Free-Boundary Modeling of NSTX Plasmas

S. C. Jardin

R. Andre, J. Chen, S. Gerhardt, C. Ludescher, D. McCune

Princeton Plasma Physics Laboratory

R. Sayer

C. S. Engineering, Oak Ridge, Tenn

APS/DPP Meeting

Nov 10, 2010

Chicago, IL

Overview

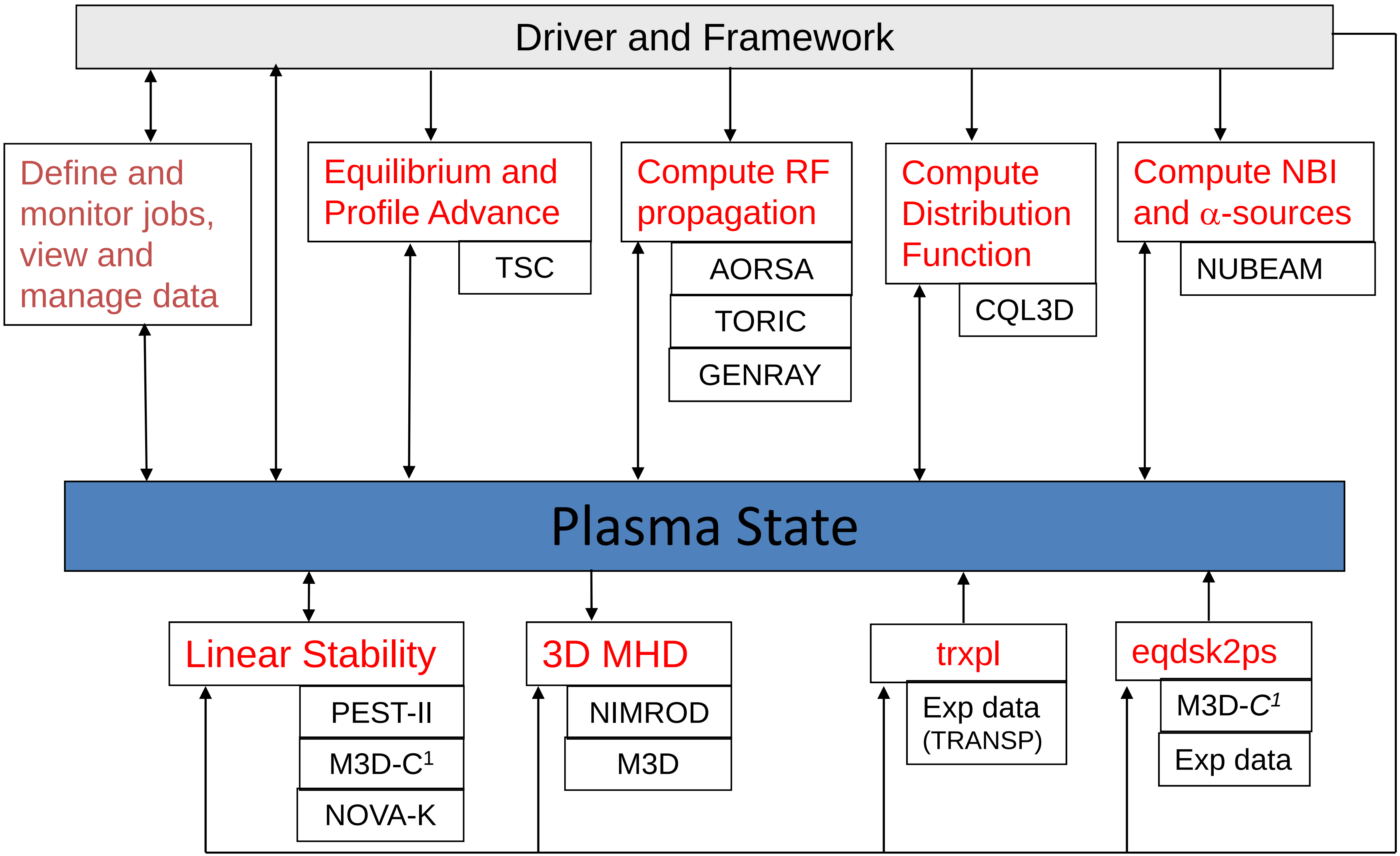
- The SWIM Proto-FSP has developed the **Integrated Plasma Simulator** (IPS): a framework for coupling together state-of-the art codes for predictive simulation of tokamaks
  - free-boundary equilibrium evolution and transport,
  - neutral beam and RF heating and current drive
  - linear and nonlinear stability

- We have applied this code system to model two types of discharges in NSTX:

  - **Onset of saturated n=1 mode:**
    - NSTX often develops a saturated n=1 mode after ~ .6-.7 seconds when $q_0 \rightarrow$ 1 from above: Can we reproduce this with MHD codes?

  - **VDE Halo-Current Modeling:**
    - intentional VDE experiments were performed that we are using to validate the TSC disruption model

A Physicist's View of the IPS



Can we reproduce the onset of the saturated n=1 mode in NSTX using: TSC + NUBEAM via SWIM?

- Actual coil currents from experimental discharge used (with feedback systems added to match plasma current and position)
- Analytic density profile used to approximately match experimental values
- TSC advances temperatures using semi-empirical transport model
- TSC advances current profile
- NBI energy and current sources calculated with NUBEAM

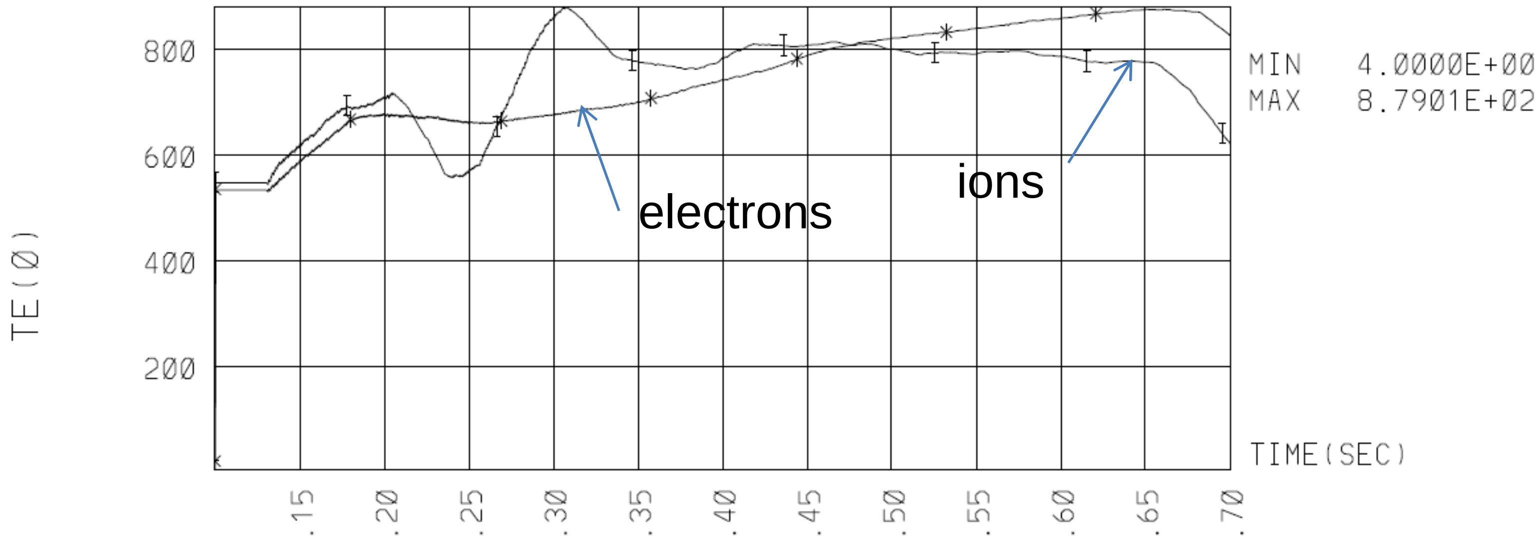
➔ This turned out to be very difficult because the thermal conductivity models were inadequate and we could not reproduce the Te(ψ,t) and Ti(ψ,t) with sufficient accuracy

- Added **TRXPL** component to the SWIM framework which allows us to import both density and temperature profiles
- Only evolve equilibrium and current profile with TSC, using calculated bootstrap current and NBCD from NUBEAM

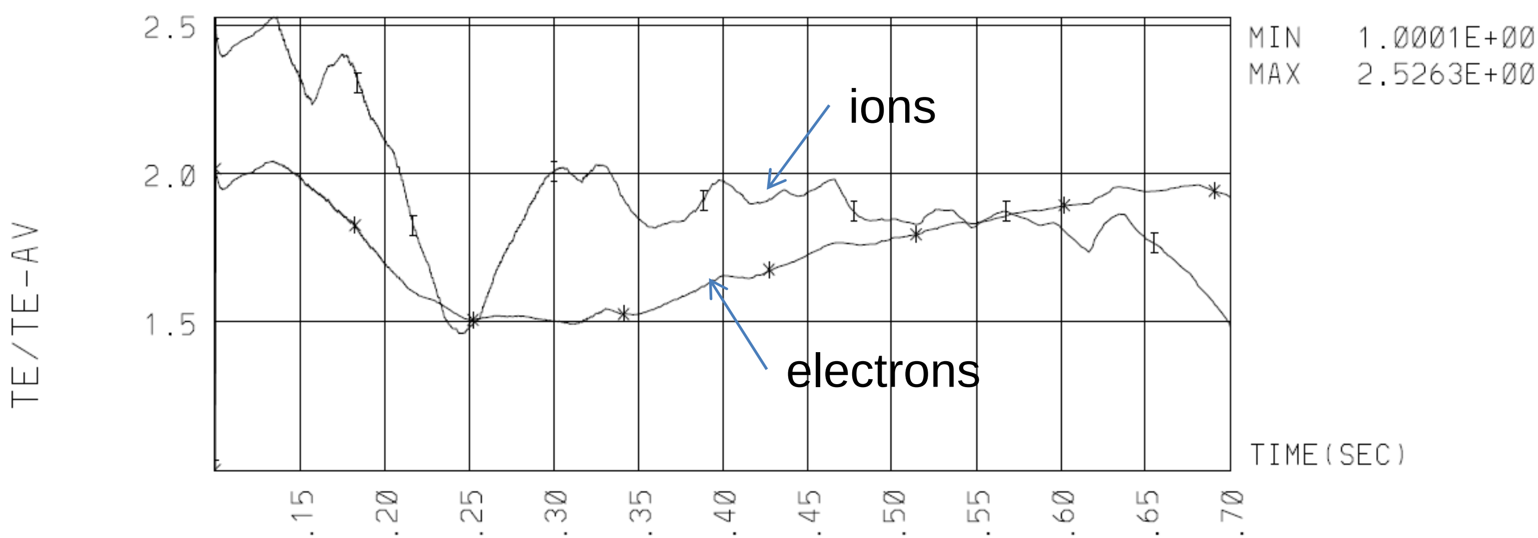
→ Much better results! … next we can incrementally add and test transport

124371

Central Temperatures

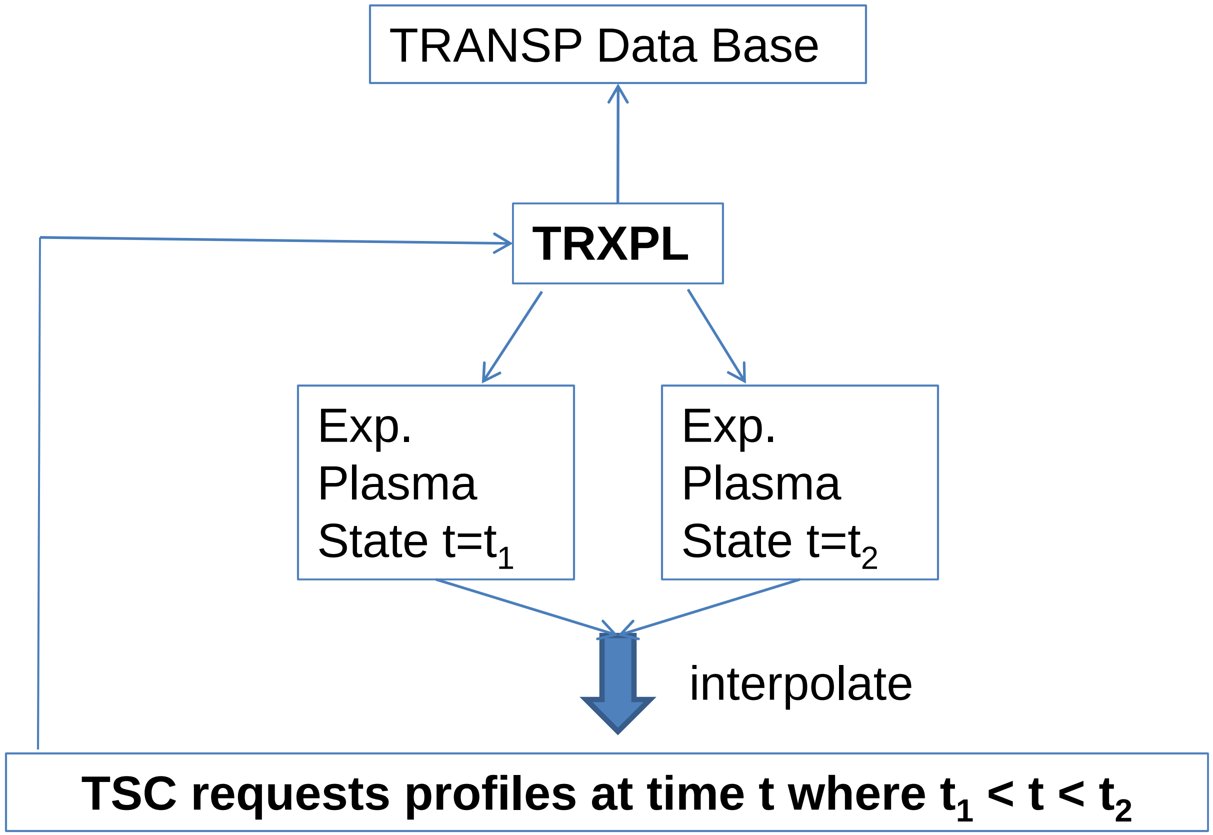


Peak /Average Temperatures



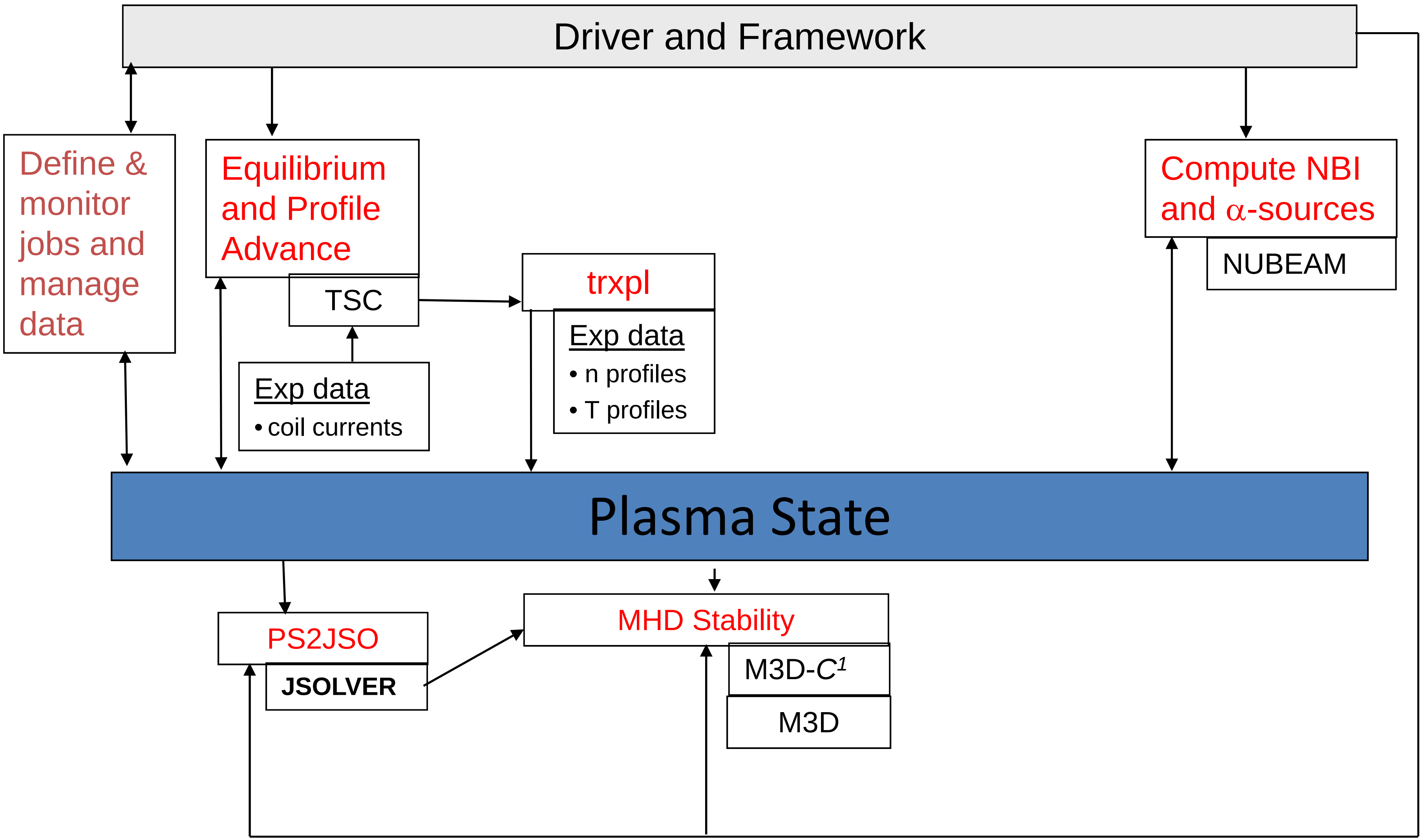
Electron and Ion temperature profiles show complex behavior

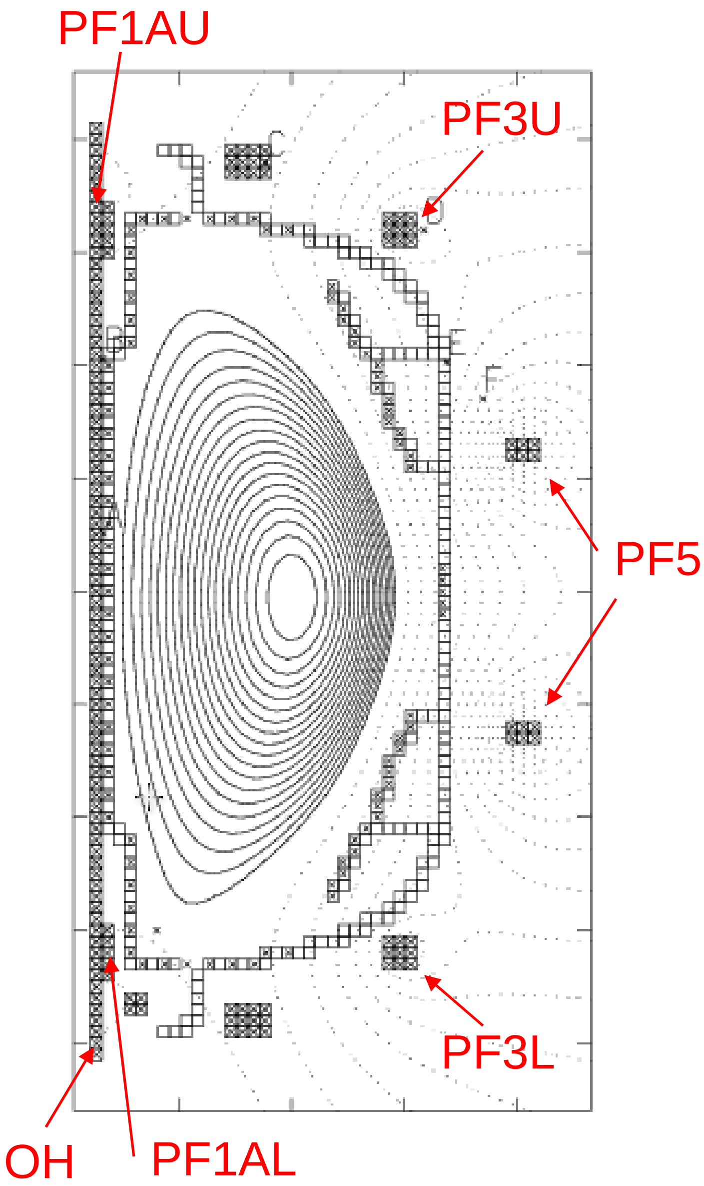
We now have the capability within the IPS of importing density and or temperature profiles into TSC from any discharge for which a TRANSP run has been made



Allows one to separate the modeling of the current profile, temperature profiles, and density profiles

Analysis of Saturated Mode in NSTX with SWIM Framework



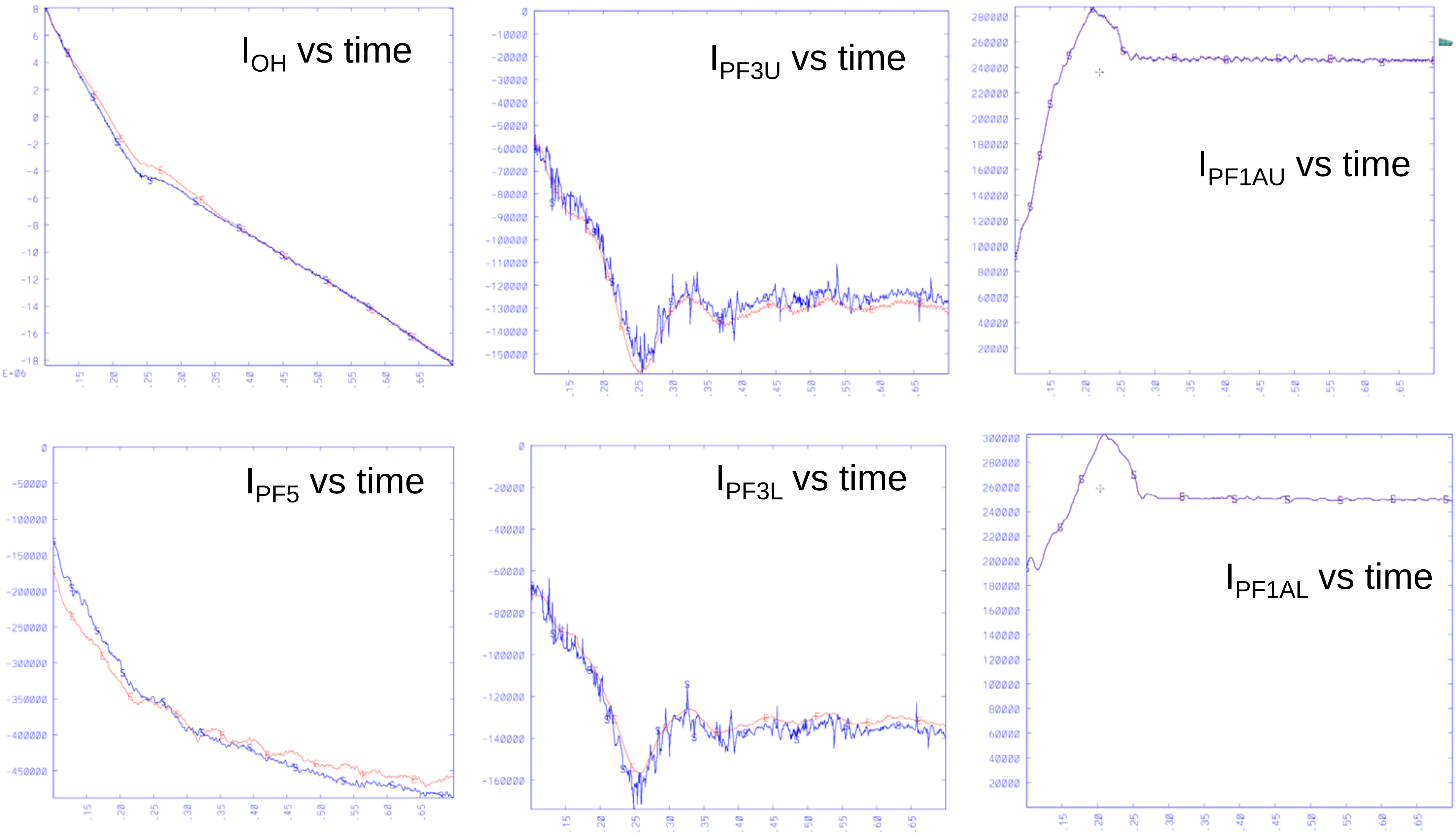


NSTX requires 3 magnetic feedback systems to operate, and so does the TSC model

Feedback systems were added to:

- The OH coil to match the plasma current
- PF3U and PF3L to match the Z position
- PF5 to match the radial position

→ The “feedback” portion of the currents used in these coils must be small in order for the simulation to be a good match to the experiment

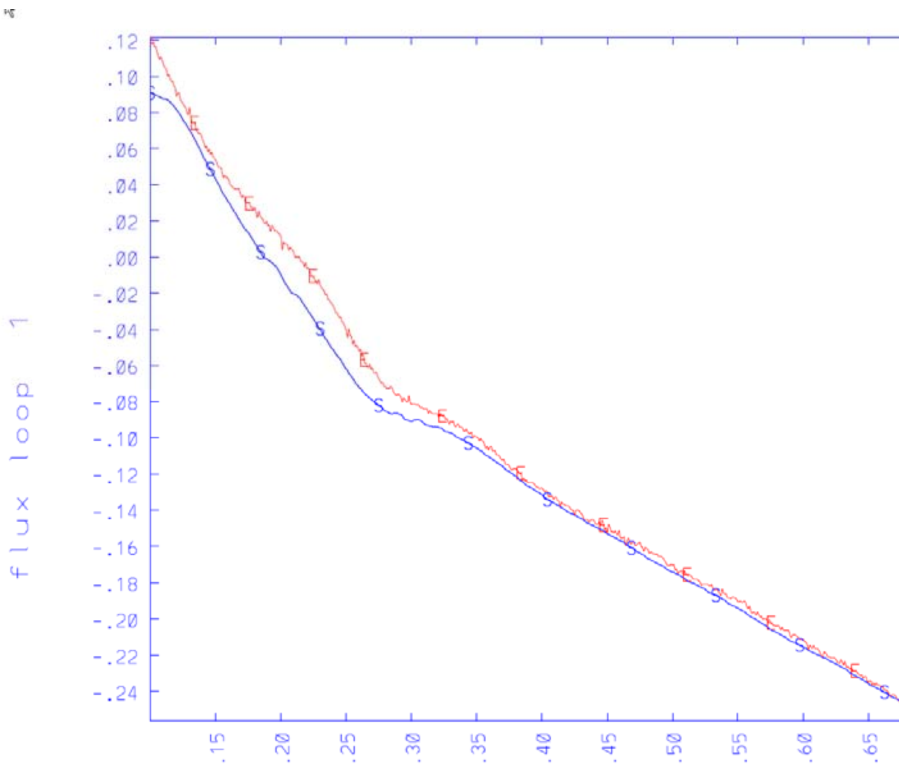


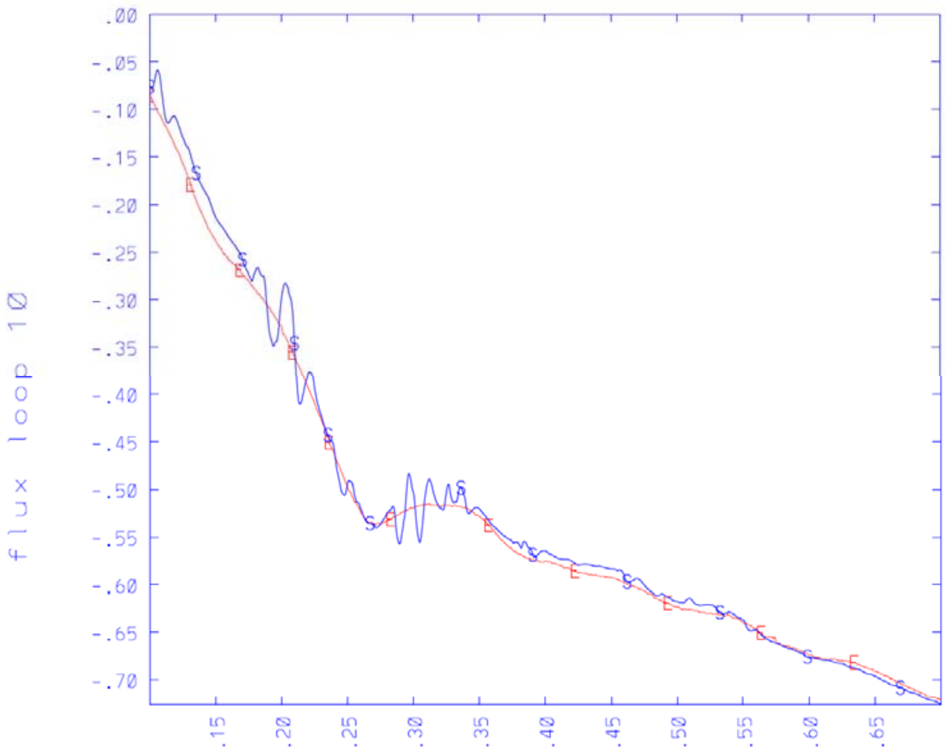
Simulation I_{OH} has feedback added to match experimental plasma current I_P

Simulation I_{PF3U} and I_{PF3L} have vertical stability feedback added

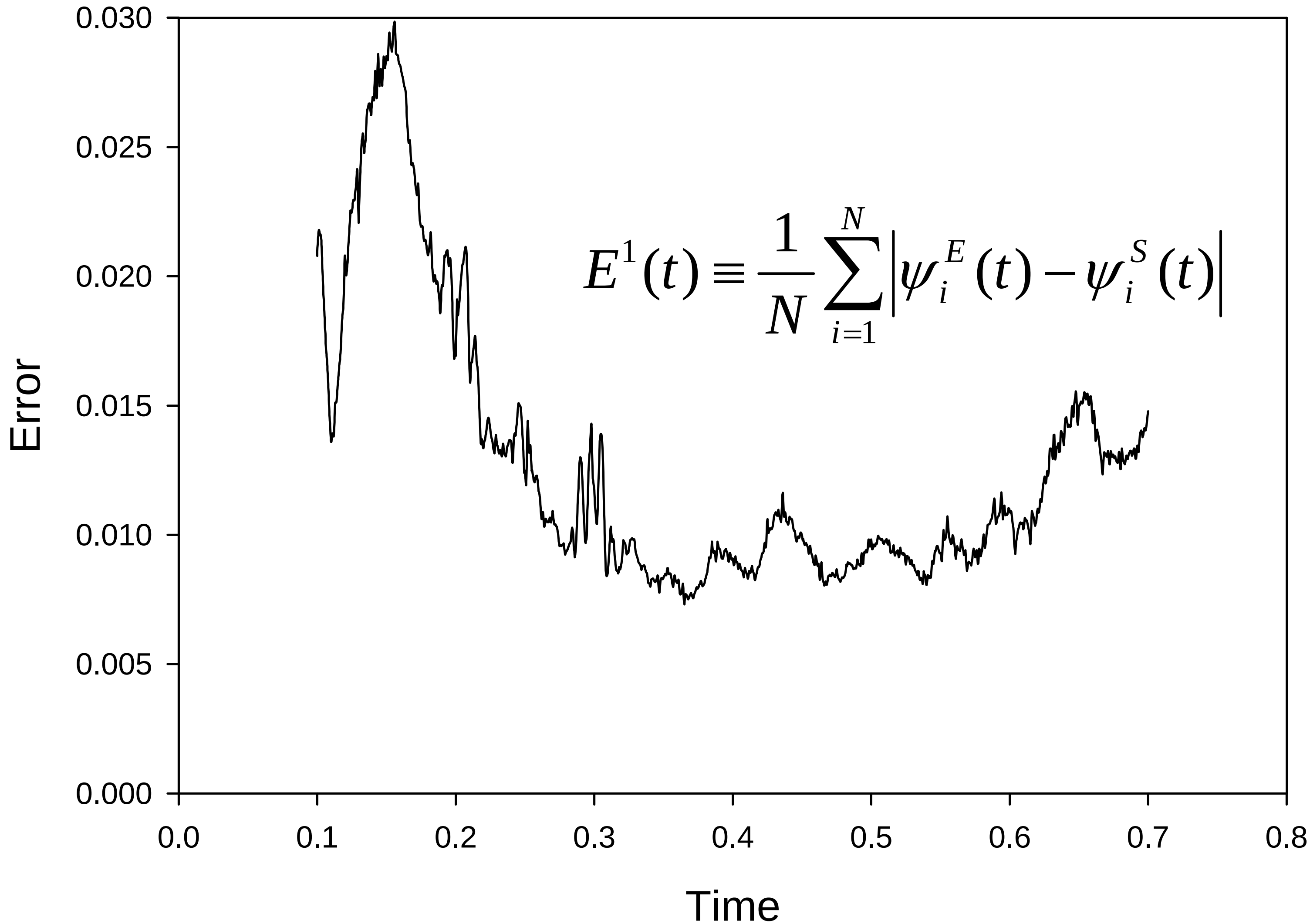
Simulation I_{PF5} have radial feedback system added

Individual flux loop measurements agree very well with experiment

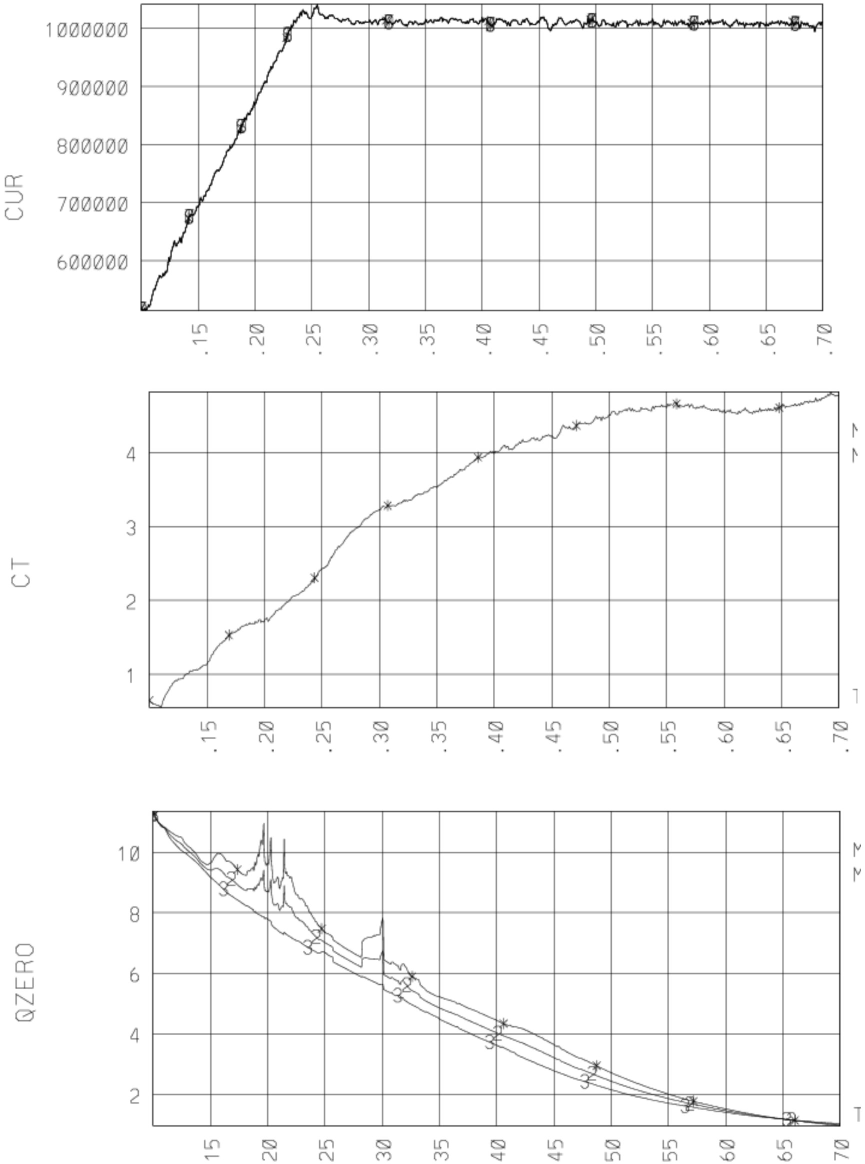


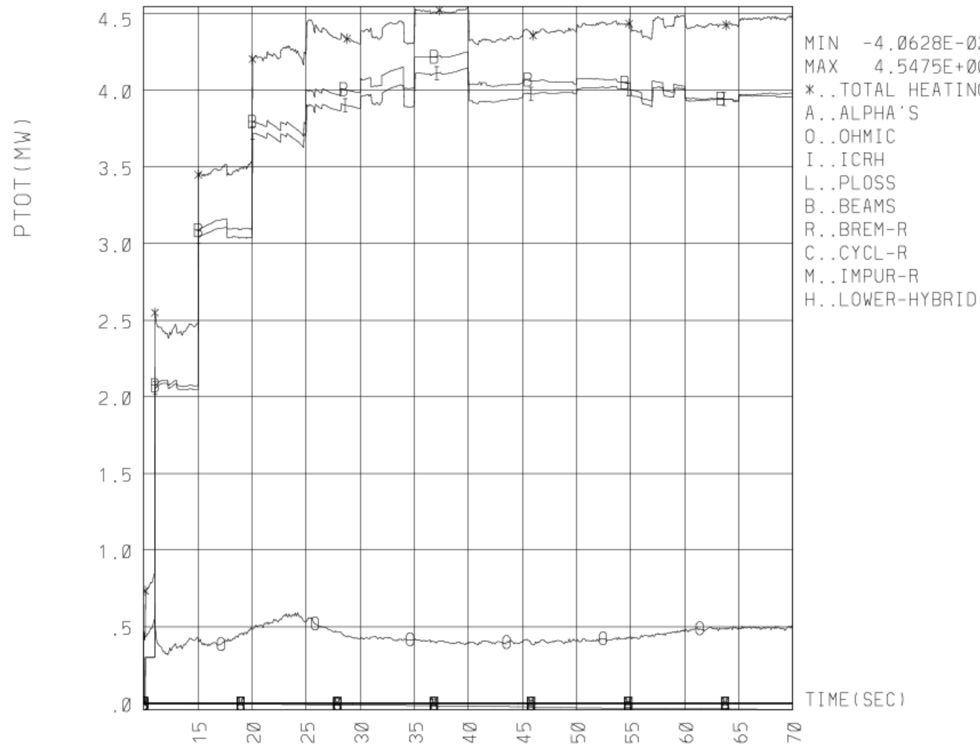


Average Flux Loop Error vs Time



Average error of a few %.   This can be used to evaluate different bootstrap models and transport models

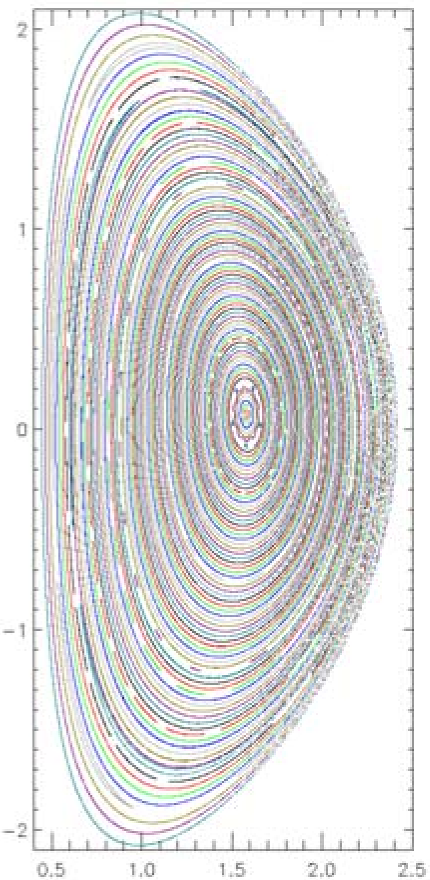


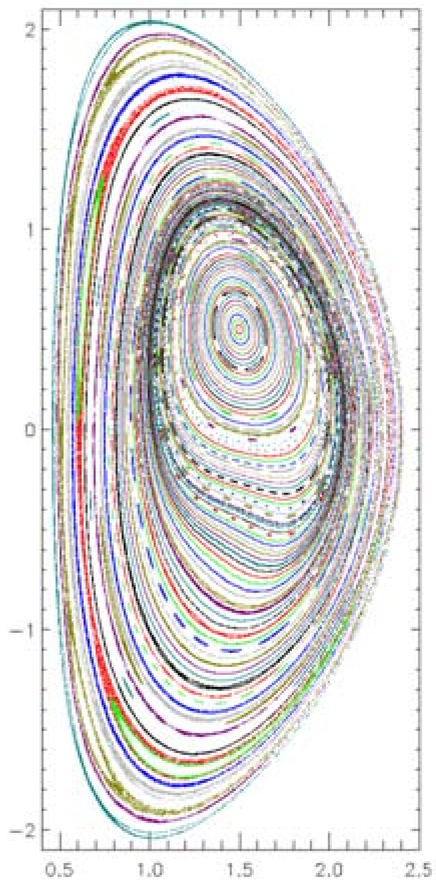


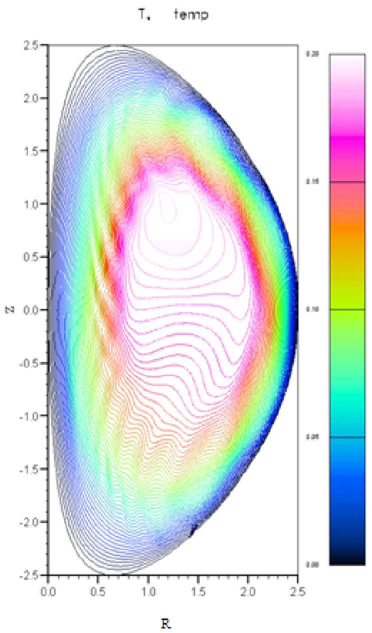
4MW of beams is applied from the beginning, but the low initial density leads to initial shine-through

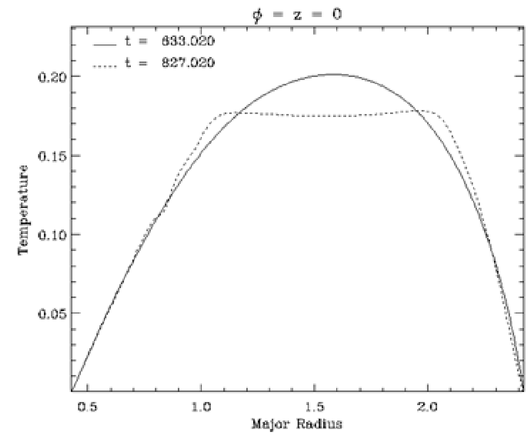
This is the time and the q_0 value when the instability sets in

M3D simulation of saturated mode in NSTX when $q_0 > 1$



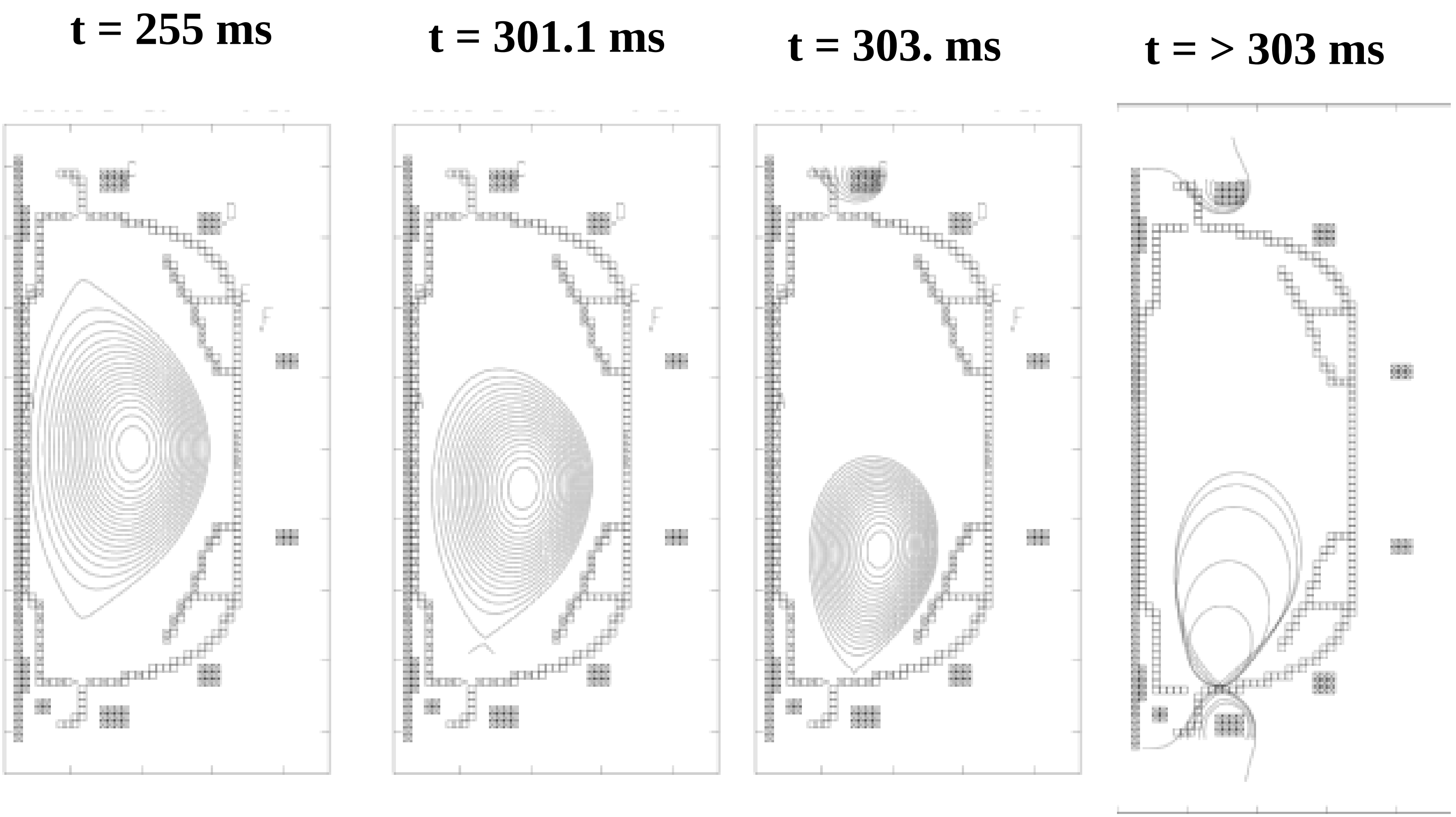






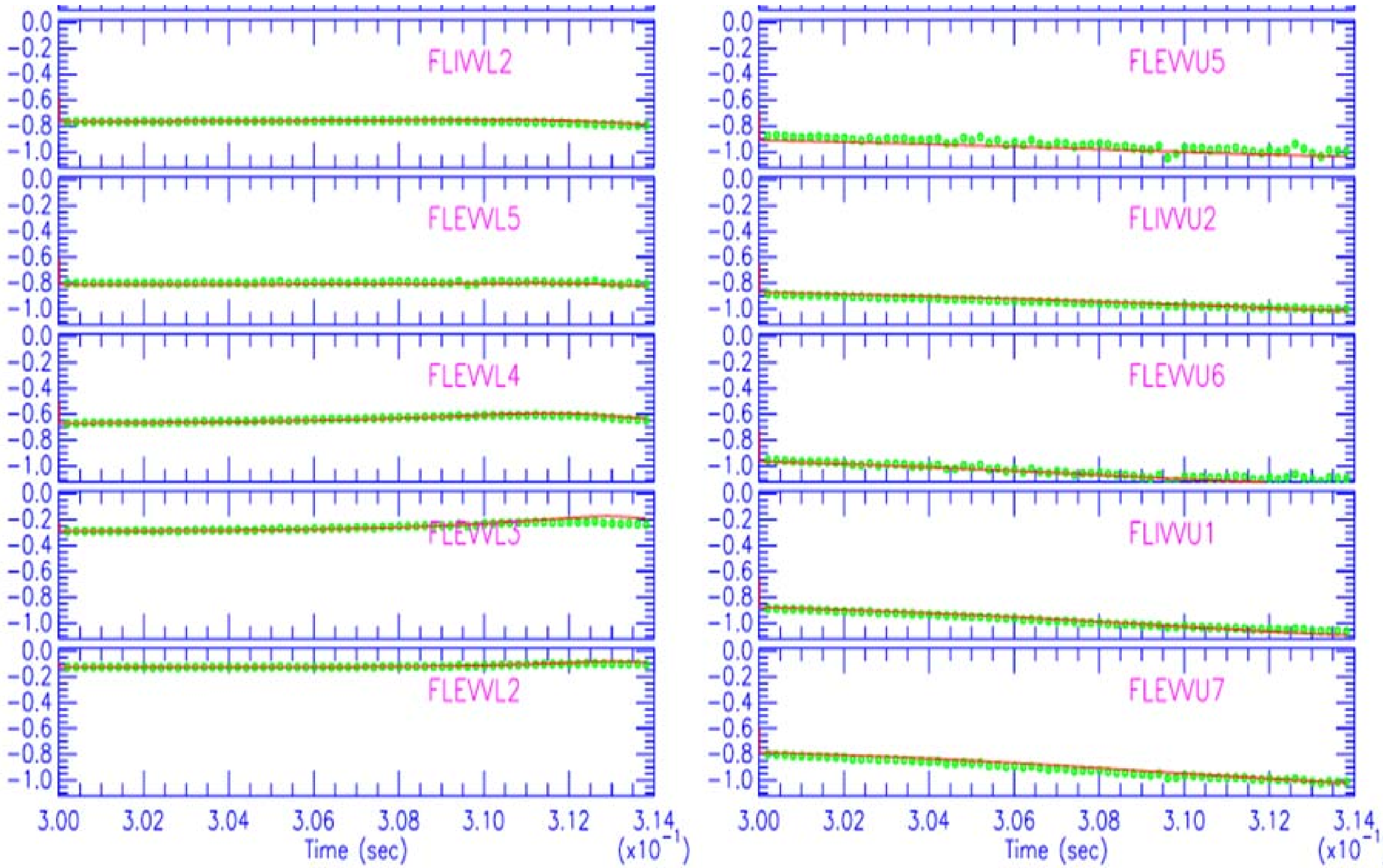
Saturated n=1 mode can set develop when q_0 slightly > 1, as seen in Poincare plot on left. Can flatten temperature (right) and also drive m=2 islands. Breslau, et al. IAEA 2010, This Meeting J04.00001

simulation of disruptions in NSTX



Importing the temperature and density profiles before the thermal quench greatly facilitated the matching of the experimental and simulated plasma motion

Very good agreement in individual flux loop traces with experimental values.



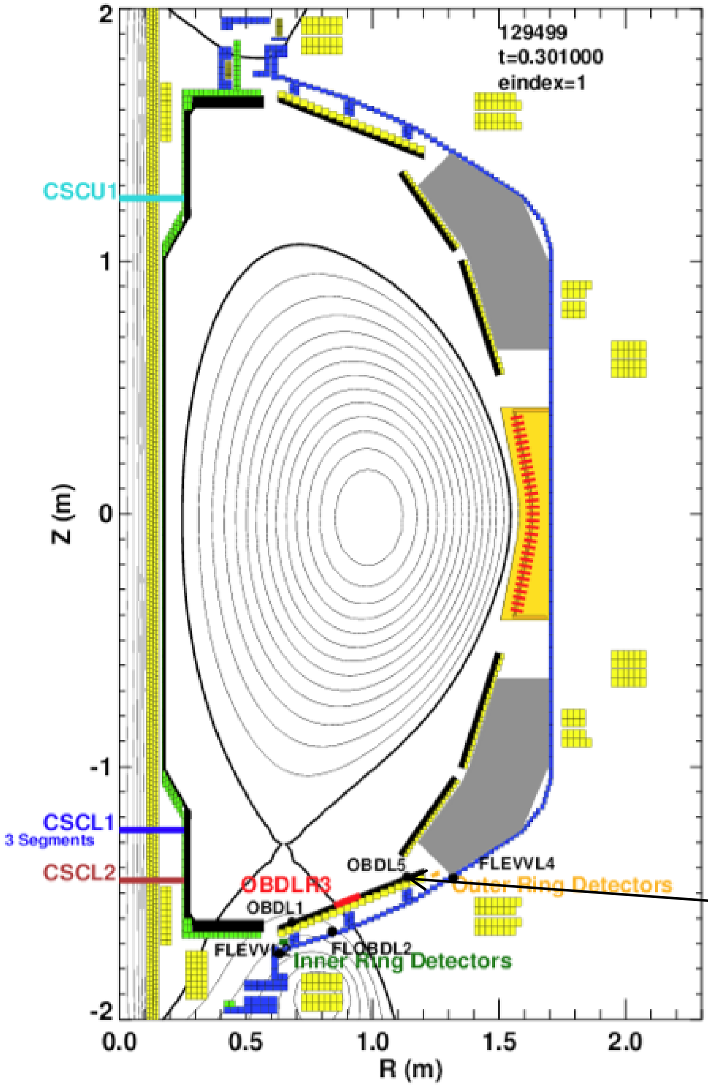
Summary

- The SWIM framework has enabled us to perform realistic free-boundary transport simulations and compare with experimental data.
  - Initial results are encouraging that good agreement with data can be obtained using imported temperature and density profiles but evolving the current profile and equilibrium

- Simulation of vertical disruptions in NSTX has been performed (ITER contract)
  - Excellent agreement can be obtained between experimental and TSC flux loop measurements
  - Halo current comparisons are being evaluated. Still work in progress

Extra Viewgraphs

Simulation of disruption halo currents in NSTX



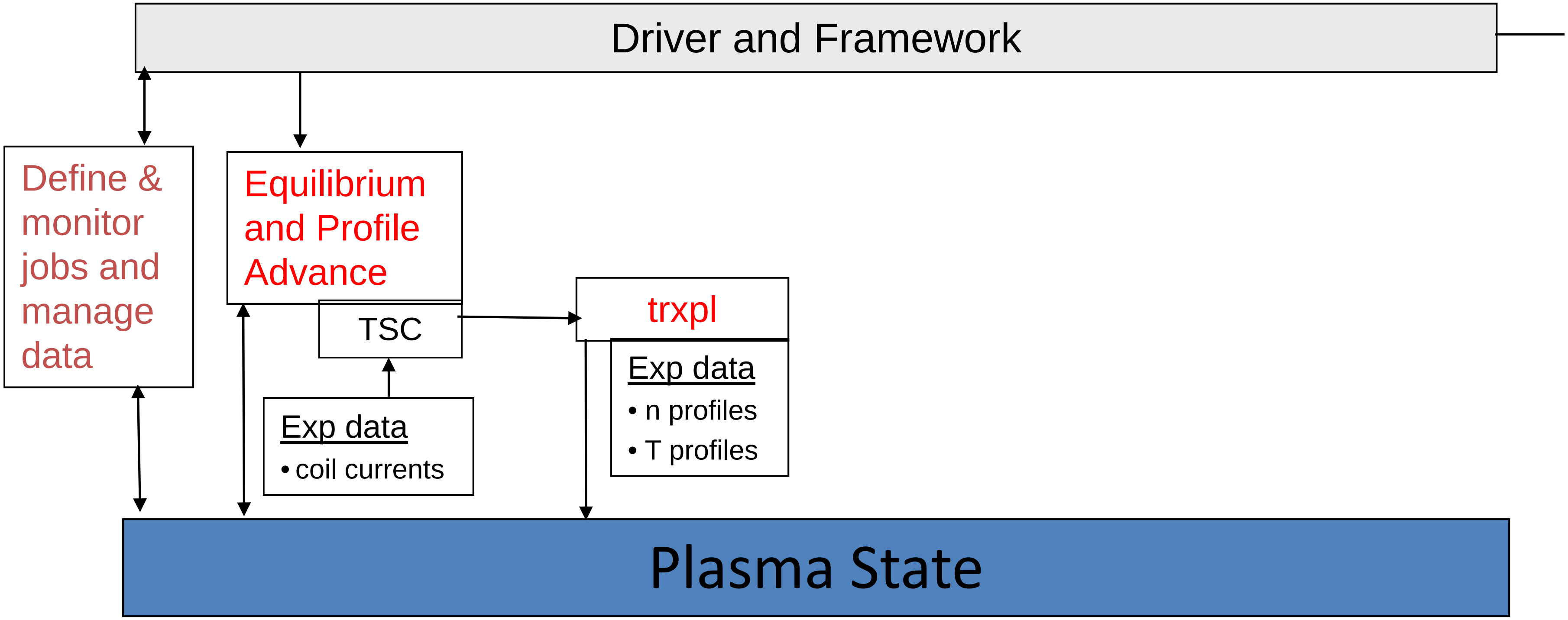
- "Halo currents" are currents on open field lines that enter the vacuum vessel during a plasma "Vertical Displacement Event" or VDE (off-normal event)

- We are using the SWIM framework to validate the TSC halo current model vs NSTX data

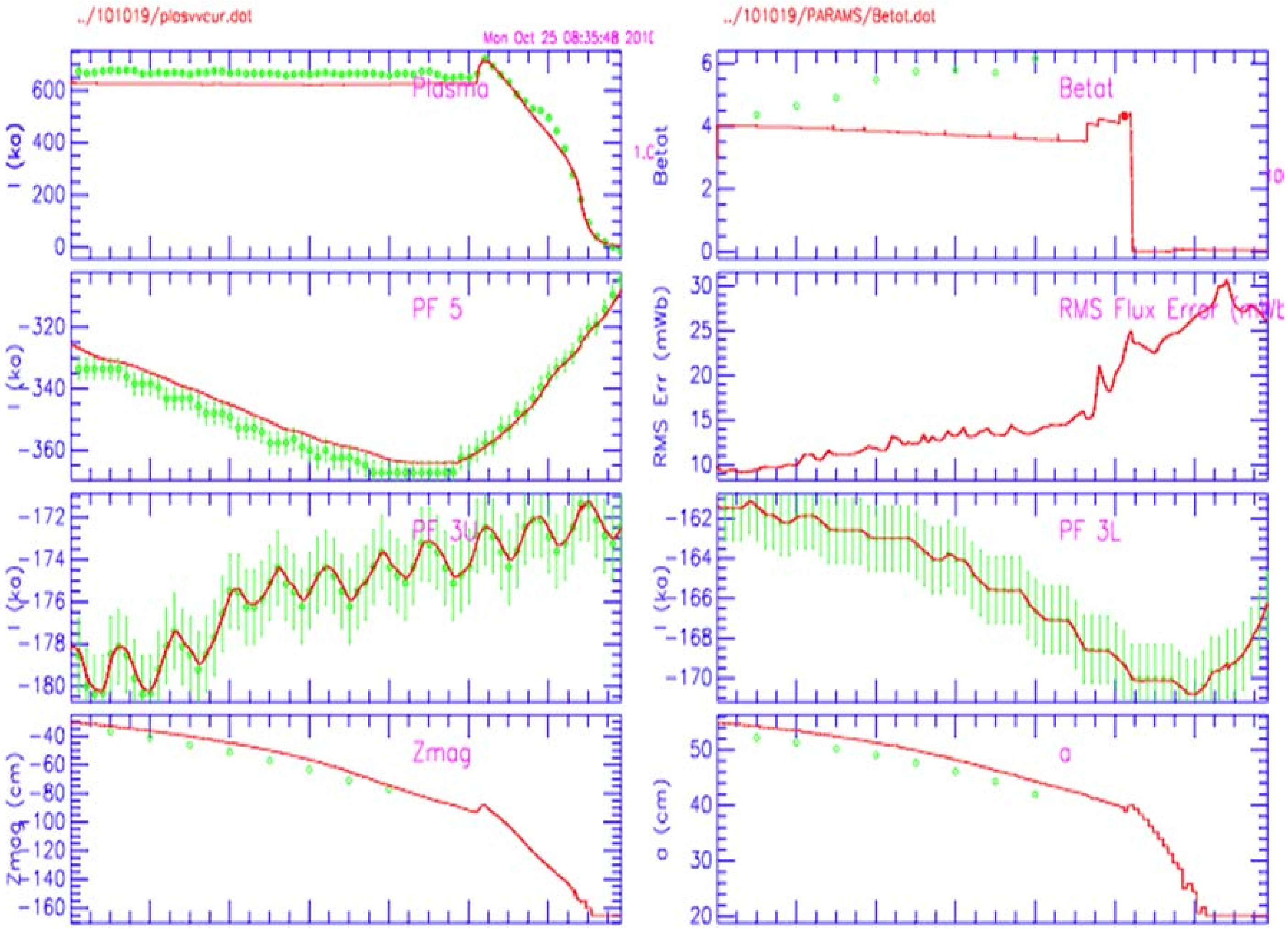
- This is funded via a ITER contract

Current entering the vessel is measured at several locations

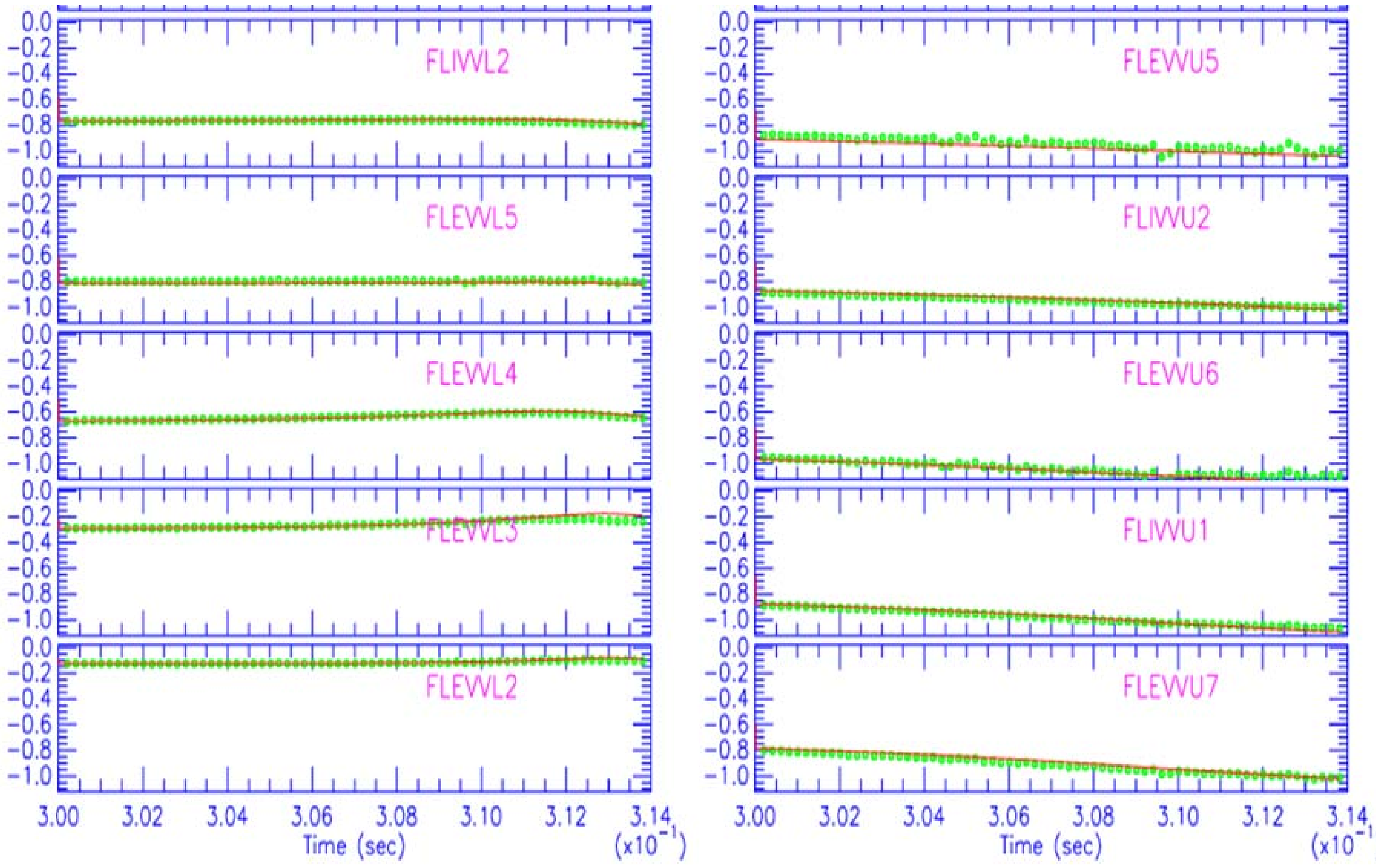
Disruption Studies in NSTX use basic SWIM Framework

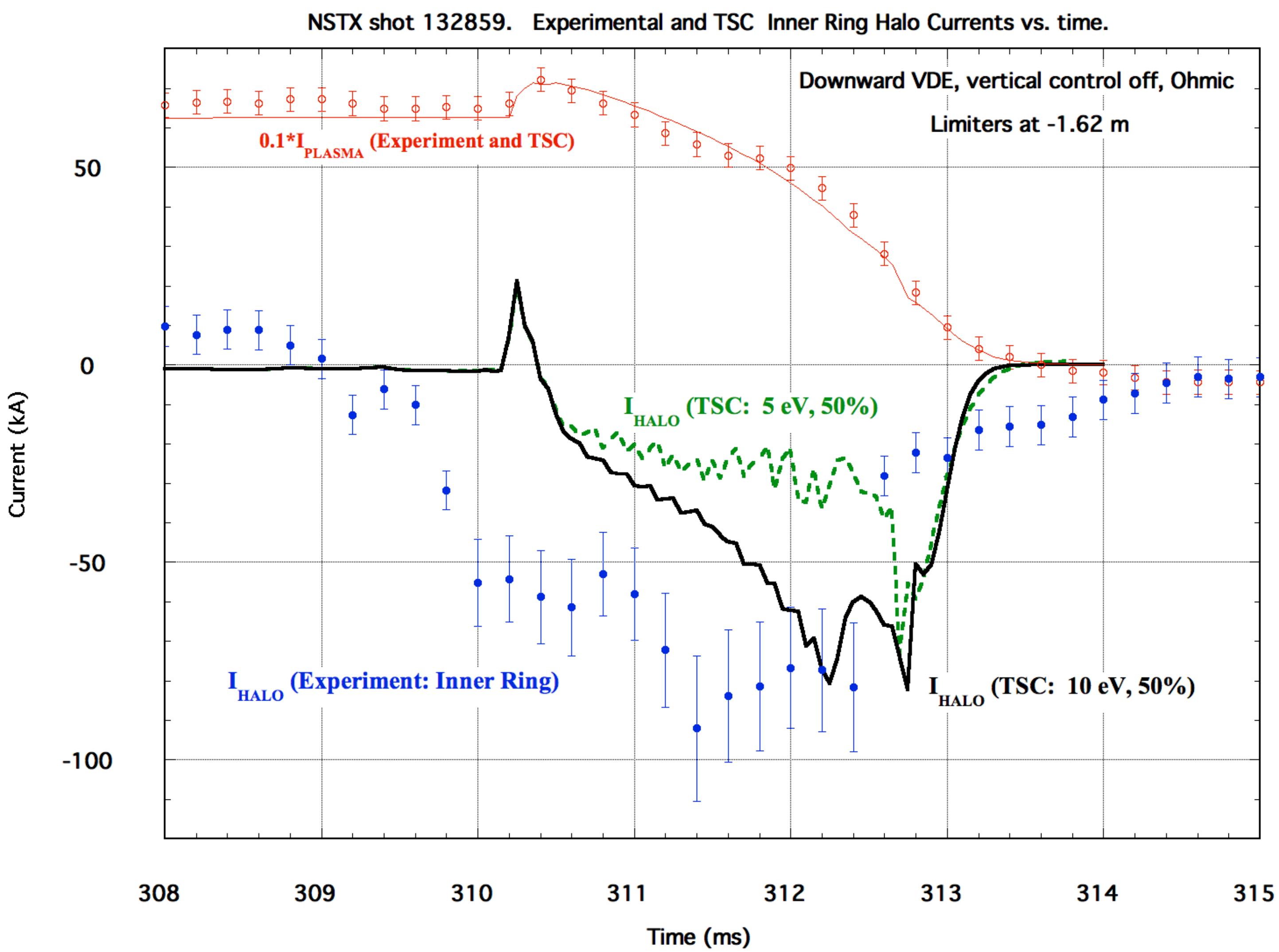


Experimental coil currents are used and results for global parameters agree with experimental values

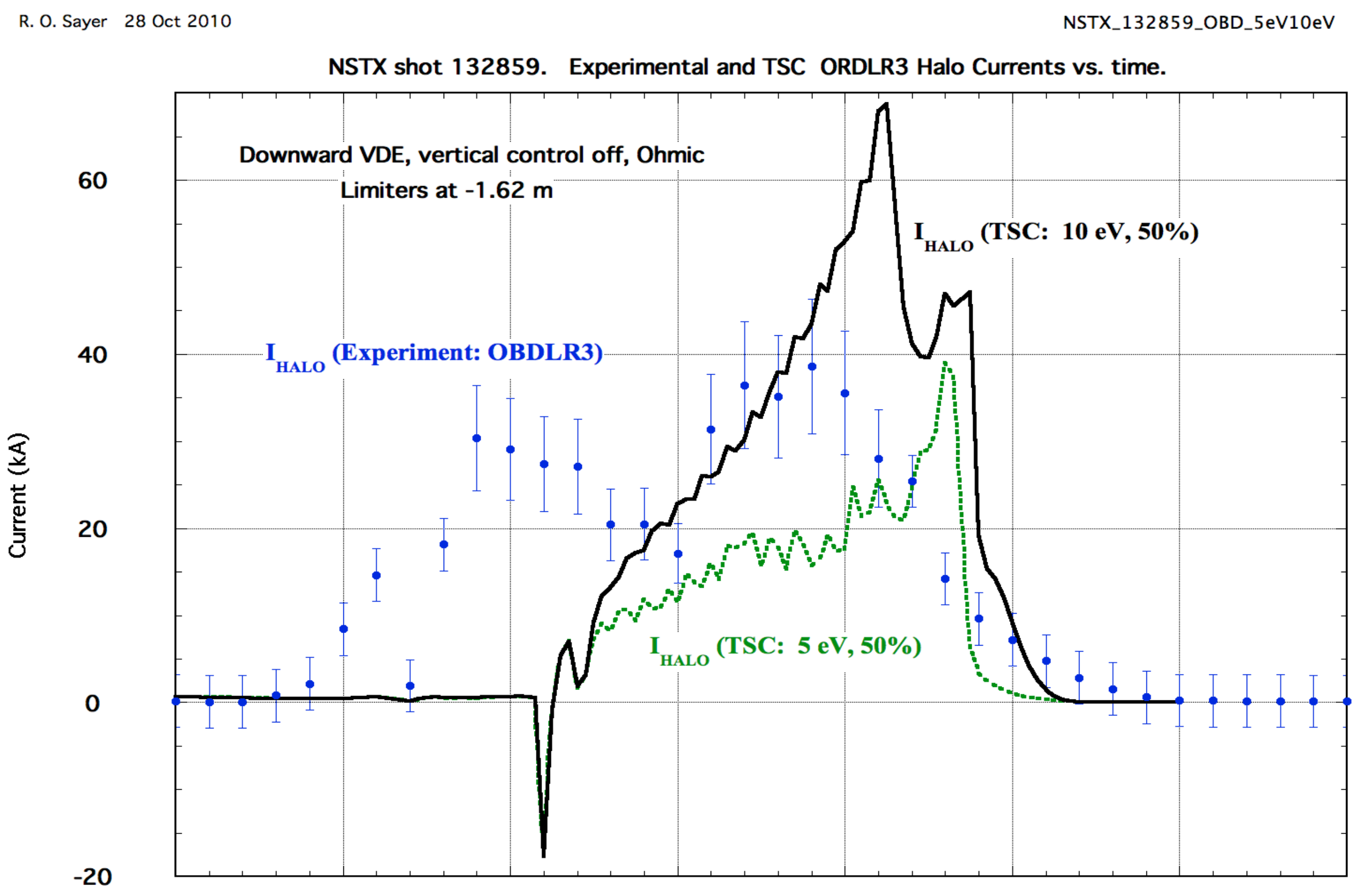


Very good agreement in individual flux loop traces with experimental values.



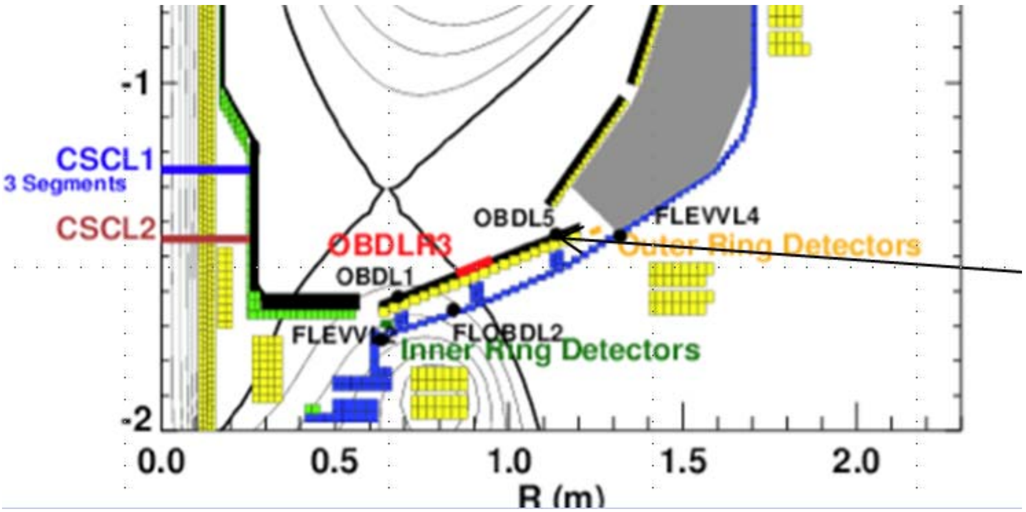


Preliminary results show that halo currents in structure approximately agree in magnitude, but not in timing. May need more detailed structure model including divertor plate.

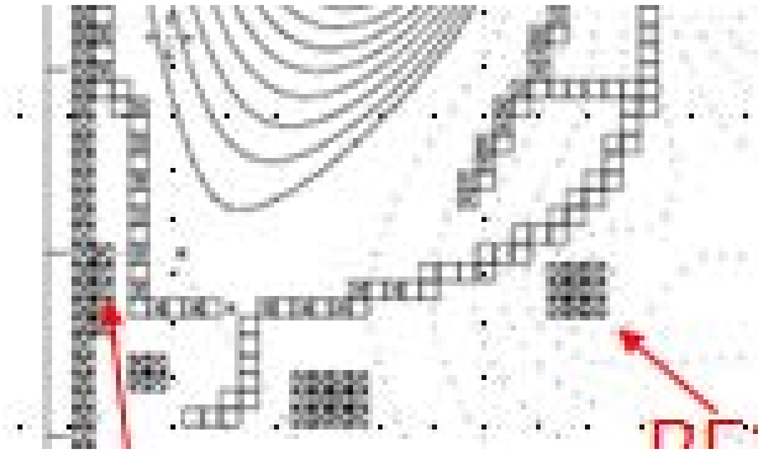


R. O. Sayer 28 Oct 2010
NSTX_132859_OBD_5eV10eV
NSTX shot 132859. Experimental and TSC ORDLR3 Halo Currents vs. time.
Downward VDE, vertical control off, Ohmic
Limiters at -1.62 m
I_HALO (TSC: 10 eV, 50%)
I_HALO (Experiment: OBDLR3)
I_HALO (TSC: 5 eV, 50%)
Current (kA)
60
40
20
0
-20

Present TSC model of divertor structure is not detailed enough to reproduce early time halo current formation



More detailed model of divertor region



TSC Model of divertor region

Need more detailed and higher resolution model of divertor region to more accurately predict halo current formation