Collisionless α- particles confinement in W7-X stellarator

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Introduction

The success of fusion partly depends on understanding the mechanisms behind the confinement of fast particles. Moreover, fast particles are excellent probes to diagnose the quality of the magnetic field trap. That is why it is crucially important to analyze the particle and energy transport of fast particles as a function of the magnetic configuration.

This work intends to simulate, analyze and extend our understanding about the confinement of collisionless α-particles for the vacuum configurations of Wendelstein 7-X stellarator, which is a quasi-omnigenius configuration.

α-particles trajectories have been obtained via integrating the equations of motion in magnetic coordinates [1], [2] using the MOCA code [3]. Here we will concentrate on prompt losses, thus making the collisionless approximation reasonable. For every configuration 16000 particles with kinetic energy of 3.5 MeV have been started at half-minor-radius with a uniform random distribution in pitch, toroidal and poloidal angles and followed for 5×10^{-3} sec.

$$\frac{\partial f}{\partial t}+\frac{\partial f}{\partial \vec r}\dot{\vec r}+\frac{\partial f}{\partial v}\dot v+\frac{\partial f}{\partial p}\dot p=C$$

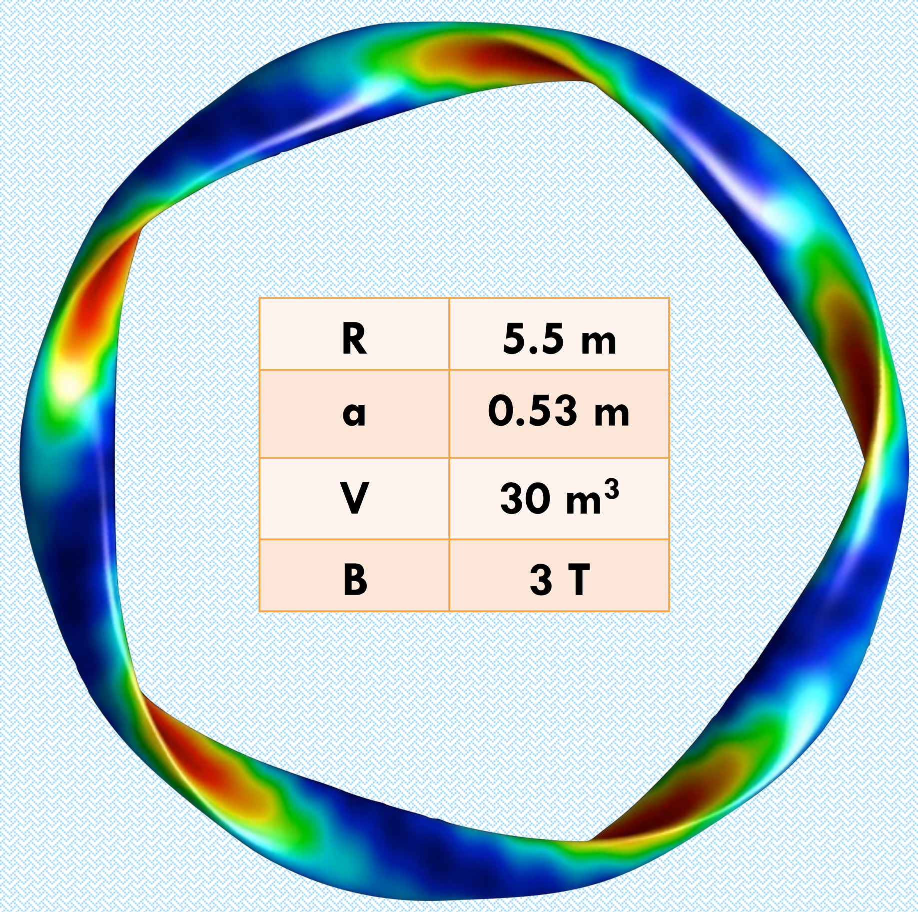
$$\dot p=-\frac{v}{2B^2}\left(1-p^2\right)\vec B\cdot\vec\nabla B-\frac{p}{2B}\left(1-p^2\right)\frac{\vec E\times\vec B}{B^2}\cdot\vec\nabla B$$

$$\dot{\vec r}=pv\frac{\vec B}{B}+\frac{mv^2}{2qB^3}\left(1+p^2\right)\vec B\times\vec\nabla B+\frac{\vec E\times\vec B}{B^2}$$

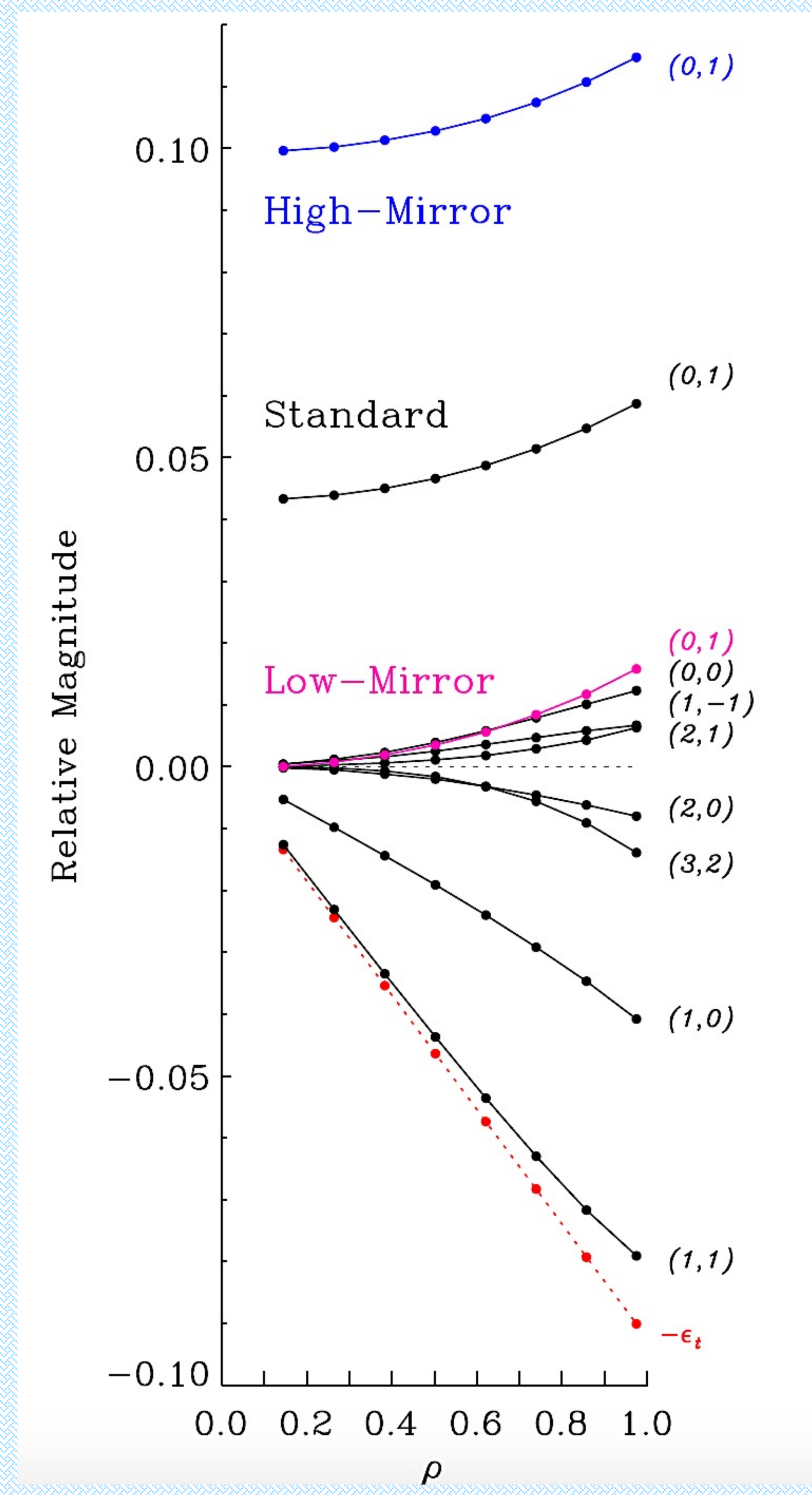
$$\dot v=-\frac{v}{2B^2}\left(1+p^2\right)\frac{\vec E\times\vec B}{B^2}\cdot\vec\nabla B$$

The W7-X stellarator

Wendelstein 7-X becomes the largest stellarator developed so far, it is capable of producing different magnetic configurations, having different toroidal mirror harmonics $b_{0,1}$ with little effect on the remainder $b_{m,n}$ of the spectrum [2]. Here we will analyze 3 different configurations: standard, 'high mirror' and 'low mirror', with respect to the confinement of α-particles.

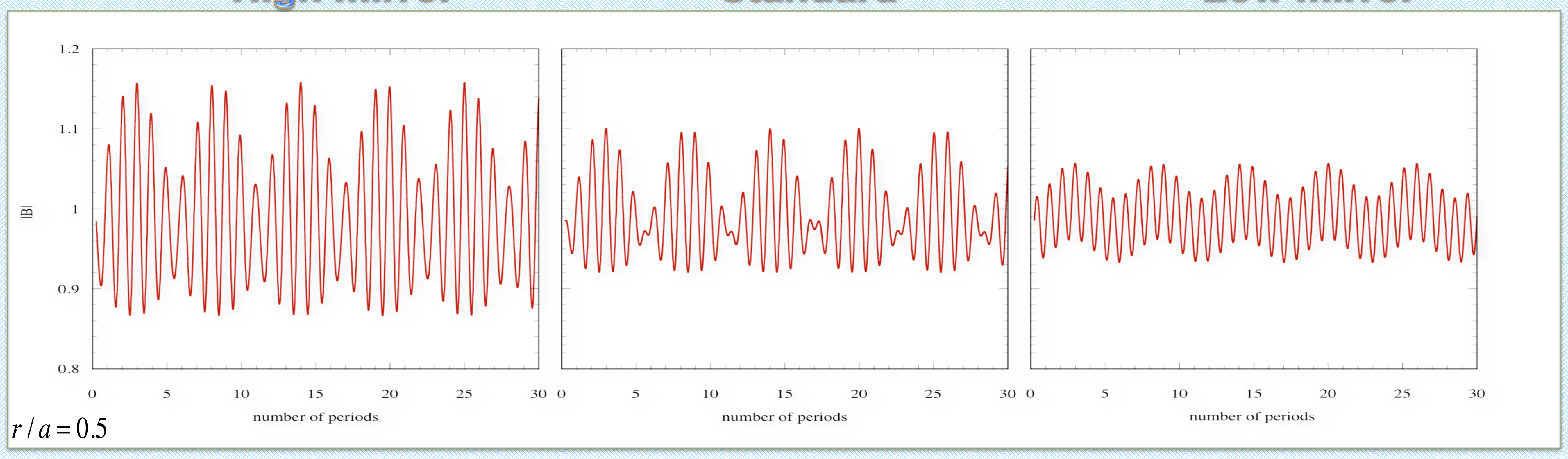


R	5.5 m
a	0.53 m
V	30 m³
B	3 T

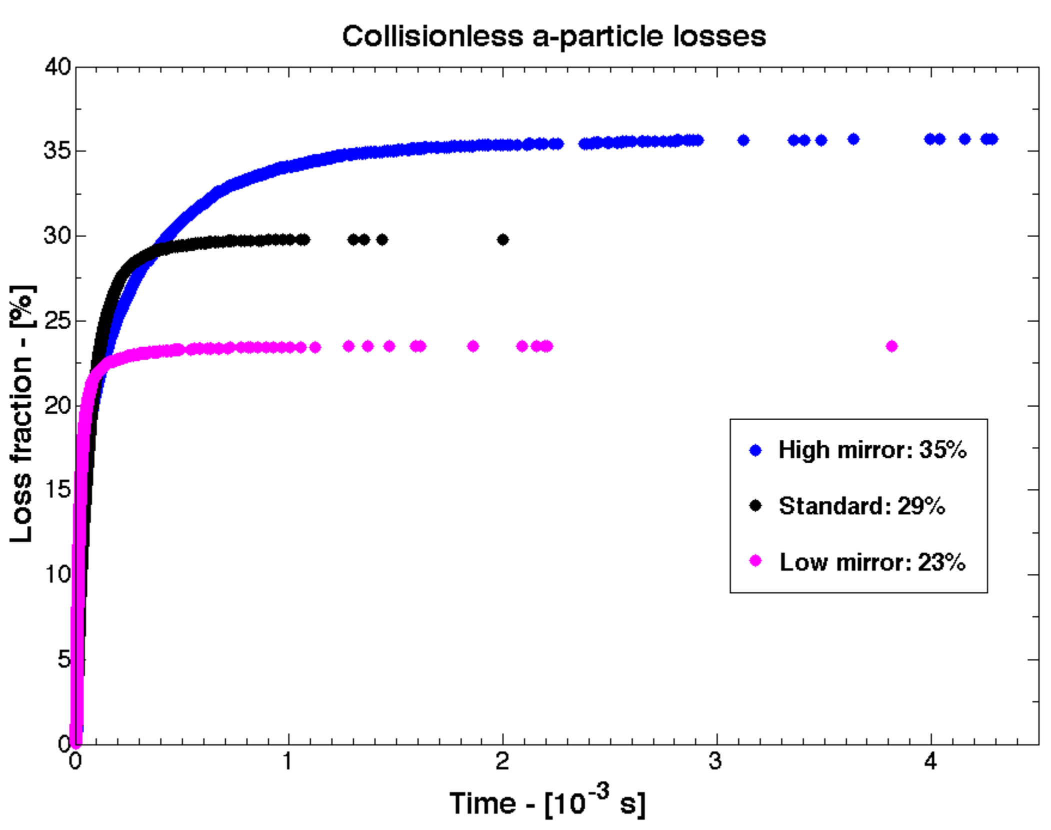


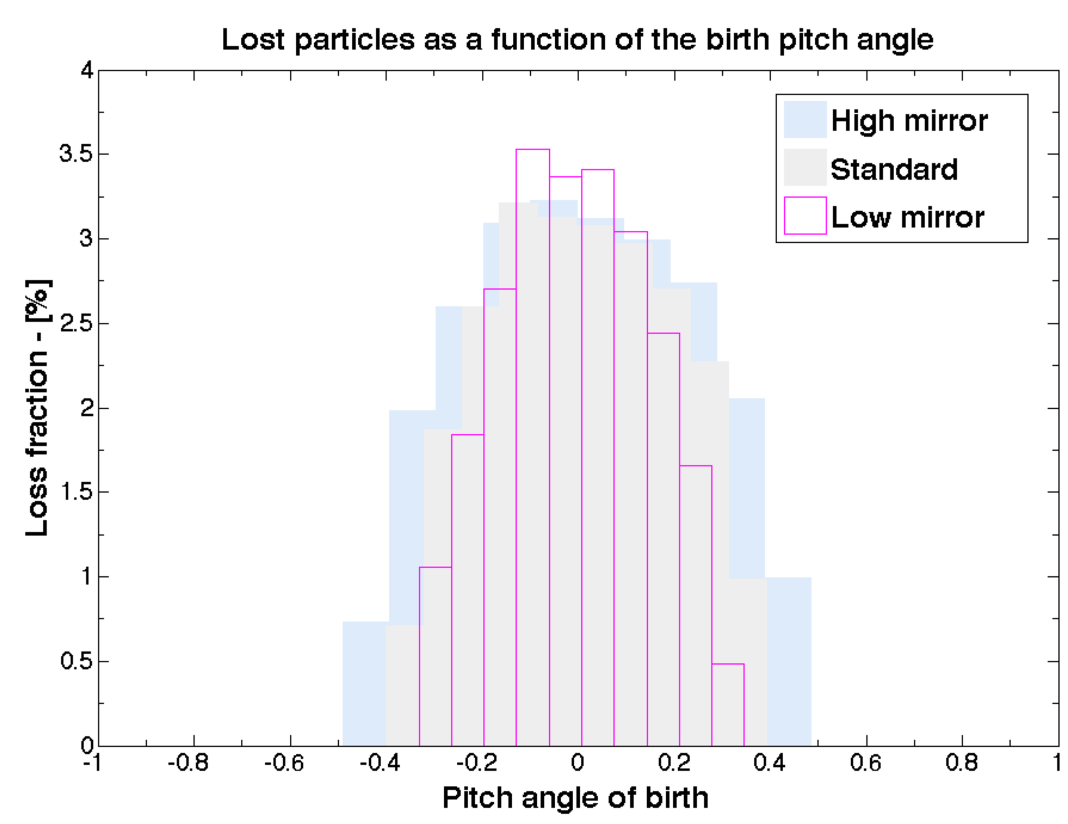
$$B=B_{00}\left[1+\sum_{m,n}b_{m,n}\cos\left(nN\varphi-m\theta\right)\right]$$

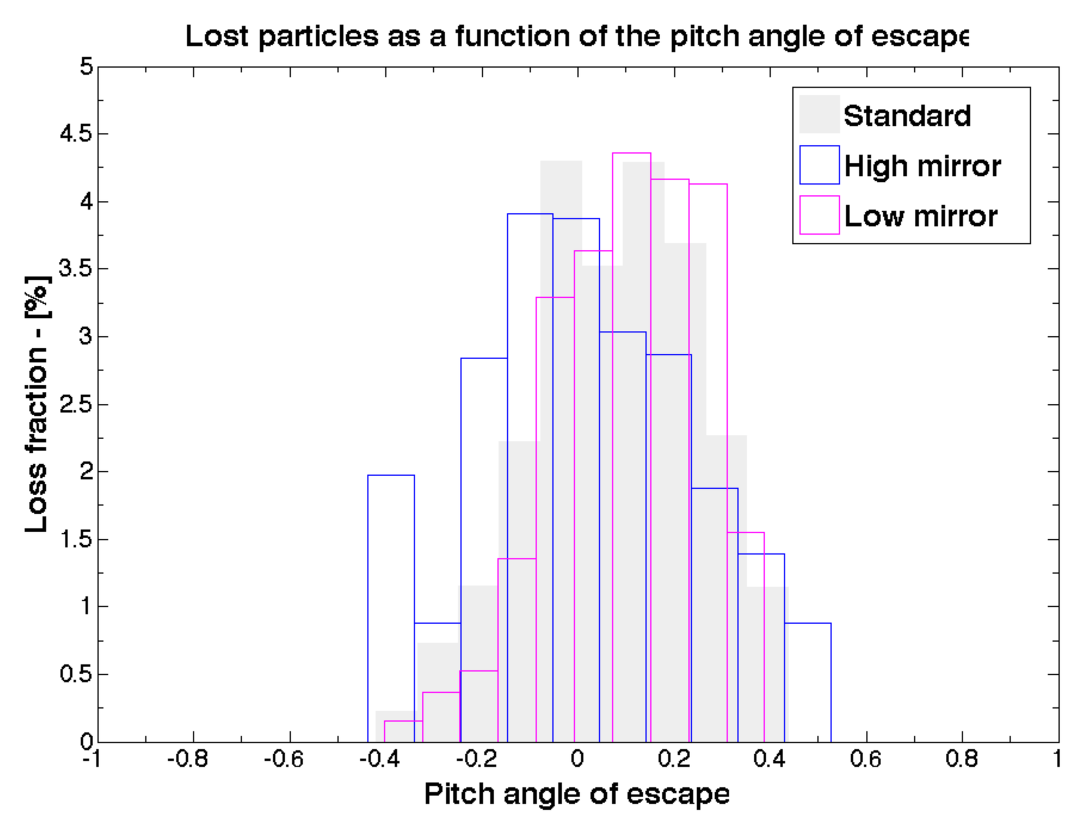
High mirror Standard Low mirror



Results of simulation standard, 'high mirror' and 'low mirror' configurations of W7-X







Conclusions

A future reactor will demand α−particles to thermalize, something which takes approximately 10^{-1} sec, and therefore should loose very few particles. The simulations for Wendelstein 7-X, shows that particles experience two clear driven-out mechanisms: loss-cone drifts for times less than 10^{-3} sec and collisionless stochastic diffusion for times larger than 10^{-3} sec. The collisionless α-particle trajectories obtained by MOCA code shows that the particle loss fraction of the 'low mirror' configuration, 23%, is smaller than for the other two configurations, 29% and 35% respectively. The flux-surface-averaged distribution of lost particles dependence on the pitch angle of birth is shown to be quite symmetric with respect to the pitch $p = 0$. Analysis of the pitch angle at the escape shows stronger differences.

Acknowledgments

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References

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