Progress on Systems Code Application to CS Reactors

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UT-BATTELLE

TOPICS

- **Features of 1-D POPCON plots**
- **POPCON analysis of Ku's ref. case**
- **POPCON analysis of a revised case**
  - **sensitivities to different assumptions**
- **Next step: better model for B_{max}/B_0 vs Δ**

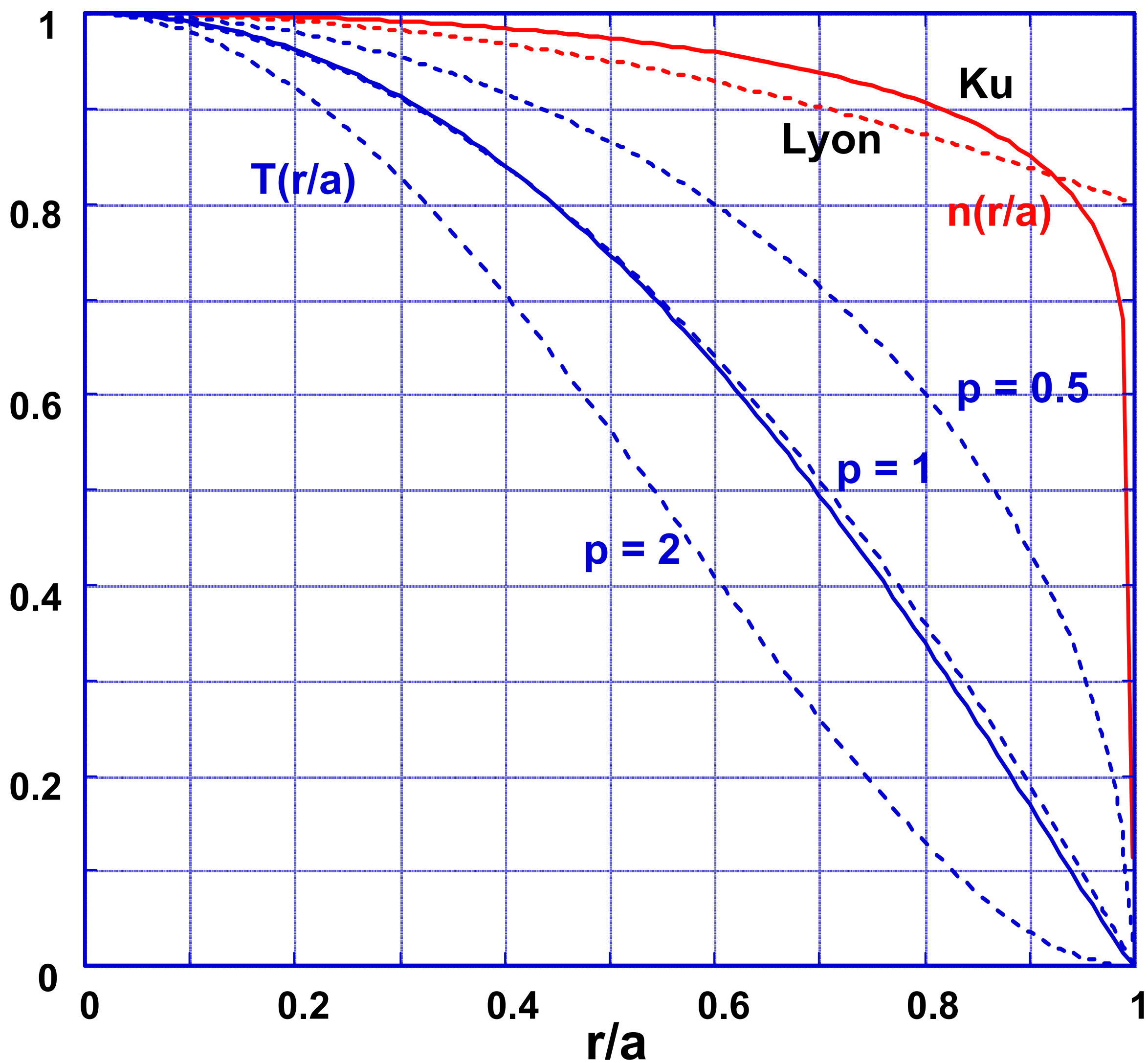
1-D POPCON Calculations

- **Input *variables***
  - magnetic configuration: $\langle R \rangle$,$\langle a \rangle$, B_0, ι(r/a),
  - plasma properties: $\tau_E^{ISS\text{-}95}$ multiplier H, τ_{He}/τ_E, α-particle loss %, n(r/a) and T(r/a) shapes, C and Fe %

- **Constraints**
  - fusion power P_{fop}, $n < 2n_{Sudo}$, $\beta < \beta_{limit}$,

- **Calculated quantities**
  - operating point: $\langle n \rangle$, $\langle T \rangle$, $\langle \beta \rangle$, P_{fusion}, %He, %D-T, Z_{eff}
  - minimum ignited point: $\langle n \rangle$, $\langle T \rangle$, $\langle \beta \rangle$, P_{fusion}
  - saddle point: $\langle n \rangle$, $\langle T \rangle$, $\langle \beta \rangle$, P_{in}
  - $P_{in}(\langle n \rangle,\langle T \rangle)$ contours
  - $P_{rad}(\langle n \rangle,\langle T \rangle)$: coronal and bremsstrahlung; P_α losses

Profile Assumptions



Other Variables

P_{fus} = 2 GW

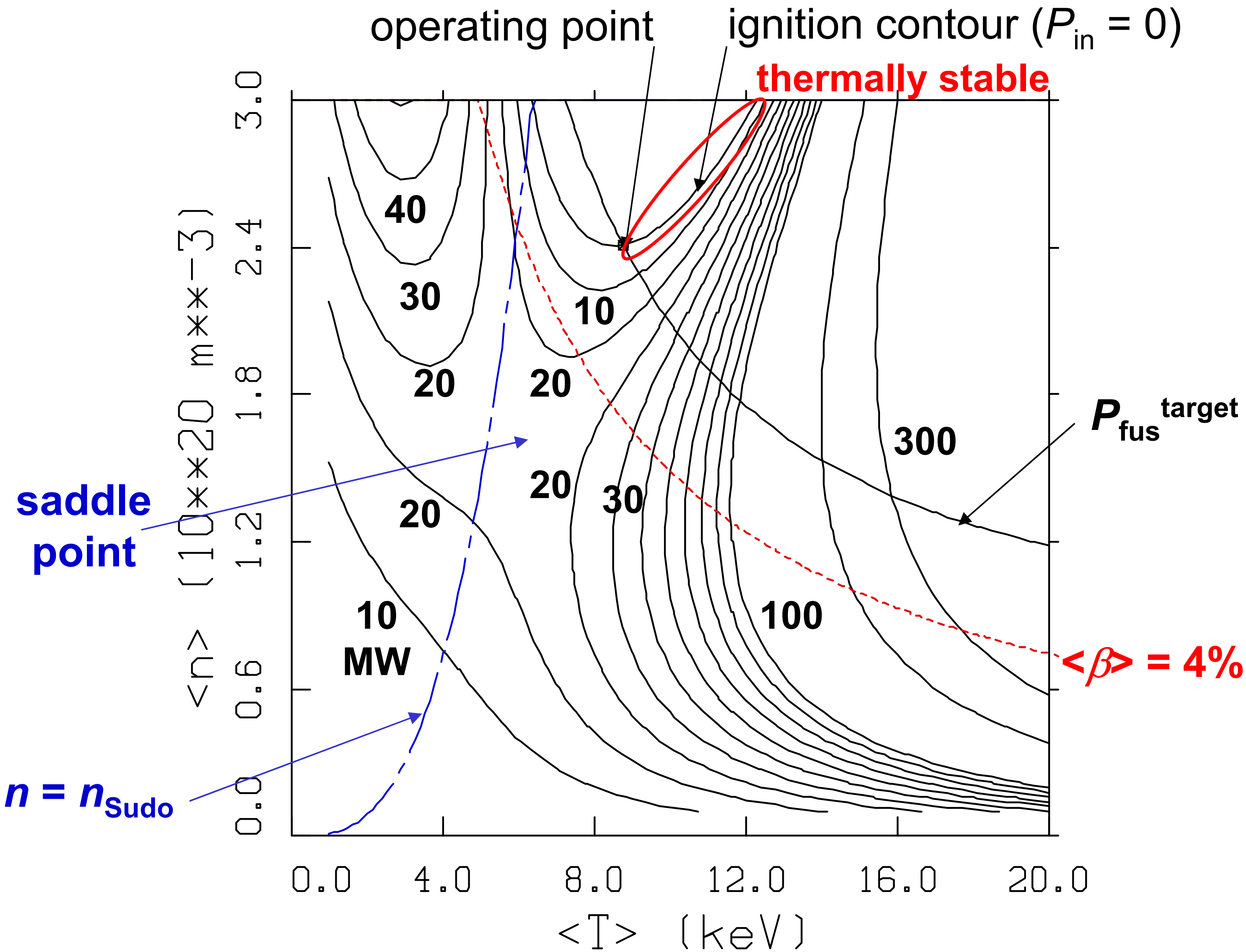
H^{ISS-95} = 3

10% α loss

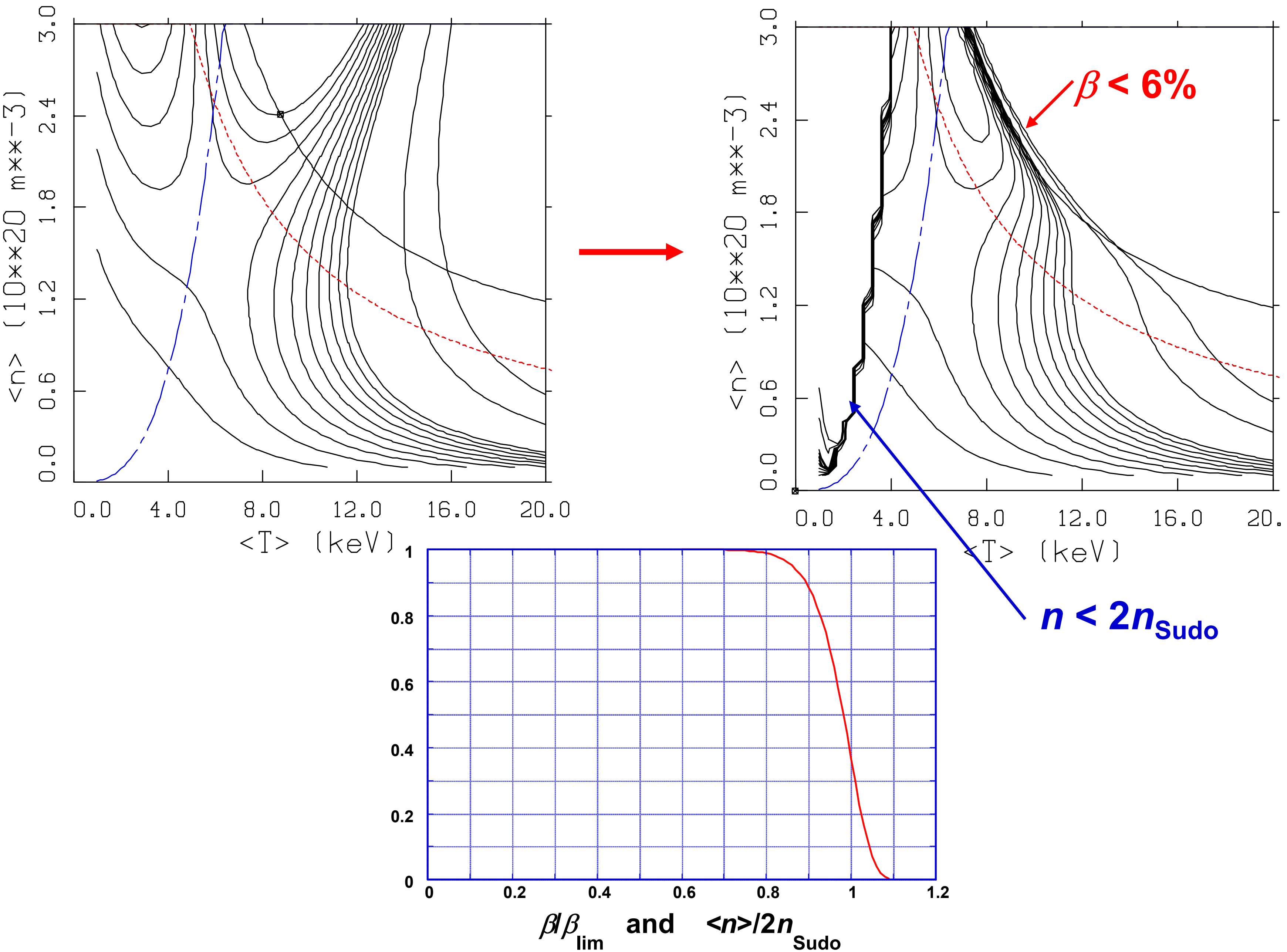
τ_{He}/τ_E = 6

C 1%, Fe 0.01%

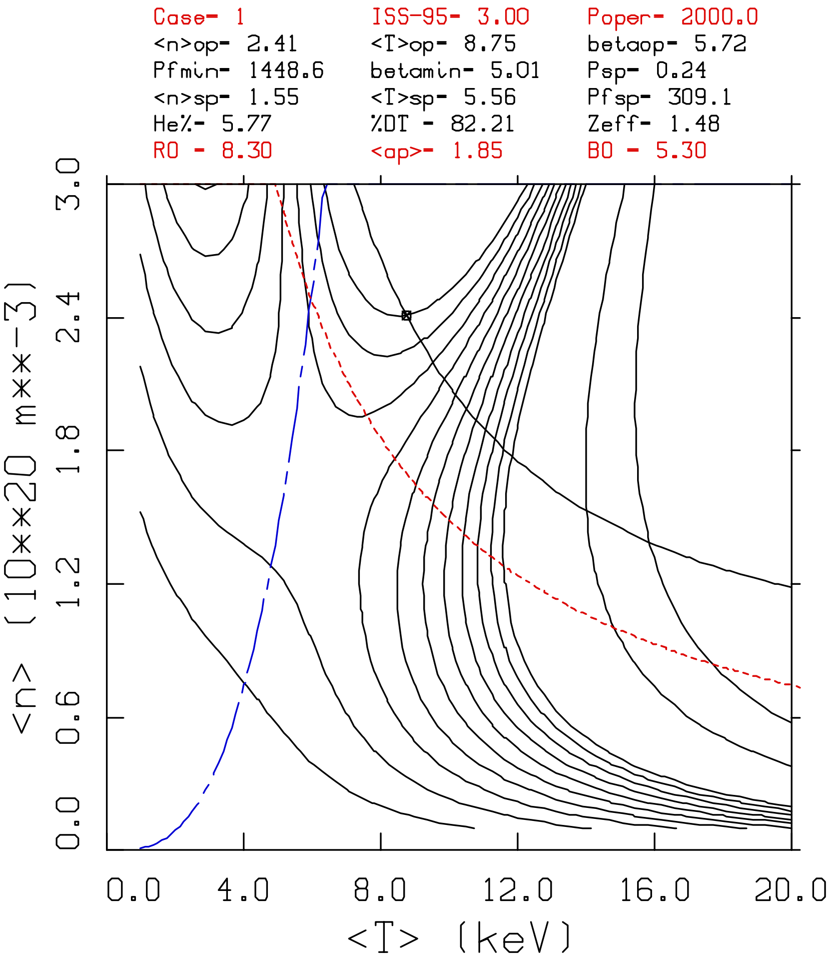
POPCON Features

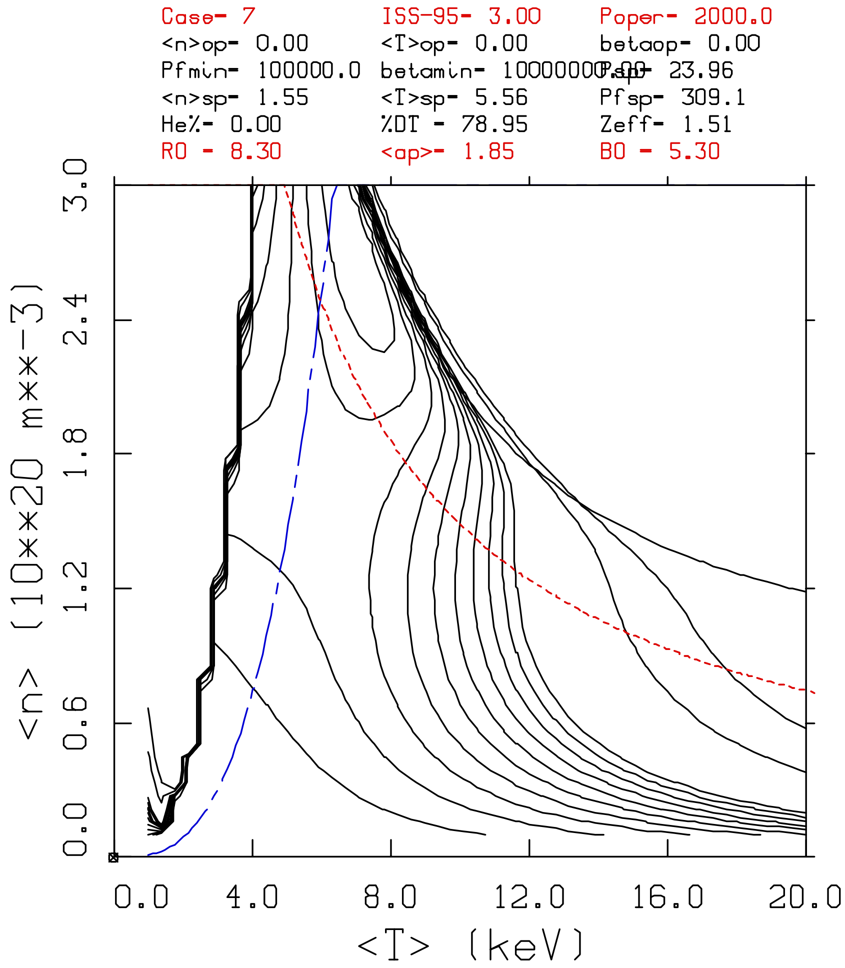


Constraints Limit Operating Space

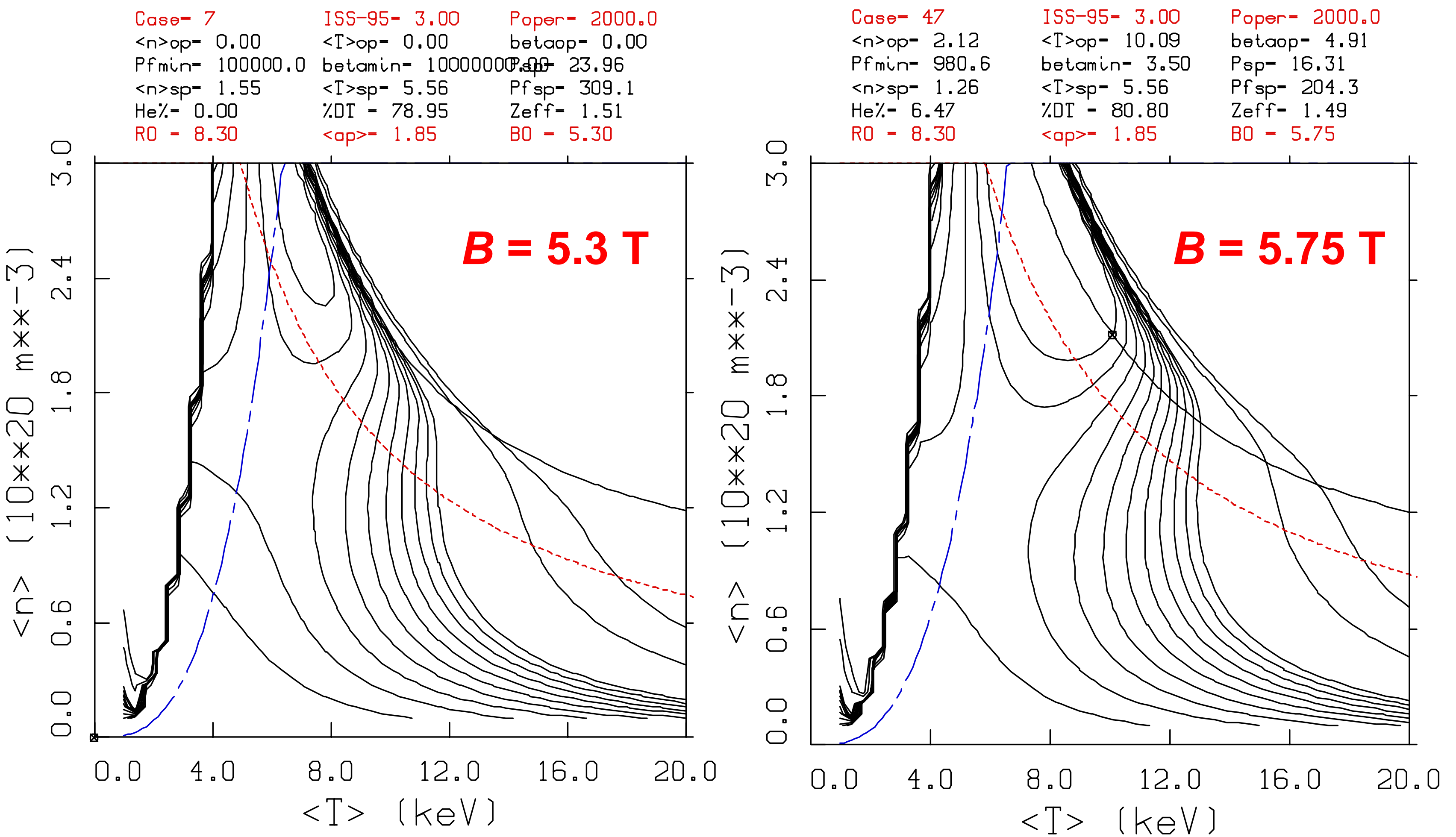


Ku Reference Parameters not Viable





Raising *B* Helps



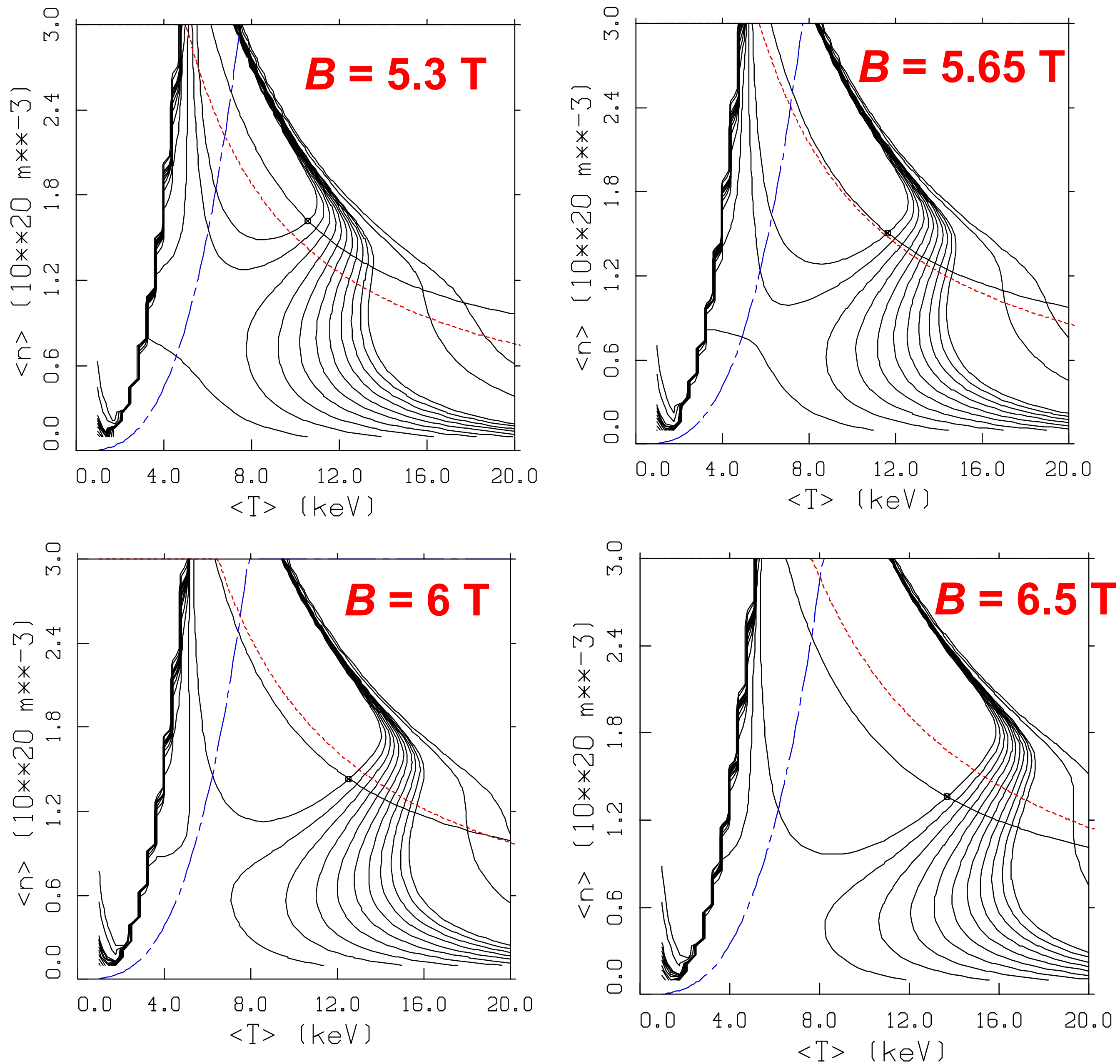
Remedies

- Increase $A_\Delta = R/\Delta$
  - leads to more complex coils and higher B_{max} on coils
- Increase B to 5.75 m and allow $<\beta>$ = 4.91%
  - increases B_{max} on coils
  - however Δ already too small
- Increase Δ to 1.4 m ==> R = 9.68 m

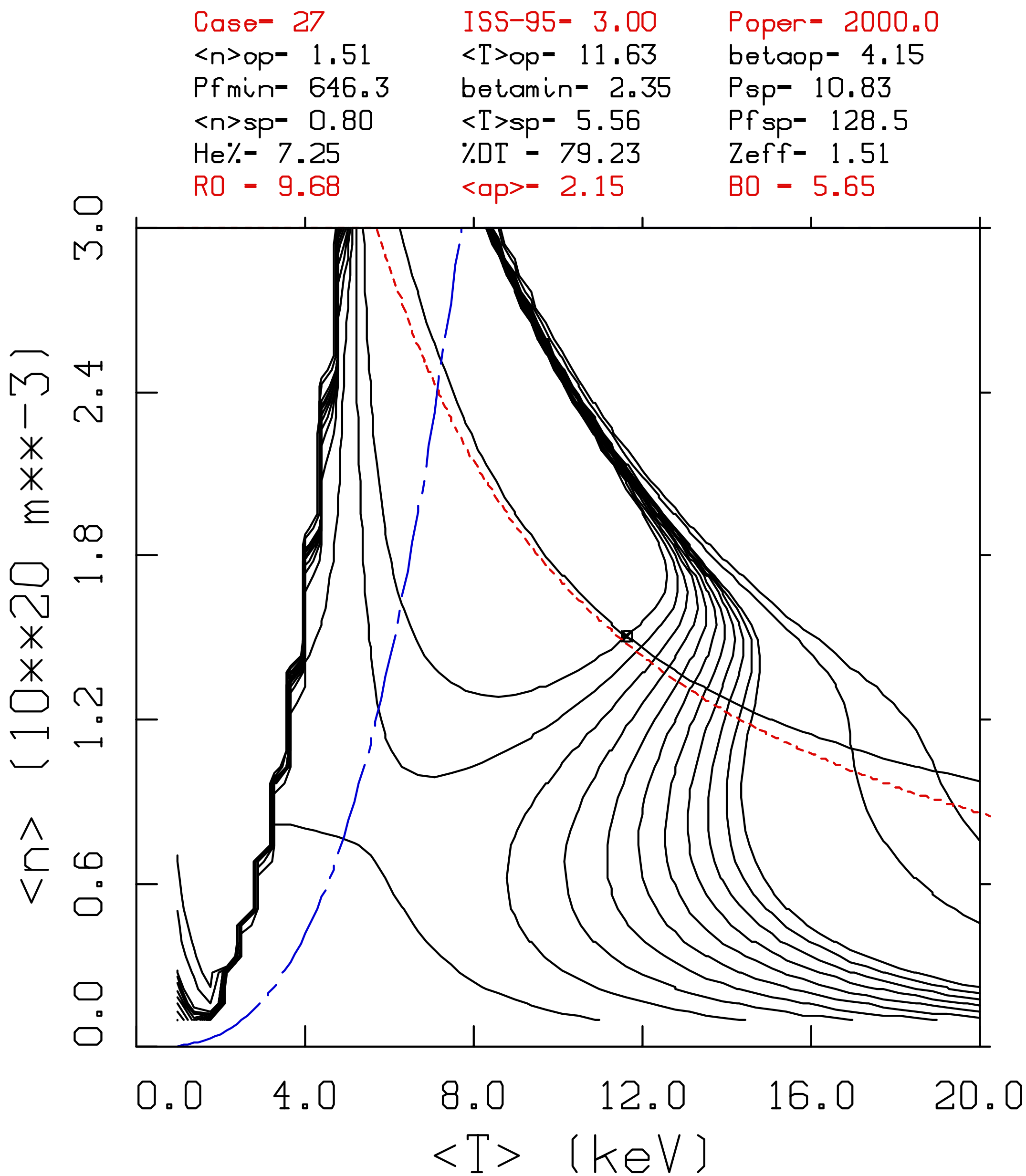
Reasons for Increasing Δ

- *R* = 8.3 m and Δ = 1.2 m
  - coil dimensions (20 cm x 20 cm) too small
    <*j*> = 32.5 kA/cm^2 not credible
  - plasma-wall distance too small -- 5 cm, 10-15 cm better
- Superconducting coil considerations (Schultz)
  - can assume *j* = 150 kA/cm^2 for SC
  - can assume *j* = 30 kA/cm^2 for Cu
  - if 1:1 for SC:Cu areas ==> 25 kA/cm^2
  - can assume 800 Mpa for conduit and 400 MPa for thick case
  - however need to allow 2/3 additional space for He
    ==> 15 kA/cm^2?
- Increasing Δ to 1.4 m ==> *R* = 9.68 m
  - allows 30 cm x 30 cm for coil -- <*j*> = 16.8 kA/cm^2 (too high?)
  - allows 10 cm extra for coil case and plasma-wall distance or more space for coil to reduce <*j*>

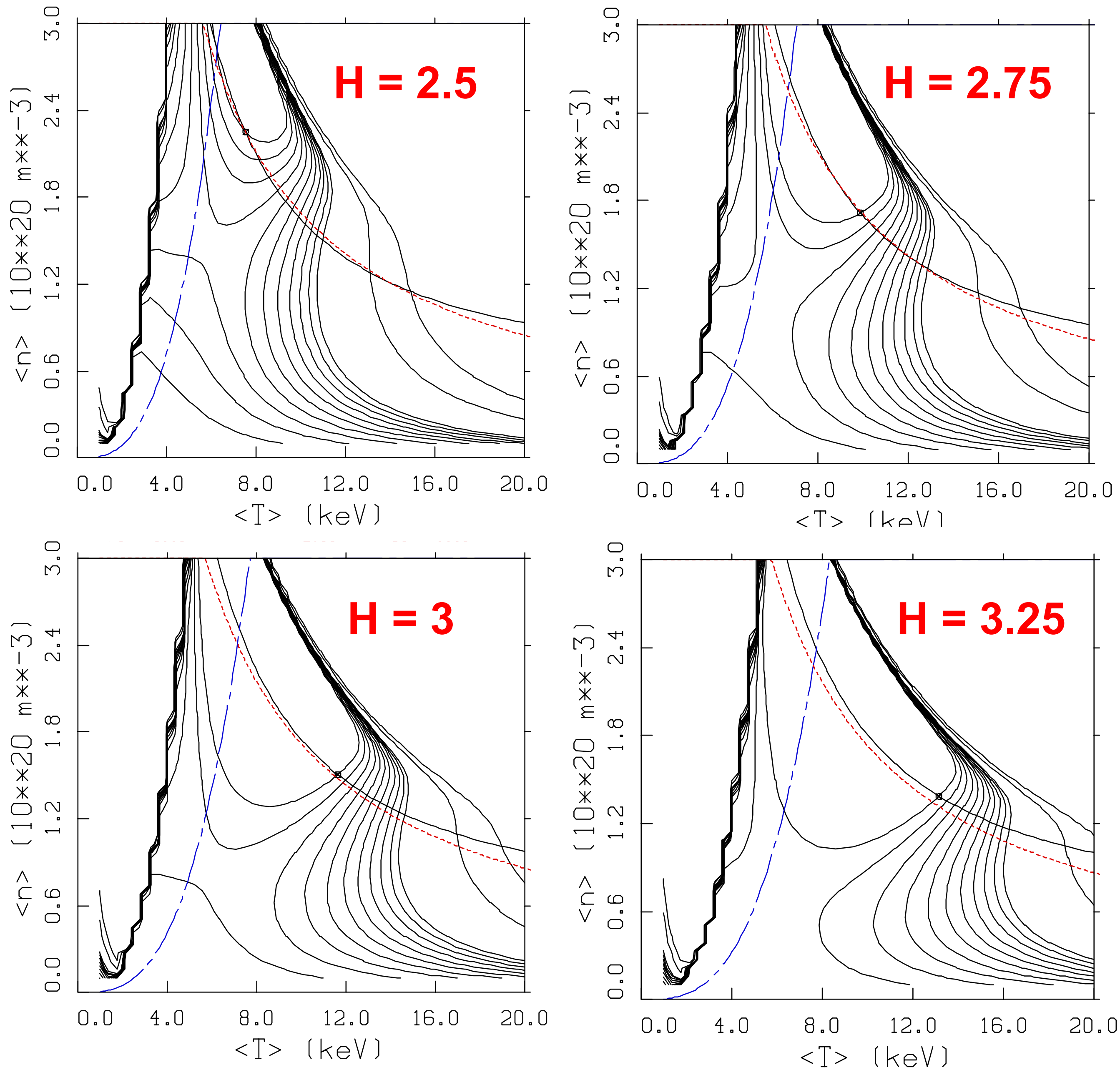
Sensitivity to *B* for *R* = 9.68 m



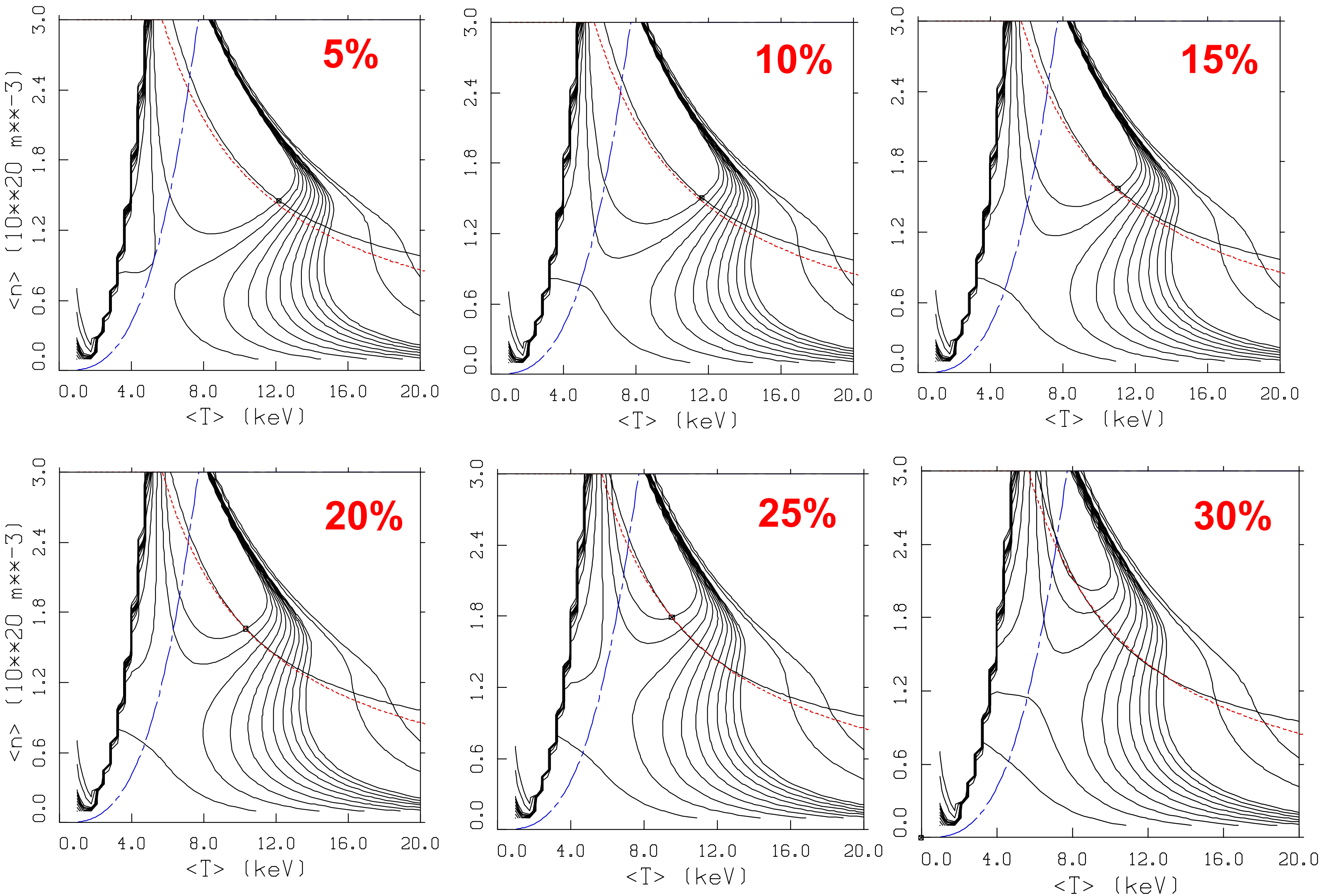
Base Case with *R* = 9.68 m



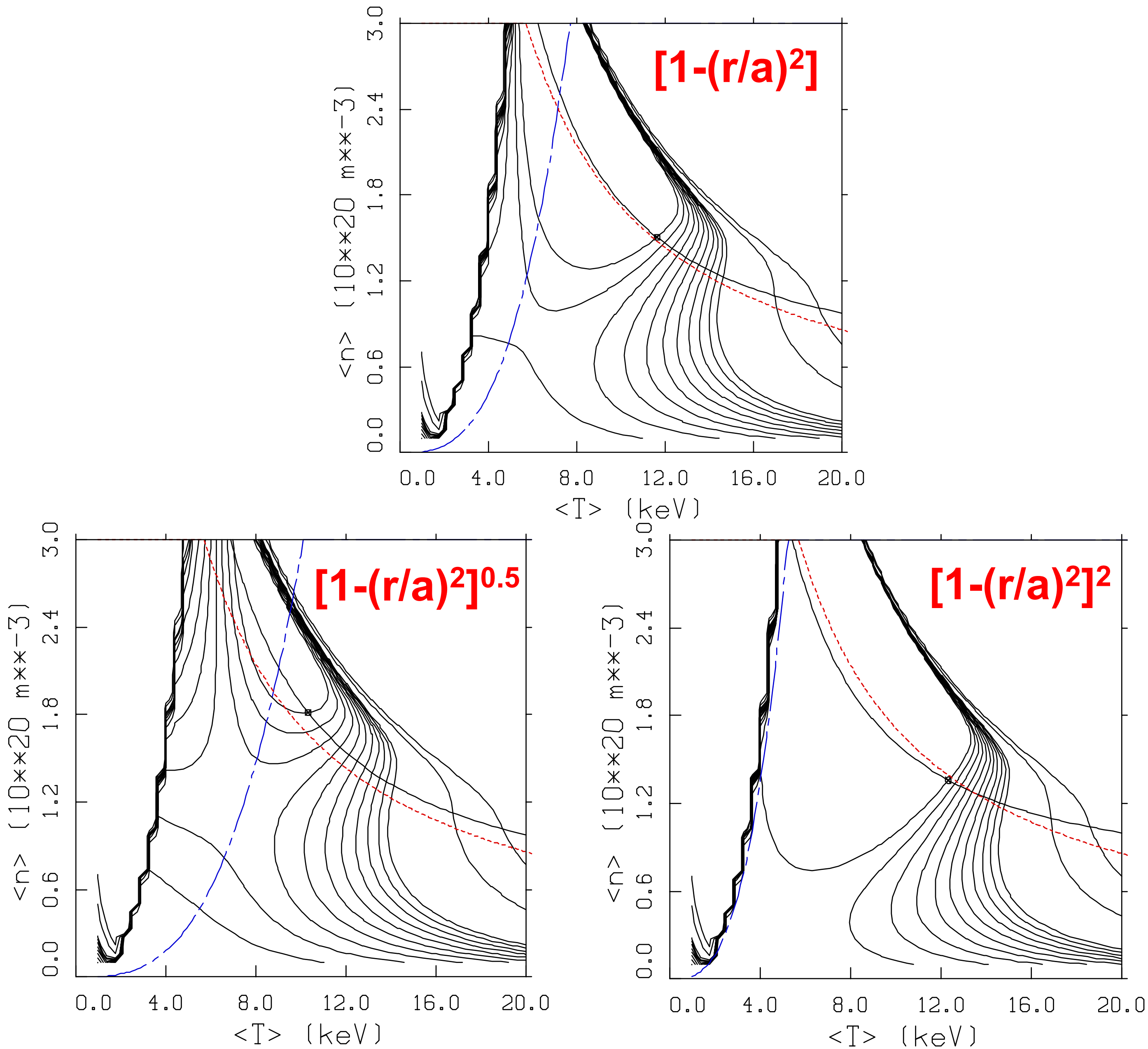
Sensitivity to Confinement (H^{ISS-95}), *R* = 9.68 m



Sensitivity to α-particle Losses, *R* = 9.68 m

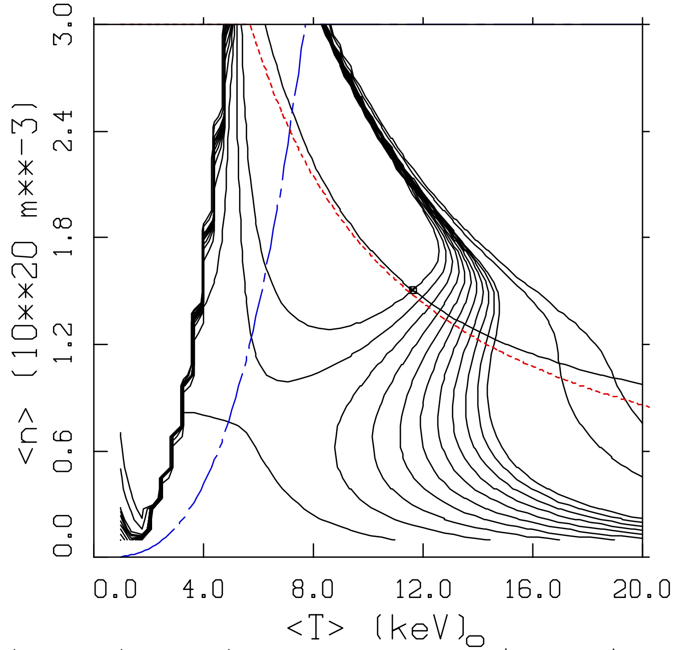


Sensitivity to *T*(r/a), *R* = 9.68 m

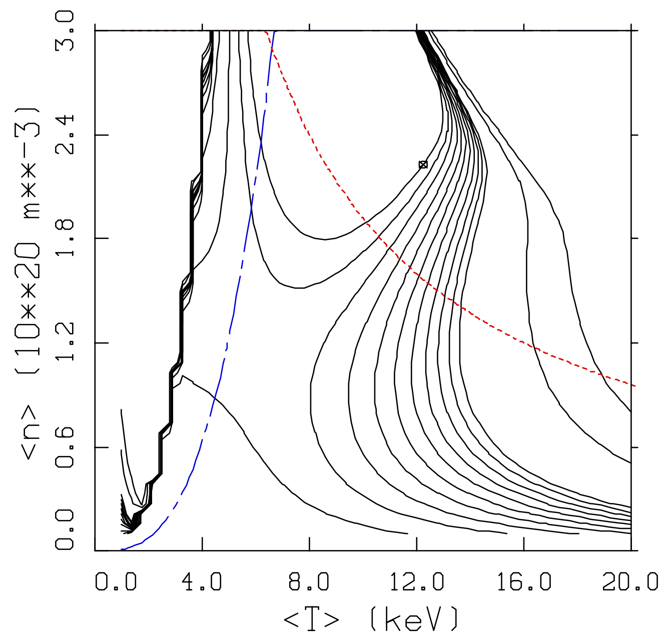


Options for Higher Power Operation, R = 9.68 m

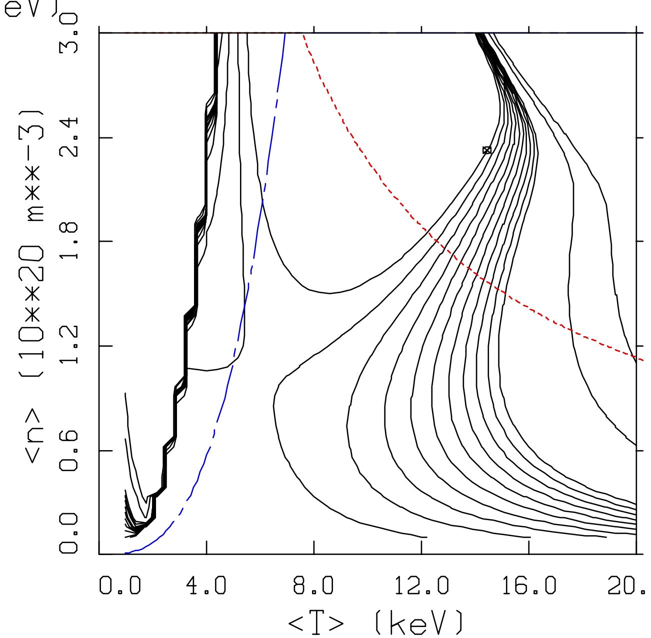
P_f = 2 GW
β = 4.15%
B = 5.65 T



P_f = 3 GW
β = 5.72%
B = 6 T



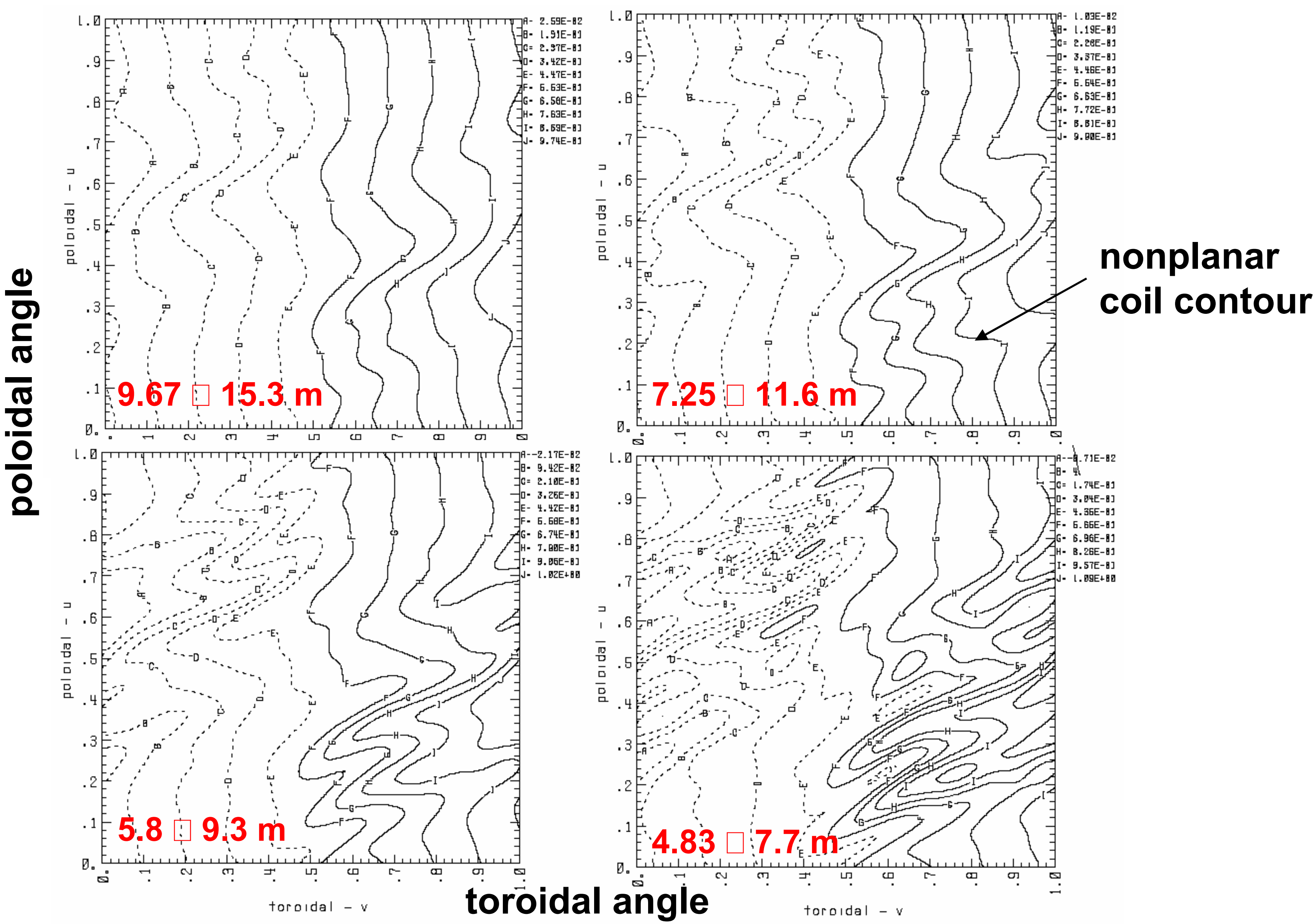
P_f = 4 GW
β = 5.96%
B = 6.5 T



Next Step

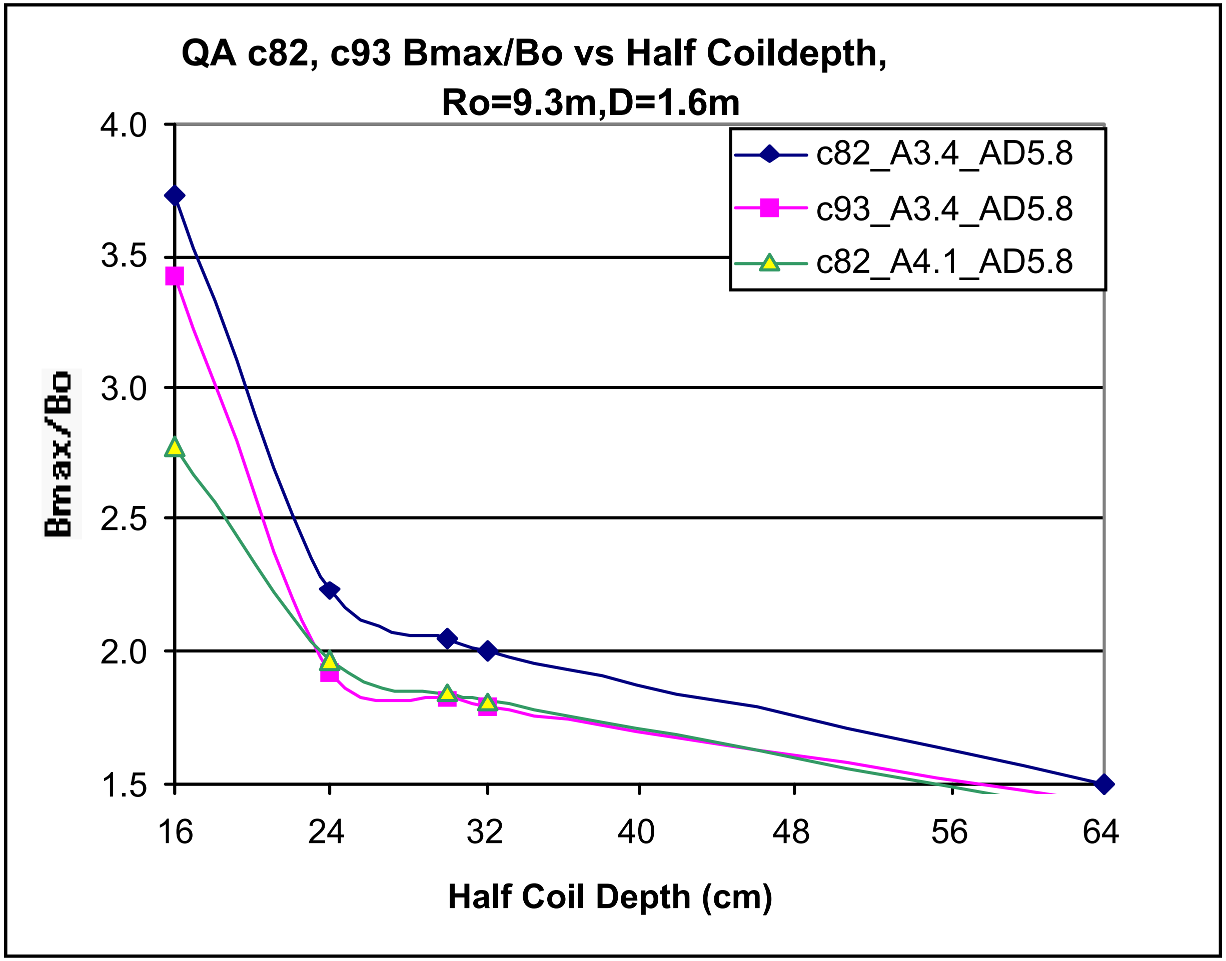
- Need better model to proceed further
  - B_{max}/ B_0 vs Δ ==> model for coils vs Δ
  - <j>(B_{max}) needs forces on the coil

Coils Become More Complex (and B_{max}/B_0 Increases) as R/Δ Decreases

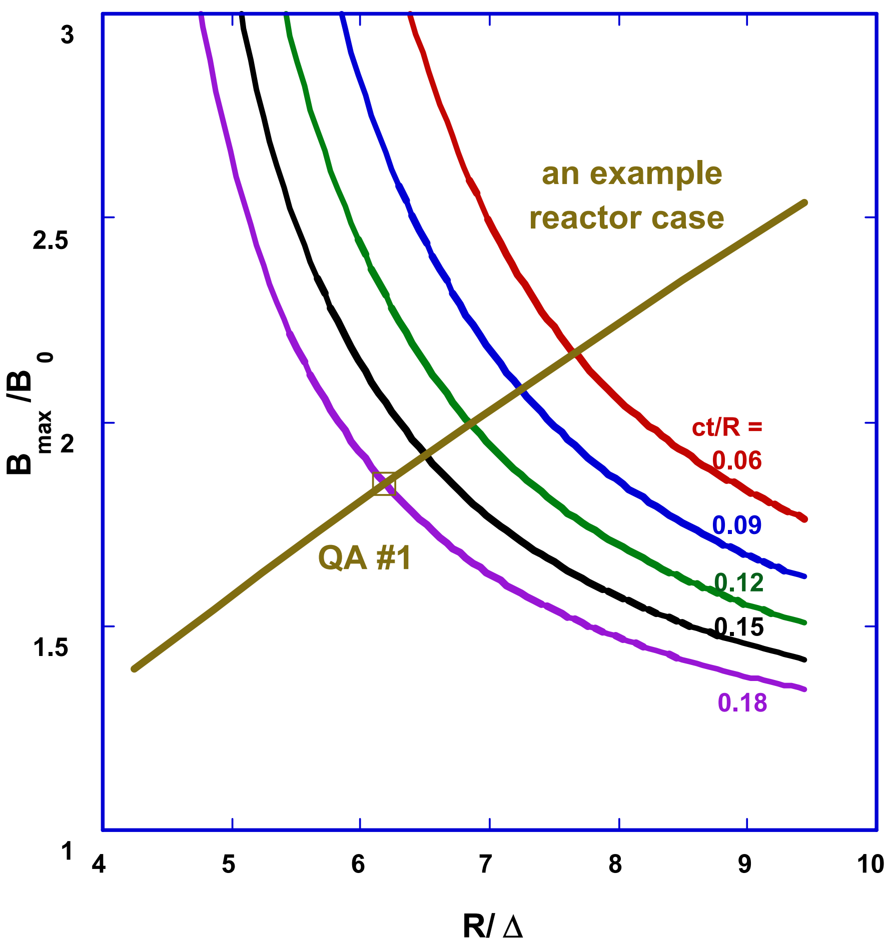


B_{max}/B_0 Scan for Reactor-Scale QA's

B_{max}/B_0 calculated at coil inner edge
(on a surface shifted inward by half coil depth)
from NESCOIL surface current solution at coil center



Scaling Model Used for Reactor Size



- NESCOIL code was used to calculate B_{max}/B_0 at a distance ct/2 radially in from a current sheet (at a distance Δ from the plasma edge) that reproduced the last closed flux surface
- B_{max}/B_0 was increased by 15% to simulate effects due to a smaller number of coils
- Minimizing B_{max}/B_0 increases the field in the plasma for a given B_{max} on the coils
- Minimizing R/Δ allows a smaller R for a reactor with a given d
- B_{max}/B_0 needed for a given $P_{electric}$ and d is proportional to $(R/\Delta)^{3/4}$

Summary of B_{max}/B_0 Scans for QA

B_{max}/B_0 is ~ 2 for QA, 25% higher than tokamak

- B_{max}/B_0 increases with decreasing A and A_Δ
- Very sensitive to radial coil depth
- Maximum where j_{surf} is maximum
- 25% higher for QA than I_{pol}-only-QA case
- j_{surf} variation on current surface accounts for almost all of the 25% increase from tokamak values
- Lowest A_Δ was for QA C82 and C93 is 5.8
  ==> Minimum QA reactor R_0 = 9.28 m
- However, this model is too crude and needs to be improved (Ku's code?)