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NSTX

Nonlinear Turbulence Simulations for NSTX H-modes

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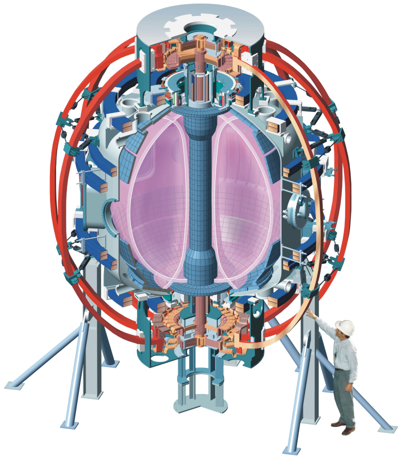

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Outline

Alcator C-Mod NSTX

To investigate turbulent microinstabilities in NSTX H-mode plasmas exhibiting unusual plasma transport

Can we understand and control confinement?

- remarkably good ion confinement and resilient Te profiles on NSTX

NSTX - MHD quiescent H-mode with resilient T_e profiles

- Linear calculations of ITG/TEM, ETG, long wavelength microtearing modes
  - ITG stability appears consistent with low $\square_i$ as inferred by TRANSP, depends on $\square_{ExB}$ shear stabilization:
  - ETG near edge and microtearing instabilities in plasma core appear consistent with high $\square_e$

Nonlinear calculations have begun

Microstability basis of transport differs in ST and tokamak

- New interpretation depends on monotonic q profiles, not yet measured.

NSTX: NBI in MHD Quiescent Discharge: $T_i > T_e$, Resilient Te Profiles

$I_p = 0.8$ MA

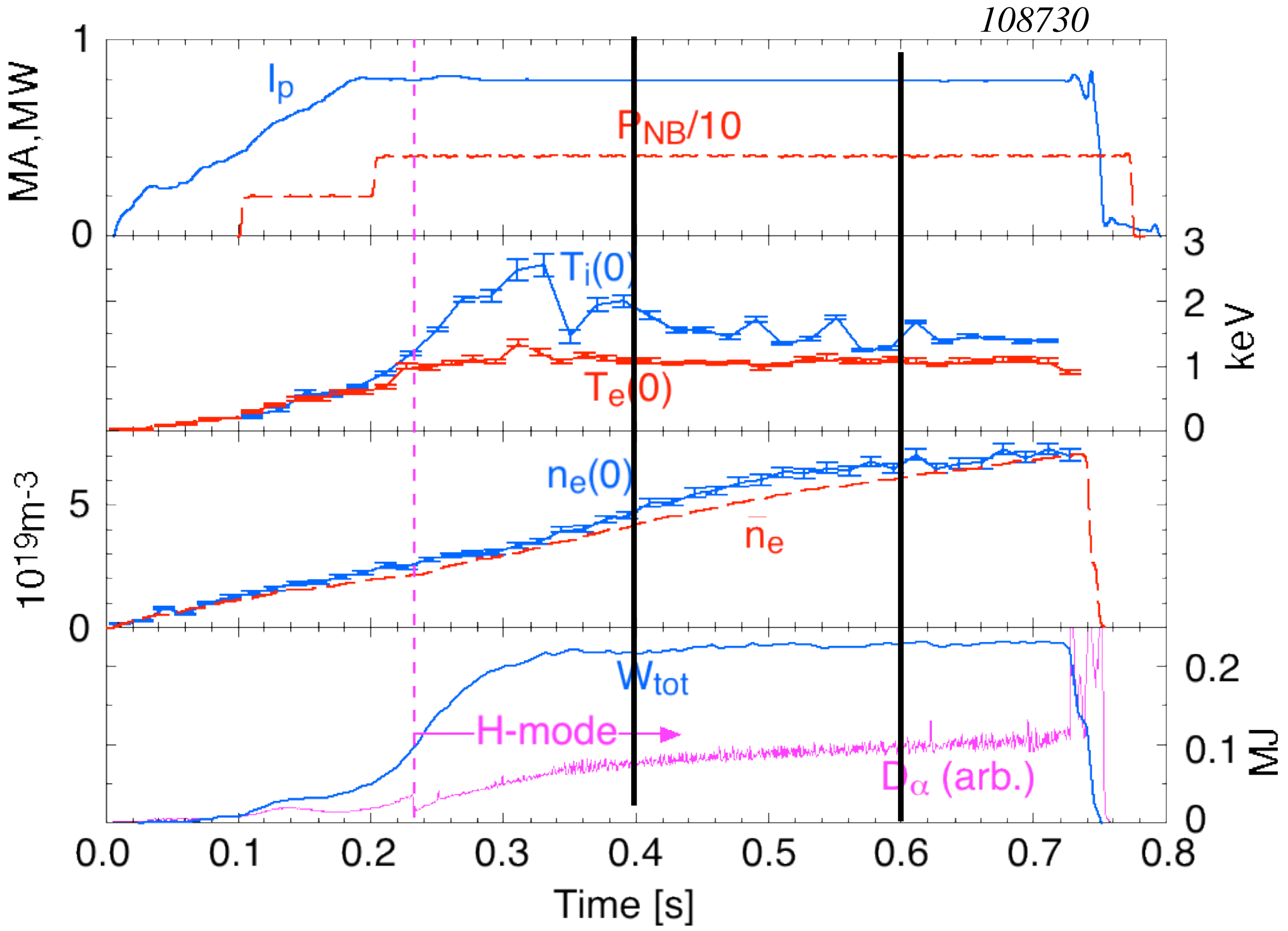
$B_T = 0.5$ T

$P_{NBI} = 4$ MW

$E_{NBI} = 90$ keV

$\beta_T = 16\%$

W = 0.23 MJ



LeBlanc-EPS-03

NSTX H-mode: Te(r) Resiliency

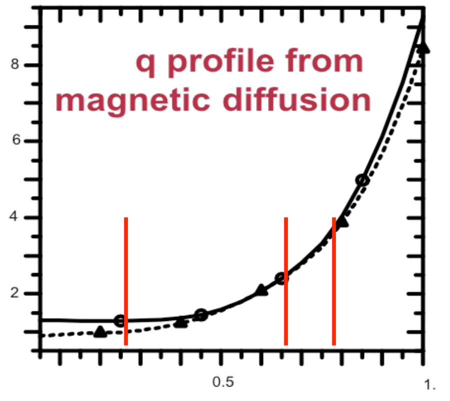
During H-mode

$T_e(r)$ remains resilient
electron density increases
ion temperature decreases

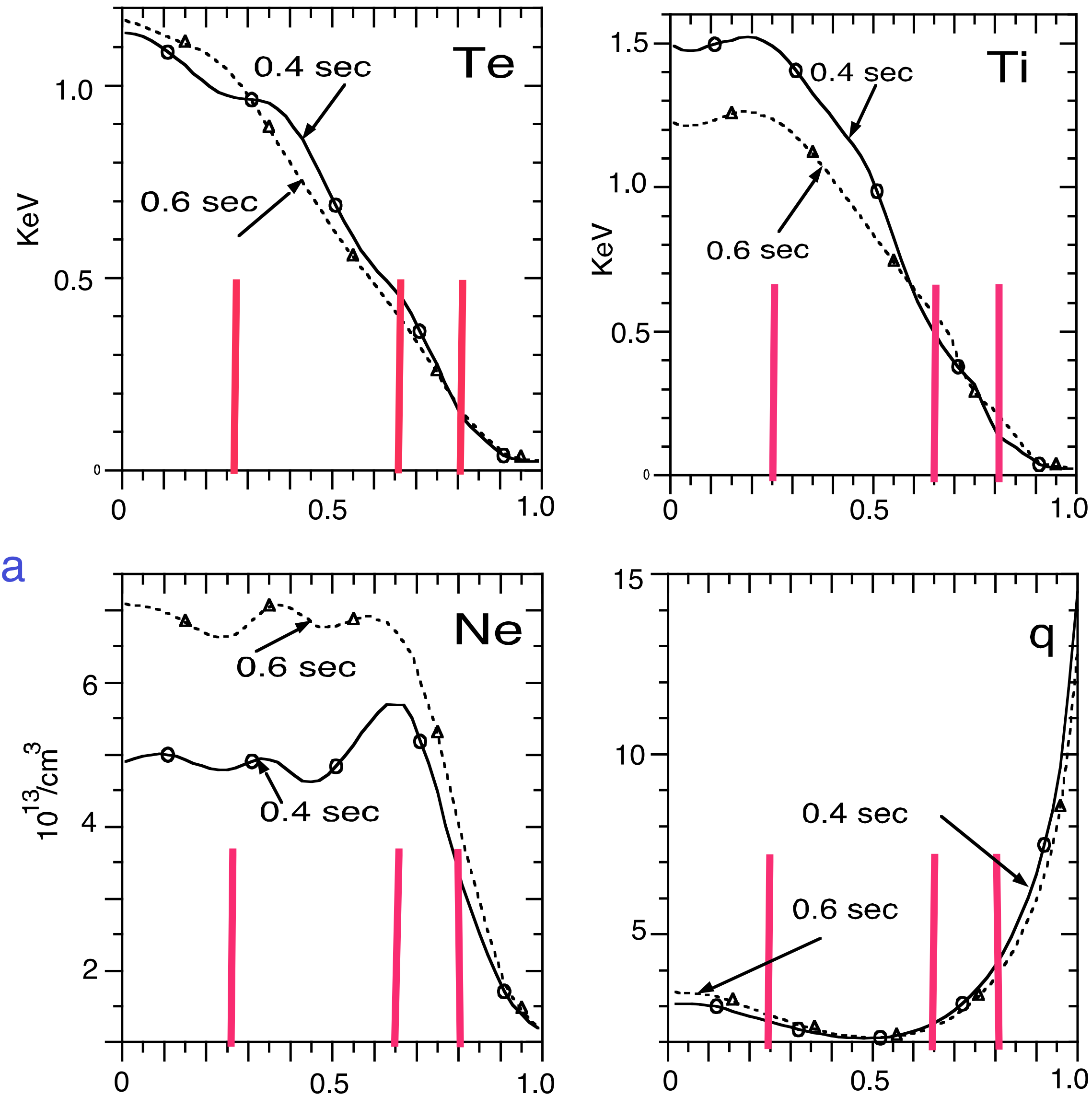
What clamps
Electron temperature profile?

Examine microinstability
Growth rates at 3 zones

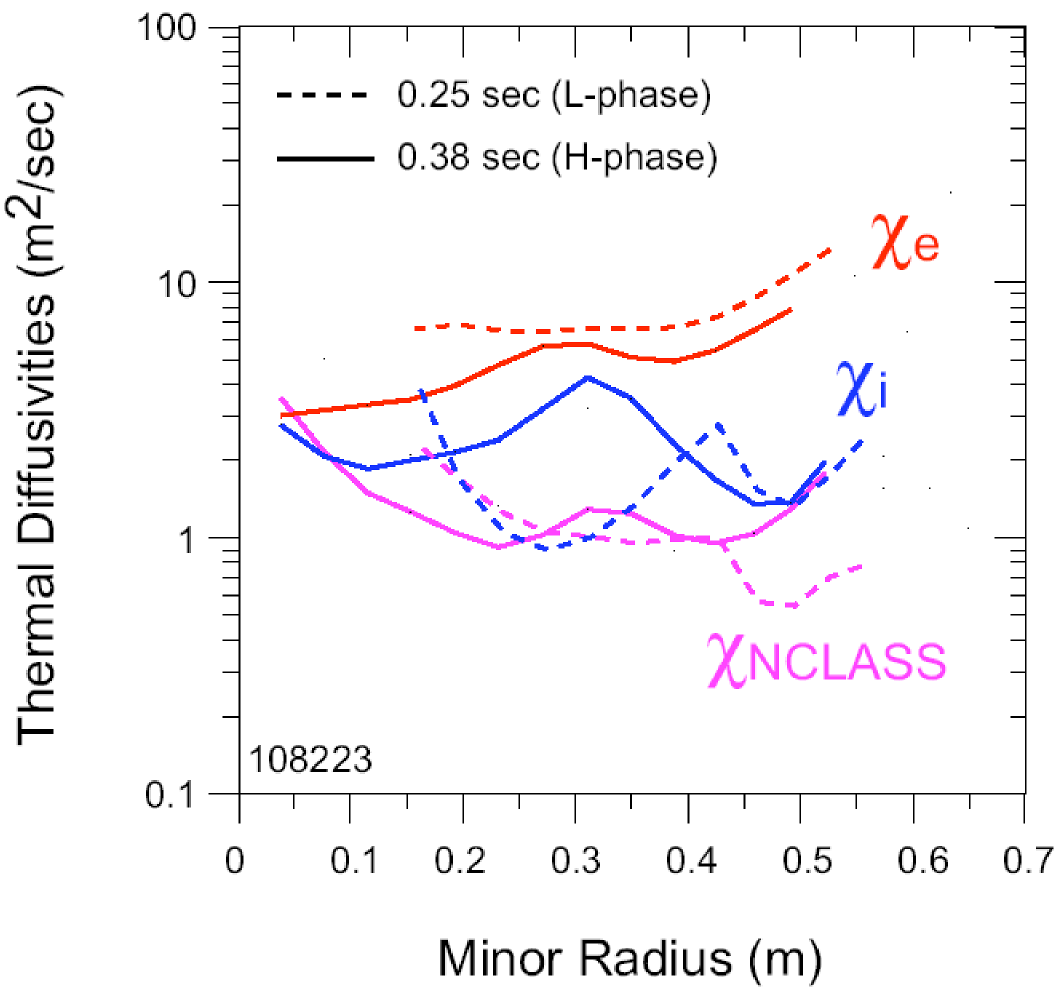
q profile: fit to external magnetic data
Need MSE measurement



q profile from magnetic diffusion



Little Change in Core Transport Going From L- to H-Phase

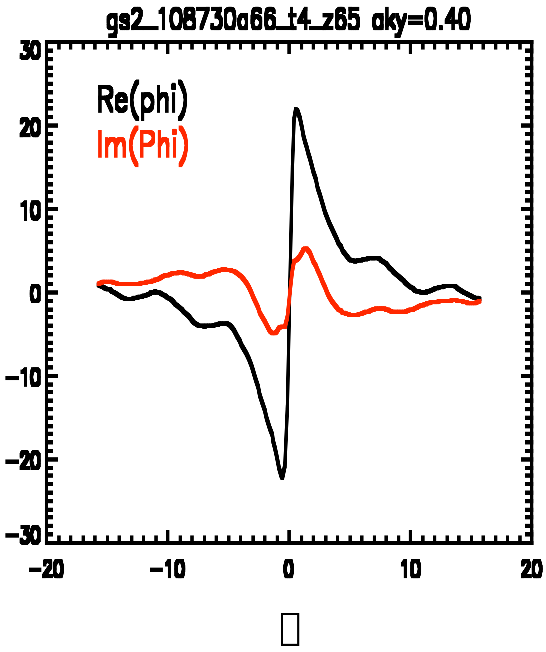


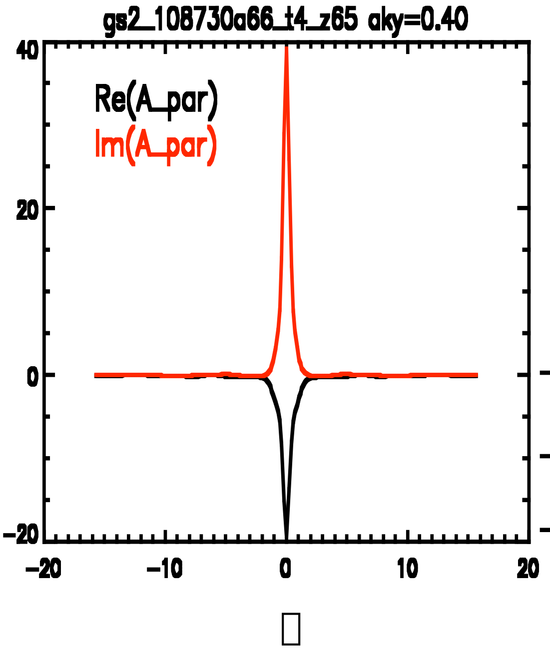
Changes in χ are generally within uncertainties

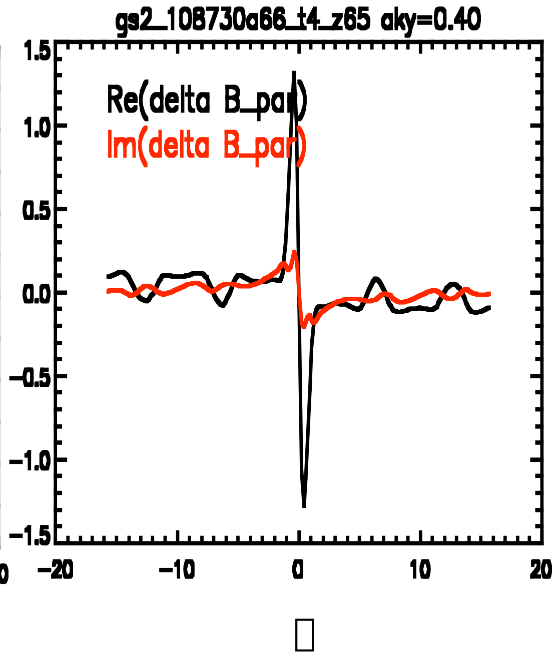
$\chi_i \geq \chi_{neoclassical}$

$\chi_e > \chi_i$

Microtearing Mode Exhibits Symmetric A_par







□ = Poloidal angle along field line in radians

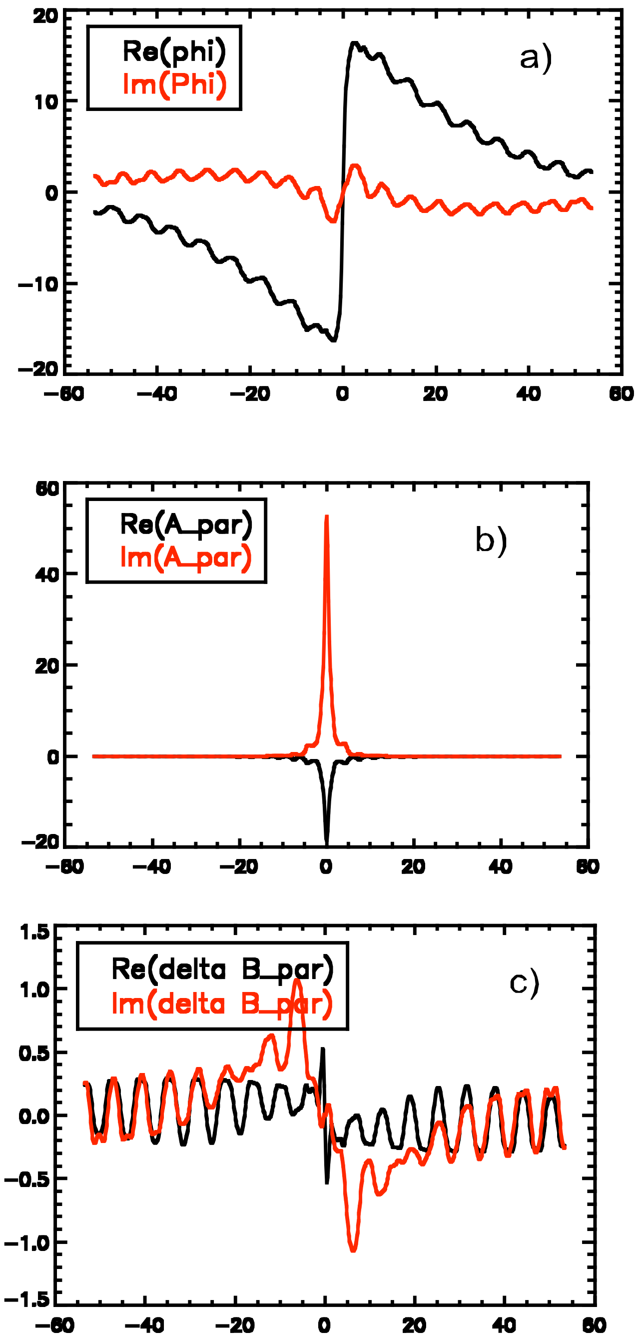
Convergence tests

Eigenfunctions of electrostatic
and electromagnetic fields
for 0.6 sec and r/a= 0.25
at $k_{□}□_{s}$=0.5

Seventeen 2□ extent
of field line length needed
to confine eigenfunctions

Corresponds to a very large
radial width in the
simplest approximation
width of $A_{//}$=□□ ~1radian

Resonant trapped particle instability
at each field period

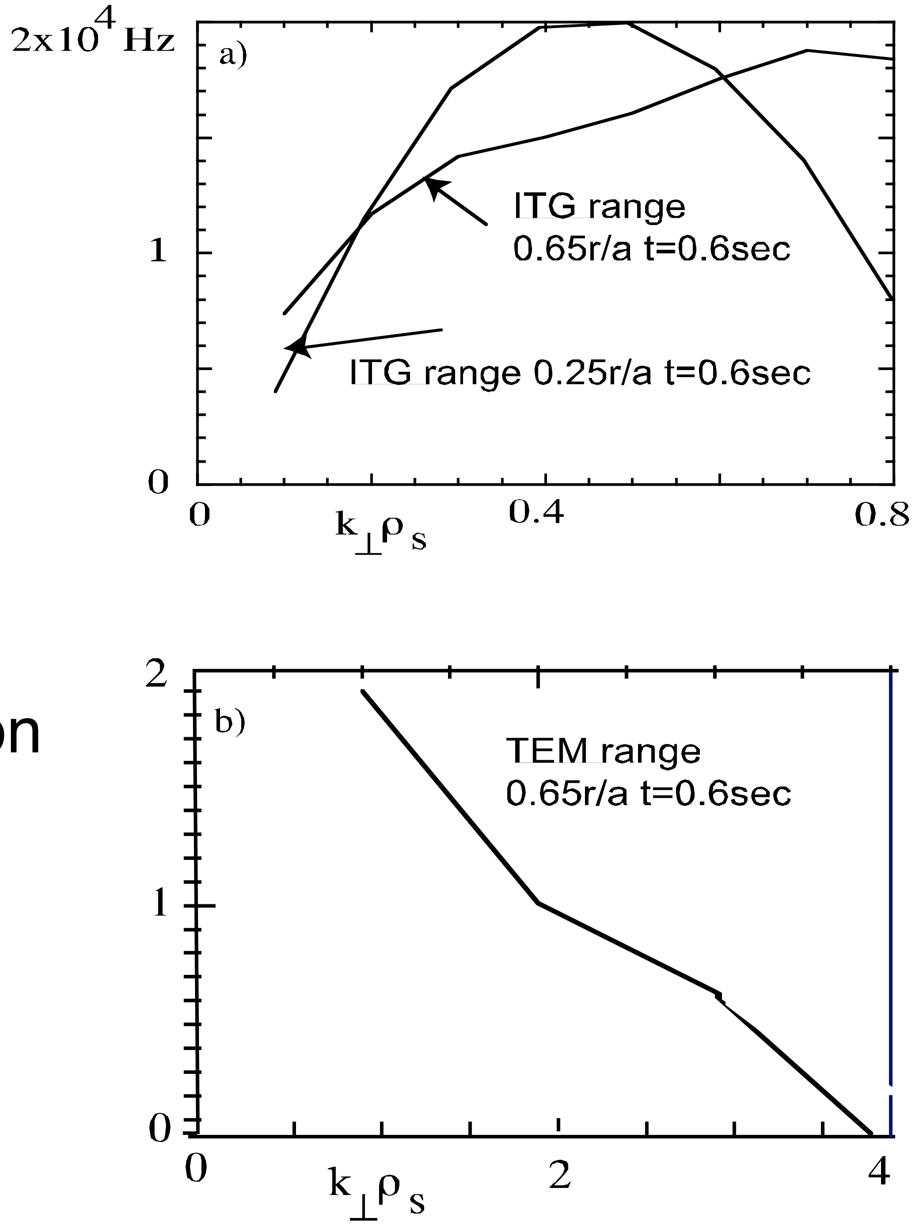


Broad spectrum of unstable modes

What causes
high electron diffusivity?

Plasma core:
Find only long wavelength
microstabilities:
neither ITG nor ETG,
exhibit tearing parity,
rotate in electron drift direction

At 0.65r/a modes extend
To smaller wavelengths than
At 0.25r/a



ITG range
0.65r/a t=0.6sec

ITG range 0.25r/a t=0.6sec

TEM range
0.65r/a t=0.6sec

Connor Condition Satisfied for Linear Instabilities

Connor, Cowley, Hastie (1990) examined linear instability conditions

for tokamak microtearing mode in the intermediate collisionality regime

For $\square_e$,$\square_i$=• , instability occurs only if $\partial_r T_i > \partial_r T_e$. Dispersion relation:

$$\frac{\square}{(\square^{T}_{*e})} = \square\hat{C}_1 \square \ell n \square + \hat{C}_2 \sqrt{\frac{\square\square_e}{\square^{T}_{*e}}} \square \hat{C}_3 \frac{\square_e}{\square^{T}_{*e}} \square \hat{C}_4 \frac{\square^{T}_{*e}}{\square_e}$$

Broad spectrum: weak, well converged modes with tearing parity

$k_\square\square$=0.1 to 0.8 at r/a =0.25 at 0.6 sec and

$k_\square\square$= 0.1 to 1.0 at r/a=0.65 at both 0.4 sec and 0.6 sec.

Well converged, unstable modes with mixed parity

at higher wavevectors, up to $k_\square\square_s < 2\square 3$ at r/a =0.65 at 0.4 and 0.6 sec.

At 0.4 sec, unstable growth rates at r/a =0.25 are smaller

and the modes, aside from $k_\square\square_s = 0.1$, do not have tearing parity.

Connor condition is satisfied in NSTX core,

except r/a =0.25 at 0.4 sec, where no tearing parity mode was found.

What is the radial width of the microtearing mode?

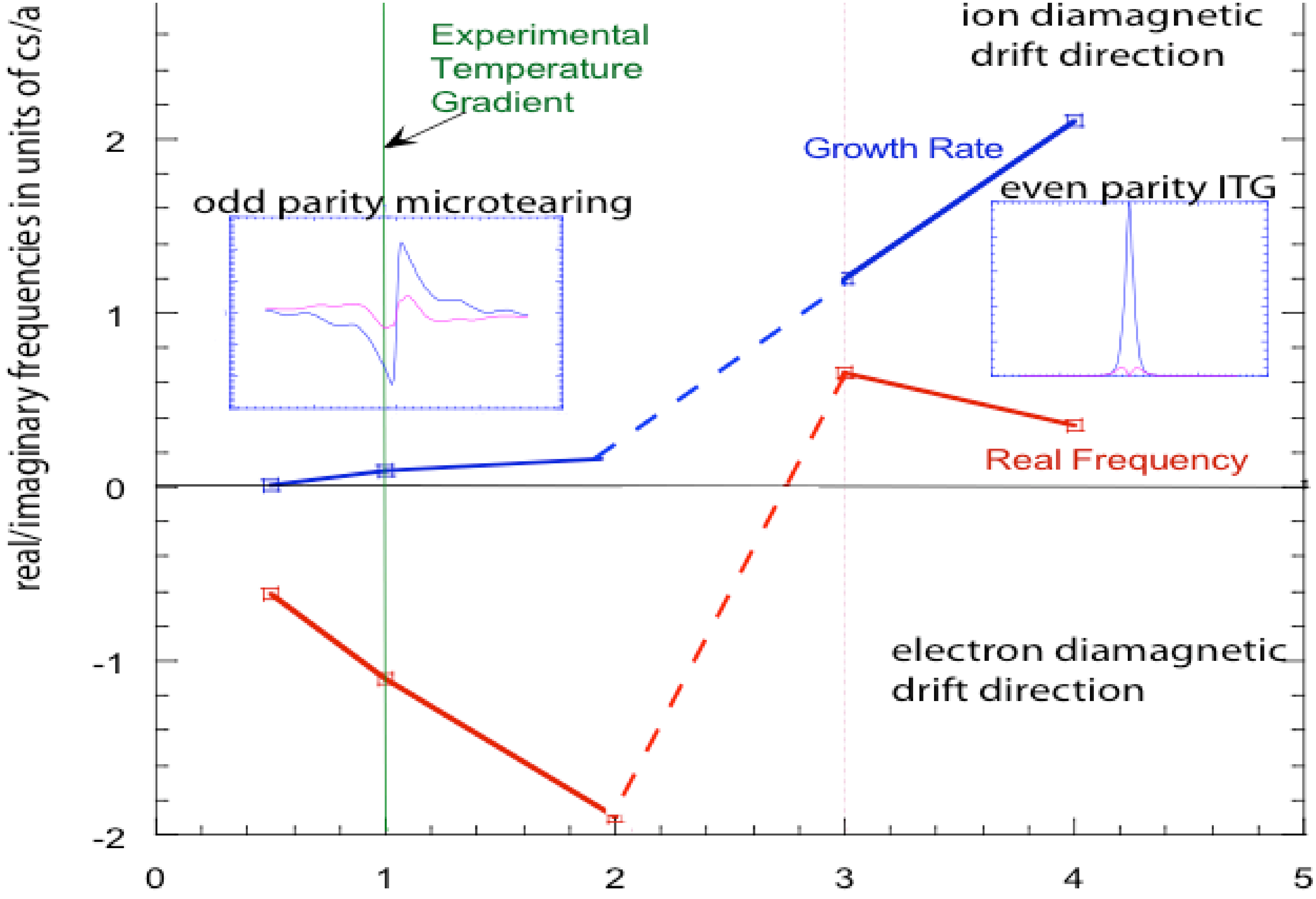
- Corresponds to a very large radial width in the simplest approximation

- Width of $A_{//}=\Delta\theta$ ~1radian. Estimate $<k_x>=<k_y>\cdot rq'/q\cdot\Delta\theta$.
  With $<k_y> = 0.5/\rho_s$, rq'/q = 0.15, $\Delta\theta$= 1.2 radians,
  Then $\Delta x=2\pi/<k_x>=84\rho_s\sim 84\rho_i$.

- Near the plasma core ρ_i = 0.017 m,
  leading to the radial width of the tearing mode:
  $\Delta r_{tearing}$~1.4 m > a_{mid}=1.2 m, the plasma minor radius.

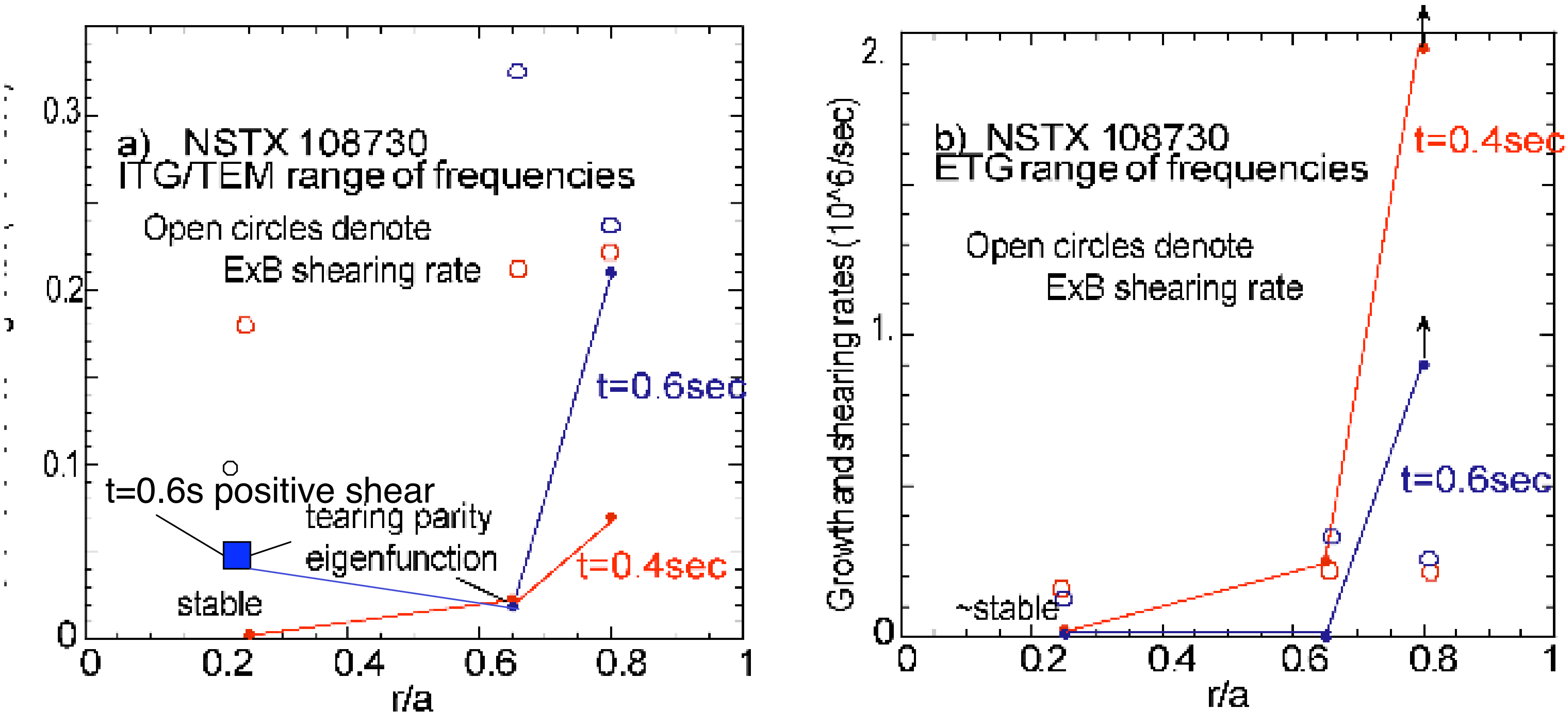
- More detailed calculations are needed
  to properly answer this question.

Microtearing Instability at 0.65r/a: effect on NSTX transport?



NSTX: Examine ITG and ETG Microstability

Find: tearing parity eigenfunction, with broad wave vector spectrum □(k$_□$□$_i$)
ITG instabilities, with symmetric eigenfunctions and parabolic □(k$_□$□$_i$)



NSTX ITG Near Marginal Stability at 0.8r/a

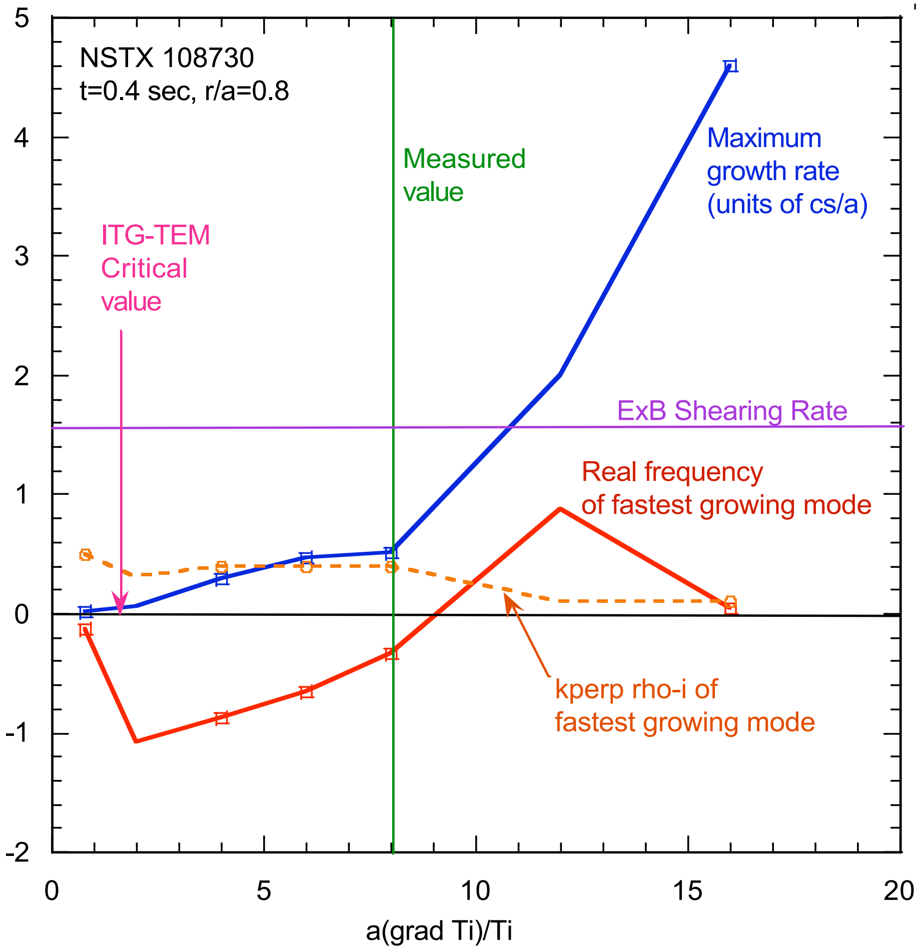
With 25% error bars on shearing rate, ITG possibly stable with

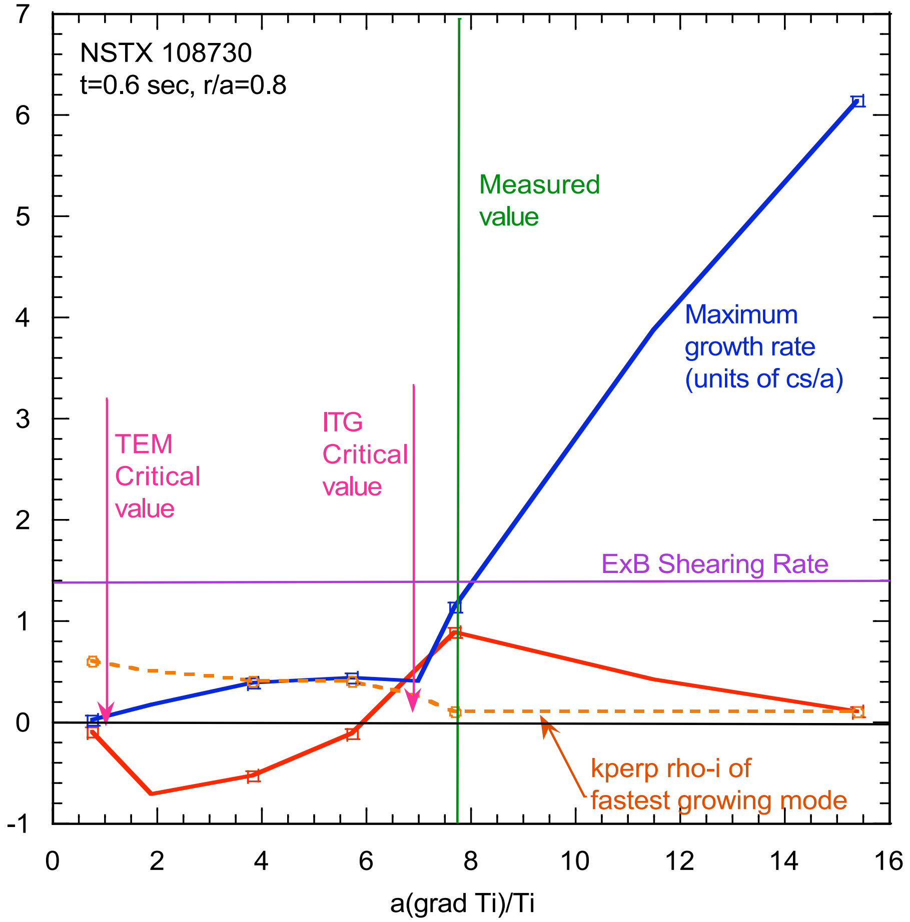
$2\square3\square^{ITG} > \square_{ExB}$ criterion

What should be the criterion for ITG stability?

Dimits (PoP 2001) requires $4\square^{ITG} > \square_{ExB}$

Nonlinear Calculations including ExB shear would resolve this



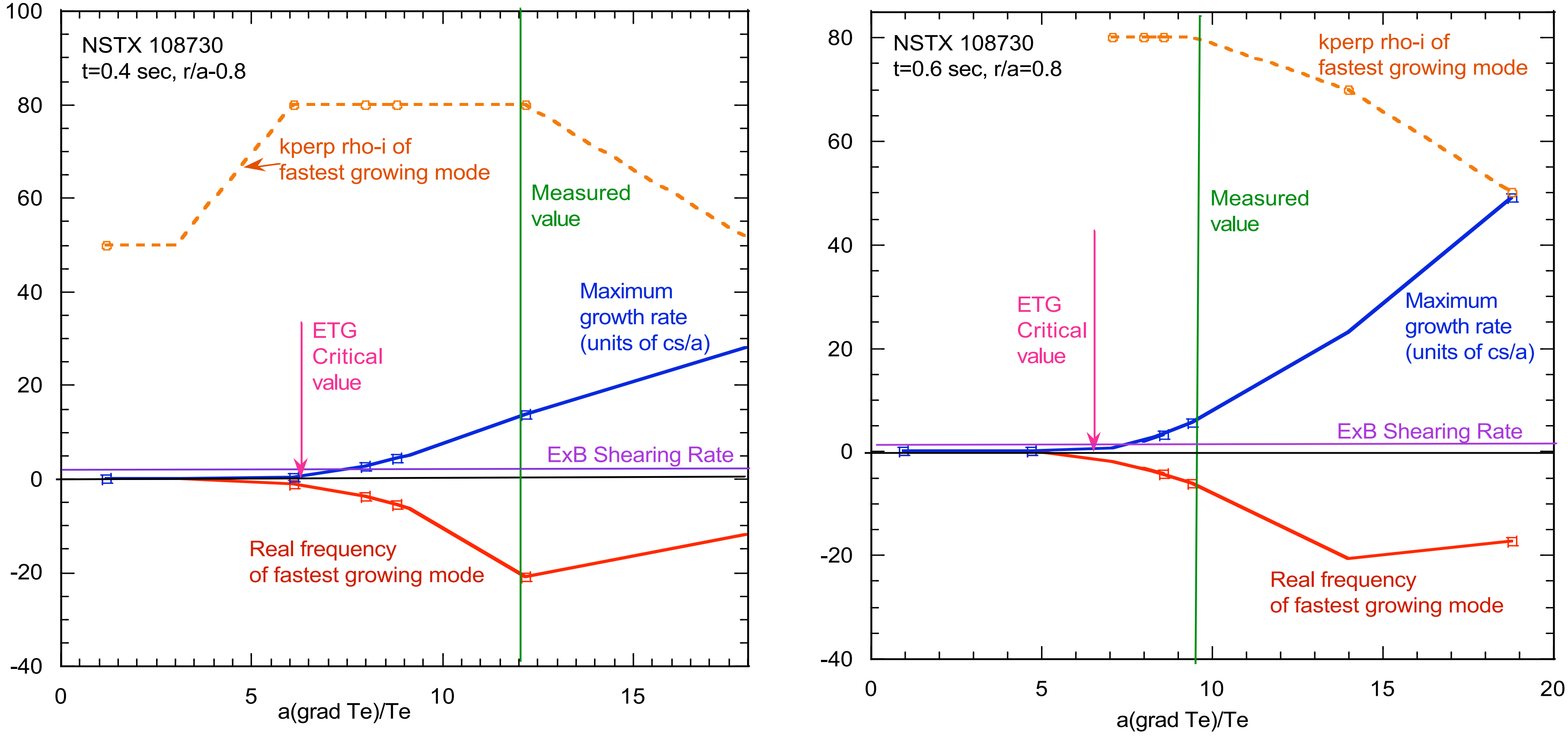


NSTX: ETG Instrinsically above Marginal Stability

At Plasma Edge: $\square_{ExB} < 2\square^{TG}$

Fastest Growing ETG Drift Mode Wavelengths and Growth Rates Decrease as $a(\square T_e)/T_e$ is Reduced

Higher Critical Gradient for ETG than TEM, Similar to ITG



Nonlinear Simulations

- Nonlinear simulations are in progress on NERSC’s IBM SP RS/6000 supercomputer, using 336 processers on 42 nodes, with 4MB memory per processor and GS2 compiled for 64 bit addressing
- Computational domain: 758 million meshpoints in a rectangular box (at the outside plasma midplane) with 15 □ in the x direction and 63 □ in the y direction.
- Nonlinear terms evaluated on a grid with 243 points in x and 27 points in y for 9 k_y modes ≤ 0, 161 k_x modes, after dealiasing.
- Generalize rule for determining the number of k_x modes: $N_x\square(2\square rq'/q)\bullet N_y\bullet(L_x/L_y)\bullet(N_p-1)/2$ when more than one field period for necessary eigenfunction connections. N_p=number of 2□ field periods

Conclusions

NSTX: Good ion confinement correlated with ITG stability

Poor electron confinement: core μtearing, edge ETG

Resilient Te profiles: likely due to unchanged

μtearing, ETG core driving forces ($a\nabla N_e/N_e$, $a\nabla T_e/T_e$)

If $2\text{-}3\gamma_{lin} < \gamma_{ExB}$ stabilizes ITG, ITG may be stable everywhere.

γ_{ExB} suppression of ETG and microtearing modes not yet known

Need MSE for q profile data. Nonlinear simulations in progress.

t=0.4/0.6s	χ_i	χ_e	ITG,μtearing	ETG
r/a=0.25	$< \chi^{neo}$	$>> \chi_i$	Stable ITG, unstable μtearing	stable
r/a=0.65	$< \chi^{neo}$	$>> \chi_i$	Likely stable ITG, unstable μtearing ExB effect unknown on μtearing	unstable/ stable
r/a=0.80	$< \chi^{neo}$	$>> \chi_i$	likely stable ITG	unstable

Does ExB shear suppress microtearing instability?