# Experimental and Model Validation of ITER Operational Scenarios

T. A. Casper and W.H. Meyer
Lawrence Livermore National Laboratory
G.L. Jackson, D.A. Humphreys, A.W. Hyatt and T.C. Luce General Atomics

50th Annual Meeting of the Division of Plasma Physics
Dallas, Texas

Session PO3 Wednesday, Nov. 19, 2008

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under

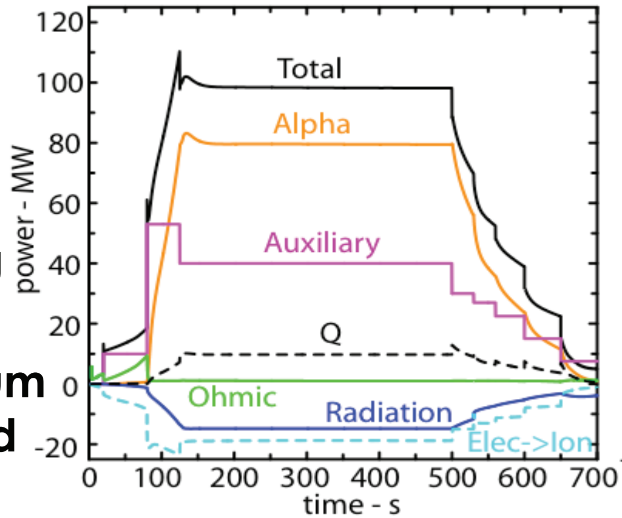
Contract DE-AC52-07NA27344 and DE-FC02-04ER54698(GA)

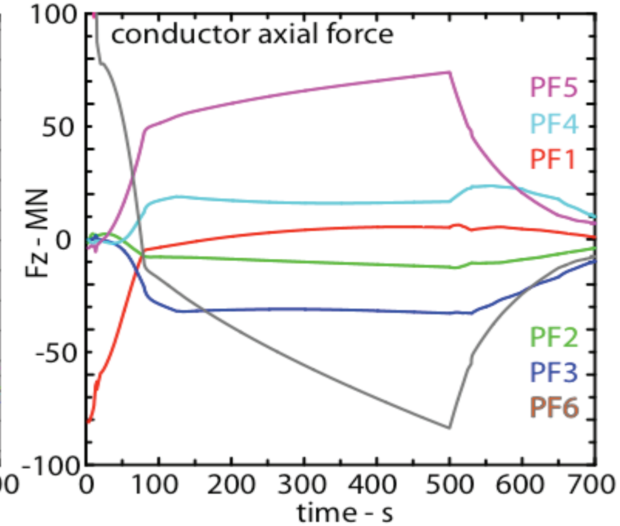
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

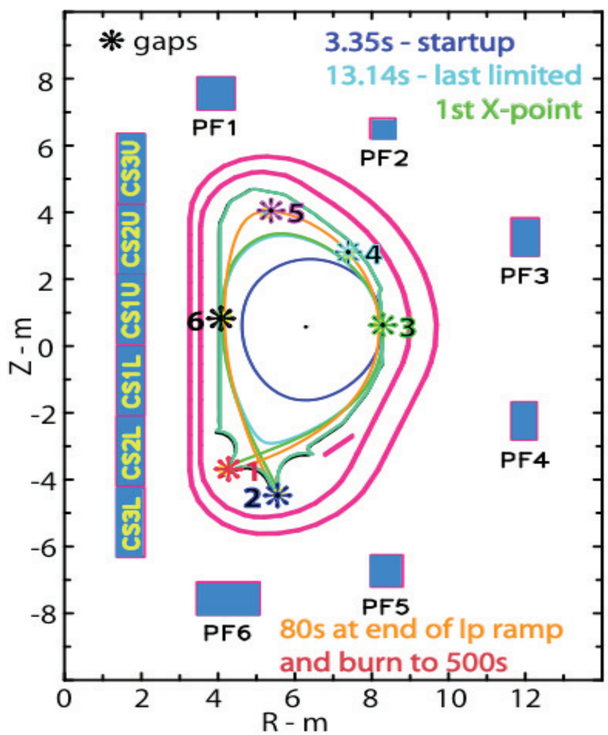
# Simulations demonstrate successful ITER operating scenarios and evaluate engineering constraints and proposed system modifications

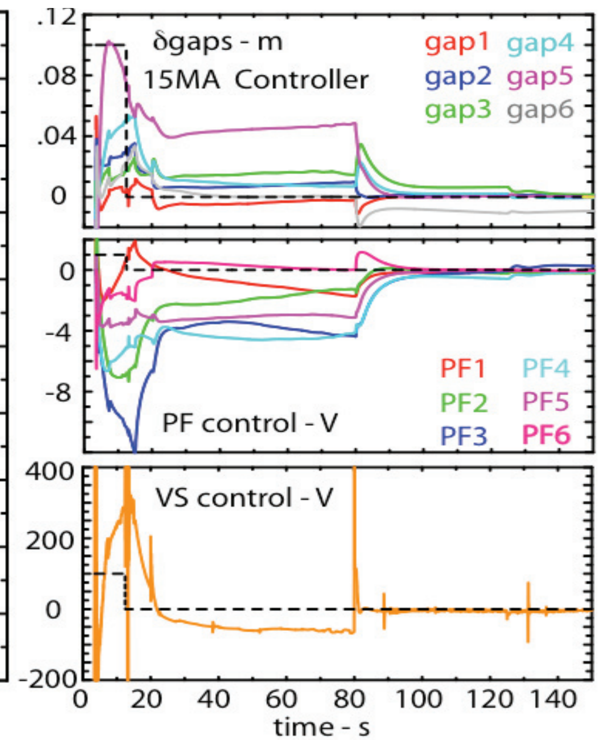
- **700s full discharge simulations**
  - » fast “reduced” models for transport and heating
  - » must explore a wide range of parameters and operating conditions
- **Multiple, free-boundary equilibrium transport codes* simulate forward control**
  - » plasma shape using “gaps” ~ shape error at fixed locations
  - » vertical position (stability)
- **Evaluate ITER operation**
  - » operating space
  - » controller robustness
  - » stability

* C. Kessel, IT/2-3, 22nd IAEA FEC, Geneva, Oct. 2008



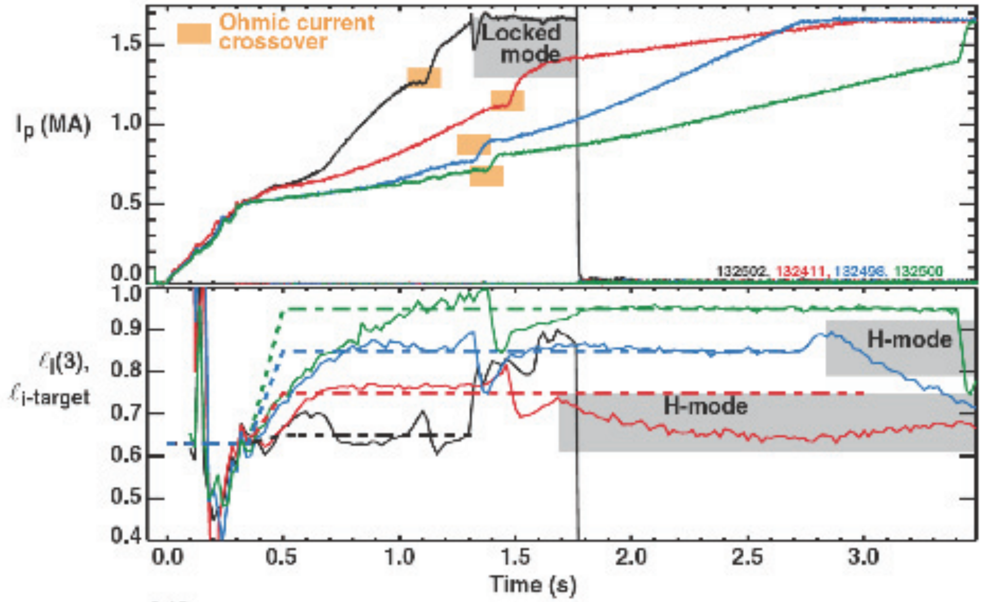



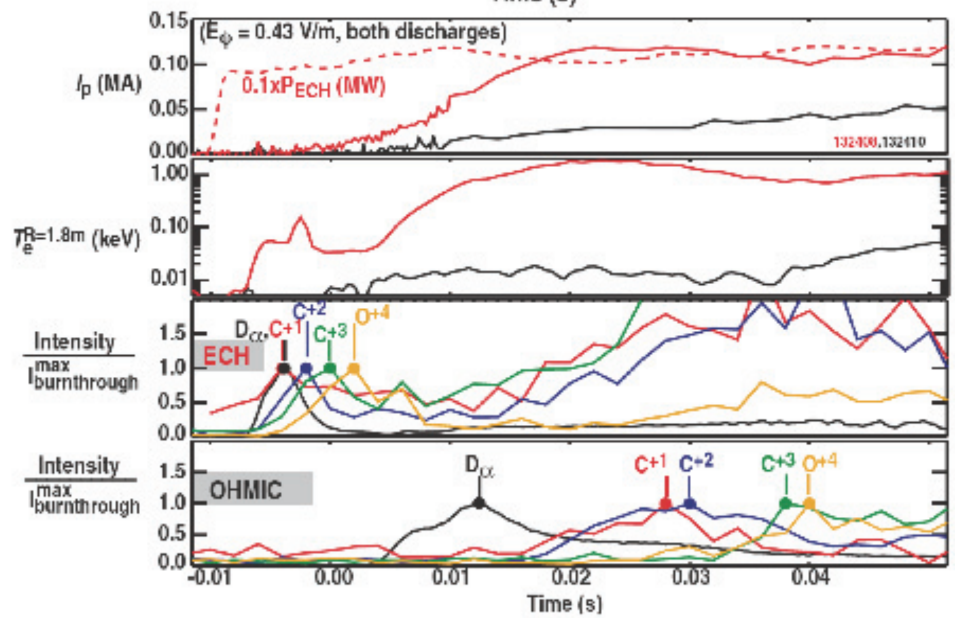



# DIII-D experiments* explore ITER startup scenarios and provide data for benchmarking simulations

- Developed large-bore plasma startup (now ITER standard)
  - » Lower internal inductance ($l_{i3}$) for vertical stability
  - » Reduces Volt-sec demand from coil system
- Demonstrated control of $l_{i3}$
  - » Feedback control of $l_i$ using dIp/dt
  - » Density control while plasma limited
  - » Neutral beam injection
- Electron cyclotron heating improves startup conditions
  - » More consistent breakdown at low voltage
  - » impurity burn through more prompt

*G.L. Jackson, JP6.00082 this meeting and IT/P7-2, 22nd IAEA FEC Geneva, Oct. 2008



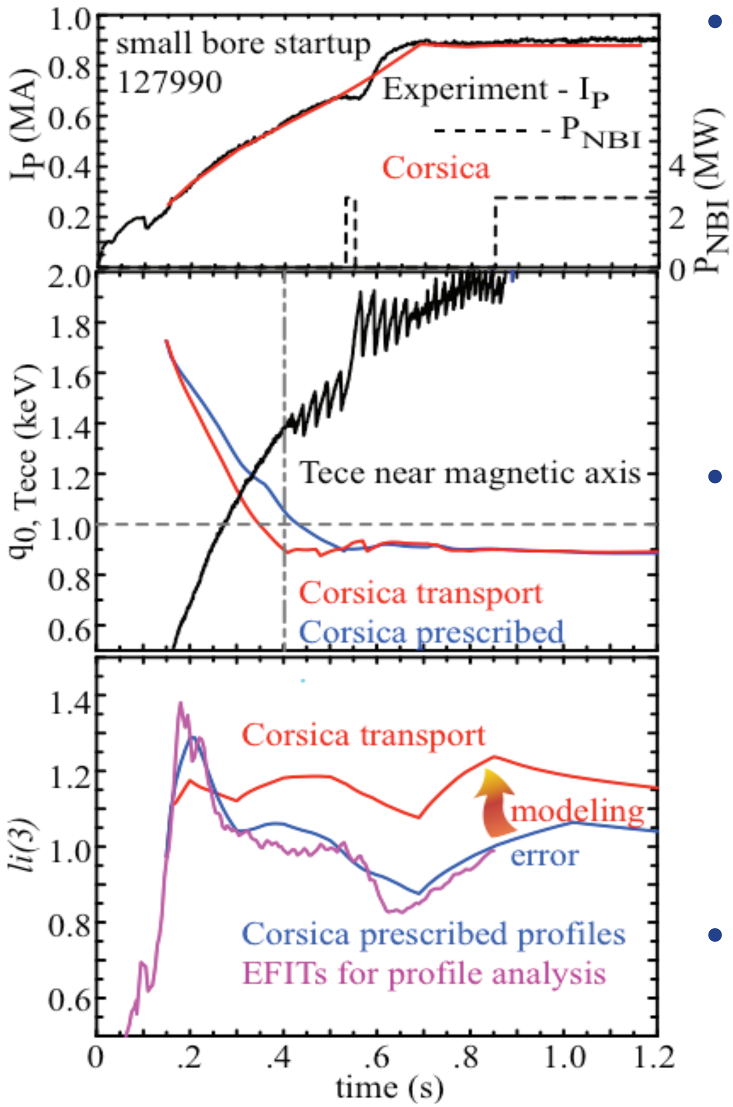

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

# Benchmark consistency of transport simulations with this experimental data Modeling details:

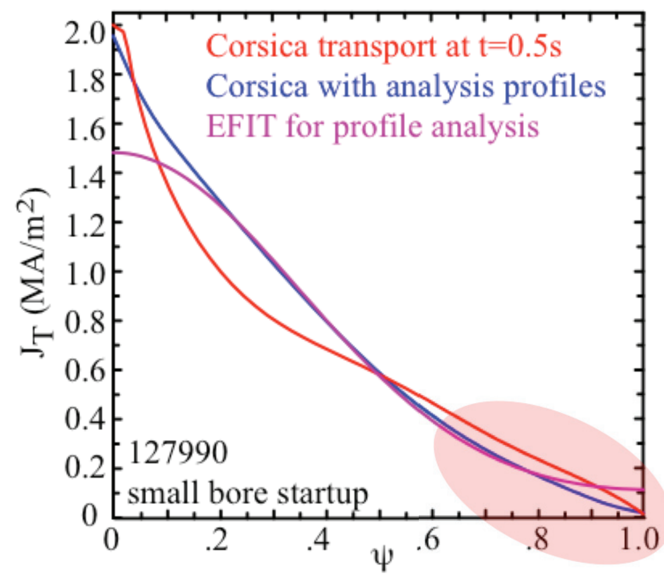
- Two methods for simulations
  - » $T_e(\rho)$ prescribed from measurements benchmarks equilibrium, shape, conductivity and current evolution
  - » $T_e(\rho)$, $T_i(\rho)$ benchmarks the transport model and its effect on conductivity and current profiles as the difference from prescribed profile evolution
- Density profile prescribed
  - » $n_e$ profile from the Thomson Scattering(TS) measurements (interpolated in time)
  - » Assume $n_{carb}/n_{deut}$ ~ .02 ($Z_{eff}$ ~ 1.5) to get ion densities
- No Neutral-beam injection (NBI) during rampup ~ ITER specification of no auxiliary heating while limited
  - » No CER data => no $T_i$ or $n_{imp}$ profiles
  - » No MSE data => no internal current density constraint in EFIT, $q_0$ uncertainty
- Best estimates of equilibrium evolution uses pressure profile measurements in “kinetic” EFIT analysis and Corsica prescribed profile simulations

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

# $l_{i3}$ evolution provides the figure of merit for stability and vertical control and $q_0$ is the predictor of the core current profile



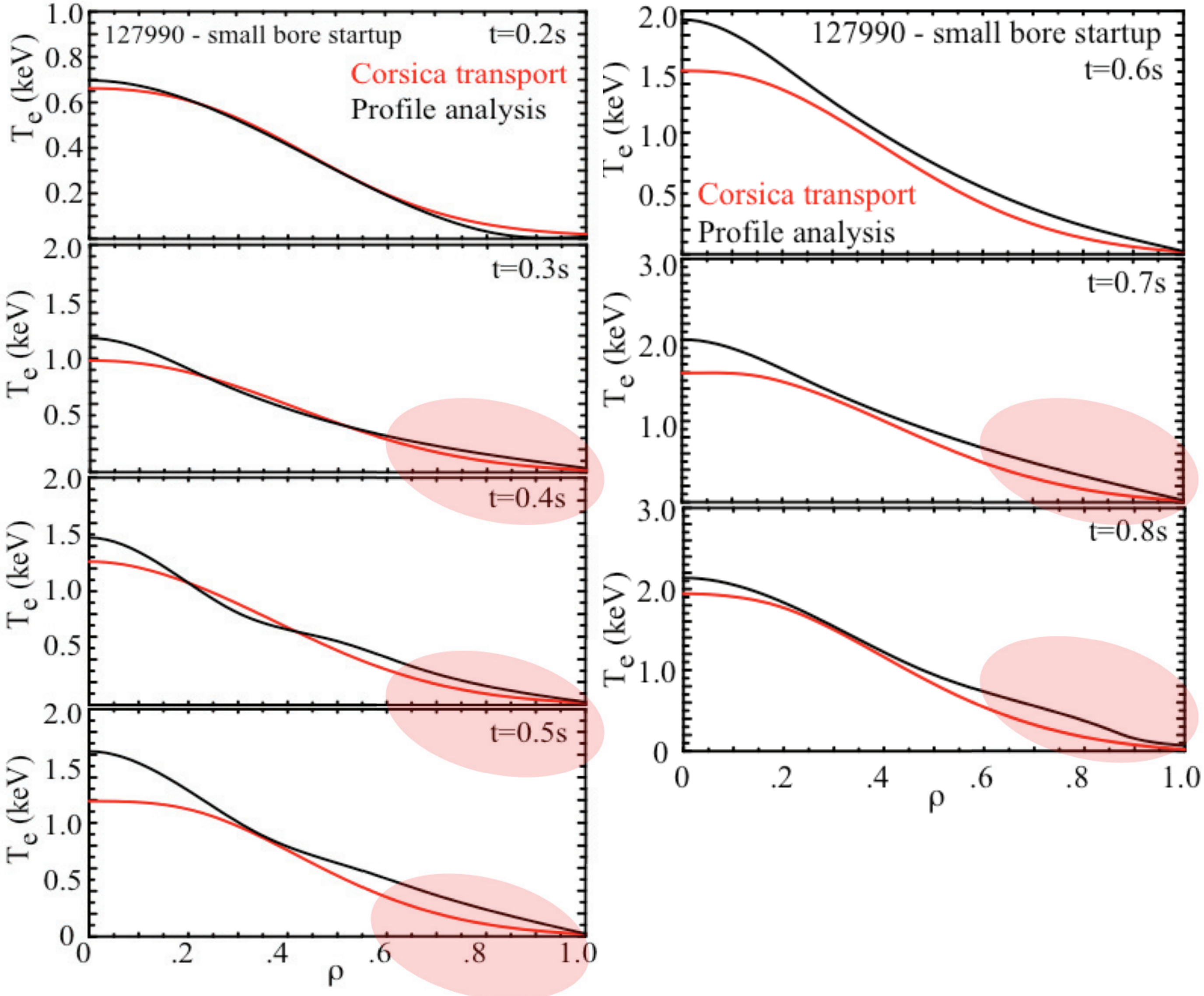

- "Prescribed pressure profile" simulations
  - » use TS $T_e(\rho)$ measurements for pressure ($T_i$~.9$T_e$)
- "Transported pressure profile" simulation
  - » $T_e$, $T_i$ profiles evolved with an L-mode model*
  - » Good Ohmic plasma model chosen for ITER studies
  - » Fast, robust and stable model defined over interval $\rho$ = [0,1] where $\rho$ = sqrt($\phi$)
- For small bore startup conditions, Corsica
  - » predicts time of sawteeth onset at $q_0$=1
  - » prescribed $T_e(\rho)$, $l_{i3}$ consistent with EFIT
  - » transport $T_e(\rho)$, $l_{i3}$ sensitive to details of $J(\rho)$
- Modeling error ~ simulation difference




* W.M. Tang, Nucl. Fusion **26** (1986) 1605.

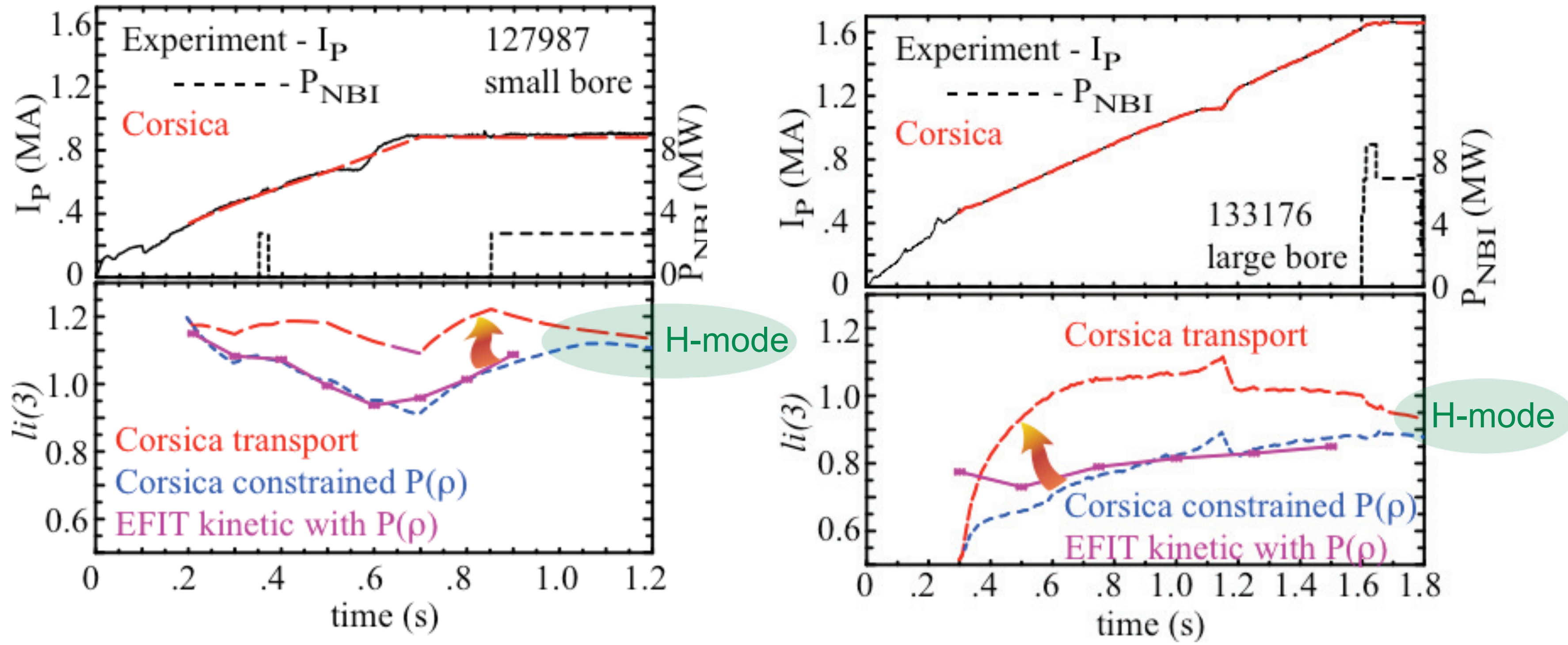
DIII-D NATIONAL FUSION FACILITY SAN DIEGO

# During most of small-bore ramp up, $T_e$ profile from transport remains relatively close to measured profile - transport model reasonably good




- **Simulation**
  - **Starts at t=.15s**
  - **Beam pulse at t=.55s**
- **$T_e$ profile near the magnetic axis results in a current density that predicts $q_0$ evolution**
- **The L-mode model consistently underestimates the $T_e$ at the edge leading to differences in $l_{i3}$**

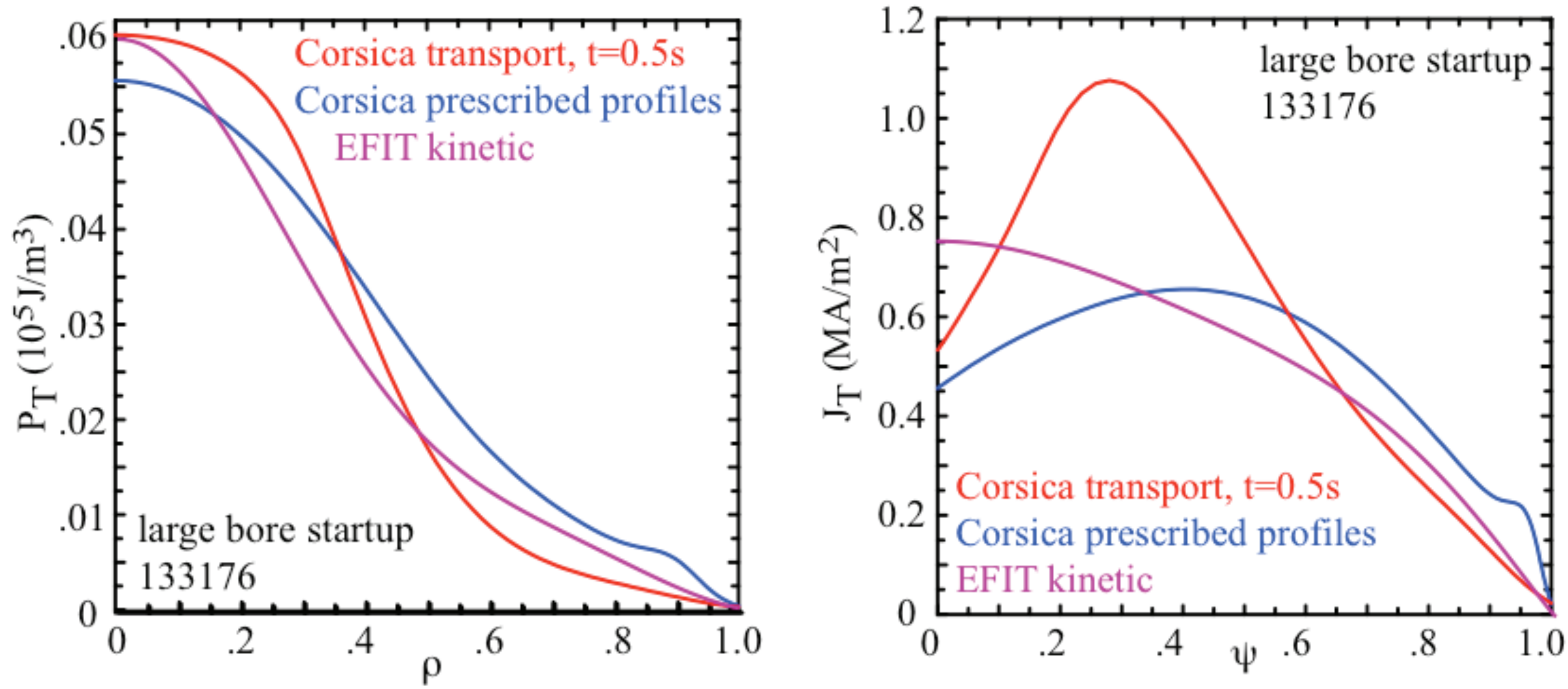
# Simulations with conductivity determined from measurements gives $l_{i3}$ in good agreement with experiments




- $l_{i3}$ **agreement with prescribed profile indicates shaped equilibrium and current distribution correctly evolving**
- $l_{i3}$ **differences with transport result from (small) variations in $T_e$ at large radius nonlinearly altering the current density profile evolution**
- $l_{i3}$ **differences tend to be smaller in H-mode simulations where large edge bootstrap current dominates**

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

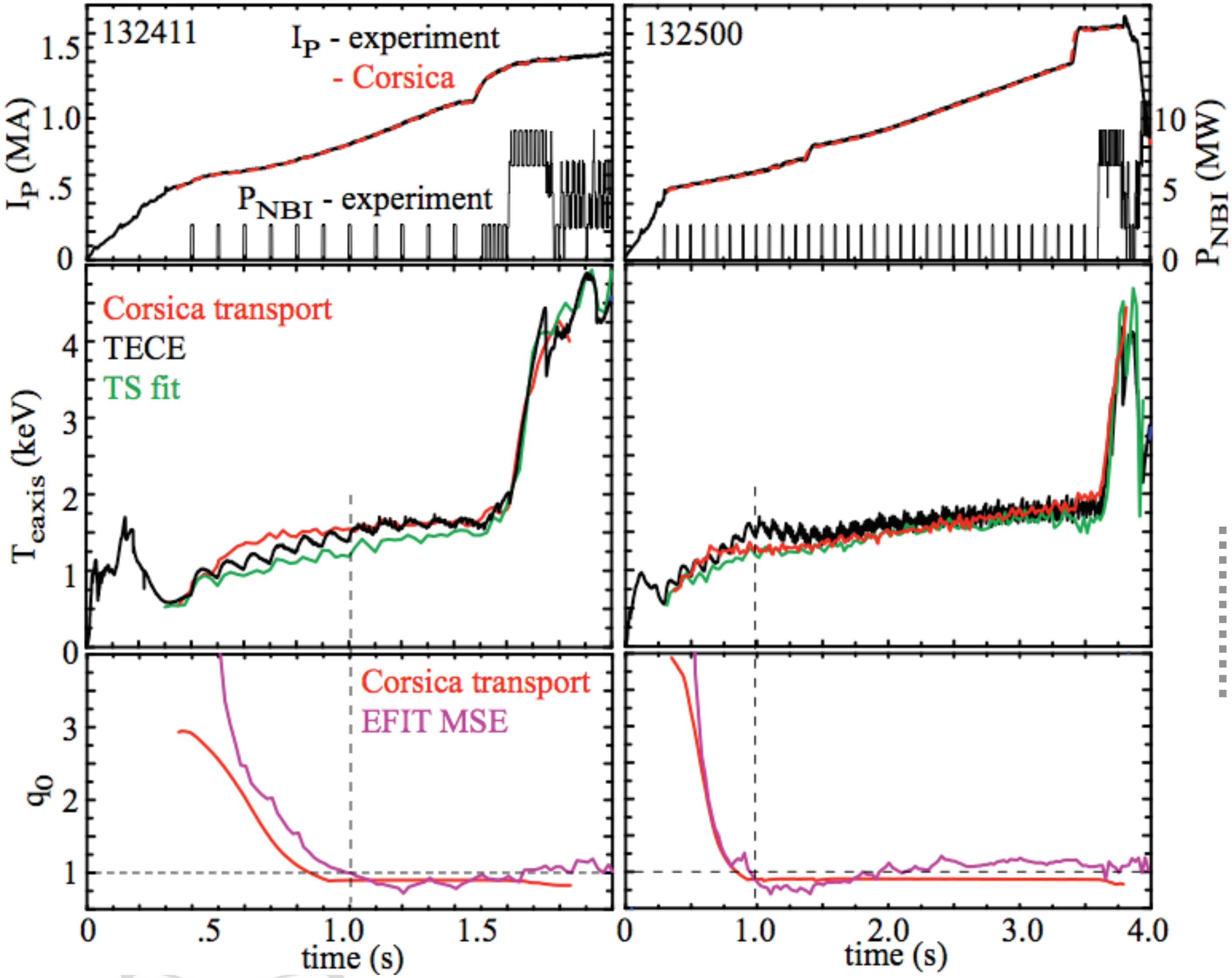
# Large-bore transport simulation current profiles tend to be more peaked than prescribed-profile simulations and EFIT analysis




- **Peaked pressure and current profiles in transport simulations gives highest $l_{i3}$**
- **Current profile from kinetic EFIT similar in width to the prescribed pressure simulations**
- **$l_{i3}$ sensitive to the evolved shape of the current distribution**

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

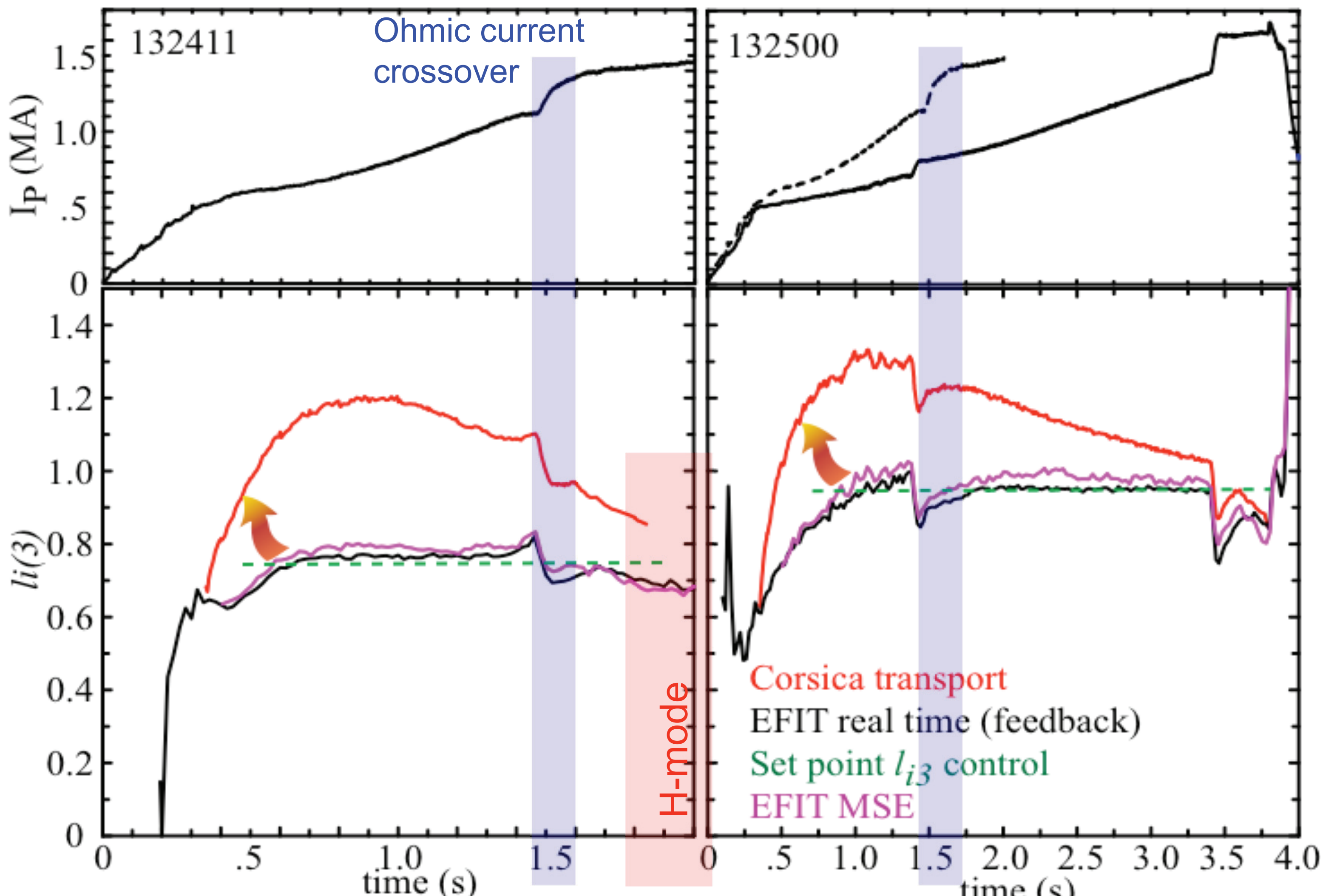
# Transport simulations using current ramp from $l_{i3}$-controlled discharges predict the on-axis $T_e$ and the onset time for sawteeth




- Large bore startup
- open loop simulation: measured $I_p$ from feedback control used
- MSE NBI beam pulses allow EFIT analysis to get $q_0$ evolution from data
- $q_0 \sim 1$ at sawteeth onset from simulations and MSE EFIT
- Beam pulses "modulating" $T_{e0}$ in simulation consistent with experiment

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

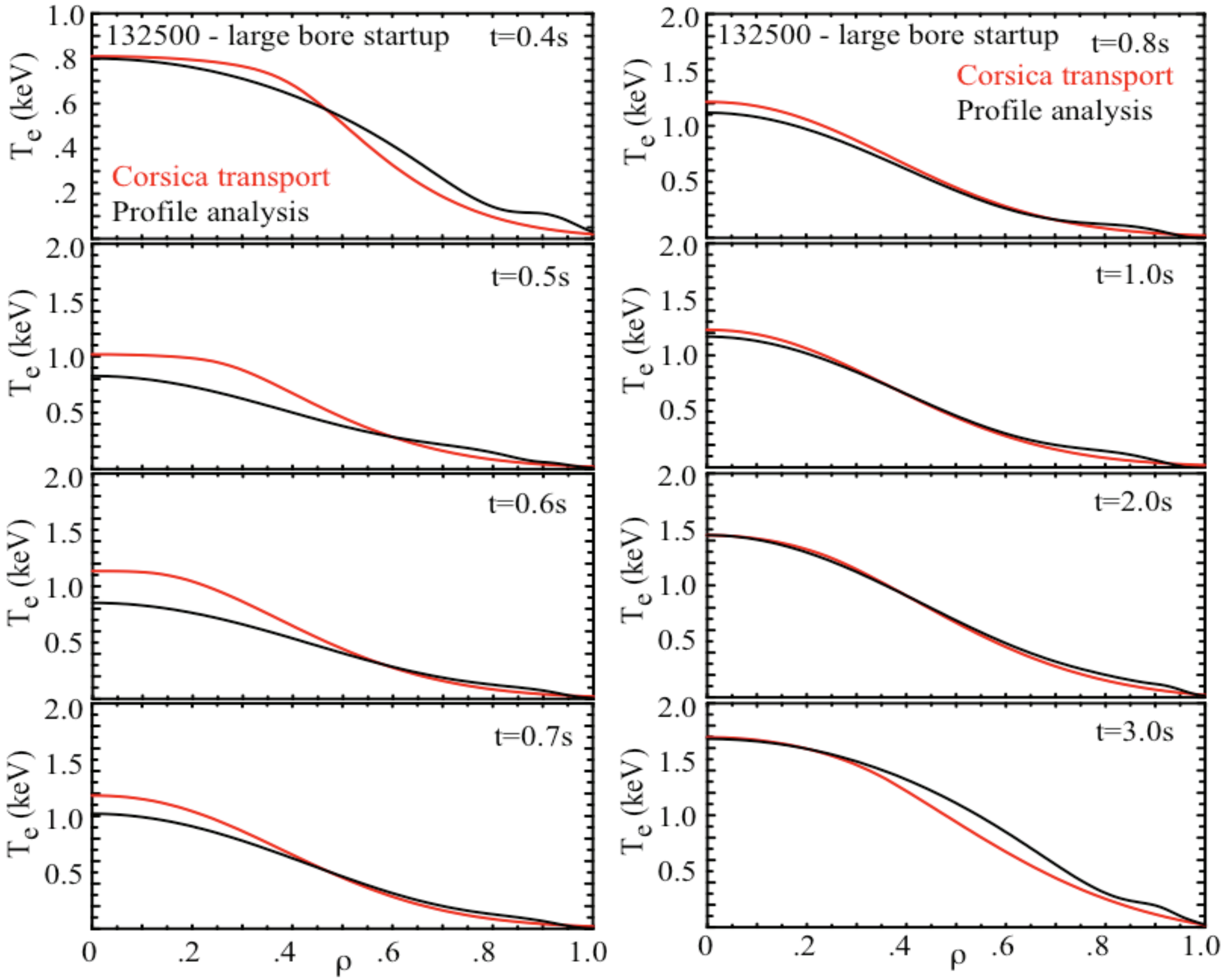
# Transport predictions with L-mode model for $l_i$-control experiments leads to moderate differences between predicted and measured $l_{i3}$




- **Simulations capture temporal variations but tend to over-estimate $l_{i3}$**

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

# For large-bore startup, the transported $T_e$ profiles exhibit a moderate discrepancy early in the current ramp but good agreement later in time




- Simulation starts at t=0.3s
- $T_e$ difference early in the current ramp leads to the difference in $l_{i3}$ evolution
- Need to explore:
  - Different simulation startup methods
  - Boundary conditions at the separatrix
  - Variations in the transport model parameters … but this is fitting

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

# Conclusion and relationship to ITER scenario modeling

- The transport model used in ITER simulations gives a reasonably good prediction for the $T_e(\rho,t)$ in the DIII-D experiments.
- The simulated evolution of $q_0$ is consistent with the onset of sawteeth indicating a good prediction of the current density near the magnetic axis
- While predicted $T_e(\rho,t)$ agrees fairly well with measurements, the current profile evolution as characterized by $l_{i3}$ is significantly affected by modeling differences early in the current ramp
- Since internal inductance is a critical parameter for assessing stability and control, in ITER studies we include a range of parameter variations to scan $l_{i3}$
- Fine-tuning of the transport model to get better $l_{i3}$ agreement is in progress - needs to be verified by data from different experiments

DIII-D NATIONAL FUSION FACILITY SAN DIEGO