NSTX-U

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NSTX-U 5 Year Plan for Transport and Turbulence

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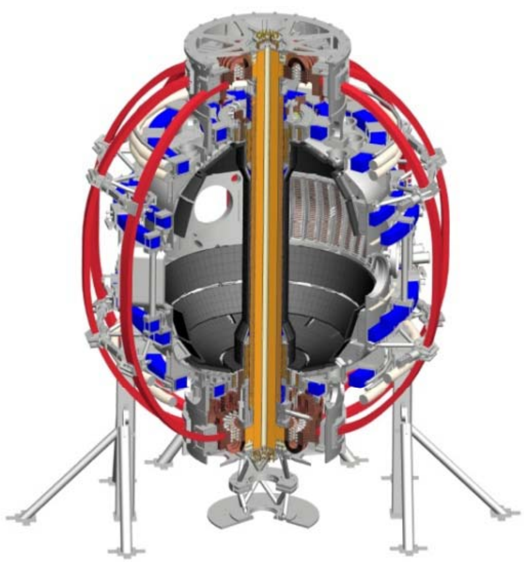

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NSTX-U T&T 5 Year Plan will Address Crucial Transport Needs of FNSF and ITER

- The goal of NSTX-U T&T research aims to establish predictive capability for the performance of FNSF and future devices
  - NSTX-U is unique in achieving high β and low collisionality regime
- Thrust 1: Characterize H-mode global energy confinement scaling in the lower collisionality regime of NSTX-U
- Thrust 2: Identify regime of validity for instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in NSTX-U
  - Low-k modes ($k_\perp \rho_s \lesssim 1$): ITG/TEM/KBM, microtearing
  - High-k mode: ETG
  - Alfven eigenmodes: CAE/GAE
- Thrust 3: Establish and validate reduced transport models

Outline

- A summary of acronyms used in presentation
- Plans for NSTX-U T&T TSG activities in FY14
- FY15-18 operational plans for thrusts 1-3
- Summary

A Summary of Acronyms (SoA)

- Instabilities
  - ITG – ion temperature gradient, electrostatic
  - TEM – trapped electron mode, electrostatic
  - KBM – kinetic ballooning mode, electromagnetic
  - MT – microtearing, electromagnetic
  - ETG – electron temperature gradient, electrostatic
  - CAE – compressional Alfven eigenmode, electromagnetic
  - GAE – global Alfven eigenmode, electromagnetic
- Codes
  - GYRO – an eulerian gyrokinetic code
  - GTS – global particle-in-cell Gyrokinetic Tokamak Simulation (GTS) code
  - GENE – Gyrokinetic Electromagnetic Numerical Experiment (GENE) code
  - XGC1 –full-f global particle-in-cell gyrokinetic code
  - TGLF – an gyro-Landau-fluid code
  - MMM08 – multi-mode anomalous transport model
  - NCLASS – a local neoclassical transport code
  - NEO – a local eulerian neoclassical transport code
  - GTC-NEO –a global particle-in-cell neoclassical transport code
  - HYM – nonlinear 3-D HYbrid and MHD simulation code (HYM)
  - TRANSP – a time dependent tokamak transport and data analysis code with free boundary and multi-zone predictive capability
  - TGYRO – a transport solver
  - MIST – Multi-Ionic Species Transport (MIST) code
  - STRAHL – an impurity transport code
  - DEGAS2– a neutral transport code
- Diagnostics
  - BES – beam emission spectroscopy (BES)
  - CHERS – charge exchange recombination spectroscopy (CHERS)
  - ME-SXR –multi-energy soft X-ray (ME-SXR)

NSTX-U T&T TSG Activities in FY14 will Focus on Preparation for NSTX-U Operation

- Continue analyzing existing data, coupled with GK simulations
  - BES, k_r backscattering, High-k scattering, reflectometry, ME-SXR
  - Identifying experiments for NSTX-U and preparing data analysis tools (BES, high-k scattering, neural network for fast T_e profile analysis using ME-SXR data)
- Continue simulation and modeling for NSTX and NSTX-U
  - Testing of transport models (TGLF, MMM08, etc...) in transport solvers (TRANSP, TGYRO) for T_e and T_i predictions in a variety of NSTX scenarios
    - Validating model growth rates and fluxes with linear and nonlinear gyrokinetics
  - First attempt in predicting core electron thermal transport in NSTX-U by coupling ORBIT code with HYM CAE/GAE mode calculations
  - Further gyrokinetic simulations for NSTX-U, e.g. GTS with kinetic electrons
- Prepare turbulence and transport diagnostics
  - Integrated bench testing of high-k scattering system
  - BES system with additional channels
  - One channel μ-wave polarimetry system (NSTX/DIII-D, back to NSTX-U)
  - ME-SXR diagnostic design optimization for NSTX-U
  - Collaboration with EAST on ME-SXR and FTU on high-Z impurity transport

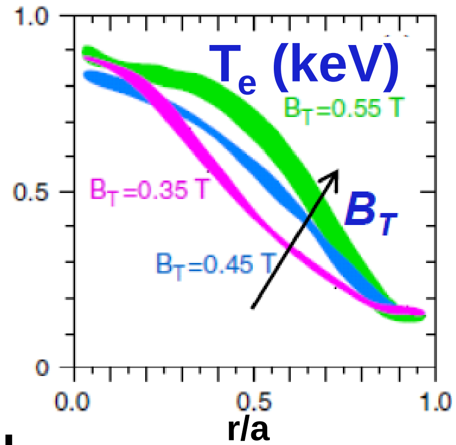
T&T Plans for FY15-18 will Exploit the Enhanced Capabilities of NSTX-U to Substantially Advance Physics Basis for Future Devices

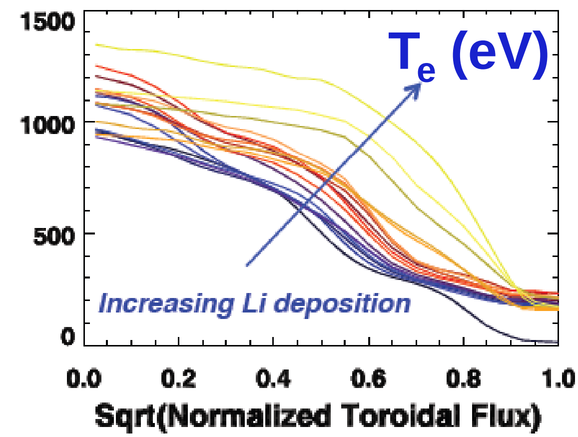
- Expanded operational capabilities of NSTX-U
  - Double B_T, I_p and NBI heating power and cryopump (lower collisionality)
  - More tangential 2nd NBI and partial NCC (q and flow profile modification)
  - Fully relaxed plasmas and fully non-inductive scenario
- Turbulence diagnostics covering ion and electron gyro-scale
  - BES with a total of 48 detecting channels for low-k and AE measurement
  - One channel polarimeter aiming to measure magnetic fluctuations
  - 16-channel reflectometer measuring density fluctuations
  - A FIR high-k scattering system measuring k_θ spectrum
- Couple with a variety of data analysis and modeling tools
  - Power balance analysis/Transport solver: TRANSP, TGYRO
  - Gyrokinetic (GK) codes: GENE, GS2, GTS, GYRO, XGC1
  - Neoclassical and reduced models: GTC-NEO, NCLASS, NEO, TGLF
  - Impurity transport codes: MIST, STRAHL
  - Neutral transport code: DEGAS2

Thrust 1: Characterize H-mode global energy confinement scaling in the lower collisionality regime of NSTX-U

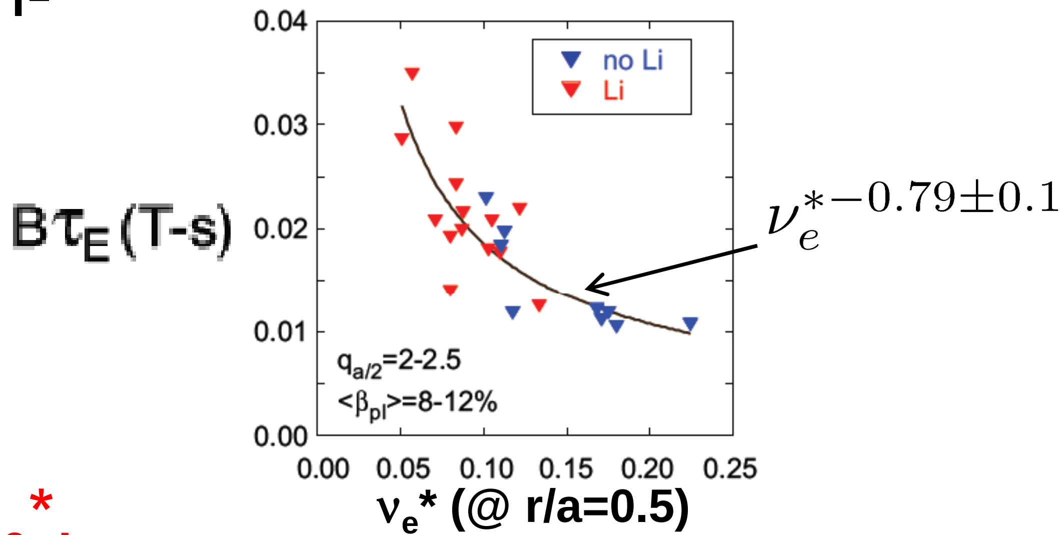
Inverse ν_e^* Confinement Scaling is Found to Unify NSTX Boronized and Lithiated H-mode Confinement Results

- 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 boronized 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 3-6 reduction
  - Lower ν_e^* stabilizing for microtearing, destabilizing to TEM/KBM
  - ETG not sensitive to ν_e^*

NSTX-U will Address ST Confinement Scaling in the Regime more Relevant to Future STs (Thrust 1)

- Near-term plan for FY15-16
  - Re-establish and extend confinement scaling to lower ν_e^* with higher B_T, I_P and NBI power
    - $B_T/I_P \leq$ 0.8 T/1.6 MA in FY15 and 1.0 T/2 MA in FY16
  - Compare I_p and B_T scaling to the different scalings found on NSTX
  - Characterize confinement scaling with different PFC materials
    - Carbon vs high-Z
  - Project 0D performance for future STs with expanded empirical confinement scaling

NSTX-U FY15 milestone (R15-2):

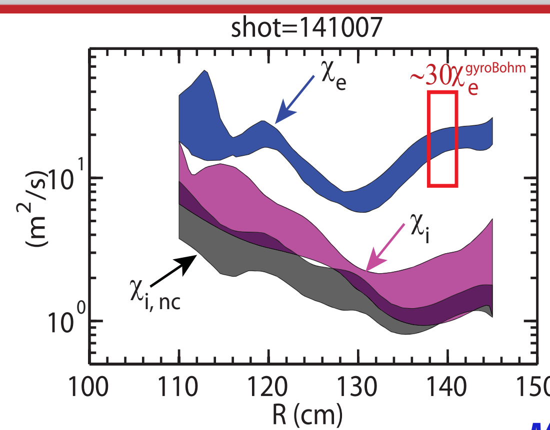
  - Assess H-mode energy confinement, pedestal and scrape off layer characteristics with higher B_T, I_P and NBI heating power

- Long-term plan for FY17-18
  - Characterize confinement scaling for
    - Fully relaxed plasmas
    - Advanced scenarios, e.g. fully non-inductive discharges, as they are developed
  - Decouple ν_e^* and ρ^* dependence of global confinement with density control from cryopump

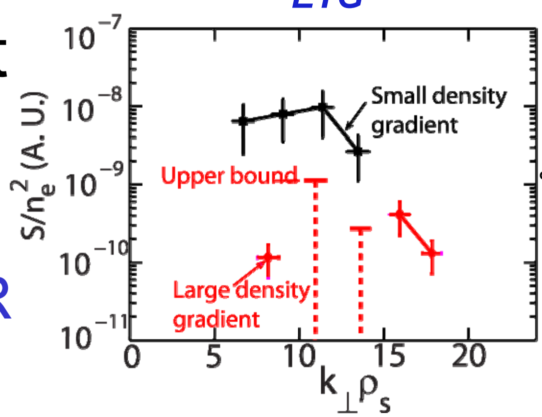
Thrust 2: Identify regime of validity for instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in NSTX-U

T&T Research on NSTX has Gained Insight into Underlying Mechanisms behind Thermal Transport

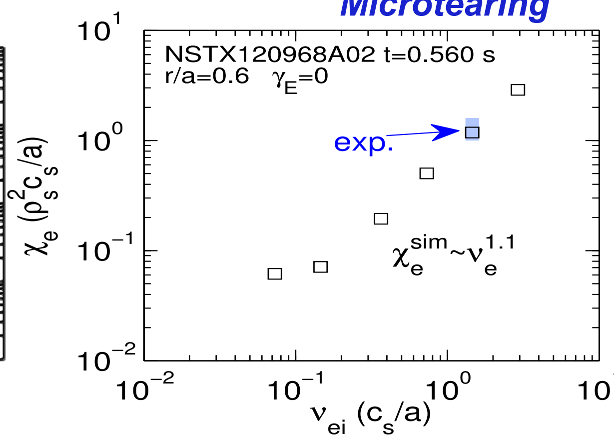
- Ion thermal transport is close to neoclassical in NSTX H-mode plasmas
  - Anomalous in L-mode plasmas
- Electron channel dominates the thermal transport in most regimes
  - Predicted dominant electron heating in NSTX-U/FNSF/ITER
- Evidence of ITG, KBM, microtearing, ETG and CAE/GAE modes on NSTX
  - ITG and ETG in L-mode
  - KBM/microtearing/ETG/CAE/GAE in H-mode



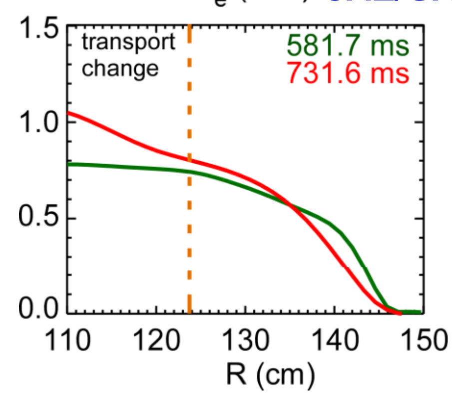
ETG



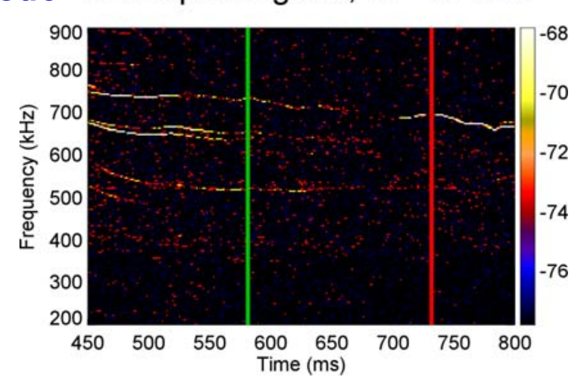
Microtearing



T_e (keV) CAE/GAE mode



BES Spectrogram, R ~ 114cm

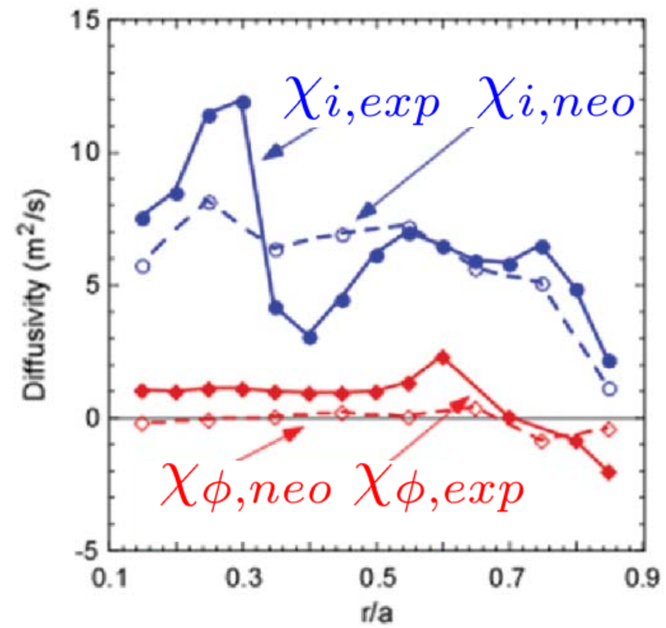


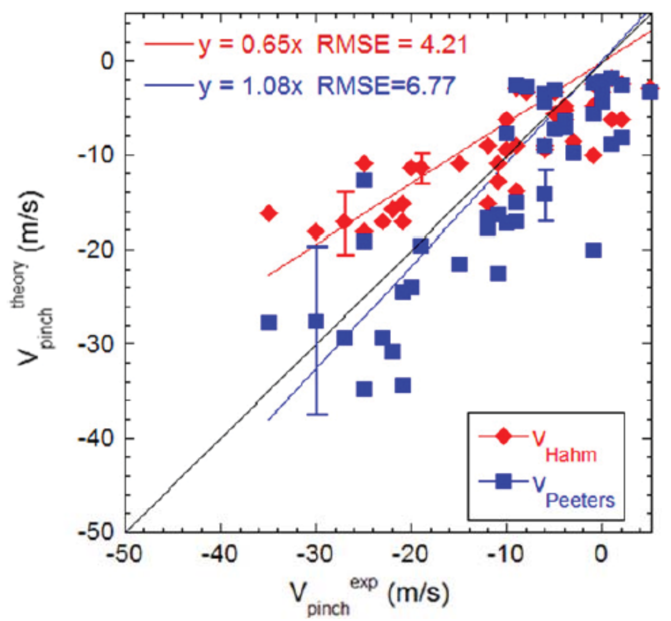
NSTX-U T&T Plan will Address Important Issues in Electron and Ion Thermal Transport (Near-term FY15-16)

- Identify dominate modes in the lower ν_e^* H-mode plasmas of NSTX-U and determine $\chi_i/\chi_{i,neo}$ vs ν_e^* (coordinated with thrust 1)
  - Characterize low/high-k turbulence along as global confinement is varied
- Characterize low/high-k turbulence and thermal transport in isolated regimes of micro-instabilities guided by GK simulations
  - MT/ETG (high/low β and ν_e^* H-mode); ITG/TEM (NBI and RF-heated L-mode)
- BES/reflectometry/polarimetry for CAE/GAE measurements with a range of B_T, I_p, ν_e^* and P_{NBI}, coupled with ORBIT code
- Profile stiffness study from cold pulse propagation with a laser blow-off system and ME-SXR
- Couple with turbulence diagnostics, GK simulations and experimental tools
  - k_θ spectrum (high-k scattering); B fluctuations (polarimeter); zonal flow (BES)
  - Global/local transport trend and turbulence characteristics with GK simulations
  - Profile variations (q and flow) for turbulence and neoclassical transport modification

NSTX Results for Momentum Transport and Intrinsic Torque/Rotation Stimulate Research Plan for NSTX-U

- Effective χ_ϕ from transport analysis found to be anomalous in NSTX H-mode plasmas
- Momentum pinch consistent with some theoretical models involving low-k turbulence
  - Measured by magnetic braking and NBI pulses
  - Not comparison with nonlinear GK simulation yet
- Edge intrinsic torque/rotation showing correlation with pressure/T_i gradient
- 2nd NBI pulses to be used in perturbative experiments for pinch and intrinsic torque measurements
- Need to couple with low-k turbulence measurements and GK simulations



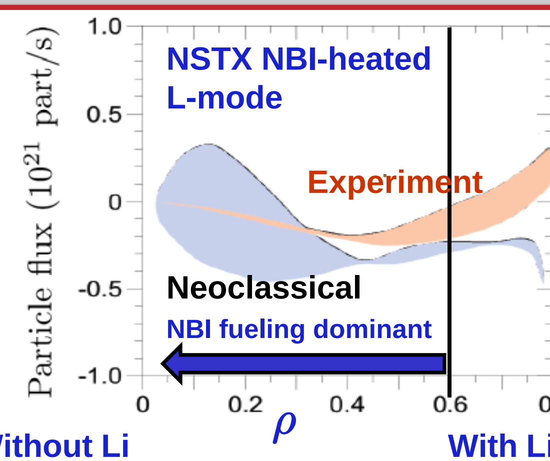


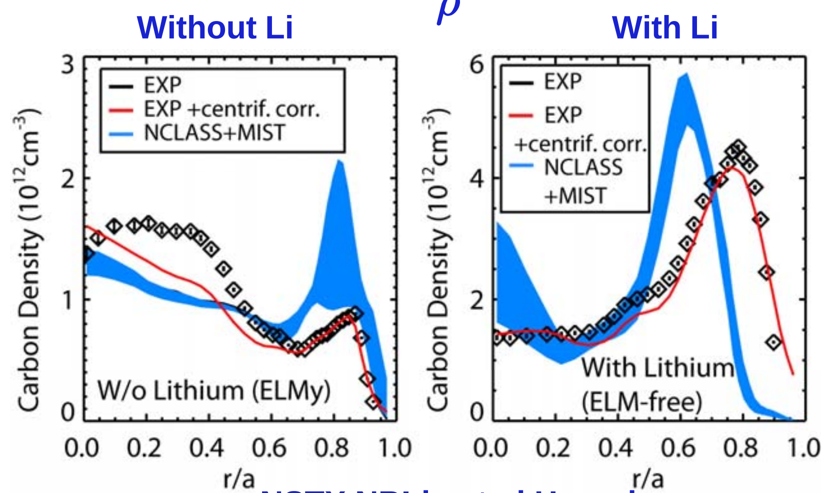
Momentum Transport and Intrinsic Torque/Rotation Studies will have Increased Emphasis in NSTX-U T&T Plan (Near-term FY15-16)

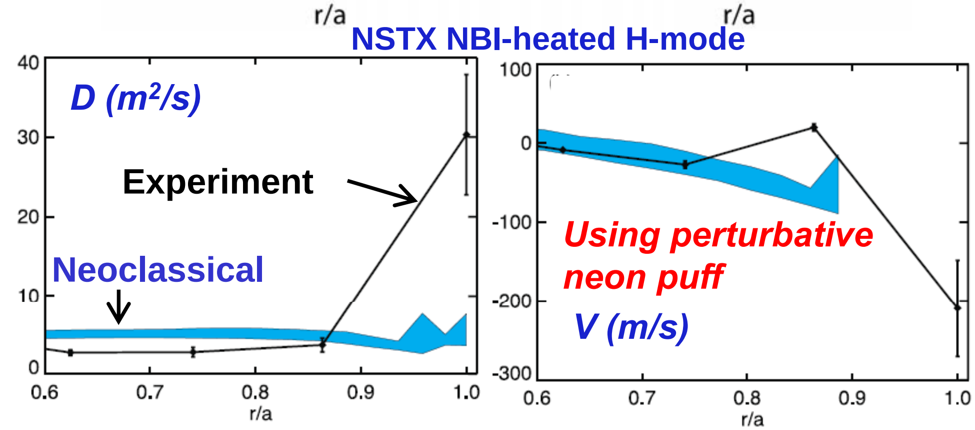
- Characterize χ_ϕ as a function of ν_e^*, B_T and I_P
  - Compare with trends in $\chi_i/\chi_{i,neo}$ and low-k turbulence
- NBI and existing external coils pulses for momentum diffusivity, pinch and intrinsic torque measurements in a variety of regimes
  - Microtearing/ETG regimes, e.g. high/low β and ν_e^* H-mode
  - ITG/TEM regimes, e.g. NBI-heated L-mode
- Vary q and flow profiles ($\hat{s}$, ExB shear) to explore the parametric dependence of χ_ϕ, pinch and intrinsic torque and the correlation with low-k turbulence
  - Use 2nd NBI and existing external coils
- Intrinsic rotation study with passive CHERS in scenarios with negligible external momentum input (RF-heated and ohmic)
- Compare momentum measurements and low-k turbulence with GK simulation predictions

Particle/Impurity Transport is often Consistent with Neoclassical Transport in Core, more Uncertain at Edge

- Main ion transport studied in L-mode with particle balance analysis using TRANSP
  - Where NBI fueling dominant (ρ<0.6)
  - Particle transport close to neoclassical, but ion thermal is anomalous
  - Will we still see this in NSTX-U?
- Core C^{6+} profile shape consistent with local neoclassical calculation (NCLASS and NEO)
  - Larger departure from neoclassical at edge with Li than w/o Li
  - Global neoclassical in future (GTC-neo)
- Neon transport close to neoclassical calculations in core
  - Deviate from neoclassical diffusion in the edge possibly due to turbulence (w/ BP TSG)







Particle/Impurity Transport Studies will be Explored in the Lower Neoclassical Transport Regime of NSTX-U (Near-term FY15-16)

- Compare particle/impurity transport with neoclassical transport as NSTX-U reaches lower ν_e^* with increased B_T, I_P and P_{NBI}
  - Trace-impurity V and D with perturbative neon puff
  - Carbon/lithium with CHERS measurements
  - High-Z impurity with the laser blow-off system and metal PFC
  - Coupled with impurity transport codes
  - Main ion transport studies through steady-state analysis, coupled with modeling (DEGAS2) and measurements of edge neutral source
- Similar experiments in isolated regimes of micro-instabilities
- Vary q, $\hat{s}$ and ExB shear to alter neoclassical transport and low-k turbulence and to explore parametric dependence of particle/impurity transport
- Compare anomalous particle/impurity transport with GK calculations and correlate it with low-k turbulence measurements

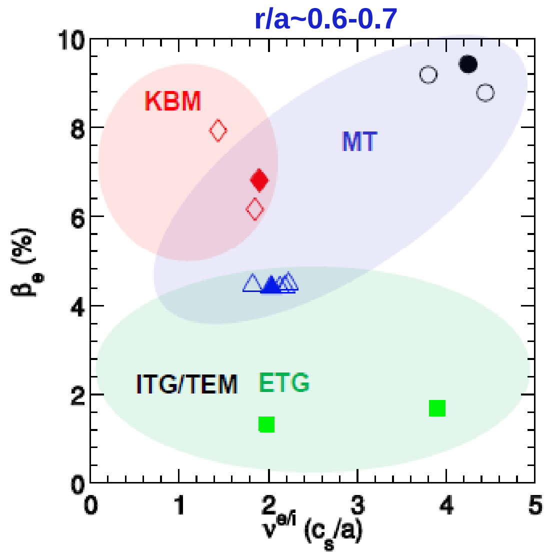
Long-term (FY17-18) NSTX-U T&T Plan to Address Thrust 2

- Identify operational regimes of ETG, microtearing, CAE/GAE and ITG/TEM/KBM modes for thermal transport
- Identify low-k turbulence responsible for momentum transport/ intrinsic torque and particle/impurity transport and its operational regimes
- Facilitated by further NSTX-U facility enhancements
  - More high-Z tiles for impurity transport
  - Decouple ν_e^* and ρ^* dependence with density control from cryopump
  - Better inter-machine experiments for R/a scaling from B_T enhancement
  - Partial NCC modification of flow profile and flow shear
- Expanding turbulence and transport parametric dependence
  - β, ρ^* (density control from cryopump), T_i/T_e (RF heating) and Z_{eff} (impurity control techniques), using full engineering capability of NSTX-U
- Emphasize transport and turbulence in long pulse fully relaxed and fully non-inductive scenarios
- Move towards an integrated and self-consistent understanding of all transport channels simultaneously

Thrust 3: Establish and Validate Reduced Transport Models

NSTX-U T&T 5 Year Plan Aims to Deliver Reduced Transport Models

- Reduced transport models are required deliverables to meet the goal of achieving predictive capability for performance of next generation STs and ITER

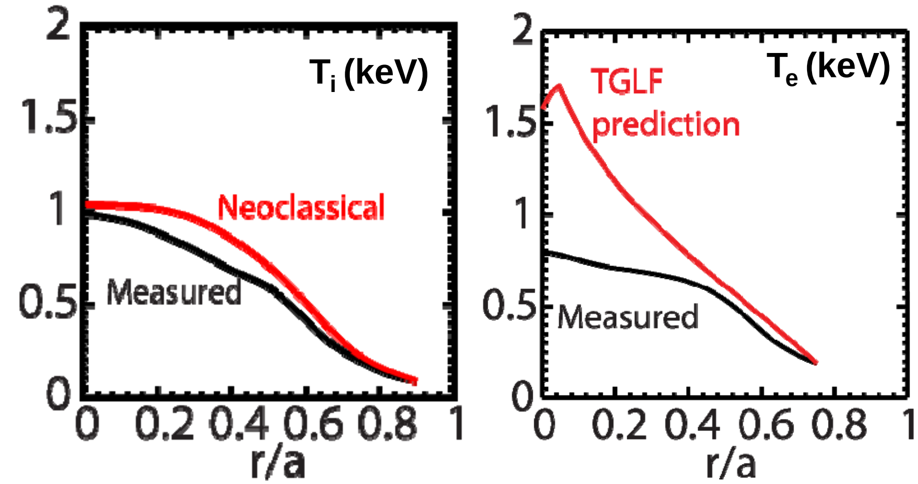


- NSTX-U will allow validation of transport models over a broad range of parameters, e.g. R/a, β, ν
  - Wide range of theoretical mechanisms to consider
  - More comprehensive validation of physics models being used for conventional aspect ratio tokamaks and ITER

- Emphasis throughout 5 years will be on predictive transport simulations using TRANSP and TGYRO coupled with core transport models:
  - Neoclassical (NC) (Chang-Hinton model, NCLASS, NEO)
  - Drift wave (DW) (TGLF, MMM08, …)
  - Energetic particle (EP) driven χ_e (stochastic ORBIT model)
- Additional emphasis on validating NC, DW & EP models with first principles simulations (GTC-neo, gyrokinetics & HYM, respectively)

FY15-16 Modeling will Focus on Ion and Electron Thermal Transport at Expanded I_p, B_T and P_{NBI}

- Predict T_e & T_i profiles using neoclassical and drift wave models and compare with NSTX-U profiles
  - Clarify the regime of validity of neoclassical model for ion thermal and impurity transport
  - Validate drift-wave-based models and identify their deficiencies for predicting core T_e



- Validate drift wave models with linear and nonlinear GK, focusing on:
  - Linear instability regimes, e.g. TEM/MT/KBM, scaling and thresholds
  - Nonlinear electron & ion heat flux scaling for the different mechanisms
- Consider developing semi-empirical or analytic models based directly on GK simulations
  - Depending on quantitative success of available DW models
- Develop model $\chi_{e,EP}$ based on ORBIT simulations using measured CAE/GAE mode structures (w/ EP TSG)

FY17-18 Long Term Plans will Focus on Complete T_e Profile Prediction for Low Collisionality & Advanced Scenarios

- Validate predictions at lowest collisionality accessible with cryopump and advanced scenario development
  - Integrate analytic $\chi_{e,EP}$ model into TRANSP predictions for core T_e profile
  - Non-linear HYM simulations for first principles GAE/CAE spectra for ORBIT $\chi_{e,EP}$ modeling

- Depending on success of T_e, T_i predictions:
  - T_e, T_i, τ_E predictions for future device, e.g. ST-FNSF, Pilot
  - Integrated scenario predictions (consistent equilibrium & q profile evolution) for fully relaxed and fully non-inductive scenarios
  - Predict density and rotation profile (n, Ω)

- Investigate non-local core effects using global gyrokinetics
  - Relatively large ρ^* in NSTX-U, possible turbulence spreading into near-axis region
  - Pursue heuristic model to incorporate non-local effects

- When feasible move to core/pedestal full-F simulations, e.g. XGC1 to investigate possible non-local influence from pedestal to core region (w/ BP TSG)

Summary: NSTX-U T&T Research will Provide Physics Basis Leading to Predictive Capability for Transport in Future ST/AT Devices

- Stimulated by the results from NSTX, the proposed T&T research thrusts for NSTX-U aim to address
  - H-mode global energy confinement
  - Transport mechanisms and their operational regimes
  - Establishment and validation of reduced transport models
- A set of turbulence diagnostics coupled with a comprehensive set of data analysis and simulation/modeling tools will greatly facilitate achieving the research goals
  - BES, reflectometry, polarimetry and high-k_θ scattering system
  - TRANSP, GYRO, GTS, XGC1, NEO, GTC-NEO etc.
- FY15 NSTX milestone well suited for providing an initial assessment of confinement performance in expanded regime of NSTX-U

Backup Slides

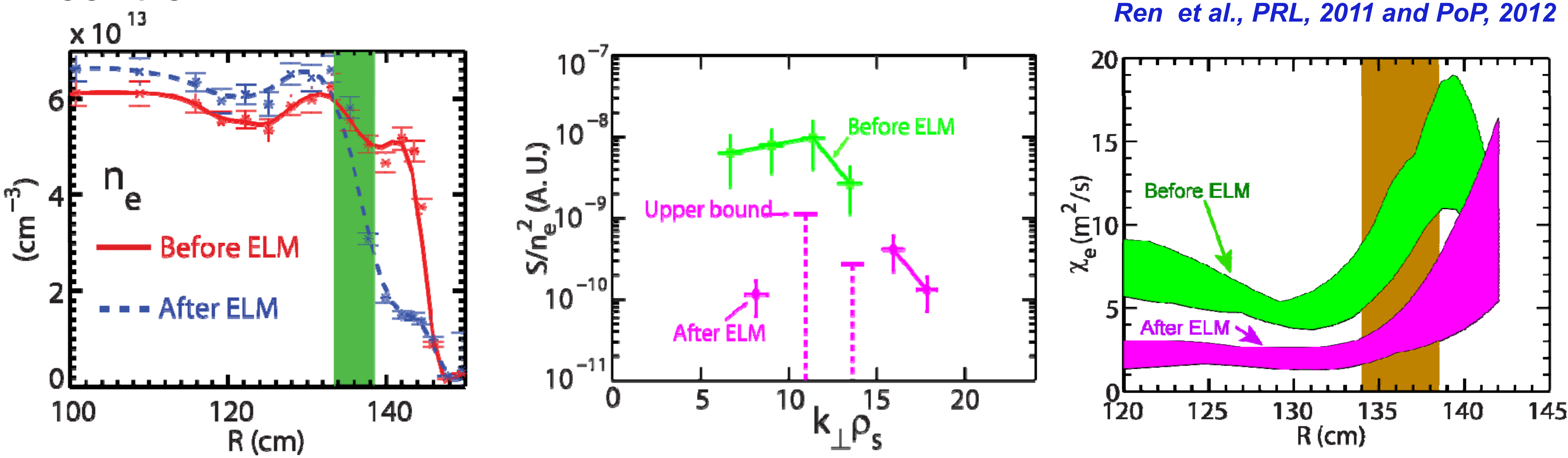
NSTX-U Plans Towards PAC31 T&T Recommendations

PAC31-34	In the framework of gyrokinetic modeling of turbulence, it is suggested to move towards increasingly realistic simulations, including the impact of rotational shear on micro- tearing, the impact of an additional C impurity species in conditions of experimentally measured large effective charges, and consider the impact of these effects on the collisionality scaling, particularly in the case that correlations between parameters are present in the experiments	NSTX-U T&T TSG gyrokinetic modeling activities have already taken initiatives in the "increasingly realistic simulations" suggested by the PAC, e.g. recent nonlinear simulations of microtearing modes in NSTX H-mode plasmas on the collisionality scaling and ITG modes in NSTX NBI-heated L-mode plasmas on ExB shear effect. Experiment and simulation comparison is an essential element of the NSTX-U T&T 5 year plan. Using realistic experimental profiles and including essential physics in gyrokinetic simulations are crucial for the comparison. This is facilitated by the continuously increasing computational power and improvement in gyrokinetic codes.
PAC31-35	Comparison between conditions in which neoclassical transport is expected to produce a significant amount of ion heat transport with conditions in which this is estimated to be smaller with respect to power balance transport levels (e.g. comparisons among L-modes and H-modes) is potentially helpful in this direction.	We have observed anomalous ion thermal transport in NSTX NBI-heated L-mode plasmas and found that ITG modes may be responsible using linear and nonlinear gyrokinetic simulations. This is in contrast to H-mode plasmas where strong ExB shear usually suppresses low-k turbulence. NSTX-U T&T research has explicit plans to study ion thermal transport in comparison with neoclassical transport in both L and H mode plasmas and the effect of ExB shear will be studied using flow profile modification capability from the 2nd NBI.
PAC31-36	Strongly connected to these research activities, it is suggested to progress towards increasingly accurate calculations of neoclassical transport, establishing the domain of applicability of conventional theory (e.g. the NCLASS and the NEOART codes), in particular with respect to the magnitude of the poloidal Larmor radius and of the impurity rotation velocity, and performing comparisons within a hierarchy of neoclassical models, including, in addition to NCLASS or NEOART, also codes like NEO and XGC0. The application of such a hierarchy of models/codes to observations of ion heat and impurity transport is of extreme interest (size of ion heat conductivity, of impurity diffusivity, and size of impurity convection to diffusion ratio).	Local neoclassical codes, NCLASS and NEO, are being extensively compared in the context of impurity transport in NSTX. It is found that NCLASS and NEO calculations for impurity transport generally agree except in the situations with strong toroidal flow where centrifugal effect has to be taken into account. Comparison with global neoclassical code, GTC-NEO, will be carried out for NSTX plasmas. In NSTX-U T&T plans, NCLASS, NEO and GTC-NEO will be used to calculate neoclassical transport in a variety of regimes and with different plasma parameters, and their regimes of validity will be assessed.
PAC31-37	It is suggested to consider the development of a model for *AE induced electron heat transport already during the outage phase (in collaboration with the TSG on Energetic Particles) to be tested against past NSTX results and to be applied then to NSTX-U.	There is a plan in FY14 to make the first attempt to predict core electron thermal transport in NSTX-U by coupling ORBIT code with HYM CAE/GAE mode calculations.
PAC31-38	Finally, in order to be ready for the exploitation of NSTX-U, the preparation of diagnostics for turbulence and transport analyses plays an important role. These diagnostics require good profile measurements, including also current density/safety factor profile (e.g. MSE-LIF) and impurity transport (e.g. ME-SXR) and multi-scale multi-field fluctuation measurements (FIR high-k? scattering, BES, polarimetry, reflectometry). When this is deemed necessary, it is suggested to verify that these diagnostics will have the appropriate radial coverage and spectral range for fluctuation measurements in the expected NSTX-U scenarios.	One important aspect of NSTX-U T&T 5 year plan for FY14 is to prepare turbulence and transport diagnostics for NSTX-U operation, e.g. a FIR high-k scattering system, BES, polarimetry, reflectometry and ME-SXR (MSE-LIF diagnostic was installed on NSTX [tested in neutral gas] and will be tested in plasma once NSTX-U is in operation.) Some modeling has been done to calculate diagnostic spatial and/or spectral coverage in NSTX-U scenarios, e.g. for the FIR high-k scattering system. Additional modeling will be carried out for the preparation of the diagnostics.
PAC31-39	During NSTX-U operation, the PAC suggests that high priority be given to establishing the impact of low collisionality, high beta, and rotation on confinement and to related modeling/validation of theory based transport models and turbulence simulations	The priority is set as the PAC suggested. The thrust 1 of NSTX –U T&T 5 year plan is specifically to characterize H-mode global energy confinement scaling in the lower collisionality regime of NSTX-U. The 2nd NBI will allow us to vary flow profile and achieve high beta and their effects on confinement will assessed. Reduced transport modeling and gyrokinetic simulations will be carried out and compared with experiments.

Density Gradient Stabilization of High-k Turbulence was Identified

- Provided the first experimental evidence of density gradient stabilization of high-k turbulence
- Correlated with a factor of about two decrease in electron thermal diffusivity
- Consistent with theoretically predicted increase in critical electron temperature gradient for ETG modes due to density gradient
- A possible way to stabilize/mitigate ETG turbulence by density profile control

Ren et al., PRL, 2011 and PoP, 2012



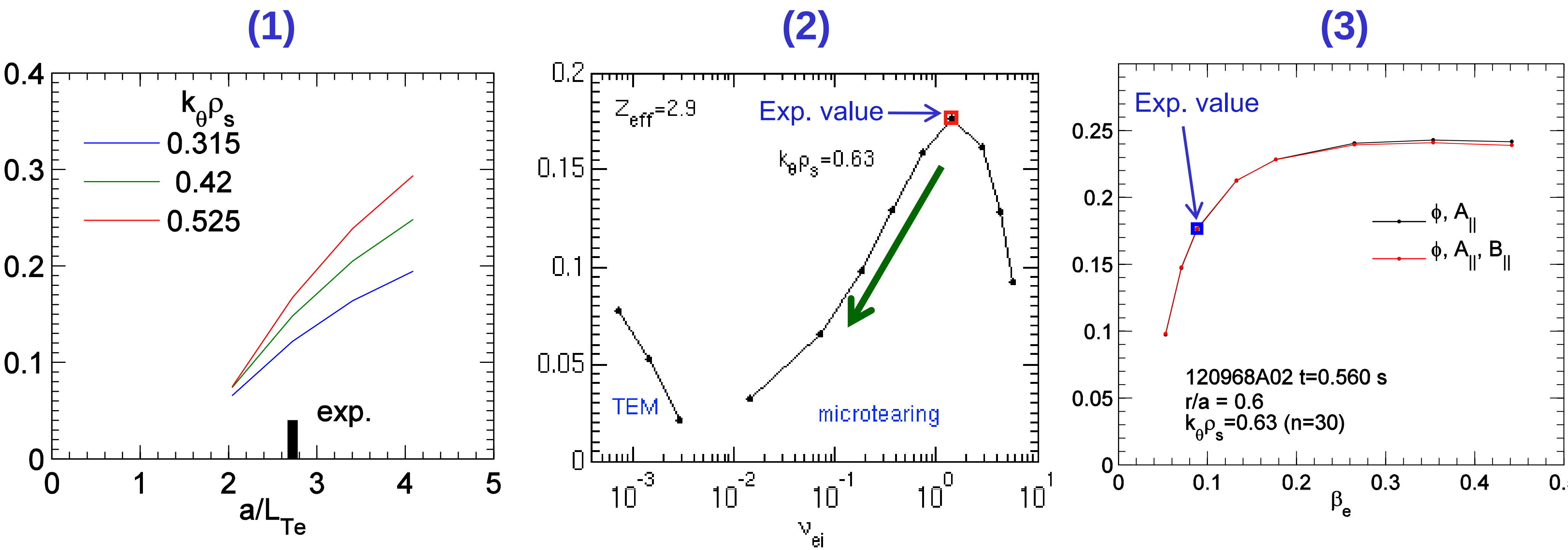
Microtearing Instability Exhibits Thresholds in Electron Temperature Gradient, Collisionality and Beta

(1) Apparent threshold in ∇T_e, $(a/L_{Te})_{crit} \approx$1.3-1.5 ($a/L_{Te,exp}$=2.7)

(2) Growth rates decrease with $\nu_e < \nu_{e,exp}$ (consistent with experimental ν_* scan)

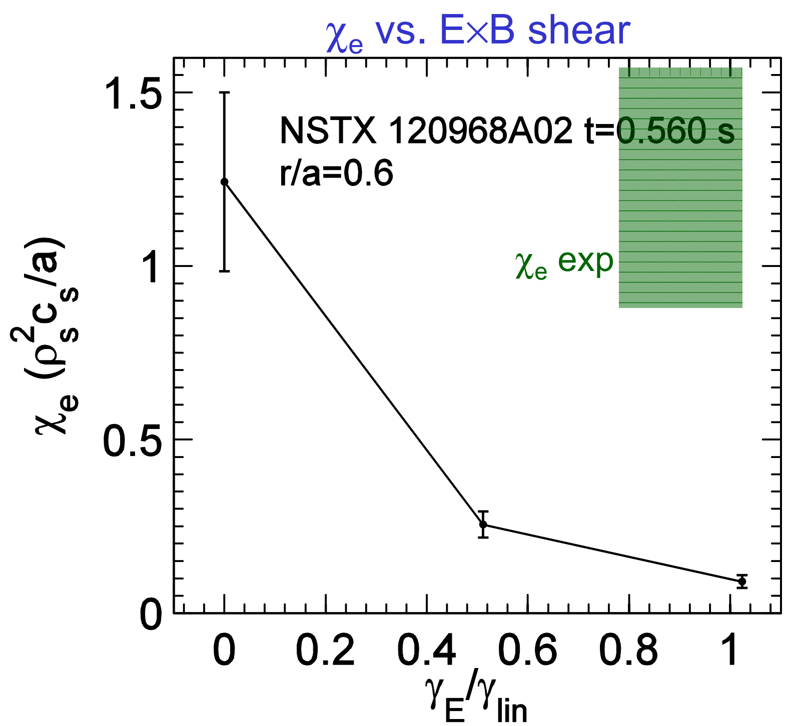
(3) Lowering beta stabilizes microtearing

Linear growth rates ($\gamma \cdot a/c_s$) for NSTX 120968 t=0.56 s r/a=0.6



Nonlinear Microtearing Transport Comparable to Experimental Transport*

- With no E×B shear predicted transport (1.2 $\rho_s^2 c_s/a$) comparable to experimental transport (1.0-1.6 $\rho_s^2 c_s/a$)
- Transport reduced when increasing γ_E to local experimental value

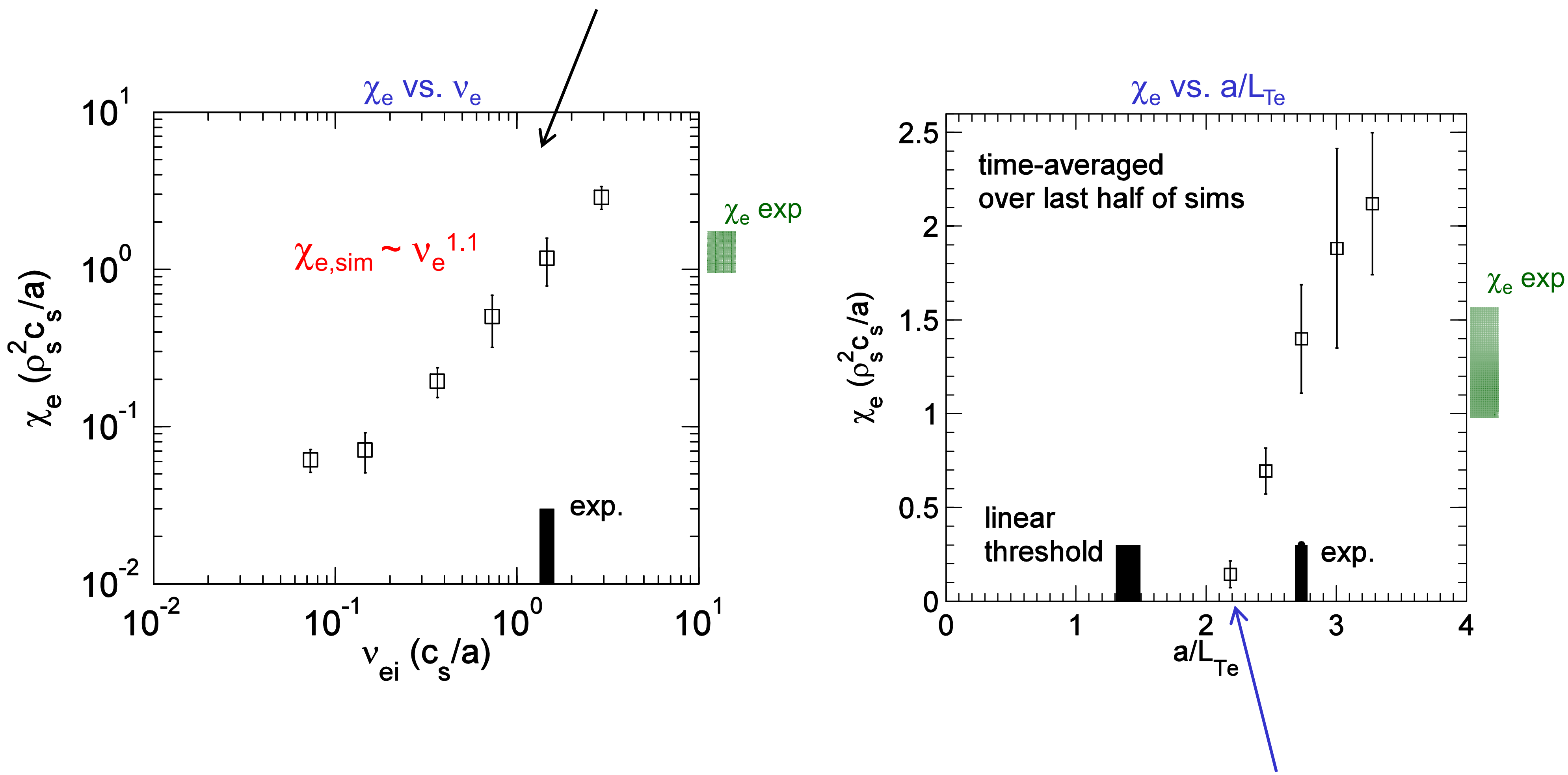


$\rho_s^2 c_s/a = 5\ m^2/s$

- What are the other important dependencies?

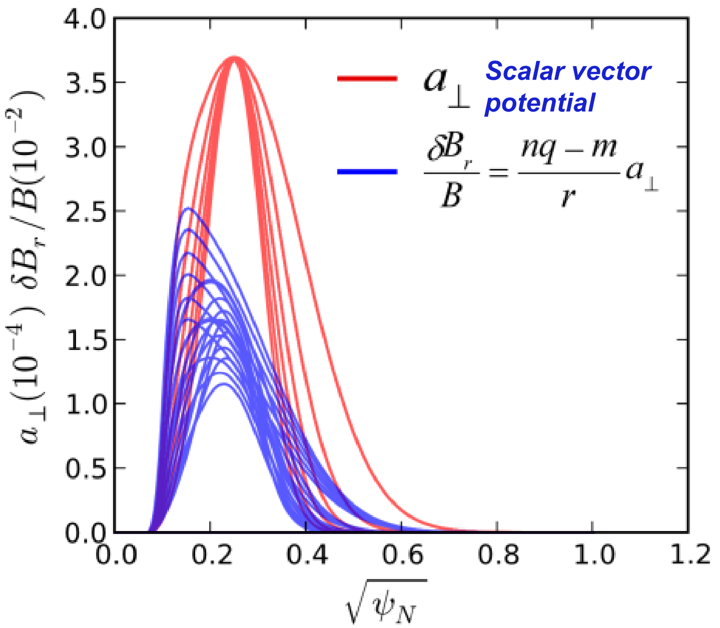
*Guttenfelder et al., submitted to PRL (2010)

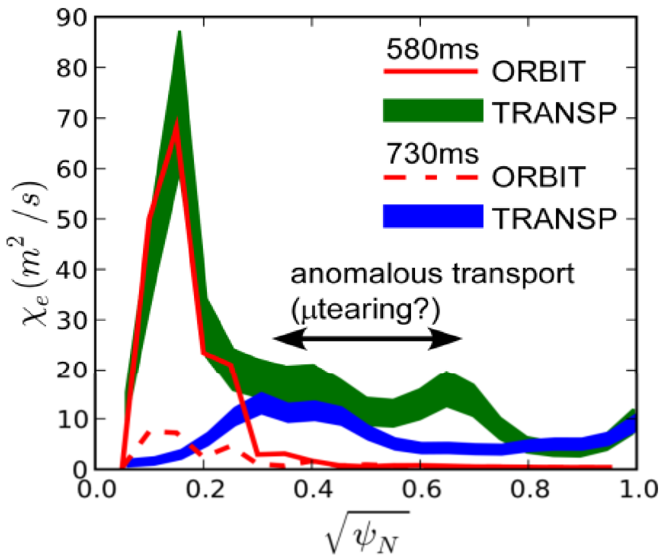
Predicted Non-linear Collisionality Dependence Consistent with Experimental Scaling

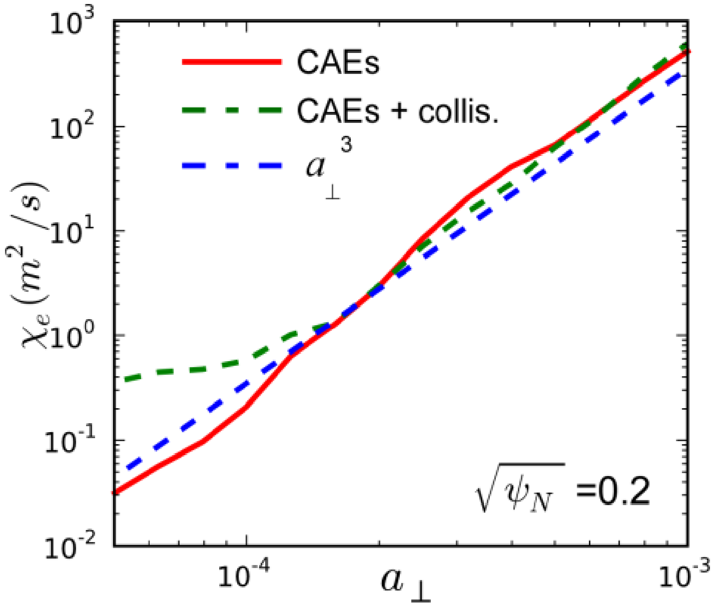


- Transport very sensitive to ∇T_e - may be more important to characterize scaling of effective threshold gradient, $(a/L_{Te})_{crit,microtearing}$
- Might help distinguish from expected ETG scaling, $(a/L_{Te})_{crit,ETG}$ – work in progress

ORBIT Guiding Center Code Used to Simulate CAE/GAE Effects on Electron Thermal Transport



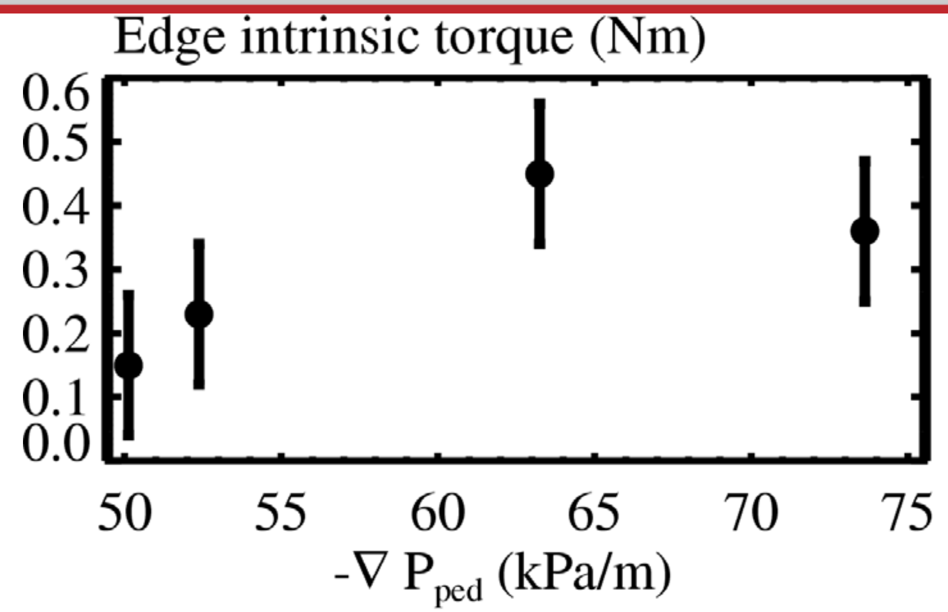




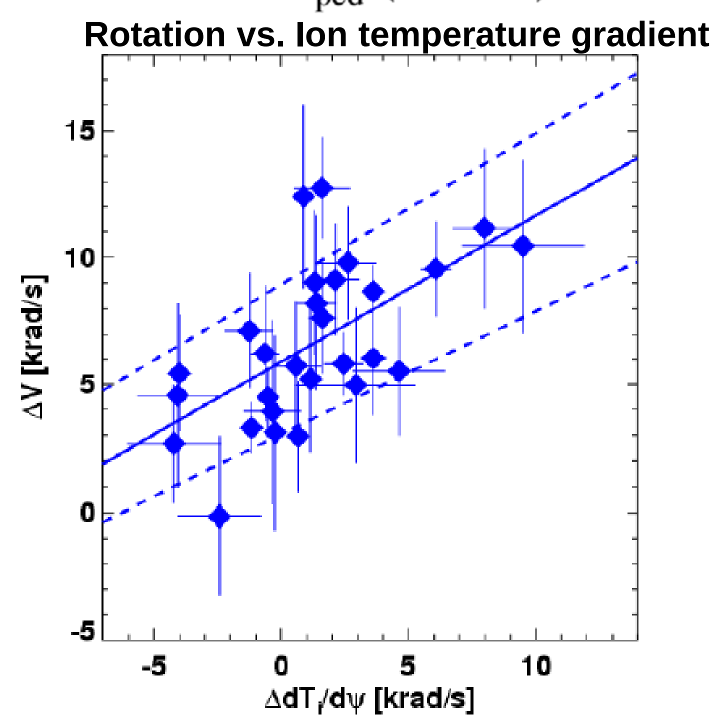
- A Gaussian radial structure for the CAE modes is chosen to match the experimentally measured mode peak location and width
- Frequencies and toroidal and poloidal mode numbers are determined using measurements and theoretical dispersion equations
- ORBIT simulations predict a strong scaling of transport with mode amplitude (~ $a^{3\text{-}4}$)
- CAE & GAE modes combined can produce high levels of electron transport (~70 m^2/s) for r/a < 0.2 at t=580 ms
- Predicted transport is much lower at t=730 ms as the number of CAE modes appears to decrease

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



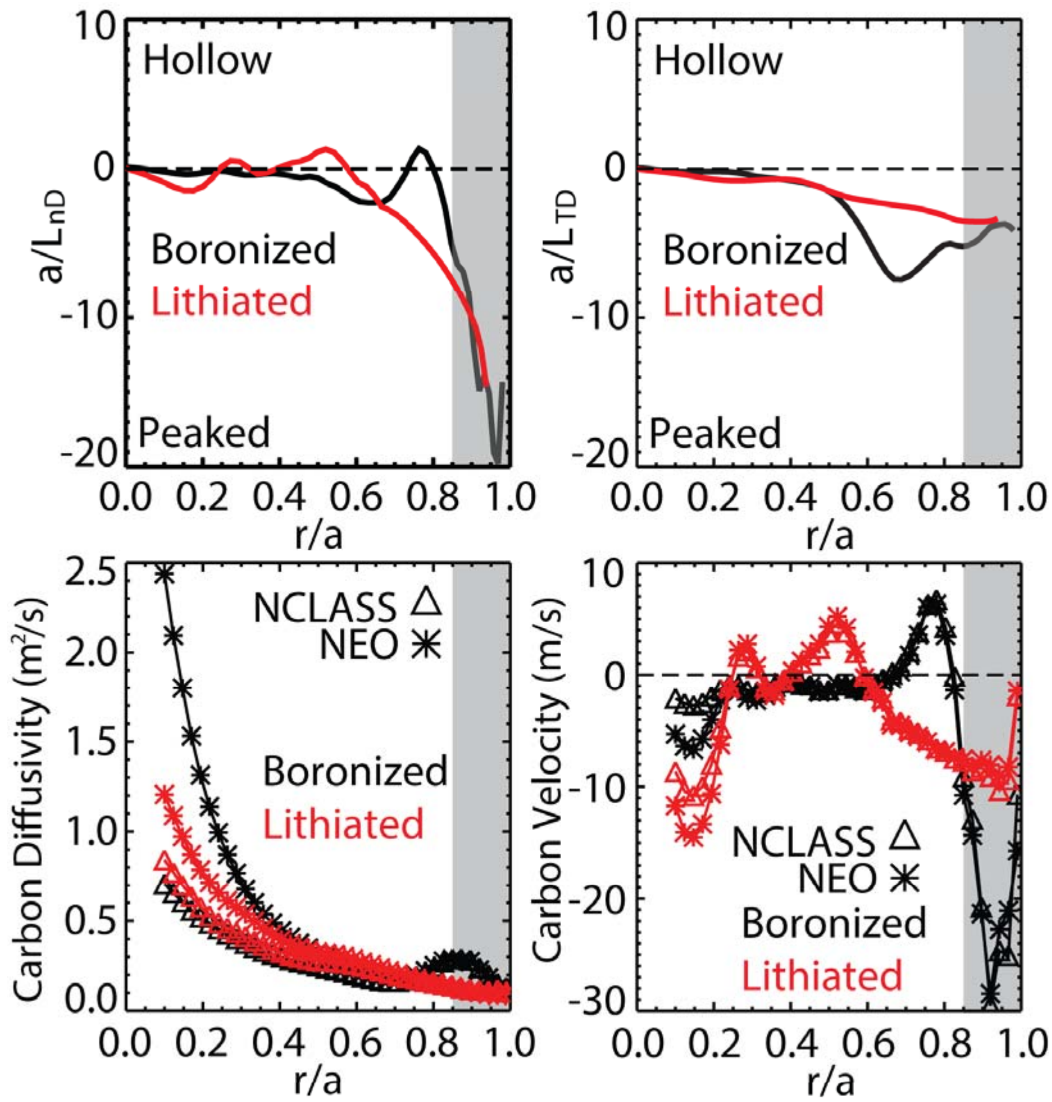
- Edge intrinsic rotation shows better correlation with T_i gradient (TC-9)
  - Measured on pedestal top through Ohmic L-H transition with passive CHERS
  - Zero input torque, small NTV torque and transport effect
  - No correlation found with T_e and n_e gradients



Changes in Main Ion Profiles with Lithium Conditioning Lead to Changes in Carbon Neoclassical Transport

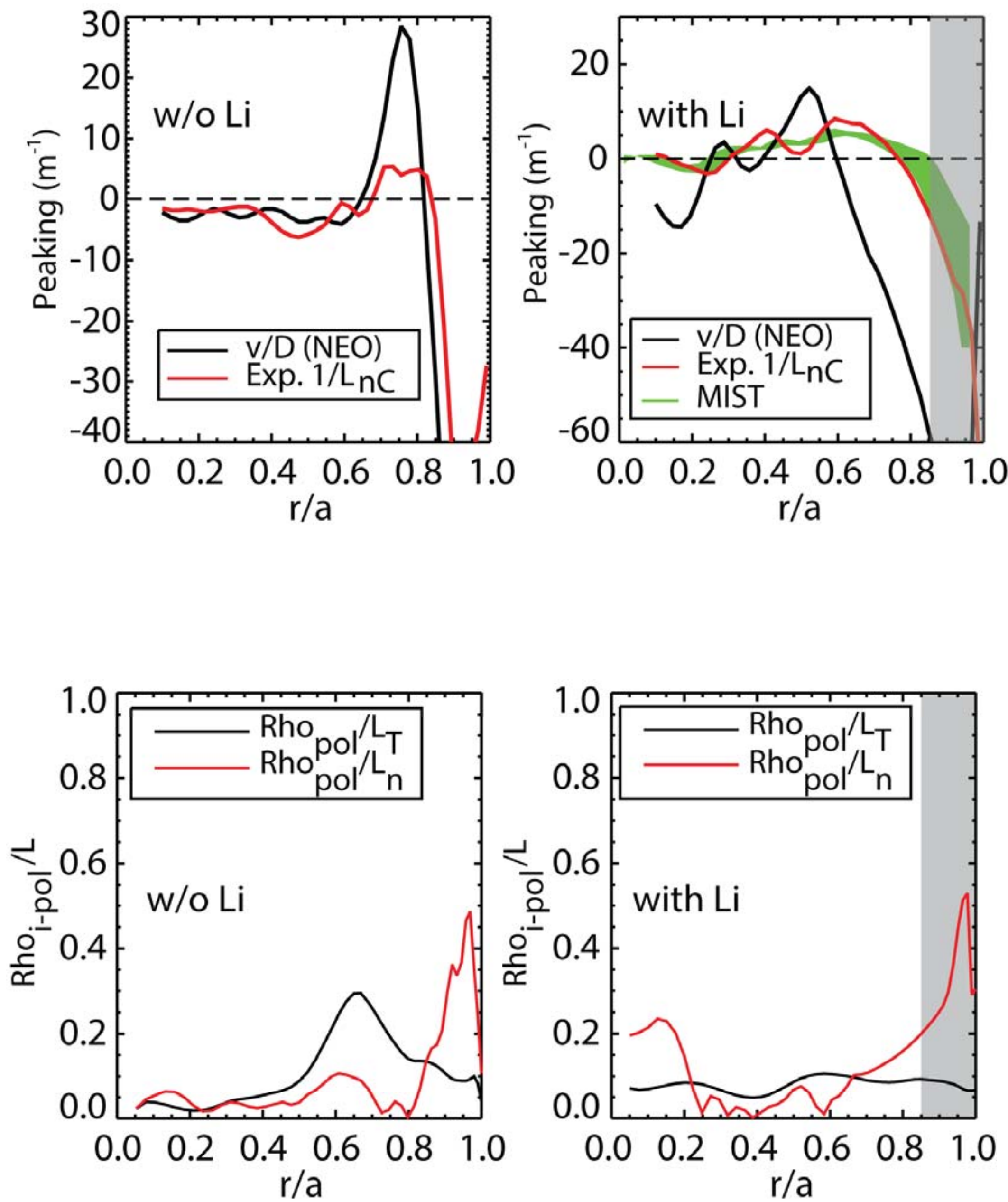
With lithium conditioning:

- Change in n_D and T_D profiles
  - Wider edge inward convection, 0.6 < r/a < 1.0
  - Increased core inward convection
  - Reduction in edge diffusivity
- Consistent results obtained using NCLASS and NEO:
  - Differences observed only in regions with large toroidal rotation
  - Comparable impurity peaking factors



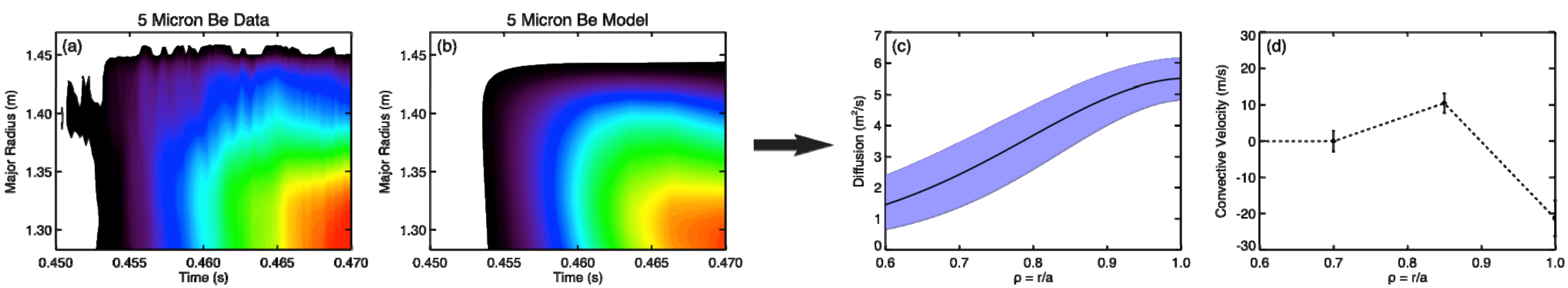
In lithium Conditioned Discharges Residual Anomalous Transport is Needed to Explain Carbon Profiles

- In steady state, source free, peaking $L_{nz}^{-1} \sim \frac{v_{exp}}{D_{exp}}$
- With boronized PFCs, carbon close to neoclassical predictions:
  - weaker edge peaking observed due to ELM flushing
- With lithium conditioned PFCs, qualitative agreement found:
  - outward convection region [0.2<r/a<0.6] and strong edge pinch
- Anomalous outward convective transport needed at pedestal top
  - Neoclassical ordering are only marginally applicable
- Consistent with deviations of ion thermal transport from neoclassical (Kaye, IAEA 2012)



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***