Ramp-up phase investigation for DEMO

F. Palermo, E. Fable et al.

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KDI#1-8 review meeting

22-24 October 2019, Garching, Germany

Ramp-up scenarios

The initial ramp-up and termination ramp-down phases of discharge have the same importance of the flat-top phase in tokamak operations

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

Try to optimize according to following recipe:

- ❑ Avoid P_{sep} increasing too much > 200 MW
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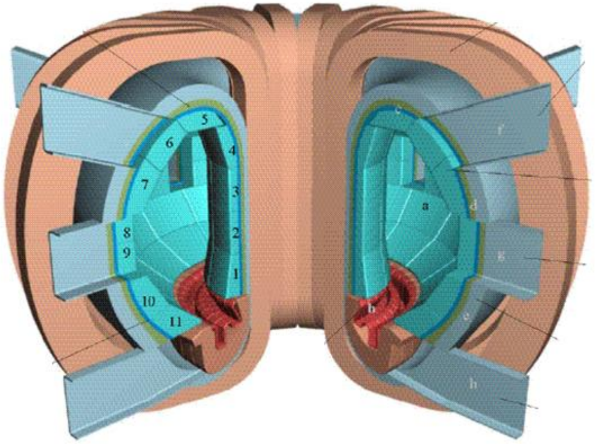


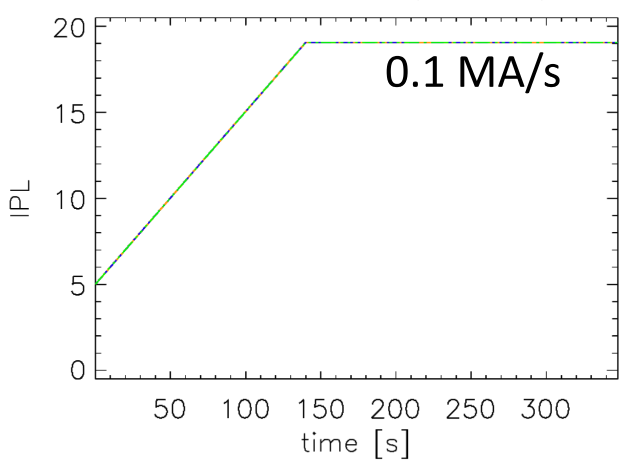
Ramp-up scenario with CREATE

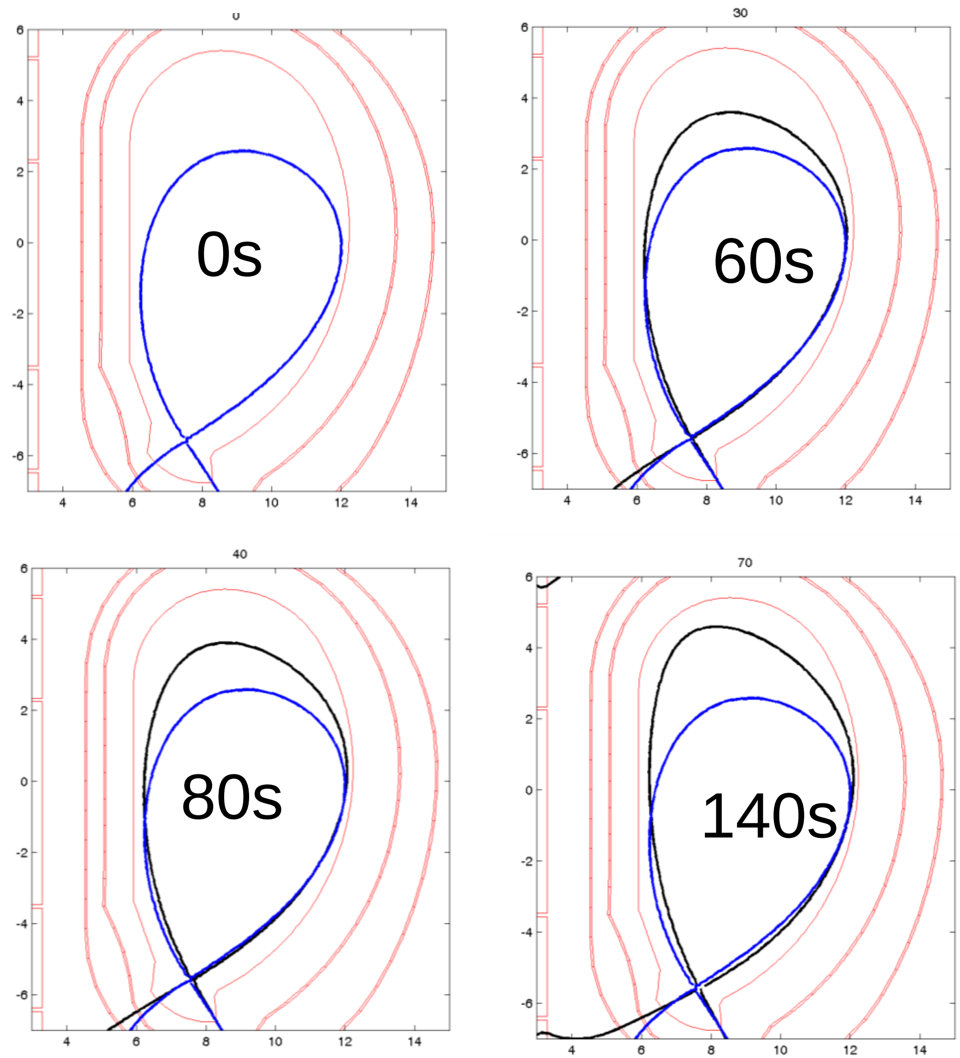
✓ The evolution of a plasma equilibrium geometry has to be taken into account in the case of simulations of entire discharges because strongly influences the plasma profiles.

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

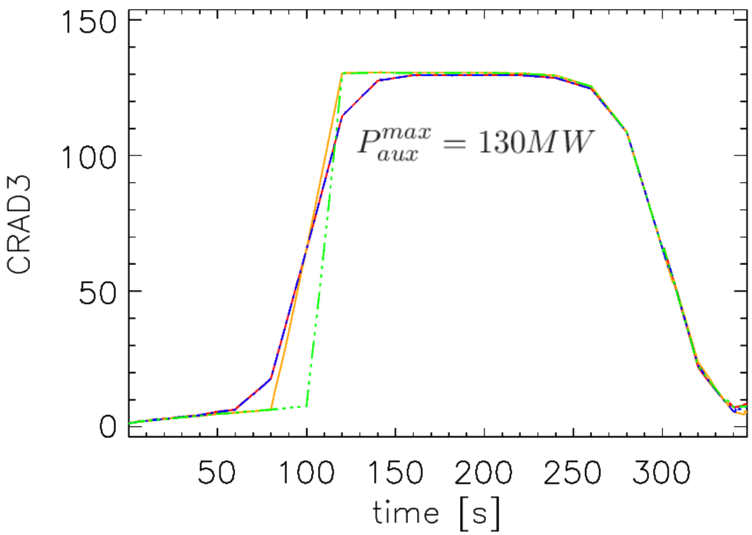
❑ Equilibrium snapshots with Plasma grows on a fixed X-point from CREATE

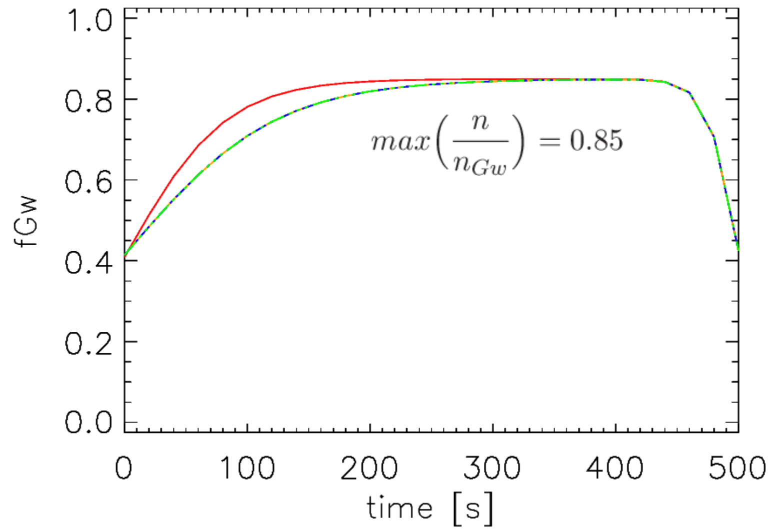
❑ Used CREATE value for Ip Ramp rate





Time traces used to optimize





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

Time at which the growing rate is maximum

Temporal whidth in which the function increases

case	$t_{P_{Ru}}$	$L_{P_{Ru}}$
Green	110	1
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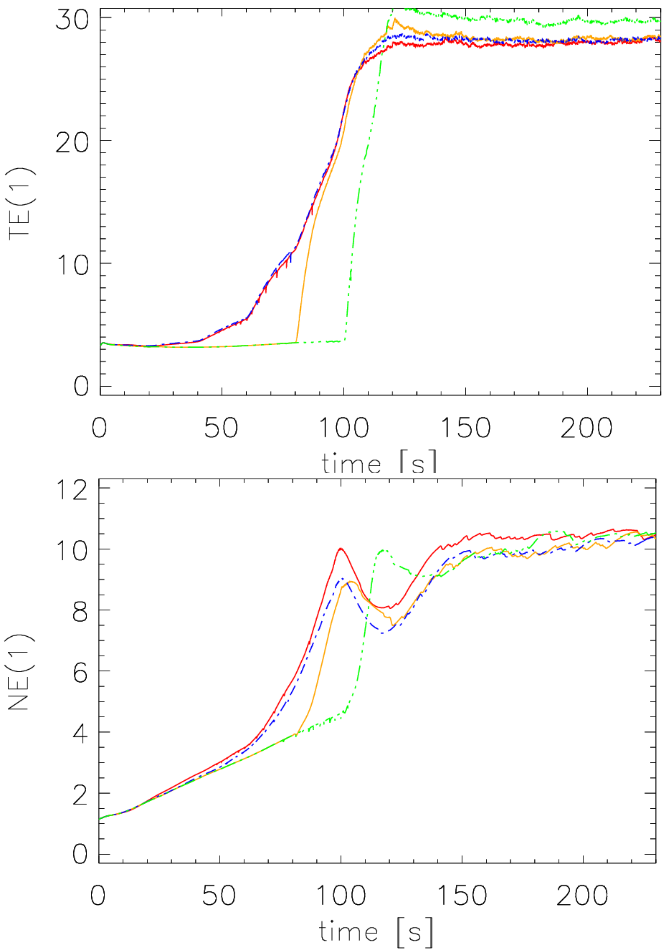
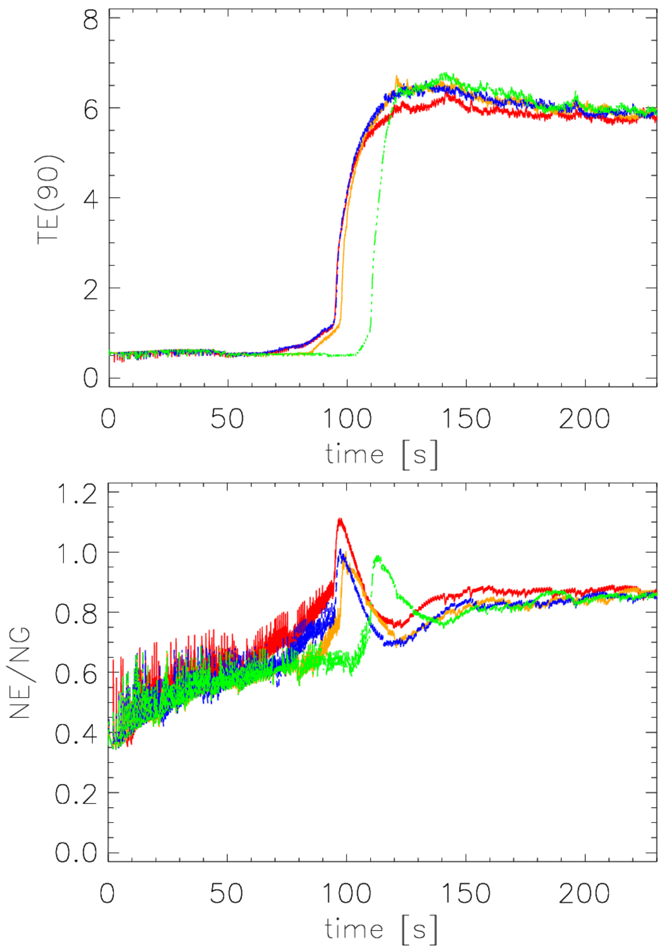
Temperature and density evolution



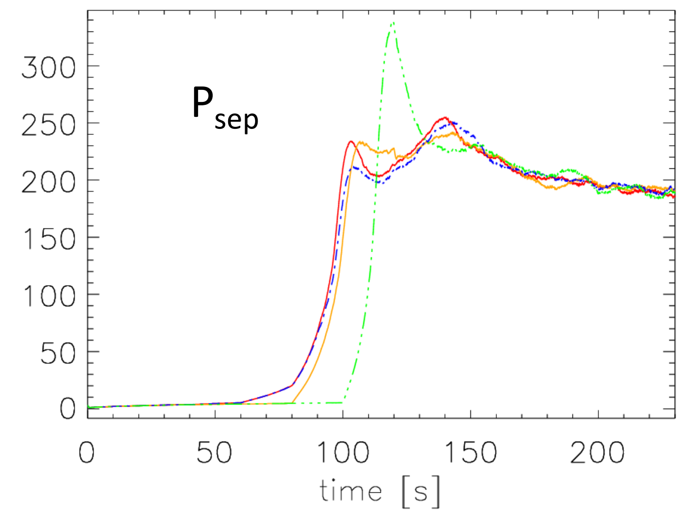


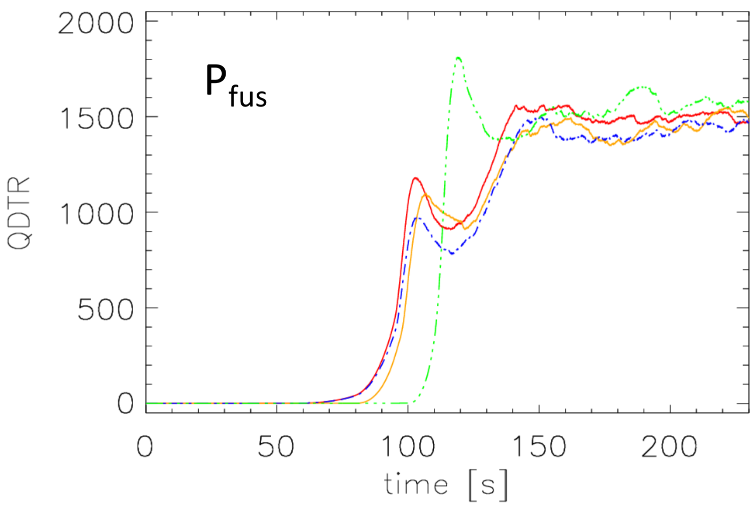
The temperature and density values in the core are indipendent of the gradient used to reach the saturation state

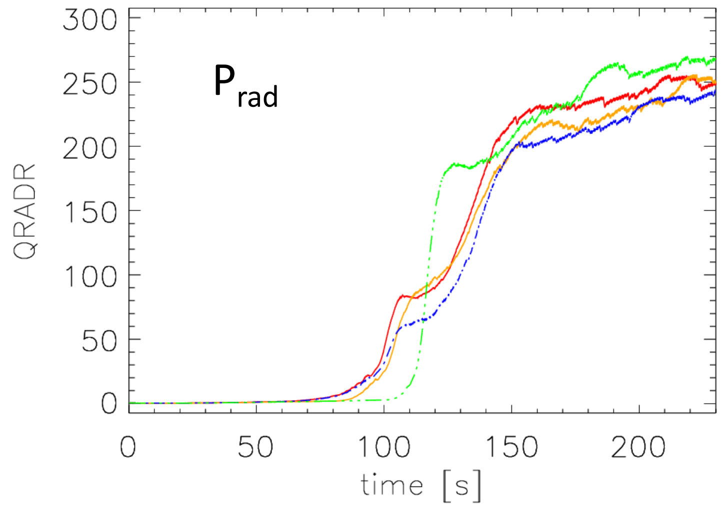
The Greenwald fraction at the pedestal top presents an overshoot in particular for the red case state

Calculated Powers

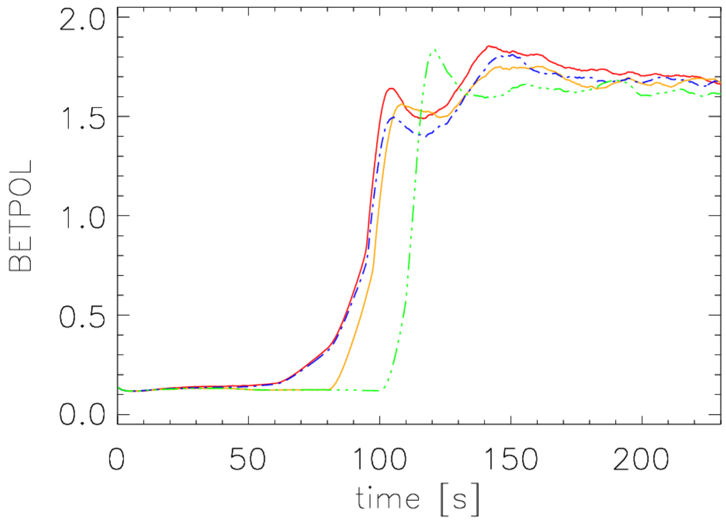
- ✓ Try to maintain Psep≈200 MW and not produce overshoots (green curve)
- ✓ P_{fus} smoothly increasing
- ✓ P_{rad} dominated by Xe



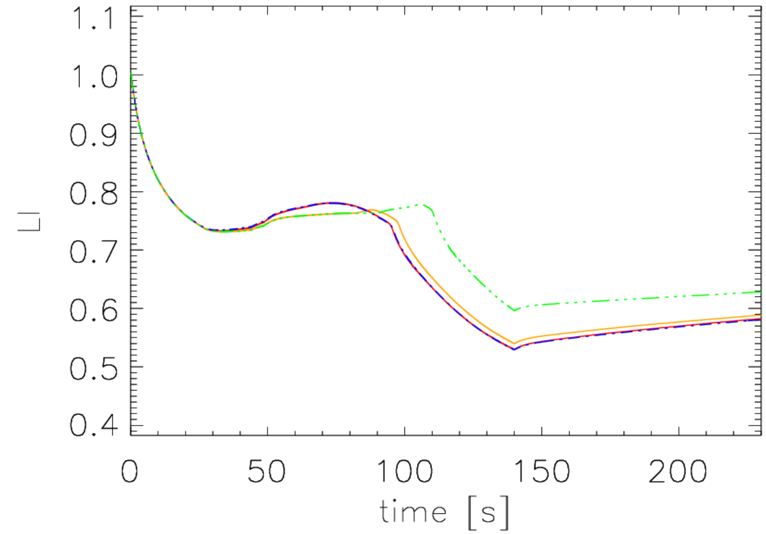


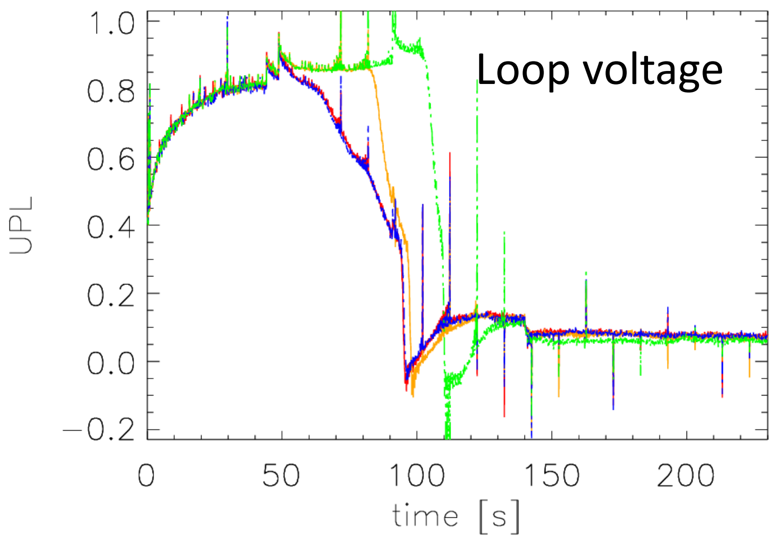


Plasma parameters



Internal inductance





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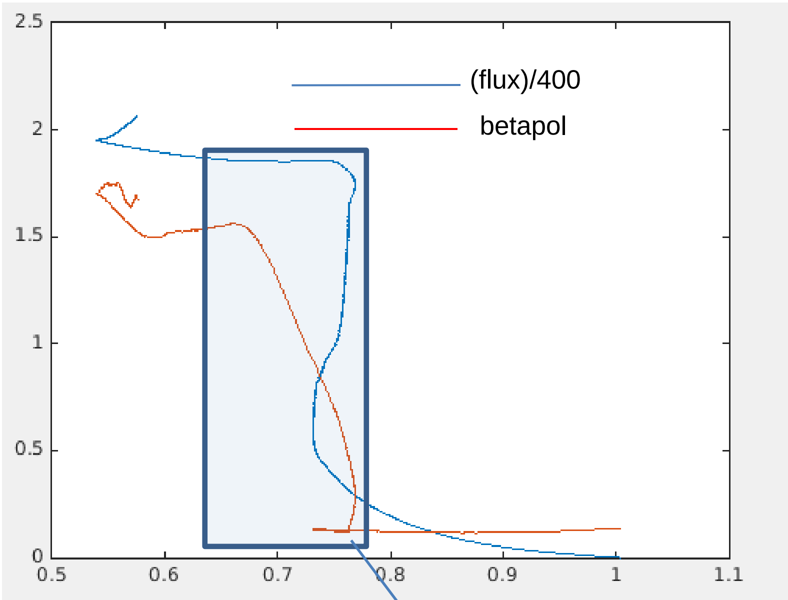

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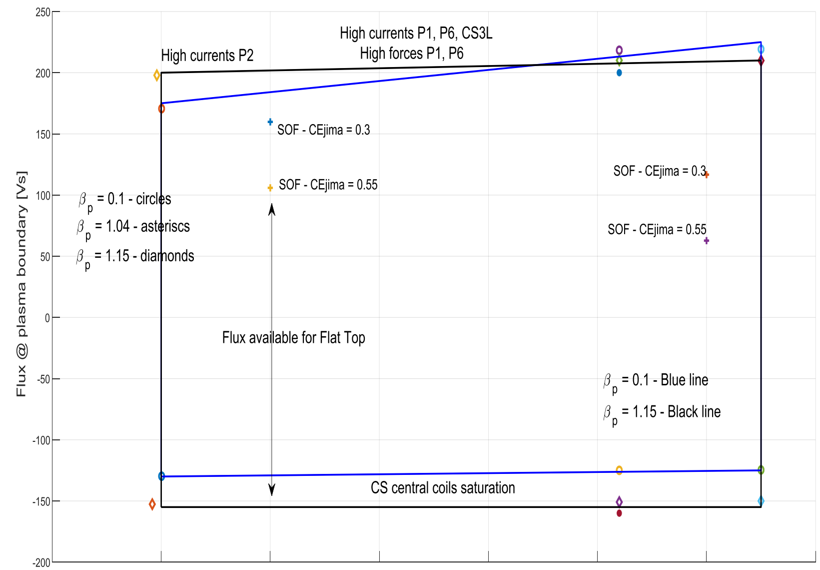
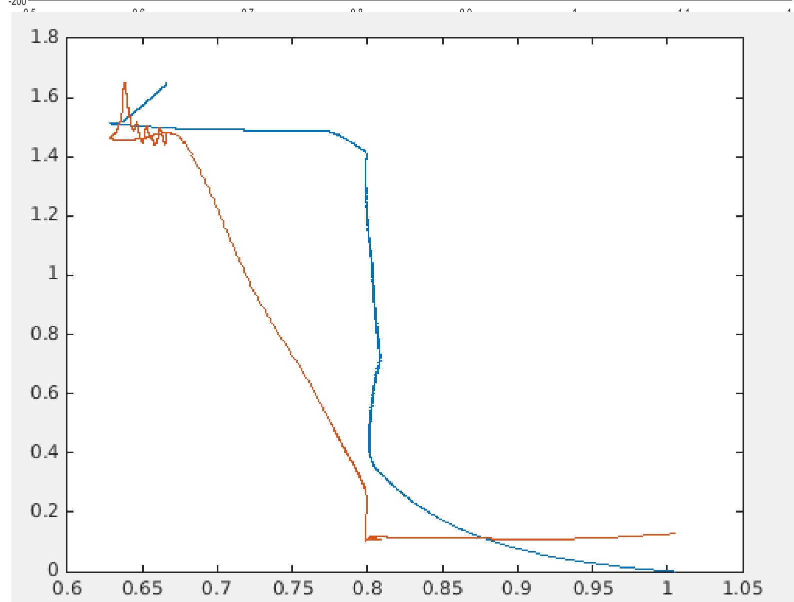
L-H transition





Discussion on ramp-up optimization

✓Still a lot of room of improvement (adding more FF traces like Xe and gas puff)

✓ It seems that it is not difficult to find combinations that satisfy many constraints

✓ Main unknown: evolution of transport coefficients around L-H transition and early flattop due to

> q profile still not fully relaxed, dependence of transport on safety factor vital for prediction (try with TGLF later on)

The 30-30-70 recipe

✓ Additional preliminary studies done with TGLF show that the following recipe could work to have simultaneous ramp-up and flat-top perturbations control (up to some limit):

- ❖~ 30 MW of unspecified source in the core (r/a < 0.3)
- ❖~ 30 MW of EC power at the q=2 surface for NTM control (more precise number coming soon from O. Kudlacek and collaborators)
- ❖~ 70 MW of EC power close to pedestal top (r/a ~ 0.9) for instability control (provide some safety margin in case of W flake and H_2O influx)

✓ This is assuming a cap of 130 MW of total installed power

✓ Some or all of it can be used for L-H transition and H-L control

Conclusion and Outlook

✓ We have started coupling with magnetic control. This will probably result in more stringent requirements on diagnostics.

✓ Most problematic points:
- Greenwald limit: optimize scheme
- Psep > PLH: optimize margins
- Detachment: find most robust scheme

✓ Model improvement:
> Er-based L-H transition, going on at AUG
> Actuators models: RABBIT for NBI available, still to be tried, TORBEAM not yet used
> Validation on present machines: models are calibrated based on present knowledge

Perturbation analysis and RU/RD phase investigation for DEMO

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Final Meeting KDI#1 and #8 -2019

10 December 2019, Garching, Germany

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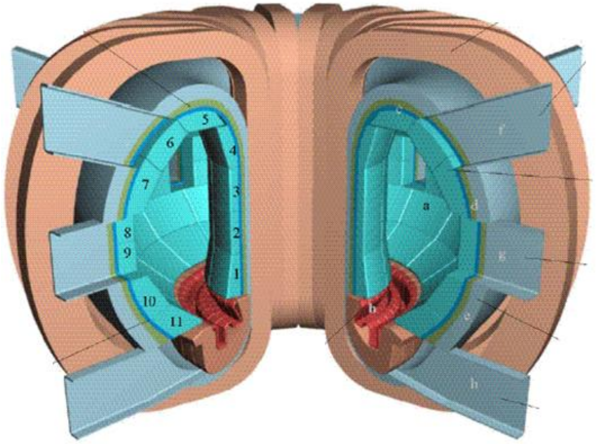

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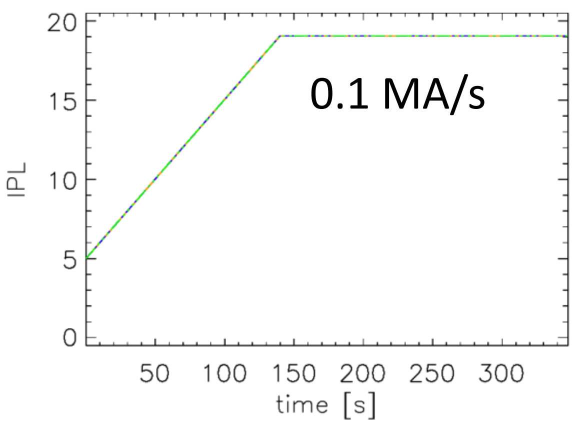

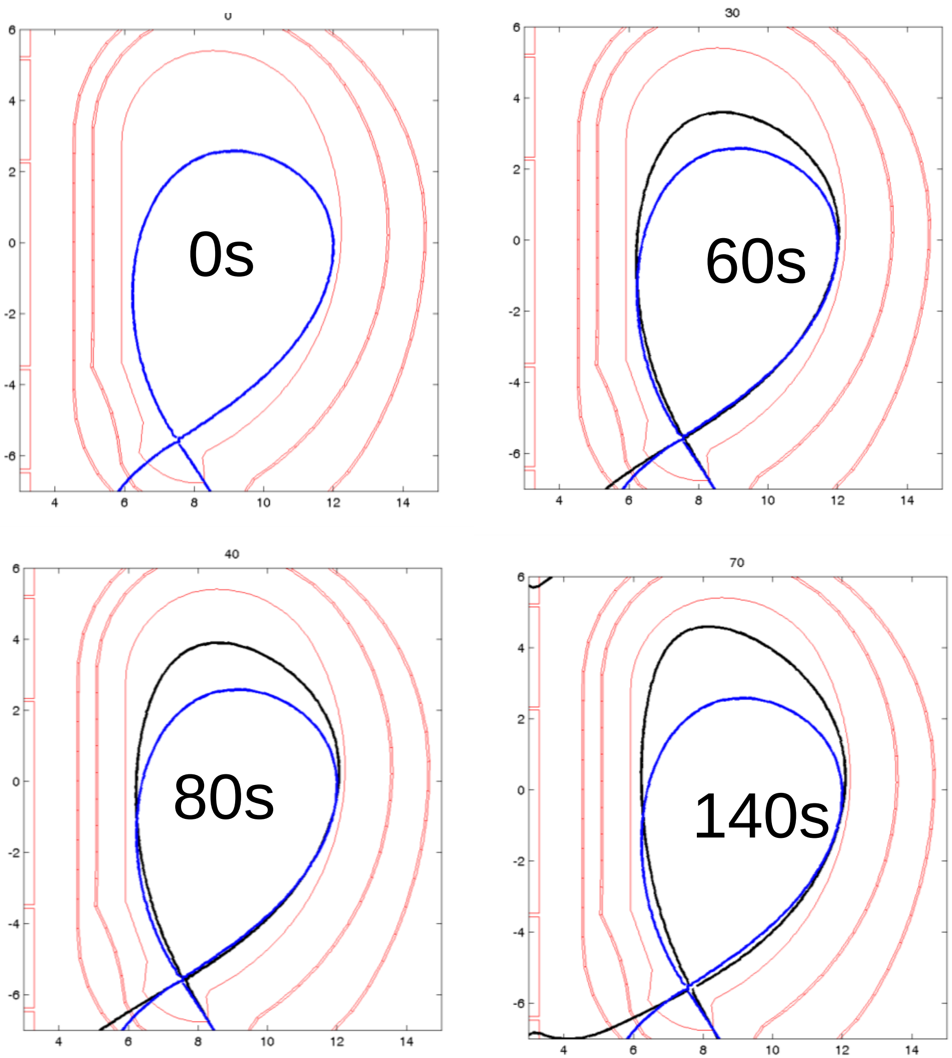

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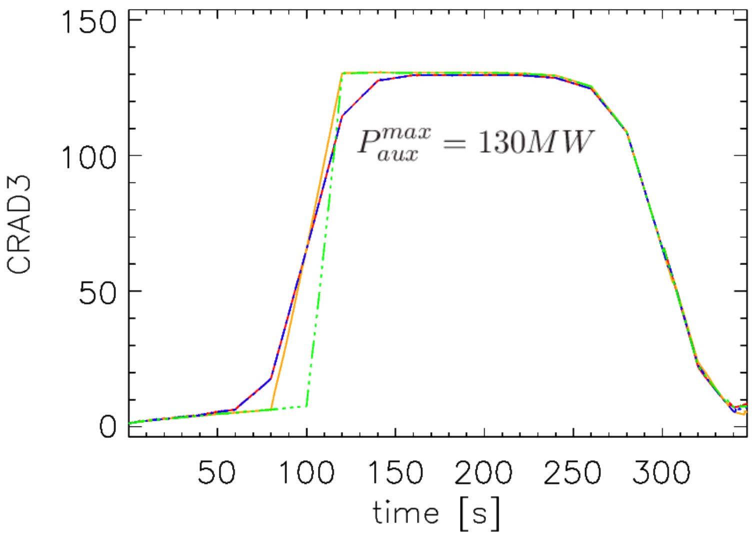

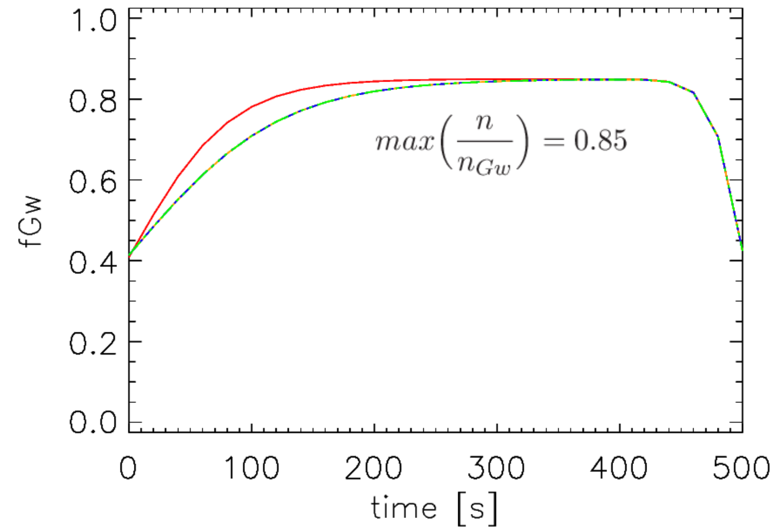

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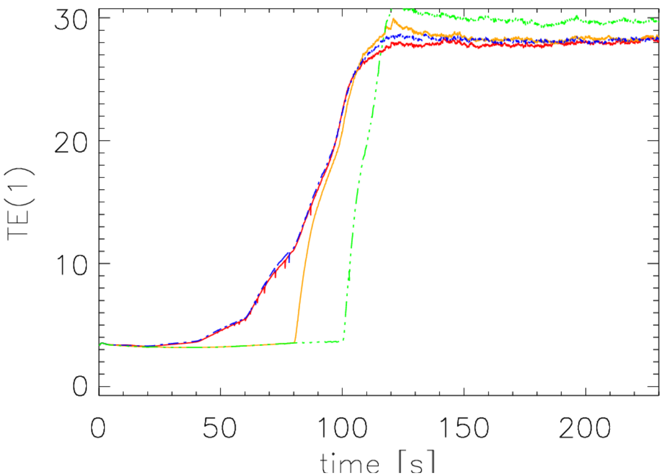

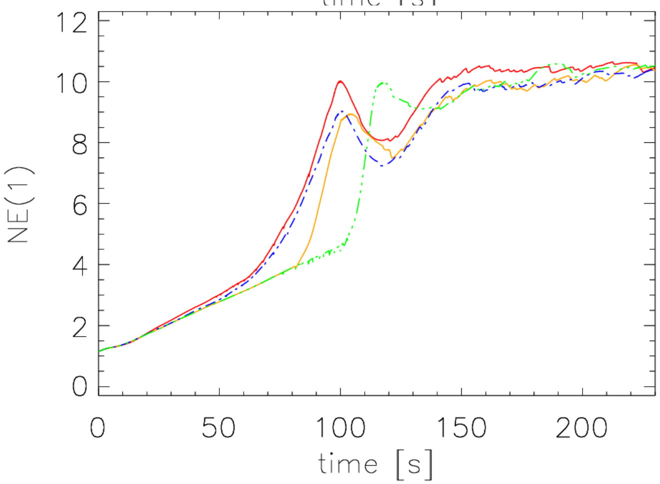

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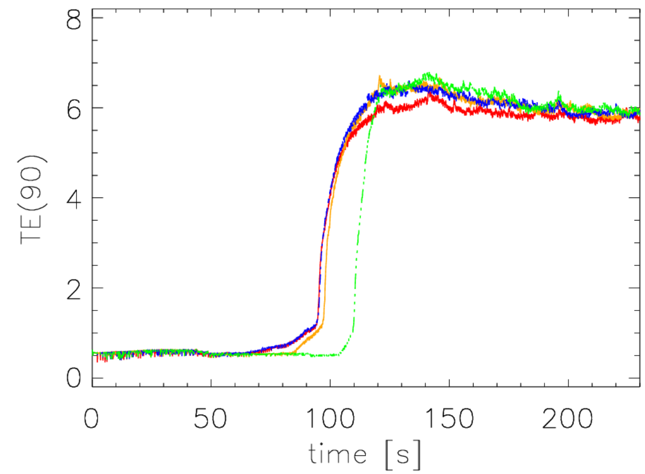

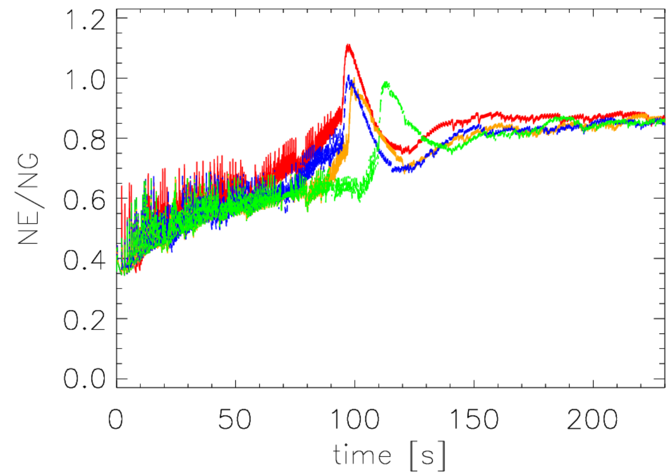

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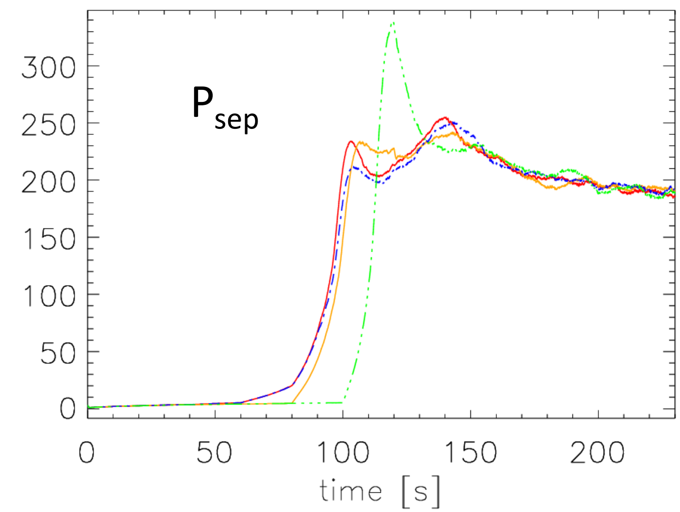

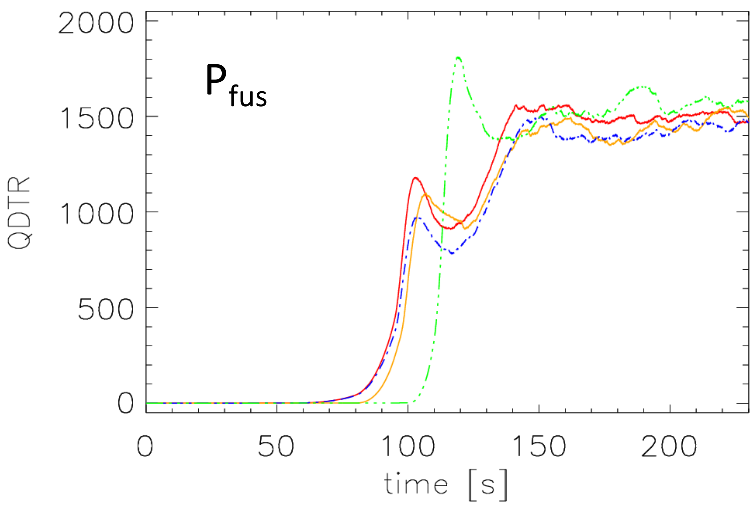

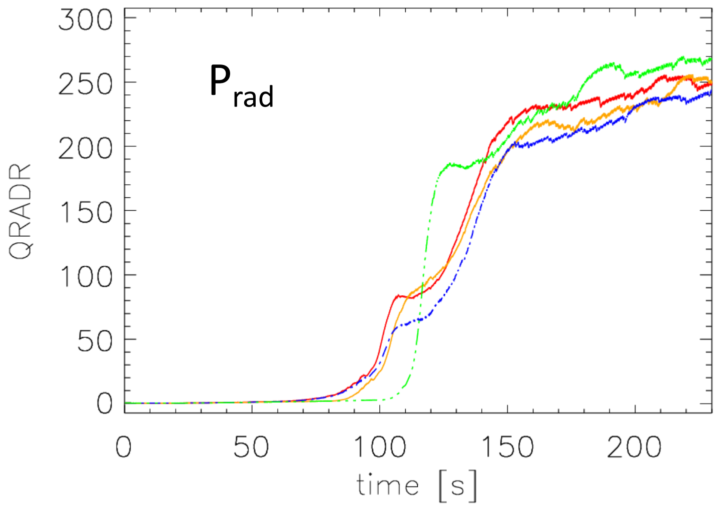

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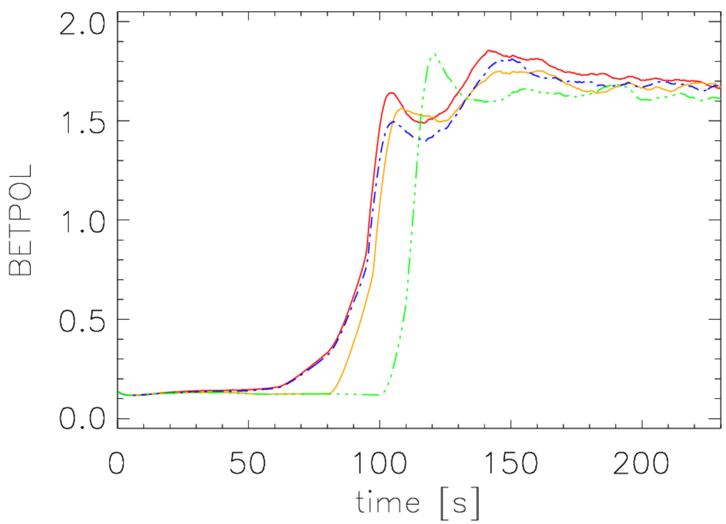
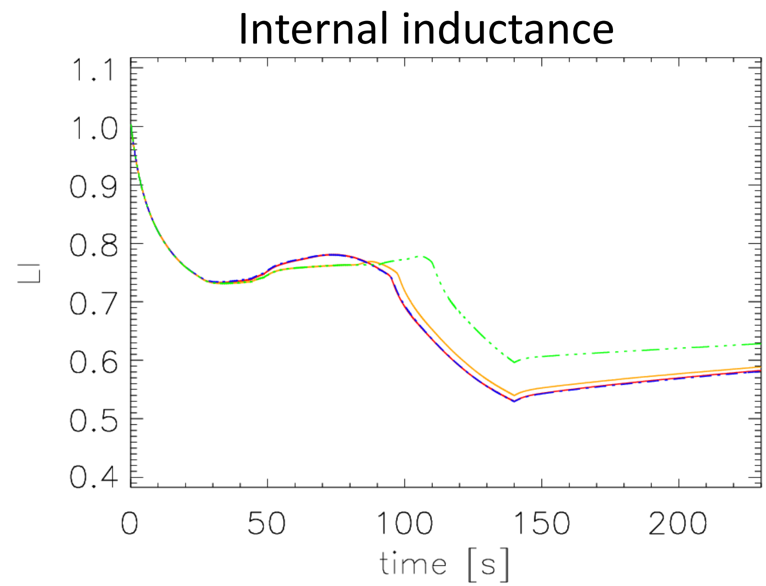
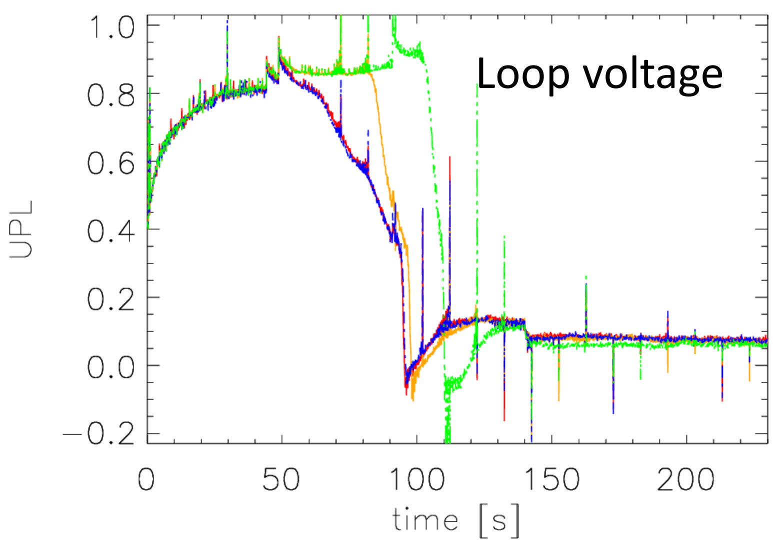
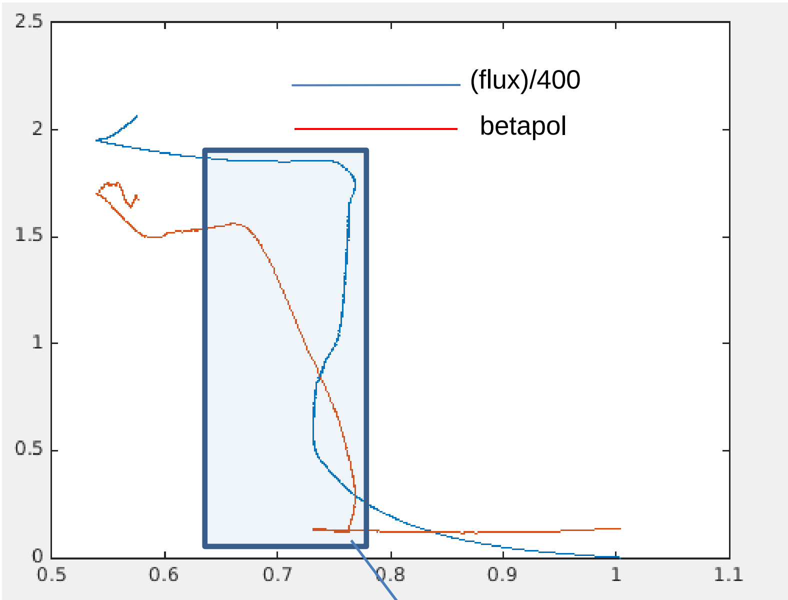






Case	Red	Green	Orange	Blue
Max β_{pol}	1.86	1.83	1.75	1.81
Max P_{sep} [MW]	255	338	241	250
N/ngw	1.14	0.98	1.0	1.01
P_{fus} [MW]	1560	1812	1546	1500

Plasma parameters



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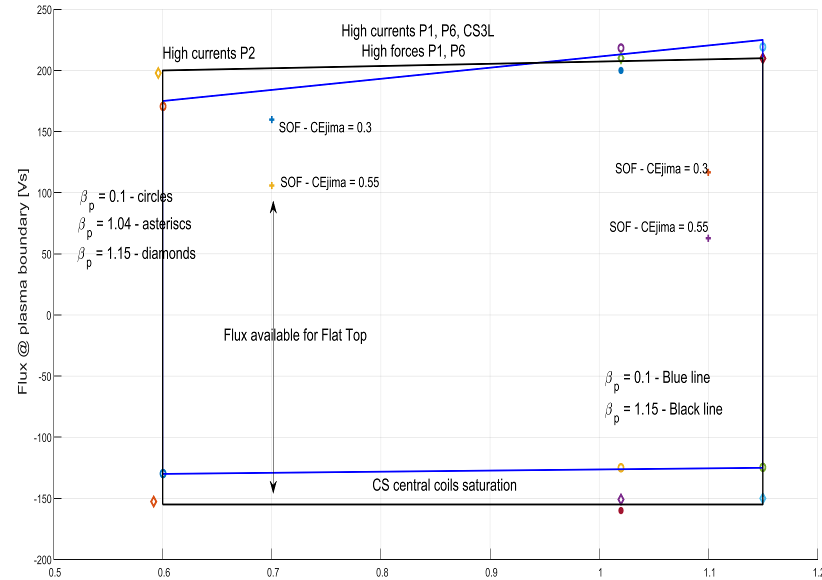

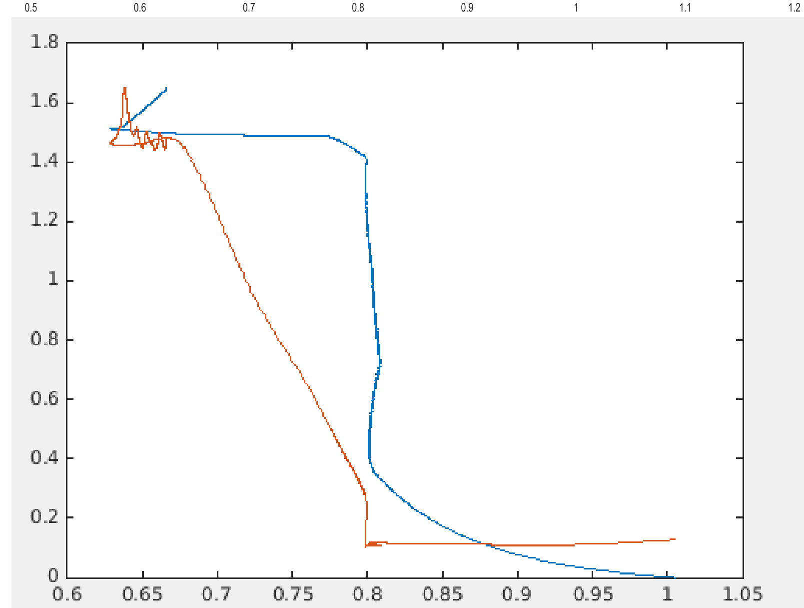

Ramp-down scenario with CREATE

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

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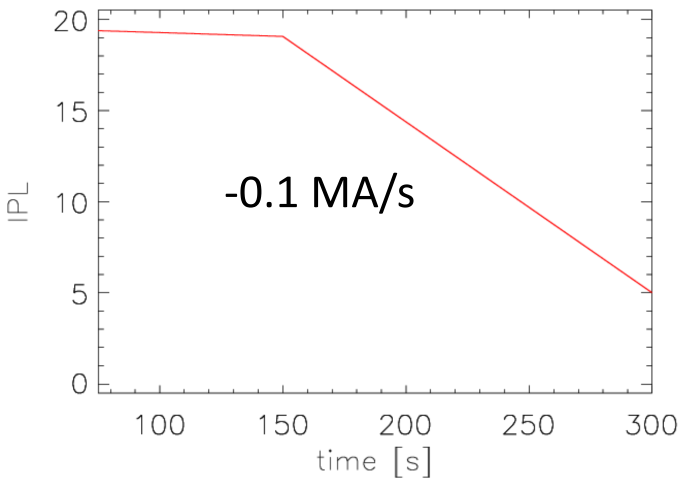
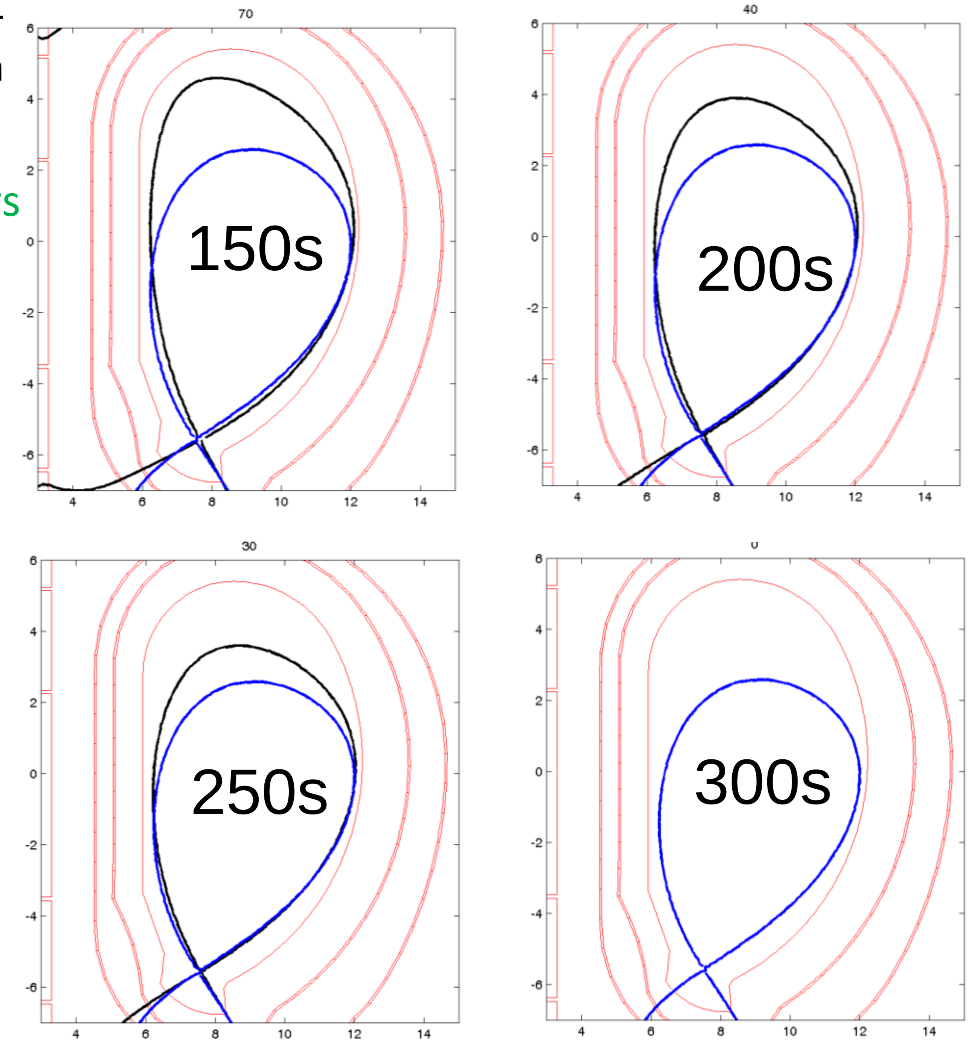
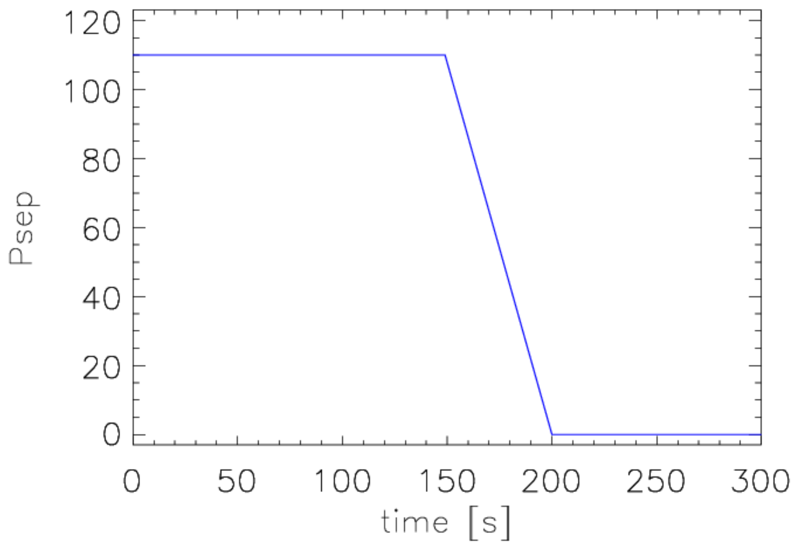
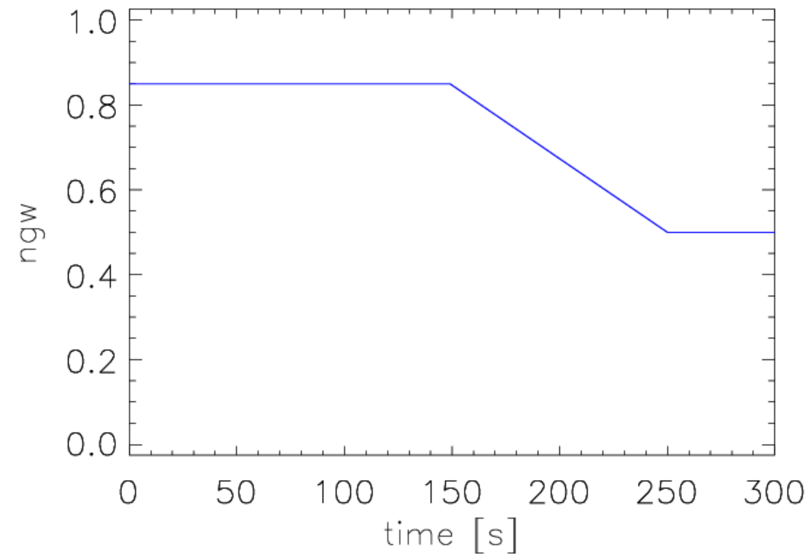
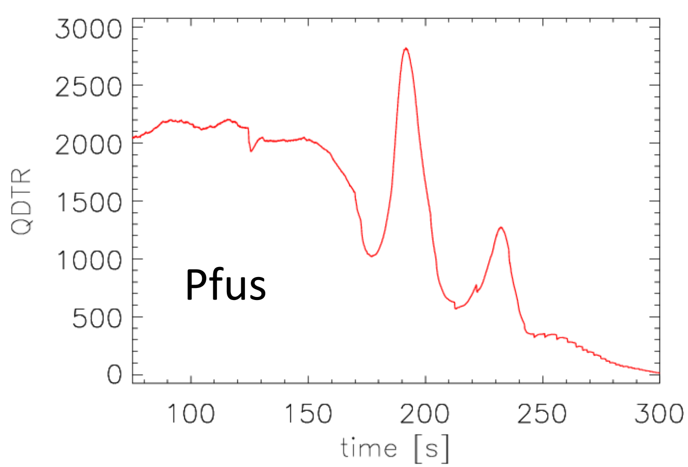


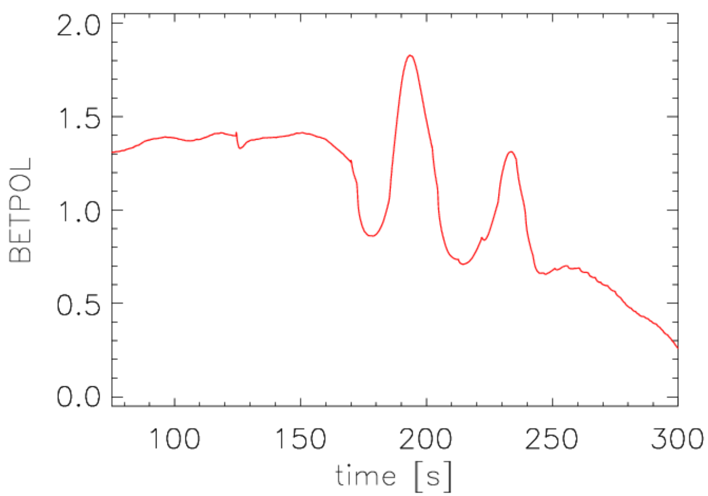


Reference case ramp-down

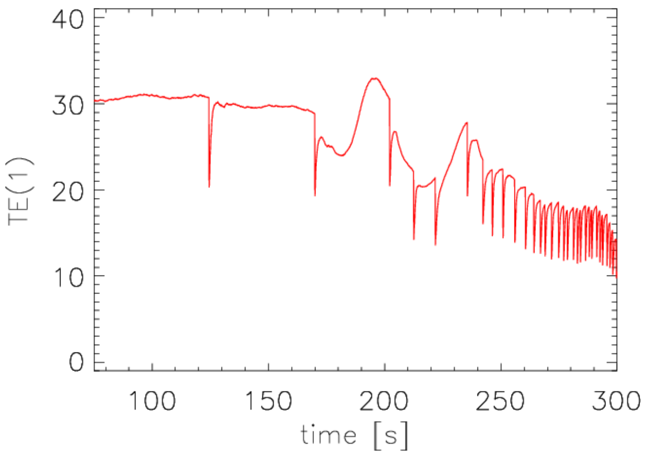


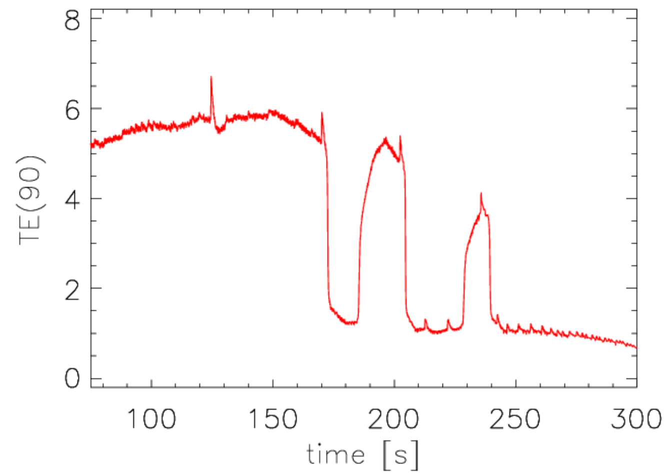


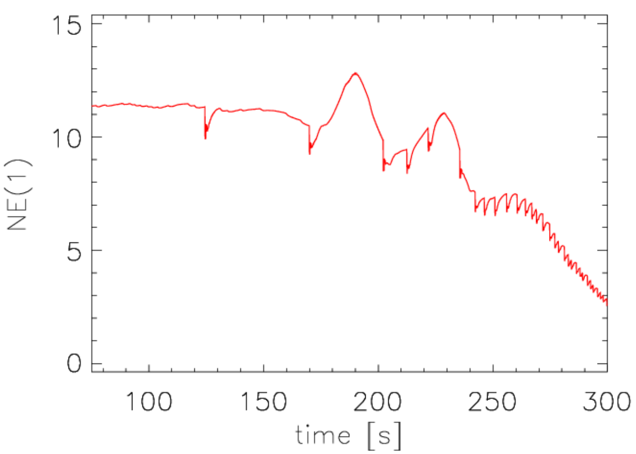


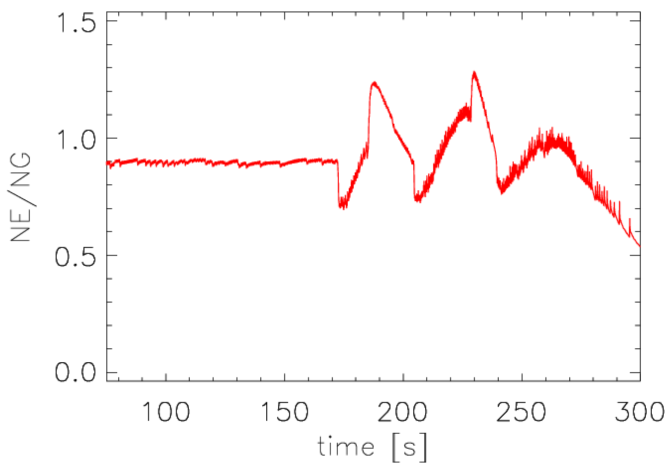


Temperature and density evolution





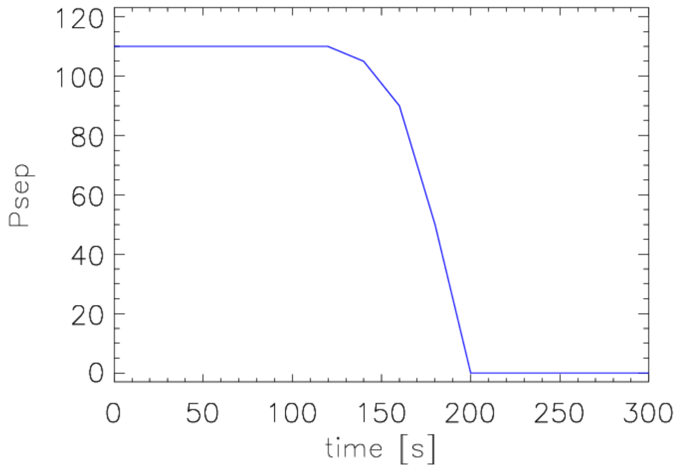


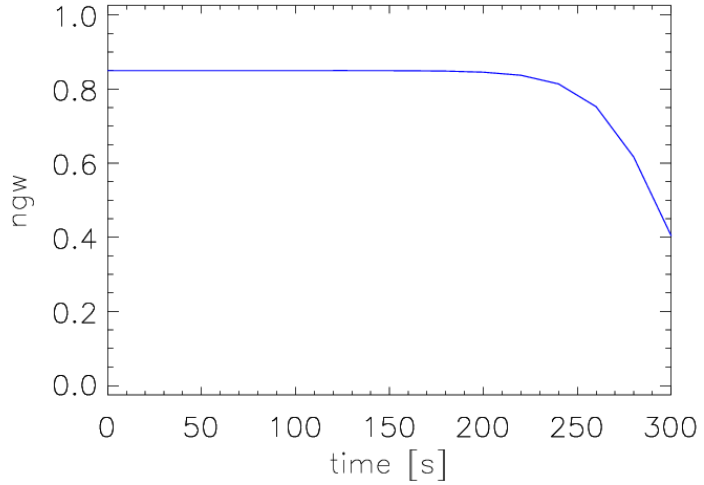


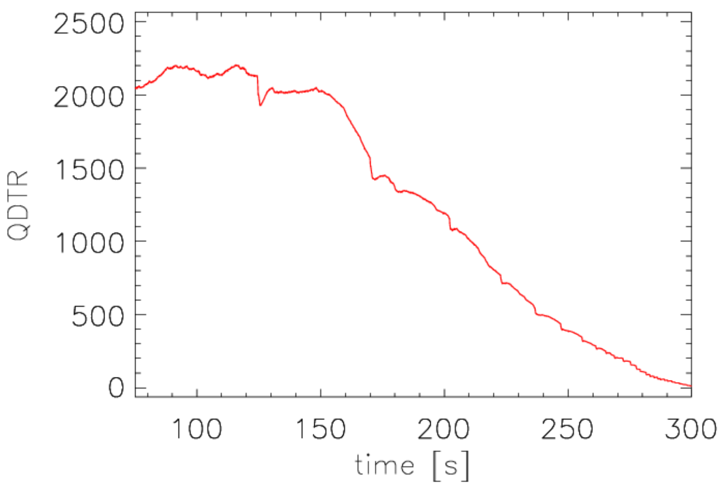
Temperature and density in the core present acceptable variations

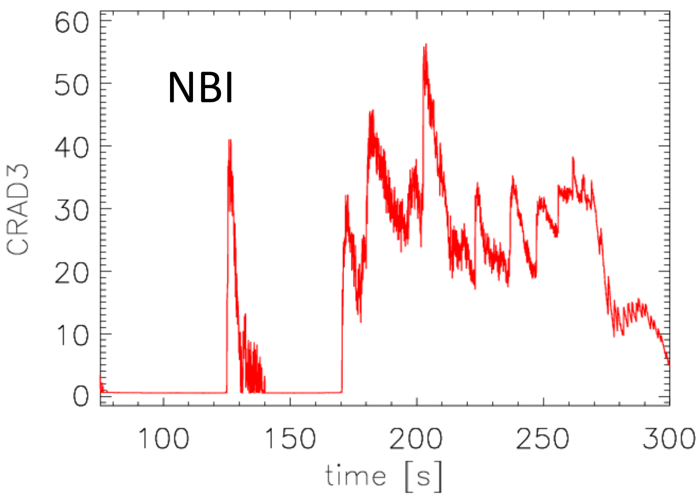
The Greenwald fraction at the pedestal top presents an overshoot

Ramp-down optimization









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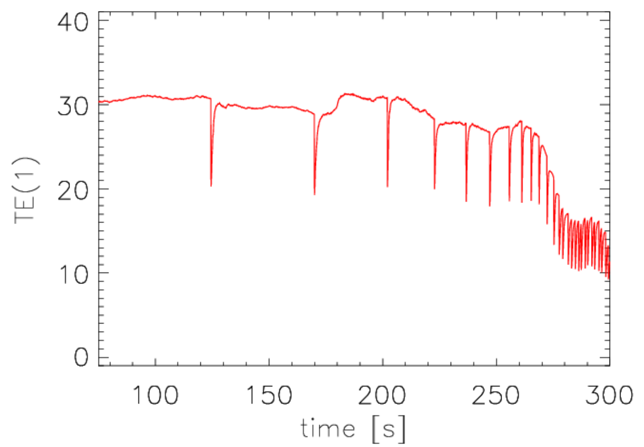

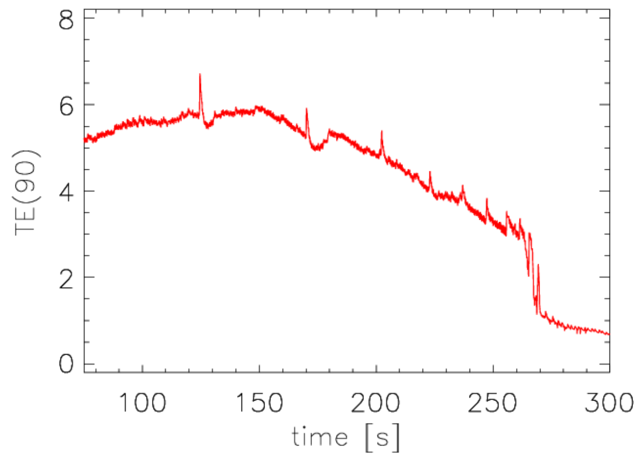

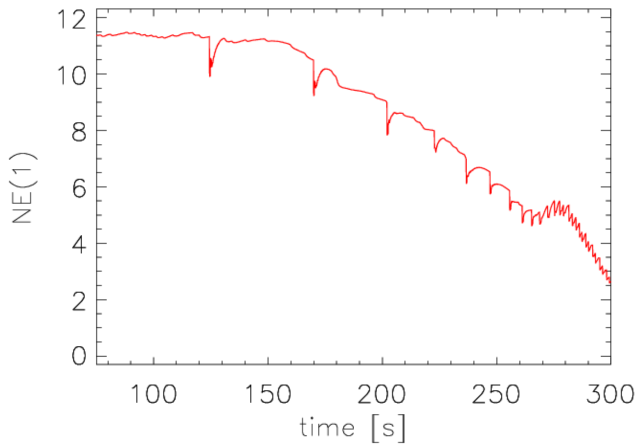

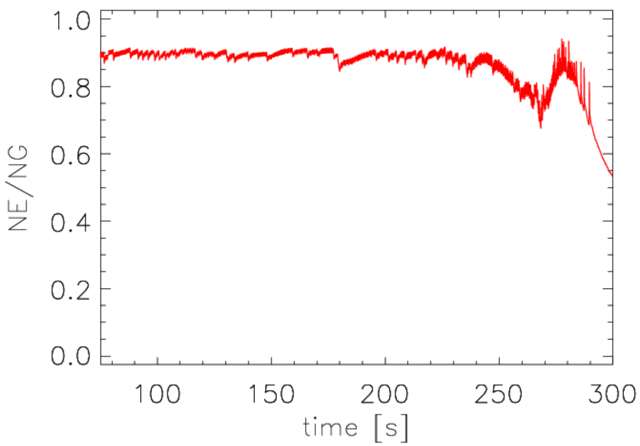

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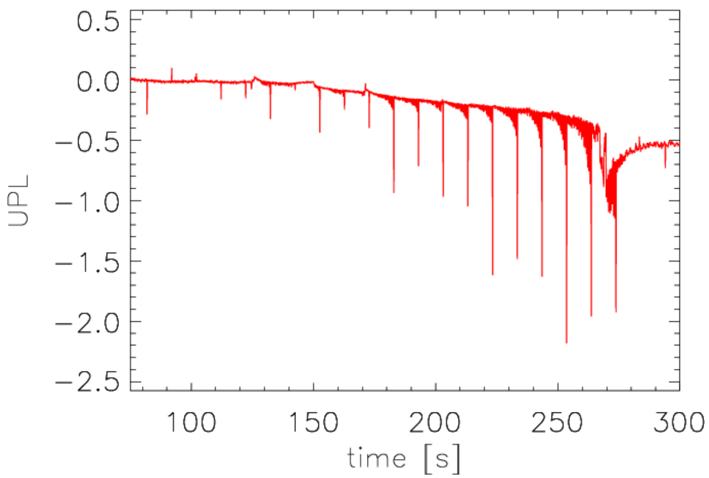
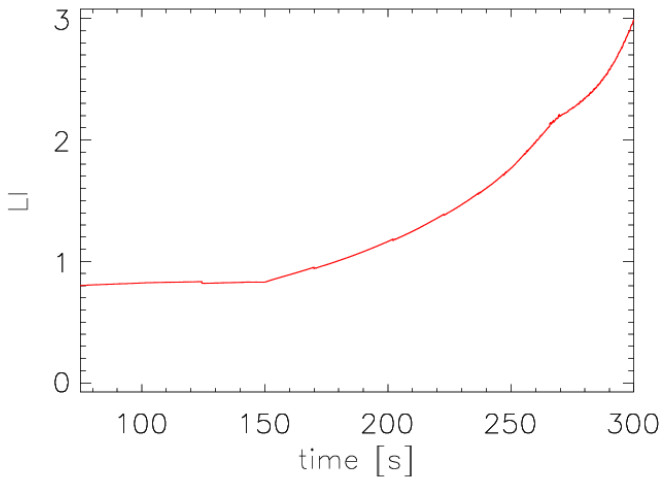


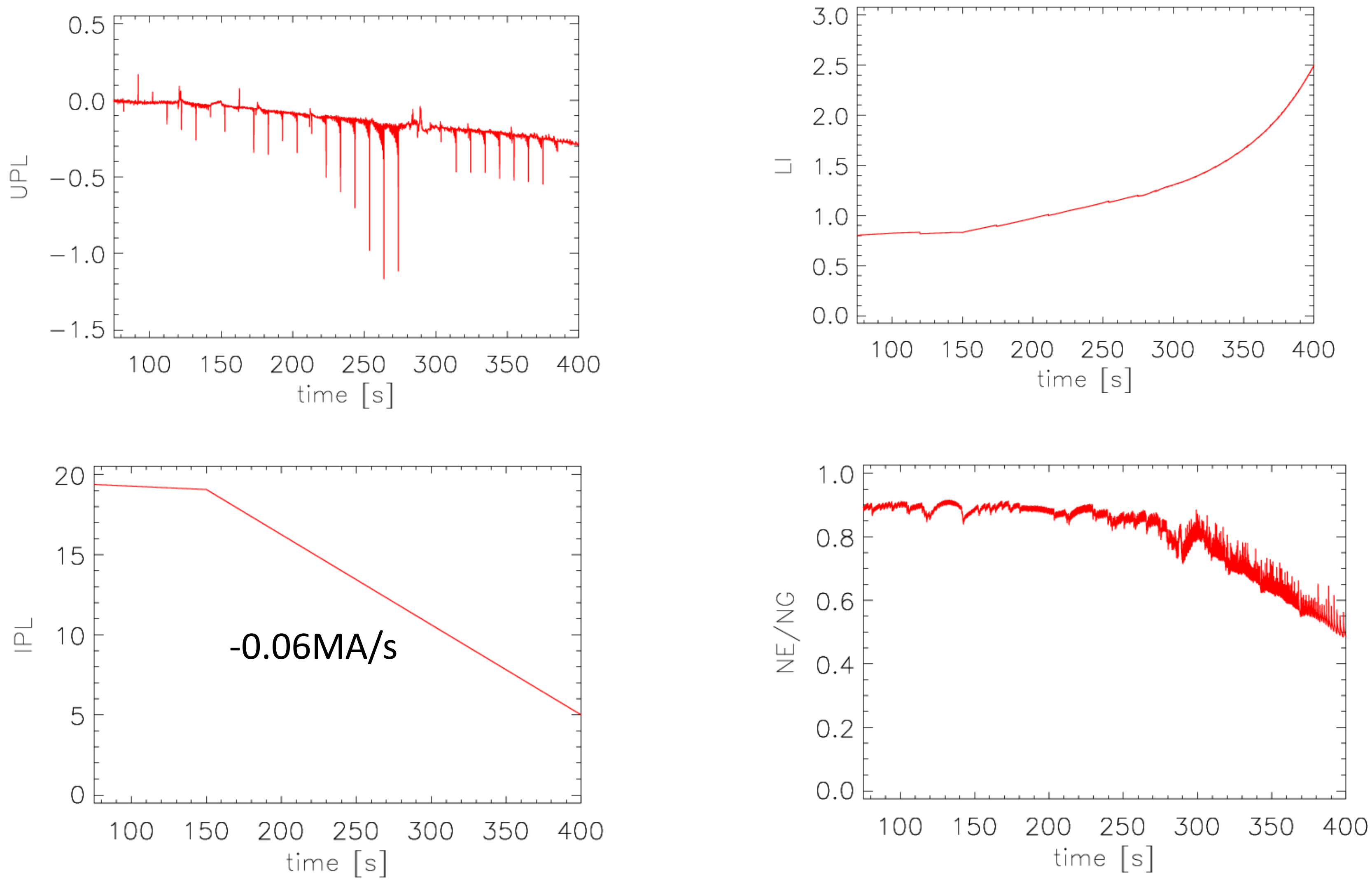


We found a negative value of the Loop voltage. This is due to the ramp rate faster than the resistive time.

In other word the inductive term is dominant with respect to the resistive term

Li increase too much in time

Ramp-down li optimization



Discussion on ramp-up/down optimization

✓ It seems that it is not difficult to find combinations that satisfy many constraints for both ramp-up and ramp-down phase
We plan to create an algoritm to automatically optimize these phases

✓Still a lot of room of improvement (adding more FF traces like Xe and gas puff)

✓ We are studying effects of the radial displacement of the NBI during the ramp-down phase (related to the recipe 30-30-70)

✓ Main unknown: evolution of transport coefficients around LH transition and early flat-top due to

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