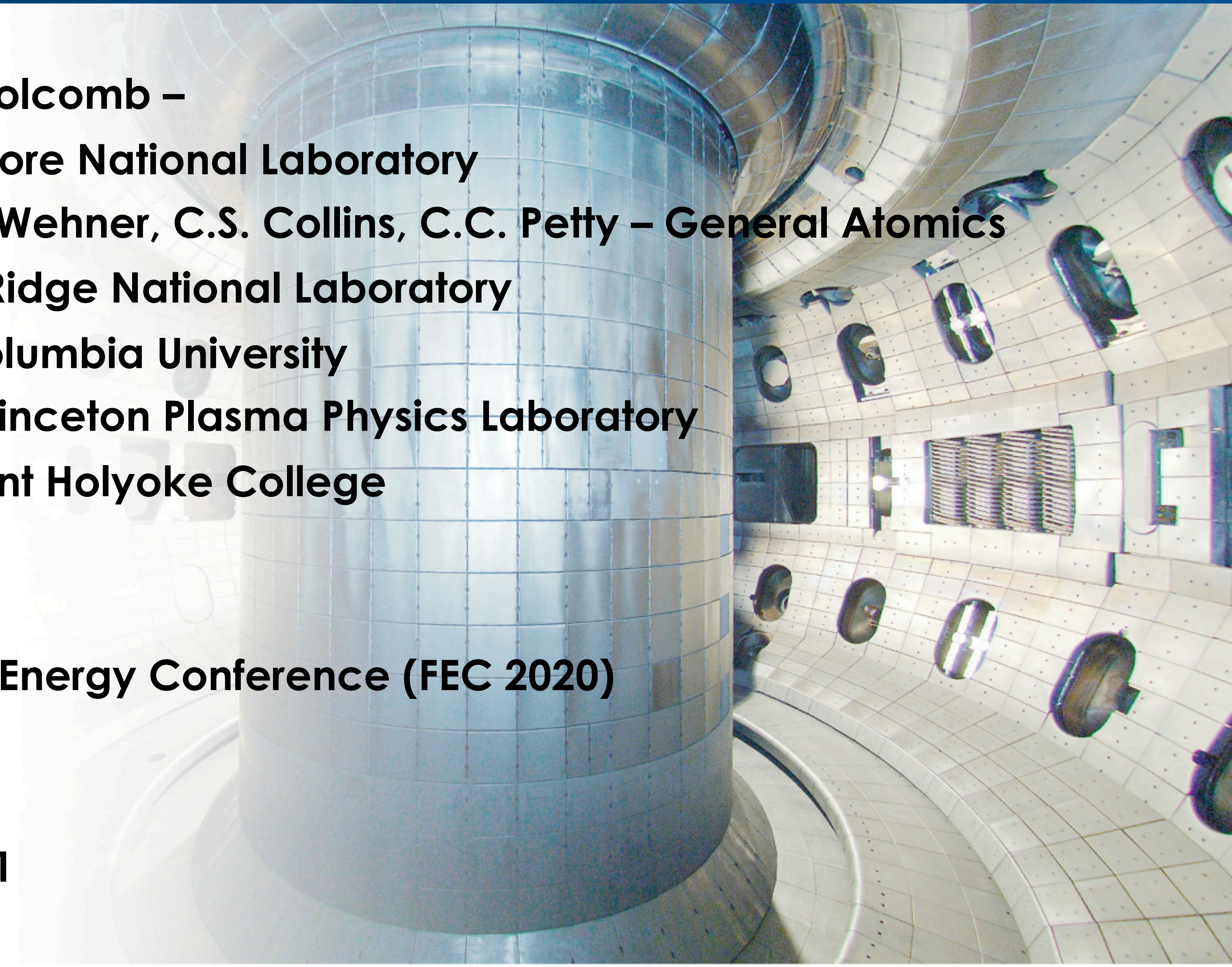
GLOBAL STABILITY OF ELEVATED-QMIN, STEADY-STATE SCENARIO PLASMAS ON DIII-D



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DIII-D NATIONAL FUSION FACILITY

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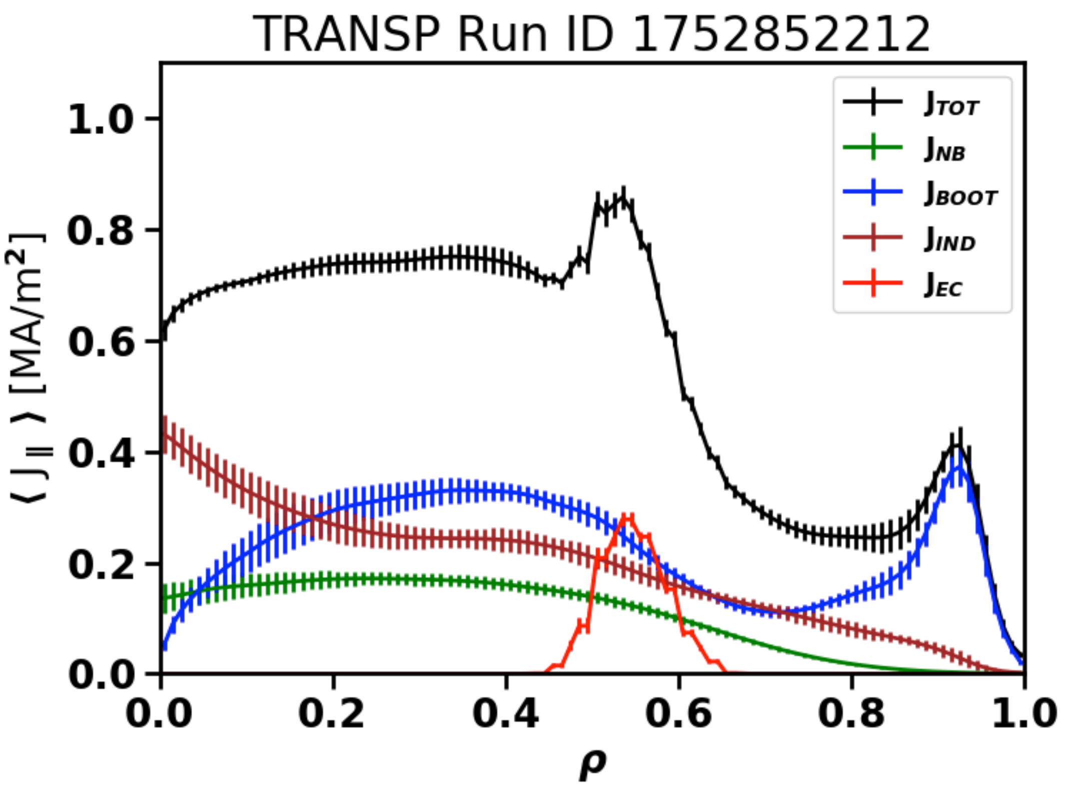
Higher q_{min} provides several advantages for advanced tokamak, steady-state scenarios

- **High ideal-wall kink mode β limit**
- **High bootstrap current fraction**
- **Avoidance of low-order tearing modes by excluding rational surfaces**
  - 2/1 modes are not a problem if $q_{min} > 2$
- **Current density profile from high q_{min} discharge shown at right**

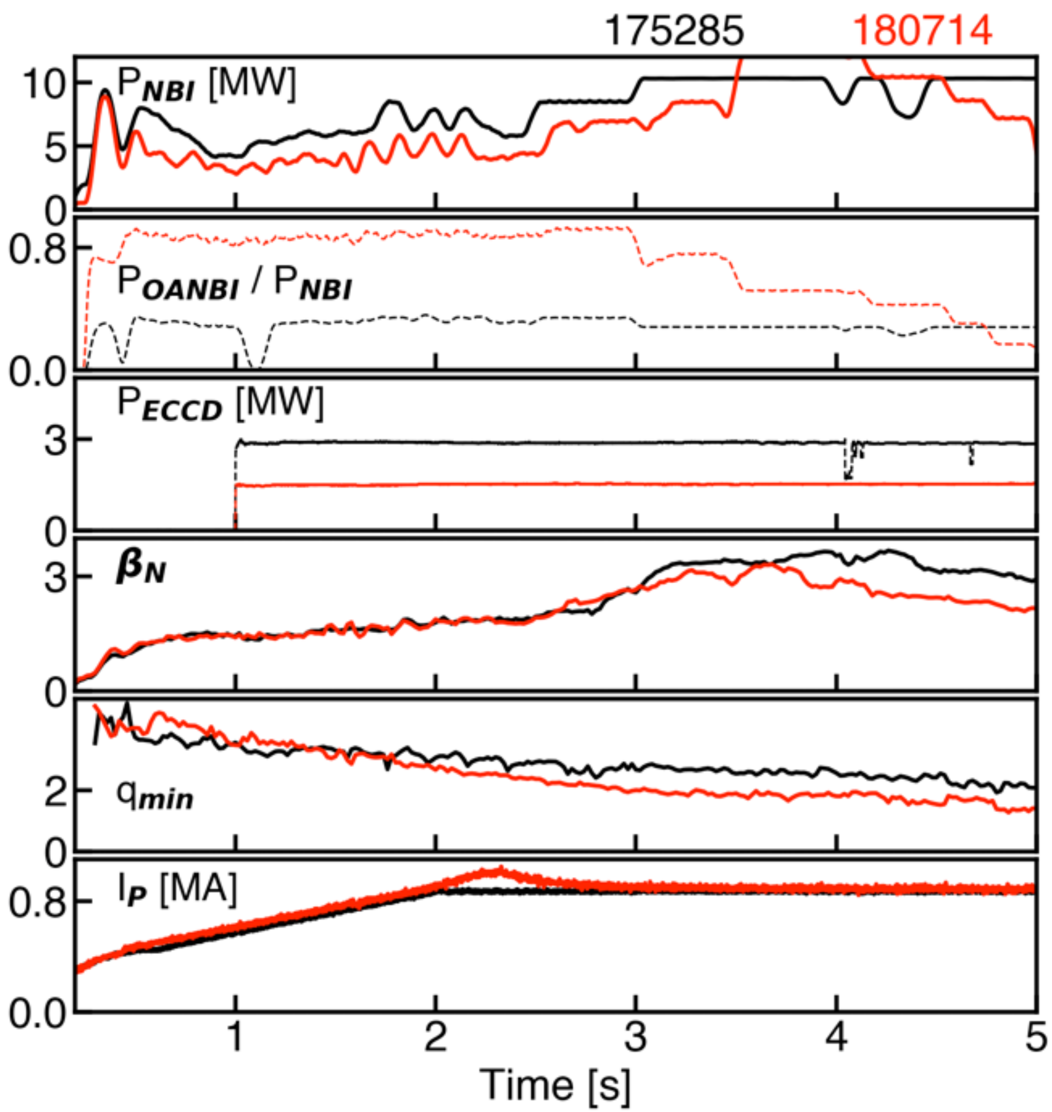


Highlights

- **New off-axis NBI power has been incorporated into high qmin discharges**
  - Broader pressure profile
- **Experimental β_N is limited by n=2 tearing modes**
  - n=2 ideal-wall β_N stability limits are lower than the n=1 limits
- **Higher stability limits and improved β_N have been achieved in plasmas with qmin~1.5 compared to qmin~2**

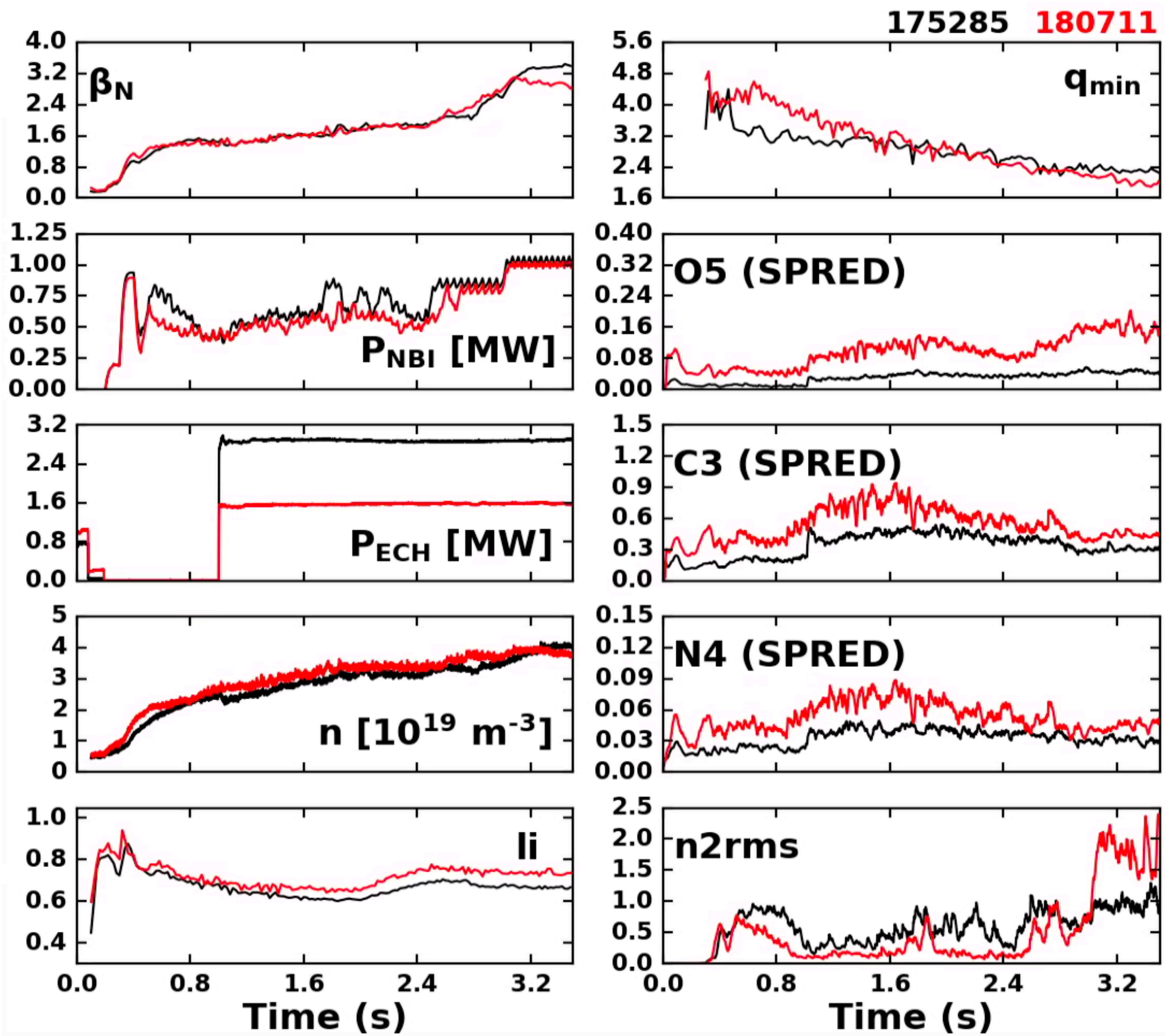
Increased off-axis beam power used for high q_{min} discharges

- **Over 80% of the beam power injected off-axis**
- **Lower EC power available for more recent discharges**
- **Continual decrease in q_{min} throughout discharge**
- **Tearing mode begins to grow from ~2800 ms**



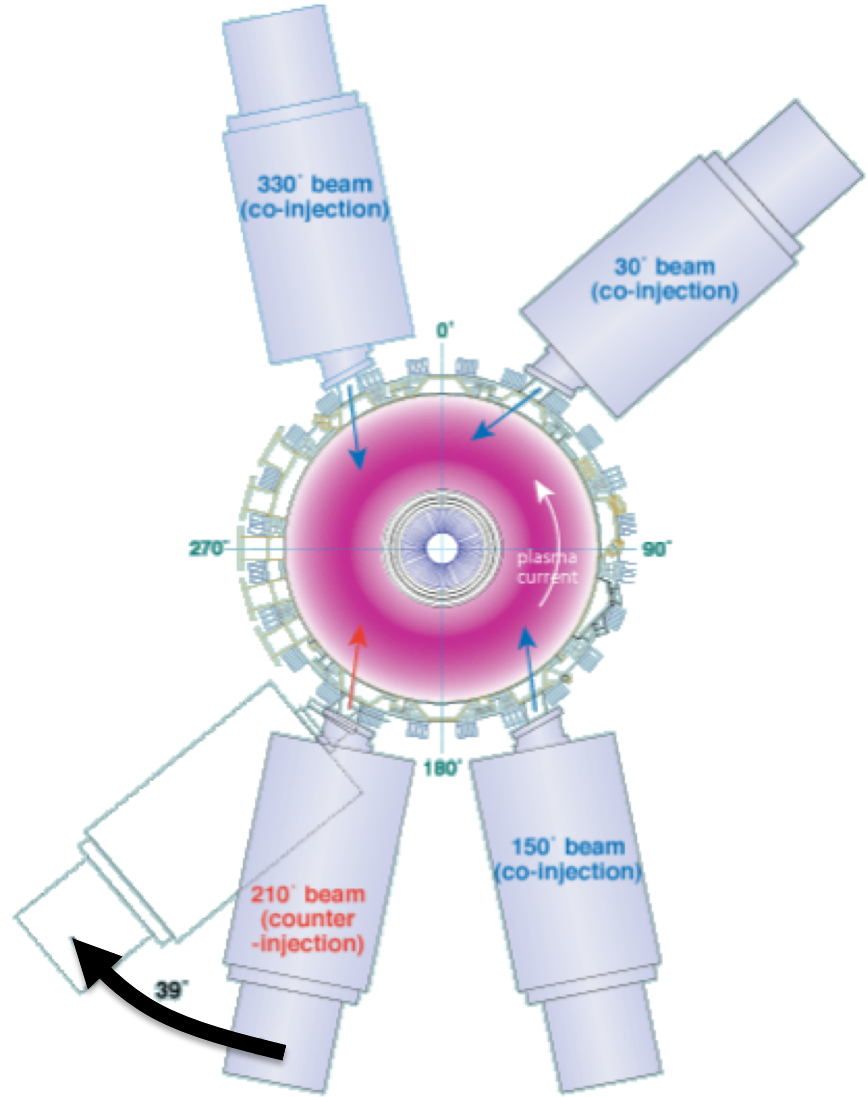
Lower EC power and higher impurity content lead to change in current density profile

- q_{min} decreases more rapidly in recent discharge
- Higher plasma inductance
- Tearing mode affecting confinement from 3.0 s



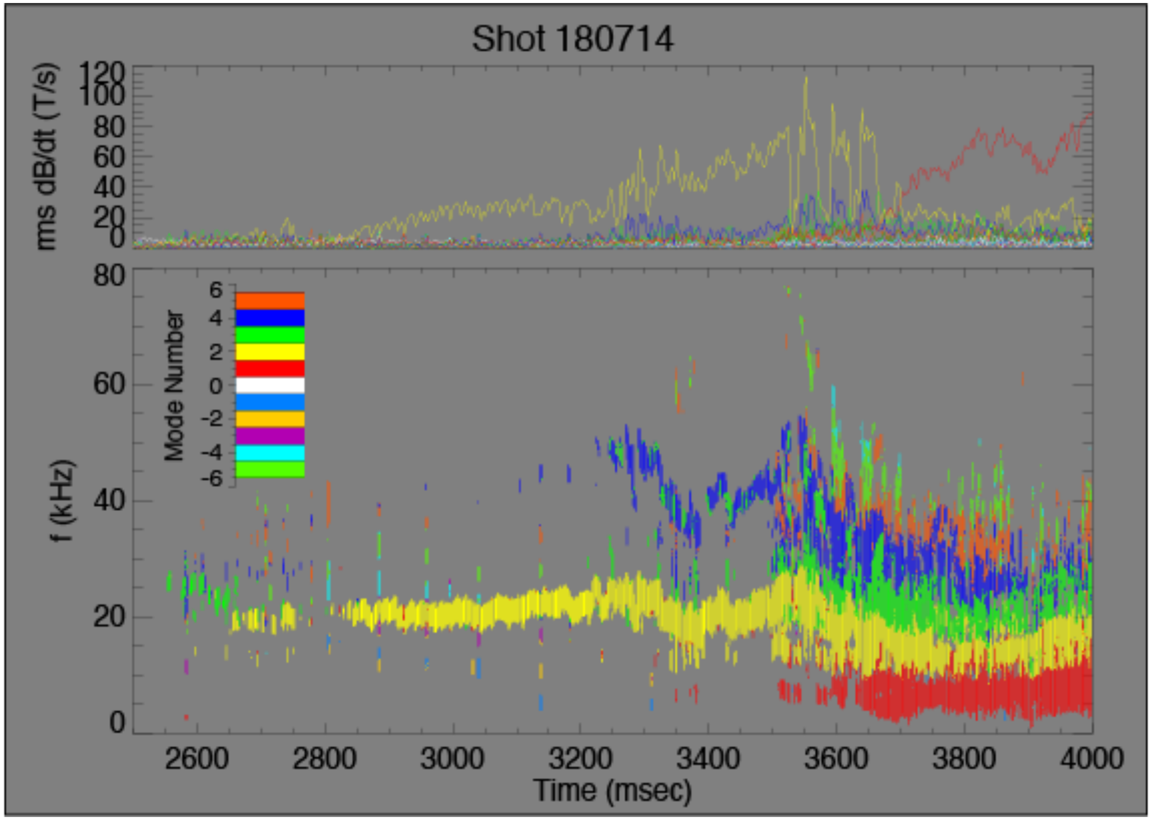
DIII-D upgraded to add a second off-axis neutral beam in the co-I_P direction

- Previously, the 210° beam line injected power along the midplane in the counter-I_P direction
- Now the 210° beam line is permanently off-axis and steerable between the co- and counter-I_P directions



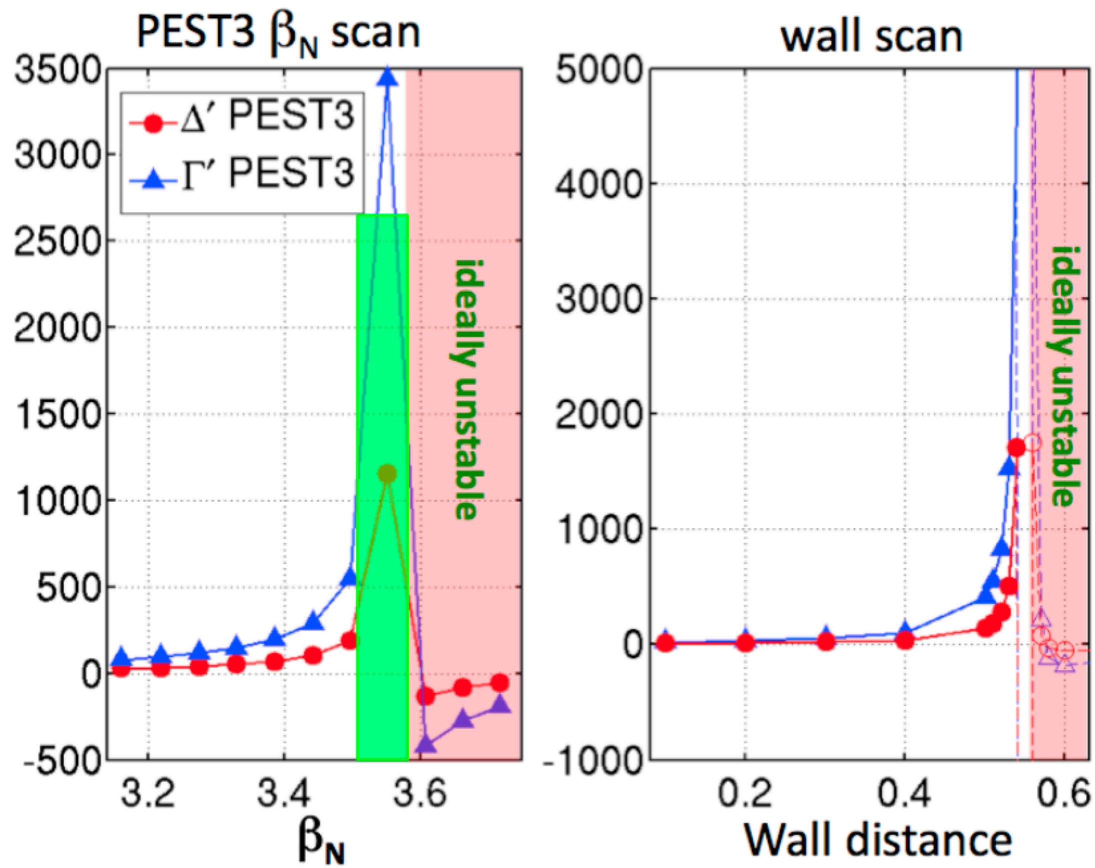
n=2 tearing mode forms near 2800 ms

- **Tearing mode forms as NBI power is increased**
- **The mode rotates with the plasma**
- **Tearing modes form in a large fraction of these plasmas**



Tearing mode stability decreases as a plasma approaches the ideal-wall stability limit

- **Δ' increases as β_N approaches the ideal-wall stability limit**
  - β_N increased by scanning the plasma pressure
- **Δ' increases as the wall distance increases**
  - Thereby reducing the ideal-wall stability limit

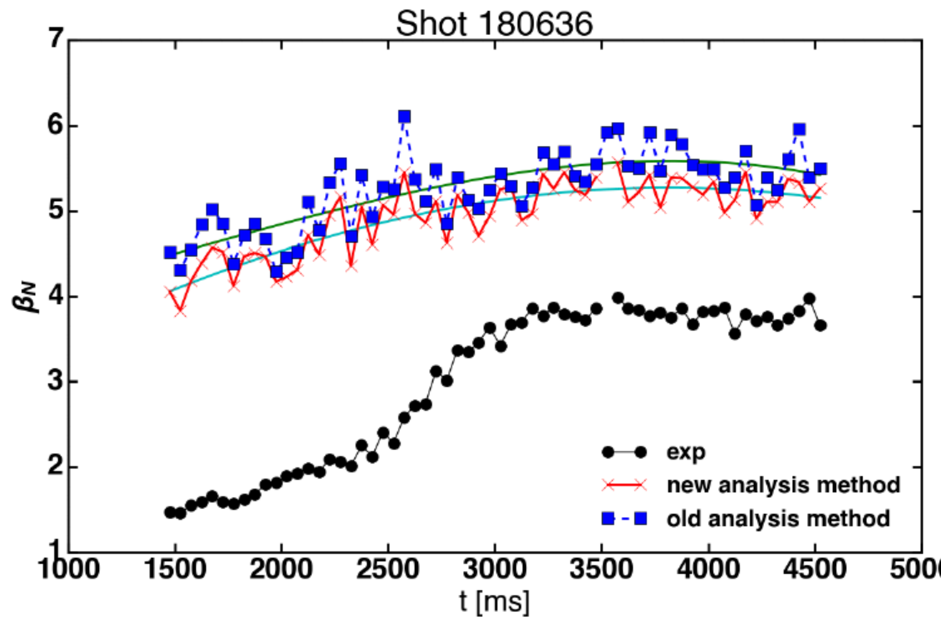


F. Turco *et al.* POP 19 122506 (2012)

➔ Proximity to ideal-wall modes can be used as a proxy for tearing mode stability

Summer student project optimized DCON and CORSICA parameters for high q_{min} discharges

- **Scanned resolution – toroidal, poloidal, radial**
- **Crop equilibrium at fractional q value**
- **Current density profile assumptions when scaling β**
  - fixed $j_{||}$ and Ip
- **Fixing edge q reduced standard deviation in β limits**

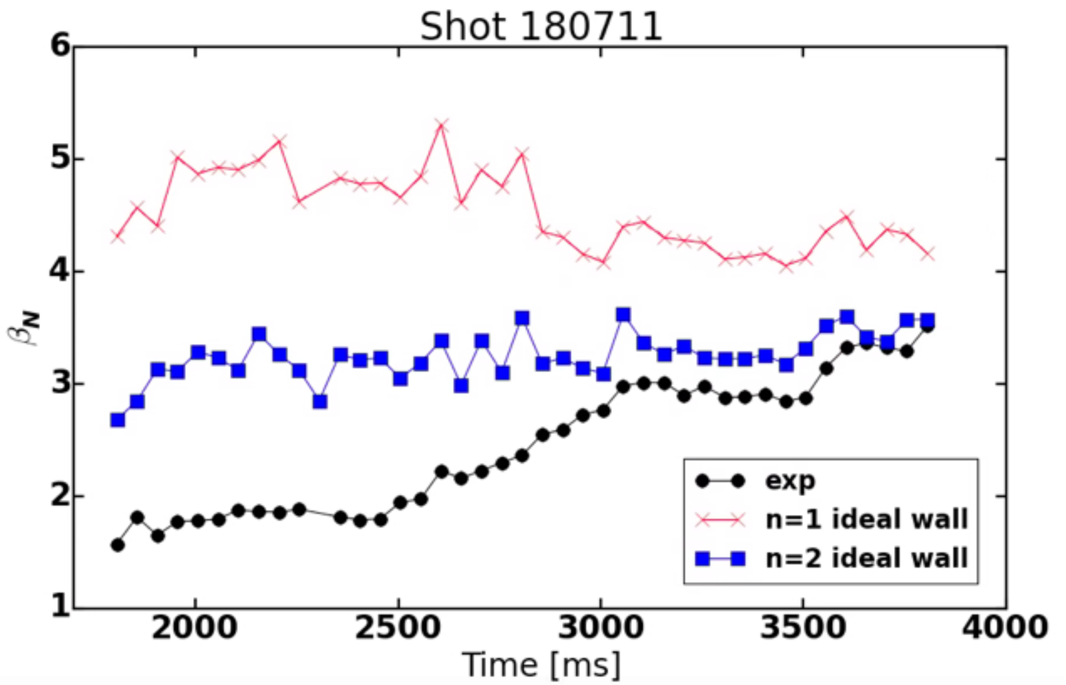


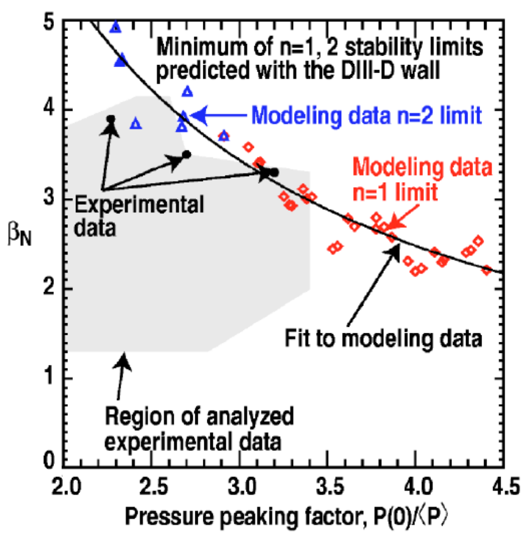
- **Old method: st. dev 0.28**
- **New method: st. dev 0.21**

Figure from M. Aslin

n=2 ideal-wall β_N limit lower than the n=1 limit

- **DCON used to find the ideal-wall β_N limits**
- **Calculation uses DIII-D wall with zero resistivity**
- **Tearing mode occurs when the experimental β_N approaches the n=2 ideal-wall β_N limit**
- **Past research showed that n=2 stability limits are lower than n=1 limits for broader pressure profiles**

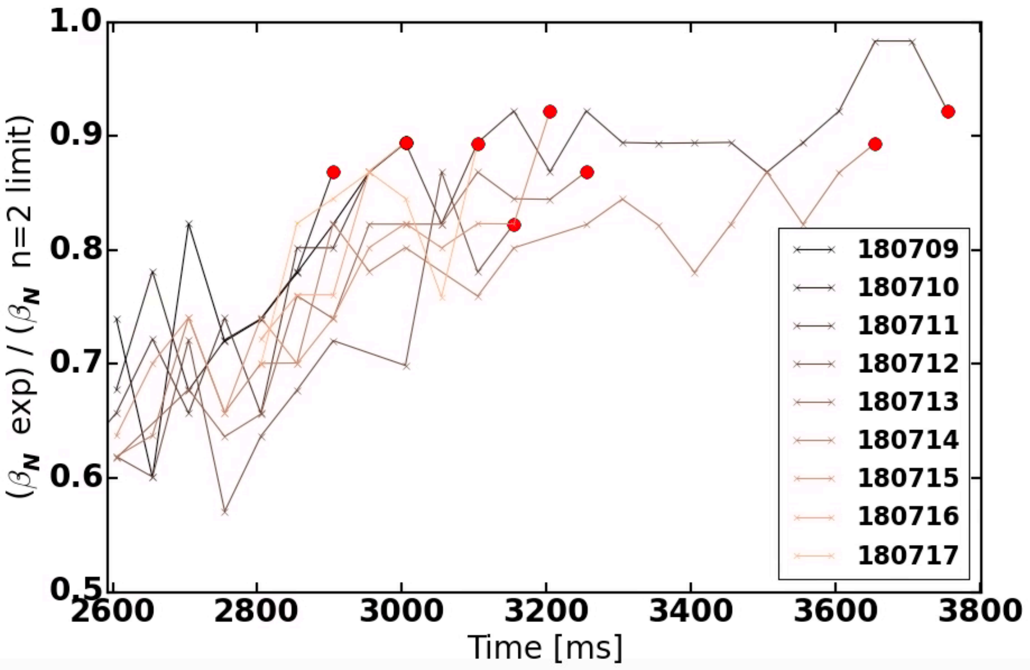




J.R. Ferron, et al., Phys. of Plasmas 12, 056126 (2005)

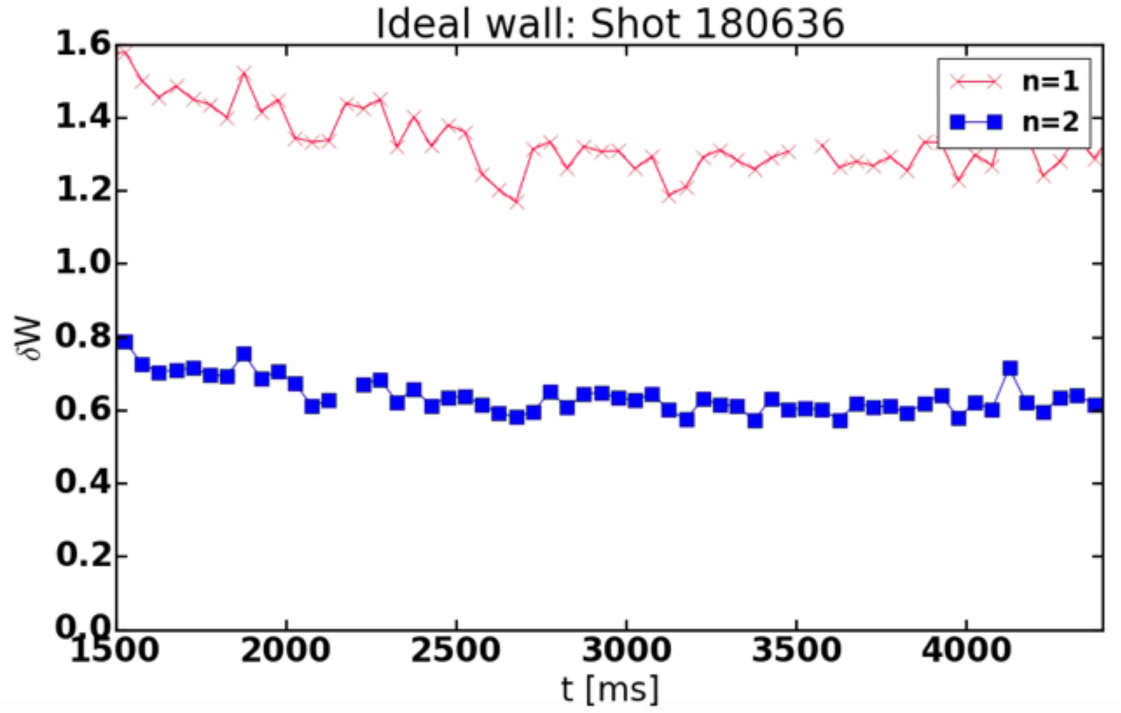
Tearing modes occur when plasma is near n = 2 ideal-wall β_N limit

- **Time traces of experimental β_N normalized by n = 2 ideal-wall β_N limit**
- **Tearing mode onset indicated by red dots**



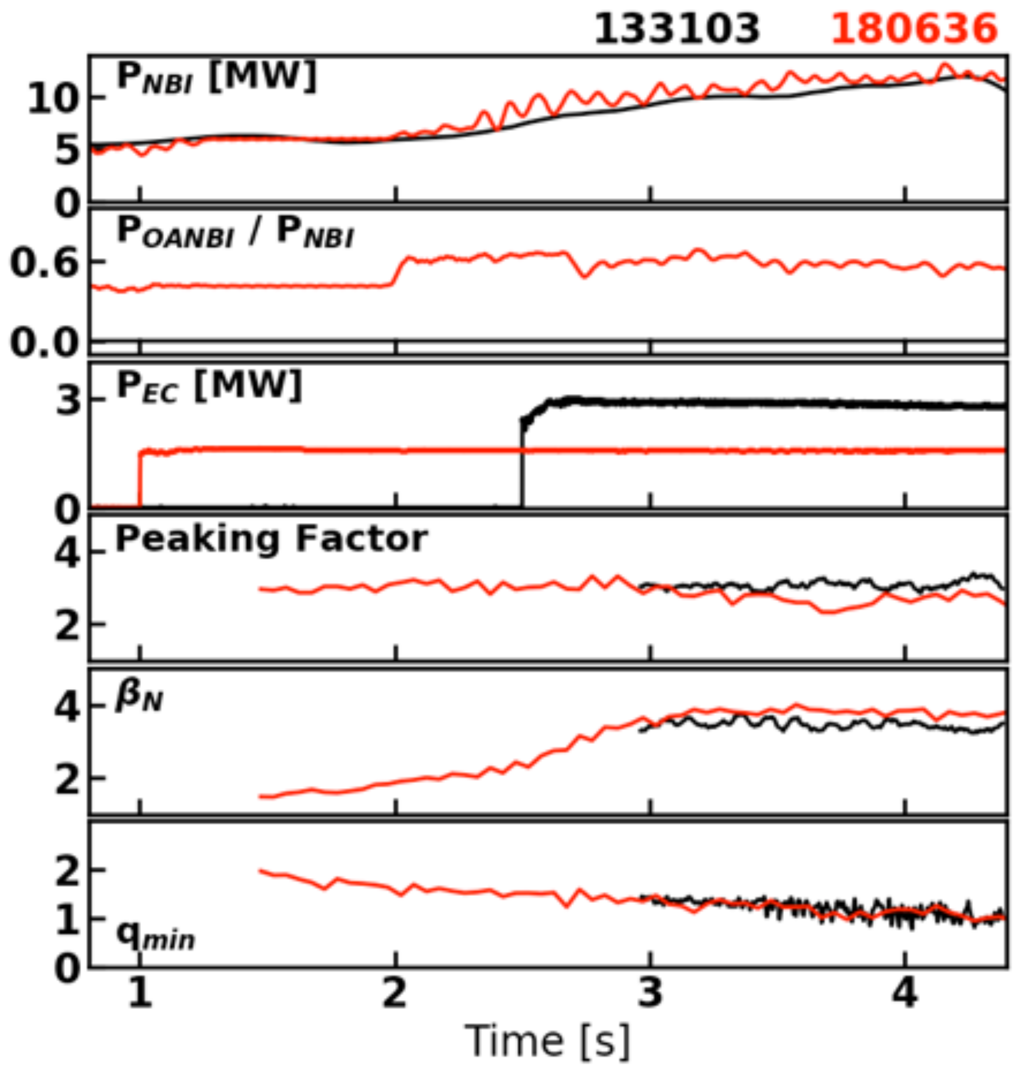
Larger perturbation required to destabilize the n=1 mode

- **Mode is unstable when $\delta w < 0$**
- **Relative measure of the energy required to cause a mode to become unstable**
- **Analysis performed on the original equilibrium without having to scale the pressure**



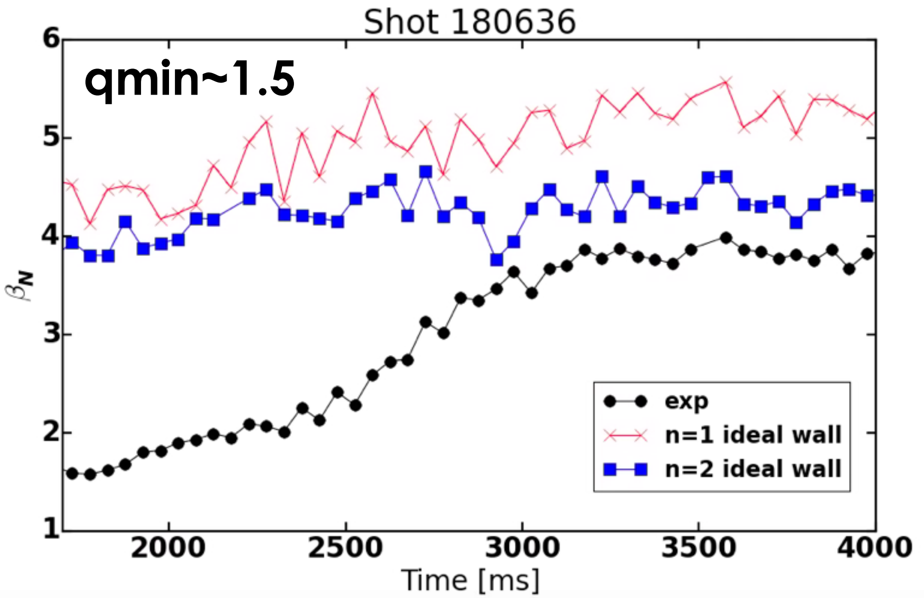
Higher β_N achieved with additional off-axis NBI power in discharge with qmin~1.5

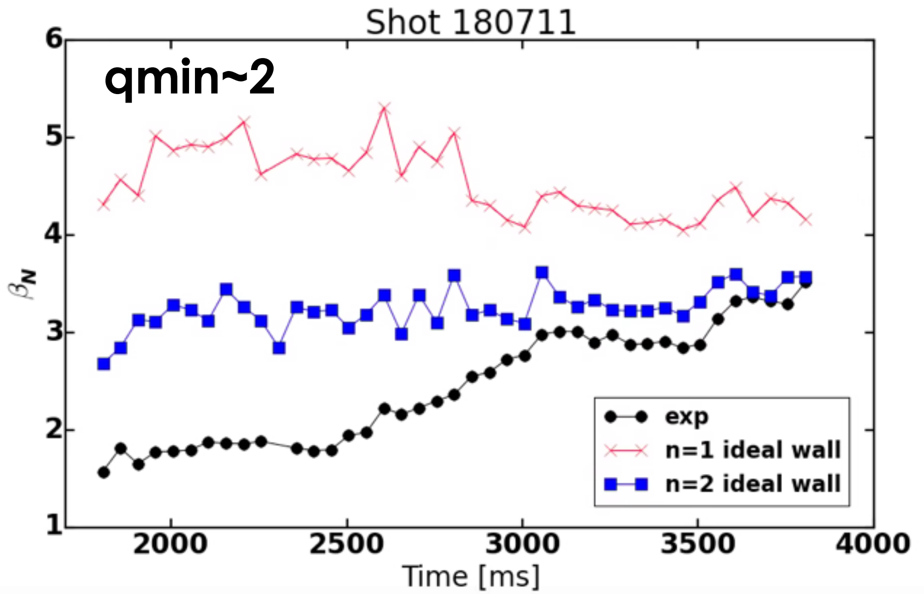
- Recent discharge has >50% off-axis NBI power
- Lower EC power available for more recent discharge
- Broader pressure profile (lower peaking factor) achieved with more off-axis NBI power
- $1<q_{min}<1.5$



Higher stability limits for qmin~1.5 discharge

- n=1 ideal-wall β_N limits ~5
- n=2 ideal-wall β_N limits ~4
- qmin~1.5 discharge had smaller gap between the plasma and the wall

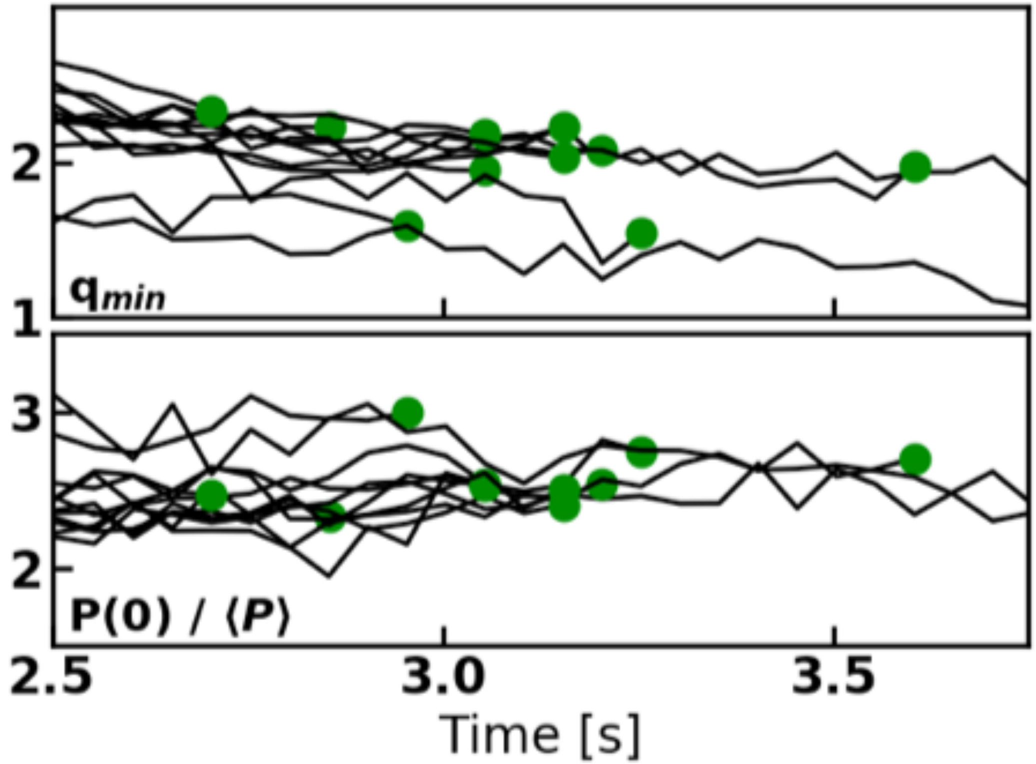




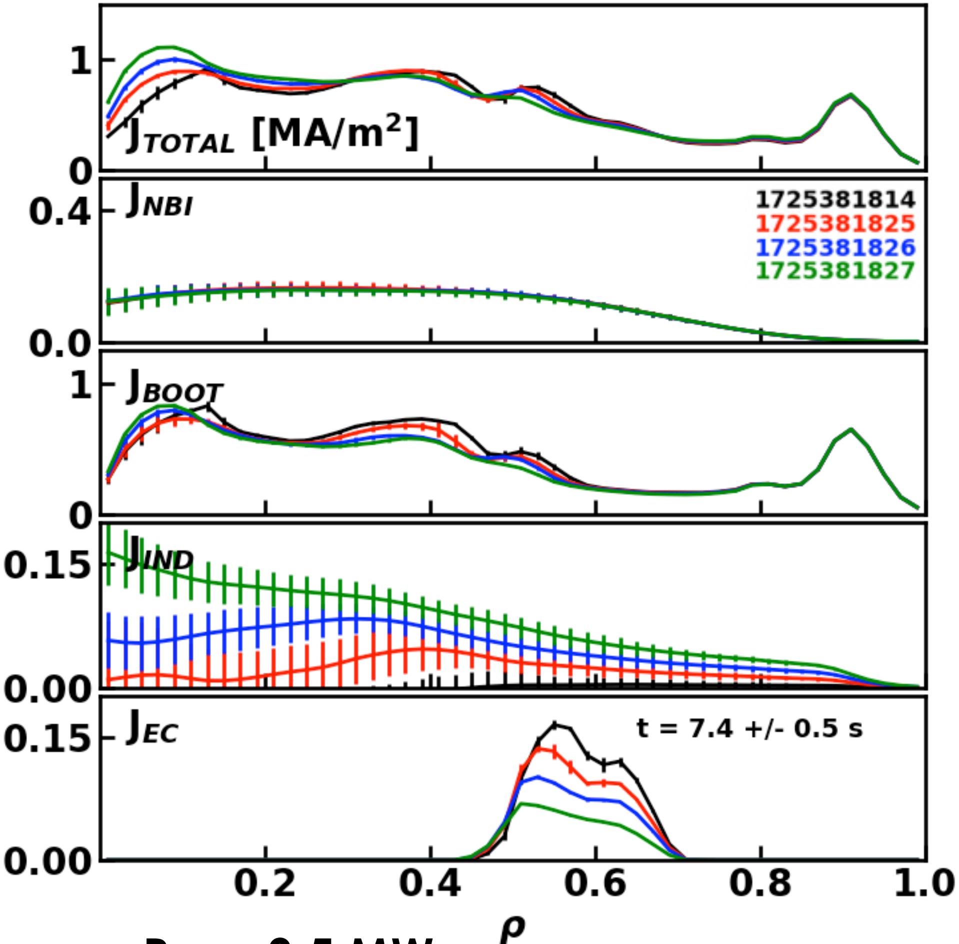
A downward trend in qmin is observed in multiple discharges

- **Tearing mode onset indicated by a green circle**

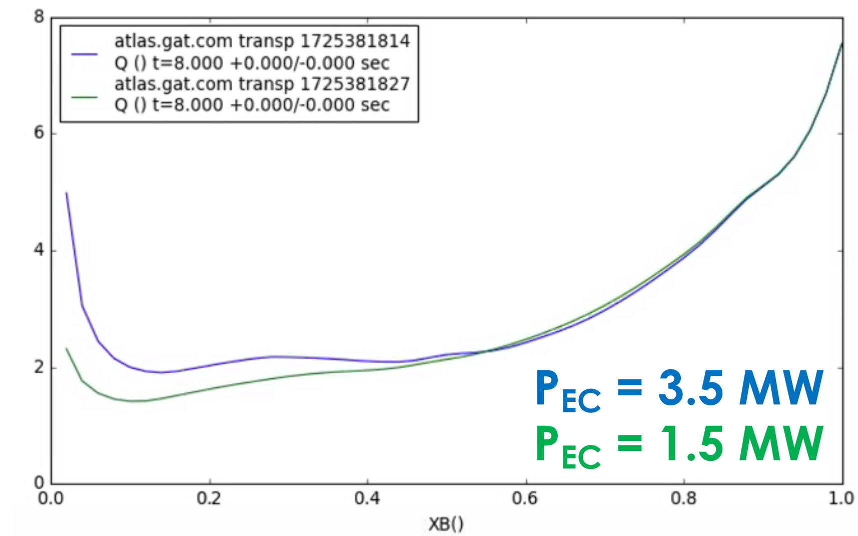
- **The peaking factor is between 2-3 for each discharge**



TRANSP simulations show more peaked current density profile with lower EC power



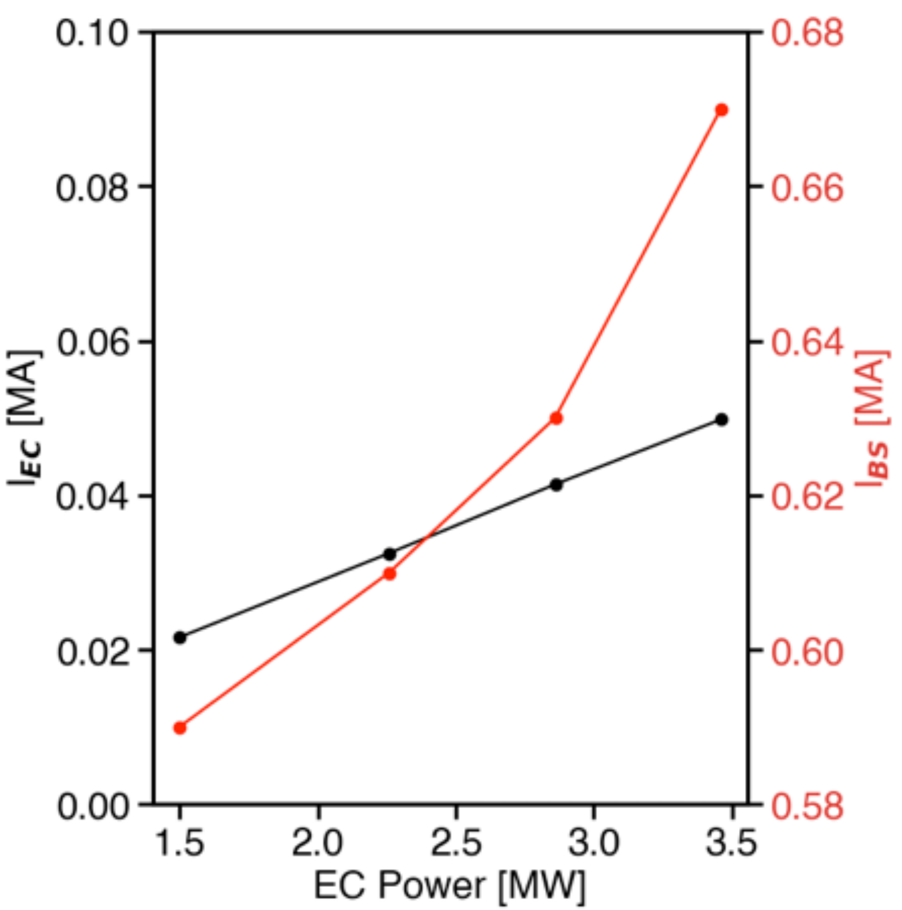
P_{EC} = 3.5 MW
P_{EC} = 2.9 MW
P_{EC} = 2.3 MW
P_{EC} = 1.5 MW



- **TGLF used to evolve the temperature, density, and current profile**
- **NUBEAM used to simulate the NBI injection**
- **TORAY used for ECH injection**

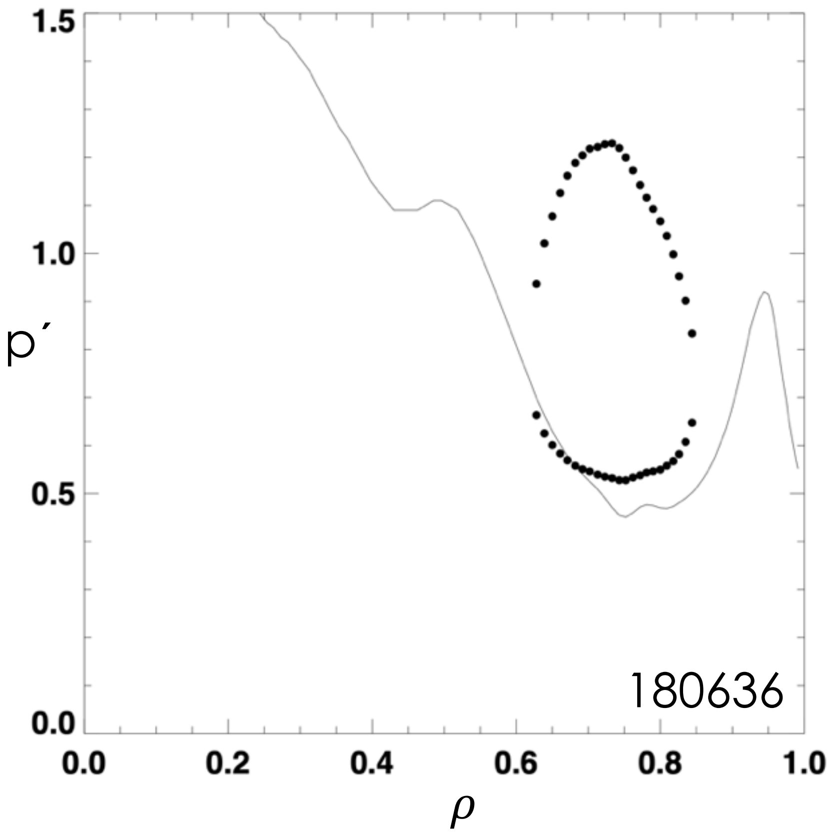
Loss of EC power reduces bootstrap and ECCD current

- **TRANSP used to understand the effects of reduced EC power**
  - Simulations run to steady-state with a range of EC power
- **EC power reduced from 3.5 to 1.5 MW**
  - Loss of 80 kA of bootstrap current
  - Loss of 28 kA of ECCD
- **Reduced EC power leads to a larger reduction in bootstrap current than in ECCD**



BALOO indicates that the plasma is near the ideal-ballooning boundary

- **Lower stability limits for higher n modes, as indicated by DCON, could indicate the first instability is a pressure driven mode**
- **Pressure gradient approaches the stability limit near ρ = 0.6 - 0.65**



Summary

- **DIII-D beam line modified to provide additional off-axis beam power**

- **Onset of n=2 tearing modes, associated with approach to the ideal-wall n=2 stability boundary, leads to a degradation in confinement**

- **q_{min}~1.5 discharges have higher stability limits and higher β_N compared to discharges with q_{min}~2**

- **Recent experiments have difficultly maintaining $q_{min} > 2$**
  - EC power important for maintaining broad current density profile