Edge Turbulence Flows at Two Different Poloidal Angles in Alcator C-Mod

S.J. Zweben[1], J.L. Terry[2], M. Agostini[3], W.M. Davis[1], O. Grulke[4], J. Hughes[2], B. LaBombard[2], M. Landreman, Y. Ma[2], D. Pace[5], B.D. Scott[6]

[1]*Princeton Plasma Physics Laboratory, Princeton, NJ 08540*
[2]*Massachusetts Institute of Technology, Cambridge, MA 02139*
[3]*Consorzio RFX, Associazione EURATOM, I-35127, Padova, Italy*
[4] *Max Planck Institute for Plasma Physics, D-17489, Greifswald, Germany*
[5] *General Atomics Corporation, San Diego, CA 92121*
[6]*Max Planck Institute for Plasma Physics, D-85748 Garching, Germany*

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Outline of This Poster

- Background and goals
- Gas puff imaging diagnostic and analysis
- Spatial structure X-region vs. midplane
- Poloidal velocity X-region vs. midplane
- Summary and conclusions

Background and Goals

- Turbulence measured by GPI in SOL of C-Mod near X-point region had a *different structure* than that at outer midplane [1]

- Turbulence measured by GPI in edge and SOL near outer midplane *sometimes* seemed to have poloidal 'zonal flows' [2]

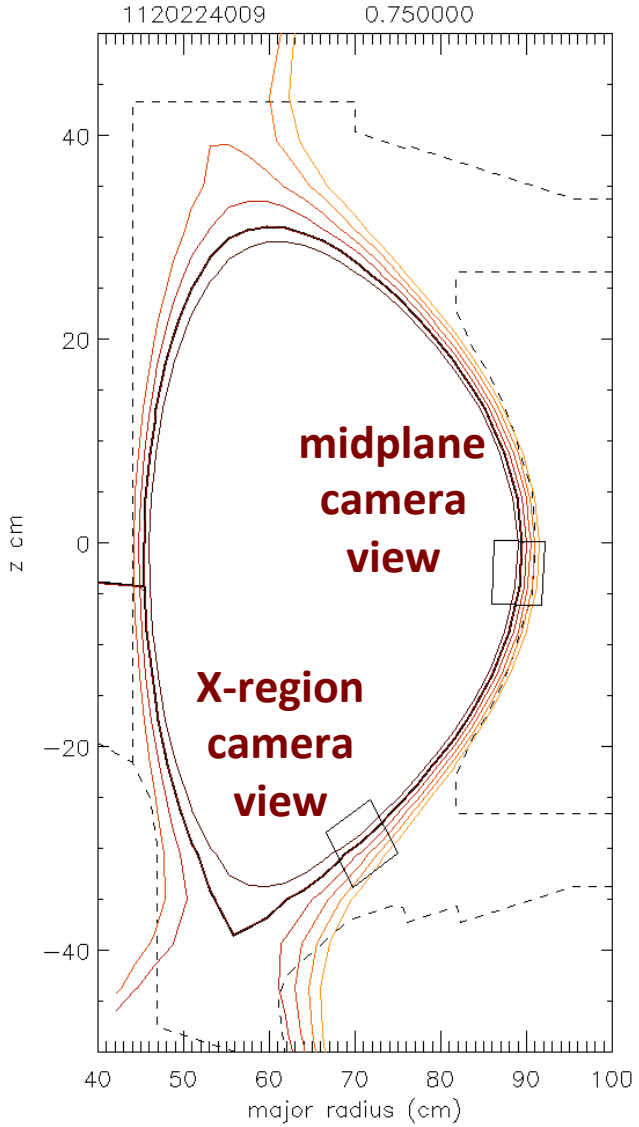
Goals:

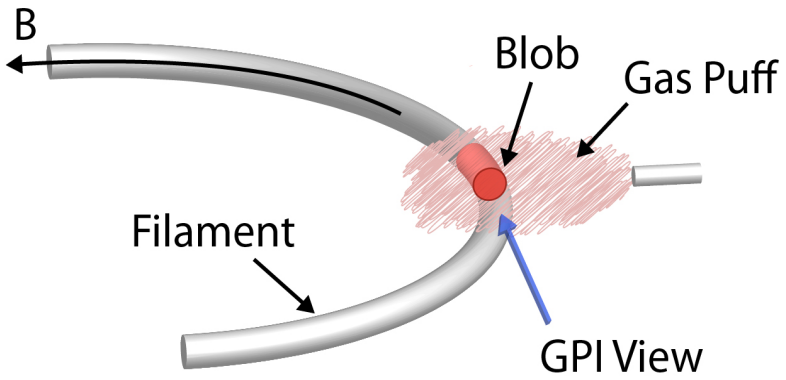
⇒ **re-visit structure of X-region SOL turbulence with better data**

⇒ **compare turbulence velocity in X-region with outer midplane**

[1] J.L. Terry, S.J. Zweben et al, J. Nucl. Mat. 390-291 (2009) 339
[2] S.J. Zweben, J.L. Terry et al, PPCF 54 (2012) 025008

Gas Puff Imaging Diagnostic on C-Mod





GPI cameras data for 2012 run

Viewing Hel emission (587.6 nm)

Viewing areas 5.9 cm x 5.9 cm

64 x 64 pixels in each view

390,800 frames/sec each camera

exposure time 2.1 µsec/frame

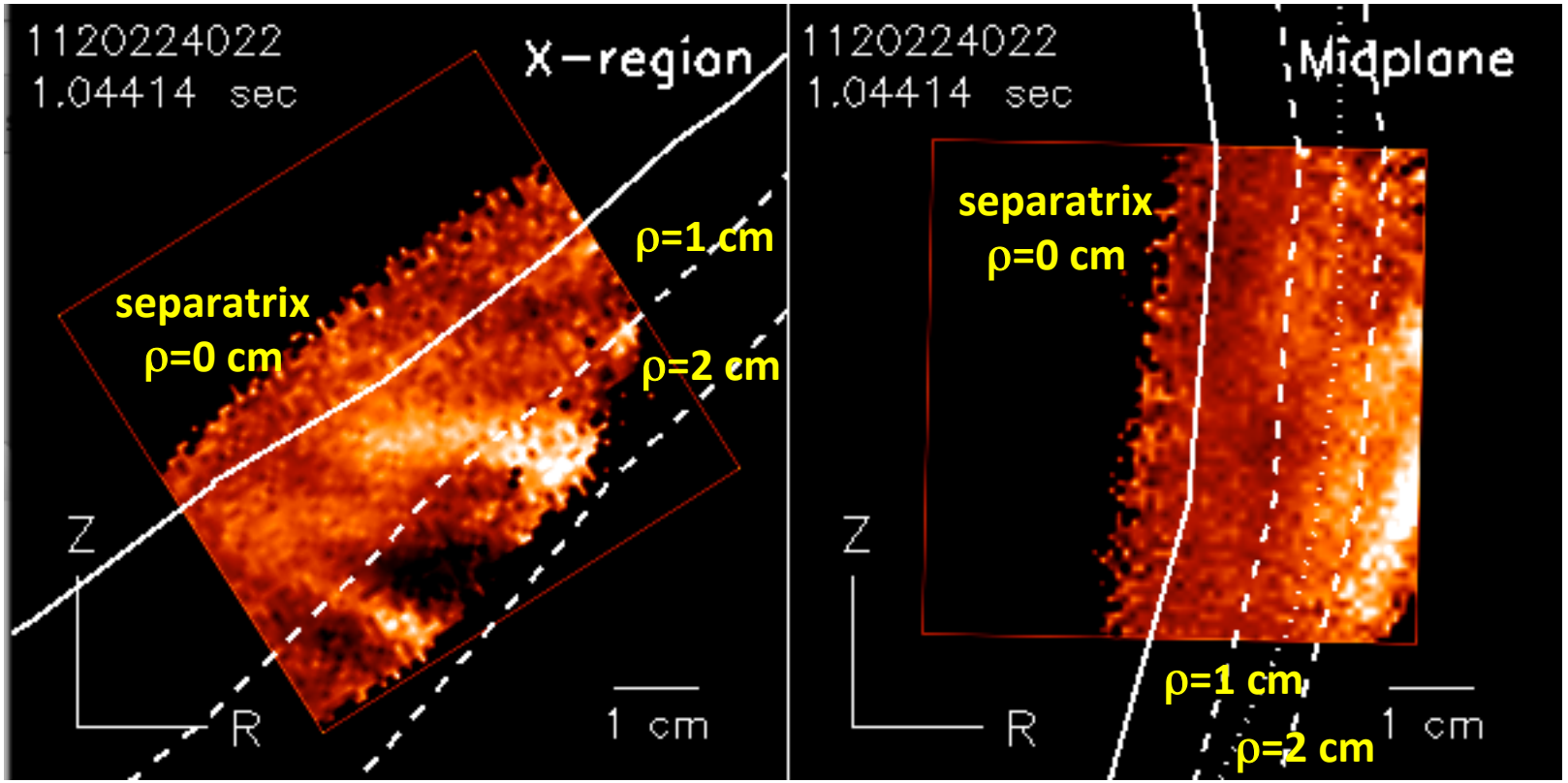
using Phantom 710 cameras

C-Mod Plasmas for this Poster

Shot	Times (sec)	I(MA)	B(T)	$n/10^{14}$	RF(MW)	Comments
1120224009	0.701-0.706	0.9	4.6	1.1	2.3	L-mode, 2 kHz oscillation
1120224015	0.801-0.805	1.0	6.0	1.3	3.7	L-mode, 4 kHz oscillation
1120224022	1.044-1.148	1.0	5.25	1.0	2.6	dithering L-H mode
1120224023	1.113-1.116	1.0	5.25	1.4	2.9	H-mode, 3 kHz oscillation
1120224024	1.130-1.135	1.0	5.25	1.7	2.8	H-mode, 2 kHz oscillation
1120224027	1.144-1.148	0.9	4.6	1.3	3.0	L-mode, 4 kHz oscillation
1120224030	1.087-1.091	0.9	4.6	2.0	3.5	L-H transition @ 1.090 sec
1120712026	1.440-1.444	0.73	4.22	3.5	0	Ohmic
1120712027	1.440-1.444	0.73	4.22	3.6	0	Ohmic
1120712028	1.440-1.443	0.73	4.95	2.6	0	Ohmic
1120712029	1.440-1.443	0.73	4.95	2.2	0	Ohmic
1120815018	1.270-1.274	0.90	5.6	2.5	2.9	H-mode
1120815021	1.190-1.193	0.91	5.6	2.0	2.0	H-mode
1120815030	1.260-1.264	0.91	5.6	1.9	2.6	H-mode
1120815034	1.150-1.153	0.91	5.6	2.0	3.1	H-mode

Turbulence Images at Midplane and X-region

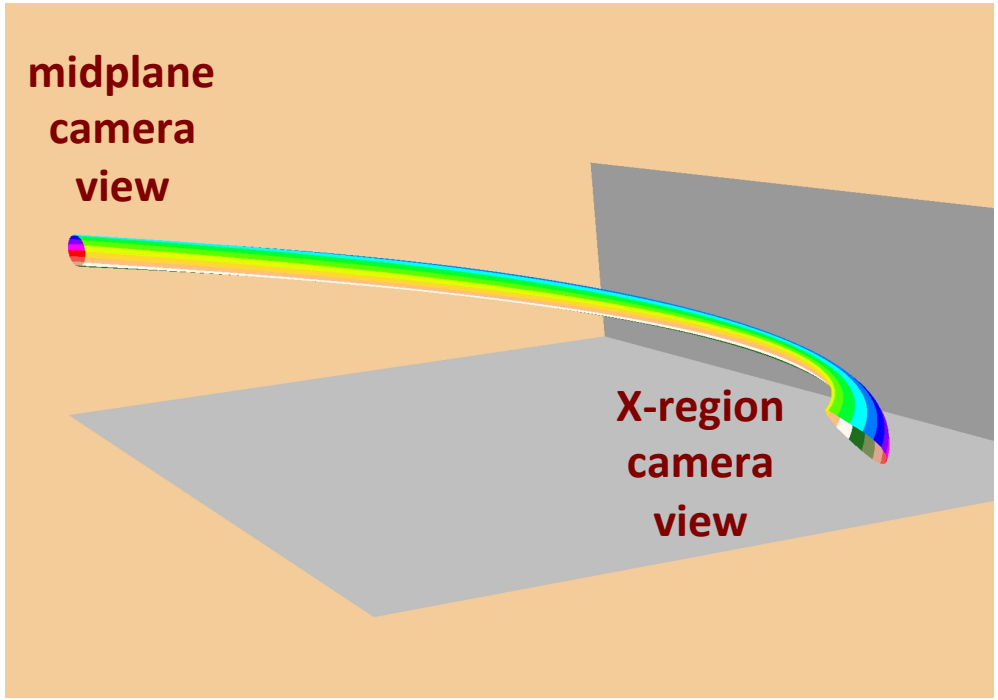
- Turbulence visible mainly outside separatrix in this database
- These images normalized to time-average (colorscale of 0.5 - 1.5)
- Movies at: http://www.pppl.gov/~szweben/CMod2012both/CMod2012both.html



Magnetic Flux Tube Mapping

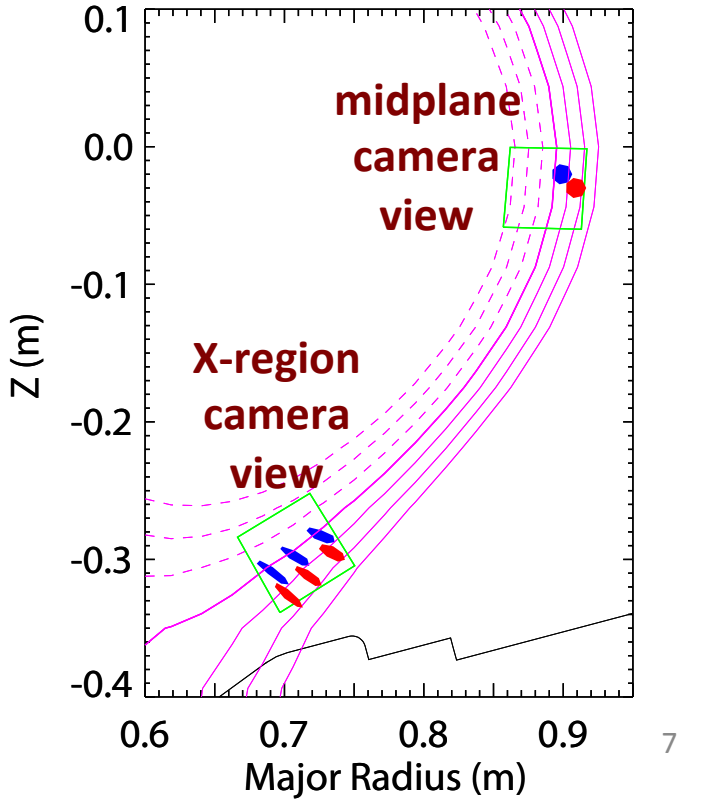
- Circular flux tubes at midplane GPI region map to tilted, radially elongated tubes near X-region due to flux expansion and shear
- These two GPI views are *not* connected along a single flux tube

3-D shape of magnetic flux tube in SOL



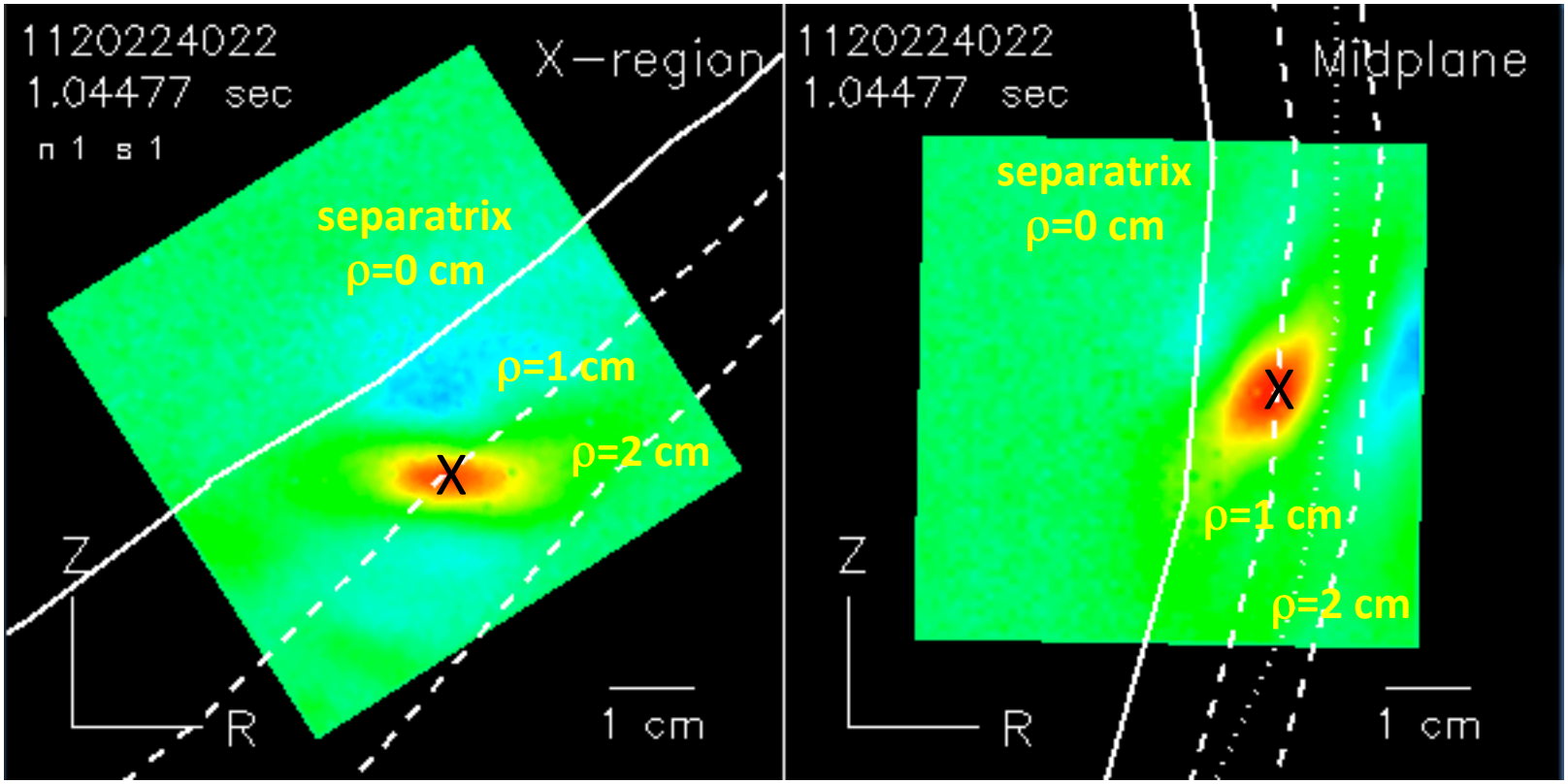
Visualization by Eliot Feibush (PPPL)

Shot 1120224022 1.11700 sec



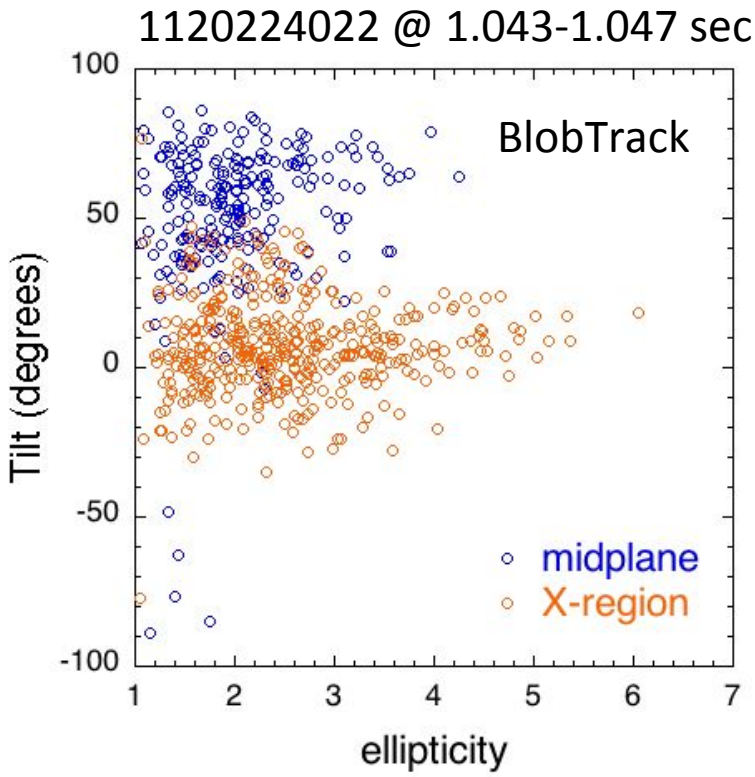
Turbuence Structure X-region vs. Midplane

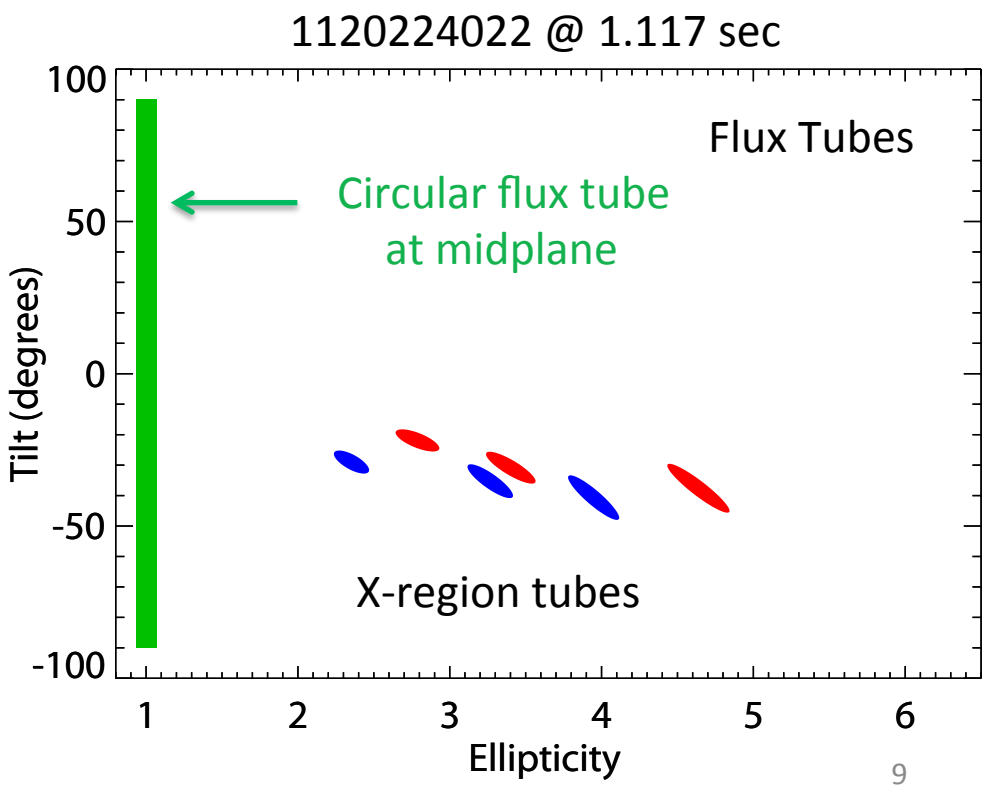
- Calculate zero-time delay cross-correlation function from a point (X)
- Shape of turbulence significantly different in X-region and midplane
- Similar to previous results from C-Mod SOL [Terry et al, JNM '09]



Blob Structure X-region vs. Midplane

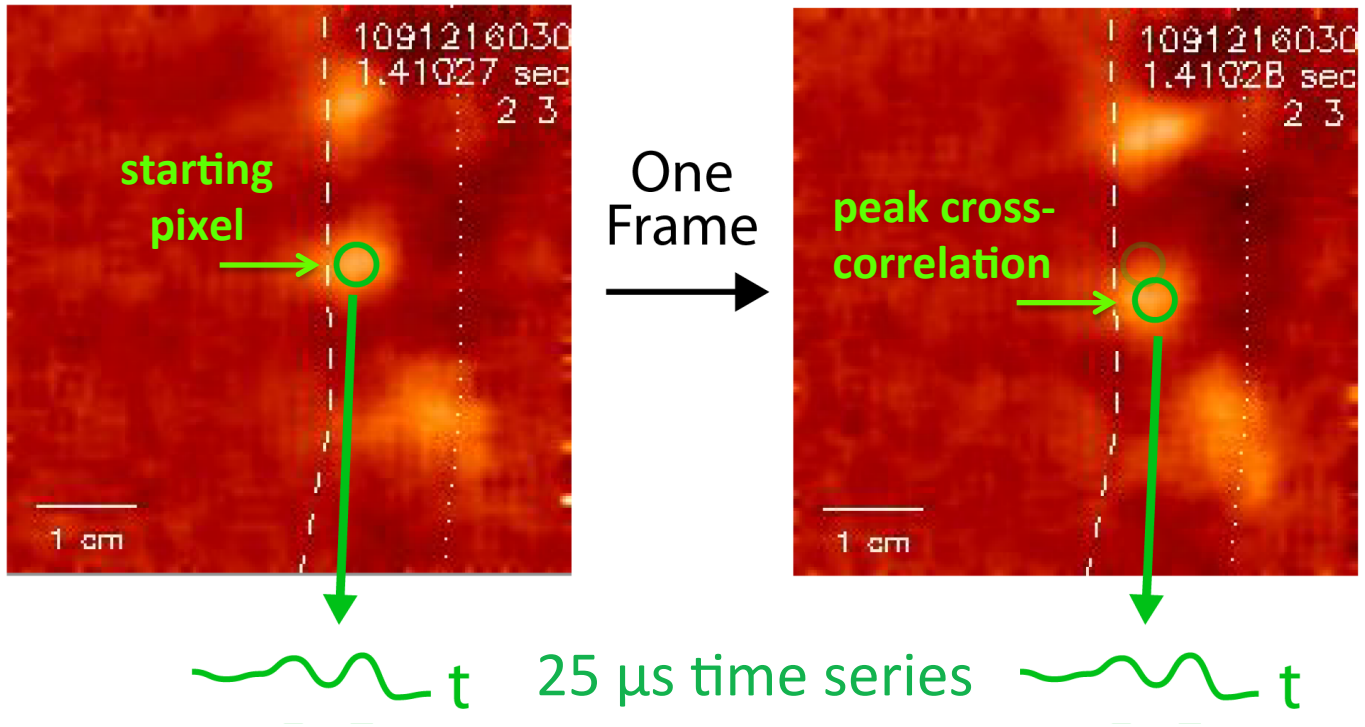
- Blob structures can be characterized using PPPL BlobTrack code by Ellipticity = long/short size and Tilt = angle with respect to major R
- Clear difference between midplane and X-region blobs in data, but not yet clear whether this is consistent with a common flux tube





Method to Evaluate Turbulence Velocity

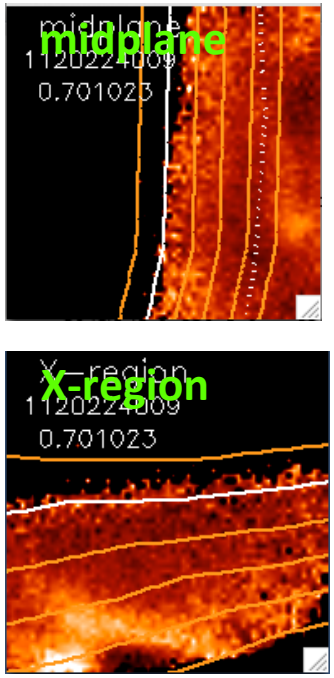
- Use time-delayed 2-D cross-correlation with one frame delay, find maximum cross-correlation over t ~25 μs and ± 0.7 cm
- Evaluate turbulence velocity for all pixels for all frames to get time dependent poloidal velocity



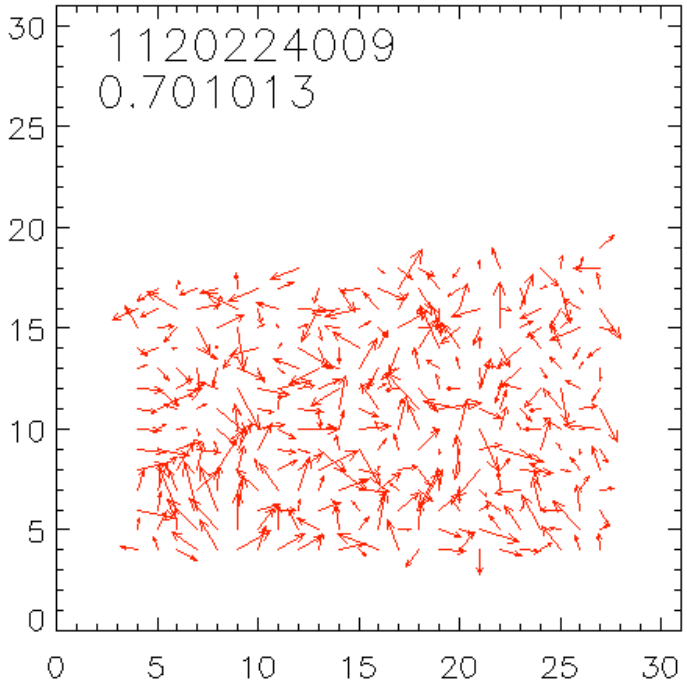
2-D Maps of Turbulence Velocity vs. Time

- Remove pixels with small signal/noise level (inside separatrix)
- Calculate 2-D velocity vectors at each pixel *at each time frame*
- Significant random (turbulent) component in these velocities

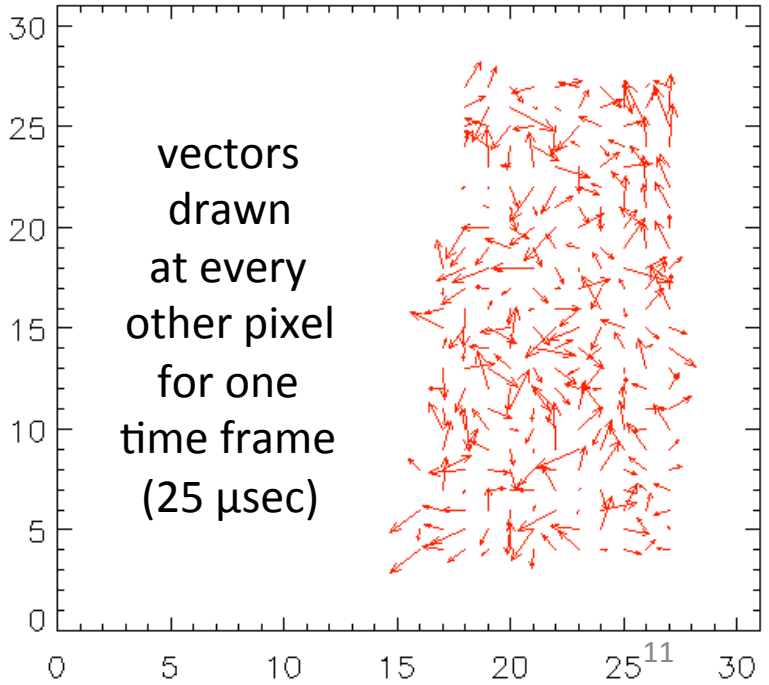
orientation



X-region velocity field

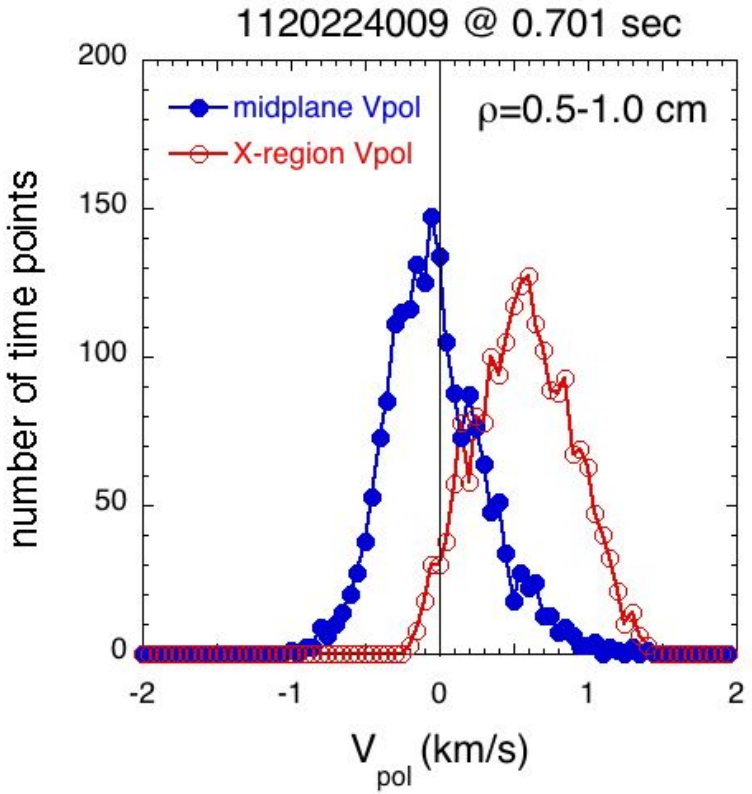


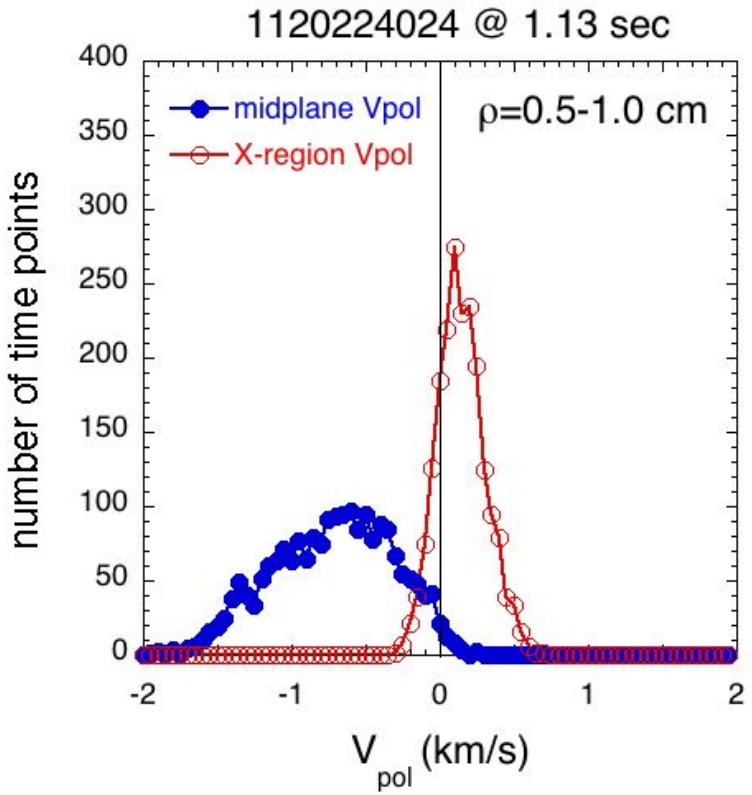
midplane velocity field



Turbulence Velocity Distributions

- Average poloidal velocities over radial zones 0.5 cm wide
- Poloidal velocity distributions usually within ± 2 km/sec
- Significant differences between midplane and X-region

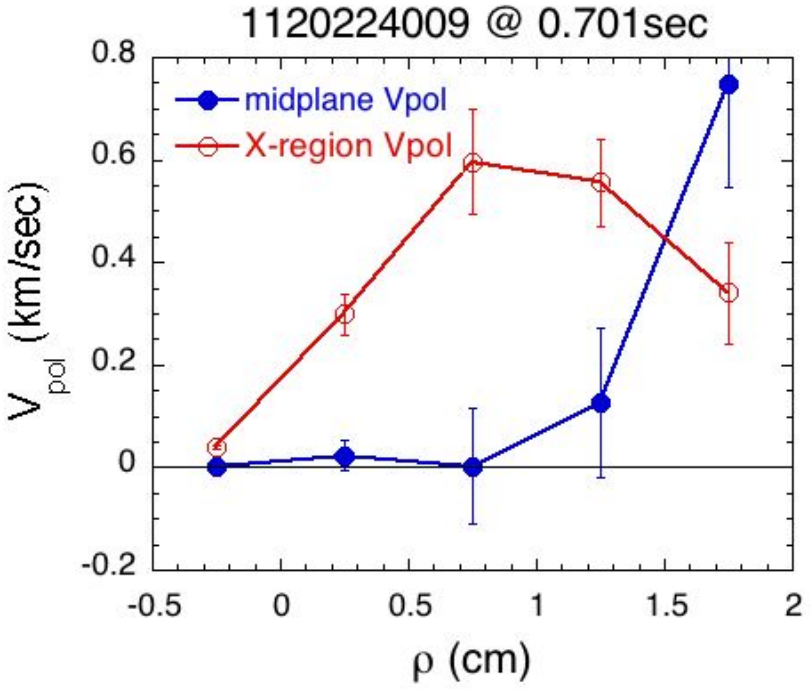




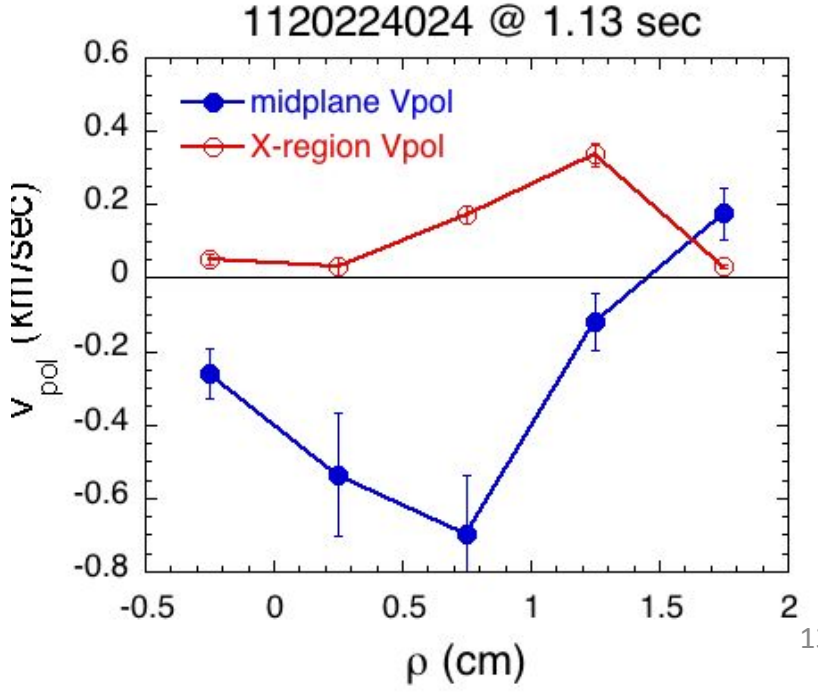
Time-Averaged Turbulence Velocity Profiles

- Radial profiles of V_{pol} are different at midplane and X-region
- Error bars are RMS fluctuations in V_{pol} vs. time at that radius

RF-driven L-mode plasma
B=4.6 T, I=0.9 MA, LSN
2.3 MW RF, 1.2×10^{14} cm^{-3}



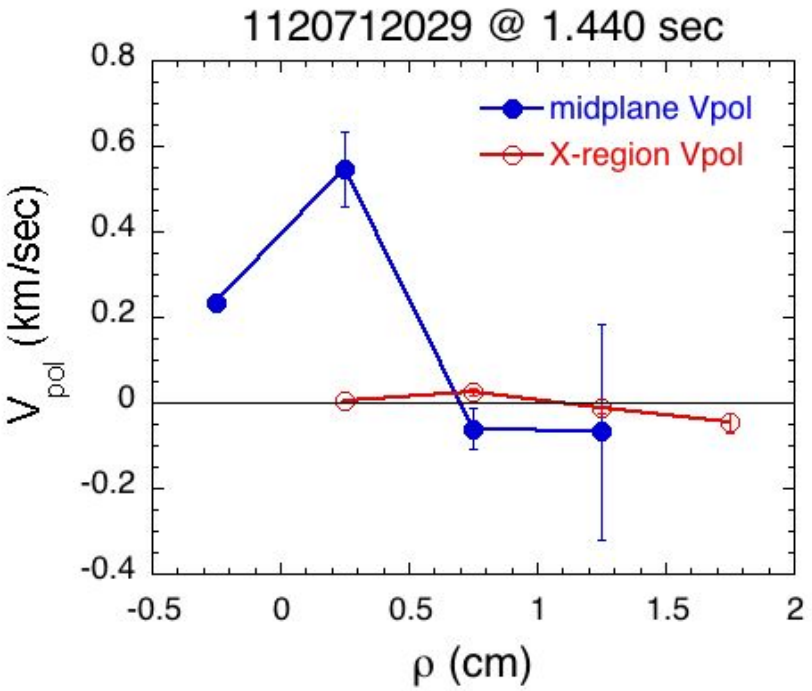
RF-driven H-mode plasma
B=5.25 T, I=1.0 MA, LSN
2.8 MW RF, 1.6×10^{14} cm^{-3}



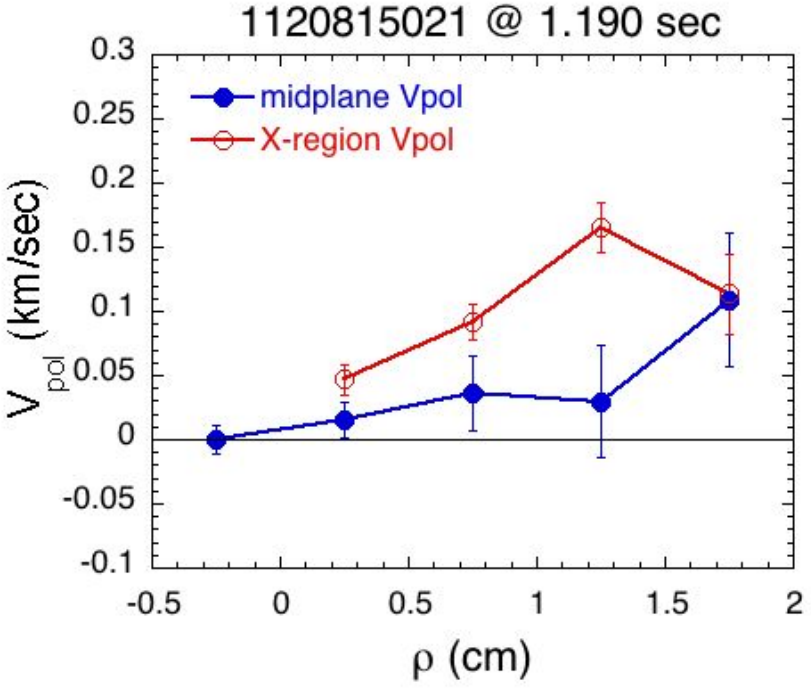
More Turbulence Poloidal Velocity Profiles

- Radial profiles of V_{pol} vary significantly with different discharges

Ohmic plasma
B=5.0 T, I=0.73 MA, LSN
No RF, 2.2x10^{14} cm^{-3}

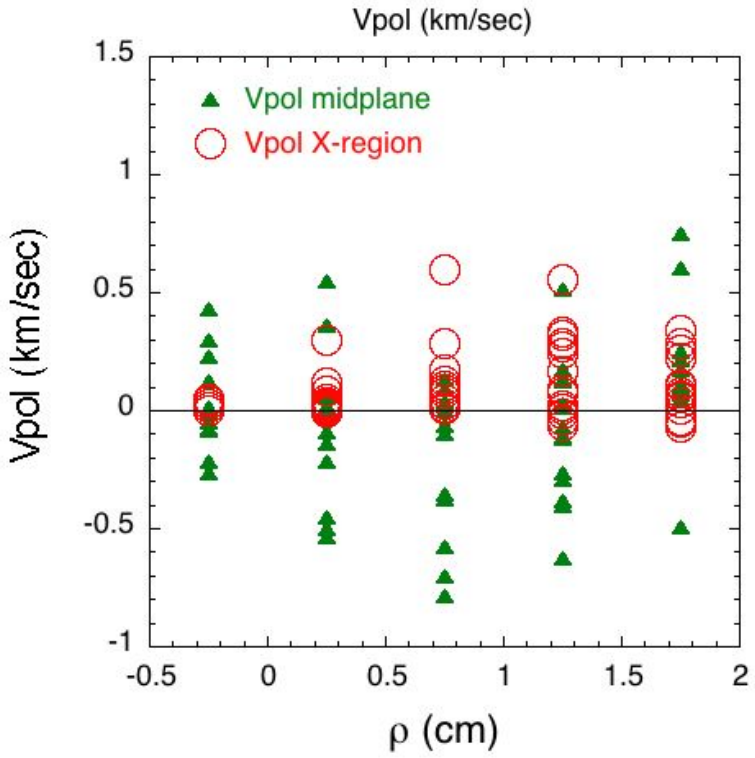


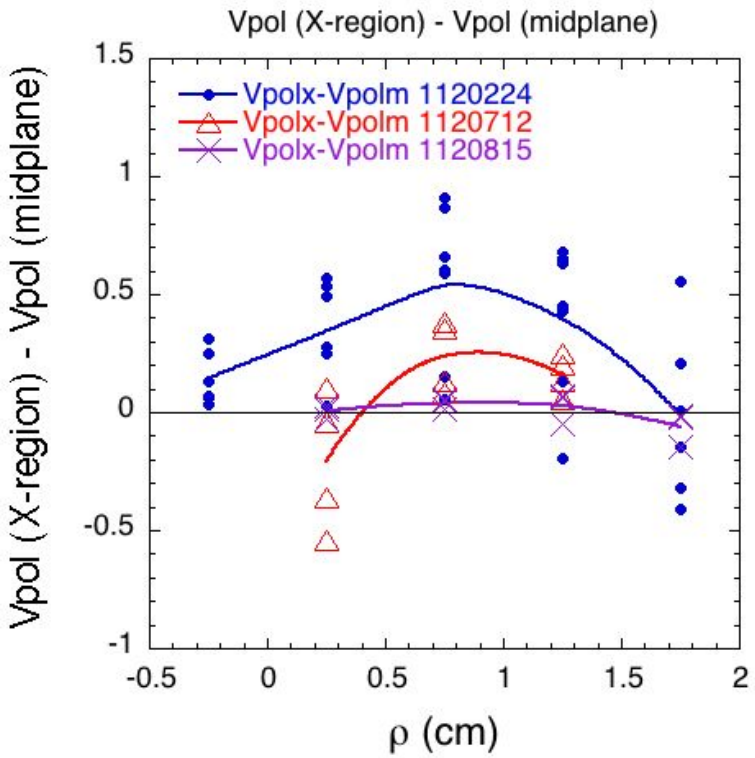
RF-driven H-mode plasma
B=5.6 T, I=0.9 MA, LSN
2.0 MW RF, 2.0 x10^{14} cm^{-3}



Midplane vs. X-region Velocity Database

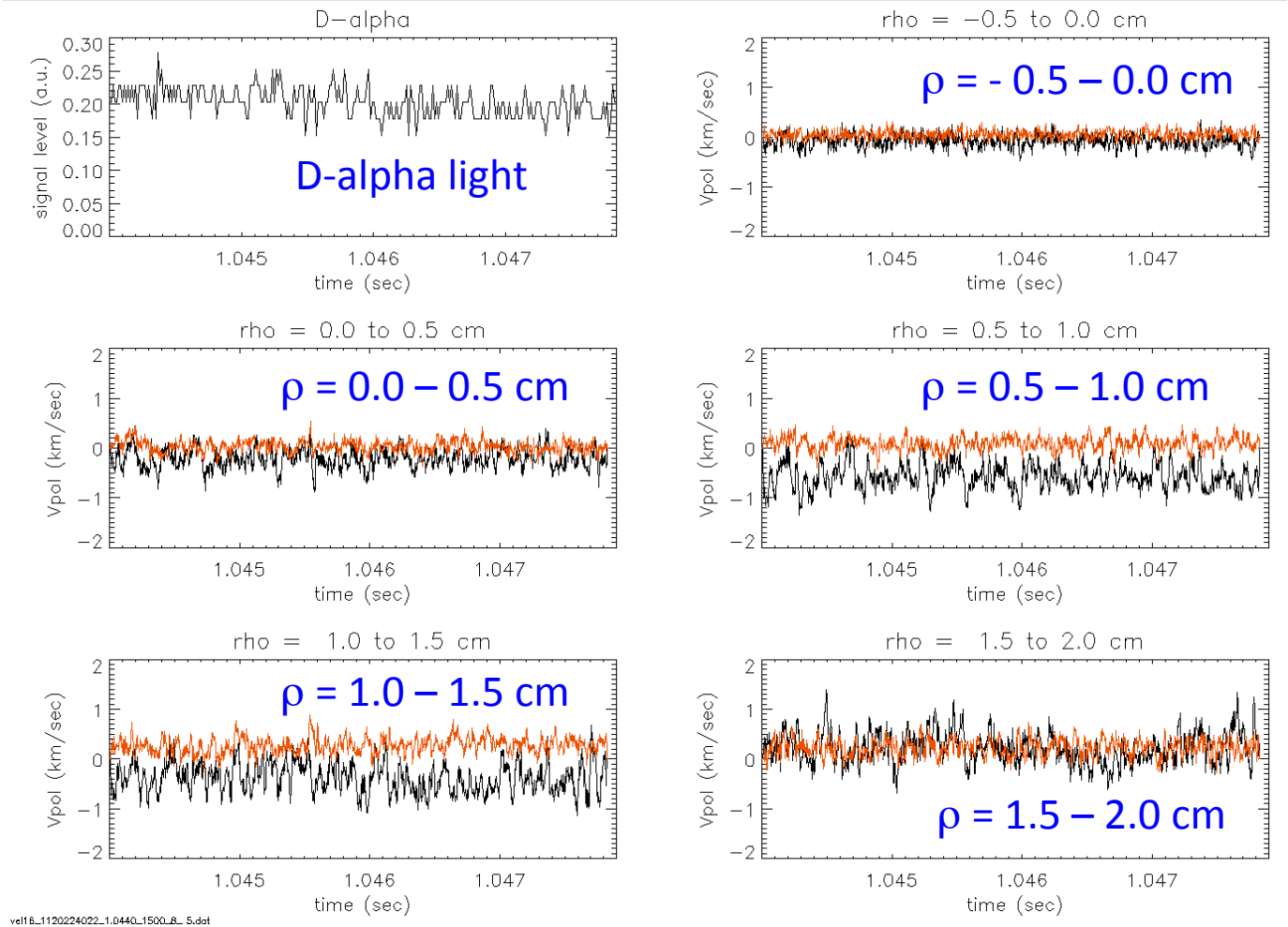
- Poloidal velocity in midplane can be either upward or downward
- Poloidal velocity in X-region is usually upward (toward midplane)
- Relative flows are usually converging toward each other (+ below)





Poloidal Turbulence Velocity vs. Time

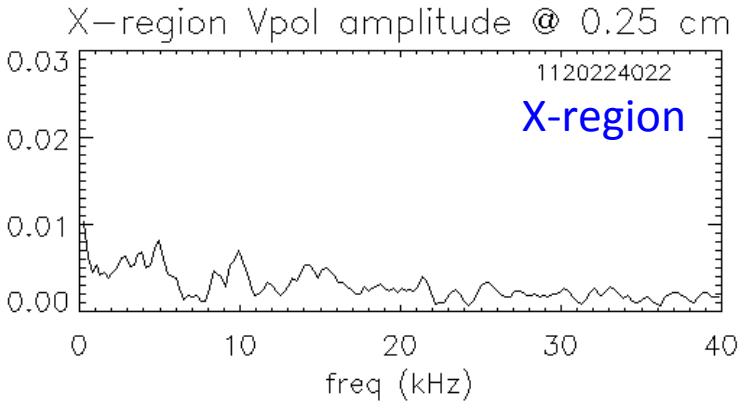
- Usually V_{pol} has random-looking fluctuations vs. time, $\delta V_{pol} \leq V_{pol}$

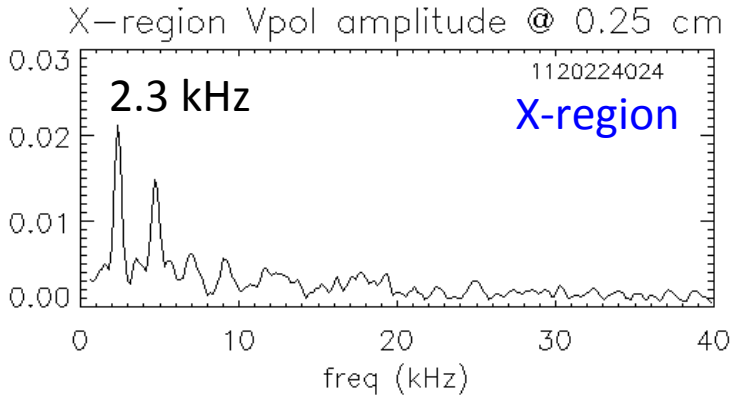


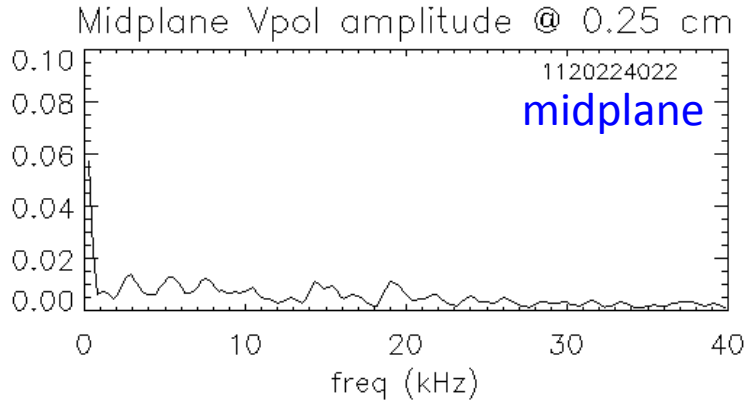
Black = midplane
Red = X-region

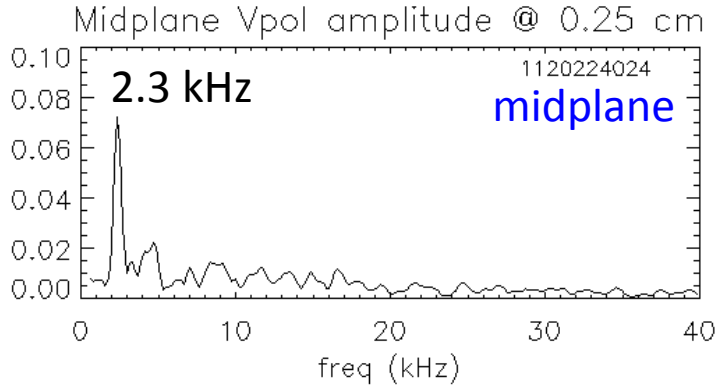
Spectrum of Poloidal Velocity Fluctuations

- Spectrum of δV_{pol} normally broad in both X-region and midplane
- Occasional strong low frequency oscillations @ 2-5 kHz in both





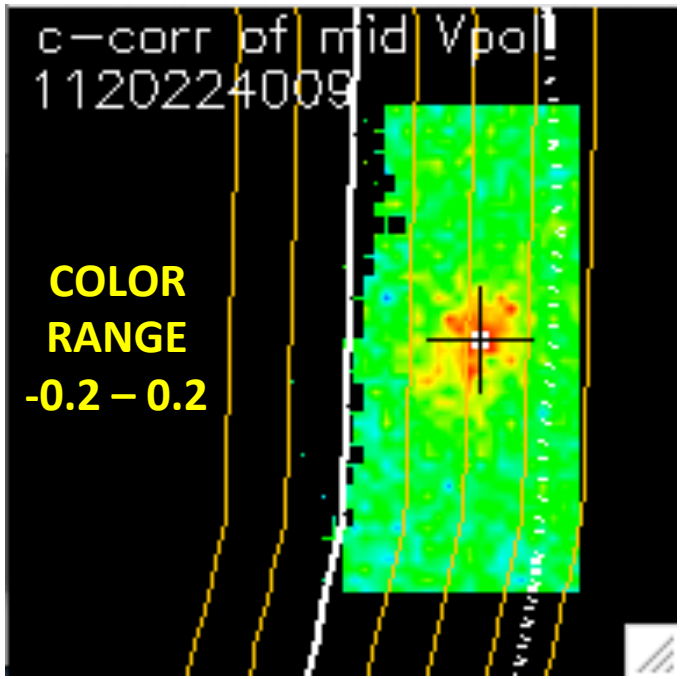


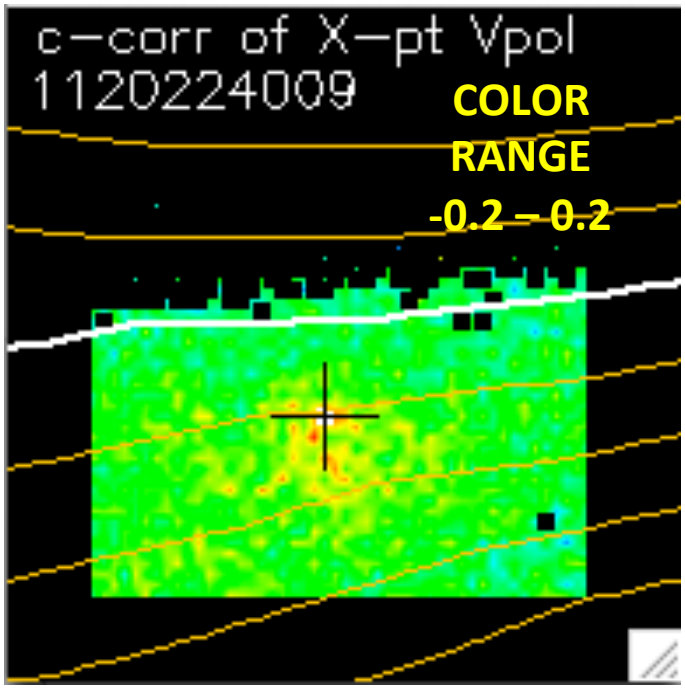


Spatial Correlation of Velocity Fluctuations

- Typically only a weak local cross-correlation of V_{pol} over space at zero time delay in either midplane of X-region of SOL

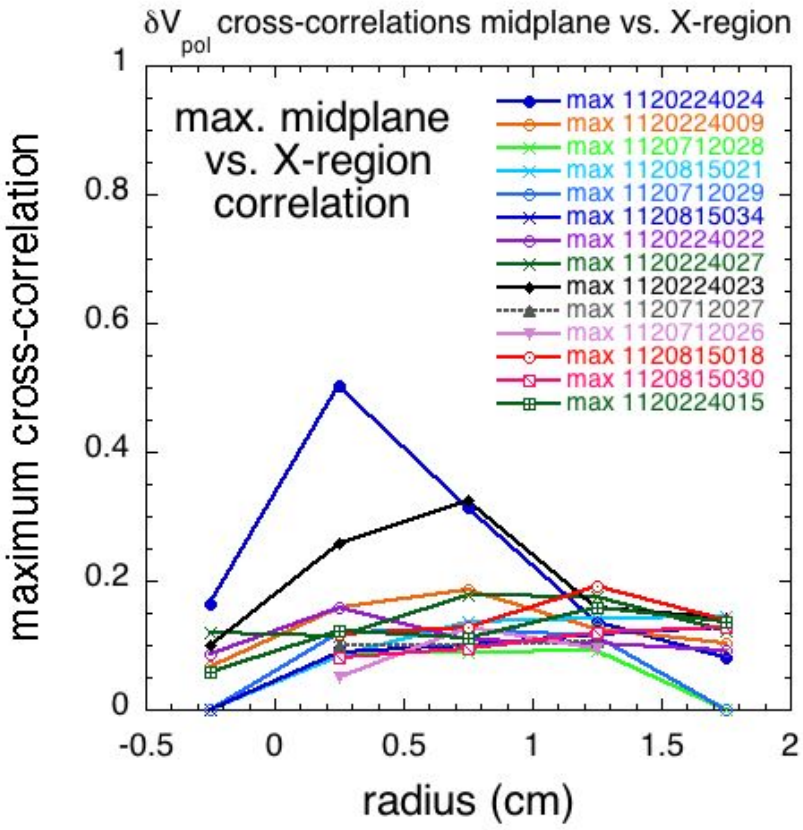
- Indicates that large-scale *"zonal flows" are not dominant* in either midplane or X-region view of SOL

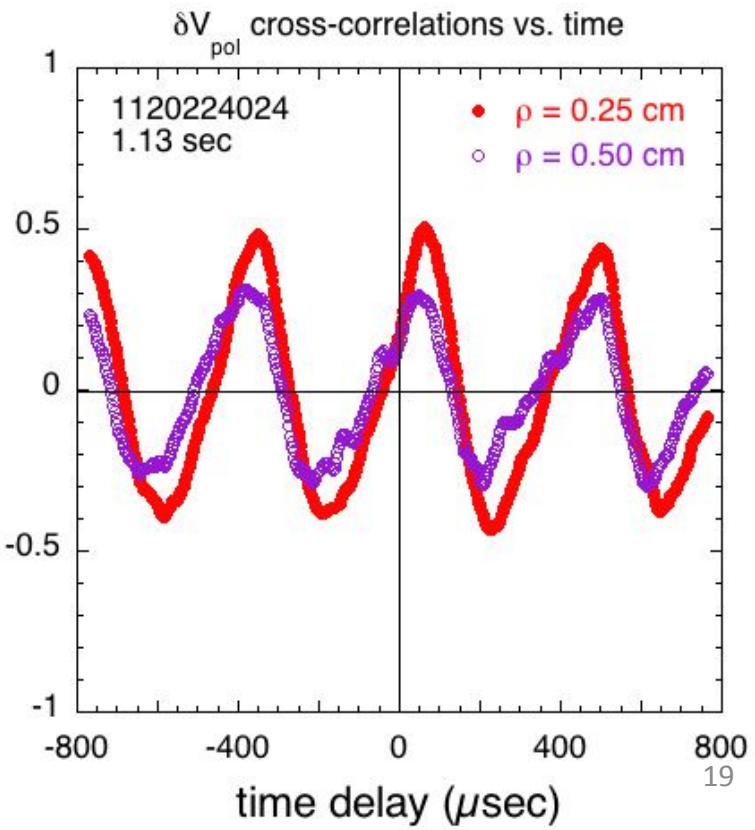




Cross-Correlation of Midplane with X-region

- Normally no cross-correlation of δV_{pol} in midplane vs. X-region
- Biggest cross-correlation with 2.3 kHz oscillation (1120224024)

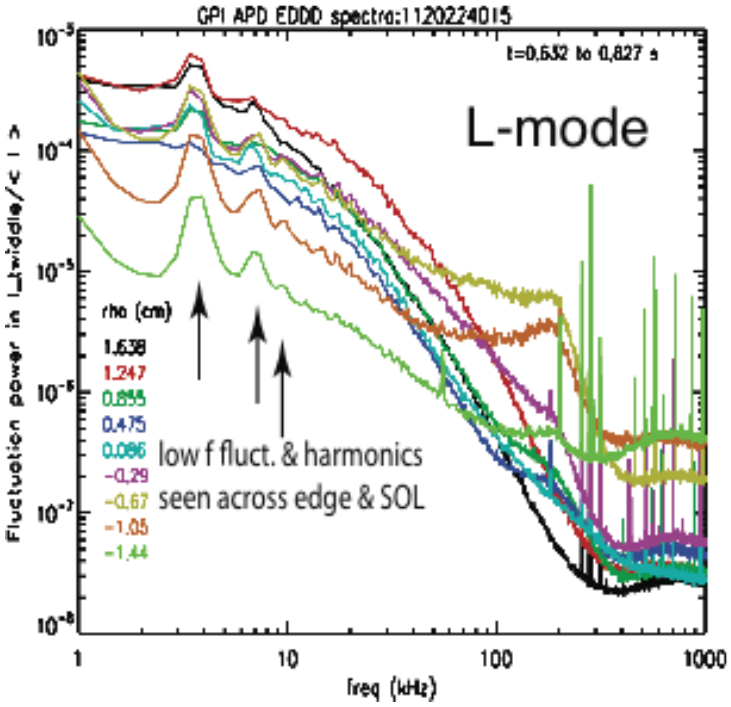




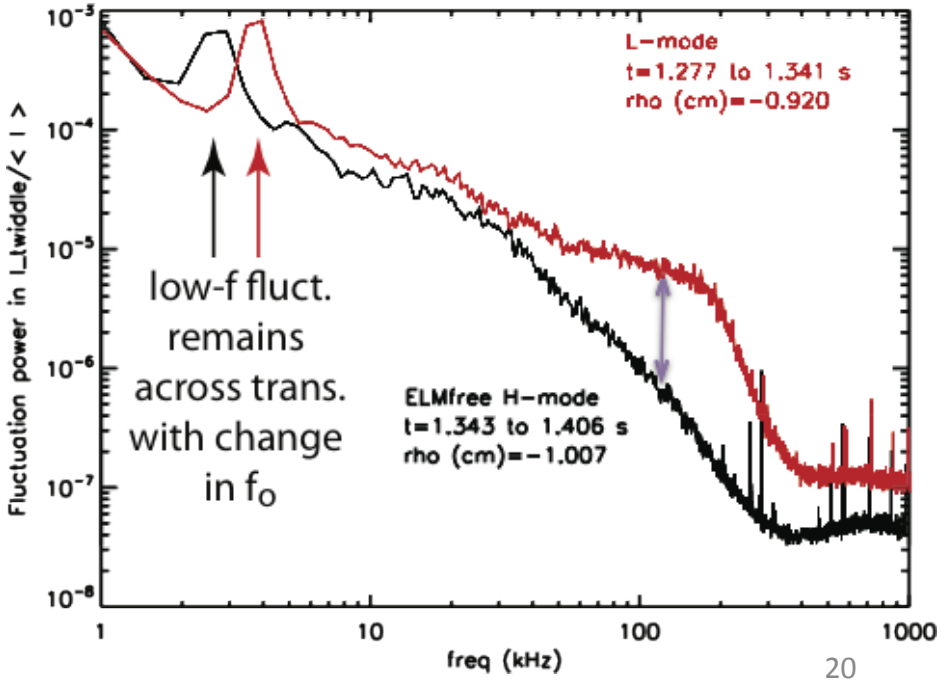
"New" Low Frequency Edge Oscillations

- Sometimes 2-5 kHz edge coherent fluctuations measured on D_α, reflectometer, probes, magnetics, and interferometer
- Perhaps similar to 'predator-prey" oscillations on DIII-D, EAST

Seen in GPI at -1.5 cm < ρ < 1.5 cm

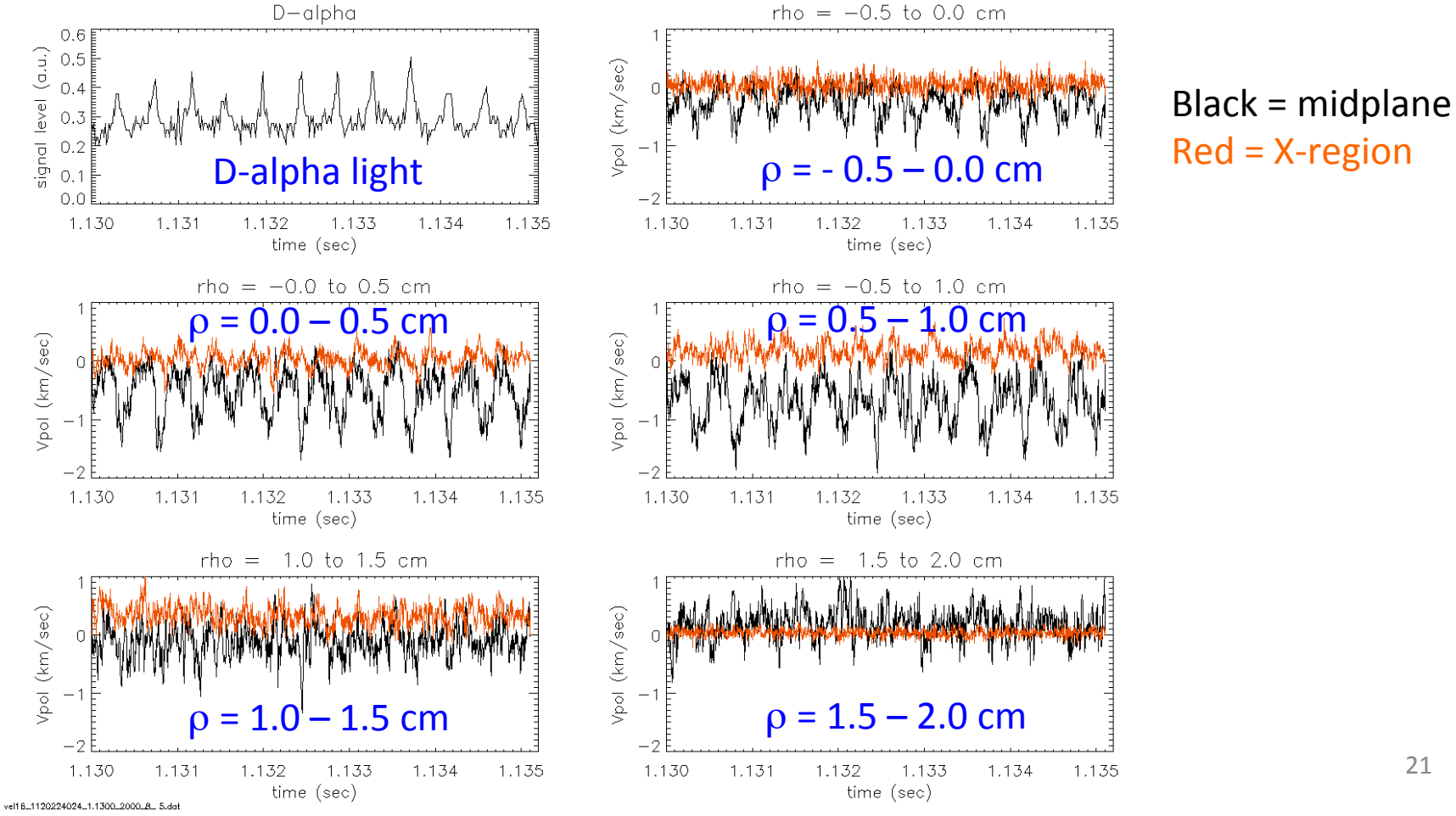


Seem in GPI spectrum across L-H transition



Poloidal Velocity During Edge Oscillations

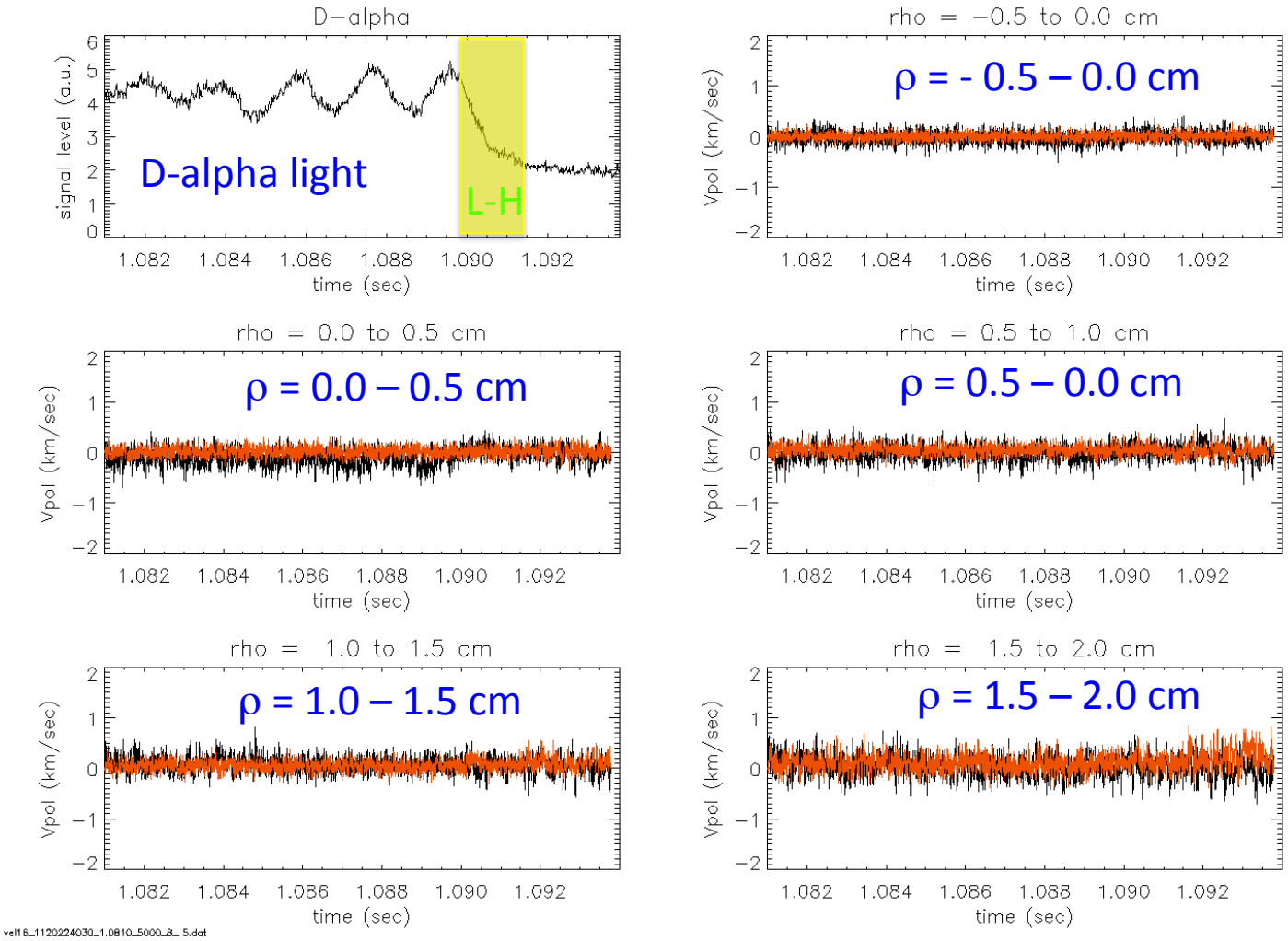
- These edge oscillations can have a large poloidal flow modulation
- Oscillation in midplane leads by ~50-65 μsec, thus *not zonal flow*



Black = midplane
Red = X-region

Poloidal Velocity During an L-H Transition

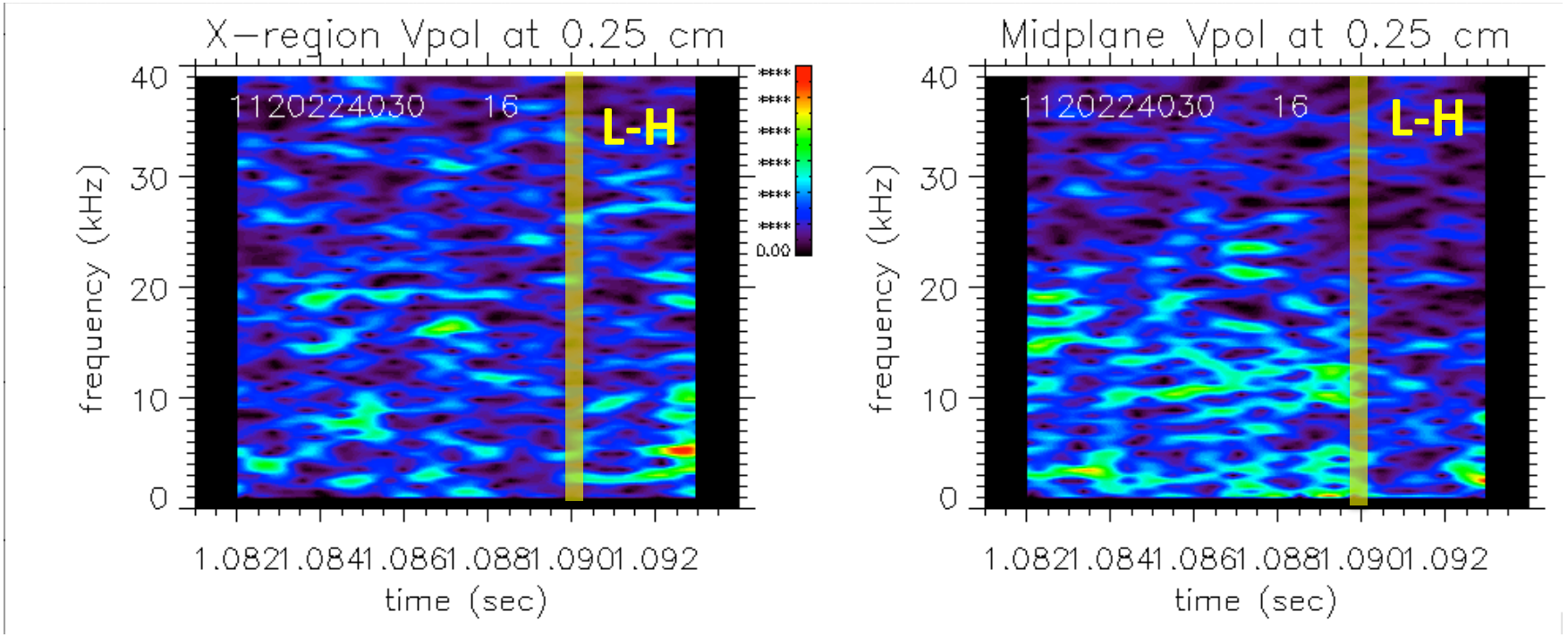
- Little or no poloidal velocity changes before L-H transition



Red = X-region
Black = midplane

Poloidal Velocity Spectra at L-H Transition

- In at least some cases in this database, *NO* clear coherent zonal flow before L-H transition, in contrast to the shot at lower density shown in Zweben et al, PPCF 2012



Summary and Conclusions

- Turbulence in X-region SOL is ***more elliptical*** than at midplane, somewhat similar to flux surfaces mapping

- Time-averaged and fluctuating poloidal velocity of turbulence in SOL is usually ***different*** between midplane and X-region

- Poloidal flow fluctuations only correlated between midplane and X-region during new low frequency mode at ***2-5 kHz***

some evidence for connection of blobs between two regions,

but no evidence for large-scale 'zonal flows' in SOL