Expected bootstrap currents in different W7-X configurations

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Background

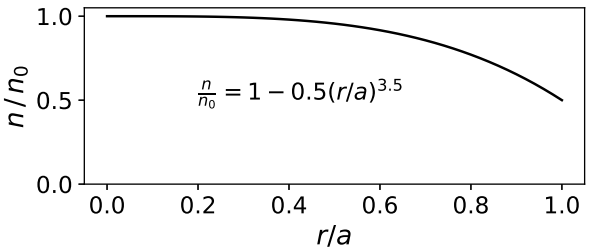
- Rapid termination of a discharge (plasma decay time $\lesssim 1$ ms)
  - could induce harmful currents in some vessel components
  - could trigger the quench detection system
- Therefore, operational restrictions have been introduced on the W7-X toroidal current, to be $I_{\mathrm{tor}} < 10$ kA (in general).
- When changing some experimental parameter, it can be helpful to know in what way neoclassical theory predicts the bootstrap current I_{bs} to change
  - especially for discharges longer than the L/R time, when I_{tor} approaches I_{bs}.
- If you know the profiles from the experient or from experience you can calculate I_{bs} yourself using Neotransp.
- The following shows the trends (assuming only ECRH heating), how I_{bs} varies as a function of density and ECRH heating power for example n and T profiles shapes.

Stored energy as a function of density and power

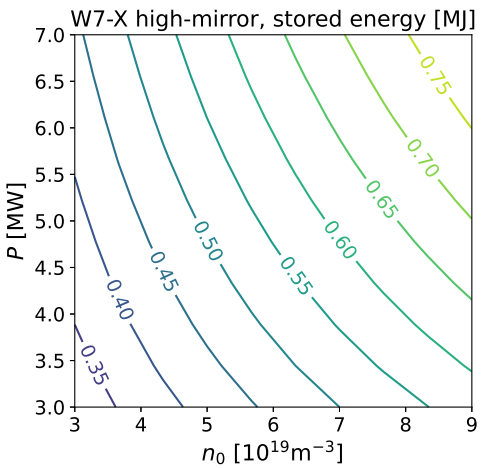
- ISS04 scaling with a renormalisation factor $f_{\mathrm{ren}} = 0.7$

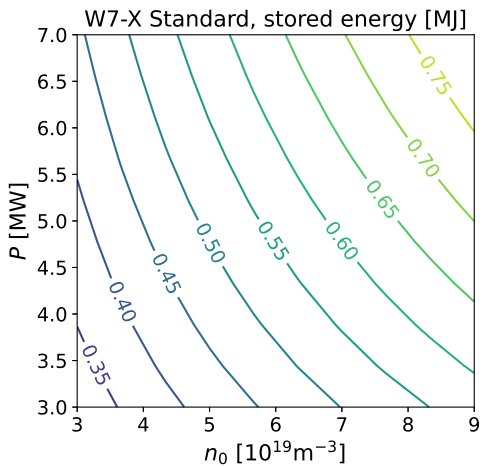
$$\tau_E = f_{\mathrm{ren}}\, 0.134 R^{0.64}\, a^{2.28}\, n_{19,\mathrm{lineav.}}^{0.54}\, P_{\mathrm{MW}}^{-0.61}\, B^{0.84}\, \iota^{0.41}$$

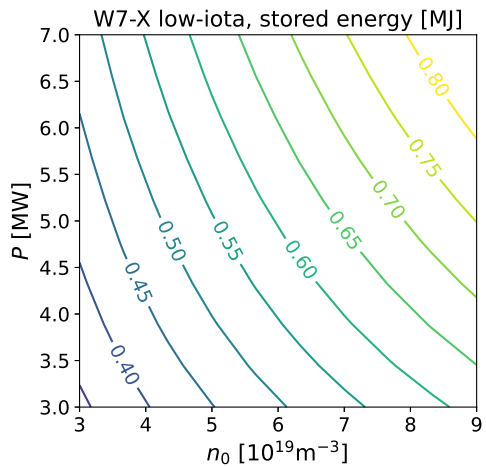
- Assume a density profile shape



- Stored energy $E(n_0, P) = \tau_E(n_0, P)P$

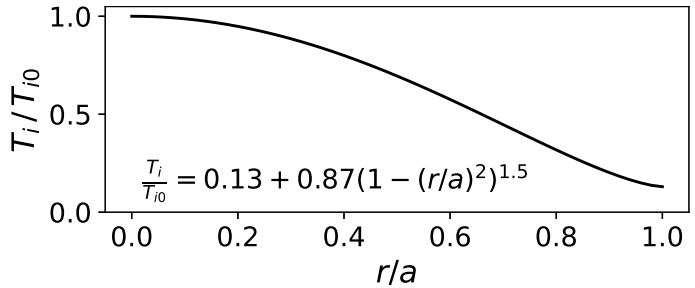




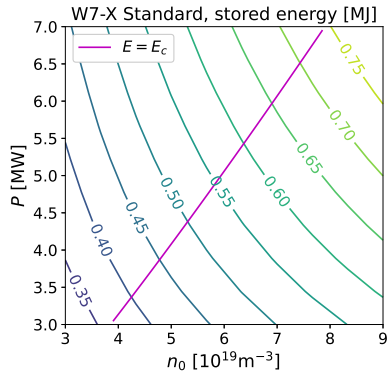


Treatment of temperature profiles

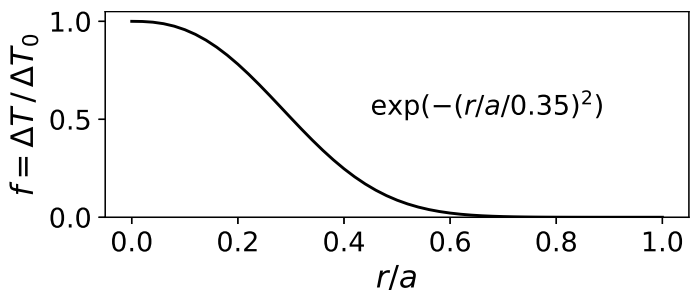
- Assume a T_i profile shape



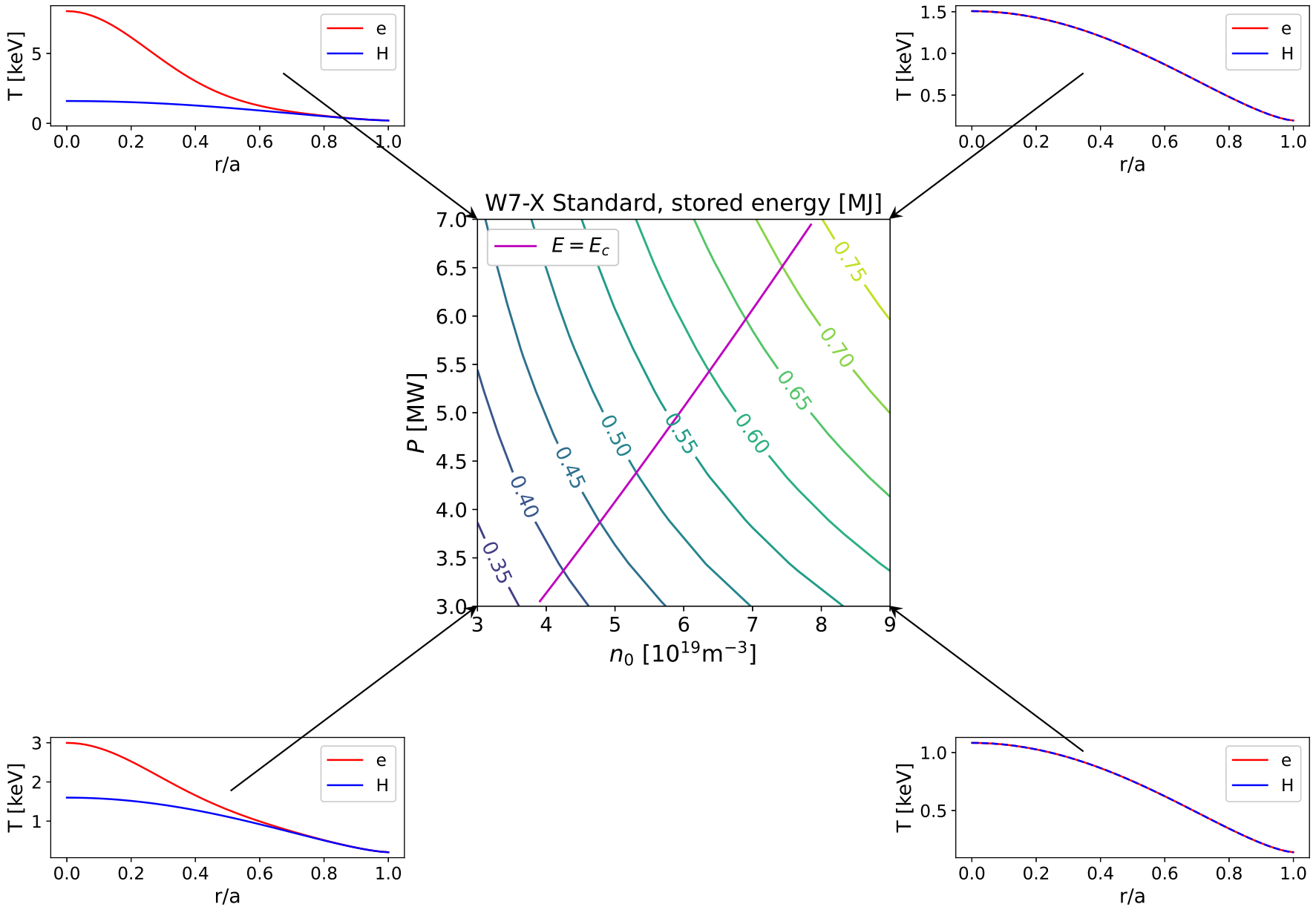
- Let E_c be the thermal energy when $T_e(r) = T_i(r)$ and $T_{i0} = T_{\mathrm{clamp}} = 1.6$ keV.



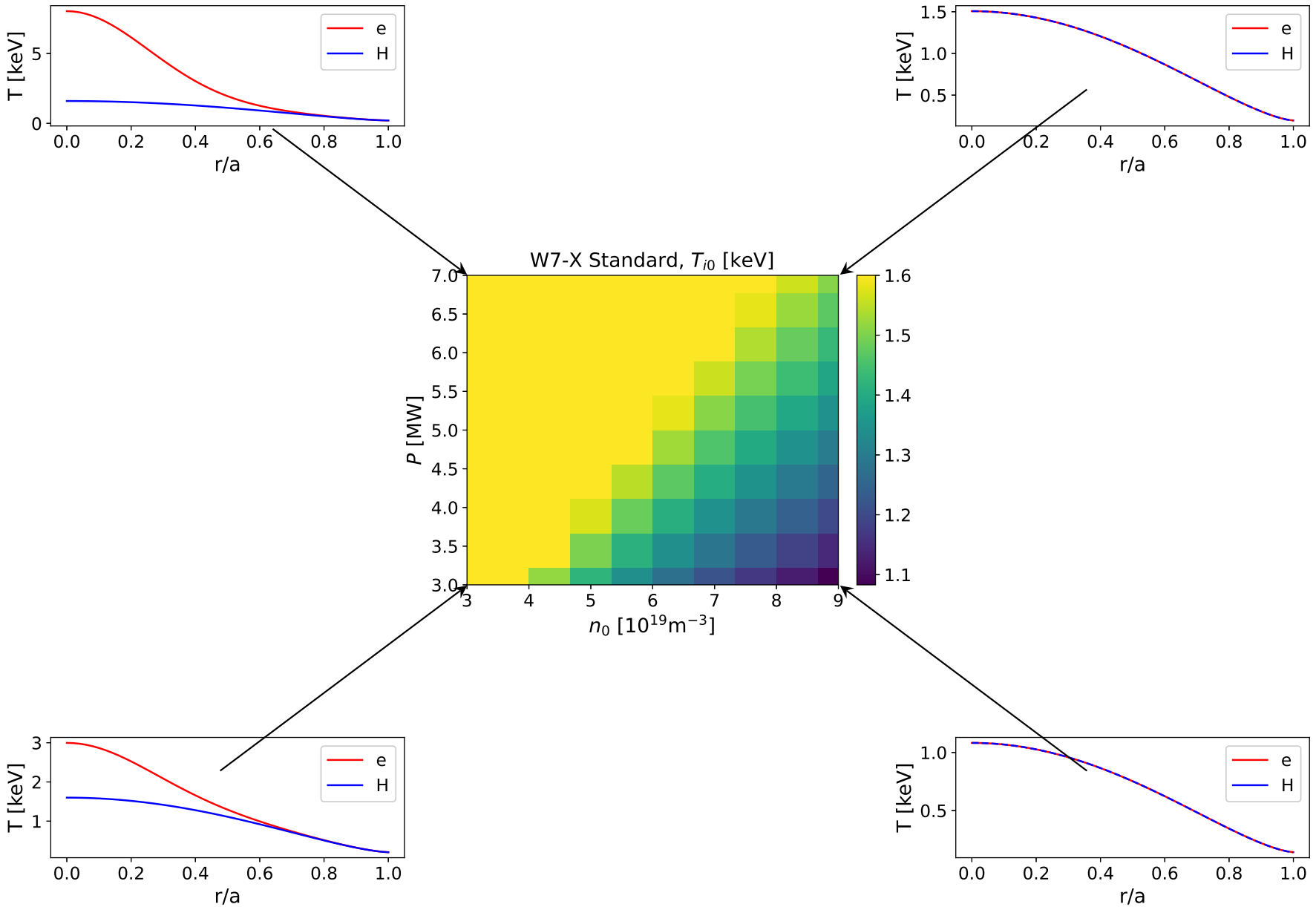
- For $E(n_0, P) < E_c(n_0)$, we let $T_e(r) = T_i(r)$, and scale both profiles to obtain the correct energy $E(n_0, P)$
- For $E(n_0, P) > E_c(n_0)$, we set $T_{i0} = T_{\mathrm{clamp}}$ and $T_e(r) = T_i(r) + \Delta T_0 f(r)$, where ΔT_0 is scaled to get E.



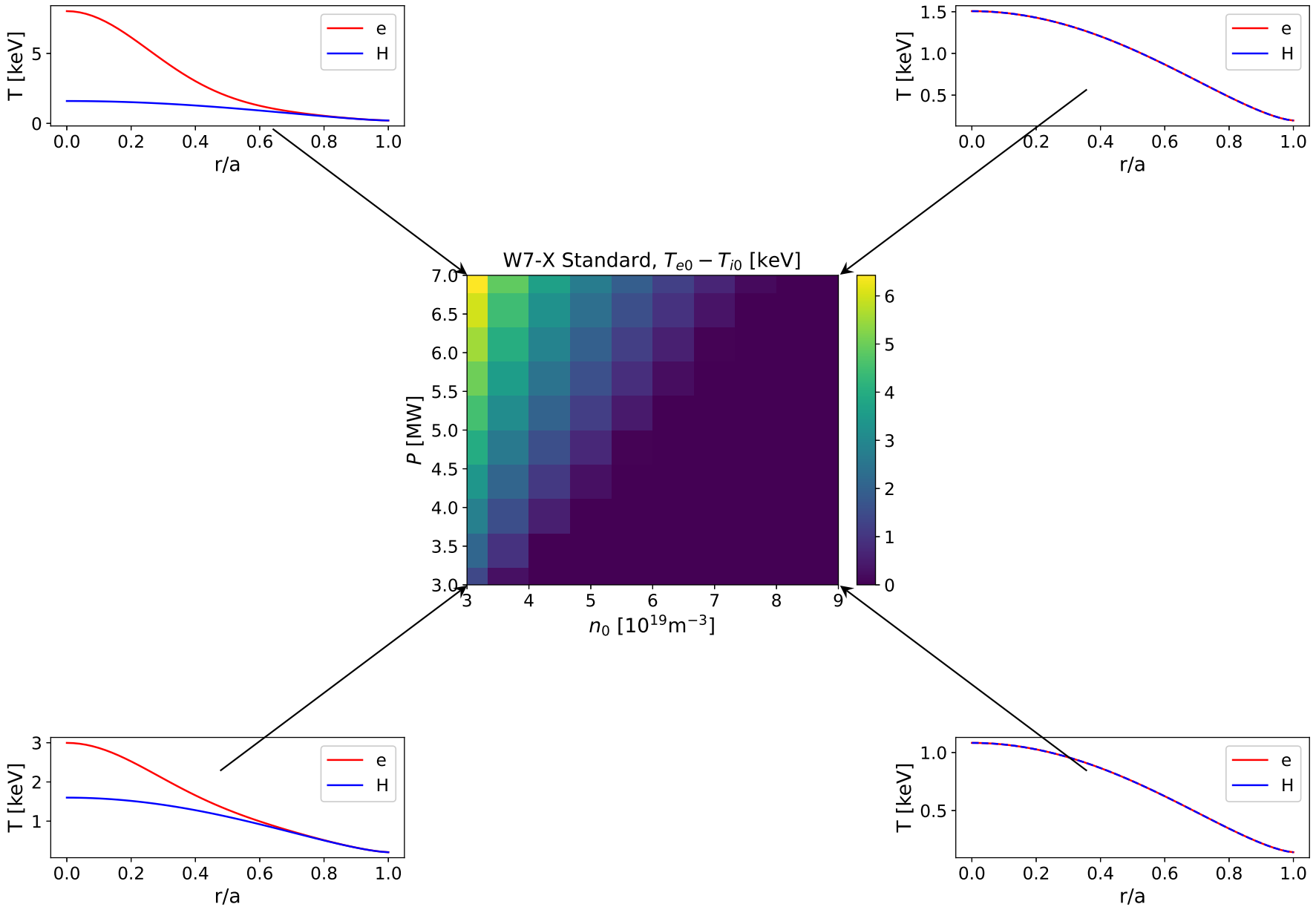
Temperature profiles



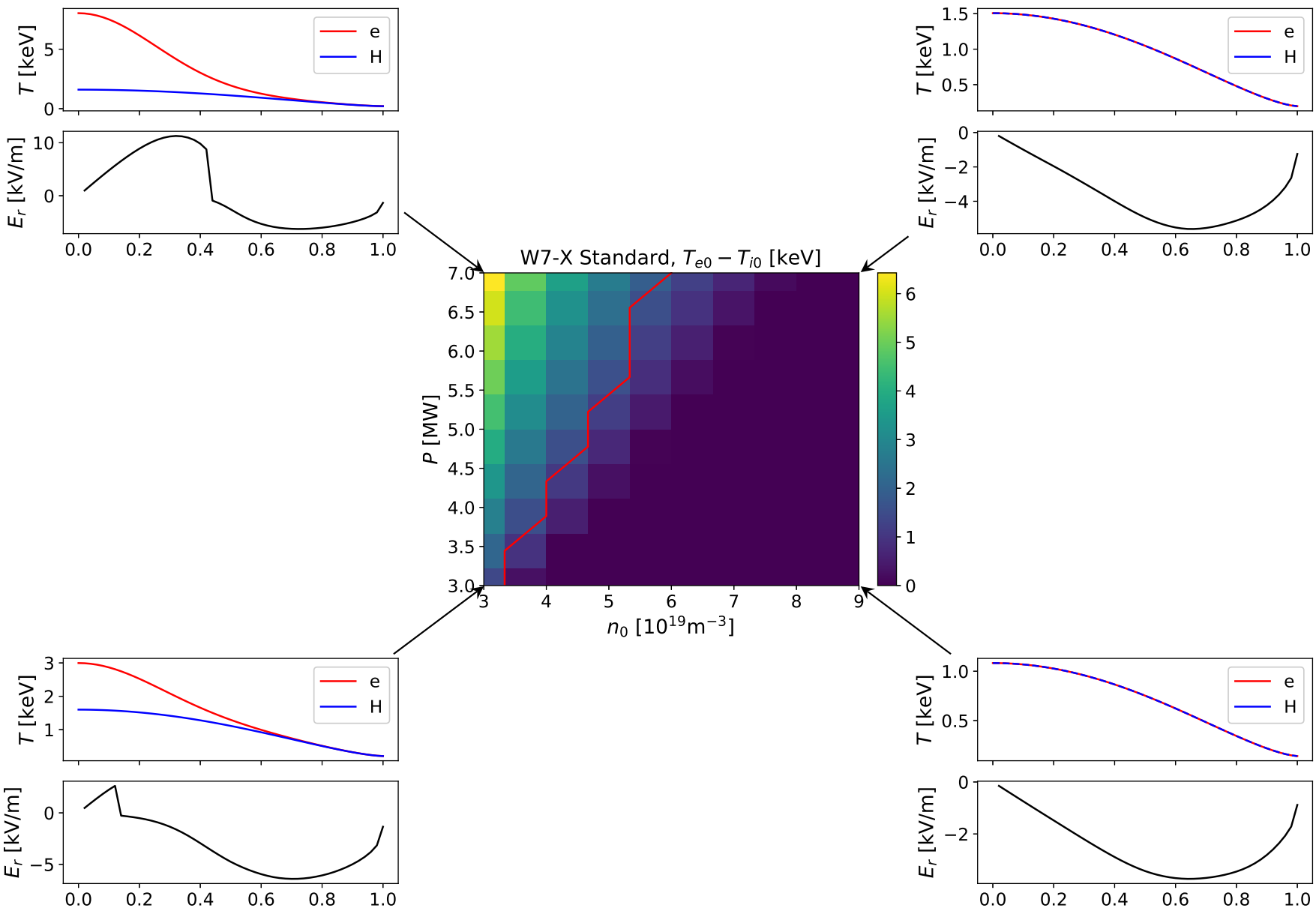
Temperature profiles



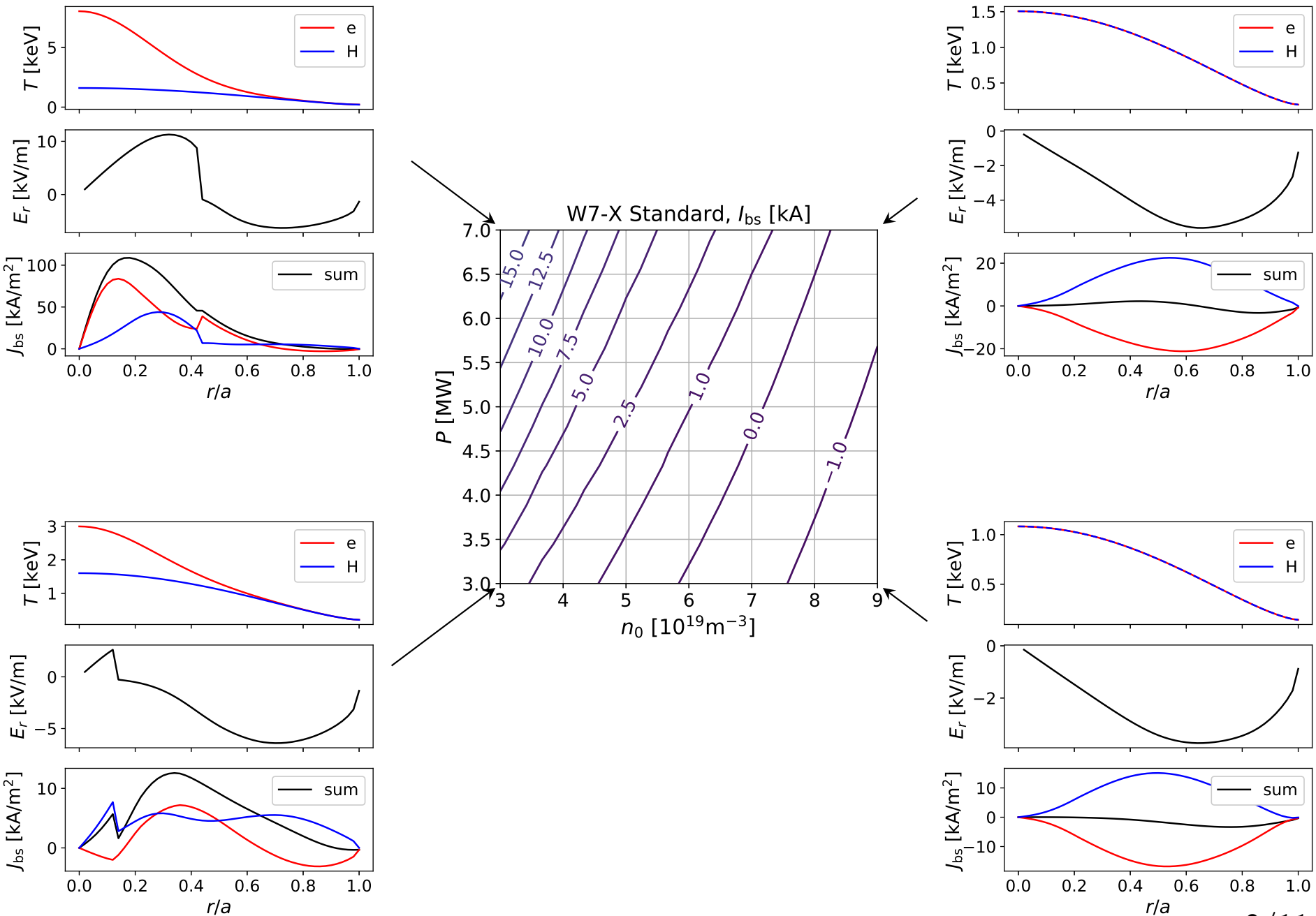
Temperature profiles



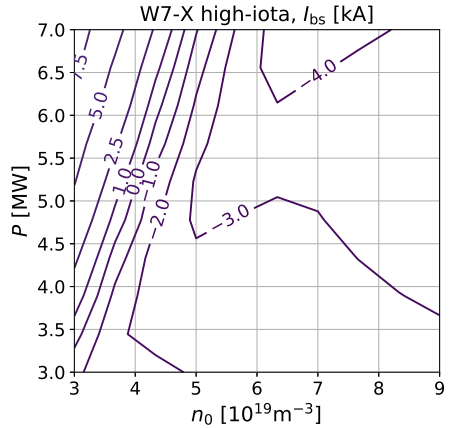
Electric fields

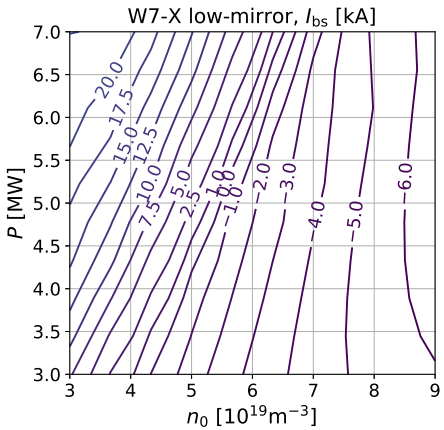


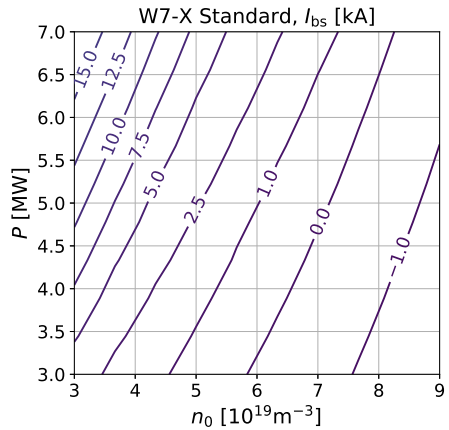
Bootstrap currents

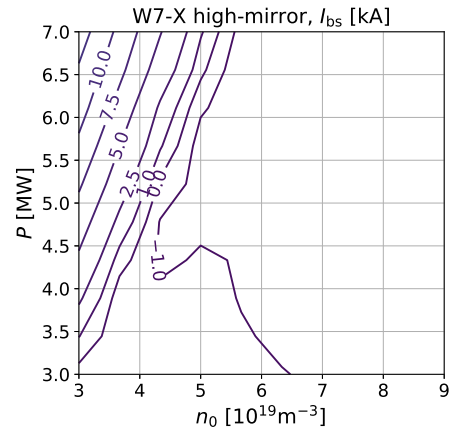


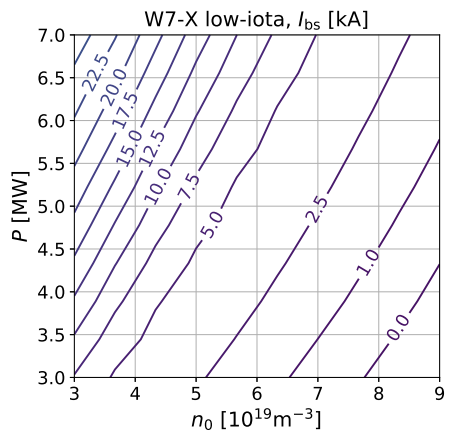
I_{bs} in 5 configurations









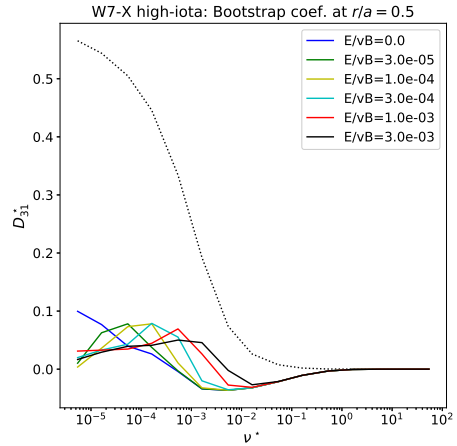


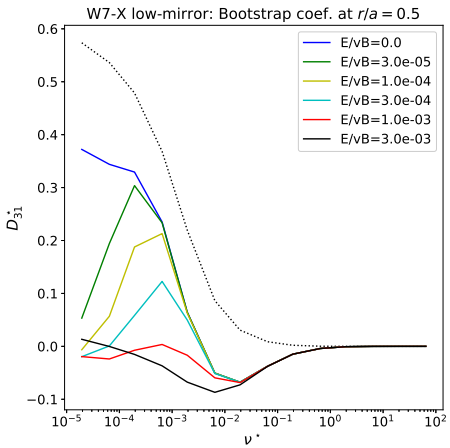
Conclusions

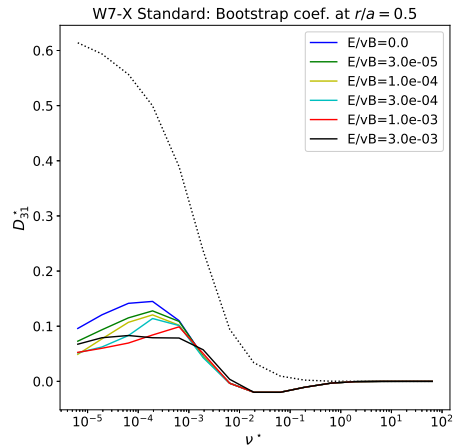
- Because the toroidal current is limited to < 10 kA it could save experimental time know from neoclassical calculations how I_{bs} depends on changing power, density and magnetic configuration
  - especially for discharges longer than the L/R time
- Using experience of expected profiles, you can do this calculation using Neotransp.
- We have shown a scan over n_o and P in an ECRH heating scenario using example profile shapes and ISS04 scaling.
- The High-iota and the High-mirror configurations have the lowest I_{bs}
- I_{bs} is pushed towards negative values when collisionality increases by increasing n_o.

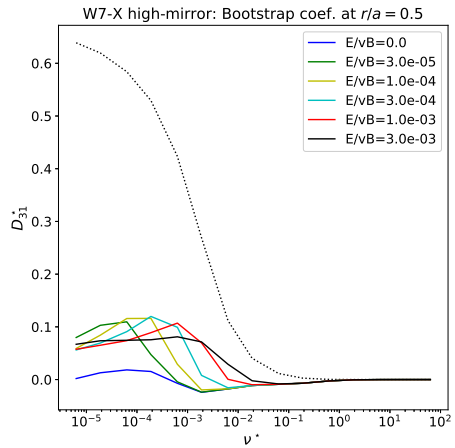
Extra

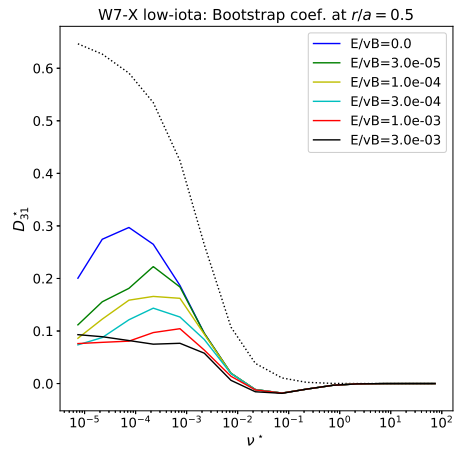
$D_{31}^{\star}$ vs. $\nu^{\star}$



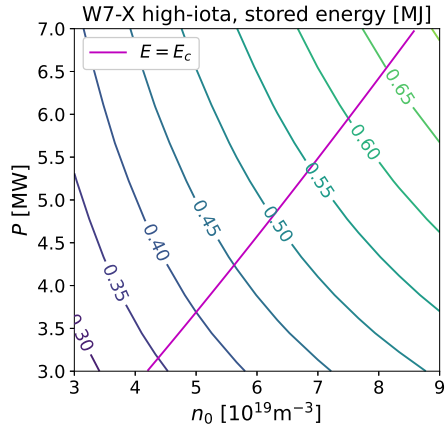


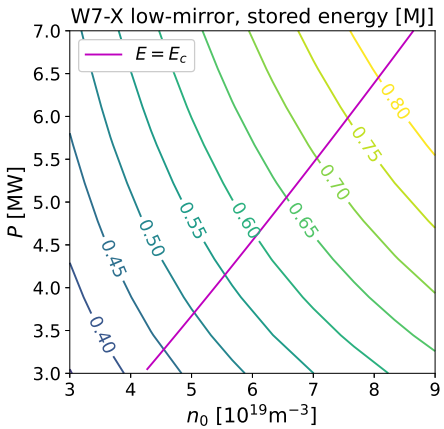


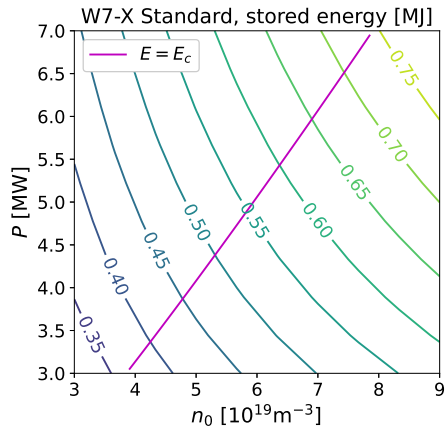


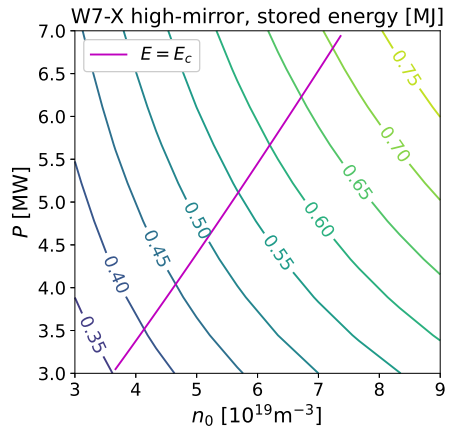


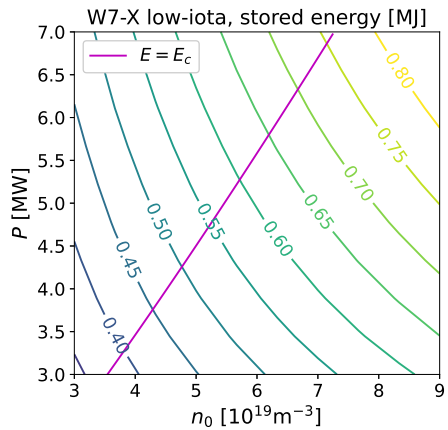
Stored energy



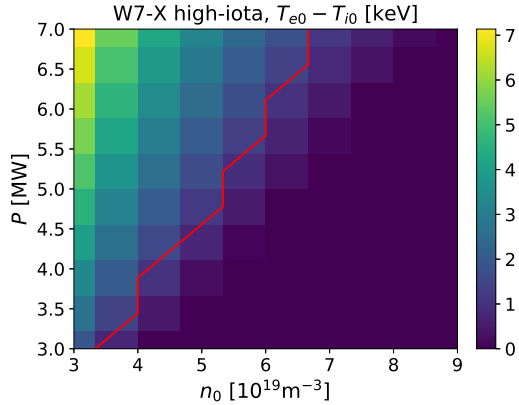


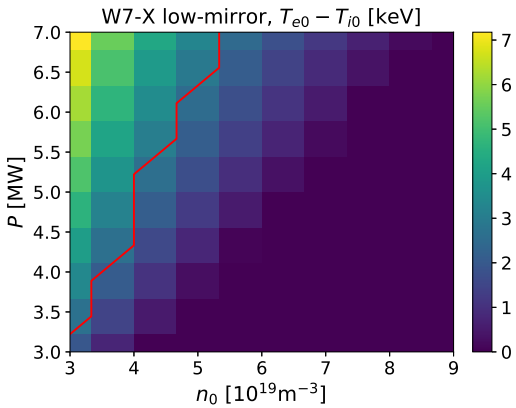


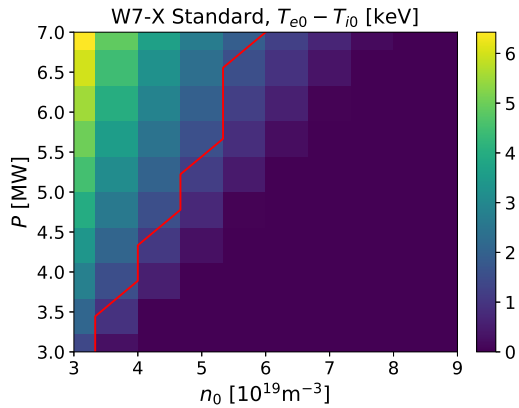


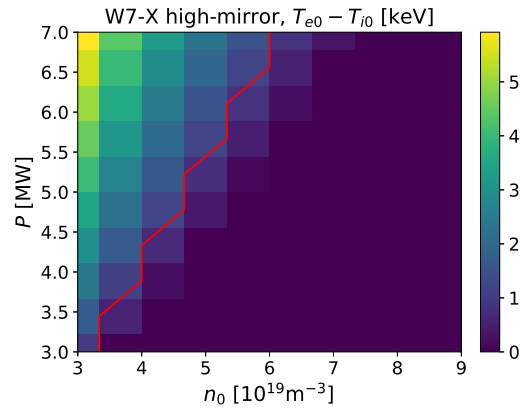


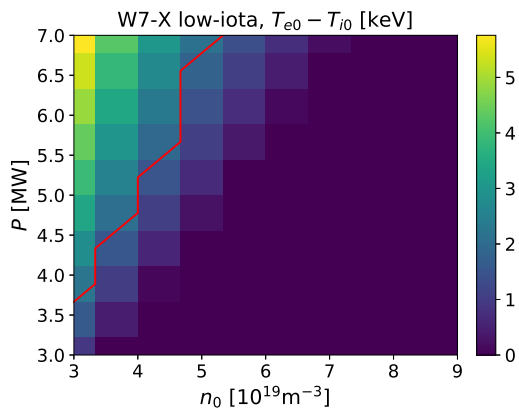
$T_{e,0} - T_{i,0}$


W7-X high-iota, $T_{e0} - T_{i0}$ [keV]
P [MW]
n_0 [10^{19}m^{-3}]

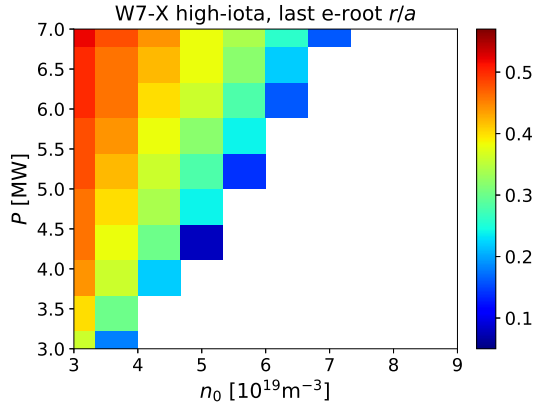

W7-X low-mirror, $T_{e0} - T_{i0}$ [keV]
P [MW]
n_0 [10^{19}m^{-3}]

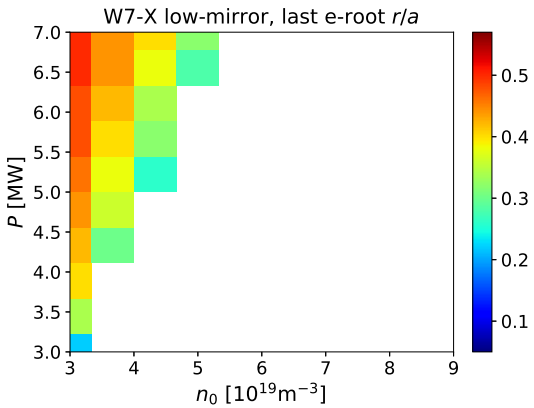

W7-X Standard, $T_{e0} - T_{i0}$ [keV]
P [MW]
n_0 [10^{19}m^{-3}]

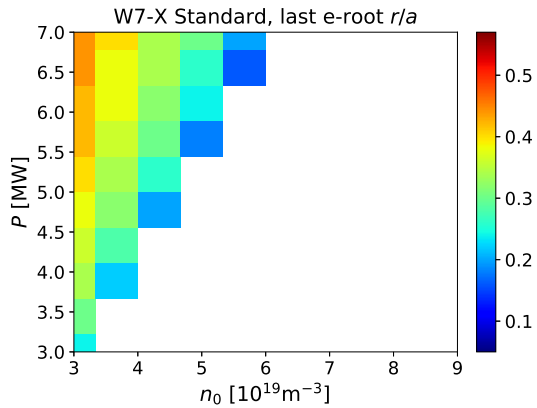

W7-X high-mirror, $T_{e0} - T_{i0}$ [keV]
P [MW]
n_0 [10^{19}m^{-3}]

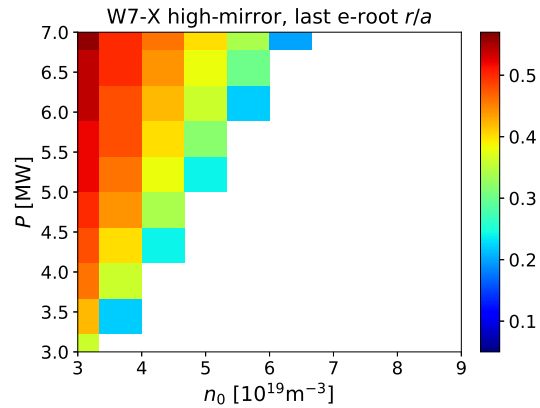

W7-X low-iota, $T_{e0} - T_{i0}$ [keV]
P [MW]
n_0 [10^{19}m^{-3}]

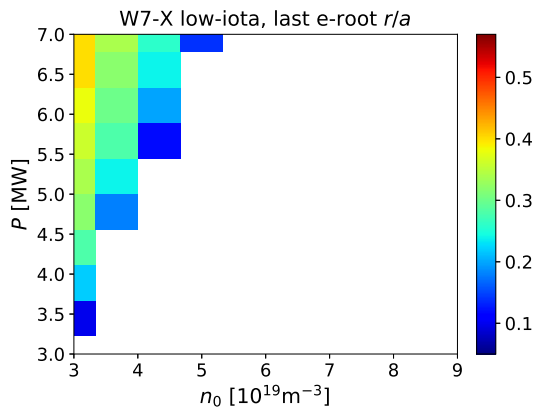
last e-root r/a



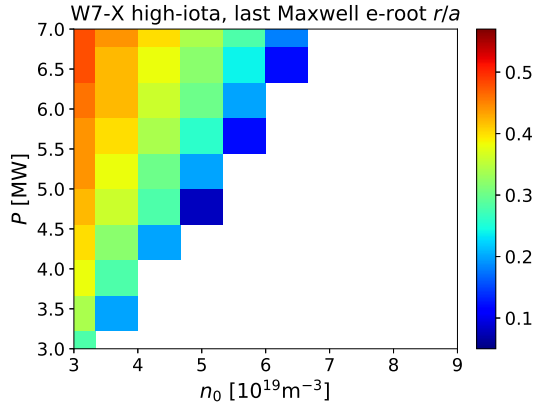


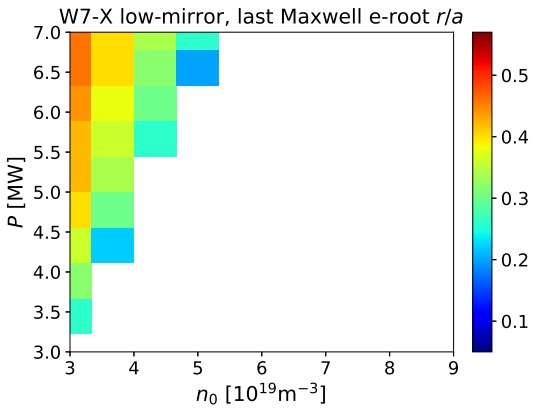


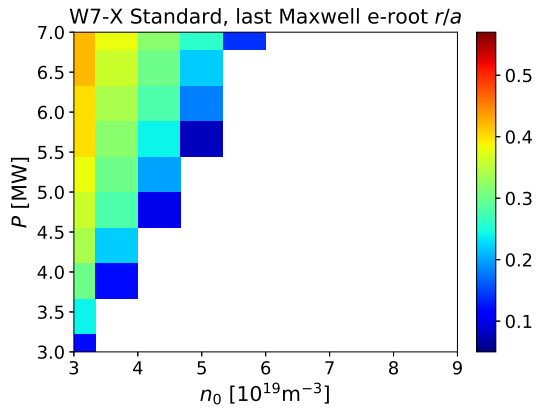


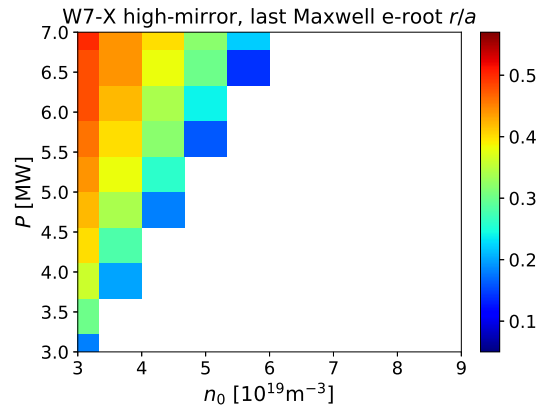


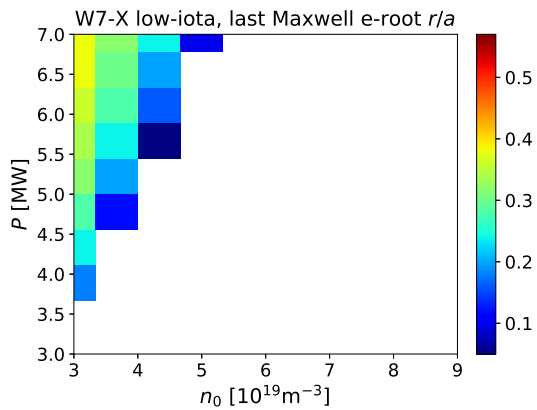
last Maxwell e-root r/a



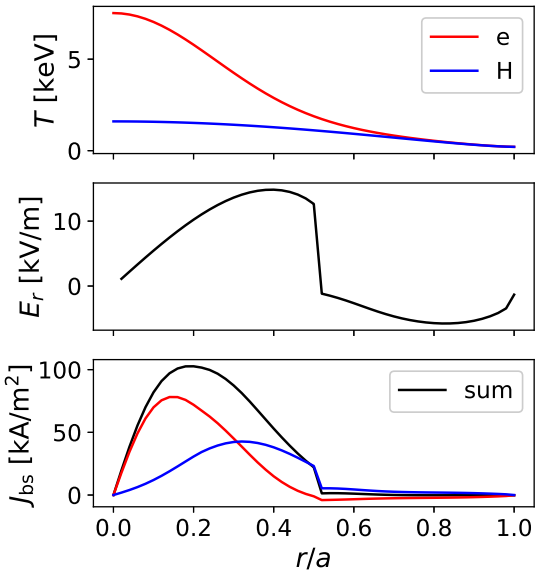


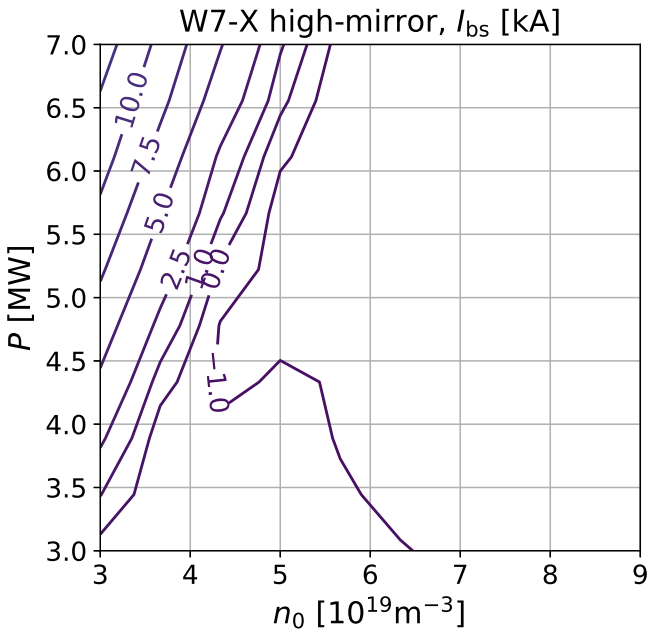


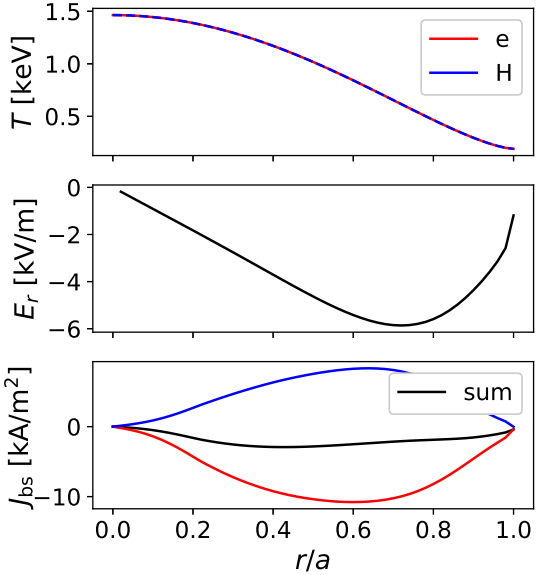


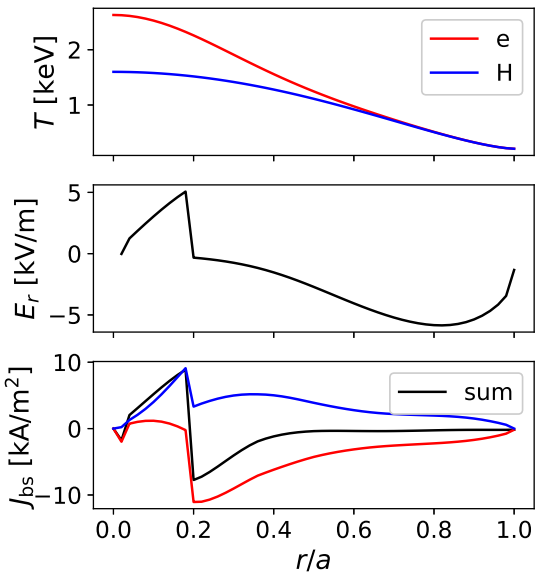


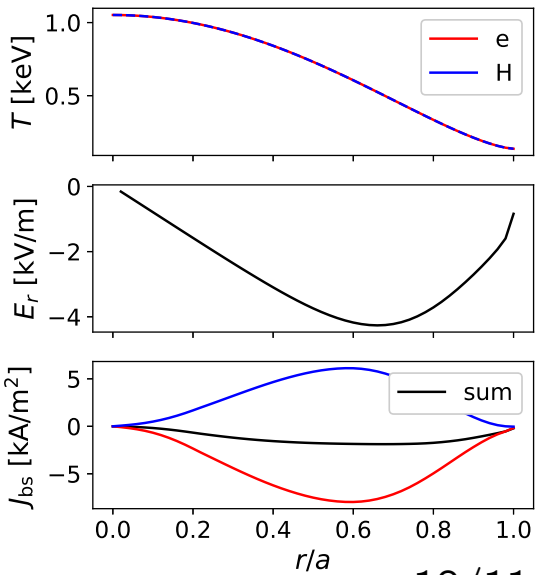
Bootstrap currents, High-mirror



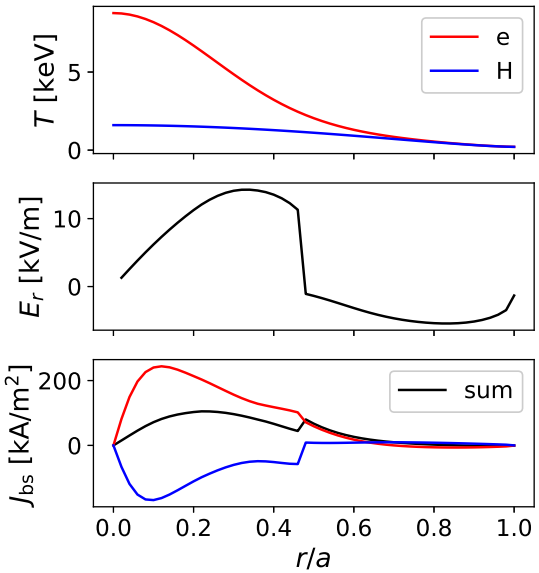


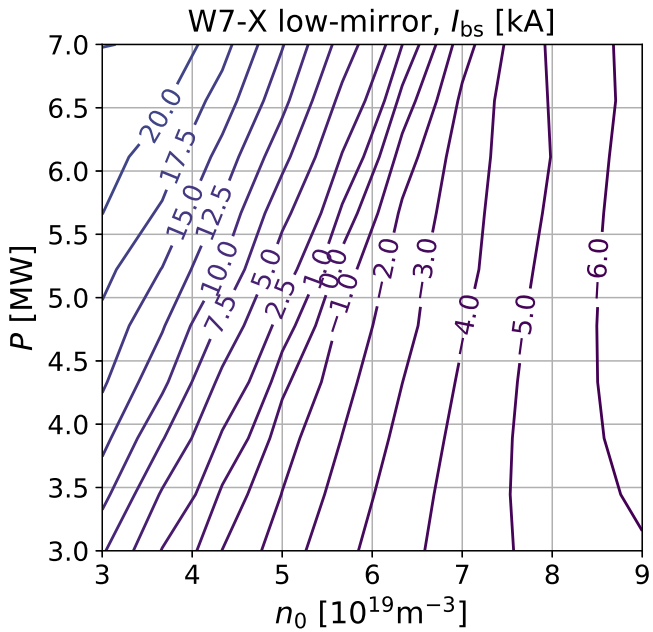


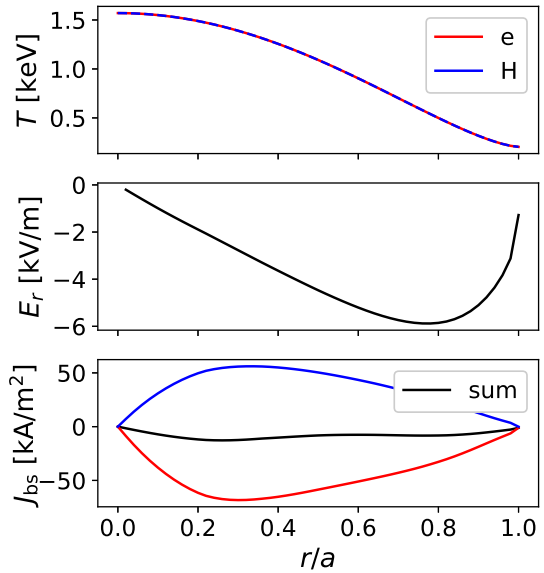


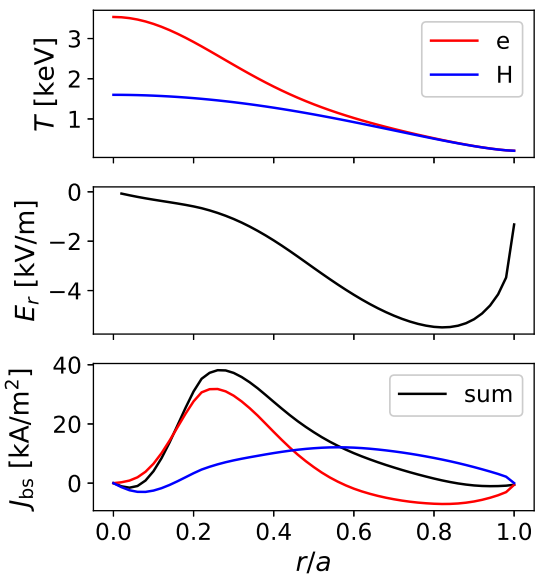


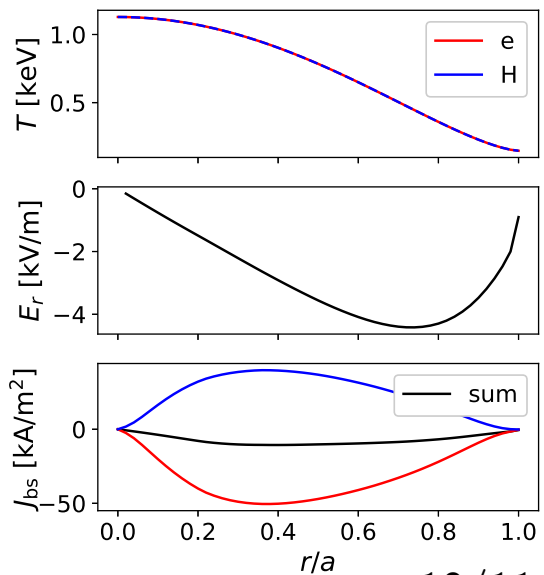
Bootstrap currents, Low-mirror



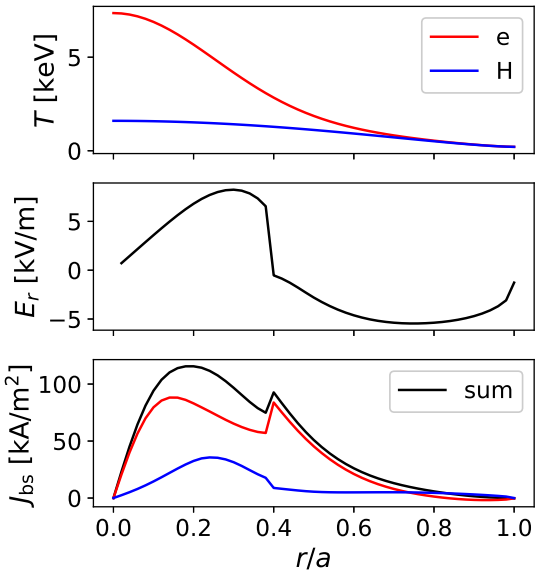


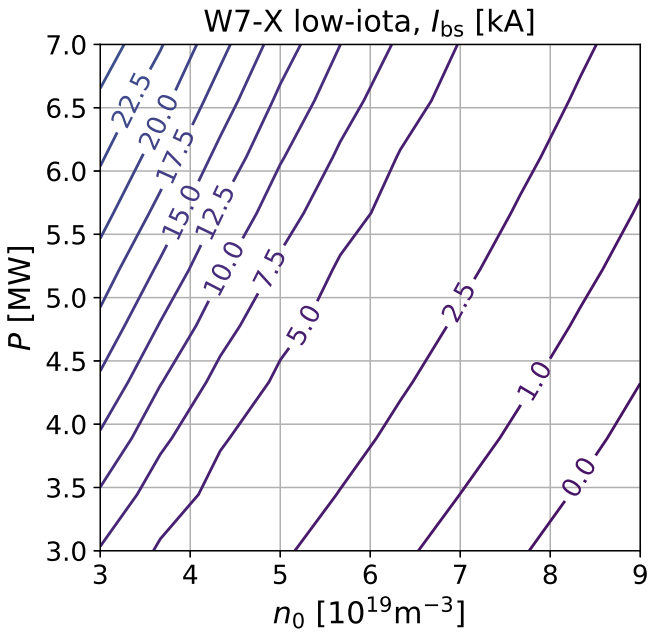


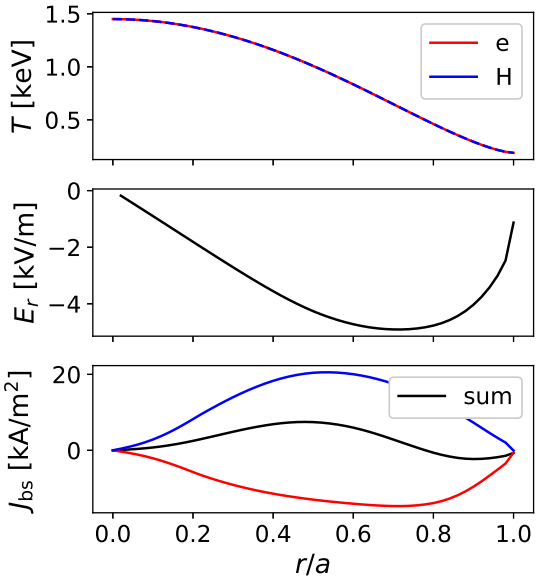


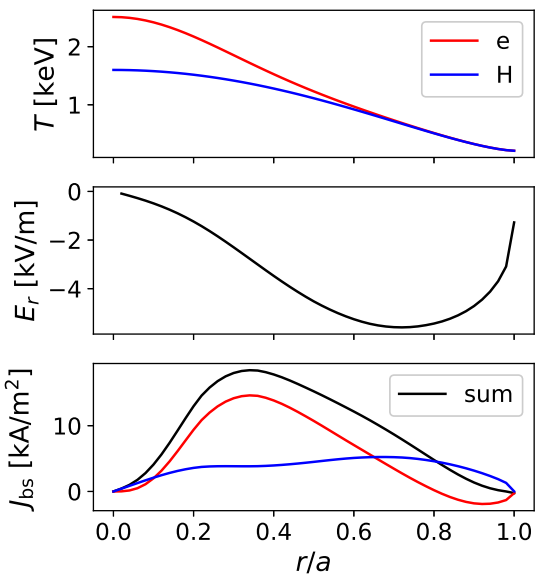


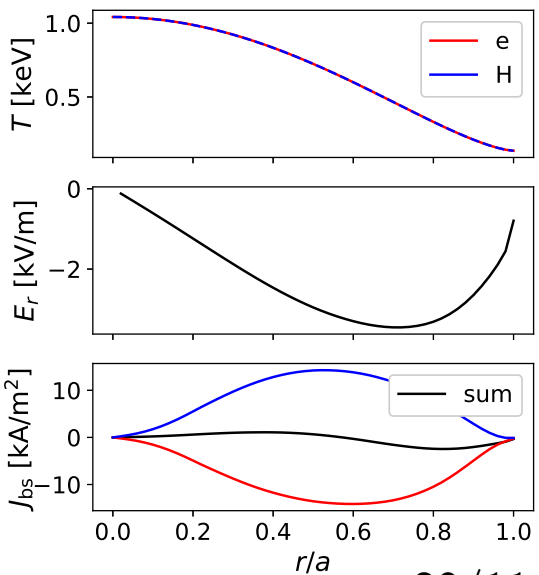
Bootstrap currents, Low-iota



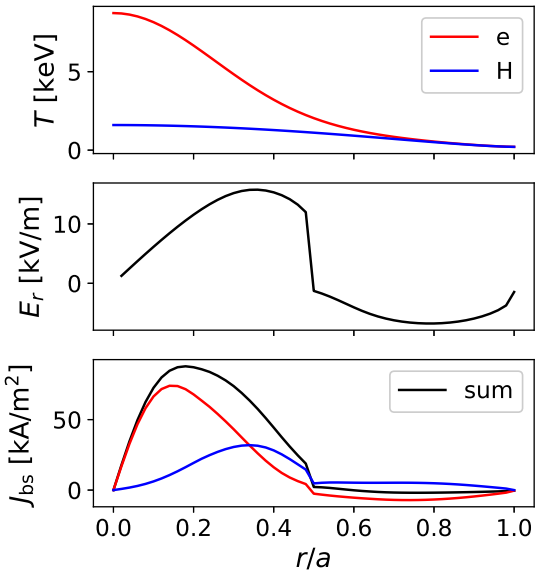


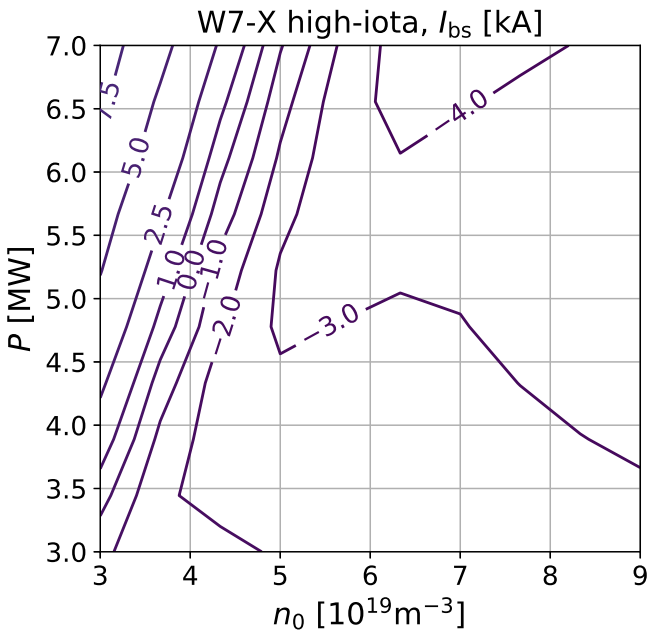


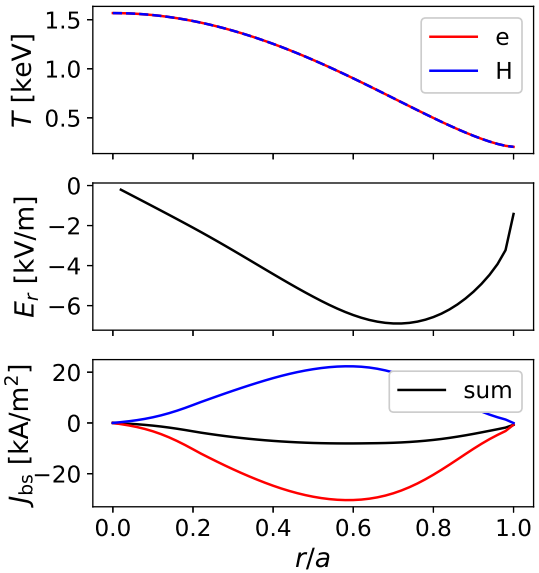


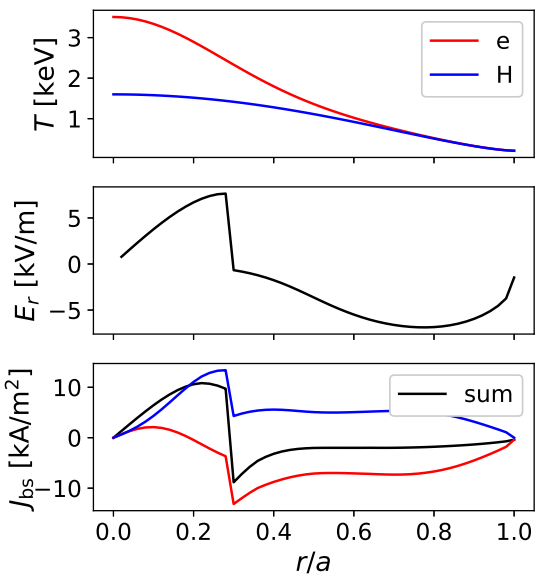


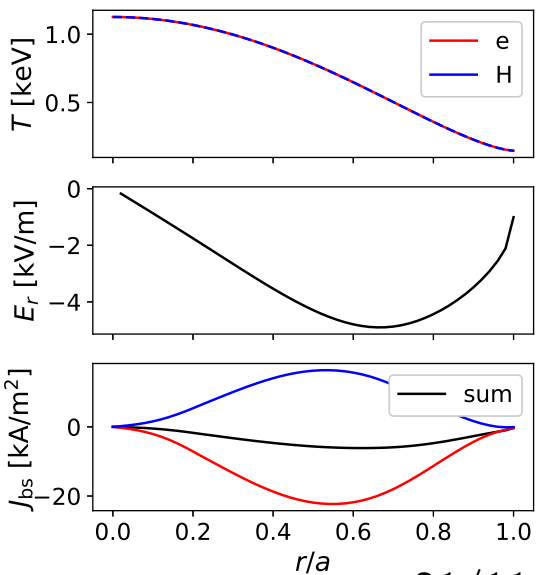
Bootstrap currents, High-iota





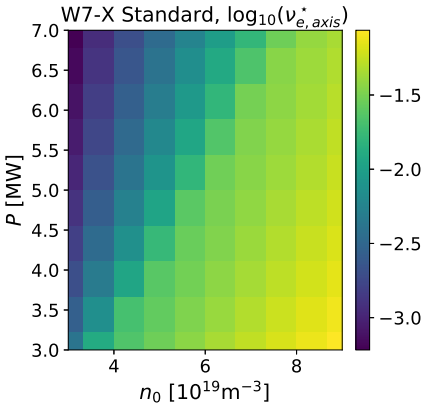


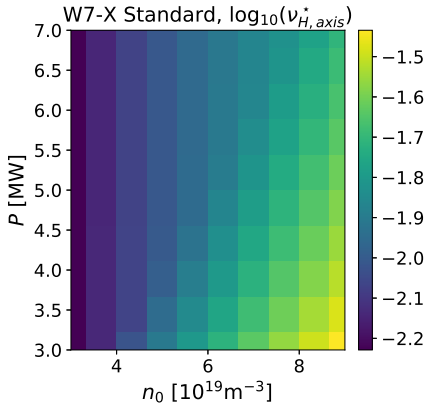




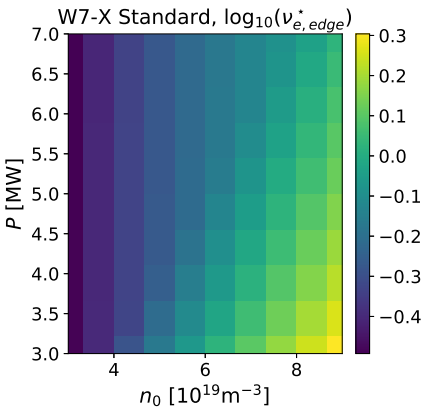
Collisionalities, W7-X standard

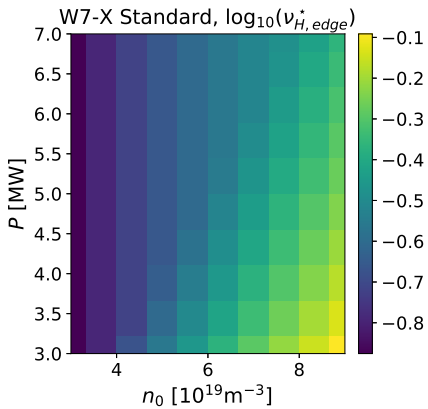
On the axis:



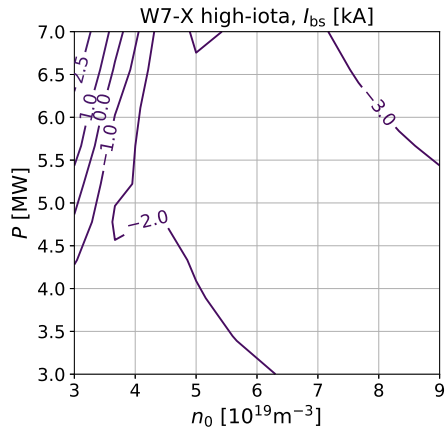


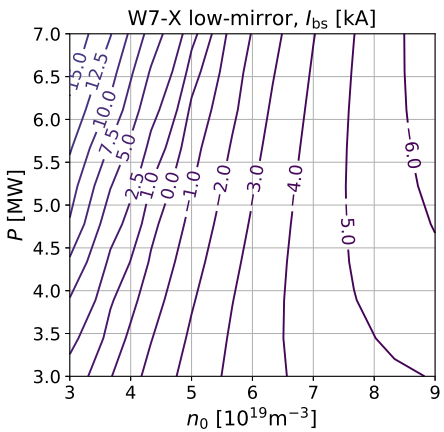
At the Edge:

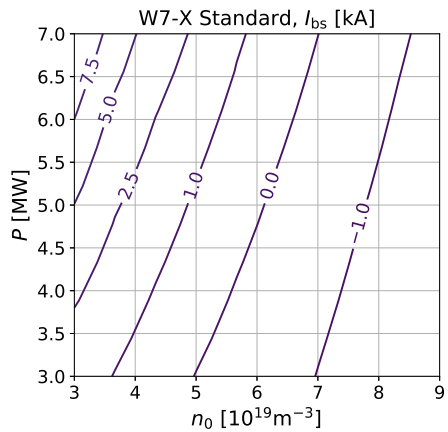


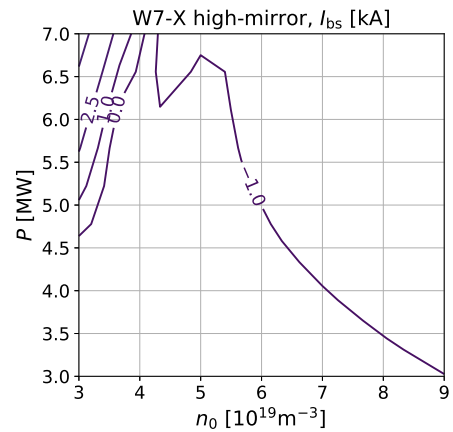


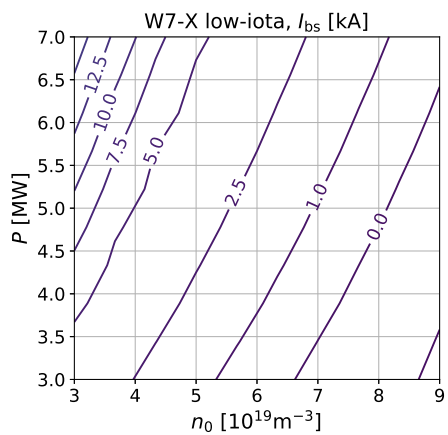
$f_{\mathrm{ren}} = 0.6,\ T_{\mathrm{clamp}} = 1.6$



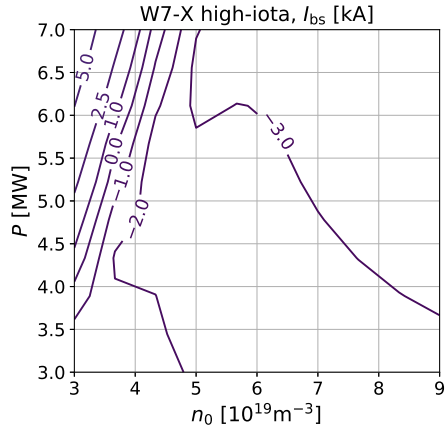


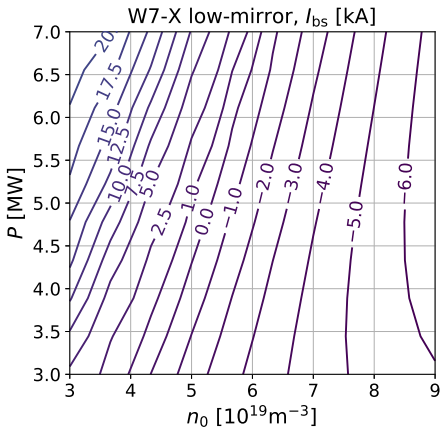


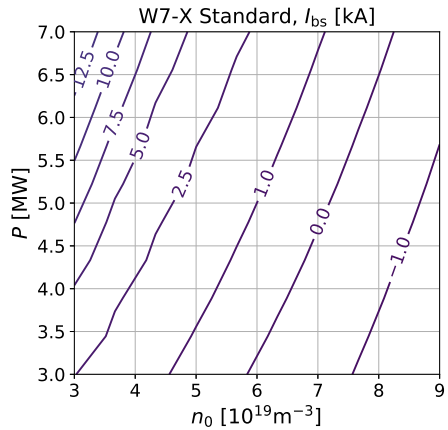


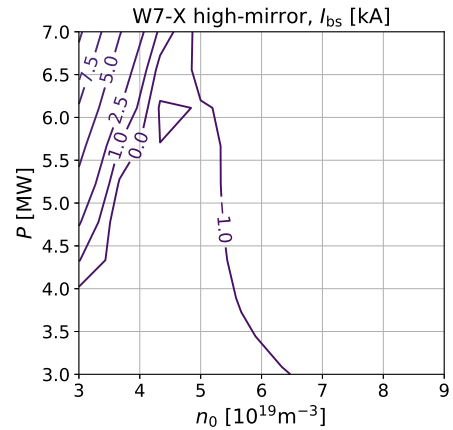


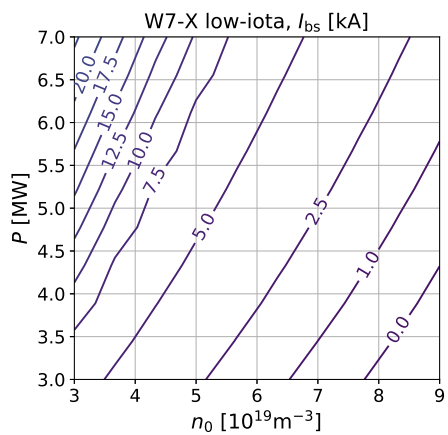
$f_{\mathrm{ren}} = 0.7,\ T_{\mathrm{clamp}} = 1.8$



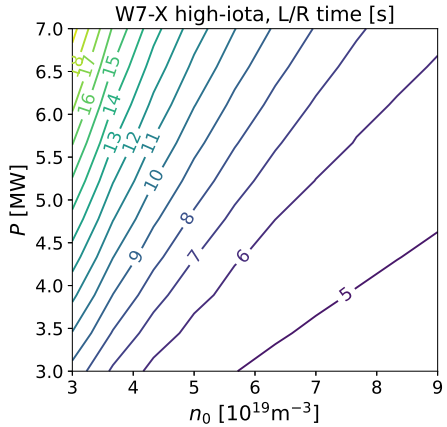


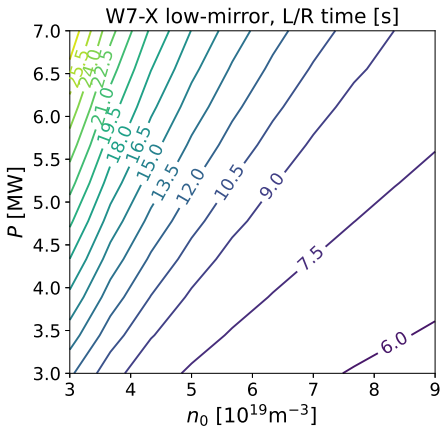


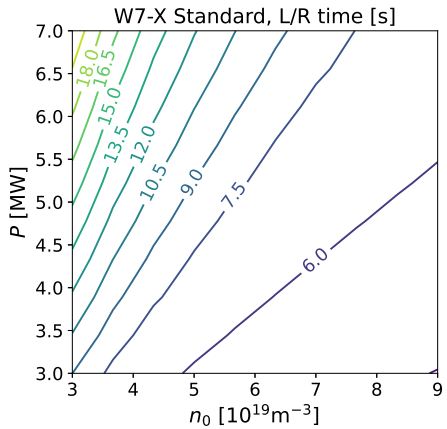


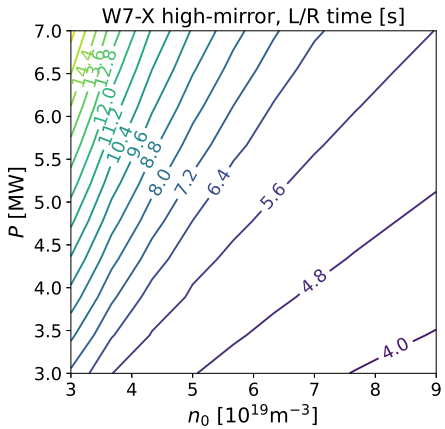


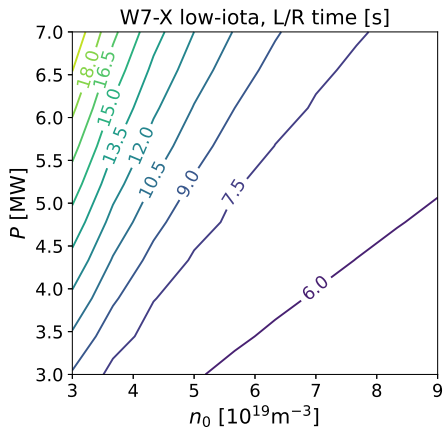
L/R times


W7-X high-iota, L/R time [s]
P [MW]
n_0 [10^{19}m^{-3}]


W7-X low-mirror, L/R time [s]
P [MW]
n_0 [10^{19}m^{-3}]


W7-X Standard, L/R time [s]
P [MW]
n_0 [10^{19}m^{-3}]


W7-X high-mirror, L/R time [s]
P [MW]
n_0 [10^{19}m^{-3}]


W7-X low-iota, L/R time [s]
P [MW]
n_0 [10^{19}m^{-3}]