Physics and Application of Plasmoid Reconnection

Joint Research among Laboratory, Observation and Numerical Simulation

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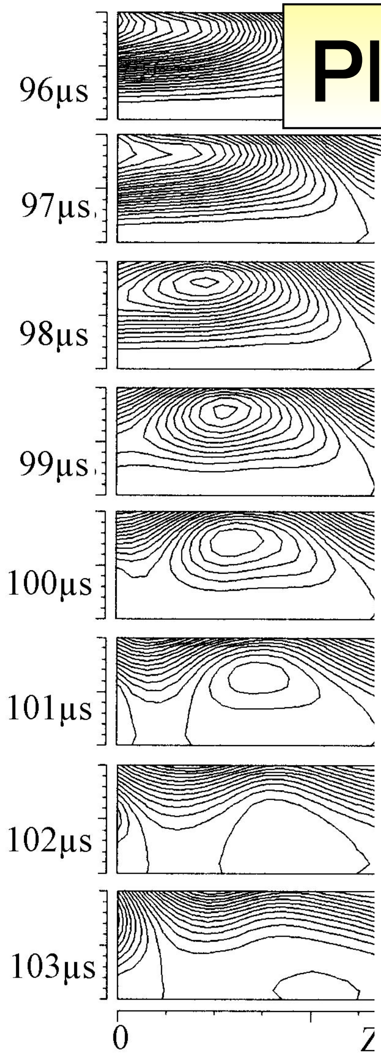


Plasmoids affects rec. and is affected by rec.

Rapid progress in plasmoid researches in solar, magnetosphere and laboratory experiments.

1. Plasmoids are produced by reconnection, especially by,
   Internal factors--- Size of current sheet L_{SP}/ρ_i
   Lindquest number S（Daughton 2011)
   External factors------ Externally-driven plasma inflow
   ➡ A New Idea of Plasmoid Divertor
2. The formed plasmoids affect reconnection as a feedback.
   The plasmoids (ejection) increase the reconnection speed triggers reconnection and promote particle acceleration.

Contents

- Impulse reconnection by plasmoid ejection

1) Low (External) inflow → Quasi-Steady Reconnection

Inflow flux ~ Outflow flux

↑

External flux injection

2) High inflow → Impulsive Rec. with Plasmoid Ejection

Inflow flux > Outflow flux

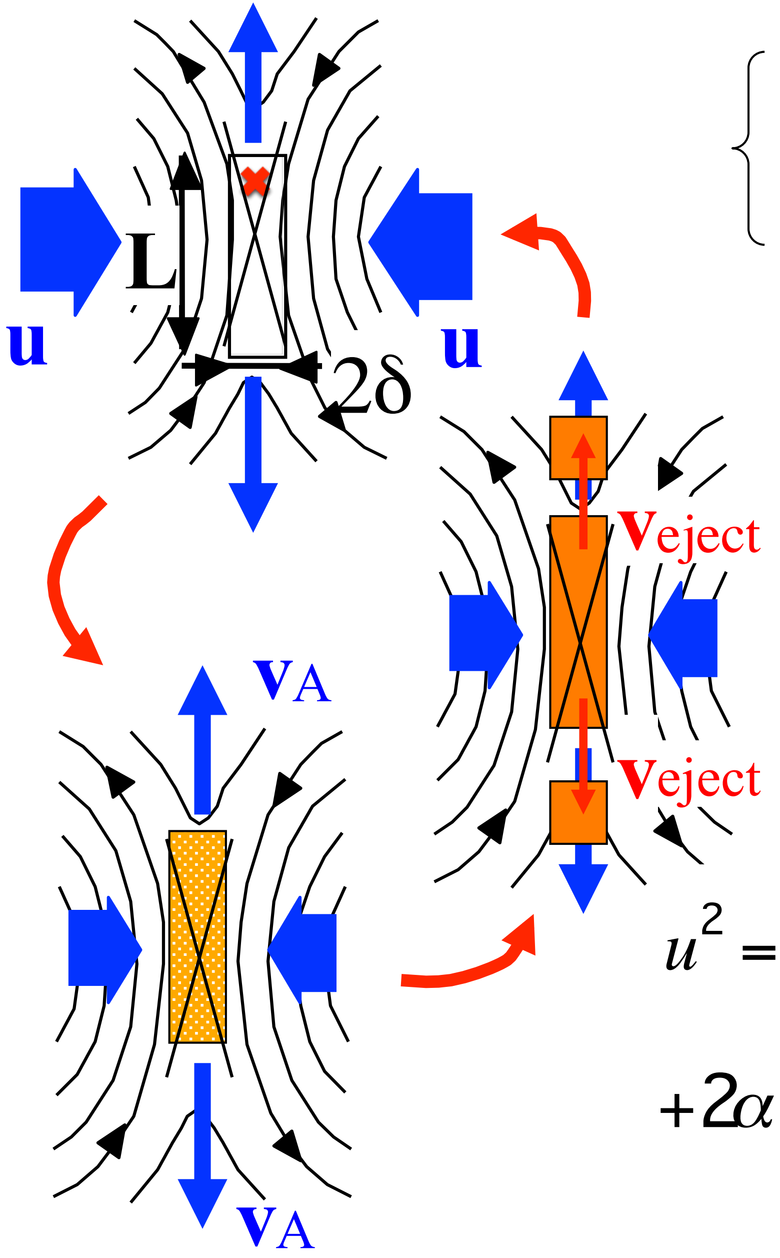
↑

External flux injection

High Inflow, low η → Plasma Pileup → Sheet Ejection

A cycle of pileup and ejection increase the averaged rec. speed.

The combination of mass pileup and ejection increases effective mass ejection and rec. speed.



$$\begin{cases} uL = 2\delta V_A + \underset{\text{Pile-up}}{\underline{L\delta(d\alpha/dt)}} + \underset{\text{Ejection}}{\underline{\underline{2\delta\alpha V_{eject}}}} \\ u = \dfrac{\eta}{\mu_0\delta'} \end{cases}$$

where pileup factor $\alpha = \dfrac{n_{sheet}}{n_0}$

$$u = \sqrt{\frac{\eta}{\mu_0}\left(\frac{2V_A}{L} + \underset{\text{Pile-up}}{\underline{\underline{d\alpha/dt}}} + \underset{\text{Ejection}}{\underline{\underline{\frac{2\alpha V_{eject}}{L}}}}\right)}$$

For simplicity,

$$\alpha = n/n_0 = n_1(1 + sin\omega t)$$

$$v_{eject} = v_1\{1 + sin(\omega t + \theta)\}$$

$$u^2 = \frac{\eta}{\mu_0 L}[2V_A + \underline{2\alpha_1 V_1} + 2L\alpha_1\omega\cos\omega t + 2V_1 sin\omega t$$

$$+2\alpha_1 sin(\omega t + \theta) + \underset{\text{Ejection}}{\underline{\underline{2\alpha_1 V_1 sin\omega t \cdot sin(\omega t + \theta)}}}$$

Contents

- Impulse reconnection by plasmoid ejection

External flux injection

Low inflow → Quasi-Steady Reconnection

High inflow → Impulsive Rec. with Plasmoid(Sheet) Ejection

High Inflow, low η → Plasma Pileup → Sheet Ejection

- Application of plasmoid – Dynamic divertor by plasmoid ejection

Divertor configuration not by divertor plate but by plasmoid

→ Ar gass-puff to the ejecting plasmoid

→ Hopefully reduction of heat flux to the divertor plate.

TS- 4 Plasma Merging Experiment 2000~

1)Reconnection Heating Experiment

2)Upscaled Exp.

R~0.5m of TS-3

3)Internal Coils

4)2D Measurement of B, T_i, (T_e, n_e)

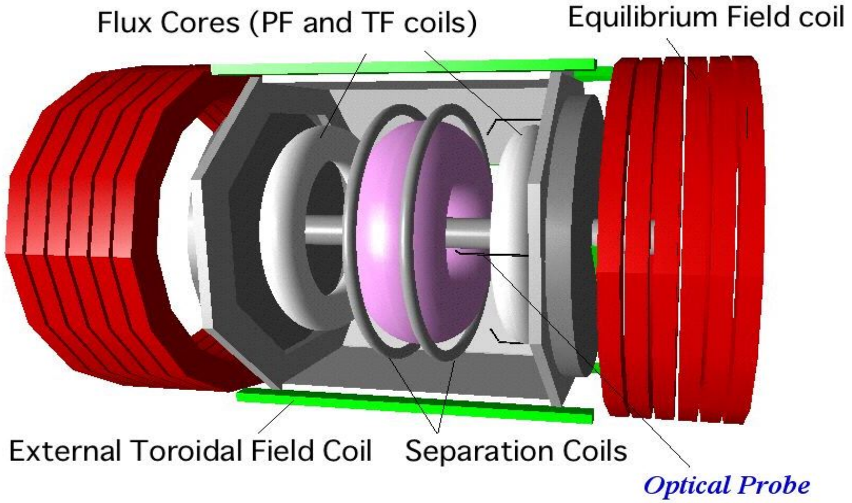
R=0.50-0.55m

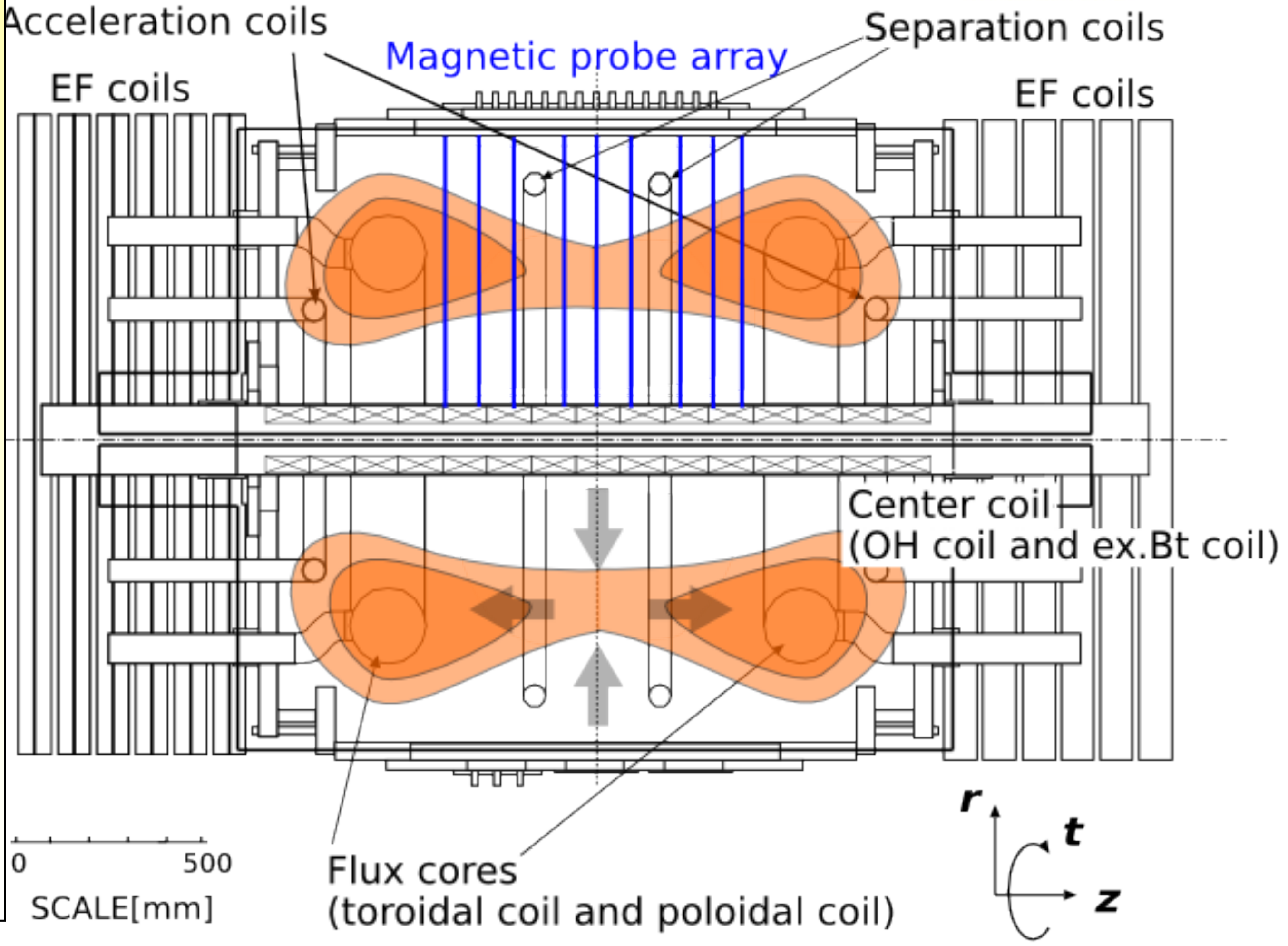
B_0=0.3-1kG

T_i=10-100eV

T_e=10-30eV

n_e=0.5-5×10^{19}m^{-3}

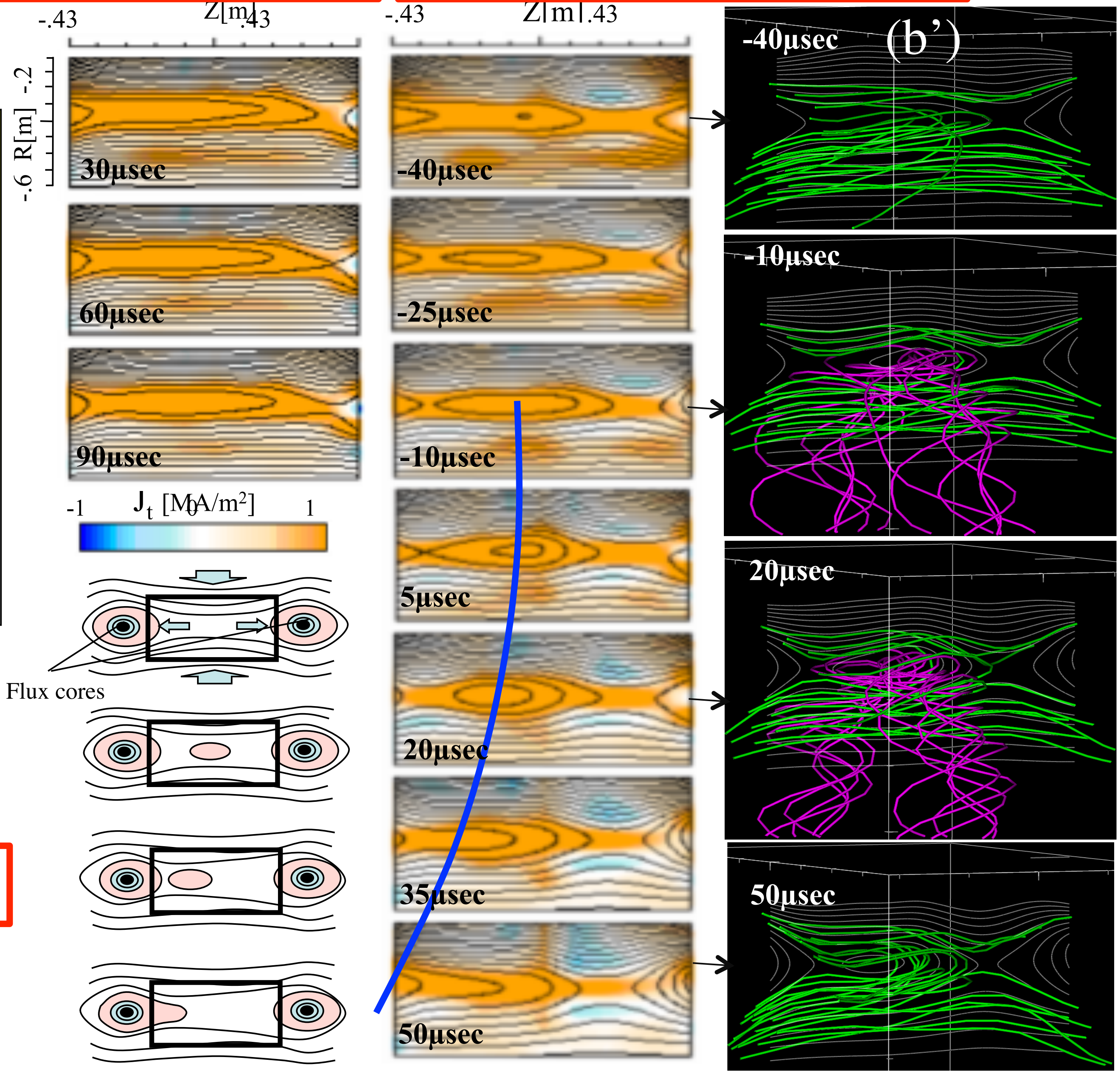




(a) Low Inflow Case

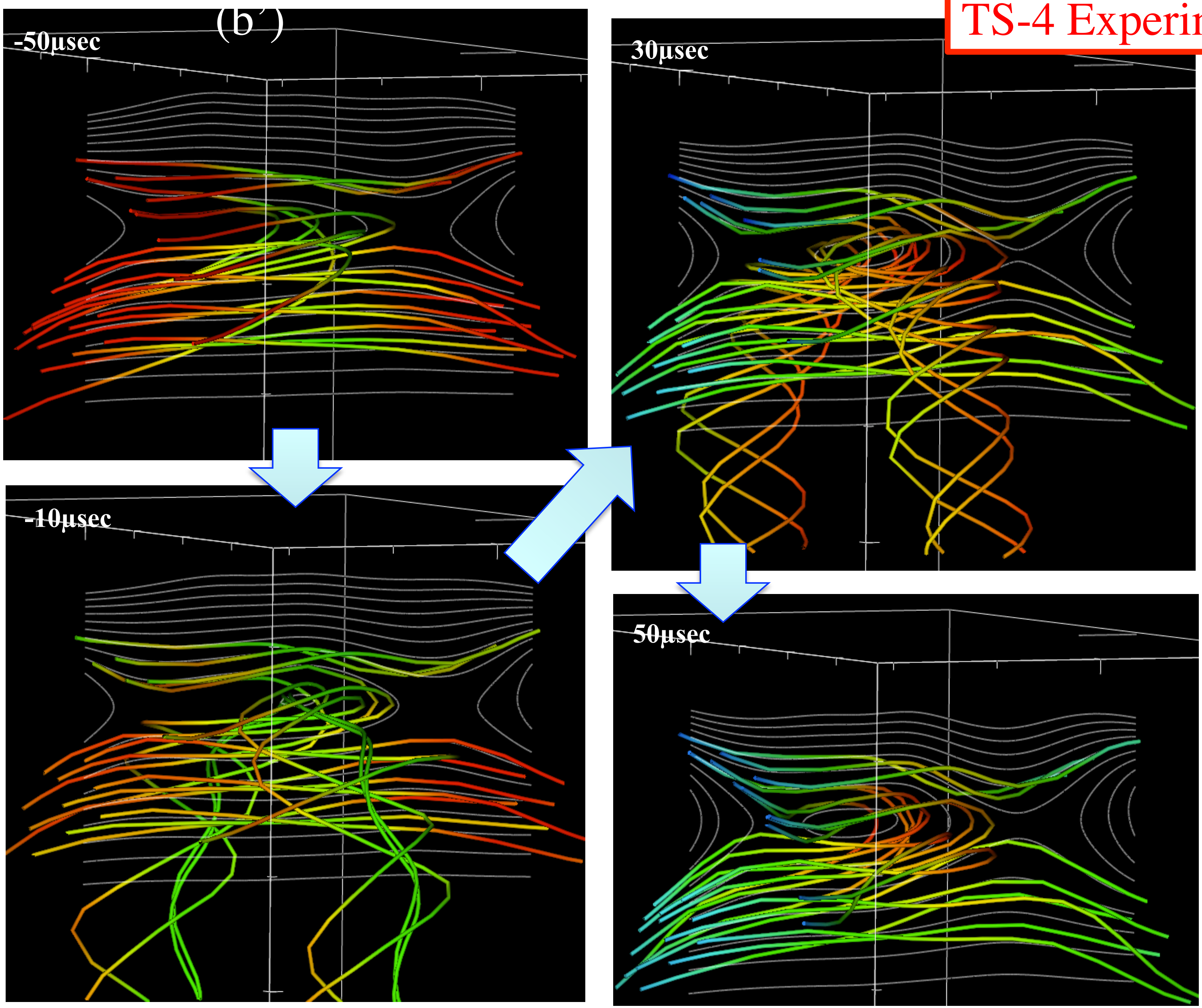
(b) High Inflow Case

High external inflow causes current sheet to eject a plasmoid, increasing reconnection speed impulsively.

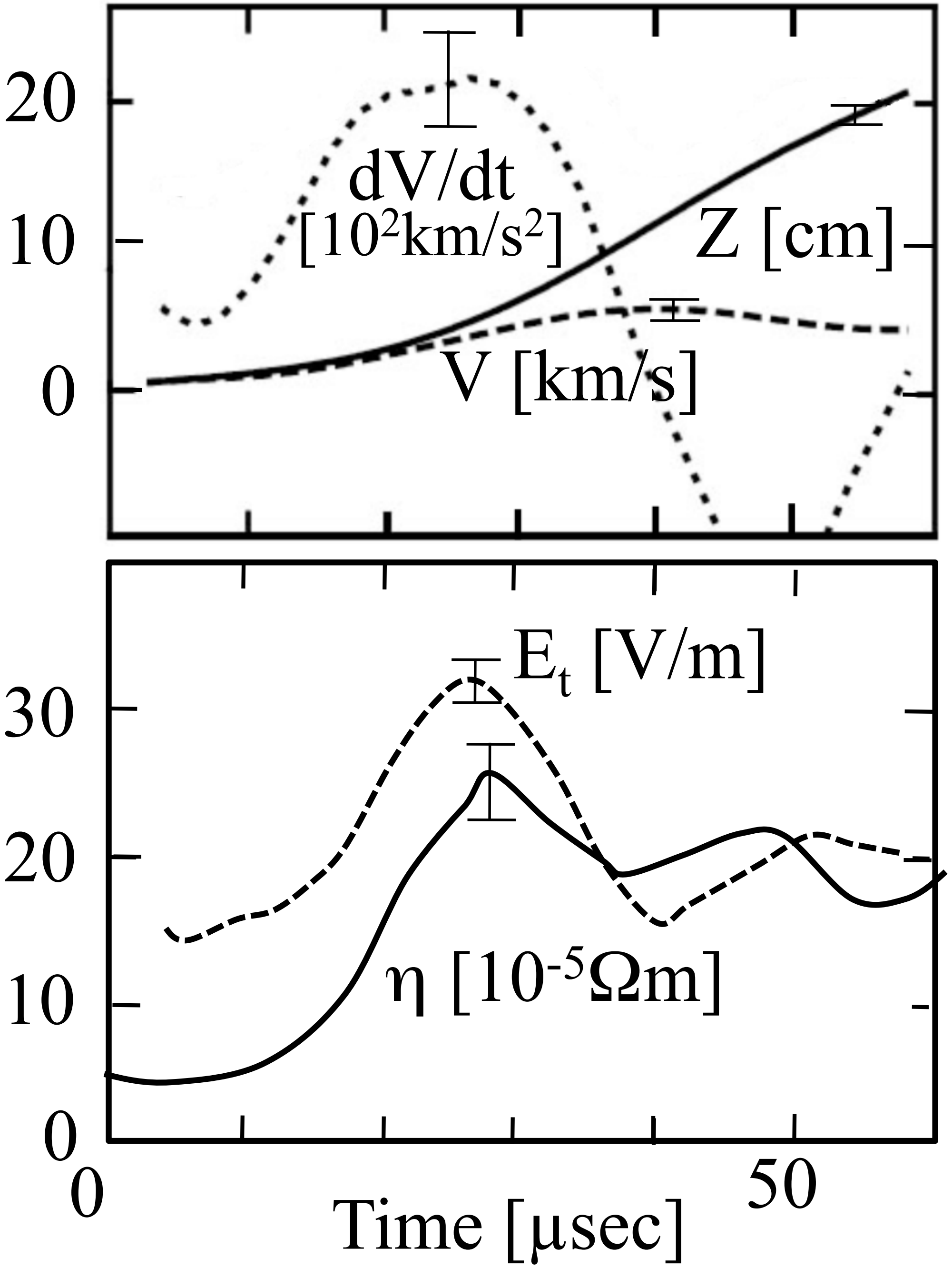


TS-4 Experiment

TS-4 Experiment



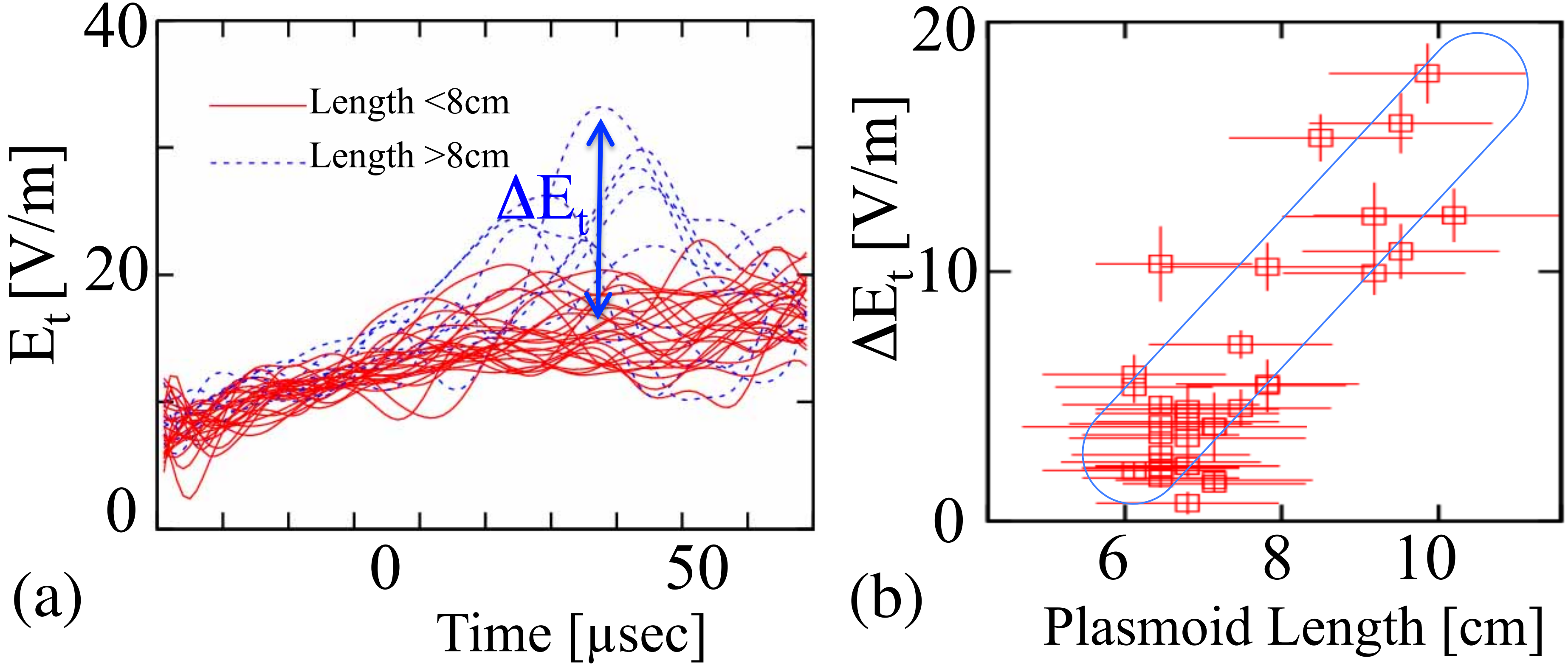
The rec. electric field becomes maximum, when the plasmoid acceleration is maximized.



Time evolutions of position Z, velocityV and acceleration dV/dt of plamoid, the reconnection electric field E_t and effective resistivity η at X-pont.

TS-4 Experiment

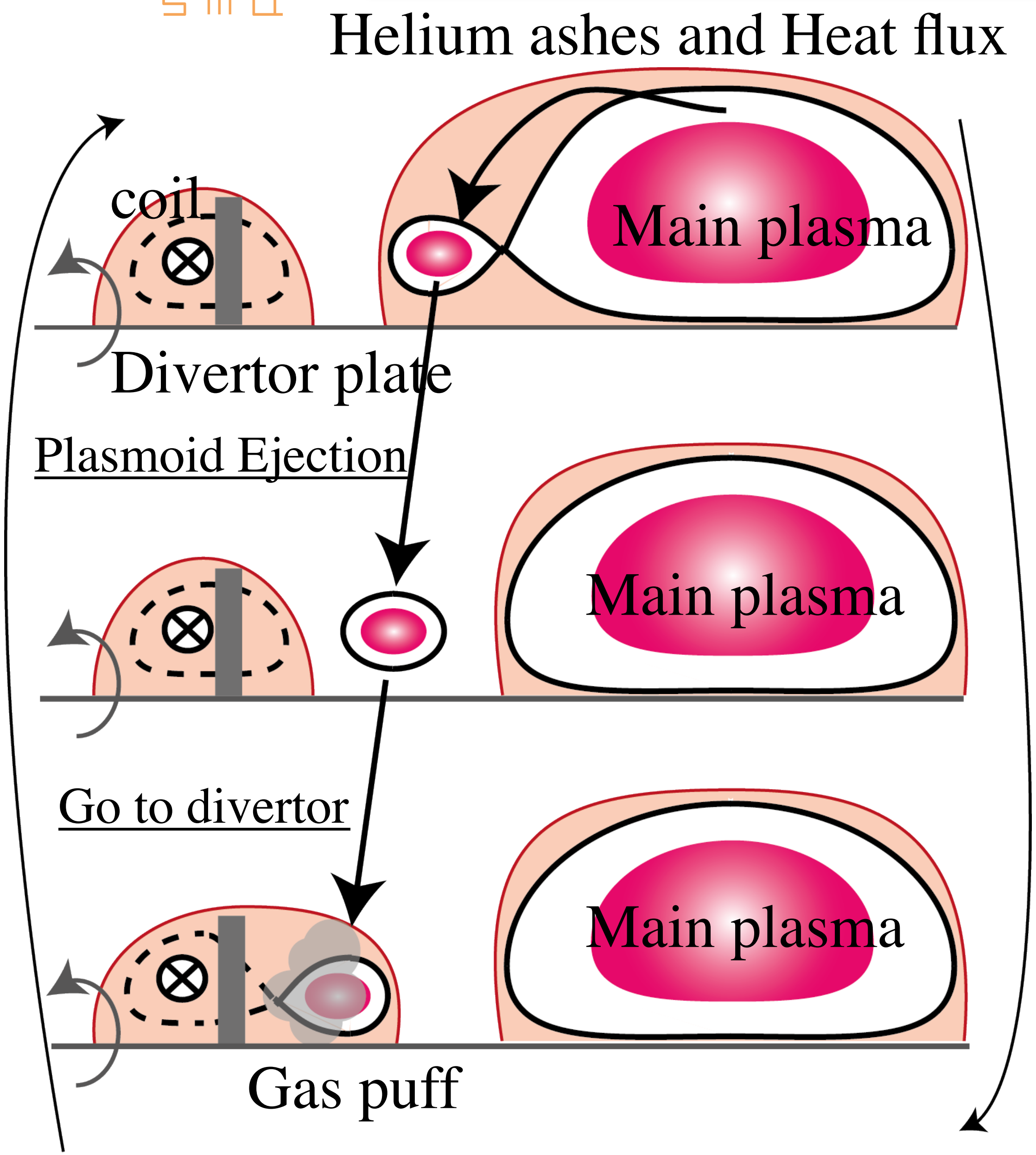
Impulsive increase in rec. electric field increases with the size of ejecting plasmoid.



Reconnection speed ⟺ Size of ejecting plasmoid

Dynamic divertor by plasmoid ejection

A plasmoid connects the main plasma indirectly and periodically with the divertor coil



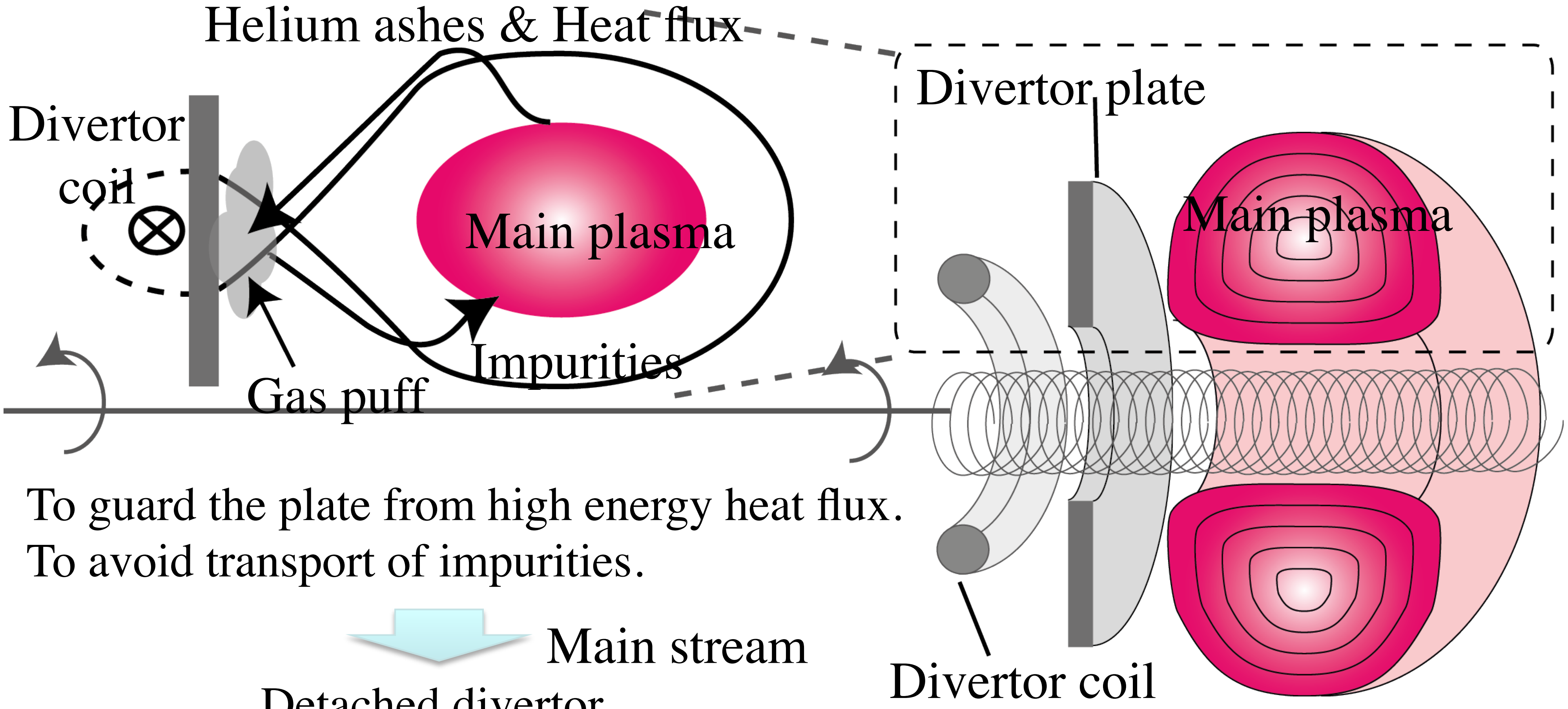
(1)Current drive and heating forms a plasmoid.

(2)Pinches off the plasmoid and cool down by argon gas puff.

(3)Plasmoid is connected with divertor plate.

A significant reduction of the heat load to divertor plate.
New type of divertor useful for heavy heat load (Type I ELM).

Classic divertor configuration whose critical issues are high energy heat flux and impurity transport.



To guard the plate from high energy heat flux.
To avoid transport of impurities.

Main stream
Detached divertor

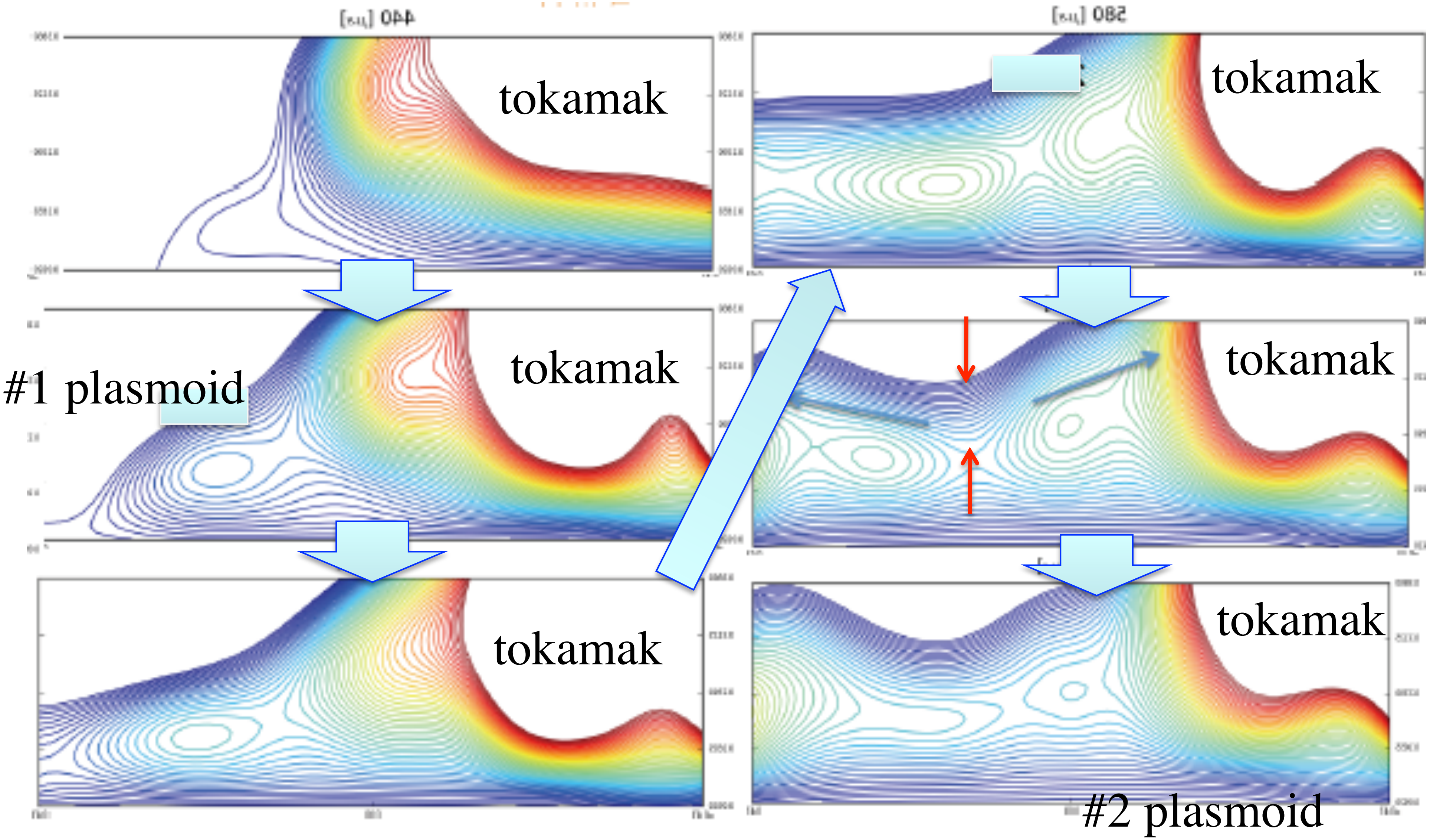
However・・

The X point connects the main plasma directly with the divertor coil.
It is difficult to achieve both aims.

TS-4 Experiment

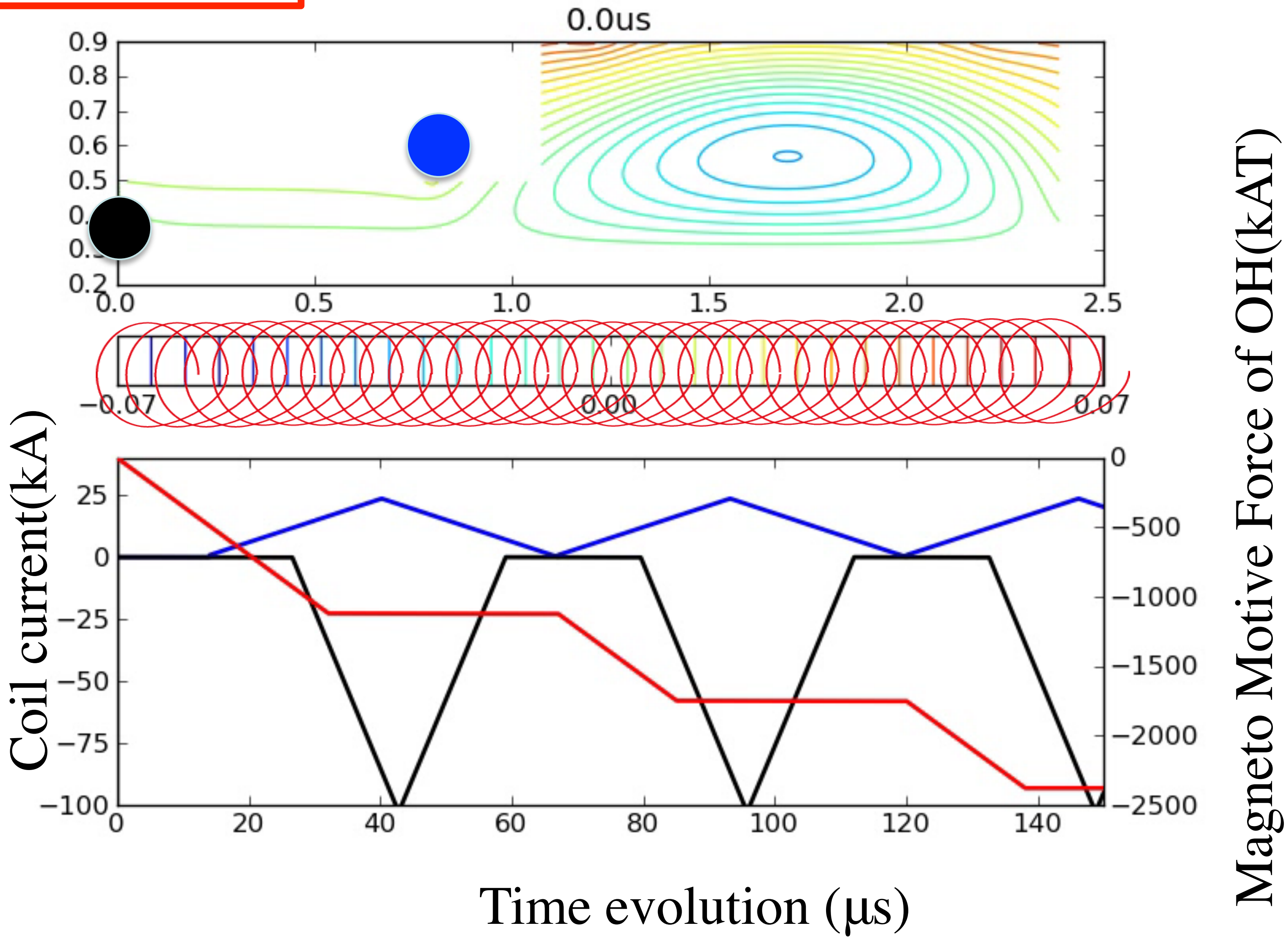
Dynamic divertor by plasmoid ejection

A plasmoid connects the main plasma indirectly and periodically with the divertor coil



Successful control of periodic plasmoid ejection by coil current control

2D MHD Simulation



Conclusions

- Impulse reconnection by plasmoid ejection

Low (External) inflow → Quasi-Steady Reconnection

High inflow → Impulsive Rec. with Plasmoid(Sheet) Ejection

High Inflow, low η → Plasma Pileup → Sheet Ejection

Mass ejection + thinning of sheet cause large increase in η and E_t

Formation of multiple island inside sheet → easy to trigger η_{anom}

A cycle of pileup and ejection increase the averaged rec. speed.

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