Modeling of NSTX Plasmas with the Tokamak Simulation Code (TSC)

S. C. Jardin

in collaboration with

J. Menard, C. Kessel, S. Kaye

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A. H. Glasser

LANL

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Summary and Overview

- The Tokamak Simulation Code (TSC) is widely used for the design of new experiments…in particular to predict flux requirements
- We have now benchmarked TSC with initial NSTX results and find excellent agreement for current and flux using measured coil currents
- TSC has been coupled with a ballooning stability code and with DCON to provide stability predictions for NSTX operation
- TSC can also model initial CHI experiments where force-free current exits and enters vessel due to applied poloidal voltage..like halo

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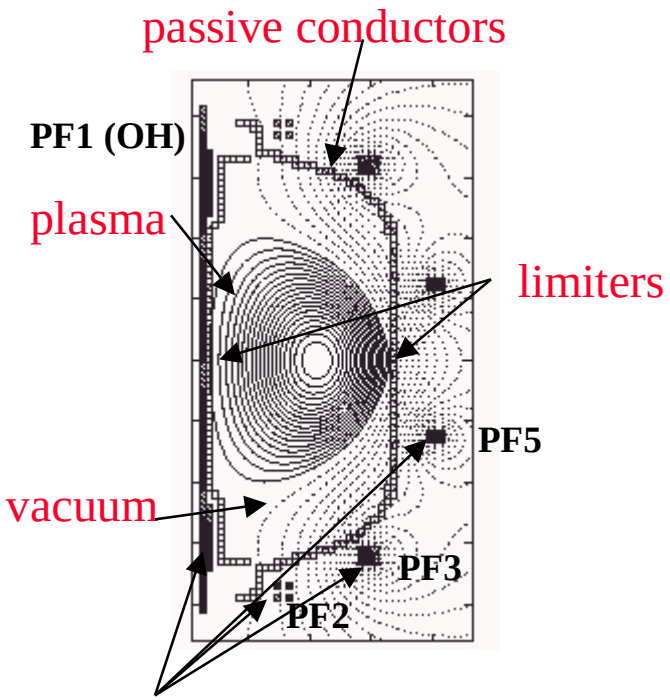
Tokamak Simulation Code (TSC)



- TSC models the evolution of a free-boundary axisymmetric toroidal plasma on resistive and energy confinement time scales.
- The plasma equilibrium and field evolution equations are solved on a two-dimensional Cartesian grid….fluxes are continuous
- The surface-averaged transport equations for the pressures and densities are solved in magnetic flux coordinates using matrix implicit method
- An arbitrary transport model can be used,
- Neoclassical-resistivity, bootstrap-current, auxiliary-heating, current-drive, alpha-heating, radiation, pellet-injection, sawtooth, and ballooning-mode transport models are all available.
- As an option, circuit equations are solved for all the poloidal field coil systems with the effects of induced currents in passive conductors included.
- Realistic feedback systems can be defined to control the time evolution of the plasma current, position, and shape.
- Open field lines can be included, and the halo current is computed as part of the calculation

TSC can be run in several modes

Either

- p(ψ,t) input
- n(ψ,t) input
- Z(ψ,t) input
- I_i (t) input or read from data file
- full device with no up/down symmetry

Or

- p(ψ,t) calculated from transport equation
- n(ψ,t) calculated from density evolution equation
- Z(ψ,t) calculated from impurity ionization physics
- I_i (t) calculated from circuit equations with feedback
- impose symmetry about the midplane

Refs: NF **33** (1993) p. 371 NF **34** (1994) p. 1145

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Tokamak Simulation Code (TSC)

TSC has always been project driven. Capabilities were added as needed:

- **S-1**- inductive formation of spheromaks using flux core
- **PBX**- the effect of strong shaping on plasma axisymmetric stability, disruption forces on the passive stabilizers, volt-second benchmarking, CD experiments
- **TCV**- design of a tokamak with a flexible shaping system, doublet formation
- **CIT/Ignitor** - volt-second consumption, disruption effects, transient ignition
- **DIII-D** - shape control, VDEs, volt-second benchmarking
- **BPX** - burn control feedback, divertor sweeping
- **TPX** - vertical control, shape control, plasma scenarios
- **ITER** - volt-second consumption, shape control, plasma disturbances
- **TFTR** - volt-second benchmarking, impurity injection experiments
- **NSTX** - volt-second requirements for a 1 MA ST

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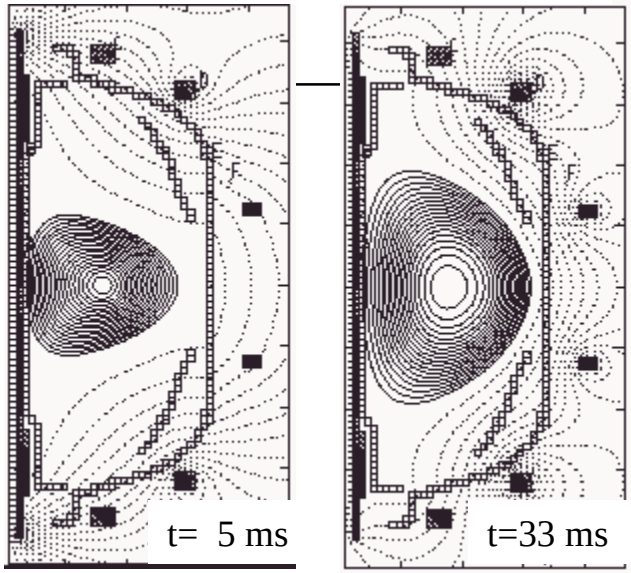
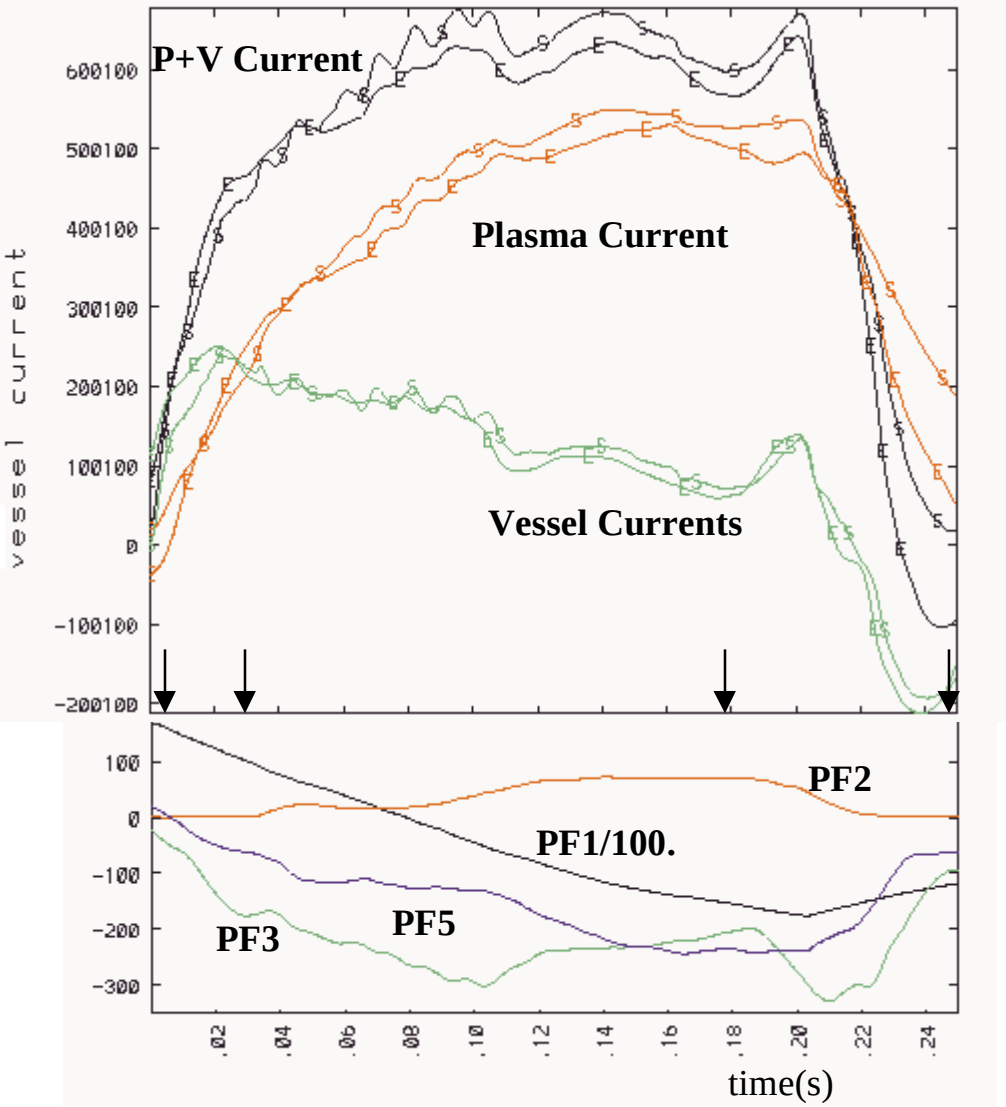
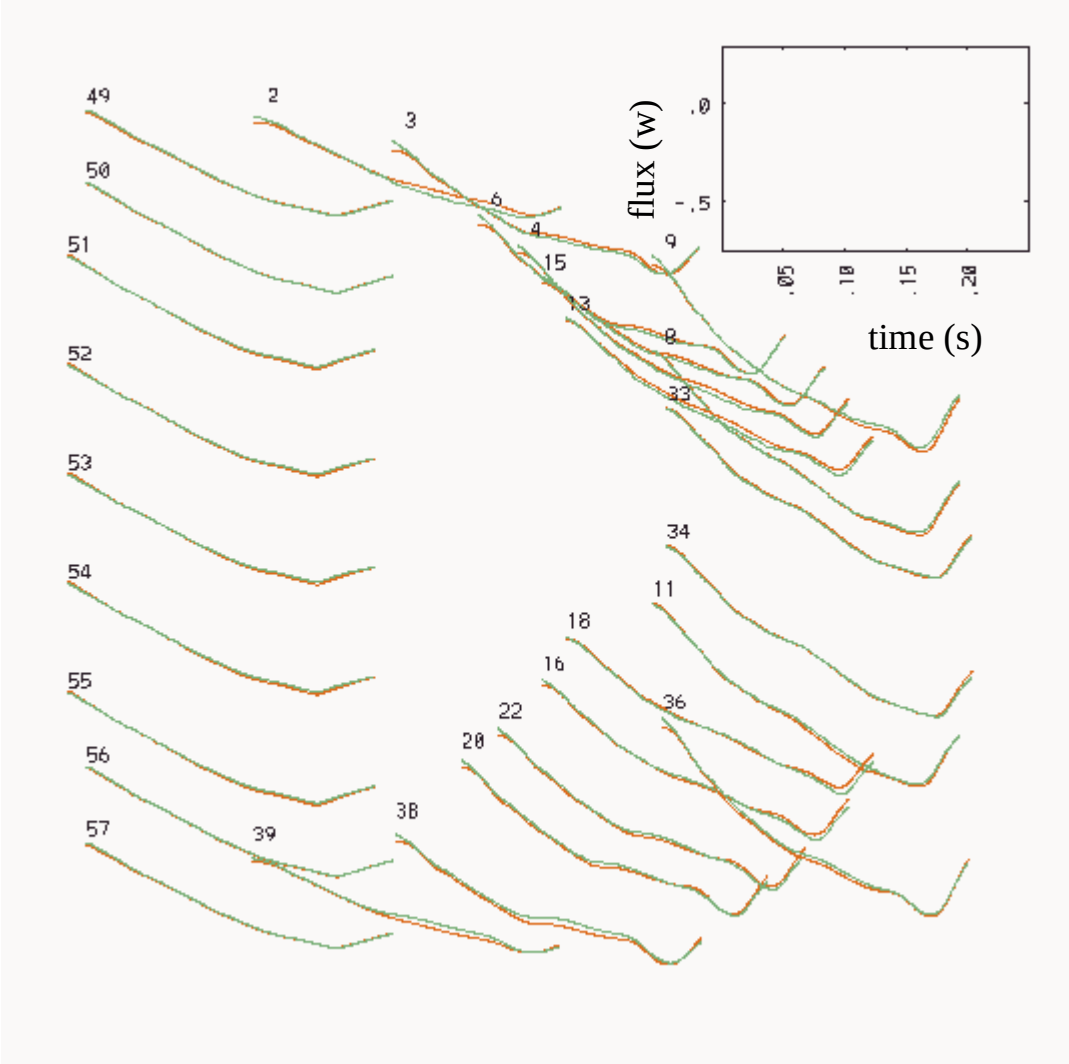
NSTX shot 100920 Predict plasma current using actual coil currents and standard transport model



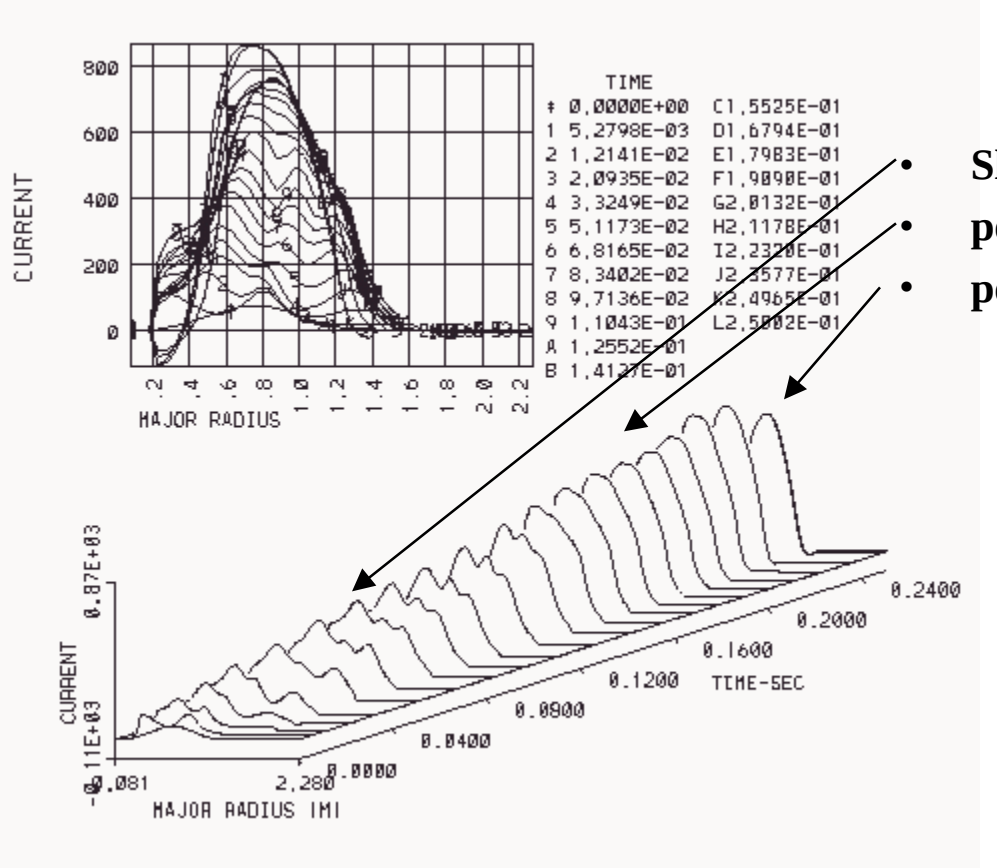


NSTX shot 100920

Comparison of TSC (red) and data (green) at different flux loop locations around NSTX vessel

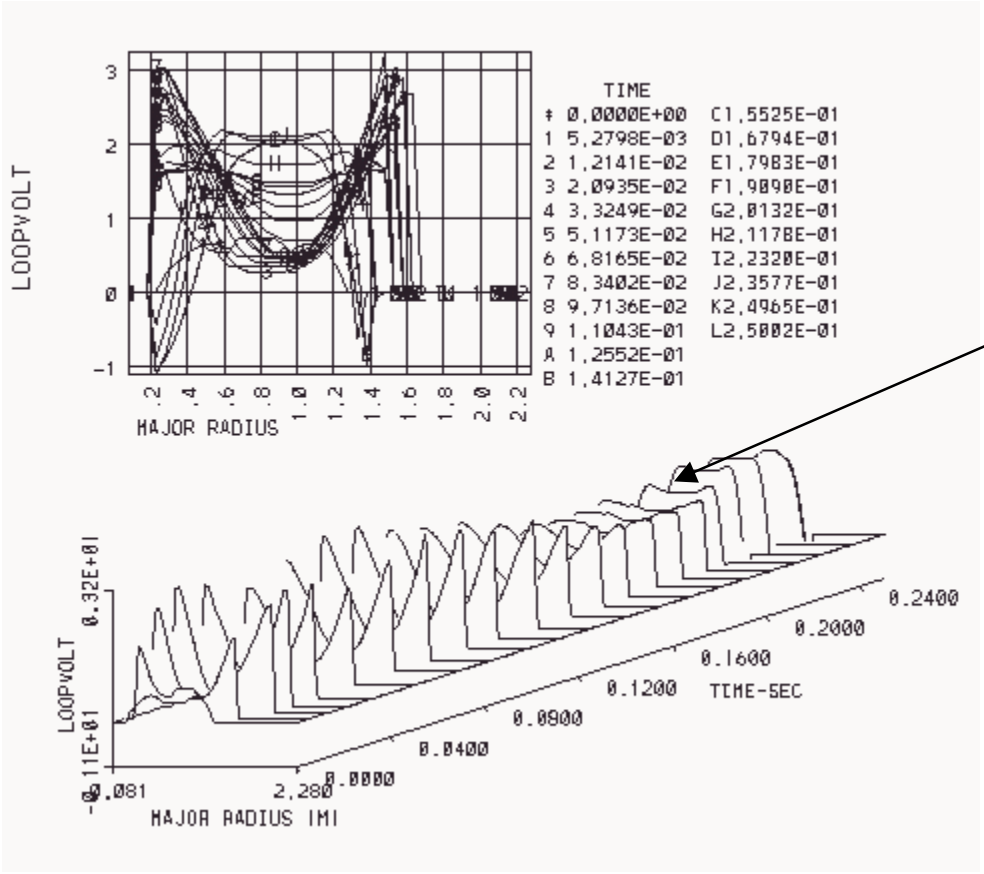


NSTX shot 100920: Current density



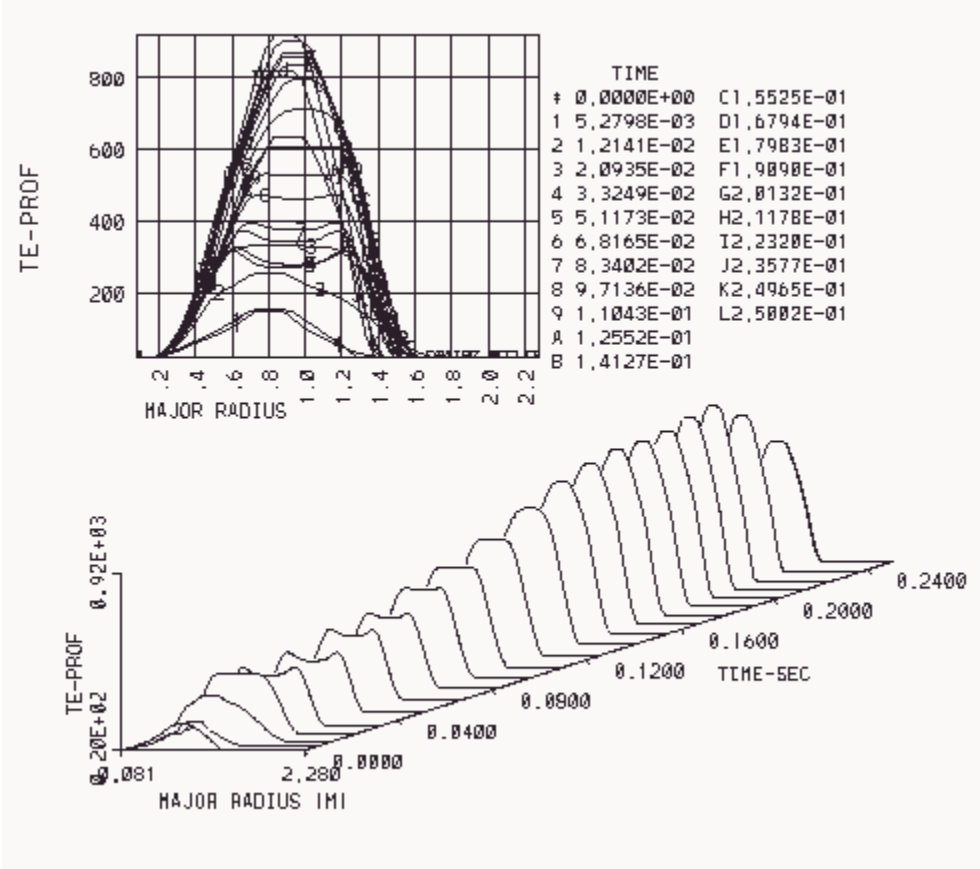
- **Slightly hollow during ramp**
- **peaked during flattop**
- **peaked during decay**

NSTX shot 100920: Loop Voltage



Note: Becomes flat at end of flattop

NSTX shot 100920-: T_e profile

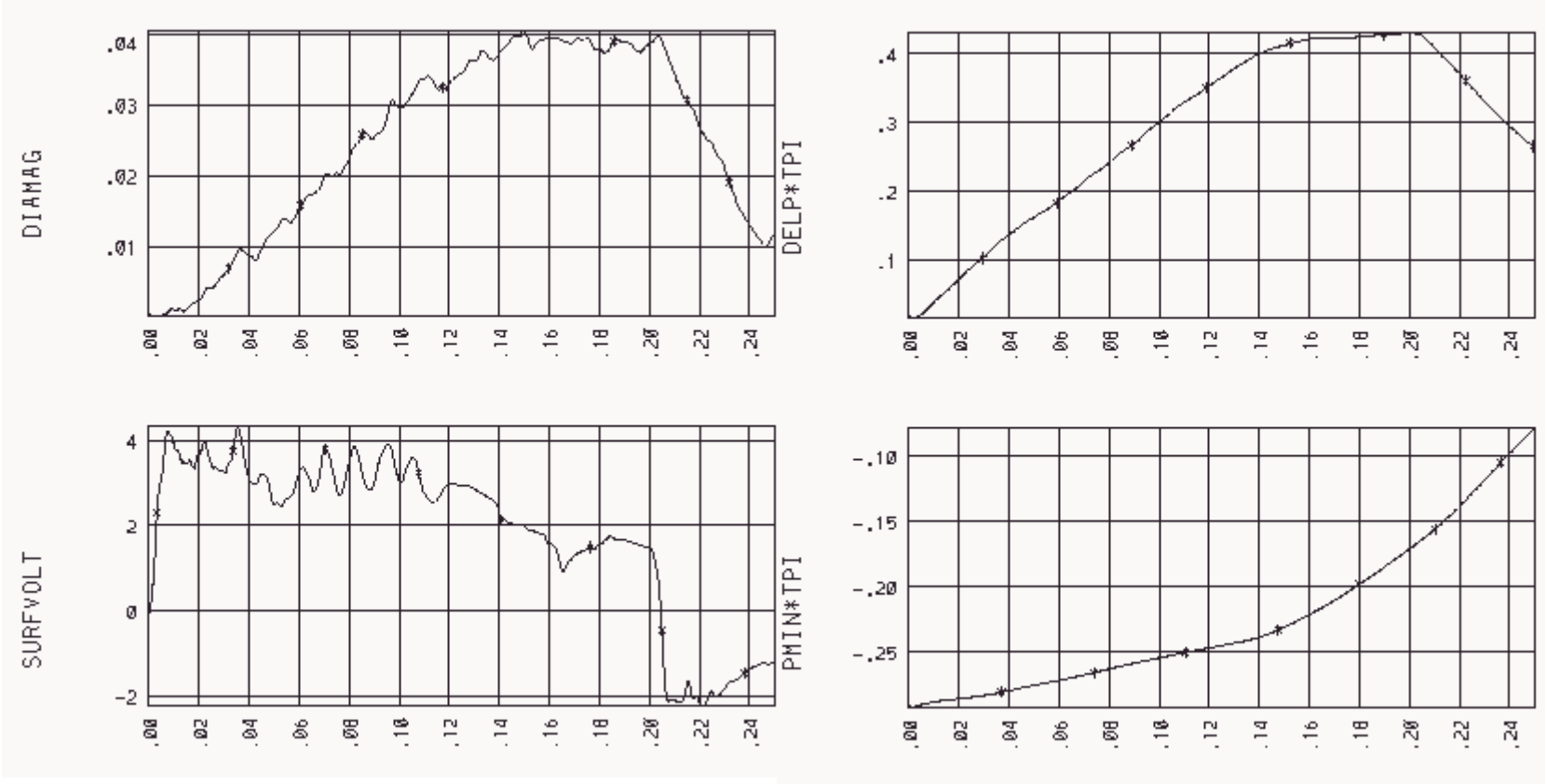


Te(0) ~ 900 ev

Note: actual value depends on density assumed

β ~ 1.4 %

NSTX shot 100920:



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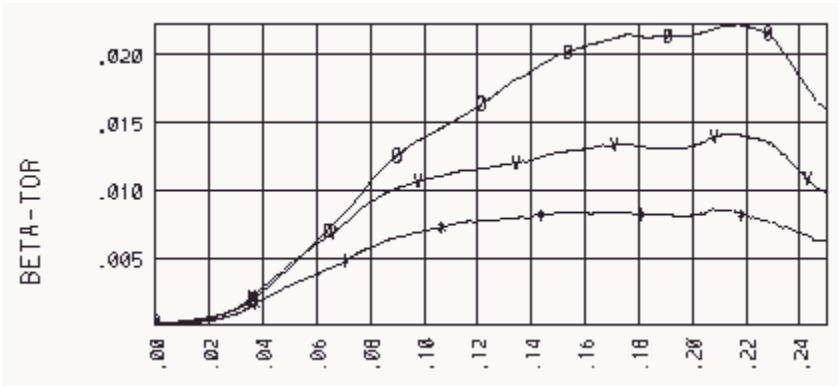
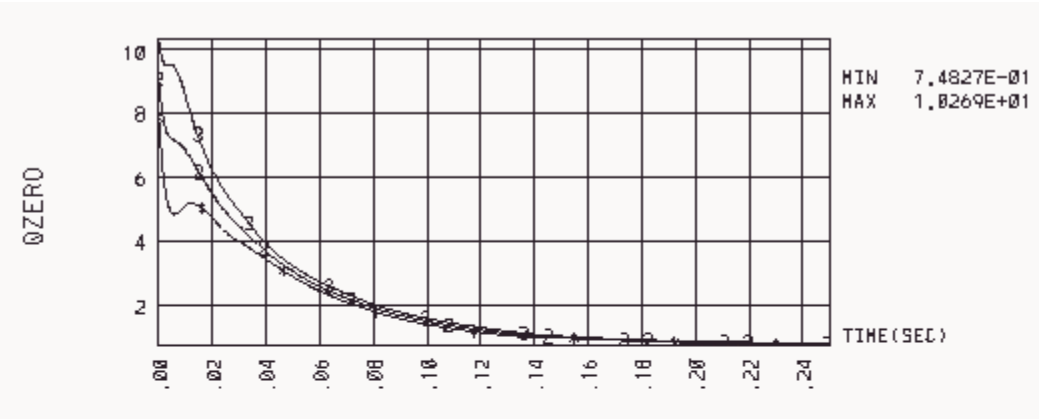
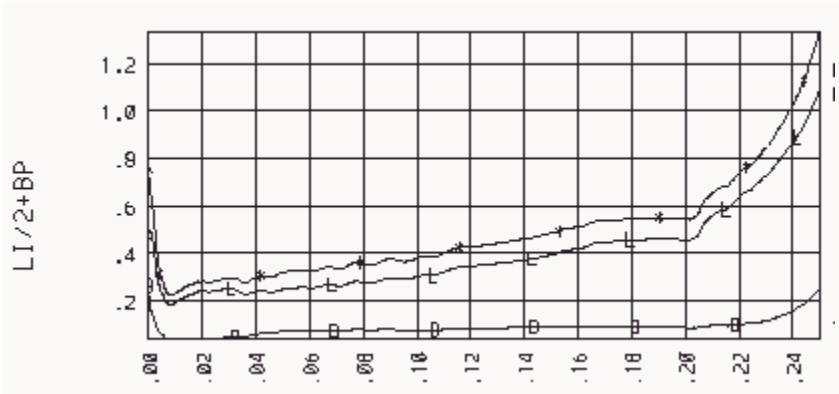
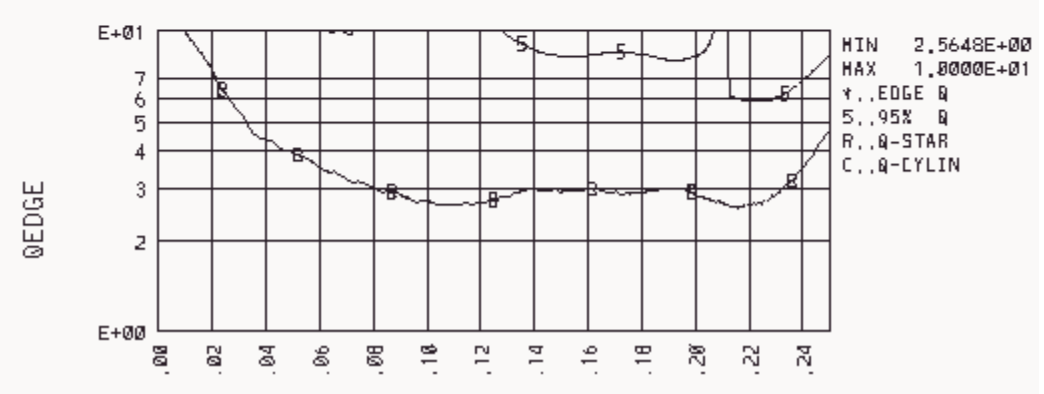
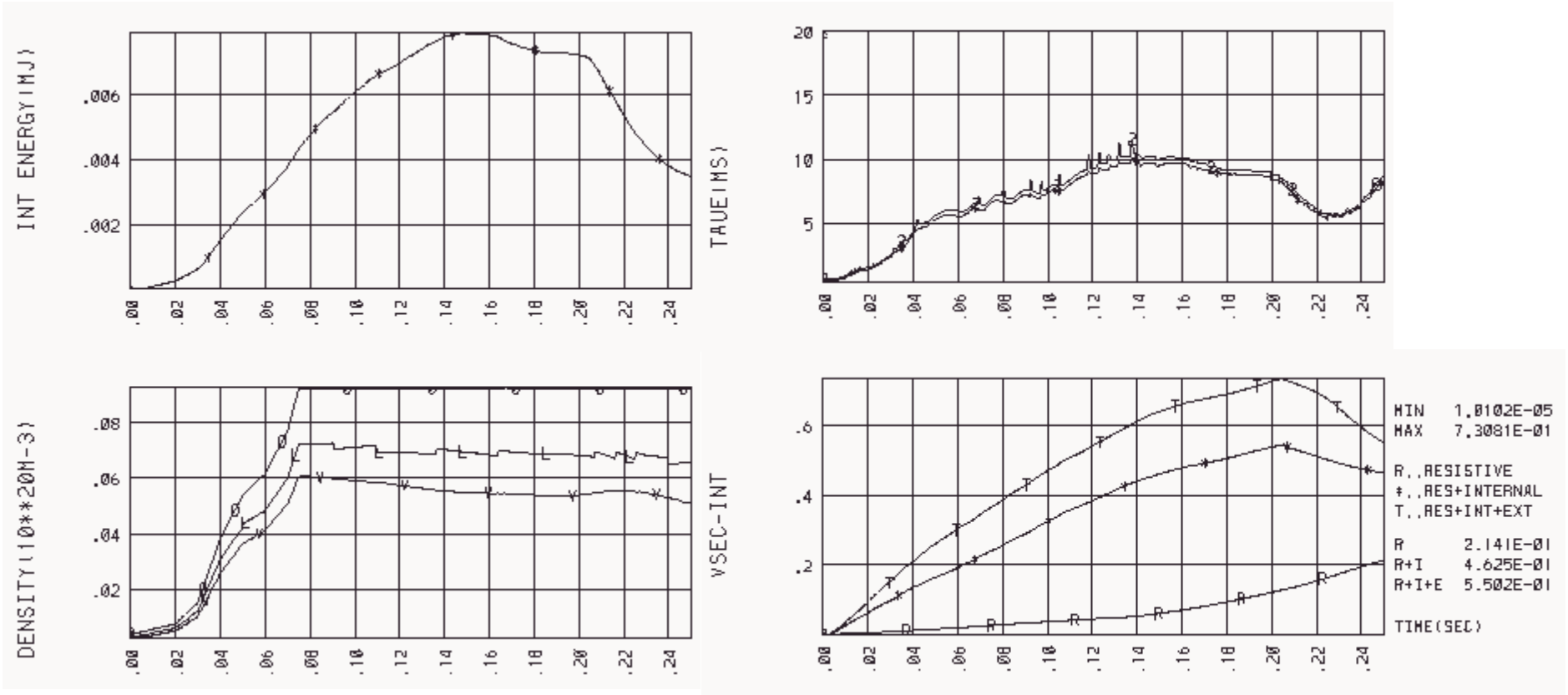








NSTX shot 100920:



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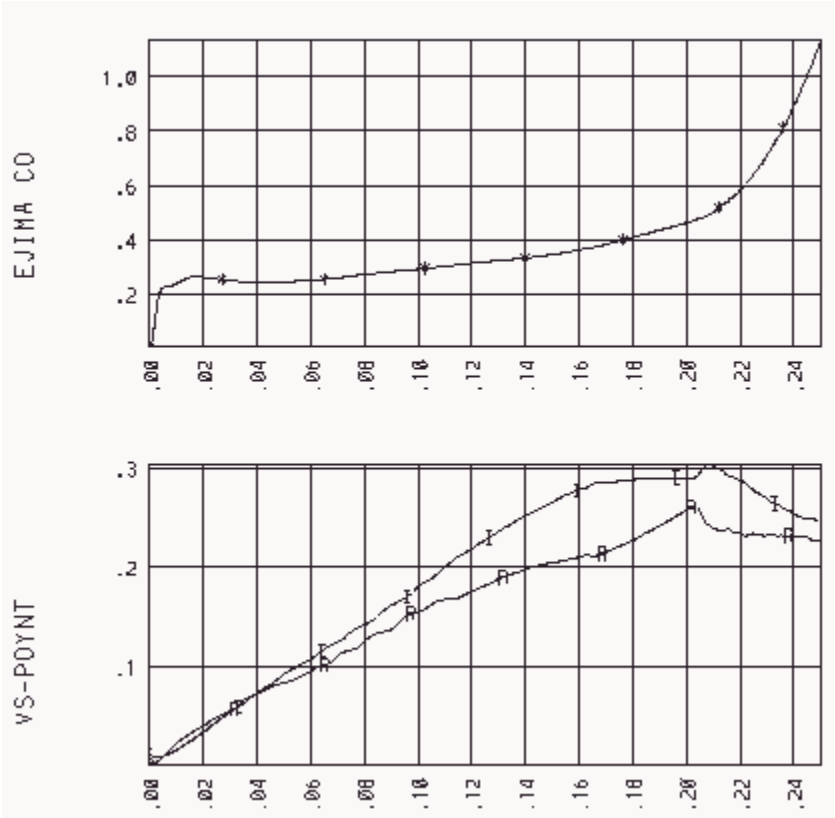
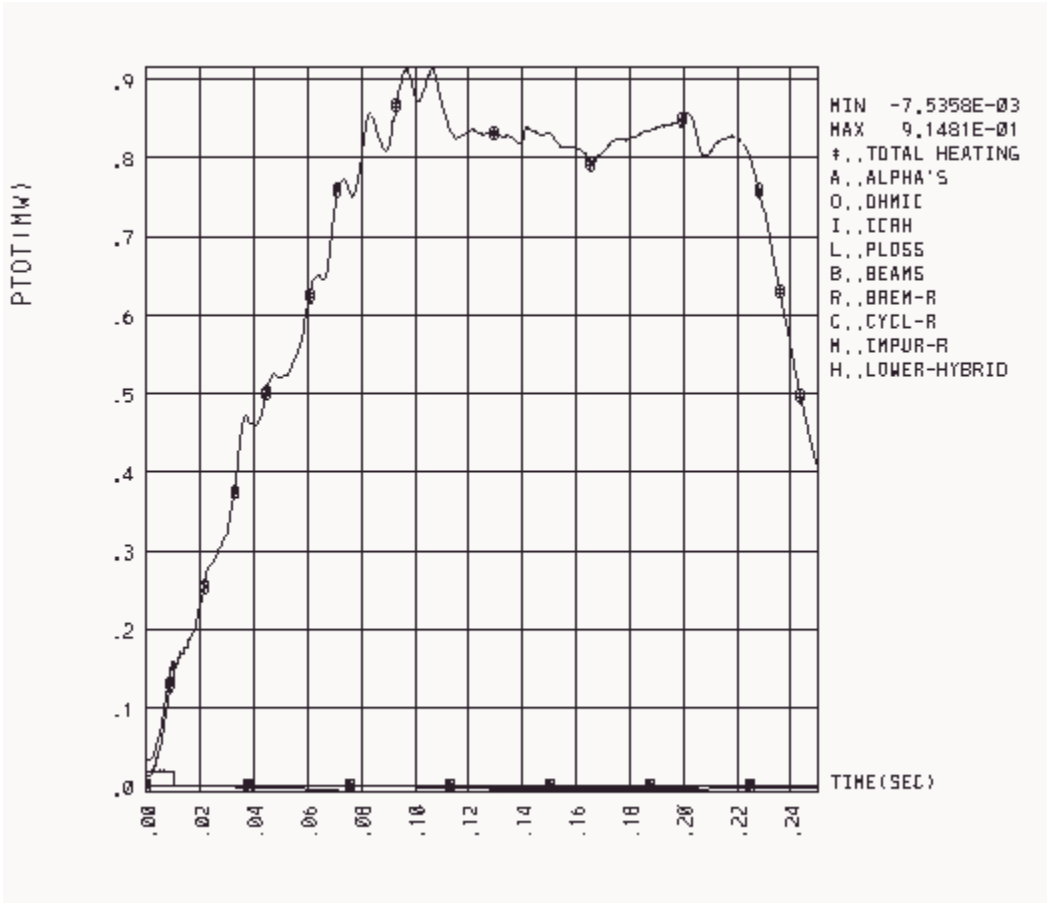
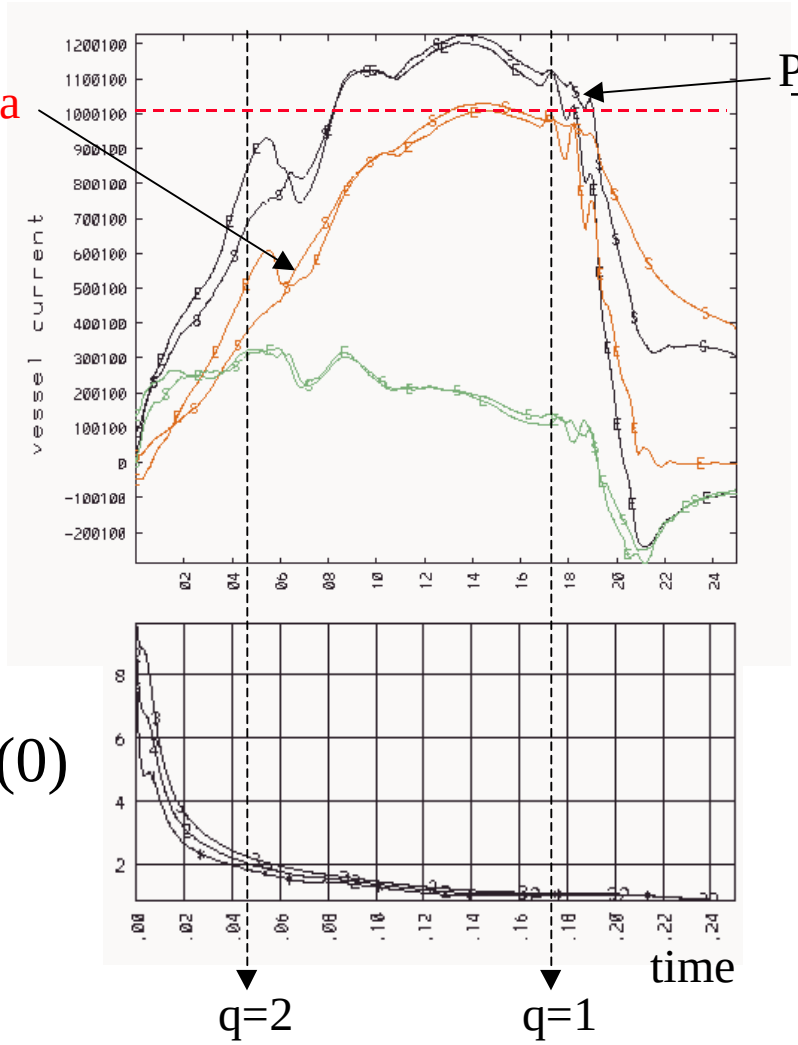
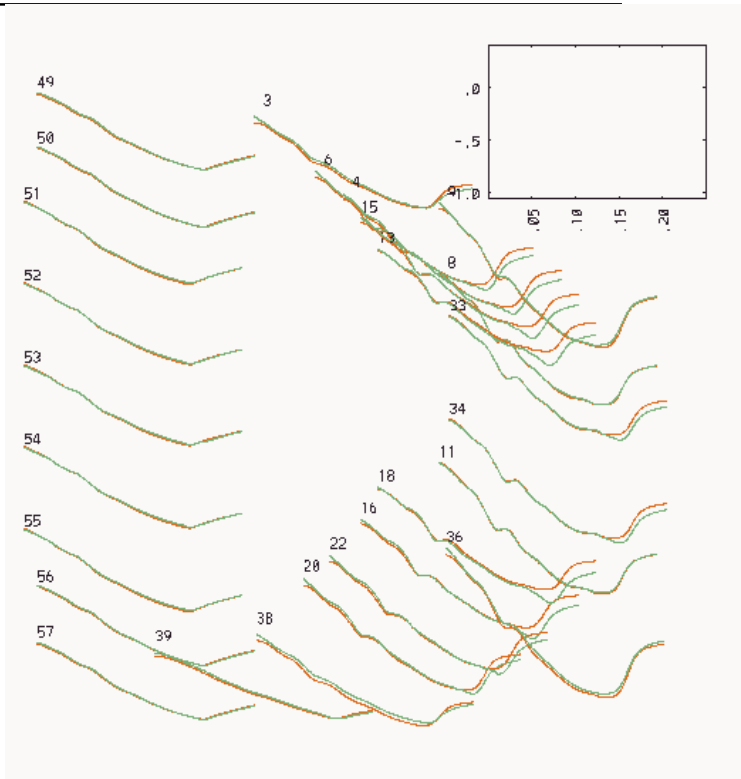




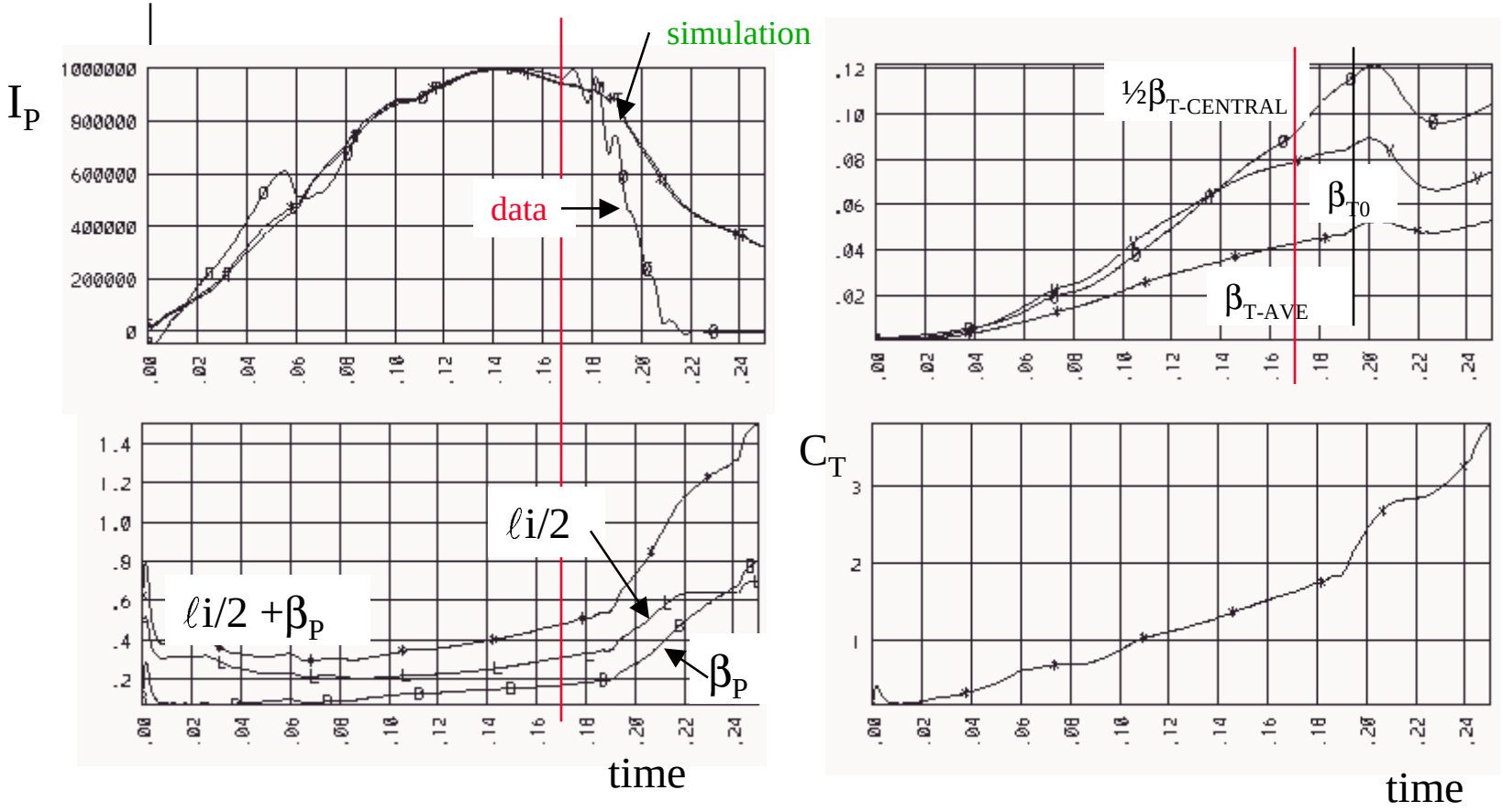
1MA shot 101522--comparison of TSC results <u>using measured coil currents</u> with data



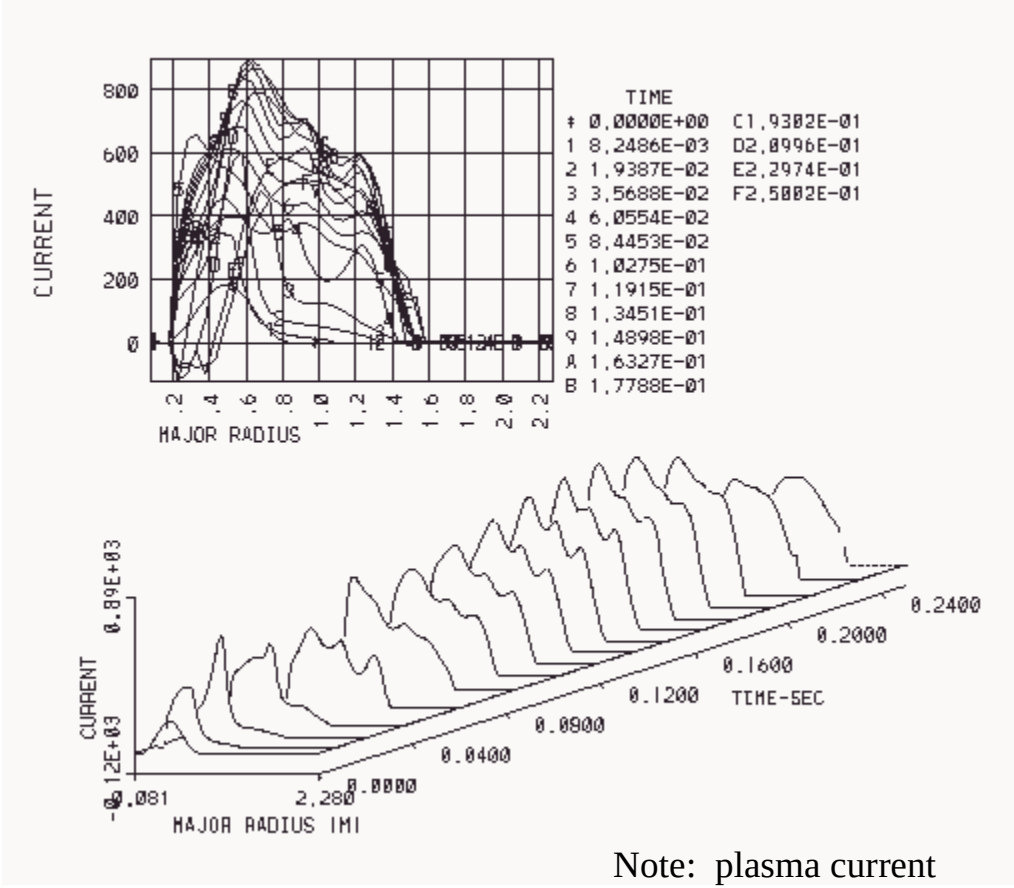


Comparison of flux loop values:
green…TSC simulation
red….Experiment

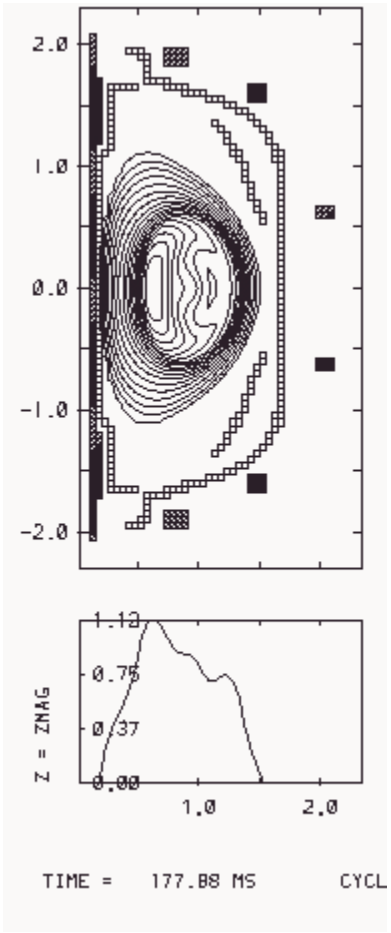
1MA shot 101522



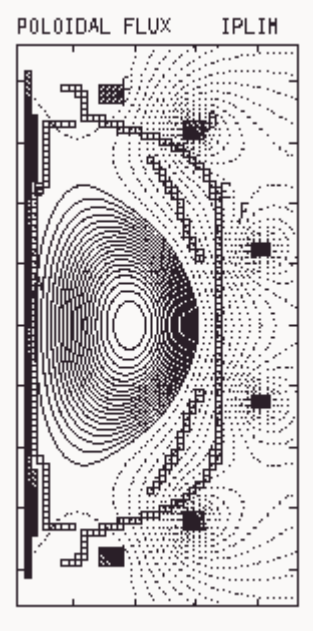
1 MA shot 101522



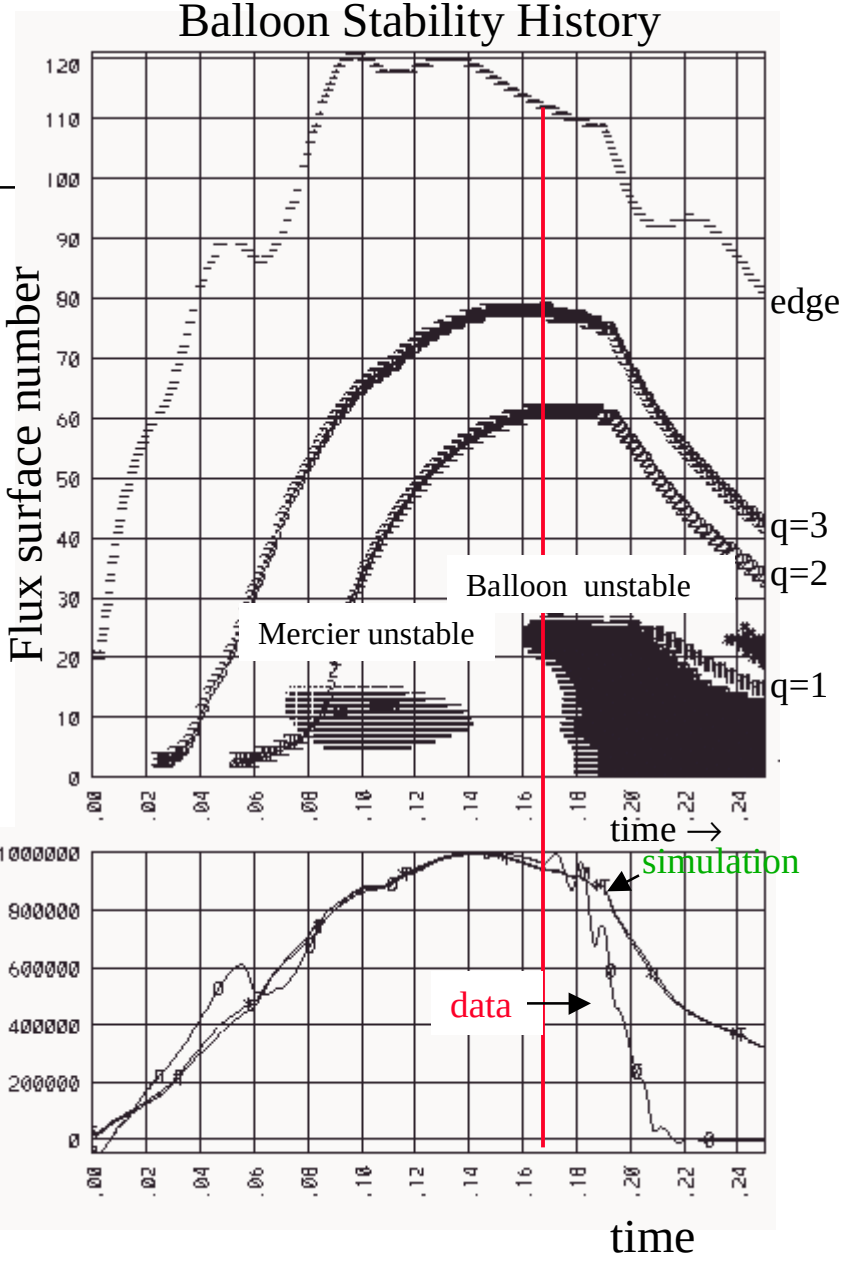
Note: plasma current not equilibrated



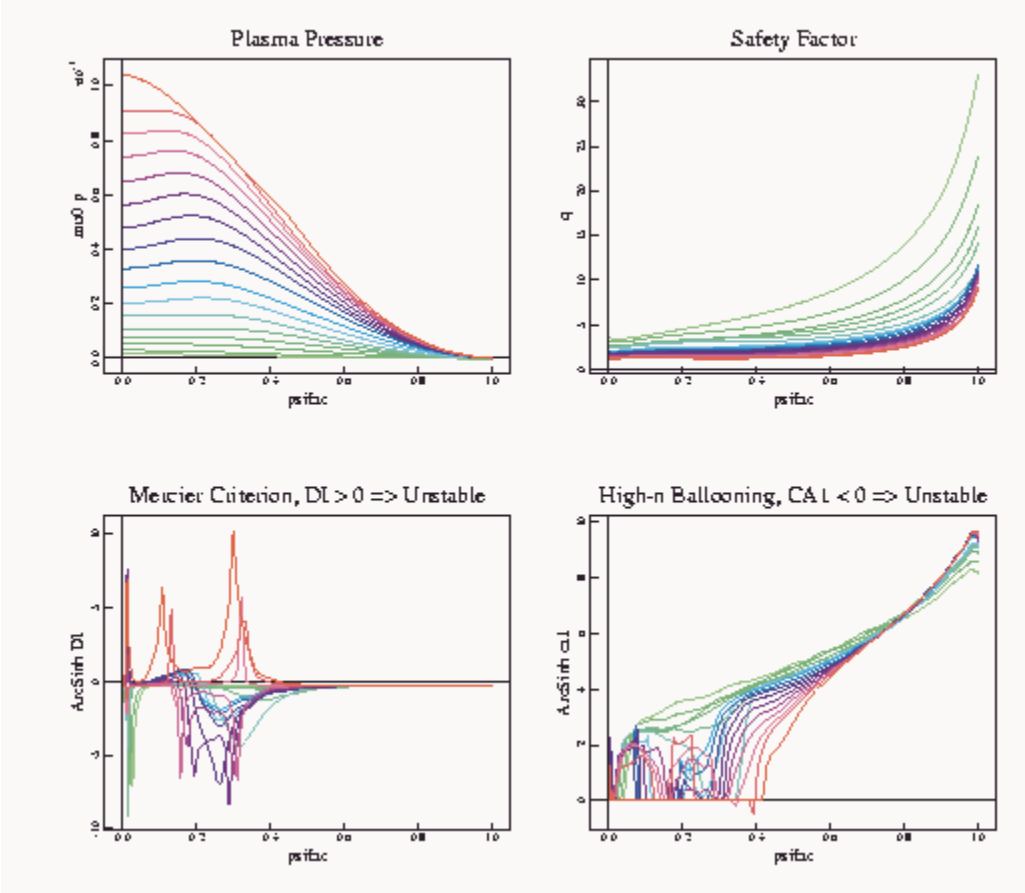
1 MA shot 101522

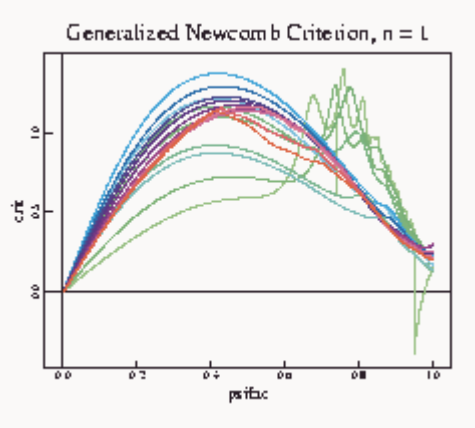


Large region of Balloon instability develops about time discharge “terminates”

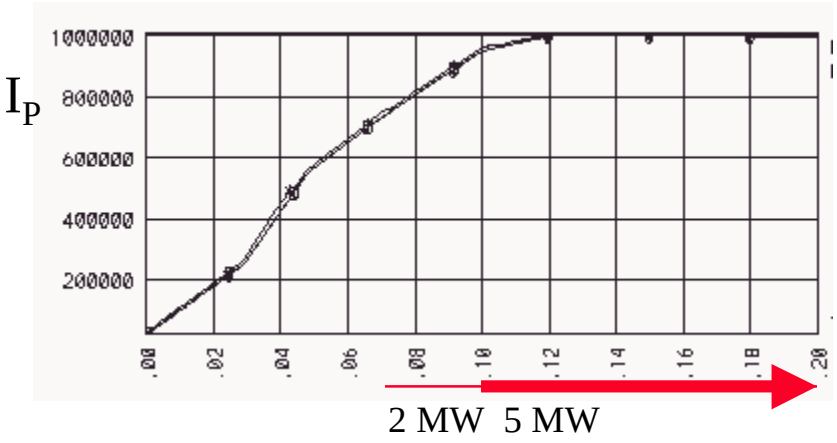


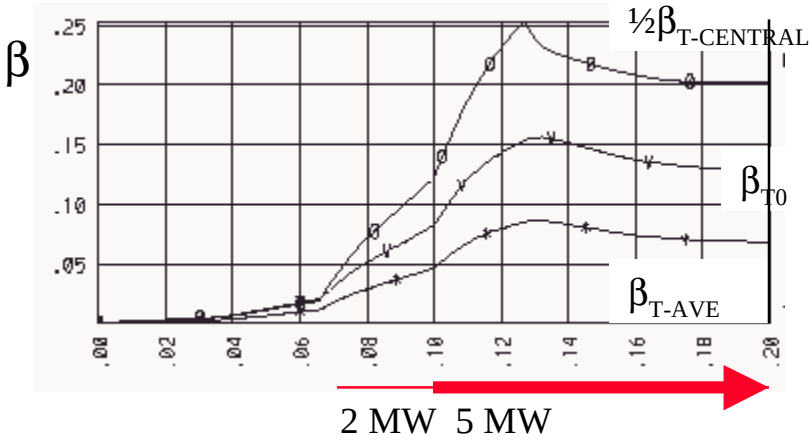
DCON analysis shows Mercier/Balloon stability near end in agreement with TSC…n=1 stable

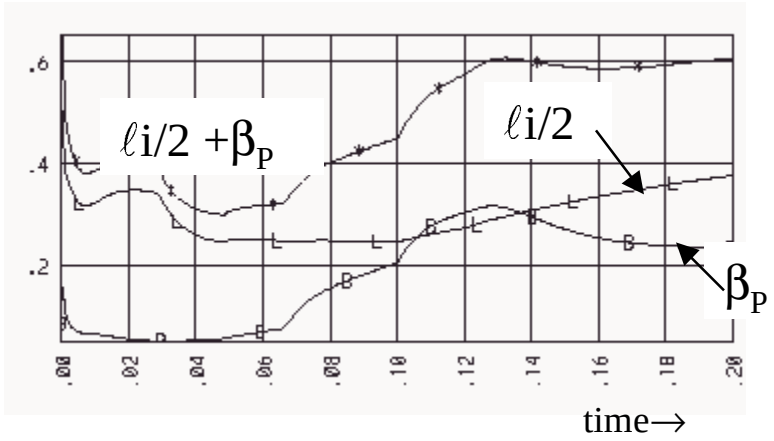


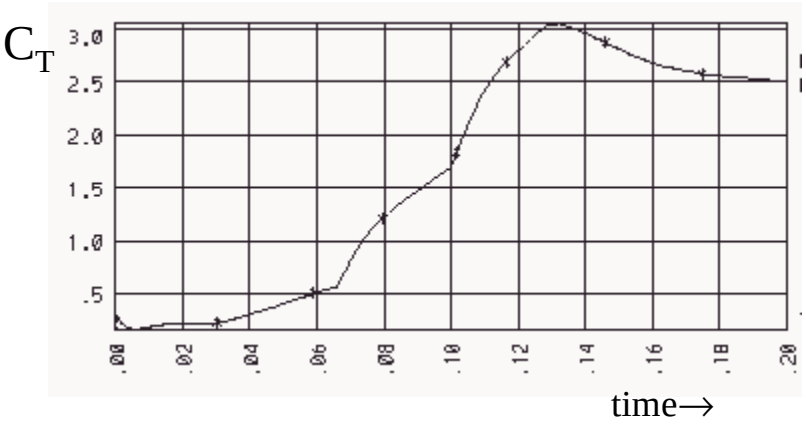


Prediction of Beam heating Shot based on 1 MA shot 101522









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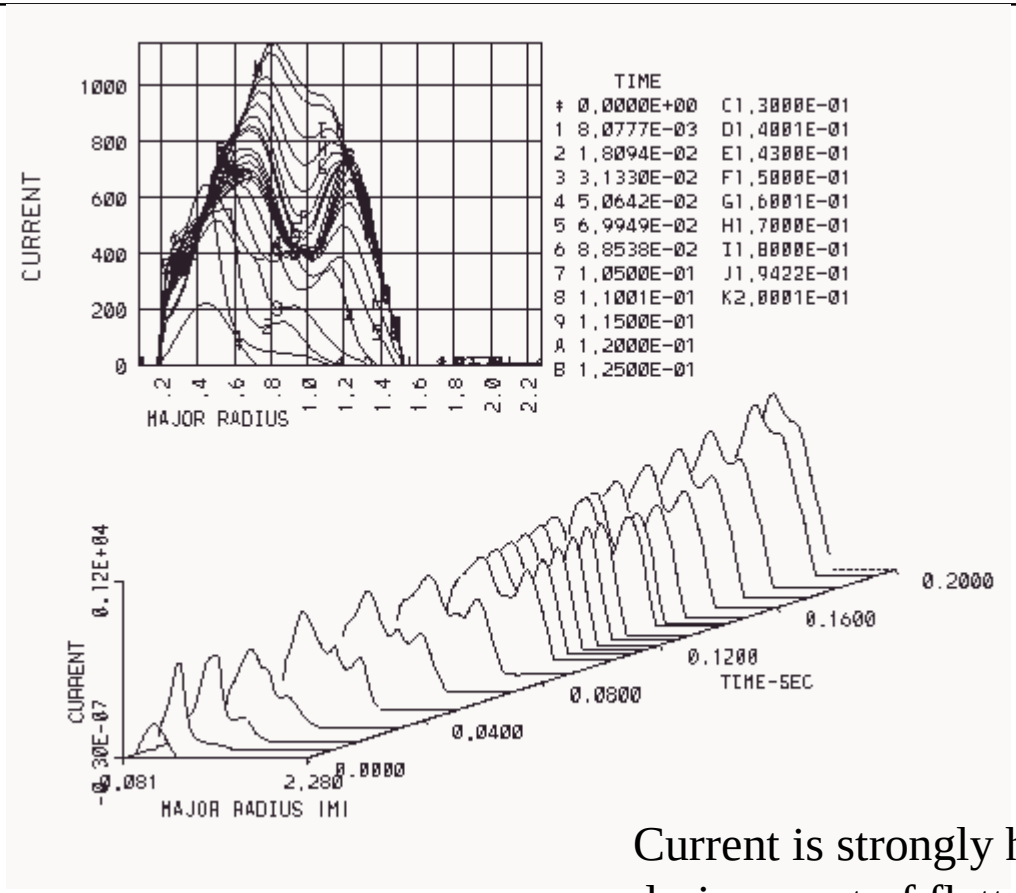


Current is strongly hollow during most of flattop

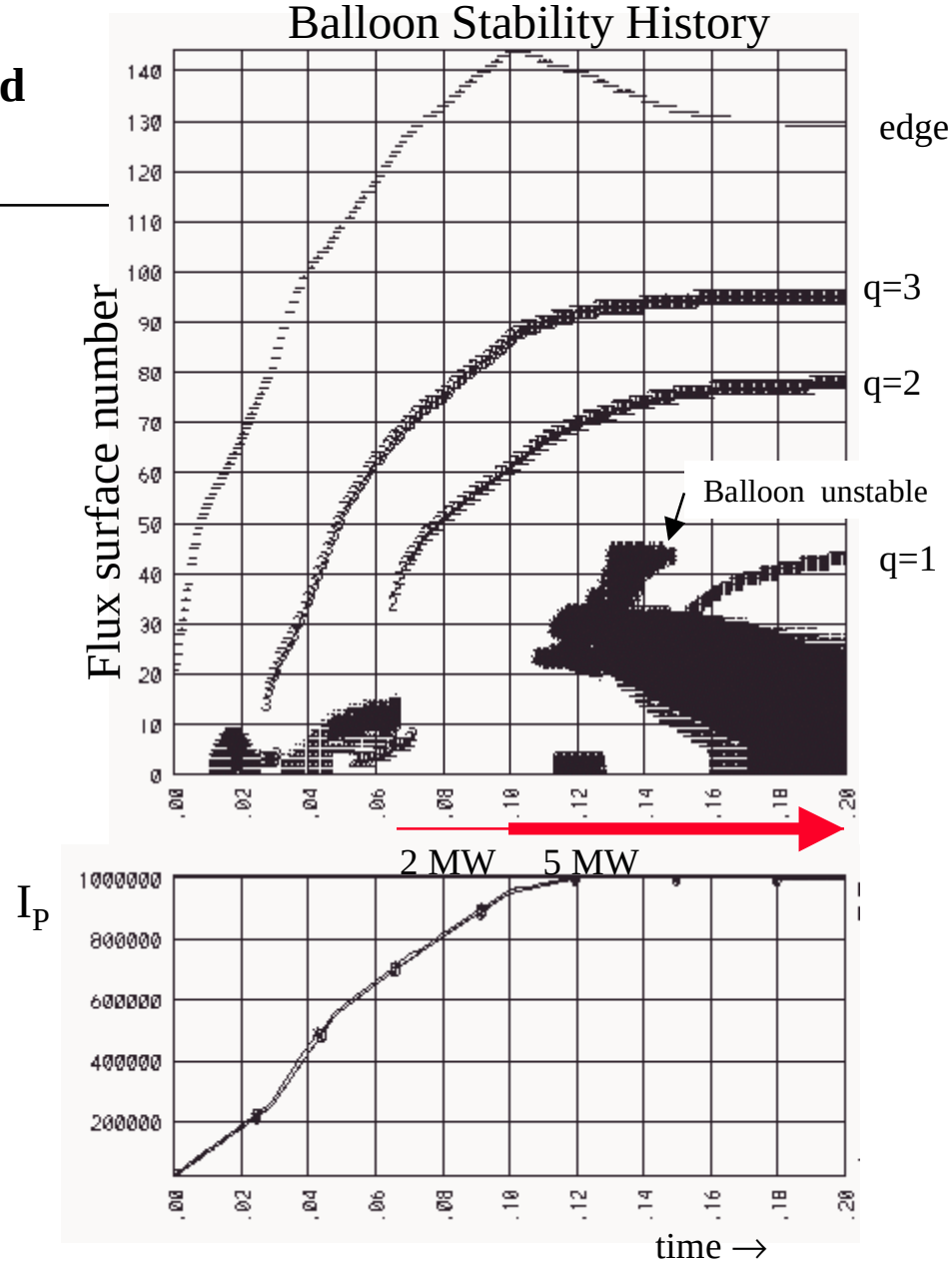
Prediction of Beam heating Shot based on 1 MA shot 101522

• Region of balloon instability develops shortly after full 5 MW of beams turned on

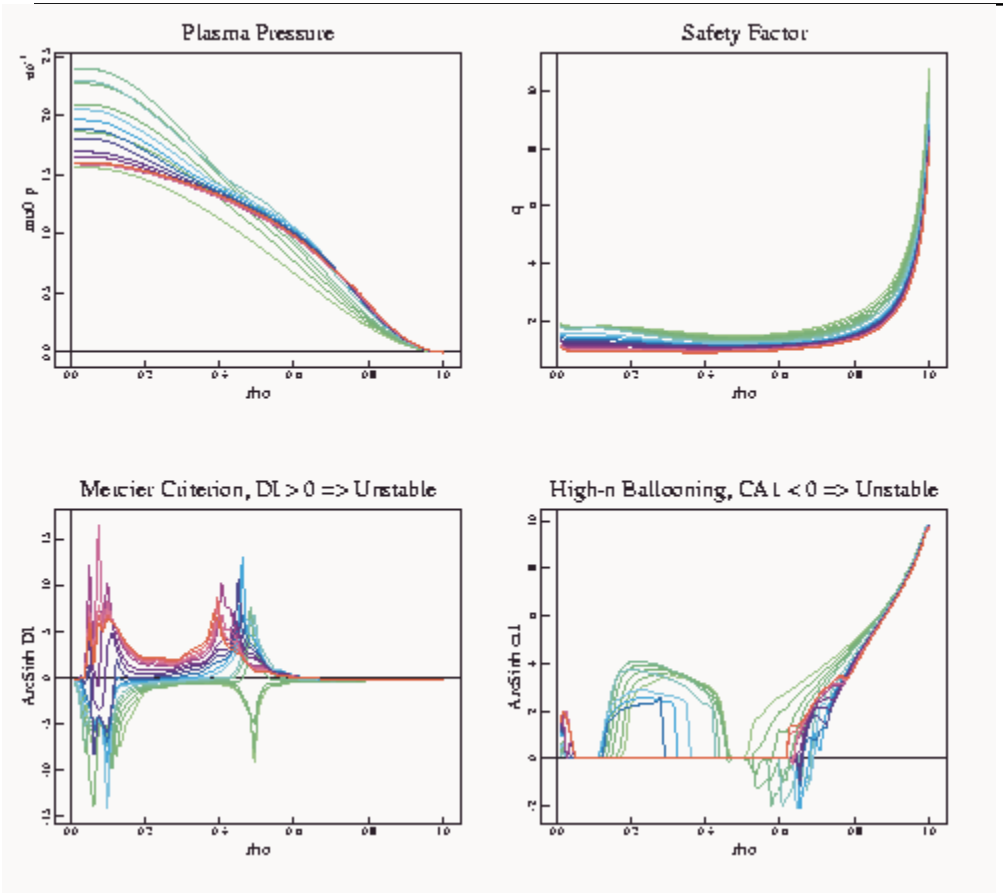
• Instability at β ~ 12% due to low shear, low ℓi, and peaked pressure profiles

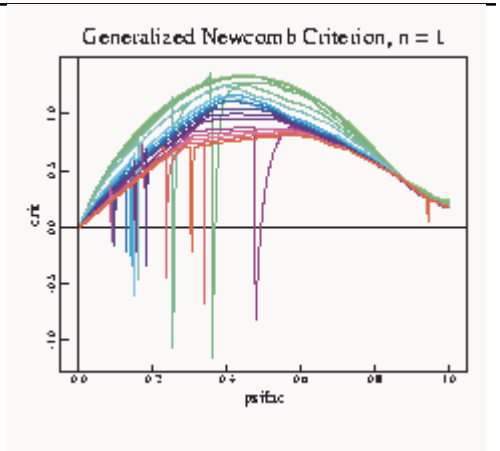
• Many variations of this are possible that will be more stable

- broader pressure
- more shear
- higher ℓi,



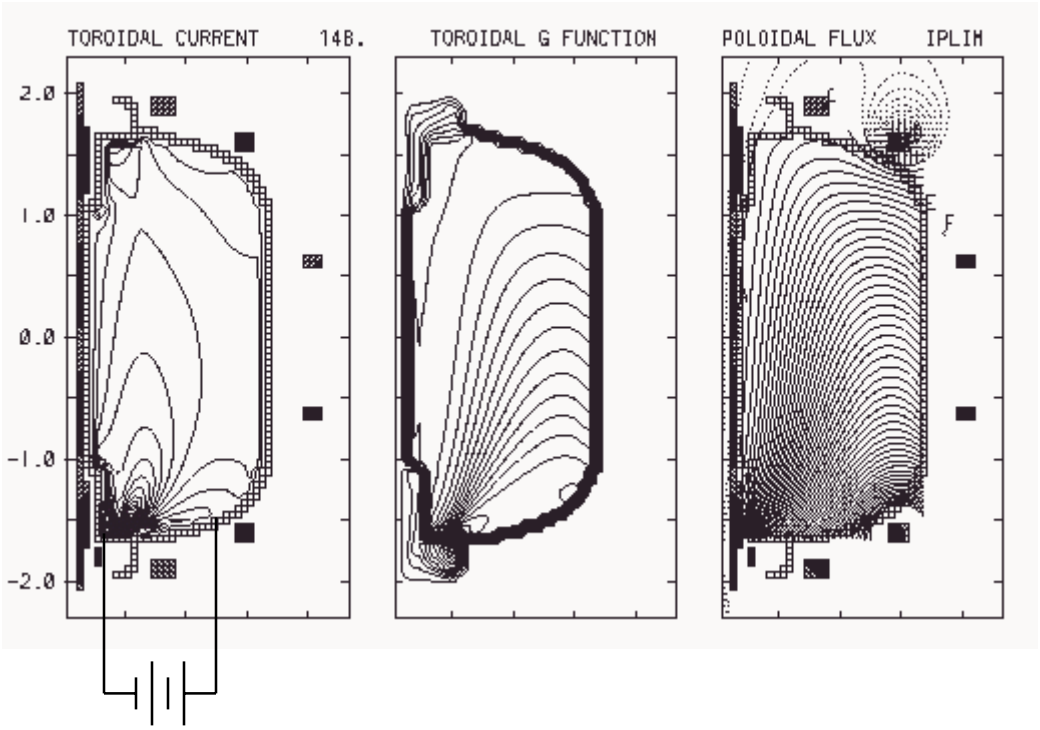
DCON analysis shows n=1 mode becomes unstable also





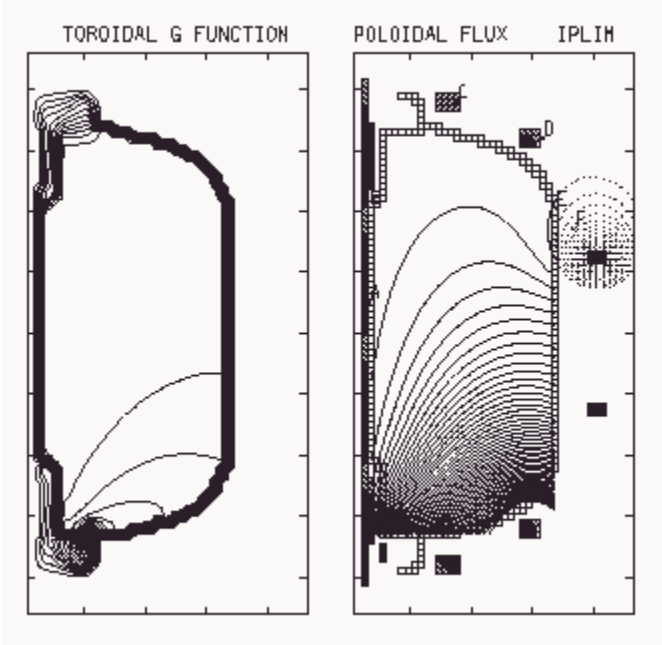
Shot 102080 CHI Experiment

RB_T

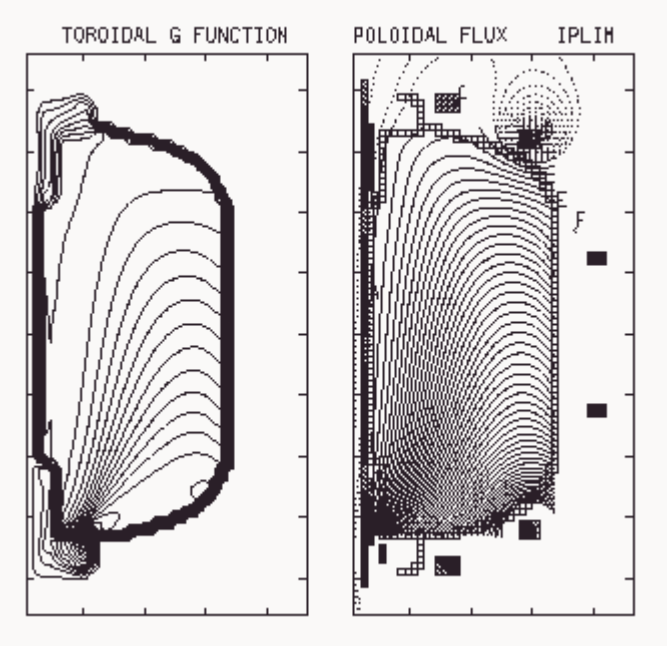


Shot 102080 CHI Experiment

I_P = 20 kA



I_P = 120 kA



Flux surfaces are greatly modified by the CHI currents, but TSC doesn't predict any closed field lines

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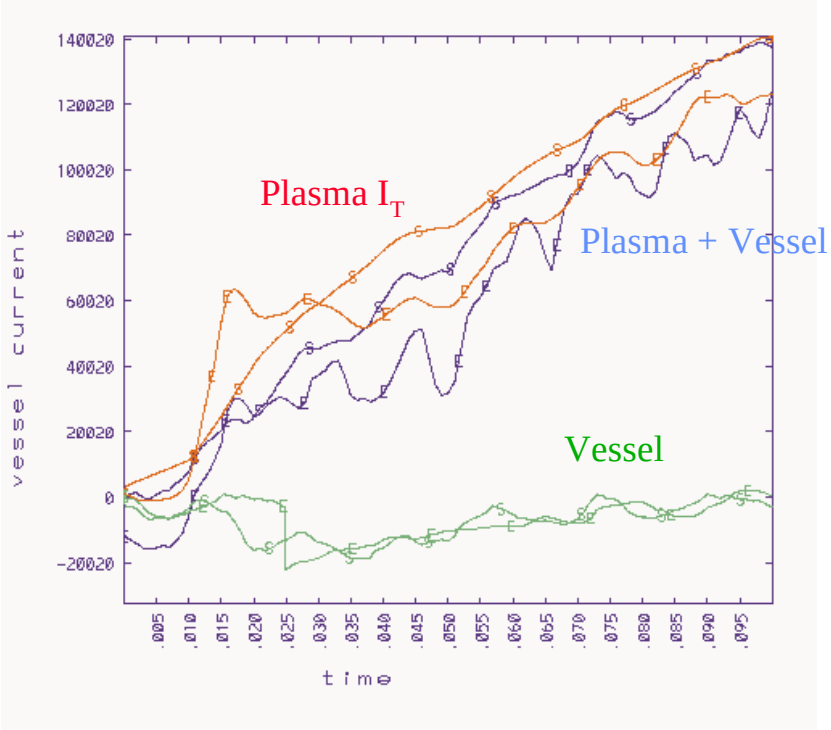
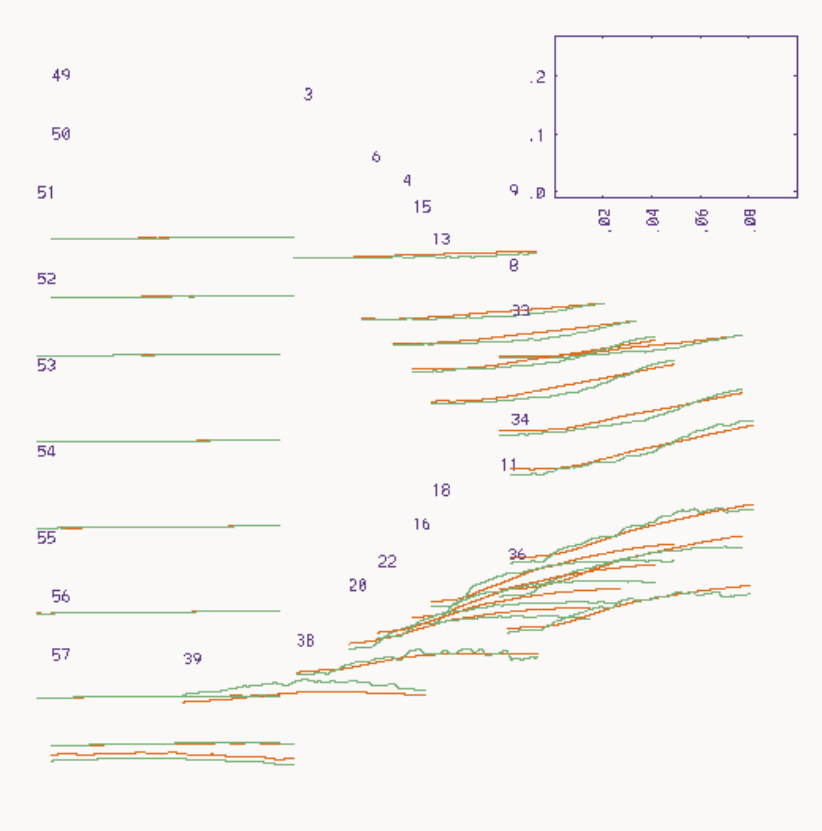
Shot 102080 CHI Experiment





TSC currents and fluxes agree well with experimental data

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