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Gyrokinetic simulations of turbulence in NSTX

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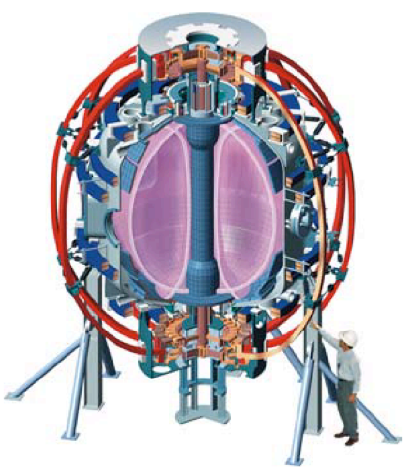

NSTX Results Review

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Introduction

Ease of ExB shear stabilization of low-k modes in STs in general has long been recognized.
Clarisse Bourdelle found $\square_{ExB} > \square_{inear}$ is indeed common for low-k modes in NSTX plasmas.
She also found that ETG modes are generally unstable in NSTX.
ETG may play an important role in NSTX, but nonlinear simulations are *very* difficult and no diagnostics are available. Further study of ETG modes has been deferred.

Need nonlinear studies to determine if $\square_{ExB}$ is sufficient to fully stabilize low-k turbulence.
Standard ExB "quench rule" applied to linear results is of questionable validity in NSTX:
"*We cannot be confident of these modifications and limitations on the quenching condition for general profiles at finite $\square_*$ without nonlinear simulations. These cannot be done with the fast flux tube codes and require three dimensional (3-D) full radius codes …*" Waltz, et al., Phys. Plasmas 5 (1998) 1784.

NSTX is high $\square$* device, so 'profile effects' are more important than in most tokamaks.
Most parameters vary significantly across a radial domain width of 50 $\square_i$, so a flux tube simulation is not appropriate for low-k modes: r/a~0.5 is too close to the edge and center.
A 'full radius' simulation is required to include profile effects.

GYRO includes essentially all physics needed for realistic simulations of low-k turbulence, including background ExB shear and a non-adiabatic electron treatment.
We would particularly like to test the predictions of ExB stabilization of low-k modes.

Simulation Methodology

TRANSP calculates the magnetic equilibrium, and maps profile data from R to r/a.
Used “outer side only” mapping of density and temperature profiles, not “slice and stack”,
this guarantees that n_e, T_i, T_e at same R map to same r.
E_r from measured v_{tor} and NCLASS calculation of v_{pol}.
Data preparation tools can be used by others, too.
Still learning how to ‘tune’ GYRO parameters for NSTX conditions.

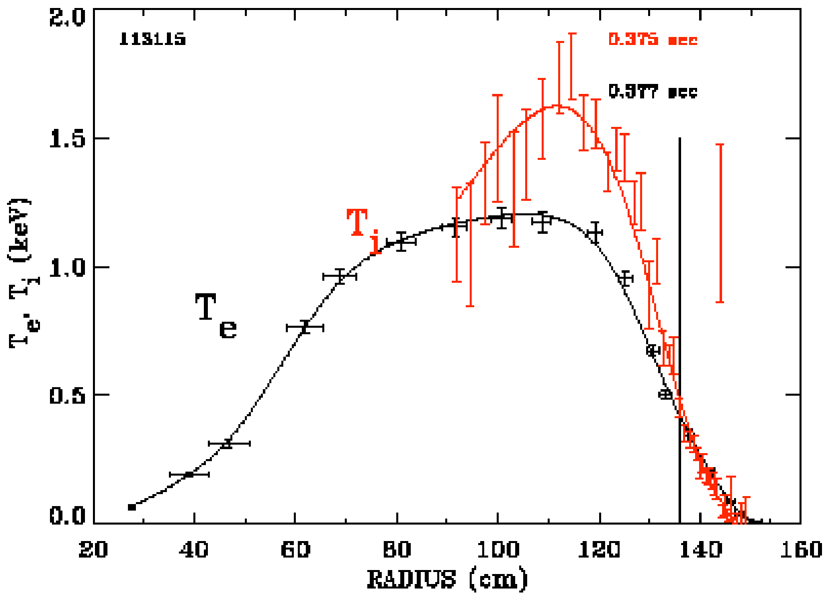
Could use EFIT equilibria in TRANSP; this will be done when the MSE system is mature.
The mapping of R to r is similar from EFIT and TRANSP for the shots studied here.
The q profiles in the core are uncertain; improvement requires MSE.

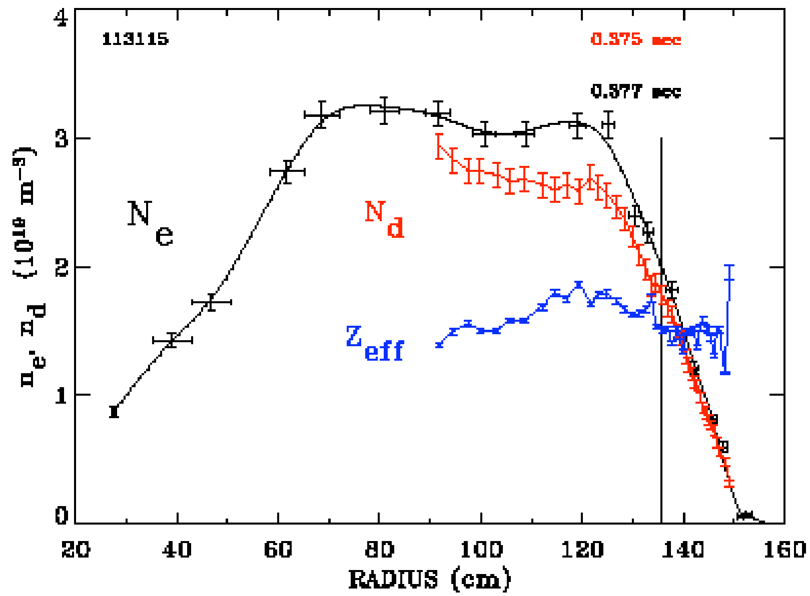
□ is low (for NSTX) so begin with electrostatic simulations (EM is possible, though)

Begin with nominal measurements of parameters, vary them within uncertainties to find the uncertainty of the turbulence predictions and to identify the important parameters.
Compare fluctuation level and correlation length.
Compare predicted power fluxes with experimental transport analysis.

Look for a set of input parameters that produces a *simultaneous* match with the measured power fluxes, turbulence level, and radial correlation length.

Simple Profile Shapes



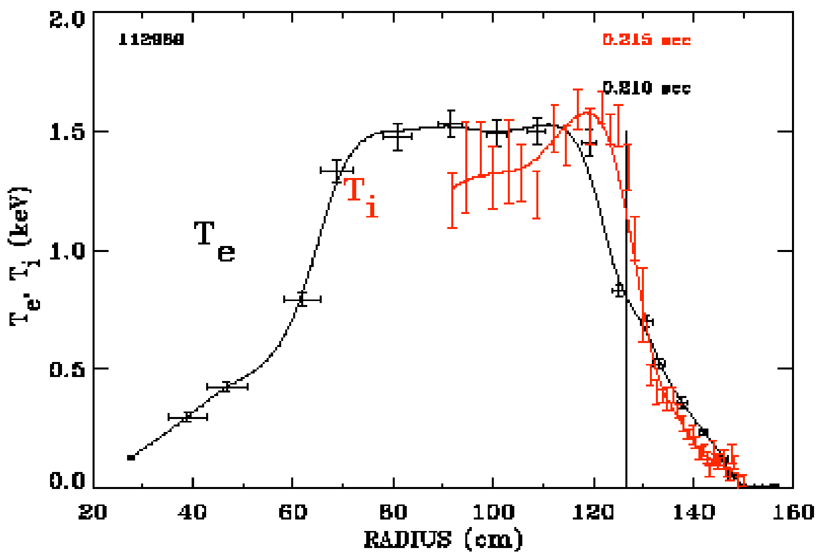


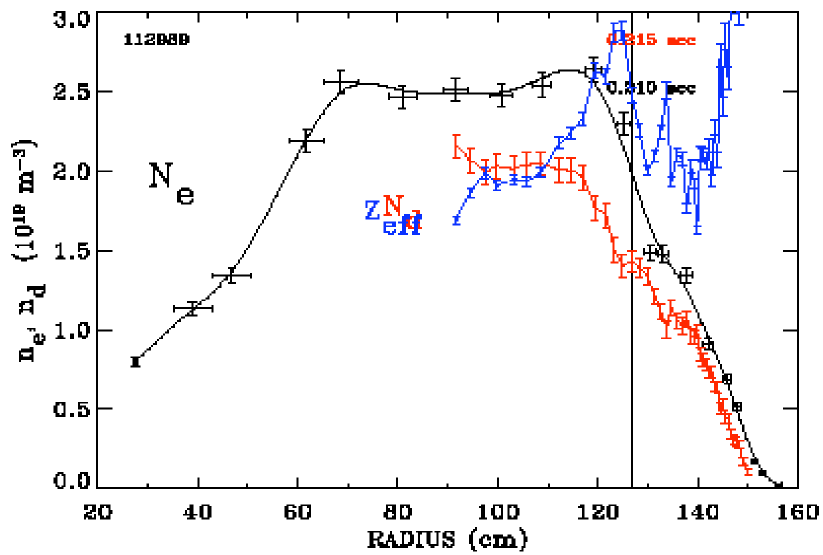
$T_i \sim T_e$ at the reflectometer radius.

Cleaner than average correlation signal.

Moderate v_{tor} rotational shear.

Possible ITBs ?





Very steep T_e and T_i are seen transiently (50 msec).

May be associated with reversed shear.

Strong temperature gradient drive for instabilities.

Has much stronger shearing of v_{tor}, too.

Status Report on Turbulence Simulations

These results are very preliminary, convergence testing has not even begun!

May need to add modes with $k_\perp \rho_i > 0.5$ (indications of significant conducted power).

1) "Pure" ITG simulations (with adiabatic electron response) with no ExB shear effects have transport that may frequently be in the vicinity of the actual power levels. This rough agreement is probably accidental because:

2) A kinetic electron treatment - still no ExB shear - hugely increases the long-wavelength transport by more than an order of magnitude. This is not ETG activity, this is only TEM boosting the ITG - a well established synergy.

3) Finally, including ExB shear derived from the measured v_{tor} frequently *nearly* completely stabilizes the turbulence found in 2) and brings the power flows back down to levels comparable to (or lower than?) the actual level in the experiment.

We conclude that it is necessary for *realistic* simulations of these plasmas to include both
1) a non-adiabatic treatment of the electrons, and
2) background ExB sheared flows.

If the level of ExB shear can be controlled in NSTX (and reduced to an insignificant level) we should be able to directly test the role of ExB shear.

Plan for detailed comparisons

Tony Peebles' group installed several reflectometers on NSTX (see Shige Kubota's talk). They have measured low-k turbulence characteristics such as $\langle \tilde{n}/n \rangle$, and $\langle \square r \rangle_{corr}$.

Heterodyne reflectometers can be used to estimate $\langle \tilde{n}/n \rangle$ at n_e =3, 2.2, and $1.1x10^{19}$ /m^3.
The correlation reflectometer can determine $\langle \square r \rangle_{corr}$ in the density range n_e =$1\text{-}2x10^{19}$ /m^3.
For some shots both types of reflectometer measurements may have good signal to noise.
These measurements will eventually be compared to GYRO's turbulence simulations.

With *complete* data sets including fluctuation measurements we can test whether predicted power flows *and* turbulence amplitudes *and* radial correlation lengths can *all* be matched.