Electron Transport in NSTX and ETG

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Overview

- Heat fluxes and diffusivities of the Electron Temperature Gradient(ETG) mode are compared with NSTX TRANSP data.
- GS2 Linear Analysis for the wide range of the poloidal wavenumber k_y.
- Linear Analysis based on 3-field fluid model
- Test simulations of the fluid model and Heat flux estimation
- Conclusion and future direction

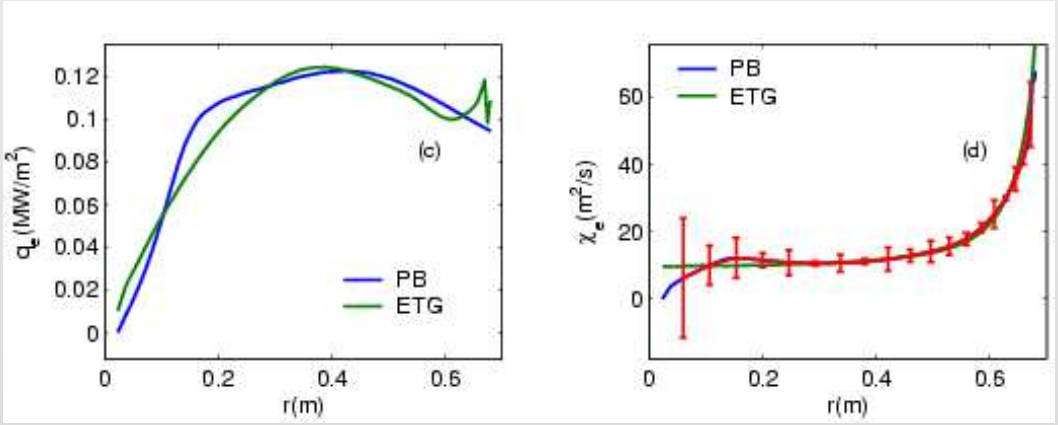
Electron Temperature Gradient(ETG)

For ETG mode,

$$q_e = C_e^{em} n_e T_e q \frac{c^2}{\omega_{pe}^2} \frac{v_e}{R} \left(\frac{R}{L_{Te}} - \frac{R}{L_c} \right) \quad \beta_e > \beta_{e,cr} \qquad (1)$$

$$q_e = C_e^{es} n_e T_e q^2 \left(\frac{\rho_e^2 v_e}{L_{Te}^2} \right) \left(\frac{R}{L_{Te}} - \frac{R}{L_c} \right) \quad \beta_e < \beta_{e,cr} \qquad (2)$$

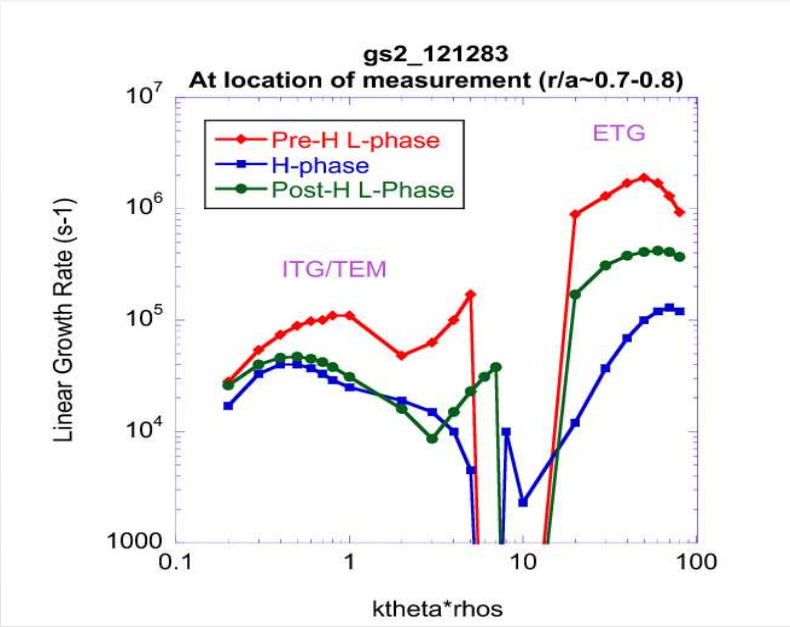
where $\beta_{e,cr} = (L_{Te}/qR)^2$ NSTX 106194 with 2.4 MW HHFW power

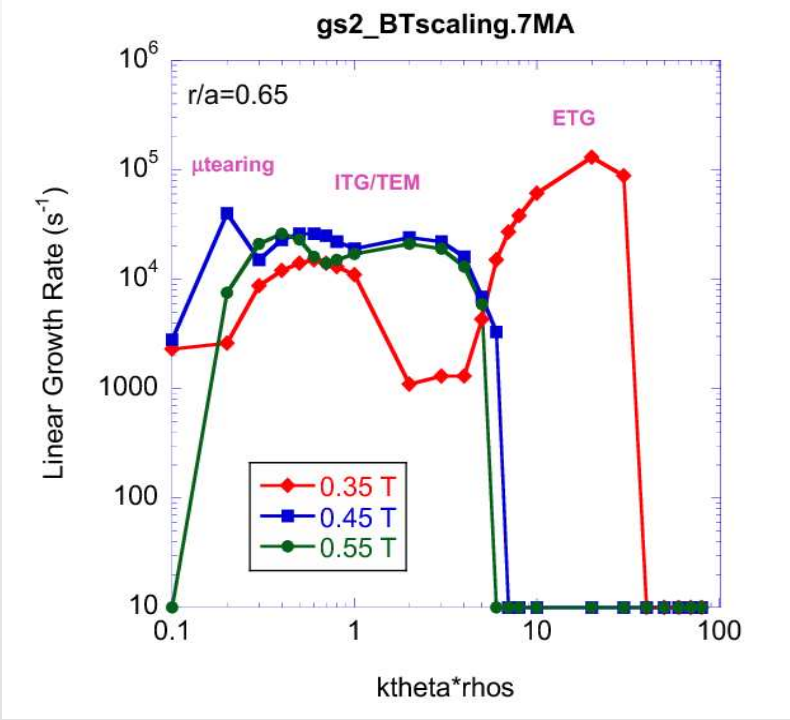


From Horton et. al. Nuclear Fusion 2005

GS2 Linear Stability

At $r/a = 0.65$, the wavenumber $k_y\rho_e \sim 1$ corresponding to ETG mode are the most unstable.

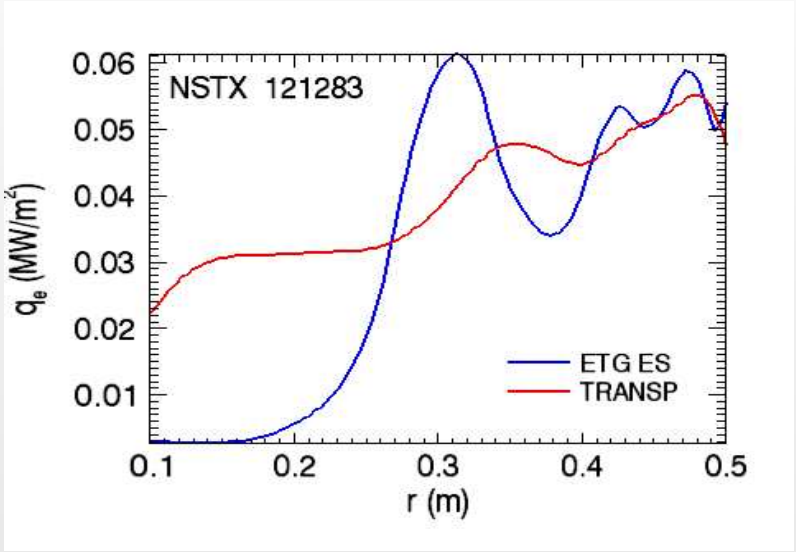


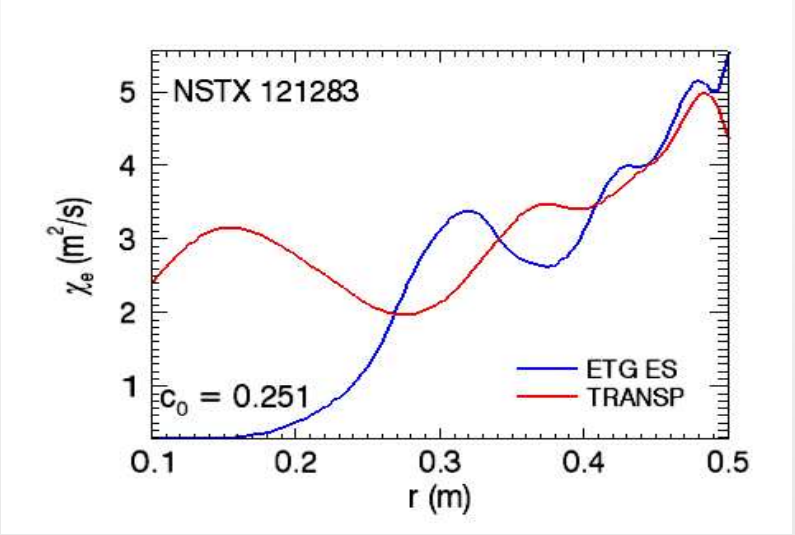


On the contrary, at the core, the modes $k_y\rho_e \sim 1$ are stable or less unstable compared to the mode, $k_y\rho_s \sim 1$ (microtearing , TEM). At high B_T, the ETG modes are suppressed.

NSTX 121283

- $\beta_e < 0.1$ at the outer region

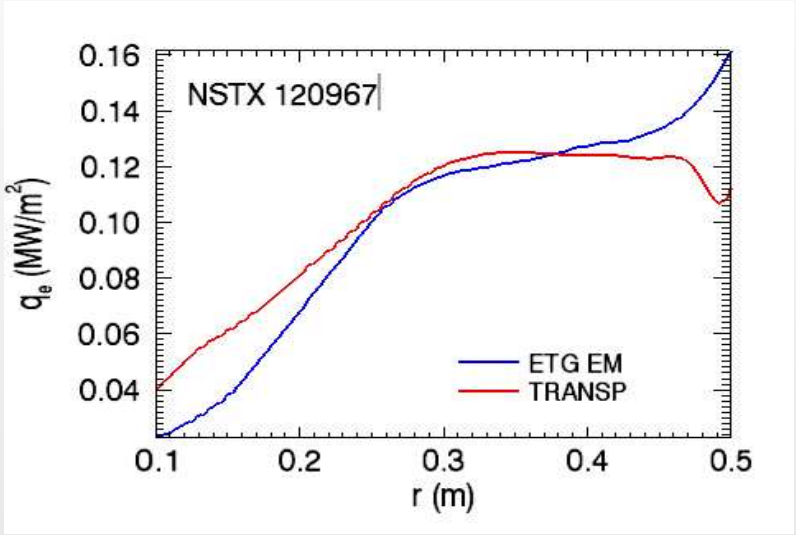


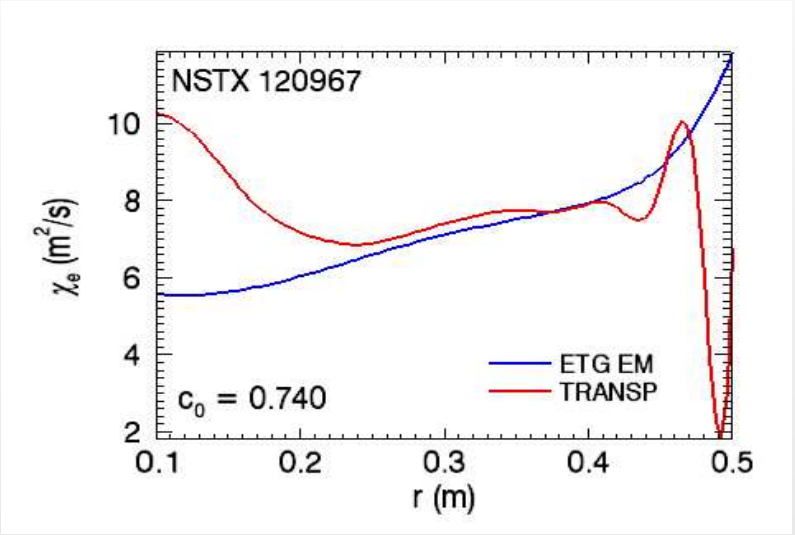


- The electrostatic scaling does have good agreement with the TRANSP q_e and χ_e in the pre-H mode and H-mode.

NSTX 120967

- $\beta_e \sim 0.1$ at the outer region



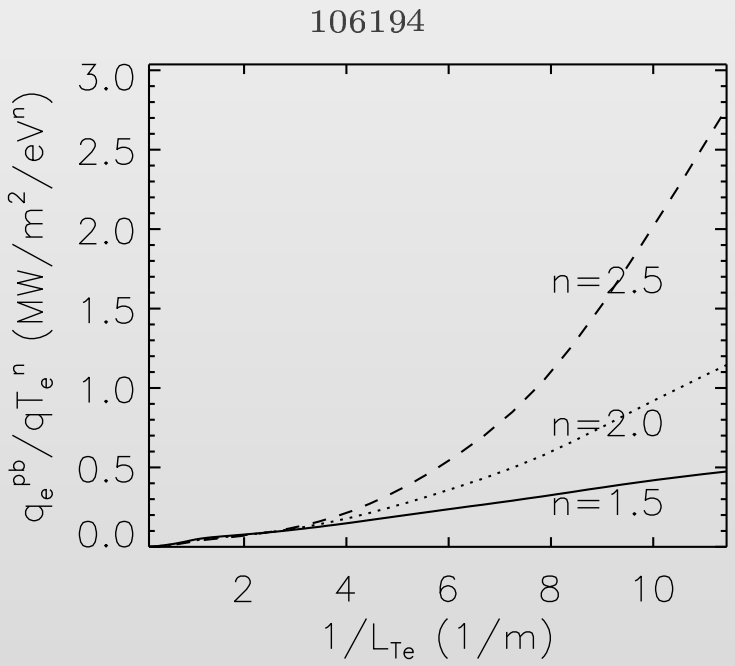


The electromagnetic scaling does have good agreement with the TRANSP ones.

Temperature Dependence

The scaling law shows that heat flux is proportional to

- ETG EM $\sim T_e^{3/2}$
- Bohm $\sim T_e^2$
- gyro-Bohm $\sim T_e^{5/2}$
- ETG ES $\sim T_e^{5/2}$



ETG Model

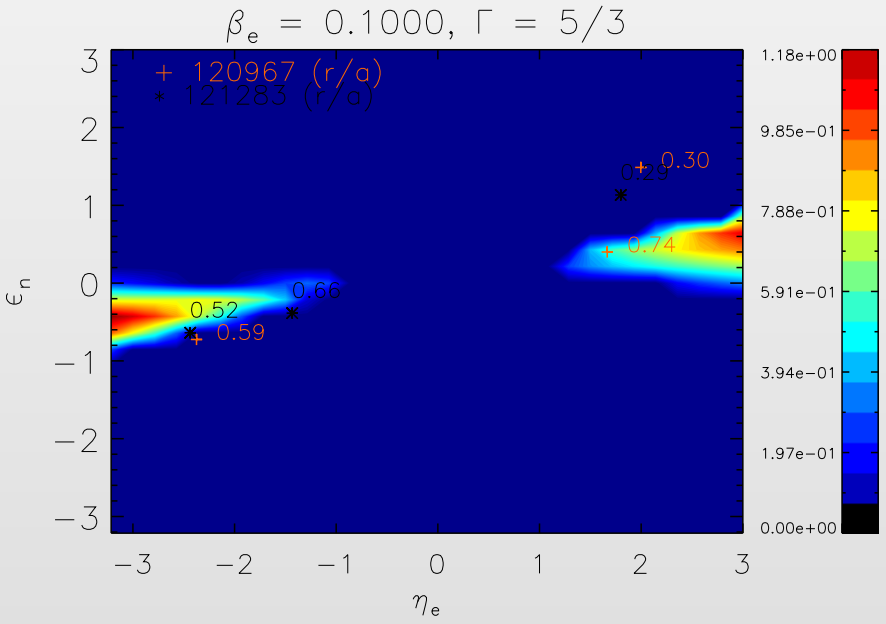
The non-dimensional ETG three-field model is derived by Horton (NF, 2005) in a locally toroidal geometry,

$$
\begin{aligned}
(1-\nabla_\perp^2)\,\frac{\partial\hat{\phi}}{\partial t} &= \left[1-2\epsilon_n+(1+\eta_e)\nabla_\perp^2\right]\frac{\partial\hat{\phi}}{\partial y}+2\epsilon_n\frac{\partial\delta\hat{T}_e}{\partial y} \\
&\quad +\left[\hat{\phi},\nabla^2\hat{\phi}\right]+\partial_\parallel^{nl}\nabla_\perp^2\hat{A}-\mu\nabla^4\hat{\phi} \\
\left(\nabla^2-\frac{\beta}{2}\right)\frac{\partial\hat{A}}{\partial t} &= \frac{\beta}{2}(1+\eta_e)\frac{\partial\hat{A}}{\partial y}+2\partial_\parallel^{nl}\hat{\phi}-\partial_\parallel^{nl}\delta\hat{T}_e-\left[\hat{\phi},\nabla^2\hat{A}\right]-\frac{\eta}{\mu_0}\nabla^2\hat{A} \\
\frac{\partial\delta\hat{T}_e}{\partial t} &= S_{\rm rf}(r)-s_{\rm edge}(r)-\left[\eta_e-4\epsilon_n(\Gamma-1)\right]\frac{\partial\hat{\phi}}{\partial y}-2\epsilon_n(2\Gamma-1)\frac{\partial\delta\hat{T}_e}{\partial y} \\
&\quad -(\Gamma-1)\partial_\parallel^{nl}\nabla^2\hat{A}-\left[\hat{\phi},\delta\hat{T}_e\right]+\chi_\perp\nabla_\perp^2\delta\hat{T}_e+\chi_\parallel\left(\partial_\parallel^{nl}\right)^2\delta\hat{T}_e
\end{aligned}
$$

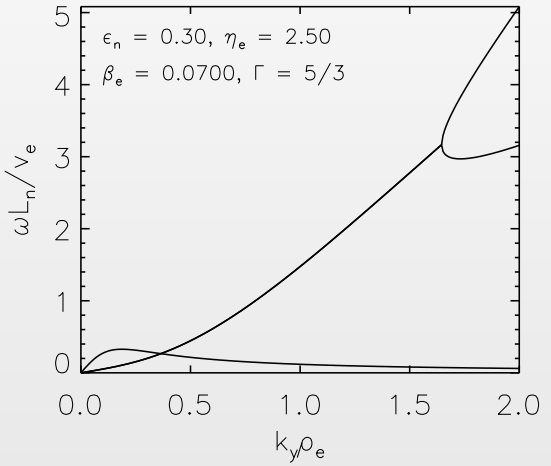
where $T_e/T_i = 1.0$ is assumed and $(x,y)/\rho_e \to (x,y)$, $tv_e/L_n \to t$.

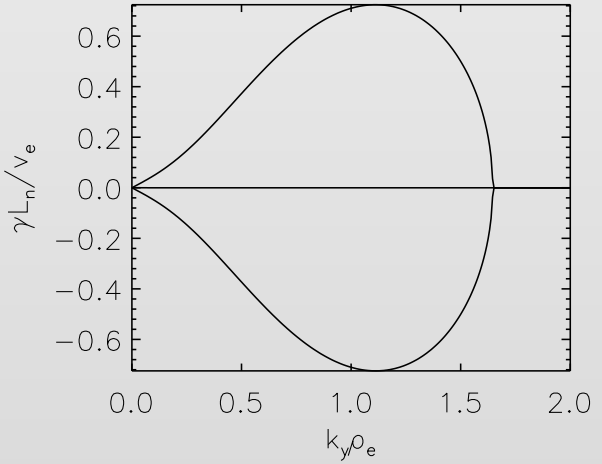
Linear Analysis

$0.3 < k_y\rho_e < 1.0$ modes have the maximum growth rates.
The most unstable modes are electrostatic in nature.



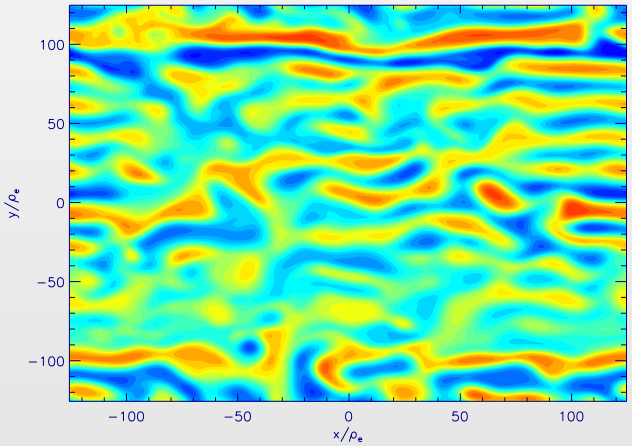
0.38

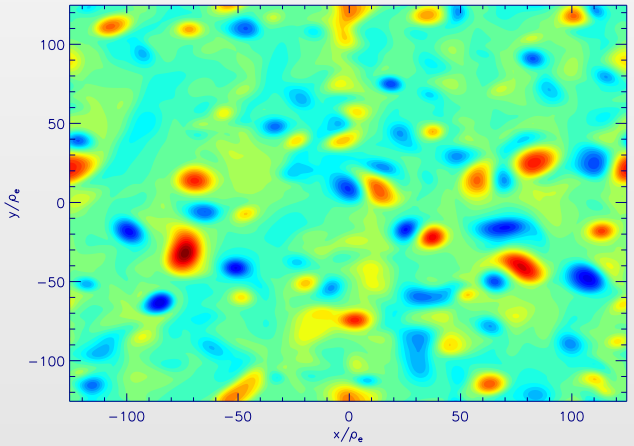




Nonlinear Simulation(TEST)

- Using the pseudospectral method, the set of the electrostatic equations are solved with $\eta_e = -2.7$, $\epsilon_n = -0.8$ and $\beta_e = 0.19$ from 120967 $r/a = 0.56$. The box size is $[240\rho_e, 240\rho_e]$.

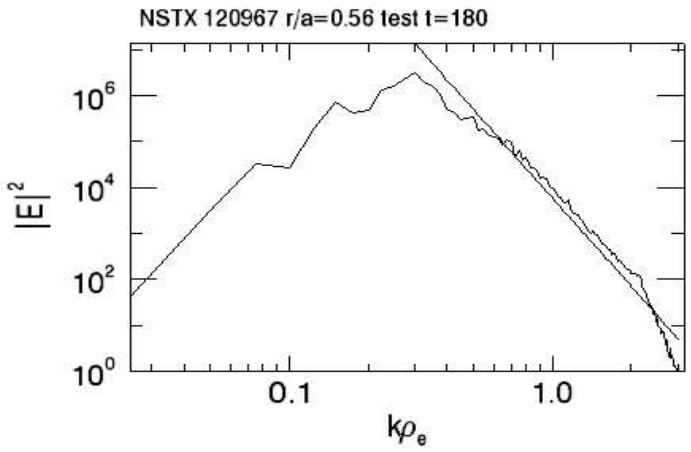


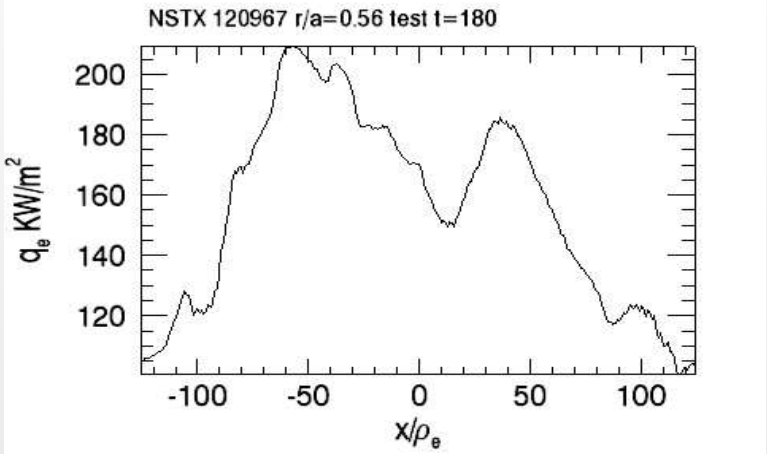


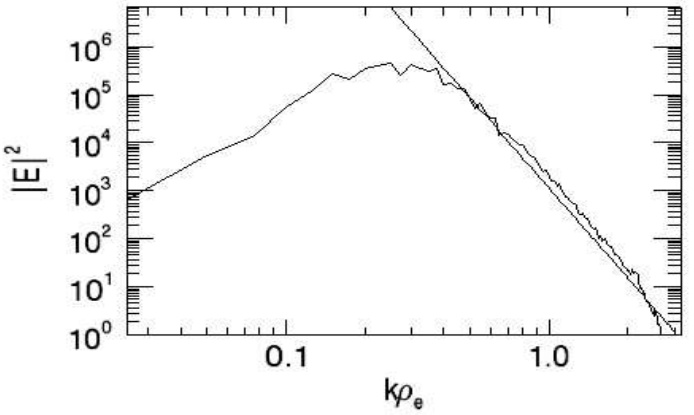
- The left figure is taken when the linear growth is fully suppressed. The streamer-like strucuture formation is almost finished.
- The right figure is taken when the structure is decay by setting $\eta_e = 0$.

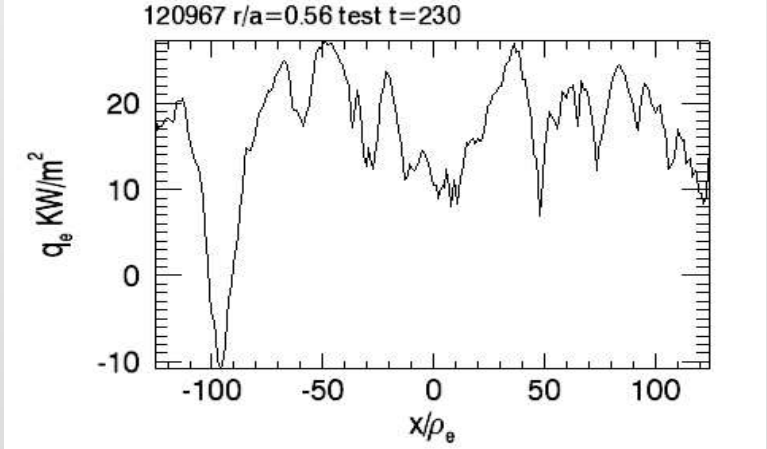
Nonlinear Simulation II(TEST)

For each case, (% $q_e = 120$ KW/m^2 from TRANSP)









Conclusion and Future Direction

- The linear analysis indicates that the ETG modes $k_y \rho_e \sim 1$ are unstable at the outer region.
- The electron heat transport in NSTX 106194 and 120967, or 121283 can be explained by the electromagnetic or electrostatic ETG modes.
- We need to refine the β_e criterion for the transition between EM and ES.
- We are going to investigate the effect of the inverted profile $\boldsymbol{\nabla} n_e \cdot \boldsymbol{\nabla} T_e < 0$ on the transport.