# Millimeter-Wave Reflectometry on NSTX

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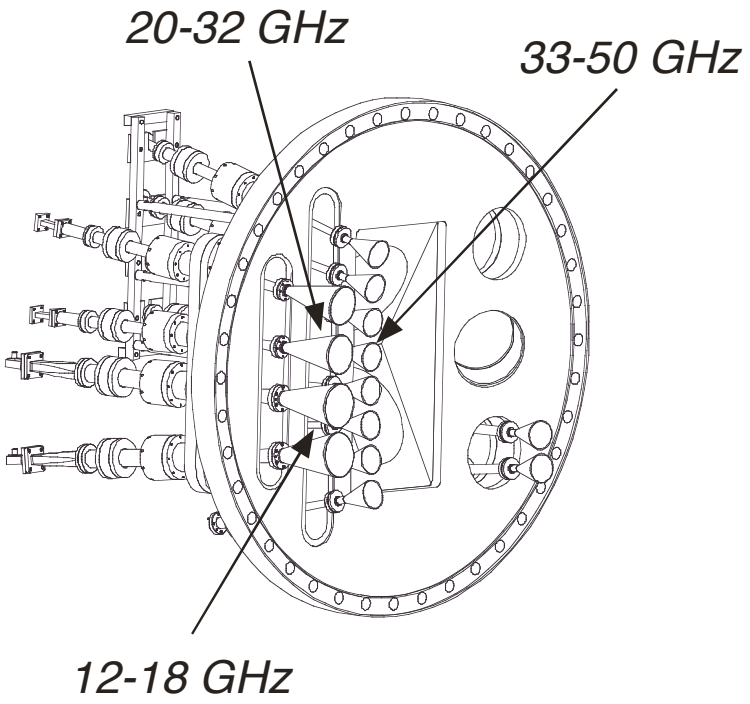
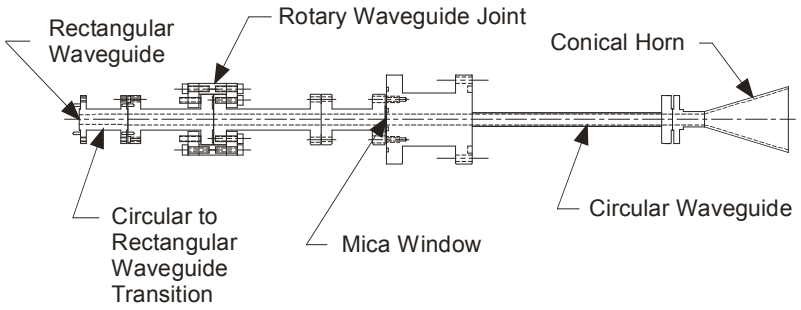
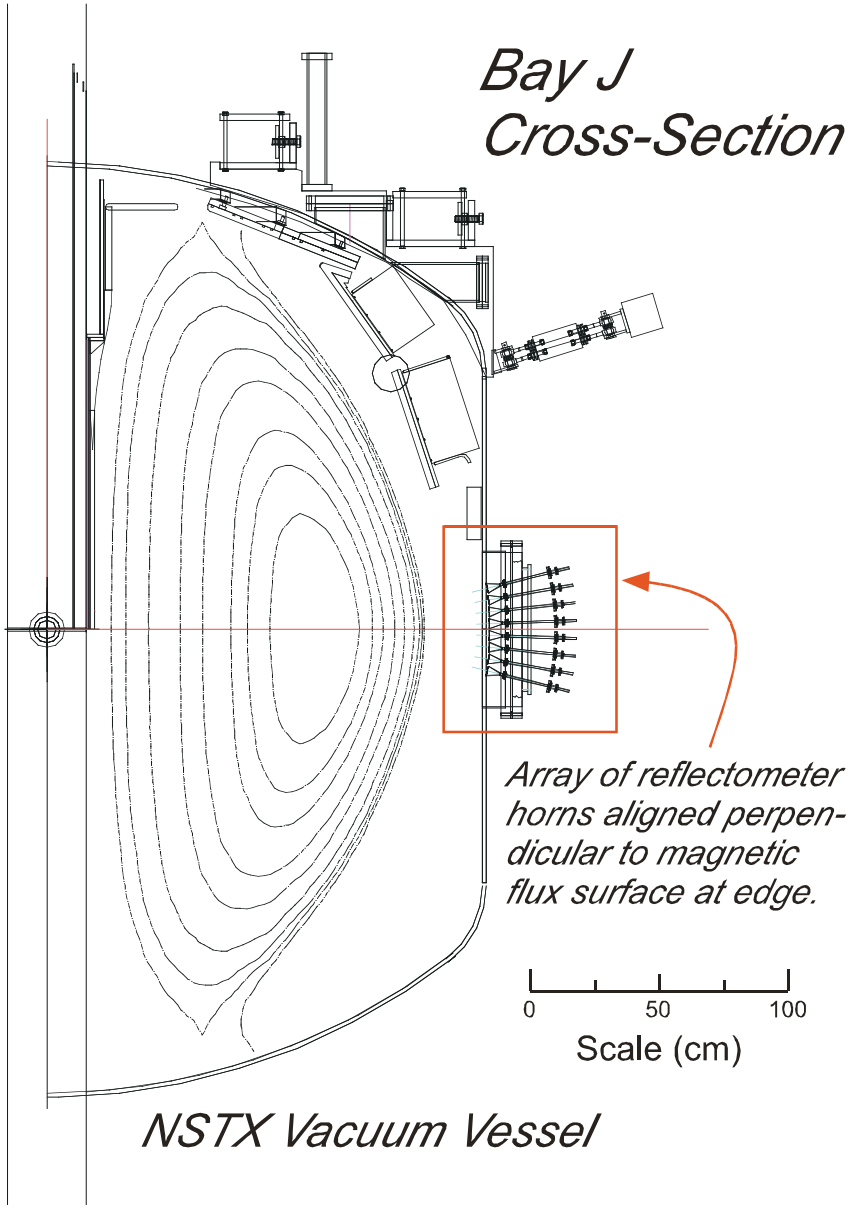
# MM-Wave Reflectometery on NSTX: Goals and Contents

- Measurements of density profile and fluctuation quantities in region overlapping plasma edge and core.
  - Sensitive, local measurements with high bandwidth and excellent temporal coverage.
  - Density profiles, turbulent correlation length, fluctuation levels, magnetic field strength, Alfven eigenmodes, etc.
  - Magnetic pitch angle (spring 2003), RF waves (proposed), etc.
- FM-CW (frequency-modulated continuous-wave) profile reflectometry.
  - Fast profile measurements for ELMy H-mode discharges.
- Fluctuation measurements.
  - Fixed frequency quadrature systems, 3 simultaneous channels.
  - Turbulence at L-H transition and during H-mode, ELMs, CAEs.
- Correlation reflectometry.
  - Turbulence radial correlation lengths.
  - Magnetic field strength measurements (dual mode operation).

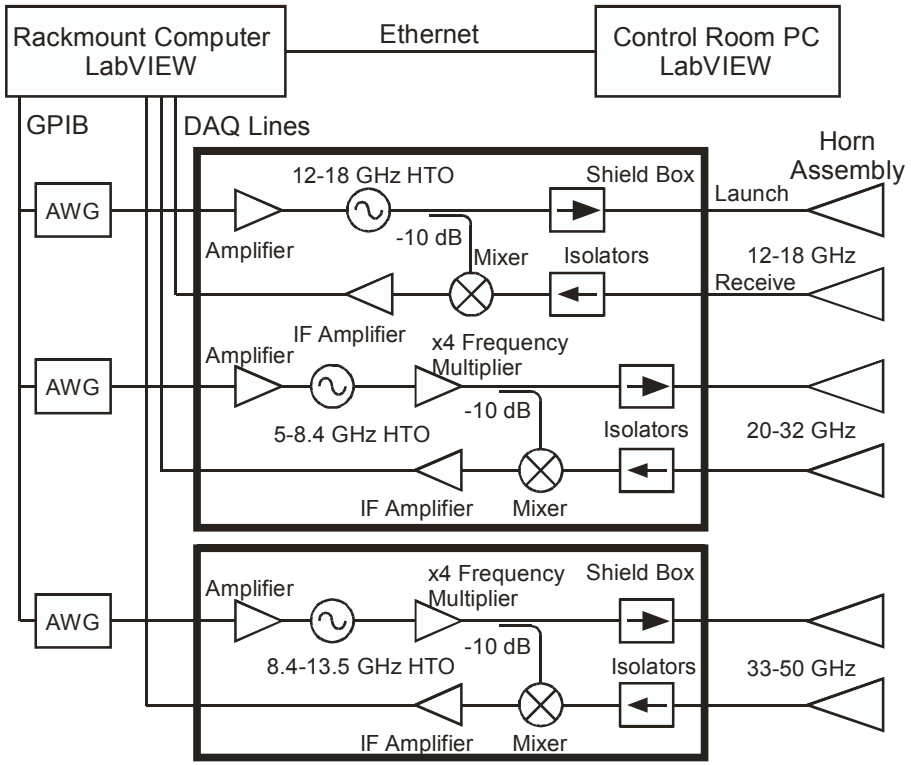
# Location of Reflectometer Diagnostics on Bay J

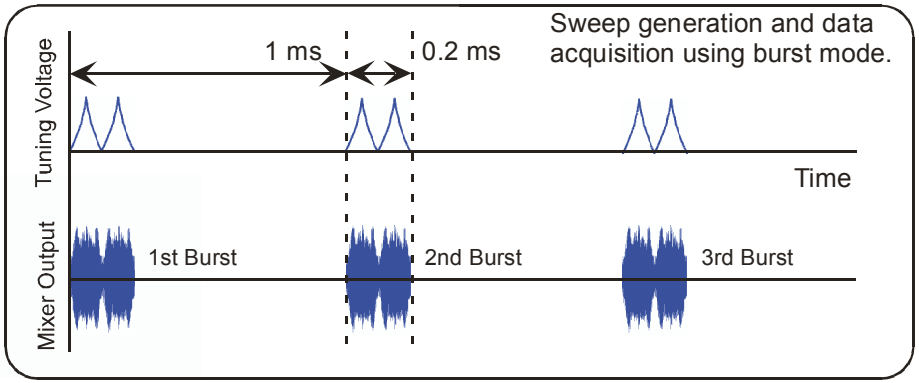


# Diagnostic System for Profile Analysis




## FMCW System

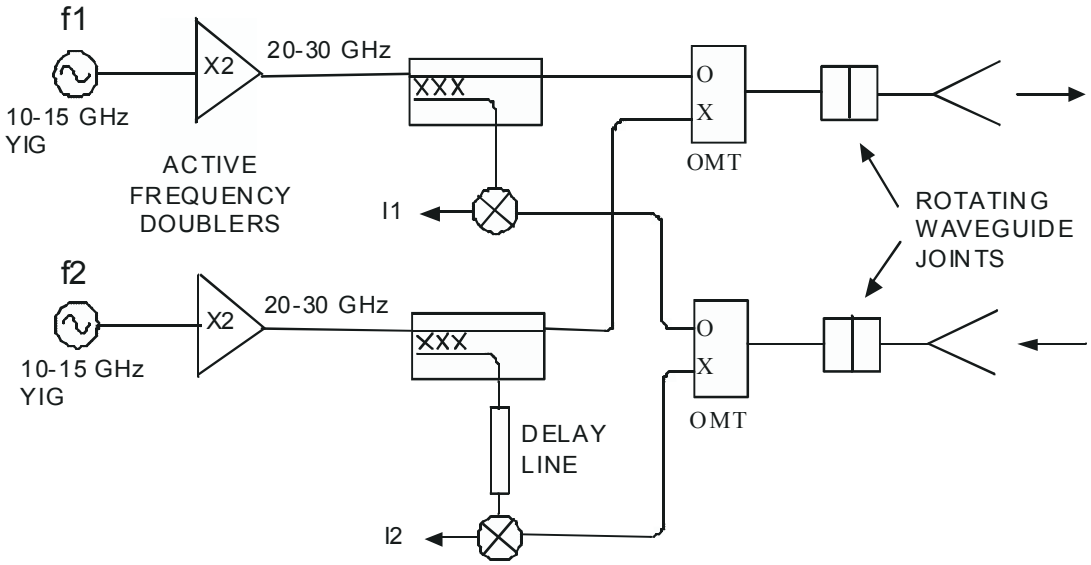
- 12-50 GHz coverage ($1.8 \times 10^{12}$ to $3.1 \times 10^{13}$ $cm^{-3}$).
- Maximum repetition rate of 100 □s/sweep (818 total profiles).
- Using spline fit to Thomson edge profile below $n_e = 9 \times 10^{11}$ $cm^{-3}$.
- Typical discrepancy of less than 2 cm between reflectometry and Thomson scattering profiles. Edge modeling and systematic uncertainties.

## Fixed-Frequency System

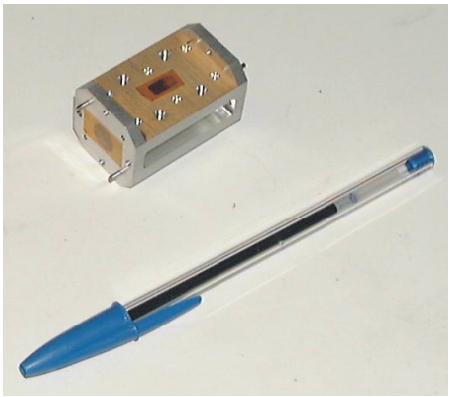
- 12-18, 28.2, 50 GHz. Density coverage of $1.8\text{-}4.0 \times 10^{12}$, $9.9 \times 10^{12}$, and $3.1 \times 10^{13}$ $cm^{-3}$.
- Dedicated 50 GHz system.
- Three channel simultaneous measurements at 10 MHz.

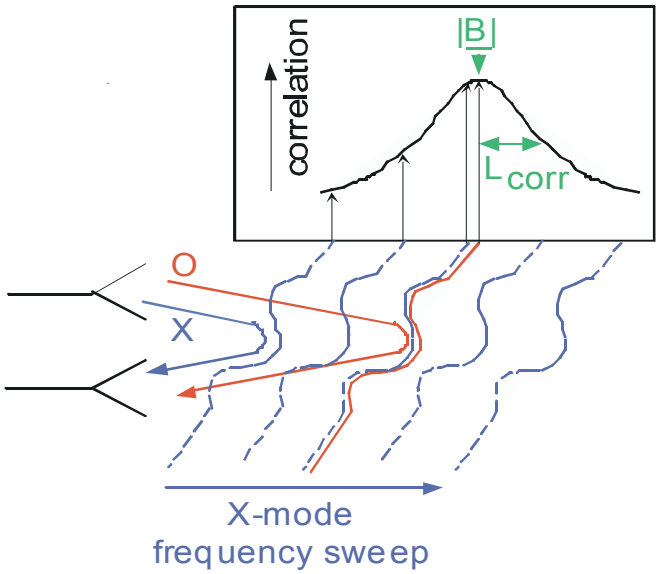
# Dual Mode Correlation Reflectometer Circuit Diagram

- 20-30 GHz homodyne system
- f1 fixed, f2 slowly swept
- f1, f2 combined in circular w/g via ortho mode transducer (OMT)
- Circuit implemented mainly with high frequency coaxial cable/devices. Transition to w/g at OMTs.
- Cutoff densities $n_e$ ≈ 0.5 – 1.0 × $10^{13}$ $cm^{-3}$ probed
- Cutoff positions in the range R/a ≈ 0.85 - 0.95



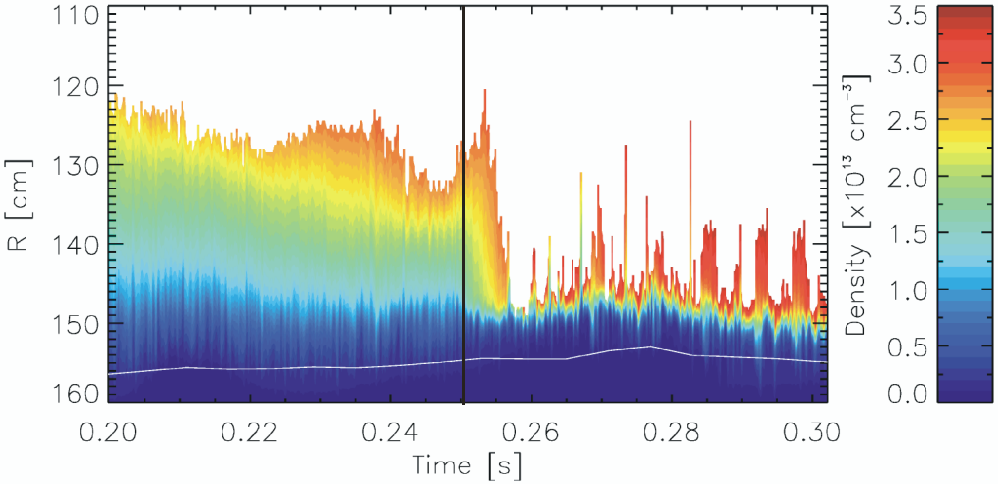

20-30 GHz OMT



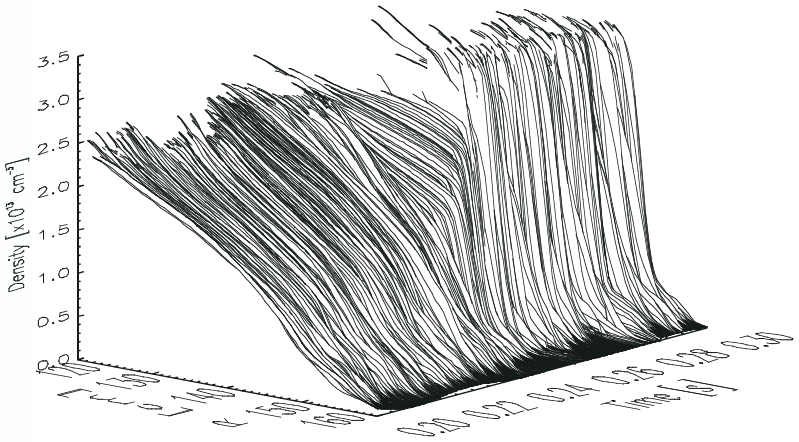


# NB-Heated Discharge: L- to H-Mode Transition (Shot 108470)

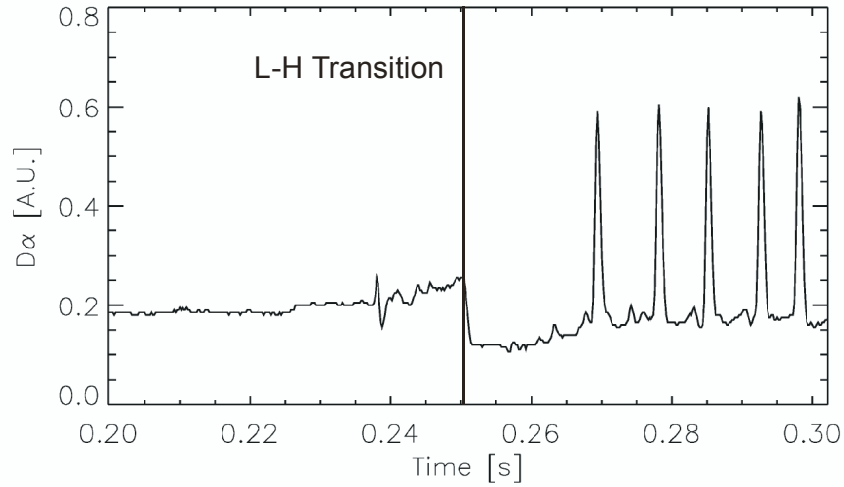
Shot 108470, Density Profile Contour Plot

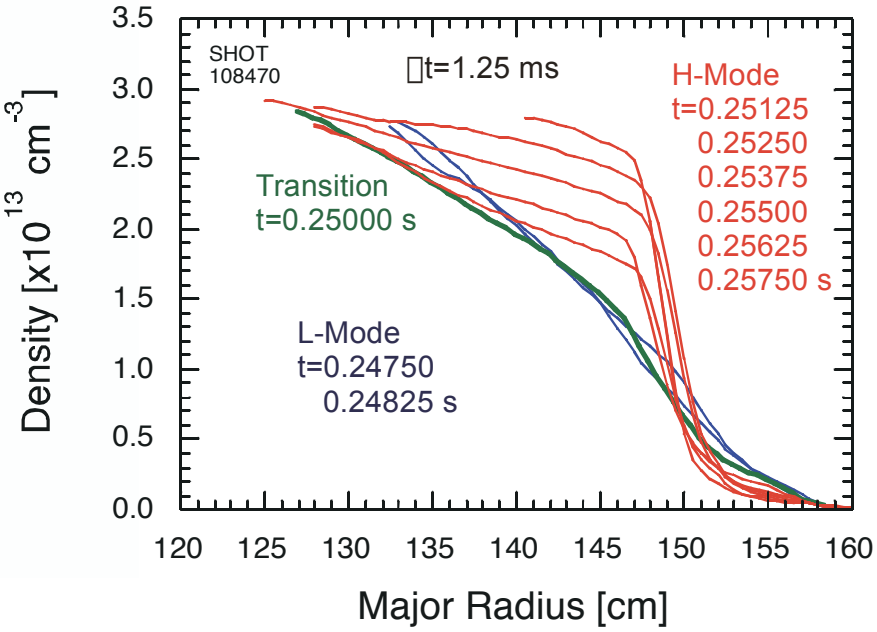



Density Profile Surface Plot (t=0.200-0.300 s)

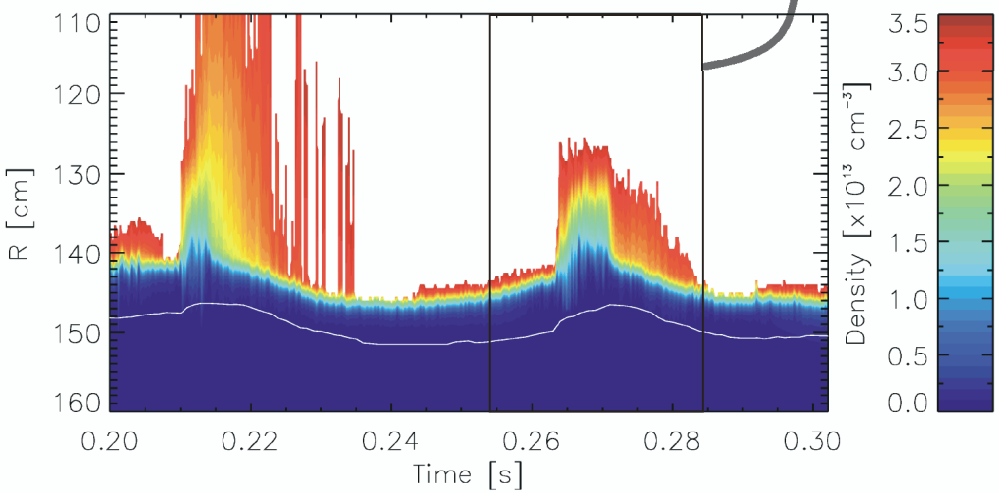


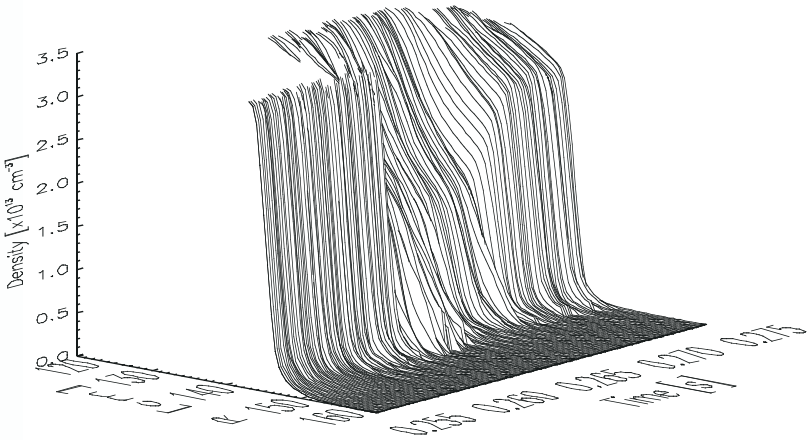

Shot 108470, Bay C Dα Intensity (Lower Divertor)

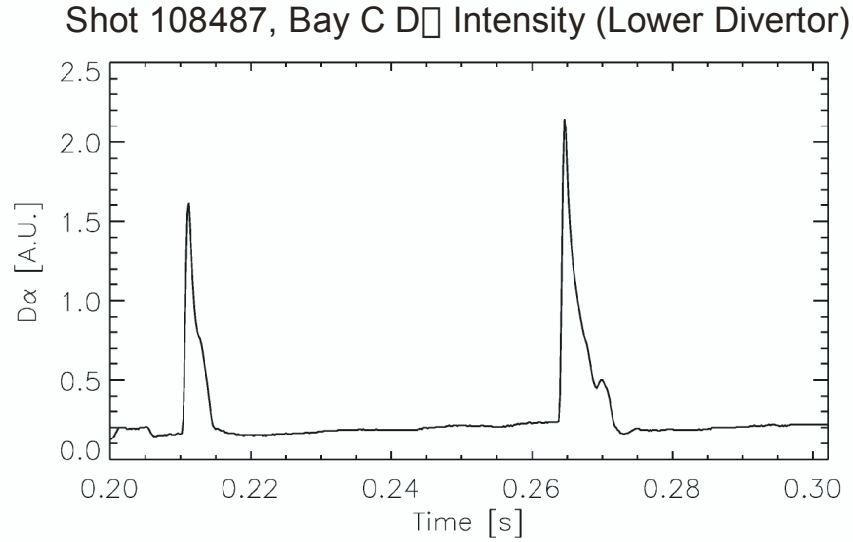


# NB-Heated Discharge: H-Mode, Giant ELMs (Shot 108487)

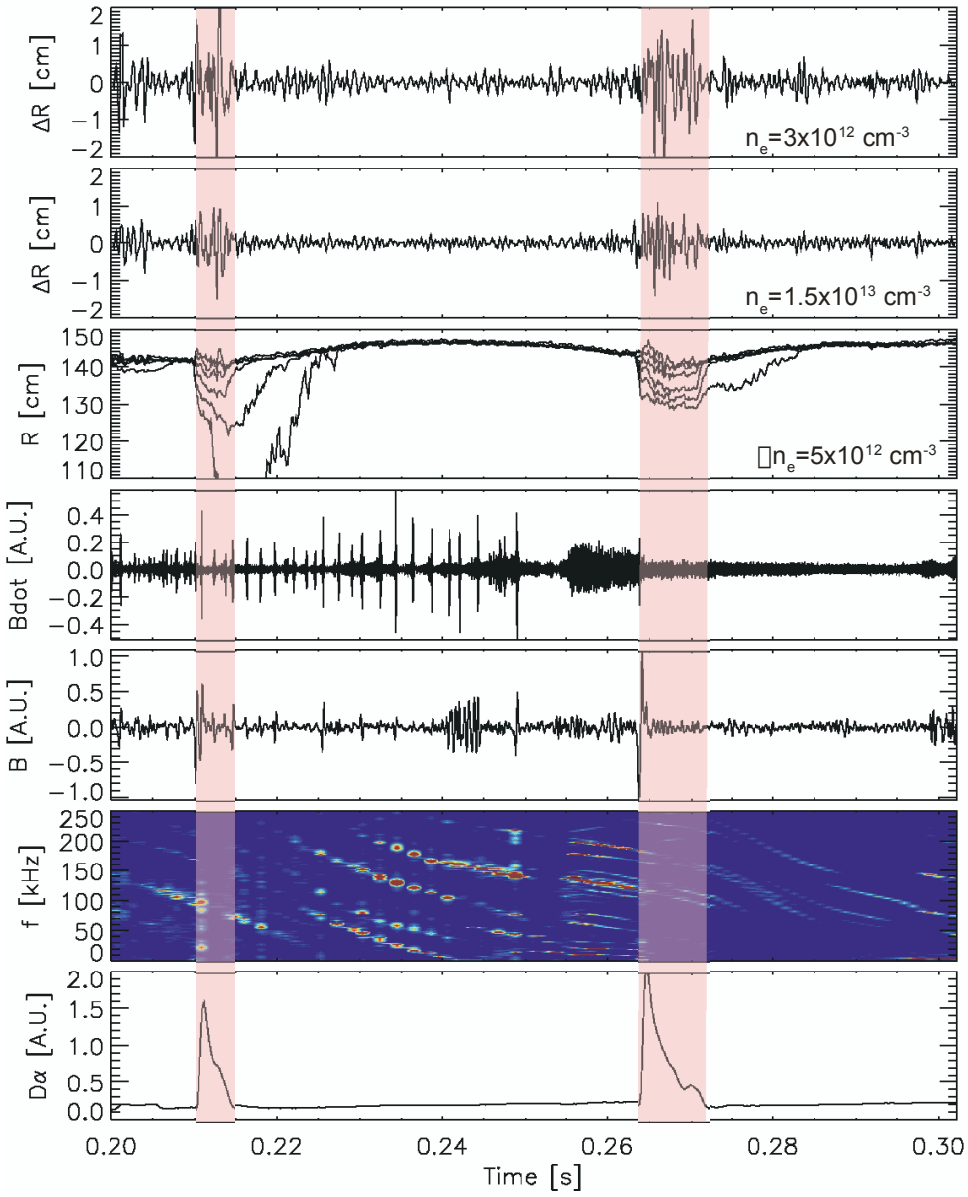


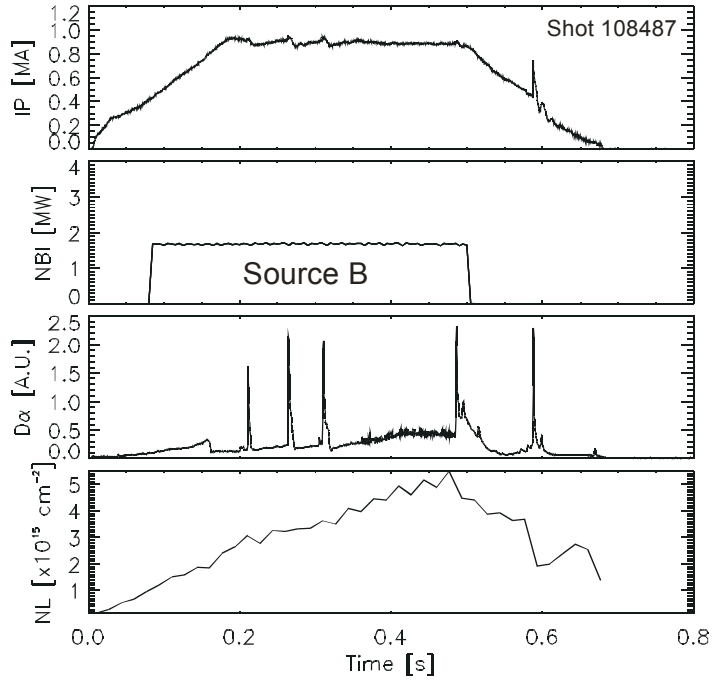




- Density contour tracks with LCFS from EFIT01.
- Rapid changes (fluctuations) in density profile with onset of ELMs. Δt=100 μs not fast enough to catch evolution.
- Fast profile changes seen without corresponding Dα signature.

# Giant ELMs/Density and Magnetic Fluctuations

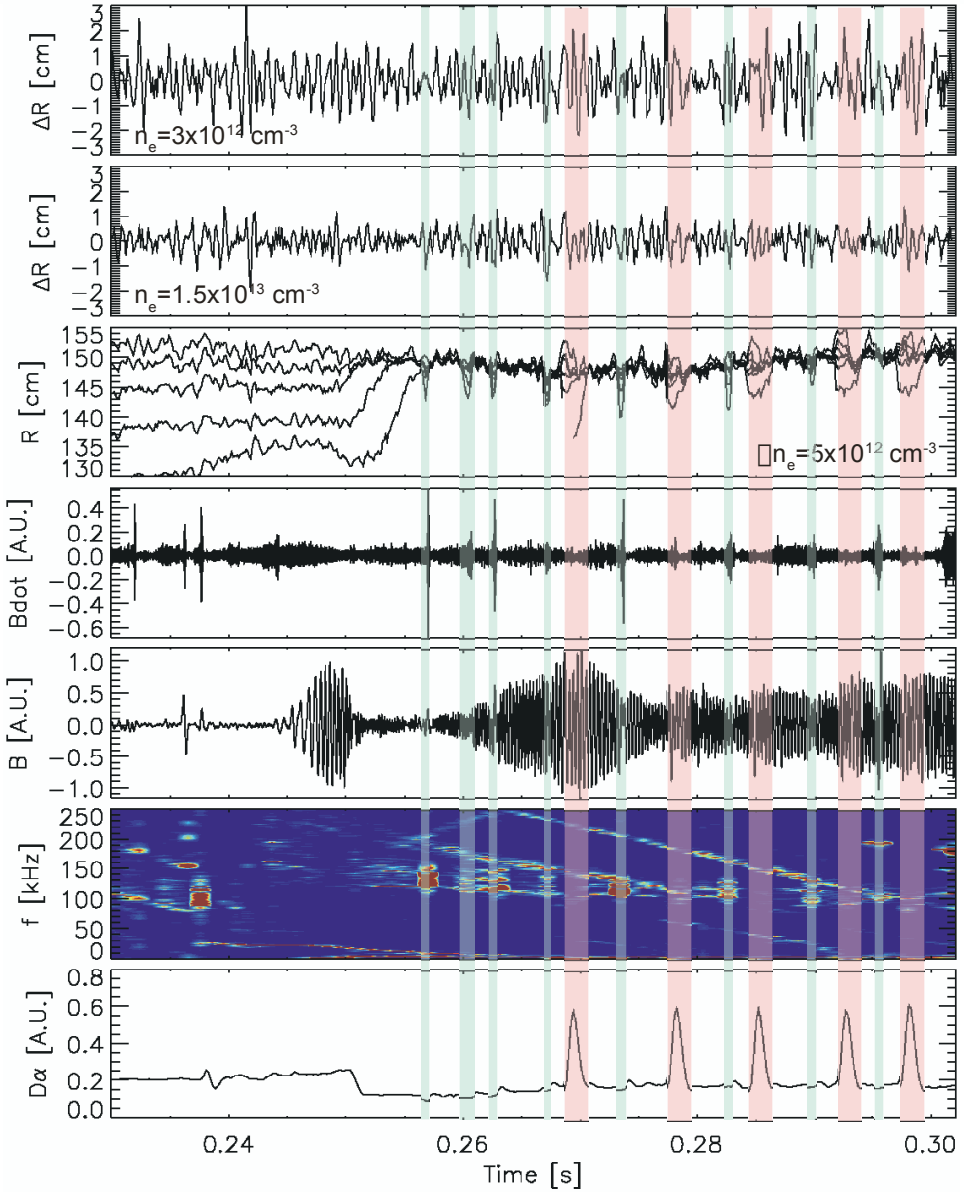


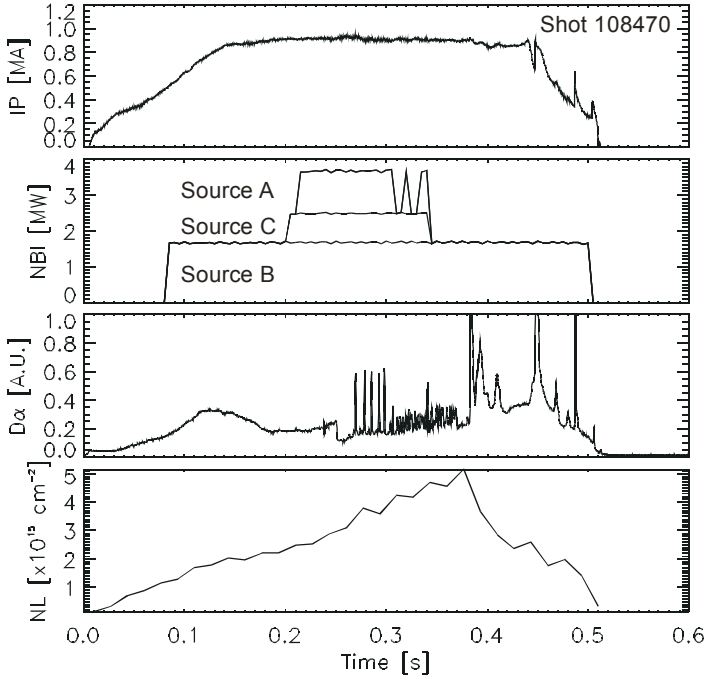




□R=R-$R_{mean}$, R=density contour.

Increased density oscillations and slow magnetic signal correlated with density profile change. Both precede D□ burst.

# L-H Transition/Moderate ELMs/Magnetic Signature



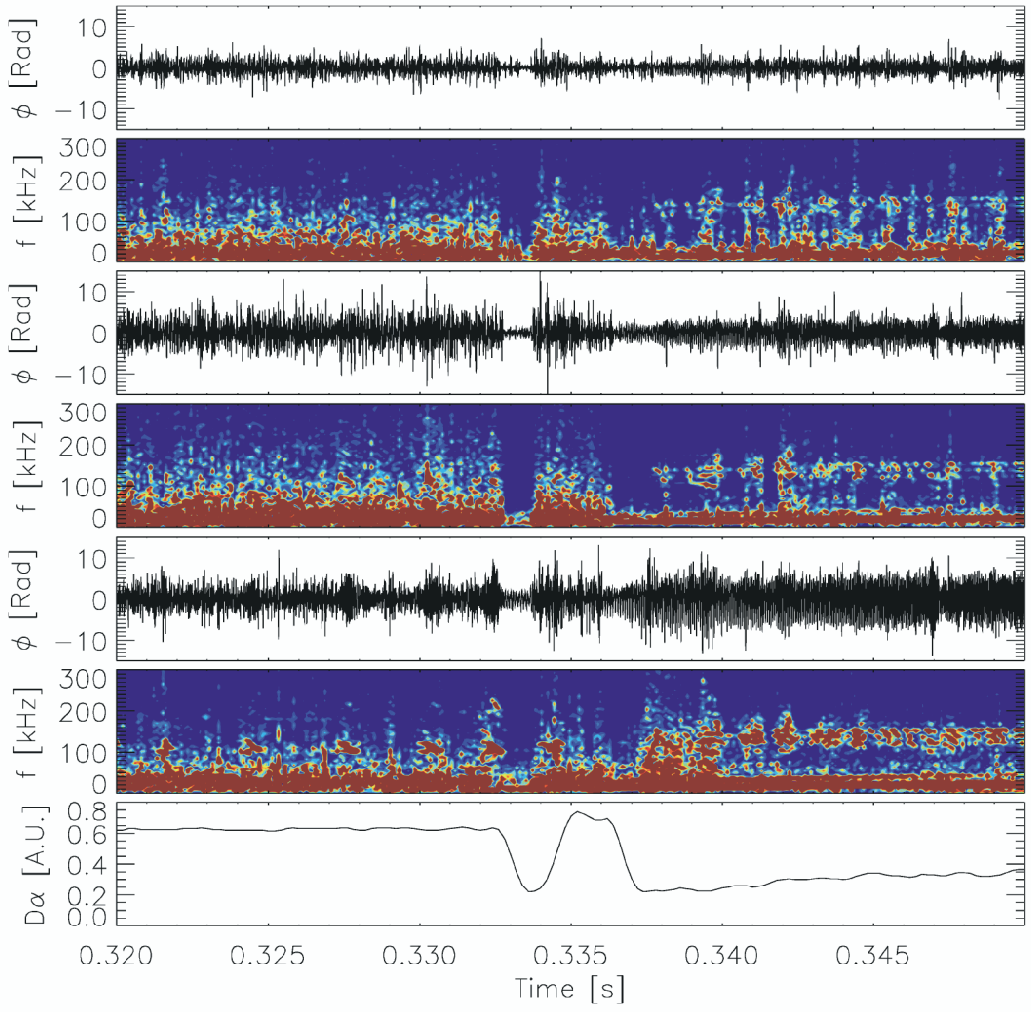




□R oscillations are larger and more prevalent. ELM precursor oscillations unclear.

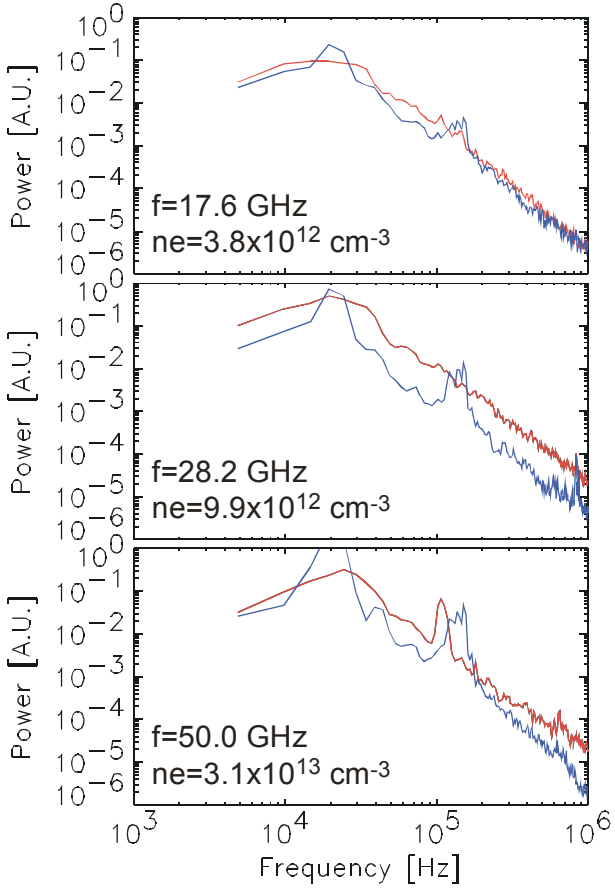
Very fast density changes (no D□ signature) associated with high frequency (100-150 kHz) magnetic oscillations.

# Turbulence Suppression/Fluctuations at L-H Transition

## Fluctuation Component of Reflectometer Phase and Spectrogram at L-H Transition




## Power Spectrum of Phase

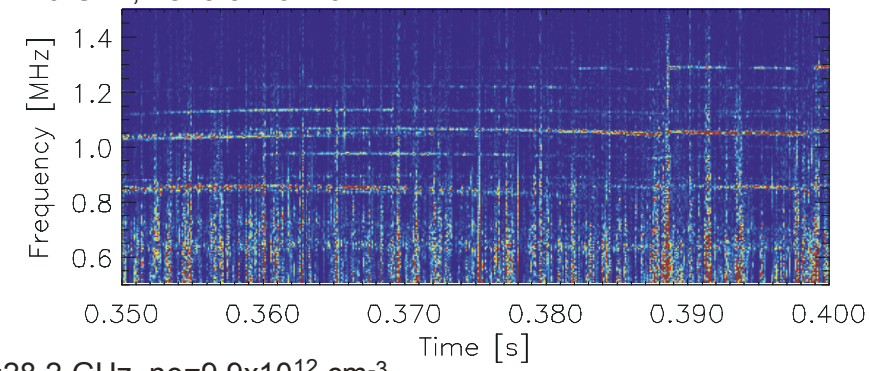



L-Mode: 0.325-0.330 s
H-Mode: 0.340-0.345 s

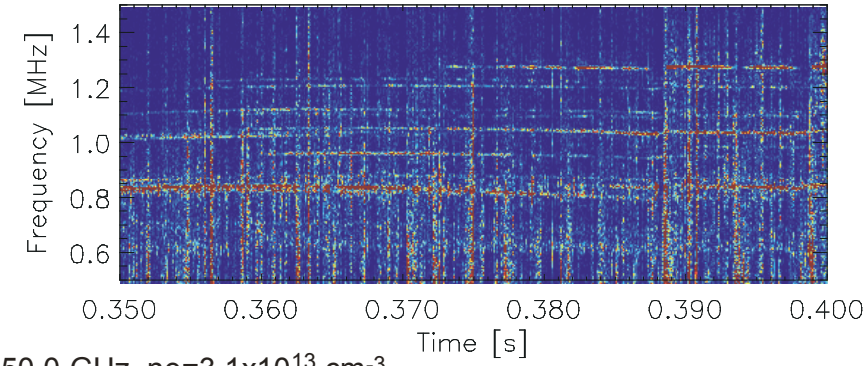
# Fluctuation Measurements: Compressional Alfven Eigenmodes

## Shot 108824, Reflectometer Phase Spectrograms

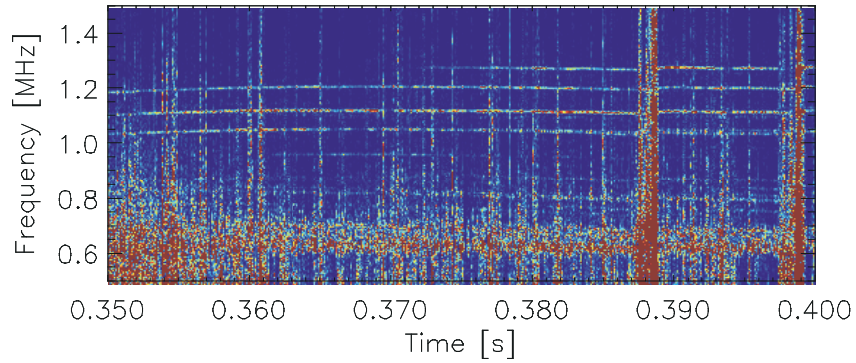
f=17.6 GHz, ne=3.8x10$^{12}$ cm$^{-3}$

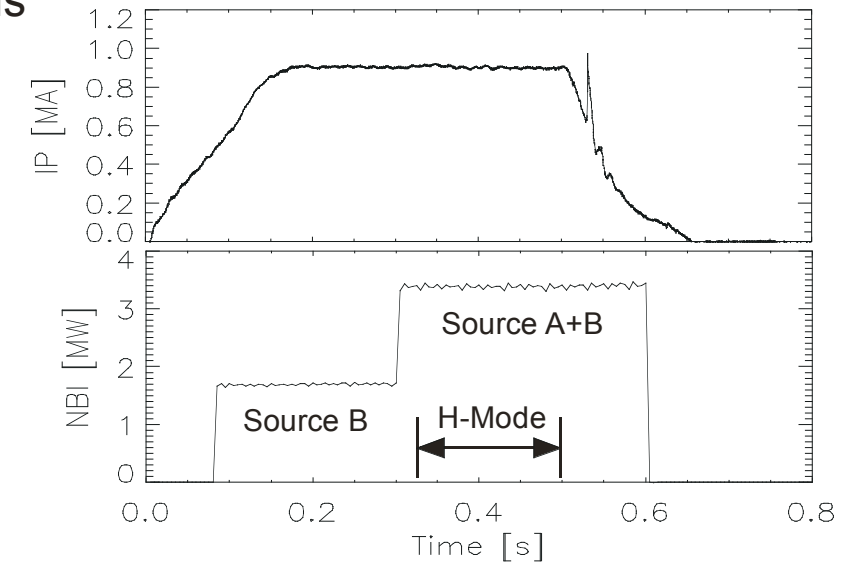


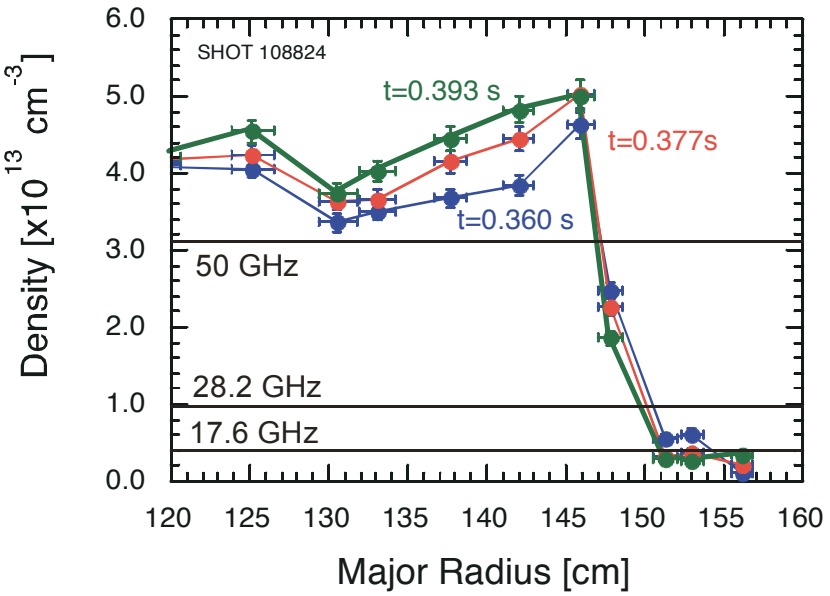

f=28.2 GHz, ne=9.9x10$^{12}$ cm$^{-3}$



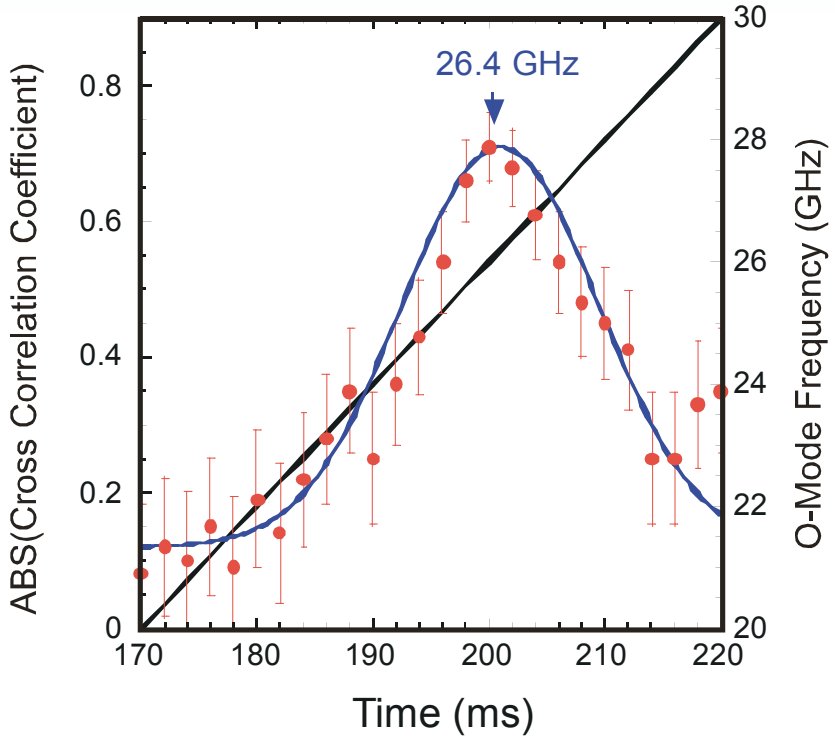

f=50.0 GHz, ne=3.1x10$^{13}$ cm$^{-3}$



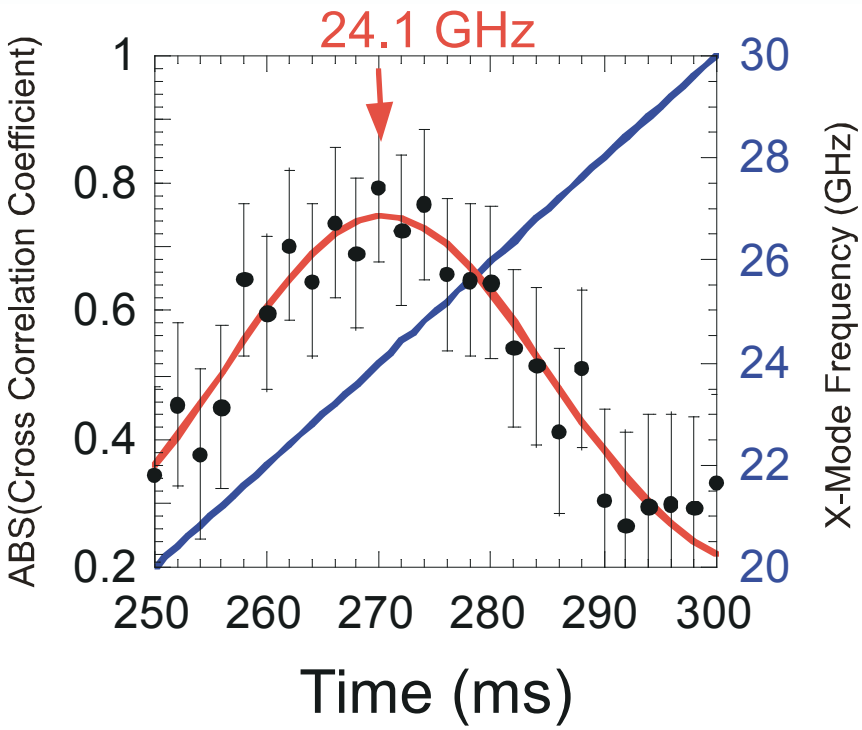



# Results from O- and X-Mode Swept Configurations




- $f_x$ = 30 GHz
- $f_o$ swept 20-30 GHz
- Gaussian fit gives $f_{o,pk}$ = 26.4 ± 0.15 GHz
- X-mode cutoff location R = 147 cm
- 1D full wave model gives $|\underline{B}|$ = 2.5 ± 0.15 kG at R =147 cm
- EFIT gives $|\underline{B}|$ ≈ 2.6 kG at this radius



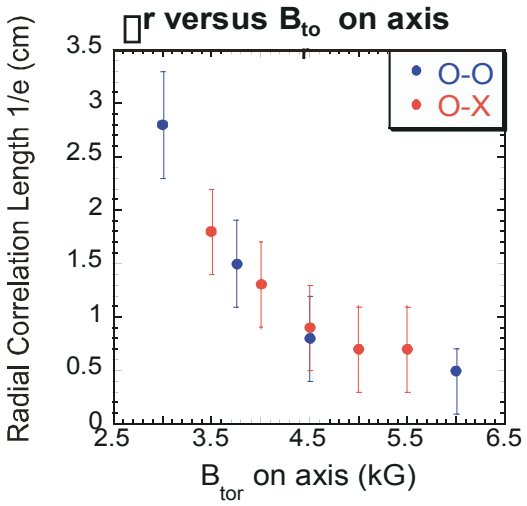

- $f_o$ = 20 GHz
- $f_x$ swept 20-30 GHz
- Gaussian fit gives $f_{x,pk}$ = 24.1 ± 0.15 GHz
- O-mode cutoff location R = 151 cm
- 1D full wave model gives $|\underline{B}|$ = 3.0 ± 0.14 kG at R =151 cm
- EFIT gives $|\underline{B}|$ ≈ 3.0 kG at this radius

# Radial Correlation Length Measurements

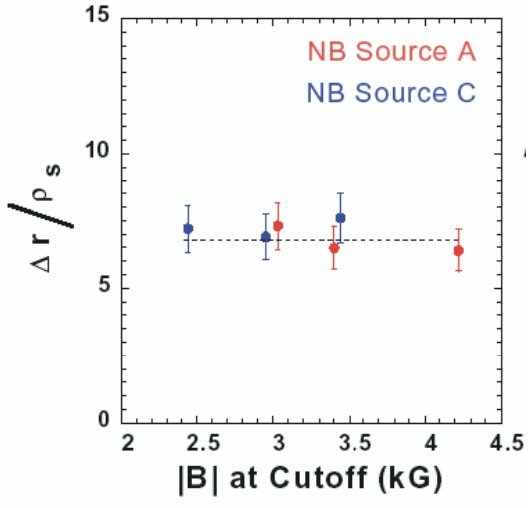
• O-X correlation lengths similar in value and appear to show same trend with $B_{tor}$ as O-O under similar conditions

• NBI heated L-mode plasmas
• Cutoff layers (30 GHz) 4-8 cm inside LCFS
• $L_n$ varies from ▯ 6 to 16 cm
• Fluctuation frequencies 20 - 500 kHz correlated

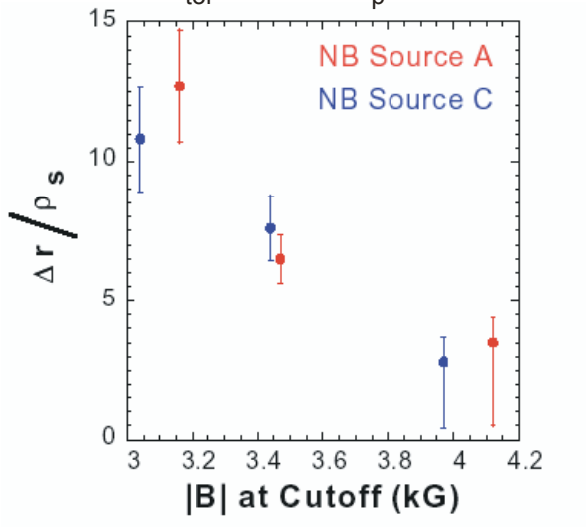
$$\rho_s \equiv \frac{c_s}{\omega_{ci}}$$



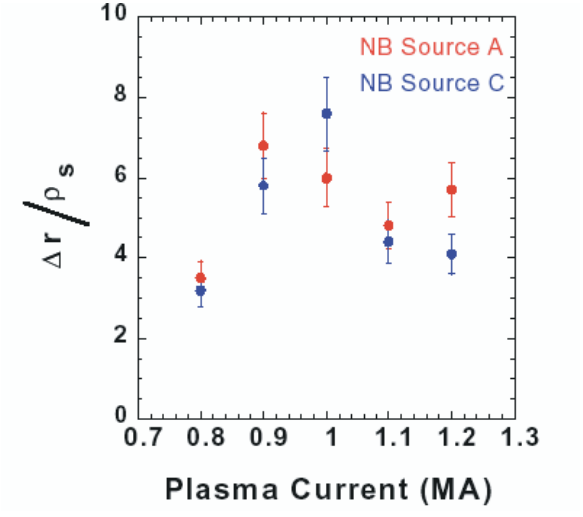

Fixed $B_{tor}/I_p$ (Constant $q_{cyl,edge}$)




$B_{tor}$ at Fixed $I_p$ (1 MA)




$I_p$ at Fixed $B_{tor}$ (4.5 kG)



# Status of MM-Wave Reflectometry Systems


- Fast FMCW, three channel quadrature, and radial correlation reflectometers available.
- Plan to have between-shot analysis for profile data, however this will depend on processor availability. Also, above systems will not be available simultaneously.
- Work is underway to decrease sweep times for and increase the frequency band for FMCW and correlation reflectometers. LabVIEW control of diagnostic and data acquisition.
- Measurement location is dependent on density profile shape. Flat profiles with steep edge or ears will mean that measurements will be mainly in edge.

# Planned and Proposed Future Work

- Profile measurements up to $5x10^{13}$ $cm^{-3}$ via higher frequency operation (up to 65 GHz)? Higher sweep rate (up to 100 kHz).
- Improve accuracy of profile measurements. Below $1.8x10^{12}$ $cm^{-3}$, use of in-vessel 4-18 GHz quad-ridged EBW antenna.
- Dedicated hardware for fixed-frequency measurements. Further analysis of CAEs, H-mode and ELM precursors, turbulence, etc. Simultaneous profile and fluctuation measurements.
- Radial correlation reflectometry for correlation length and |B| measurements. Broader profile coverage, faster time response.
- Measurement of magnetic field pitch angle. Planned for spring 2003.
- Measurement of RF waves (proposed). Look at directionality due to antenna phasing, radial wave number.