Transport Analysis of Multi-Phase H-Mode Shot at TCV

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Introduction

The Tokamak à Configuration Variable (TCV) is well suited for studies of electron transport due to its well developed electron cyclotron resonance heating (ECRH) system. In this work the electron transport is investigated in the four different H-mode phases present in TCV shot 29892[1]. The transport analysis using ASTRA shows a confinement improvement in agreement with experiment when the ELMs are suppressed by modulation of the ECRH heating. GLF23 fails to predict this improvement of the confinement, but recovers the confinement degradation which occurs after a minor disruption.

TCV transport features:

1. A well developed ECRH system
   $\Longrightarrow$ This makes it very suited for electron transport analysis.
2. No direct ion heating.
   $\Longrightarrow$ High density needed for substantial ion heating through thermal equilibration.
3. Third harmonic X-mode (X3) heating.
   $\Longrightarrow$ Substantial electron heating at high density.
   $\Longrightarrow$ **Allows for H-mode studies with strong electron heating!**

Overview of #29892

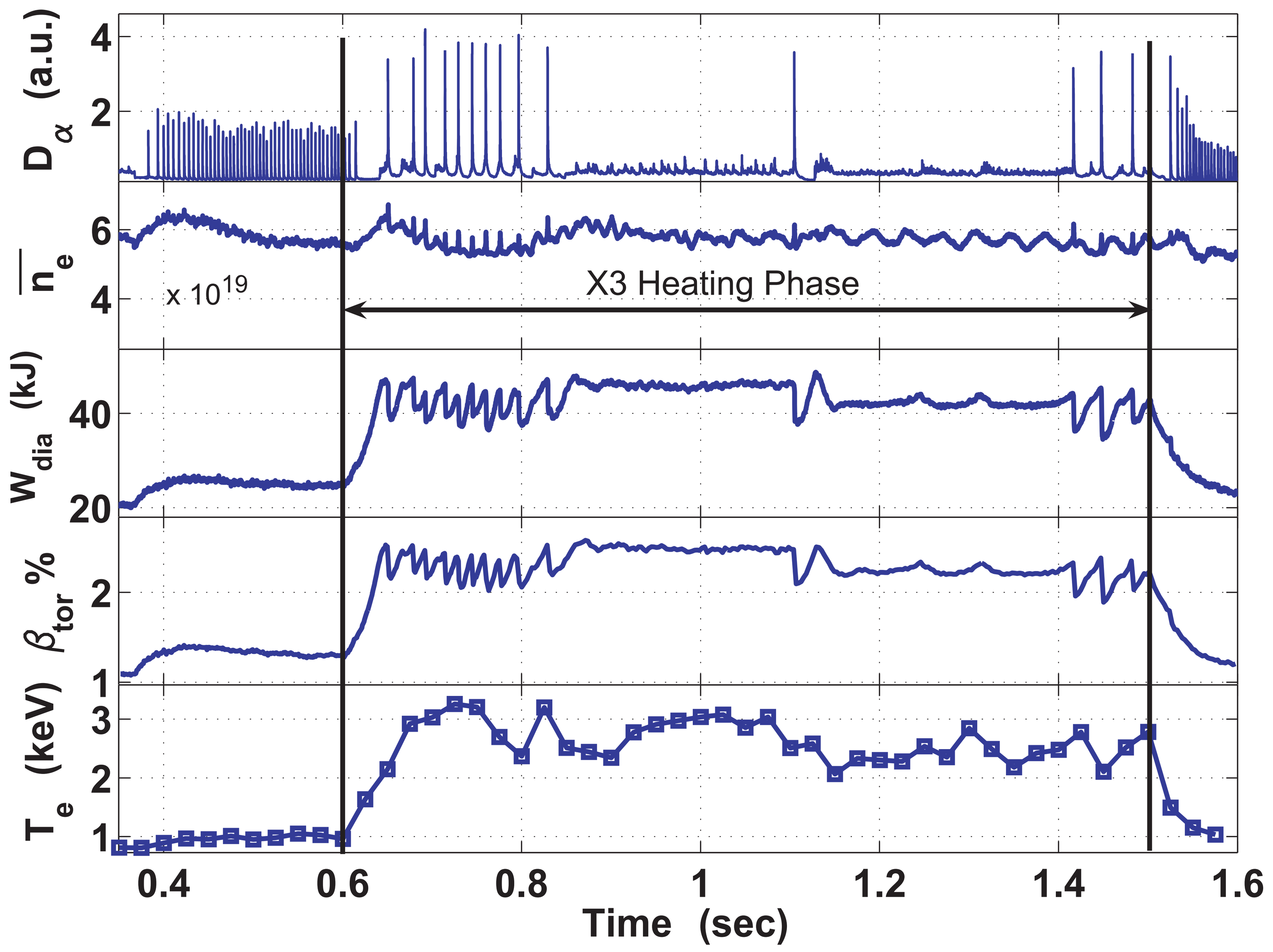


Figure 1: Time traces of TCV shot 29892

Description of TCV shot 29892

This shot comprises four different H-mode phases:

$\mathbf{t < 0.6s}$ Standard Ohmic ELMy H-mode.

$\mathbf{0.6 < t < 0.8s}$ Full power constant X3 heating applied
$\Longrightarrow$ ELMy H-mode

$\mathbf{0.8 < t < 1.4s}$ Modulated X3 heating applied.
$\Longrightarrow$ Quasi-stationary ELM-free H-mode

t=1.1s Minor disruption
$\Longrightarrow$ The quasi-stationary ELM-free H-mode persists but MHD modes arise which reduces the confinement.

Note: Throughout the shot sawteeth are present.

Reconstruction of the ion temperature profile

The ion temperature, T_i profile was not measured in TCV shot 29892.
Reconstruction method:

1. Generally the shape of the T_i profile follows T_e.
   $\Longrightarrow$ Assume $T_i \propto T_e$.
   Note: In ASTRA two proportionality constants can be choosen, on-axis and at the edge.
2. Charge exchange (CXRS) data available in the edge of a similar TCV shot.
   $\Longrightarrow$ The edge proportionality constant determined by TCV 29475 CXRS data.
3. Total plasma energy, W_{tot}, measured by diamagnetic loop (DML).
   $\Longrightarrow$ Ion energy, $W_i = W_{tot} - W_e$ (W_e calculated from Thomson measurements) density.
   $\Longrightarrow$ On-axis proportionality constant can be determined by matching the calculated W_i with its reconstructed value.

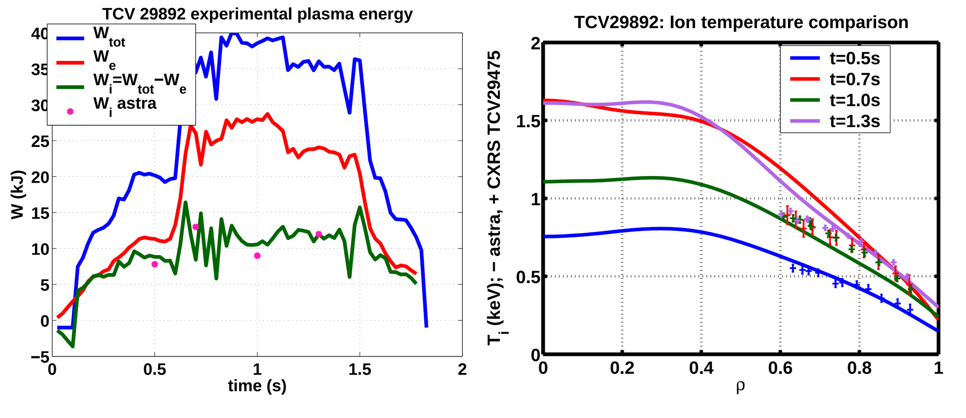
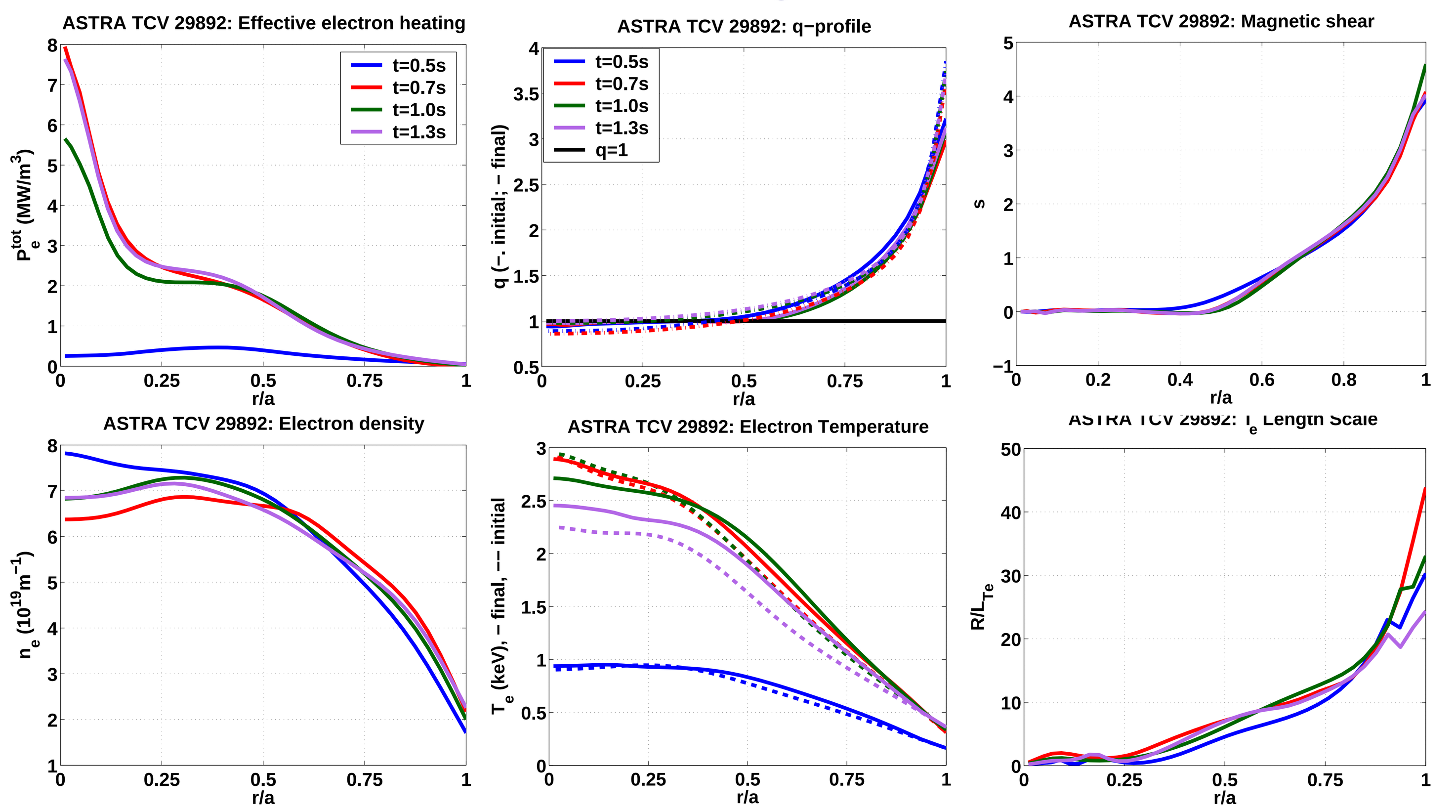


Figure 2: The reconstructed W_i (left, magenta dots) and T_i profiles (right), using the method stated above. These plots show that the both the total reconstructed W_i and the edge T_i are well reconstructed. The data CXRS data from TCV 29475 indicates that the core temperatures may be lower for t $\geq$ 0.7.

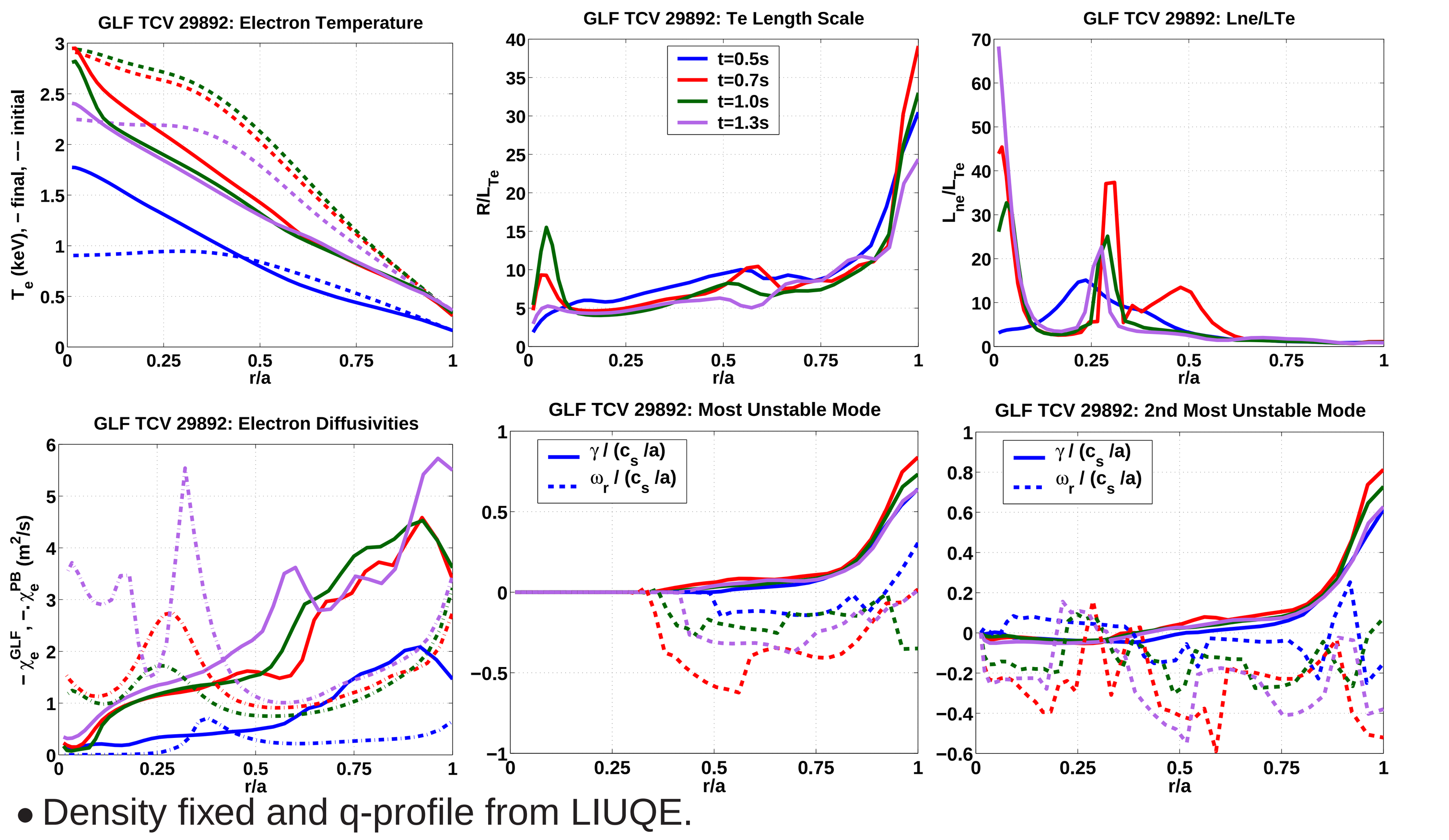
However, if a lower core T_i was to be used, the reconstructed W_i would become much smaller than its calculated value (left, green solid line). These plots used the equilibrium solver LIUQE to calculate the q-profile.

ASTRA sawtooth modeling



- Sawteeth are present throughout the shot.
  $\Longrightarrow$ Run ASTRA interpretatively with a sawtooth model package and the electron heat diffusivity a multiple of the experimental power balance (PB) χ_e (see 1st figure 3rd column, 2nd row).
  – At t=0.5s $\chi_e = 3\chi_e^{PB}$
  – For t $\geq$ 0.7s, $\chi_e \approx \chi_e^{PB}$
- ASTRA gives that the q-profiles are similar to the ones calculated with LIUQE.
  $\Longrightarrow$ The LIUQE profiles can be used in GLF simulations to analyze the transport.
- Temperature profiles are well reproduced by ASTRA (density fixed).
  – T_e profiles shown are taken at the same phase in the sawtooth cycle.

GLF23 transport modeling



- Density fixed and q-profile from LIUQE.
  $\Longrightarrow$ Only T_e predicted by GLF23. Outer boundary at r/a=0.9.
  t=0.5s: T_e well predicted outside the sawtooth inversion radius at r/a $\approx$ 0.4.
  t $\geq$ 0.7s: The transport is overpredicted, especially in the edge, resulting in too low T_e.
  $\Longrightarrow$ problems with electron heating effects on confinement in GLF23 and H-mode type profiles?.
- Main instabilities are of ITG type ($\omega_r < 0$, $k_y\rho_s < 1$).

Global confinement comparison

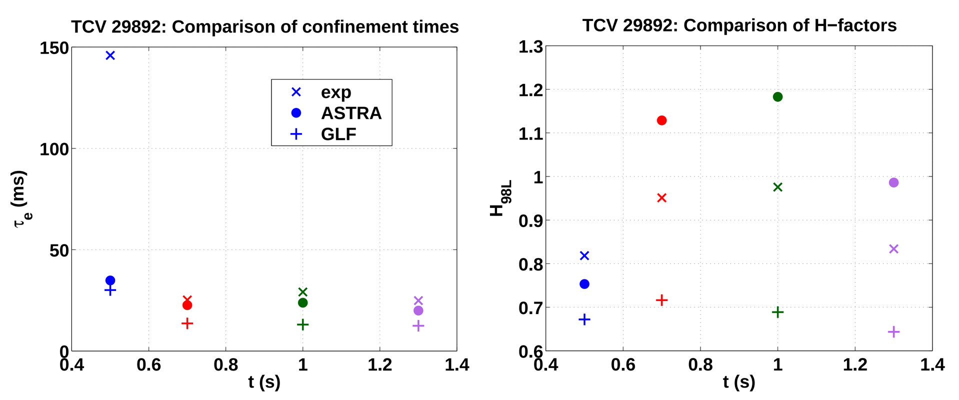


Figure 3: Comparison of the global electron energy confinement times τ_e (left) and H-factors (right). Except for the experimental τ_e (left, blue x), τ_e remains pretty constant throughout the discharge. Both ASTRA and GLF23 systematically underestimate τ_e. The H-factor shows more clearly how the confinement improves when the X3 heating is turned on at 0.6s. However, there is only a slight increase of the confinement at 1.0s when X3 modulation is killing off the ELMs. On the contrary, GLF23 predicts a decrease in confinement, but does capture the poorer confinement after the minor disruption at 1.1s.

Future plans

- In depth transport analysis to determine the important terms by using:
  – analytical tool developed at the IFS.
  – GLF23 stand-alone code.
- Resolving the problem with the overestimated transport in GLF23.
- Modeling the transport with GLF23 and the sawtooth model simultaneously.
- Modeling the transport with the Weiland model.

References

[1] L. Porte et al, "Plasma Dynamics with the Second and Third Harmonic ECRH on TCV", Proceedings of 21st IAEA Fusion Energy Conference, EX/P6-20 (2006).

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