Magnetic Shear Effects on Plasma Transport and Turbulence at High Electron to Ion Temperature Ratio in DIII-D and JT-60U Plasmas

By

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In Collaboration with

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QST JT-60U

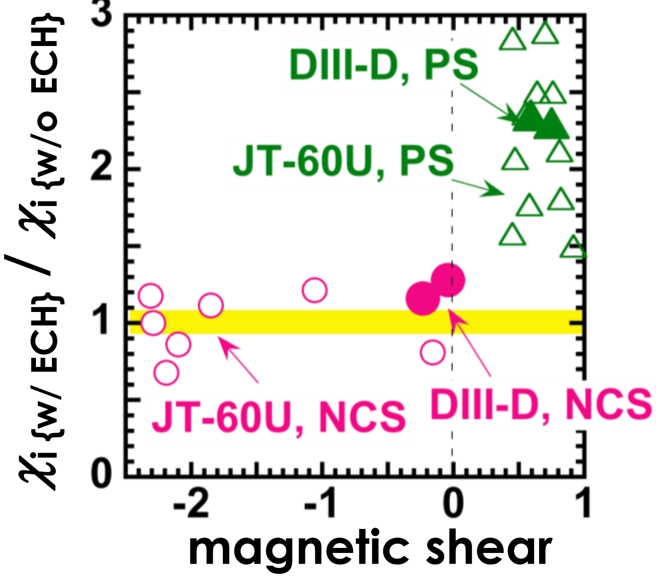
Main Results: Negative Central Shear Plasma Reduces Transport and Turbulence at T_e/T_i~1

Conclusions

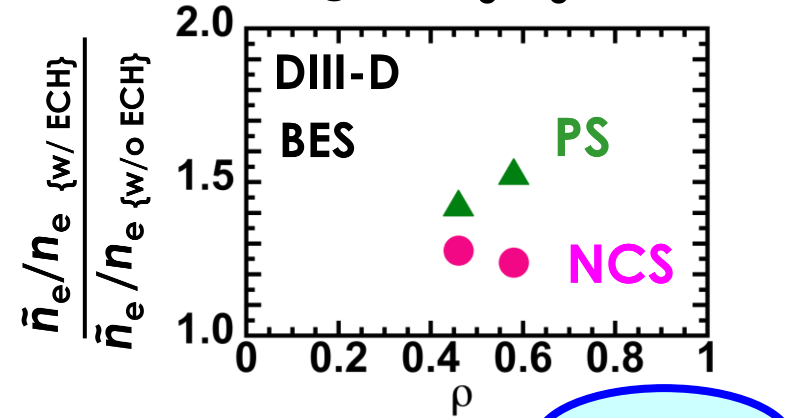
- **Consistency between DIII-D and JT-60U**
  - DIII-D and JT-60U show NCS plasma minimizes confinement degradation with increasing T_e/T_i through ECH

- **Physics mechanisms in DIII-D**
  - DIII-D shows mechanism through smaller rise in low-*k* turbulent fluctuations and gyrokinetic simulations

Change in χ_i with ECH



Change in $\tilde{n}_e/n_e$ with ECH



χ_i: Ion thermal diffusivity
ITB: Internal transport barrier
$\tilde{n}_e$: Density fluctuations

JT-60U

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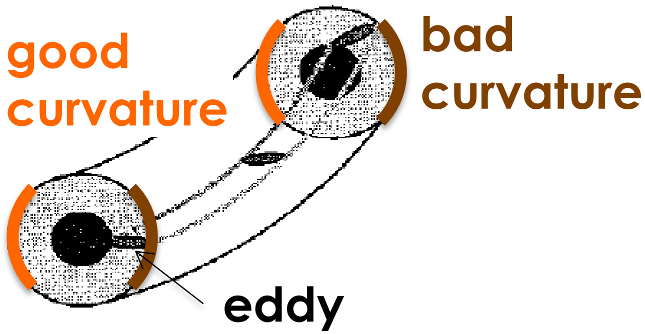
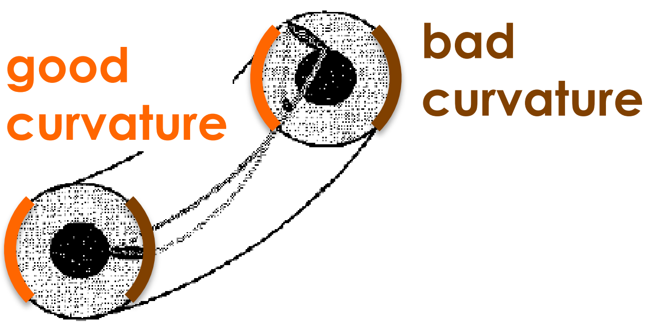
Background: Negative, Zero, Small Positive Shear Predicted to Have Transport Benefits

Positive Shear ($\hat{s}$>0)

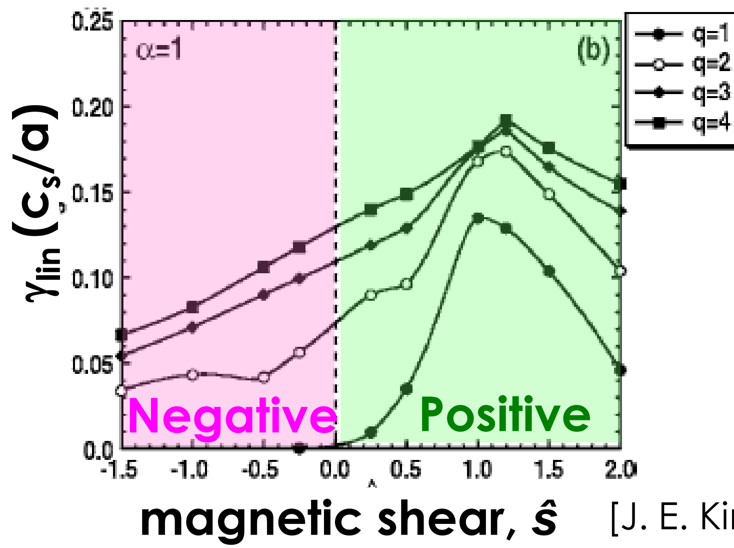


Negative shear ($\hat{s}$<0)



[T. M. Antonsen, PoP1996]

Turbulence linear growth rate dependence on $\hat{s}$ and q



[J. E. Kinsey, PoP2006]

- **Negative magnetic shear twists eddy to the good curvature direction**

  => stabilize turbulence
- **Negative, Zero, Small positive shears have lower linear growth rates**

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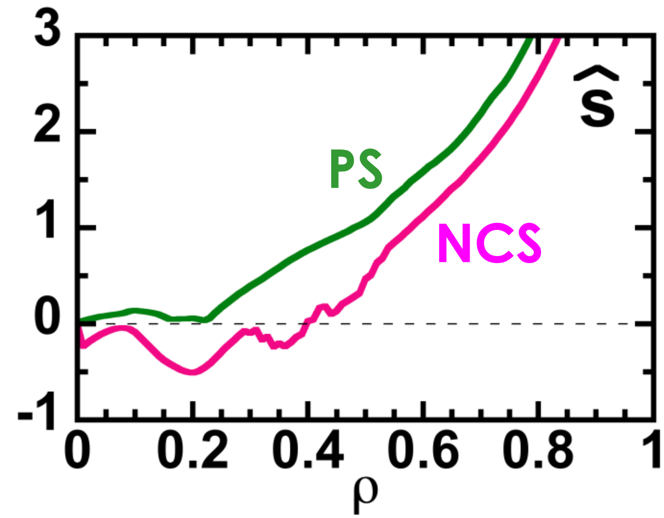
Investigated Transport Degradation with Electron Heating for Different Magnetic Shears

DIII-D experiment

- **Positive Shear (PS) and Negative Central Shear (NCS) quasi-steady-state operations**
  - I_P = 1.2 MA, B_T = 1.9 T, q_{95} = 4.6
  - P_{NB} ~ 6.4 MW, P_{ECH} ~ 3.2 MW at ρ~0.3-0.5
  - ELMy H-mode, modest ITB, β_N~2.2-2.7



- **NCS plasma had lower magnetic shear ($\hat{s}$) relative to PS plasma**
  - Smaller magnetic shear can be beneficial

NCS, PS	T_e/T_i (ρ~0.3-0.6)
w/o ECH	~0.8
w/ ECH	~1.1

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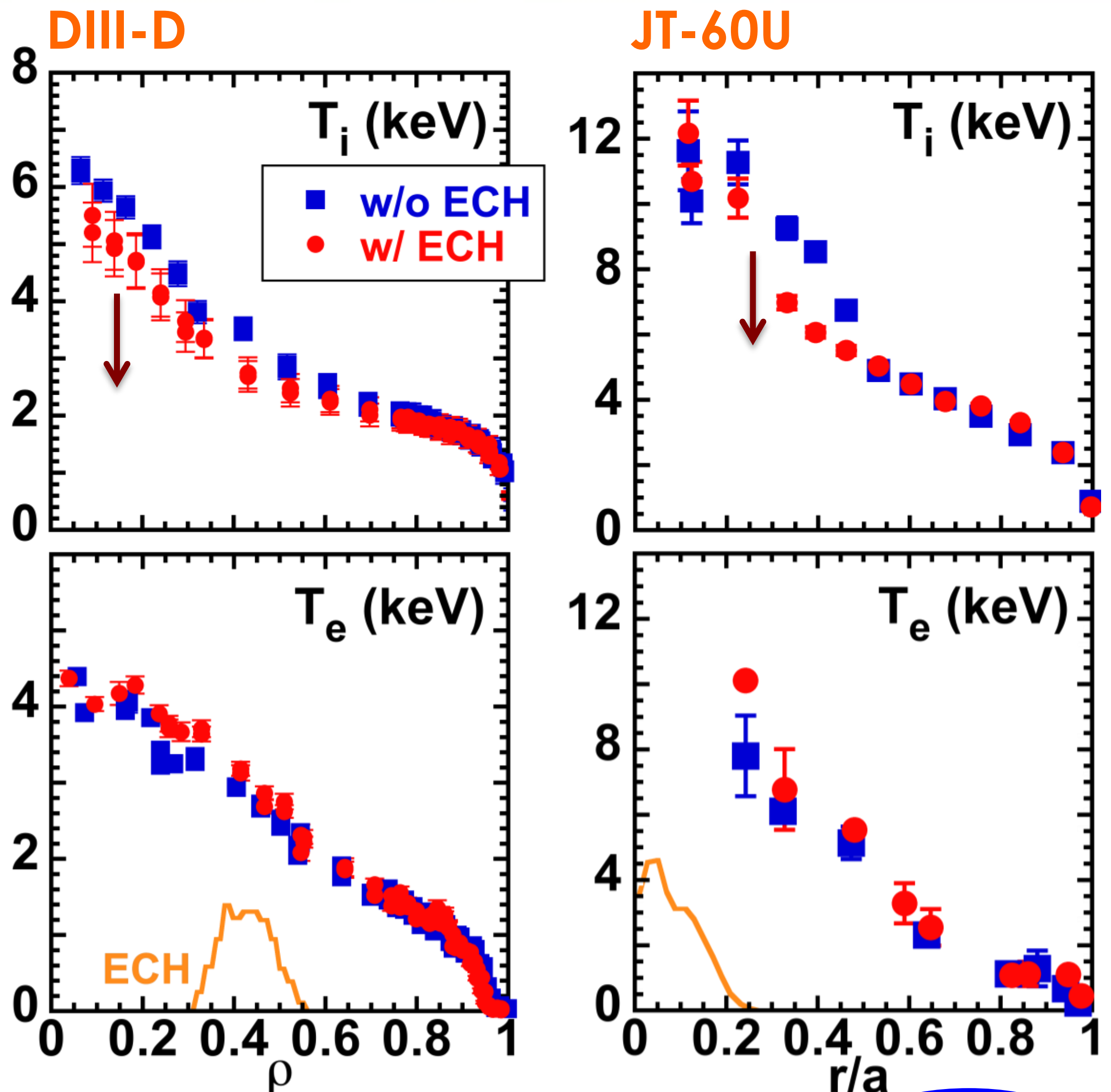
DIII-D and JT-60U Observed T_i Reduction in Positive Shear Plasmas as T_e/T_i Increased

- Core-T_i reduces in PS on both DIII-D and JT-60U as T_e/T_i increases
  - n_e reduction is ~20% in DIII-D, ~10% in JT-60U

T_e/T_i	DIII-D	JT-60U
w/o ECH	0.8	0.7
w/ ECH	1.1	1.0



I_P/B_T=1.5 MA/3.7 T,
P_{NB}~17.1 MW, P_{EC}~2.7 MW in JT-60U

JT-60U

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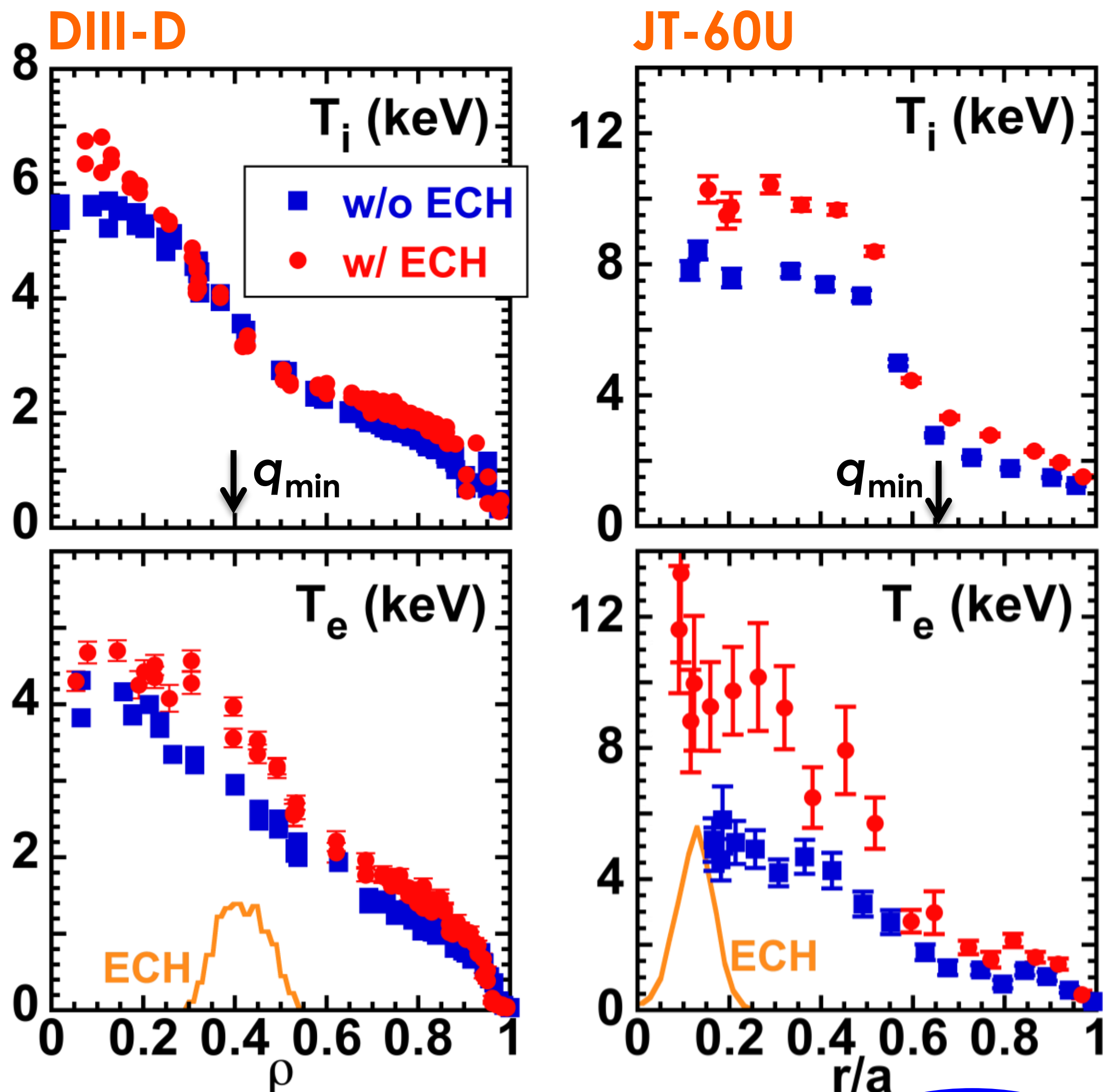
DIII-D and JT-60U Observed T_i Profile Maintained in Negative Central Shear Plasmas as T_e/T_i Increased

- **T_i profile is maintained in NCS on both DIII-D and JT-60U as T_e/T_i increases**
  - n_e reduction is ~10% in DIII-D, no reduction in JT-60U

T_e/T_i	DIII-D	JT-60U
w/o ECH	0.8	0.6
w/ ECH	1.1	0.8

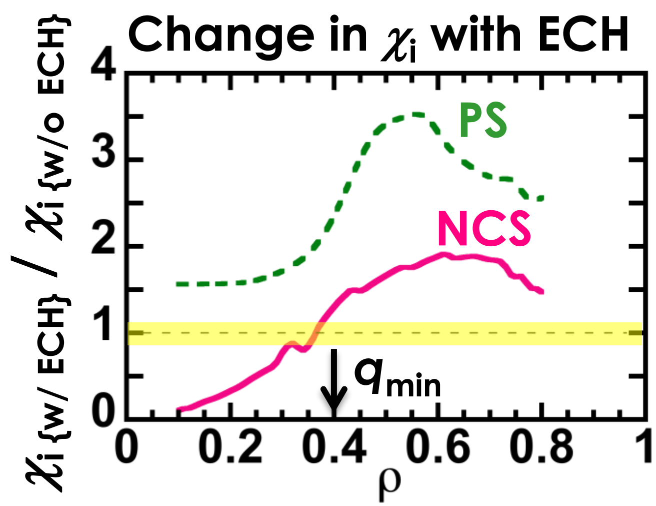


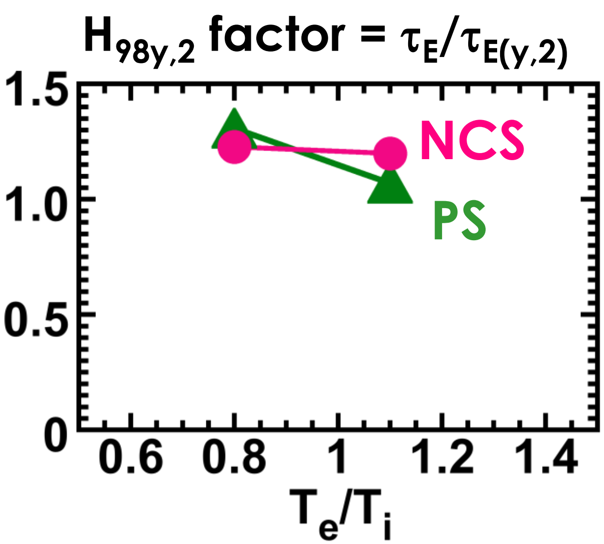
I_P/B_T=1.2 MA/3.7 T,
P_{NB}≈9.3 MW, P_{EC}≈2.9 MW in JT-60U

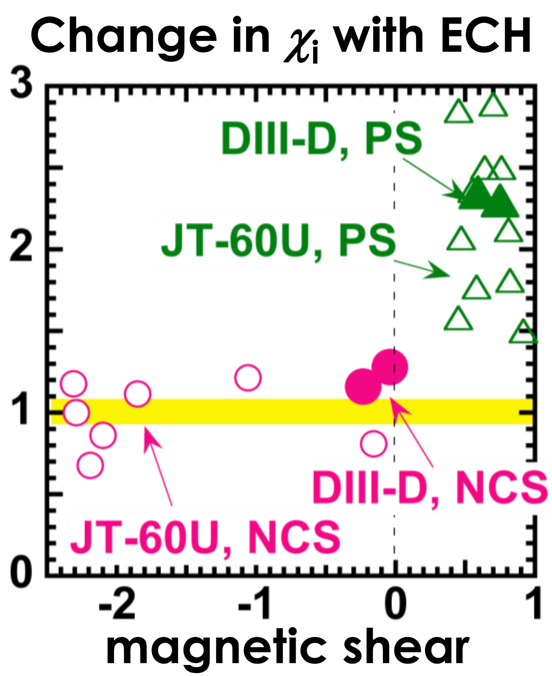
DIII-D and JT-60U Demonstrated NCS Minimizes Confinement Degradation as T_e/T_i Increased

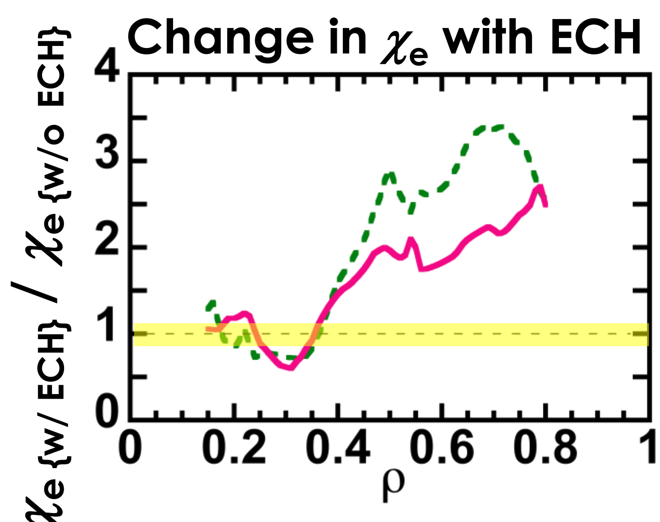
- **Ion and electron thermal diffusivities significantly increase in PS plasma**
- **The confinement degradation is mitigated in NCS plasma across the profile**
- **Higher improved confinement factor is maintained in NCS plasma**

DIII-D









JT-60U

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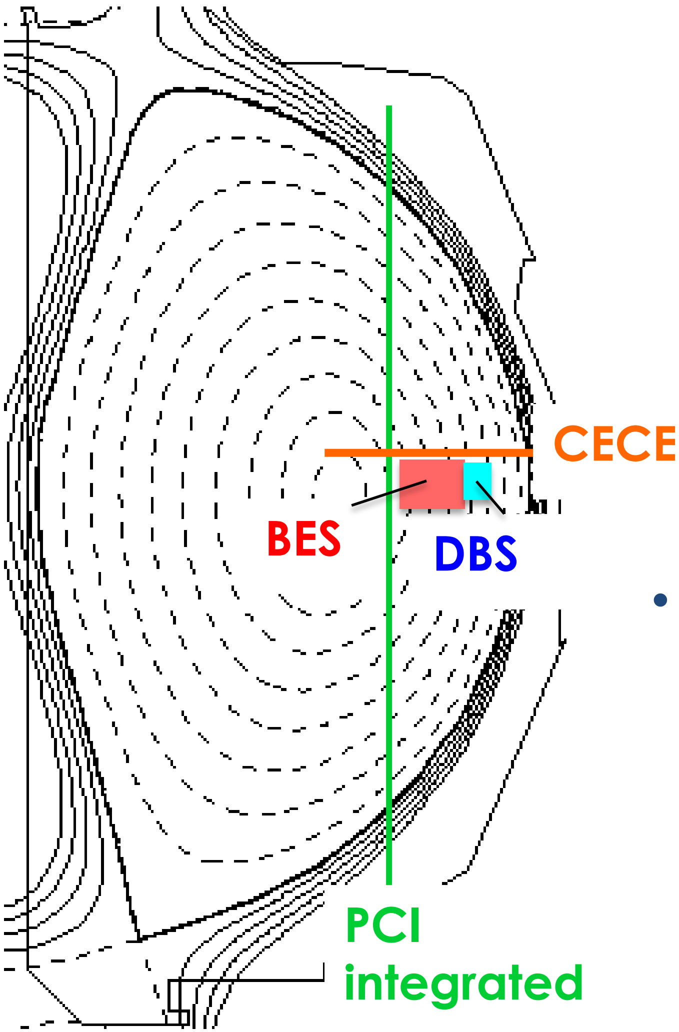
Magnetic Shear Effect on Transport was Assessed Using a Suite of Fluctuation Measurements



BES: **low-*k*** $\tilde{n}_e$

DBS: **intermediate-*k*** $\tilde{n}_e$

PCI: **intermediate to high-*k*** $\tilde{n}_e$

CECE: **low-*k*** $\tilde{T}_e$

- ***Show data outside of*** q_{min} ***mainly***
  - *Low signal levels inside of* q_{min}
  - *Transport differences across the profile*

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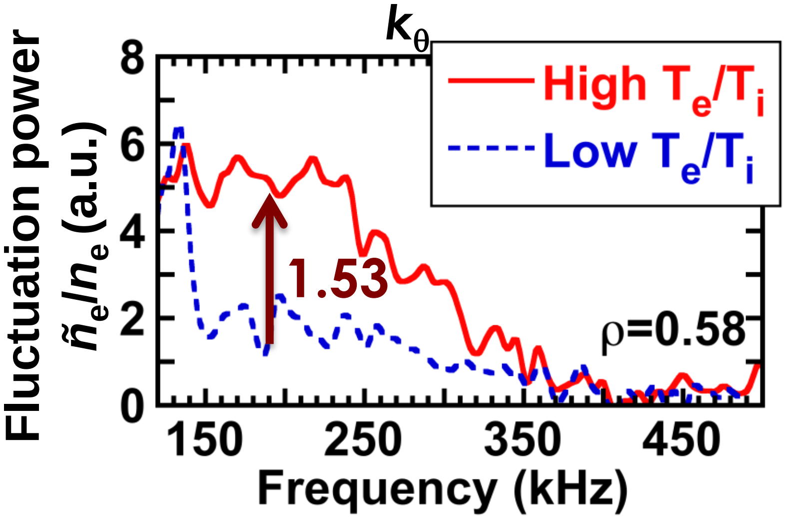
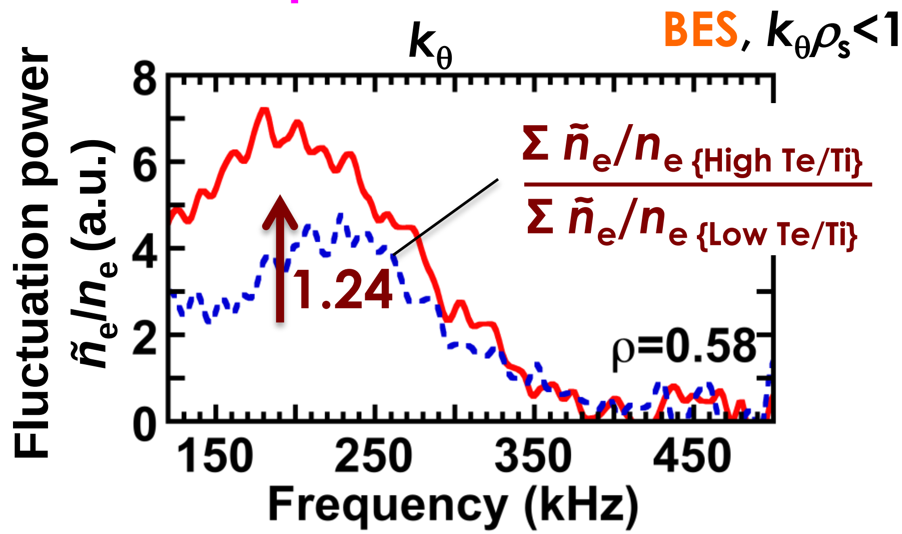
k: wavenumber

Low-*k* Density Fluctuations Increase Less in NCS Plasma with Increasing T_e/T_i

PS plasma

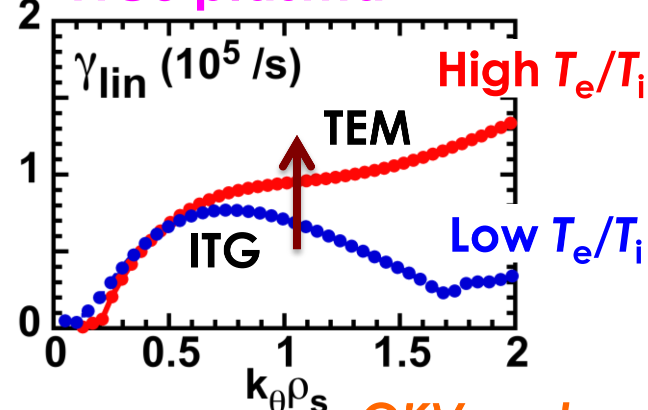


NCS plasma



- **Low-*k* density fluctuations increase with increasing T_e/T_i**
  - Low-*k* fluctuations typically reflect ITG/TEM
  - GK predicts linear growth rates increase
- **Increase in frequency-integrated fluctuations is ~24% in NCS plasma, smaller than PS plasma of ~53%**

NCS plasma



GKV code

ITG: Ion Temperature Gradient mode
TEM: Trapped Electron Mode

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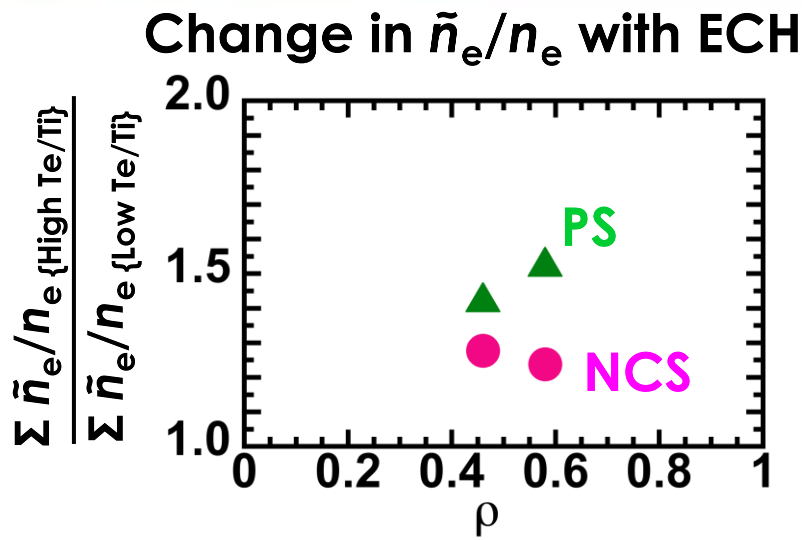
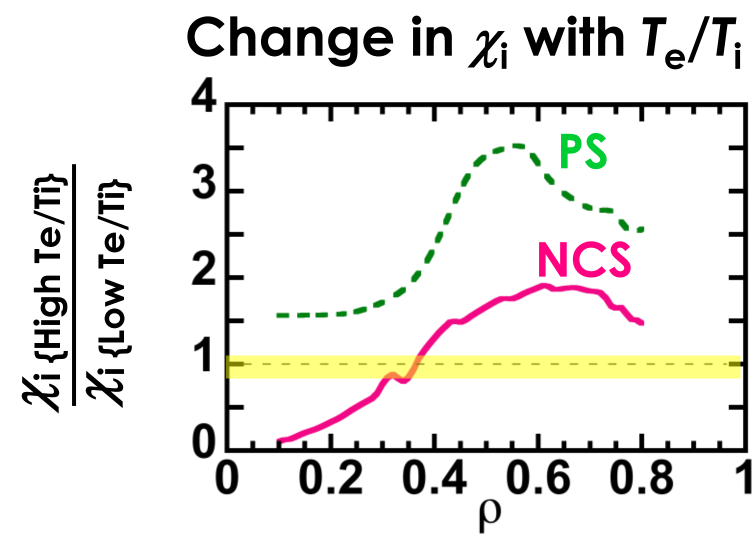
Modest Increase in Low-*k* Fluctuations Correlates with Modest Increase in Transport

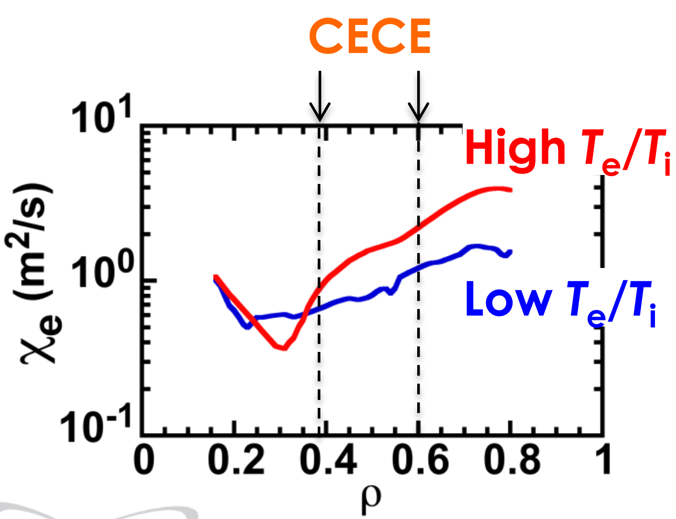
- **Increase in broadband turbulent fluctuations with increasing T_e/T_i in the NCS plasma was smaller than that in the PS plasma**
  - Smaller low-*k* turbulence (ITG/TEM) accounts for higher confinement in NCS plasma at T_e/T_i~1

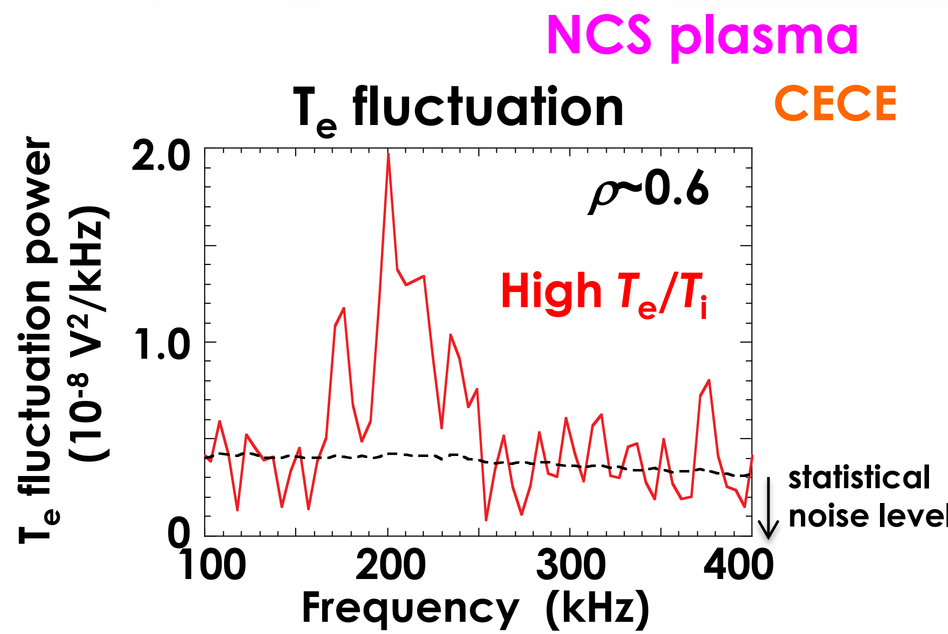


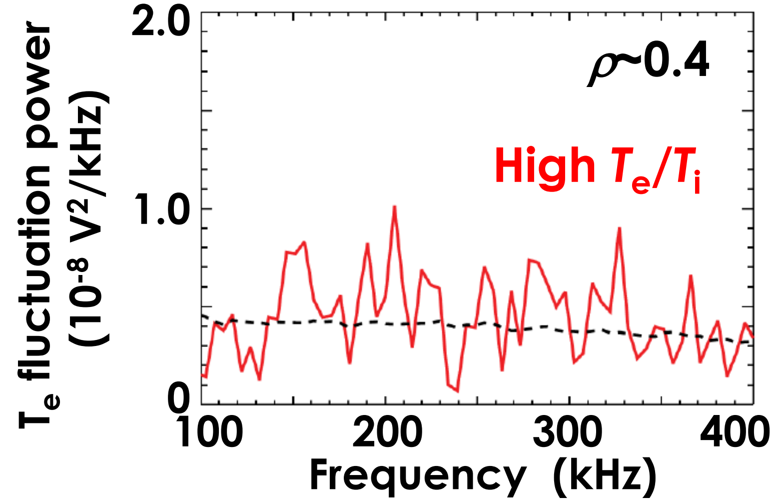


T_e Fluctuations are Excited in the Outer Region with Increasing T_e/T_i

- **T_e fluctuations in the outer region, accompanying n_e fluctuations around f=200 kHz**
  - No clear broadband T_e fluctuations in the inner region
  - Consistent with thermal transport in outer region being enhanced by low-k fluctuations







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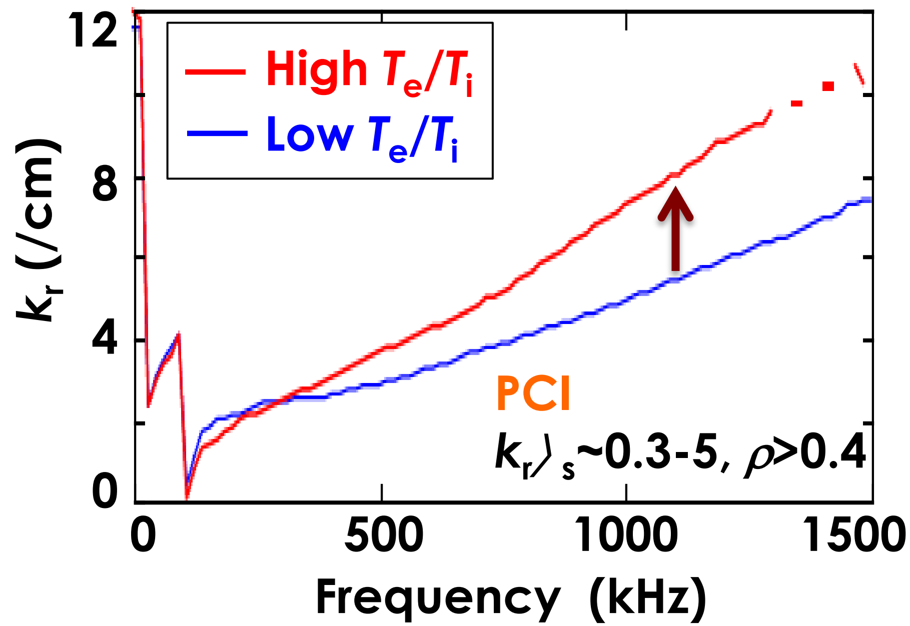
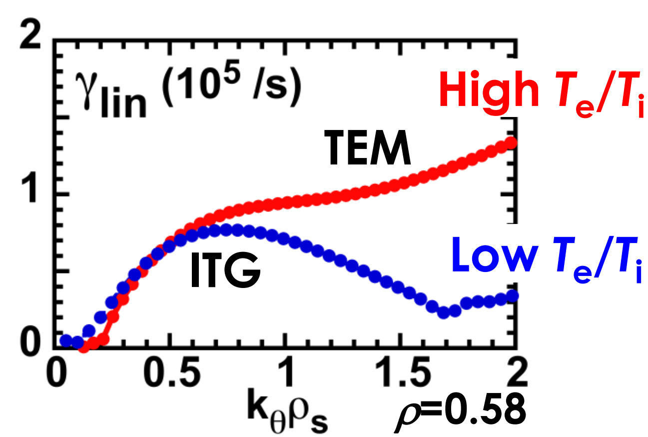
Intermediate-k Density Fluctuations Altered with Increasing T_e/T_i

NCS plasma

- **Wavenumber at a given frequency increases with increasing T_e/T_i**
  - Possible indication of change in TEM/ETG stability
- **GK simulations predict switch of dominant mode from ITG to TEM**

Maximum wavenumber of $\tilde{n}_e$





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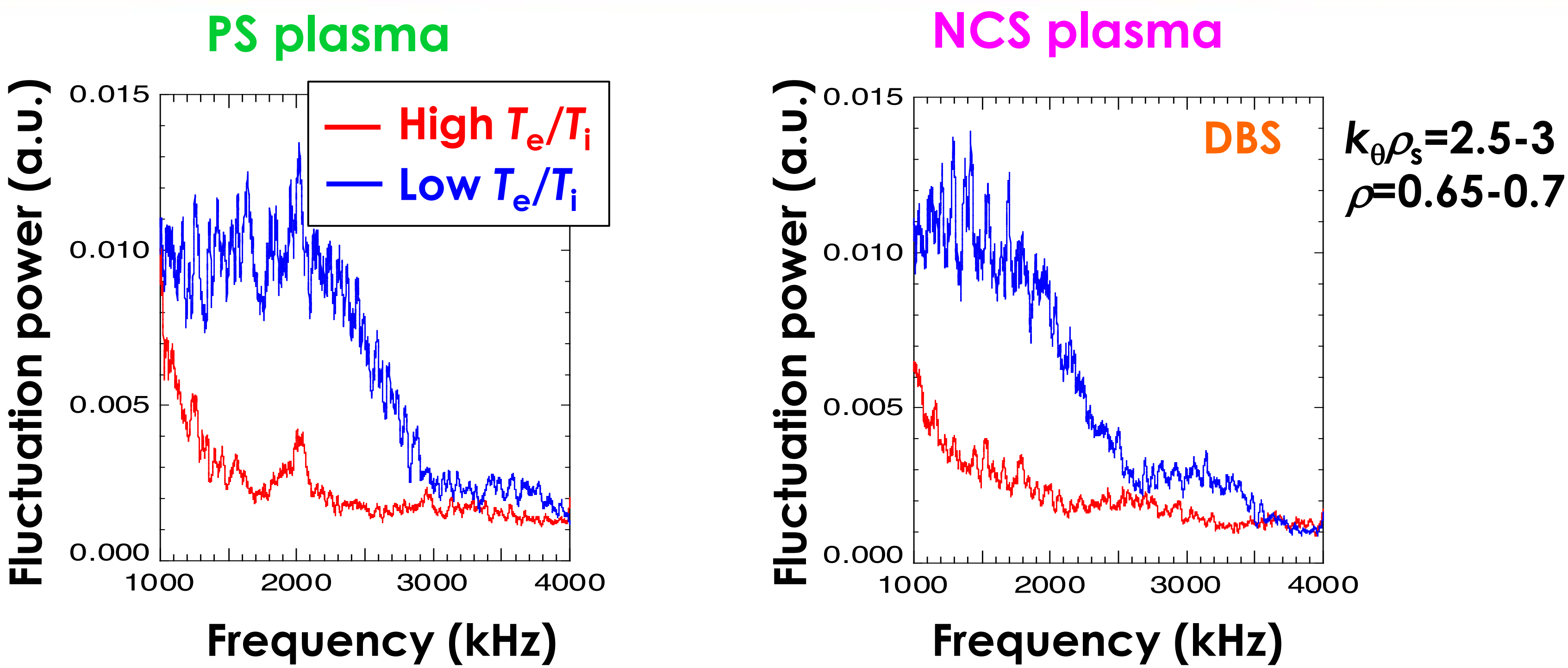
Intermediate-*k* Density Fluctuations Decrease in Outer Region with Increasing T_e/T_i



- **Intermediate-*k* fluctuations decrease with T_e/T_i in the outer region**
  - Consistent observation in PCI
- **No significant difference between the PS and NCS plasmas**
  - Multi-scale interactions may play a significant role in determining saturated turbulence amplitudes

Fluctuation Measurements Lead to Better Understanding of the Magnetic Shear Effect

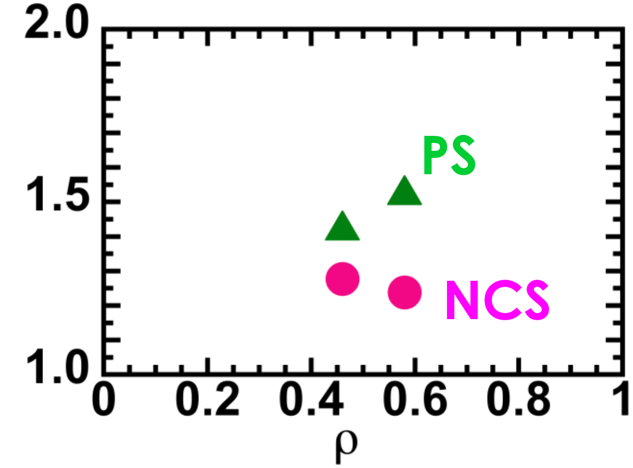
As T_e/T_i increases

	Transport	Fluctuations	Gyrokinetic simulations
NCS plasma	• Mitigated across the profile	• Smaller increase in low-*k* fluctuation • Move to higher-*k* • T_e fluctuations in outer region • Intermediate-*k* decrease with ECH	• Smaller increase in γ_{lin} • Change in TEM/ETG stability • Intermediate-*k* increase with ECH
PS plasma	• Increase significantly	• Larger increase in low-*k* fluctuations • Intermediate-*k* decrease with ECH	• Larger increase in γ_{lin} • Intermediate-*k* increase with ECH

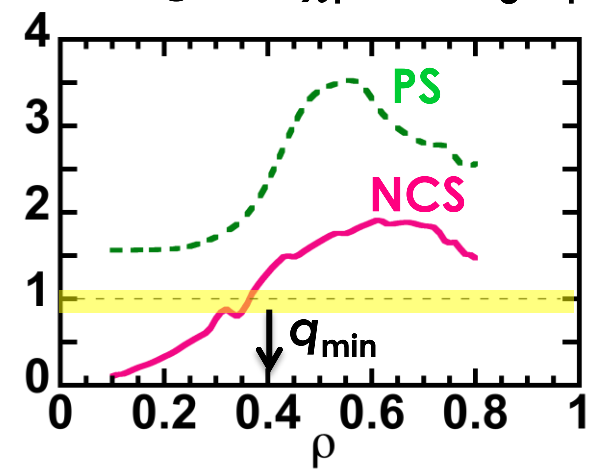
Summary: DIII-D and JT-60U Show NCS Minimizes Confinement Degradation Relative to PS at T_e/T_i~1

- **Benefit of NCS extends outside q_{min}**
- **DIII-D shows smaller rise in low-*k* turbulent fluctuations in NCS plasmas**
- **In NCS plasmas, increase in T_e/T_i results in smaller change in GK linear growth rates and less increase in ion/electron thermal transport**

Change in $\tilde{n}_e/n_e$ with ECH



Change in χ_i with T_e/T_i



Contribute to improve confinement with controlled magnetic shear in ITER and DEMO advanced scenarios

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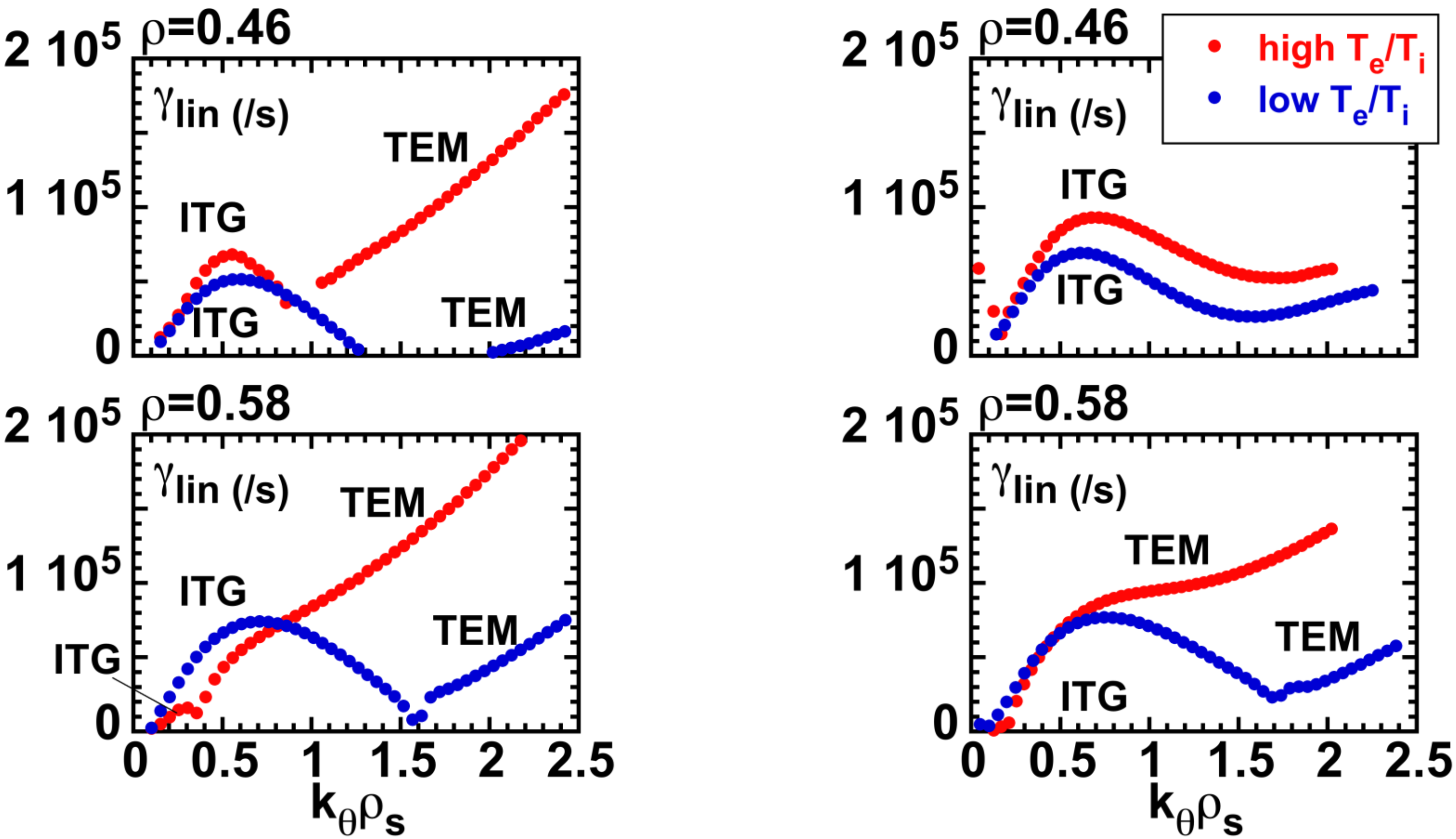
JT-60U

Increase in T_e/T_i results in smaller change in GK linear growth rates in NCS plasmas

Positive shear **Negative shear**



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