Comparison of DIII-D Experimental Ion Temperature Gradients with the Critical Gradient as Calculated by the GKS Code

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The ion thermal diffusivities (χ_i) in DIII–D discharges exhibit a strong nonlinear dependence on the measured temperature gradients. This non linear dependence has the appearance of a critical gradient in the sense that when the temperature gradient is less than a certain value χ_i is small and when it reaches or surpasses this value then χ_i increases rapidly. Here we present a comparison between the measured ion temperature gradients and the 'critical' gradient as calculated by the GKS code. The existence of a 'critical' gradient can depend on whether the electrons are treated adiabatically or kinetically. It also depends on the relative size of the density gradient. For large density gradients the transport due to trapped electron modes can produce transport even when the ion temperature gradient mode is stable. This could eliminate the effect of a critical gradient. We will compare the incremental ion thermal diffusivity deduced from the experimental data with the predictions of gyrofluid and gyrokinetic ITG turbulence simulations.

‘Typical’ DIII-D L-mode Discharge

101391

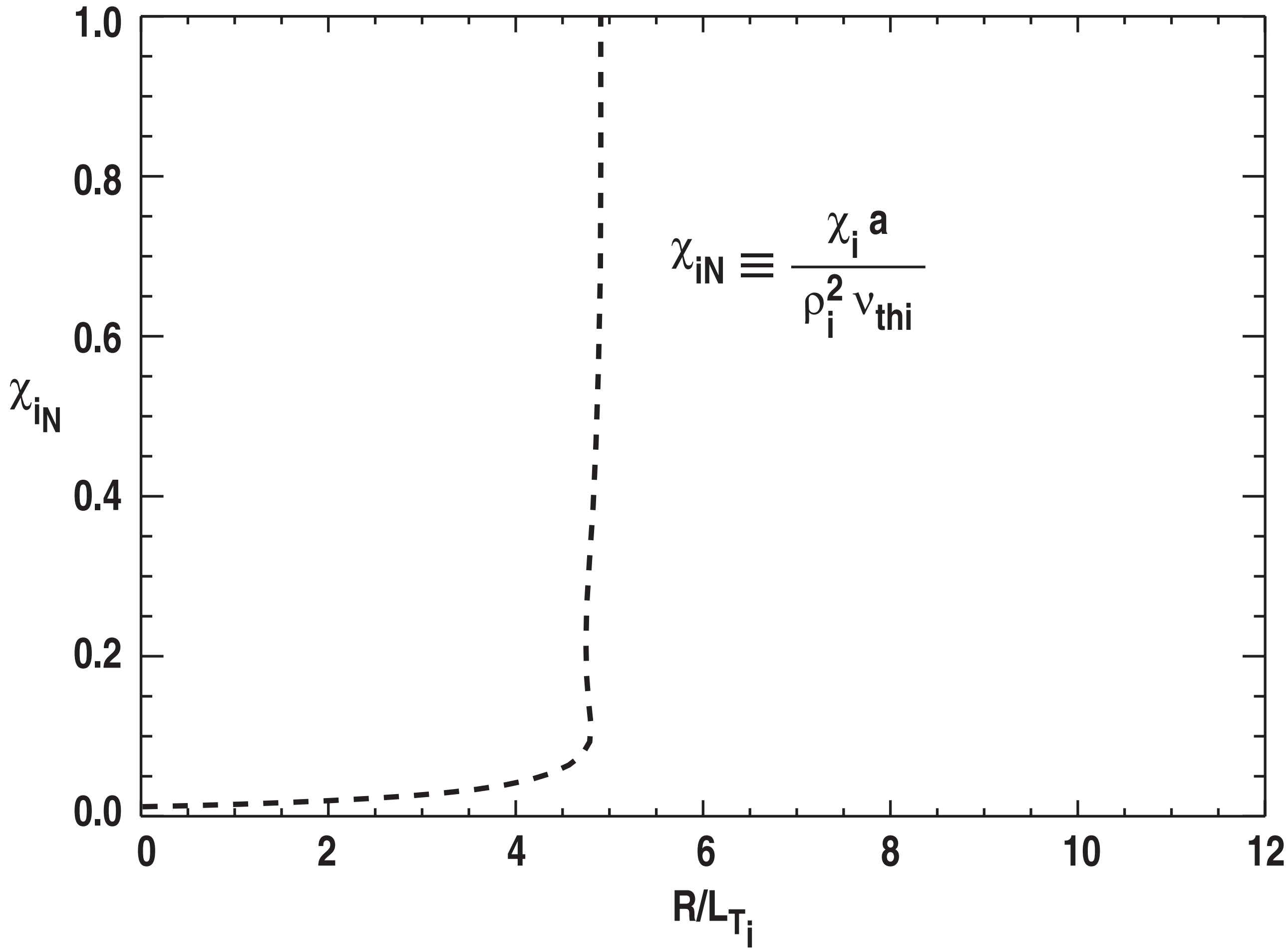
B_T=2.1 T, Ip=1.3 MA, ne=4.5 10^{19} m^{-3}, Te=2.7 KeV, Ti=3.0 KeV

Is this a sign of a critical gradient?

The normalized ion thermal diffusivity increases rapidly when the normalized gradient reaches a certain value.

The “critical” gradient is defined as a gradient above which some electrostatic mode is unstable, i.e. where $\gamma_{max} > 0$. (This point usually exists for ITG modes when density profiles are not too steep)

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



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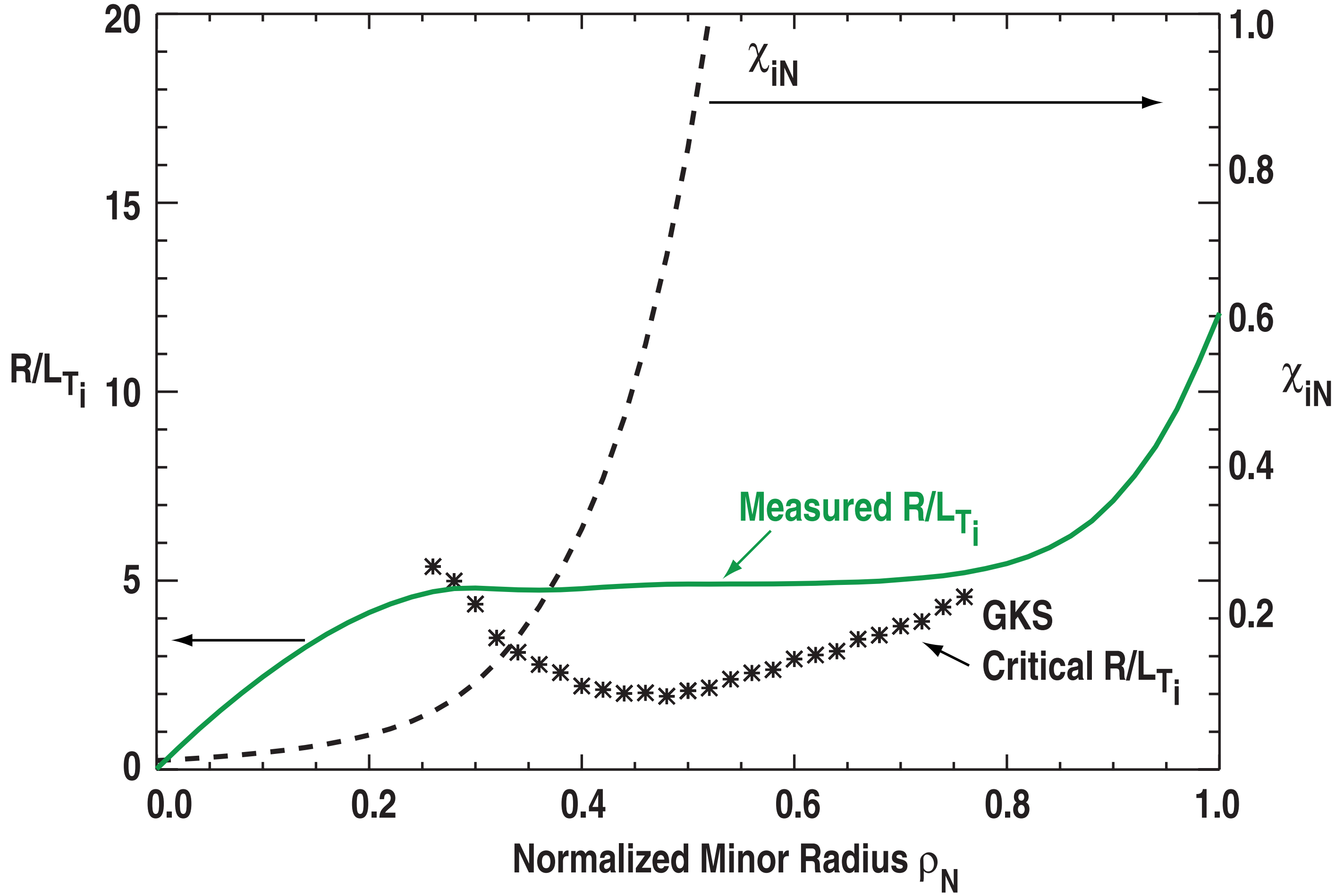
Calculate the “critical” normalized gradient with the GKS code.

(In the case when no critical gradient exists due to some non-adiabatic electron effects, the gradient for the minimum growth rate is chosen. This is not always well defined)

Observe where the experimental gradient is greater than the calculated critical gradient.

- This is usually close to where the gradient ‘turns over’

χ_i RISES WHEN EXPERIMENTAL GRADIENT IS GREATER THAN GKS CRITICAL GRADIENT



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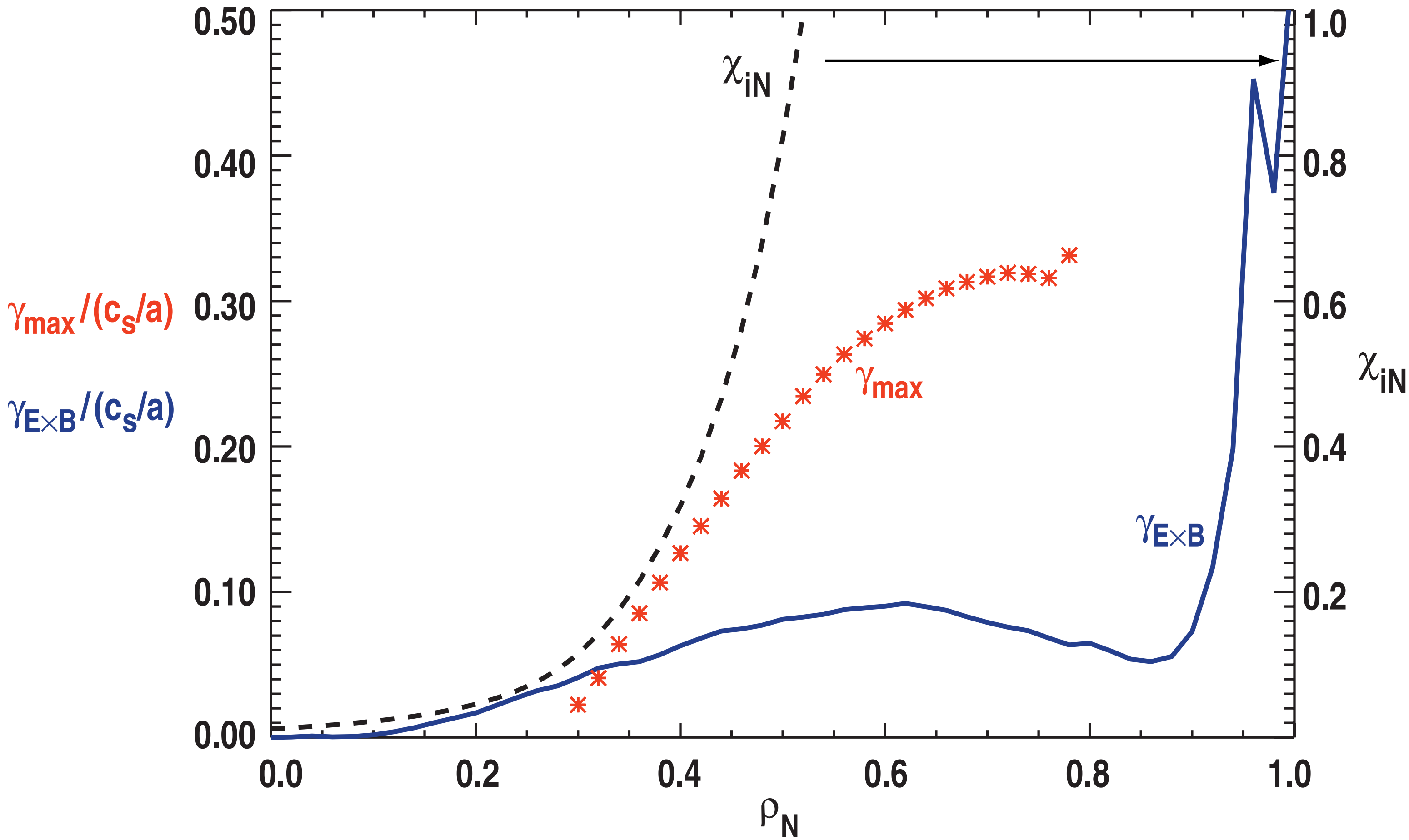
When rotation is low to moderate and γ_{ExB} is low then χ_i starts to increase near the point where the experimental gradient is larger than the GKS calculated critical gradient and is near the local maximum of the normalized gradient (or where the gradient 'turns over').

When γ_{ExB} becomes larger, then the effective critical gradient seems to be where $\gamma_{max} > \gamma_{ExB}$.

In some cases χ_i is high even when the measured gradient is less than the GKS critical gradient.

- This is usually associated with unstable TEM modes

χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E\times B}$



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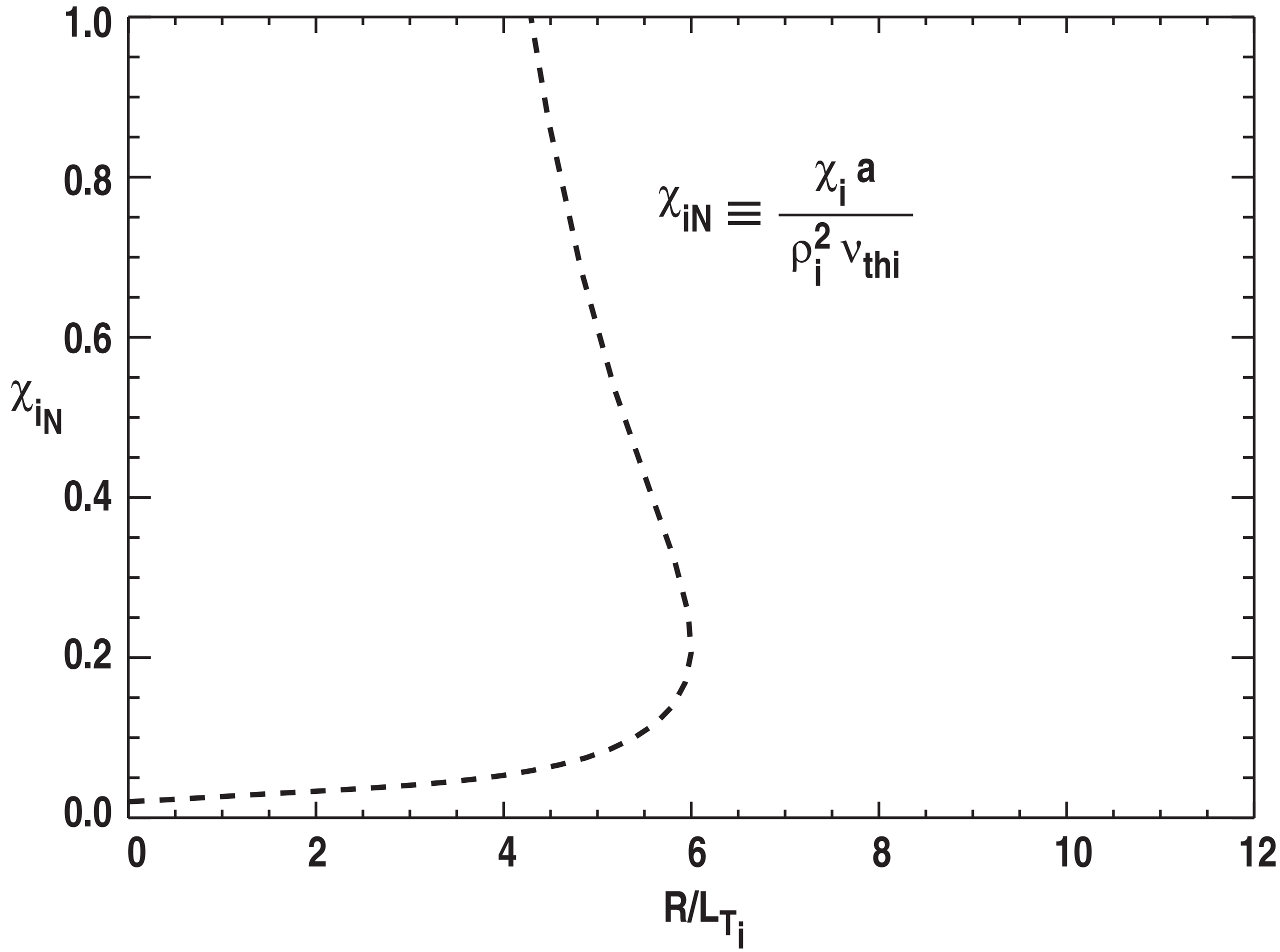
‘High’ ρ_* DIII-D L-mode

101381

B_T=1.05 T, Ip=.65 MA, ne=1.8 10^{19} m^{-3}, Te=1.8 KeV, Ti=2.1 KeV

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



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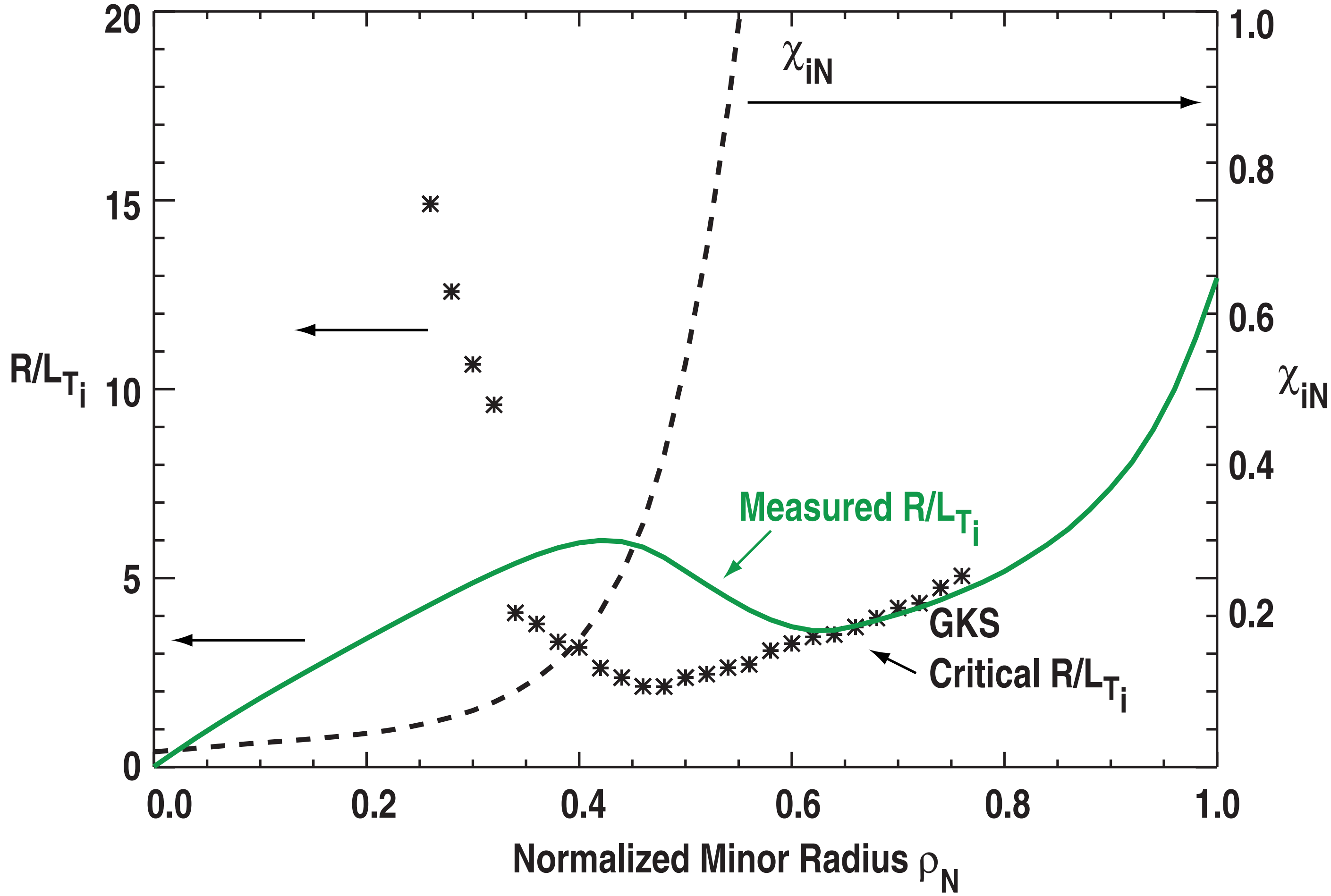
χ_i RISES WHEN EXPERIMENTAL GRADIENT IS GREATER THAN GKS CRITICAL GRADIENT



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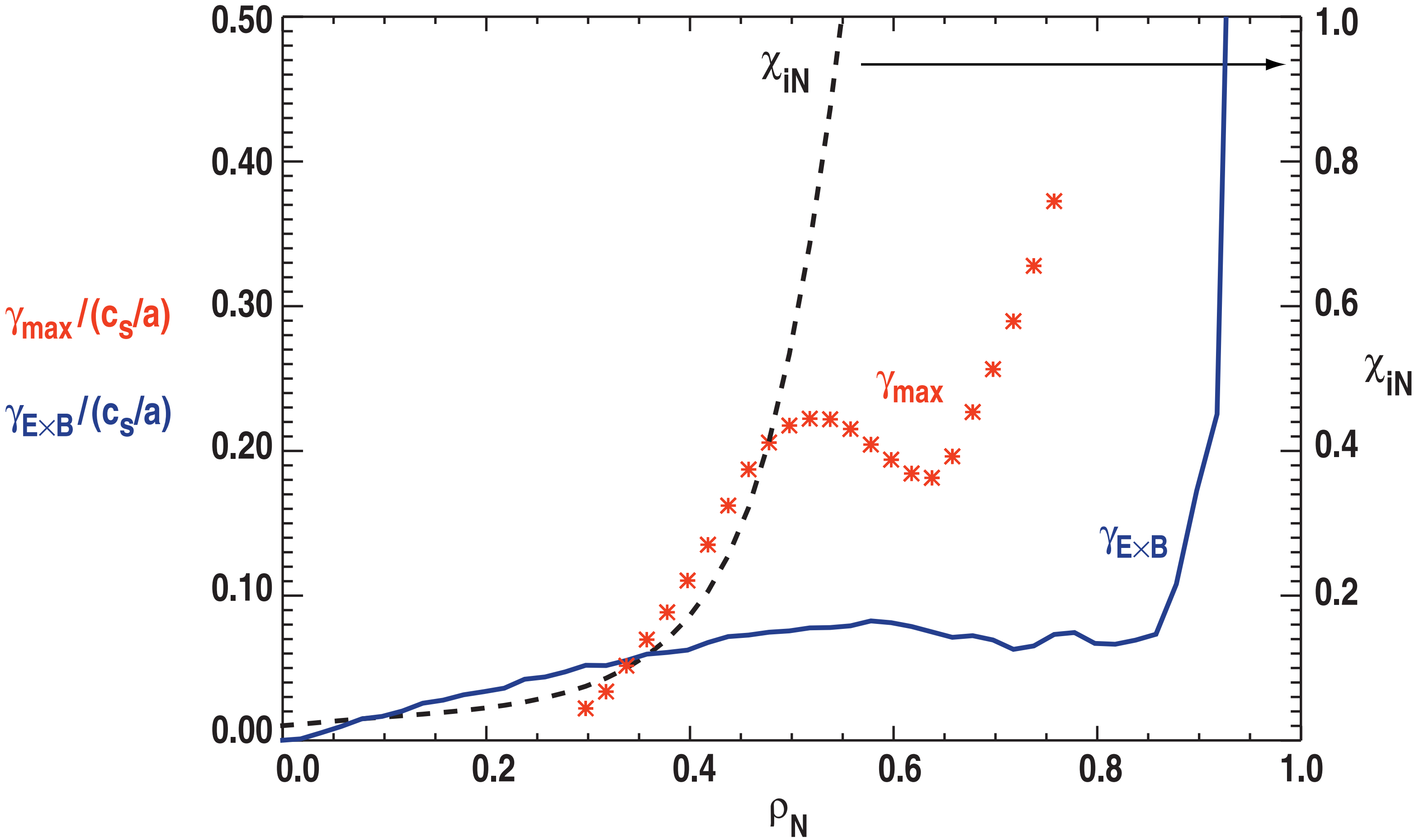
χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E\times B}$



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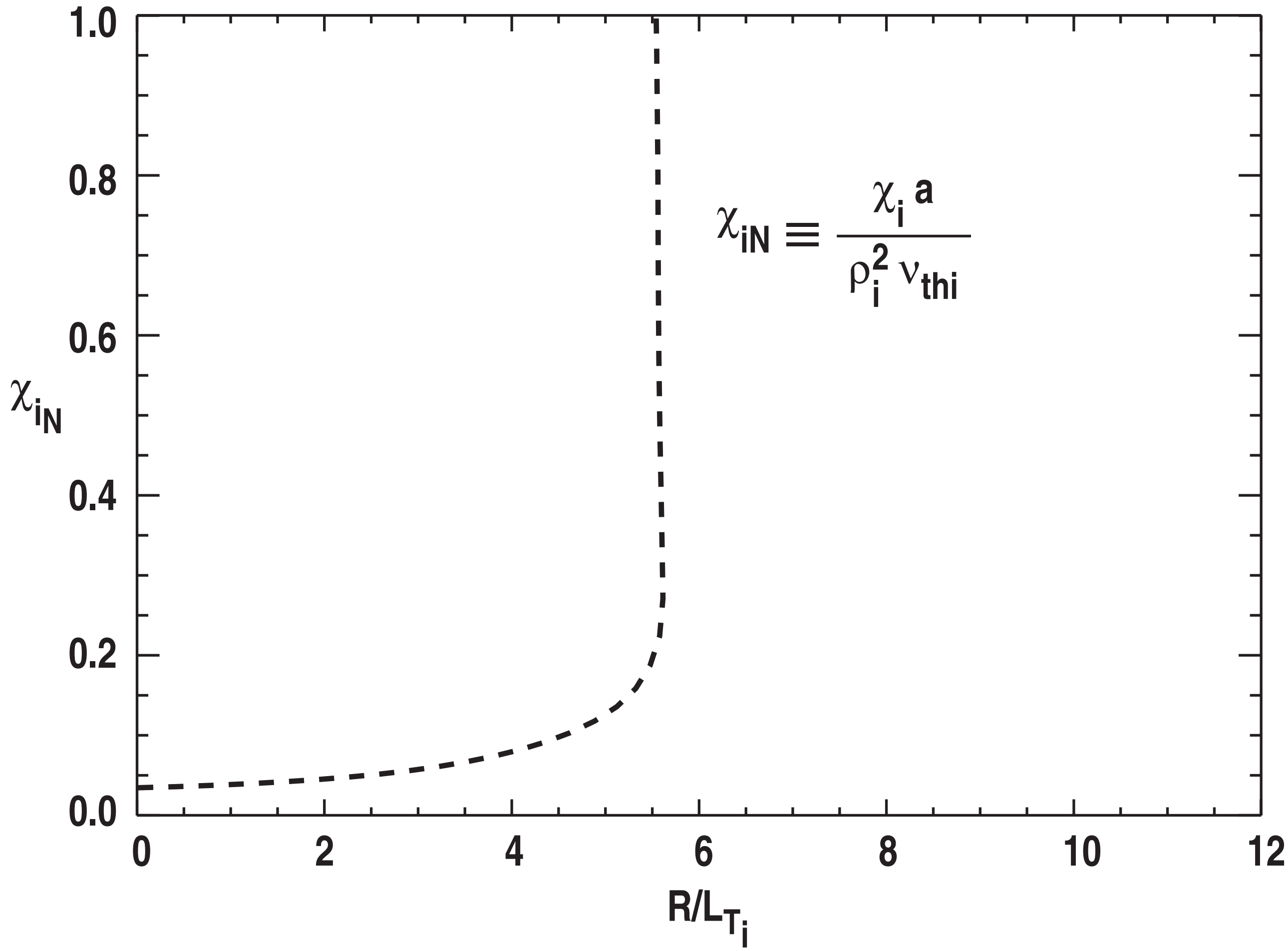
Circular Cross Section DIII-D L-mode

102995

B_T=2.0 T, Ip=1.0 MA, ne=3.5 10^{19} m^{-3}, Te=3.5 KeV, Ti=5.0 KeV

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



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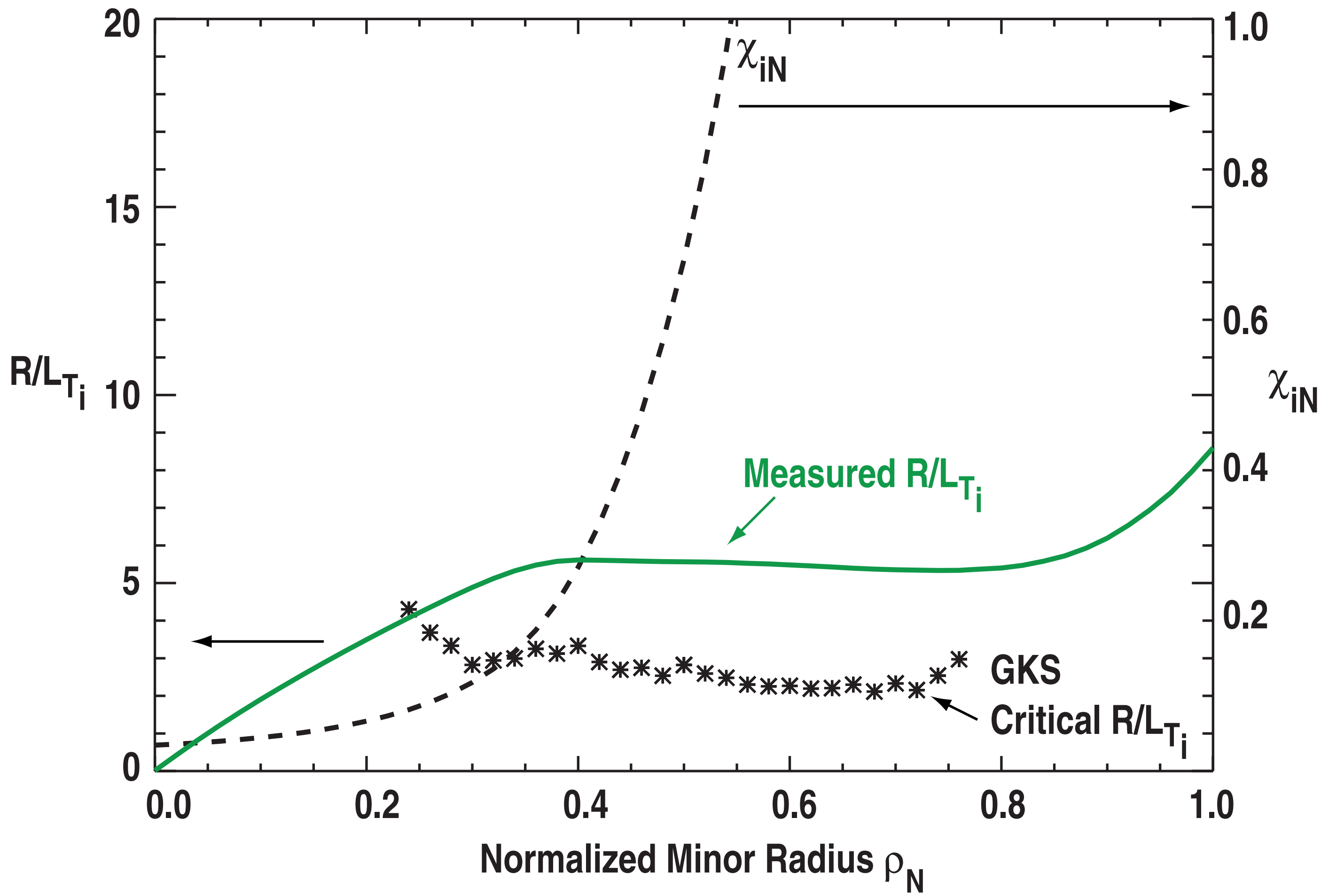

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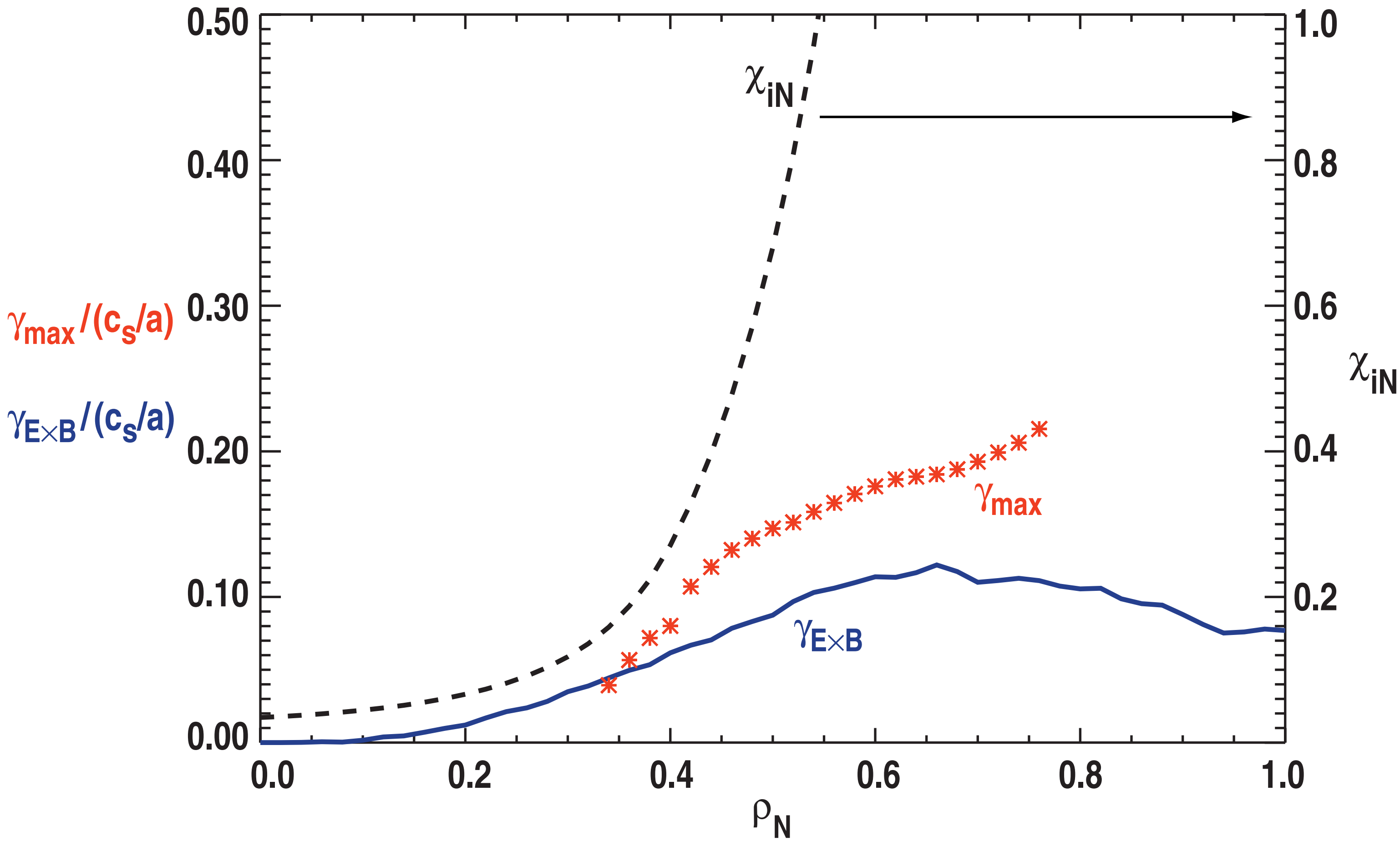
χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E\times B}$



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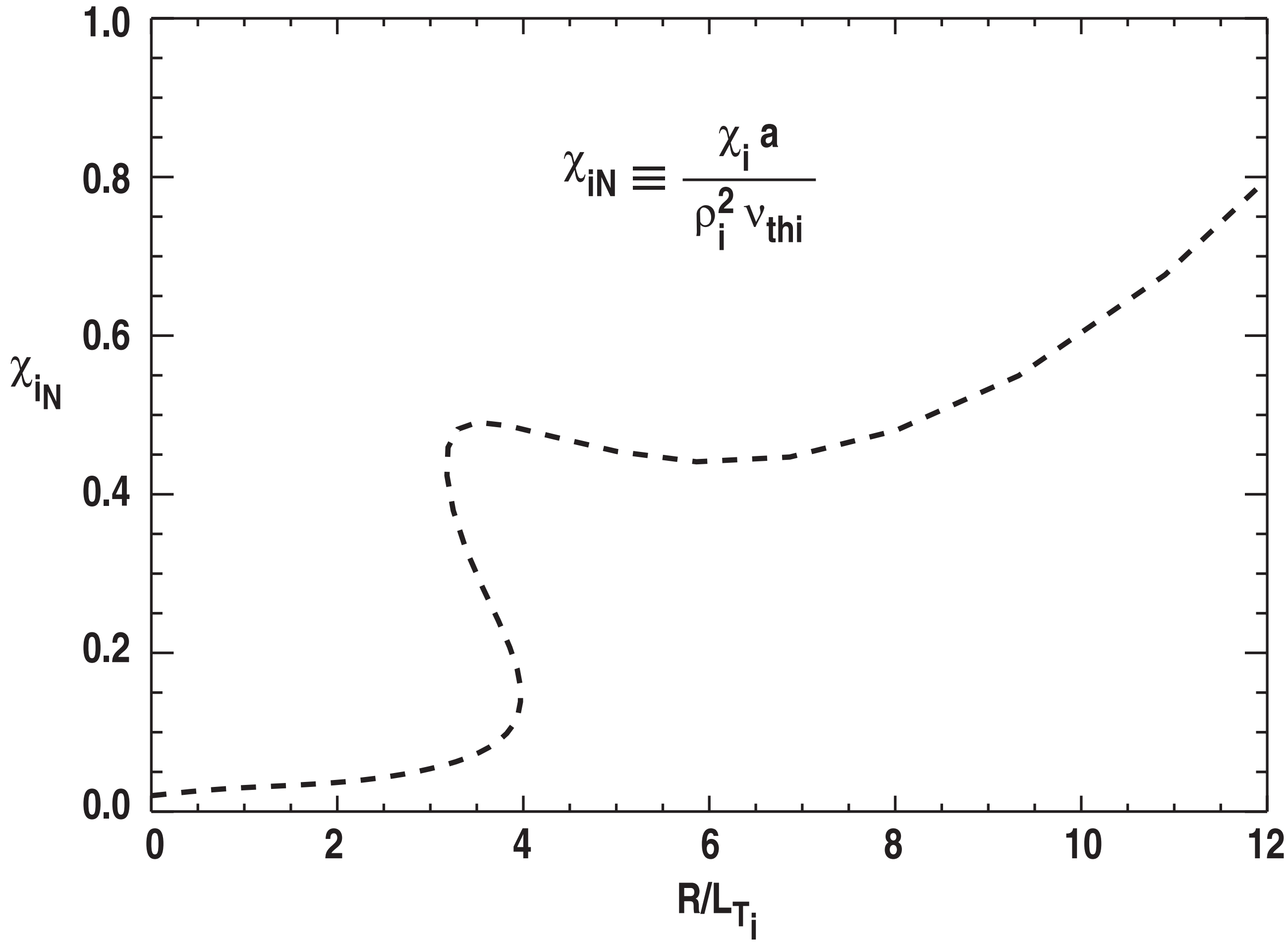
DIII-D L-mode Near Marginal Stability

82788

B_T=.95 T, Ip=.65 MA, ne=2.6 10^{19} m^{-3}, Te=1.5 KeV, Ti=2.7 KeV

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



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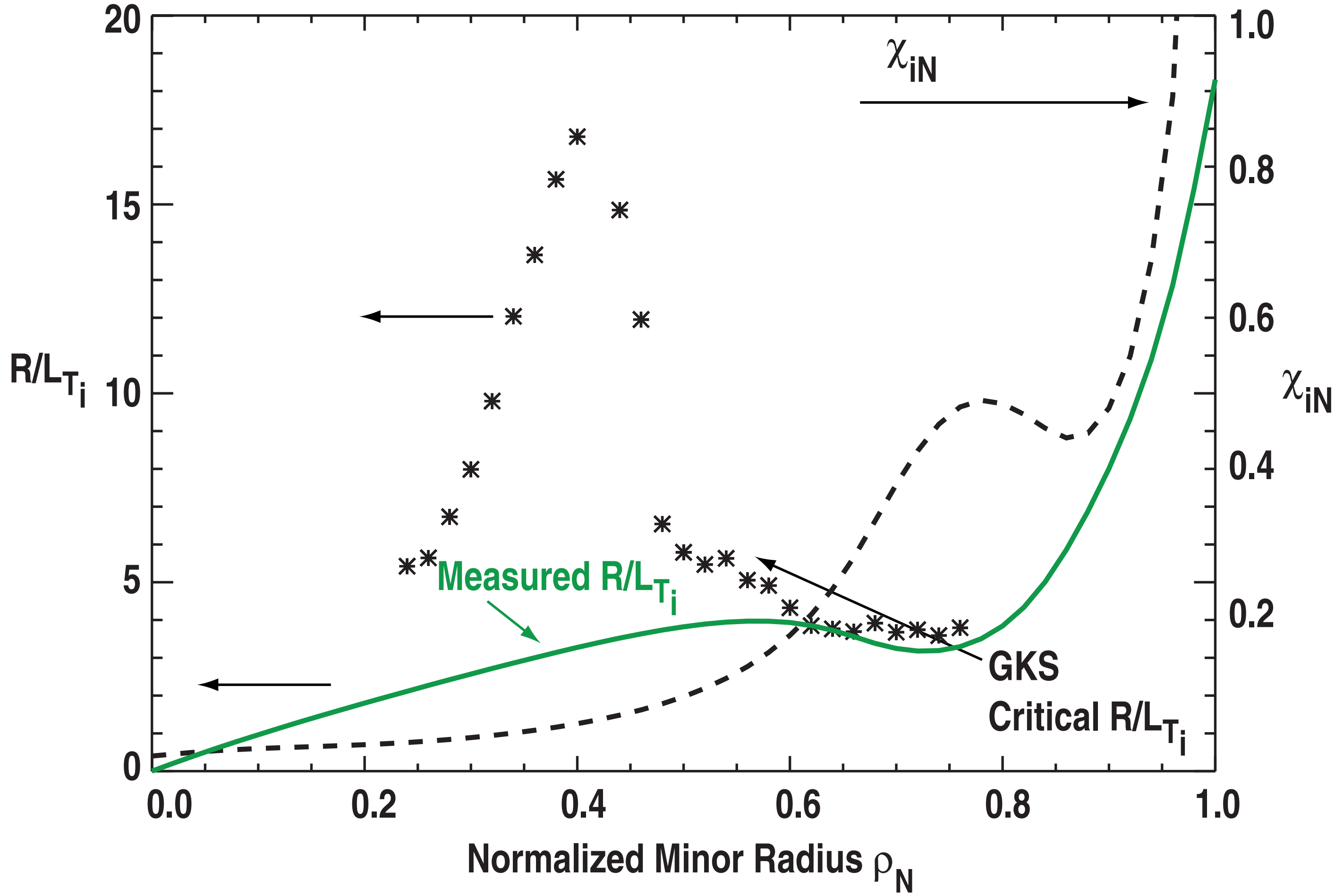

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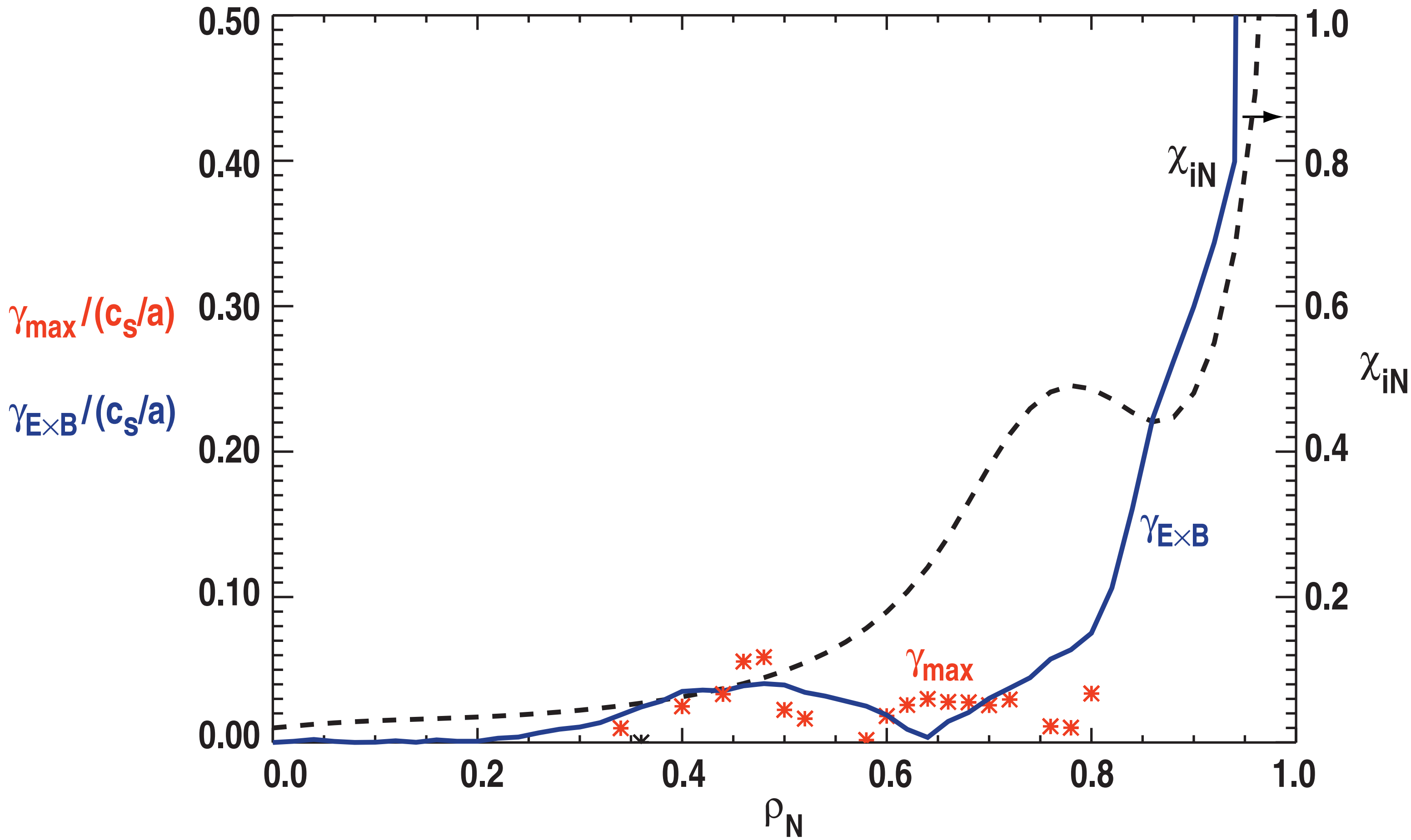
χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E \times B}$



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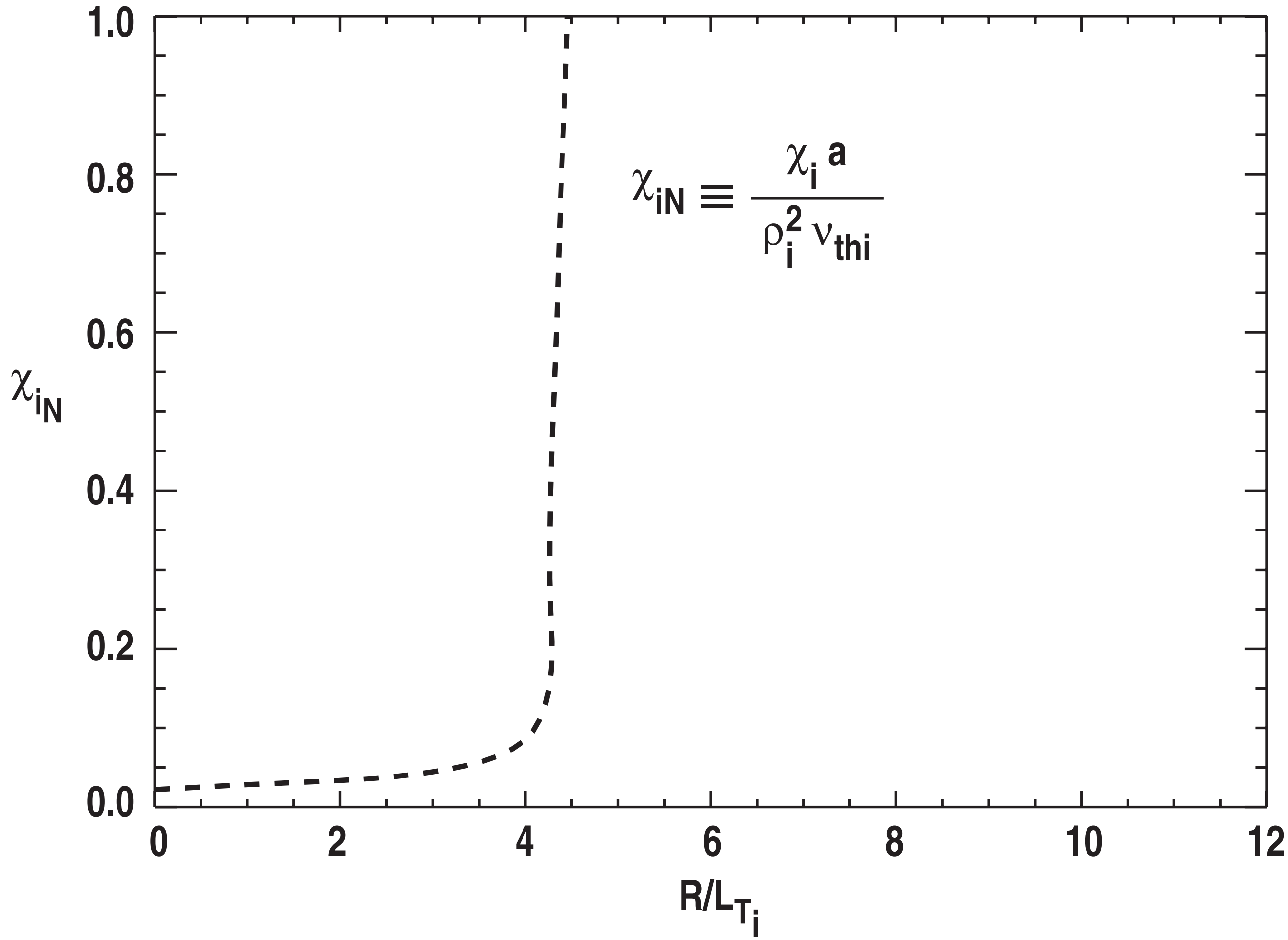
Moderately High Rotation L-mode

95812

B_T=1.0 T, Ip=.65 MA, ne=2.0 10^{19} m^{-3}, Te=1.8 KeV, Ti=2.4 KeV

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



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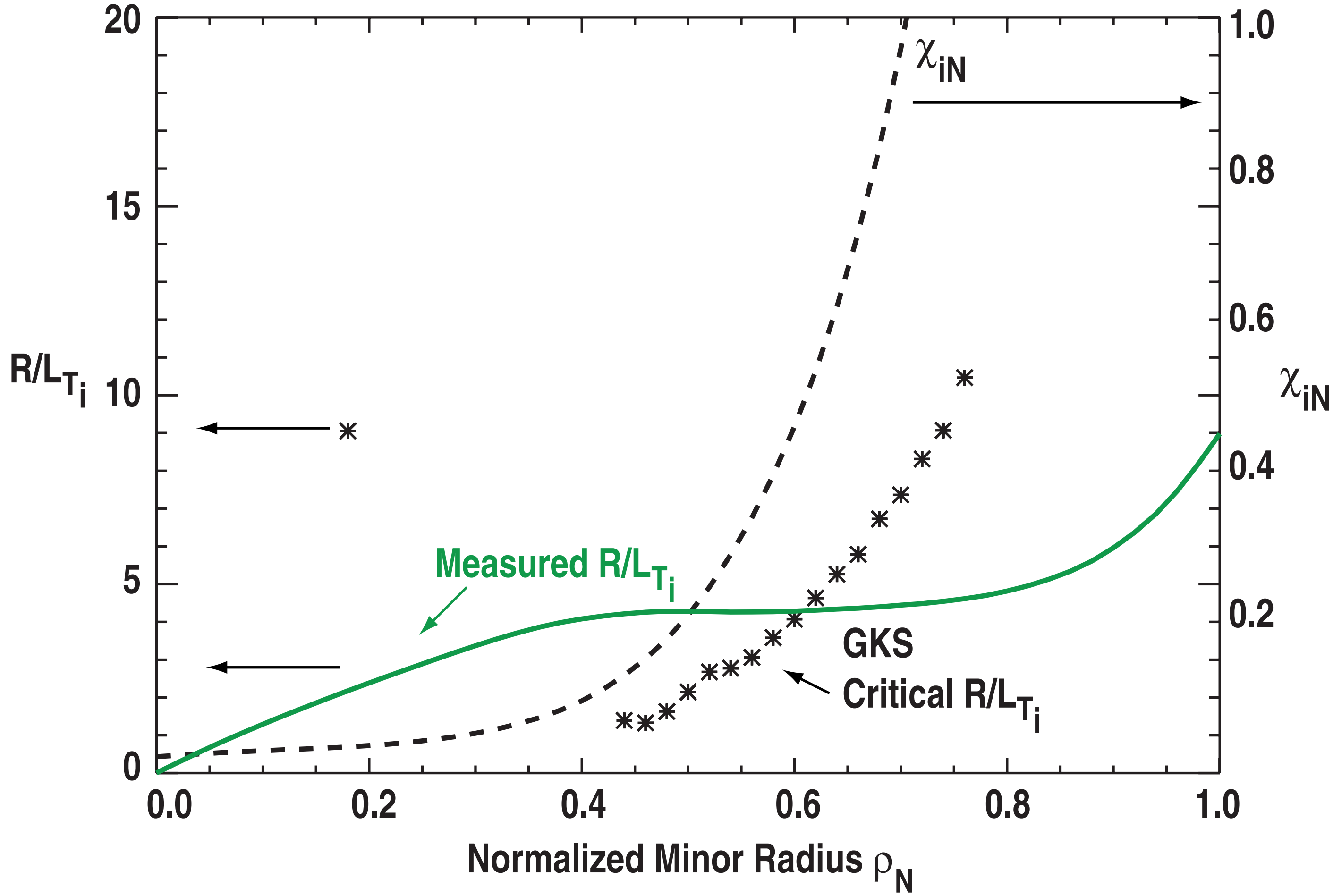

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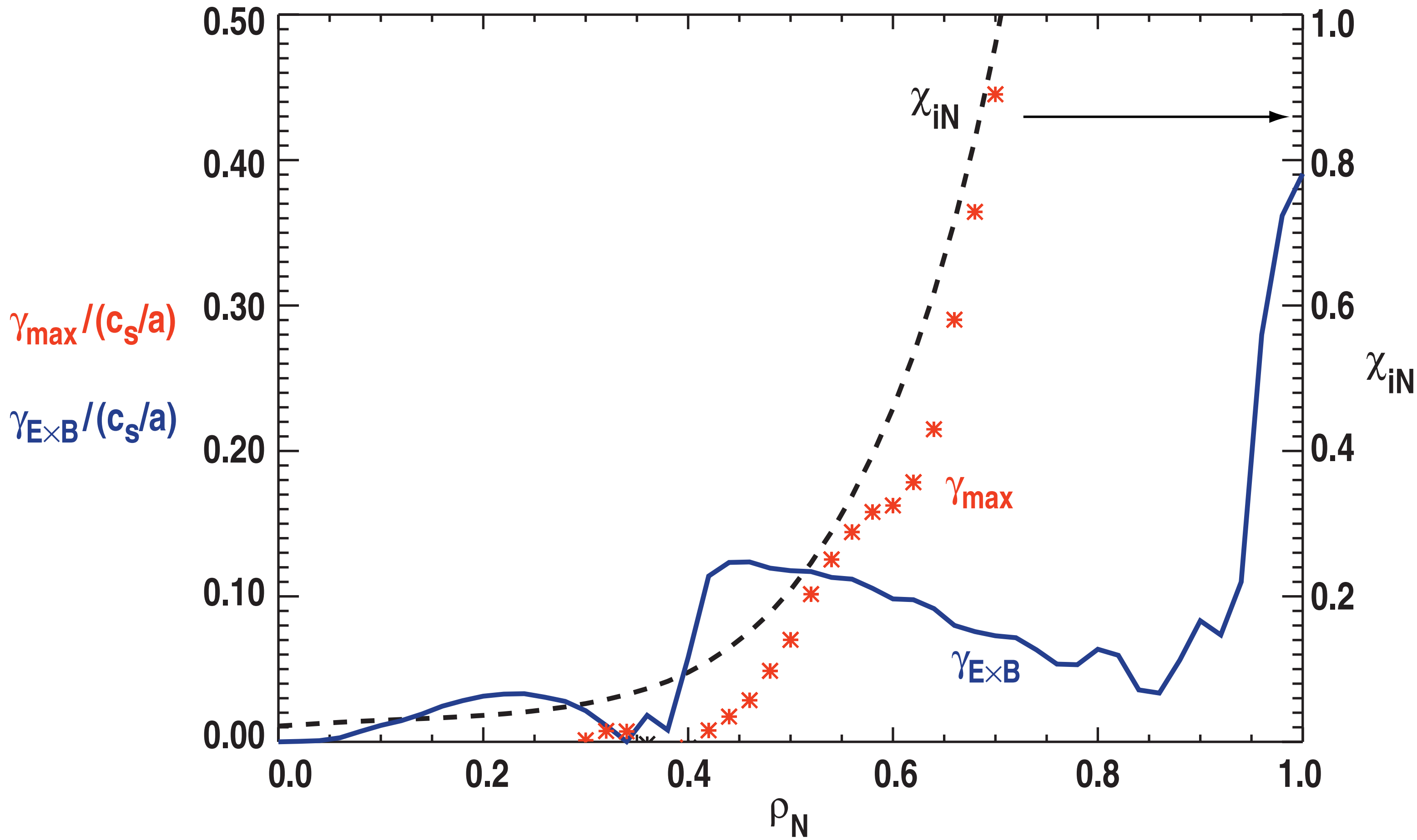
χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E\times B}$



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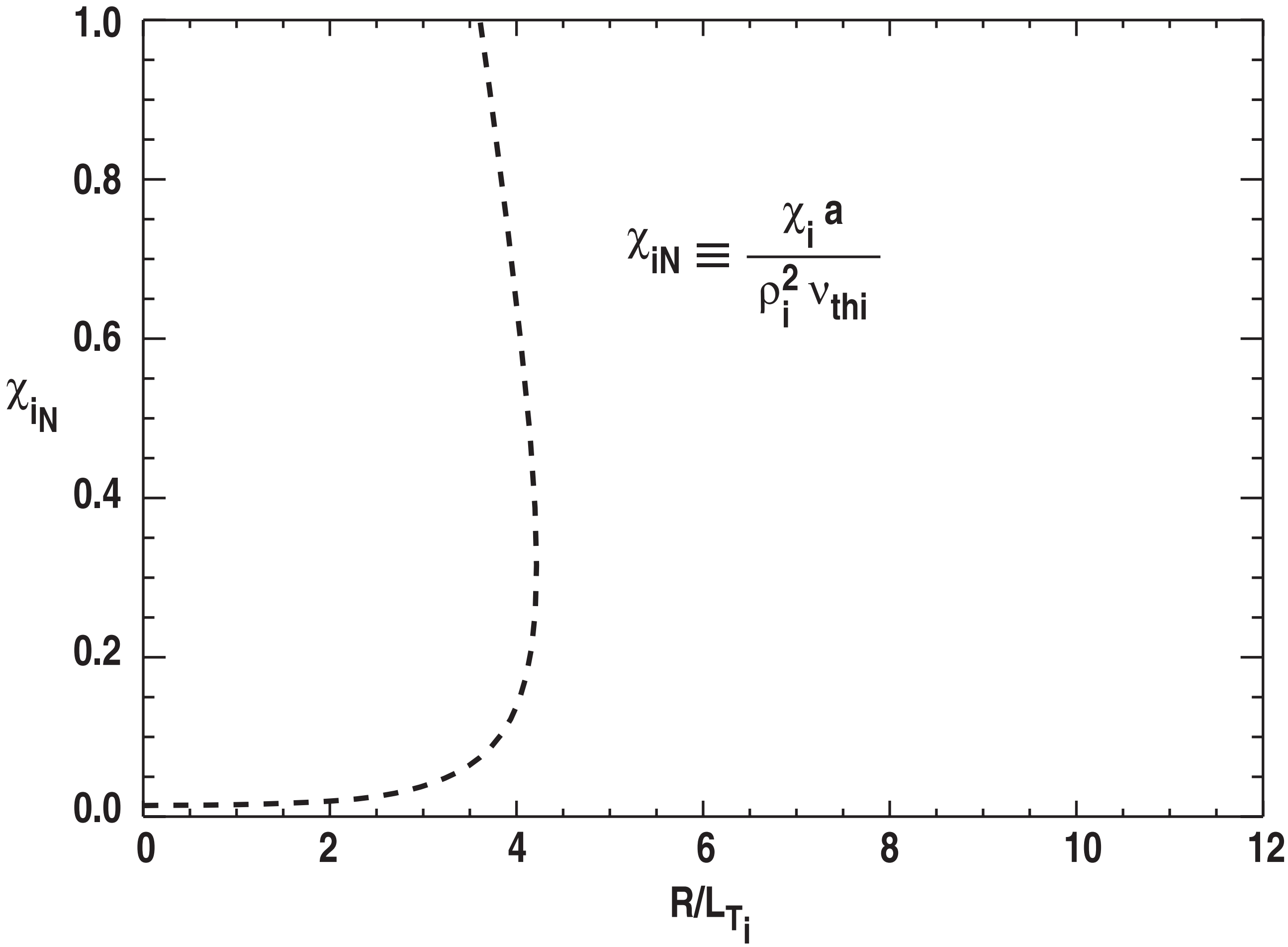
DIII-D Counter Injection L-mode

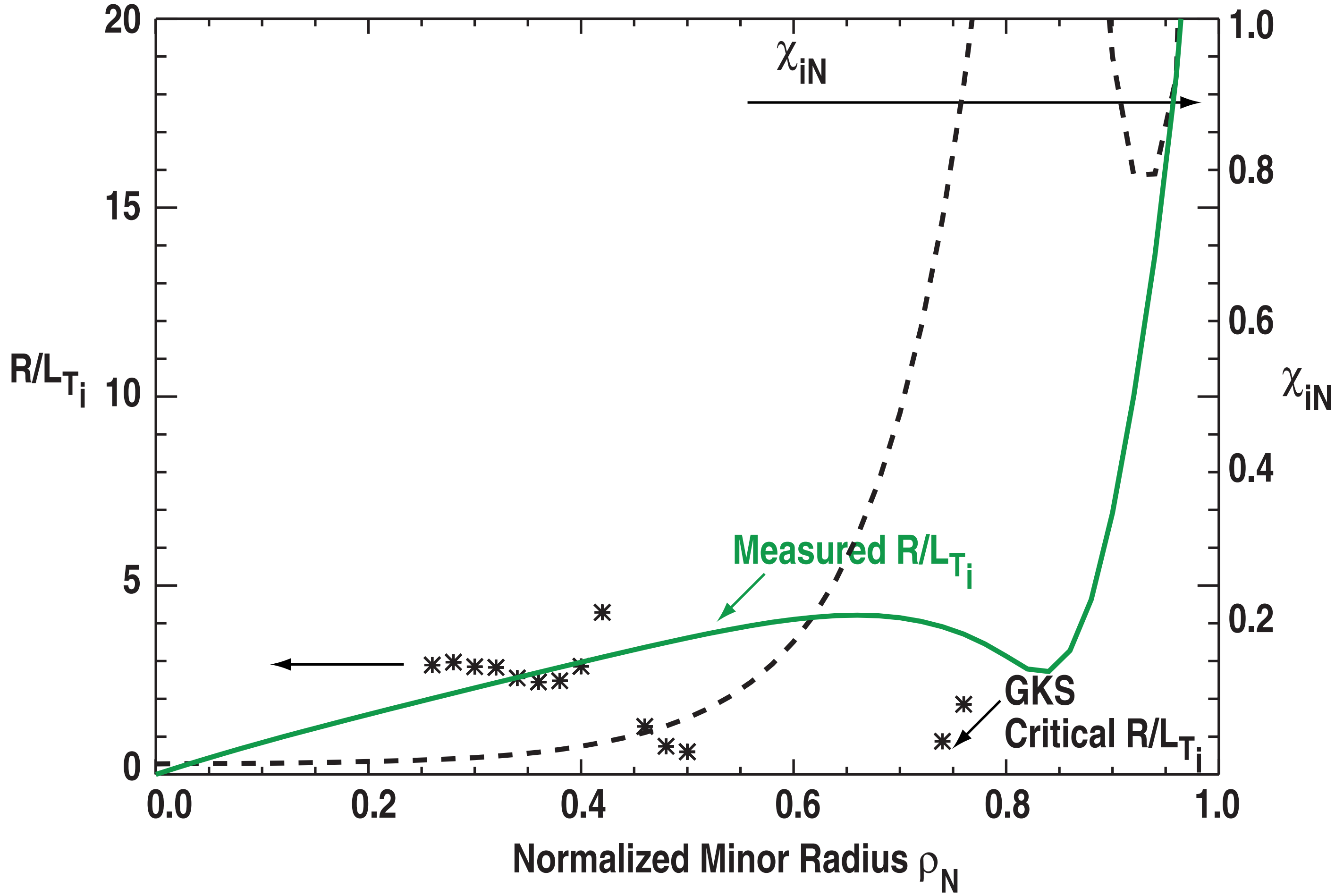
99251

B_T=1.9 T, Ip=1.35 MA, ne=6.0 10^{19} m^{-3}, Te=2.8 KeV, Ti=4.8 KeV

χ_i RISES SHARPLY AT A CERTAIN GRADIENT



χ_i RISES WHEN EXPERIMENTAL GRADIENT IS GREATER THAN GKS CRITICAL GRADIENT



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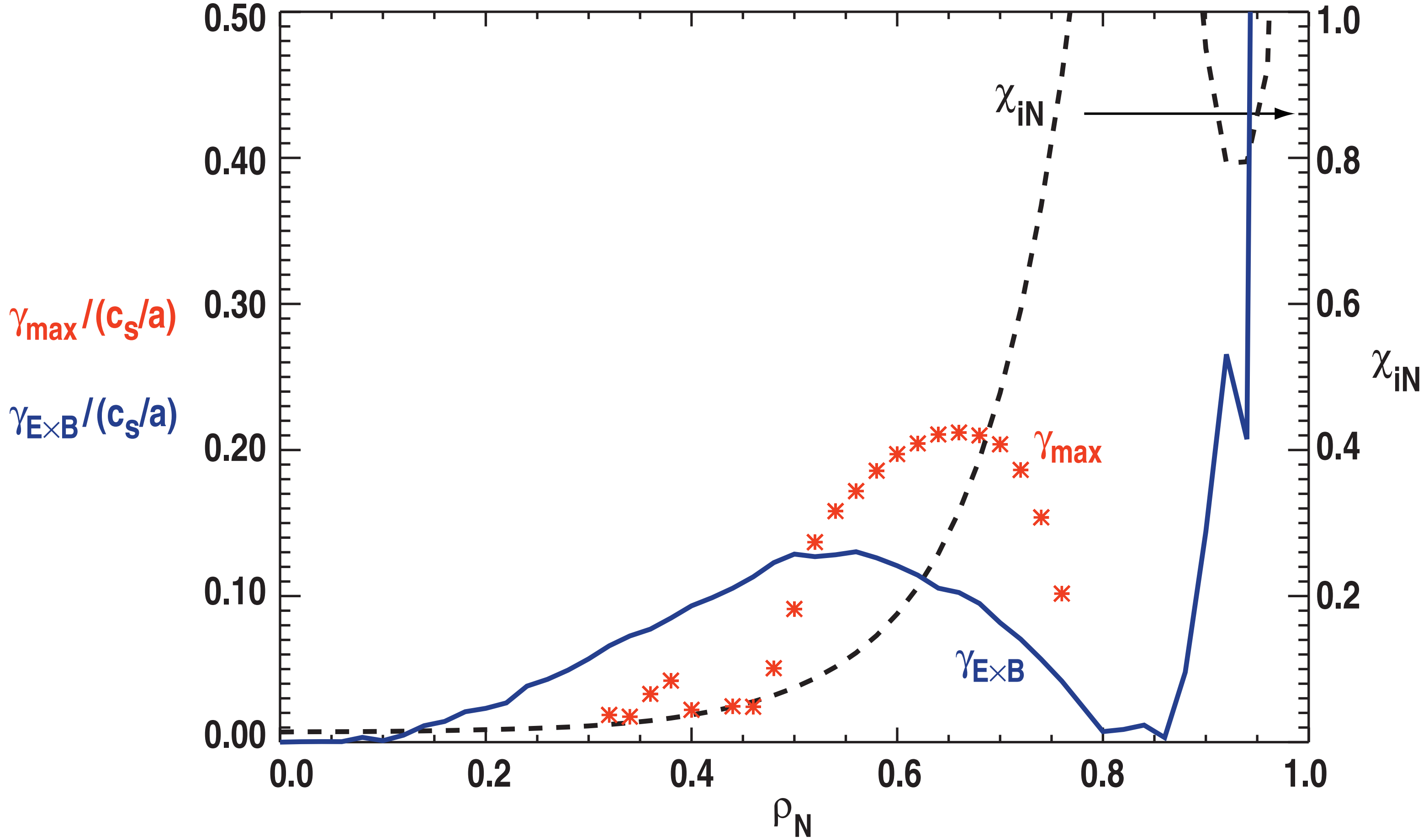
χ_i RISES WHEN γ_{max} BECOMES GREATER THAN $\gamma_{E\times B}$



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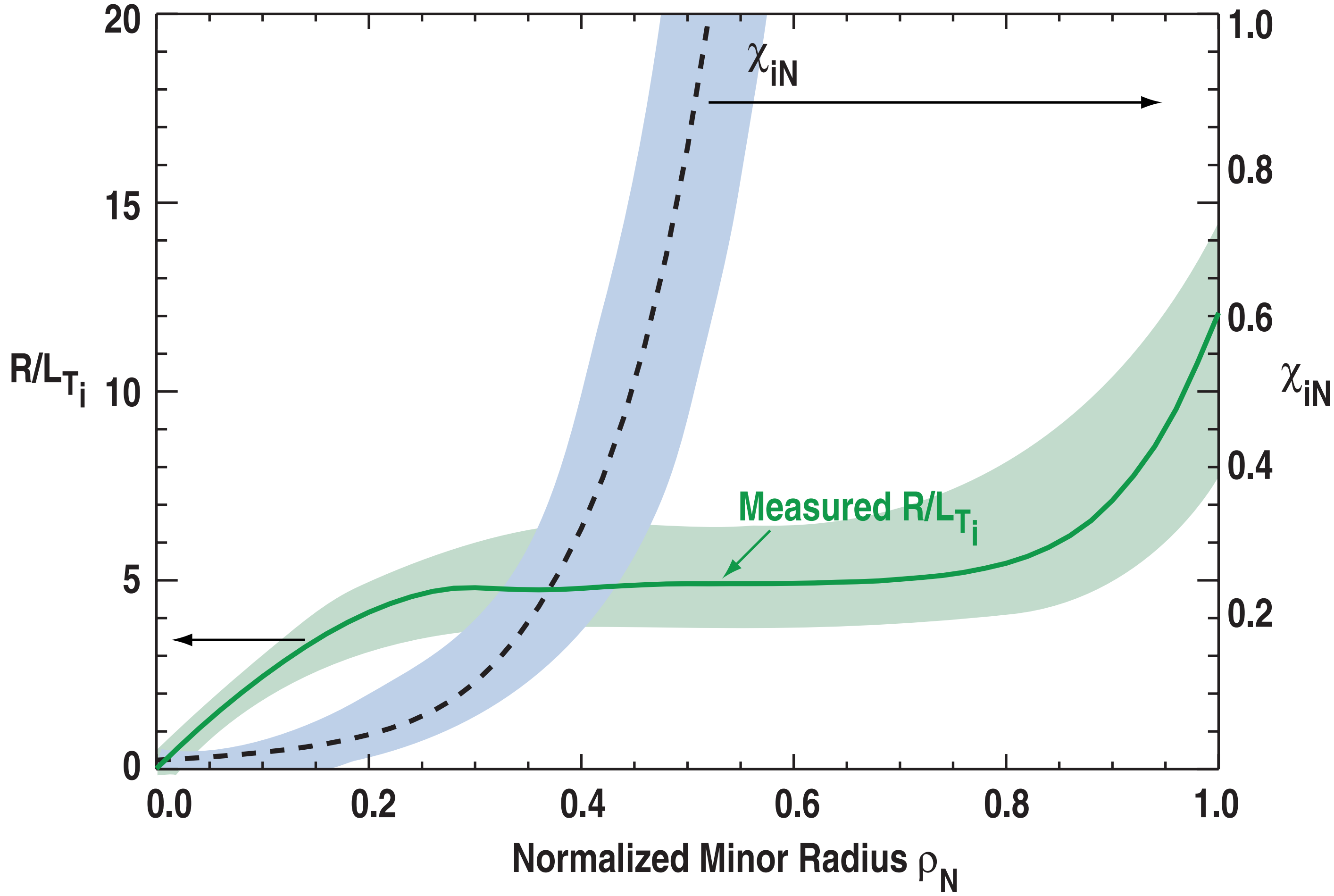
TYPICAL ERROR BARS



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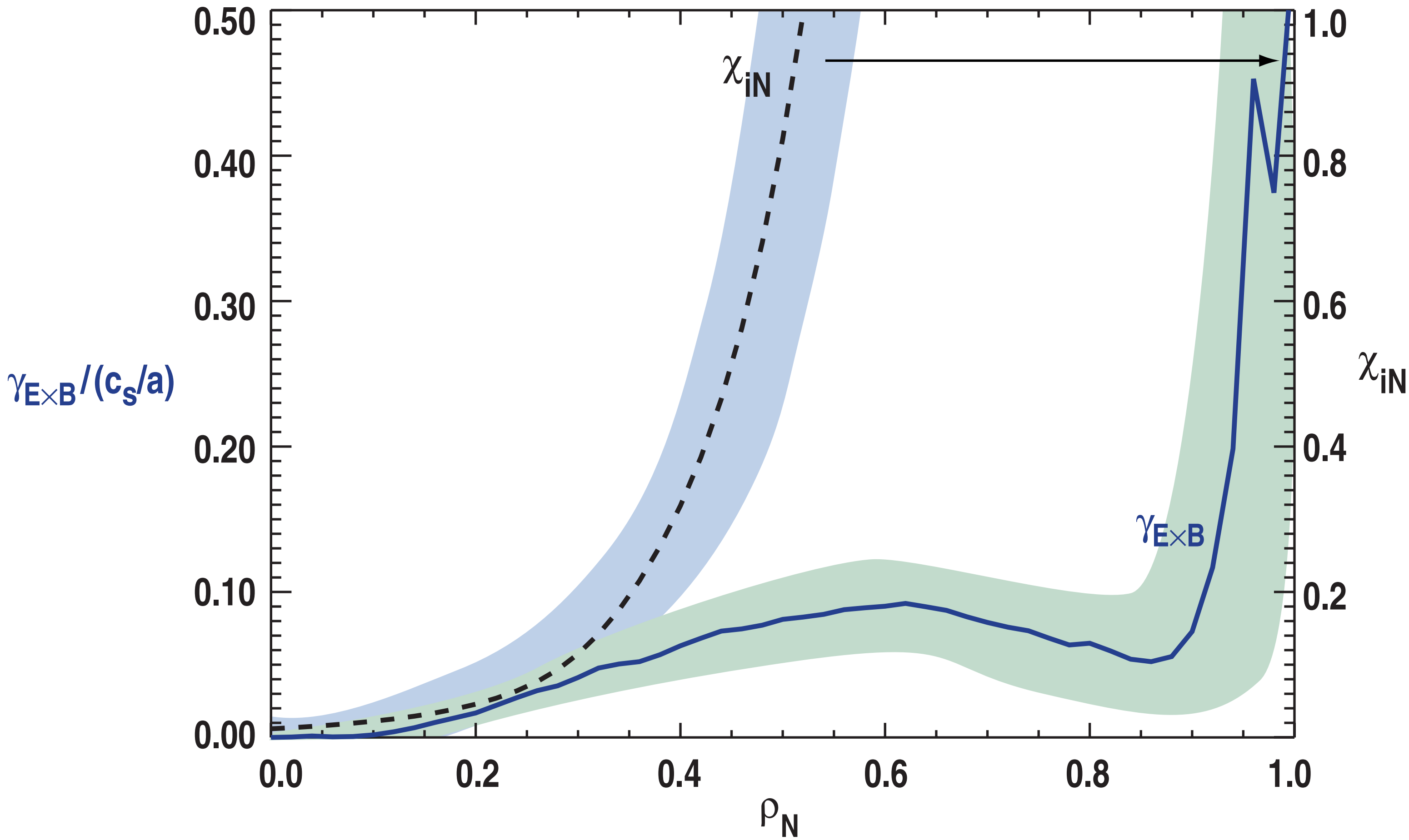

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Conclusions

Within the Experimental Error the Ion Temperature Shows Signs of a Critical Gradient When the Rotational Shear is Taken into Account.

χ_i Starts to Become Large When γ_{max} is Calculated to be Larger Than γ_{ExB}

Comments

There is no sharp break in the normalized diffusivity when the experimental gradient becomes larger than the calculated critical gradient

This is because:

- The profiles are fit with a smooth curve
- Other modes than ITG can cause transport near the center

Caveats:

Experimental Error in the Ion Temperature Gradient is Large

Experimental Error in the Rotational Shear (γ_{ExB}) is Large

From: "*A gyro-Landau-fluid transport model*"

R.E. Waltz, G.M. Staebler, W. Dorland, G.W. Hammett,
M. Kotschenreuther, and J.A. Konings,

Phys. Plasmas, **4**, (1997) 2482