Suppression of turbulent transport in NSTX internal transport barriers

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EX/P3-1

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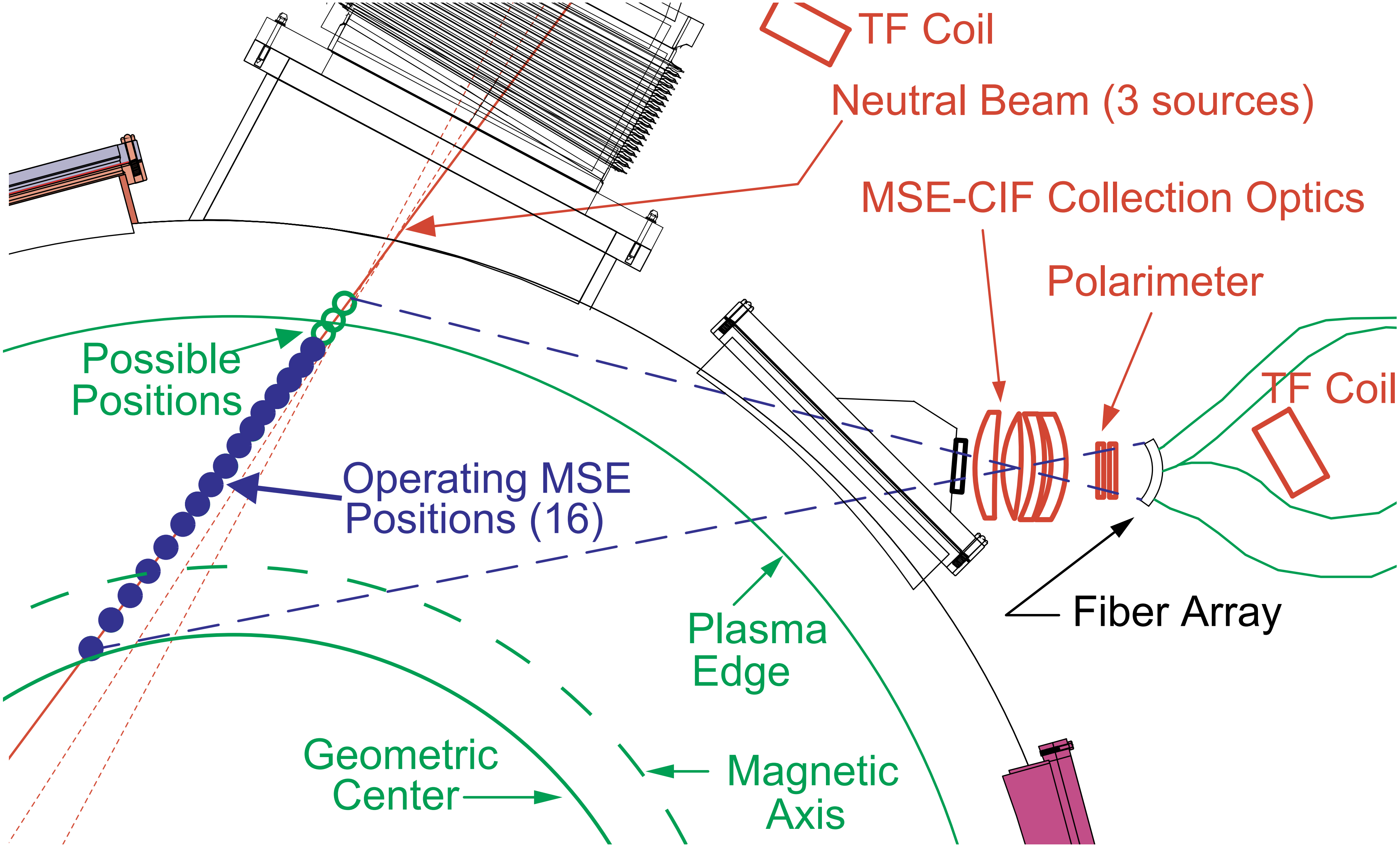
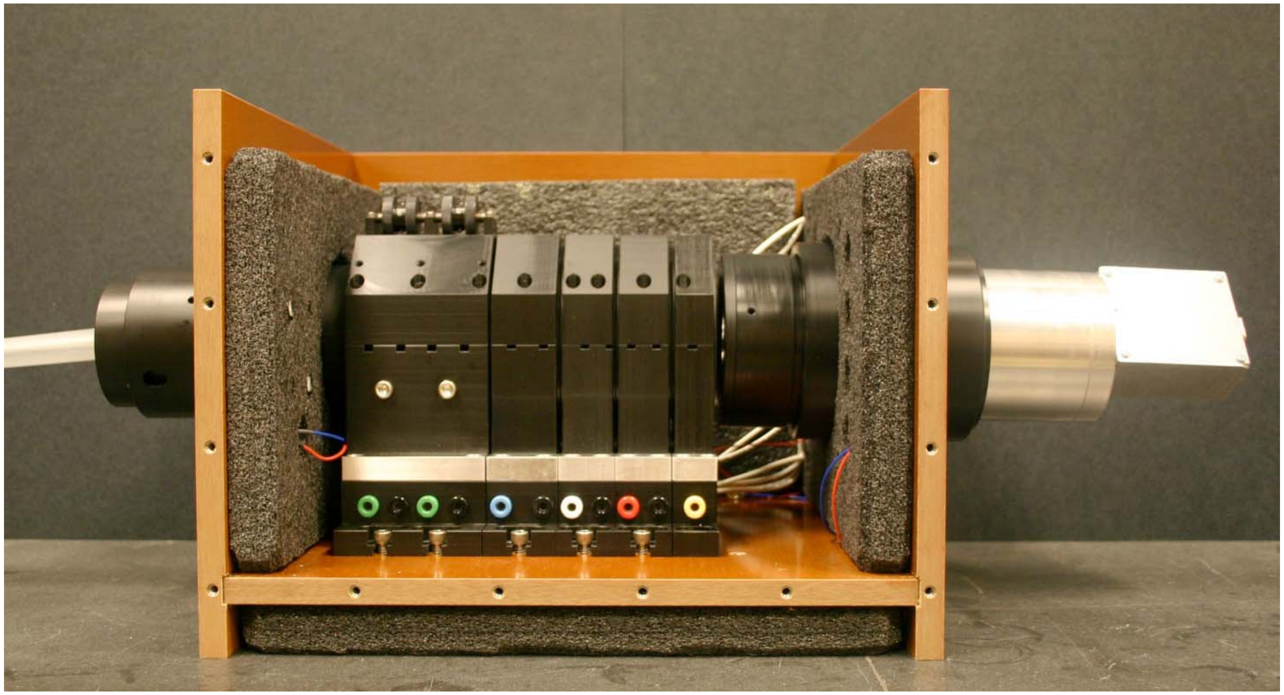
16 ch MSE constrains reconstruction of dynamic NSTX current profiles

- Low field Lyot filter based MSE system expanded to 16 channels
- Diagnoses nearly all NSTX plasmas with beam heating or beam blips
- Provides full coverage from edge to well past magnetic axis



Low field on NSTX requires use of Lyot filters

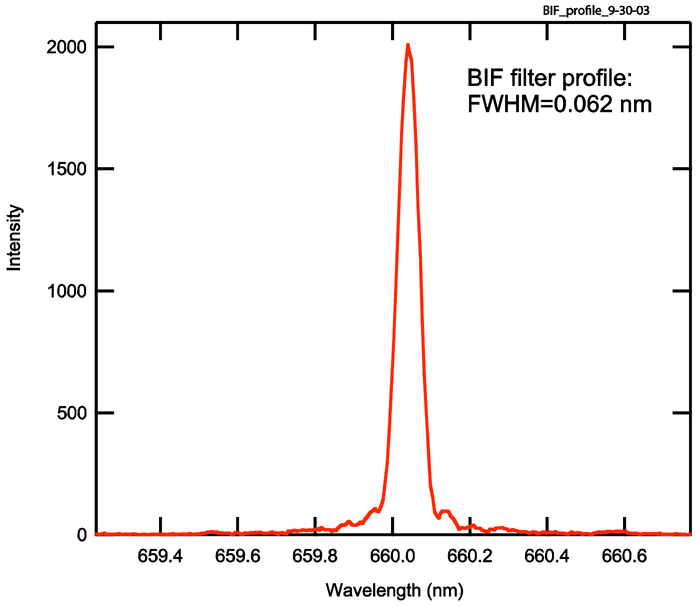


- Lyot filter, collimating and focusing optics, APD detector, HV for wavelength tuning, and temperature control are built into compact modules
- Achieved a spectral FWHM of 0.062 nm

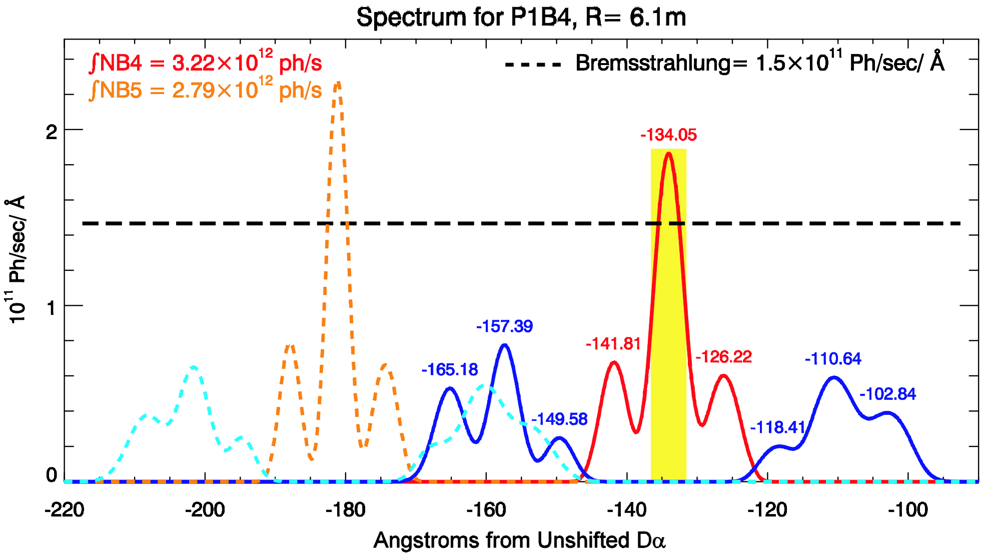
Instrument	input aperture A(mm^2)	Δ λ (nm)	f/#	Etendue U (mm ^{2} – sr)	Trans-mission t	Luminosity U ? t	Relative to BIF
BIF(NSTX)	59.7	0.062	1.2	32.6	10%	3.3	1
Fabry-Perot	1	0.062	1.2	.5	25%	.13	1/ 25
Grating(ref.)	.04	.1	5.	10^{-3}	80%	8×10^{-4}	$1/(4 \times 10^{3})$
Grating(trans)	.04	.1	1.8	10^{-2}	80%	8×10^{-3}	1/ 400

Lyot filter properties suitable for ITER MSE

Filter Bandpass

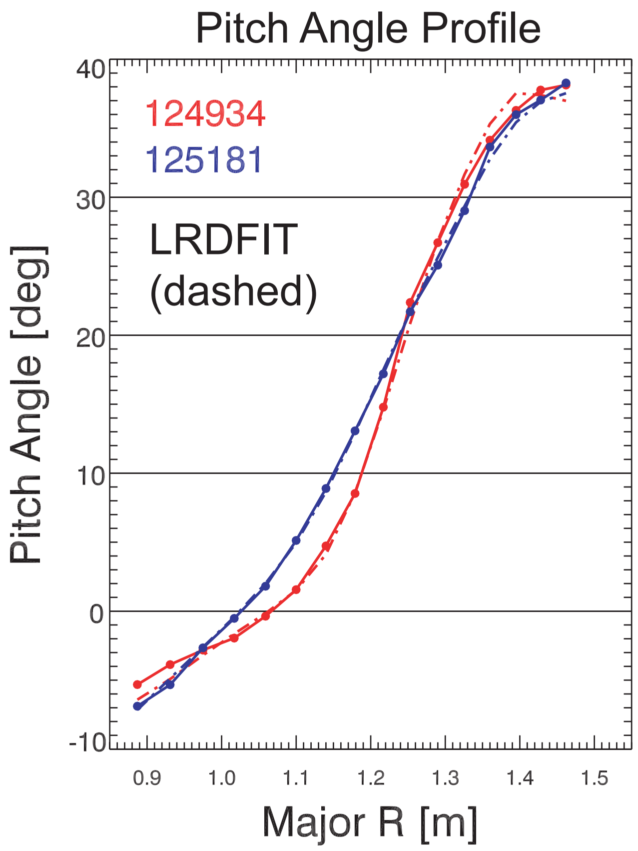


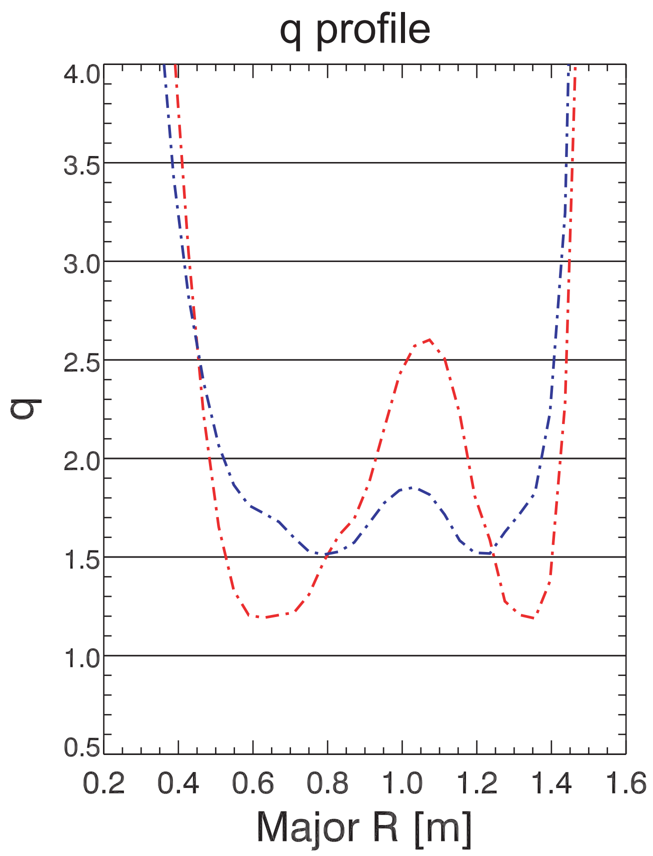
ITER simulated Stark Spectrum

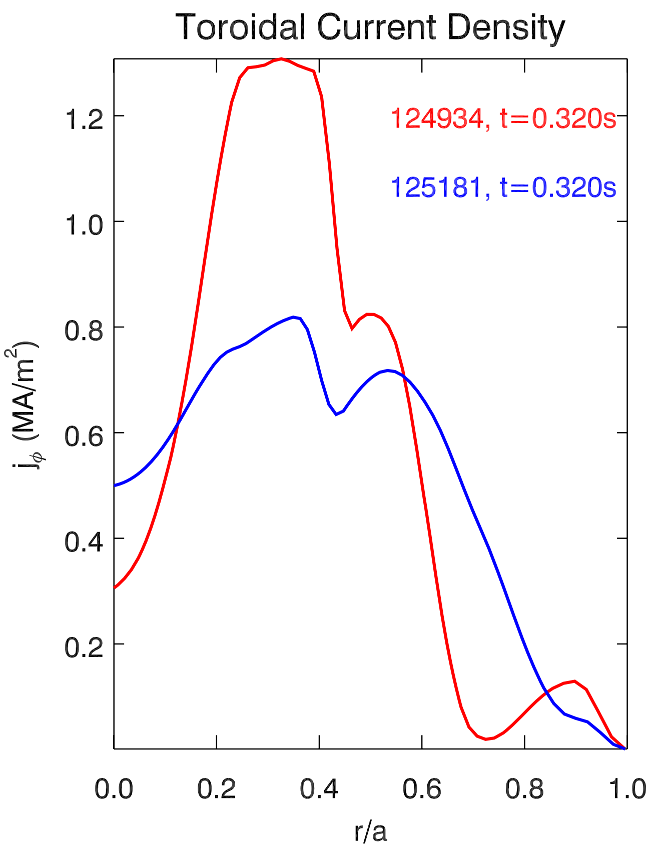


- High Bremsstrahlung to signal ratio favors viewing only the highest intensity Stark multiplet (σ_0)
- High throughput, low bandpass filters allow the ITER MSE system enough etendue viewing σ_0 only
- Would require interference filter in a large size not available commercially

MSE accurately constrains q and j profiles of reversed shear profiles

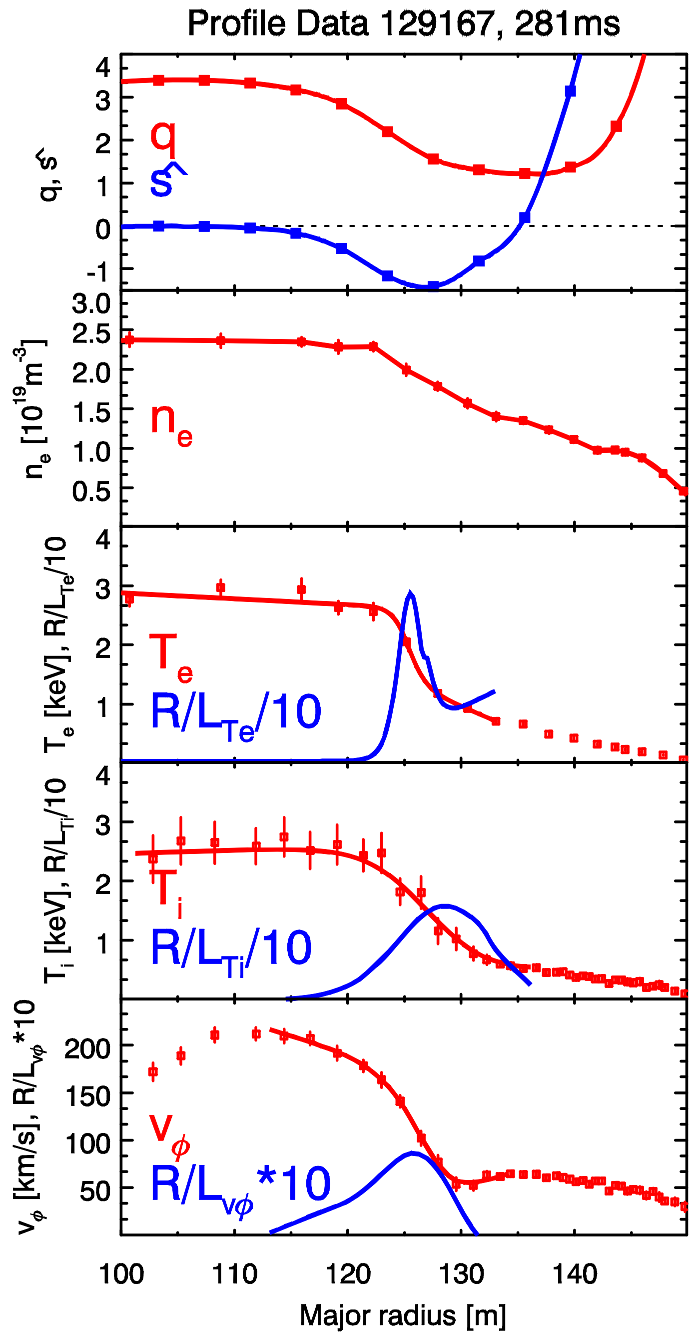

Pitch Angle Profile


q profile


Toroidal Current Density

- Minimization of flux consumption on NSTX plasma startup favors low ℓ_i, reversed shear plasmas
- Reconstructions performed using LRDFIT (a inductance-resistance 2D axisymmetric circuit model of a tokamak which can be constrained to fit various combinations of diagnostic data. Reconstruction shown here uses magnetics, E_r correction, T_e isothermal flux surfaces, and rotation)

Internal transport barrier in Te, Ti, v_ϕ profiles



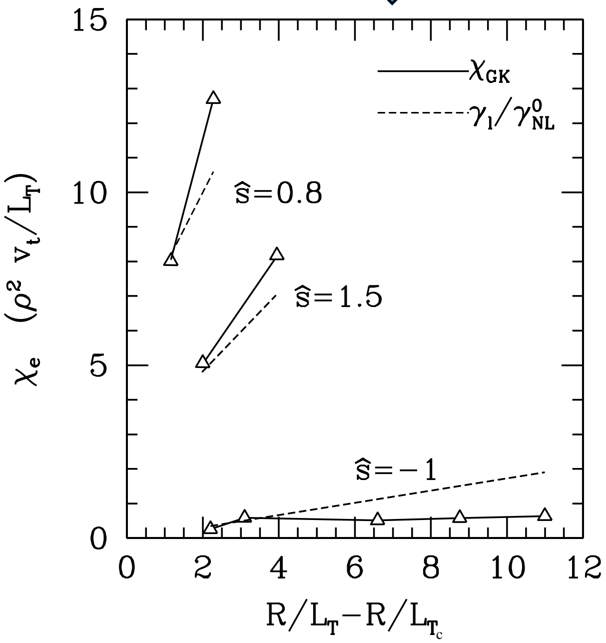
- Peaked core gradients in electron and ion temperatures, and toroidal velocity
- Electron density gradient does not show much change with ITB, reducing possibility ITB is dominated by inward particle pinch
- NSTX profile diagnostics
  - 51 channel CHERS
  - 30 channel TS
  - 16 channel MSE
- Profiles optimally fitted with modified Tanh or splines

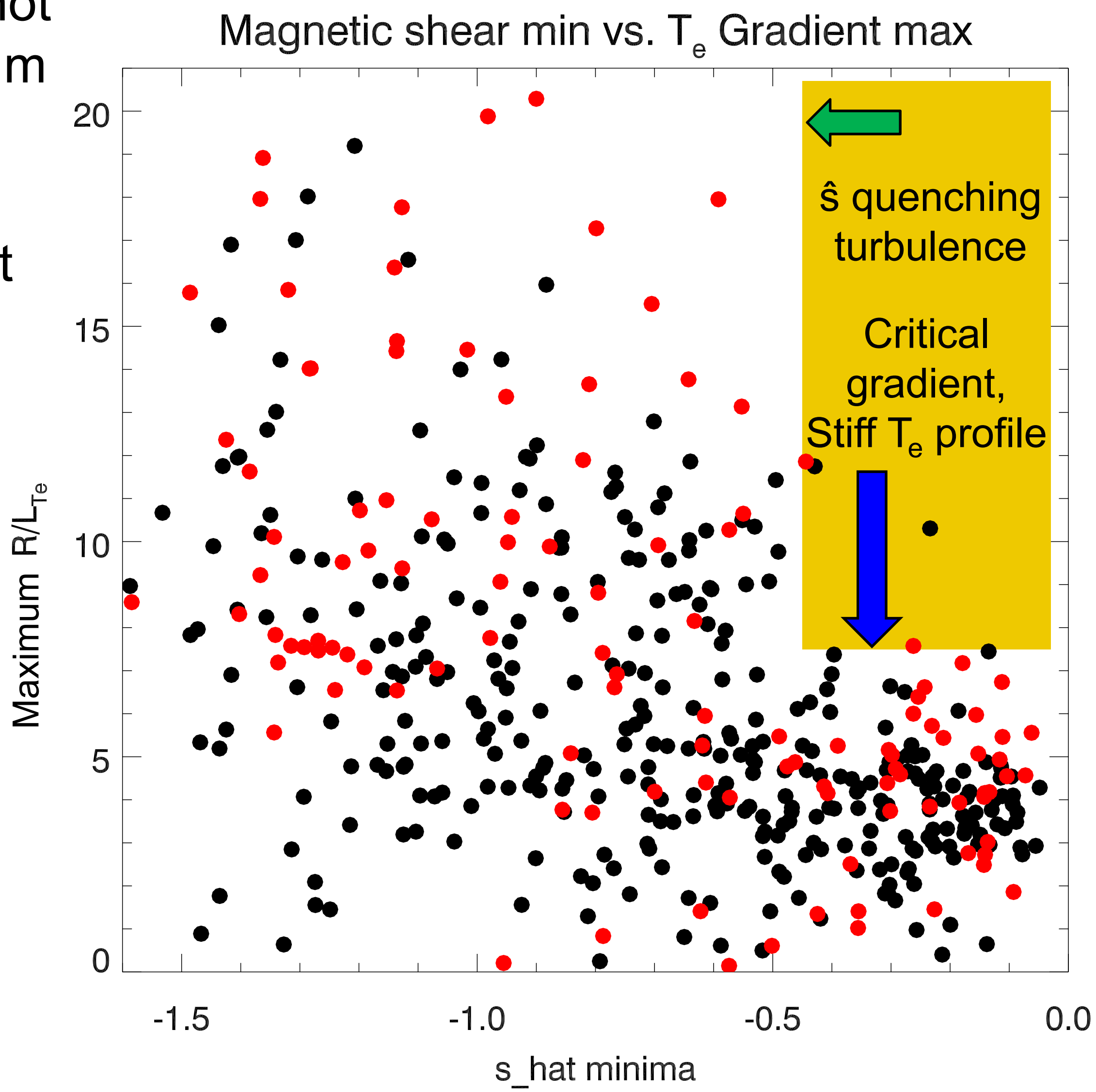
2MW NBI
1.3MW HHFW

Electron transport quenching via negative magnetic shear

- Increasing heating power does not increase T_e gradients for minimum magnetic shear above -0.45
- Parallels the idea of $\gamma_{E\times B}$ quenching of ITG turbulence, but ETG quench mechanism is via negative magnetic shear
- Consistent with Jenko, Dorland nonlinear gs2 predictions

[PRL **89**, (2002)]

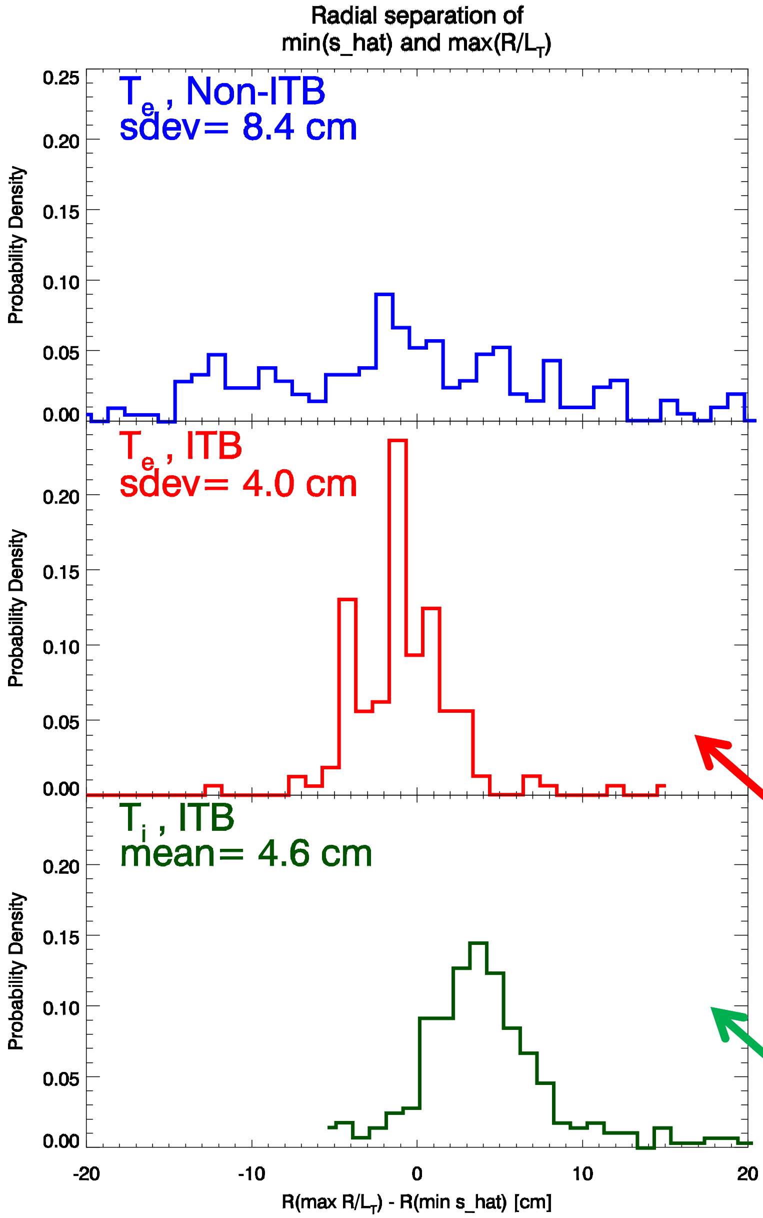




Red points = >1MW RF heating avg. during previous 50 ms

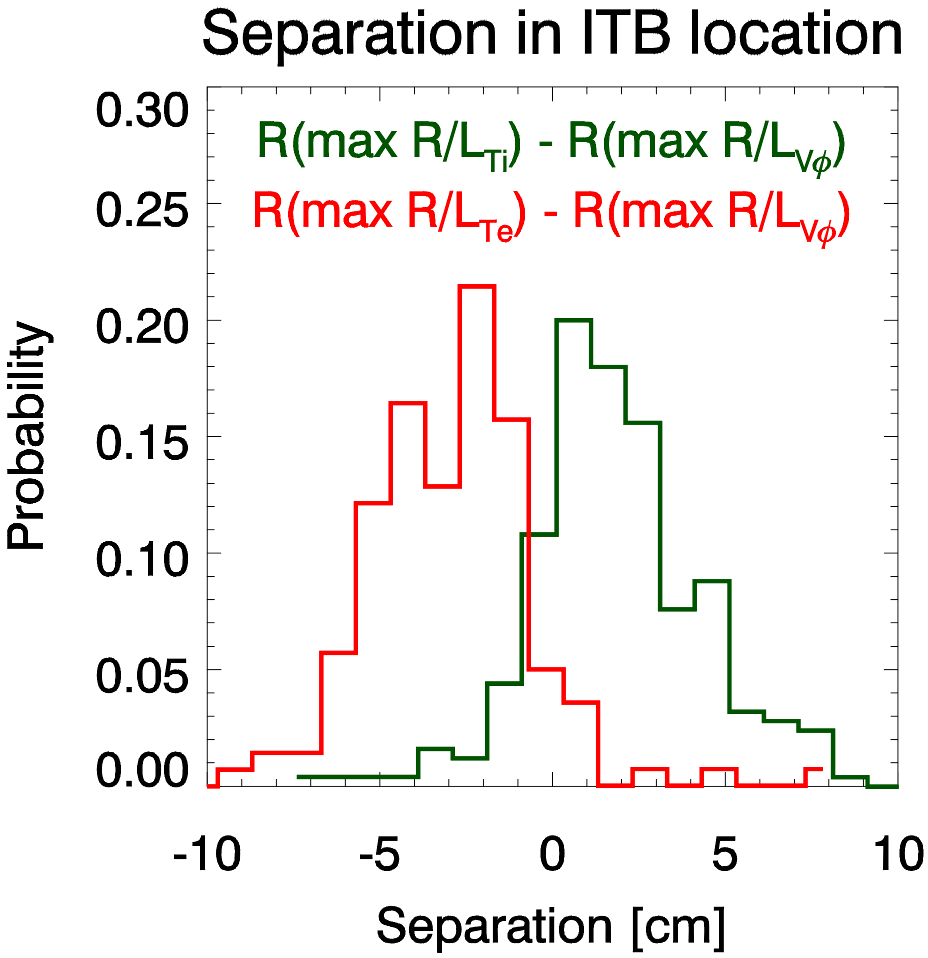
All points have 2MW NBI heating

Peak R/L_{Te} location highly correlated with ŝ minima



- Statistical analysis of profiles using data from ~80 shots with about 460 profiles
- Radial location of minima in magnetic shear (ŝ) compared with locations of maximum gradients, but only for high R/L_{Te} (ITB) profiles
- Standard deviation of the separation for electron ITB cases (4 cm) is significantly below the convolution width of the radial locations of min(ŝ) and max(R/L_{Te}) (7.5cm)
- **minimum magnetic shear (ŝ) location is highly correlated with peak gradient location**
- **Location of ion-ITB shows mean offset from minimum shear location**

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

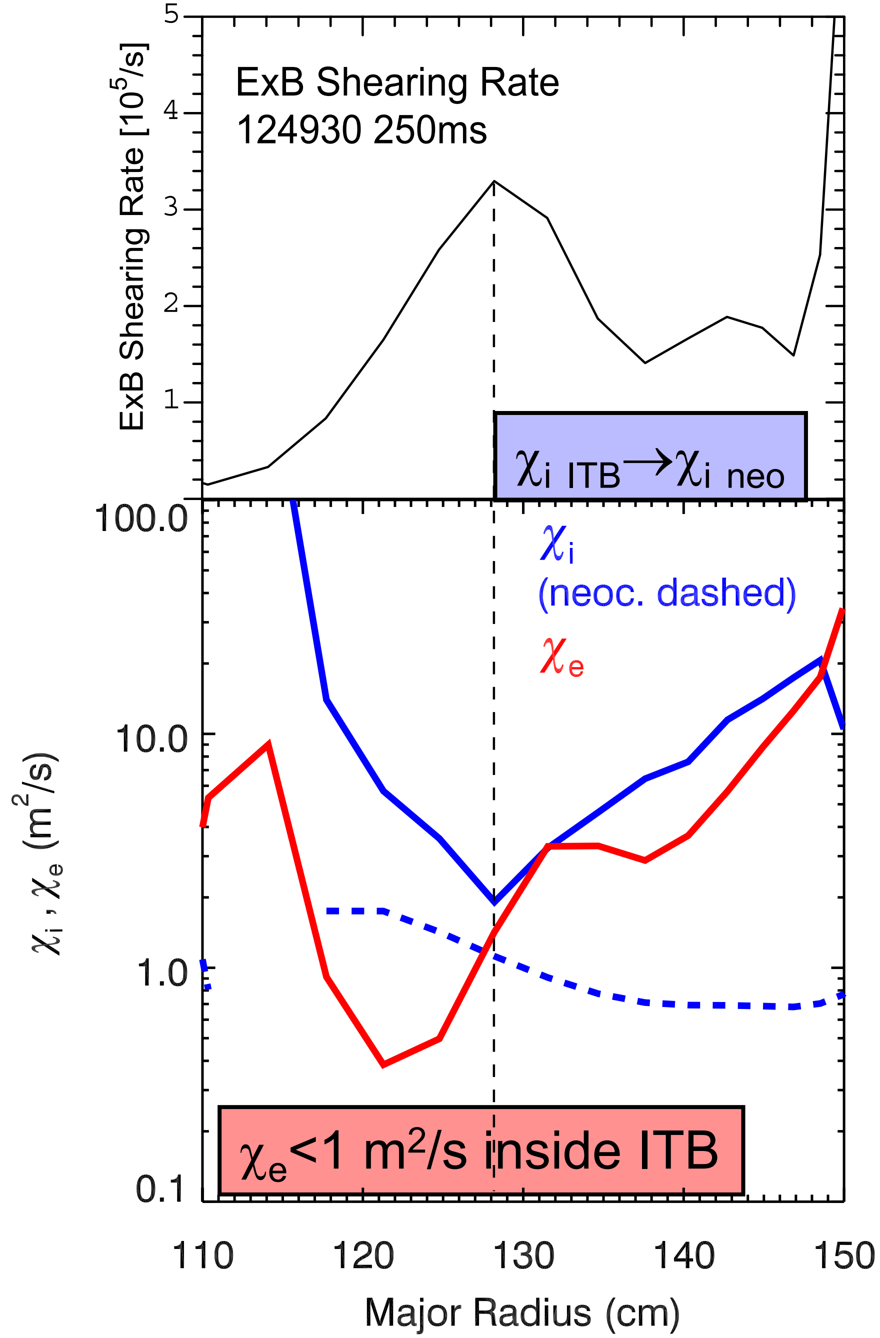


- The radial locations for ITBs in T_e, T_i, and V_ϕ are offset
- The T_i-ITB is tends to be furthest out, followed by V_ϕ-ITB, and T_e-ITB closest to the magnetic axis

- 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

Ion ITB occurs at maximum E×B shear

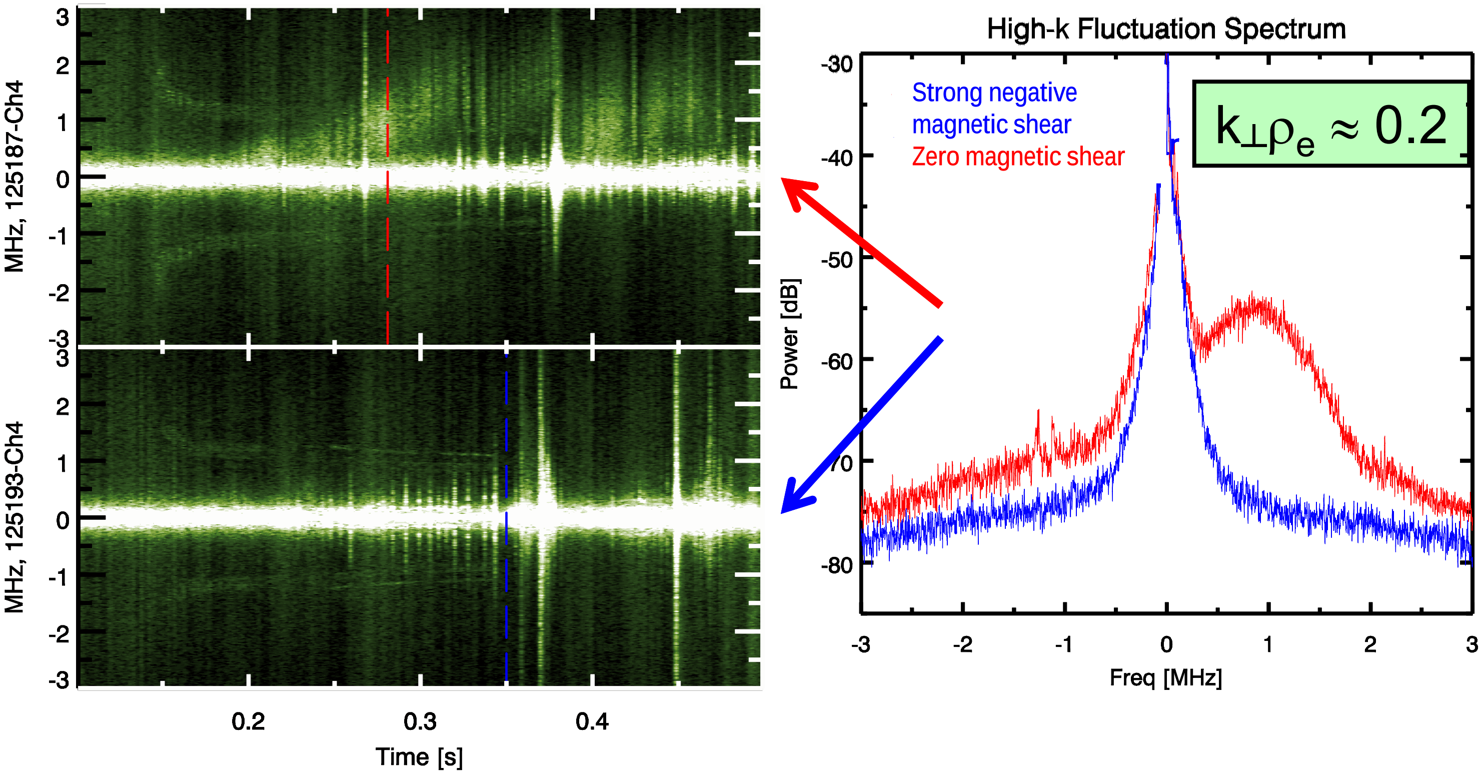


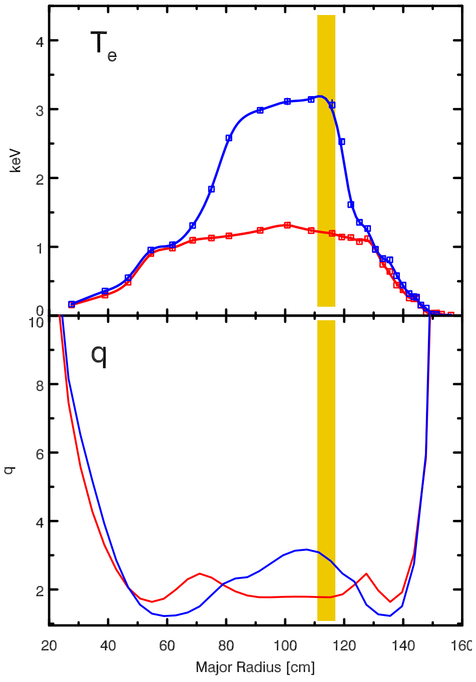
$\chi_{i\ ITB} \rightarrow \chi_{i\ neo}$

$\chi_e < 1\ m^2/s$ inside ITB

- Ion ITB coincides with peak E×B shearing rate but electron ITB does not
- Result shown is for beam heated only ITB discharge
- TORIC HHFW power deposition profile has very recently been incorporated into TRANSP
- RF heated ITB discharges show increased T_e gradients
- Ongoing analysis will show dependence of χ_e on input power for ITB discharges

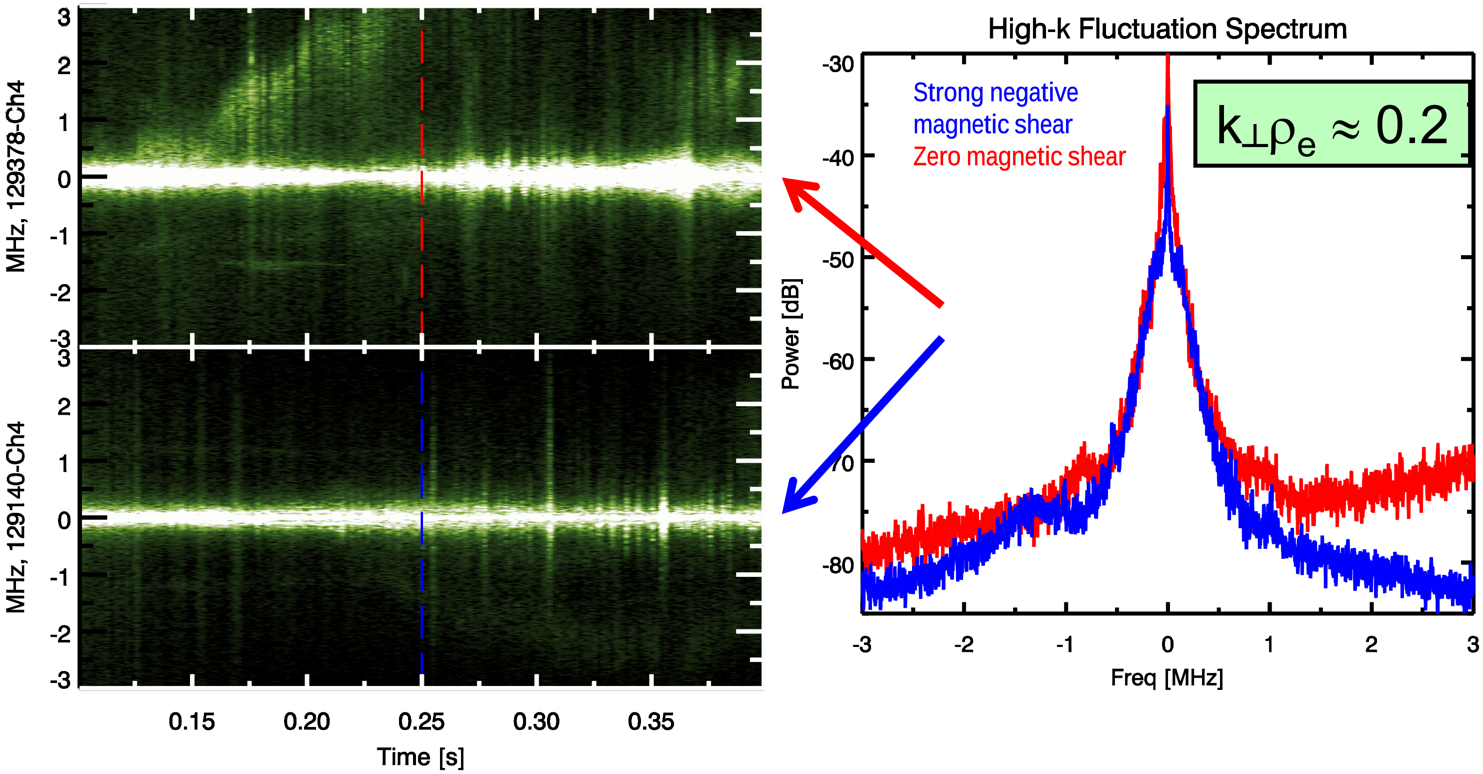
High-k scattering comparison, top of electron-ITB (R=114cm)

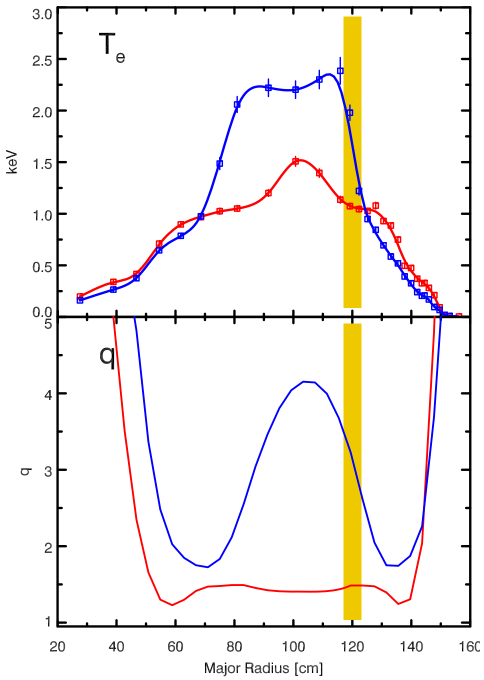




- High-k scattering measures reduced local n_e fluctuations in the ETG k range for ITB discharges.
- Compare measurements in ITB vs. non-ITG cases
- Shows strong activity for non-ITB case despite weak gradients
- Beam heated discharge, flow shear and T_i-ITB also present

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

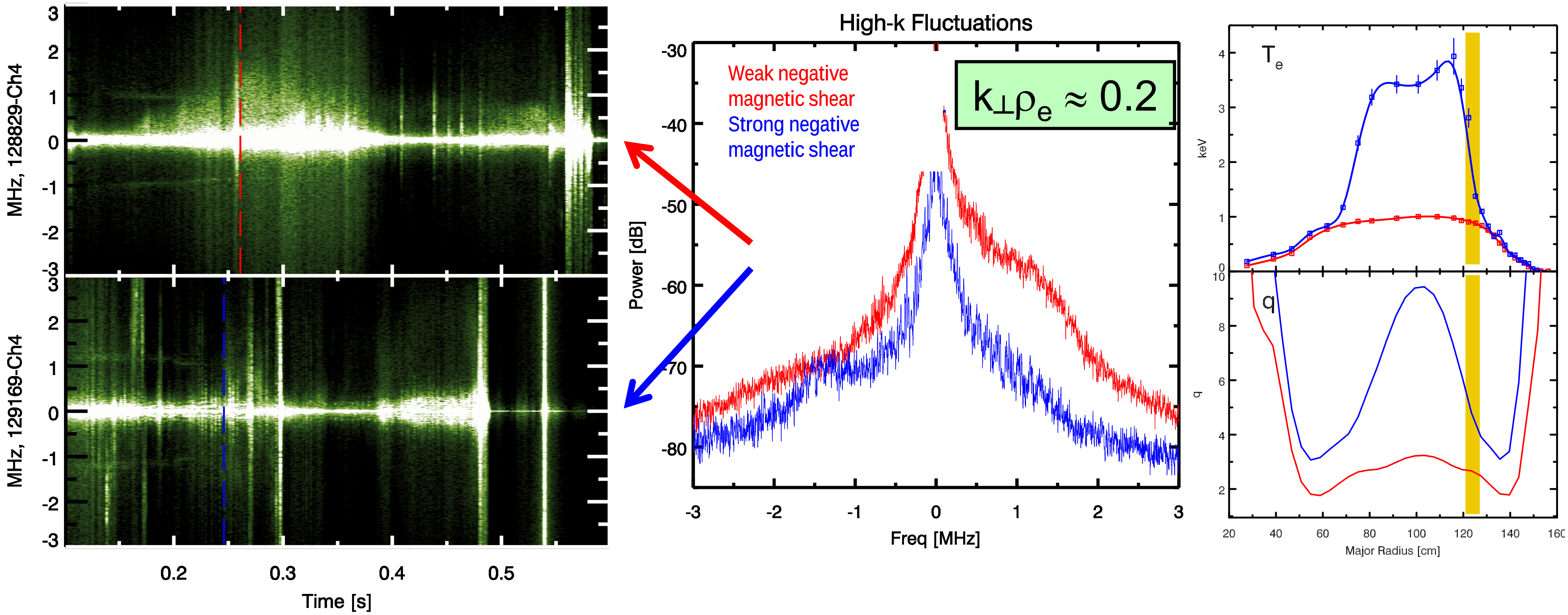




- Measured frequency is in electron diamagnetic direction but strongly Doppler shifted by toroidal rotation
- High-k fluctuations strongly suppressed in reversed shear ITB case, despite strong gradients (R/L_{Te}=10)

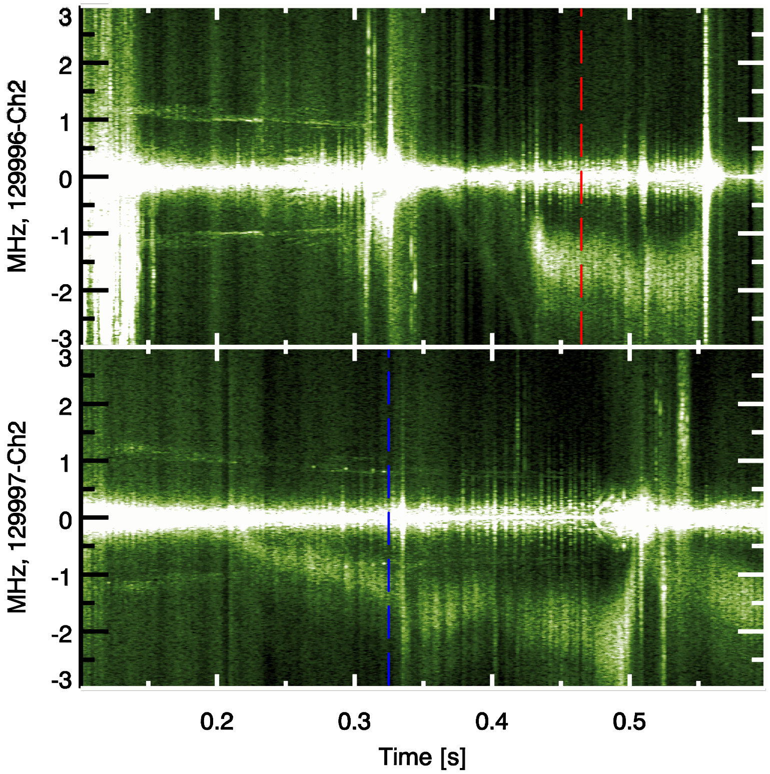
Mazzucato, EX/10-2Ra

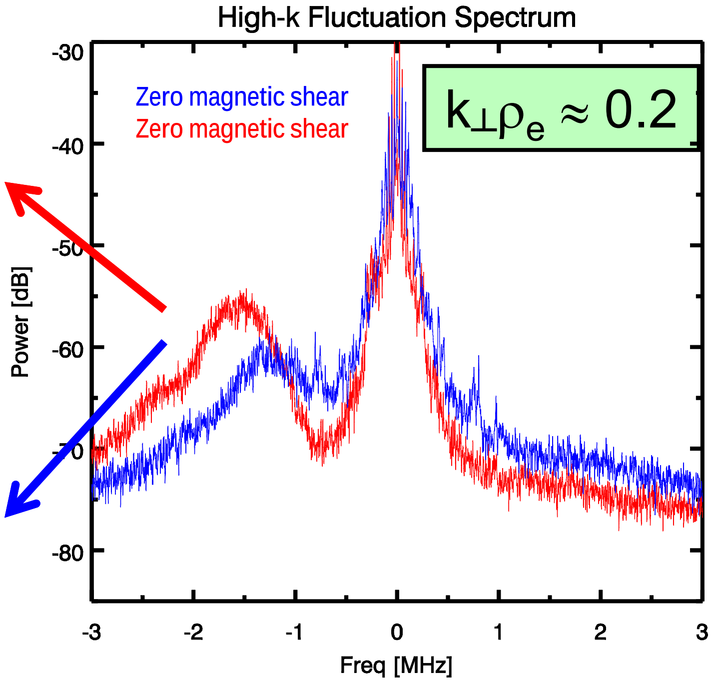
High-k scattering comparison, foot of electron-ITB (R=124cm)

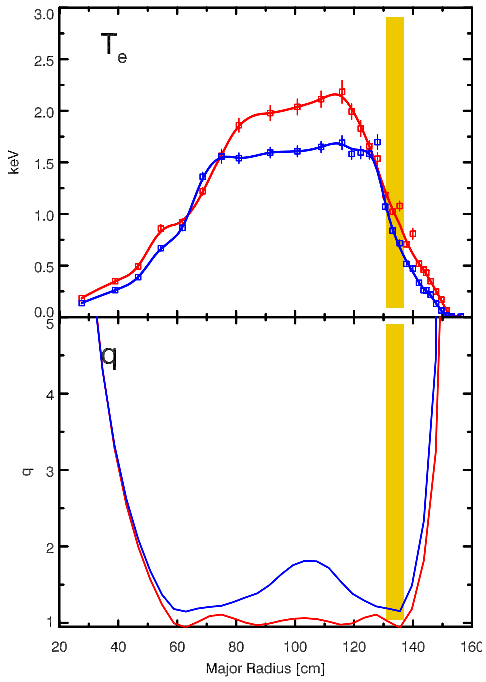


- Similar suppression of fluctuations in strongly reversed shear ITB discharges near the foot of the ITB.
- Weak negative shear does not suppress high-k fluctuations

High-k scattering comparison, outside electron-ITB (R=134cm)

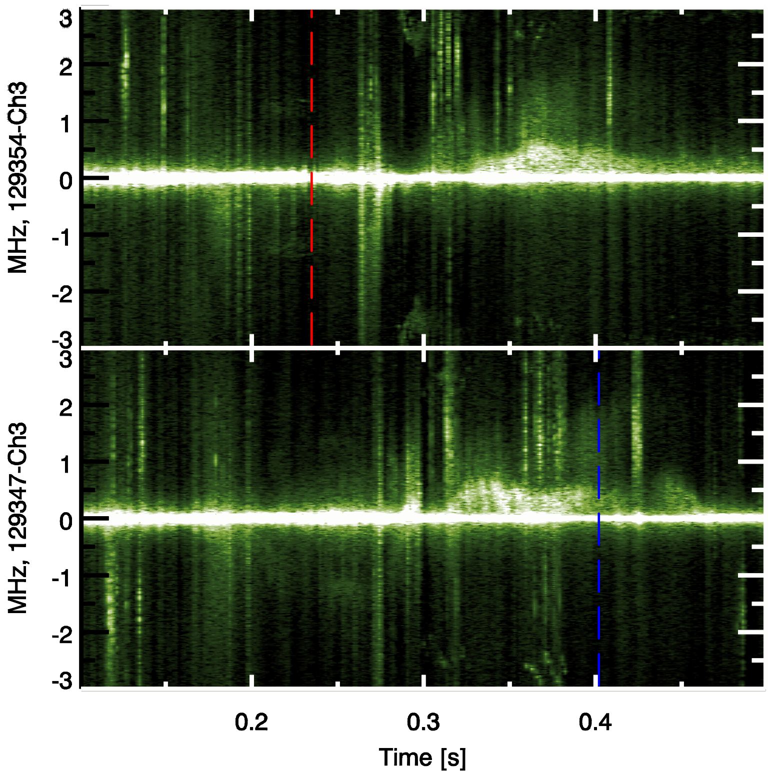


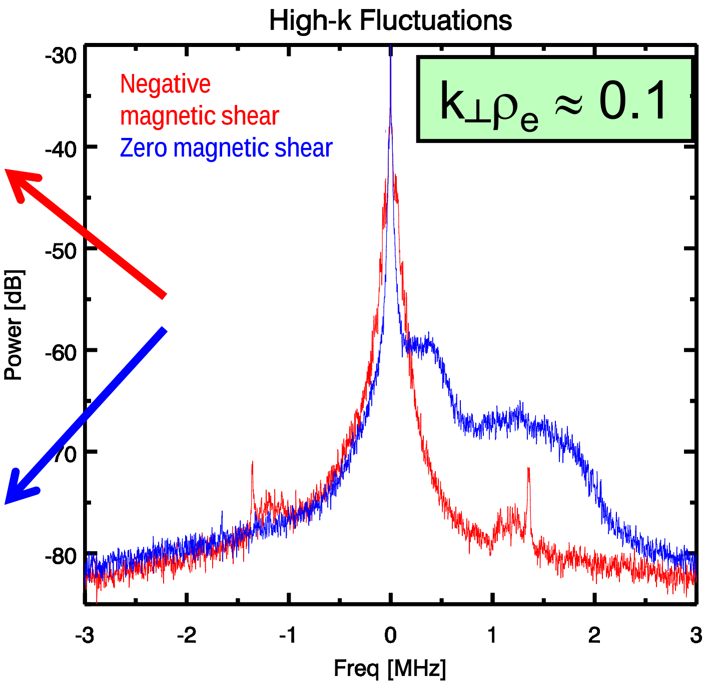


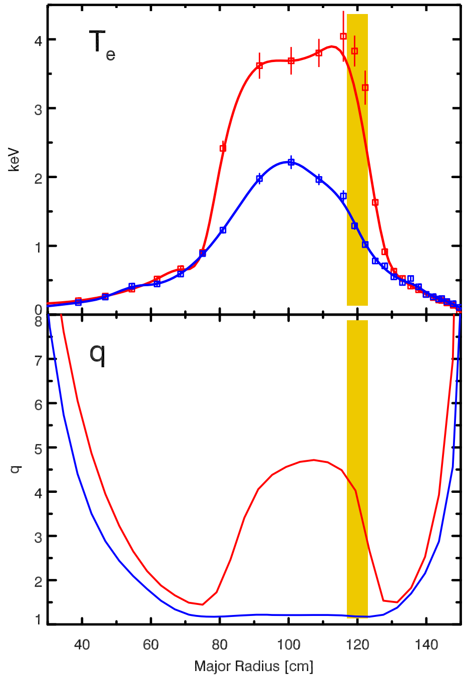


- Near or outside of q_{min}, there does not appear to be dramatic reductions in high-k fluctuations regardless of ITB formation
- For this location the directions are reversed from other cases, frequencies have reversed signs but still in electron direction

Negative magnetic shear can suppress electron thermal transport without flow shear...

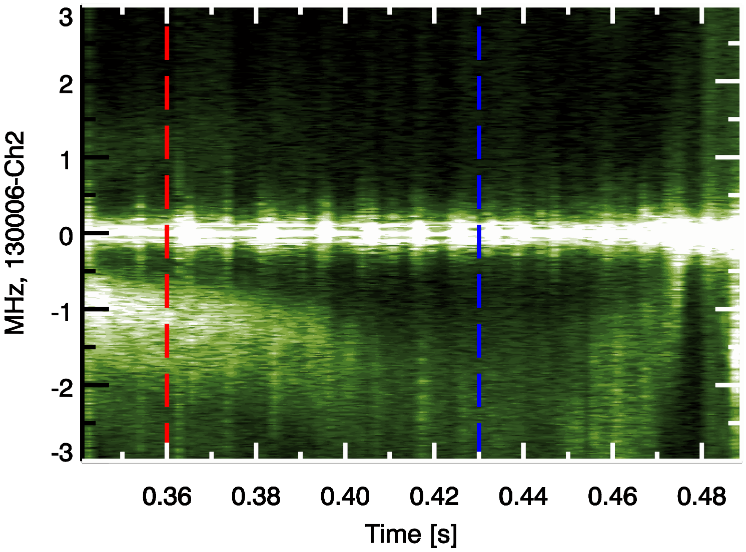


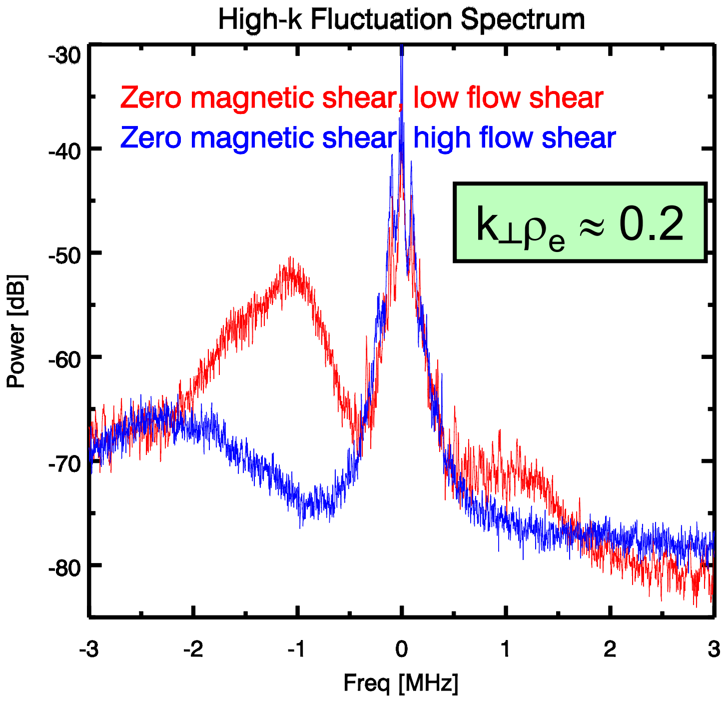


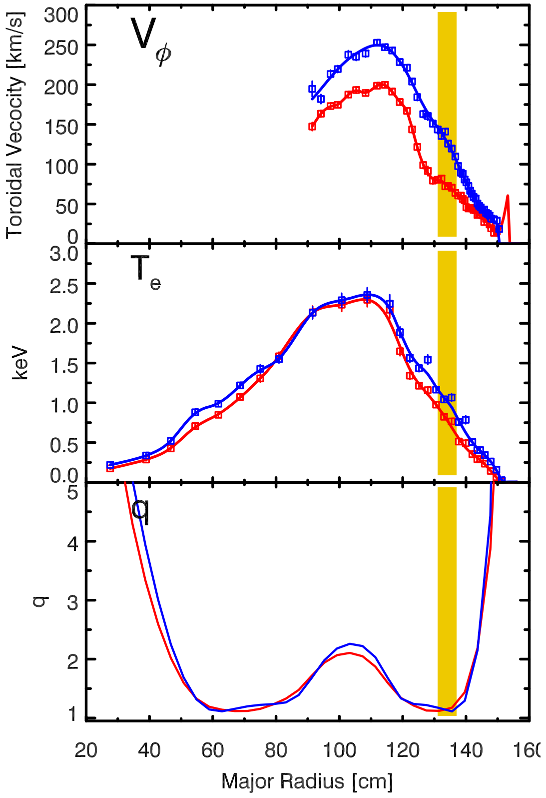


- Comparing 2 identical discharges with only HHFW (High Harmonic Fast Wave, Landau damped on electrons) heating
- MSE data taken using 50ms NBI blips, but at different times during discharge
- Only early phase of discharge is reversed shear with an ITB profile
- Later profile with lower gradients and monotonic q-profile shows increased high-k fluctuations
- **No momentum input, minimal toroidal rotation, near zero flow shear. No ion-ITB**
- **Magnetic shear alone can suppress electron thermal transport**

...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**

Kaye, EX/3-2

Conclusion:
Negative magnetic shear suppresses electron transport

- Electron ITB location strongly correlated with minima of negative magnetic shear
- Ion ITB does not occur at $\hat{s}$ minima, but closer to maximum E×B shear location
- T_e gradients appear to be limited to $R/L_{Te} \leq 7.5$ for cases where $\min(\hat{s}) > -0.45$
- High-k fluctuations with ETG wavenumbers shows reduced amplitude in ITB regions with negative magnetic shear despite high gradients
- Magnetic shear can suppress electron transport and form electron ITBs even without flow shear, but flow shear does affect fluctuations at the ETG scale