Edge Turbulence Correlations Preceding L-H Transitions in NSTX

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- GPI diagnostic and L-H transition data set from 2010 run
- Correlation results for one L-H transition (#142006)
- Average results from database of 17 transitions
- Low frequency "zonal flows" vs. L-H transitions
- Summary and theoretical interpretations

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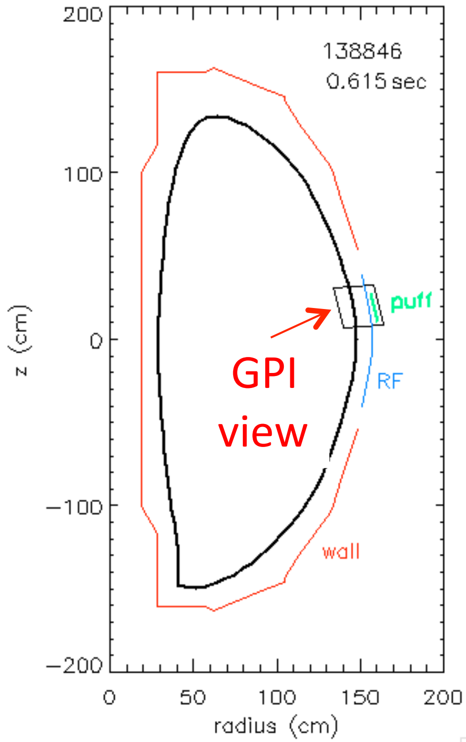
Abstract

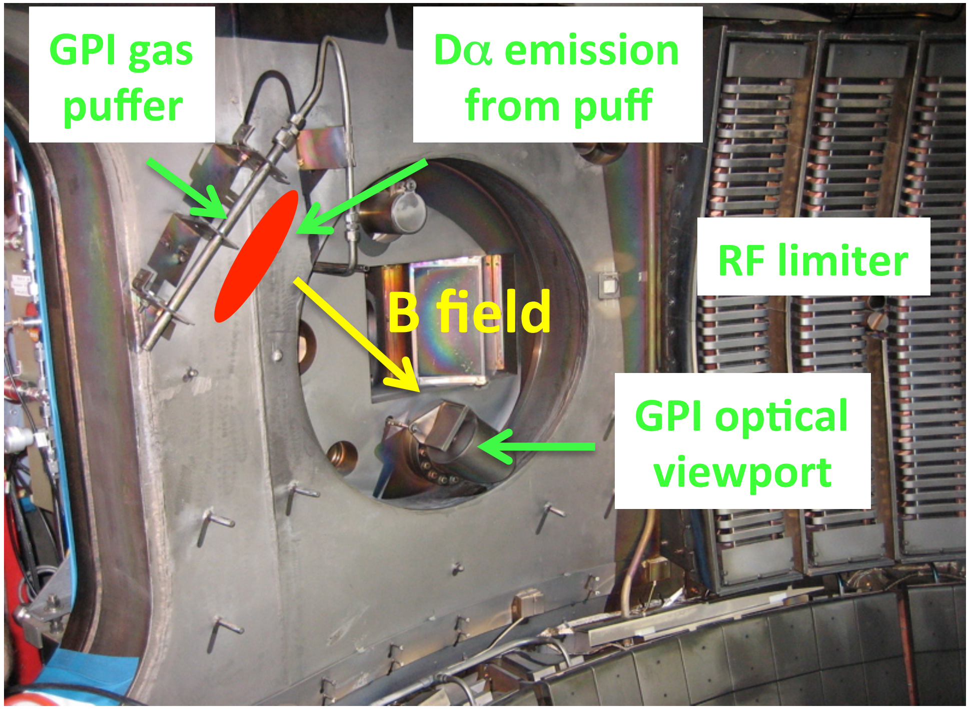
Changes in edge turbulence are generally considered to be the cause of the L-H transition, but the exact mechanism of the transition is not yet clear. This poster describes edge turbulence correlation measurements made using the gas puff imaging (GPI) diagnostic on NSTX for 17 L-H transition shots from 2010 data (OH, NBI and RF). These L-H transitions are seen as a sudden (~100 µs) change in the edge Dα emission profile during the transition, coincident with a reductions in both the relative GPI light fluctuation level inside the separatrix and blob activity outside the separatrix. Analysis to be described includes radial and poloidal correlation lengths, the 2-D tilt angle of the correlation function, radial and poloidal turbulence velocities, poloidal velocity shear of the turbulence, autocorrelation times, and fluctuation levels and spectra. There is clear evidence for low frequency oscillating poloidal ('zonal') flows at ~2-3 kHz preceding the transition, similar to results from 2009 NSTX data [1], but the causal connection between these flows and the L-H transition is not yet clear. Some theoretical interpretations of these results will be presented.

[1] Y. Sechrest et al, Phys. Plasmas 18, 012502 (2011); S.J. Zweben et al, Phys. Plasmas 17, 102502 (2010)

Gas Puff Imaging (GPI) Diagnostic on NSTX

- D_2 gas puffed from GPI manifold on outer wall above midplane
- Dα light emission from gas puff viewed from along local B field
- Fluctuations in Dα light emission interpreted as edge turbulence

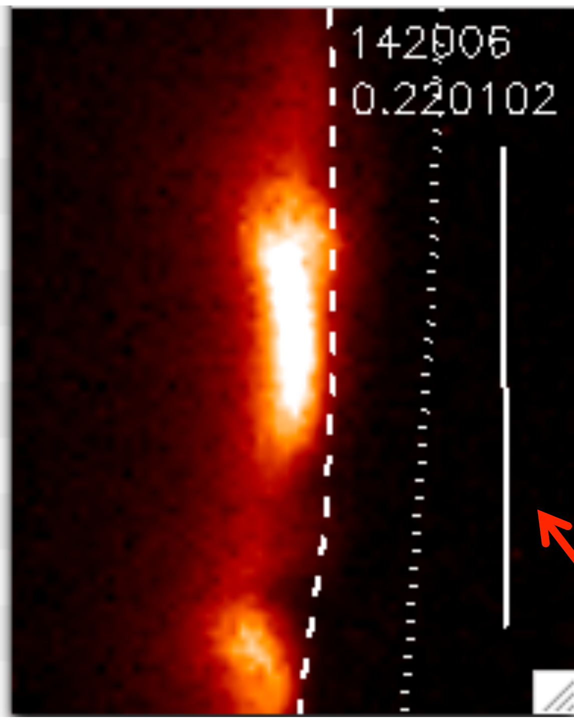




Typical GPI Images

- Exposure time/frame = 2.1 μsec/frame @ 400,000 frames/sec

L-mode

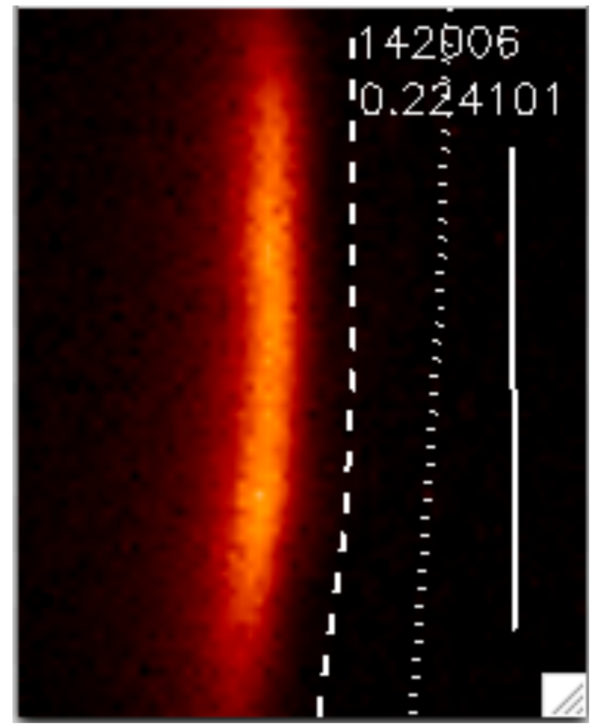


separatrix

RF antenna shadow

GPI gas injector

H-mode

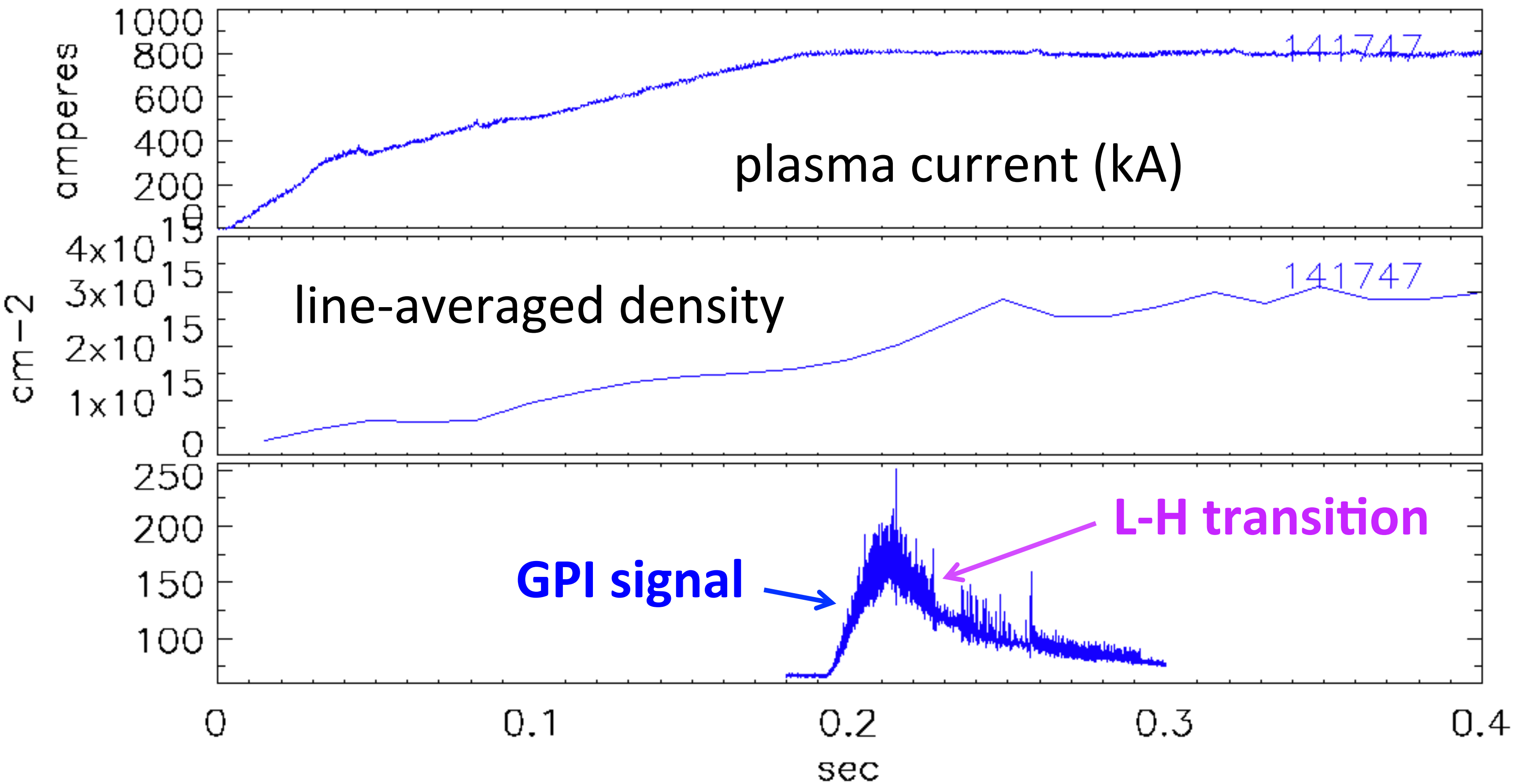


poloidal
80 pixels
30 cm

radial
64 pixels
24 cm

Typical Time Dependence of GPI Signal

- GPI gas puffed once during shot and images taken for ~100 msec
- L-H transition is seen as a sharp drop in GPI fluctuation level



GPI Database for L-H Transitions in 2010

- GPI data only obtained on a small sub-set of L-H transition shots
- List includes only transitions during current-flattop after 0.1 sec

Shot #	L-H time (ms)	Btor (kG)	Ip (kA)	Pnbi (MW)	Prf (MW)
138113	254.9	4.4	910	1.4	-
138114	252.5	4.4	910	1.4	-
138115	243.0	4.4	910	0	-
138116	251.6	4.4	910	0 (just after 1.0)	-
138117	245.8	4.4	910	0	-
138118	249.5	4.4	910	0	-
138119	268.4	4.4	910	1.2	-
139955	364.3	4.4	900	1.0	-
141745	227.7	3.6	800	-	-
141746	244.9	3.6	800	-	-
141747	226.5	3.6	800	-	-
141751	235.0	3.6	800	-	-
141919	231.1	4.4	910	-	0.64
141920	241.5	4.4	910	-	0.60
141922	237.5	4.4	910	-	0.73
142006	223.0	4.4	910	-	0.50 (near end)
142229	401.8	4.4	800	1.0	-

Turbulence Analysis Methods

Fluctuation levels vs. time:

1) smooth each raw image frame in 2-D plane over 3 pixels (~ 1cm)
2) find rms/mean vs. time at each pixel over 11 frames (~30 μsec)
3) for fluctuation level at each radius, average these over 60 pixels poloidally (~22 cm)

Spatial correlations vs. time:

1) choose starting radius for cross-correlation function using mid-vertical pixel (j=40)
2) do spatial cross-correlations within ± 15 pixels (± 6 cm) in 2-D plane, averaging in time for each point over ± 50 frames (± 125 μsec) to reduce noise level
3) find poloidal and radial correlations lengths from FWHM of correlation functions
4) find tilt and ellipticity from elliptical fit at a cross-correlation level of 0.8

Velocities vs. time:

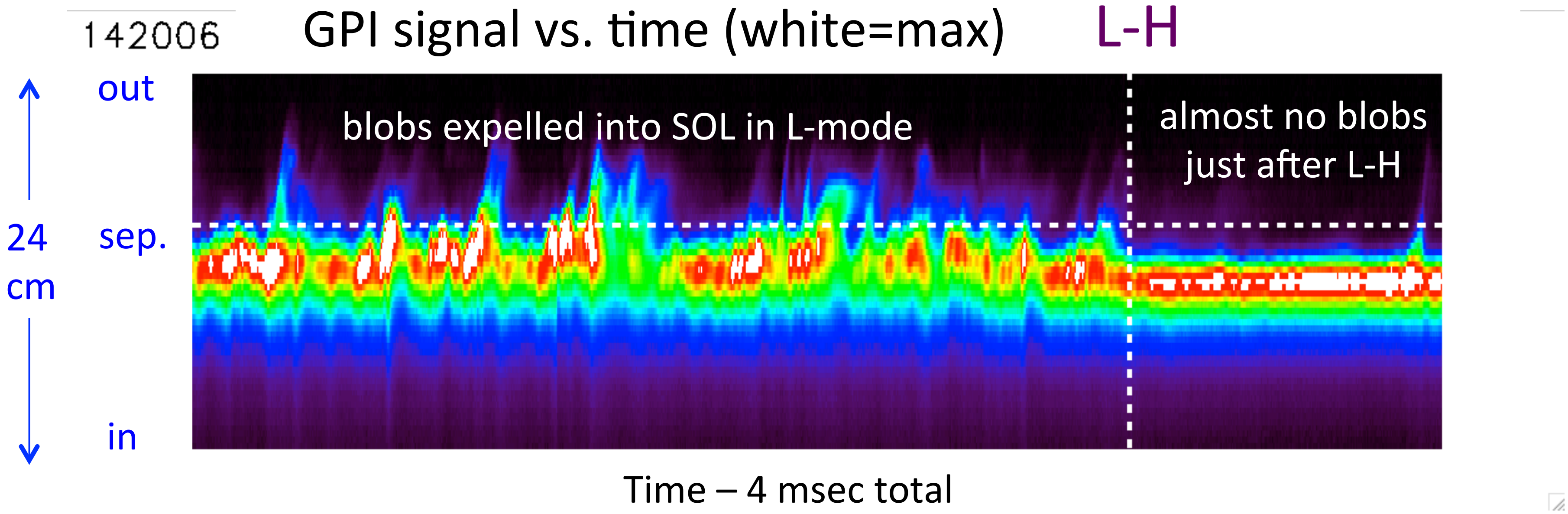
1) choose starting pixel and frame in 2-D image to do time-delayed cross-correlations
2) do cross-correlation of starting pixel vs. time with nearby test pixels vs. time but with 1 frame time delay (± 2.5 μsec) in test pixels, averaging over ± 11 frames (±30 μsec)
3) find location of maximum in cross-correlations within test range ±10 pixels in 2-D (±4 cm)
4) calculate local poloidal and radial velocity from location of maximum cross-correlations
5) average these velocities in time over ±5 frames (±12 μsec) to reduce noise in velocities
6) for average velocities at each radius, average these over 60 pixels poloidally (~22 cm)

Correlation Results

- First show examples for one typical shot - 142006 (RF shot)
- Then all 17 shots vs. time, sorted into OH, NBI, and RF (by color)
- All quantities evaluated 1 cm inside separatrix for these results

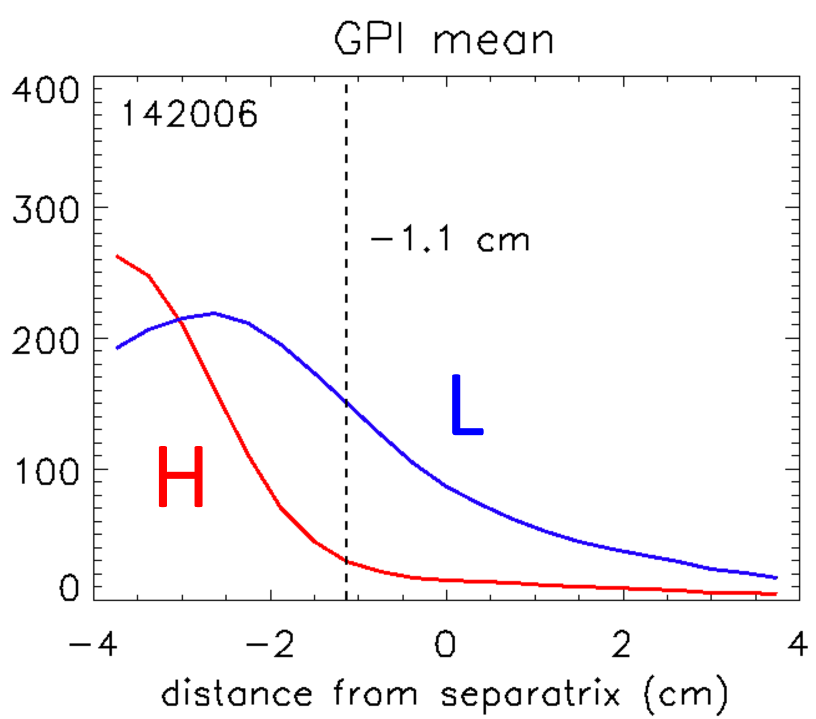
Radial Profile of GPI Signal vs. Time (142006)

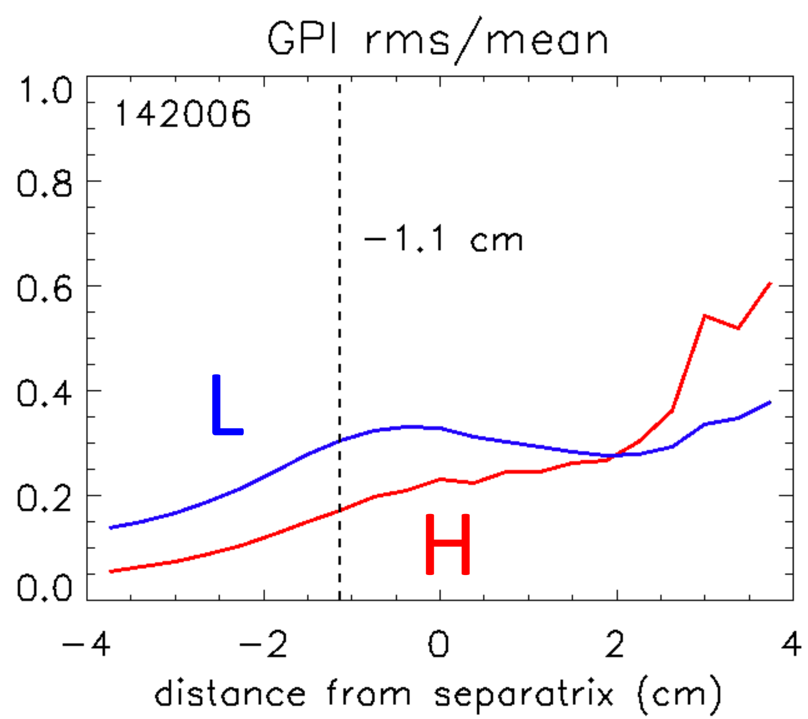
L-H transitions are seen as a sudden (~100 μs) change in the edge GPI Dα emission profile during the transition, coincident with reductions in both the relative GPI light fluctuation level inside the separatrix, and blob activity in GPI outside the separatrix



GPI Signals and Fluctuation Levels (142006)

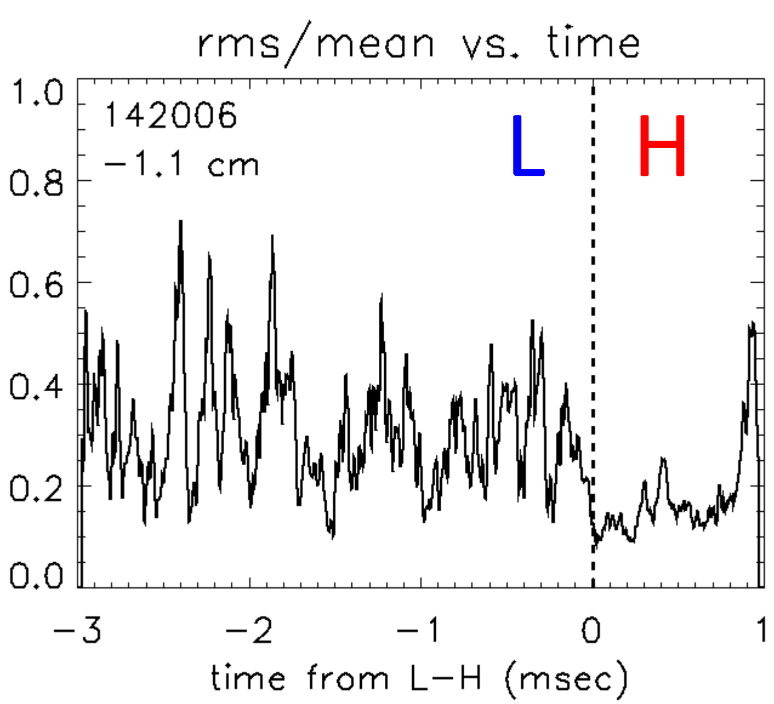
- GPI profiles change at L-H transition due to plasma profile changes
- Relative GPI fluctuation levels drop inside separatrix at transition
- Profiles averaged over 3 msec in L-mode and 1 msec in H-mode

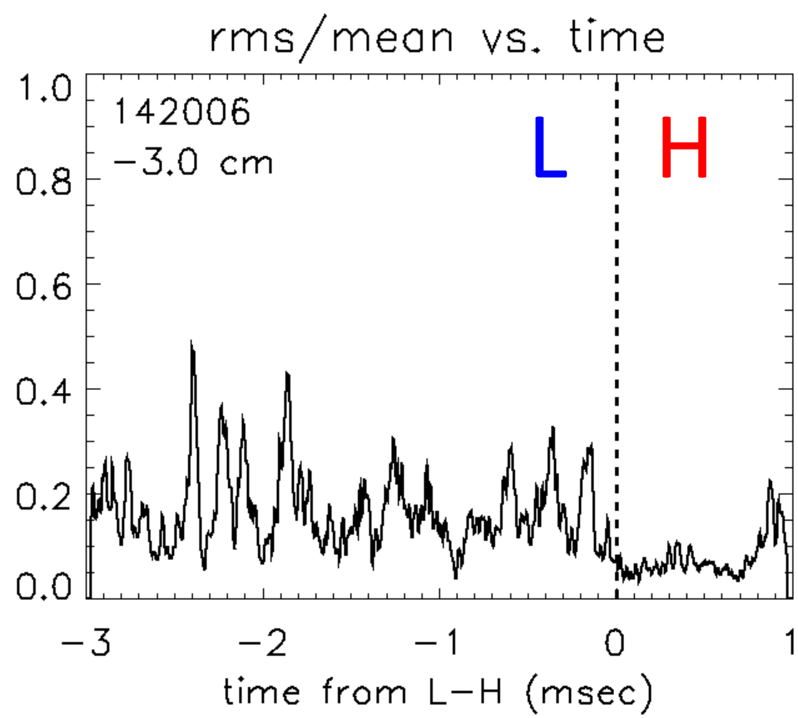




Relative Fluctuation Levels vs. Time (142006)

- Relative fluctuation levels decrease over ~100 μsec at L-H transition
- Similar decreases everywhere inside separatrix, e.g. -1 cm and -3 cm

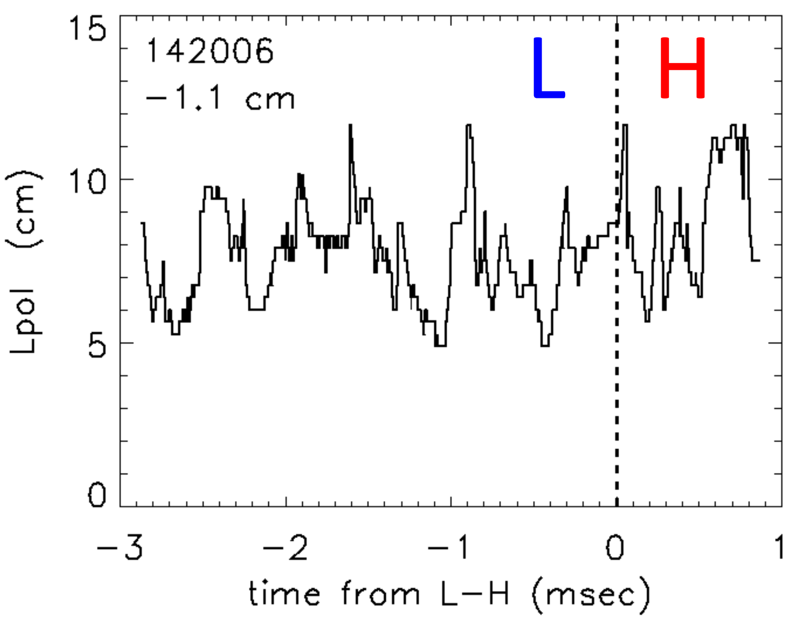




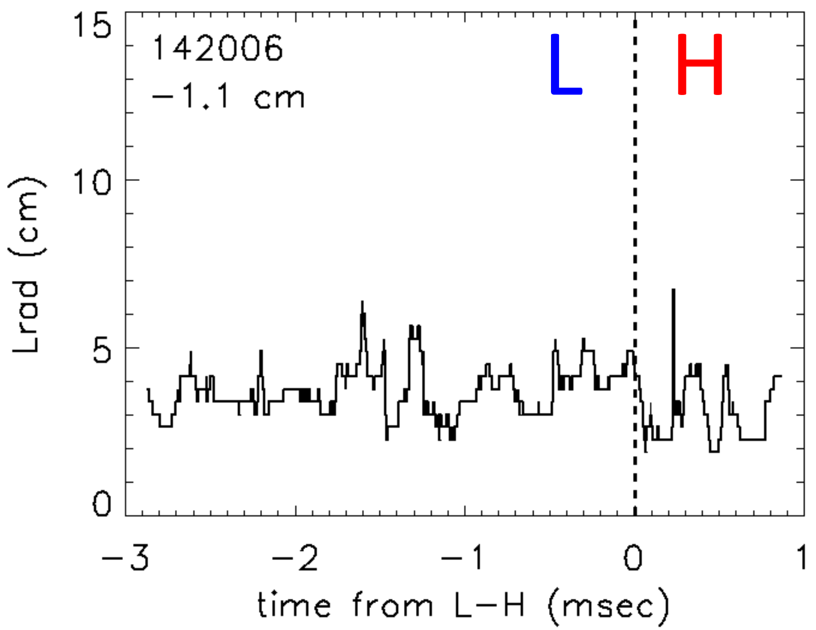
Correlation Lengths vs. Time (142006)

- Correlation lengths calculated from FWHM of cross-correlation function at a given radius at middle of GPI poloidal (z) range
- No clear change in L_{pol} or L_{rad} across L-H transition in this case

poloidal correlation length



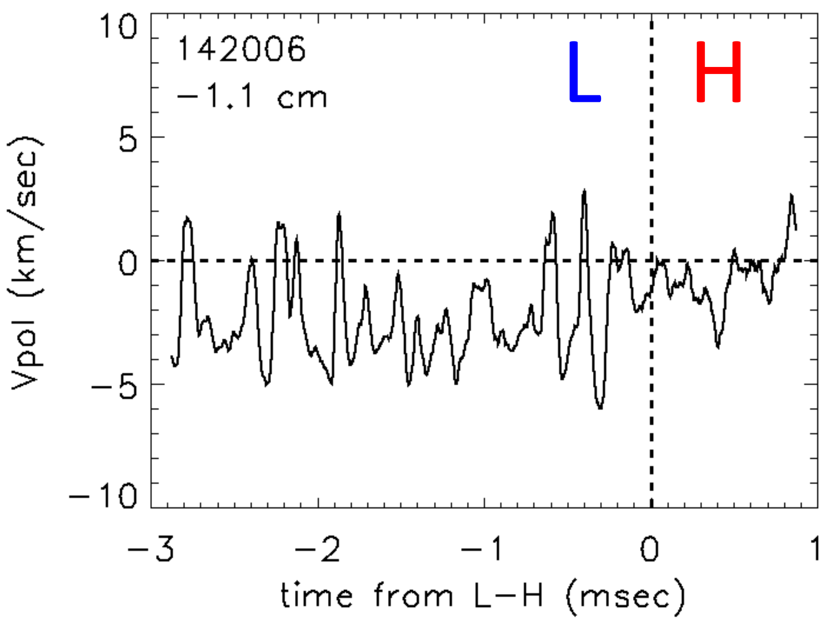
radial correlation length



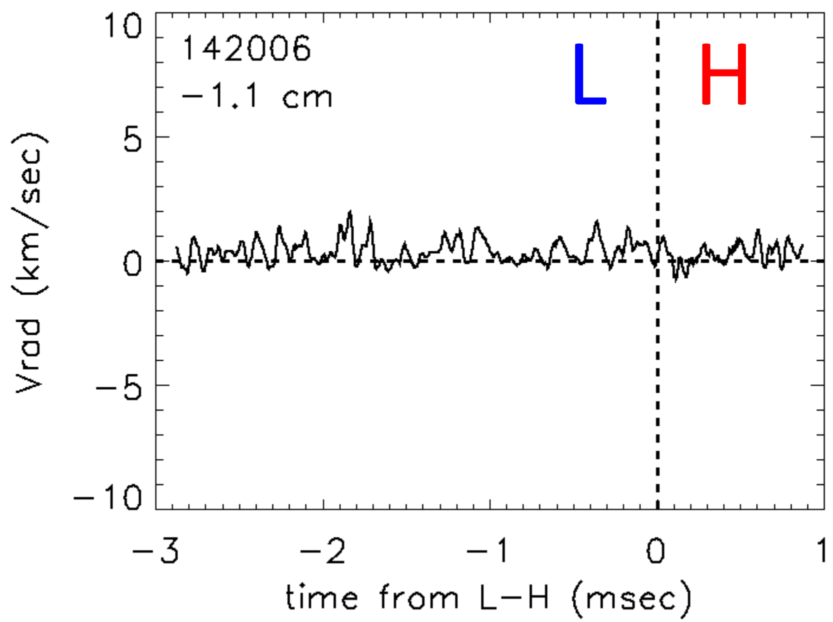
Turbulence Velocities vs. Time (142006)

- Turbulence velocities calculated from location of cross-correlation maximum in 2D image after ±1 frame time delay, averaged over poloidal angle within GPI field of view
- No clear change in V_{pol} or V_{rad} across L-H transition in this case

turbulence poloidal velocity



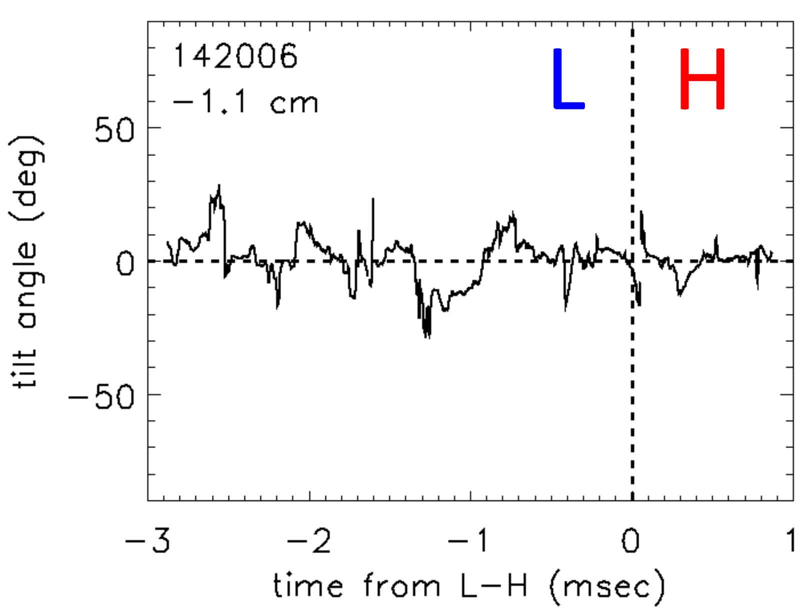
turbulence radial velocity



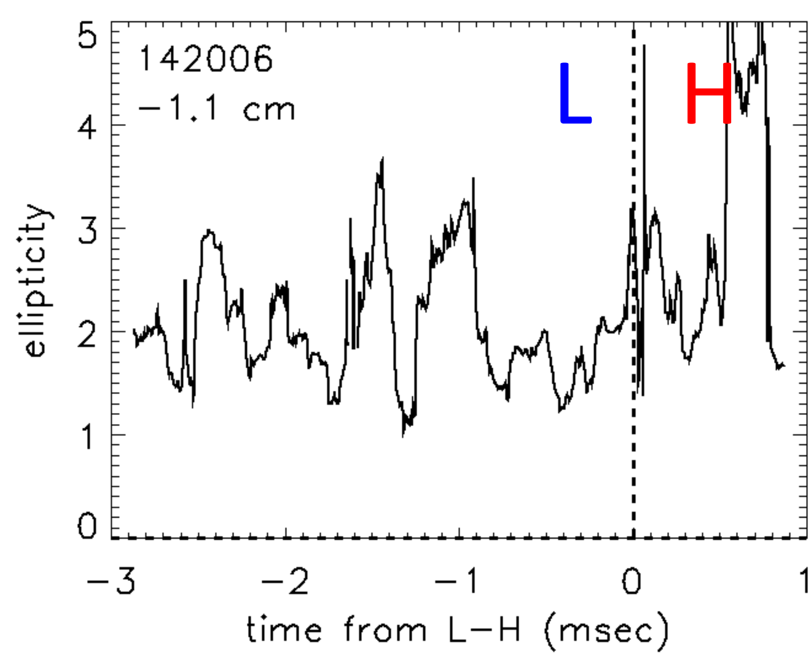
2-D Correlation Shape vs. Time (142006)

- Tilt angle and ellipticity of correlation ellipse in 2-D images is found from elliptical fits of correlation functions vs. time
- No clear change in tilt or ellipticity before L-H transition in this case

correlation tilt angle



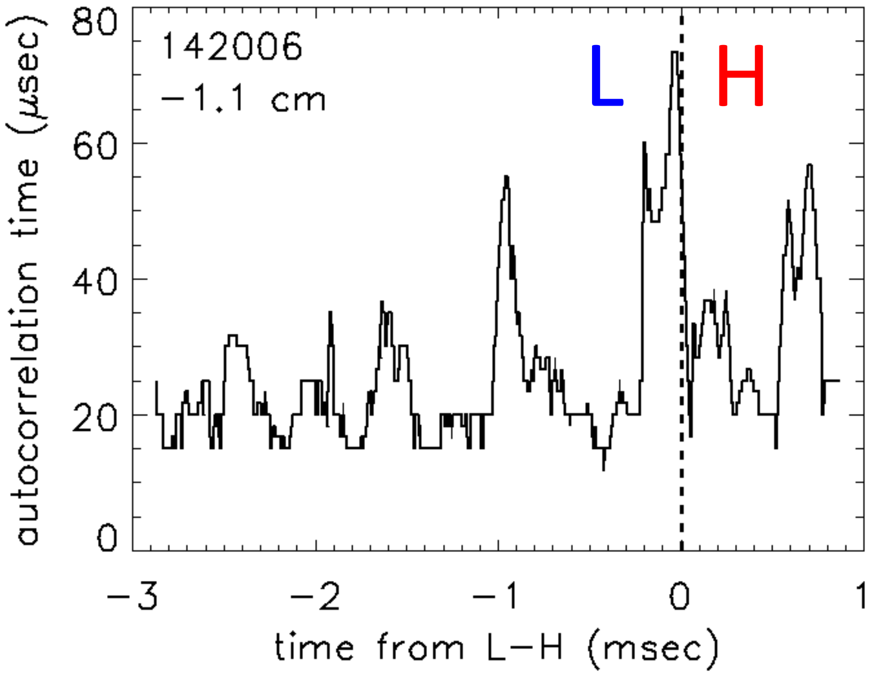
correlation ellipticity

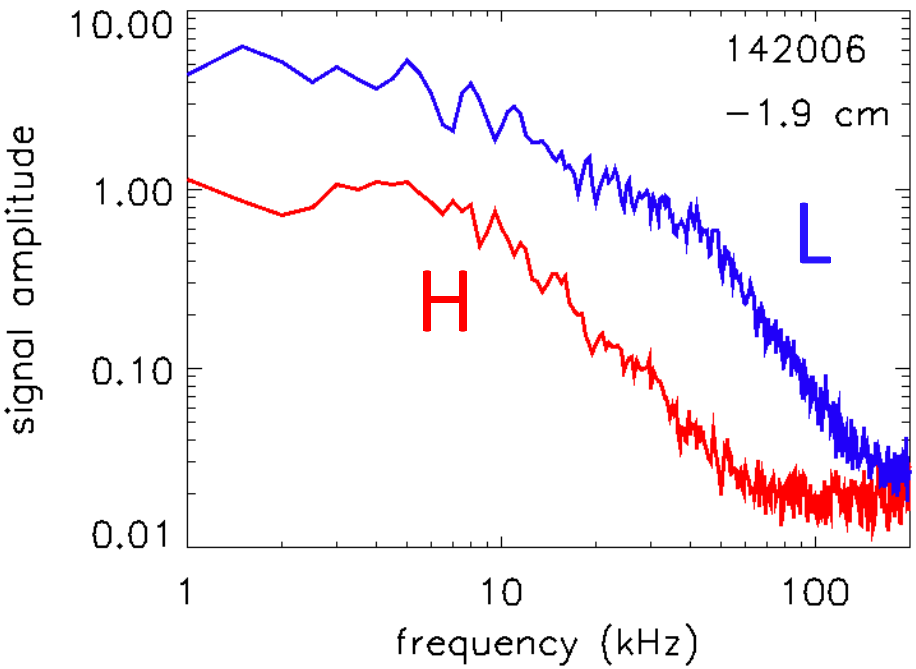


Autocorrelation and Frequency (142006)

- Possible increase in autocorrelation time in 0.3 msec preceeding L-H transition in this case (not generally true, see below)

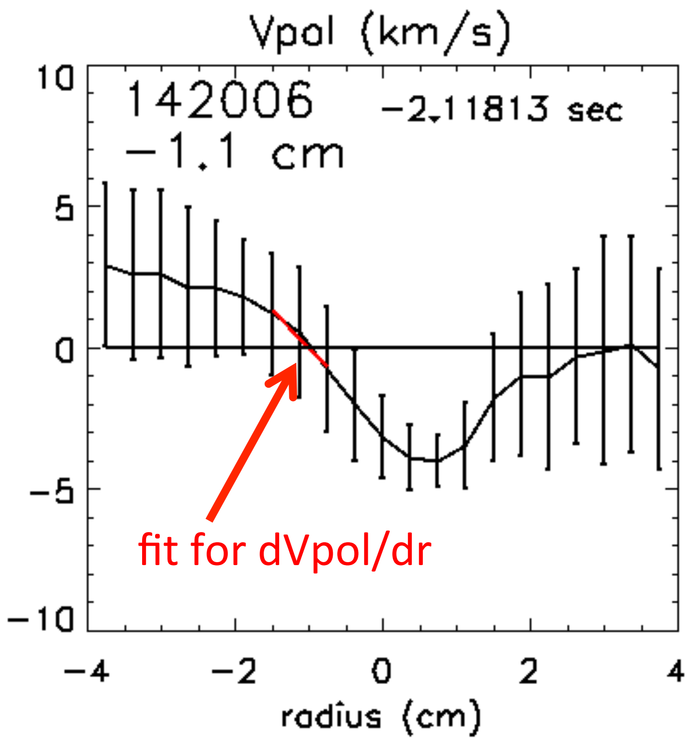
- Frequency spectra of signal is similar in L and H, with perhaps a decrease in higher frequencies 20-100 kHz in H-mode

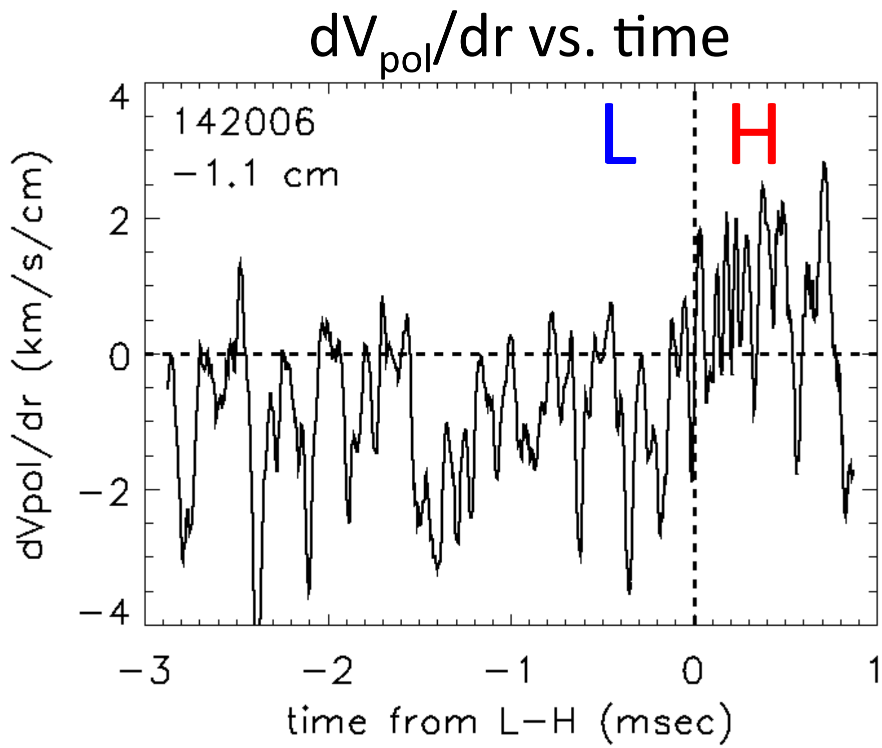




Poloidal Velocity Profile and Shear (142006)

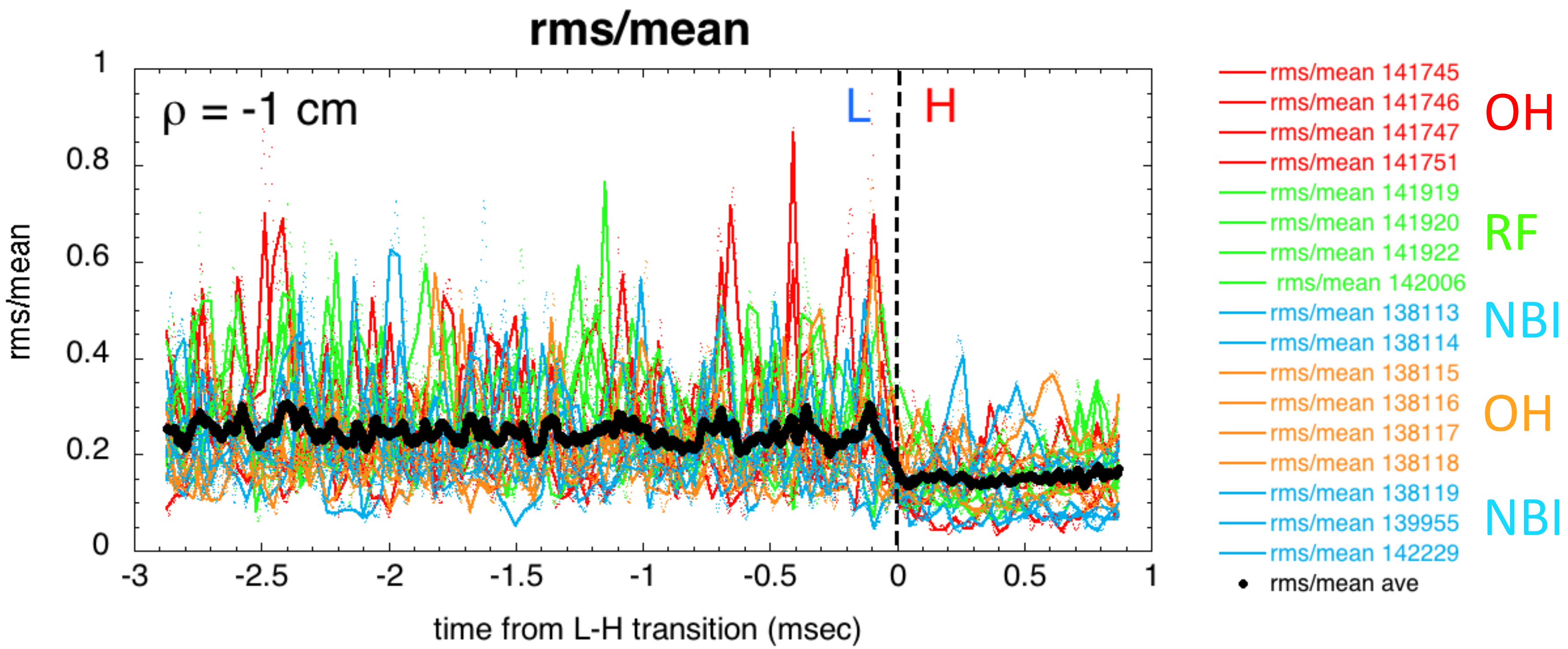
- V_{pol} profiles are smoother vs. radius than expected from 'error bars' associated with rms variation of V_{pol} over poloidal range
- No clear change in autocorrelation time or poloidally-averaged dV_{pol}/dr calculated before L-H transition in this case





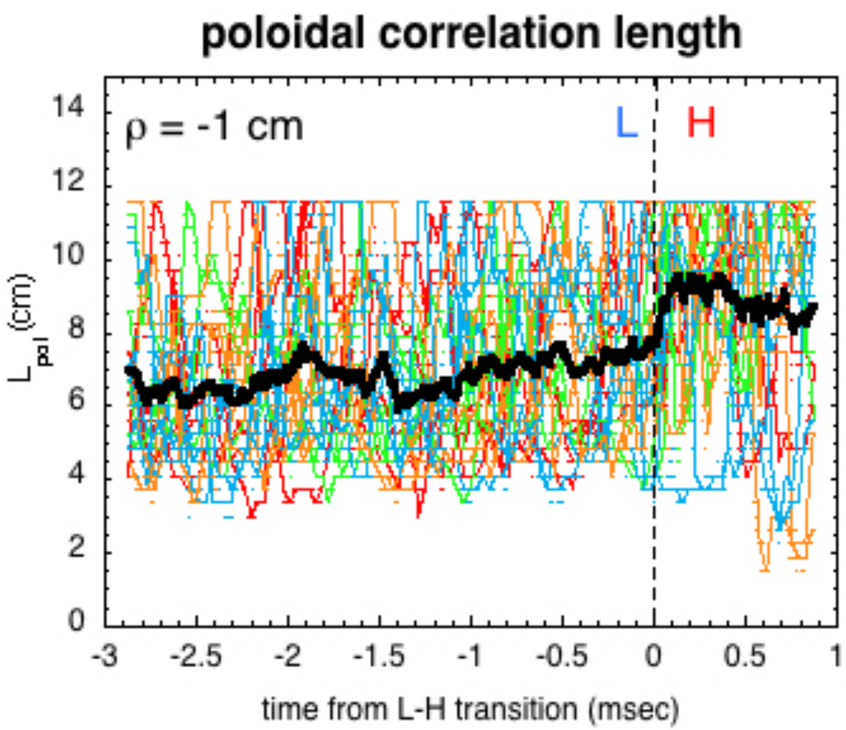
Fluctuation Levels - Database

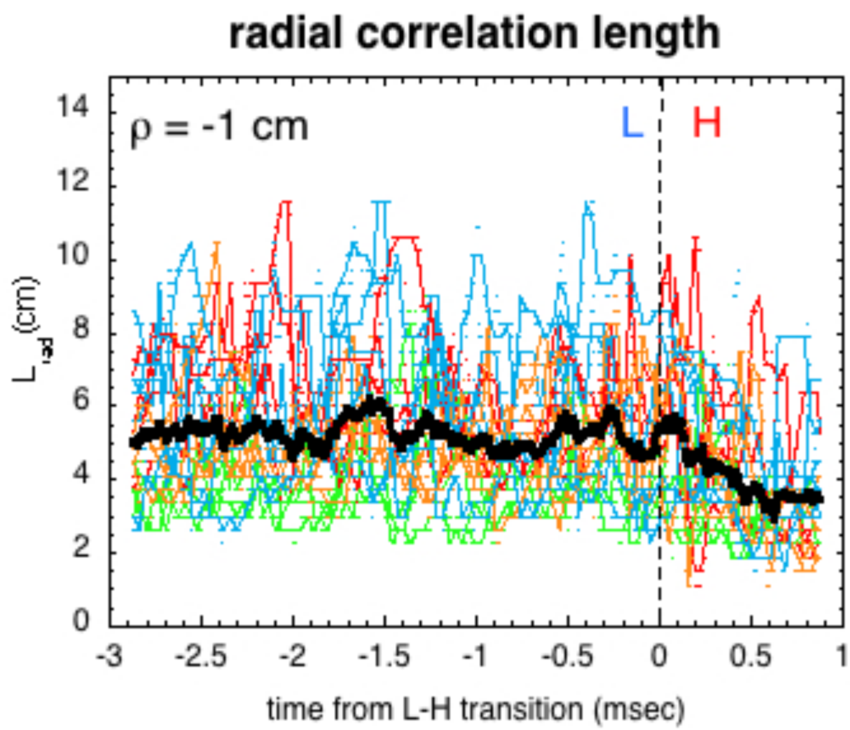
- Average δI/I changes from ~25% in L-mode to ~15% in H-mode
- Timescale for drop in fluctuation levels ~ 100 μsec at transition



Correlation Lengths - Database

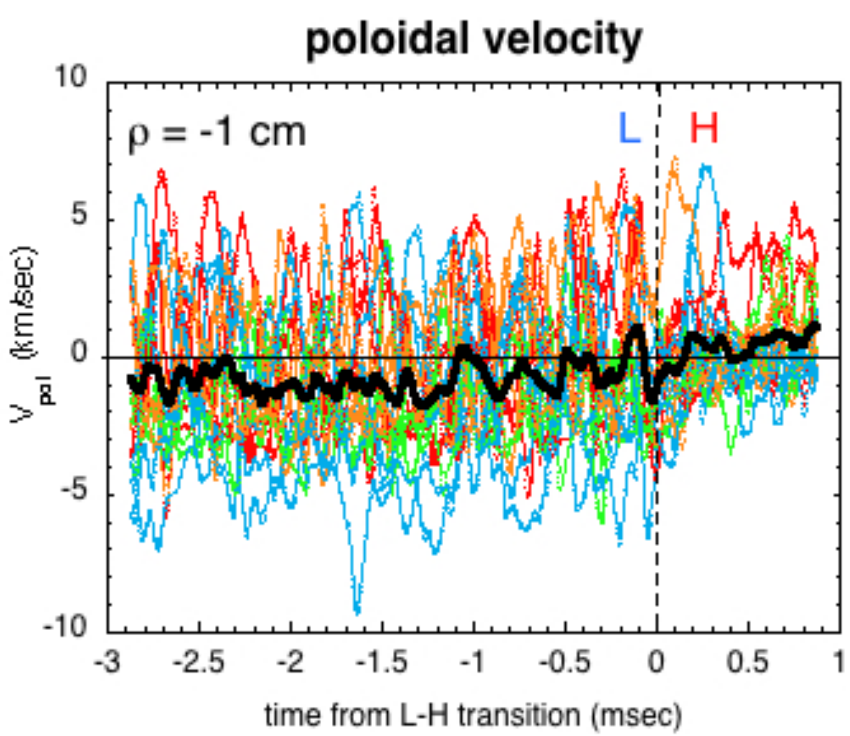
- Average L_{pol} increase from 6.8 cm in L-mode to 8.8 cm in H-mode
- Average L_{rad} decreases from 5.3 cm in L-mode to 3.8 cm in H-mode

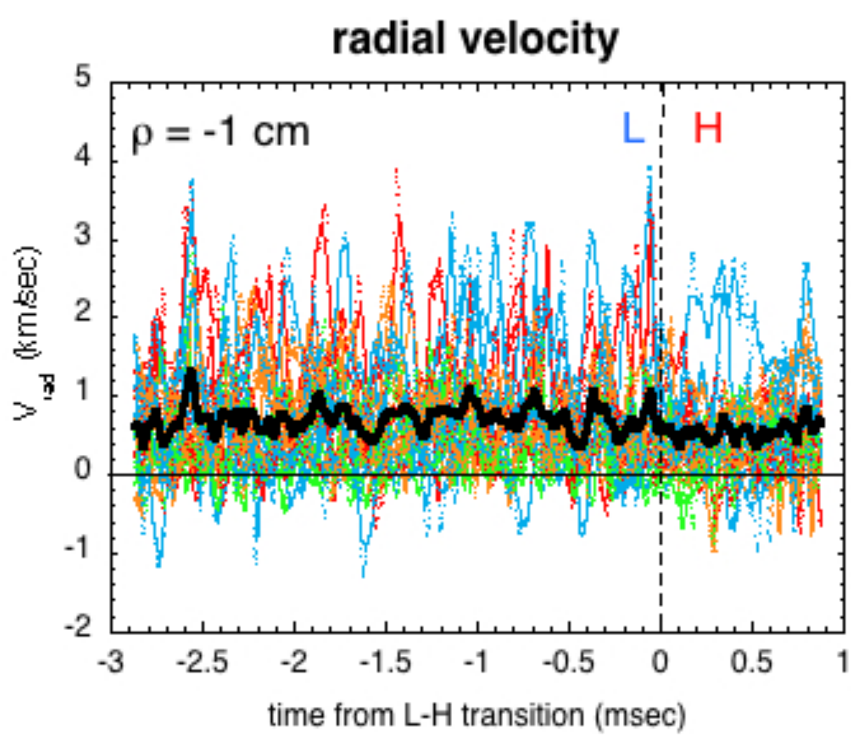




Turbulence Velocities - Database

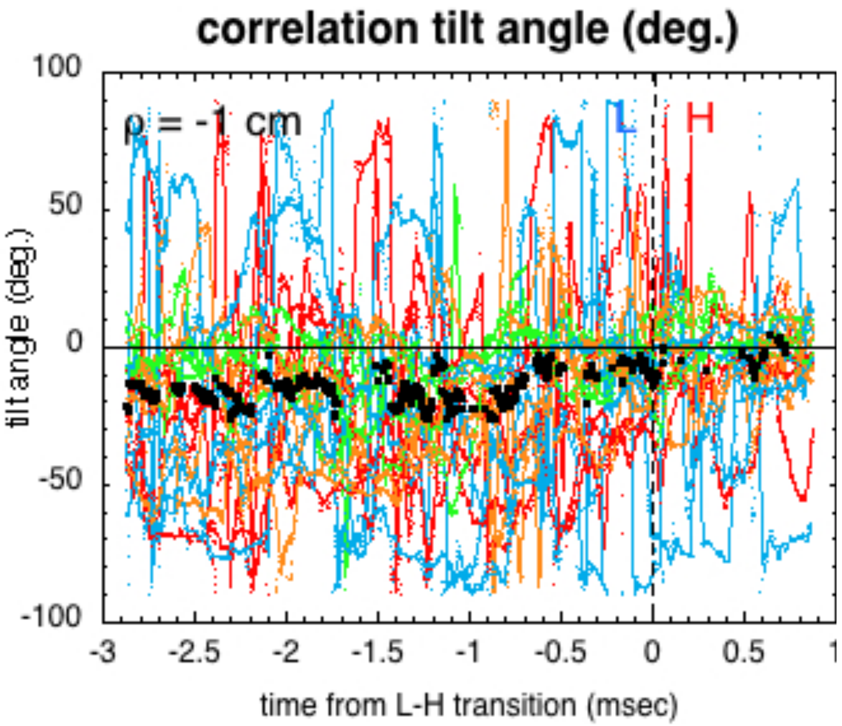
- Average V_{pol} = -0.85 km/s in L-mode and +0.53 km/s cm in H-mode
- Average V_{rad} = +0.53 km/s in L-mode and +0.56 km/s in H-mode
- Average V_{pol} changes from IDD before to EDD after transition

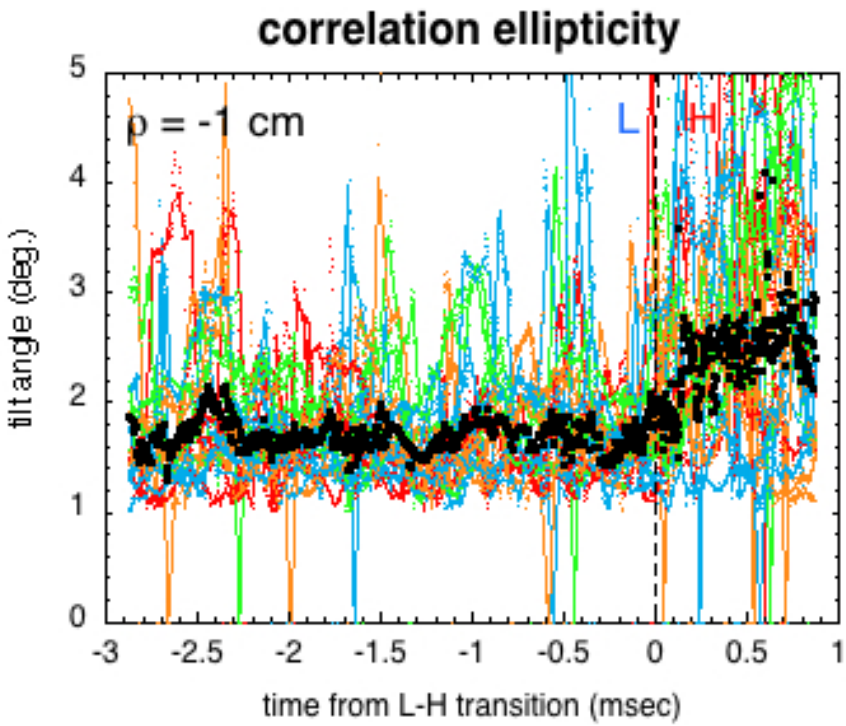




2-D Correlation Shape - Database

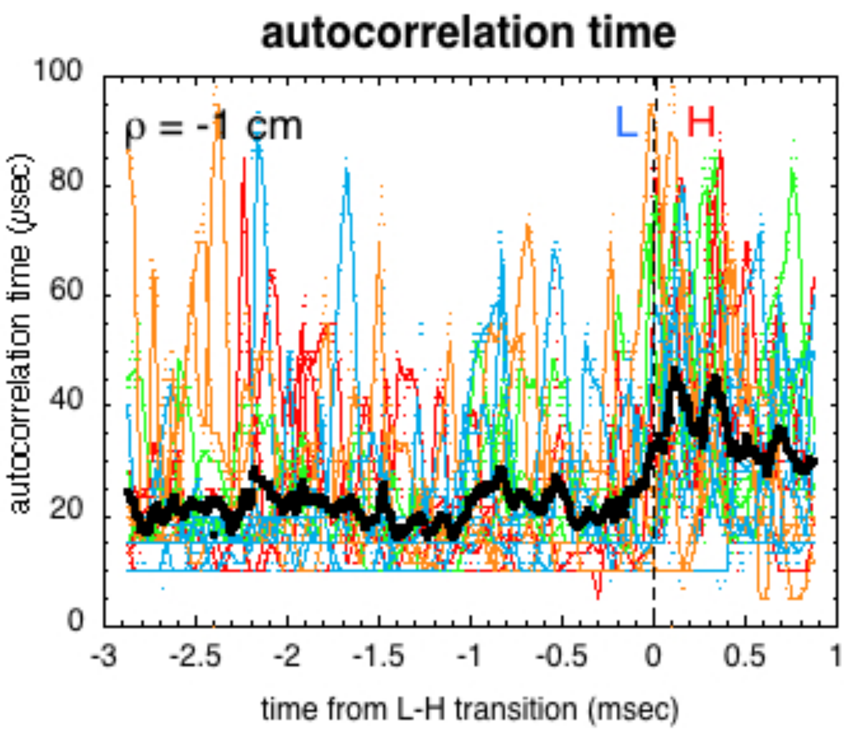
- Average tilt angle of correlation varies widely in L- and H-mode
- Average ellipticity of correlation = 1.7 in L-mode and 2.5 in H-mode

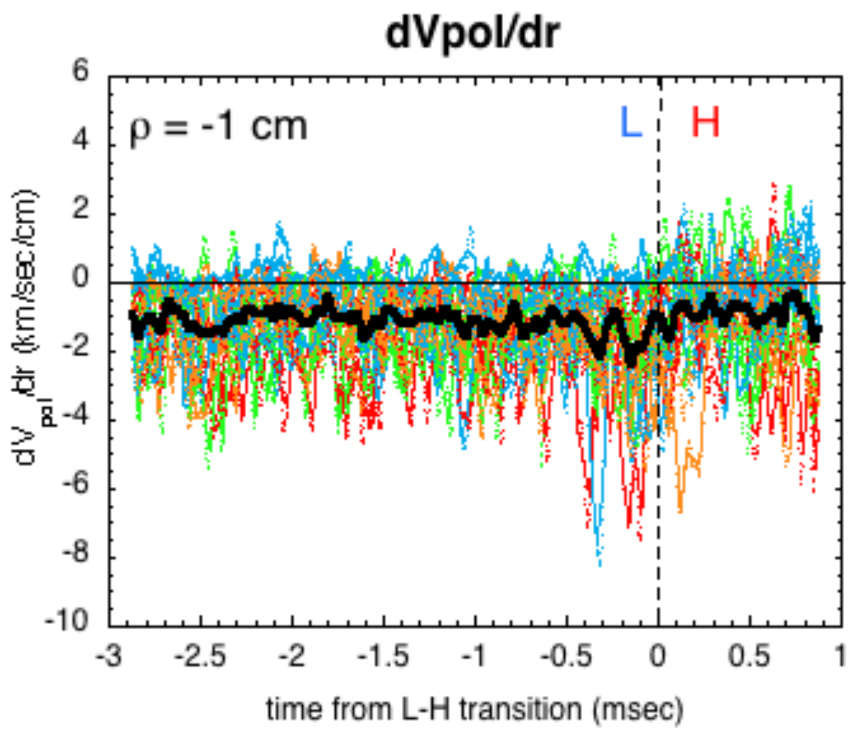




Autocorrelation and dVpol/dr – Database

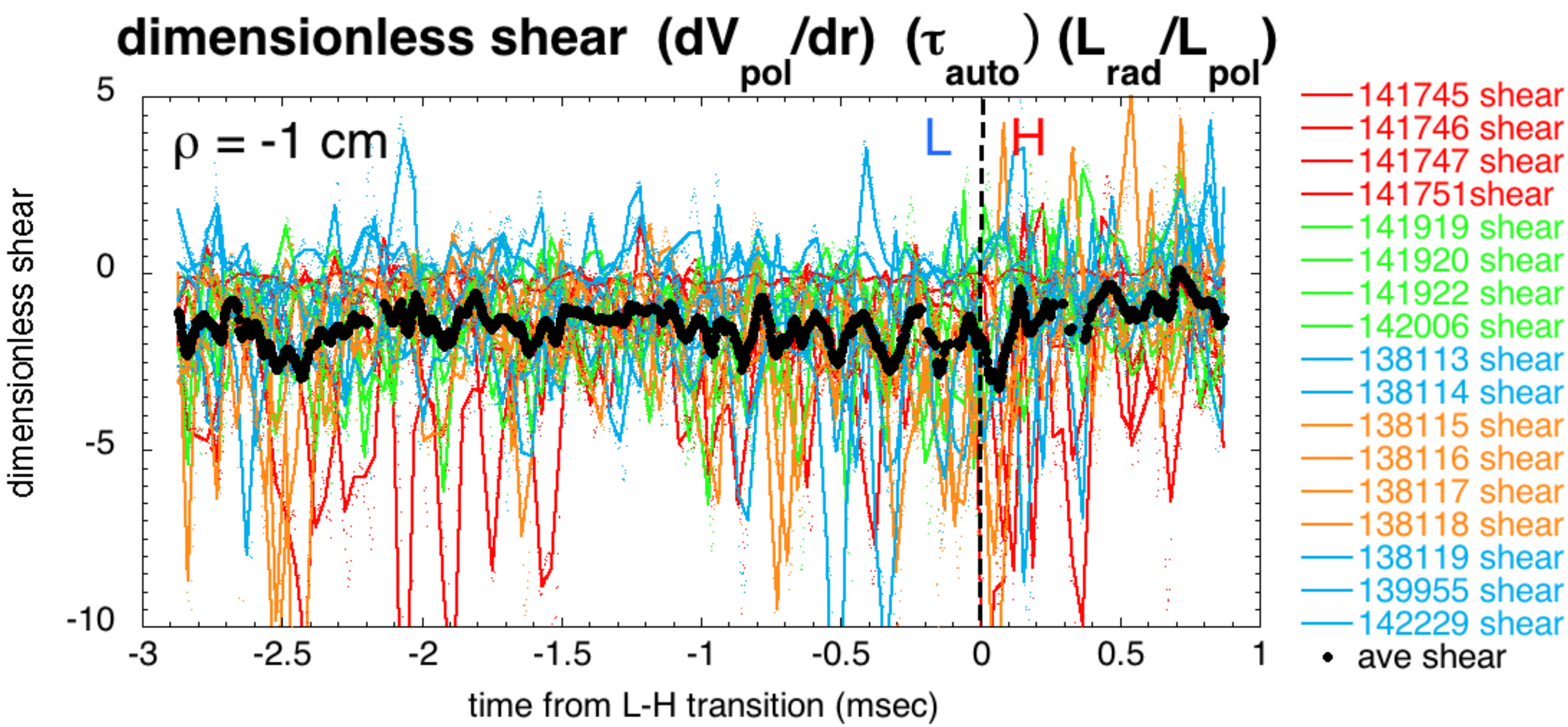
- Average autocorrelation time =22 μsec in L and 34 μsec in H-mode
- Average dV_{pol}/dr= - 1.1 km/s/cm in L and - 0.85 km/s/cm in H-mode





Dimensionless Velocity Shear

- Estimate dimensionless shear as: $S=(dV_{pol}/dr)\ (L_{rad}/L_{pol})\ \tau_{auto}$
- Time-averaged S~-1.6±0.5 (L-mode) and S~-0.9±0.4 (H-mode)
- No clear change in shot-averaged S preceding L-H transition

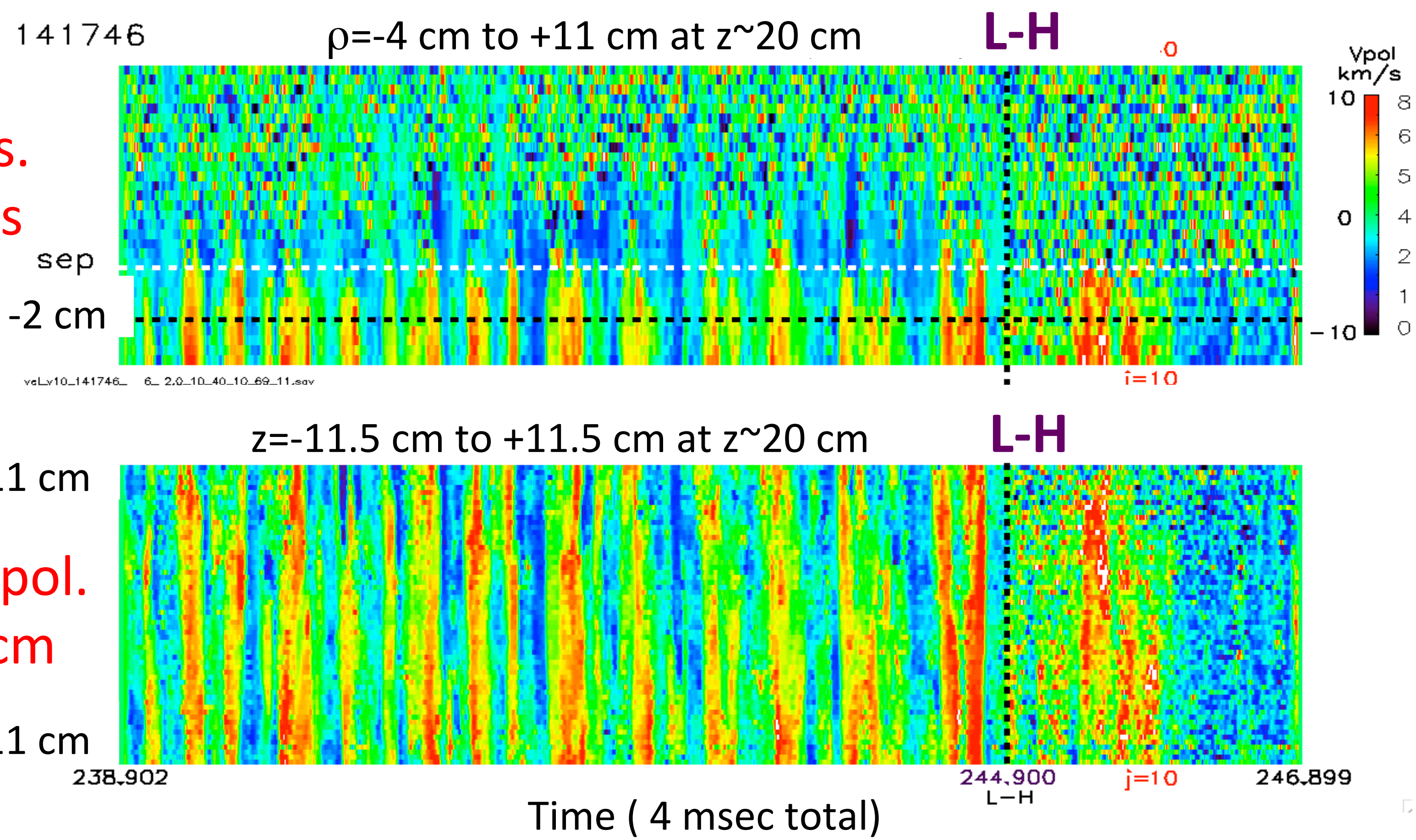


Low Frequency “Zonal Flow”

- Most shots have ~2-4 kHz oscillations in V_{pol} extending most of the poloidal distance across the GPI image inside separatrix (similar to results in Secrest PoP 2011 & Zweben PoP 2010)

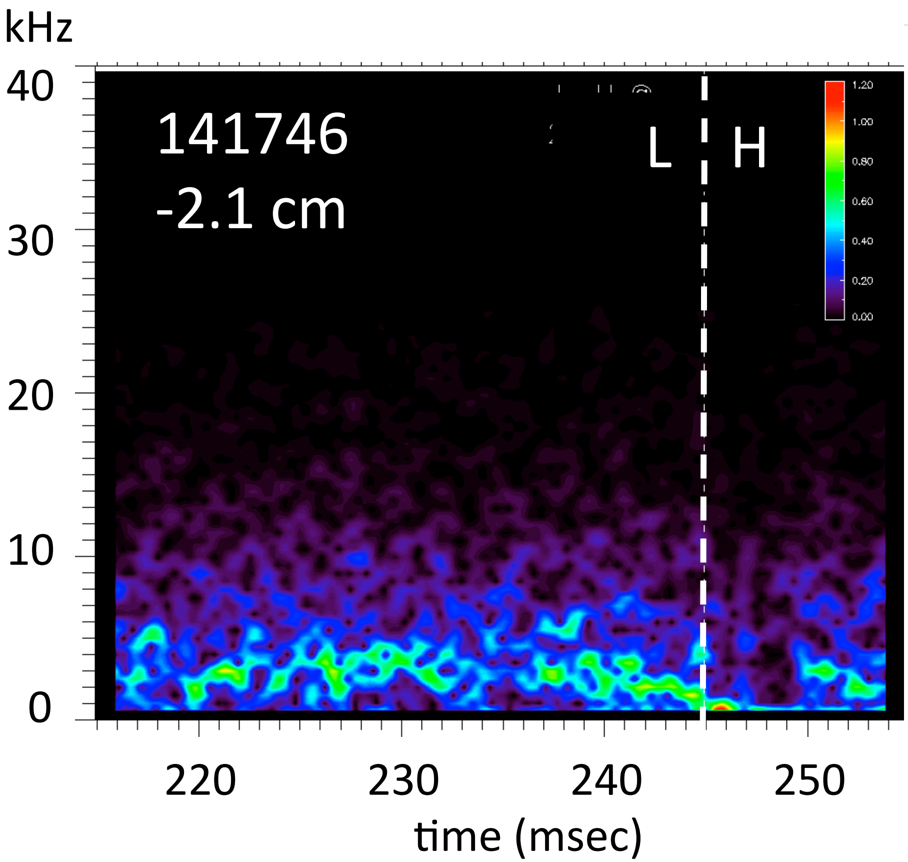
V_{pol} vs. radius

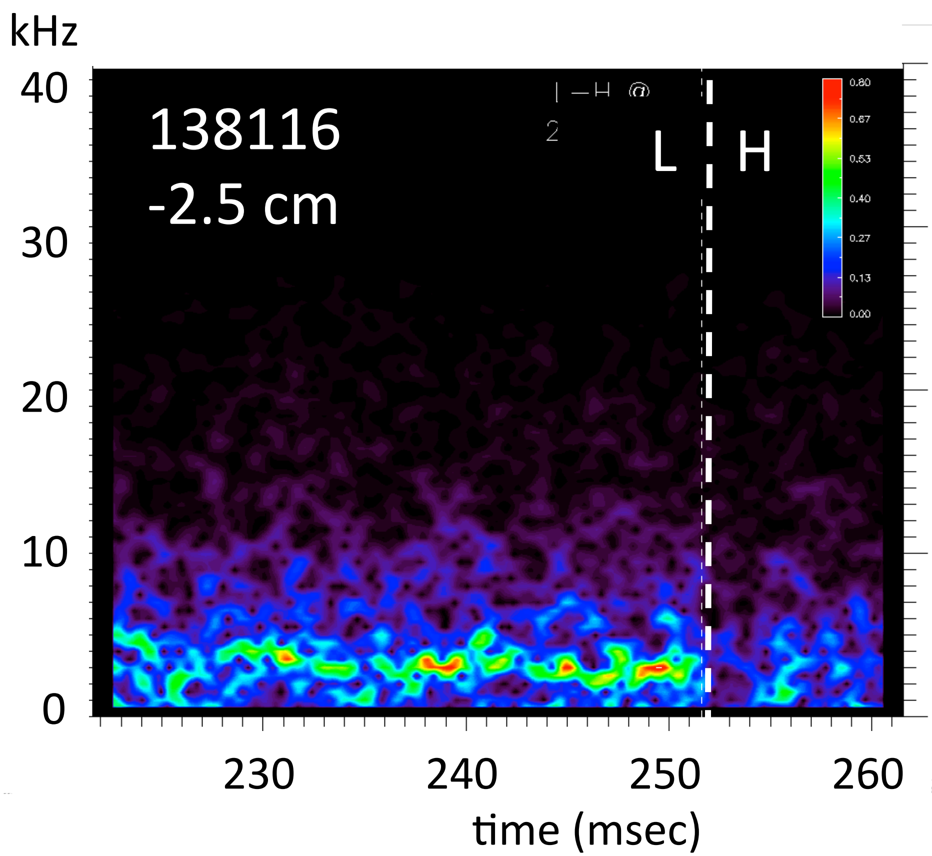
V_{pol} vs. pol. @ -2 cm



Zonal Flow Oscillations vs. L-H Transition ?

- Poloidal flow oscillations can either increase or decrease vs. time during the 30 msec of L-mode preceding the L-H transitions, and they can also appear later during the H-mode (GAMs ?)





Changes From L-Mode to H-mode

- These are all at 1 cm inside separatrix and averaged over 17 shots

- Time averaged 3 msec to 0.2 msec before transition for L-mode, and 0.2-1 msec after transition for H-mode

  - Relative fluctuation levels *decrease* by ~ 40%
  - Poloidal correlation lengths *increase* by ~30%
  - Radial correlation lengths *decrease* by ~30%
  - Poloidal *velocities change from IDD to EDD*
  - Radial velocities outward *decrease* by ~20%
  - Tilt in correlation function is *highly variable*
  - Ellipticity of correlation functions *increase* by ~50%
  - Magnitide of V_{pol} gradient *decreases* by ~20%
  - Autocorrelation time *increases* by ~ 50%

Is there a Visible "Trigger Mechanism"

None of the measured turbulence quantities has a clear and consistent change within the 3 msec period just before the L-H transition, averaged over shots in this dataset

Theoretical Interpretations

- Turbulence level as seen in GPI does go down at the L-H transition, consistent with many previous theoretical models

- However, turbulence flow shear is virtually unchanged across the L-H transition, obviously inconsistent with the idea of flow shear tearing apart the eddies as the cause of the transition

Caveats:

- in this poster the flow shear was analyzed only at -1 cm inside the separatrix (further analysis of this data set is needed)

- flow shear was determined from velocity of turbulence motion, which is not necessarily the same as the ExB fluid velocity