NSTX

NOVA PHOTONICS

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Suppression of turbulent transport in NSTX internal transport barriers

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Howard Yuh, Nova Photonics

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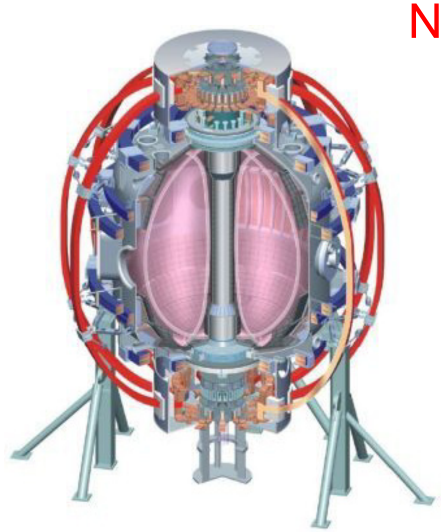

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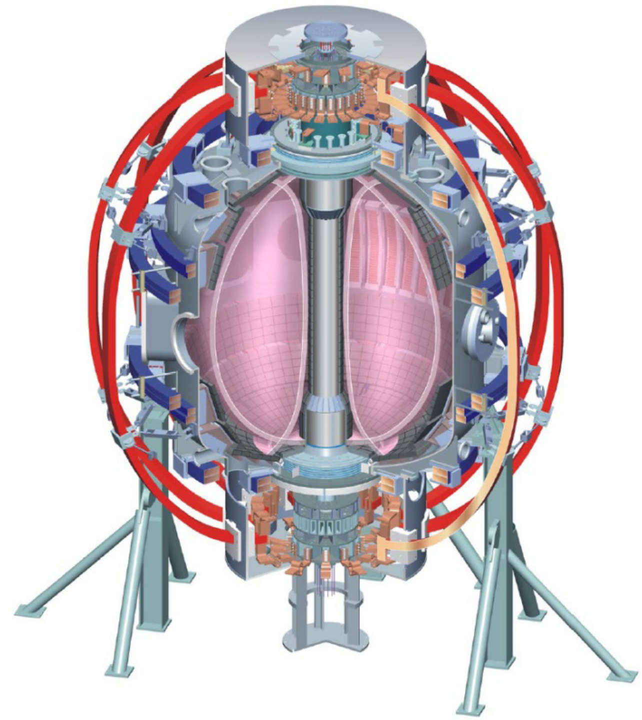
Motivation to understand confinement

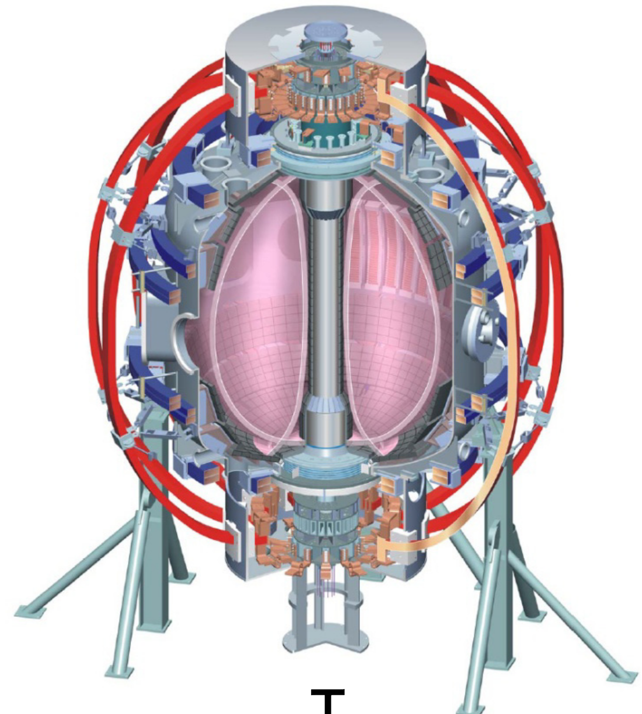
- NSTX is a high performance spherical torus that has achieved very high β
- Ion transport is typically neoclassical in H-modes

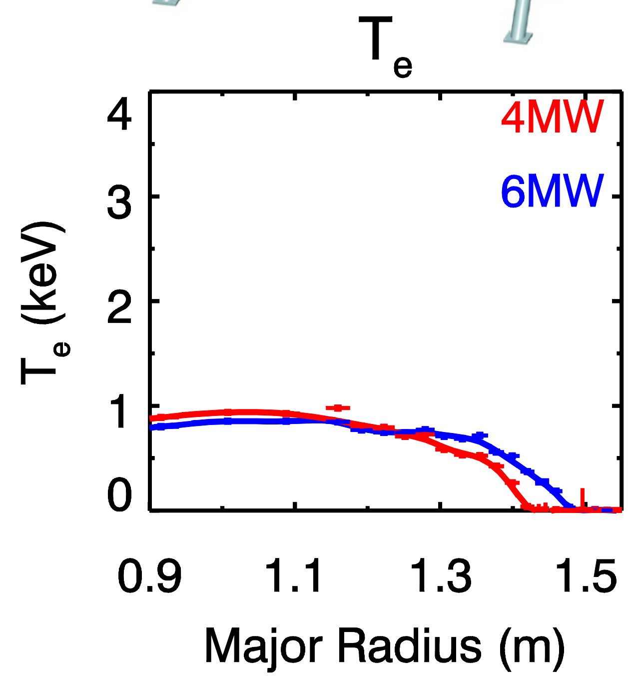


Major radius	0.85 m
Aspect ratio	1.3
Plasma current	1 MA
Toroidal field	0.55 T
Neutral Beams	6 MW
High Harmonic Fast Wave	3 MW
Elongation	2.7
Triangularity	0.8

Motivation to understand confinement

- NSTX is a high performance spherical torus that has achieved very high β
- Ion transport is typically neoclassical in H-modes
- Anomalous electron transport dominates heat loss
- ST fusion reactors must achieve improvements in core electron confinement
- NSTX is well equiped to study electron confinement





Motivation to understand confinement

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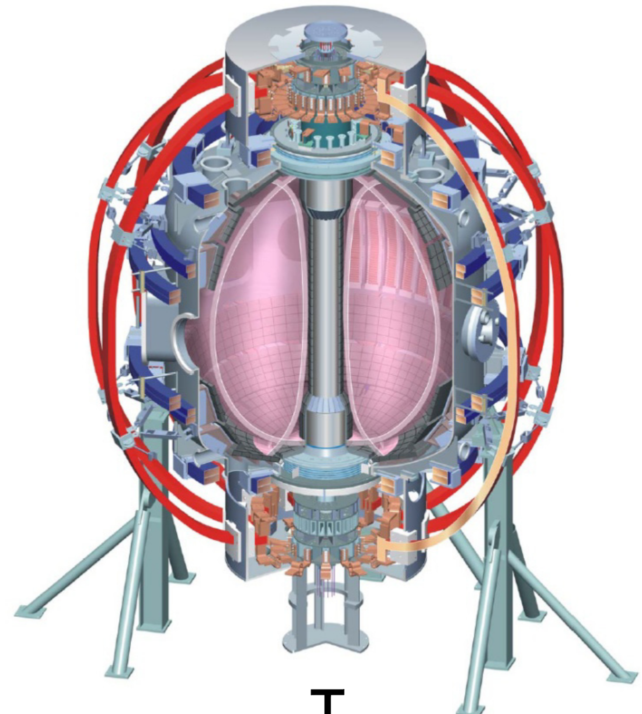
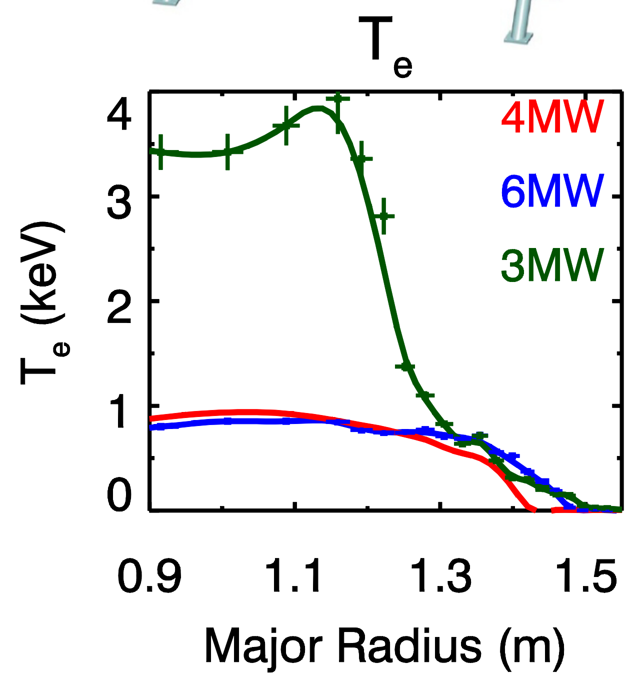
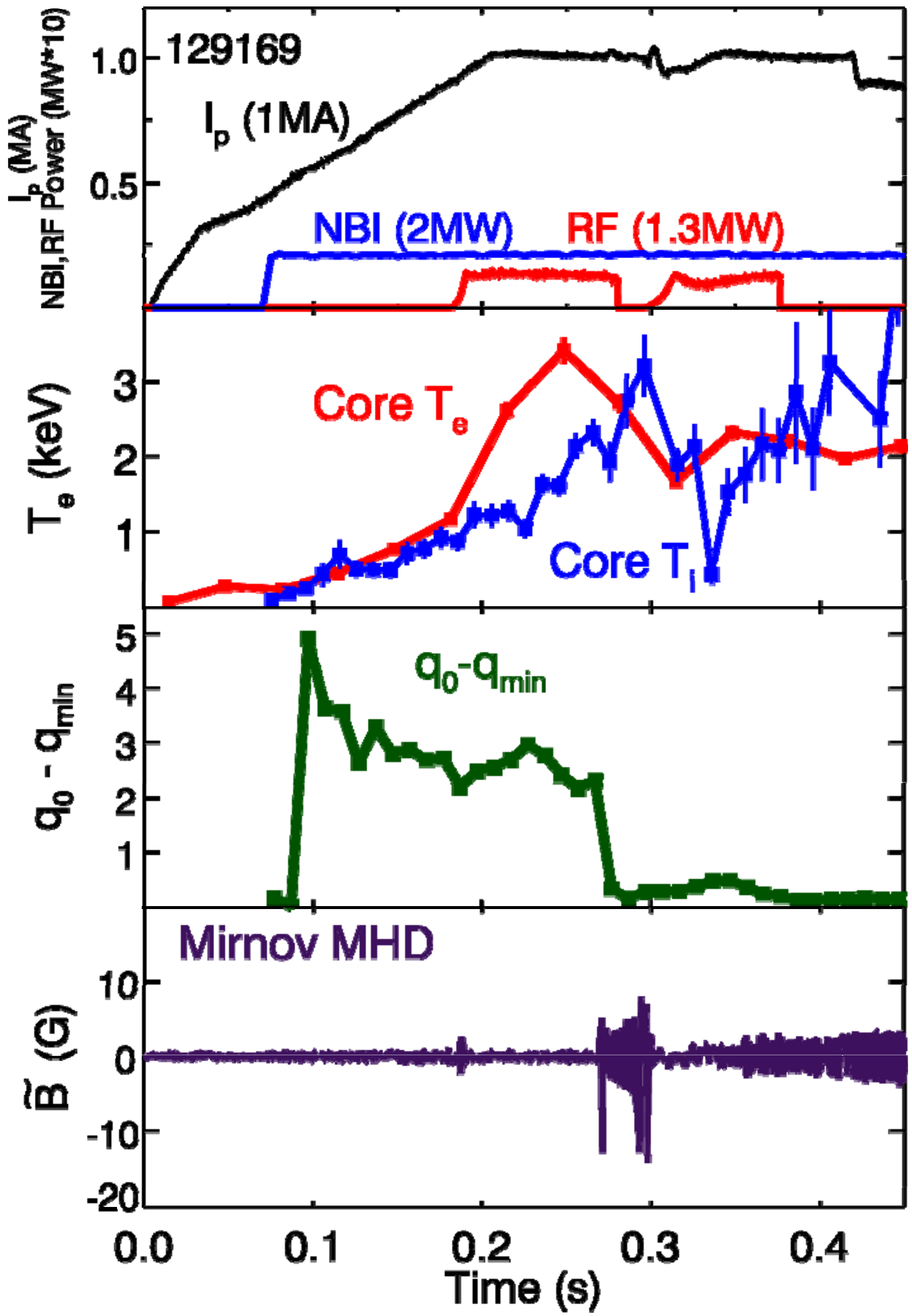
- Anomalous electron transport dominates heat loss
- ST fusion reactors must achieve improvements in core electron confinement
- NSTX is well equiped to study electron confinement
- Internal Transport Barriers (ITBs) lead to dramatic improvements in core electron confinement



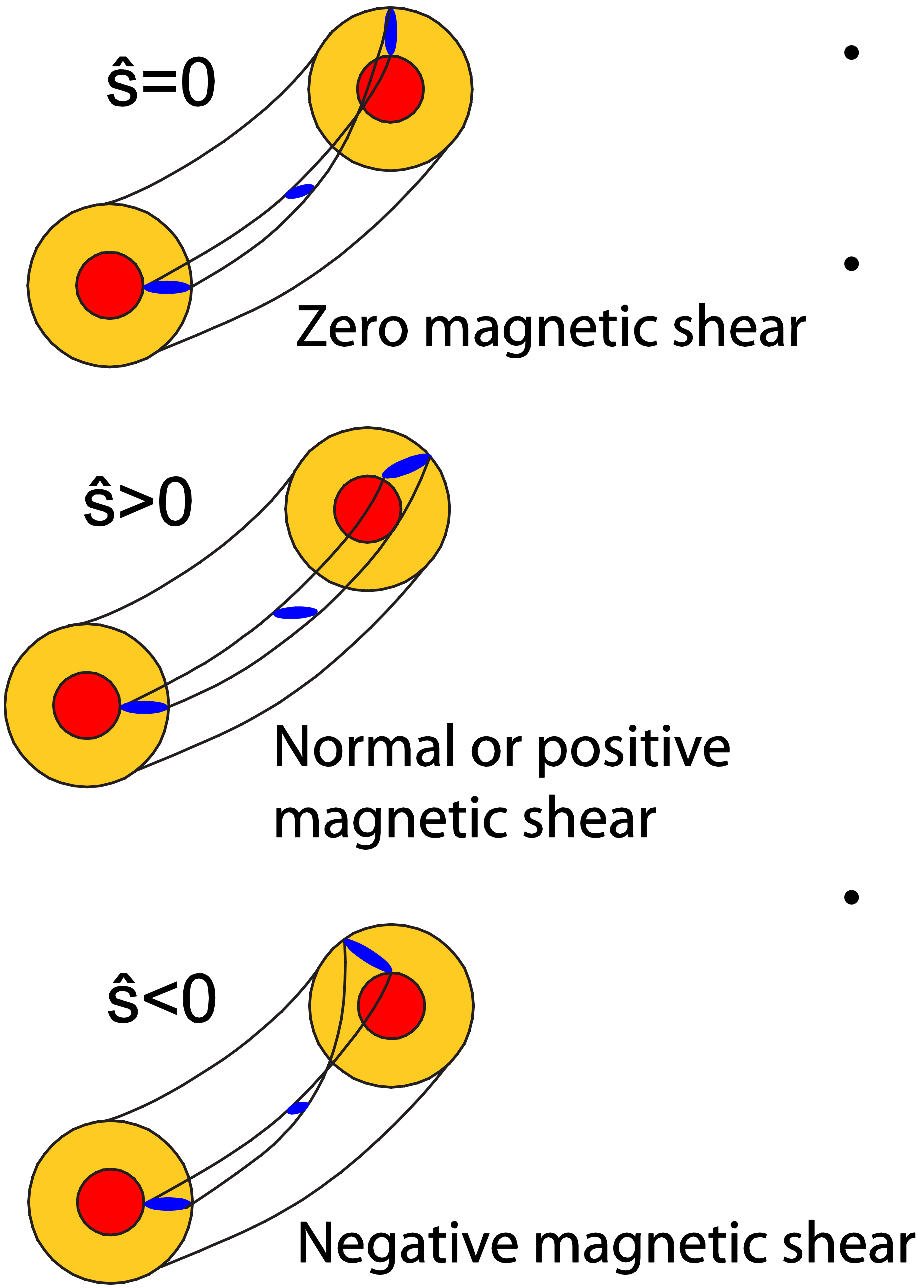


Reversed (negative) magnetic shear plasmas show dramatic confinement improvements



- NSTX L-mode plasmas can display an early period of enhanced confinement
- Core electron and ion temperatures, as well as core toroidal velocity increase rapidly during periods of enhanced confinement
- Loss of high confinement phase coincident with MHD activity redistributing current and loss of reverse shear

Negative magnetic shear twists radial eddies away from curvature drive



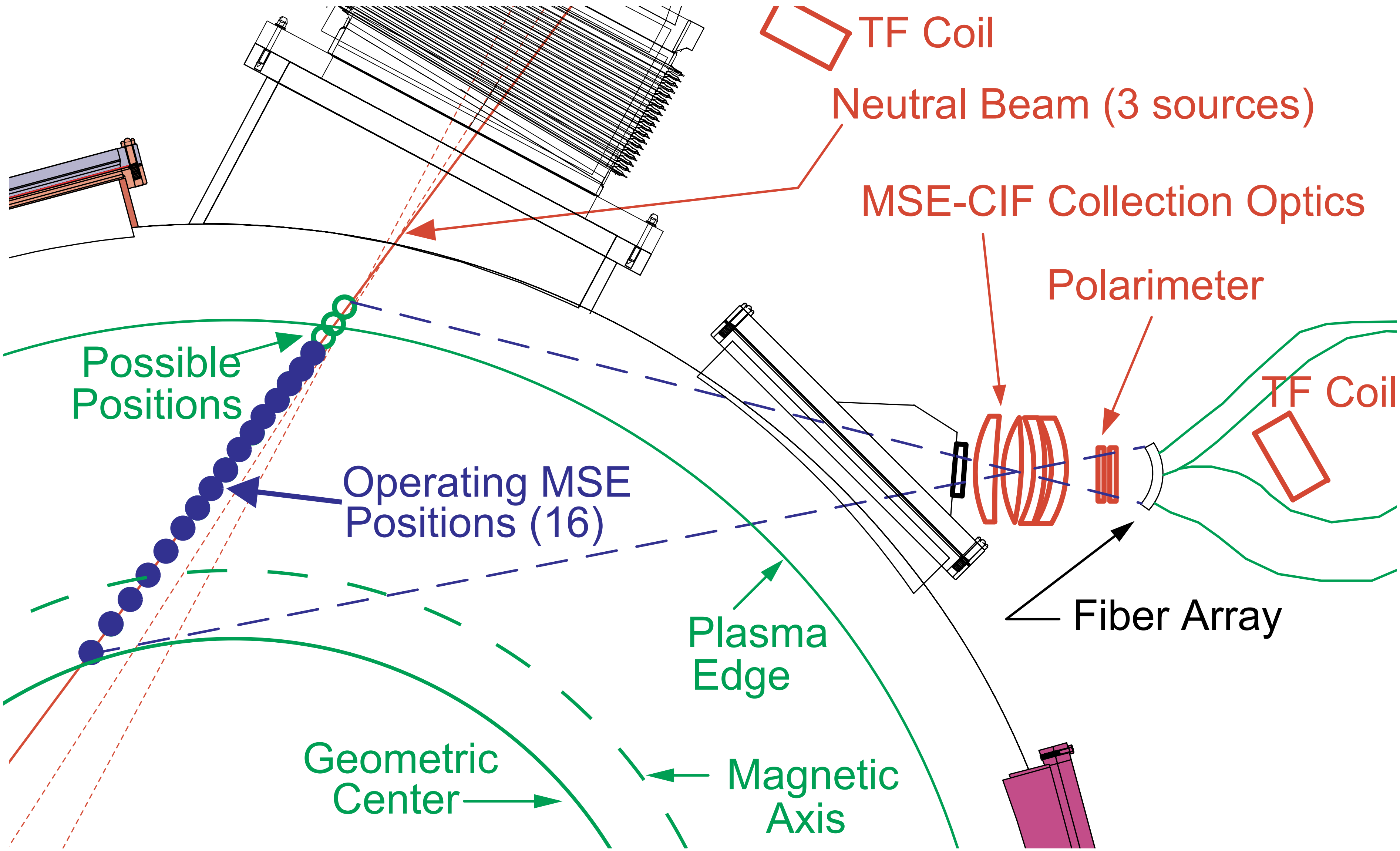
- $\hat{s}=r/q\,(dq/dr)$
- Antonsen [PoP **3**,2221,(1996)] showed pictorially how negative magnetic shear stabilizes ballooning type modes and simulation results showing the breaking up of radially extended streamer structures
- Negative shear rotates radially extended streamers such that they are no longer aligned with the curvature drive

Outline

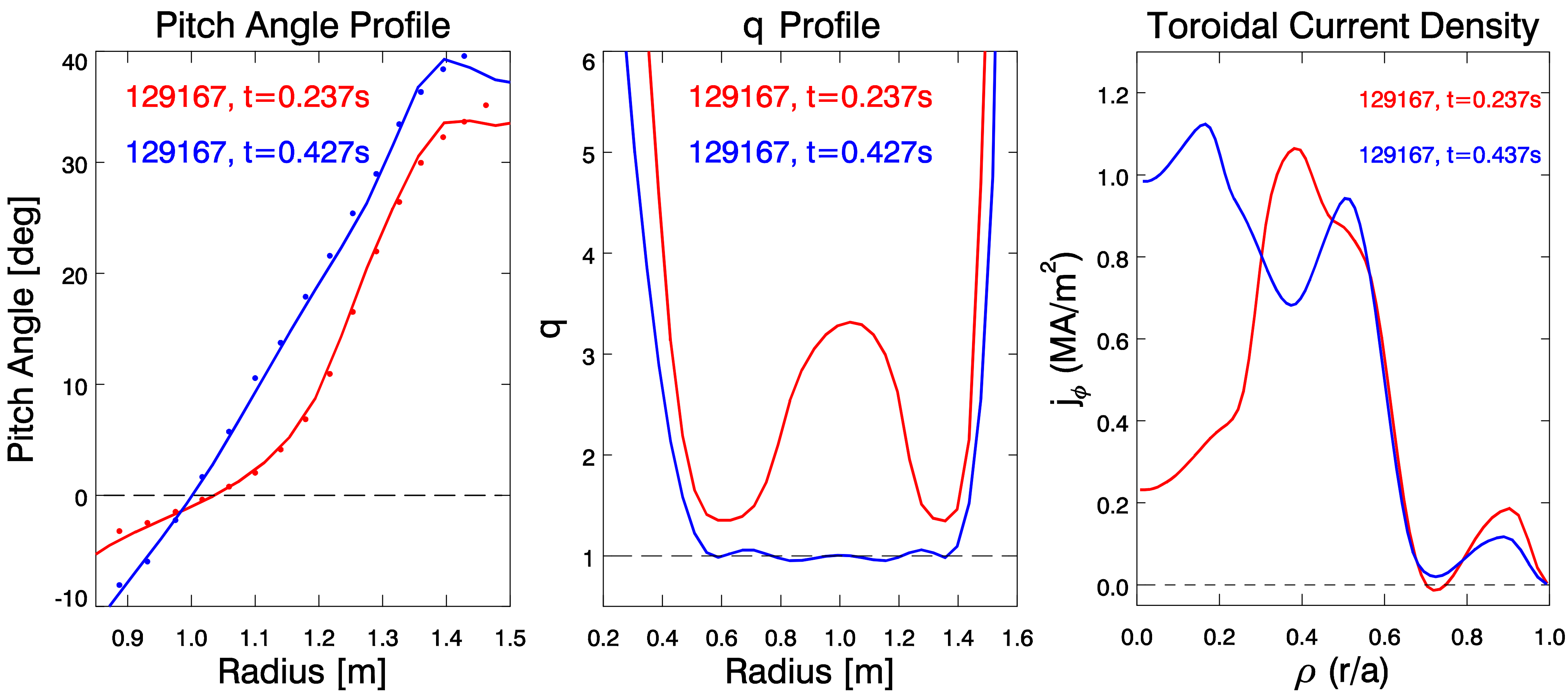
- **Experimental profiles of ITBs**
- **Statistical analysis of the kinetic profile database**
- **High-k fluctuation data in the ITB at the electron scale**
- **Comparison between experimental and simulation results**
- **Conclusion**

16 channel Motional Stark Effect (MSE) diagnostic measures internal magnetic pitch angles

- Lyot filter based MSE system provides 10ms resolution at ≤0.3T
- Provides full coverage from edge to well past magnetic axis
- Diagnoses nearly all NSTX plasmas with beam heating or beam blips

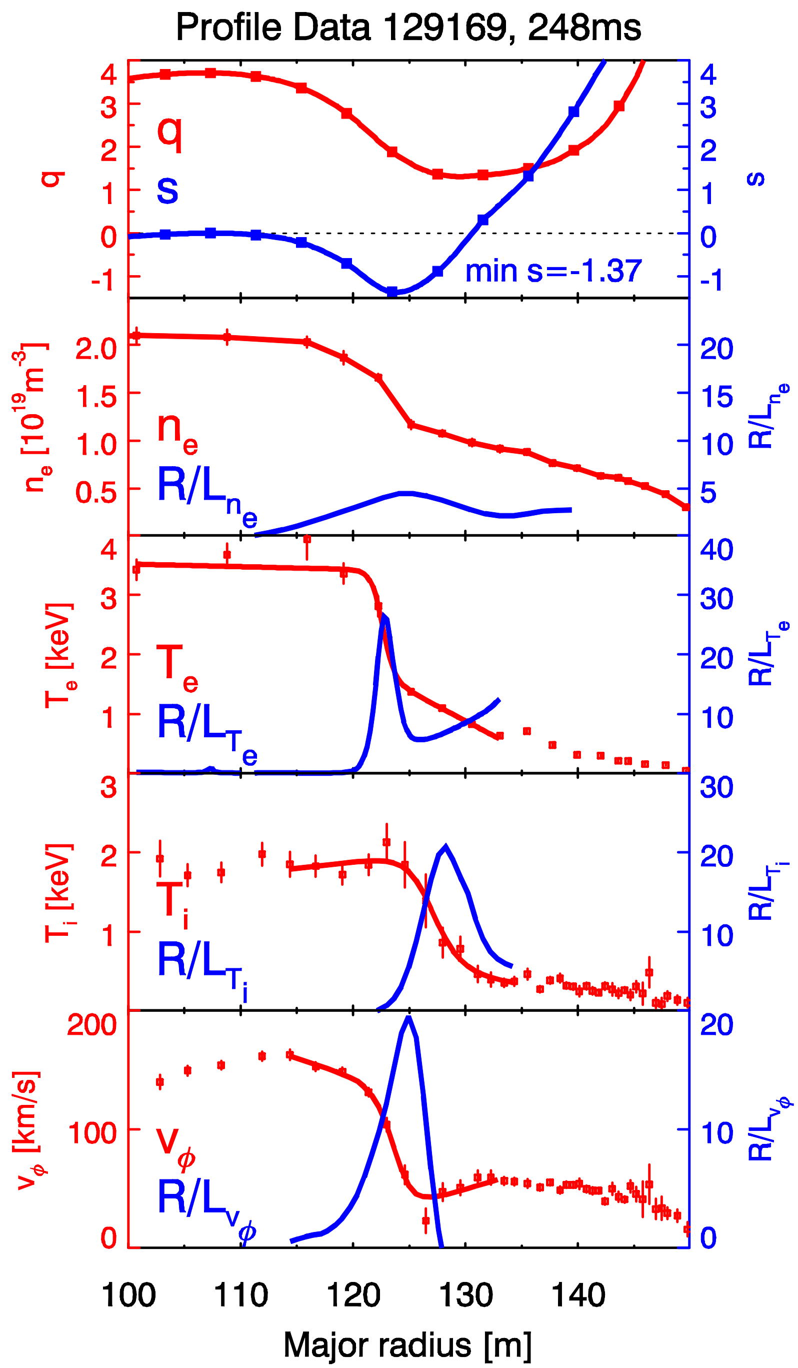


MSE accurately constrains q and j profiles of reversed shear discharges



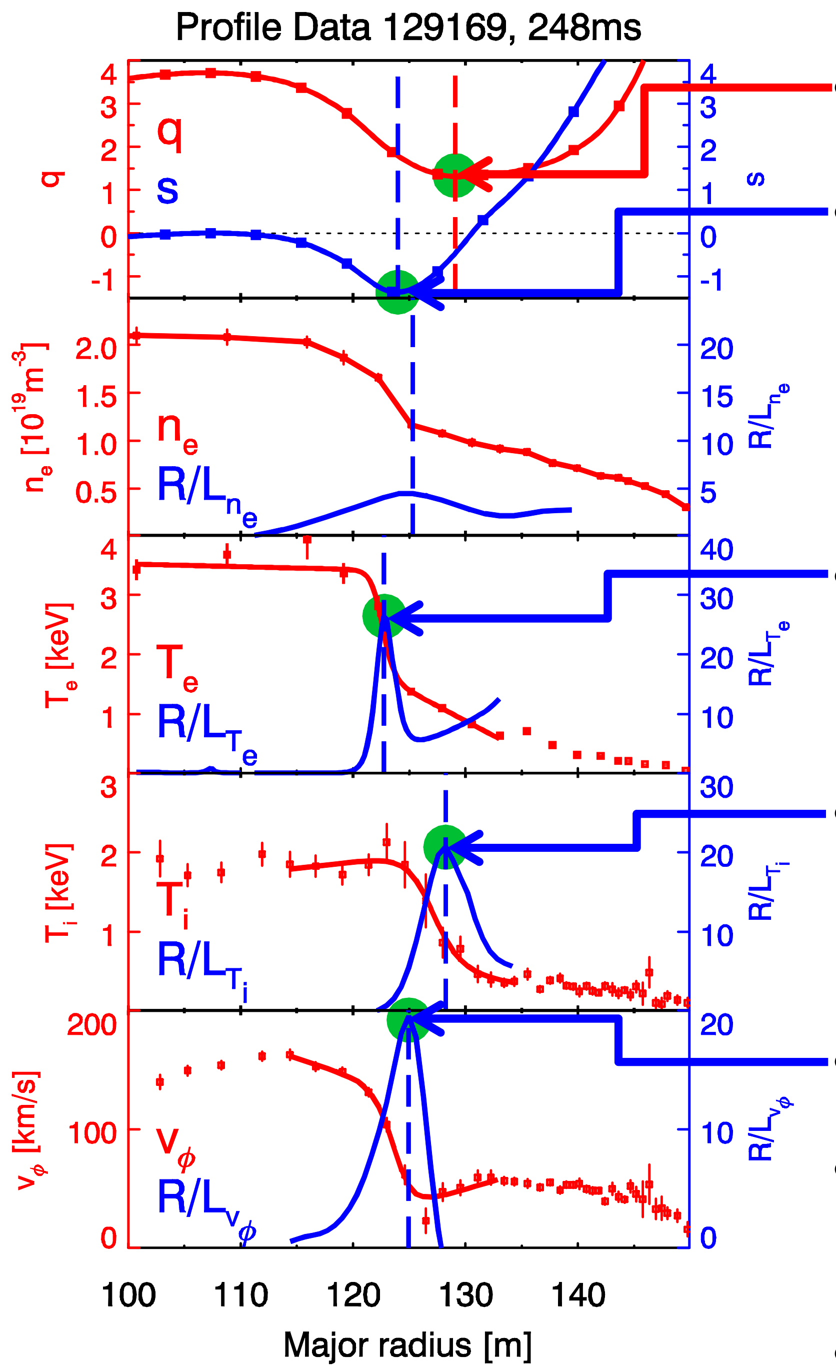
- The minimization of flux consumption on NSTX plasma startup frequently results in early reversed shear q-profiles
- Reconstructions performed using LRDFIT (J. Menard)
  - Free boundary, Grad-Shafranov solver using magnetics, E_r corrected MSE, T_e isothermal flux surfaces, and rotation

Internal transport barriers form when magnetic shear is negative



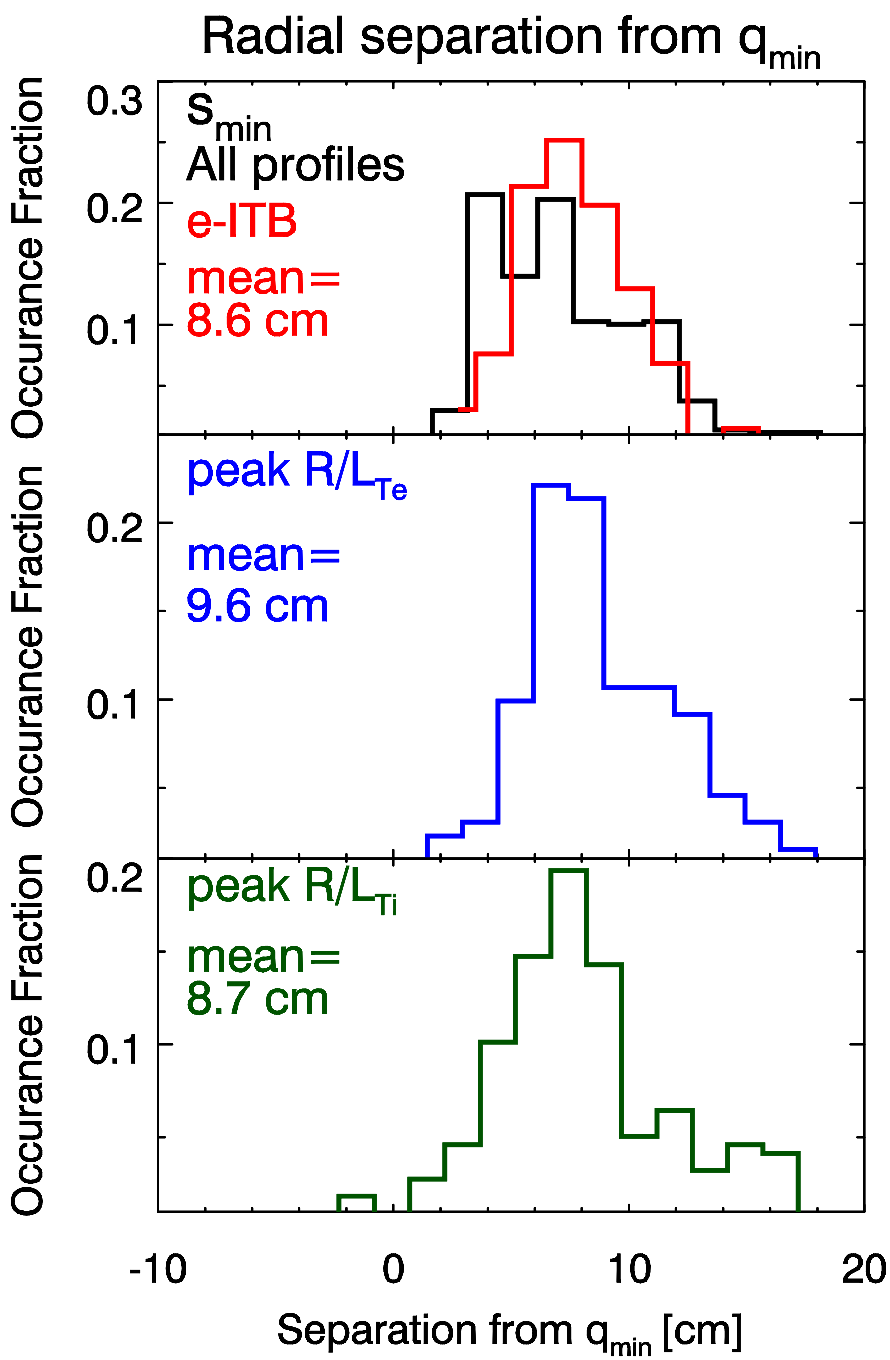
- Peaked core gradients in electron and ion temperatures, and toroidal velocity
- Electron density gradient does not show much change with ITB
- NSTX profile diagnostics
  - 51 channel toroidal CHarge Exchange Recombination Spectroscopy (CHERS) measures T_i,v_ϕ
  - 30 channel Thomson scattering measures T_e, n_e
  - 16 channel MSE

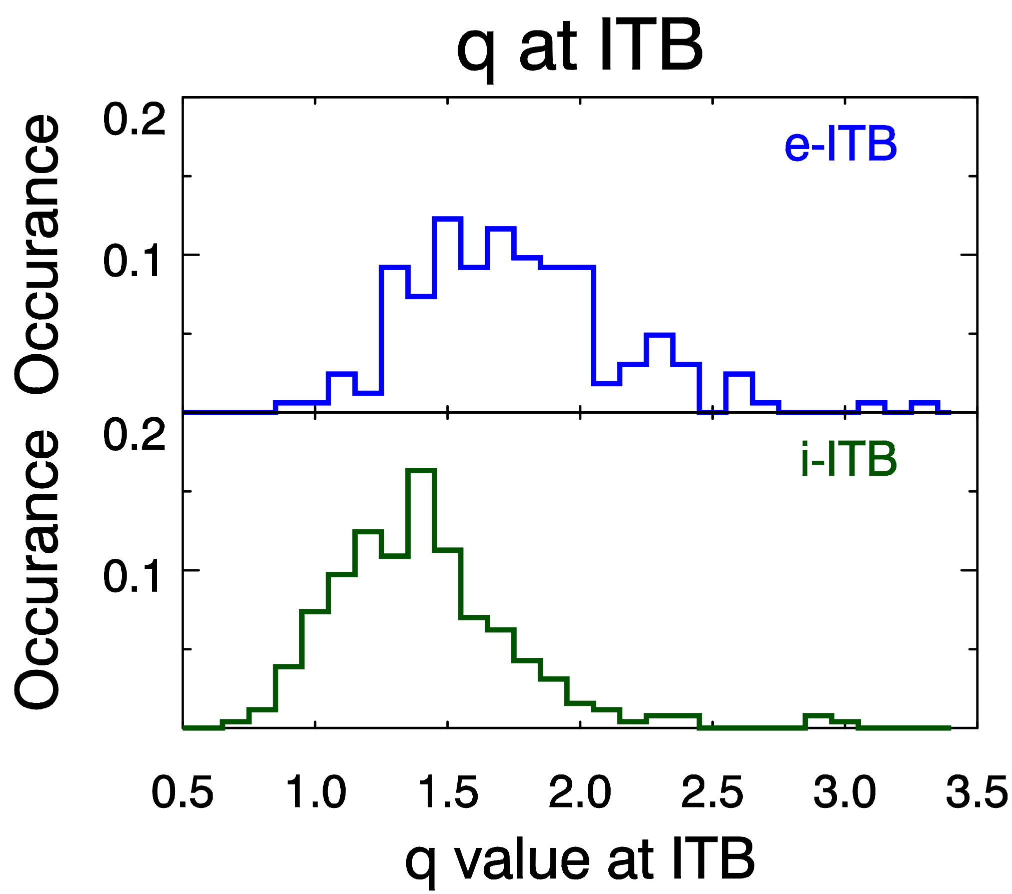
Definitions of profile quantities for statistical analysis



- q_{min} and location
- s_{min} and location
- maximum R/L_{Te} and location (e-ITB)
- maximum R/L_{Ti} and location (i-ITB)
- maximum $R/L_{v\phi}$ and location
- Profiles from over 80 ITB discharges with over 500 timeslices
- Tanh or spline fitted

ITB locations do not coincide with q_{min} or rational q



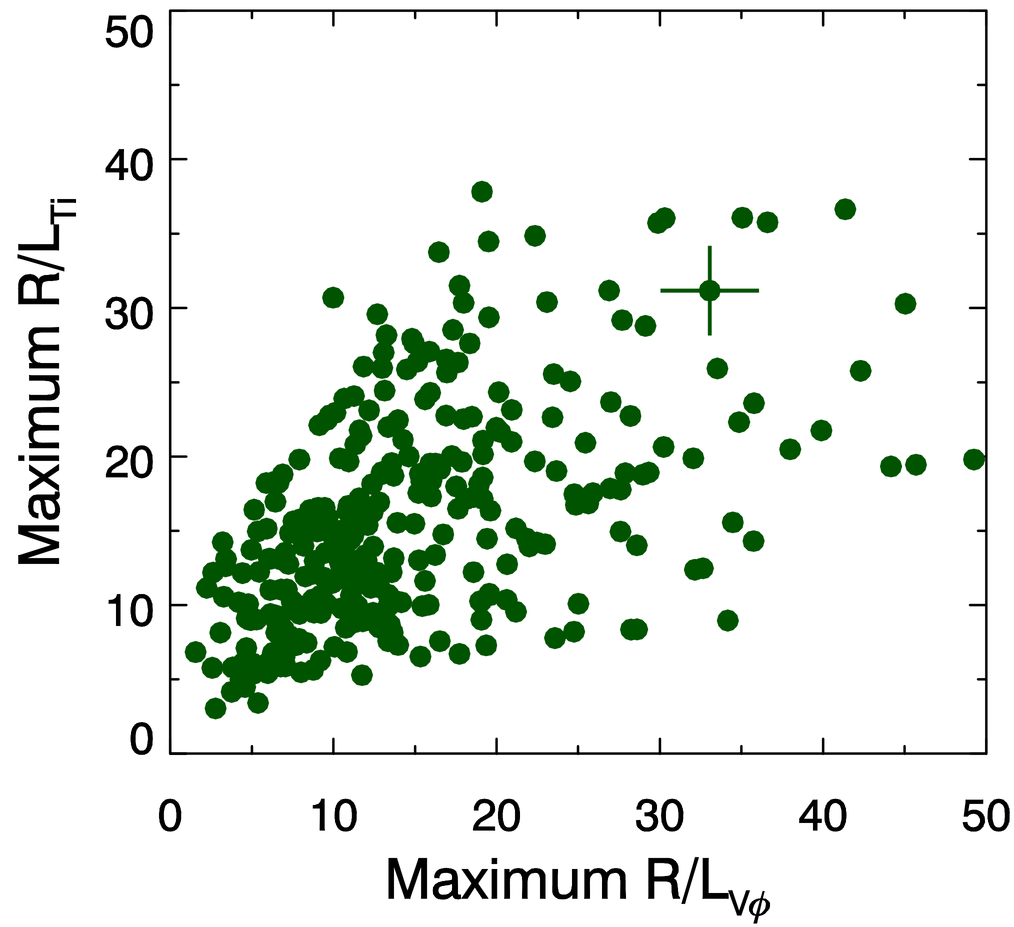


- Peak gradient locations well separated from q_{min}
- ITBs occurs over a range of q values

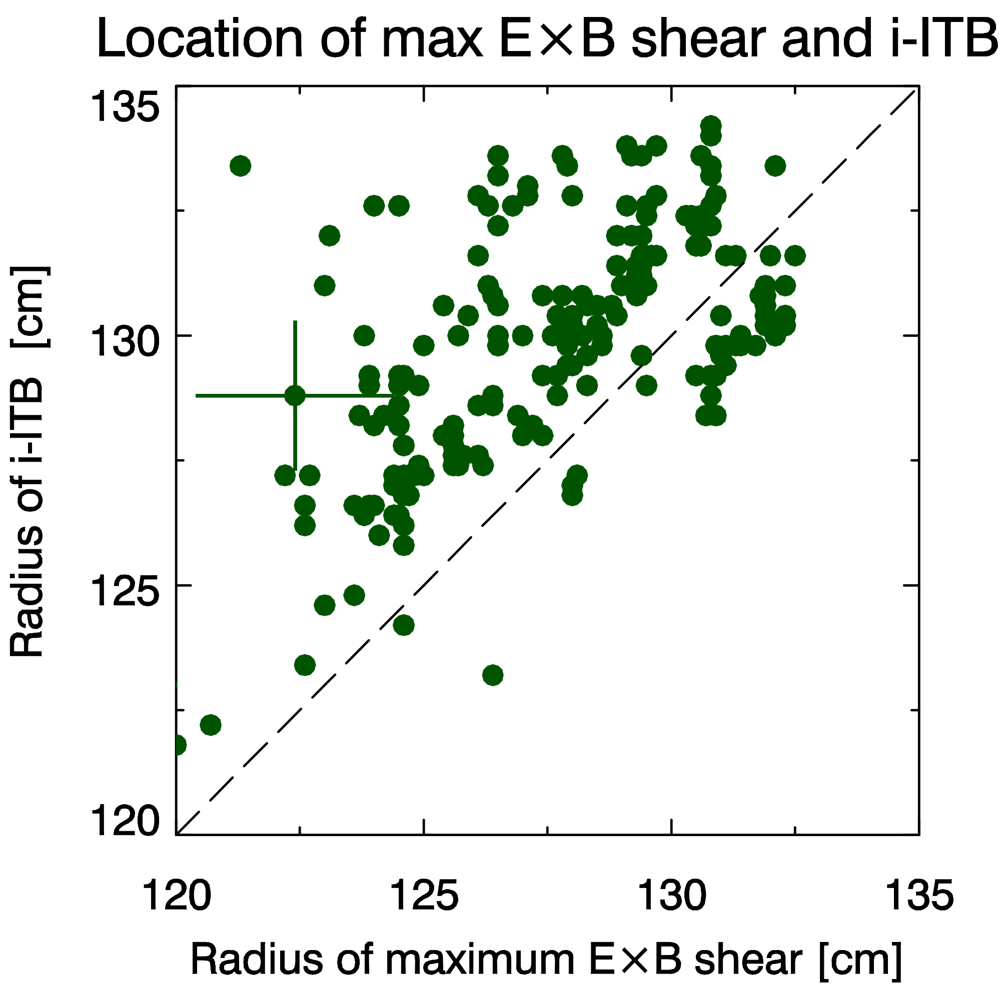
T_i gradient increases with increasing flow shear

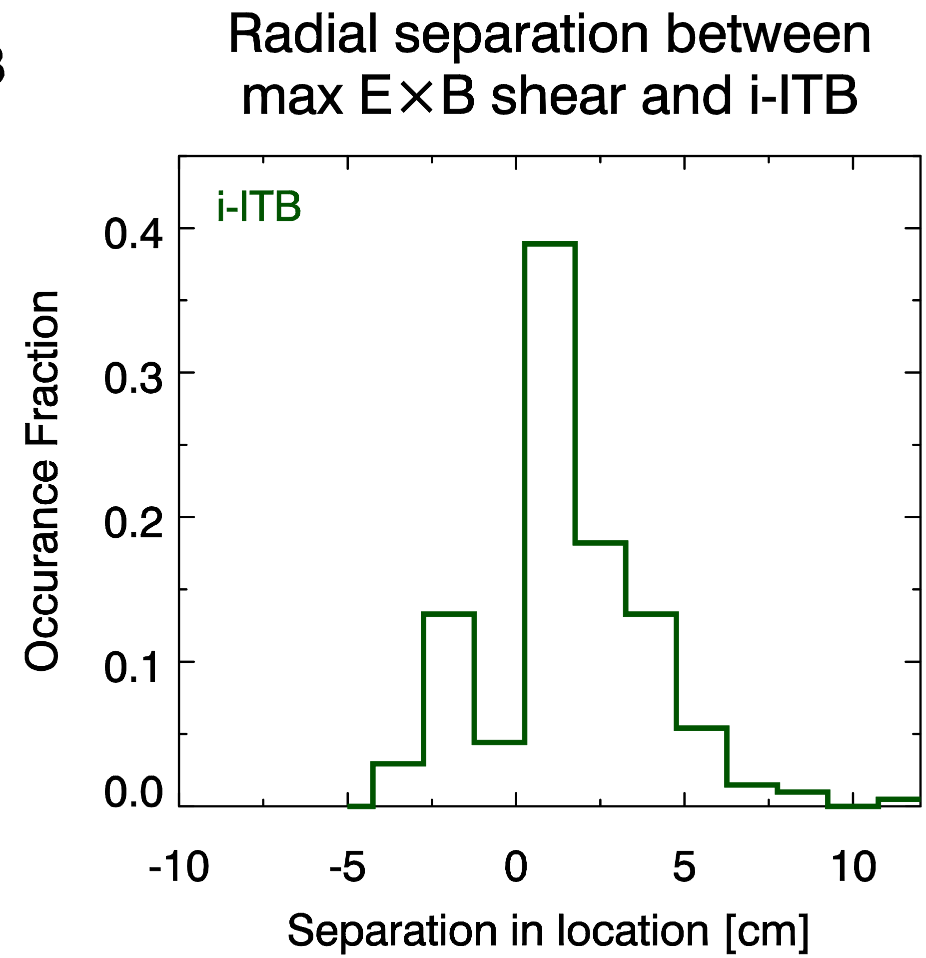
- E×B shearing rate can quench ITG
- Toroidal velocity shear is the largest component of E×B
- Simulations results show ITG linearly stable in many cases for NSTX

Core max $R/L_{V\phi}$ vs. max R/L_{Ti}



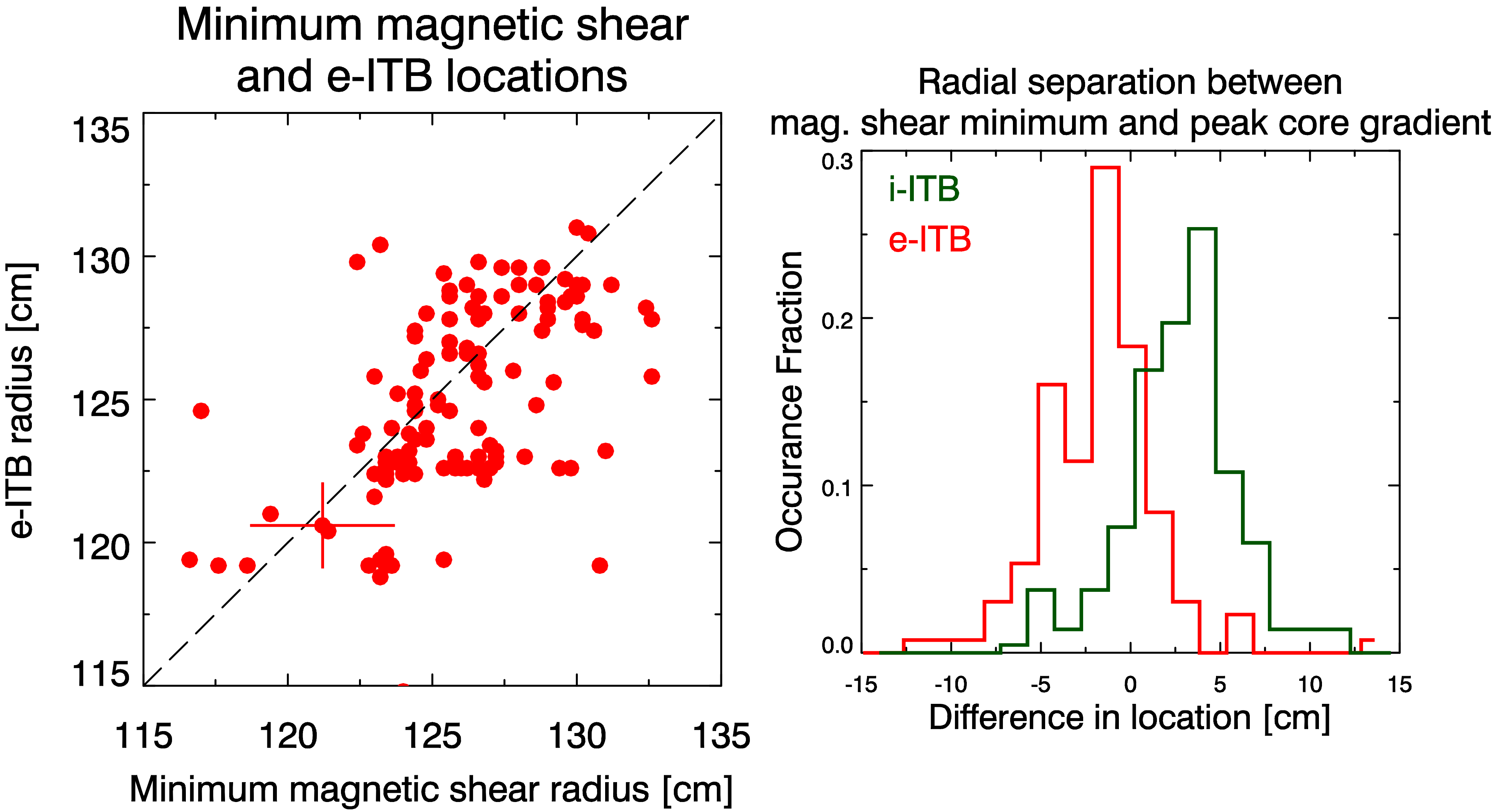
i-ITB location is closely correlated to peak E×B shearing rate location





- i-ITB occurs most frequently just outside peak E×B location

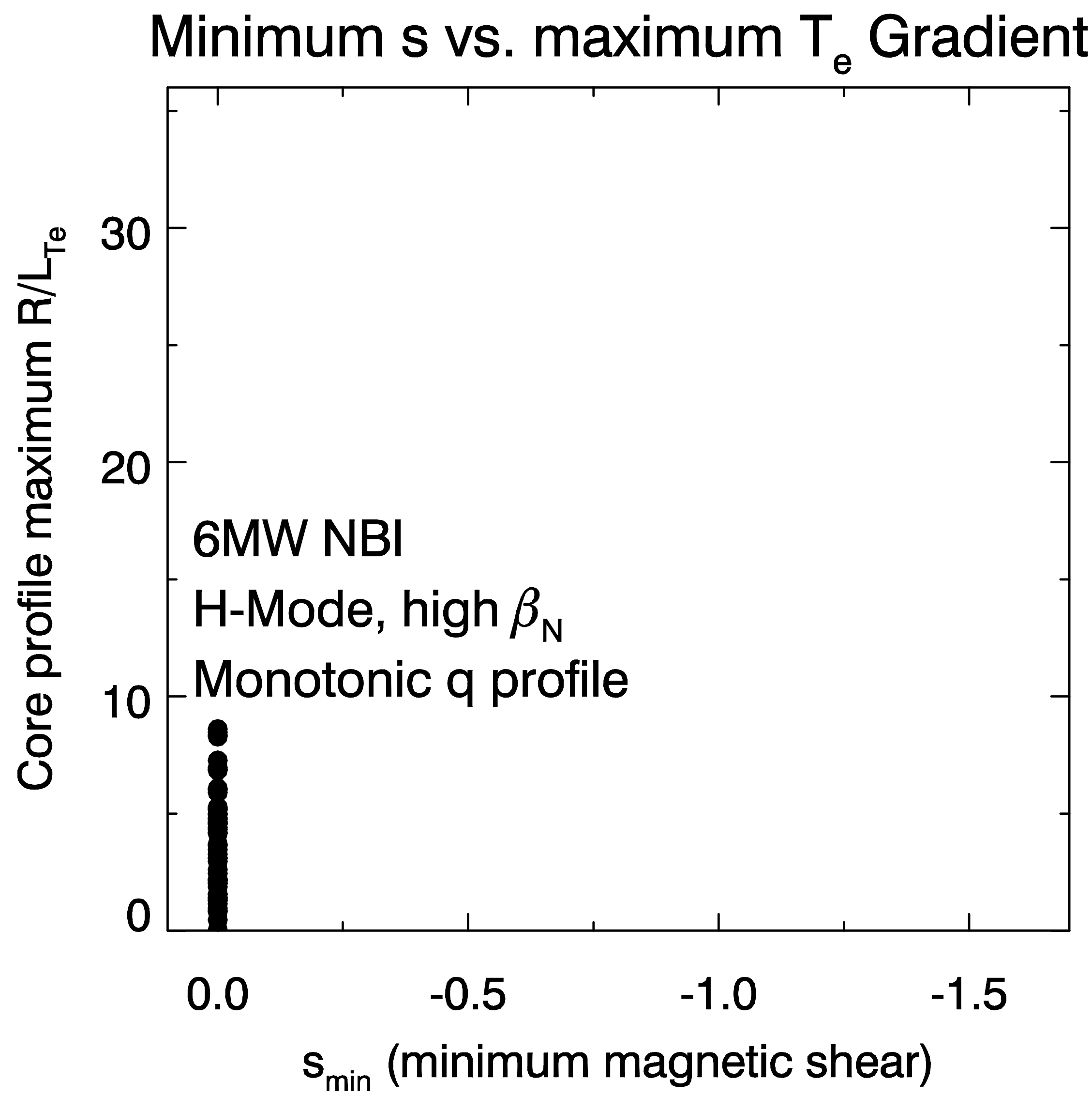
e-ITB coincides minimum magnetic shear location



- e-ITB occurs most frequently just inside $s_{min,}$ only very rarely outside
- i-ITB occurs well outside s_{min}

How does negative magnetic shear correlate with T_e gradients?

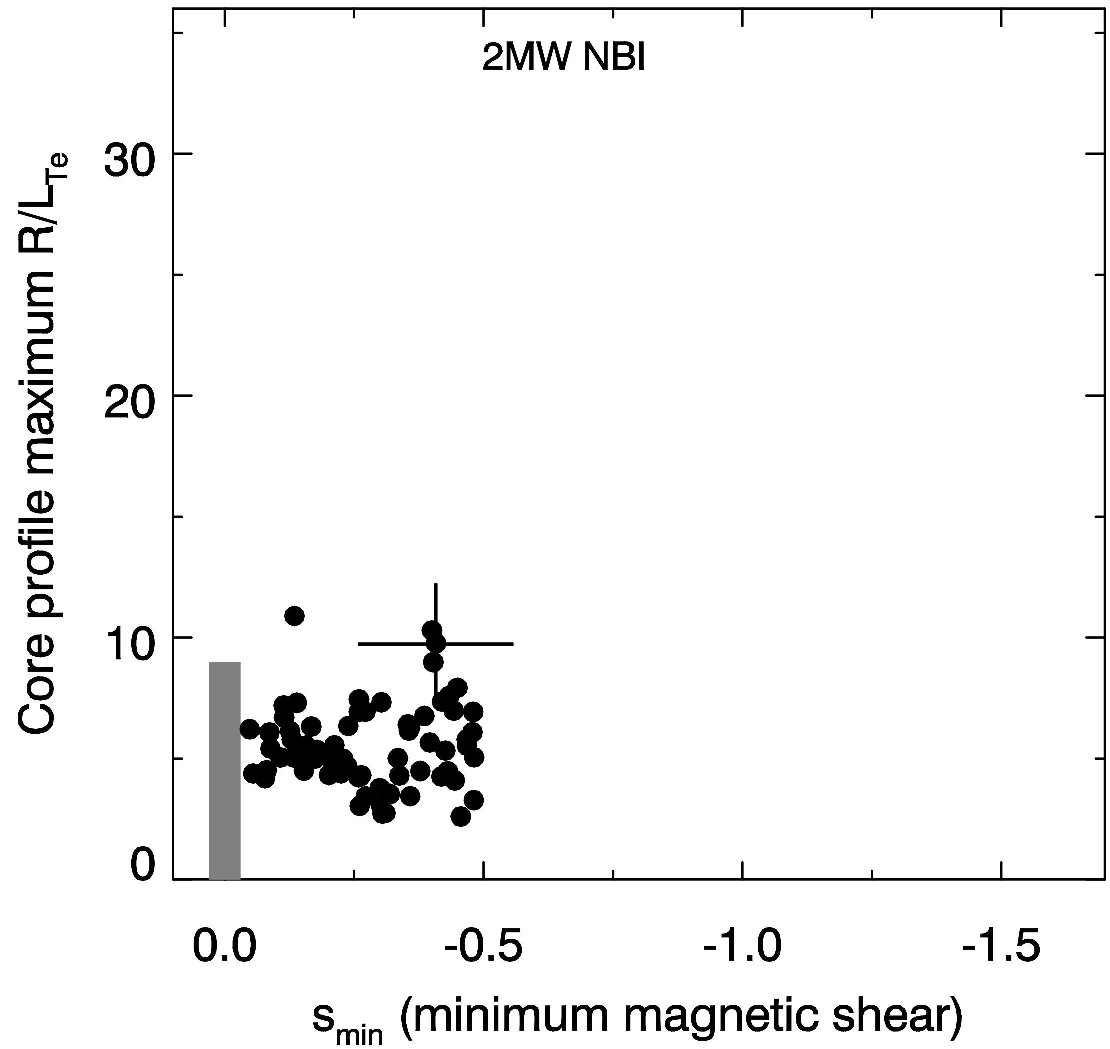
- Long pulse, high power, high β_N discharges provides baseline electron confinement performance



Gradients in weakly reversed shear L-mode plasmas are similar to baseline

- Long pulse, high power, high β_N discharges provides baseline electron confinement performance

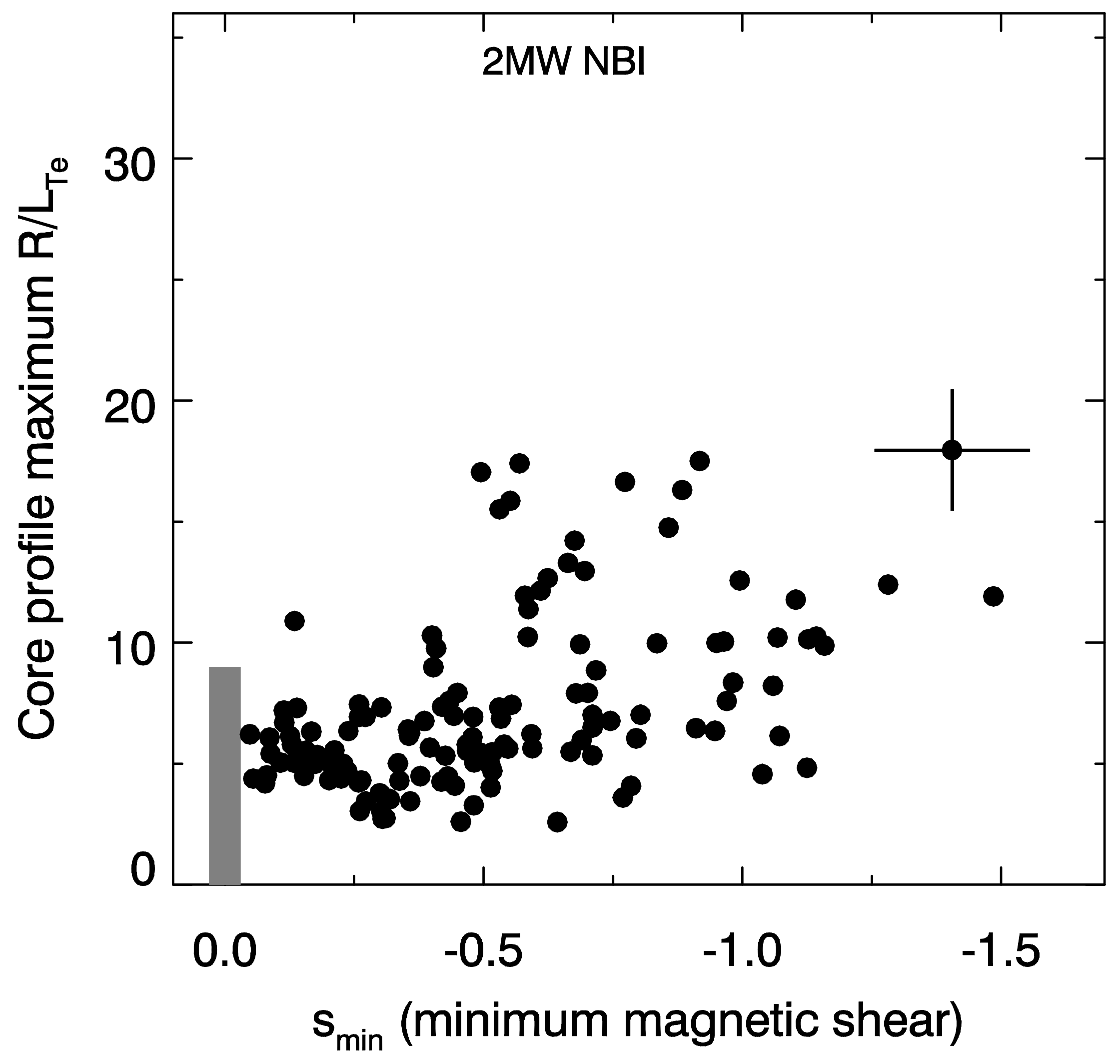
Minimum s vs. maximum T_e Gradient



Strongly negative magnetic shear improves T_e gradient performance

- Long pulse, high power, high β_N discharges provides baseline electron confinement performance
- Gradients in weakly reversed shear L-mode plasmas are similar to baseline

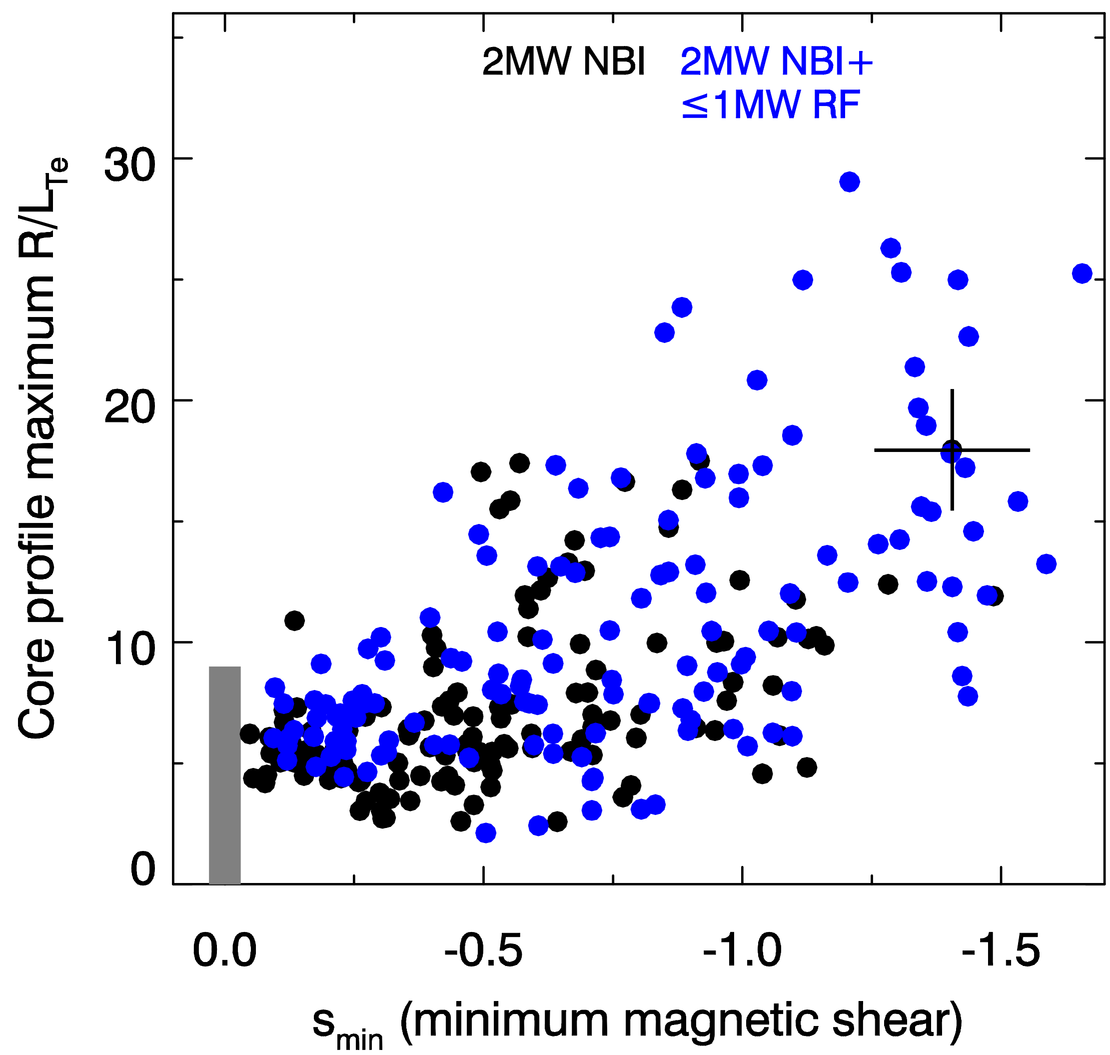
Minimum s vs. maximum T_e Gradient



Increasing power increases T_e gradients...

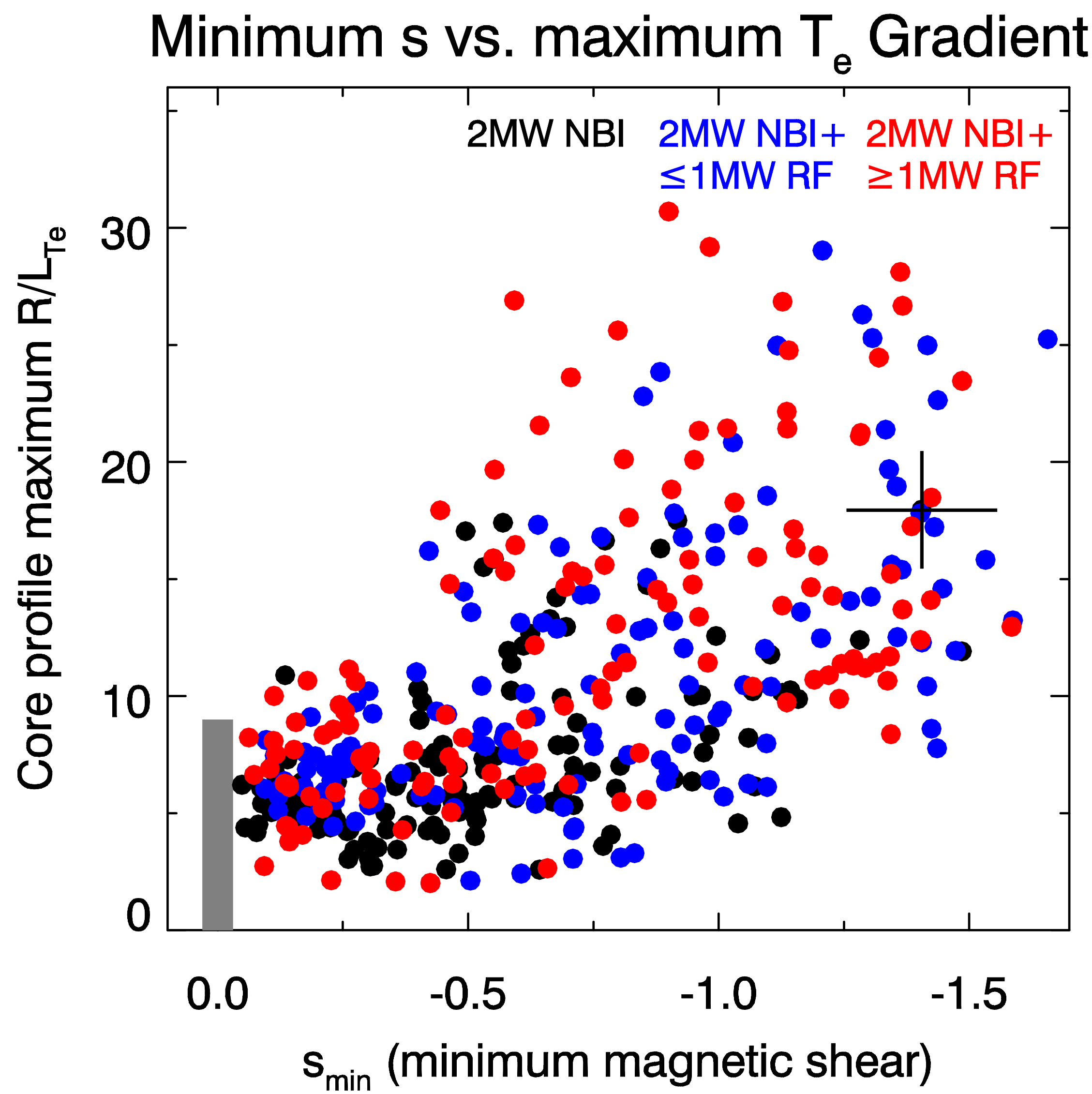
- Long pulse, high power, high β_N discharges provides baseline electron confinement performance
- Gradients in weakly reversed shear L-mode plasmas are similar to baseline
- Strongly negative magnetic shear improves T_e gradient performance

Minimum s vs. maximum T_e Gradient



...but only for profiles exhibiting strong negative magnetic shear

- Long pulse, high power, high β_N discharges provides baseline electron confinement performance
- Gradients in weakly reversed shear L-mode plasmas are similar to baseline
- Strongly negative magnetic shear improves T_e gradient performance
- Increasing power increases T_e gradients...

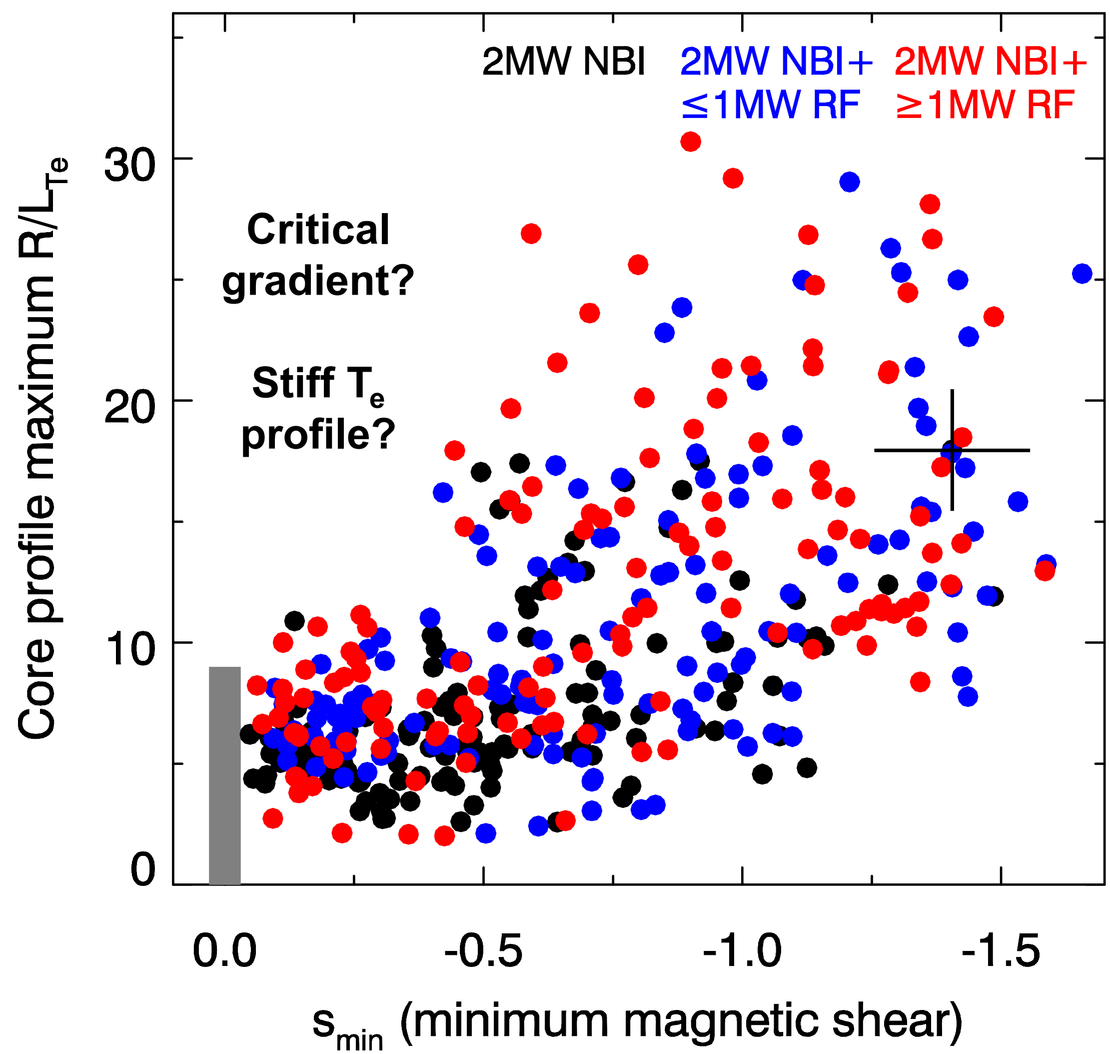


Is the profile stiff at zero and weakly negative shear?

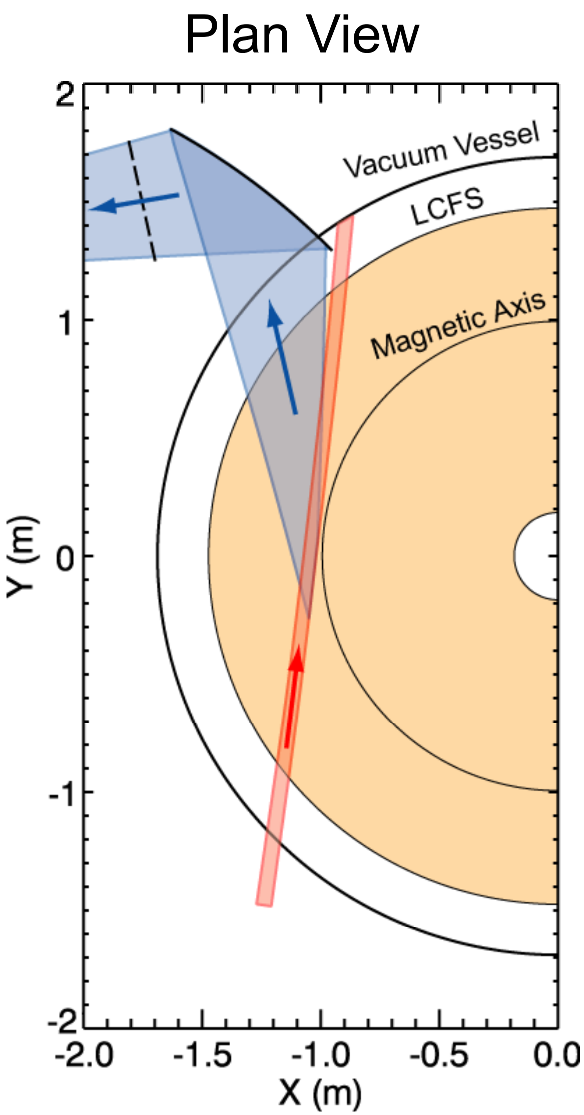
- Long pulse, high power, high β_N discharges provides baseline electron confinement performance
- Gradients in weakly reversed shear L-mode plasmas are similar to baseline
- Strongly negative magnetic shear improves T_e gradient performance
- Increasing power increases T_e gradients...
- ...but only for profiles exhibiting strong negative magnetic shear

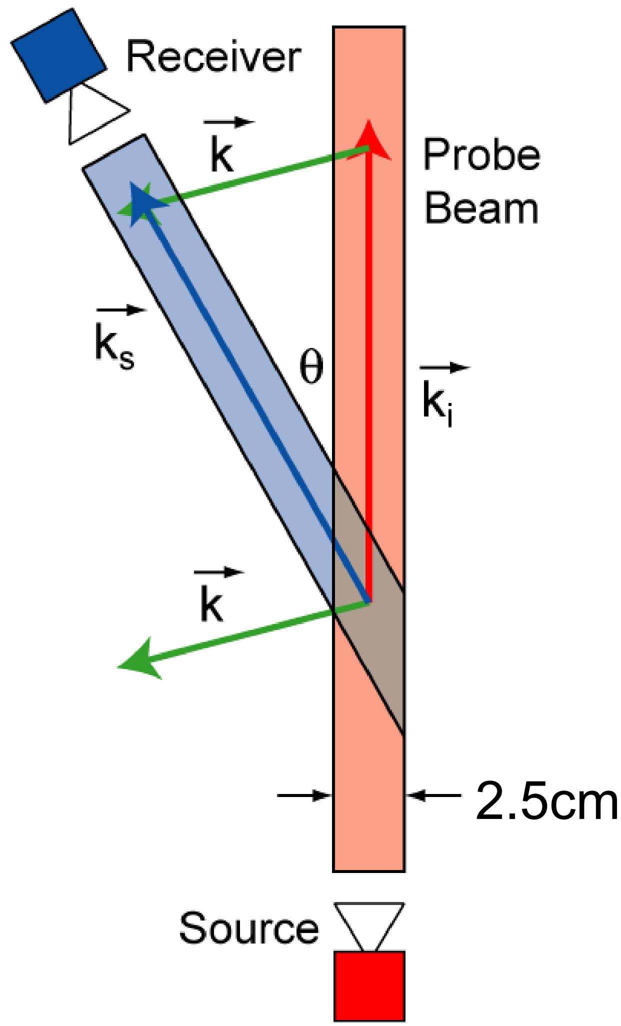
- Are there changes in electron-scale turbulence that accompany the change in the electron temperature gradient?

Minimum s vs. maximum T_e Gradient



High-k microwave scattering diagnostic measures n_e fluctuations at electron scale wavenumbers

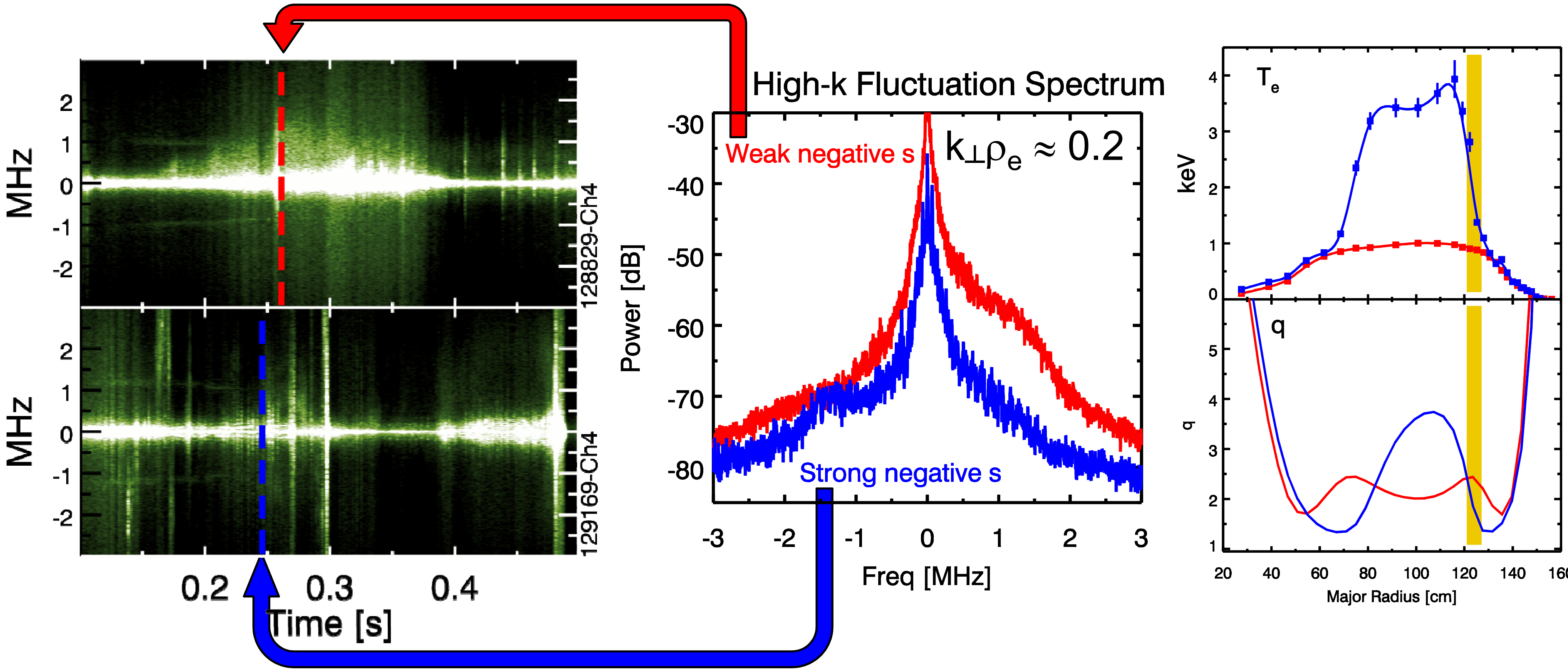




- $k_\perp \rho_e \leq 0.6$ can be measured
- Multiple detection channels can measure fluctuations at multiples k values simultaneously
- Localized scattering volume, radial resolution ~2.5cm

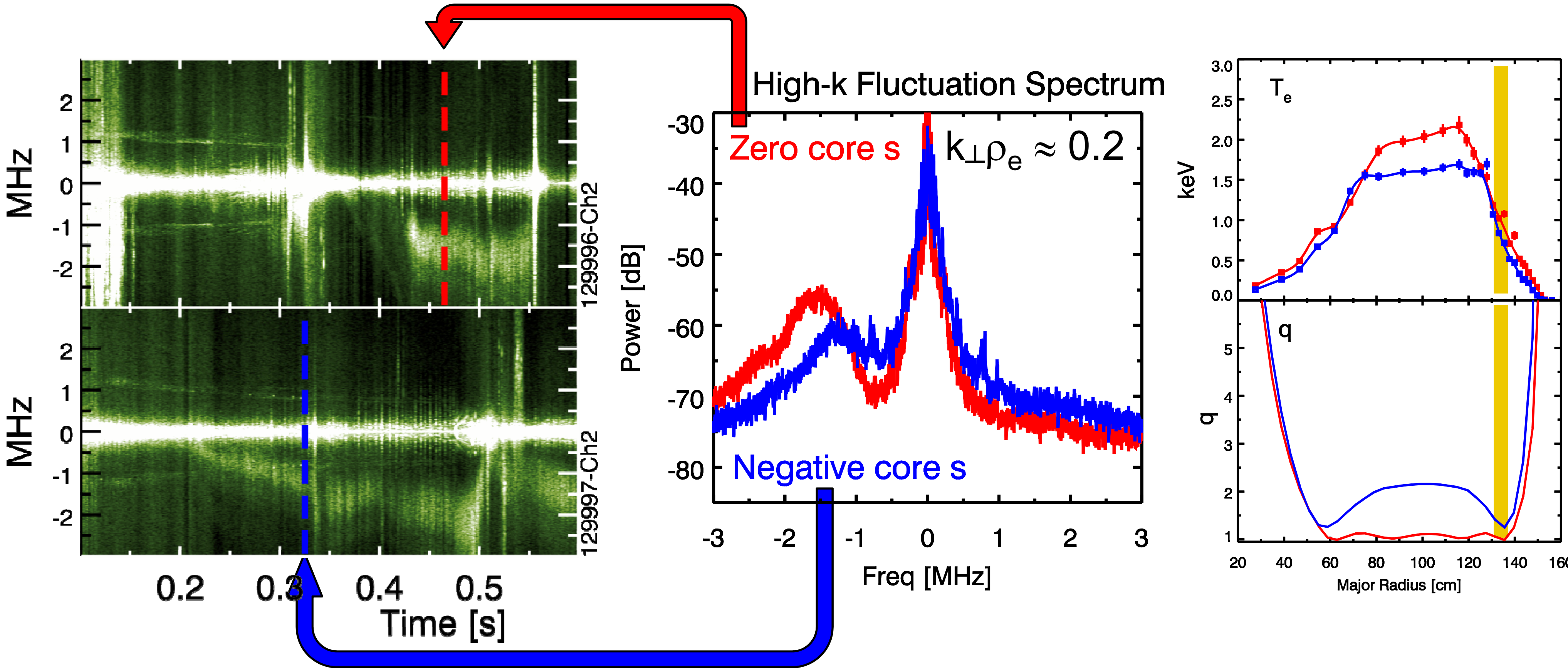
D.R. Smith
YI2.005

High-k scattering fluctuations are reduced inside e-ITB



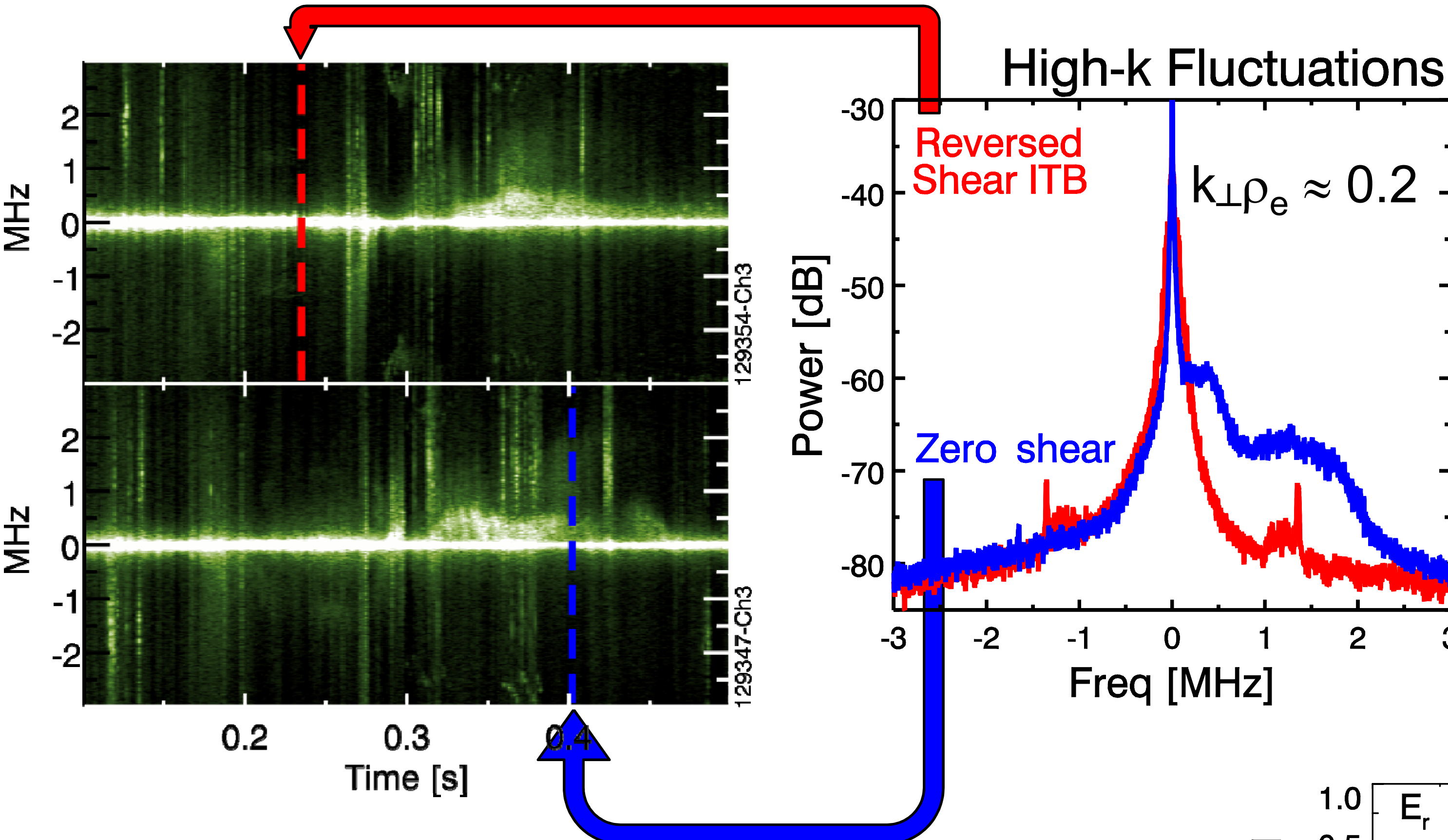
- Low high-k fluctuation amplitude seen in strongly reversed shear e-ITB
- Weak negative shear shows higher high-k fluctuations despite lower T_e gradients

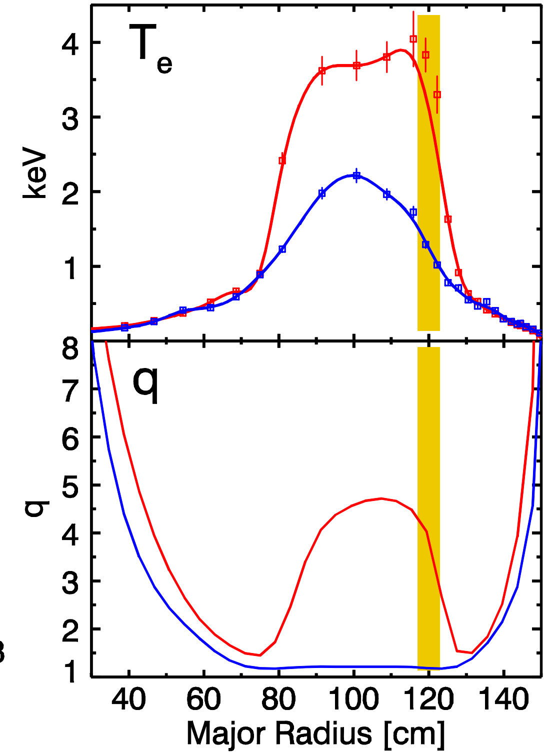
High-k scattering fluctuations persist just outside e-ITB

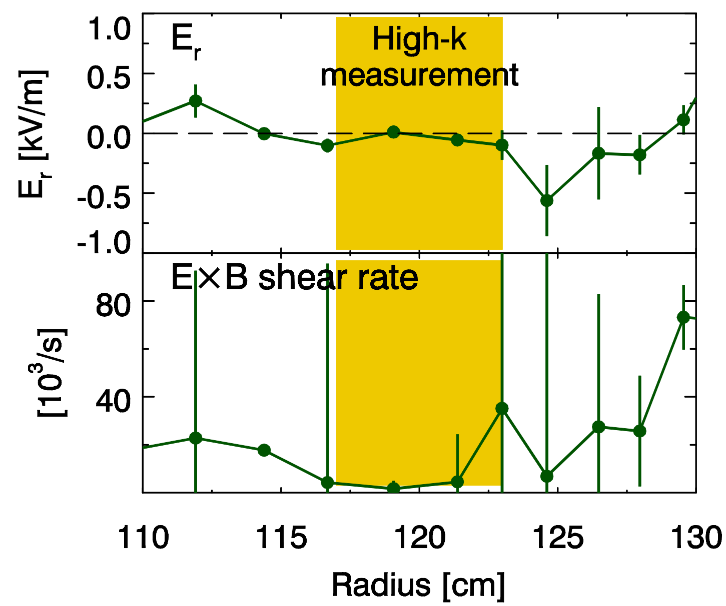


- Fluctuations depend on local value of magnetic shear
- High-k fluctuation are in the electron diamagnetic drift direction but Doppler shifted by toroidal rotation

Negative magnetic shear can suppress electron thermal turbulence without flow shear

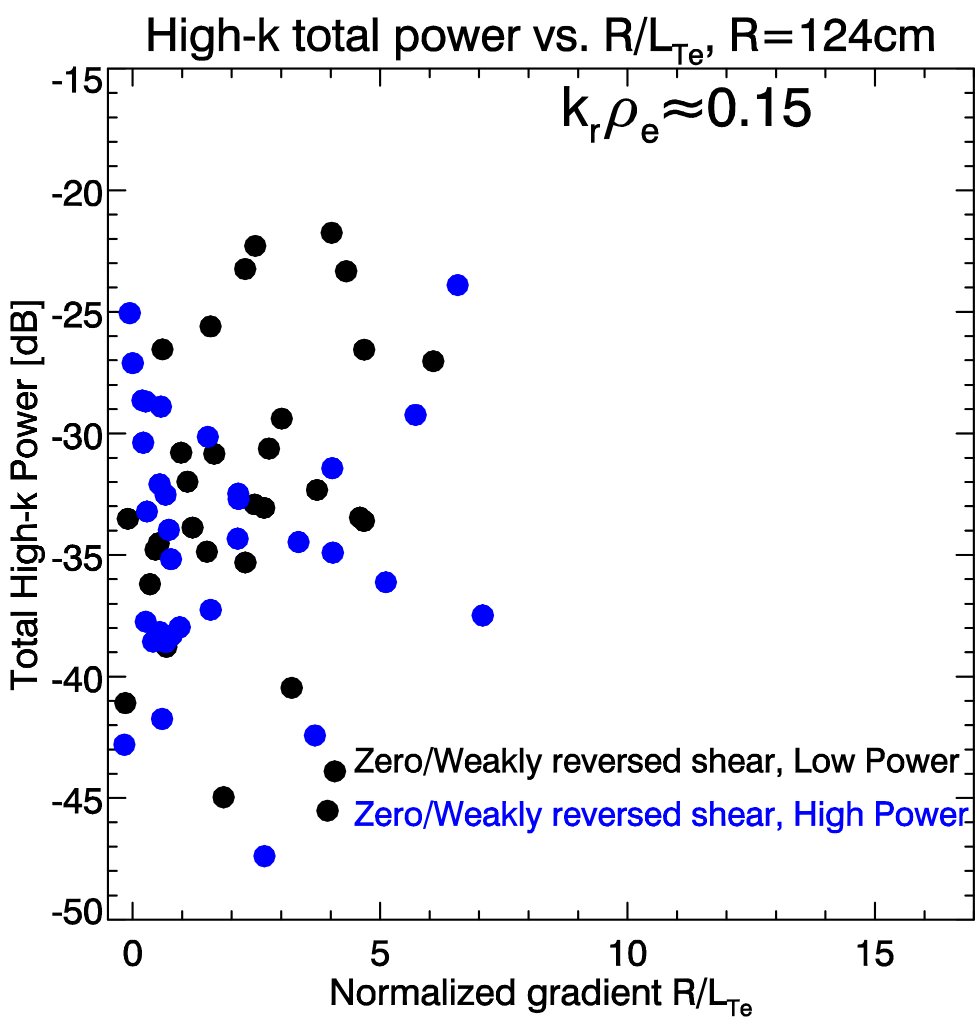


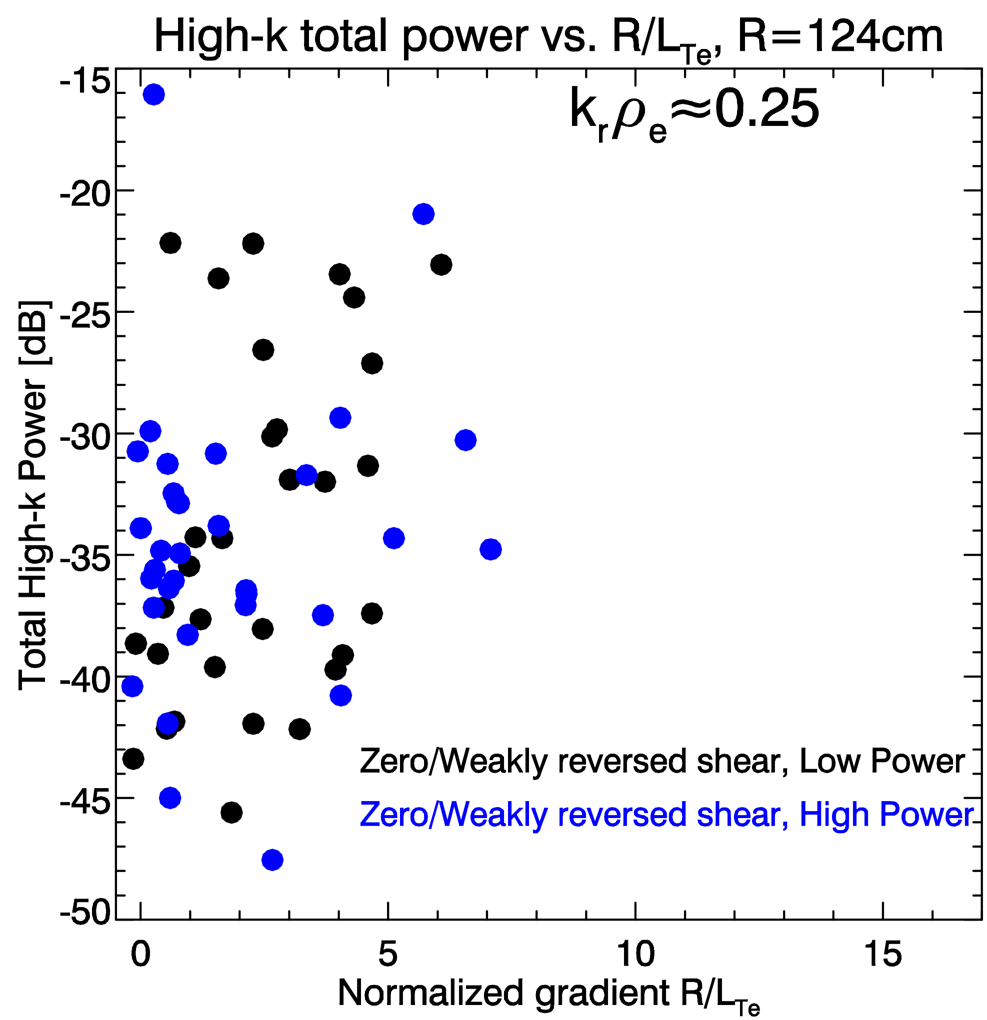




- HHFW only with beam blips
- Minimal ExB shearing rate due to cold ions with low toroidal rotation
- **Magnetic shear alone can suppress electron turbulence**

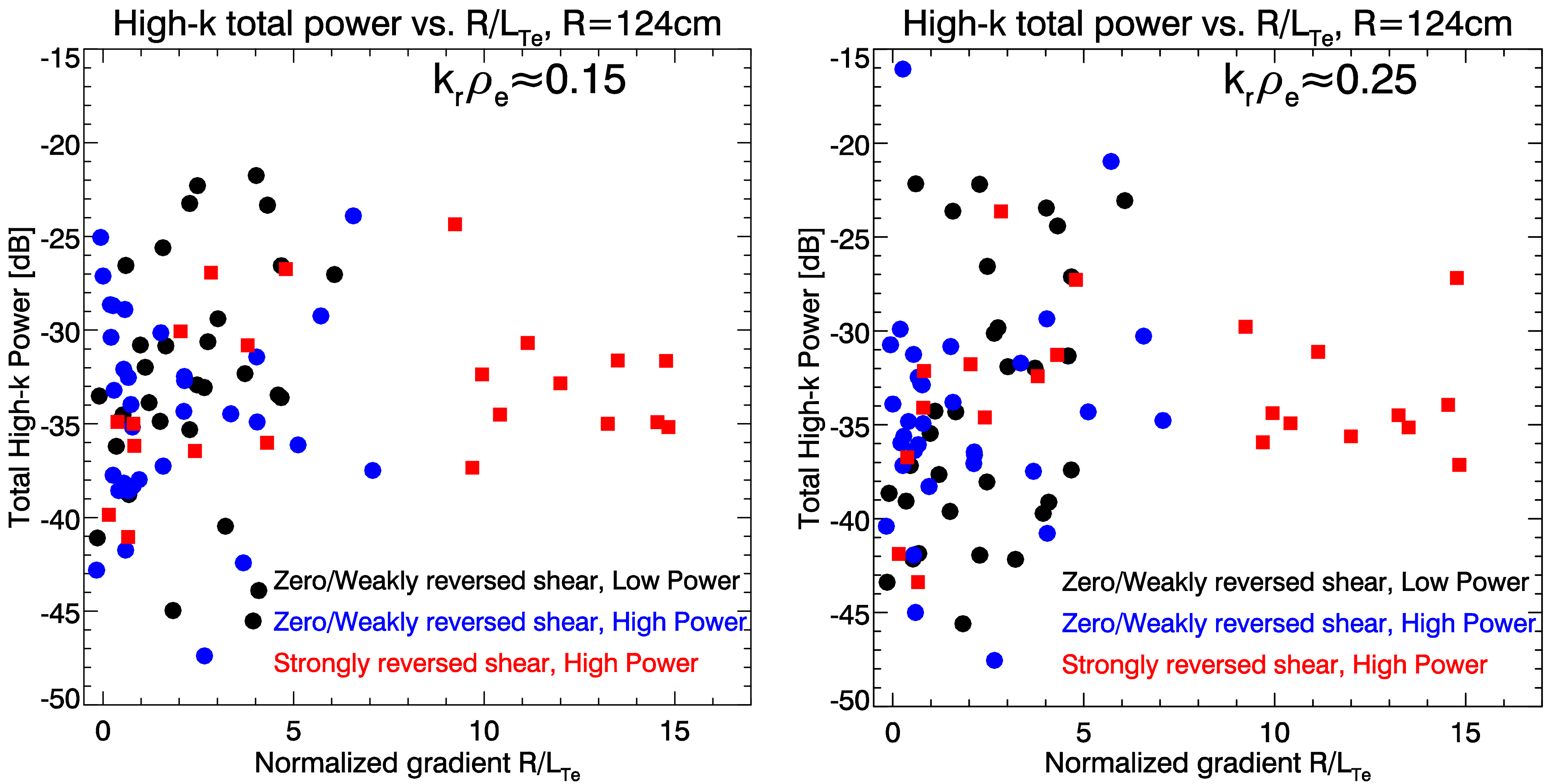
Zero/weakly reverse shear establish a range for high-k fluctuations at low R/L_{Te}





- Slight trend of increasing high-k fluctuation power with increased gradients
- Additional power not able to increase local gradients

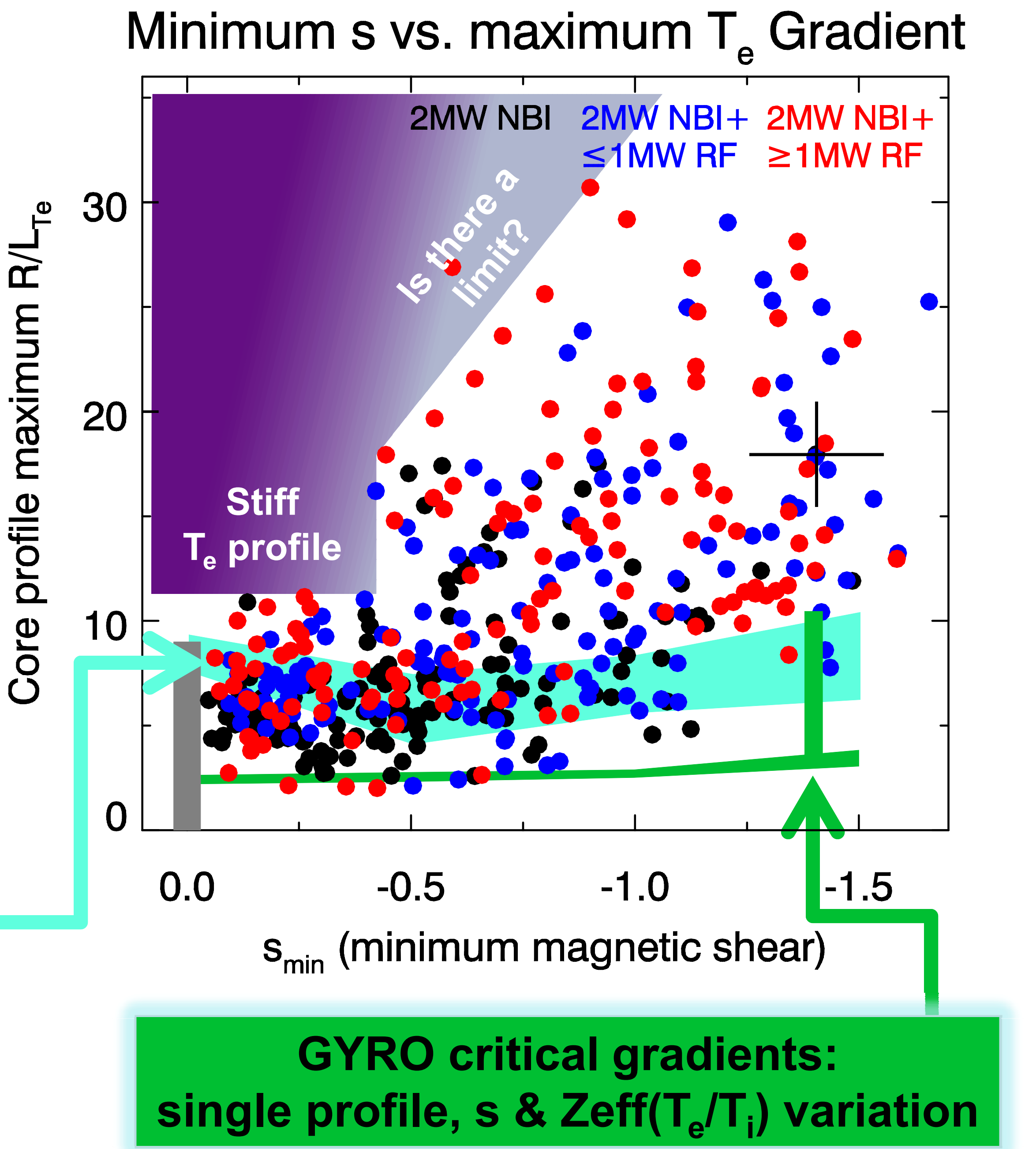
Strongly reversed shear e-ITBs show low high-k fluctuation power despite strong ∇T_e gradient drive



Do measurements of increased T_e gradient and reduced fluctuations agree with theory and simulation?

Measured gradients well above predicted ETG critical gradient

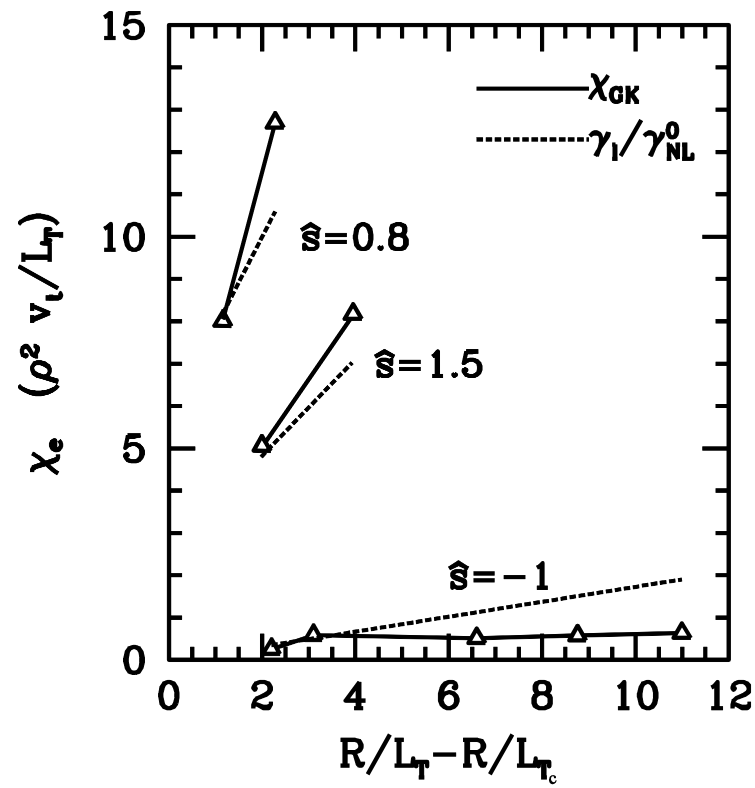
- GS2 and GYRO linear simulations performed across profile range
- Critical gradients for ETG instability greatly exceeded in e-ITBs
- Low high-k fluctuation power measured in ITB
- Can negative magnetic shear suppressing transport caused by ETG ?

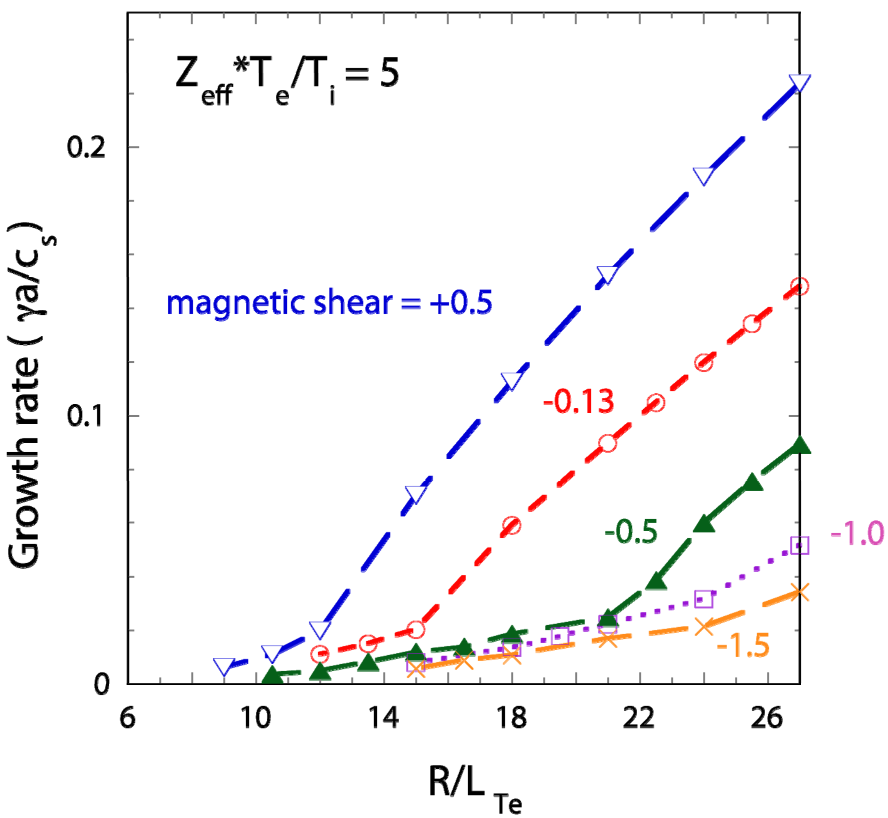


J. Luc Peterson
NP6.094

Previous non-linear simulations has shown negative magnetic shear can reduce transport by ETG

- Negative magnetic shear suppression of ETG transport has been predicted by Jenko, Dorland [PRL **89**, 225001 (2002)]
- Secondary instability better able to compete with primary mode at negative magnetic shear





D. Mikkelsen
NP6.093

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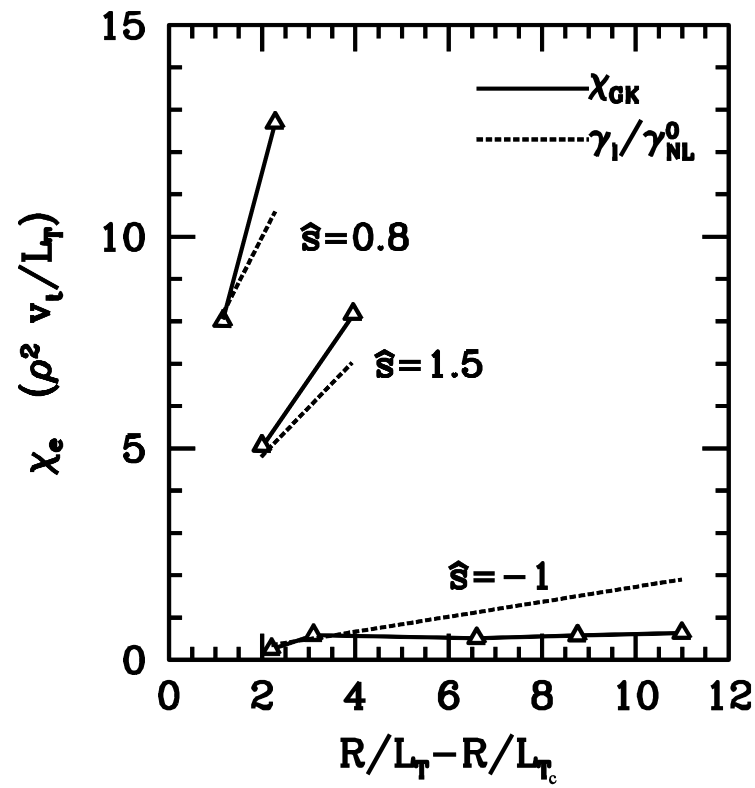

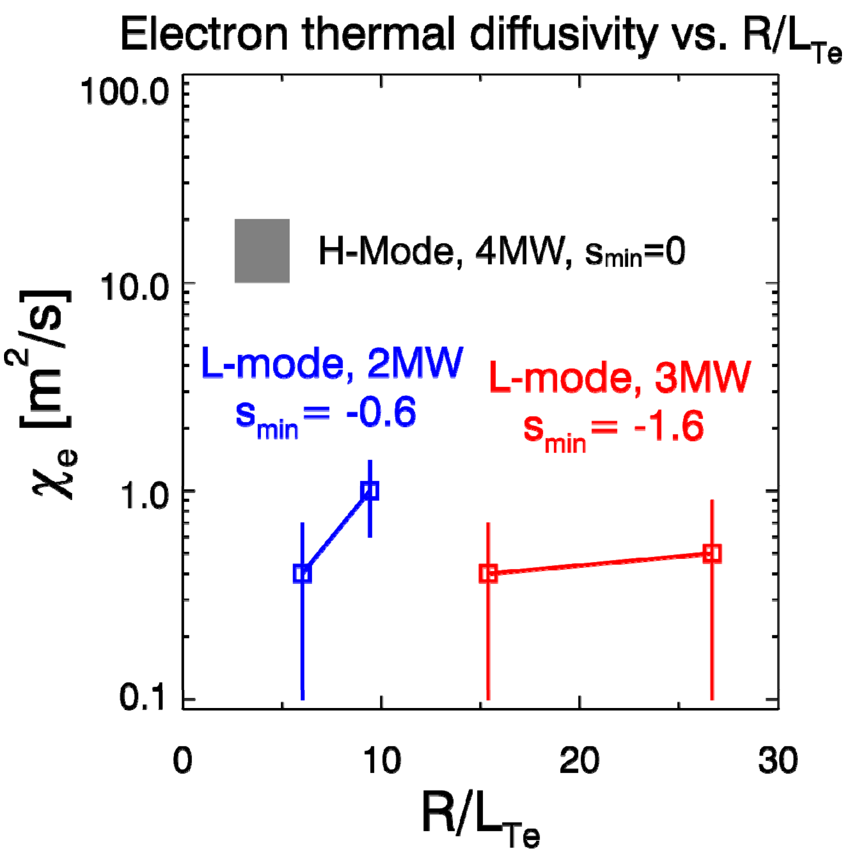

- Experimental data shows a similar reduction in χ_e with low sensitivity to increasing temperature gradients

Conclusions

- Electron ITB location strongly correlated with minimum of negative magnetic shear
- Ion ITB does not occur at s minimum, but closer to maximum E×B shear location
- T_e profiles appear to be stiff for zero and weak negative magnetic shear
- Strong negative magnetic shear reduces electron scale turbulence in ITB regions despite high gradients
- Reduced transport is observed in negative magnetic shear regions

Thank You for listening

- Questions?

Suppression of turbulent transport in NSTX internal transport barriers

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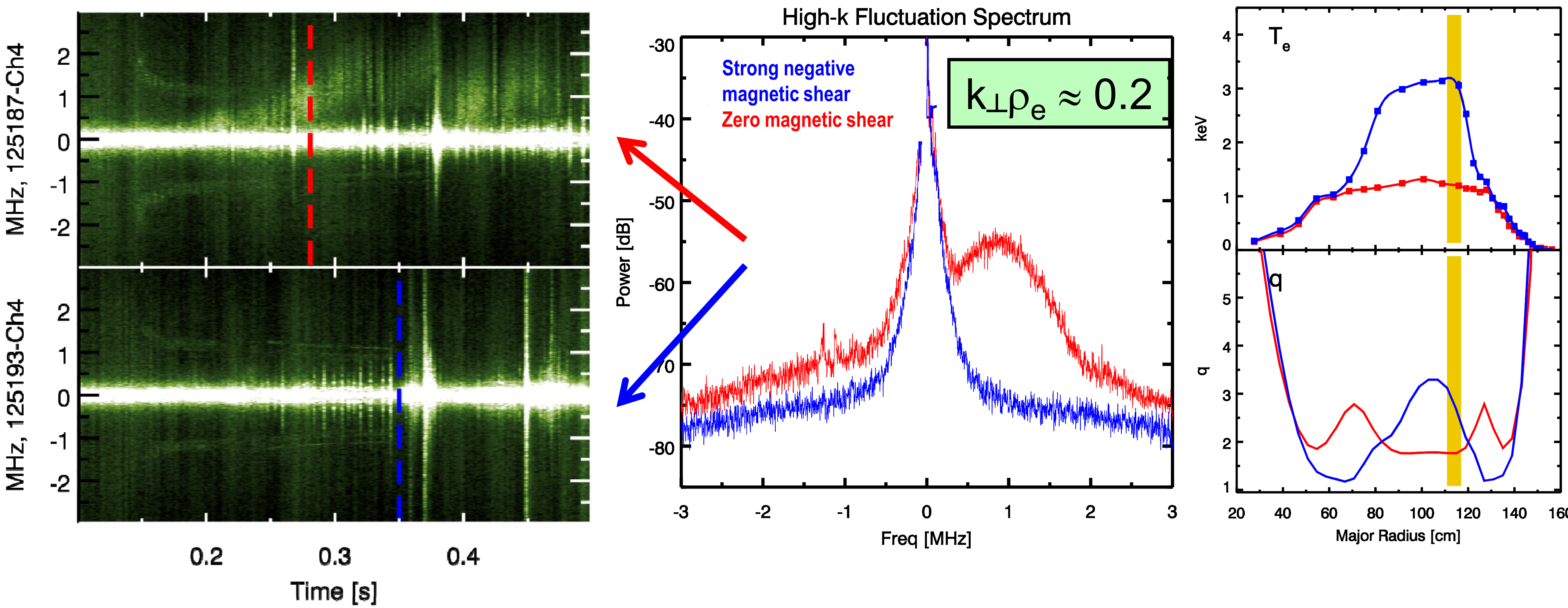
and the NSTX Research Team

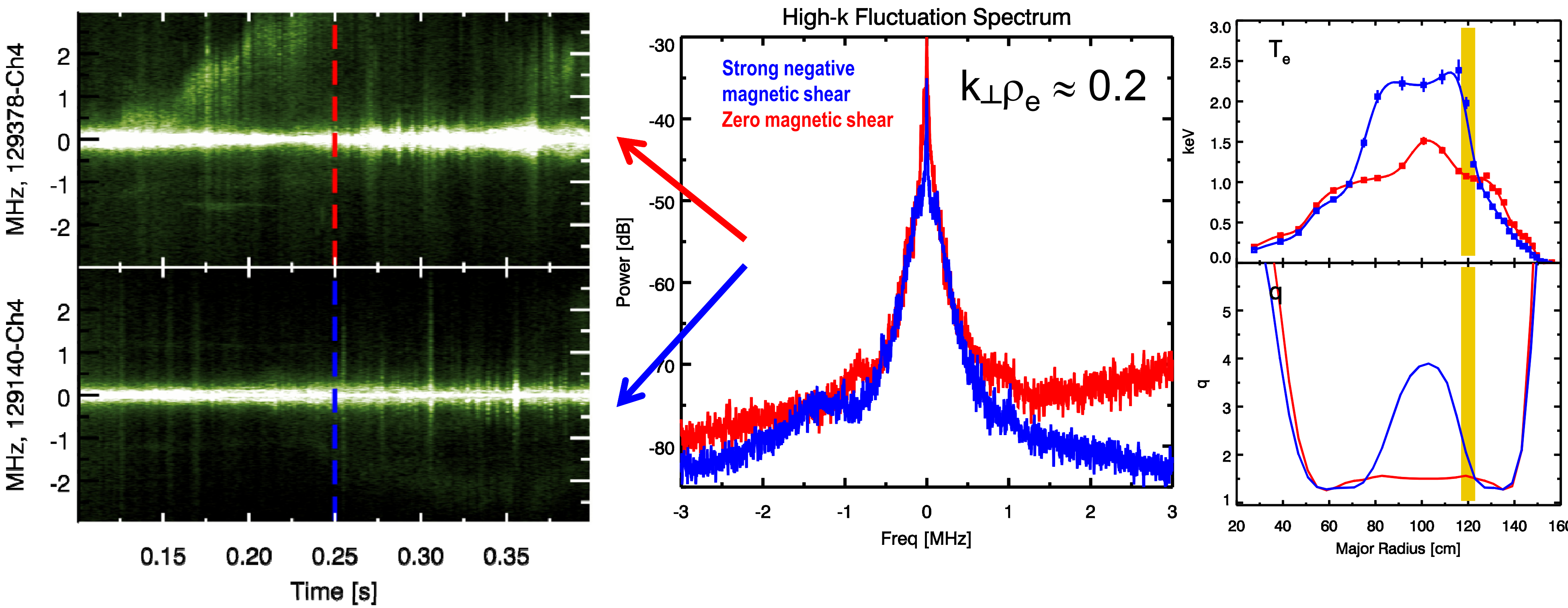
TI2.05 – LANDMARK B
THURSDAY, NOV 20, 2008
11:30AM – 12:00PM

High-k scattering comparison, top of electron-ITB (R=114cm)



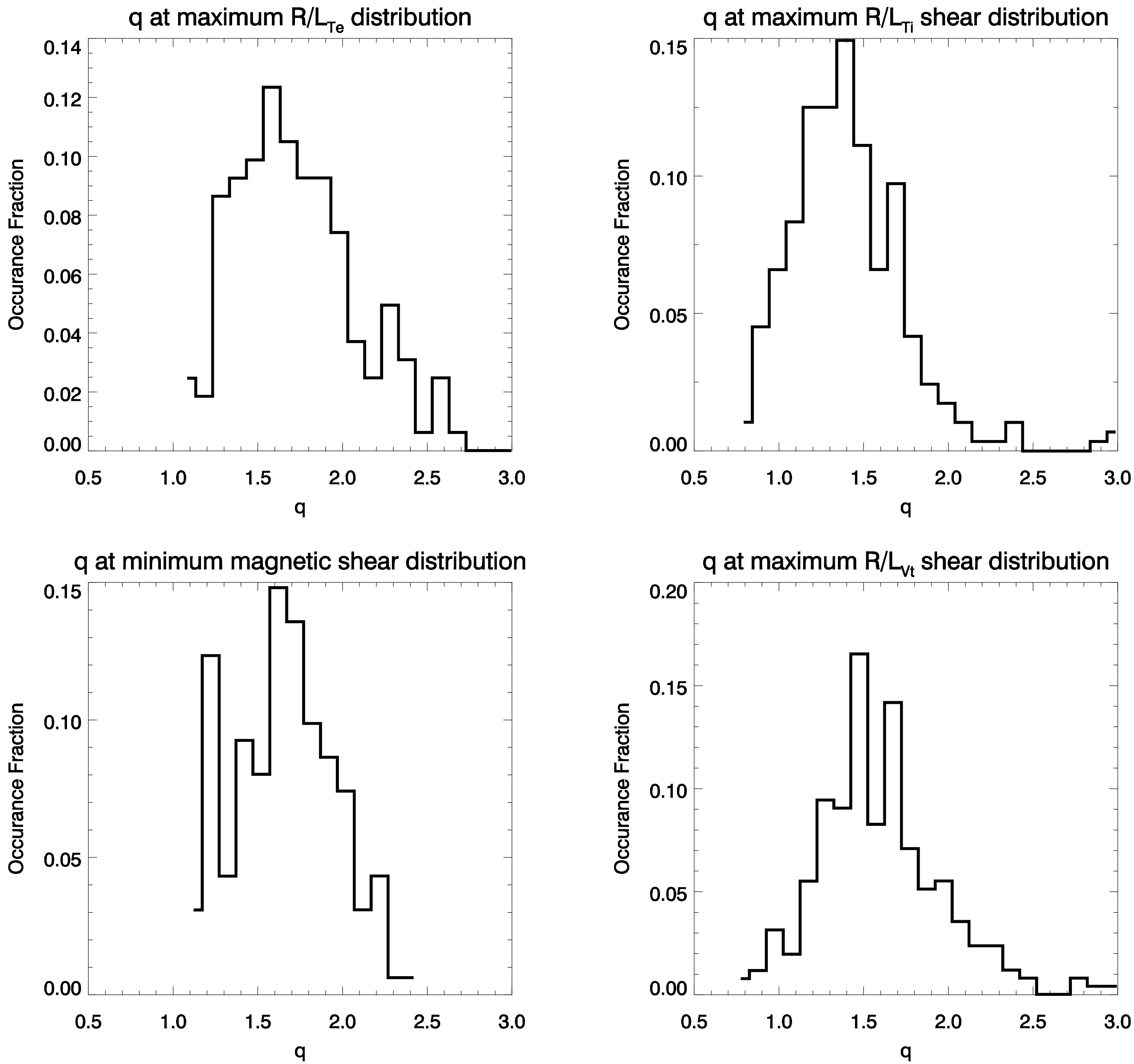
- High-k scattering measures reduced local n_e fluctuations in the ETG k range for ITB discharges.
- Compare measurements in ITB vs. non-ITG cases
- Shows strong activity for non-ITB case despite weak gradients
- Beam heated discharge, flow shear and T_i-ITB also present

High-k scattering comparison, peak R/L_{te} electron-ITB (R=120cm)

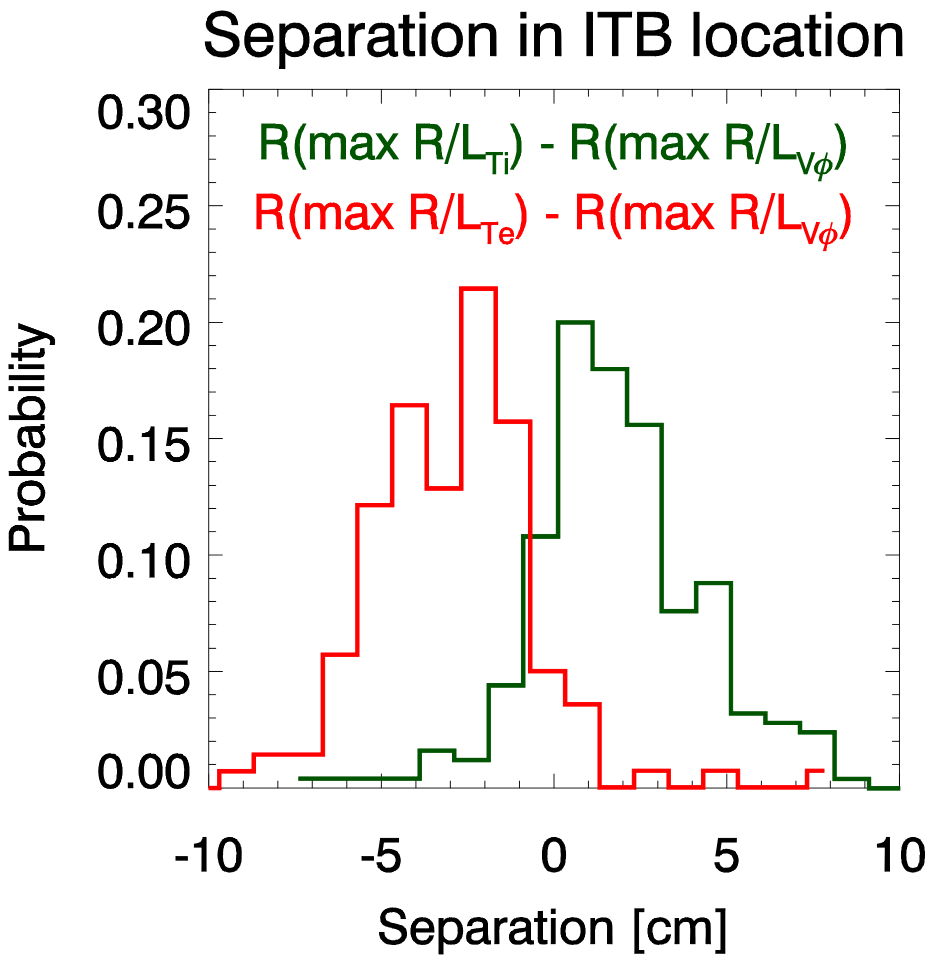


- Measured frequency is in electron diamagnetic direction but strongly Doppler shifted by toroidal rotation
- High-k fluctuations strongly suppressed in reversed shear ITB case, despite strong gradients (R/L_{Te}=10)

q values at ITB peak gradient does not show favored rational surfaces

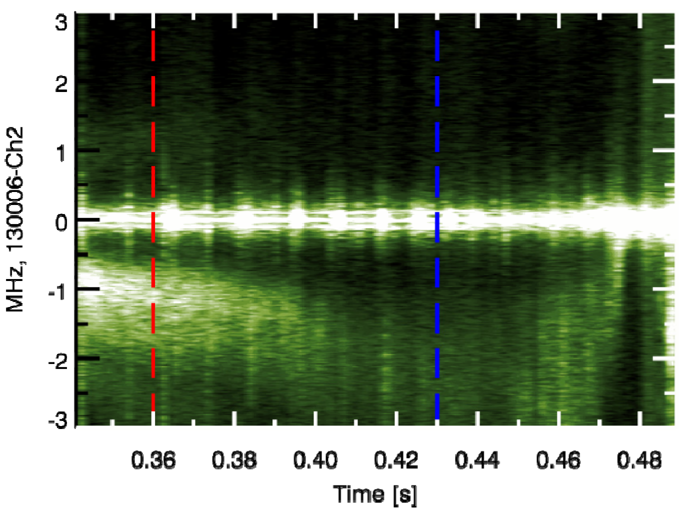


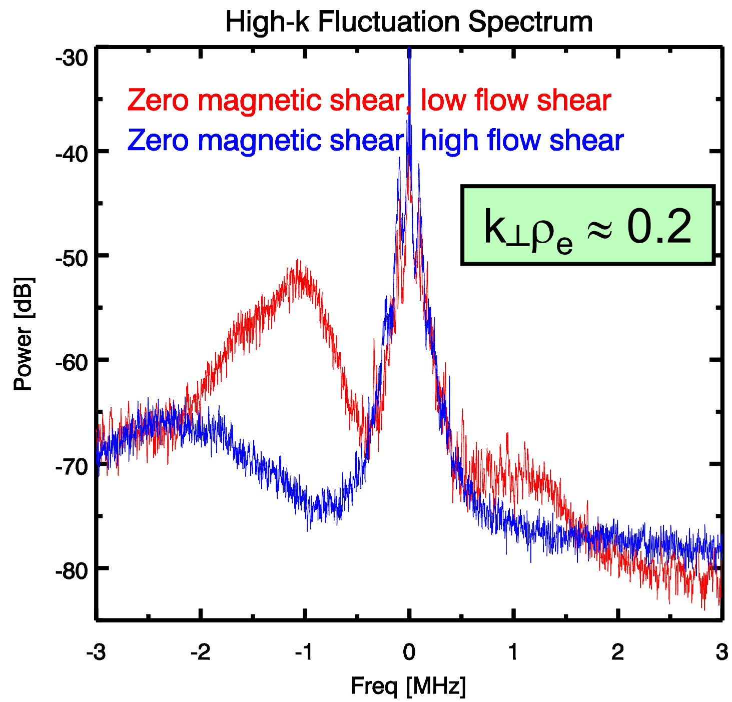
Peak $R/L_{V\phi}$ location tends to be between peak R/L_{Te} and R/L_{Ti}

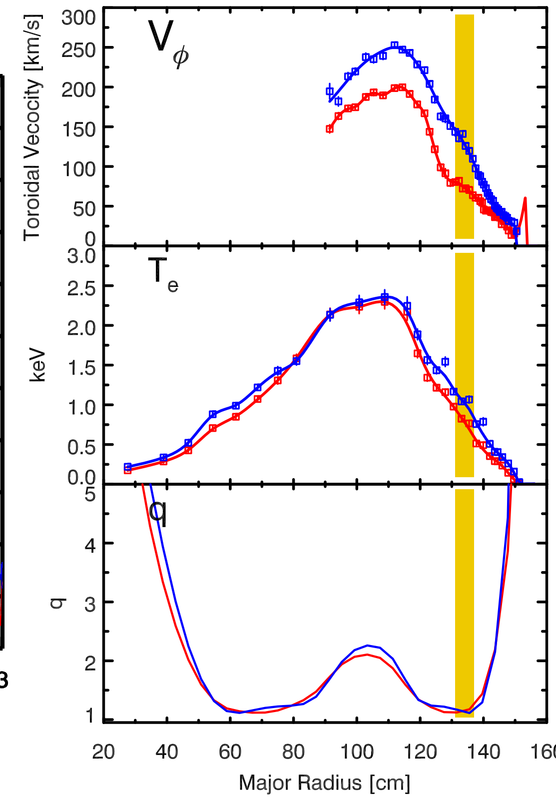


- The radial locations for ITBs in T_e, T_i, and V_ϕ are offset
- The T_i-ITB is tends to be furthest out, followed by V_ϕ-ITB, and T_e-ITB closest to the magnetic axis
- Separation between T_i-ITB location and minima in magnetic shear suggests magnetic shear is not the dominant suppression
- Analysis shows peak E×B location to be at foot of V_ϕ pedestal, close to the location of the T_i-ITB
- Consistent with hypothesis that:
  - E×B shear quenches ITG
  - Negative magnetic shear quenches ETG

...but flow shear can also affect electron turbulence

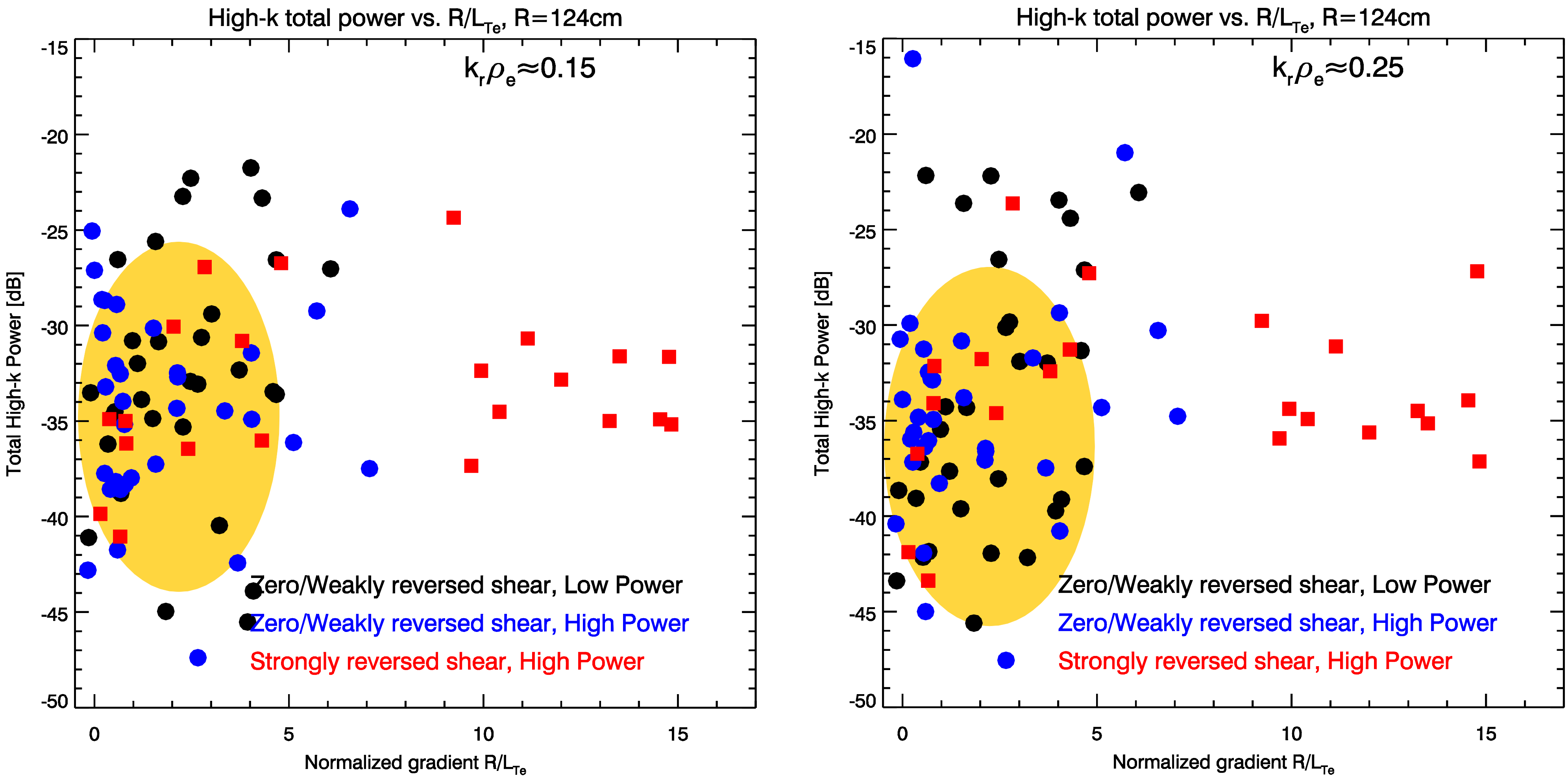






- Comparing two profiles from single discharge, beam heating only for both times
- Rotation profile is increasing E×B shearing rate at high-k measurement location
- q-profile is stationary throughout time period, and measurement is at q_{min}
- Frequency evolves due to increase in Doppler shift
- **The observed amplitude of high-k fluctuations decrease with increasing v_ϕ shear rate**

Negative magnetic shear reduces high-k fluctuations simultaneous with increasing T_e gradient



- Strong negative shear, low gradient, low high-k power points lie inside ITB
- Flat profile inside ITB likely not due to ETG turbulence
- Another transport mechanism or is lack of current reducing confinement

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