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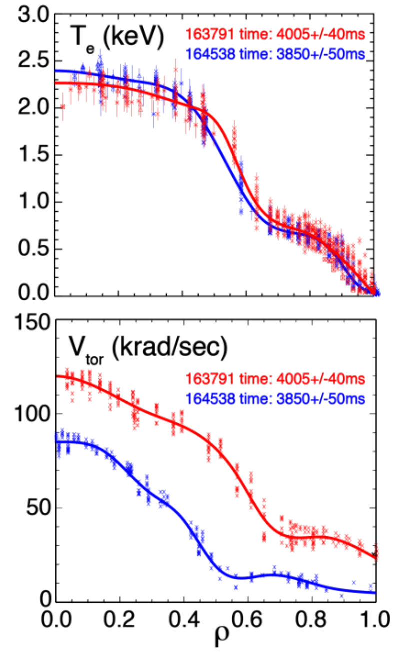
NEW PHYSICS UNDERSTANDING PROVIDES ATTRACTIVE PATH FOR DEVELOPING FUSION ENERGY VIA A STEADY-STATE TOKAMAK

International collaboration advances physics basis for excellent tokamak confinement at low rotation and potential to extend this scenario toward a fusion reactor.

U.S.- and China-based magnetic fusion scientists in the control room of the DIII-D tokamak in San Diego

The Science

For decades, operation of high performance tokamak plasmas has suffered from confinement quality degradation whenever the plasma rotation is reduced. This is because fast rotation and its radial shear (the so-called “E×B shear”) can suppress micro-turbulence and reduce the radial energy transport. For a reactor-relevant rotation condition, this effect is expected to be weak, leading to potentially lower plasma confinement. In recent research, scientists from the US and China have discovered a new steady-state plasma operation regime which provides a turbulence suppression mechanism (called “Shafranov Shift”) through magnetic shear that is independent of rotation.



Almost identical electron temperature profiles are produced in the experiments with both high and low rotation on DIII-D. Both discharges have very high confinement.

The Impact

A long-standing challenge for fusion scientists has been how to achieve good confinement in a reactor without relying on rapid plasma rotation. In the new plasma operation regime, the beneficial effect of rotation shear is replaced by magnetic shear, which also opposes the formation of large turbulent eddies. Maintaining high plasma confinement without plasma rotation could enable the economically attractive operation of a steady-state fusion reactor. The low transport achieved in these studies lead to very high levels of performance through a "transport barrier" in the plasma.

Summary

A collaboration of U.S.- and China-based magnetic fusion scientists is developing the physics basis for maintaining excellent energy confinement even in low-rotation plasmas where confinement normally suffers. Joint experiments on the DIII-D tokamak (San Diego, USA) have demonstrated an operating scenario known as "high poloidal beta (β_P) scenario" that achieves improved energy confinement quality relative to standard H-mode ($H_{98}\geq1.5$) through the formation of an internal transport barrier (ITB) at large plasma radius that persists even at low plasma rotation. The international team of scientists systematically analyzed the influence of toroidal rotation, plasma pressure, and current profile on turbulence suppression both in experiment and simulation. They discovered that in this scenario the Shafranov Shift, proportional to the plasma pressure normalized to the poloidal field pressure, is responsible for turbulence suppression and the formation of the large-radius ($\rho\geq0.7$) ITB. Rotation plays a minor role in the turbulence suppression. Transport simulations are in excellent agreement with the DIII-D experiments, giving confidence in the understanding of the mechanism and in the predictions for scenario extension. Experiments to adapt the DIII-D scenario on the superconducting tokamak EAST (Hefei, China) have led to the realization of the first 61 sec pure RF heating fully non-inductive H-mode with ITB

features, an important first step for extending this scenario to long pulse high performance. Modeling using the TGLF transport code shows favorable projections of the high β_P scenario to burning plasmas in ITER and China Fusion Engineering Test Reactor (CFETR).

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