Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.1.1.2 (Experimental)

**Plasma Edge Conditions During Pellet Induced H-mode Transitions in DIII-D**[1] P. GOHIL, K.H. BURRELL, General Atomics, L.R. BAYLOR, T.C. JERNIGAN, Oak Ridge National Laboratory — H–mode transitions have been produced as a direct result of pellet injection in DIII–D. Significant changes to the plasma edge conditions occur during these pellet induced H–mode transitions. Analysis of these changes can result in a greater understanding of the key quantities responsible for the formation of the edge transport barrier at the L–H transition. H–mode transitions were produced by pellets injected from the inner wall into the high toroidal field side (HFS) of the plasma and also by pellets injected from the outer wall into the low field side (LFS) of the plasma. Both the HFS and LFS pellets produced substantial increases in the edge electron density with a simultaneous decrease in the edge temperature at the L–H transition. This was followed by the establishment of clear H–mode electron density and temperature pedestals at the plasma edge. Pellet injection was able to produce H–mode transitions at lower NBI powers of 4.9 MW, compared to non-pellet discharges which remained in L–mode at NBI powers of 7.3 MW, hence, resulting in an effective reduction of the H–mode power threshold by 2.4 MW.

[1]Supported by U.S. DOE Contracts DE-AC03-99ER54463 and DE-AC05-96OR22464.

- [ ] Prefer Oral Session
- [X] Prefer Poster Session

P. Gohil
gohil@gav.gat.com
General Atomics

Special instructions: DIII-D Poster Session 1, immediately following RJ Groebner

Date printed: July 16, 1999

Electronic form version 1.4

# OVERVIEW

- H–mode plasmas have been produced by injecting frozen deuterium pellets into L–mode plasmas in DIII–D
  - Pellets injected from the low field, outside edge of the plasma and from the high field, inside plasma edge were both able to produce H–mode plasmas
- The large influx of particles at the plasma edge from the pellet leads to substantial reductions in the edge electron and ion temperatures. The lowered temperatures are still condusive for the formation of the H–mode transport barrier
  - A critical edge temperature is not necessary in these H–mode transitions
  - Pellet induced H–modes have LH transitions at plasma parameters far below theoretical predictions
- The power threshold for the H–mode transition is reduced by about 2.4 MW (by up to 33%) using pellet injection
  - Pellets produced H–mode plasmas at lower input power than reference plasma discharges without pellets
  - Reference plasma discharges without pellets stayed in L–mode throughout the applied neutral beam heating even in the presence of strong sawteeth and higher NBI power

# EXPERIMENTAL SETUP

- An unbalanced, double-null diverted discharge with the $\nabla B$ drift away from the dominant X–point was investigated. This plasma configuration resulted in a high H–mode power threshold such that L–mode conditions were maintained at high input power. Pellets from the high toroidal field side or low toroidal field side were launched into steady L–mode plasmas to determine their ability to produce H–mode plasmas

- Operational parameters
  - Plasma current, $I_p$ = 1.6 MA
  - Toroidal magnetic field, $B_T$ = 1.8–2.1 T
  - Target electron density, $\bar{n}_e = 3.0–4.0 \times 10^{19}\ m^{-3}$
  - Auxiliary heating power (NBI) = 4.9–9.2 MW
  - Safety factor: on-axis, q(0) = 0.9–1.0<br>edge, $q_{95}$ = 3.3–3.4

- Plasma configuration
  - Unbalanced, double-null diverted discharge, predominantly diverted on upper divertor
  - Elongation, $\kappa$ = 1.63–1.71
  - Upper triangularity, $\delta_{upp}$ = 0.70–0.85
  - Lower triangularity, $\delta_{low}$ = 0.28–0.29

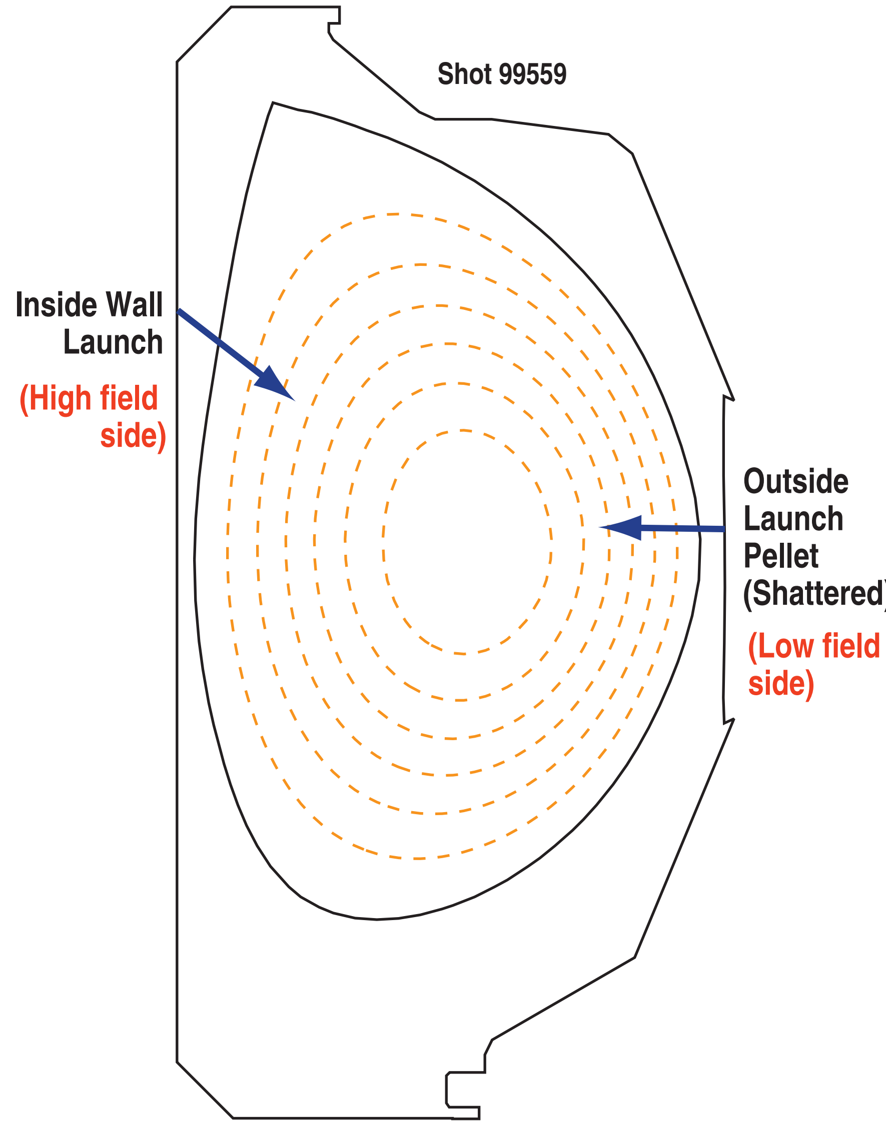
# PELLETS WERE LAUNCHED FROM THE LOW FIELD SIDE OR HIGH FIELD SIDE OF DIII–D

- Outside wall launched pellets (low field side) were shattered prior to entry into plasma in order to minimize pellet penetration $\Rightarrow$ predominantly edge density perturbation

- Type: solid deuterium
  Pellet size: 2.7 mm
  Equivalent number of particles: $2 \times 10^{20}$
  Rep rate: up to 10 Hz
  Speed: 100–350 m $s^{-1}$

  Speed for Specific Shots:

| Shot | |
|---|---|
| 99559 | 314, 194 and 160 m $s^{-1}$ (shattered pellets – outside launch) |
| 100162 | 222 m $s^{-1}$ (inside launch) |
| 100170 | 235 m $s^{-1}$ (inside launch) |

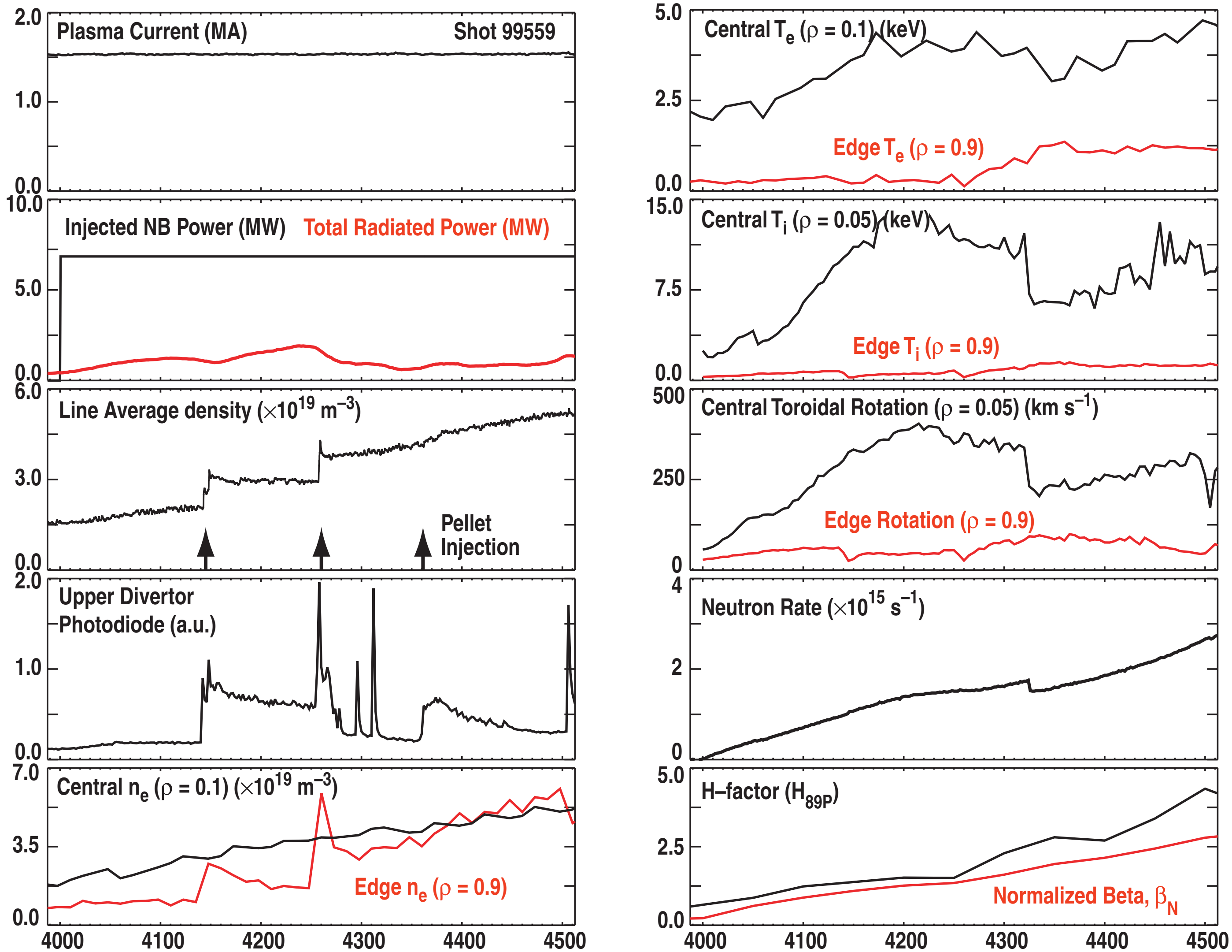



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

ornl

220-99/rs

# TEMPORAL EVOLUTION OF PELLET INDUCED H–MODE (PIH–MODE) DISCHARGE (SHATTERED, LOW FIELD SIDE PELLET)

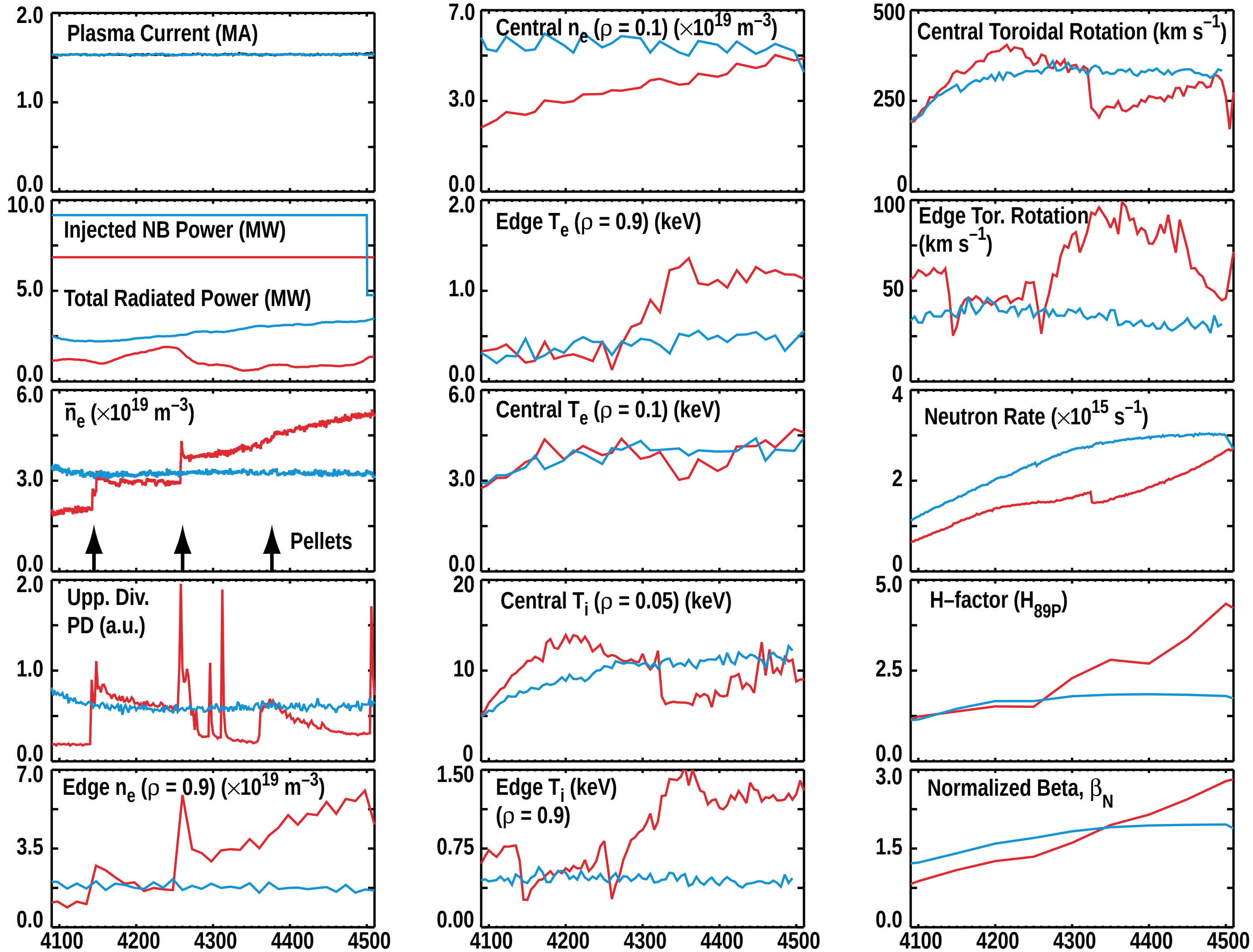



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# COMPARISON OF PIH–MODE DISCHARGE ($P_{NBI}$ = 6.8 MW) WITH NO PELLET, L–MODE DISCHARGE ($P_{NBI}$ = 9.2 MW)




- The power required to access H–mode is reduced by at least 2.4 MW using pellet injection

Shattered LFS Pellet

— PIH–Mode (Shot 99559)

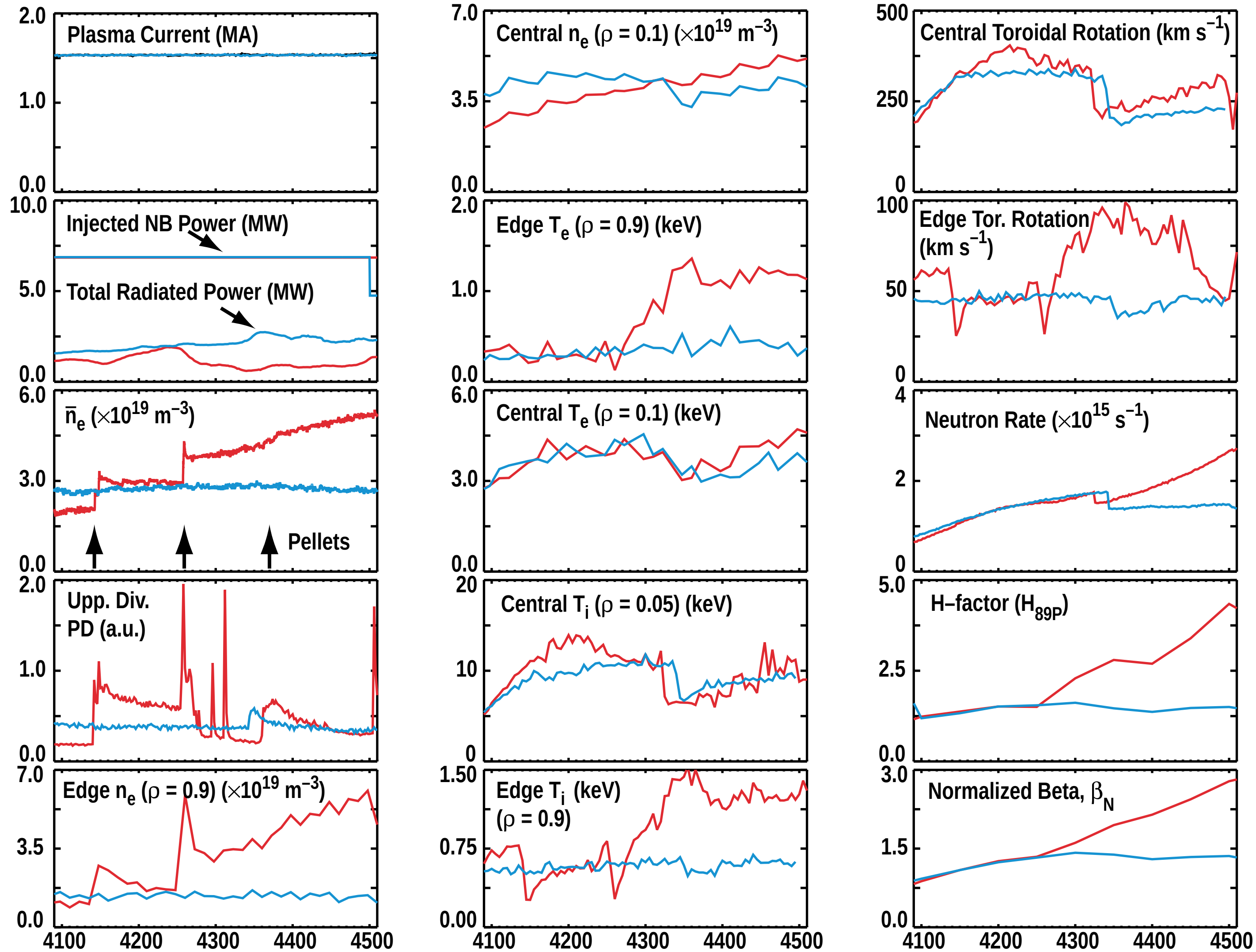
— No Pellet, L–Mode (Shot 99573)

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

# COMPARISON OF PIH–MODE DISCHARGE WITH NO PELLET L–MODE REFERENCE DISCHARGE ($P_{NBI}$ = 6.8 MW FOR BOTH DISCHARGES)




Shattered LFS Pellet

— PIH–Mode (Shot 99559)

— No Pellet, L–Mode (Shot 99572)

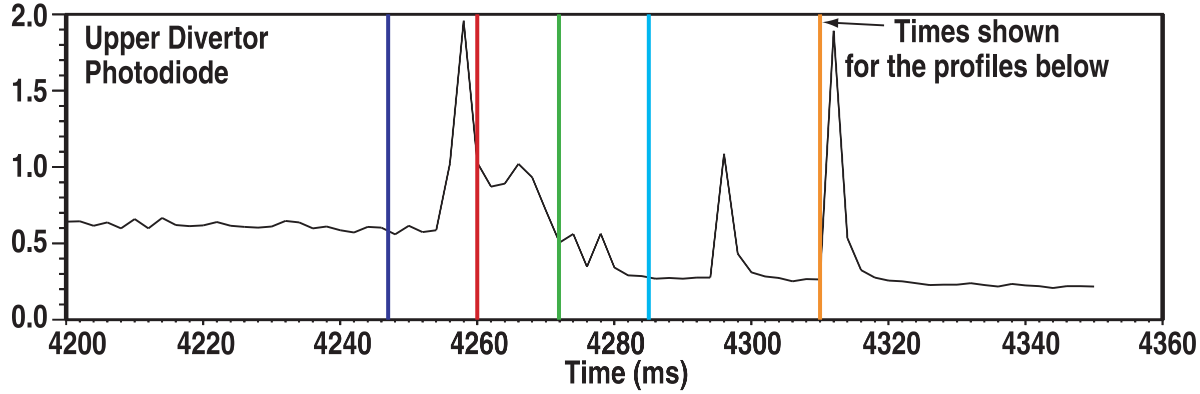
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

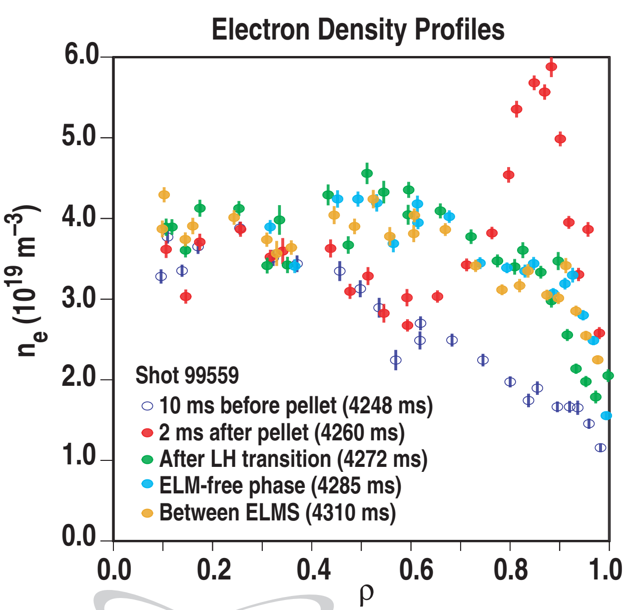
GENERAL ATOMICS

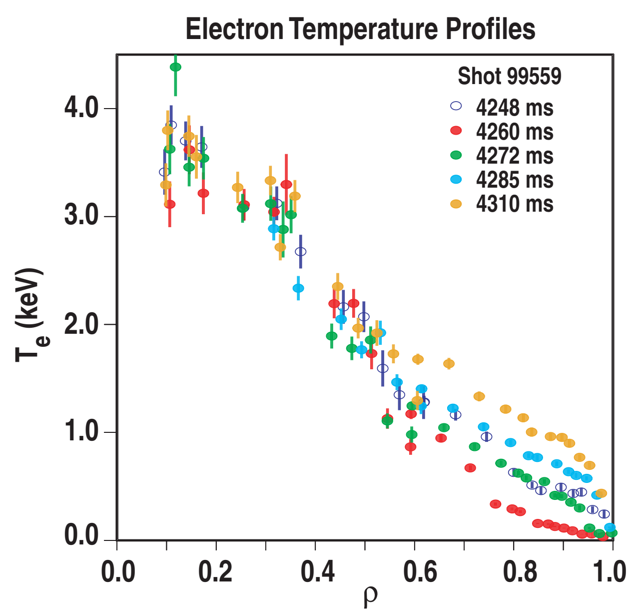
346-99/rs

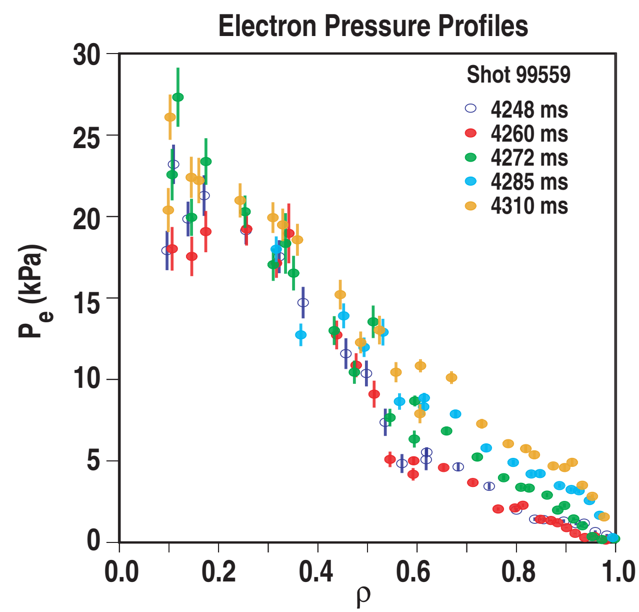
# EVOLUTION OF ELECTRON KINETIC PROFILES IN THE PELLET INDUCED H–MODE PLASMA

- The edge electron temperature is reduced at the L–H transition — disagrees with H–mode theories requiring edge critical electron temperature



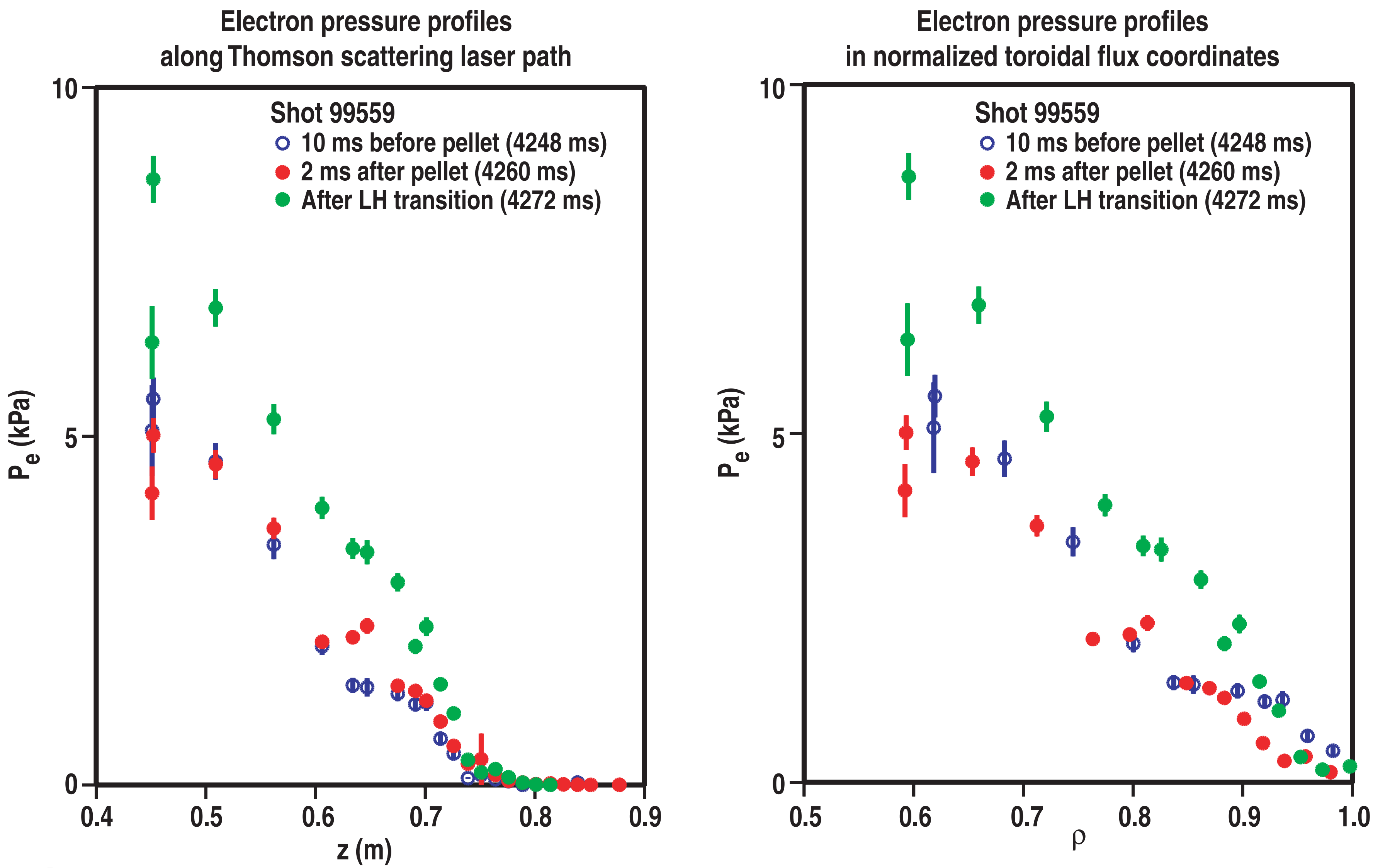




DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# THE INCREASE IN THE EDGE ELECTRON PRESSURE PEDESTAL AND GRADIENT CLEARLY SHOWS THE TRANSITION TO H–MODE



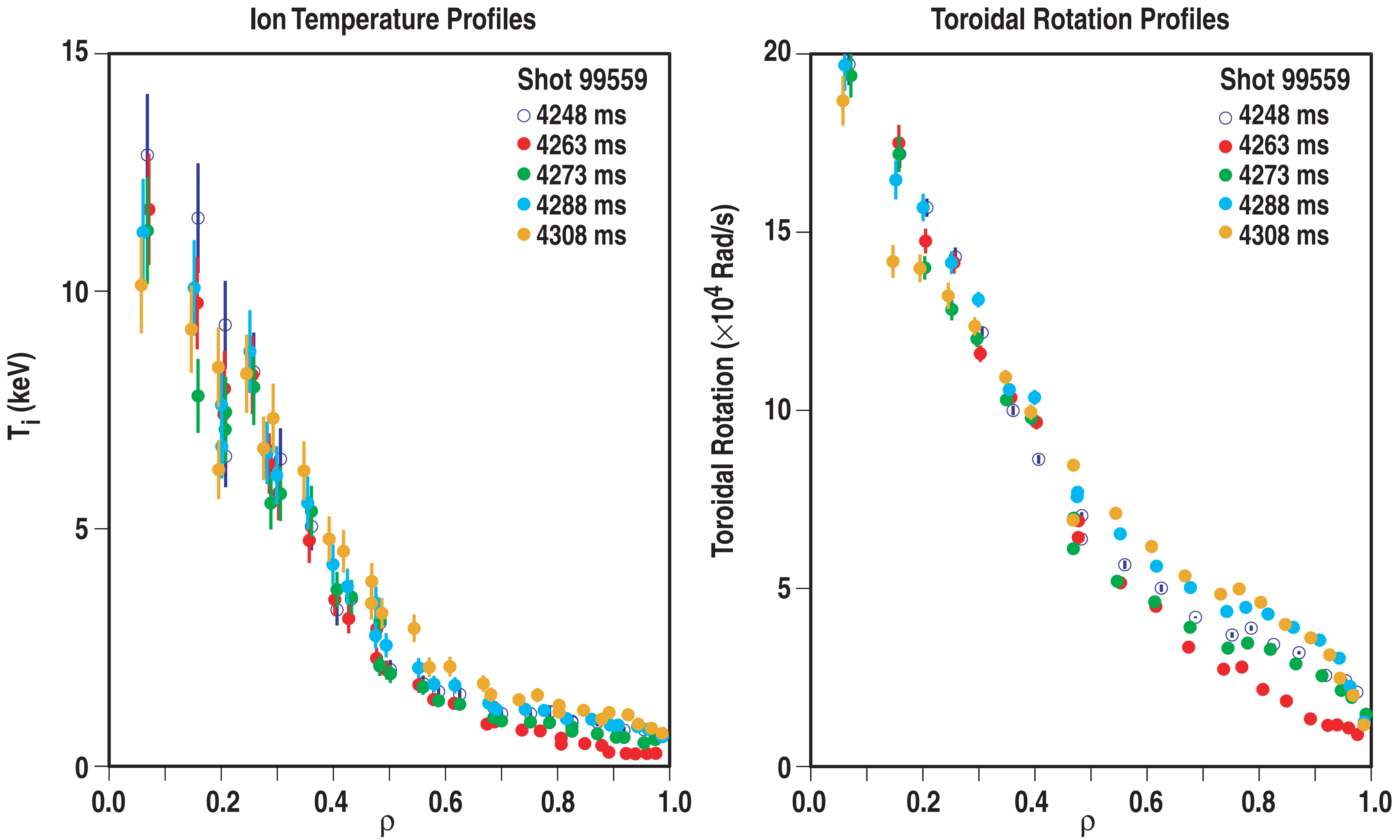

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# BOTH THE EDGE ION TEMPERATURE AND TOROIDAL ROTATION ARE REDUCED AFTER PELLET INJECTION

- Pellet injection time = 4258 ms
- Integration time = 5 ms



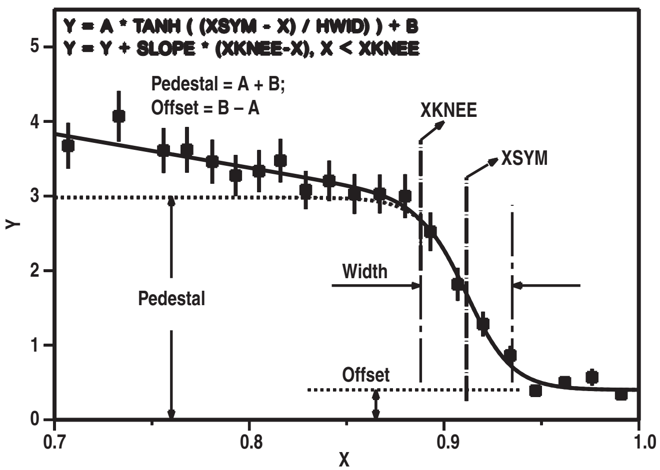

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

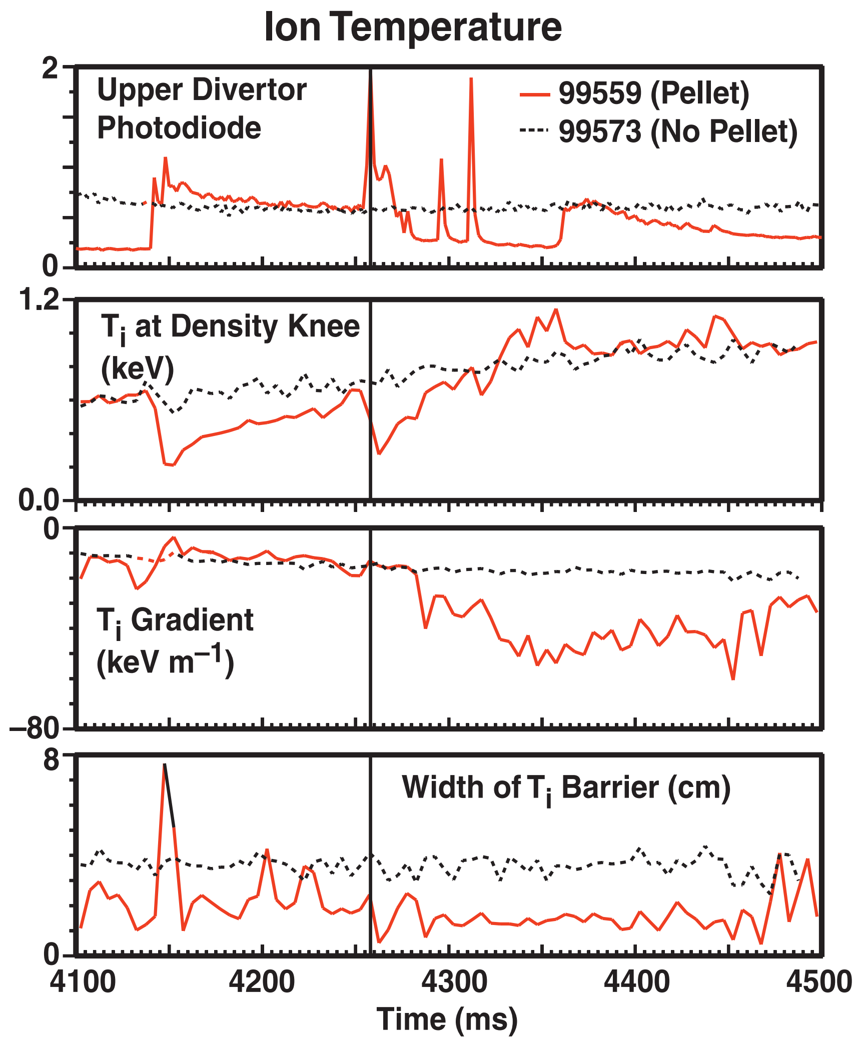
220-99/rs

# EDGE ION TEMPERATURE PEDESTAL AND GRADIENT INCREASE INTO THE H–MODE

- Tanhfit analysis is used to determine edge local parameters




- Note: gradients are shown on a negative scale



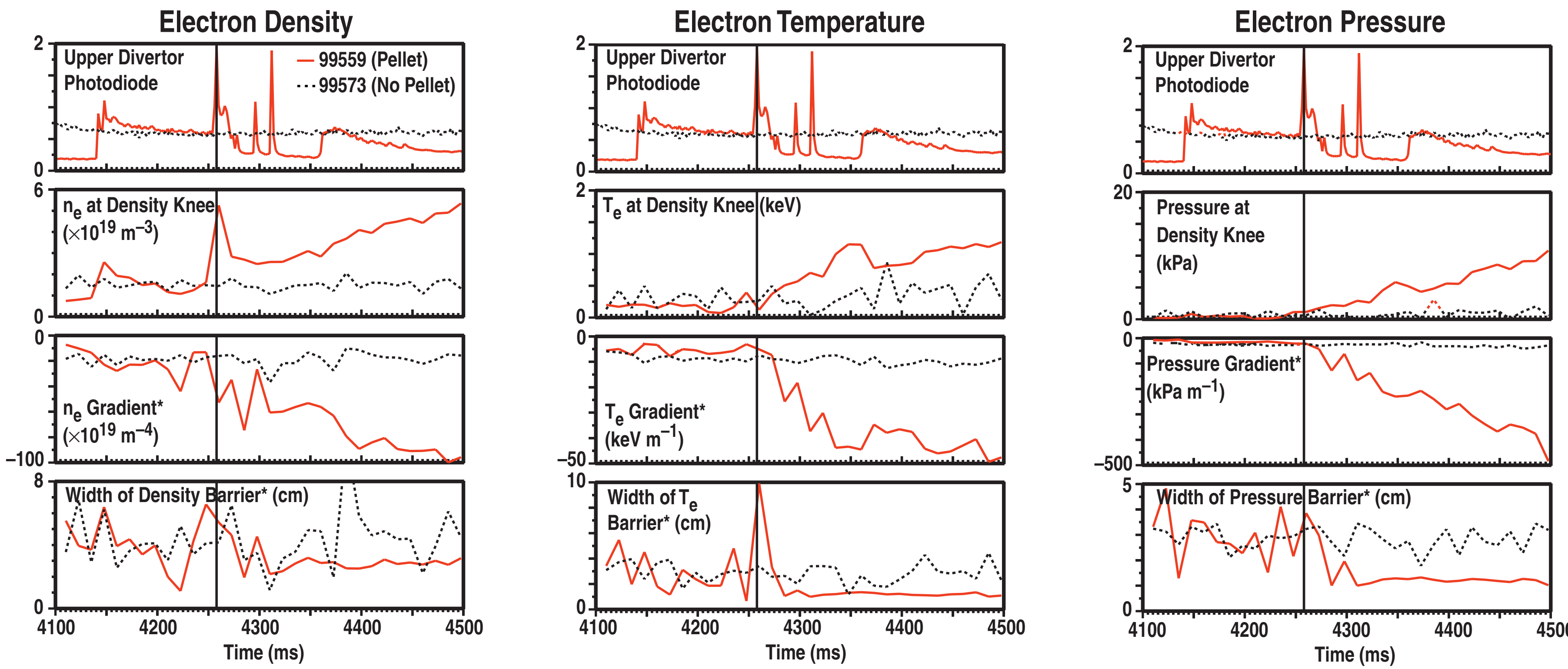

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

# EDGE LOCAL PARAMETERS DETERMINED FROM TANHFIT ANALYSIS CLEARLY SHOW THE TRANSITION TO H–MODE WITH PELLET INJECTION

- PIH–mode at $P_{NBI}$ = 6.8 MW (shot 99559)
- Discharge with no pellet stays in L–mode even at higher $P_{NBI}$ = 9.2 MW (shot 99573)



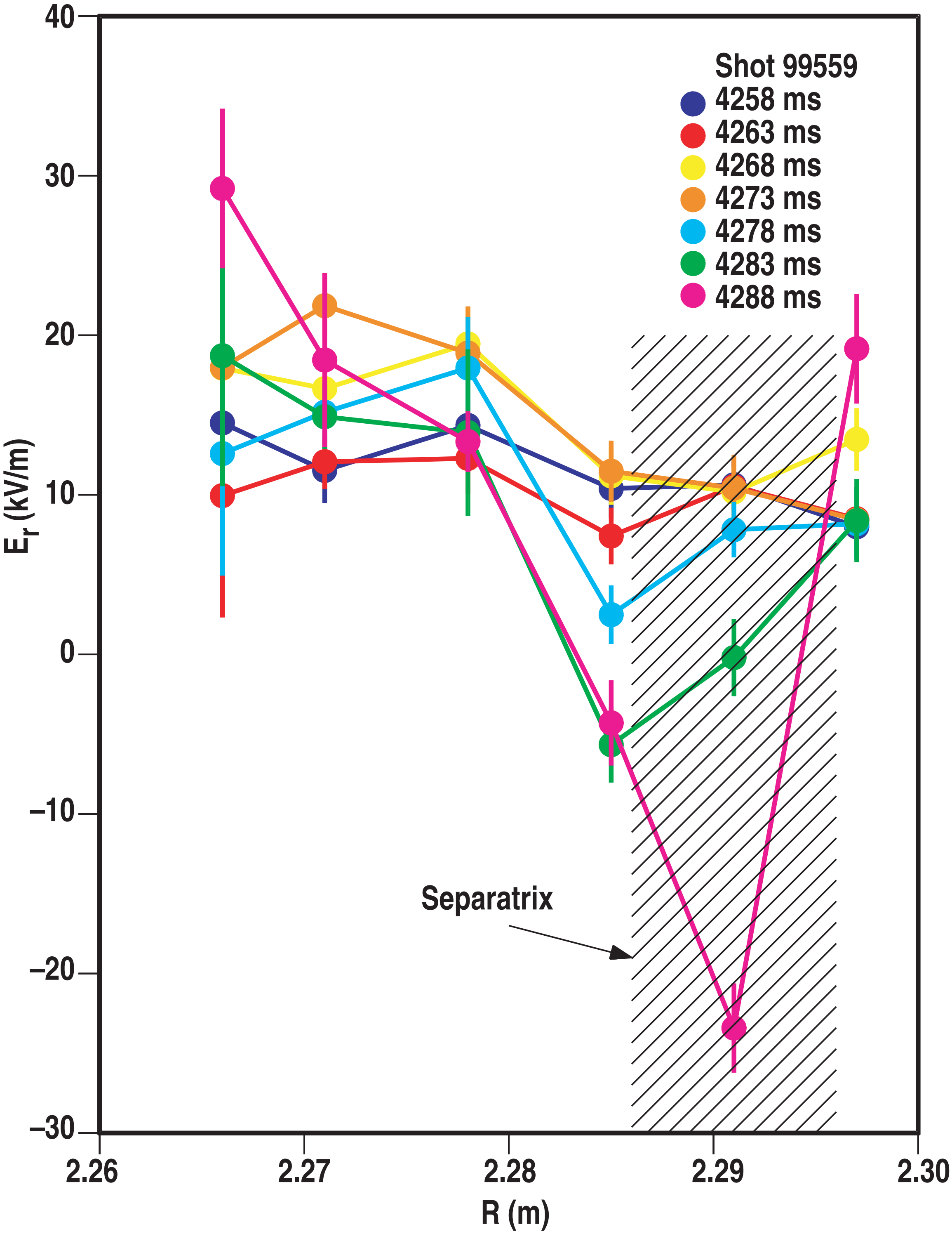

*Spatial measurements are along the laser path in the z-direction, not at the midplane

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# THE SHEAR IN THE EDGE $E_r$ PROFILE GRADUALLY INCREASES AFTER PELLET INJECTION



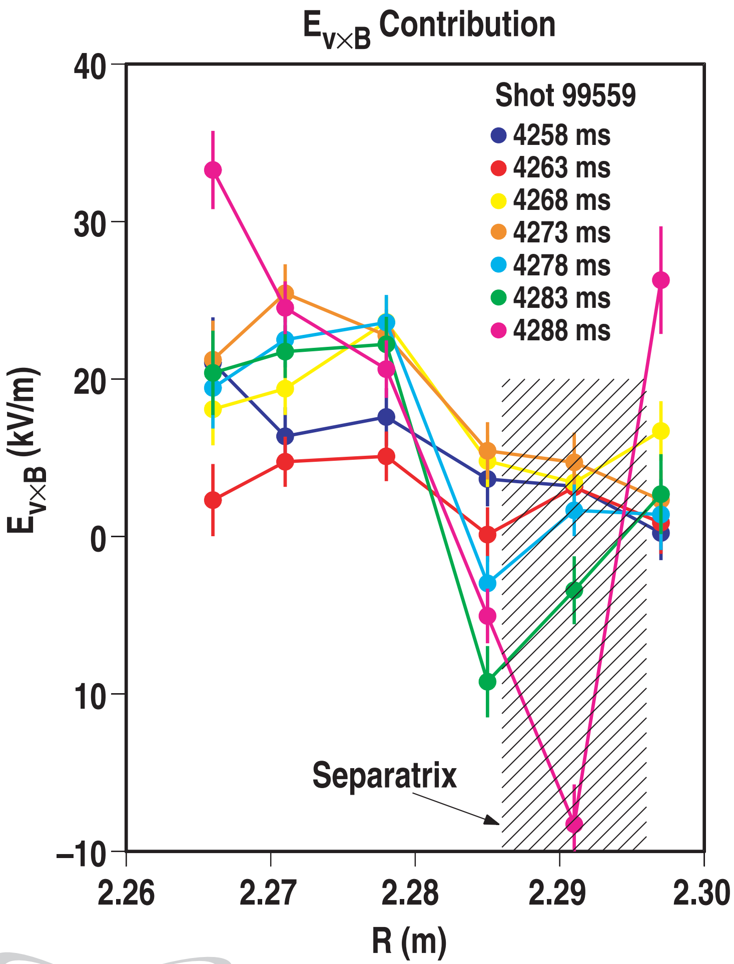

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

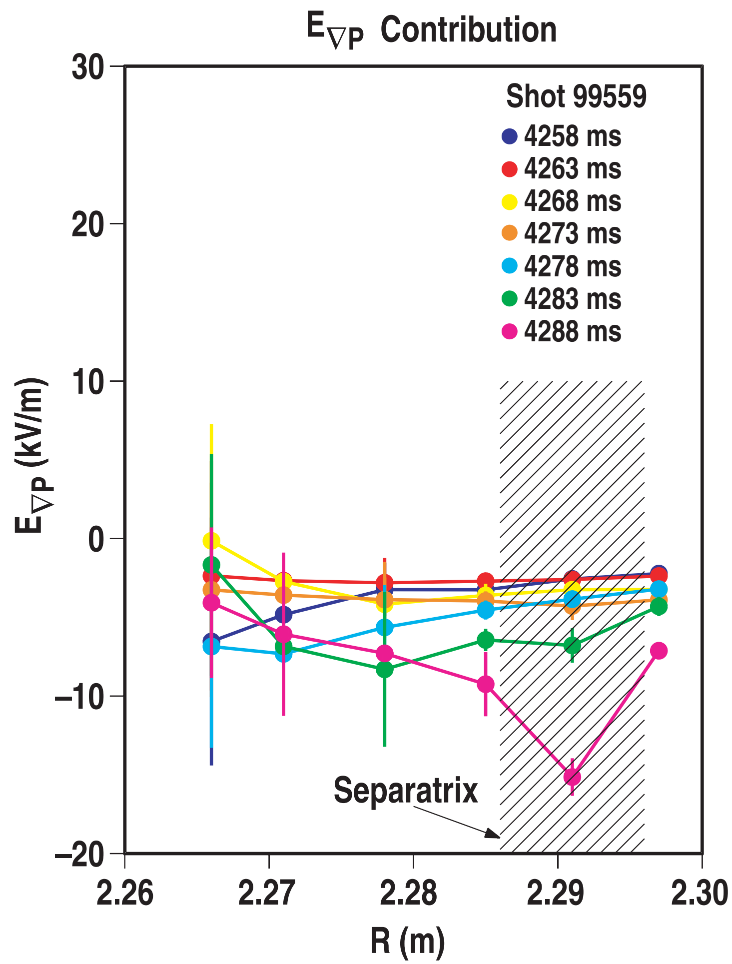
GENERAL ATOMICS

220-98/rs

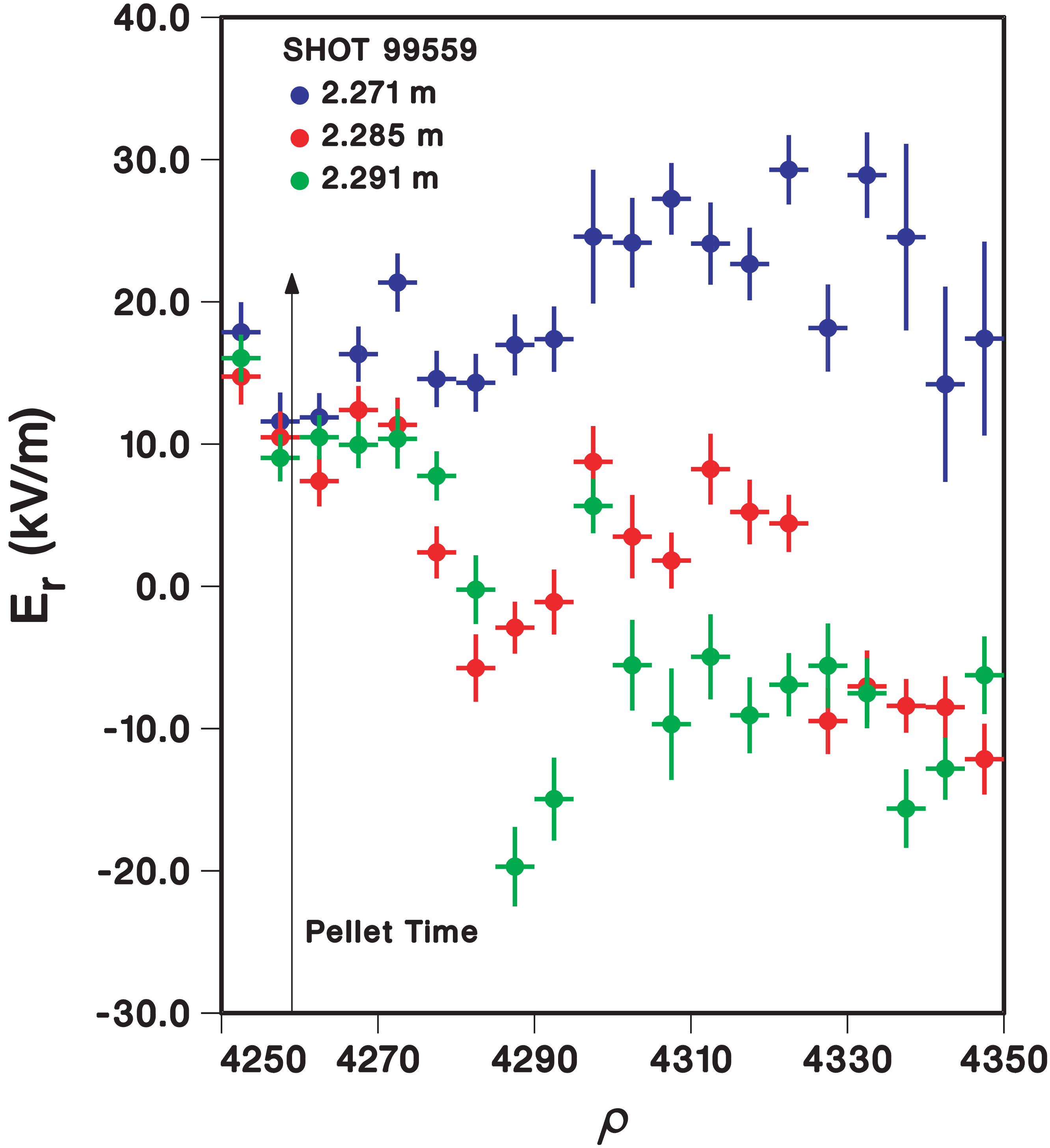
# CHANGES IN THE TOROIDAL AND POLOIDAL ROTATION OF THE CARBON IMPURITY ION HAVE THE GREATEST EFFECT ON $E_r$

- $E_r = \dfrac{\nabla P_i}{Zen_i} - \underline{v} \times \underline{B} = E_{\nabla P} + E_{v \times B}$
- Integration time of measurement = 5 ms



# THE GRADIENT IN THE EDGE Er IS ESTABLISHED AFTER PELLET INJECTION AND IS MAINTAINED INTO THE H–MODE



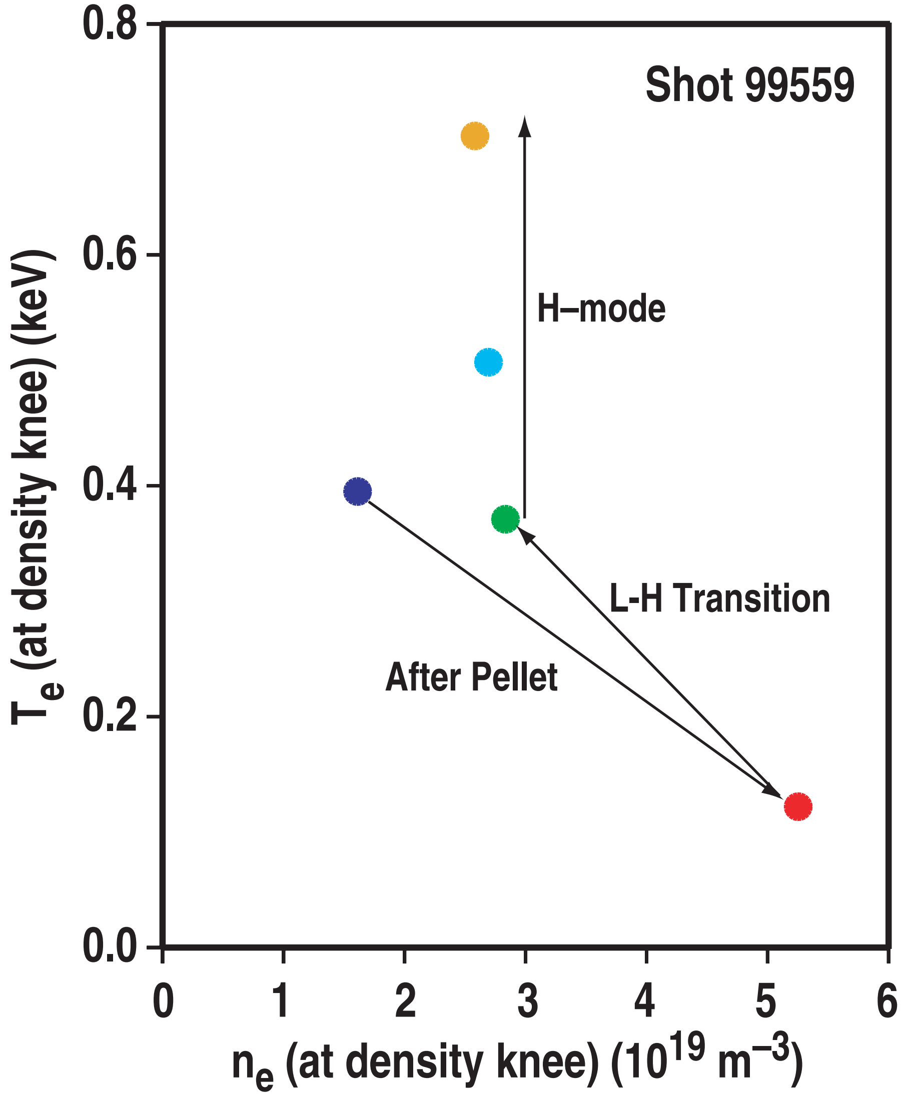

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

# Te REDUCTION OCCURS AFTER PELLET INJECTION PRIOR TO H–MODE TRANSITION – INVARIANT TO PLACE OF MEASUREMENT

- The edge electron temperature increases significantly at nearly the same edge electron density into the H–mode

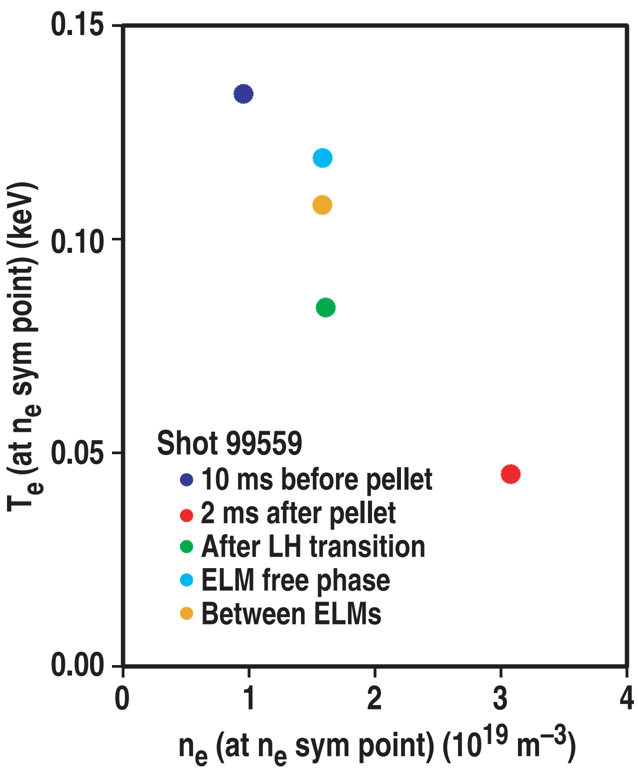




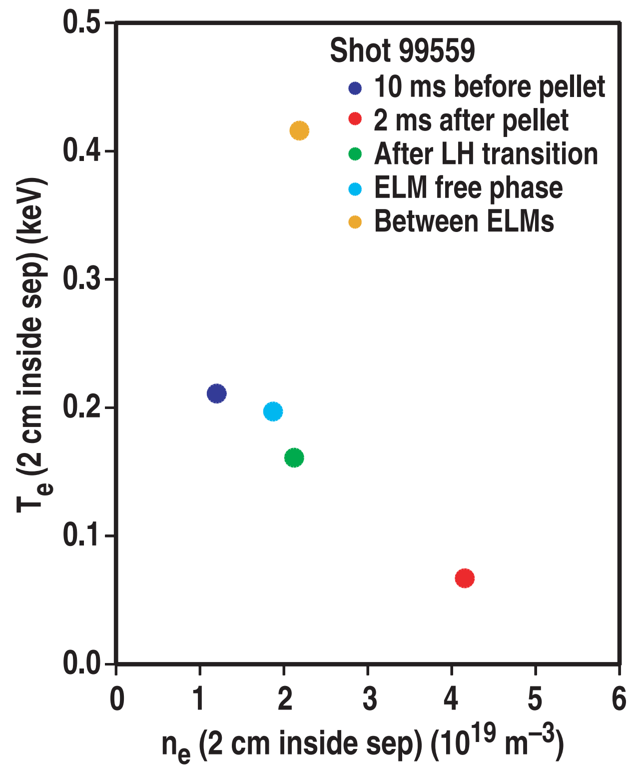

346-99/rs

# VARIATION OF THE EDGE ELECTRON TEMPERATURE AND ELECTRON DENSITY AT DIFFERENT LOCATIONS ALONG THE DENSITY GRADIENT

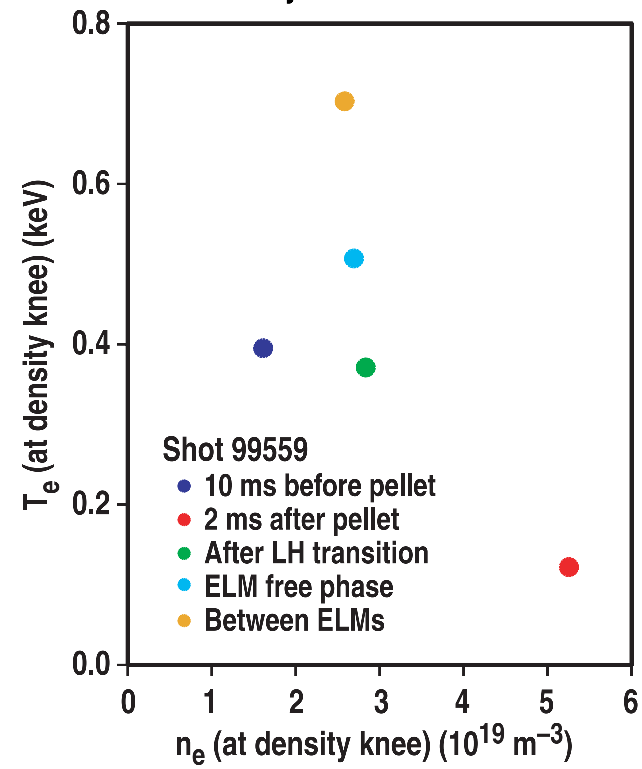
**The edge electron temperature at the density symmetry point in H–mode is still below the L–mode value**




**$T_e$ and $n_e$ 2 cm inside the separatrix**




**The edge electron temperature increases significantly at nearly the same edge electron density into the H–mode**



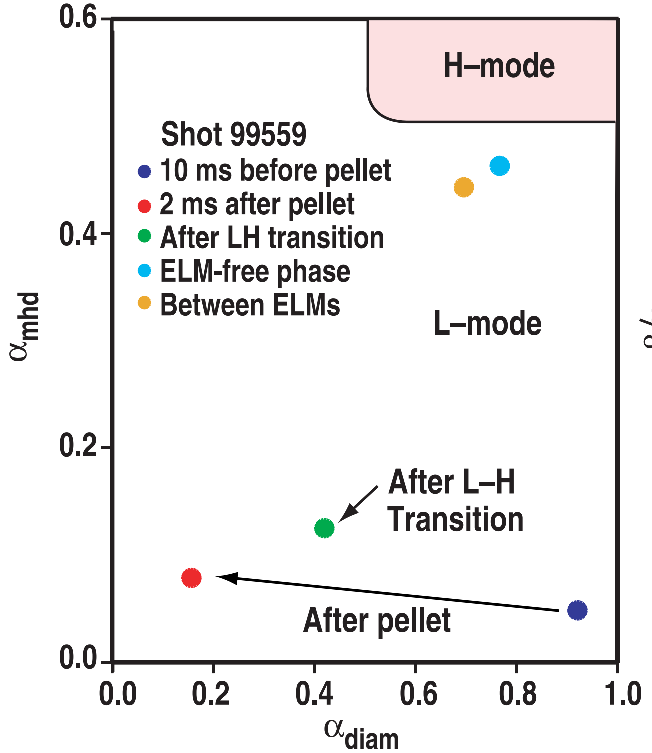

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

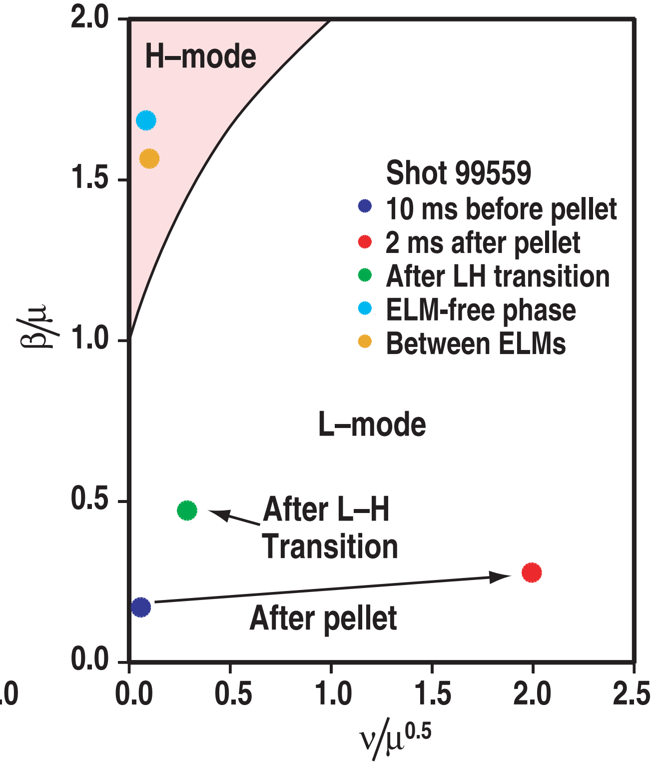
220-99/rs

# PELLET INDUCED H–MODES HAVE LH TRANSITIONS AT PLASMA PARAMETERS FAR BELOW THEORETICAL PREDICTIONS

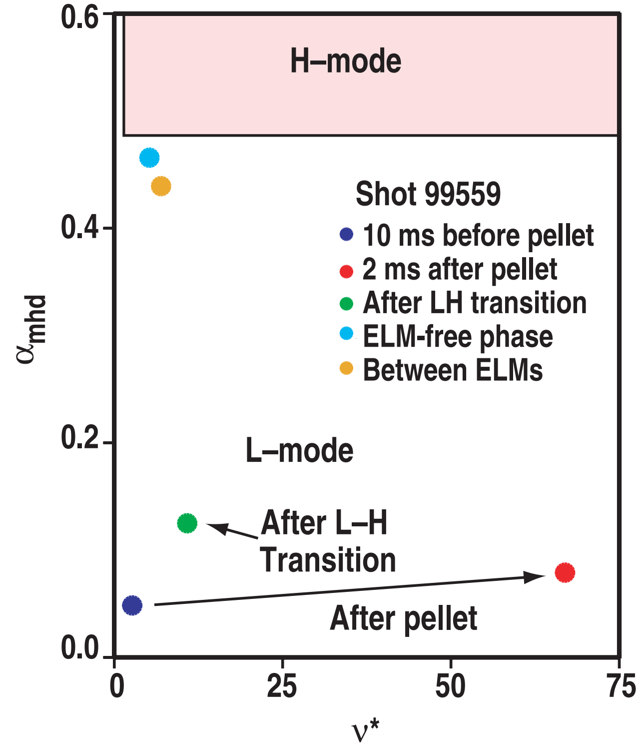
Rogers et al. Proc. 17th IAEA Fusion Energy Conf. Yokohama, Japan 1998, paper IAEA-CN-69/THP2/01




Pogutse et al. Proc. 24th EPS Conf. 1997 (P3-1041)




Wilson et al. Proc. 17th IAEA Fusion Energy Conf. Yokohama, Japan 1998, paper IAEA-F1-CN-69/TH3/2

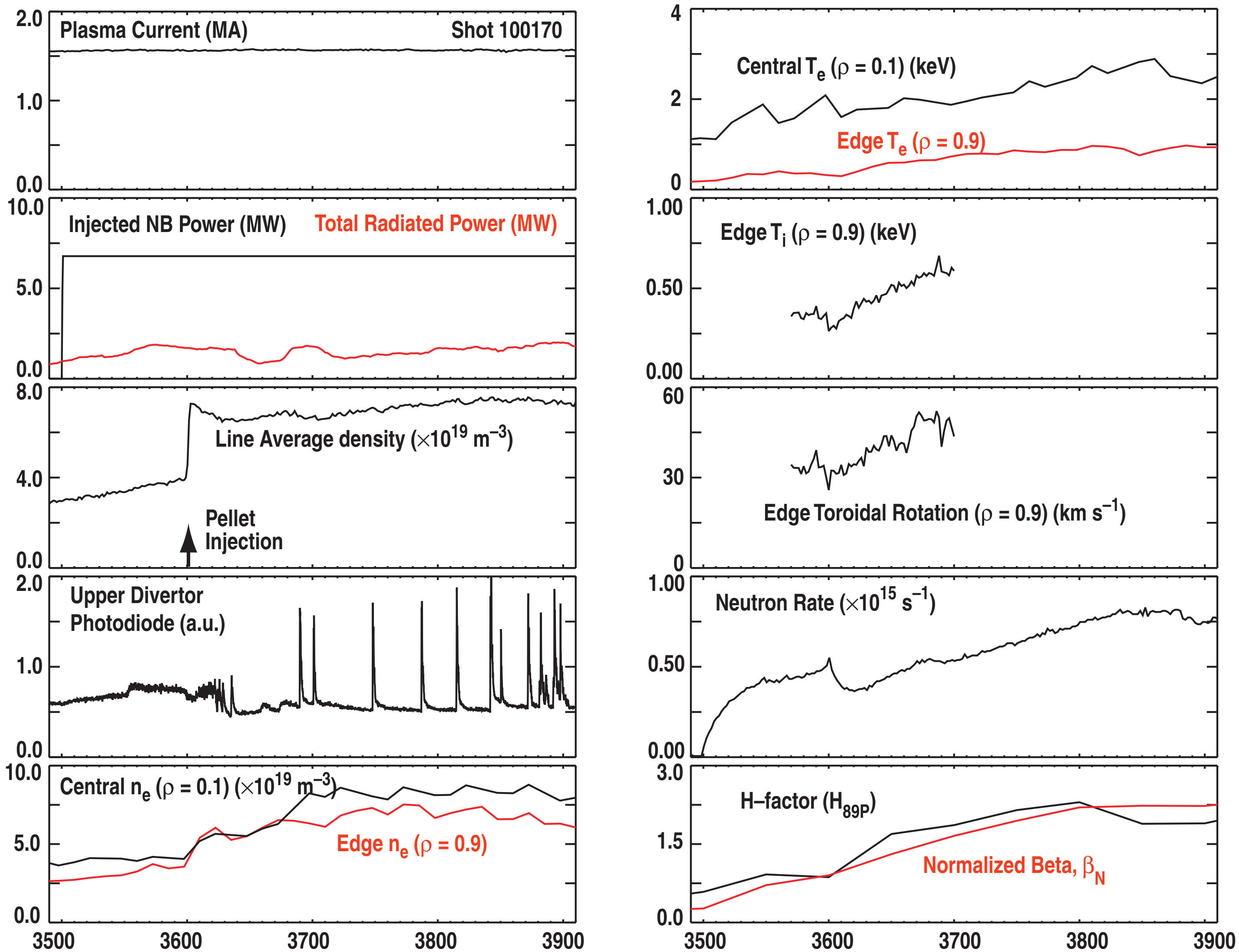



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

# EVOLUTION OF PELLET INDUCED H–MODE DISCHARGE WITH HIGH FIELD SIDE PELLET ($P_{NBI}$ = 6.7 MW)

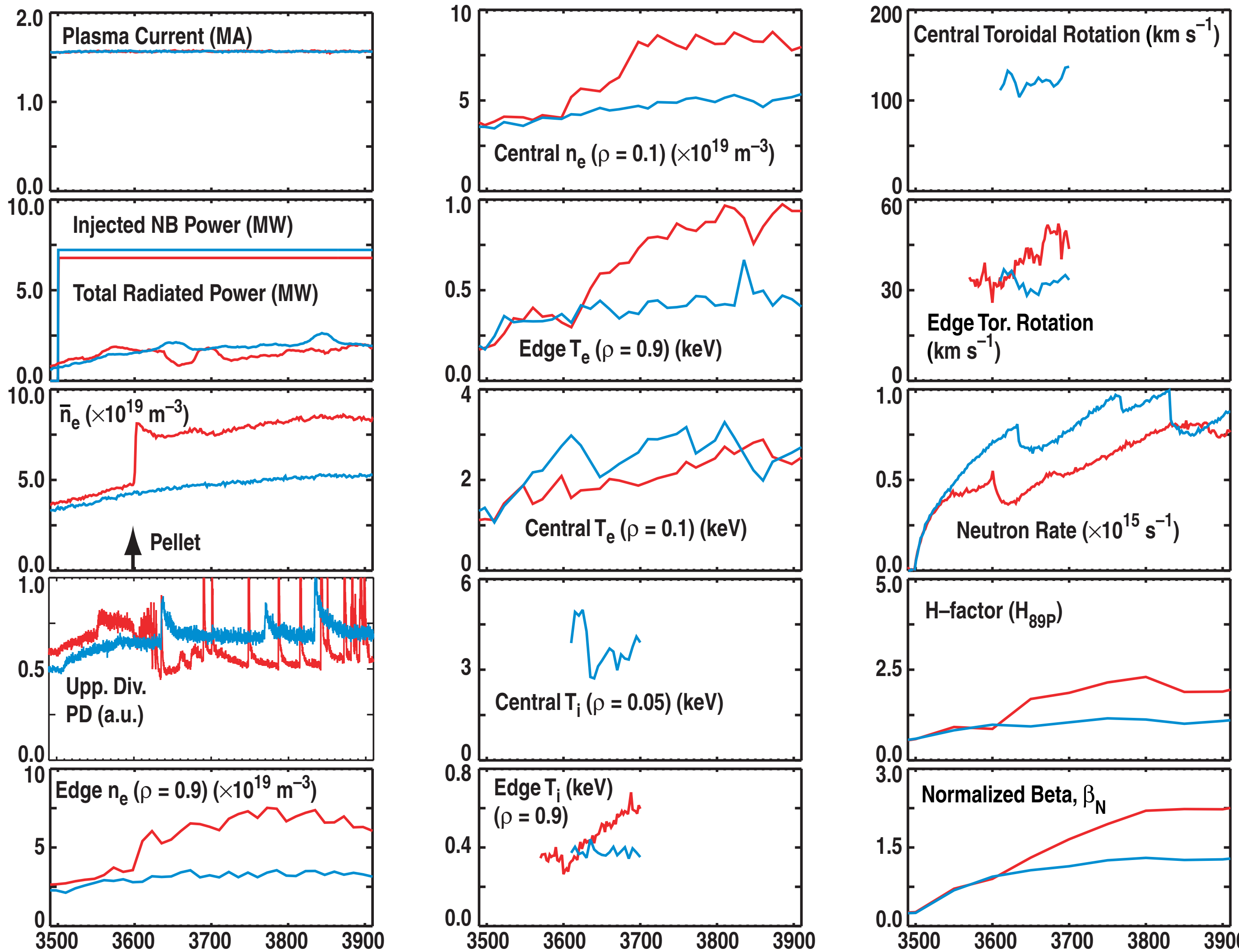



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# COMPARISON OF PIH–MODE DISCHARGE ($P_{NBI}$ = 6.7 MW) WITH NO PELLET, L–MODE DISCHARGE ($P_{NBI}$ = 7.2 MW)




High Field Side Pellet

— PIH–Mode (Shot 100170)

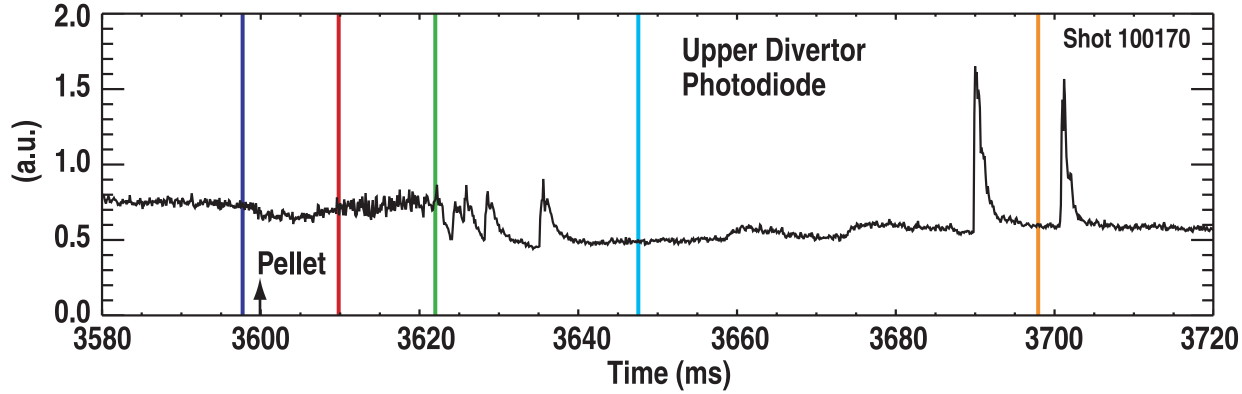
— No Pellet, L–Mode (Shot 100161)

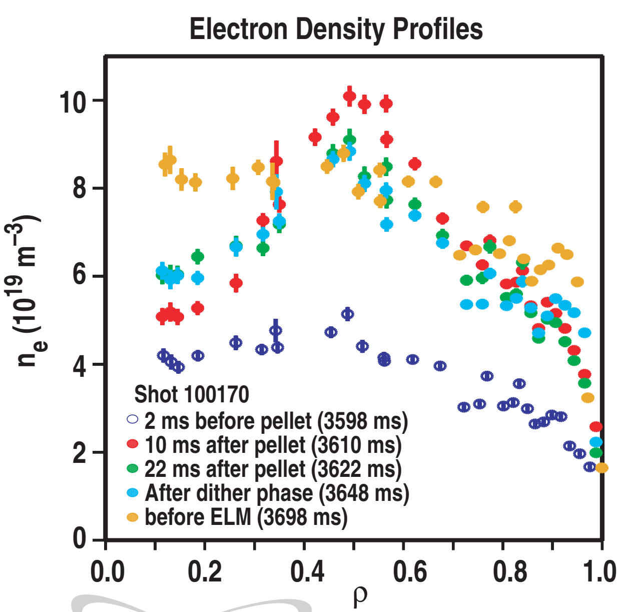
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

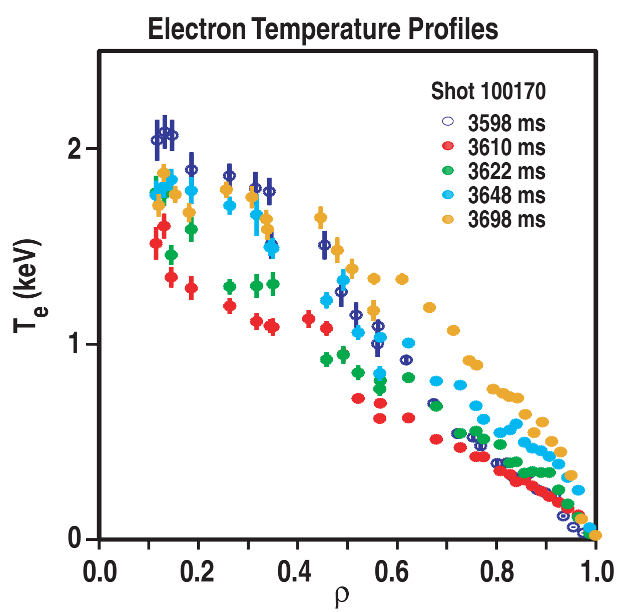
GENERAL ATOMICS

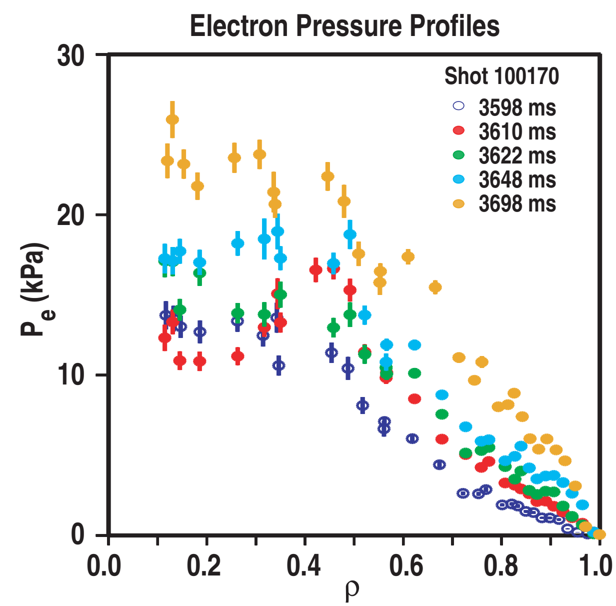
346-99/rs

# THE HFS PELLET PENETRATES MUCH FURTHER INTO THE PLASMA INTERIOR, BUT STILL PRODUCES SIGNIFICANT DENSITY PERTURBATION AT THE PLASMA EDGE



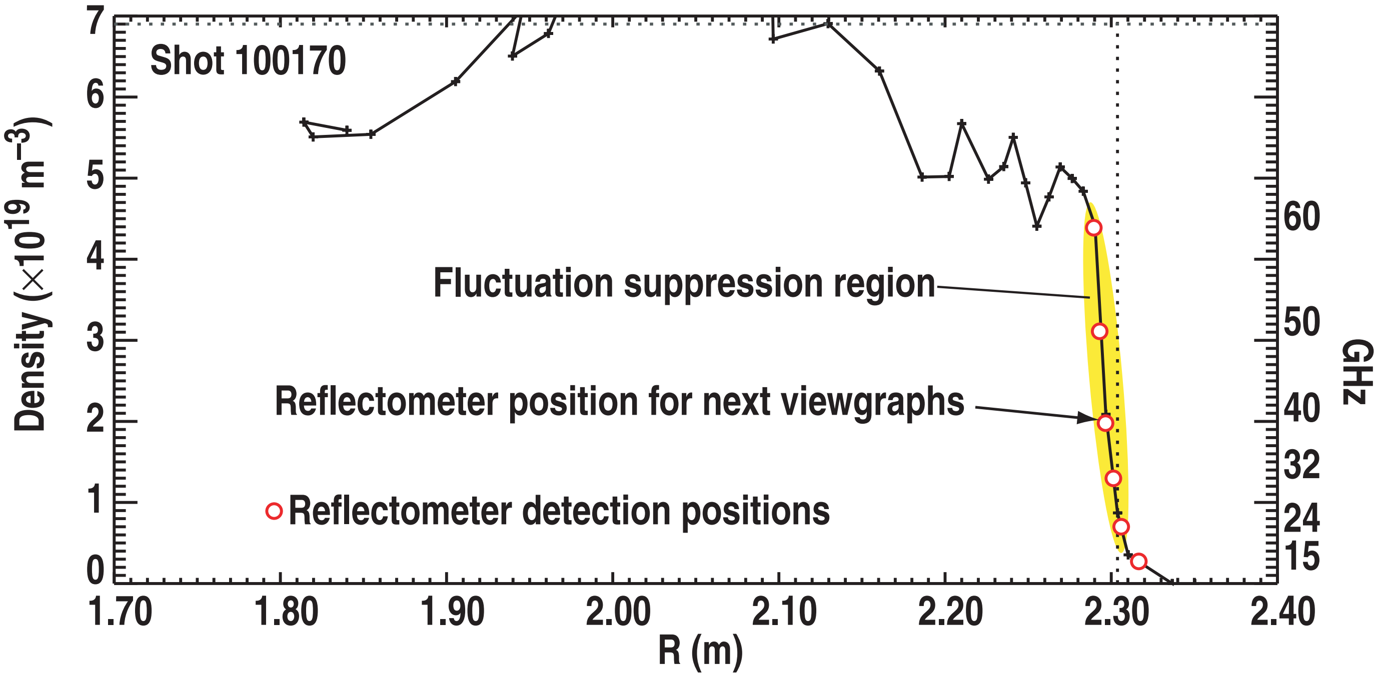

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

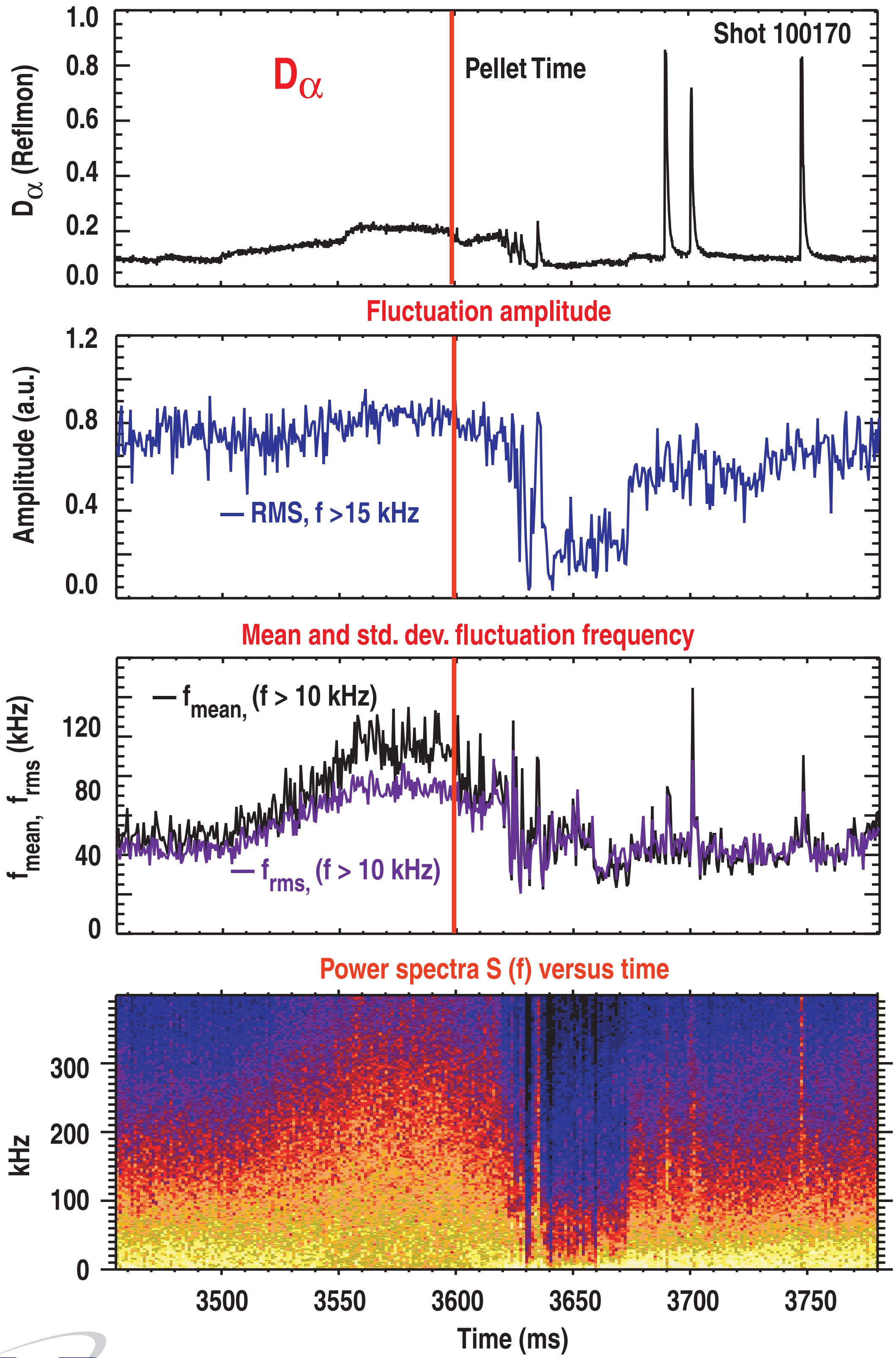
# FLUCTUATION SUPPRESSION IS OBSERVED SHORTLY AFTER PELLET INJECTION

- Fast dithering or bursting of fluctuation levels appear ~10 ms after pellet injection (see following viewgraphs)
- Fast dithering develops into ELM free H–mode (see following viewgraphs)
- Behavior of fluctuation suppression very similar to that observed in spontaneous H–mode (see following viewgraphs)



# FAST DITHERING DEVELOPS INTO ELM FREE H–MODE

- Behavior of fluctuation suppression very similar to that observed in spontaneous H–mode



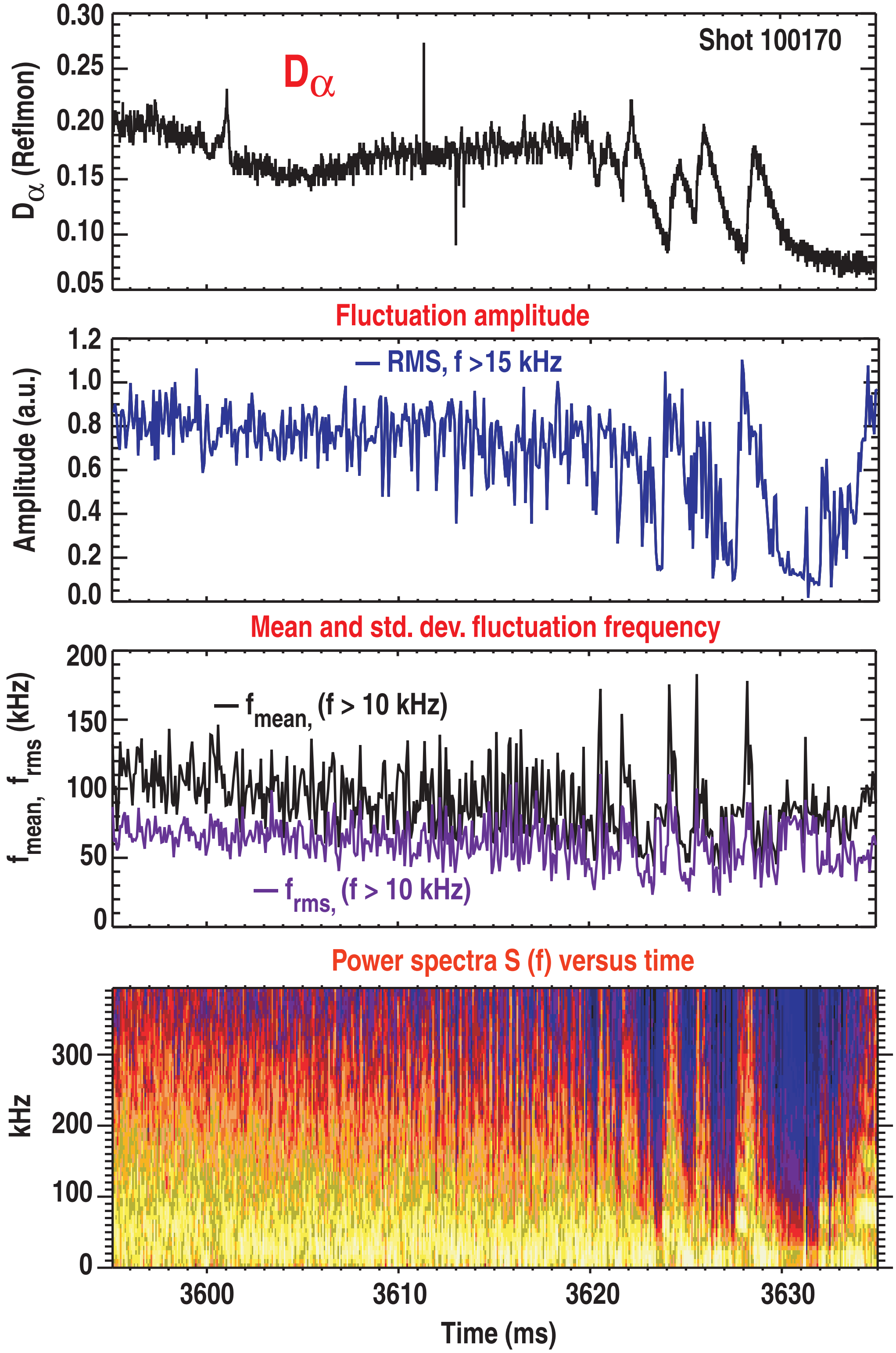

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

UCLA Electrical Engineering

GENERAL ATOMICS

220-98/rs

# FAST DITHERING OR BURSTING OF FLUCTUATION APPEAR ~10 ms AFTER PELLET INJECTION




DIII-D NATIONAL FUSION FACILITY SAN DIEGO

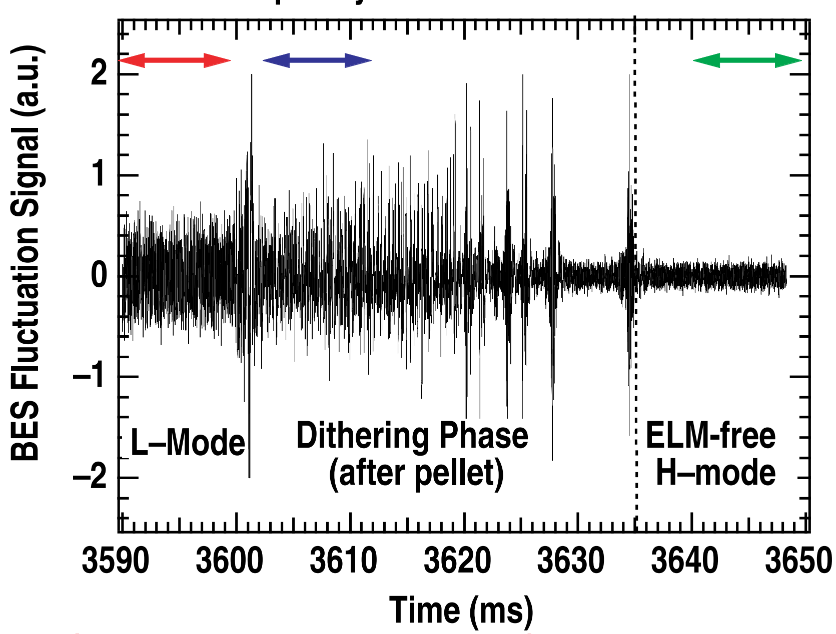
UCLA Electrical Engineering

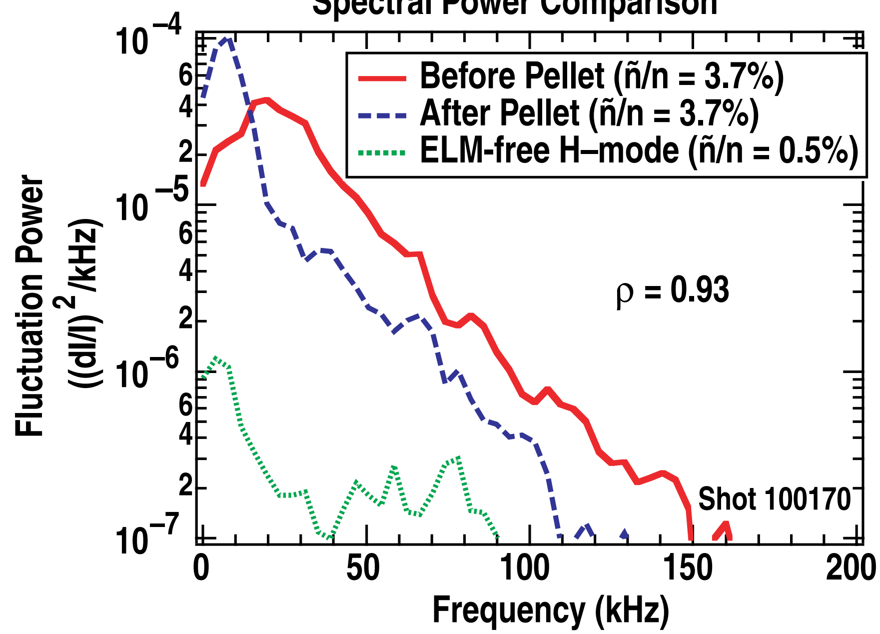
GENERAL ATOMICS

220-98/rs

# EDGE TURBULENCE DURING PELLET-INDUCED H–MODE TRANSITION

- Beam Emission Spectroscopy measurements show different stages of transition behavior ($0 < k < 3\ cm^{-1}$, $2 \leq f \leq 200$ kHz, $\rho = 0.93$)
- Power spectra condenses to low frequency after pellet injection
  - Integrated power remains nearly the same
- H–mode phase shows markedly reduced fluctuation level (2 orders of magnitude reduction in power)



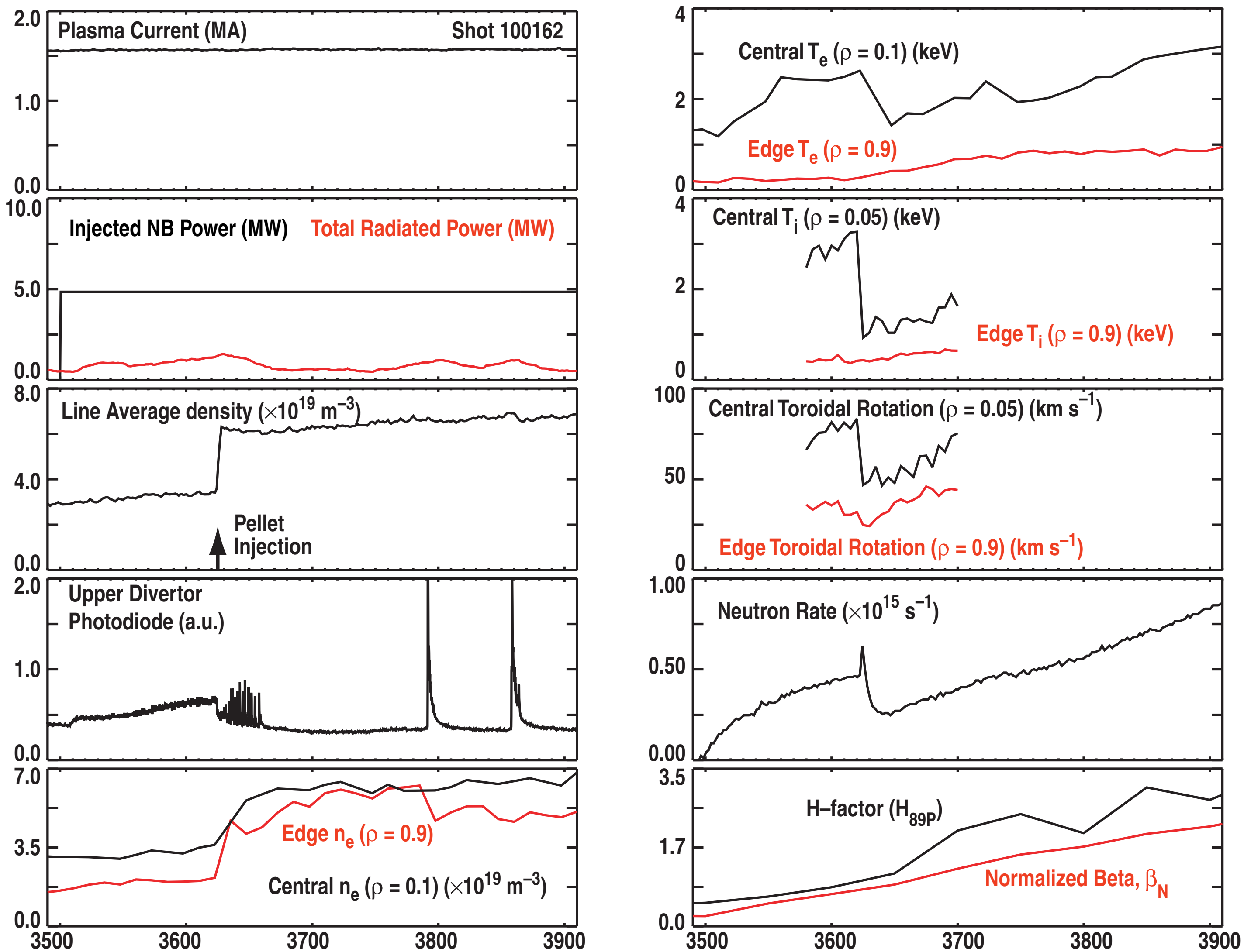




1) Pre-pellet L–mode phase (moderate fluctuations)

2) Post-pellet, L–mode → dithering phase (lower frequency fluctuations, dithers)

3) H–mode (very low fluctuation level)

# PIH–MODE DISCHARGE WITH HIGH FIELD SIDE PELLET AT REDUCED NBI POWER ($P_{NBI}$ = 4.9 MW)

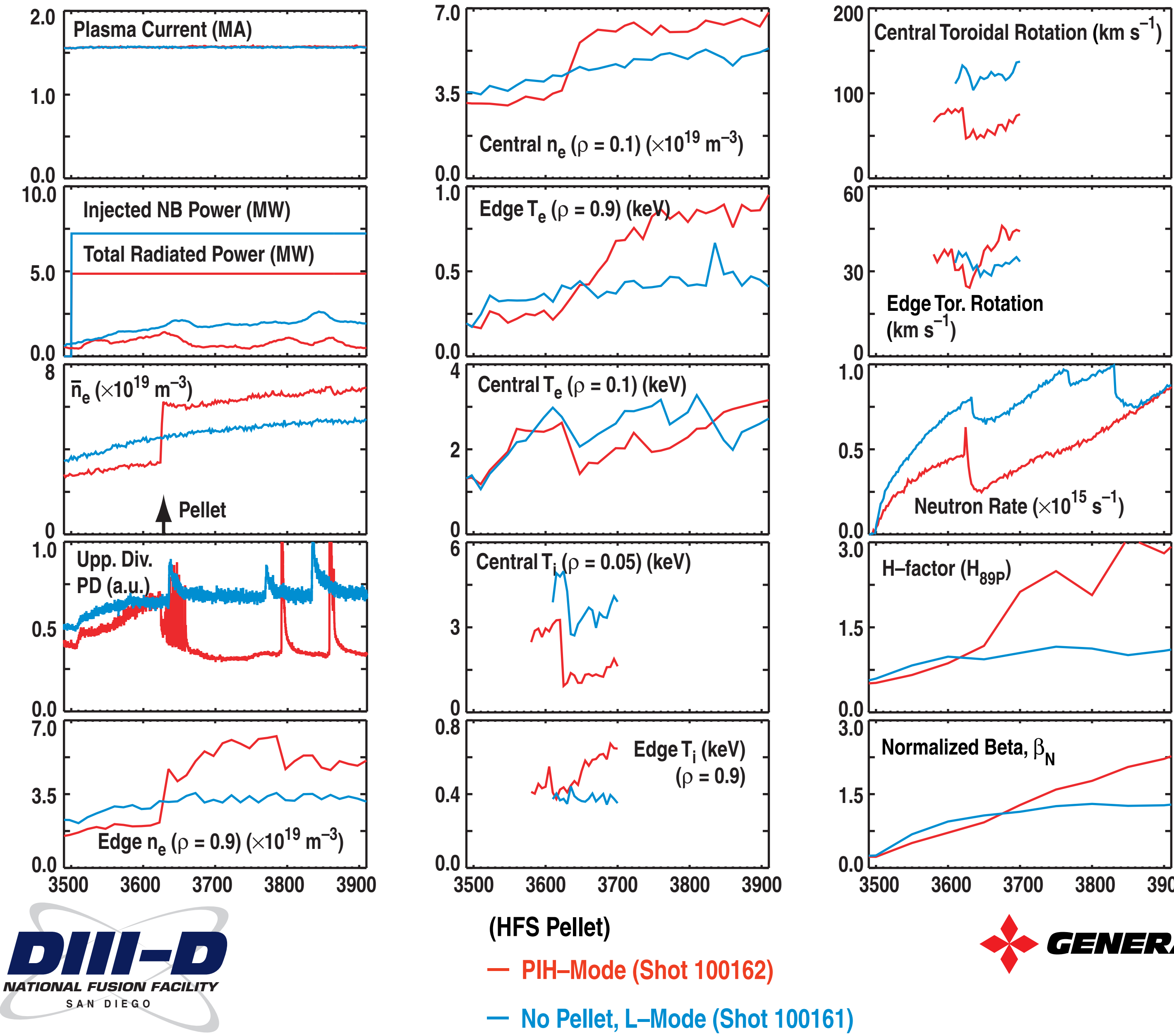



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

220-99/rs

# COMPARISON OF PIH–MODE DISCHARGE ($P_{NBI}$ = 4.9 MW) WITH NO PELLET, L–MODE ($P_{NBI}$ = 7.2 MW) USING HIGH FIELD SIDE PELLET




- The power required to access H–mode is reduced by 2.3 MW using high field side pellet injection

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

GENERAL ATOMICS

346-99/rs

# SUMMARY

- **H–mode plasmas have been directly produced by injecting frozen deuterium pellets into L–mode plasmas**
  - Pellets injected from the low toroidal field side and high field side were both able to produce H–mode transitions

- **The edge electron and ion temperatures are substantially reduced by the large influx of particles from the pellet**
  - The lowered temperatures still lead to an H–mode transition
  - A critical edge temperature is not necessary in these H–mode transitions

- **Pellet induced H–modes have LH transitions at plasma parameters far below theoretical predictions**

- **Just after pellet injection, the edge fluctuations exhibit fast dithering or bursting behavior before steady H–mode conditions are achieved**
  - Similarly, fluctuation bursting is observed in transitions to VH–mode plasma and plasmas with internal transport barriers

# SUMMARY (Continued)

- The shear in the edge $E_r$ increases gradually during the period of fluctuation bursts
  - $E_r$ measurement is averaged over bursts so cannot determine fast changes in $E_r$
  - Future experiments will have increased time resolution
- The power threshold is reduced by about 2.4 MW (by up to 33%) using pellet injection
  - Pellets produced H–mode plasmas at lower input power than reference plasma discharges without pellet
  - Reference plasma discharges without pellets stayed in L–mode throughout the applied neutral beam heating even in the presence of strong sawteeth and higher NBI power