New Development in Plasma and Coil Configurations

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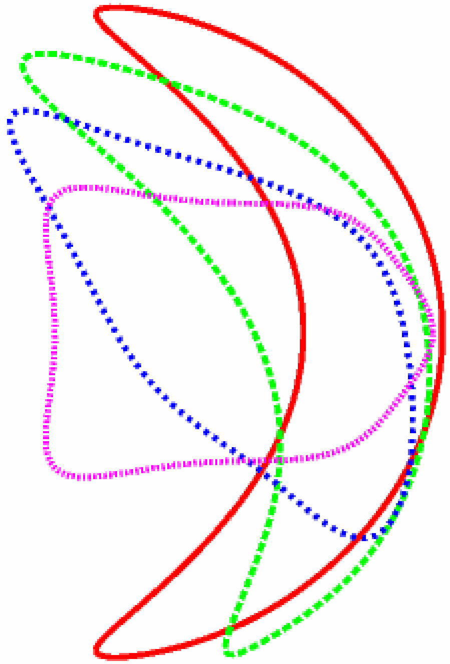
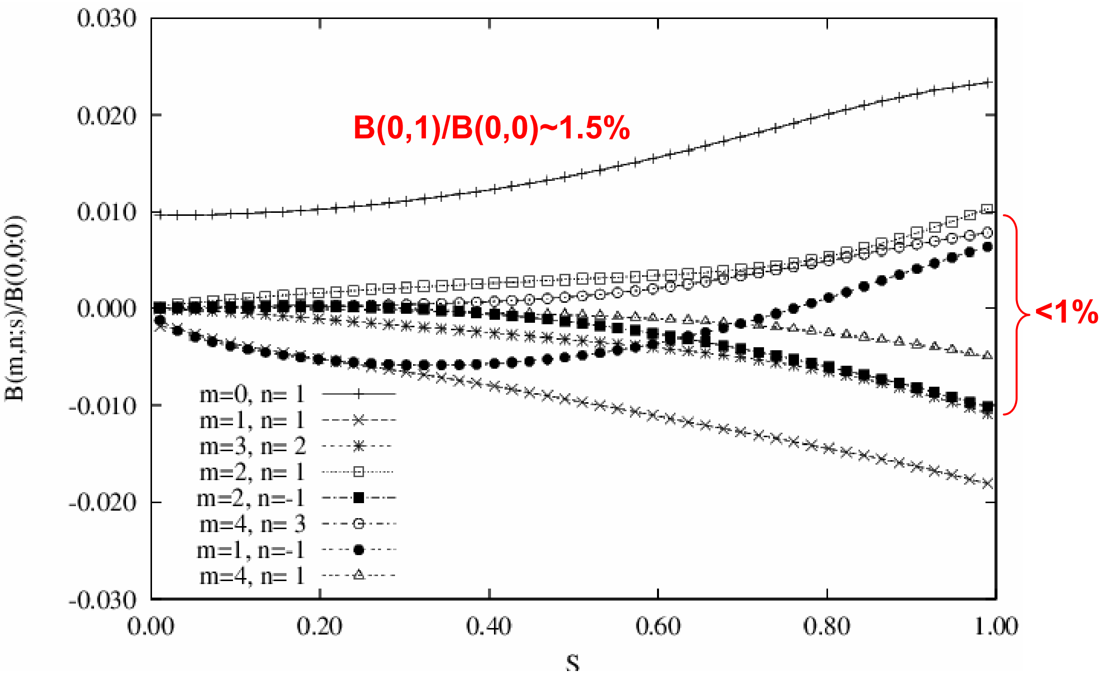
Re-cap of January discussions

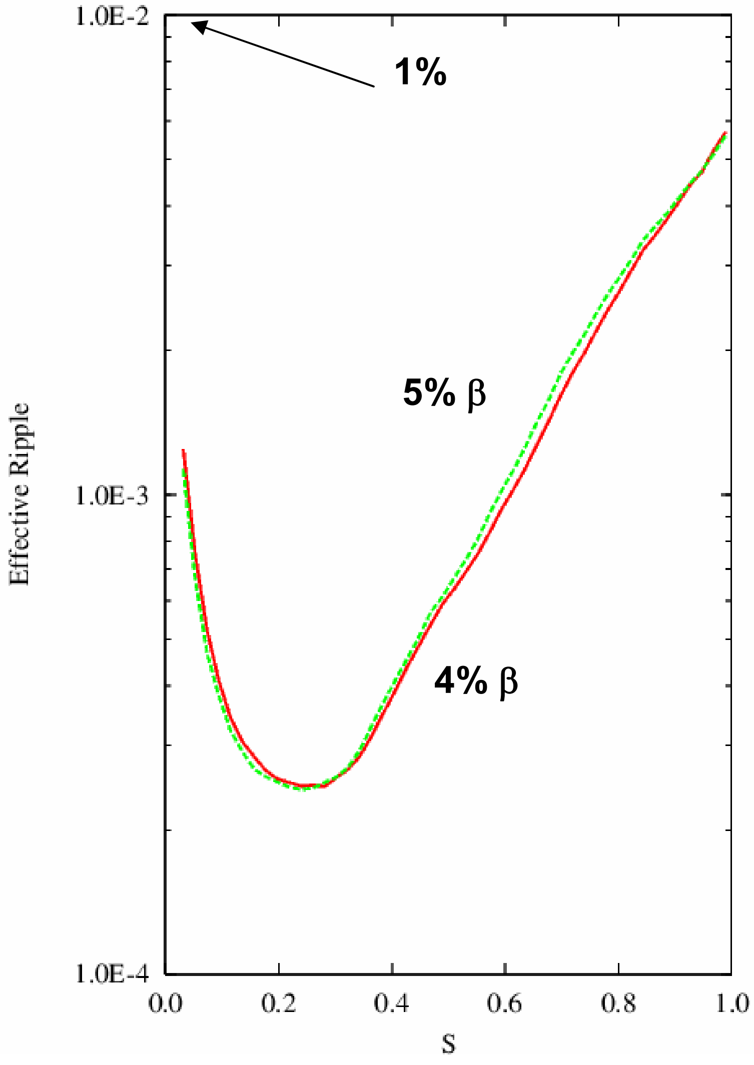
- **The baseline 11/05 configuration, N3ARE, is robust -- Our analysis indicates that essential physics properties are not significantly different using the density and temperature profiles based on either NCSX or the systems code.**

- **The confinement of α particles in our configurations depends strongly on the device size, field strength and collisionality with background ions. To maintain α energy loss <10%, high field and high density consistent with the maximum allowable field in the coil and density in the plasma are desirable.**

N3ARE, a configuration of the NCSX-class, with a small but non-negligible mirror component introduced in the magnetic spectrum has been demonstrated to have good "all around" physics properties desirable for power producing reactors.







N3ARE has very low effective ripples (ε–eff), hence good transport properties, while it also maintains favorable MHD stability characteristics. It is "calculated" to be stable at 4-5% β (external kinks, ballooning and Mercier). The loss of α may be limited to < 10%. The configuration is robust to changes in temperature and density profiles as well.

Work plans presented in January meeting

- Continue to examine physics aspects of the baseline design selected by the systems code. Additionally, expand the study to include the A=4 configuration with three periods since there may be advantages to lower the aspect ratio.

Today's discussion

- Optimize internal transforms by varying p and J profiles.

- Continue the effort of using biased magnetic spectrum to improve configurations.

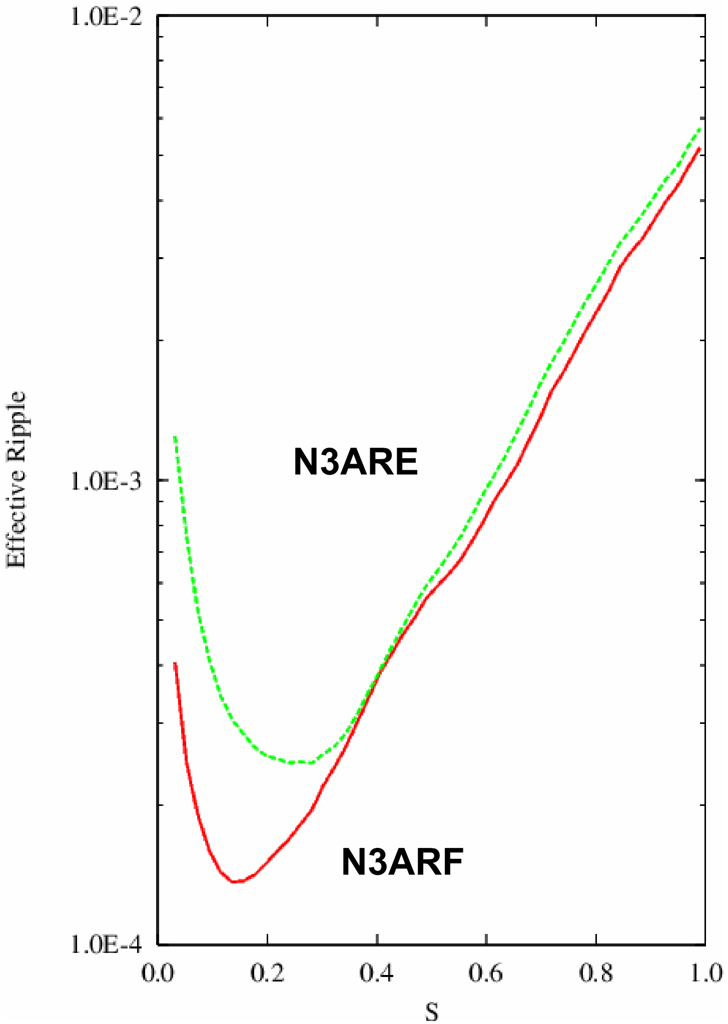
  – Add iota constraint for surface quality improvement
  – Study coil complexity and plasma aspect ratio

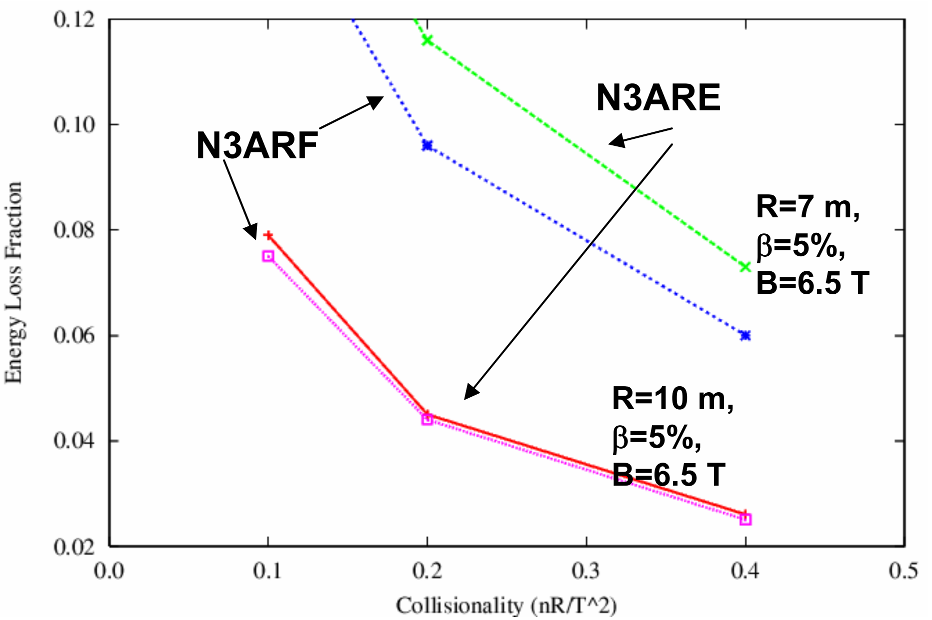
Today's topics

- Improving alpha loss by further optimizing the baseline configuration, N3ARE.
  - Lowering ε-eff even more in the core region.
- Improving alpha loss by reducing plasma aspect ratio.
  - $R \sim \Delta_{min} \cdot A_c$, $P_f \propto B^4 \beta^2 R^3 / A_p^2$, α confinement $\propto B^2 (R/A_p)^2$
    $\Gamma_w \propto P_f A_p / R^2$
  - For given P_f, B, R, lower A_p => better α confinement and lower β, hence better MHD stability, and lower neutron wall load.
- Improving alpha loss by increasing core transform.
  - Higher transform in core => better α confinement
  - Transform can be modified to further improve surface quality.

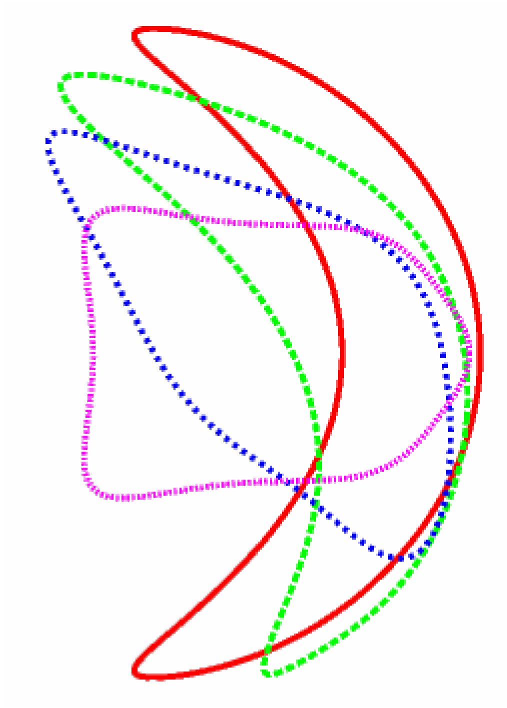
I. Improving α confinement by further optimizing N3ARE.

N3ARE may be further optimized to improve the α confinement by reducing ripples even more, particularly in the core region.

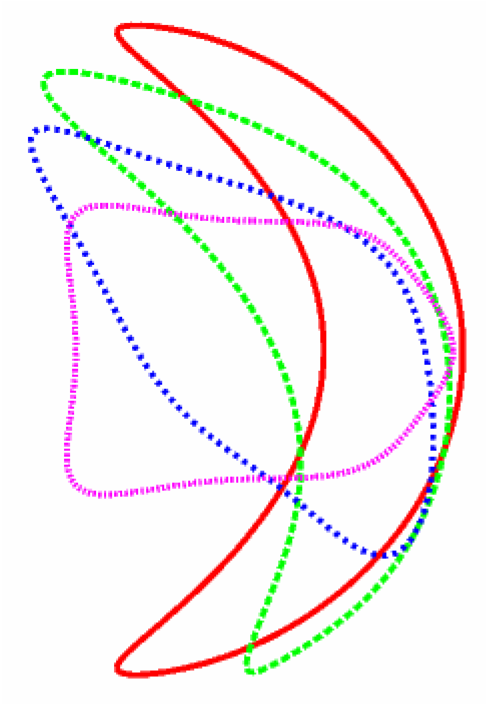




Change in shape of the last closed magnetic surface is insignificant.



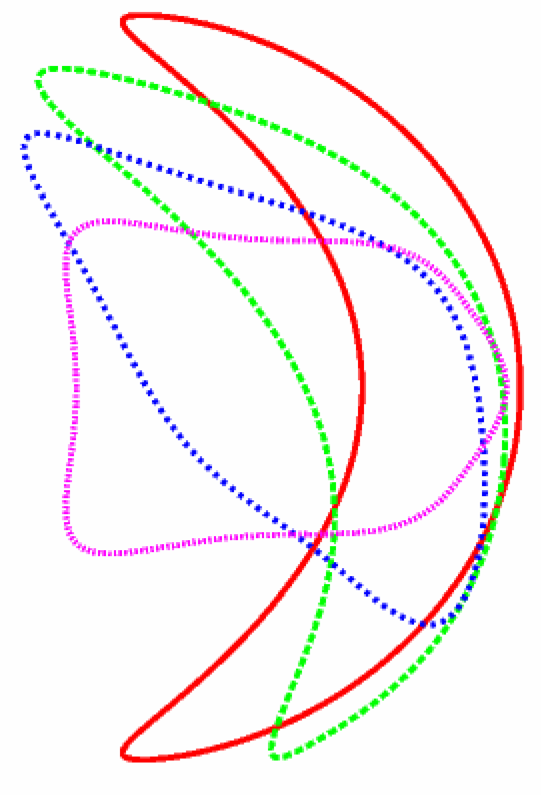
N3ARF



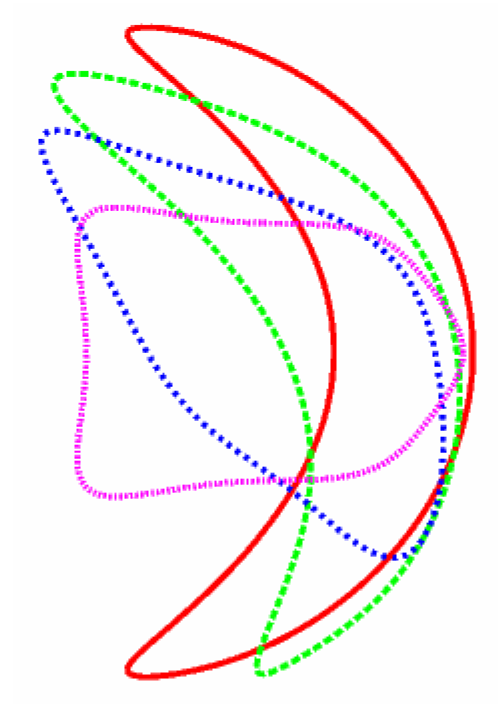
N3ARE

II. Improving α confinement by reducing plasma aspect ratio.

A configuration, N3CRE, whose QA and MHD stability properties are similar to those of N3ARE but whose aspect ratio is smaller by ~10%, may be more attractive as a reactor.

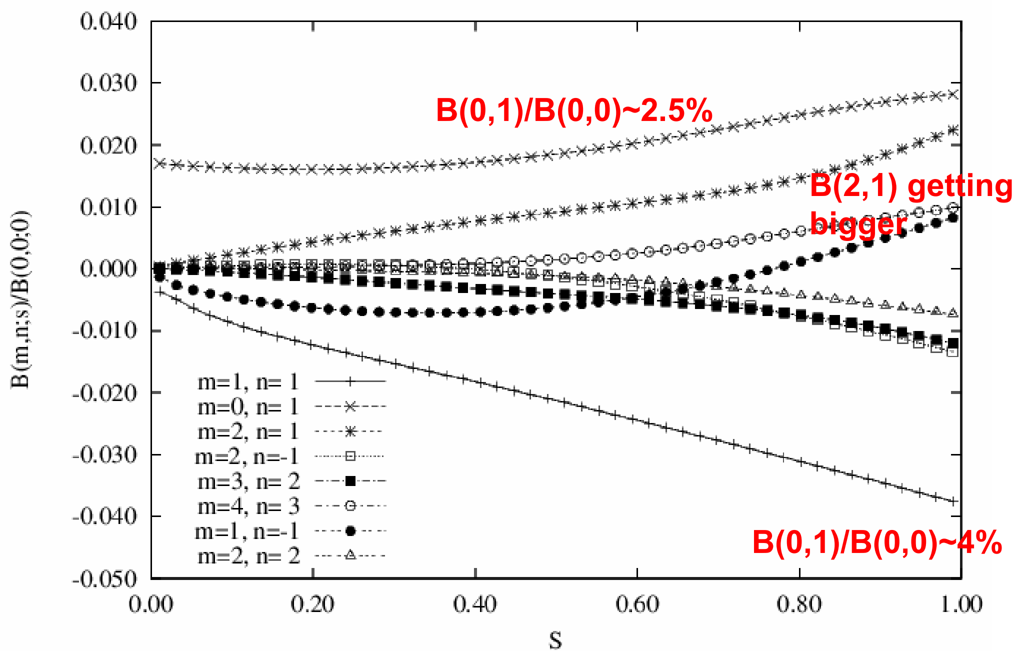


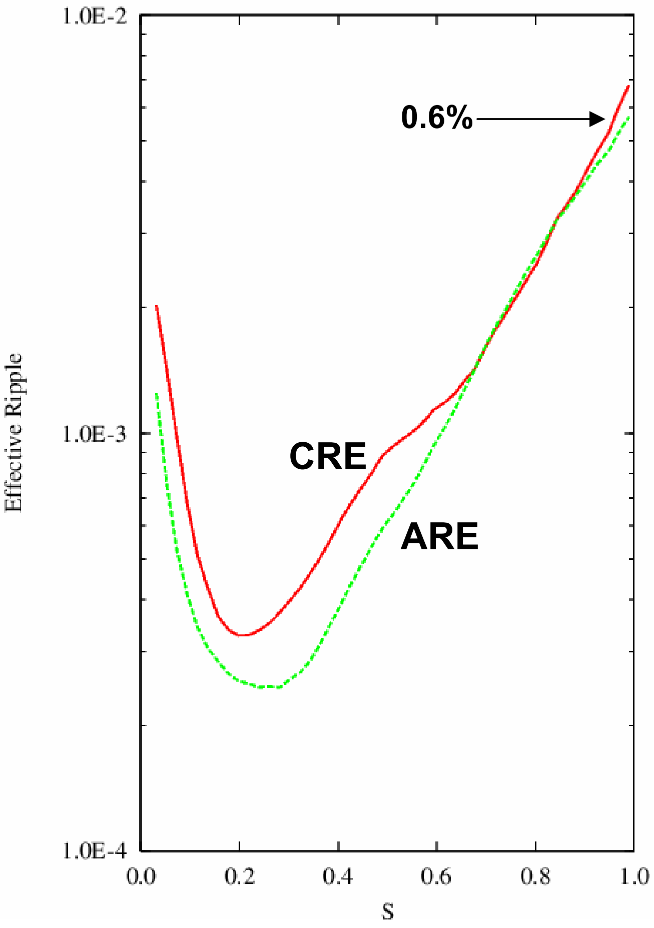
N3CRE, A~4



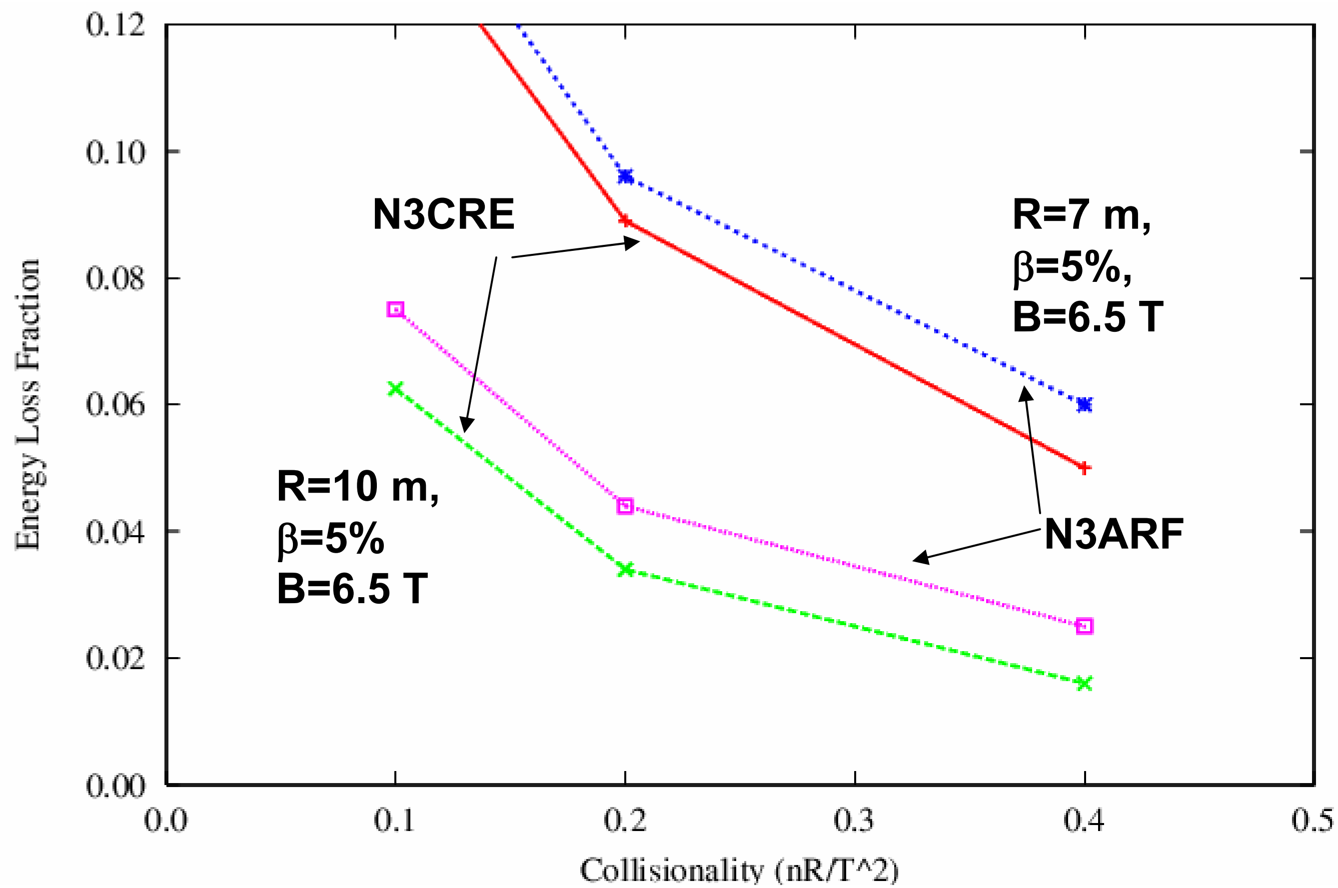
N3ARE, A~4.5

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.



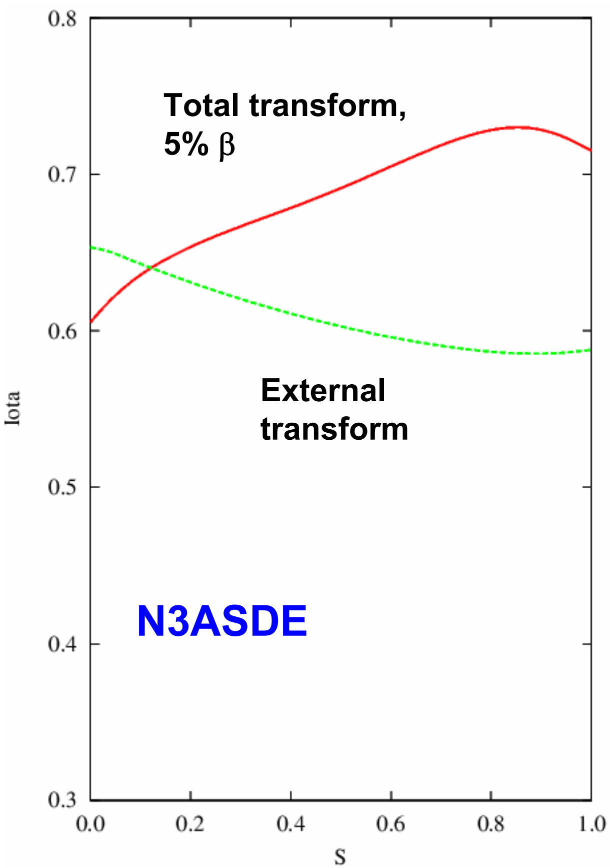


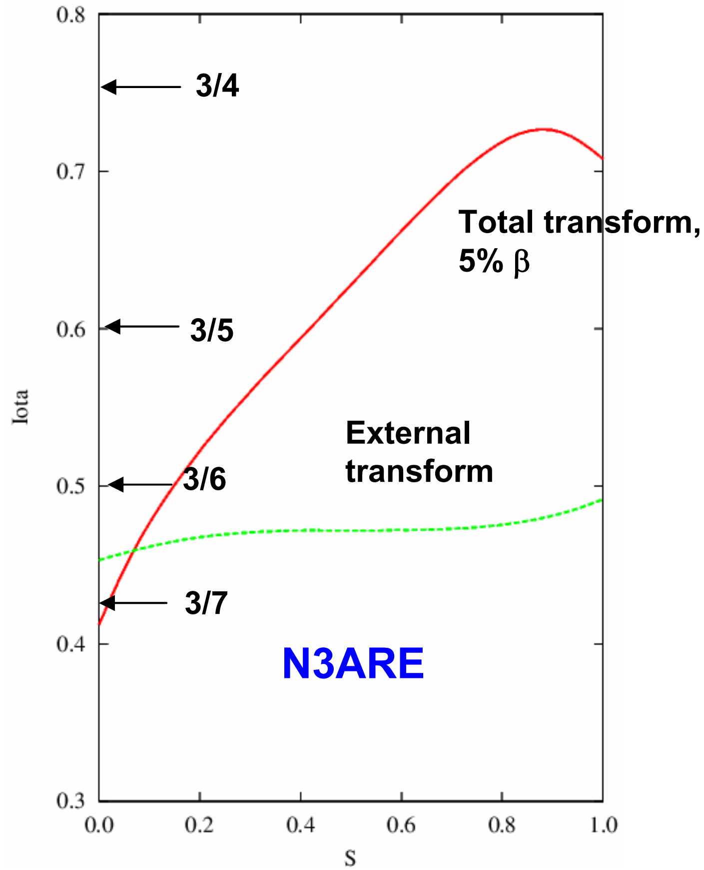
Under the same conditions the lower aspect ratio N3CRE has better α confinement characteristic than N3ARF, the confinement improved version of N3ARE.



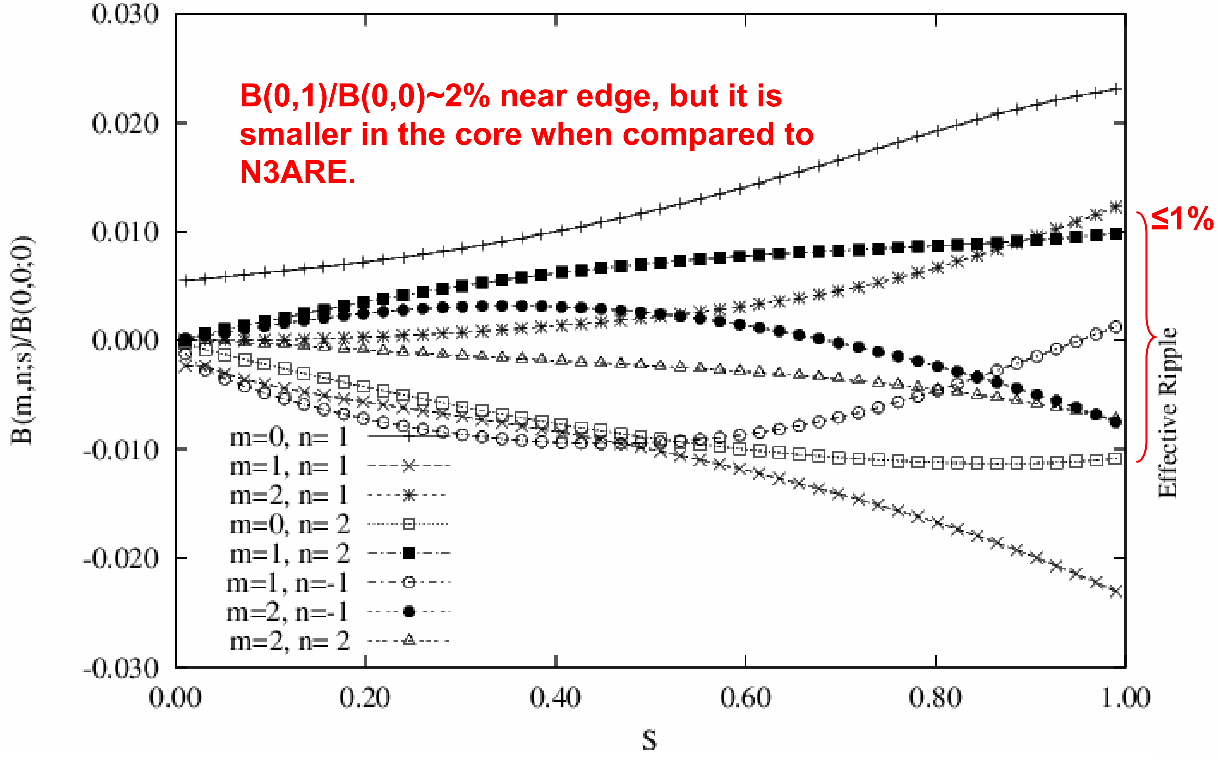
III. Improving α confinement by increasing core transform.

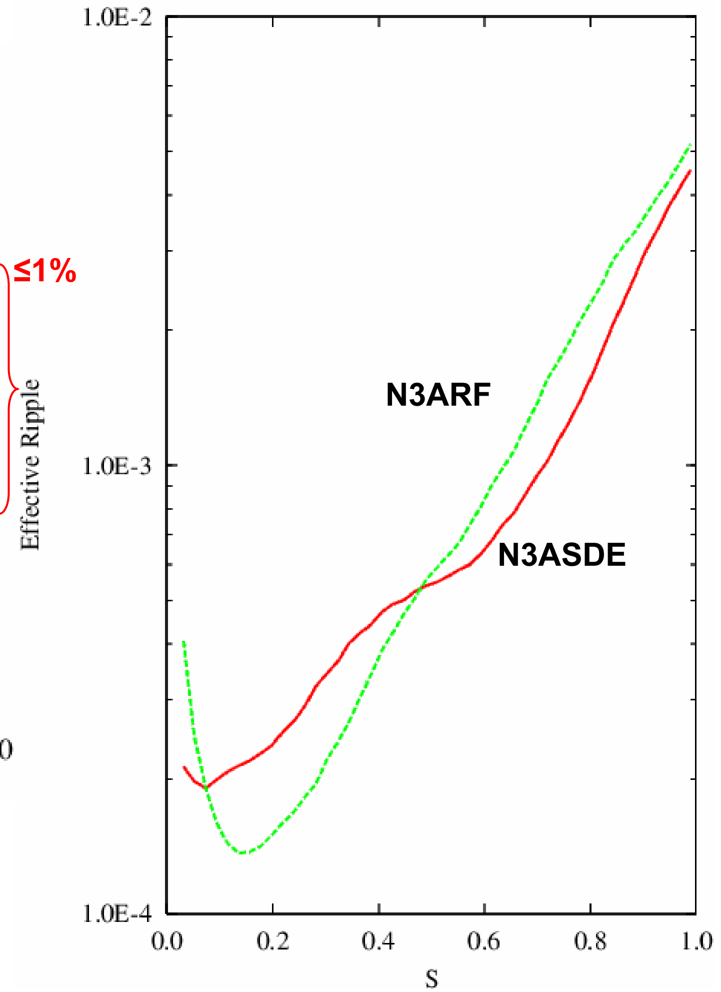
A new class of configurations has been developed which combines features of N3ARE and SNS, offering large core transform, very low ripples, good α confinement, excellent flux surface quality, a decent inherent magnetic well and good MHD stability properties. An example, N3ASDE, with A_p~4.5 is used here for illustration.



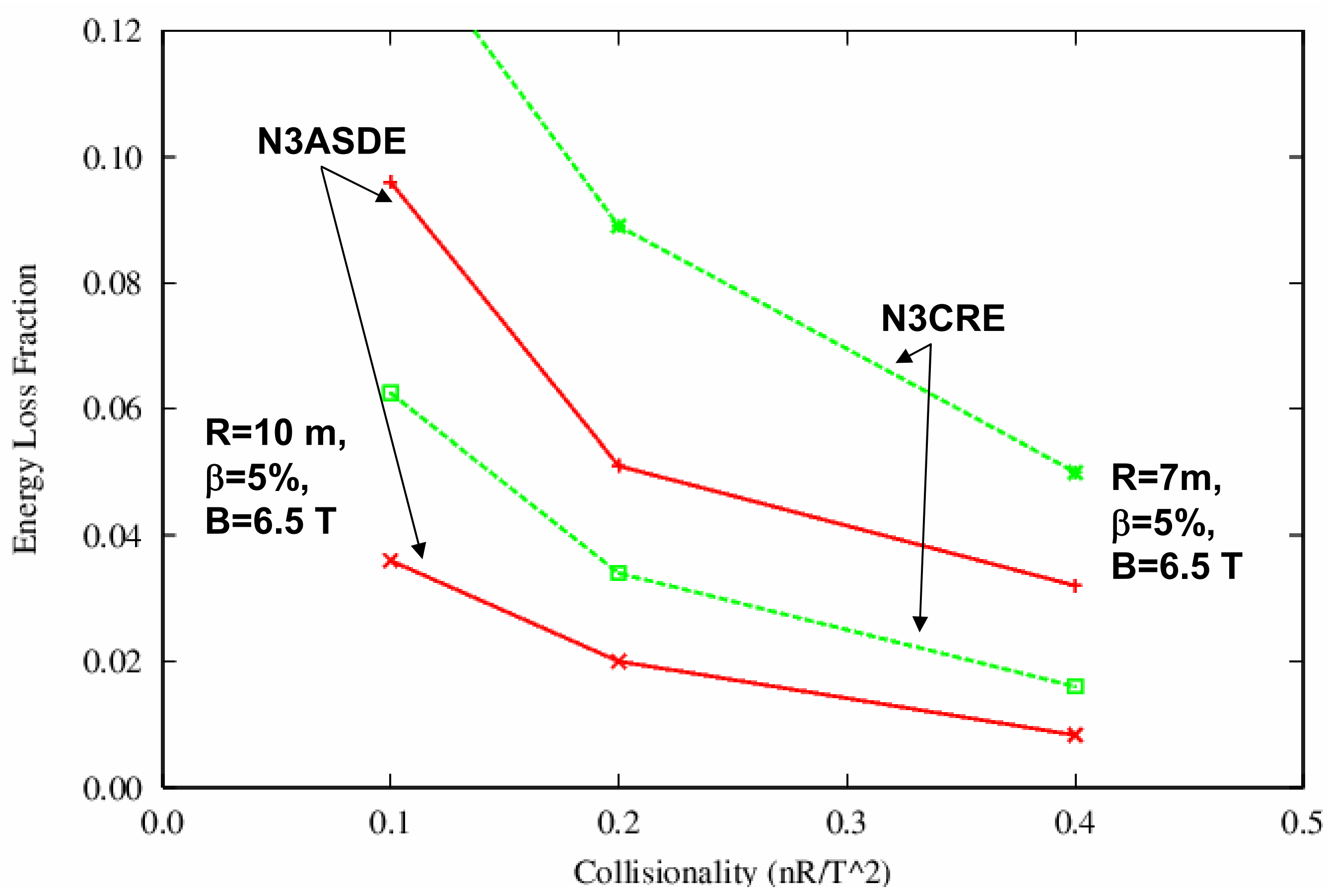


All significant residues in the magnetic spectrum are low order harmonics with B(0,1) and B(1,1) again dominating, just like in N3ARE/N3CRE. The effective ripples are very small (<0.5%), and mostly smaller than those in N3ARF.

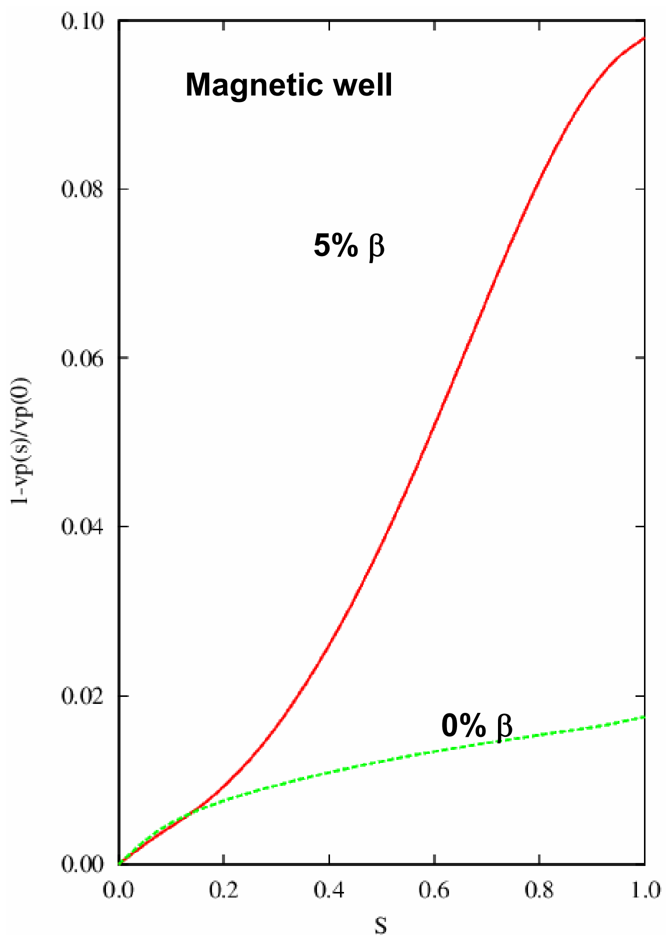


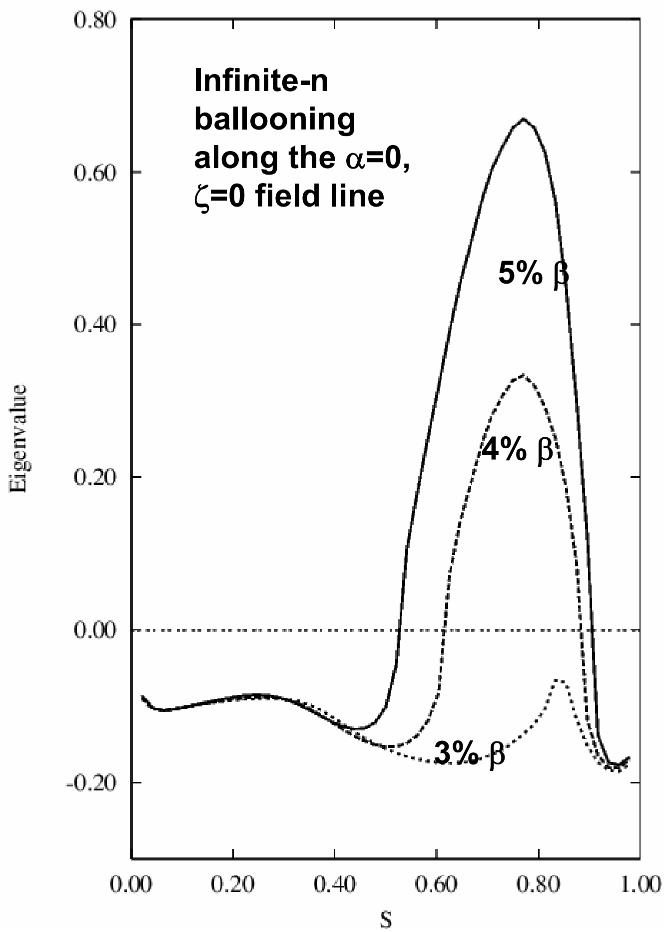


The α confinement of N3ASDE is significantly better than even that of N3CRE under the same conditions. The energy loss fraction <5% may be achievable.

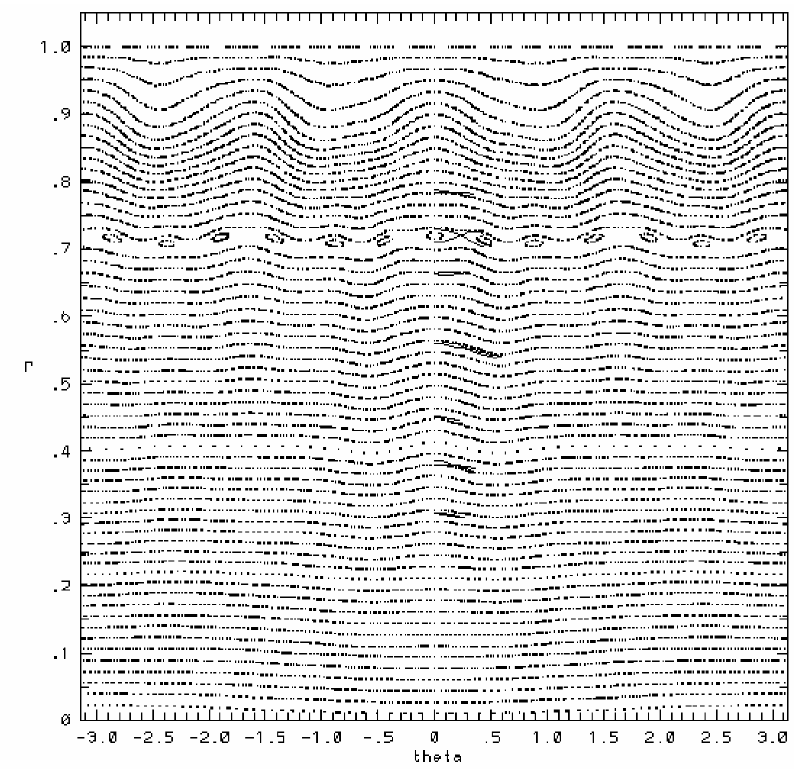


N3ASDE is expected to be marginally stable to the kink modes at 5% β. It has ~2% inherent magnetic well, making it less susceptible to interchange-types of instability. The calculated infinite-n ballooning is stable at ~3.5% β.

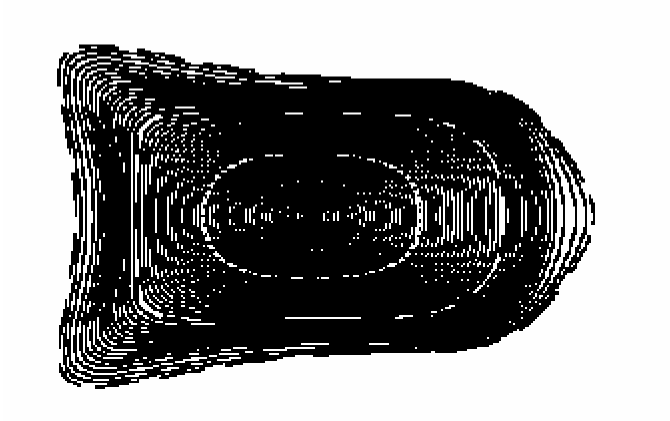




The rotational transform at 5% β skirts all low order resonances. Results from PIES calculation indicate that an excellent flux surface quality is expected.

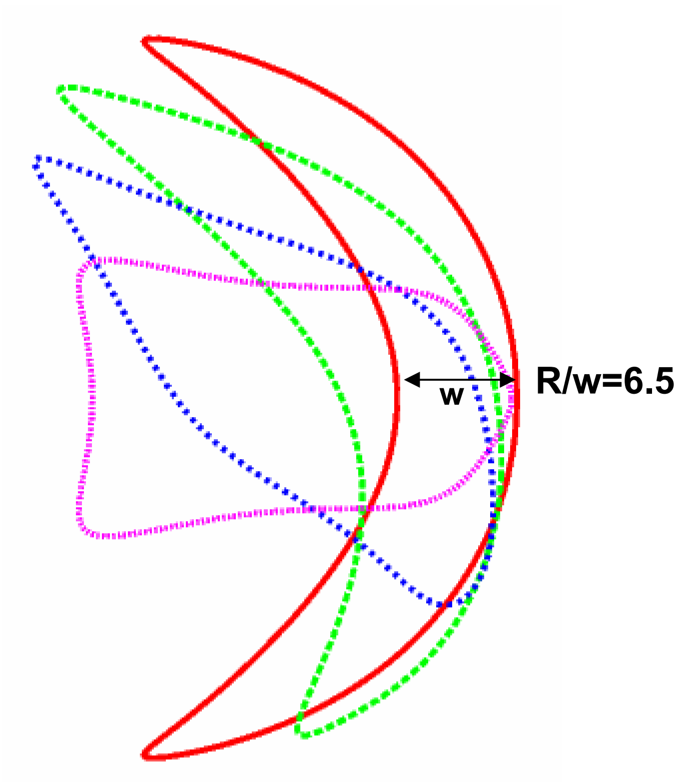


Flux surfaces viewed in (ρ, θ) at ϕ=0 plane.

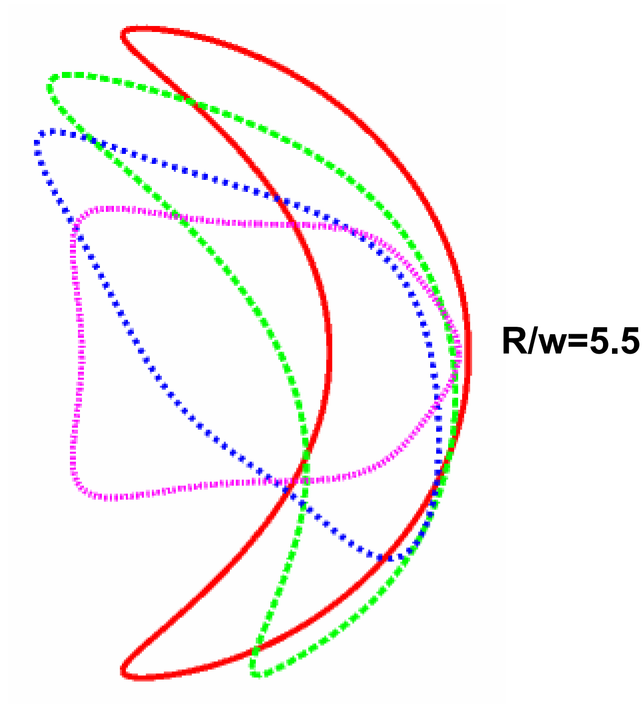


Flux surfaces viewed in (x,y) at ϕ=π plane.

Higher core transform requires stronger shaping, resulting in sharper tips and narrower widths in some cross sections. It remains to be seen if the shaping poses insurmountable difficulty in designing coils.



N3ASDE



N3ARE

Summary and Conclusions

- **Further progress has been made to reduce α loss and to improve the overall attractiveness of QAS as power producing reactors.**
  - **The 11/05 baseline configuration was optimized further to reduce ripples in the core with little sacrifice of other properties.**
  - **An A=4 configuration with properties similar to the 11/05 baseline was examined. It may be more attractive than the 11/05 baseline as it allows lower wall load and smaller α loss for the same major radius and fusion power.**
  - **A hybrid of SNS and spectrum-biased configuration was newly developed which offers very high quality QA, MHD stability and flux surface integrity. If the coil design can be sufficiently advanced, this new class of configurations may prove to be the one having all the desirable features for a power producing reactor.**

Work Plan

- **Continue the development of the new hybrid in**
  - **Configuration**
  - **Physics**
  - **Coils**
- **Cursory design of coils for the A=4 configuration.**