SOL and divertor-leg filaments in the NSTX/NSTX-U divertor

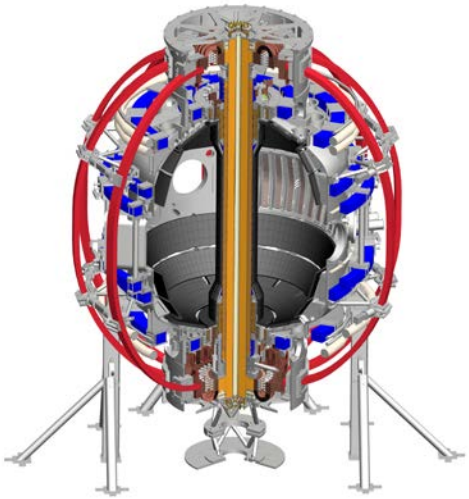
NSTX-U Monday Physics Meeting

F. Scotti, S. Zweben (PPPL), V.A. Soukhanovskii, D. Baver, J. Myra (Lodestar)

Lawrence Livermore National Laboratory

Fusion Energy Sciences

NSTX Upgrade



PPPL

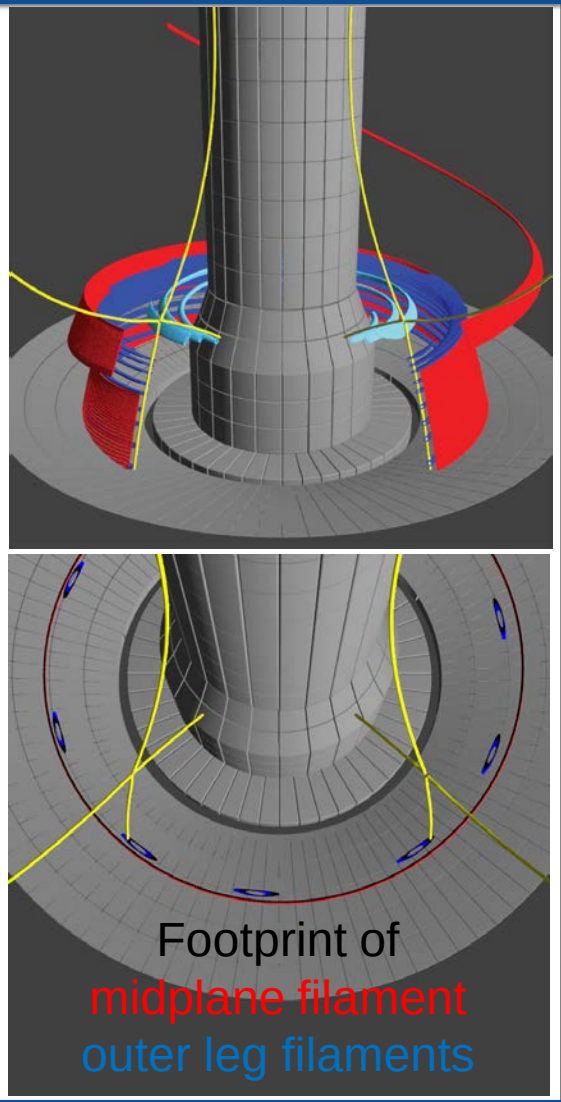
U.S. DEPARTMENT OF ENERGY | Office of Science

LLNL-PRES-729911

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Fusion Energy Sciences.. Lawrence Livermore National Security, LLC

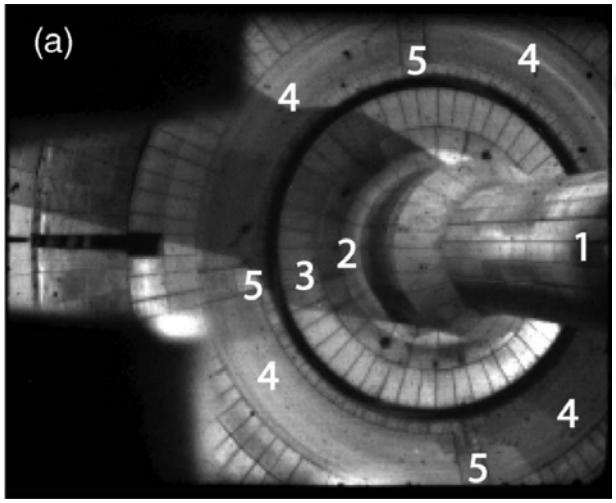
Characterization of SOL and divertor turbulence in NSTX/NSTX-U via imaging of divertor fluctuations

- Understanding SOL/divertor turbulence important for:
  - Characterization of divertor heat flux, wall particle fluxes
  - Interpretation of divertor transport/power balance
- Divertor fluctuations due to midplane blobs:
  - Collisionality, X-point may disconnect blobs from target
  - Turbulence disconnection can affect blob radial velocity
  - Characterization of divertor turbulence due to bobs:
    - Turbulence spatial scales and propagation
    - Correlation with midplane blobs
    - Comparison with analytical models for mode disconnection
- Divertor fluctuations due to divertor-leg instabilities:
  - Characterization of divertor-localized fluctuations:
    - Statistical properties, correlation lengths, radial localization
    - Comparison with modeling to establish driving mechanisms



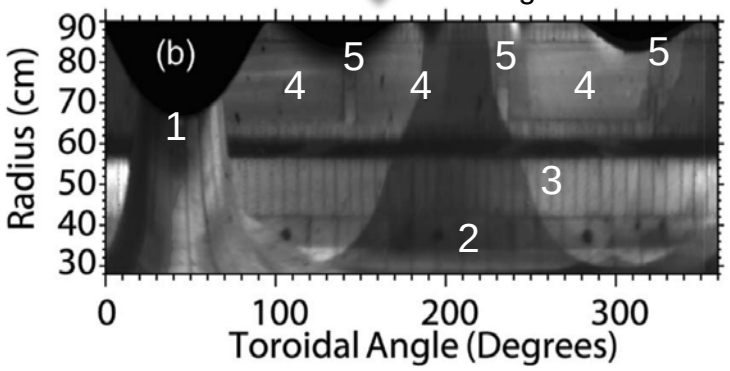
Midplane and divertor turbulence diagnostics for turbulence connection characterization

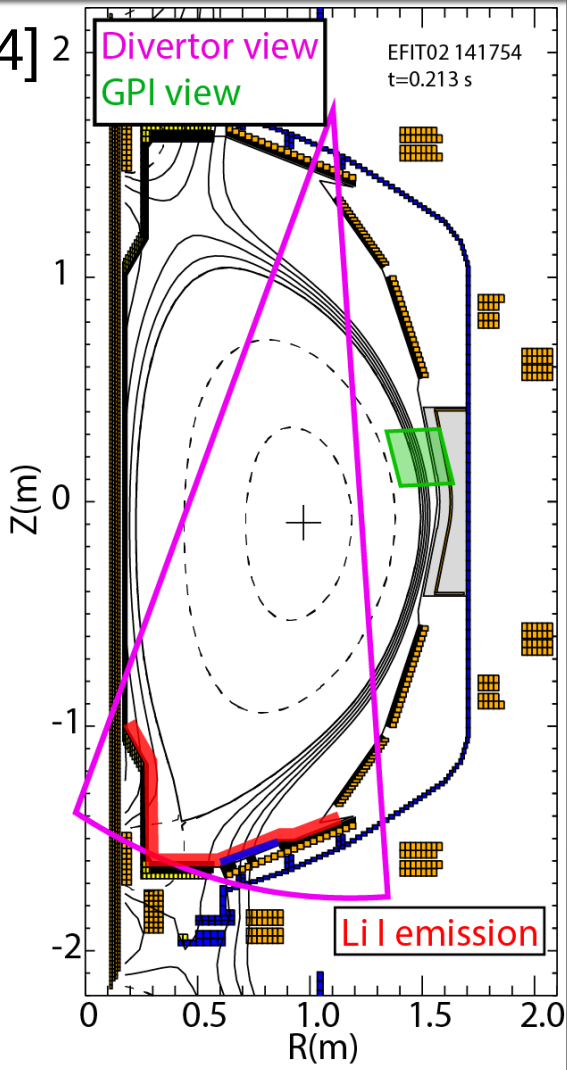
- Midplane: Gas Puff Imaging (GPI) [Zweben NF04]
  - Dα emission, 400kHz, 2 μs, 1 cm resolution
- Wide angle divertor imaging:
  - Li I emission, 100kHz, 9 μs, 0.8 cm resolution
  - Lithium emission localized to divertor surface
    - — Intersection of turbulent filaments with divertor target
  - Toroidal remap for easier analysis [Scotti RSI 2012]
- Langmuir probe array [Jaworski RSI 2010]



Remapped vs (r,ϕ)

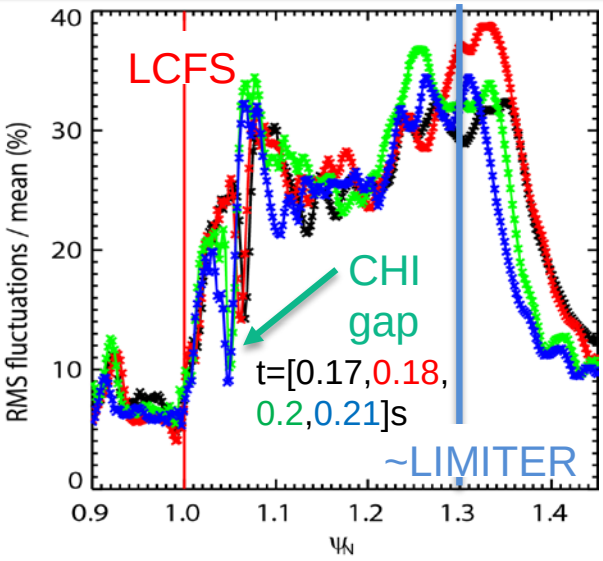
1 - Center Stack
2,3 – Inner Divertor
4 – Outer divertor
5 – Diagnostic tiles

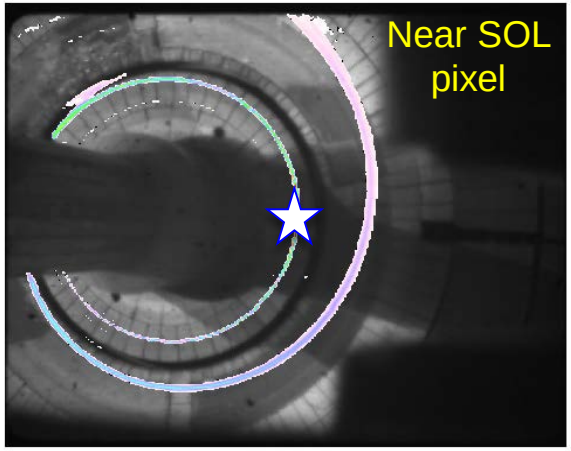




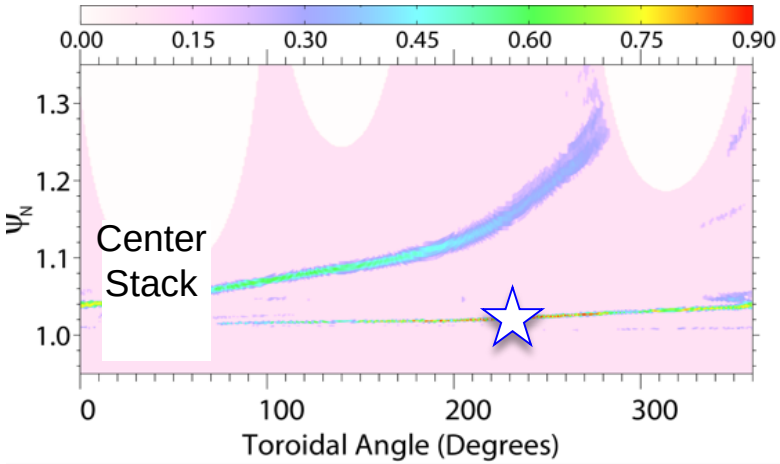
In diverted L-modes discharges, fluctuations in divertor Li I emission observed with δI/I up to 30-50%

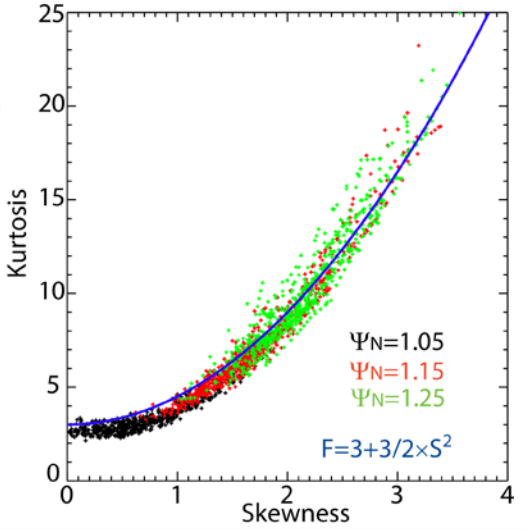
- NSTX Ohmic L-mode discharges
- Broadband fluctuations in region connected to midplane:
  - Fluctuation level decreasing approaching LCFS
- Fluctuations intermittency increases radially
  - Parabolic dependence of kurtosis vs. skewness
- Zero-delay cross correlation shows helical correlation regions at the divertor





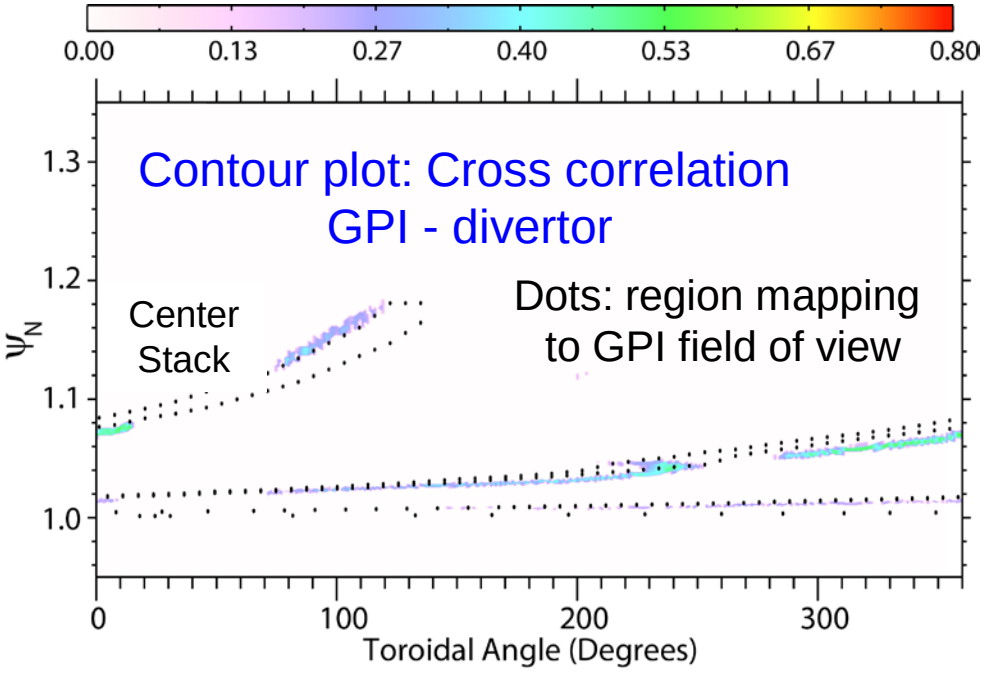
Zero-delay cross correlation

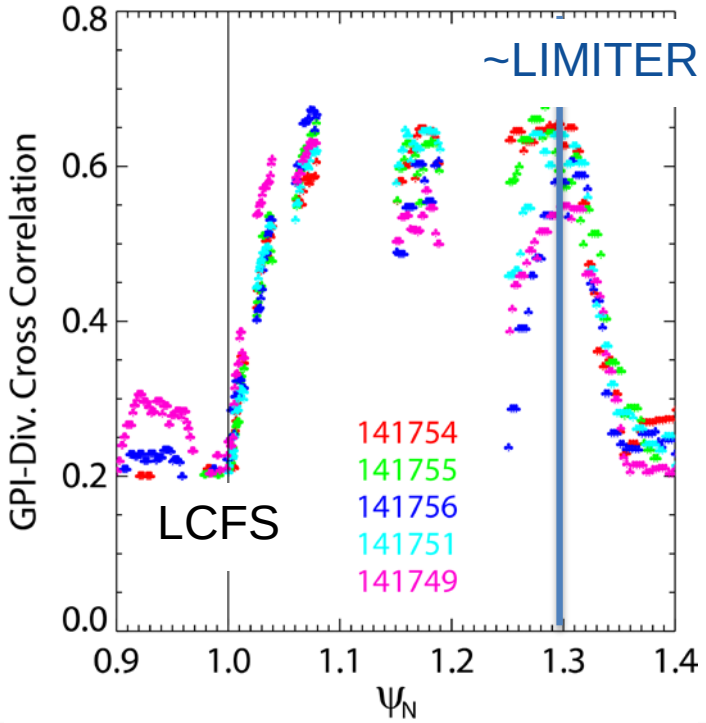




Region correlated with upstream blobs corresponds to region with large divertor fluctuations

- Divertor correlates to GPI over region that magnetically maps to GPI field of view, as in [Maqueda NF 2010]
  - Correlation up to 0.65 over ψN ~1.08-1.3, peaked at zero delay
- Decrease in cross correlation towards separatrix:
  - Consistent with reduction in fluctuation level in same region
  - Turbulence disconnection

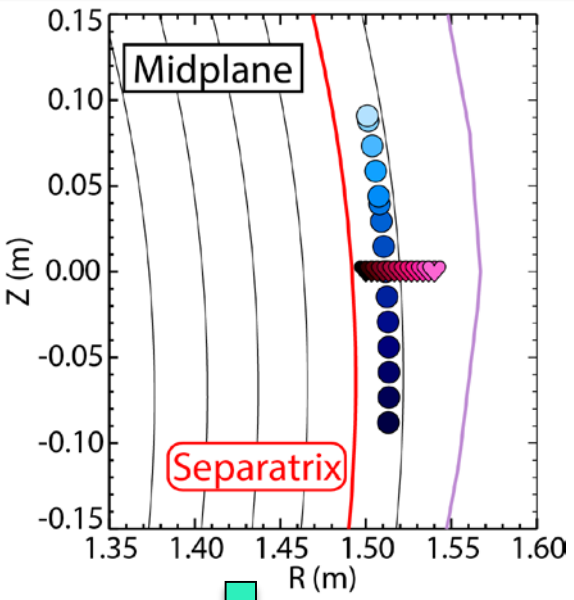


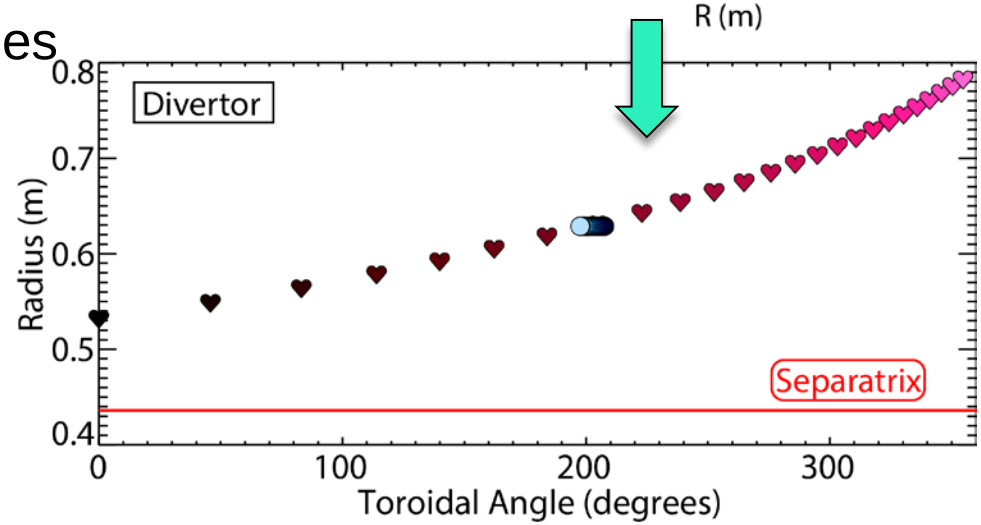


Turbulence scale lengths and propagation calculated from cross correlation maps

- Corr. lengths from zero-delay cross corr.
- Propagation from time-delay cross corr.
- Divertor L_{RAD} interpolating corr. map along filament
  - Projected on R axis
- Divertor L_{TOR} interpolating corr. map at fixed R
  - Projected on φ axis
- Midplane L_{TOR} converted into L_{POL} assuming field-aligned fluctuations

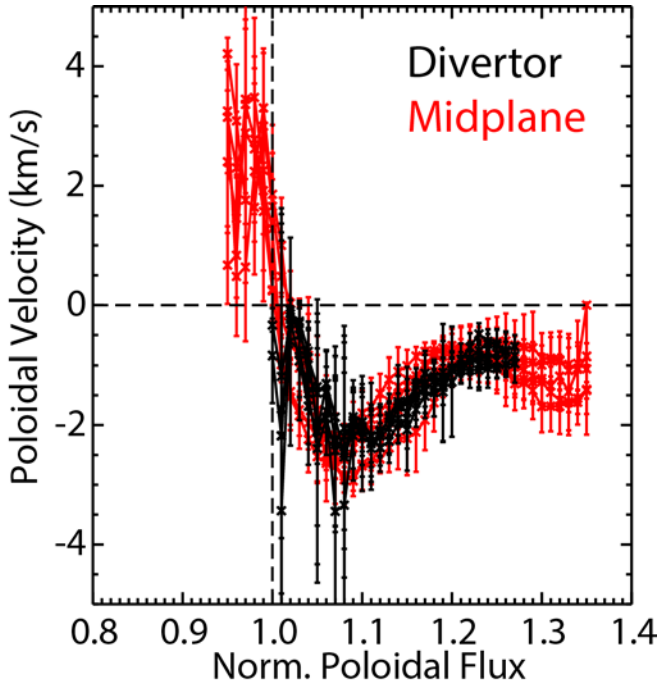
- 5 repeated Ohmic L-mode discharges (141749-141756)
- Uncertainties estimated evaluating quantities at different poloidal / toroidal locations

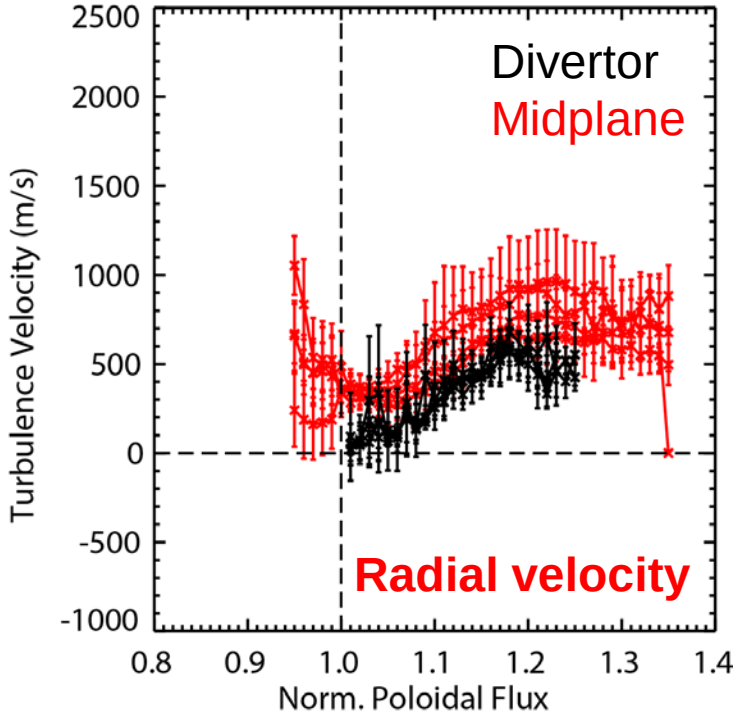




Reduced radial turbulence velocities for divertor filaments in disconnected region

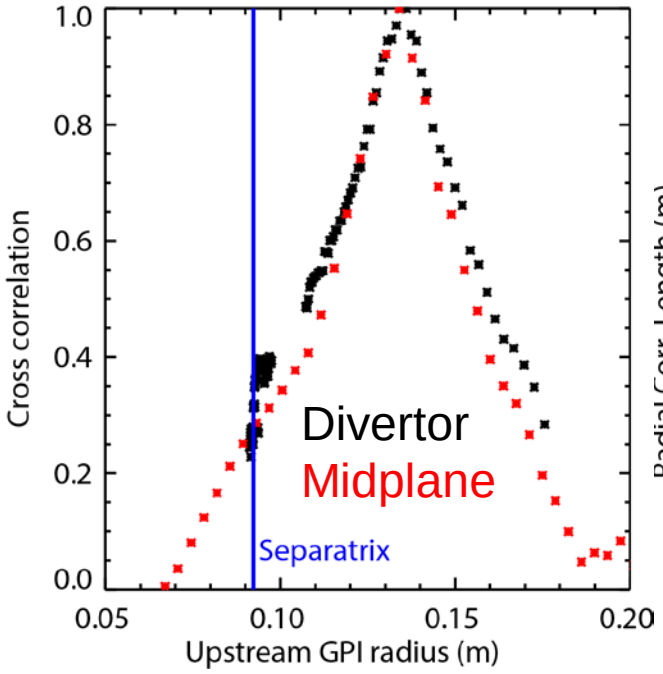
- Divertor V_{rad} agree with midplane V_{rad} in far SOL
  - Reduction in V_{rad} with respect to upstream V_{rad} approaching separatrix in disconnected region
- Midplane poloidal velocities in agreement with target filament velocity
  - Shift of 0.05 in normalized flux necessary to match velocity profiles

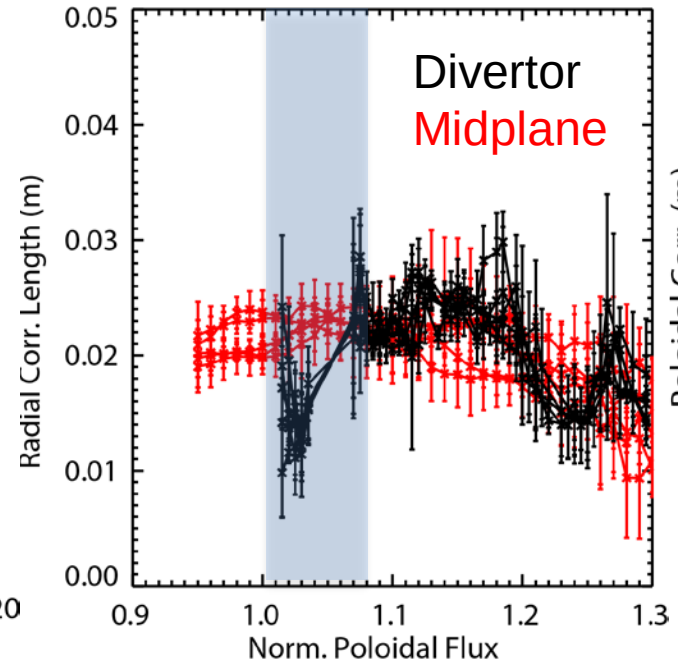


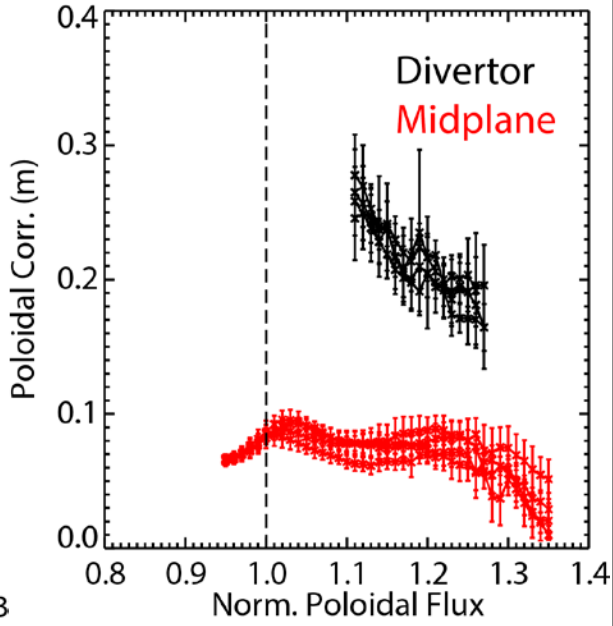


Reduced radial correlation lengths for divertor filaments in disconnected region

- Divertor L_{rad} evaluated from HWHM of radial correlation function on the SOL side
  - Divertor L_{rad} agree with midplane correlation lengths in far SOL
  - Reduction in L_{rad} with respect to upstream L_{rad} approaching separatrix in disconnected region
- ~2X larger poloidal corr. length on divertor target

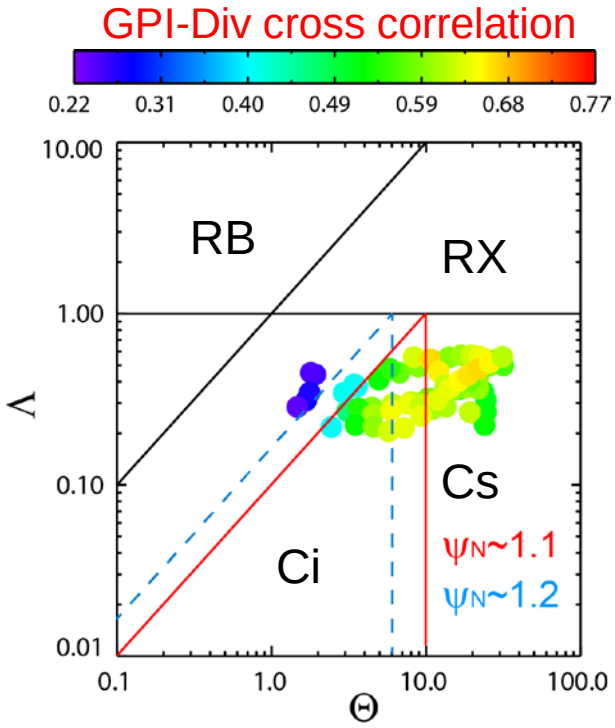


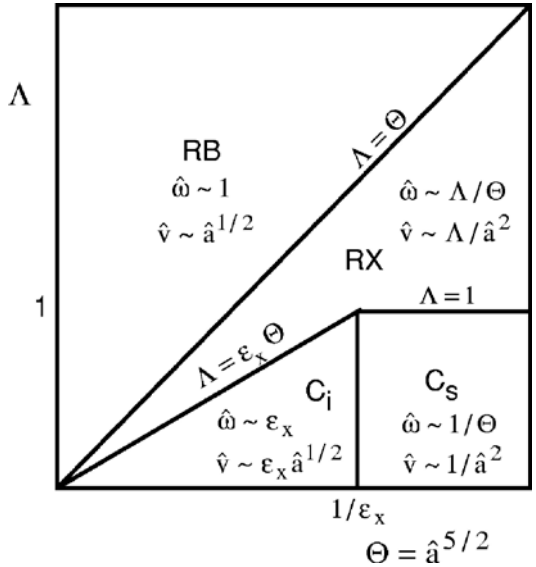




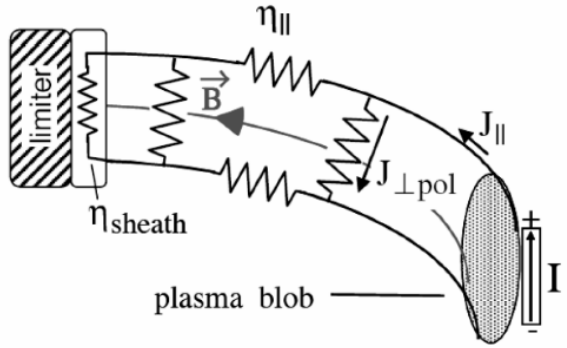
Disconnection of divertor turbulence observed approaching resistive X-point blob regime

- Experimental observations are compared with electrostatic two region model [Myra, Pop 2006]
- Blobs observed to lie between sheath connected and resistive X-point regime
- Disconnection of divertor turbulence from upstream blobs observed approaching ideal-interchange and resistive X-point regime
- Radial velocity reduction consistent with reduction in polarization drive due to X-point





Λ - normalized collisionality
Θ – normalized blob size

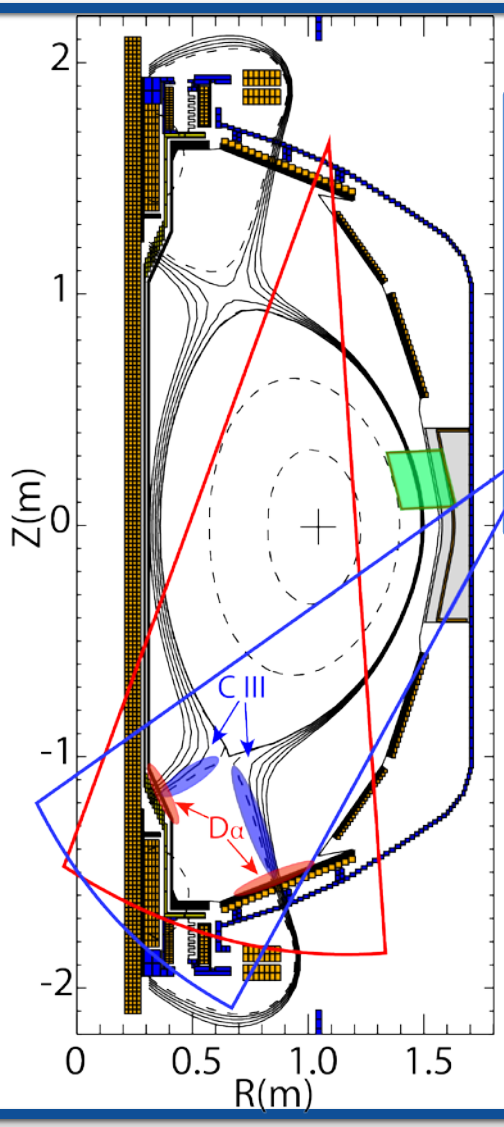


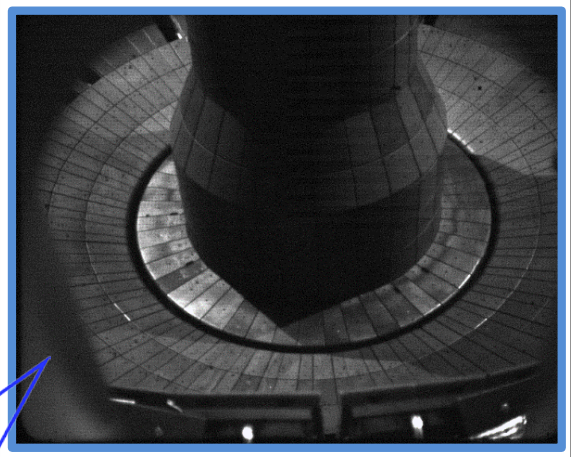
Summary

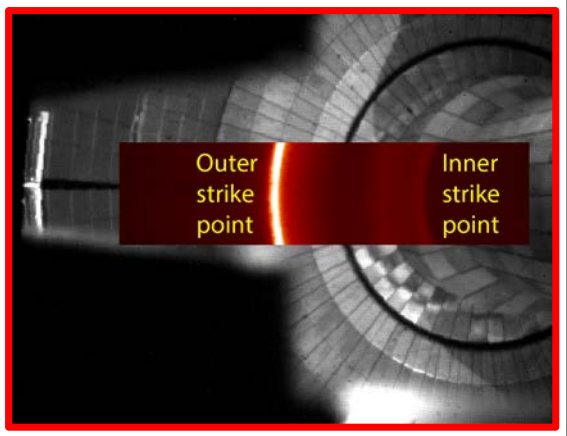
- Connection of midplane turbulence to divertor target in NSTX:
  - Decreased fluctuations observed approaching strike point
  - Decreased fluctuations correspond to region with reduced correlation with midplane
  - Divertor filaments scale lengths and propagation consistent with midplane turbulence
  - Reduction in correlation qualitatively consistent with 2-region blob model with X-point geometry causing filament disconnection

New fast camera and high X-point discharges enabled divertor-leg filaments imaging in NSTX-U

- NBI-heated NSTX-U L-mode
  - Lower divertor biased double null
  - I_p = 650 kA, f_G ~ 0. 3, BT=0.65T
- Simultaneous imaging with 3 fast cameras
- D-α imaging for midplane turbulence (GPI view, 100kHz)
- Divertor C III imaging (100kHz)
  - Emission along divertor leg
  - Poloidal filament structure
- Divertor D-α imaging (280kHz)
  - Surface localized emission
  - Intersection with target and radial filament structure

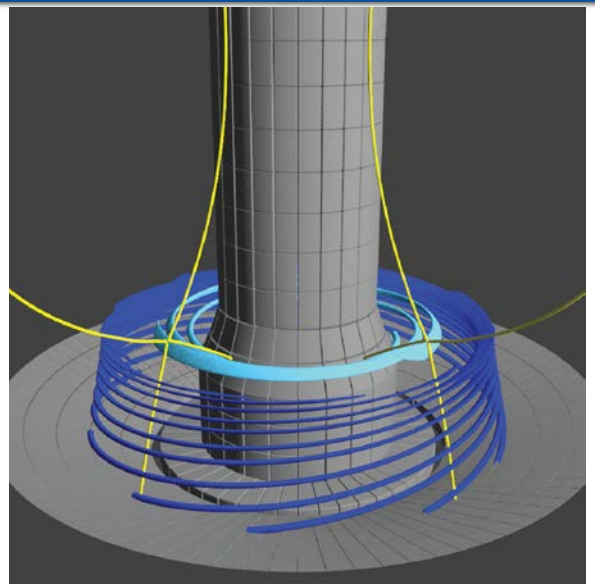


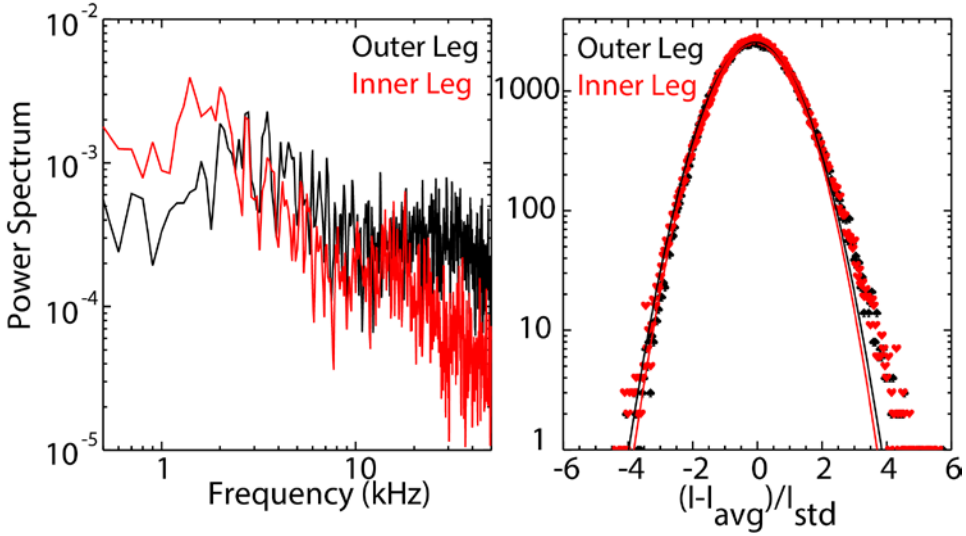


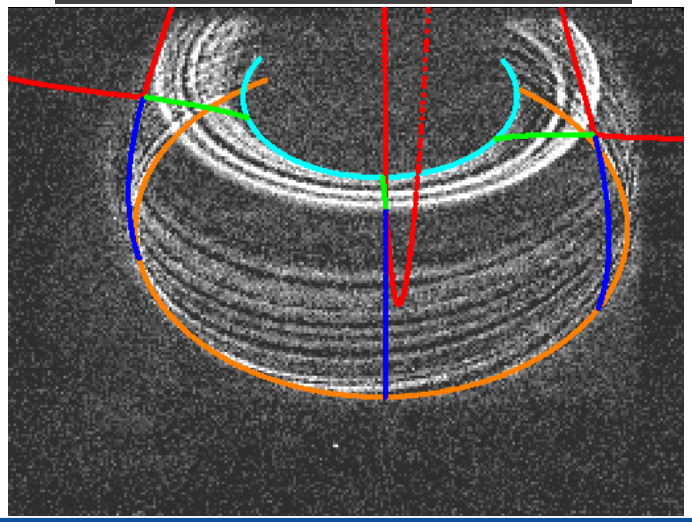


Divertor leg fluctuations are proportional to ~ $\tilde{n}_e$, no correlation with upstream fluctuations

- Broadband fluctuations ~10-50kHz, δI/I ~10-20%, lifetime ~50-100 μs
- Flute-like filament shape suggests generation in divertor region
- Intensity fluctuations ~ $\tilde{n}_e$
  - C III and D-α fluctuations correlated
- Comparable near-Gaussian PDF for inner and outer legs filaments
- No correlation with midplane blobs

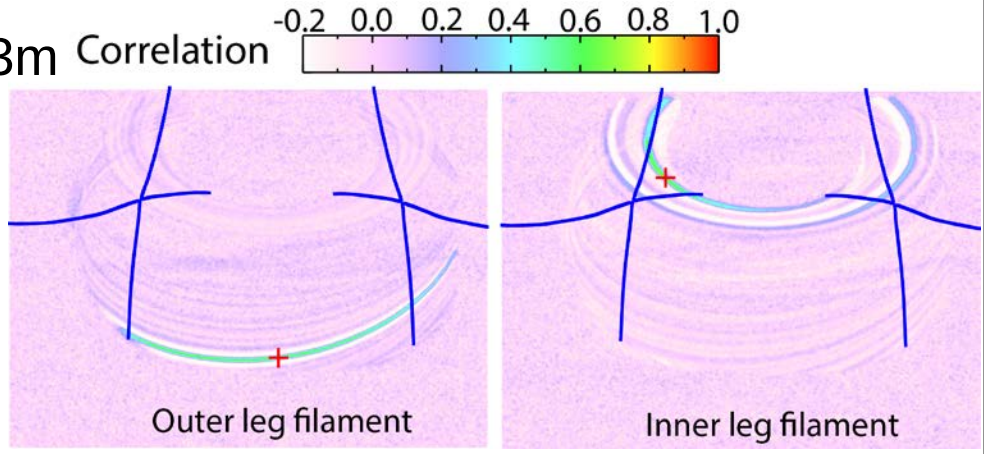


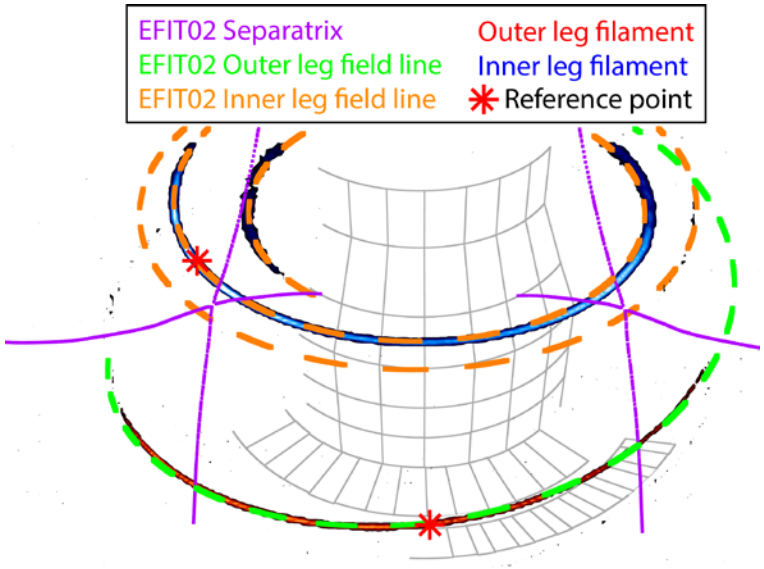


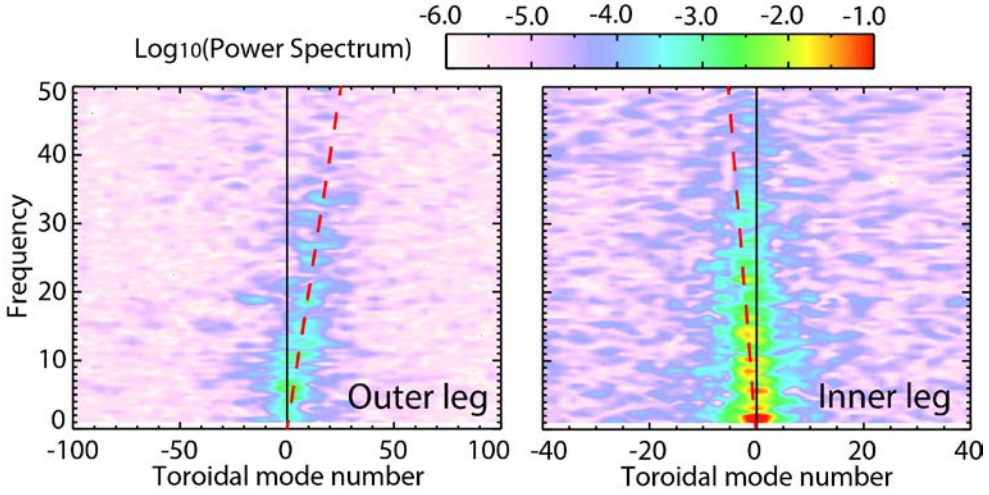


Field-aligned fluctuations, no correlation between inner and outer leg filaments

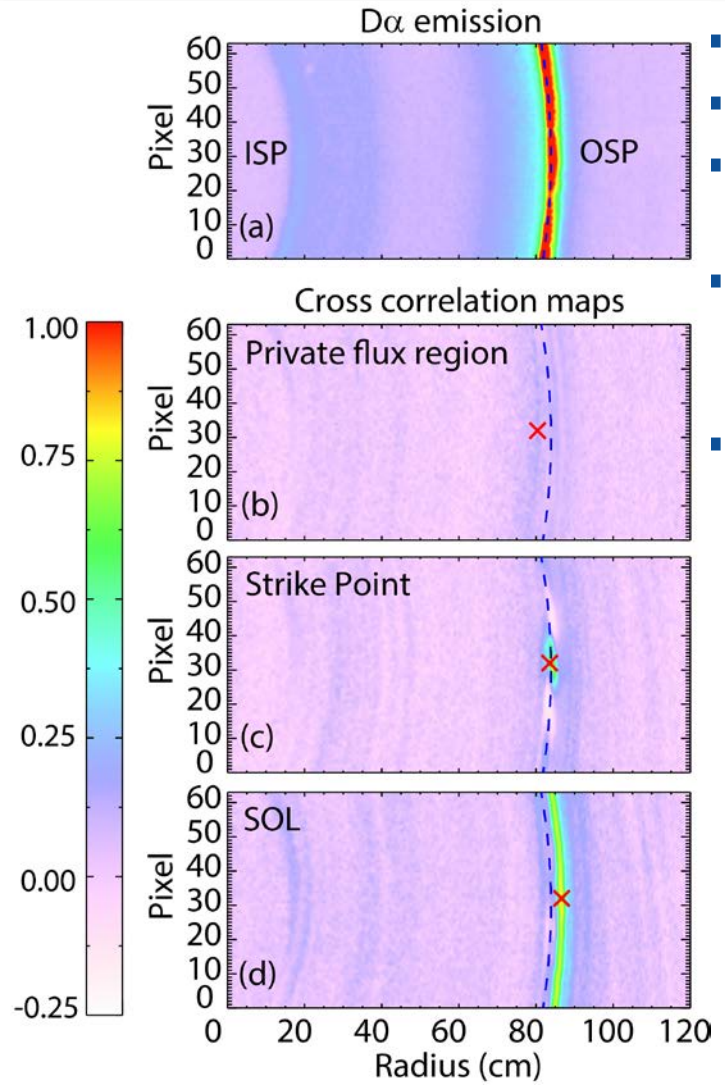
- Cross corr. (5 ms) from radial view
- L_{POL}~1-3 cm, $k_{pol}\rho_i$~0.01-0.1, $L_{//}$~2-3m
- Toroidal mode number:
  - 10-30 outer leg, 2-10 inner leg
- No correlation inner to outer leg
- Field-aligned, localized around leg
  - Inner leg filaments in private flux region



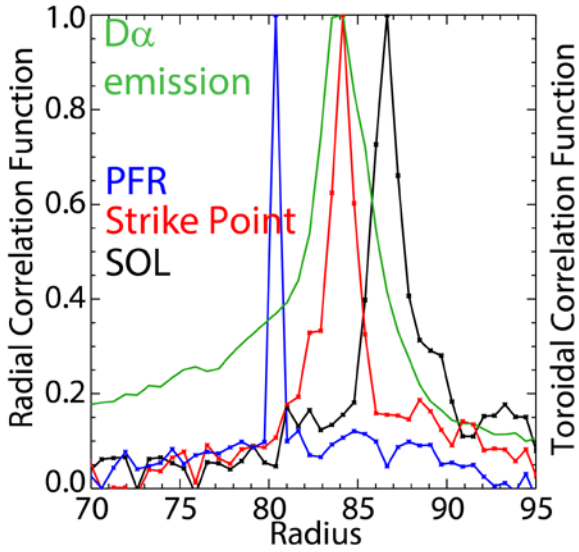


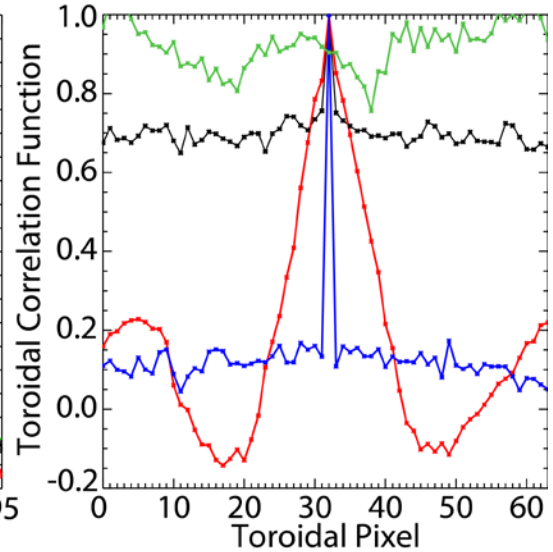


Outer leg filaments are connected to target plate, localized to bad curvature side of strike point



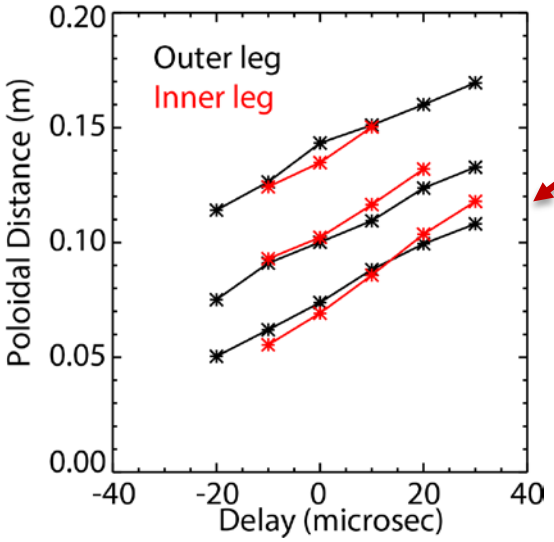
- Cross corr. (5ms) from top-down view (D-α)
- No correlation regions observed in private flux region
- In SOL, correlated structures have spiral shape
  - Footprint of midplane blobs
- Approaching LCFS, correlation regions have finite toroidal correlation length, L_{RAD}~1-2 cm
  - Footprint of divertor filaments
- Radial separation betw. divertor and midplane modes
  - Limited penetration of midpane modes close to separatrix





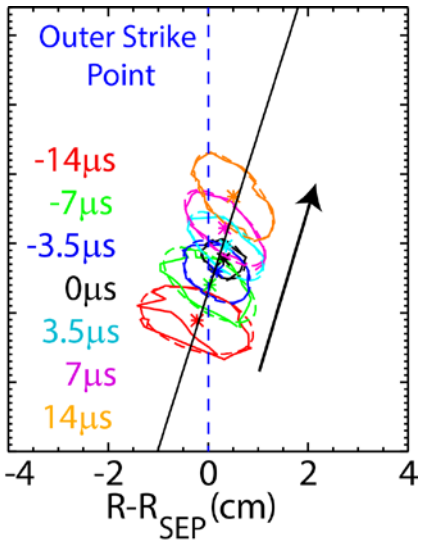
Inner and outer leg filaments rotate in opposite toroidal direction, poloidal velocity ~1 km/s

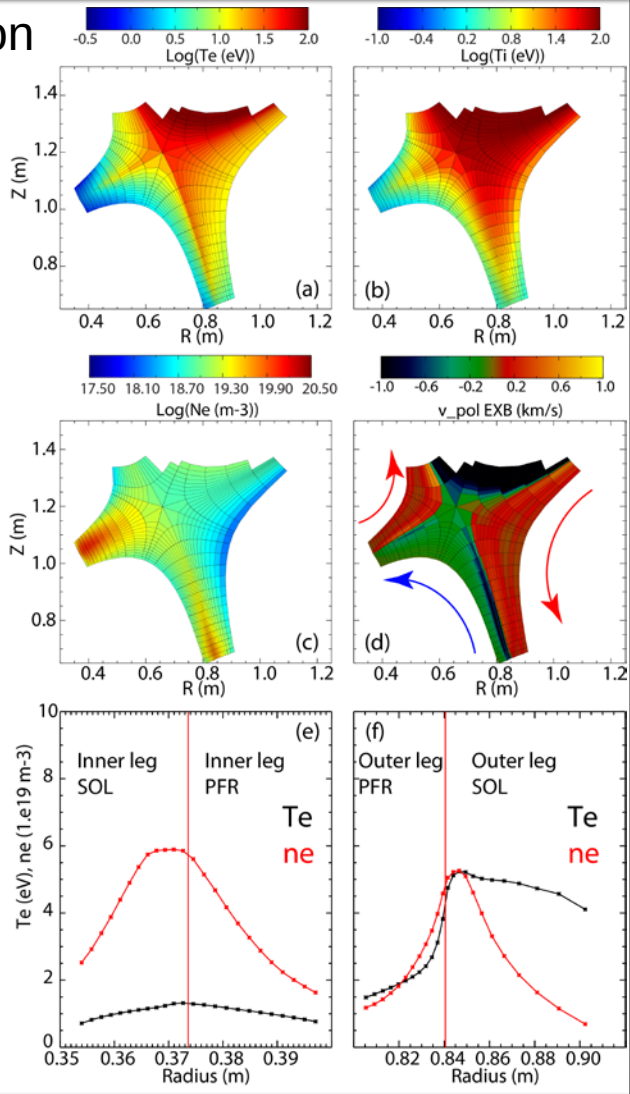
- Time-delayed cross corr. for average filament propagation
- Poloidal motion (1-2km/s) for inner/outer leg filaments towards X-point
- Outer leg filaments propagate radially outwards at 0.25km/s
- Multi-fluid UEDGE sim. with full cross field drifts model
  - Filament velocity in outer leg qualitatively consistent with UEDGE estimates for ExB velocity
  - Provide background plasma profiles for simulations



Radial view

Top-down view





Summary

- Divertor-localized fluctuations in NSTX-U:
  - Intermittent field-aligned filamentary structures localized to the divertor on bad curvature side of inner and outer divertor legs
  - Divertor filaments are connected to the divertor plate
  - Evidence for X-point disconnection:
    - Inner and outer leg filaments are not correlated
    - Divertor filaments and midplane blobs are not correlated
  - Radial separation between divertor-leg modes and midplane blobs
    - Consistent with limited penetration of midplane modes observed in ArbiTER simulations
  - Observations motivated simulations on grid limited to divertor legs only with ArbiTER
    - Unstable resistive ballooning modes observed on both legs in qualitative agreement with experimental observations