Modeling of DIII-D Discharges With Feedback Control of the Safety Factor Profile Evolution

by
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Presented at the
48th Annual Meeting
of the Division of Plasma Physics
Philadelphia, Pennsylvania

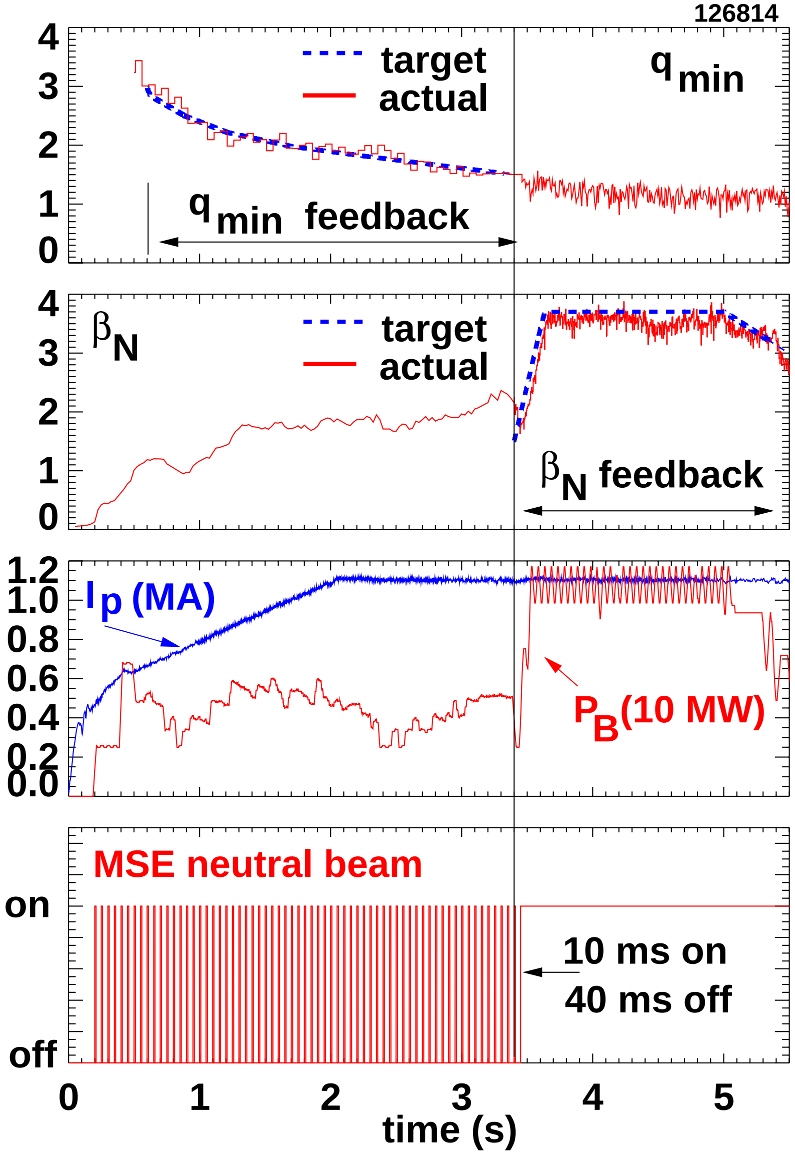
October 30 through November 3, 2006

DIII-D NATIONAL FUSION FACILITY

GENERAL ATOMICS

JRF/APS06

Feedback control of the q_{min} evolution has been used to form the target q profile for high β_N DIII-D AT discharges



- **q profile target for high β_N phase:**
  - $1.5 < q_{min} < 2.5$
  - $q(0) - q_{min} \approx 0.5$
- **H-mode during the I_p ramp**
- **Changes in conductivity (σ, or effectively T_e) used to modify the time evolution of the inductive current profile**

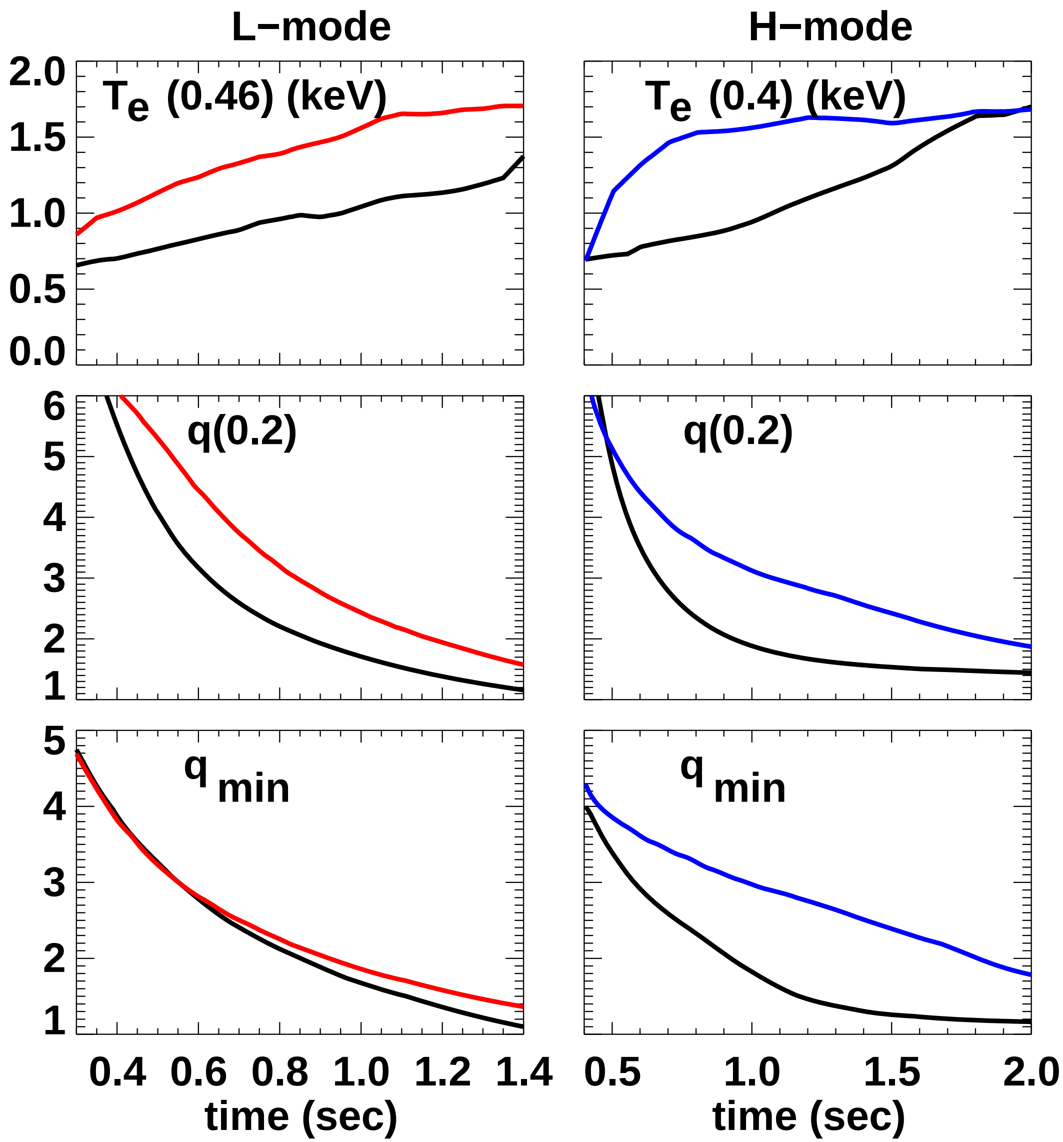
Simulations of the current profile evolution during AT discharge formation are used to test the physics models

- **Transport codes reproduce changes in current profile evolution achieved by varying conductivity (σ)**
  - $J = J_{ind} + J_{NI} = \sigma E + J_{BS} + J_{EC} + J_{NB}$
- **Inductive current dominates during discharge formation**
- **Models of B_p diffusion, J_{BS} and J_{NB} reproduce experiment in many cases**
- **Transport codes in use to develop and test feedback controllers**

Transport code is used with measured density and temperature profiles to predict the q profile evolution

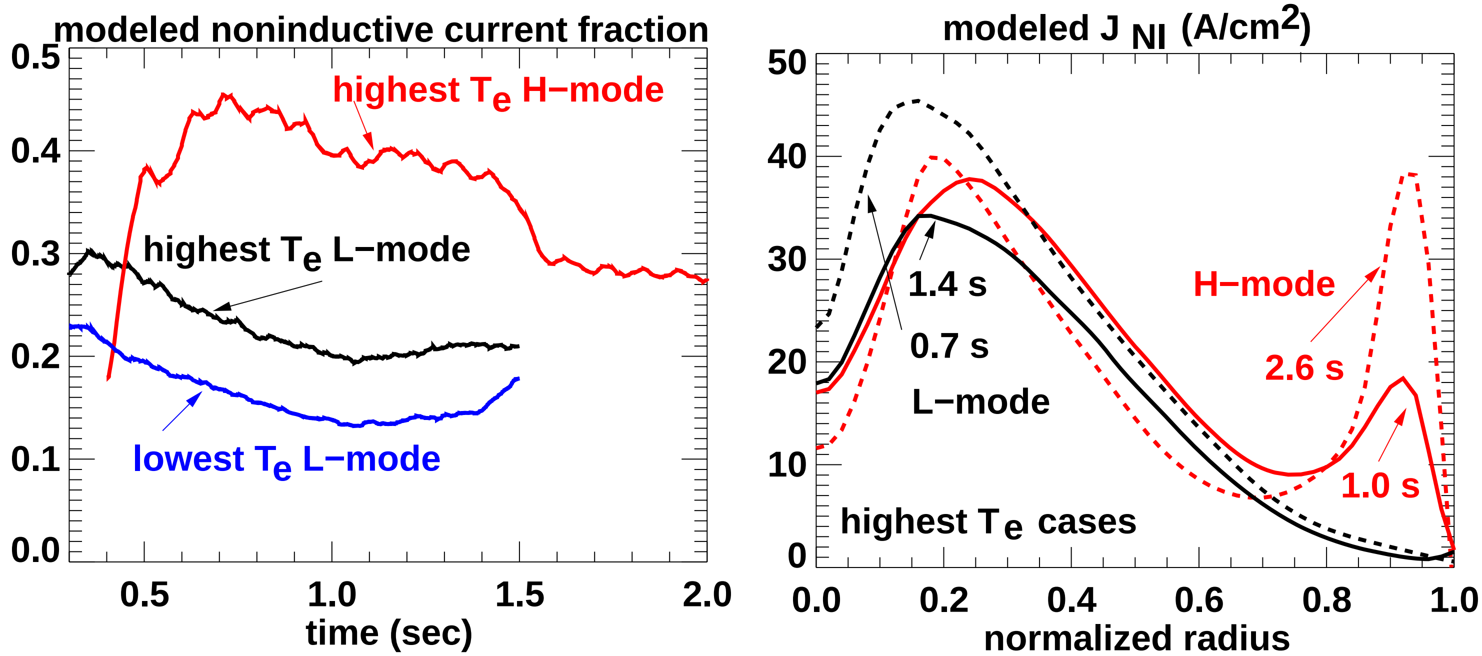
- **ONETWO used primarily, also CRONOS, TRANSP, CORSICA**
- **Starts with an initial current profile obtained by fitting magnetic and MSE data with EFIT**
- **Total plasma current versus time is specified**
- **Experimental values for comparison with simulations are obtained from EFIT equilibrium reconstructions using MSE data**
  - J and q profiles
  - Electric field from $E = d\psi/dt$
  - $J_{IND} = \sigma E$ (σ from neoclassical model)
  - $J_{NI} = J - J_{IND}$

q evolution predictions reproduce the dependence on Te and the choice of L or H-mode observed in the experiment



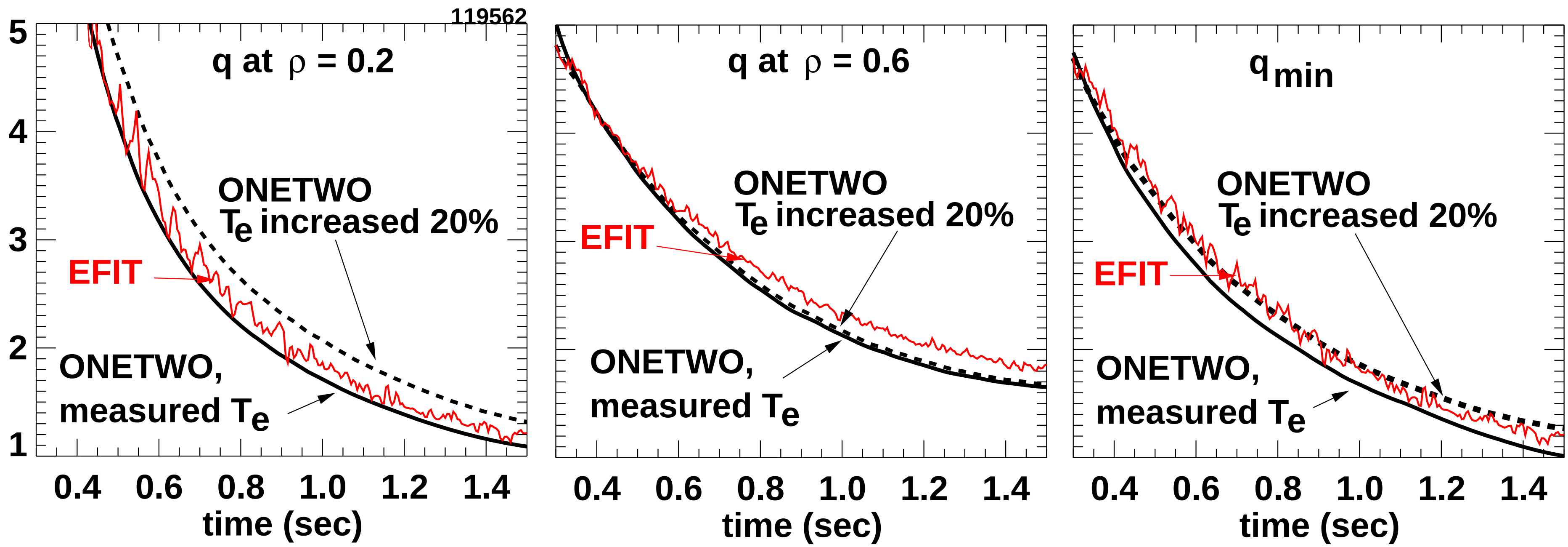
- **q profile evolves more slowly as T_e is increased**
  - result of increase in σ
- **Decay of q is slower in H-mode for comparable mid-radius T_e**

The noninductive current remains relatively low and shows little change in profile shape as the q profile evolves



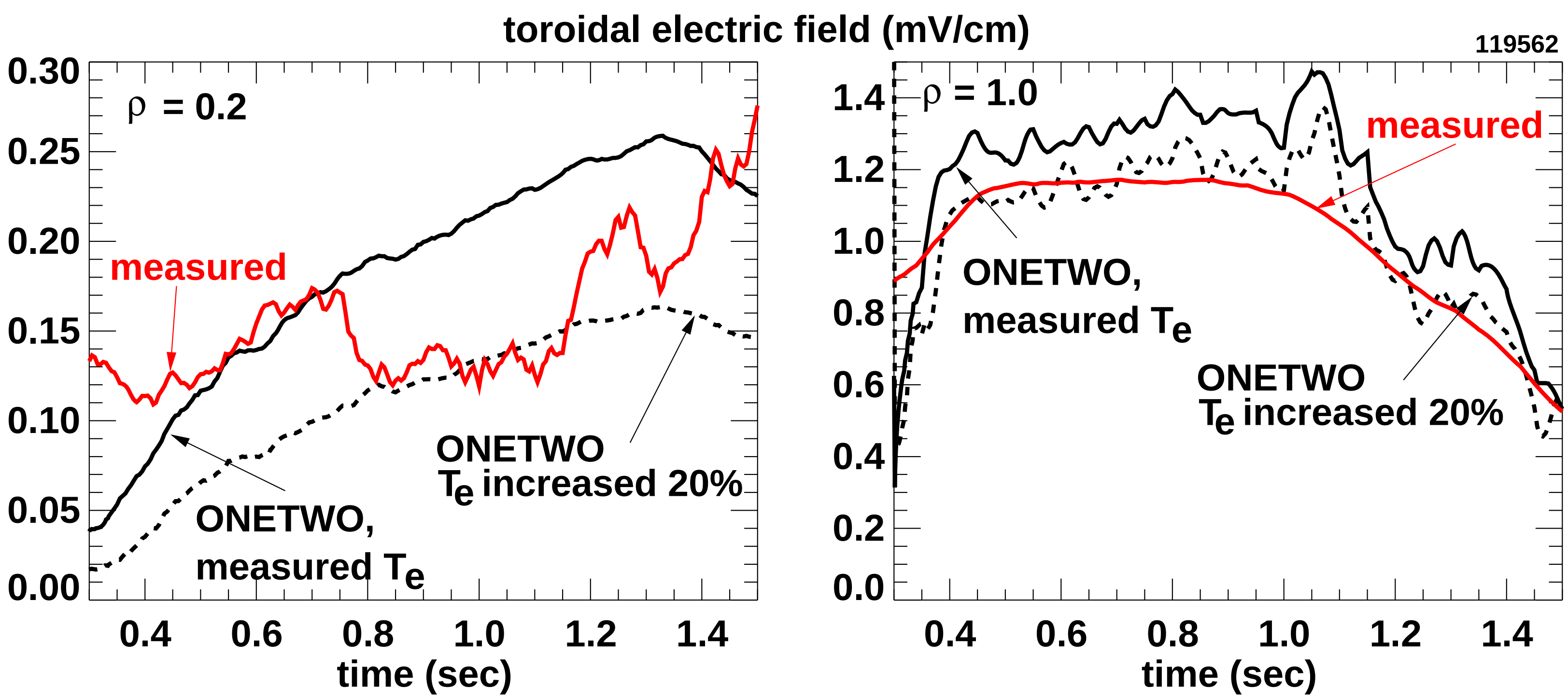
- **I_{NI}/I_{total}<0.5: inductive current evolution dominates**
  - But J_{NI} is large enough to change q profile, particularly as T_e increases
- **Predicted profile of J_{NI} nearly constant in time**
  - No practical means to change the profile to change q

The simulation can reproduce the measured time evolution of the q profile in L-mode discharges with low f_{NI}



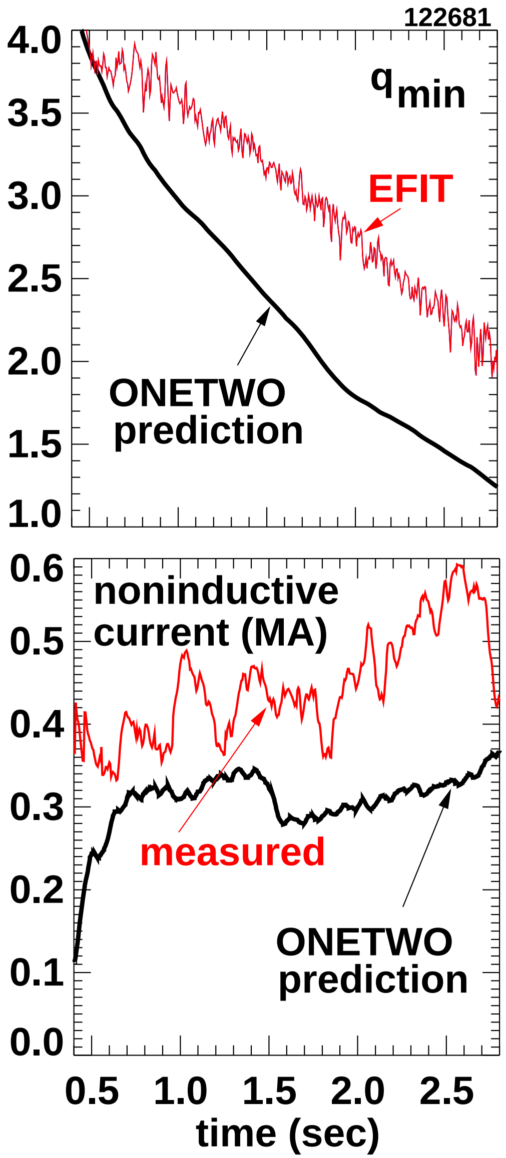
- This example is the lowest T_e case where $f_{NI} = I_{NI}/I_{total}$ is the smallest.
- The two simulations bracket the experimental results

Electric field at the core and boundary show reasonable agreement between simulation and experiment

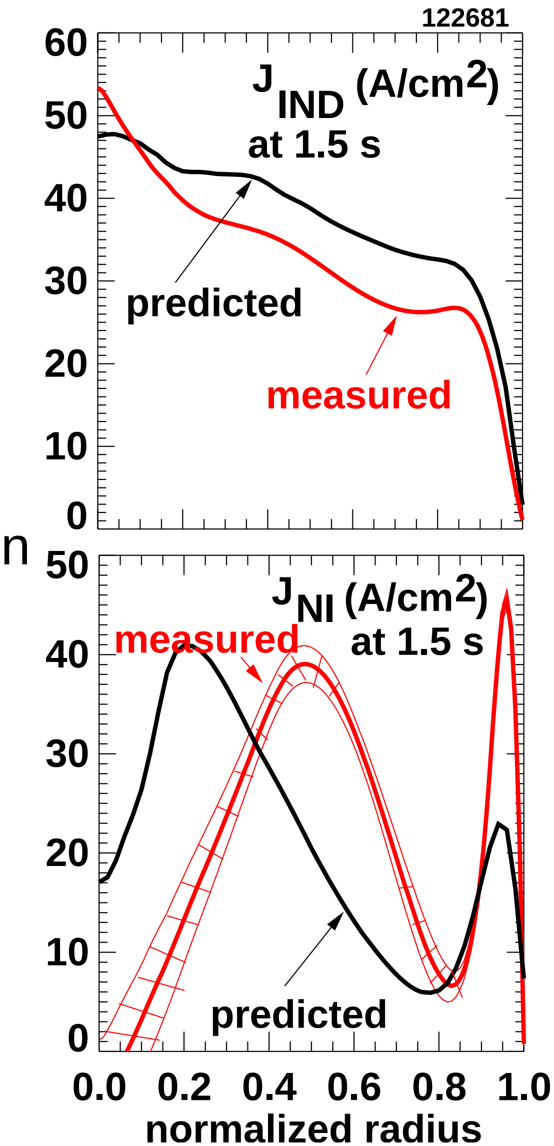


- Rising E in core reflects relaxation of J_{IND} profile
- Predicted E (ρ= 1) above the measured value could indicate either the modeled I_{NI} or the modeled σ is too low

For many H-mode discharges, faster q profile evolution than observed is predicted by the transport code models



- **Predicted inductive current profile shape roughly matches experiment**
  - Predicted J_{IND} is too large
- **Predicted J_{NI} peaks closer to the axis than measured**
  - Predicted I_{NI} is smaller than measured



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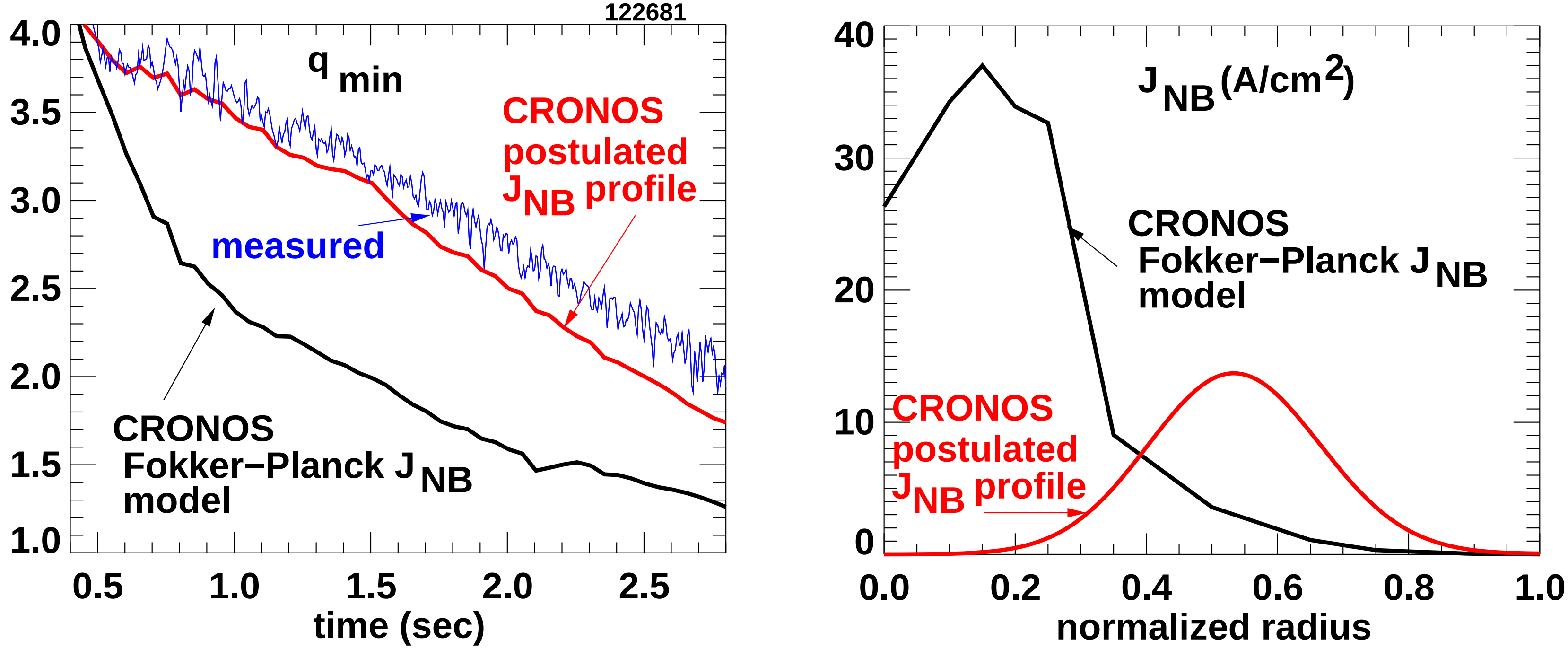
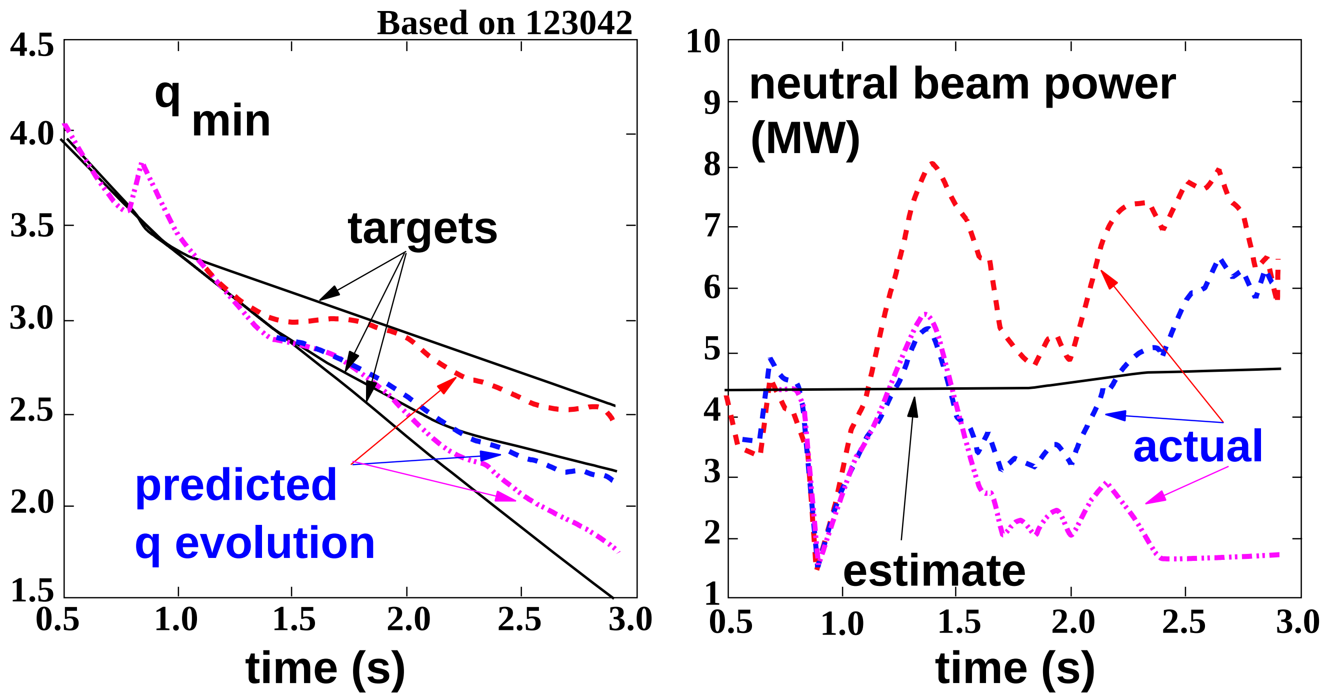
Postulating that the neutral beam-driven current is located off-axis results in a better match to the experiment



- **Total NB-driven current is the same in both simulations**
- **Redistribution of fast ions by Alfvén eigenmodes could possibly result in an altered J_{NB} profile**
  - See VanZeeland BI1.4 and Heidbrink UP1.14 (IAEA EX6-3)

The CRONOS code successfully models the capability of the real time controller to modify the time evolution of q_{min}



- P_{NB} = estimate + gain * (actual q_{min} – target q_{min})
- Time evolution of n_e, T_i, Z_{eff} specified
- T_e profile calculated using an empirical electron heat diffusivity model
- Postulated J_{NB} profile is used

Transport code simulations can be used to test closed loop feedback control of the current profile evolution

- **Code predictions match the experiment when the noninductive current fraction is small**
- **Differences in the J_{NI} profile between the models and experiment remain to be resolved**
  - Code predicts faster q evolution than observed
  - Possibly Alfvén eigenmodes changing J_{NB} profile
- **CRONOS can reproduce the closed loop control of the q evolution that has been implemented in DIII-D experiments**
- **Future plans include model-based current profile control**
  - See GP1.7 by Y. Ou, C. Xu, E. Schuster et al., Lehigh University
  - Simplified model of poloidal flux evolution for controller design
  - Extremum seeking algorithm to predict the actuator waveforms that will take ψ profile from the initial state to a specified final state