Energetic Particle Transport in Optimized Stellarators

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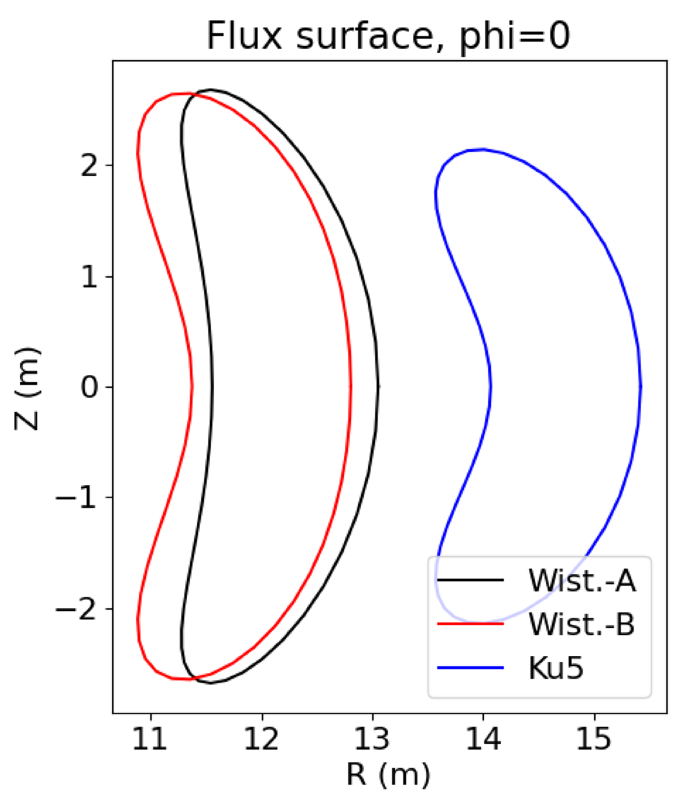
Motivation

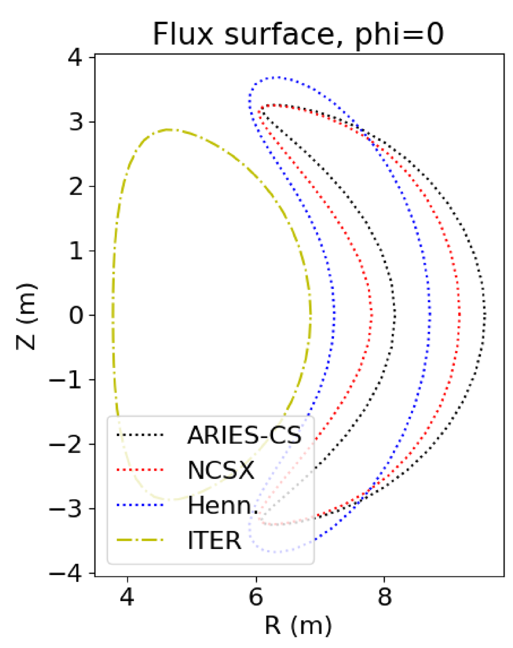
- Alpha particle confinement is a key issue for stellarators
- It is often difficult to compare between configurations
- What features and proxies are best predictive of good energetic particle confinement?

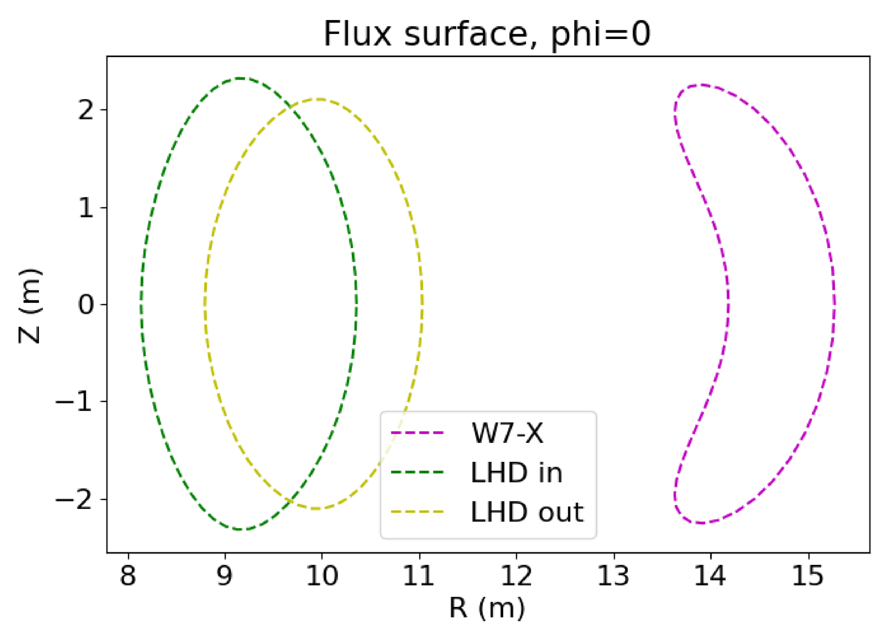
Configurations

- Configurations scaled to have ARIES-CS volume (450 m^3 and field (5.7 T)
- 3 QHs, 3 QAs, 1 QO (W7-X), 2 Heliotrons (LHD) and 1 Tokamak (ITER) are scaled and compared

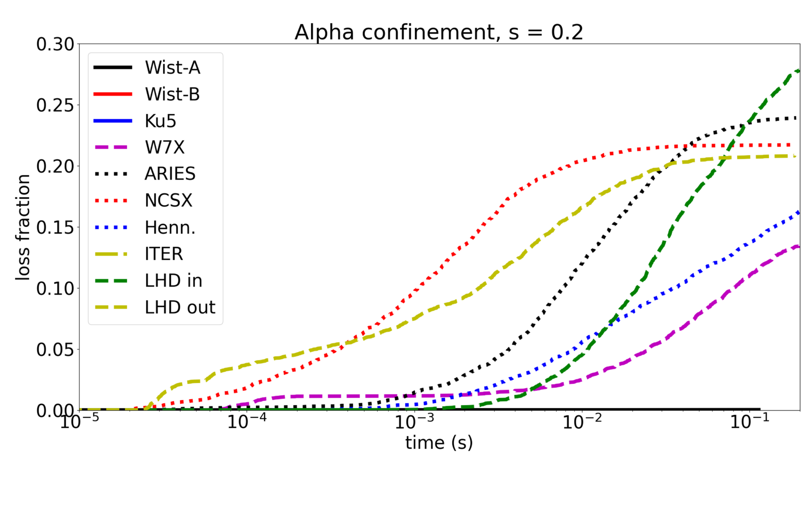
Name	Type	Periods	Aspect ratio	β
Wistell-A[1]	QH	4	6.7	Vacuum
Wistell-B	QH	5	6.6	Vacuum
Ku5[2]	QH	4	10.0	10.0%
ARIES-CS[3]	QA	3	4.5	4.0%
NCSX[4]	QA	3	4.4	4.3%
Henn.[5]	QA	2	3.4	3.5%
W7-X[6]	QO	5	10.5	4.4%
LHD st.[7]	Heliotron	10	6.5	Vacuum
LHD in.[7]	Heliotron	10	6.2	Vacuum
ITER[8]	Tokamak	N/A	2.5	2.2%

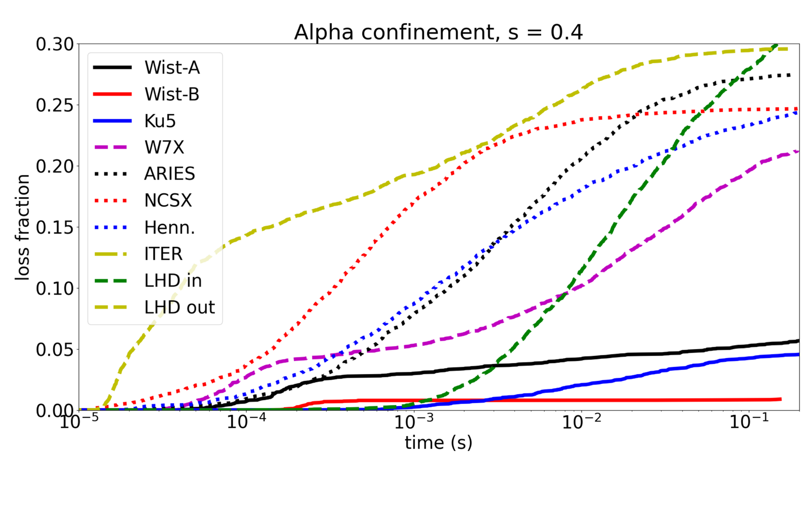


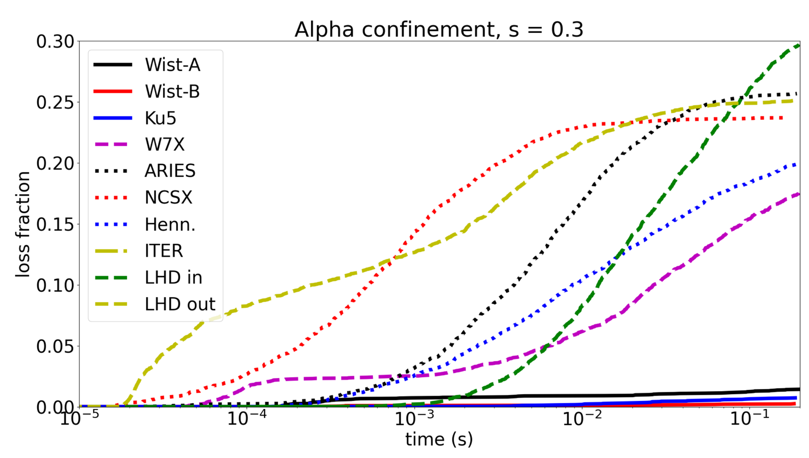




Collisionless Calculations





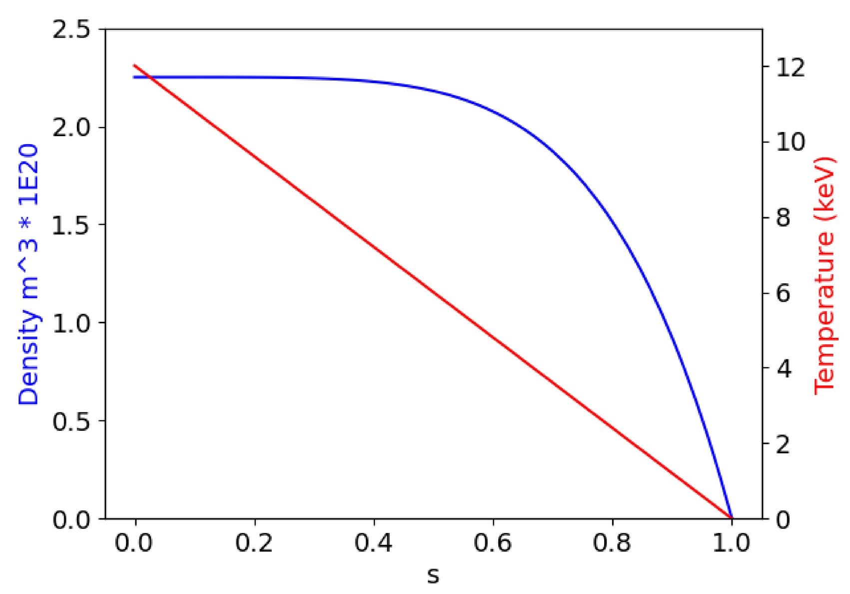


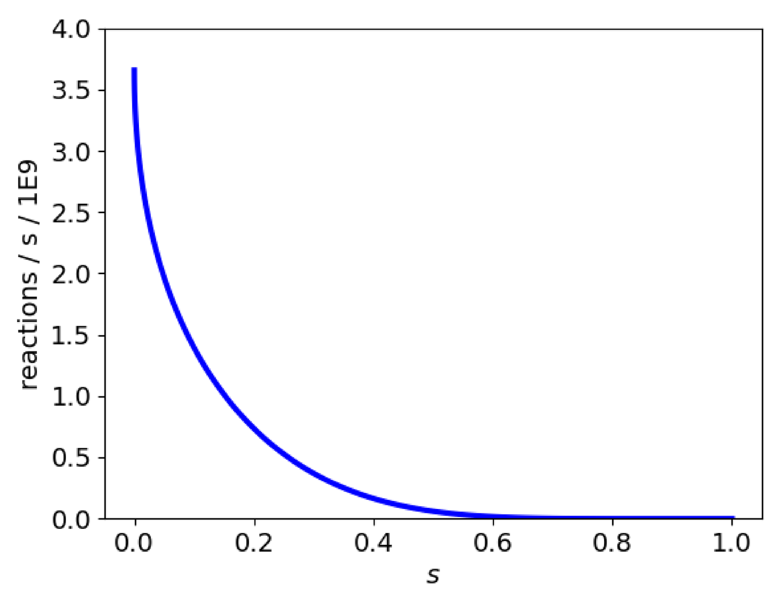
- Particles sourced uniformly on a flux surface
- Followed until the exit the LCFS
- QH strongly outperforms other stellarator configurations in collisionless losses
- ITER shows no collisionless losses

Input plasma profiles

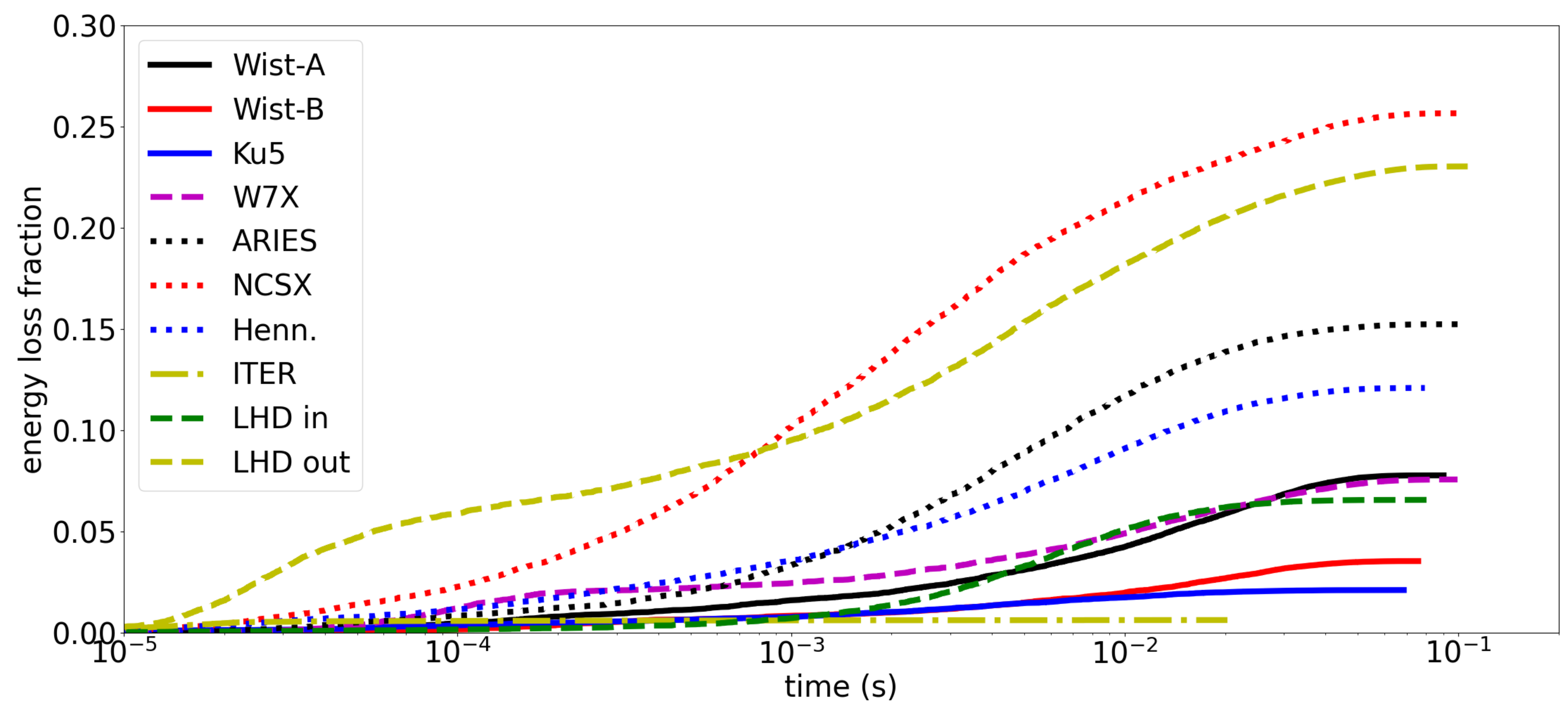
- Flat density and temperature profiles are used to source particles

$$n = 2.25 * 10^{20}\left(1 - s^5\right) m^{-3};\ T = 11\left(1 - s\right)\mathrm{keV}$$



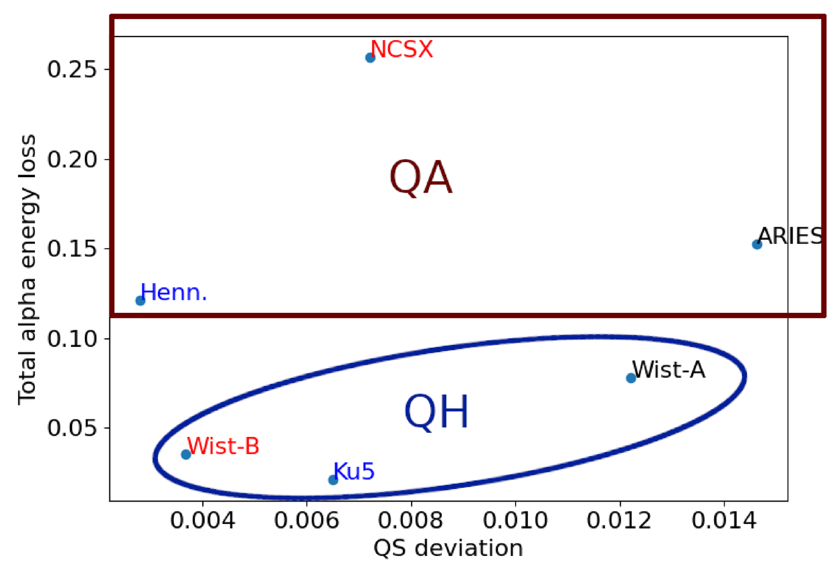


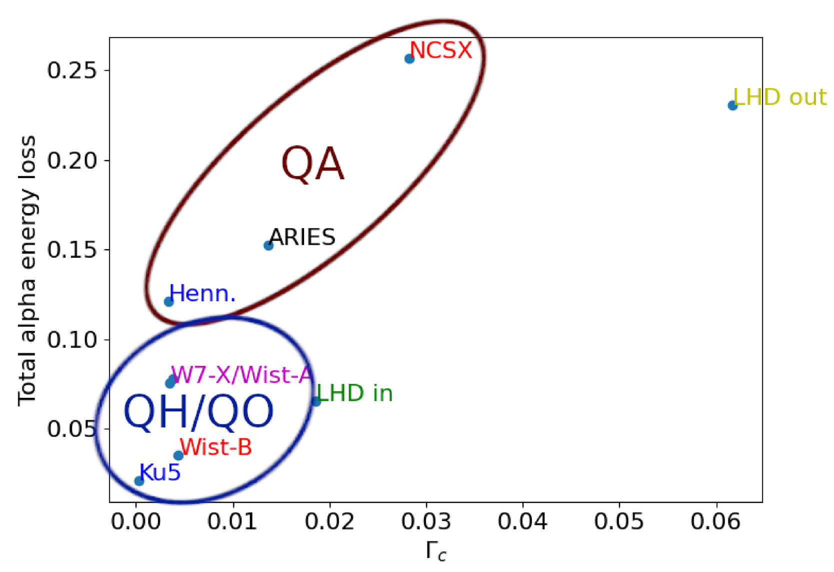
Collisional Calculations



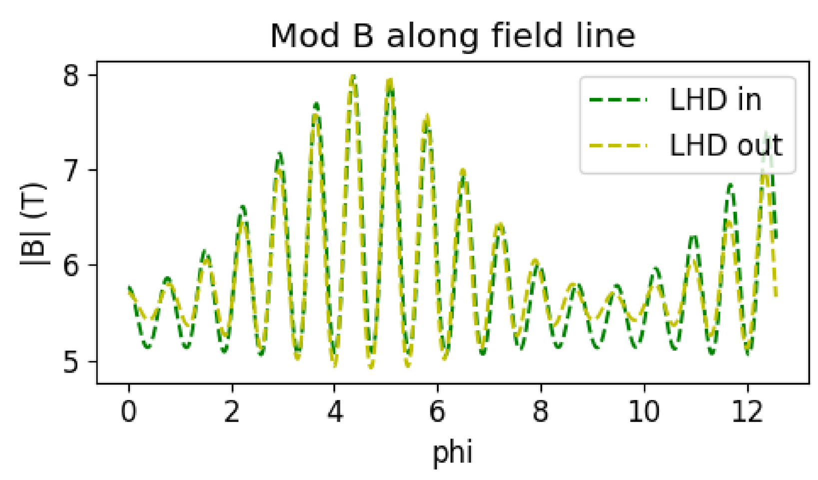
- When collisions added, QHs still perform well, but not as well compared to other configurations
- Wistell-A, LHD-inward, and W7-X all perfrom nearly equivalently with collisions
- ITER outperforms best QHs but only by a small margin
- Metric analysis shows collisional energy loss is correlated with Γ_c and (less so) with quasisymmetry

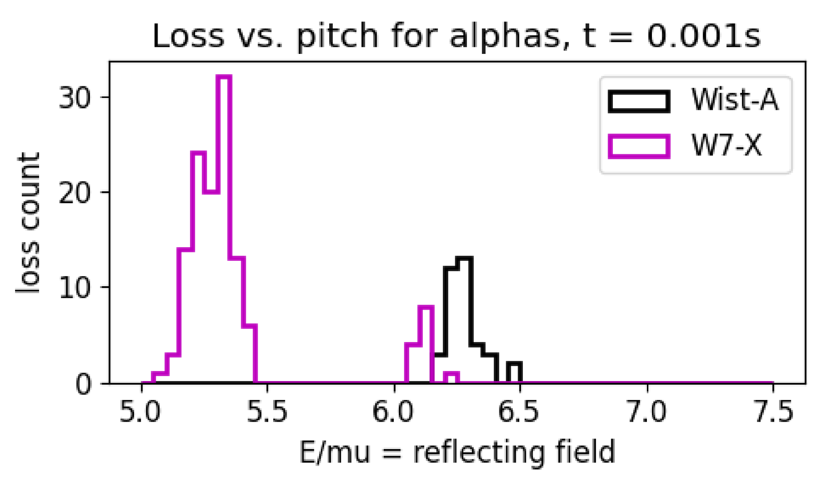
$$\Gamma_c = \frac{\pi}{\sqrt{8}} \lim_{L_s\to\infty} \left(\int_0^{L_s} \frac{ds}{B}\right)^{-1} \int_1^{B_{\max}/B_{\min}} db' \sum_{\mathrm{well}_j} \gamma_c^2 \frac{v\tau_{b,j}}{4B_{\min} b'^2};\ \gamma_c = \frac{2}{\pi}\arctan\frac{v_r}{v_\theta}$$





- LHD-inward, W7-X, and Wistell-A all perform similarly in collisional calculations but differently in collisionless results.
  - LHD: no prompt losses, all particles lost eventually, but slowly (improves relatively with collisions)
  - Wistell-A: Some prompt losses, occur near trapped passing boundary where diffusion is high (losses increase with collisions)
  - W7-X: Some prompt losses, occur in deeply trapped regions where diffusion is low (losses do not increase with collision)
- LHD inward-shifted configuration has smoothly varying field along a field line and alignment of minima





- Prompt losses are dangerous for plasma facing components
- Slower losses are often tolerable
- Heating profiles may differ (future work)

Conclusions

- Various stellarator configurations scaled to ARIES-CS size and field strength
- QH configurations appear to have the best energetic particle confinement
- Γ_c provides a useful metric to optimize for energetic particle confinement, but good confinement is possible without it
- LHD results indicate that aligning minima of magnetic field along a field line is useful for reducing prompt losses

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