ISTW 2011, NIFS, Sep. 29th, 2011

Merging startup experiments in UTST and MAST

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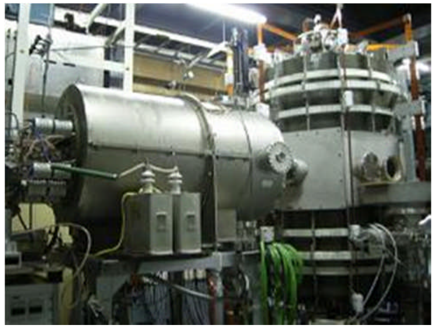
THE UNIVERSITY OF TOKYO

CCFE CULHAM CENTRE FOR FUSION ENERGY

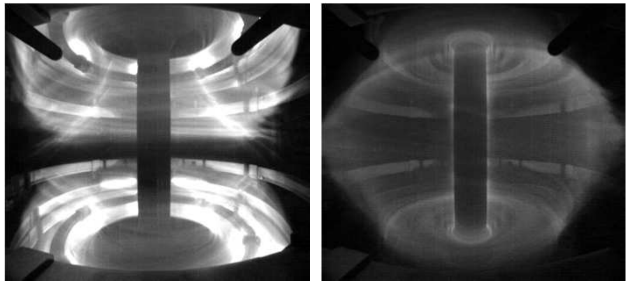
Magnetic reconnection releases a large amount of magnetic energy to plasma flow and thermal energies, both in fusion plasmas and astrophysics.

UTST – double null merging (Univ. Tokyo)



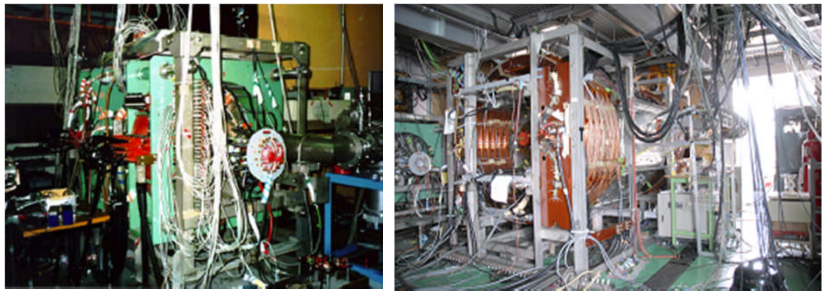
- Uses external magnetic coils

MAST – merging compression (CCFE)



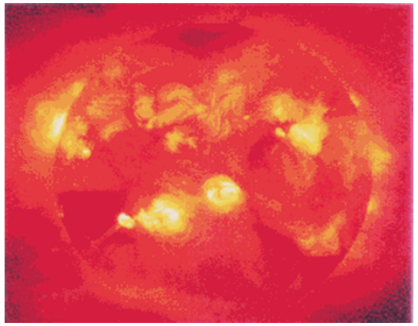
- High magnetic field
- Reliable diagnostics

TS-3/TS-4 – merging compression (Univ. Tokyo)



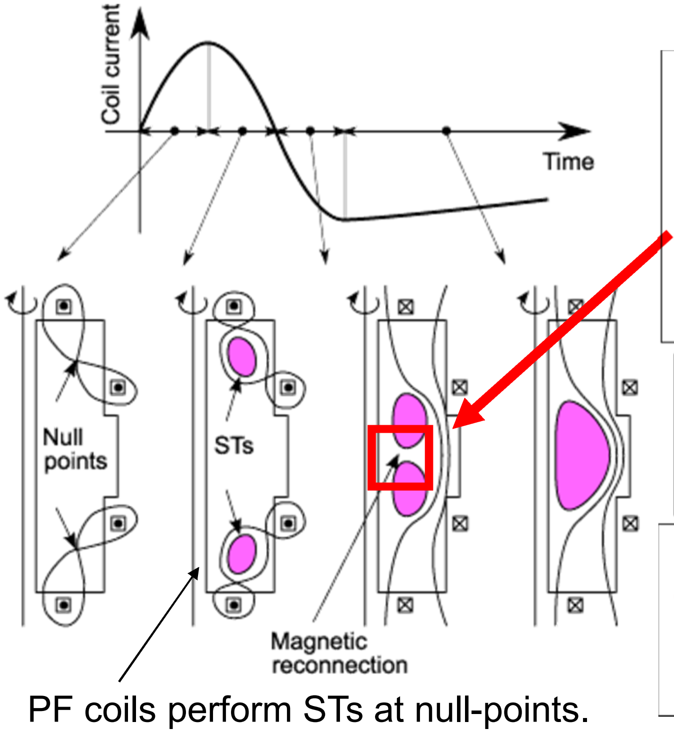
Y. Ono's talk, 28-1-1i, this WS

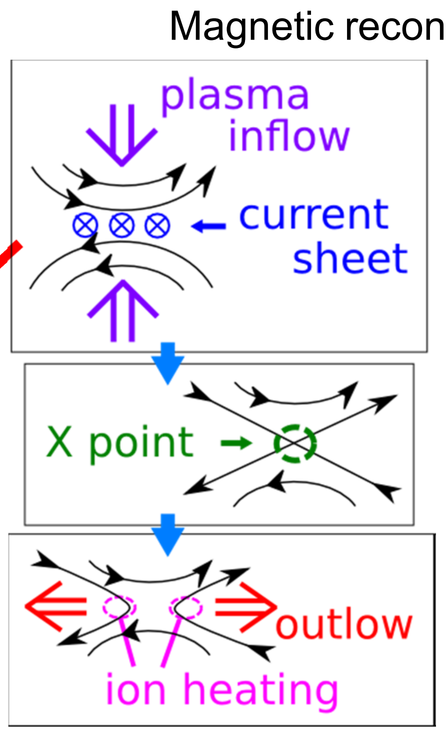
Astrophysics



Solar flares, solar winds, and auroras

UTST adopts double null merging (DNM) method for plasma formation.





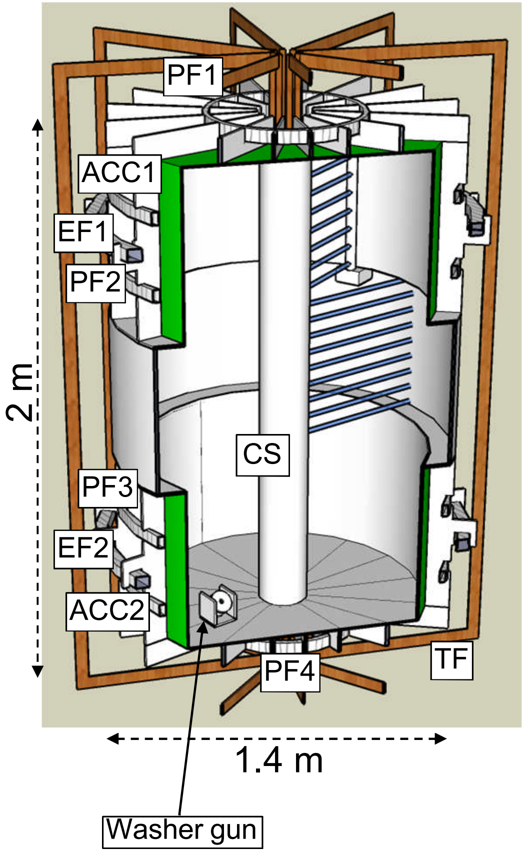
Two plasmas are merged and magnetic field reconnects.

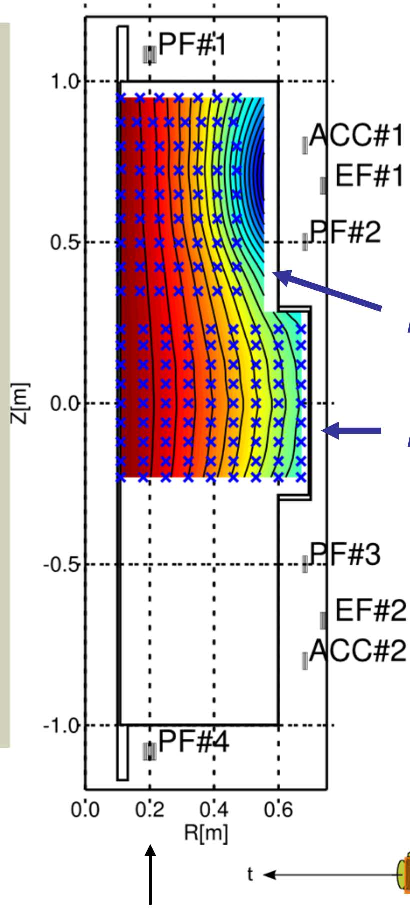
Magnetic energy is converted to plasma kinetic / thermal energy.

High-beta ST can be created!

At UTST, DNM start-up is performed by ***outer*** PF coils to produce a high-beta ST in a reactor relevant situation.

UTST has pickup coil arrays inside the vessel.





An example of the poloidal flux, Ψ, of EF.

UTST has 290 pickup coils inside the vessel. By using B_t and B_z pickup coil arrays, many variables can be calculated.

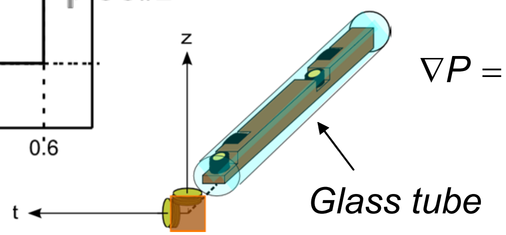
$$\Psi = 2\pi \int B_z r \, dr$$

$$B_r = -\frac{1}{2\pi r}\frac{\partial \Psi}{\partial z}$$

$$E_t = -\frac{1}{2\pi r}\frac{d\Psi}{dt}$$

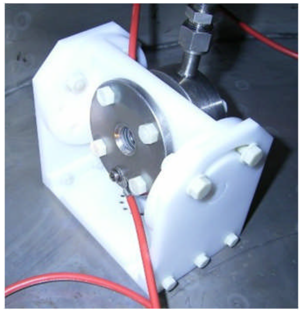
$$\mathbf{j} = \frac{1}{\mu_0}\nabla \times \mathbf{B}$$

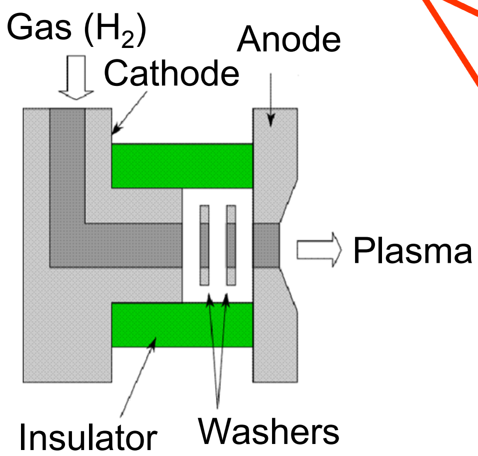
$$\nabla P = \mathbf{j} \times \mathbf{B}$$

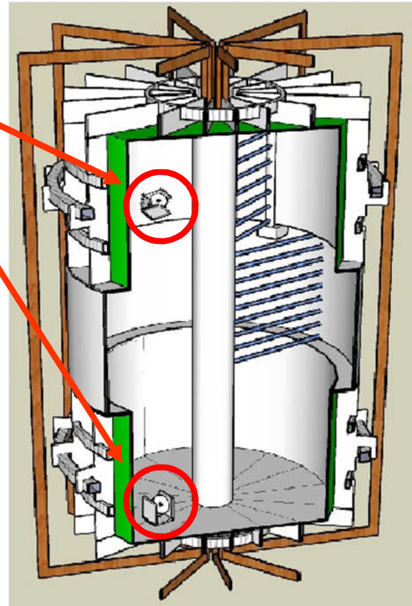


Typical discharge of the UTST plasma

Two washer guns are used for pre-ionization.







Seed plasma in a spiral magnetic field.

Two main discharge scenarios.

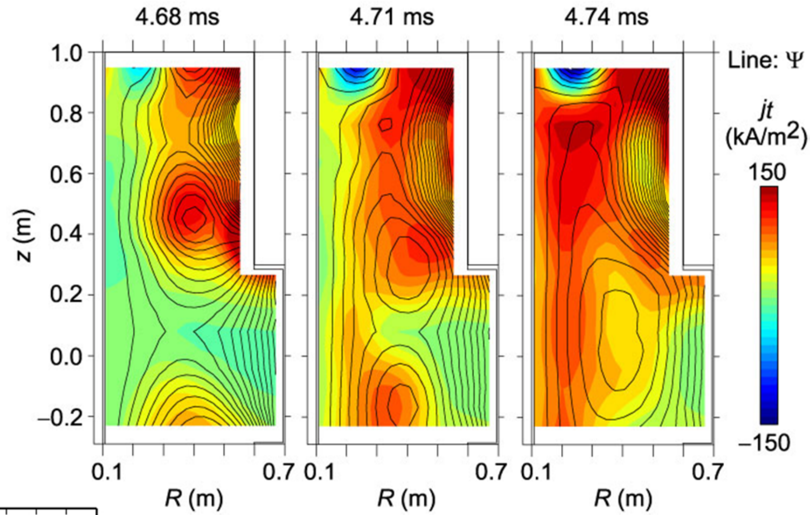
A. DNM start-up + direct induction (DI) by CS
for high-beta ST sustaining experiment

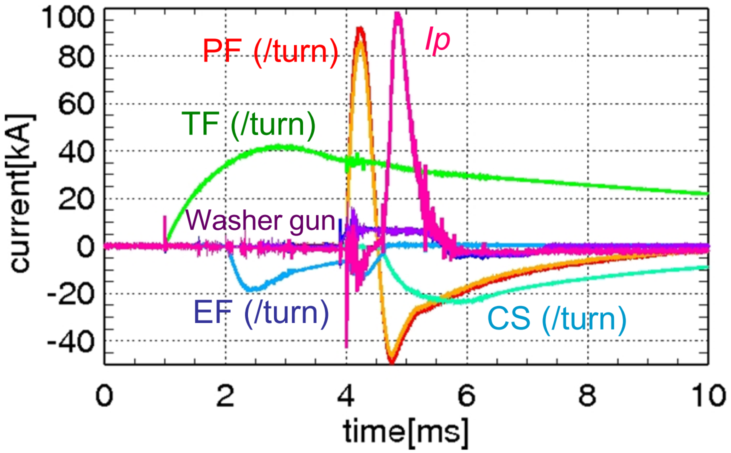
B. DNM start-up discharge w/o CS
to establish a new CS-less start-up method

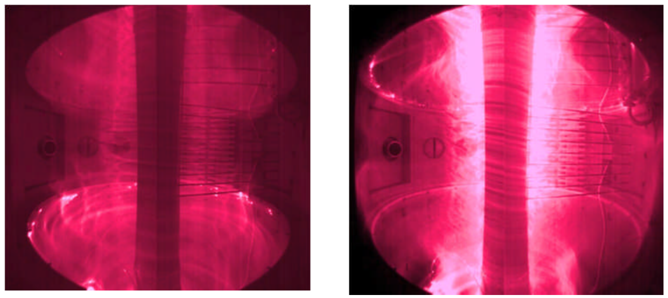
A. DNM + DI discharge

Plasma current reached 190 kA by using the DNM start-up and also direct induction by CS.

Magnetic reconnection was clearly observed by the pickup coil measurement.







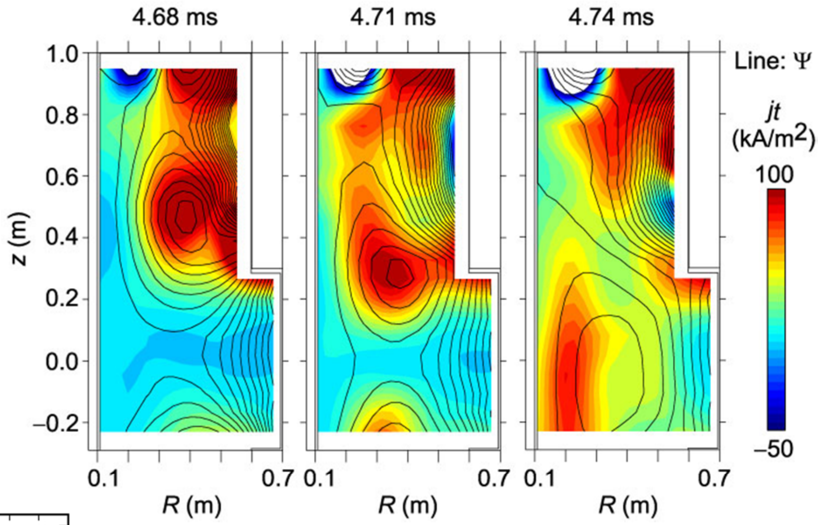
Fast camera images

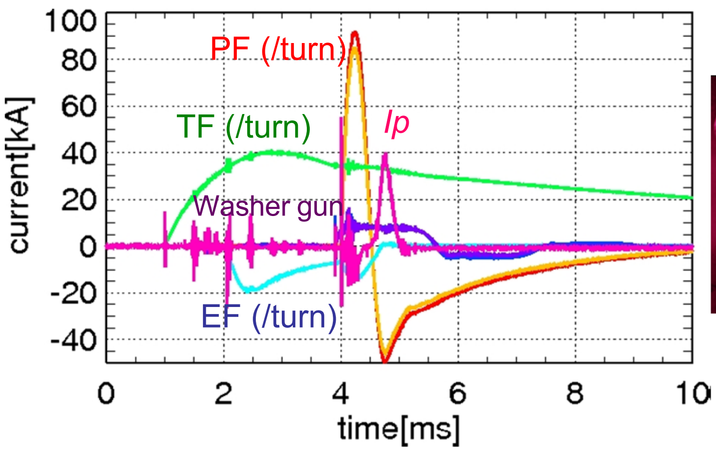
T. Yamada *et al.*, PFR **5**, S2100 (2010)

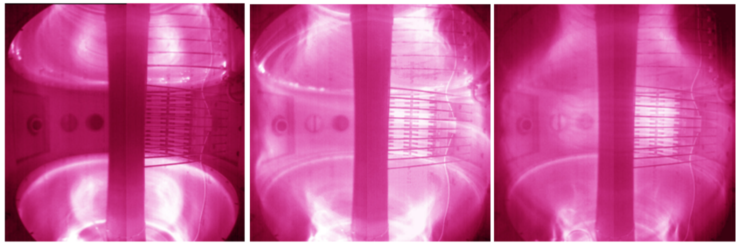
B. DNM only discharge

Plasma current reached 50 kA by using only the DNM start-up.

Magnetic reconnection was also clearly observed in this case. Proposed a new CS-less start-up method for ST formation.







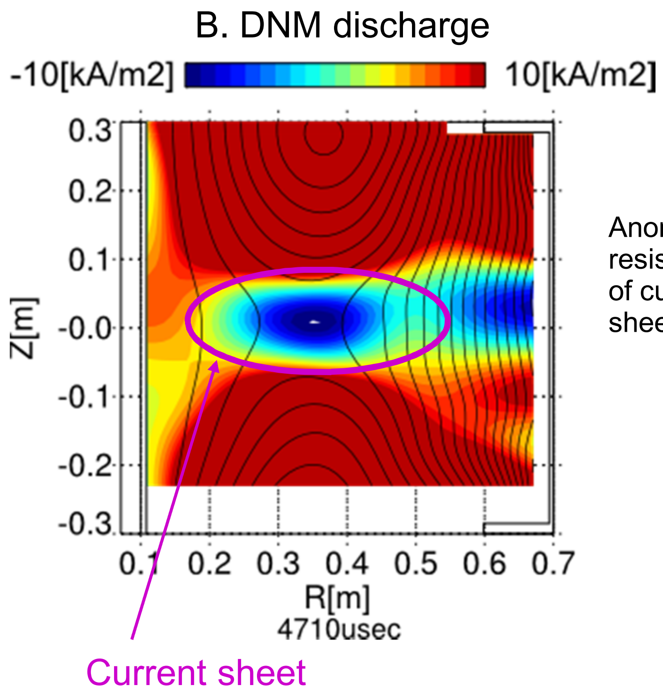
Fast camera images

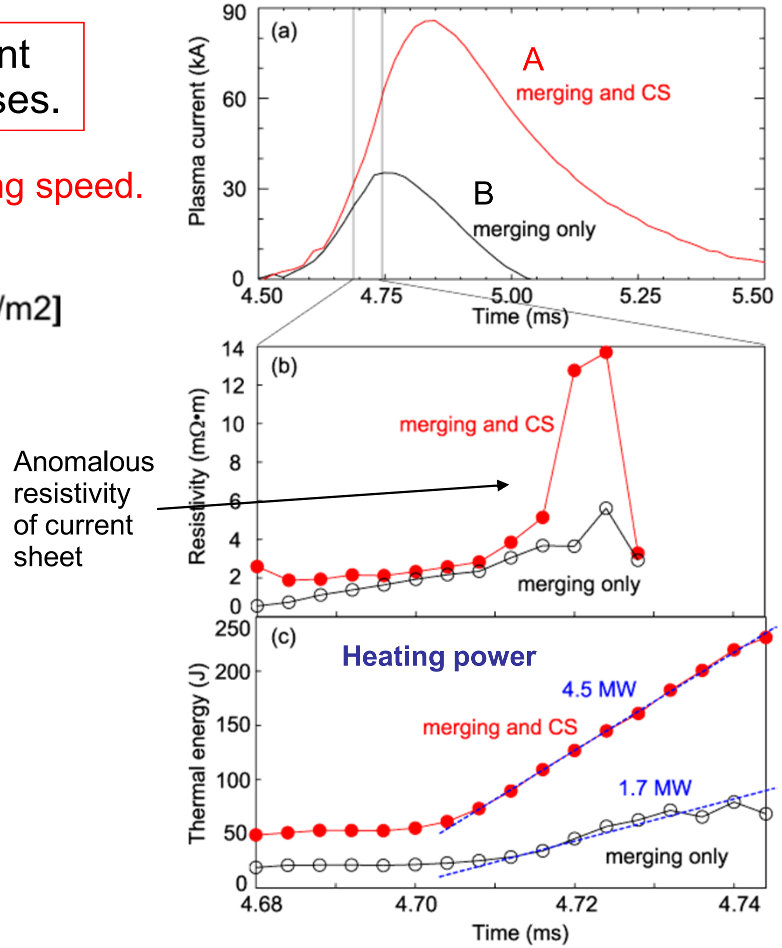
T. Yamada *et al.*, 23rd IAEA FEC (2010)

Current sheets were observe during DNM.

By using acceleration coils, current sheets were observed in both cases.

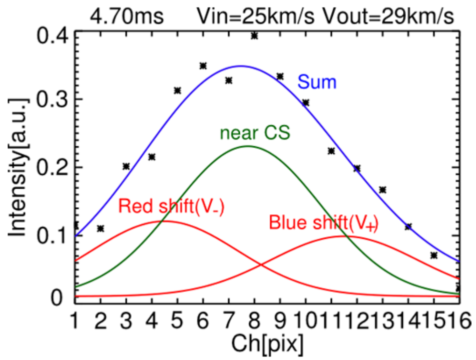
Acceleration coils increase the merging speed.

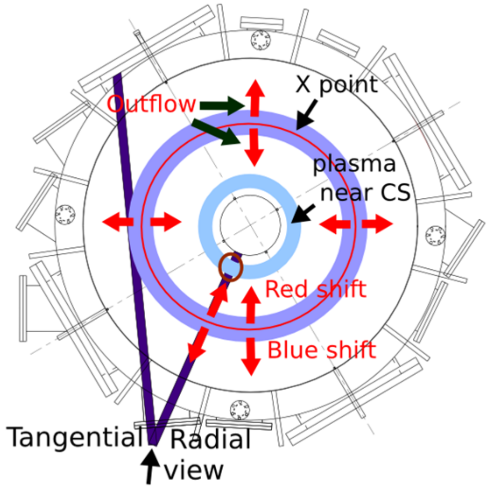


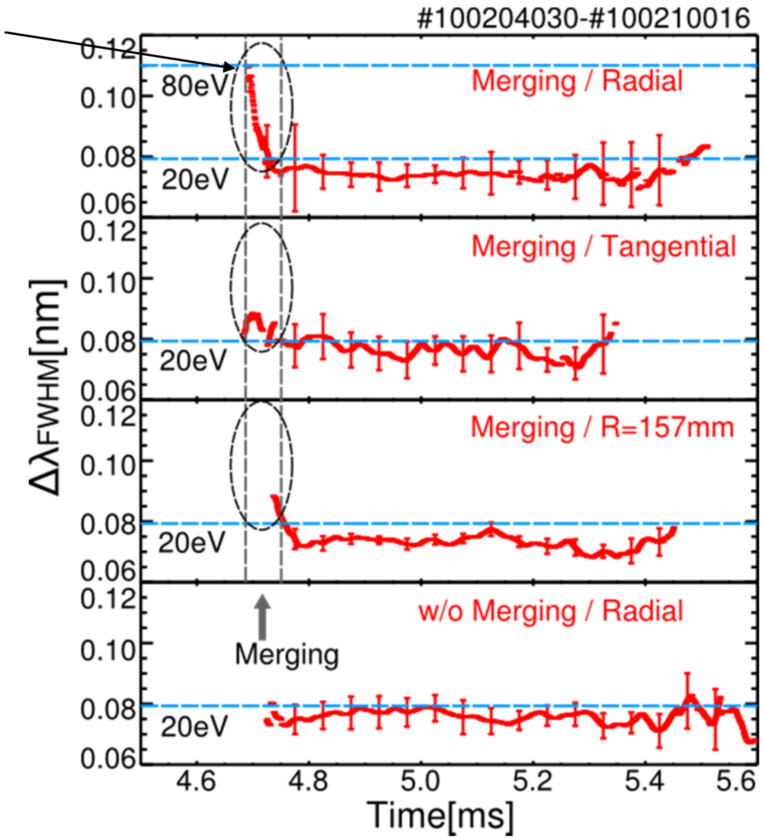


Spectrometer measured Doppler broadening at the radial view during the merging.

Explained by three components

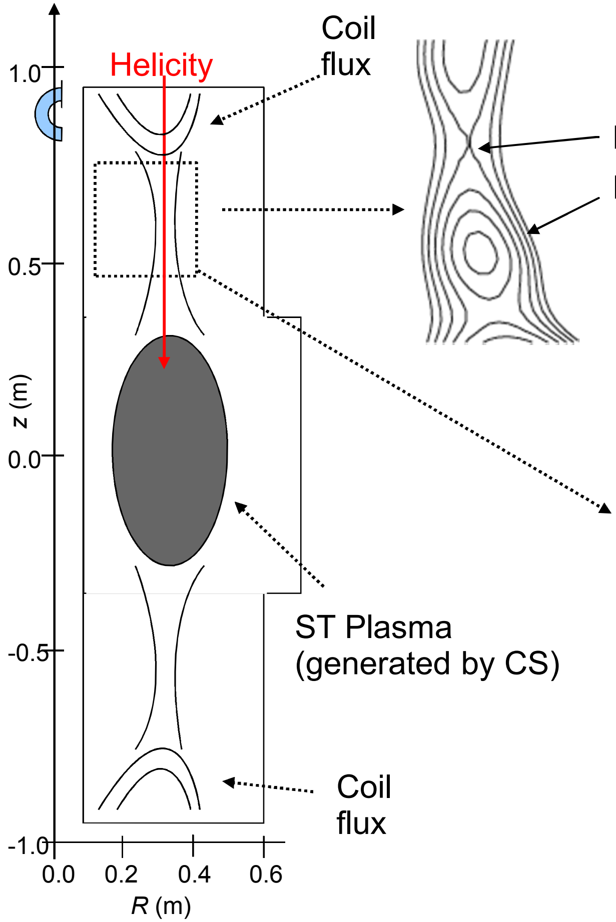




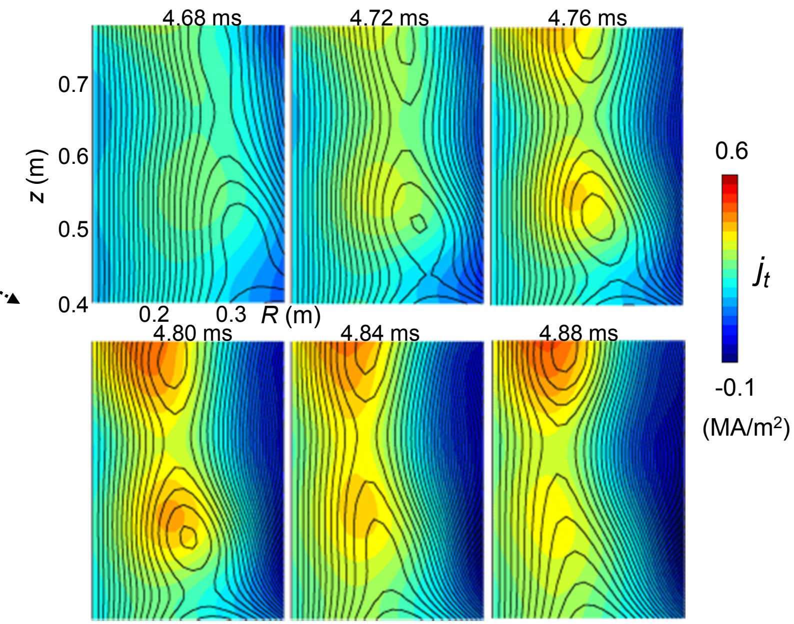


S. Kamio *et al.*, PFR **6**, 2402033 (2011)

Helicity injection from coil flux to ST through reconnection was observed in UTST.

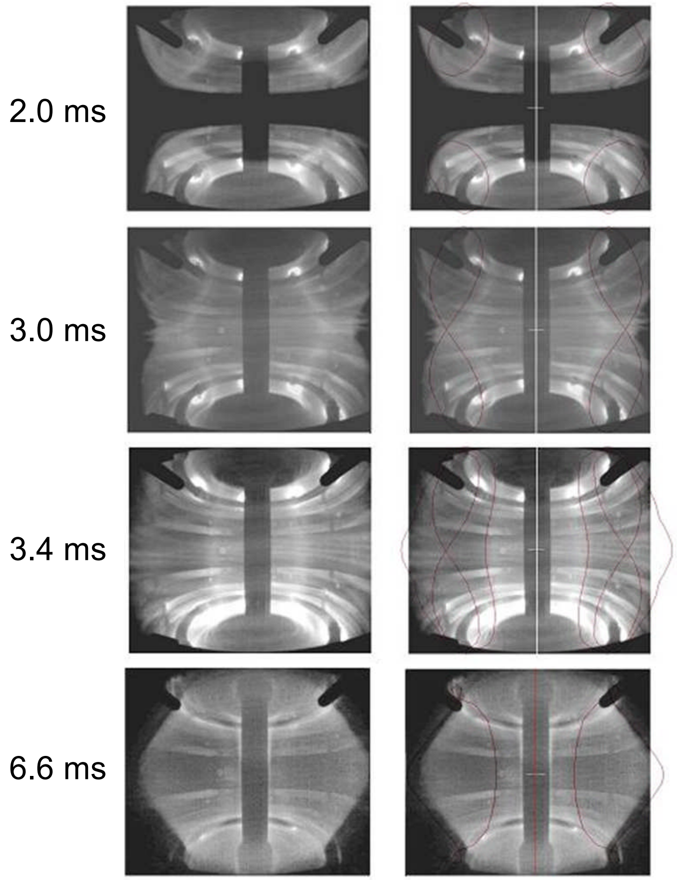


Reconnection produced plasmoids, which carry magnetic helicity.



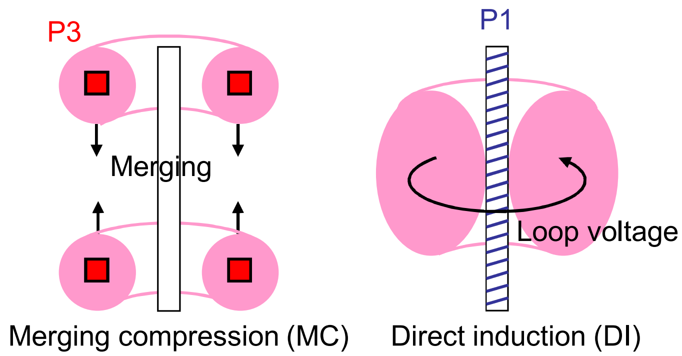
T. G. Watanabe *et al.*, PFR **6**, 1202131 (2011)

MAST adopts merging compression (MC) as well as DI for plasma formation.

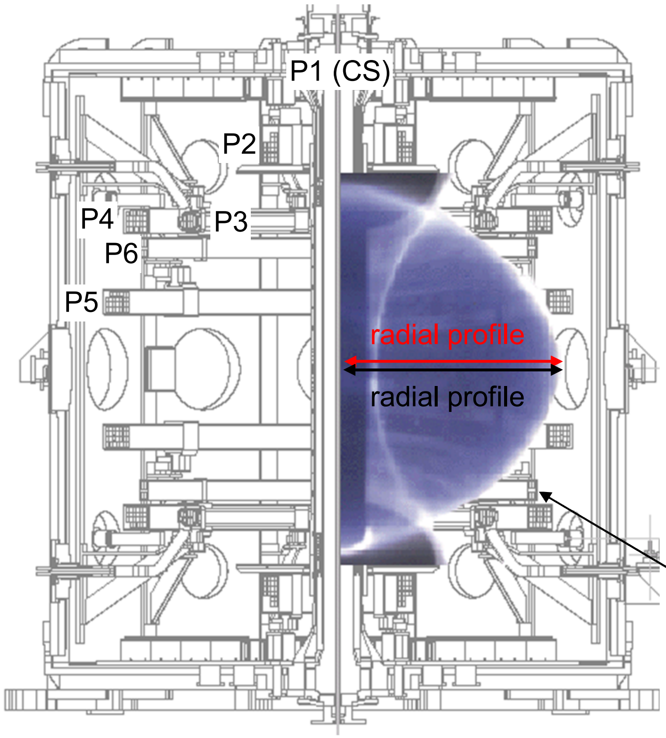


Two plasma rings, inductively formed around P3 in-vessel coils (2.0 ms), merge (3.0 ms), and eventually produce plasma current up to 0.45 MA (6.6 ms).

Reconnection of poloidal flux occurs in mid-plane accompanied by rapid heating of ions and electrons.



Temperature and density measurements of MAST MC plasmas are reported here.



Major/minor radii	0.8/0.6 m
Toroidal field	0.6 T @ 0.7 m
Plasma current	1.35 MA
Temperature	up to 3 keV
Density	10^{20} m^{-3}

Electron temperature and density measurements by Thomson scattering (TS):

130-ch YAG TS (z = 1.5 cm)

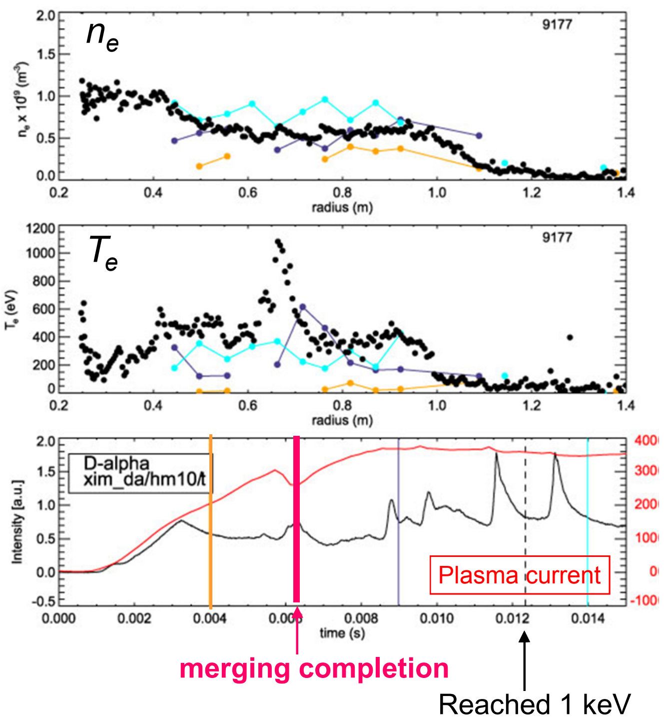
300-ch Ruby TS (z = –1.5 cm)

P6 can shift the plasma vertically.
-> 2D profiles can be obtained.

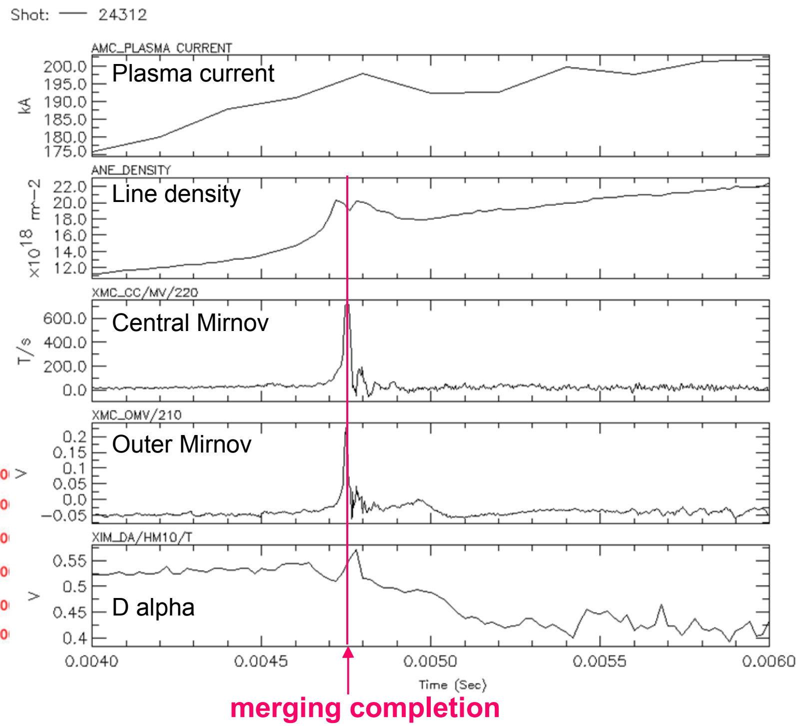
Temperatures in MC shots increase very high within a short time period (~10 ms) compared to DI shots (~200 ms).

More than 1 keV of T_e was achieved by MC.

T_e reached 1 keV, about 6 ms after the merging completion.

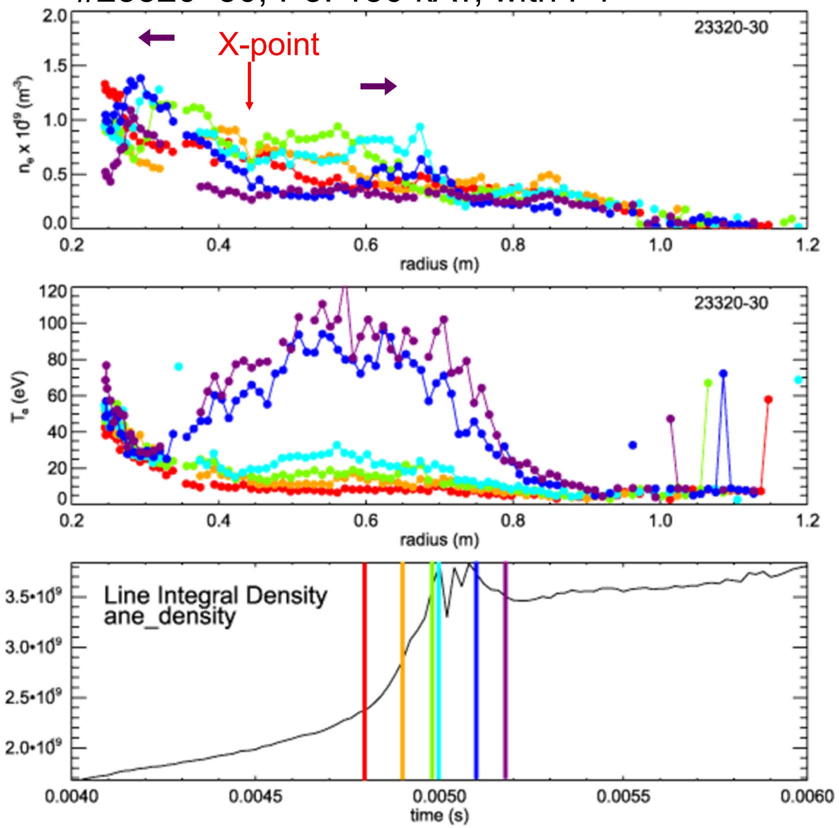


Spikes in many signals were observed at the end of the merging.



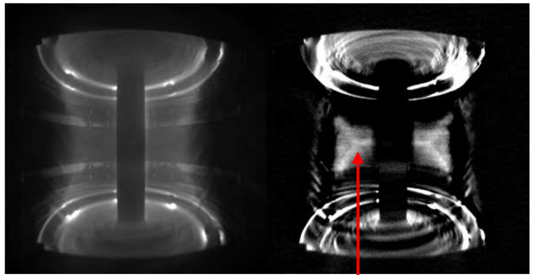
During MC, fast change of the n_e profile and sudden increase of T_e were observed.

#23320–30, P3: 150 kAT, with P1



The peak of the n_e profile is separated at the X-point, and the two peaks move inward and outward.

The T_e profile increases abruptly after the density spike.



#23324, 4.7 ms

X-point, R ~ 0.45 m

Central peak and outer peaks appear after magnetic reconnection.

#24312–13, P3: 150 kAT, with P1

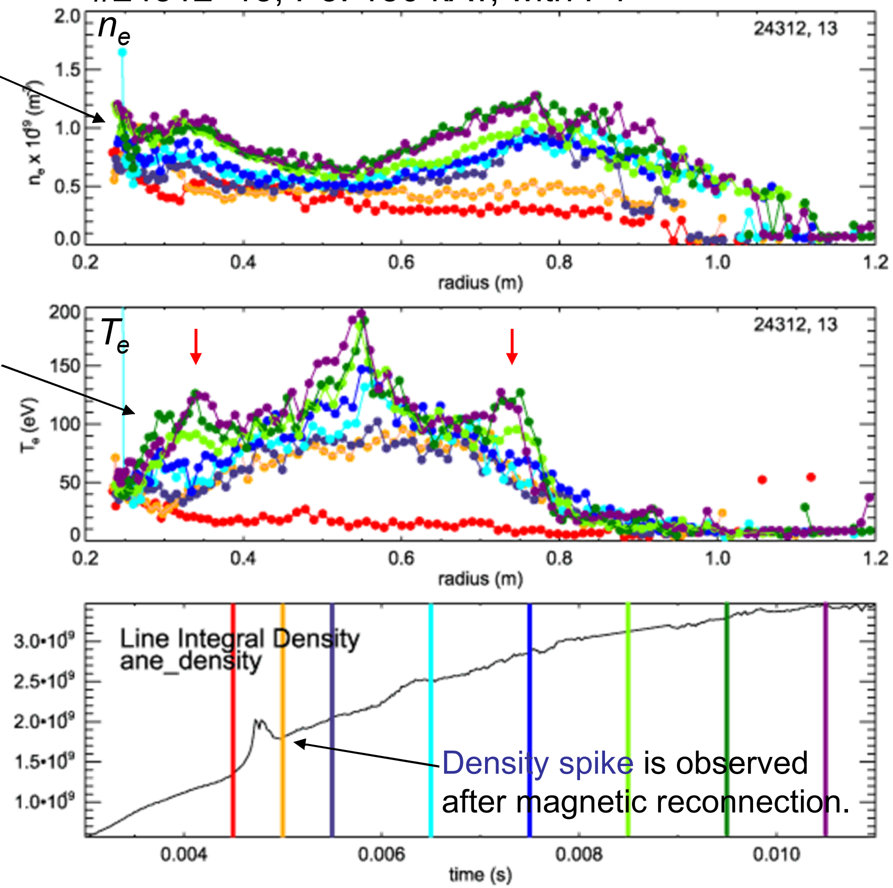
Electron density increases after the density spike.

It becomes a hollow profile.

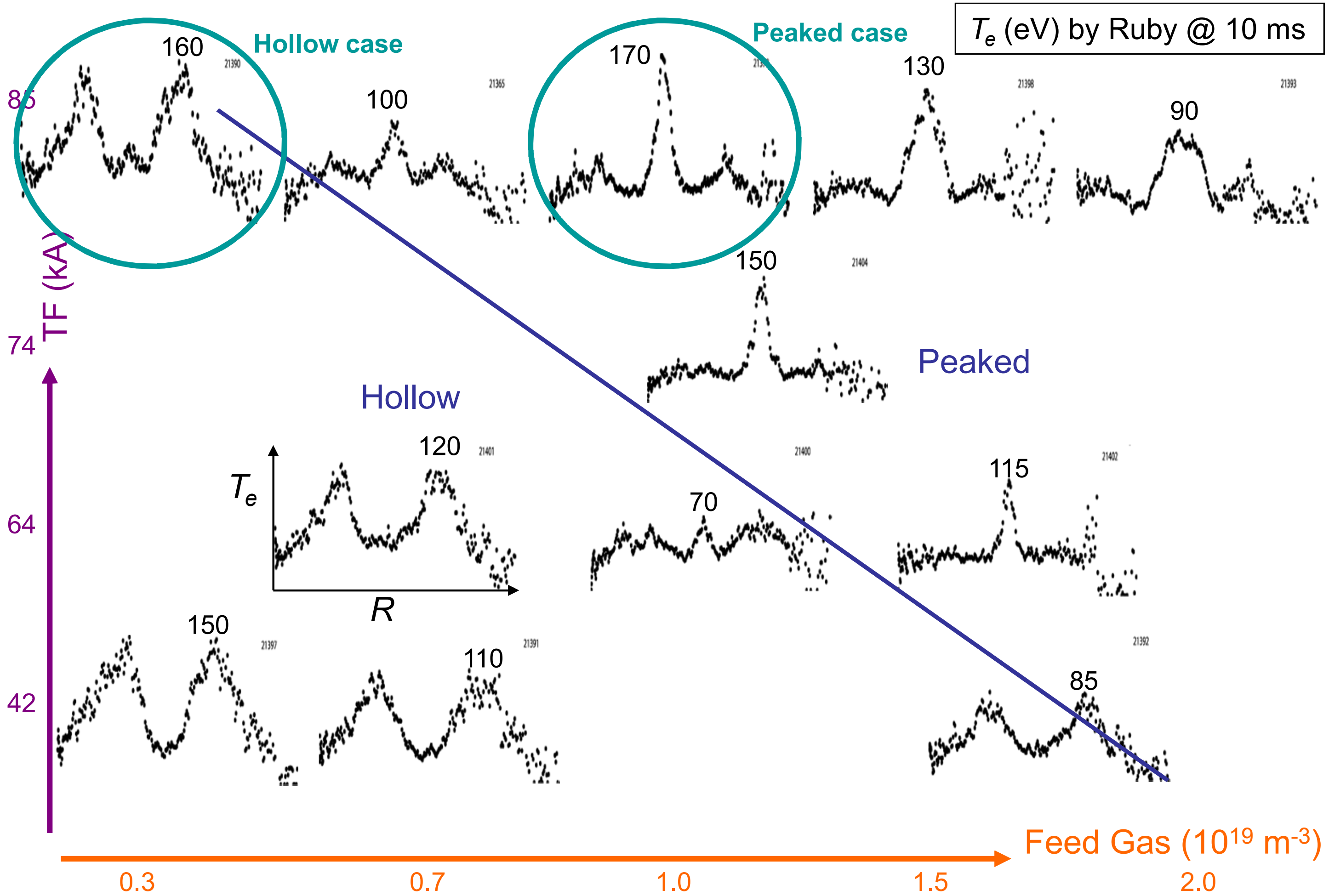
Electron temperature suddenly increases after the density spike. At 6.5 ms, the central peak appears.

At 9.5 ms, the outer peaks appear.

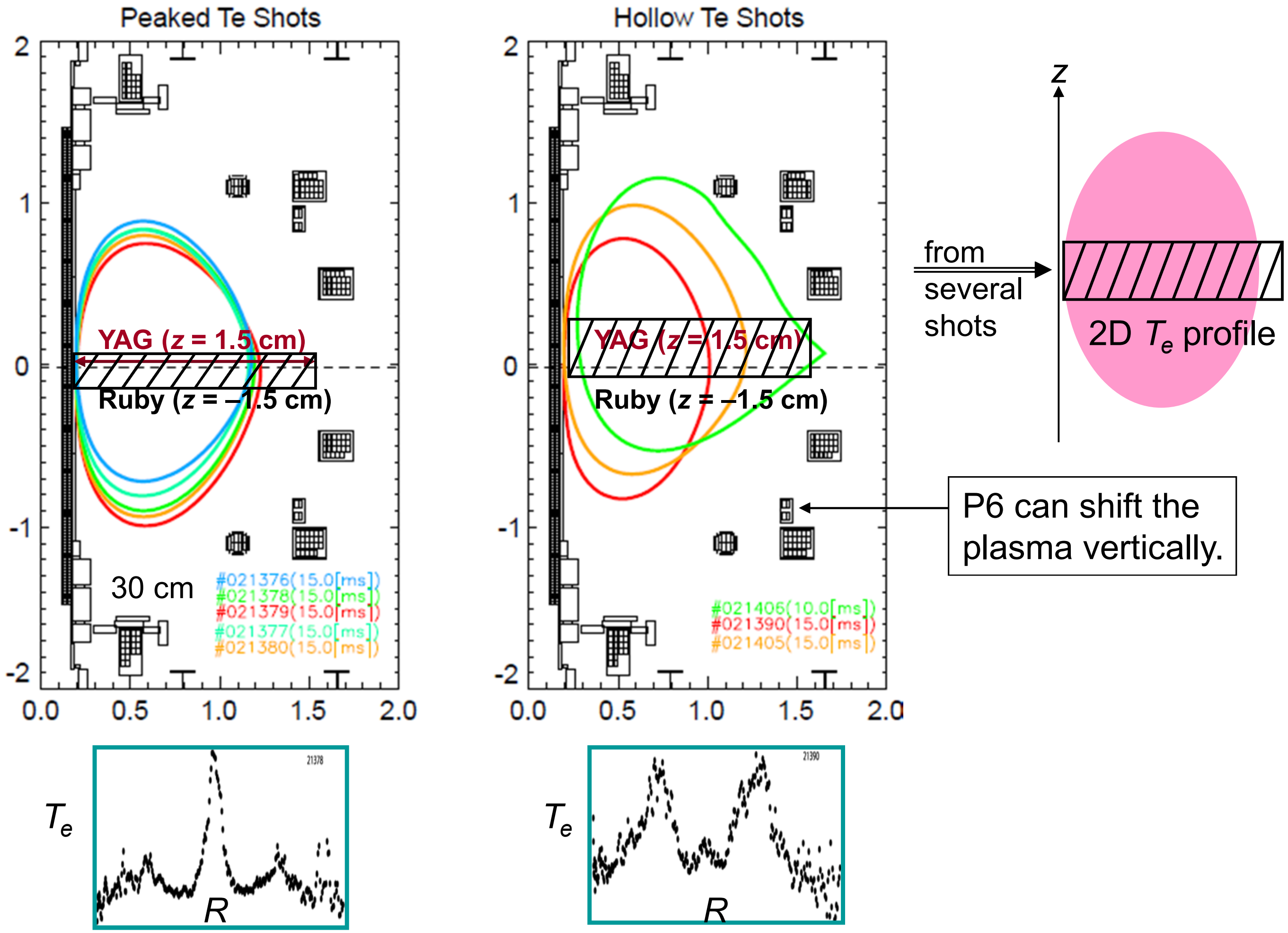
It is interesting to know the origins and evolutions of the central peak and outer peaks.



Changing TF & feed gas affects the T_e profile.

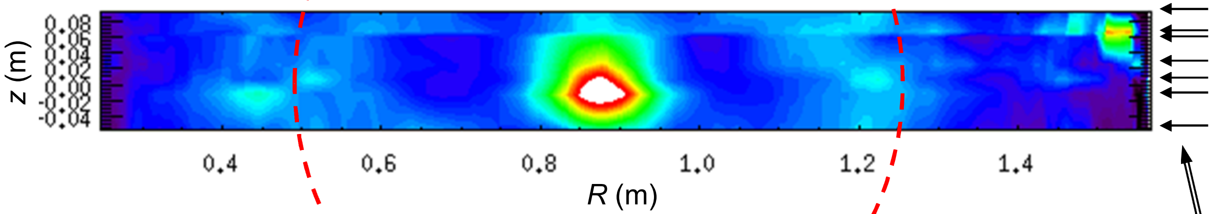


2D T_e profs were obtained by shifting plasma.



Central peak and outer rim were observed in the 2D Te profile.

[redacted]

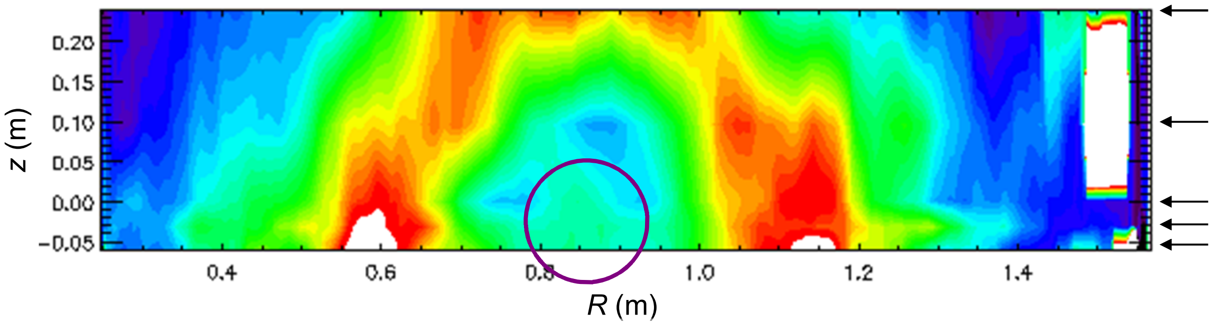


Central peak is the result of the heating by reconnection.

Outer rim is also observed in the peaked case.

Height of Axis calculated by EFIT

Hollow case (0.5×10^{19} m^{-3}), Ruby @ 10 ms



The origin of the outer rim is not clearly explained yet.

There is also a small central peak in the hollow case.

Summary

UTST

- Plasma start-up by DNM method was successfully observed in UTST.
- Plasma current up to 50 kA was achieved and proposed a new CS-less start-up method.
- With CS assist, plasma current reached 190 kA.
- By using acceleration coils, current sheet was observed.

MAST

- During MC, radial density propagation both inward and outward from the X-point was observed.
- The T_e profile suddenly increased after the merging completion.
- 2D T_e profile after the merging revealed to have a central peak and an outer rim. Feed gas and TF determined the ratio.