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Largest Particle Simulations Downgrade the Runaway Electron Risk for ITER

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Fusion energy will be the ultimate clean energy source for mankind. The ITER device under construction by international partners will bring this goal one-step closer. Before constructing the first prototype fusion power plant, one of the most visible concerns that needs to be addressed is the threat of deleterious runaway electrons (REs) produced during unexpected disruptions of the fusion plasma. Massive REs can carry up to 70% of the initial plasma current in ITER, and understanding their dynamical behavior is crucial to assess the safety of ITER. However, the complex dynamics of REs in a realistic fusion reactor is almost impossible to simulate numerically because it requires efficient long-term algorithms and super-large scale computing power. In the present study, we deploy the world's fastest supercomputer, Sunway TaihuLight, and the newly developed relativistic volume-preserving algorithm to carry out long-term particle simulations of 107 sampled REs in 6D phase space. The size of these simulations is in the range of 1018 particle-steps, the largest ever achieved in fusion research. Previous studies suggest that REs can be accelerated to 350MeV or higher in ITER, and randomly strike the first wall of the reactor to cause grave damage. Our simulations show that in a realistic fusion reactor, the concern of REs is not as serious as previously thought. Specifically, REs are confined much better than previously predicted and the maximum average energy is in the range of 150MeV, less than half of previous estimate. As a consequence, most of the energy carried by these electrons will be released through the benign process of synchrotron radiation without causing damage to the first wall. These simulations on Sunway TaihuLight ease the concern over REs, and give scientists more confidence in the outcome of ITER and Chinese Fusion Engineering Test Reactor (CFETR), which is the post-ITER device currently being designed.

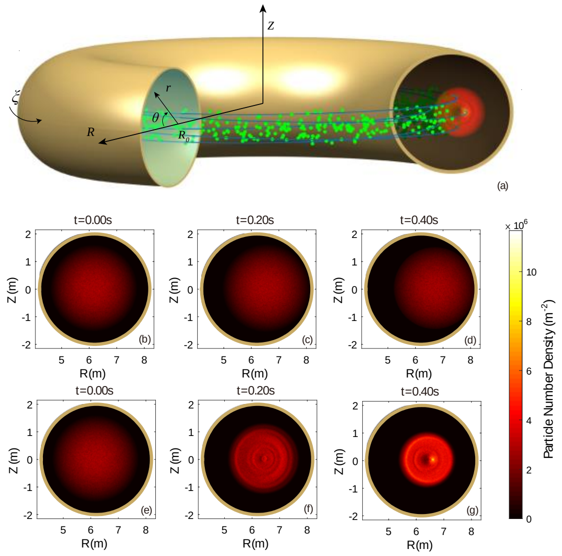

Figure 1: (a) Illustration of runaway dynamics in a tokamak and evolution of the RE distribution in a poloidal cross-section in (b)-(d) the ideal configuration and (e)-(g) the realistic configuration. The color bar indicates the number density of sampled REs within the poloidal cross-section.

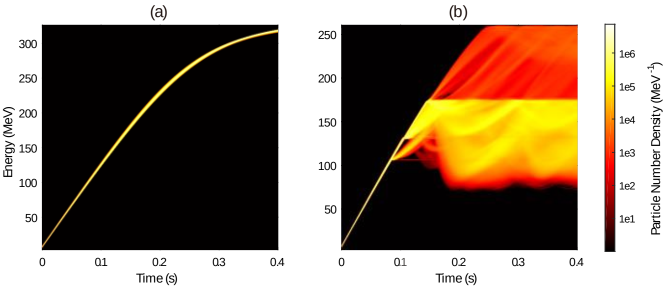

Figure 2: Evolution of the energy distribution of the REs in (a) the ideal and (b) the realistic configuration.

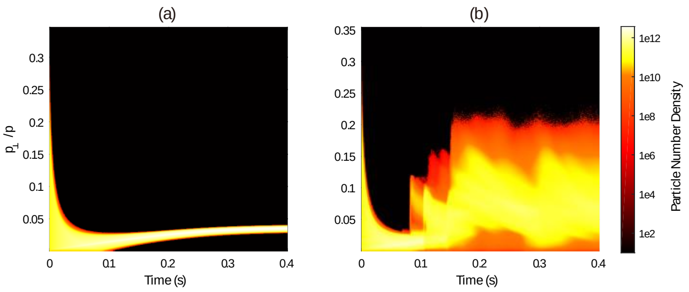

Figure 3: Evolution of the pitch-angle distribution of the REs in (a) the ideal and (b) the realistic configurations due to collisionless neoclasical pitch-angle scattering.

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