Application of merging/reconnection heating for spherical tokamak in MAST

Hiroshi Tanabe
(tanabe@ts.t.u-tokyo.ac.jp)

T. Yamada[2], K. Yamasaki[1], T.Watanabe[1], K. Gi[1], M. Inomoto[1], M. Gryaznevich[3], R. Scannell[3], N. Conway[3], B. Crowley[3], C. Michael[3] and Y. Ono[1]

[1] *Graduate School of Frontier Sciences, University of Tokyo, Tokyo 113-0032, JAPAN*

[2] *Faculty of Arts and Science, Kyusyu University, Fukuoka, 819-0395, JAPAN*

[3] *CCFE, Culham Science Centre, Abingdon, Oxfordshire OX14 3DB, UK*

Outline

- Reconnection studies in MAST

  --- latest report on MAST M9 campaign ---

- Contents:

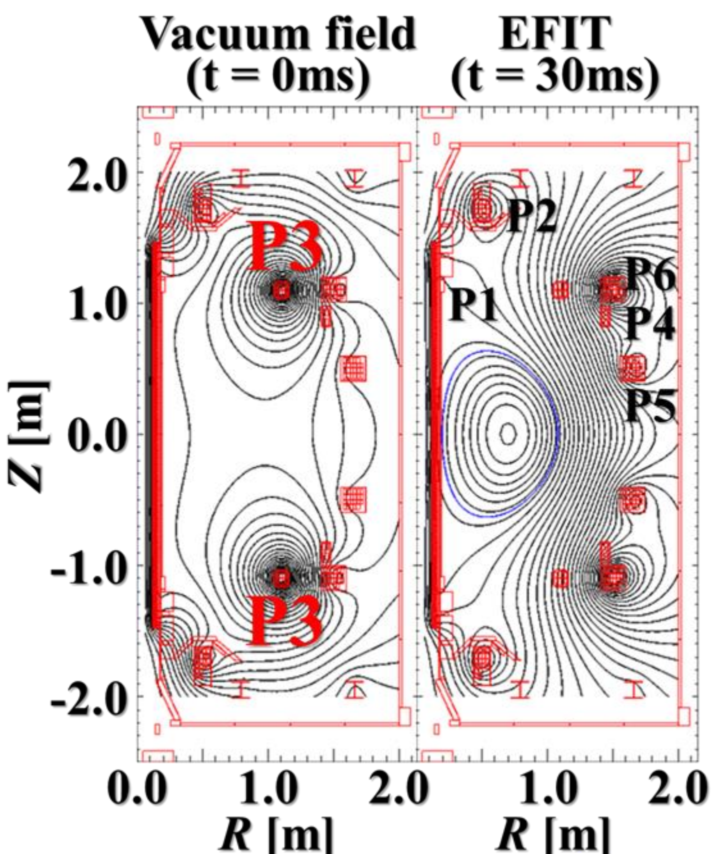
  > Detailed profile measurement of T_e, n_e and T_i.
  (New ion Doppler tomography diagnostics installed)

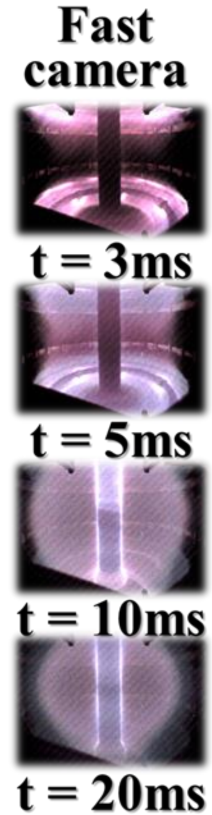
  > 2D imaging measurement of T_e, n_e and T_i.
  (Magnetic reconnection heats locally electrons at the X point and ions globally downstream.)

  > Energy relaxation of characteristic temperature profile in the time scale of τ^E_{ei} → triple peak

  > Effect of reconnecting field and guide field.

Typical waveform of "standard shot" in MAST





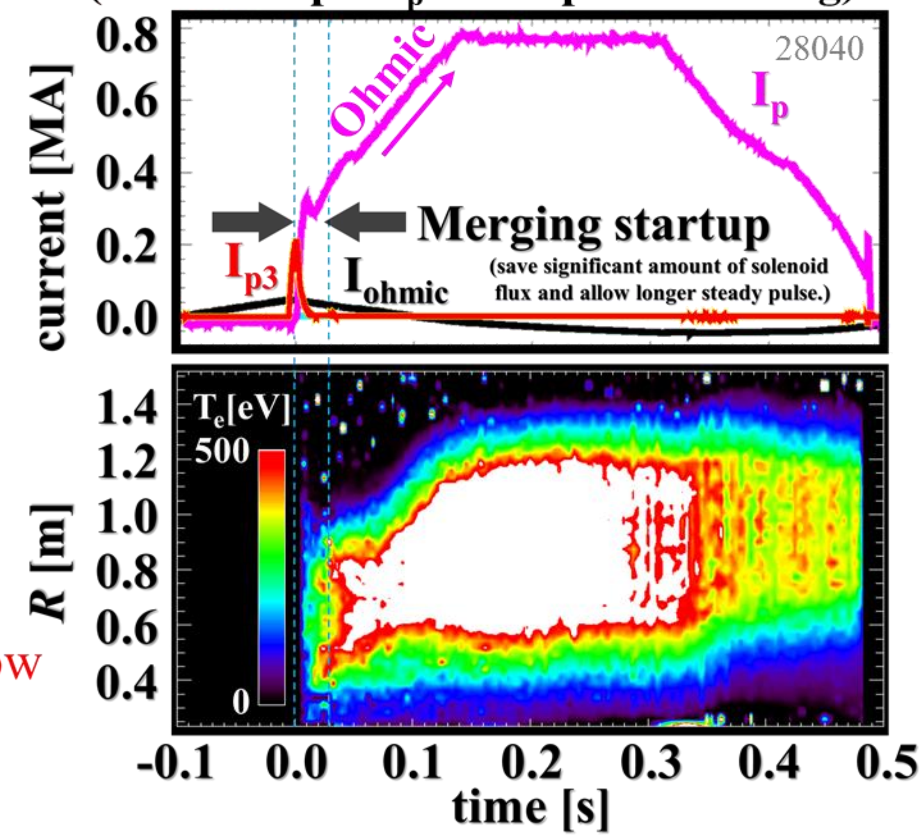
Parameter range during reconnection

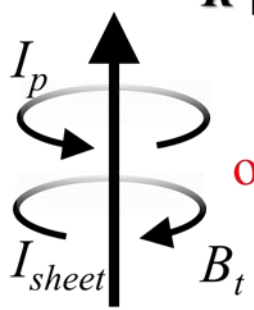
· n_e : ~1.0×10^{19} · T_i, T_e: 0.01 ~ 1 keV

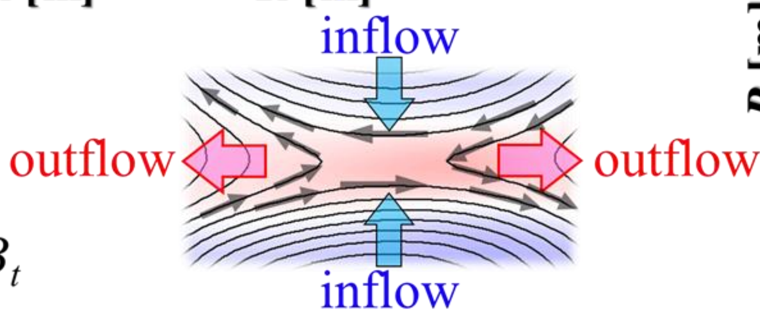
· B_{rec} : ~ 0.1T · B_t : 0.4 ~ 0.8T

Typical waveform of "hybrid" standard shot

(CS-less rapid I_p startup and heating)



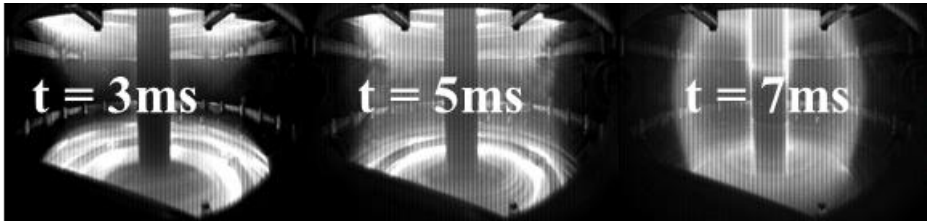




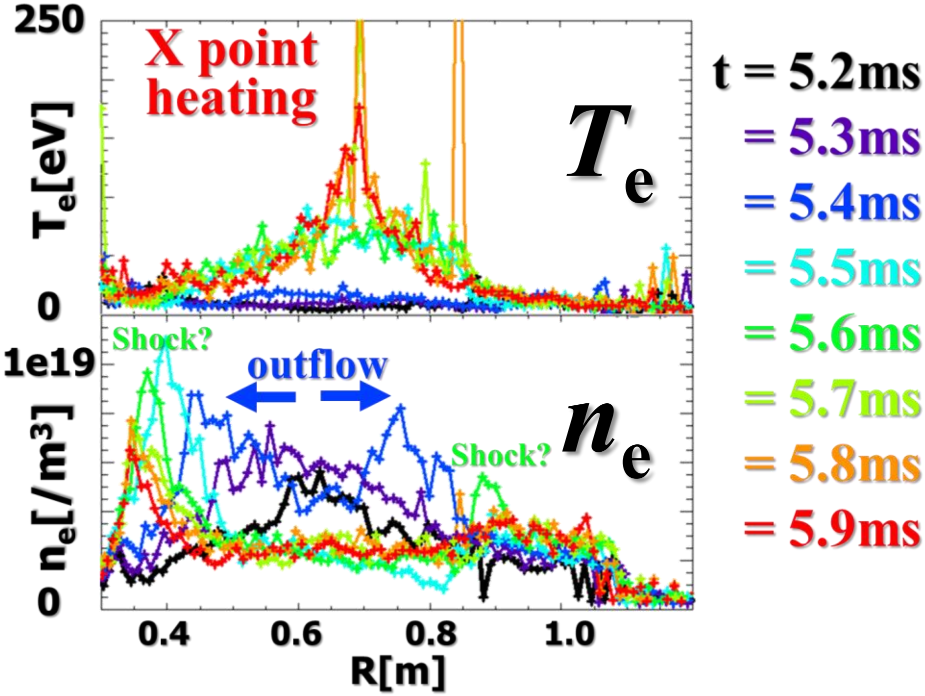
Thomson scattering measurement of T_e and n_e profile

130 chords YAG-TS revealed two types of characteristic heating profile

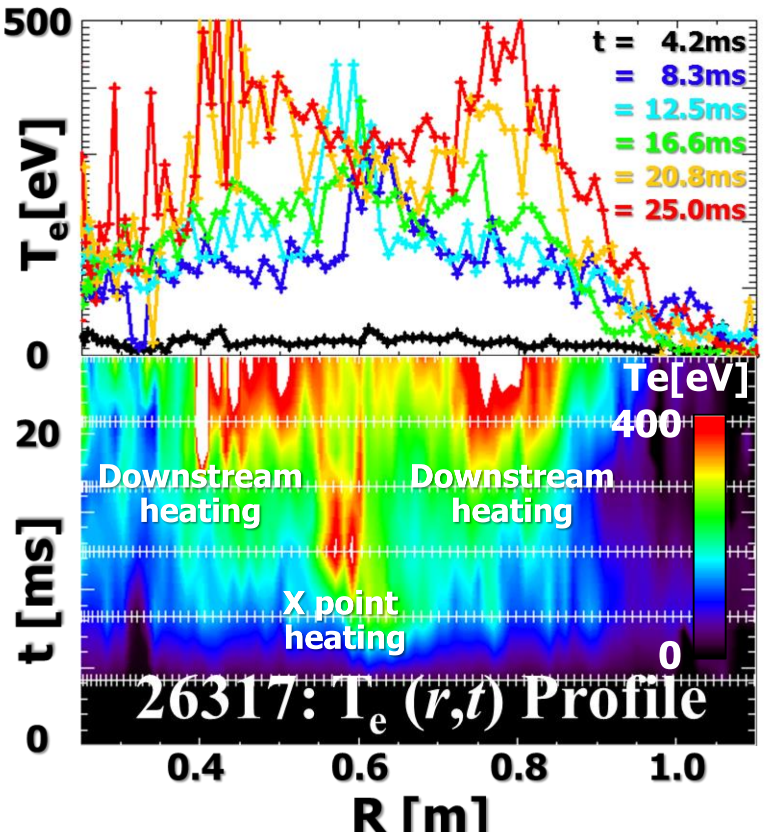
- **Faster time scale with Δt = 100μs: direct electron heating at X point**



shot 25740 (I_{P3} ~ 200kAturn)

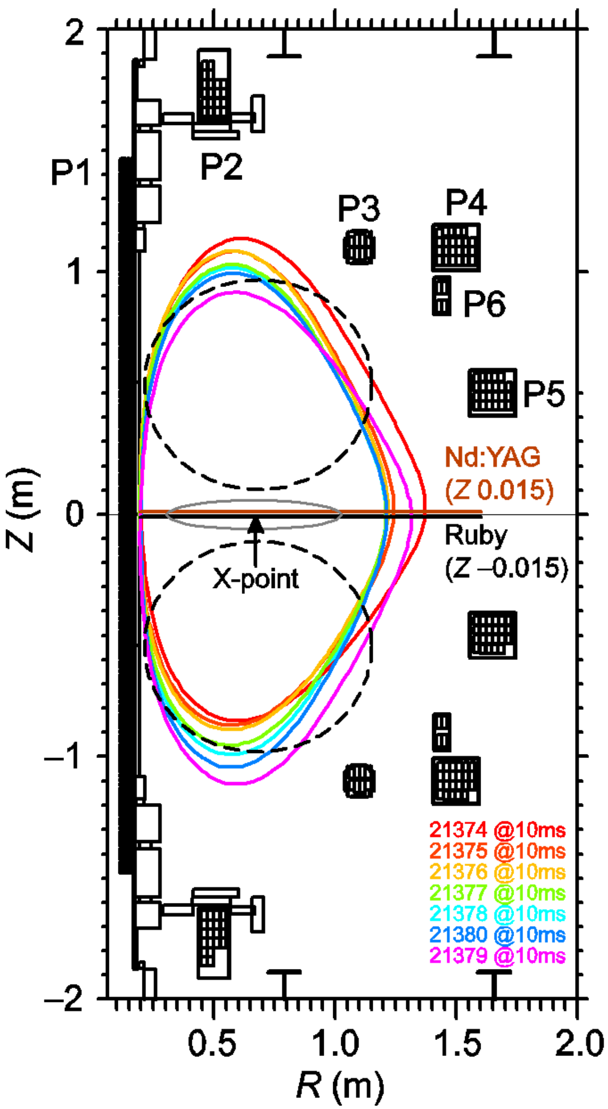


- **Slower time scale comparable to ion-electron energy relaxation time**

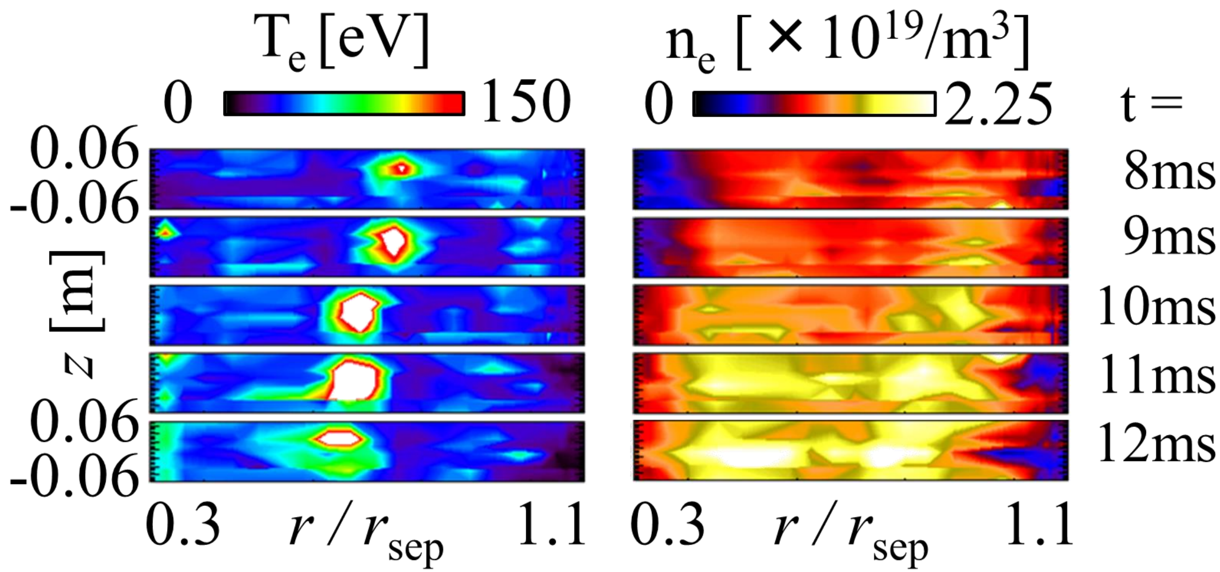


In addition to the X point, T_e also increases downstream (probably from ions?)

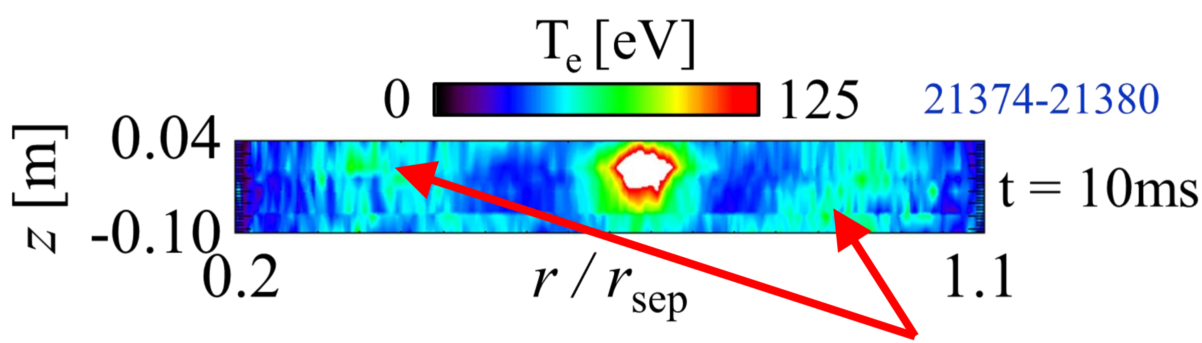
2D Thomson scattering measurement of T_e and n_e



YAG Thomson (5 pixels for wavelength)



Ruby Thomson (302 pixels for wavelength)

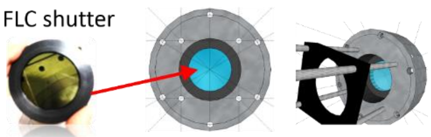


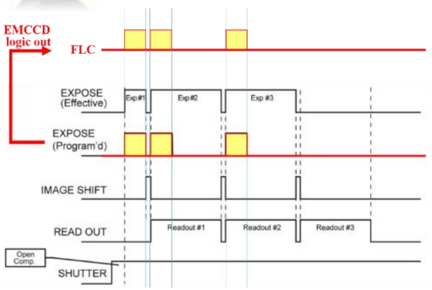
From ions?

In the past collaboration, no T_i profile measurement during startup → a new 32 chords ion Doppler tomography was installed on MAST

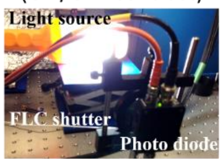
- 512 pixel proEMCCD (16μm/pixel)
- Spectral resolution: ~0.008nm/pixel (f = 1.0m, g=1800L/mm)
- frame rate: ~2.7ms for 32ROI (achieved with "FLC" liquid crystal shutter)

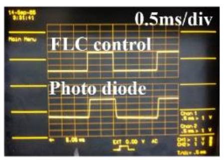
FLC shutter

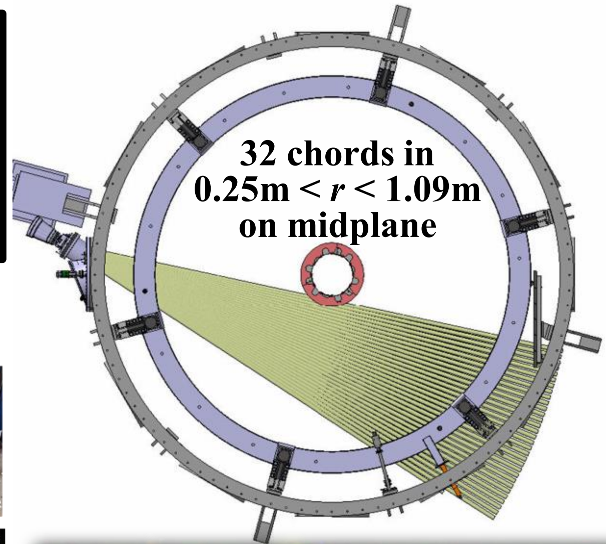


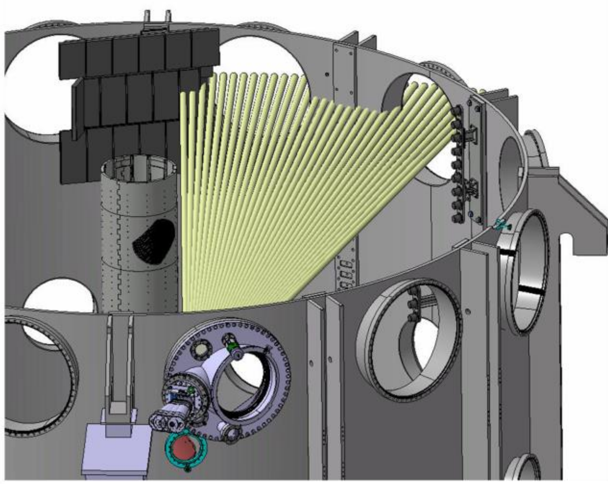


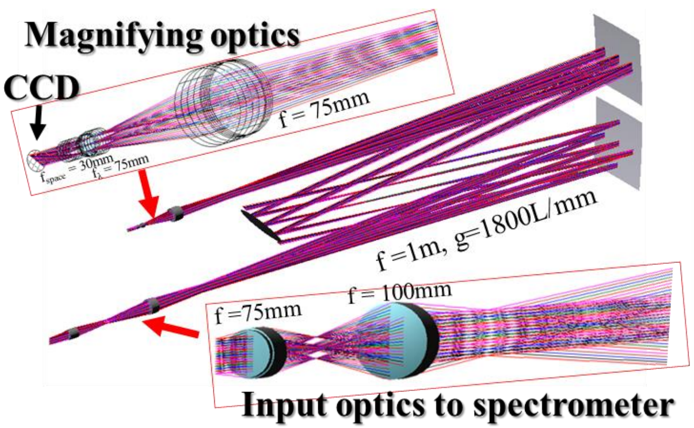
FLC shutter Performance test (ON/OFF contrast)

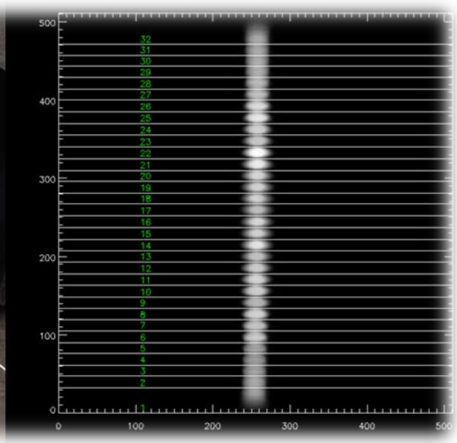




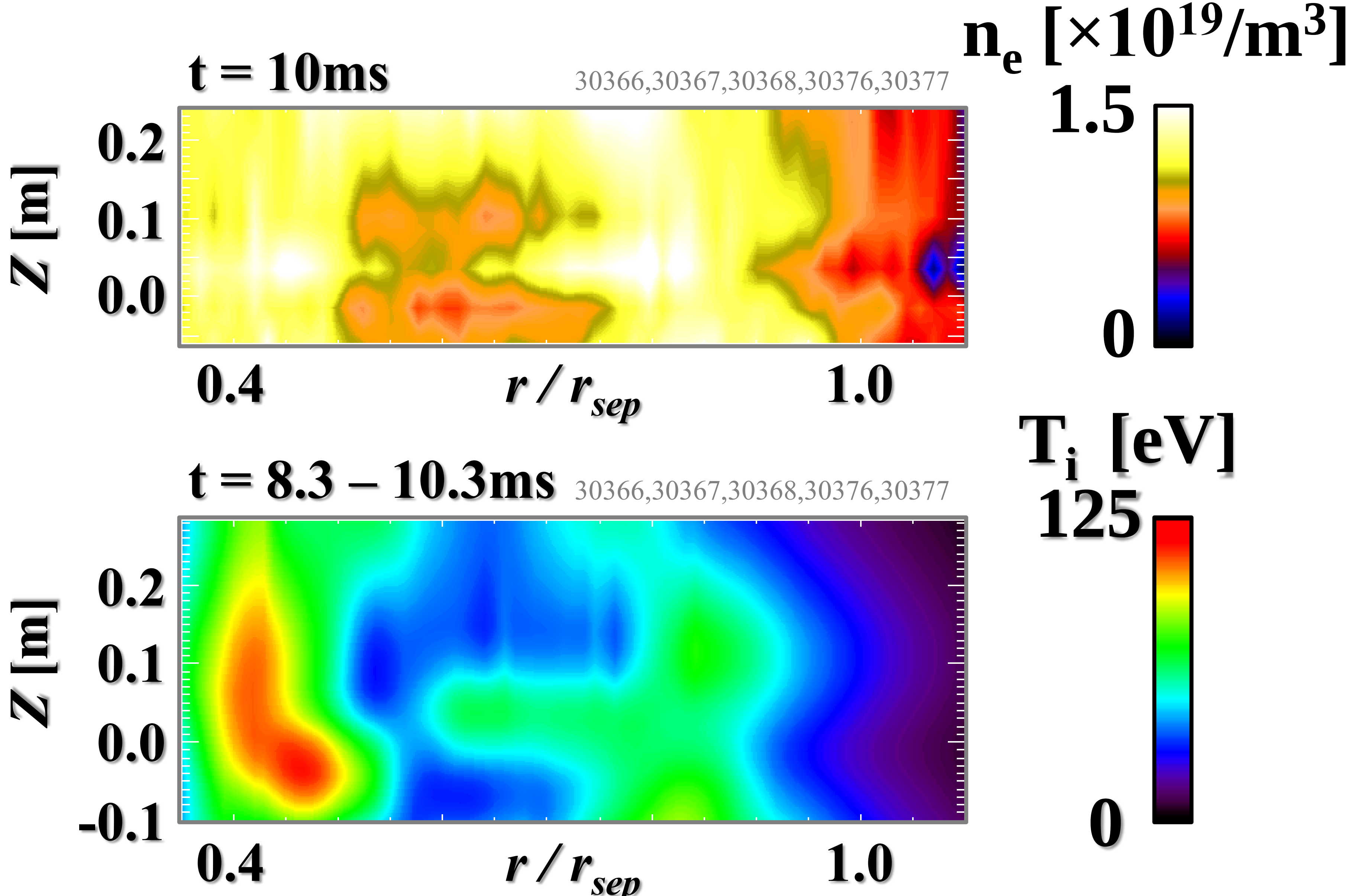






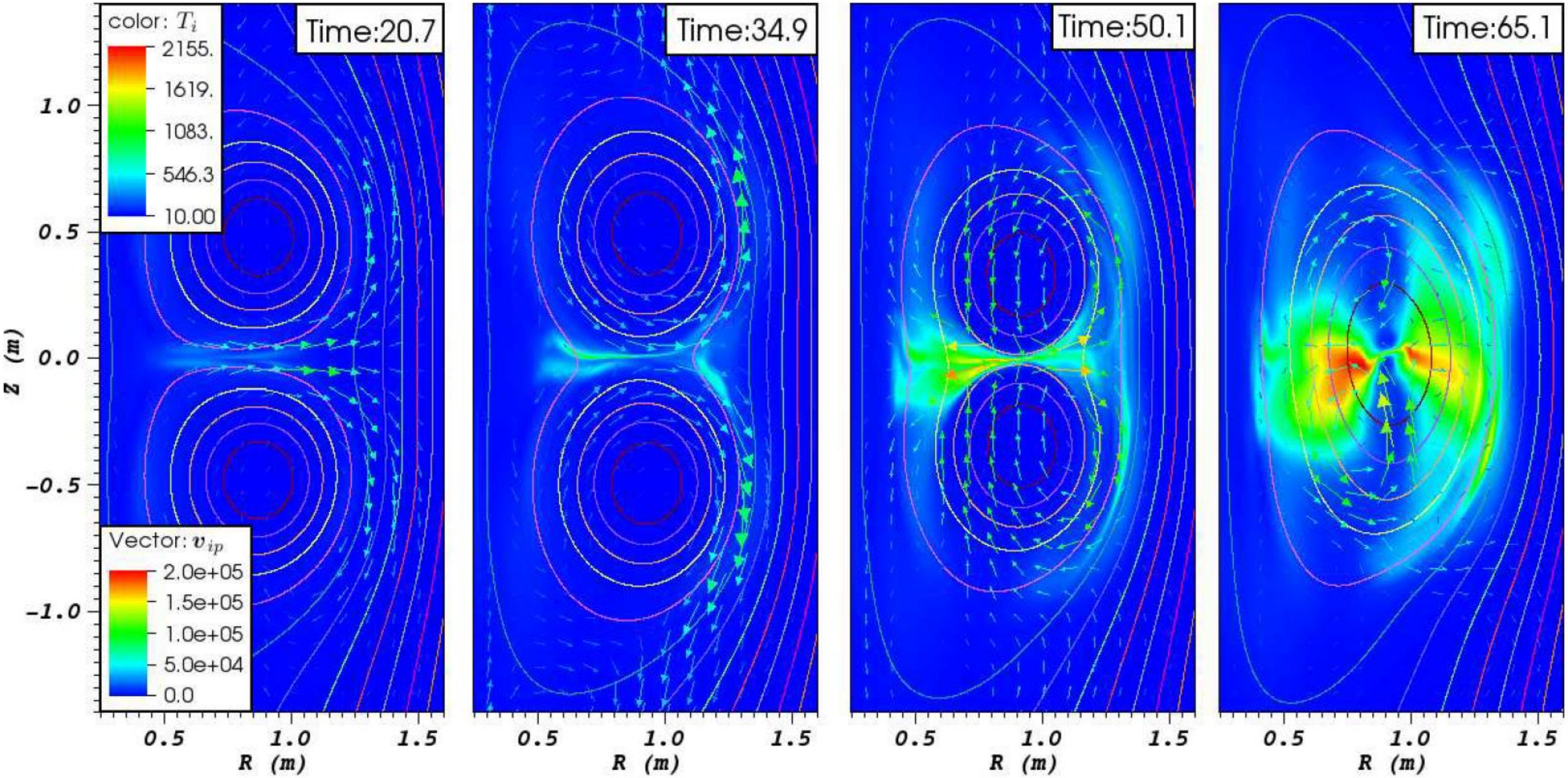


2D measurement of T_i (ion Doppler tomography) and n_e (YAG-TS): outflow heating is confined at the closed flux surface of reconnected field.



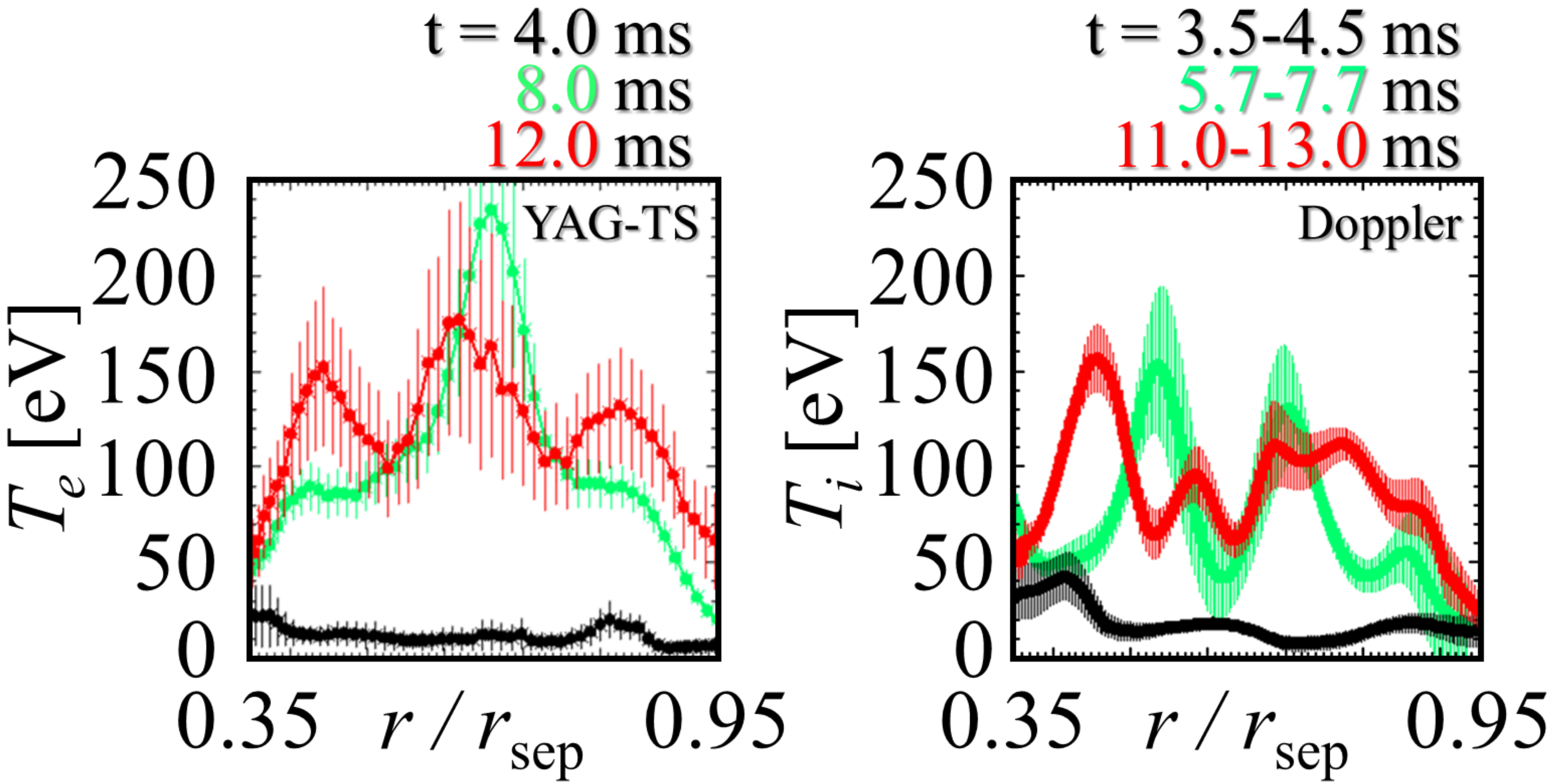
Reference two fluid simulation by P. Browning *et.al.*

For their HIFI simulation which include toroidal effect, similar bulk ion heating downstream was predicted. (fundamental viscosity dissipation term (Braginskii) included.)



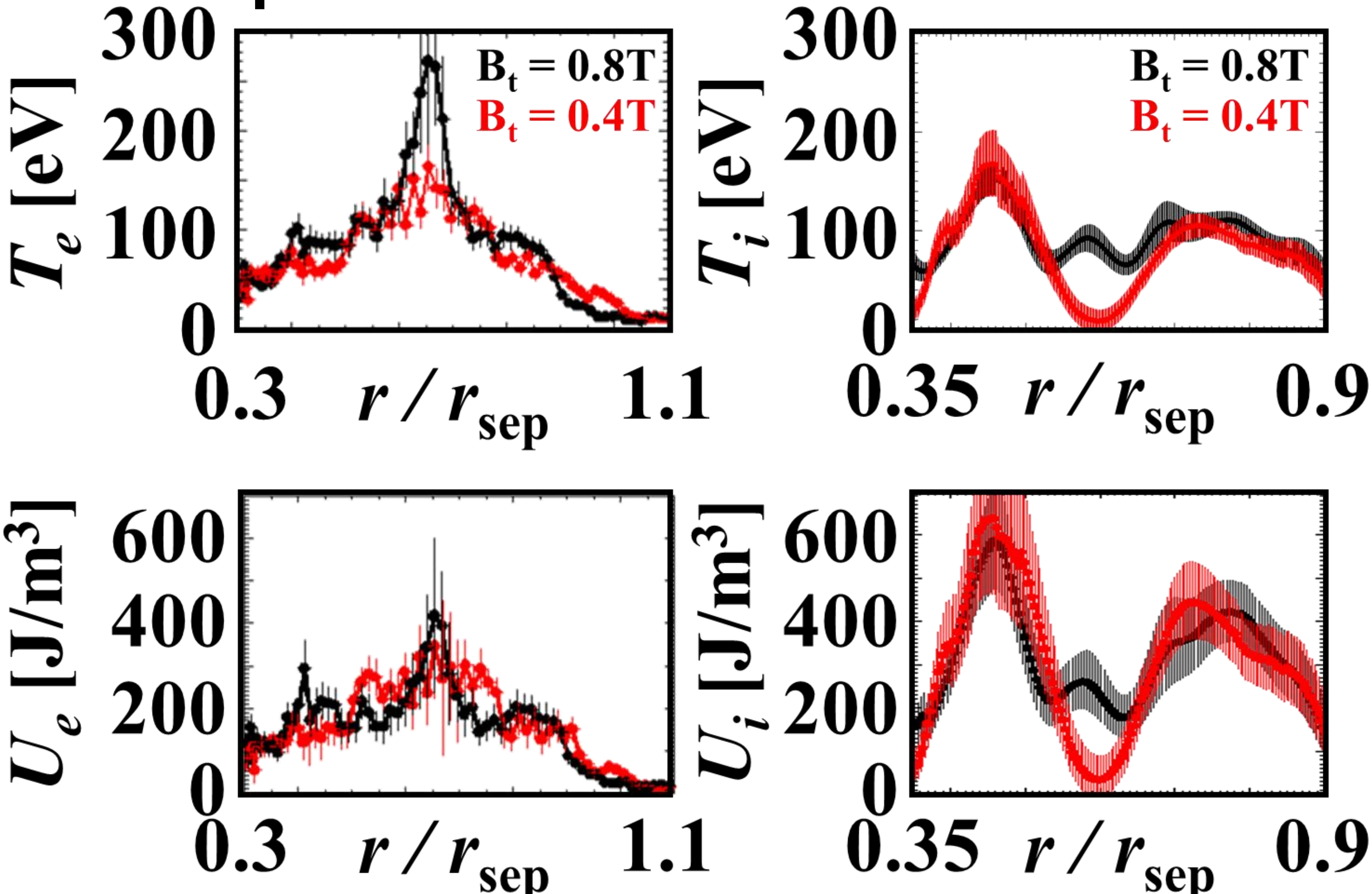
Time evolution of T_i and T_e profile

With the delay of comparable time scale of τ^E_{ei}, collisional coupling between electrons and ions to equilibrate both temperature was observed.



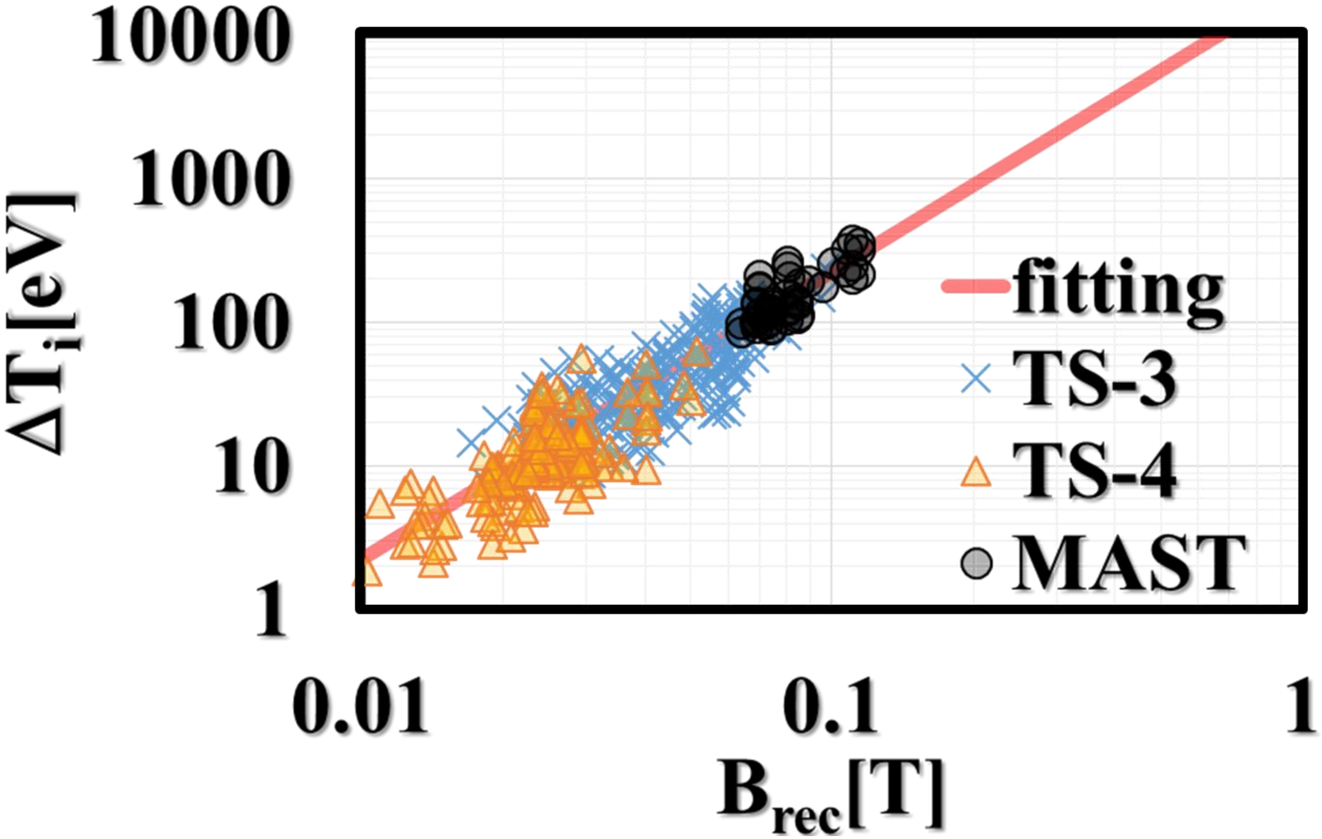
Toroidal field B_t mostly contributes T_e profile around X point and does not for downstream

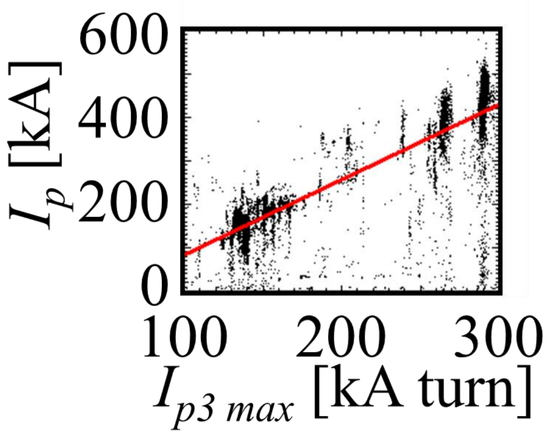
With higher guide field, perpendicular heat conduction is strongly inhibited with the weight of $1/B_t^2$ and forms more steep electron distribution.

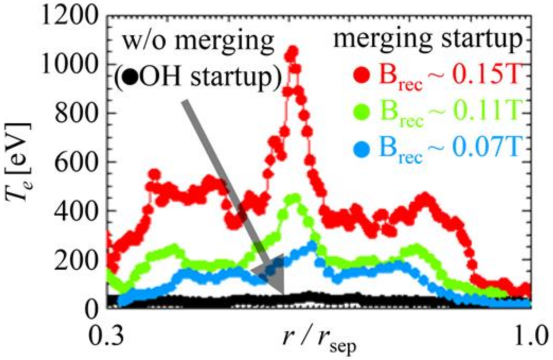


Achieved ion heating scales $B_{rec}^2 \propto I_{p3}^2$

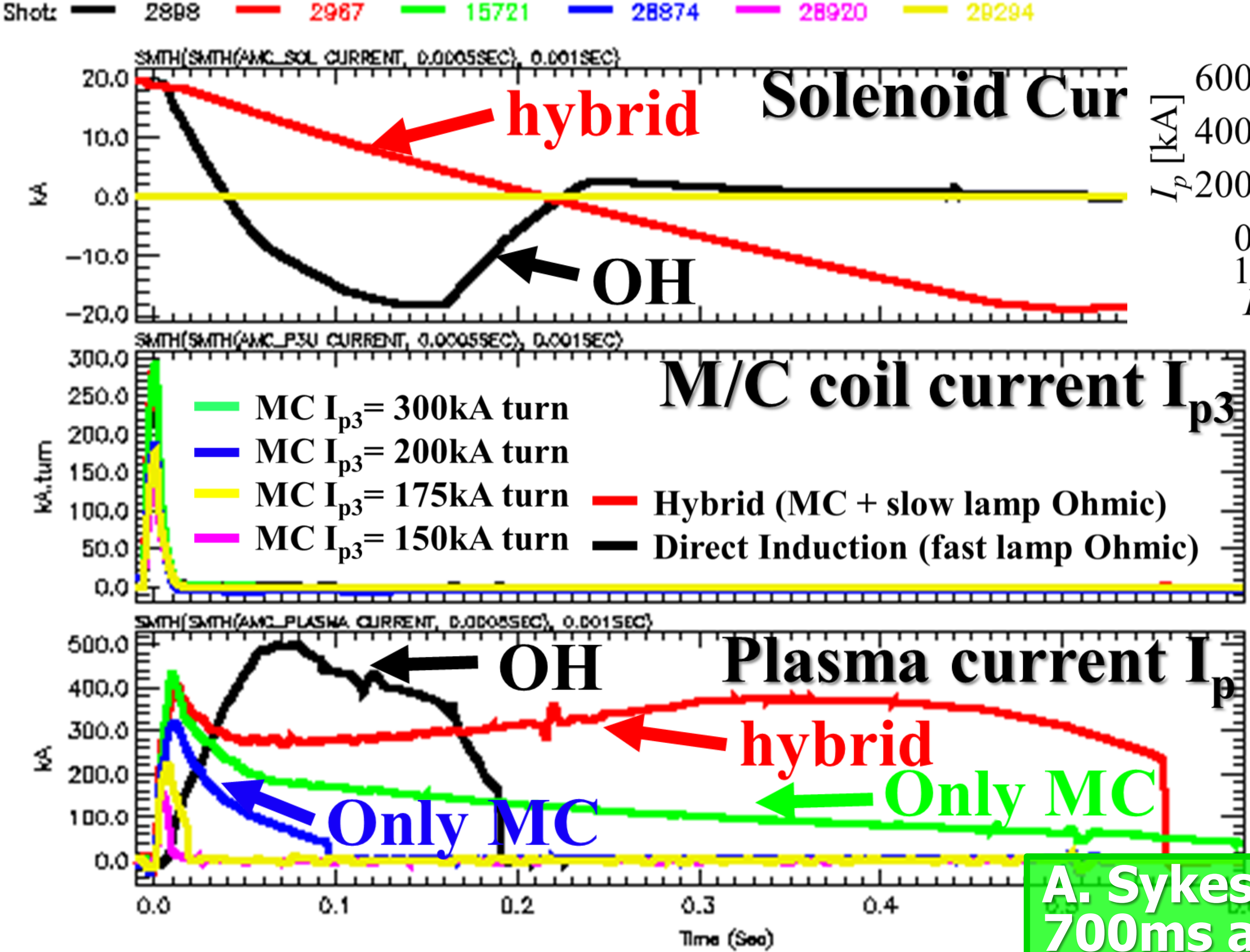
Achieved startup parameter mostly depends on reconnecting field B_{rec} which is controlled by startup PF coil current I_{p3}.

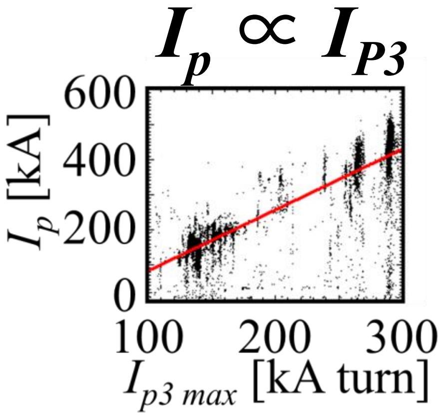






Application of reconnection startup for CS-less operation: Merging startup saves significant amount of solenoid flux.





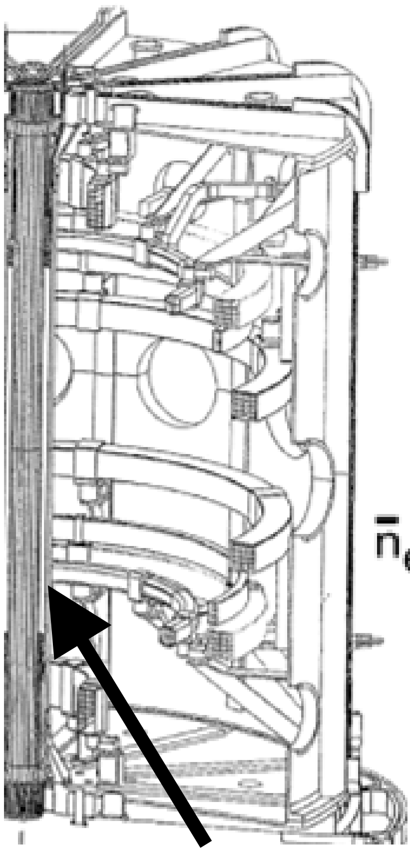
Achieved T_e:
- T_e > 400eV
- T_e ~ 60eV
- T_e < 10eV (no signal)

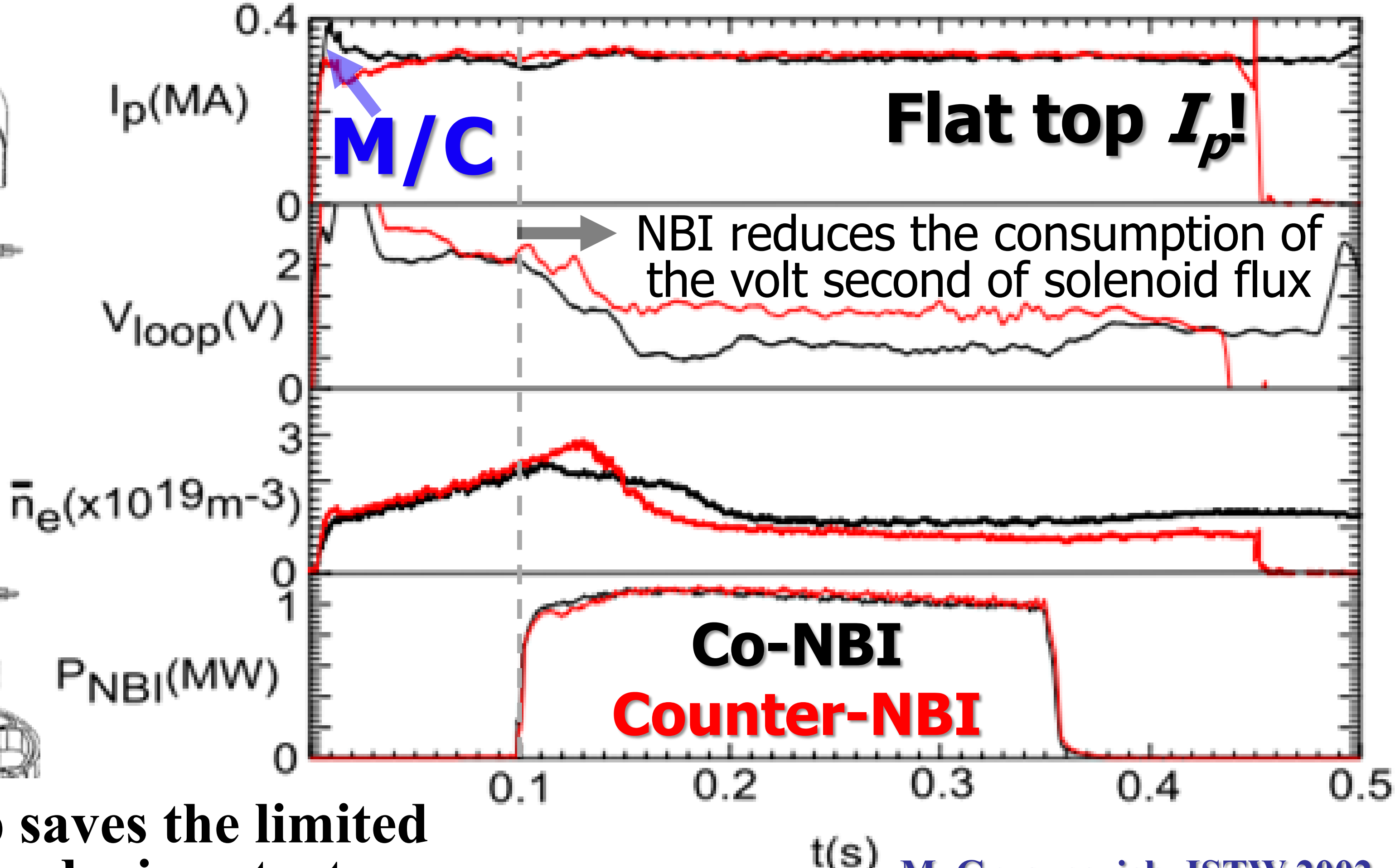
High T_e pulses tends to last much longer.
(threshold by radiation barrier?)

A. Sykes record: 700ms achieved without solenoid!

Scenario development for steady ST scenario

If the desired plasma current is same as the startup value, *rapid I_p startup* and *steady operation* is also possible!





M/C startup saves the limited solenoid flux during startup

M. Gryaznevich, ISTW 2002

Summary

M9 experiment of *Reconnection Studies* has successfully finished and revealed:

1: Highly localized electron heating at the X point
2: Downstream bulk ion heating by outflow damping
3: Both profile relaxation → triple peak distribution
4: B_t contributes localized electron heating at the X point but does not for bulk ion heating downstream
5: Achieved bulk ion heating $\propto B_{rec}^2 \sim B_p^2$

Those results will be submitted as follows:

to be published at the end of next week (PRL)

1: *Electron and ion heating characteristics during magnetic reconnection in MAST.*
2: More detailed reports (POP or PPCF?)
3: Scenario development for spherical tokamak

Future Works and related presentations

- **Physics issues**: What happens at the X point?

  > Fast electron scenario?

  → UTST (M. Inomoto (Oral / Friday) and K. Yamasaki (poster / today))

  > Plasmoid?

  → UTST (M. Inomoto (Oral / Friday) and K. Yamasaki (poster / today))
  → TS-3: effect of inflow drive? (Y. Ono (extended / oral))

  > Heat transport?

  → Transport analysis with ASTRA code has been started by M. Gryaznevich.

- **Engineering issues**:

  > Scenario development by external PF coils

  → UTST (M. Inomoto (Oral / Friday) and K. Yamasaki (poster / today))
  (Similar scenario (DNM) might be also tried in MAST-U using internal PF (M. Gryaznevich))

  > Further upgrade scenario **New fund: 1MGBP!**

  → TS-U project by Y. Ono (extended oral / today)
  → ST40 project by M. Gryaznevich (oral / yesterday)