

High-precision, time-resolved measurements of core plasma potential dynamics by heavy ion beam probe diagnostics

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In fusion plasmas, the plasma potential is widely recognized as a key physical quantity governing particle confinement, transport properties, and confinement regime transitions. However, high-precision and time-resolved measurements of the plasma potential in the high-temperature, high-density core plasma region have long remained an experimental challenge [1]. To address this issue, we have continuously developed a heavy ion beam probe (HIBP) diagnostic system using a 6-MeV gold beam on the Large Helical Device (LHD), achieving a substantial improvement in measurement performance. In particular, a new concept to mitigate space-charge limitations in heavy ion beam transport has been successfully implemented [2,3], enabling a significant increase in the beam current. As a result, we have achieved direct, time-resolved measurements of the temporal evolution of the core plasma potential profile over a frequency range from several kHz up to approximately 100 kHz, which had previously been inaccessible. These measurement capabilities provide a unique experimental basis for investigating the role of plasma potential dynamics in transport regulation and confinement transitions. Recent experimental results [4], including invited presentations at APS-DPP and upcoming invited talks at EPS, demonstrate that energetic-ion-driven regulation can induce bifurcated particle transport states in LHD plasmas. The HIBP diagnostic offers a direct and quantitative link between these transport phenomena and the underlying potential dynamics, highlighting its value as a core diagnostic for high-temperature plasma research.

In this invited presentation, we will describe the core technologies that enable high-precision, time-resolved HIBP measurements and focus on recently identified bifurcated transport behavior regulated by energetic ions, discussing its relationship with plasma potential dynamics.

[1] T. Ido et al., “Experimental study of radial electric field and electrostatic potential fluctuation in the large helical device”, *Plasma Physics and Controlled Fusion* 52, 124025 (2010).

[2] M. Nishiura et al., “Enhanced beam transport via space charge mitigation in a multistage accelerator for fusion plasma diagnostics”, *Nuclear Fusion* 65, 116017 (2025).

[3] M. Nishiura et al., “Overcoming the space-charge dilemma in low-energy heavy ion beams via a multistage acceleration lens system”, submitted to *Physical Review Applied* (2026).

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