TRANSP in OMFIT

by
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Presented at the 2017 TRANSP Users Meeting

Princeton, NJ

May 4-5 2017

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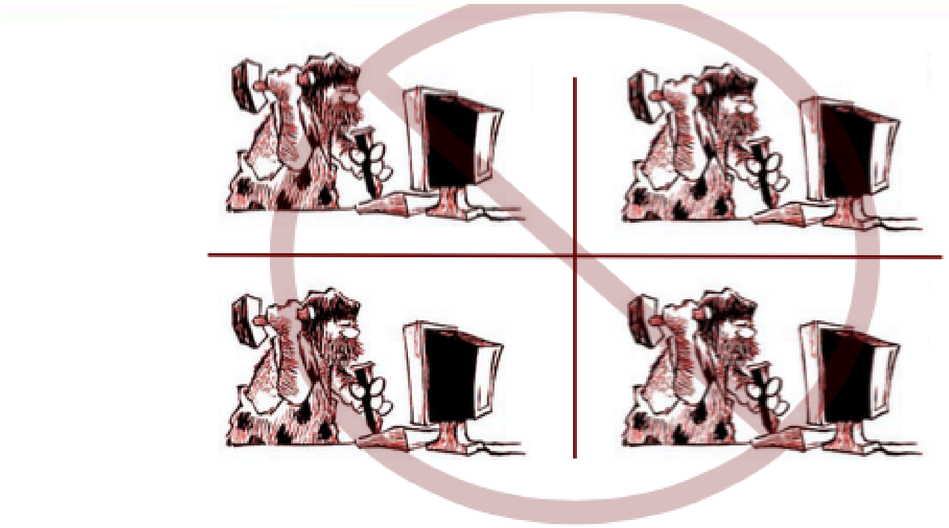
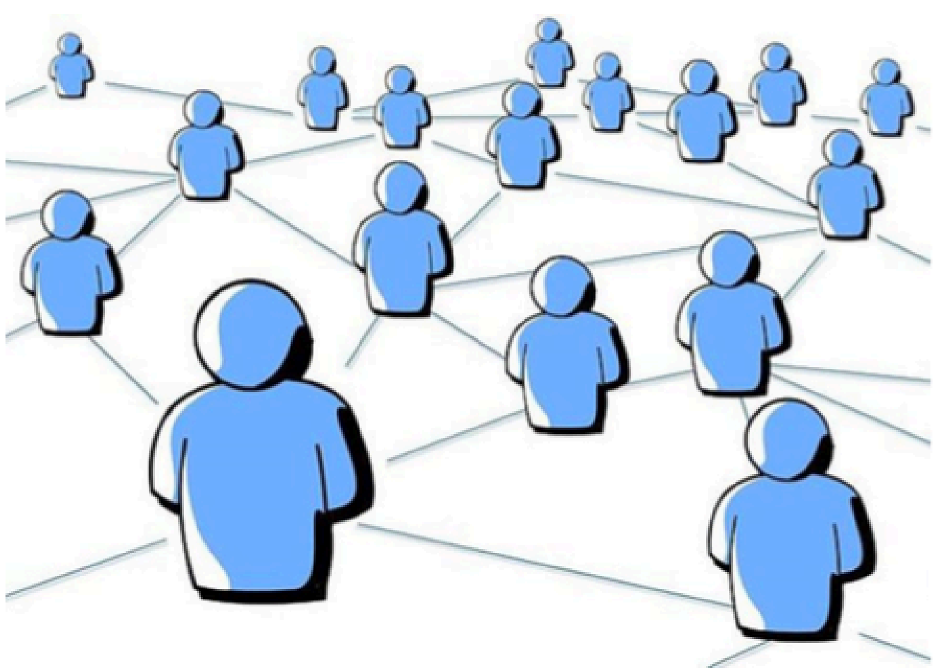
PPPL

Advantages of Using OMFIT for Your Transport Studies with TRANSP



- **One common tool for many tokamaks - only required to learn one interface for DIII-D, NSTX, JET, etc…**
  - We've learned a lot about present and legacy physics assumptions by building a common tool and fostered collaborations



- **Leverage the experience, workflows and visualizations from a large TRANSP user community**
  - No need for each machine/institution/ person to re-invent the same wheel over and over again!
- **Contribute your wisdom, intuition, and productivity capabilities to the community**
  - Propagate to the future, retain institutional knowledge

TRANSP Usage Has Expanded Rapidly Through the Production Capability of OMFIT

DIII-D

László Bardóczi
Igor Bykov
Jie Chen
Luo Chen
Xi Chen
Colin Chrystal
Mitchell Clement
Cami Collins
Lang Cui
William Eggert
David Eldon
Darin Ernst
Jeremy Hanson
Shaun Haskey
Bill Heidbrink
Edward Hinson
Chris Holcomb
Chris Holland
Wenhui Hu
Matthias Knölker

Daniel Lin
Nikolas Logan
Alessandro Marinoni
Joseph McClenaghan
Orso Meneghini
Masanori Murakami
Filomena F Nave
Raffi M. Nazikian
Michio Okabayashi
Dmitriy Orlov
Jai Sachdev
Sterling Smith
Wayne Solomon
Choongki Sung
Kathreen Thome
Benjamin John Tobias
Patrick Vail
Brian Victor
Takuma Wakatsuki
Hexiang Wang

David Weisberg
Robert Wilcox
Theresa Wilks
Maiko Yoshida
Yubao Zhu
Kathreen Thome
Benjamin John Tobias
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Hexiang Wang
David Weisberg
Robert Wilcox
Theresa Wilks
Maiko Yoshida
Yubao Zhu
Brian Grierson

JET

James Buchanan
Michael Fitzgerald
Filomena Nave
Krassimir Kirov
David Keeling
J Ferreia
Fulvio Auriemma
Yuriy Baranov
Francesca Poli
Jacob Eriksson
Ziga Stancar

NSTX

Stan Kaye
Steve Sabbagh
Jai Sachdev
Vlad Soukhanovskii
Brian Grierson
Orso Meneghini

C-Mod

Pablo Rodriguez-Fernanadez

EAST

Lang Cui

CCFE

Existing and Expanding Capabilities for TRANSP in OMFIT Workflow Manager

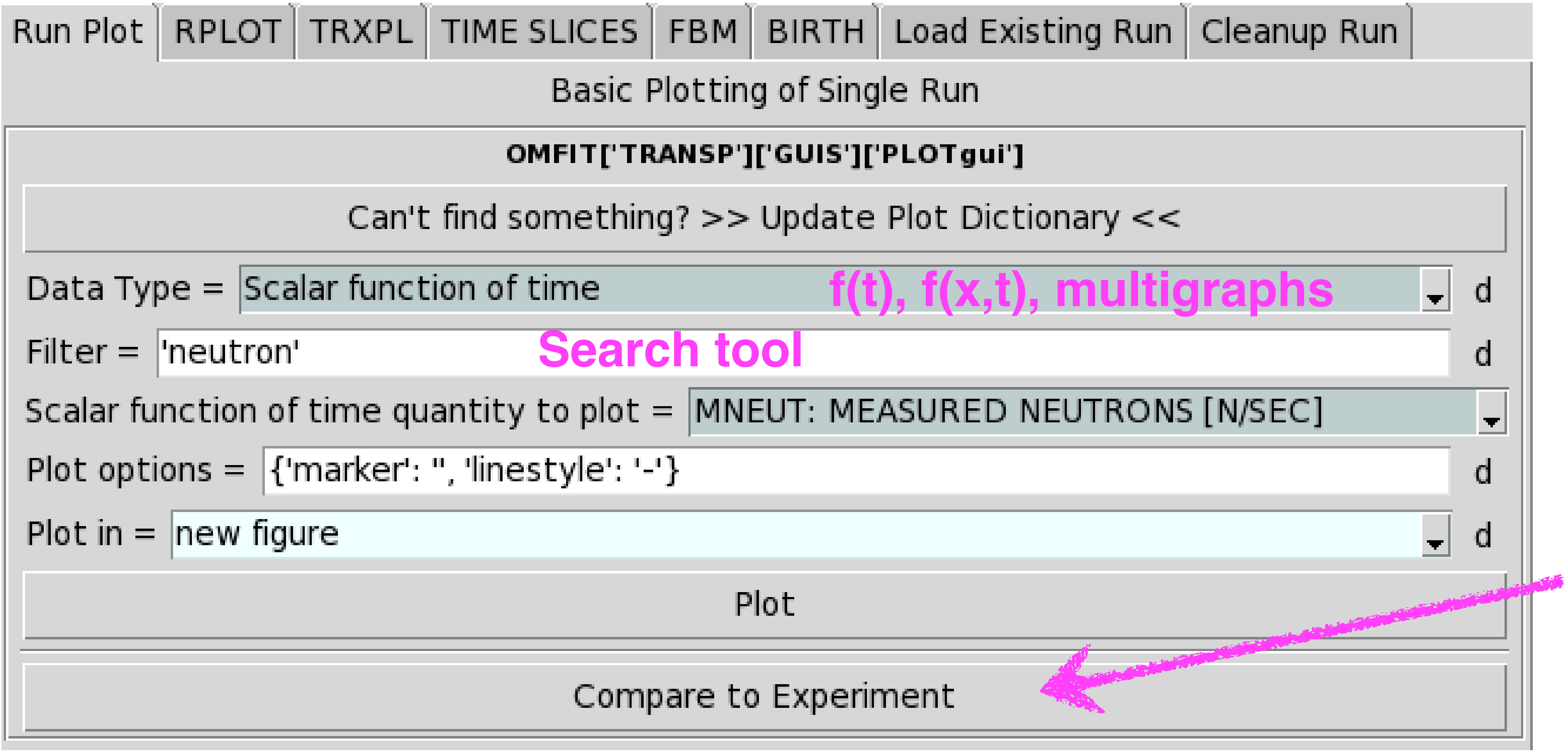
- Prepare and submit TRANSP for DIII-D, NSTX, JET, C-MOD (from MDSplus), EAST (from MDSplus)
- Output modules for TRXPL, TIME_SLICES, GET_FBM (+plotting), BOXN0 (+plotting), birth (+plotting)
- "Compare to experiment" button for verification
- Comprehensive plotting with OMFIT's RPLOT

Has been there a while

- "Flight Simulator" workflow for designing shots (user Ip, Bt, profiles, heating)
- tr_look, tr_cleanup available through the GUI, tr_fetch coming soon for CDF and ACFILEs
- Plotting CDF file output developed in last few week
- Soon search, review plots and export options using CDF file

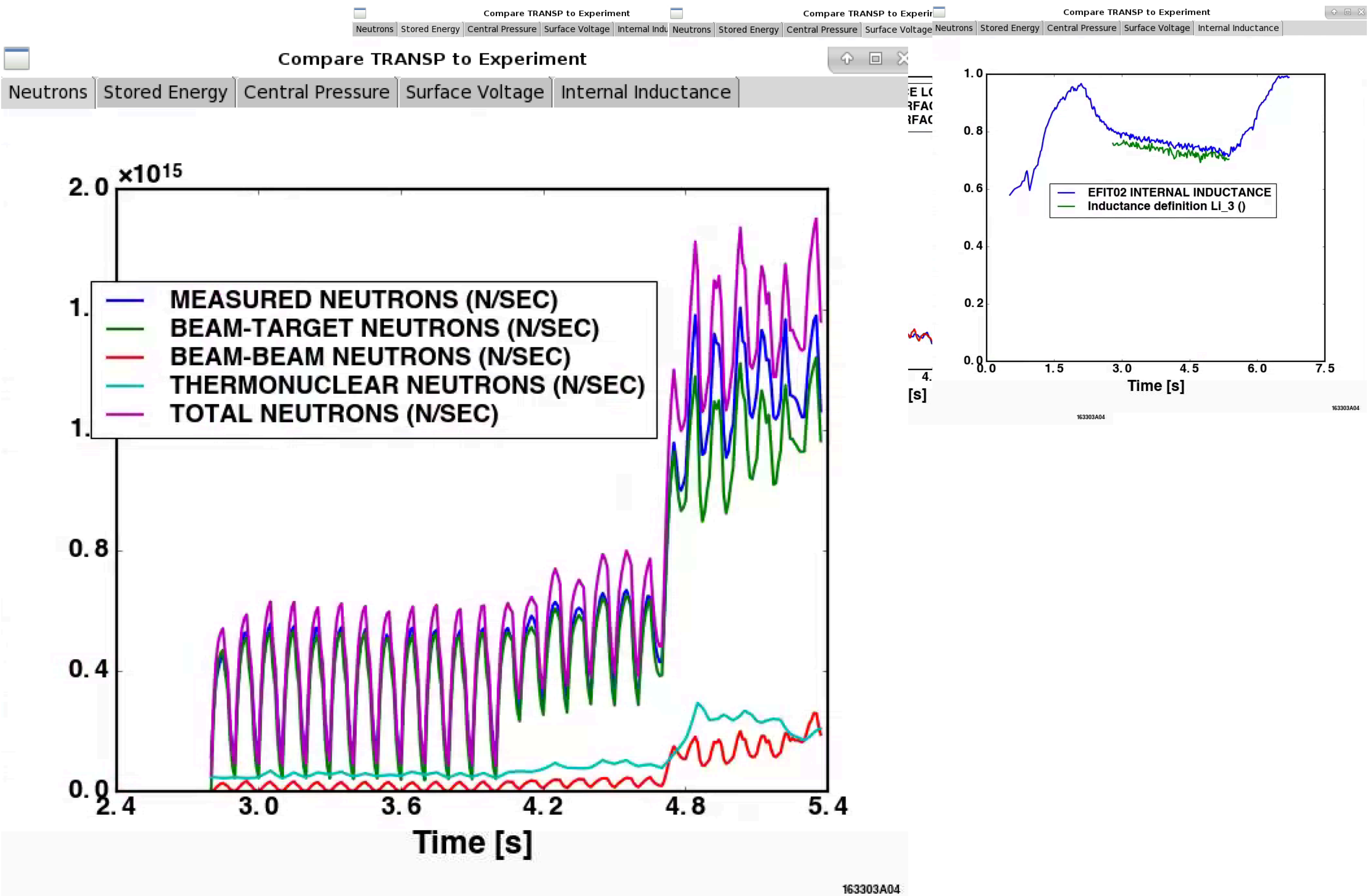
New and coming soon

Common Set of Verification Metrics are Emerging Including Workflows for Assessing Systematic Uncertainties



- **Every analyst requested to put “Compare to Experiment” in their analysis workbooks**

Neutrons, Stored Energy, Central Pressure, Surface Voltage and l_i Plotted For Any Case



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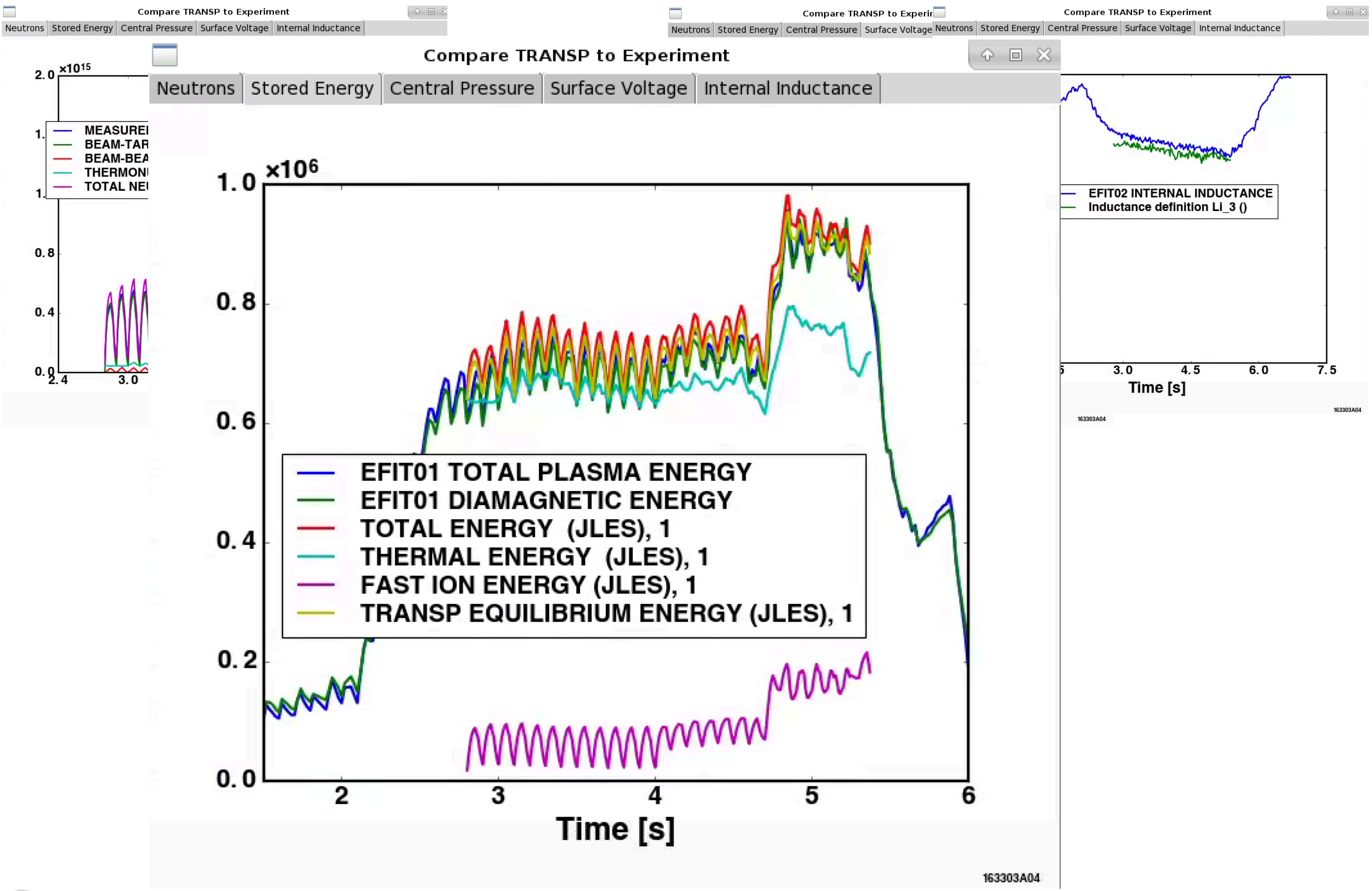

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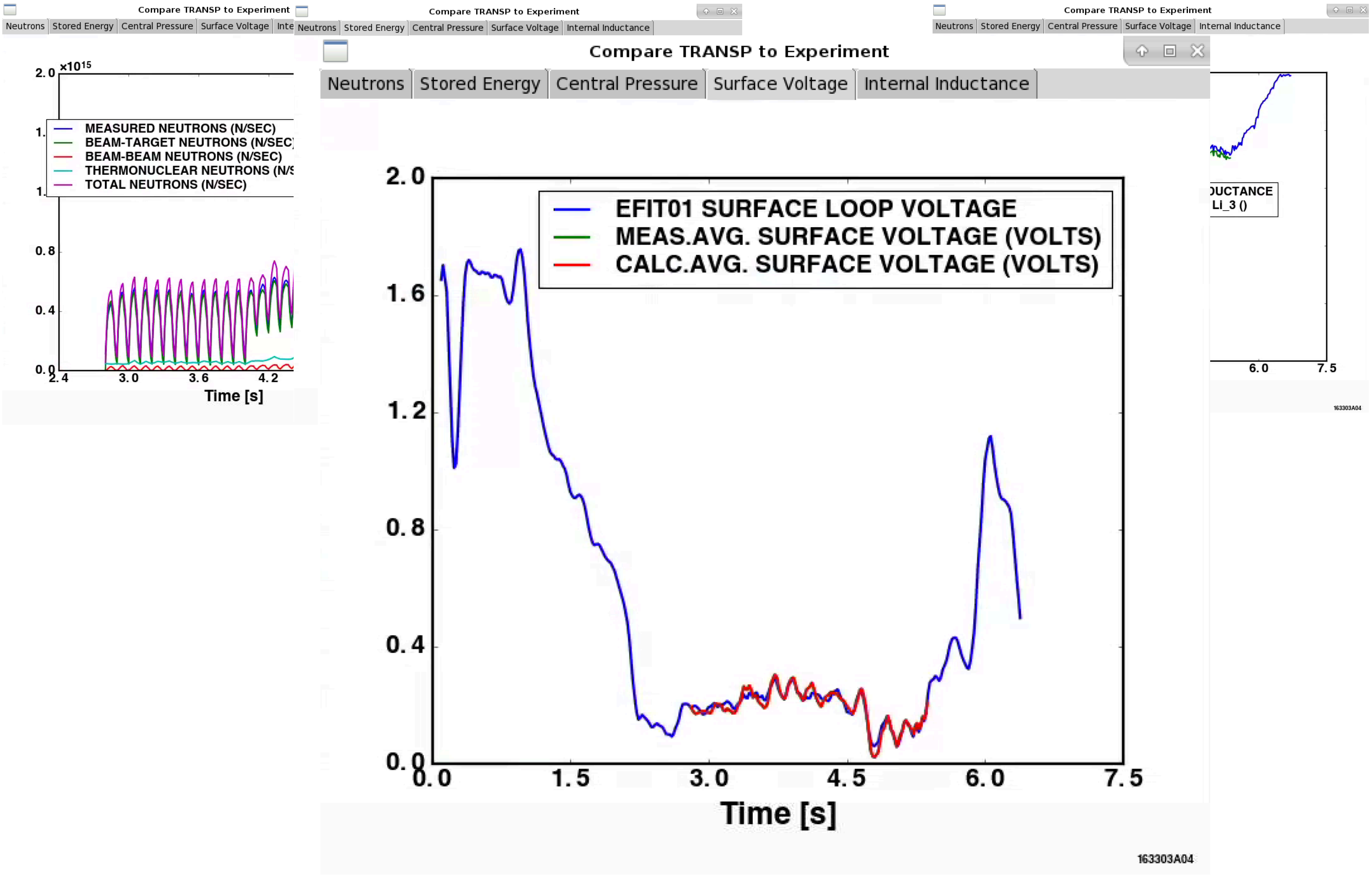

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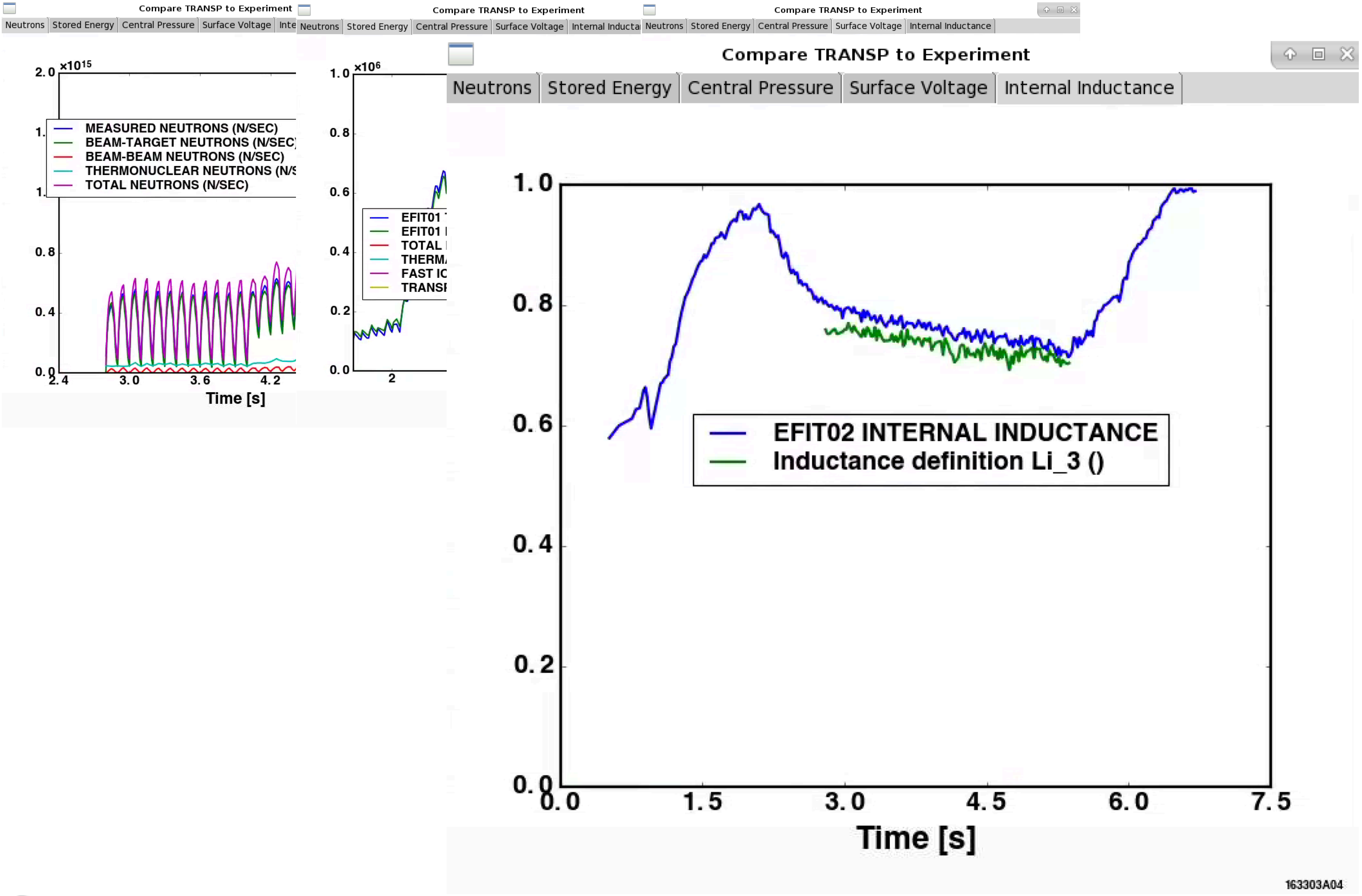
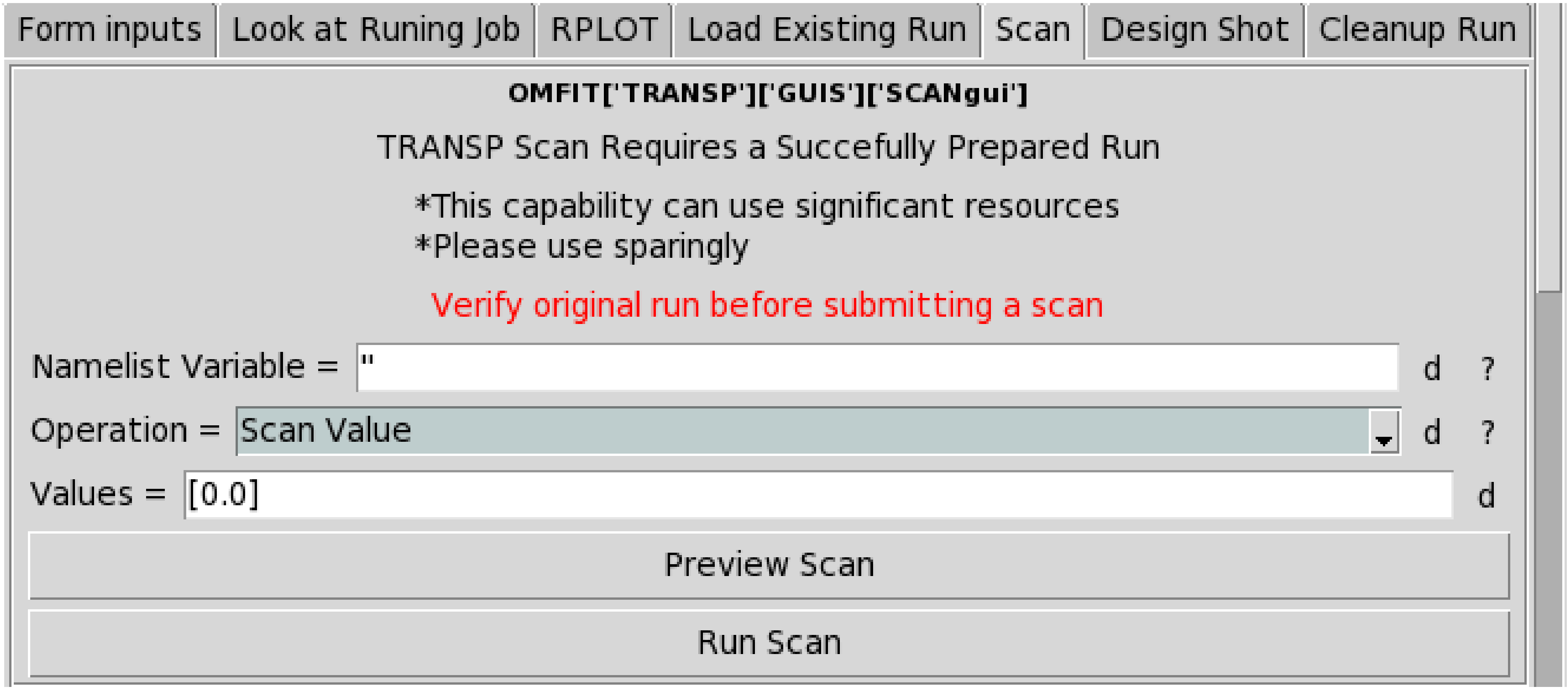
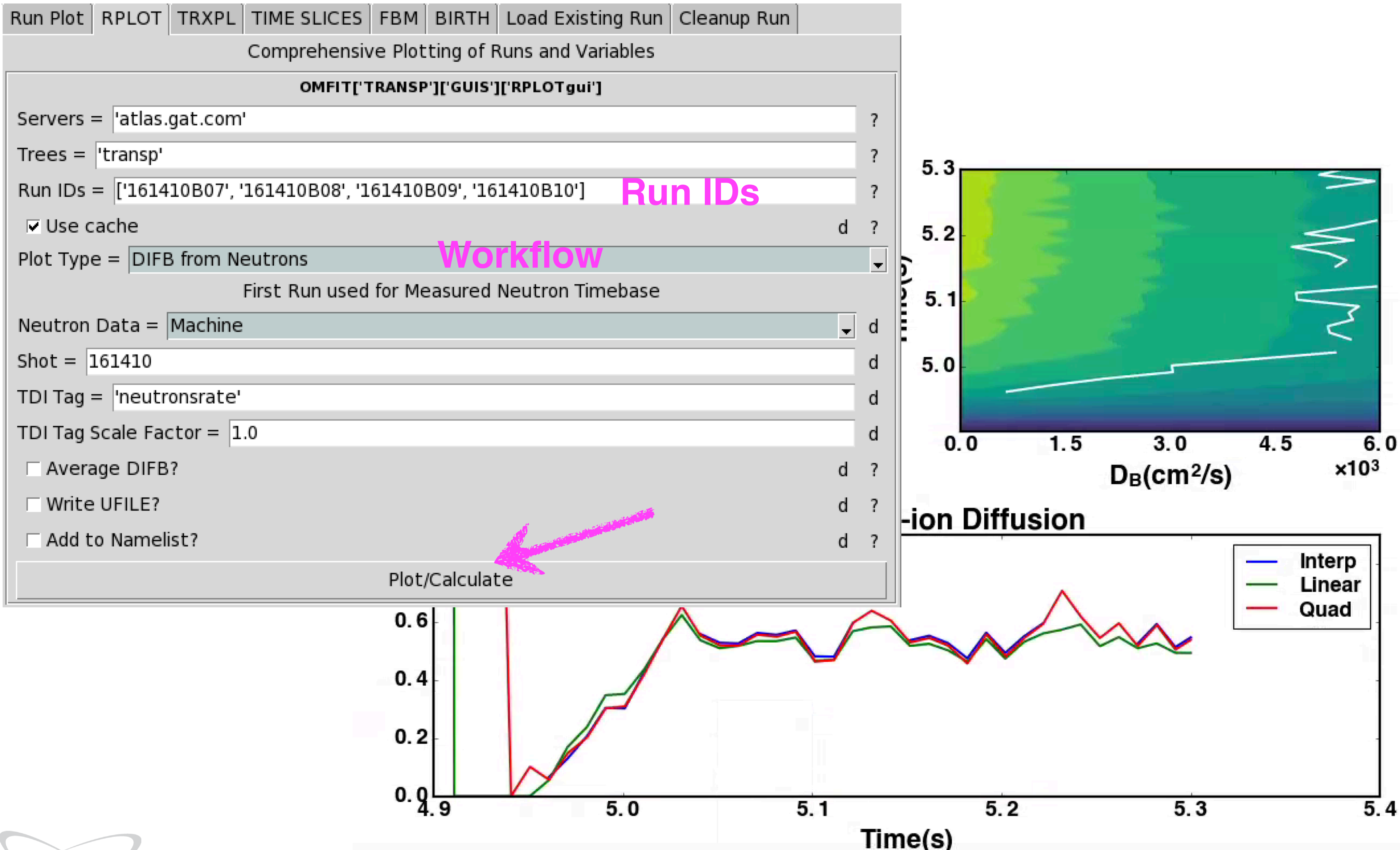


Variable Scan Permits Sensitivity Analysis to Systematic Changes in Profiles



- **Scan fast-ion diffusion, Zeff, etc… for input data consistency and verification**

Scan Fast-ion Diffusion, Create New UFILE, Run



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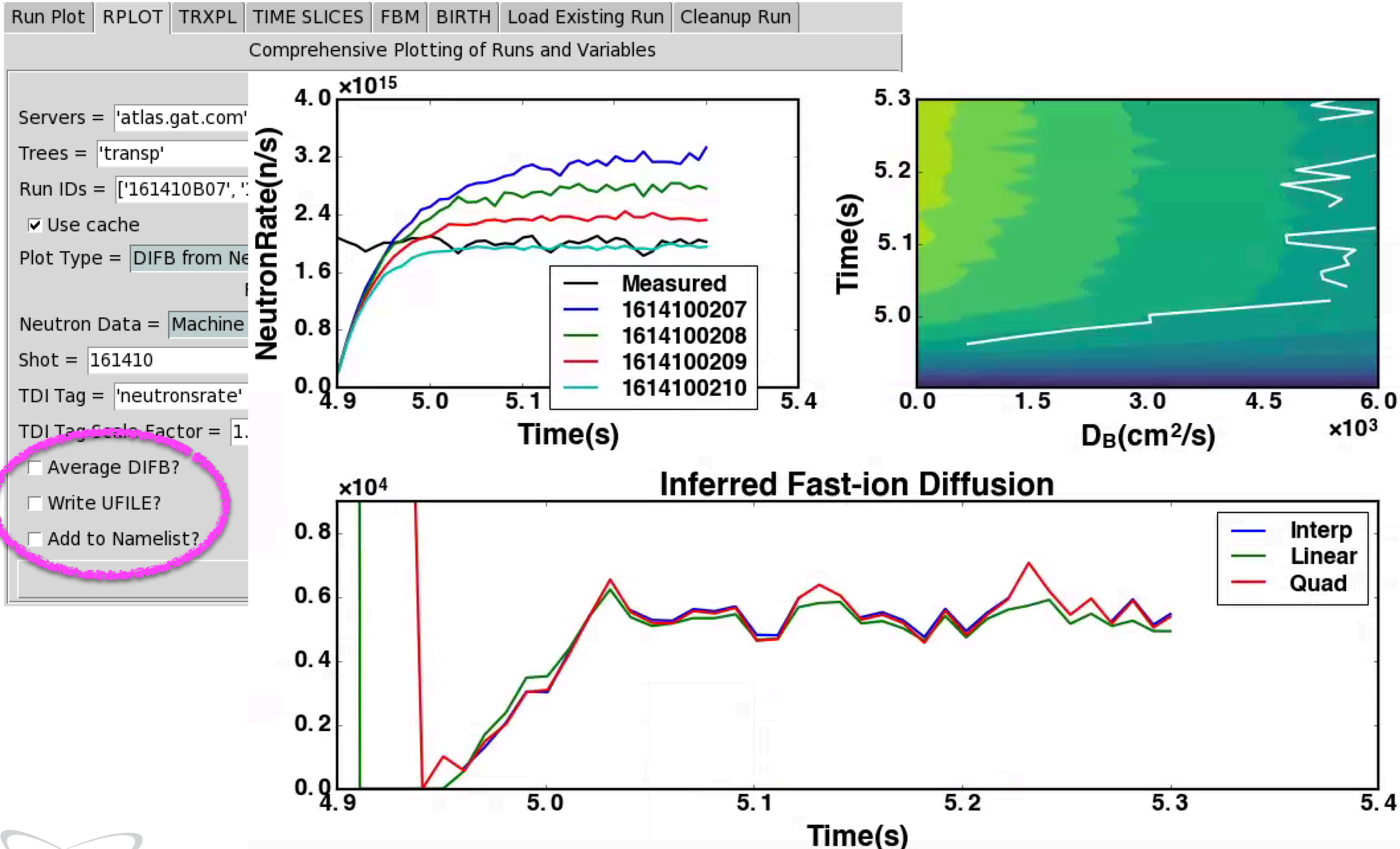
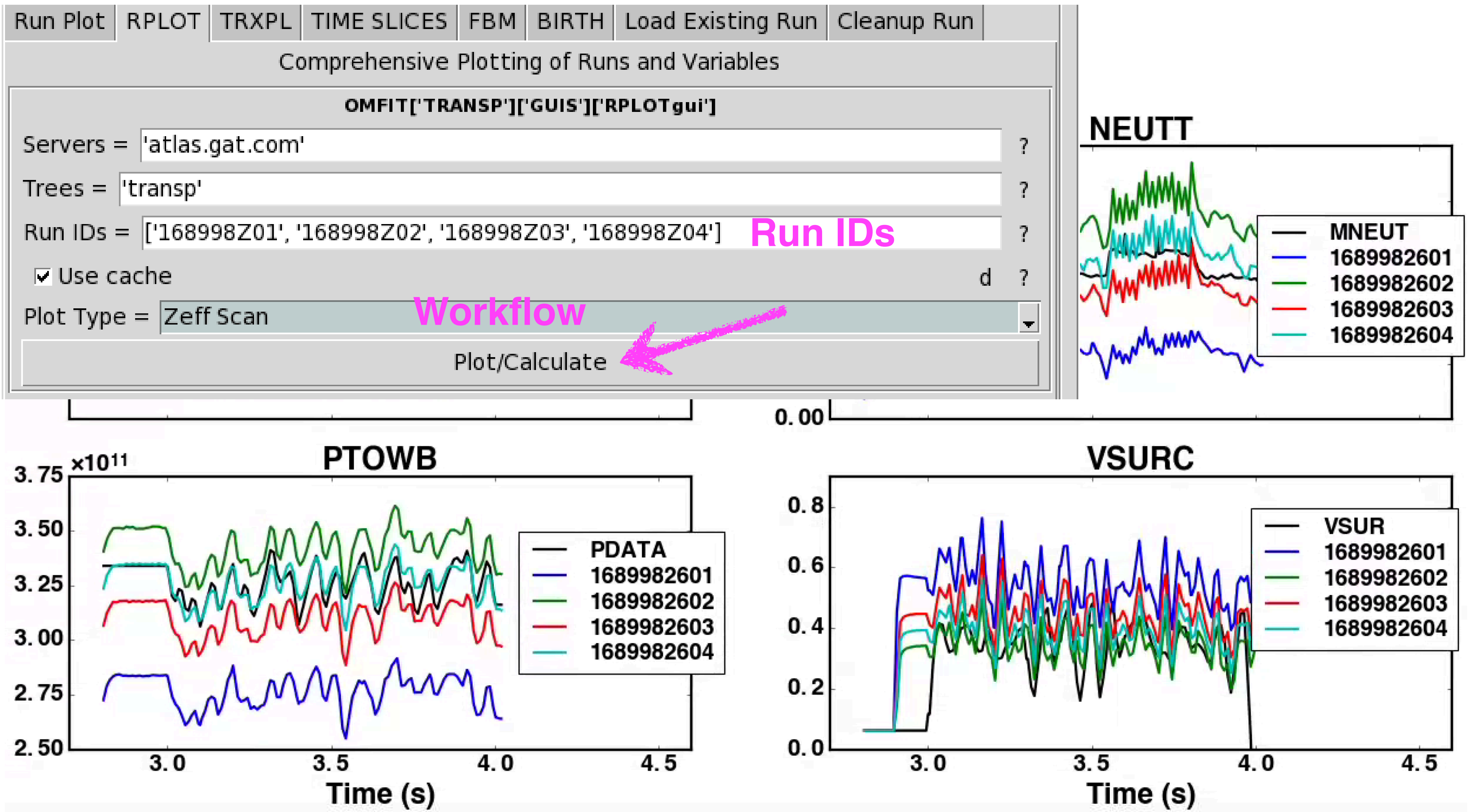
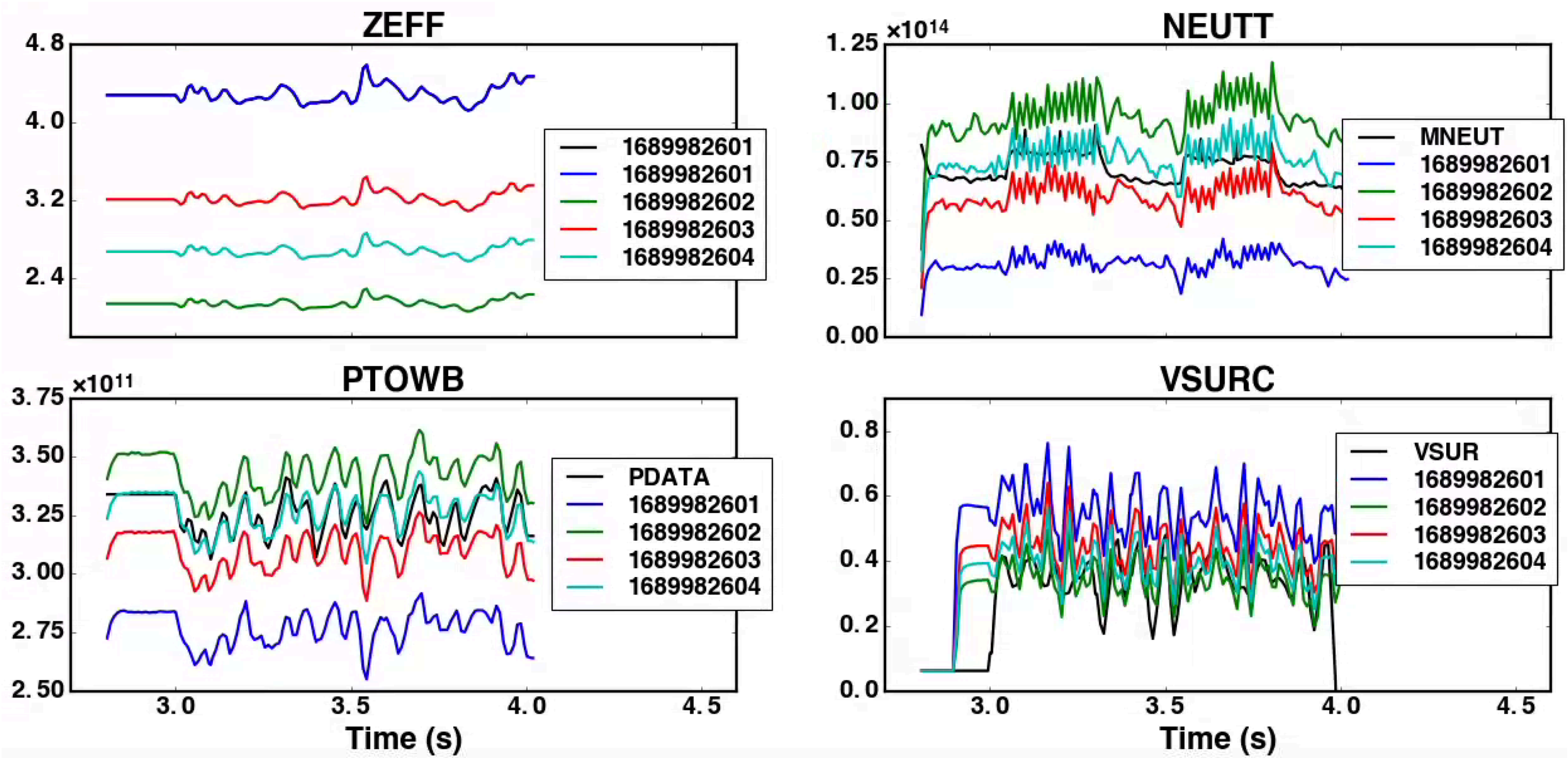


Zeff Scan Leverages Different Sensitivities to Core, Broad and Edge Quantities



Zeff Scan Leverages Different Sensitivities to Core, Broad and Edge Quantities

- `SC_ZF2` **scans Zeff without modifying UFILE data**



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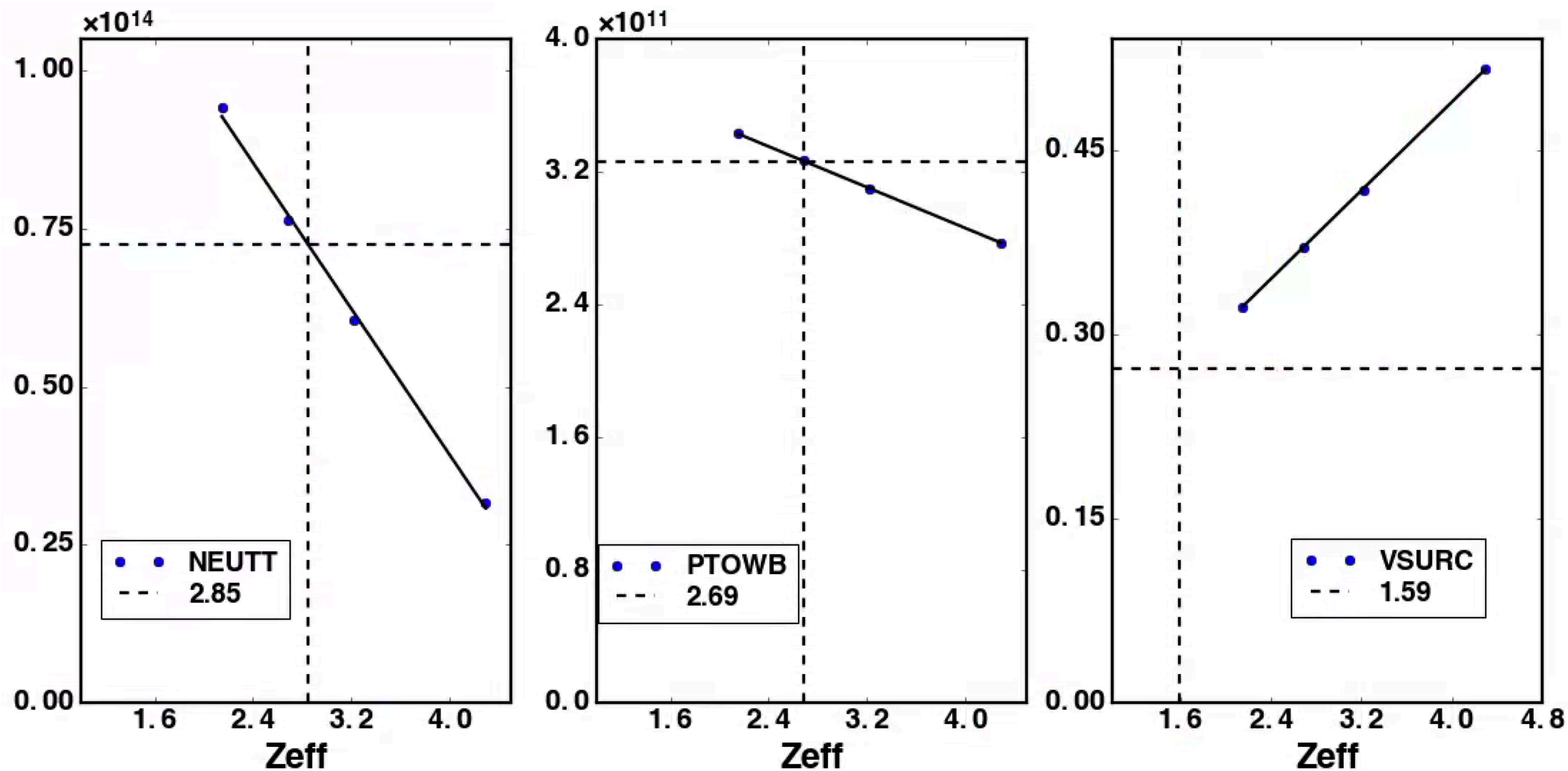
Zeff Scan Leverages Different Sensitivities to Core, Broad and Edge Quantities

- **Slope of response from core neutrons, stored energy and loop voltage are different and opposite sign (for V_{sur})**



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Flipping Inputs and Outputs
→ Interpretive Analysis to Predictive Simulation

- **Predictive runs will replace the transport flux with a transport model**
  - *Transport models* produce flux given gradients (GLF23, TGLF, MMM)
  - *Transport solver* required to solve nonlinear system (PT_SOLVER, TGYRO, FASTRAN)
- **Final result of evolution/iteration matching is a new profile**

Initialize X=X measured

Model flux = $F(a/L_T, a/L_n, T_e/T_i, q, \kappa, \ldots)$
will not match power balance
Evolve/iterate until matches
→ predicted profile

New profiles for gradients and sources

$$\partial X/\partial t + \nabla \cdot \mathbf{F} = S$$

~~measured~~
predicted
i.e. $X \equiv n_e(\rho,t)$

Computed with model
$S = S_{beam}+S_{wall}-S_{recom.}$

Computed with model
$F = \Gamma_e$ from TGLF

New gradients for profile

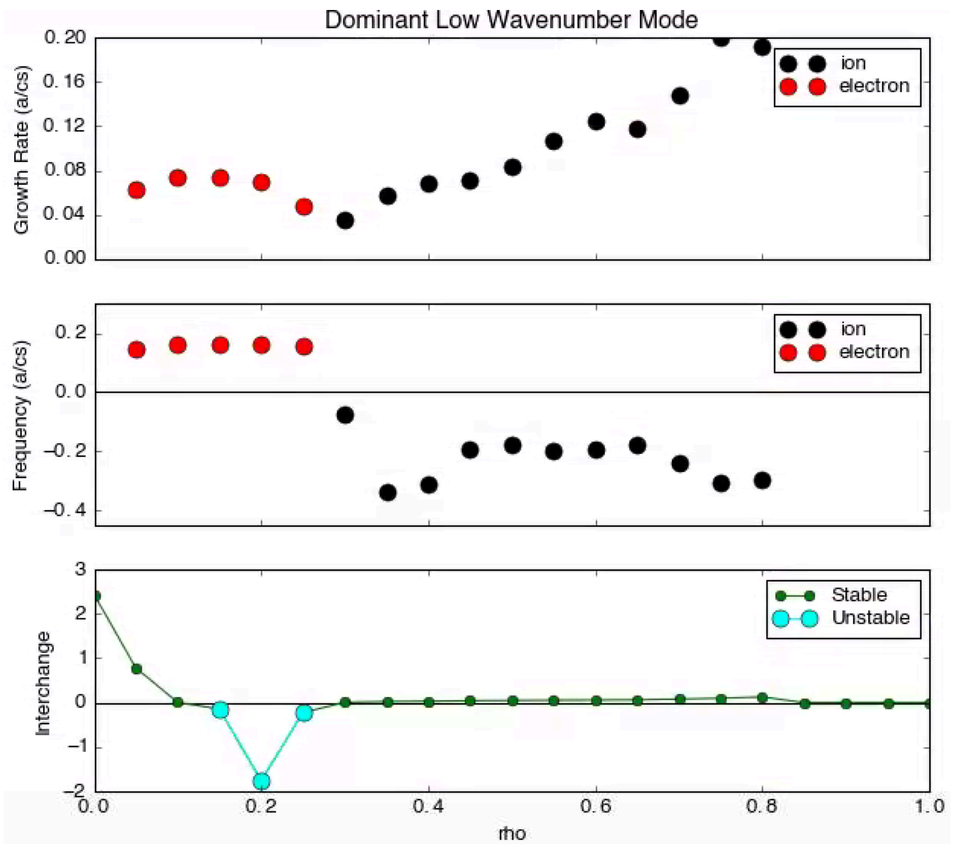
TRANSP PT_SOLVER Available as Standalone for Anyone with Direct Login to PPPL Computers Driven by OMFIT Workflow

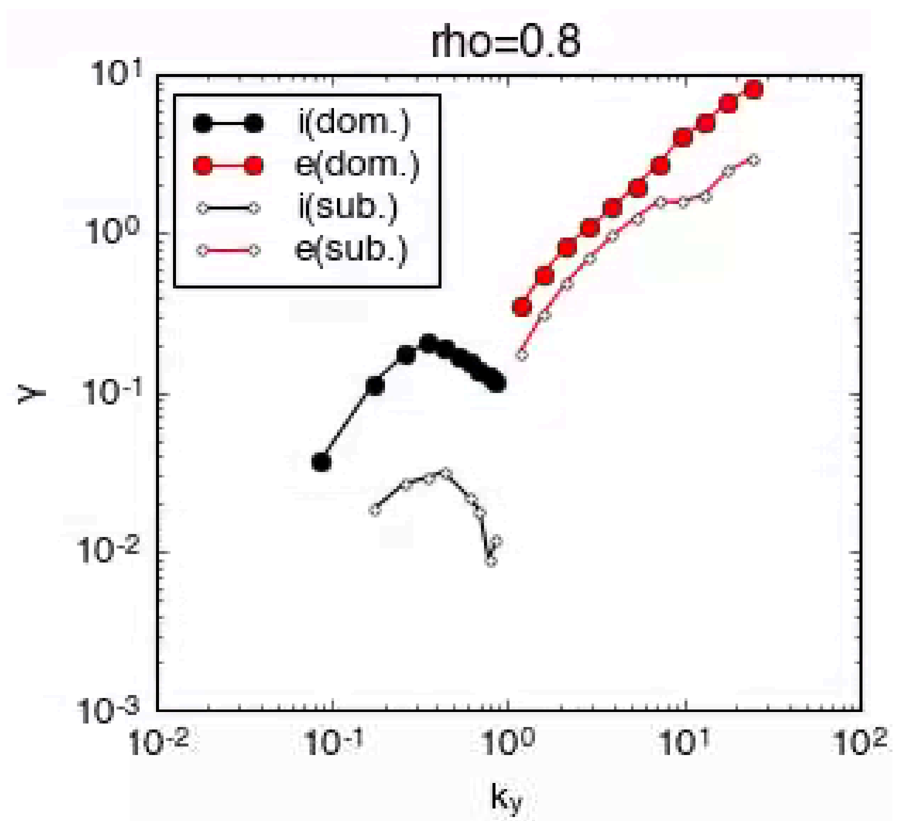
- **Select relatively stationary time in discharge and average with TRXPL**
  - "Ramping" conditions inappropriate for snapshot analysis; flux can be negative
- **Note Q_e, Q_i from TRANSP depend on Te/Ti so power balance flux re-computed at each time step "dynamic exchange"**
- **Produces predicted profiles inside of boundary condition**

$$\partial X/\partial t + \nabla \cdot \mathbf{F} = S \qquad X(\rho) = X^* \exp[\int d\rho\, a/L_X(\rho)]$$

$\partial X/\partial t \rightarrow$ 0 as t→∞

Profile B.C. Flux-matching





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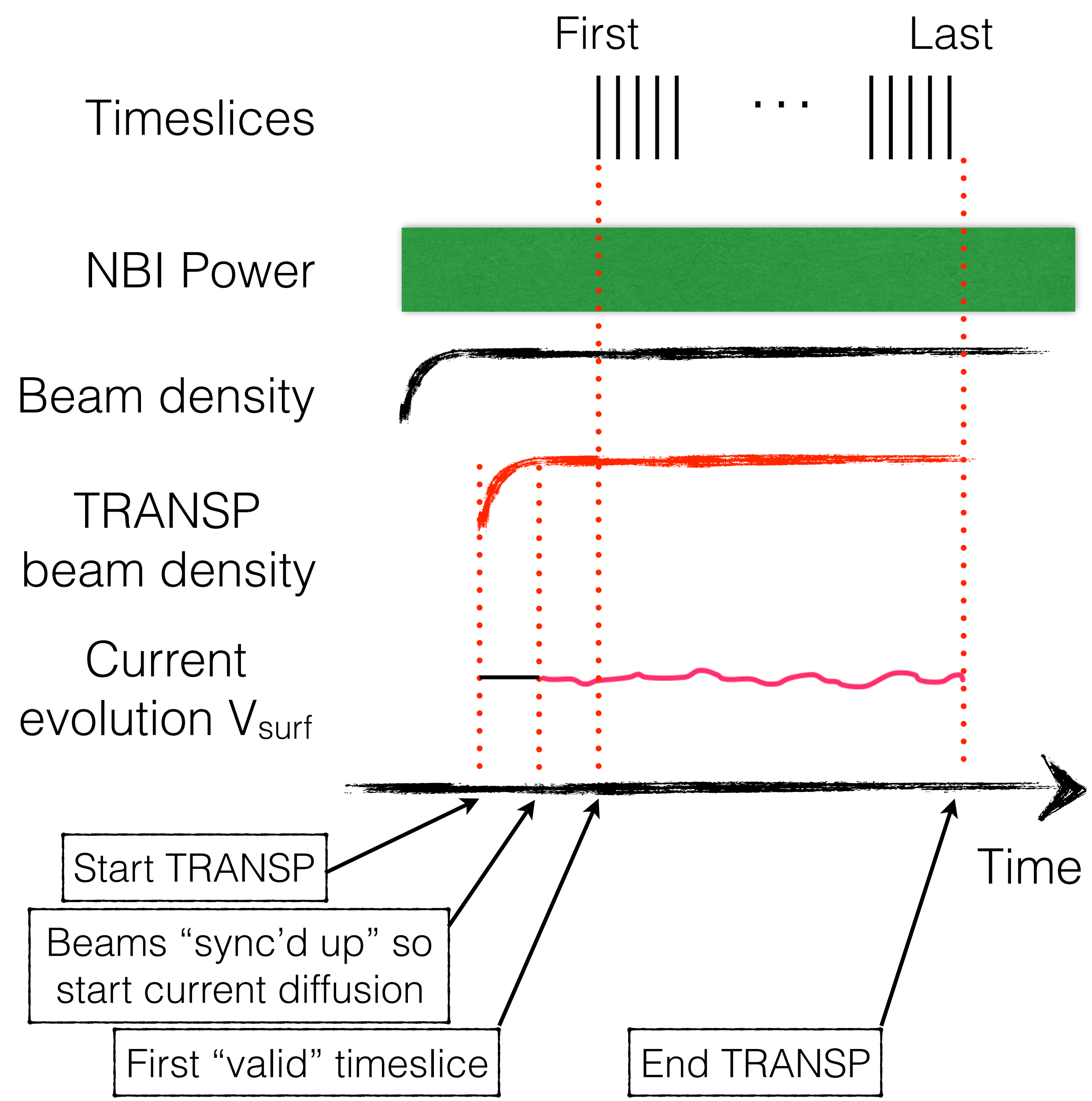
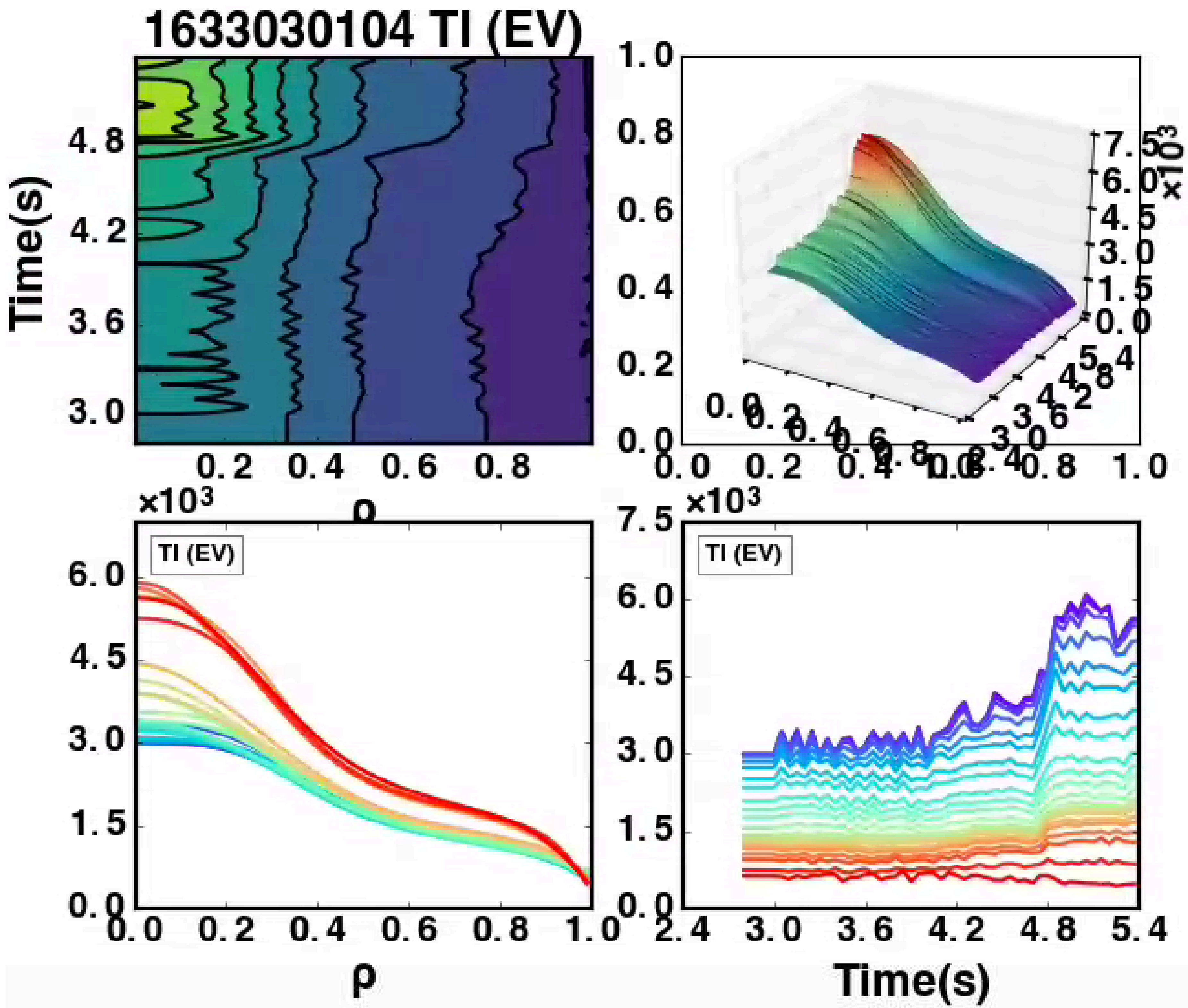
Time-Dependent Prediction Permits Time-Evolving Equilibrium, Profiles and External Actuators

- **TRANSP run initialized without auxiliary heating**
  - Predictive run may begin during high power phase; high temperature but effectively zero source
- **Requires time for beams to "build up" synchronizing profiles and heating sources**
- **Prediction carries profiles forward after transient establishment of power balance flux matching**



Result of Time-Dependent Predictive Simulation is Evolving Profiles and Anything Derived Therefrom

- **Measured**
- Simulated



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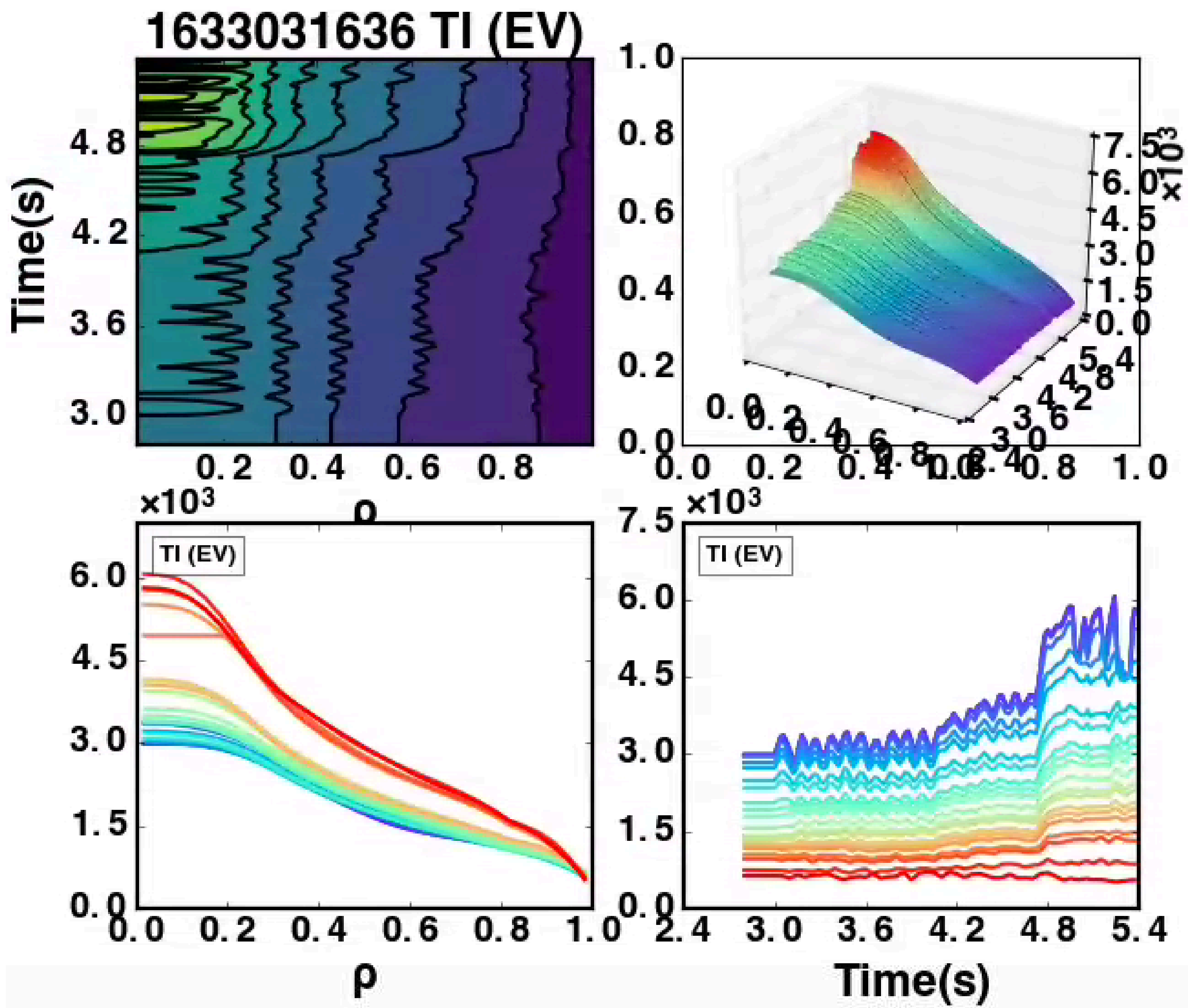
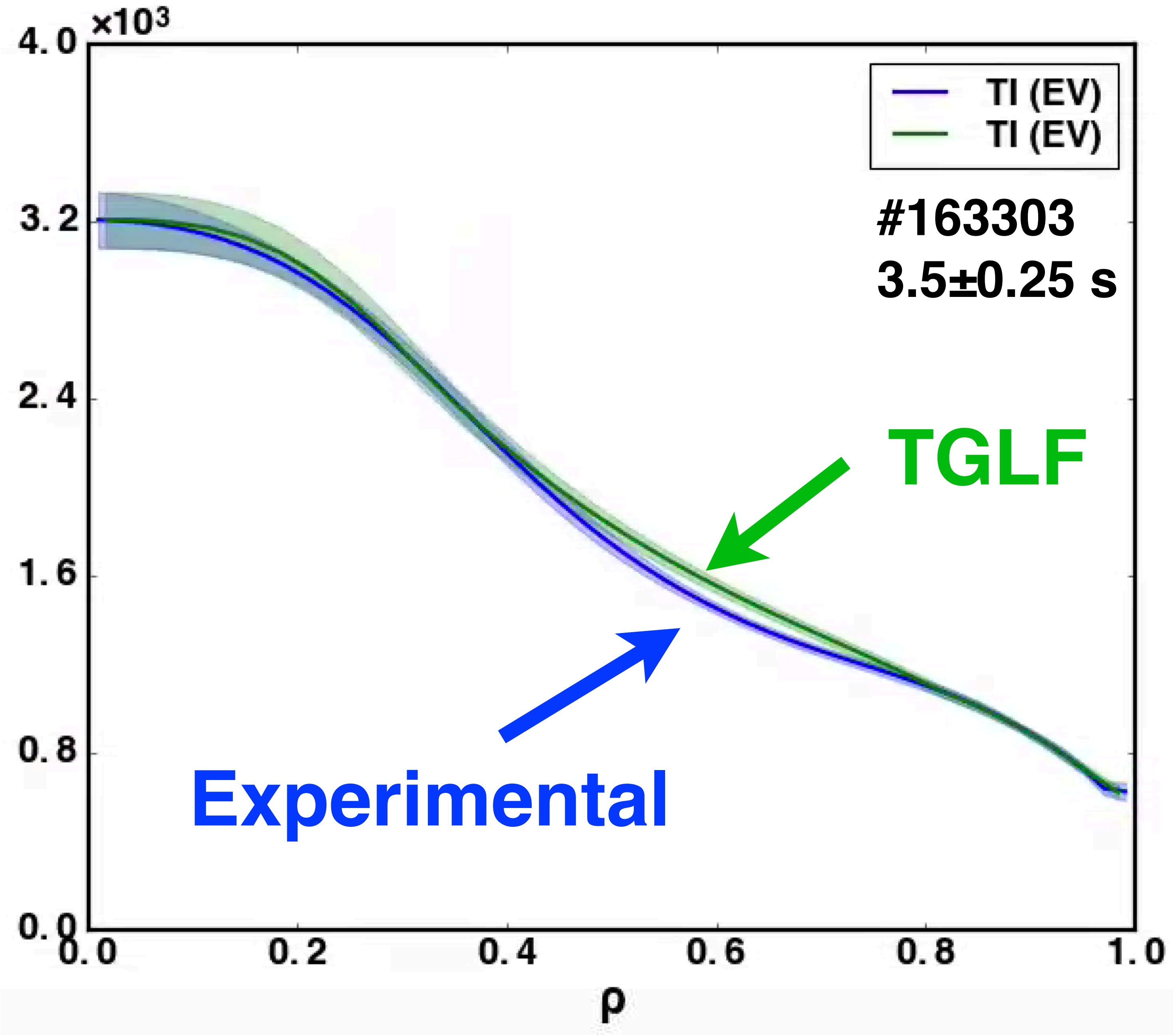


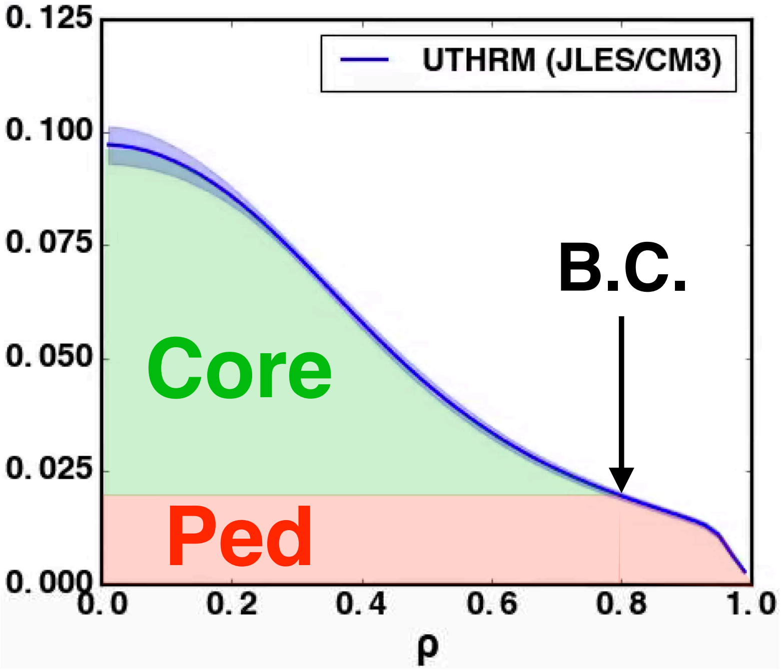
Result of Time-Dependent Predictive Simulation is Evolving Profiles and Anything Derived Therefrom

- Predict T_e or n_e?
  - Will get different resistivity, li, V-s consumption, bootstrap current
- Predict T_i?
  - Will get different neutron rate



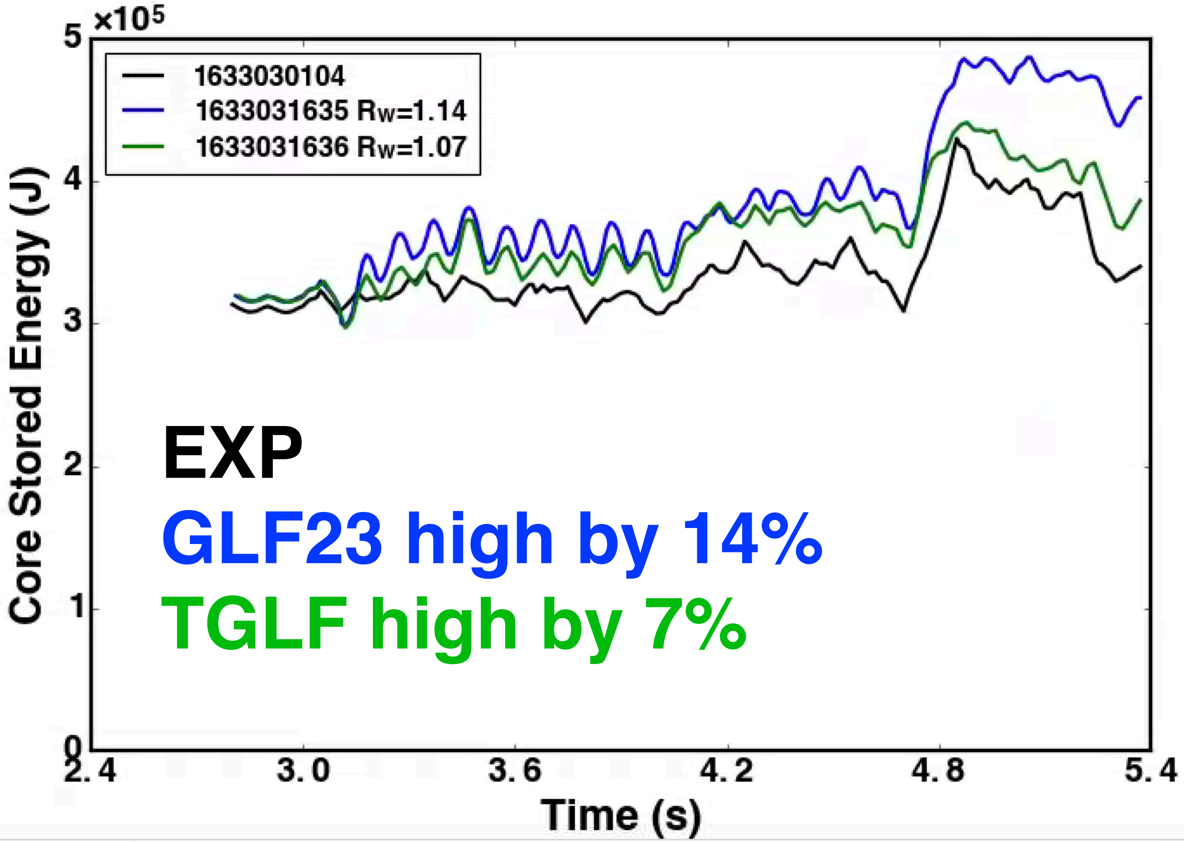
Predictive TRANSP Provides Profiles and OMFIT Computes ITPA Validation Metrics

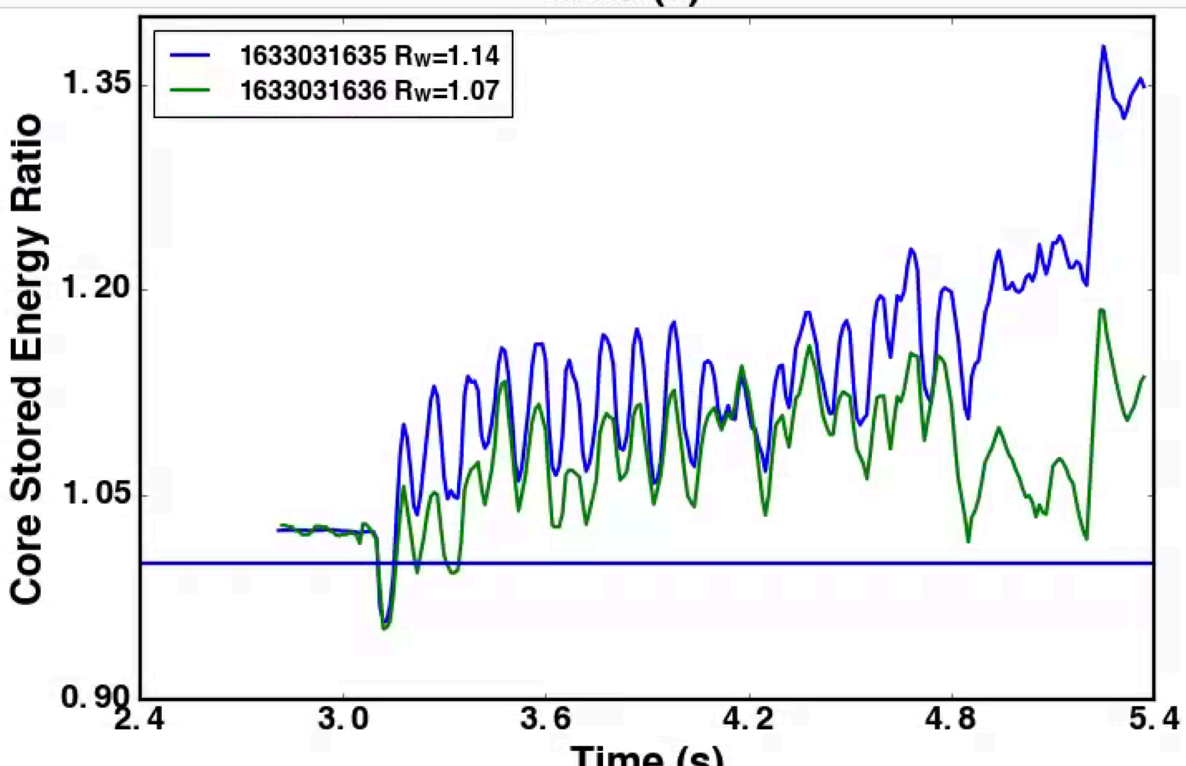
- So how did TGLF do?
- ITPA profile metrics *quantify* transport model *accuracy*



$W = \int \delta V(\rho) U_{core}(\rho) d\rho$

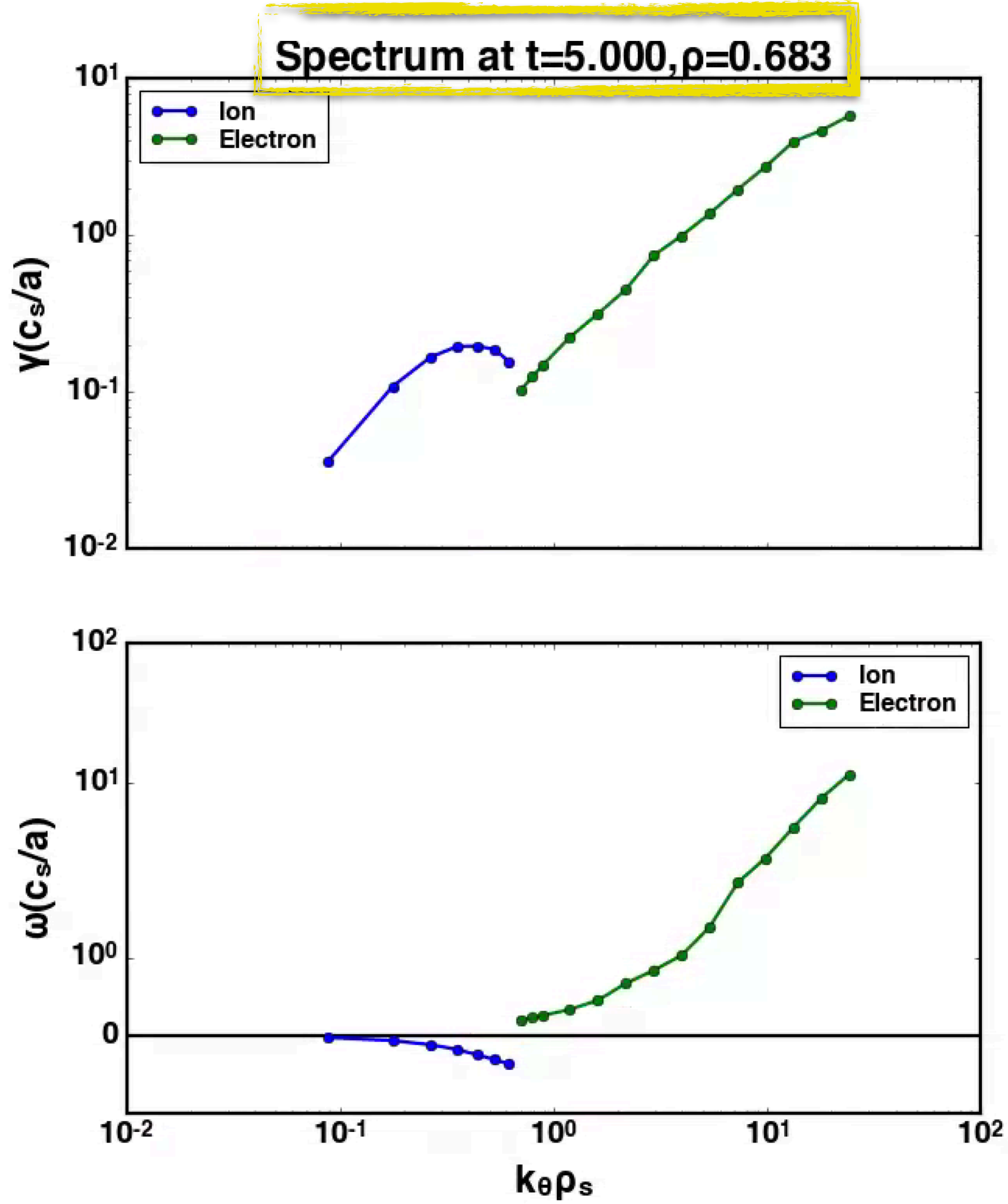
$R_W = W_{sim}/W_{exp}$





Predictive TRANSP Provides Turbulence Spectrum and OMFIT Provides ITPA Validation Metrics

- **Profiles provide performance prediction but the physics is in turbulence spectrum**
  - Say more here
- **Growth rate $\gamma(k_y)$ and frequency spectrum $\omega(k_y)$ produced at each radius and each time**
  - Tells you if ITG/TEM/ETG, etc…



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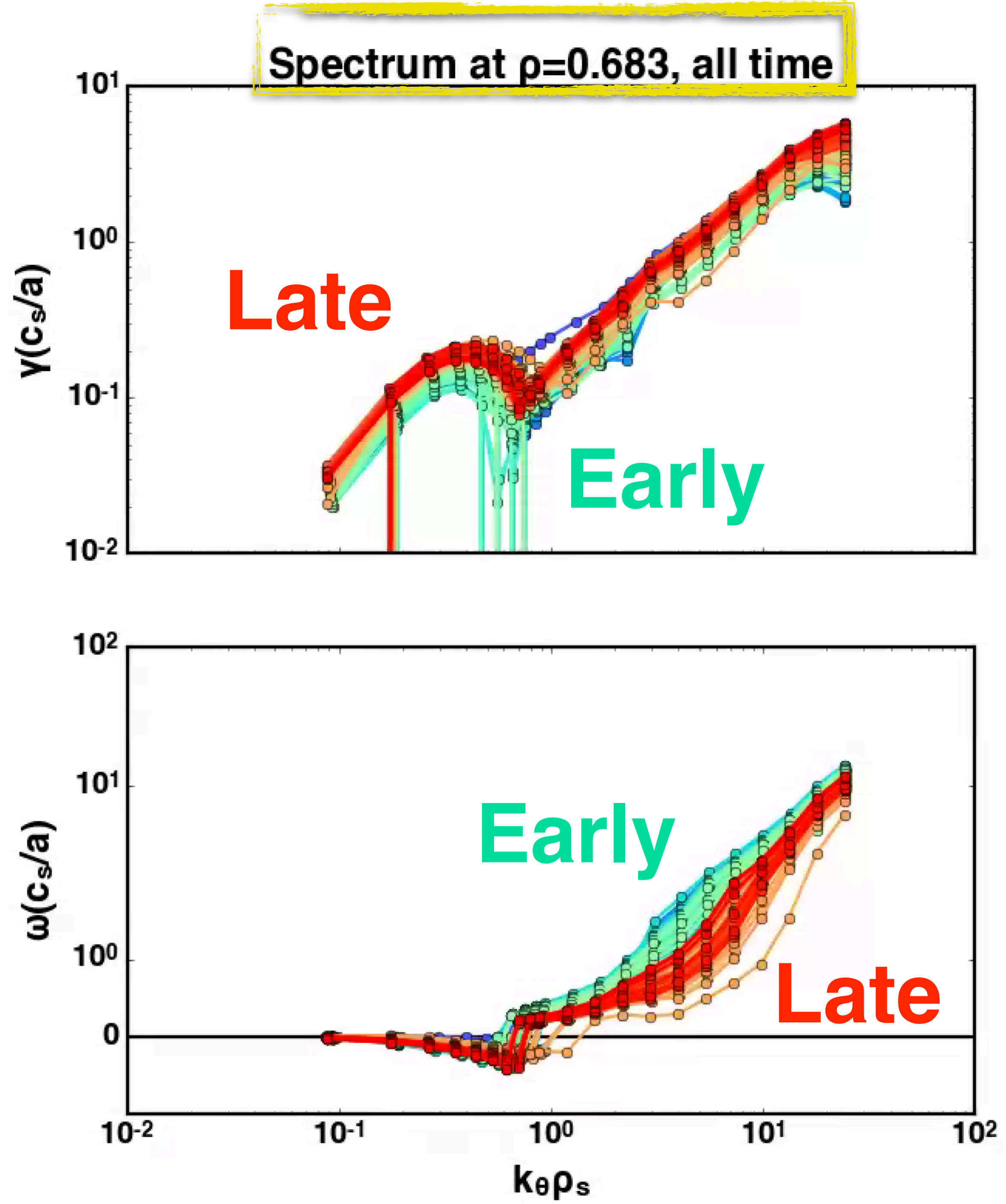

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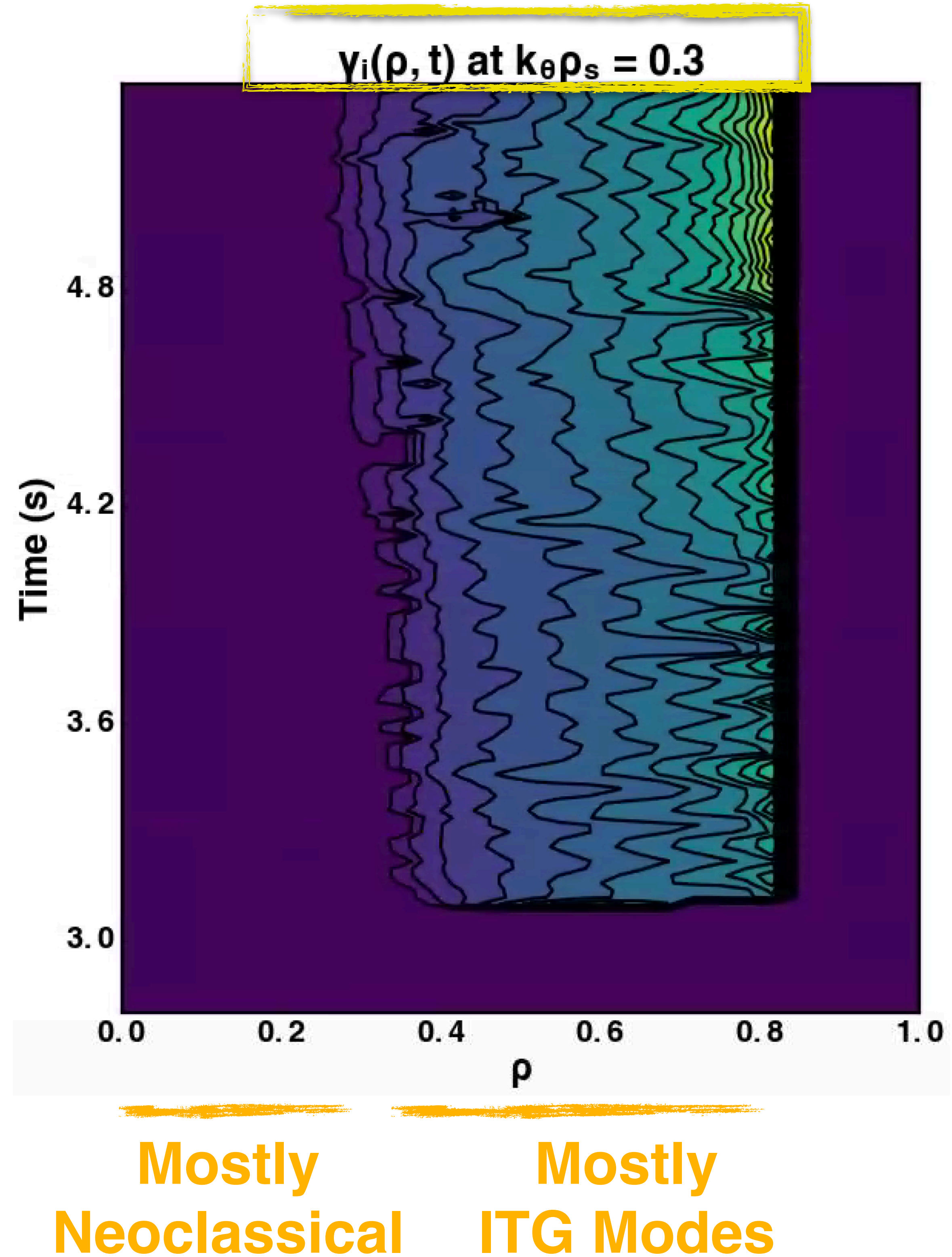


OMFIT is Integrating TRANSP as a Component in a Workflow Manager for Analysis and Design Tool

- **Commonly, TRANSP preparation tools at the various labs assume existing tokamak data**
  - i.e. trSetup [shot], DIII-D autotransp tools, etc…
- **OMFIT allows you to “drop in” H&CD from a different shot**
- **OMFIT “design shot” workflow requires only equilibrium boundary shape and user can design entire discharge**

Designing a New Experiment as Tokamak "Flight Simulator" in OMFIT

- **Critical step is establishing the "controllable" quantities**
  - Equilibrium boundary shape, toroidal field, plasma current and H&CD powers (timing, aiming) typically delivered by pre-program request and feedback
- **Assumptions about the pedestal are typically required**
  - Self-consistent time-dependent core +pedestal modeling is an emerging capability
- **OMFIT allows you to seamlessly replace experimental data with "designed conditions"**

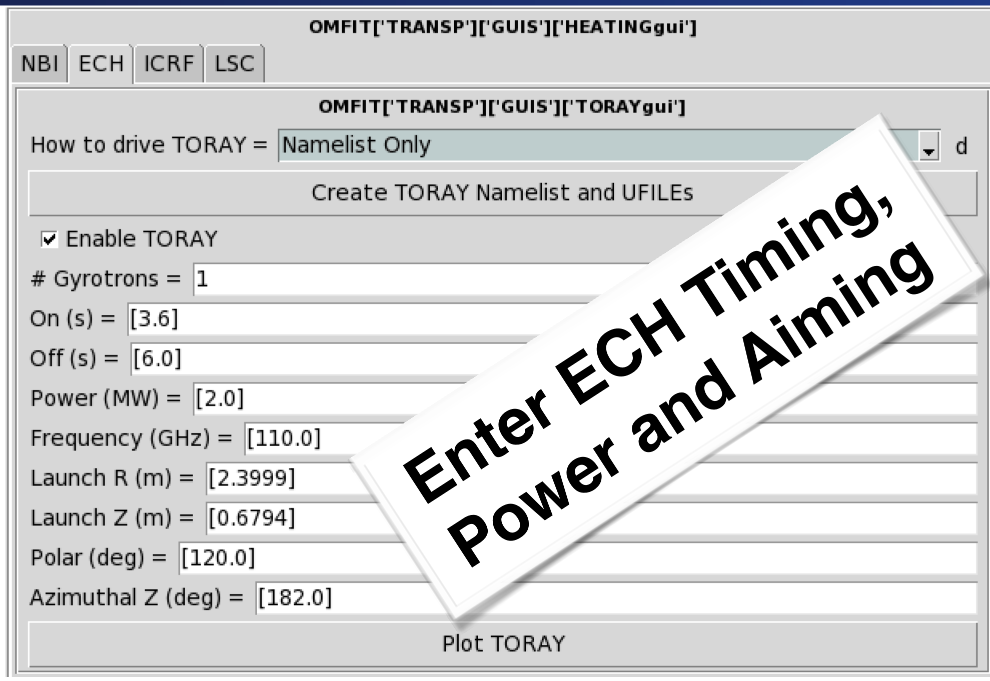
"Flight Simulator" Requirements

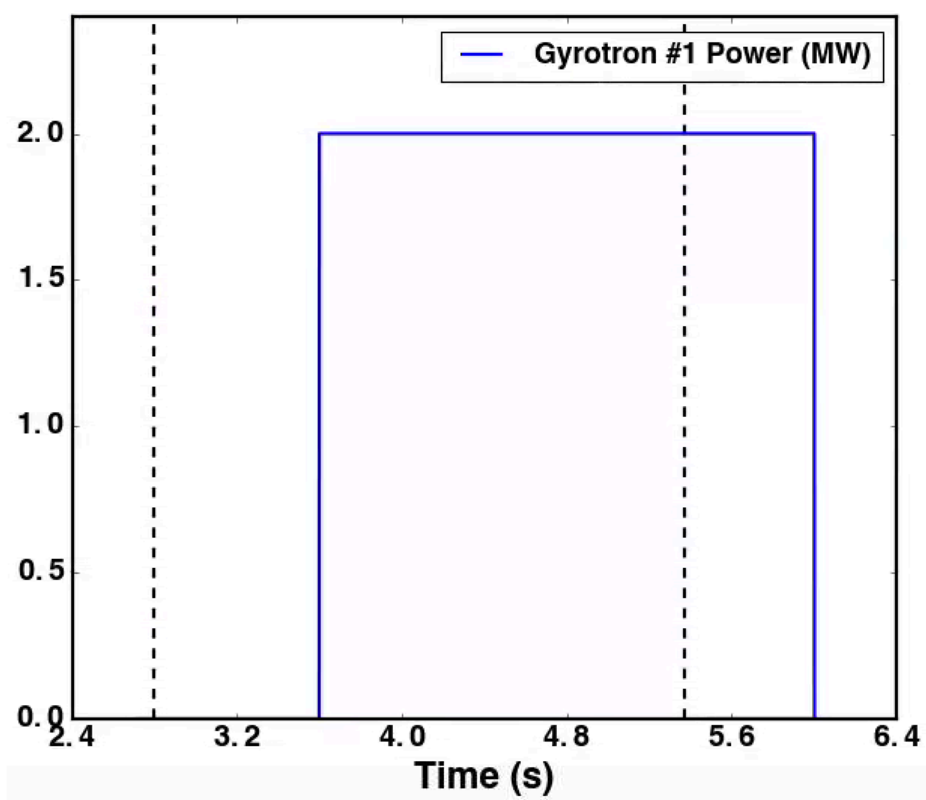
- **Boundary shape from reference EQ**
- **$B_t(t)$, $I_p(t)$, $V_{sur}(t)$ control points**
- **Heating systems aiming, timing and power**
- **Initial profiles**
- **Pedestal profiles (n_e, T_e, T_i, Ω) and Z_{eff}**

"Flight Simulator" Can Predict

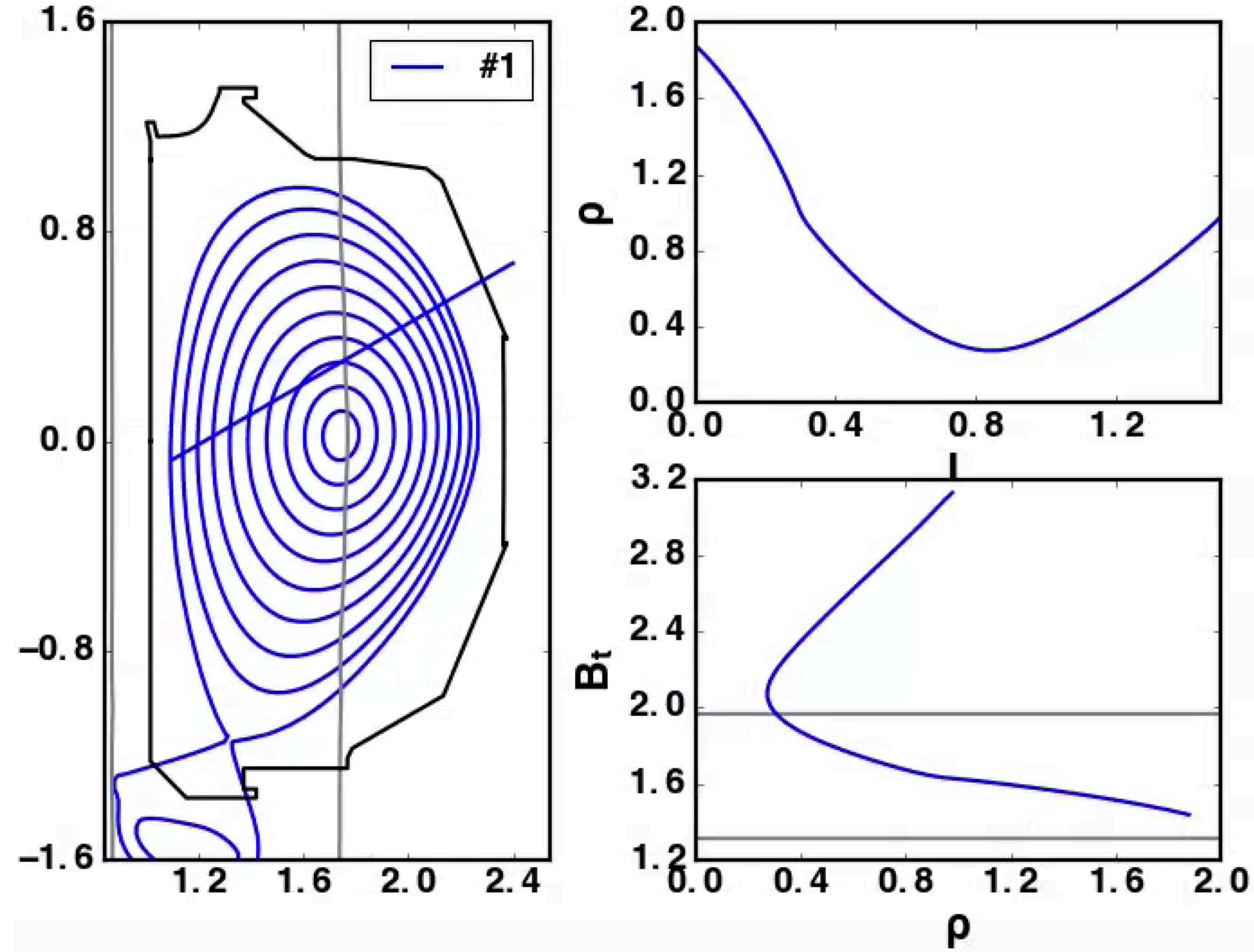
- **Core profiles (ne, Te, Ti, Ω), stored energy, performance**
- **Current and q-profile evolution**
- **Free-boundary equilibrium**
- **Diagnostics (MSE, CO2)**

One of the Simplest Relevant Examples is Adding ECH Power to Existing NBI Heated Shot



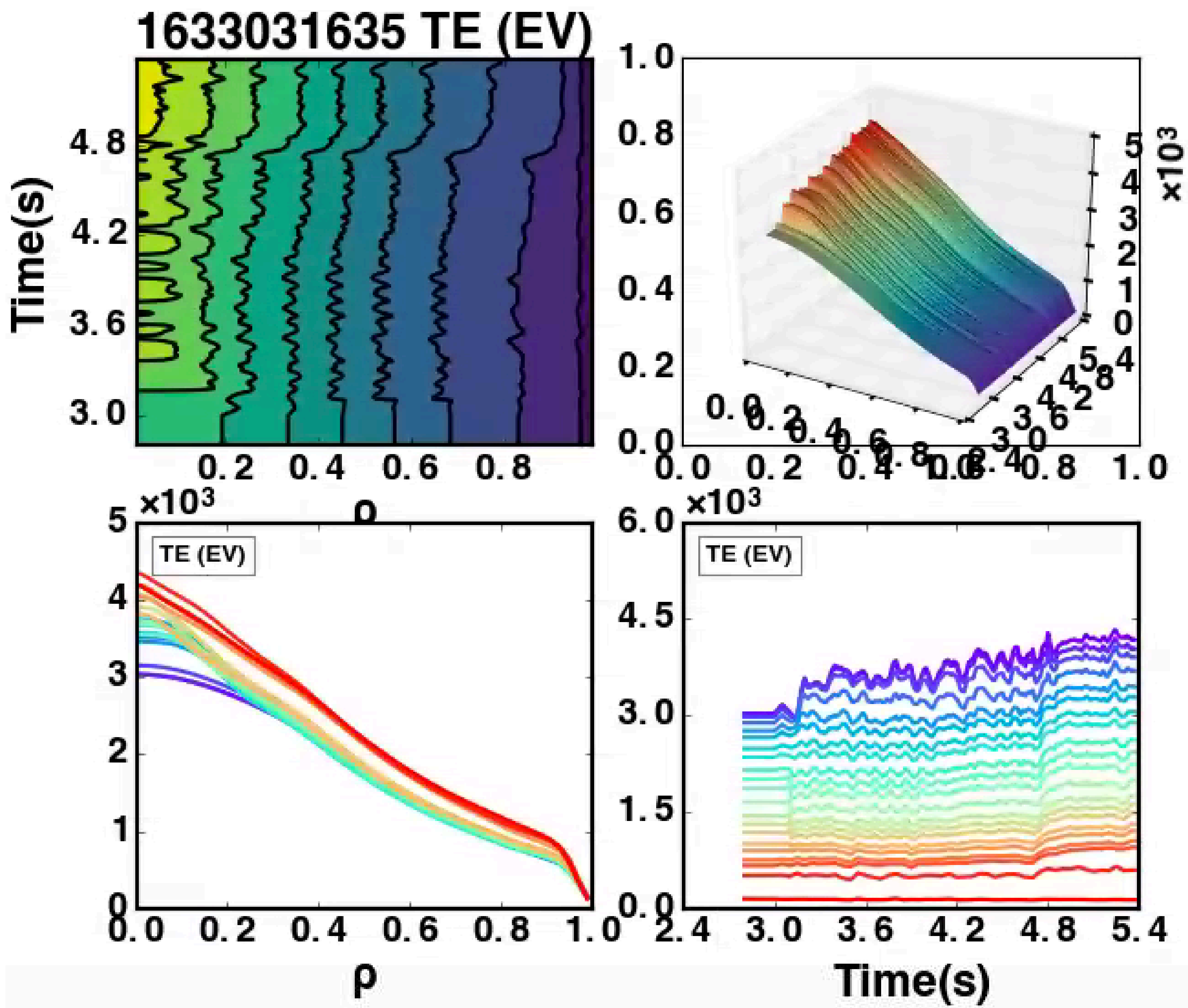


- **Program the ECH and NBI and then predict what will happen**



Result of Time-Dependent Predictive Simulation is Evolving Profiles and Anything Derived Therefrom

- **Simulation**
- Simulated with ECH



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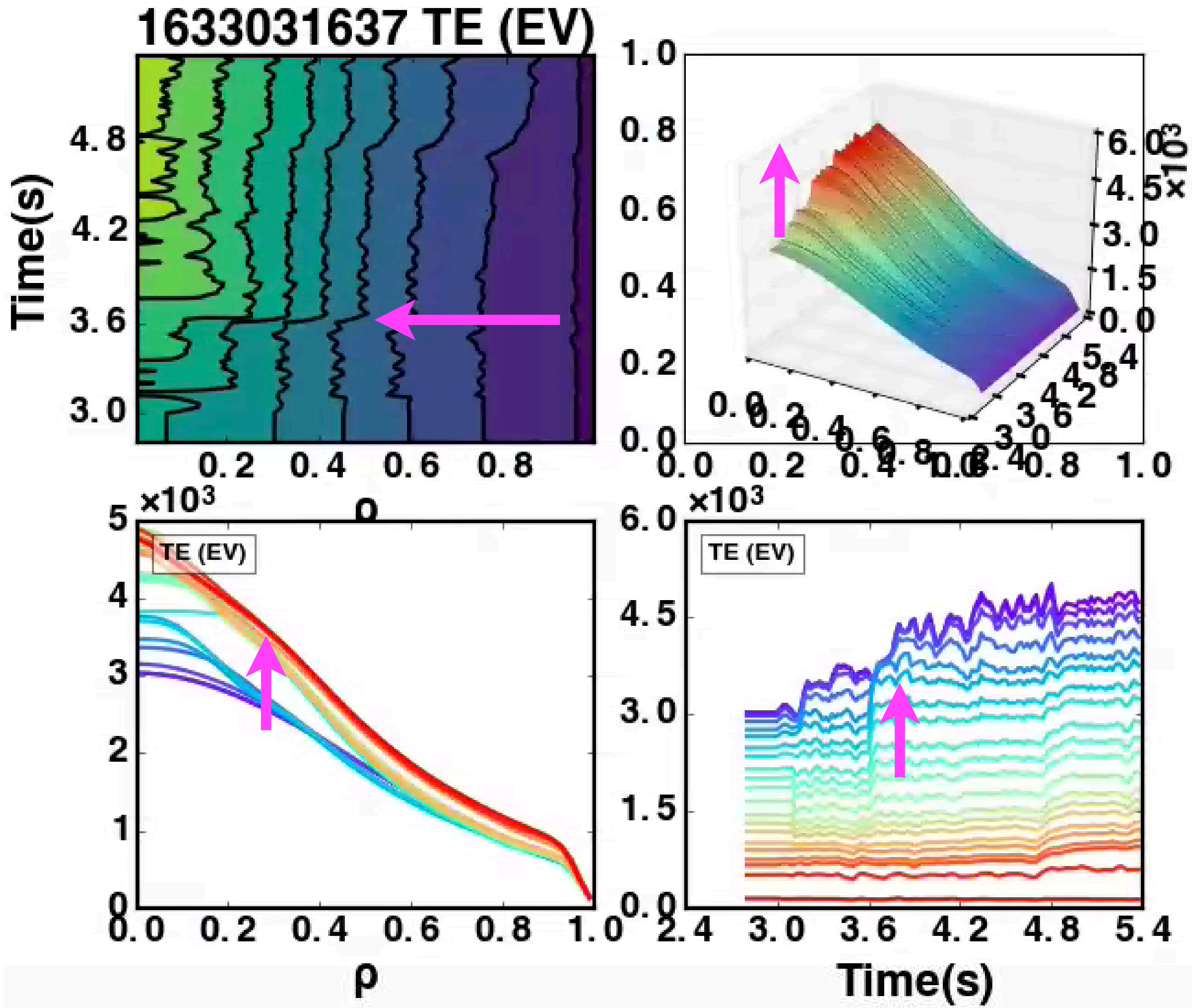
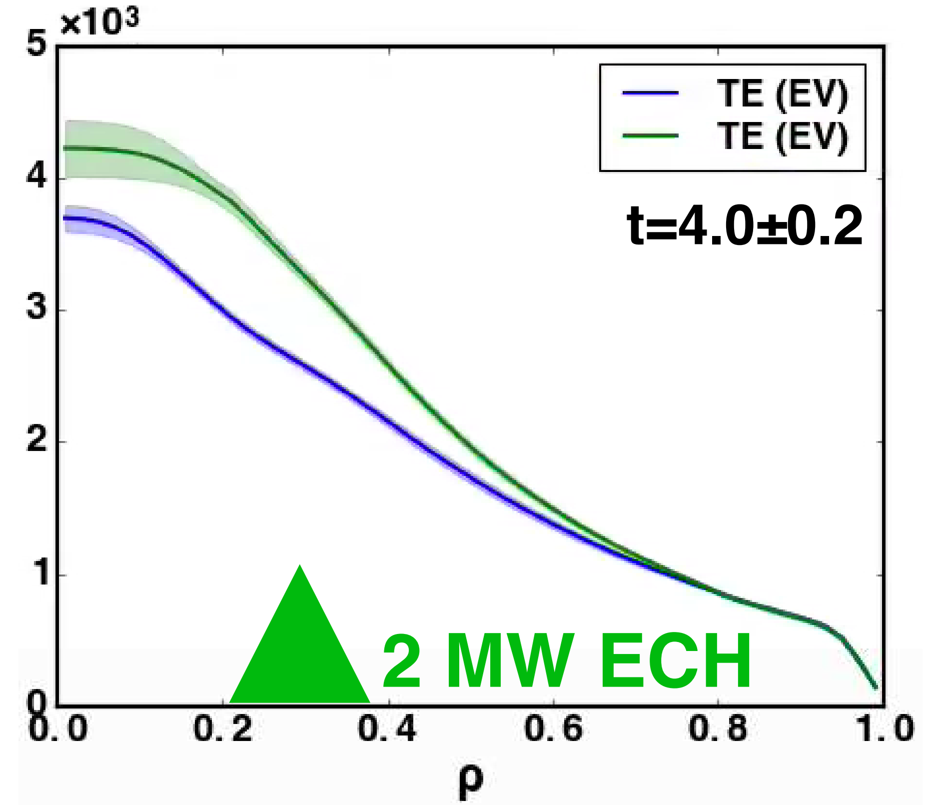
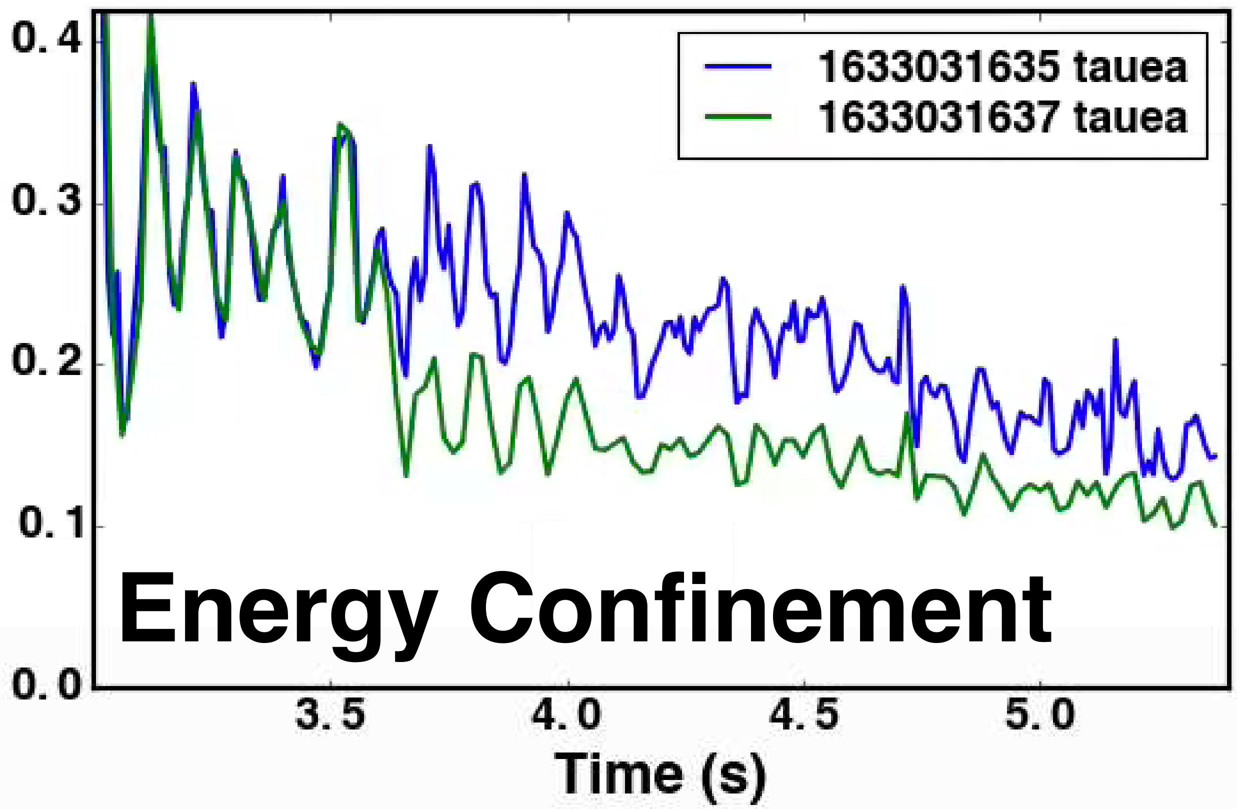
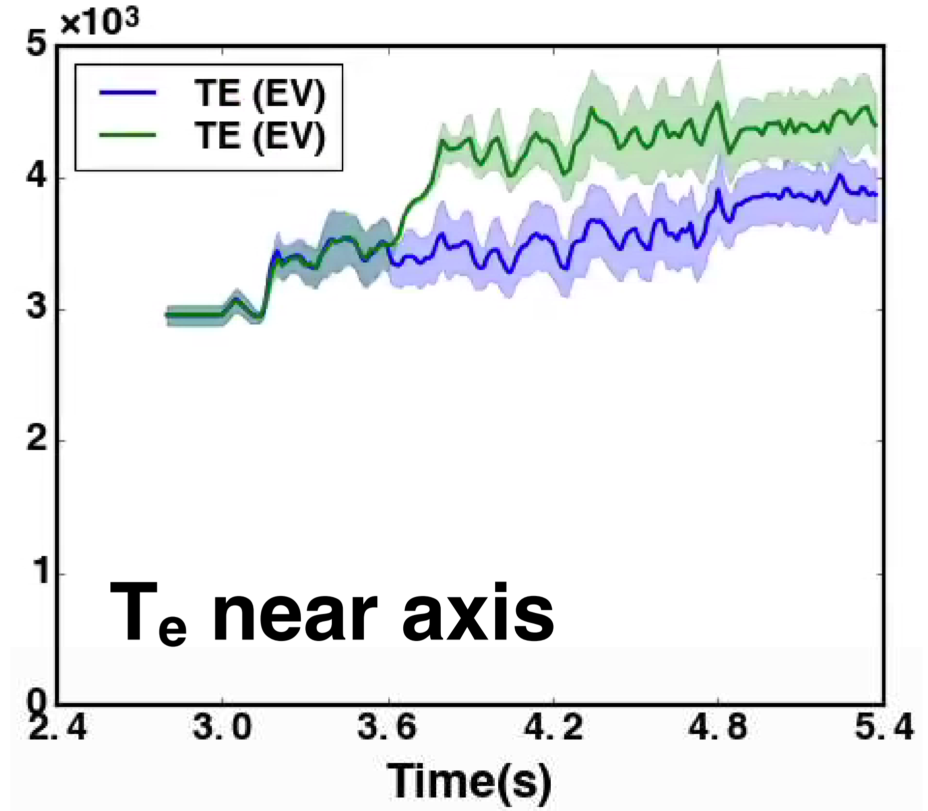


Predictive TRANSP Runs Directly Compared to Any other TRANSP run: Predictive or Interpretive

- ECH heating raises T_e, Ti less so
- Energy confinement degrades







OMFIT Provides Powerful Capability for Preparing, Executing and Visualizing TRANSP Analysis and Predictions

- **Single platform for all supported tokamaks + large user community**
- **Powerful visualization and post-processing capabilities**
  - Fast-ion diffusion scans, Zeff scans, etc…
- **Predictive simulations**
  - GLF23, MMM, TGLF
- **Namelist variable scan for submitting many runs at once**
- **Input data scaling for sensitivity analysis and uncertainty quantification**