Future Trend of Compact Tokamak Power Reactor

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for

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Headlines

- COE(cost of electricity) of tokamak reactors
- The lower aspect ratio, the better reactor !
- The higher field, the better reactor !
- Future trend of tokamak power reactor
- Summary

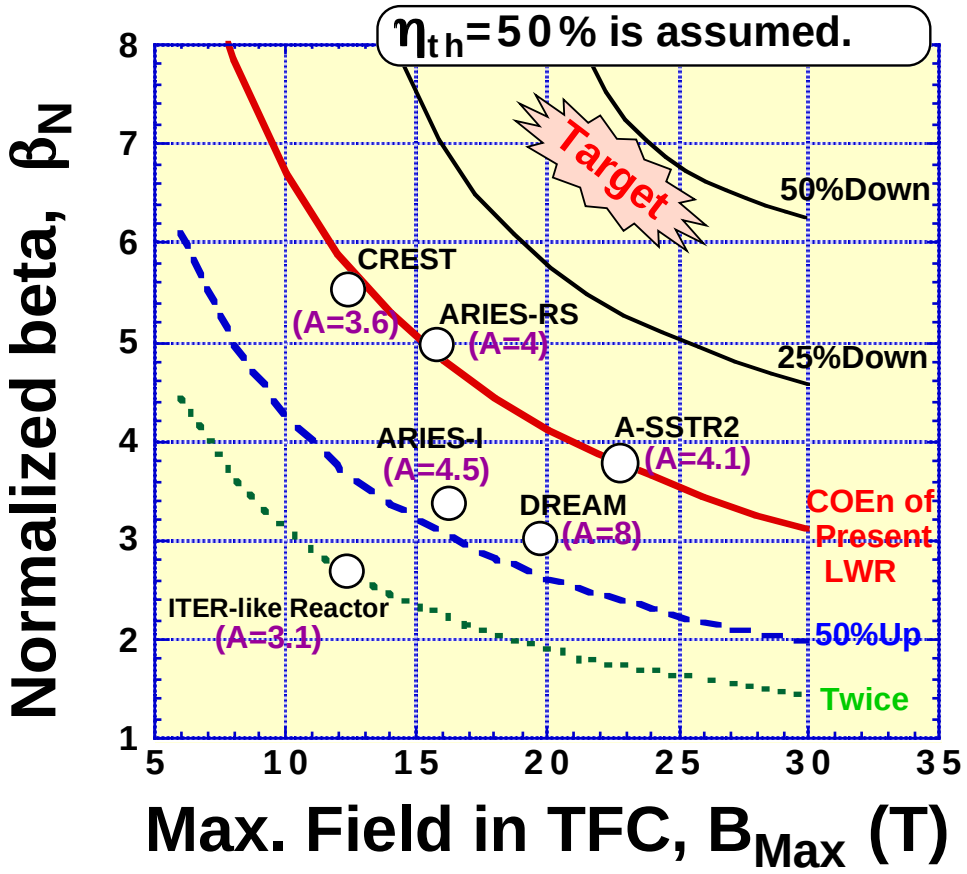
COE of Tokamak Power Plant

Scaling Law of COE (by K. Okano, et al)

$$COE_n = \frac{11.8}{\beta_N^{0.9}\, B_{Tmax}^{0.63}\, \eta_{th}}$$

normalized by 1GWe LWR

for standard tokamaks (A=3~4)



Much more inexpensive COE is demanded.

Both high beta and high field are needed.

Is that expecting too much, or not ?

In Line with High β

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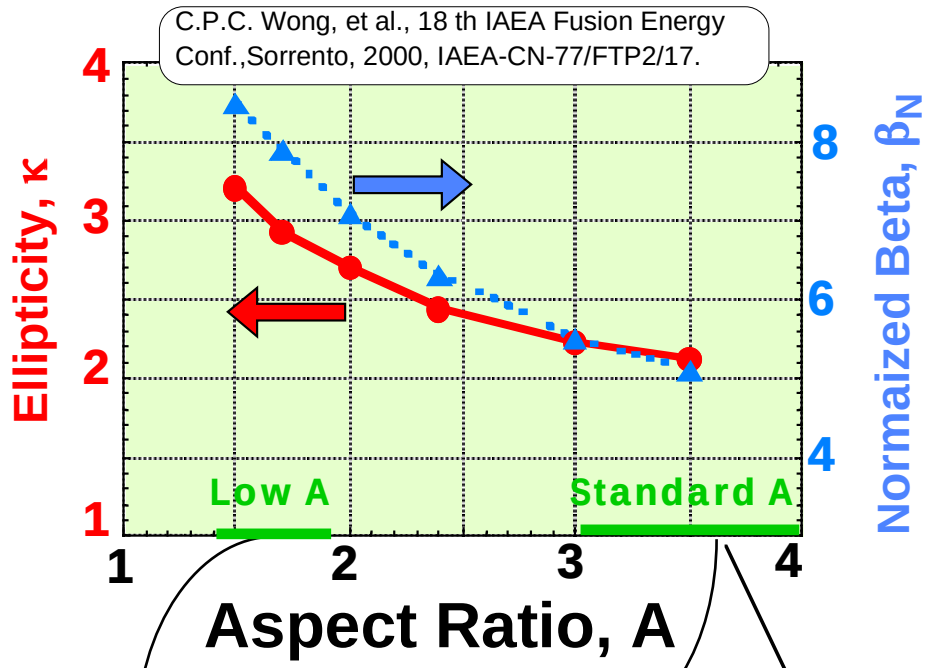
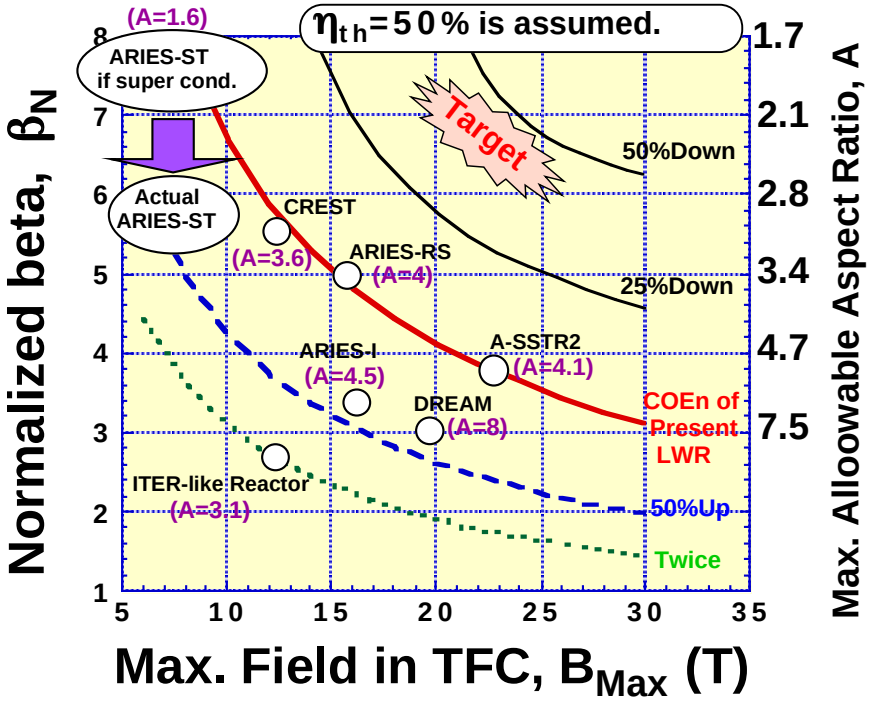
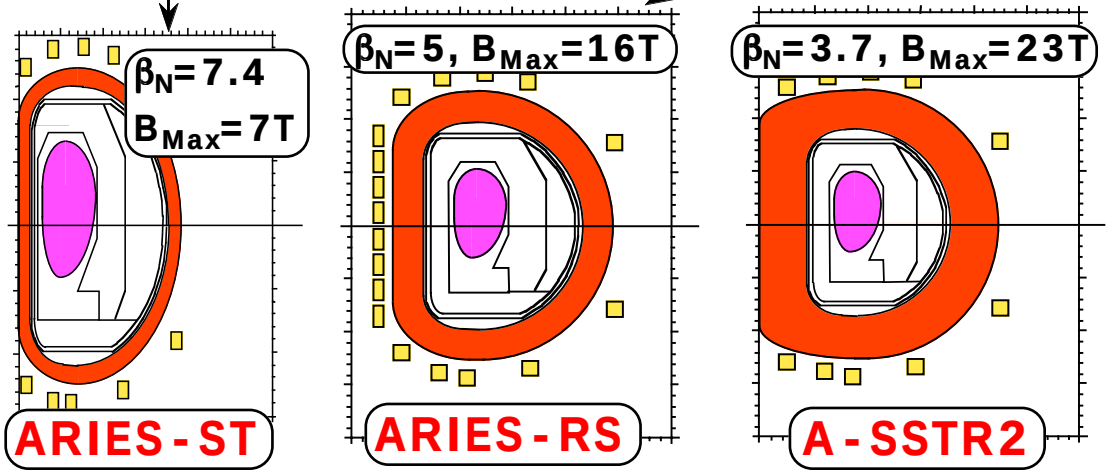
Second stability, bean shape, FRC and etc.

Aspect ratio lowering is a truthworthy way !







Low A (High β_N)

&

High Field

Extra Profit of CS Coil Discard

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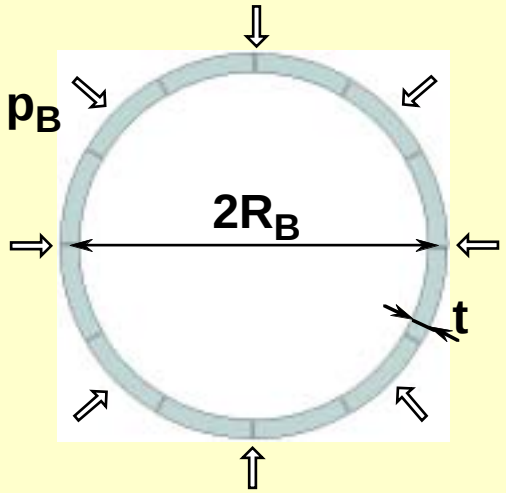
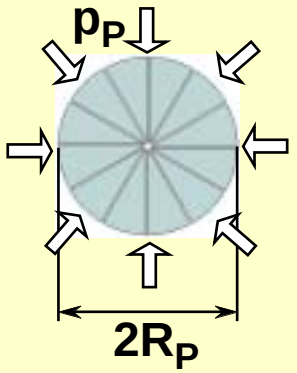
Barrel Structure
(conventional)



$\sigma_r \sim 0$
$\sigma_\theta = -(R_B/t)p_B$

Wedge Support

Solid Post Structure
(new approach)



$\sigma_r = \sigma_\theta = -p_P$

Isotropic Support

Same Quantity of Material : $2\pi R_B t = \pi R_P^2$

Same Quantity of Load : $W = 2\pi R_B p_B = 2\pi R_P p_P$

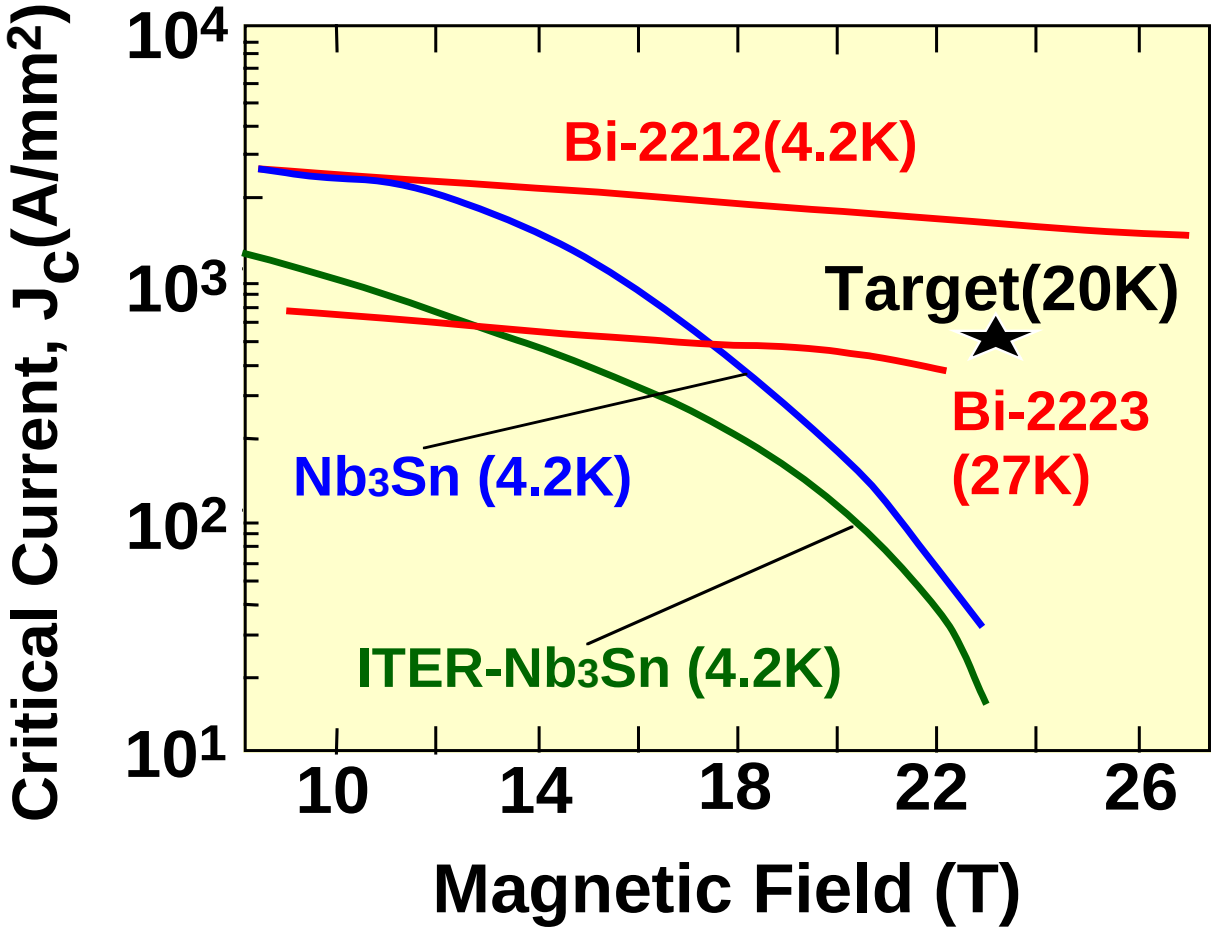
eg. when R_B=10 and t=1, R_P=4.5.

Stress intensity of Barrel Structure is 4.5 times higher than Solid Post Structure.

Allowable current density of Solid Post Structure is 2.1 times higher than Barrel Structure.

Feasibility of High Field Coil

- ~25 T is not necessarily dream in future !



SC material : Bi2212/Ag/Ag Multi-filamentaly (J_{op}=500A/mm^2 ,B_{op}=20~25T, T_{op}=20K)

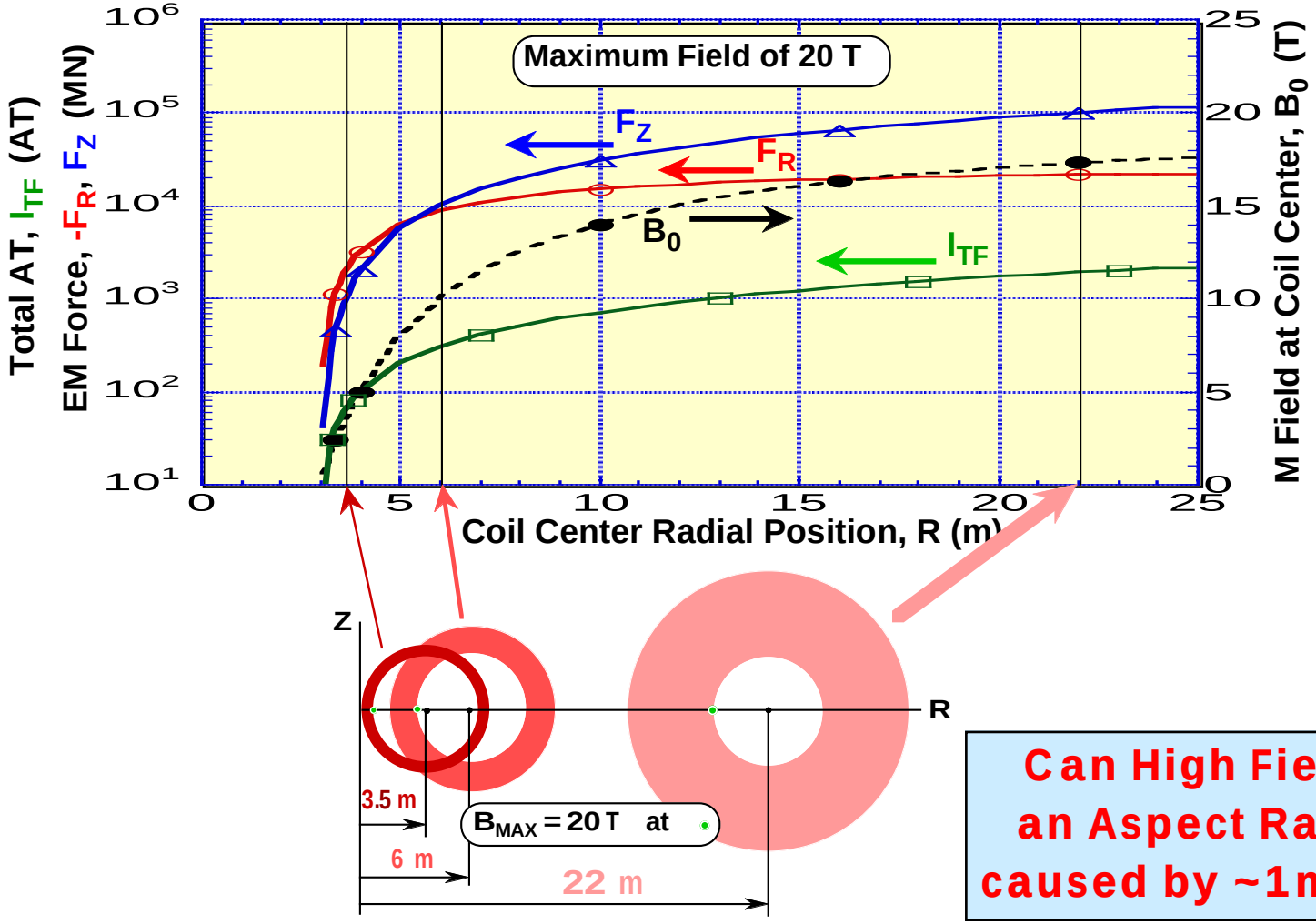
Temp. margin : 3~5K (Induced Voltage<20kV, Current<200kA)

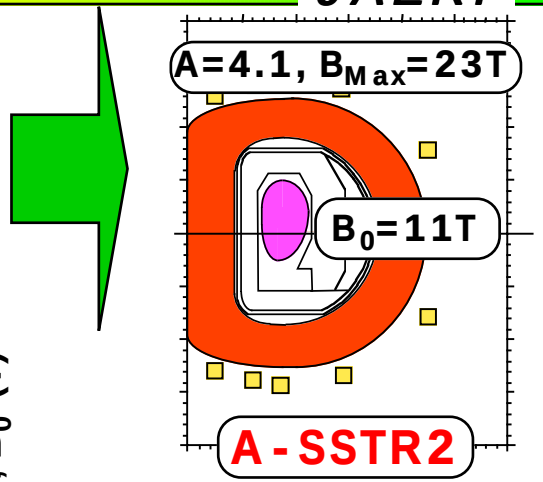
Structure Mat. : JN1 or JJ1 (S_m=700~800MPa)

In Line with High Field

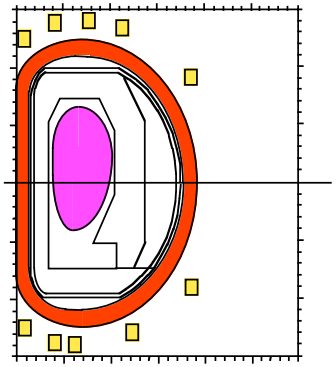
High Field & High A → Massive TFC

High Field on Plasma Axis → Small Plasma





New Approach



Can High Field compensate an Aspect Ratio Rise (β drop) caused by ~1m Shield Thickness ?

Aspect Ratio : Low or High ?

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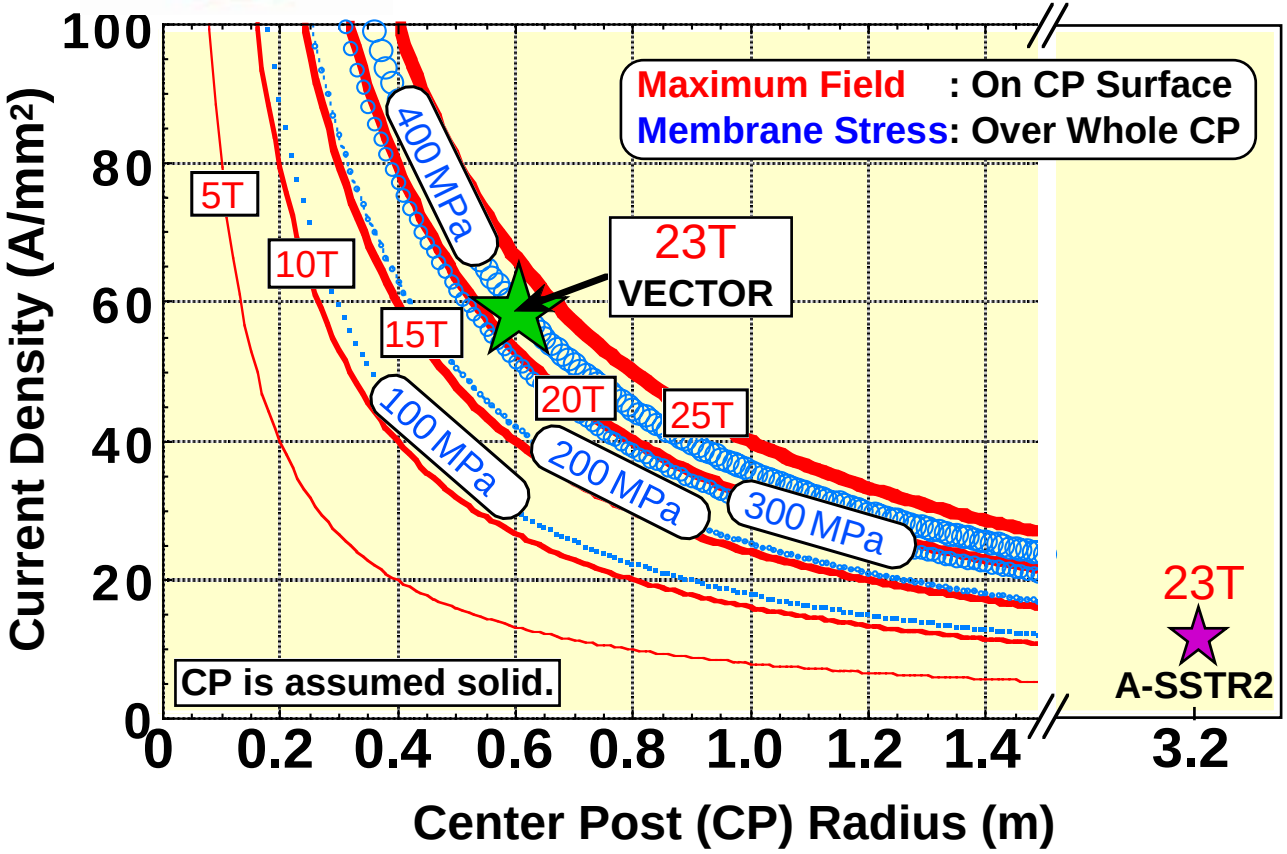
New Approach

~ 1000 tons

Low Aspect ratio (desirable)
&
Low Field on Plasma Axis (undesirable)

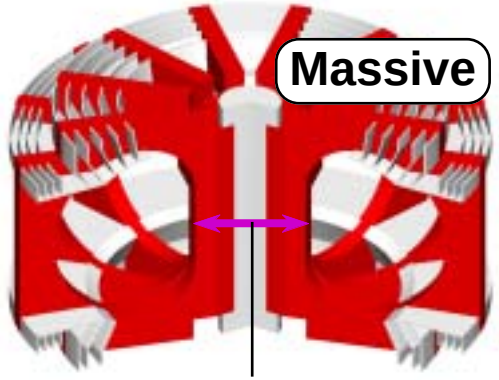
VS

High Field on Plasma Axis (undesirable)
&
High Aspect ratio (desirable)



A-SSTR2

~ 13000 tons



Toroidal Field Coil of VECTOR

SC material : Bi2212/Ag/Ag Multi-filamentaly (J_{op}=500A/mm^2 ,B_{op}=20~25T, T_{op}=20K)
Temp. margin : 3~5K (Induced Voltage<20kV, Current<200kA)
Structure Mat. : JN1 or JJ1 (S_m=700~800MPa)

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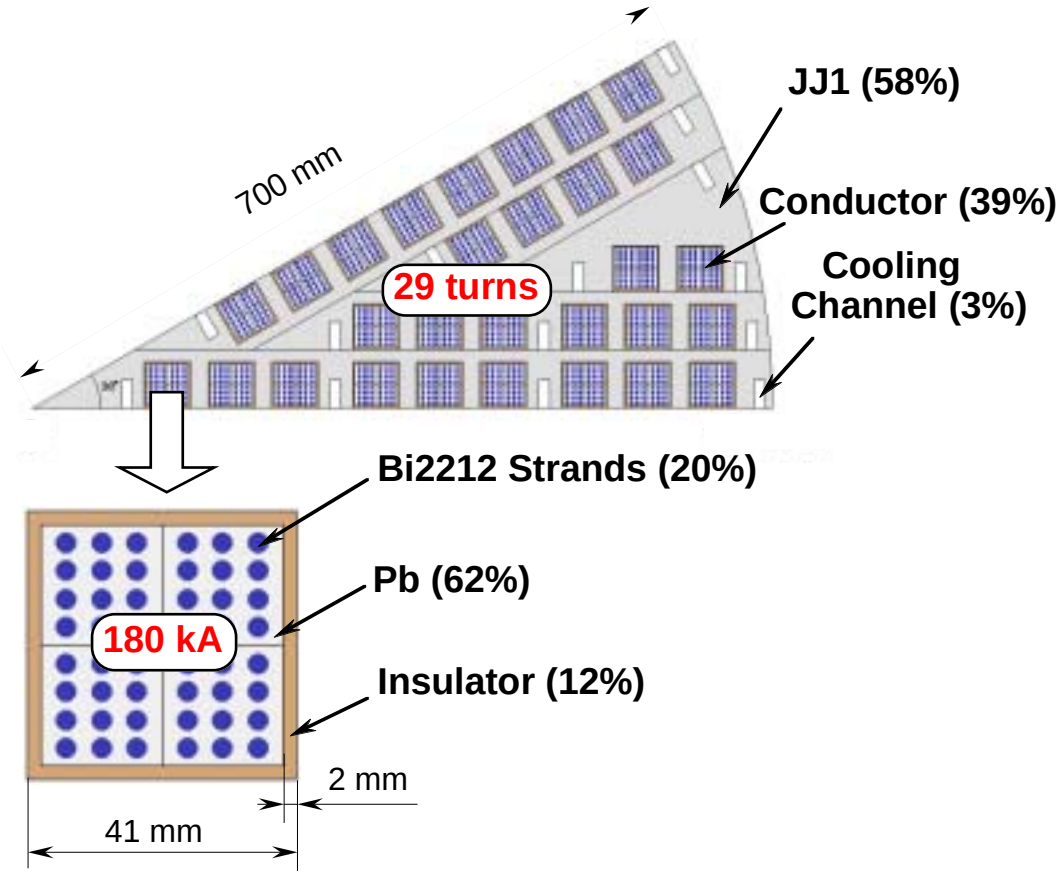
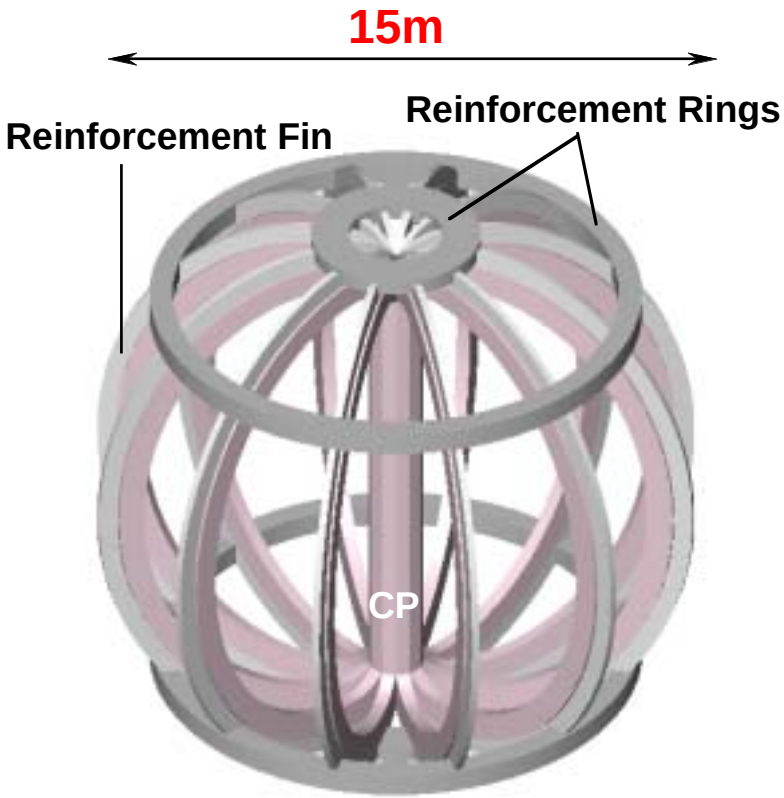


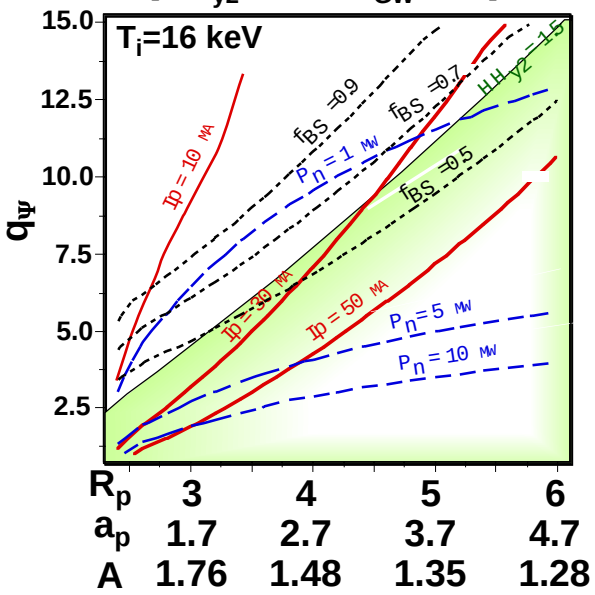


Coil Number : 12
Weight : ~150 ton/coil
Stored Energy : ~10 GJ (cf. ITER:44GJ, A-SSTR2:180GJ)

Obtainable Plasma Performances

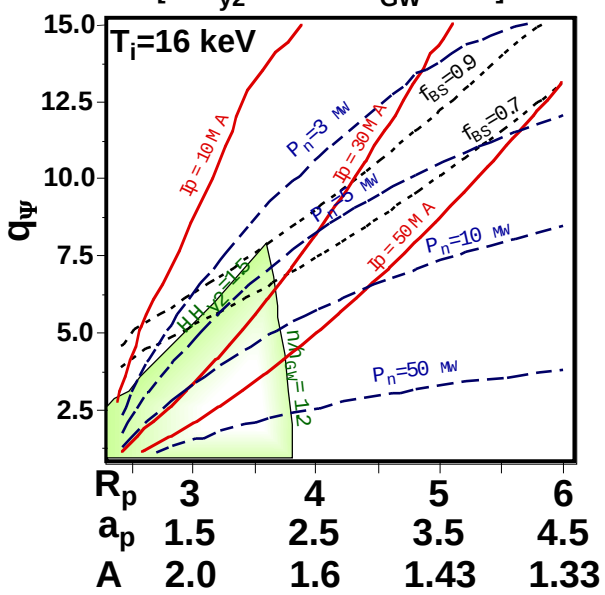
Maximum field is decided by mechanical stress limit.

R_{CP} = 0.3 m, Δ_{SH} = 1.0 m, B_{MAX} = 20 T
[HH_{y2} < 1.5 & n/n_{GW} < 1.2]



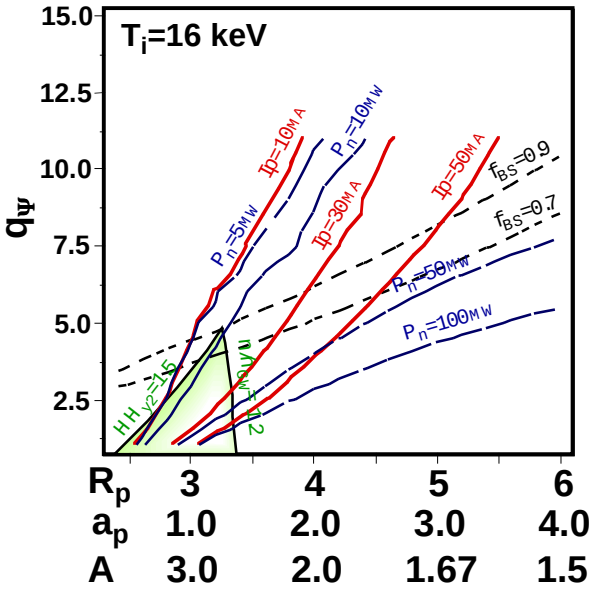
R_p	3	4	5	6
a_p	1.7	2.7	3.7	4.7
A	1.76	1.48	1.35	1.28

R_{CP} = 0.5 m, Δ_{SH} = 1.0 m, B_{MAX} = 20 T
[HH_{y2} < 1.5 & n/n_{GW} < 1.2]



R_p	3	4	5	6
a_p	1.5	2.5	3.5	4.5
A	2.0	1.6	1.43	1.33

R_{CP} = 1.0 m, Δ_{SH} = 1.0 m, B_{MAX} = 20 T
[HH_{y2} < 1.5 & n/n_{GW} < 1.2]



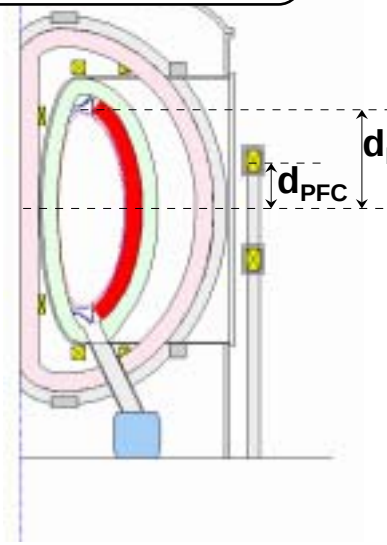
R_p	3	4	5	6
a_p	1.0	2.0	3.0	4.0
A	3.0	2.0	1.67	1.5

Slender CP : Low field on plasma axis, Large plasma size, High plasma current, Low BS current, Low power density, Wide operation window

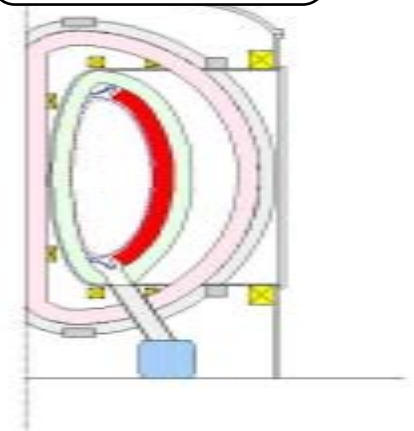
Thick CP : High field on plasma axis, Small plasma size, Low plasma current, High BS current, High power density, Narrow operation window

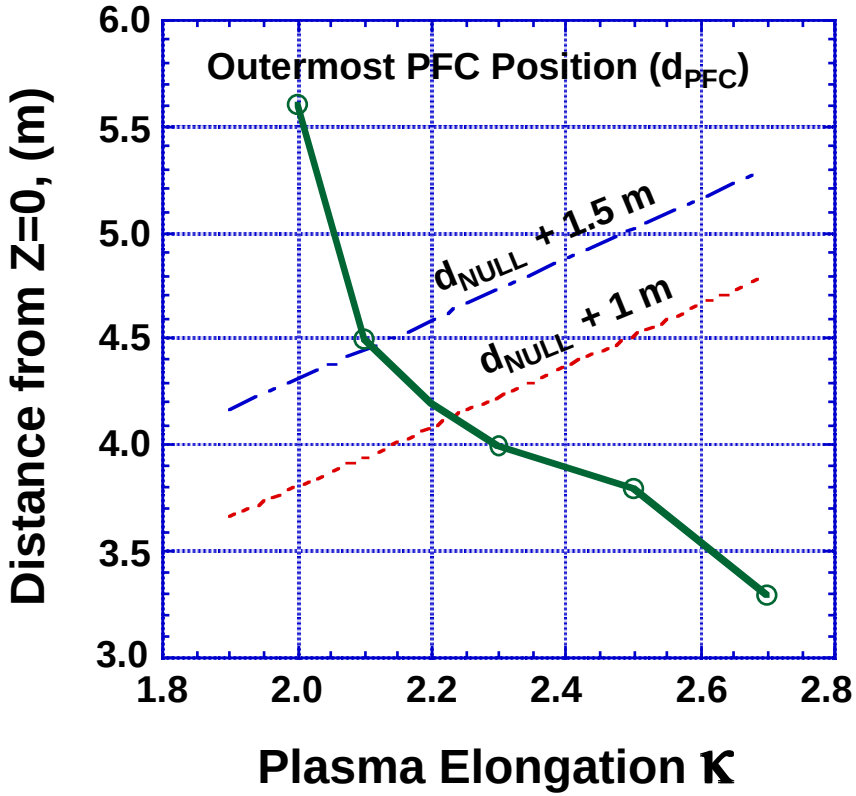
Plasma Elongation & Coil Position

High κ (>2.2)



Low κ (<2.2)





High κ & Difficult Maintenance

VS

Low κ & Easy Maintenance

New Approach is Attractive(1)

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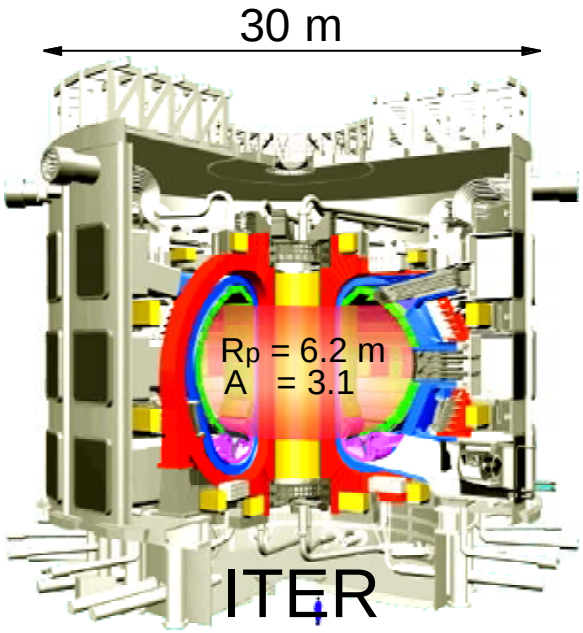
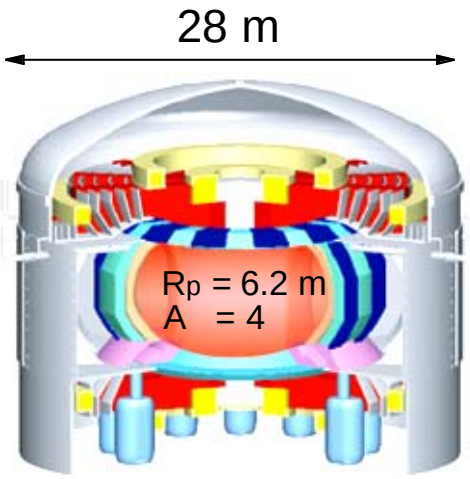
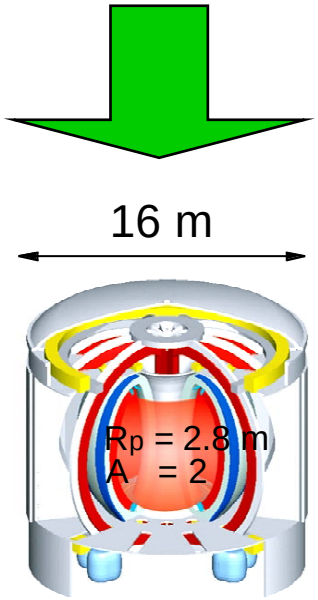
New Approach



ITER
(18000 ton)
P_F=0.5 GW

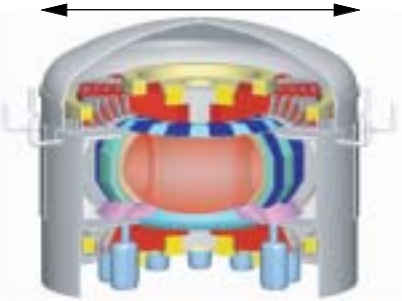
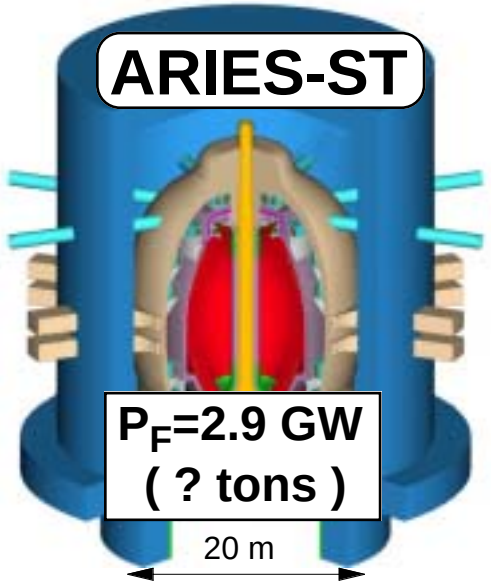
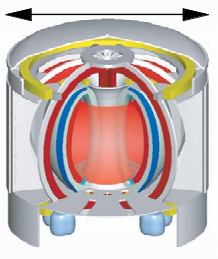


A-SSTR2
(28000 ton)
P_F=4 GW



VECTOR
(~9000 ton)
P_F = 3.7 GW

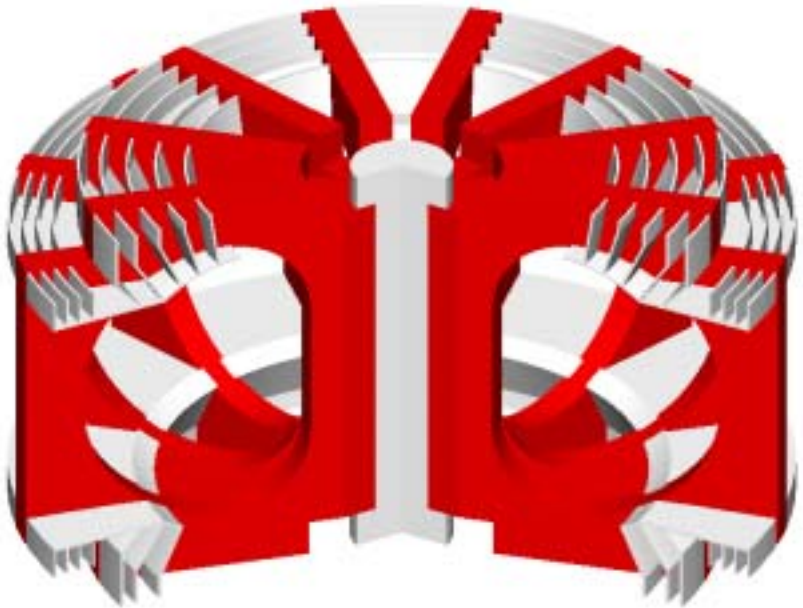
New Approach is Attractive(2)

	A-SSTR2	ARIES-ST	VECTOR
	28 m  P_F=4 GW (28000 tons)	 P_F=2.9 GW (? tons) 20 m	16 m  P_F=3.7 GW (~9000 tons)
Aspect Ratio	4.1	1.6	2.0
β_N	< 4	7.4	~ 6.5
B_{Max}	23 T	7.6 T	23 T
B_0	11 T	2.1 T	5 T
SC / NC	SC	NC	SC
COE_n	1	1.3	0.6~0.7 (?)

Conclusion

- **Future tokamak configuration must be a spherical torus type. Coil conductor should be optimized from this point of view.**

Present Massive TFC



Future Slender TFC