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EXL-50U Experiments, Addressing Key Physics Issues for Future Spherical Torus Proton-Boron Reactors

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The EXL-50U spherical torus (ST) [1] is China's first large ST device with toroidal fields greater than 1 T, major radii up to 0.8 m, and plasma currents up to 1 MA [2]. The main parameters are provided Table 1.

Table 1. The main parameters of EXL-50U

Parameters	Value
Plasma current	0.5MA (already achieved in first phase) 1MA (second phase)
Major radius	0.6-0.8m
Toroidal magnetic field (R=0.6m)	1.0T(first phase) 1.2 (second phase)
Aspect ratio	1.4-1.85
Elongation	1.4~2
Discharge TF flattop duration	2.5s @1.2 T 1.5MW/50kV/5s
NBI	1MW/25kV/2s (second phase) 1MW/200kV/2s (third phase)
ECRH	3×0.4MW/28GHz/5s 2×0.5MW/50GHz/1s 0.5MW/80GHz/2s (second phase)
ICRF	3-26MHz/100kW/CW 13.56MHz/80kW/CW 2MW/25MHz~40MHz/1s (second phase)
LHCD	2×0.2MW/2.45GHz/CW

It is built to test and explore the physics properties of proton-boron plasmas in the high temperature collisionless plasma regime anticipated in future ST p-^{11}B reactors. Key objectives include advancing non-inductive current drive, developing stable high-density hot ion modes (T_{i0} = 3–10 keV), establishing energy confinement scaling for aspect ratios (1.4–1.8) and magnetic fields (0.5–1.2 T), and exploring the new properties of ST proton-boron plasmas. Commissioned in late 2023, EXL-50U achieved first plasma in January 2024. Initial experiments demonstrated a plasma current of 580 kA using electron cyclotron resonance heating (ECRH) and properly timed central solenoid (CS) induction. Stable discharges at 500 kA in limiter and 400 kA in divertor configurations are obtained. A novel ECRH start-up and ohmic-assisted ramp-up scenario reduced loop voltage (<0.15 V/m) and CS flux consumption, a result of high relevance to future reactors. A record 270 kA fully non-inductive current was sustained via 380 kW ECRH. Boron powder injection, a first for full-metal-wall STs, enhanced core density and electron pressure by a factor of four to 4 x 10^{19}/m^3, offering insights for real-time boron wall conditioning for reactors [see, Figure 1]. Core ion temperatures of 1 keV were achieved with 270 kW neutral beam injection, while ohmic heating yielded energy confinement times of ~30 ms. These results validate EXL-50U's role in informing the physics design of the follow-up EHL-2 ST [3], to investigate p-^{11}B plasma burn physics. Engineering and operational experiences from EXL-50U also help clarify the feasibility of future ST p-^{11}B reactor designs. More recent progress to 1 MA plasma current on EXL-50U will also be reported.

References
[1] SHI Y.J. et al., Plasma Sci. Technol. 27, 024003 (2025).
[2] SHI Y.J. et al., to be published.
[3] LIANG Y.F. et al., Plasma Sci. Technol. 27, 024001 (2025).

Figure 1. Boron-powder injection led to density (a) and pressure (b) increase by a factor of four under constant heating power.