# Optimization of the current ramp-up phase for hybrid ITER discharges *(EPS 2011)*

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Motivation for work:

Current Ramp-up for baseline 15 MA ITER scenario well studied (e.g.EPS2010)

However not well established for hybrid scenario (~12 MA)

Questions:

1.Find best scenario to arrive at hybrid q profile (q0~1, large low shear region) at L-H transition (varying ramp rate, density, settings of ECRH/ECCD, LH)

2.Assess sensitivity of result with regard to choices like

- density profile shape
- density
- Zeff
- boundary conditions (Te)
- transport model used (L- or H-mode scaling; Bohm-gyroBohm)

# Assumptions made

(i)Expanding ITER shape, starting on LFS of the torus.
X-point formation takes place after 15s, when Ip = 3.5 MA.

(ii) $Z_{eff}$ profile flat, decreasing in time with increasing $n_e$, with final value of 1.7

(iii) A rather low density of $n_e = 0.25\ n_{eGW}$ is taken.

(iv) $n_e$ profile parabolic with moderate peaking factor $n_e(0)/\langle ne \rangle = 1.3$
Compromise between the (unrealistic) flat ne profile used by the ITER team and the peaking factor of ~1.5 predicted by scaling studies

(v)Total input power below the L-H threshold during whole ramp-up phase;

(vi) Ip ramp rate is chosen such that Ip = 12 MA is reached after 80 s.

Other assumptions ($T_{e,i}$ (edge), initial $T_{e,i}$ , li) based on experimental evidence

The simulations start 1.5 s after breakdown, when Ip = 0.5 MA.

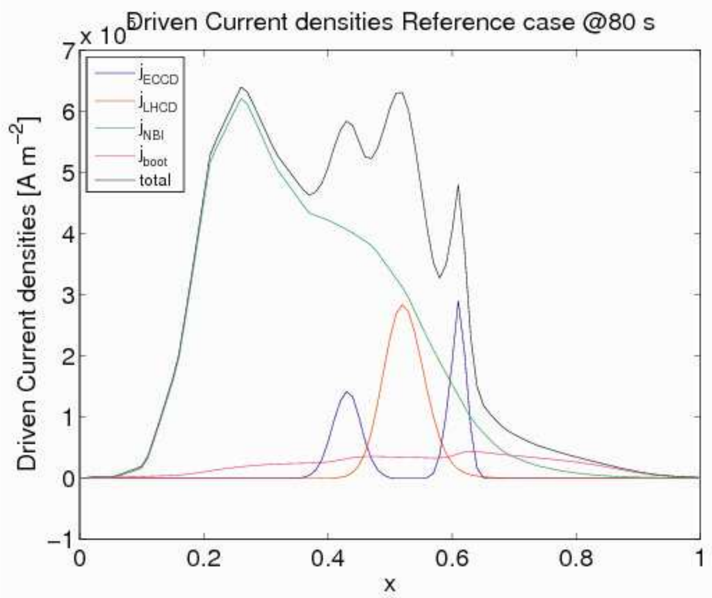
# Choice of heating and current drive scheme

To avoid too fast drop of q profile we need off-axis heating & cd

ICRH and EQL-ECCD heat very centrally (for ramp-up parameters)

Useful: NBI (off-axis mode), UPL-ECCD and LHCD

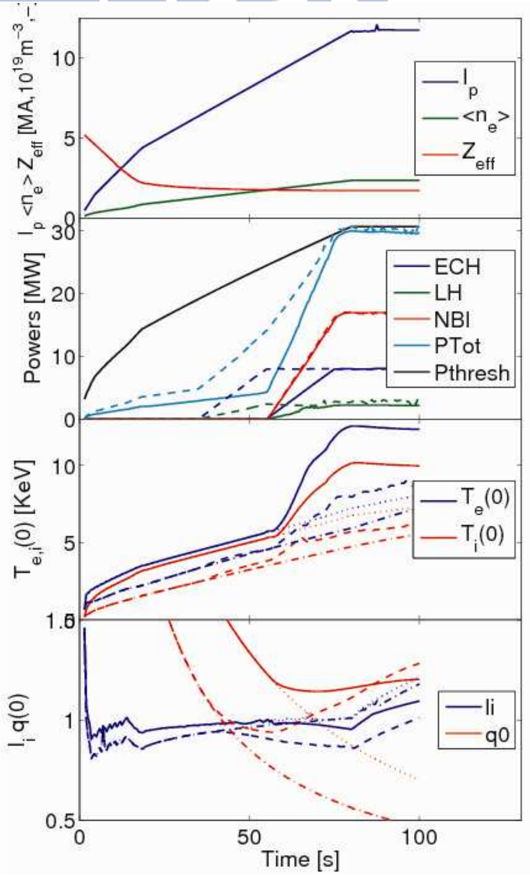
| CD method | $\rho_{dep}$ | width | notes |
|---|---|---|---|
| UPL ECCD 1st antenna | $\geq 0.4$ | narrow | depends on poloidal angle |
| UPL ECCD 2nd antenna | $\geq 0.6$ | narrow | depends on poloidal angle |
| LHCD | 0.3 - 0.6 | narrow | depends on plasma parameters |
| off-axis NBI | 0.3 | wide | |

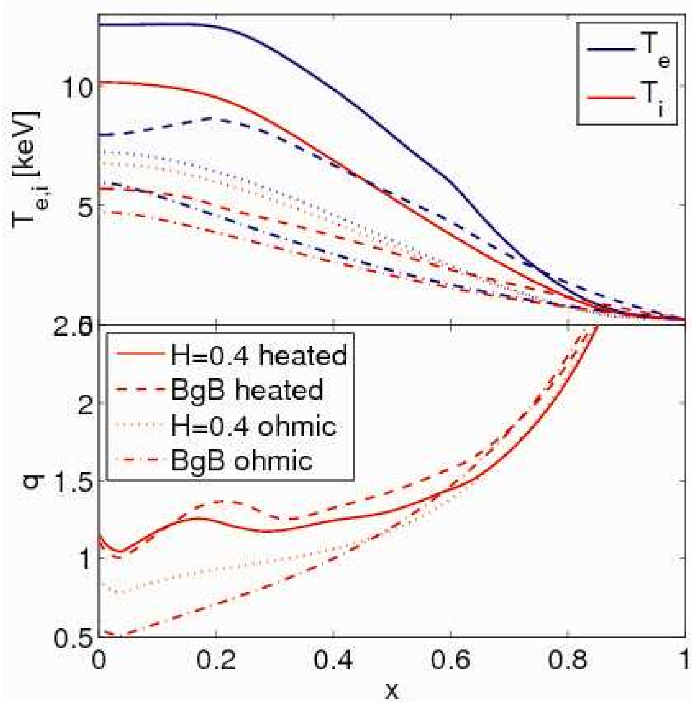



*Example of driven current densities, for reference case at 80 s: 5 + 15 MW of ECCD from the 2 UPL antennas (blue), 4 MW of LHCD (red) and 16.5 MW of NBI (green).*

*Note that this is merely an example; since the total power significantly exceeds $P_{LH}$, this is not the power mix used in the remainder of this paper.*

# Reference case – optimized heating scheme




*Left: Time traces for the reference case, assuming scaling model (full lines) or Bohm-gyroBohm model (dashed lines). The figure also shows the time traces without any additional heating (dotted and dashed-dotted lines, respectively).*

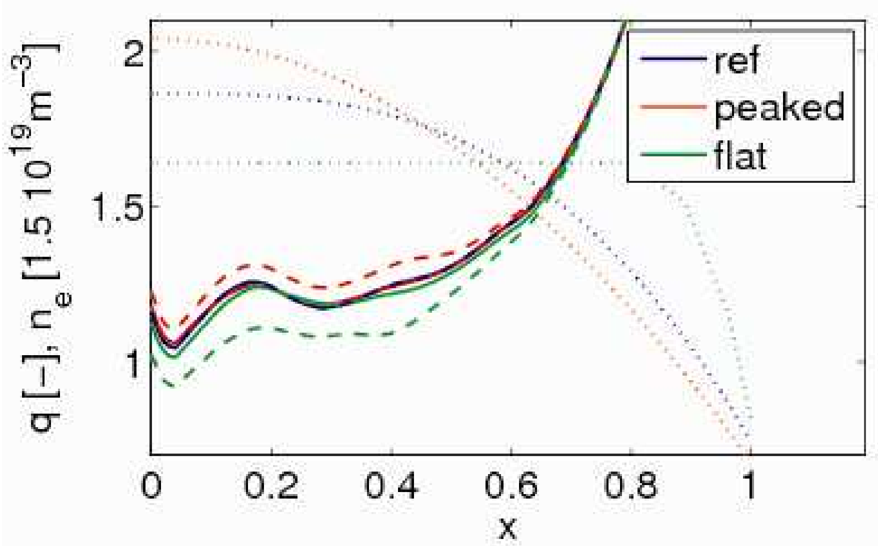
*Right: Tei and q profiles for the same cases and with the same line coding*

# Sensitivity analysis

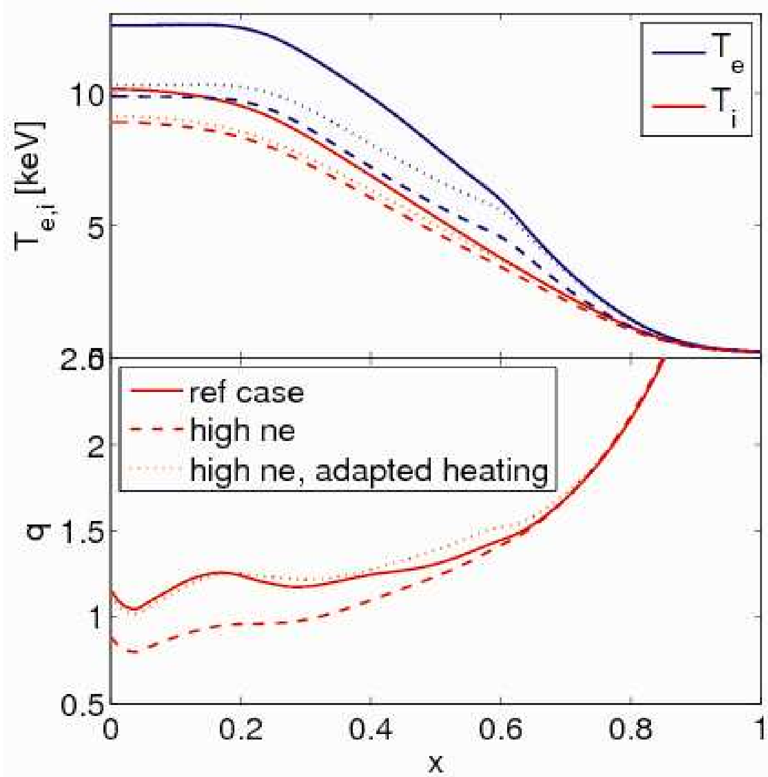
Here only shown 2 examples:

- flatter/more peaked density

- higher density




*Effect of flat or extra peaked ne. Shown are ne and q profiles at 80 s for the 3 cases (see legend), without (dashed lines) and with adapted heating scheme (full lines).*




*Profiles of reference case (full lines), high ne case with the same heating scheme (dashed) and with adapted heating scheme (dotted).*

# Conclusions

The heating systems available at ITER allow, the attainment of a hybrid q profile at the end of the current ramp-up. Using NBI, ECCD (UPL) & LHCD

Optimum heating scheme depends on chosen transport model.

Modified assumptions on ne peaking, edge $T_{ei}$ and $Z_{eff}$ can be easily accounted for by a shift in time of the heating scheme.

Higher density during the ramp-up phase can be accounted for equally well, and might even be profitable because it gives more freedom in the application of the heat sources.

*not shown here: FREEBIE post-processing shows scenario well within operational limits*

# Outlook

Recently ITER team is considering breakdown at HFS instead of on LFS → different geometry in the very early phase of the discharge. Effect of this on the current density evolution, although expected to be small, will be considered in future sensitivity study

Also the effect of faster Ip ramp will be subject  of further study.