NSTX

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NSTX Transport and Turbulence Research Plan Overview

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Howard Yuh, Nova Photonics

Stan Kaye, PPPL

and the NSTX Research Team

NSTX PAC-27
PPPL, Room B-318
Feb 3-5, 2010

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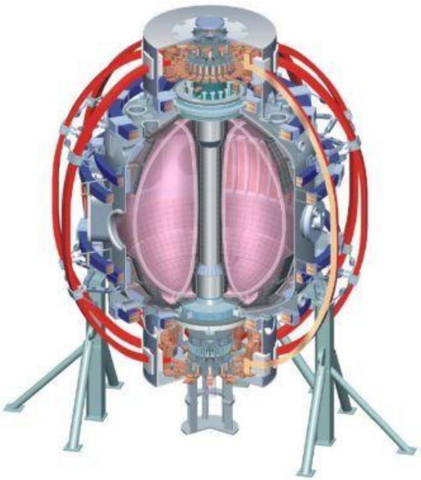
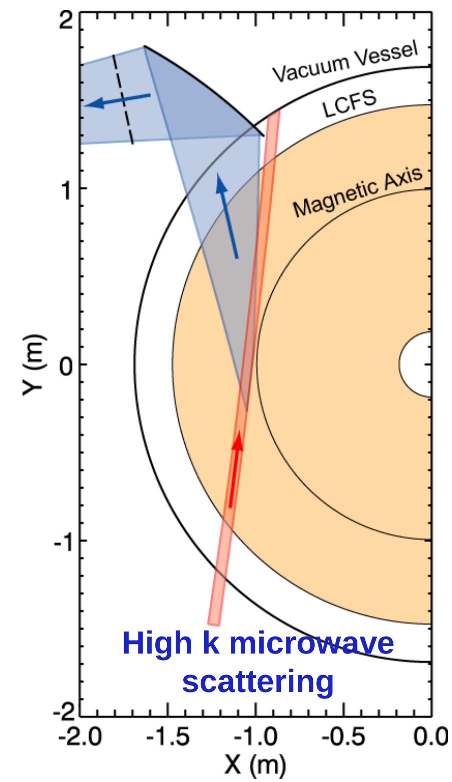


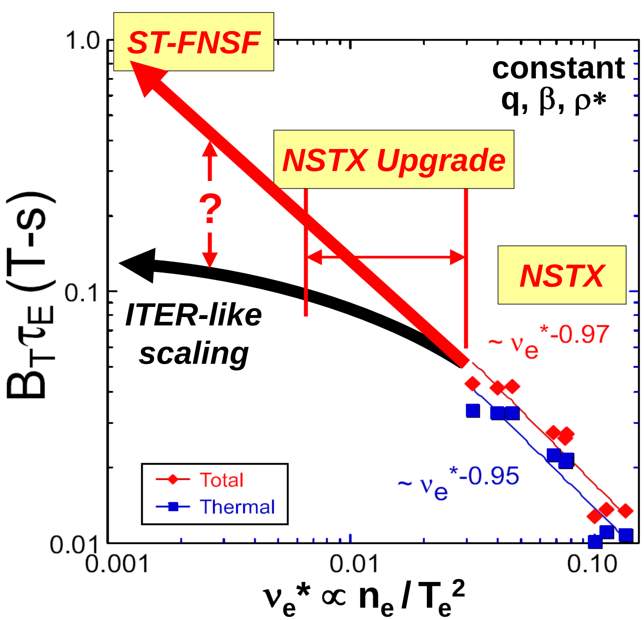
Overview Outline

- Motivation for research priorities
- Recent results
- 2010 T&T research priorities and ITPA involvement
- New diagnostic capabilities
- 2011 Milestone
- 2012 Milestone
- Summary

Understanding electron thermal transport is a top priority for both ST and tokamak programs

- ST has unique physics regime which can provide new insights into transport physics
  - high β, strong E×B flow shear, large ρ_e
  - high-k scattering diagnostic for electron gyro-scale fluctuations
- Transport mechanism understanding for tokamaks, especially for electrons, is limited
- NSTX can achieve neoclassical ion transport due to strong rotational flow shear, but electron transport is anomalous and high

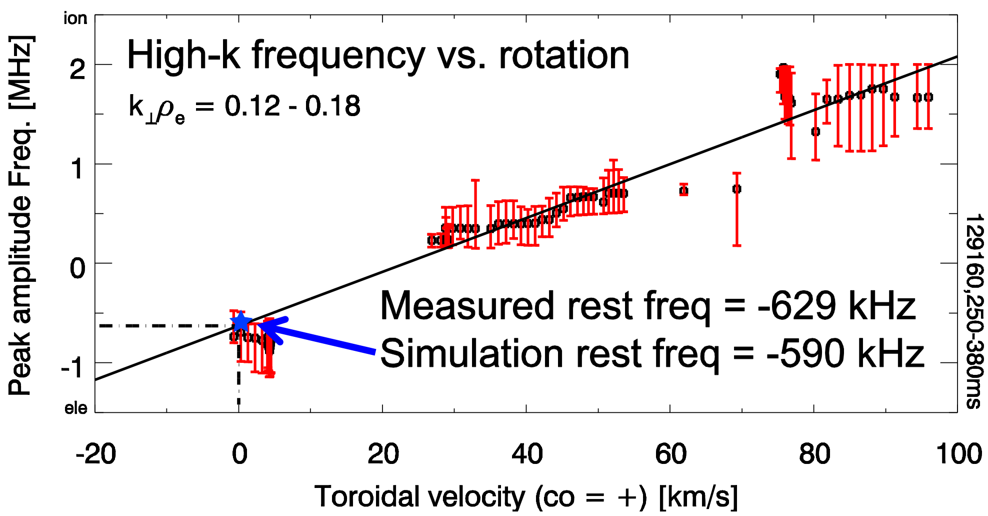




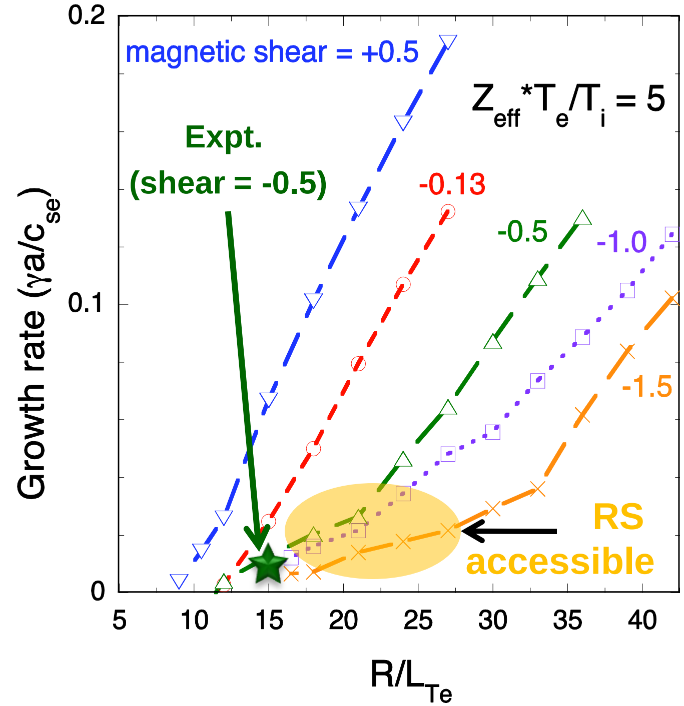
- Additional understanding of ST transport at low collisionality is required for future devices
- LLD will allow study of transport and turbulence in the low collisionality regime

ETG believed to be important for driving anomalous electron transport

- ETG mode has been identified by comparing linear growth rate and rest frequency of measured fluctuations to linear GS2/GYRO calculations
- ETG in e-ITB found to be suppressed by reversed magnetic shear, allows access to supercritical electron temperature gradients



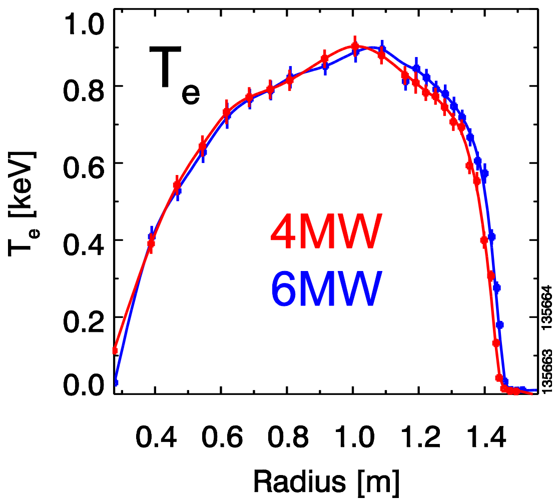
Rest frequency of peak amplitude mode measured by subtraction of Doppler shift due to plasma rotation

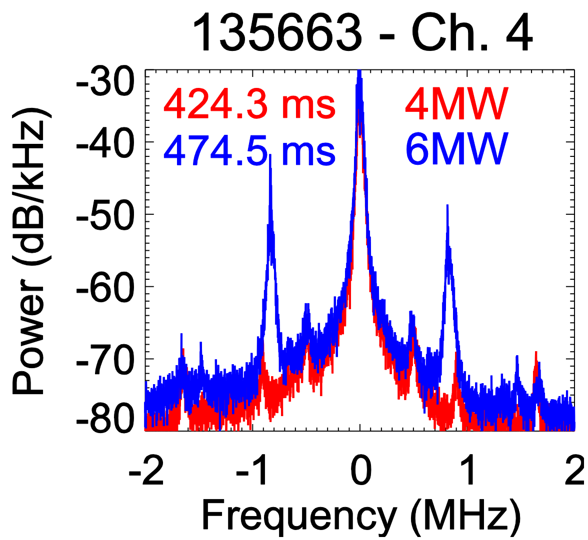


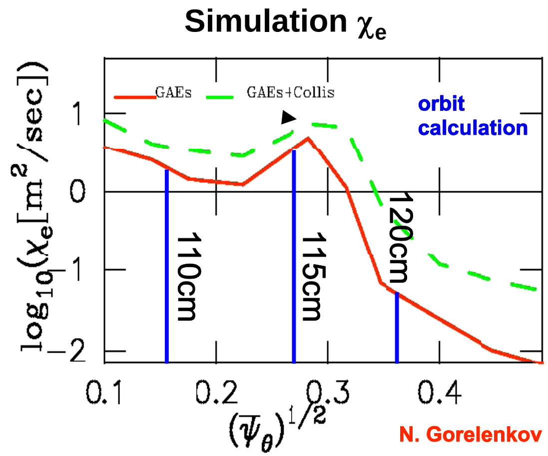
Linear GS2 / GYRO simulations of ETG mode growth rates are consistent with high-k measurements

PAC25-22

Density fluctuations at GAE frequency increases with higher fast ion drive in NBI-heated positive shear H-modes







- Core T_e shows no increase with additional beam power
  - Core thermal diffusivity appears to be driven by fast ion density (Stutman, PRL 2009)
  - Core T_e gradients are ETG subcritical
- High-k in interferometric mode has measured increased fluctuations coincident with increased beam power
  - GAE (Global Alfvén Eigenmode) is driven by super-Alfvénic ions
- ORBIT calculations show GAE driven by beam ions can cause substantial core electron transport, but radial fluctuation profiles to benchmark transport
- Radial scan from high-k and upgraded bandwith FIReTIP in 2010

PAC25-22

T&T research priorities for FY10

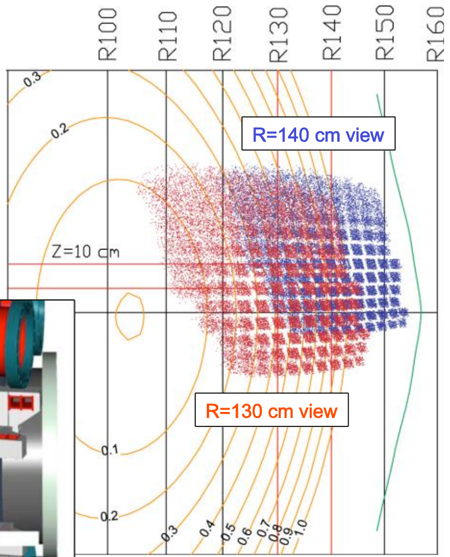
- Investigate the mechanisms governing ion and electron transport (5 days)
  - Investigate effect of flow shear, T_e/T_i, magnetic shear, GAE, collisionality, on turbulence and transport
  - [TC-10] Experimental identification of ITG, TEM and ETG turbulence and comparison with codes
  - [TC-12] H-mode transport and confinement at low aspect ratio
- L-H transition physics (1.5 days + 1 from ITER high priority)
  - [TC-2] Power ratio - hysteresis and access to H-mode with H~1
  - [TC-4] H-mode transition and confinement dependence on ionic species
- Momentum transport and intrinsic rotation (1 day)
  - Role of ITG in driving momentum transport
  - [TC-9] Scaling of intrinsic plasma rotation with no external momentum input
- Particle/impurity transport
  - Fluctuation measurements will be made leveraging experiments in other task groups to provide valuable results to understanding of plasma response to changes to LLD

In 2010, new NSTX diagnostics extend wavenumber and spatial coverage of turbulence and transport measurements

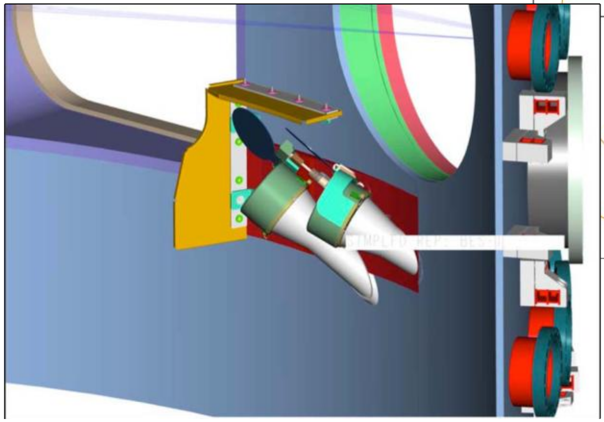
- BES (**B**eam **E**mission **S**pectroscopy)
  - 2 viewing optic sets necessitated by steep NSTX pitch angles
  - First light, commissioning, calibration, in 2010
  - Low-k turbulence measurements continues in 2011

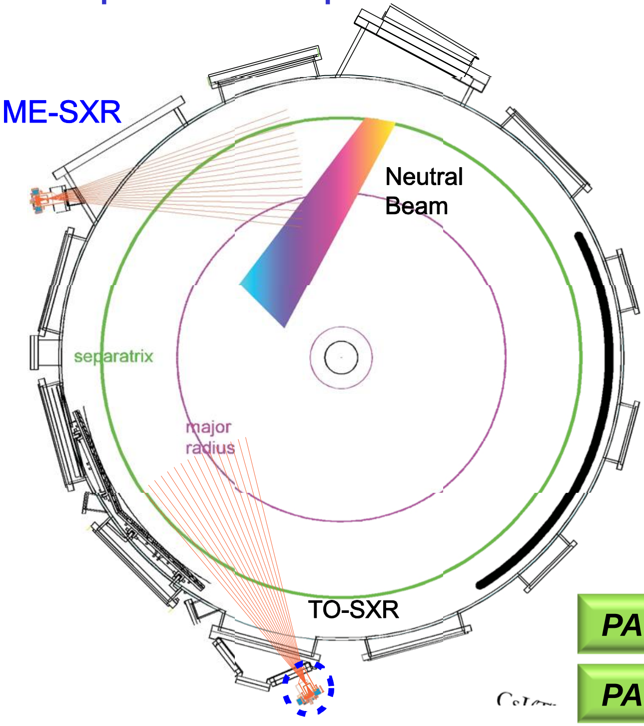
- ME-SXR (**M**ulti-**E**nergy **S**oft **X**-**R**ay array)
  - Prototyped in 2009, full system 2010
  - Fast measurements of n_e, T_e, n_{imp} edge profiles using 5 energies
  - Will measure edge plasma fluctuations changes during different LLD operational phases

BES sightlines cover most of outboard plasma



CAD rendering of dual BES vacuum side optics





PAC25-19

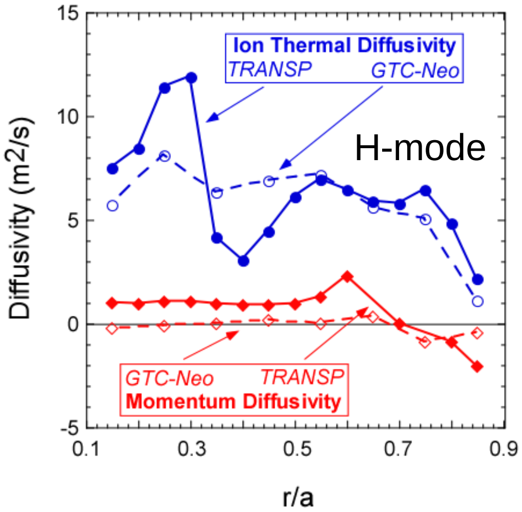
PAC25-20

Upgraded NSTX fluctuation diagnostics complement existing suite to allow detailed measurements of turbulence and transport

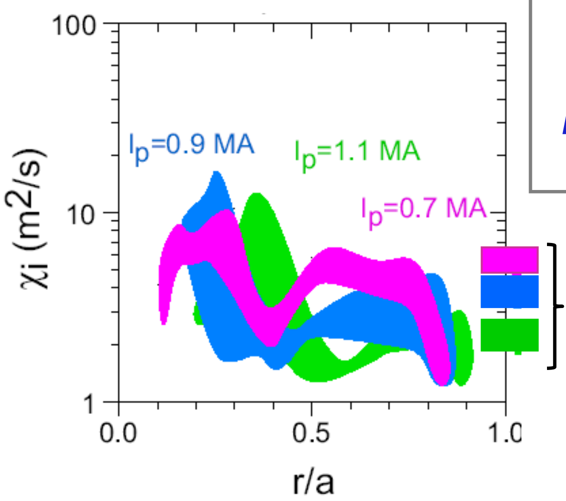
- High-k microwave scattering will have higher availability
  - Problems in 2009 with source have been repaired, additional personnel supporting diagnostic
  - Backup and solid state source are in hand
- 2012 NSTX-U NB upgrade displaces high-k_r diagnostic
  - Optimize high-k usage in 2010-2012
  - Initial planning for replacement high-k_θ diagnostic underway
- FIReTIP (**F**ar **I**nfra**R**ed **T**angential **I**nterferometer/**P**olarimeter) frequency response upgraded (from 0.25 MHz to >3MHz)
  - GAE frequencies (0.5-1MHz) can now be measured using multichord FIReTIP
- Frequency-modulated continuous-wave, poloidal correlation reflectometer
  - Hardware extensively tested in 2009, full profile fluctuation measurements, careful scheduling will make full use of limited availability due to competing demand for alternate configurations of reflectometer hardware
  - Can measure radial profile of fluctuation amplitude for peaked density profiles

R(11-1): Measure fluctuations responsible for turbulent ion and electron energy transport

- NSTX will begin in 2010 to explore turbulent transport micro-instabilities for the 2011 T&T milestone
- Core turbulence and transport
  - Low-k with BES and reflectometer, FIReTIP
    - ITG induced ion transport relative to neoclassical
    - ITG role in driving momentum transport
    - Microtearing
  - High-k with microwave scattering, reflectometer
    - ETG
    - Radial profile of GAE mode amplitude
- Edge turbulence and transport
  - Using GPI, fast cameras, soft xray arrays
    - Edge collisionality effect on boundary turbulence
- Specifically study the role of
  - Collisionality
  - Magnetic shear
  - T_e/T_i
  - Flow shear



Is low-k turbulence responsible for anomalous momentum transport?

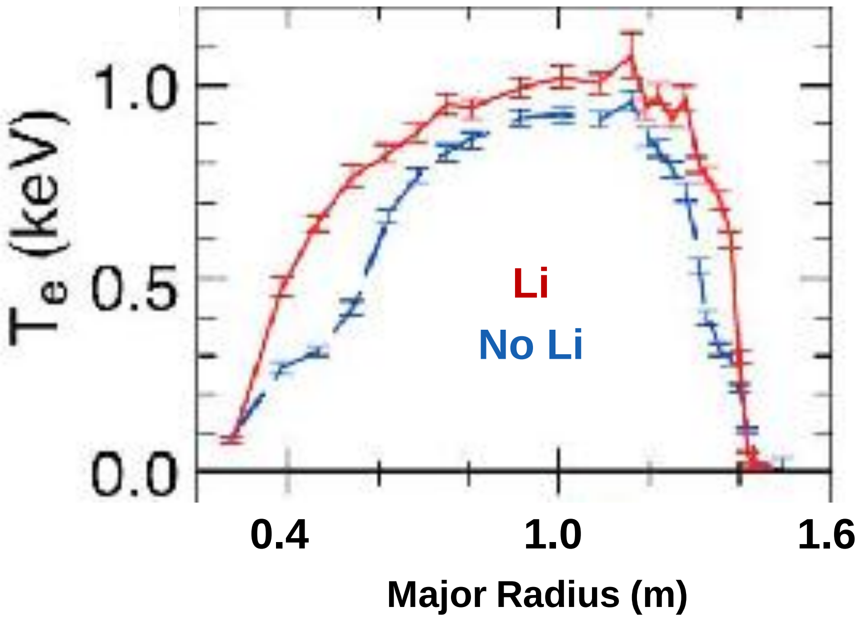


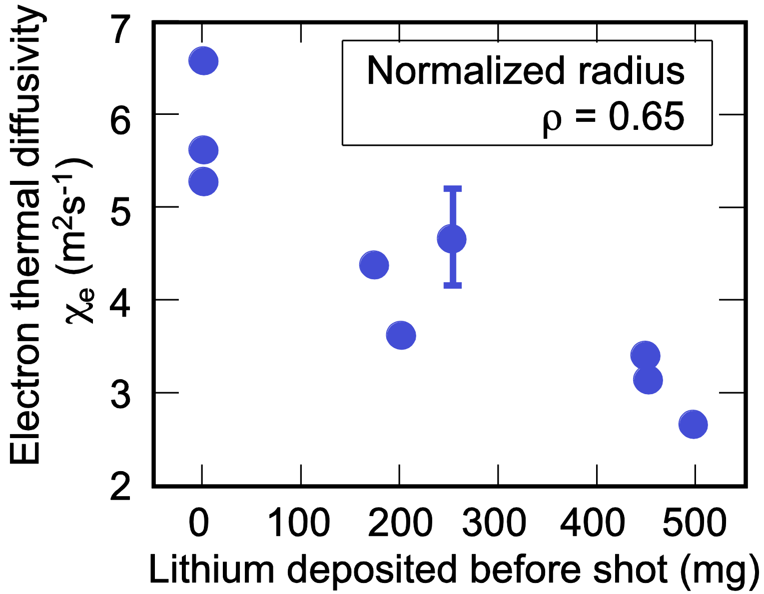
Is low-k turbulence stable across profile? Dependence on flow shear?

GTC-Neo χ_i includes finite banana width (non-local)

LLD will allow NSTX to explore the effect of collisionality on the characteristics of turbulence and transport

- T_e broadening effect from LITER in 2009 shown to be improvement in local electron confinement leading to broadening of T_e profile
- Fluctuation measurements to be made inside improved confinement region
  - k spectrum to be covered using BES, high-k, and reflectometry
- Test confinement sensitivity to ν^* reduction expected with LLD





PAC25-13

Nonlinear turbulence simulations showing promise for understanding electron transport

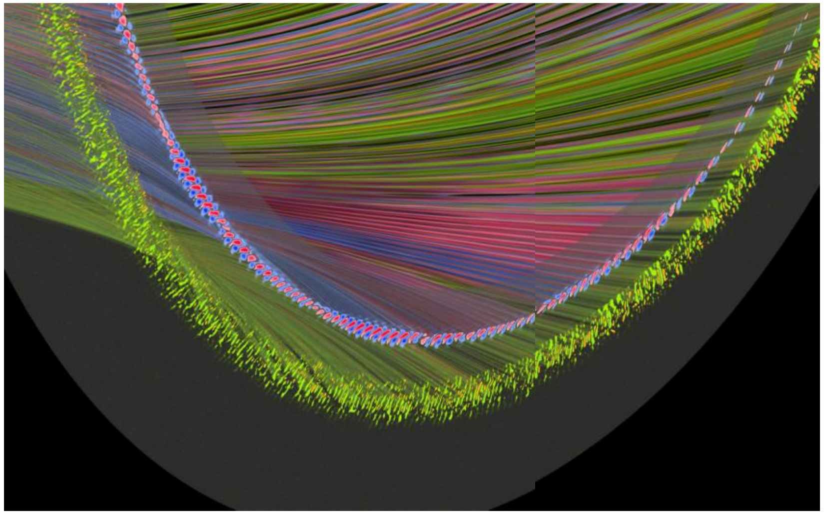
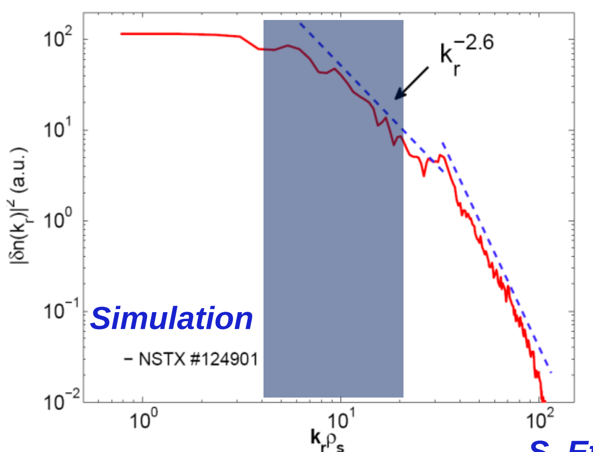


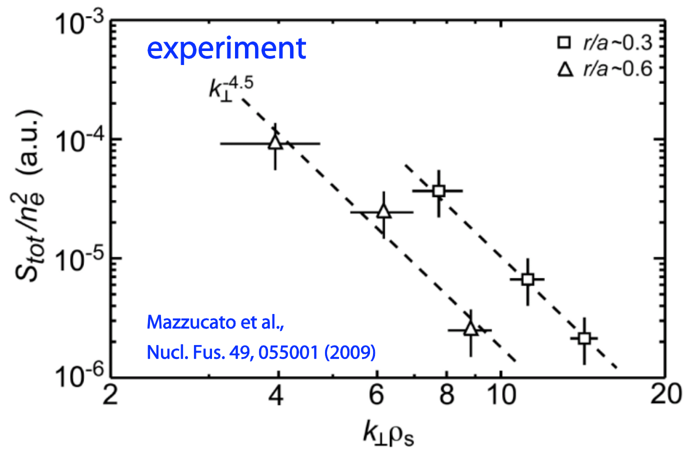
Image generated by Kwan-Liu Ma (P.I.), Chad Jones, and Chris Ho of UC Davis, as part of the SciDAC Ultrascale Visualization Institute

- Multiple efforts ongoing at PPPL, both PIC codes and Eulerian
- New full time post-doc joining NSTX, specifically tasked to simulate NSTX plasma
- Synthetic diagnostics matching NSTX instruments are necessary and will be developed for experiment-code comparisons

GTS simulations comparing ETG k-spectrum to experiment shows synthetic diagnostics needed to match the actual region of k-space (r,θ) measured by the instrument



S. Ethier

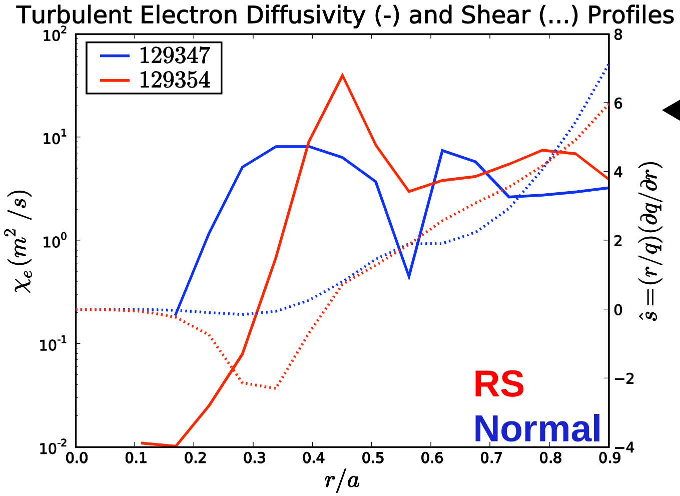


PAC25-22

2012 T&T milestone extends understanding through comparison to theory and simulation

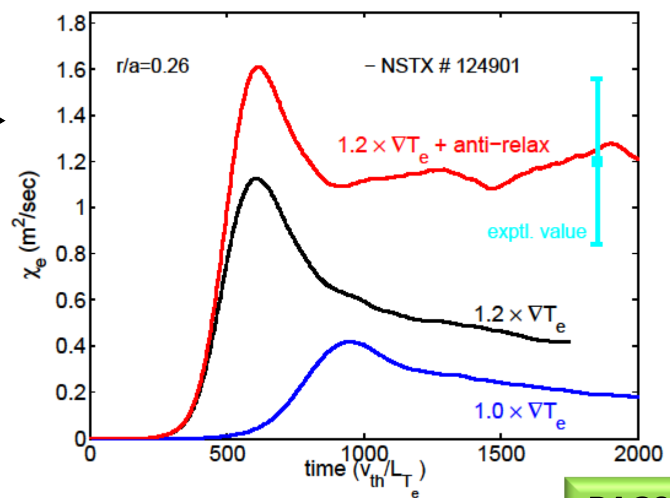
R(12-1): Enhance physics understanding of turbulent transport mechanisms by comparing theory and simulation to measured fluctuations

- Fluctuation measurements will be compared with micro-instability calculations such as GYRO, GTS, GS2, GTC-NEO, and others as they become available
- Synthetic diagnostics built into modern high-performance simulation codes will be compared to experimental measurements of fluctuating quantities and their spectral characteristics
- Insight of how micro-instabilities affect energy transport can be improved by incorporating turbulence simulation results into transport codes such as TGLF



J.L. Peterson

← ***GYRO and GTS simulations of reversed shear χ_e*** →



W. Wang

PAC25-22

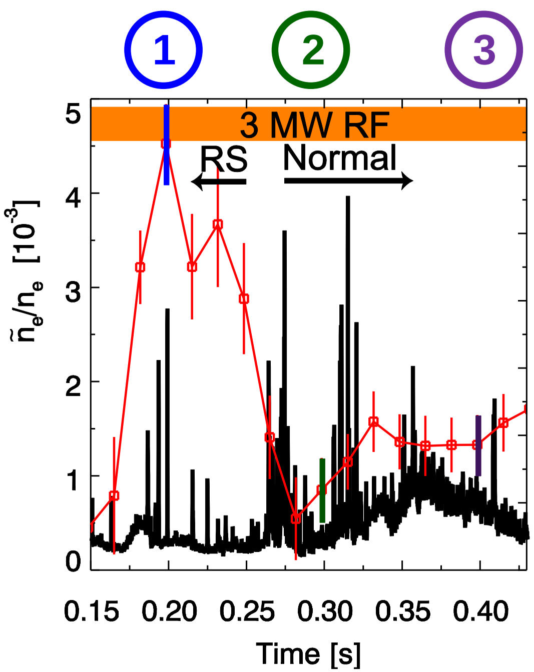
NSTX will exploit powerful new diagnostic capabilities to better understand turbulent transport

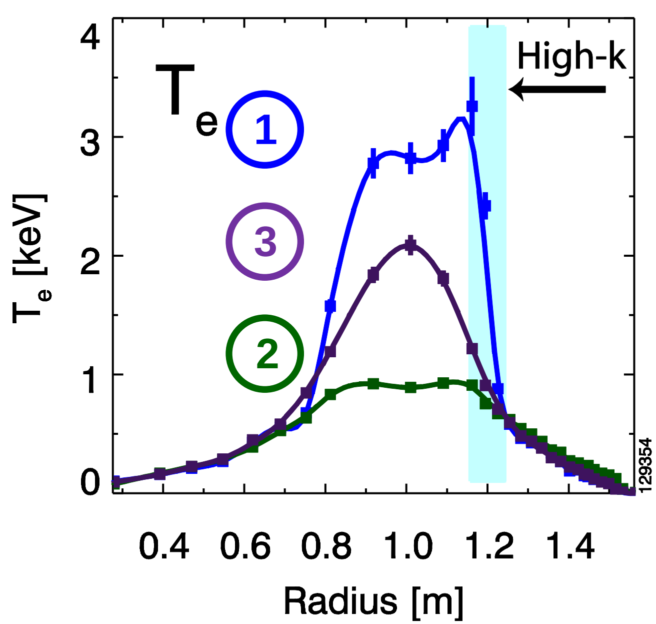
- NSTX transport and turbulence priorities well aligned with ST priorities and tokamak research needs
- 2010 transport and turbulence run time devoted to initial operation and measurements necessary to fulfill 2011 milestone
- New and upgraded diagnostics allows NSTX to measure a more complete k spectrum of turbulence across the plasma profile
- 2012 milestone focuses on increasing understanding of fluctuation measurements through simulation and theory

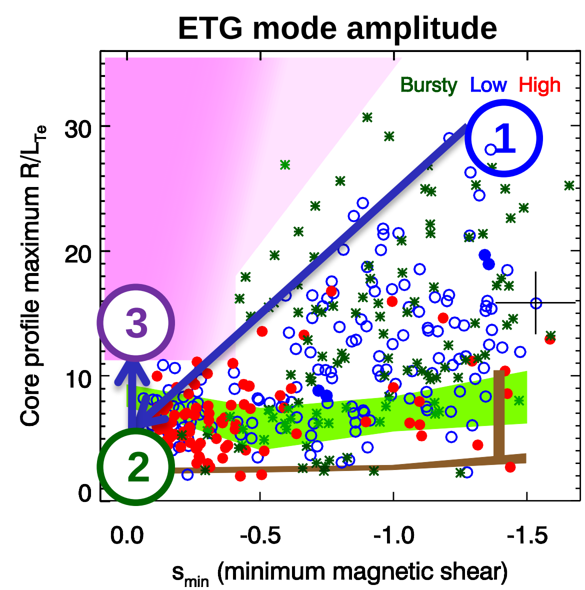
Backup Slides

Reversed shear suppresses mode growth even at supercritical ETG gradients during e-ITBs

1. Intermittent, short duration bursts of ETG observed during RS phase
   - Average ETG mode amplitude low, T_e gradient well above ETG critical
2. A series of large amplitude, closely spaced in time bursts of ETG collapses Te profile
   - Magnetic shear becomes zero/positive due to anomalous current redistribution
3. T_e profile can only be reheated to ETG critical gradient at zero shear
   - ETG mode amplitude grows to a moderate continuous level







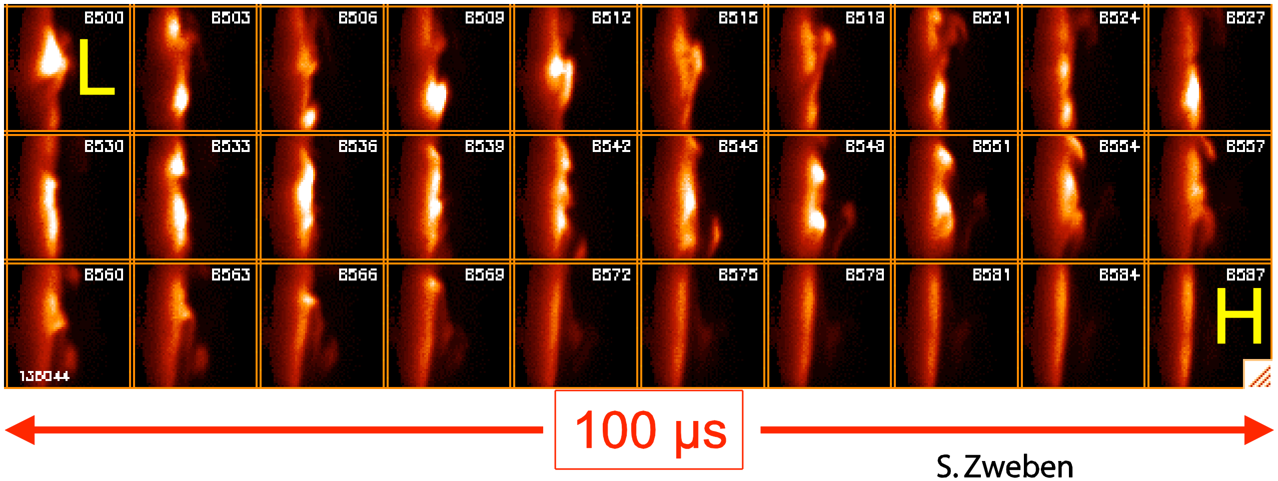
2010 campaign begins works on T&T 2011 research milestone

Author	Title	P1	P2	Primary Goals
S. Kaye D. Smith W. Solomon	Impact of rotation on turbulence and energy and momentum transport Investigation of low-k fluctuations as a source of anomalous momentum transport Determination of NTV offset rotation on NSTX	1	½	**Rotation (E×B shear) effect on turbulence**
D. Battaglia S. Zweben	L-H power threshold for D and He plasmas using RF current drive w/symmetric phasing Ultra-high Speed GPI Measurements of the L-H transition with RF Heating	1		**RF L-H transition species dependence and edge turbulence**
Y. Ren	Study of the Parametric Dependence of High-k Turbulence	1		**Collisionality dependence**
D. Smith S. Kubota	Investigation of multi-scale turbulence Survey of Low-, Intermediate-, and High-kr turbulence, Simultaenously and Everywhr	½	½	**Turbulence dependence on Te/Ti**
S. Kubota K.C. Lee	Ohmic H-Mode Reynolds Number Measurement on H-mode Transition	½		**Poloidal correlation reflectometry, L-H transition Reynolds number**
H. Yuh	Sustained ITBs and H-Mode ITBs	½	½	**Dependence on magnetic shear**
R. Bell	Joint NSTX DIII-D poloidal rotation experiment	½		**Momentum confinement**
W. Solomon	Characterization of intrinsic torque using torque transients	½		**Intrinsic torque**
K. Tritz	Investigation of *AE induced electron transport		½	***AE electron transport**
		5.5	2	

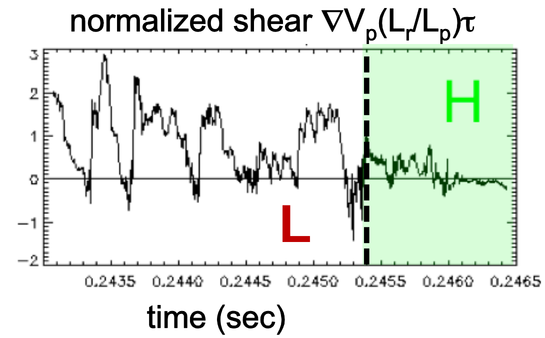
NSTX efforts towards PAC25 T&T recommendations

PAC25-13	NSTX should investigate whether the increase in electron stored energy is due to a confinement increase or whether there is another mechanism.	Effect of Li has been found to be the broadening of T_e profiles due to a local improvement of electron thermal diffusivity at a radius of ρ=0.65. The core T_e does not appear to be increased.
PAC25-19	In addition, the PAC recommends an assessment of the interplay between edge plasmas with Li PFCs and electron transport.	In 2010-11, a number of diagnostics (High-k, BES, reflectometer, FIReTIP, ME-SXR) will be used to study turbulence in this region of the plasma to try and understand the effect of Li PFCs on micro-instabilities.
PAC25-20	However it is also recommended to investigate impurity transport.	Impurity transport will be studies using the soft x-ray diagnostics (ME-SXR, TO-SXR) during varying LLD operations to determine changes in turbulence that may cause impurity accumulation.
PAC25-21	It is recommended, however, to investigate in somewhat more detail the physics of turbulent transport suppression at the LH transition and the residual transport after the transition. Regarding this question, correlation length measurements by reflectometry appear very promising. Also, CHERS measurements of the poloidal velocity should be very helpful.	Analyzed pCHERS data will become available in 2010. NBI heated L-H transitions were measured with high time resolution in 2009, and RF L-H transitions will be diagnosed in 2010. The reflectometer in several configurations will be used to measure L-H transitions, including ohmic transitions.
PAC25-22	As a final recommendation, the NSTX staff is encouraged to pursue its efforts to. strengthen the interaction between theoreticians and experimentalists and also to continue its fruitful collaborations with US and foreign laboratories	NSTX will have additional personnel dedicated to using simulation codes to make comparisons between theory and measurements. Multiple ongoing efforts are in place utilizing community codes, with stronger validation efforts culminating in the T&T 2012 milestone.

High frame rate camera utilized to improve measurements of the L-H transition



S. Zweben



GPI measurement of poloidal velocity shear across L-H transition

- GPI captured NBI heated L-H transitions in 2009
- 300k frames/s captures details of L-H transition (~100 µs) and precursor activity
- ELM formation, comparing externally triggered vs. natural
- RF power ramp capability for L-H transition studies was demonstrated in 2009, RF driven transitions will be compared with beam heating
- Impurity transport and edge turbulence changes during LLD operation will be measured

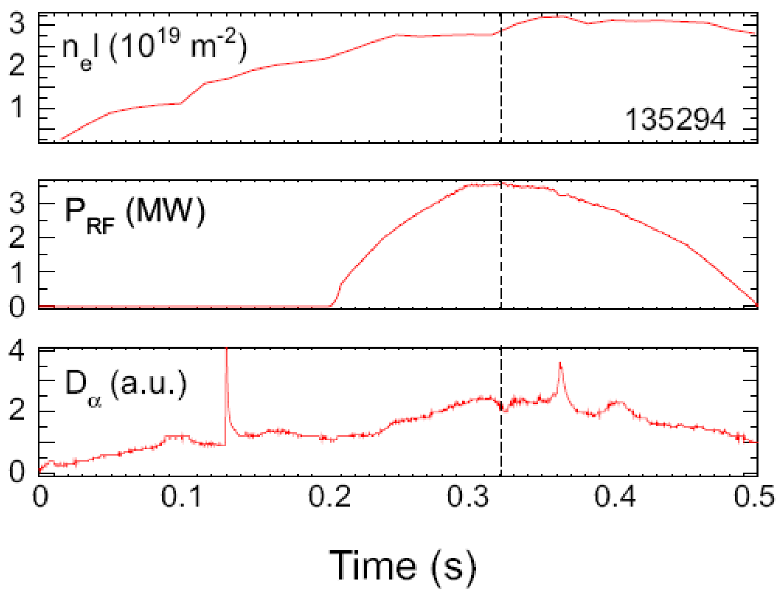
PAC25-21

L-H/H-L Power Thresholds in Pure Helium and Deuterium Plasmas Were Explored in NSTX

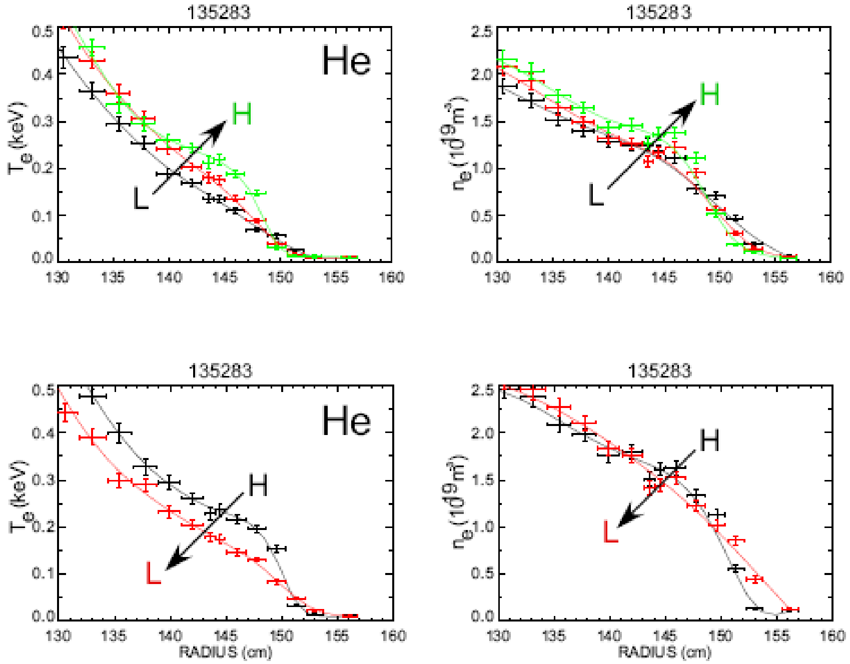
- High Harmonic Fast Waves (HHFW) were used to heat pure helium and deuterium plasmas
- Continuous ramping of HHFW power allowed for “fine” determination of P_{LH} and P_{HL}
- “Perturbation technique” used to determine HHFW electron heating efficiency (<0.16>±0.1)
  - Ion heating efficiency similar
  - In what follows, P_{RF} is taken to be $P_{RF,e}$

Forward or back transitions not always Obvious in D_α signal even for D-plasmas.

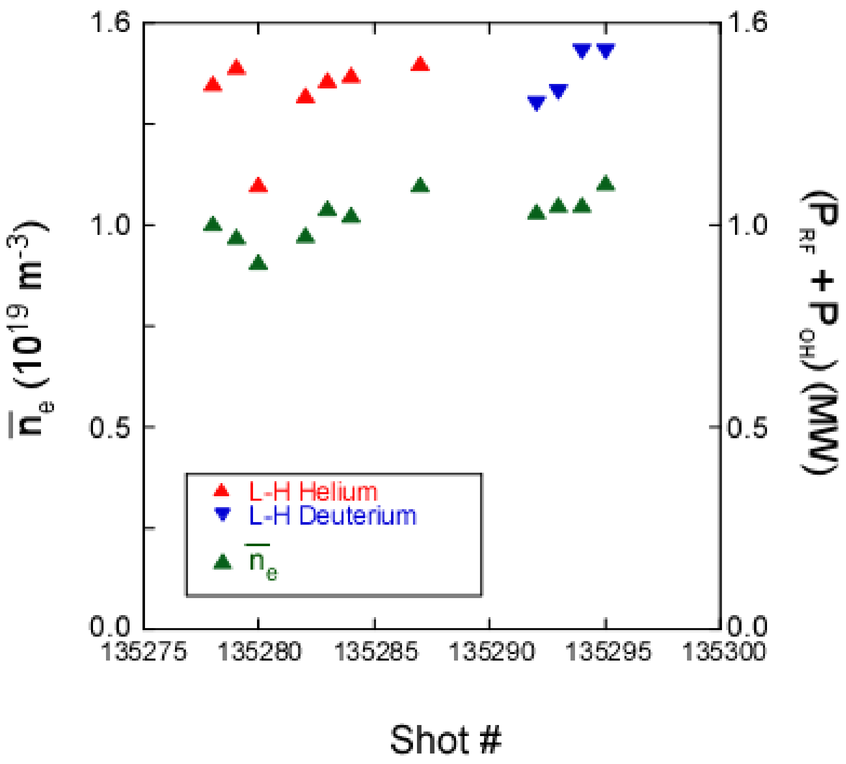
- No D_α indication in He-plasmas

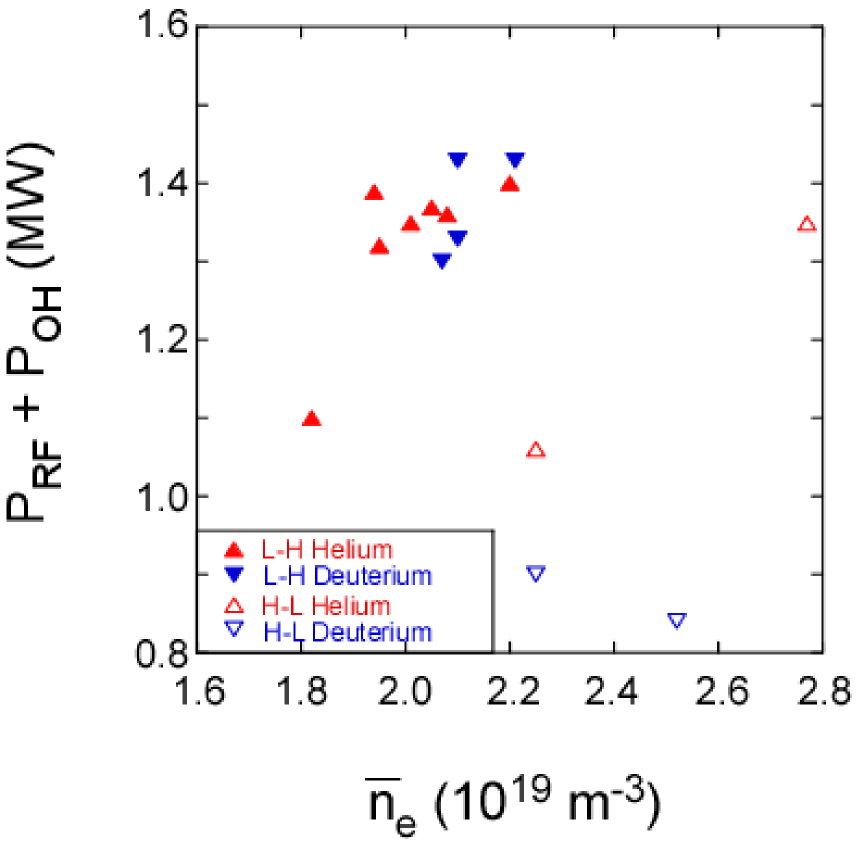


Use change in edge profiles as an Indication of both L-H and H-L transition



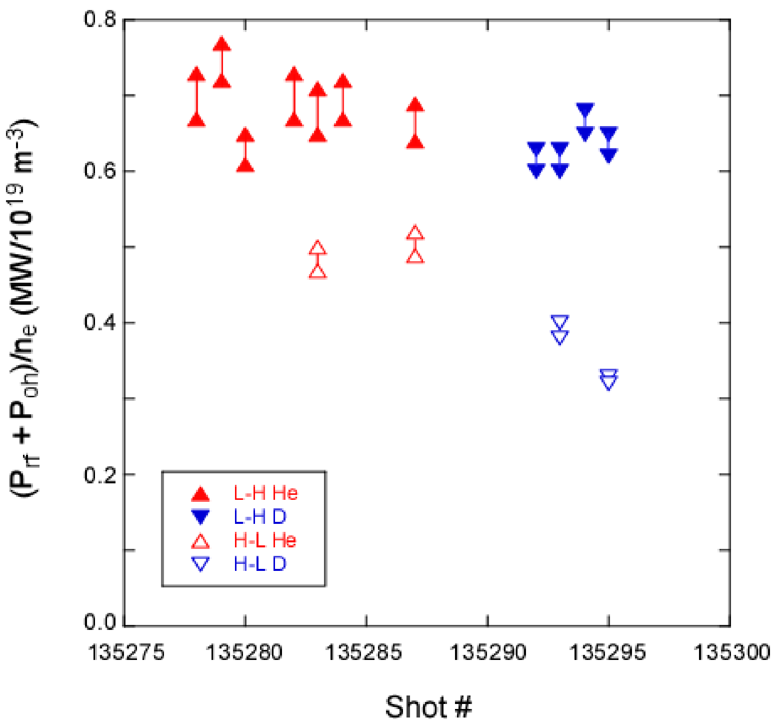
L-H Transition Powers Generally Depend on Density; Not True for H-L Transitions

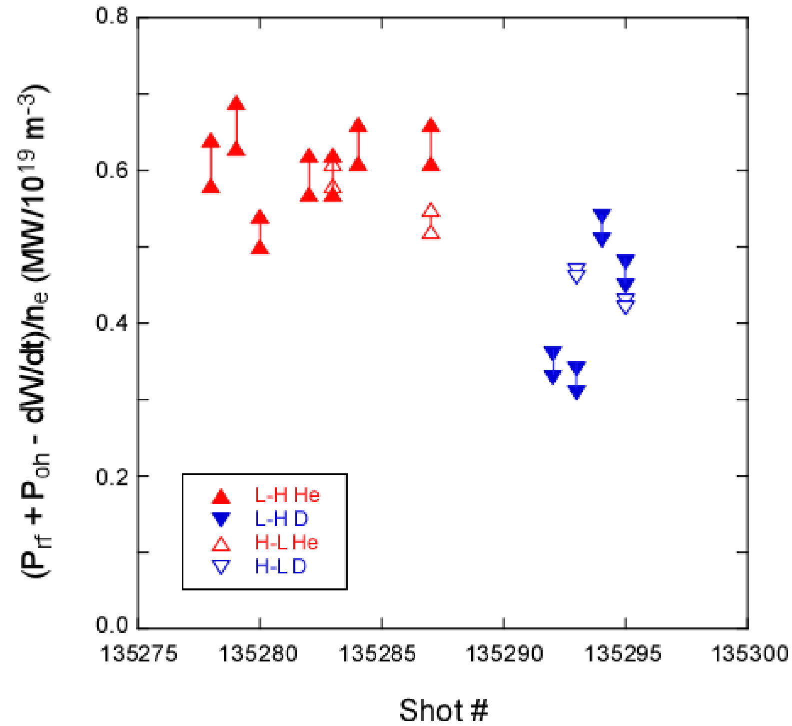




P_{LH} (He) ≥ P_{LH} (D)
- Depends on Definition of P_{LH} -

H-L power thresholds lower for P_{RF} + P_{oh}, indicating some hysteresis

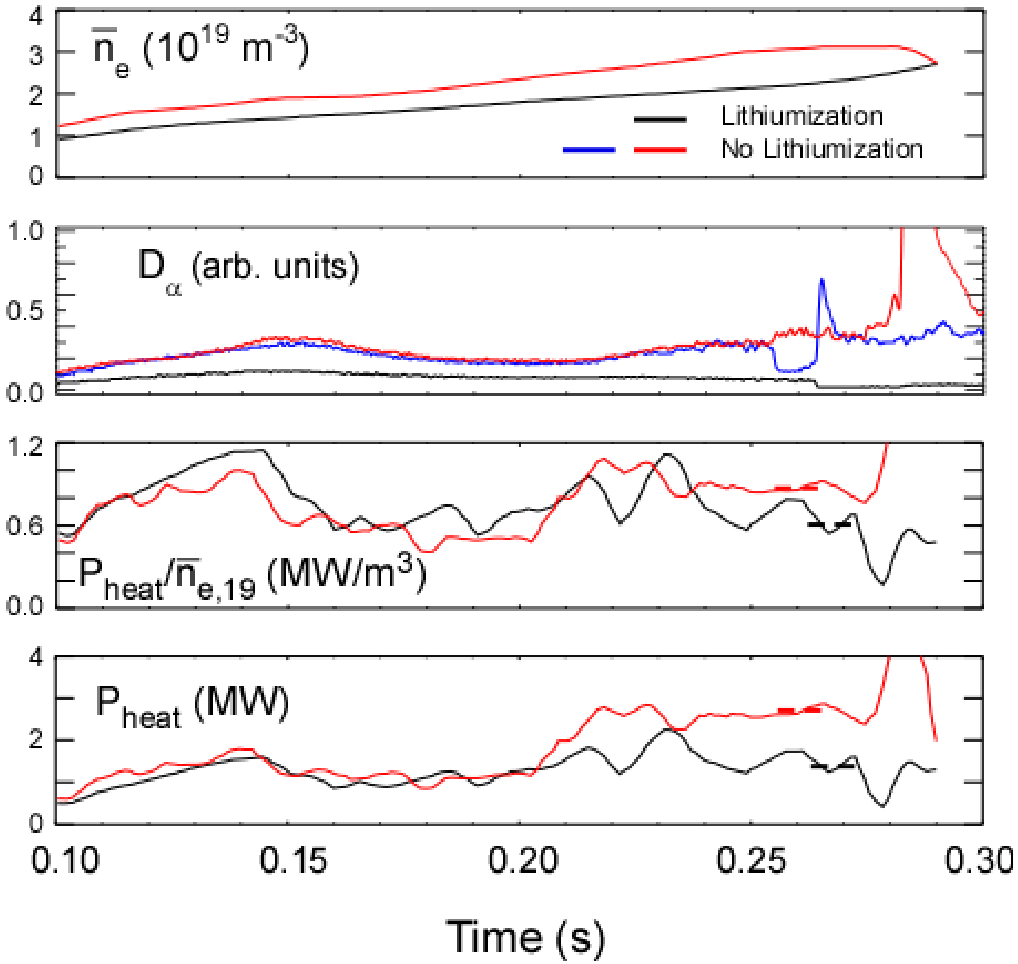




Normalize P_{RF} + P_{OH} by density for comparison
Large error bars due to uncertainty in heating efficiency!

Lithium Evaporation Led to a Significant Reduction in L-H Power Threshold

P_{LH} ~ 2.7 MW NBI without Li evaporation (P_{heat}/n_e~0.9 MW/10^{19} m^3)
~ 1.4 MW NBI with Li evaporation (0.6 MW/10^{19} m^3)



- $P_{LH} \propto n_e$ from HHFW expts
- Normalize P_{LH} by n_e due to density differences between plasmas with and without Li evaporation
- ***Effect of neutral density differences?***