UCLA mm-wave diagnostics work scope and systems on NSTX-U

Update for NSTX-U team
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UCLA Staff working on NSTX-U project

- Kshitish Barada, staff researcher, full-time on-site UCLA leader
- Shige Kubota, staff researcher, on-site (75% LTX-β, 25% NSTX-U)
- New Postdoctoral Scholar, TBD, full-time on-site
- UCLA Graduate researcher, TBD, on-site late CY 2021
- Roman Lantsov, UCLA engineer, off-site
- Larry Bradley, technician, off-site
- Neal Crocker, Senior Researcher, off-site
- Terry Rhodes, PI, off-site

Project Objectives – Three main goals

- **Implementation and operation of three millimeter wave diagnostic systems measuring density and magnetic turbulence/fluctuations and turbulence flows.**
- **Continued and expanded data analysis and science collaboration on topics that directly address the main focuses of NSTX-U's research program.**
- **Education and training of Graduate Students and Postdoctoral Scholars.**

- **Some references for DBS/CPS/etc.**
  - W. A. Peebles, et al., 'A novel, multichannel, comb-frequency Doppler backscatter system', RSI, 81, 10D902 2010
  - J C Hillesheim, et al., 'Intermediate-k density and magnetic field fluctuations during inter-ELM pedestal evolution in MAST', Plasma Phys. Control. Fusion 58 (2016) 014020
  - T. L. Rhodes, et al., 'Optimized quasi-optical cross-polarization scattering system for the measurement of magnetic turbulence on the DIII-D tokamak', RSI 89, 10H107 (2018)

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Project Objectives – Diagnostics

- **Implementation and operation of three millimeter wave diagnostic systems measuring density and magnetic turbulence/fluctuations and turbulence flows.**
  - **reflectometer (Q and V-band) for low-k spatially resolved density fluctuations (e.g. energetic particle modes, Alfvénic activity, MHD, etc.),**
  - **A four-channel Doppler backscattering (DBS) system (W-band) for low to intermediate-k density fluctuations and turbulence flows**
  - **A four-channel cross-polarization scattering (CPS) system (W-band) for internal, localized magnetic turbulence measurements.**

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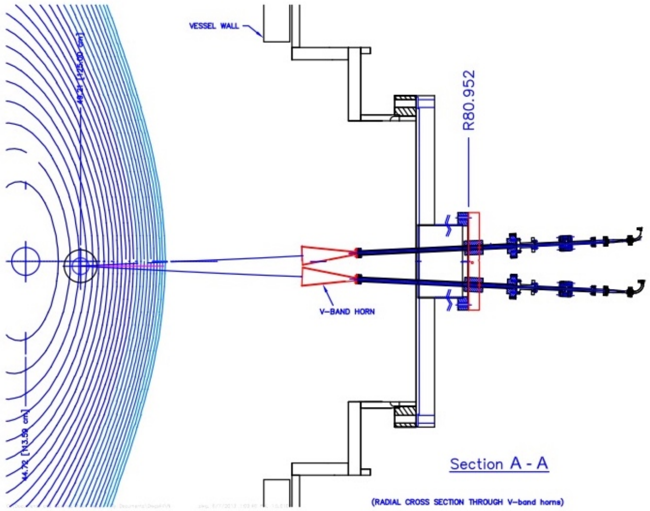
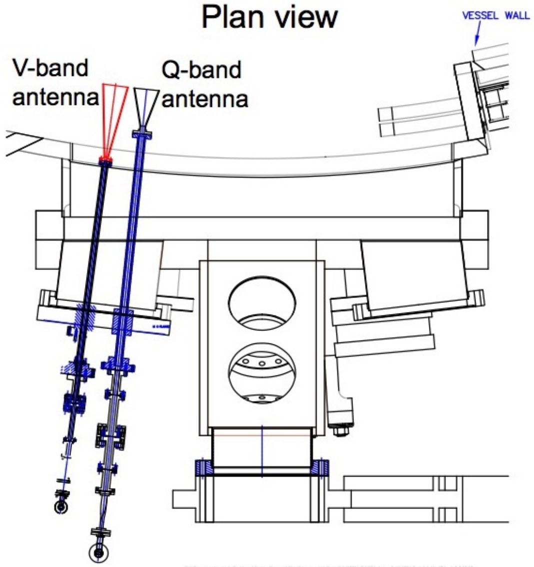
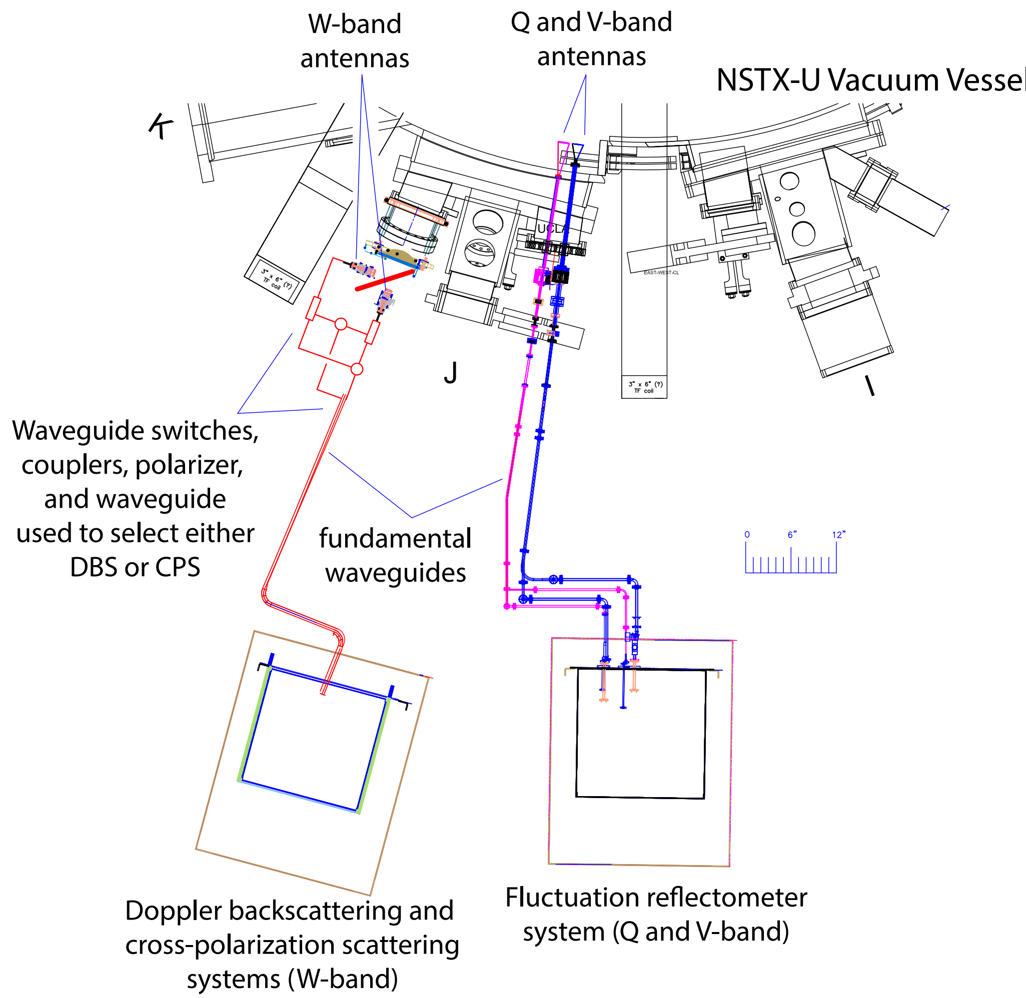
UCLA systems on NSTX-U: DBS, CPS, and fluctuation reflectometers located at Bay J

Elevation view



Plan view





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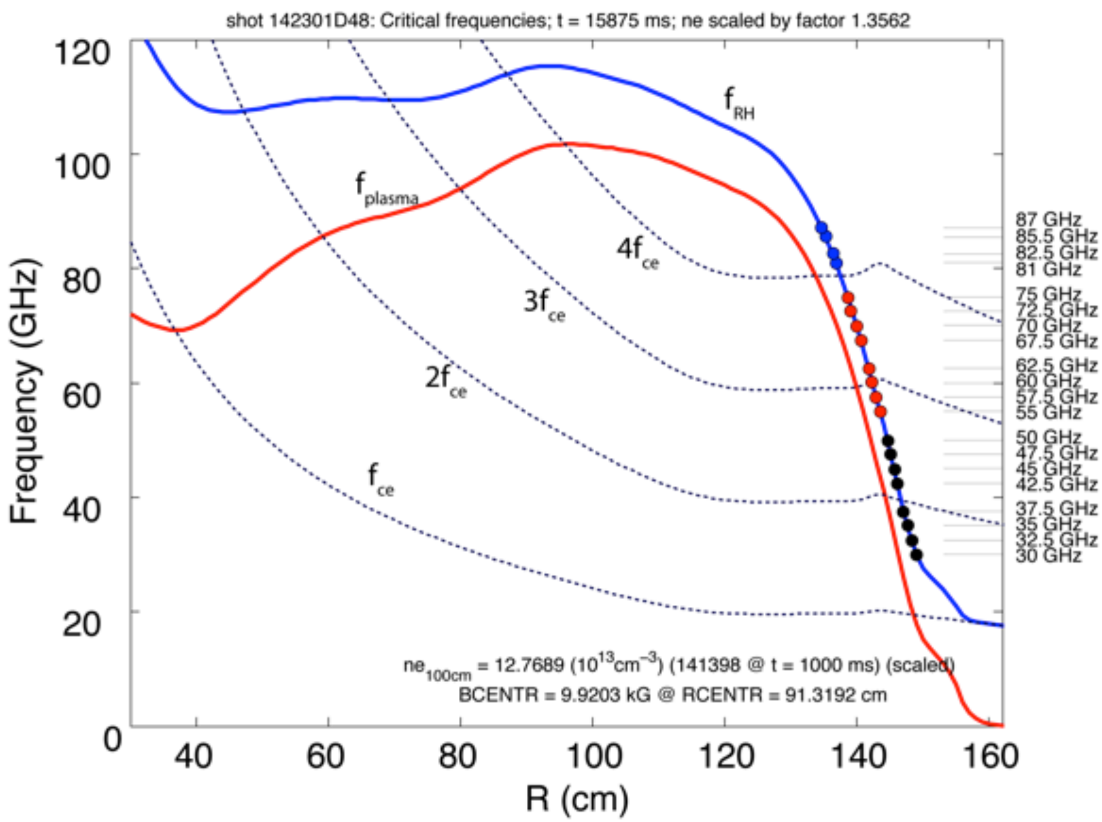
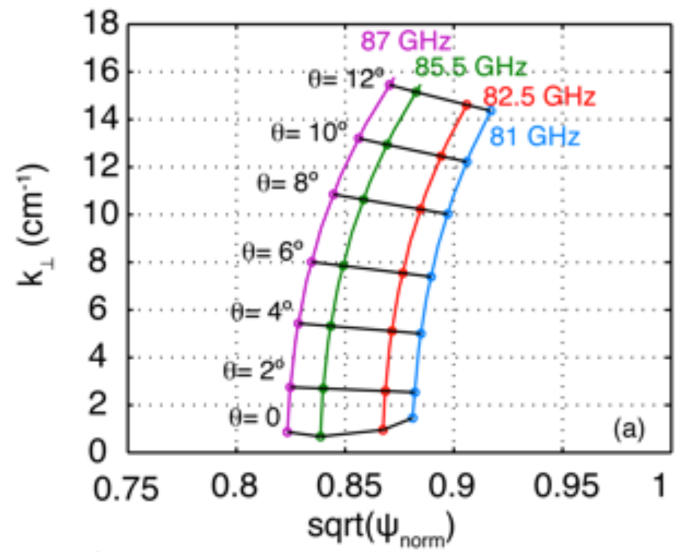
Predicted NSTX-U H-mode cutoffs showing representative radial locations of fluctuation measurements

- **Fluctuation reflectometer measures low-k density fluctuations**
- **Spatial coverage is improved over previous system**



- **Wavenumber coverage of DBS system**



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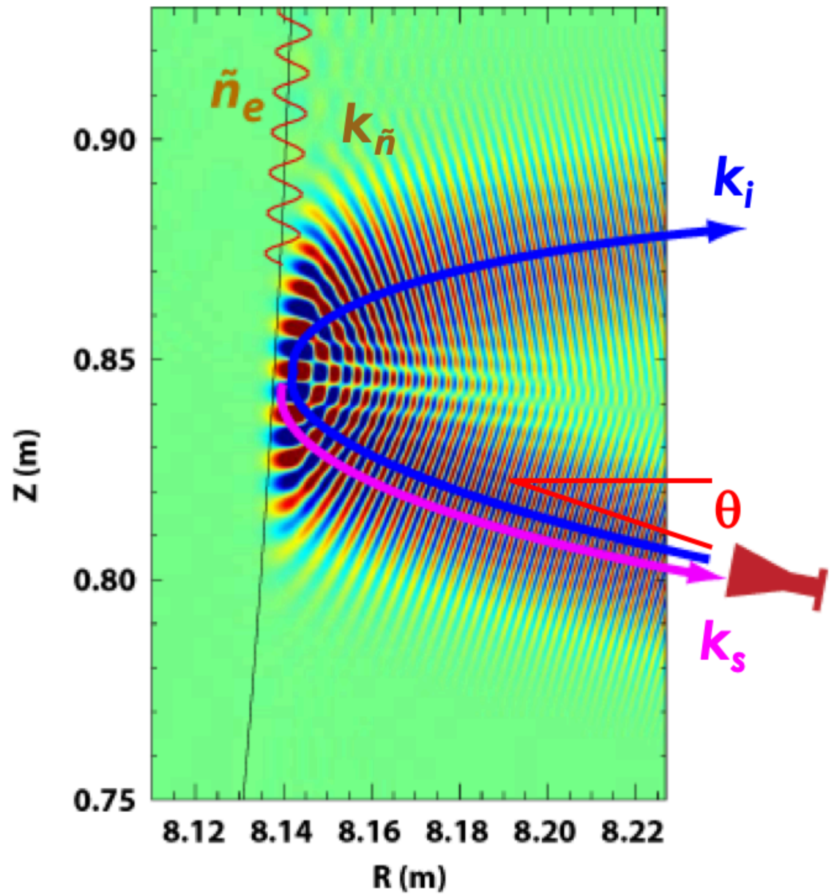
Doppler backscattering (DBS) technique first introduced on ASDEX-U and is now a widely used technique



Hirsch, PPCF 2001, Bulanin PPR 2000, Hennequin RSI 2004, **Conway, PPCF 2008,** Schmitz RSI 2008, Xiao PS&T 2008, Happel RSI 2009, Hillesheim NF 2015

- Often referred to as Doppler reflectometry
- Radiation injected at angle θ, with wavenumber k_i
- Scattering at k_s occurs according to Bragg scattering relation:

  For $k_i \sim k_S$, can show that

  $k_{\tilde{n}} = 2k_i \sin(\theta/2)$, θ is scattering angle
- Scattered signal proportional to ñ at $k_{\tilde{n}} \pm \Delta k$
- Doppler shift is $\Delta\omega = k_{\tilde{n}} (V_{ExB}+V_{phase})$
- Full wave calculation shows long wavelength propagating structure near cutoff
  - It is this structure that scatters from longer wavelength ñ.
  - Value of scattered k_s, spatial and k resolutions determined by this structure and beam pattern.

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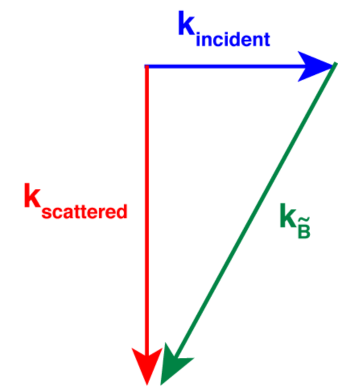
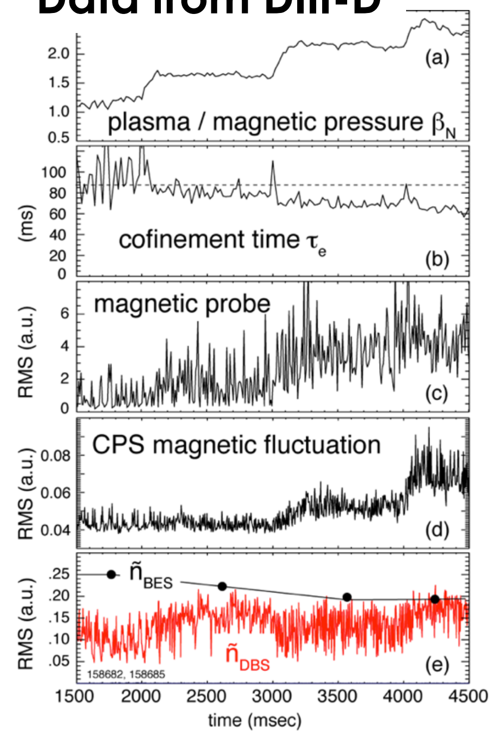
Cross-polarization scattering technique due to scattering of incident radiation into orthogonal polarization by magnetic fluctuations

- **CPS is a scattering technique similar to DBS**
  - $k_{scattered} = k_{incident} + k_B$ for wavevectors
  - $\omega_{scattered} = \omega_{incident} + \omega_B$ for frequencies
  - where $k_{incident}$ and $k_{scattered}$ are the incident and scattered wavevectors and k_B is the wavevector of the magnetic fluctuation (similarly for frequencies $\omega_{incident}$, $\omega_{scattered}$, and ω_B).



- **Assuming probe beam perpendicular to local B, magnetic fluctuations induce a polarization change perpendicular to local magnetic field:**
  - The electric field of incident radiation E_i accelerates electrons which interact with magnetic perturbations resulting in an induced current $J_\perp$ orthogonal to E_i, $J_\perp \sim E_i \times \tilde{B}$ [Zou95]. This perturbed current then radiates into a polarization orthogonal to E_i and $\tilde{B}$.
  - It is this scattered field, orthogonal to the incident radiation and proportional to and $\tilde{B}$, that is then detected.
- **Resulting k_B wavenumber range measured by CPS depends on the particular plasma conditions, probing wavenumber, and scattering geometry used.**

Data from DIII-D



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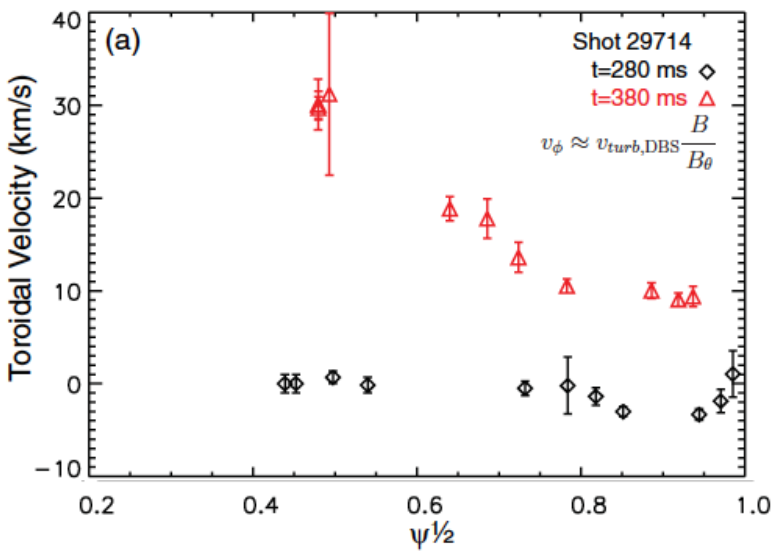
DBS and CPS data from MAST tokamak

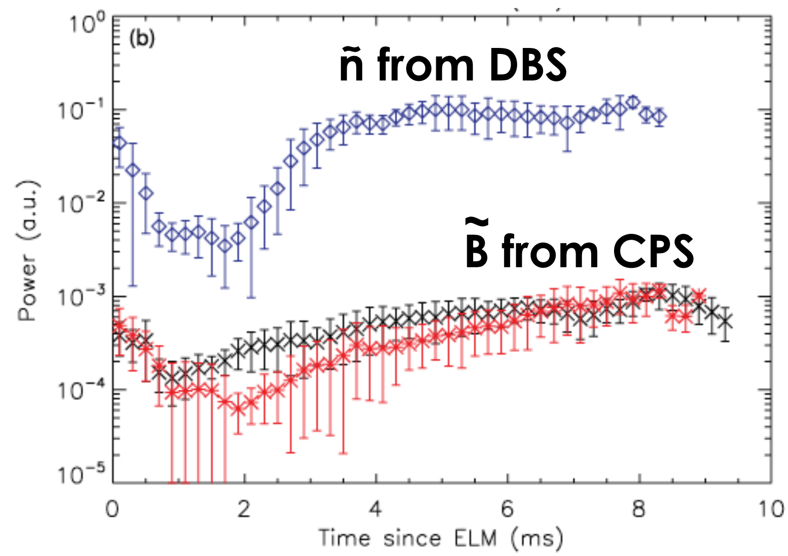
- Collaboration on MAST between John Hilleshiem (CCFE), Neal Crocker (UCLA), and Tony Peebles (UCLA)
- Used UCLA DBS equipment

- Estimate toroidal rotation using DBS data
- Ohmic plasma
- Variation due to density decrease, 380 ms with lower density



Hillesheim, Nucl. Fusion 55 (2015) 032003

- Between ELM data
- Magnetic fluctuations from CPS much smaller than DBS density fluctuations.
- Paper concluded data was consistent with ETG rather than MTM



Hillesheim, Plasma Phys. Control. Fusion 58 (2016) 014020

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Impact and contributions to NSTX-U goals

- UCLA will contribute to NSTX-U research topics:
  - Objective 1
    - ‘Characterize and understand H-mode performance at lower ν^* using increased B_T, I_p, PNBI’,
    - ‘Identify transport and stability mechanisms that determine core and pedestal profiles and overall performance’,
    - ‘Develop reduced stability and transport models required to run and validate integrated predictive simulations’, including EP (working with N. Crocker, et al.)
  - Objective 2 – Possible contributions to
    - Particle control and heat flux mitigation necessary for stationary discharges – ’Sustain enhanced energy confinement regimes without large ELMs’
  - Objective 3
    - Develop and understand techniques to mitigate/eliminate edge transients and the associated enhancement of PMI
- Testing and validation of turbulence simulation predictions using measurements.
- UCLA will lead experiments and research topics where our strengths can best contribute.

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Project Objectives – Education and training

- **Education and training of Graduate Students and Postdoctoral Scholars.**
  - **A Postdoctoral Scholar will be stationed on-site and trained at NSTX-U**
  - **It is planned that a UCLA Graduate Student will be added in year 2 (~2022)**

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Current status of effort

- Kshitish Barada to be stationed on-site (asap within Covid19 constraints)
  - Brings significant edge/pedestal turbulence and transport expertise
- DBS/CPS system
  - we will hold an additional final design review (additional FDR is due to length of time since the first FDR)
  - Updated designs are now ready for this review
- Fluctuation reflectometer system
  - Waveguides, digitizers, etc. to reinstalled (after K Barada is on-site)
  - Replacement Q-band transmitter/receiver being fabricated (original was sent to MAST-U after consultation with DOE OFES)
- Digitizers
  - Need to replace aging DTACQ 216's
  - Have received quotes, looking at which vendor to select – in consultation with NSTX-U IT staff.
  - Issue: additional NBI will increase neutron load in test cell which will adversely affect devices with DRAM (so called soft error, wikipedia.org/wiki/Soft_error)
- Testing of all systems are required prior to plasma tests
- We plan to have all systems ready for first plasmas however this target date awaits re-baselining, etc.
- Searching now for Postdoctoral Scholar

Thank you!

Overview of the UCLA diagnostics to be implemented on NSTX-U

Diagnostic	Measurement Importance
Fluctuation Reflectometer	AE mode structure, surface displacement, sixteen-channels covering edge to high density core.
Doppler Backscattering (DBS)	Intermediate-k ñ, flows, GAMs, core. Fills known gap in k-space between BES and high-k scattering. Four-channels relative ñ(r), ExB flows and sheared flows (no NBI necessary), frequency and k spectra.
Cross Polarization Scattering (CPS)	Measurement of magnetic fluctuations critically important in high beta NSTX-U. Currently no local $\tilde{B}$ in core, four-channels of relative $\tilde{B}$ (r), and frequency spectra