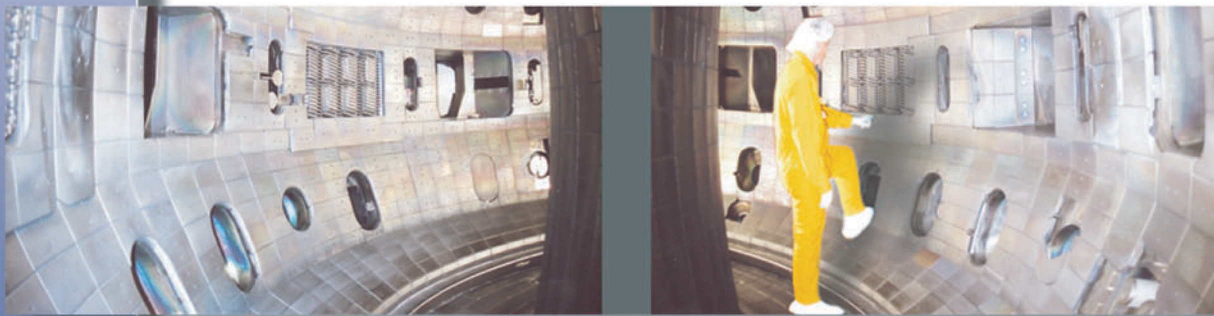

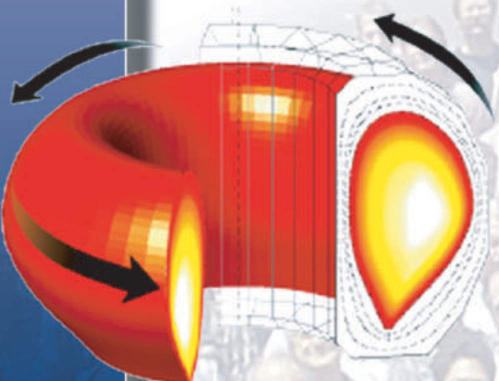

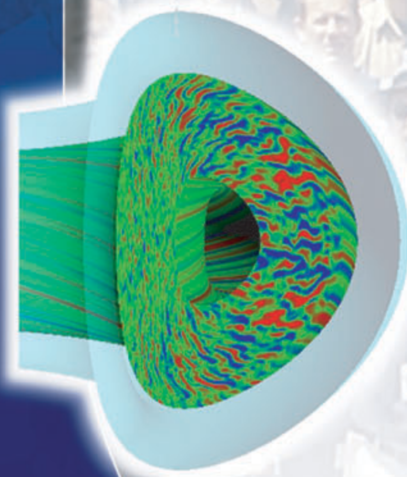

100% Noninductive Operation at High Beta Using Off-Axis ECCD

by
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in collaboration with

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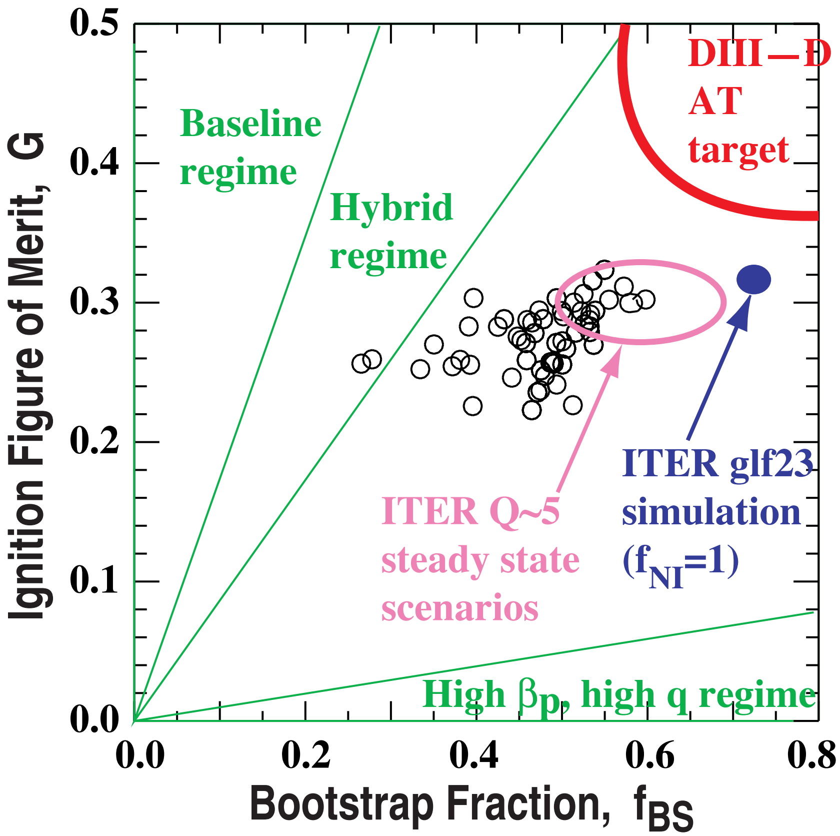
SAN DIEGO

ornl

DIII-D *AT* PROGRAM GOAL:
SCIENTIFIC BASIS FOR STEADY STATE, HIGH PERFORMANCE OPERATION

- **Steady-state**
  - 100% noninductive
  - High bootstrap current fraction $f_{BS} \propto \beta_p$
- **Maintaining sufficient fusion gain with reduced engineering parameters**
  - Hgh β_T
  - High τ_E
  - $\Rightarrow$ High Normalized fusion performance $G = \beta_N H/q^2$
- **DIII-D *AT* experiments have demonstrated performance required for *ITER* steady state scenario**



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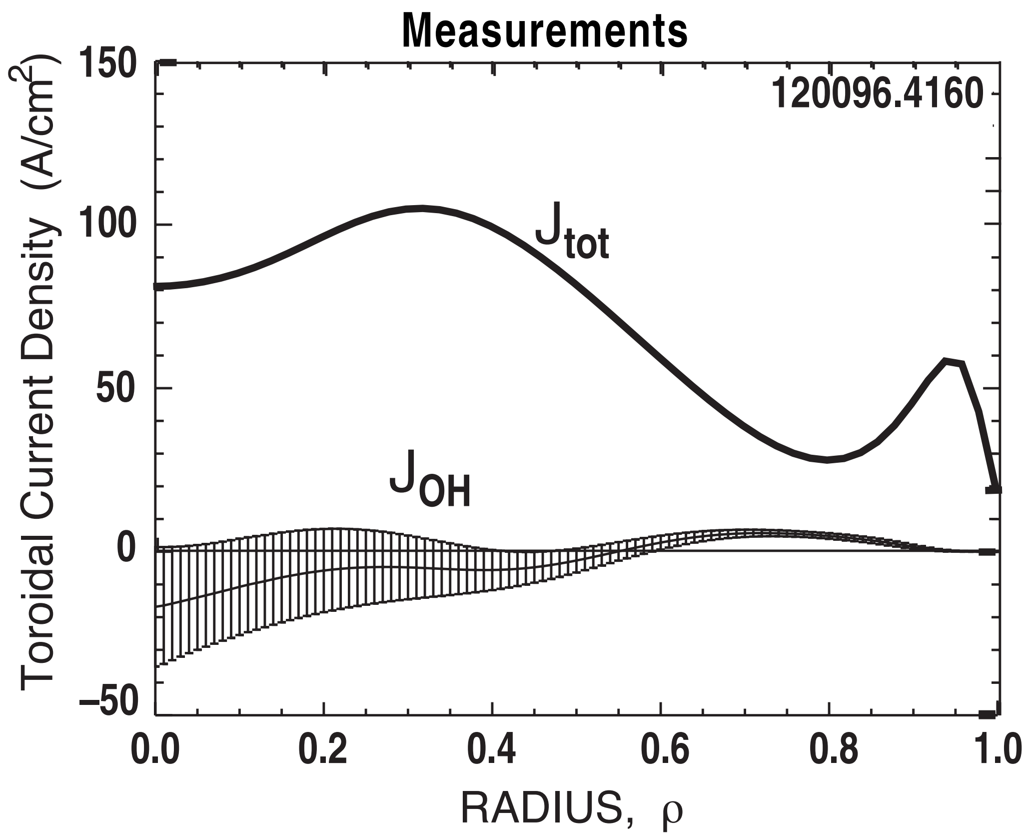
100% NONINDUCTIVELY DRIVEN PLASMAS WITH GOOD CURRENT DRIVE ALIGNMENT



- $f_{NI} = 1 - f_{OH}$; $J_{OH} = \sigma_{neo} E_{I} \propto \sigma_{neo} \partial\Psi_{pol}/\partial t$
- f_{OH} = 0.5%, f_{NI} = 99.5%
- β_T= 3.5%, β_N = 3.6, q_{95} = 5.4

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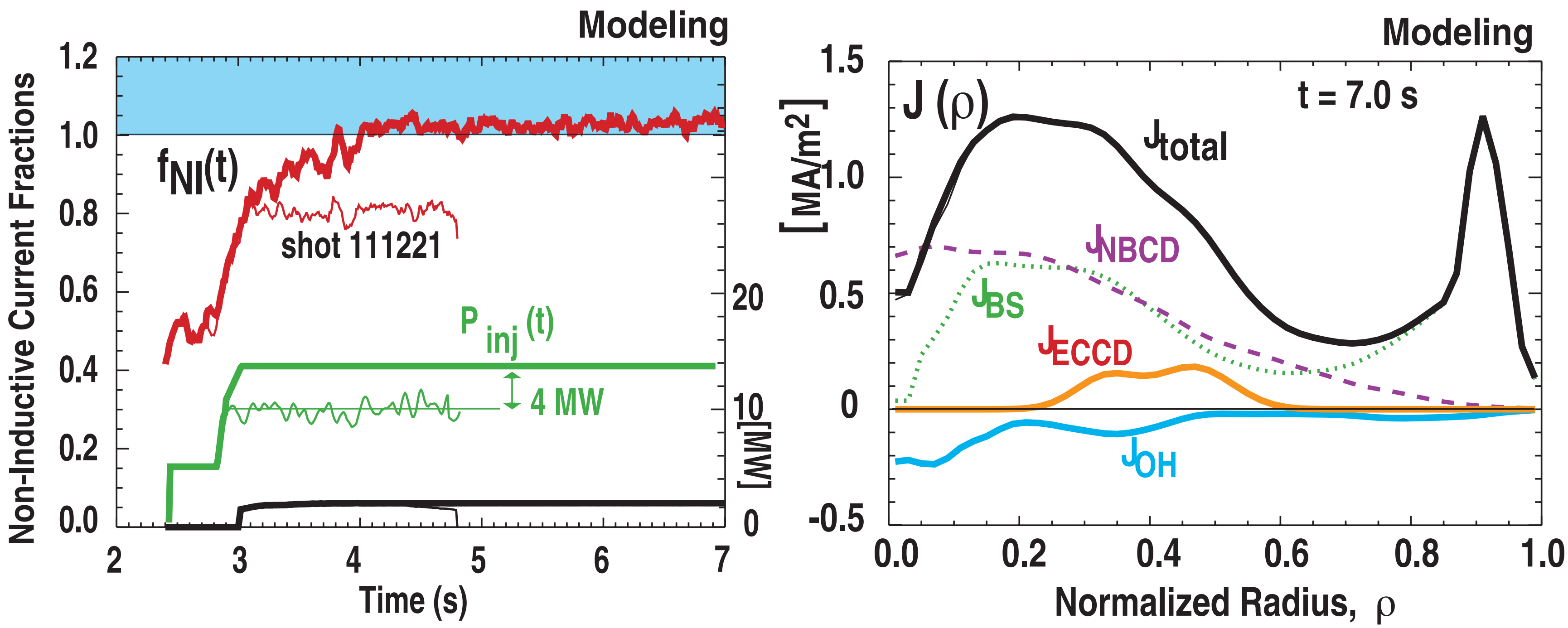
CRITICAL ISSUES COVERED IN THIS TALK

- Self-consistent solutions for full noninductive, high performance operation requires:
  1. f_{NI} = 100%
  2. Good current drive alignment
  3. Pressure profile evolution stable for ideal MHD and NTMs
  4. Integration ⇒ Current profile stops evolving ($E_{||} \approx 0$ everywhere)

- Modeling validated against experiments is applied to
  — Projection for longer sustainment of f_{NI}=100% in DIII-D
  — ITER steady-state *AT* scenario

PREDICTIVE SIMULATIONS INDICATE PREVIOUS ECCD DISCHARGE COULD BE EXTENDED TO 100% NONINDUCTIVE WITH INCREASED NBI POWER



- Two transport models produce consistent results:
  - Scaled experimental transport coefficients
  - Recalibrated GLF23
- Modeling has become essential tool for the experimental program
  - Used both to plan and interpret experiments

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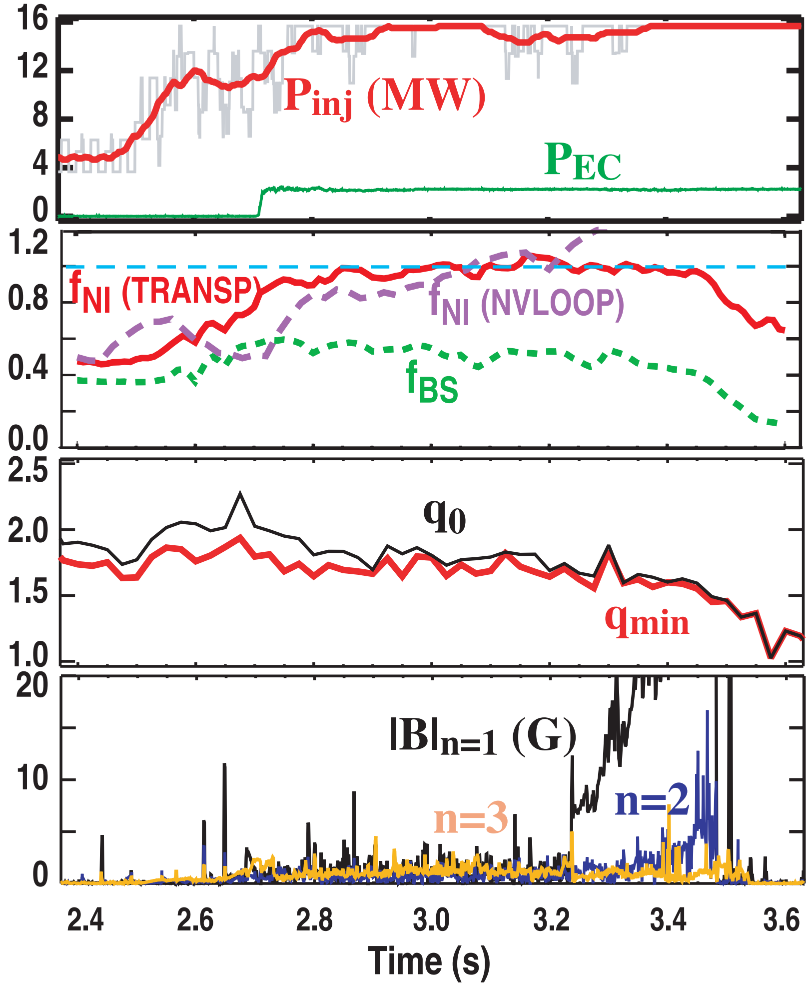
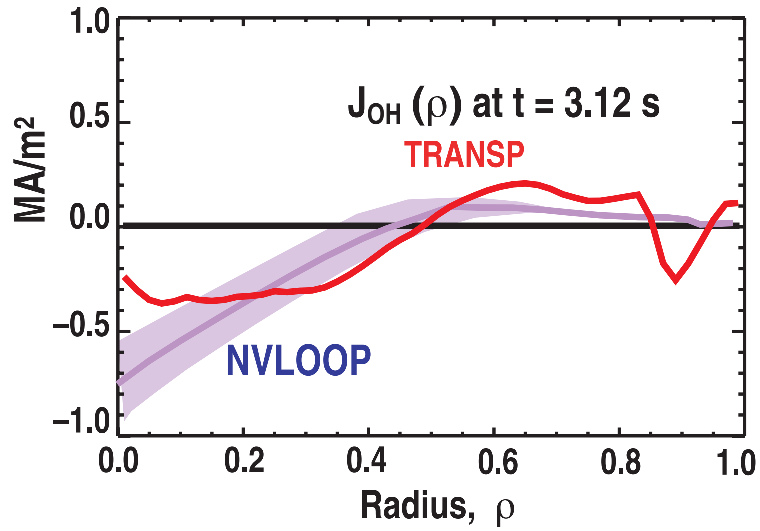
NEUTRAL BEAM OVERDRIVE NEAR THE AXIS DECREASES q_0, RESULTING IN *NTMs*





- Achieved net $f_{NI} \approx 100$ % with $\beta_N \approx 3.5$, $\beta \approx 3.6\%$
- Net Ohmic current is zero, but local Ohmic current is NOT zero
- Confinement somewhat degraded (large P_{NB} demand) in these discharges
  - Rotation velocity often slower
  - Flatter q profiles ... often more monotonic

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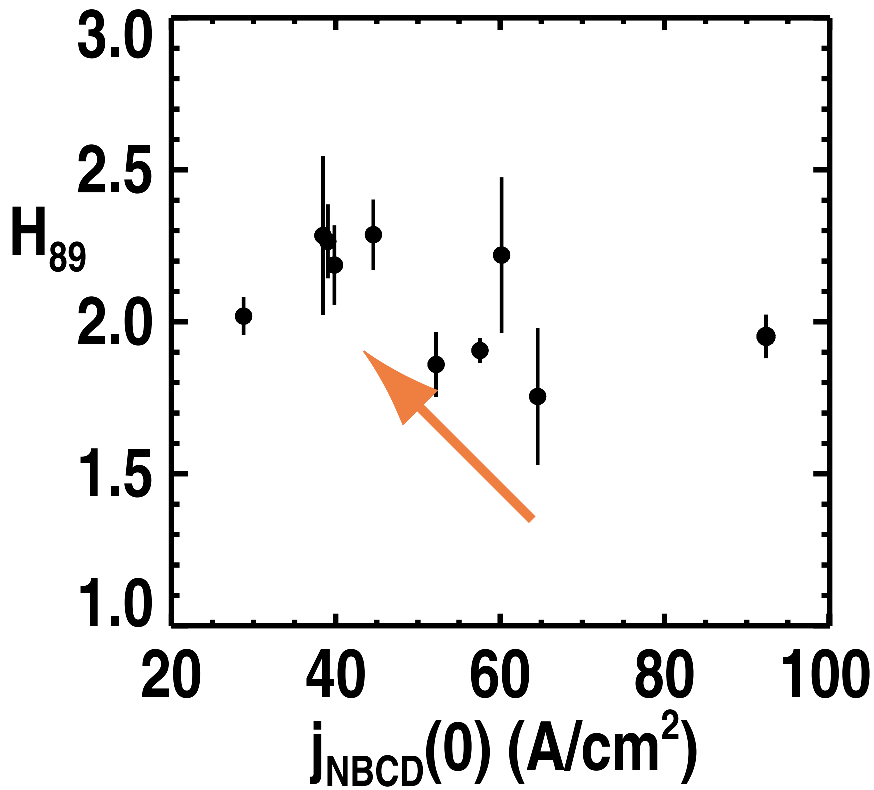
IMPROVED CONFINEMENT RESULTS IN REDUCED NEUTRAL BEAM CURRENT DRIVE NEAR THE AXIS



- Confinement improvement in recent experiments is attributed to:
  - Optimized non-axisymmetric field feedback
  - Slightly negative central shear

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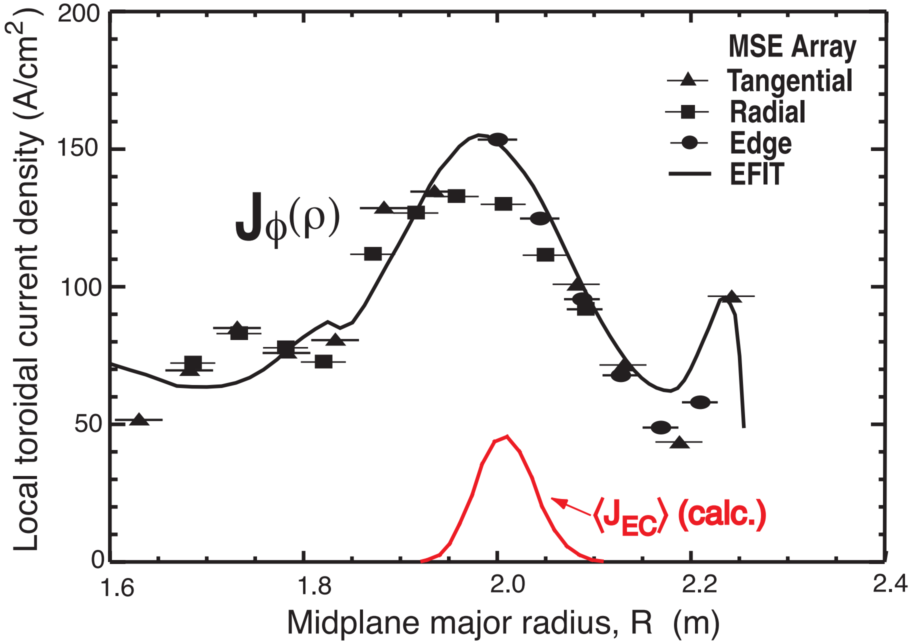
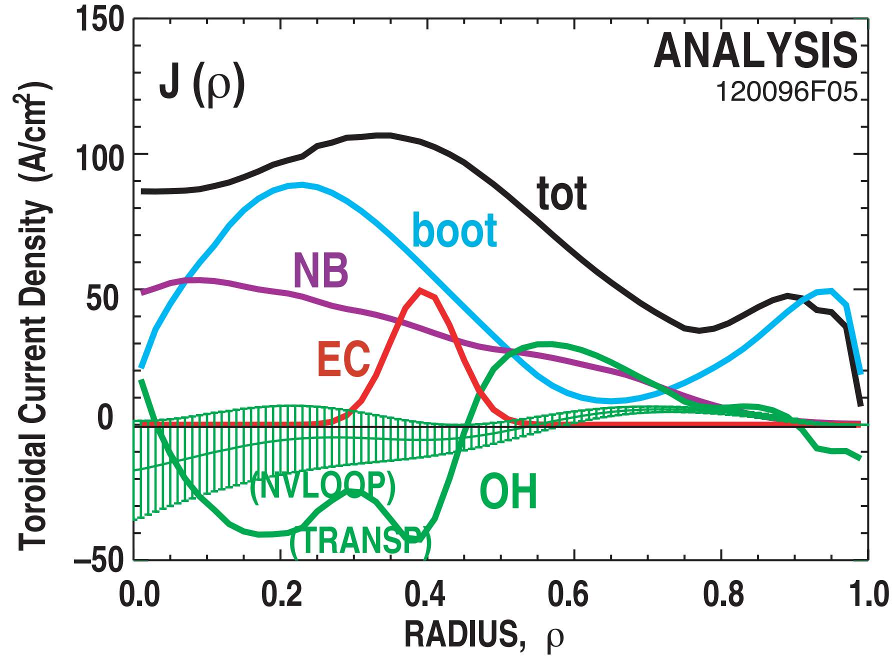
WITH IMPROVED CONFINEMENT, f_{NI}=100% ACHIEVED WITH GOOD CD ALIGNMENT





- **Measure of CD alignment:** $$\xi_{tot} = 1 - \frac{\int (n_e/T_e)\,|J_{OH}|\,dA}{\int (n_e/T_e)\,|J_{tot}|\,dA}$$

Case:	Present	NB-overdrive
ξ_{tot}	0.94	0.90

- f_{BS}=59% f_{NB}=31% f_{EC}= 8% f_{NI}= 98%

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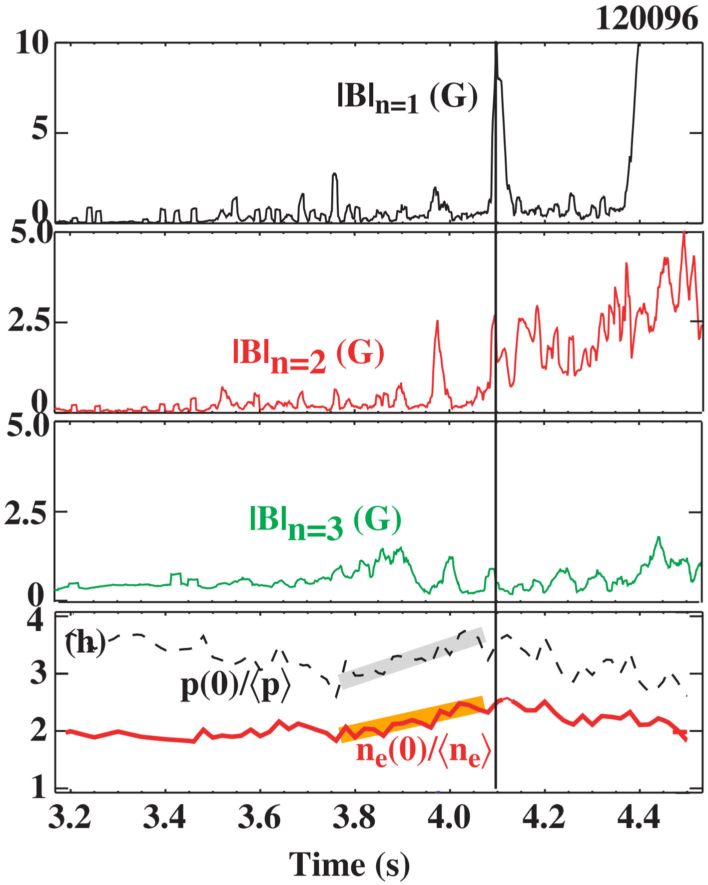
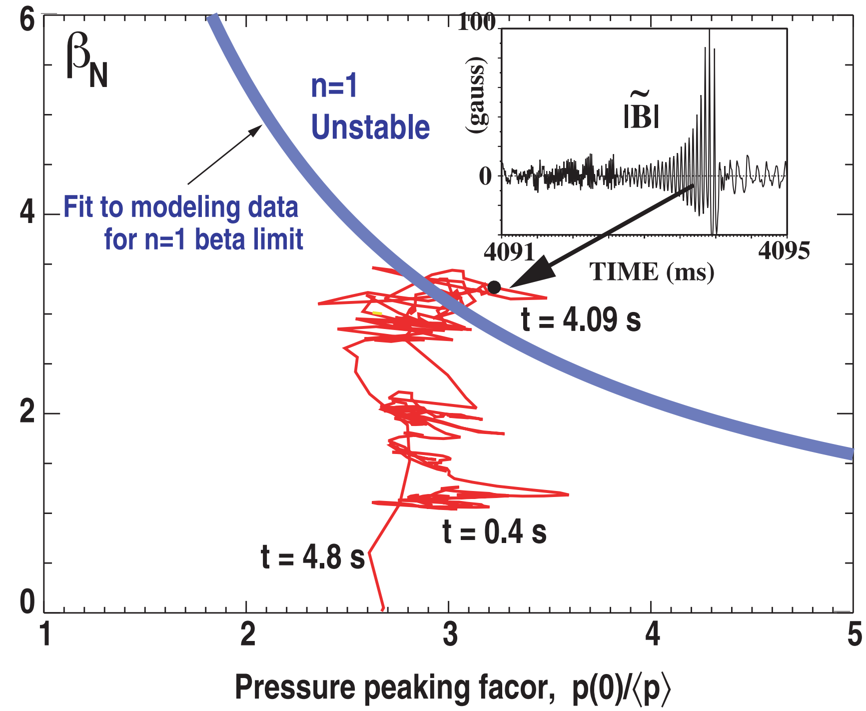
PRESSURE EVOLUTION RESULTED IN n=1 FAST GROWING MODE WHICH TRIGGERED n=1 *NTM*

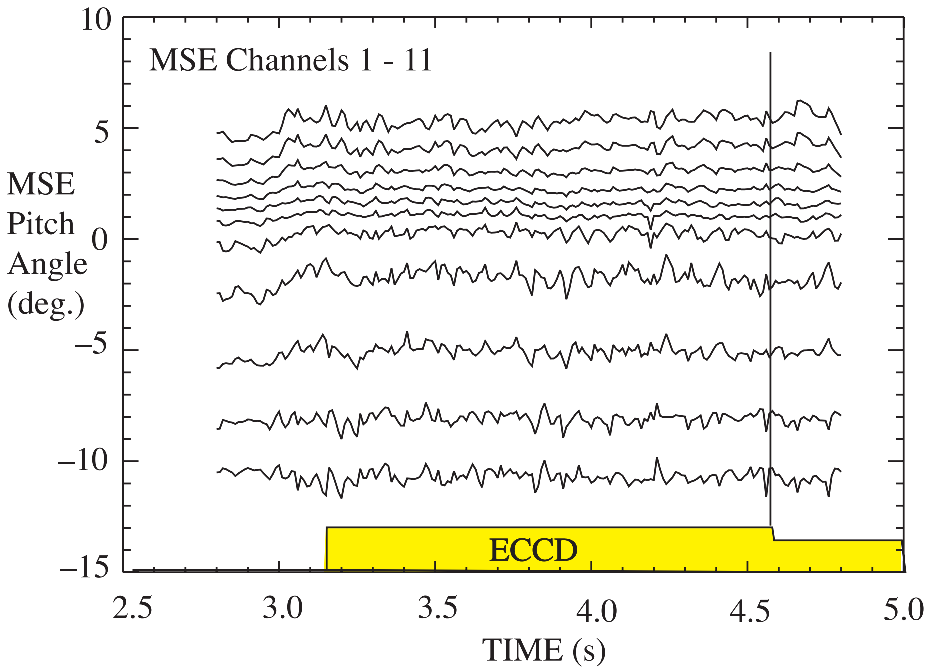


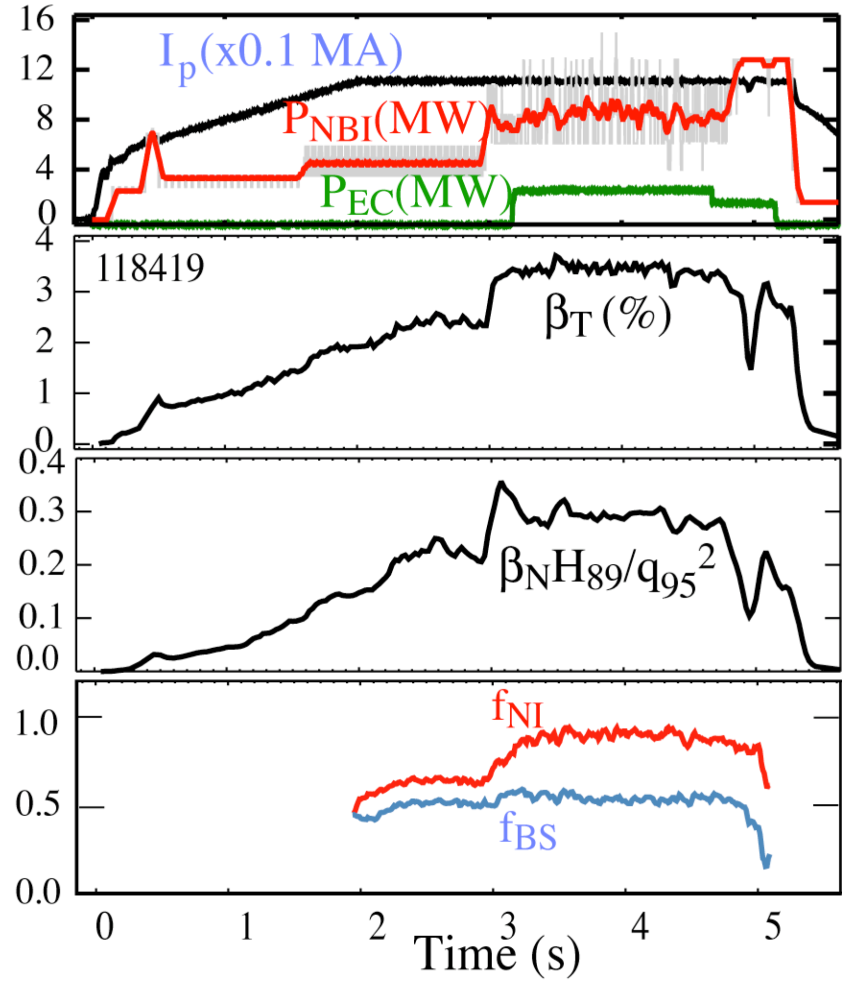


- n=1 ideal instability caused by pressure peaking primarily due to density peaking

J. Ferron: EX/P-2-20

NEARLY FULL NONINDUCTIVE, STATIONARY DISCHARGE OBTAINED, LIMITED ONLY BY GYROTRON PULSE LENGTH





- **MSE signals stationary**
  - **⇒ $J_{\phi}(\rho)$ stopped evolving**
- **f_{NI}~ 90% for 1 τ_R (=1.8s)**
- **β_T = 3.7%, β_N = 3.5, q_{95} = 5.1**
- **$G=\beta_N H/q^2$ = 0.3 with f_{BS}=63%**

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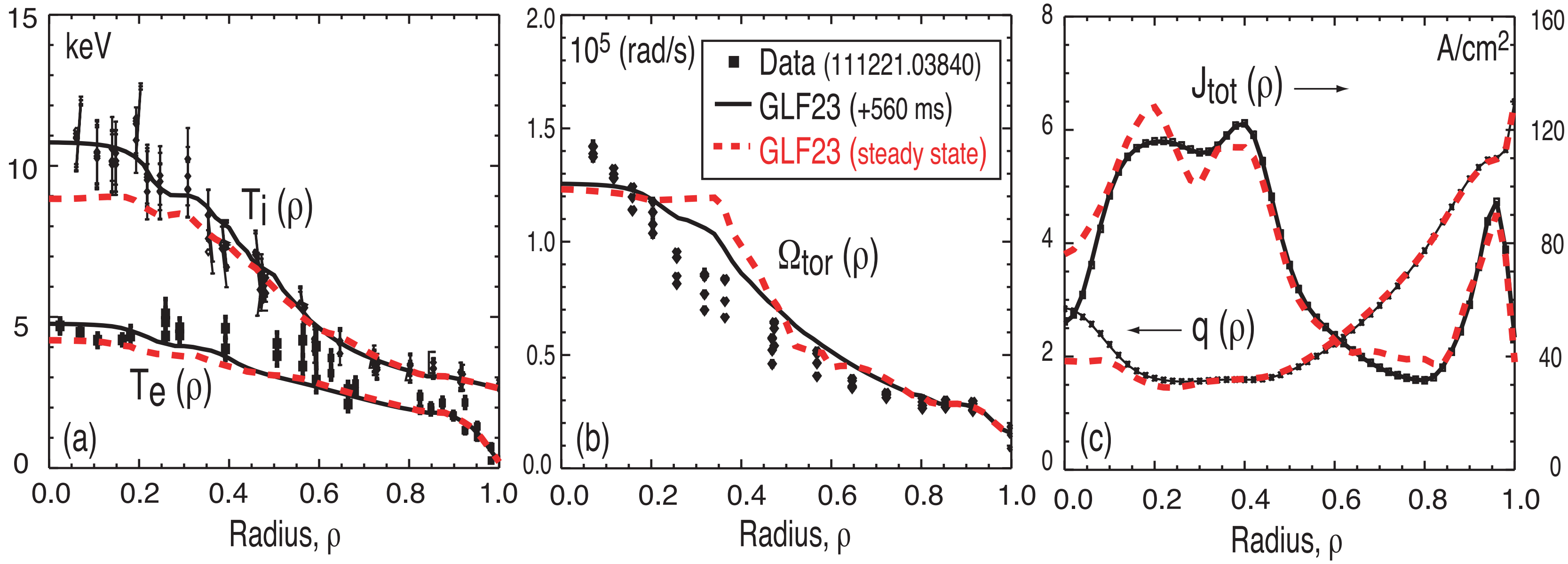
GLF23/ONETWO CAN REPRODUCE EXPERIMENTAL PROFILES REASONABLY WELL, AND ALSO CAN PREDICT STEADY STATE PERFORMANCE IN TOKAMAKS



- **Good coupling between experiment and modeling**
- **Numerical advance (global convergence technique) incorporated into ONETWO allows prediction of steady state in one step (without time stepping calculation)**

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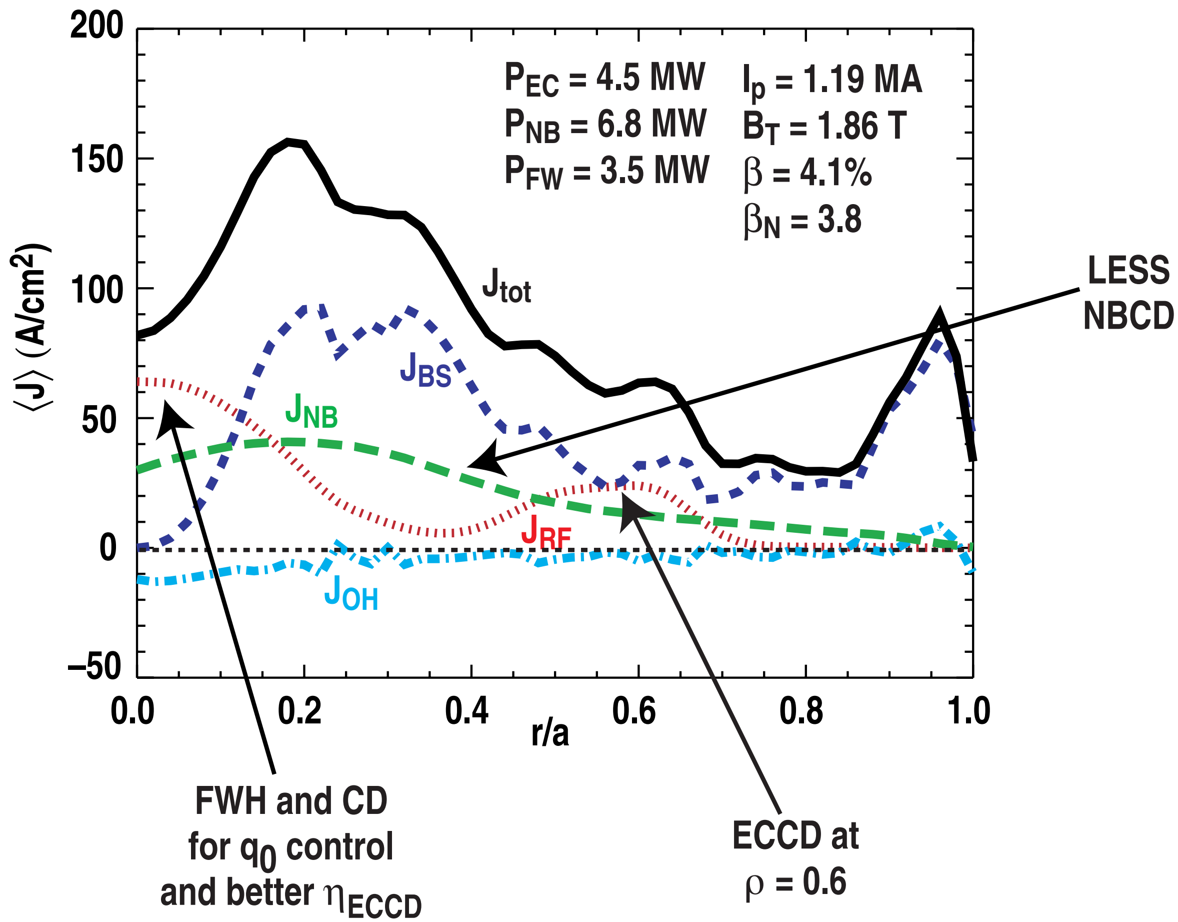
GLF23 MODELING INDICATES THAT STEADY STATE OPERATION IS POSSIBLE WITH β VALUES CONSISTENT WITH STABILITY LIMITS



- Modeling uses hardware improvements planned for DIII–D:
  - Better control of J(ρ) and p(ρ) at high beta with more EC and FW power with long duration
  - Advanced plasma control system

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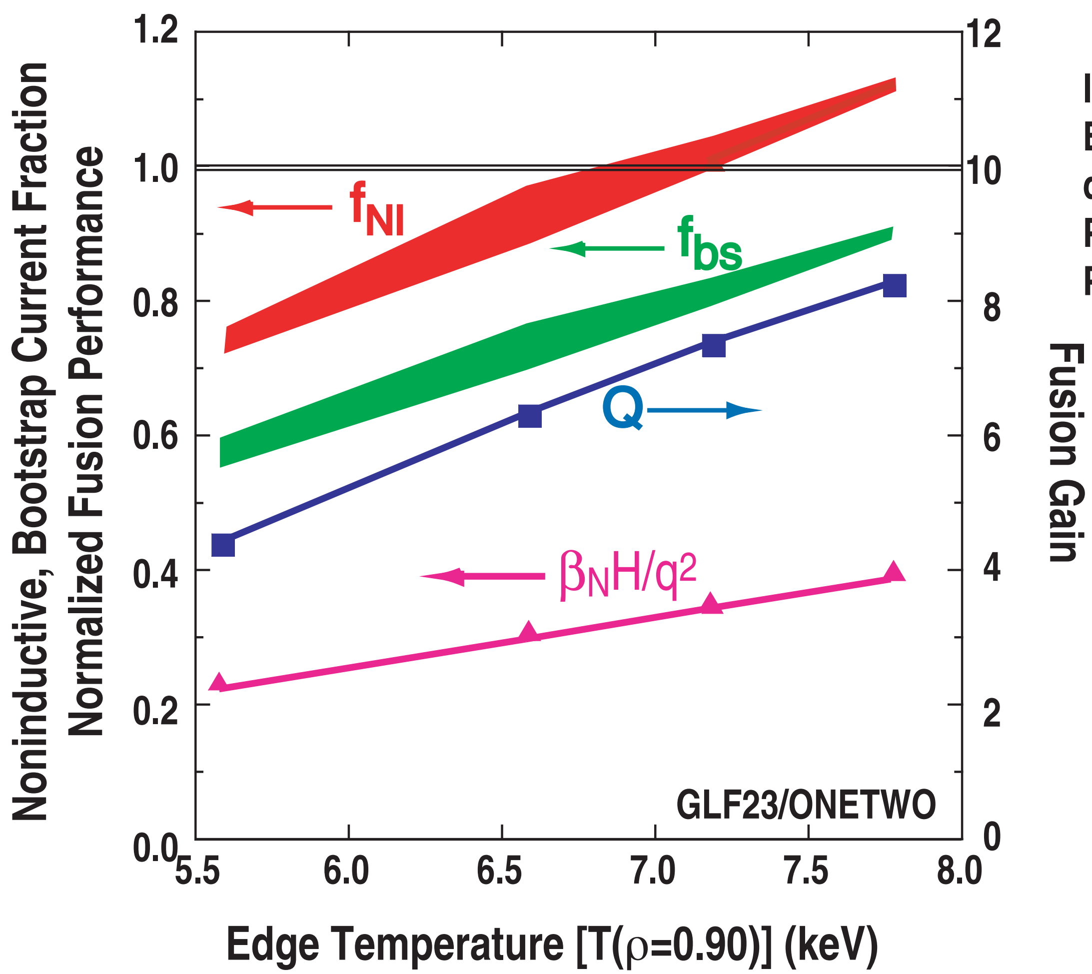
MODELING APPLIED TO ITER *AT* SCENARIO PREDICTS f_{NI} = 100% FEASIBLE WITH Q > 7



ITER Day-1:
B_T = 5.3 T, I_p = 9 MA
q_{95} = 4.5, n_e = 1.04 n_{GW}
P_{NB} = 33 MW, P_{IC} = 20 MW
$P_{EC} \leq$ 8 MW

- Stiff transport model ⇒ core performance related to edge ⇒ edge temperature scan
- Emphasizes importance of understanding the edge pedestal in AT plasmas
- More details will be discussed by W. Houlberg [IT/P3-33]

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CONCLUSIONS

- 100% noninductively driven plasmas with good *CD* alignment at $\beta_T \leq 3.6\%$ and $\beta_N \leq 3.5$ for up to one current relaxation time
- With good coupling between experiment and modeling, progress has been made in several important areas:
  - Current drive alignment
  - Current profile stationary over one current relaxation time
  - Challenge: Control of pressure profile evolution to avoid ideal MHD and *NTM* instabilities to further extend high performance phase
- Future plans include:
  - Better control of $J(\rho)$ and $p(\rho)$ at high beta with more EC and FW power with long duration
  - Advanced plasma control system
- The scientific basis being developed on DIII–D is leading to increased confidence in establishing steady-state scenarios for ITER and beyond