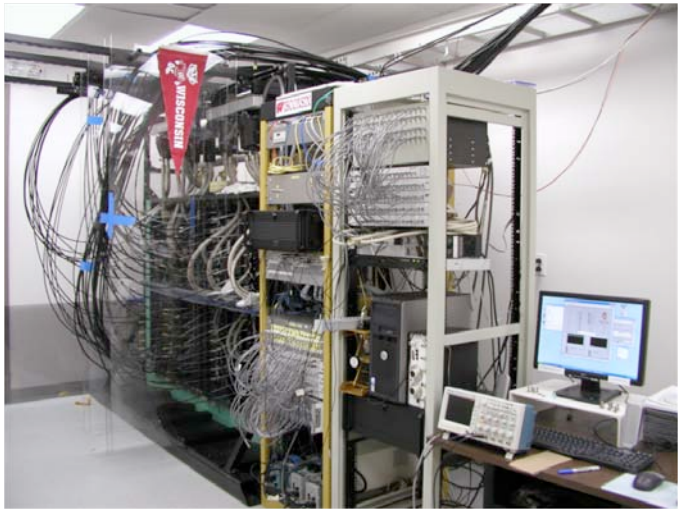
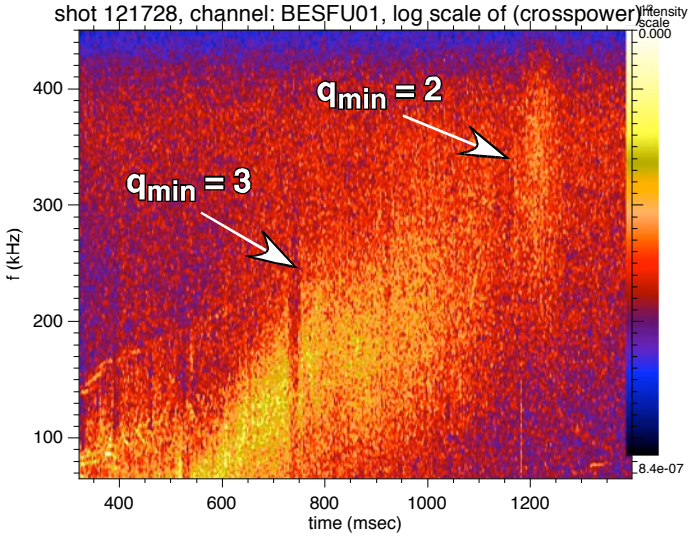
# DEVELOPMENTS IN BES FOR FLUCTUATION STUDIES ON KSTAR

**G. McKee**

***University of Wisconsin-Madison***






***US-KSTAR Workshop***
***General Atomics, San Diego, California***
***April 15, 2009***

DIII-D NATIONAL FUSION FACILITY

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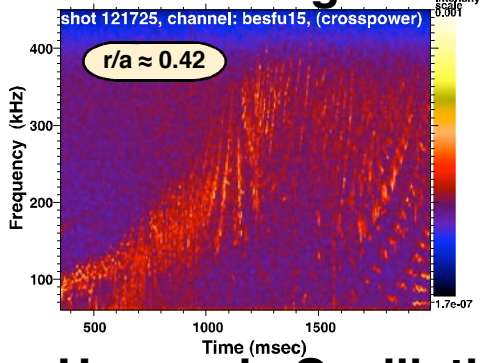
# INTRODUCTION AND OVERVIEW

- **Motivation for advanced fluctuation studies**
- **BES Capabilities**
- **Structure of UW Diagnostic Development Research Program**
- **KSTAR-specific design issues**
- **Synergy between KSTAR and NSTX-BES development work**
- **Port Optical Design**
- **Future KSTAR-BES Development Plan**

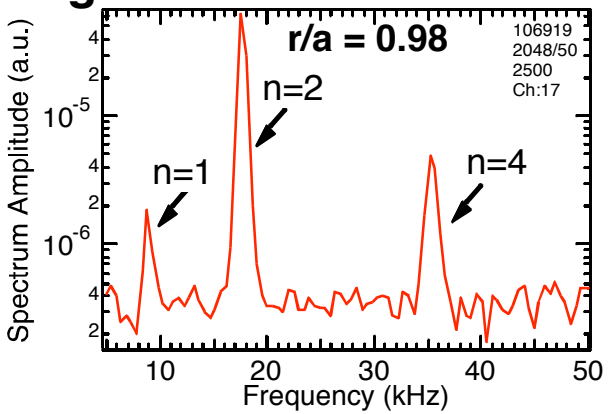
# BES Measurements Applicable to Wide Variety of Plasma Instabilities

- **Measurements provide important data on a wide range of phenomena:**
  - *Energetic-particle-driven modes: Alfven Eigenmodes*
  - *Neoclassical Tearing Modes*
  - *Sawtooth interchange effects*
  - *Pedestal dynamics*
  - *Edge Localized Modes*
  - *Edge Harmonic Oscillation (in Quiescent H-mode)*
  - *Quasi-Coherent Mode (in Enhanced $D_\alpha$ H-mode)*
  - *Resonant Magnetic Perturbation Effects*
  - *Edge - Scrape Off Layer interaction: "blob" generation*

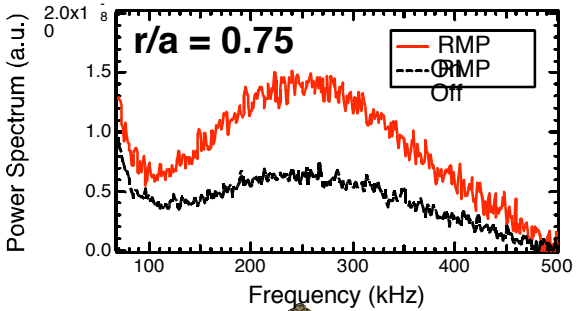
**Reversed-Shear Alfven Eigenmodes**




**Edge Harmonic Oscillation**




**Turbulence with RMP**



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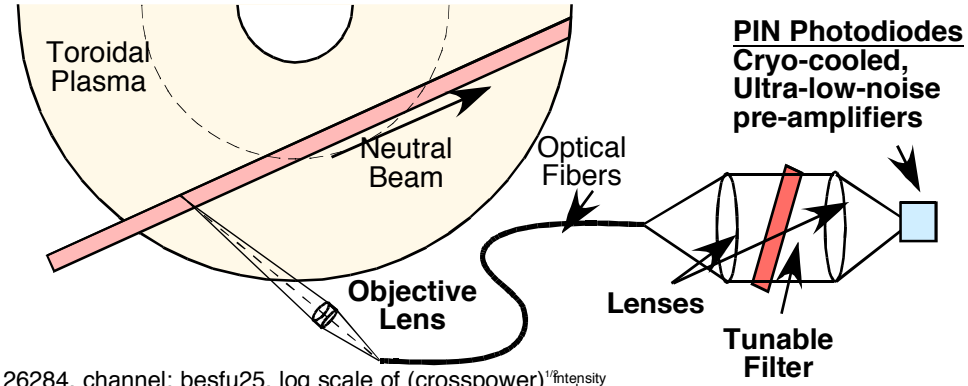
# BES Measures Spatio-Temporal Characteristics of "Long-Wavelength" ($k_\perp \rho_i < 1$) Density Fluctuations

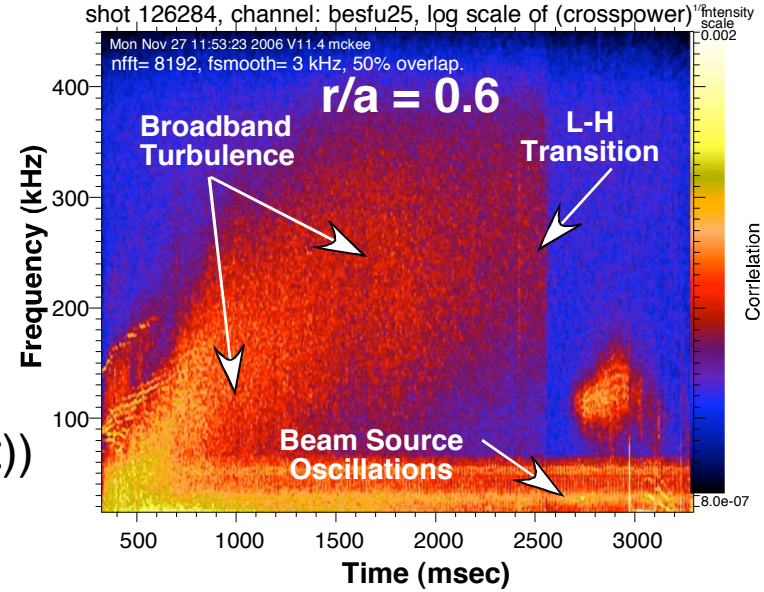
- **Measures intensity of $D_\alpha$ (Doppler-shifted) from collisionally-excited neutral beam atoms:**
  - Relate *I* to *n* (via atomic physics)
  - Core, edge & SOL
  - $\Delta R$, $\Delta Z \sim 1$ cm,
  - Multi-channel (R,Z) ==> 2D imaging

**BES Viewing Geometry Concept**

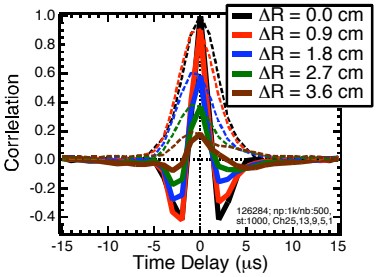



## Turbulence Properties Measured:

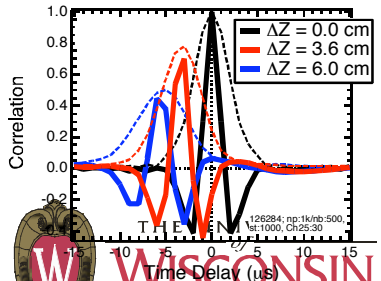
- Local Turbulence Spectra
- Fluctuation amplitude ($\tilde{n}/n$)
- Correlation Lengths: $L_{c,r}$, $L_{c,\theta}$
- Decorrelation Time, $\tau_c$
- Poloidal advection, $v_\theta$
- Eddy structure via imaging
- Time varying poloidal flows ($\tilde{v}_\theta(t)$) (Zonal Flows, GAMs)
- Bispectra, phase coherence (nonlinear: energy transfer)
- Velocity Field (**v**(r,θ,t) via velocimetry

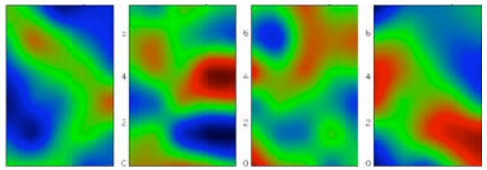



Radial Correlation

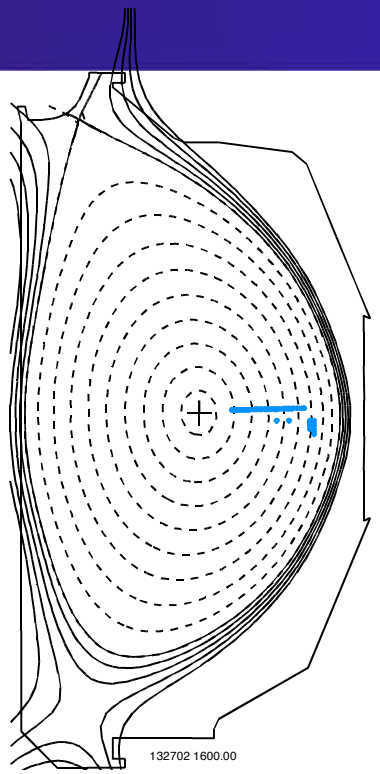



Poloidal Correlation

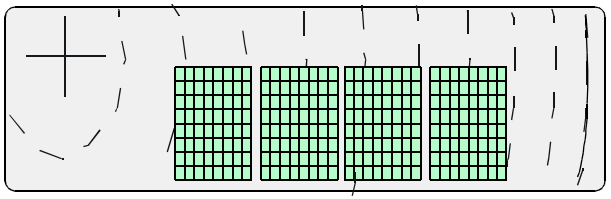


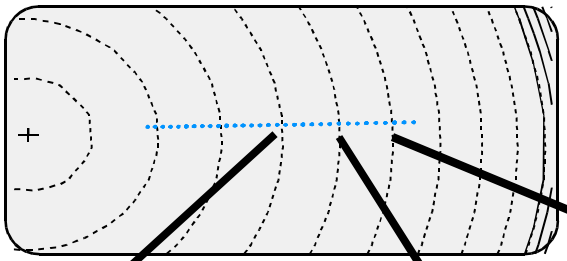
# Expansion Enables Measurement of Fluctuation Dynamics Across Minor Radius



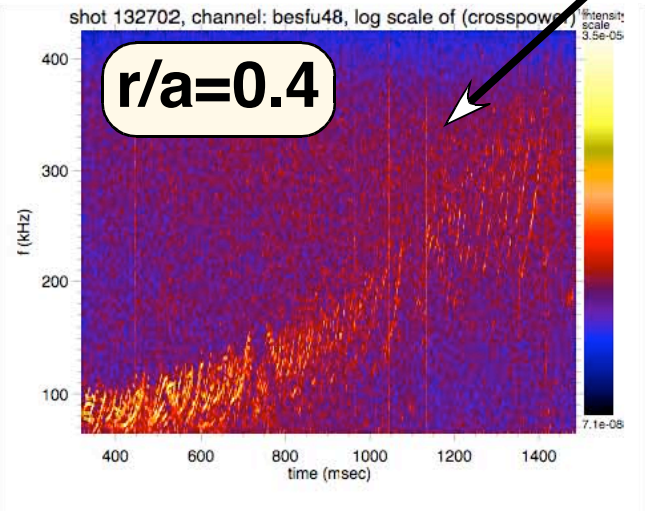

**2D 8x8 Array:**

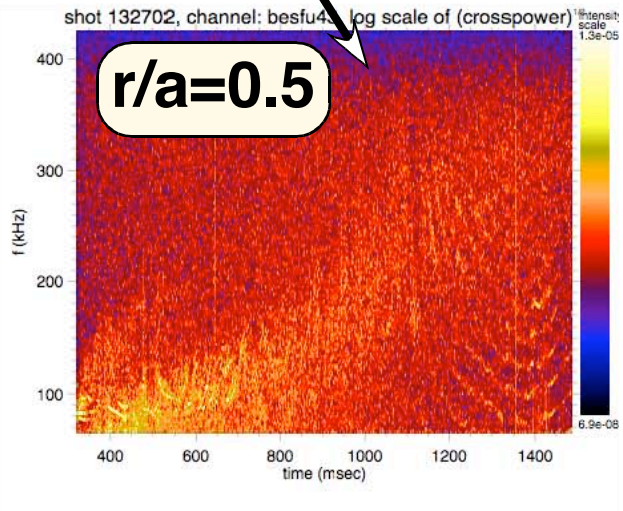


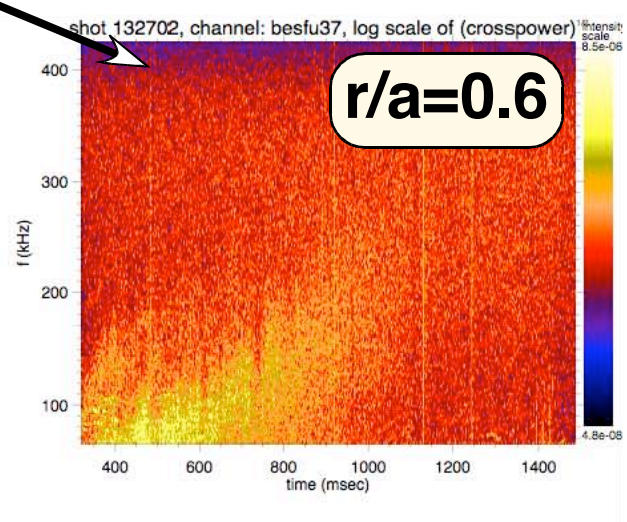
**Radially Extended Array:**



- **Simultaneous Turbulence Measurements:**
  - Density Fluctuations, $\tilde{n}_e/n_e$
  - Turbulence Flow, $v_\theta \sim v_{ExB}$
  - Correlation Length, $L_{cr}$, $L_{c\theta}$
  - Correlation Time, $\tau_c$
- **Expansions is a UW-PPPL collaboration**



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# Advanced Fluctuation Diagnostics are Key to Understanding Physics of Turbulent Transport

- **Understanding turbulent transport is a core component of US Fusion Energy Sciences program**
- **Characterize small-scale fluctuations associated with instabilities**
- **Turbulence inherently 2D**
  - *Measurement of radial-poloidal characteristics and dynamics is crucial*
- **Beam Emission Spectroscopy system for measuring localized, long wavelength ($k_\perp \rho_i < 1$) density fluctuations in radial-poloidal plane:**
  - *Spatial and temporal turbulence characteristics*
  - *Mode structure of Energetic Particle-Driven Modes (RSAE, TAE, BAAE)*
  - *Pedestal dynamics*
- **Measure fluctuations in multiple fields to test and challenge models:**
  - *Density*
  - *Ion temperature*
  - *Parallel Velocity*
  - *Perpendicular Velocity (via analysis techniques)*
- **Comparison with nonlinear simulations is central to code validation**

# UW Diagnostic Development Program Focuses on New Measurement Technologies and Scientific Applications

**University of Wisconsin Diagnostic Development Program**

- Diagnostic Experts
- Optical Measurement Laboratory Facilities
- Graduate Students
- Post-doctoral Researchers
- Technical Resources

**Development and Application at DIII-D**

- 64-channel 2D BES system
- Ti-fluctuation diagnostic development
- Analysis technique development
- Advanced transport physics experiments
- Model validation program (collaboration)
- Instability studies (collaboration)

**Development and Application at NSTX**

- Diagnostic design
- Prototype testing
- Full-system deployment
- Studies of ST transport physics

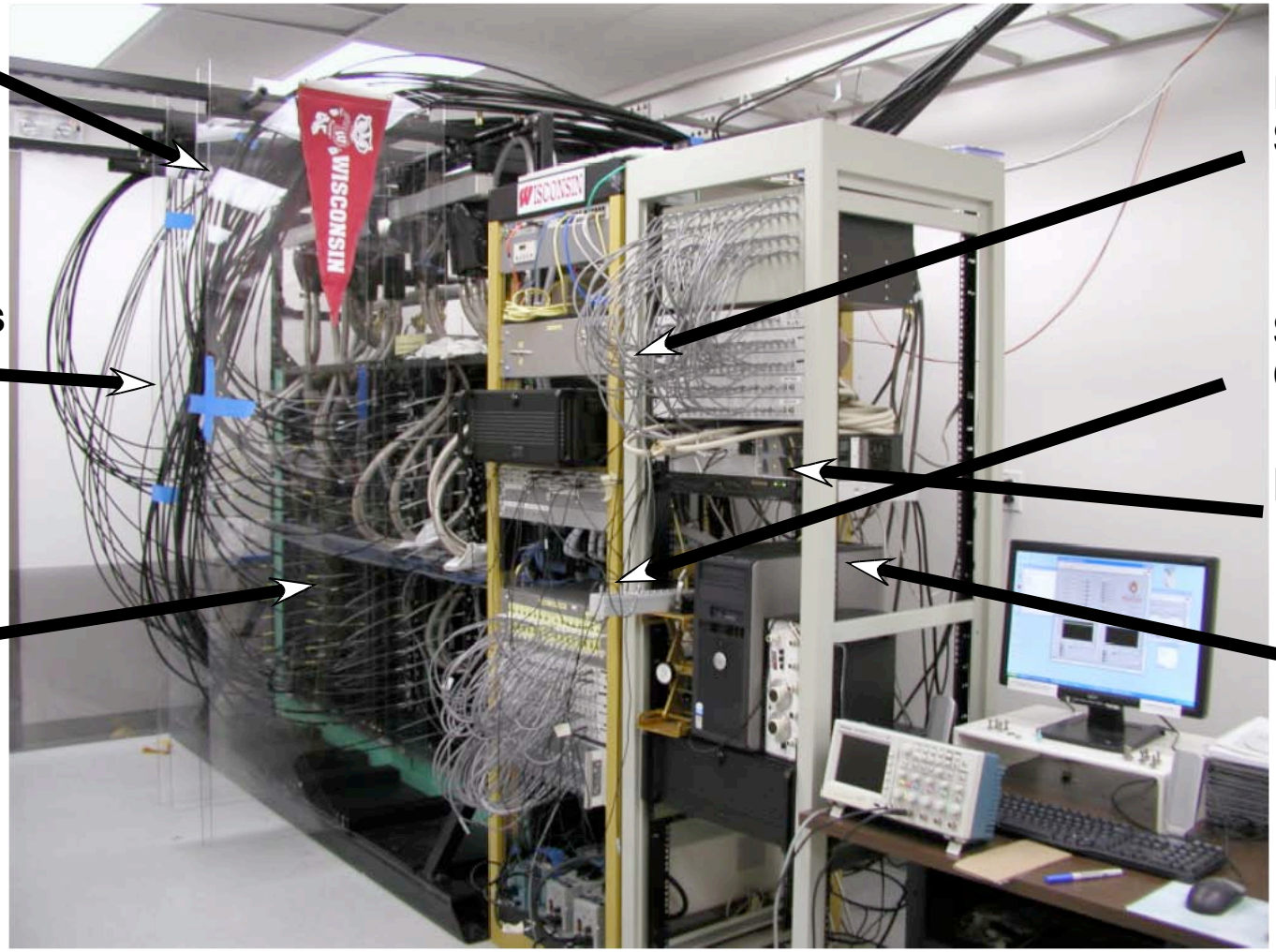
**KSTAR BES Diagnostic**

- Design work performed
- Collaboration with KSTAR, PPPL, ORNL
- Advanced Tokamak studies

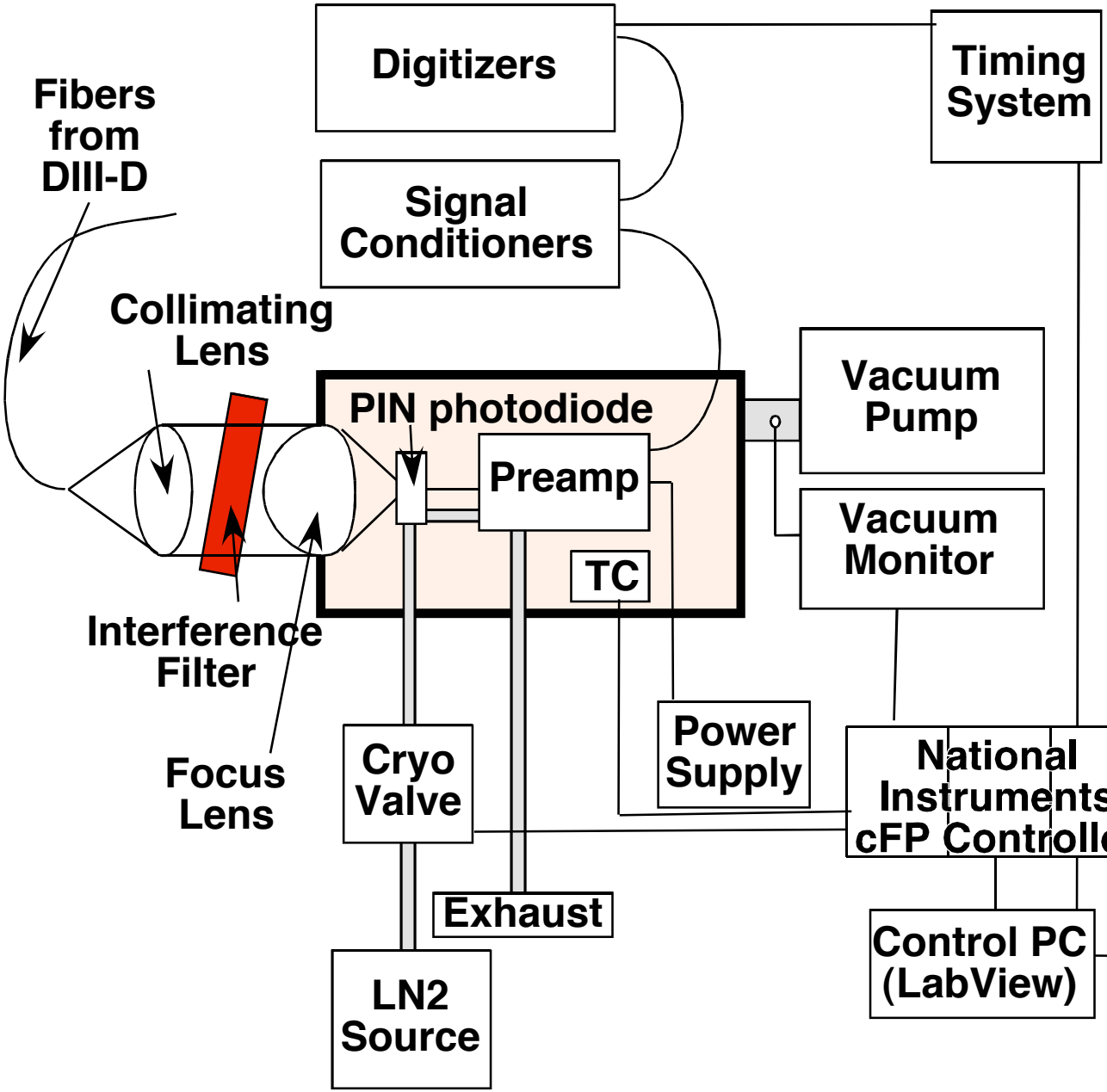
# 2008-2009 UW-DIII-D Diagnostic Development Program: Advanced Fluctuation Diagnostics For Understanding Turbulence

- **UW has not been directly involved in KSTAR BES Design in 2008**
  - *Lack of resources, not funded in 2008 (work continued with ORNL)*
  - *Initial design work performed previously with PPPL, ORNL, KSTAR*
  - *Strong interest to resume collaboration*
- **Expansion of upgraded, high-sensitivity BES system to 64 channels**
- **UFIT: Ultra-Fast Ion Temperature diagnostic**
- **NSTX BES system design and construction with PPPL**
- **Analysis Techniques**
- **Built a larger research program and team**
  - *3 new post-doctoral researchers: DIII-D, NSTX, UW*
  - *Part-time technician*
  - *Faculty at UW*
- **Well-positioned to resume KSTAR diagnostic development work**

# BES Deployed in Expanded Laboratory Facility at DIII-D



# BES Detector and Control System Provides Integrated Control and Fully Remote Operations

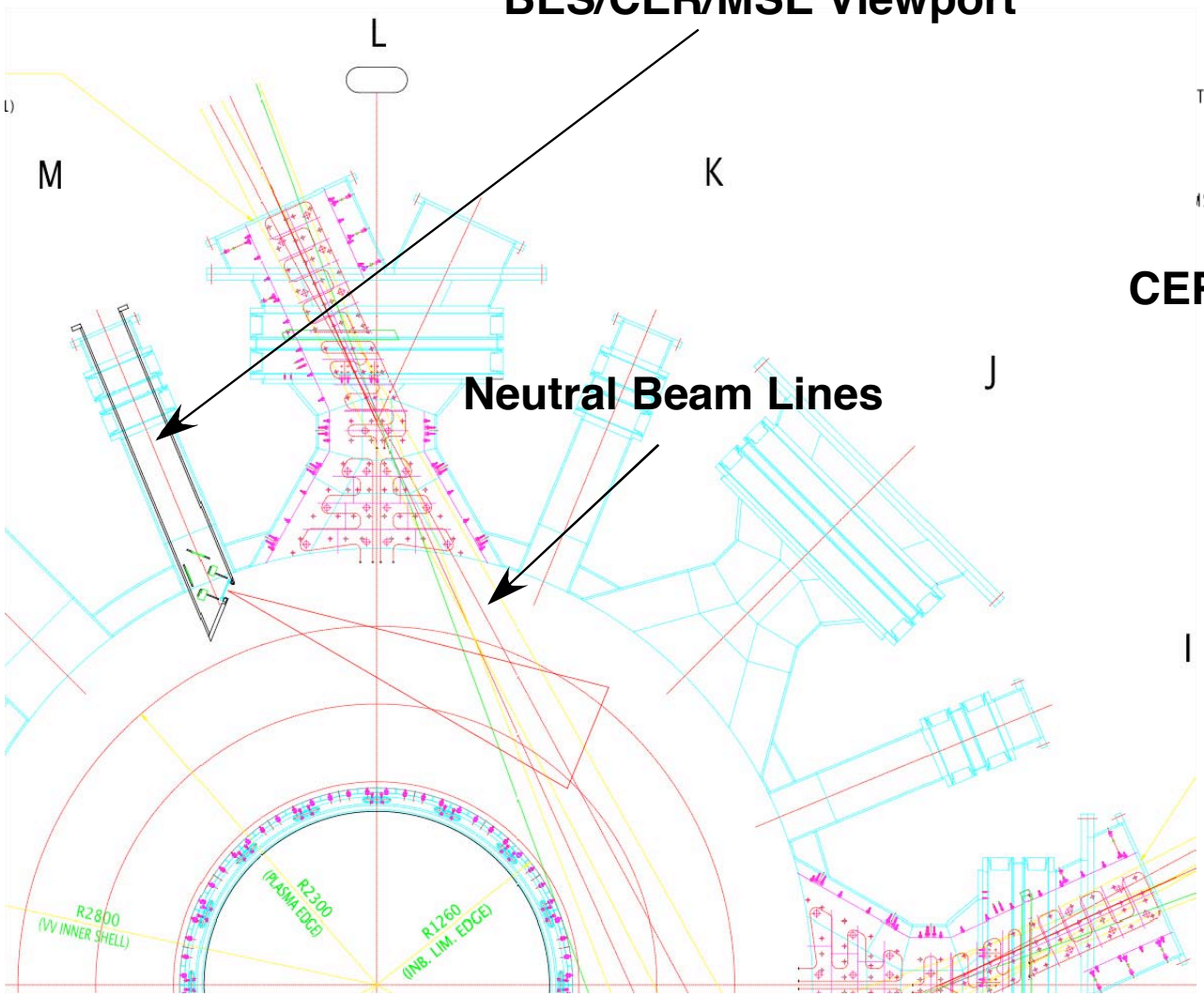


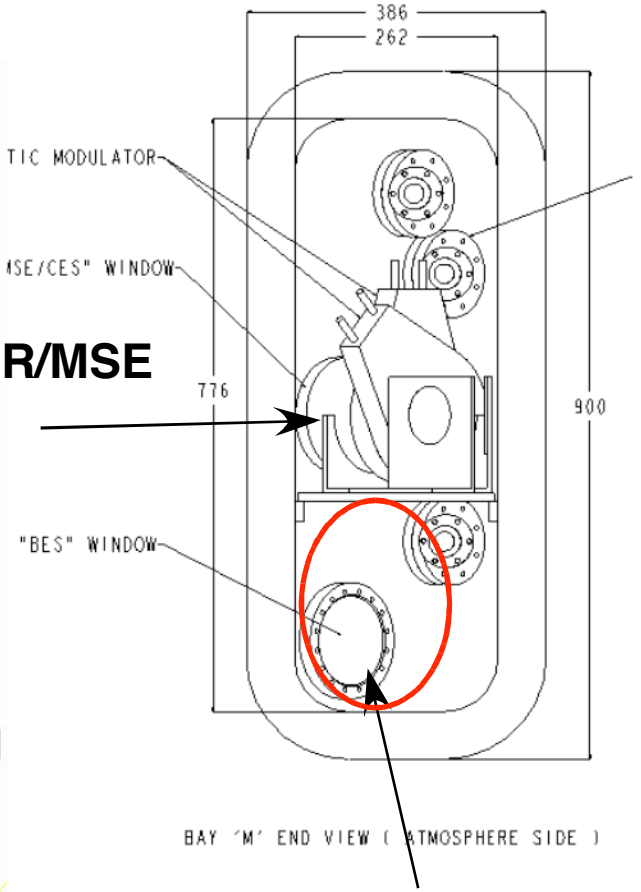

**Labview "Virtual Instruments" provide user interface, control and equipment safety functions**

**Digitizers:**

**D-tAcq (ACQ16PCI):**
**16 channels/board**
**14-bit, 1 MHz, simultaneous sampling;**
**128 MB onboard memory:**
**4.2 sec continuous record**

# Overview of KSTAR BES Viewing Geometry at Bay M




CER/MSE

BES Window



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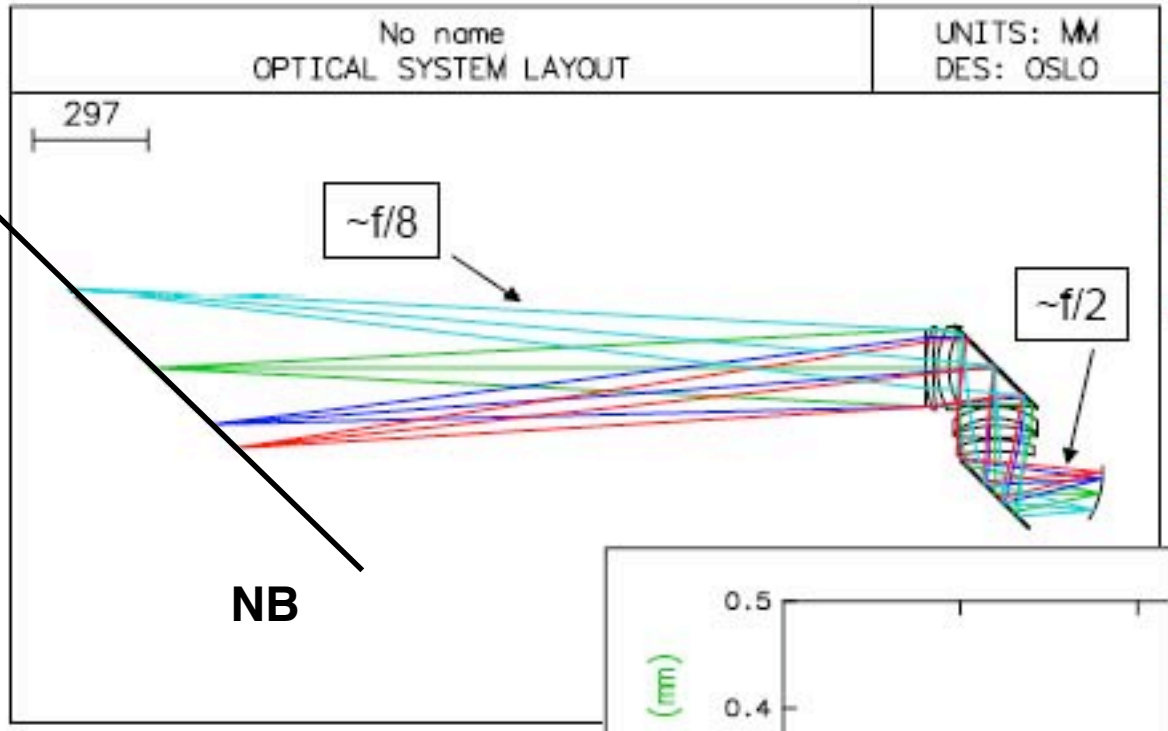
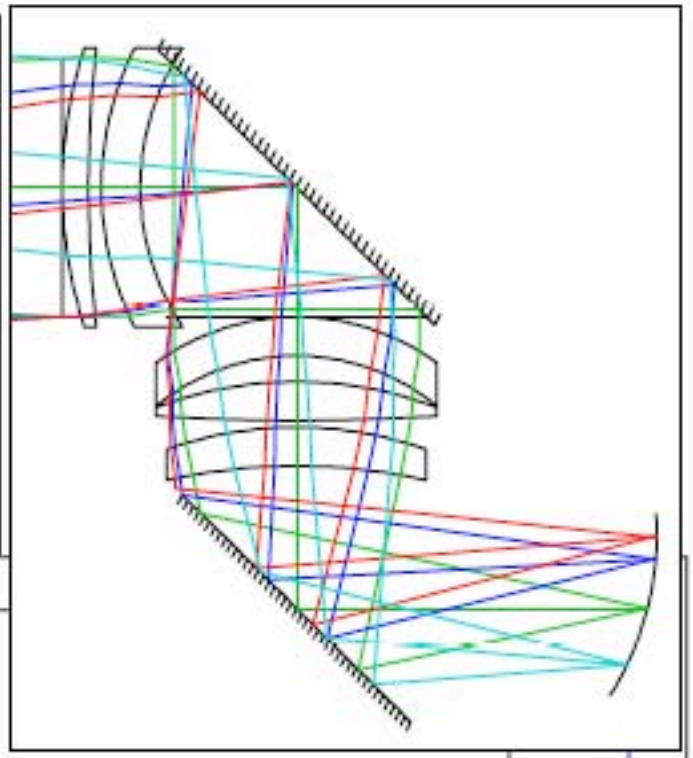
# KSTAR BAY M BES OPTICS DESIGN (R. FEDER-PPPL)

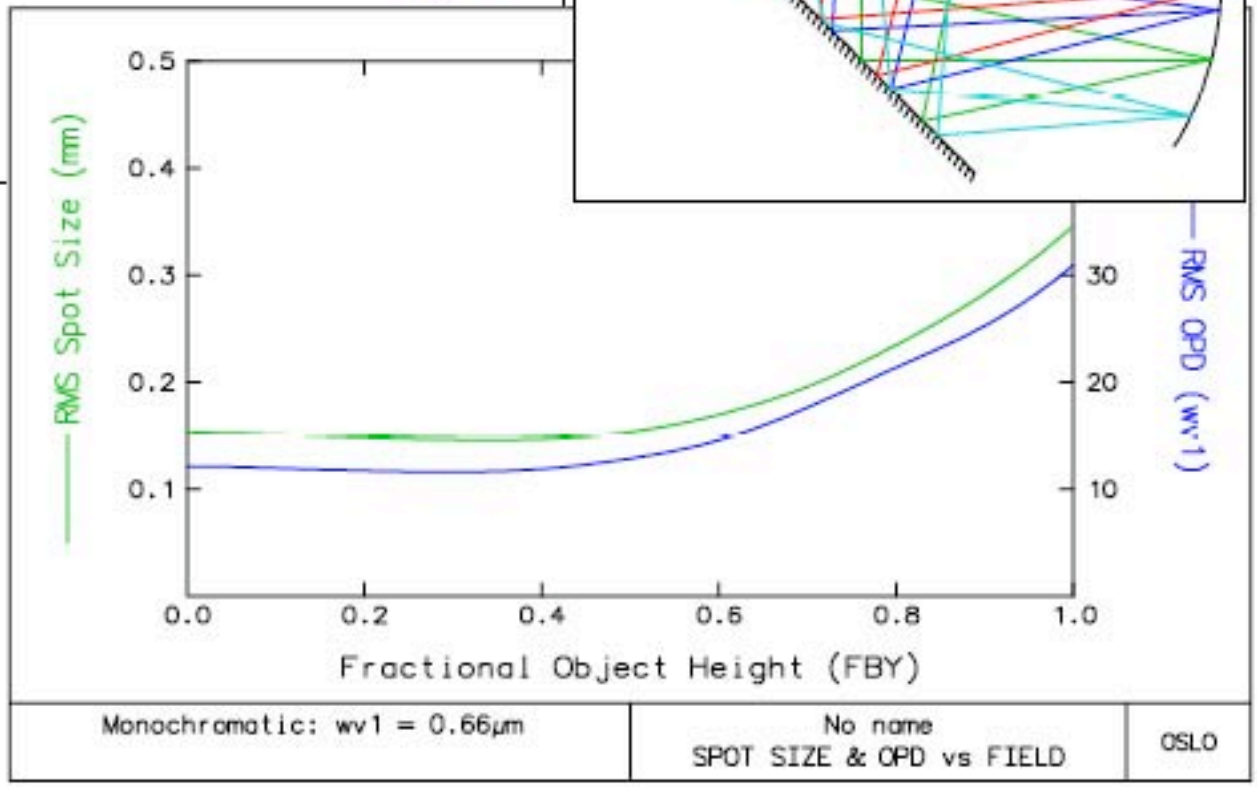


**KSTAR Bay-M BES**

~200 mm Optics
Folded BES System

→Work on reducing diameter
Of lenses to fit and to allow
MSE to stay at Midplane.

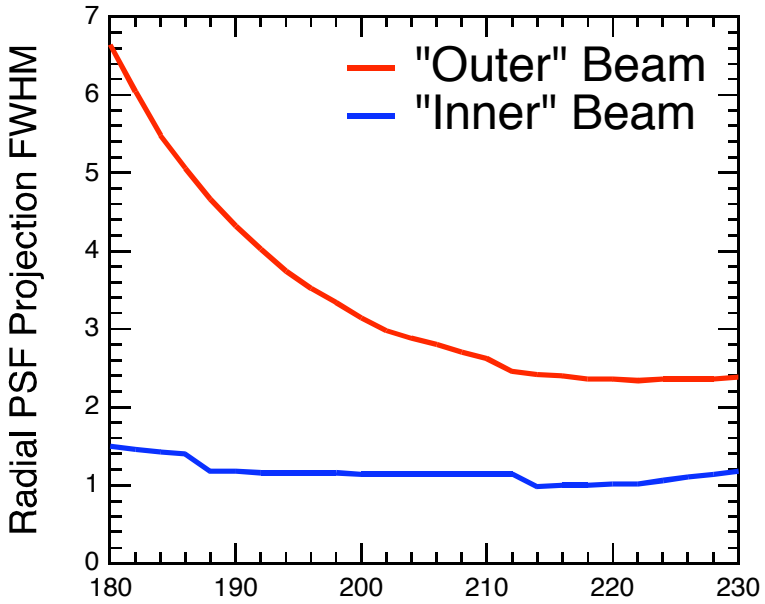


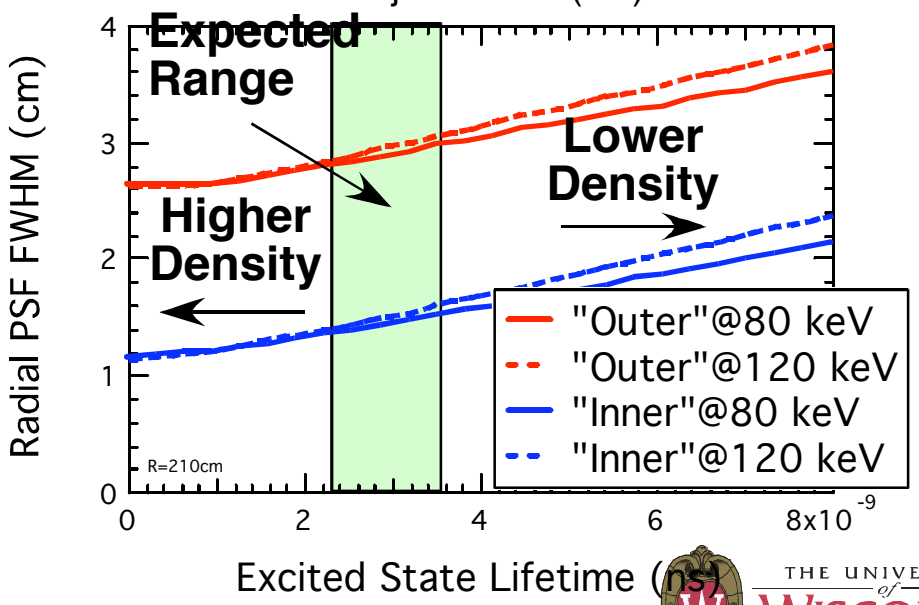

PPPL RFEDER 071607

# KSTAR BES Spatial Resolution Significantly Different for Each Beam

- **Inner beam exhibits good radial resolution across much of minor radius**
- **Outer beam suffers significant loss of resolution**
- **Finite lifetime effects modestly reduce resolution for typical plasma densities (few $10^{19}$ $m^{-3}$)**

  *- higher density beneficial*
- **Using both beams simultaneously will severely compromise measurements**
- **Re-examine with current 3-beam source geometry**

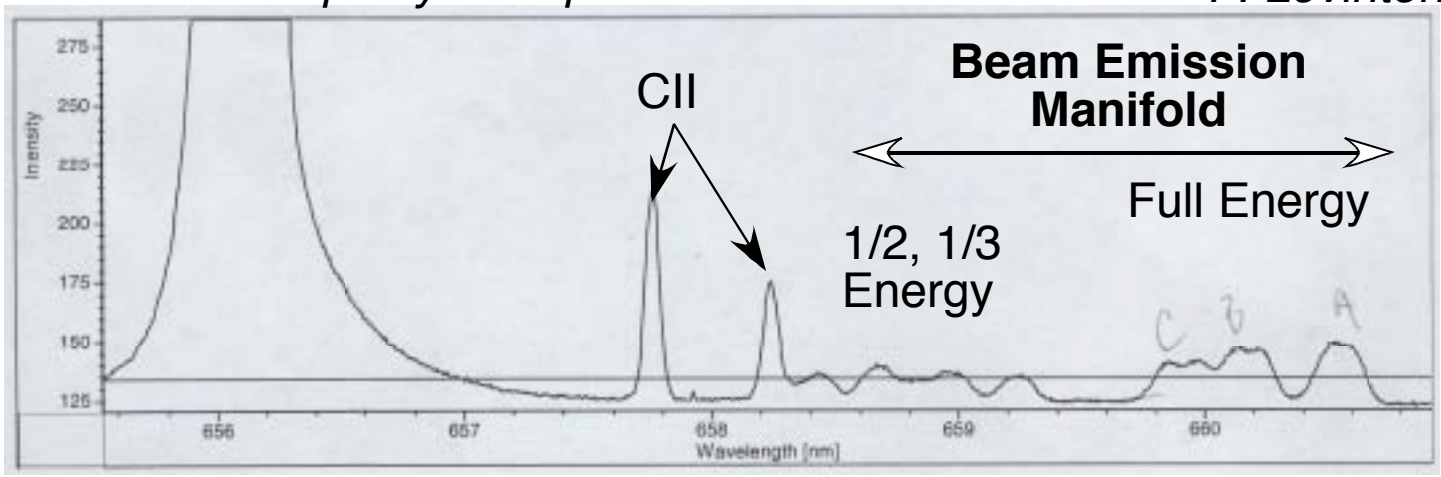


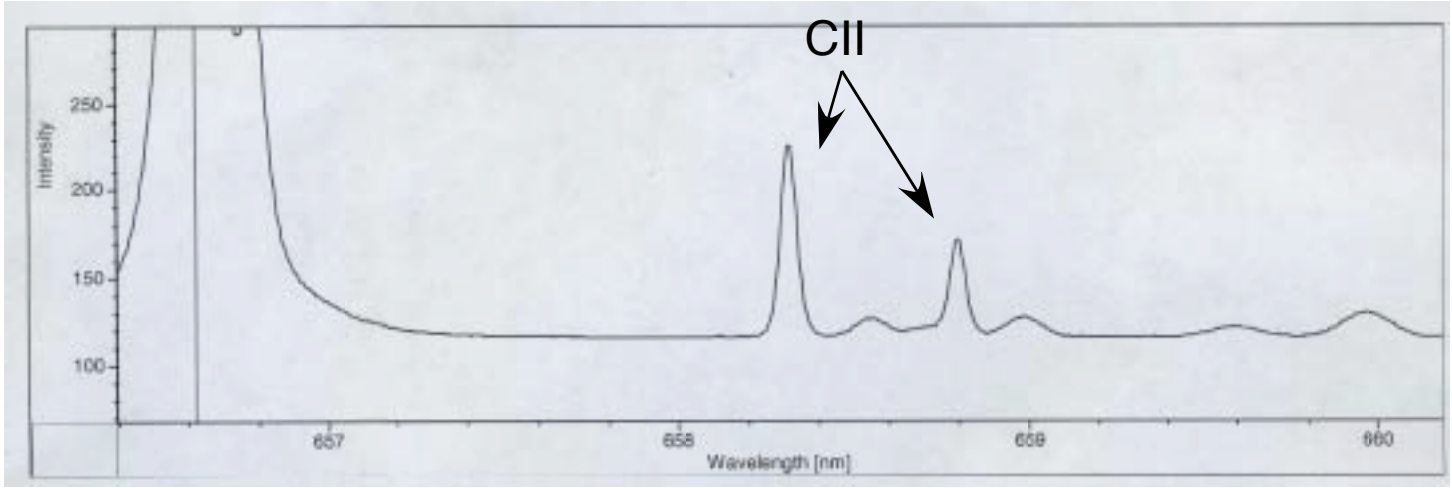
# SYNERGISM BETWEEN NSTX & KSTAR DEVELOPMENTS

- **Red-shifted viewing geometry**
- **Similar Beam energy**
- **Graphite first walls**
  - *Impurity line spectral contamination*

**MSE Measurements on NSTX**
*F. Levinton, Nova Photonics*




Core Spectrum




Edge Spectrum
(R=136 cm)



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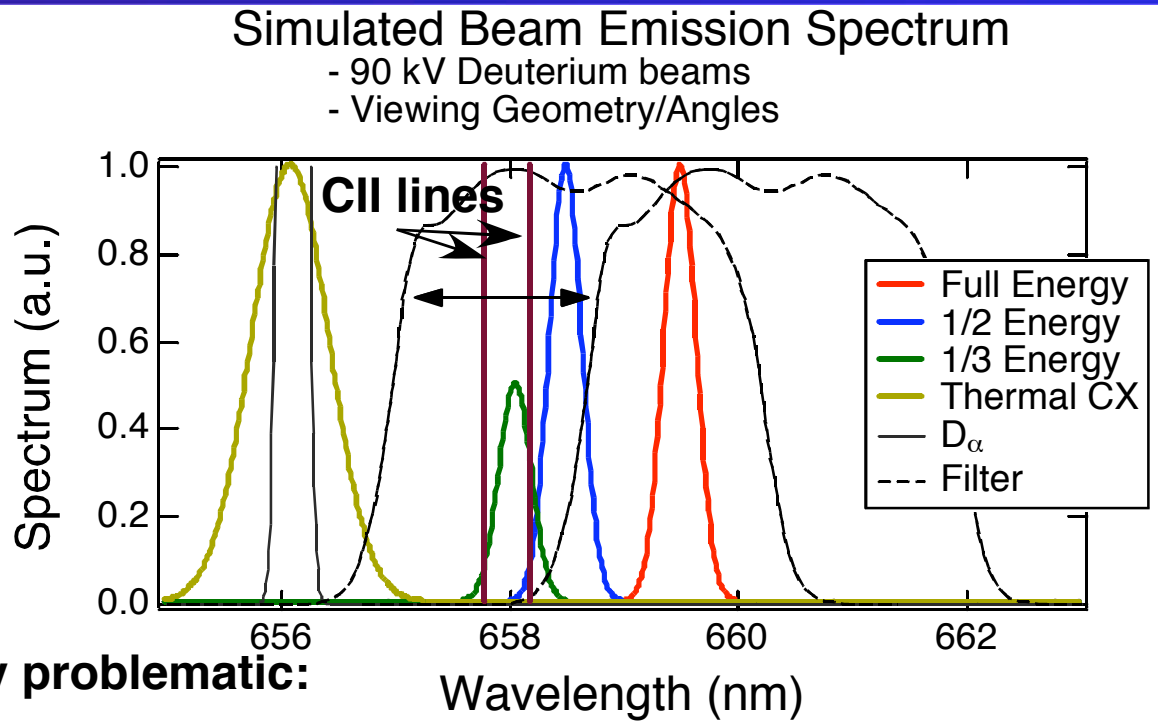
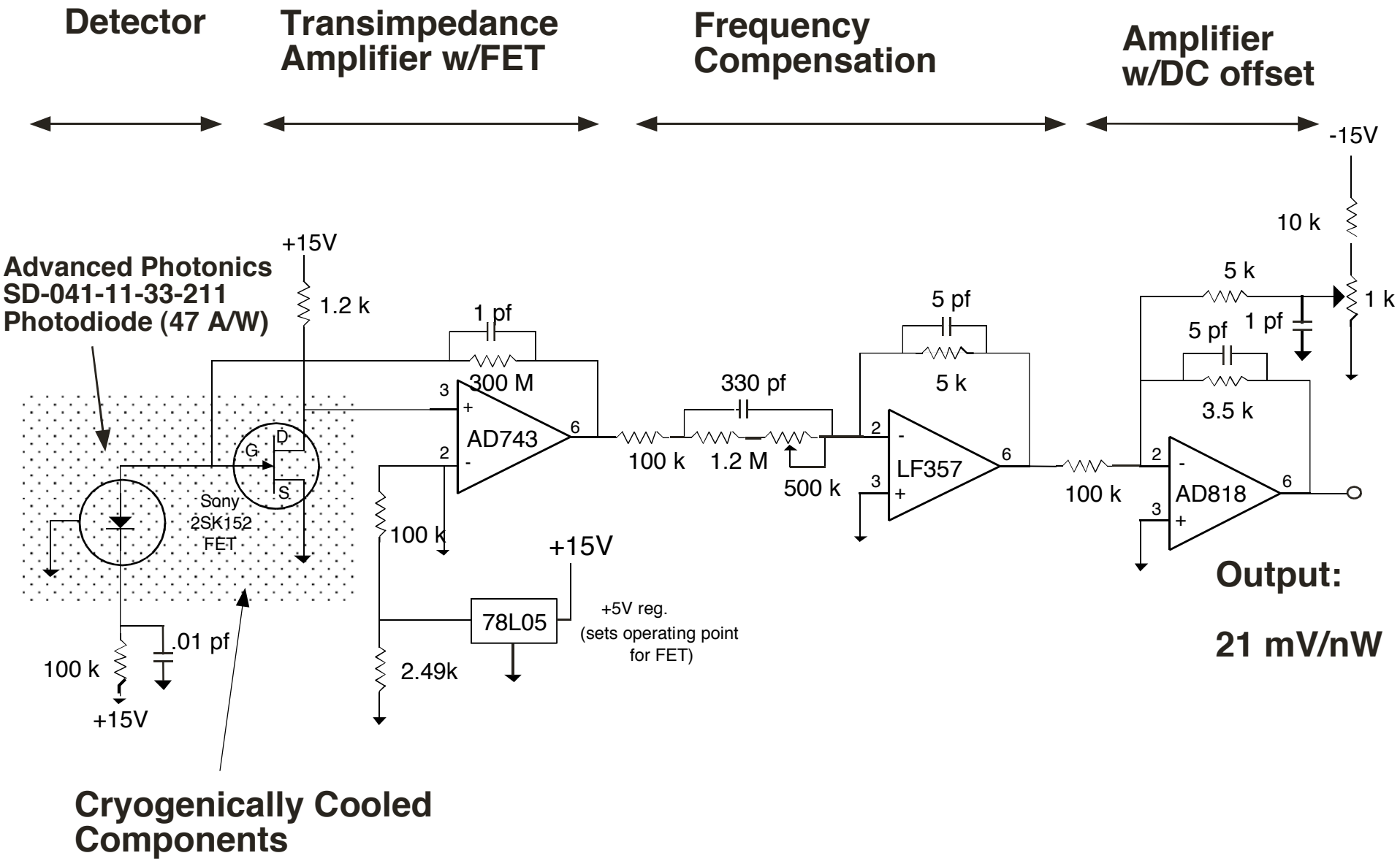
# KSTAR BES Will Observe Red-Shifted Neutral Beam Emission

- **Improved spatial resolution relative to blue-shifted view**




- **Edge Carbon lines potentially problematic:**
  - Extra photon noise
  - Delocalized fluctuation signal
  - Error to normalization, ñ/n
- **Solution:**
  - Angle-tunable filter: design to avoid CII
  - tilt-tune to optimize total signal
  - small signal: minimal photon noise, low frequency fluctuations
- **Designed and procured custom filters: to be tested later in 2009 on NSTX**

# Enabling Technology for BES: Cryogenically-cooled Transimpedance Preamplifier Provides Ultra-Low-Noise Signal Amplification



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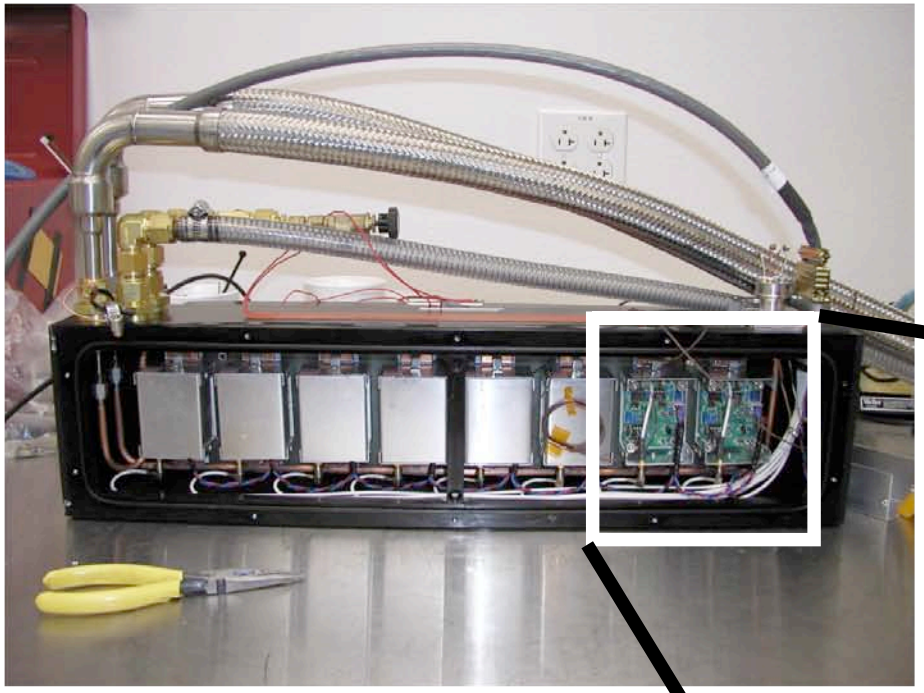
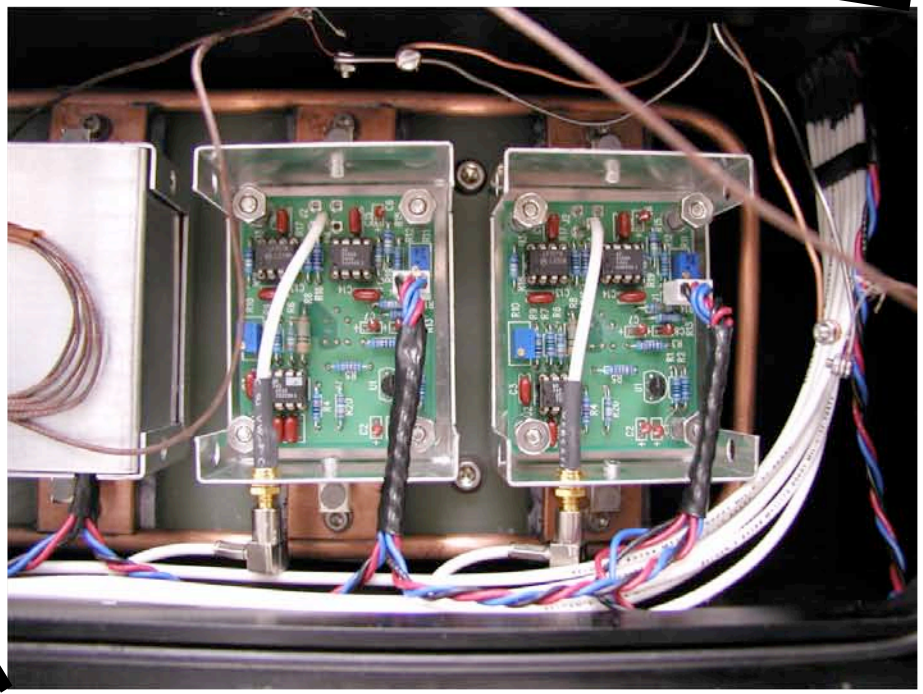
# Customized Detector Module and Preamplifier Provide Ultra Low-Noise Signal Detection



**Input/Exhaust Vacuum-jacked LN2 lines**

**Vacuum pump lines (operated near 30 mTorr)**



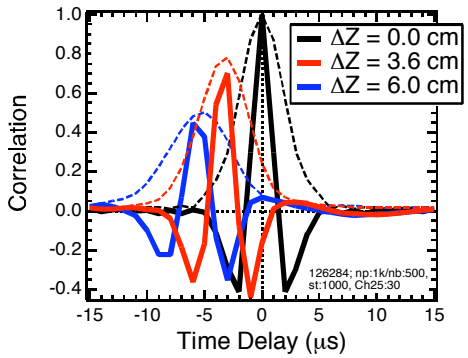
**Copper LN2 line provides thermal transfer to PIN photodioes and first-stage FET**

# Modern Pre-Amplifier Designs Under Development

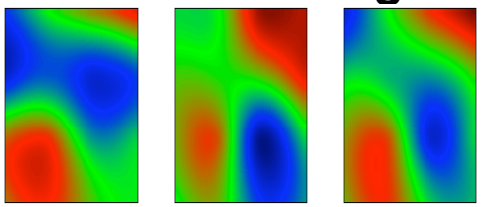
- **Presently-implemented cryogenic pre-amplifiers employ out-of-date circuit components**
- **New surface-mount electronics**
- **Low-noise FET components**
- **Reduced capacitance (e-noise)**
- **Utilize local refrigerant rather than LN2 cryogenics**
  - *simplified design, implementation and control*
  - *lower costs*
- **Diagnostic group working with Space-Astronomy Laboratory experts to design and fabricate modern preamplifier circuits**
- **KSTAR design can implement if testing is successful (late 2009)**

# New Research Fostered through Development of New Measurement Capabilities

- **Expanded fluctuation diagnostic capability being deployed to probe plasma turbulence:**
  - *Expanded BES diagnostic for wide-field 2D turbulence imaging*
  - *Spectroscopic ion temperature fluctuation diagnostic*
  - *New analysis capability to exploit multipoint, multi-field data*
- **Enhanced research capability for turbulence and other instability investigations:**
  - *Determine nonlinear properties of turbulence*
  - *Validation of Turbulence and Transport simulations*
  - *Turbulence Dynamics at the L-H Transition*
  - *Energetic-Particle-Mode-Driven Instabilities*
  - *MHD, Sawteeth*
  - *Pedestal: ELMs, RMP-ELM suppression*
- **Program:**
  - **2 UW Graduate Students pursuing Ph.Ds on DIII-D**
  - **3 Postdoctoral Researchers**
  - **1 Scientist + Part-time Faculty**




**Turbulence Images**





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# FUTURE BES DESIGN AND DEVELOPMENT PLAN

- **Complete port optics design:**
  - *Objective lens (PPPL), shutter system*
  - *Fiber layout, channel deployment*
- **Fibers to spectroscopy laboratory**
- **Specification of laboratory infrastructure**
  - *cryogenics*
  - *vacuum*
  - *network, data acquisition, archival analysis*
  - *remote operations*
- **Detection system design and fabrication**
  - *employ new technologies (filters, preamplifier circuits)*
- **Implementation, testing, optimizing and application**
- **Personnel: part-time scientist, technician, post-doctoral scientist graduate students**

# SUMMARY

- **New measurement capability being developed and deployed through collaborations between UW and DIII-D & NSTX**
- **New technologies being developed to modernize and advance fluctuation measurement via BES**
  - *Red-shifted beam emission filters to avoid CII contamination*
  - *Modernized transimpedance preamplifiers*
- **UW diagnostic development research group has been expanded**
  - *new post-doctoral researchers*
  - *new and continuing graduate students*
  - *part-time technician & faculty*
- **Look forward to continuing to design and develop a BES fluctuation diagnostic system for KSTAR to pursue advanced tokamak research for fusion plasma science and enhanced performance**