Effects of Toroidal Rotation on Hybrid Scenario Plasmas

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GENERAL ATOMICS

The ITER hybrid scenario and hybrid plasmas:

ITER definition:

An advanced (better than standard H-mode) scenario;
long pulse inductive, with "substantial" noninductive current drive;
producing high neutron fluence.
Intermediate in performance between standard H-mode and AT steady-state noninductive scenarios.

There is no more precise definition.

(You know it when you see it.)

DIII-D hybrid plasmas:

★ bootstrap fraction ~ 0.3-0.5

q0 ~ 1

completely relaxed, stationary profiles (J, n_e, T_e, T_i, V_ϕ)

★ broader current profile than standard H-mode

⇒ less susceptible to *m*/*n* = 2/1 NTM

⇒ higher β

reduce or eliminate sawteeth

⇒ better confinement

⇒ remove trigger for 2/1 NTM

★ modified current profile is definitely due to presence of stationary MHD activity – almost always a 3/2 NTM;

no definitive identification of mechanism

★ hybrids have excellent confinement

possibly due to combined effects of better rotation profile and better q profile.

Toroidal rotation effects:

- Most of the tokamak experience base is limited to plasmas with strong toroidal rotation (thanks to NB heating).
- There is significant concern that ITER (& DEMO & reactors) will have low rotation.
- And that low rotation reduces ExB shear, increasing turbulence levels and the resulting transport.
- And that low rotation may reduce the β thresholds for NTMs and RWMs.

DIII-D experiments:

Use the recently (2005) modified NB configuration (2 of 7 NB sources in the counter direction) to study the effect of rotation on the performance of hybrid plasmas.

Summary of observations:

We performed systematic scans of rotation at several values of density and q95

- **Central Mach number has been reduced by up to a factor of 5, to $M_0 \approx 0.1$, maintaining stationary conditions.**

- **Confinement is reduced.**
  - → Fusion performance parameter G (= $\beta_N H_{89}/q_{95}^2$) is reduced by 10-30%, but remains above ITER level for Q_{fus} = 10 operation at low q_{95}. I.e., The overall performance drops from "excellent" to "very good".

- **3/2 NTM island width increases** with a noticable but minor effect on confinement.

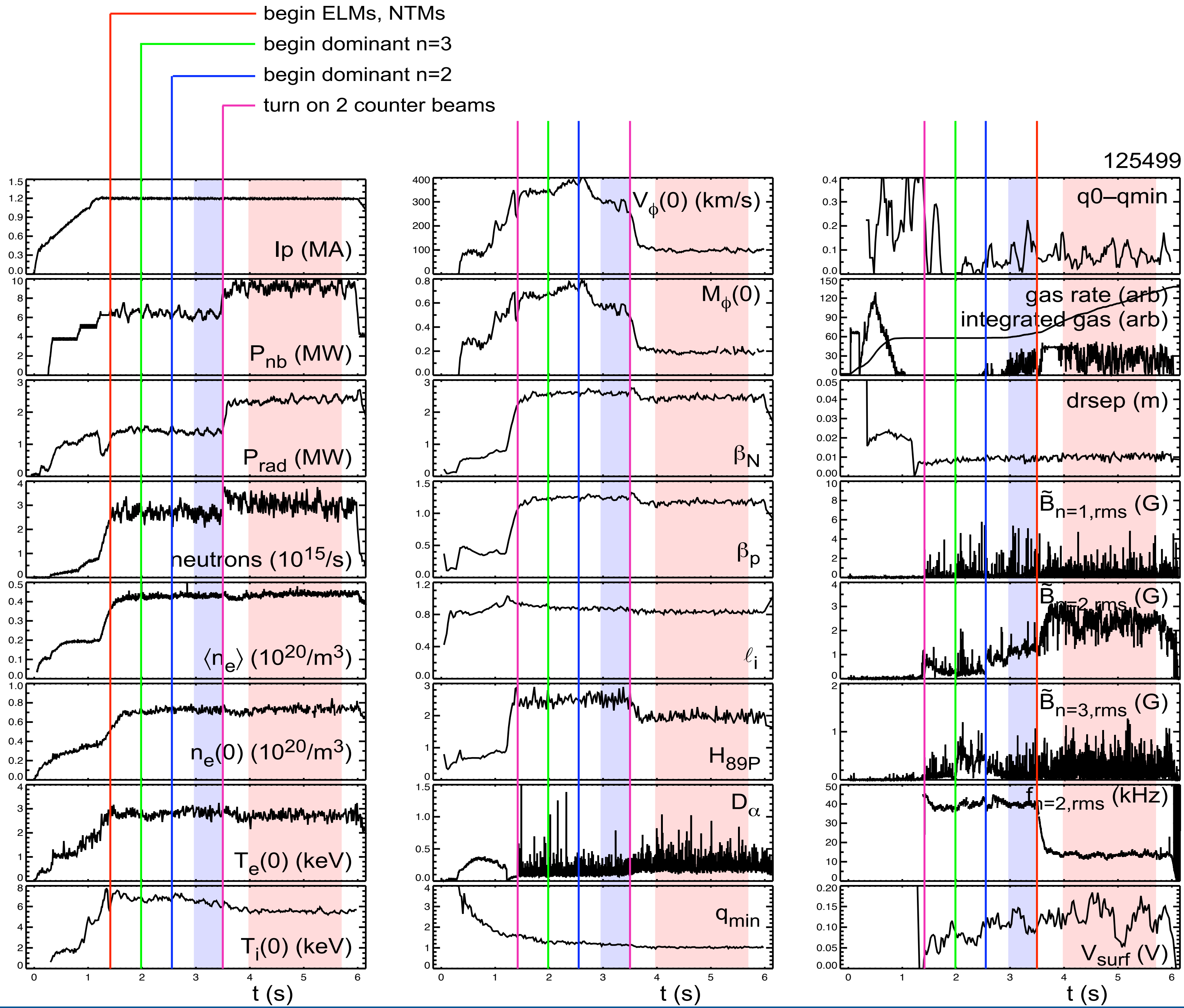
- **Primary confinement effect appears to be via reduction of ExB flow shear.**

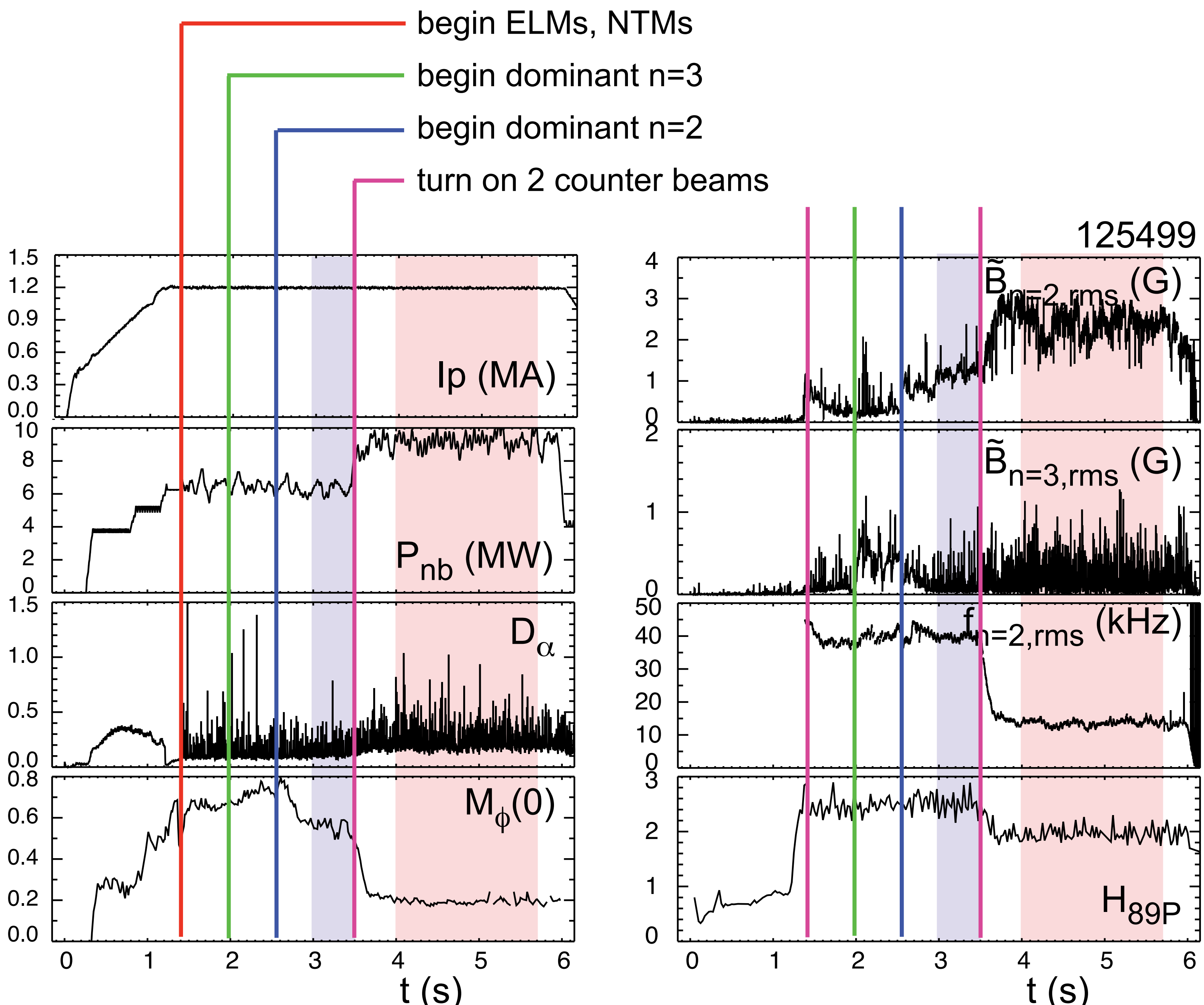
Outline:

➜ Examine the changes in properties of a single discharge when the input torque is reduced.

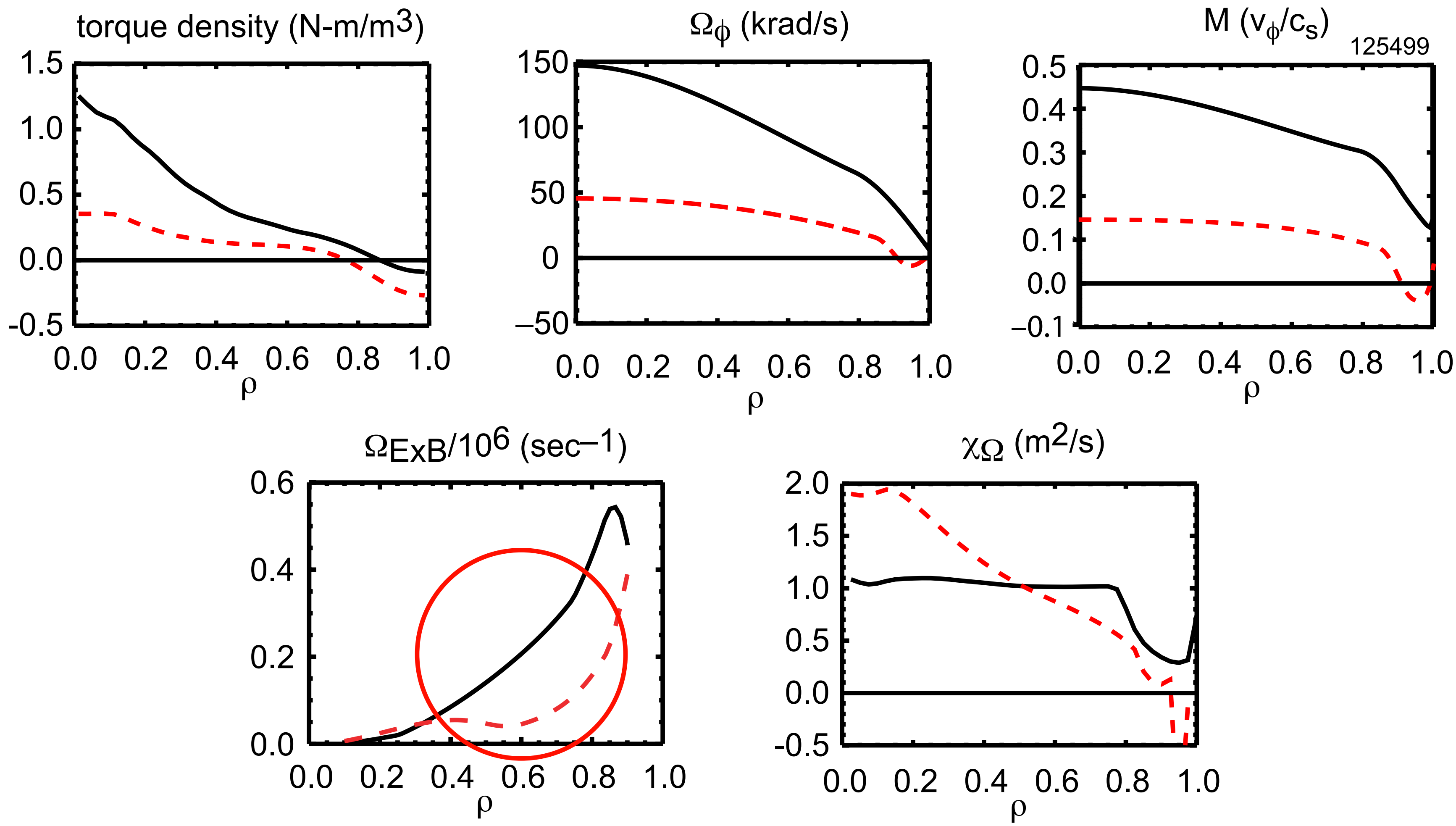
➜ Briefly look at the relationship between torque and angular momentum.

➜ Examine the changes in confinement and MHD behavior as a function of angular momentum.

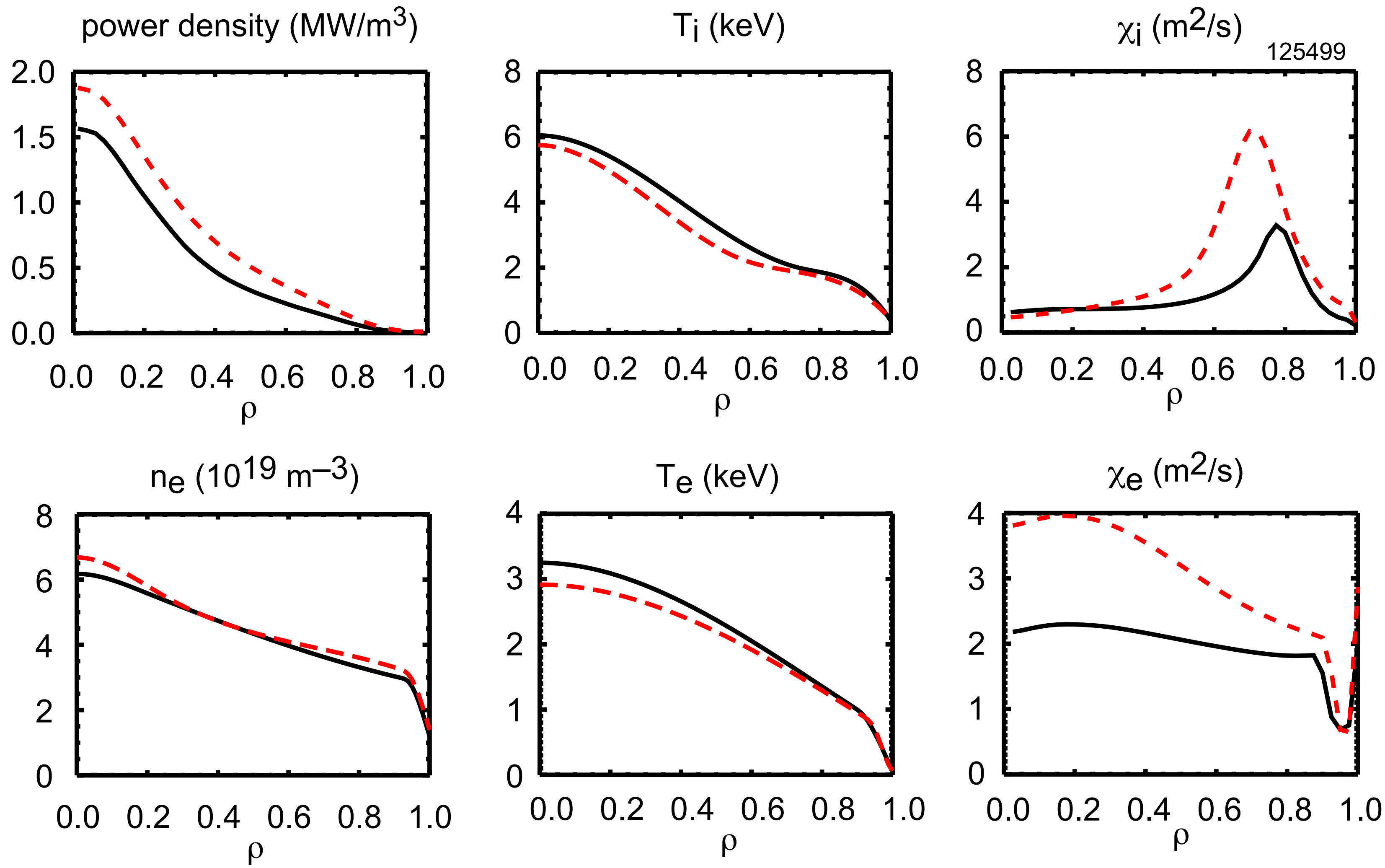

begin ELMs, NTMs
begin dominant n=3
begin dominant n=2
turn on 2 counter beams
125499
Ip (MA)
P_{nb} (MW)
P_{rad} (MW)
neutrons (10^{15}/s)
$\langle n_e \rangle$ ($10^{20}/m^3$)
$n_e(0)$ ($10^{20}/m^3$)
$T_e(0)$ (keV)
$T_i(0)$ (keV)
$V_\phi(0)$ (km/s)
$M_\phi(0)$
β_N
β_p
ℓ_i
H_{89P}
D_α
q_{min}
q0–qmin
gas rate (arb)
integrated gas (arb)
drsep (m)
$\tilde{B}_{n=1,rms}$ (G)
$\tilde{B}_{n=2,rms}$ (G)
$\tilde{B}_{n=3,rms}$ (G)
$f_{n=2,rms}$ (kHz)
V_{surf} (V)
t (s)


begin ELMs, NTMs
begin dominant n=3
begin dominant n=2
turn on 2 counter beams
125499
Ip (MA)
P nb (MW)
D α
M φ (0)
B̃ n=2,rms (G)
B̃ n=3,rms (G)
f n=2,rms (kHz)
H 89P
t (s)
t (s)

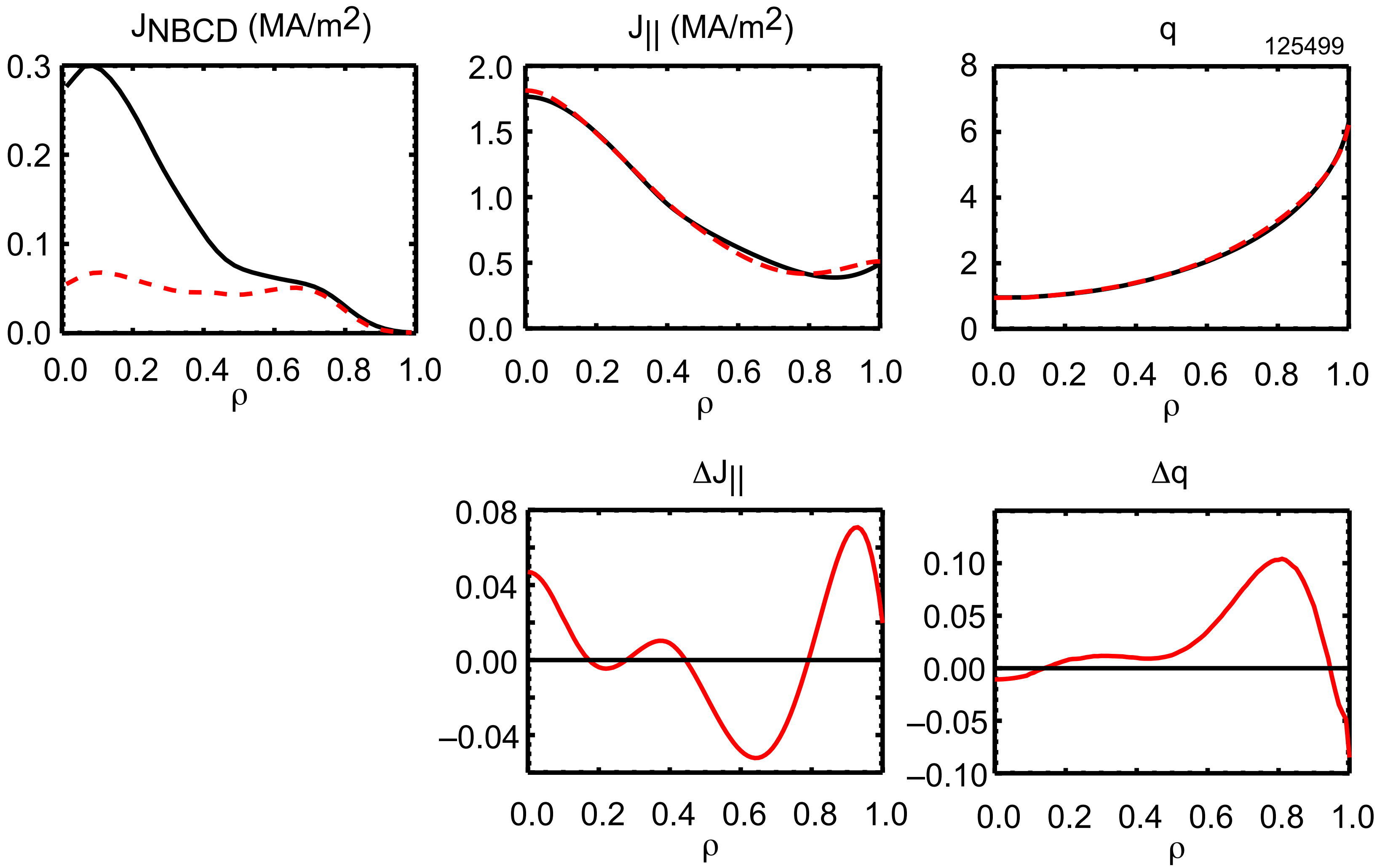
Reducing torque by factor ~3 reduces rotation by a similar factor and leads to large reduction in ExB flow shear at mid-radius.



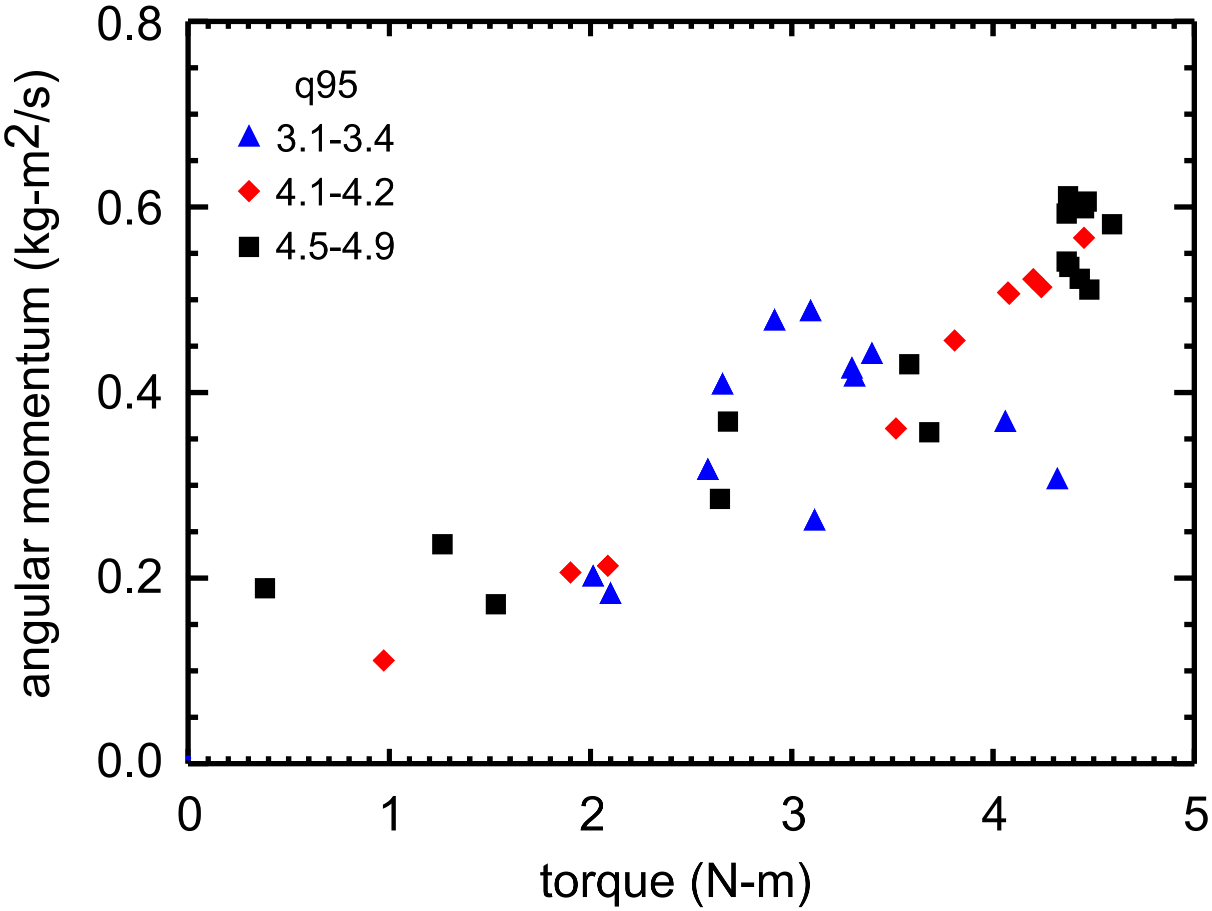
Density and temperature profiles change little (both β_N and $\bar{n}_e$ are controlled).



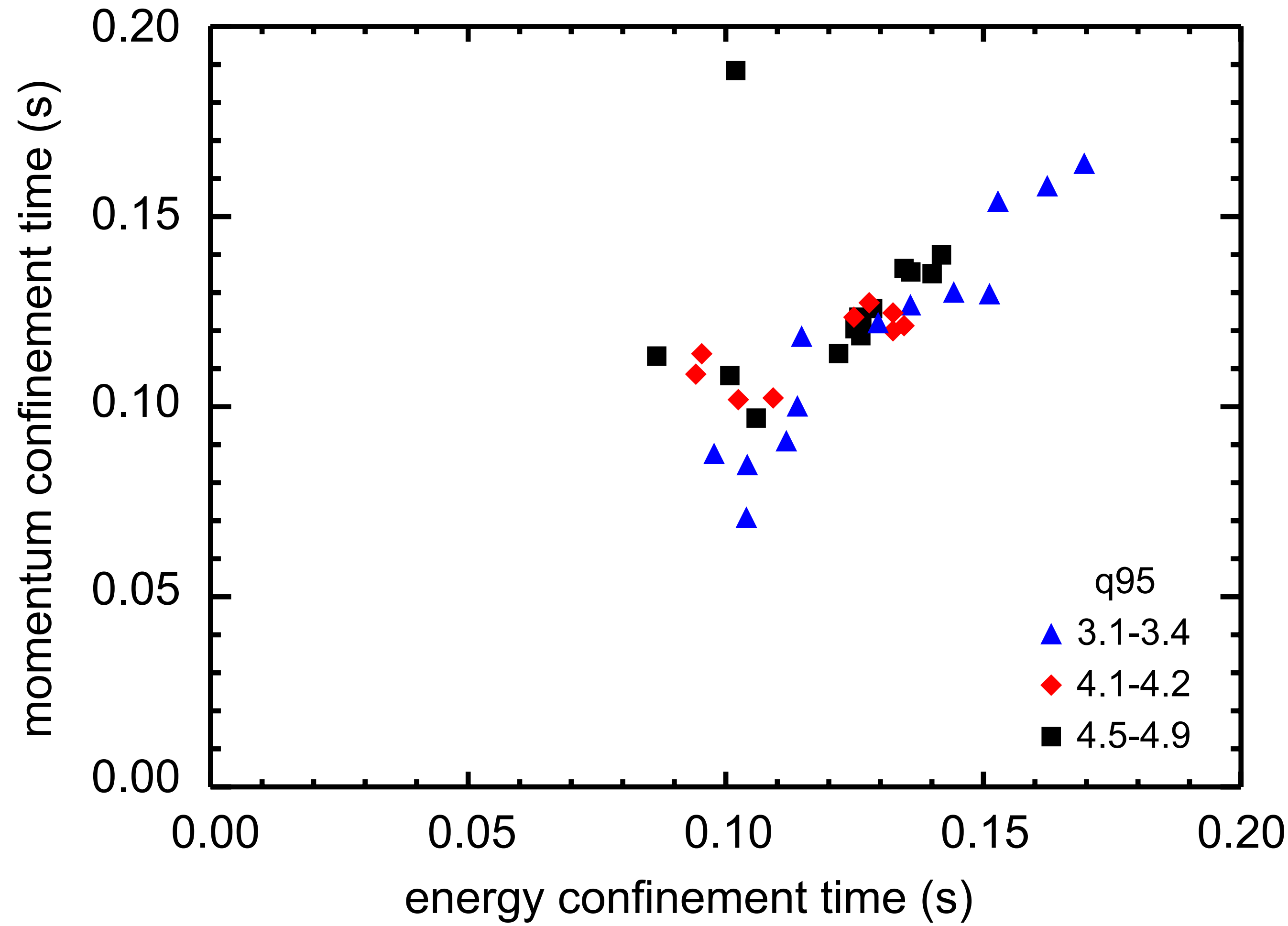
Current and q profiles change very little (J_{NBCD} is a small fraction of the total current).



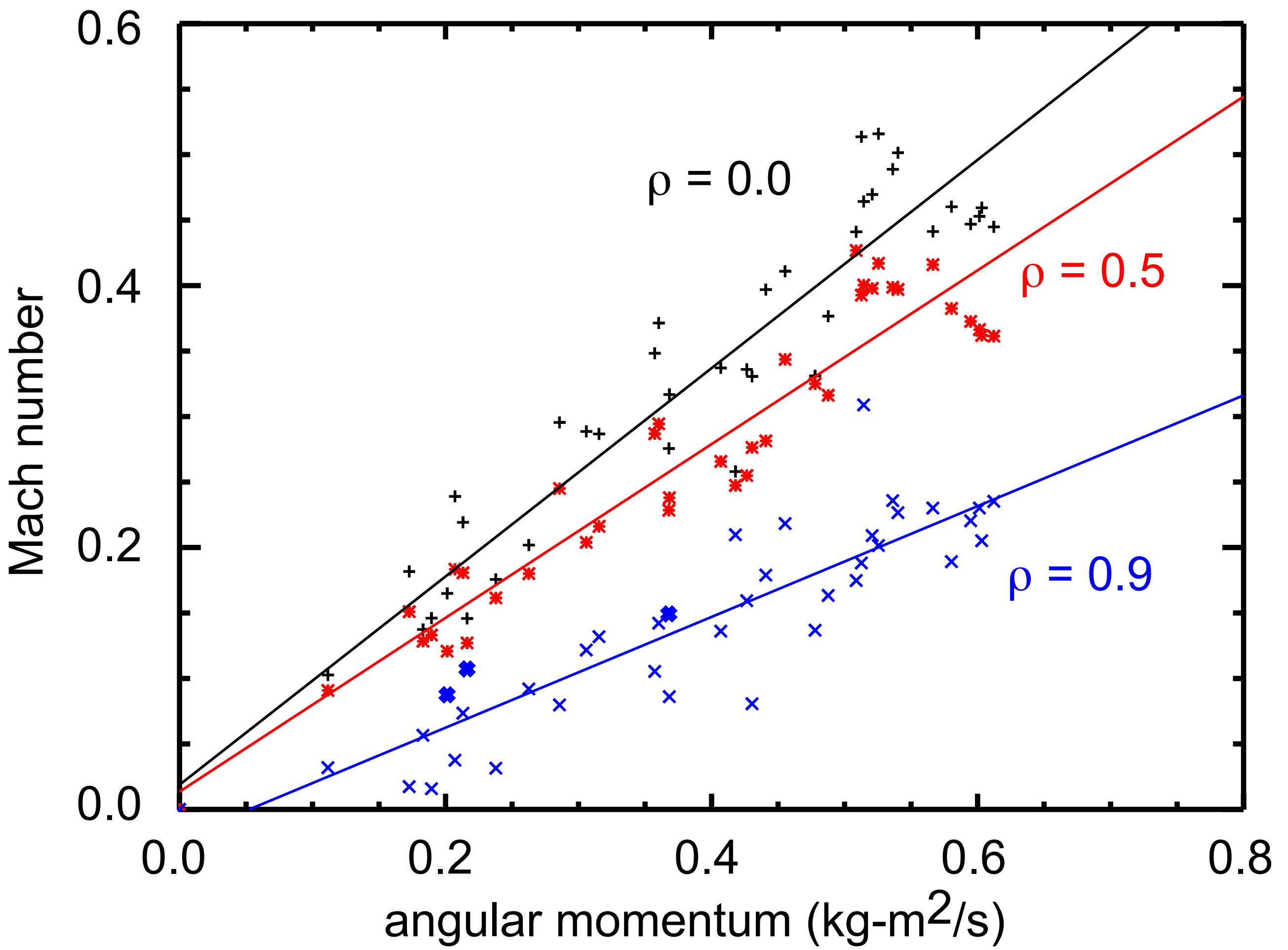
Angular momentum is proportional to torque, except for some indication of inherent rotation at low torque.

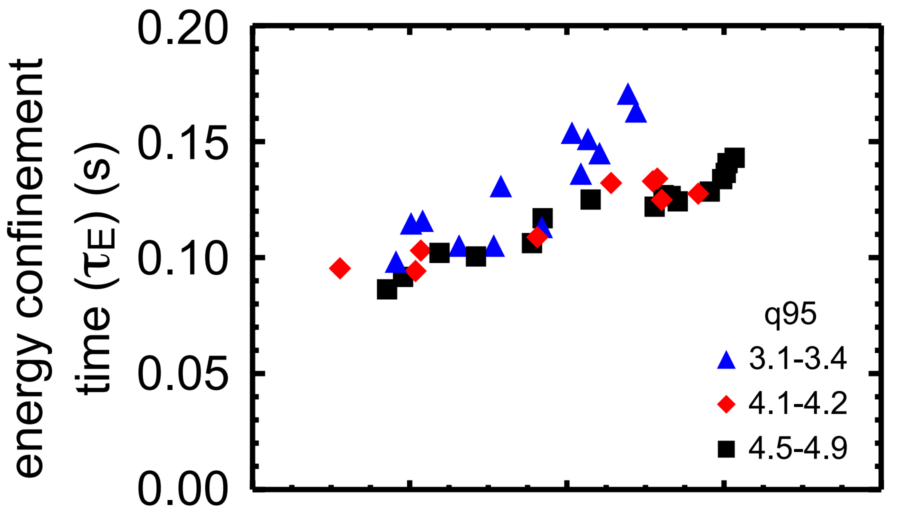


$\tau_\Omega \approx \tau_E$, except for very low torque points

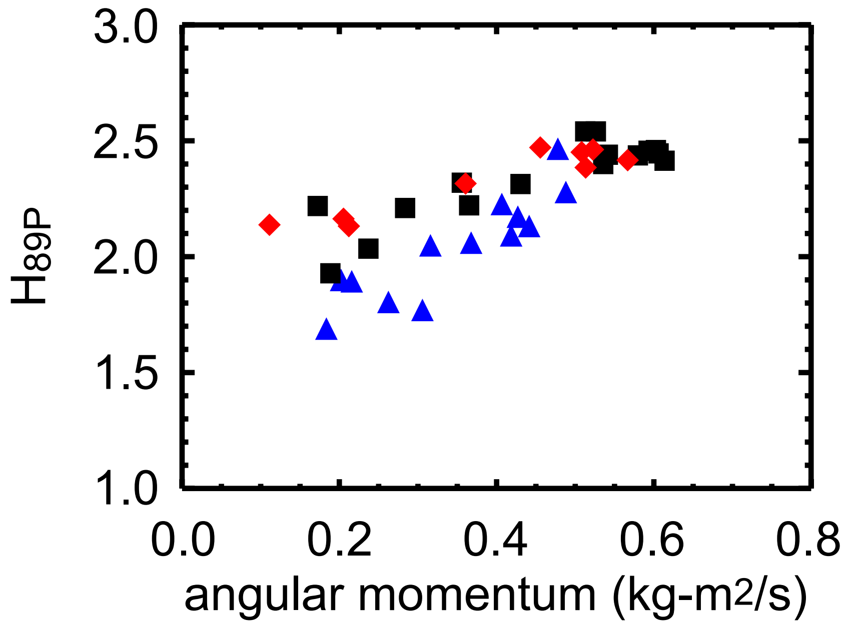


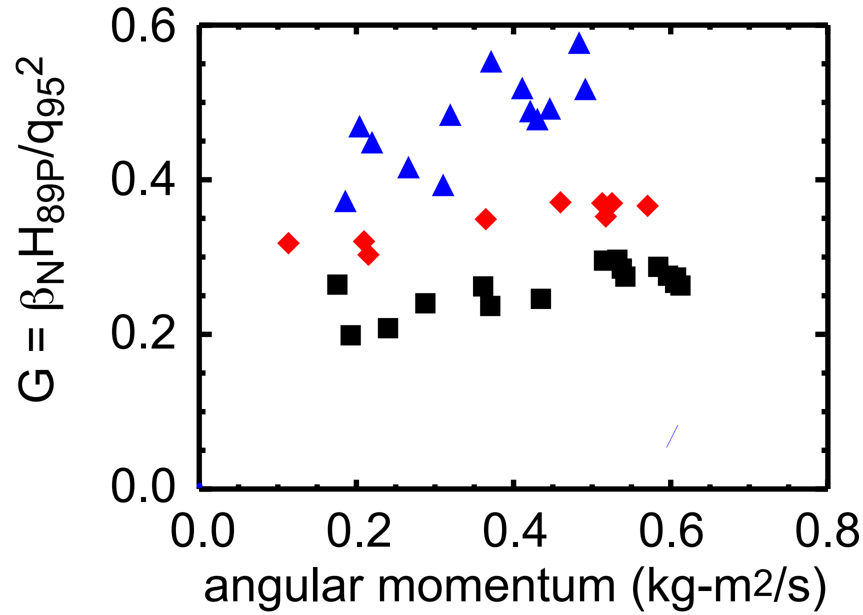
Mach number is proportional to angular momentum, except near edge, where $v_\phi \rightarrow 0$ at finite total angular momentum. (Related to locking?)



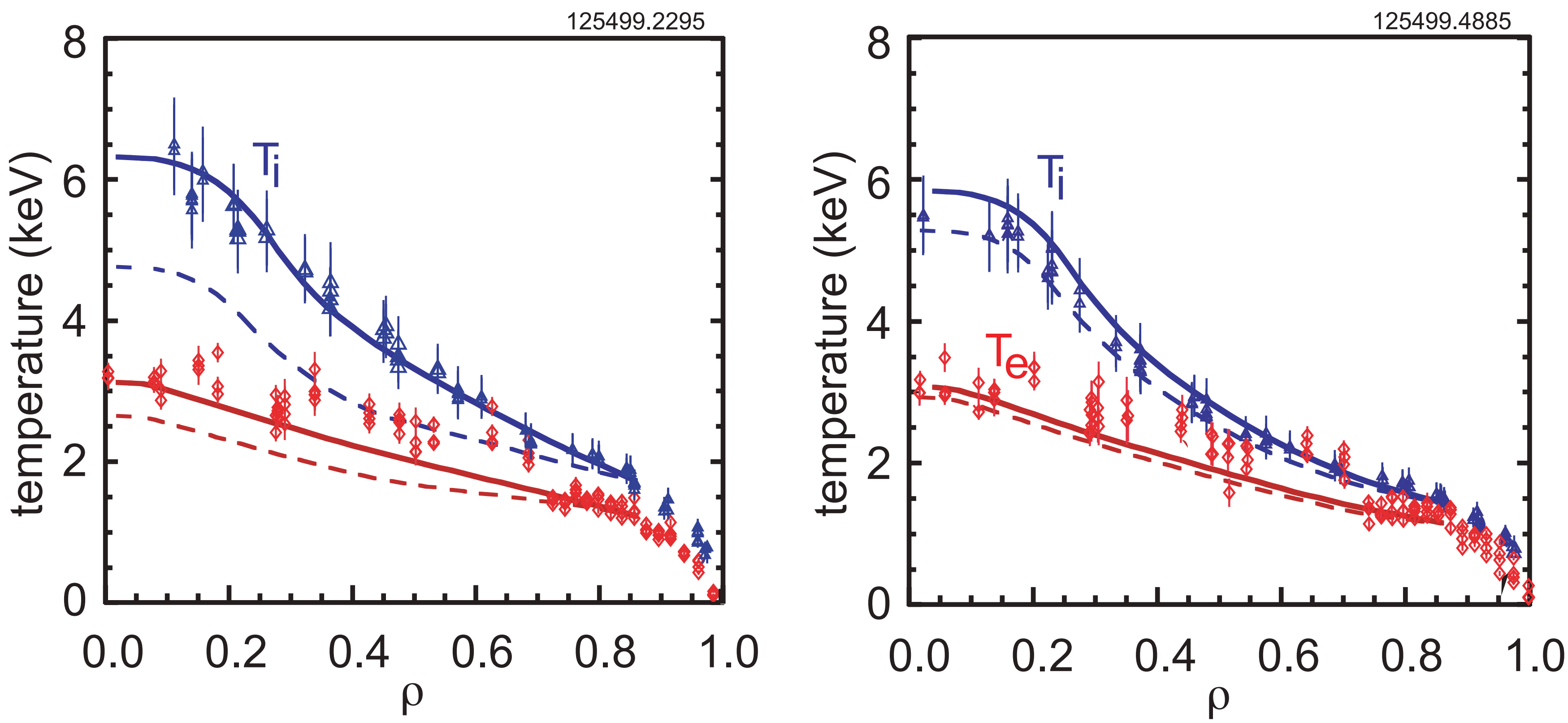


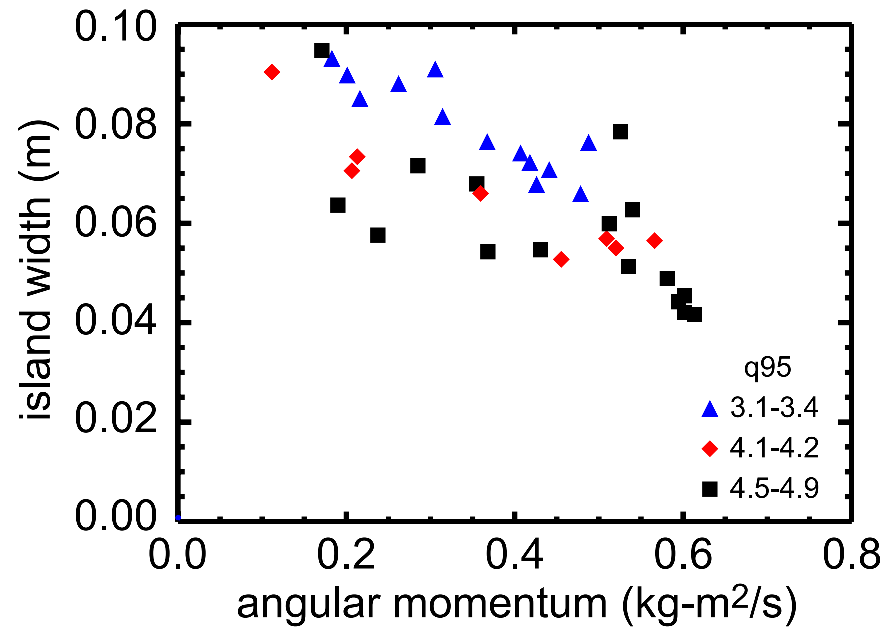
Three ways of looking at confinement as a function of angular momentum.



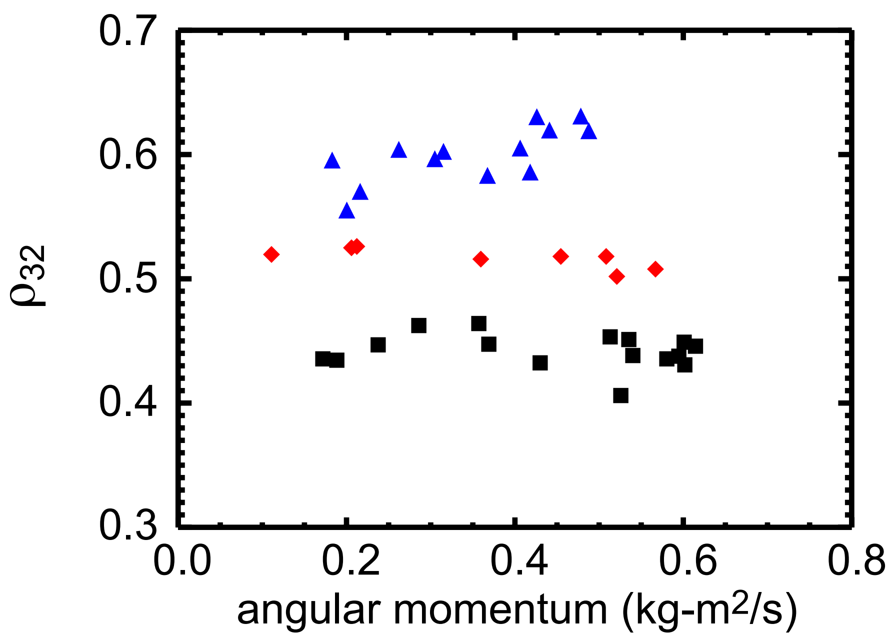


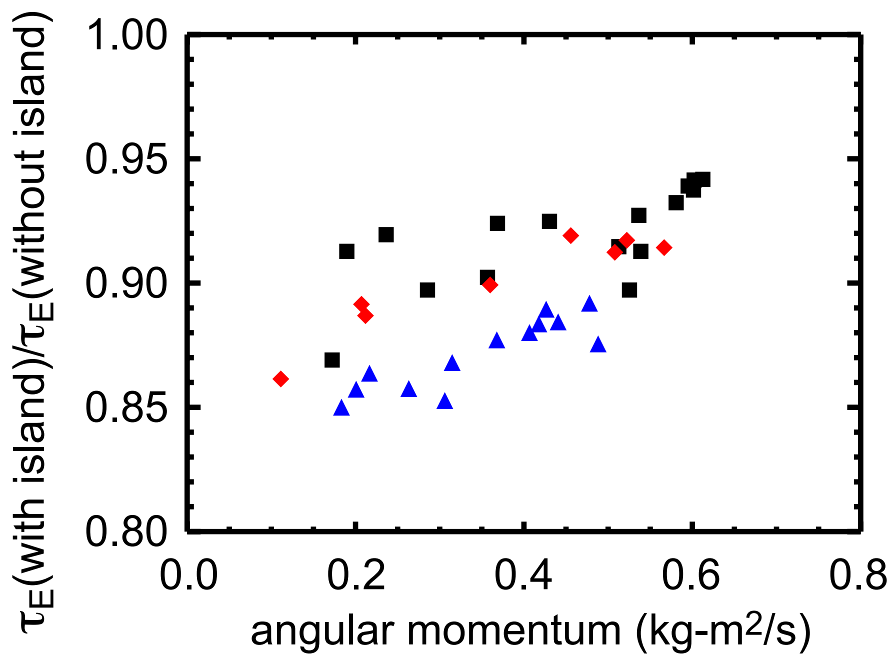
GLF23: ExB shear flow is needed to match Te and Ti profiles at high rotation, but not at low rotation.
⇒ change in ExB flow shear is responsible for most of confinement change.





Change (increase) in NTM island width accounts for an ~5% change in τ_E. Small compared to ~30% overall reduction.





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