



Stability and non-inductive current drive in NBI-heated long-pulse NSTX discharges

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for the NSTX Research Team

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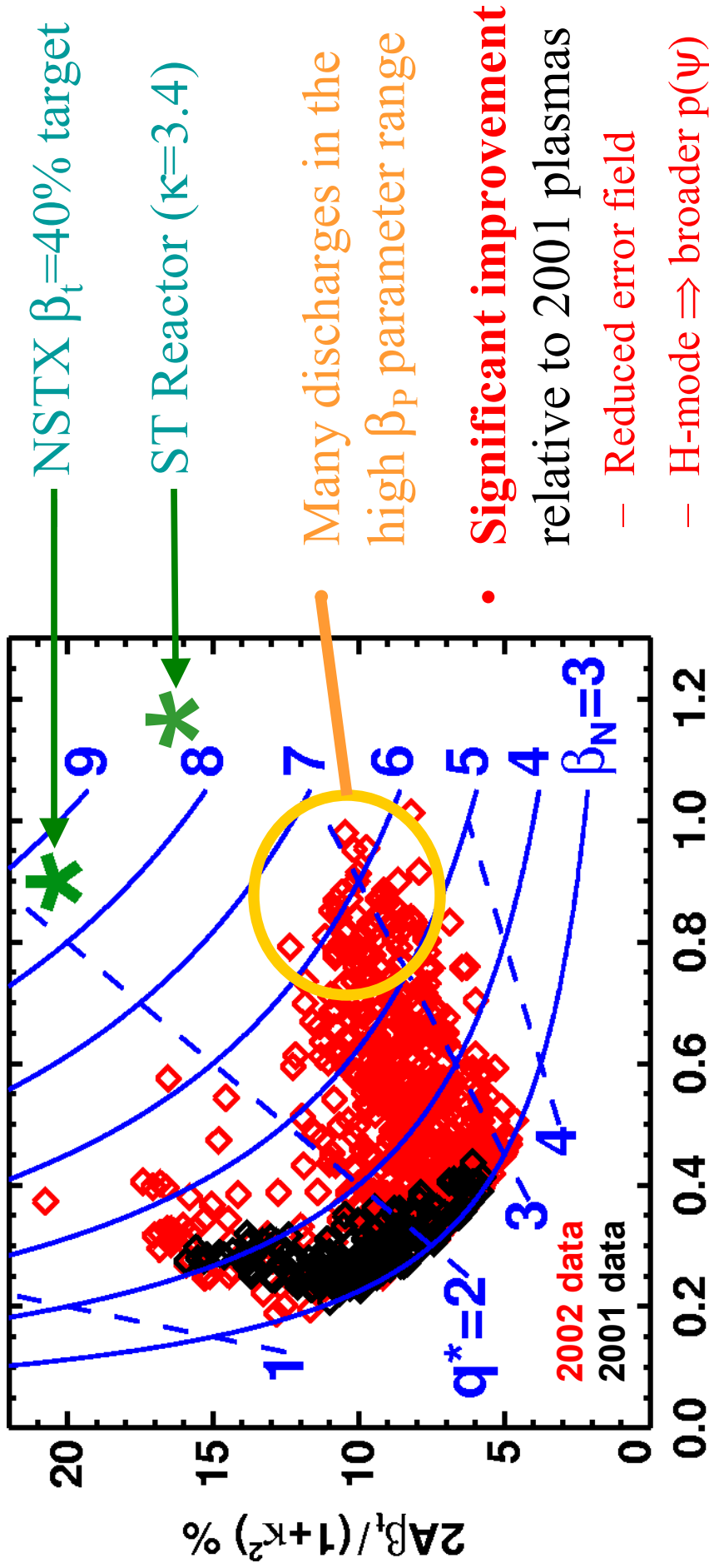
Orlando, Florida



NSTX now operating at high β_P , β_N , & f_{BS}

Achieved long pulses with $\beta_P > 1.2$ & $\beta_N > 5.5$

$q^* = 2.5$ to 3.5



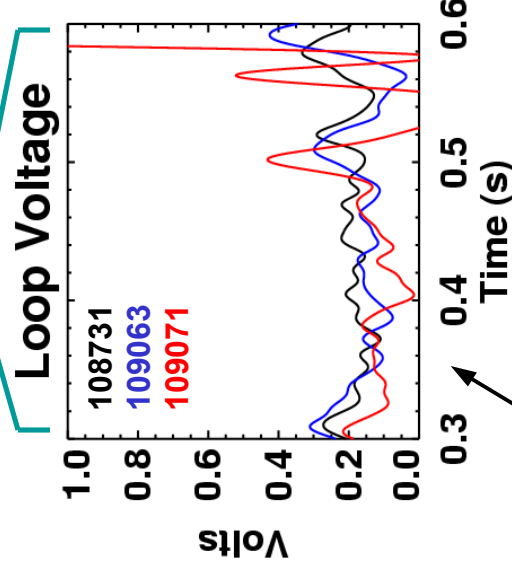
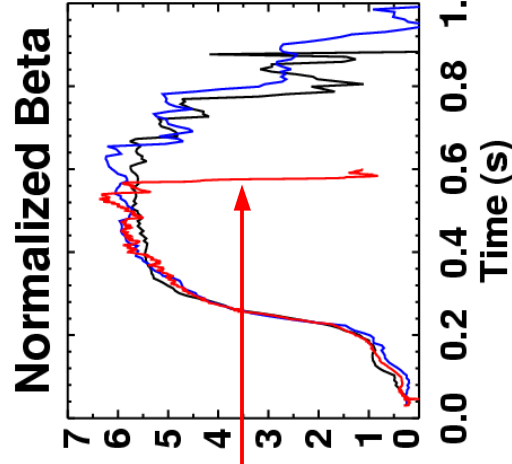
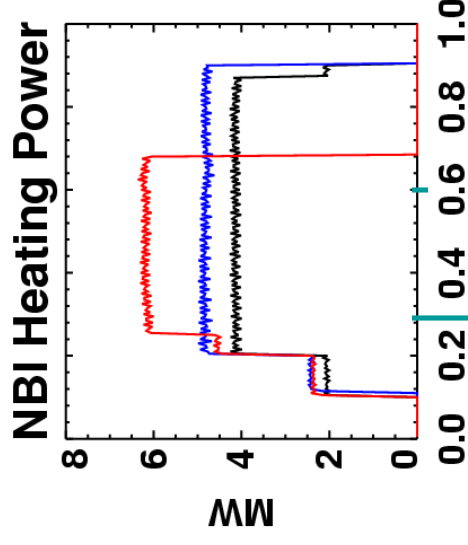
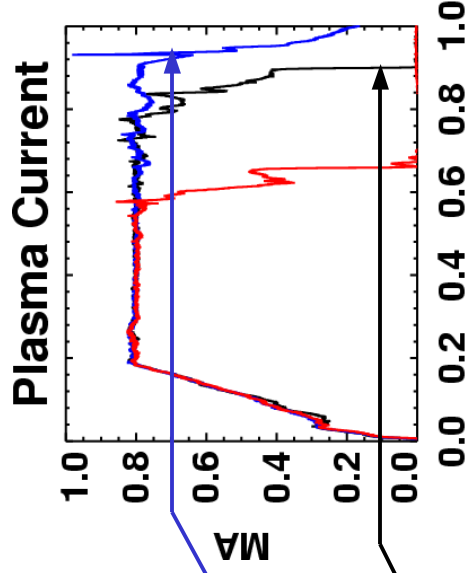
Achieved 1s pulse with 700ms, 800kA flat-top



Several parameters simultaneously optimized:

- $B_{t0} = 5\text{kG}$ out to $t = 950\text{ms}$
 - Higher TF delays MHD
- $80 \rightarrow 100\text{kV}$ on NBI:
 - Extra CD helpful
 - 4.8MW no more disruptive than 4MW
- $P_{\text{NBI}} > 5\text{MW}$ disruptive
- No shots sustained
- W_{TOT} past 750ms
 - Thermal disruption largely internal

- $V_{\text{LOOP}} < 200\text{mV}$ for $300\text{ms} \approx 1 \tau_{\text{CR}}$

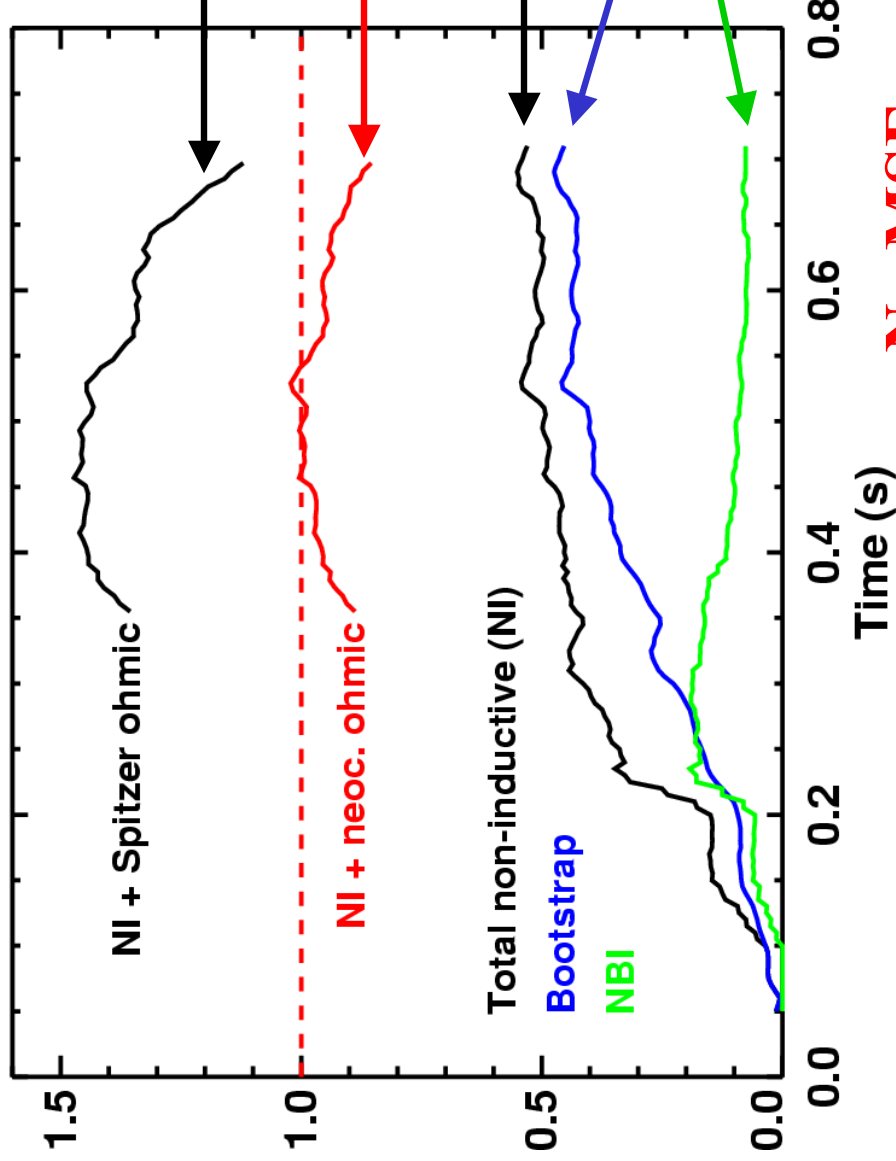


50-60% non-inductive CD during low V_{LOOP} phase



Use $T_e(\psi)$ and EFIT $\partial\psi/\partial t$ to compute conductivity σ & J_{OH}

Current fractions for shot 108730A58



- Add computed Ohmic I_P to TRANSP NI I_P

Classical σ too large

- Good agreement using NC conductivity

Typical long-pulse has 50% non-inductive CD

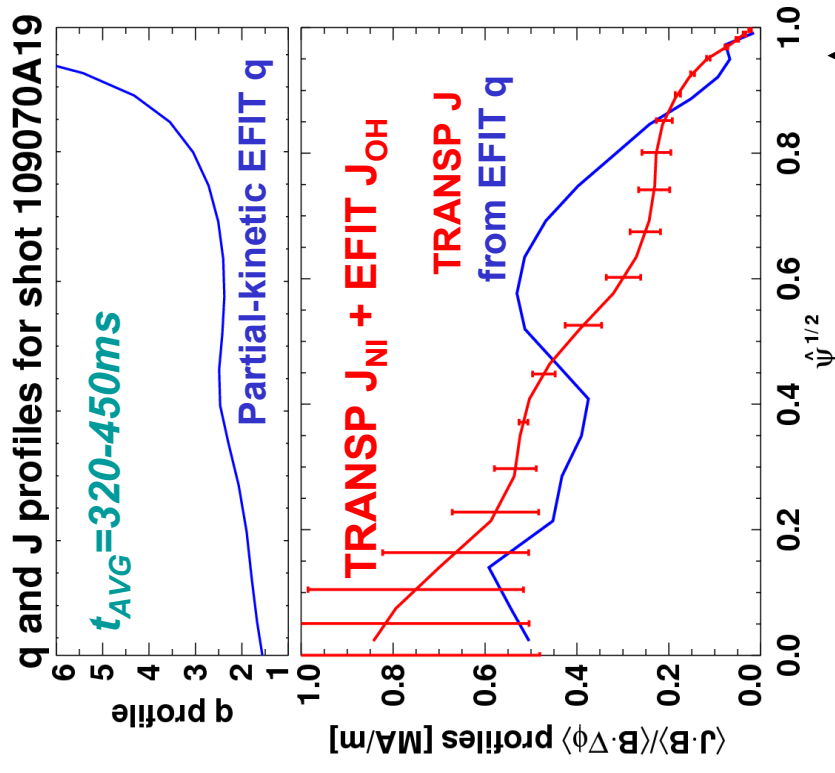
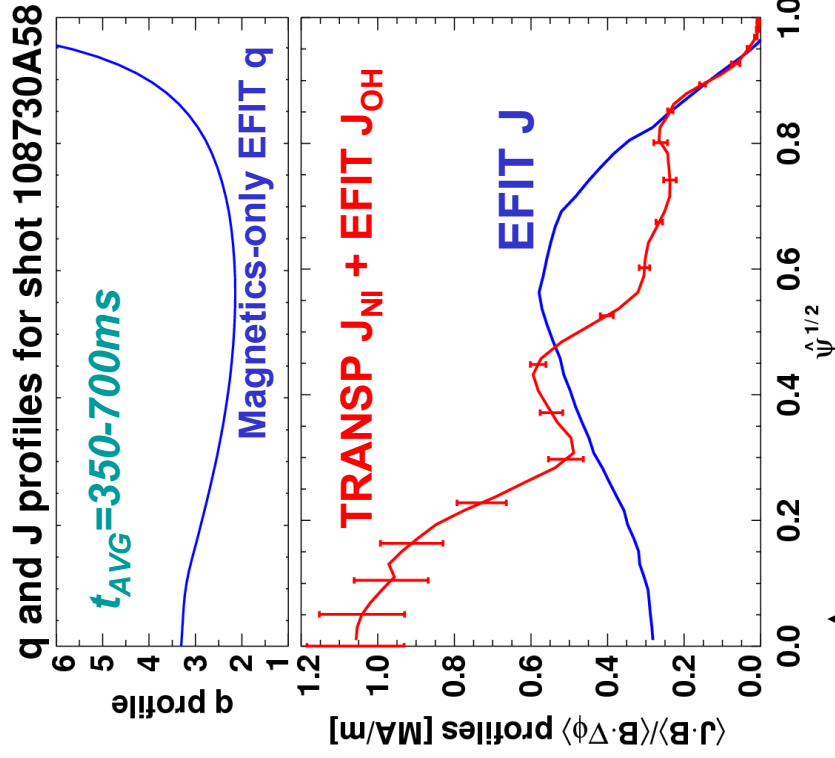
Bootstrap CD \uparrow and NBI CD \downarrow as density rises during shot

No MSE \Rightarrow uncertainty in J profile

Consistency tests of J profiles have begun



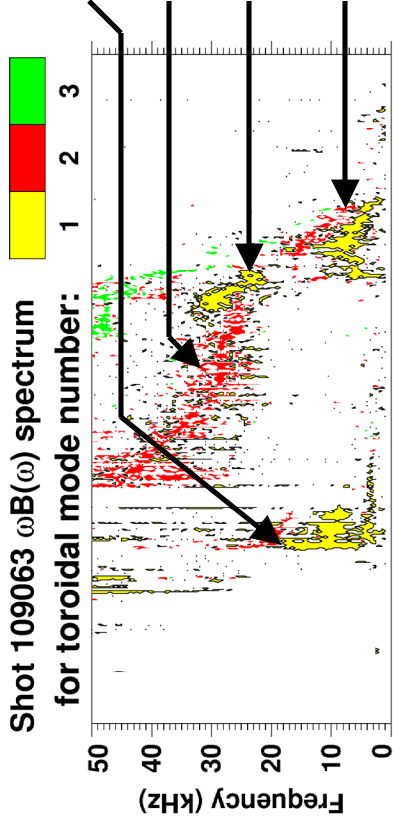
- Total integrated current matches I_p in both cases



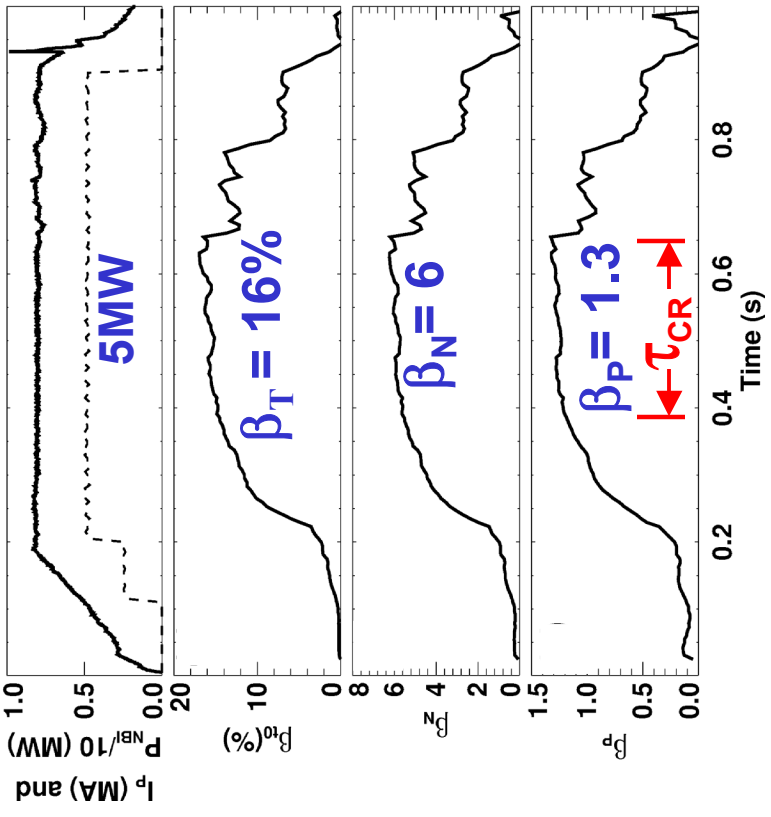
← $J_{NICD} + J_{OH}$ inconsistent with reversed-shear $q(\psi)$

Better agreement with monotonic $q(\psi)$ in core

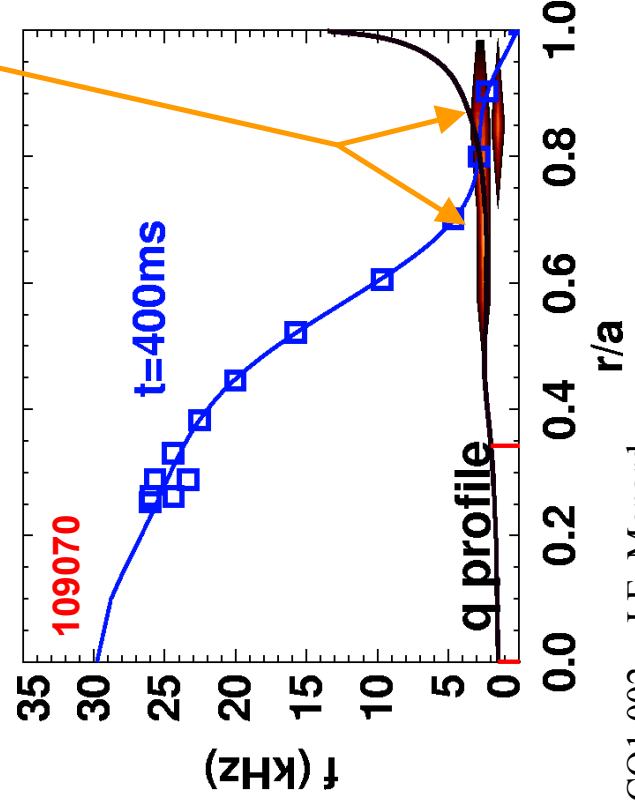
MHD events in long-pulse discharges:



early $n=1$, transient at high B_T
 long-lived $n=2$ mode in flat-top
fast $n=1$ internal mode disrupts β
 residual $n=1, 2$ rotating modes – NTMs?



Prior to internal collapses,
 SXR shows only edge 2/1 or 3/1



High β_P discharges operate above theoretical no-wall limit



- Recent theory work shows:

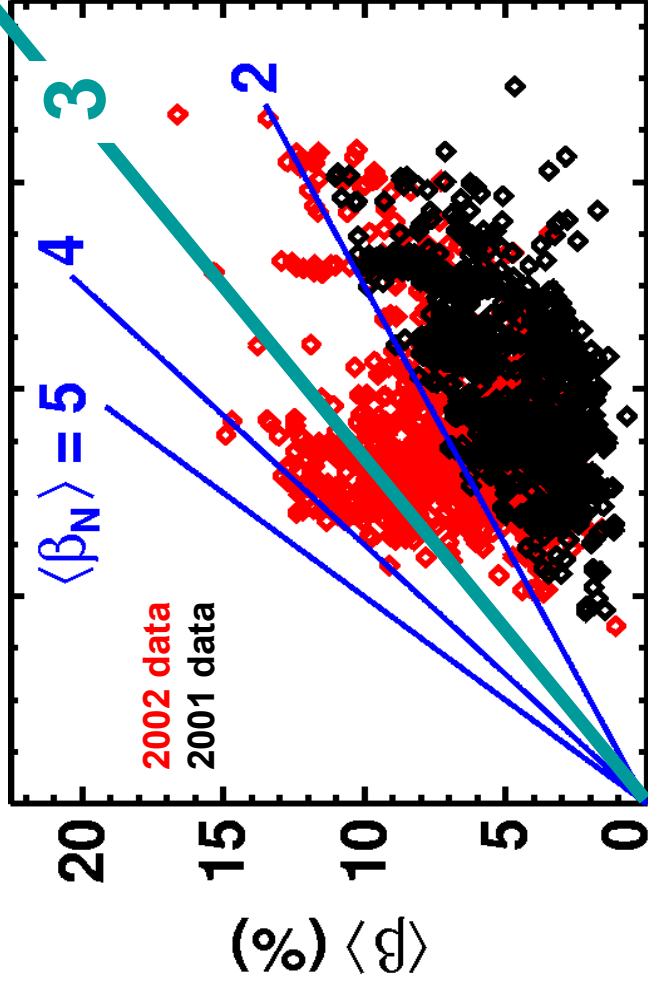
ideal no-wall limit is $\langle \beta_N \rangle \approx 3$
 independent of R_0/a for $q^* > 1.7$

$$\langle \beta \rangle \equiv 2\mu_0 \langle p \rangle / \langle B^2 \rangle$$

$$\langle \beta_N \rangle = 5$$

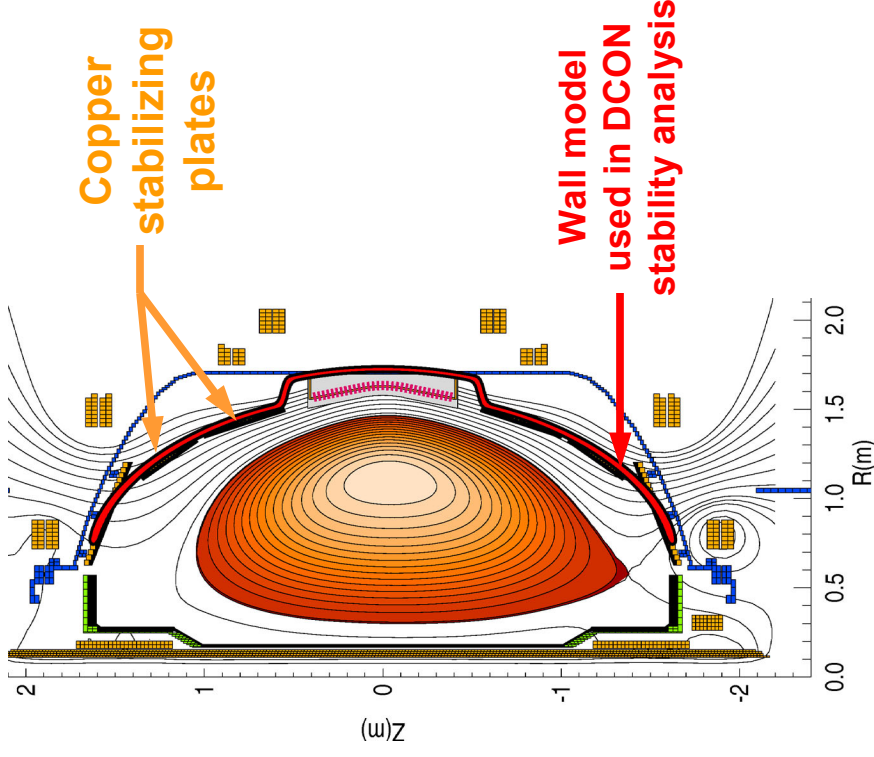
$$\langle \beta_N \rangle = 4$$

$$\langle \beta_N \rangle = 3$$



- High β_P shots exceed this limit for $I_P / aB_{t0} = 2$ to 3.5

- Obtained in LSN



Stability analysis finds $\beta > \beta_{\text{no-wall}}$ for many $\tau_E, \tau_{\text{wall}}$

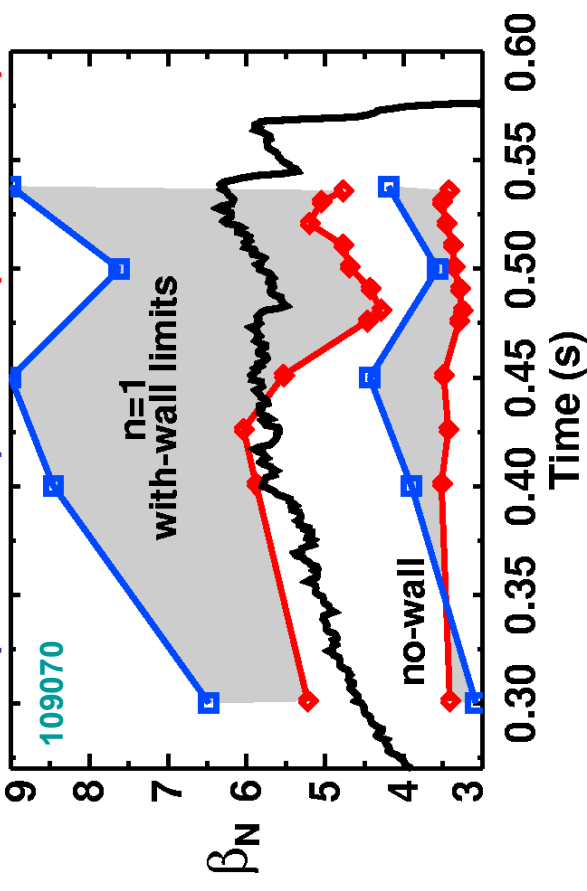
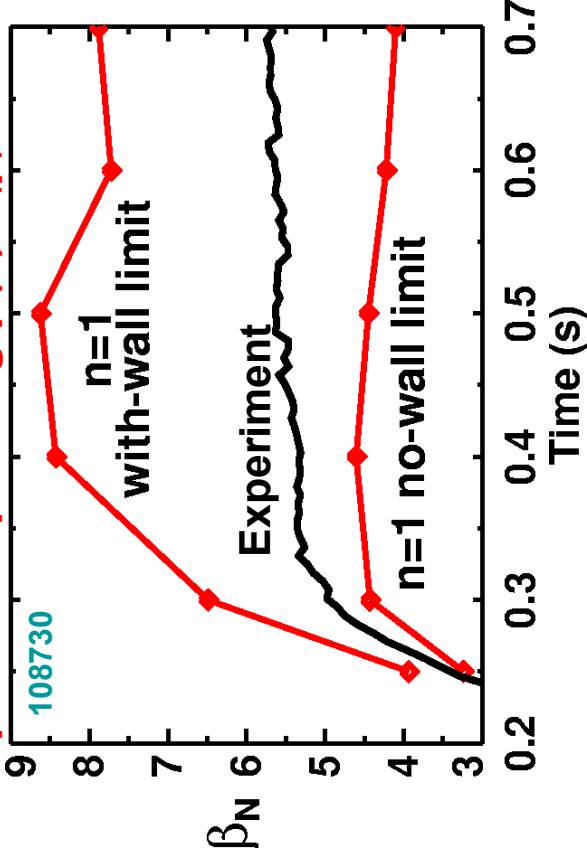


Reversed-shear $q(\psi)$ with $q(\text{min}) > 2$

Nearly monotonic $q(\psi)$ with $q(0) < 2$

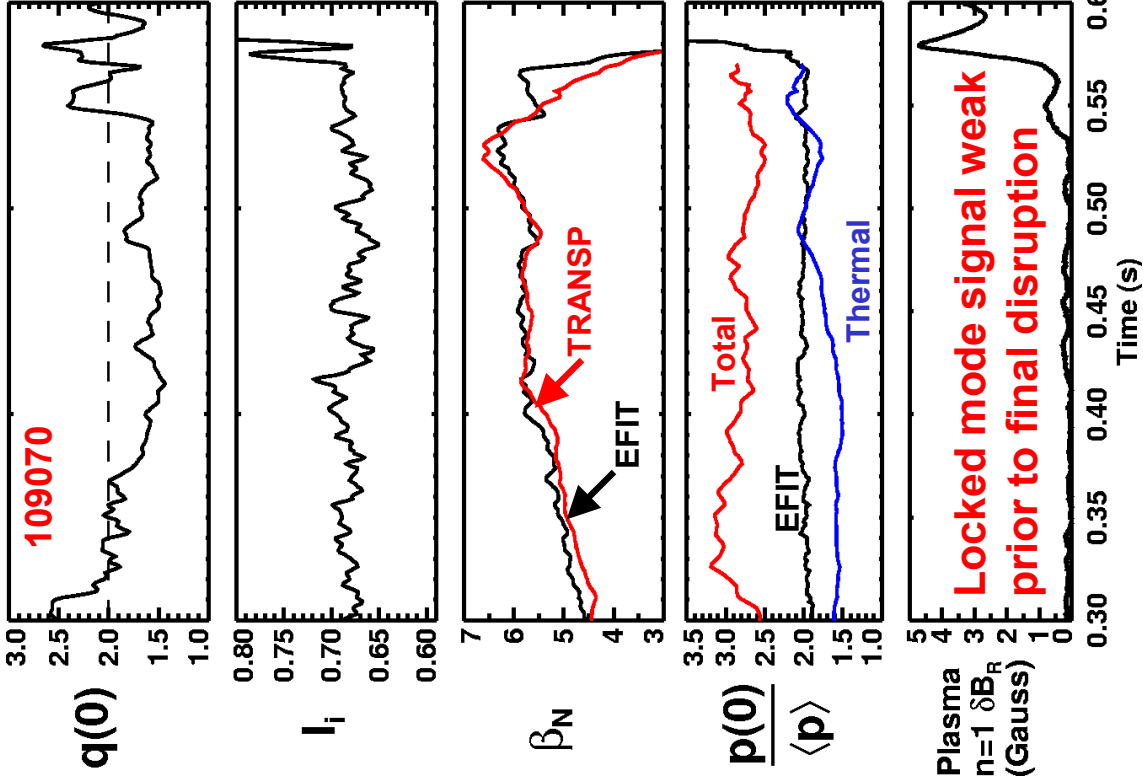
Use TRANSP $p(\psi)$ which has
pressure peaking $p(0) / \langle p \rangle = 2.5$

Vary pressure peaking $p(0) / \langle p \rangle =$
2.0 (PK-EFIT) to 2.7 (TRANSP)



- $n=1$ no-wall limit $\beta_N = 3.5$ to 4.5 clearly exceeded
- With-wall limit sensitive to p & q profile shapes:
 - Limit lowered by monotonic $q(\psi)$ with $q=2$ in plasma
 - Limit lowered with increased $p(\psi)$ profile peaking

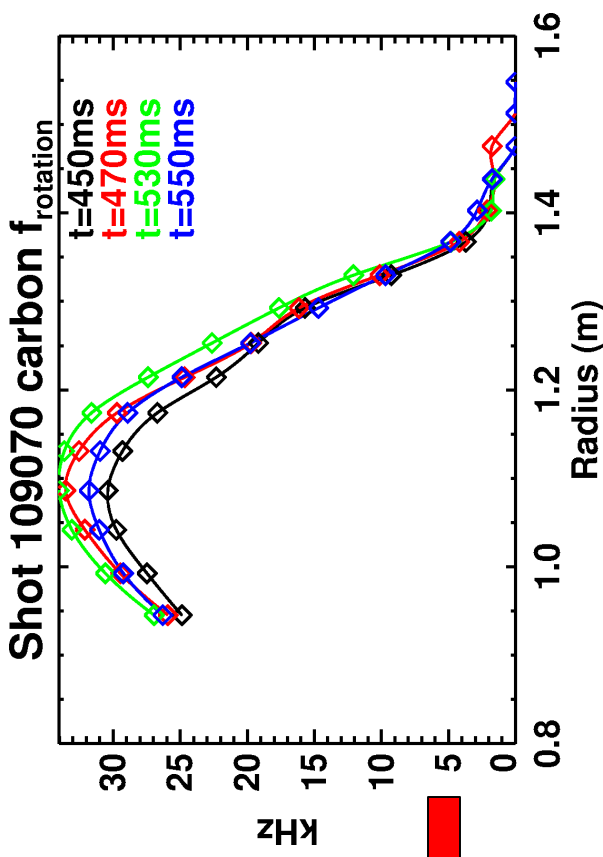
Highest β_p disrupting near with-wall limit?



- $P_{\text{NBI}}=6\text{MW}$, $\beta_N \approx 6.3$, $\beta_p \approx 1.4$

– $q(0) \approx 1.5$, $I_i = 0.65\text{-}0.7$

- $p(0)/\langle p \rangle$ and β_N evolve slowly
- Rotation decay not observed
- preceding final disruption phase:



Summary



- NSTX has combined $\beta_p > 1.2$ with $\beta_N > 5.5$
 - 1s discharge with 700ms, 800kA flat-top
- 50-60% NICD consistent with neoclassical ohmic CD
- Routinely operating above n=1 no-wall limit
- Long-pulse shots interrupted by “bursting” n=1 modes
 - Possibly hitting n=1 with-wall limit?
 - Could be double-tearing if q profile is reversed...
 - Or, other fast ion-driven MHD?
- Uncertainty in q and p profiles limits interpretation of disruptions above no-wall limit.
- Rotation damping and RWMs discussed in following talk

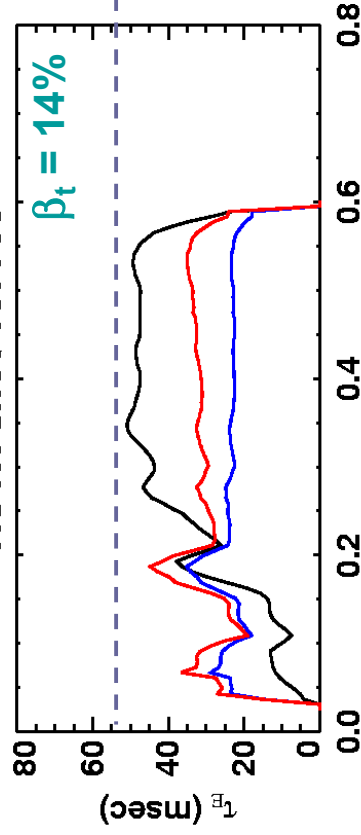
Long-pulse discharges obtain high H_{89P} values



Confinement improved at higher V_{NBI} , B_T

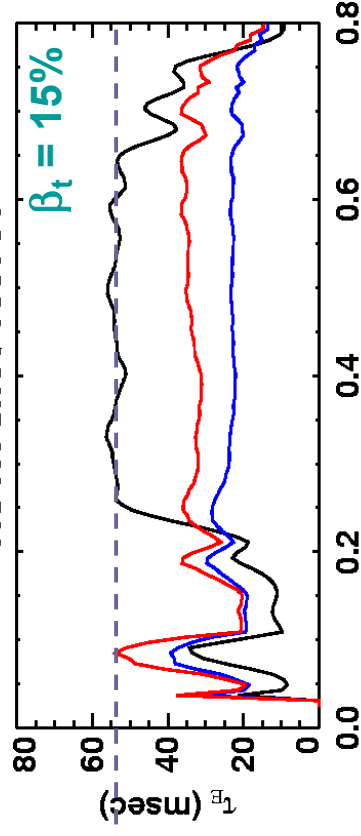
- A+B at 80kV, 3.2MW, 4.5kG
- A+B at 90kV, 4.0MW, 5.0kG
- $H_{89P} = 2.1$, $\beta_N = 4.8 \Rightarrow \beta_N H_{89P} = 10$
- $H_{89P} = 2.4$, $\beta_N = 5.5 \Rightarrow \beta_N H_{89P} = 13$

NSTX shot 107796



— EFIT — ELMY98y,2 — ITER89P

NSTX shot 108731



— EFIT — ELMY98y,2 — ITER89P

