Develop Early H-mode Startup for Access to High q-min

by

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Why Early H-mode? Allows Access to Current Profiles with Weak Shear At Substantially Higher q_{min}

- Accessing High q_{min} Requires Raising the Electron Temperature Near the Mid-Radius in order to Slow Down Penetration of Current Density: $\sigma = T_e^{3/2}$

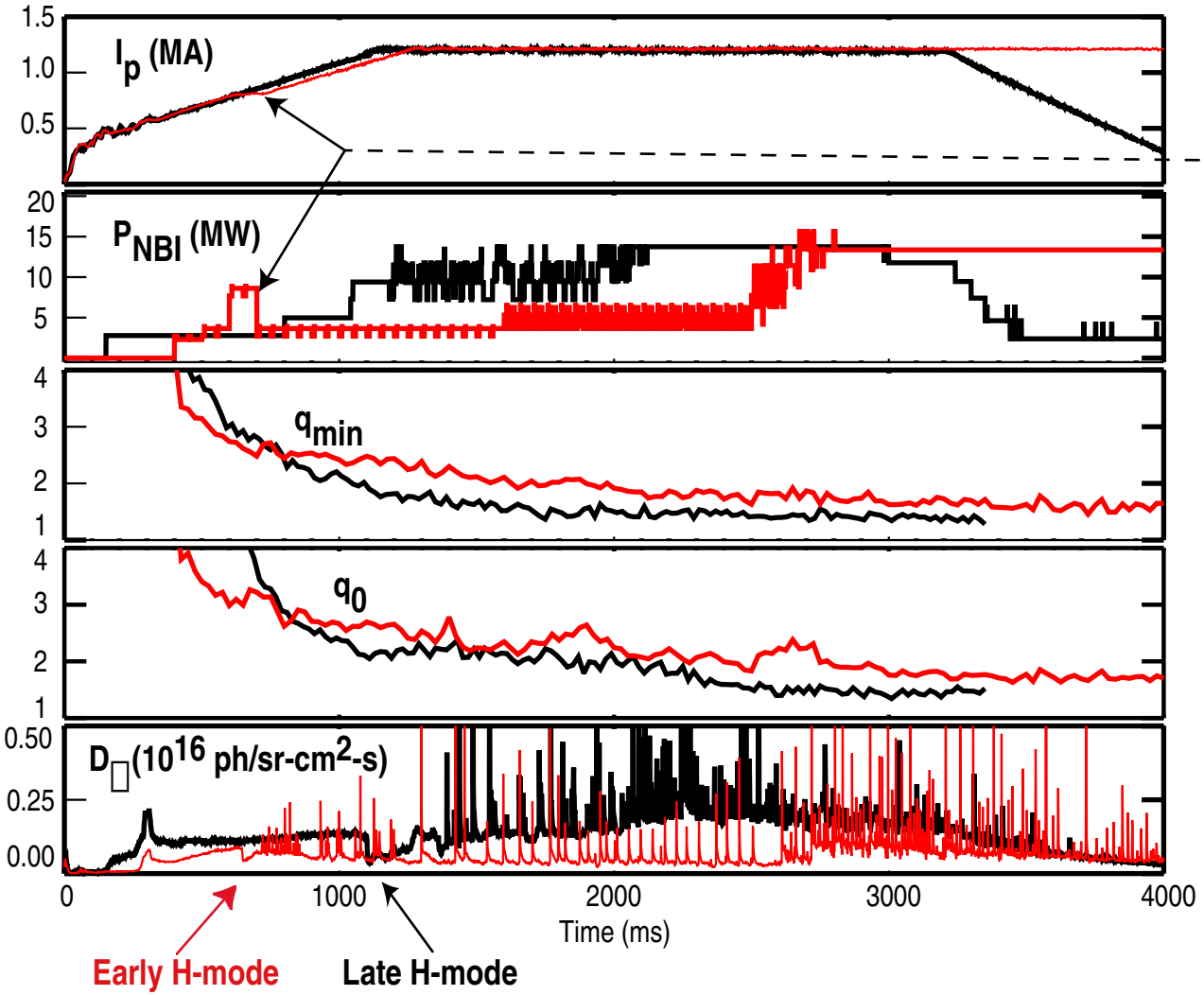
- Because Poloidal Field is Low During the Current Ramp, Confinement Is Generally Not Good and Increasing T_e Requires Substantial Amounts of Electron Heating

- If Mid-Radius T_e is Increased via Heating System That Deposits Majority of Power On-Axis, then central conductivity will generally become very high, resulting in very little current penetration in in the core region.

- This generally leads to current profiles with strong negative shear, that have been shown to be less favorable for achieving and sustaining high β

===> Need a method that raises mid-radius T_e without causing an unacceptable increase i the central T_e

Triggering an Early H-mode Allows Access to Higher q_{min} Without Strong Shear Reversal

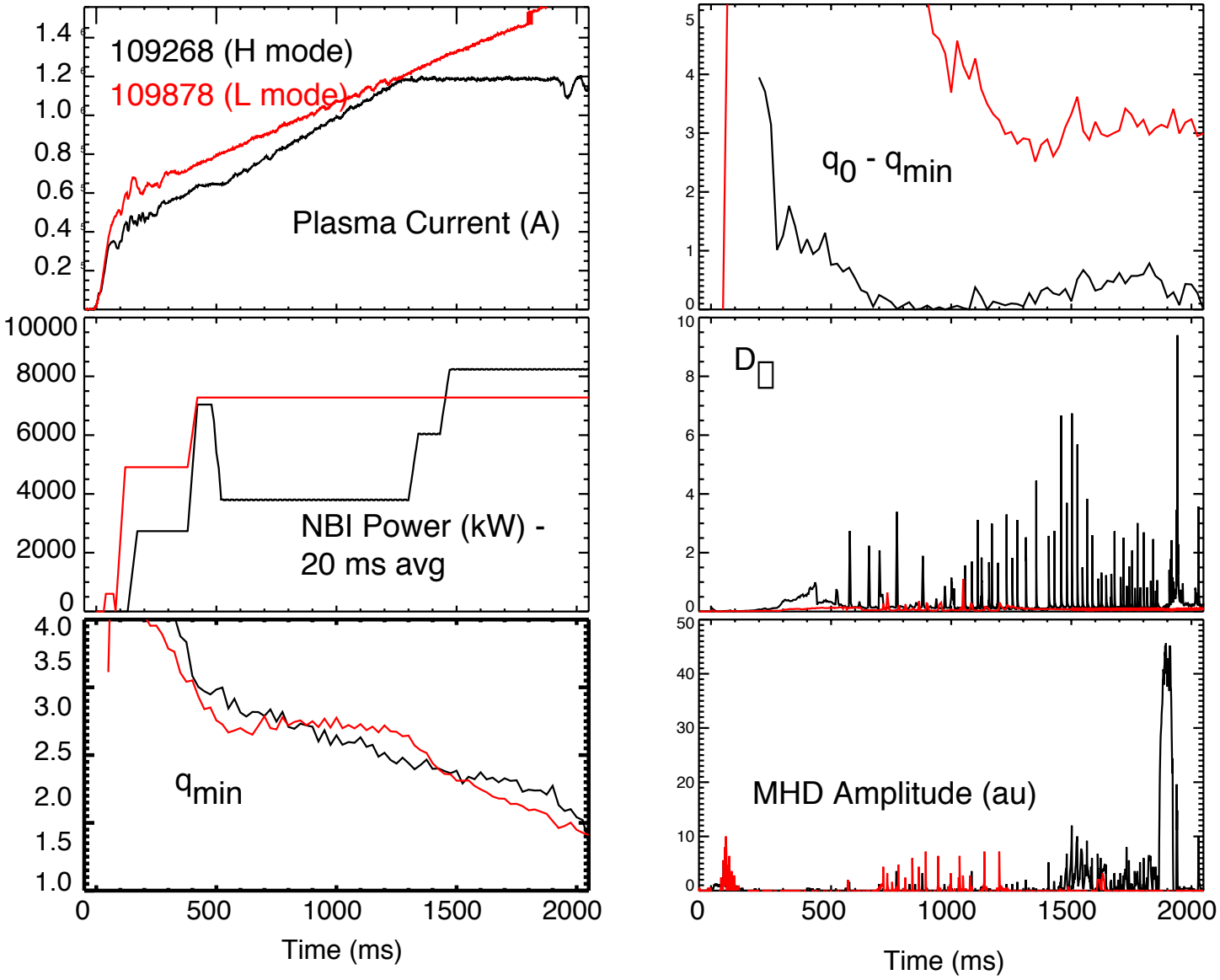


In DIII-D, H-mode induced by short step up in P_{NBI} concurrent with a brief period with $dI_p/dt = 0$

$q_{min} > 2.5$ at end of current ramp with modest central shear with $q_0 - q_{min} \sim 0.5$

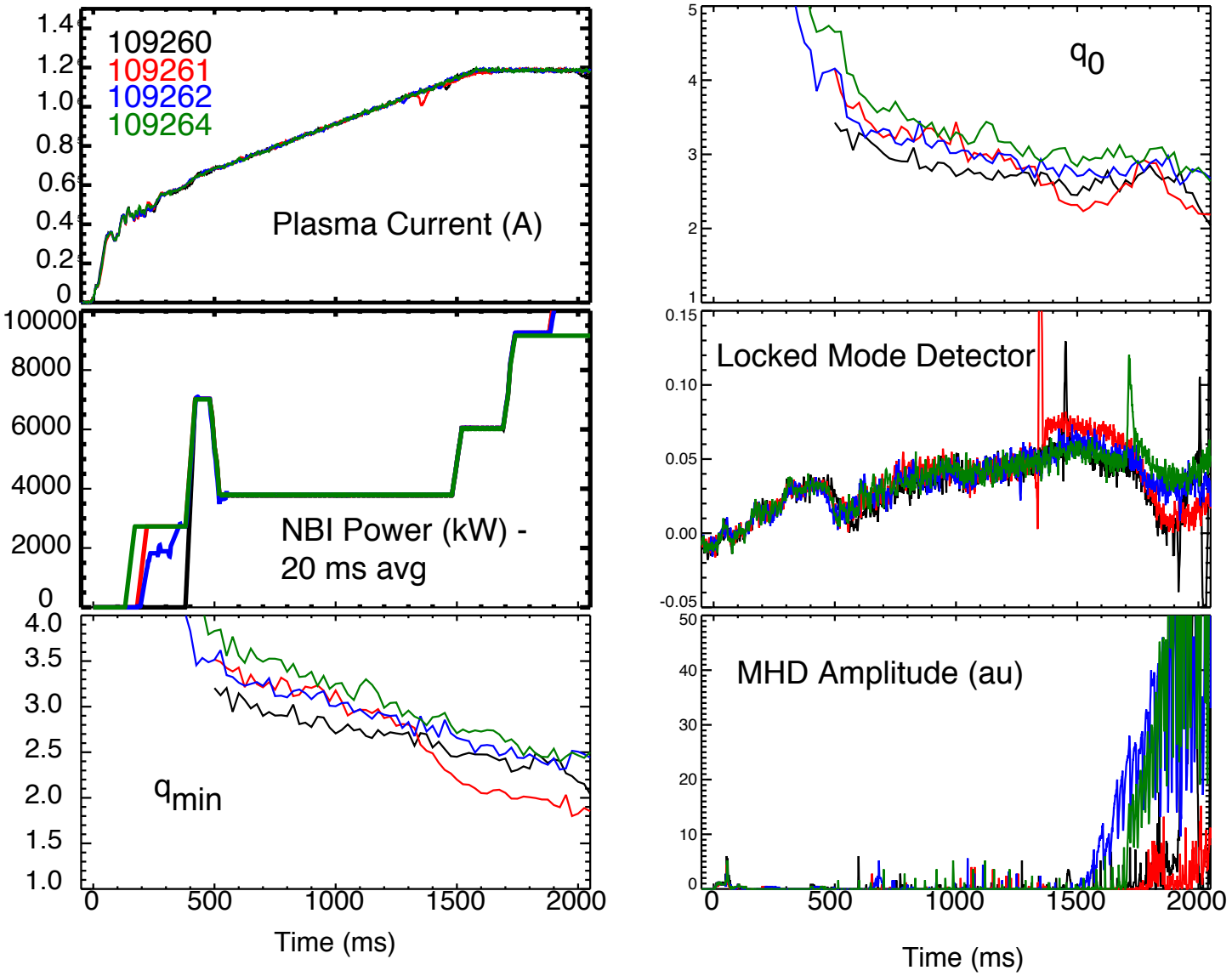
Note that access this approach allows access to many different q_{min} values with the same central shear

Example of Difference in Obtained Central Shear in L-mode and H-mode in Discharges with Similar q_{min} Evolution



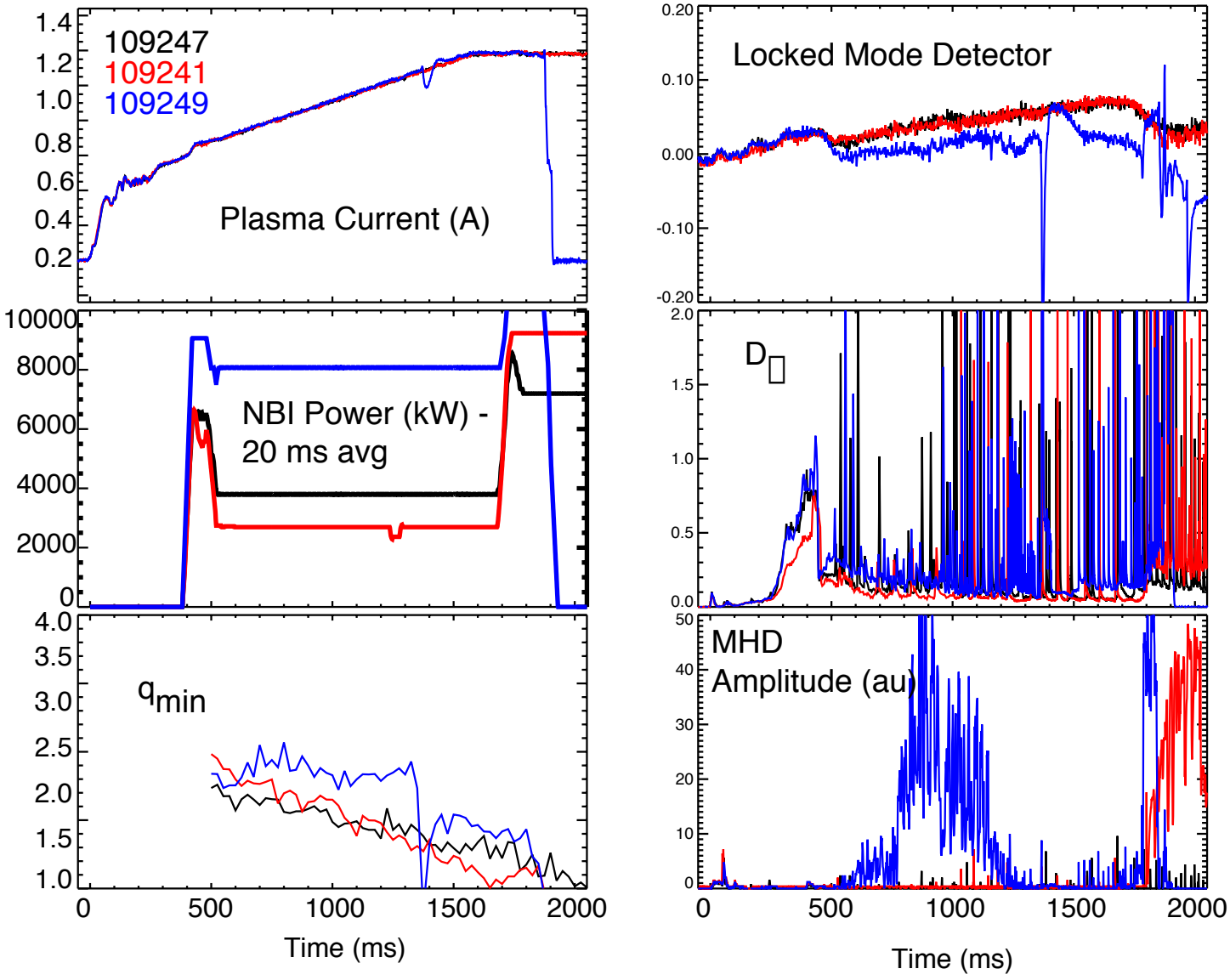
As Expected, Increasing the Heating Power Before H-mode Transition is Effective in Increasing q_{min} and q_0

... But Locked Modes Become More Prevalent

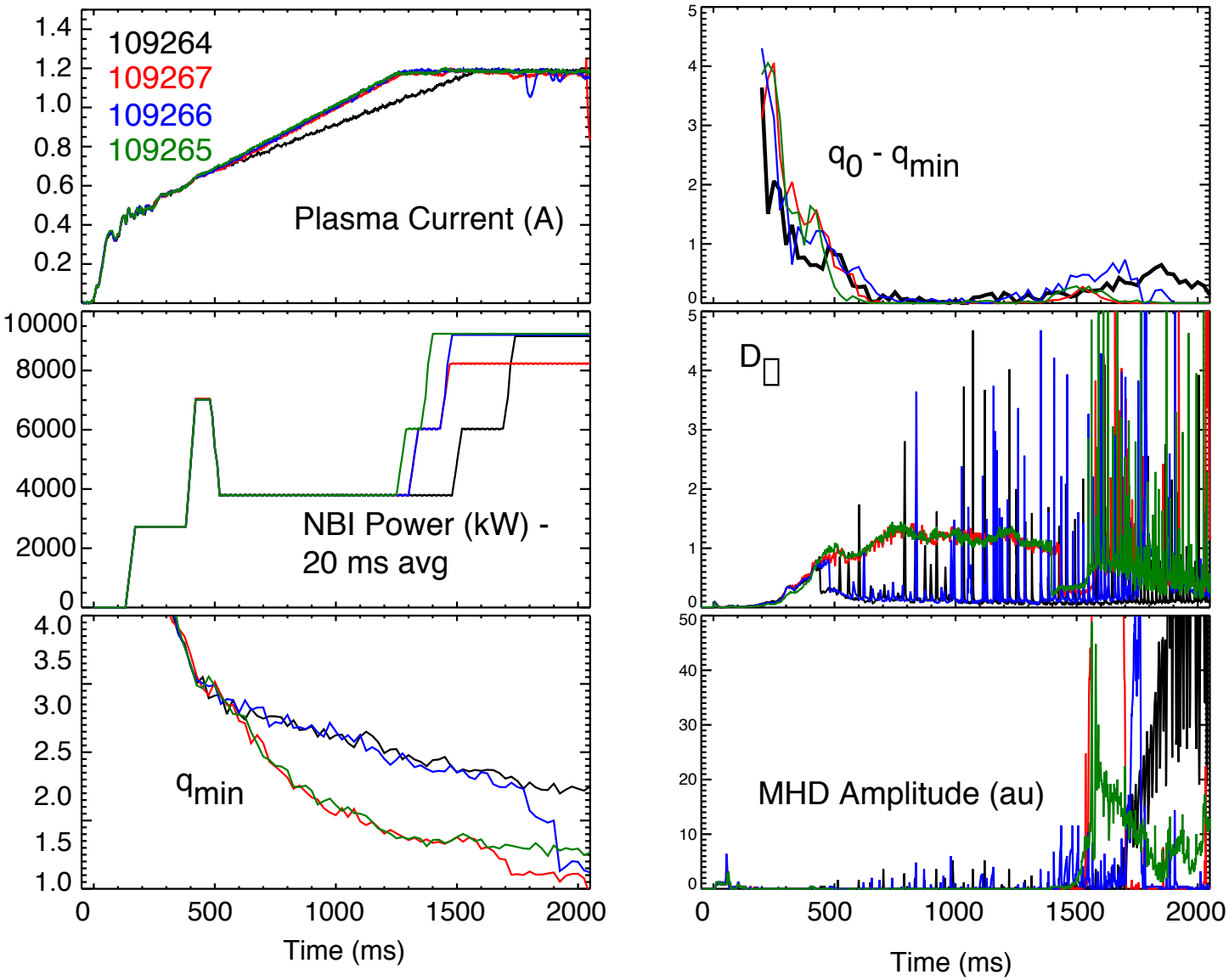


Current Profile Evolution is Sensitive to Applied Power Following H-mode Transition

- As expected from classical resistive diffusion

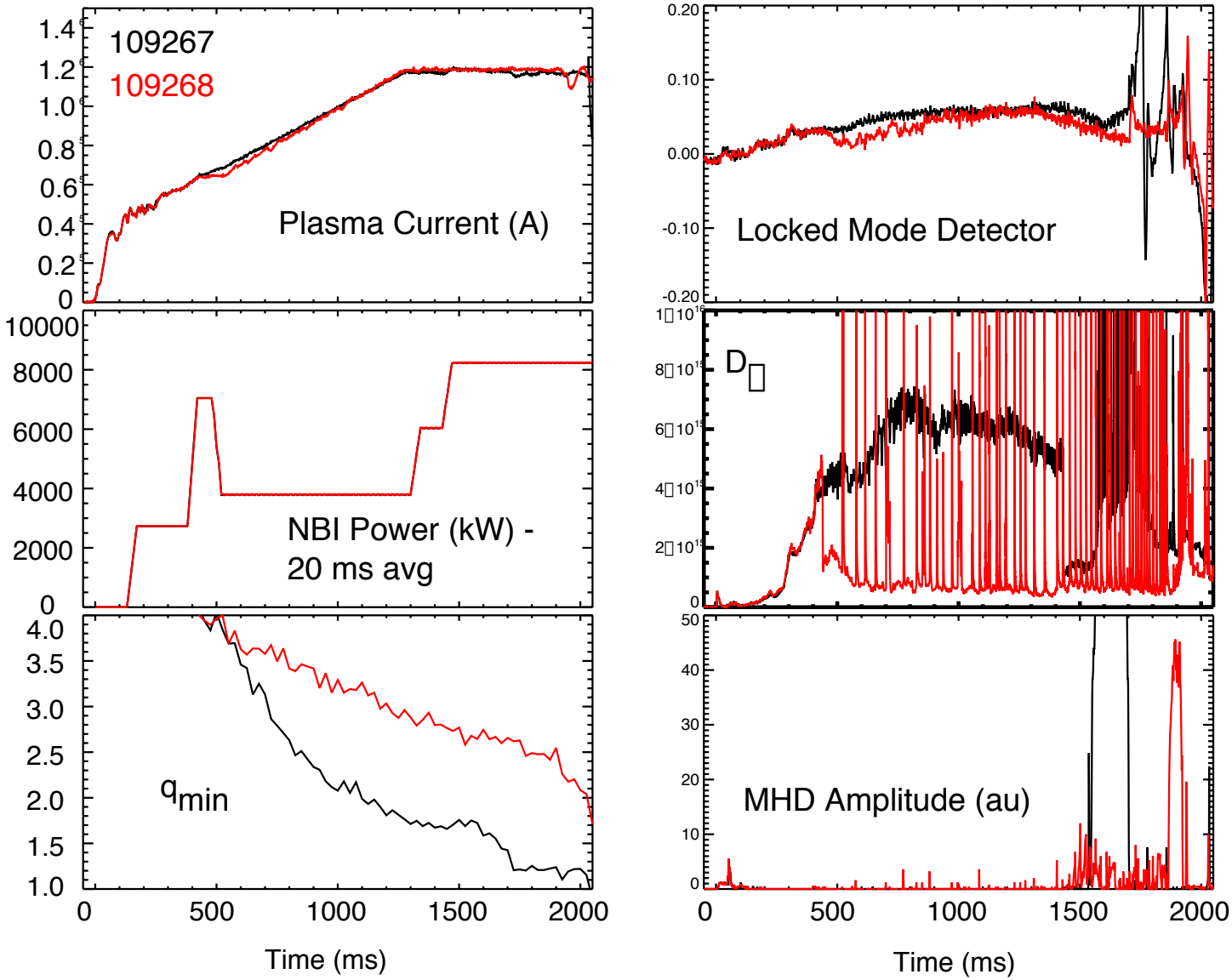


Accessible q_{min} is Weakly Dependent on Current Ramp Rate; However, H-mode Transition Reproducibility Suffers



Briefly Stopping Current Ramp Allows Reproducible Access to H-mode Early in Current Ramp Phase

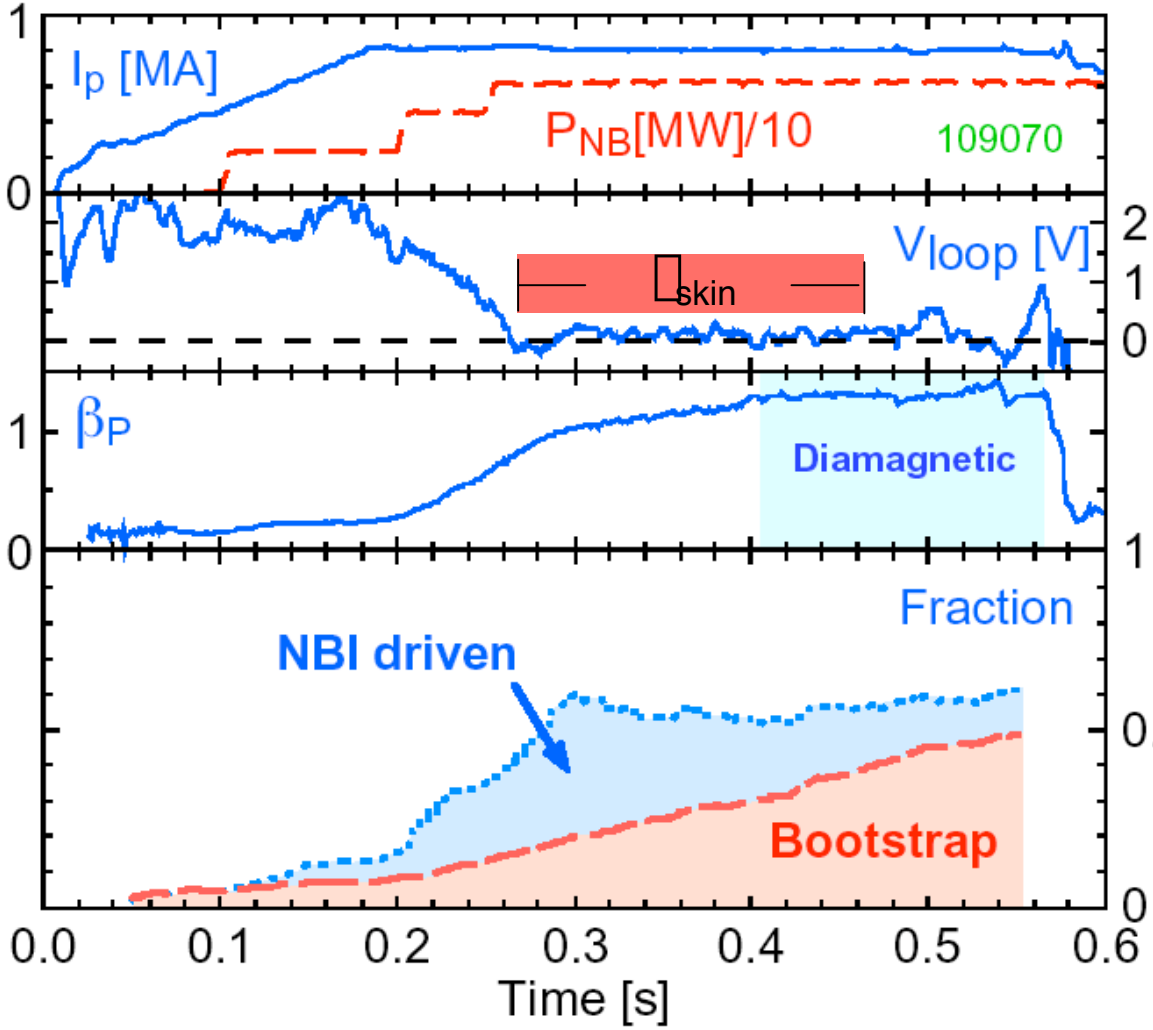
Takes Advantage of Well Documented Dependence of H-mode Threshold on Current Ramp Rate



Experimental Plan

- Target Plasma: to be determined (109070 looks like it has the right features)
- Start by Reproducing a Typical High Performance discharge with Neutral beams applied during the Current Ramp but Maintaining Plasma in L-mode. Want to start NBI at earliest possible time.
- L-H transition timing (6 shots):
  Scan L-H transition timing (through timing of change from limiter to divertor configuration) from end of current ramp to technical limit is steps of roughly 20 ms. No changes in beam timing/power during this step unless additional power is necessary for L-H transition.
- Post L-H transition Power Scan (3 shots):
  At earliest achievable L-H transition, scan NB power following L-H transition in steps of 1/2 source to determine maximum limit on heating power before locked modes occur.
- Current Ramp Rate Scan (4 shots):
  Using earliest achievable L-H transition and highest possible NB power, scan current ramp rate following L-H transition up in 0.25 MA/s steps to determine maximum achievable ramp rate without locked modes.
- Combined Current Ramp Rate/Power Scan (10 shots):
  Scan current ramp rate down in steps of 0.25 MA/s. At each step, starting from maximum power point, scan power subsequent up in steps of 1/2 source to technical limit to determine limit on heating power at each current ramp rate level.
- Reproducibility (3 shots):
  Take best and case and try to repeat 2 times to determine reproducibility of method.

High Fraction of Non-Inductive Currents Achieved in Long-Pulse High β_{pol} Discharges



- $\beta_p \sim 1$, I_{NI} Fraction = 60%
- β_N = 5.8 > no-wall stability limit
- $\beta_N H_{89p} \sim 15$ at β_T = 15% sustained over τ-skin, constant l_i
- However, density still evolving; need particle control