Measurements of Core Electron Temperature Fluctuations in DIII-D with Comparisons to Density Fluctuations and Nonlinear GYRO Simulations

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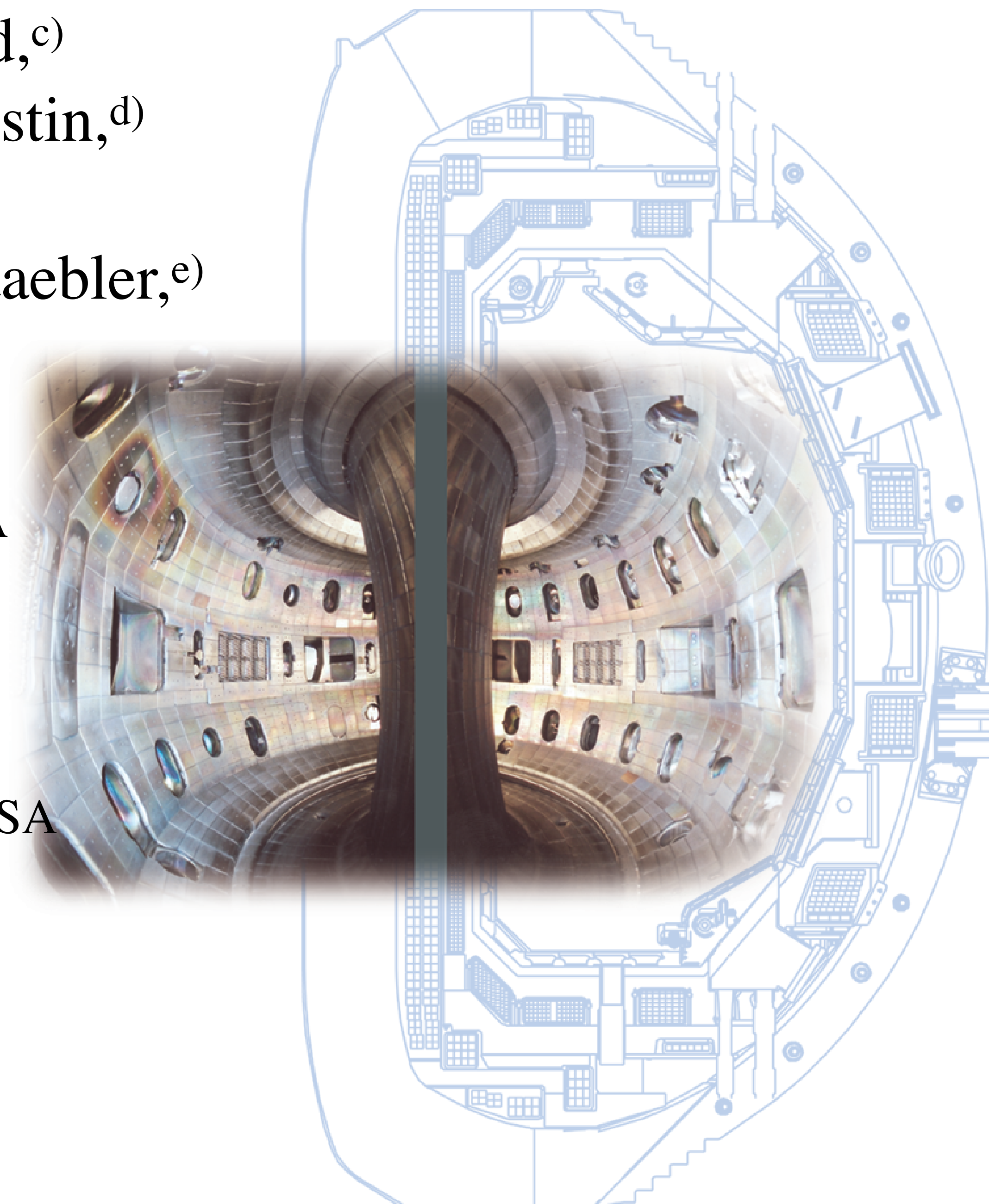

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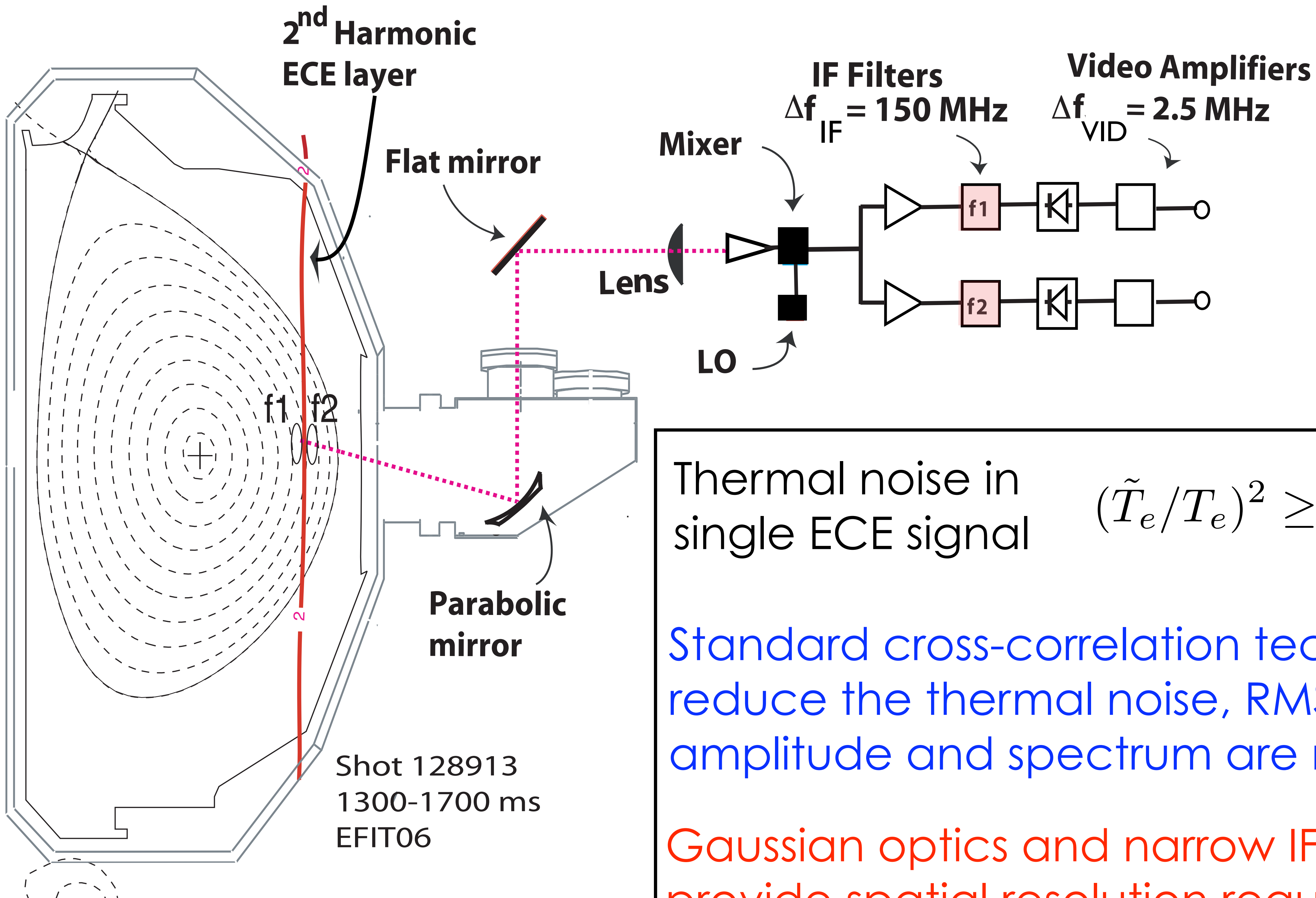
Correlation Electron Cyclotron Emission (CECE) diagnostic measures local, low-k electron temperature fluctuations



Thermal noise in single ECE signal $$(\tilde{T}_e/T_e)^2 \geq \frac{\Delta f_{VID}}{\Delta f_{IF}}$$

Standard cross-correlation techniques reduce the thermal noise, RMS amplitude and spectrum are measured

Gaussian optics and narrow IF filters provide spatial resolution required for turbulence measurements

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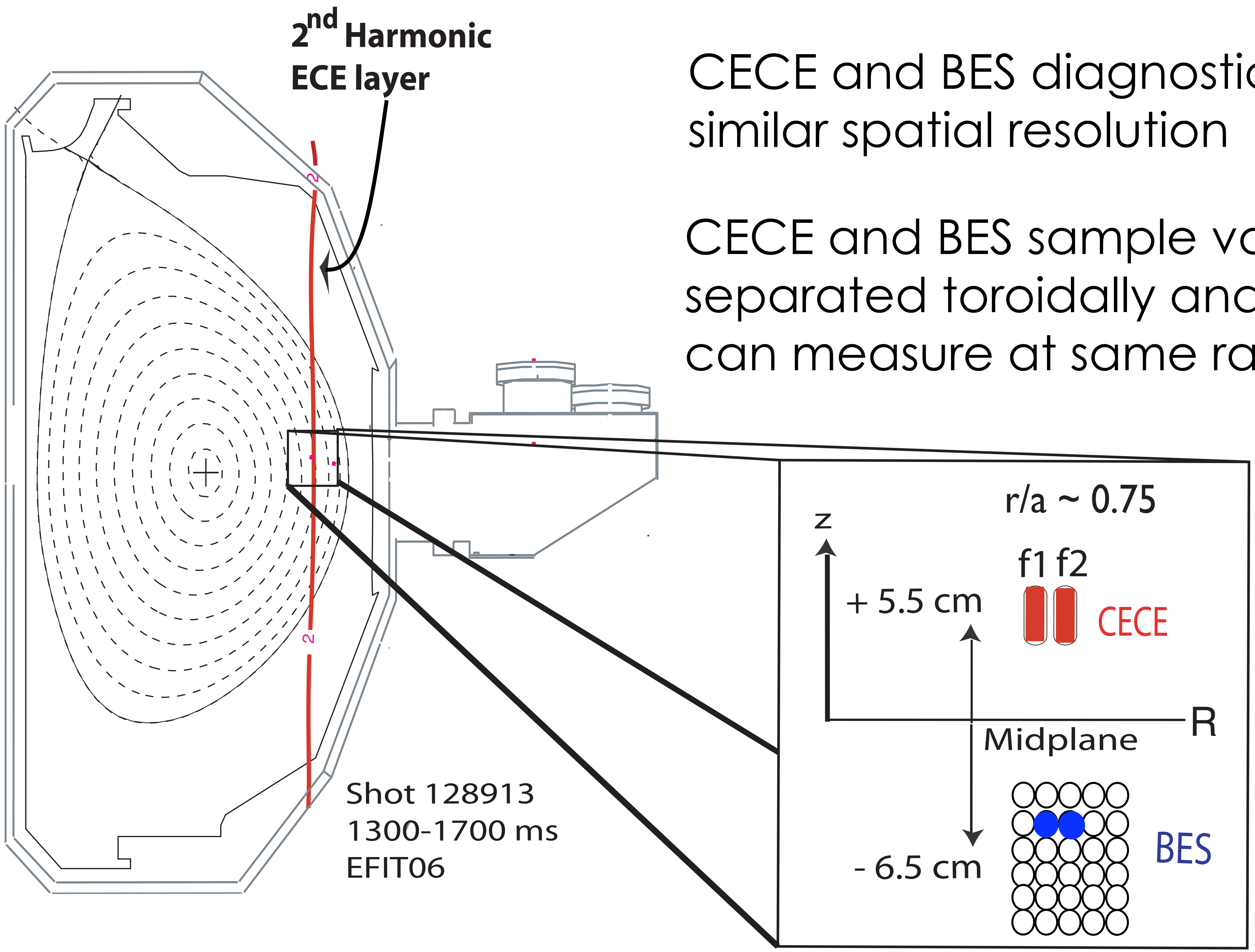
Beam Emission Spectroscopy (BES) diagnostic measures local, low-k density fluctuations



CECE and BES diagnostics have similar spatial resolution

CECE and BES sample volumes are separated toroidally and vertically, but can measure at same radial location

CECE $\tilde{T}_e/T_e$

$k_\perp < 1.8 cm^{-1}$

BES $\tilde{n}/n$

$k_\perp < 3 cm^{-1}$

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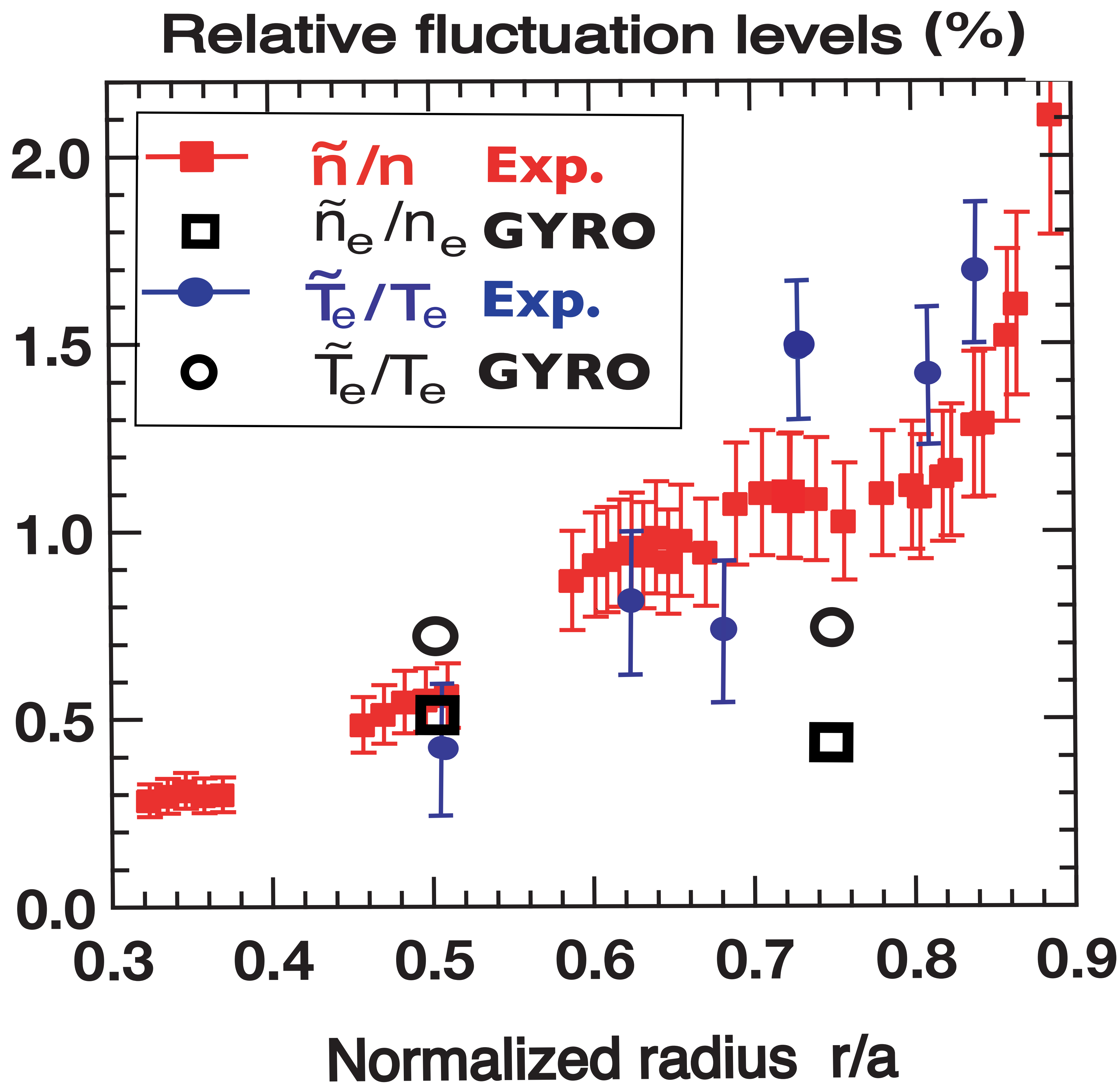
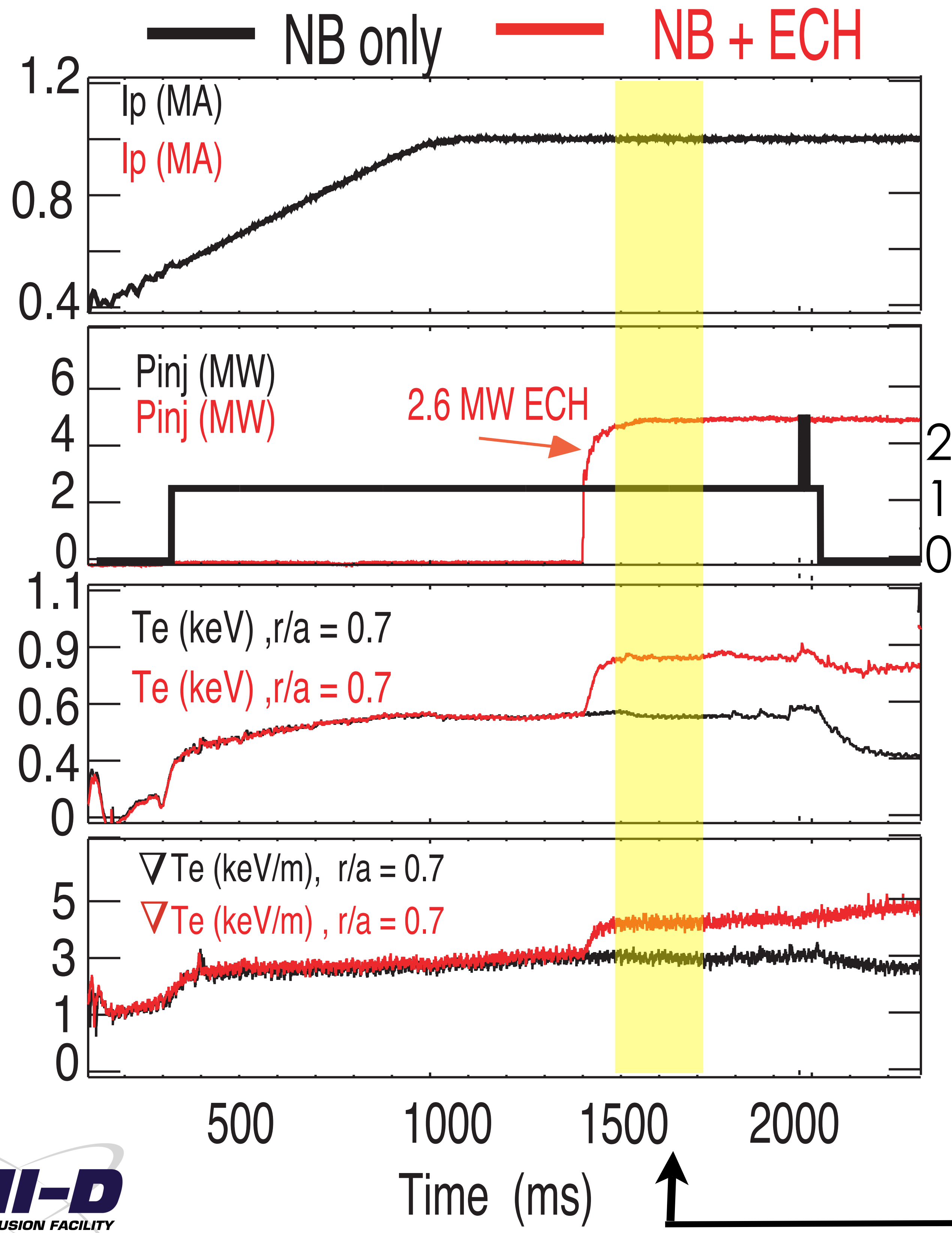
Issues for comparison and validation studies

- How can CECE measurements be used to study the TEM?
  - T-perp carries information about trapped population
  - Conditions when X-mode ECE measures T-perp, CECE measures T-perp fluctuations. Can this be tested?
  - Is there a clear difference predicted for n-tilde/Te-tilde for ITG vs TEM?
- Can ne-tilde and Te-tilde amplitudes/spectra alone give valuable information for validation studies?
- Phase measurements <ne-tilde Te-tilde>?
- Oblique CECE? O-mode CECE? Pick out differences between T-par and T-perp? O-mode ECH vs X-mode ECH?
- Can multi-field fluctuation measurements be used to help define metrics and methods of 'validation' beyond 'comparison' ?



Relative fluctuation levels (%)
ñ/n Exp.
ñe/ne GYRO
T̃e/Te Exp.
T̃e/Te GYRO
2.0
1.5
1.0
0.5
0.0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Normalized radius r/a

Experiment using local ECH to change local T_e gradient and turbulence drives



Baseline discharge with beam heating only

Ip = *1* MA, *BT* = *2.0* T, 2.5 MW of co-injected beam power

Compare to discharge with additional EC heating at r/a ~ *0.17*

With ECH: Chi, Q increase and TGLF indicates increase in TEM growth rate

Times used in analysis 1500-1750 ms

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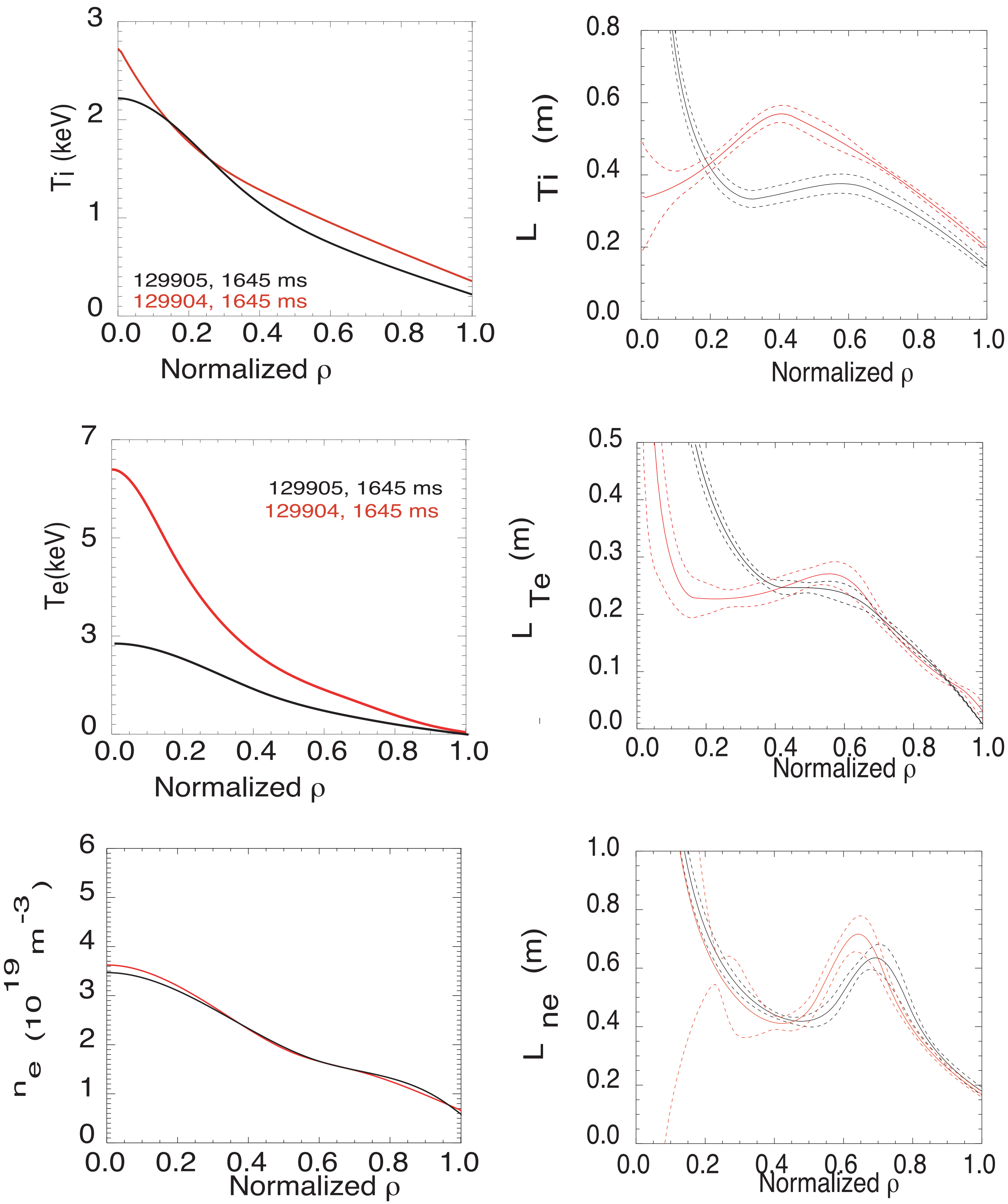


R/LTi - decrease (all three radii)

R/LTe - increase rho ~ 0.6

R/Lne - increase rho ~ 0.6

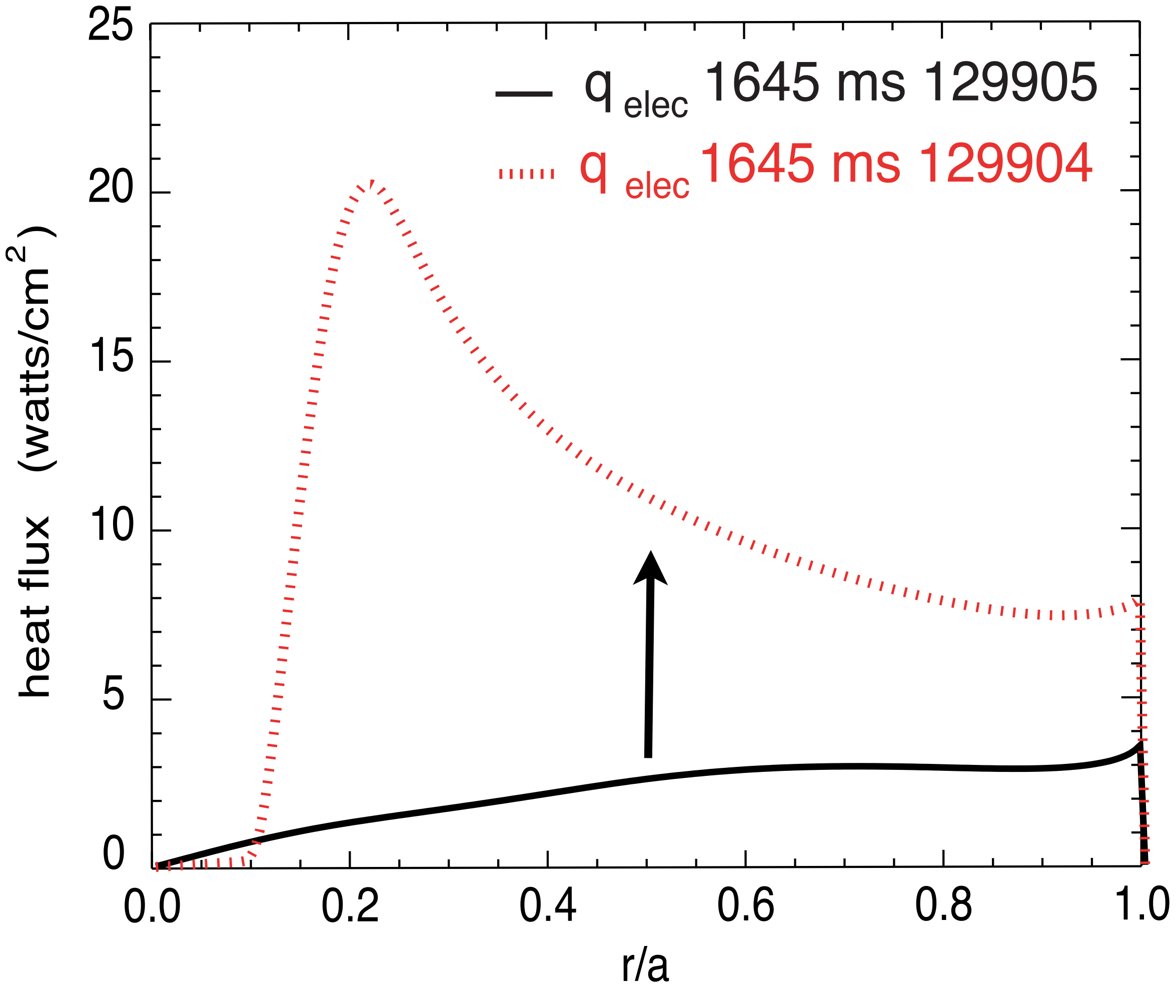
Zeff - increase (all three radii)

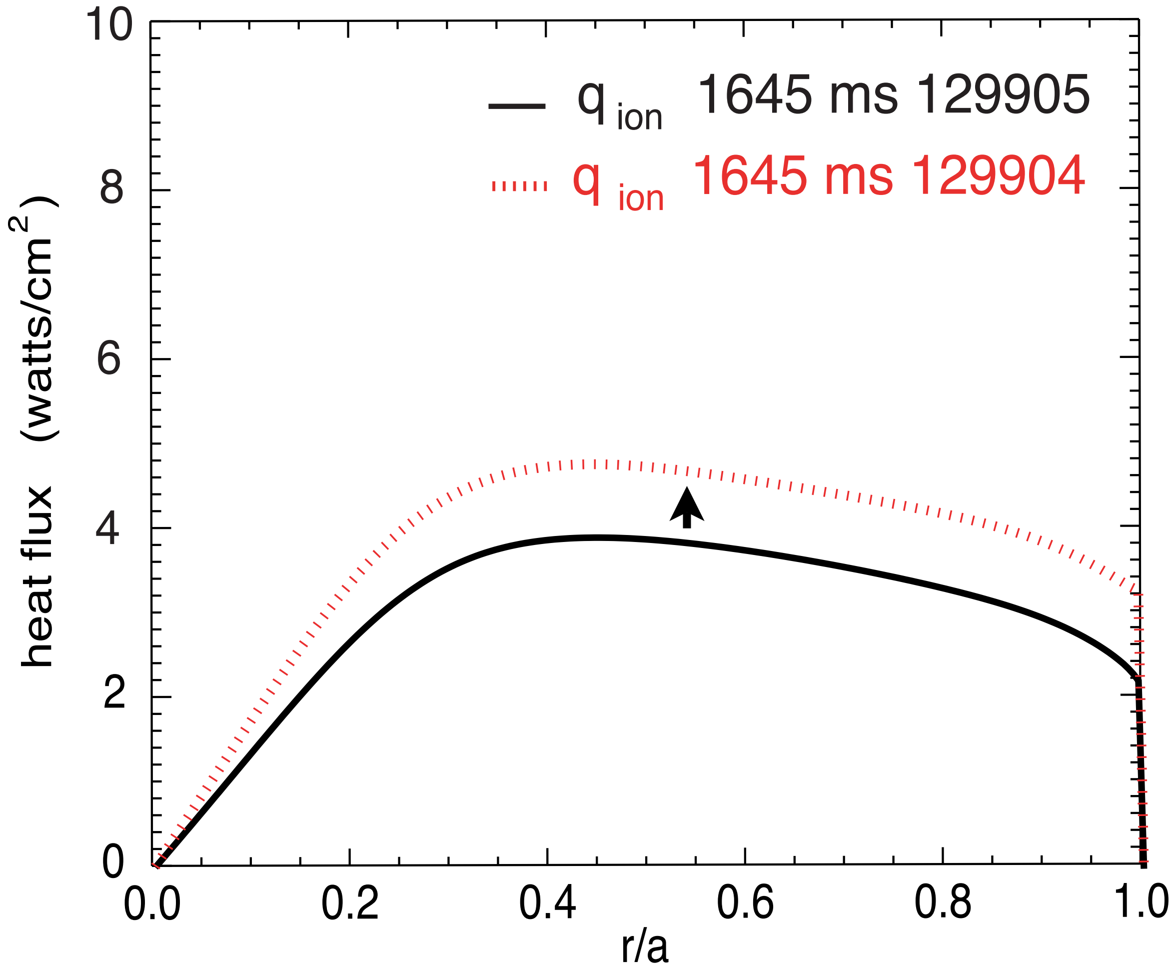
eta_i - decrease (all three radii)

Te/Ti - increase (all three radii)

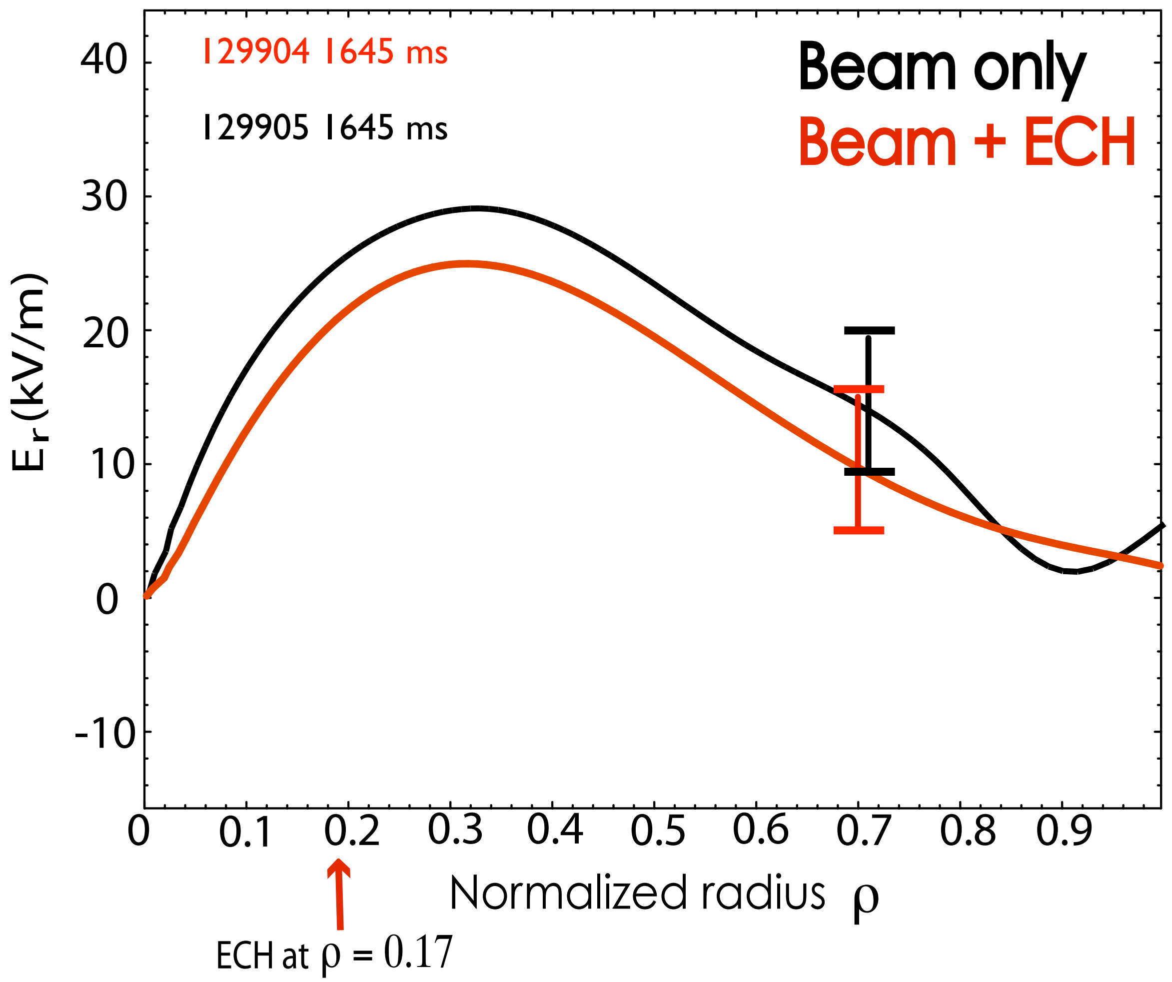
shear - decrease (inner radii)

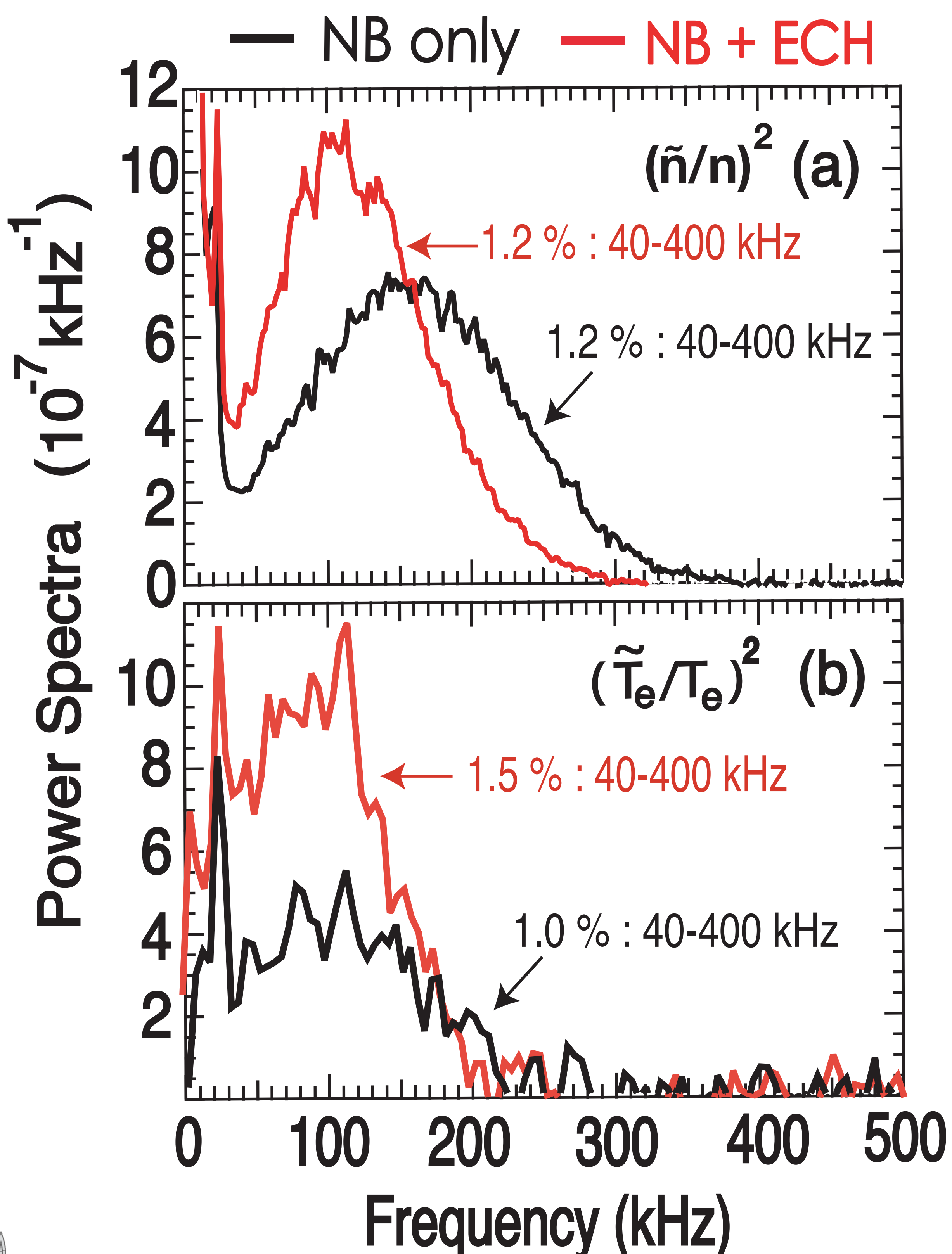
ECH experimental results : Electron flux increases (~ 3x) at all radii with ECH. Ion heat flux increases (~ 30%) at all radii





ECH experimental results rho = 0.7 : Temperature fluctuation amplitude increases -- density fluctuation amplitude stays the same





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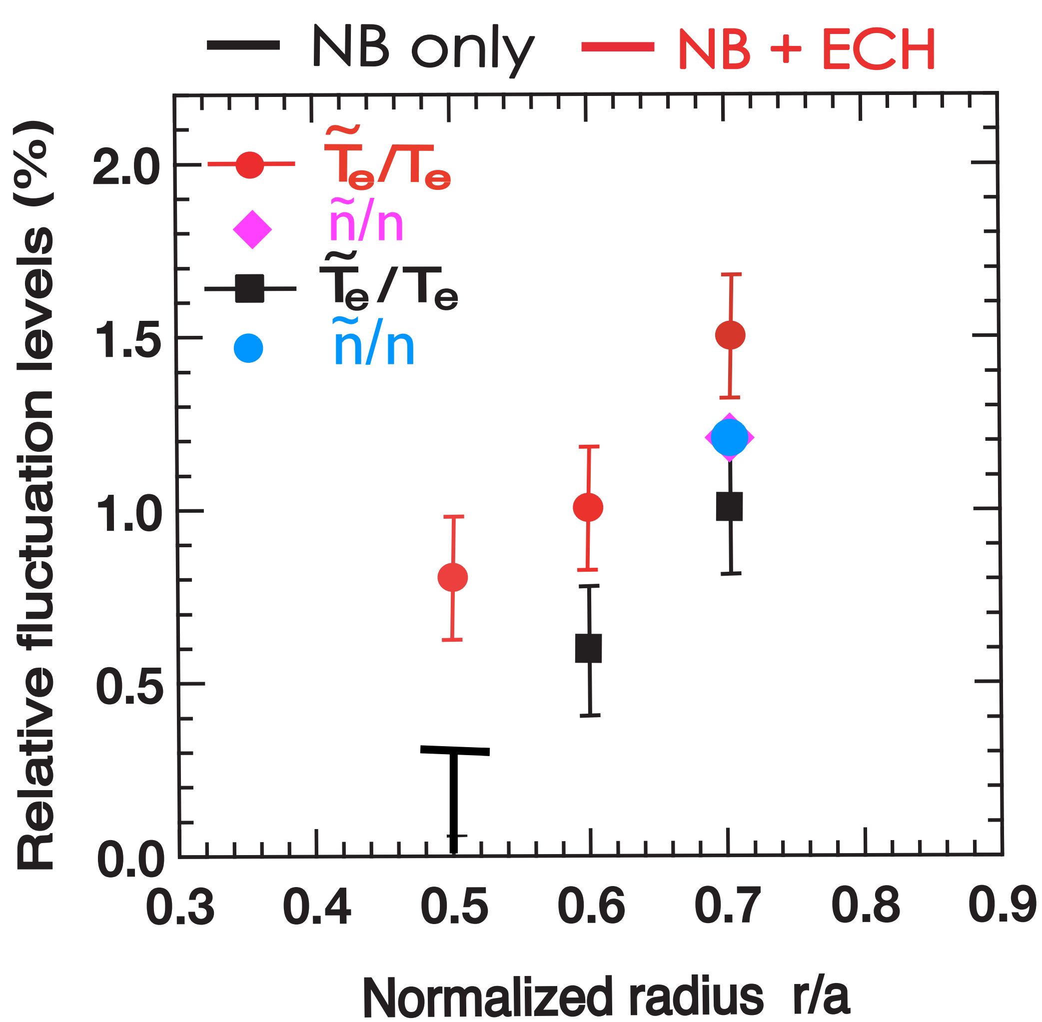
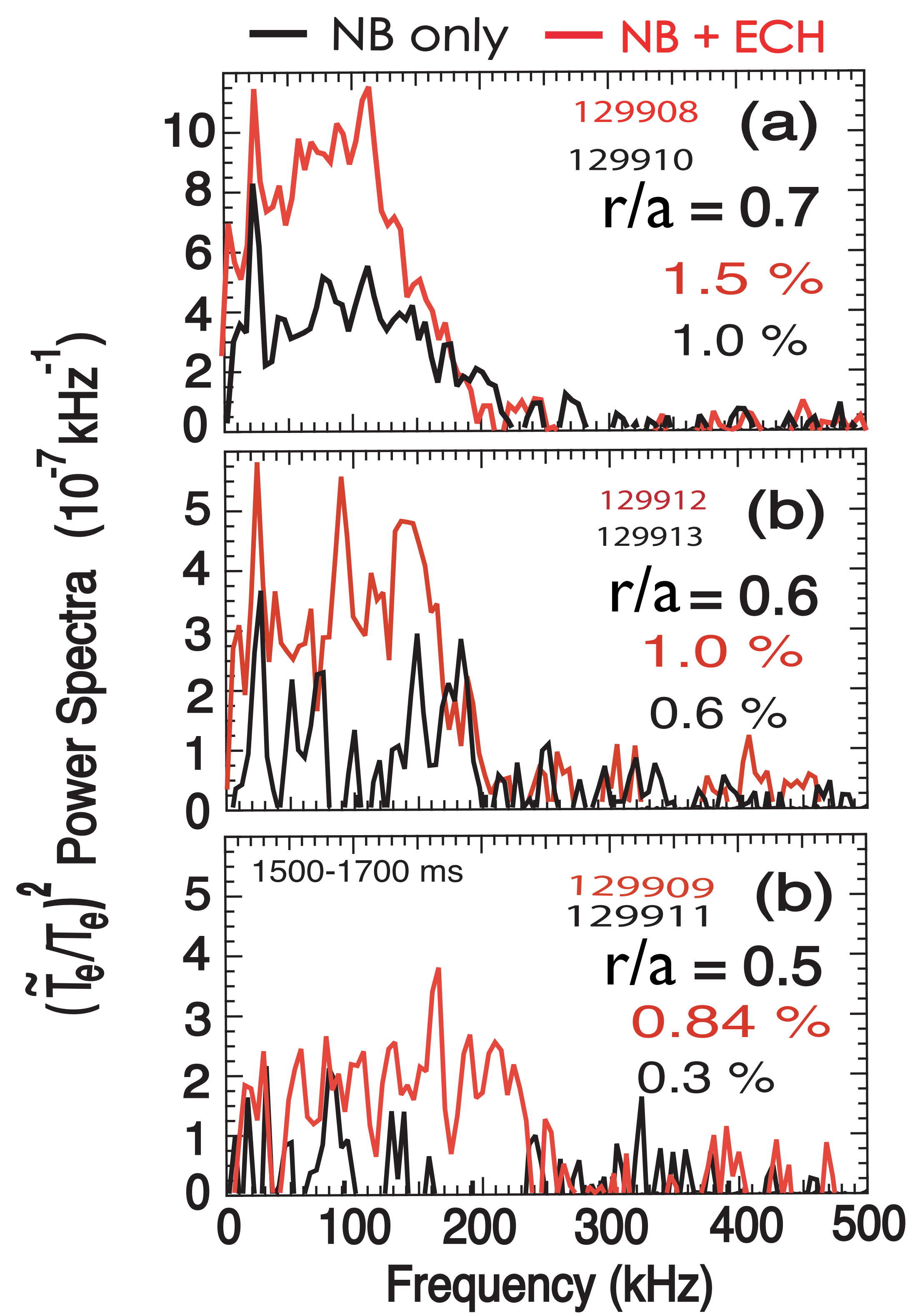
ECH experimental results : Temperature fluctuation amplitude increases at three radial locations. Largest increase at r/a = 0.5





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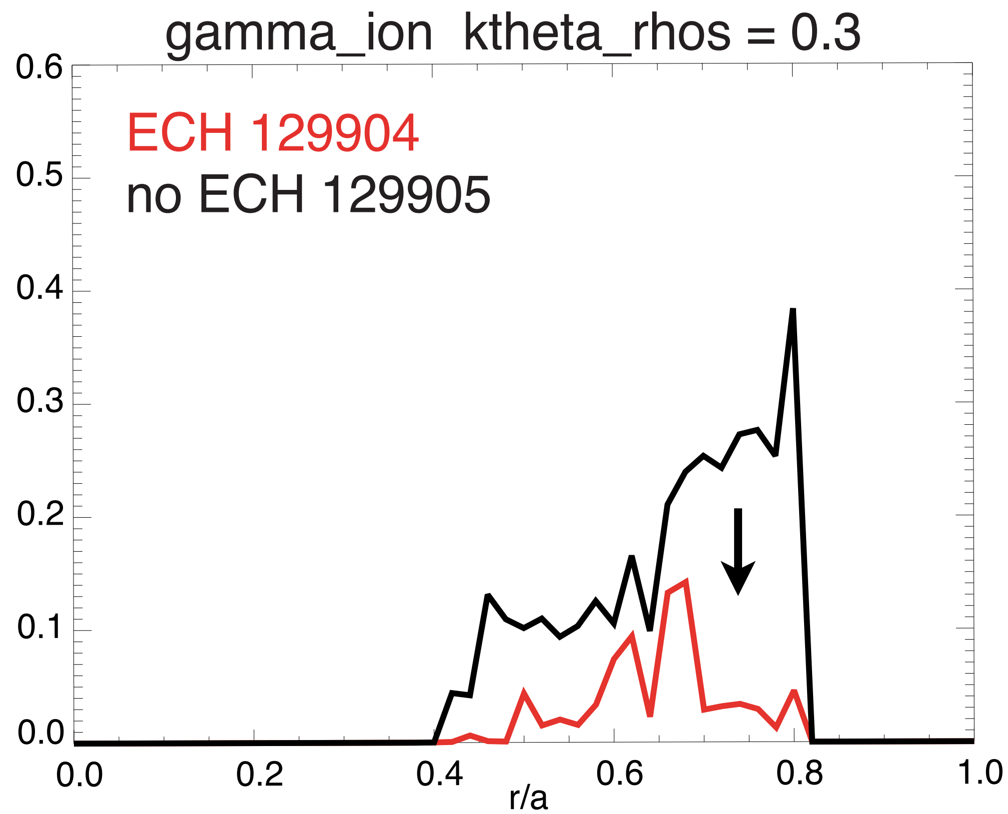
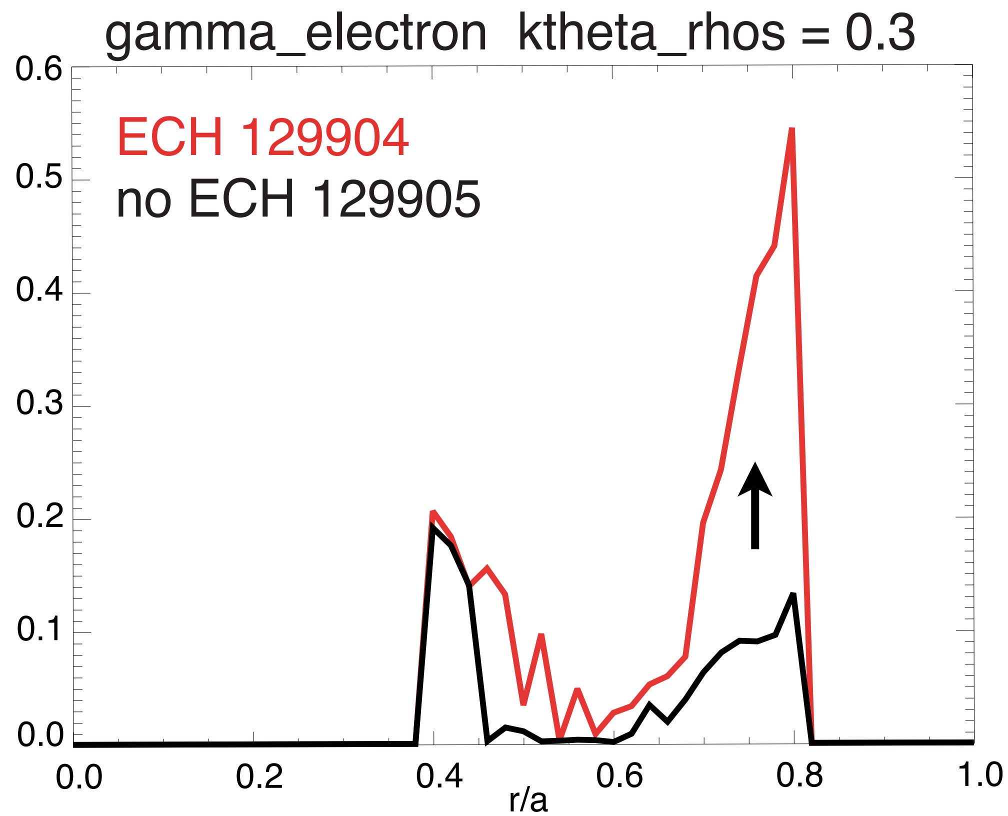
Linear stability results : ITG growth rate decreases at relevant scales, TEM growth rate increases at relevant scales

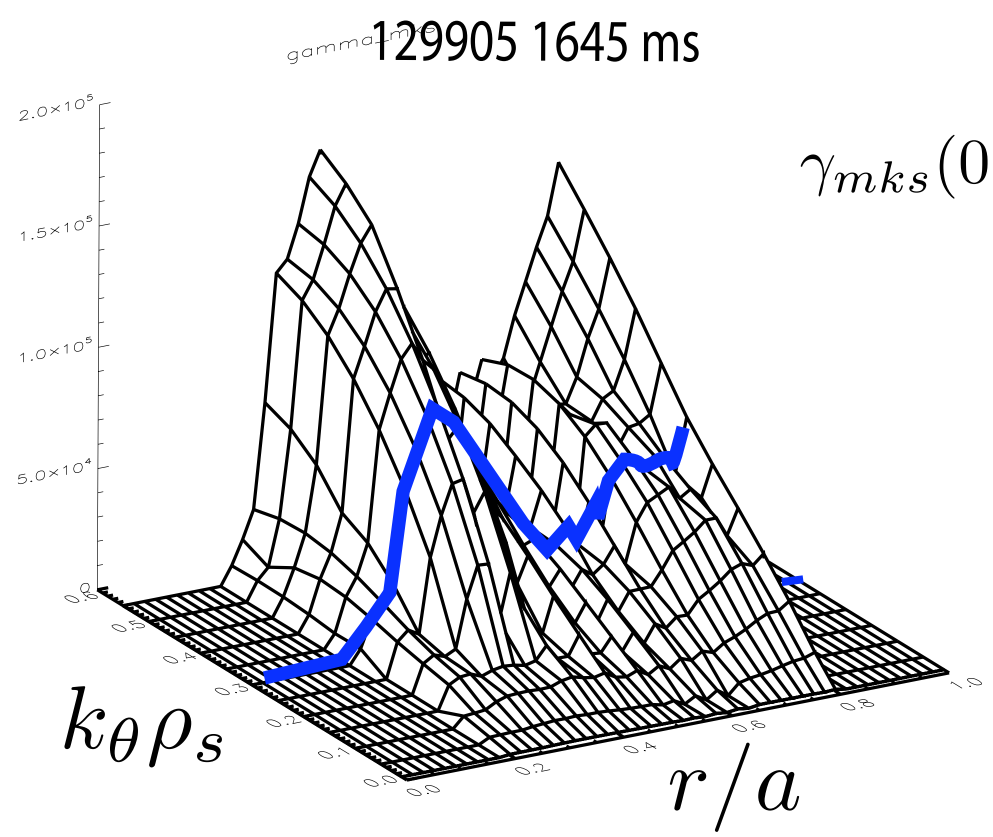


Growth rate of ion mode at fixed $k_\theta \rho_s = 0.3$ decreases at all radii.

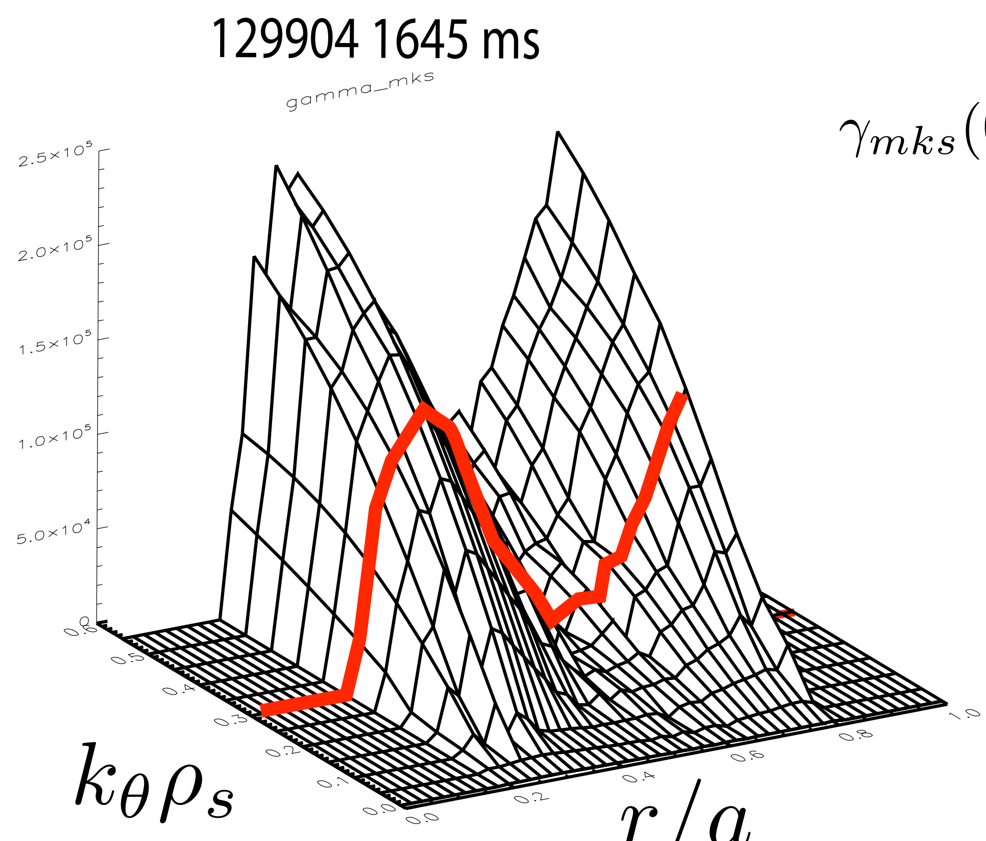


Growth rate of electron mode at fixed $k_\theta \rho_s = 0.3$ increases across the radius, but largest increase at rho~ 0.75

TGLF results : growth rate of most unstable mode largely unchanged at ktheta_rhos = 0.3, r/a = 0.5, 0.6, 0.7



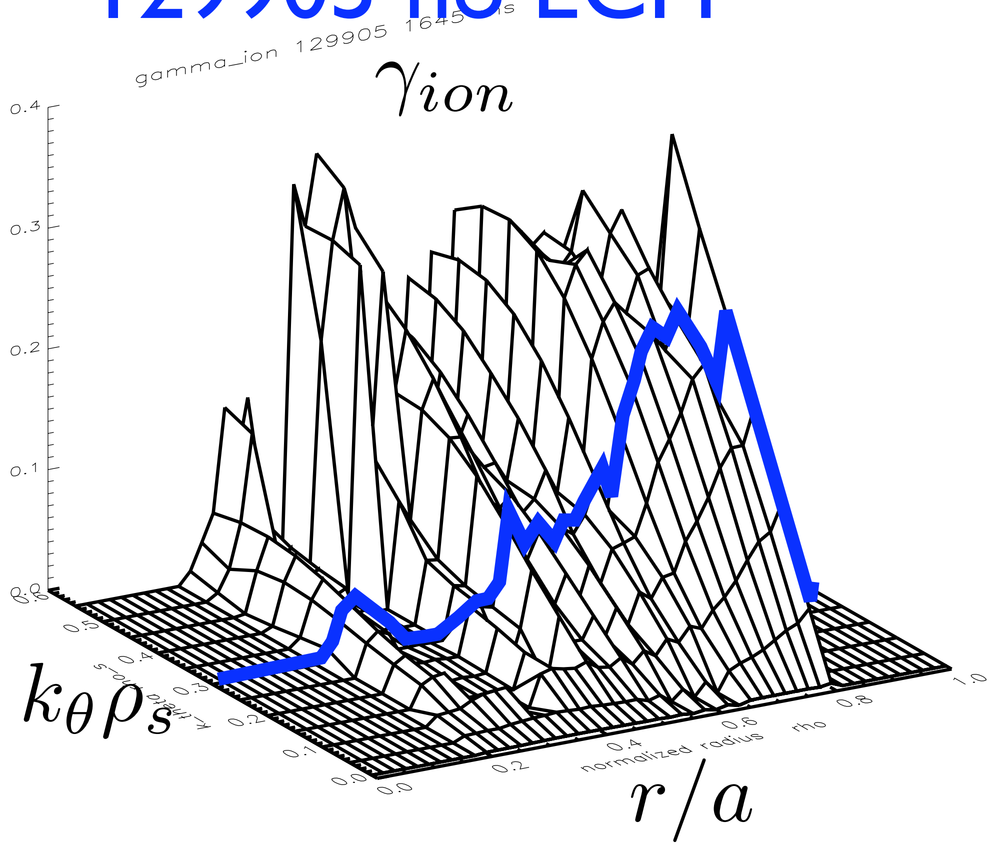
$$\gamma_{mks}(0.5, 0.6, 0.7) = (0.5, 0.7, 0.8) \times 10^5 rad/sec$$

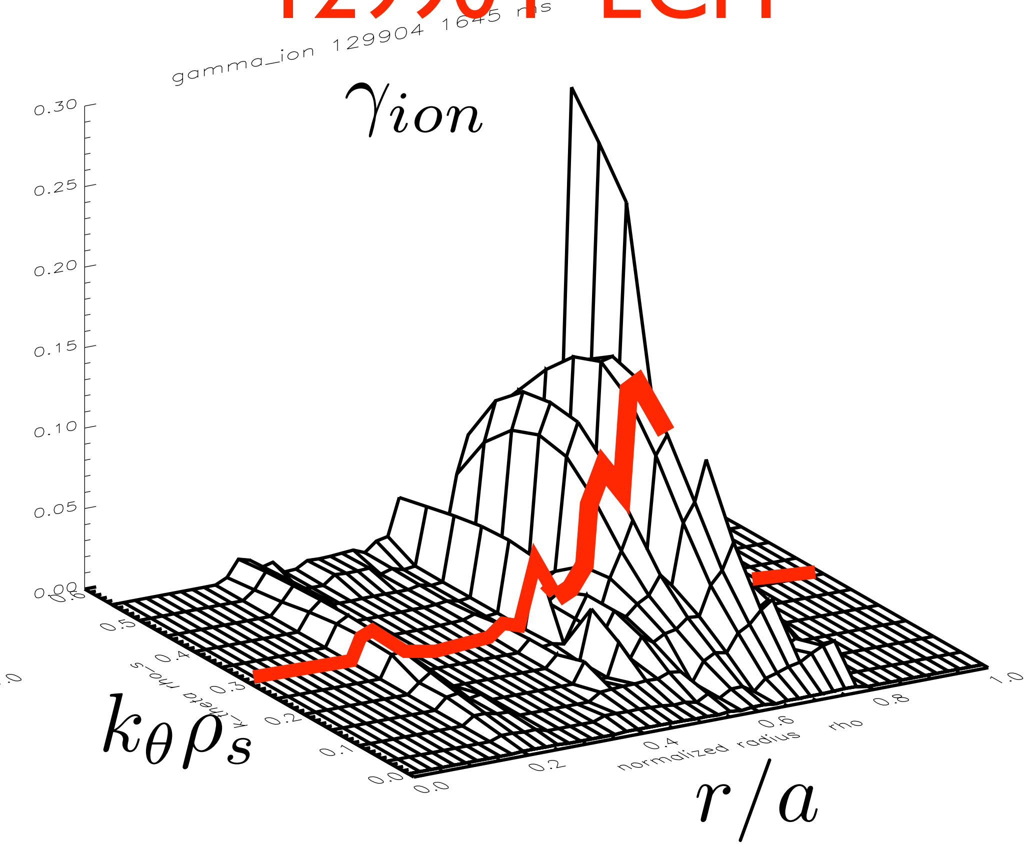


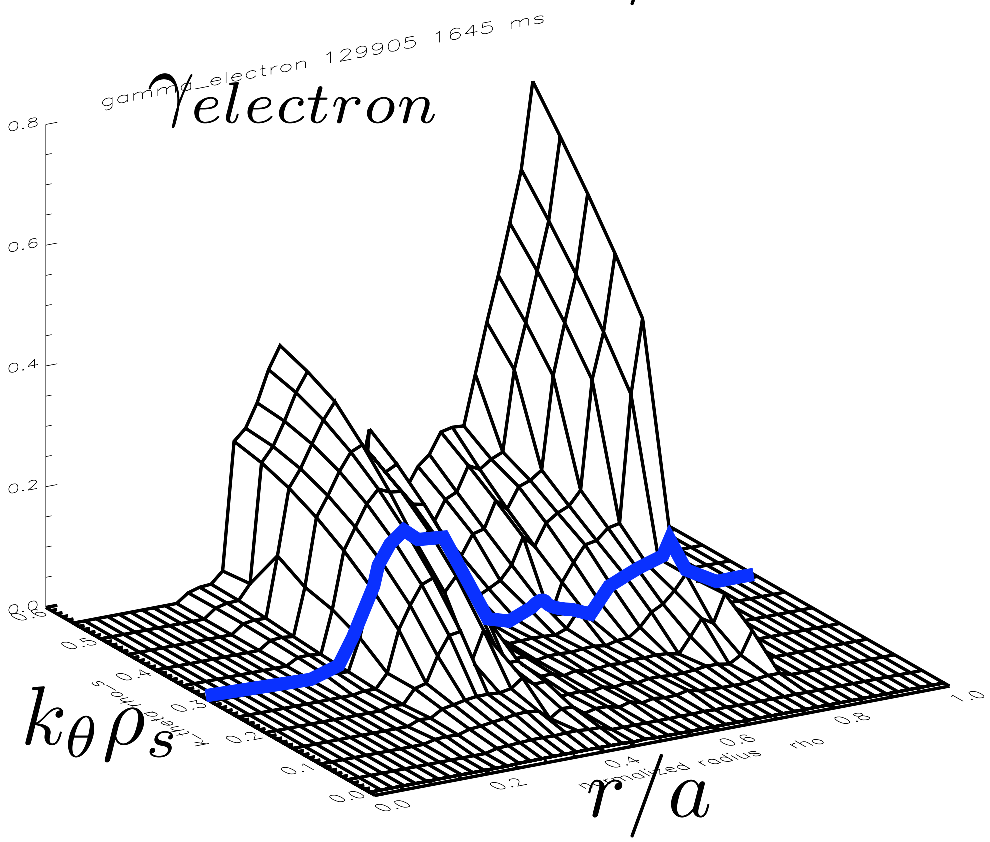
$$\gamma_{mks}(0.5, 0.6, 0.7) = (0.5, 0.7, 0.9) \times 10^5 rad/sec$$

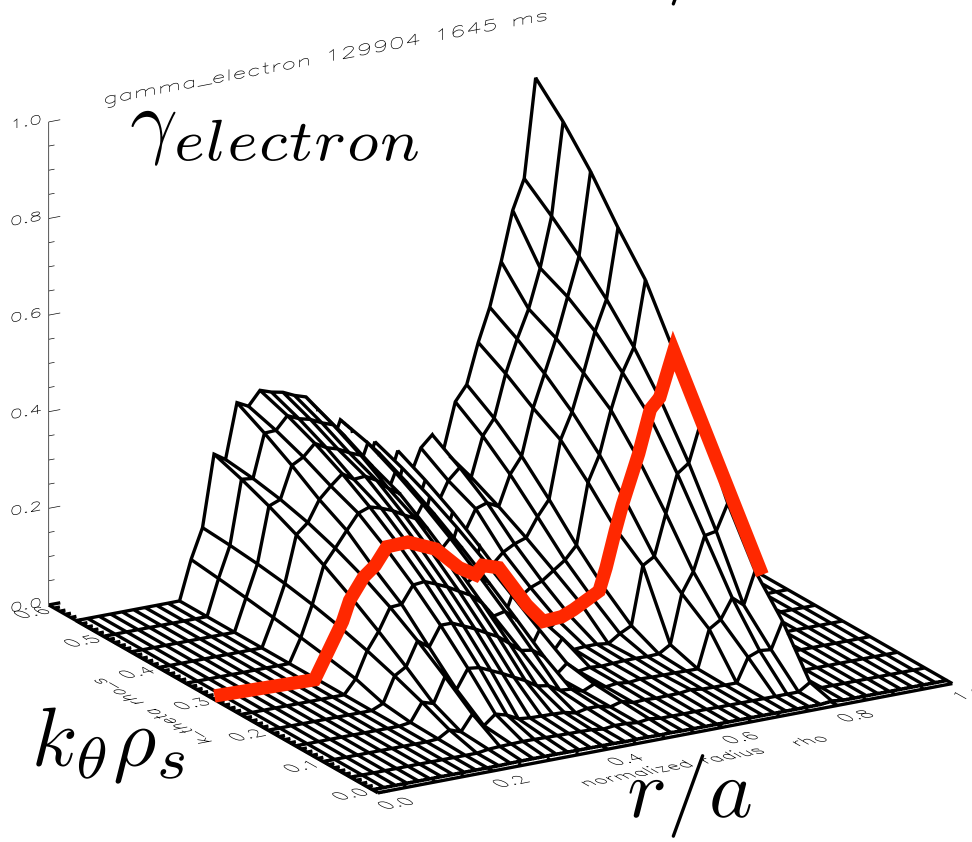
Linear stability results : ITG growth rate decreases at relevant scales, TEM growth rate increases at relevant scales

129905 no ECH | 129904 ECH

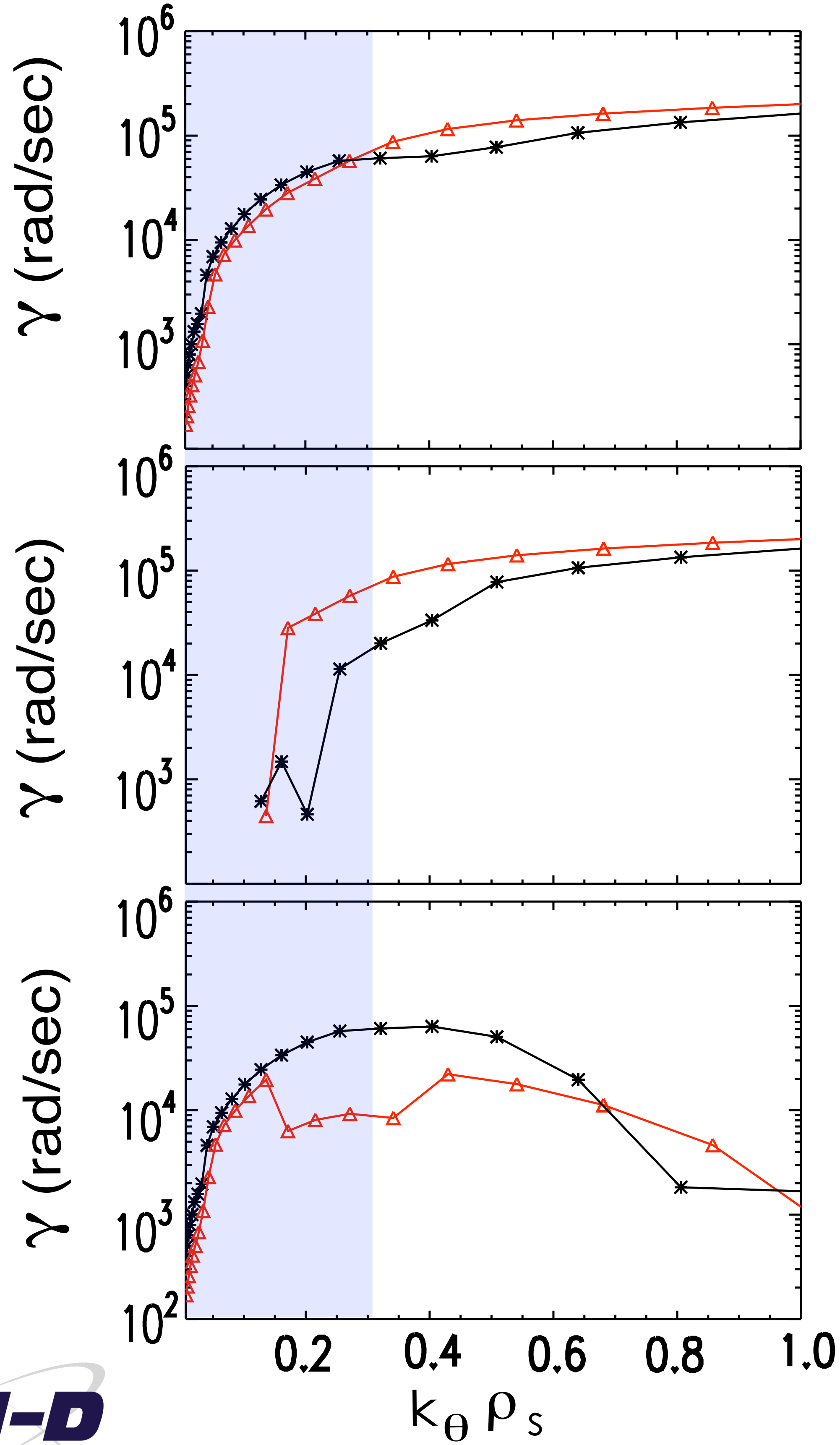








TGLF results : growth rate of most unstable mode largely unchanged for k_theta rho_s < 0.3 at rho = 0.7, but TEM increases, ITG decreases



rho = 0.7

Growth rate of most unstable mode largely unchanged with and without ECH

TEM growth rate increases at long wavelengths with ECH

ITG growth rate decreases at long wavelengths with ECH

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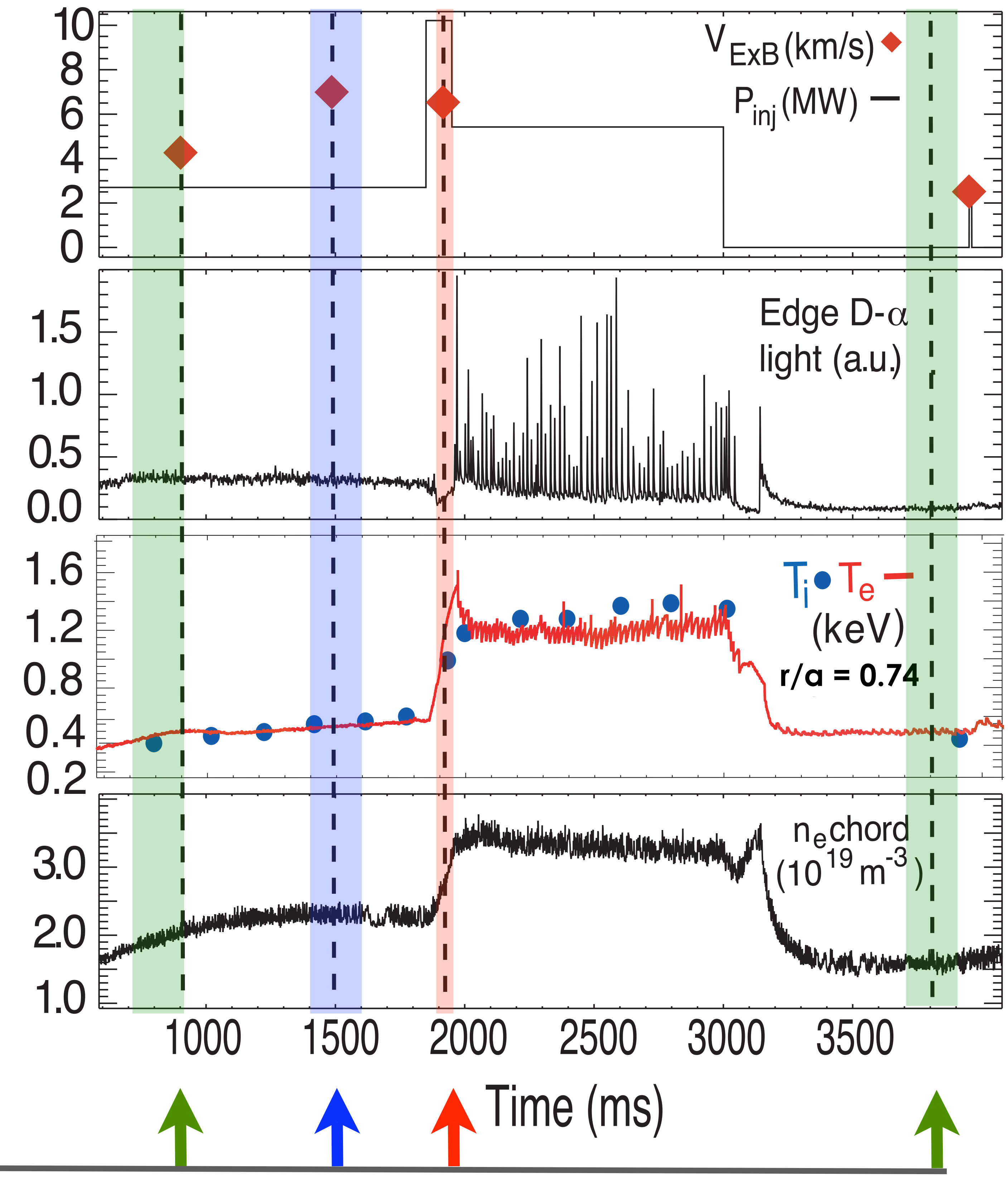
Temperature fluctuations are measured in L-mode, H-mode and Ohmic plasmas in a single discharge

Ip = 1 MA, B_T = 2.1 T, 2.5 -10 MW injected beam power, upper single null

Measure $\tilde{T}_e/T_e$ in

Early L-mode	700-900 ms
Stationary L-mode	1400-1600 ms
ELM-free H-mode	1895-1930 ms
Ohmic	3700-3900 ms



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Doppler shift broadens spectrum and $\tilde{T}_e/T_e$ is reduced in H-mode

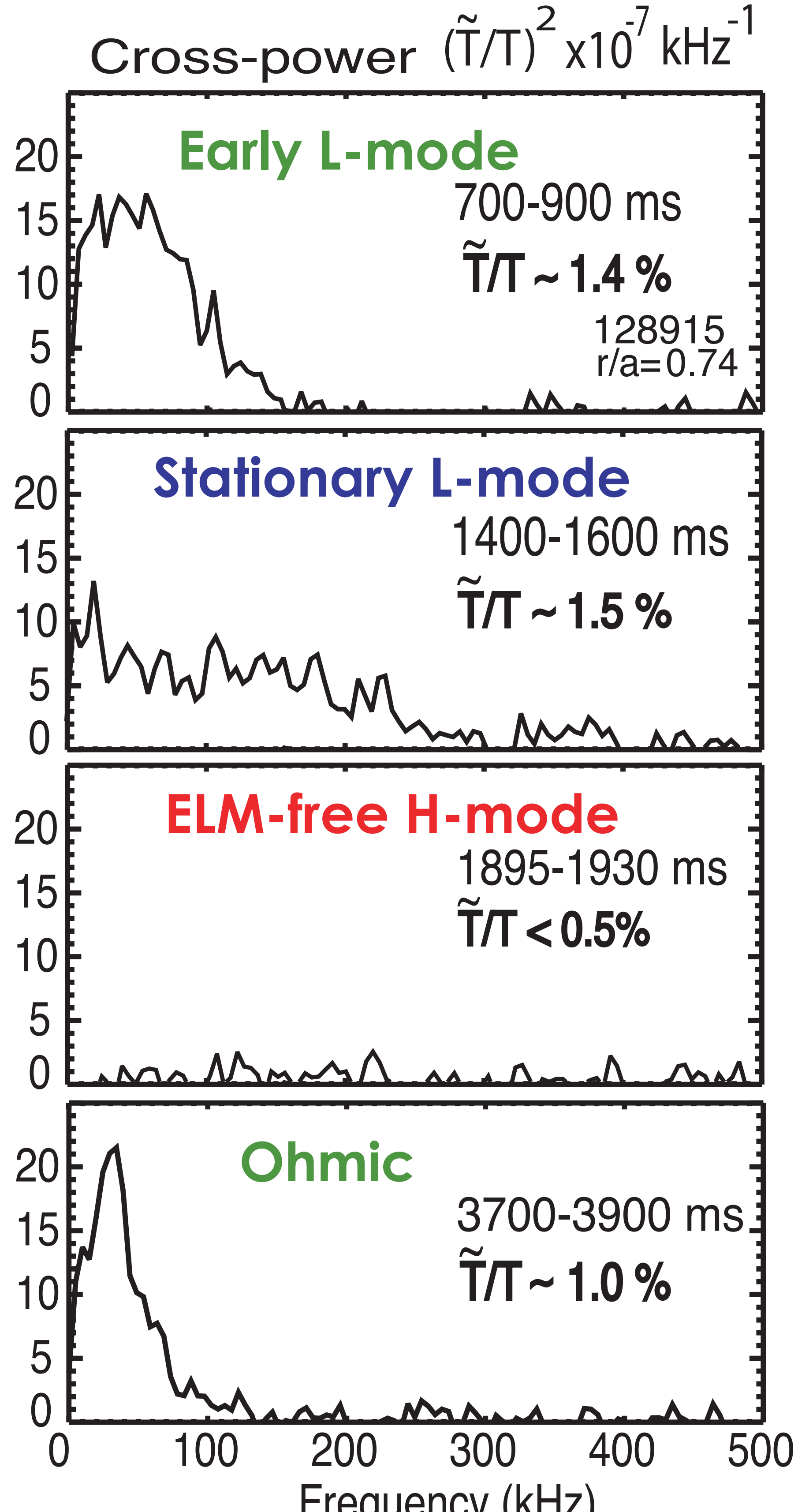
Typical cross-power spectra of $\tilde{T}_e/T_e$ at $r/a = 0.74$

Spectrum broadens and narrows in response to Doppler shifts due to changing ExB rotation

H-mode temperature fluctuations are below sensitivity limit (0.5%, 35 ms)

Corresponds to factor of 3 reduction in normalized fluctuation level

Normalized fluctuation levels in Ohmic (1%) are lower than L-mode (1.5%) at same radius



V_{ExB} = 4.1 km/sec

V_{ExB} = 7.1 km/sec

V_{ExB} = 6.5 km/sec

V_{ExB} = 2.4 km/sec

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