

# High $q_{min}$ Steady State Scenario Development Using Off-axis Neutral Beam Injection on DIII-D

by

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with

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# Summary: New Off-Axis NBI Used to Explore the Steady-State Potential of Plasmas With $q_{min} > 2$

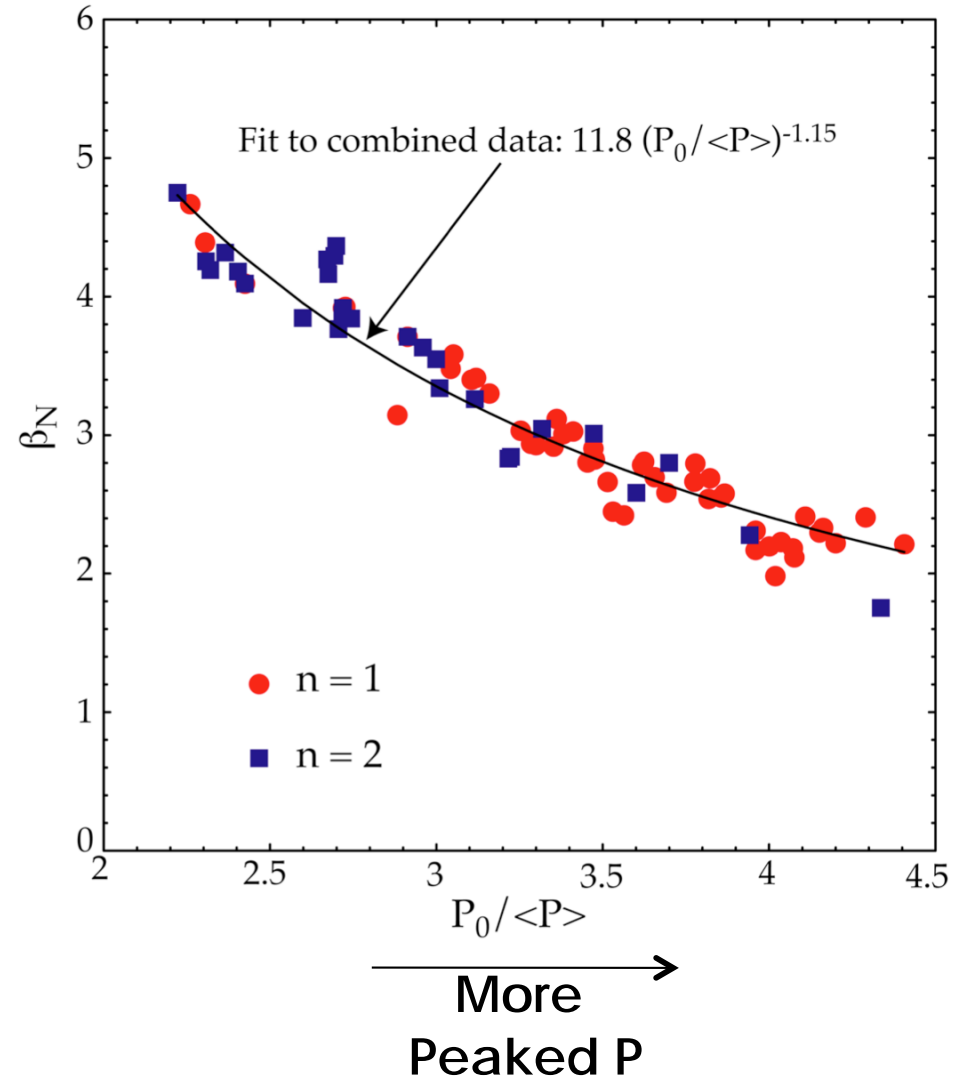
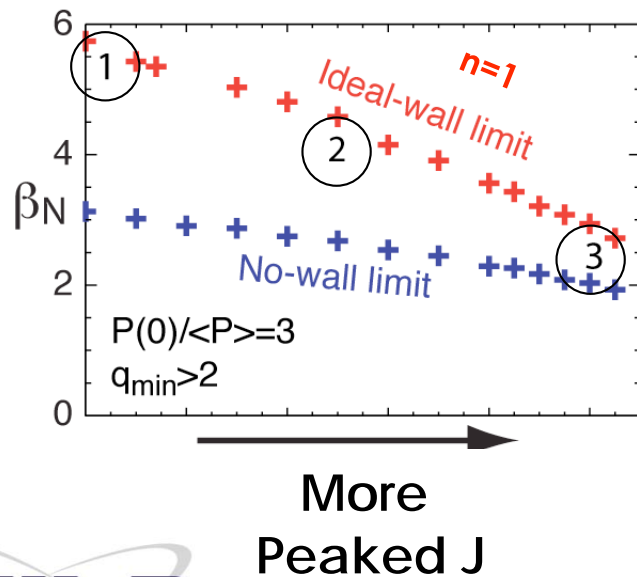
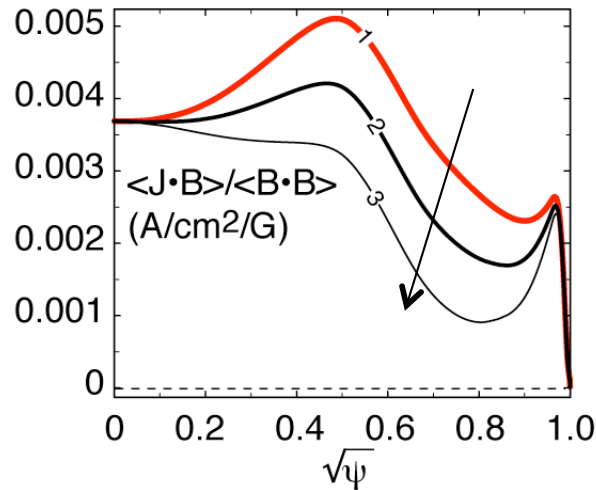
- With off-axis NBI & additional ECH, it is now possible to sustain  $q_{min} > 2$  at high  $\beta_N$
- Plasmas with off-axis NBI have broader current and pressure profiles ( $\rho_{qmin} \approx 0.5$ , and  $P(0)/\langle P \rangle < 3$ )
- Achieved  $\beta_N \approx 3.2$  limited by transport, not stability
- The computed  $n=1$  ideal-wall  $\beta_N$  limits are higher than in similar plasmas without off-axis NBI
- Current evolution with Off-axis NBI is consistent with neoclassical Ohm's Law and standard current drive models

# Motivation: A Steady-State Tokamak Scenario With $q_{min} > 2$ Offers Many Attractive Features

- Avoid 2/1 and 3/2 tearing modes that can limit  $\beta_N$
- Bootstrap current  $\propto q\beta_N$
- Small or negative magnetic shear can reduce transport
- High pressure limits are predicted with broad current and pressure profiles at  $q_{min} > 2$

# Long History of Modeling Showing Broad Current Profiles and Broad Pressure Profiles Raise the Ideal-Wall Stability

## Corsica/DCON Modeling: 2 Separate Studies



# Experiment With Off-Axis NBI & More ECCD Power

## Easily Sustained $q_{min} \approx 2.4$ at Larger $\rho_{qmin}$ & Broader Pressure

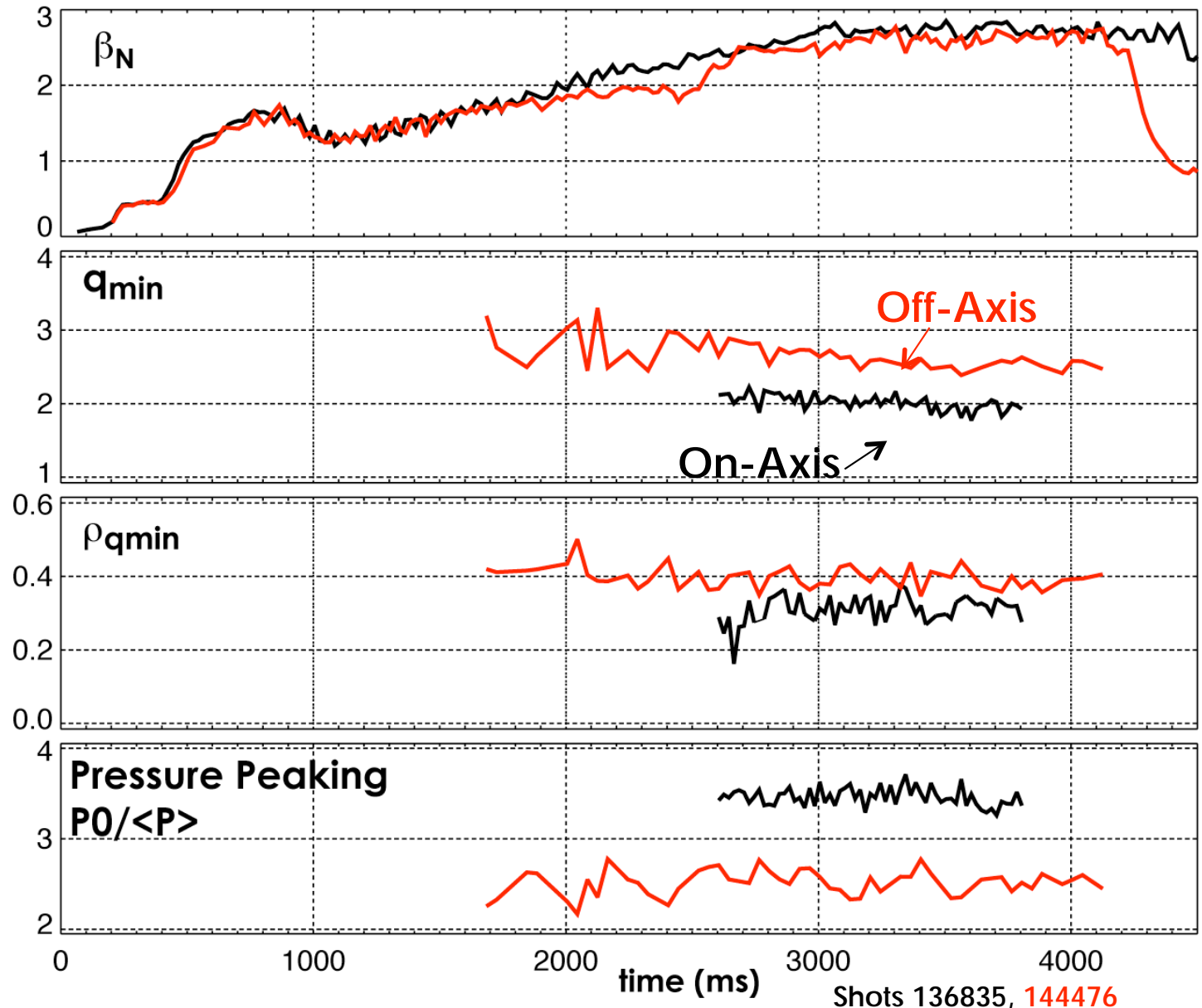
NBI power used to feedback control  $\beta_N \approx 2.7$

Applied power (MW) on/off/ECH

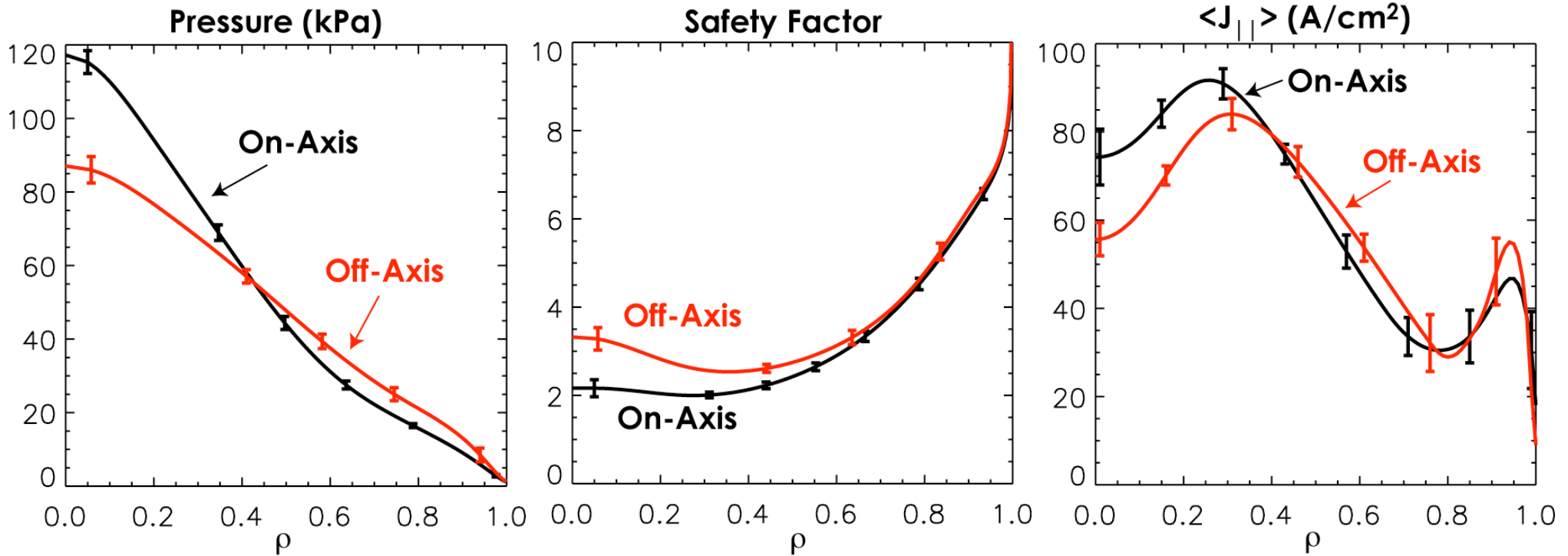
10.2/0/2.25

8.1/2.7/3.35

Off-axis beams in  $\beta_N$  feedback mode from  $t=400$  ms



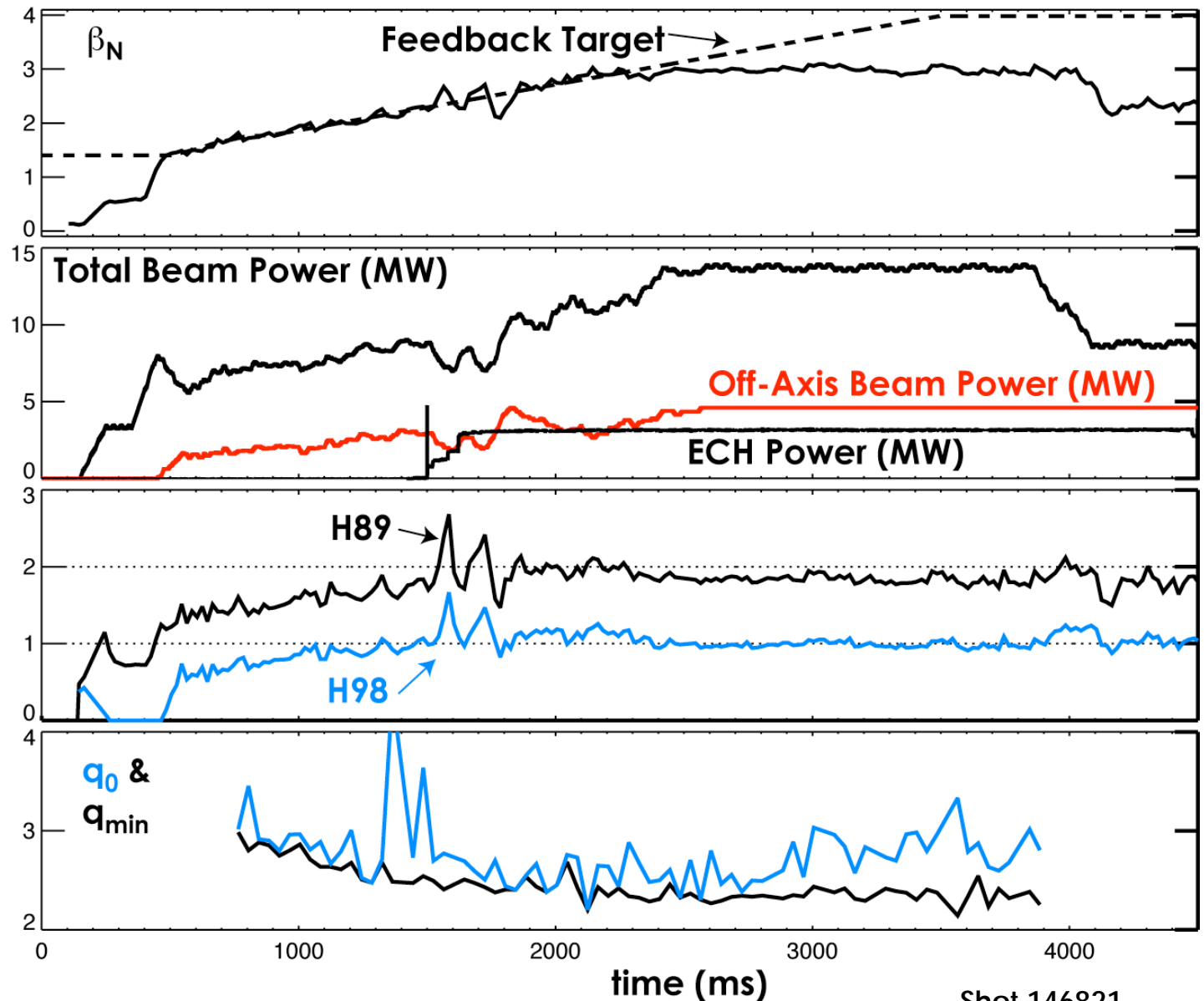
# Time Averaged Pressure, Safety Factor, and Current Profiles in $\beta_N$ Flattop Are Broader With Off-Axis NBI



Shots 136835, 3-3.8 s , 144476, 3.2-4.1 s

# Achieved $\beta_N=3.2$ Limited By Transport, Not Stability

- Ideal instabilities not yet encountered
- Tearing modes sometimes present: 3/1, 7/2, 5/2
- Main reasons for low H-factor not yet understood

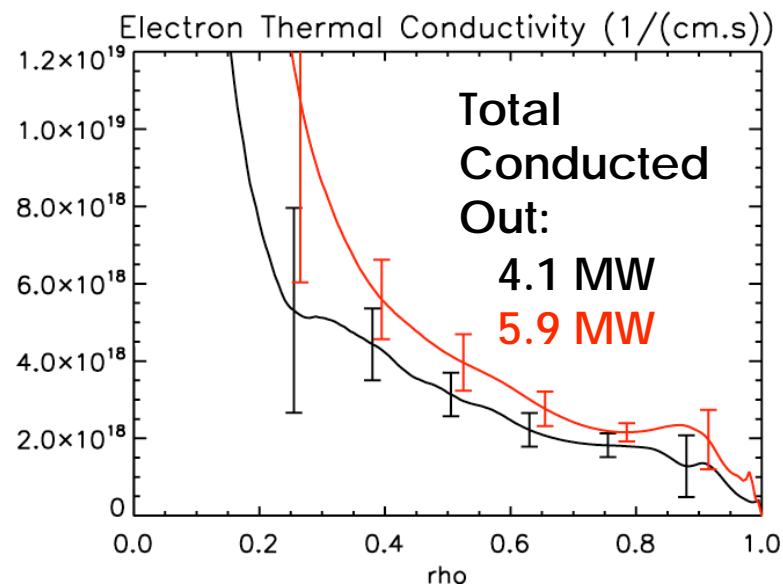
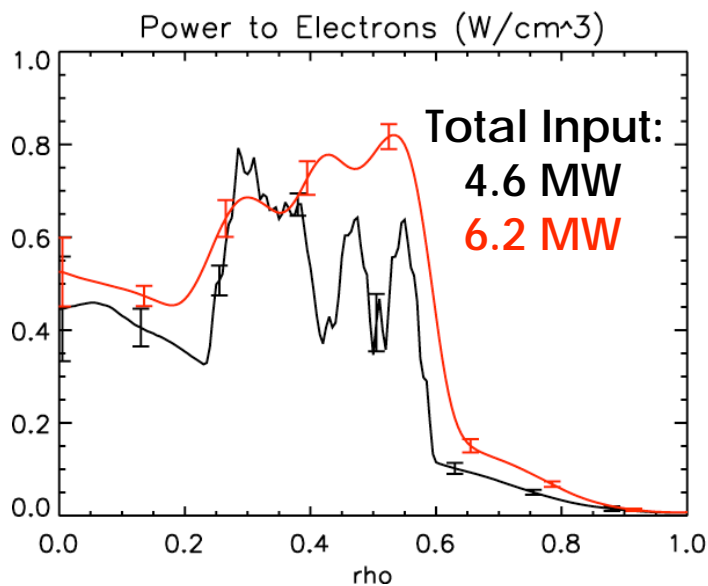
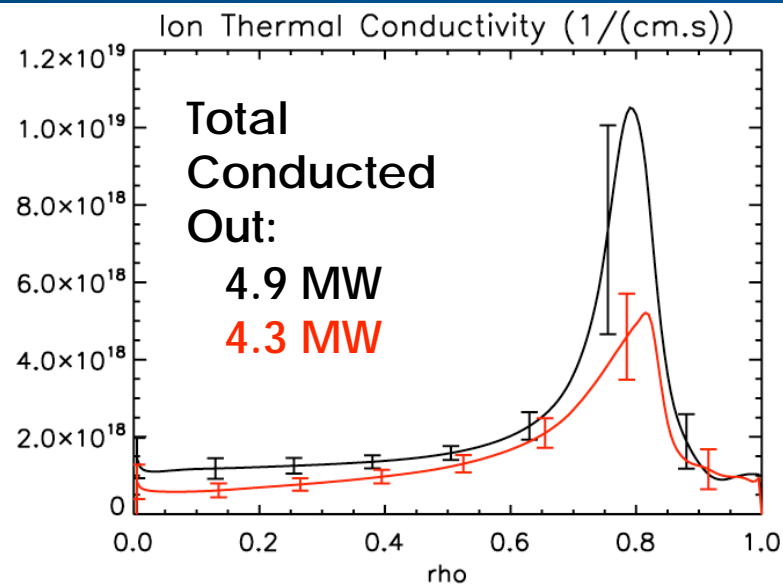
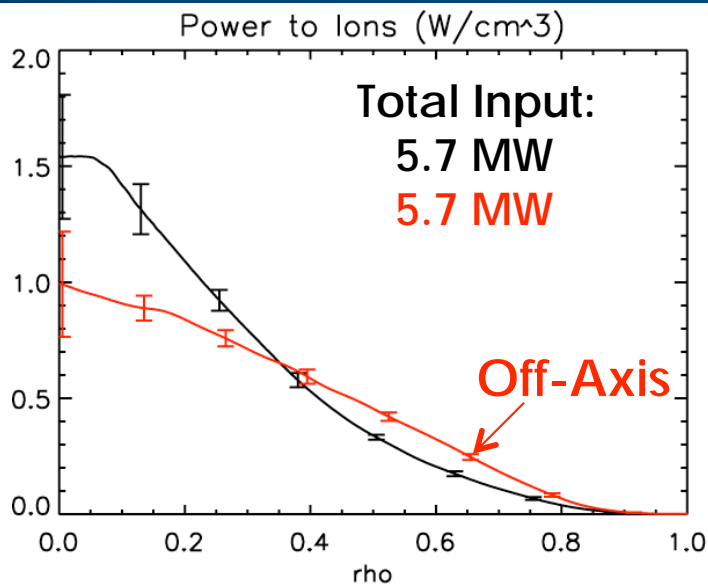


Shot 146821

# Lower $\tau_E$ May be Caused by Putting More Power Off-Axis Without Changing Thermal Conductivity Very Much

\*Work in Progress:

Future systematic experiments needed to address confinement

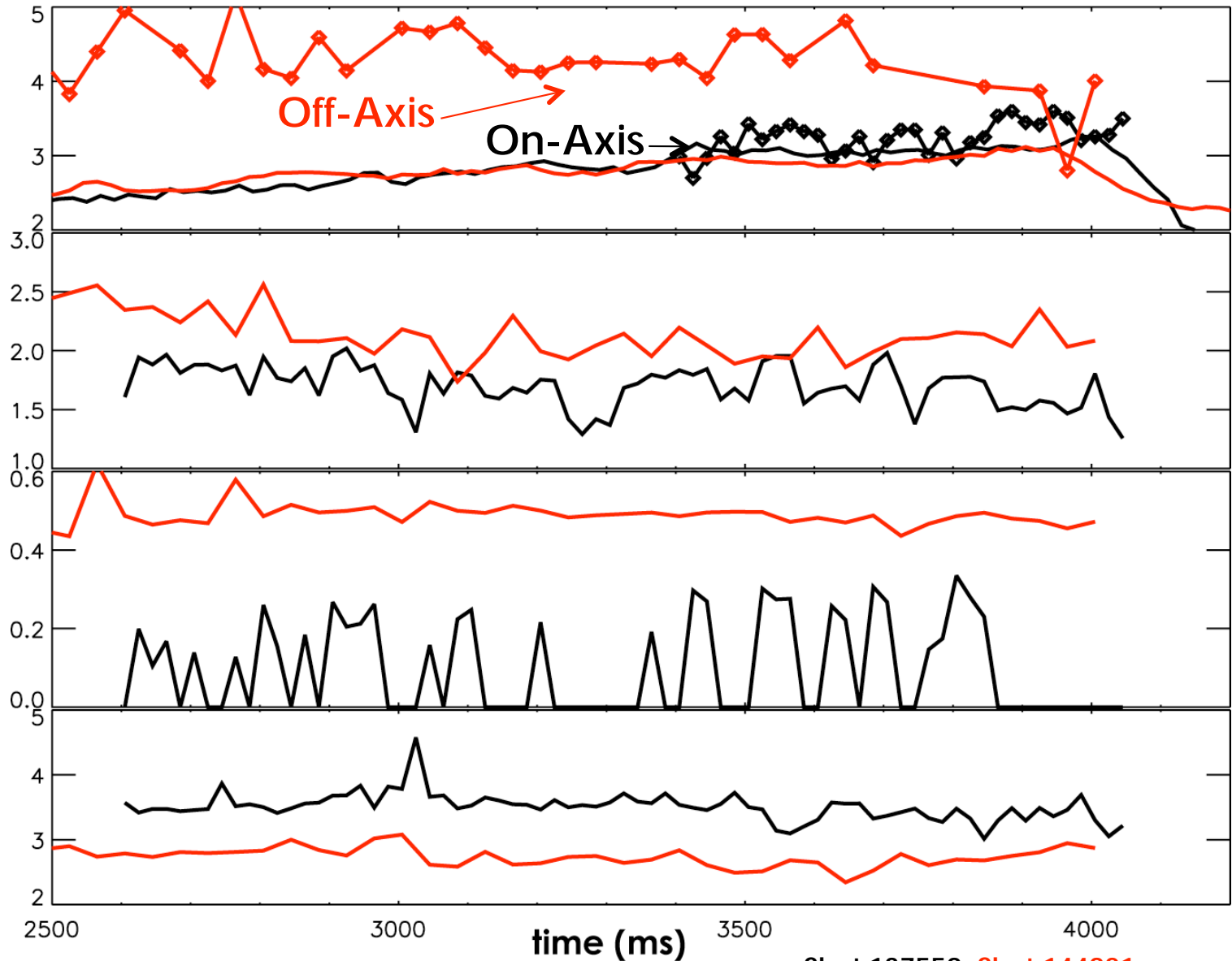


Shots 136835, 3-3.8 s, 144476, 3.2-4.1 s



# Calculated Ideal Wall n=1 Kink Mode $\beta_N$ Limits Have Been Increased by Broadening Profiles Using the Off-Axis NBI

$\beta_N$  and  
Calculated  
n=1 Ideal-Wall  
Limit

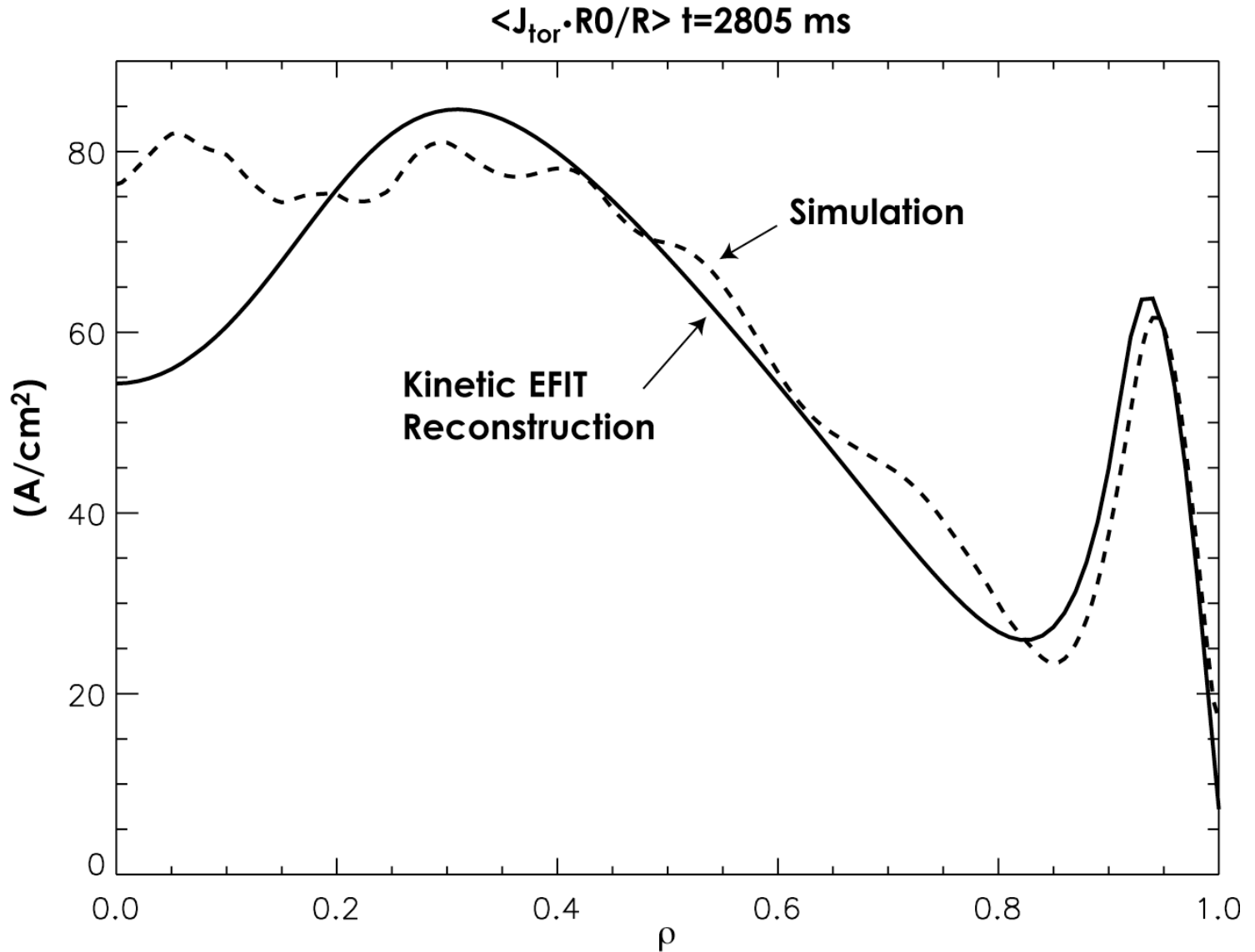


Shot 137559, Shot 144921

# Reconstructed $J(\rho)$ is Consistent With Neoclassical Current Drive for $\rho > 0.2$

ONETWO  $j(\rho)$  simulation launched with experimental initial conditions at  $t=1645$  ms

Agreement is worse after this time when Alfvén eigenmodes may reduce fast ion confinement



Shot 144476

# Summary of Steady-State Scenario Development Using Off-Axis NBI on DIII-D in 2011:

- With off-axis NBI and additional ECH, it is now possible to sustain  $q_{\min} > 2$  at high  $\beta_N$
- Plasmas with off-axis NBI have broader current and pressure profiles ( $\rho_{q\min} \approx 0.5$ , and  $P(0)/\langle P \rangle < 3$ )
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See J. Ferron's Poster on Thursday & F. Turco's Invited Talk on Friday

