Optimizing ITER Current Ramp-up for hybrid scenario

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

Differences with earlier work (EPS2010):

- "official" ITER geometry and ramp-up rates
- ramp-up till12 MA (@ 80 s) in stead of 15 MA
- real limitations of heating systems

  (previously just a location of ECRH/ECCD deposition was assumed)
- for hybrid good "landing" of q profile more important

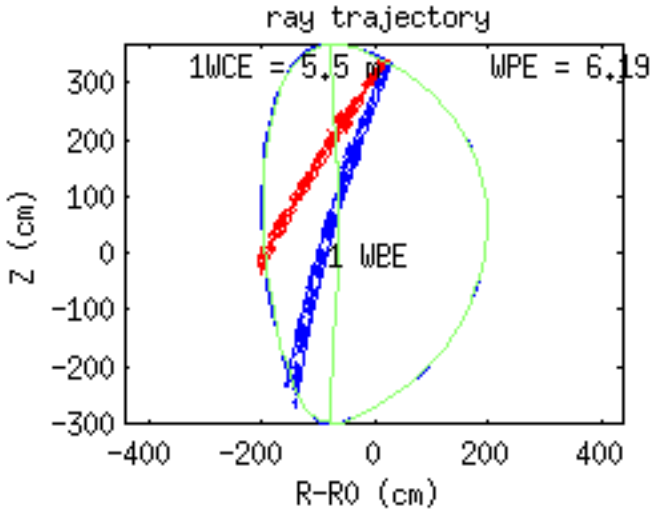
To avoid too fast drop of q profile we need off-axis heating & cd
Will consider ECCD and LHCD

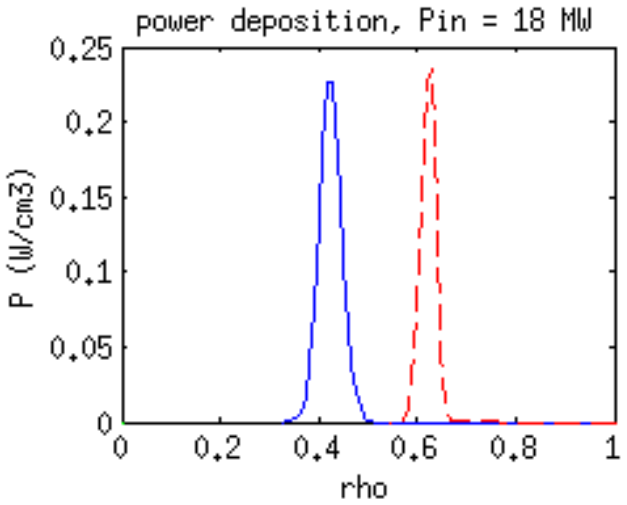
During ramp-up phase:

- equatorial ECH launcher: <u>too central</u> (ρ_{dep} ~ 0.1);

  at end of ramp-up better (ρ_{dep} ~ 0.3)
- upper port ECH launcher: <u>very good</u> :

  ρ_{dep} ~ 0.4-0.6 depending on poloidal angle *(see plots below)*
- LHCD: <u>very good</u>: ρ_{dep} ~ 0.4-0.5





Scenarios run so far:

- Either 20 MW of ECCD or 20 MW of LHCD
- Power linearly ramped up between 30 and 50 s

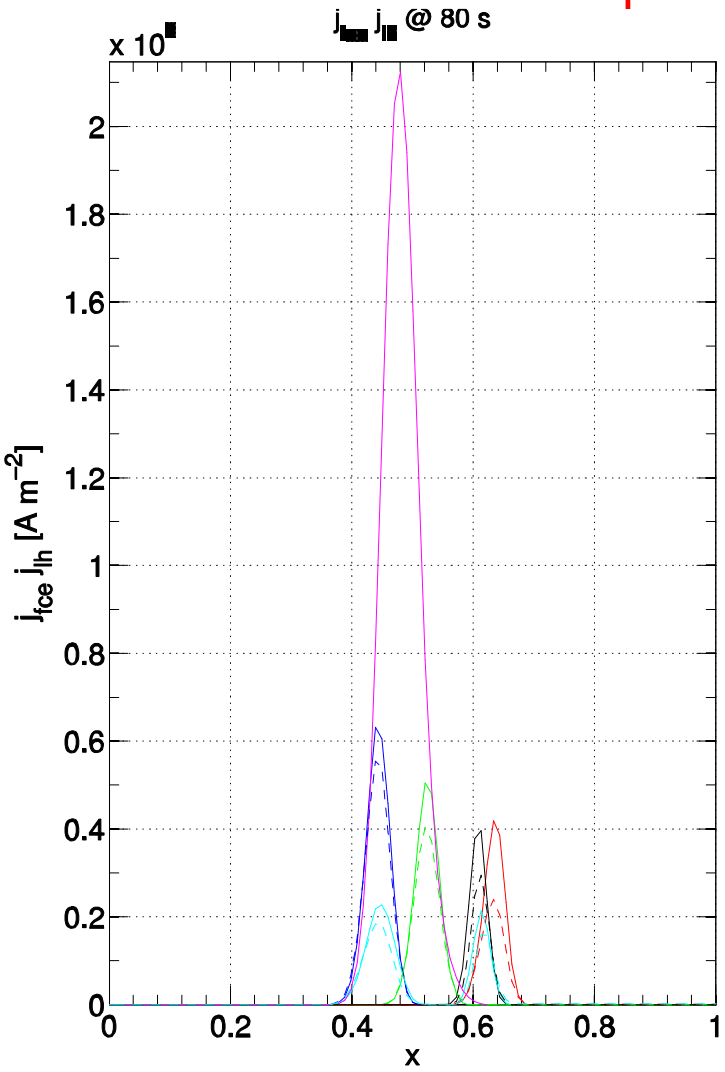
Two transport models:

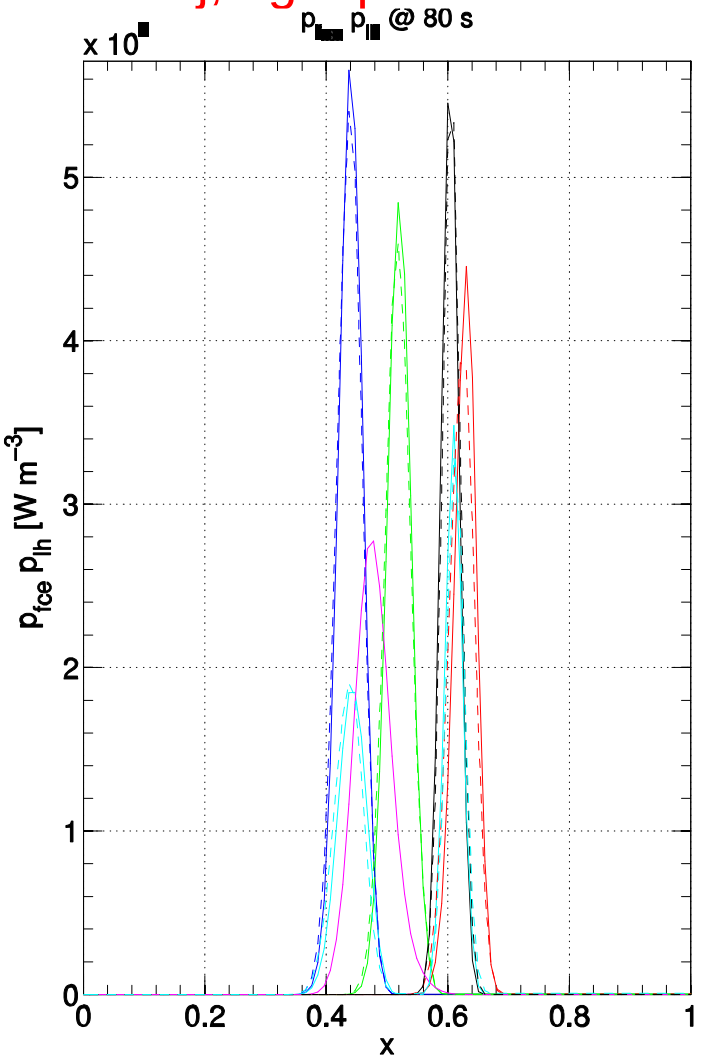
- H-mode scaling model with H=0.4 (**full lines** in following plots)
- Bohm-gyro Bohm (**dashed lines** in following plots)

5 heating scenarios, indicated with different colours in plots:

- **blue** ECCD UPL 4^{th} antenna $\theta = -68^{o}$
- **green** ECCD UPL 4^{th} antenna $\theta = -65^{o}$
- **red** ECCD UPL 4^{th} antenna $\theta = -60^{o}$
- **black** ECCD UPL 5^{th} antenna $\theta = -56^{o}$
- **cyan** ECCD UPL 4^{th} + 5^{th} antennas $\theta = -68/-56^{o}$ 8/12 MW
- **magenta** LHCD

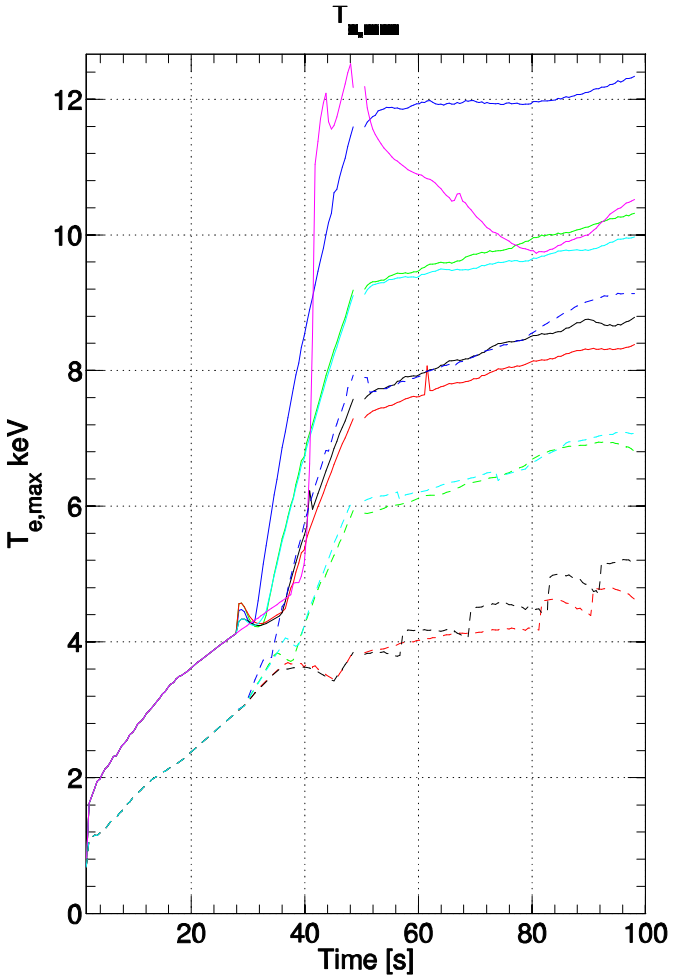
All profiles @ 80s – left j, right p

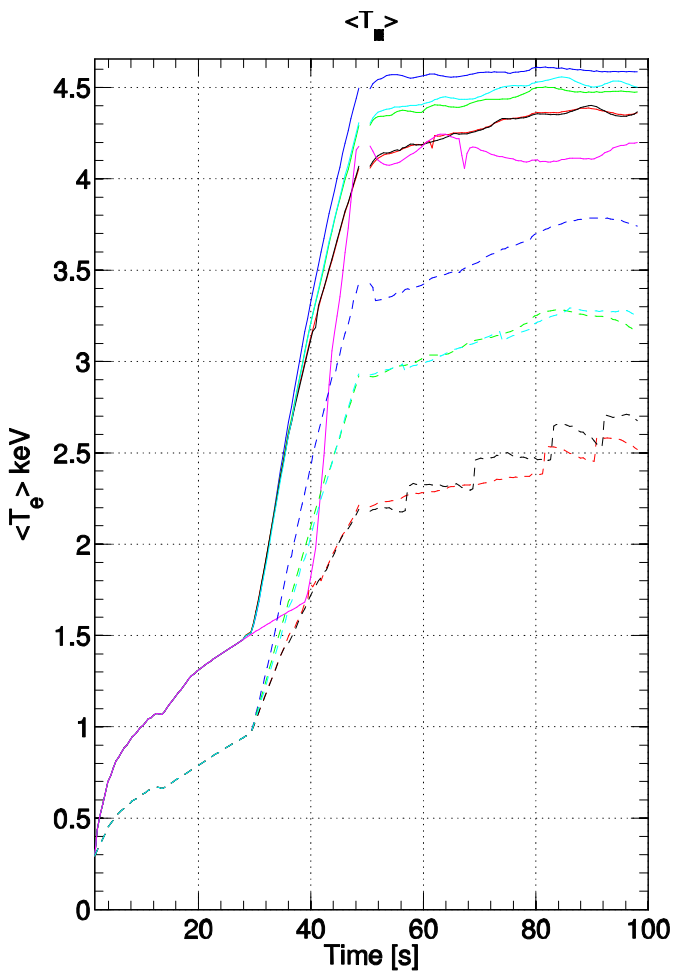




LH drives much more current than ECCD

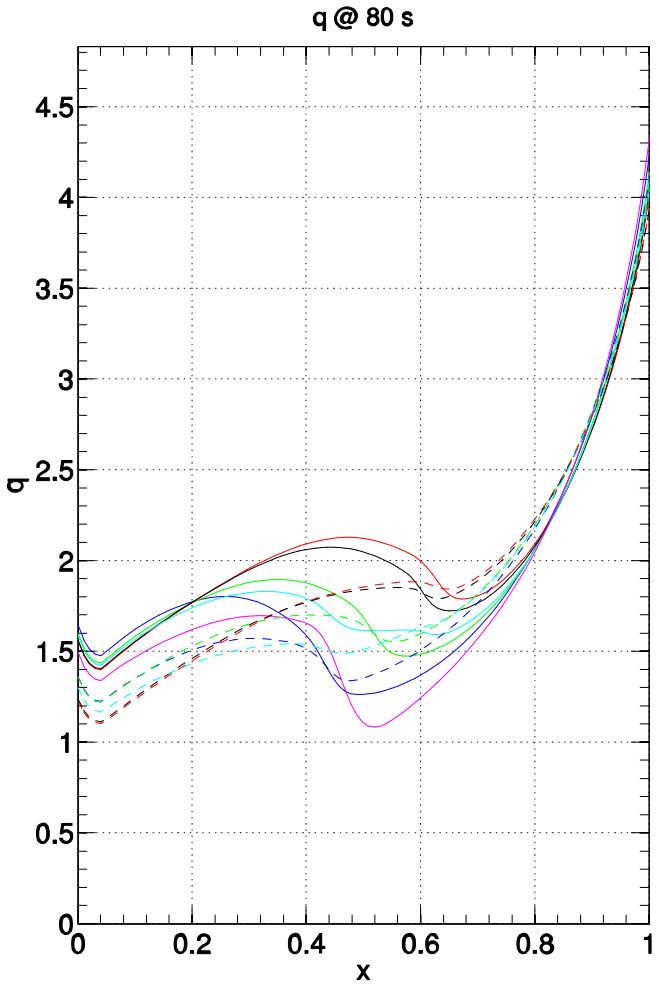
left Temax, right <Te>

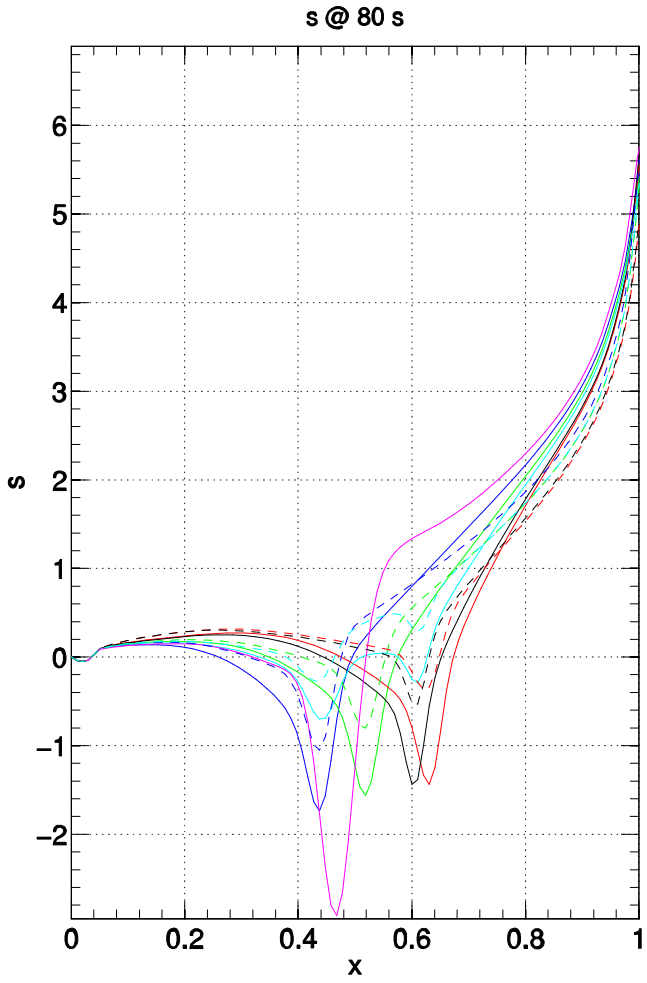




- Scaling more optimistic than Bohm-gyroBohm
- Apparently power dep rad no effect in scaling model – weakness of model

left q, right shear





- Farthest off-axis heating gives larges low shear region
- 20 MW of LHCD is maybe too localized (strong local s<0)

Conclusions so far:

- With ECCD and/or LHCD good hybrid-like q profile can be reached at end of ramp-up phase

Plans until EPS:

- Tune ECCD + LH (settings & timing) to get optimized q profile at end of ramp-up *(probably combination of both heating methods)*
- Sensitivity analysis – how does q depend on assumptions, and how can one modify heating to counteract changes
  (note: for ohmic case sensitivity study already done – snot shown here)
- consistency check of optimum runs with PF coils limitations

Plans after EPS and later:

- couple with free boundary equilibrium solver