EXPERIMENTAL DESIGN TO EXAMINE THEORY BASED TRANSPORT MODELS USING PERTURBATIVE TECHNIQUES IN THE DIII–D TOKAMAK

Presented by

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GENERAL ATOMICS

IN COLLABORATION WITH

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KEY POINTS

- Two days of DIII–D experimental time have been scheduled to test theory based transport models
  - June 19, 1997 and July 24, 1997
  - Miniproposal review May 13, 1997 and July 1, 1997

- A set of experimental conditions exist where the plasma's response to modulated ECH will allow models to be distinguished
  - We are presently designing only for the first day

- Experimental design continues and we ask for input from the theoretical and experimental community during this process
  - Ideas solicited during DIII–D Brainstorming (http://Fusion.gat.com)
  - A DIII–D Model Testing Working Group has been formed and is working on experimental design (http://Fusion.gat.com/dps-ext/model/model_test.html)

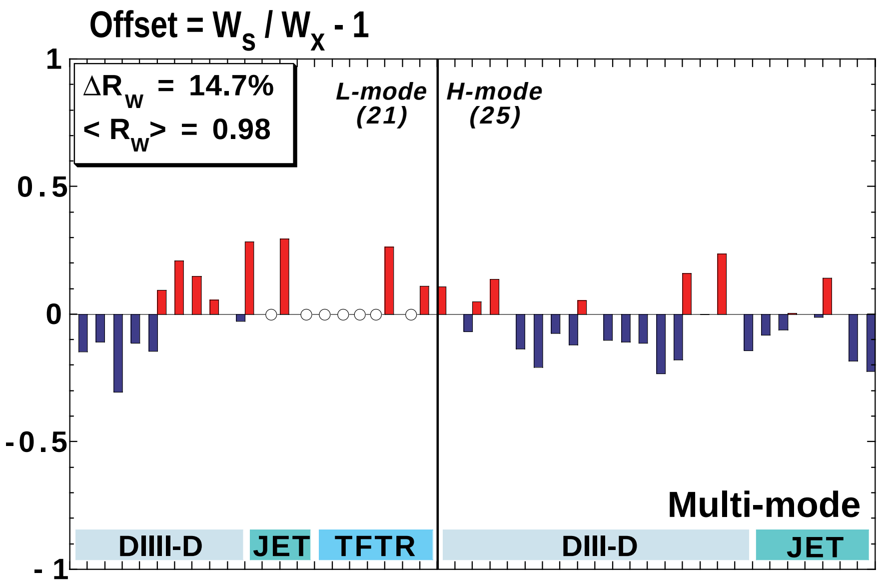
MOTIVATION OF PERTURBATIVE EXPERIMENTS

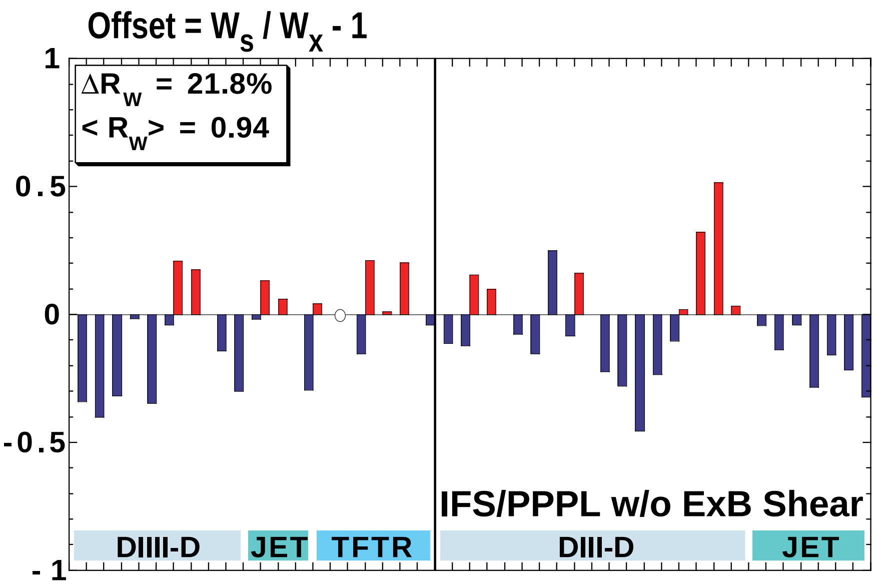
- To move away from predictions based on empirical scaling relationships and toward predictions based on reliable local transport models
    - There is a rich history of perturbative experiments within the community and here we will try to combine perturbative techniques with model predictions

- To acquire experimental data that will allow the community to clearly differentiate between different local transport models
    - The ongoing model validation activity with the ITER profile database has not found large variations in the steady–state temperature profiles from various model predictions
    - Agreement to within approximately ±15% to ±25%

THERE ARE NOT LARGE SCALE VARIATIONS IN THE STEADY–STATE TEMPERATURE PROFILE PREDICTIONS

- Range in RMS deviation from 26.9% for GLF23, 24.1% for IIF, 21.8% for IFS/PPPL, to 14.7% for Multi–mode





from Kinsey 4/97 TTF

$\mathrm{RMS} = \Delta R_W = [\Sigma_i\, (W_{si}/W_{Xi}-1)^2/N]^{1/2}$

$\mathrm{Avg} = \langle R_W \rangle = \Sigma_i\, (W_{si}/W_{Xi}-1)/N$

DIII–D DIAGNOSTIC AND HEATING CAPABILITIES TO BE CONSIDERED DURING EXPERIMENTAL DESIGN

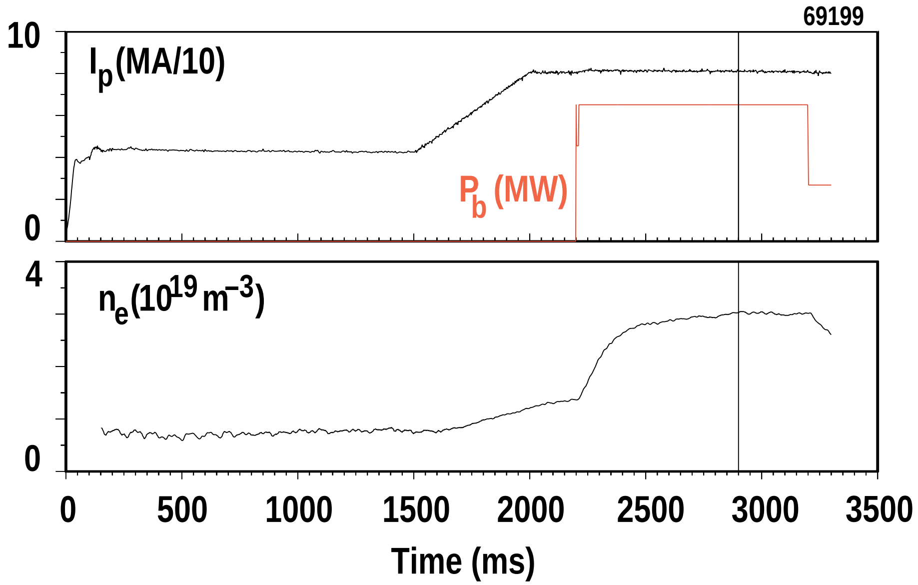
- Target plasma profiles determined by extensive DIII–D diagnostic set
  - Thomson scattering: eight 20 Hz multipulse lasers with 44 spatial points
  - CO2 interferometers: 3 vertical and 1 radial viewing laser
  - ECE radiometer: 16 channels at 100 kHz
  - Charge exchange recombination: 40 channels with > 0.5 ms response
  - Visible Bremsstrahlung: 16 channels with 2 ms response

- The perturbed electron and ion temperature can be measured
  - CER at 1 ms response (500 records), > 50 eV with averaging
  - ECE at 1ms response, plasma coverage optimized at 2.1 T, > 10 eV
  - Additional information from Visible Bremsstrahlung and Soft X–ray

- Experimentally the ECH system is the only suitable perturbation source
  - 1 MW deposited power for electron heating
  - 110 GHz with a toroidally fixed steerable antenna

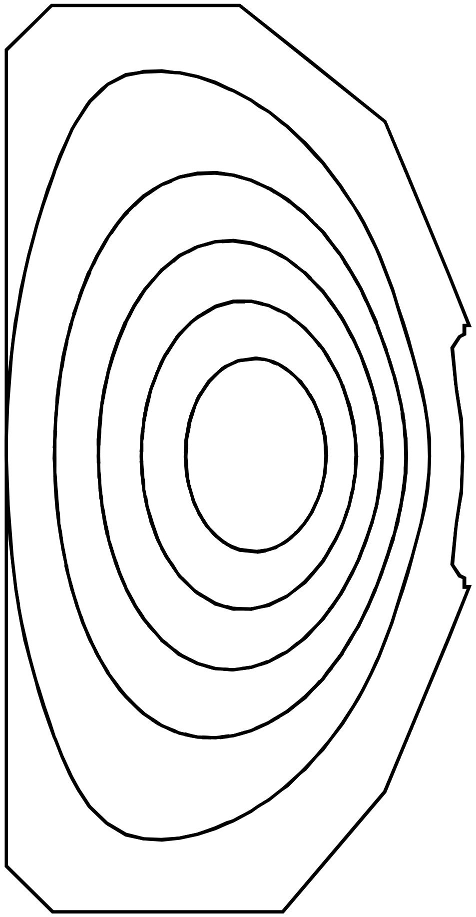
L–MODE TARGET PLASMA FOR MODULATED ECH

- Inside wall limited L–mode
  - 6.6 MW NBI, 0.8 MA, 2.1 T
  - 3×10^{19} m $^{-3}$, $T_{e,i}$ (0) = 4.0, 3.6 keV
- Sawtooth free and ELM free



R (m) = 1.64 a (m) = 0.63

κ = 1.8



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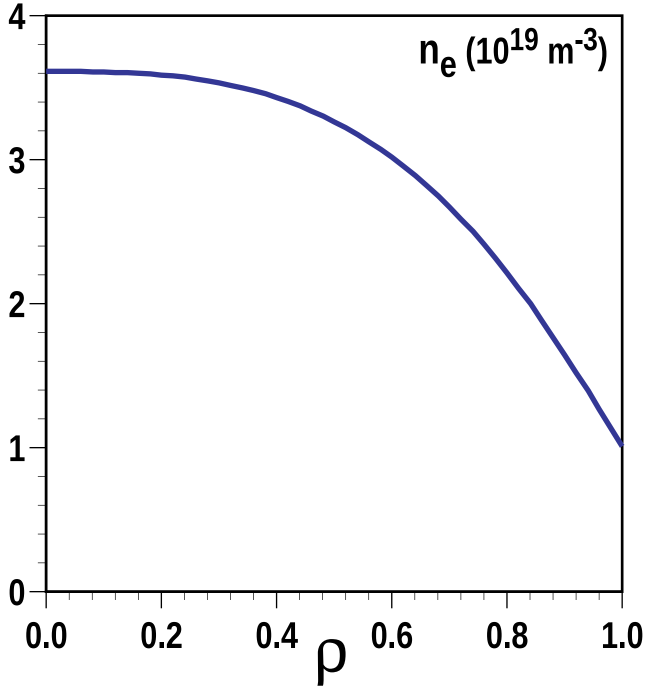
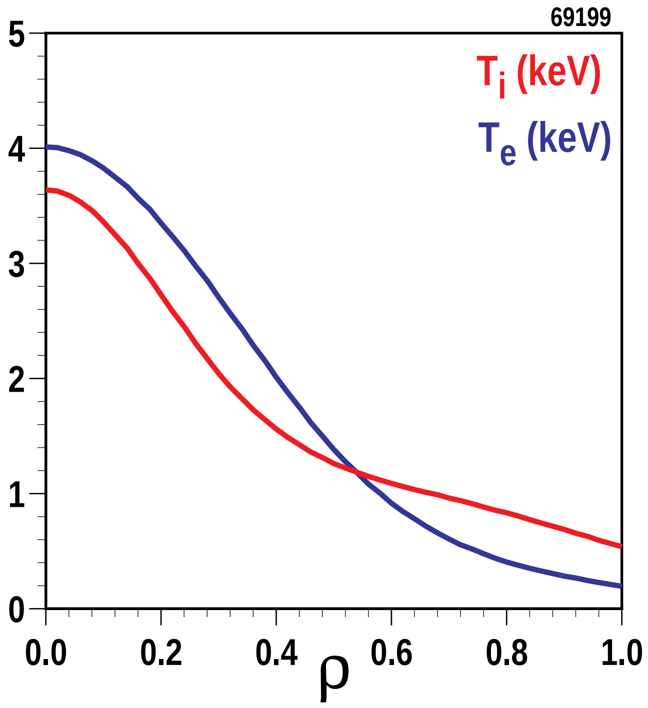
L–MODE TARGET PLASMA PROFILES

Electron density from CO_2 and Thomson scattering

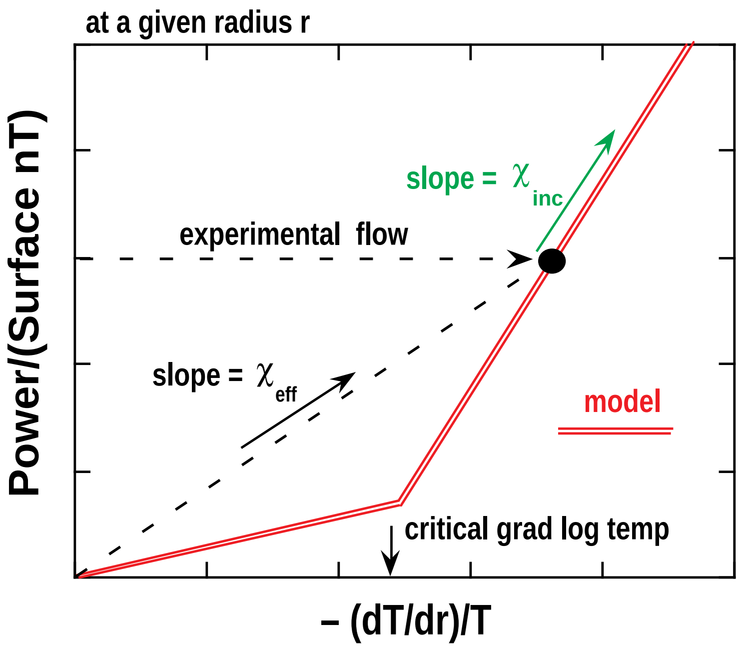


Temperatures from CER, HECE, and Thomson scattering



STIFFNESS: PERTURBATION AROUND A POWER BALANCE

- Slope to transport solution point χ_{eff} or χ_{pb}
  - χ_{eff} = [P/SnT] / [-(dT/dr)/T]
- Local slope at solution point χ_{inc} or χ_{hp}
  - $\chi_{inc} = \Delta$ [P/SnT] / Δ [-(dT/dr)/T]
- Define stiffness as χ_{inc} / χ_{eff}



- Large stiffness tends to force marginality to critical gradient no matter how large the power flow
  - Gyro–fluid ITG model: stiffness O(100); multimode model: O(10)
  - Itoh–Itoh–Fukayama model has no critical gradient. Model is a gentle concave curve with a very small stiffness O(1)

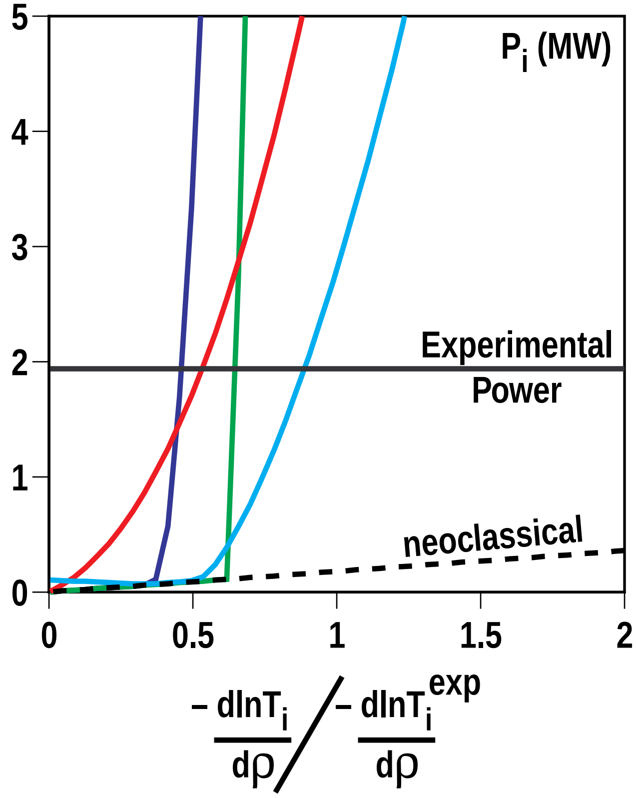
MODELS CONSIDERED DURING EXPERIMENTAL DESIGN

- Dorland–Kotschenreuther–Hammett (IFS/PPPL) gyro-fluid model
  - Critical gradient model but excluding sheared E × B flow
- Itoh–Itoh–Fukuyama (IIF) model
  - One–fluid transport without critical gradient
  - Renormalized by 0.3
- Multi–Mode (MM) model
  - Combines drift wave and ballooning transport models to predict temperature
  - Critical gradient model
- Waltz’s MLT code used to predict models’ response to temperature perturbation

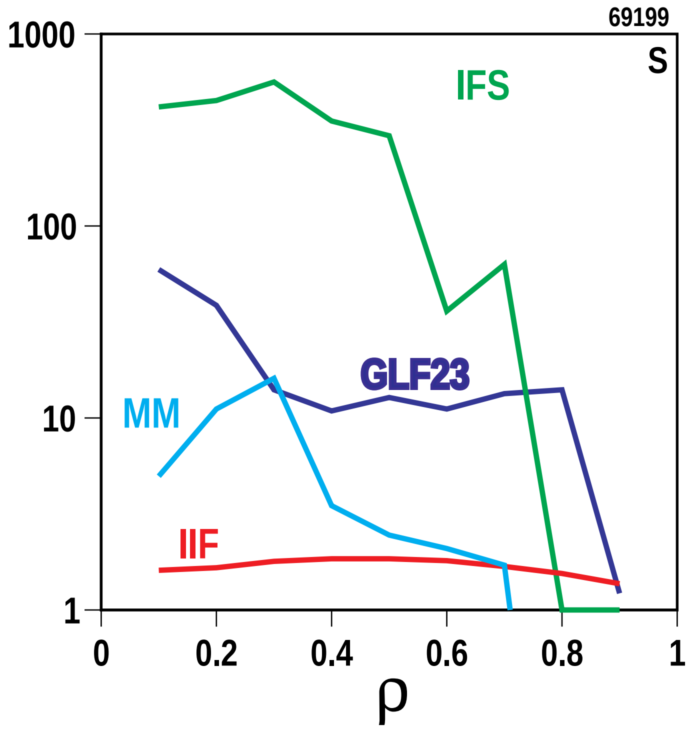
DIFFERENT MODEL STIFFNESS MAKES TRANSIENT TECHNIQUES AN IDEAL APPROACH TO COMPARE EXPERIMENT TO THEORY

Ion Power Flow at $\rho = 0.4$

$$\frac{-\,d\ln T_e}{d\rho} = \frac{-\,d\ln T_i}{d\rho}$$

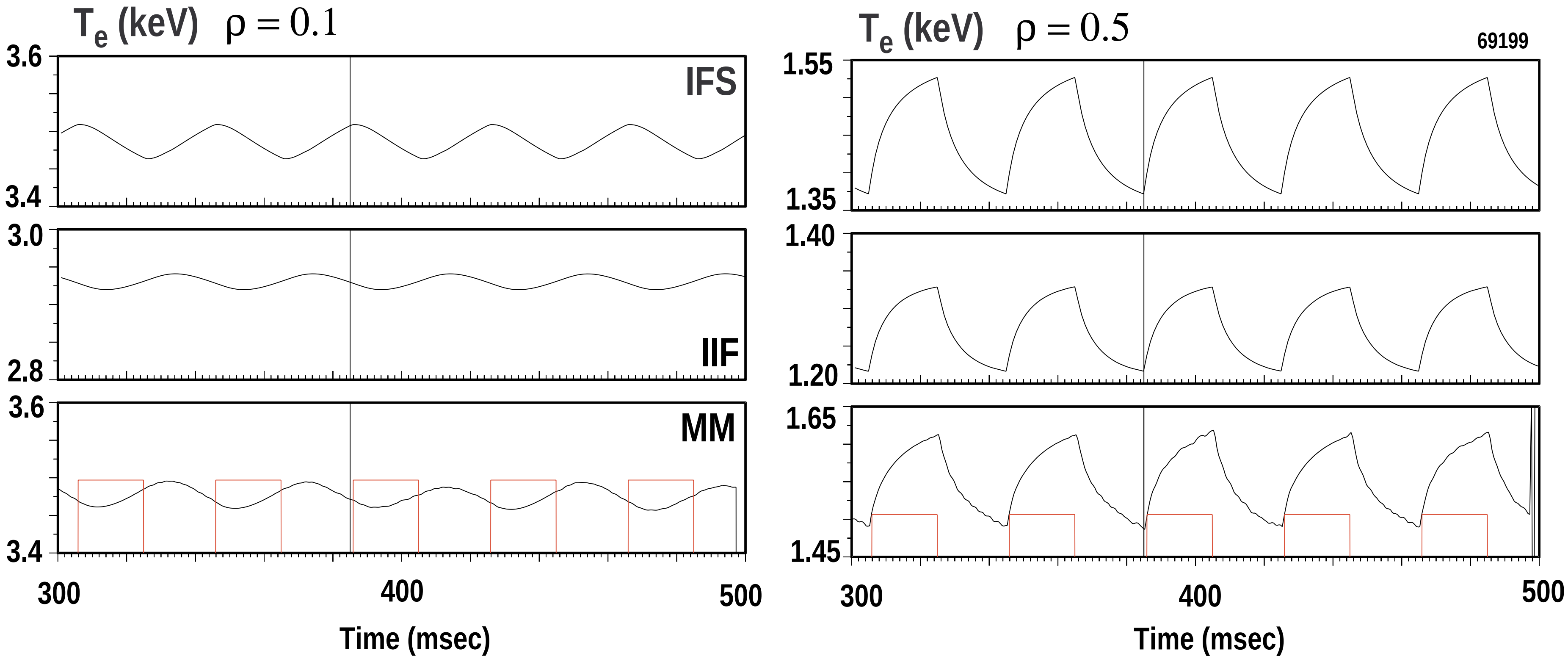


Model stiffness across the Plasma volume



THE ELECTRON TEMPERATURE PHASE AND AMPLITUDE RESPONSE SEPARATES THE IFS MODEL FROM IIF AND MM

- 1 MW ECH for 20 ms on, 20 ms off deposited at $0.4 < \rho < 0.5$ ($n_e = 3 \times 10^{19}$ m $^{-3}$)
- Clearly detectable difference in the T_e response at $\rho = 0.1$



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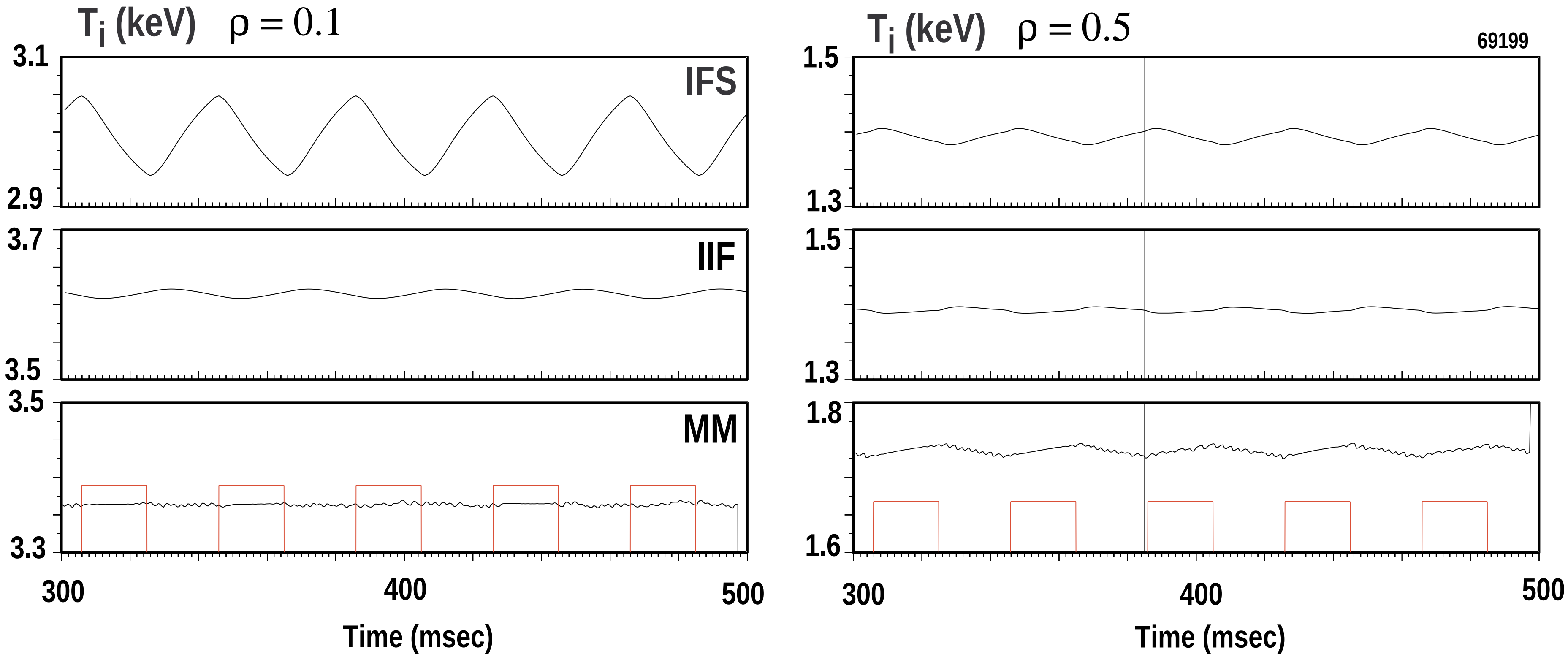
ION TEMPERATURE RESPONSE SHOULD BE LARGE ENOUGH FOR RELIABLE PERTURBATIVE MEASUREMENTS

- 1 MW ECH for 20 ms on, 20 ms off deposited at $0.4 < \rho < 0.5$ ($n_e = 3 \times 10^{19}$ m $^{-3}$)
- The 100 eV peak–to–peak T_i variation for IFS should be detectable
  - The 25 eV peak–to–peak T_i variation for IIF will not



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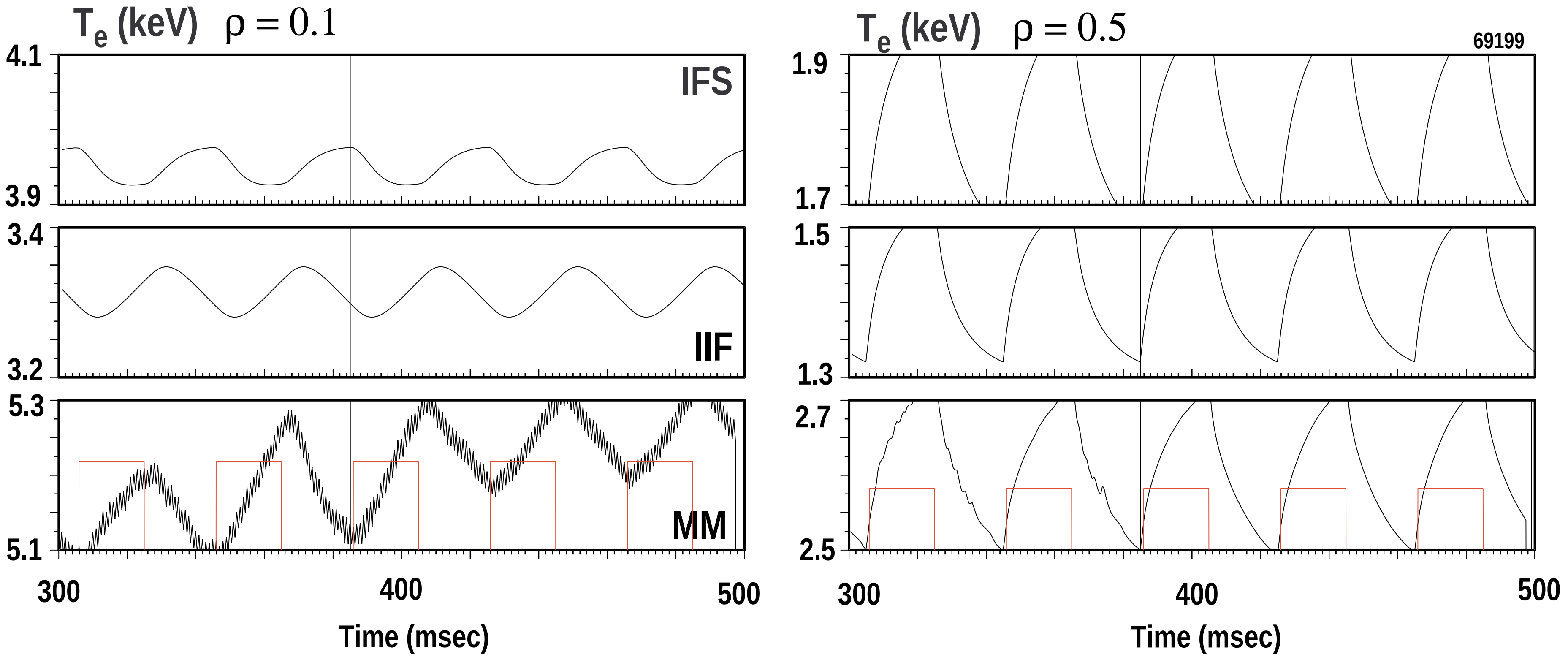
REDUCING THE DENSITY INCREASES THE ELECTRON TEMPERATURE RESPONSE

- 1 MW ECH for 20 ms on, 20 ms off deposited at $0.4 < \rho < 0.5$ ($n_e = 1.5 \times 10^{19}$ m $^{-3}$)
- The T_e response of the IIF model has increased in magnitude at $\rho = 0.1$
  - Phase difference between the IIF and IFS model predictions



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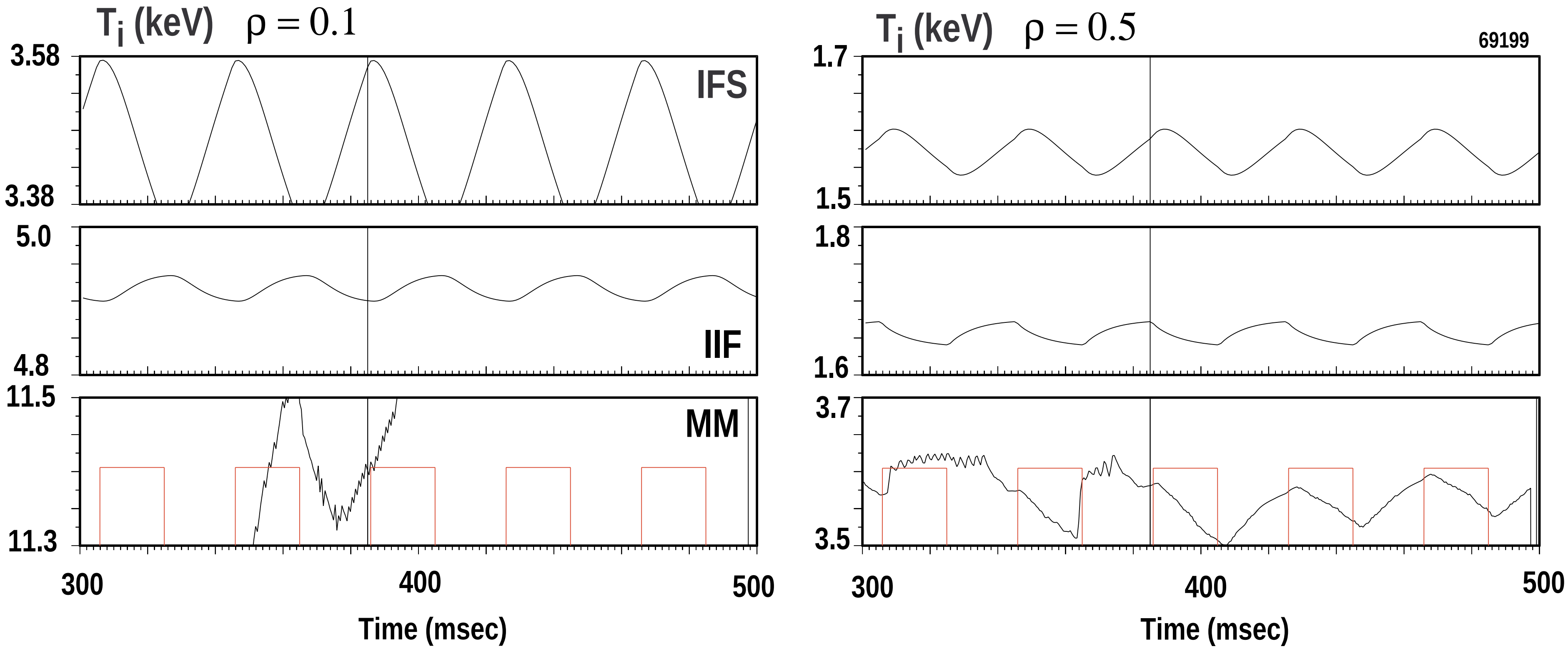
REDUCING THE DENSITY INCREASES THE ION TEMPERATURE RESPONSE TO A CLEARLY MEASURABLE LEVEL

- 1 MW ECH for 20 ms on, 20 ms off deposited at $0.4 < \rho < 0.5$ ($n_e = 1.5 \times 10^{19}$ m $^{-3}$)
- The T_i variation is now greater than 200 eV peak–to–peak for the IFS model
  - IFS ion response is out of phase with the ECH pulse



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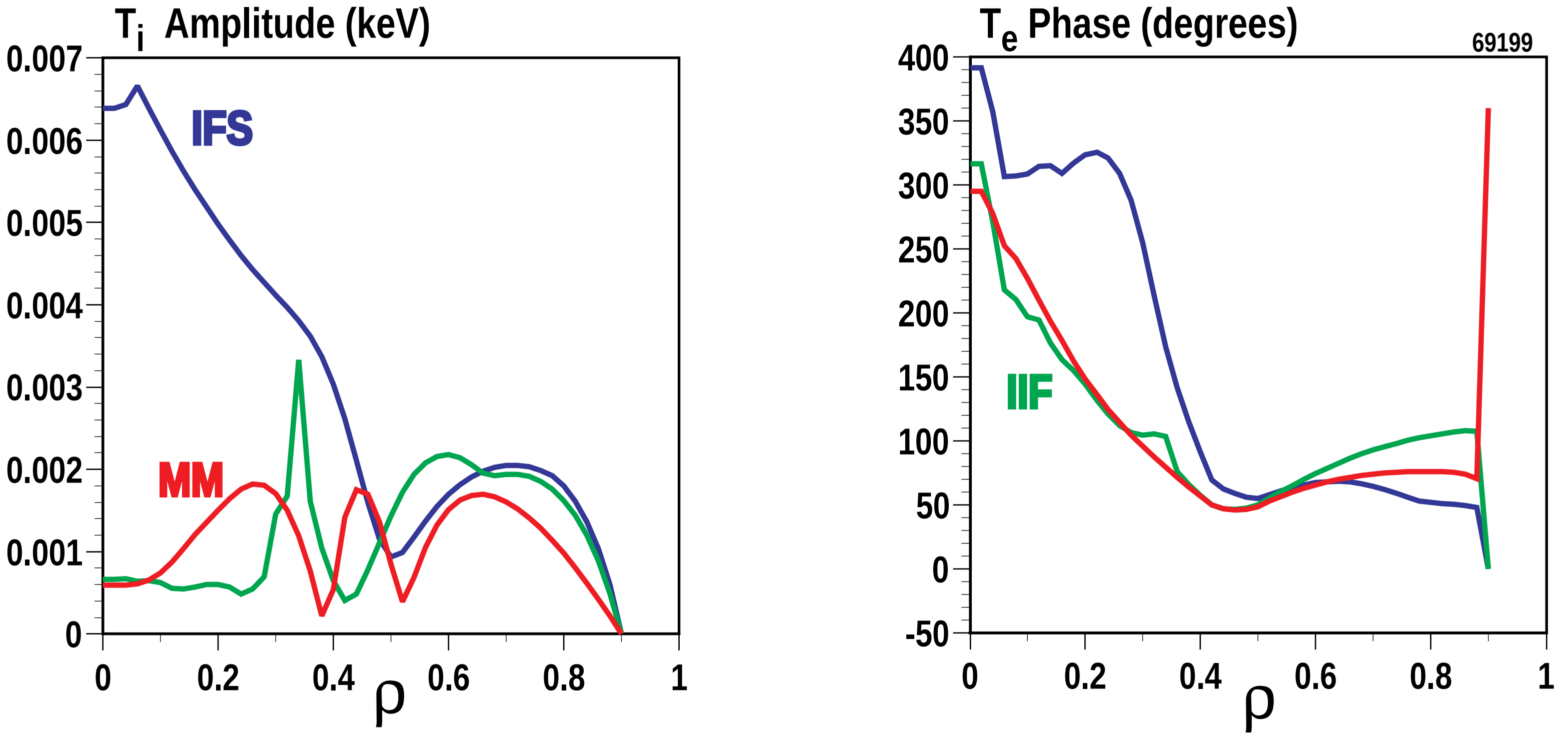
FOURIER ANALYSIS WILL BE USED TO ANALYZE ACTUAL EXPERIMENTAL DATA

- First harmonic analysis for 1 MW ECH modulated at 10 ms on and 10 ms off shows a separation between the IIF and MM models and the IFS model



SUMMARY

- A set of experimental conditions has been found that separate the IFS model from the IIF and MM models
  - Differences in the T_e and T_i response for both phase and amplitude
- Lower target density increases central temperature response
  - IFS model predicts a greater than 200 eV central T_i drop at the time of the ECH pulse
- The experiment as presently envisioned would include a scan to low density in an inside wall limited L–mode plasma
  - Operation at several neutral beam power levels would be possible
  - Several H–mode pulses can be investigated during this first day to access usability of the LH heat pulse perturbation and modulated ECH in the steady–state ELM phase
- What target plasma will allow us to distinguish the IIF and MM models or under what conditions does the stiffness of the two models differ the most?
  - High power H–mode?
  - Elongation scan?