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Session P5

Role of Core Radiation Losses from Plasma and its Impact on ST Design Parameter Choices

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ABSTRACT

- Attractive physics features and potential low cost make spherical tokamaks (ST) an attractive choice for fusion reactors, especially with the new developments happening on the high temperature superconductors

- In this work, the role of core-radiation is examined for the constraints it poses in the parameter choices

- It is seen that, for low-power designs, it is quite challenging to get a reasonable Q, as radiation fraction from the core needs to remain low

- This gets worse when the fraction of power deposited by the fusion alpha particles is less than unity

MODEL EQUATIONS & ASSUMPTIONS

$q = \frac{5RB_t\,S_\kappa}{A^2 I_p}$ The shape-factor involves κ, δ and A

$\beta_N = \beta\,(aB_t)/I_p$ (β is in %)

$W_\beta = 3\,nT = \frac{3\pi}{8}\frac{\kappa S_\kappa}{qA^3} R^3 B^2$ Stored energy (calculated for given β)

$P_h - P_r = P_L$ In steady-state, the heating is balanced by core-radiation and transport,

$P_L = W_\beta/\tau_E$ transport power-loss estimated for a specific choice of confinement scaling.

$Q_{LF} = P_L/P_f$

$Q = P_f/P_a$ figures-of-merit

$f_r = P_r/P_h$ $P_h = P_\alpha + P_a$ $P_\alpha = f_\alpha\left(\frac{P_f}{5}\right)$ $(1-f_r)\,P_h/P_f = P_L/P_f$

$$\boxed{Q = \frac{1}{\left(\frac{Q_{LF}}{1-f_r}\right) - \frac{f_\alpha}{5}}}$$

- ITER IPB H(98,y2) scaling is used for τ_E. (For the results given here).
- Average Ion Model is used for calculation of impurity radiation
- The helium dilution assumes He-ion confinement time as 10 τ_E

q : MHD safety factor (incl. elongation and aspect ratio factor)

β_N : Normalized toroidal beta

κ, δ and A : the elongation, triangularity and aspect ratio

f_r : fraction of the heating power, escaping as radiation

f_{bs} : fraction of the current driven by bootstrap

f_G : fraction of the Greenwald density limit

f_α : fraction of the alpha power deposited in the plasma

H_h : The H-enhancement factor

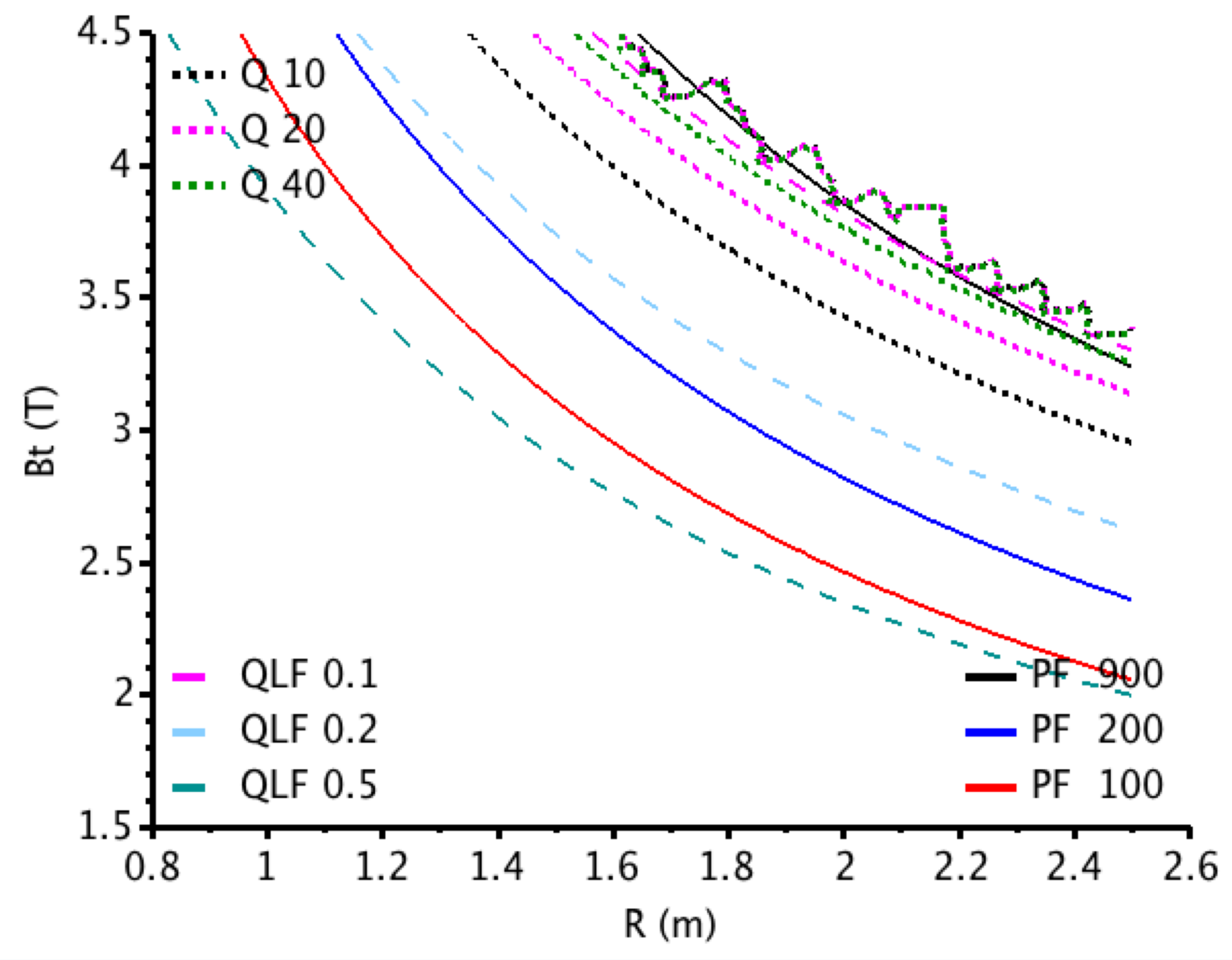
M : the average mass, taken as 2.5 (D and T)

S_n : 0.5 (parabolic density profile exponent)

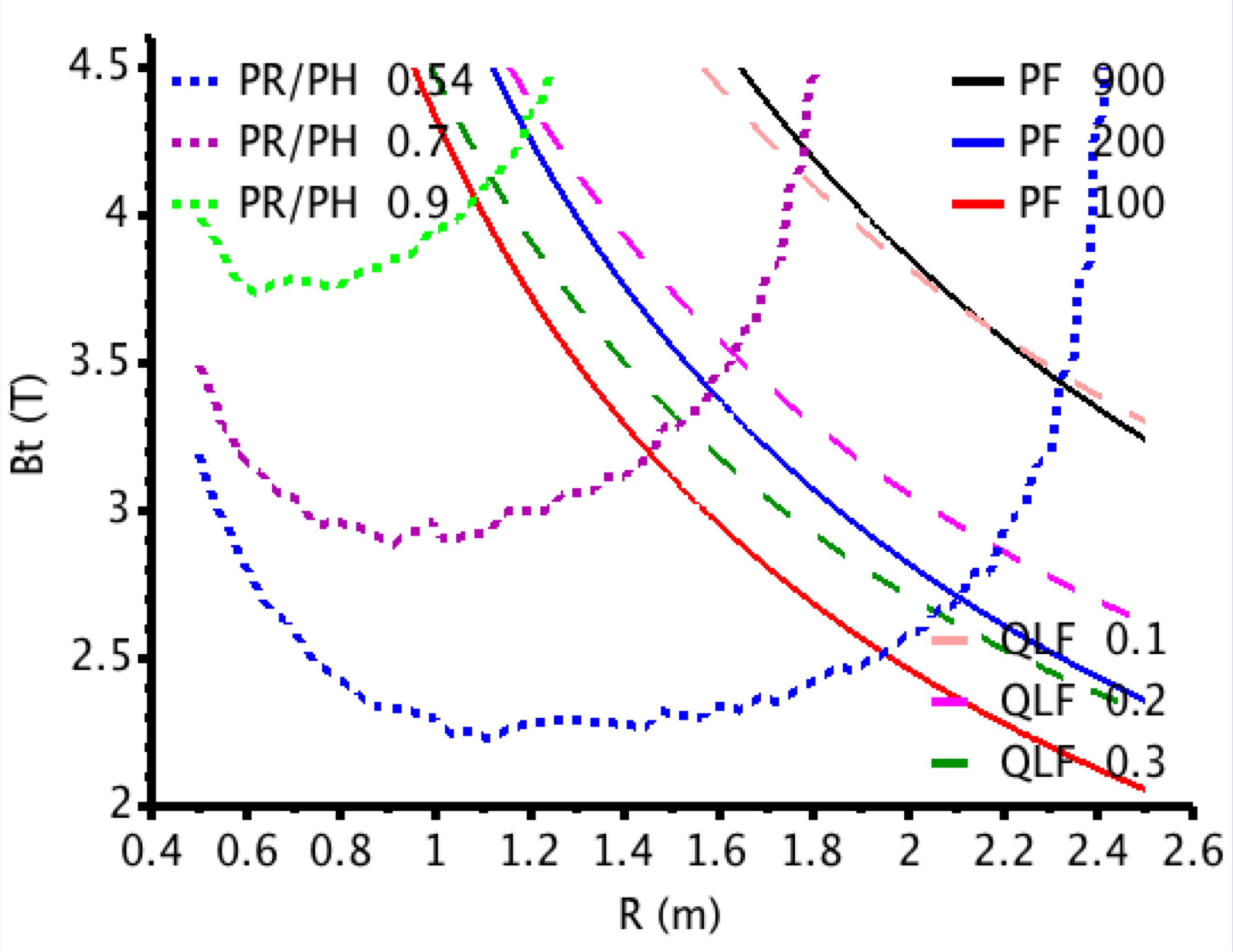
S_T : 1 (parabolic temperature profile exponent)

fz_Fe, fz_Ne and fz_W: impurity concentrations for iron, neon and tungsten

All the above 16 parameters are held constant in R-Bt space scan



The figure above shows contours of fusion power, fusion-gain, and normalized separatrix (transport) power loss. Here a constant fraction of radiative loss (Prad/Pheat) of 0.54 has been held constant. Notice that the high Q curves are much above PF 200 contour. For the 100 MW case, Q would be ~ 1, making it necessary to have a H&CD investment of 100 MW, thus of questionable practicality.



The figure above shows contours of fusion power, normalized separatrix (transport) power loss and ratio of radiated power to heating power. This assumes a fixed tungsten impurity concentration of 10^{-5} (n_W/n_e). Notice that the for the 900 MW case, a reasonably large Q is possible, but size needs to be large for a modest radiated fraction. More compact reactor would need higher radiated fraction.

SUMMARY

Given the fact that compact tokamaks can have strong erosion and hence greater likelihood of core impurities, the role of radiation assumes importance in parameter-space scoping, especially in conjunction with (possibly) unconfined alphas.

The power balance requirement (with) ITER IPB scaling applied to ST, shows that compact reactors (~100 MW) may require significant H&CD investment.

More studies are needed for efficient CD, high bootstrap fraction and concomitantly improved confinement time scalings.