

Recent Development in Plasma and Coil Configurations

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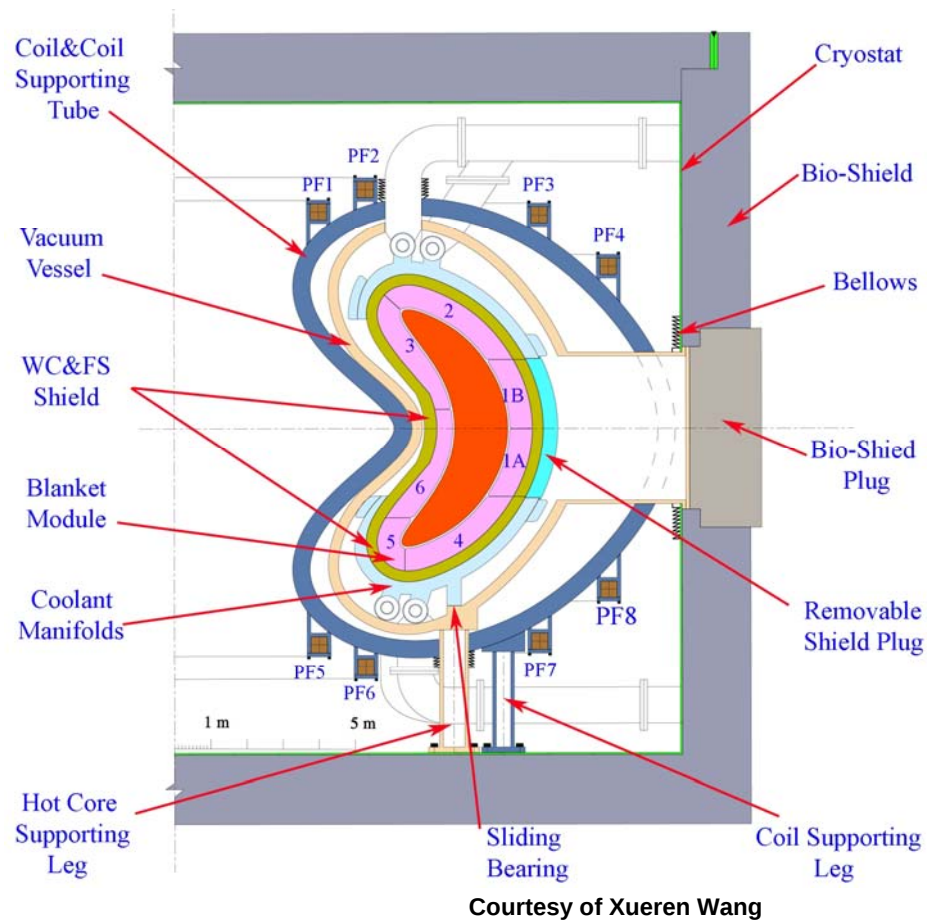
Re-cap of April discussions

- We improved the alpha loss for the baseline configuration, N3ARE.
 - Lowering ε -eff even more in the core region.
- We showed an $A=4.0$ configuration which has lower alpha loss rates than the baseline configuration with the same R and B .
 - For given P_f , B , R , lower $A_p \Rightarrow$ better α confinement, better MHD stability (lower β) and lower neutron wall load (larger surface area).
- We showed that it is possible to reduce alpha loss and improve flux surface quality at once by increasing the core transform.
 - Hybrid of SNS and magnetic spectrum tailoring.

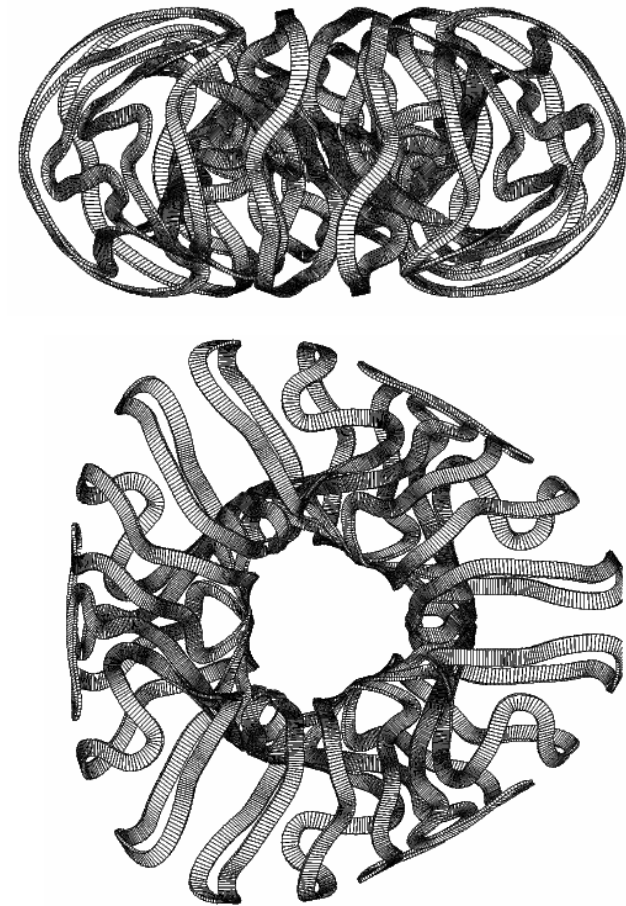
Today's discussion

- Coils for $A=4.5$, $R=7.75$ m configuration.
 - Action items on providing geometry for modular+PF coils.
- Cursory design of coils for $A=4.0$ configuration.
 - Coils similar in complexity to those for larger plasma aspect ratios.
- Further development of configurations with high core transform.
 - Avoidance of low order resonance possible for both zero and reference operating beta.
 - Increase of waistline possible by reducing plasma aspect ratios.

I. Coils for A=4.5, R=7.75 m configuration.



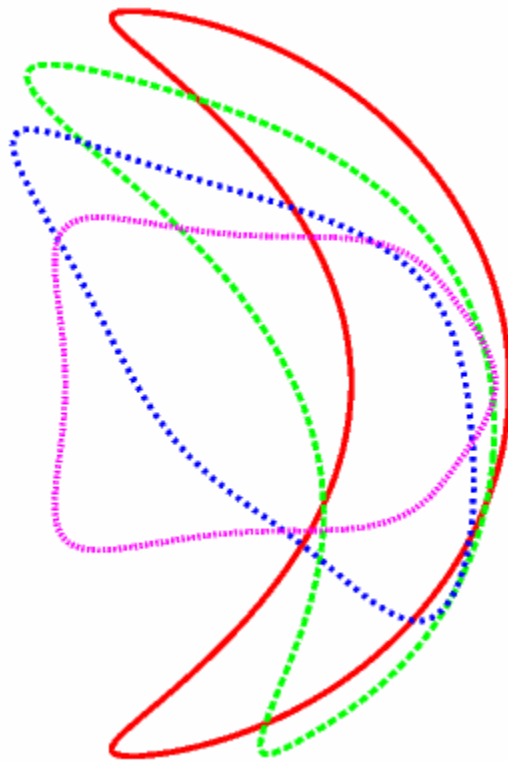
PF1-PF5, PF2-PF6, PF3-PF7, PF4-PF8 up-down symmetric, respectively, $I(\text{max}) < 5 \text{ MA}$.



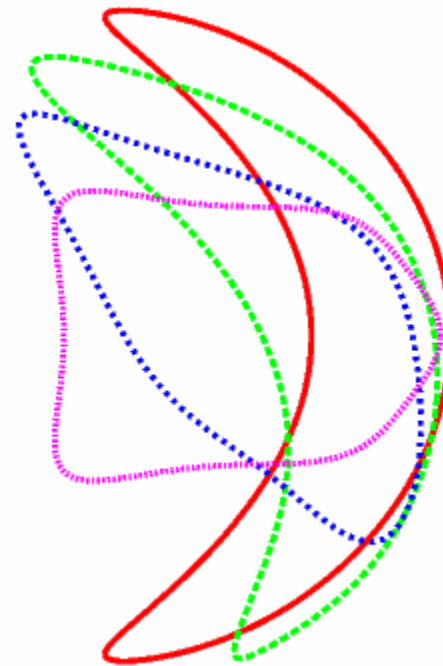
Modular coil winding pack: $0.194 \text{ m} \times 0.743 \text{ m}$
 $I(\text{max}) \sim 13.5 \text{ MA}$, $B(\text{max}) \sim 15 \text{ T}$.

II. Coils for $A=4.0$ configuration N3CRE.

N3CRE, whose QA and MHD stability properties are similar to those of N3ARE but whose aspect ratio is smaller by $\sim 10\%$, is more compact and hence may be more attractive as a reactor provided that small coil aspect ratios can also be obtained.

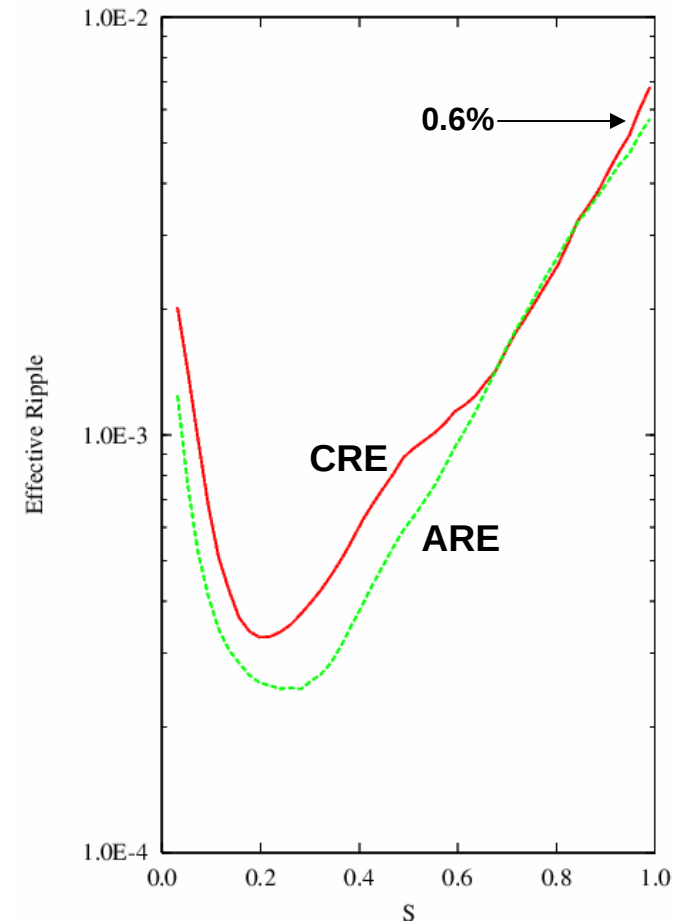
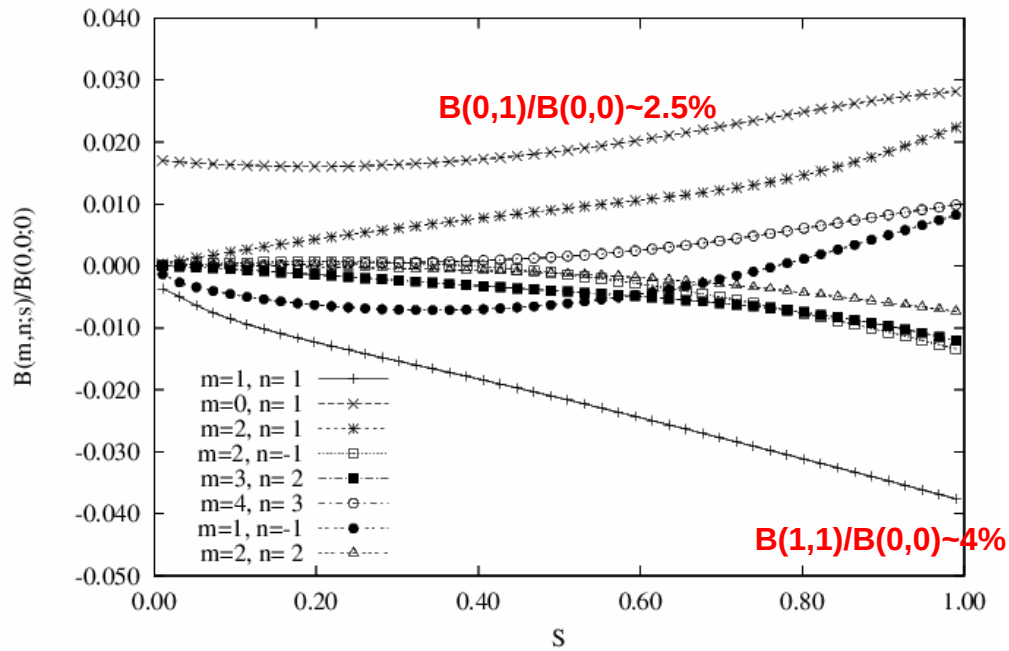


N3CRE, $A \sim 4$

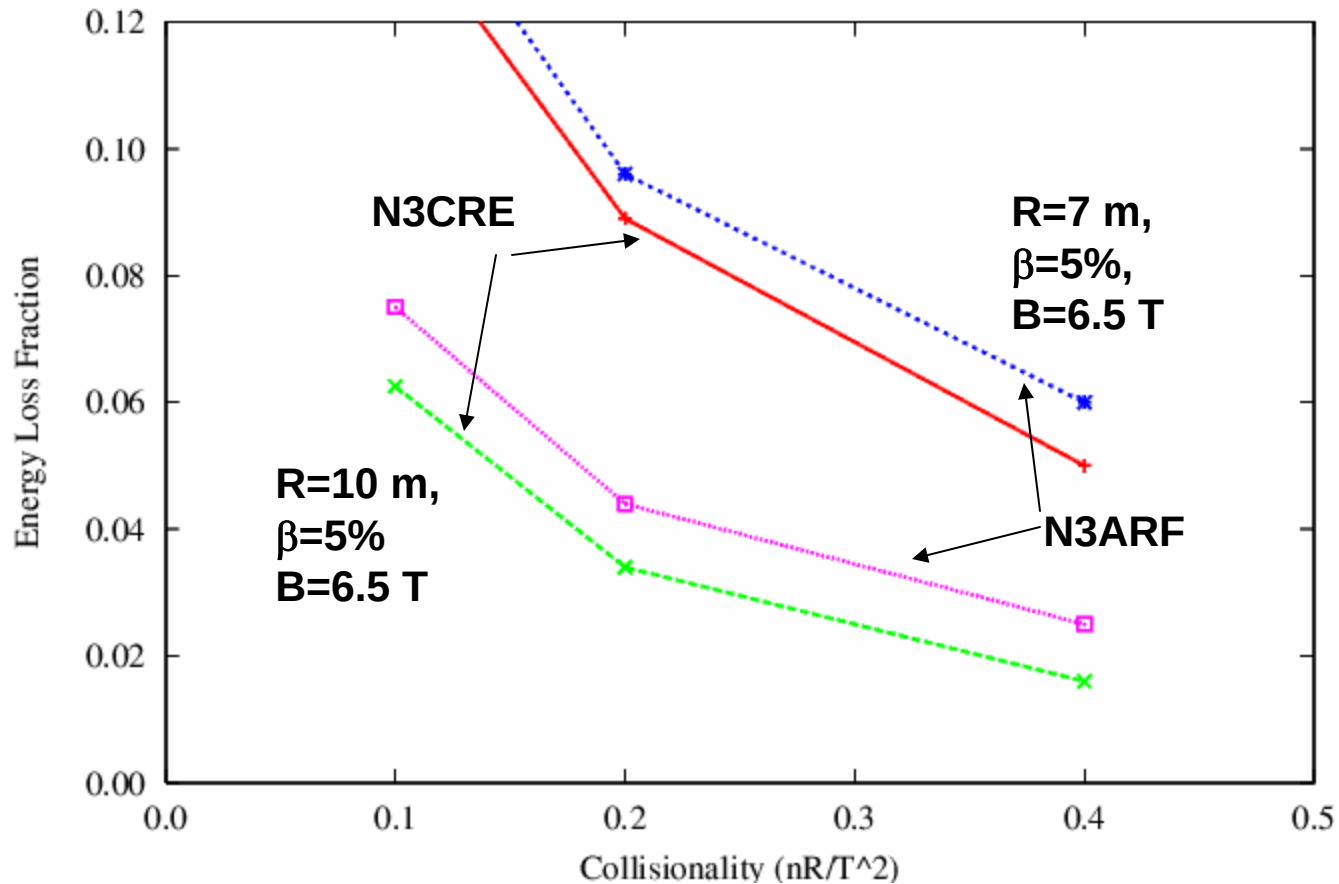


N3ARE, $A \sim 4.5$

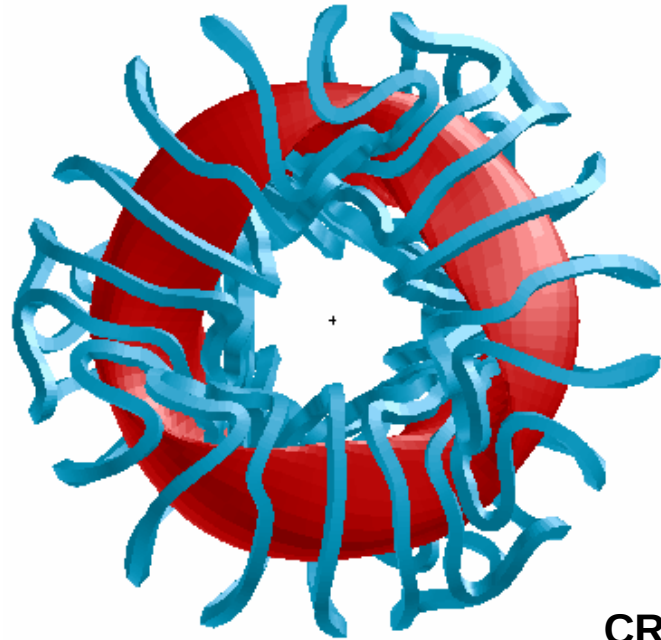
N3CRE has the same feature in its composition of the dominant residues in the magnetic spectrum as N3ARE. The magnitude of the effective ripple is also comparable to that of N3ARE.



Under the same conditions the lower aspect ratio N3CRE has better α confinement characteristic than N3ARF, the confinement improved version of N3ARE.

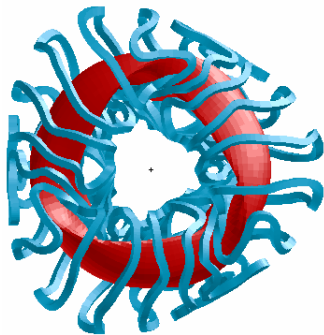
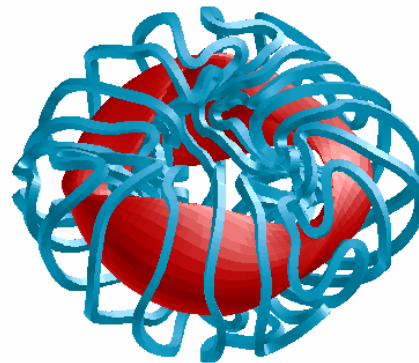


A preliminary design of modular coils for N3CRE shows that they have similar complexity as the KZD coils for the baseline configuration.

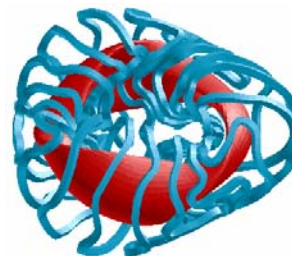


CRE13

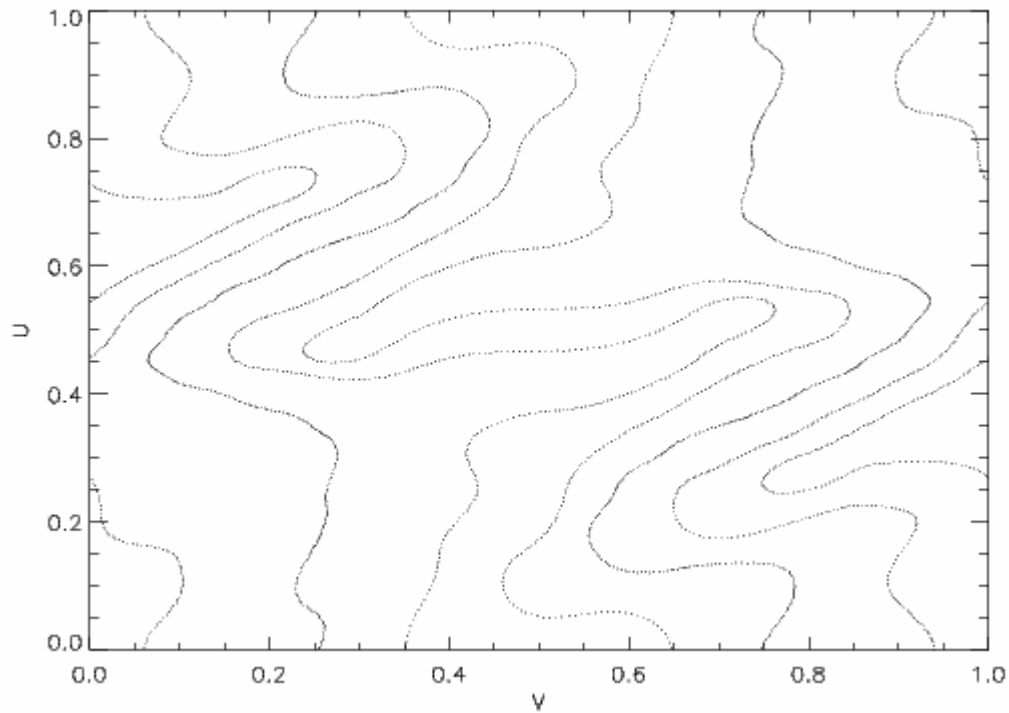
$$\begin{aligned} R/\Delta_{\min}(\text{c-p}) &\sim 6 \\ R/\Delta_{\min}(\text{c-c}) &\sim 10 \\ R/\rho_{\min} &\sim 14 \end{aligned}$$



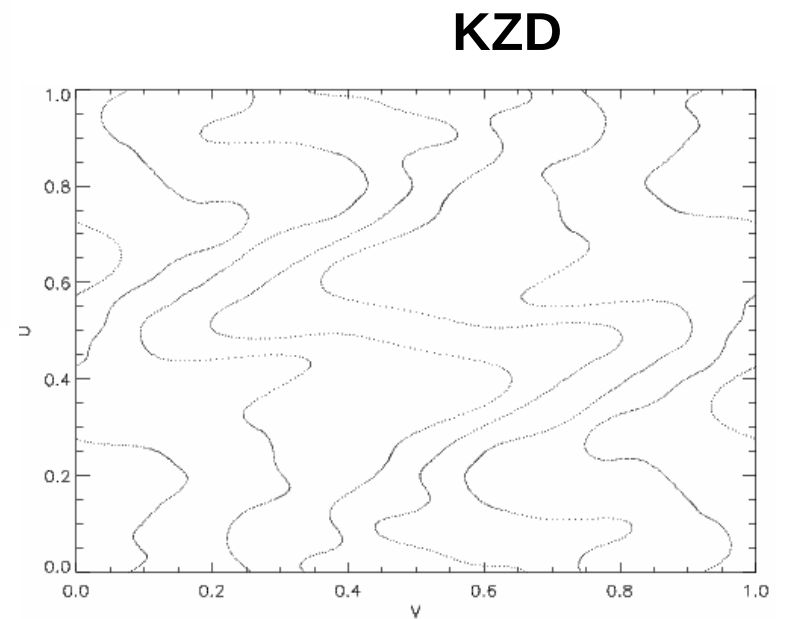
KZD



Coil contours on the current carrying surface show that the inboard winding for CRE13 needs improvement.



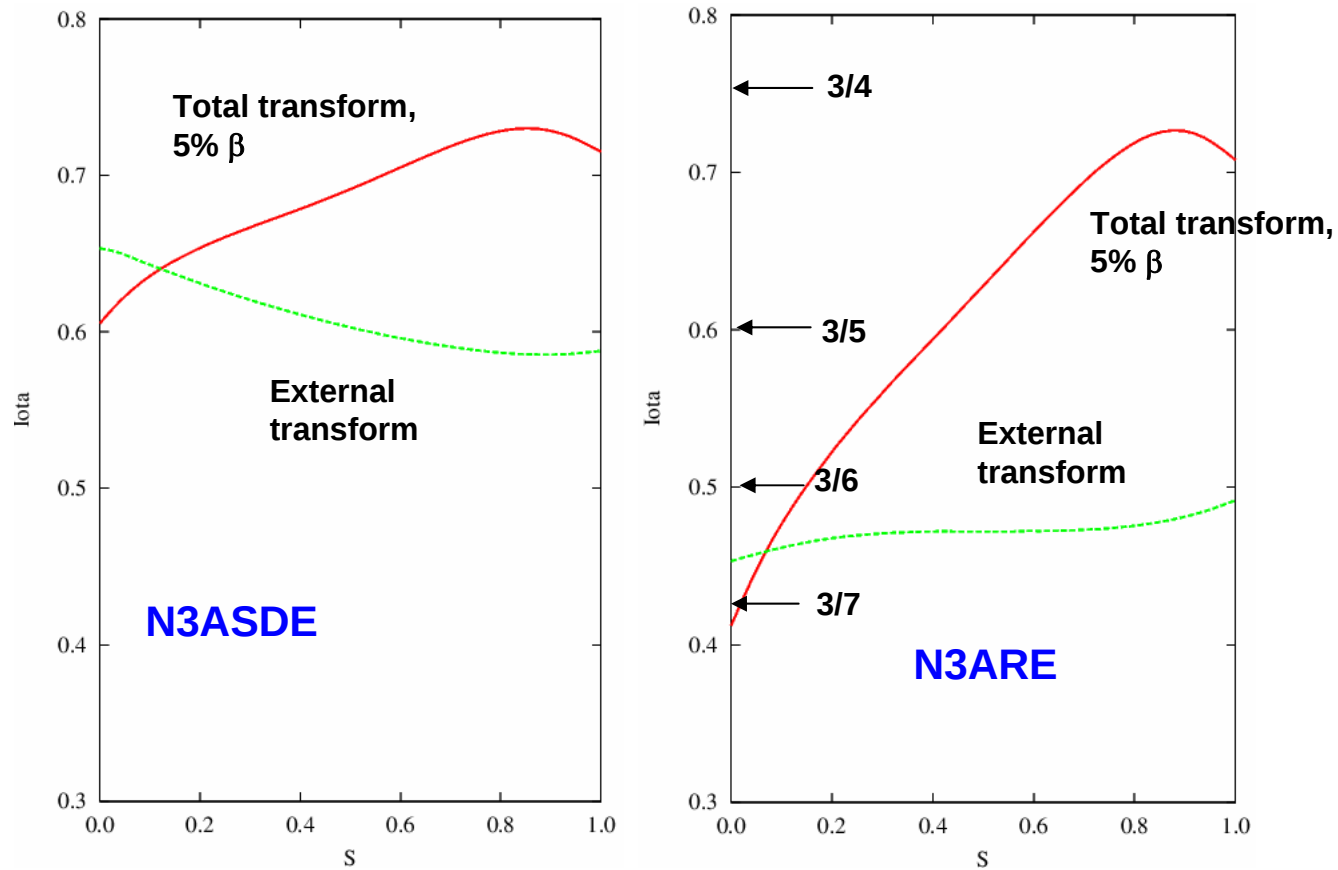
CRE13



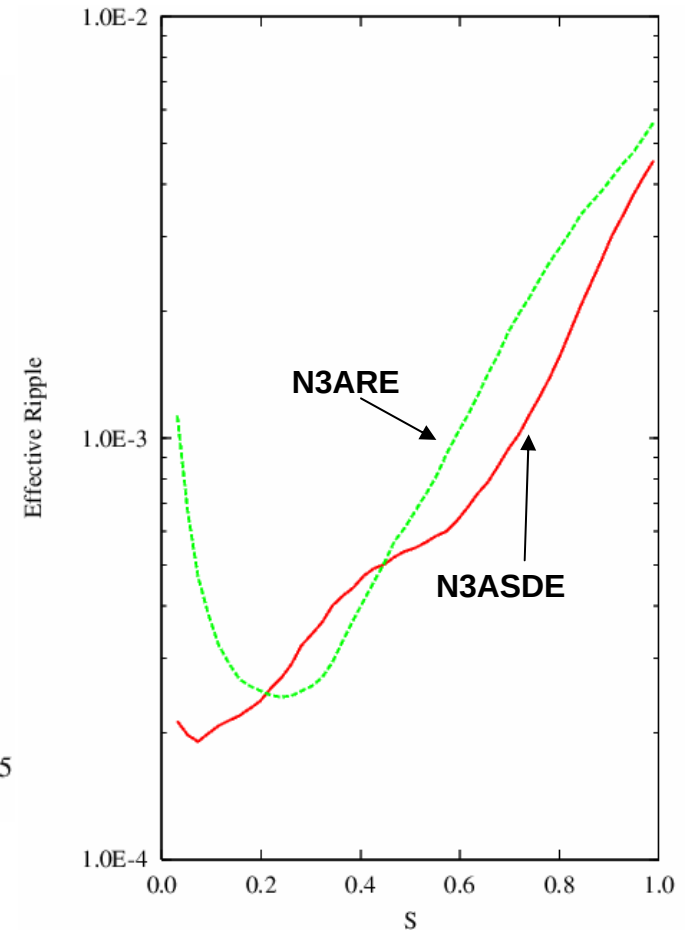
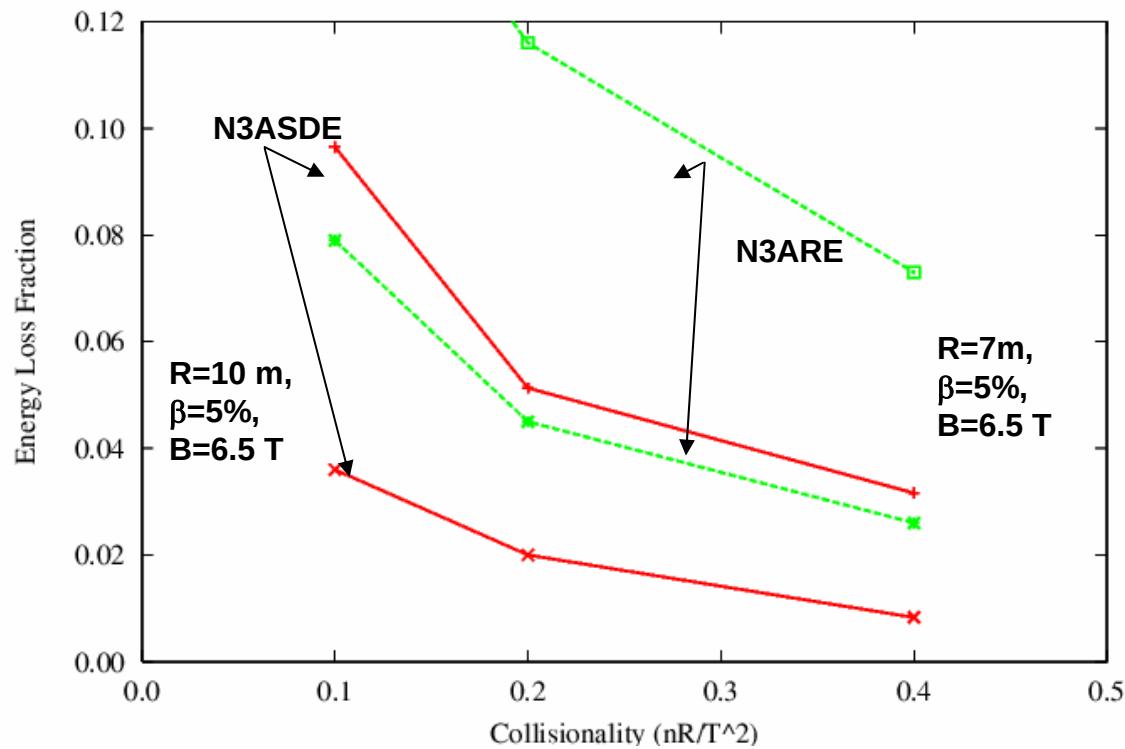
KZD

III. Hybrid of SNS and N3ARE.

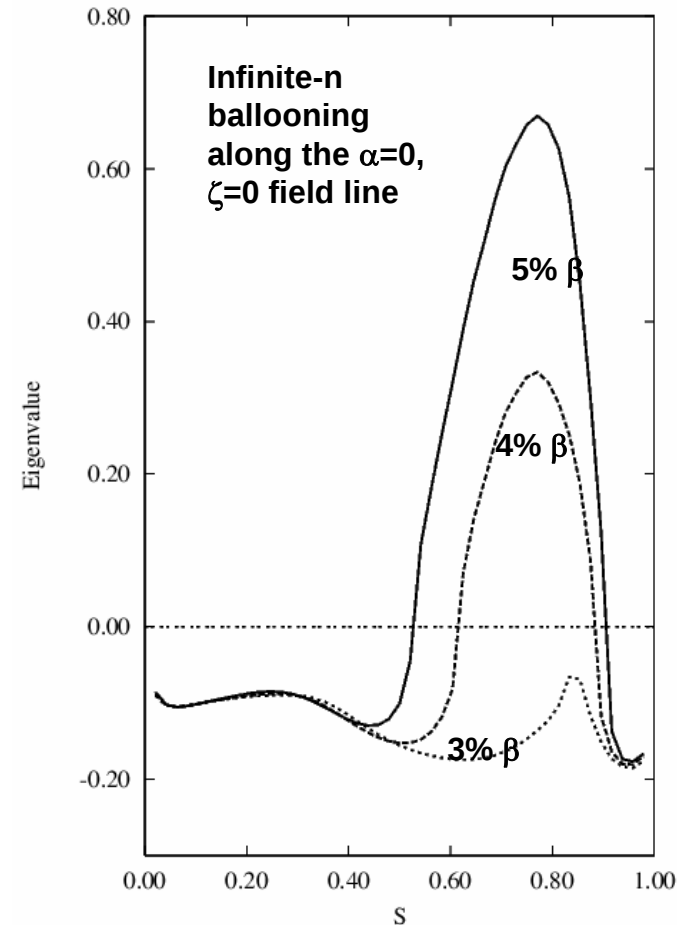
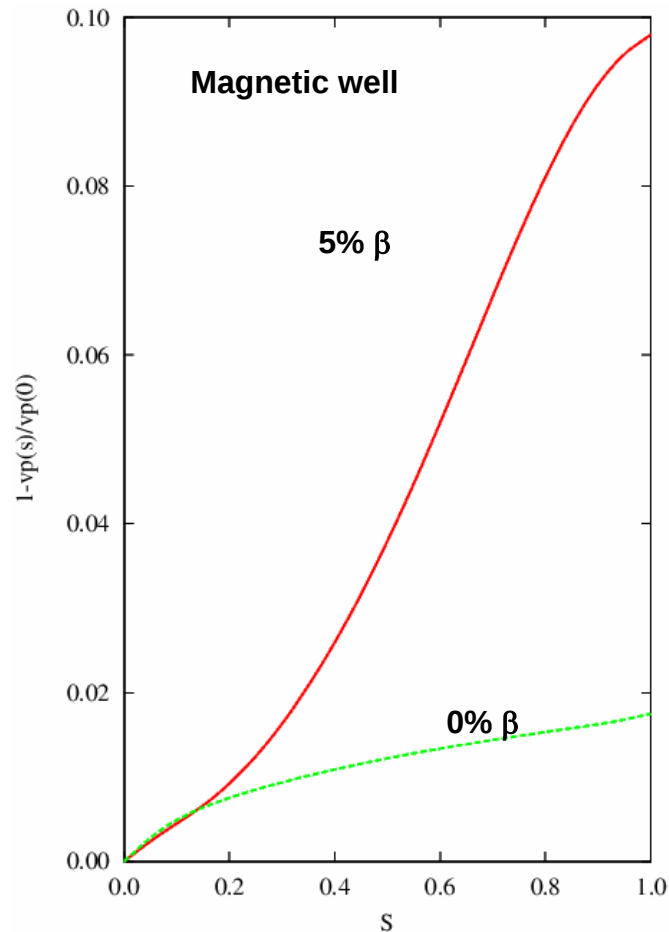
We've constructed a class of configurations which combine features of N3ARE and SNS, offering large core transform, low effective field ripples, good α confinement, excellent flux surface quality, decent inherent magnetic well and good MHD stability properties.



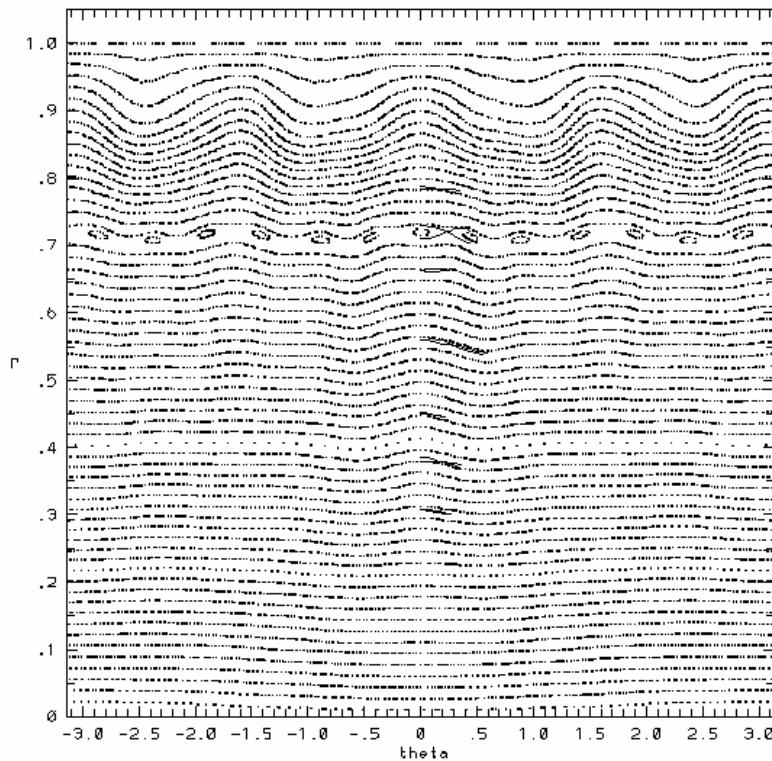
The effective ripples are very small ($<0.5\%$) and the α confinement is significantly better than N3ARE.



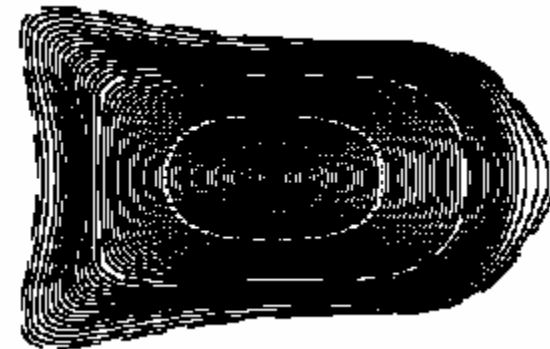
The hybrid can be made stable to the kink modes at 5% β . They have inherent magnetic wells, making them less susceptible to interchange-types of instability. The calculated infinite-n ballooning is typically stable at $\sim 3.5\%$ β .



The rotational transform at 5% β skirts all low order resonances. Results from PIES calculation indicate that an excellent flux surface quality is expected.

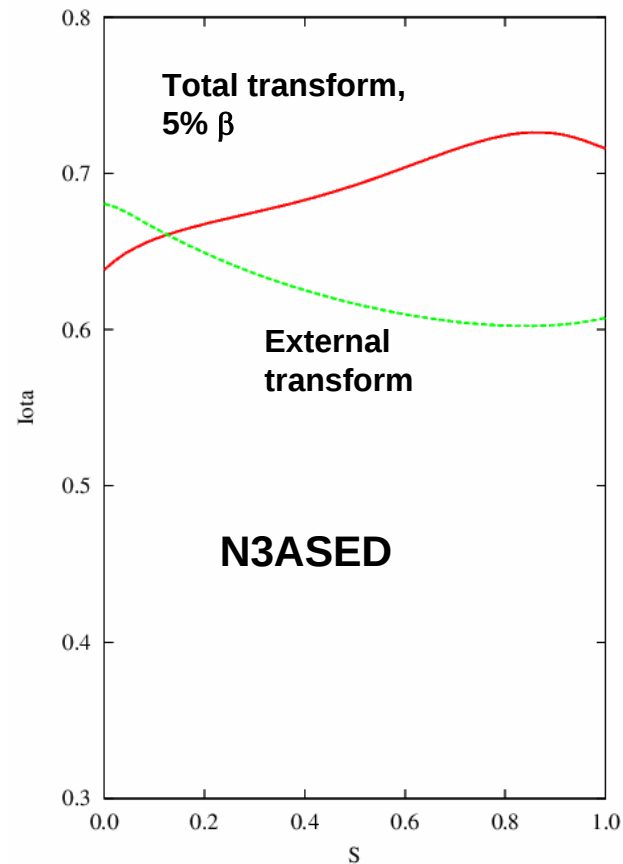
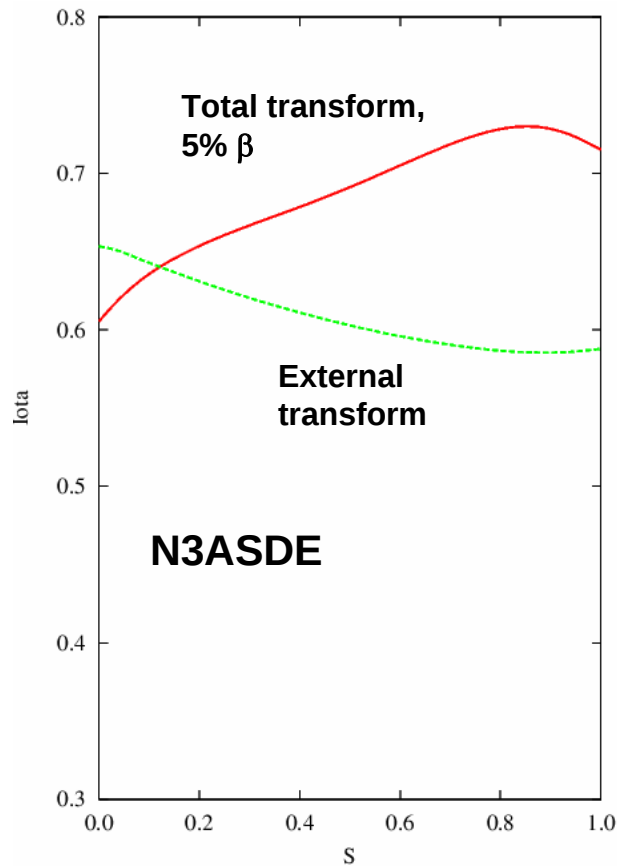


Flux surfaces viewed in (ρ, θ)
at $\phi=0$ plane.

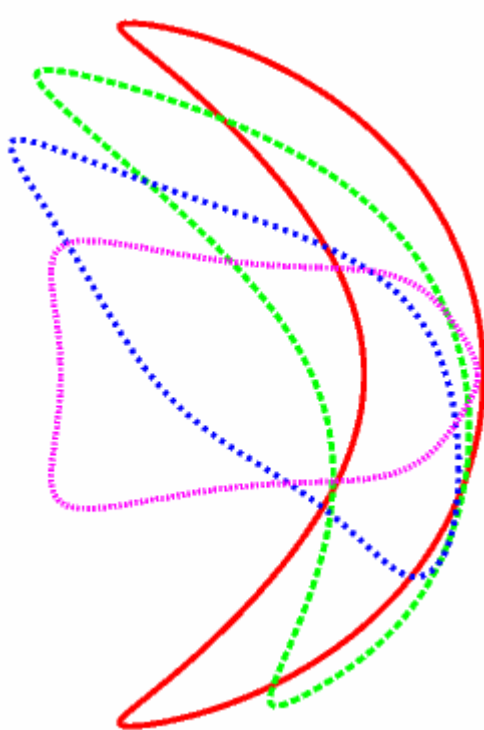


Flux surfaces viewed in (x, y)
at $\phi=\pi$ plane.

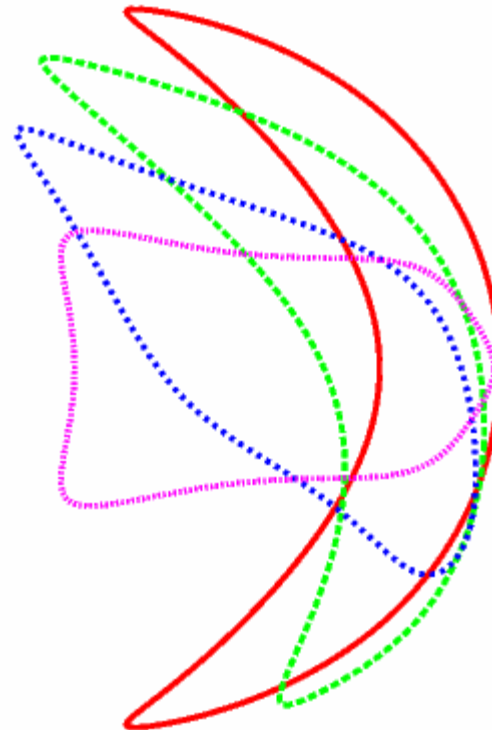
It is possible to adjust the shaping such that the vacuum transform also stays away from low order resonances, making flux surfaces robust through the entire discharge.



The additional shaping to increase the external transform for the case N3ASDE is modest enough that changes in LCMS are hardly visible by naked eyes.

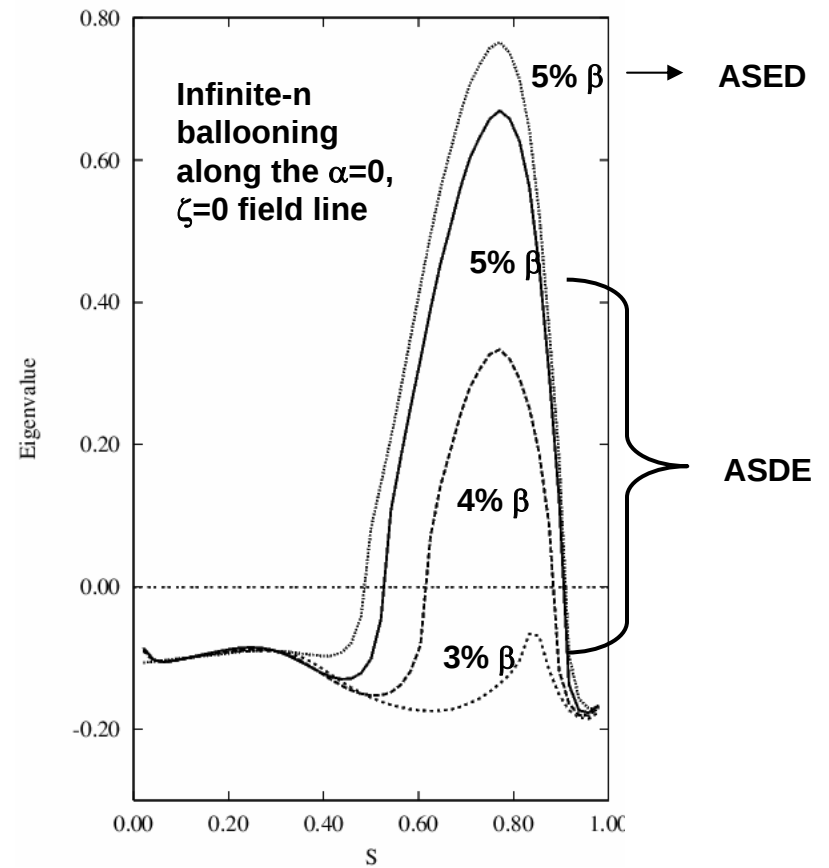
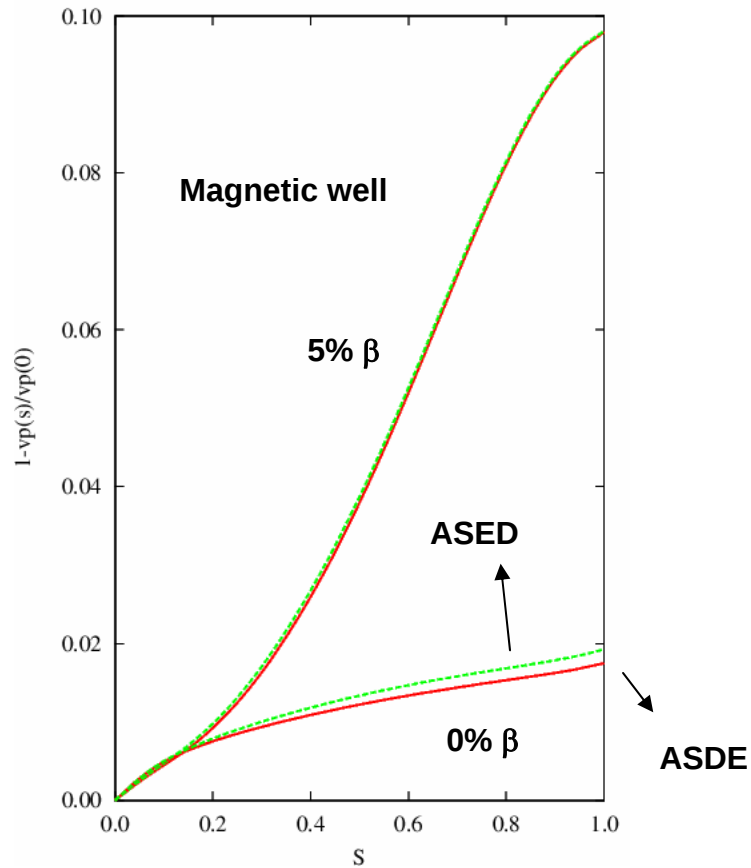


ASED

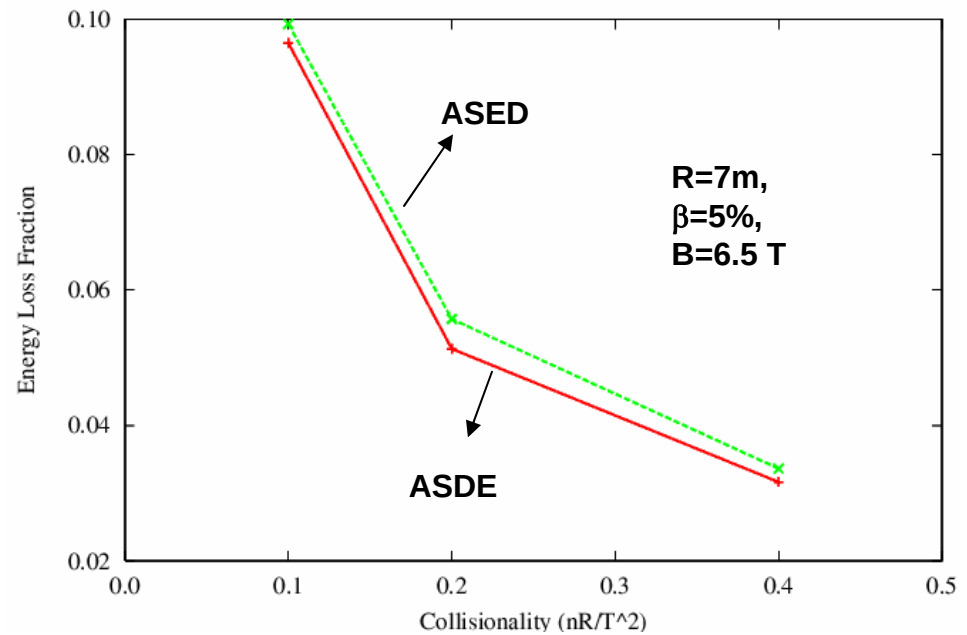
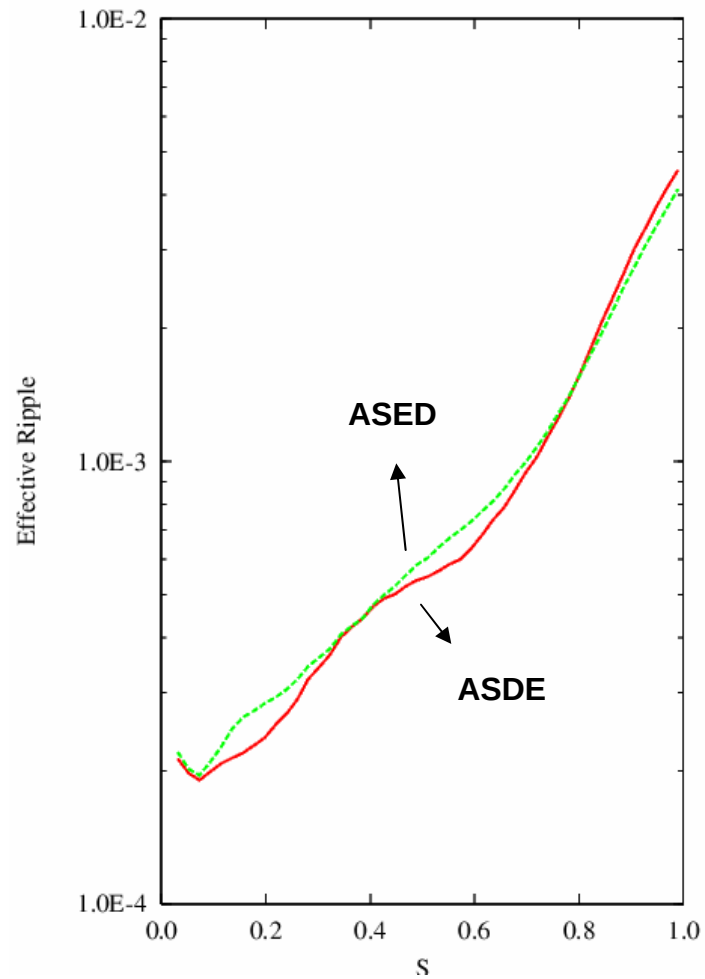


ASDE

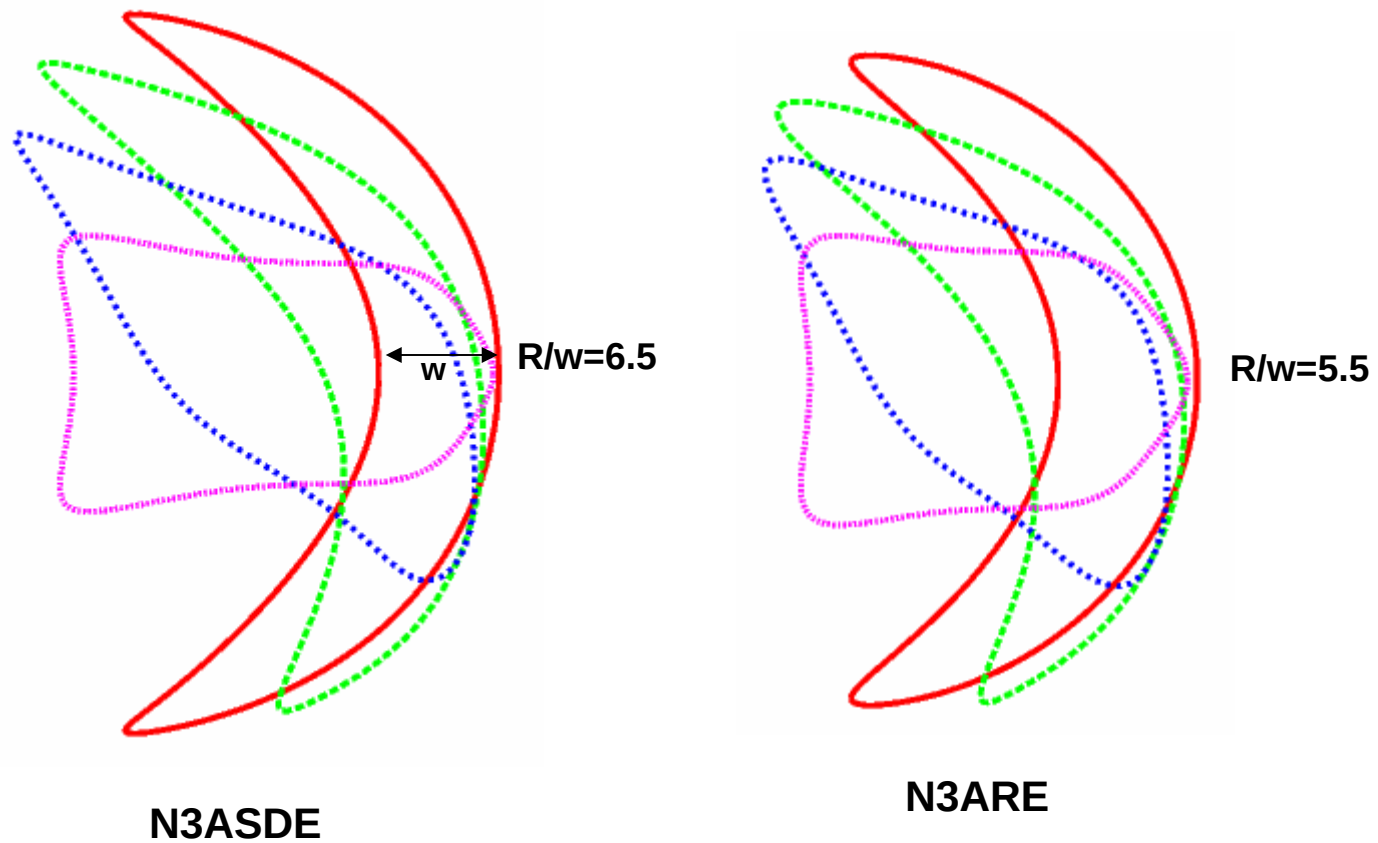
The additional shaping does not have significant effects on the MHD stability properties.



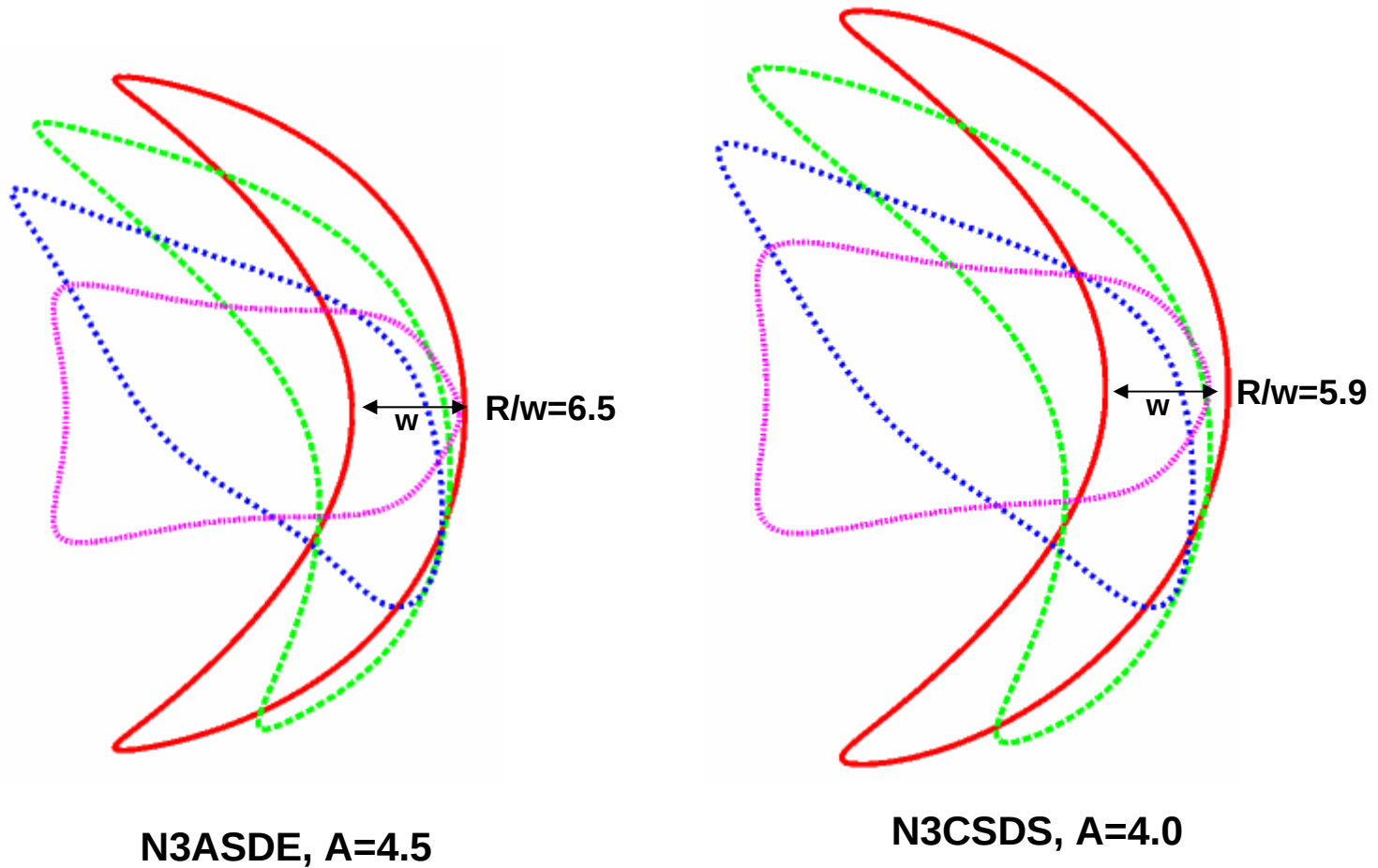
Nor does the additional shaping significantly impact the transport properties.



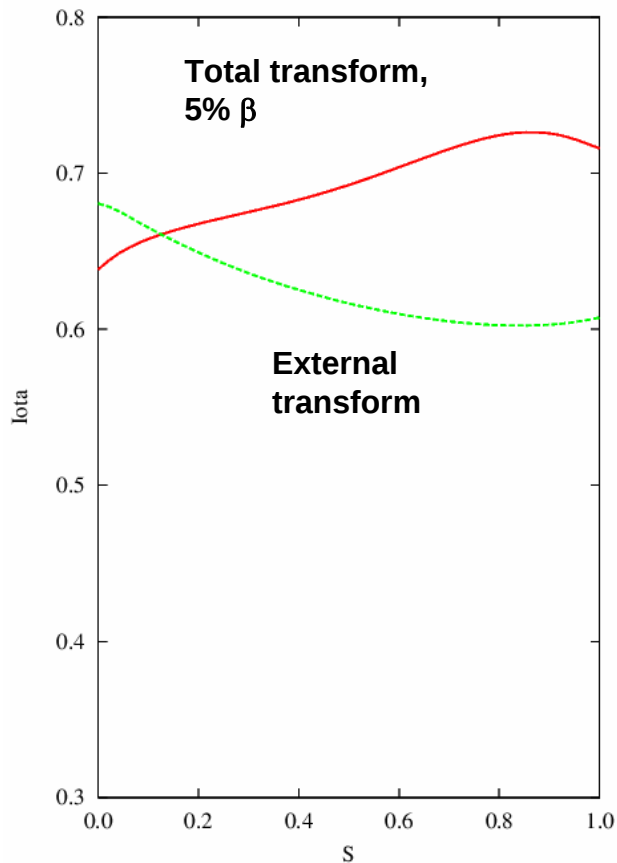
Higher core transform typically requires stronger shaping, resulting in sharper tips and narrower widths in some cross sections.



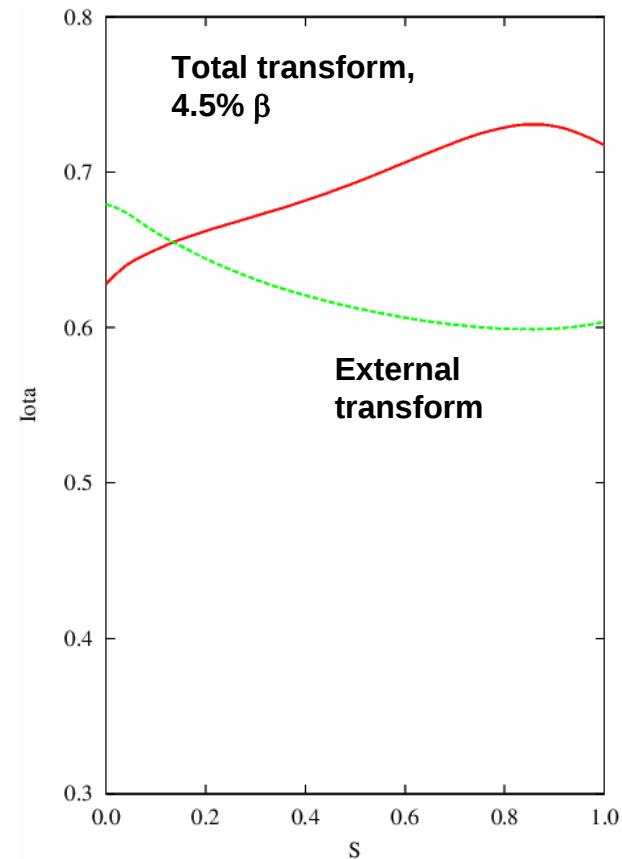
The waistline may be increased by reducing the plasma aspect ratio.



The lower aspect ratio configuration may be made to have similar rotational transforms as the higher aspect ratio one, thus preserving the essential feature of being able to avoid all low order resonances.



N3ASDE, A=4.5



N3CSDS, A=4.0

Summary and Conclusions

- We have carried out a preliminary design of modular coils for A=4 N3CRE whose transport and MHD stability properties are similar to those of the reference N3ARE configuration.
 - The initial results indicate that coils are complex but may not be more complex than the KZD coil set or the NCSX coils.
- The SNS and spectrum-biased hybrids have been further improved to show that it is possible to avoid low order resonances at all plasma pressures, thus significantly increase the attractiveness of this class of configurations.
 - Further optimization of rotational transforms does not significantly impact transport properties and MHD stability characteristics.
 - Still further improvement may be made by reducing the aspect ratio, but work is still preliminary.