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System Code Analysis of Plasma Performance in Helical Reactors

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Objective and Scope

- Preliminary study on reactor parameters and comparison with tokamak reactors
- To explore the R&D issues in helical system.
- Scope of this study is following two devices;
  - (a) Ignition Device
  - (b) Power Plant

Physics Constraints

- Plasma Equilibrium
  - → no equilibrium calculation at present
  - → limitation of plasma aspect ratio is taken into account.
    (i.e., $A > 3$)
- Plasma Confinement
  - → several confinement scalings in helical plasmas are employed.
    (neoclassical transport, α-particle confinement is not taken into account.)
- Density Limit
  - → Density limit scaling is taken into account.
- Beta Value
  - → no stability calculation at present
    (In LHD higher beta value theoretically predicted has been achieved.)

Plasma Confinement Scaling

- ISS95 $$\tau_E(ISS95) = 0.079 a_p^{2.21} R^{0.65} \underline{n_e}^{0.51} B^{0.83} \iota_{2/3}^{0.4} P^{-0.59}$$
- LHD $$\tau_E(LHD) = 0.035 a_p^{2} R^{0.75} \underline{n_e}^{0.69} B^{0.84} P^{-0.58}$$
- Lackner-Gottardi

$$\tau_E(L-G) = 0.043 a_p^{2} R \underline{n_e}^{0.6} B^{0.8} \iota_{2/3}^{0.4} P^{-0.6}$$

(ref. Tokamak Scaling)

$$\tau_E(ITER89P) = 0.048 A_i^{0.5} I_p^{0.85} a_p^{0.3} R^{1.2} \underline{n_e}^{0.1} B^{0.2} \kappa^{0.5} P^{-0.5}$$

Strong density dependence in helical plasmas

Density Limit Scaling

Helical

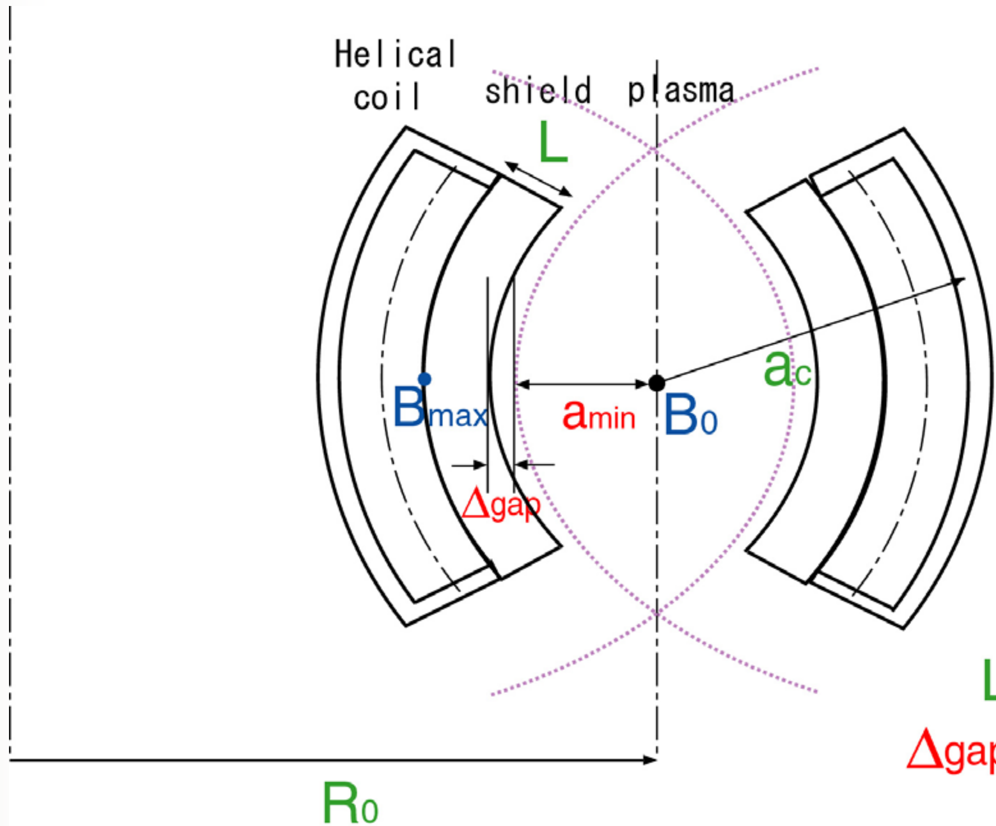
$$n_c = Min\left(\underline{0.25\sqrt{\frac{P_{tot}B}{a^2R}}}, \quad 0.35\frac{P_{tot}\sqrt{B}}{aR} \right)$$

tokamak

$$n_c = \frac{I_p}{\pi a^2} \propto \frac{B}{qR}$$ and Current Drive Efficiency (i.e., Pcd ~ n)

A low temperature operation is desirable for divertor heat load.
In tokamak plasmas a high density operation is limited, resulting in high temperature operation (i.e., T = 15~20keV).

Radial build (LHD-type reactor is adopted.)

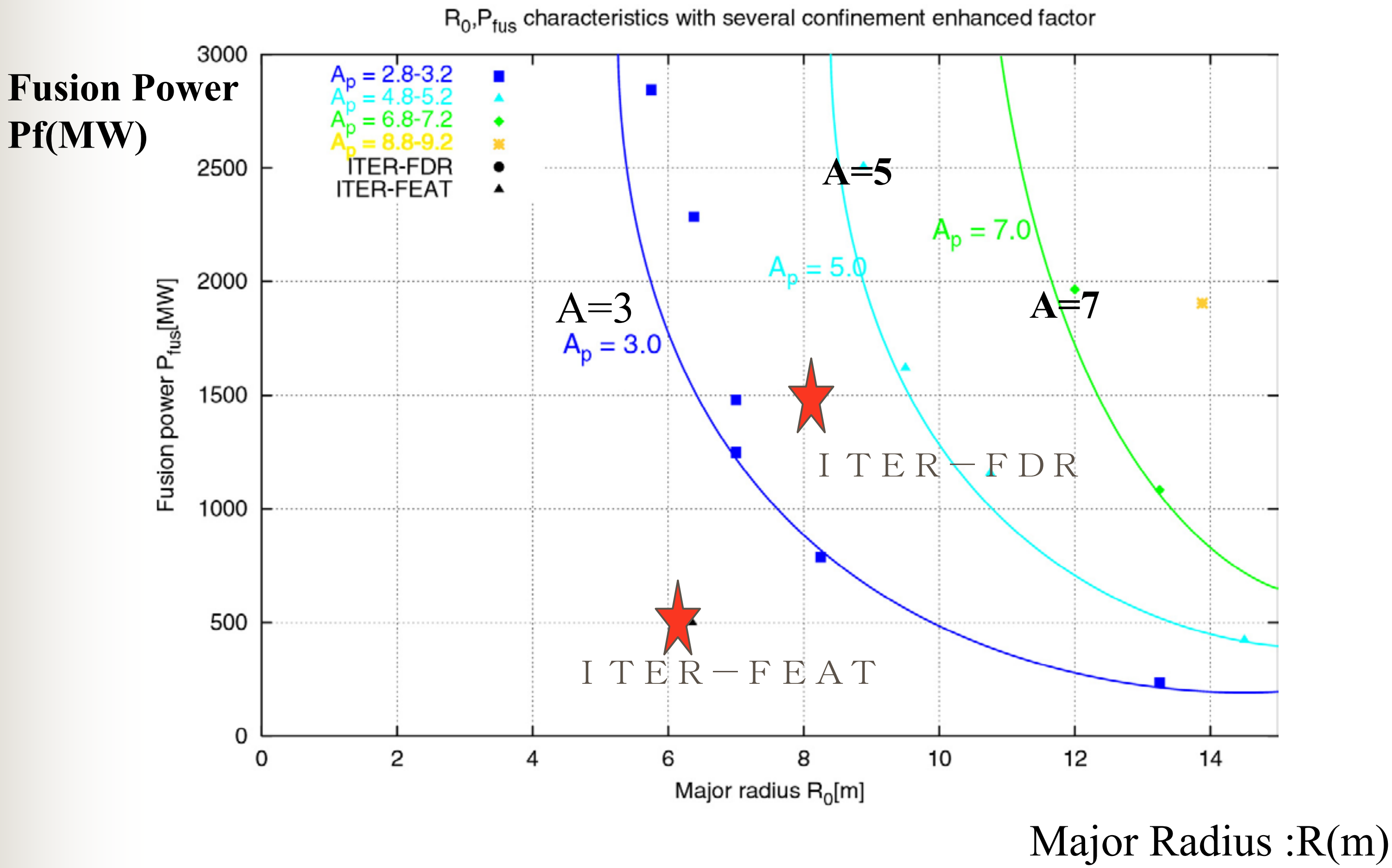


L=1.0m (Blanket)
Δgap=0.1m (Clearance)

Ignition Machine

- Small size with a moderate fusion power
- Present technology

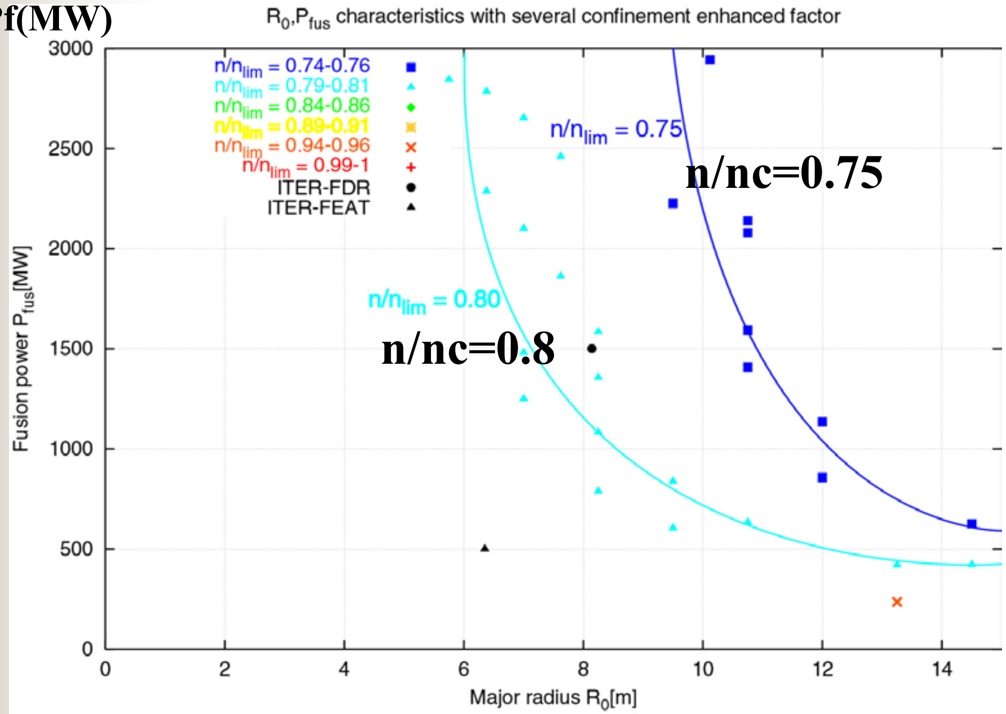
Ignition device (H=2, Bmax=13T,T=12keV)



A low aspect ratio is required for a small device.

Ignition device (H=2, Bmax=13T,T=12keV)

Fusion Power
Pf(MW)



Major Radius :R(m)

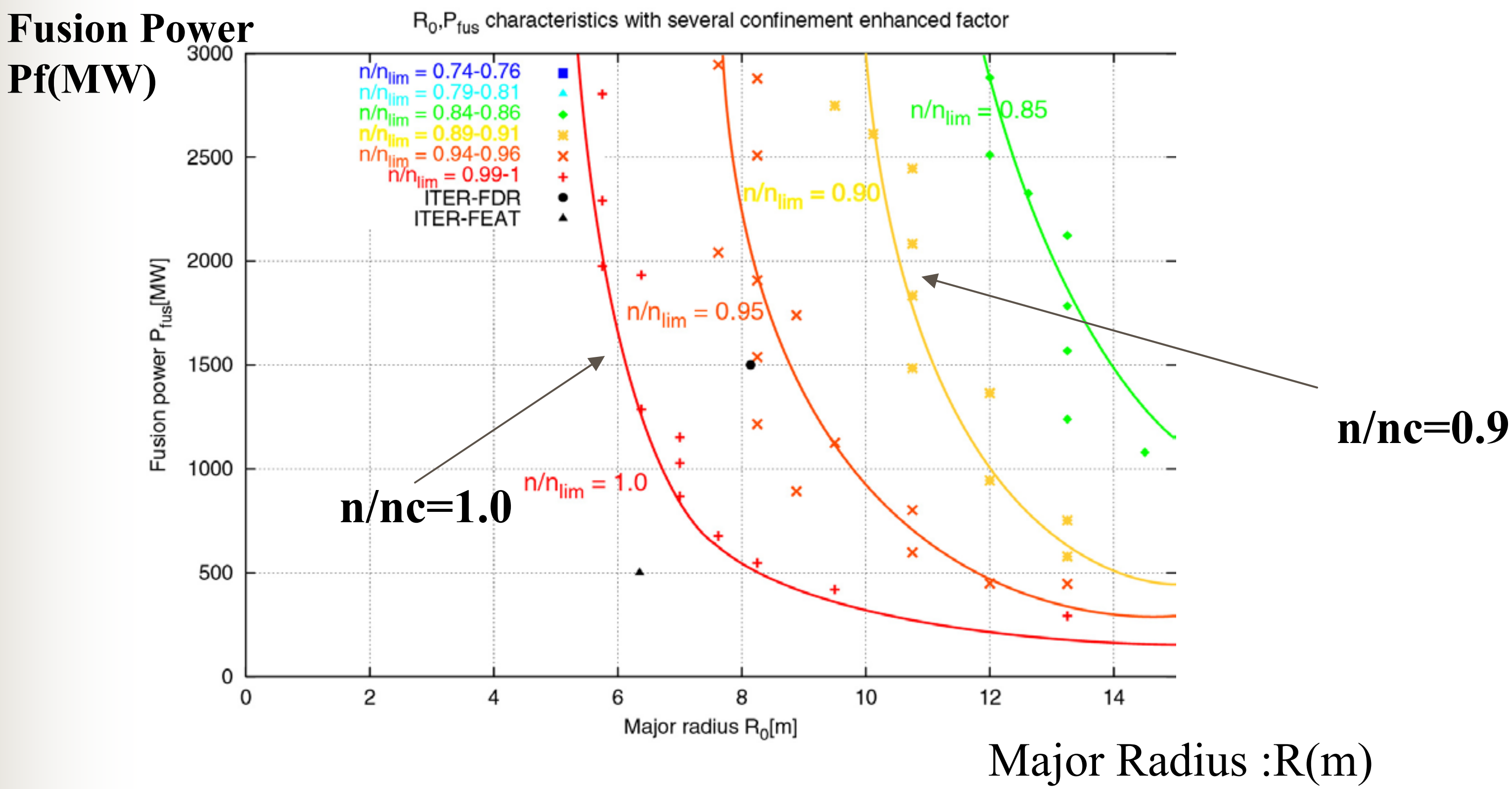
$$n_c \propto \sqrt{\frac{P_{tot}B}{a^2R}} \propto \sqrt{\frac{n^2T^2a^2RB}{a^2R}}$$

$$\propto nT\sqrt{B}$$

$$\frac{n}{n_c} \propto \frac{1}{T\sqrt{B}}$$

Still we have a margin to the density limit.
The temperature and the magnetic field might be reduced.

Ignition device (H=2, Bmax=10T,T=10keV)

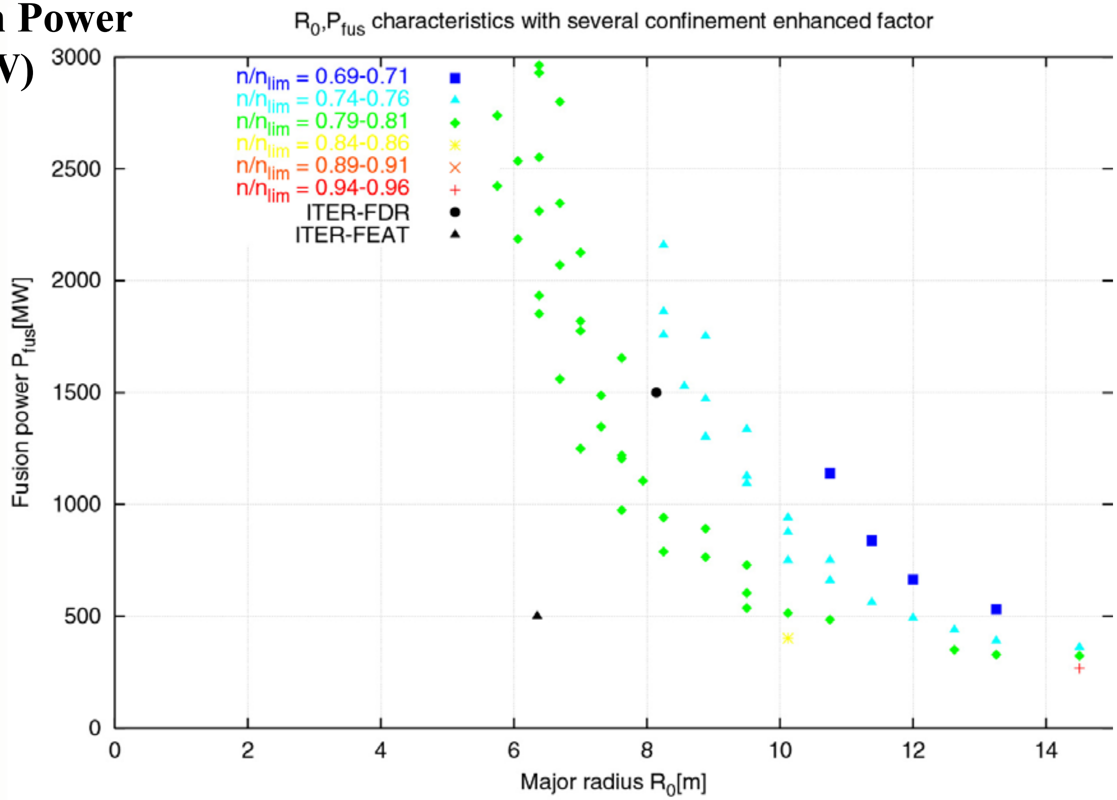


If the density is increased to the density limit,
the Bmax and the operation temperature are reduced.

Ignition device (Lackner-Gottardi scaling)

(H=2, Bmax=13T,T=12keV)

Fusion Power
Pf(MW)

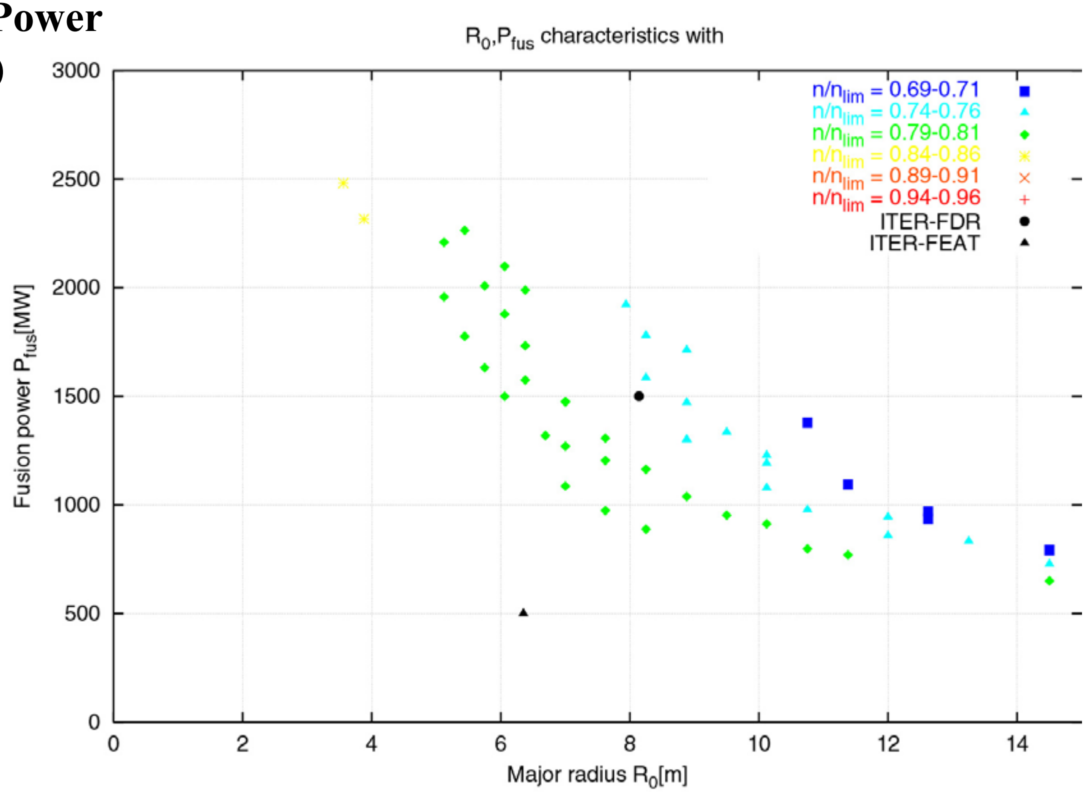


Major Radius :R(m)

Ignition device (LHD scaling)

(H=2.5, Bmax=13T,T=12keV)

Fusion Power
Pf(MW)

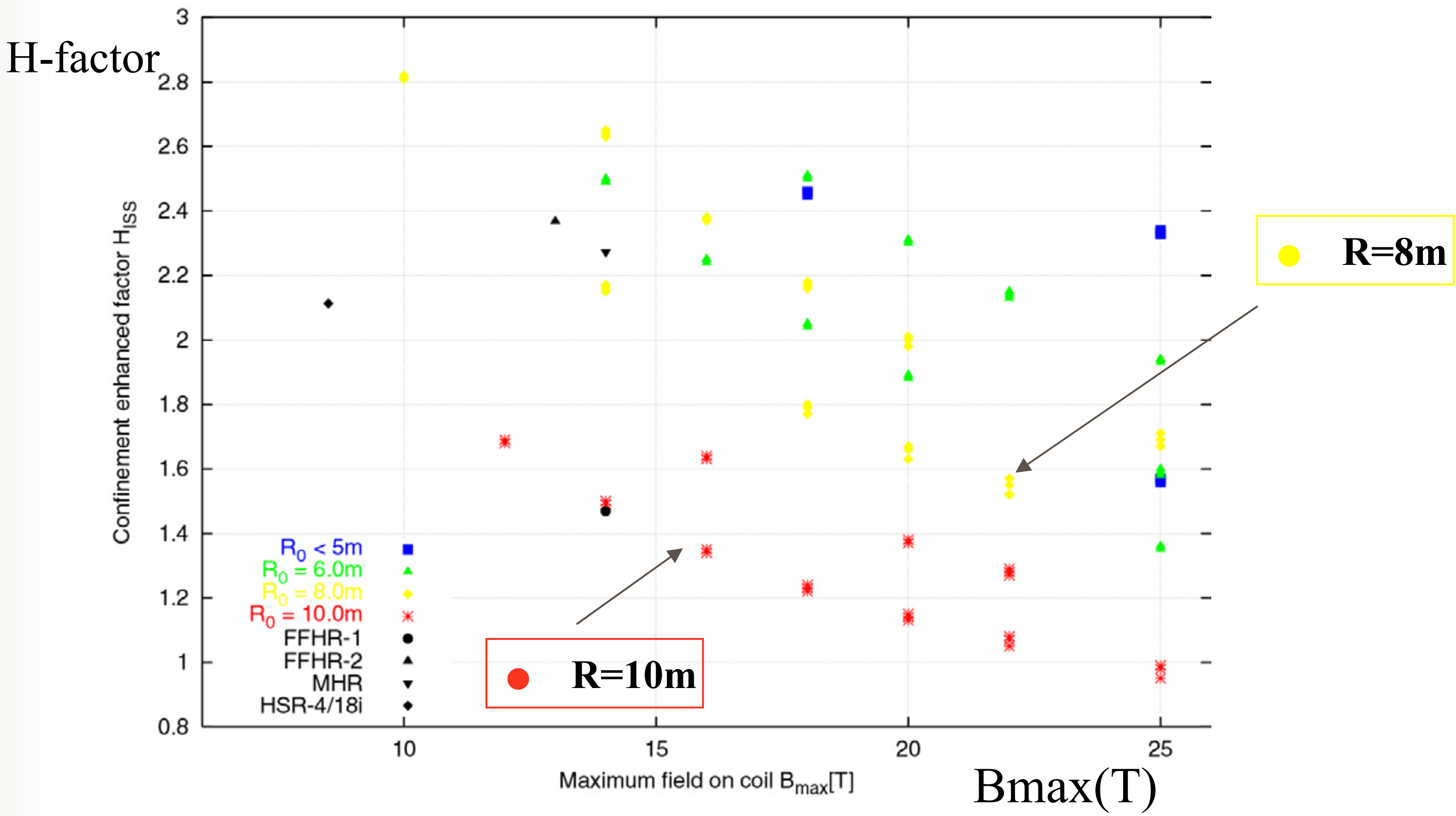


Major Radius :R(m)

Power Plant

- 3GW thermal power
- Engineering Progress might be expected.

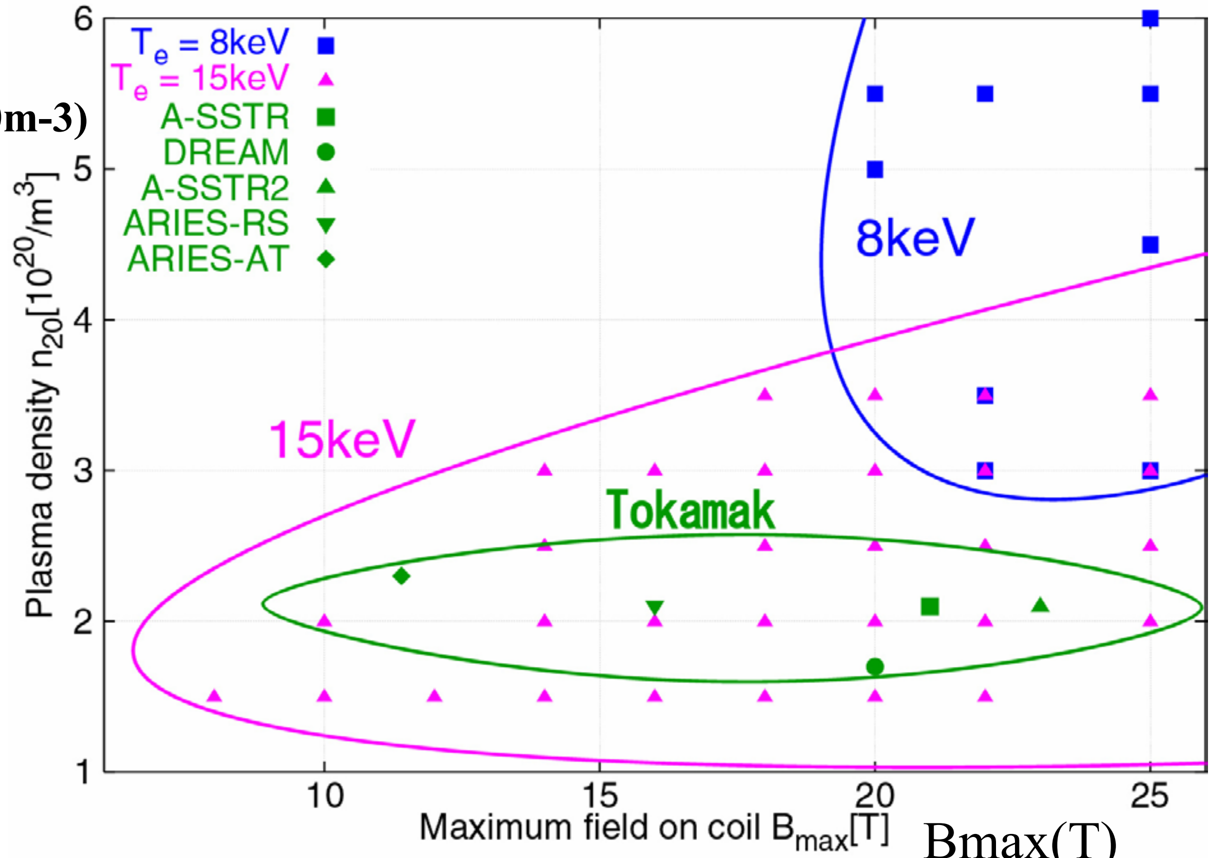
Power Plant (H vs Bmax)



If the magnetic field is strengthened, the H factor is relaxed.

Power Plant (density vs Bmax)

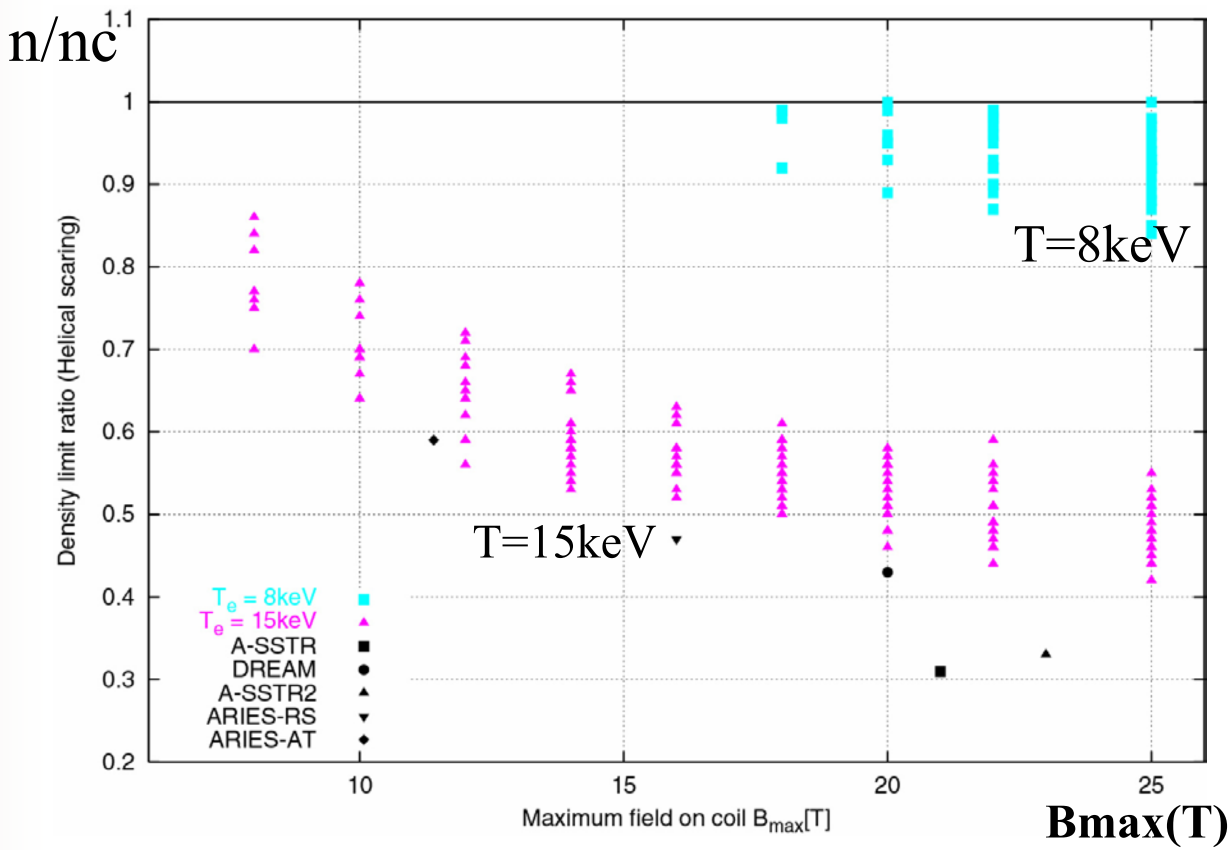
density
n(10E20m-3)



Bmax(T)

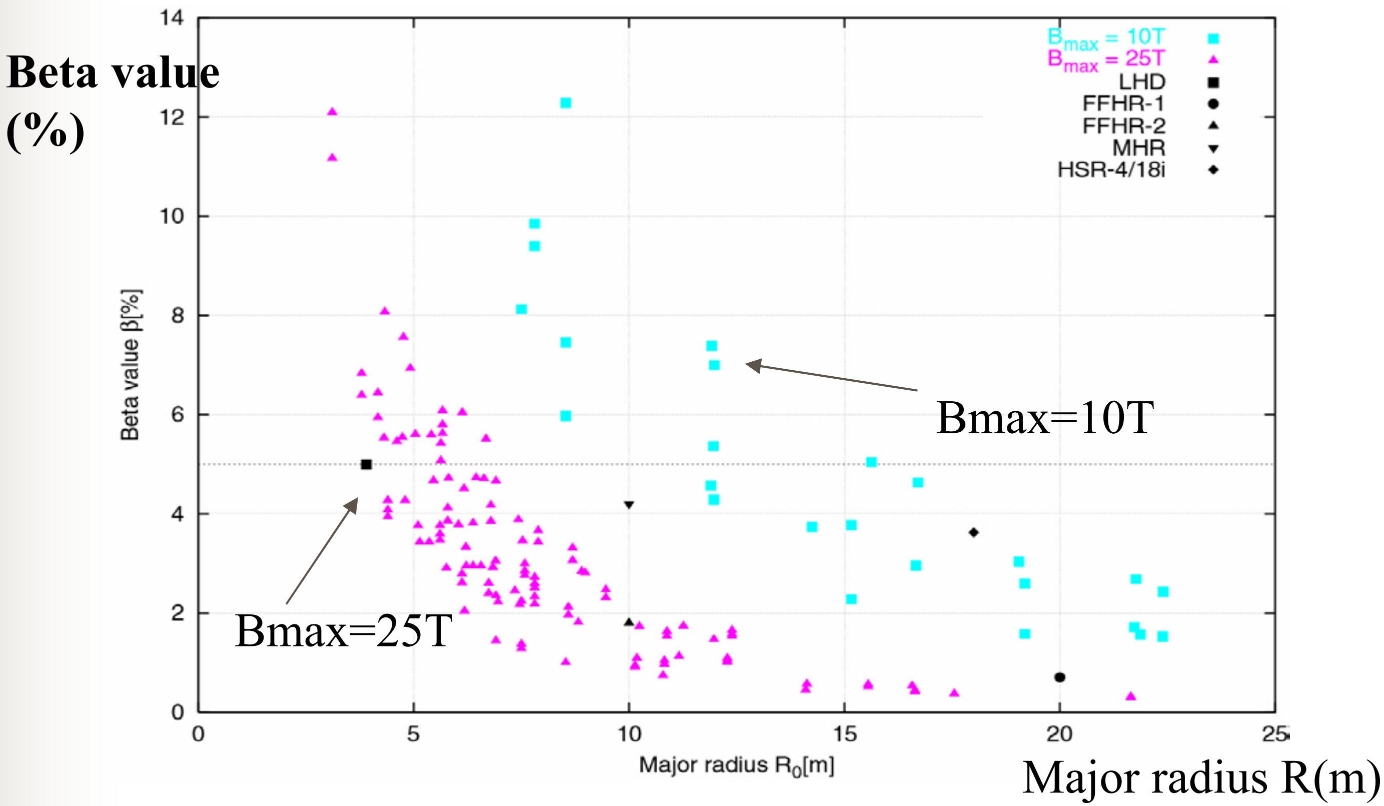
A low temperature operation is available in helical system,
if the magnetic field is increased.

Power plant (Density limit vs Bmax)



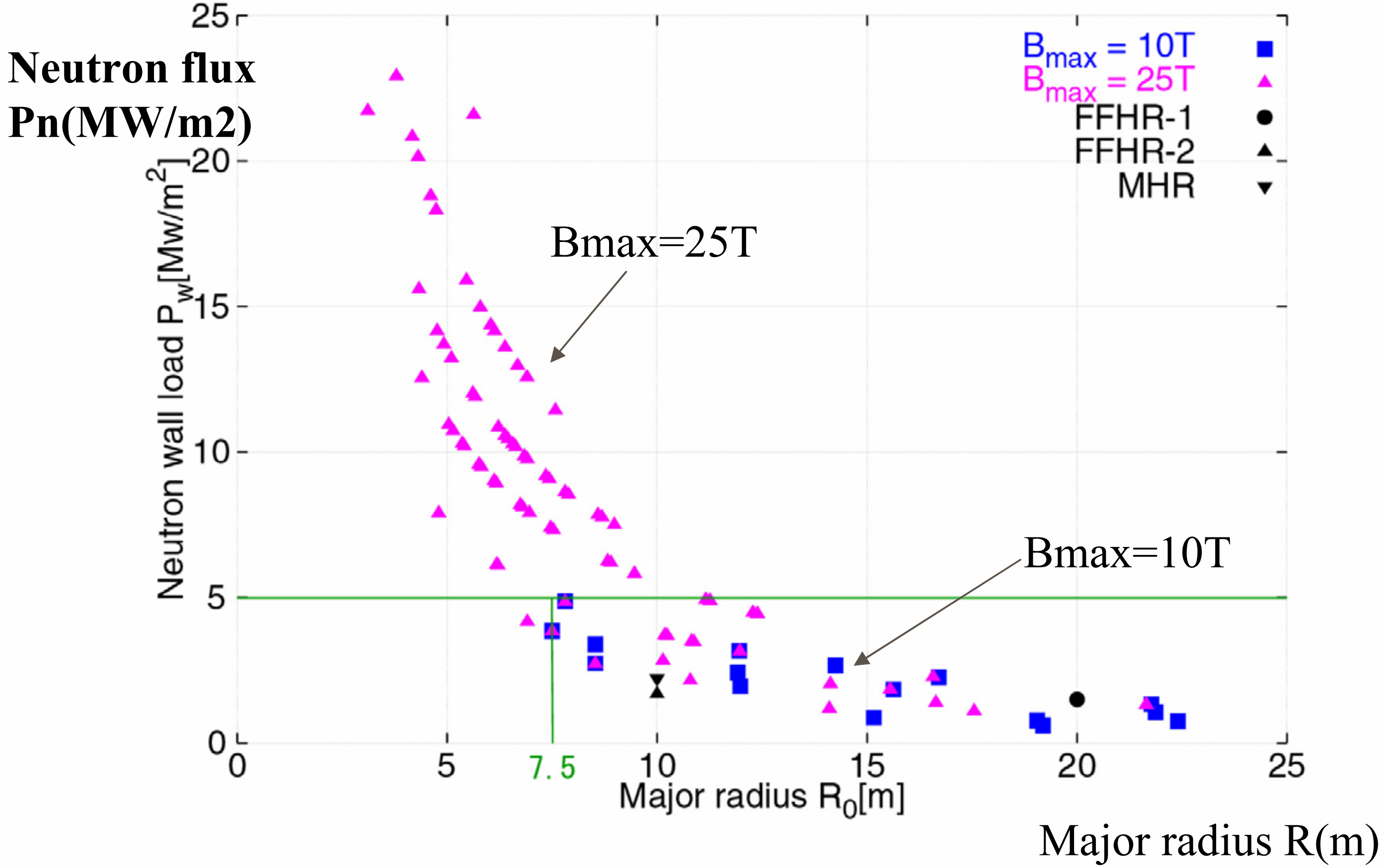
A critical density limits the operation temperature.

Power Plant (Beta value)



If the maximum magnetic field strength Bmax is increased,
a smaller device is available and a margin to the beta value is relaxed.

Power Plant (neutron flux)



A neutron flux will limit a size of the device.

Summary

For Ignition Device

- H=2~2.5 might be necessary.
- For Pf = 1GW device
  R ~ 8 m in A = 3
  R ~ 12 m in A = 5

For Power Plant

- High Density Operation might be feasible.
- High Field is beneficial.

On Plasma Physics & Technology

- Low aspect ratio (A = 3~5)
- Confinement improvement by a factor of 2 ~ 2.5
- Exploration for high density operation
- Development of a high field magnetic coil