

Relationship Between Edge Zonal Flows and L-H Transitions in NSTX

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What Causes the L-H Transition ?

Theoretical ideas:

- Shearing of edge turbulence by mean (steady) flows
- Shearing of edge turbulence by zonal (fluctuating) flows
- Stabilization of L-mode instability without flow shearing ?

Experimental evidence:

- Clear evidence of improved confinement due to biasing
- Clear evidence of turbulence reduction at L-H transition
- But transition 'trigger' is still an open issue (Wagner '07)

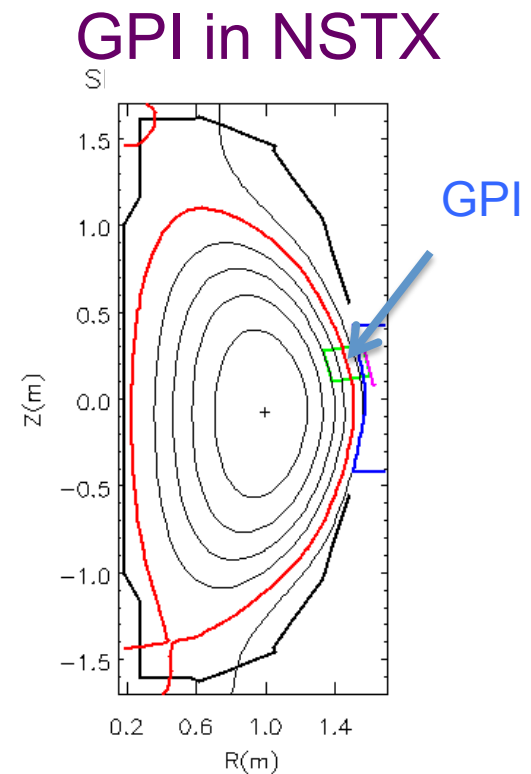
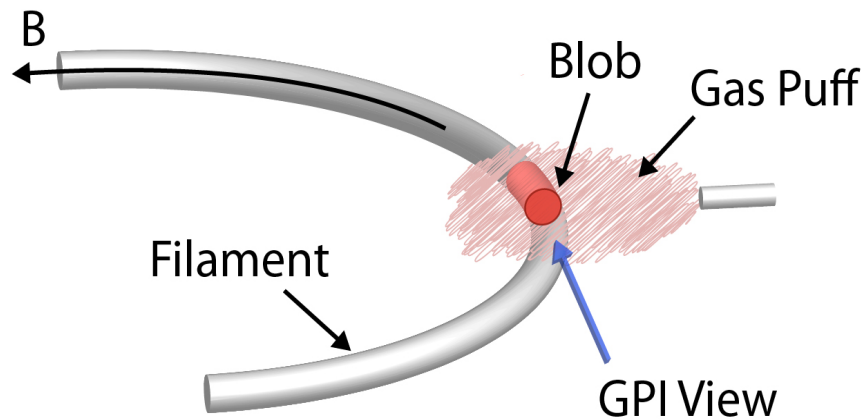
We don't have a good answer yet !

Outline of this Talk

- Latest fast camera movies of L-H transition on NSTX
- Edge zonal flow spectra derived from these movies
- Relationship between edge zonal flow and transition
- Comparison with preliminary result from Alcator C-Mod

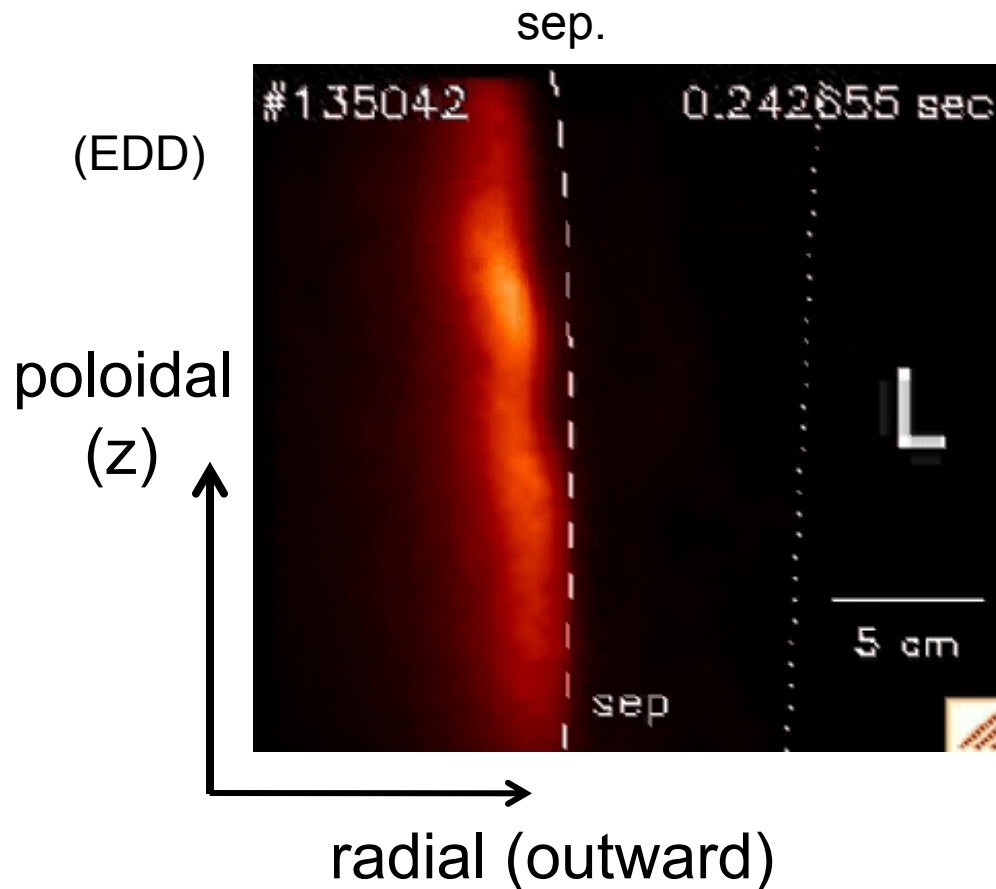
Gas Puff Imaging (GPI) Diagnostic

- Optics view along B toward D_{α} emission from D_2 gas puff
- Oriented to view 2-D radial vs. poloidal plane at gas puff



Movie of L-H Transition in NSTX

- Viewing area ~ 25 cm radially x 25 cm poloidally
- This movie 285,000 frames/sec for ~ 3.5 msec



#135042
B=4.5 kG
I=0.92 MA
P=2.6 MW NBI

L-H transition
@ 0.2455 sec

playback @
50 μ sec/sec

What Are We Seeing in GPI ?

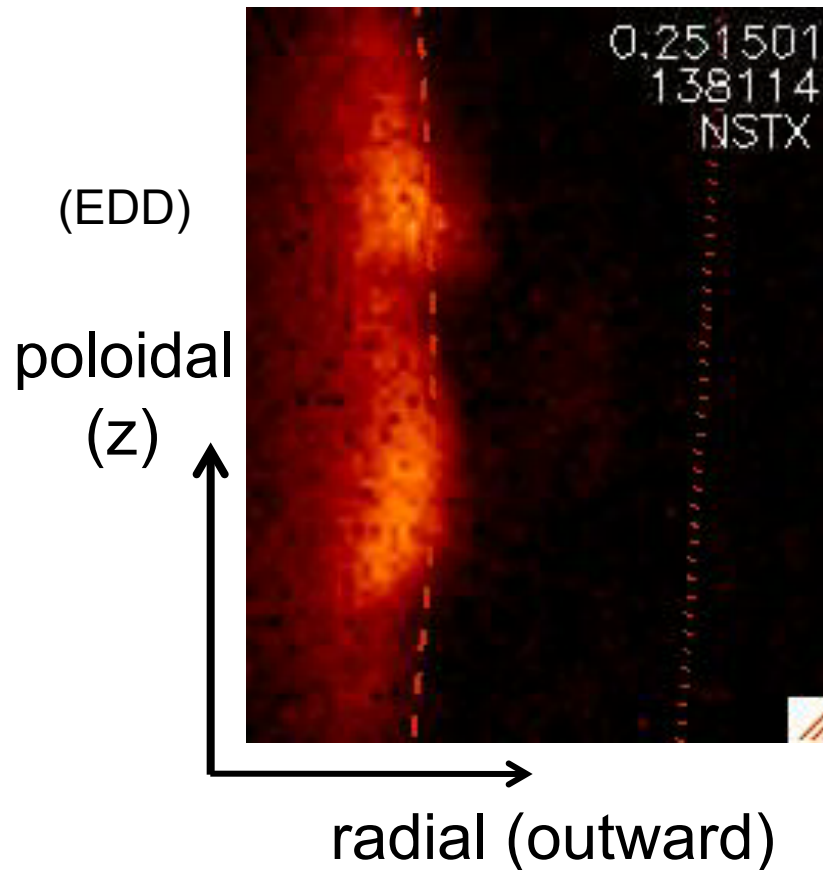
- Seeing local emission of $D_\alpha \sim n_o f(n_e, T_e)$ within window where D_α is emitted in plasma edge, where $T_e \sim 10 - 100$ eV
- Can measure 2-D **turbulence structure and motion** even if response of D_α is nonlinear (like contrast knob on a TV)
- Can **not directly measure fluid (ion) flow** or ExB flow, but measures turbulence flow velocity, as done previously*

* McKee et al, PoP '03 using BES on DIII-D

Conway et al, PPCF '05 using Doppler reflectometry on AUG

L-H Transition NBI-Heated Case

- Viewing area ~ 25 cm radially x 31 cm poloidally
- This movie 400,000 frames/sec for ~ 2 msec



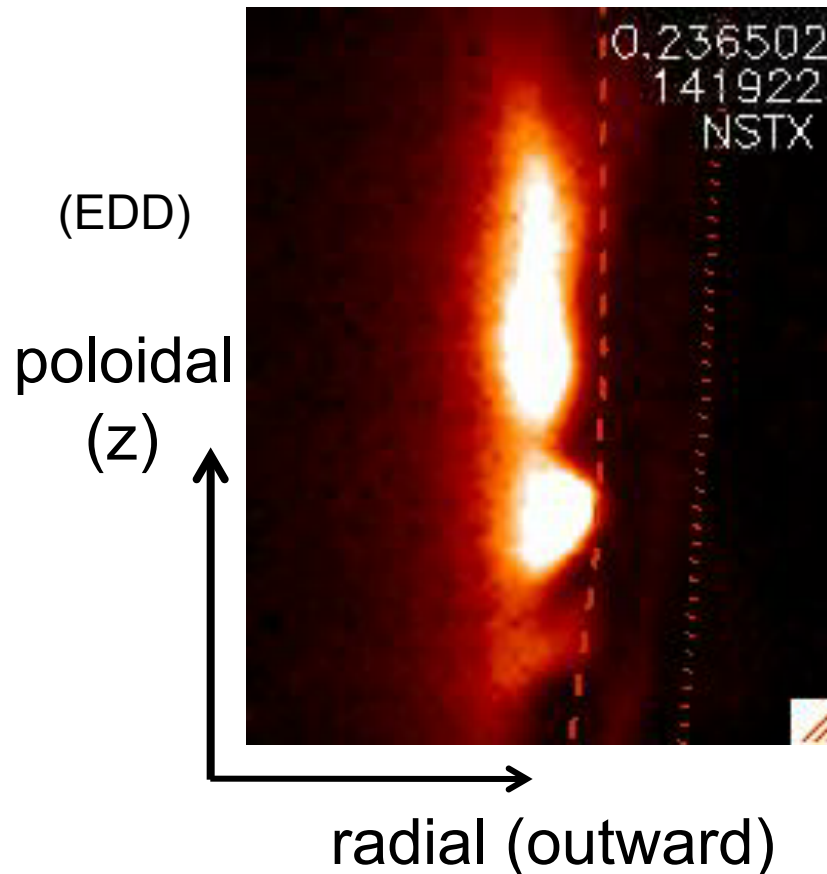
#138114
B=4.4 kG
I=0.91 MA
P=1.3 MW NBI

L-H transition
@ 0.2530 sec

playback @
40 μ sec/sec

L-H Transition RF-Heated Case

- Viewing area ~ 25 cm radially x 31 cm poloidally
- This movie 400,000 frames/sec for ~ 2 msec



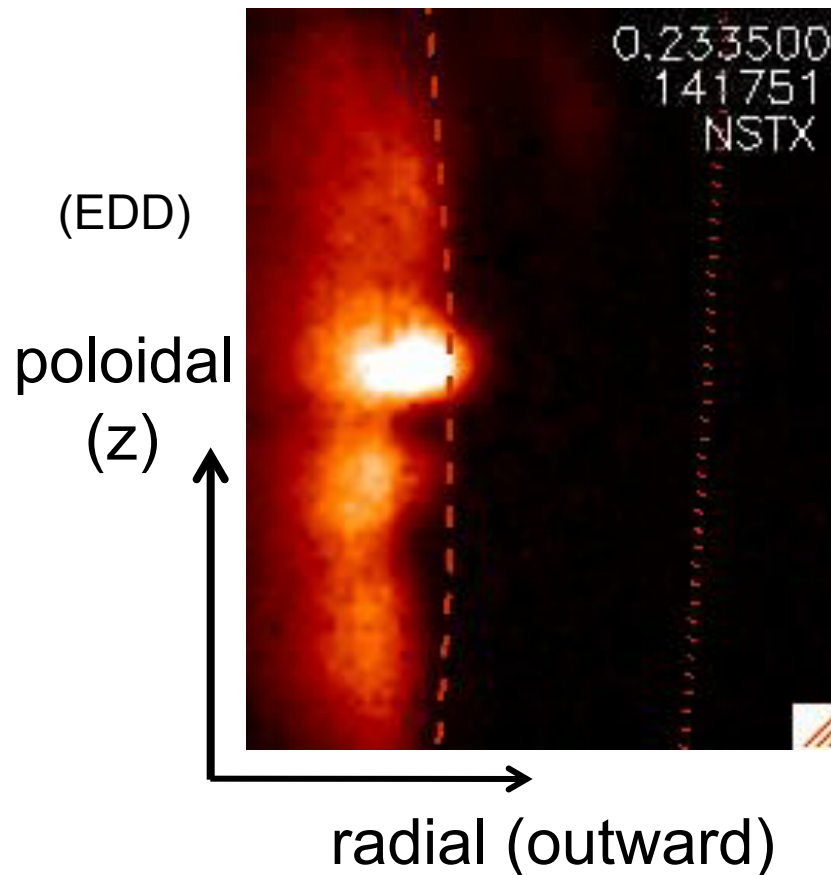
#141922
B=4.4 kG
I=0.91 MA
P=0.7 MW RF

L-H transition
@ 0.2378 sec

playback @
40 μ sec/sec

L-H Transition in Ohmic Case

- Viewing area ~ 25 cm radially x 31 cm poloidally
- This movie 400,000 frames/sec for ~ 2 msec

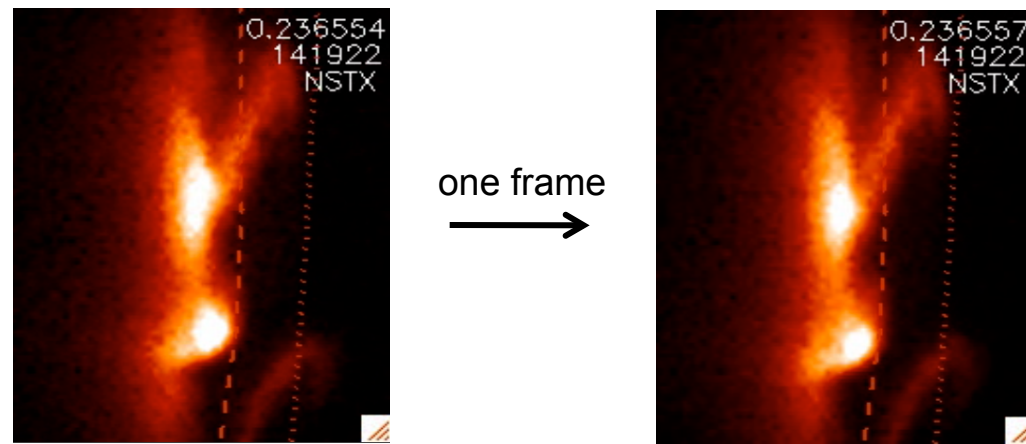


#141751
B=3.6 kG
I=0.80 MA
Ohmic

L-H transition
@ 0.2350 sec

playback @
40 μ sec/sec

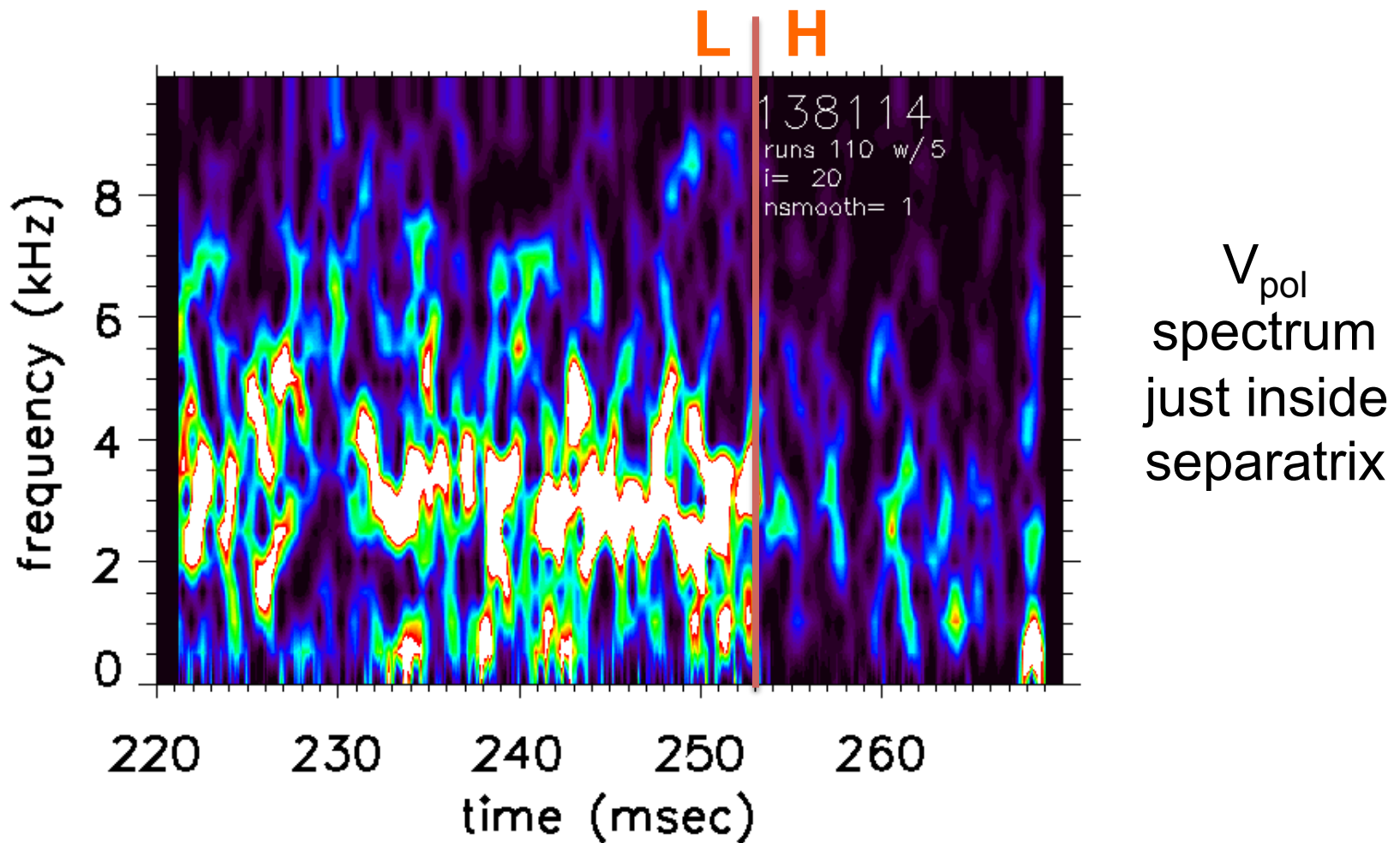
Method to Calculate Zonal Flows



- for each pixel in each frame, make a short time series of the normalized GPI signal at that pixel over a $\sim 40 \mu\text{s}$ interval
- find highest cross-correlation to this time series in pixels of the *next* frame and get 2-D velocity from the displacement
- **average ~ 25 cm poloidally to get “zonal flow” velocity**

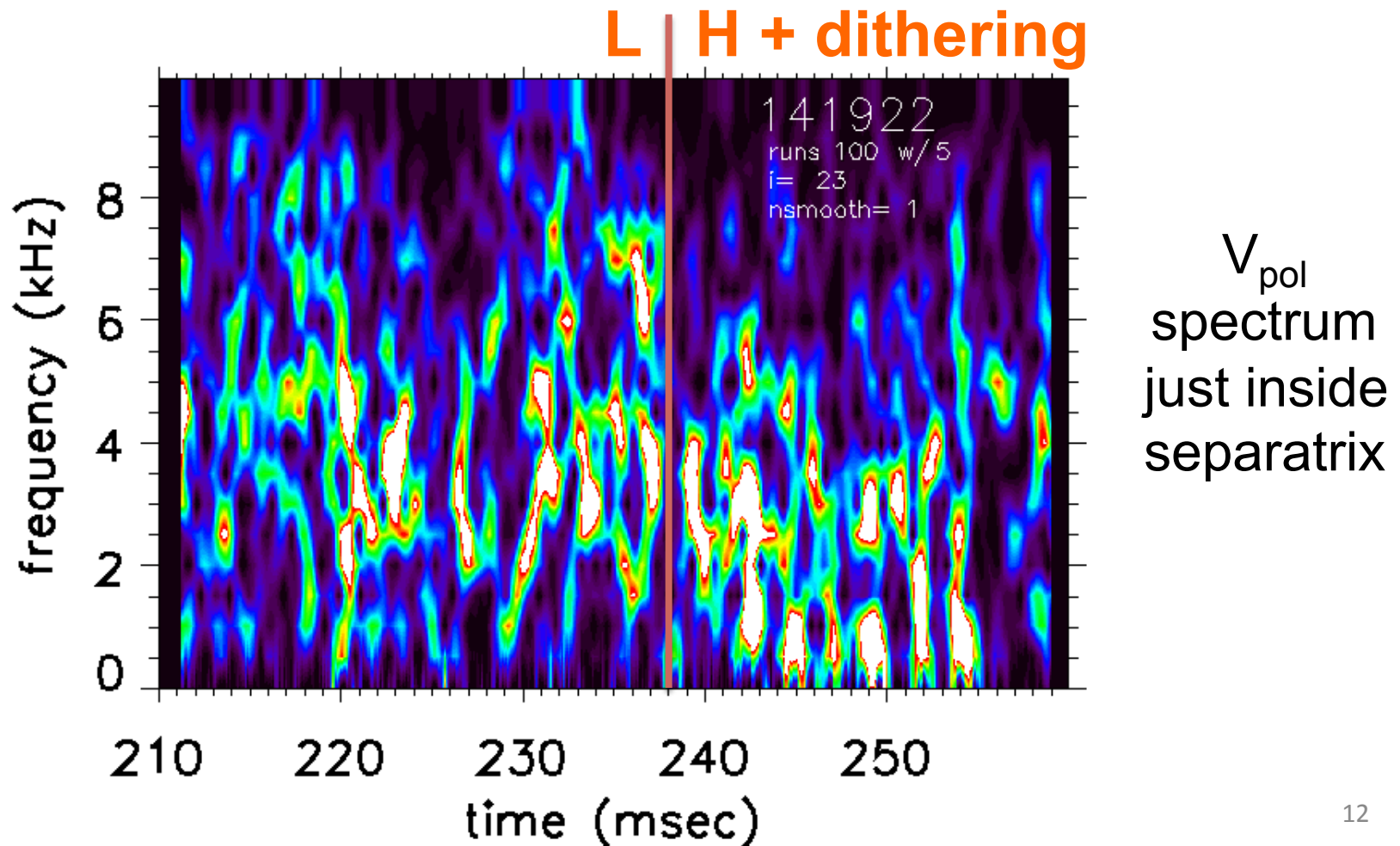
Zonal Flow Spectrum in NBI Case

- See near-coherent peak at ~ 3 kHz preceding transition



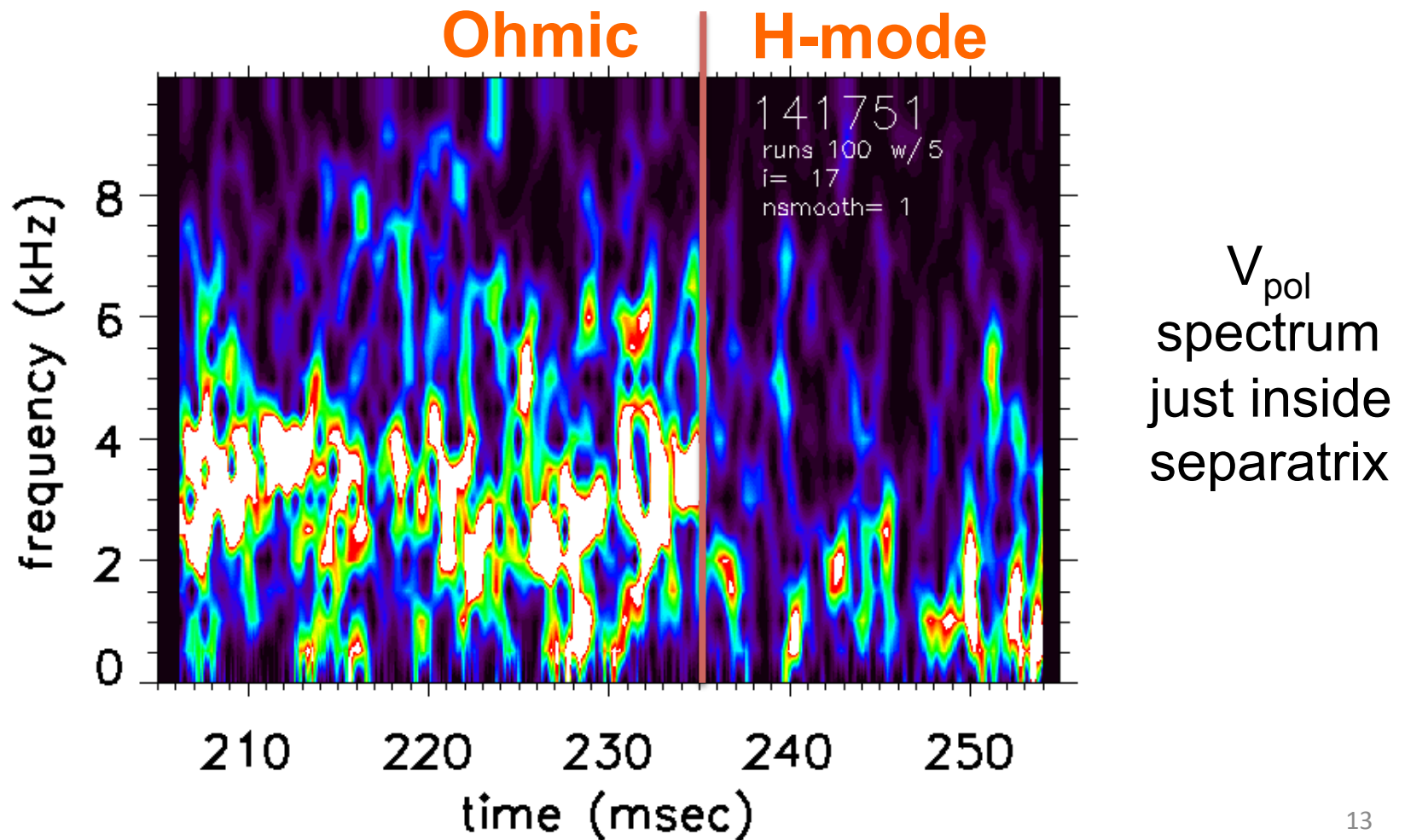
Zonal Flow Spectrum in RF Case

- See broadband, intermittent spectrum preceding transition
- Dithering of H to L to H etc. in $D\alpha$ starts at 243 msec



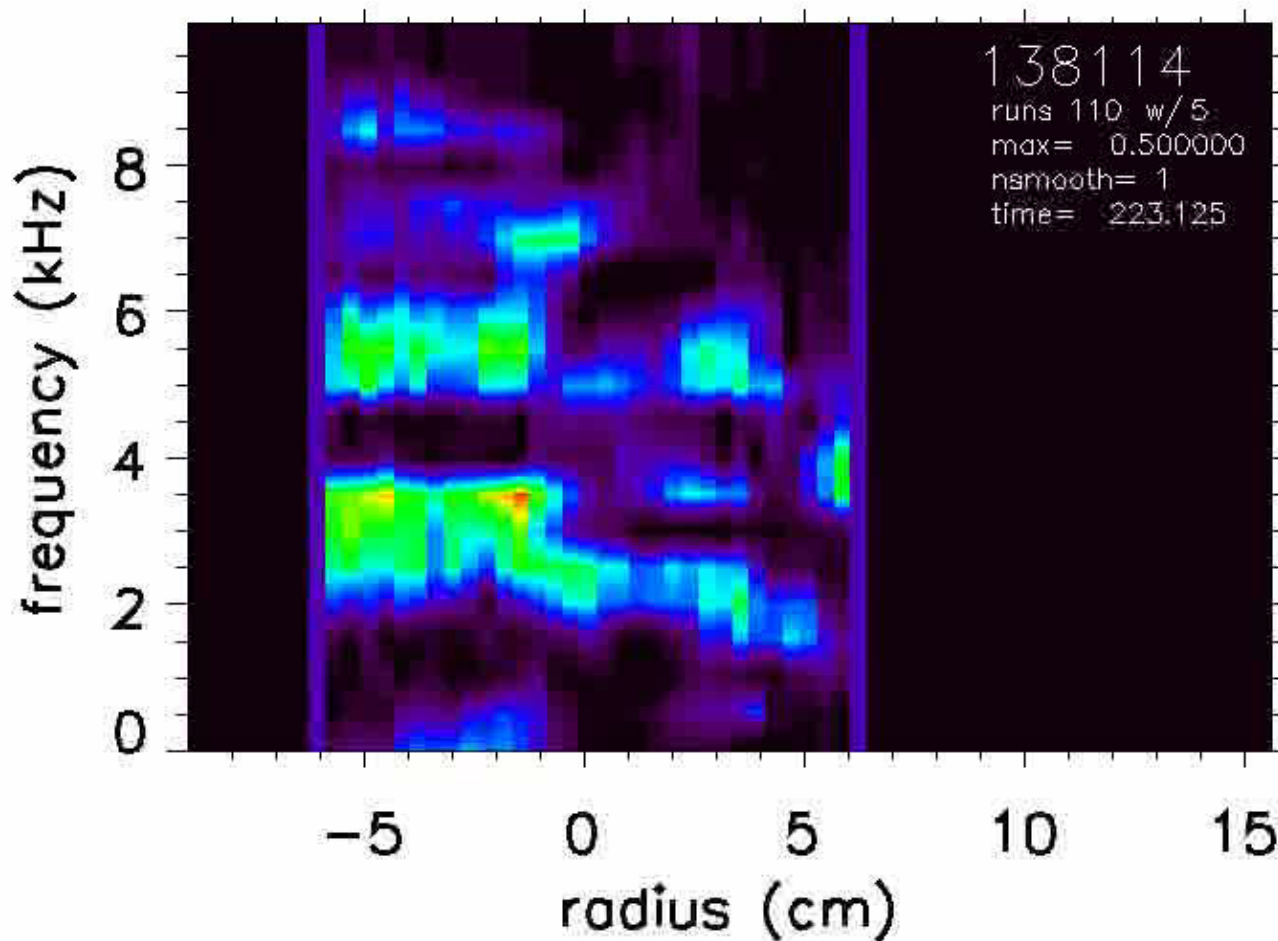
Zonal Flow Spectrum in Ohmic Case

- See near-coherent peak at ~ 3 kHz preceding transition



Radial Profile of ZF- NBI Case

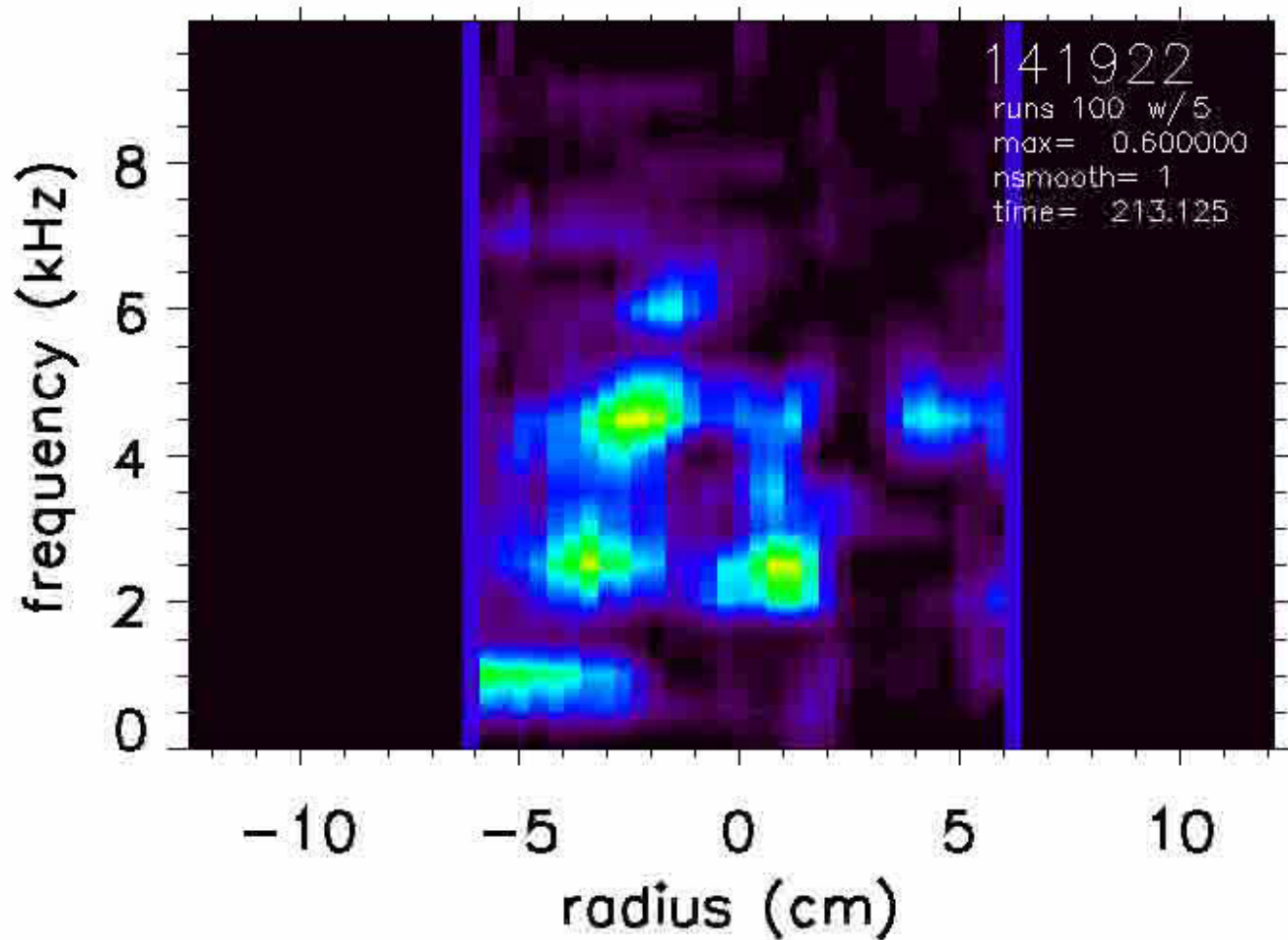
- L-H transition at 253 msec



V_{pol}
spectrum
vs. time

Radial Profile of ZF - RF Case

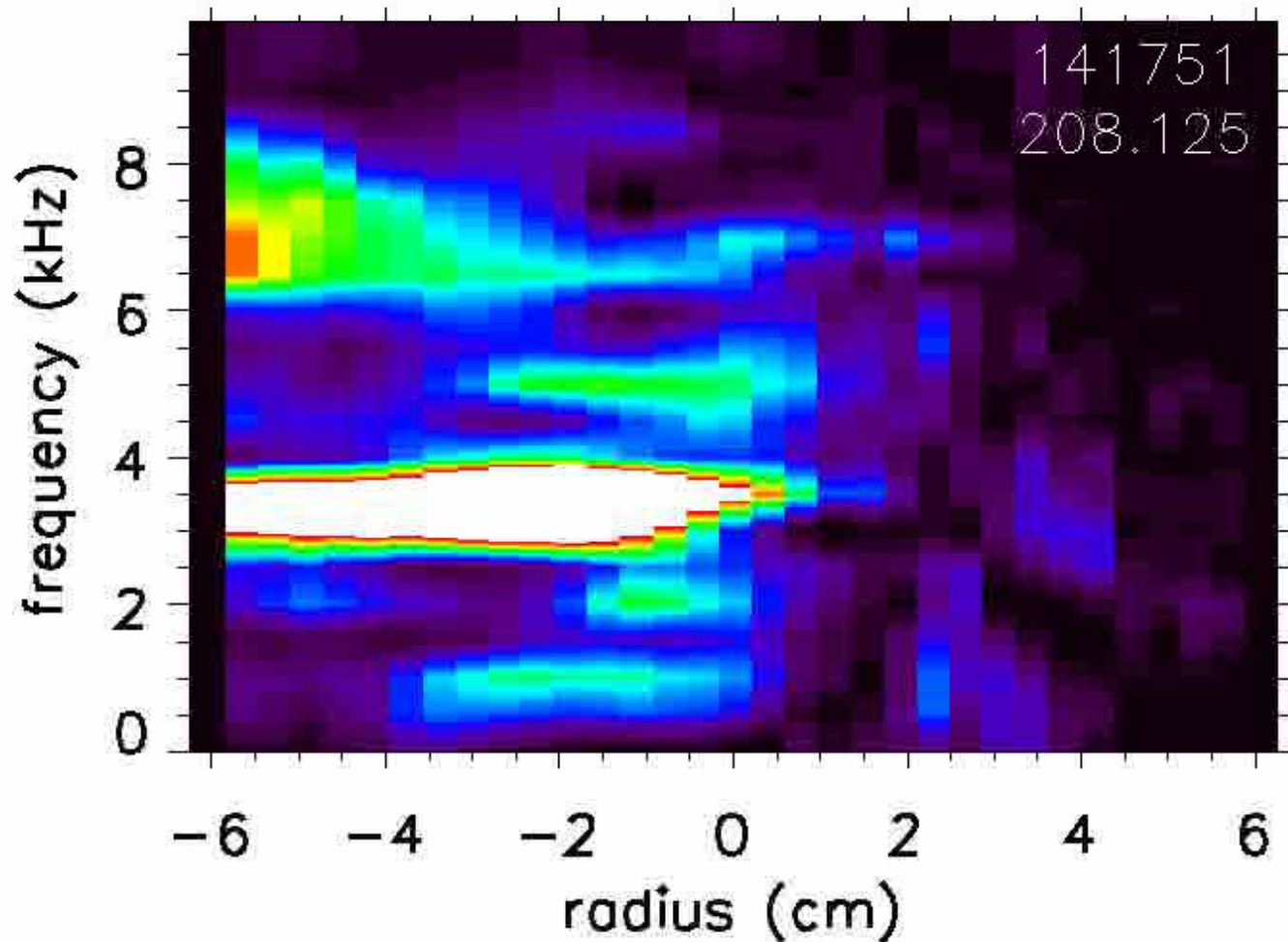
- L-H transition at 238 msec



V_{pol}
spectrum
vs. time

Radial Profile of ZF– OH Case

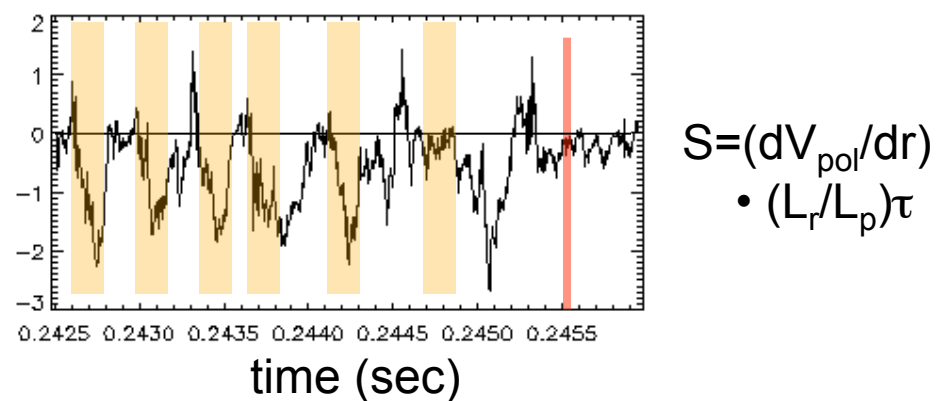
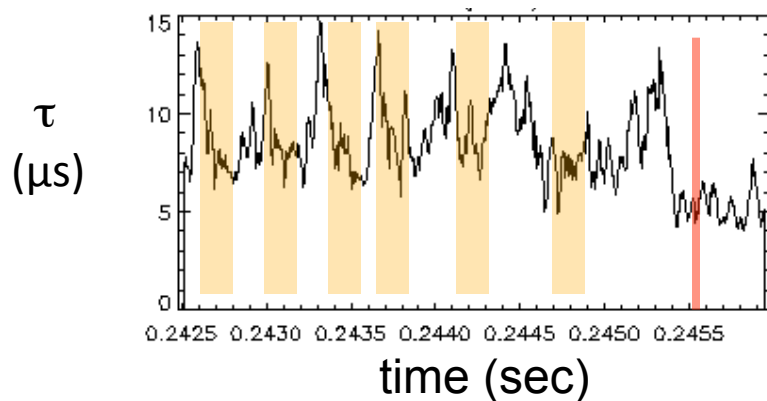
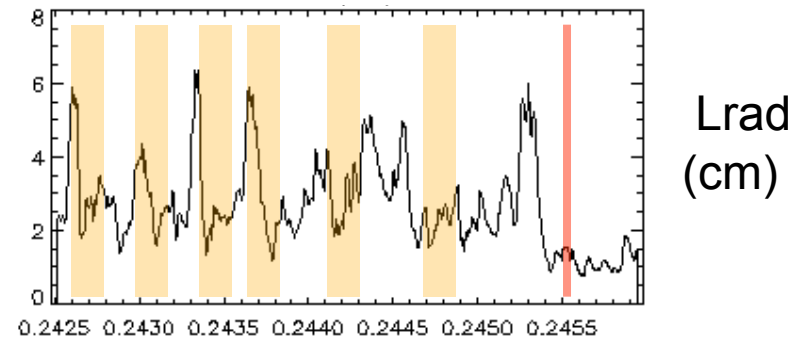
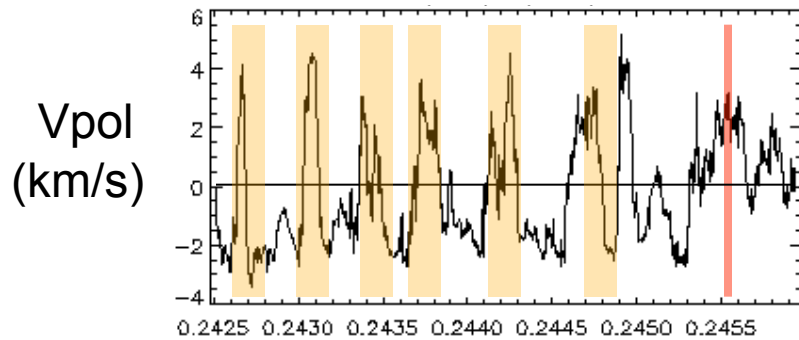
- L-H transition at 235 msec



V_{pol}
spectrum
vs. time

Relationship of ZF and Transition ?

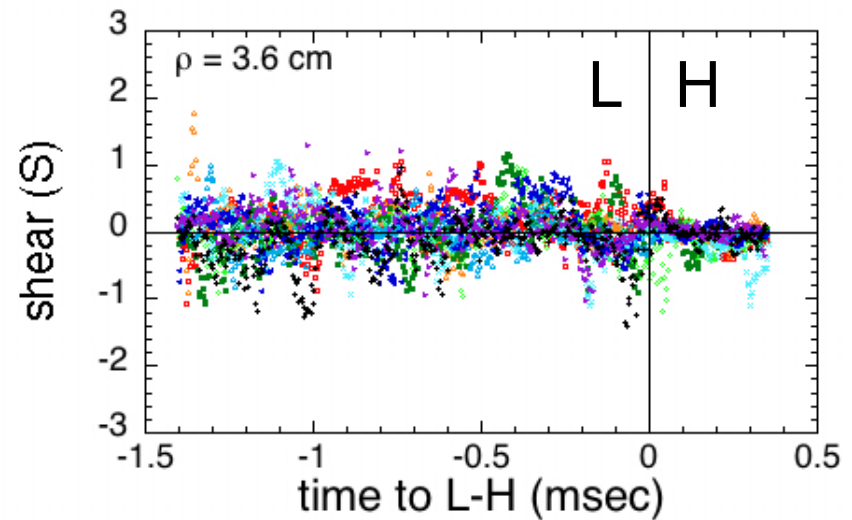
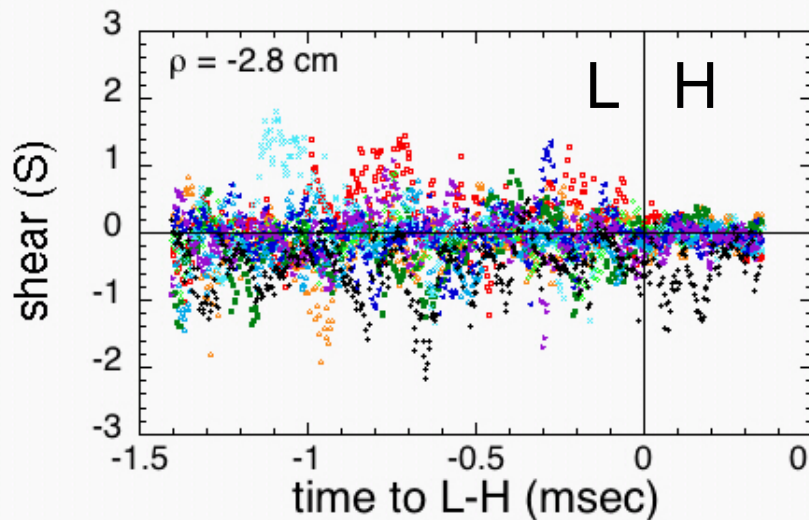
- Look at changes in V_{pol} and turbulence before L-H transition
- No obvious 'trigger event', e.g. at $\rho \sim 0.4$ cm in NBI transition*



*Zweben et al, POP '10 ; Sechrest et al, POP '11

Shear Flow Preceding Transition

- Evaluate $S = (dV_{pol}/dr)(L_r/L_p)\tau$ for 9 similar NBI transitions*
- No clear, systematic increase in S just before transition



*Zweben et al, POP '10

Summary of NSTX Results

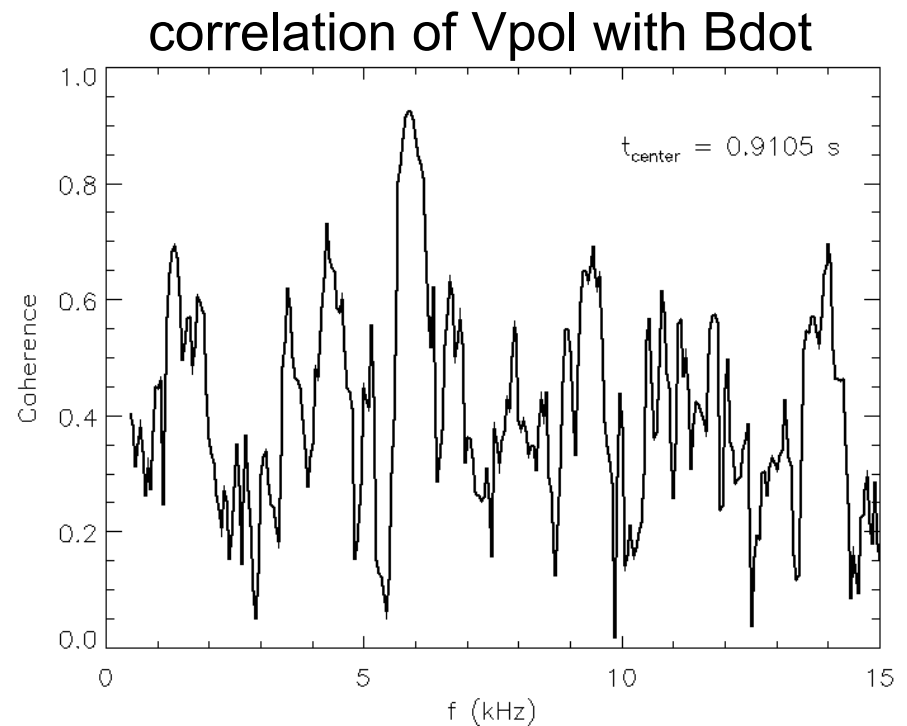
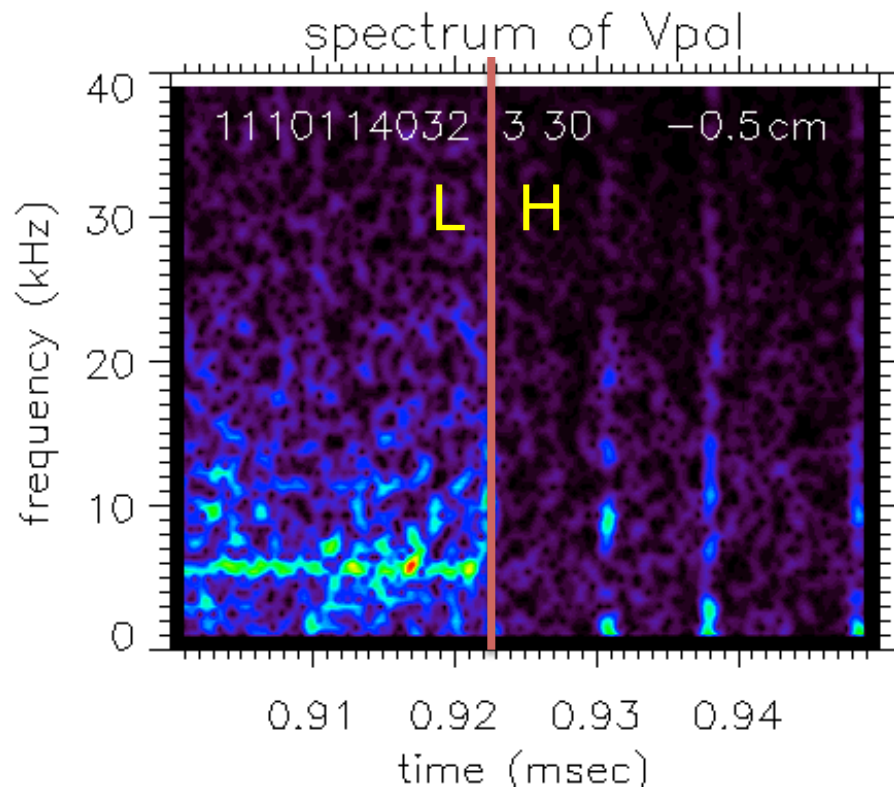
- See clear reduction in edge turbulence at L-H transition
- Often see coherent zonal flow preceding L-H transition
- But sometimes see broadband, intermittent flow instead
- No clear increase in zonal flow or shear before transition

*Causal relationship between zonal flow
and L-H transition not yet clear !*

Comparison with Alcator C-Mod

w/ J. Terry, D. Pace, T. Golfinopoulos and the Alcator Group

- Coherent V_{pol} @ ~ 6.5 kHz before RF-induced L-H transition
- Good correlation of V_{pol} with Bdot (probably $n=0$) - EGAM ?



Questions for Discussion ?

- How can we identify cause of L-H transition experimentally ?
- How can we establish quantitative connection with theory ?