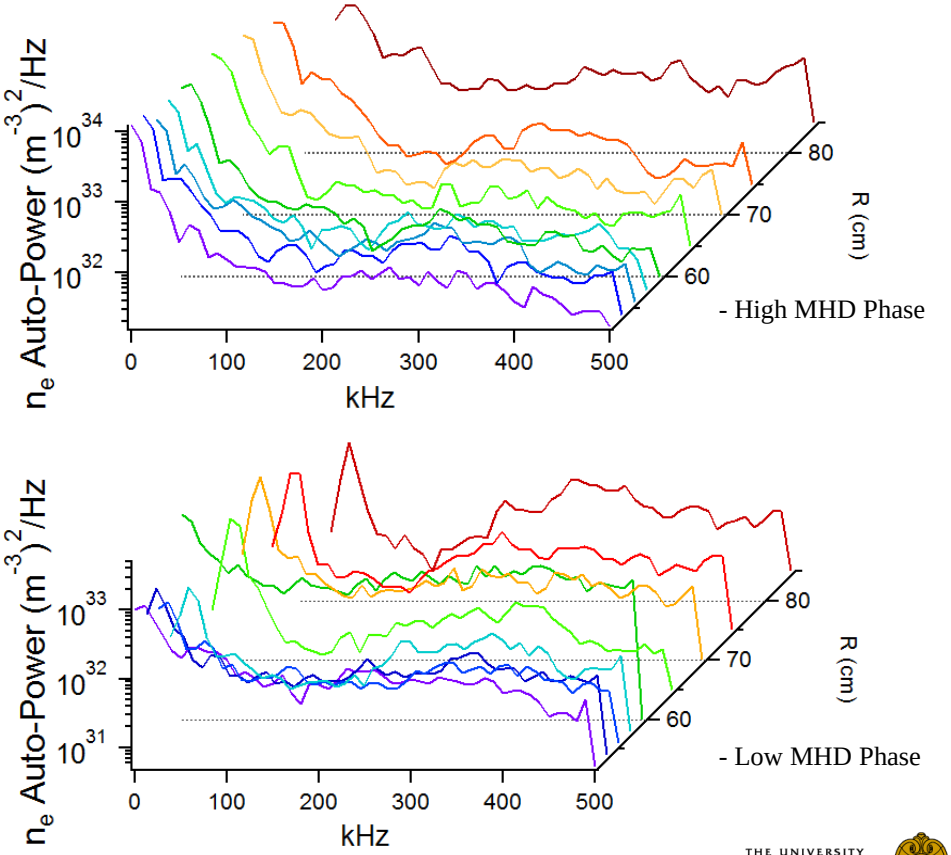
- The MHD transition is observed as a sharp decrease in low-f n=1 activity
- Transition allows for access to higher I_p
- Understanding transition is critical to physics of current drive mechanism for HFS LHI

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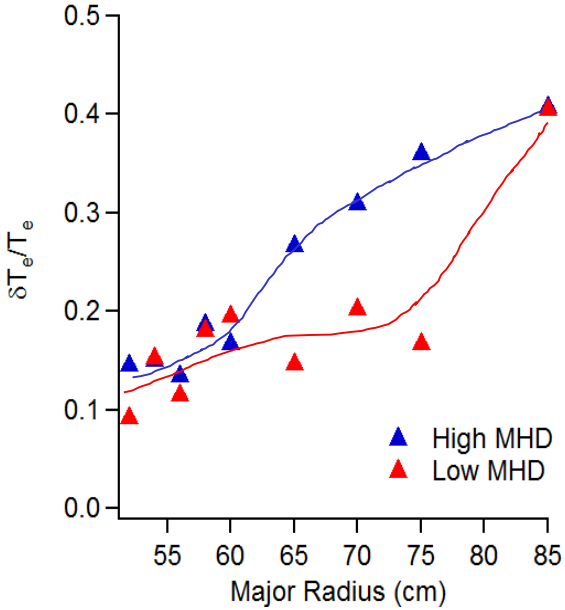
Radial n_e Turbulence Profiles Show Change in Dynamics Around MHD Transition

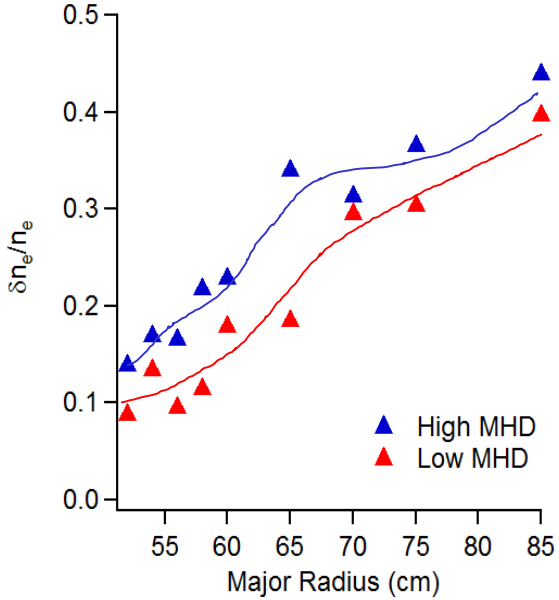
- $\tilde{n}$ at high frequency is stronger on outboard side after the transition
- Indication of change in turbulence behavior in low MHD
  - Fluctuation amplitude decreases radially across plasma edge moving inward

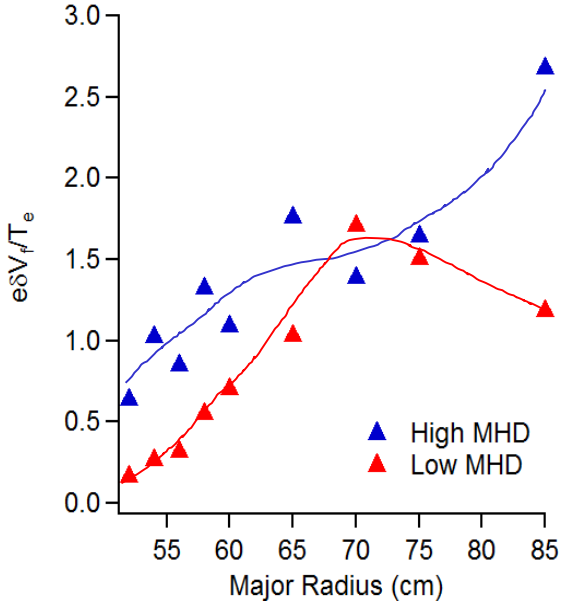


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Fluctuation Amplitudes Decrease Toward Plasma Core



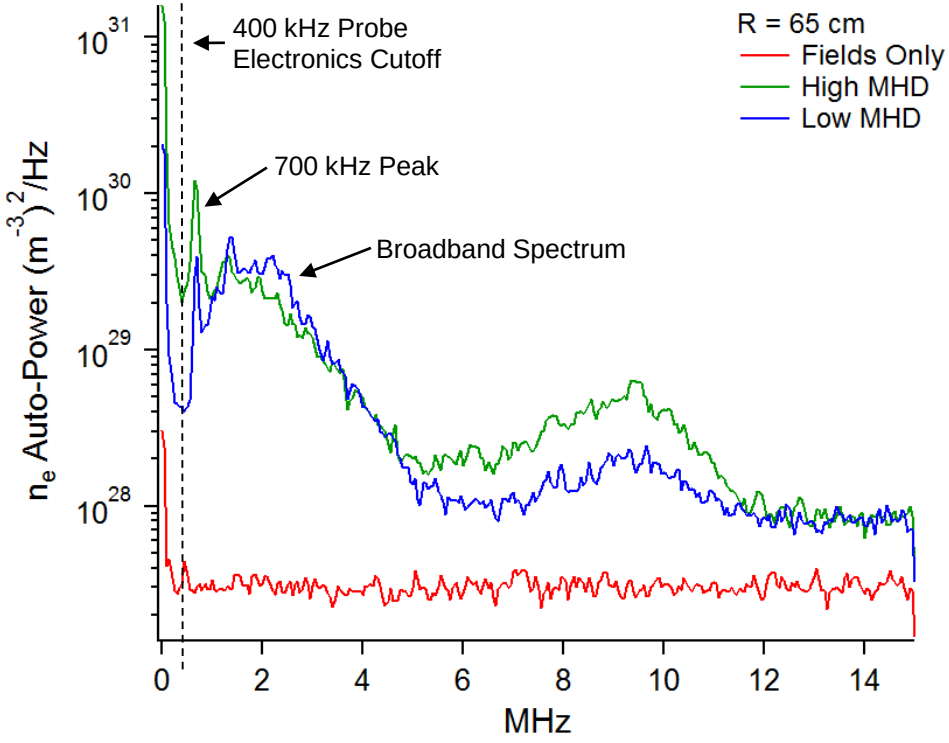




- Radial trend of fluctuation amplitudes is similar to conventional tokamaks

High Bandwidth Measurements Reveal Spectral Content Above 400 kHz Cutoff

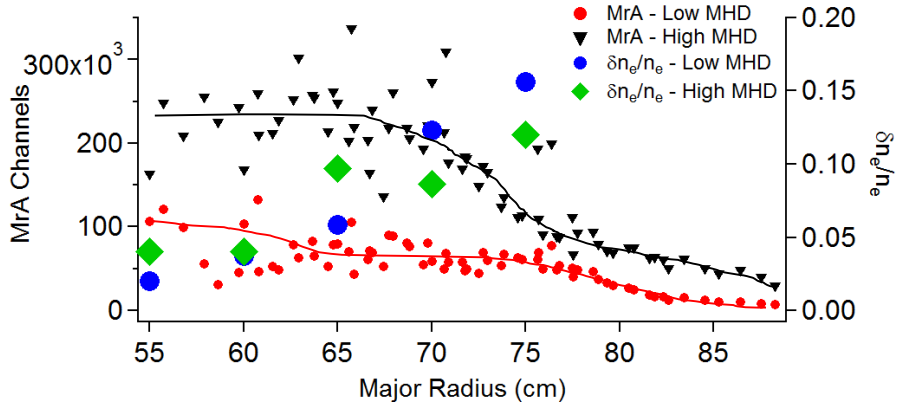
- Probe processing electronics bypassed using a digital oscilloscope (PicoScope 5442B) and differential probes
- Measure $I_{s,i}$, $(V_h - V_f)$, $(V_h - V_l)$ at 30 MHz bandwidth
- Additional features observed above previous cutoff
  - Narrow peak at ~700 kHz
  - Broadband spectrum centered around 2 MHz

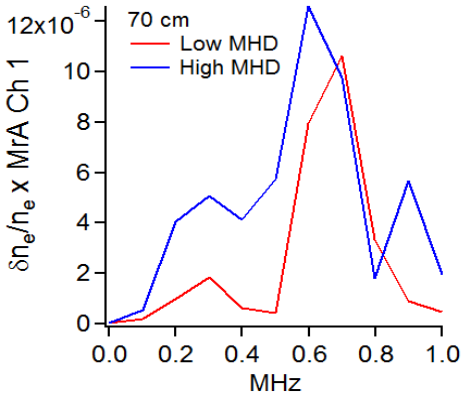


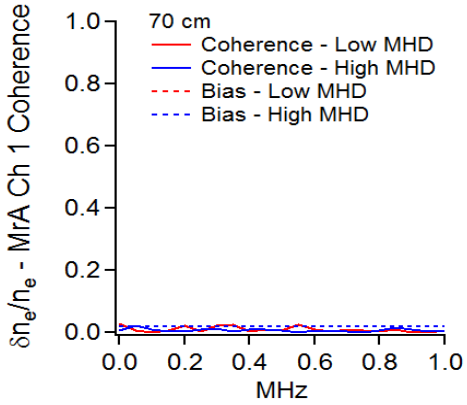
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700 kHz Peak in High Bandwidth Spectra Also Observed in Magnetics

- Peak at 700 kHz exhibits different radial trends for $\tilde{n}_e$ and $\tilde{B}$
  - Power increases toward low R for $\tilde{B}$
  - Power increases toward high R for n_e
- Large cross-power, but weak coherence between $\tilde{n}_e$ and $\tilde{B}$
  - LP and magnetics probe likely not on the same field line; separation of 18 cm



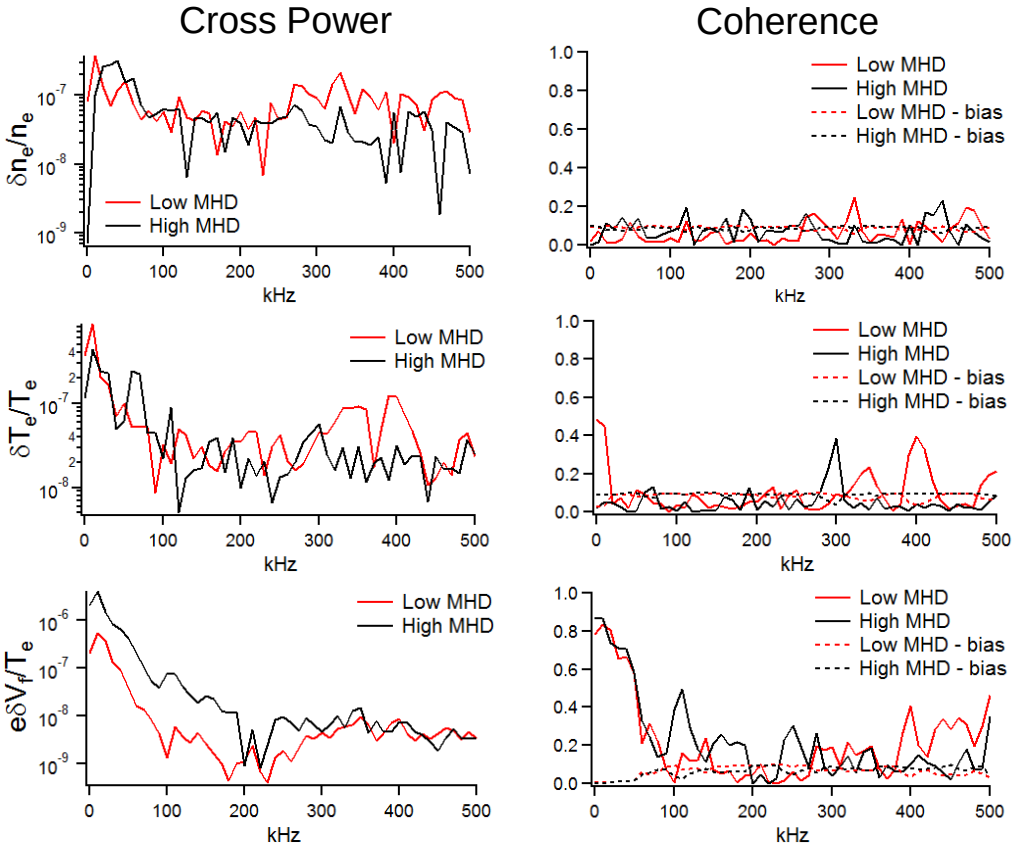




Direction of Electrostatic Measurements at High-β

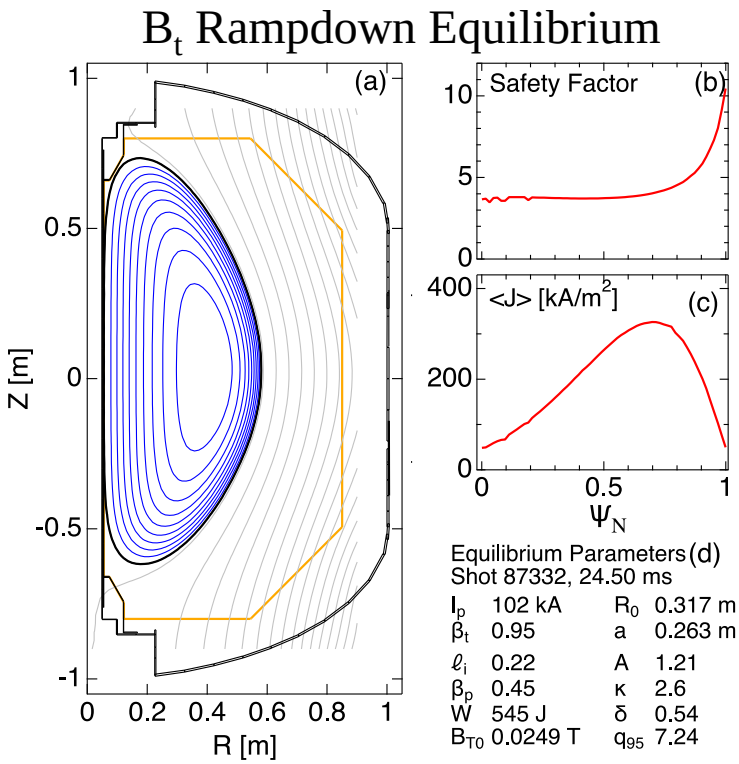
Correlation of Electrostatic Fluctuations Indicates Weak Coupling Between Probes

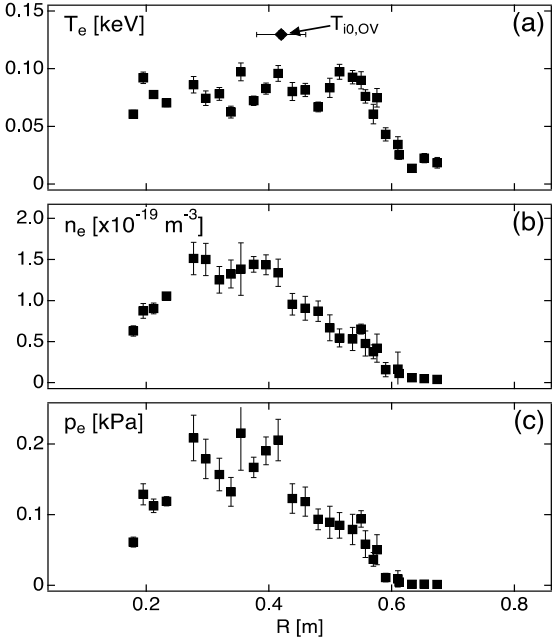
- Two point correlations between LP1 and LP2 inside plasma edge
- V_f fluctuations are well correlated near DC
- n_e, T_e, V_f exhibit weak correlation for higher frequencies
  - Probe separation is likely larger than poloidal turbulence scale length



Divertor LHI Provides Access to β_t~1

- Edge location and core pressure constrained by TS profiles





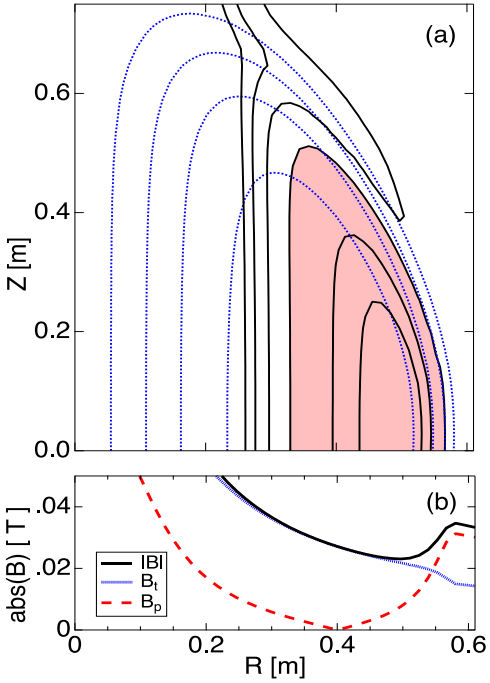
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Unique Feature of High- β_t LHI Plasmas: Sustained min |B| Region

- High-β_t equilibrium contains min $|B|$ region
  - Spans up to 47% of plasma volume
  - Well deepens and broadens as β_t increases
- Region persists for several energy confinement times
- Potentially favorable for stabilization of drift modes, reduction of stochastic transport
  - Presently under investigation
  - Min $|B|$ region is accessible to probes



Conclusions and Future Work

- The deployed triple Langmuir probes function successfully as a diagnostic for T_e, n_e, and electrostatic fluctuations
  - Probe T_e measurements show good agreement to Thomson measurements
  - Upgrade to measurement electronics using PicoScopes will provide a reliable measurement up to 30 MHz
- Amplitude of electrostatic fluctuations decreases with decreasing R, similar to conventional tokamaks
- Broadband electrostatic spectra observed for f $\leq$ 100 kHz and for f ~ 2 MHz
  - Narrow peak observed at 700 kHz which also appears in magnetics, but is not well correlated
- Many phenomena in LHI plasmas still to be investigated:
  - Turbulence scale lengths in the plasma edge
  - Further investigation into the $|B|$ well to confirm effect on electrostatic fluctuations

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