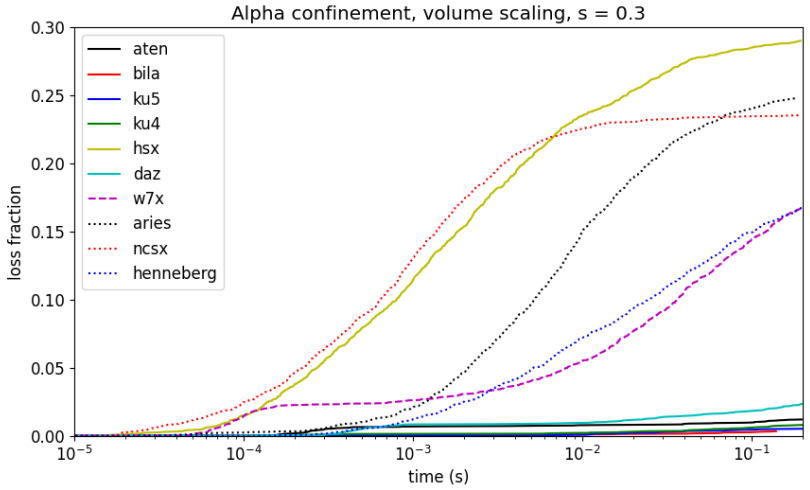
Comparisons of Stellarator Configurations w.r.t Alpha Confinement

A. Bader
with help from
M. Drevlak, J.C. Schmitt, M. Landreman, T. Kruger, and others

Wistell 2020, Dec 11

Alpha particle confinement calculated for many configurations



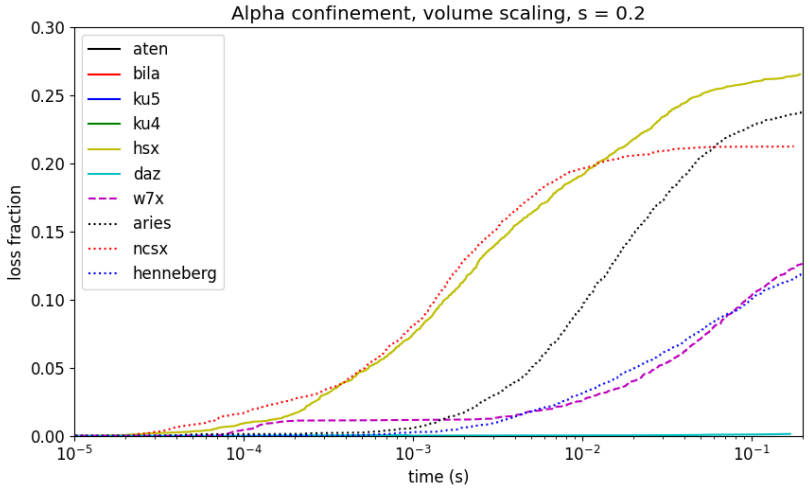
Overview of configurations

Config	Type	Per.	AR	Beta(%)	a (at 450m^3)	V (at a=1.7 m)
HSX	QH	4	10.0	0	1.3	970
Aten	QH	4	6.7	0	1.5	656
Bila	QH	5	6.6	0	1.5	649
Daz	QH	4	6.8	3.3	1.5	663
Ku4	QH	4	8.1	4.0	1.4	789
Ku5	QH	5	10.0	10.0	1.3	978
NCSX	QA	3	4.4	4.3	1.7	427
ARIES	QA	3	4.5	4.1	1.7	450
Henne.	QA	2	3.4	3.5	1.9	330
W7-X	QO	5	10.5	4.5	1.3	1022

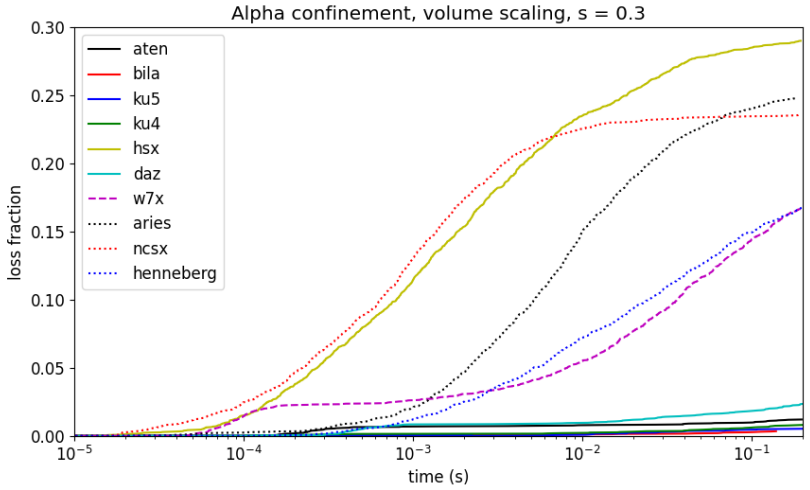
Scaling procedures

- To make comparisons as close as possible, configurations are scaled to ARIES-CS field (5.7 T) and separately scaled to either match volume (450 m^3) or minor radius (1.7 m)
- Plasma pressure, β is held constant, by scaling pressure by B_t^2/B_0^2
- To keep rotational transform profile fixed, plasma current is scaled by $a_t B_t / a_0 B_0$
- All calculations are done using ANTS, collisionless first, then collisional in the second half

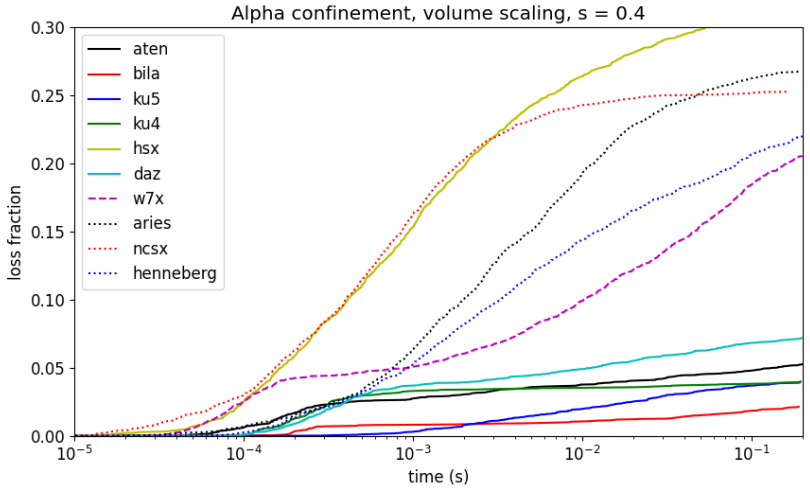
Alpha particle confinement volume scaling, s=0.2



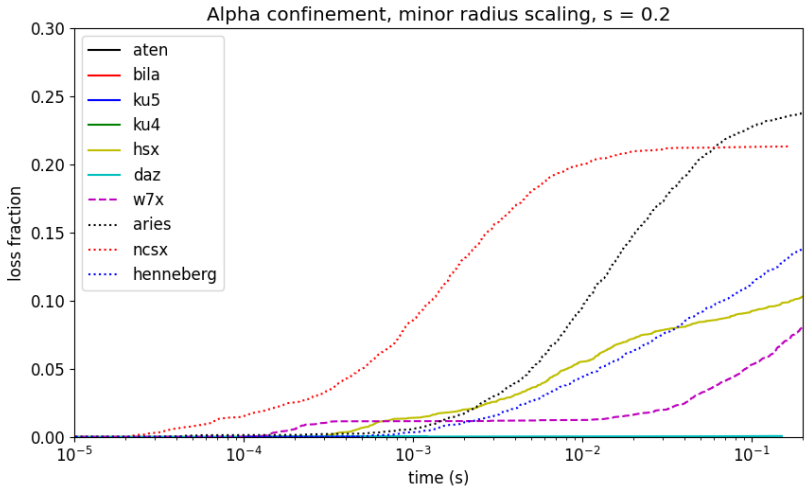
Alpha particle confinement volume scaling, s=0.3



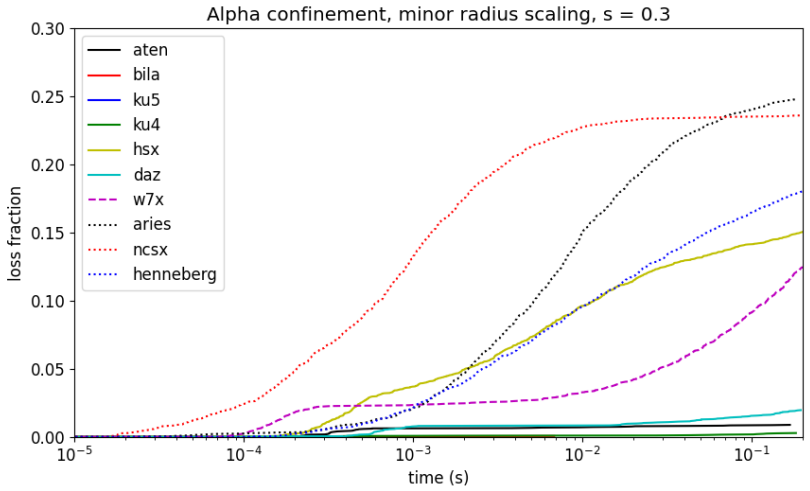
Alpha particle confinement volume scaling, s=0.4



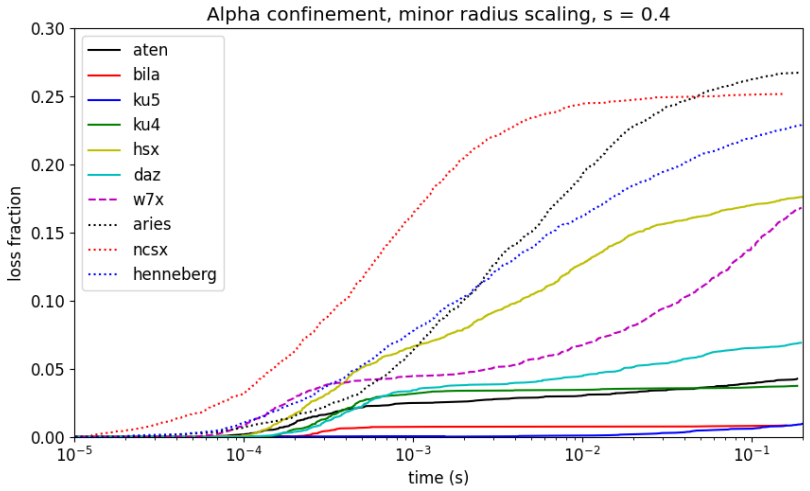
Alpha particle confinement minor radius scaling, s=0.2



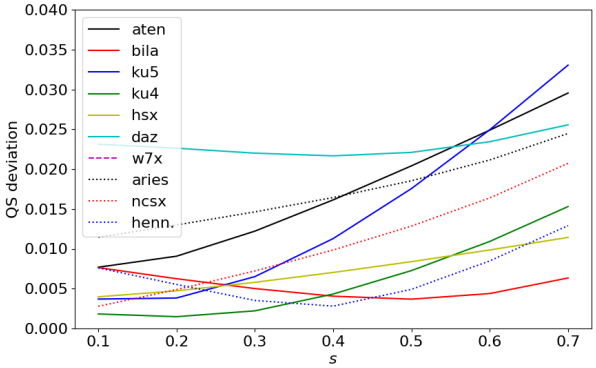
Alpha particle confinement minor radius scaling, s=0.3

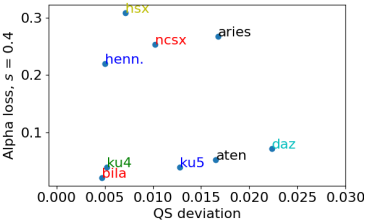


Alpha particle confinement minor radius scaling, s=0.4



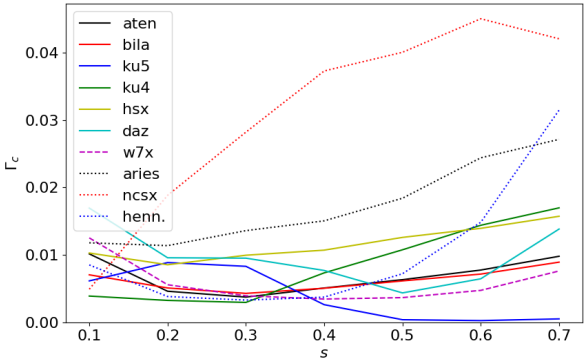
Configuration comparison: quasi-symmetry

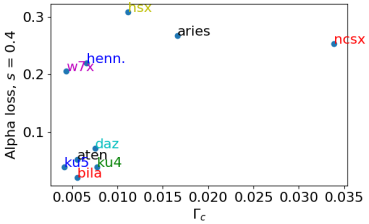




- Correlation exists between QS and alpha losses for QH and QA separately

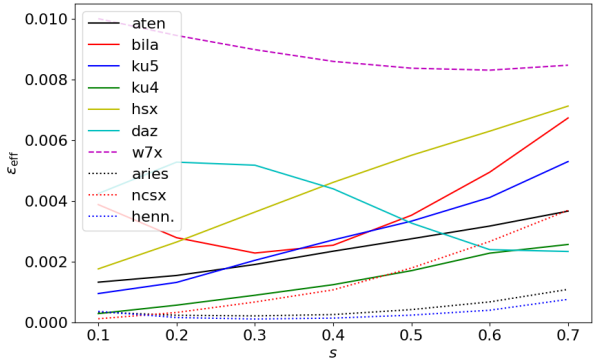
Configuration comparison: Γ_c

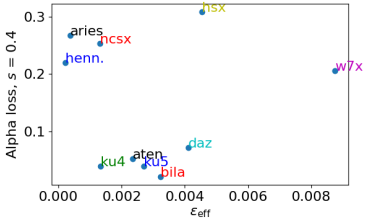




- Correlation less strong for Γ_c
- Neither metric properly captures coil ripple effects (HSX outlier)

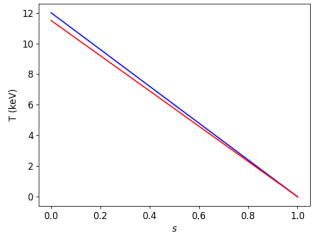
Configuration comparison: ϵ_{eff}

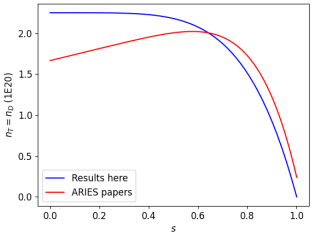


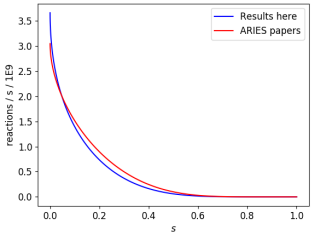


- Almost no correlation for ϵ_{eff}

Setting up collisional profiles for ANTS

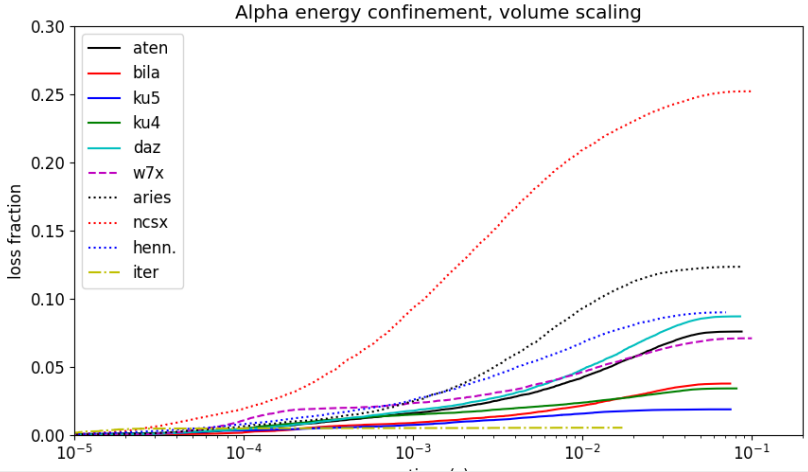






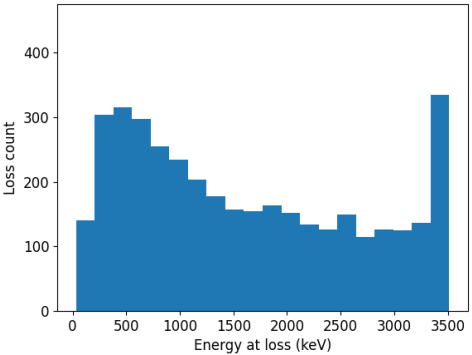
- Density profile $n = n_0(1 - s^5)$; Temperature $T = T_0(1 - s)$
- Density profile is flat, but monotonically decreasing, in contrast to the hollow ARIES profile. Reactivity is thus slightly more peaked
- Reactivity profile prescribes ANTS particle sourcing in the radial direction

Main collisional results

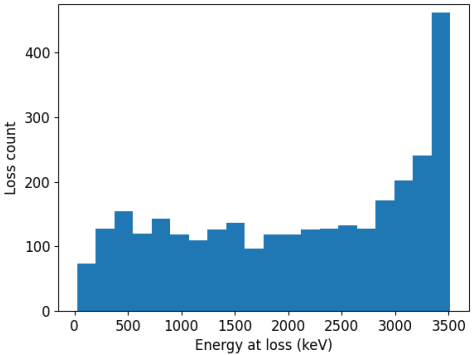


Energy distribution losses also favor QH

QH - Daz



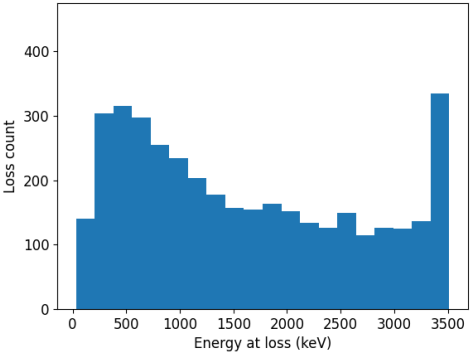
QS - Henn.



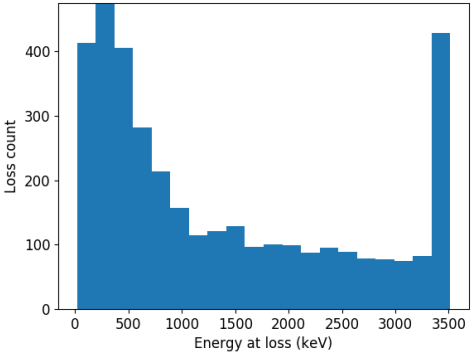
- In all QHS configs, the losses are skewed towards low energy particles
- QA usually has a flat distribution

w7X performs on par with some QH stellarators

QH - Daz



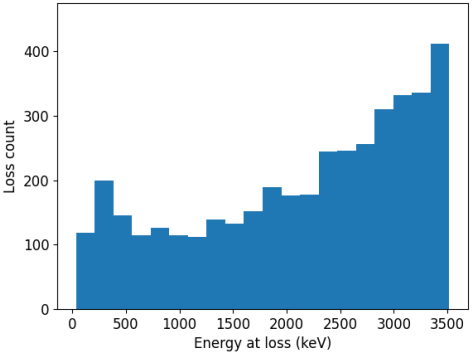
QO - W7-X.



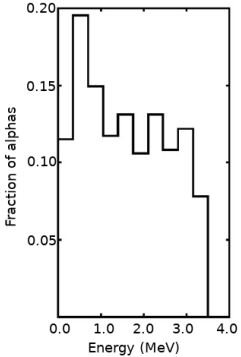
- In W7-X losses are also heavily skewed towards lower energy particles

w7X performs on par with some QH stellarators

ARIES-CS - ANTS

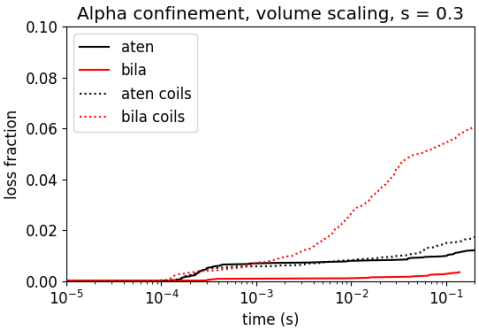


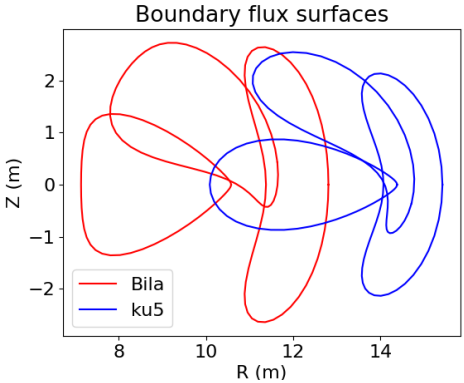
ARIES-CS published results



- Published ARIES-CS results claimed lower losses (5%) and a different loss distribution than calculated with ANTS

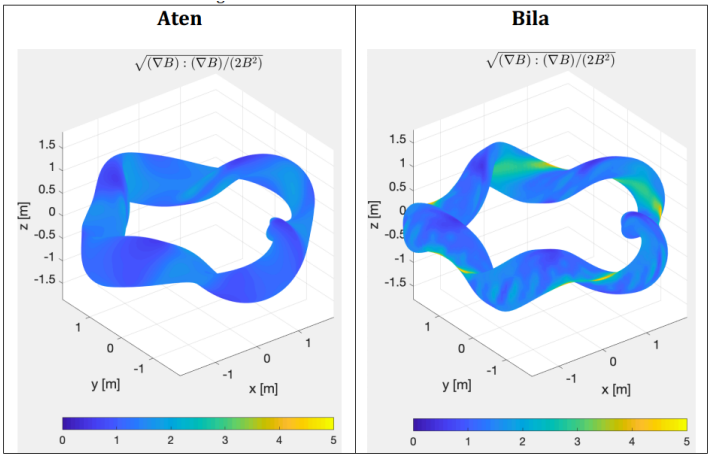
Best QH configs appear difficult to produce with coils





- Indentation in teardrop shape is a major problem area for coil generation codes

New metric may help indicate problem configs



Metric and picture courtesy of Matt Landreman

Conclusions and thoughts

- QH appears to regularly outperform QA
  - QH configs have higher aspect ratio. Will QA performance increase at high AR?
  - The best QH configs have difficult/impossible coils. The 2nd tier (ATEN/Daz) are doable
  - Does Γ_c really matter for QA? Is it possible to improve on Henneberg's QA?
- W7-X performs better when collisions are included compared to QH or QA
  - How well would optimized QIs and QPs perform, even ones with impossible coils.
  - Is Γ_c useful for QI, if not, what metric should truly be focused on? Maximum-J? Something else?