Disruption dynamics in NSTX long-pulse discharges

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for the NSTX Research Team

Workshop on Active Control of MHD Stability:
Extension of Performance

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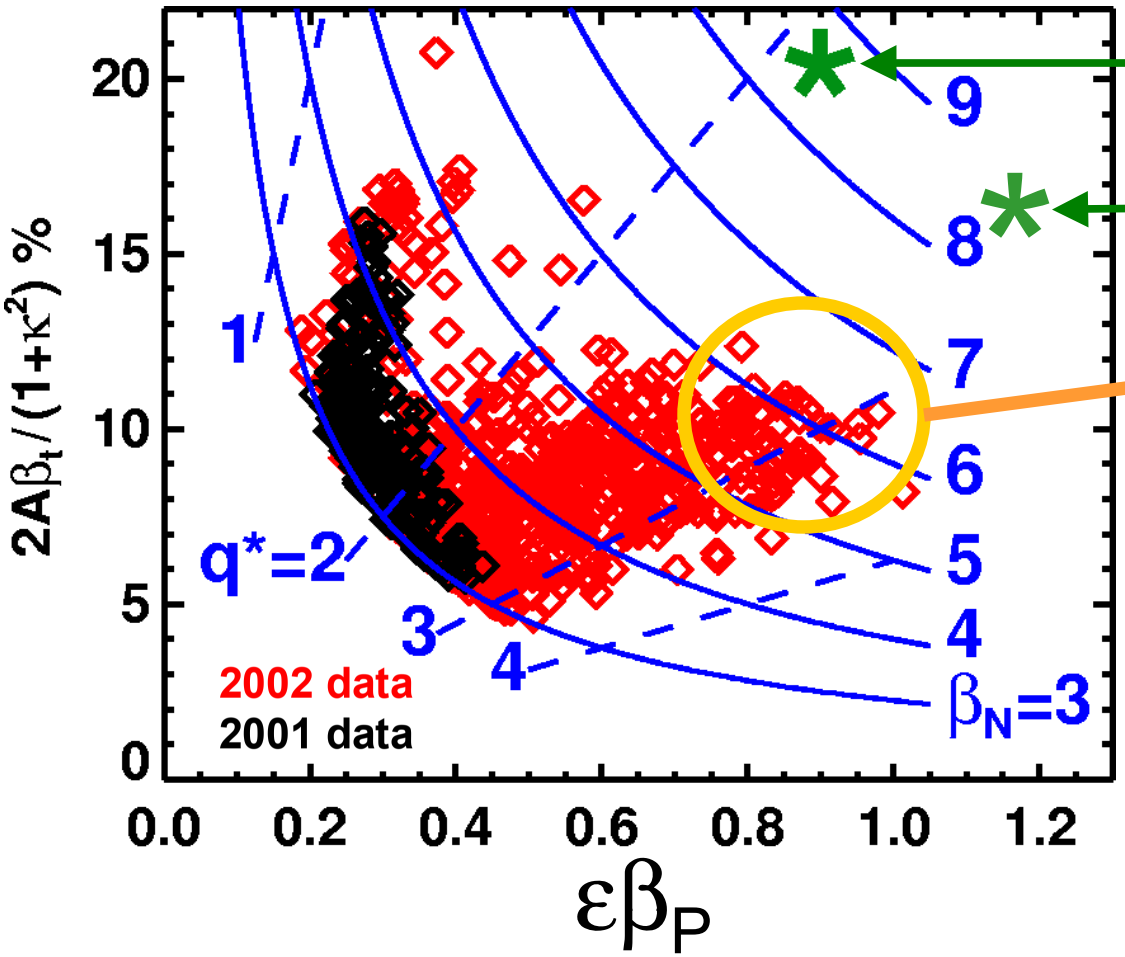
Department of Applied Physics and Applied Math
Room 200, Seeley W. Mudd Building
Columbia University, NY

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



NSTX β_t=40% target

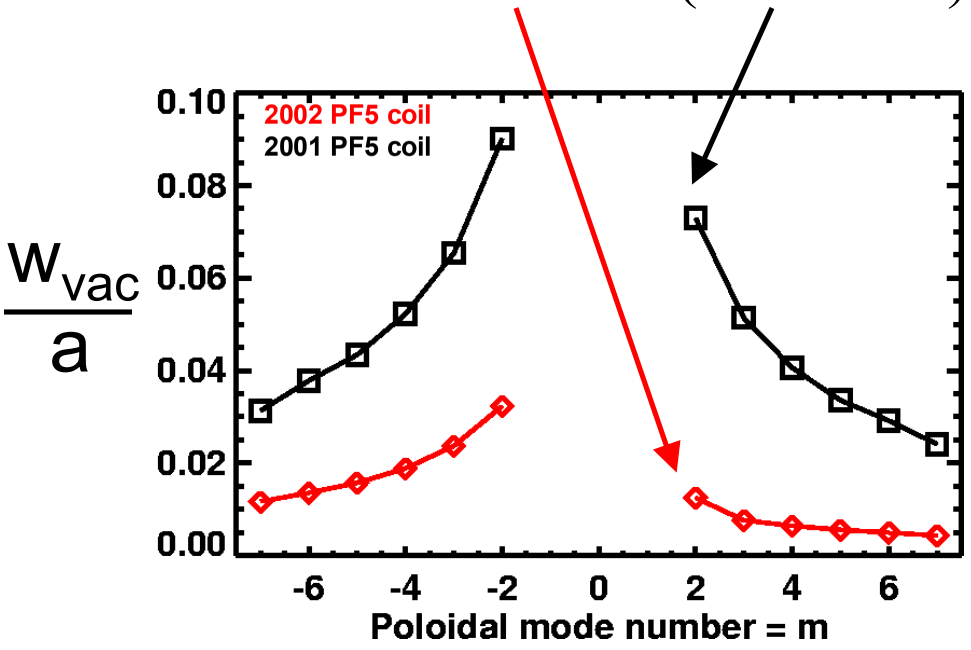
ST Reactor (κ=3.4)

Many discharges in the high β_P parameter range

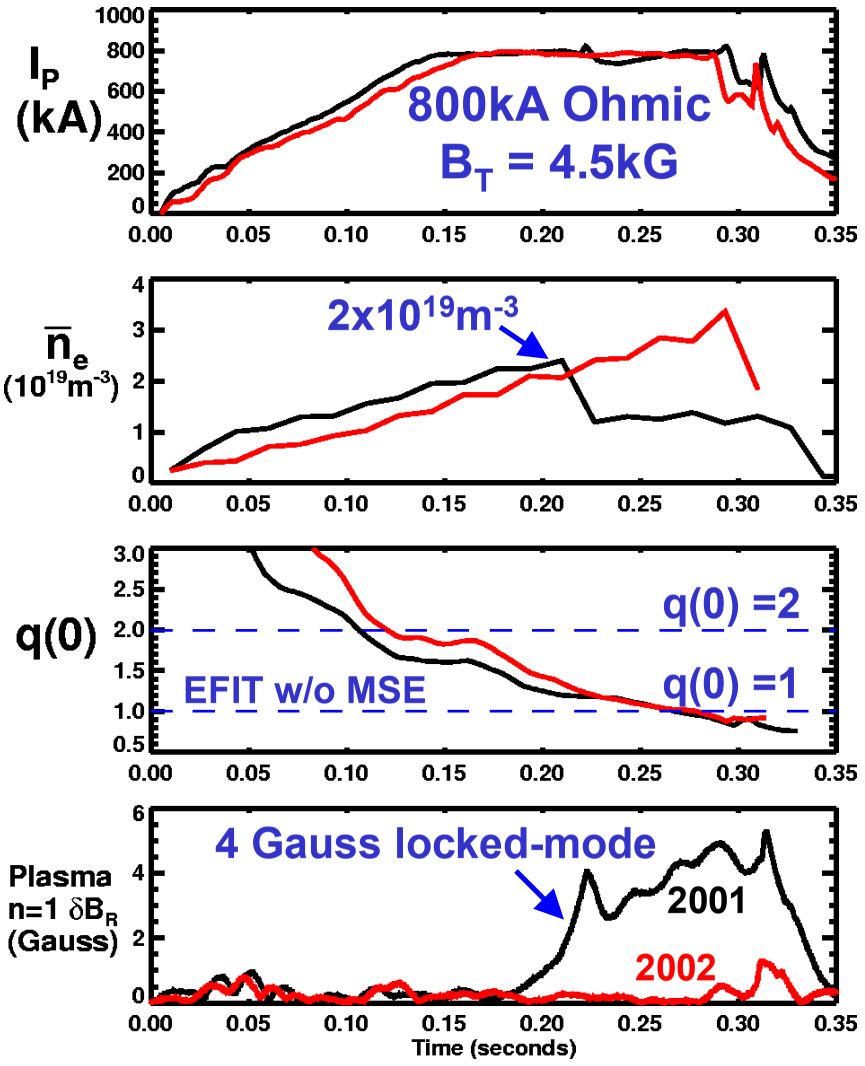
- **Significant improvement** relative to 2001 plasmas
  - Reduced error field
  - H-mode ⇒ broader $p(\psi)$

Reduced error-field → reduced mode locking

- Vertical field coils found to generate large n=1 δB_r
- **Coils subsequently re-shaped**
- Vacuum island widths now ***reduced to < 1cm*** (from 5cm)



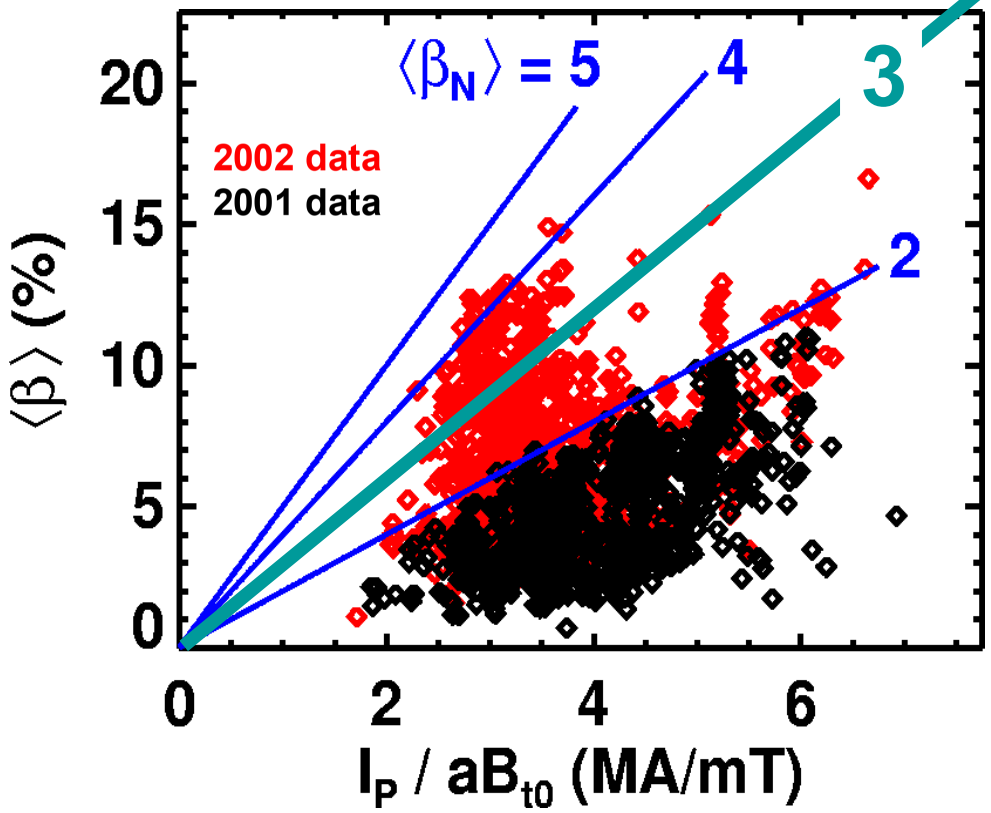
(NSTX operates with m > 0 resonant)



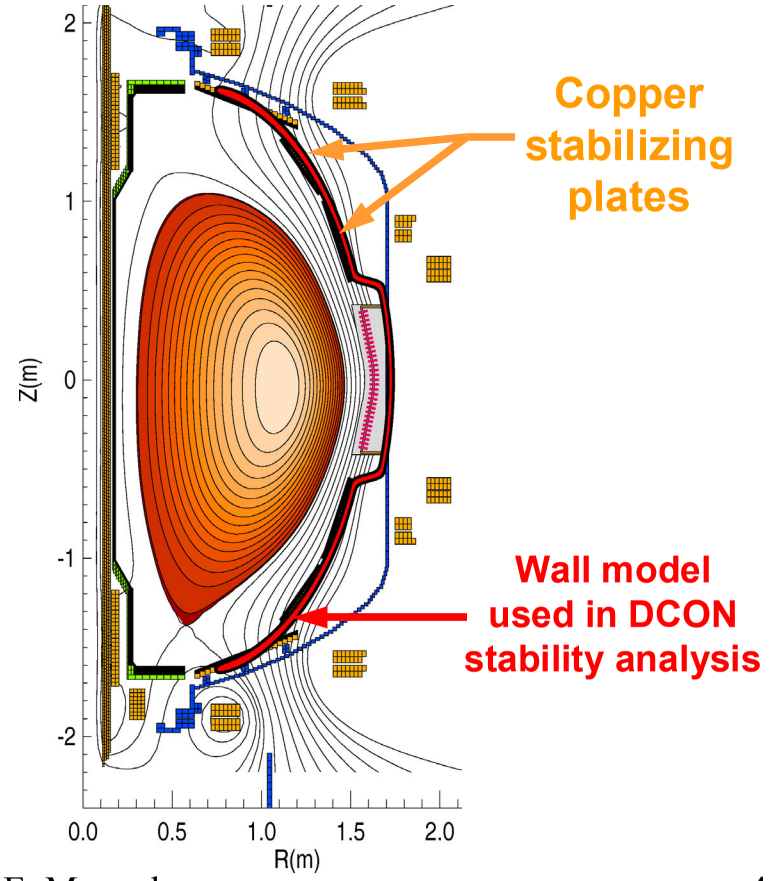
High β_P discharges operate above theoretical no-wall limit

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

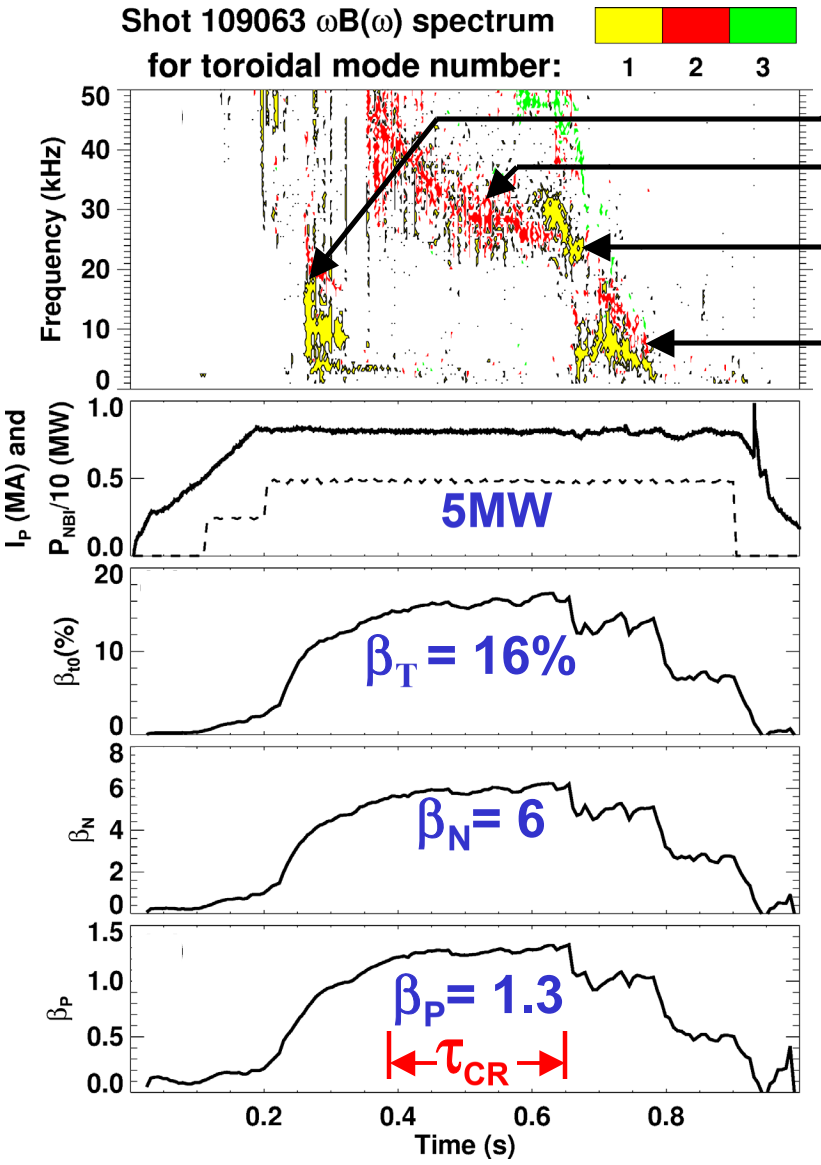
$\langle\beta\rangle \equiv 2\mu_0\langle p\rangle / \langle B^2\rangle$



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



MHD events in longest pulse discharge:



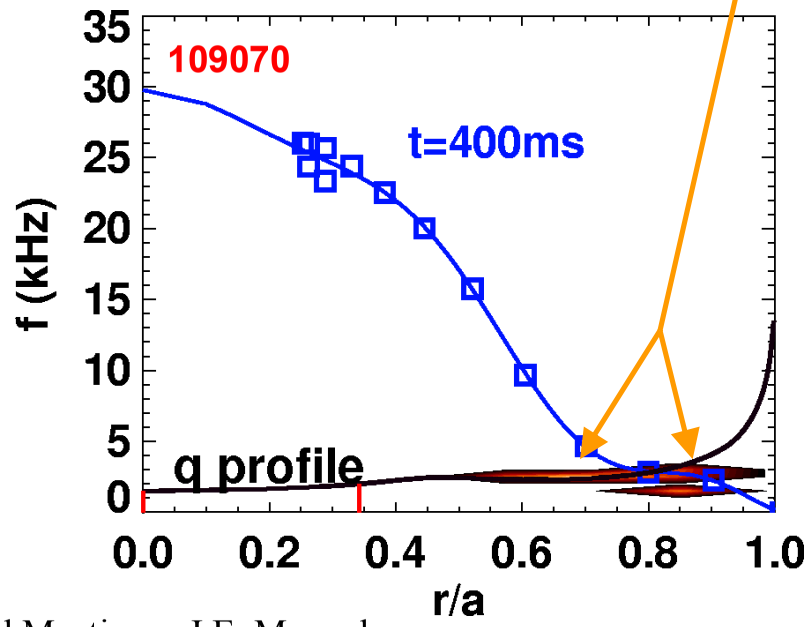
early n=1, transient at high B_T

long-lived n=2 mode in flat-top

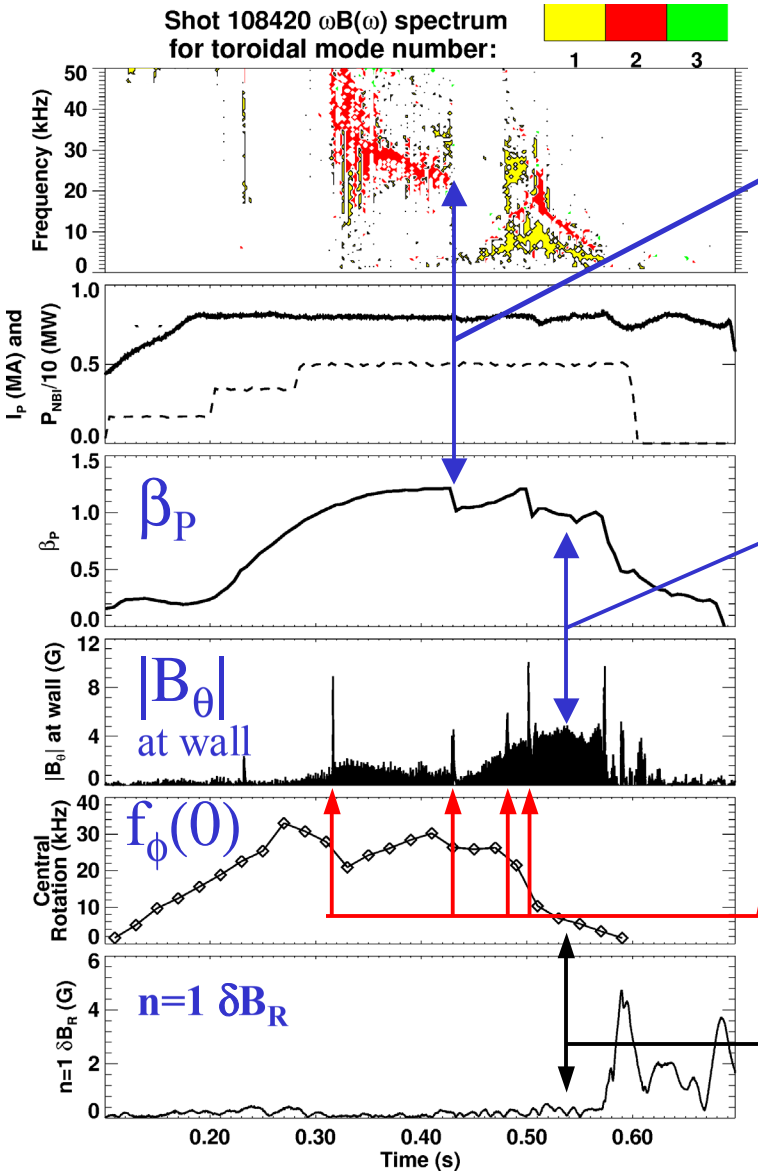
fast n=1 internal mode disrupts β

residual n=1,2 rotating modes – NTMs?

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



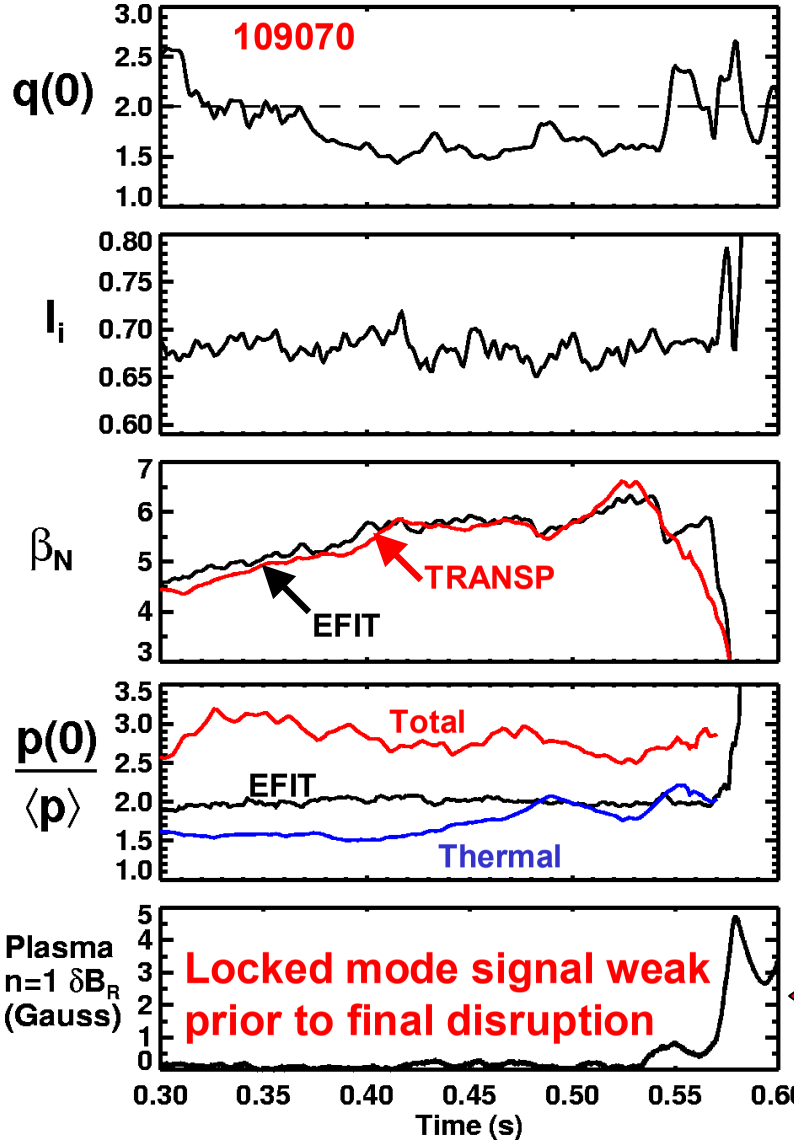
Rotation decay correlated with rotating MHD modes



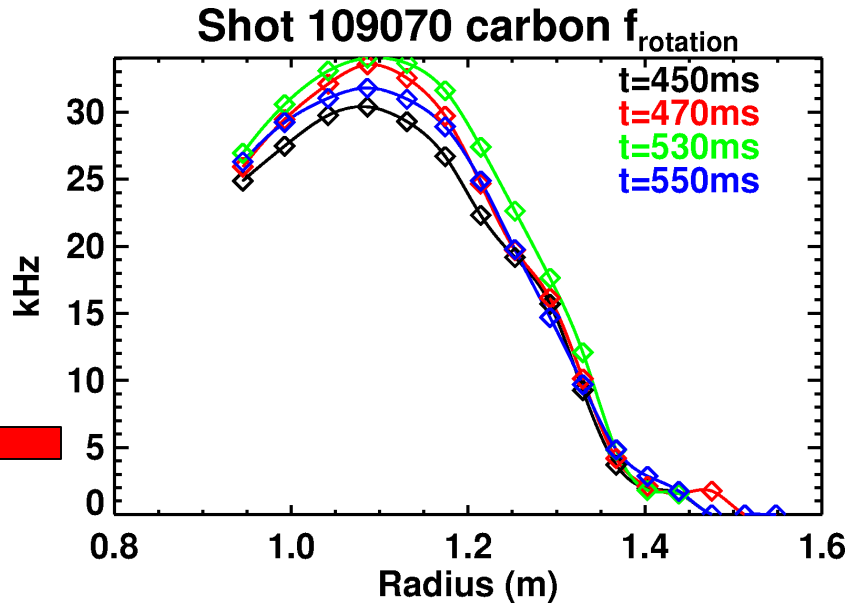
- n=1 bursts have τ_{growth} = 200-500μs
  - Consistent with (hybrid) ideal τ_{growth}?
  - Peak amplitude up to 10 Gauss at wall
- Continuous modes clamp β_P?
- Each n=1 burst reduces rotation
  - Also triggering continuous modes?
- RWM evident only at low $f_\phi(0)$
  - Causes final collapse of plasma

Does continuous mode or small RWM induce late rotation decay?

Highest β_P disrupting near with-wall limit?

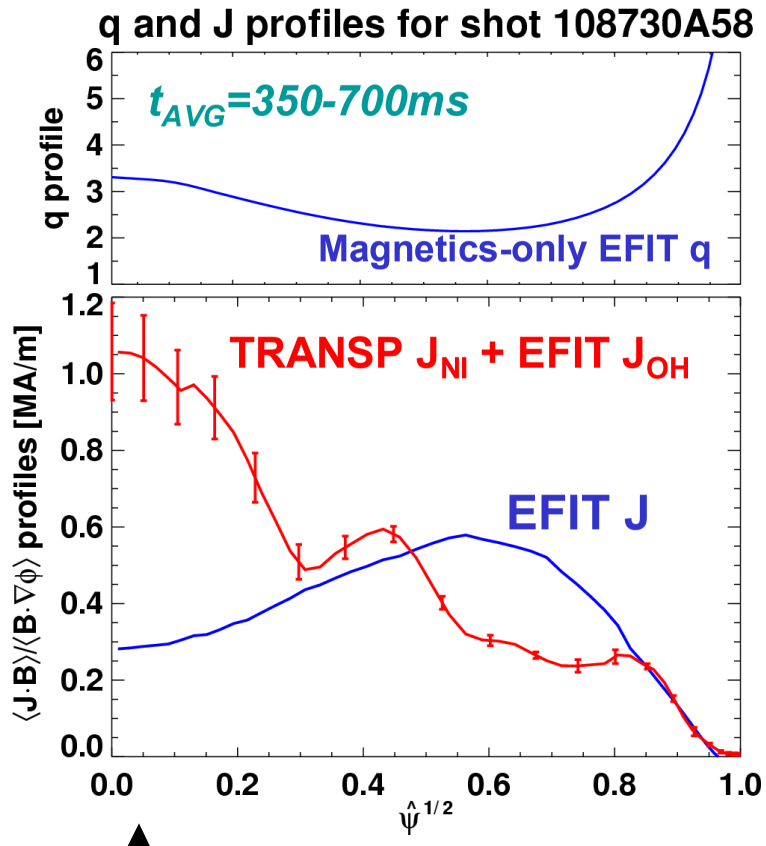


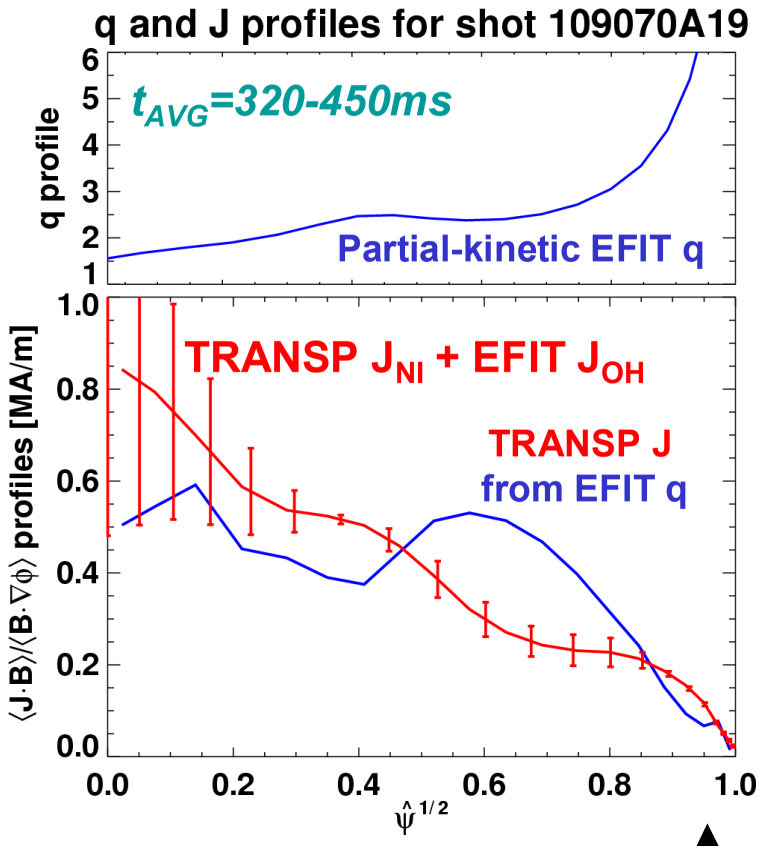
- **P_{NBI}=6MW, $\beta_N \approx 6.3$, $\beta_P \approx 1.4$**
  - $q(0) \approx 1.5$, $l_i = 0.65$-0.7
- $p(0)/\langle p \rangle$ and β_N evolve slowly
- Rotation decay not observed preceding final disruption phase:



No MSE ⇒ check J profile against NC theory

- Total integrated current matches I_p in both cases





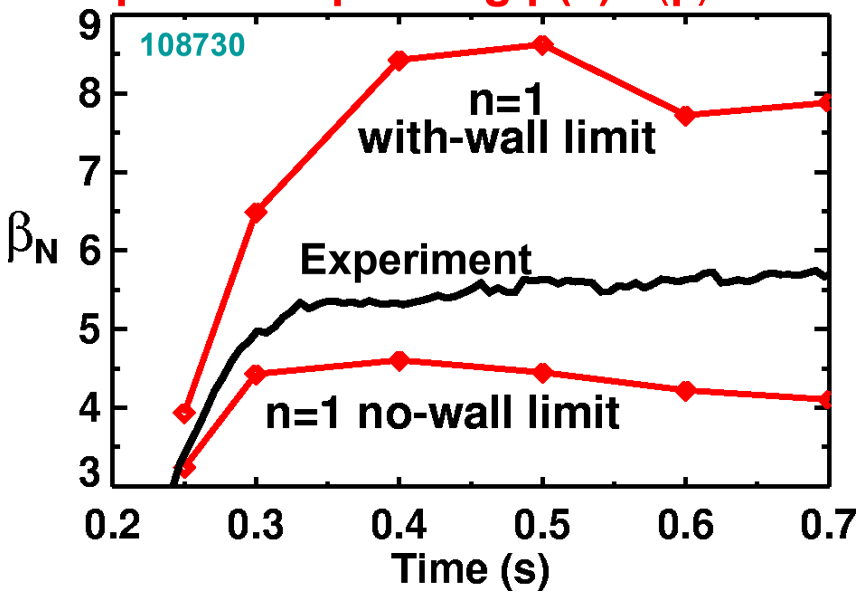
$J_{NICD} + J_{OH}$ inconsistent with reversed-shear q(ψ)

Better agreement with monotonic q(ψ) in core

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

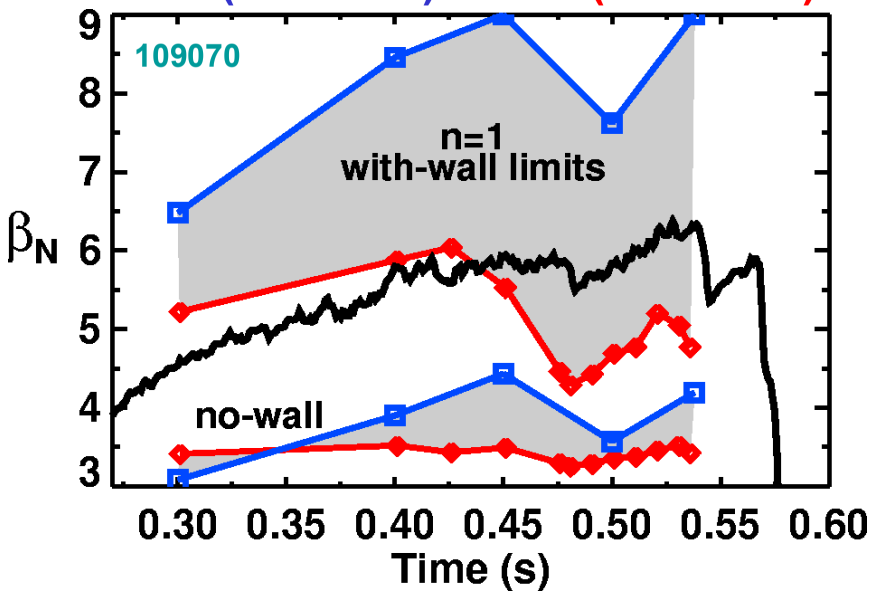
Reversed-shear q(ψ) with q(min) > 2

Use TRANSP p(ψ) which has **pressure peaking p(0) / ⟨p⟩ = 2.5**



Nearly monotonic q(ψ) with q(0) < 2

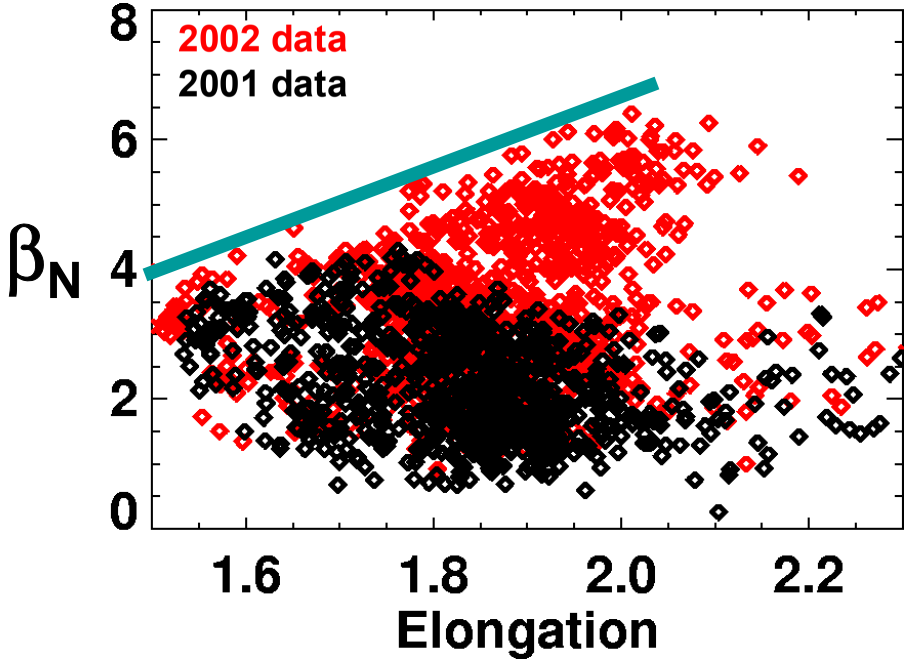
Vary pressure peaking p(0) / ⟨p⟩ = **2.0 (PK-EFIT) to 2.7 (TRANSP)**



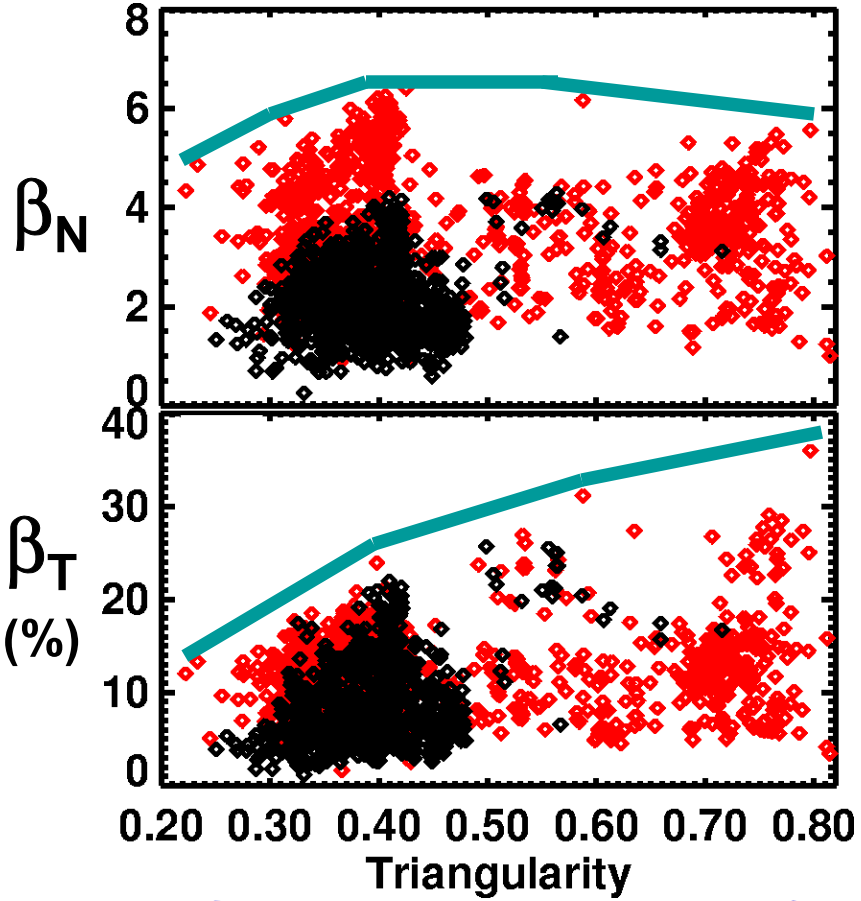
- n=1 no-wall limit β_N = 3.5 to 4.5 clearly exceeded
- With-wall limit sensitive to p & q profile shapes:
  - **Limit lowered by monotonic q(ψ) with q=2 in plasma**
  - **Limit lowered with increased p(ψ) profile peaking**

High β obtained with high κ and δ

- β_N increases with increasing elongation
  - β_N degraded for $\kappa > 1.8$ in previous run year



β_N weak function of δ for $\delta > 0.4$

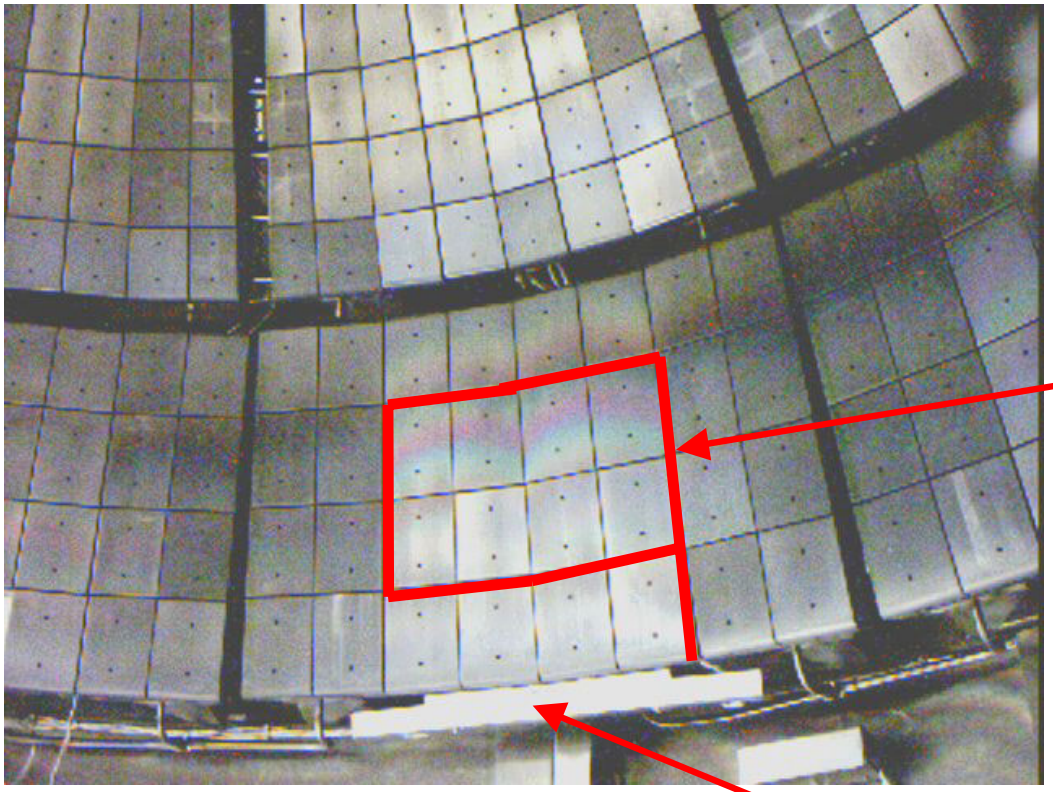


High $\delta \rightarrow$ higher I_p/aB_{t0} & β_T

Near-term NSTX control upgrades:

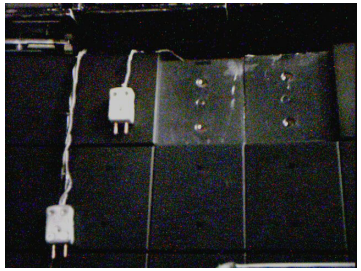
- NBI feedback for β control ($ limited at present)
- Collaboration with G.A. to assess and possibly improve NSTX vertical position control
  - Higher $\kappa \Rightarrow$ lower l_i, higher β_N ? (NSST κ=2.5, δ=0.6)
- Collaboration with C.U. designing RWM feedback system with DCON+VALEN
- Internal RWM/EF sensors already installed
  - Finishing wiring and awaiting integrators and DAQ
  - Will benchmark models and use for feedback

Each primary plate will measure $B_\perp$ and B_P

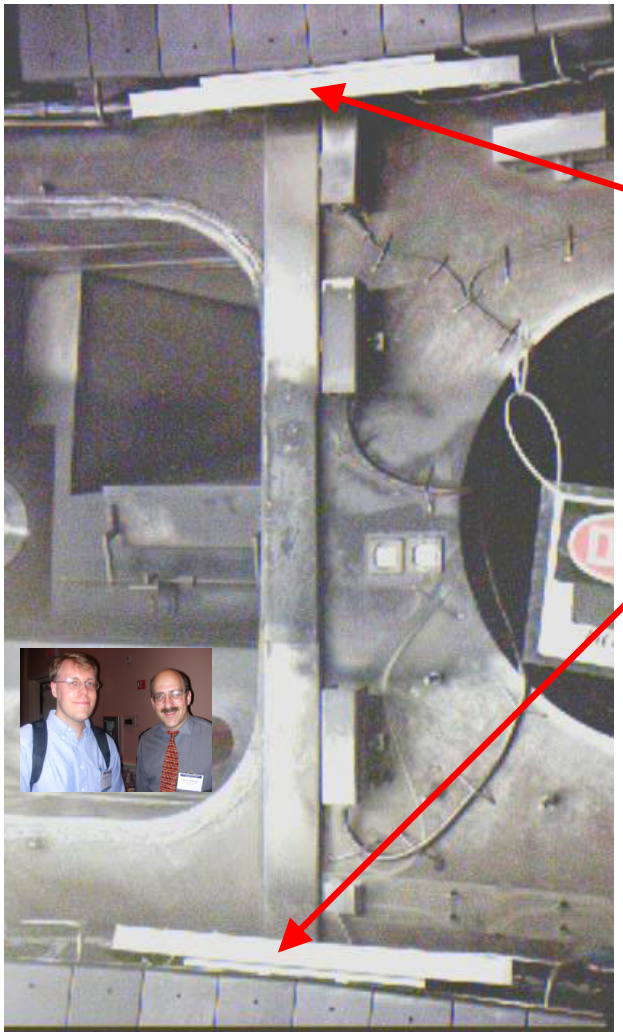


- Full toroidal coverage
  - 24 $B_\perp$ and 24 B_P
    - Each 12 above, 12 below
- $B_\perp$ measured by single turn loop
  - Embedded in tiles
  - Centered in plate
- B_P measured at ends of primary plates
  - Glass insulated Cu wire wound on macor forms
  - SS304 shields

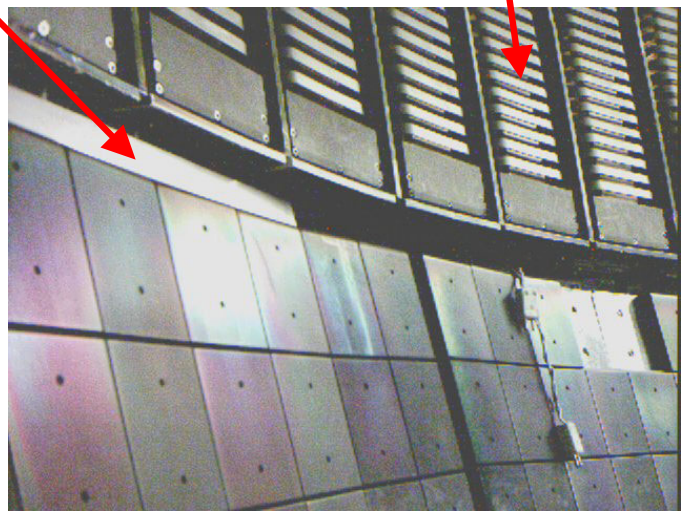
Thermocouple connectors allow easy installation and upgrade potential (PnP)



Sensors will measure RWM/EF helicity



- B_P and $B_\perp$ mounted symmetrically above and below mid-plane:
  - Chosen to avoid ports, etc….
  - Mounted 1/2” behind limiter boundary
  - B_P sensors must avoid HHFW antenna



Use up/down average for n=1 feedback

Summary

- NSTX has combined $\beta_P > 1.2$ with $\beta_N > 5.5$
  - 1s discharge with 700ms, 800kA flat-top
- Routinely operating above n=1 no-wall limit
  - Static error field reduction and H-mode operation key
- 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.
- NSTX RWMs and error fields will be diagnosed with extensive new set of internal $B_\perp$ and B_P sensors
- Higher κ and active RWM/EF control should increase β