The confinement analysis in ST40 spherical tokamak

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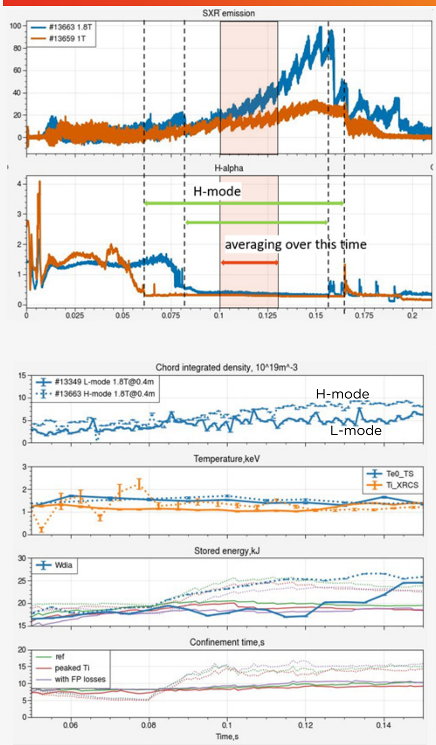
Abstract

The dependence of plasma energy confinement time on the magnetic field was demonstrated to be much stronger in spherical tokamaks (STs), such as **MAST, NSTX** and **GLOBUS-M2**, than in conventional tokamaks with high aspect ratio A>2.5 [1]. The maximum toroidal field achieved in those STs was 0.9 T [2] and, therefore, to be applicable for future ST-based fusion devices with a foreseen toroidal field of 4-5 T, extrapolation of the ST confinement scaling law is required.
Experiments on the high-field spherical tokamak **ST40** [3,4] with an NBI beam power of around **1 MW** were carried out, with a toroidal magnetic field scan **0.6 - 1.7 T** at the geometric axis, in **L- and ELM-free H- modes** plasmas with plasma current **390 - 500 kA** .
Interpretation of these experiments took into consideration all available measurements including spectroscopic data, SXR radiation, neutron data, magnetic sensors and Thomson scattering data.

B-scan experiments in ST40



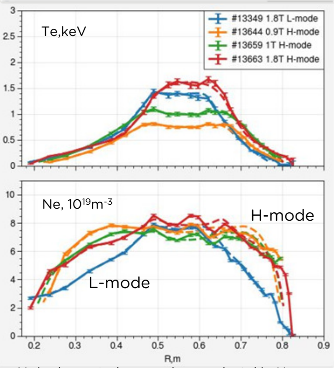
Typical features of B-scan shots

- Diverted plasma
- Sawteeth oscillations
- Different L-H transition timing
- Chosen the steady state time for analysis

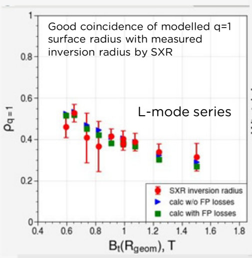
Measured data used in calculations

T_e and N_e profiles are measured by Thomson scattering.

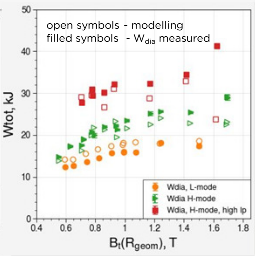
Ti is determined by chord integrated Argon line emission



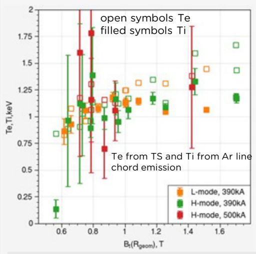
N_e is shown to have a clear pedestal in H-mode at the time of interest however L-mode N_e profile is much more peaked. T_e profiles have not a clear difference between L and H modes but are flat in the plasma centre revealing the impact of sawteeth. Dashed profiles used in calculations taken from TS using ASTRA-SPIDER equilibrium and EFIT boundary



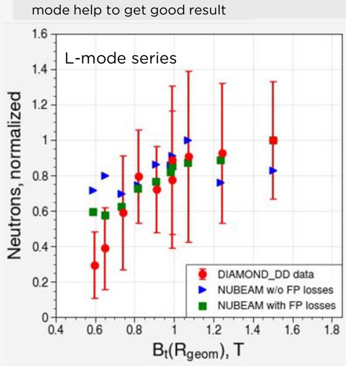
Inversion radius (red) for ST three crashes before time of interest. Peaked profiles in L-mode help to get good result



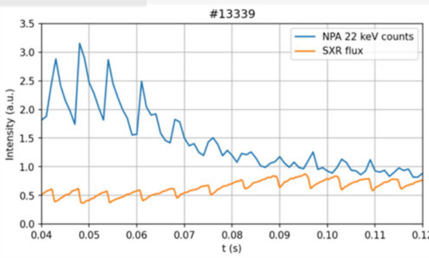
Measured stored energy by diamagnetic signals for 3 B-scan series



Te rises with TF, Ti has a weaker dependence

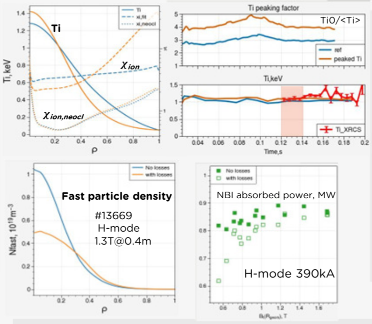


Data from diamond detector normalized to maximum values 50ms averaging in time. Modelling interpretative results are also shown by blue and green. Introducing fast particle losses in modelling gives a better coincidence with the slope over TF



NPA signal for high energetic neutrals gives an evidence of fast particle losses in correlation with sawteeth oscillations. This is the additional evidence of introducing anomalous fast particle losses in the modelling.

Model for interpretative analysis



$\tau_E^{th}=W_{th}/P_L$, where $P_L = P^{Ohm} + P^{NBI}_{abs} - dW_{th}/dt$

- **Te** and **Ne** profiles from Thomson scattering data
- poloidal flux evolution equation : $\sigma = \sigma^{neo}$
- **ASTRA** transport code [5] with a boundary taken from **EFIT** reconstruction analysis.
- **P^{Ohm} and P^{NBI}_{abs}**(HNBI only shots) power is calculated in ASTRA and **NUBEAM** [6]
- **dW_{th}/dt~0** time slice to be taken for analysis
- **Zeff** is taken as uniform and prescribed (=2.5 is close to measurements) with equal contribution from **Ar** and **C**
- **No radiation** is included to the model

Main uncertainties

- Ti profile: Ion heat transport equation is solved
  $\chi_{ion}=\chi_{ion,neocl}+C_1\cdot(1+C_2\cdot\rho^5)$; C_2=(0;20), C_1 is calculating to fit $T_{i,XRCS}$
  Ti(0)/<Ti>=2.5-4, Higher Ti(0) – lower confinement

- fast particle losses : introducing anomalous losses inside q=1 surface **D_{an}=0-1 m^2/s**
  Redistribution of fast particles over the radius causes enhanced CX and orbital losses
  Lower field - larger fast particle losses
  Higher losses – higher confinement

- neutral density profile: Calculated, boundary neutrals density (“Wall”) is set as a parameter
  N_{wall}= 10^{16} -10^{17} m^{-3}
  Not affected much on confinement time

Interpretative analysis results

1.**Error bars** for confinement time are mostly caused by two factors:

- Modelling uncertainties for Ti and fast particles
- Ti_XRCS error bars data.

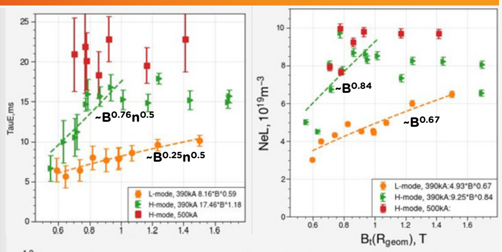
2.Increase of the confinement time with TF **saturates** at around 1.1T in H-mode1 case.

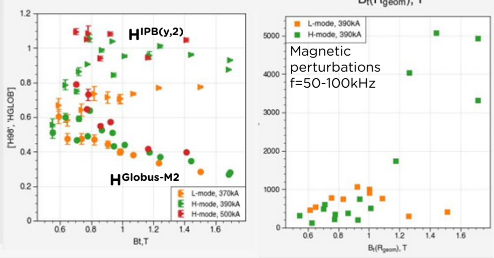
3.For B_t>1.1T there are no evidence of confinement time or $H^{IPB(y,2)}$ factor increase with B_t .

4.Clear increase of confinement with the **plasma current**.

5.For B_t <1T the τ_E dependence on B is similar to $\tau_E^{Globus-M2}$ scaling.

6. χ_{ion} in H-mode is close to neoclassical value





Removing density factor using ITER (y,2) and Globus-M2 scalings:
$\tau_E^{IPB(y,2)}$~$B_t^{0.15}n_e^{0.4}$, $\tau_E^{Globus-M2}$ ~$B_t^{1.05}n_e^{0.65}$ taking τ_E (ST40) ~ $n_e^{0.5}$ =>
τ_E (L-mode) ~ **$B_t^{0.25}$** τ_E (H-mode1) ~ **$B_t^{0.76}$** for B_t<1.1T

CONCLUSIONS

1. H-mode plasma in 390kA and 500kA series is about IPB(y,2) scaling
2. In H-mode 390kA series it is clearly seen that confinement increase saturates when B_t >1.1T
3. Saturation of confinement rise with B_t in H-mode shots can be caused by the increase of magnetic perturbations activity in the frequency range 50-100kHz.
4. In H-mode 500kA series it is unclear if confinement saturates because of missing discharges at low field
5. Confinement time is obtained to be below the Globus-M2 scaling for STs but for lower field region shows similar dependence on the magnetic field. Note that no radiation is included to calculations.
6. The increase of confinement with the plasma current is clearly seen
7. No saturation of confinement is seen in the L-mode and it has a stronger Bt dependence than IPB(y,2) scaling: TauE ~ $B_t^{0.25}$

References

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