NSTX

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Gyrokinetic Turbulence Simulation Challenges in the NSTX Spherical Torus

J. Luc Peterson*
Princeton University, PPPL

G. W. Hammett, D. Mikkelsen, S. Kaye (PPPL)
J. Candy, R. E. Waltz (General Atomics)
and the NSTX Research Team

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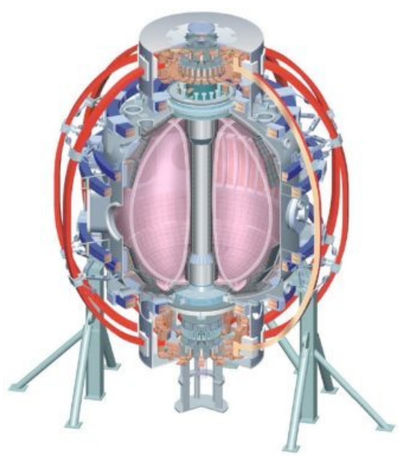

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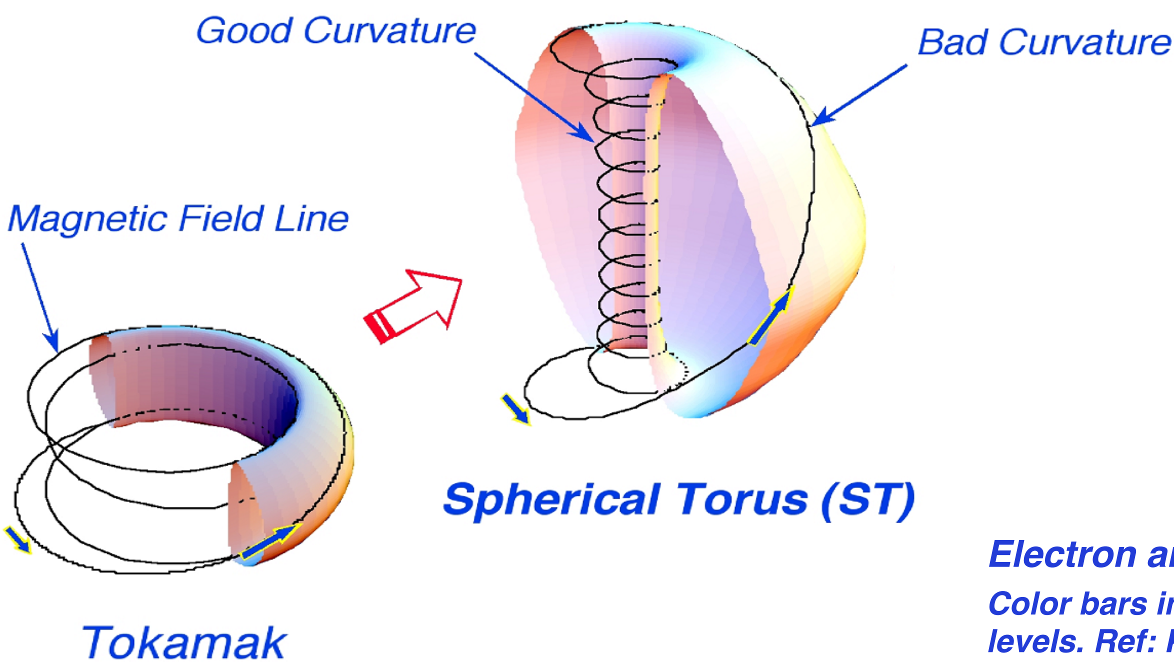
*jpeterso@pppl.gov

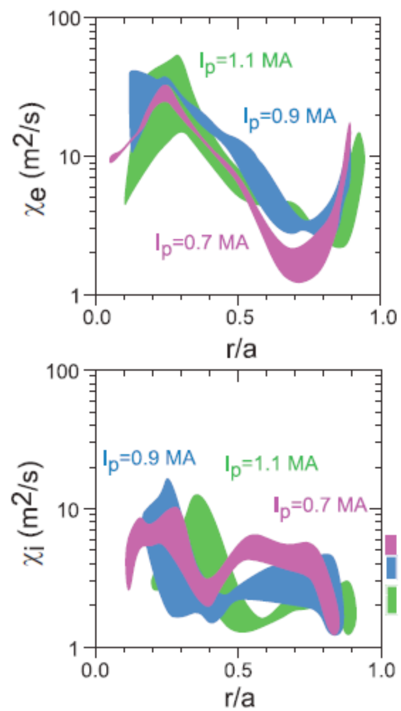
Electron Transport is an Outstanding Problem in Fusion Research

- Anomalous heat losses still plague fusion experiments – Why?
- What is the nature of electron turbulence?
- Can this turbulence be controlled and/or suppressed?
- Does electron turbulence lead to large levels of transport?
- Understanding turbulent transport is essential to the viability of fusion reactors

NSTX is a Unique Laboratory for Studying Electron Losses

- Low aspect Ratio ST, Neutral Beam Power, Strong Sheared Flows, High β_N , Strong Reversed Shear, Good Curvature
- Ion transport in NSTX near neoclassical levels
  - Electrons are dominant loss mechanism
  - Kaye et al. PRL 98, 175002 (2007)





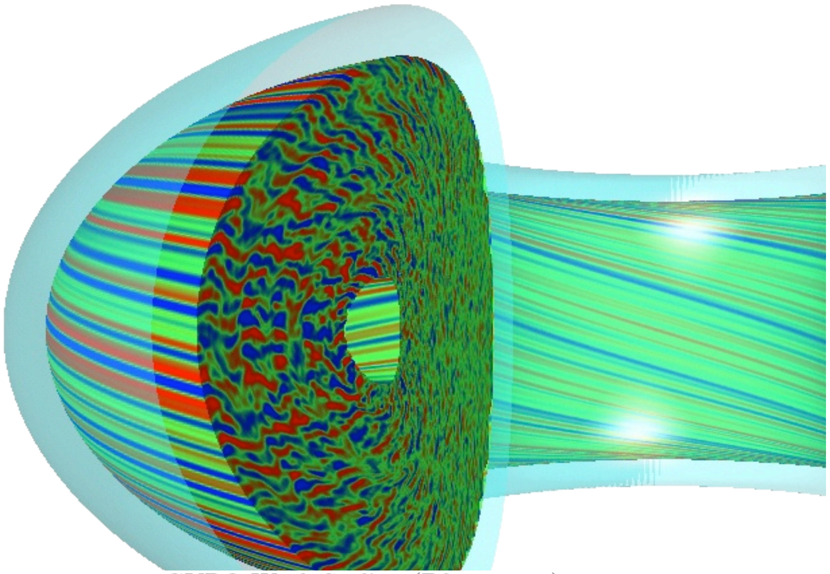
Electron and Ion Thermal Diffusivities in NSTX.

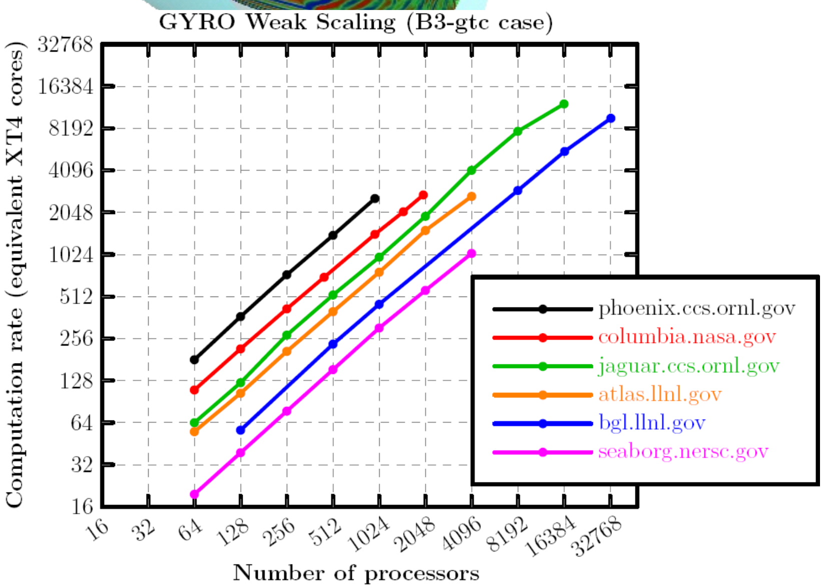
Color bars indicate calculated neoclassical transport levels. Ref: Kaye et al 2007.

Tools to Study Electron Turbulence on NSTX

- Experimental: High-k Scattering System
  - Unique scattering system to measure electron scale fluctuations
  - See D. Smith **YI2.00005**
- Experimental: Multi-Channel Motional Stark Effect Diagnostic
  - Detailed measurements of q profiles, magnetic shear
  - See H. Yuh **TI2.00005**
- Theoretical: Gyrokinetic Simulations
  - GK Sims on STs have been met with difficulty
    - GS2: Applegate PhD Thesis, Imperial College London
  - Low freq microtearing and adiabatic ion ETG modes sometimes fail to converge
  - Coupling between ion and electron scales requires large simulations
- But, if sheared flows in NSTX suppress low frequency modes, may not need to worry about scale coupling: better simulation resolution

GYRO is a 5D Eulerian Global Continuum Non-Linear Gyrokinetic Simulation Tool

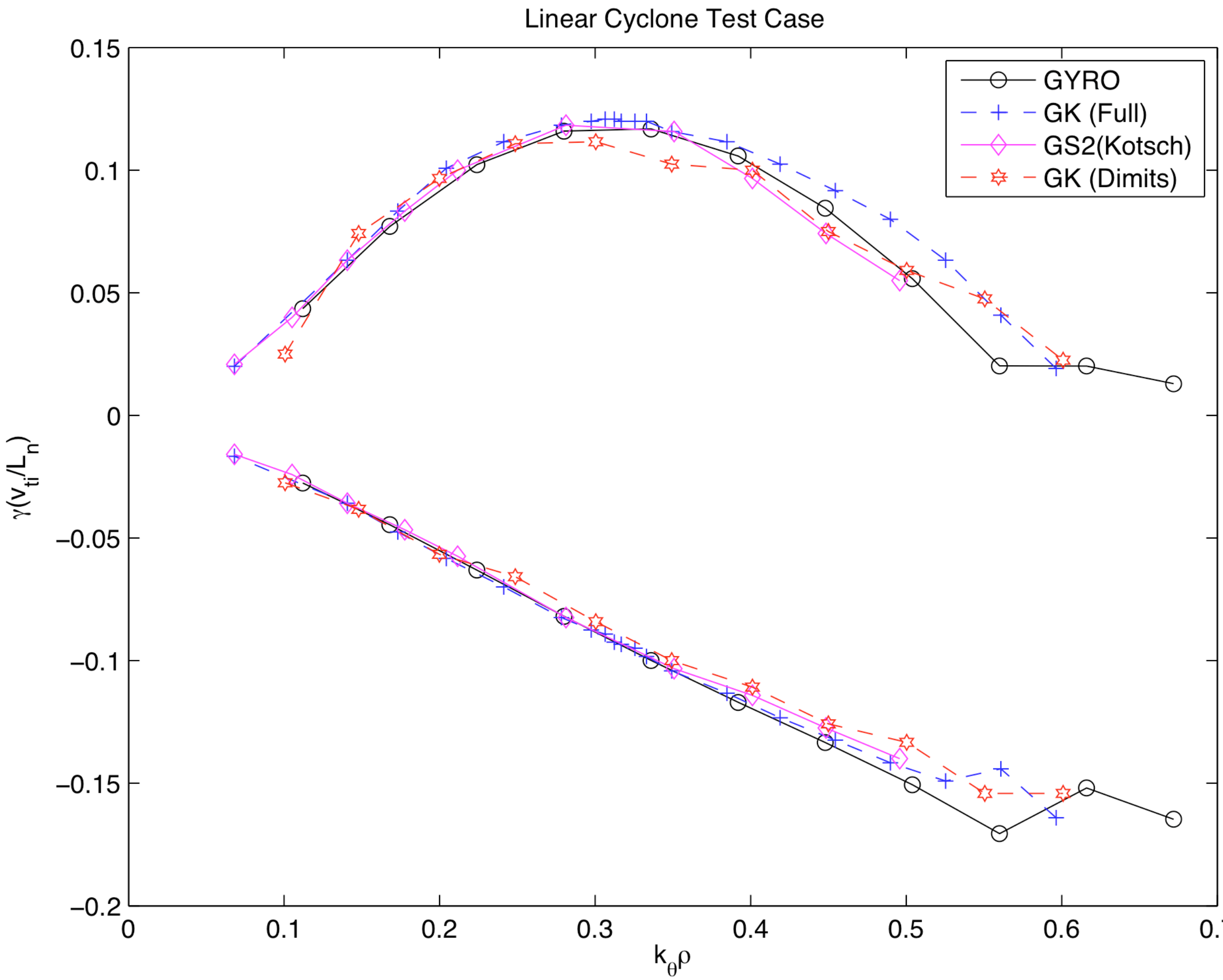




- Uses advanced numerical techniques to obtain higher accuracy with lower resolution
- Flux tube or global
- Adiabatic Ions, Adiabatic Electrons, Kinetic Electrons and full GK compatibility
- ExB shear flow compatibility
- Highly parallelizable

J Candy, R. E. Waltz et al. J. Phys Conf Ser 78, 012008 (2007)

GYRO In Good Agreement with Linear Calculations from Many Codes



Linear ITG test case.

GYRO data: Peterson. Other data see Dimits et al (2000)

Adiabatic Ion Approximation Allows for Faster Linear Calculations

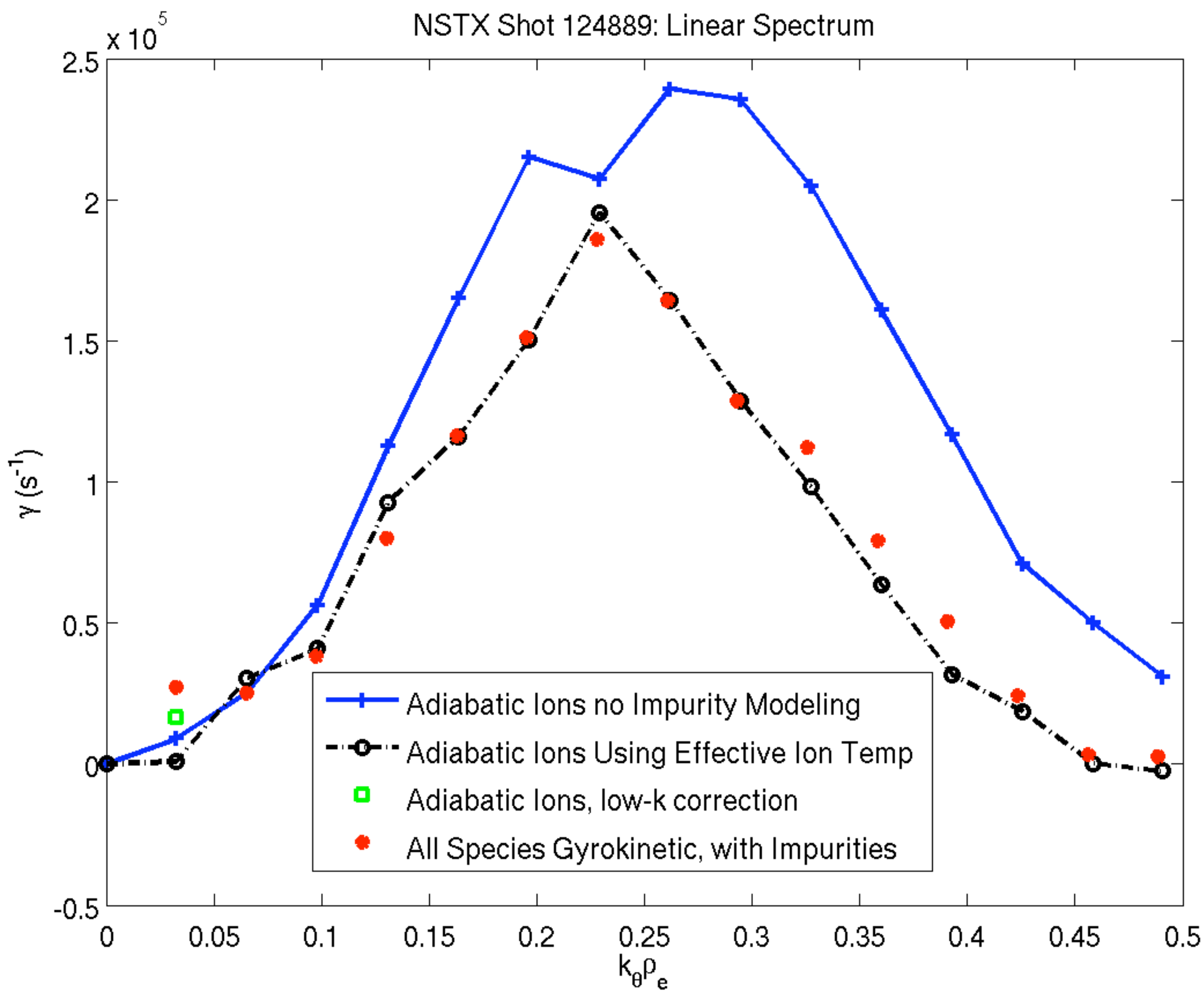
- Adiabatic Ions give good agreement to full GK simulations if one uses an effective ion temperature that accounts for impurities
- Discrepancies at low wavelengths from Adiabatic Ion Approximation
  - Non-linearly destabilizing, unless modes are suppressed
  - Linearly stabilizing:

$$\sum_i \tilde{n}_i e_i = -e^2 \frac{\Phi}{T_i} \underbrace{\sum_i n_{i0} Z_i^2}_{n_e Z_{eff}} \left[1 - \Gamma_0\left(k_\perp \rho_{ti}\right)\right]$$

$$\sum_i \tilde{n}_i e_i \approx -e^2 n_e \frac{\Phi}{T_i} Z_{eff} \underbrace{\left[\frac{k_\perp^2 \rho_{ti}^2}{1 + k_\perp^2 \rho_{ti}^2}\right]}$$

Low-k correction = 1 for standard "Adiabatic Ion" run

Using Adiabatic Ions with Model Impurities is a Good Approximation to Full Gyrokinetic Simulation



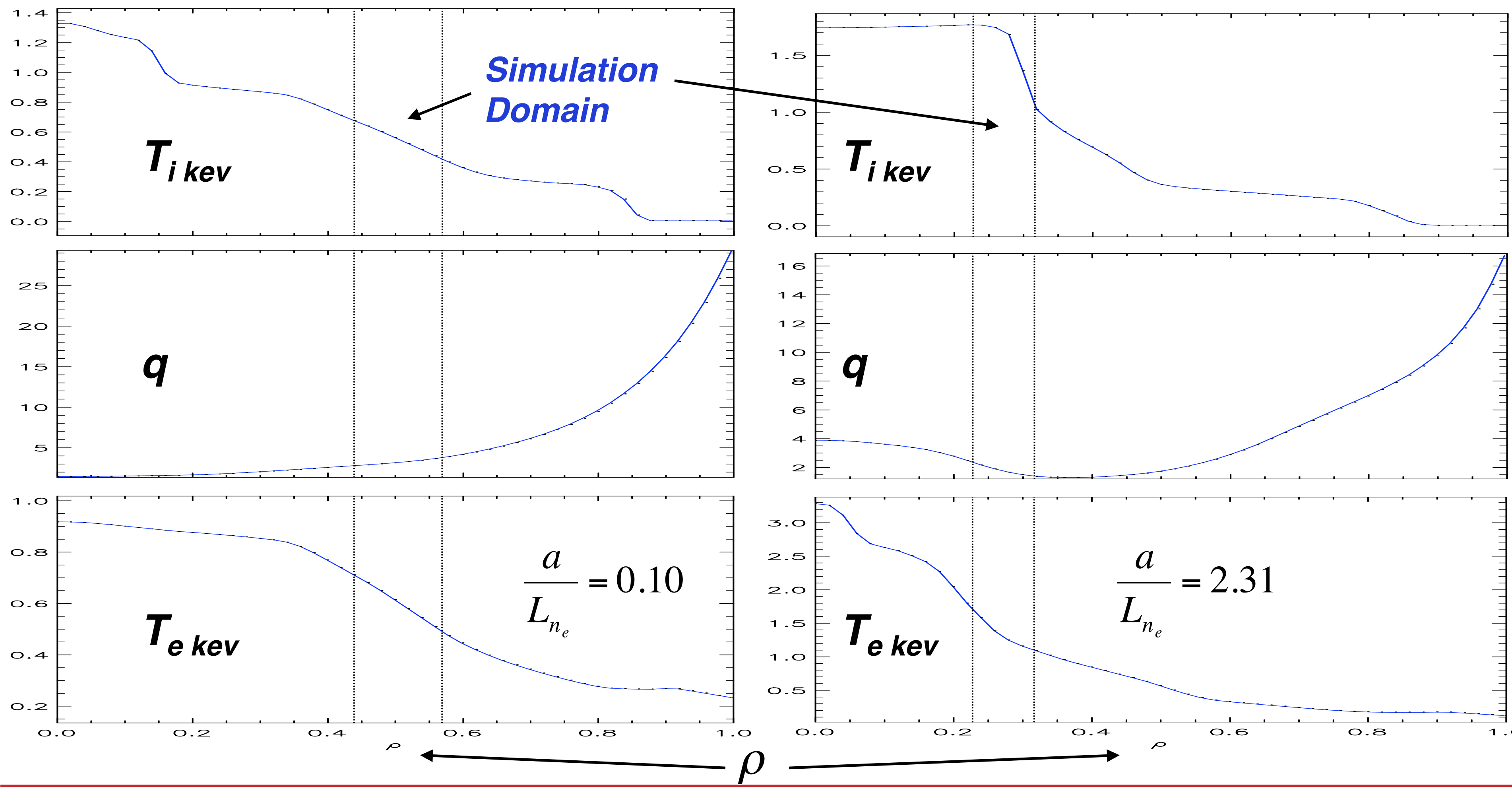
NSTX Baseline Shots

124889A08

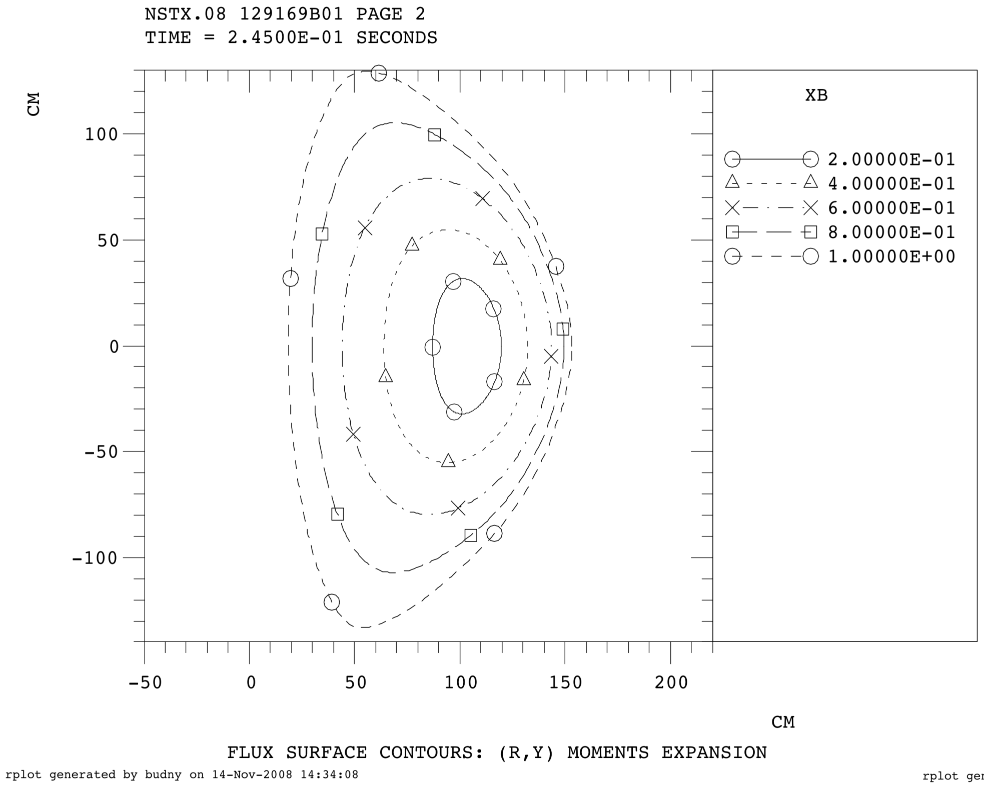
- 135 cm, 330 ms, D2

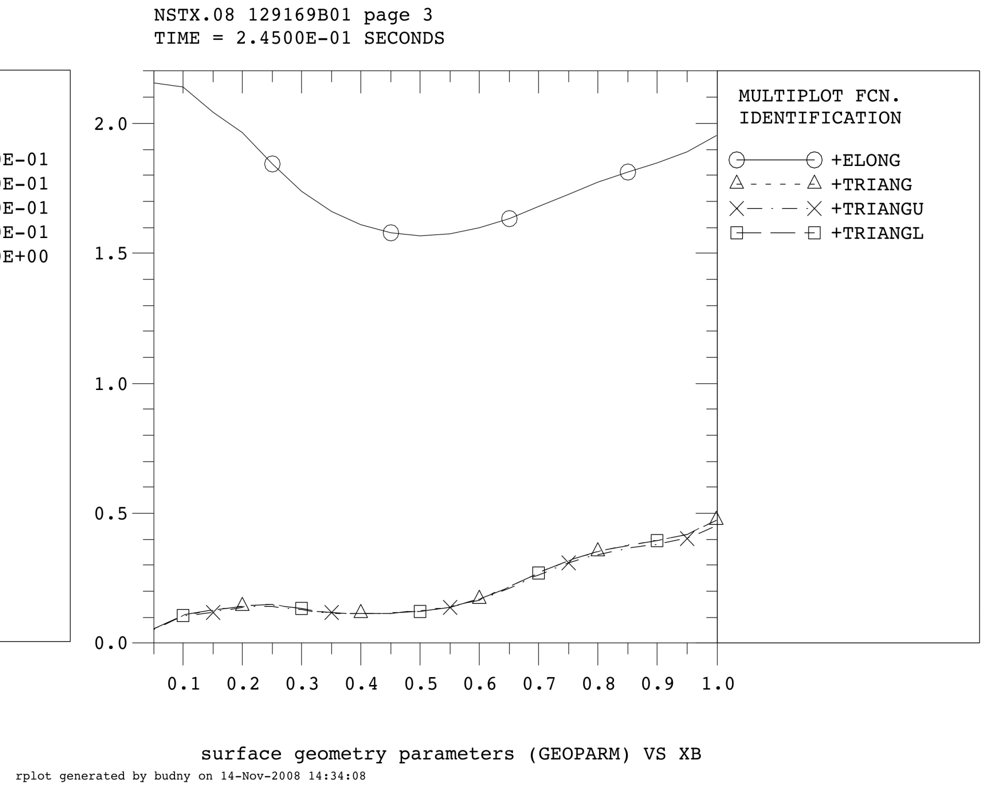
126169B01

- 124 cm, 245 ms, He



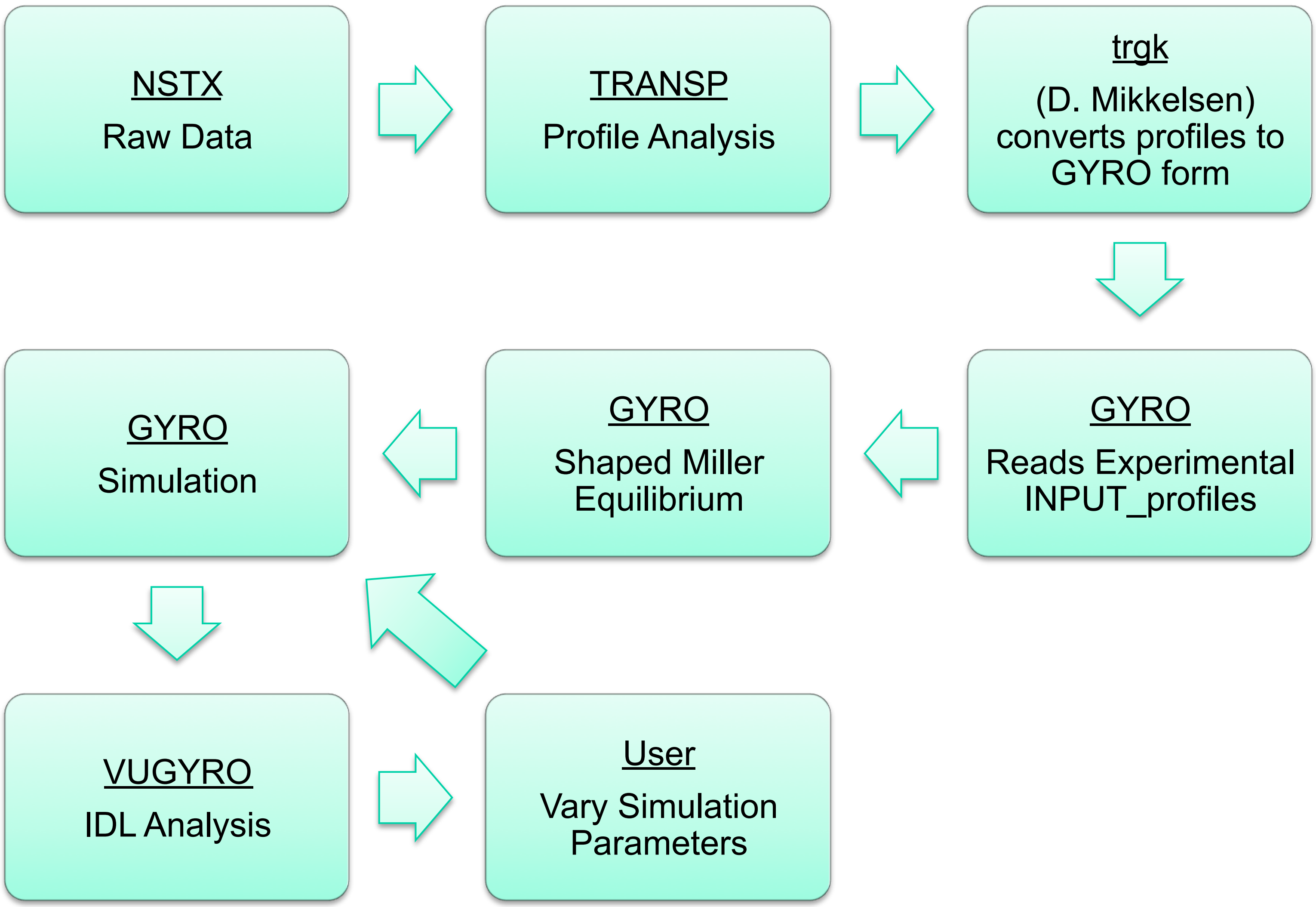
NSTX's Unique Geometry Complicates the Problem





- Low aspect-ratio, high β and strong shaping of NSTX cause strong variation of grid metric coefficients.
- May need higher resolution to accurately resolve
- Being investigated

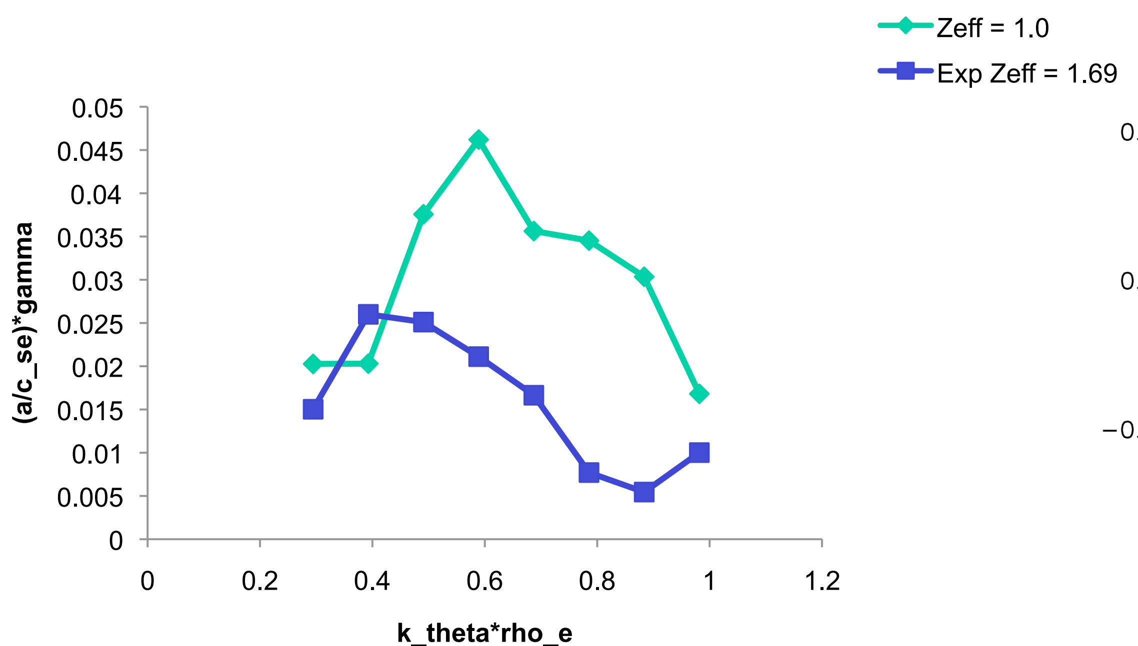
From NSTX to GYRO



Linear Simulations Show ETG Unstable, ITG Stable in NSTX

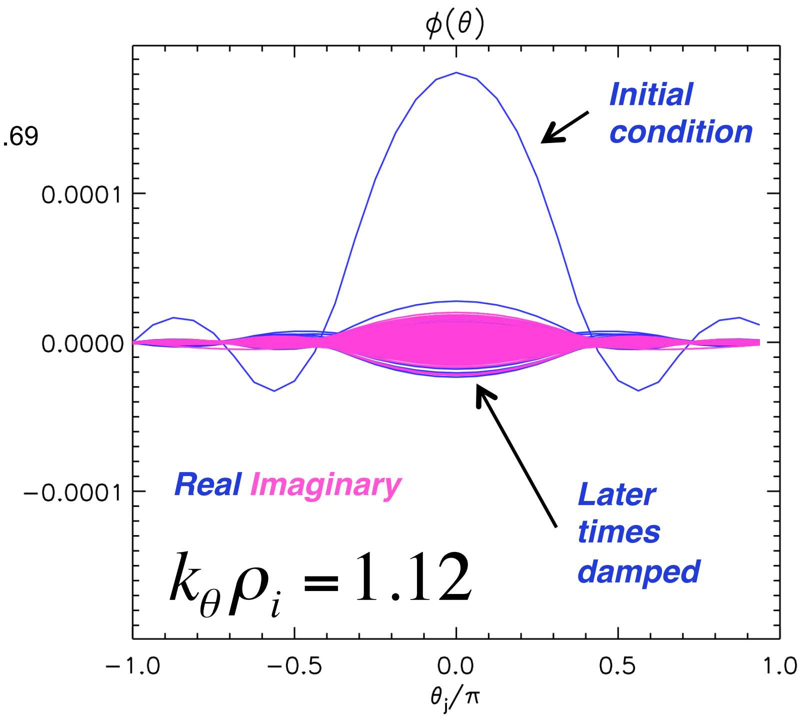
- Peak ~ 0.3 $k_\theta \rho_e$
- Ion scales show no growth
- Mode structure is even
- Electrostatic

NSTX 129169 Linear Growth Spectrum



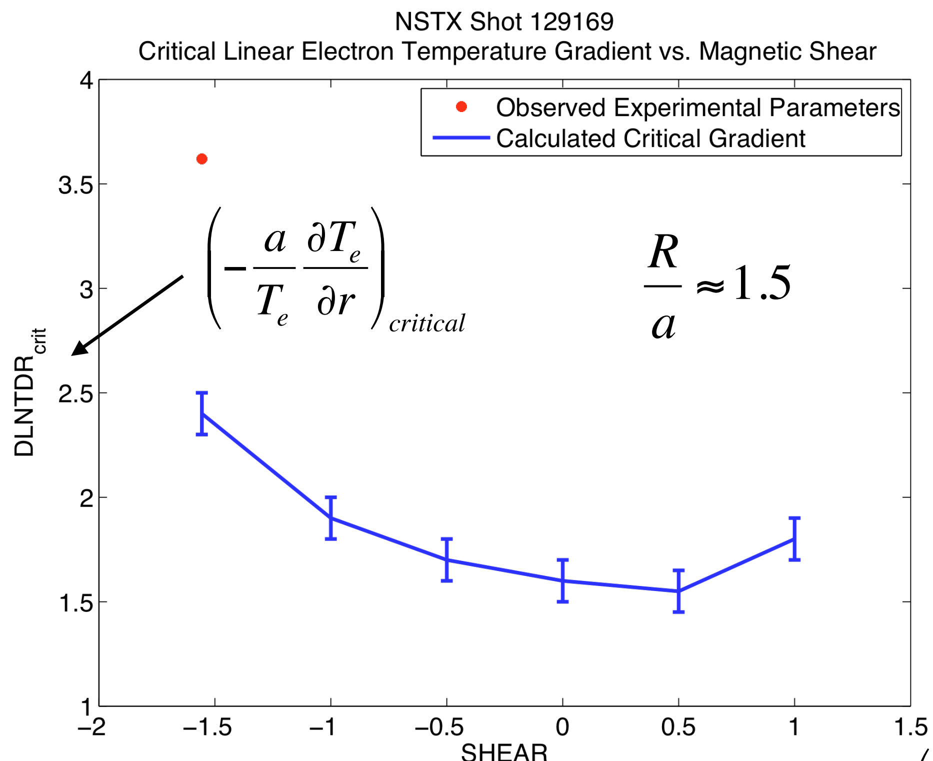
Ion Scale Electrostatic Potential

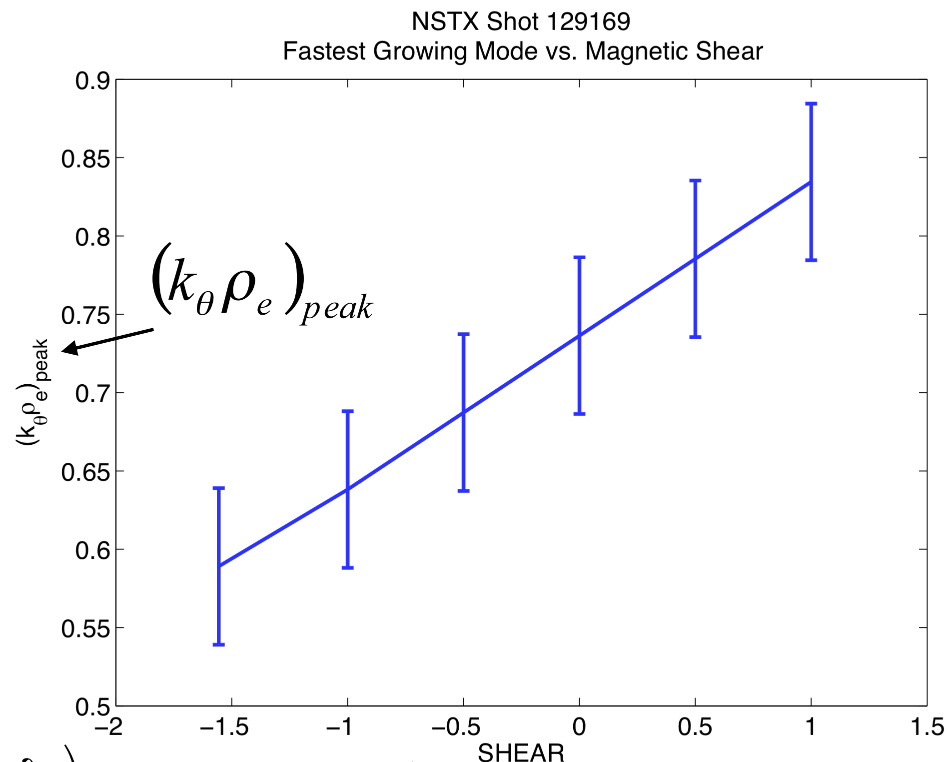
"peak" mode, all times



Negative Shear Does Not Linearly Stabilize NSTX Discharges

- Reverse Shear does raise critical ETG gradient, but not enough to account for observations (H. Yuh **TI2.00005**)
- Spectrum shifts downward with shear

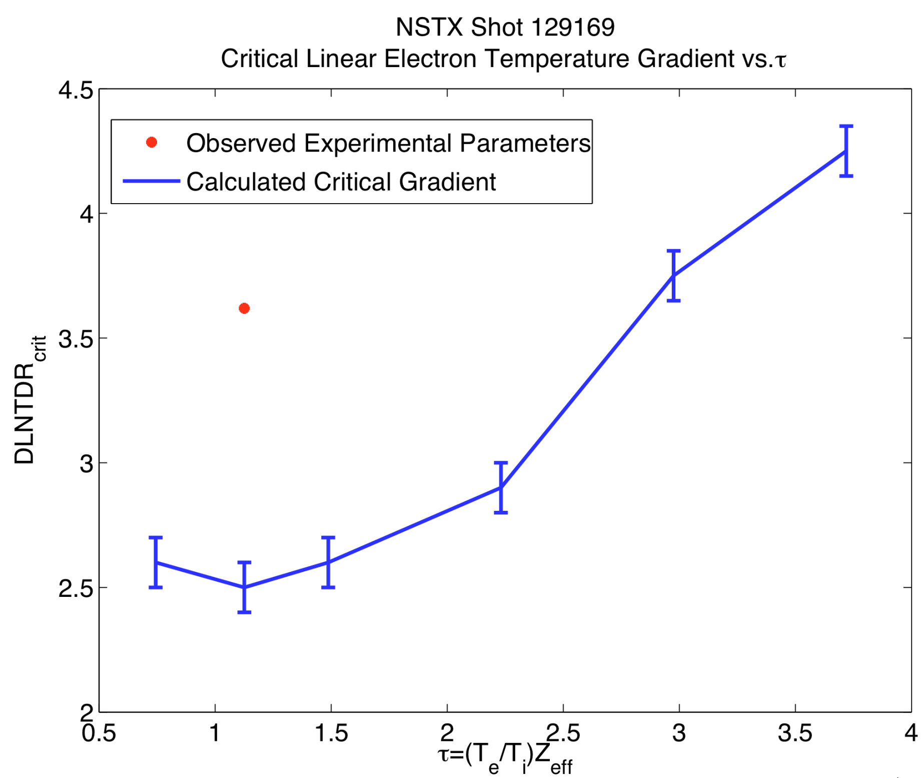


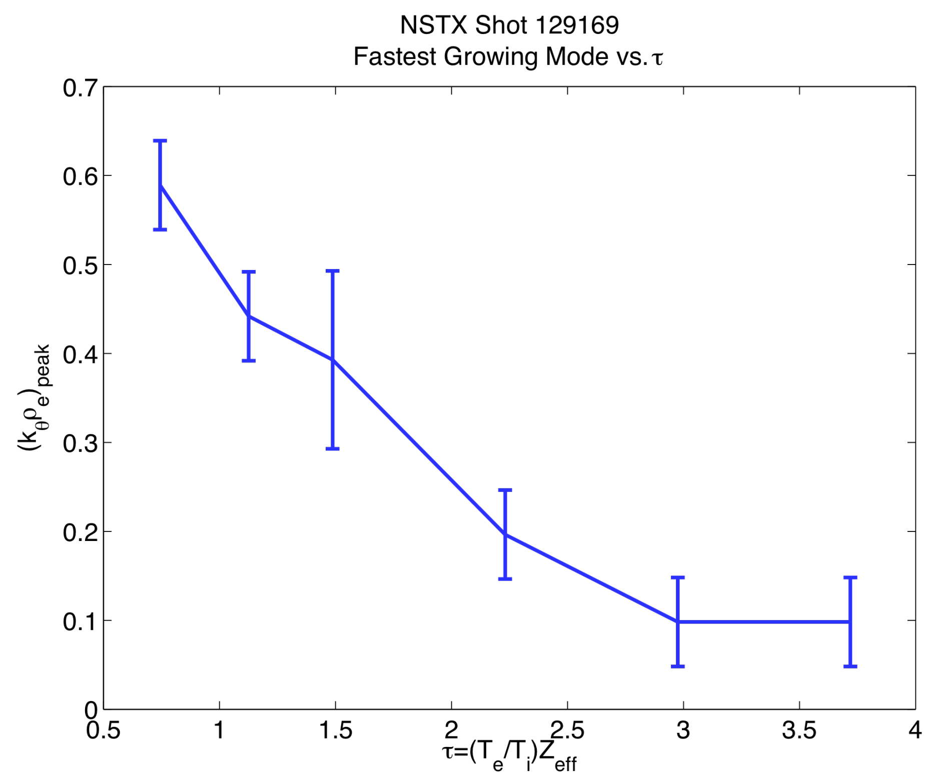


$$\left(\frac{r}{q}\frac{\partial q}{\partial r}\right)$$

Z_{eff} May Also Alter Linear Stability for NSTX by raising Linear Critical Gradient

- Effects of impurities important (What about Lithium?)
- Again, spectrum shifts downward as linear threshold increases

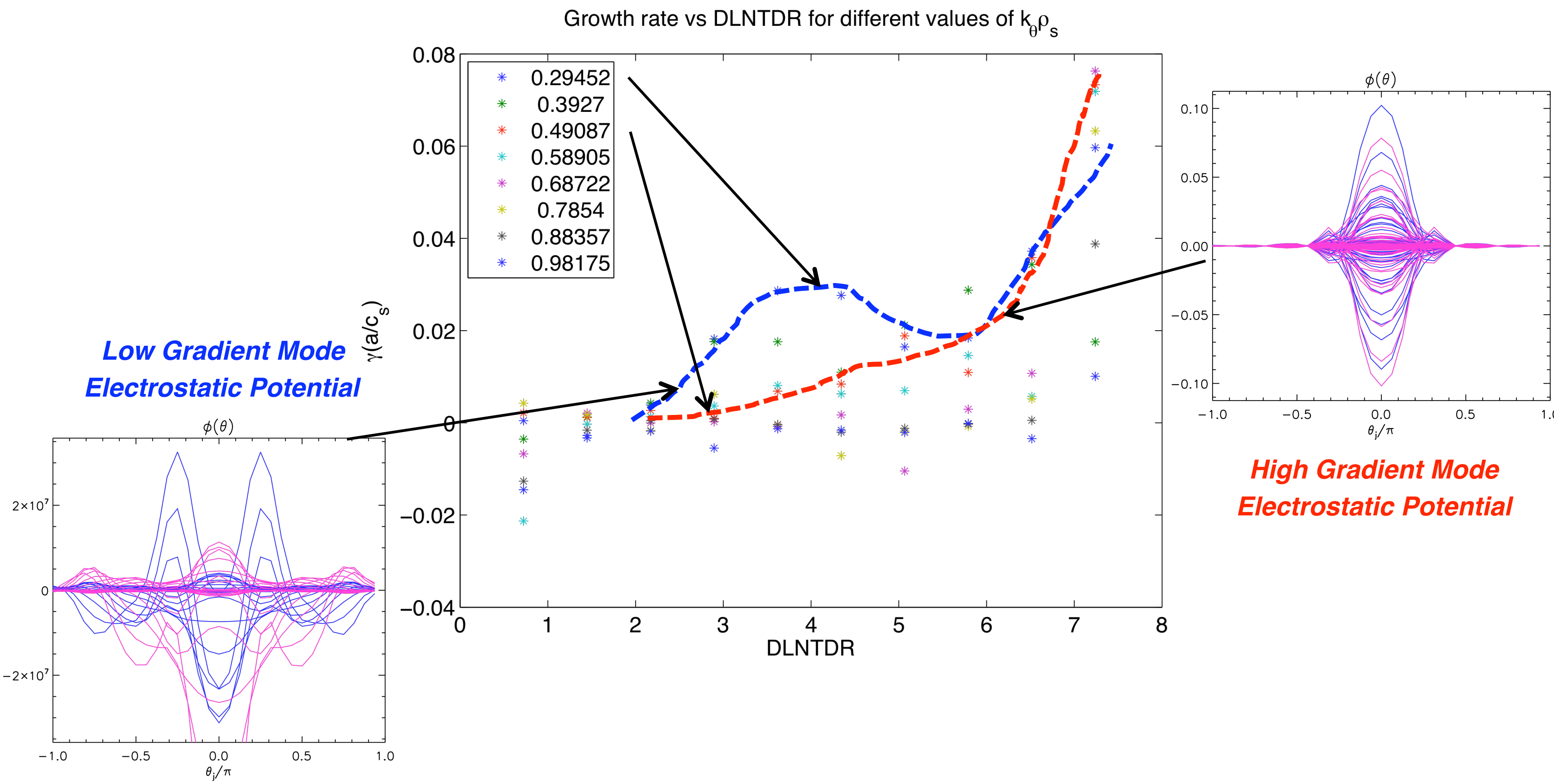




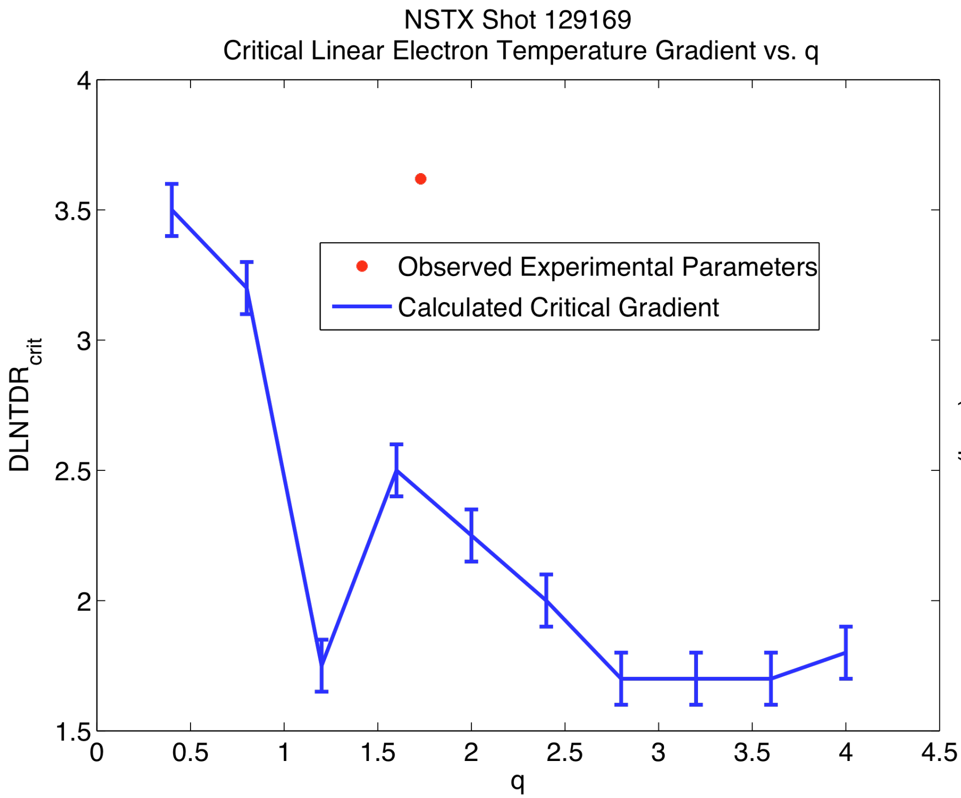
$$\tau = \left(\frac{T_e}{T_i}\right) Z_{eff}$$

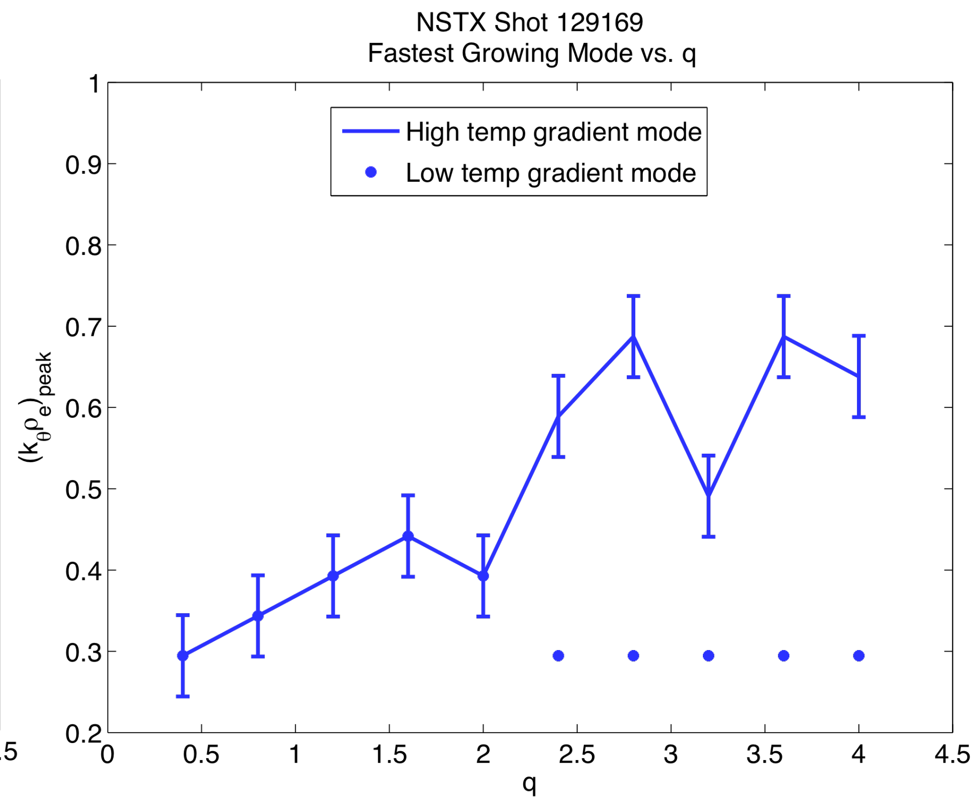
At high q, multiple eigenmodes appear. Fastest growing mode depends on temperature gradient.

- "Broad" mode is stronger at gradients closer to critical gradient
- "Narrow" mode becomes dominant at higher driving gradients



As q Increases, Linear Critical Gradient Approaches a Constant





- **In all cases, experiment is well above linear threshold for ETG instability**
- **High gradient mode follows same spectrum shifting pattern**

Future Goals: Nonlinear Simulations and Connection to Transport

- D. Smith (**YI2.00005**) suggests that the relation between the measured high-k turbulence and electron transport is not straightforward
- Need non-linear simulations
- Hypothesis: Strong ExB flows in NSTX suppress the long-wavelength modes that make full all-species gyrokinetic electron-ion simulations difficult
  - Do not have interactions with low frequencies
  - Can use reduced (adiabatic) ion models to relax resolution requirements

Conclusions

- We have successfully completed Electrostatic linear gyrokinetic simulations of NSTX
- NSTX discharges are linearly unstable to ETG and stable to ITG
  - Microtearing & TEM may be at play too
- Reverse Magnetic Shear alters linear critical gradients, but not sufficiently to explain observed gradients in NSTX
  - Possible non-linear suppression of eddies: Jenko and Dorland (2002)
- Multi-mode parameter scans suggest spectrum shifts with critical gradient: more stable, lower frequency peak
- Adding ExB shear may suppress long wavelength modes in simulations, thereby reducing the resolution requirements for non-linear runs