NSTX-U

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Transport and Turbulence Physics Progress and Plans

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NSTX PAC-31
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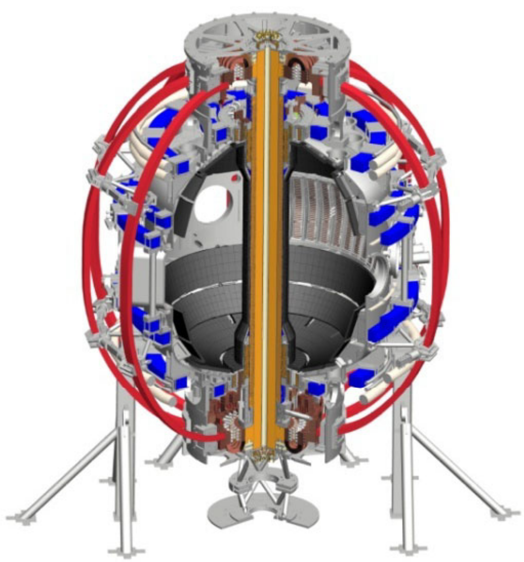

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Outline

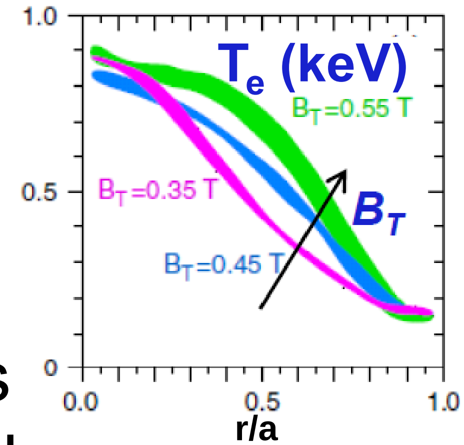
- NSTX-U Transport and Turbulence (T&T) research goals and milestones
- Recent results and plans for FY12 and FY13
- Research plans and diagnostic/facility upgrade requirements for the first two years of operation of NSTX-U and beyond
- Summary

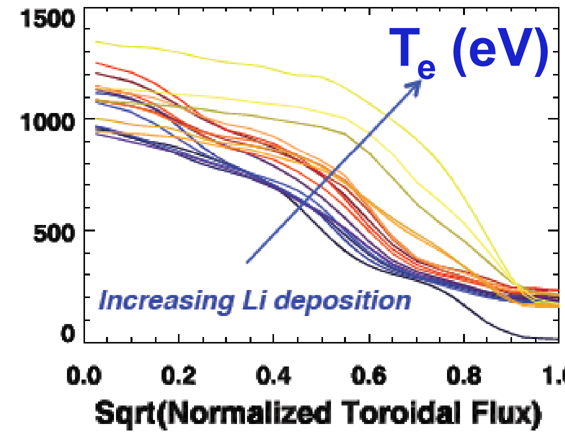
NSTX-U T&T TSG is Addressing Crucial Transport Issues for NSTX-U, FNSF and ITER

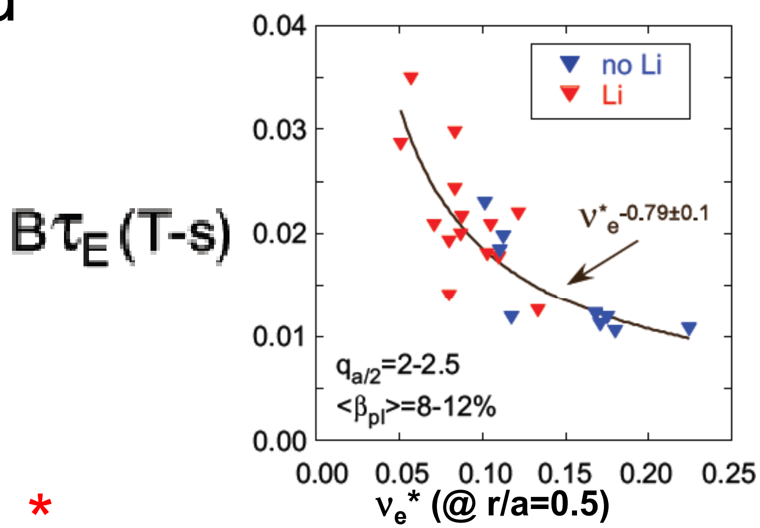
- The goal of NSTX-U T&T research is to establish predictive capability for the performance of FNSF and future devices
  - Thrust 1: Identify instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport
    - Low-k turbulence ($k_\perp \rho_s \lesssim 1$): ITG/KBM, TEM, microtearing
    - High-k turbulence: ETG
    - Alfvenic eigenmodes
  - Thrust 2: Establish and validate reduced transport models (0D and 1D)
- T&T research milestones:
  - FY12 JRT: simultaneous comparison of model predictions with experimental energy, particle and impurity transport levels and fluctuations in various regimes
  - R13-1: integrated physics and optical design of a new FIR high-k_θ scattering system

Inverse ν_e^* Confinement Scaling is Found to Unify Both NSTX Lithiated and Un-Lithiated H-mode Plasmas (TC-12)

- T_e broadening is an important element for ν_e^* reduction
  - Correlated with B_T without Li
  - Correlated with Lithium deposition
- Observed ν_e^* scaling reconciles NSTX un-Lithiated and Lithiated H-mode Plasma dimensional scalings
  - $\sim B_T^{0.85}$ and $\sim I_p^{0.38}$ without Li
  - $\sim B_T^{-0.09}$ and $\sim I_p^{0.94}$ with Li
- NSTX-U will investigate if this scaling extends to even lower ν_e^*, i.e. a factor of five reduction
  - Lower ν_e^* stabilizing microtearing
  - ETG not sensitive to ν_e^*

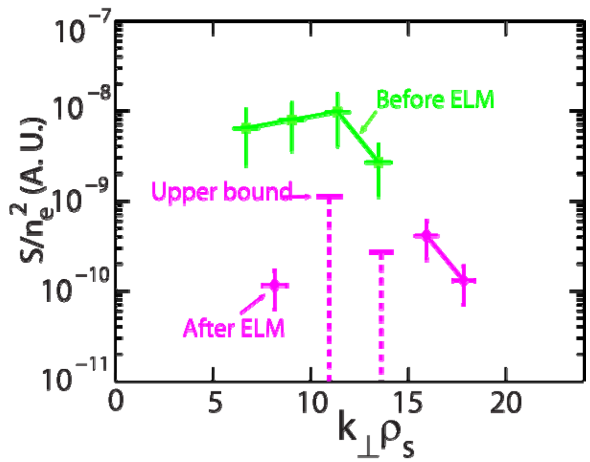


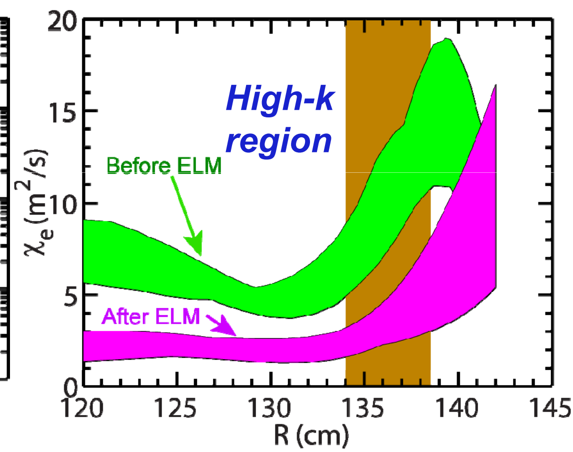


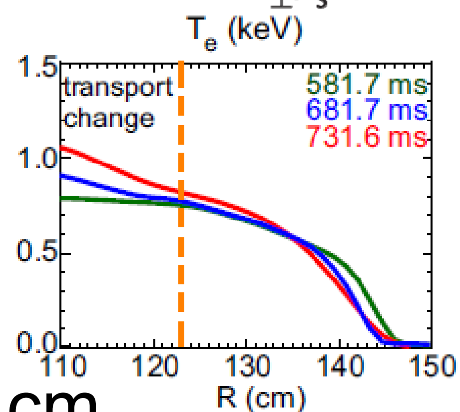


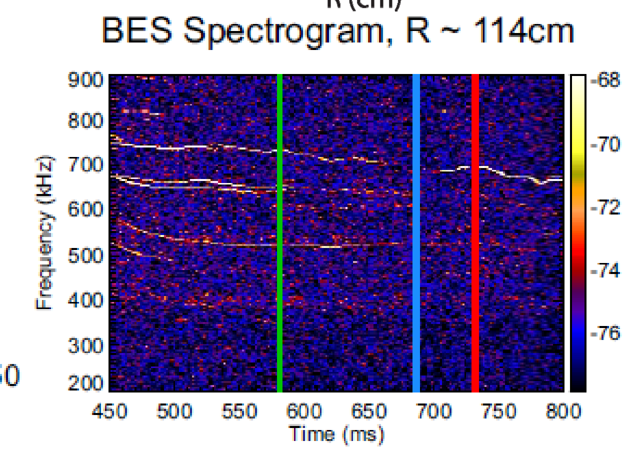
BES and High-k Scattering Measurements Provide Insight to Anomalous Electron Thermal Transport

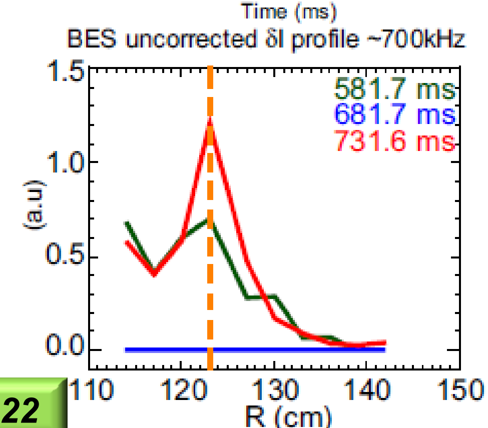
- Density gradient induced by an large ELM event is observed to stabilize high-k turbulence (TC-10)
  - Confinement improved
  - Supported by linear and nonlinear ETG simulations
  - Li-induced larger density gradient may lead to reduced high-k turbulence **PAC29-23**







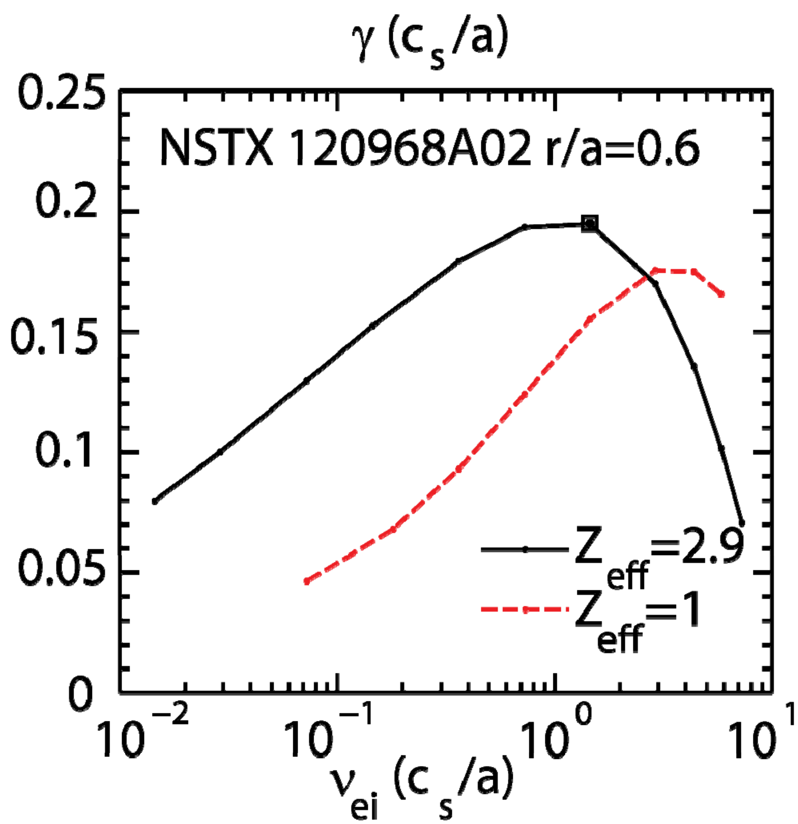


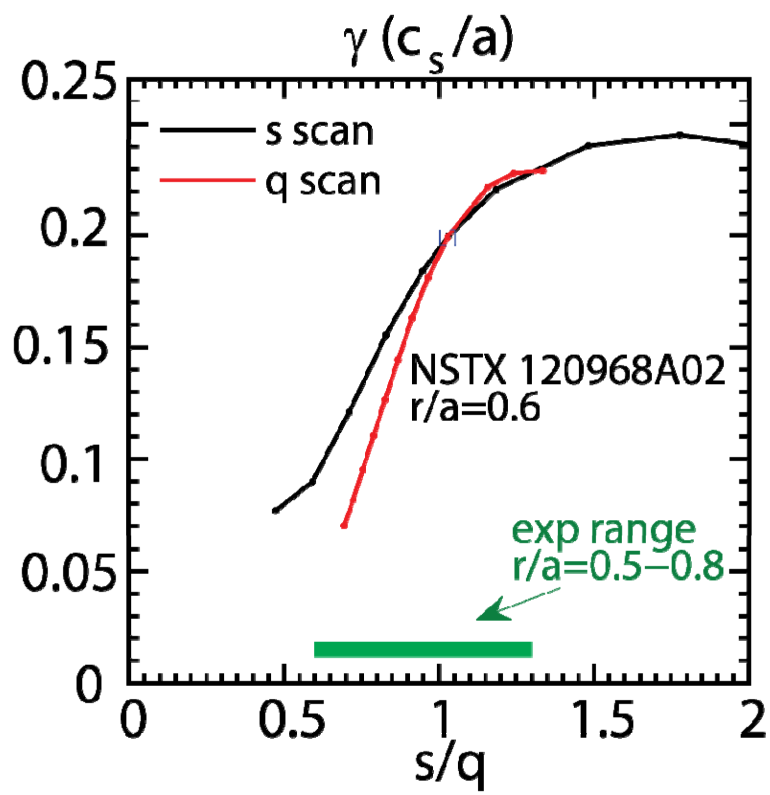


- Decrease in *AE activity R<123 cm correlated with central T_e peaking
  - ORBIT predicts high core χ_e with multiple *AE mode overlap/field stochastization
  - T_e remains peaked even with large single *AE mode, consistent with ORBIT simulations **PAC29-22**

Parametric Studies of Microtearing Modes Using GYRO Code Provide Insight on How to Identify Modes in NSTX-U

- Based on NSTX parameters unstable to microtearing but stable to ETG
- Both the Z_{eff} and s/q scaling opposite to those expected for the ETG instability





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Neoclassical Theory is being Tested as Model for Explaining Impurity Transport in NSTX

- Li deposition modifying edge profiles
  - Smaller n_D and larger T_D (r/a>0.8)
  - Increased ∇n_D and reduced ∇T_D

$$V_{C,pinch}^{neo} \propto \left(\frac{\partial ln(n_D)}{\partial r} - 0.5 \frac{\partial (lnT_D)}{\partial r} \right)$$

- Large C accumulation with Lithium deposition consistent with neoclassical calculations
  - Reduced D_c at edge (r/a>0.8)
  - Increased inward/outward pinch
- Small Li (~1% of C) in NSTX Lithiated H-mode plasmas
  - Large diffusion for Li at edge (collision with C)

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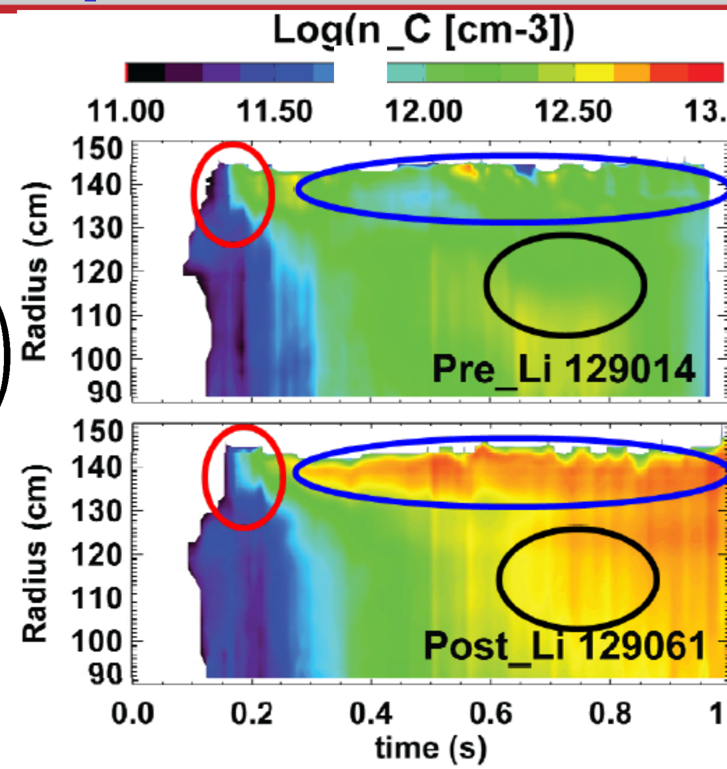
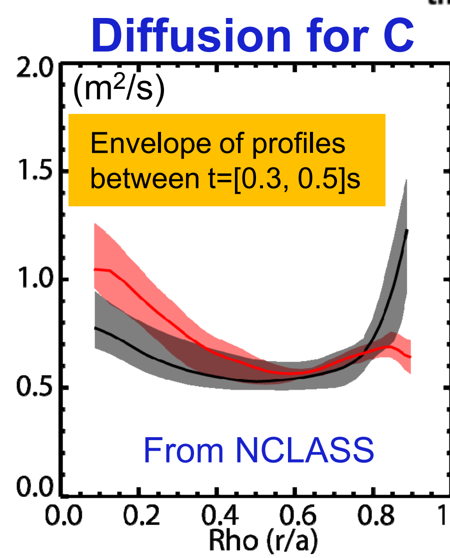
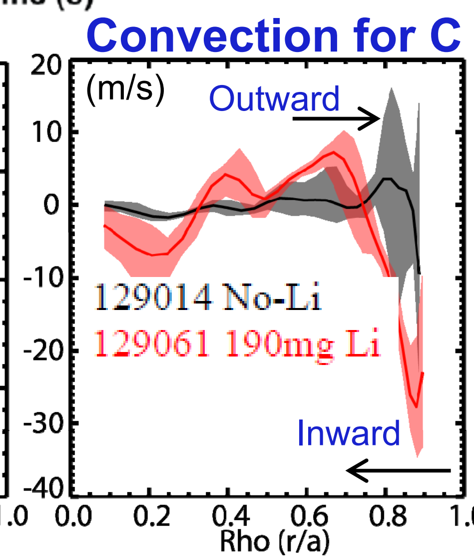
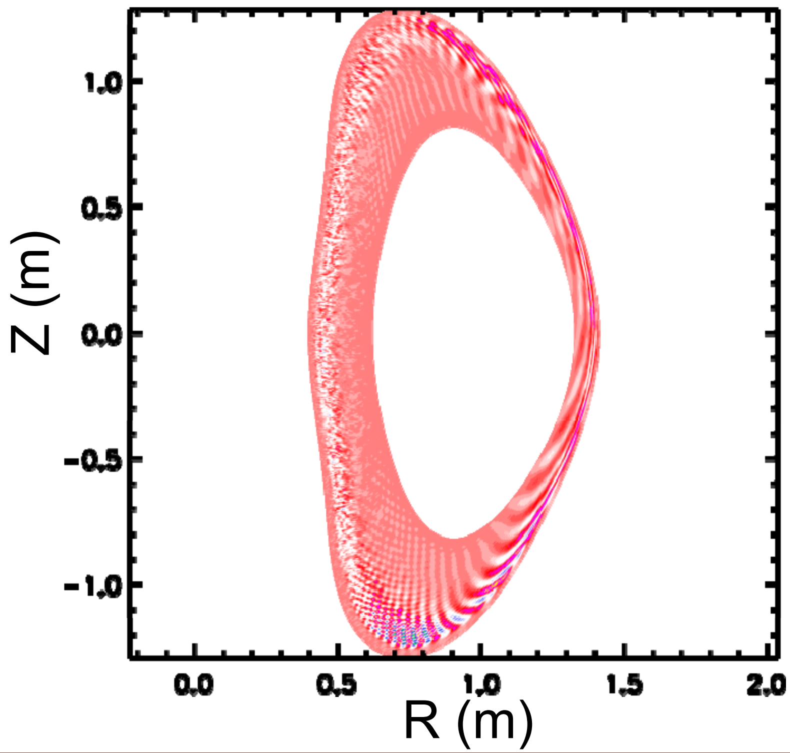


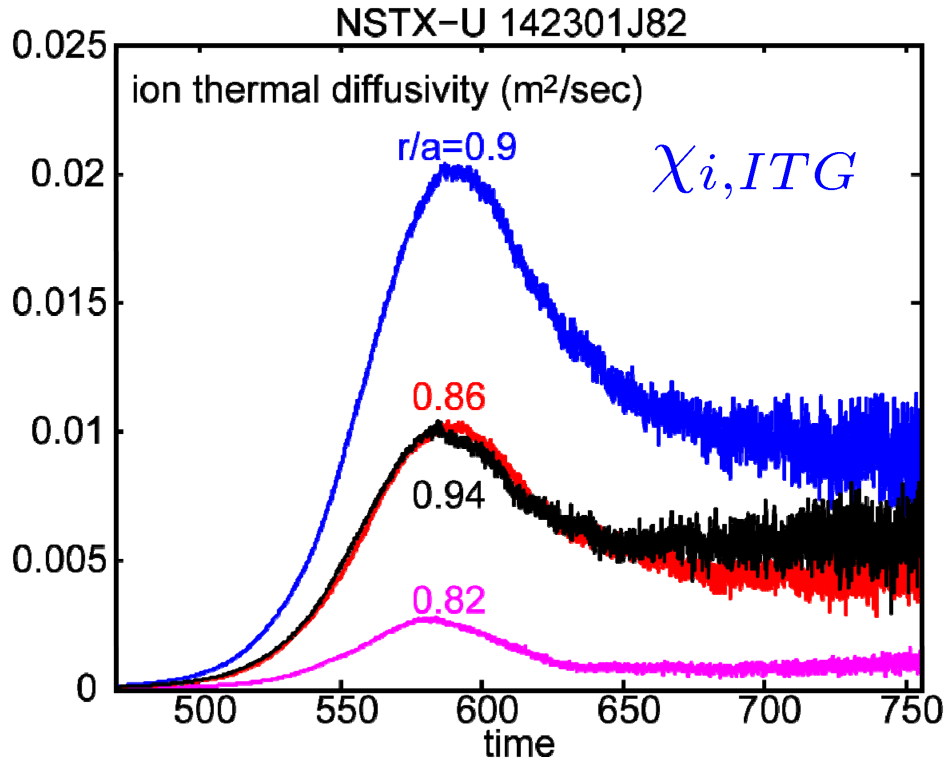




Predictive Modeling Shows Ion Thermal Transport mostly Neoclassical for NSTX-U

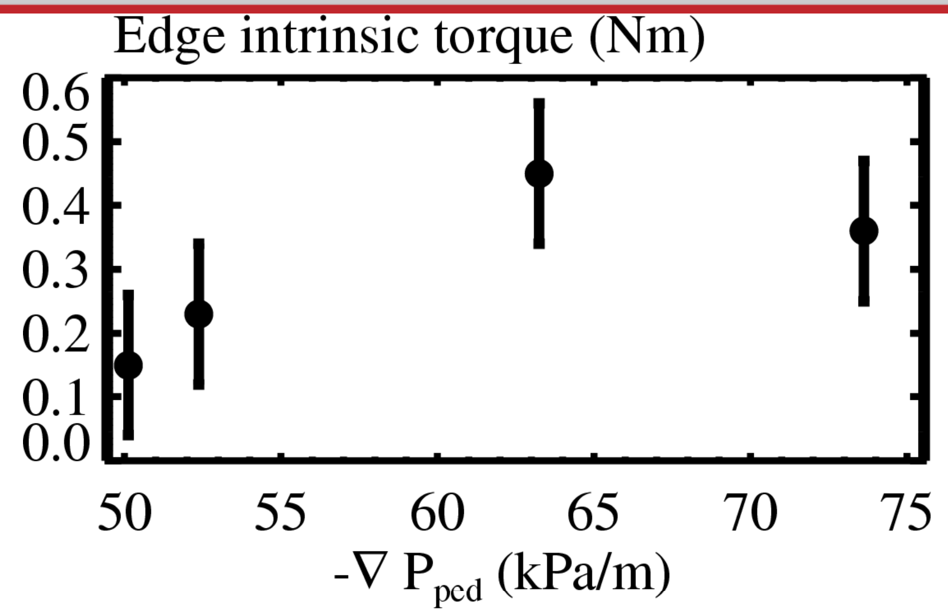
- Nonlinear ITG simulation with predicted NSTX-U profiles shows much smaller χ_i than neoclassical value (1 T, 1.7 MA, 12.6 MW)
  - With GTS+GTC-Neo
  - Global ion-scale simulation carried out at r/a=0.6-1 with no ExB shear
  - $\chi_{i,ITG} \approx 0.01\ m^2/s$ in contrast to $\chi_{i,neo} \approx 1.6\ m^2/s$ at $r/a = 0.9$
  - Neoclassical level of χ_i to be tested on NSTX-U



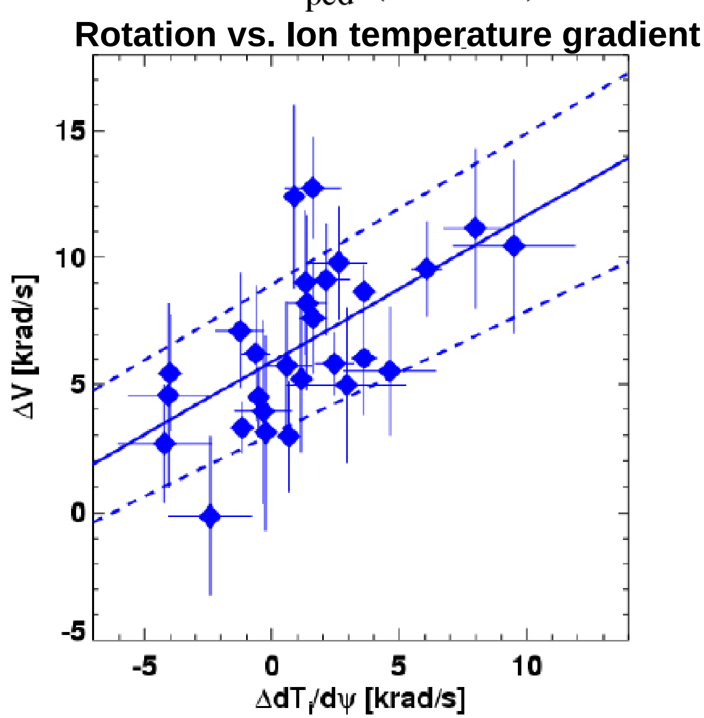


NSTX Edge Intrinsic Torque and Rotation Show Dependence on Pressure Gradient and T_i Gradient, Respectively

- Edge intrinsic torque shows some correlation with pressure gradient
  - Measured with NBI torque steps
  - Qualitatively similar dependence on pedestal gradients as DIII-D

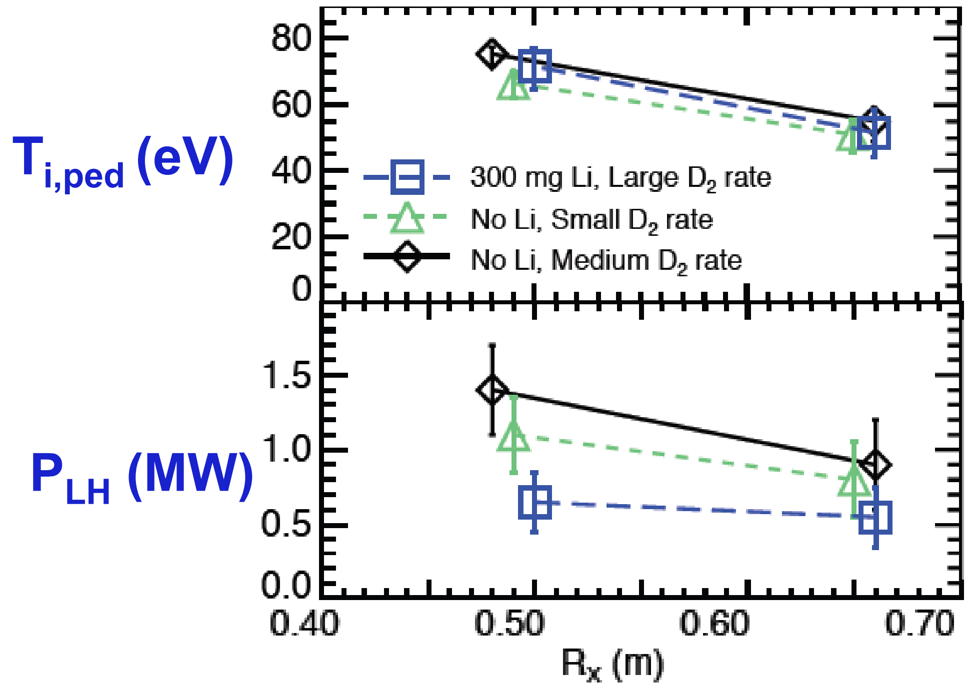


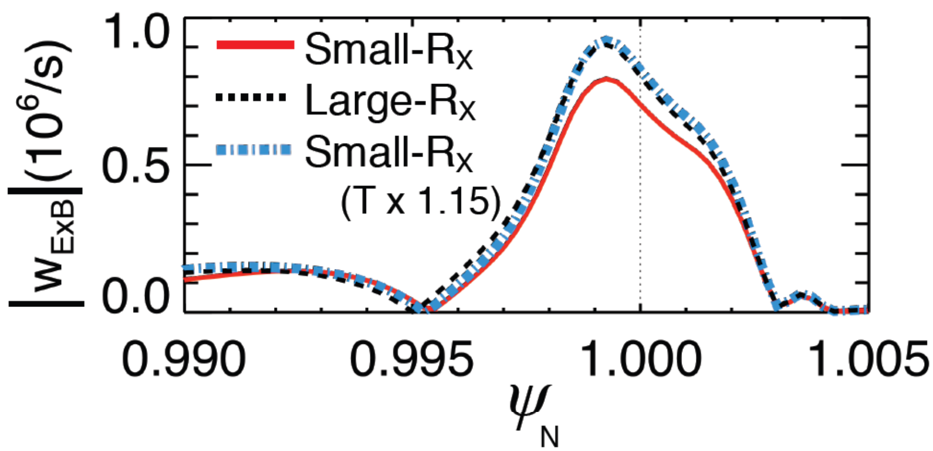
- Edge intrinsic rotation shows better correlation with T_i gradient (TC-9)
  - Measured on pedestal top through Ohmic L-H transition with passive CHERS
  - Zero input torque, small NTV torque and transport effect
  - No correlation found with T_e and n_e gradients



NSTX L-H Transition Study Improves Understanding of the Transition Threshold

- Critical T_i decreasing with R_x
  - T_i (~T_e) evaluated at a weak density pedestal in L-mode phase
  - Mostly independent of divertor pumping and CS fueling
- Consistent with smaller critical energy for ion orbit loss at X-point with larger R_x from XGC0
- More P_{LH} to achieve critical T_i with more edge cooling
- ExB shear rate smaller with smaller Rx with matched profiles from XGC0
  - Larger T_i needed to match ExB shear with larger R_x





Planned NSTX Data Analysis, Modeling and Physics Design in FY 12-13 will Provide Insight into Important T&T Issues

- Contribute to FY12 JRT with existing NSTX data
  - Target shots identified and data analysis ongoing
  - A subset of shots to be determined for nonlinear gyrokinetic simulations
- Analyze existing turbulence data
  - BES, k_r backscattering, High-k scattering, reflectometry
  - Coupled with linear and nonlinear simulations
- Perform validation tests of existing reduced transport models to a variety of NSTX scenarios
  - TGLF, GLF23, DRBM
  - Coupled with linear and nonlinear gyrokinetic calculation, where appropriate
- Integrated physics and optical design of the new high-k_θ FIR scattering system (R13-1)
  - Optimize spatial and spectral resolution and coverage
  - Design the FIR laser for the scattering system

Collaboration Plans for FY12-13 are Aimed at Preparing for NSTX-U Operation/Research

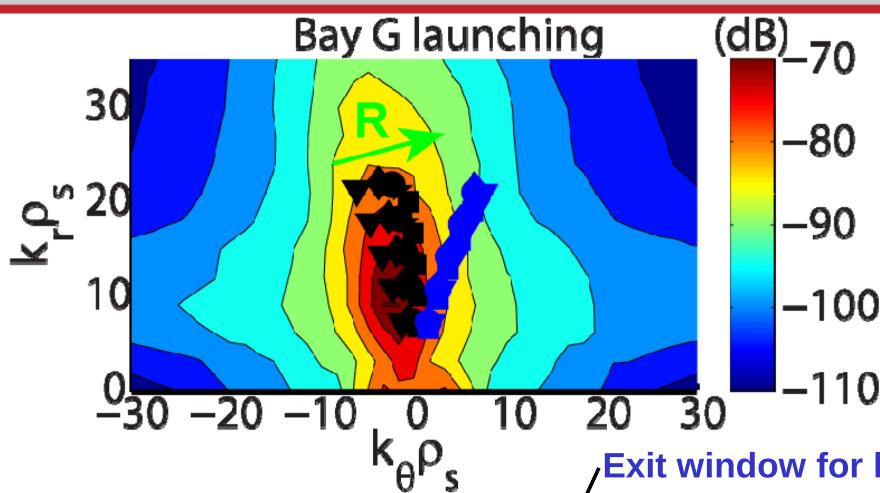
- Explore electromagnetic turbulence, e.g. micro-tearing turbulence, relevant to NSTX-U at other facilities
  - Multi-field turbulence measurements on DIII-D, in particular with BES, CECE, reflectometry and polarimetry
  - BES measurements on MAST
- Collaborate with DIII-D on BES data analysis
  - Migrate analysis codes to NSTX-U
- Collaborate with EAST on an in-vessel ME-SXR system
  - Transport measurements, ELM physics, and MHD/RWM studies
  - An operation test bed for optimizing the funded system for NSTX-U
- Potential collaboration with C-MOD in diagnostic development and facility upgrade
  - Possible implementation of a PCI diagnostic system on NSTX-U
  - A laser blow-off system funded for NSTX-U

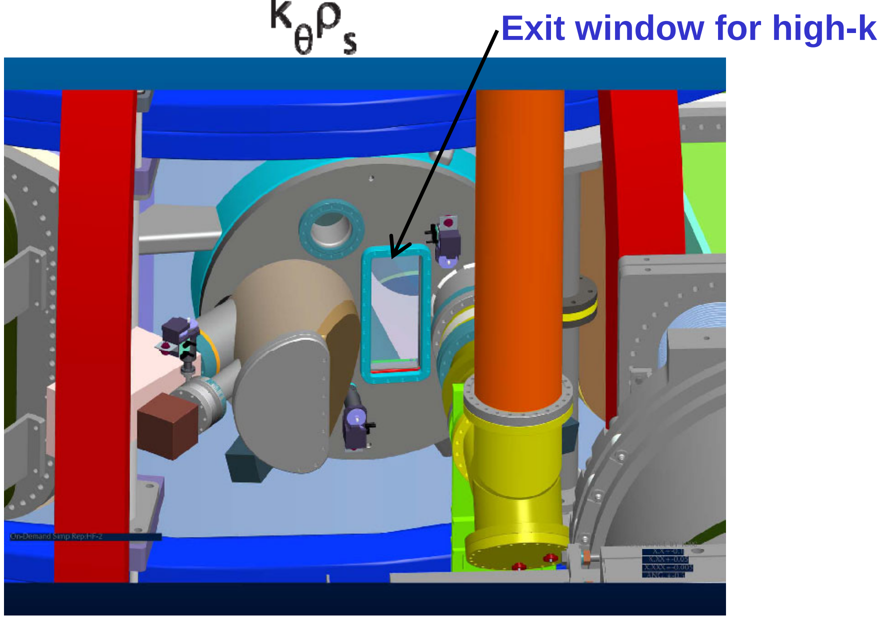
T&T TSG Research Plans for the First Two Years of Operation of NSTX-U

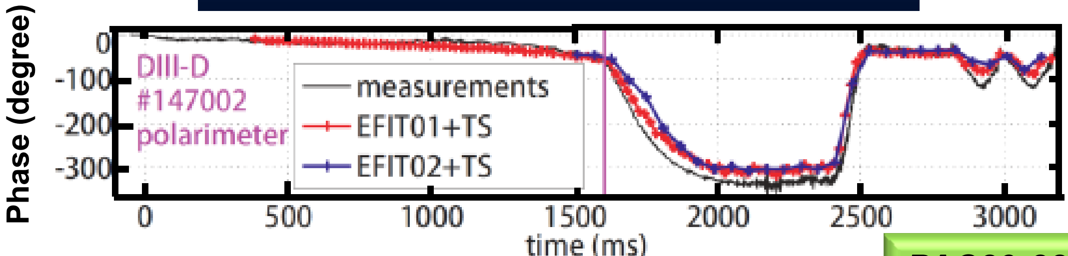
- Measure instabilities responsible for anomalous electron thermal, momentum and particle/impurity transport (Thrust 1)
  - Focusing on low-k and take preliminary high-k measurements (BES, high-k scattering, polarimetry and reflectometry)
  - Differentiate/control turbulence (higher B_T and I_p, 2^{nd} NB and 3D coils)
  - Determine if χ_i is still near neo-classical level in lower ν^* H-mode plasmas
  - Correlate transport channels with low/high k turbulence
  - Compare with gyro-kinetic/neo-classical calculations
  - Calibrated BES/reflectometry for *AE mode structure with a range of B_T, I_p, ν^* and NB power
  - Similar measurements in L-mode (ITG/TEM dominant) and ITB plasmas
- Establish & validate 0D scaling and start 1D modeling (Thrust 2)
  - Establish/Validate 0D confinement scalings with higher B_T, I_p and lower ν^* and project 0D performance of FNSF/Pilot
  - Start applying existing reduced transport models (TGLF, GLF23, etc) to NSTX-U parameters, coupled with linear/nonlinear gyrokinetic calculations

Key Diagnostics and Facility Upgrades are Planned to Support the T&T Research Goals

- A new FIR high-k_θ scattering system being designed
  - Scattering scheme identified
  - Receiving port cover designed
- A polarimetry system built for NSTX-U being tested on DIII-D
  - ≤ 1° phase resolution (2-3° from nonlinear NSTX μ-tearing simulation)
  - Experiments for micro-tearing mode and Alfvenic eigenmodes proposed
- More BES channels are planned for NSTX-U
  - >= 48 channels for NSTX-U
- 2nd NB for q and flow profile control







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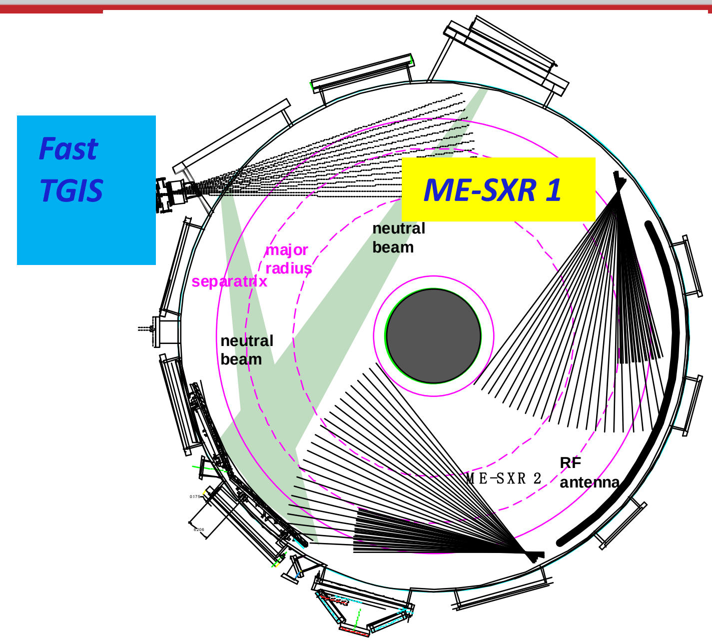
NSTX-U Long Term Research Goals for Years 3-5

- Identify responsible k ranges for different transport channels in H-mode plasmas by correlating measured local transport trends (against ν_e, I_p, B_T, γ_E, s, q, …) with low/high-k and *AE measurements and theoretical predictions (Thrust 1)
  - Identify key local transport dependences on plasma parameters to identify/develop the most appropriate transport models for NSTX-U
  - Identify ETG and microtearing modes and their operational regimes using the high-k_θ scattering system, BES and polarimetry measurements
  - Identify instabilities responsible for particle/impurity, momentum transport
  - Use steady state transport analysis and perturbative techniques
- Establish & validate 0D and 1D models (Thrust 2)
  - Validate 0D confinement scalings with full range of Bt, Ip and ν* and use it to project 0D performance of FNSF/Pilot
  - Reduced transport models for micro-turbulence/*AE against first-principle models in improved NSTX-U parameter regimes
    - Apply predictive transport simulations for NSTX/NSTX-U/MAST

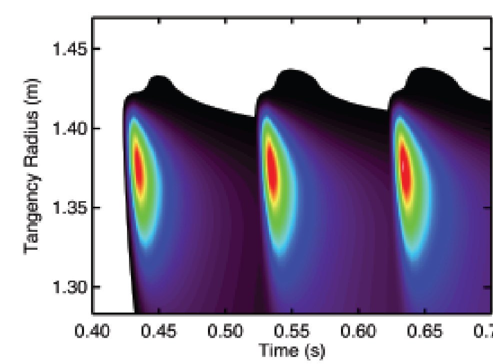
Further Diagnostic/Facility Upgrades would Support the Long Term Research Goals for Years 3-5

- In-vessel multi-energy SXR (ME-SXR) arrays
  - Fast, high resolution T_e, n_e and n_z profiles
  - Impurity/electron perturbative transport measurements from the edge to the core using gas puff/ repetitive laser blow-off



- Repetitive laser blow-off impurity injection system
  - Cold pulse experiment with ME-SXR
  - Non-recycling impurity injection for impurity transport

ME-SXR Model: Non-Recycling Impurity



T&T Research at NSTX-U is Moving toward Physics Understanding of Transport in Future ST/AT Devices

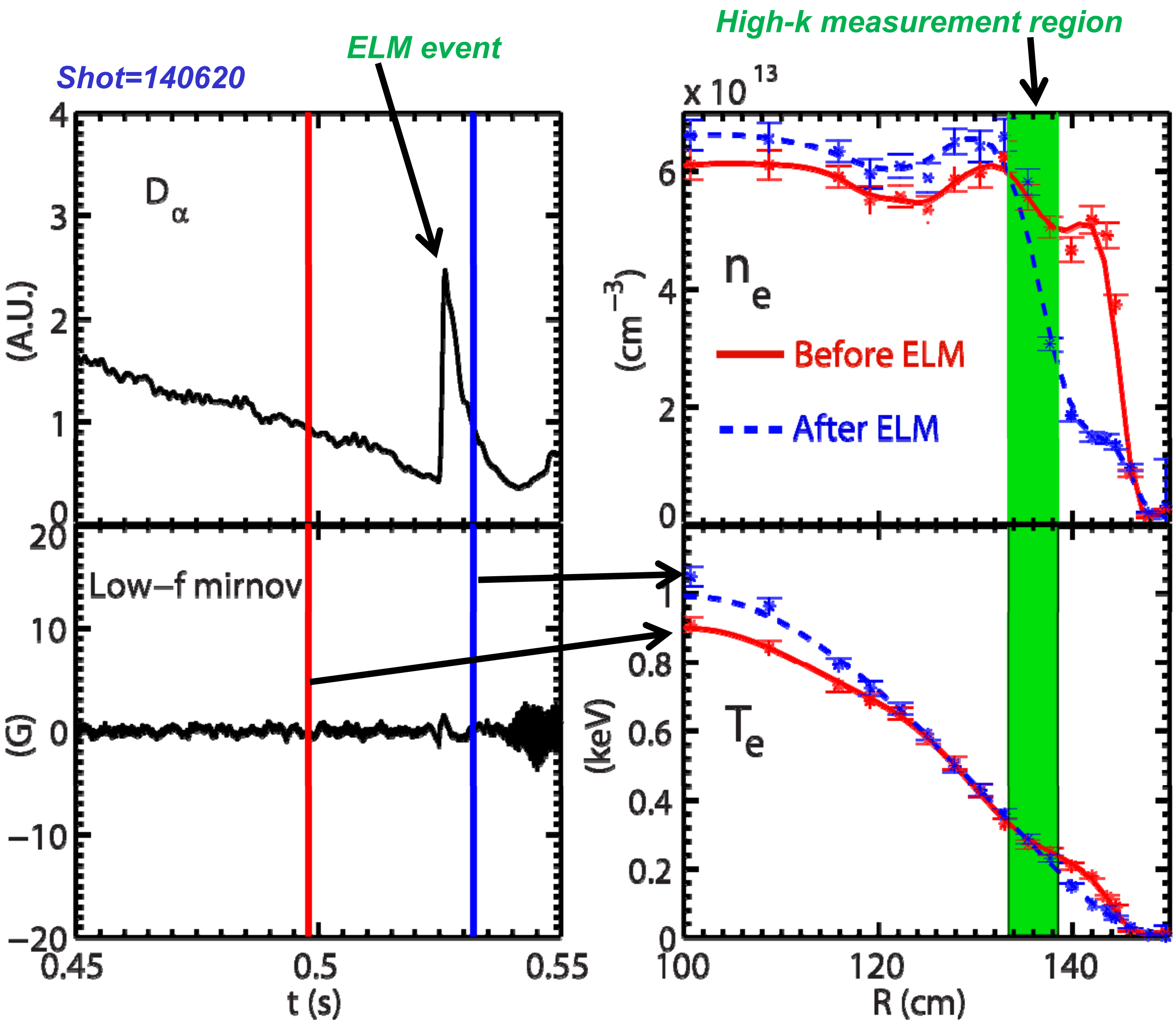
- A suite of fluctuation and profile diagnostics coupled with linear/nonlinear simulations have improved our understanding of:
  - H-mode confinement scaling at low aspect ratio
  - Processes that drive electron thermal transport
  - Impurity accumulation in Lithiated H-mode plasmas
  - The source of edge intrinsic torque and rotation
  - Mechanism behind L-H transition
- Research and collaboration activities in FY12 and 13 will lay a solid foundation for NSTX-U research/operation
  - Start predictive transport simulations for various NSTX scenarios
  - Collaboration with other facilities on diagnostic design/operation and physics relevant to NSTX-U
- Research plans for the initial operation of NSTX-U and beyond aim to provide physics basis for achieving predictive capability for confinement performance of FNSF/Pilot

Backup Slides

NSTX Efforts Towards PAC29 T&T Recommendations

PAC31-22	Therefore the PAC encourages the NSTX team to pursue its investigations to clarify the relative role of microtearing, GAE and ETG modes. The combination of low and high k fluctuation measurements will certainly be useful in that matter. Regarding this point, the PAC was very pleased to see that the NSTX team is making progress in designing a new high-k diagnostic, which will replace the present one in FY 13 or 14.	The investigation of microtearing, GAE and ETG modes is continued with the existing NSTX data and will be carried out when NSTX-U comes back to operation. The design of the new high-k_θ scattering system is in progress: scattering scheme is identified (launching from Bay G and receiving from Bay L); receiving port cover with an exit window for the high-k_θ scattering system has been designed. A polarimetry system designed for NSTX is currently being tested on DIII-D, demonstrating good polarimetry phase resolution capable for detecting microtearing modes on NSTX.
PAC31-23	Also it appears that the L-H power threshold is sensitive to the major radius at the X-point, in accordance with predictions of the XGC0 code. Among the various unresolved issues, one may quote the large difference in the level of fluctuations that is observed with and without Li, the dynamics of the L-H transition and its propagation to the core, and the conditions for the onset of the EP H mode. These issues certainly deserve some attention, given the central importance of this topic for MFE.	It is found that density gradient is increased at the plasma edge (Ψ~0.9) with Li in contrast to without Li. By using the high-k_r scattering system, density gradient has been shown to stabilize ETG turbulence. Thus, with the observed reduction in high-k turbulence with Li is consistent with the increase of density gradient at the plasma edge (Ψ~0.9). We have observed oscillations in density gradient and turbulence spectral power at ETB location prior to L-H transition, although the cause of this oscillation is not yet understood. Further investigation of these recommendations suggested by PAC will be carried out during NSTX-U operation.
PAC31-24	Progress on impurity transport is also noticeable. This is an important issue in view of long pulse operation on NSTX. Preliminary measurements using the new SXR diagnostic are encouraging. This activity should be amplified in order to assess impurity transport in the core. Molybdenum should be given special attention, as it is a possible choice for divertor tiles.	The new SXR diagnostic has been used to determine impurity transport profiles in the NSTX plasma edge. Impurity transport simulations (STRAHL) are coupled with a synthetic ME-SXR diagnostic and fit to data to obtain diffusion, convection profiles with much improved spatial resolution and sensitivity. The observed neon diffusivity is close to neoclassical level. However, some anomalous pinch has been observed. Further investigation of these recommendations suggested by PAC will be carried out during NSTX-U operation.
PAC31-25	Also the PAC recognizes the effort that has been done to develop techniques for controlling the impurity content, in particular ELM triggering, unfavourable ion ∇B direction controlling impurities in the core should be further investigated.	The observed accumulation of C at plasma edge and small Li accumulation in the core with Li deposition by CHERS diagnostic is found to be consistent with the changes in neoclassical transport resulting from changes in plasma profiles with Li. Namely, the increased ∇n_D and reduced ∇T_D lead to increased outward and inward pinch of C, and reduced n_D and increased T_D lead to smaller diffusion of C. The large C accumulation results in large diffusion for Lithium and thus lead to small Li accumulation in the plasma core. Techniques for controlling the impurity content will be investigated during NSTX-U operation.

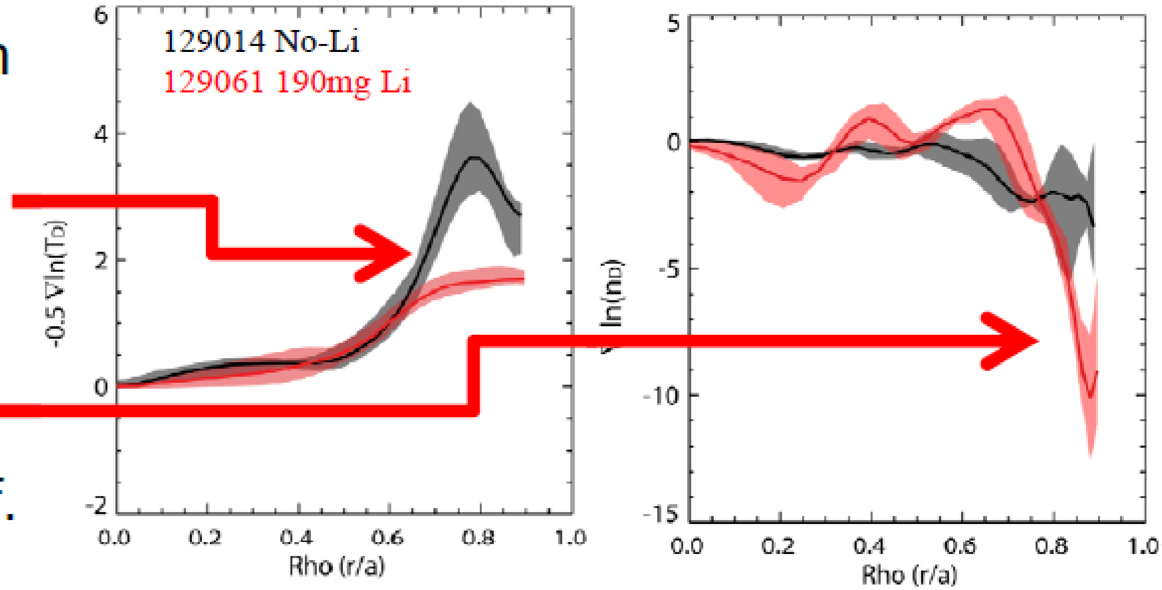
Large Density Gradient Induced by the ELM Event

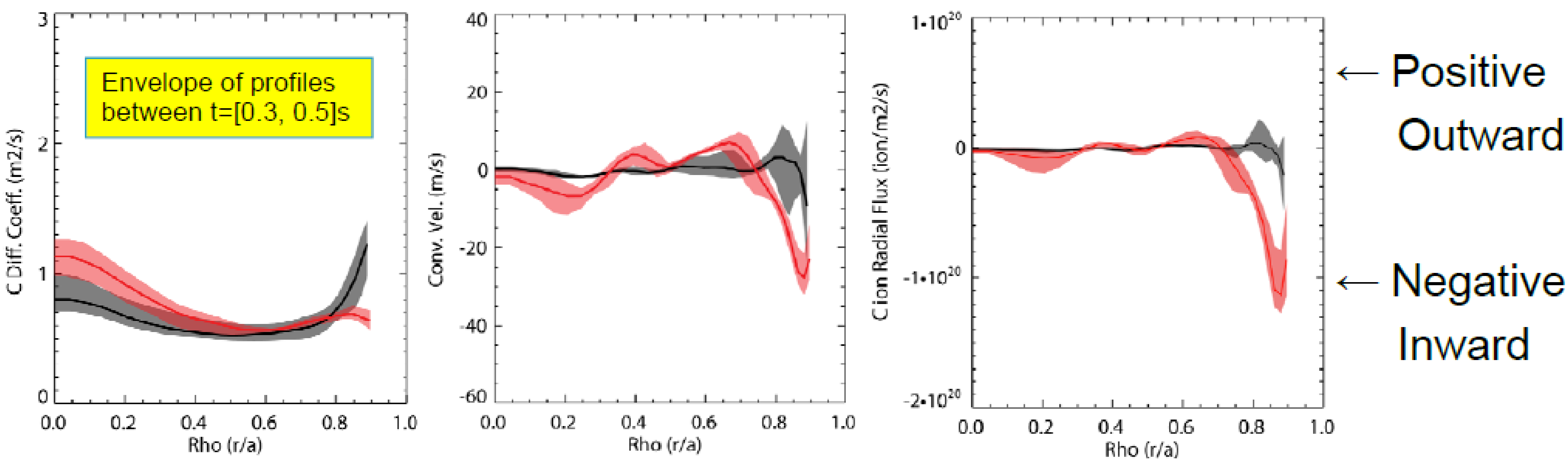


- After the ELM event:
  - Large density gradient developed in the high-k measurement region.
  - Electron temperature gradient also increases
  - Electron density has only a moderate decrease
  - Electron temperature remains essentially constant
- No large rotating MHD mode before or right after ELM

Neoclassical Theory Indicates Change in Carbon Convective Transport as T_D and n_D Gradients Change

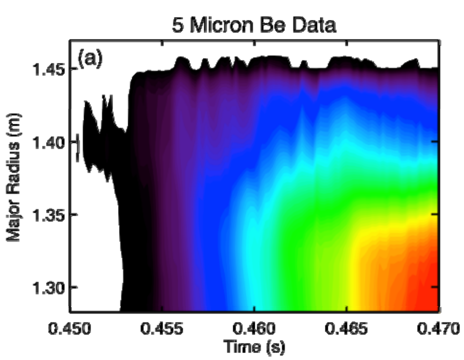
- NCLASS simulations show that in Li conditioned discharges :
  - Change in ∇T_D reduces impurity screening
  - Change in ∇n_D leads to inward pinch
  - Reduced v reduces diffusion coeff. at the edge



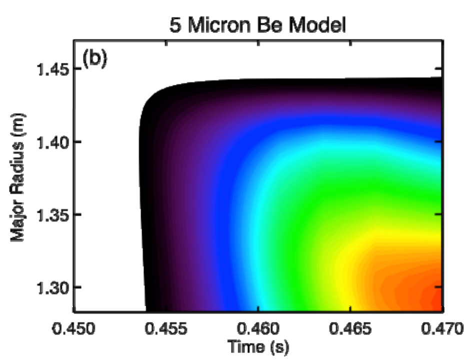


Multi-Energy SXR Technique is Used to Determine Impurity Transport Profiles in the NSTX Plasma Edge

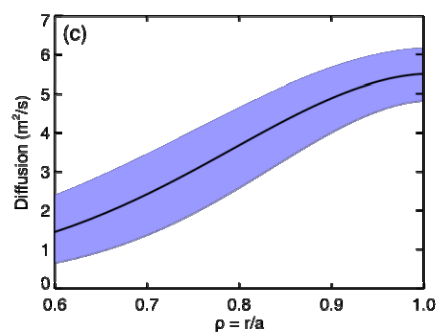
- Perturbative impurity transport measurements were performed using neon gas puffs in the plasma edge (non-perturbative to bulk plasma)
- ME-SXR arrays measure emission from many charge states of neon with high space and time resolution, coarse spectral resolution
  - Five 20-channel photodiode arrays with different filters (one with no filter for bolometry) provide tangential SXR emissivity measurements in five energy bands
  - 1 cm radial resolution (r/a ~ 0.6–1.0) and 10–100 kHz time resolution
  - Filtered ME-SXR arrays measure emission from highly-charged neon
  - Bolometer measures emission from lower charge states, thus providing the source term for higher charge states via ionization
- Impurity transport simulations (STRAHL) are coupled with a synthetic ME-SXR diagnostic and fit to data to obtain diffusion, convection profiles



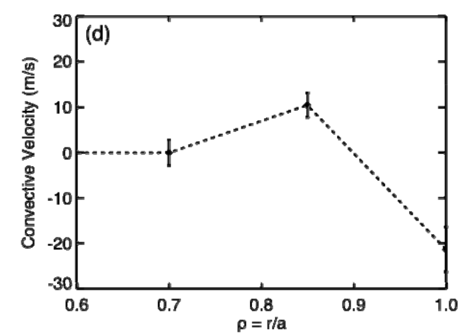
5 µm Be Data



5 µm Be Simulation



Radial Diffusion



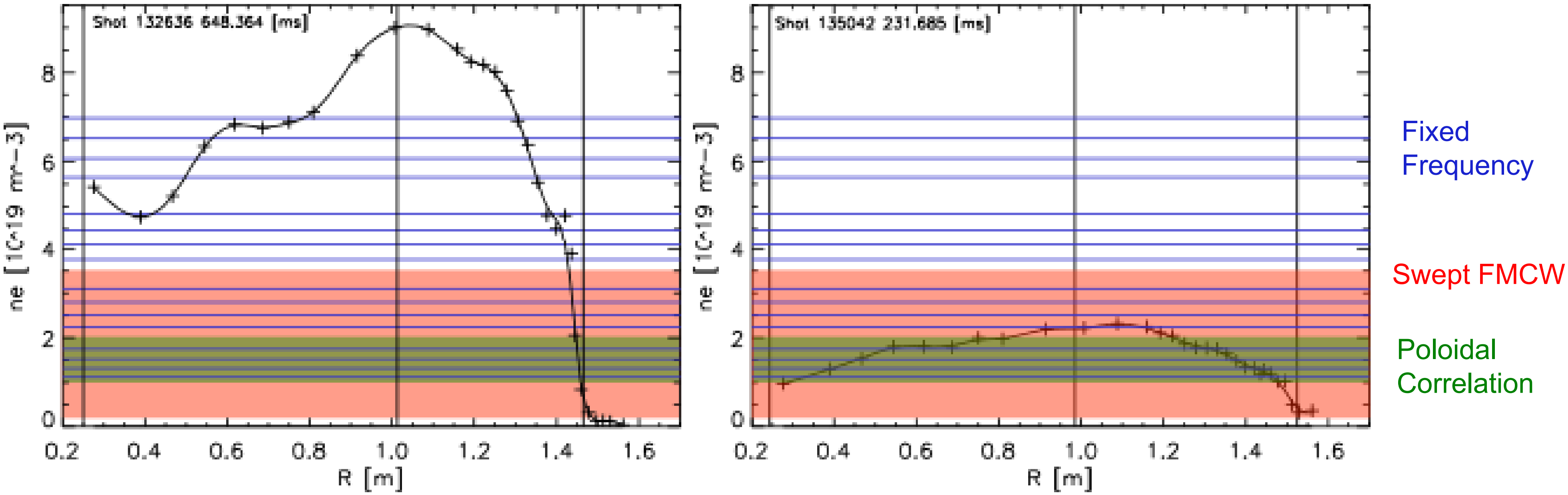
Radial Convection

PAC29-24

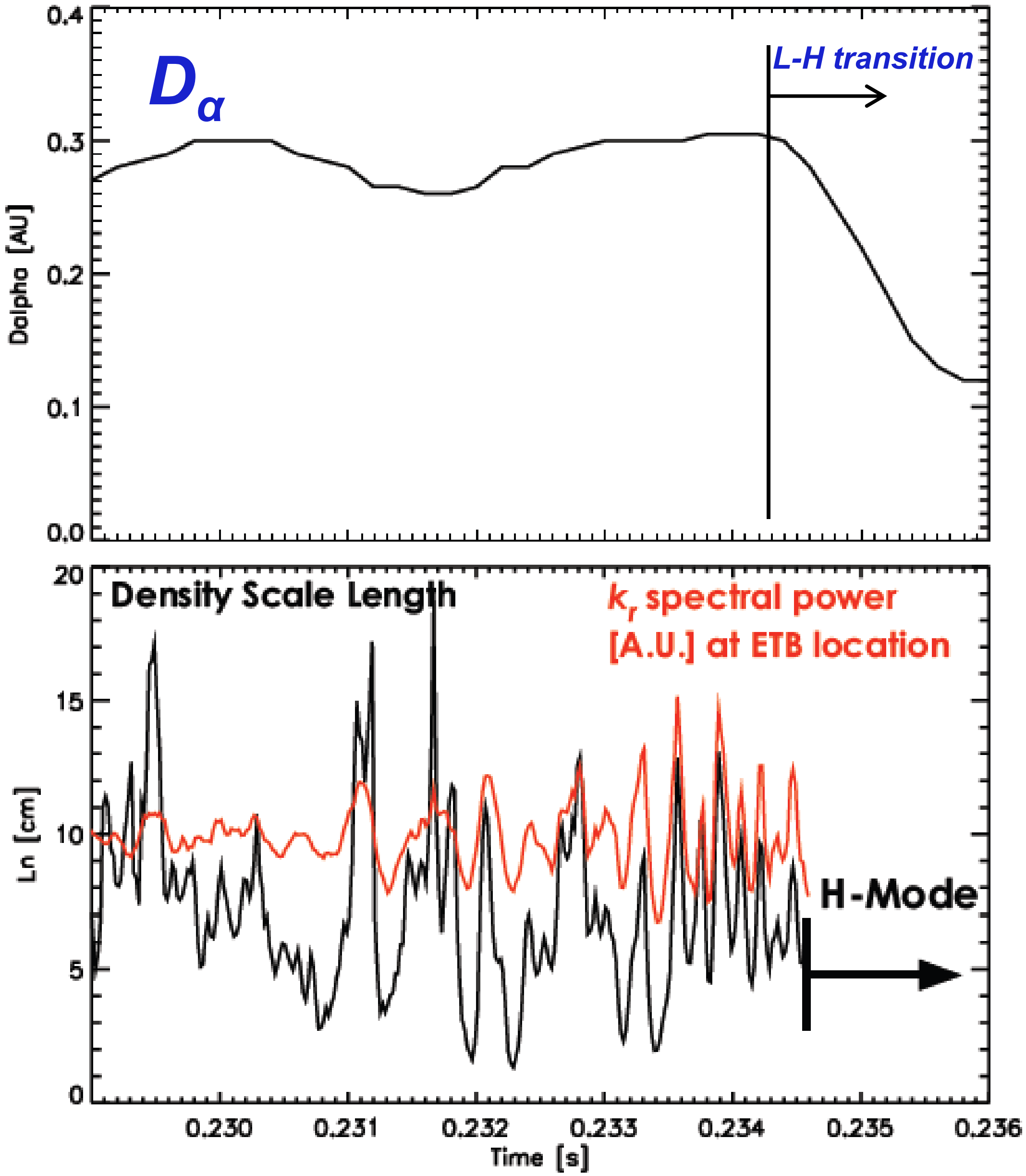
UCLA Reflectometers on NSTX

Millimeter-wave reflectometers available for 2010 (Bay J mid-plane)

- Ultra-fast swept FMCW reflectometers coupled with new analysis techniques
  - Electron density profiles with ≥4 μs time resolution, 13-53 GHz
  - Sub-millisecond turbulence radial correlations
  - k_r back-scattering with radial resolution
- Poloidal correlation reflectometer (2 channel, 28.5-40 GHz)
  - Turbulence flow
  - Poloidal correlations
  - k_r back-scattering with radial resolution
- 16 channel fixed-frequency reflectometers (30 to 75 GHz)
  - Detailed profile of coherent and turbulent fluctuation levels (2.5 MHz bandwidth)



Oscillations in Density Gradient and Spectral Power at ETB are Observed Prior to L-H Transition in NSTX



- Measurements of density profile and backscattered power from FMCW reflectometers
- Oscillations seen in the density scale length and k_r spectral power
  - Change only seen localized at ETB location R~144 cm
  - Amplitude and degree of correlation increases closer to L-H transition
  - Could be sign of underlying flow/turbulence dynamics

Large density gradient developed further into H-mode prevents localized turbulence measurement

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