Importance of the Ideal Ignition Conditions and Intermediate Objectives of Ignitor

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Ignitor Project

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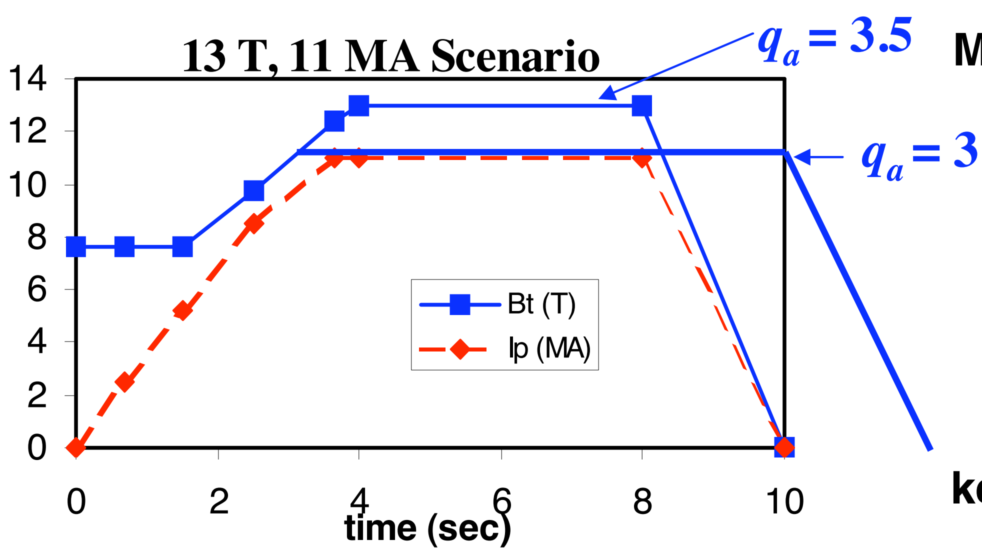
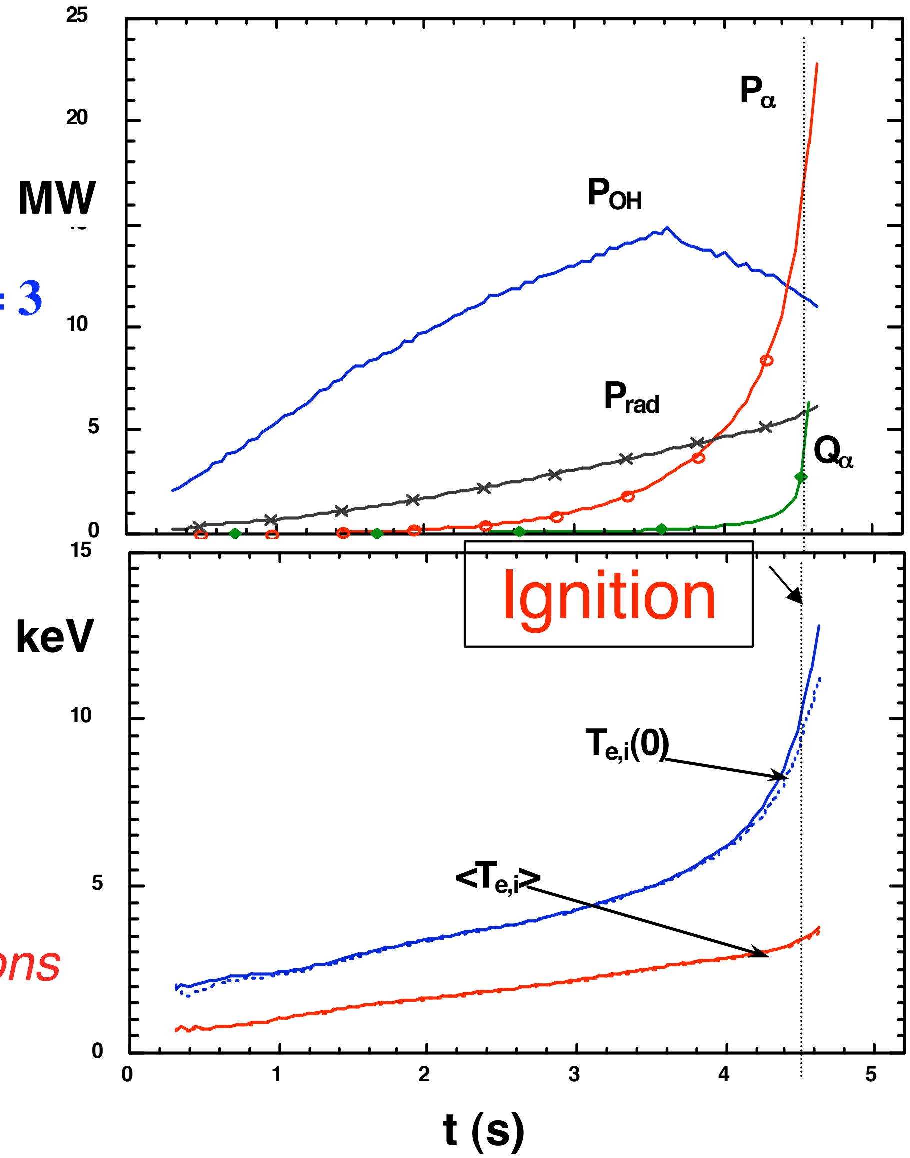
Ohmic Ignition





JETTO code simulations

Airoldi and Cenacchi, *Nucl. Fusion* **37**,1117(1997)

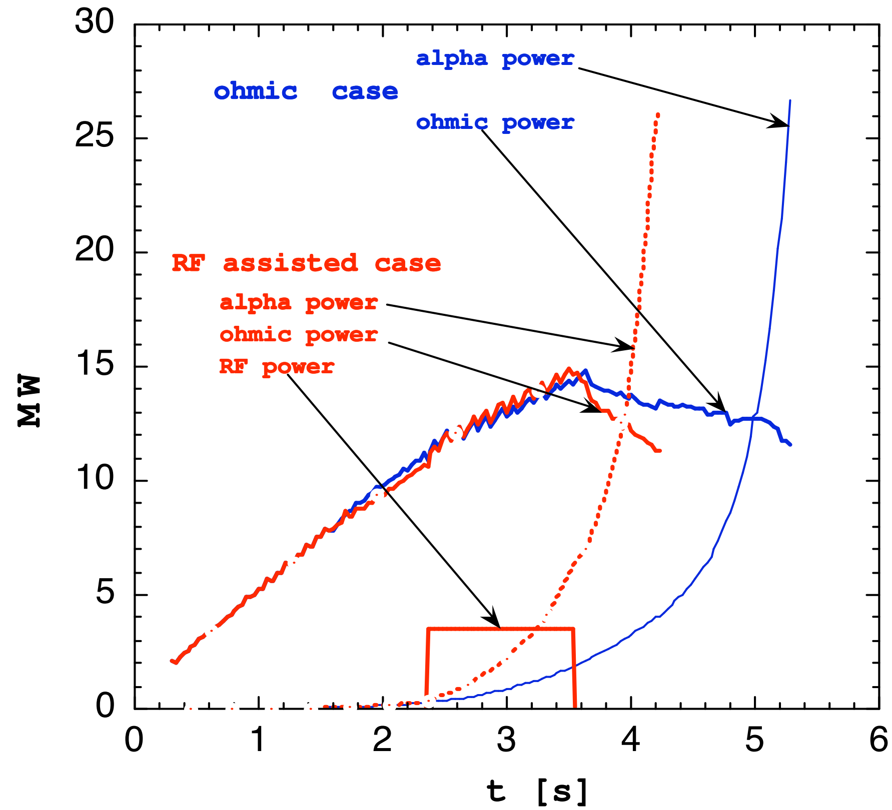
RF Assisted Ignition

Ignition can be accelerated by the application of modest amount of ICRH during the current rise.

The full current flat top is available to study the plasma in burning conditions.

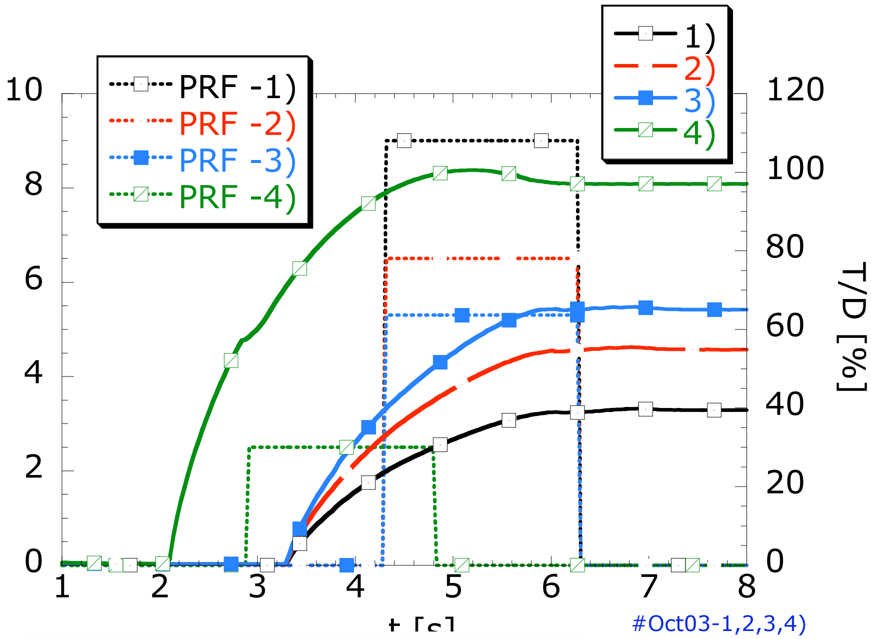
(Note that ignition occurs when ohmic heating only is present)

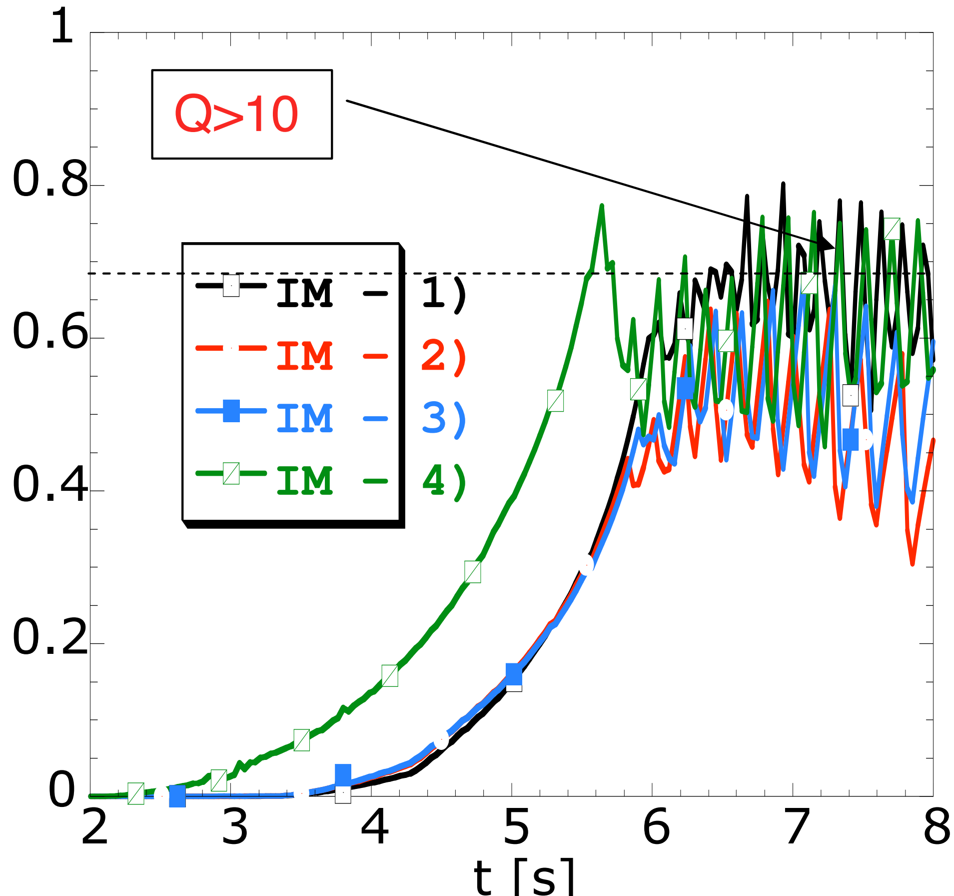
A. Airoldi and G. Cenacchi

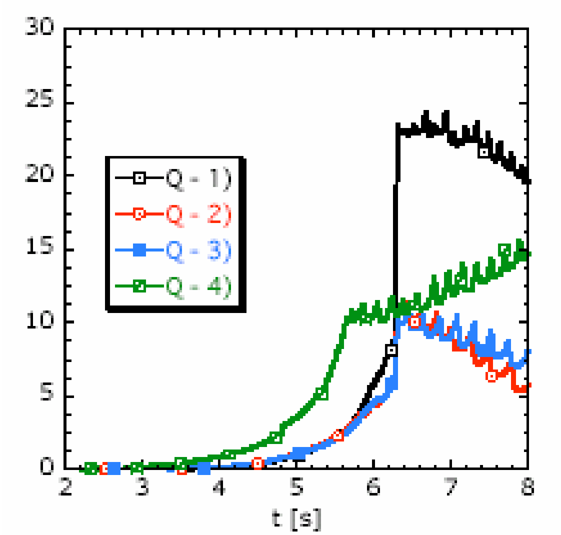


Comparison of Ohmic and RF assisted ignition scenarios (JETTO code).

Ignition control by means of Tritium and RF







With proper timing, the RF power compensates for the unbalanced fuel ratio. As a result, only small differences in the ignition margin are observed.

Abstract

At the ideal ignition temperature, in D-T plasmas where the produced α-particles can be confined by the necessary current, the energy loss by bremsstrahlung emission is compensated by the α-particles heating. Once this condition is reached, the plasma density can be raised, during the plasma heating phase, without encountering a radiation barrier. This is a meaningful intermediate objective for Ignitor operating with $B_T \cong 9$ T, a double X-point (on the first wall) configuration, and $I_p \cong 6$ MA, as well as in the "extended limiter" configuration with $BT \cong 9$ T and $Ip \cong 7$ MA. Numerical simulations have been performed considering volume average $n_e \cong 2 \times 10^{20}$ m^{-3}, average $Z_{eff} \cong 1.5$, and 5 MW of ICRH power absorbed by the plasma. Even without accessing the H-regime and with pessimistic assumptions on the confinement time (such as that corresponding to the ITER97L scaling) the peak temperatures are 5.5 to 6.5 keV and the α heating power can be as high as 2 MW. The available ICRH power, combined with the Ohmic and α-particle heating, makes the access to the H-regime possible in this case as well as in that for which full ignition can be approached $BT \cong 13$ T, $Ip \cong 9$ MA).

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Scenarios with reduced parameters

Magnetic field up to 9T

- **Plasma current up to**

  7MA ("limiter" configurations) or

  6MA (double X-point configurations)

- **Pulse length consistent with mechanical and thermal requirements, and flux available**

Main objectives

- Investigation of possible scenarios
- Optimization of current ramp
- Optimization of density evolution
- Evaluation of allowed flat-top length
- Verification of stability conditions
- Flux balance control
- Tuning of injected heating power

Simulation layout

- JETTO equilibrium-transport code*.
- Bohm-gyroBohm transport model for electrons and ions:

$$\chi_{e,i}=D_B(\alpha_{Be,i}q^2 f(s)+\alpha_{gBe,i}\rho^*)(a/L_{Te}) + \chi_{i\text{-}neo}$$

D_B : Bohm diffusion coefficient,

$f(s)=H(s)[s^2/(1+s^2)]$: step function of the magnetic shear s;

a : minor plasma radius; q : local safety factor;

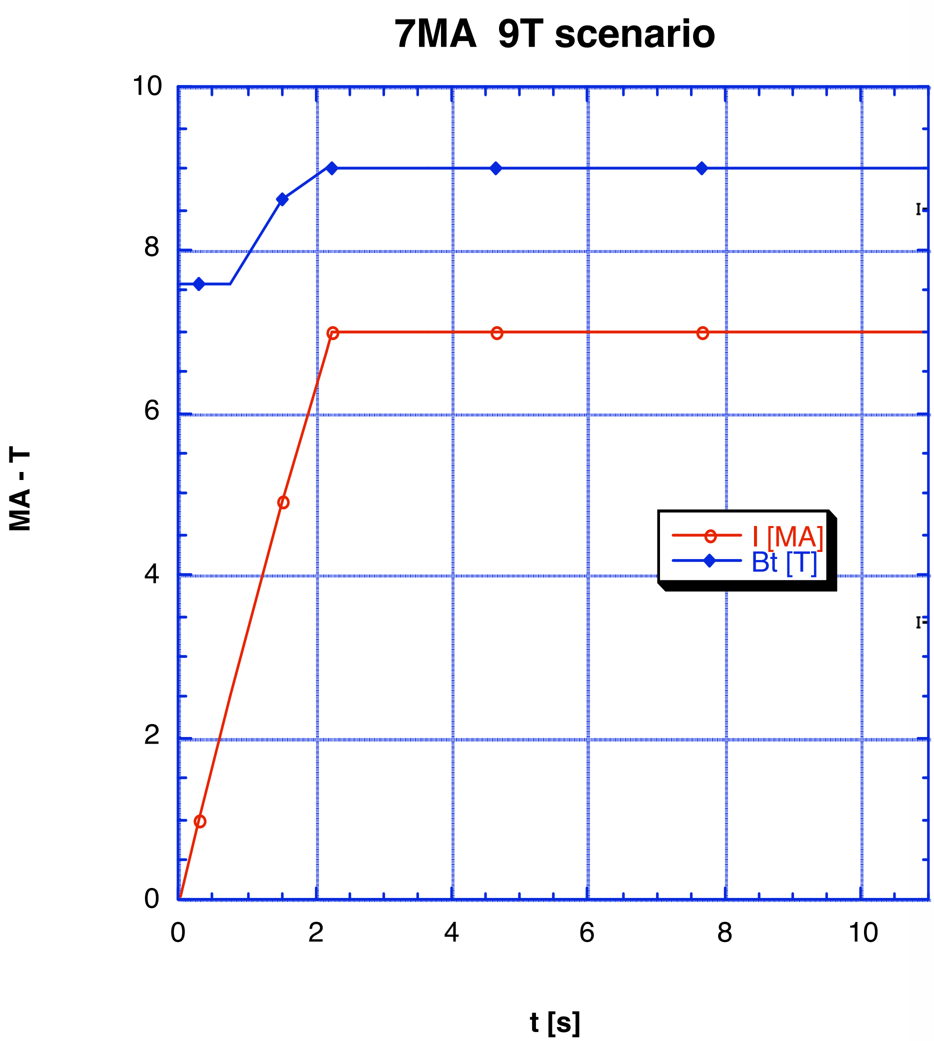
L_{Te}: characteristic temperature gradient length;

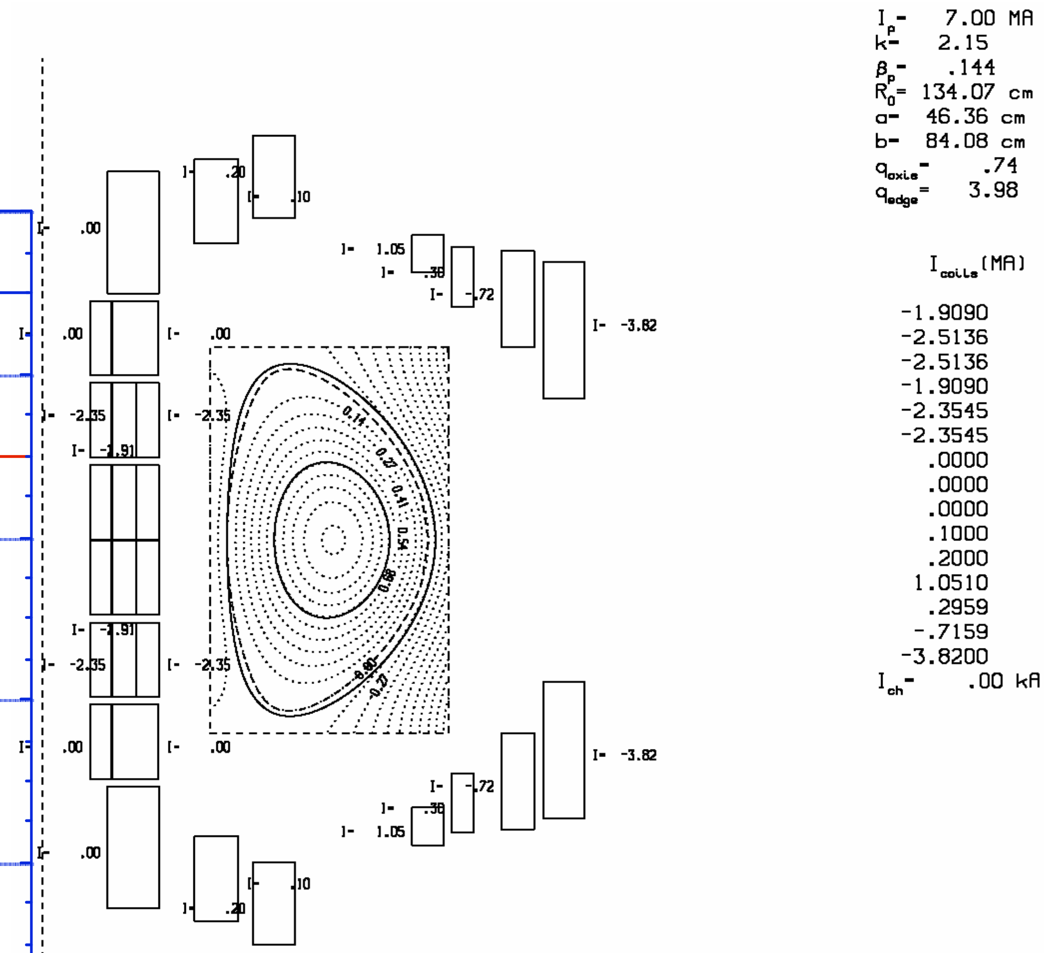
$\chi_{i\text{-}neo}$: neoclassical ion thermal diffusivity.

- Neoclassical resistivity.
- Sawtooth oscillations triggered by a critical peaking factor of the plasma pressure ($p_{kc}=p(0)/\langle p\rangle=2.7$), chosen on an empirical basis.

A.Airoldi and G.Cenacchi, IFP Report FP 04/4 (2004)

7 MA "Limiter" Scenario





Equilibrium configuration at 7.35s

B_T = 9 T, I_P= 7 MA, "limiter"

Plasma parameters

§Working density along the flattop : <ne>~$2x10^{20}m^{-3}$,

§ impurity content such as to produce $<Z_{eff}>$~1.5

§D-T plasma with tritium fed 0.8 s after the discharge start-up.

§ RF pulse (~7.7 MW) from 3.5 s until the end of flattop

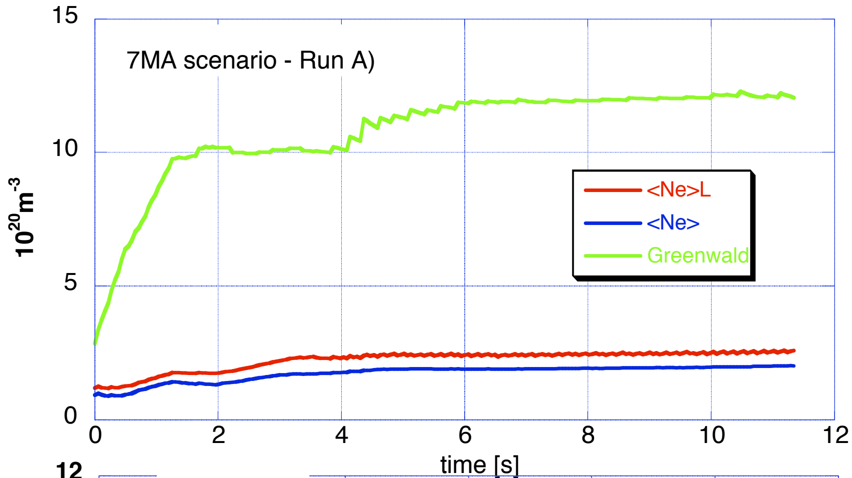
§ Bohm-GyroBohm transport model with coefficients such as to produce confinement times in agreement with

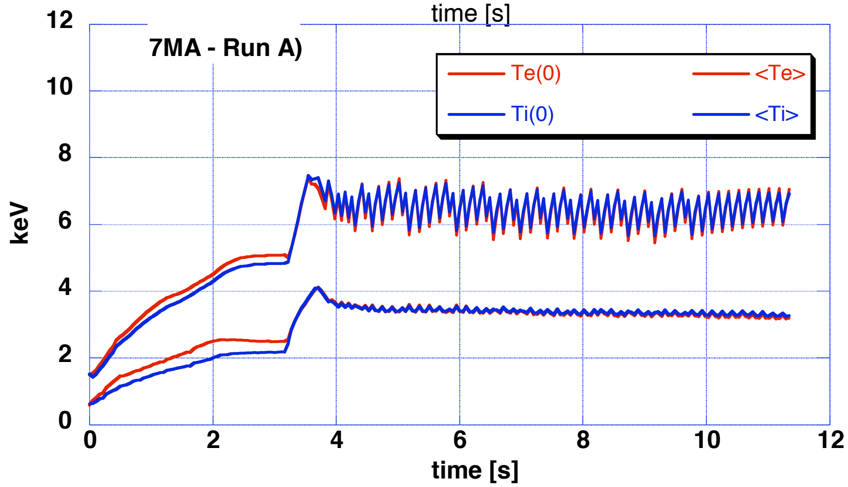
⇒ITER97L scaling law (RUN A)

⇒ ~1.5 × ITER97L (RUN B)

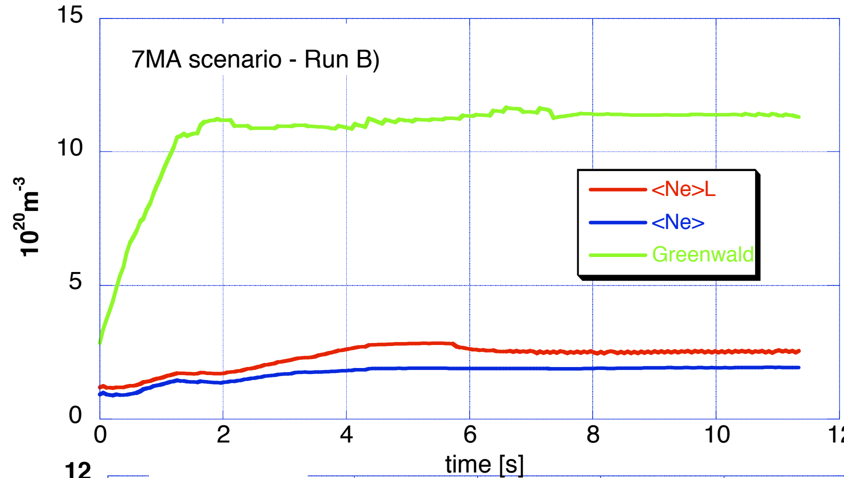
Density and temperature evolution

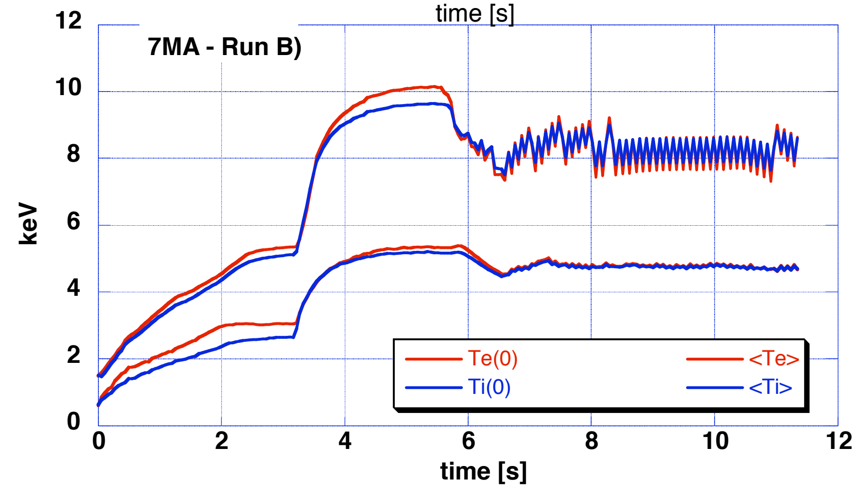
RUN A





RUN B





RUN A: $\alpha_{Be}=0.43x10^{-3}$; $\alpha_{gBe}=0.10$

$\alpha_{Bi}=0.34x10^{-3}$; $\alpha_{gBi}=0.10$

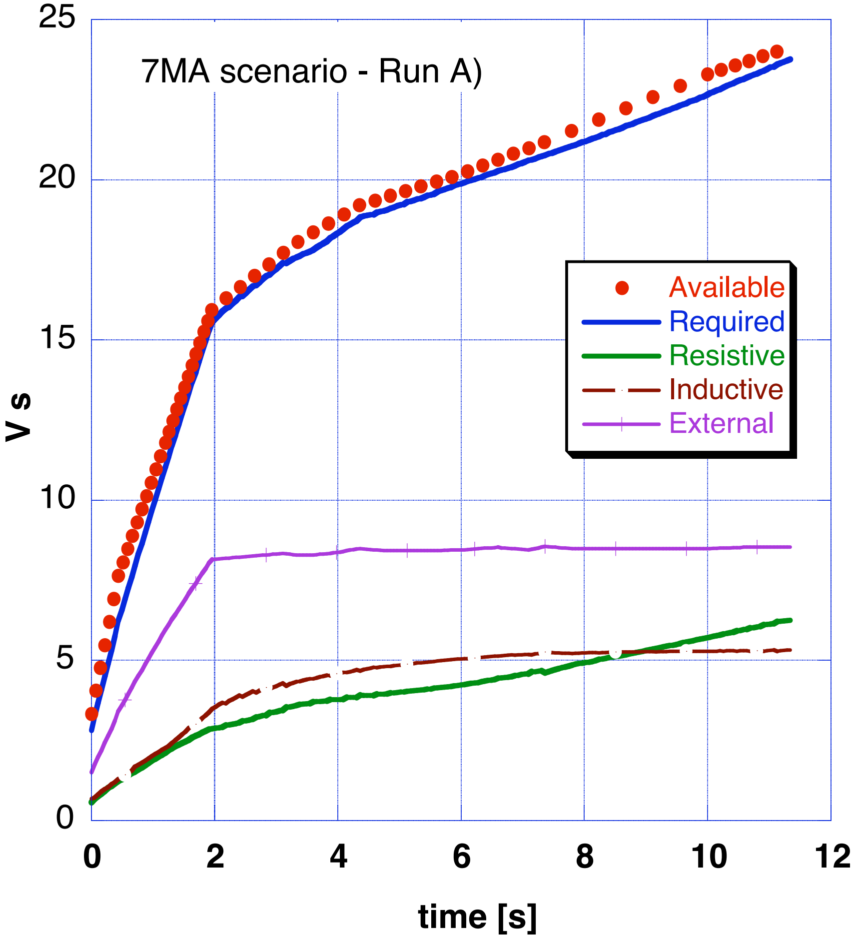
RUN B: $\alpha_{Be}=0.13x10^{-3}$; $\alpha_{gBe}=0.10$

$\alpha_{Bi}=0.10x10^{-3}$; $\alpha_{gBi}=0.10$

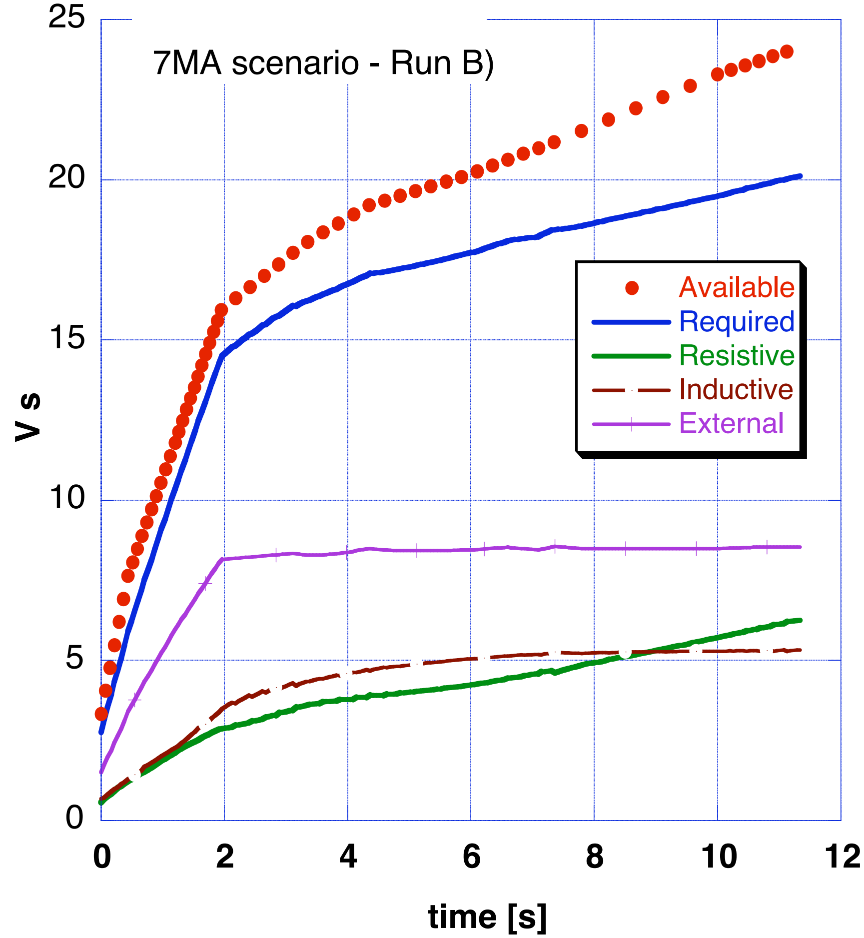
B_T = 9 T, I_P= 7 MA, “limiter”

Flux balance

RUN A



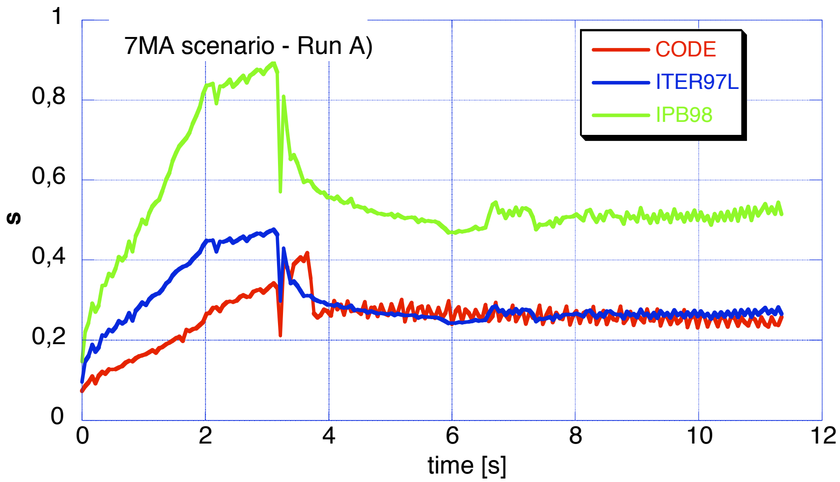
RUN B

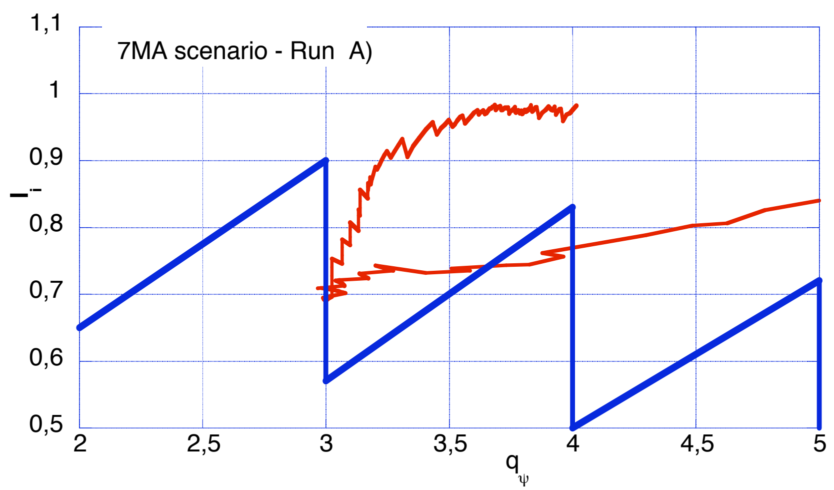


B_T = 9 T, I_P= 7 MA, “limiter”

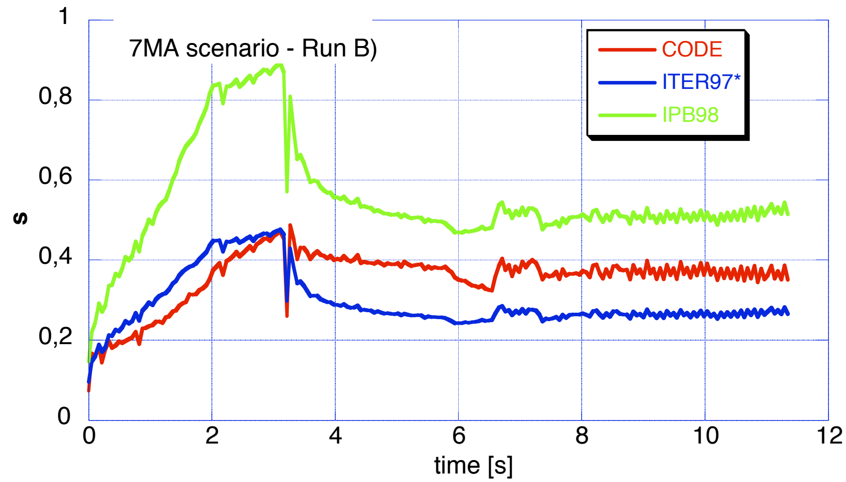
Confinement times and (l_i,q_ψ) diagrams

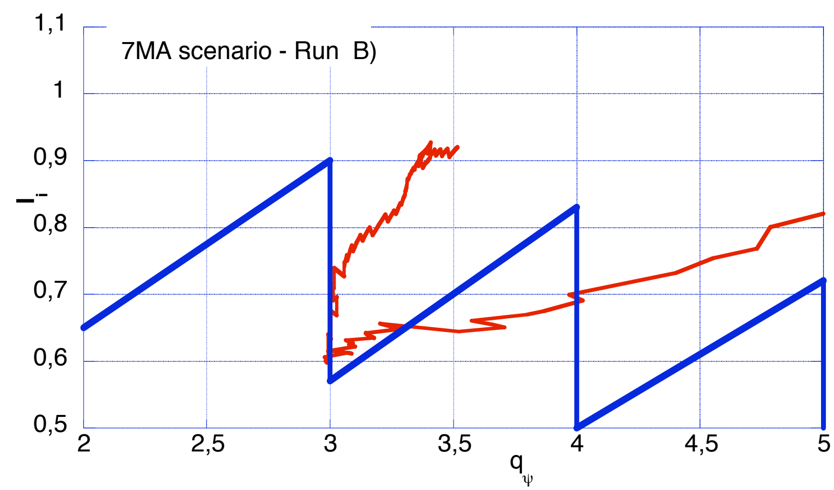
RUN A





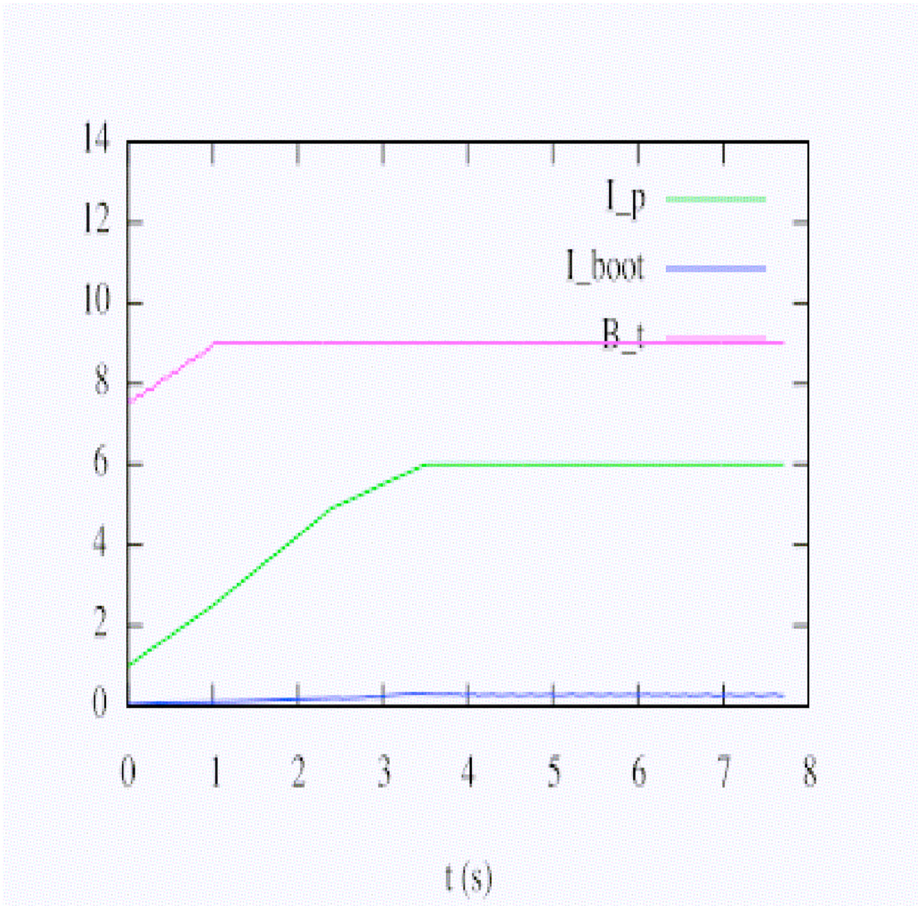
RUN B

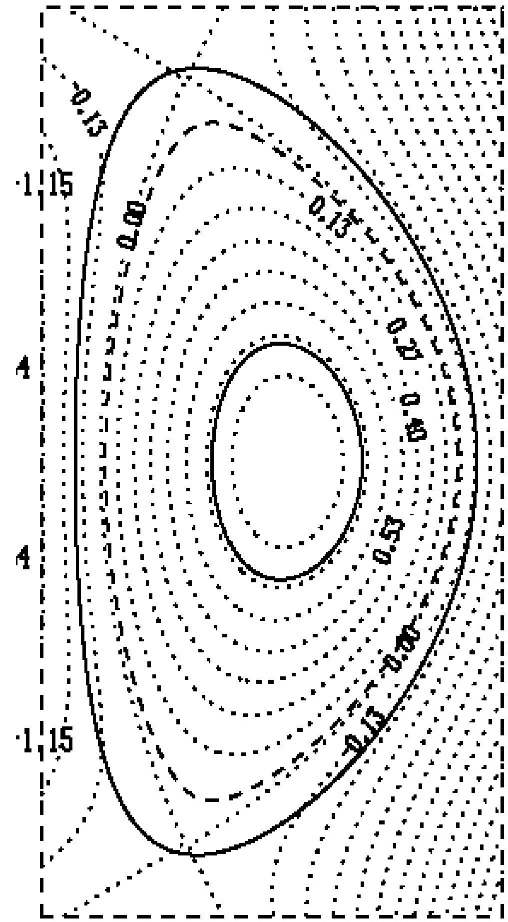




B_T = 9 T, I_P= 7 MA, “limiter”

Double X-Points Scenario





Equilibrium configuration with X-points inside the first wall

Rx=1.17m

Zx=0.84m

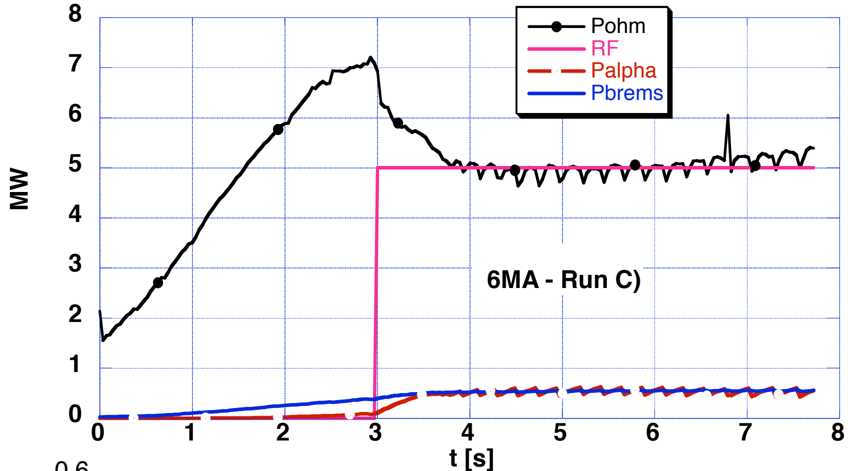
B_T = 9 T, I_P= 6 MA, DN

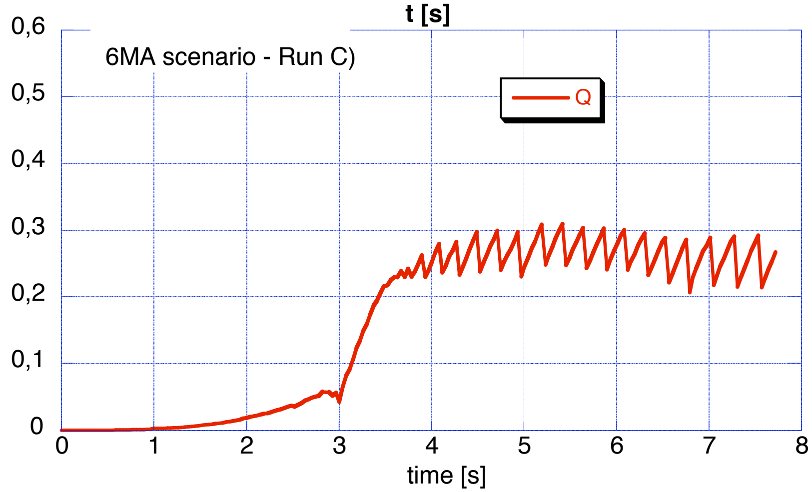
Plasma parameters

- Working density along the flattop: $<ne>\sim 2.4\times 10^{20} m^{-3}$
- impurity content such as to produce an effective charge $<Z_{eff}>\sim 1.4$
- D-T plasmas with tritium fed 0.8 s after the discharge start-up.
- RF pulse (~5MW) from 3.3 s until the end of flattop
- Same two sets of transport coefficients are assumed
- H-Mode confinement is not introduced yet

Evolution of Powers and Fusion Gain Q

RUN C

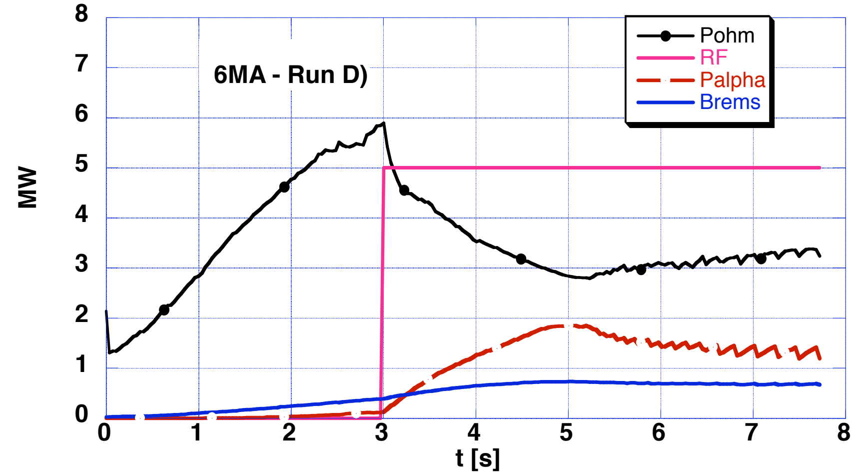


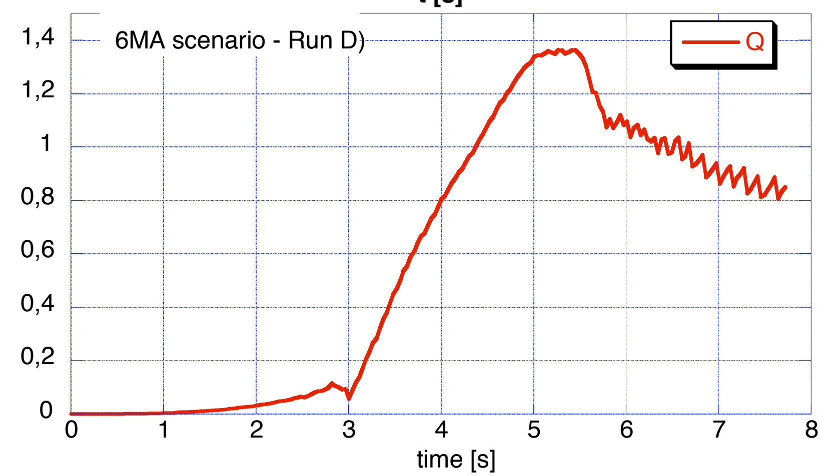


α_{Be}=0.43x10^{-3}; α_{gBe}=0.10

α_{Bi}=0.34x10^{-3}; α_{gBi}=0.10

RUN D



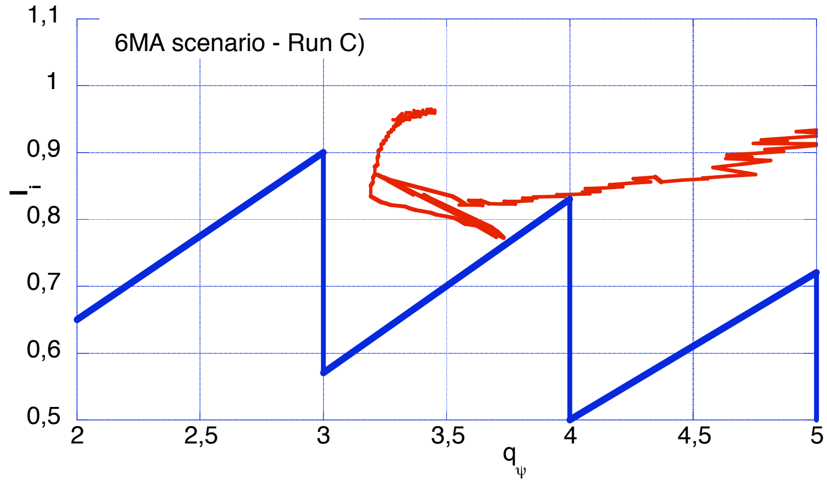


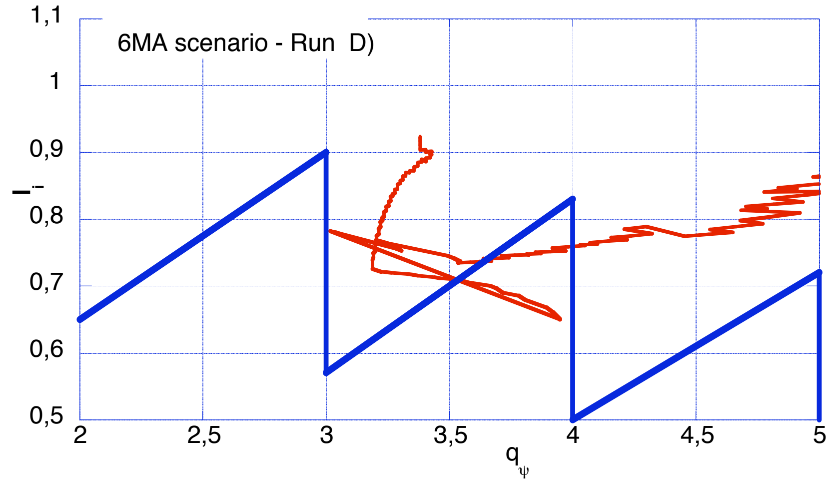
α_{Be}=0.13x10^{-3}; α_{gBe}=0.10

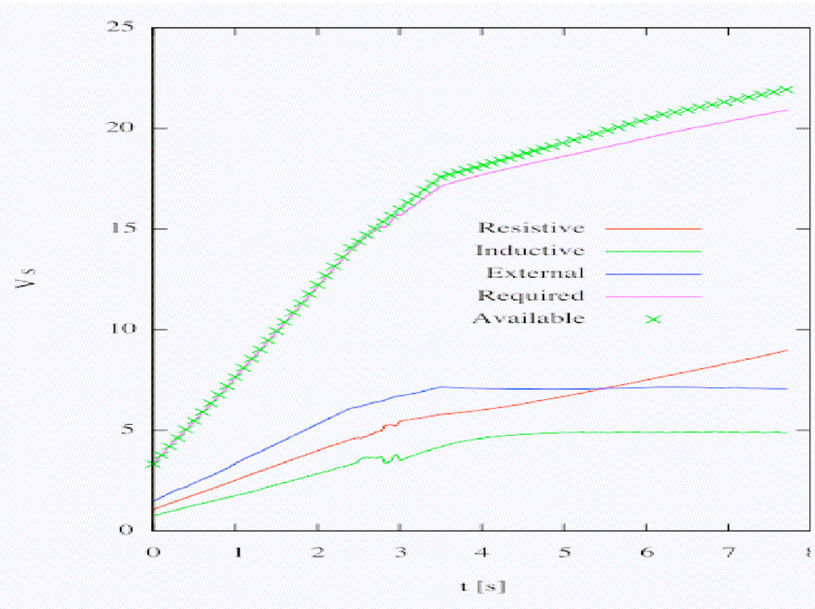
α_{Bi}=0.10x10^{-3}; α_{gBi}=0.10

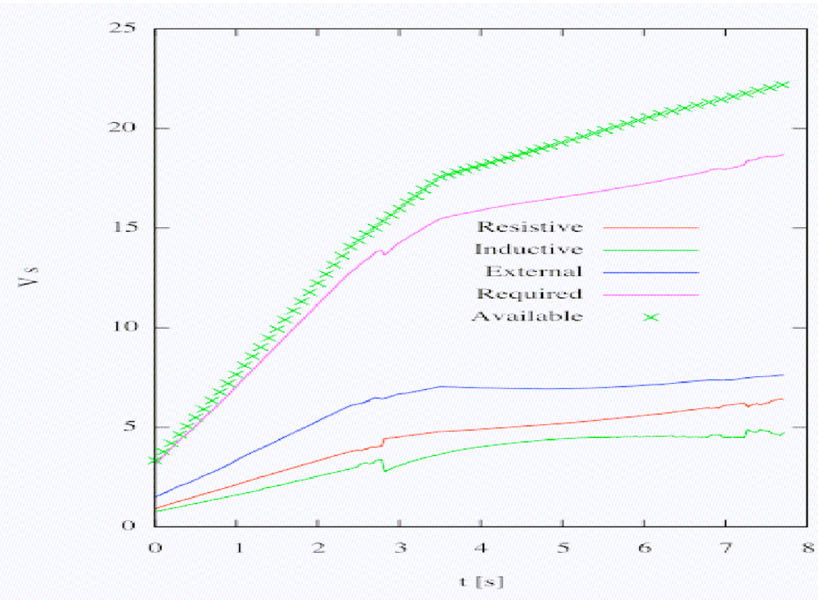
B_T = 9 T, I_P= 6 MA, DN

Stability (l_i,q_ψ) diagrams and flux consumption



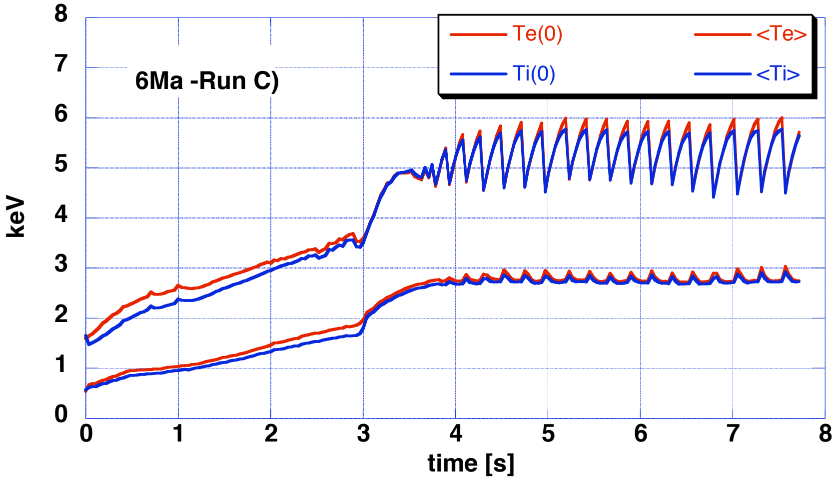


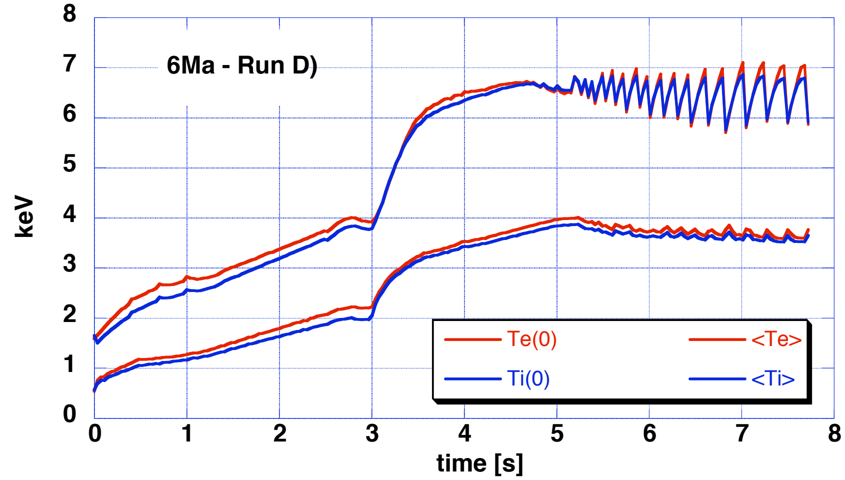


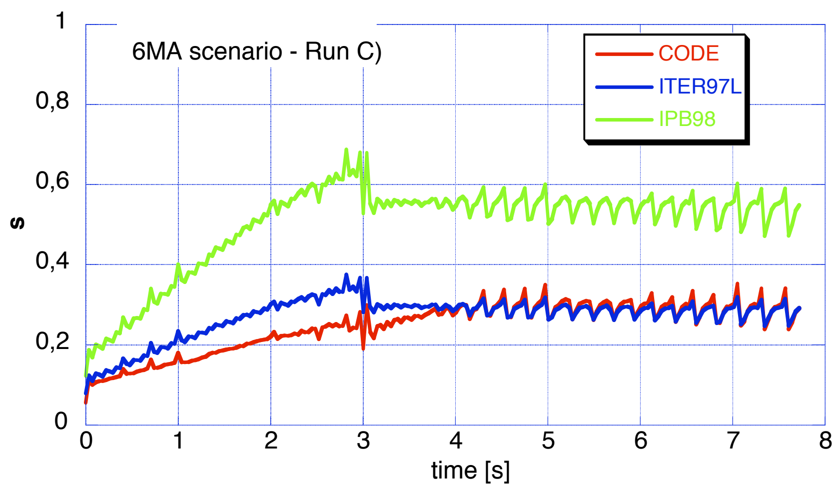


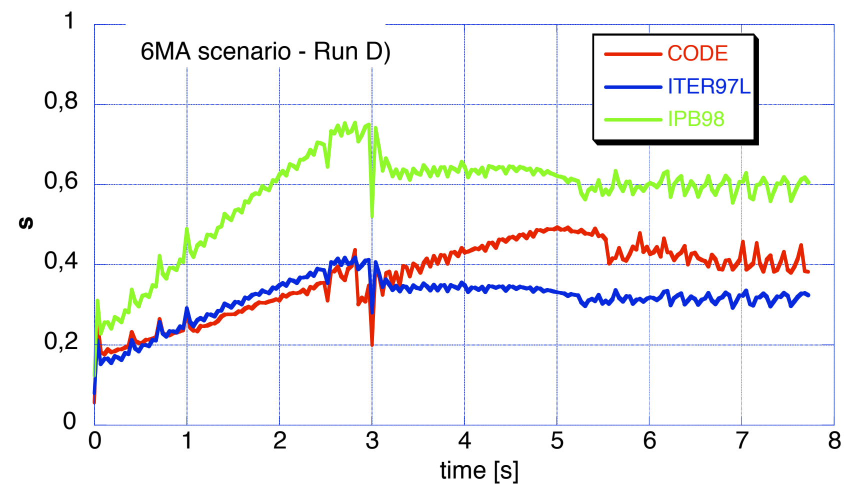
B_T = 9 T, I_P= 6 MA, DN

Temperatures and energy confinement times





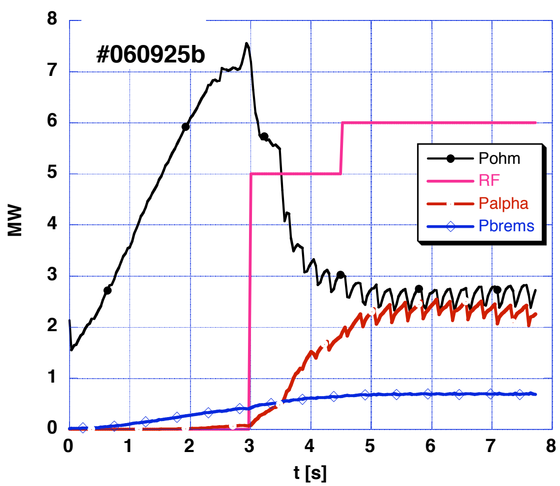


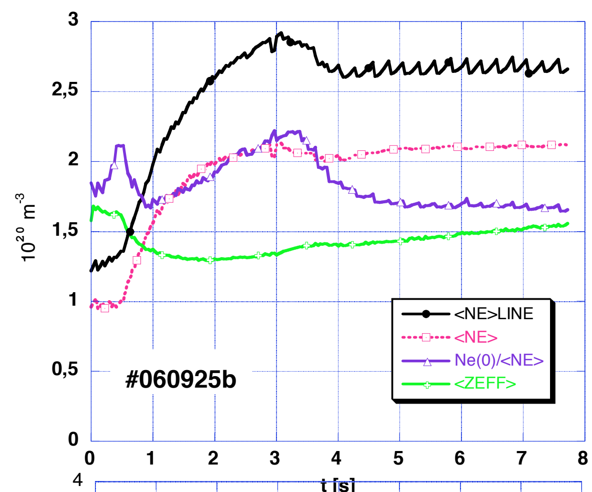


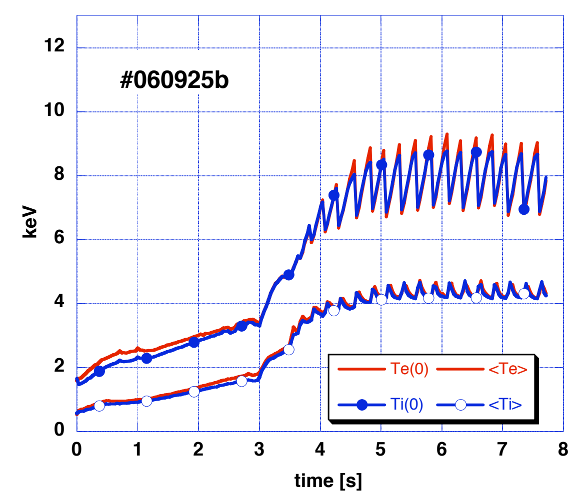
B_T = 9 T, I_P= 6 MA, DN

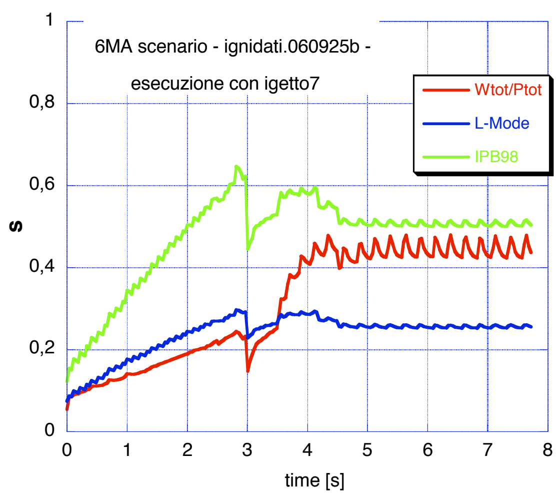
Enhanced Confinement

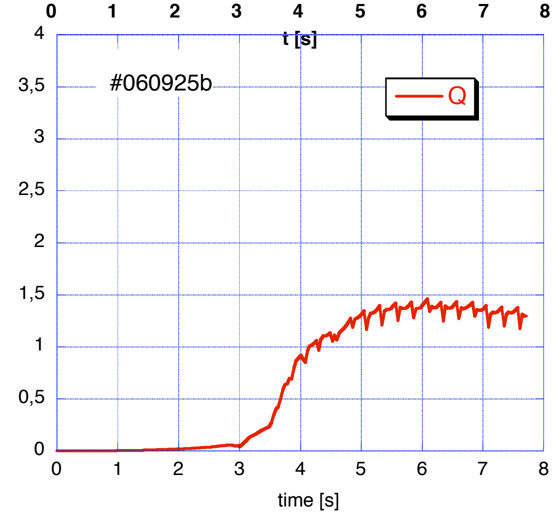
Preliminary results of simulations with enhanced confinement at B_T = 9 T, I_P= 6 MA, double X points configuration, lead to conditions above those for ideal ignition.











Density is the critical parameter.

B_T = 9 T, I_P= 6 MA, DN

Summary

Significant performances can be reached in both scenarios even with pessimistic hypotheses on the confinement time

In the 7 MA scenario a current flattop 9 s long is compatible with the characteristics of the poloidal and toroidal field systems.

The amount of injected heating power can be adjusted so as to compensate for different transport conditions.

Preliminary simulations have been carried out with enhanced confinement conditions.