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Two-dimensional dynamics of reconnection heating/transport process in ST40 and TS-6

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Here we present two-dimensional dynamics of heating/transport process of magnetic reconnection under the influence of toroidal guide field during mering plasma startup of spherical tokamak in ST40 and TS-6. The U-Tokyo high-resolution ion Doppler tomography was shipped to ST40 and we have started 2D imaging measurement in both experiments. In addition to the 32CH Doppler tomography which was operated until 2023, it has now been upgraded to 96CH and 2D imaging of ion temperature profile has been started in ST40. In addition to the extension of ion heating scaling $\Delta T_i \propto B_{rec}^2$ in keV range as demonstrated in MAST, our recent experiments in ST40 and TS-6 explored the following 3 new findings using the 2D ion Doppler tomography and 30CH Thomson scattering diagnostics:

- Formation of poloidally asymmetric global ion heating structure and highly localized electron heating around the X-point via parallel electric field acceleration ($E_{//} = \boldsymbol{E}\cdot\boldsymbol{B}/|B|$)
- Extension of the heating scaling with $\Delta U_i \propto B_{rec}^2$ to 10kJ/m^3 by including the contribution of electron density in collaboration with Thomson scattering measurement (the increment of ion thermal energy ΔU_i in the downstream region is ~30% of the upstream magnetic energy of reconnecting field B_{rec})
- Exploration of further electron heating via magnetic reconnection under the influence of high guide field in the keV range in ST40.

The poloidally asymmetric ion heating structure depends on the polarity of toroidal field B_t and the fine structure gets flipped when the guide field direction is reversed. Under the influence of high guide field, E×B drift is mainly driven by in-plane/poloidal electric field E_p from the quadruple potential structure, while parallel electric field $E_{//}$ is mainly driven by reconnection electric field E_{rec} (spontaneously formed toroidal electric field E_t around X-point) and higher T_i appears where plasma potential is positive, while high T_e mainly appears around the X-point. The portion of toroidal electric field E_t for parallel electric field $E_{//}$ is higher for high guide field condition ($B_t > 3B_{rec}$) and the peaked electron heating structure around the X-point becomes clearer when higher guide field is applied. Under the influence of toroidal effect to have higher guide field in the inboard side of outflow direction ($B_t \propto 1/r$), downstream heating also forms poloidally asymmetric structure, and more heating appears in the high field side. Perpendicular heat conduction in the outflow region is strongly suppressed by high guide field which enhances gyro frequency ω_{ci} ($\kappa^i_{//}/\kappa^i_{\perp} \sim 2(\omega_{ci}\tau_{ii})^2 >> 1$) and the field-aligned transport process leads to the formation of poloidally ring-like global structure after merging.

References

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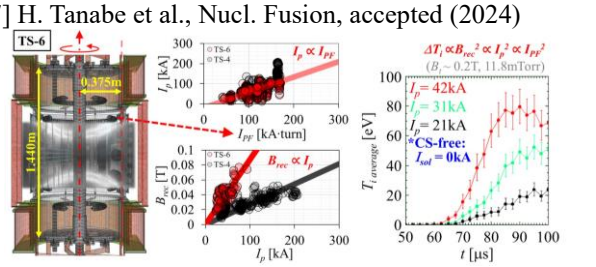

Figure 1 Merging/reconnection heating depends on the amplitude of reconnecting field B_{rec} which depends on plasma current I_p and merging driving coil current I_{PF}[7].

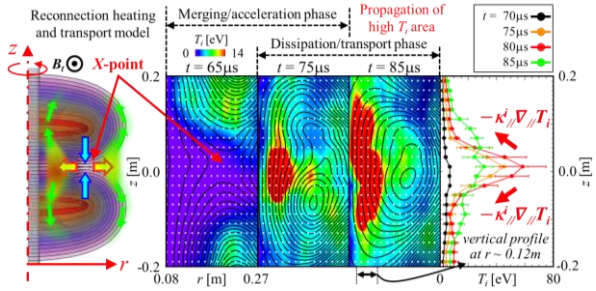

Figure 2 *Full-2D* imaging measurement of ion heating/transport during merging/reconnection phase in TS-6 [6].

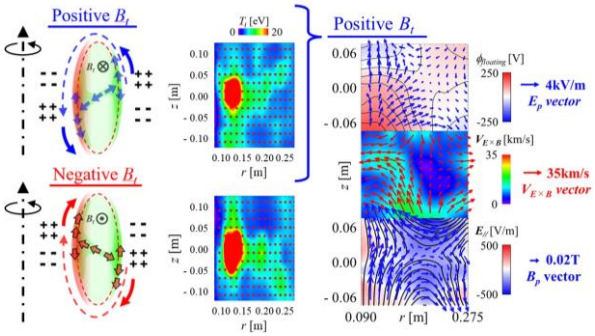

Figure 3 Ion heating via parallel acceleration of magnetic reconnection by $E_{//} = \boldsymbol{E}\cdot\boldsymbol{B}/|B|$. When guide field direction is reversed, high T_i region gets flipped to have higher T_i in the positive potential side by negative $E_{//}$ which is mainly driven by toroidal/reconnection electric field E_t[6].