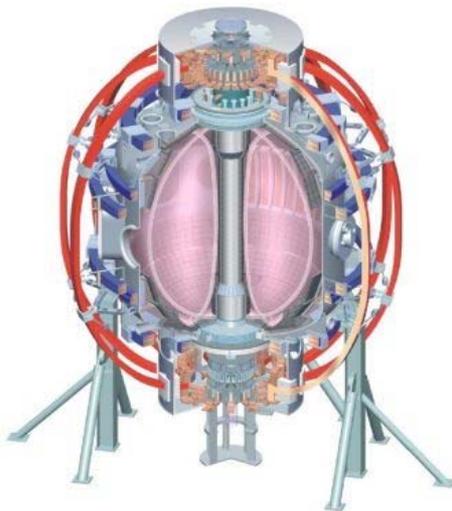


Density fluctuation measurements from the NSTX Beam Emission Spectroscopy (BES) diagnostic system

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CEA, Cadarache

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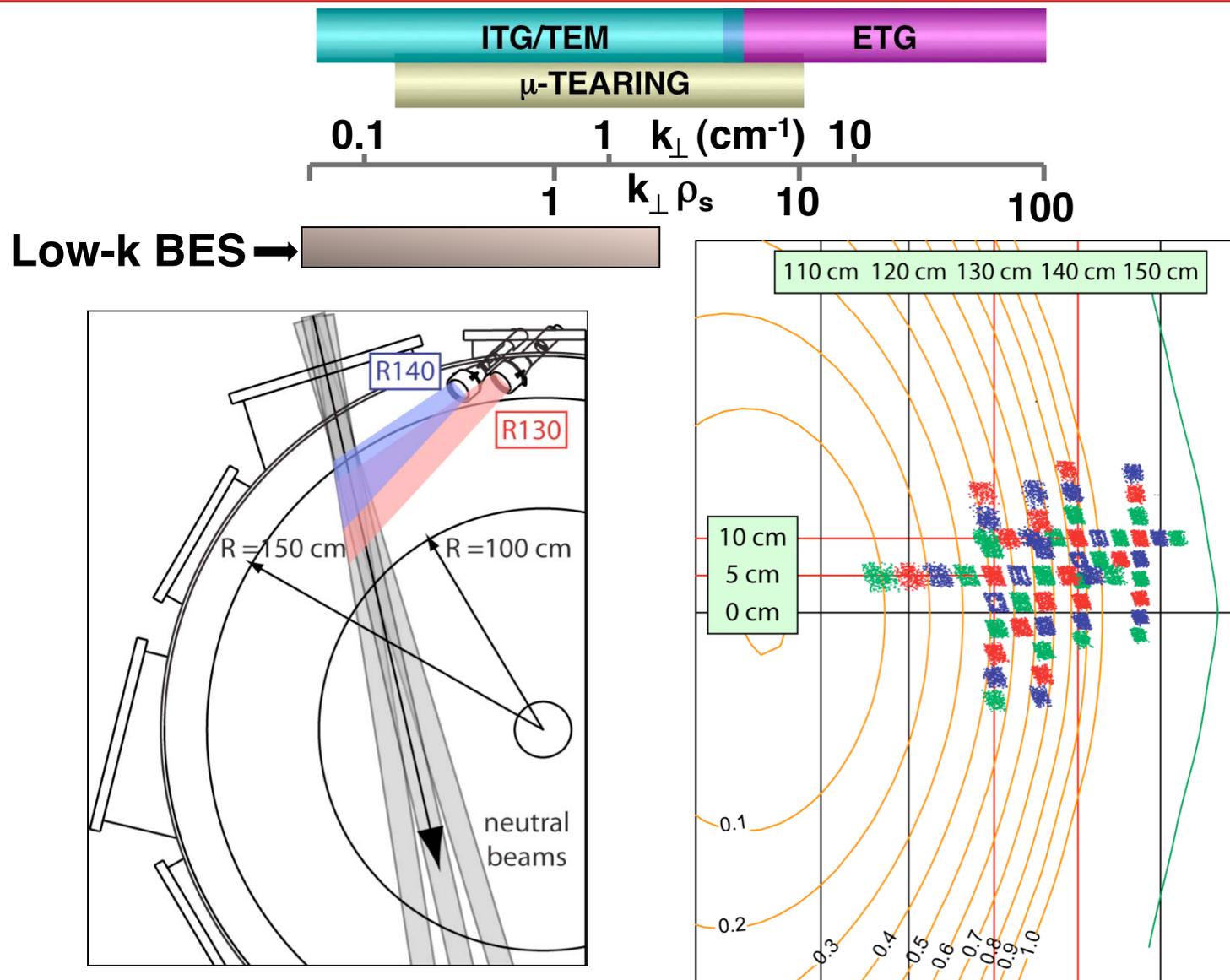
IPP, Garching

ASCR, Czech Rep

U Quebec

College W&M
Colorado Sch Mines
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Beam emission spectroscopy (BES) provides low-k fluctuation measurements for studying plasma turbulence in NSTX



Outline

- BES diagnostic overview
 - Optical and detection system
 - Measurement capabilities
- Initial observations
 - Fluctuations decrease at LH transition
 - Eddy poloidal motion **reverses** after LH transition
 - **Large poloidal correlation lengths**
 - Correlation lengths depend on $|B|$ and I_p
 - Post-ELM harmonic features **localized** at top of pedestal
 - GAE and TAE mode structure observed
- Summary and plans

BES provides long-wavelength density fluctuation measurements with $k_{\perp}\rho_i < 1$

- BES measurements contribute to several NSTX research areas

- Turbulence and transport

- ITG/TEM turbulence
- ZFs and GAMs
- Flow fluctuations

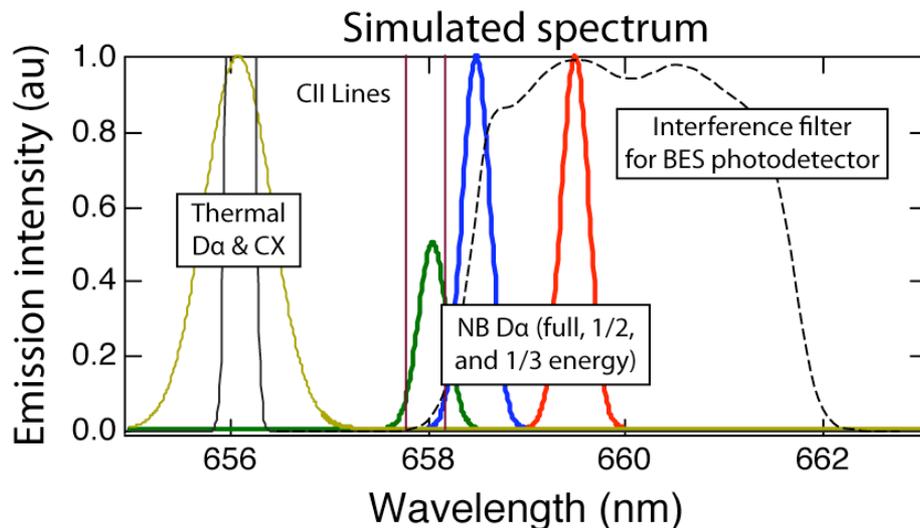
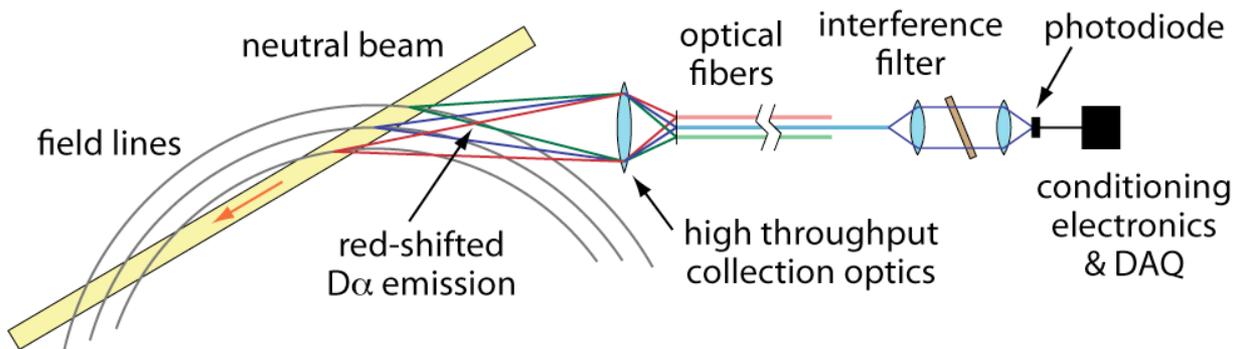
- Boundary physics

- LH transition
- Edge & SOL fluctuations
- ELMs and EHOs

- Waves-particle interactions

- TAE/EP/GAE mode structure

- Doppler shift and optical filter isolate NB D_{α} emission from thermal D_{α}



$$\frac{\delta I_{D\alpha}}{I_{D\alpha}} = \frac{\delta n_i}{n_i} \times C(E_{NB}, n_e, T_e, T_i, Z_{eff})$$

neutral beam
 D_{α} emission

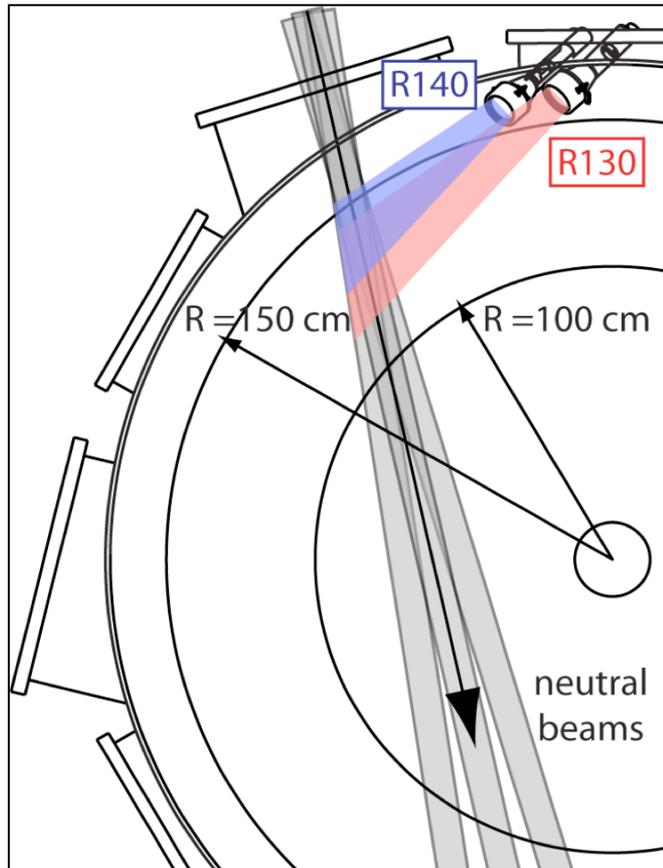
ion density
fluctuation

$C \approx 1/2$

NSTX BES system was commissioned in 2010

- Doppler shift and optical filter isolate NB D_α emission from thermal D_α

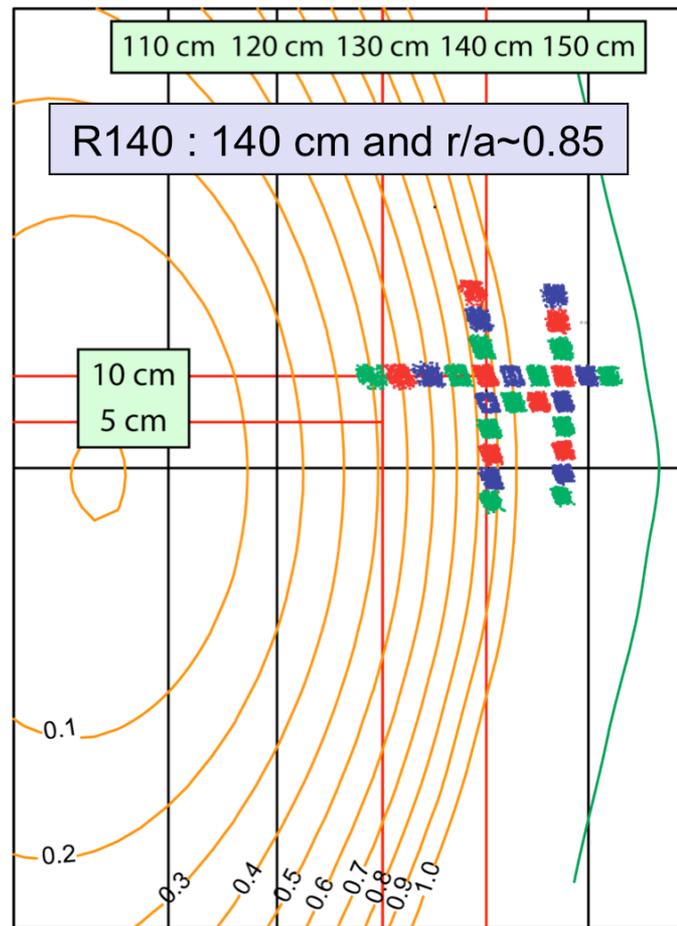
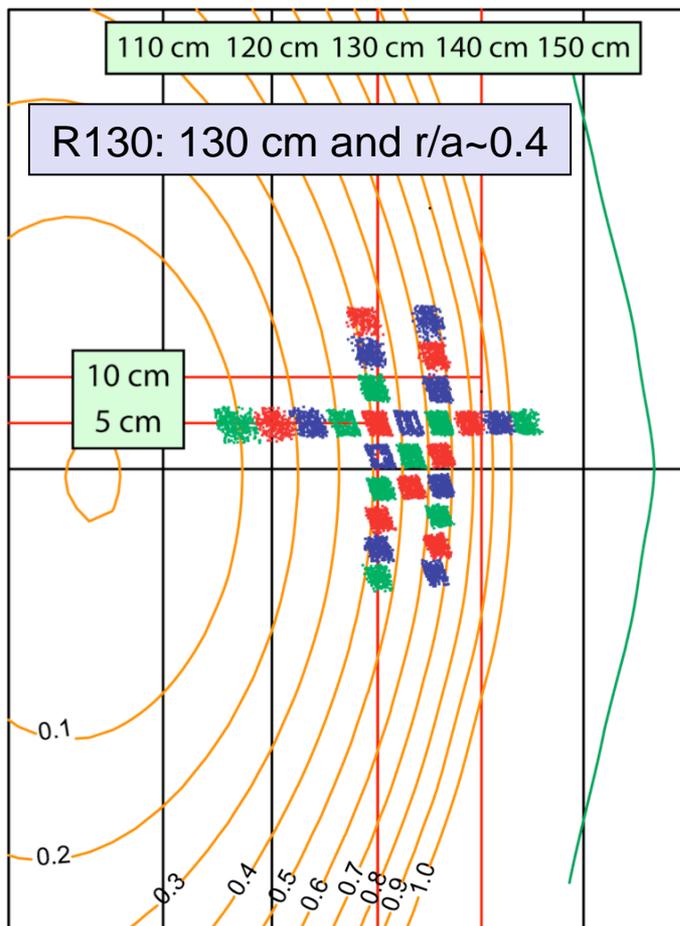
- Two optical views are aligned to steep pitch angles in NSTX plasmas



D. R. Smith et al, **RSI** 81, 10D717 (2010)
N. Schoenbeck et al, **RSI** 81, 10D718 (2010)

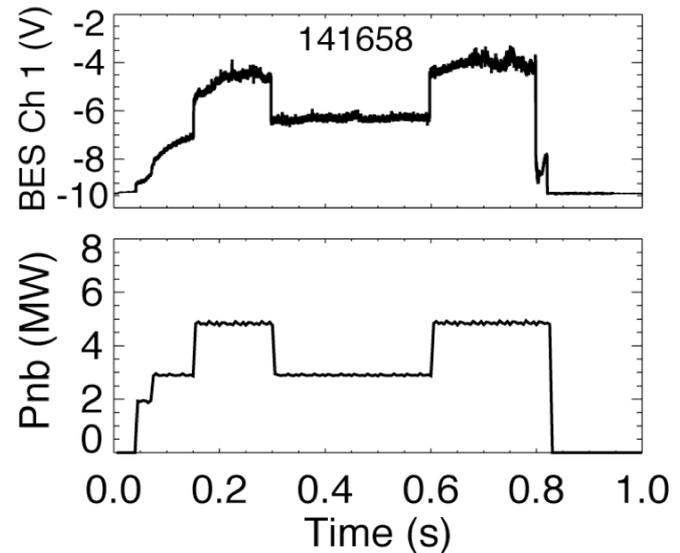
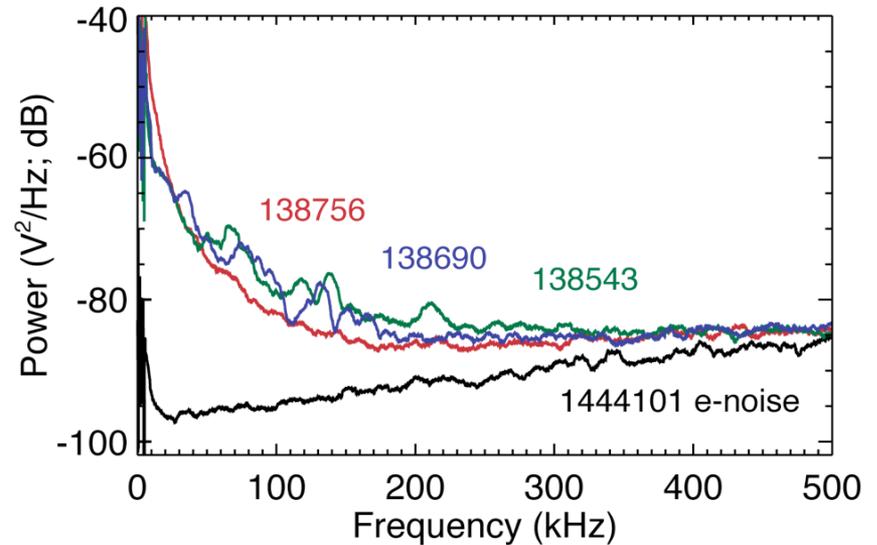
Two optical views and 32 detection channels provide radial coverage from $r/a \approx 0.1$ to SOL with 2-3 cm spot sizes

Image patterns provide **radial** and **poloidal** correlation lengths, k-spectra, and flow fluctuations

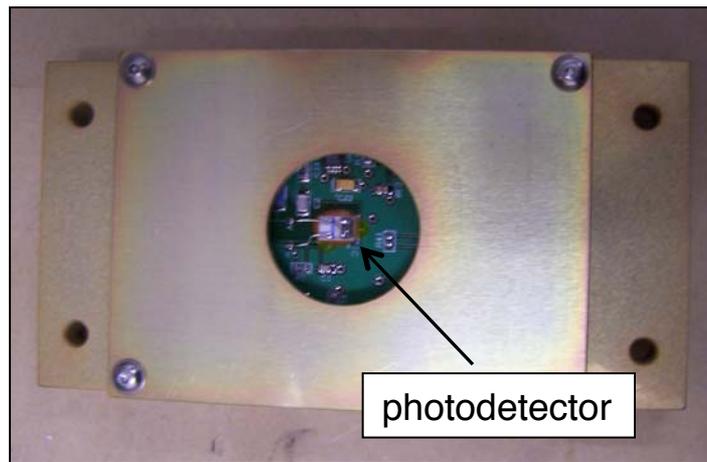
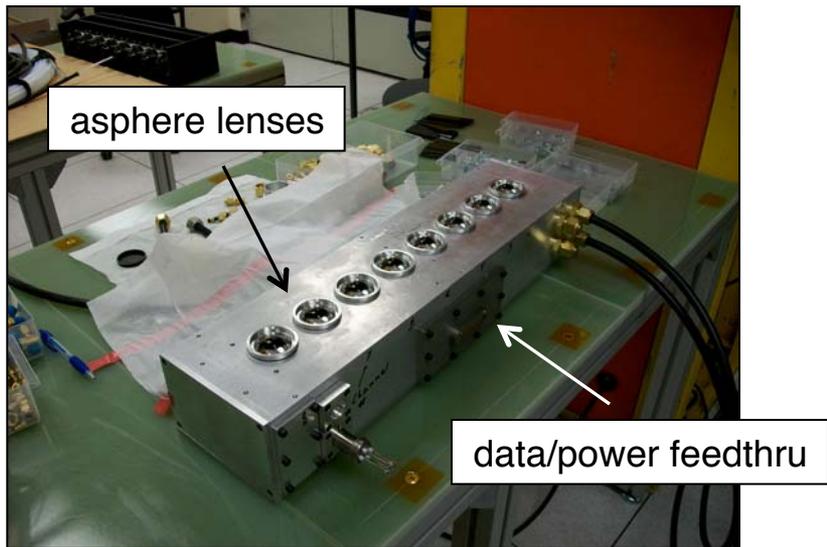
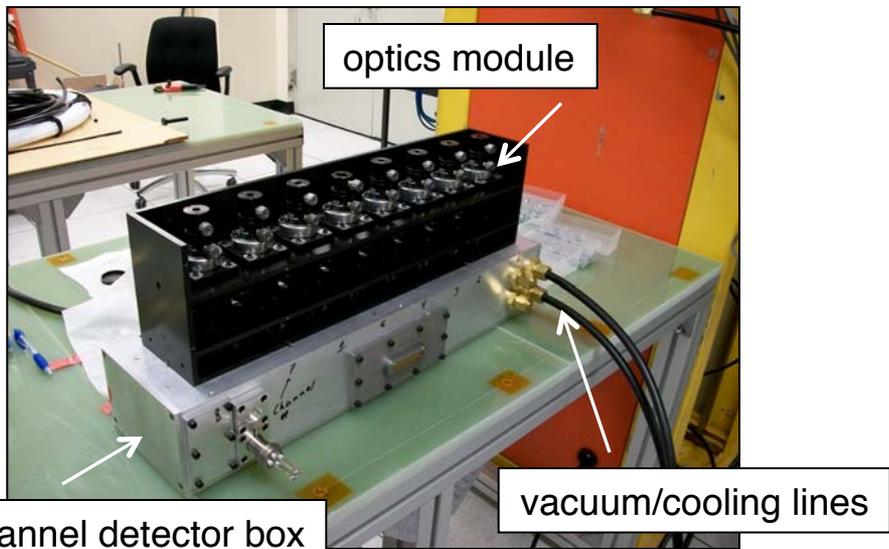


Measured signals exceed amplifier noise and respond to NB power

- Optical design
 - Red shift view
 - 2.3 mm²-ster etendue
 - 4 nm optical filter at 661 nm
- Photodetector
 - PIN PD and low-noise amplifier
 - 85% QE and 4.5 mV/nW response
 - Refrigerant cooling at -20° C
 - Evacuated enclosure
- Digitizer
 - 32 channels
 - 32 MHz input sampling
 - Onboard FPGA provides 950 kHz low-pass FIR filter
 - 2 MHz output sampling
 - 16 bit resolution



Photodetectors, detector box, and optics module

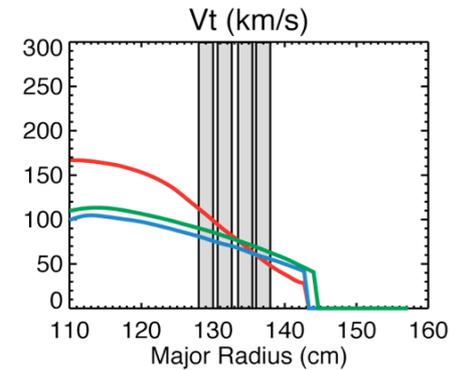
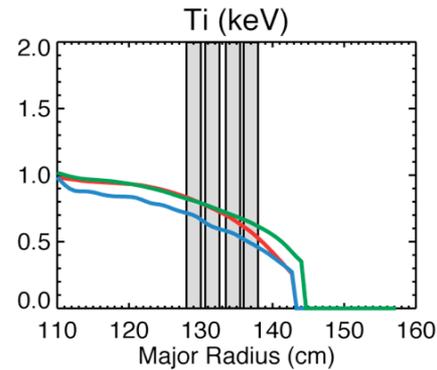
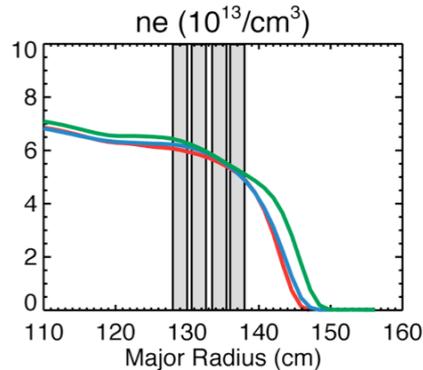
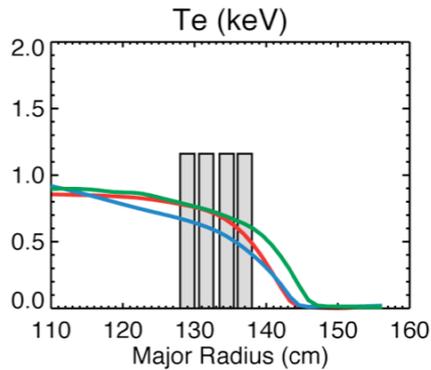
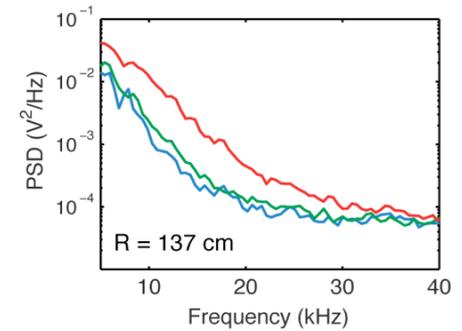
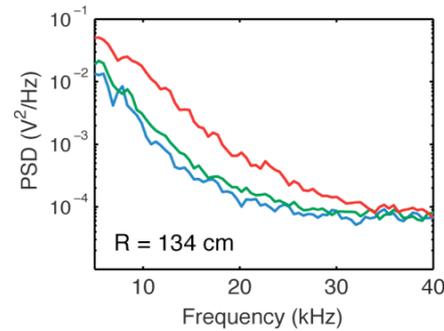
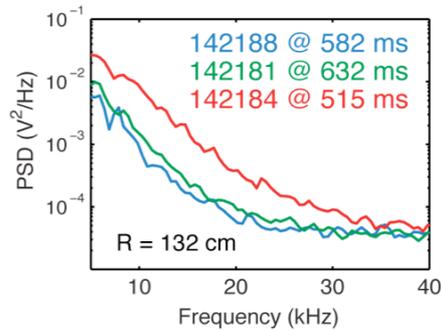
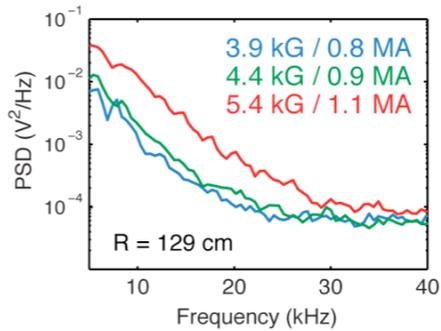


General characteristics of low-k turbulence in NSTX

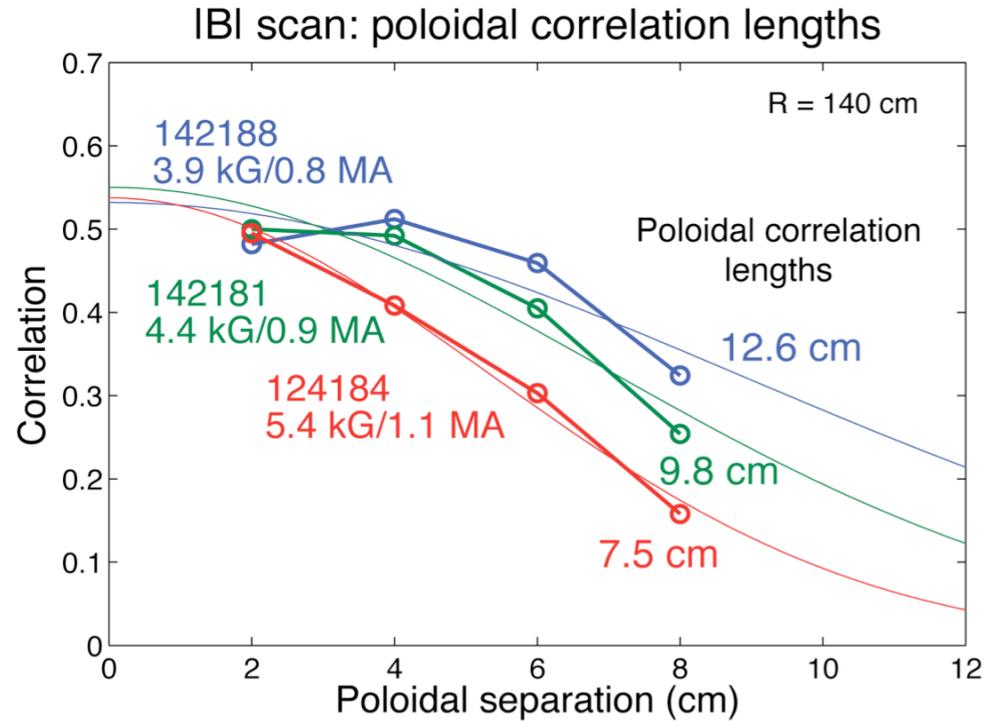
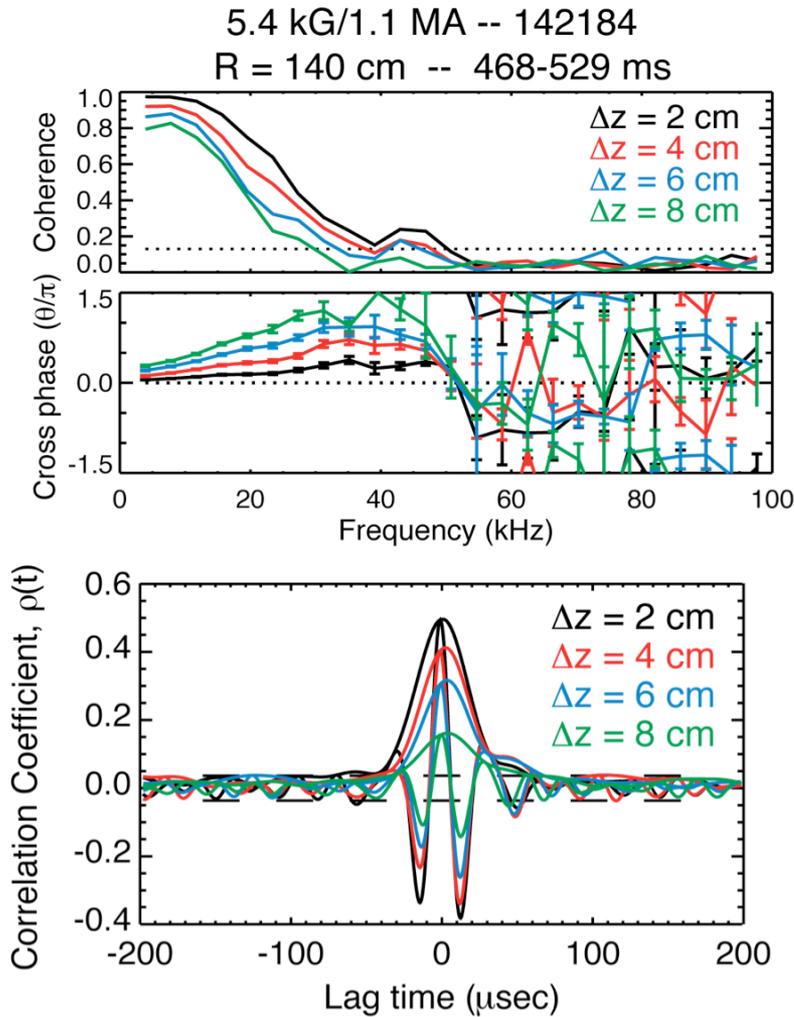
- Poloidal correlation lengths on the order of 10 cm
- Broadband turbulence with frequencies up to 100 kHz
- Poloidal flow speeds in the range 5-10 km/s and consistent with $E \times B$ flows
- Fluctuations can decrease at LH transition, but subsequently increase during H-mode evolution
- Reduced fluctuations at LH transition can extend into core region

BES power spectra consistent with larger fluctuation amplitudes at higher |B|

NSTX confinement scaling (Kaye et al, NF (2007)): $\tau_e \sim B_T \sqrt{I_P}$



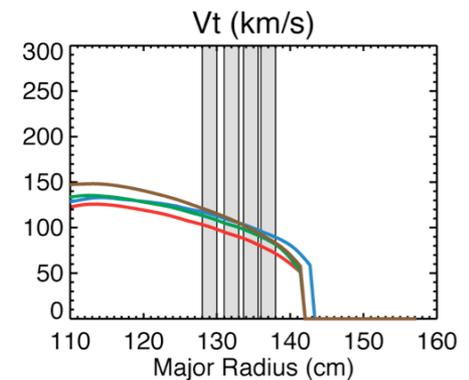
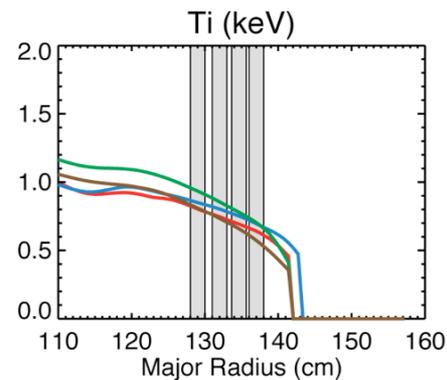
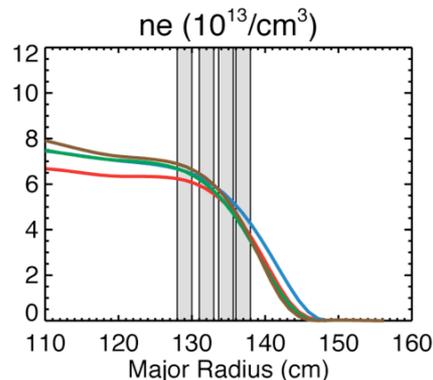
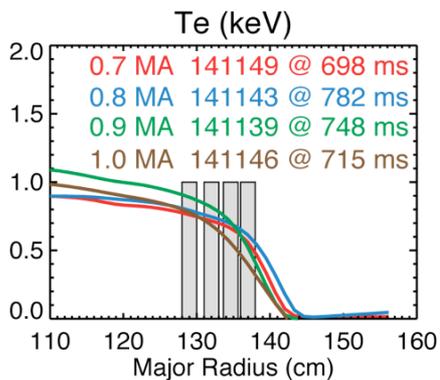
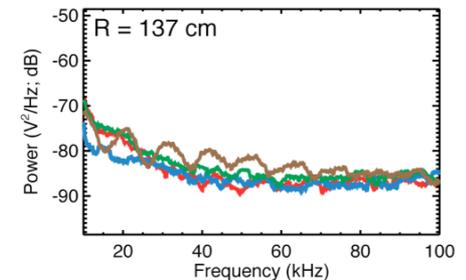
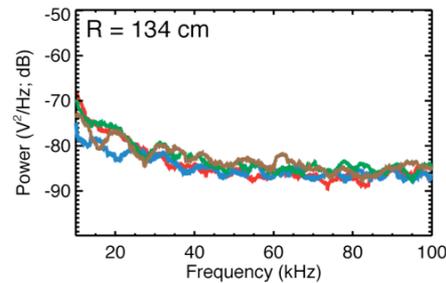
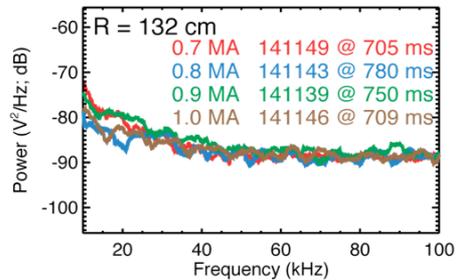
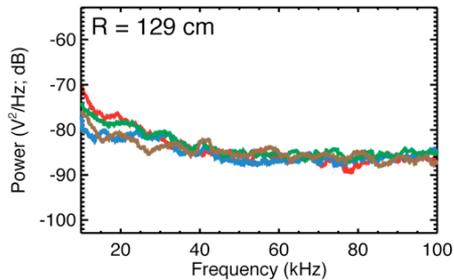
Poloidal correlation lengths decrease at higher |B|



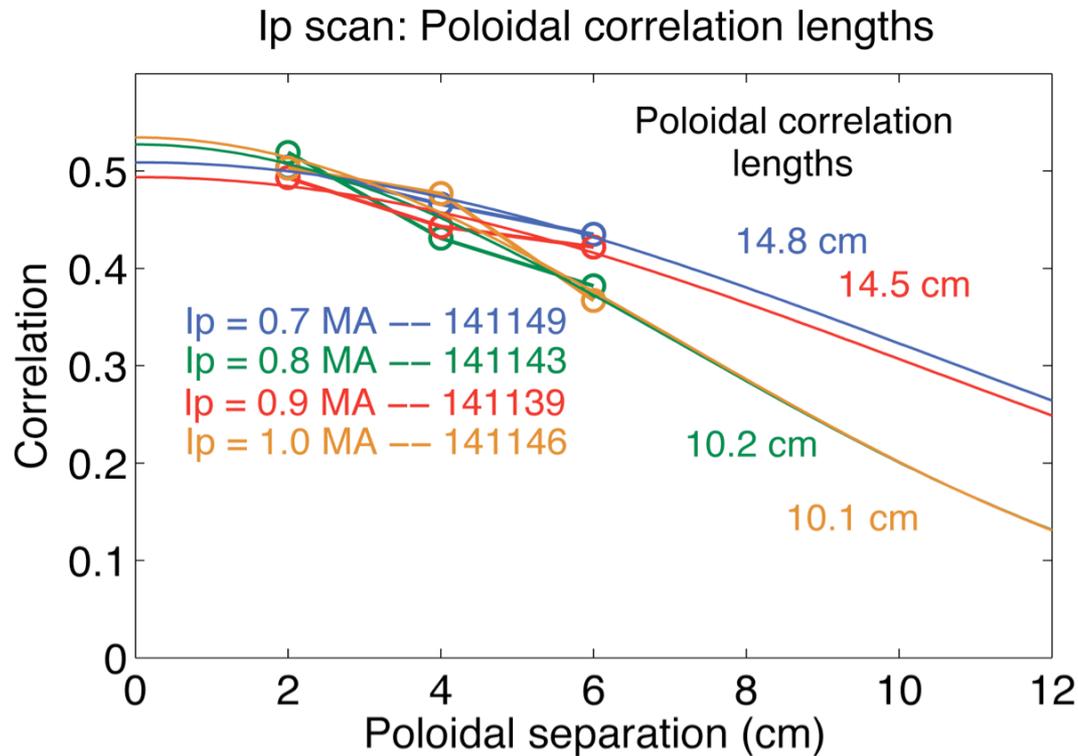
Intuitively consistent with NSTX scaling:

$$\tau_e \sim B_T \sqrt{I_P}$$

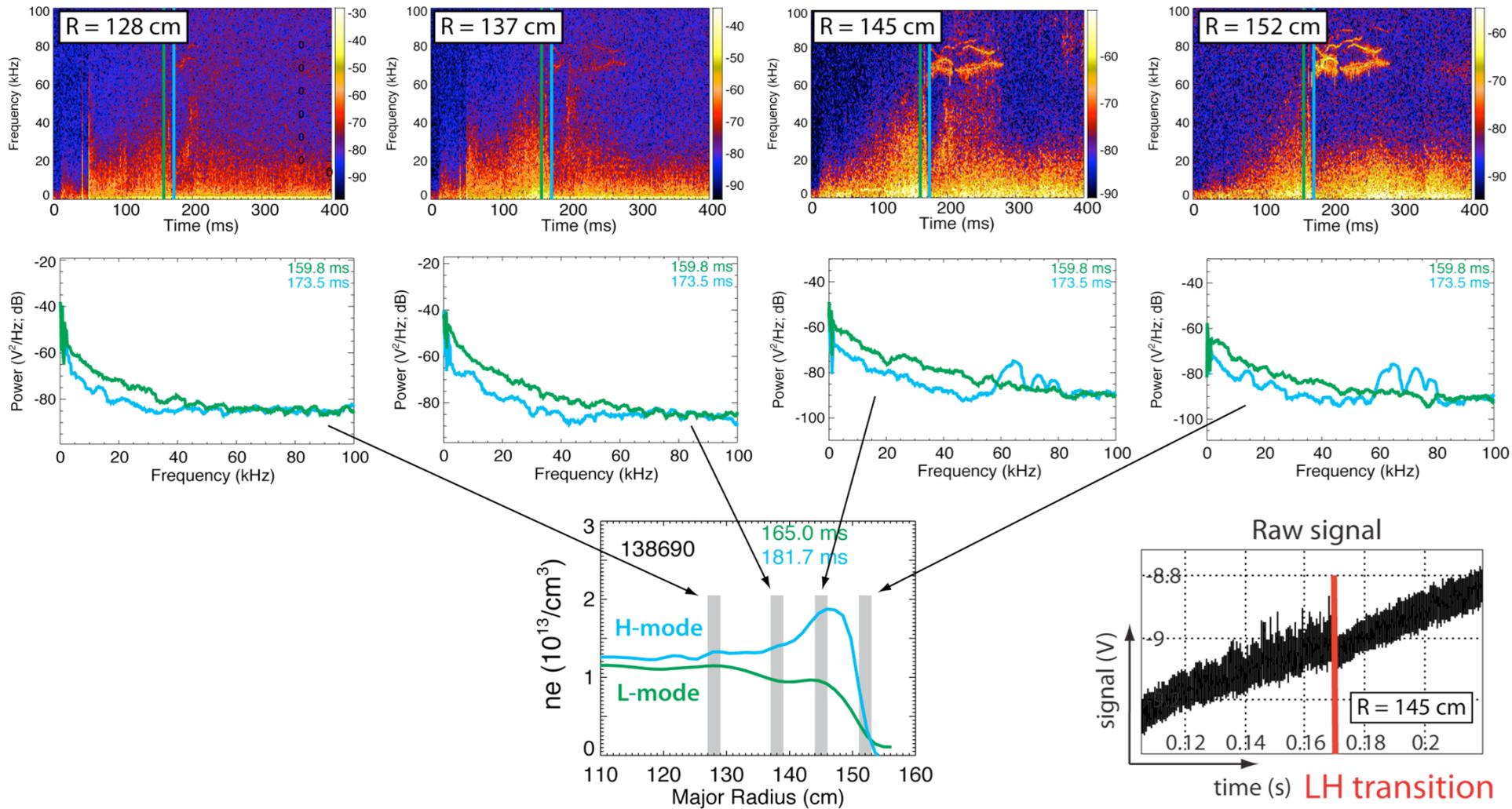
BES power spectra do not show a clear trend with I_p



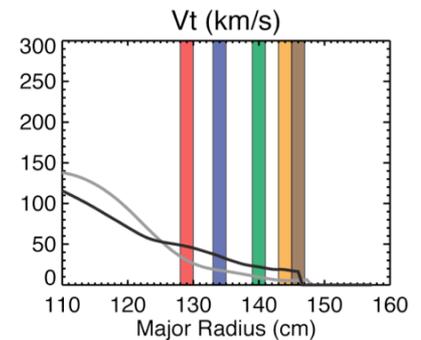
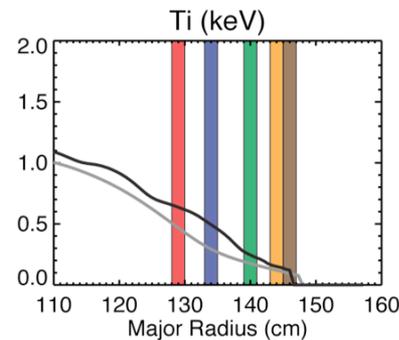
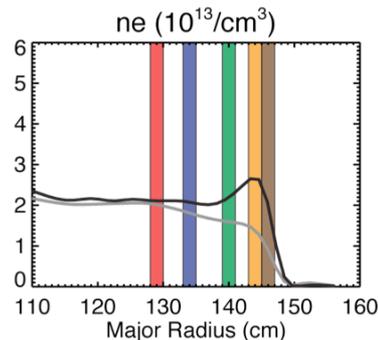
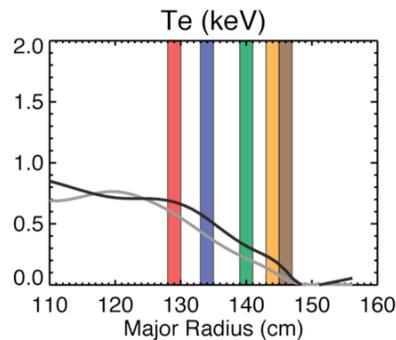
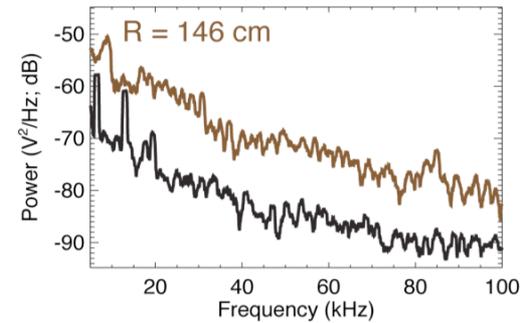
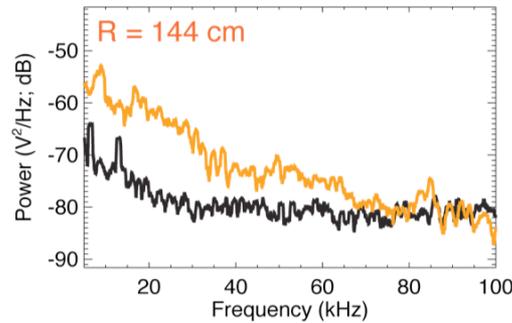
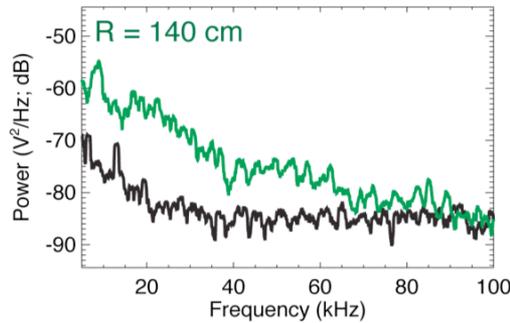
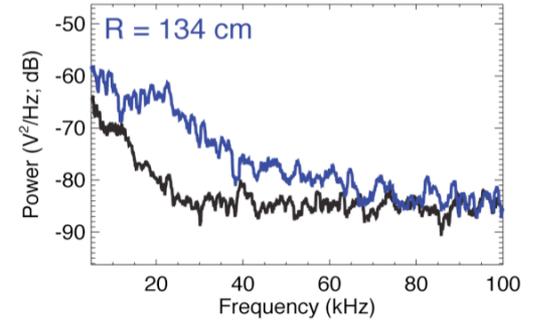
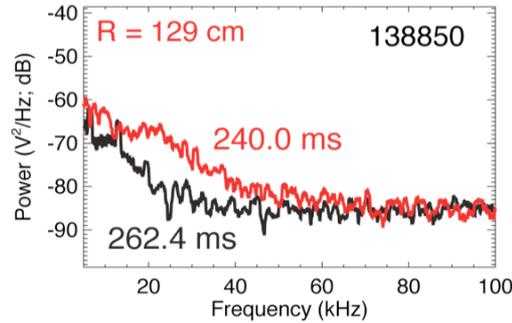
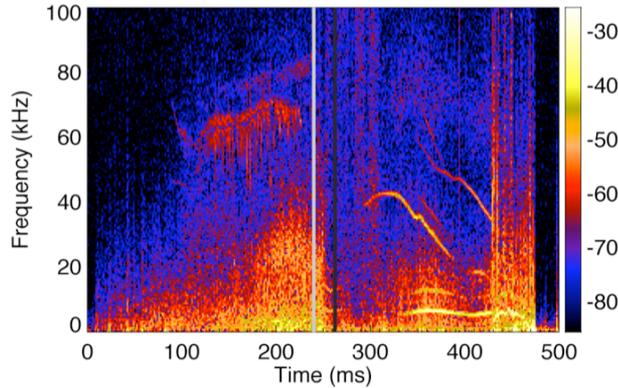
Poloidal correlation lengths do not show a clear trend with I_p



Decrease in fluctuations at LH transition observed from edge to core in some discharges



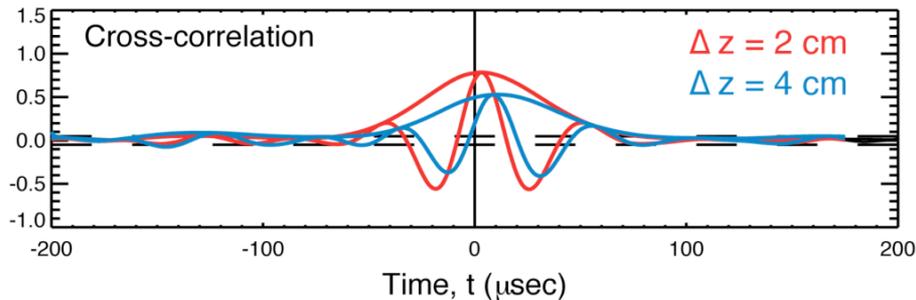
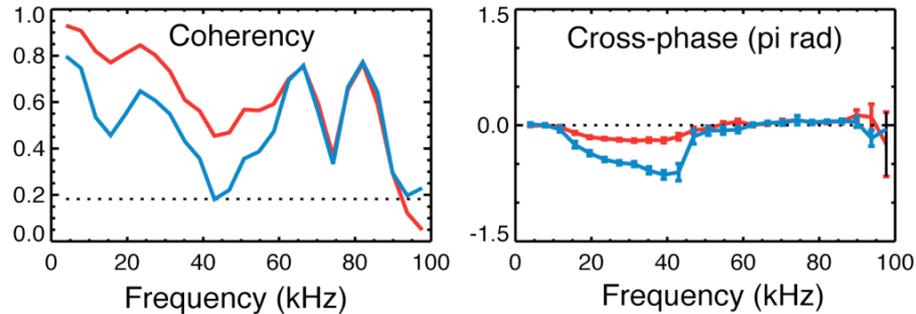
Decrease in fluctuations at LH transition observed from edge to core in some discharges



Correlation analysis indicates the apparent motion of eddies changes from electron to ion directions at the LH transition

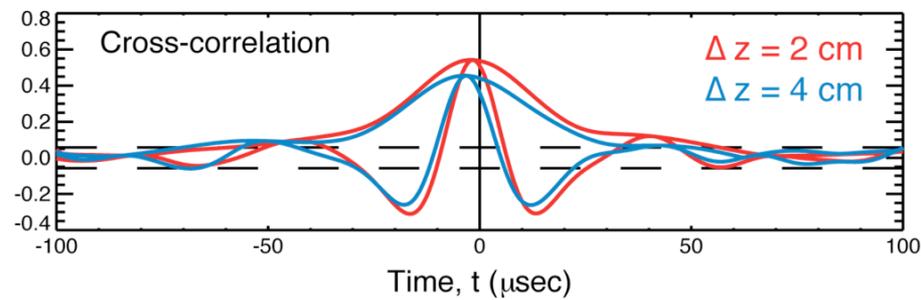
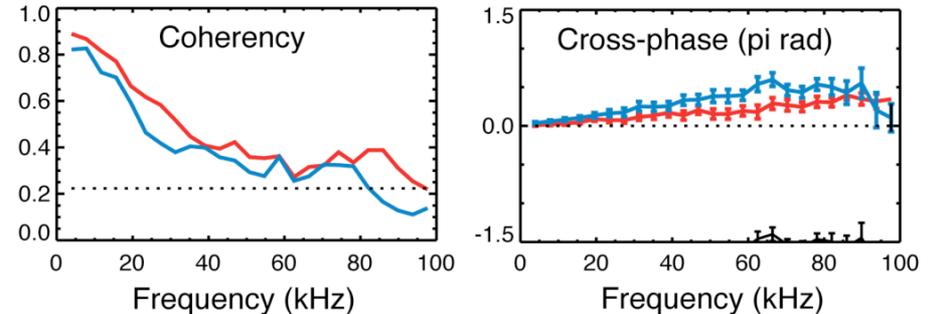
Poloidal coherency/correlation in 138850 at R = 140 cm

L-mode phase: 219-249 ms



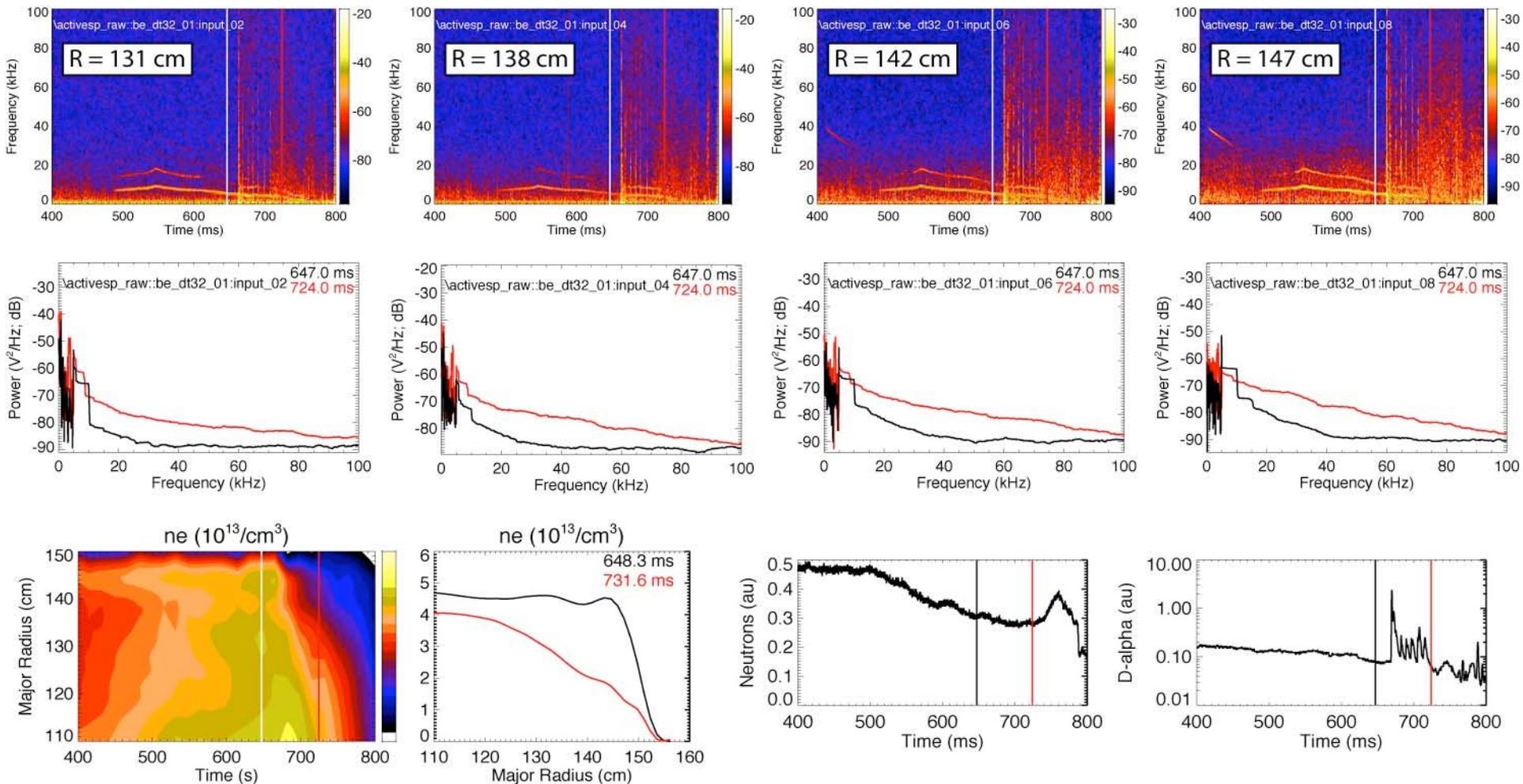
Time lag indicates motion in the **electron** drift direction

H-mode phase: 266-287 ms



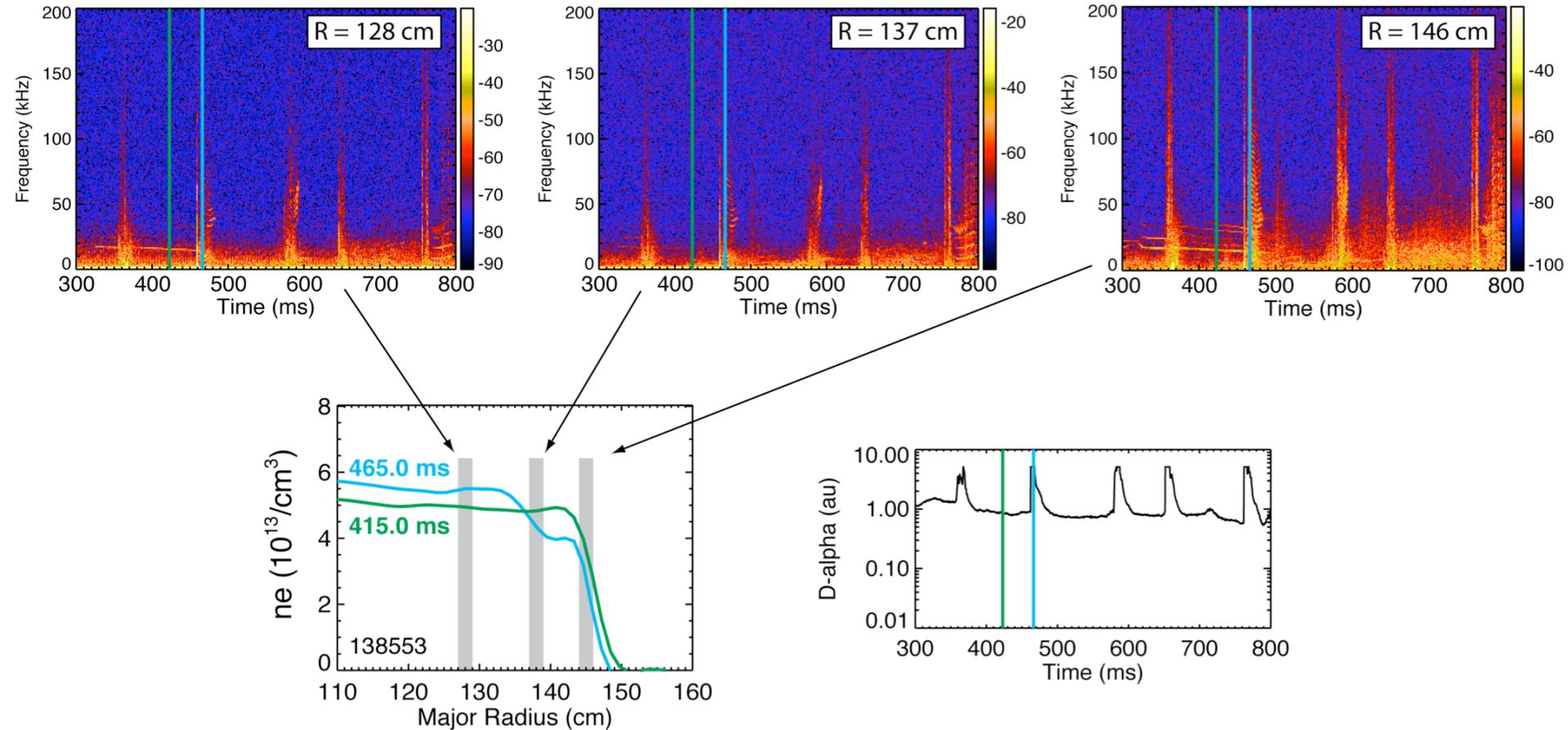
Time lag indicates motion in the **ion** drift direction;
 E_r increases at LH, so greater $E \times B$ in ion drift direction

Fluctuations increase following HL back-transition

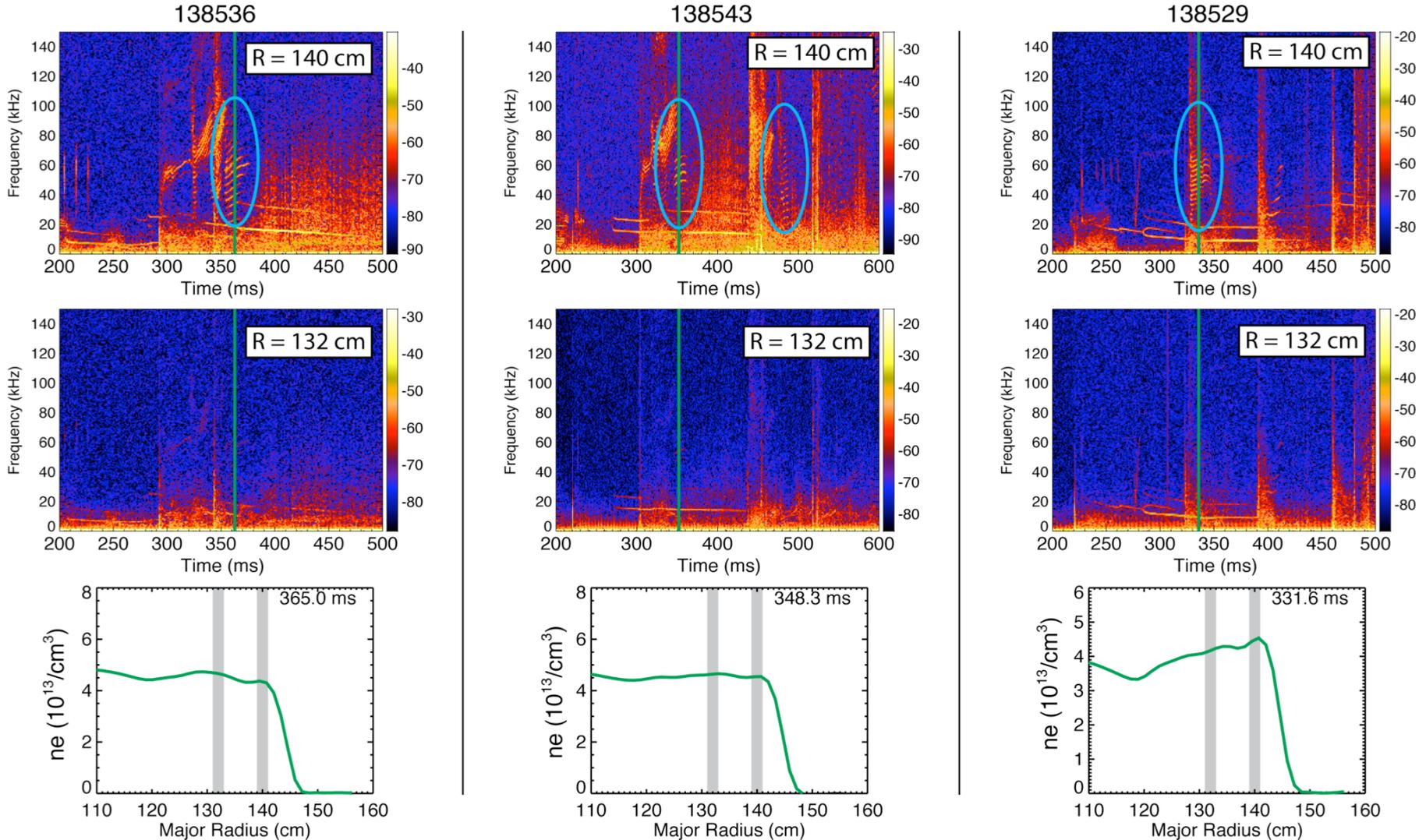


138690 XMP70 Smith

Fluctuations increase during large ELM events



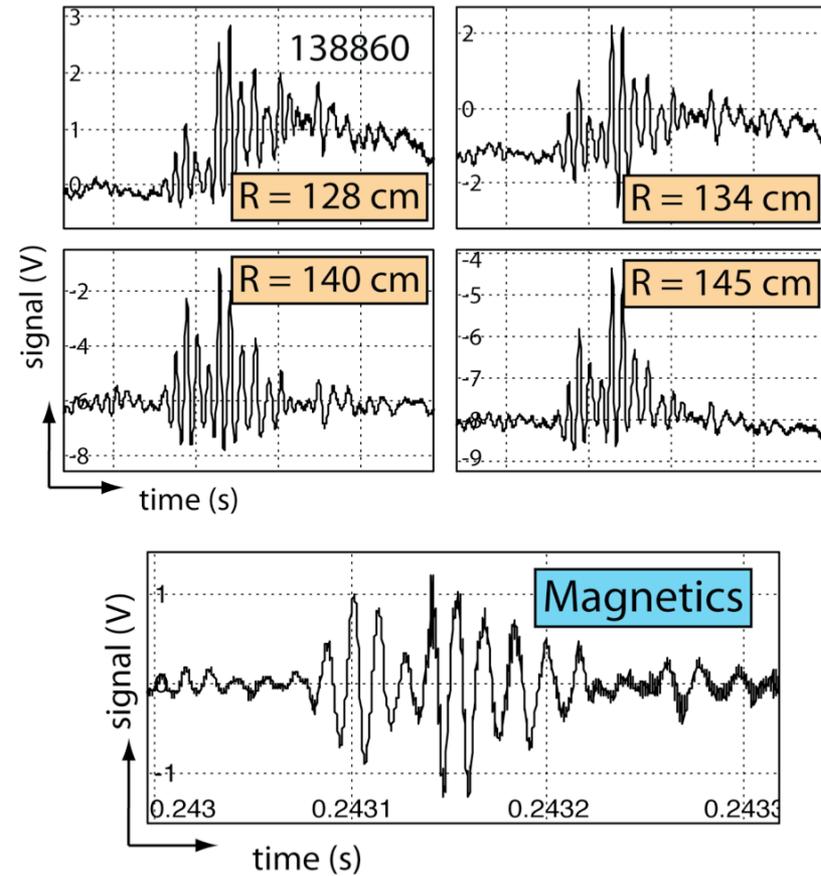
Post-ELM harmonic features at 50-100 kHz are localized at the top of the pedestal



Harmonic features are either absent from or weakly present in magnetic spectra

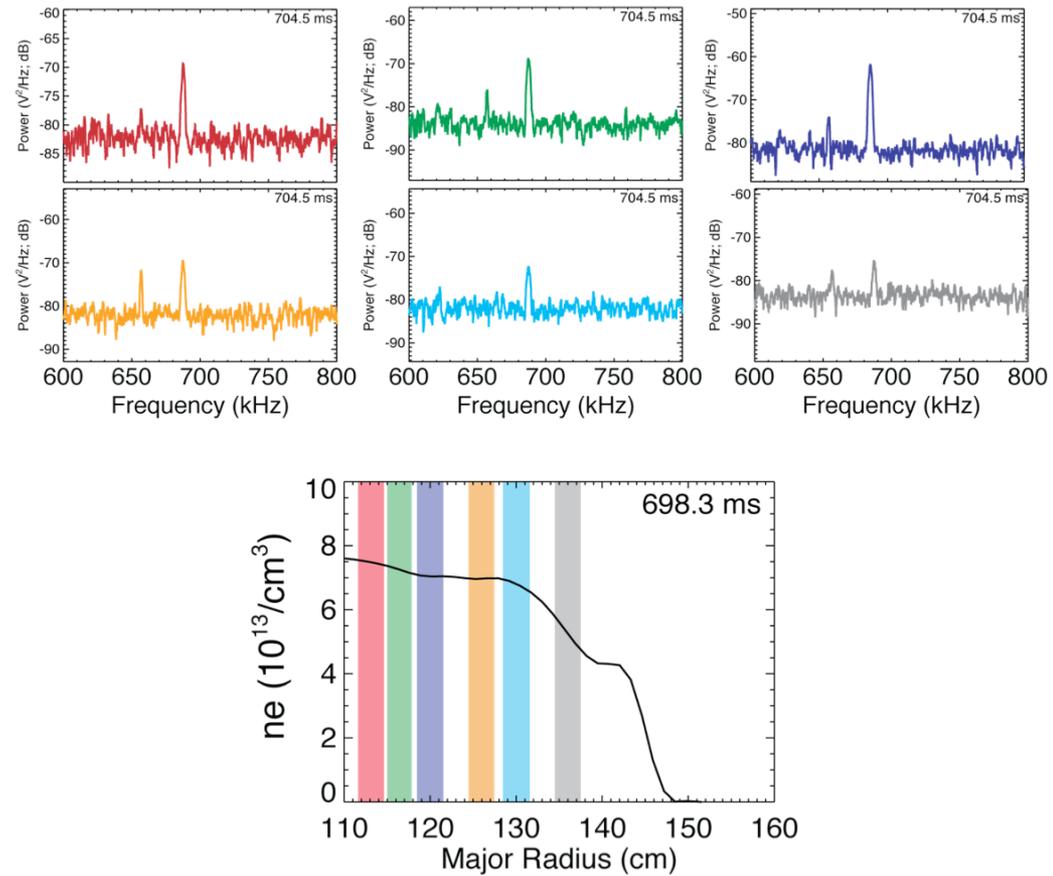
TAEs and GAEs have been observed in extended radial regions

TAE burst



Heidbrink, CO4

GAE mode



Tritz, PI2

Summary

- NSTX BES system commissioned in 2010
- System measures fluctuations with $k\rho_i < 1$
 - 32 detection channels (56 fiber views)
 - Radial and poloidal arrays covering core to SOL
 - 2 MHz sampling
 - 2-3 cm spot sizes at NB
- Initial observations
 - Poloidal correlation lengths on the order of 10 cm
 - Broadband turbulence up to 100 kHz observed
 - Poloidal flows in the range 5-10 km/s
 - Fluctuations decrease at LH transition
 - Post-ELM harmonic features (50-150 kHz) localized to pedestal