

# Center for Simulation of Wave Interactions with MHD (SWIM)

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**Proto-FSP workshop**  
**January 11–13, 2010**  
**ORNL**

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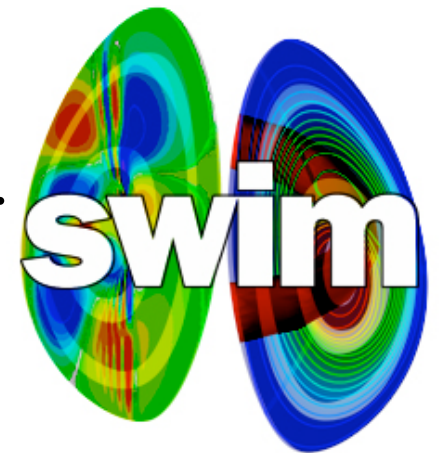
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*See our fun website at:*

[www.cswim.org](http://www.cswim.org)



# The scientific rationale for SWIM is based on two simple experimental observations

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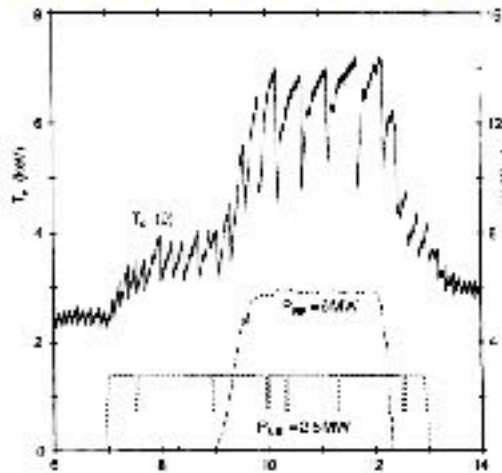
**Macroscopic instabilities can limit plasma performance in fusion devices – modeled by extended MHD**

**RF waves can mitigate and control instabilities – sometimes producing instability, sometimes reducing or eliminating instability**

- **Understanding and predicting the effects of RF waves on plasma stability would have significant scientific and economic benefits**
  - **A major element of the coupling between RF and plasma stability is the effect that RF (and other sources of energy and particles) has on plasma equilibrium, thermal plasma profiles and non-thermal particle distributions**
- ⇒ There is a natural synergy between understanding RF/MHD interaction and improving the modeling capability of tokamak core plasma, including all source and transport effects:**

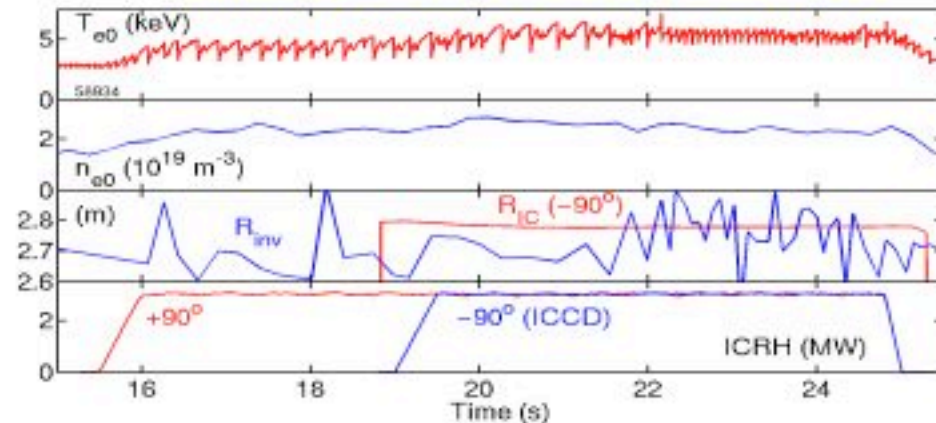
# There are several experimentally demonstrated mechanisms by which RF waves can control the “sawtooth” instability

## ICRF stabilization on JET



- ICRF heating can produce “monster” sawteeth – period and amplitude increased
- Likely stabilization mechanism – energetic particle production by RF

## Sawtooth control with Minority Current Drive on JET

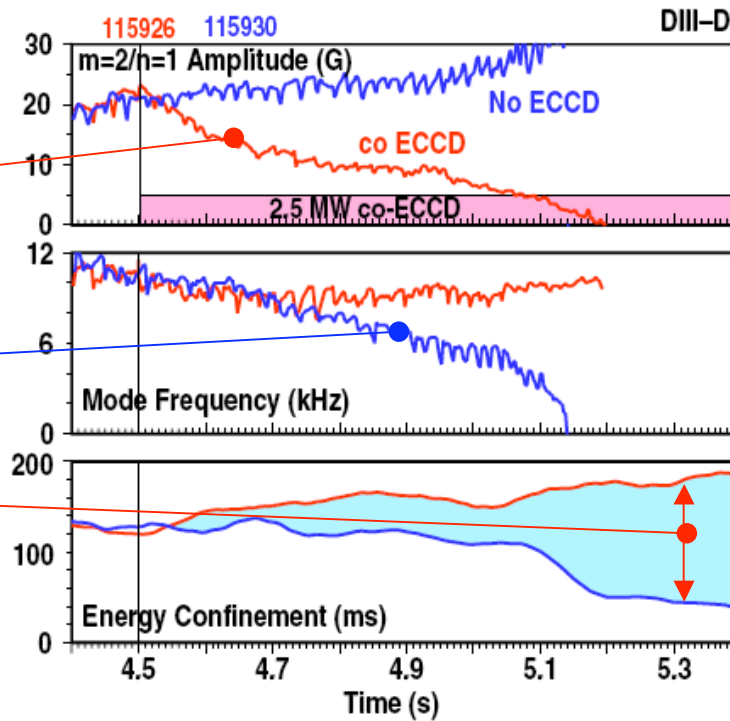


- ICRF minority current drive can either increase or decrease period and amplitude
- Likely stabilization/destabilization mechanism – RF modification of current profile

- Sawteeth can limit plasma performance themselves, or can trigger other instabilities – disruptions, neoclassical tearing modes
- Many physics processes interact – *qualitative* understanding exists but *quantitative* verification and *prediction* is lacking

# Suppression of “neoclassical tearing modes” (NTM) by RF leads to improvement in confinement

- Electron cyclotron current drive drives down mode amplitude
- keeps mode rotating (no drop in frequency)
- improves energy confinement



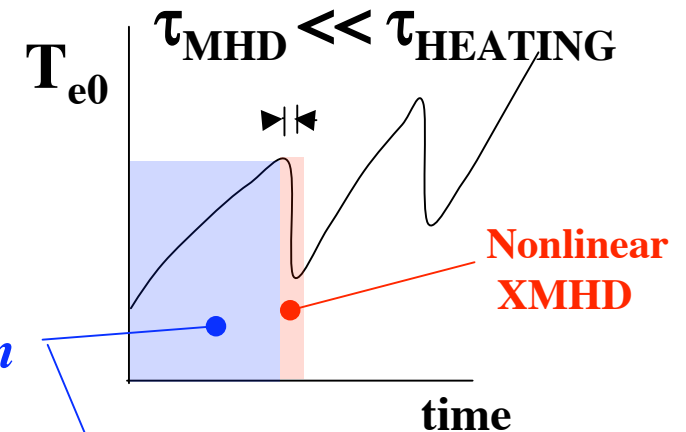
R. Prater  
APS 2003

- Empirical scaling of NTM pressure limits in ITER leave little margin in performance
- “Understanding the physics of neoclassical island modes and finding means for their avoidance or for limiting their impact on plasma performance are therefore important issues for reactor tokamks and ITER” – ITER Physics Basis (1999)

# The SWIM project is carried out in two physics campaigns distinguished by the time scale of unstable MHD motion

## Fast MHD phenomena – separation of time scales

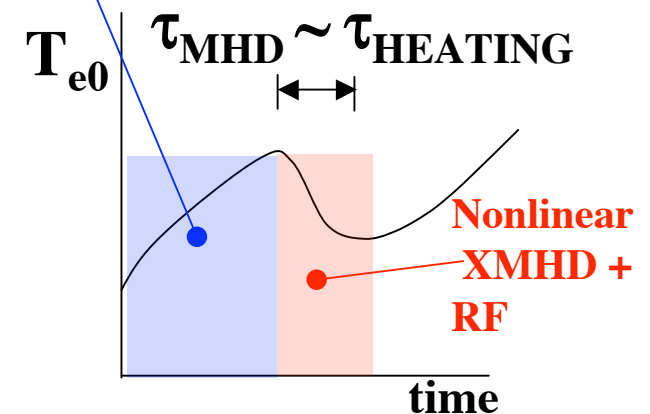
- Response of plasma to RF much slower than fast MHD motion – transport time-scale
- RF drives slow plasma evolution, sets initial conditions for fast MHD event
- Example: sawtooth crash



*Slow plasma evolution*

## Slow MHD phenomena – no separation of time scales

- RF affects dynamics of MHD events  $\Leftrightarrow$  MHD modifications affect RF drive plasma evolution
- Deals with multi-scale issue of parallel kinetic closure including RF (mainly ECRH)
- Example: Neoclassical Tearing Mode



## Software infrastructure: Integrated Plasma Simulator (IPS)

A flexible, extensible computational framework capable of coupling state-of-the-art models for energy and particle sources, transport, and stability for tokamak core plasma

## Project goals

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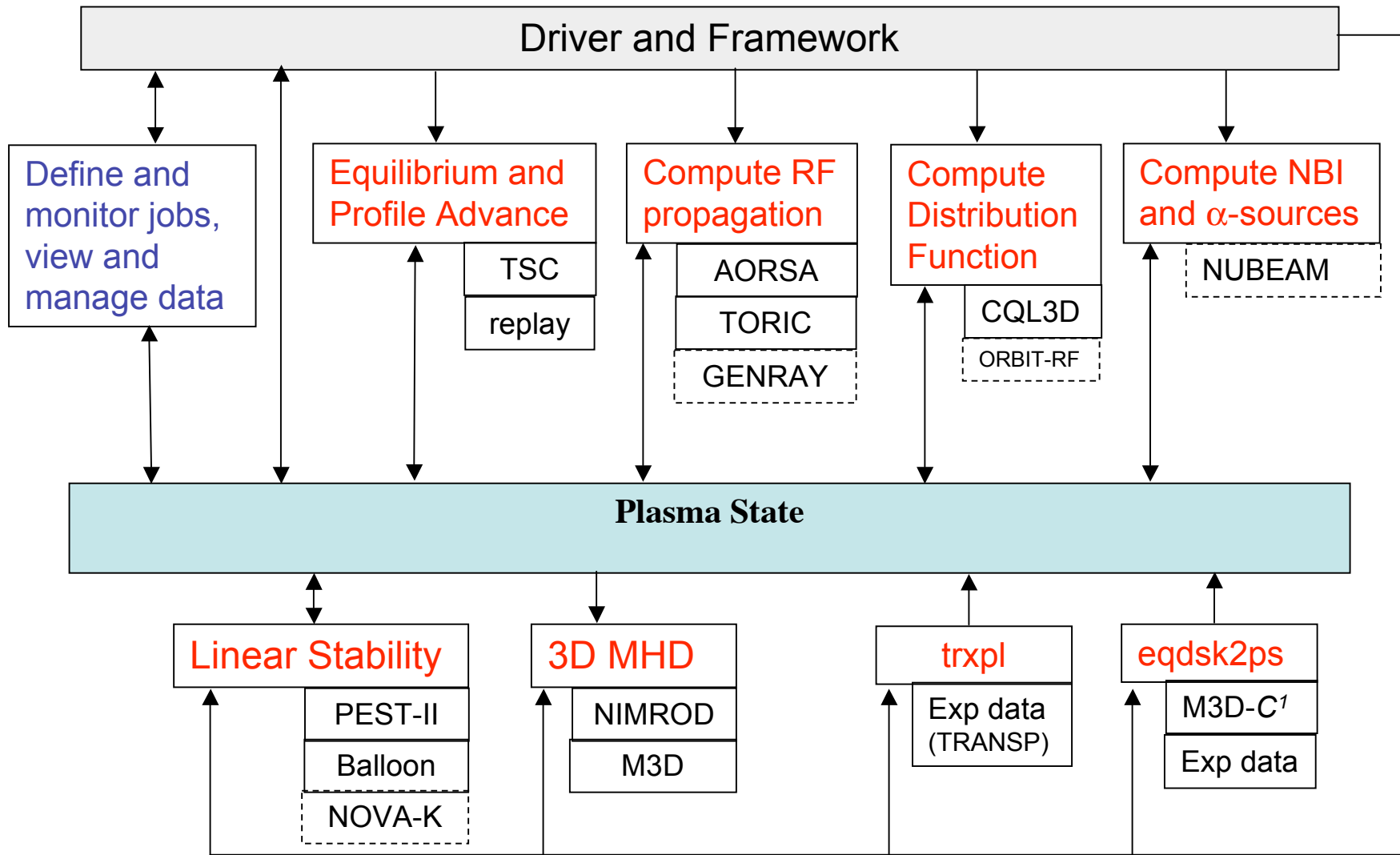
- **Develop IPS so that it provides a computational environment satisfying the SWIM project's needs for concurrency, performance, and data management and is the tool of choice for those performing tokamak simulations**
- **Demonstrate capability of the SWIM system to address important questions of sawtooth instability behavior and their control by RF (Fast MHD campaign)**
- **Complete the coupling of ECCD, non-linear MHD and kinetic closure for study of RF stabilization of Neoclassical Tearing Modes (NTM) (Slow MHD campaign) and performed numerical simulations comparing with NTM experiments**
- **Provide a base of experience with framework/component architecture applied to integrated fusion simulation that can be factored into the design of a larger scale Fusion Simulation Project.**

# IPS Design Approach

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- **Framework/component architecture**
  - **Effective division of labor** – multiple groups can work independently, if they respect the interface
  - **Flexibility** – multiple codes can implement components interchangeably
  - **Extensibility** – easy to add components to framework
- **Components implemented using existing whole codes wrapped in standard interface (→ single executable later)**
  - **Rapid deployment** – minimize changes to physics codes to adapt
  - **Avoid bifurcation of physics modules** – not different SWIM/stand-alone versions
  - **Ease of system debugging**
- **File-based communication (→ in-memory data exchange now also)**
  - **Zero change to physics code** – use existing I/O file structures
  - **Avoid name-space/compiler/library incompatibilities between components**
- **Plasma State: official transfer mechanism for time-evolving data that must be transferred between components**
- **Target MPP computers from the start**

# The IPS is based on a framework/component model using well-validated fusion physics codes



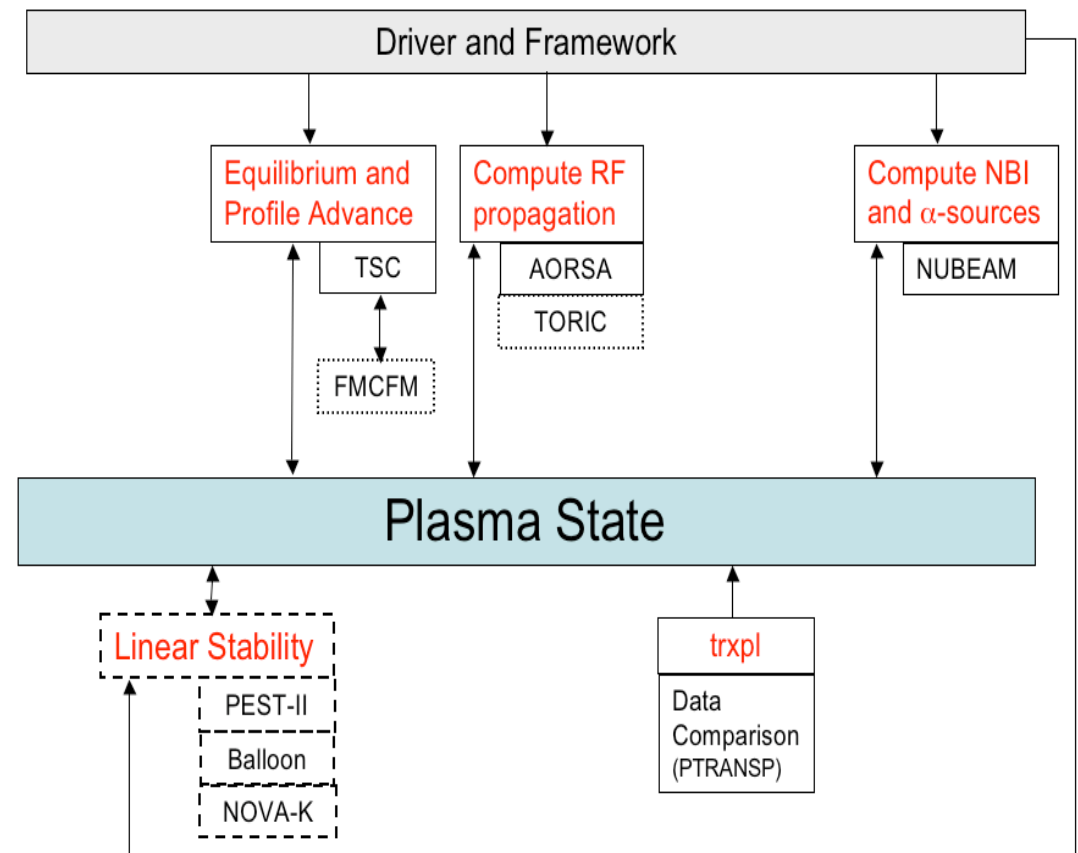
**Near term goal: demonstrating the capability to use massively-parallel computers to greatly accelerate the integrated simulation process for ITER, while also improving the level of physics fidelity of the simulations.**

**Coupling of TSC (Free-Boundary Equilibrium and Profile Advance)**

**AORSA (massively parallel RF Ion Cyclotron solver) - 256x256 poloidal Fourier modes**

**TORIC (semi-spectral ICRF solver) – 149 poloidal modes, 409 radial nodes**

**NUBEAM (parallel neutral beam injection) – 1,000,000 Monte Carlo particles**



# We are now carrying out simulations of the ITER device in a few days with high levels of levels of physics resolution

IPS simulation – *1 day running time*

TSC – GLF23 transport

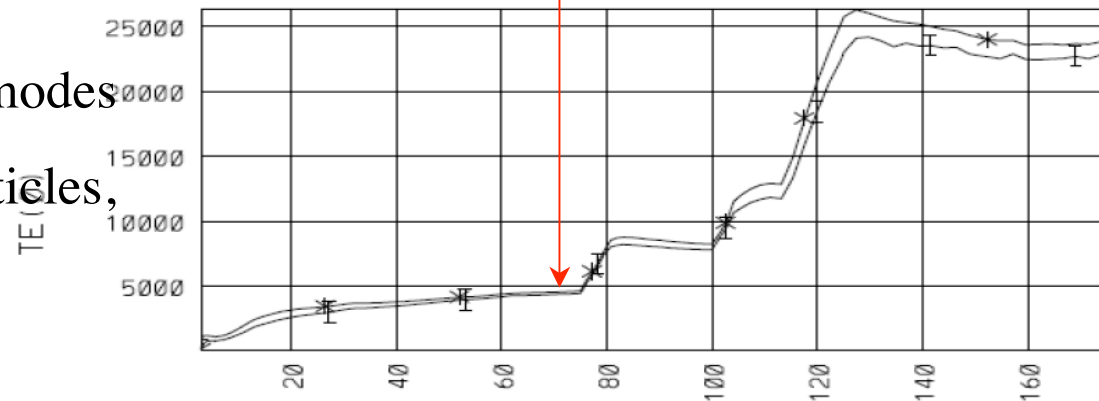
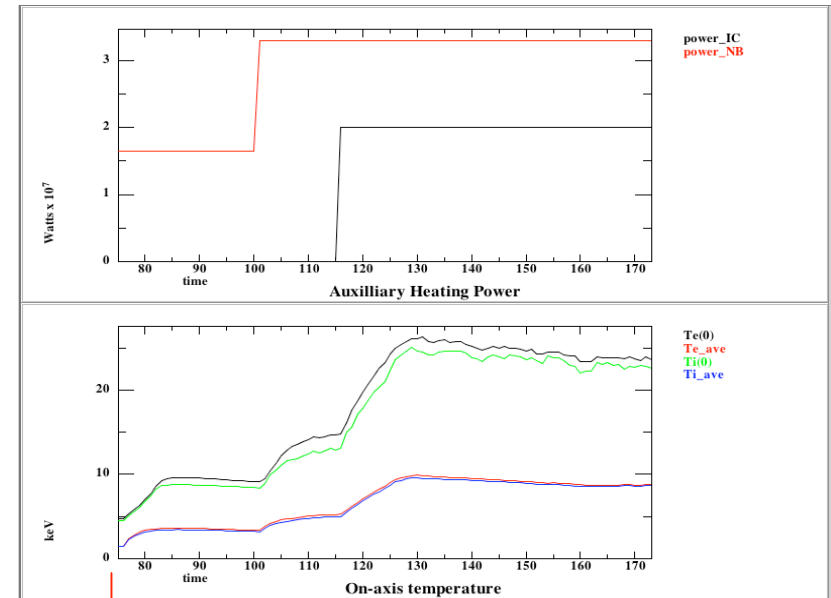
parallel AORSA – 256×256 (R, Z modes)

parallel nubeam –  $10^6$  NBI particles,  
 $10^6$  fusion particles

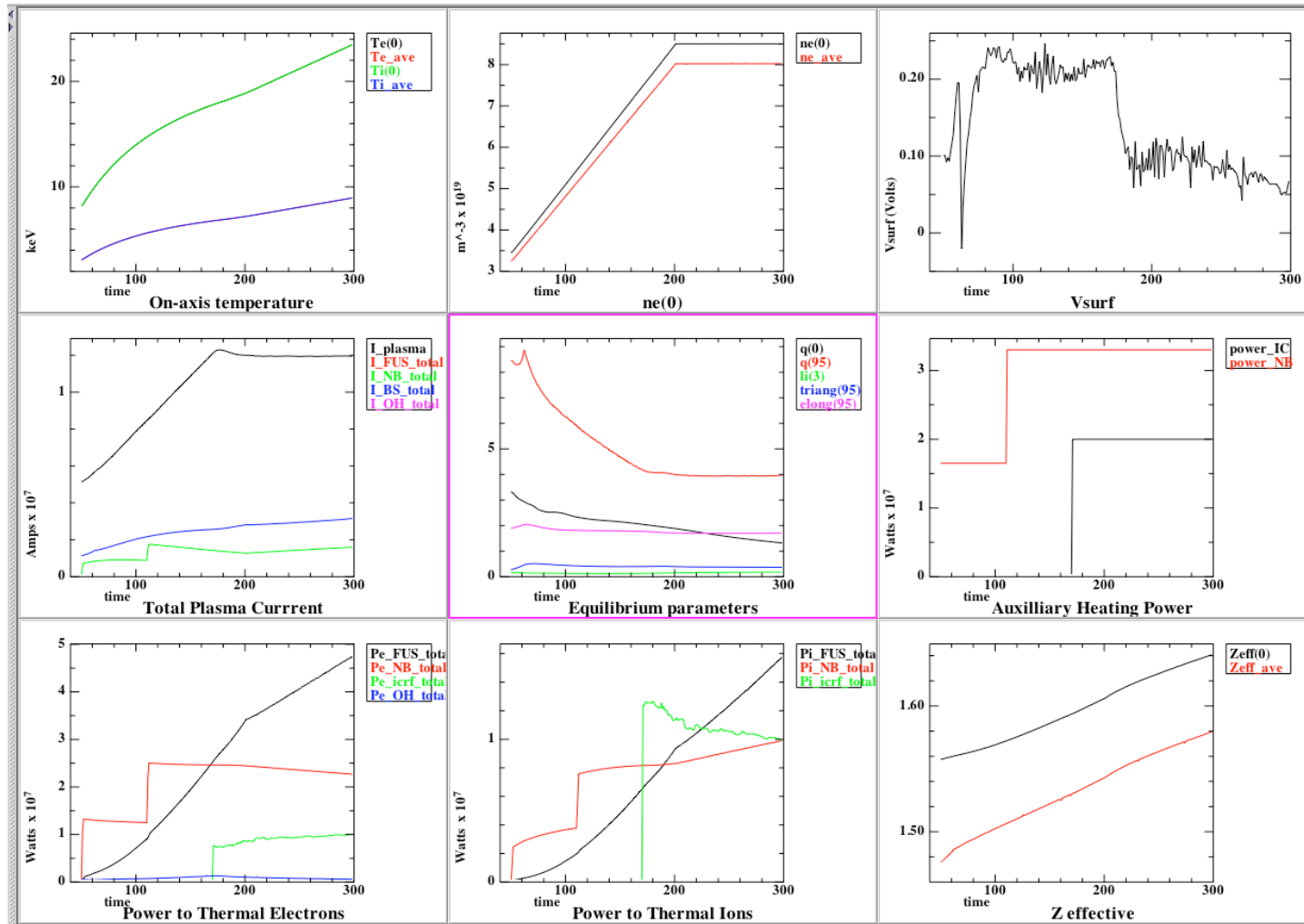
Previous TSC simulation – *full 1,000 sec run, 6 week running time*

serial TORIC – 31 poloidal modes

serial nubeam –  $10^3$  NBI particles,  
 $10^3$  fusion particles



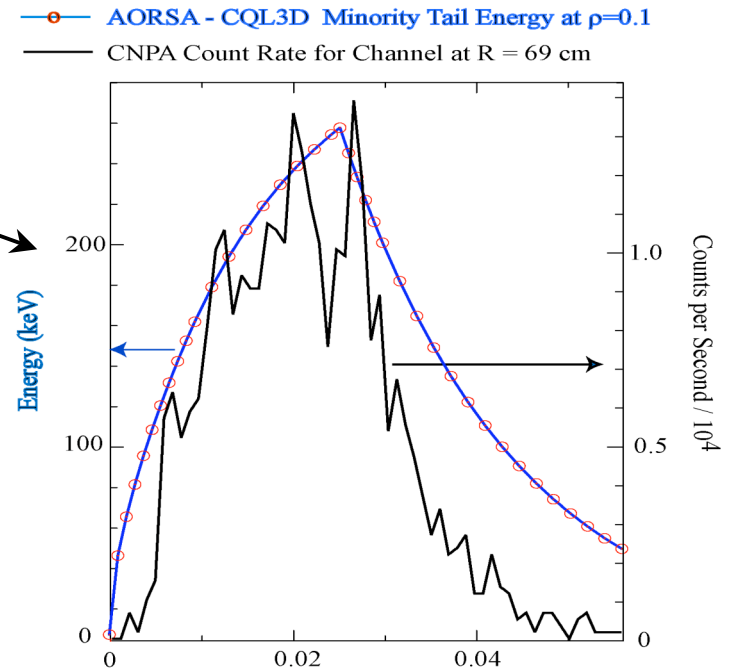
# ITER 40700T10 benchmark – TSC, TORIC (147 poloidal modes), NUBEAM ( $10^6$ MC particles for NBI & fusion) → 20 hr on 1,000 processors



We have repeated this calculation with NUBEAM and TORIC running simultaneously

# Other physics studies in progress

- Detailed, quantitative, time-dependent modeling of ICRF energetic minority tail formation on Alcator C-Mod → also serve as validation studies



- Preliminary studies with NIMROD on classical tearing modes in tokamak geometry, including specified RF driven current perturbation, and demonstrated non-linear island shrinkage

