

Project Overview

Don Batchelor SWIM Project Meeting Sept. 29 – Oct. 2, 2009

D. B. Batchelor, L. A. Berry, S. Diem, D. Green, E. F. Jaeger, D. A. Spong – *ORNL Fusion Energy*

D. E. Bernholdt, E. D’Azevedo, W. Elwasif, V. Lynch (NCCS) – *ORNL Computer Science*

S. C. Jardin, E. Feibush, D. McCune, J. Chen, L. P Ku, M. Chance, J. Breslau – *PPPL*

G. Abla, M. Choi, D. P. Schissel – *General Atomics*, R. W. Harvey – *CompX*

R. Bramley, S. Foley – *Indiana University*, D. Keyes – *Columbia University*, D. Schnack, T. Jenkins – *U. Wisconsin*

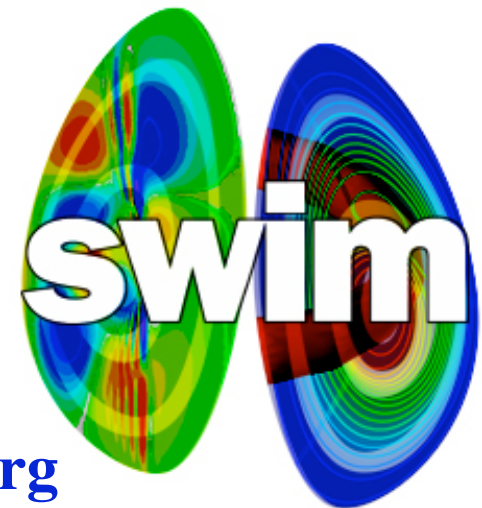
P. T. Bonoli, J. Ramos, J. Wright – *MIT*, S. Kruger – *TechX*, G. Bateman – *Lehigh University*

Unfunded participants:

J. D. Callen, C. C. Hegna, C. Sovinec – *University of Wisconsin*, E. Held – *Utah State*

H. St. John – *General Atomics*, A. Kritz – *Lehigh Univ.*

- **Project goals and strategy**
- **Highlights of accomplishments**
- **Objectives for this workshop**



See our fun website at: www.cswim.org

Remember what we set out to do

Study effects of RF on Macro-stability

- Use of RF (and other sources) to control slow plasma evolution and affect fastMHD events, $\tau_{\text{MHD}} \ll \tau_{\text{Heating}} \rightarrow$ **sawteeth**
- Use of RF (primarily ECH) to control slowly growing modes, $\tau_{\text{MHD}} \sim \tau_{\text{Heating}} \rightarrow$ **Neoclassical Tearing Modes**

Be a prototype for a comprehensive FSP

- Learn about physics and math of integration of multi-scale, multi-physics phenomena arising from RF/transport/MHD
- Learn to couple state-of-the-art codes that describe multiple plasma phenomena on state-of-the-art computers

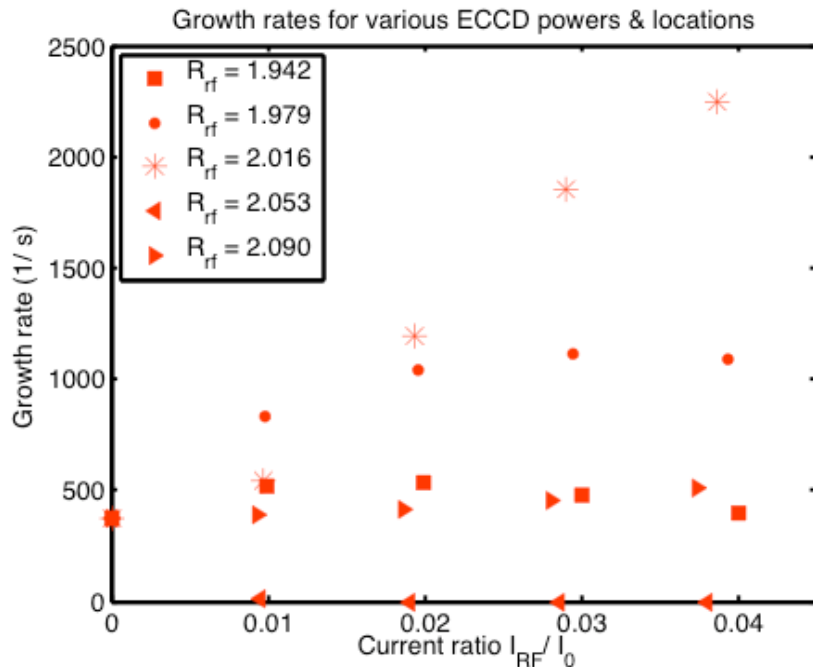
Develop a powerful integrated plasma simulator

- A system that is sufficiently extensible to include any fusion code that conforms to the specified interfaces
- A system that has high standards of useability, data integrity and accessibility
- A simulation system that will be the tool of choice for modelers studying present experiments, ITER, and beyond

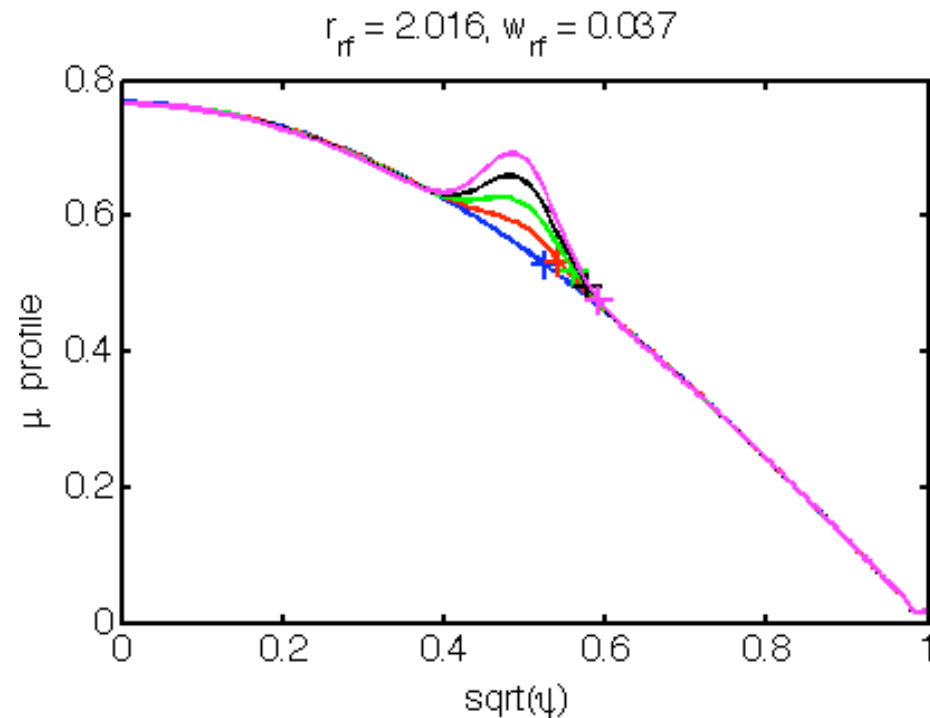
Outline of approach to achieve objectives – (This is from our review panel presentation)

High Level Goal	Specific objectives	Principal Supporting Tasks
Develop IPS to satisfy science needs	IPS becomes simulation tool of choice	Metadata management, generalize monitoring, improve load balancing (MCMD), streamline job setup and submission
Demonstrate IPS capability for Tokamak modeling	Ensemble of validated, <u>coupled simulations</u> Support ITPA activities	New and improved physics components (ray tracing RF, NBI, Monte-Carlo Fokker Planck, Transport interface, experiment data access
Demonstrate capability to study RF effects on Sawtooth	ICRF sawtooth modification exp on C-mod. <u>Energetic particle effects on JET and others.</u>	Non-linear MHD initialized by IPS, linear stability analysis, improved reduced ‘Porcelli like’ model, Nova-K component, particles-to-distribution transform
Demonstrate capability to study ECCD effects on NTM	NTM simulations with coupled non-linear MHD, ECCD, kinetic closure.	Couple ECCD quasilinear operator to NIMROD, implement tight (in memory) coupling in IPS, couple kinetic closure
Serve as basis for FSP design decisions	Evaluate limits of coarse-grain factorization. <u>Study achievable tight coupling with component/framework.</u>	Explore ability of MCMD to accommodate range of SWIM physics components, optimize transport/transport-coefficient and slow MHD coupling, investigate math issues of stability and accuracy with coupled models

Simulations with the NIMROD code have reproduced many of the qualitative features seen in experiments, including the stabilization or destabilization of the instability as the location of the RF current deposition is changed



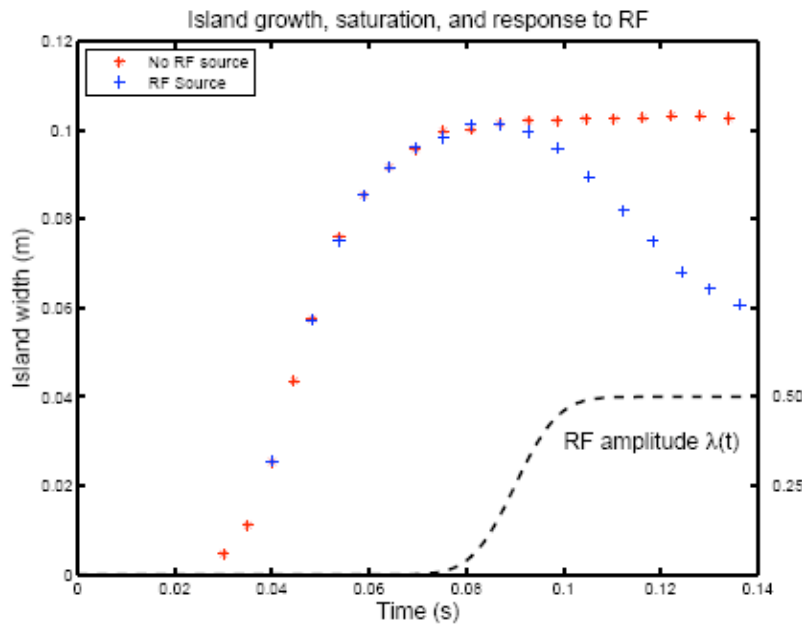
The stabilization or destabilization of the tearing mode, in response to different deposition locations for RF-induced current, is clearly seen in the numerical results from NIMROD.



The rational surface position, denoted by the cross, shifts increasingly outward as higher RF powers induce larger localized plasma currents near the original rational surface position

It is important to track the RF nonlinear modification of the equilibrium current profile

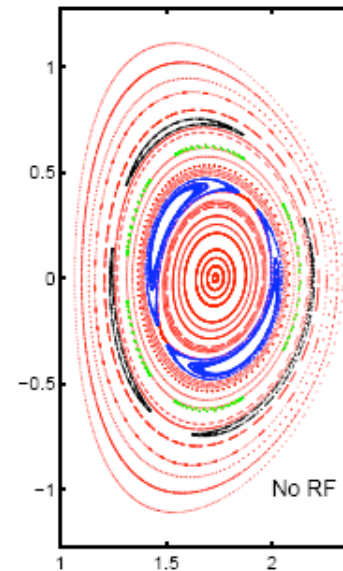
The magnetic island width is reduced in the presence of RF current drive – non-linear MHD (NIMROD), externally specified axisymmetric RF force



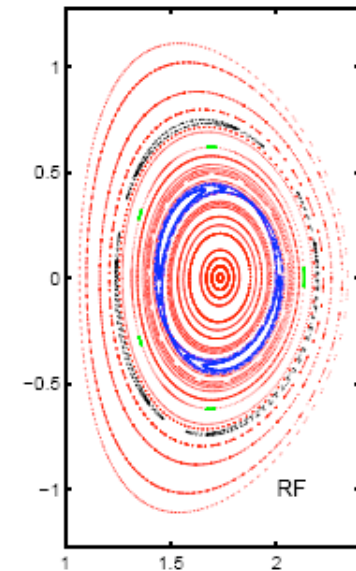
- In DIII-D geometry, begin with an equilibrium unstable to (2,1) resistive tearing mode; grow mode to saturation
- Magnetic islands shrink in response to RF current

- In the absence of RF, the (2,1), (3,1), and (5,2) islands grow to saturation
- In the presence of RF, all island widths are reduced [especially (2,1)]
- More detailed modeling under way – toroidal variation, time-dependent phasing, coupling to GENRAY, etc.

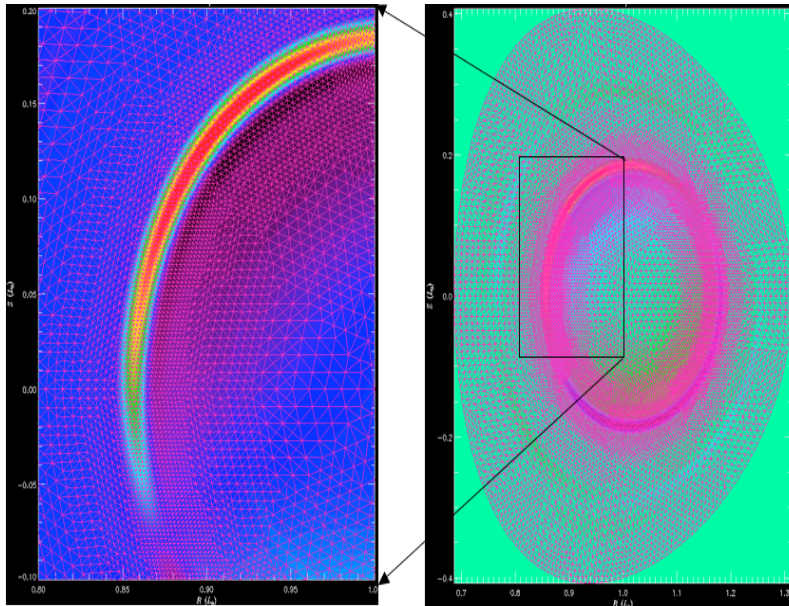
Magnetic islands, $t = 0.12815$ s



Magnetic islands, $t = 0.12721$ s

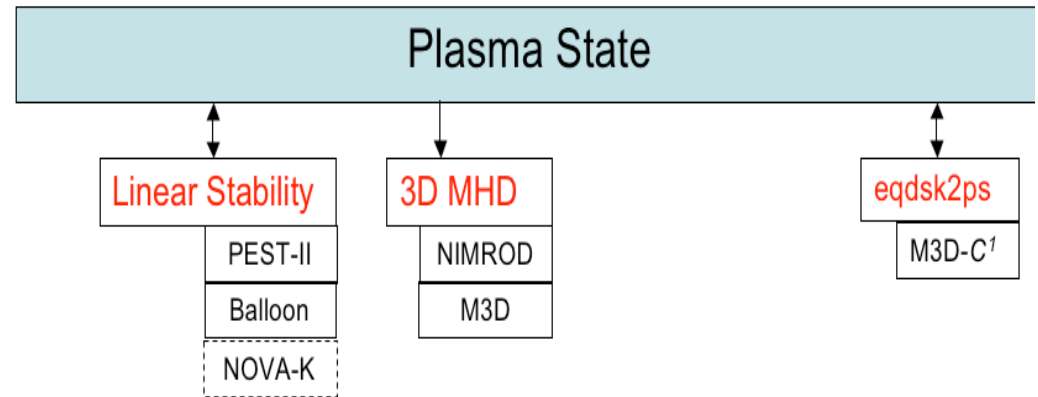


Evaluating the ideal and resistive MHD stability of a CMOD discharge simulated using the IPS



Perturbed toroidal current density for a resistive instability in CMOD with Lundquist number $S=10^7$. The linear phase of a $n=1$ resistive instability as calculated by the new toroidal MHD stability code M3D-C1.

We are able to use realistic values for the resistivity and other parameters by packing the mesh points around the magnetic flux surface where the magnetic island forms (using routines provide by the RPI SCORE Center).



The stability codes read the equilibrium from the plasma state as the simulation proceeds

IPS is supporting ITER simulations for International Tokamak Physics Activity (ITPA) tasks

A planned operational scenario of ITER is the “*hybrid mode*” → achieve high fusion yield for long discharge time

These raise a number of critical questions:

- **Are these states achievable with the heating and current drive systems available?**
- **Are such states controllable to maintain stationary current, density and temperature profiles?**
- **Are such states stable and which sorts of instabilities are most dangerous?**
- **What are the beta (plasma pressure) limits and how close to the limits is it possible to operate?**
- **How sensitive is the performance to assumptions?**
 - Energy transport
 - Pedestal properties
 - Plasma edge conditions

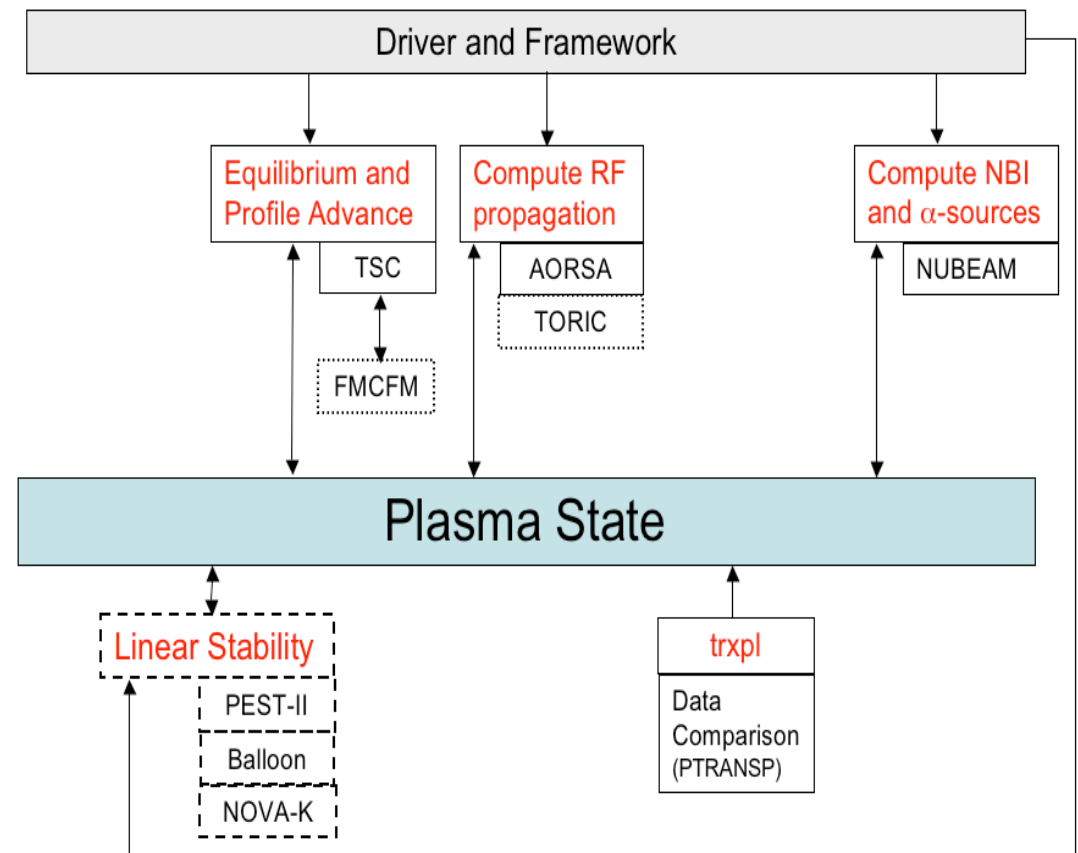
Integrated simulations, in conjunction with experiments on present day experiments provide the physics basis for such planned scenarios

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)

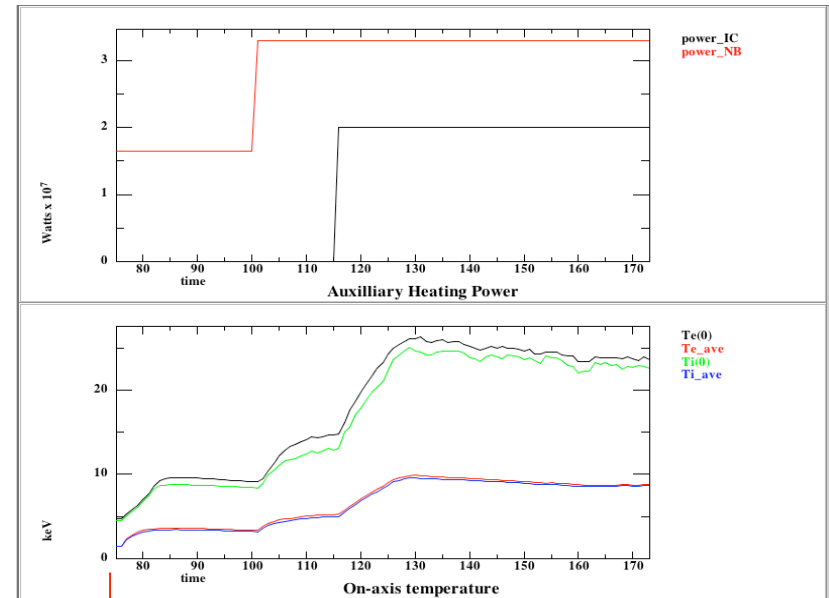
AORSA (massively parallel RF Ion Cyclotron solver) - 256x256 poloidal Fourier modes

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

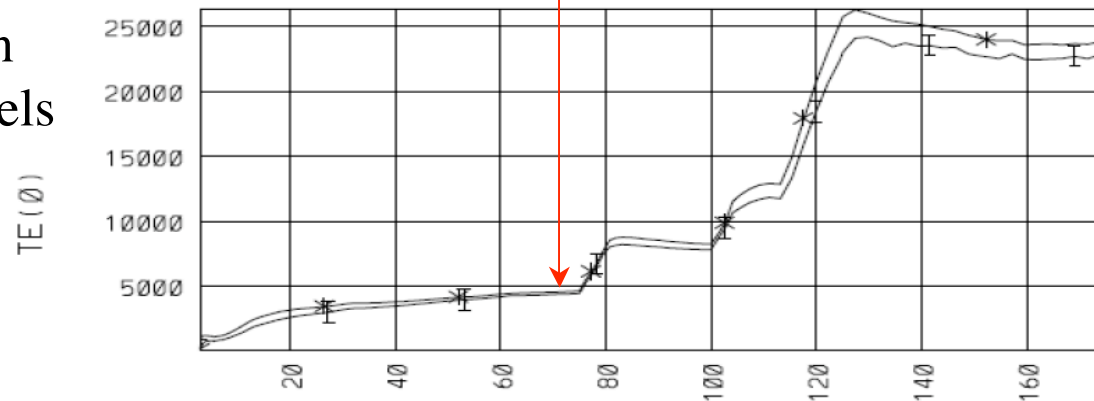


We are now carrying out simulations of the ITER device in a few days with levels of physics detail that were previously unfeasible

IPS simulation with coupled TSC, parallel AORSA, and parallel nubeam



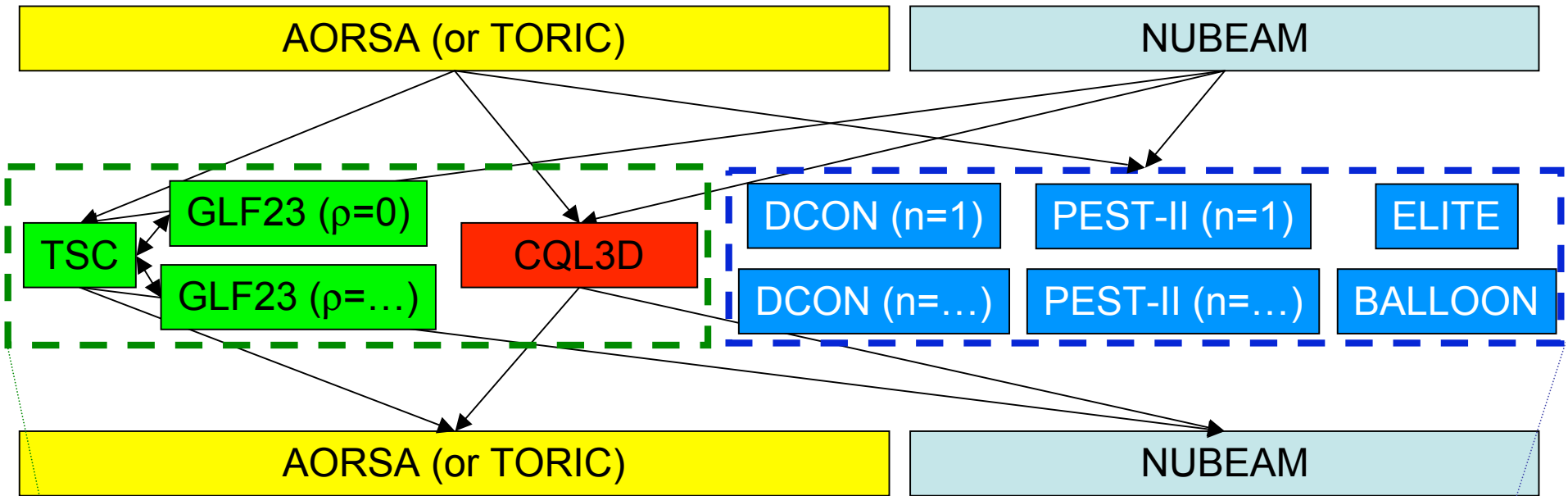
Previous TSC simulation with internal source models



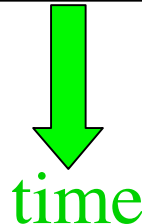
Results are comparable to previous calculations – detailed comparisons in progress

Simulations such as ITER scenario investigations can benefit from MCMD by minimizing time in (near) serial operations

Highly parallel components alternating with many smaller components, performing analyses of completed time step and initial phases of next time step.



Equilibrium and profile advance for step t , including parallel anomalous transport tasks for each flux surface, all running concurrently with the Fokker Planck component.



Multiple stability analysis components running on multiple toroidal modes, all running concurrently on $t-1$ results.

Next steps

- **Coupled IPS simulations of Classical tearing modes using NIMROD coupled to GENRAY for electron cyclotron current drive**
- **Systematic studies of resolution requirements for ITER simulations – number of Monte Carlo particles in NUBEAM, number of poloidal and toroidal modes for AORSA/TORIC**
- **Inclusion of GENRAY ECH/ECCD component for ITER simulations**
- **Activation of existing MHD stability component for use in IPS runs**
- **Activation of CQL3D Fokker-Planck component to carry out studies of energetic ion tail formation dynamics in ICRF heated tokamaks – Alcator C-Mod**
- **Completion and testing of energetic particle stability component based on NOVA-K code. Application to Toroidal Alfvén modes in C-Mod**

Plans for Coming Year – IPS Environment

- **Complete MCMD implementation**
- **Generalized monitoring component and web interface**
 - More flexibility, easier configuration of what is exported for monitoring
- **Add authentication and personalization capabilities to portal**
- **Bring prototype metadata management capabilities into production**
- **Preliminary implementation of tight coupling capability**
 - Support components coupling more frequently, exchanging more data
 - Task launch overheads become too high
 - File-based data exchange may be insufficient
 - Conceptual model: CCA-like environment with tightly-coupled components in a single parallel job, exchange data through subroutine calls
 - Implementation will be more intrusive into physics codes than current components
 - Pay-off is generality, reusability of new components in other IPS contexts

Verification and Validation Strategy

The major projects providing SWIM components have V&V programs. We benefit from that (CEMM, CSWPI, TRANSP, PTRANSP)

SWIM Verification

- “Dummy” physics components permit verification of IPS framework, Portal, and monitoring functions

Component benchmarking

- SWIM plug-and-play architecture plus Plasma State data exchange facilitate component V&V efforts – AORSA/TORIC, M3D/NIMROD, many more planned

Comparison with reduced or analytic models

- SWIM supports easy substitution of reduced models which can be compared to more complete models in overlapping range of validity – e.g. ICRF Stix model compared to CQL3D, ORBIT-RF in collisional (isotropic) limit.

Validation – comparison with experiment

- Example: C-Mod time dependent tail formation comparisons
- Synthetic diagnostic development a priority
- Experimental data access component is facilitating simulation validation

Validation of coupled simulation is a challenge. But the ability to couple the most sophisticated physics models is essential to approaching that challenge

Workshop objectives

- **Identify a few (3 or 4) physics studies to have in good shape by March (2010), anticipating some kind of review possible leading to a project extension.**
- **For each of these studies identify all of the tasks and develop a plan to actually accomplish them**
Remember last year's 7 deadly questions? This year there are 8.
- **Identify additional studies to be done during a program extension (1 to 2 years)**
- **Identify IPS developments or experiments with IPS, that might not necessarily be needed for the physics studies, but that would give us leverage with FSP or that would be good CS in its own right.**

Questions for physics study discussions

- 1) What are the physics issues to be addressed and why? scope, logic**
- 2) What experimental data is to be compared, or what validations studies will be done?**
- 3) What components are needed for the work?**
- 4) What visualization and data analysis will be required**
- 5) What development is needed to complete the studies? – physics code development, component script development, generalization of IPS time stepping logic ...**
- 6) What are the major milestones toward completion and what is the schedule?**
- 7) Who is going to do what in the study, and when will they do it?**
- 8) What publications/presentations are envisaged? What is the schedule for that?**

Physics studies on the agenda

- **ITER modeling for ITPA – Batchelor**
- **Lower Hybrid current ramp up in C-Mod – Harvey**
- **Sawtooth instability studies in C-Mod and NSTX – Jardin**
- **Dynamics on ICRF minority on C-Mod – Berry or Bonoli**
- **Sawtooth modification with MCCD and LHCD profile control – Bonoli**
- **TM/NTM stabilization with ECCD – Kruger**

- **This is plenty**
- **There is overlap and we might want to combine some**
- **There needs to be one guy who is going to push each project and make sure it happens. The names listed could shift around, but this is a reasonable distribution**