



WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON



NSTX-U

Measurement of Long-Wavelength Fluctuations in High-Beta Spherical Tokamak Plasmas

David R. Smith (co-PI), George McKee (PI)
and Benedikt Geiger (Academic Advisor)

University of Wisconsin-Madison

NSTX-U Collaboration Overview

March 1, 2021

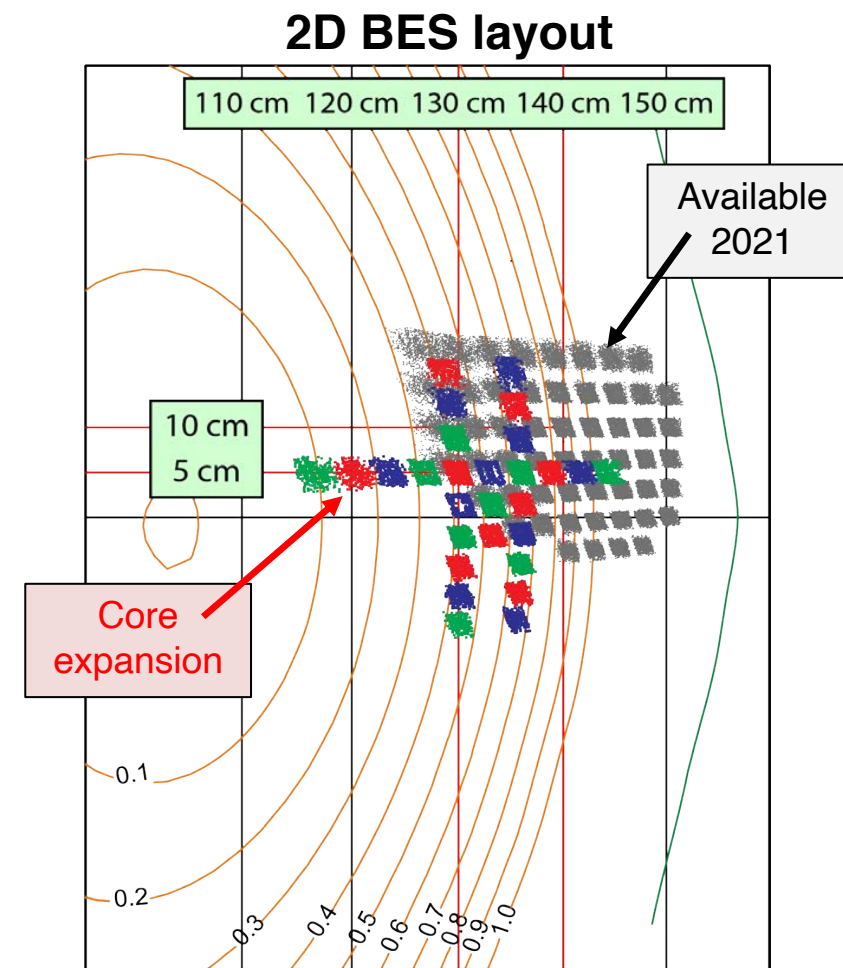
DOE Award No. DE-SC0001288

<https://fusionlab.ep.wisc.edu/turbulence/>



Project objectives

1. Measure and characterize *2D turbulence and flow properties* in the pedestal and core at low collisionality, low aspect ratio, and high normalized pressure (β_N) **(5YP Obj. 1 and 2)**
2. Measure and characterize *2D carbon impurity dynamics* by modifying BES detectors for carbon CX measurements **(5YP Obj. 2 and 3)**
3. Measure and characterize the *core-to-edge radial mode structure* of disruptive and Alfvén/energetic particle instabilities **(5YP Obj. 1 and 2)**
4. Develop machine learning models for rapid 2D BES velocimetry to study flow dynamics at the L-H transition
5. Explore the capability of 2D BES to measure and validate the spatial distribution of HHFW field intensity in the core



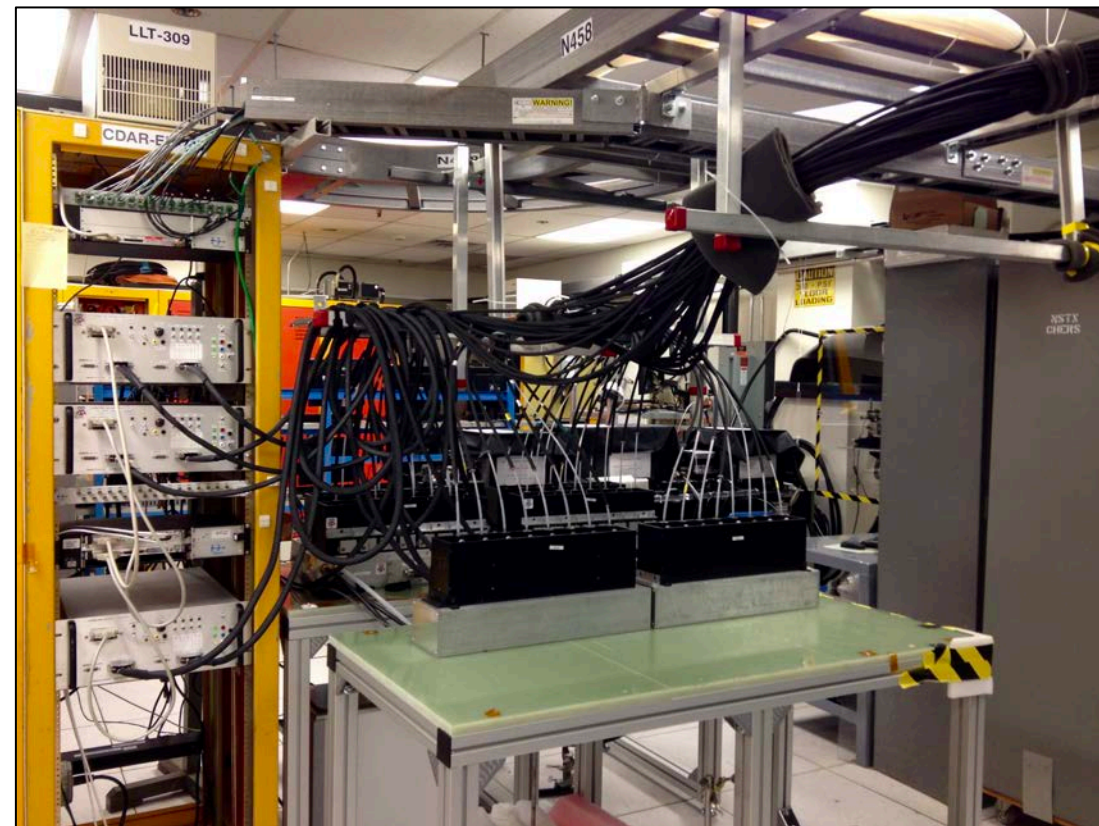
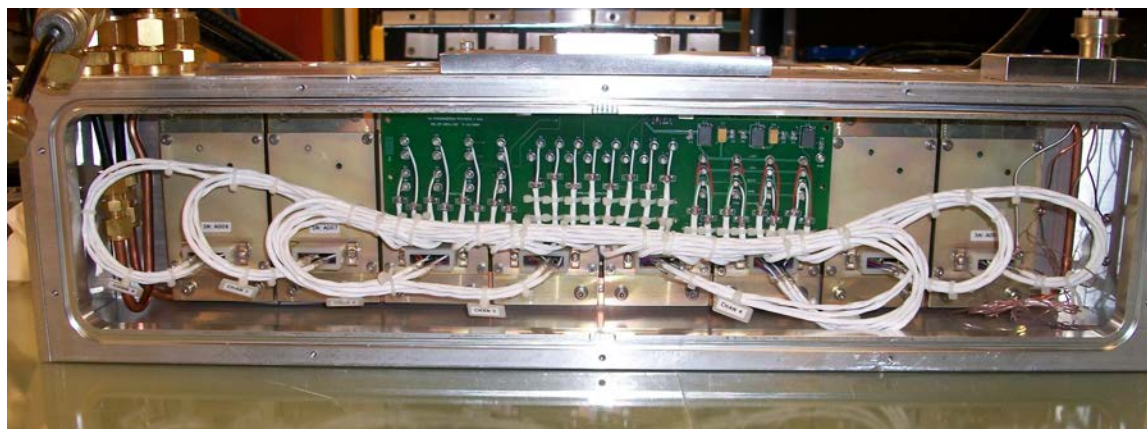
Ion-scale density fluctuations

- $\Delta R, \Delta Z \sim 2-3$ cm, $f=2$ MHz
- $L_{c,r}, L_{c,\theta}, \tau_c, S(k_r, k_\theta), v_\theta, v_r$
- ITG, TEM, KBM, MTM

Expansion to 64 custom-built, photon-noise-limited detectors



2 MHz sampling captures broadband turbulence, Alfvén/EP modes, and Alfvén-scale ELM events



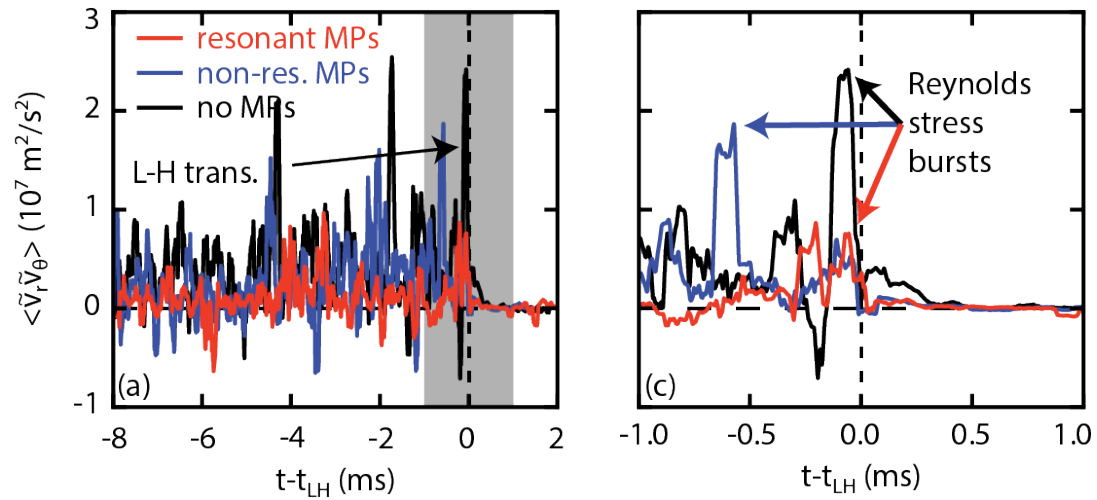
48 detectors shown; final 16 detectors presently at DIII-D for Carbon CX Imaging (CXI) prototype



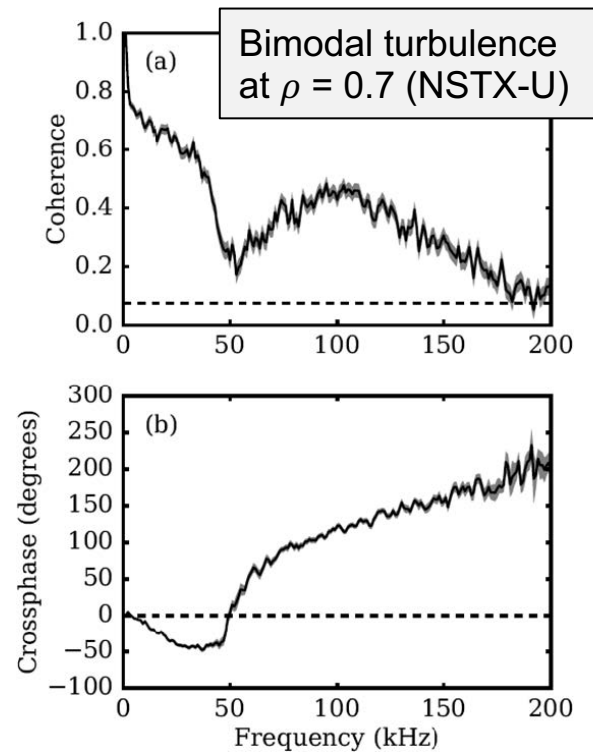
- Low ν^* , high β_N , at low A
- Compare to 2D turbulence and flows in high A tokamak
- LH trigger, transition, and power threshold

- Core-to-edge 2D coverage
 - Emphasis on edge, pedestal and SOL
- Impact of 3D fields
- Core-edge coupling in advanced scenarios

Impact of magnetic perturbations on Reynolds Stress near LH (DIII-D BES)

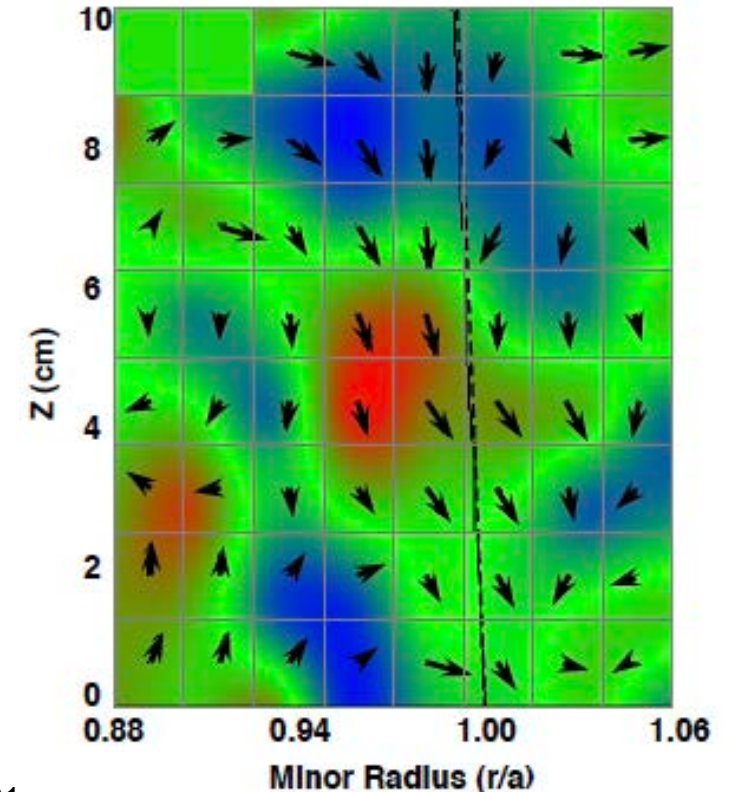


D.M. Kriete et al., Phys. Plasmas 27, 062507 (2020)



G. McKee, D. Smith, and B. Geiger, UW/NSTX-U collaboration, 3/1/2021

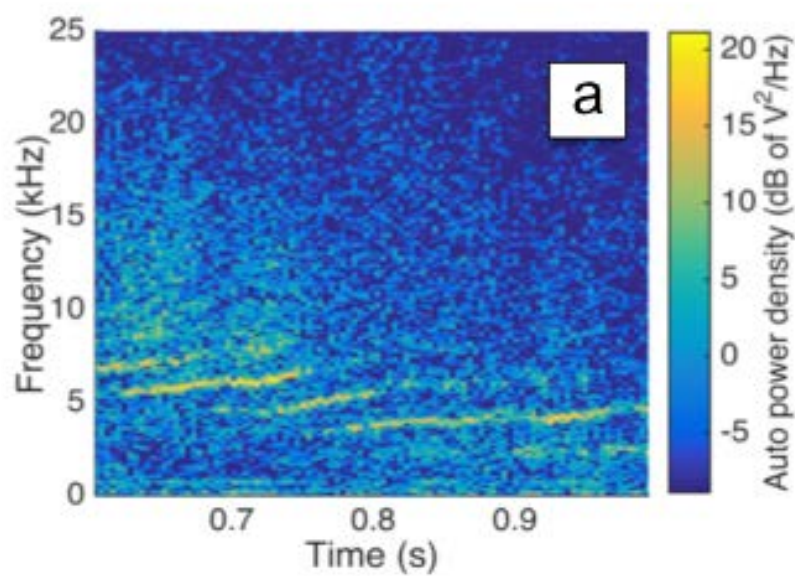
Velocimetry from DIII-D BES



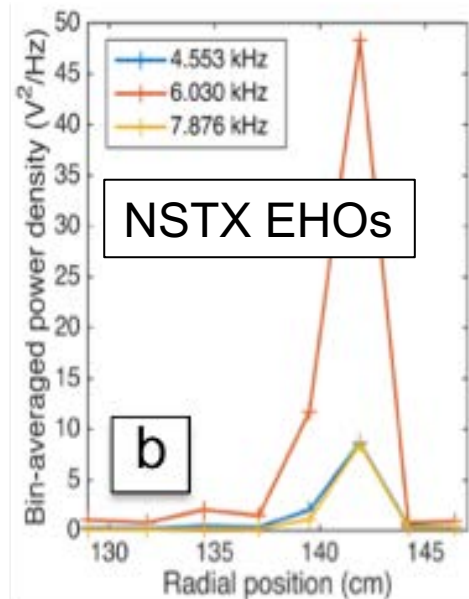
2D Carbon and impurity dynamics at high time resolution



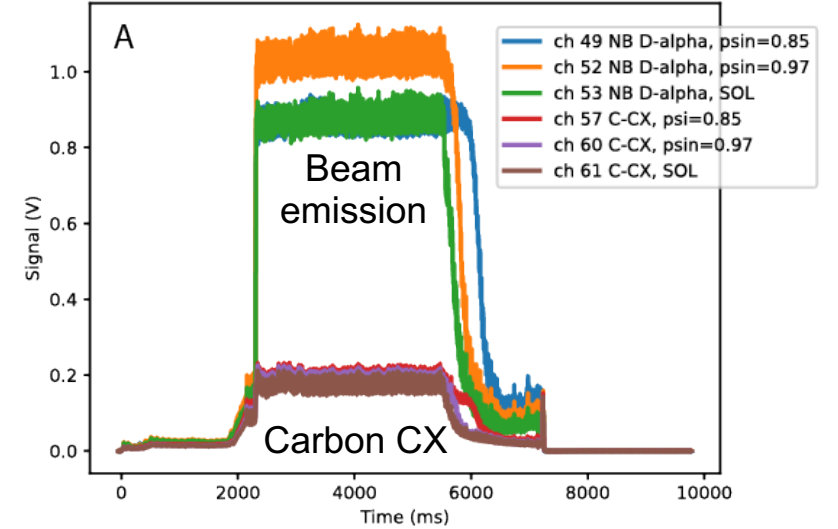
- Carbon response at high time resolution
 - EHO and particle pumping
 - Post-ELM
 - RMP
 - Turbulence, impurity pinch, perturbative transport
 - Enhanced spatial resolution



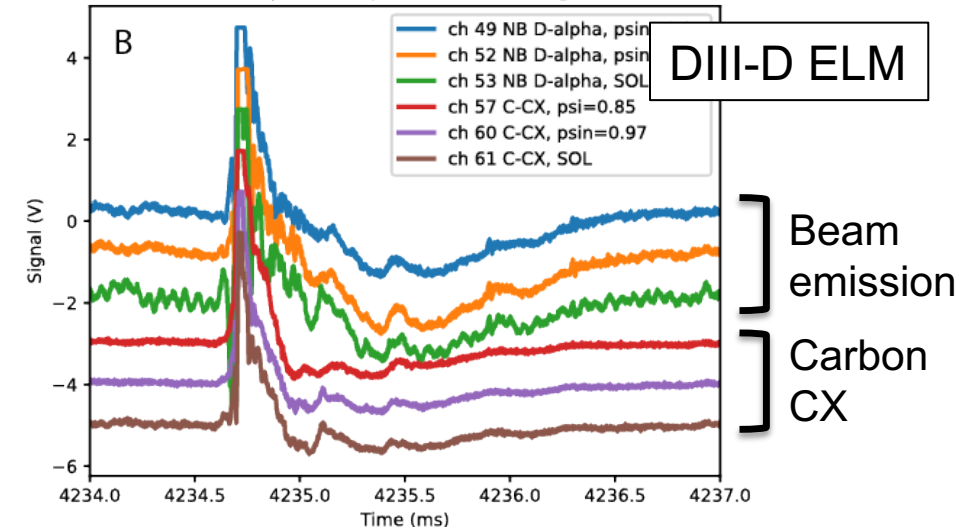
shot 145049. channel: besfu54/besfu46. log scale of (crosspower)



Shot 176778 | DC-coupled slow BES signal



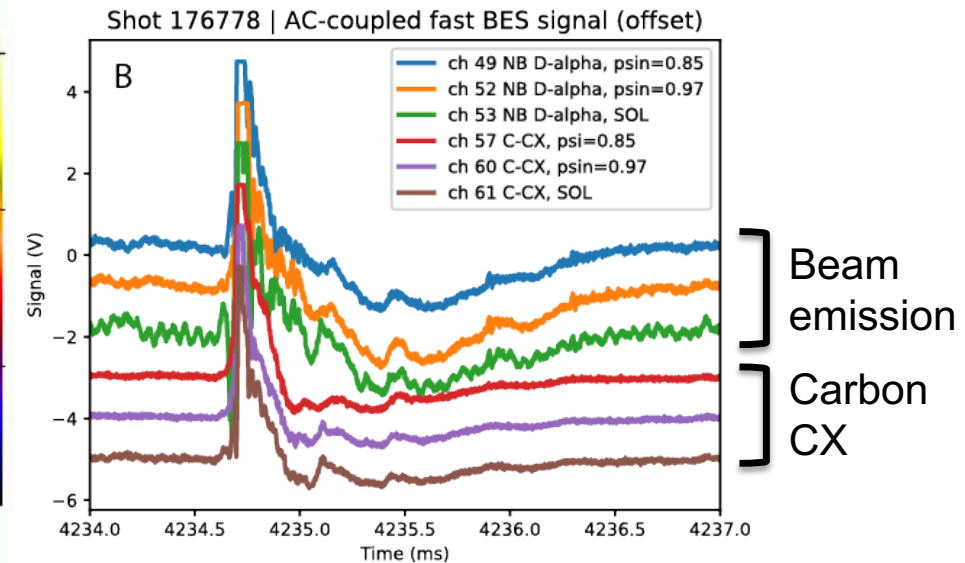
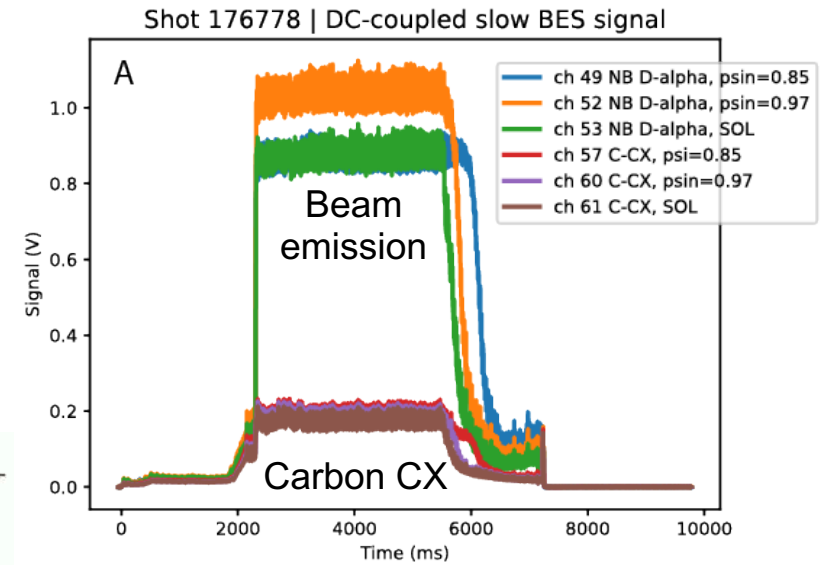
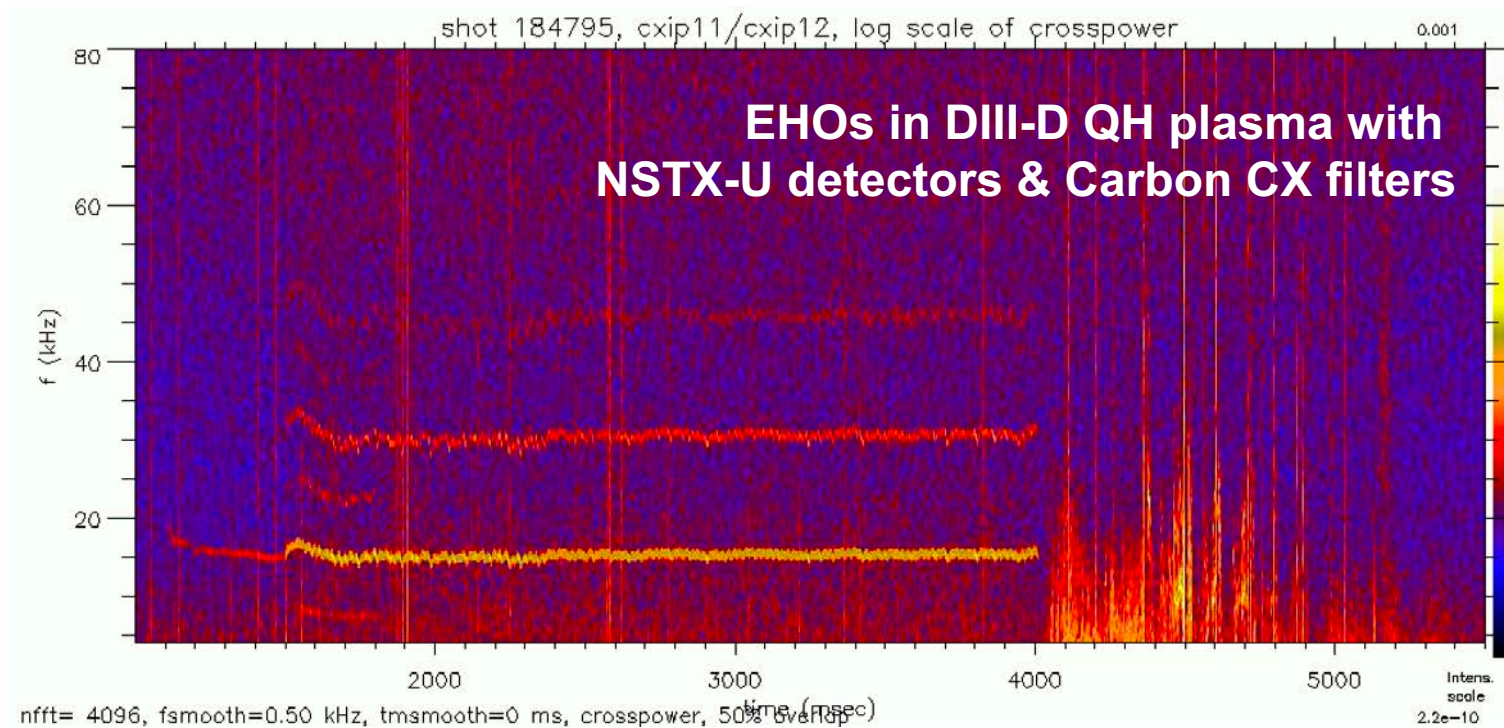
Shot 176778 | AC-coupled fast BES signal (offset)



2D Carbon and impurity dynamics at high time resolution



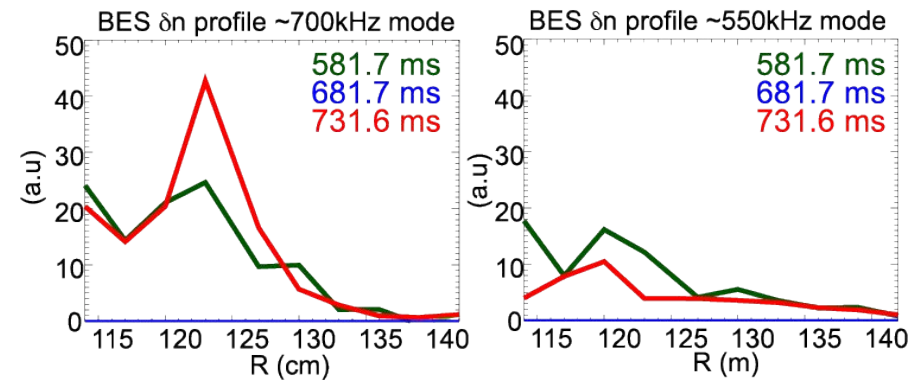
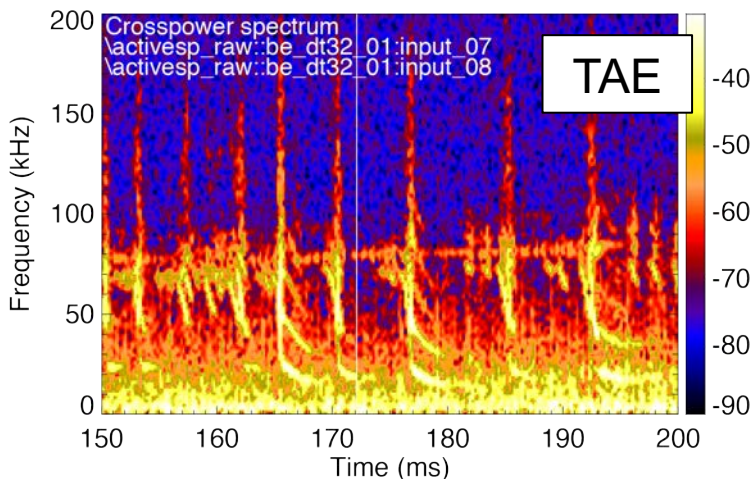
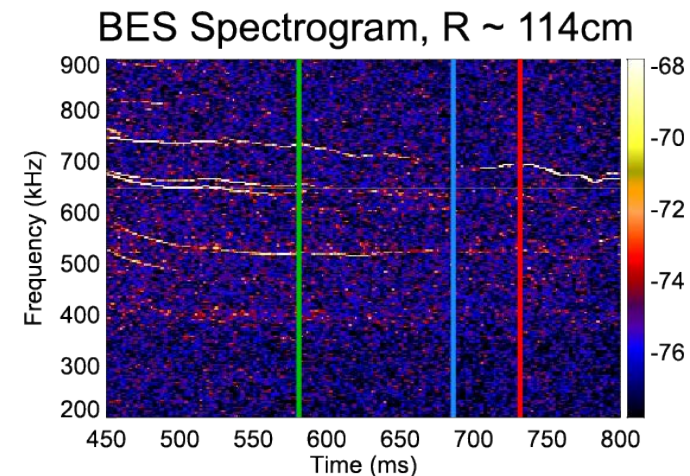
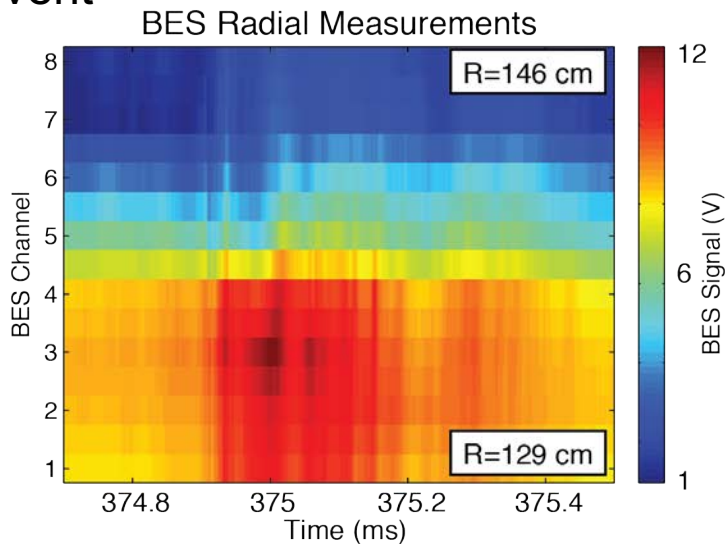
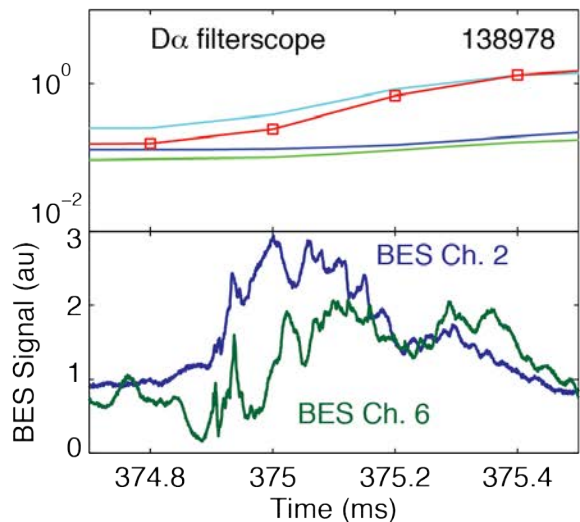
- Carbon response at high time resolution
 - EHO and particle pumping
 - Post-ELM
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 - Turbulence, impurity pinch, perturbative transport
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Core-to-edge radial mode structure of disruptive and Alfvén/EP modes



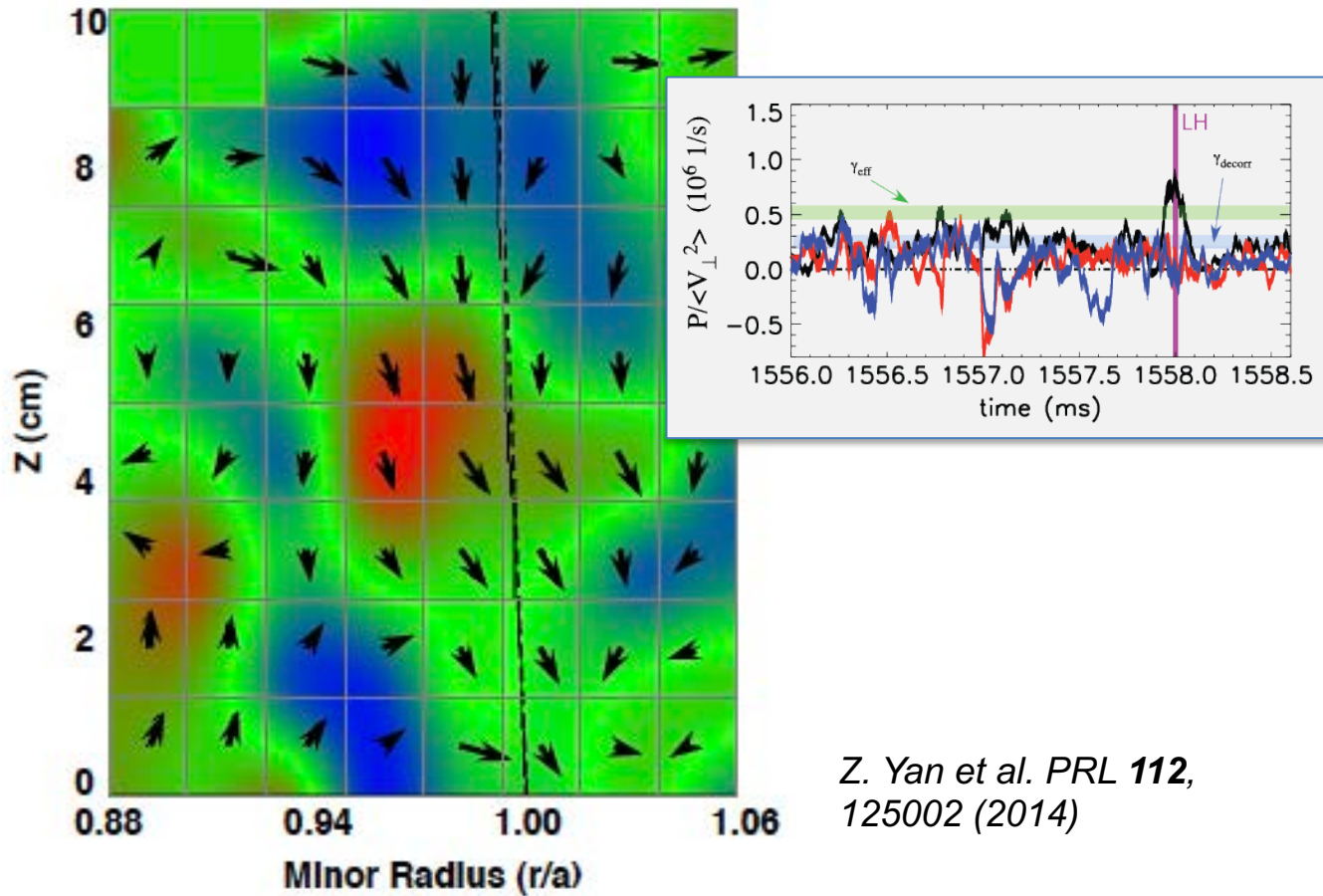
Alfvén-scale ELM event



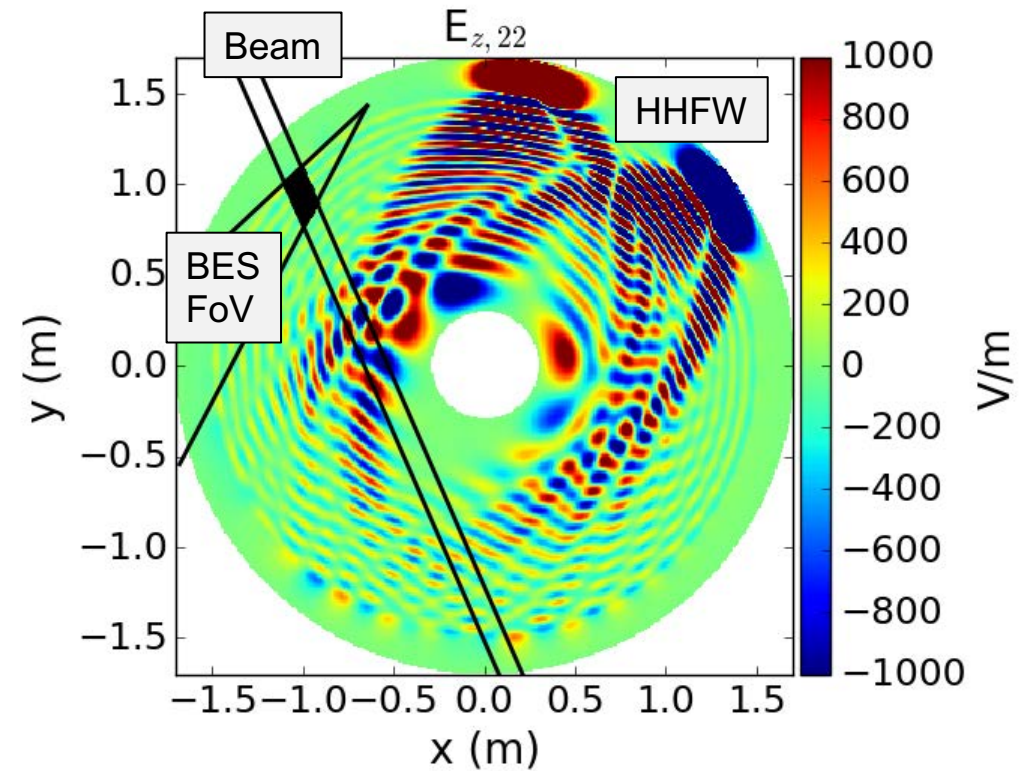
GAE radial mode structure, K. Tritz et al.



ML models to accelerate 2D velocimetry



Exploratory experiment to observe HHFW field with 2D BES by imposing beat frequency in RF sources



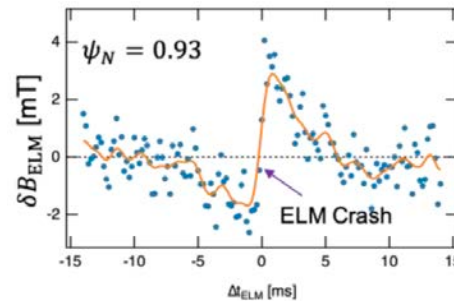
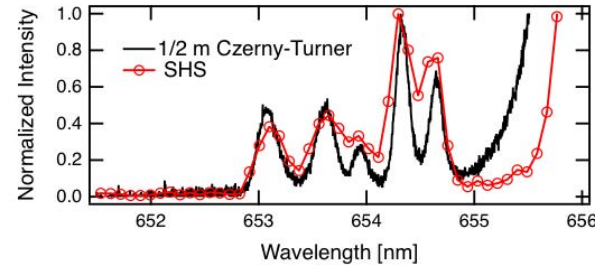
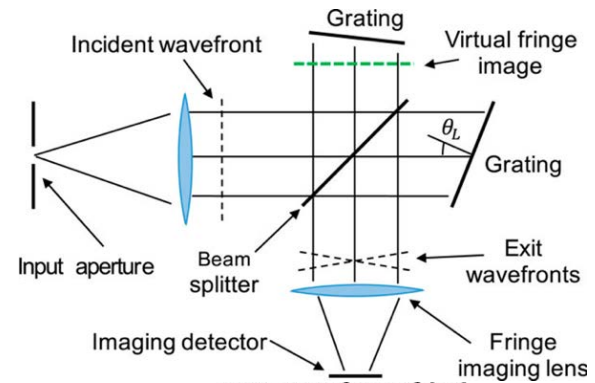
G. Rutherford, S. Shiraiwa, D. Smith, and N. Bertelli, submitted to RSI

Explore feasibility of new fluctuation diagnostic capabilities for multi-field turbulence measurements

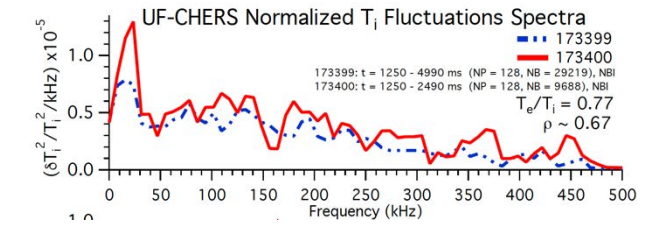
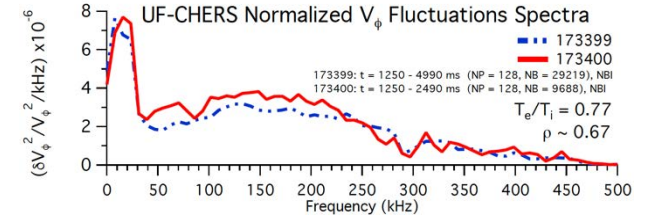
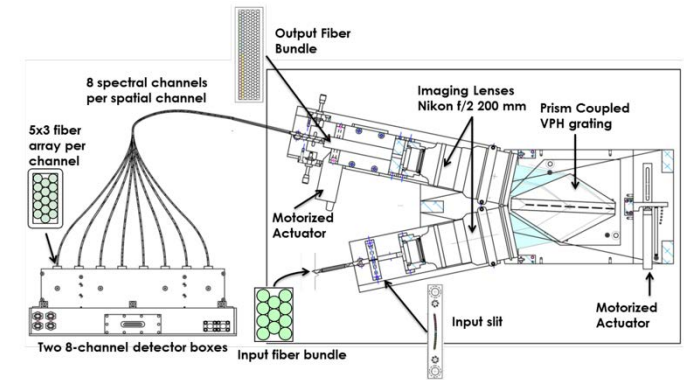


- Proposed but not funded activities:
 - High resolution survey spectrometer for future diagnostics: UF-CHERS, SHS, CXI
- UF-CHERS: ion temperature and toroidal velocity fluctuations @ 1 MHz
 - Measured broadband T_i and V_{TOR} fluctuations
 - Observed Geodesic Acoustic Mode
- SHS: electrostatic and magnetic fluctuations (10s-100s of kHz)
 - Imaging interferometric technique
 - High luminosity-resolution measurements of π and σ beam emission components
 - Observed fast $|\vec{B}|$ field changes at ELM and L-H

Spatial Heterodyne Spectroscopy (SHS)



Ultra-Fast Charge Exchange Recombination Spectroscopy (UF-CHERS)





	FY21	FY22	FY23	FY24	FY25
2D turbulence and flows					
Install 16 new channels at NSTX-U (presently at DIII-D)					
Implement Carbon CX filters					
2D carbon dynamics					
ML models for velocimetry					
Implement fiber bundles for core expansion					
Explore BES measurements of HHFW field distribution					
Core-to-edge mode structures					



■ Personnel

- Co-PI and full-time onsite scientist – David Smith
- PI – George McKee
- Academic advisor – Asst. Prof. Benedikt Geiger
- Two UW Graduate students for NSTX-U dissertation research
 - First student beginning Fall '21: Aidan Edmondson
- Postdoc/Assistant Scientist support (0.5 FTE)
 - UW-Madison: student support, diagnostic design and implementation
 - Engineering support and integration
- Undergraduate students
- Integration with closely affiliated UW research programs
 - DIII-D BES, CXI, UF-CHERS, and SHS (DIII-D Nat. Fus. Fac.)
 - HL-2A & HL-2M BES (SWIP, China)
 - W7-X stellarator (IPP, Germany)



George
McKee



David
Smith



Benedikt
Geiger



- Expand BES to 64 channels for turbulence and flows
 - 48 channels currently installed at NSTX-U + 16 newly developed
 - New 16 presently at DIII-D for CXI prototype testing
- Implement Carbon filters for fast impurity transport dynamics
 - Procure CVI filters (529 nm) to measure fast carbon emissions
 - Replace existing BES filters in modular detectors temporarily as needed
- Expand BES coverage to core
 - Procure fibers bundles for core view at R130 port
 - Radial array to $0.1 < r/a < 0.5$
 - 8-channel Core poloidal array near $r/a=0.4$
- Scientific objectives:
 - β_N , v^* dependencies of turbulence properties at low-A
 - Pedestal instabilities, ELM dynamics, EHO, EPH-mode characteristics
 - L-H trigger mechanism, xAE instabilities, disruption precursors
 - Contribute to model and simulation validation

2D BES layout

