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NUMERICAL SIMULATION OF EFFECT OF POLOIDAL INJECTION GEOMETRY ON LI-PELLET TRIGGERED ELM UNDER BOUT++ FRAMEWORK

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ABSTRACT

- The ELM triggering threshold for injection from HFS X-point is found to be smaller than that for injection from LFS X-point.
- Unlike scenario LFS-X-point, in scenario HFS-X-point there exhibits a broad parameter window for small pellet sizes, under which the triggered ELM size is only about 0.1%. The result highlights a unique advantage of high-field-side pellet injection in ELM control.
- In scenario LFS-X-point, the triggered ELM undergoes phases of fast crash, turbulent transport, and saturation; in scenario HFS-X-point, the triggered ELM exhibits turbulent characteristics

BACKGROUND

- ELMs are commonly observed at edge plasma in H-mode operation experiments; they facilitate the expulsion of excess particles and impurities from the core, while the associated high transient heat fluxes can cause severe material damage.
- Pellet injection has been demonstrated in multiple devices to effectively regulate ELMs, however, the understanding of the physical mechanisms behinds is still insufficient, especially for impurity pellet injection
- Experiments and simulations have not investigated the effect of poloidal injection geometry on the ELM triggering process by impurity pellet. A previous JOREK work found that the size threshold for D pellet ELM triggering is lowest for HFS injection, however, it did not provide an in-depth analysis of the underlying mechanisms.
- As the planned poloidal injection position for ITER is near the X-point, it is essential to reveal the effect of poloidal injection geometry on pellet triggering ELM

Model and simulation set up

- A BOUT++ three-field MHD code coupled with an impurity model is employed here to investigate the process of ELM triggering induced by Li pellet injection from different poloidal injection positions under the EAST experimental configuration. For the details about the BOUT++ model, as well as the EAST equilibrium and the pellet ELM triggering model, please refer to [M. Li, et al, Nucl. Fusion 65 (2025) 026007].
- The simulated poloidal injection positions included the low-field-side X-point (scenario LFS-X-point) and the high-field-side X-point (scenario HFS-X-point), with a schematic provided in Fig. 1

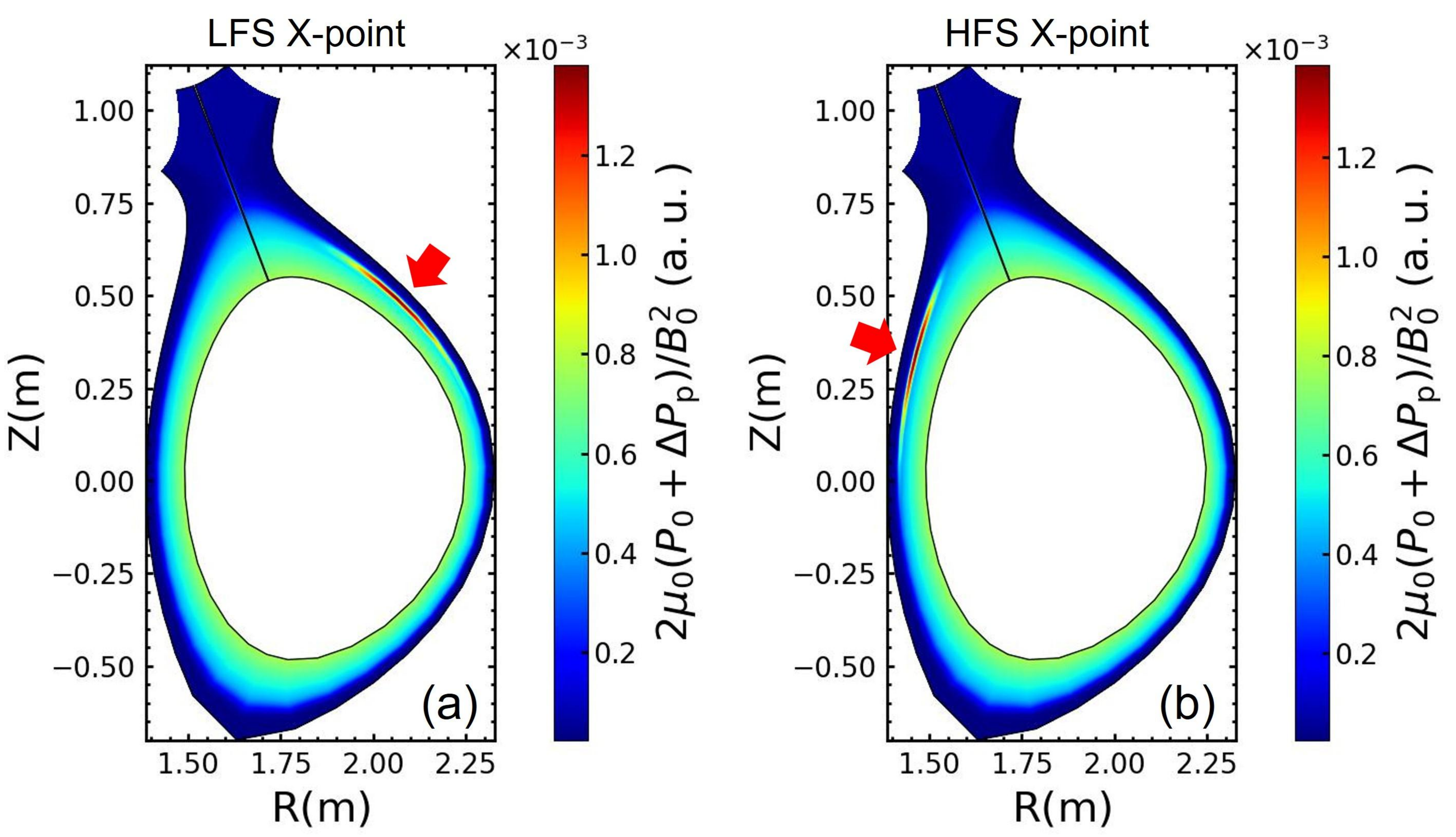

Fig. 1. Diagram of poloidal injection geometries in scenarios (a) LFS X-point and (b) HFS X-point.

OUTCOME

Dependence of ELM size on pellet deposition amount

- The ELM triggering threshold is smaller when lithium pellets are injected from the high-field side, compared to the low-field side
- In scenario HFS-X-point, when $\Delta E_{\mathrm{tot,norm}} < 2\times10^{-6}$, the ELM sizes are on the order of 0.1%, rather than zero.
- the amplitudes of pellet-triggered ELMs in scenario HFS-X-point are both smaller than those in scenario LFS-X-point

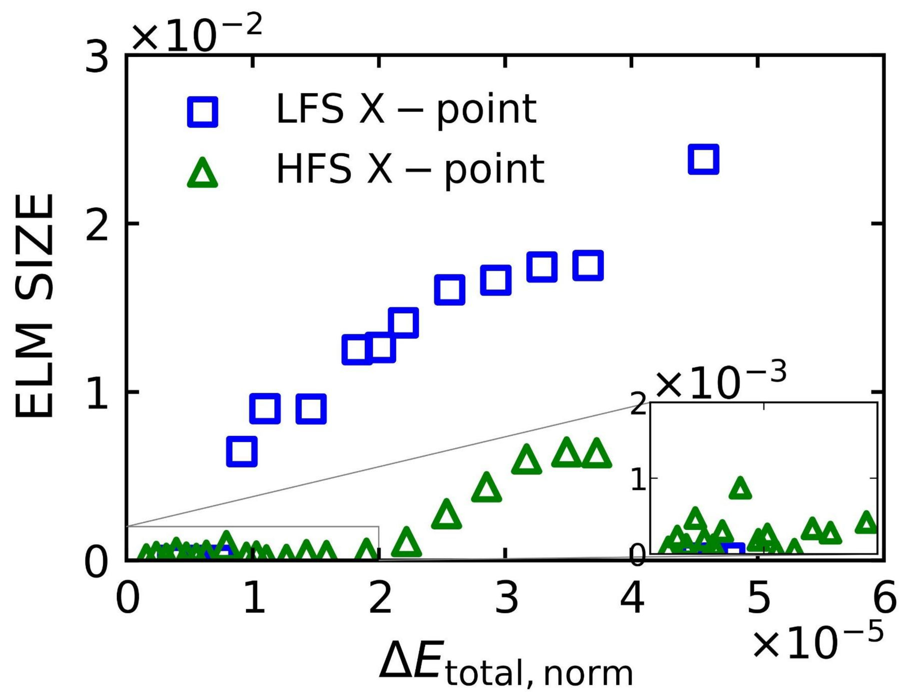

Fig. 2. ELM size versus initial change in normalized internal energy $\Delta E_{\mathrm{tot,norm}}$ in scenarios OMP, LFS-X-point and HFS-X-point. The quantity $\Delta E_{\mathrm{tot,norm}}$ can be used to present the pellet deposition amount [M. Li, et al, Nucl. Fusion 64 (2022) 086061].

Time evolution of Pedestal energy loss

- In scenario LFS-X-point, no pedestal energy loss is observed when R_p = 1.4. When R_p > 1.4, the injected pellets can both trigger ELMs with significant amplitude, whose evolution after ELM onset consists of the phased of fast crash, turbulent transport and saturation
- In scenario HFS-X-point, although pellet injection induces pedestal energy loss even in the smallest Rp case, the fast crash phase of the ELM evolution is negligible; the triggered ELMs resembles the turbulent crash mentioned in [P.W. Xi, Phys. Rev. Lett. 112 (2014) 085001]

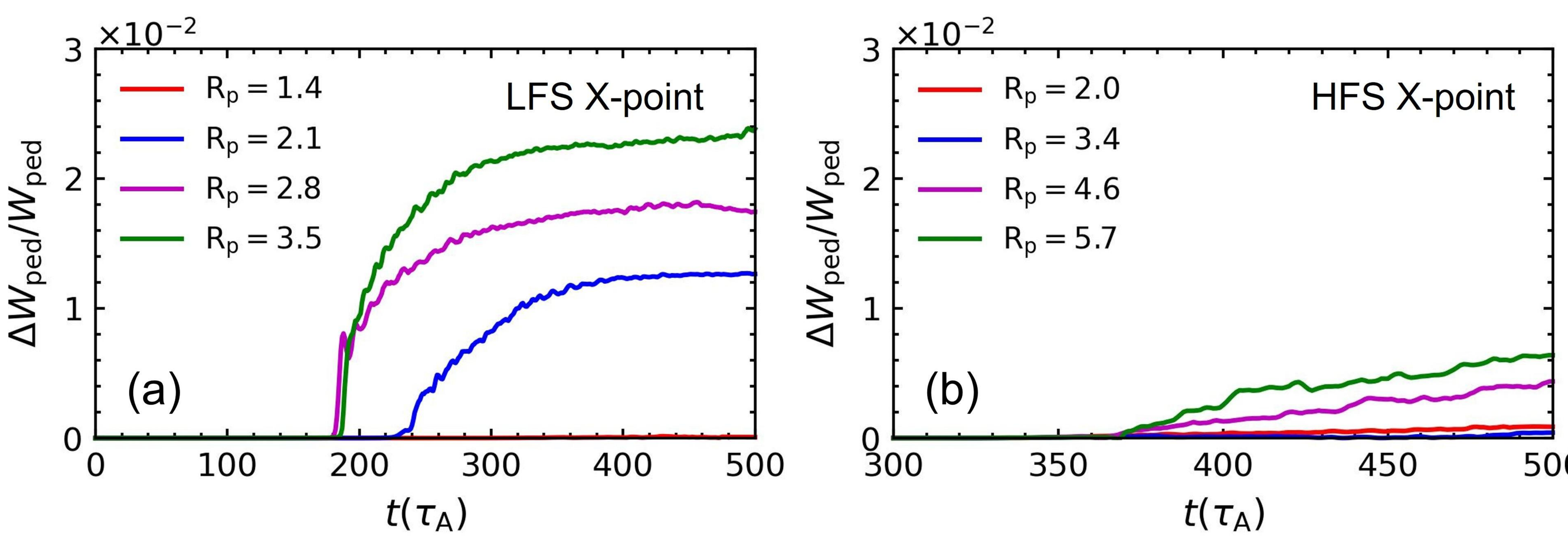

Fig. 3. Time evolutions of ELM sizes in scenarios (a) LFS-X-point and (b) HFS-X-point. The parameter Rp is defined as the rate of the modified pressure over the unperturbed one at the radial peak deposition, which is used to represent the pellet deposition peak in a given scenario [M. Li, et al, Nucl. Fusion 65 (2025) 026007]

CONCLUSION

- Nonlinear simulations shows that there exist significant differences in the characteristics of pellet-triggered ELMs in scenarios LFS-X-point and HFS-X-point.
- The comparison among the two scenarios clearly showed that the ELM triggering threshold was lower for high-field-side pellet injection, compared to low-field-side X-point injection, which is in agreement with previous JOREK results [S. FUTATANI, Nucl. Fusion 54 (2014) 073008.]
- The injection of a small pellet from HFS-X-point can enhance the edge particle transport without significantly degrading plasma confinement. This highlights the unique advantage of high-field-side pellet injection for ELM control.