NSTX-U

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

Experimental Observation of High-k Turbulence Evolution across L-H Transition in NSTX

Y. Ren[1]

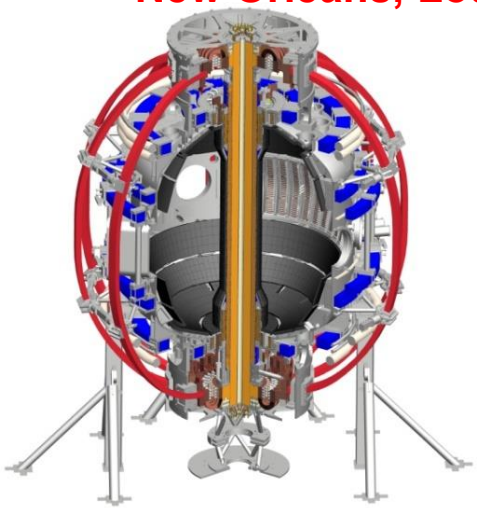
R.E. Bell[1], D.R. Smith[2], S.J. Zweben[1], W. Guttenfelder[1], S.M. Kaye[1], B.P. LeBlanc[1], E. Mazzucato[1], K.C. Lee[3], C.W. Domier[4], L. Shao[5], H. Yuh[6] and the NSTX Team

1. PPPL 2. UW-Madison 3. NFRI 4. UC-Davis 5. ASIPP 6. Nova Photonics

56th Annual Meeting of the APS Division of Plasma Physics
New Orleans, Louisiana, October 27-31, 2014

Coll of Wm & Mary
Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Lehigh U
Nova Photonics
Old Dominion
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Tennessee
U Tulsa
U Washington
U Wisconsin
X Science LLC

Culham Sci Ctr
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Inst for Nucl Res, Kiev
Ioffe Inst
TRINITI
Chonbuk Natl U
NFRI
KAIST
POSTECH
Seoul Natl U
ASIPP
CIEMAT
FOM Inst DIFFER
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep



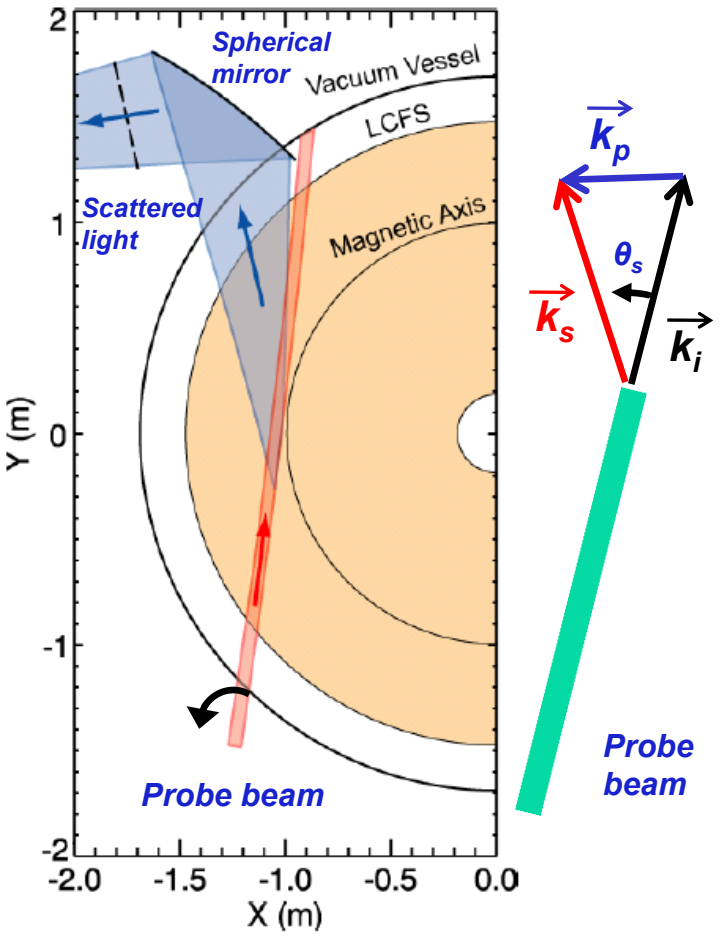
Highlights

- First detailed measurements of high-k (electron-scale) turbulence across L-H transition in NSTX
  - L-H transition at current flattop
  - High-k turbulence quasi-stationary before L-H transition, intermittent after L-H transition and significantly suppressed ~15 ms after L-H transition
  - Suppression of high-k turbulence at lower wavenumbers, i.e. $k_\perp \rho_s \leq 9\text{-}10$
- Low-k turbulence measured by BES and GPI at different radii but similar temporal behavior with high-k measurement
  - Showing suppression of low-k turbulence into H-mode at r/a>0.8
- Linear stability analysis using GS2 code showing some consistency with turbulence measurements
  - Decreased ETG growth rate into H-mode
  - Low-k turbulence more suppressed by ExB shear into H-mode

Turbulence Diagnostics in the Experiment Cover from Low-k to High-k

Turbulence Diagnostic configuration for the experiment

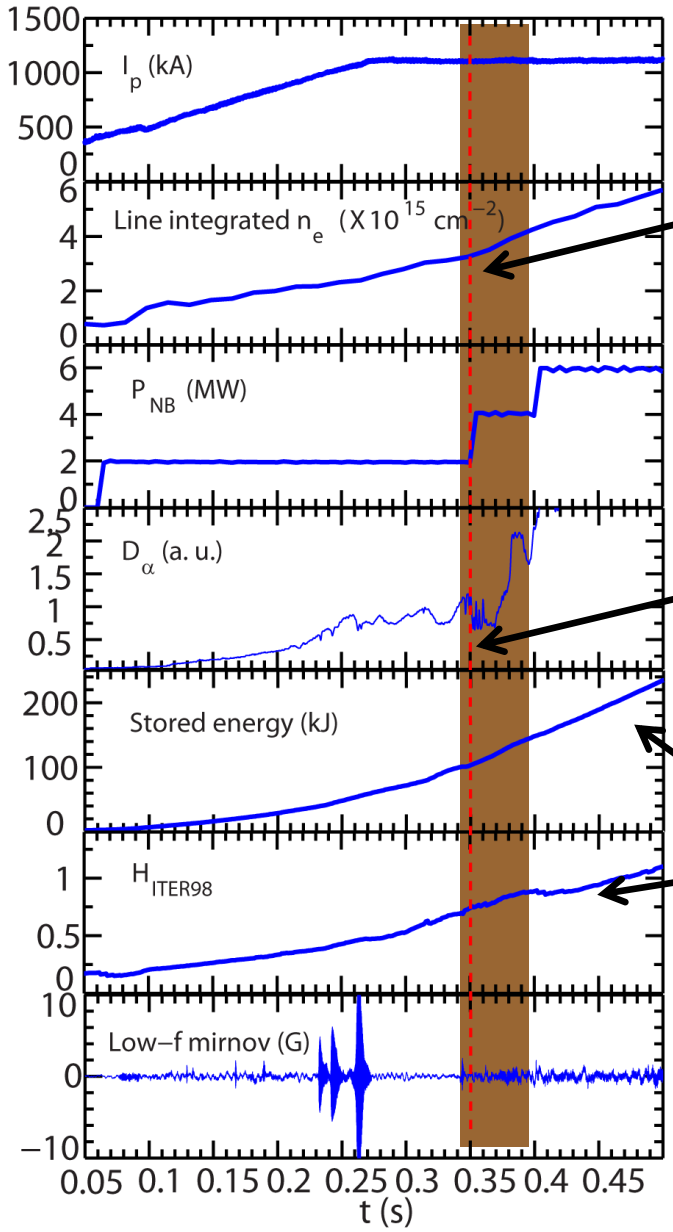
High-k turbulence measurement			
	r/a	Measured quantity	Spatial & temporal resolution
280 GHz Microwave scattering system	~0.7-0.8 (core-edge transition region)	Density fluctuation	$3 \le k_\perp \rho_s \le 12$ $\Delta R \sim \pm 2$ cm f~ 5 MHz
Low-k turbulence measurement			
BES	>0.8	Density fluctuation	ΔR~ 1cm f~ 1 MHz
GPI	>0.8	GPI D_α emission	ΔR~ 1 cm f~ 500 kHz



D.R. Smith, PhD thesis, 2009

L-H Transition is Triggered by NBI Power Step-up during Current Flattop

- L-H Transition at current flattop reduces measurement complications
- Better high-k measurement due to favorable Doppler frequency shift
- Less MHD activity



Shot=139442

B_T =5.5 kG

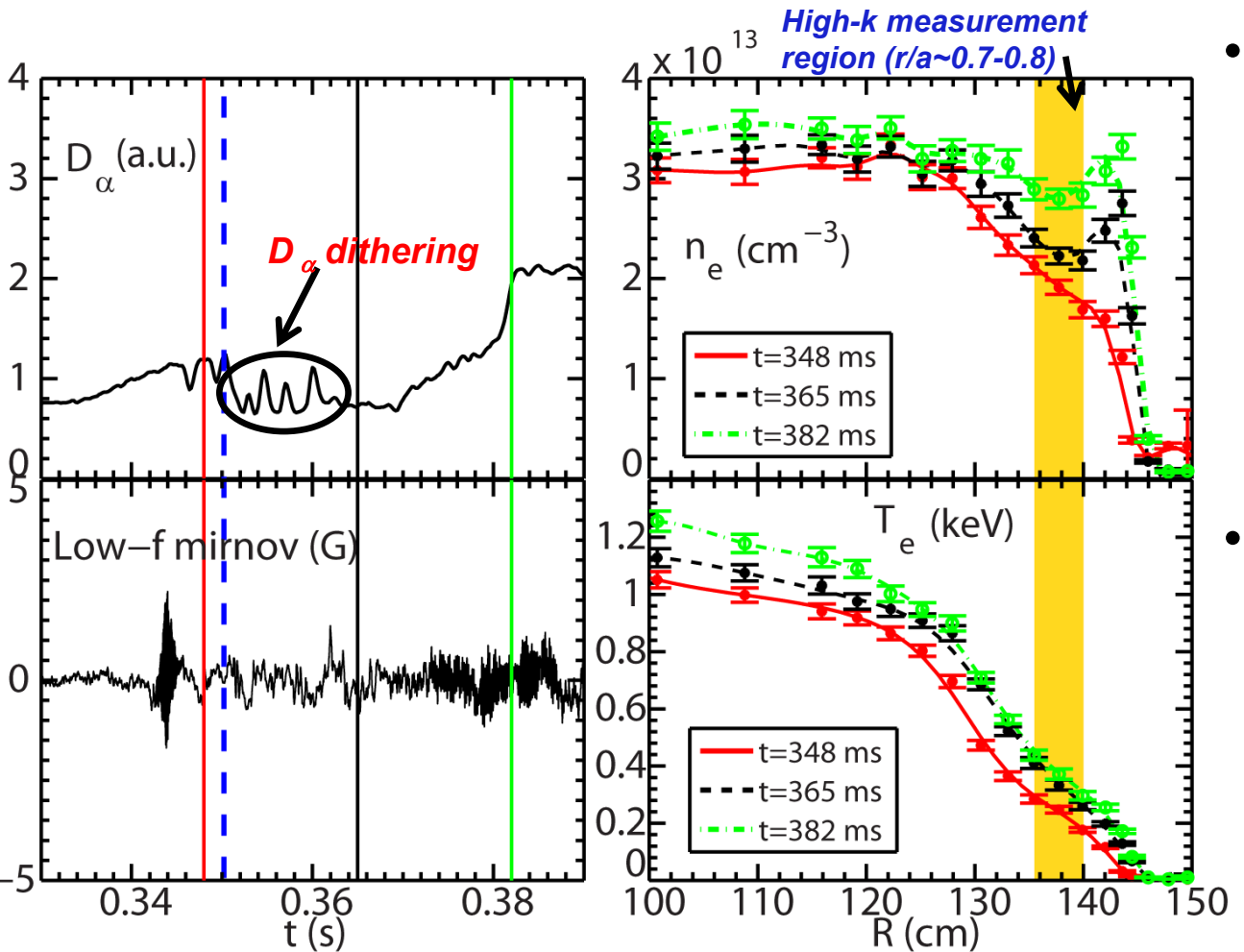
Time range of interest

L-H transition

From TRANSP

Edge Transport Barrier (ETB) is Established after the Dithering Phase

- Spikes in divertor D_α after the L-H transition show the dithering feature of the L-H transition
- Low-f MHD activity is relatively benign after the L-H transition

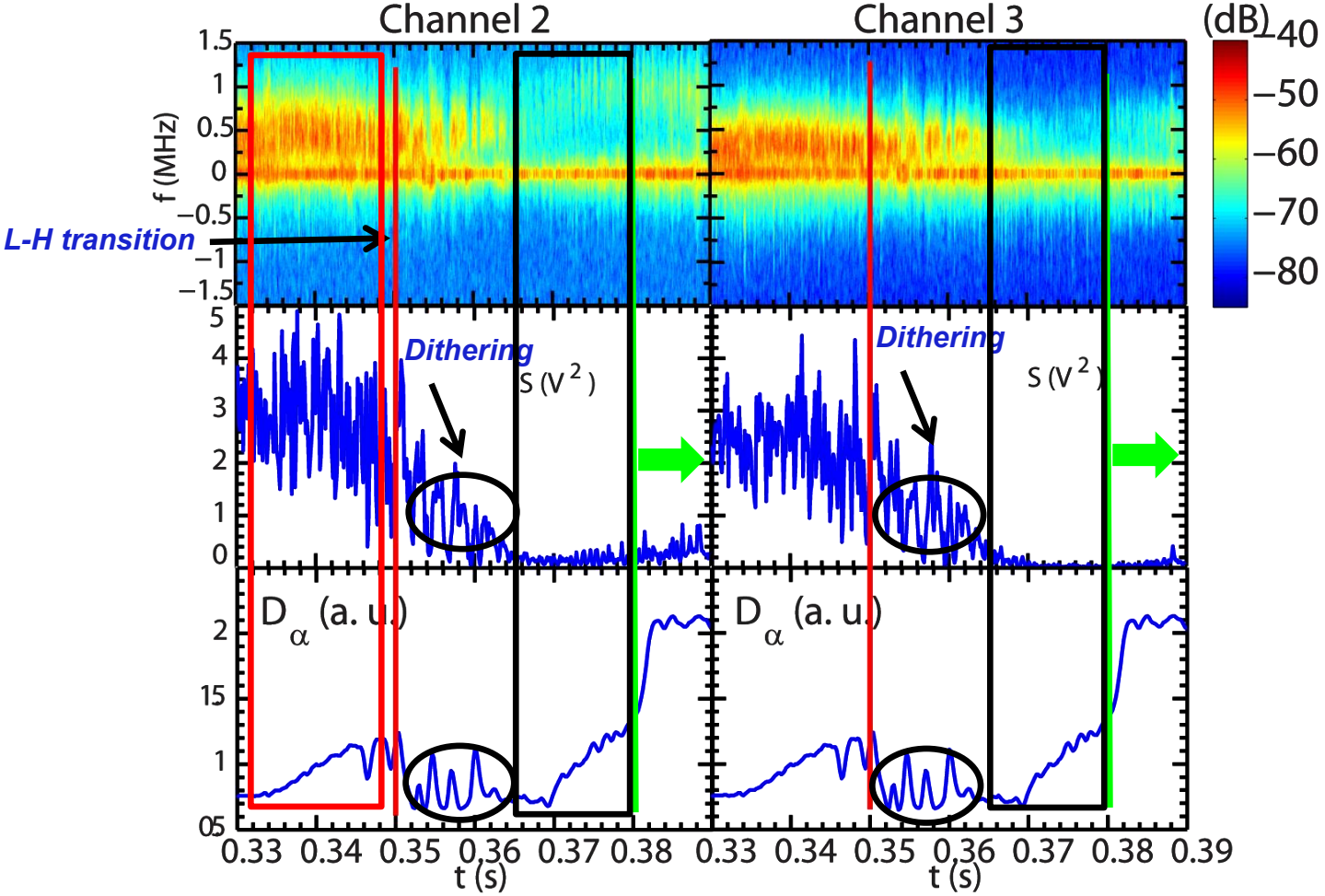


- Clear H-mode density ear appears at t=365 ms, showing the establishment of ETB
  - The density ear due to edge accumulation of carbon impurity
- High-k scattering system measures turbulence k spectrum at r/a~0.7-0.8 and ETB is at r/a>0.9

LCFS at R=146 cm

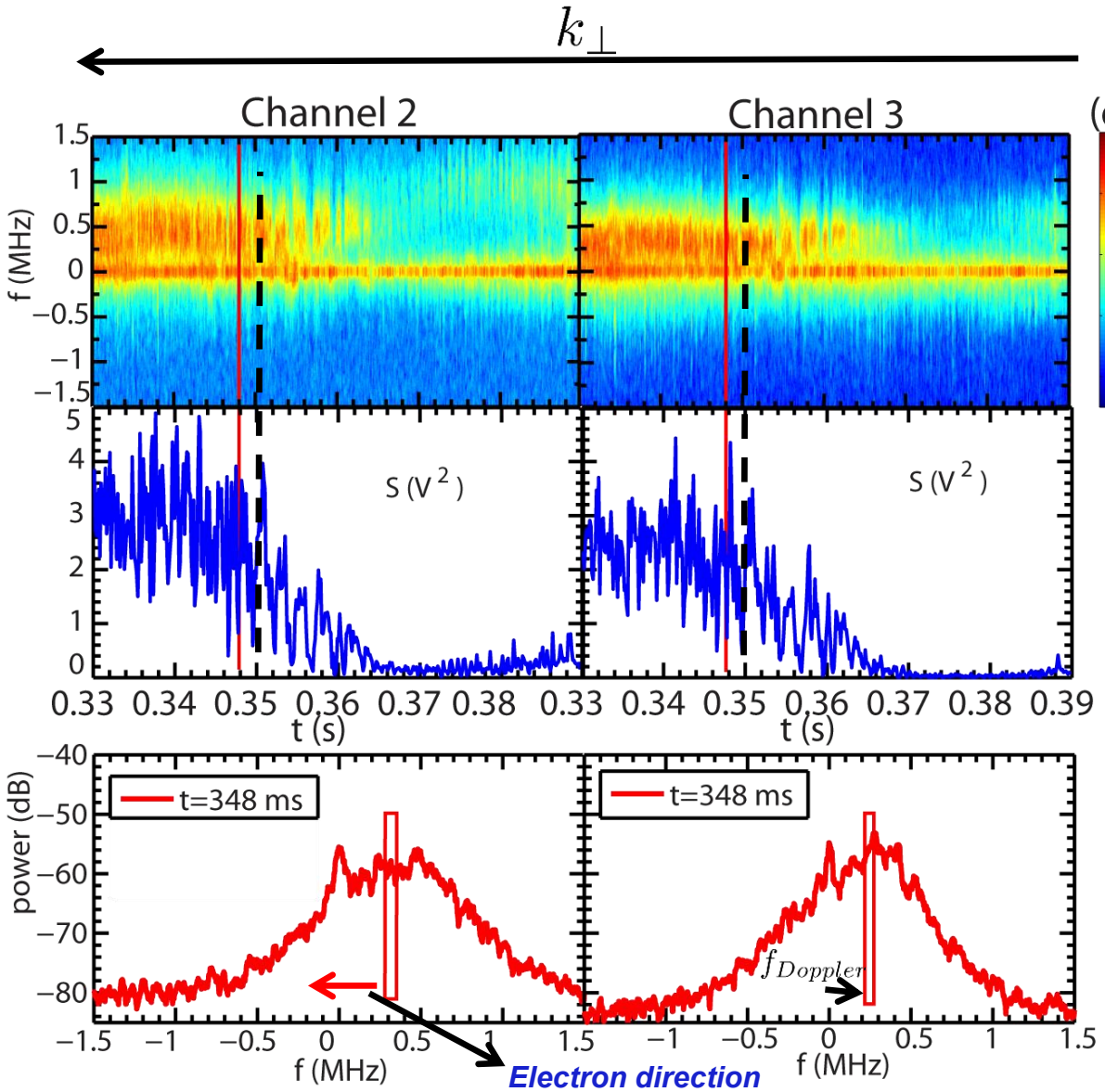
Four Phases in the High-k Turbulence Evolution can be Identified

- Quasi-stationary turbulence before the L-H transition
- Dithering in high-k spectral power observed after L-H transition
- Significant suppression of high-k turbulence in 365<t<380 ms
- Some increase in turbulence at t>380 ms

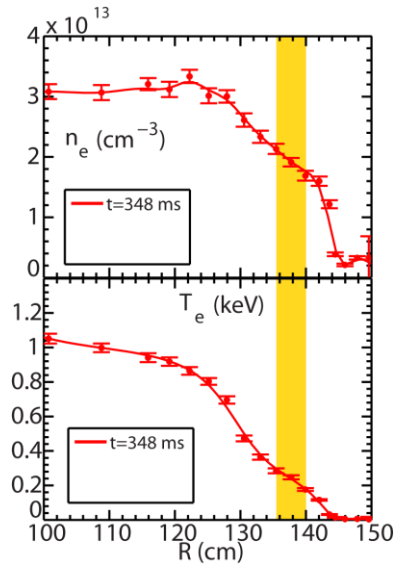


- *Off-center peak denotes the scattered signal*
- *f=0 peak is from stray radiation*

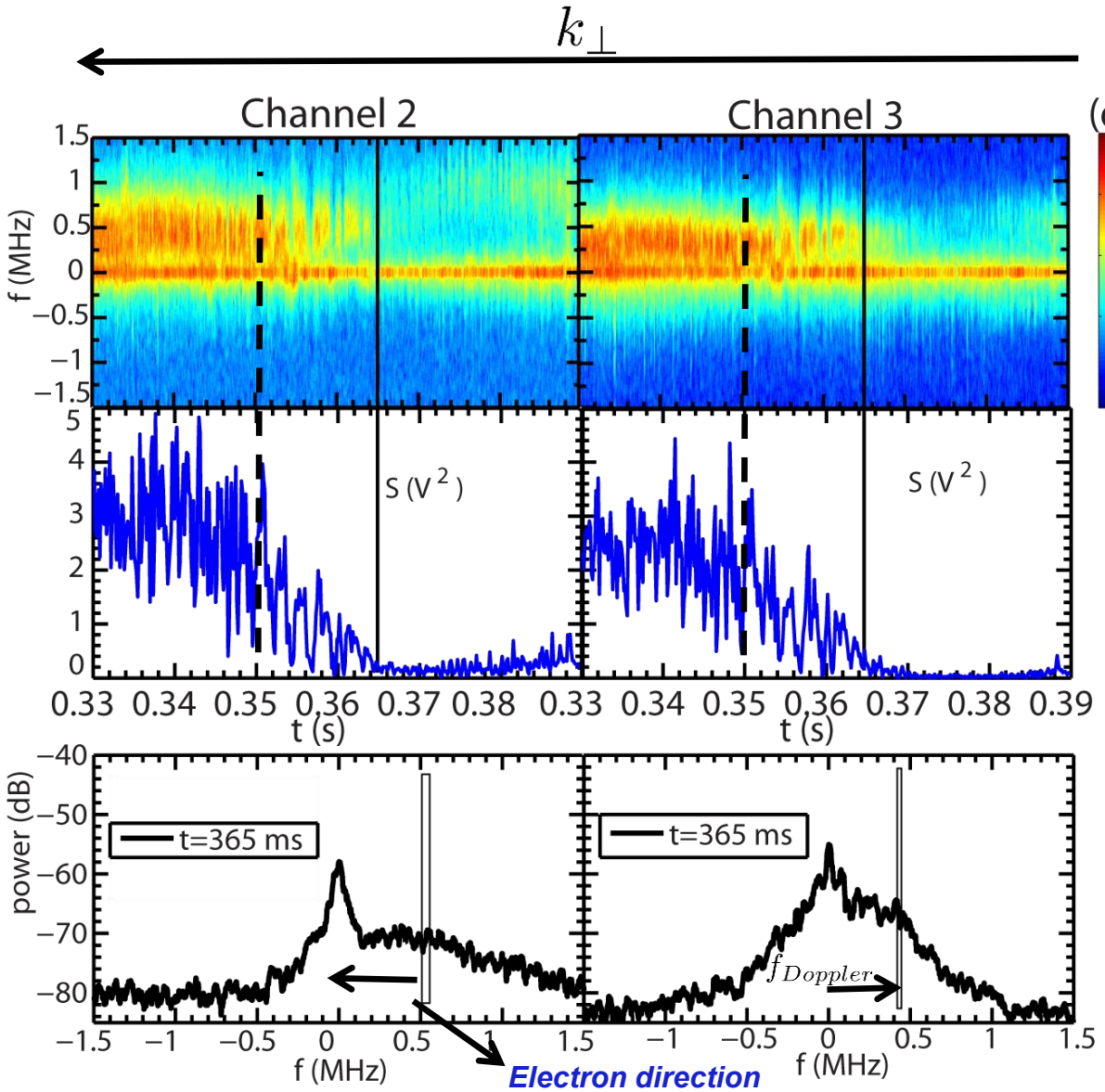
Broad Band High-k Turbulence is Seen across the L-H Transition



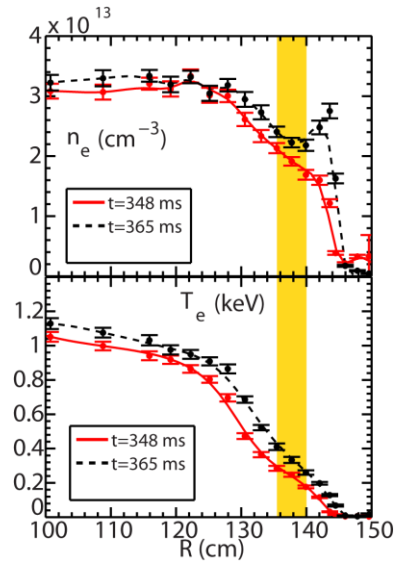
- Frequency spectra are shown for an exact Thomson time point: t=348 ms
- Mean real frequency much smaller than Doppler frequency shift



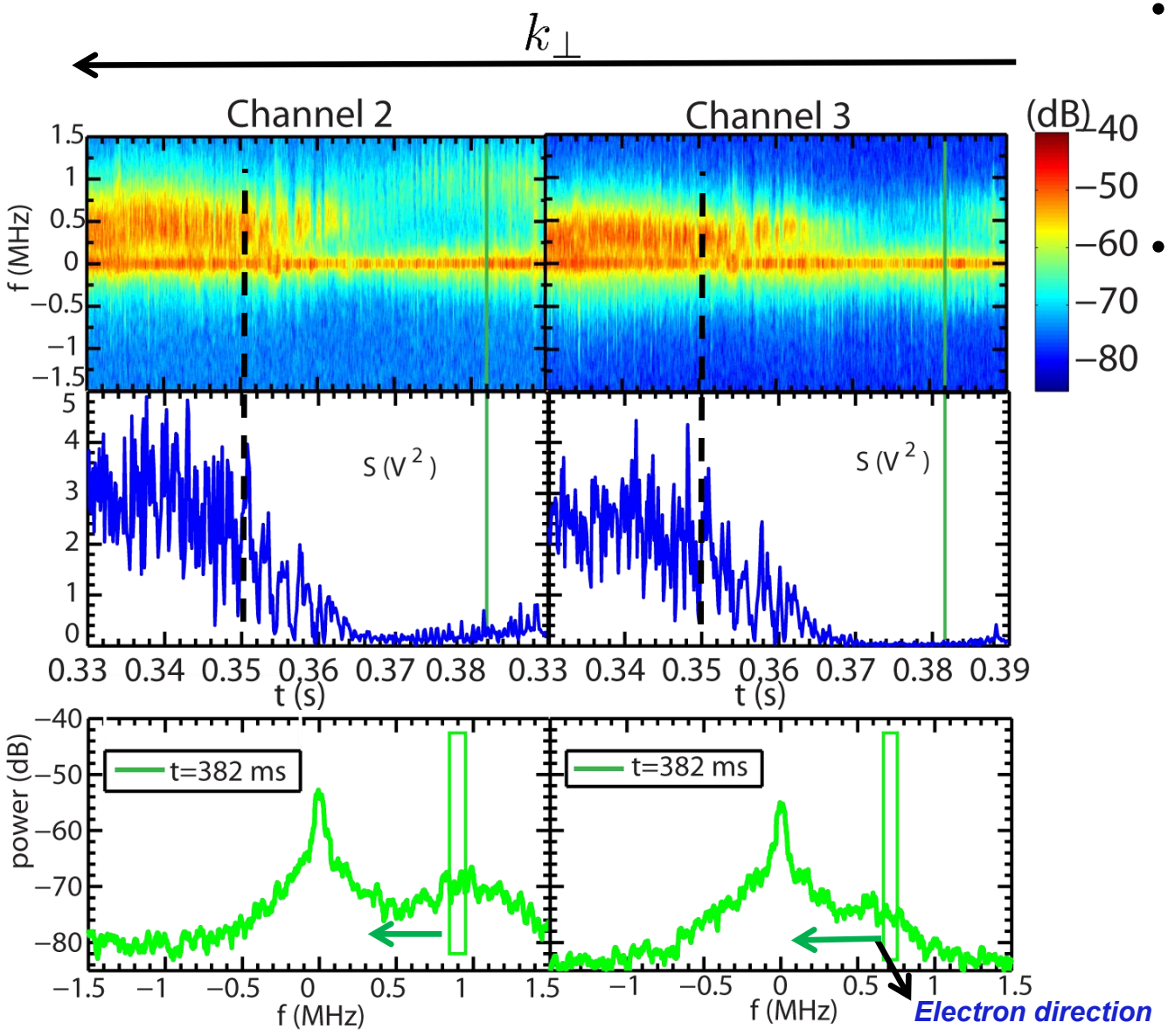
Broad Band High-k Turbulence is Seen across the L-H Transition



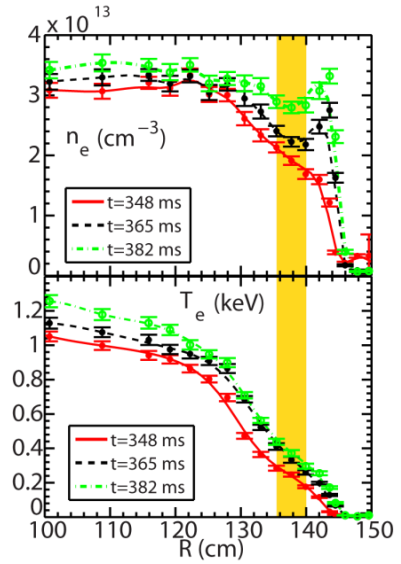
- Frequency spectra are shown for an exact Thomson time point: t=365 ms
- Turbulence propagates in the electron diamagnetic direction



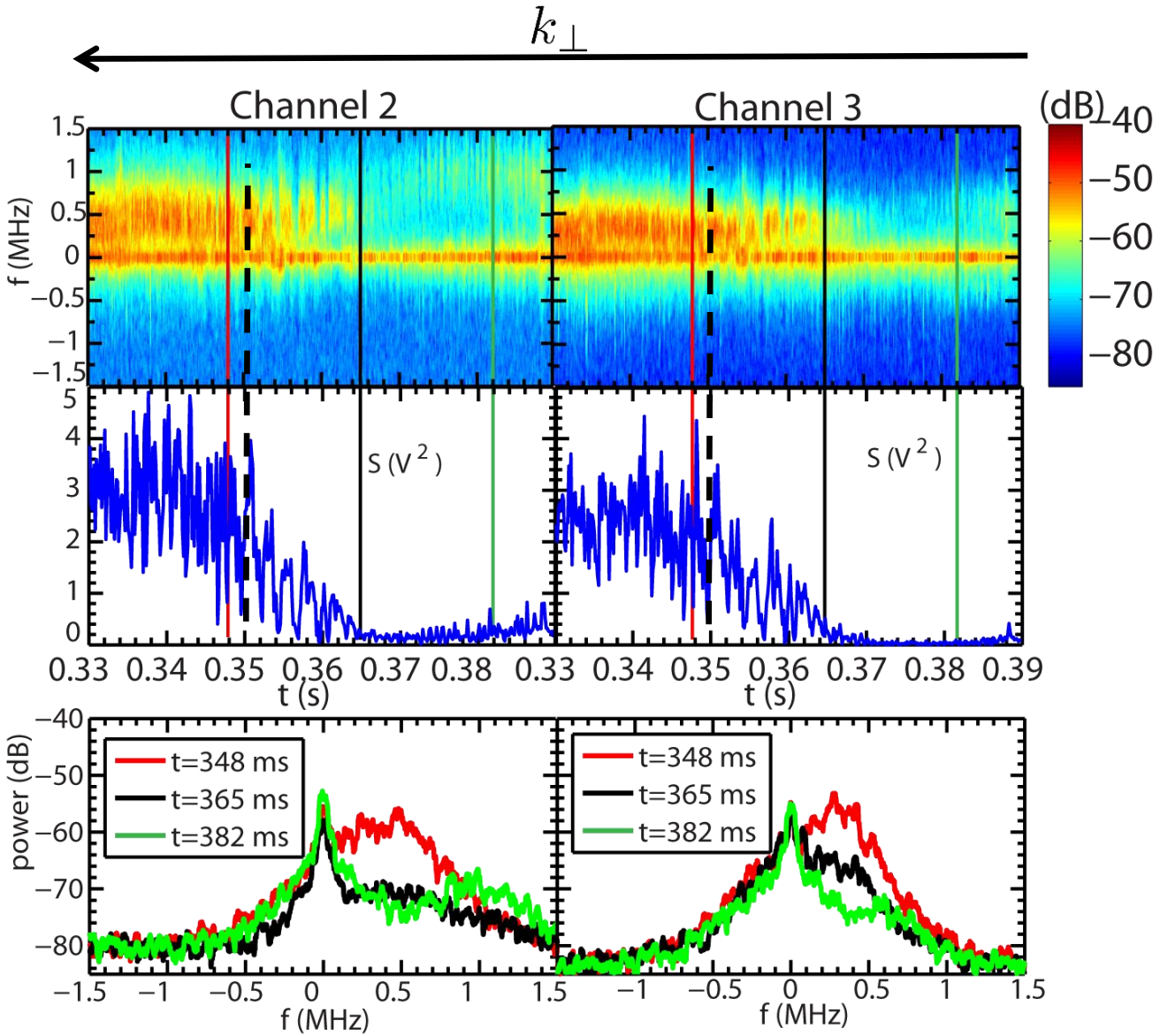
Broad Band High-k Turbulence is Seen across the L-H Transition

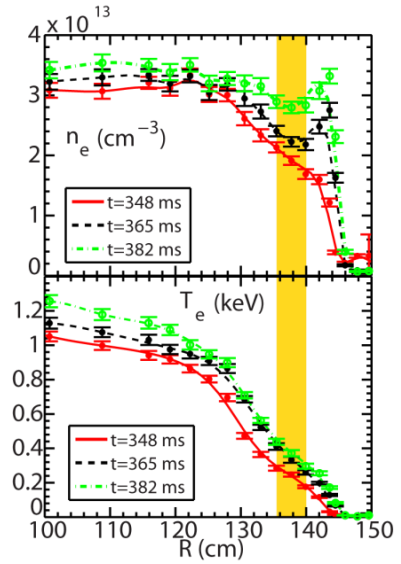


- Frequency spectra are shown for an exact Thomson time point: t=382 ms
- Real frequency distinguishable from the Doppler frequency shift for channel 3



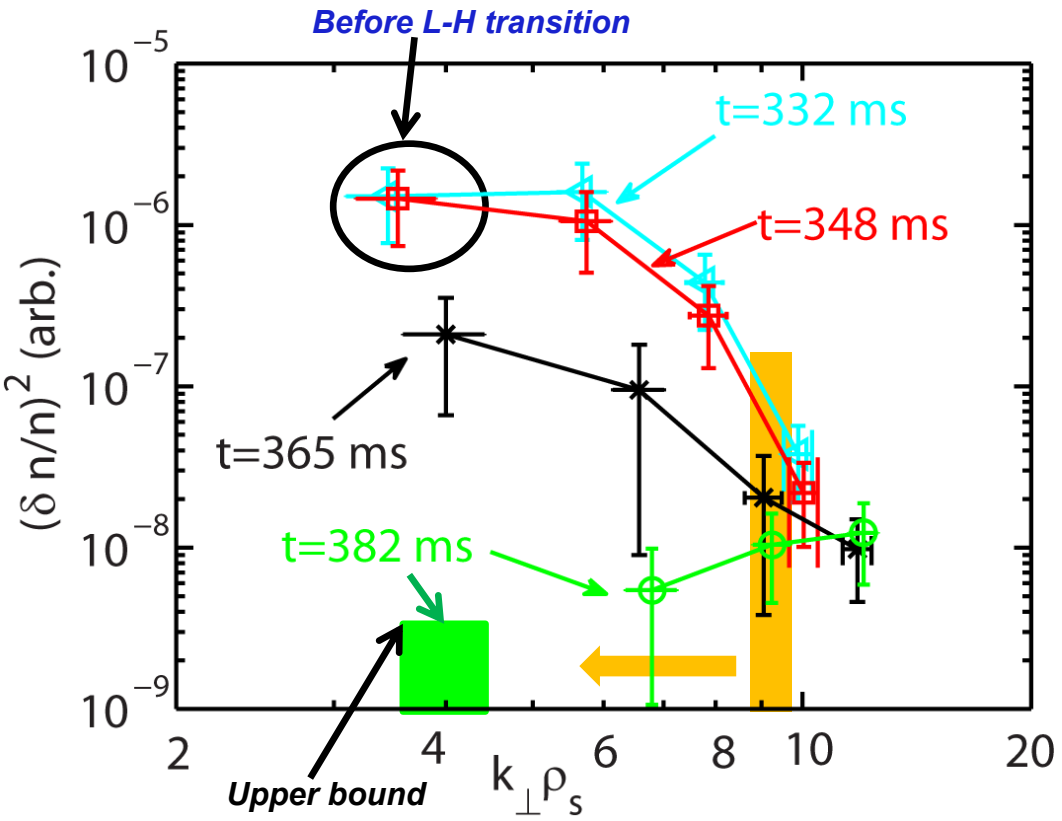
High-k Turbulence Changes in Amplitude and Frequency across the L-H Transition

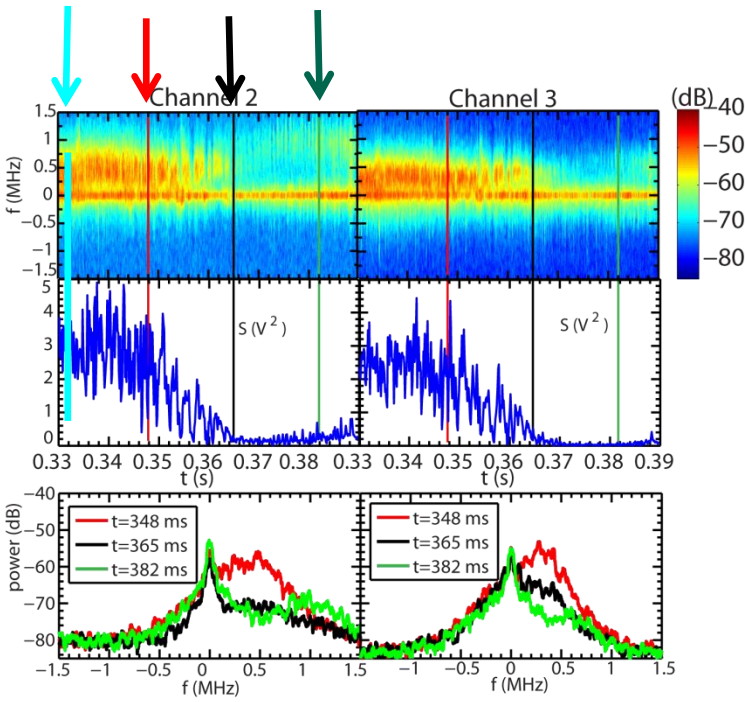




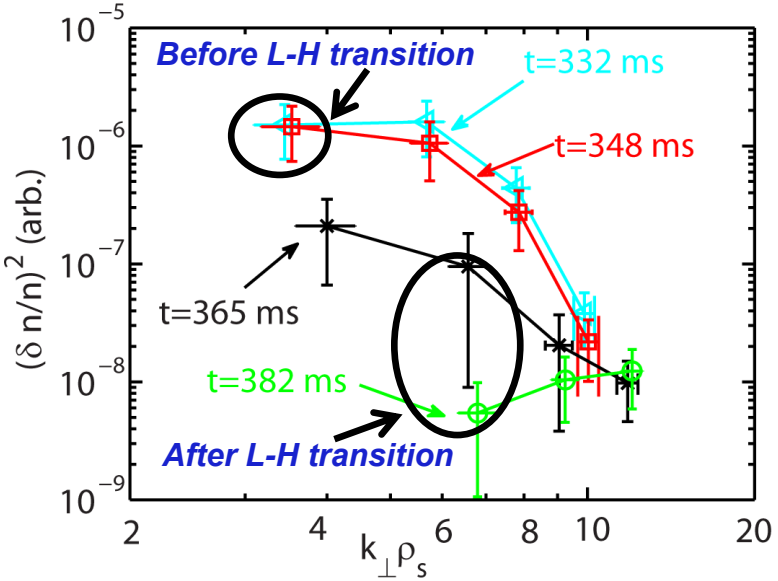
Significant Drop of Spectral Power in Lower Wavenumbers is Observed in the High-k Spectrum

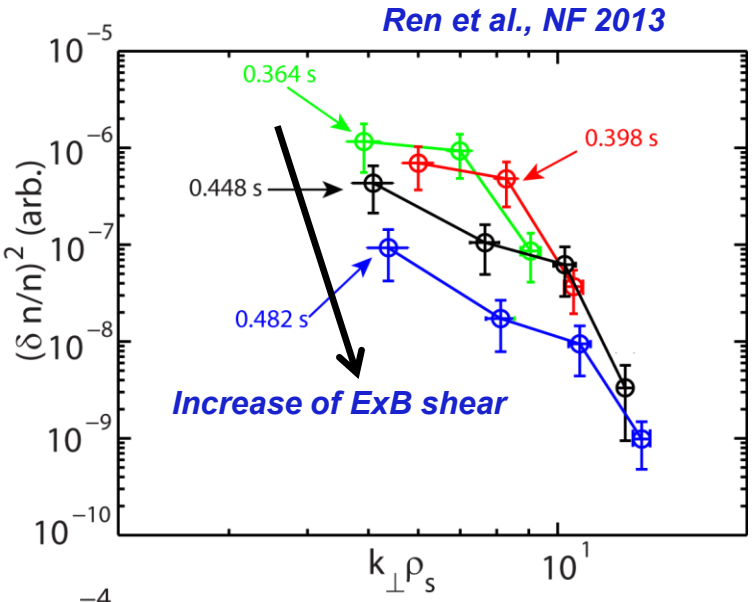
- Small variation before the L-H transition: quasi-stationary
- Significant drop, i.e. a factor of about 7, in the peak spectral power at t=365 ms after the L-H transition
  - Even smaller at 382 ms
- The drop in spectral power only occurs at $k_\perp \rho_s$ <9-10



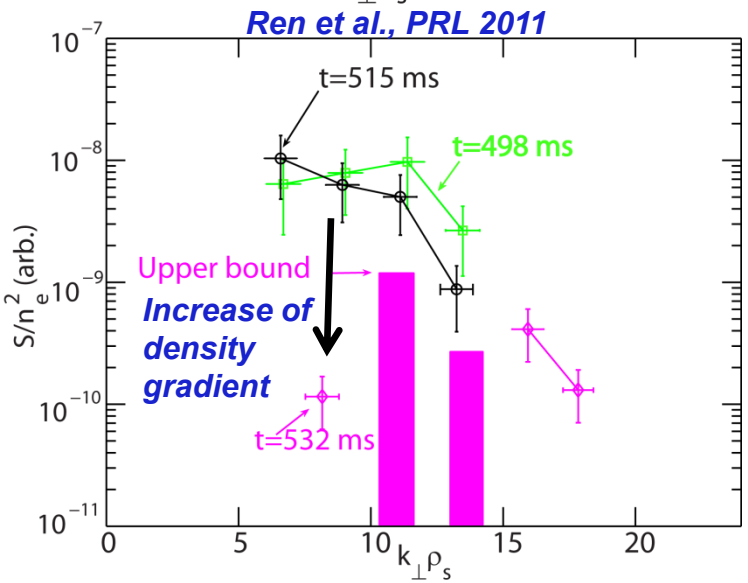


Similar Observations in Spectral Power Drop in Lower Wavenumbers in Different NSTX Scenarios

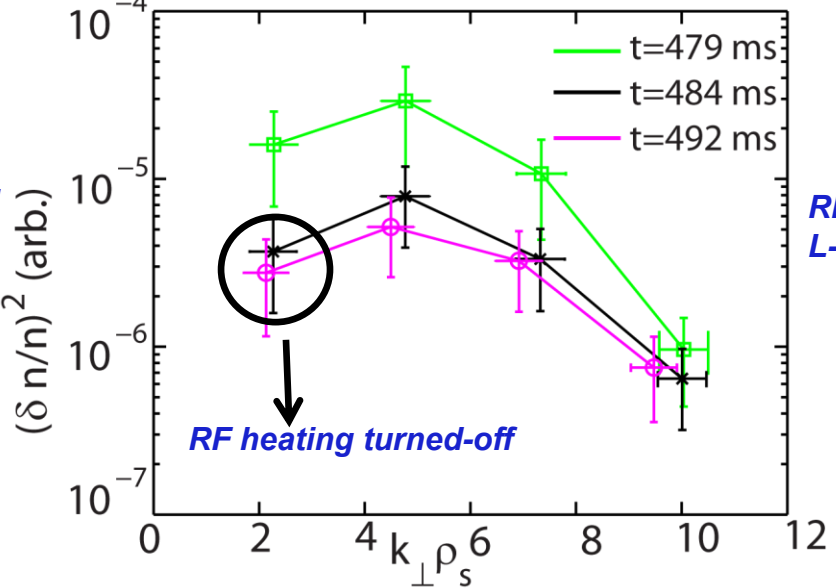




NBI-heated L-mode



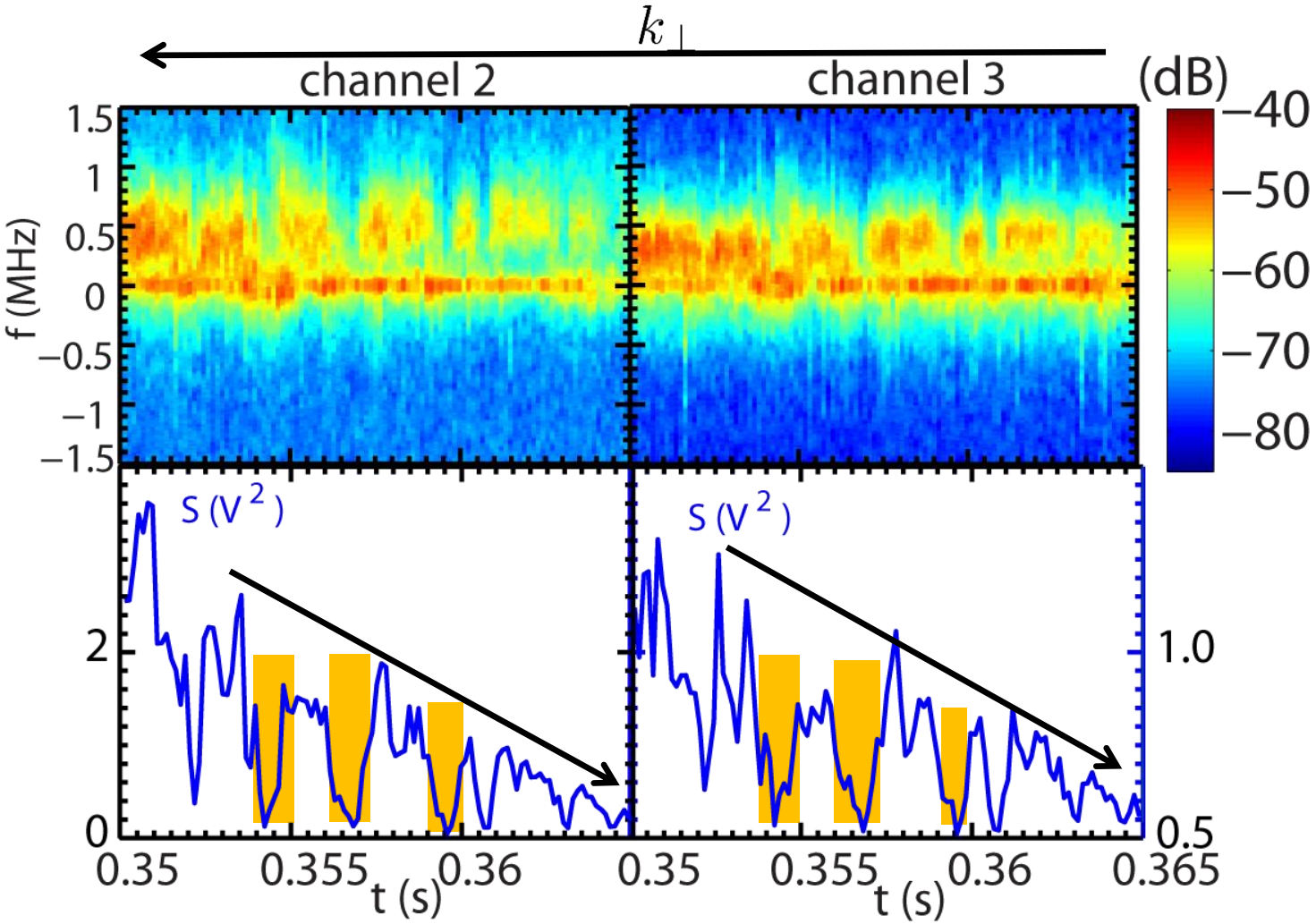
NBI-heated H-mode



RF-heated L-mode

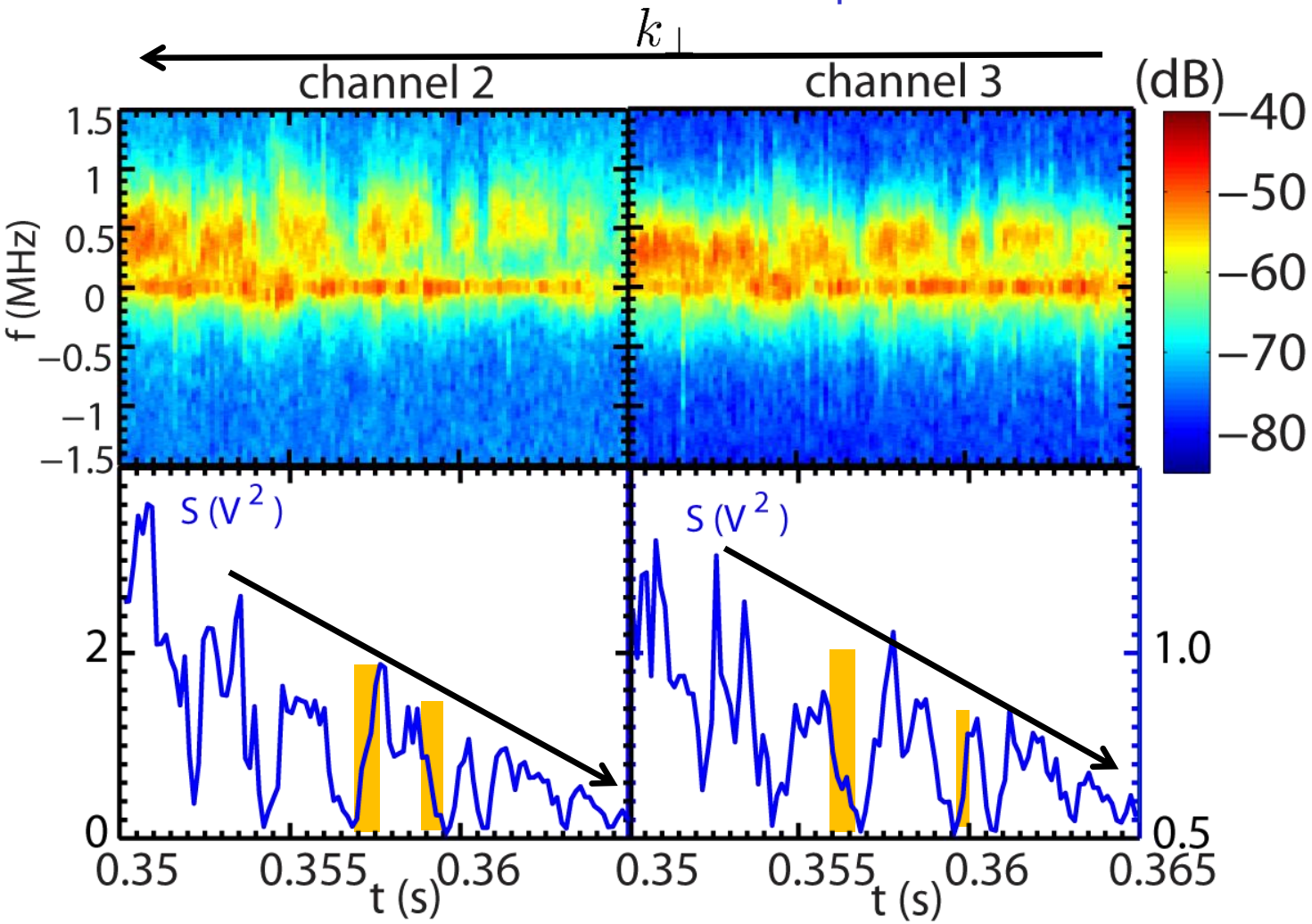
Large Intermittency (Dithering) in High-k Turbulence from t=350 to 365 ms

- Overall turbulence power decreases into H-mode
- Periods of minimum turbulence appear intermittently (~1-1.5 ms)



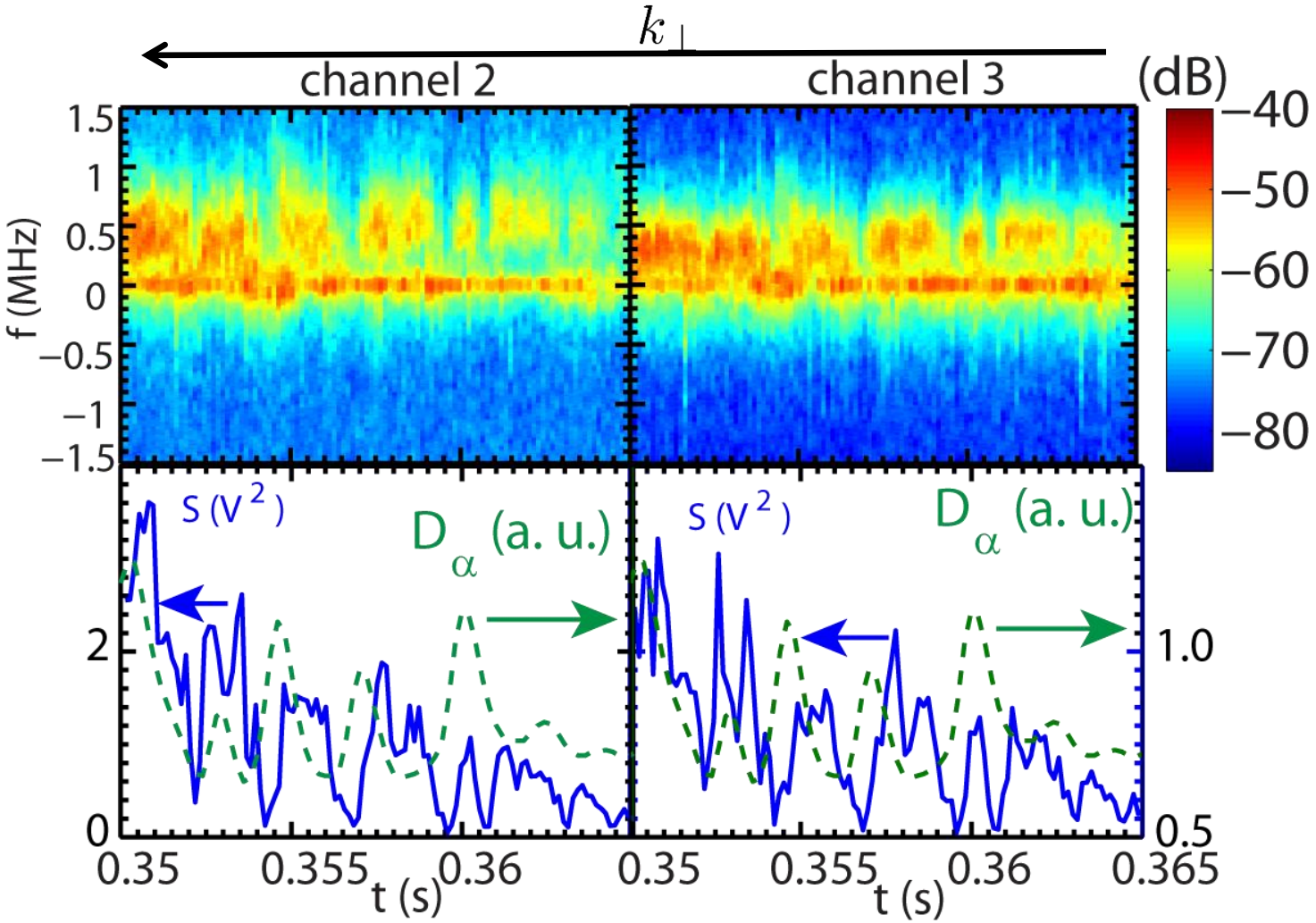
Large Intermittency (Dithering) in High-k Turbulence from t=350 to 365 ms

- Overall turbulence power decreases into H-mode
- Periods of minimum turbulence appear intermittently (~1-1.5 ms)
  - Fast decrease and rise of turbulence power in 0.5-1 ms



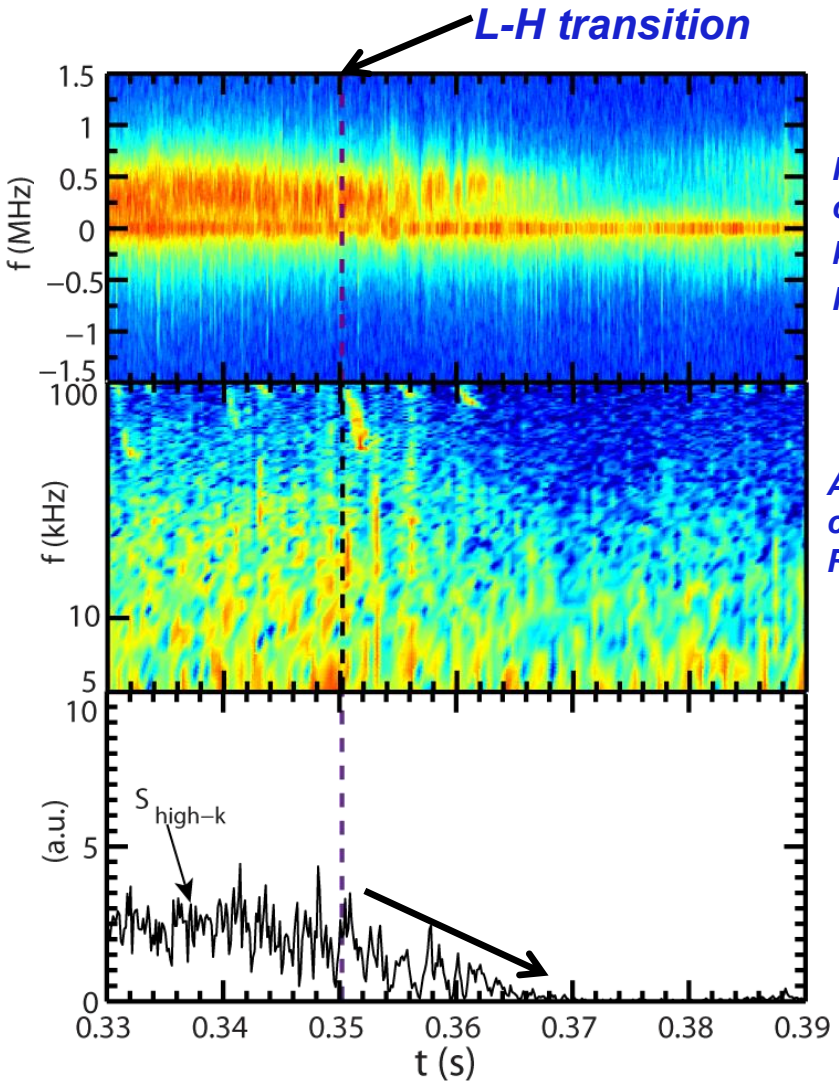
Large Intermittency (Dithering) in High-k Turbulence from t=350 to 365 ms is Similar to Divertor D_α

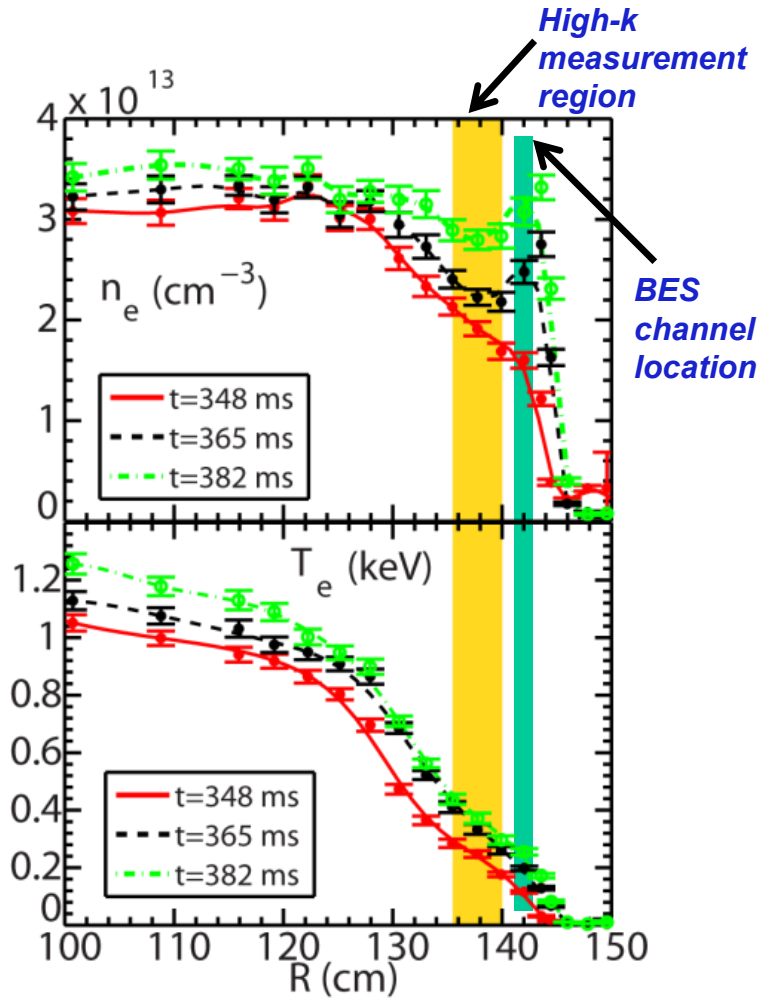
- High-k turbulence intermittency is on the same time scale as the dithering of divertor D_α
- A definite correlation is not yet established



Low-k Turbulence Measured by BES Shows Similar Temporal Behavior as High-k Turbulence

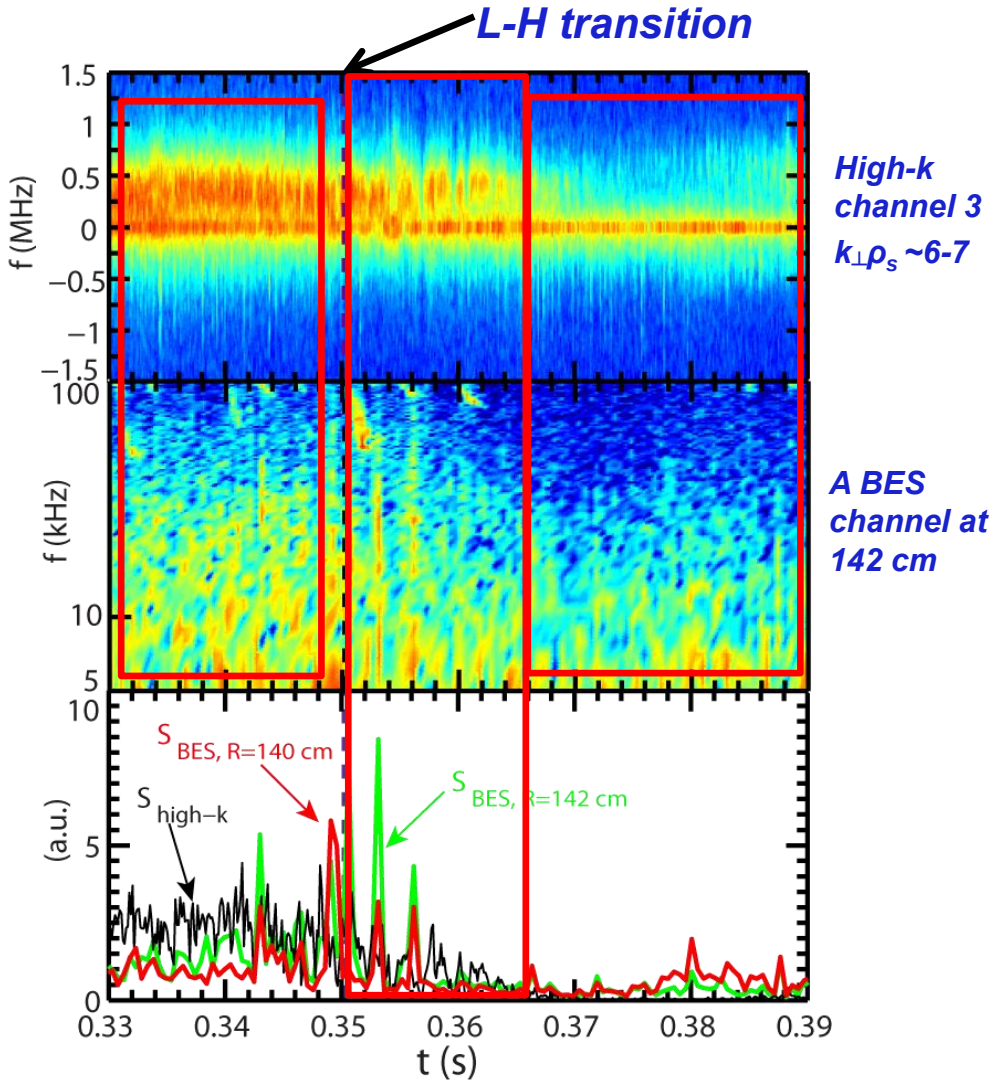
- High-k channel 3 measuring $k_\perp \rho_s$ ~6-7 is compared with BES measurement at R=142 cm (top of the H-mode pedestal)





Low-k Turbulence Measured by BES Shows Similar Temporal Behavior as High-k Turbulence

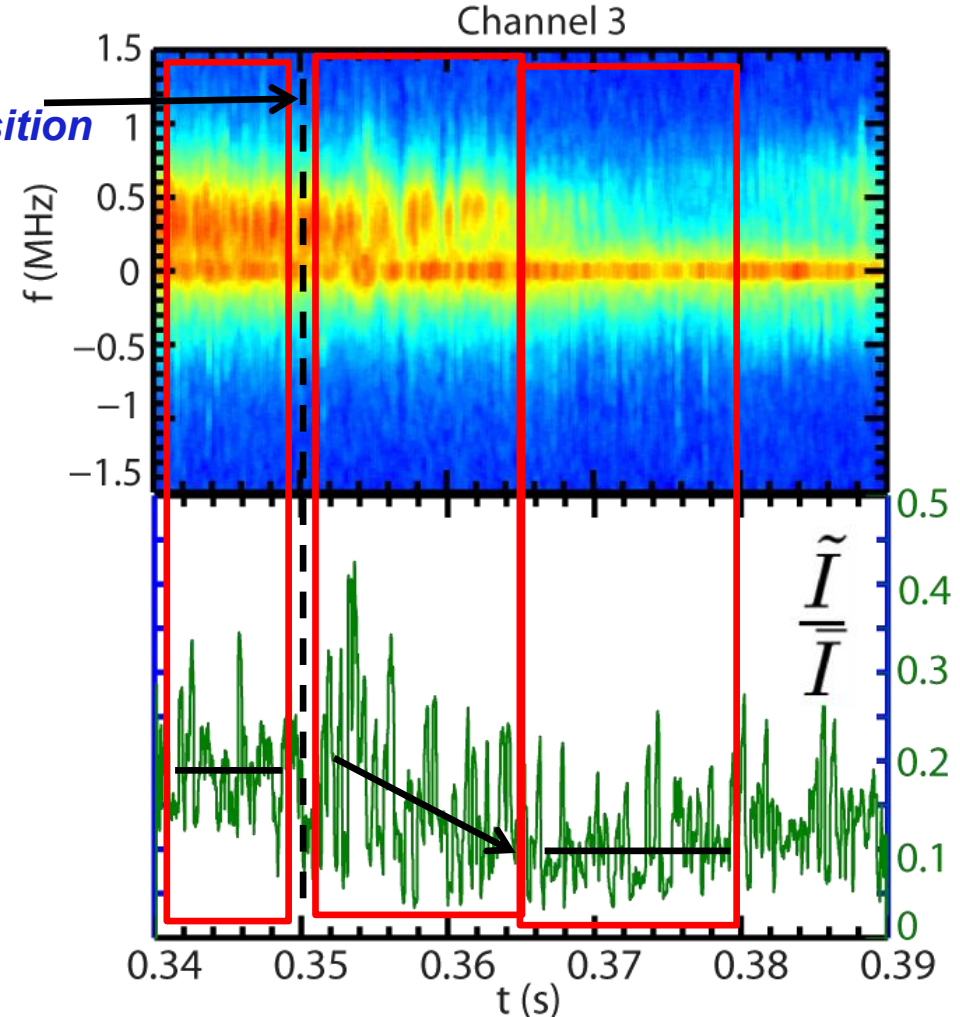
- High-k channel 3 measuring $k_\perp \rho_s$ ~6-7 is compared with BES measurement at R=142 cm (top of the H-mode pedestal)



- Quasi-stationary turbulence before the L-H transition
  - $\frac{\tilde{n}}{n} \approx 2.9\%$ from BES
- Reduced turbulence into H-mode
  - t~365-390 ms
  - $\frac{\tilde{n}}{n} \approx 0.94\%$ from BES
- Intermittent turbulence right after the L-H transition
  - t ~ 350-365 ms
  - Similar temporal intermittency in low-k and high-k

GPI Measurements also Show Similar Overall Temporal Behavior as the High-k Turbulence

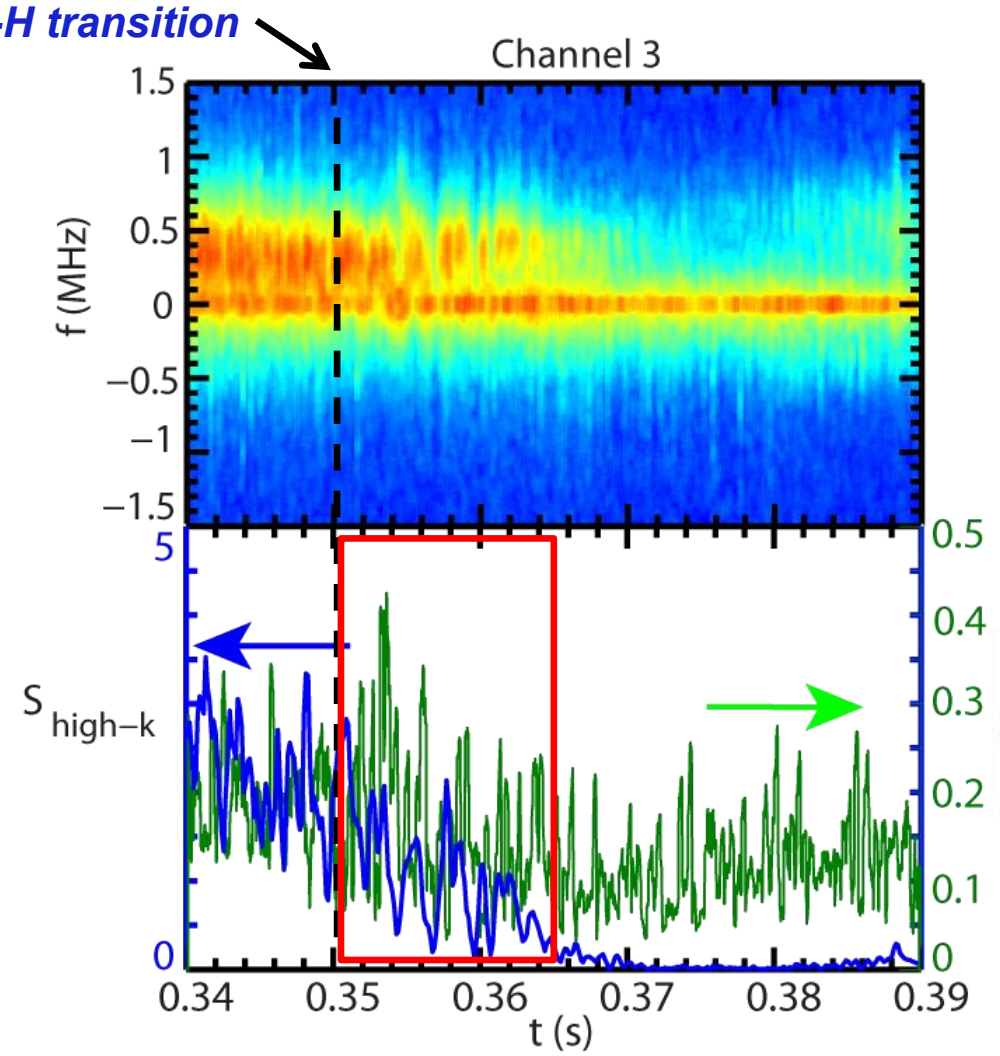
- Quasi-stationary turbulence before the L-H transition
- Intermittent and decreasing turbulence right after the L-H transition
- Suppressed turbulence in t ~ 365-380 ms



- $\tilde{I}$ is the RMS value of the GPI emission fluctuation over every 0.13 ms
- $\bar{I}$ is the mean of the GPI emission over every 0.13 ms

GPI emission at R=144 cm

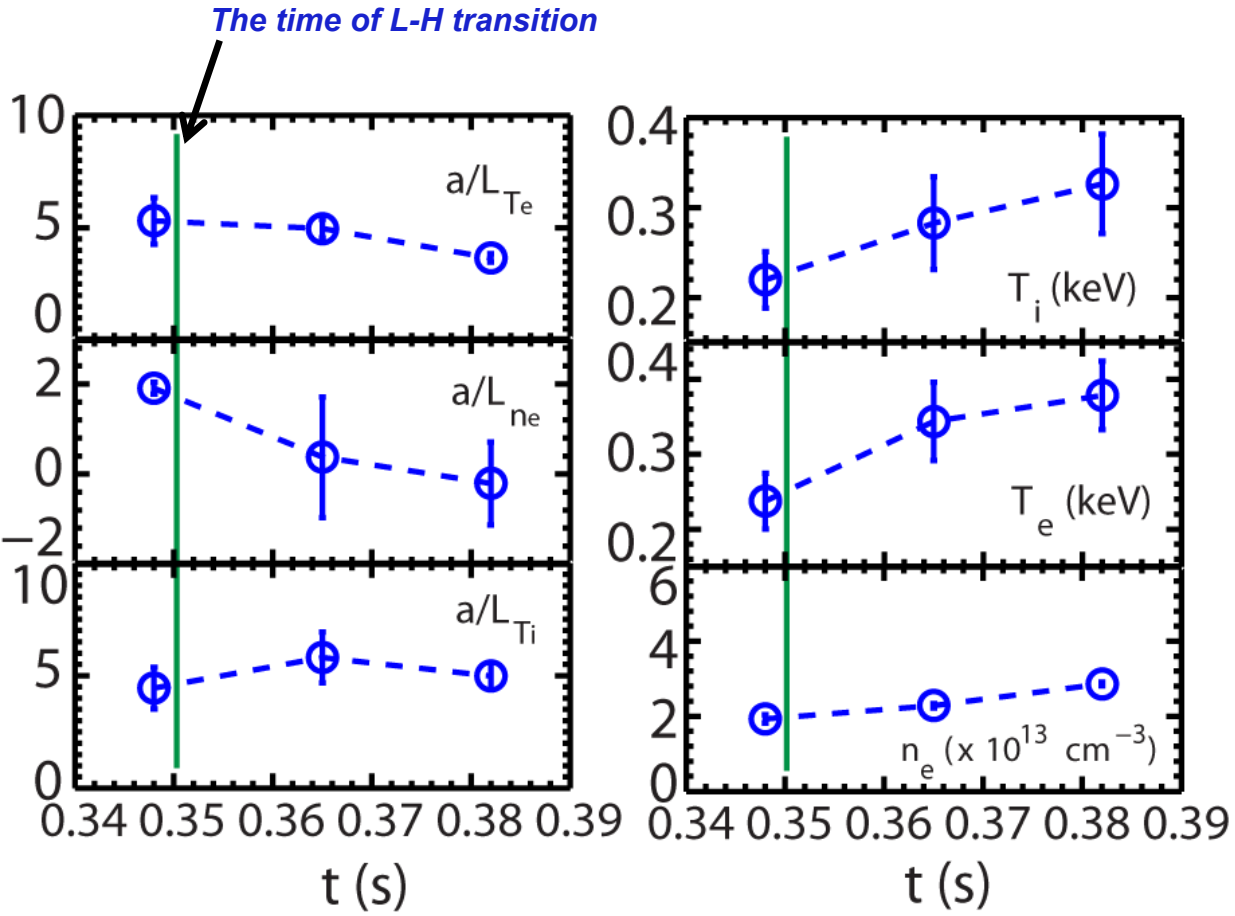
GPI Measurements are more Intermittent than the High-k Turbulence



- $\tilde{I}$ is the RMS value of the GPI emission fluctuation over every 0.13 ms
- $\bar{I}$ is the mean of the GPI emission over every 0.13 ms

GPI emission at R=144 cm

Equilibrium Profiles Changes can be Significant across the L-H Transition

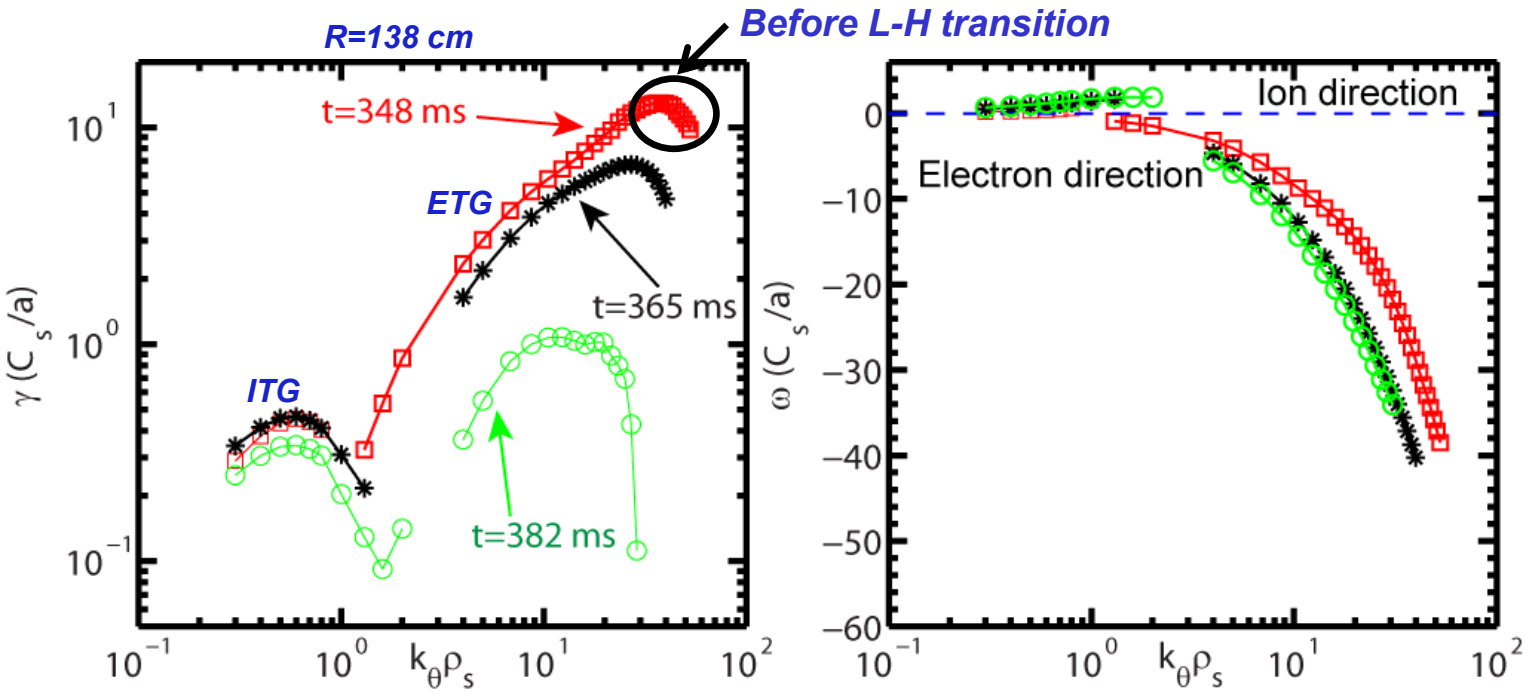


Quantities averaged in the high-k measurement region

- ~30% decrease in normalized inverse ETG scale length
- ~30% variation in decrease in normalized inverse ITG scale length
- Significant decrease in normalized inverse density gradient scale length
- Significant increase in T_e, T_i and n_e (~45-60%)

Linear Stability Analysis Shows that ITG and ETG are both Unstable

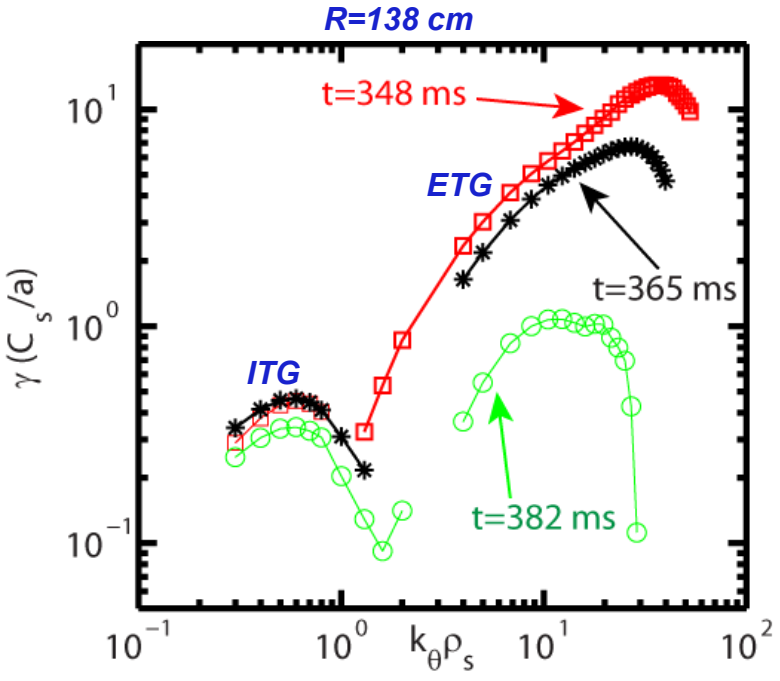
- ETG linear growth rates decrease into H-mode
  - ETG mode real frequency increases
- ITG growth rates vary much less significantly

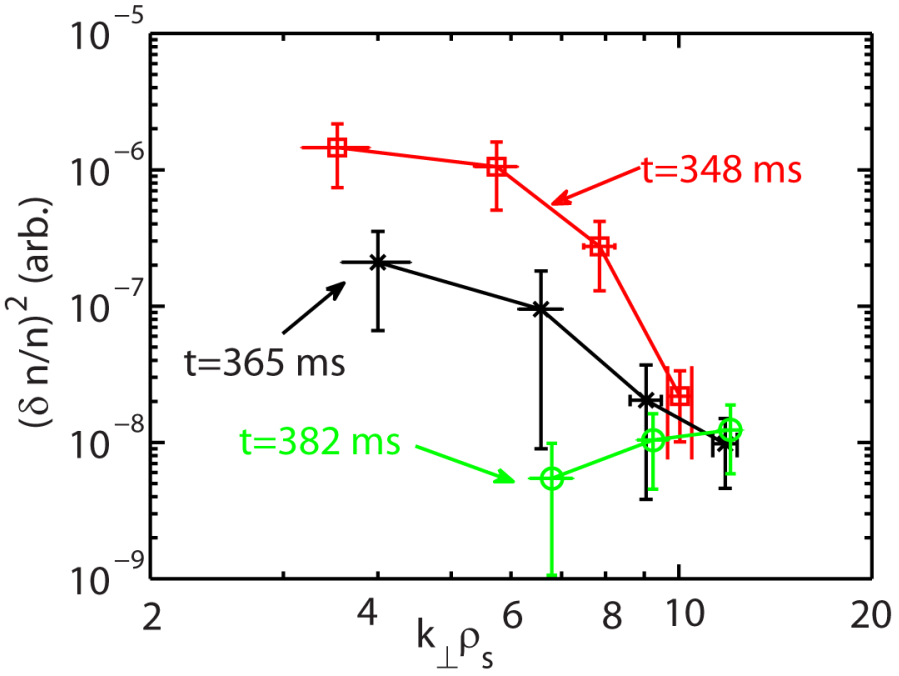


- Stability Analysis was performed with the GS2 code (Kotschenreuther et al., 1995) with Miller local equilibrium

ETG Stability across the L-H Transition is Consistent with the Measured High-k Turbulence Variation

- ETG linear growth rates decrease into H-mode
- The measured high-k turbulence also decreases into H-mode
- The observed intermittency requires nonlinear processes

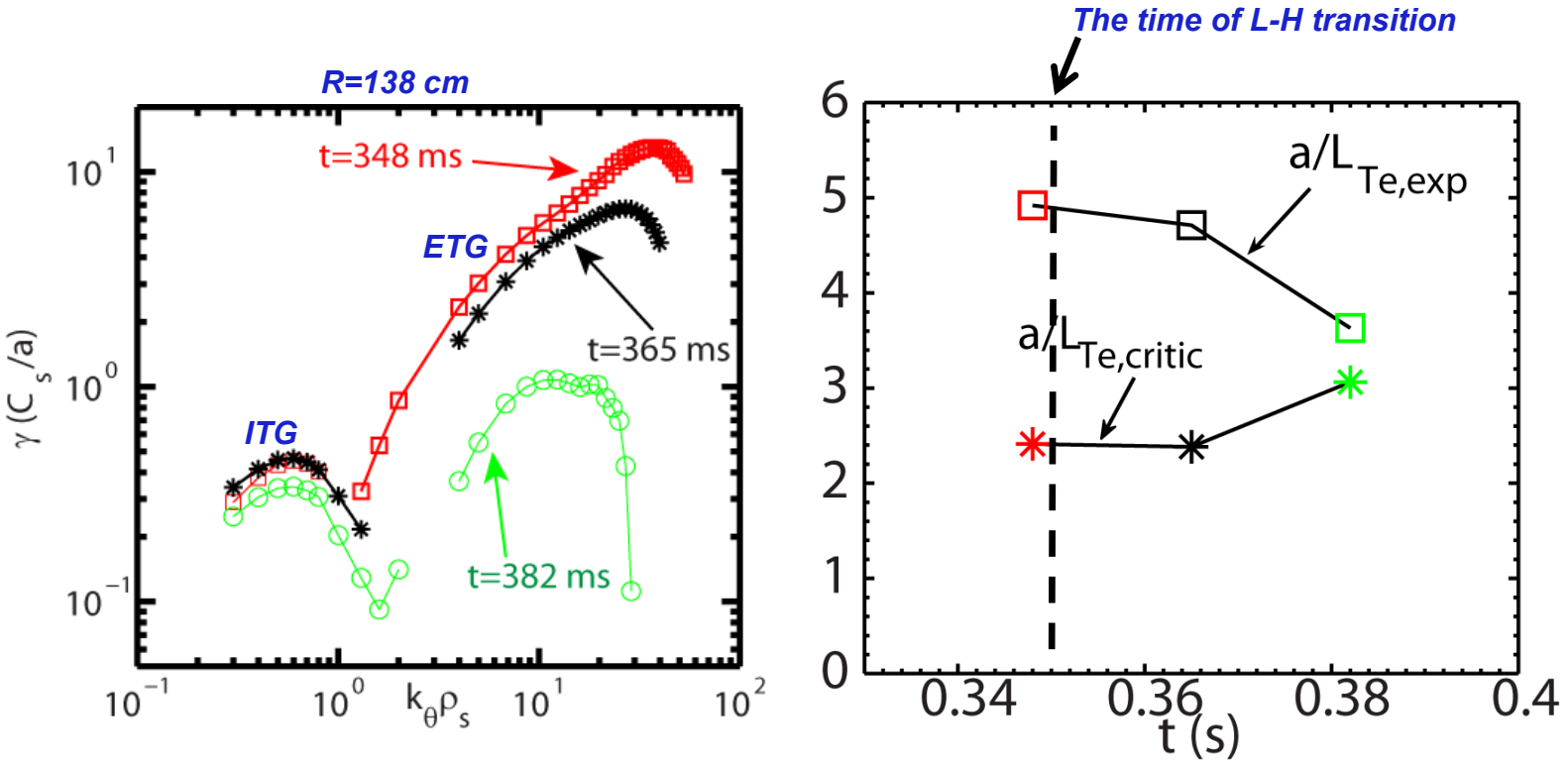




- Stability Analysis was performed with the GS2 code (Kotschenreuther et al., 1995) with Miller local equilibrium

ETG Close to Marginal Stability in the High-k Measurement Region Further into H-mode

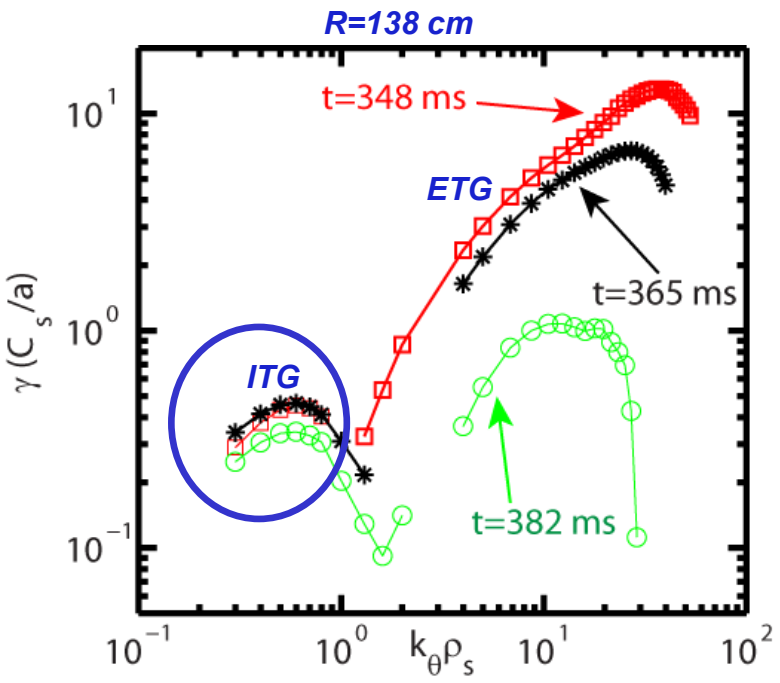
- The decrease in ETG linear growth rates is due to the decrease of ETG and increase of critical ETG

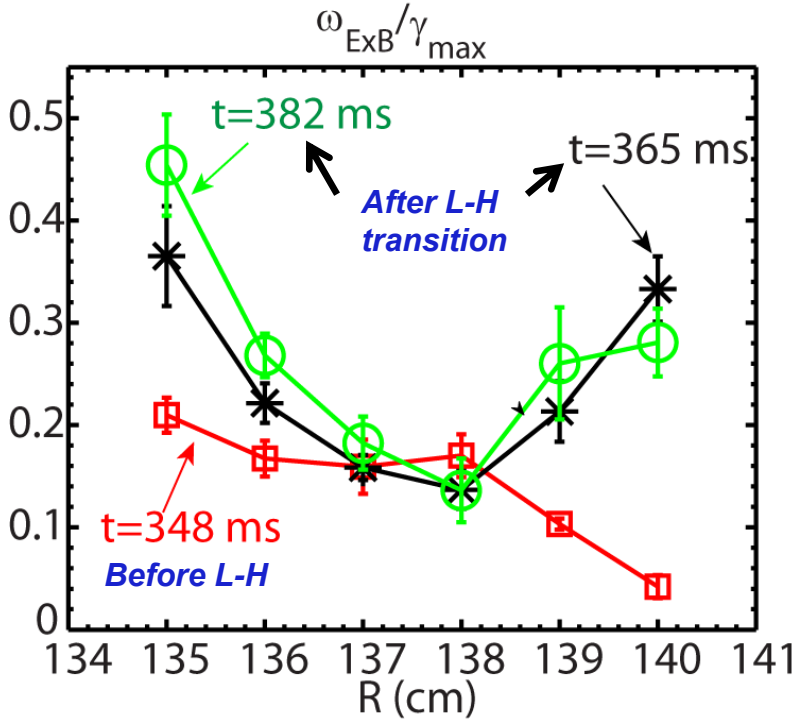


- Stability Analysis was performed with the GS2 code (Kotschenreuther et al., 1995) with Miller local equilibrium

Ion-scale Modes are more Suppressed into H-mode

- $\omega_{E\times B,WM}/\gamma_{max}$ is used to assess ExB shear effect on ion-scale modes
- $\omega_{E\times B,WM}/\gamma_{max}$ increases in the high-k measurement region into H-mode





- Stability Analysis was performed with the GS2 code (Kotschenreuther et al., 1995) with Miller local equilibrium

Summary

- First detailed measurement of high-k (electron-scale) turbulence across L-H transition in NSTX
  - Quasi-stationary high-k turbulence before L-H transition, intermittent after L-H transition and significantly suppressed ~15 ms after L-H transition
  - Suppression of high-k turbulence at lower wavenumbers, i.e. $k_\perp \rho_s \leq 9\text{-}10$, similar observations also in different NSTX scenarios
- Low-k turbulence measured by GPI and BES at different radii but similar temporal behavior as high-k turbulence observed
  - Intermittency observed after L-H transition, similar to high-k turbulence
  - Showing suppression of low-k turbulence into H-mode at r/a>0.8
- Linear stability analysis using GS2 code showing some consistency with turbulence measurements
  - Decreased ETG growth rate into H-mode
  - Low-k turbulence more suppressed by ExB shear into H-mode
  - Nonlinear processes needed for explaining the observed intermittency

Acknowledgement: Work supported by DoE