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Onset of the thermonuclear instability and oscillatory states near ignition

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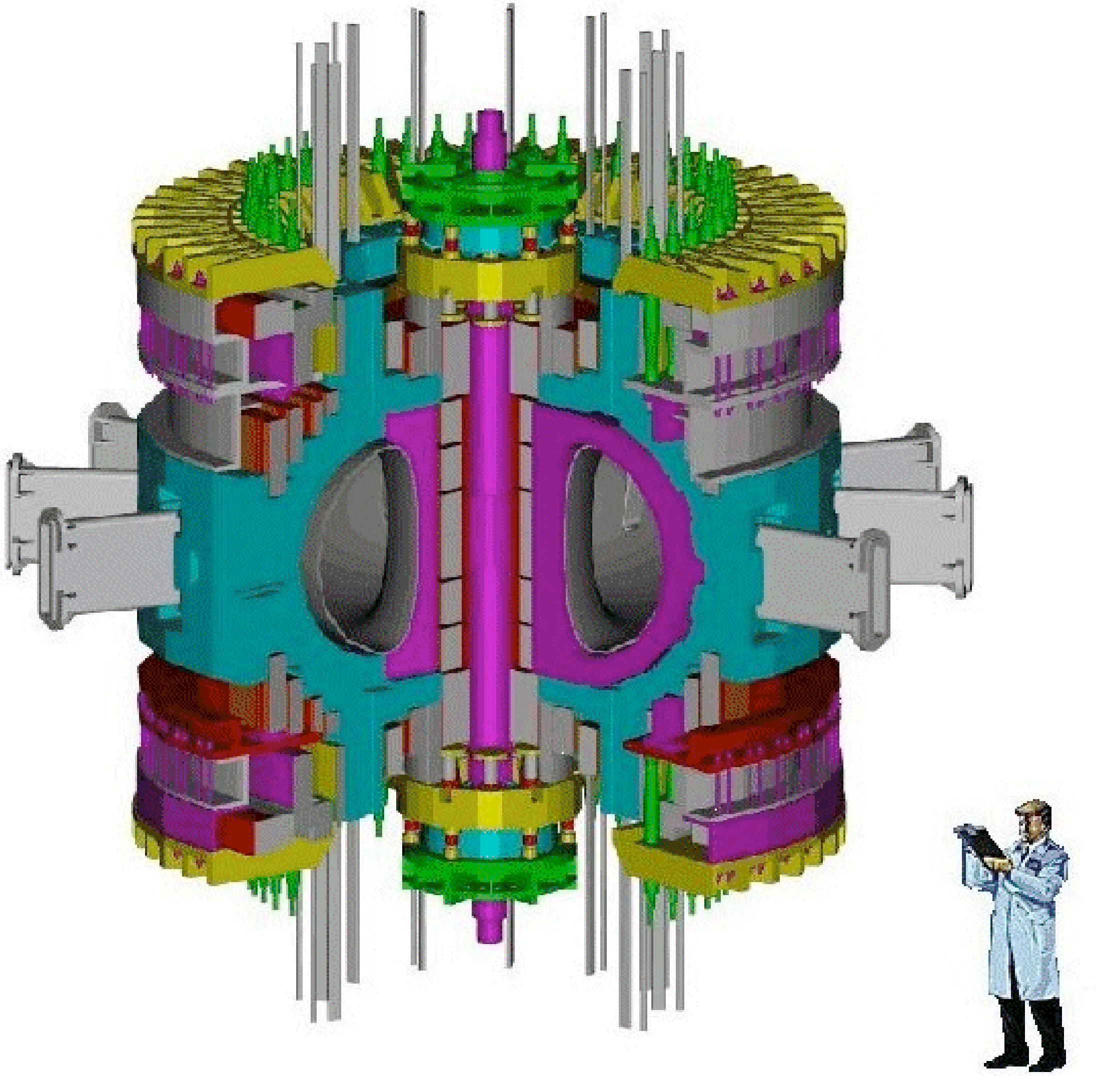
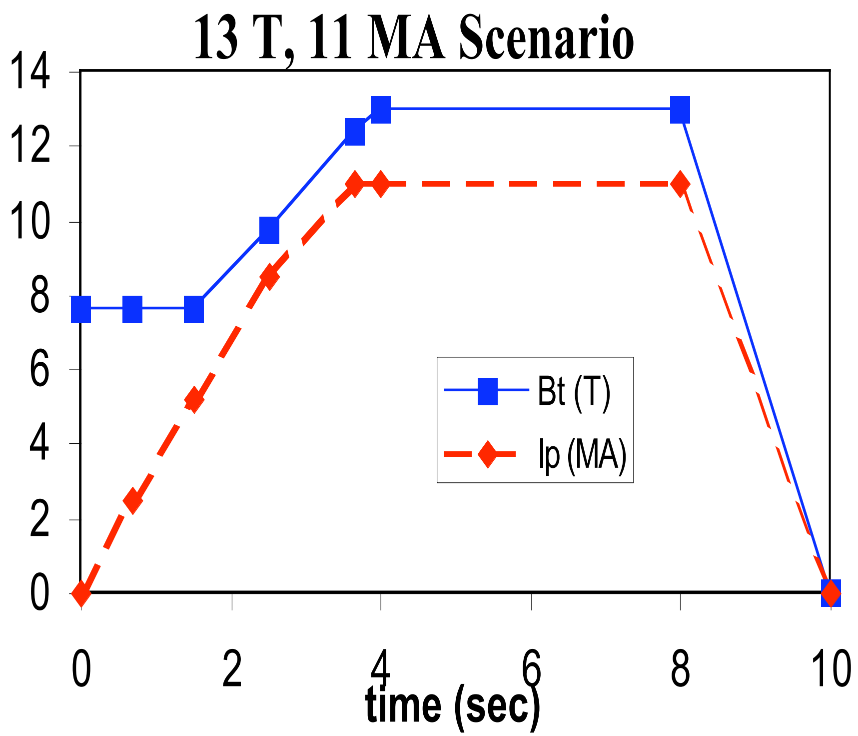
Abstract

The Ignitor experiment [1,2] is conceived to benefit from the programmed increase of the toroidal magnetic field (up to 13T), the plasma current (up to 11MA) and the particle density. In the reference scenario the plasma current reaches the maximum value in 4s and the subsequent flattop lasts 4s. The high ratio B_t/R_0 ensures peak plasma densities around 10^{21} m^{-3} and line averaged values that are far from the known density limits [3] for good plasma confinement. A number of simulations carried out with the JETTO transport code [4,5] to study the attainment of ignition have pointed out that Ignitor can reach its goals by operating in L-mode regimes, where no pressure pedestal is formed at the edge of the plasma column. Steady state sub-ignited conditions were investigated by varying the plasma composition and the ion cyclotron heating [6]. In the present study we describe representative discharges where oscillatory states are maintained near ignition.

IGNITOR MACHINE



Standard Ignitor scenario



Major radius	R_0	1.32m
Minor radii	$a \times b$	0.47m × 0.86m
Aspect ratio		2.8
Elongation	k	1.8
Triangularity	δ	0.4
Toroidal field	$B_T(R_0)$	13T
Toroidal current	I_p	11MA
Poloidal current	I_ϑ	8 MA
Plasma Volume	V	10 m^3
Plasma Surface	S_a	36 m^2
Safety factor	q_Ψ	3.6
Discharge time	t	(4 + 4)s

Thermal transport model

In the JETTO code the MHD equilibria are evaluated and coupled to the diffusion equations for the toroidal current density, the electron and ion thermal energies, the plasma fuel densities and two impurity ion densities. The electron thermal transport model is based on the semiempirical Bohm-gyroBohm expression [7]:

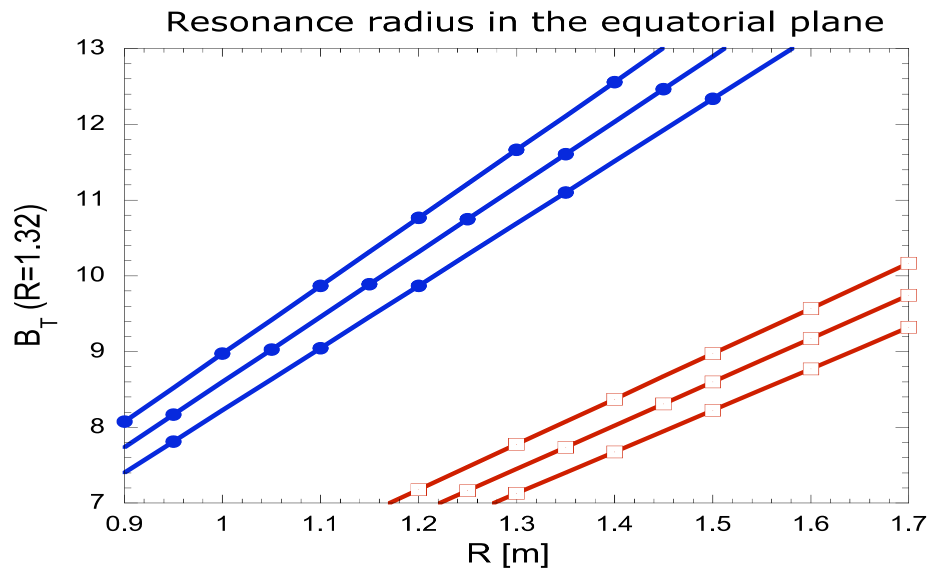
$$\chi_e = D_B(\alpha_B q^2 f(s) + \alpha_{gB} \rho^*)(a/L_{Te})$$

being D_B the Bohm diffusion, $\alpha_B = 4.3\times10^{-3}$ and $\alpha_{gB} = 0.1$ numerical coefficients calibrated so that the energy confinement time is around the value predicted by the ITER97L-mode scaling, $f(s)=H(s)[s^2/(1+s^2)]$ a step function of the magnetic shear s, a the small plasma radius, q the local safety factor and L_{Te} the characteristic temperature gradient length. This model was found to reproduce many experimental results and specifically some FTU data in the presence of electron cyclotron resonance heating at high density.

RF assisted conditions

The radio frequency system foreseen in the machine [8], allows a flexible frequency coupling to various plasma scenarios.

The resonance for T and He_3 in the central part of the plasma column can be assured. Previous analyses [9] have shown that a limited RF power can give a boost to the fusion performance.



Red lines refer to the frequencies 110,115,120MHz for Hydrogen 1st harmonic and Deuterium 2nd

Blue lines refer to the same frequencies for Helium3 1st harmonic and Tritium 2nd

Modelling set-up

Sawtooth oscillations are considered adopting a complete reconnection model (that is pessimistic according to modern theories and experimental indications) triggered by an assigned value of the pressure peaking factor. The ICRH power injection process is represented including the width of the deposition region, the application time and the total absorbed power [6].

The evolution of each individual density profile is governed by a diffusion equation. The density increase is modelled by an inward inflow lasting from the fuelling time t_{fon} to t_{foff}. Each ion species has its specific values for these parameters. In the diffusion equations for the primary ions the boundary condition includes the recycling that assures density conservation in the absence of external inflow. Moreover it is possible to maintain or not after t_{foff} the density value reached and a further knob allows to reduce the tritium inflow when the averaged electron temperature overcomes an assigned value.

Subignited representative conditions

In the first case tritium is fed 2s after the discharge start-up so as to assure equal contents of deuterium and tritium (See Fig. 1, left panel) during the flattop duration.

The working density during the flattop time is 5.4×10^{20} m^{-3} and the impurity content produces an effective charge $\langle Z_{eff} \rangle \sim 1.3$.

An RF pulse (3MW), whose wide spatial distribution is centered at half plasma column, is provided from 3s to 5s (See Fig. 2, left panel).

Notice the boost given to the temperature increase by the RF pulse around the value of 5-6 KeV when the alpha power overcomes the bremsstrahlung loss at ~4s.

Sawteeth are triggered when the pressure peaking factor ($p_{kf}=p(0)/\langle p \rangle$) outreaches a selected value assumed to be 3.0.

Plasma density and powers evolution

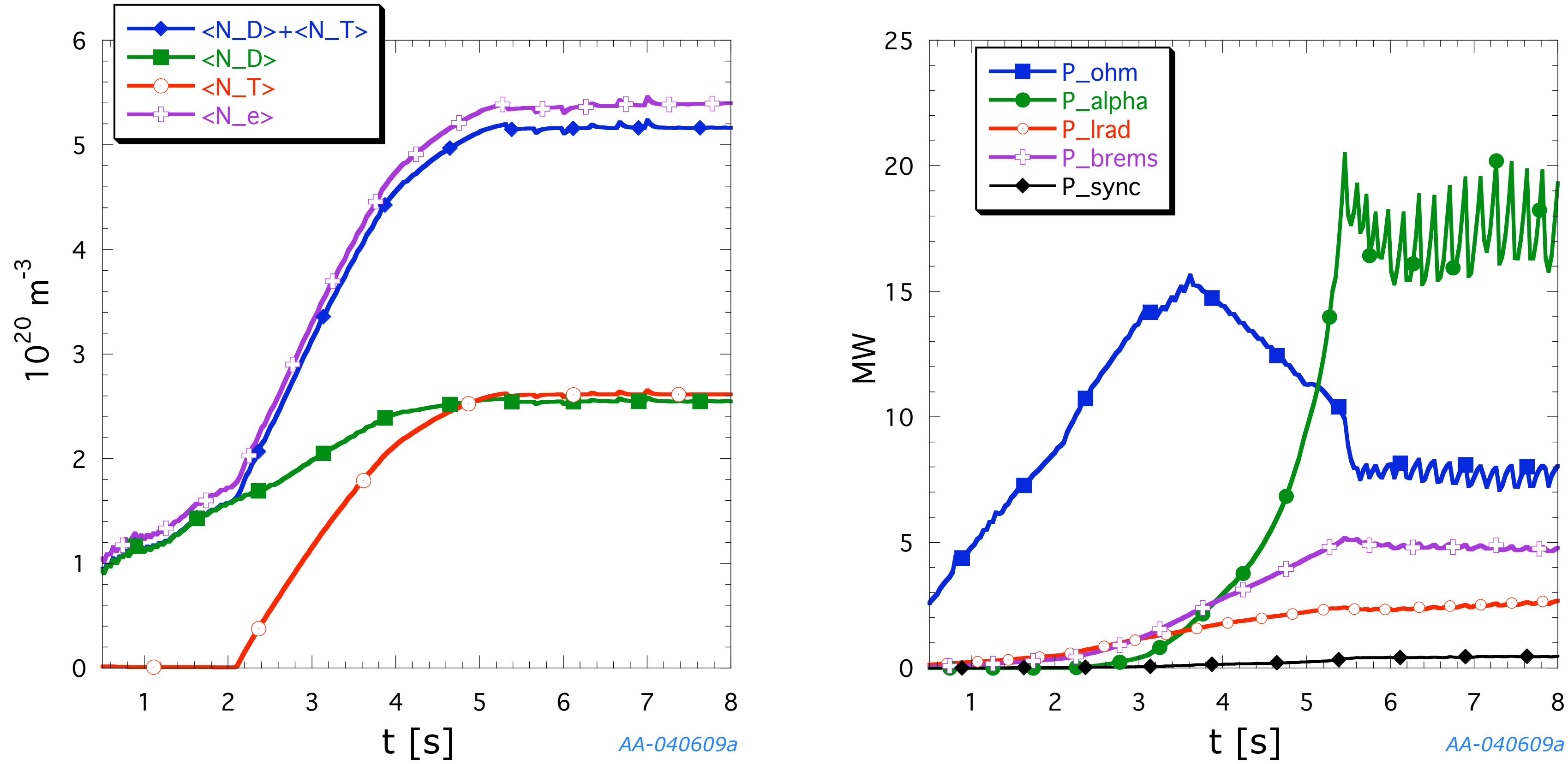


Fig 1. Time evolution electron and ion densities in the left panel; ohmic and alpha powers together with radiative losses in the right panel .

$T_{e,i}(0)$, pressure peaking factor and q(0)

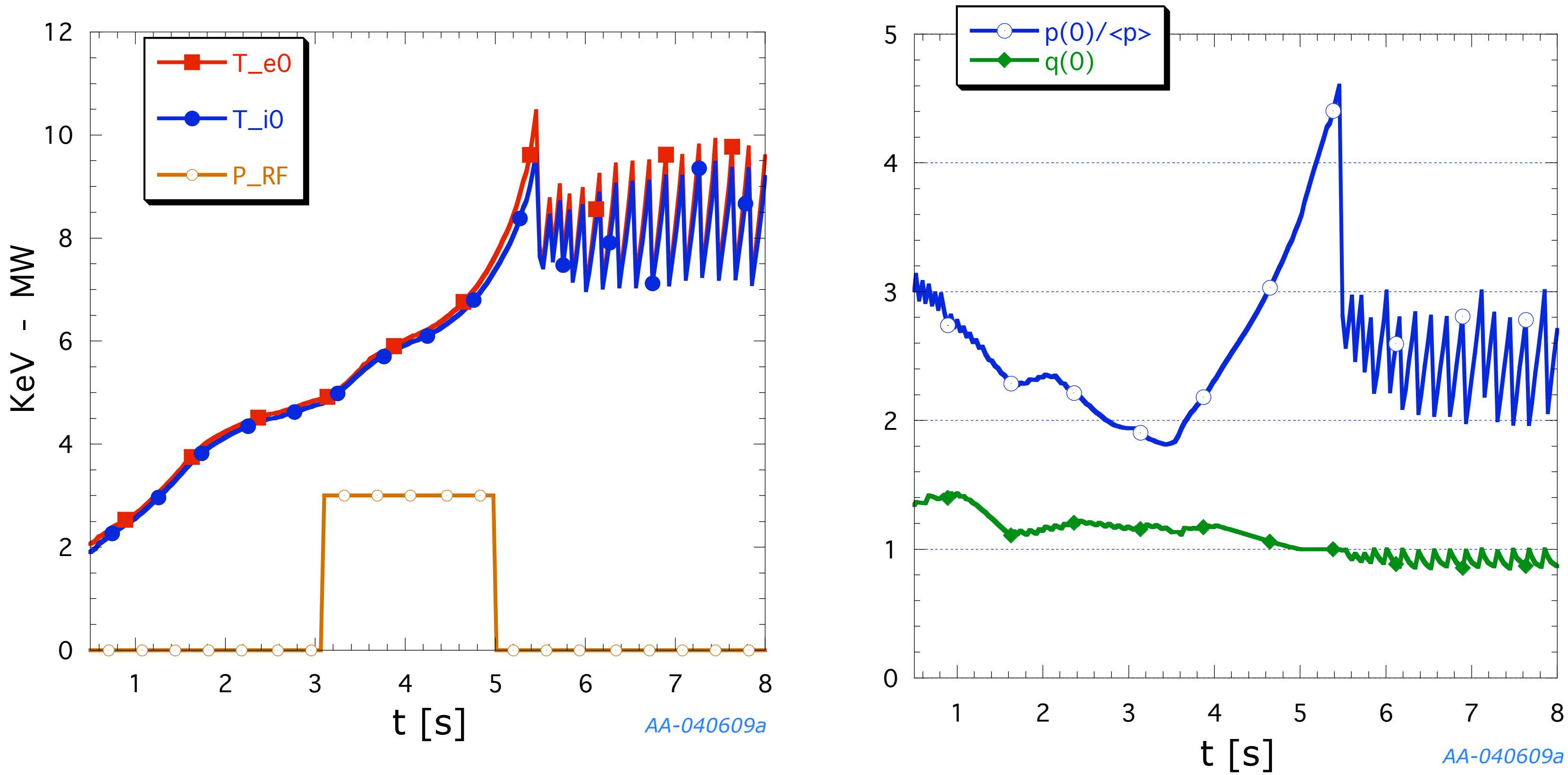
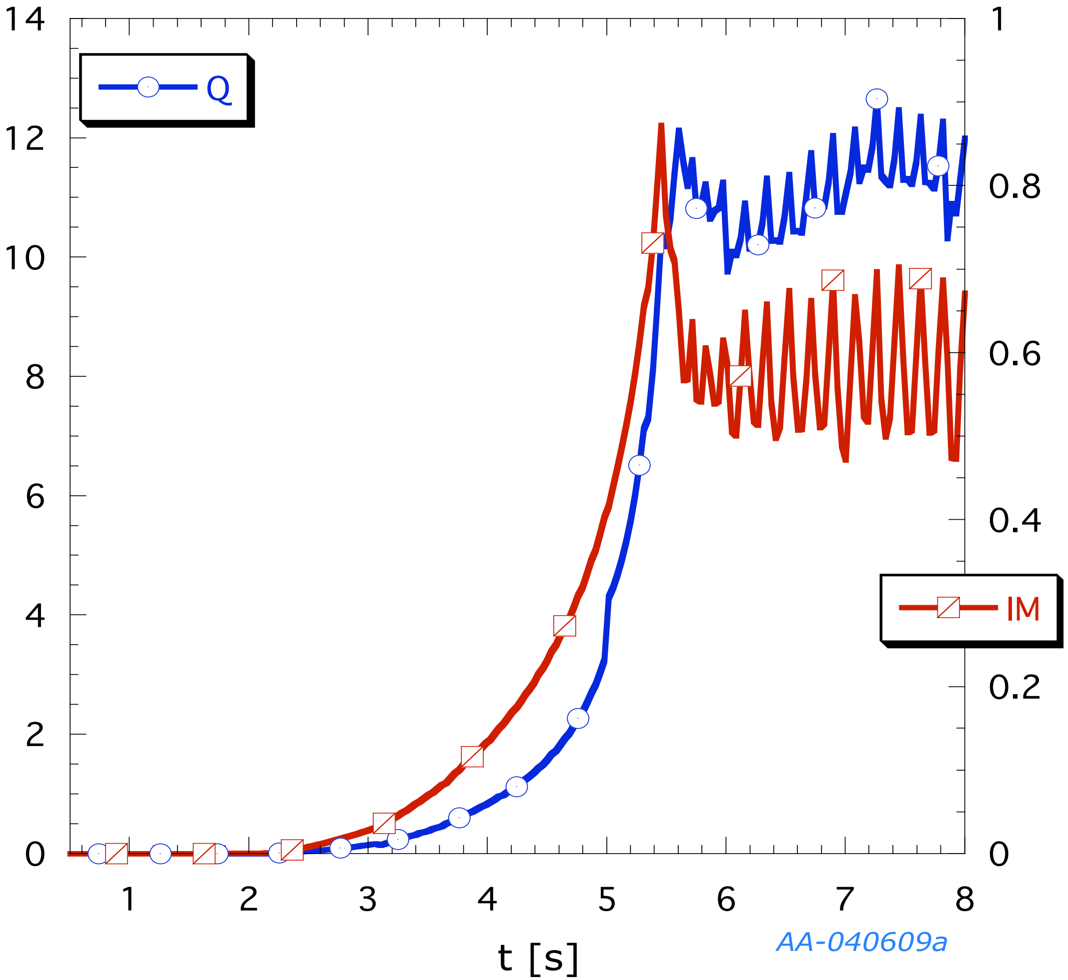


Fig 2. Time evolution of the peak temperatures for electrons and ions contrasted with the RF power (left panel); pressure peaking factor and central safety factor (right panel)

Fusion gain Q



The fusion gain $Q=P_{fus}/P_{input}$ remains over 10 and the ignition margin, $I_M=P_\alpha/P_{input}$, after reaching ~ 0.9 before the first crash, oscillates around 0.6. This performance, actually considerable and comparable with those foreseen for ITER, can be improved by a bit more RF power as it will be shown in the next shots.

Post-ignited conditions

By injecting 3.2MW, with all other conditions unchanged, ignition is attained before the first sawtooth crash and afterwards alpha power grows steadily reaching values unsustainable by the machine structure. A possible way to control the thermonuclear instability is the reduction of the fuel feeding when the averaged electron temperature overcomes a fixed value. Two shots whose difference is the tritium feeding reduced when <Te> reaches 4.5 KeV (Shot 2) or 4.8 KeV (Shot 3) are now analyzed. The temperature evolution and the tritium density are plotted in the left panel of Fig.3. The lower tritium content causes an immediate increase in the temperature, but afterwards produces a reduction in the alpha power (See right panel of Fig.3). However it must be observed that even in this condition the alpha power produced, although not explosive, could be excessive, particularly in the Shot 3.

$<T_e>$ and tritium density

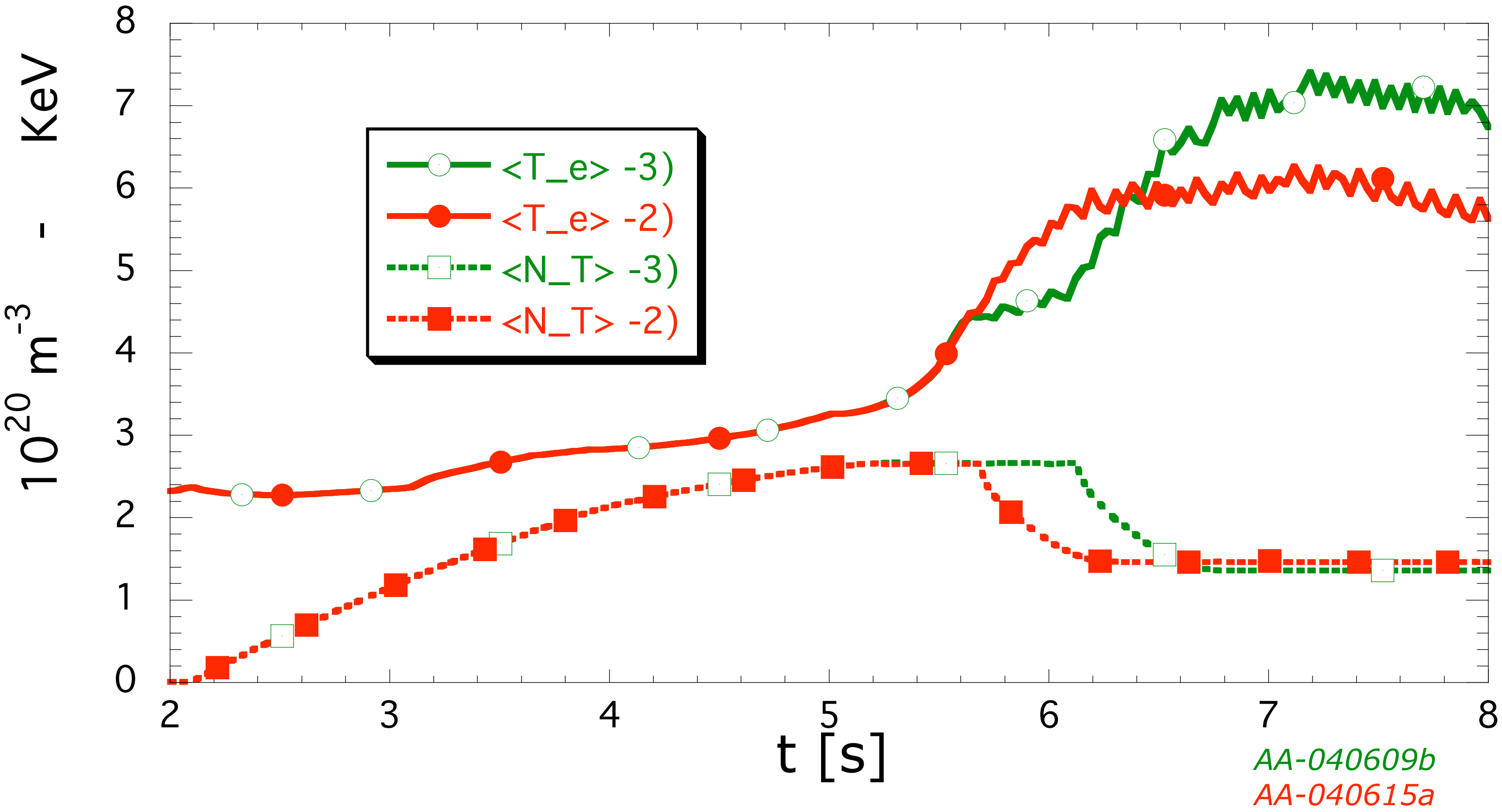


Fig 3. Time evolution of averaged electron temperature and tritium density

Alpha and RF powers

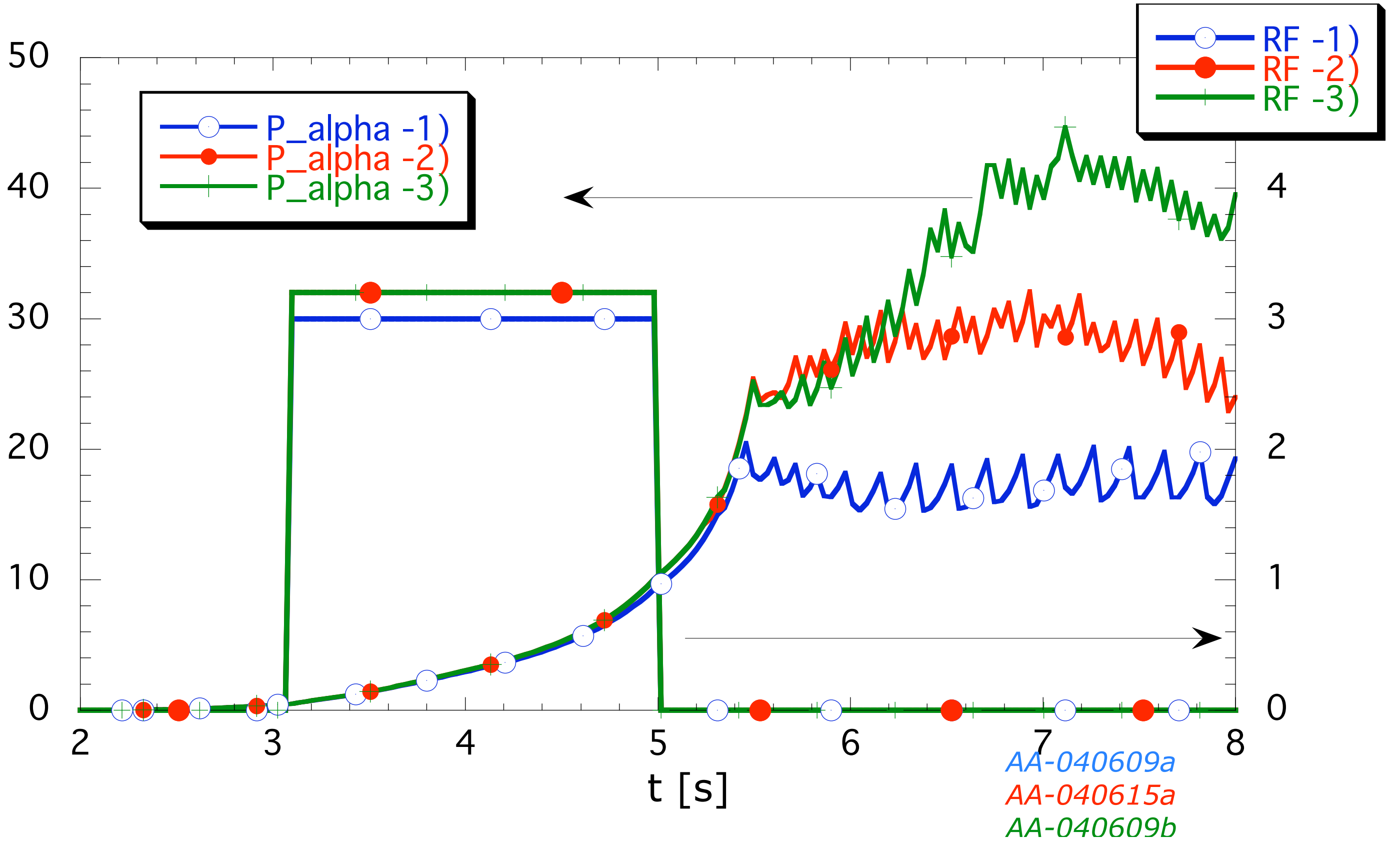


Fig 4. Time evolution of RF injected and alpha power

Ignition margin and Q - Shots 1), 2), 3)

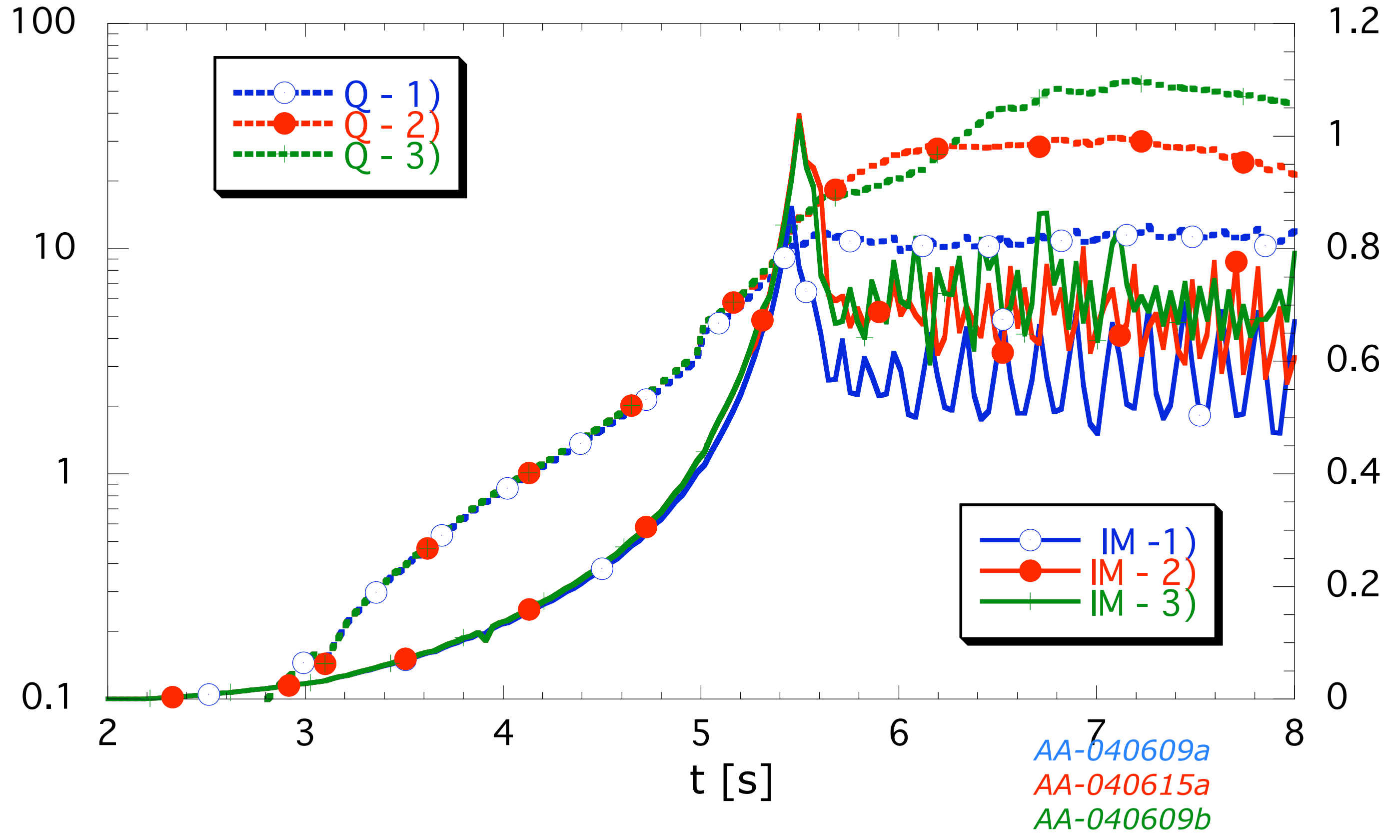


Fig 5. Time evolution of ignition margin and fusion gain

Comments

- In shots 2) and 3) ignition is achieved at 5.5s and, after the first crash, the ignition margin oscillates around a value higher than the one in shot 1), that is ~0.7 instead of 0.6.
- The ignition attainment triggers the thermonuclear instability with a production of alpha power which could be excessive.
- It is safer to consider operative scenarios in subignited conditions: in fact an ignition margin near 0.6 is sufficient to assure a fusion gain, *Q*, overcoming 10.

References

[1] B. Coppi, al., Report PTP99/06, MIT, Cambridge, MA (1999)

[2] B.Coppi, et al., *Nucl. Fusion* **41**, 1253 (2001);

[3] M. Greenwald, et al., *Nucl. Fusion* **28**, 2188 (1988) ;

[4] A.Airoldi, G.Cenacchi, *Nucl. Fusion* **37**, 1117 (1997);

[5] A.Airoldi and G.Cenacchi, *Nucl. Fusion* **41**, 687 (2001);

[6] A.Airoldi and G. Cenacchi, IFP Report FP 03/8 (2003)

[7] G. Vlad, et al., *Nucl. Fusion* **41**, 687 (2001)

[8] R. Maggiora et al., *Fus Eng. Design* **38**, 353 (1998)

[9] G. Cenacchi, A.Airoldi and B. Coppi, APS Bulletin, **47,** 267 (2002)