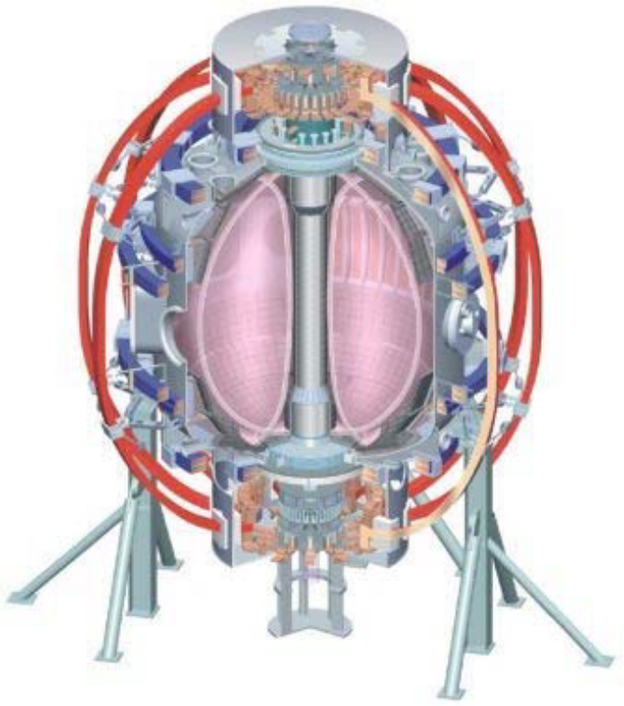
University of Wisconsin Collaboration with NSTX-U: 2012-2016

Investigations of Long-Wavelength Turbulence and Instabilities in the Spherical Torus

G. McKee, R. Fonck, D. Smith

University of Wisconsin-Madison



NSTX Diagnostic Plan Meeting
PPPL
July 26, 2012

THE UNIVERSITY of WISCONSIN MADISON

Overview of UW Collaboration at NSTX

- **Present goals are to characterize and understand long-wavelength density fluctuations associated with turbulence and other instabilities in spherical torus plasmas**
  - $\tilde{n}/n(r)$, $S(k_r,k_\theta)$, 2D imaging, xAE modes, pedestal instabilities
- **Primary research tool is an advanced Beam Emission Spectroscopy density fluctuation diagnostic system**
  - $0.1 < r/a < 1.0+$ (SOL); $k_\perp \rho_i < 1.5$; radial & poloidal coverage
  - 24 channels operating since 2010; 32 channels available (2011)
  - 56 viewing channels available
- **Research staff:**
  - Dr. David Smith (co-PI, UW, on-site full time at PPPL)
  - Prof. Ray Fonck (co-PI, UW)
  - Dr. George McKee (PI, UW, based at DIII-D)
  - D. Thompson (UW graduate student), Technician, Instrumentation Engineers (UW)
- **Present Research Grant: June, 2012-June, 2016**

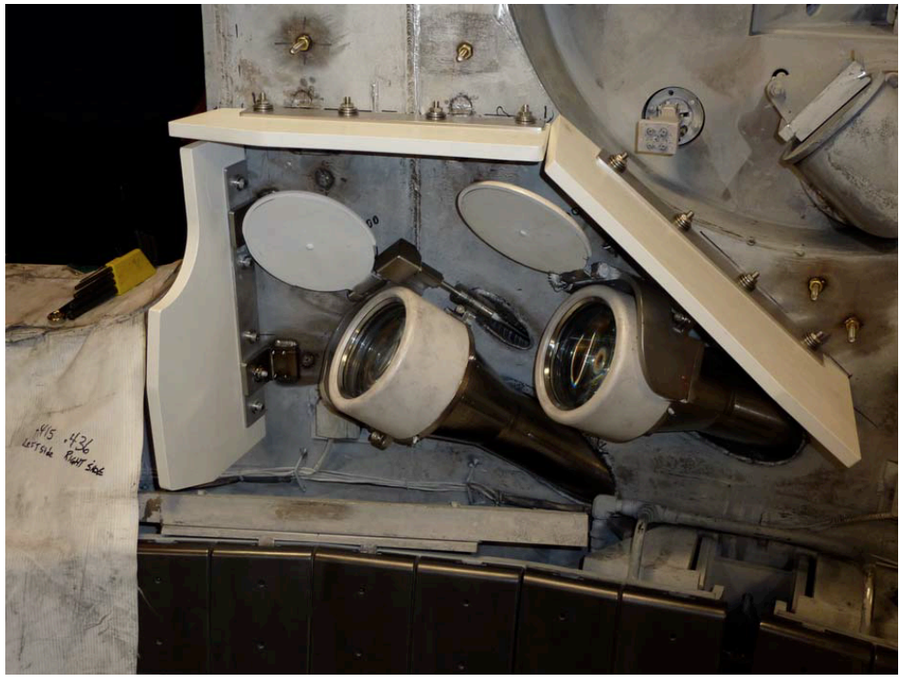
Summary of Recent and Near-term Research Activities

- **32-channel BES used to characterize H-mode pedestal and core fluctuations: 2010-2011**
  - 24 channels in 2010
  - Assess: turbulence, energetic particle modes, MHD, ELMs, pedestal
- **Comprehensive analysis of pedestal fluctuation characteristics**
- **Scientific presentations at:**
  - APS-DPP (contributions to Invited talks: K. Tritz (2010), A. Diallo (2011))
  - Transport Task Force
  - High Temperature Plasma Diagnostics Conference
  - Seminars: UW, PPPL
- **Publications**
  - 3 RSI (HTPD) on BES diagnostic and detector systems
  - Microtearing (D. Smith, PPCF); low-coherence backscattering (DS, APL)
  - Phys. Plasmas submission (imminent): H-mode pedestal fluctuations (DS)
- **Upcoming conferences:**
  - IAEA-FES (2012); APS Invited Talk (2012), D. Smith

New Generation of BES Detectors Deployed at NSTX

8-Ch Detector Module

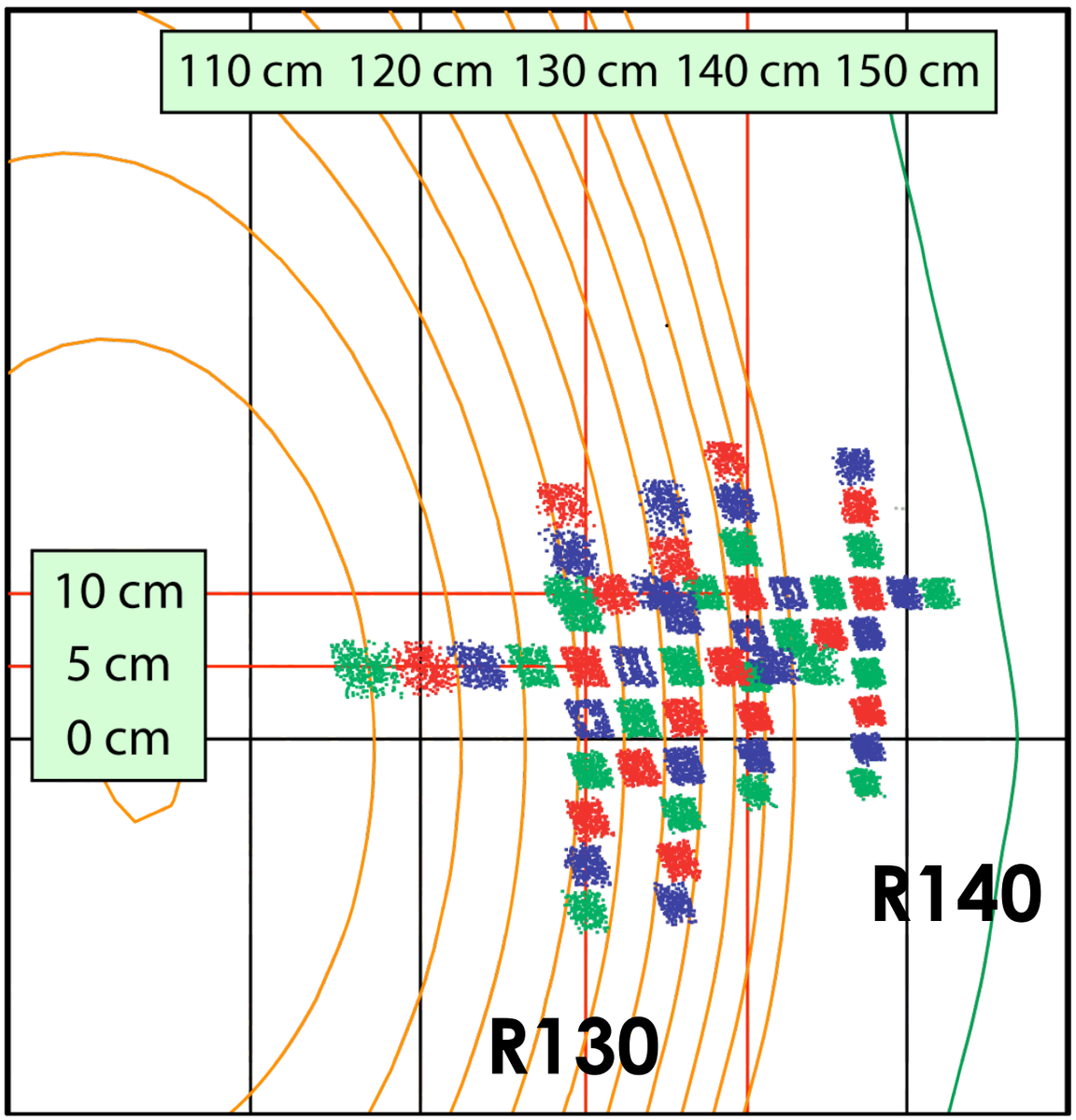
R130 & R140 Viewports



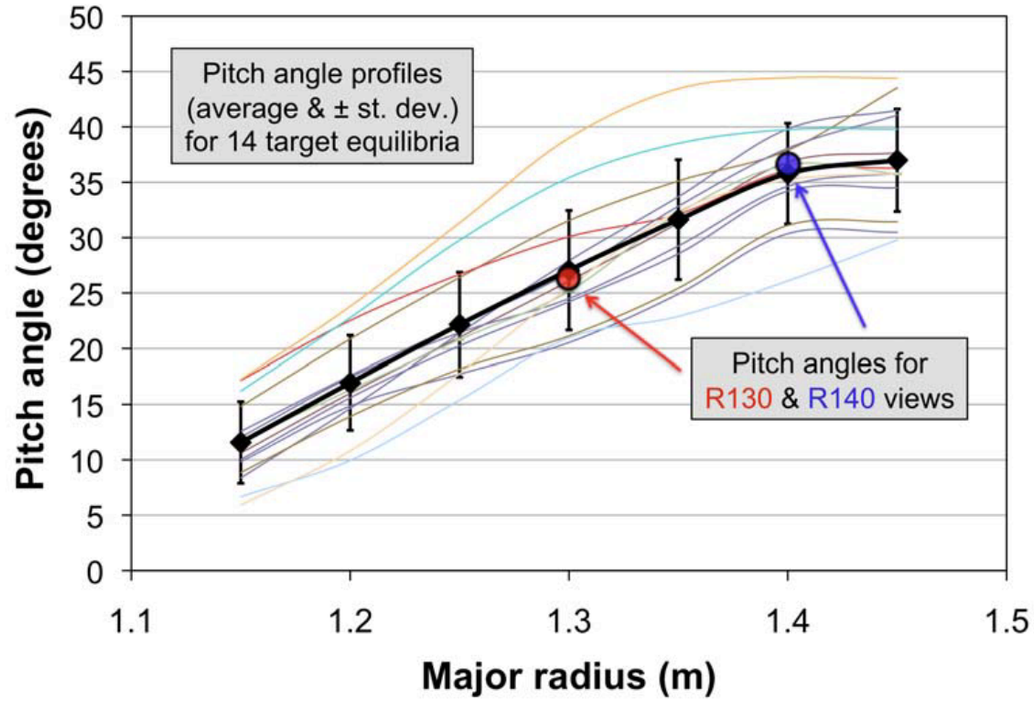
- **New preamplifiers & photodiodes**
  - Surface-mount components
- **Refrigerant-cooled (non-cryo)**
- **2 MHz sampling (CAE/GAE modes)**
- **FPGA FIR Digital Filter**
  - no analog anti-alias filters required

- **High-throughput (f/1.5) viewing lens**
- **High-etendue**
  - 2.3 mm^2-ster/chanel (9 1-mm fibers)
- **Pitch-angle aligned**
- **Replaceable first window**
- **$k_\perp \rho_i < 1.5$**
- **Excellent SNR**

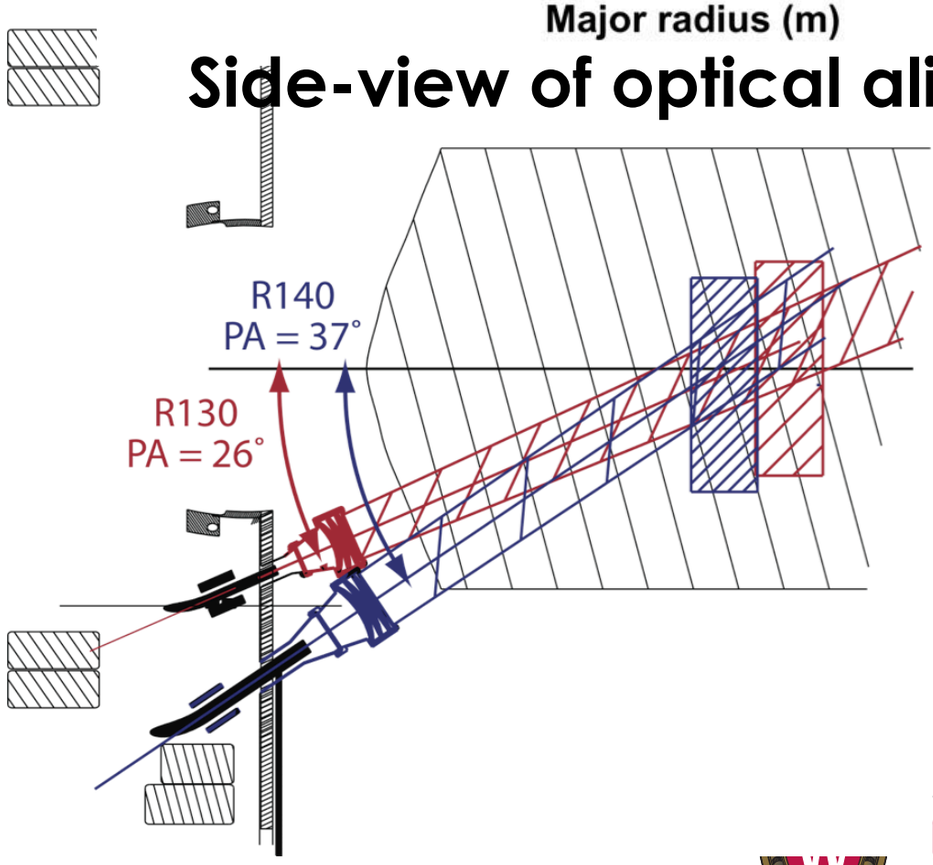
56 Spatial Channels Span Radius; Aligned to Pitch Angles



View Angle designed for NSTX Field Pitch

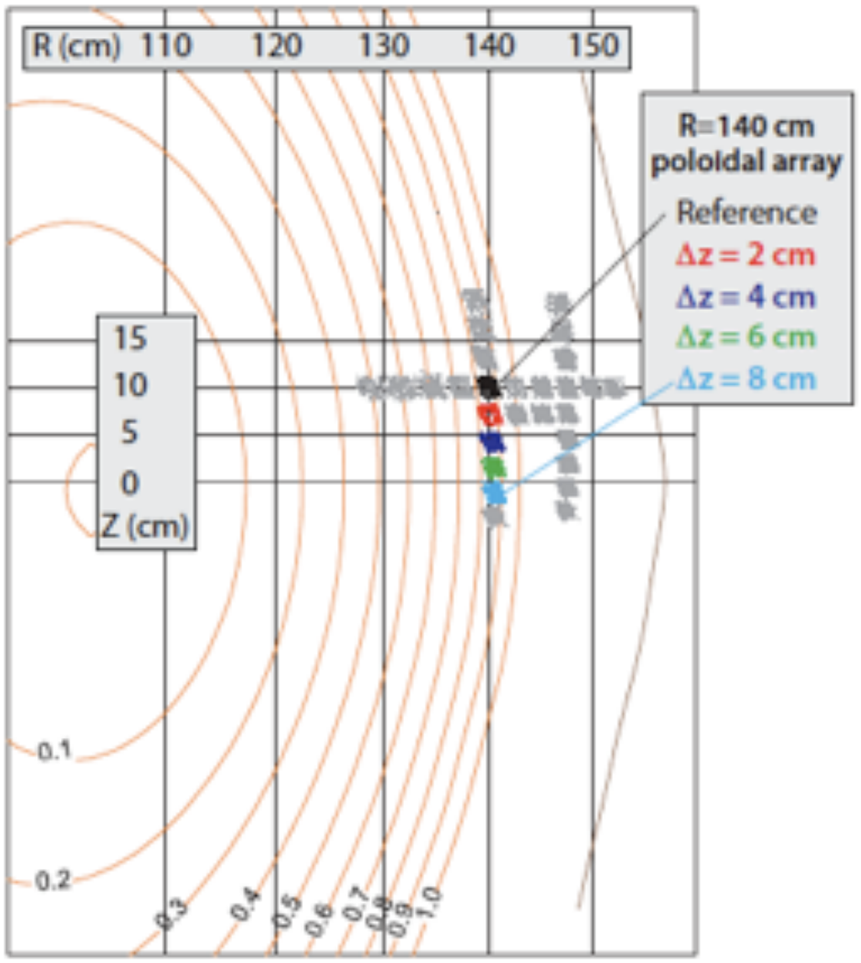


Side-view of optical alignment

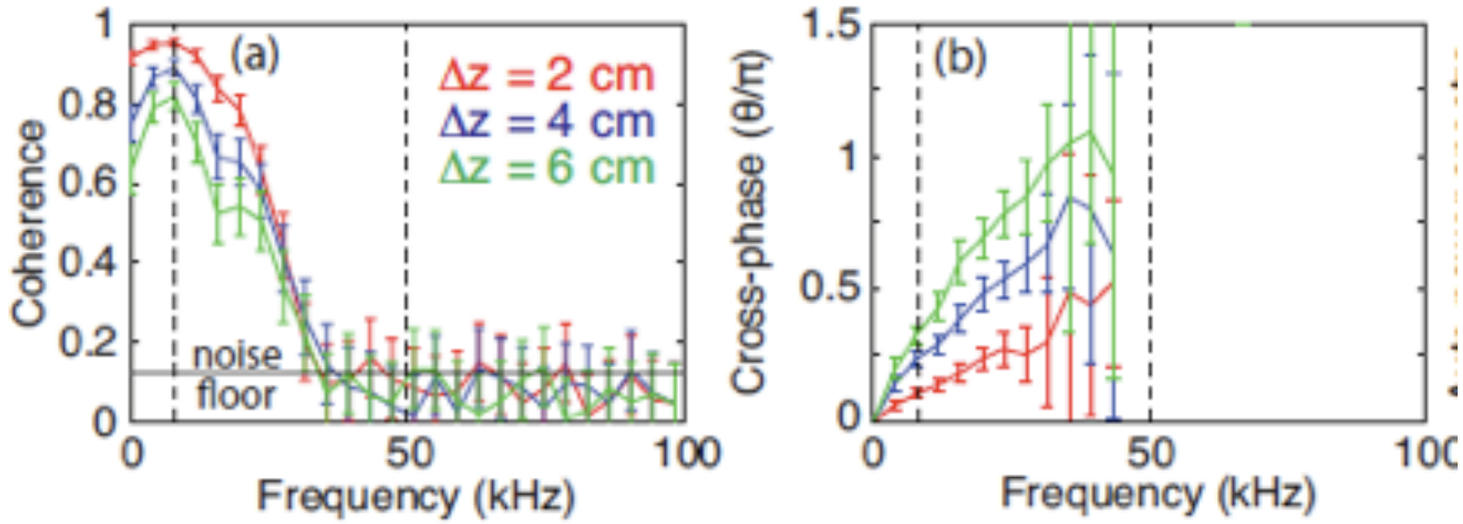


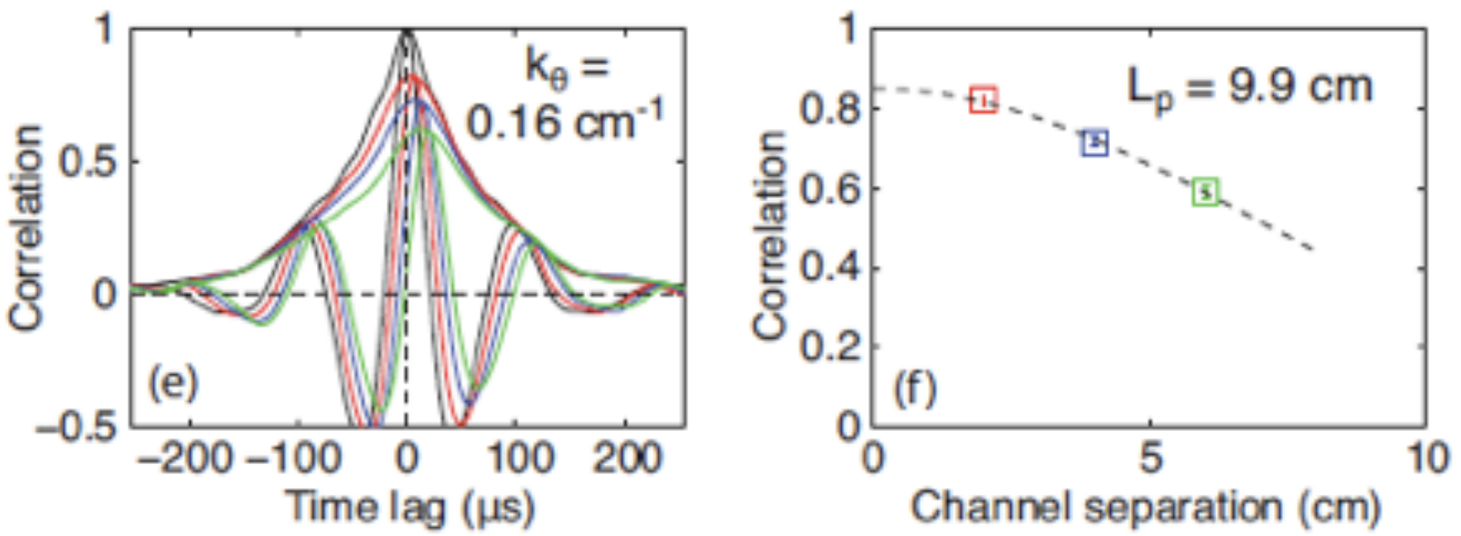
Initial Characterization of Pedestal Fluctuations on NSTX

Channel Layout R140 View



Broadband Fluctuation Properties in Pedestal (r/a=0.85)



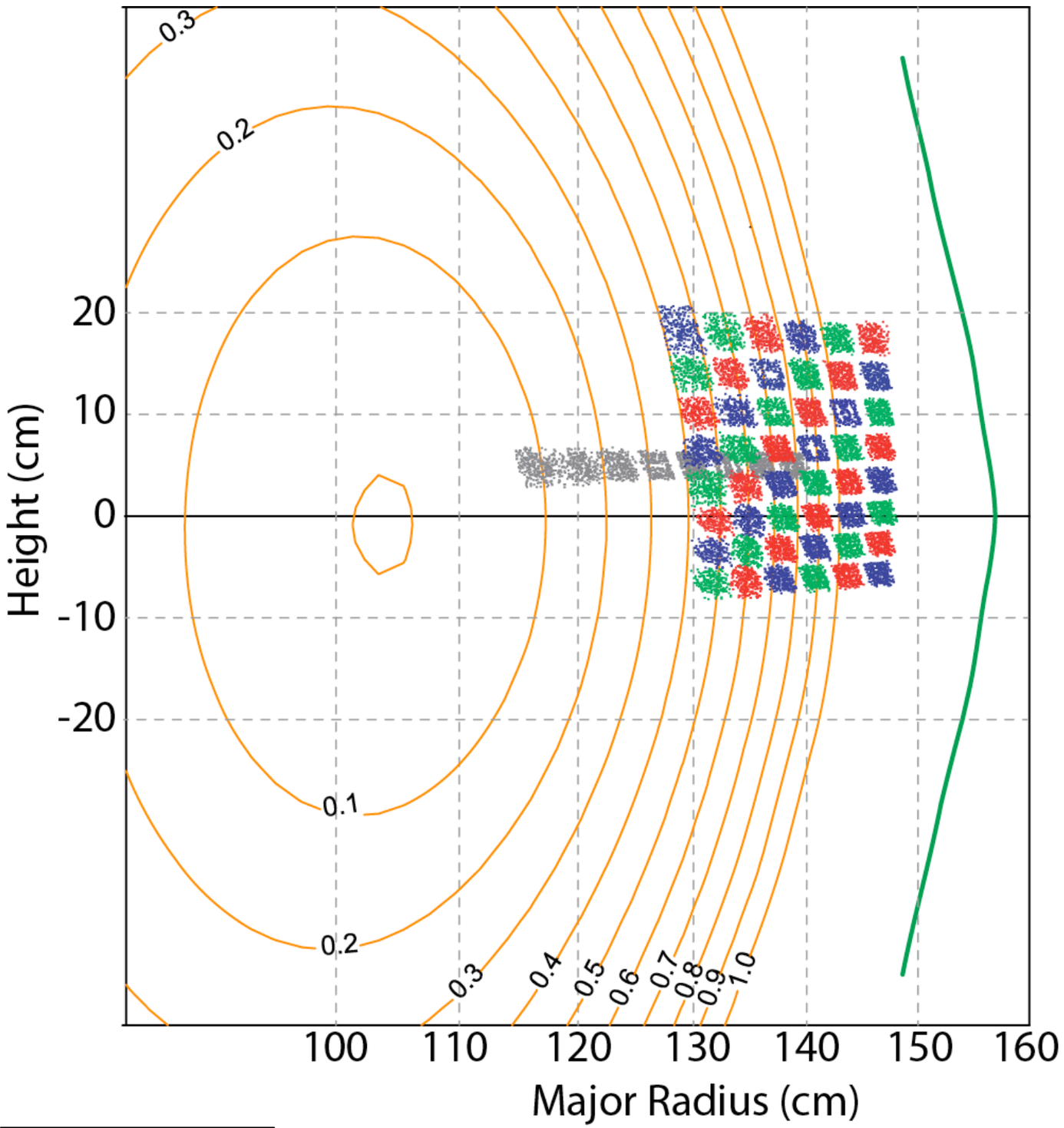


$L_{c,\theta}$~15 cm (10 ρ_i), τ_c~15 μs (5 a/c_s)

Objectives for 2012-2016

- **Develop and install 16 new BES channels (2 8-channel modules):**
  - Total of 48 spatial channels for 2014/2015 NSTX-U operation
- **2D viewing configuration**
  - Image turbulence, measure zonal flow (GAM), flow shear
  - Radial/poloidal eddy structure
- **Analysis of acquired fluctuation data**
  - Measure radial correlation properties and fluctuation amplitudes (ñ/n)
- **Simulation comparison and validation**
  - GEM, BOUT++, XCG1 (pedestal), GYRO (core)
- **Analysis technique development and application**
  - Time-delay-estimation (TDE): zonal flow (GAM?)
  - Turbulent velocity fluctuations (via velocimetry of 2D data)
- **ST-relevant experiments at other facilities:**
  - DIII-D, Pegasus, MAST, KSTAR
- **NSTX-U Experiments on Turbulence and Transport**
  - Measure turbulence vs. relevant plasma quantities

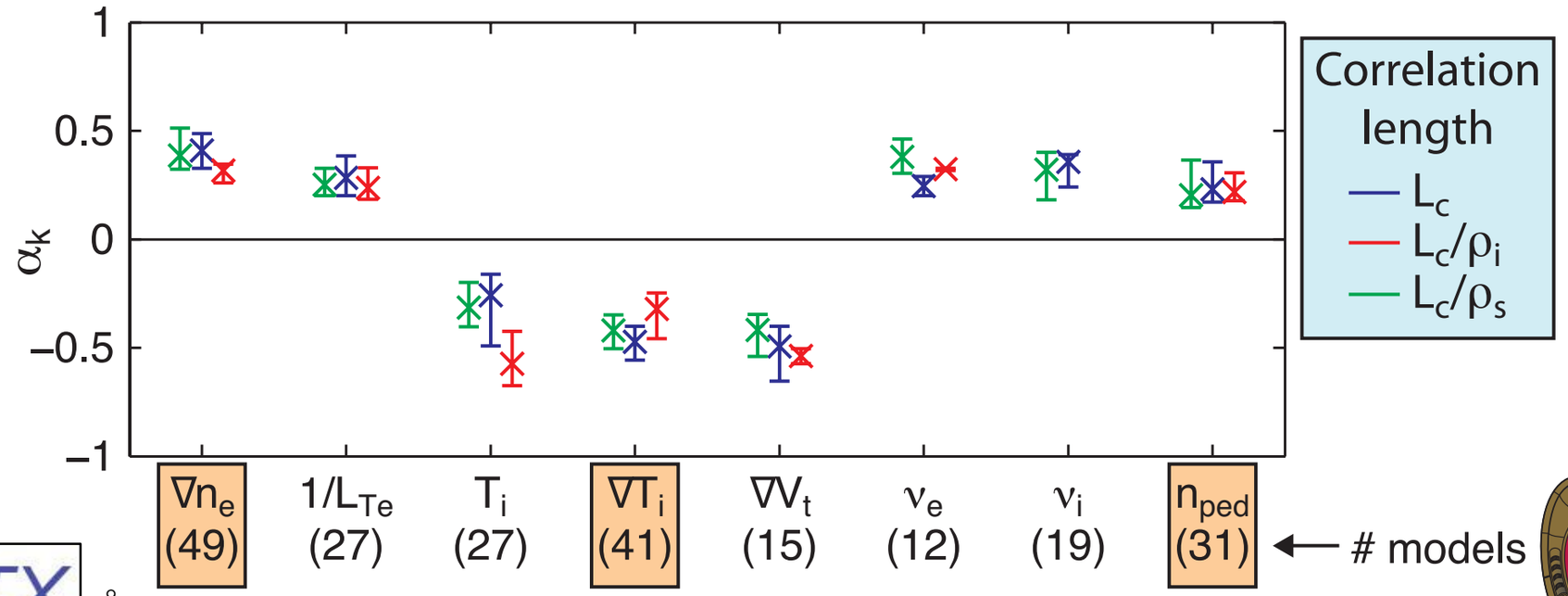
Planned 2D Deployment for 48-channel System



- **Full 2D measurements from mid-radius to edge**
  - Pedestal
  - SOL
  - Contoured to "typical" flux surface geometry
- **Core radial array**
  - Energetic particle-driven modes
  - Global Alfvén Eigenmodes
    - *600-800 kHz band*
- **Requires design and installation of a new aperture plate at R140 BES view port**

Compare BES Fluctuation Measurements with Simulations of Pedestal and Core

- **Height of pedestal pressure establishes boundary condition that strongly impacts global energy confinement**
  - Region of large pressure gradients, current density, strong shear
  - ELM generation, Physics of ELM stabilization techniques (Li, RMP,QH…)
- **Pedestal challenges transport simulations codes**
  - GEM, BOUT ++, XGC1
- **Core simulations: GYRO**
- **Initial effort to perform simulations of NSTX edge and compare to BES fluctuation characteristics, motivated by comprehensive database:**
  - How do turbulence characteristics ($L_{c,r}$, τ_c, k_θ) correlate with parameters:



Investigate Turbulence Properties via NSTX-U Experiments

- **Rotation and rotational shear variation**
- **ρ * scaling**
  - Aided by higher-field capability
- **T_e/T_i scaling**
- **3D/RMP field effects**
  - ELM-suppression/drive may be determined by turbulence dynamics
- **Beta scaling**
  - Search for microtearing mode effects
- **Aspect-ratio scaling**
  - In collaboration with DIII-D
- **Energetic-particle-driven modes**
  - TAE, GAE, effects on electron and ion transport
- **Pedestal instabilities**
  - KBM, micro-T, TEM, ITG?
- **Crucial for simulation validation in the ST regime**

Potential Future Activities (presently un-funded)

- **Expansion to 64 channels**
  - Nearly full core-edge 2D coverage
- **Higher spatial-resolution pedestal views**
  - Increased fidelity for examining pedestal instabilities
- **Toroidally-displaced viewport**
  - Toroidal n-number measurements (zonal flow/GAM, ELM precursors)
- **UF-CHERS**
  - Ion temperature & toroidal velocity fluctuation measurements
  - High efficiency, very high throughput optics (BES)
  - Fast, high-QE detectors (APD@1-2 MHz)
- **High resolution spectrometer**
  - Characterize beam emission manifold in detail
  - Development of new diagnostic capability

Summary of Objectives for 2012-2016

- **Develop and install 16 new BES channels (2 8-channel modules):**
  - Total of 48 spatial channels for 2014/2015 NSTX-U operation
- **2D viewing configuration**
  - Image turbulence, measure zonal flow (GAM), flow shear
  - Radial/poloidal eddy structure
- **Analysis of acquired fluctuation data**
  - Measure radial correlation properties and fluctuation amplitudes (ñ/n)
- **Simulation comparison and validation**
  - GEM, BOUT++, XCG1 (pedestal), GYRO (core)
- **Analysis technique development and application**
  - Time-delay-estimation (TDE): zonal flow (GAM?)
  - Turbulent velocity fluctuations (via velocimetry of 2D data)
- **ST-relevant experiments at other facilities:**
  - DIII-D, Pegasus, MAST, KSTAR
- **NSTX-U Experiments on Turbulence and Transport**
  - Measure turbulence vs. relevant plasma quantities

Timeline for UW-NSTX Research Activities

- **2012-2013:**
  - Analysis of available data, focus on pedestal fluctuation features
  - Begin simulations (pedestal focus)
  - APS Invited talk, IAEA-FEC presentation, publications
  - Build new detector systems (procure components, assembly, testing)
- **2013-2014:**
  - Continue pedestal simulations & comparisons; begin core simulations
  - Installation of 16 new spatial channels (2 detector modules)
  - 2D aperture plate and fiber configuration
  - Propose turbulence & pedestal experiments for NSTX-U
- **2014-2015:**
  - NSTX-U experiments on turbulence & transport & initial analyses
  - UW Graduate student performing thesis research
- **2015-2016:**
  - NSTX-U experiments; detailed comparison w/simulation
  - Advanced analysis technique development & application
- **2016-2018 (funding dependent on future grant cycle):**
  - Continue validation of core and pedestal simulations
  - Pursue currently unfunded activities: 64-channel, UF-CHERS, high-res pedestal views, toroidally-displaced views, high-res spectrometer