# Recent Progress on QH-Mode Plasma Studies in DIII–D


**by**

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**in collaboration with**

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# QH/QDB PLASMAS

- Quiescent H–mode (QH–mode) plasmas exhibit H–mode confinement levels ($H_{89}$ ~ 2) without the presence of ELMs
  - Constant density and radiated power achievable for long duration (>4 s or 30 $\tau_E$ or 2–3$\tau_R$)
  - Quiescent double barrier (QDB) plasmas have an internal transport barrier (ITB) with a QH–mode plasma edge
  - QH–mode plasmas have been observed on several tokamaks of varying sizes and $\rho_*$: $3.5 \times 10^{-3} \leq \rho_* \leq 1.5 \times 10^{-2}$ (DIII–D, AUG, JT-60U, JET)

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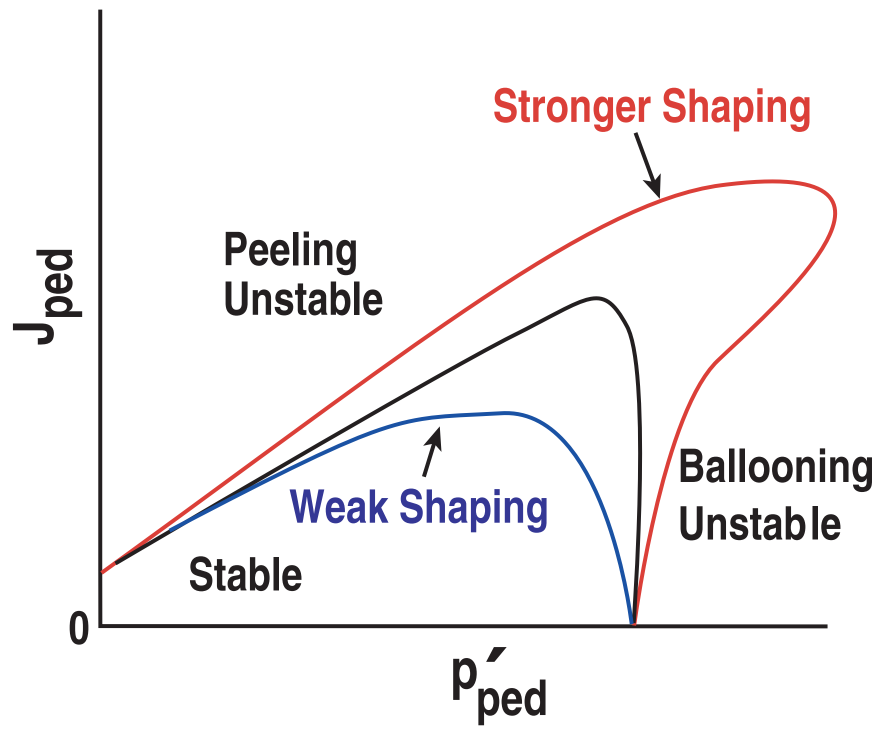
# MAIN POINTS

- The QH–mode pedestal at high $\delta$ is marginally stable to current driven modes at low to medium n
- Impurities are exhausted faster in a QH–mode plasma than in an ELMing plasma
- ECH, ECCD and NBI have been used as effective tools to control $q_0$ in QDB plasmas
- QDB plasmas compare favorably in performance with other AT plasma regimes e.g. hybrid, RS (determined from a multi-machine database)

# STABILITY ANALYSIS OF QH-MODE DISCHARGES

- Why do the ELMs go away?
  - Nonlinear growth of coupled peeling/ballooning modes is the leading model for the ELMs
  - Determine where QH-mode edge plasma conditions lie on stability diagram
  - Stronger plasma shaping (higher $\delta,\kappa$) results in higher boundary values for $J_{ped}$ and $P'_{ped}$
  - Stability analysis using ELITE code




Snyder et al., Phys. Plasmas, 9, 2037 (2002)

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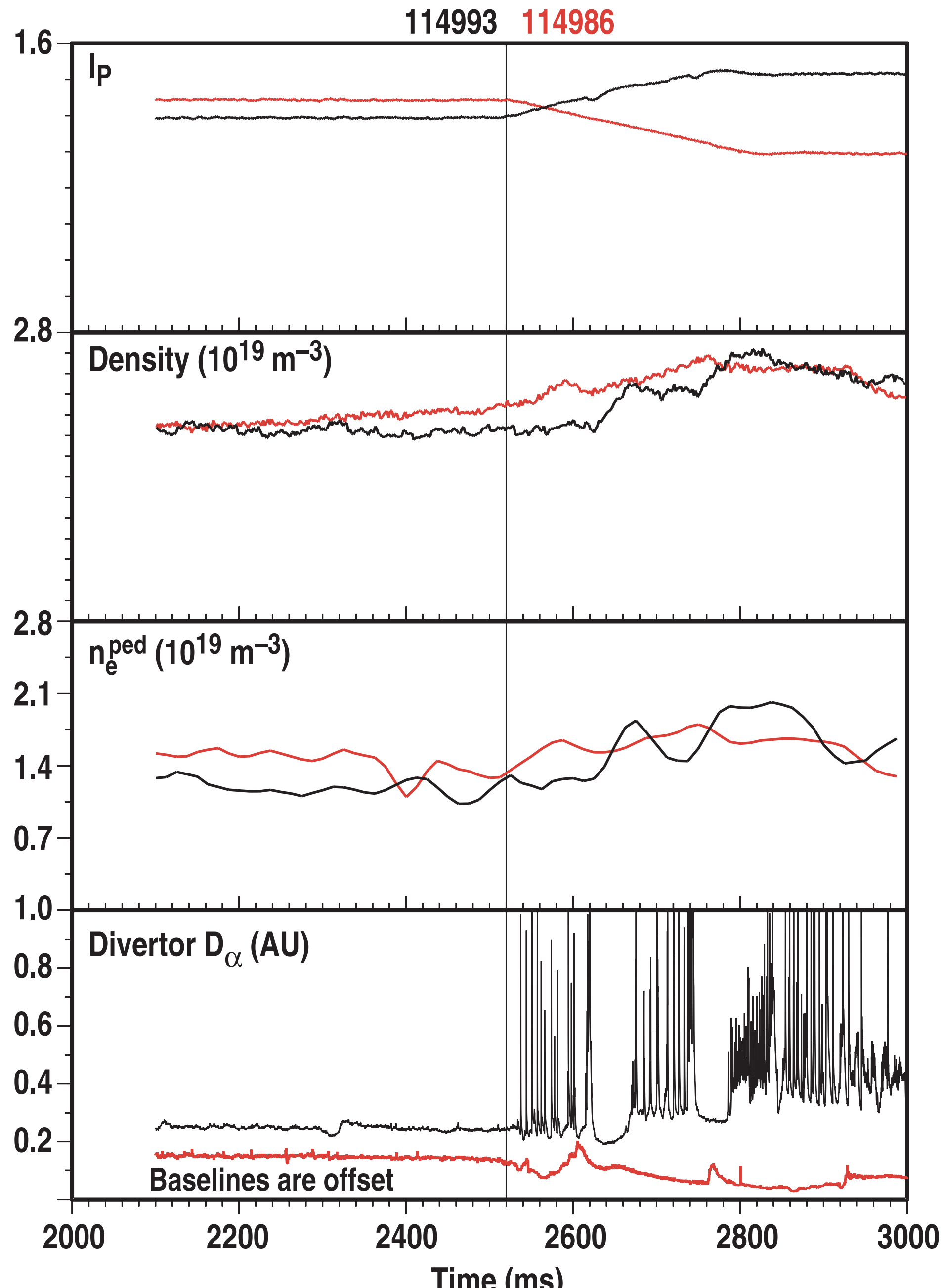
# DIII–D OPERATES NEAR EDGE CURRENT LIMIT TO PEELING MODES

- Increasing plasma current (1 MA/s) in QH–mode plasmas causes return of ELMs in about 20 ms, while decreasing current at same rate allows plasma to stay in QH–mode
  – Ramp rates as low as 0.15 MA/s cause return of ELMs

- This behavior indicates the QH–mode edge is close to the $J_{edge}$ limit in the peeling -ballooning mode diagram

- Being close to this limit is also consistent with control room observation that QH–mode is easier to get at lower plasma currents

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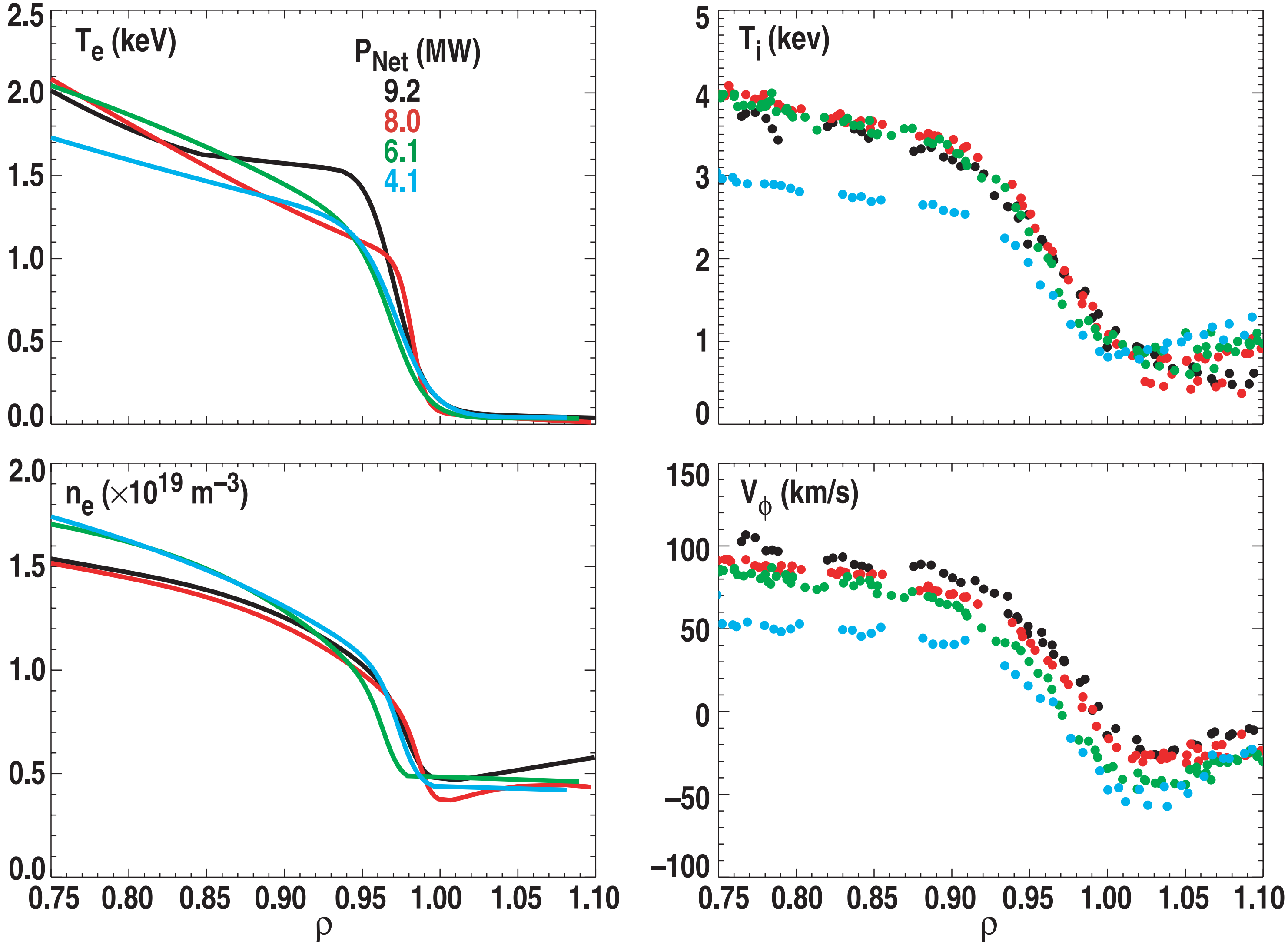
# INPUT BEAM POWER IS CHANGED IN ATTEMPT TO CHANGE EDGE GRADIENTS

- Edge gradients saturate as power increases
- Process limiting edge gradients allows QH–mode operation at powers up to core beta limit

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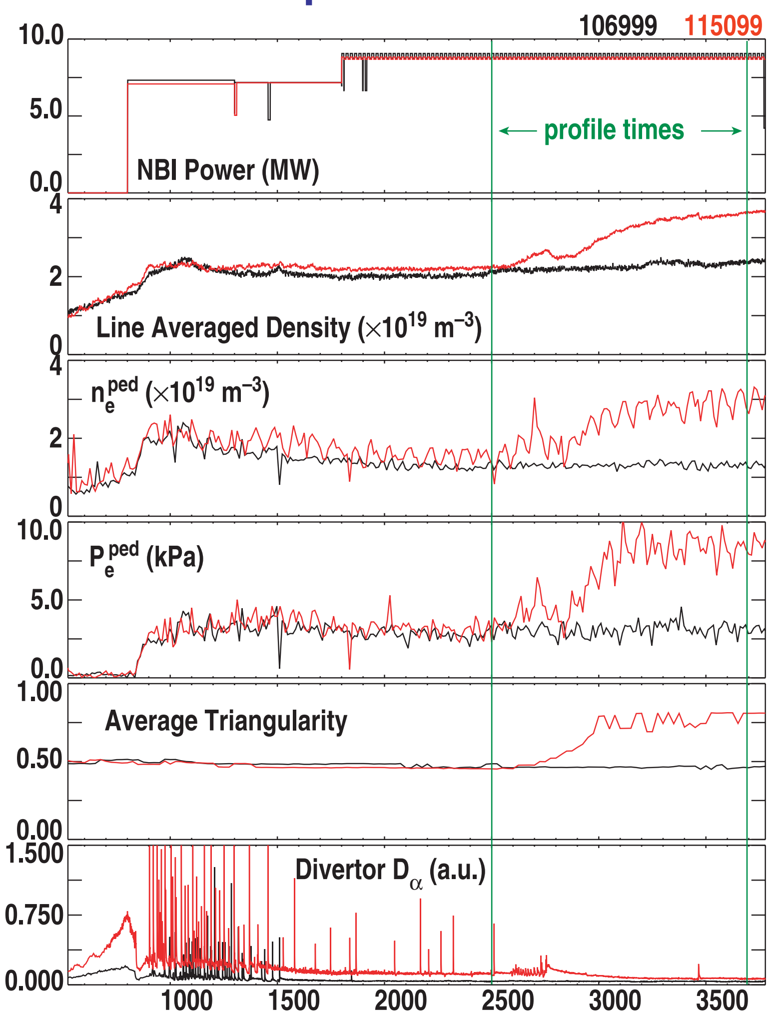
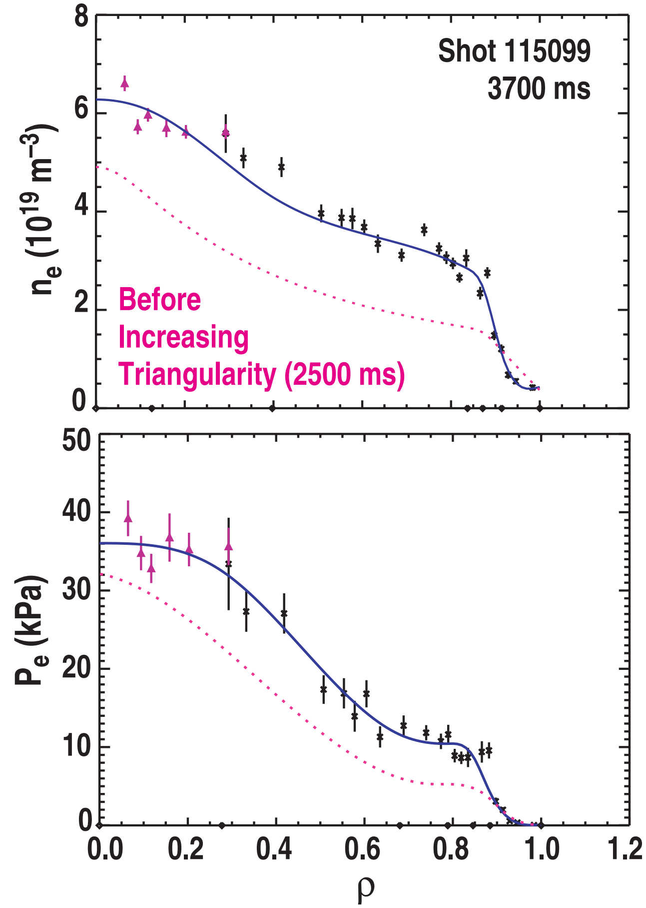
# INCREASING THE TRIANGULARITY LEADS TO DOUBLING OF THE THE PEDESTAL DENSITY AND PEDESTAL PRESSURE

- Increased triangularity increases the density and pressure across the whole plasma

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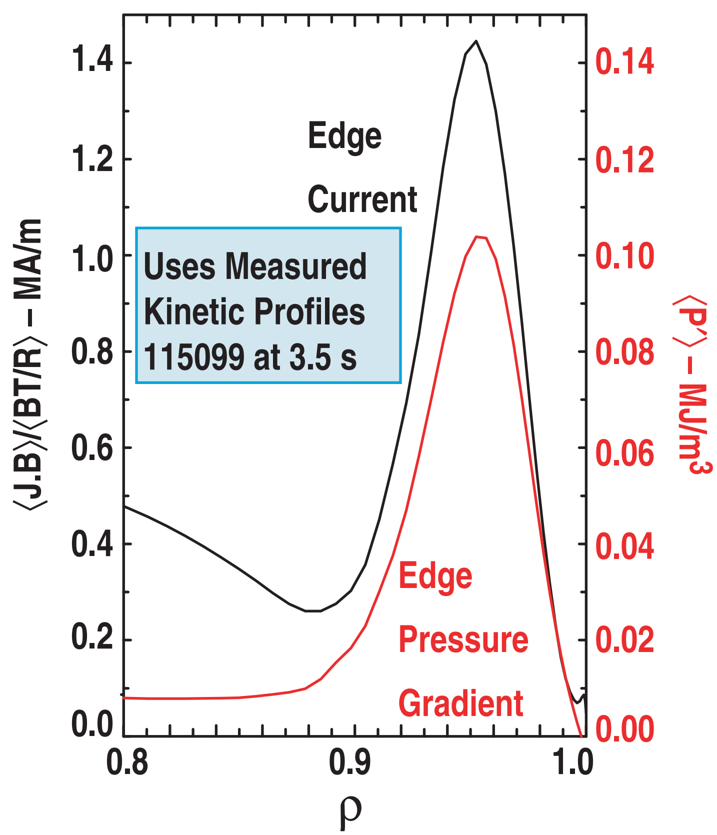
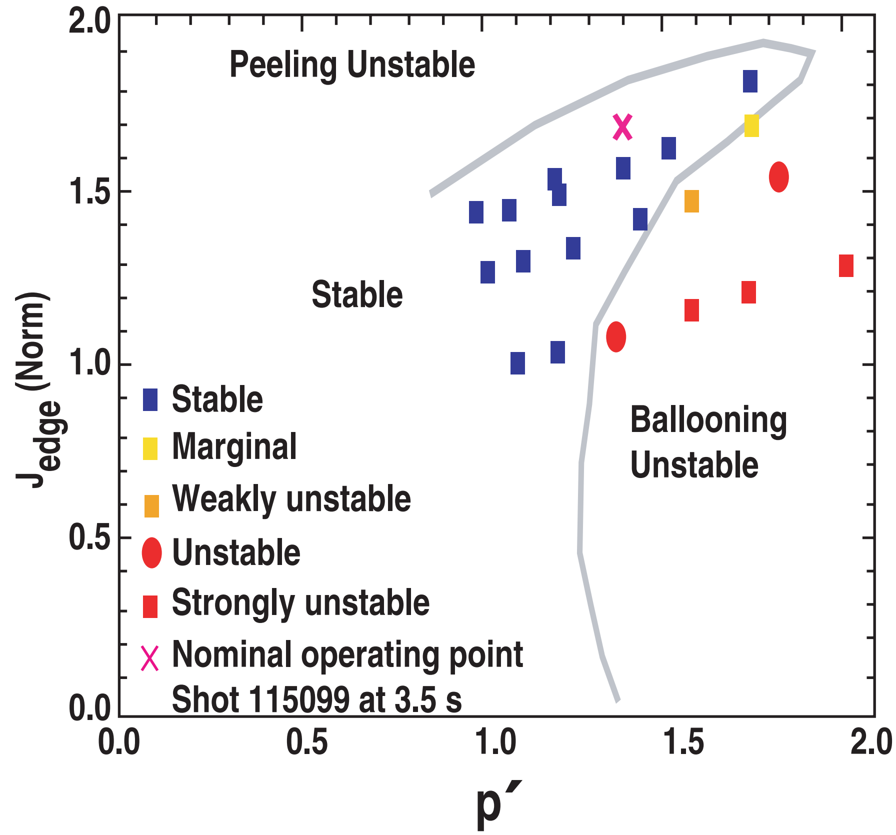
# HIGH TRIANGULARITY QH–MODE PLASMAS ARE MARGINALLY STABLE TO CURRENT DRIVEN PEELING/BALLOONING MODES

## Edge Current (from NCLASS) and Pressure Profiles in CORSICA equilibrium




## ELITE Stability Diagram from the experimental case, x, and perturbed equilibria, ■

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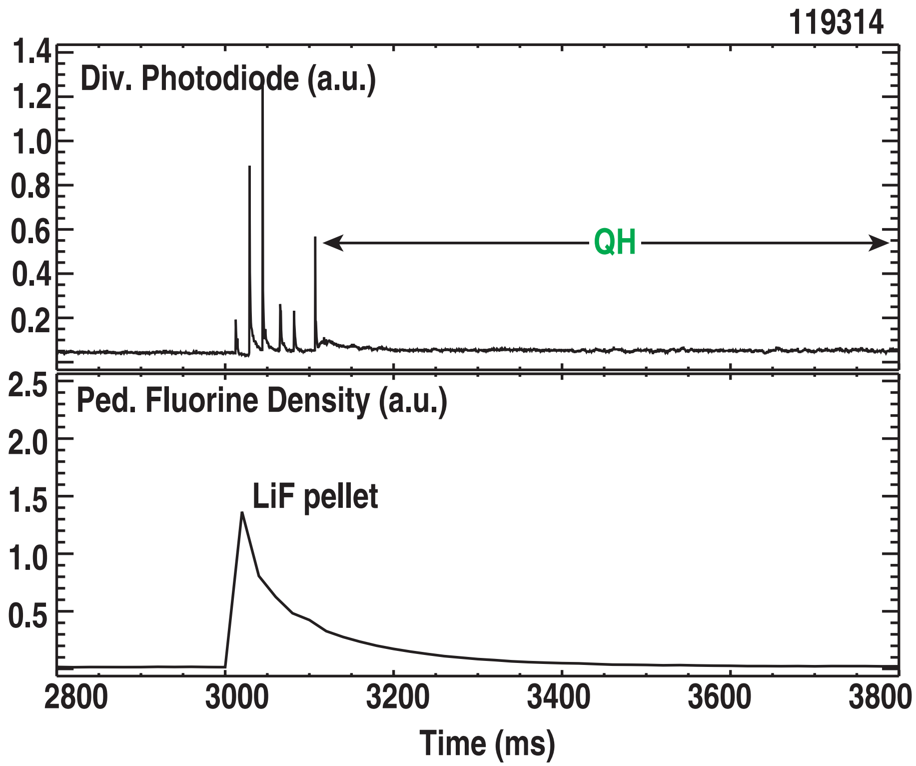
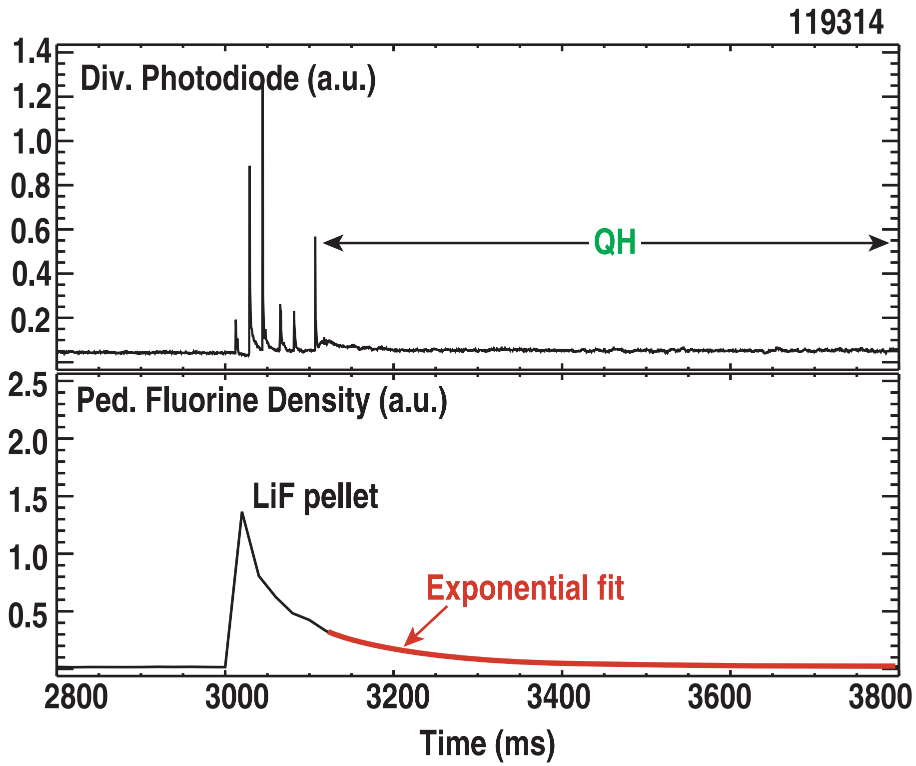
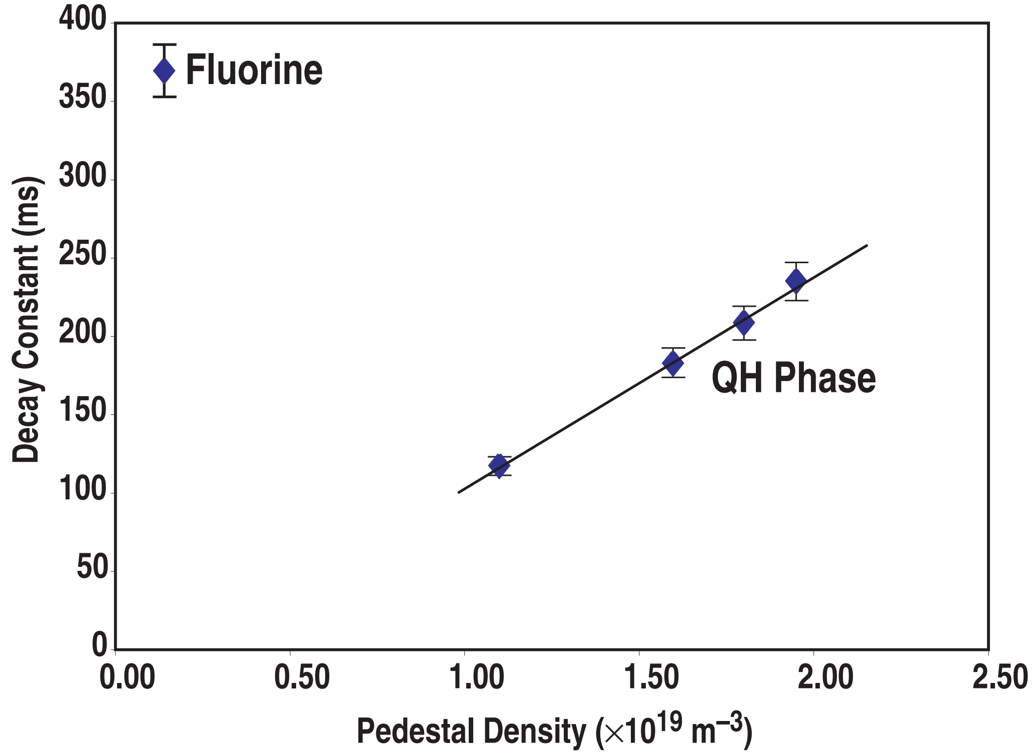
# IMPUTITIES AT THE PLASMA EDGE ARE EXHAUSTED FASTER IN THE QH-MODE PHASE THAN IN THE ELMING PHASE



# IMPURITIES AT THE PLASMA EDGE ARE EXHAUSTED FASTER IN THE QH-MODE PHASE THAN IN THE ELMING PHASE

- The impurity decay constant at the plasma edge increases with the pedestal density

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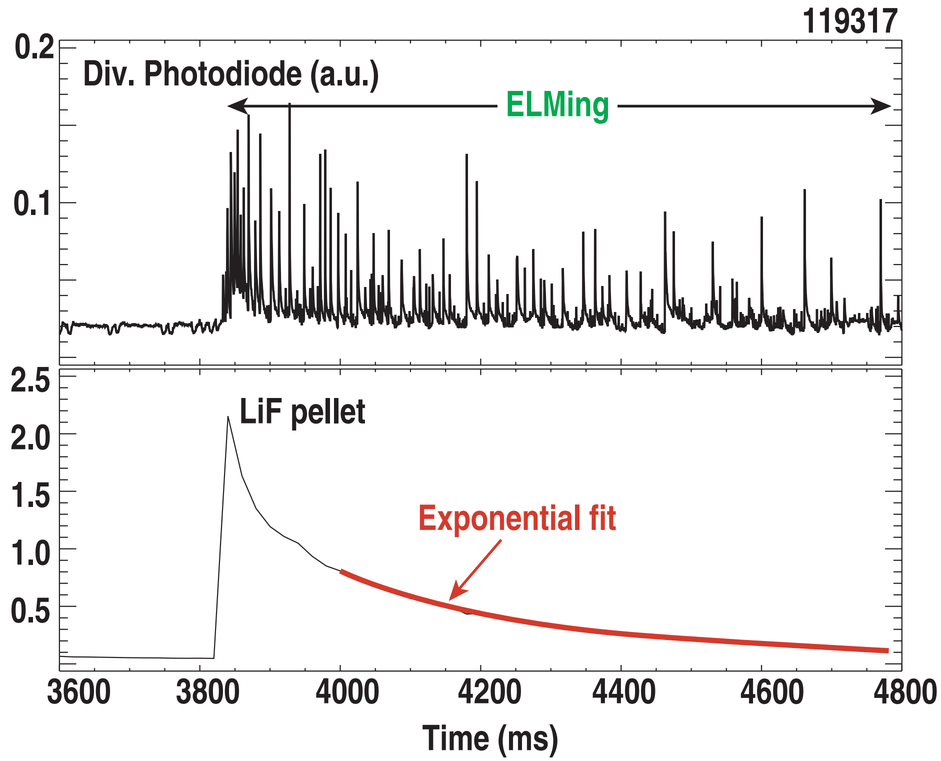
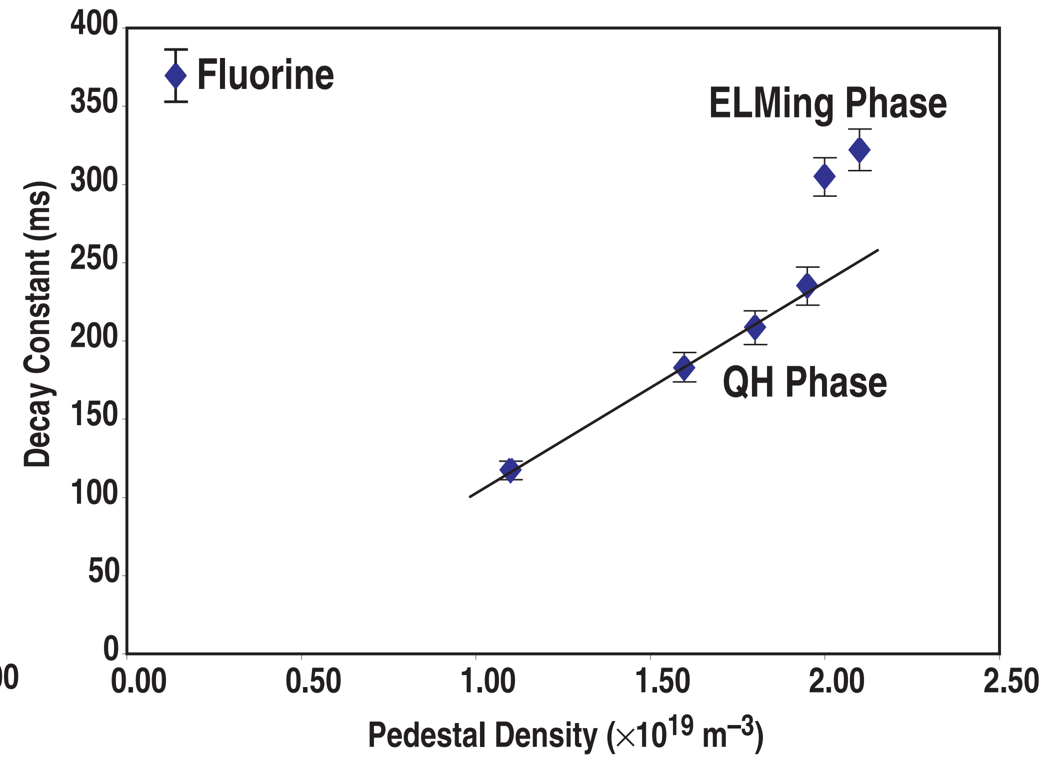
# IMPURITIES AT THE PLASMA EDGE ARE EXHAUSTED FASTER IN THE QH-MODE PHASE THAN IN THE ELMING PHASE

- The impurity decay constant at the plasma edge increases with the pedestal density
- EHOs exhaust impurities faster than the ELMs

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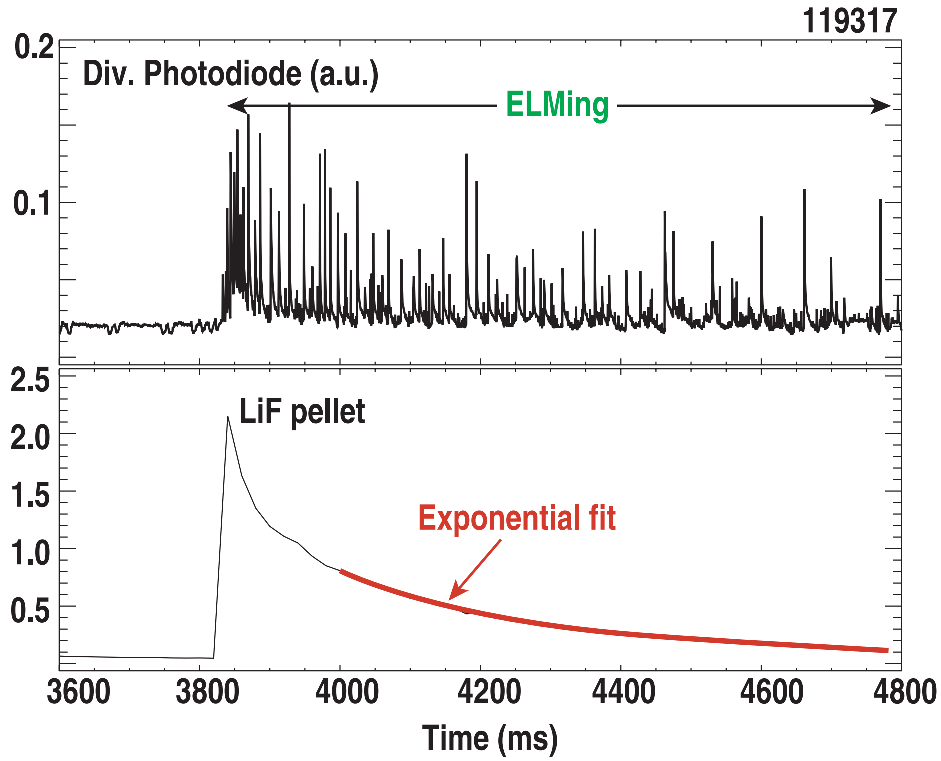
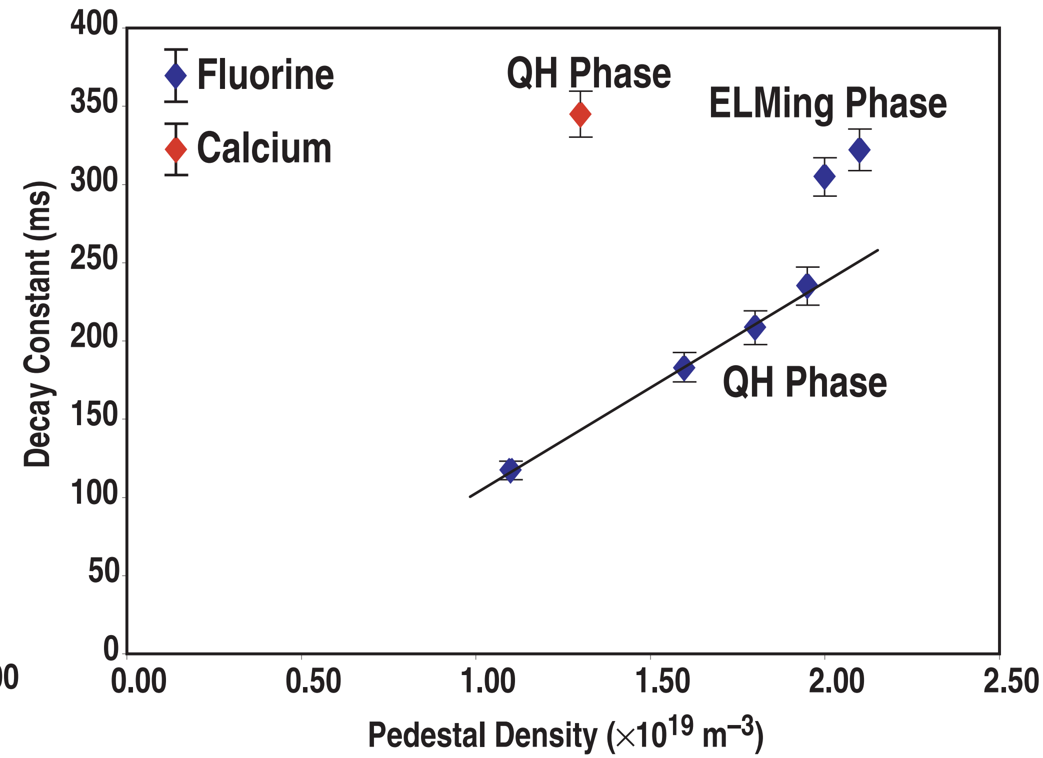
# IMPURITIES AT THE PLASMA EDGE ARE EXHAUSTED FASTER IN THE QH-MODE PHASE THAN IN THE ELMING PHASE

- The impurity decay constant at the plasma edge increases with the pedestal density
- Edge impurity confinement increases with Z

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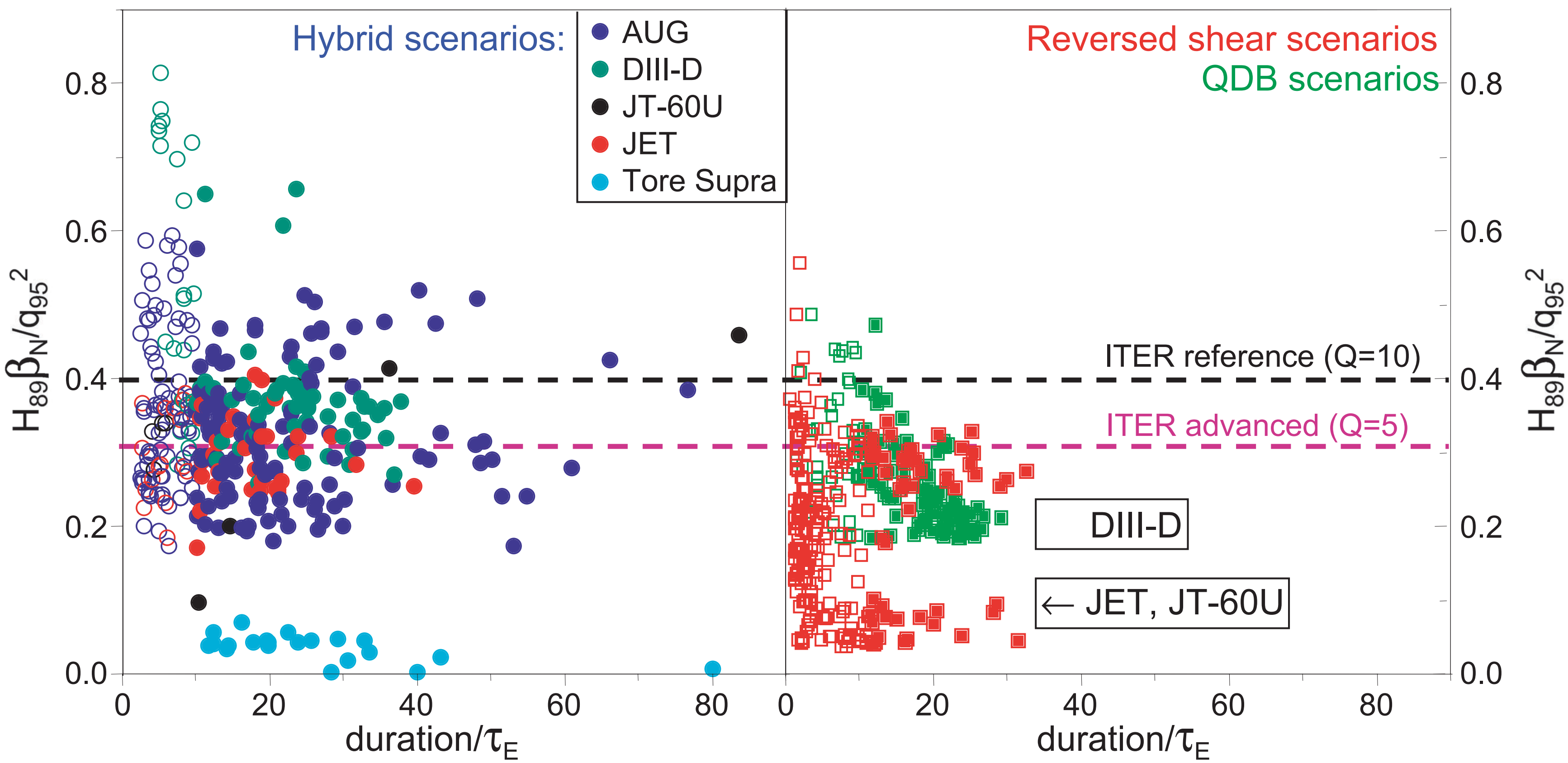
# DIII–D QDB DISCHARGES HAVE COMPARABLE PERFORMANCE TO HYBRID AND REVERSE SHEAR DISCHARGES




**Sips et al., IAEA (Vilamoura), IT/P3-P36 (2004)**

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# CONCLUSIONS

- The QH–mode pedestal at high $\delta$ is marginally stable to current driven modes at low to medium n
  - Determined from edge stability modeling using the ELITE stability code combined with edge profile analysis
  - QH–mode and ELM behaviour is very sensitive to inductive current ramps
- Impurities are exhausted faster in a QH–mode plasma than in an ELMing plasma
  - The edge impurity confinement increases with the pedestal electron density
- ECH, ECCD and NBI have been used as effective tools to control $q_0$ in QDB plasmas
- QDB plasmas compare favorably in performance with other AT plasma regimes e.g. hybrid, RS (determined from a multi-machine database)