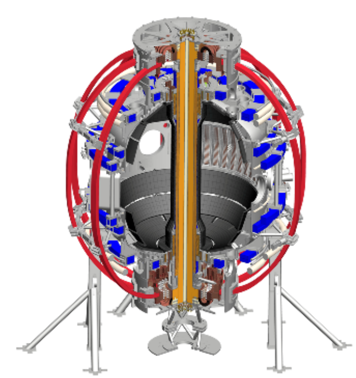
Initial Characterization of L-mode and H-mode Edge Turbulence in NSTX-U using Beam Emission Spectroscopy

Matt Kriete[1],

R. Fonck[1], W. Guttenfelder[2], G. McKee[1], D. Smith[1]

[1]*University of Wisconsin–Madison*, [2]*PPPL*

58th APS-DPP Meeting
San Jose, CA
October 31 – November 4, 2016



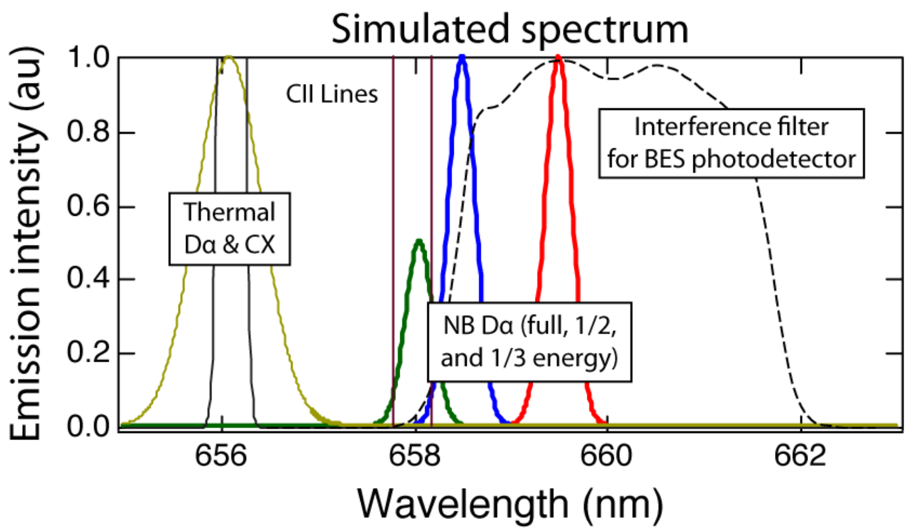
BES introduction	BES expansion	Diagnostic future work	L-mode turbulence	L-H results
BES intro and physics motivation	Motivation for 2D channel layout	Replacement photodiode testing	W. Guttenfelder simulations + overview of L-mode shots	L-H transition in raw BES signals
How BES works	New sightline layout	New preamp PCB layout	Crosspower spectra + fluctuation amplitudes	Turbulence amplitude reduction across L-H
Sightlines and wavenumber sensitivity	Noise debugging and correction	Motivation for spectrometer (impurity line ID & $\tilde{E}$)	Crossphase spectra show bimodal turbulence	Cross spectra analysis in H-mode, compare to L-mode
Pictures of BES hardware	DTACQ frequency mismatch debugging	Spectrometer design specs	Radial cross spectra + turbulence mode ID	Conclusion

Beam emission spectroscopy (BES) is used to study instabilities and ion gyroscale turbulence

- High spatiotemporal resolution turbulence measurements
  - Contribute to validating nonlinear simulations of transport required for designing future fusion facilities
  - Investigate unique features of turbulence at low aspect ratio
  - Study dynamics of the L-H transition

- ELM studies at Alfvénic timescales
  - Better understanding of ELM transport required to mitigate damage in future fusion devices
  - Nonlinear ELM dynamics play key role in ELM evolution
  - Common diagnostics cannot capture nonlinear, Alfvén-scale ELM dynamics

BES measures Doppler-shifted D_α emission from a deuterium heating beam

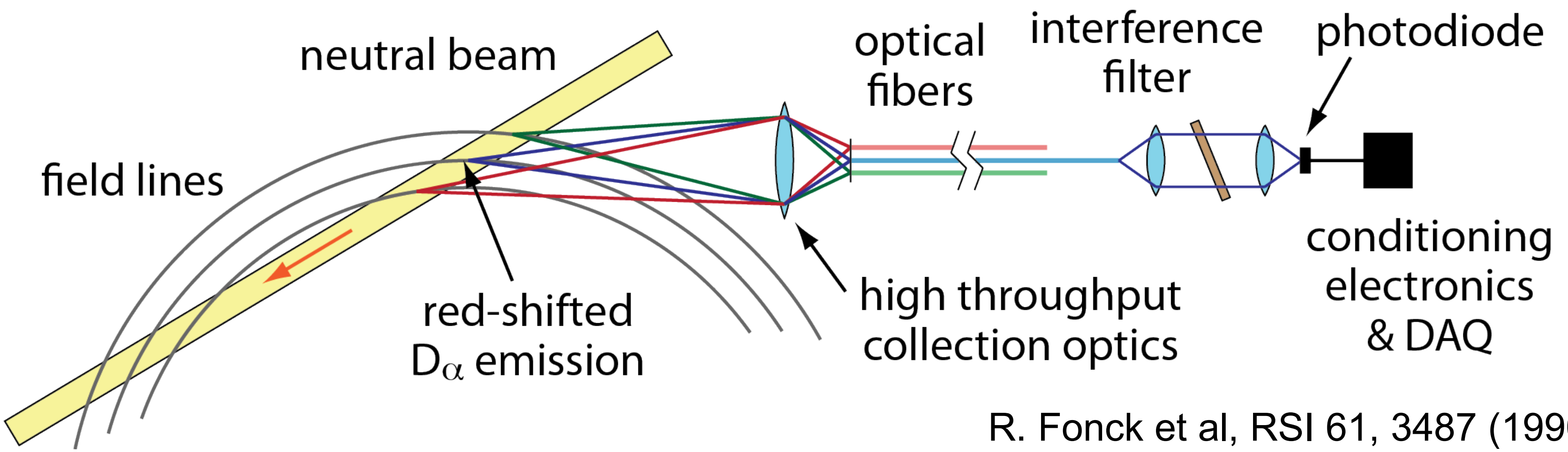


$$\frac{\delta I_{D\alpha}}{I_{D\alpha}} = \frac{\delta n}{n} \times C\left(E_{NB}, n, T_e, Z_{eff}\right)$$

neutral beam D_α emission

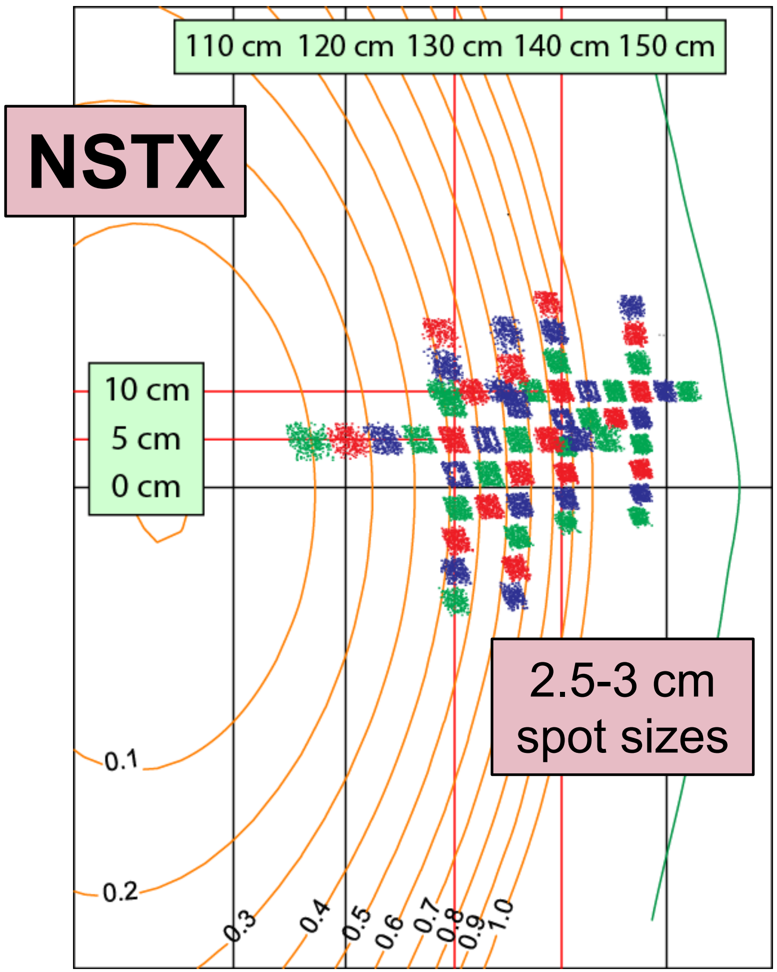
density fluctuation

$C \approx 1/2$

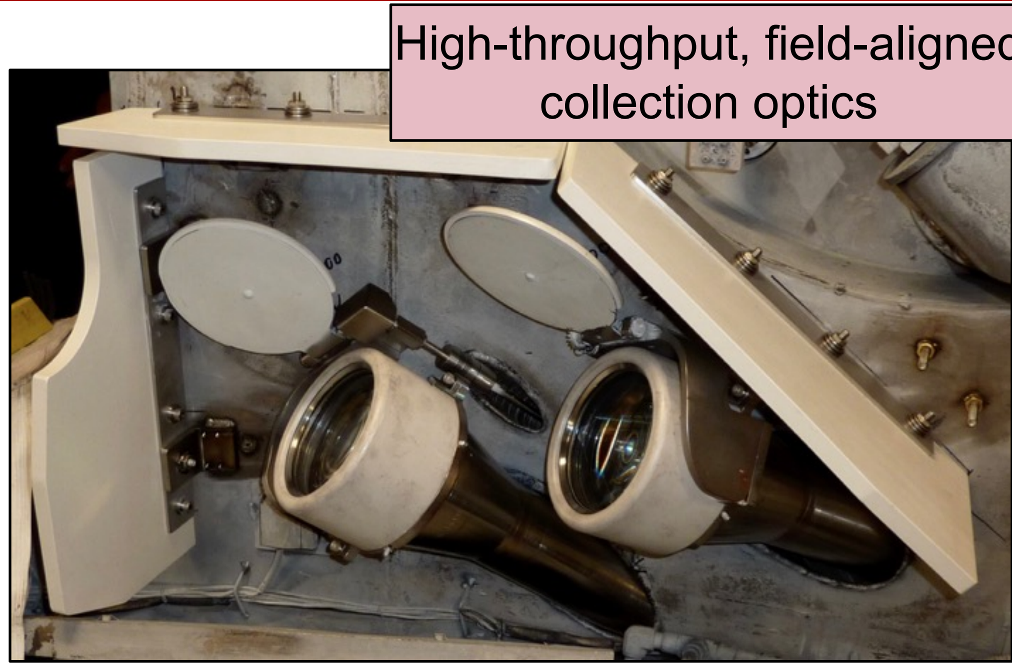


R. Fonck et al, RSI 61, 3487 (1990)
R. Fonck et al, PRL 70, 3736 (1993)

BES is sensitive to density fluctuations with $k_{\perp}\rho_i \leq 1.5$ down to ${}^{\delta n}/_{n} \approx 0.1\%$

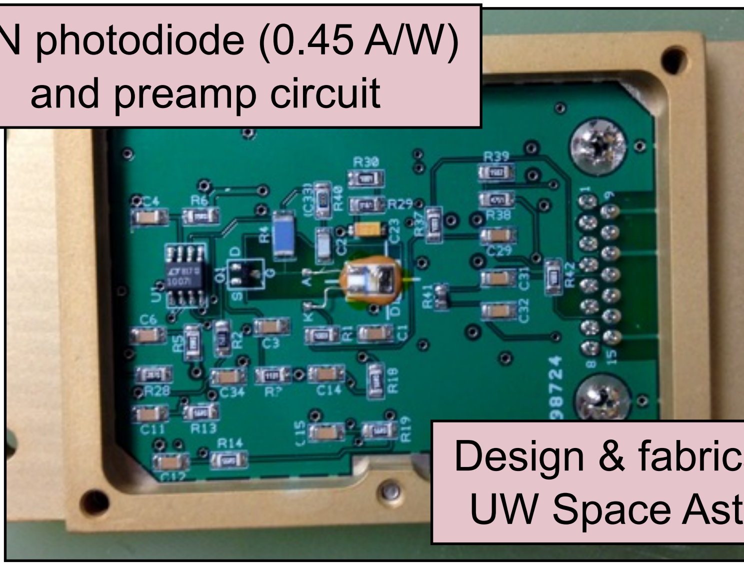


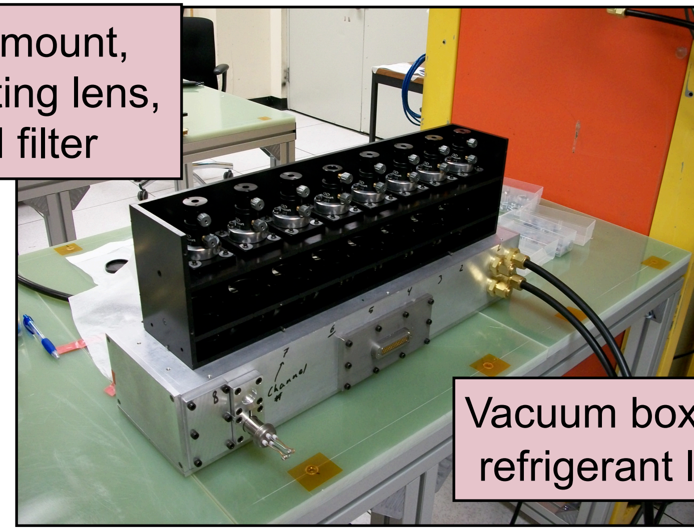
D. Smith et al, RSI 81, 10D717 (2010)
N. Schoenbeck et al, RSI 81, 10D718 (2010)
D. Smith et al, RSI 83, 10D502 (2012)

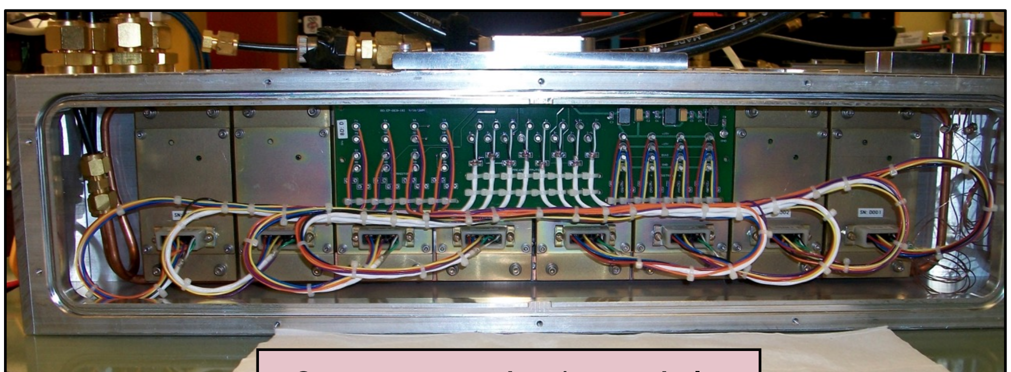


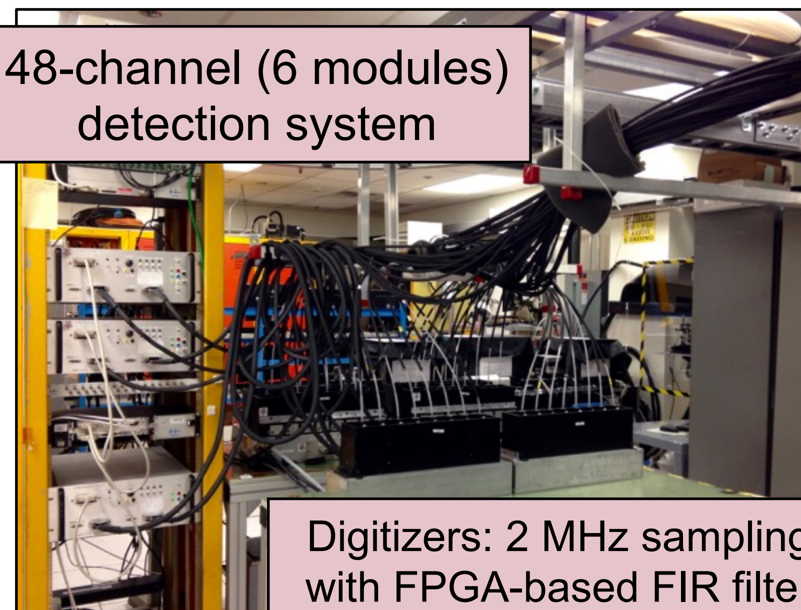
- Sightline layout has wide coverage, but limited locations for correlation analysis
- Only subset of sightlines could be detected at once

Modular hardware design enables simple expansion



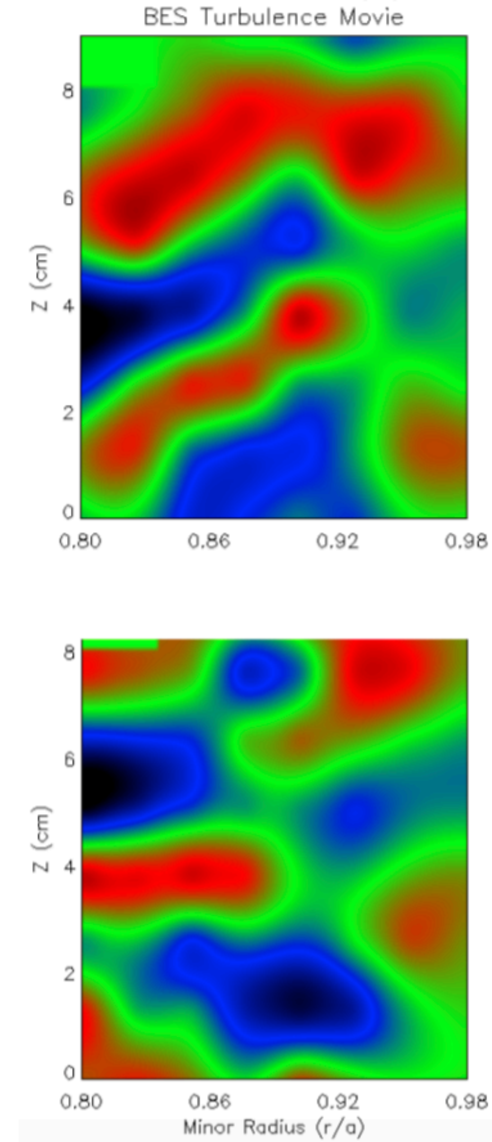






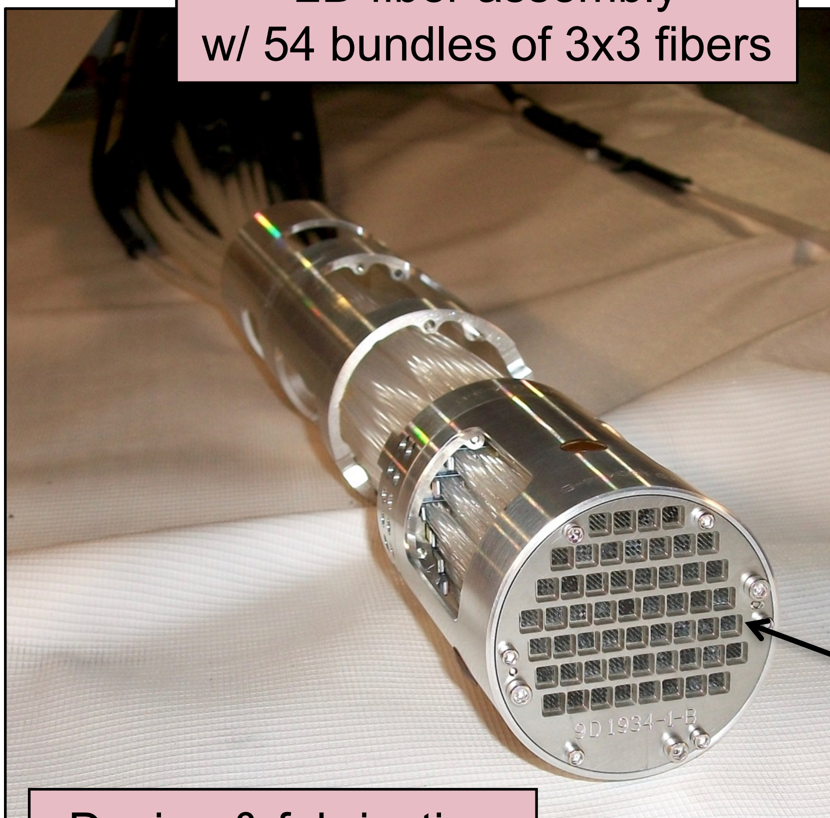
BES expanded and reconfigured for detailed 2D turbulence and instability studies

- 2D turbulence imaging
  - Radial and poloidal dynamics of low-k turbulent eddies important for transport
  - Velocimetry techniques extract flow fields from 2D density measurements
- Zonal flow and L-H dynamics
  - Role of shear flow in L-H transition
  - Stronger zonal flow drive predicted in ST
- Alfvén eigenmode/energetic particle mode structure and dynamics



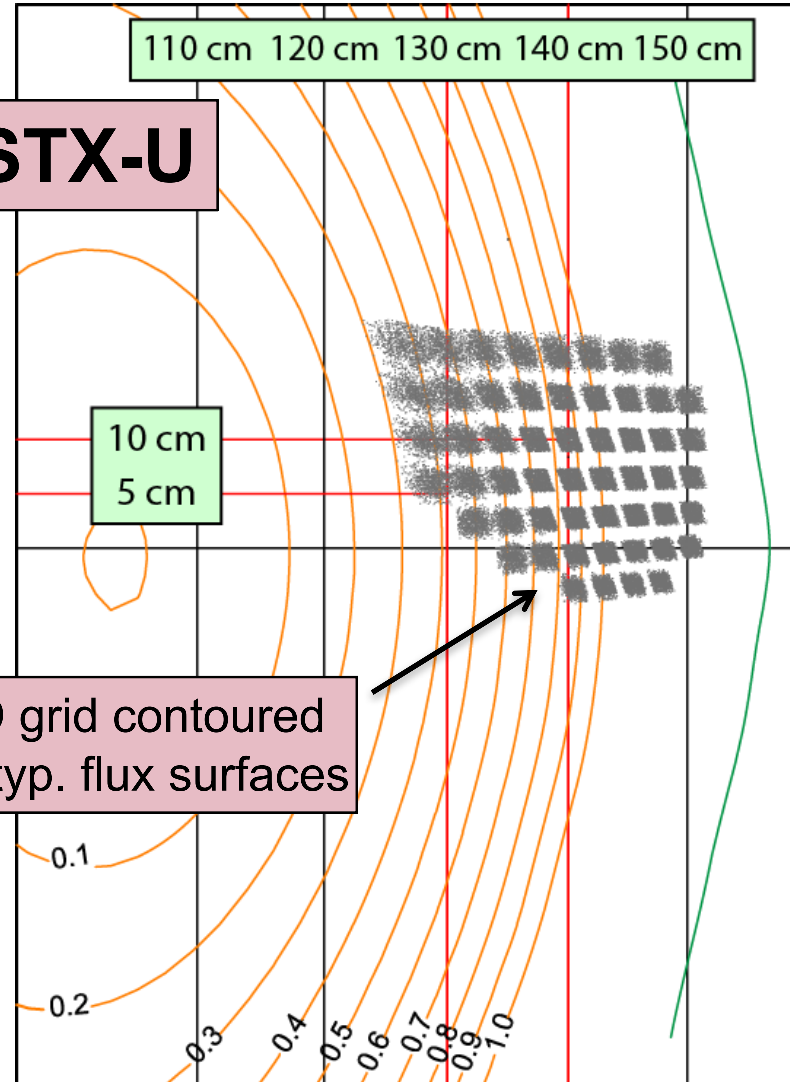
NSTX-U sightlines provide detailed coverage of edge

2D fiber assembly
w/ 54 bundles of 3x3 fibers



Design & fabrication
by UW Phys. Sci. Lab

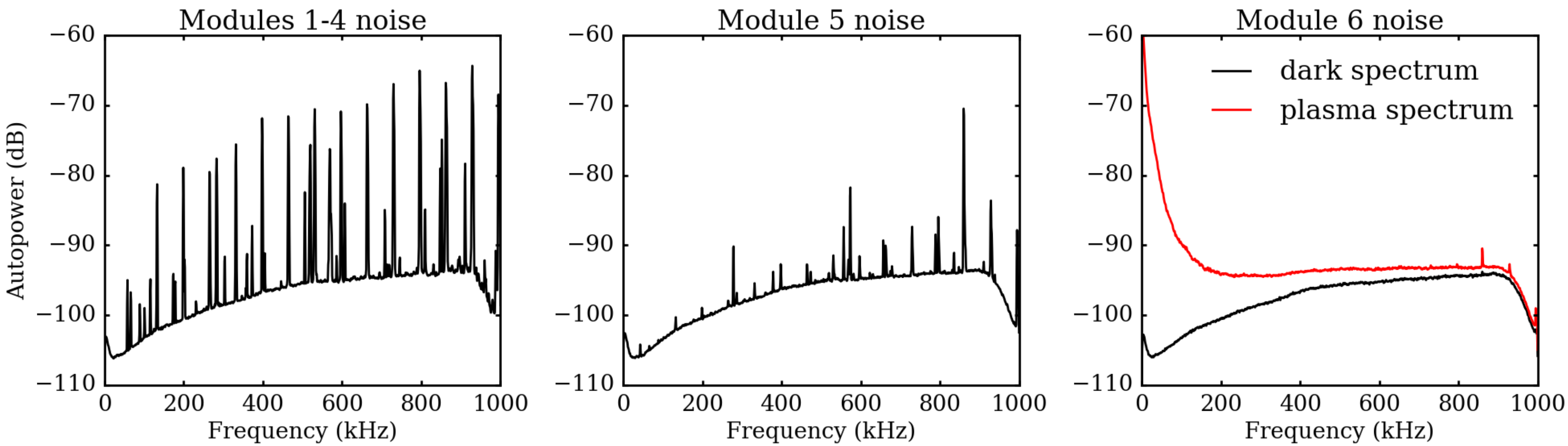
NSTX-U



2D grid contoured
for typ. flux surfaces

Electronic noise eliminated

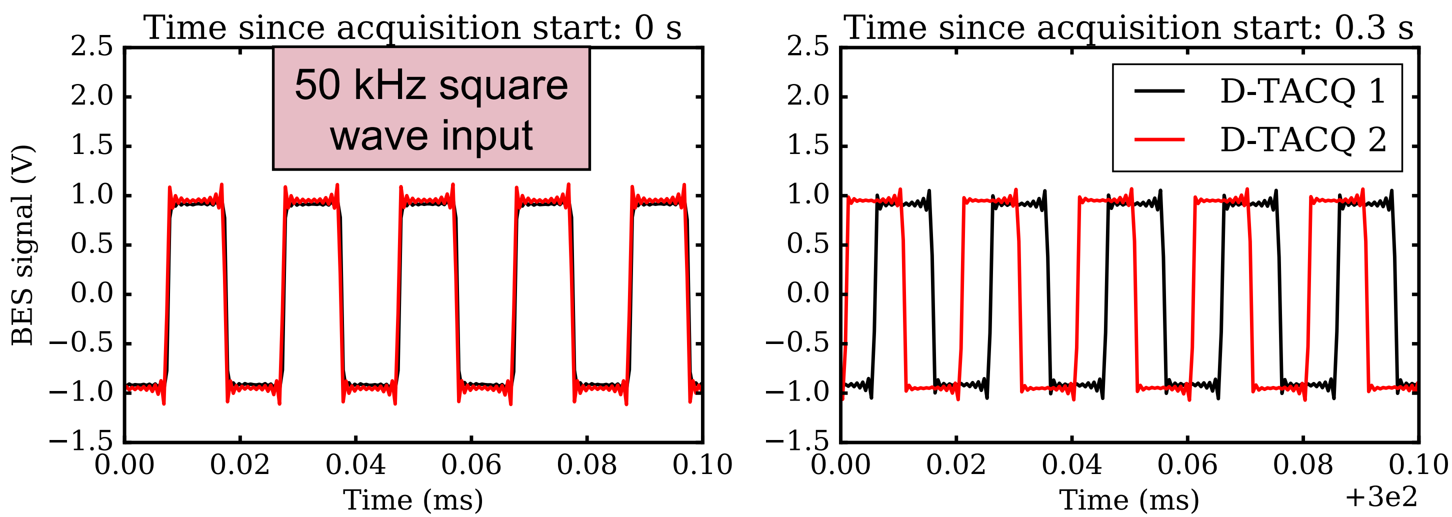
Dark spectrum



- 40/48 channels picked up noise at discrete frequencies
  - Significant noise pickup for 32 channels, moderate for 8 more
- Fixed by changing ground configuration
  - Digitizer power supply noise coupled into system via ground loop

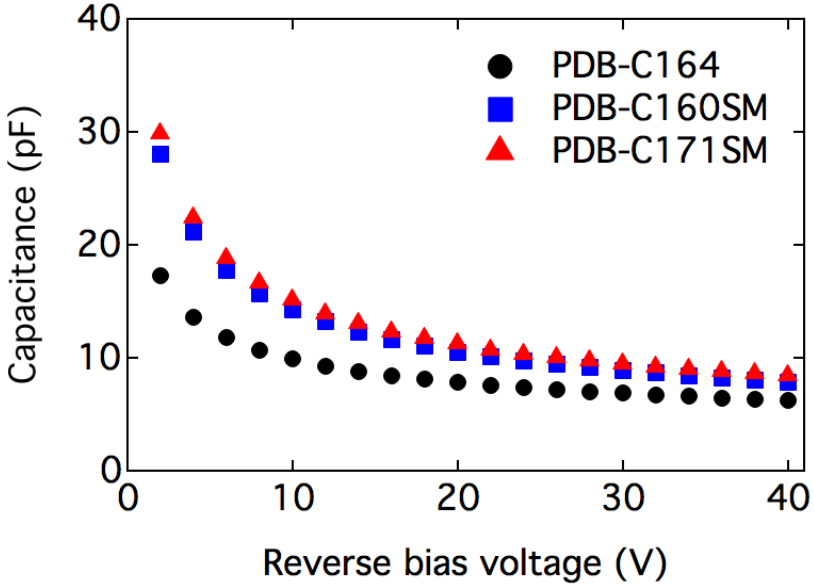
Digitizer sampling frequency mismatch debugged

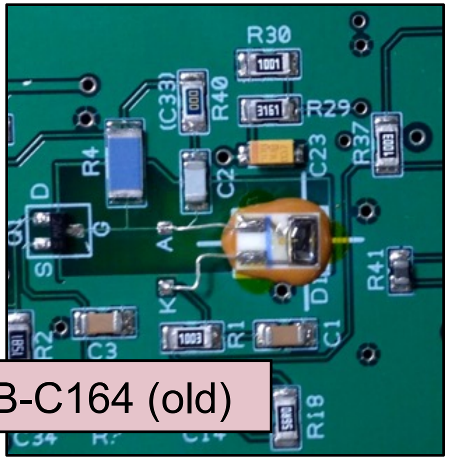
- BES uses two D-TACQ ACQ132 digitizers (f_s = 2 MHz)
  - Correlation analysis requires synchronized sampling of data
- 50 Hz f_s mismatch between digitizers
  - Solved by testing variety of triggering/software configurations



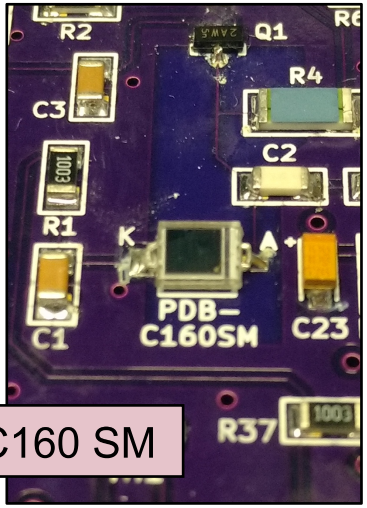
Replacement photodiode tested

- Detector photodiode discontinued, need replacement
  - High sensitivity at 656 nm (D_α)
  - Low capacitance at 40 V reverse bias
  - Low dark current





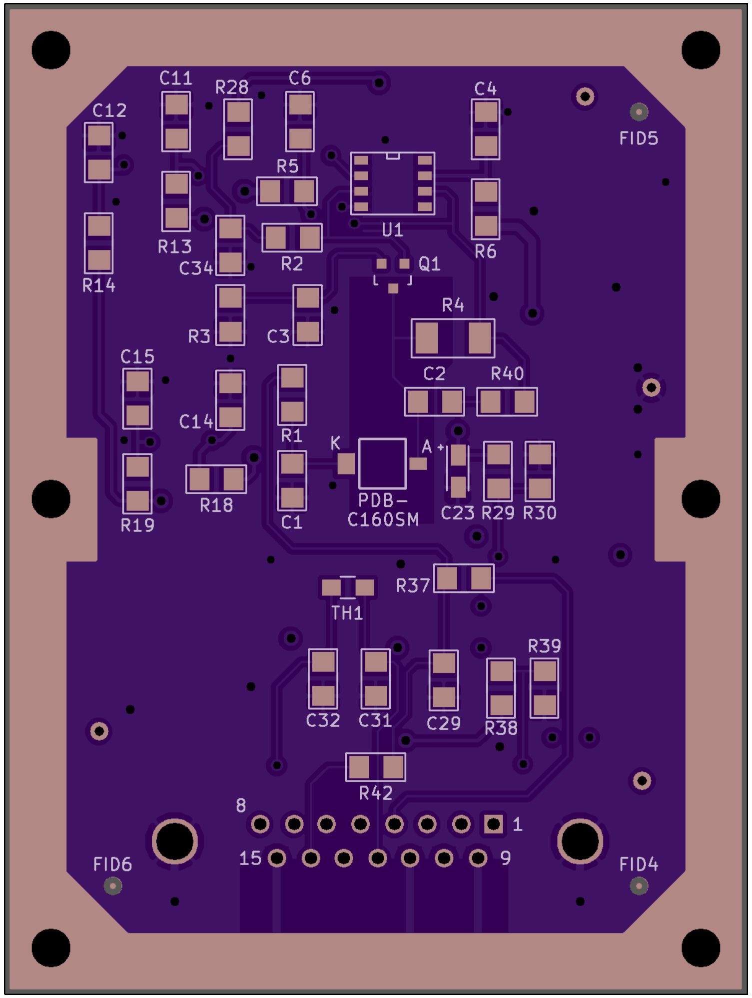
PDB-C164 (old)



PDB-C160 SM

Electronic Design Automation (EDA) enables rapid prototyping and automated assembly

- Preamp design in KiCad EDA
  - Open source
  - Links together schematic, PCB layout, assembly instructions, and component distributors
- Easily test new photodiodes
- Future BES expansion to 64 channels at lower cost



Feasibility of high-speed impurity density measurements will be investigated

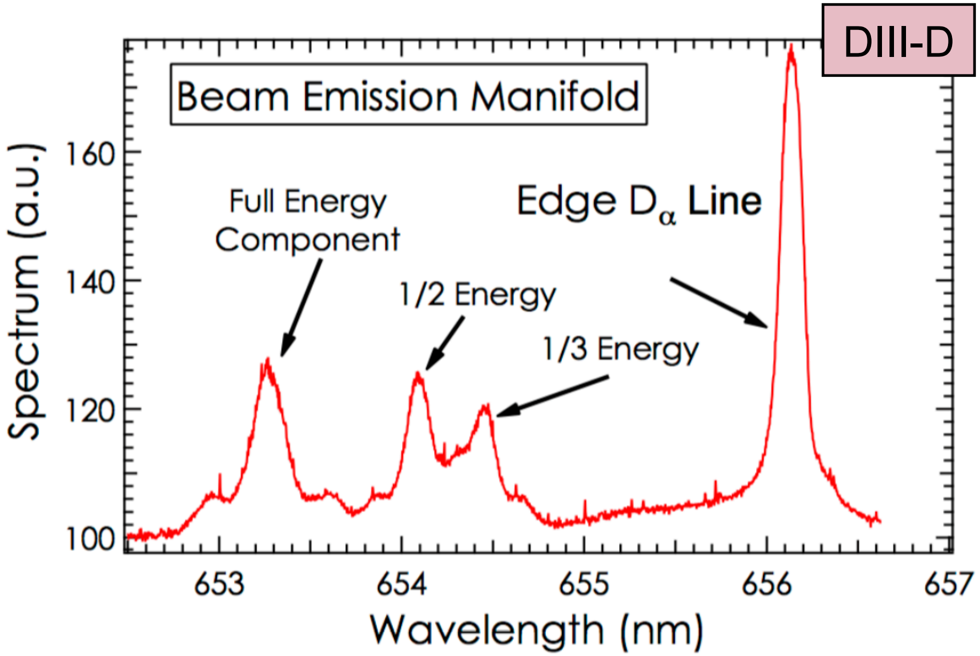
- High-speed, localized, multi-channel impurity measurements
  - Add new optical filters to BES detectors to isolate CX or impurity lines
- Explore impurity sources, transport, and dynamics
  - Impurity expulsion/accumulation in ELMy/ELM-free regimes
  - Characteristics of lithium, boron, carbon, and metal PFC sources
  - Connection between impurity transport and low-k turbulence
- Suitable CX or impurity lines must first be identified

Survey spectrometer utilizing existing BES sightlines to be deployed

- Measure beam emission manifold in NSTX-U
  - Determine intensity of carbon lines overlaping beam components
  - Provide data on line splitting for new Ẽ diagnostic[1]

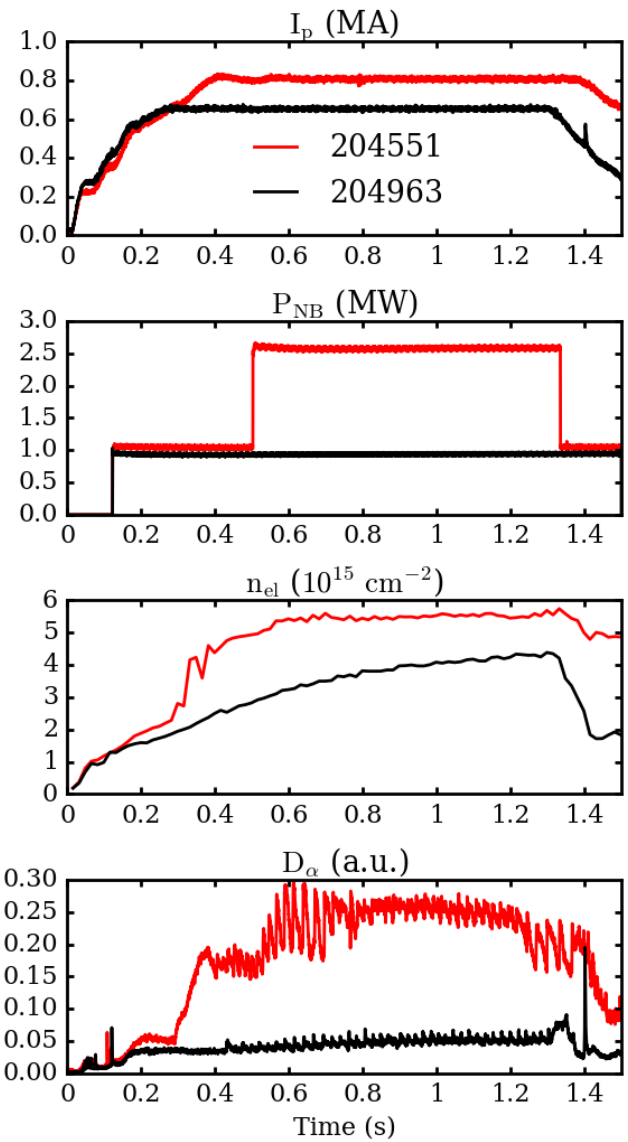
- Potential CX lines
  - C-VI, O-VIII, Li-III, He-II
  - Ne-X, Al-XI, Li-I, W-I

- Spectrometer specs
  - Focal length: ≈ 0.5 m
  - f-number: f/4–f/8
  - Spectral resolution: < 0.05 nm

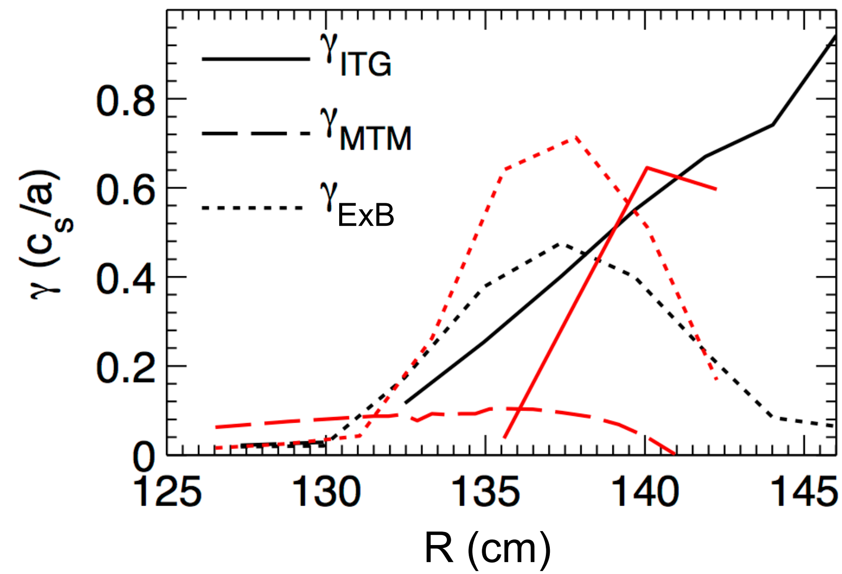


[1]See Burke, NP10.57

BES detects turbulence where ITG and MTM are predicted unstable in NSTX-U L-mode discharges

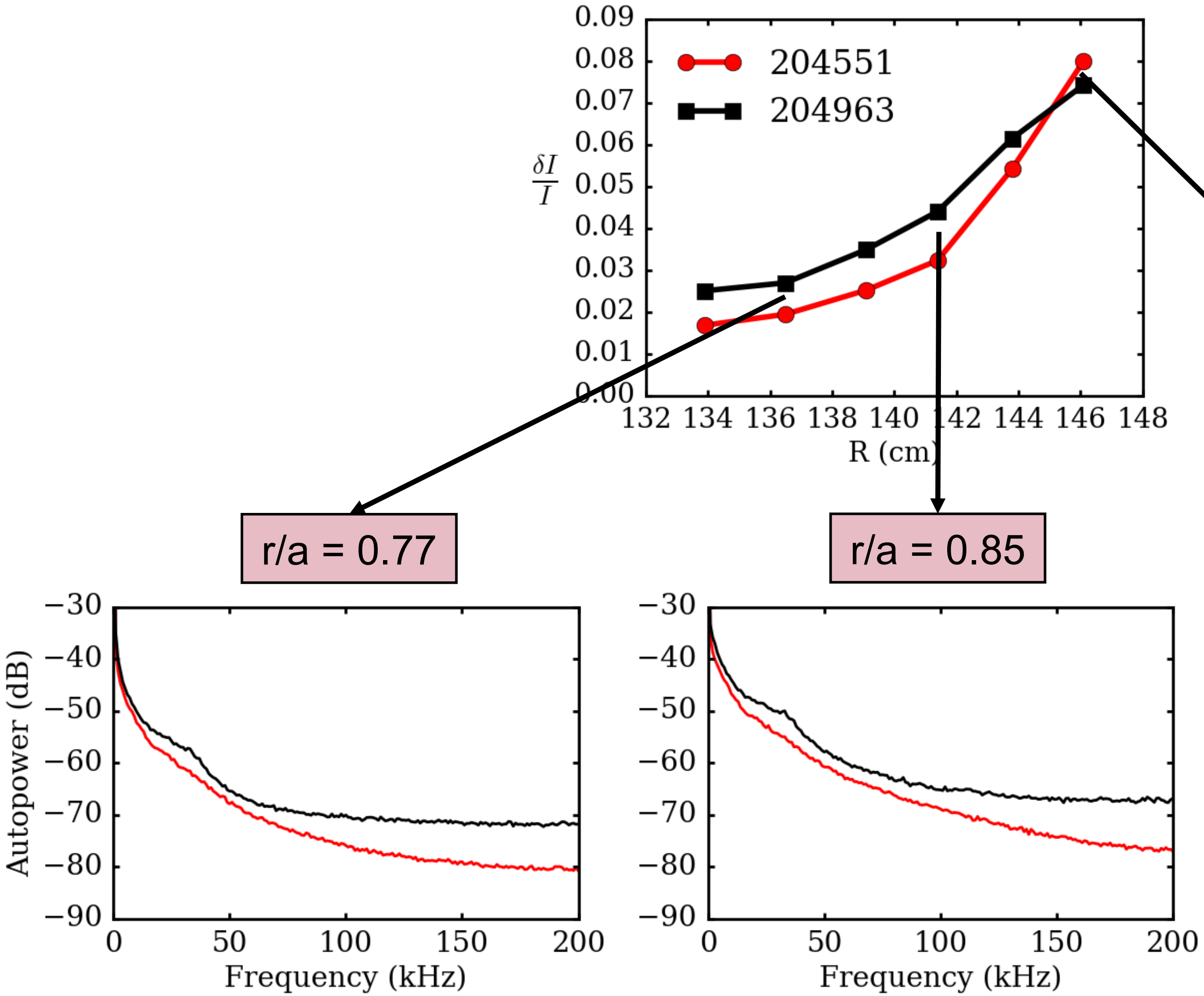


- Local, nonlinear GYRO simulations[1]
  - $\beta_N \approx 2 \rightarrow$ EM effects destabilize MTM
  - 204963 has lower T_i/T_e, broader range where ITG is unstable



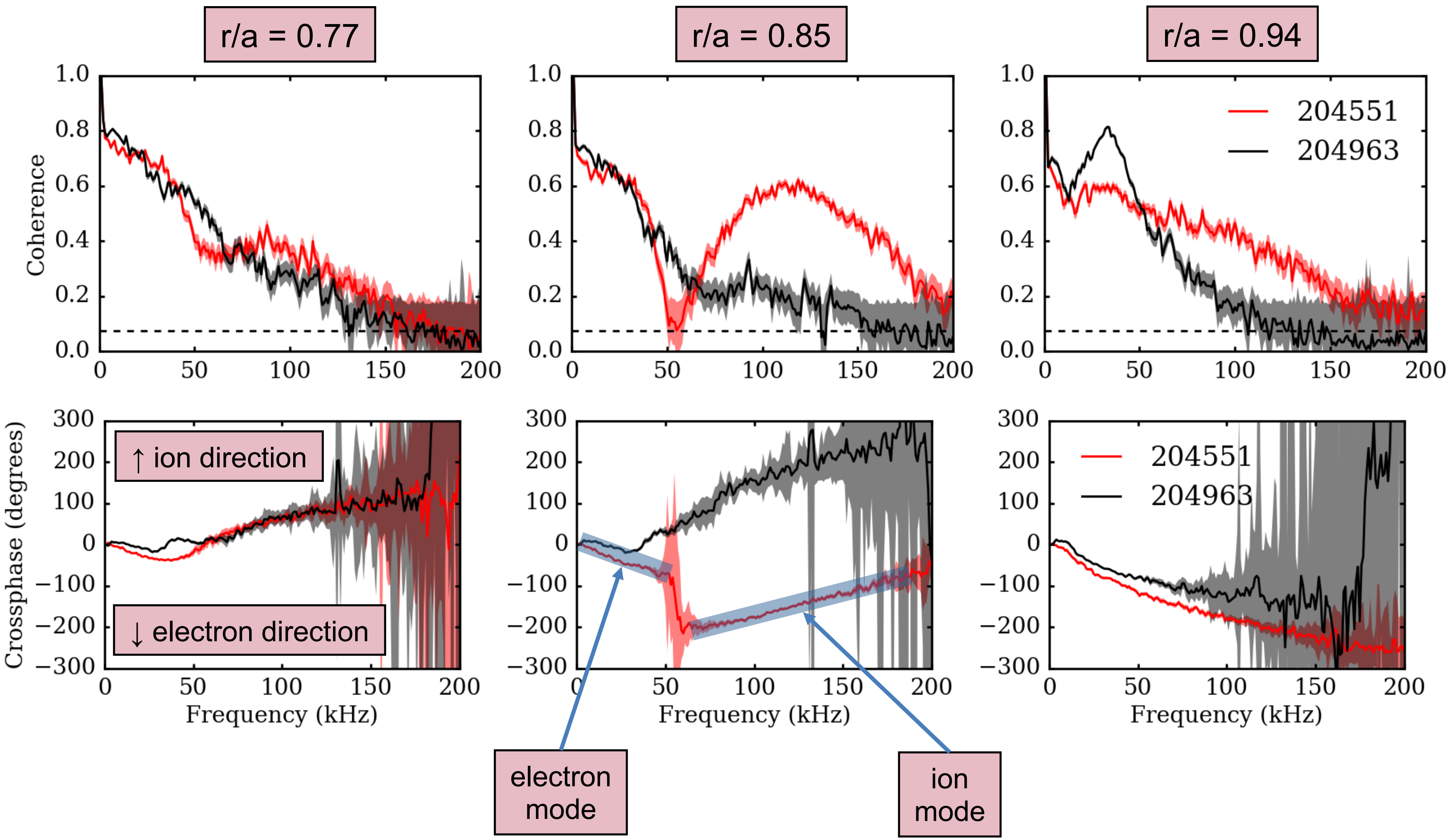
[1]See W. Guttenfelder, GO6.4, (Tues AM)

Autopower spectra show increasing broadband fluctuation amplitudes toward the edge



- Δt: 0.9–1.2 s
- Conditional sampling to remove sawteeth

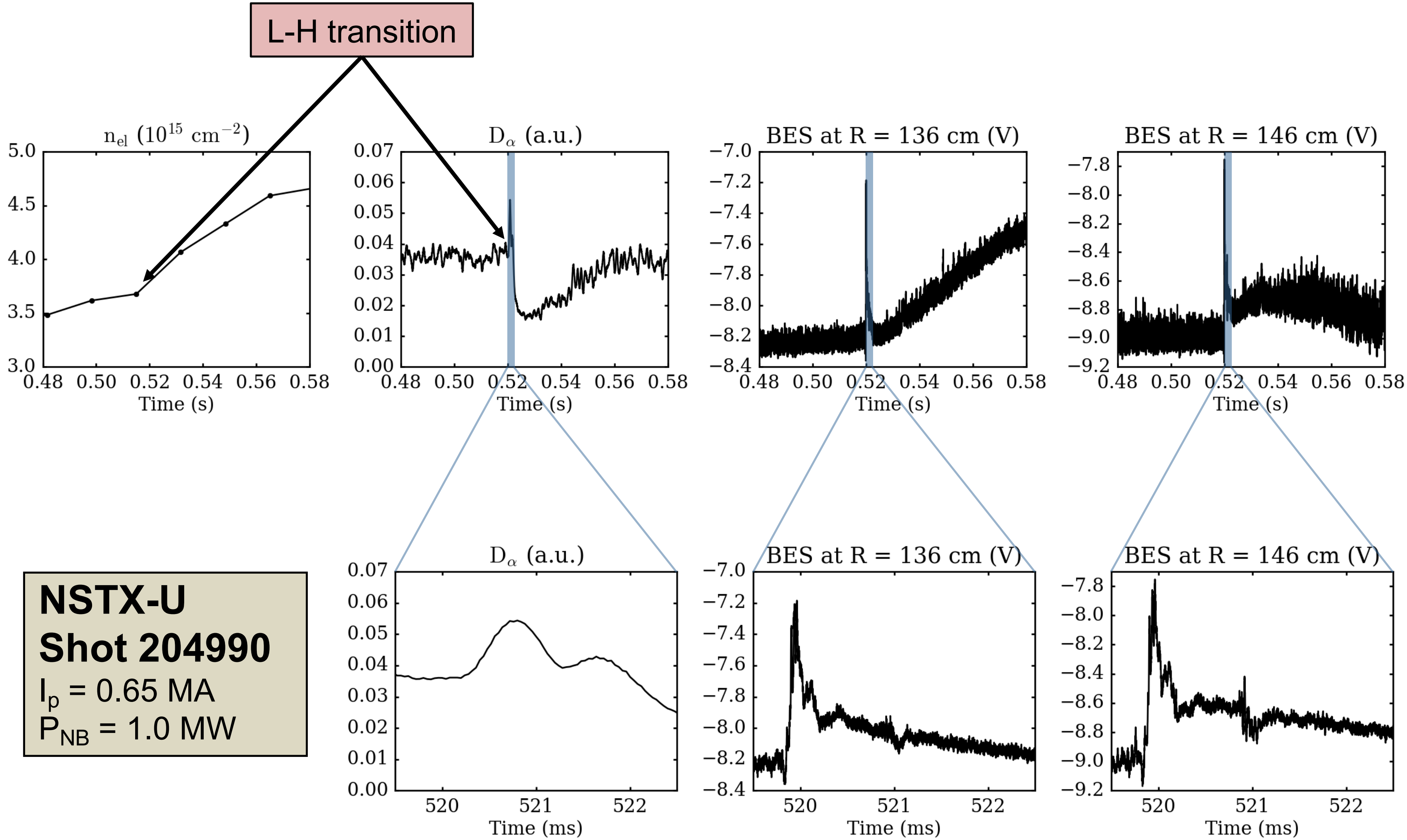
Bimodal, counter-propagating turbulence is observed



Observations of ion-scale turbulence show some consistency with GK simulations

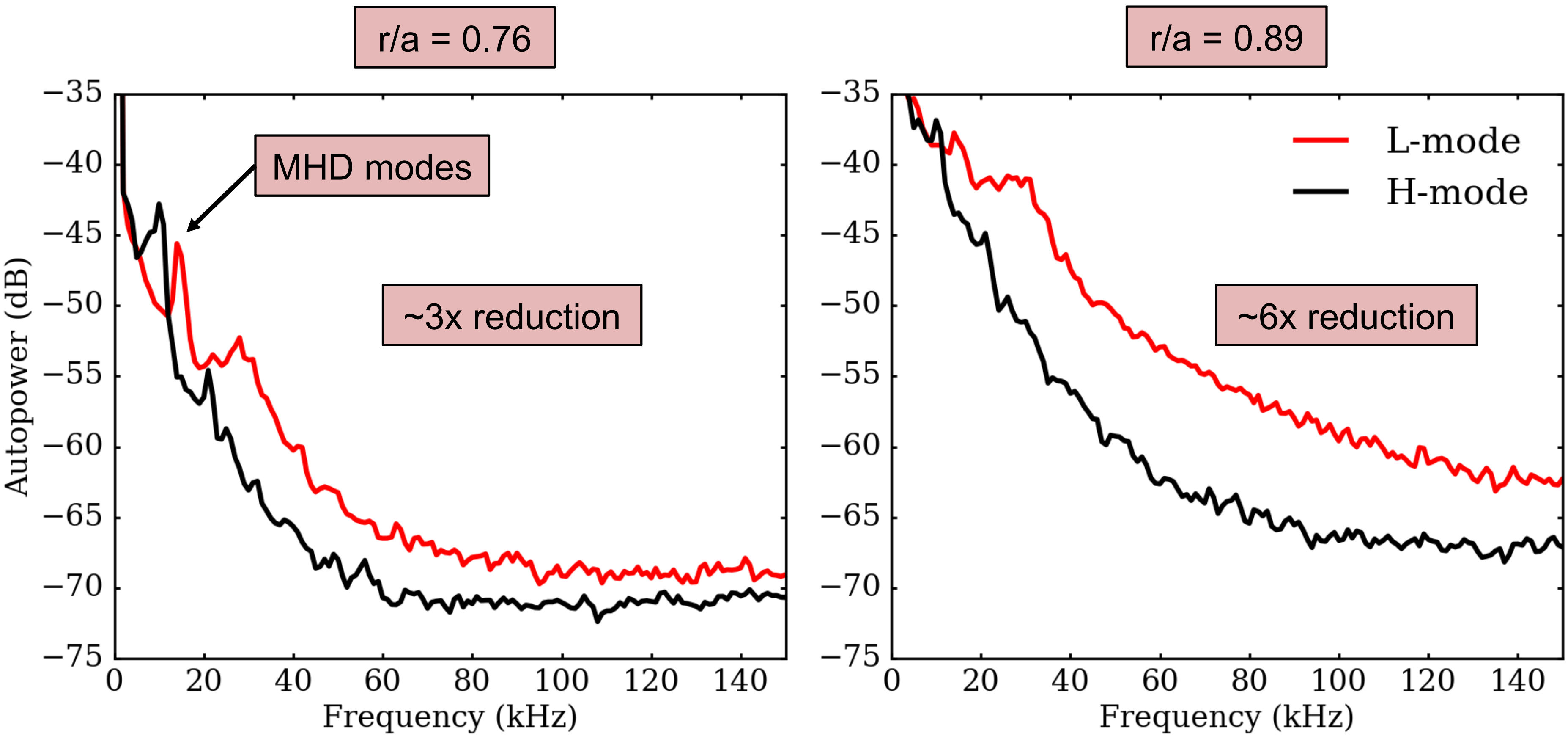
- Ion directed mode in 204551 shows up most clearly in region where simulation predicts $\gamma_{ITG} > \gamma_{ExB}$
- Turbulence amplitudes are higher in 204963, which has larger ITG growth rate and less ExB shear
- However, electron mode seen in region where MTM is predicted stable
  - Effects of edge-induced common-mode fluctuations will be investigated in future

BES detects fast dynamics of the L-H transition



NSTX-U
Shot 204990
I_p = 0.65 MA
P_{NB} = 1.0 MW

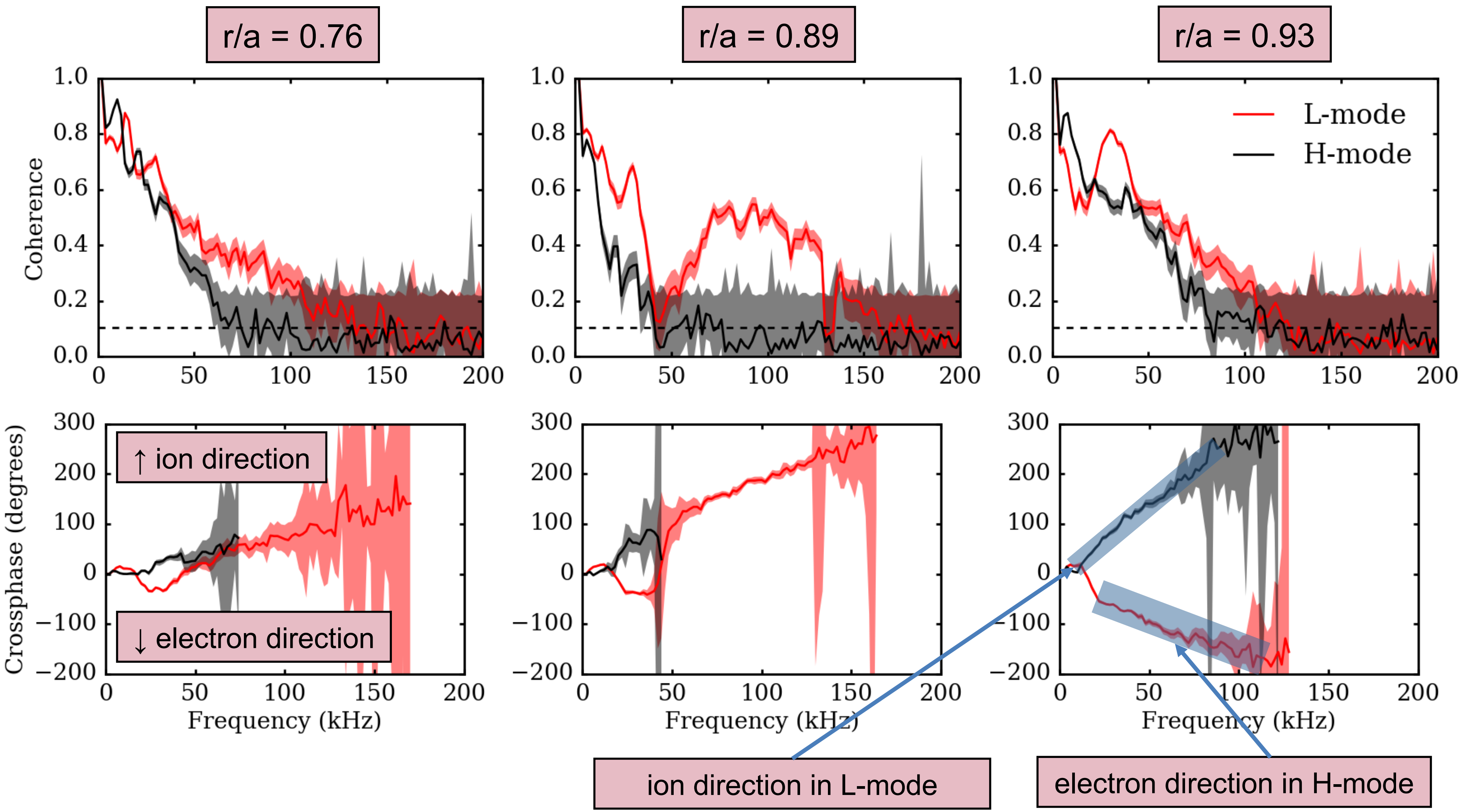
Turbulence amplitudes decrease after L-H transition



L-mode: Δt = 448–518 ms

H-mode: Δt = 522–592 ms

In contrast to L-mode, H-mode exhibits unimodal turbulence in ion direction



Summary

- 2D BES fully operational for future run campaigns
- Spectrometer to be used to scope out emission spectrum for future fast impurity diagnostic
- L-mode plasmas show bimodal turbulence, consistent with GYRO simulations
  - Observed ion directed mode consistent with ITG prediction
- After L-H transition, turbulence nature changes from electron to ion directed mode and amplitudes drop