Development of an Integrated Modeling and Fitting Tool to Support DIII-D and EAST Research and Operation

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Motivation

- **Integrated modeling is important for tokamak research and operation**
  - *Experimental analysis and planning*
  - *Model validation*
- **Much important tokamak physics involves processes that interact strongly**
  - *Sawteeth, AEs, ELMs, RWMs*
- **Need efficient tool to facilitate integration of different physics analysis modules to support experiments**
  - *Efficient integration of Equilibrium, Stability, and Transport codes for experimental data analysis and modeling*

Outline

- **IMFIT is developed to provide an efficient integration platform to support tokamak research and operation**
- **Current version employs a PYTHON-based framework to manage tasks with a TASK-FLOW based execution model**
- **Analysis codes and tools are integrated into IMFIT through different PHYSICS and SERVICE MANAGERS**
- **Extensive GUI and web-based support are developed for ease of use**
- **IMFIT state file development and compound task Beta limits development is ongoing**
- **Ongoing physics tasks include NTV and 3D equilibrium reconstruction**
- **IMFIT 1st version has been released for DIII-D and will be released for EAST shortly**

IMFIT Is Designed To Efficiently Integrate Different Physics Modules To Support Multiple Devices For Data Analysis And Modeling

EQUILIBRIUM
EFIT…

TRANSPORT
ONETWO…

STABILITY
GATO…

CURRENT DRIVE
NUBEAM…

…

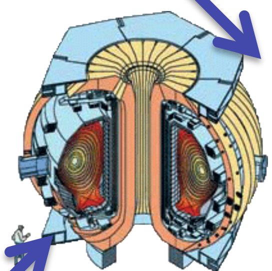
MDSplus

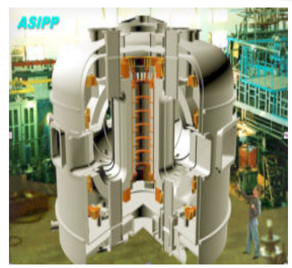
netCDF

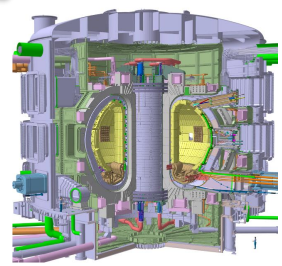
ITERDB

PlasmaState

…



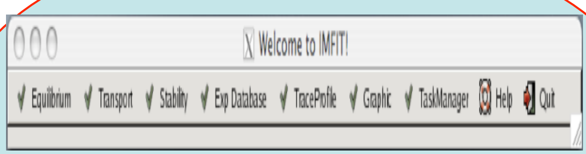




DIII-D

EAST

ITER

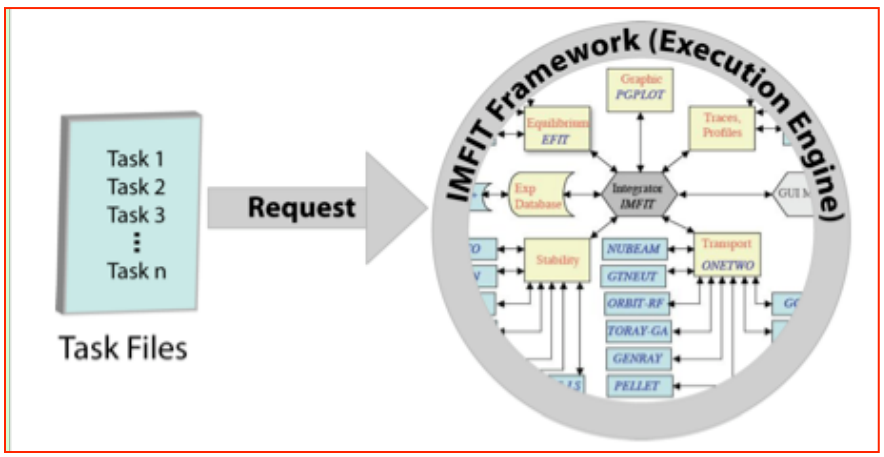


Web-based support

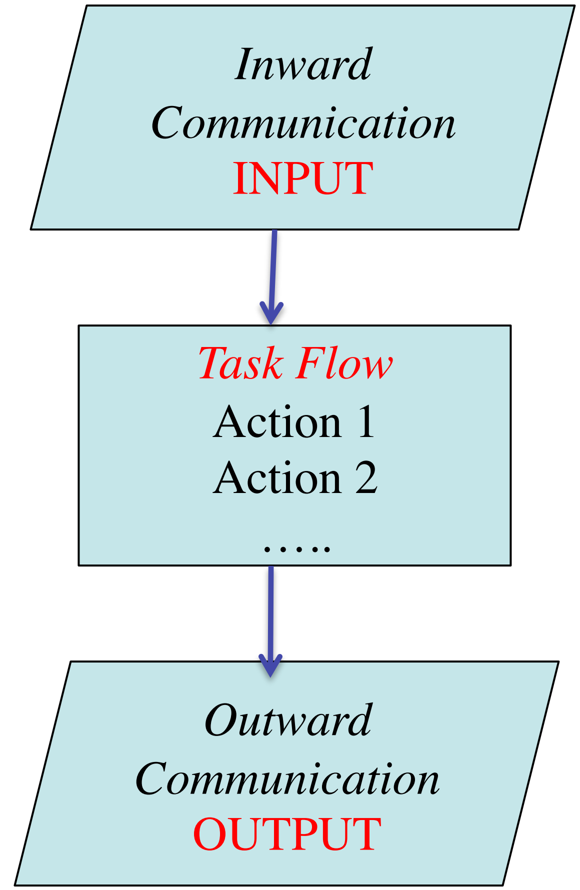
Efficient Integration Platform to Support Tokamak Research and Operation

IMFIT Manages Tasks Using PYTHON Task-Flow Based Framework and Task File

- **Framework is an architecture that:**
  - provides standard logic for managing various physics codes
  - provides certain rules for development of components
- **Tasks are generally defined in terms of *Task Flow*, *Communication* in Task File**
  - *Compound Task*: combination of simple tasks
- **Framework reads in *Task File* and dynamically generate a sequence of actions**

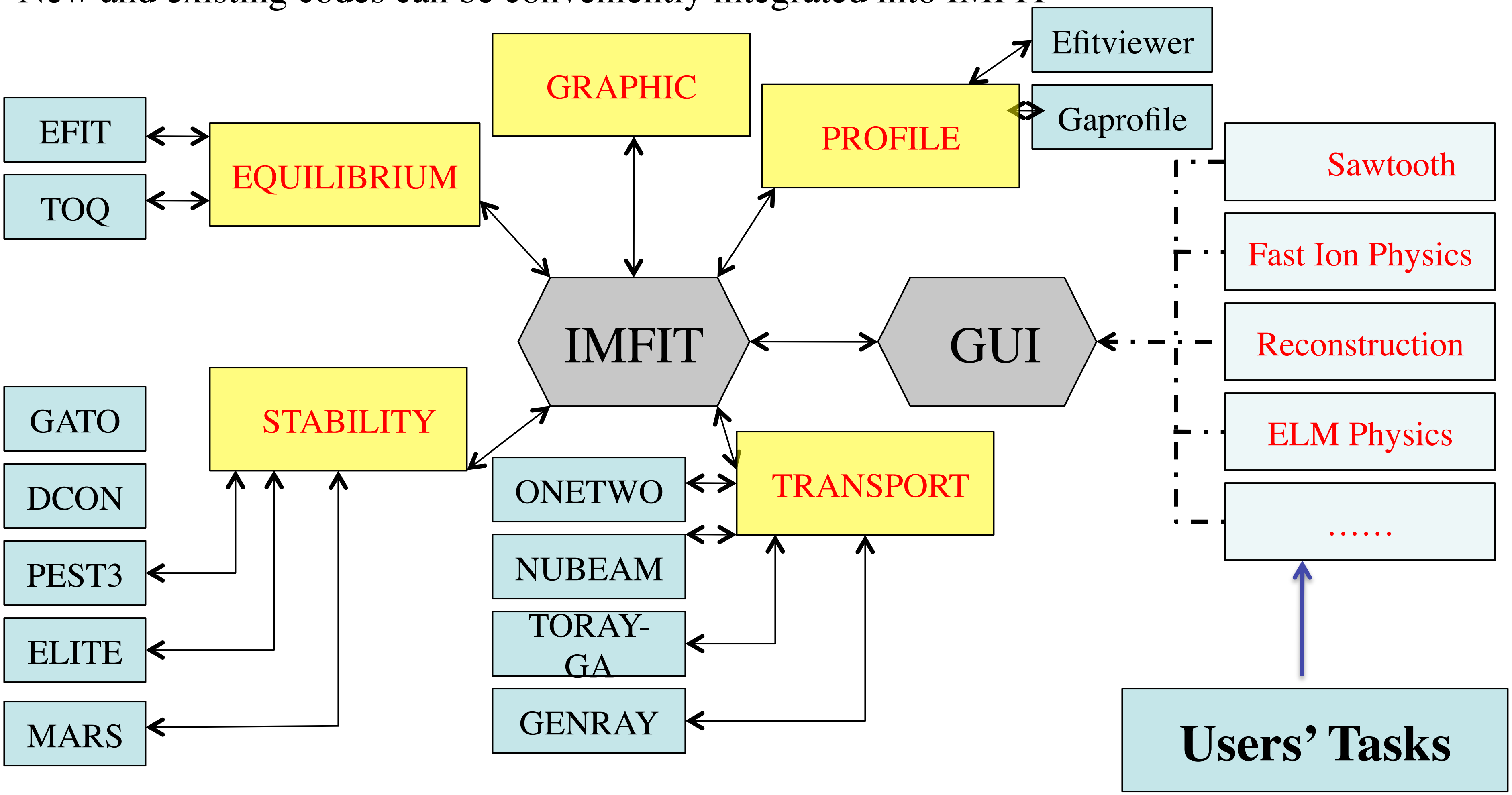


Simple Task Description



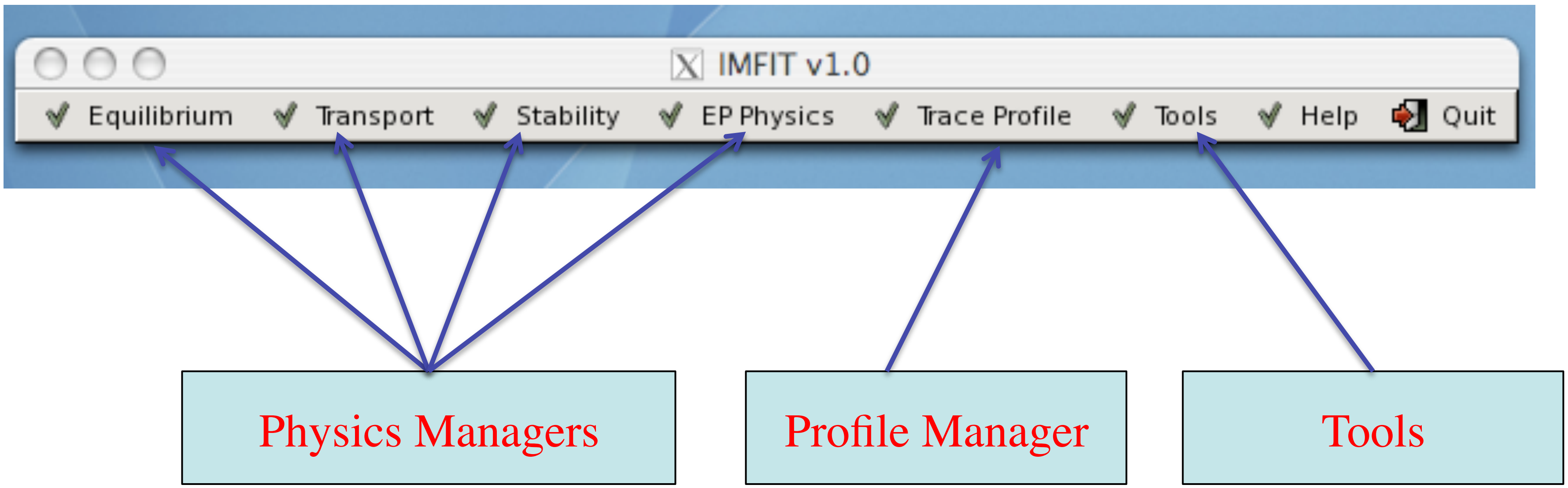
Responsible Managers Carry Out Assigned Tasks By Calling Corresponding Components

- New and existing codes can be conveniently integrated into IMFIT

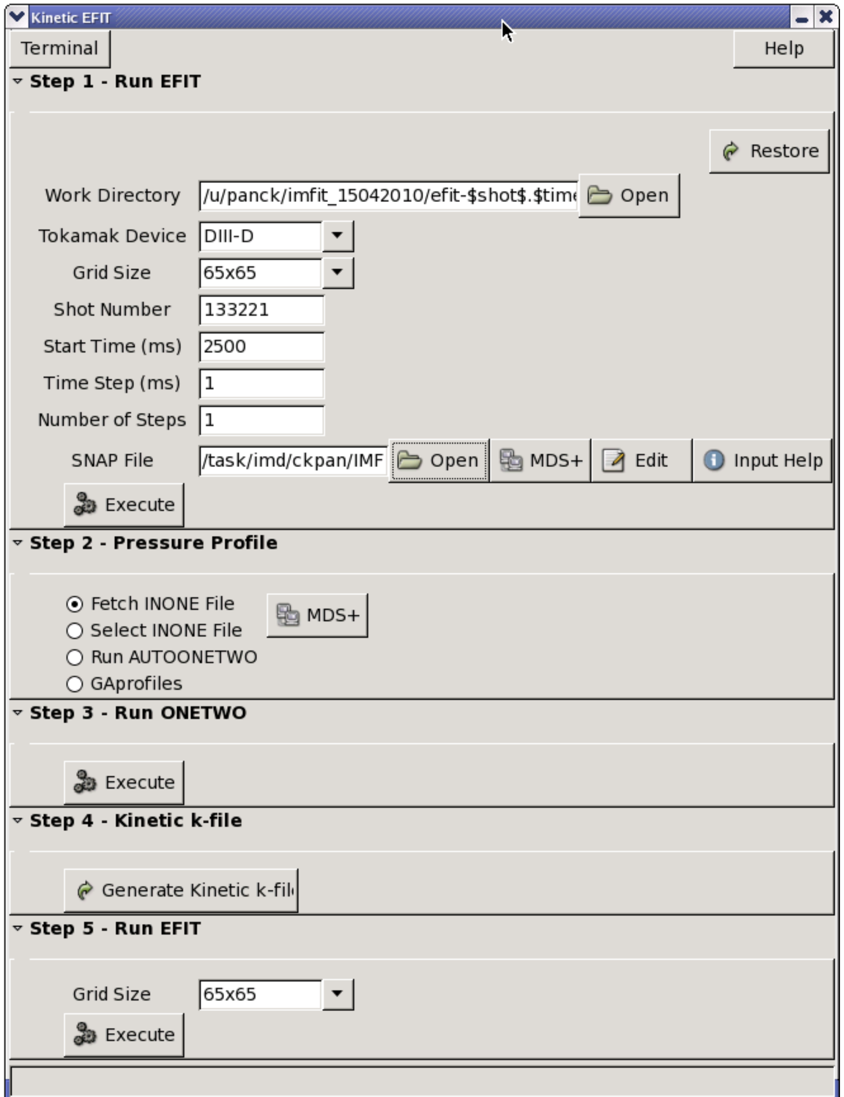


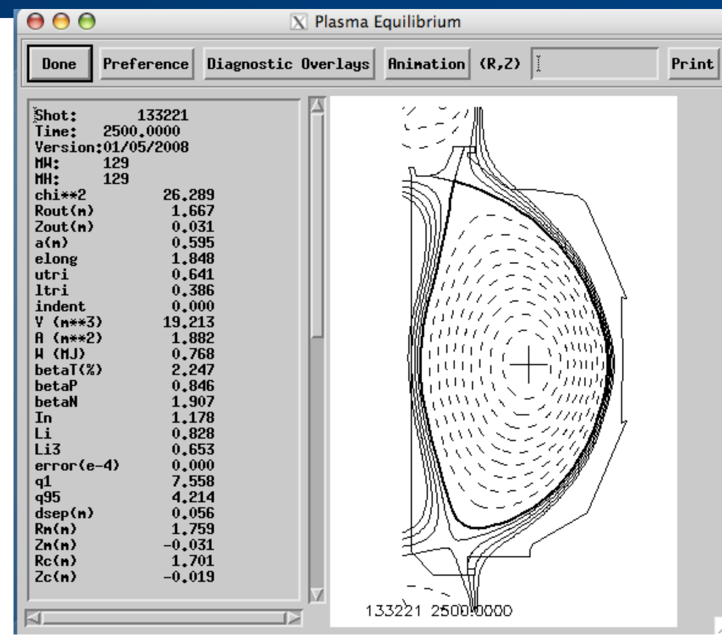
Extensive GUI Support Is Developed For Ease Of Use

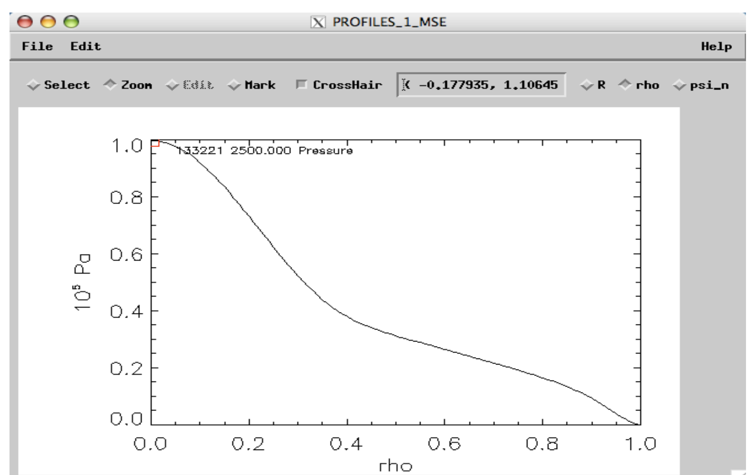
Based on PYGTK, open source graphic user interface toolkit for PYTHON



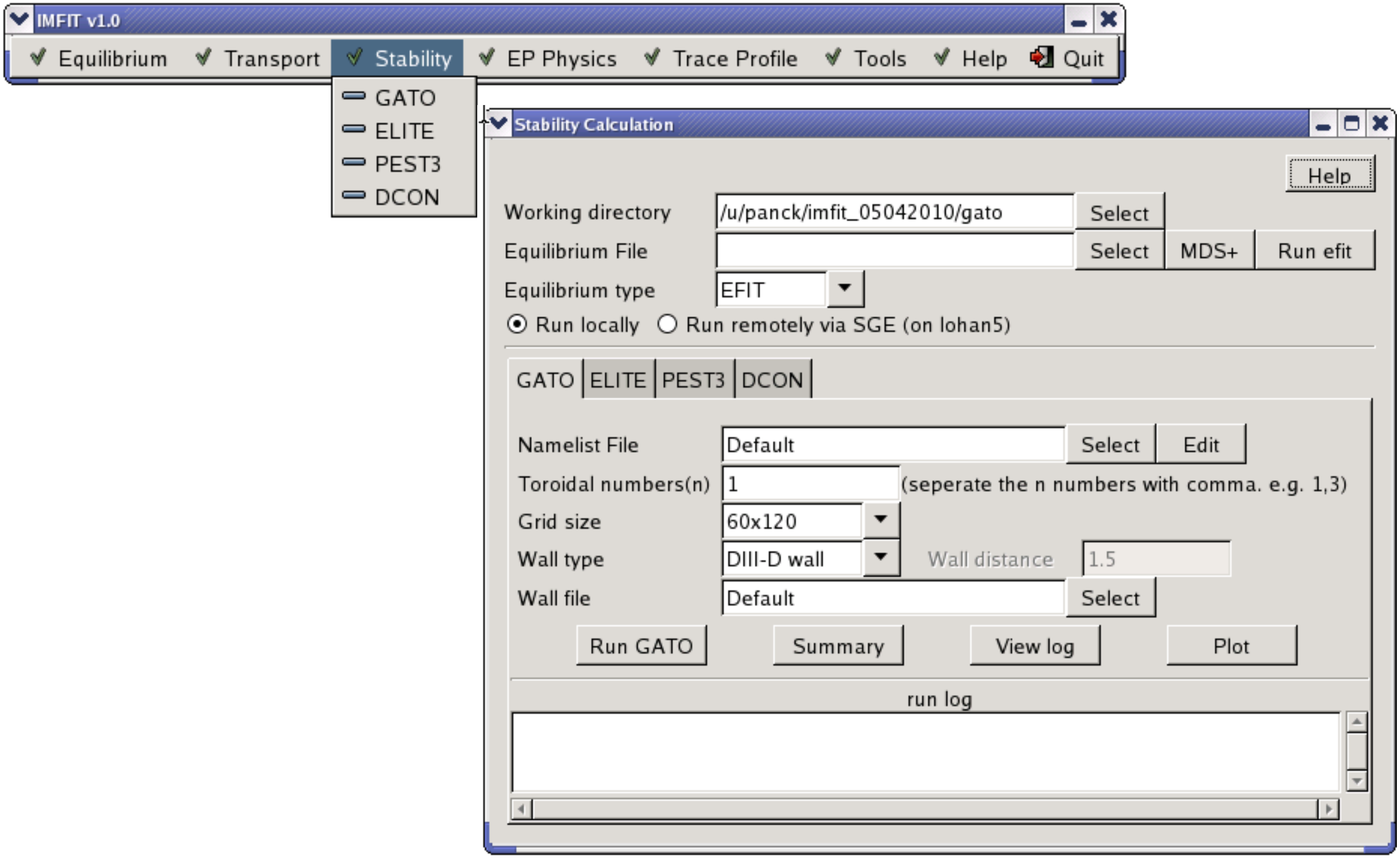
Extensive GUI Support: Kinetic EFIT Reconstruction Example



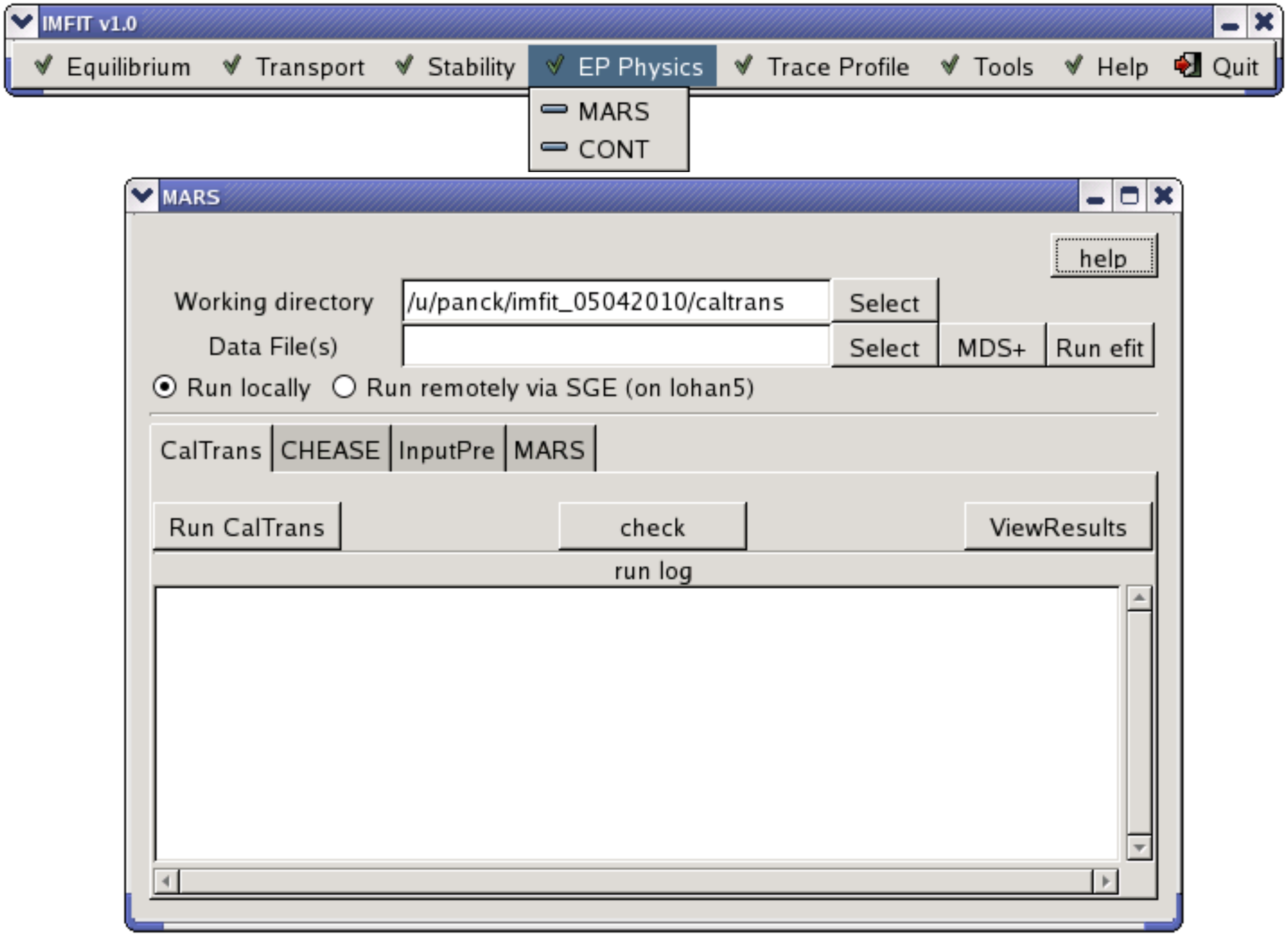




Extensive GUI Support: Stability Example



Extensive GUI Support: EP Physics Example



IMFIT *StateFile* Development Is Ongoing

- **IMFIT goal is to make experimental and theoretical modeling more efficient**
  - Automate routine tasks to generate datafrom experiment and theory.
  - Framework driven automatic coupling of physics codes with as little user intervention as possible

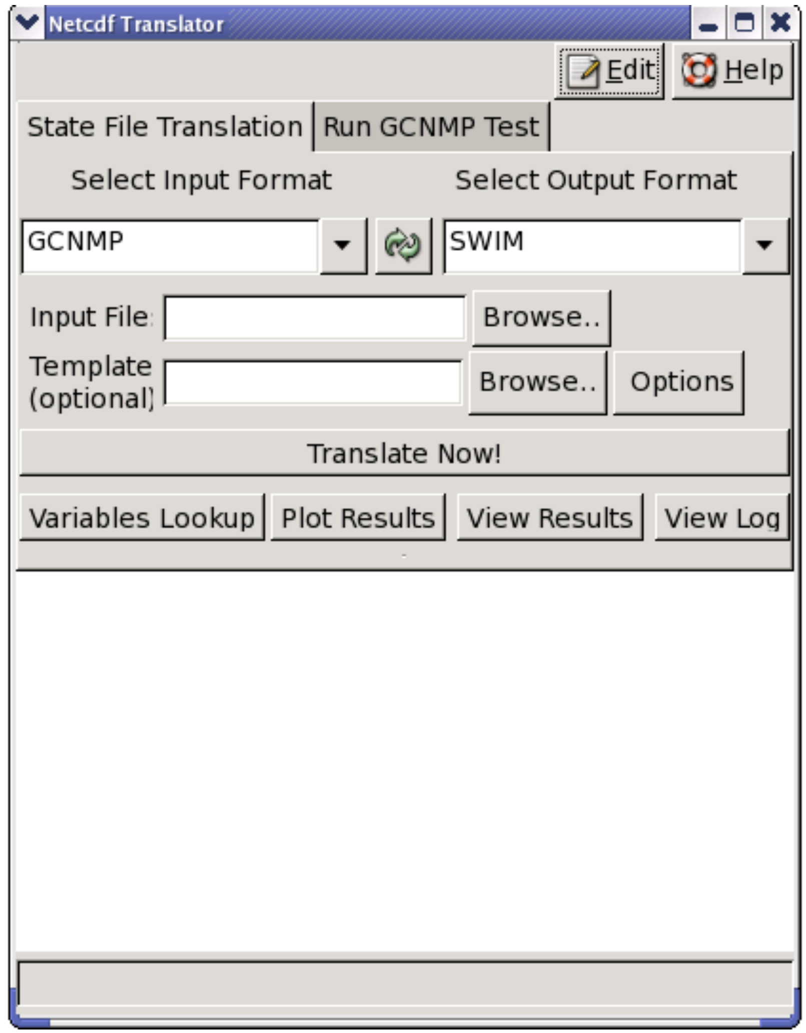
- ***StateFile* serves as a database of definitions and units for all variables that might be passed between codes**

- **IMFIT Framework takes information in *StateFile* and allows dynamic construction of compound task input files**

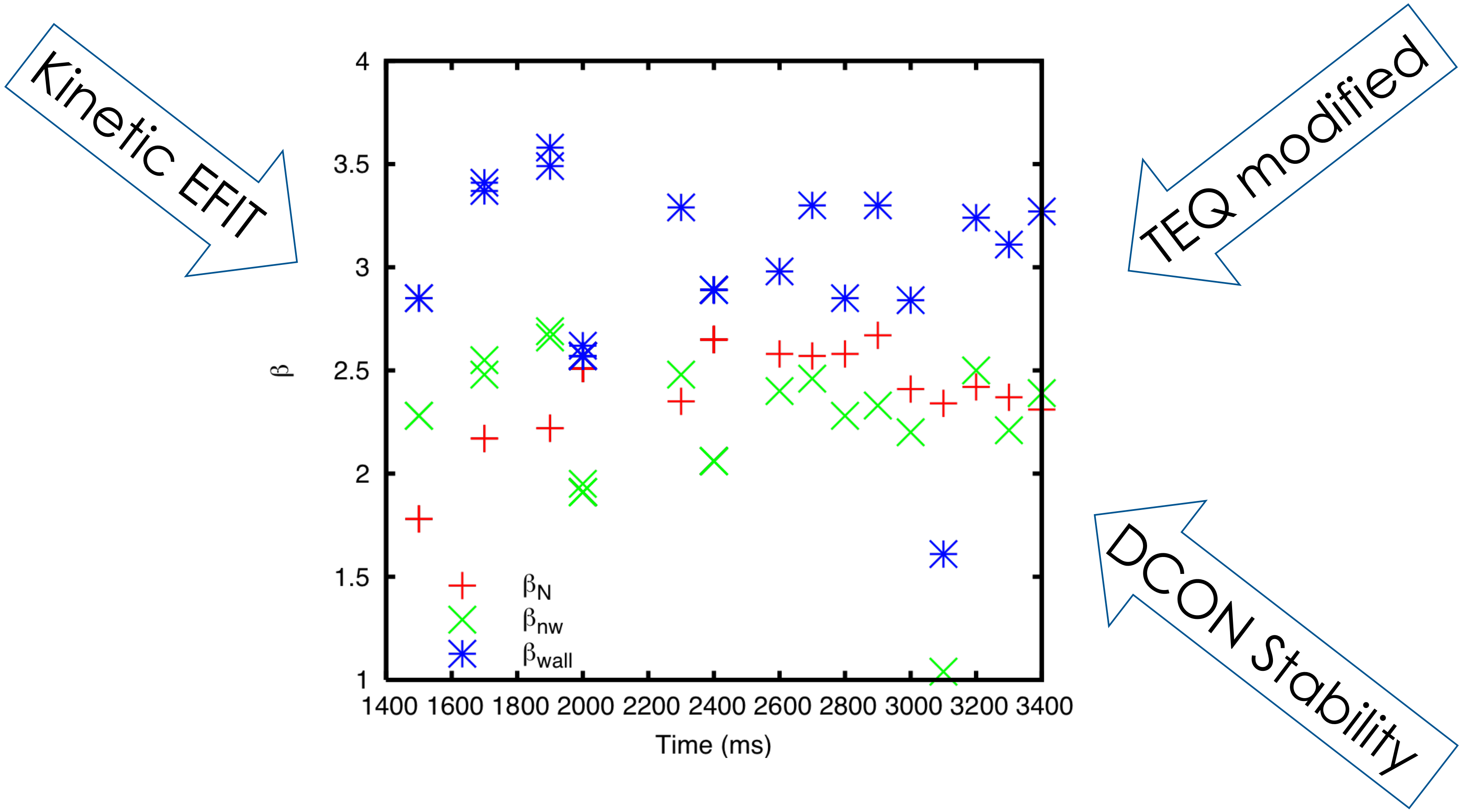
- **IMFIT Framework manages reading of output results, updates *StateFile*, writes to MDS+ and other databases**

IMFIT Translator Tool

- **Translator is an add-on tool to IMFIT that allows users to conveniently work across modules.**
- **Translator translates IMFIT NETCDF state files between GCNMP, SWIM and XPTOR back and forth.**
- **This tool enables users to communicate and compare running results between physics modules.**



Stability β Limits: A compound Task Requiring An Initial Equilibrium and Stability Of Modified Equilibria



- **This compound task is being developed for IMFIT**

3D MHD With Variational Method (VMOM3D)

- **Based on the stationarity of the energy integral**

$$W = \int_V dV \left(\frac{B^2}{8\pi} + \frac{p}{\gamma - 1} \right)$$

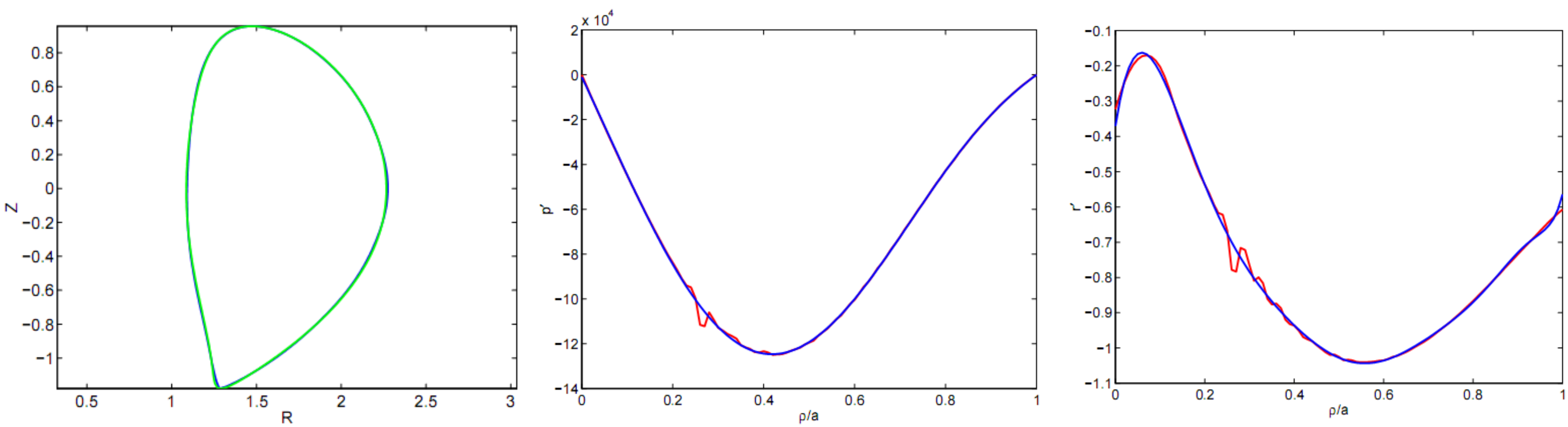
- **Magnetic field is expressed** $\mathbf{B} = \nabla\rho \times \nabla\lambda$ **with**

$$\lambda(\rho, \theta, \zeta) = [\phi'(\rho)\theta - \chi'(\rho)\zeta + \Lambda(\rho, \theta, \zeta)]\,/(2\pi)$$

- **Solve a set of ODEs with specified plasma boundary**
- **Interface between EFIT and VOMOM3D developed**
- **3D MHD equilibrium of DIII-D, other devices will be constructed (less computational time)**

Interface Between EFIT And VMOM3D

- **Plasma boundary from EFIT converted into harmonics**
- ***p*, *1/q* and their derivatives fed to VMOM3D**
- **Plasma boundary (— harmonics and — EFIT) and profiles (— polynomial and — cubic spline) of a DIII-D divertor equilibrium # 126006**

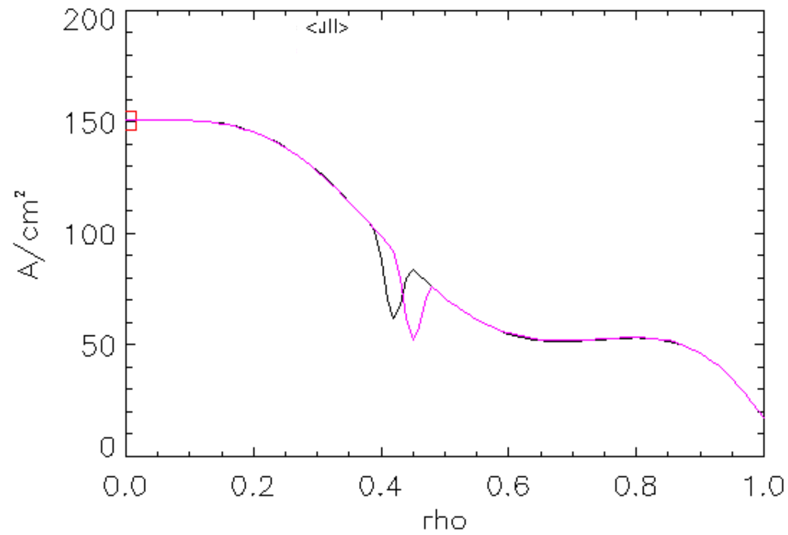


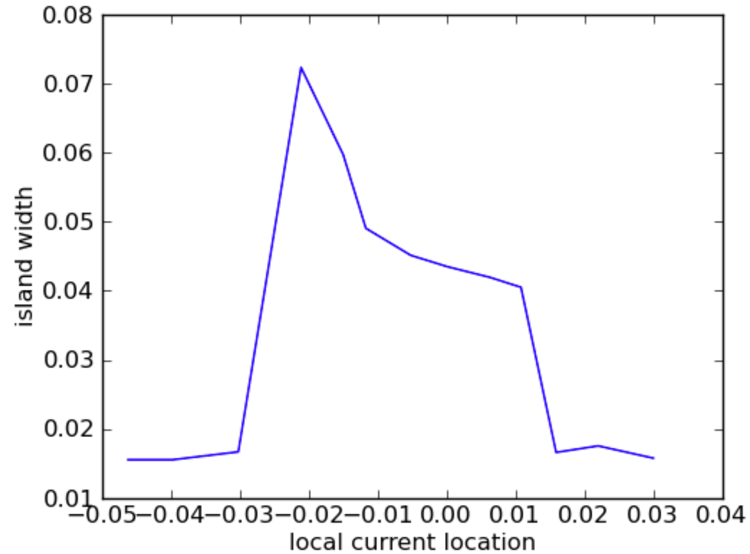
Lehigh University NTCC ISLAND Module To Calculate Island Width

- **Counter ECCD can excite the neoclassical tearing mode**
- **Equilibria reconstructed using EFIT with a local current representation**
- **Saturated island width is computed with ISLAND**
- **Island width is sensitive to the local current location**

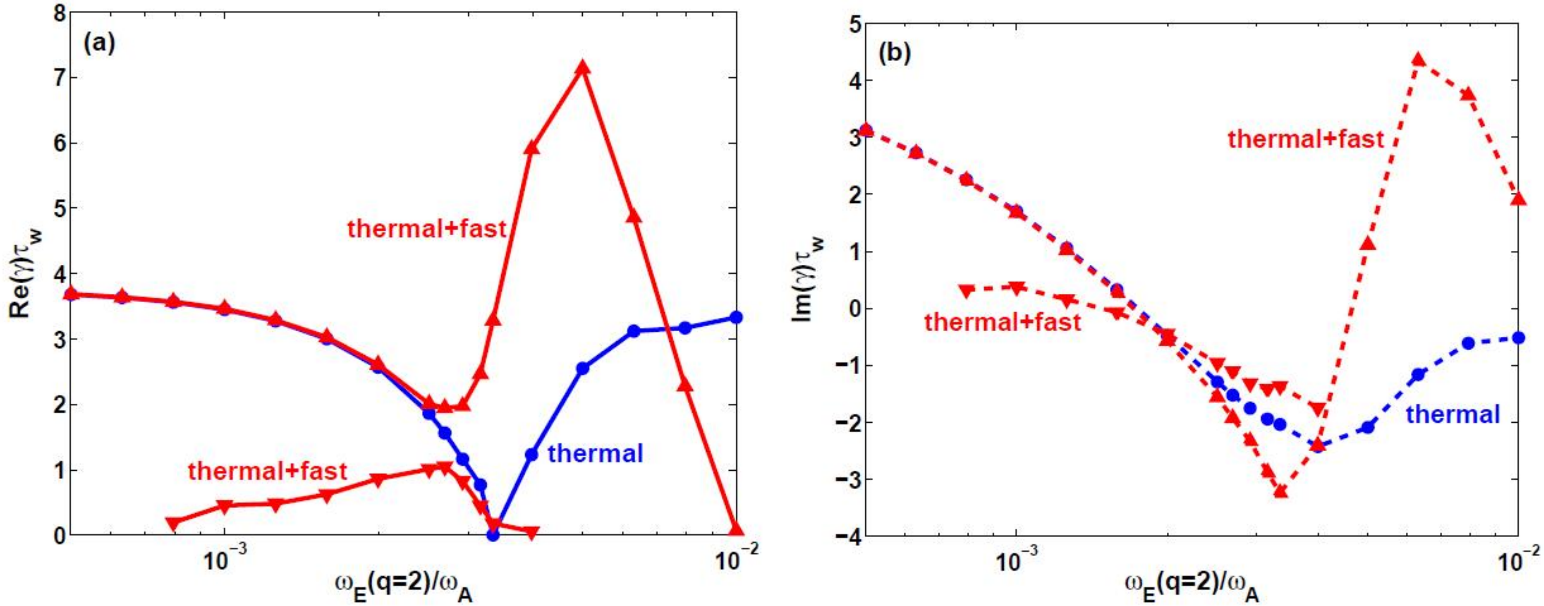
Federico D. Halpern, Glenn Bateman and Arnold H. Kritz, **Phys. Plasmas 13 (2006) 062510**

Canh N. Nguyen, Glenn Bateman and Arnold H. Kritz, **Phys. Plasmas 11, 3460-3471 (2004)**





RWM Analysis with Fast Particles Using IMFIT EP Physics Module — MARS-K



(a)Real and (b)imaginary part of RWM eigenvalue, computed by MARS-K with a self-consistent approach. The results with thermal particle kinetic effects only (filled circles) , and with thermal and fast particles effect together (filled triangles) are compared.

***Y.Q. Liu, M.M. Chu, W. Guo*, et al (in submission)**

ONETWO NTV Implementation Is Ongoing

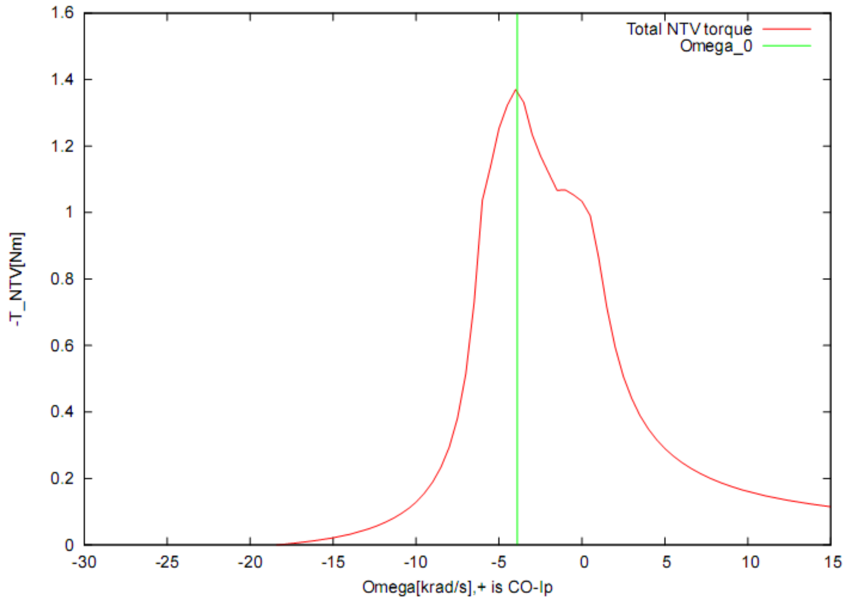
- **NTV Damping rate**

$$\frac{\partial \Omega}{\partial t} = -\mu_{//P}(\Omega)\left(\frac{\delta B_n}{B_0}\right)^2 \left[\Omega - \bar{\Omega}_*\right]$$

- **Total NTV Torque**

$$-T_{NTV} = 4\pi^2 R_0 \int_0^a r dr \rho_M \mu_{//P} \left(\frac{\delta B_n}{B_0}\right)^2 \left[\Omega - \bar{\Omega}_*\right] \left\langle R^2 \right\rangle$$

A.J. Cole, J.D. Callen, et al.
(to be published)

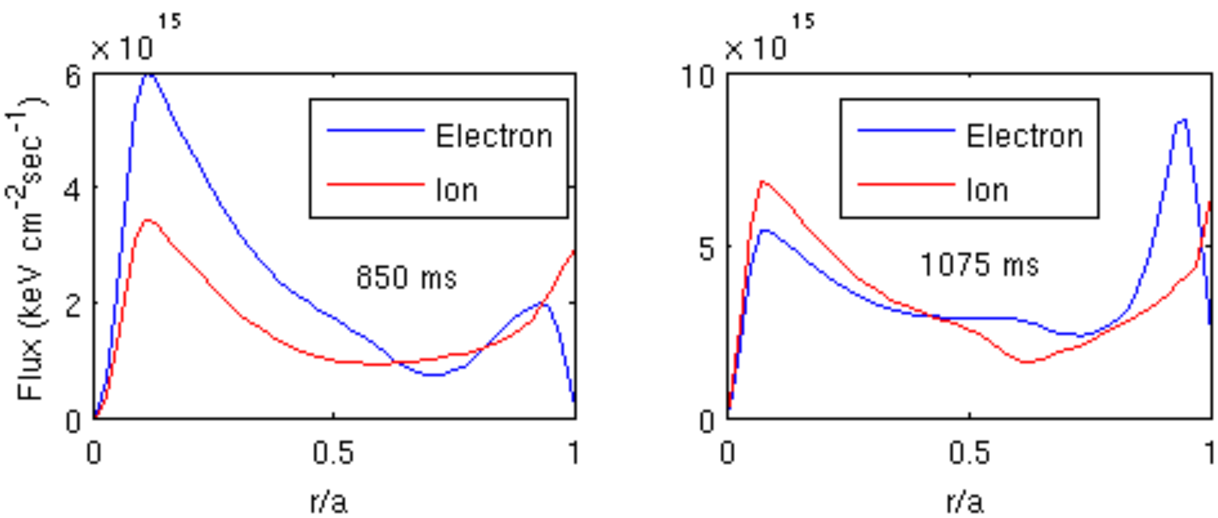


Toroidal rotation scan for theoretical NTV torque

This work is being done in collaboration with J.D. Callen, A.J. Cole

EFIT/ONETWO Coupling

- **Transport (fast scale) and equilibrium (slow time scale) are coupled with a Python interface**



Preliminary electron and ion energy fluxes for a DIII-D divertor discharge #132003 at *t* = 850 ms and 1075 ms

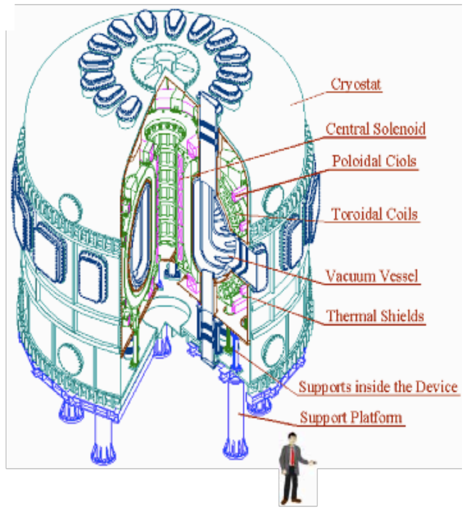
IMFIT Applied to Model EAST Advanced Tokamak Scenario Development

Main Parameters

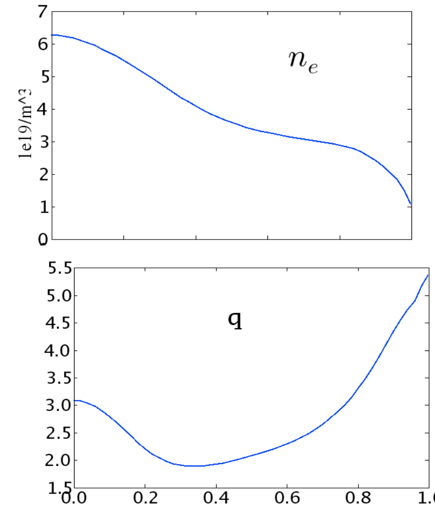
	Nominal	Upgrade
B_o	3.5 T	4.0 T
I_p	1 MA	1.5 MA
R_o	1.7 m	1.7 m
a	0.4 m	0.4 m
R/a	4.25	4.25
K_x	1.2-1.5	1.5-2
δ_x	0.2-0.3	0.3-0.5

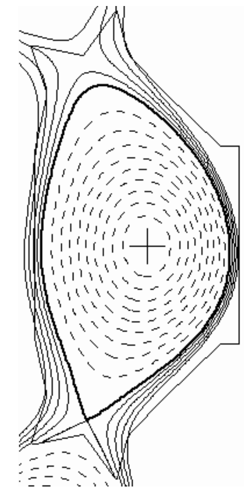
Pulse length 1000 s

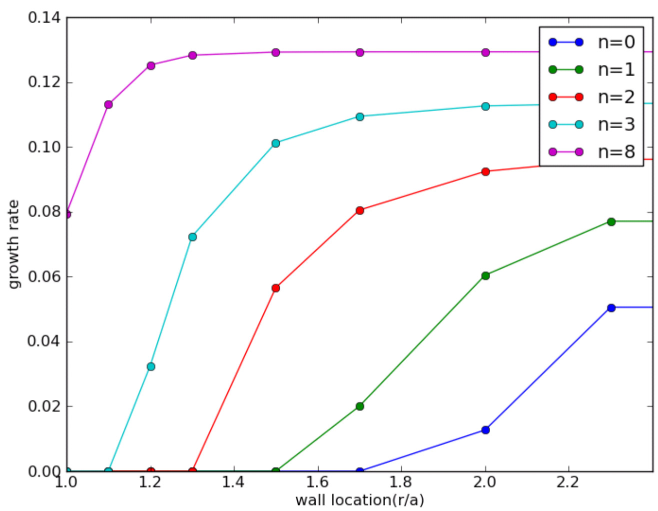
Configuration: Double-null divertor
Single-null divertor

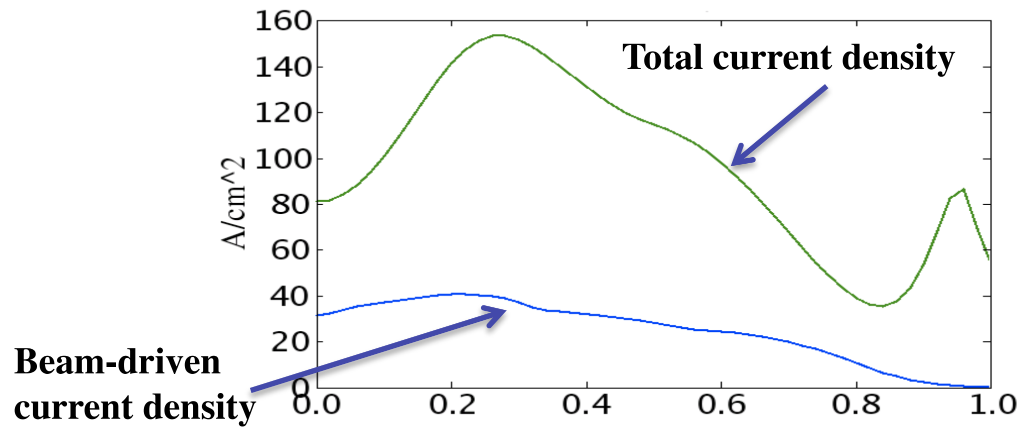


NBI Simulation Using IMFIT









Summary/Future Work

An Integrated Modeling and Fitting Tool *IMFIT* Based on Python Is Being Developed to Support DIII-D and EAST Research

Primary Goal:

- To increase experimental data analysis productivity and streamline analysis
- To allow new physics modules to be conveniently integrated to ease theory-experiment comparison
- 1st IMFIT version has been released for DIII-D and will be released for EAST shortly

Future Work:

- Development of compound tasks
- Improvement of branching and error handling of Framework
- Improvement of physics codes as well as development of tools to facilitate analysis