Report on IOS-JA1.0: Modeling of ITER-like experiments

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JA1.0: Modeling of ITER-like experiments

- April 2011: Organization of existing results on current rampup phase

The present part of this IOS JA will be on the current rampup phase of ITER-like experiments. It should be noted that we can not assess V-s aspects without going through the flattop phase, so this will need to be included as necessary. The current rampup phase of the baseline 15 MA discharge in ITER is approximately 100 s, with a fastest rampup of about 65 s. There does not appear any technical reason to go slower than 100 s. The current diffusion time for this phase of the discharge (using <Te> = 2.5 keV, n = 4.5e19, Zeff = 2.0, κ = 1.8, and q = 2) is about 13 s, so there are about 7-8 current diffusion times in the ramp phase. This is variable depending on the transport, but the ramp time is clearly several current diffusion times. The current ramp phase consumes most of the volt-seconds (V-s) available from the solenoid, and the time available for the flattop burn phase is determined by the leftover V-s. This V-s limit is really a limit on the central solenoid (CS) coil's current and field, in particular, the CS1 coil. It is desirable to have flexibility in the rampup phase V-s consumption in order to preserve access to ~500 s flattop burn. In addition, the control of the current profile in the rampup phase is of interest to avoid vertical instabilities associated with high li, or peaked current profiles. The Ip ramp rate, heating, and H-mode onset time, and density are the primary tools for manipulating the V-s consumption and current profile evolution. The various heating sources are expected to have different effects on the rampup characteristics through their species heating and current drive.

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- Experimentally the four tokamaks (D3D, JET, AUG, C-Mod) above have already generated discharges and many of these have been simulated in one form or another.

- Need to gather simulations performed to date on the present experiments
- Examine primary similarities and differences (heating sources, divert times, Ip rampup trajectories, and V-s and li evolutions).
- Need to gather simulations that have been done to reproduce these experimental discharges, and organize how these were done (models used, codes used, etc.)
- We may want to do further simulations to utilize similar approaches
- *Cross-modeling of various devices with various energy transport models*
- Develop some conclusions about what these experiments and simulations are telling us,
  - Are we reducing V-s consumption over ohmic rampup, by how much, with which source
  - Are we modifying the current profile with the heating/CD source
  - Is there a energy transport model that is sufficiently accurate to recommend for ITER
  - Can density reduction be an effective way to save V-s
  - How well are the simulations reproducing these discharge features
  - Is there physics outside our simulations that is important , should we pursue it

- I am requesting that modelers/experimentalists who have participated in these ITER-like expts or simulations to gather what they have done. I have included an example for myself as a guide.

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Example for myself:

Alcator C-Mod / TSC modeling:
Early discharges (2008, 1080201010 – ohmic, 1080201031 - ICRF) demonstrated V-s savings with ICRF heating, but the li evolution was unreliable to assess due to variations in the rampup phase – using TSC (ICRF from TRANSP) modeling with CT energy transport, modified to agree with the experiment, confirmed the V-s savings – comparison of transport models (CT, BgB, and CDBM) showed some agreement that varied among the models. Original CT model had excessively peaked profiles and did not match Te(rho) profiles. Adjustments were made to thermal diffusivity to provide broader Te and adjust the central Te(0) in order to agree better with experiments.

Newer discharges (2009, 1090911006 – ohmic, 1090911012 – ICRF, 1090911026 - ICRF) developed early divert and reproducible rampup which again showed that V-s were saved with ICRF heating, but li was unchanged from ohmic when 1 and 1-2 MW of ICRF were injected – TSC modeling reproduced both the V-s savings and the lack of li variation, however, the CT model can not reproduce the details of the Te profile even when adjusted to match Te(0) and profile overall.

Cont'd

The ICRF is found to make very specific changes to Te profile in the plasma core, but otherwise make little change in the outer half of the plasma minor radius. Slightly different values were necessary with these discharges as for earlier ones. Need to examine BgB and CDBM for these cases. These discharges are being made available for modeling.
Rampup experiments were done to examine density variations for ohmic, ICRF heated and LH heated discharges. Only the lowest densities with heating showed V-s savings over ohmic discharges, however rampups were not as well controlled, and flattop phases were not controlled so complete assessment of V-s savings is not clear. Will likely redo these expts.

Requested similar input from others to start to gather information…..got one response from Irina Voitsekhovitch

Culham meeting; presentations by Litaudon, JM Park
Seoul meeting: presentations by JM Park, Litaudon
Princeton meeting: presentations by Kessel, Budny, Parail, …

What are we after?

We are trying to provide information to ITER on rampup phase of the discharge based on

Experimental results

Modeling of experiments, to test models against experiments, match multiple parameters simultaneously

Extrapolability to ITER

Spending lots of time on transport models….because they influence V-s and current profile evolution…..database setup

What are we looking at? Te(ρ), Ti(ρ), li(1), q(0)/sawtooth onset, V_{surf}, Te(0), Ti(0), T(0)/<T>, sawtooth radius, τ_E, …..

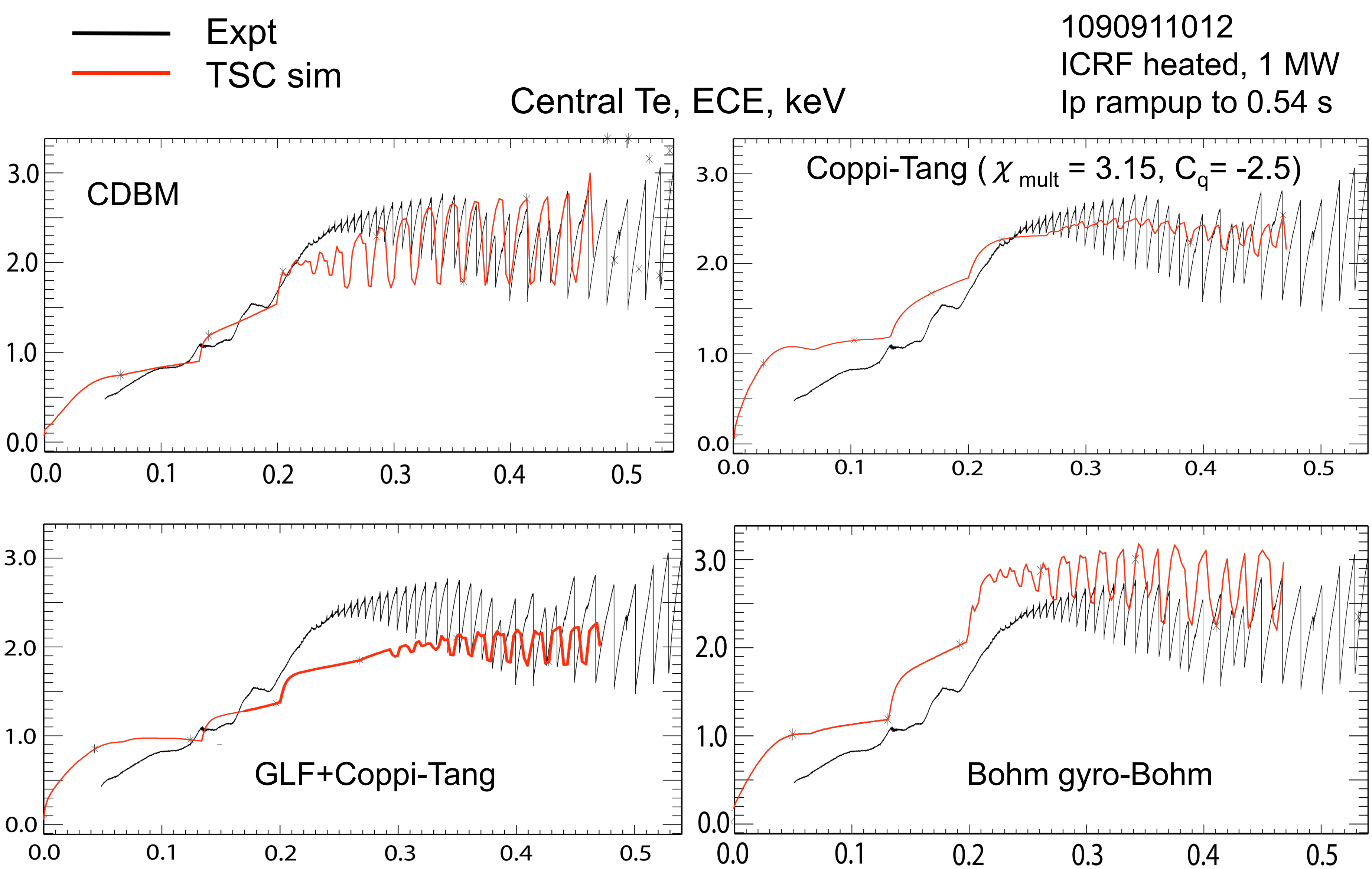
Have we shown that we can save V-s with heating? By how much and with what source.

Have we shown that we modify li significantly or not with heating, from a given source?

Is there a limit to ramping up Ip fast and heating…MHD?

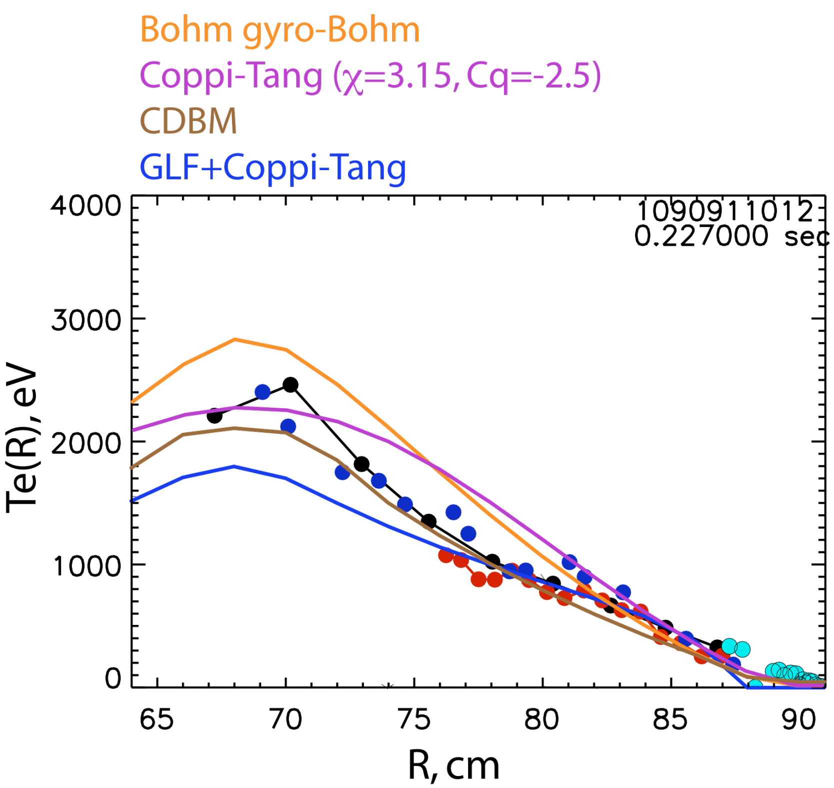
Other methods for rampup control; density, early H-mode, Ip ramp rate

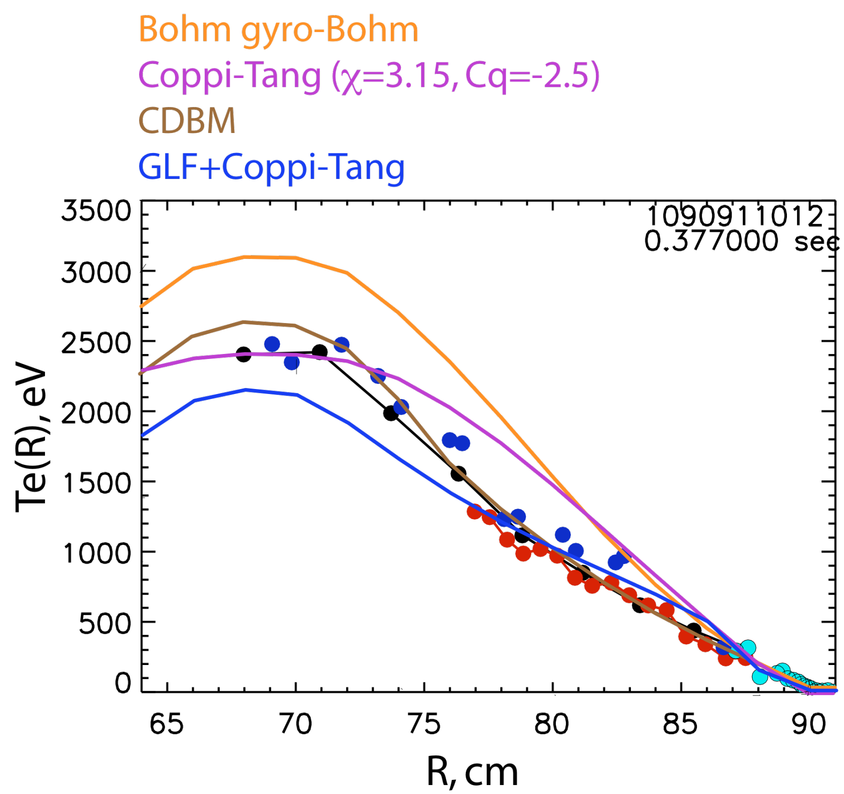
Recent C-Mod analysis of transport models



Profile comparisons at 2 time slices for C-Mod 1090911012

This observation is typical, models are not BAD, they are just not accurate, and their level of accuracy varies between points in the ramp, or between discharges





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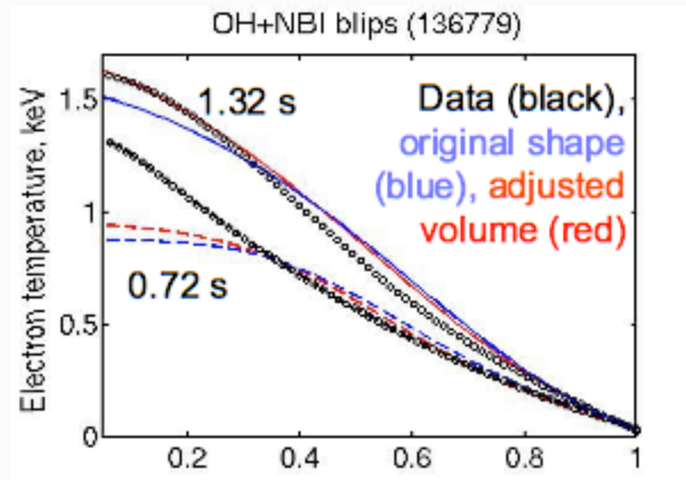
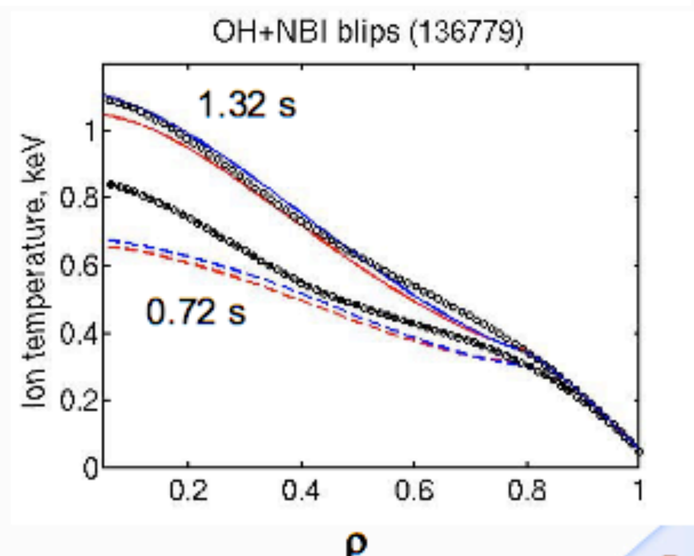
Validation of transport models: Bohm-gyroBohm model

- **Plasma model:**
  - equilibrium, current diffusion (NCLASS), Te and Ti are simulated
  - prescribed electron & carbon impurity density, toroidal rotation and NBI heating profiles
- **DIII-D:**
  - $\rho > 0.35 – 0.45$ – relatively accurate Te&Ti prediction for 3 discharges
  - core transport, low Btor: χs are over-estimated during the first half of the Ipl ramp up, but well predicted during the 2nd half of the Ipl ramp up
  - core transport, high Btor: over-predicted transport during the whole ramp up phase
- **JET OH discharges:** relatively accurate prediction at low ne, over-predicted Te at high ne





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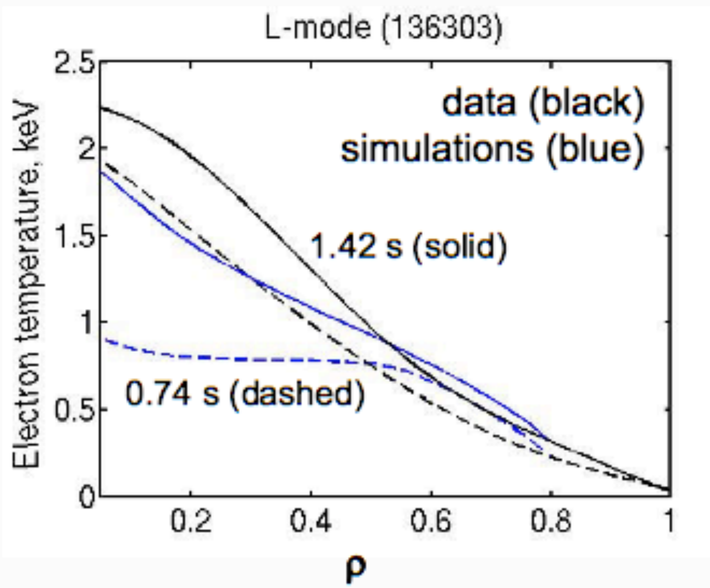
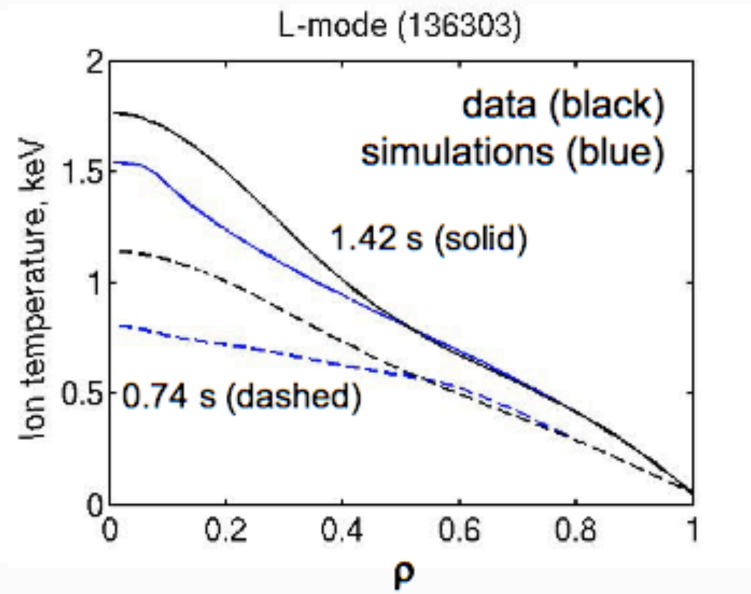
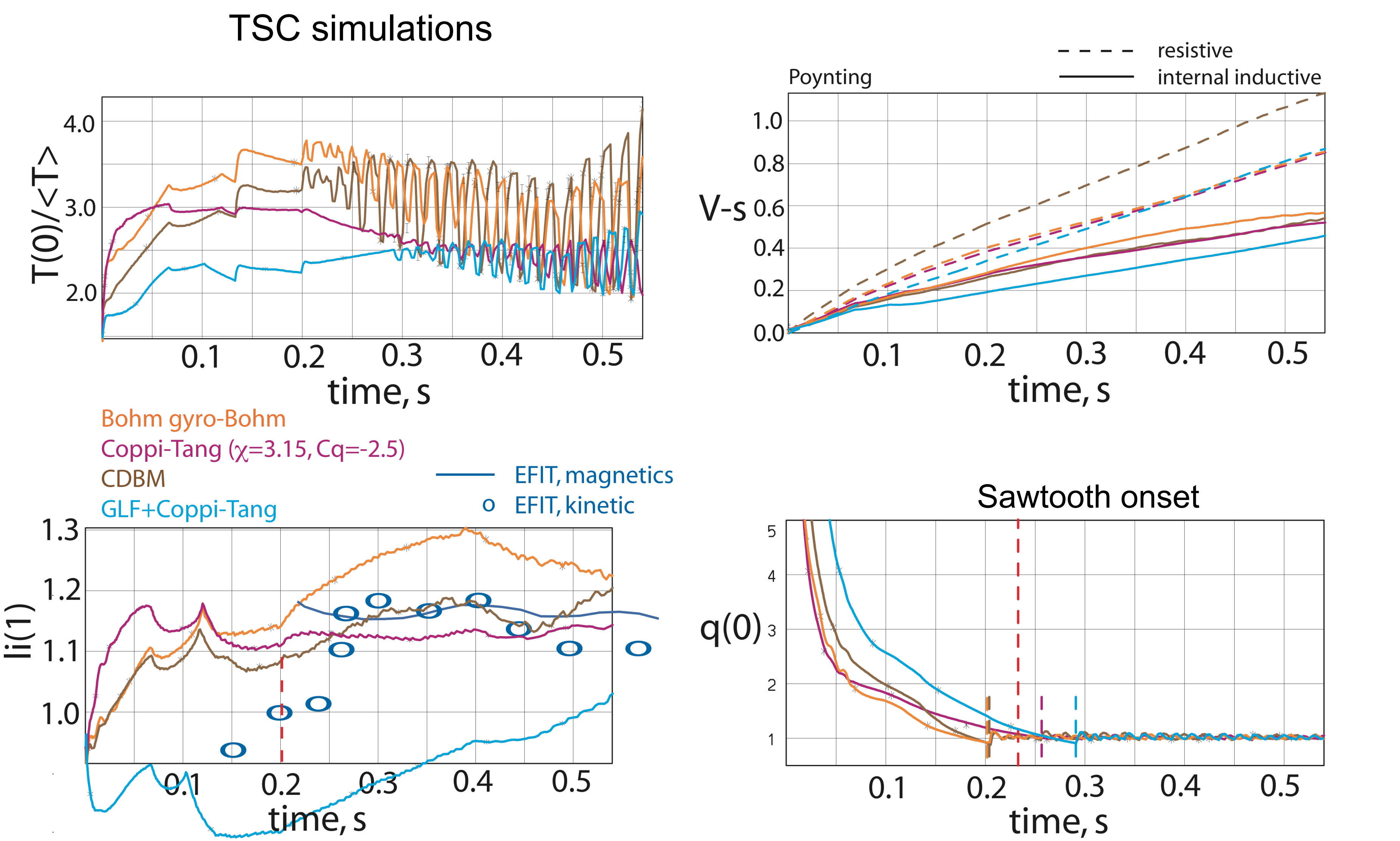
Validation of transport models: GLF23 model



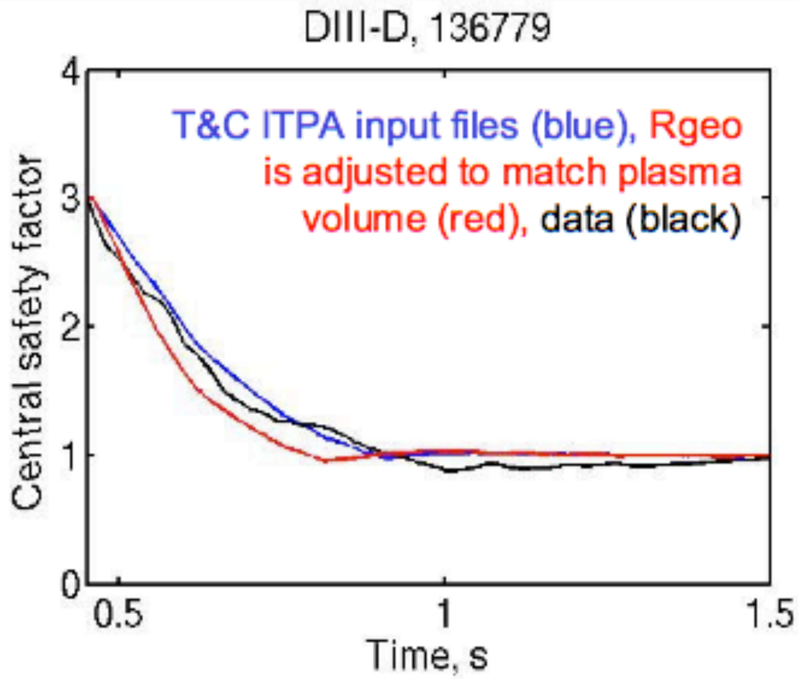


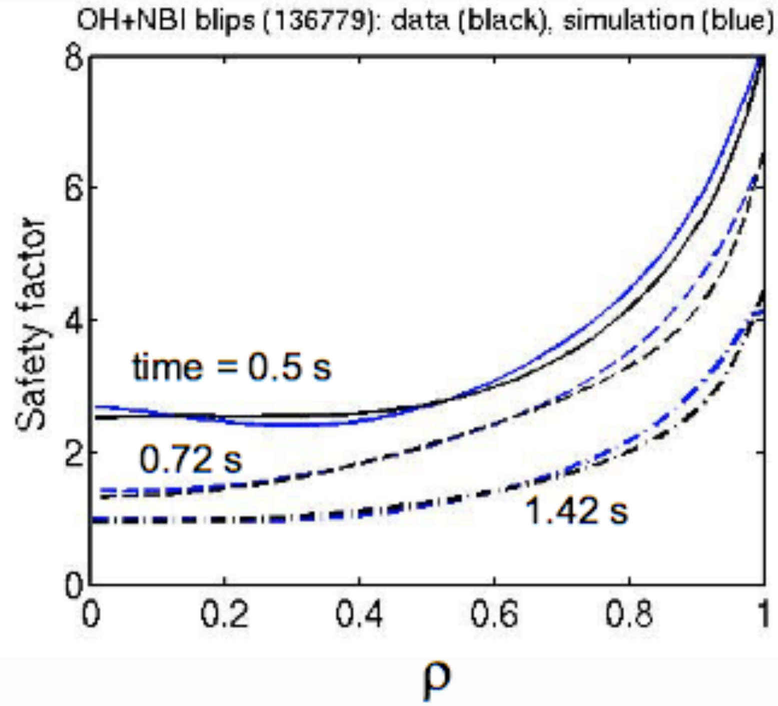
- *selected time slices: 0.74 s (peaked n_e) and 1.42 s (flat n_e);*
- *over-estimated χe and χi in the region of peaked n_e ($0.2 \le \rho \le 0.4$) leading to flat temperatures, discrepancy is larger during the 1st half of the Ipl ramp up*
- *better temperature prediction in the outer half of plasma*

Impact of transport models on various quantities, C-Mod



Current profile diffusion in DIII-D discharges





Current profile evolution is accurately predicted with NCLASS/ASTRA in three DIII-D discharges. Similar results to G. L. Jackson et al, Phys. Plasmas 2010

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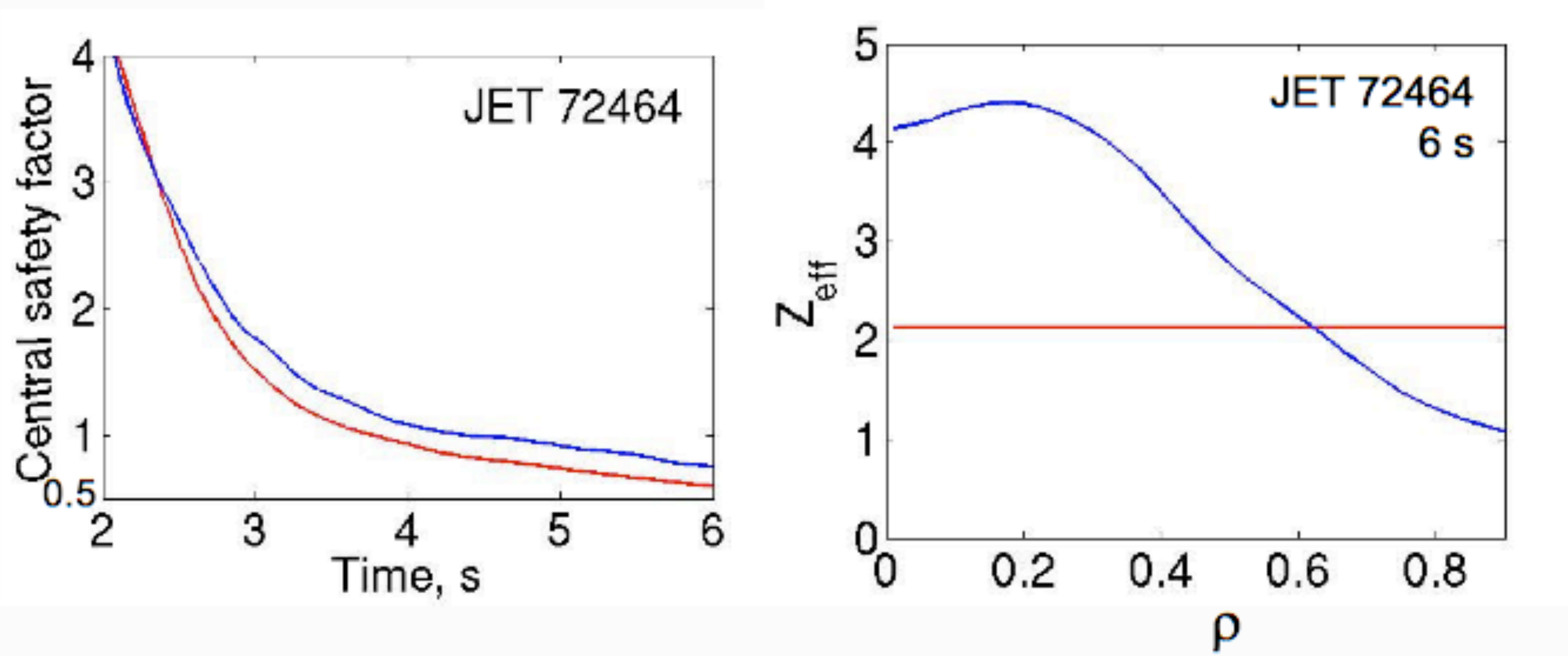
Current profile diffusion in JET ITER-like discharges

OH #72464: 0.36 MA/s, n/nGW=0.2, sawtooth-free current ramp up during 6 s



Too rapid reduction of q0 assuming flat Zeff, but possible to match the time of the first sawtooth crash (q0>0.75) by modifying Zeff profile (but matching measured line averaged Zeff) [G.M.D. Hogeweij et al, EPS 2007, EPS 2010; I. Voitsekhovitch et al, PPCF 2010]

What will we tell ITER about energy transport in rampup and its consequences?

It appears there are no sufficiently accurate transport models for the L-mode rampup phase, therefore ITER should

1) Use any model they prefer and force it to match a global energy confinement time (89P or 97L)
2) Same as # 1, but also provide a temperature profile width or shape that reflected experimental discharges (this probably requires different shapes for different regimes like ohmic, ICRF heated, NB heated, EC heated…)
3) Introduce a fix to GLF23 and use it
4) ?????

Then we model our experiments with the “model” we recommend for ITER and quantify the differences

Subsequent modeling of ITER with the “model”, and demonstrate that the ramp rate, heating power, or other technique can compensate possible differences between the “model” and the actual values, and avoid excessive V-s consumption or vertical instability

Discussion

For JA 1.0 focused on the rampup phase, what are the tasks to do….

1) Begin collecting rampup data from experiments (database cases first) to focus modeling activities
   1) compare V-s, li, q(0), Te(ρ),etc. VS ohmic, heated, varying sources, dIp/dt, density, H-mode onset time

2) Continue transport model simulations of experiments, and establish ability to reproduce the experimental parameters
   1) Exercise with database
   2) How do we measure agreement between expt and simulation?
   3) What parameters are compared with expt, besides Te(rho) and Ti(rho)

3) Examine energy confinement times of plasmas during rampup, check against L-mode scalings

4) Examine experimental Te profiles from various machines and ohmic/heated discharges for shapes

5) What else???