RU/RD modelling for DEMO with ASTRA-Simulink

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Acknowledgments:
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Final Meeting KDII#8 -2020

1 July 2020, Garching, Germany

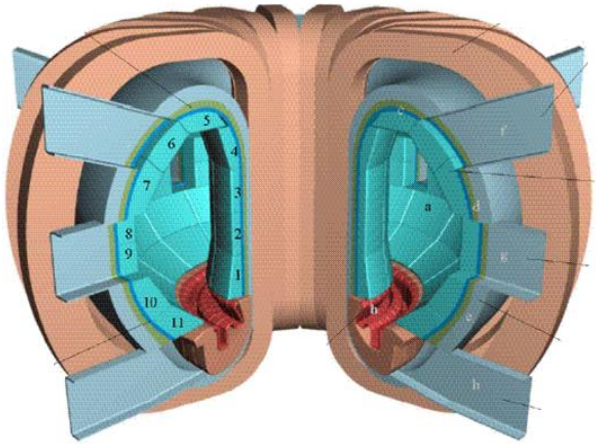
Ramp-Up and Ramp-Down phases

The Ramp-Up and Ramp-Down in DEMO are phases of major interest in view of the definition of a plasma operating scenario.

From the physical point of view, the plasma parameters have to evolve within specific limits to keep the plasma non-disruptive.

Trying to optimize according to following recipe:

- Avoid P_{sep} increasing too much > 200 MW (RU)
- Avoid n/n_{Gw} going above 1
- Avoid β_{pol} time derivative to be too large
- Reach P_{fus} target from below without overshoots (RU)
- Avoid that *li* becomes too large (RD)



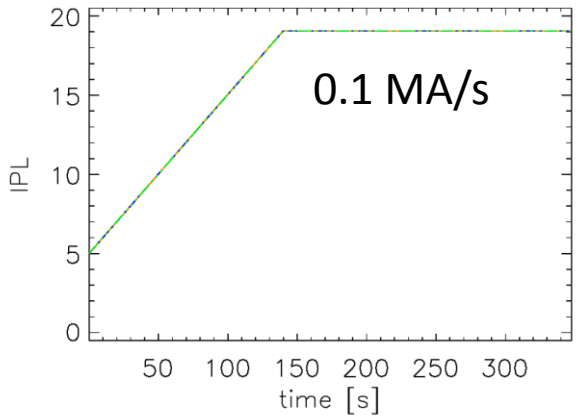
Ramp-Up scenario with CREATE

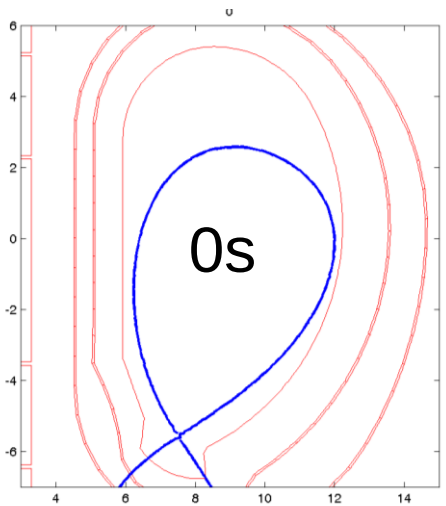
✓ The evolution of a plasma equilibrium geometry has to be taken into account in the case of simulations of entire discharges because it strongly influences the plasma profiles.

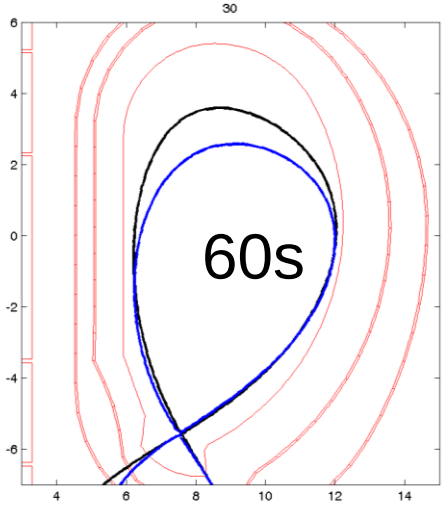
✓ Significant changes in the plasma state occur during the ramp-up, including a fast evolution of the plasma boundary.

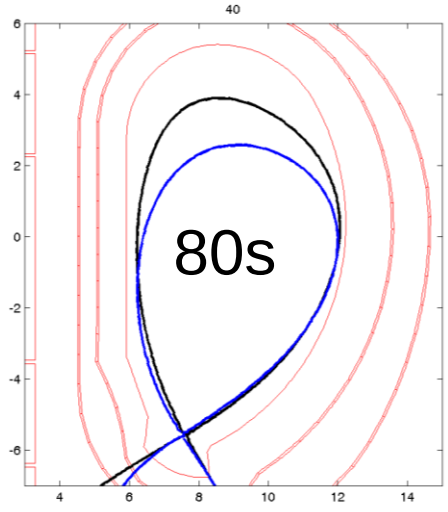
❑ Equilibrium snapshots with Plasma grows on a fixed X-point from CREATE

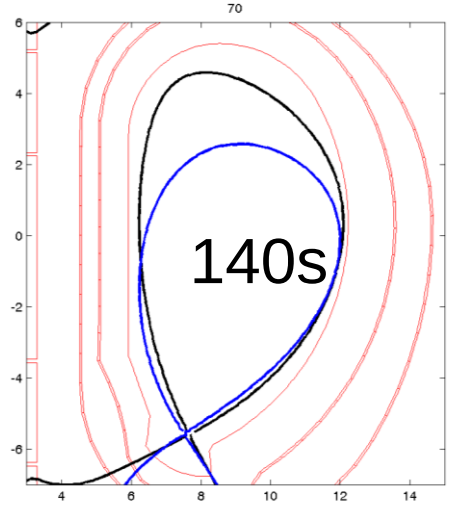
❑ Used CREATE value for I_p Ramp rate



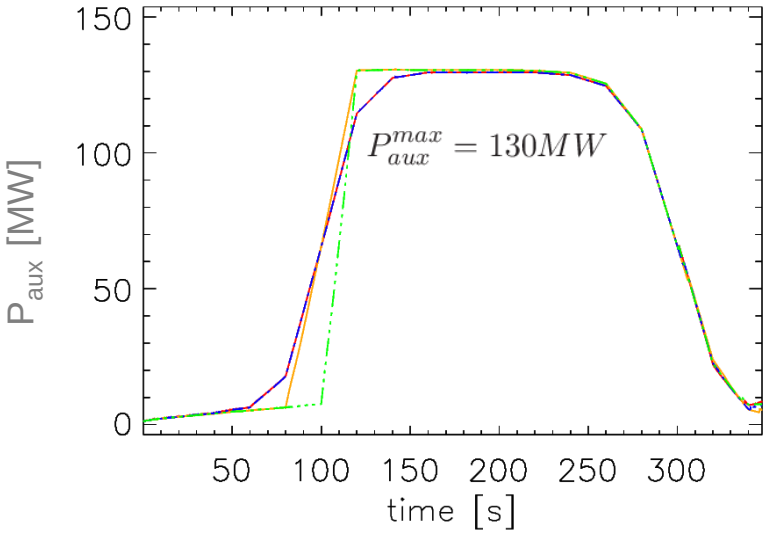


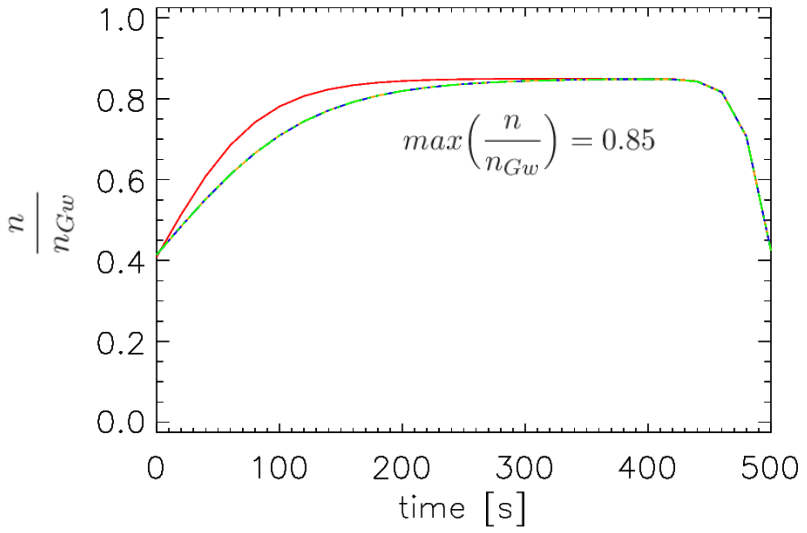






Time traces used to optimize Ru/Rd





$$P_{aux} = P_{aux}^{max}\frac{1}{2}\left[\tanh\frac{(t-t_{P_{Ru}})}{L_{P_{Ru}}} - \tanh\frac{(t-t_{P_{Rd}})}{L_{P_{Rd}}}\right]$$

Time at which the growing rate is maximum

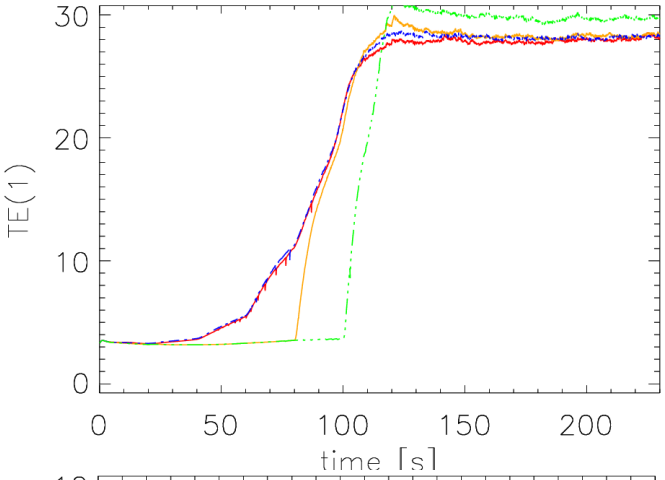
Temporal width in which the function increases

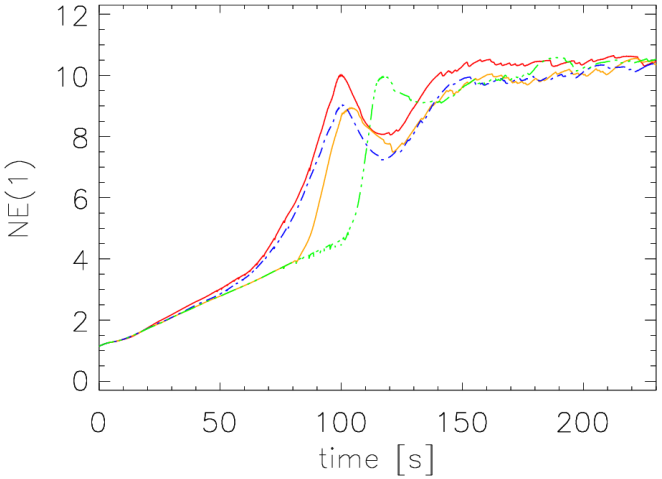
case	$t_{P_{Ru}}$	$L_{P_{Ru}}$
Green	110	1
Orange	100	5
Blue	100	20
Red	100	20

$$\frac{n}{n_{Gw}} = max\left(\frac{n}{n_{Gw}}\right)\frac{1}{2}\left[\tanh\frac{(t-t_{n_{Ru}})}{L_{n_{Ru}}} - \tanh\frac{(t-t_{n_{Rd}})}{L_{n_{Rd}}}\right]$$

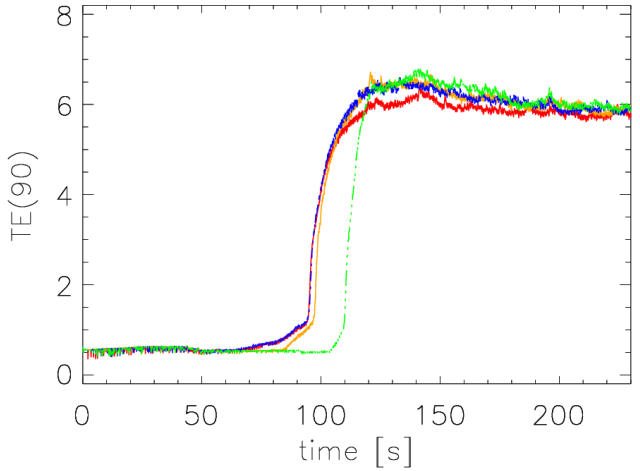
case	$t_{n_{Ru}}$	$L_{n_{Ru}}$
Green	3	120
Orange	3	120
Blue	3	120
Red	3	80

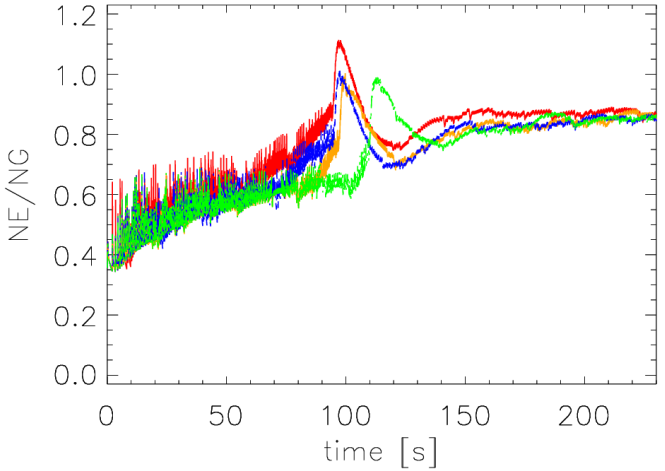
Temperature and density evolution





The temperature and density values in the core are indipendent of the gradient used to reach the saturation state

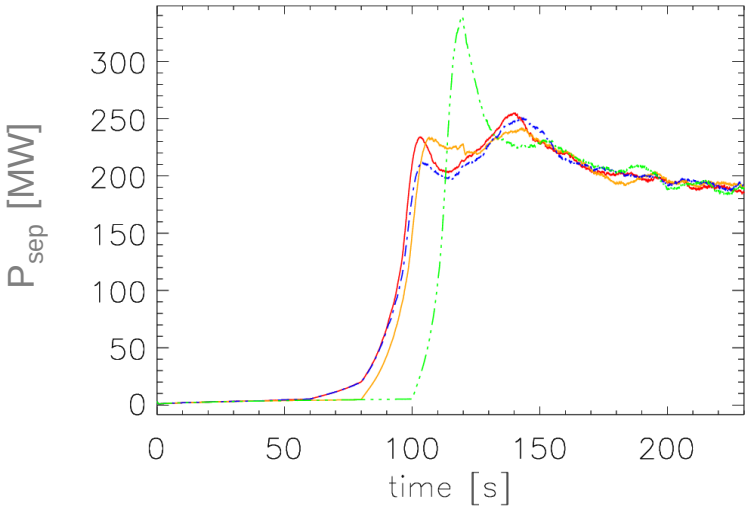


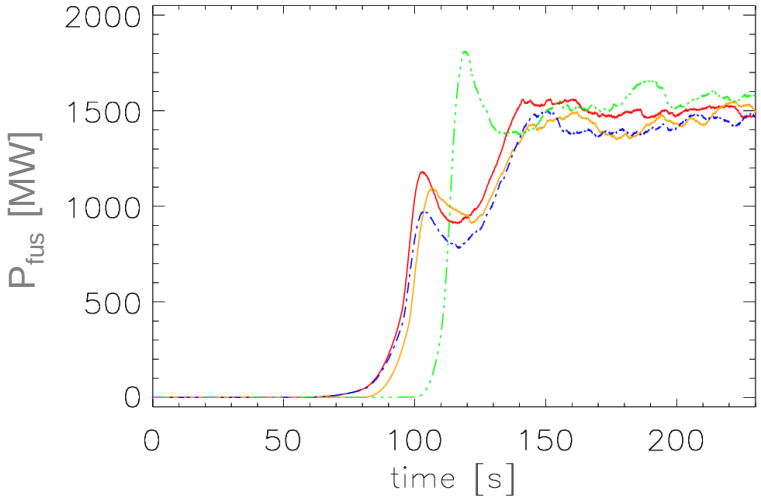


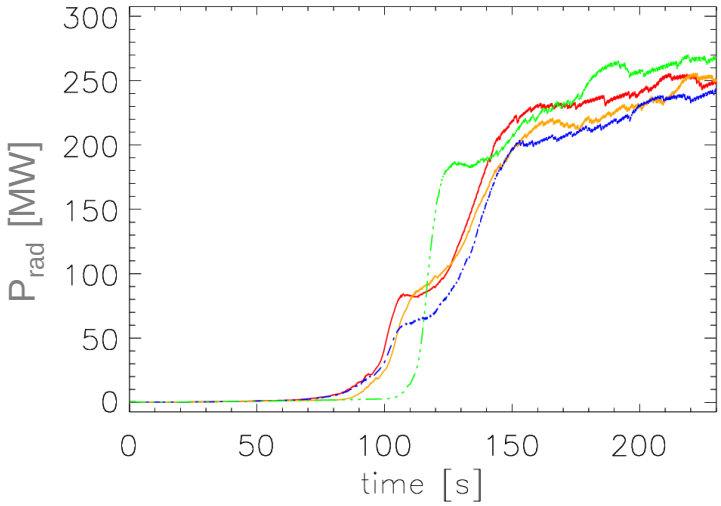
The Greenwald fraction at the pedestal top presents an overshoot in particular for the red case state

Calculated Powers

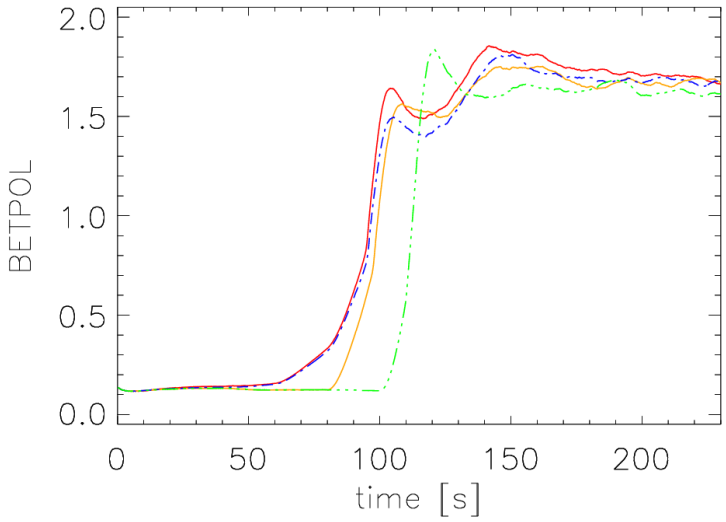
- ✓ Try to maintain Psep≈200 MW and to not produce overshoots (green curve)
- ✓ P_{fus} smoothly increasing
- ✓ P_{rad} dominated by Xe



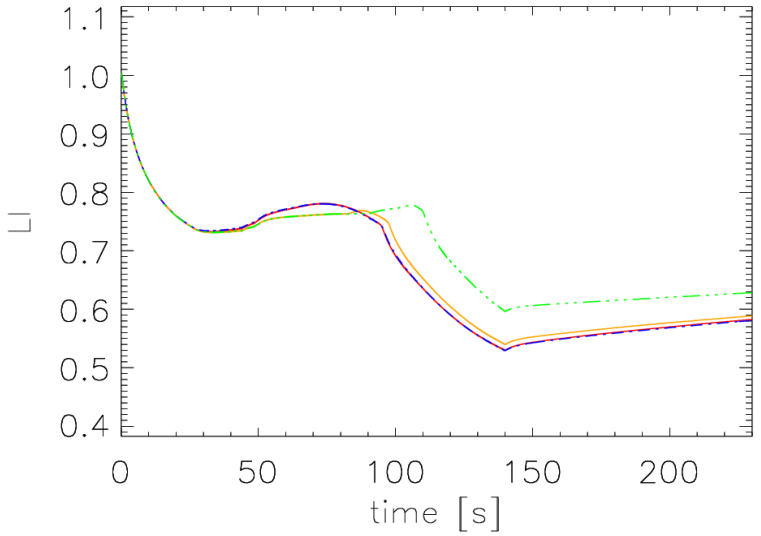


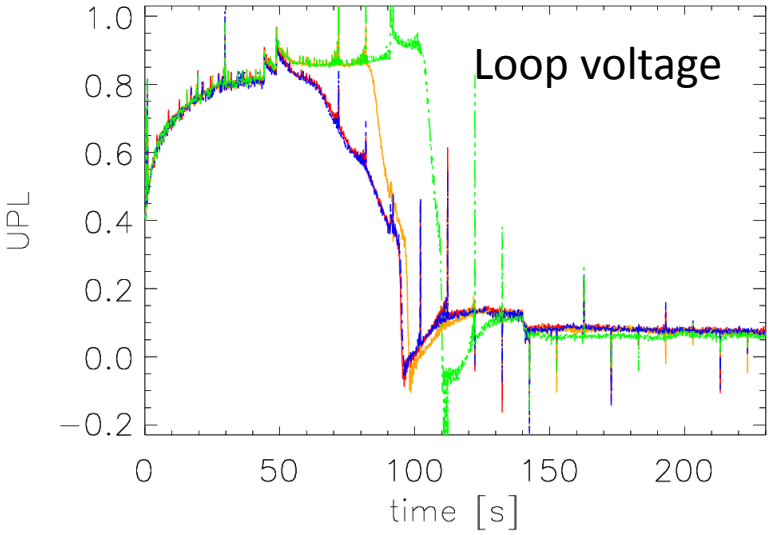


Plasma parameters



Internal inductance





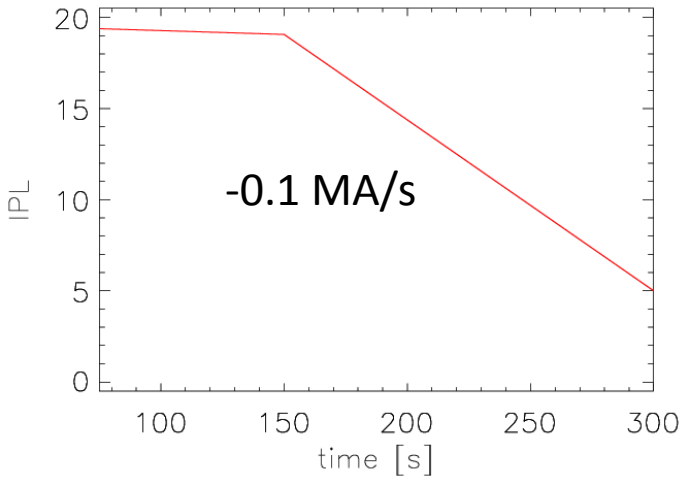
Case	Red	Green	Orange	Blue
Max β_{pol}	1.86	1.83	1.75	1.81
Max P_{sep} [MW]	255	338	241	250
N/ngw	1.14	0.98	1.0	1.01
P_{fus} [MW]	1560	1812	1546	1500

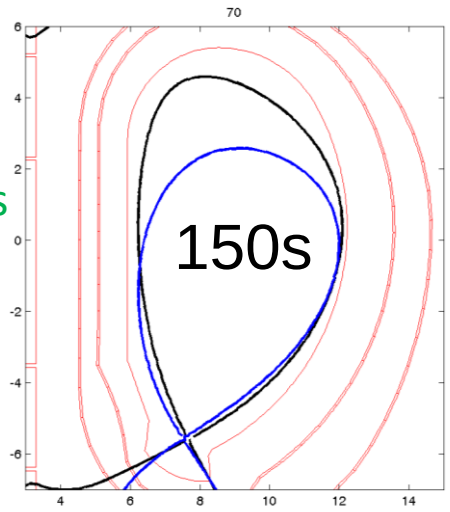
Ramp-Down scenario with CREATE

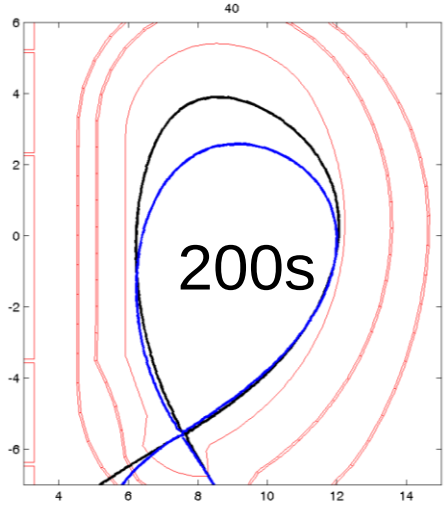
✓ Significant changes in the plasma state occur during the ramp-down, including a fast evolution of the plasma boundary.

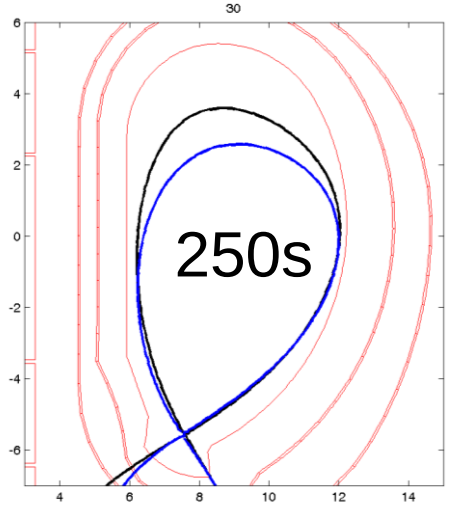
❑ Equilibrium snapshots with Plasma grows on a fixed X-point from CREATE

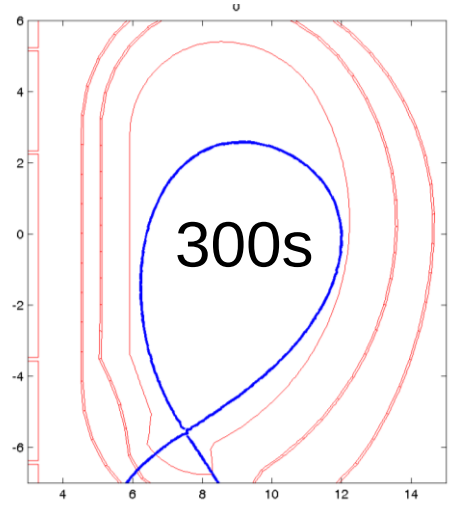
❑ Used CREATE value for I_p Ramp rate



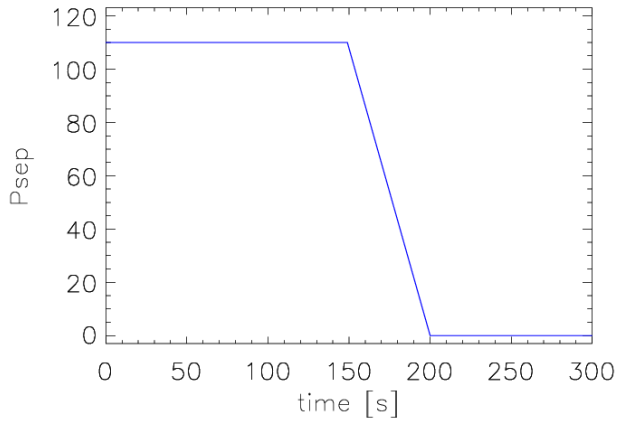


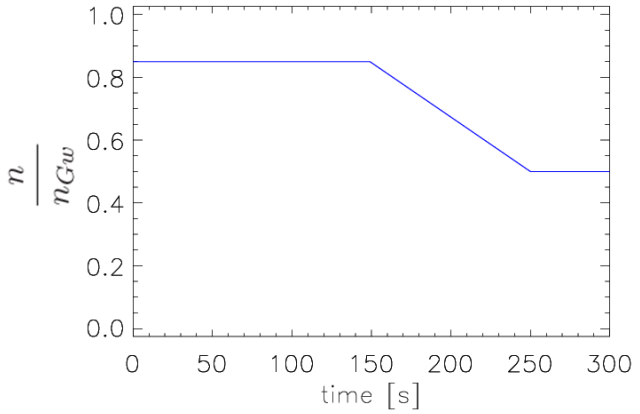


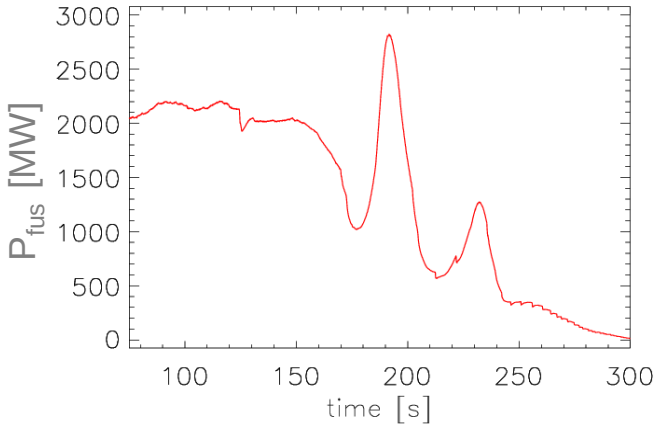


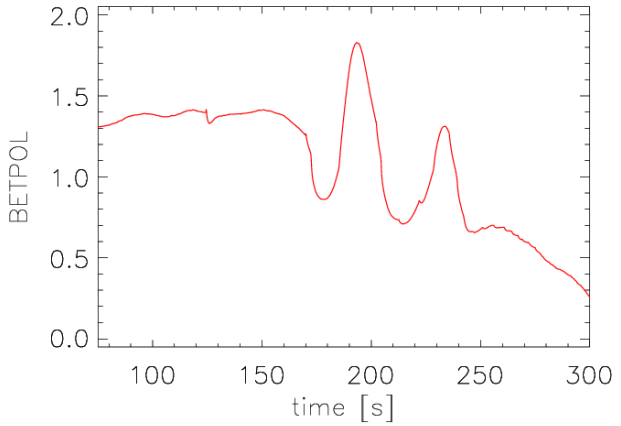


Starting case Ramp-Down

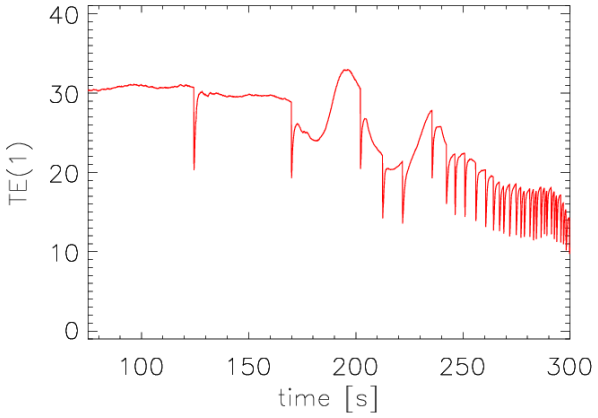


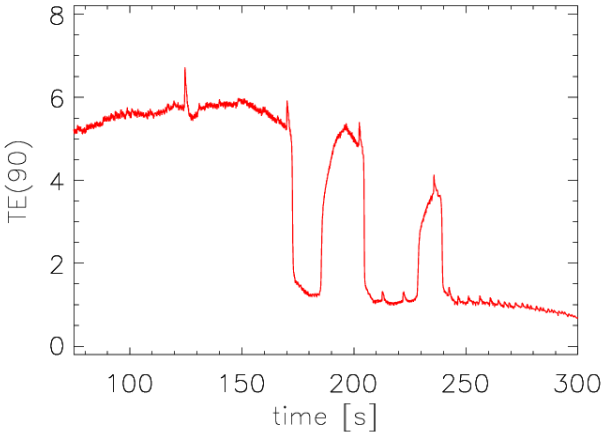


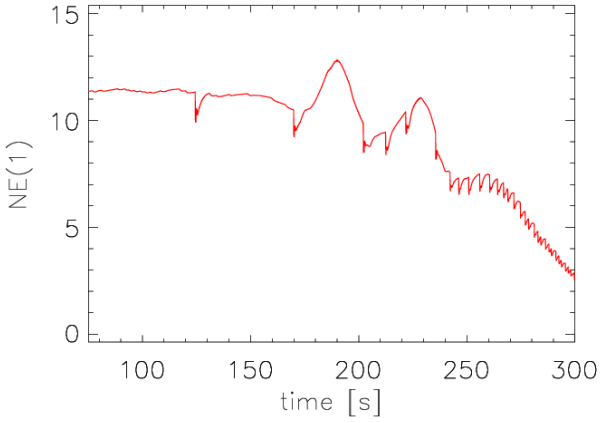


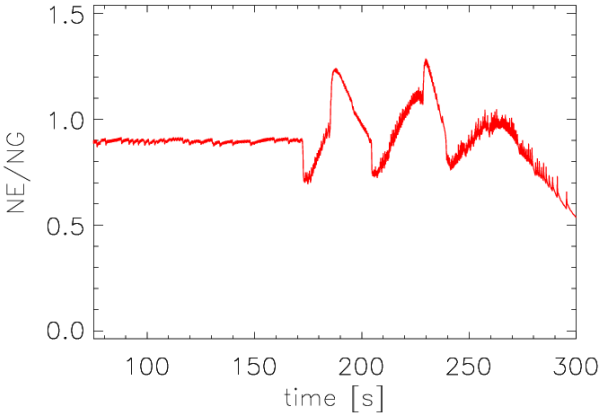


Temperature and density evolution (1)





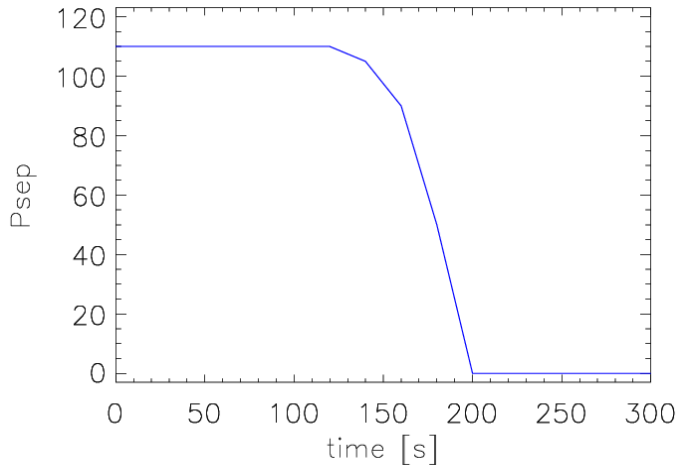


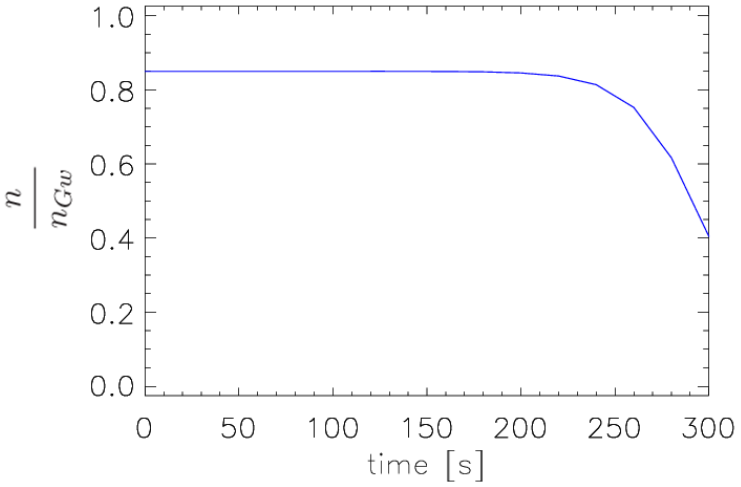


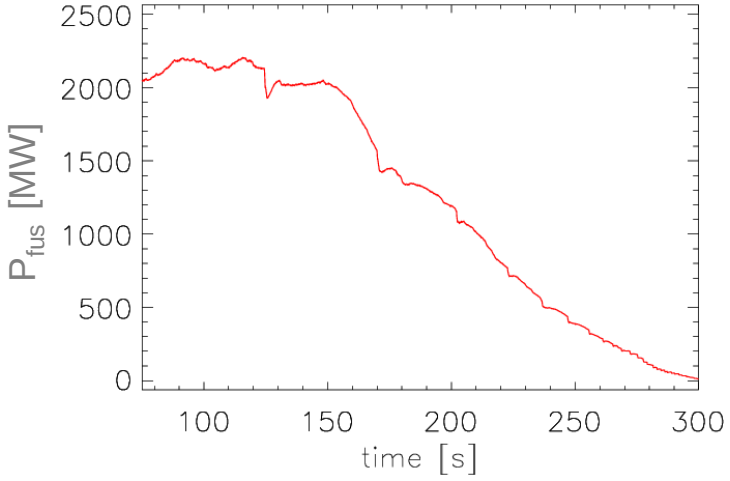
Temperature and density in the core present acceptable variations

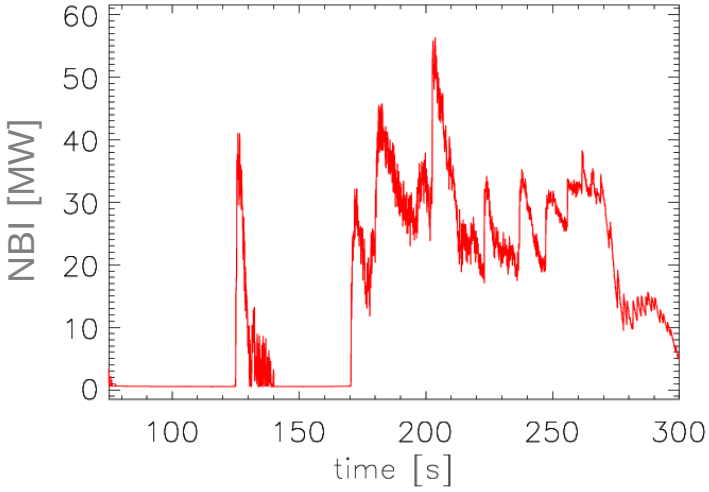
The Greenwald fraction at the pedestal top presents an overshoot

Ramp-Down optimization

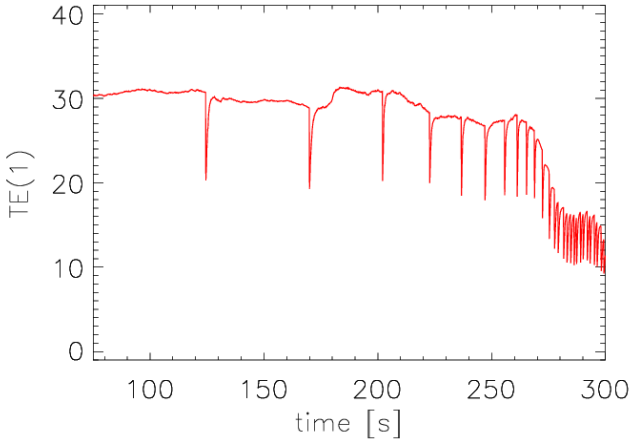


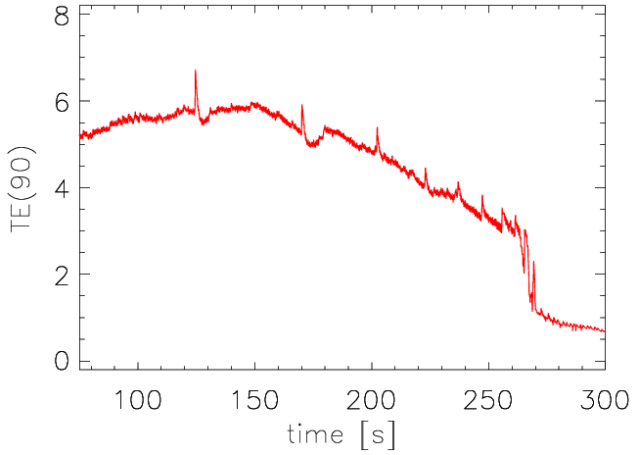


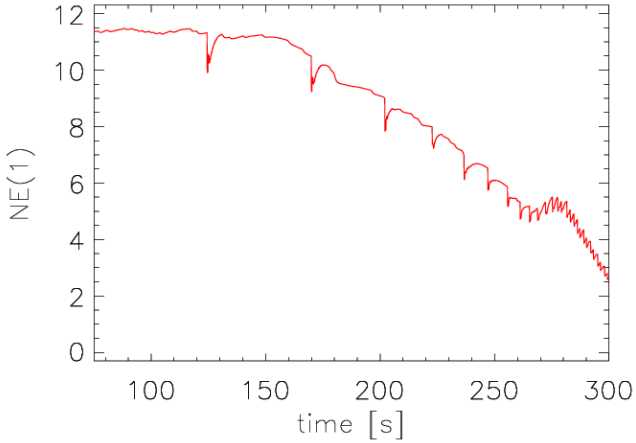


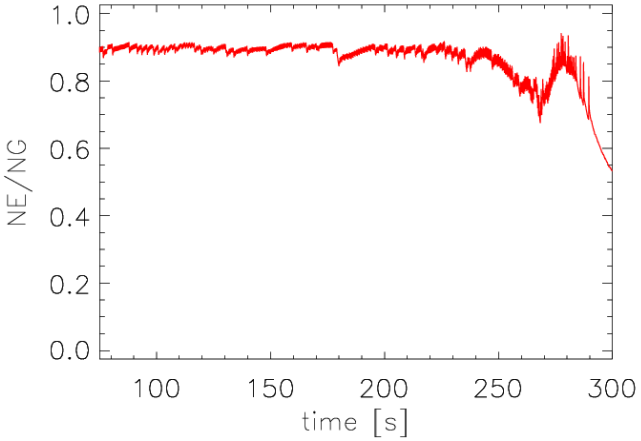


Temperature and density evolution (2)

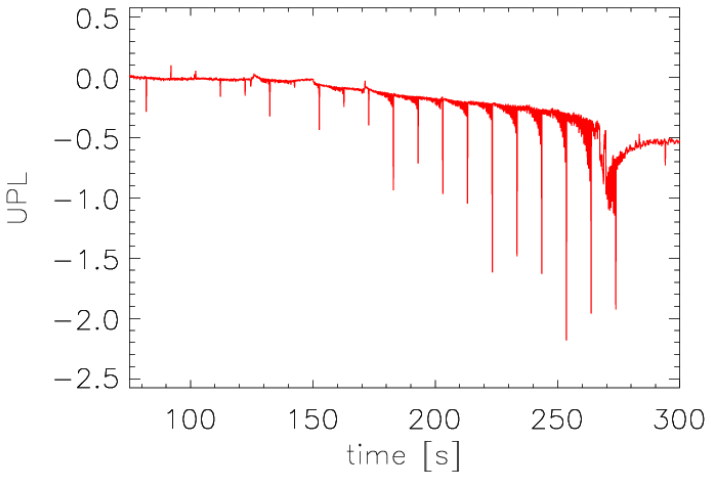


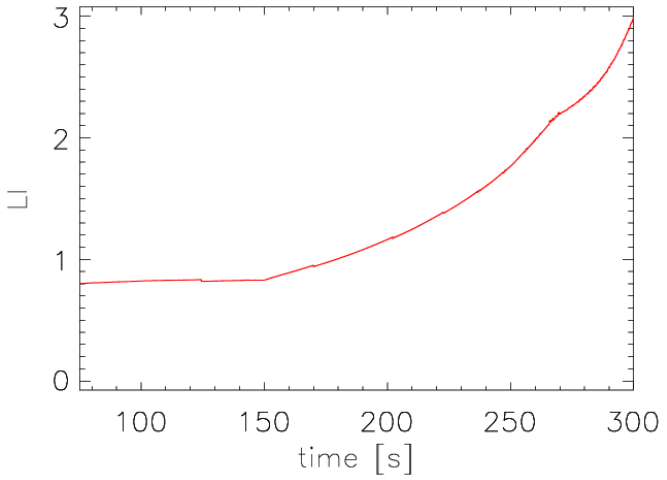






Ramp-Down optimization

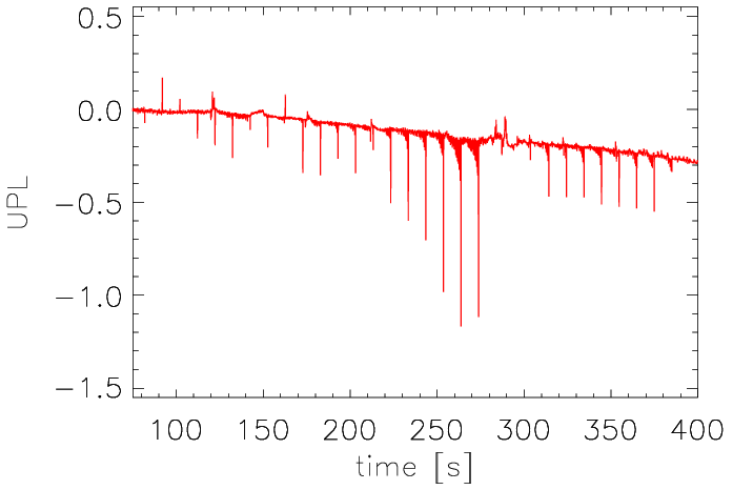


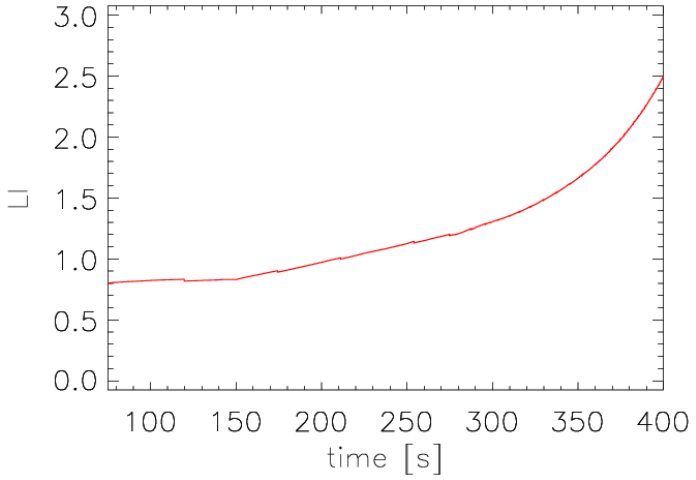


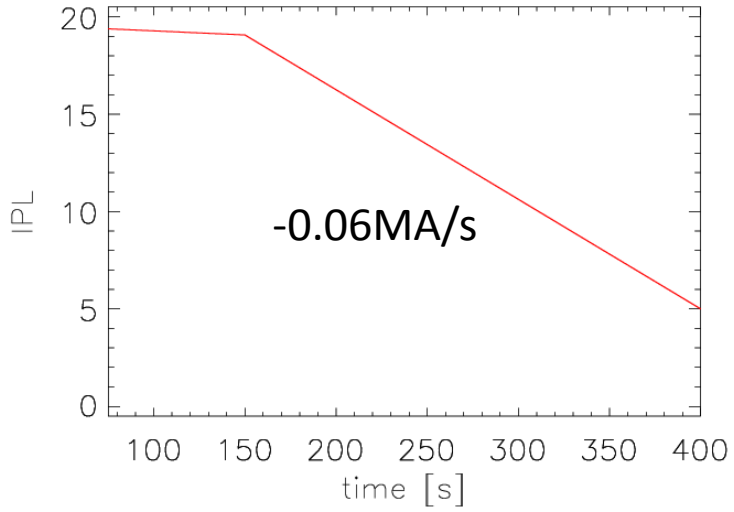
We found a negative value of the Loop voltage. This is due to the ramp rate faster than the resistive time.
In other word the inductive term is dominant with respect to the resistive term

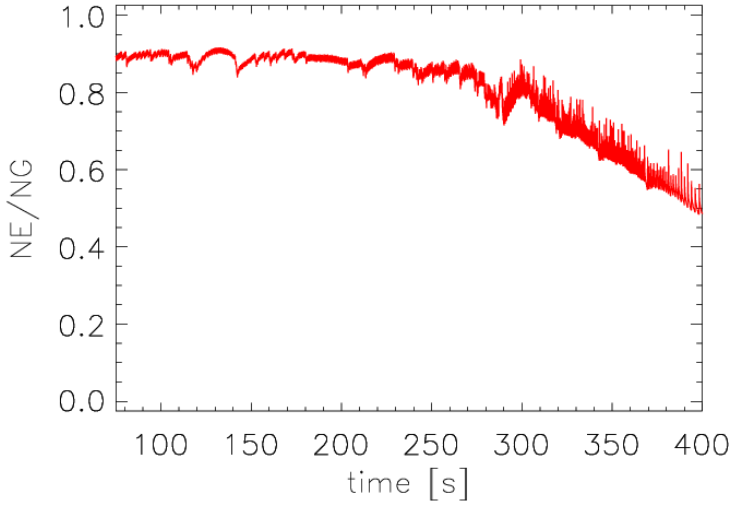
li increases too much in time

Ramp-Down *li* optimization

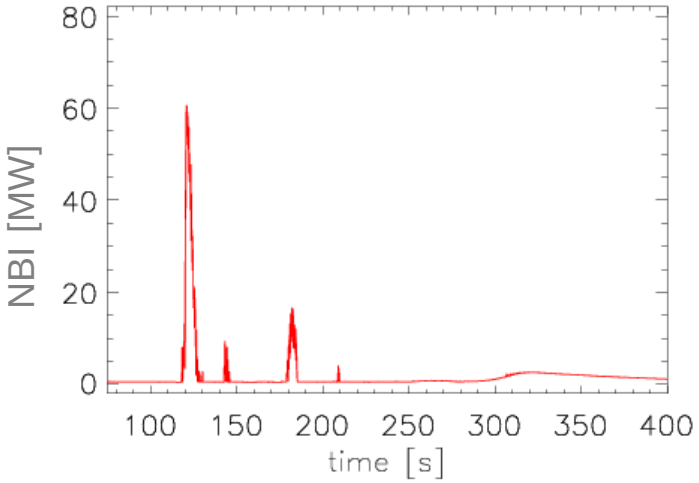


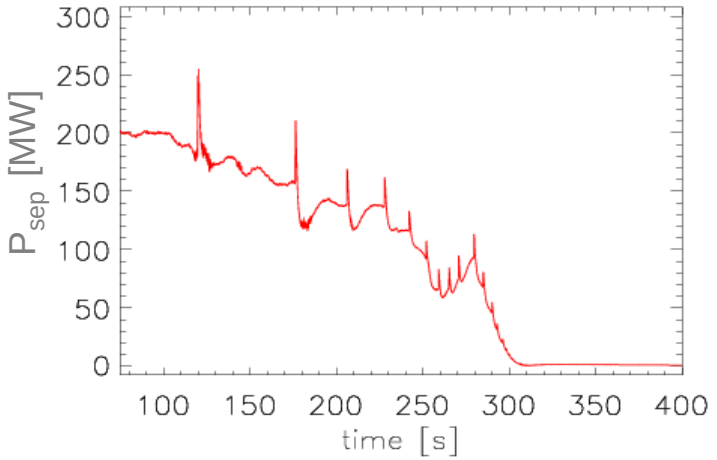


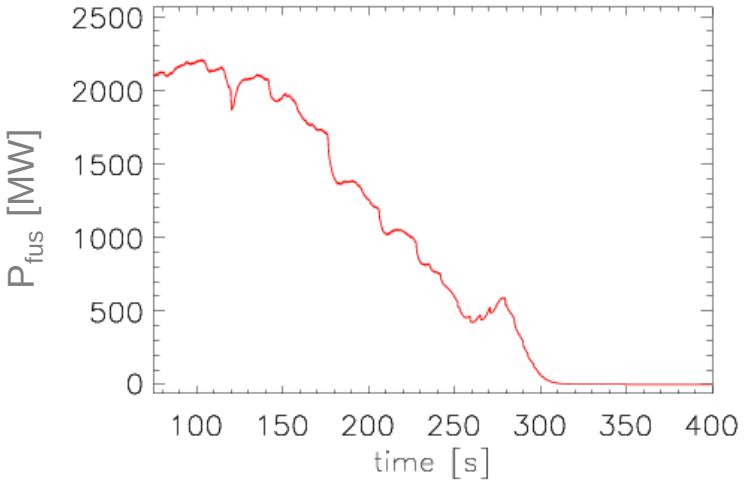


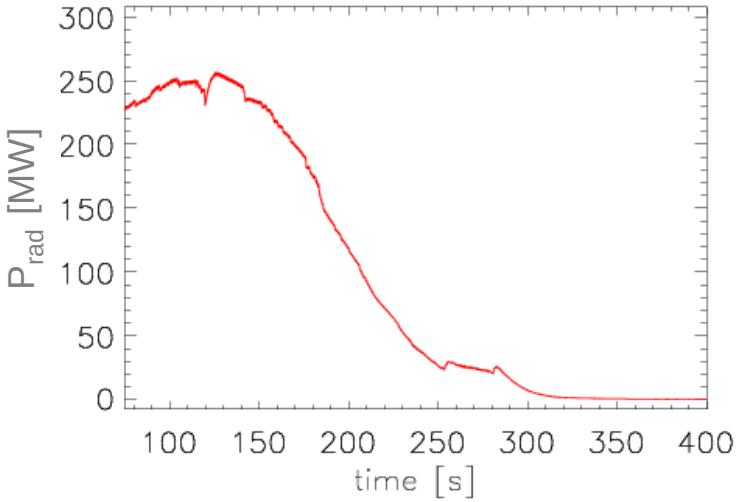


Reference Ramp-Down case

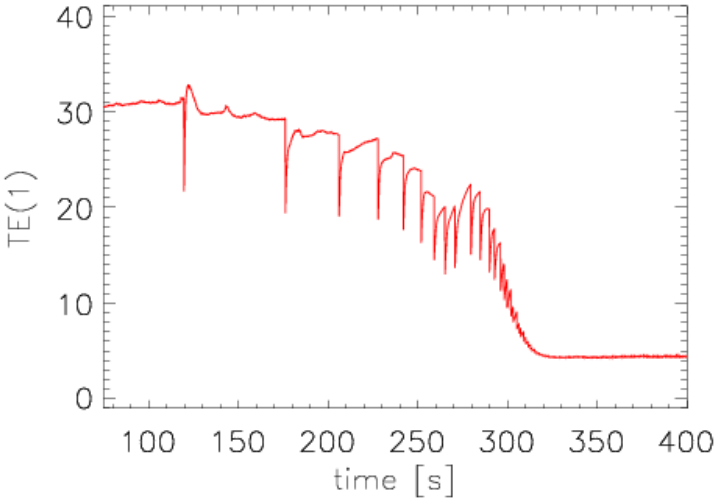


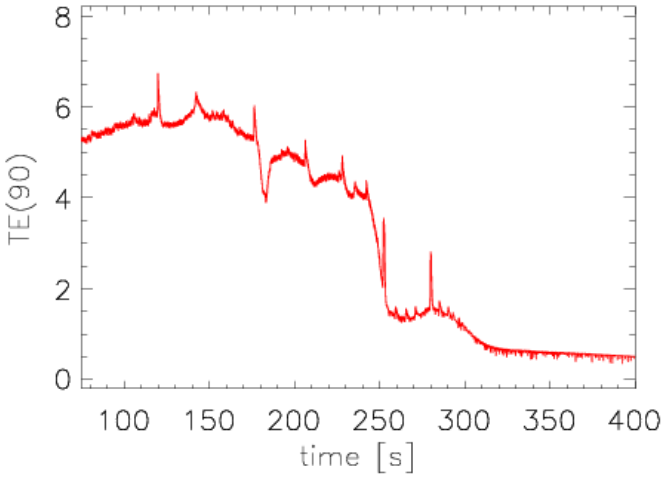


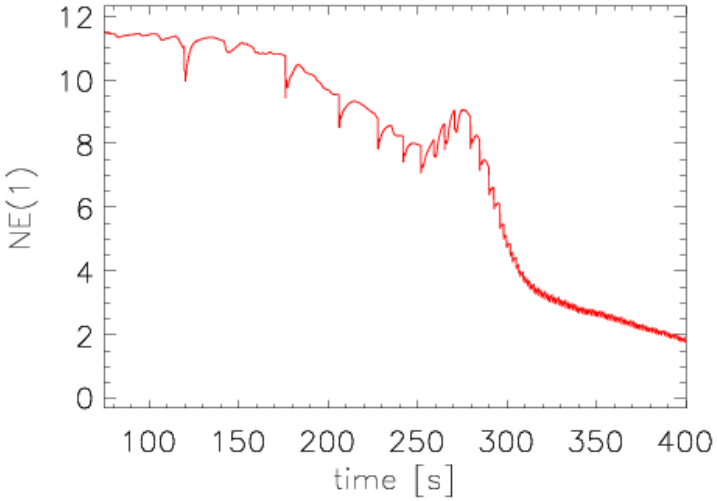


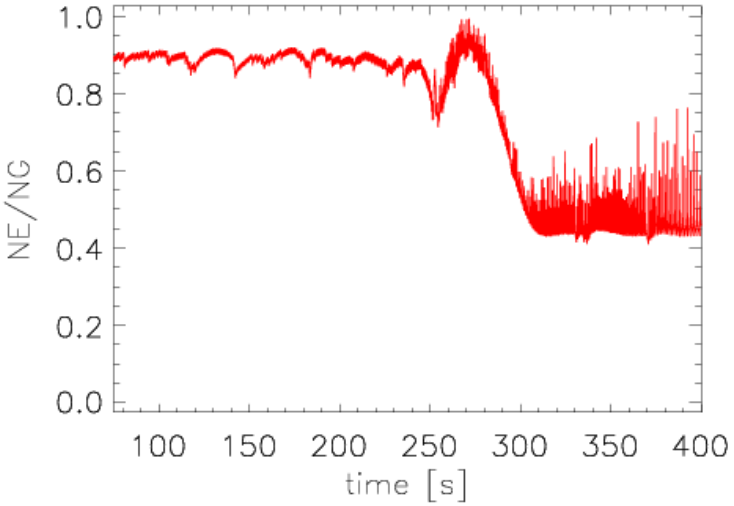


Temperature and density evolution (3)

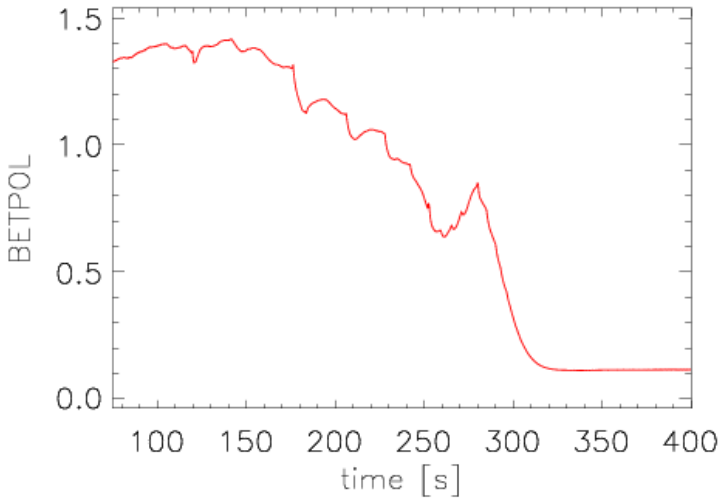


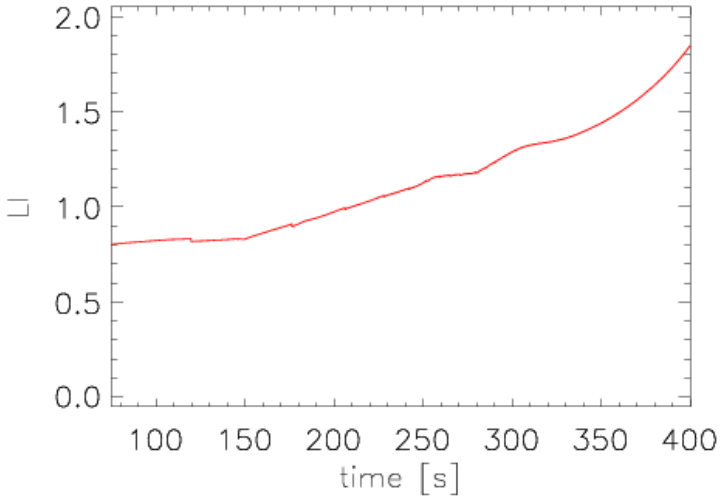


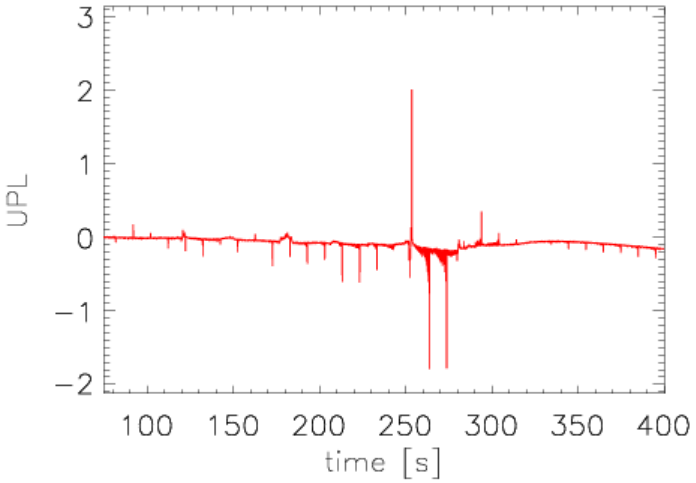




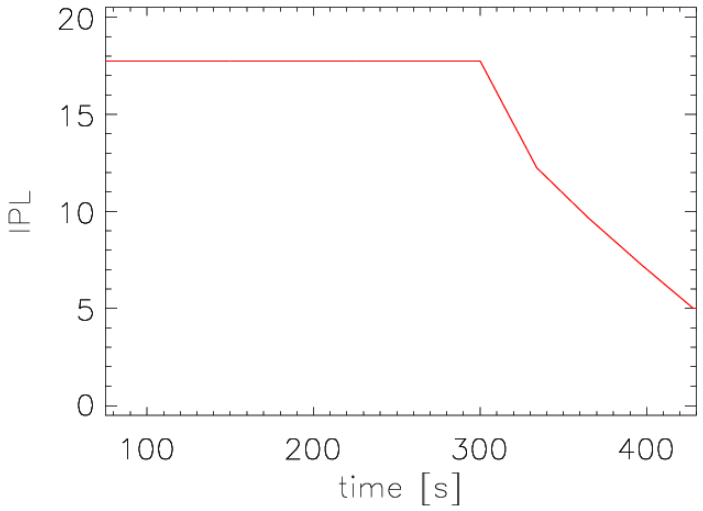
Ramp-down *li* optimization







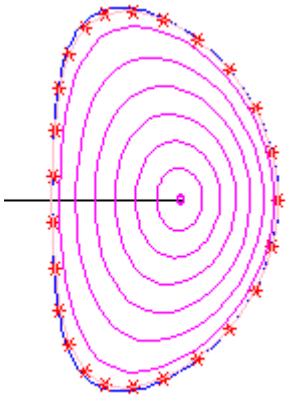
Elongation effects on Ramp-Down phase

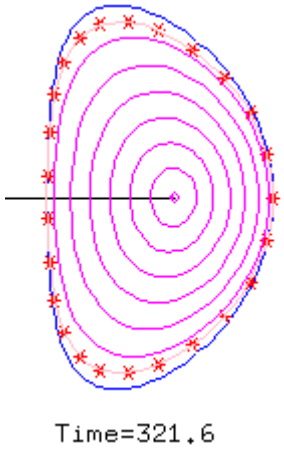


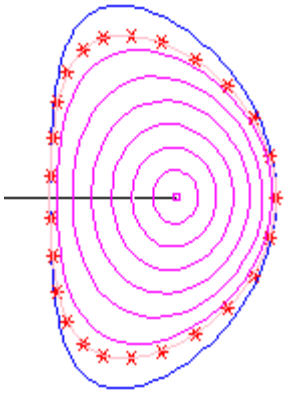
t=0	1.6699
t=300	1.6699
t=334	1.4834
t=364.7	1.4511
t=397.1	1.3899
t=427.8	1.3918

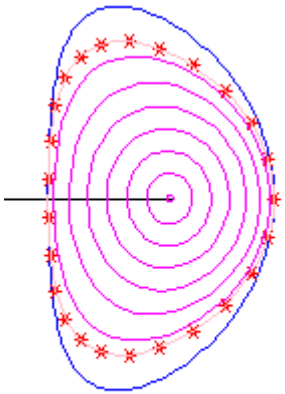
Trian = 0.35

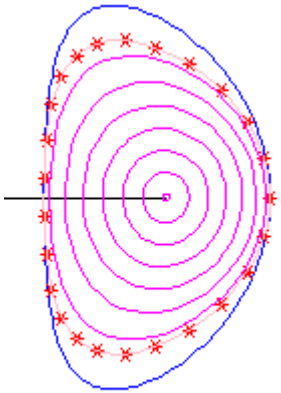
B=5.76 T
R=8.938m
r=2.95m



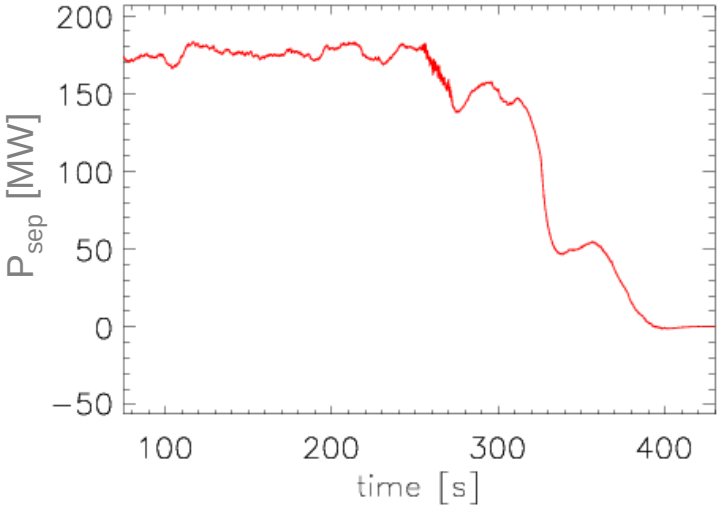


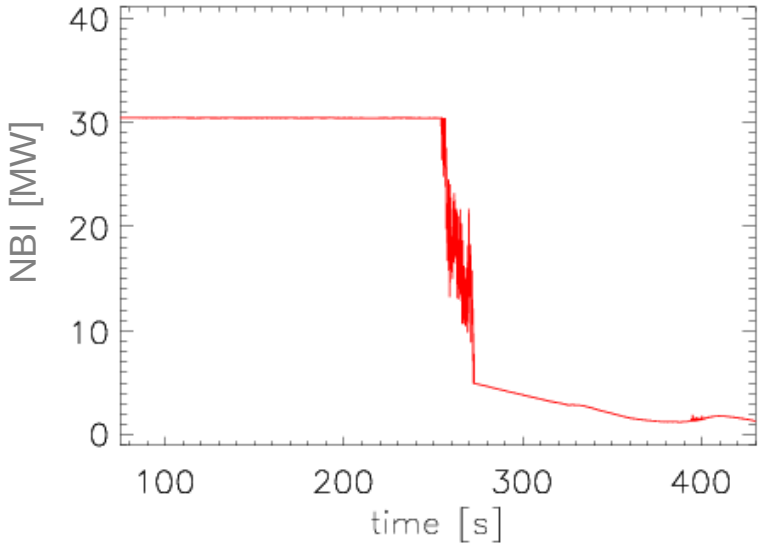


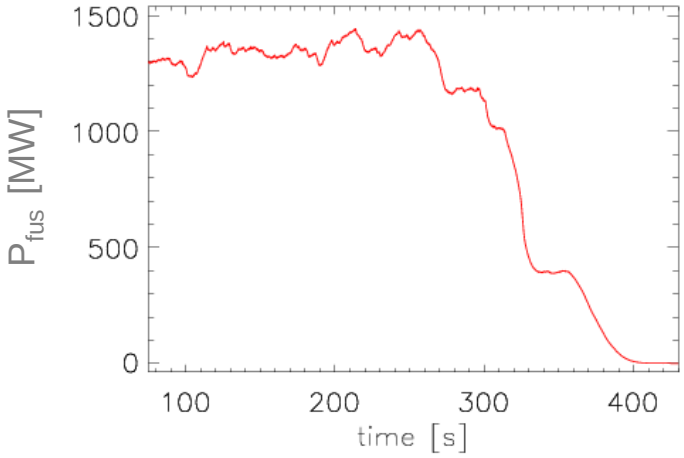


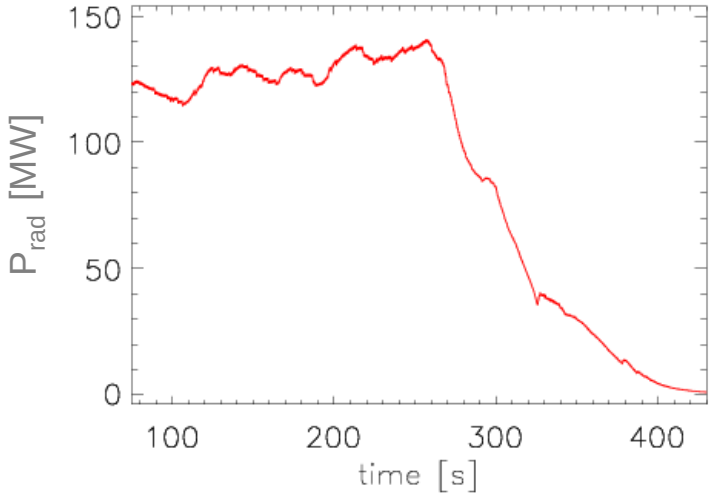


Time traces of the power

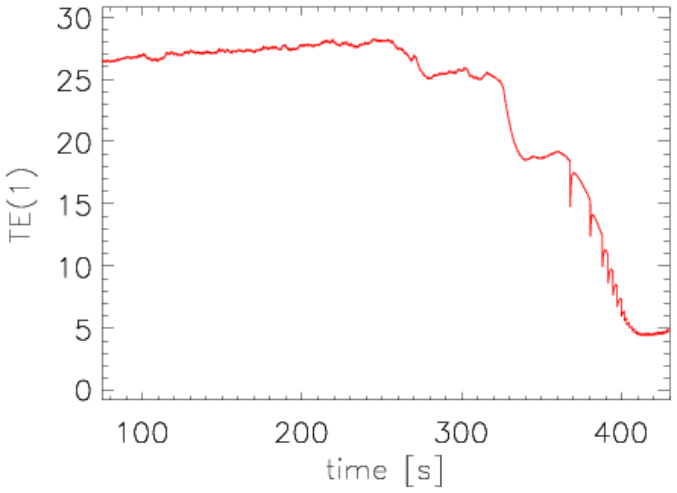


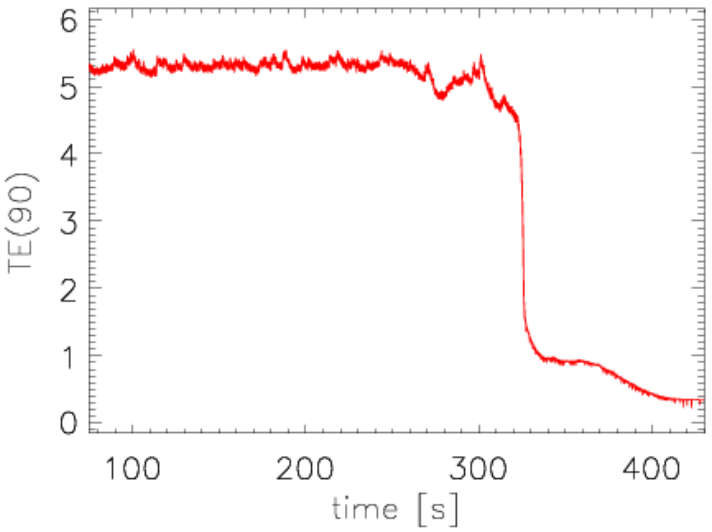


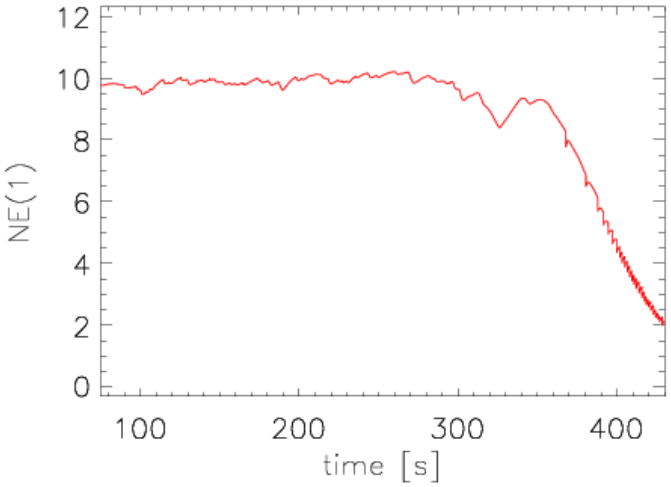


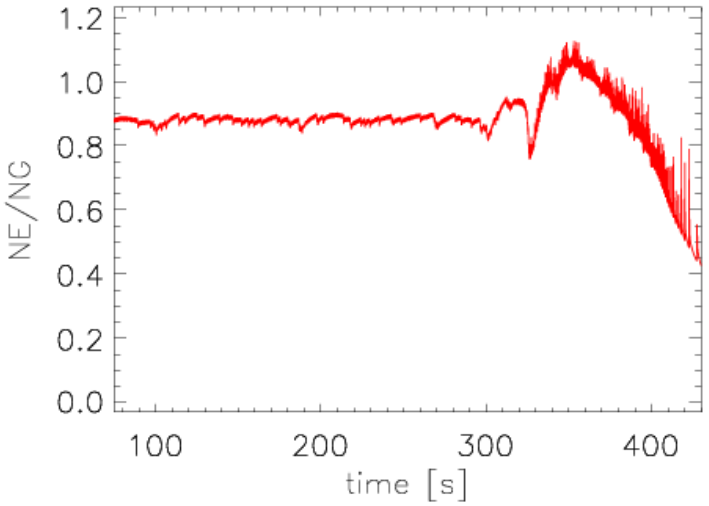


Temperature and density evolution

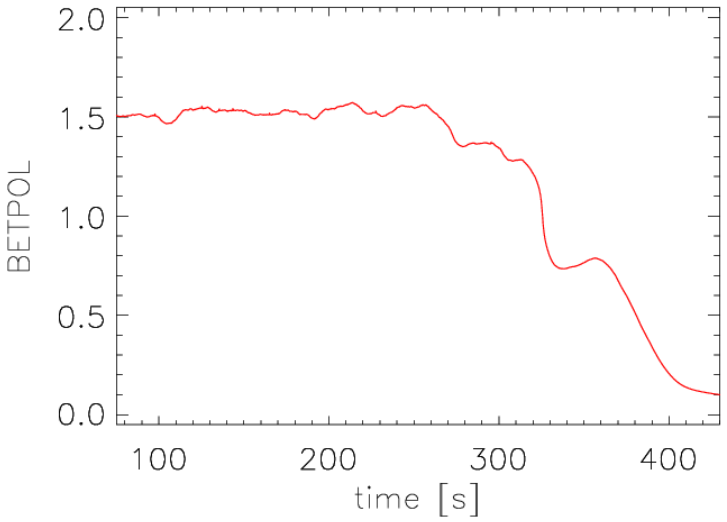


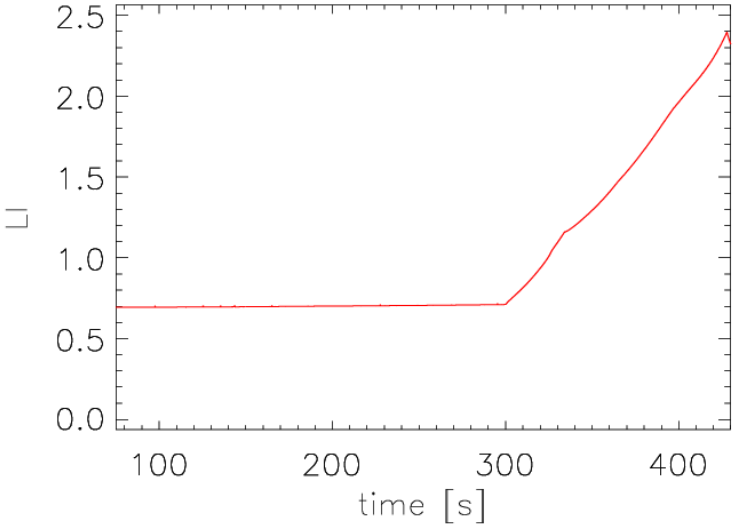


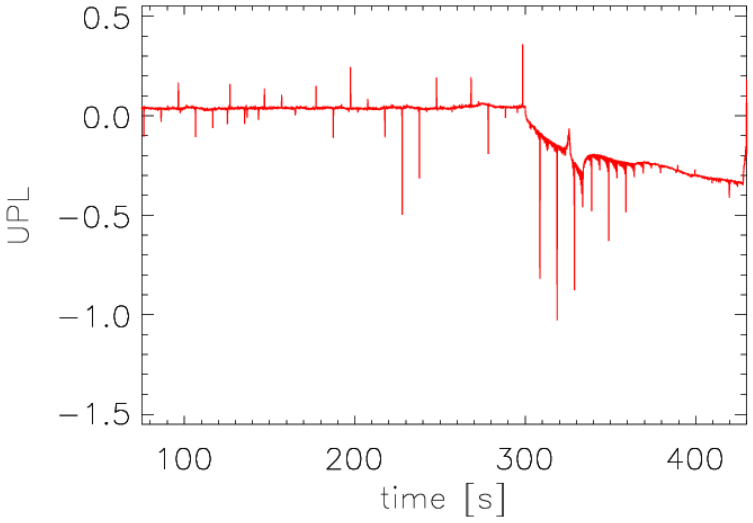


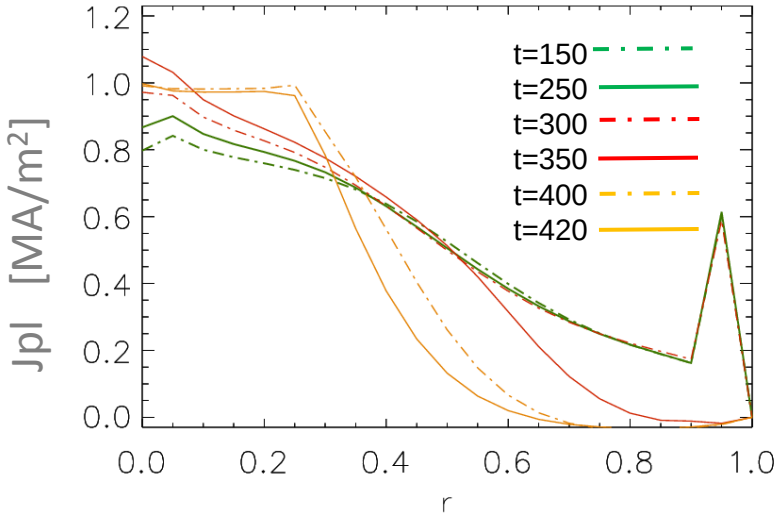


Current density evolution









Conclusions

Reference case for Ramp-Up and Ramp-Down has been provided.

This work help to understand the most critical parameters for the future improvement of Ramp-Up and Ramp-Down phases.

- Ramp-Down appears not symmetric with respect to Ramp-Up phase.
- Overshoot in Ramp-Up phase can be avoided by selecting a correct injection rate of auxiliary power.
- *li* represents the most critical parameter concerning the vertical stability and can be controlled by means of:
  - ✓Reduction of the current ramp rate
  - ✓Change of the elongation