Improved energetic ion confinement in low <β> Wendelstein 7-X experimental plasmas with reduced turbulence

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Stellarators based on the helias concept are optimized with respect to the neoclassical transport of energetic ions [1]. Their optimization relies to a great extent on the diamagnetic effect: at finite β, a stronger radial variation of the magnetic field pushes the magnetic drift to be, on average, in the direction that is tangential to the flux-surface. This optimization strategy is especially effective for the prompt losses, whose very high energy could be most damaging for the performance and the integrity of the device. In Wendelstein 7-X (W7-X), the diamagnetic effect has been expected to become significant at high <β>, around 3 - 4% (e.g. [2]). Unfortunately, these values are far above those obtained in the first experimental campaigns [3], due to the low ion temperatures achieved. This would imply that the experimental validation of energetic ion confinement should rely on operation at low magnetic field or on upgrades of the power supply system.

In this talk, we perform a numerical study of the confinement of energetic ions in high performance plasmas [4] of the first experimental campaign of W7-X. This high performance is associated to a large density gradient (caused by pellet series injection or by neutral beam injection) that reduces the ITG-driven turbulent transport of energy, an effect that seems to be particularly strong for the magnetic configuration of W7-X [5]. We reconstruct the magnetic equilibria employing the plasma profiles measured in the experiment and study their properties with respect to energetic ion confinement. We demonstrate that, even though <β> is relatively low, below 1.2%, the same density gradient that reduces the level of turbulence is large enough to cause a strong diamagnetic effect that should confine the collisionless energetic ions. We confirm this by means of collisionless orbit-averaged Monte Carlo simulations [6].

This theoretical prediction has important implications on several areas of stellarator research. On the experimental front, it widens the range of plasmas in which the optimization of energetic ion confinement can be experimentally validated. In particular, this validation could be done earlier in the lifetime of W7-X (without, e.g., power system upgrades), and thus help inform ongoing stellarator optimization activities. The latter activities are strengthened by another fact: the improvement in energetic ion confinement that is predicted by accurate simulations is also well captured by the figures of merit currently employed for stellarator optimization [7,8]. With respect to operation scenarios, the favorable impact of the diamagnetic effect discussed in this work is specific of helias stellarators. Consequently, so is the joint improvement of turbulent transport and energetic ion confinement. Finally, the good confinement of energetic ions at relatively low <β> means that helias devices would be able to operate in some of the physics design points [9] that would become accessible if high temperature superconductors could be applied to high-field stellarator reactors.

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