Current Ramping to Achieve Reversed Shear Confinement for Ignitor

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Abstract

Previous ohmic tokamak experiments show that improved confinement regimes called IOC require peaked density profiles. The performance of Ignitor has been shown to depend critically on the density profile (W. Horton, F. Porcelli, P. Zhu, A. Aydemir, Y. Kishimoto, and T. Tajima, Nucl. Fusion **42**, 169 (2002)).

Previous transport simulations used either fixed density profiles or obtained flat density profiles. Flat density profile drives up the ITG and ETG turbulent transport.

Current ramping to create reversed shear confinement enhancement and peaked density profiles are crucial in achieving ignition conditions in Ignitor. Here we propose the use of high rate plasma current ramping, which leads to the reversed magnetic shear and peak density profile.

Simulation Code

BALDUR, 1-1/2 transport code

Transport Model

JETTO, mixed Bohm/gyro-Bohm model

$$\chi_{\mathrm{e,i}} = \chi_{\mathrm{e,i}}^{\mathrm{B}} + \chi_{\mathrm{e,i}}^{\mathrm{gB}} \qquad \text{Bohm term + gyro-Bohm term}$$

$$\chi_{e,i}^{\mathrm{B}} = \alpha_{\mathrm{e,i}}^{\mathrm{B}} \frac{cT_{\mathrm{e}}}{eB} \frac{q^2 a}{L_{p\mathrm{e}}} \langle L_{T_{\mathrm{e}}}^{*} \rangle_{\Delta V}^{-1} \qquad \text{Bohm term}$$

$$\chi_{\mathrm{e,i}}^{\mathrm{gB}} = \alpha_{\mathrm{e,i}}^{\mathrm{gB}} \frac{cT_{\mathrm{e}}}{eB} \frac{\rho_{\mathrm{si}}}{L_{T\mathrm{e}}} \qquad \text{gyro-Bohm term}$$

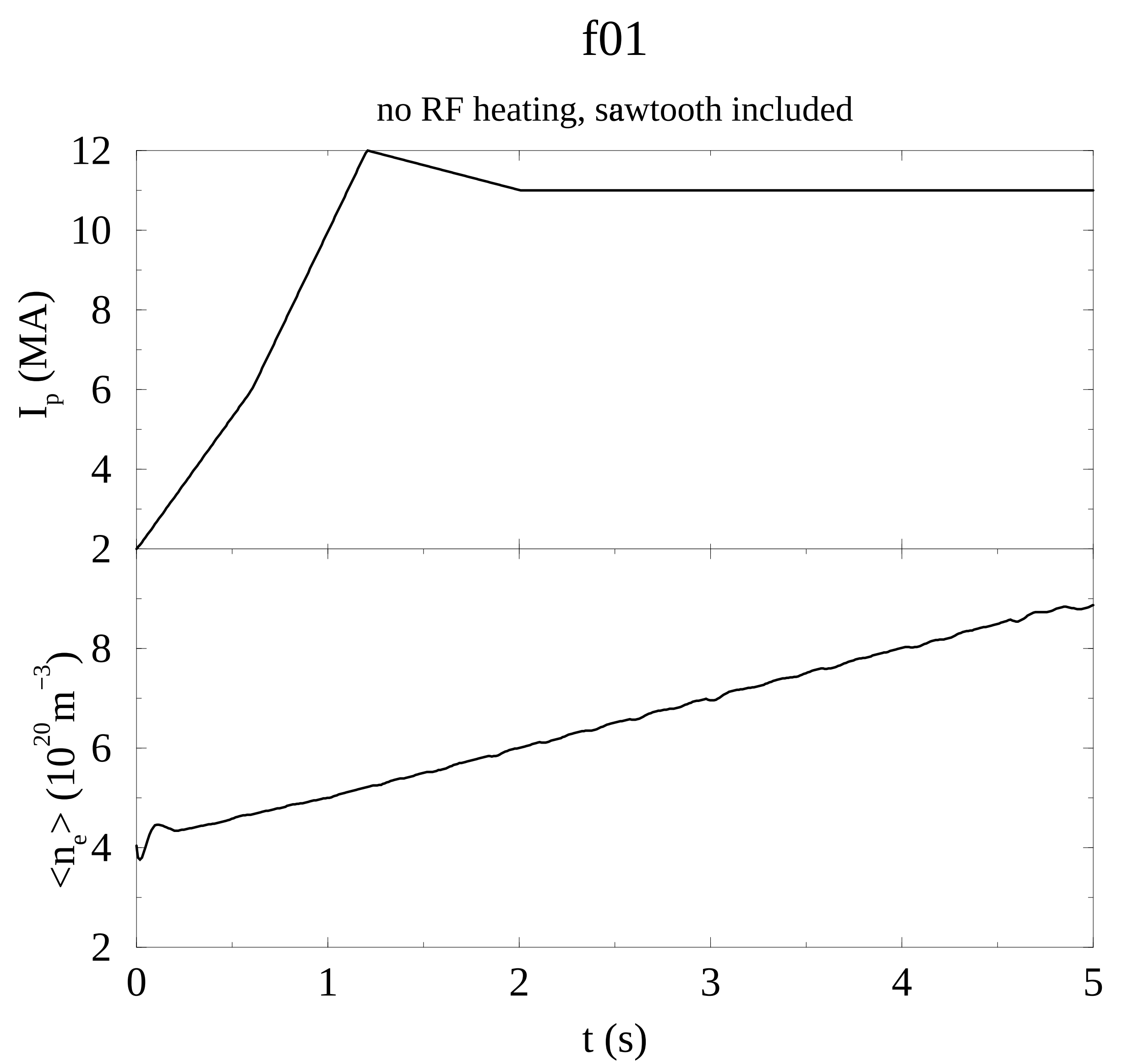
Simulation Parameter Setting

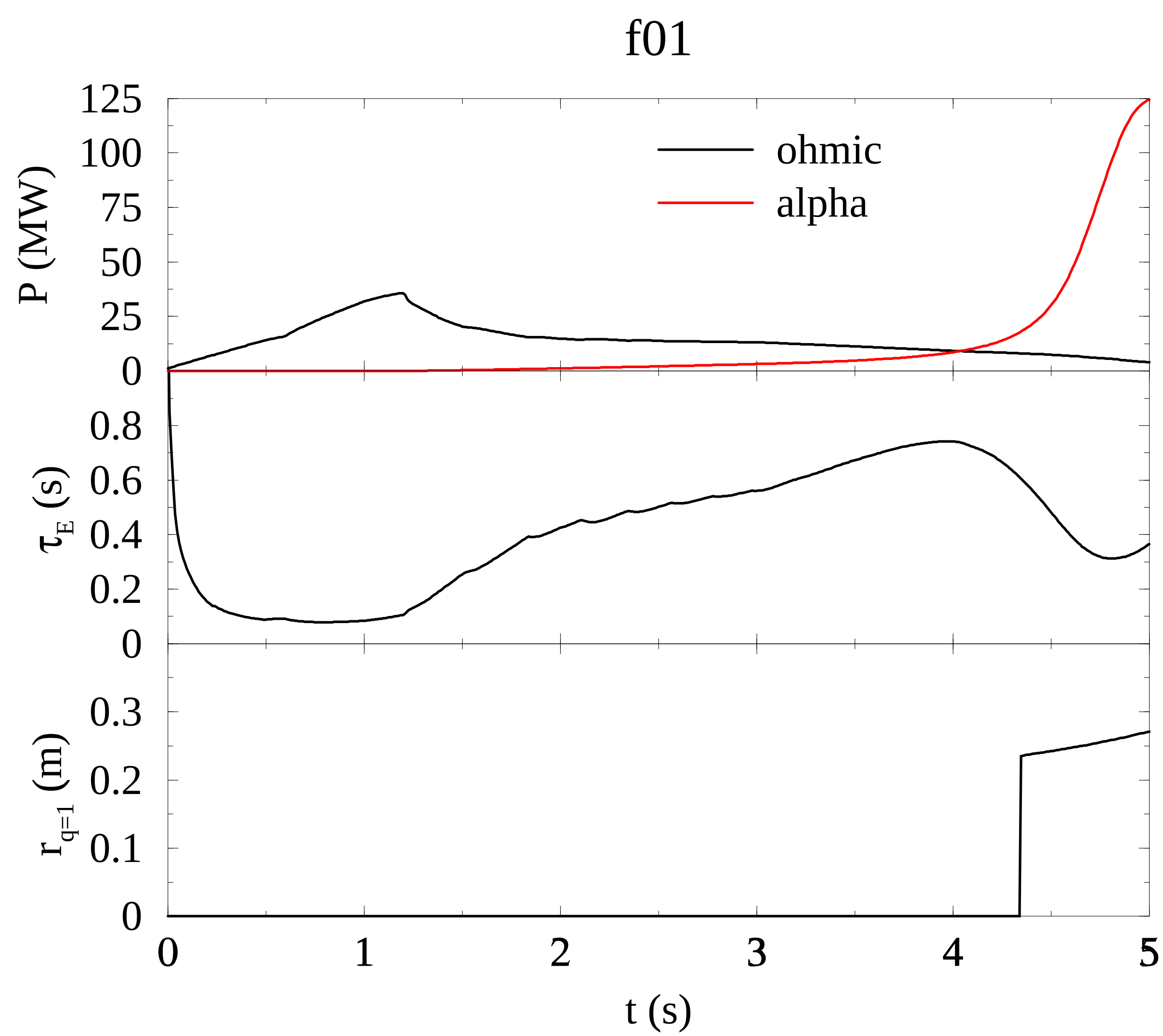
- Key parameters: current ramping and density ramping.
  - plasma toroidal current I_p ramping
  - line-averaged density $\langle \overline{n_e} \rangle$ ramping
- Global parameters
  - Geometrics: major radius R_0, half-width a(volume ramping), elongation κ, and triangularity δ.
  - Vacuum toroidal field B, and Z_{eff}.
- Boundary conditions
  - Electron and ion temperatures at the edge.
  - Density of all ion species at the edge.

Global parameters for Ignitor simulation

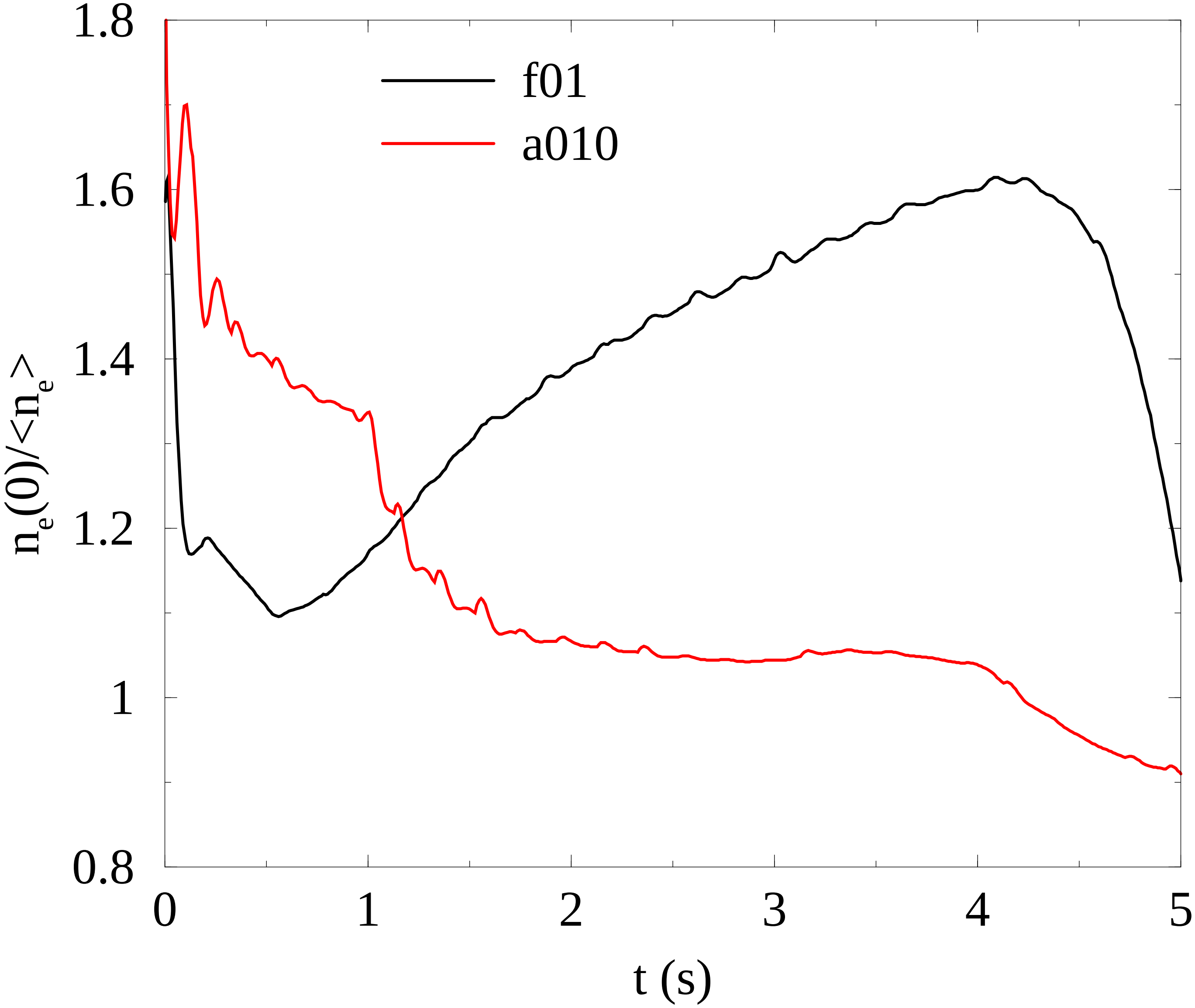
major radius	R (m)	1.32
minor radius	a (m)	0.47
elongation	κ	1.83
triangluarity	δ	0.43
toroidal field	B_{T} (T)	13

Ignition with reversed magnetic shear



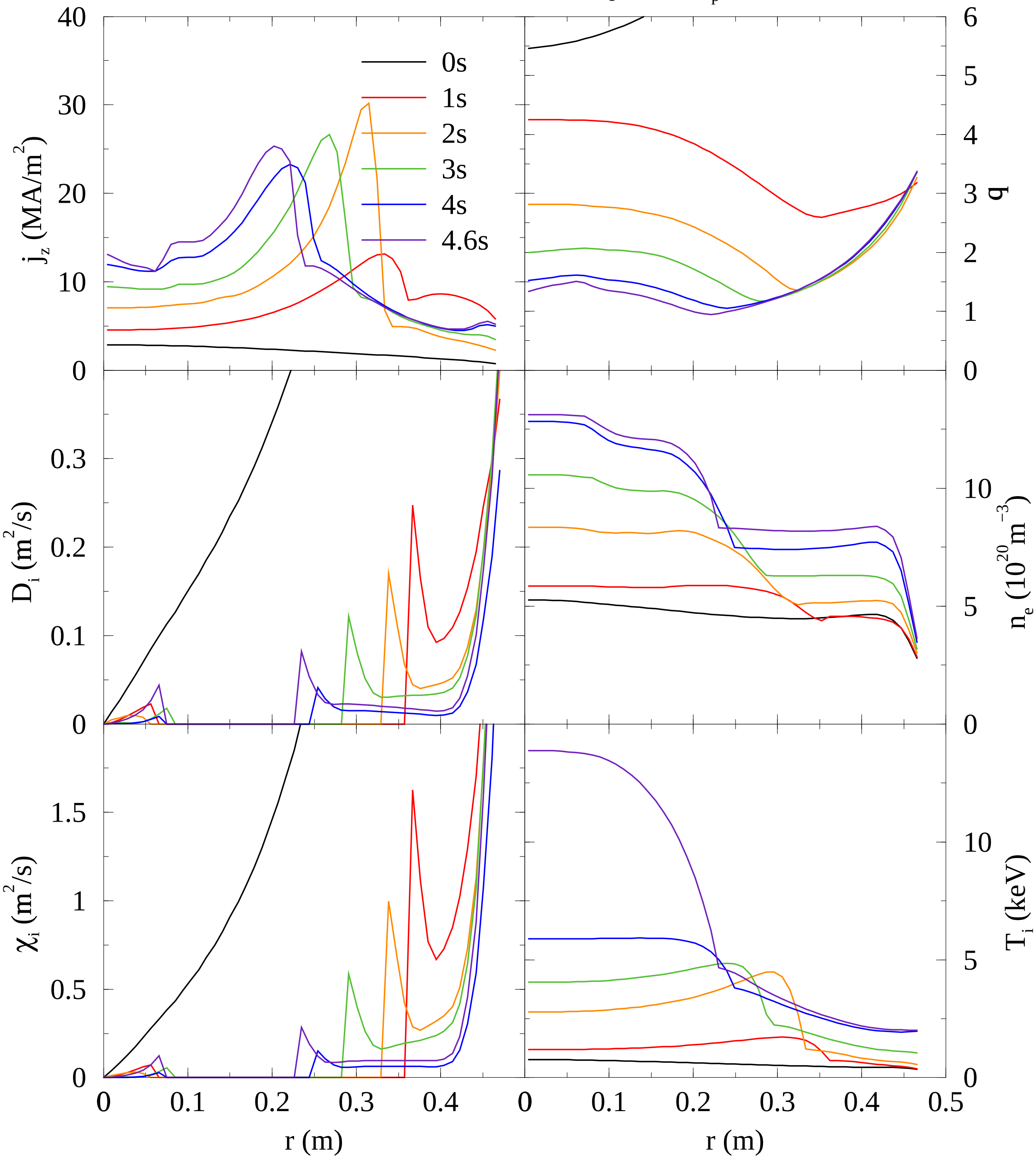

f01
P (MW)
ohmic
alpha
τE (s)
rq=1 (m)
t (s)
125
100
75
50
25
0
0.8
0.6
0.4
0.2
0
0.3
0.2
0.1
0
0
1
2
3
4
5

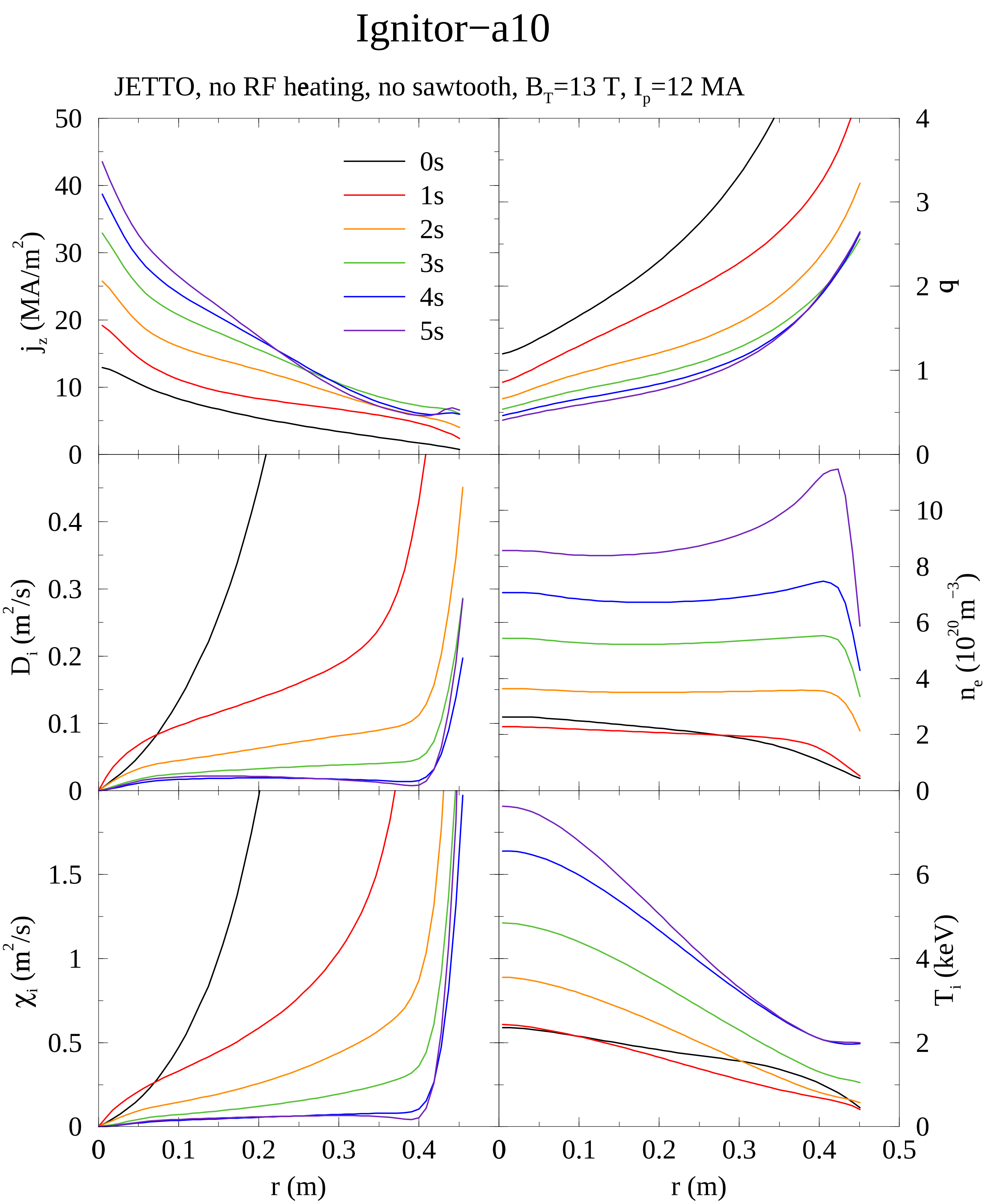
Comparison with the reference discharge a010 given in Horton *et al.* (Nucl. Fusion **42**, 169 (2002))



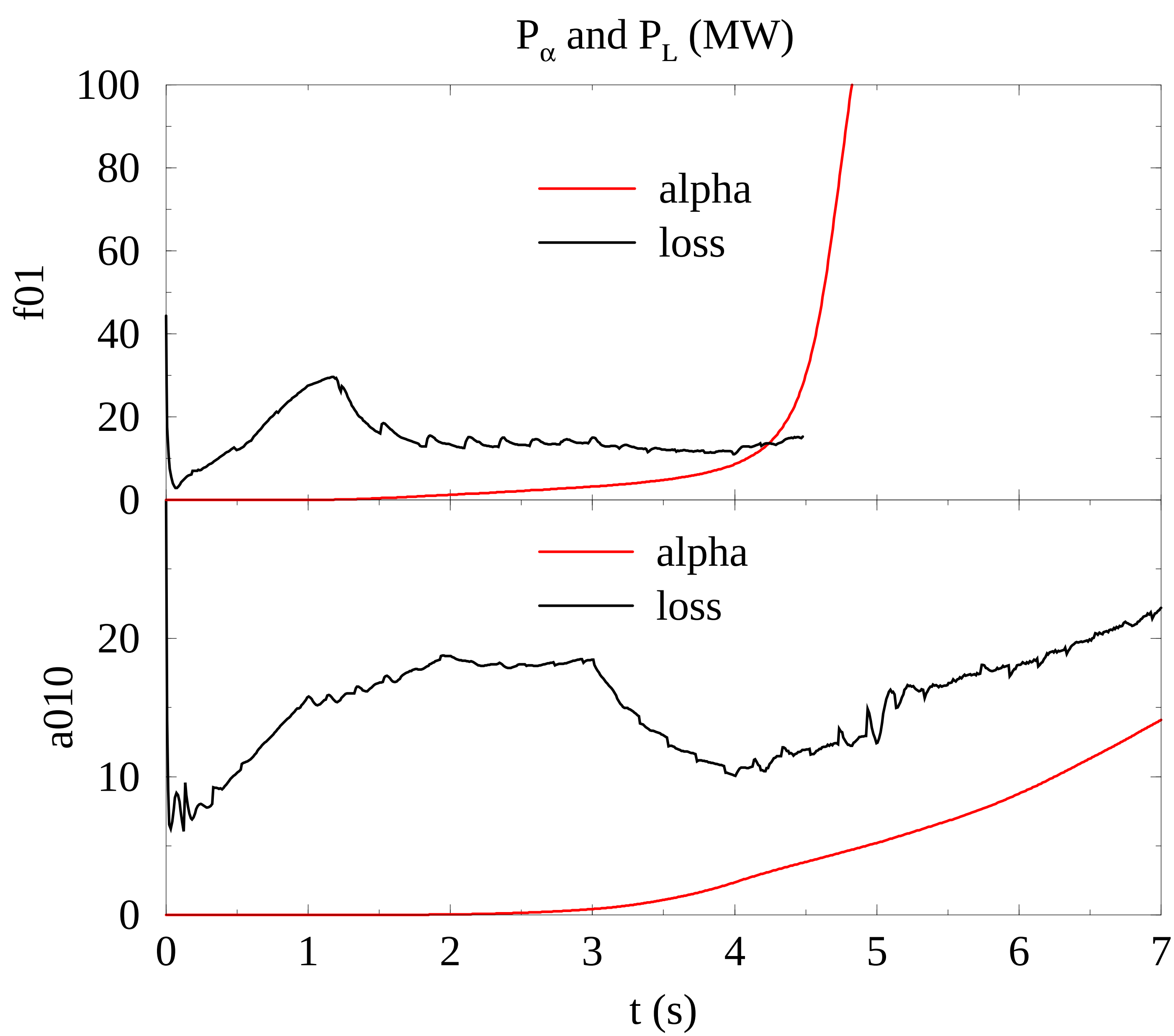
Ignitor−f01

JETTO, no RF heating, sawtooth included, B_T=13 T, I_p=12 MA





Ignitor−a10
JETTO, no RF heating, no sawtooth, B_T=13 T, I_p=12 MA
0s
1s
2s
3s
4s
5s
j_z (MA/m^2)
q
D_i (m^2/s)
n_e (10^20 m^−3)
χ_i (m^2/s)
T_i (keV)
r (m)
r (m)



P$_{\alpha}$ and P$_{L}$ (MW)
f01
alpha
loss
a010
alpha
loss
100
80
60
40
20
0
20
10
0
0
1
2
3
4
5
6
7
t (s)

We have used a current ramping rate of 8 MA/s, achieved ignition at $t = 4.24$ s before sawtooth happened ($t = 4.34$ s) and obtained fusion gain $Q = 8.2$, alpha power $P_\alpha = 14$ MW and energy confinement time $\tau_{\mathrm{E}} = 0.67$ s.

Summary

- Reversed magnetic shear is produced by controlled fast plasma current ramping.
- High plasma current density, high ohmic heating density outside of the core.
- Reversed magnetic shear q-profile may delay the sawtooth, and make it appear outside of the core after ignition.
- Reversed magnetic shear may supress the transport coefficients, and create the internal transport barrier.
- Density profile doesn't have to be peak at the begining. Because of the transport barrier and density ramping (edge gas puffing), it will be peaked later, before the ignition.
- Reversed magnetic shear may enhance the confinement.

Remarks

- Such a programmed Ohmic heating scheme is demonstrated to be an effective approach to the ignition of a burning D-T plasma.

- Since the reversed magnetic shear is a natural by-product of rapid plasma current ramping as well as a well confirmed mechanism in the formation of transport barrier, such a scheme of density profile peaking is intrinsic to the Ohmic heating process as in Ignitor, and independent of the particular transport model used in simulations.

- Reversed magnetic shear (RS) plasma confinement has become one of the main approaches to achieving fusion grade plasmas in tokamaks.

- This reversed shear or optimized shear confinement enhancement is also planned in most advanced tokamaks, such as KSTAR and Tore Supra, even though their scenarios for obtaining reversed shear are different.
- The fast current ramps used to reach ignition in our simulation are similar to those used for the successful creation of an internal transport barrier in Tore Supra (Hoang *et al.*, Phys. Rev. Lett. **84**, 4593 (2000)).