Investigation of electron energization mechanism during merging startups developed in UTST

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E-mail : yamasaki@ts.t.u-tokyo.ac.jp

K. Yamasaki, T. Ushiki, X. Guo, T. Sugawara, K. Matsuyama, N. Kawakami, A. Sato, Y. Fukai, H. Yamanaka, R. Tamura, S. Kamio[1], H. tanabe, T. Yamada[2], M. Inomoto, Y. Ono
the University of Tokyo, National Institute for Fusion Science[1], Kyusyu University[2]

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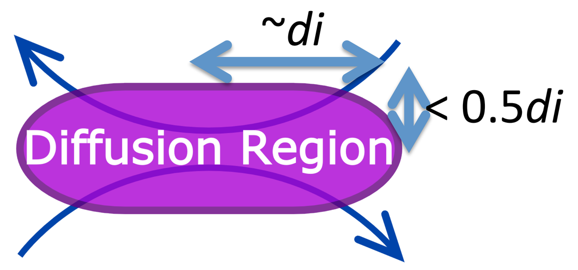
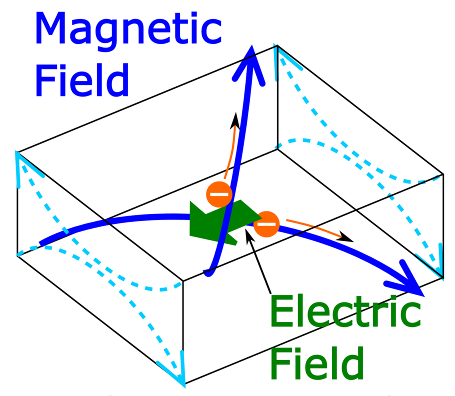
abstract

(i)Diffusion region



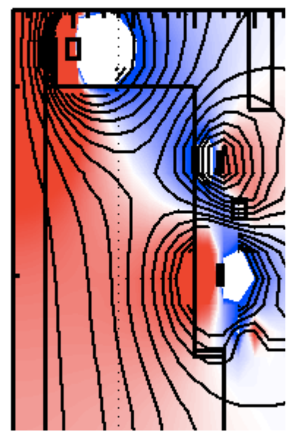
Field-aligned electric field become strong within half the ion skin depth from the X-point, i.e. **ideal MHD criterion breaks within this region**.

(ii)Electron Acceleration



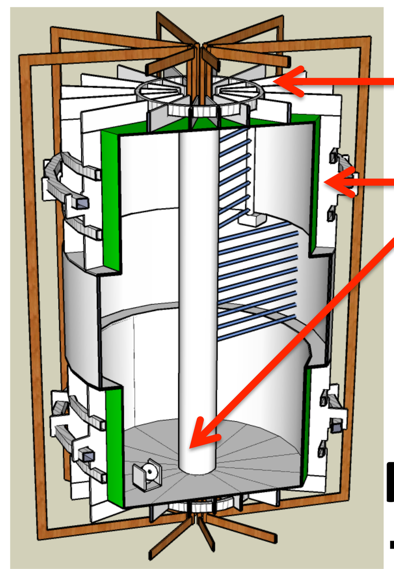
Energetic electrons are localized along the one pair of separatrices. **Electrons become more energetic with stronger guide field**.

(iii)Modify Double Null startup

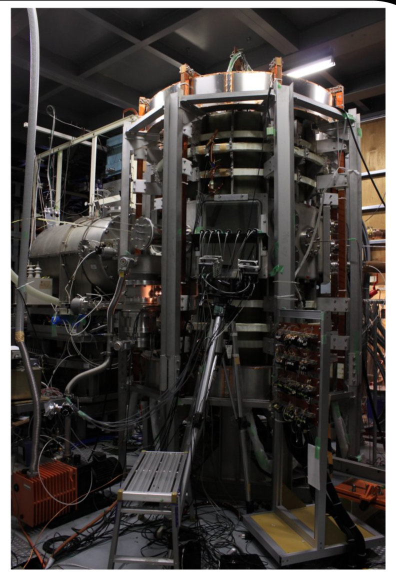


Double null startup method that does not largely depend on eddy current is performed. Though merging of two STs is not observed, **wide null region (|Bp|<5mT) is formed** during this startup method.

UTST



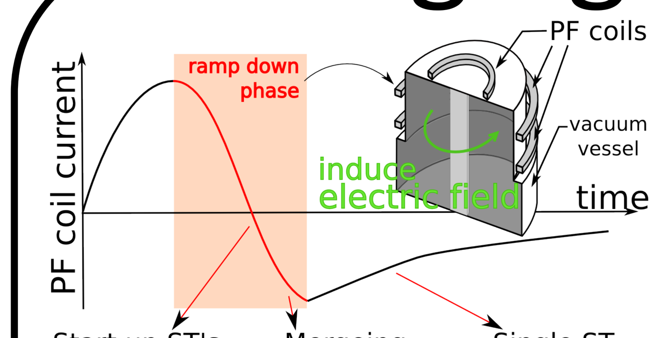
・All coils are placed outside the vacuum vessel.
・1.5mm thin wall.
・Washer gun is used for pre-ionization.

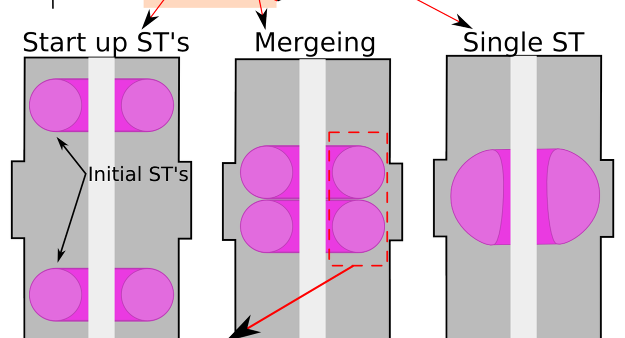


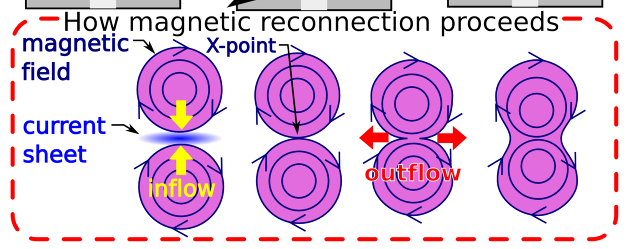
Purpose of the UTST

・Establish CS-less startup method w/o internal coil.
・High-β ST formation by magnetic reconnection.

Merging startup

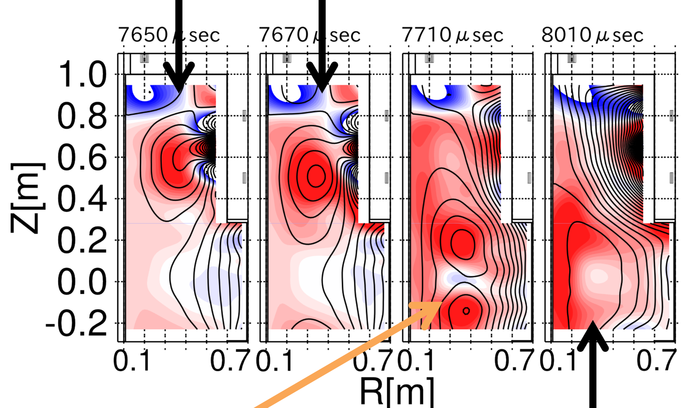






typical merging experiment

Initial STs formation



Merging phase (current sheet)

Single ST

Basic Concept

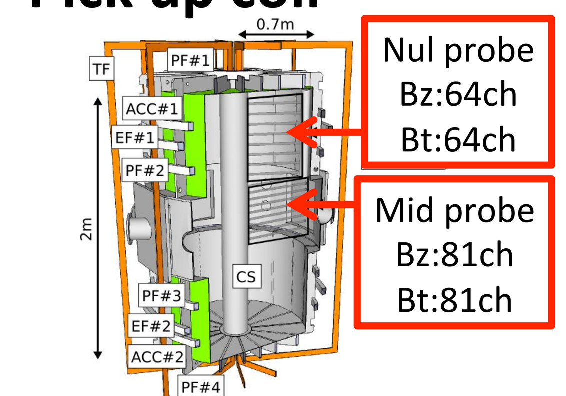
・When the PF coil current is ramped down, toroidal electric field is induced in the upper and lower region of vacuum vessel. This electric field drives the current of initial STs.
・Reversed coil current push the initial STs into midplain.
→ **Magnetic reconnection** occurs.
・Ion and electrons are heated/accelerated during magnetic reconnection, forming high-β ST.

Physical parameters

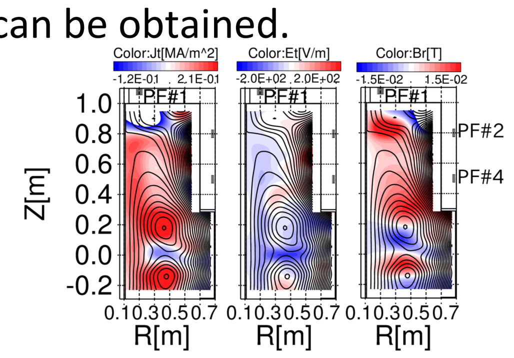
Guide field	0.1~0.3T	Ion gyro radius	0.3~0.5cm
Reconnecting magnetic field	0.01~0.02T	Electron gyro radius	0.01cm
Density	0.5~3.0x10^{19}m^{-3}	Ion skin depth	10~15cm
Electron temperature	20~30eV	Electron skin depth	0.1~0.2cm
Ion temperature	~50eV	Electron mean free path	47cm
Poloidal Alfvén speed	69km/s	Ion cycrotron frequency	0.76MHz
Reconnection electric field	~100V/m	Electron cycrotron frequency	5.6GHz
Lundquist number	~10^7	Lower hybrid frequency	64MHz

Measurement

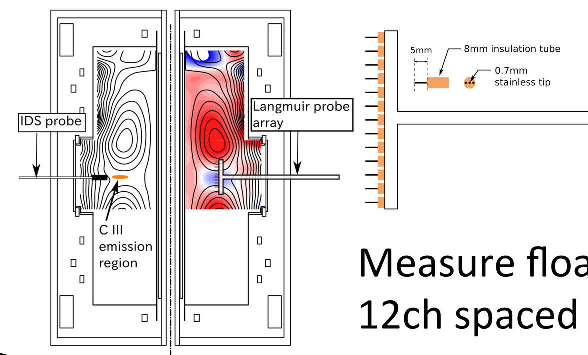
・Pick up coil

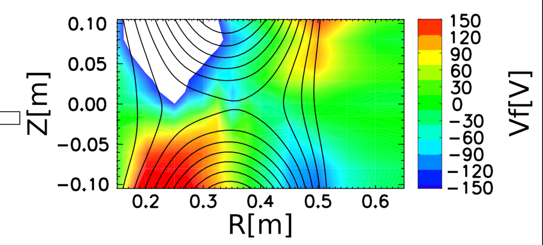


Toroidal current, electric field, poloidal magnetic field etc. can be obtained.



・Langmuir probe



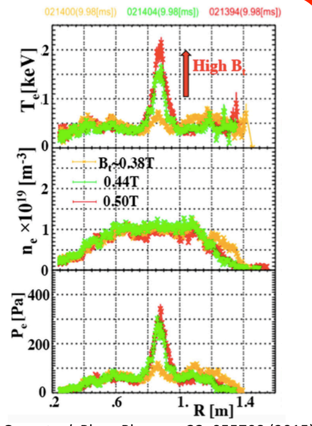


Measure floating potential φ_f at 12ch spaced in z-direction.

Purpose

Understanding energy conversion mechanism during merging startup is necessary to understand the feature of merging startup STs.

・Investigate the electron energization mechanism during merging startup.



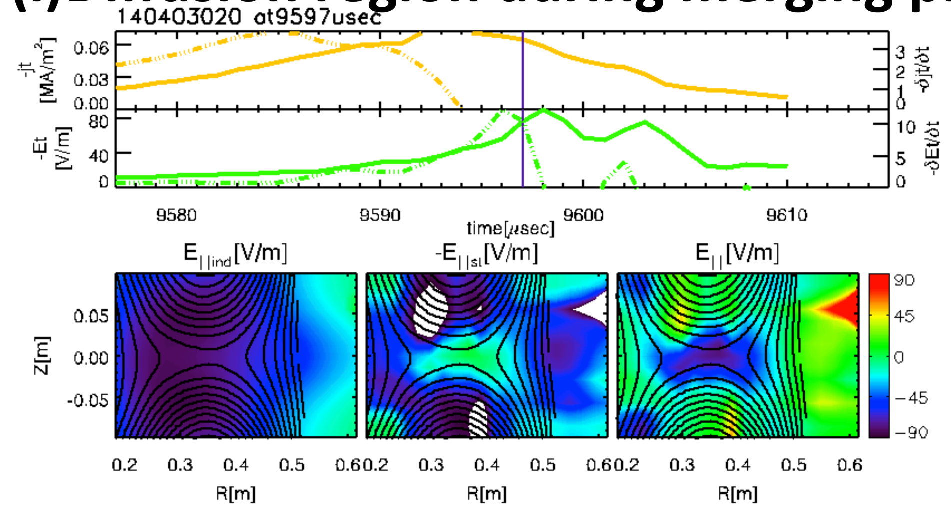
Y. Ono et al. Phys. Plasmas, 22, 055708 (2015)

・In order to improve the flux consumption efficiency and initial plasma temperature, startup of the initial plasmas must be as long as that performed in MAST.

・Improve the initial plasma formation efficiency and temperature by lengthening the startup duration.

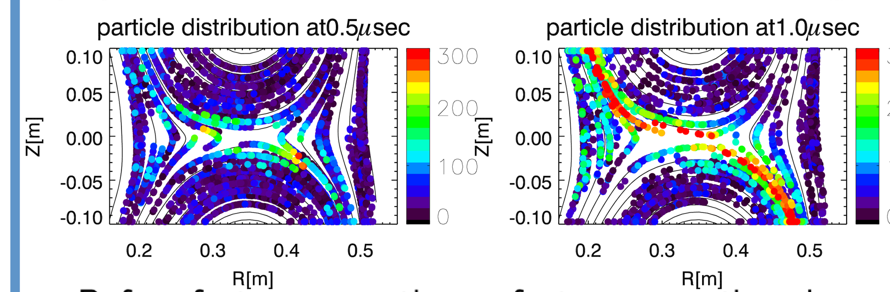
Results

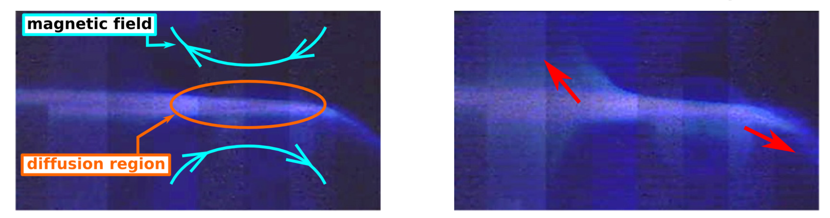
(i)Diffusion region during merging phase



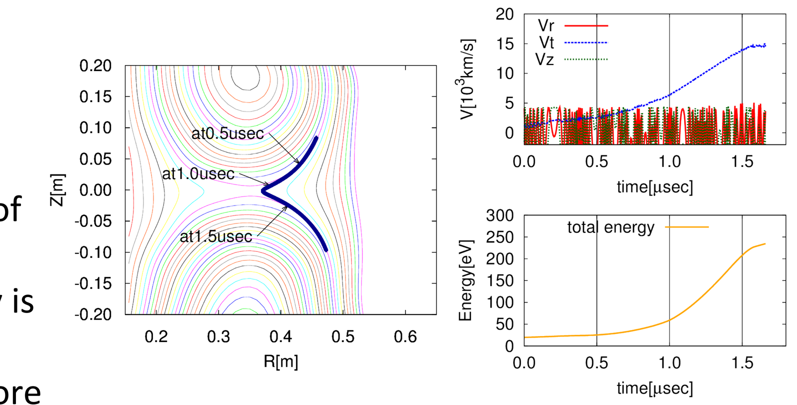
・Field-aligned component of electric field is calculated from experimentally obtained magnetic field and electric field.
・Away from the X-point, field-aligned component of inductive electric field ($E_{||ind}$) and electrostatic electric field ($E_{||es}$) cancel out as expected in the ideal MHD condition, while around the X-point, $E_{||ind}$ dominate $E_{||es}$. **The diffusion region width and length are 0.5*di* and *di*, respectively.**
・The diffusion region observed in UTST experiment is **symmetric about the neutral line**, while in VTF experiment(J. Egedal, et al., PRL, **90**, 3 (2003)) and numerical studies(C. Huang, *et al*, Phys. of Plasmas (2010)) indicate that the diffusion region is localized along a pair of separtrices.

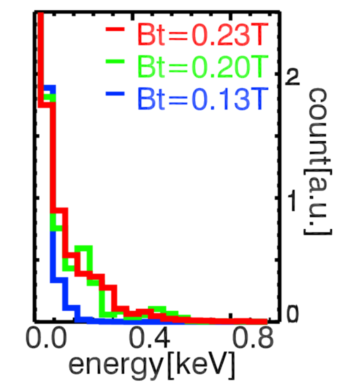
(ii)Electron acceleration during merging phase





・Using the measured magnetic field and electric field profile, trajectory of electrons around the X-point with different initial position and velocity is calculated.
・Some electrons are accelerated more than 300eV in less than 1μsec. **These electrons are localized along the upper left and lower right separatrices.**
・Bright CIII emission abruptly observed on the same separatrix.

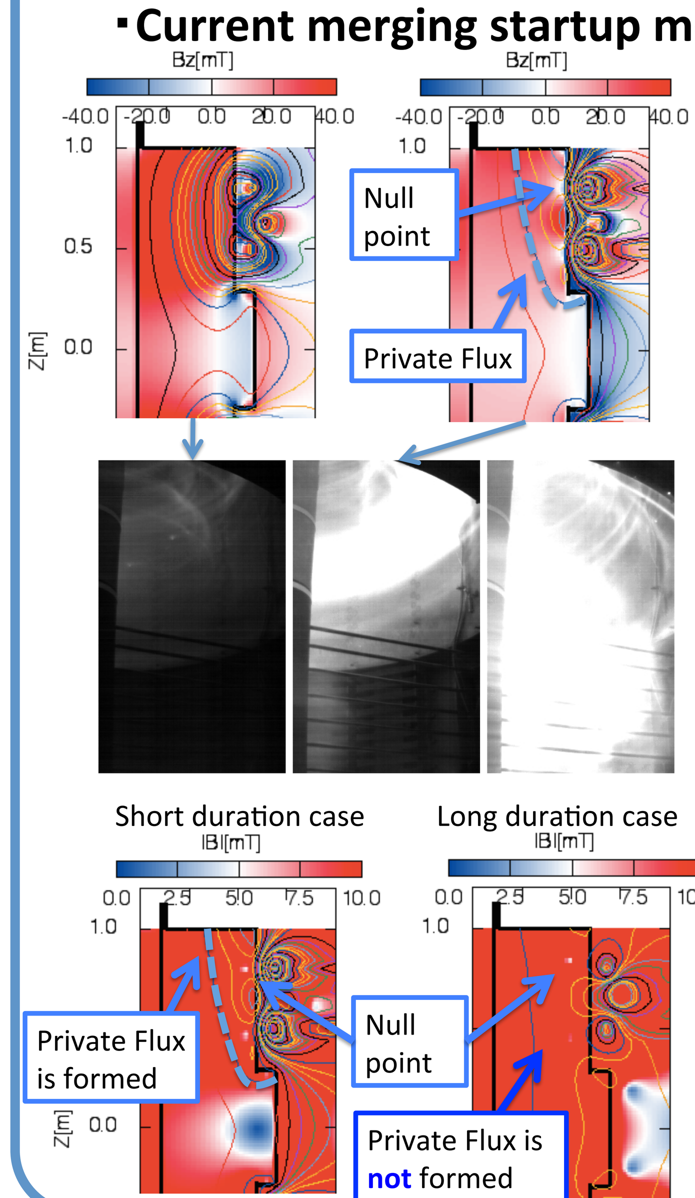




・Electrons are most efficiently accelerated when they come close to the X-point, similar to PIC simulation with B_g/B_{rec}~0.5 case (C. Huang, *et al*, Phys. of Plasmas (2010)).
・**Electrons' energy become more energetic with stronger guide field in Bg/Brec > 10 case.** Similar trend is documented by Thomson scattering measurement during merging startup in MAST.(Y. Ono, et. al., Phys. Plasmas, **22**, 055708 (2015))

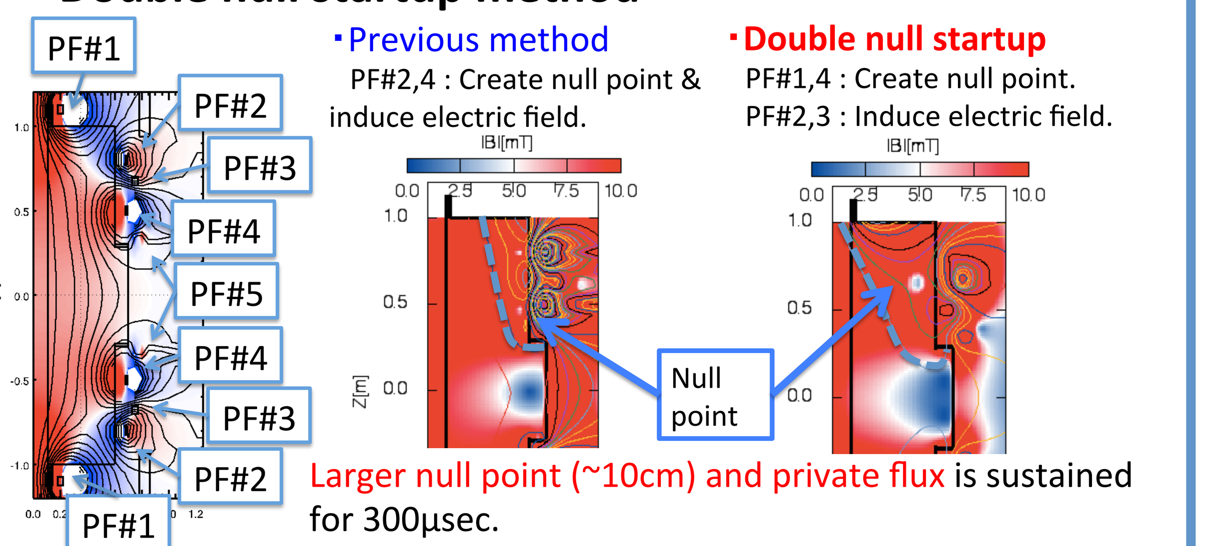
(iii)Modification of Double Null startup method

・Current merging startup method



・Eddy current analysis indicates that null points (|Bp|<5mT) are formed when the initial plasma is formed (M. Inomoto, et. al., Nuclear fusion, **55** (2015)). Also, private flux is created around these null points.
・Typically, the diameter of **the null point is 3cm, which is quite small** compared to hexapole null performed in NSTX (J. Kim, et. al., PPCF, **46** (2004)) and solenoid-free startup in DIII-D (J. A. Leuer, et. al., Nuclear Fuion, **51**, 063038 (2011))
・Current startup method deeply relies on the eddy current on vacuum vessel. Therefore, **the null points disappear in 40~50μsec**.
・Current PF swing startup is performed with long swing duration (2.3ms, typical swing duration is 0.4ms), but plasma was not initiated due to the lack of private flux around the null points.
→PF#2,4 swing method, currently performed merging method in UTST, is not suitable for long duration startup.

・Double null startup method

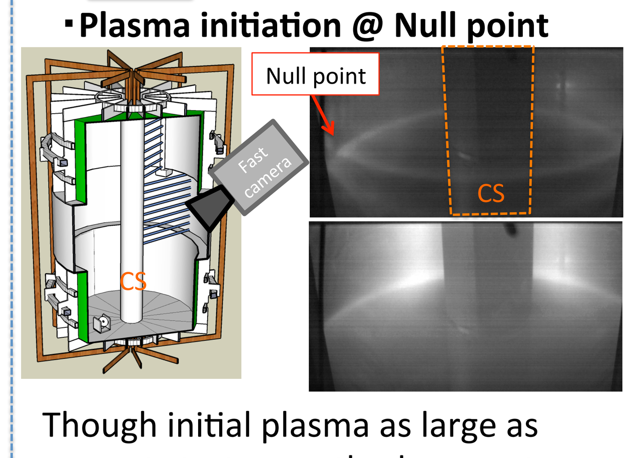


・Previous method
PF#2,4 : Create null point & induce electric field.

・Double null startup
PF#1,4 : Create null point.
PF#2,3 : Induce electric field.

Larger null point (~10cm) and private flux is sustained for 300μsec.

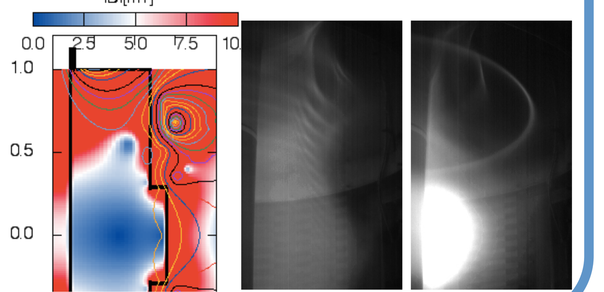
・Plasma initiation @ Null point



Though initial plasma as large as current startup method was not produced, bright ring at null points are observed.

・Wide null point in Mid region

Wide null point (width:40cm, height:60cm) is formed when the double null points come into mid region. ST with 6kA is formed for 0.3msec.



Summary

•**$E_{||}$ become strong within half the ion skin depth** from the X-point during fast reconnection phase. This indicate that the ideal MHD criterion breaks within this region. **The size of diffusion region is not affected by the guide field strength.**
•With stronger guide field, **more energetic electrons are expected** to be produced.
•Double Null startup method is modified to improve the null point size and its duration.
•Though initial STs were not observed, eddy current analysis indicates that **wide null region is formed during this Double null startup method** and the bright emission with similar shape is observed.