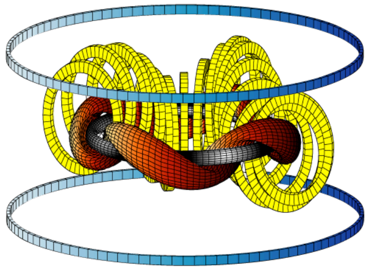


Recent Experimental Results in Tohoku University Heliac (TU-Heliac)

S. Kitajima, H. Utoh, H. Umetsu, J. Sato, K. Ishii, A. Okamoto, T. Kobuchi, M. Sasao,
Y. Tanaka[a], S. Inagaki[b], M. Takayama[c], A. Komori[d], K. Nishimura[d], Y. Suzuki[d],
M. Yokoyama[d], H. Takahashi[d]

Department of Quantum Science and Energy Engineering, Tohoku University, Sendai
980-8579, Japan
[a] *Japan Atomic Energy Agency, Naka 311-0193, Japan*
[b] *Research Institute for Applied Mechanics Kyushu University*
6-1 Kasuga-kouen, Kasuga, Fukuoka 816-8580, Japan
[c] *Akita Prefectural University, Honjyo, Akita 015-0055, Japan*
[d] *National Institute for Fusion Science,322-6 Oroshi-cho, Toki 509-5292, Japan*

Recent Experimental Results in Tohoku University Heliac (TU-Heliac)

In Tohoku University Heliac (TU-Heliac), **the improved mode transition** has been studied by electrode biasing using a hot cathode made of LaB_6. The radial electric fields were actively controlled by changing the electrode current. The poloidal **viscosity** was successfully estimated from the ***J*** **×** ***B*** **external driving force** [1].

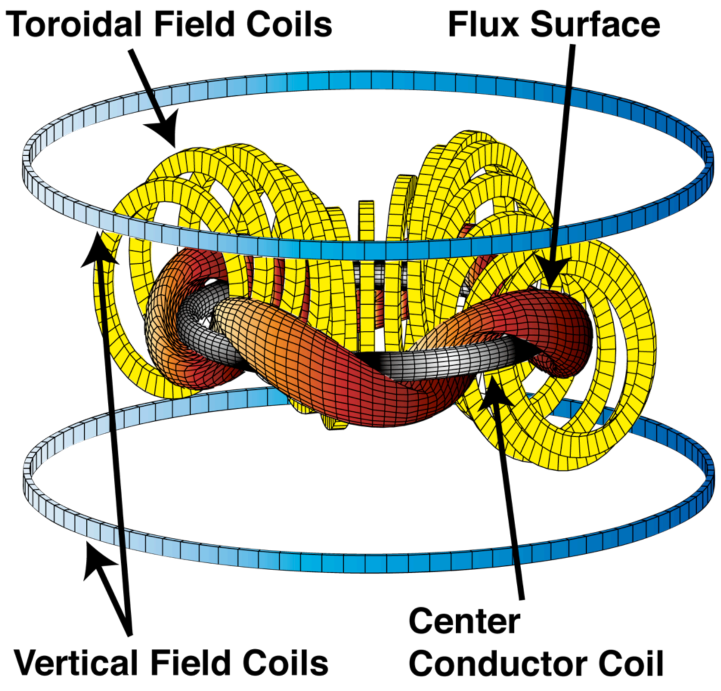
- The **density collapse** was observed in the improved confinement mode sustained by the hot cathode biasing [2].
- For the development of a new field in biasing experiments, we have fabricated the **new type electrode** made of hydrogen storage metal for the particle injection (electron, ion and neutral particle). The high-density plasma ($>10^{19} m^{-3}$) was produced and the beta value increased up to about 0.5 % using the new type electrode made of gold (Au)-coated palladium (Pd) [3].
- **New method for the rotating magnetic islands** by the external perturbation fields was proposed in TU-Heliac. The perturbation fields were produced by 4 pairs of cusp field coil. The phase difference in the floating potential signals measured by the two Langmuir probes confirmed that the magnetic islands rotated in the ion diamagnetic direction. These experimental results suggest the ability of the producing plasma poloidal rotation driven by rotating islands [4].

[1] S. Kitajima *et al.*, Nucl. Fusion **46** (2006) 200.
[2] Y. Tanaka *et al.*, Plasma Fusion Res. **3** (2008) S1055.
[3] H. Utoh *et al.,* Fusion Sci. Tech. **50** (2006) 434.
[4] S. Kitajima *et al.*, Plasma Fusion Res. **3** (2008) S1027.

Tohoku University Heliac (TU-Heliac)

Device Parameter

Field period : 4
Major radius R_0 : 48 cm
Minor radius a : ~ 6 cm
Toroidal field B : 0.3 T
Plasma production : 18.7 kHz AC ohmic
35 kW

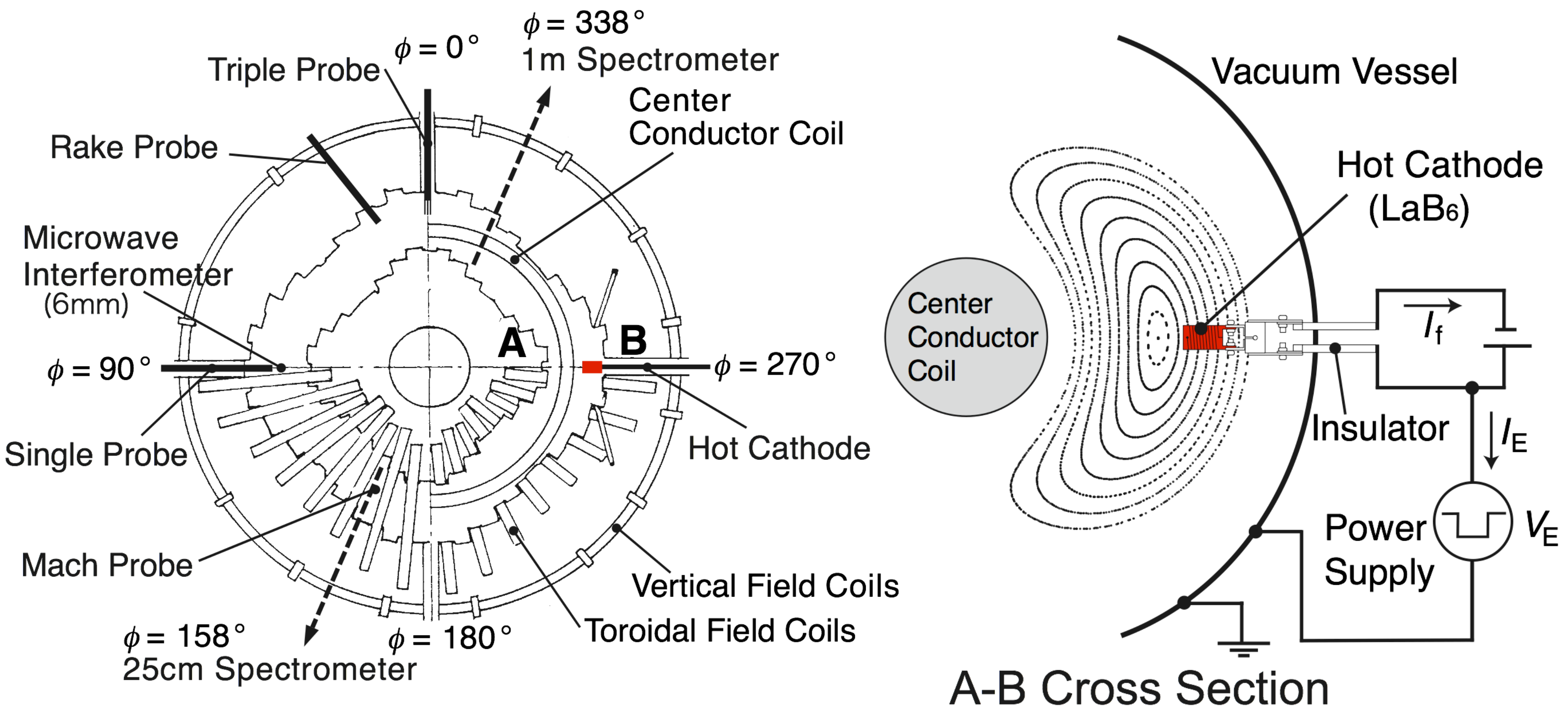


TU-Heliac

Biased plasma shows:

- formation of the radial electric field and $\boldsymbol{E} \times \boldsymbol{B}$ poloidal rotation;
- increase in the stored energy and energy confinement time;
- transition to the improved confinement mode.

The poloidal **viscosity** was successfully estimated from the $\boldsymbol{J} \times \boldsymbol{B}$ **external driving force**.

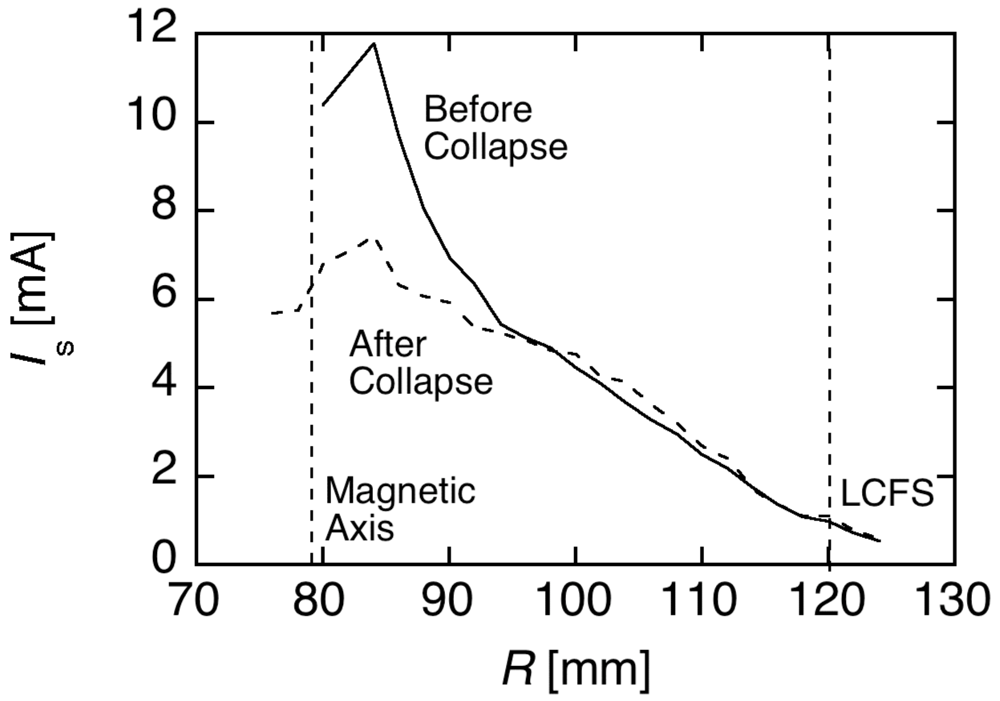


Density Collapse in Improved Confinement Mode Sustained by the Hot Cathode Biasing

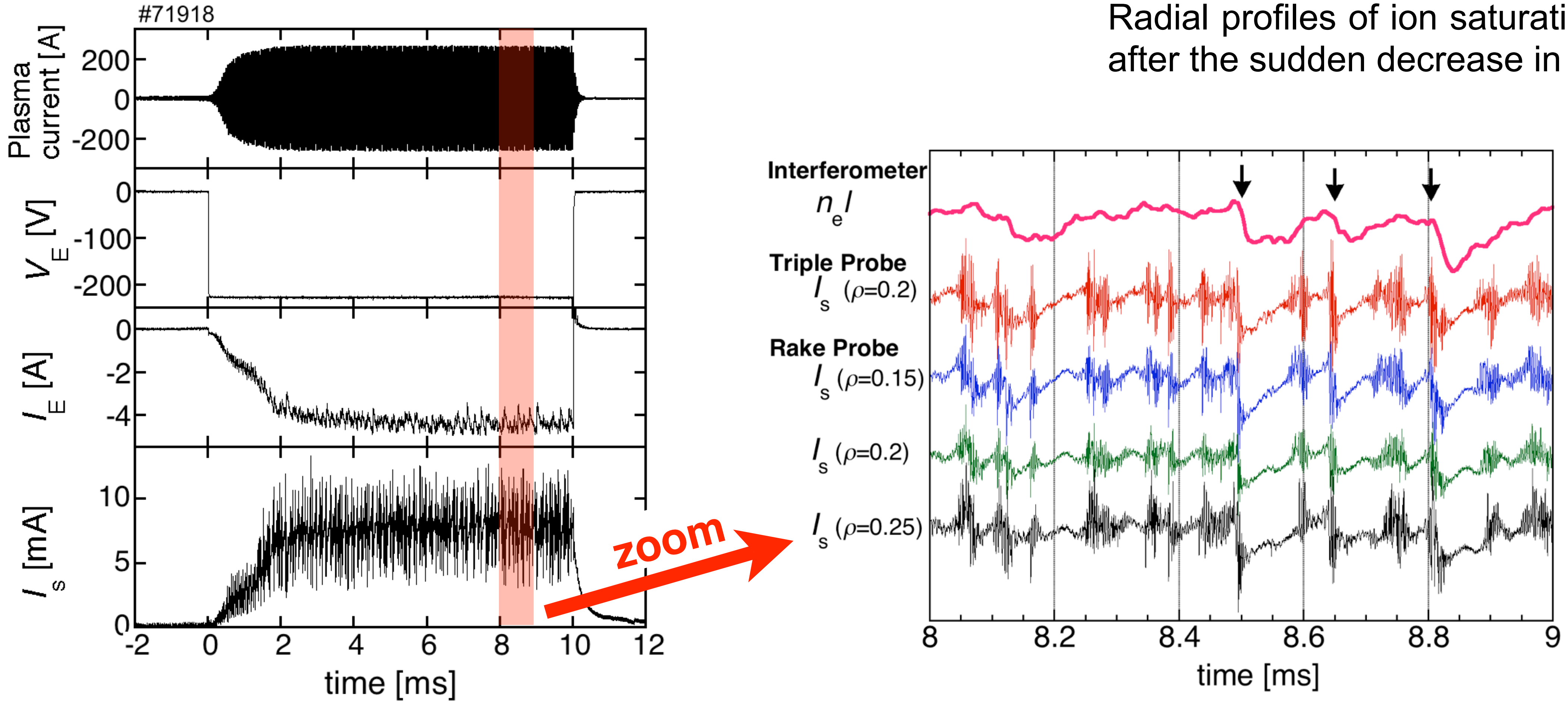
Ion saturation current I_s (ρ = 0.2) and line density $n_e l$ during the hot cathode biasing shows:

- sudden **density drops** and many small dips in the line density;
- **bursting fluctuation** signals in the ion saturation current measured by the triple probe (ρ = 0.2) and the rake probe (ρ = 0.15, 0.2 and 0.25), which synchronized with the decrease in the line density.

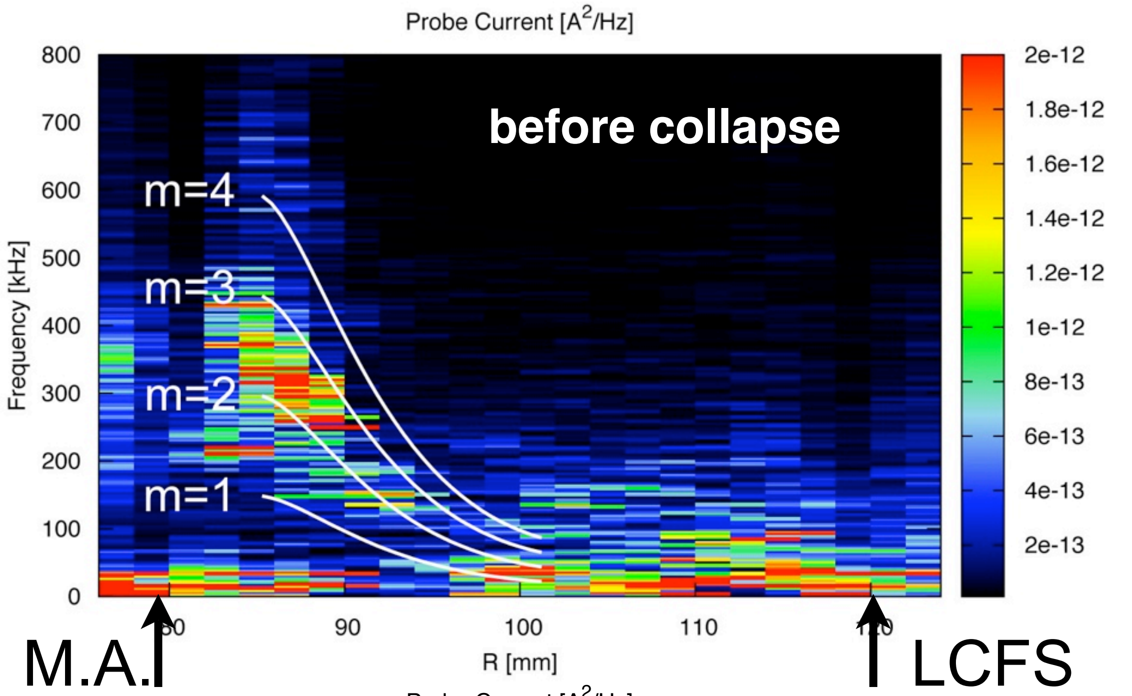
Radial profile of the ion saturation current has the **steep gradient** before collapse. After collapse the ion saturation current increased accompanied with the decrease in the core plasma region.

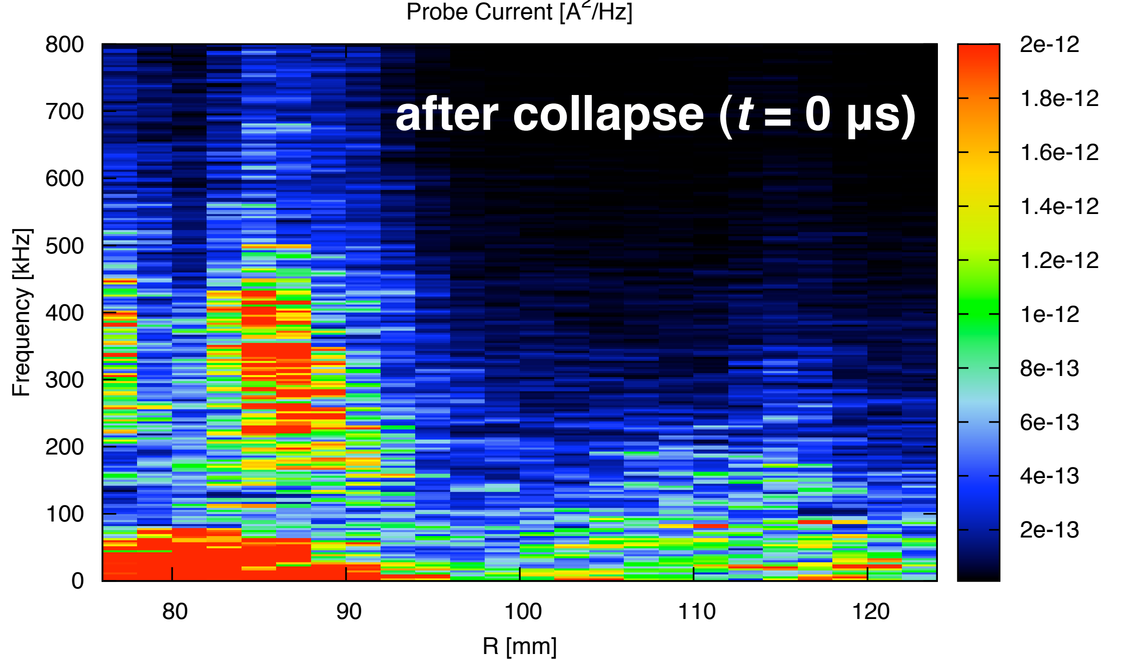


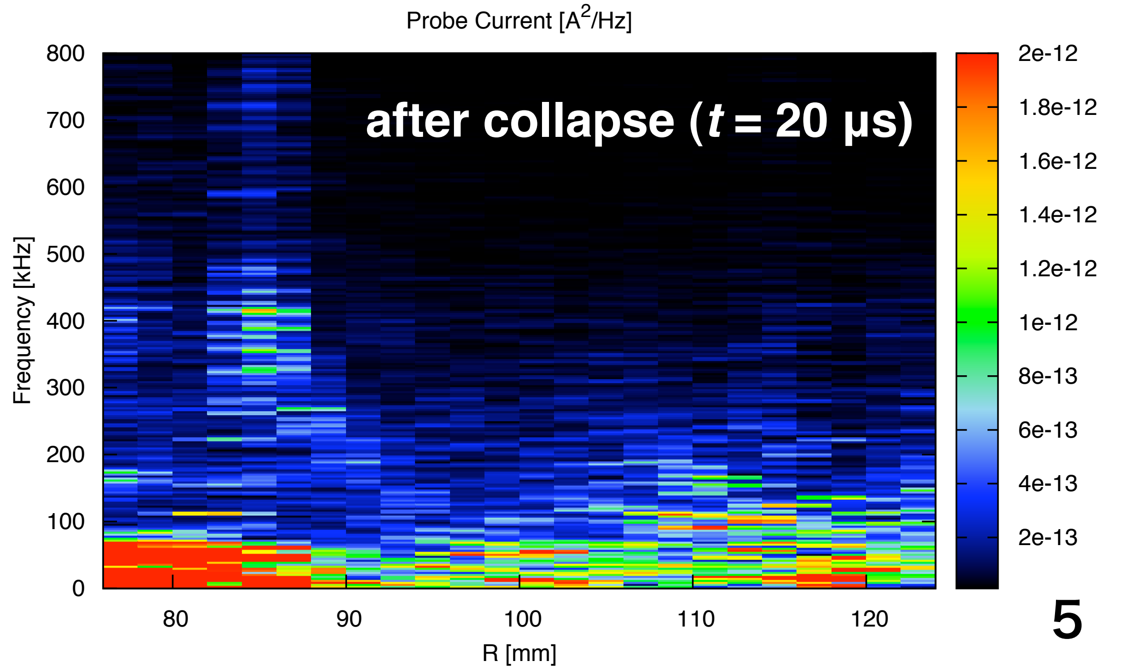
Radial profiles of ion saturation current before/after the sudden decrease in the density



Radial Distributions of the Power Spectrum of the Bursting Fluctuations







Before collapse

- Bursting fluctuations in the density collapse had the spectrum in the region of 100 < *f* < 500 kHz and the peak frequency of the spectrum was decreasing with increase in the radial position.
- Frequency agreed well with the ***E*** × ***B*** plasma rotating frequency $\boldsymbol{f}_{\mathbf{ExB}}$.

After collapse (*t* = 0 μs)

- Bursting fluctuations had the broader spectrum than that before collapse.
- increase in the power spectrum

After collapse (*t* = 20 μs)

- decrease in the power spectrum in the range of *f* > 200 kHz

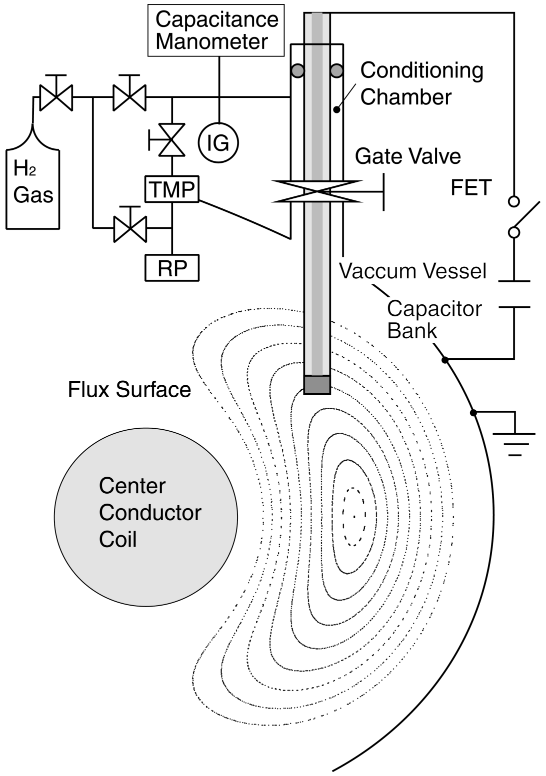
$\boldsymbol{f}_{\mathbf{ExB}}$: ***E*****×*****B*** poloidal rotation frequency
(*m*: poloidal mode number、B_φ: toroidal field)

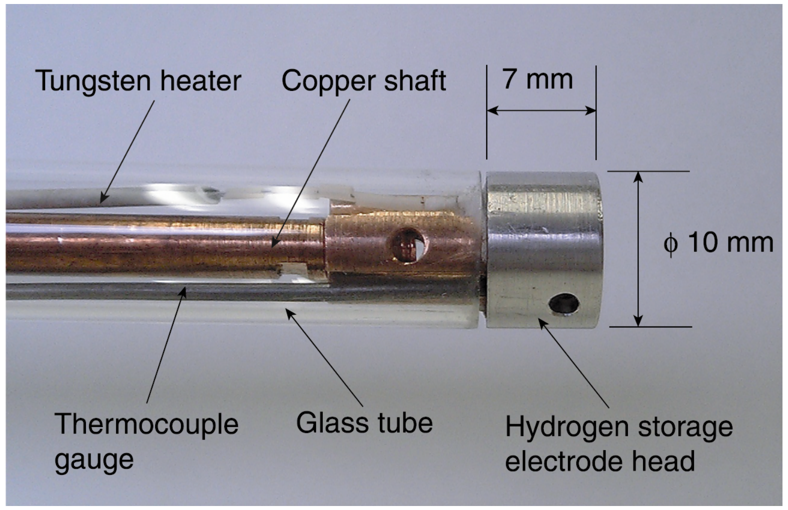
$$f_{E\times B} = \frac{mE_r}{2\pi\langle r\rangle B_\phi}$$

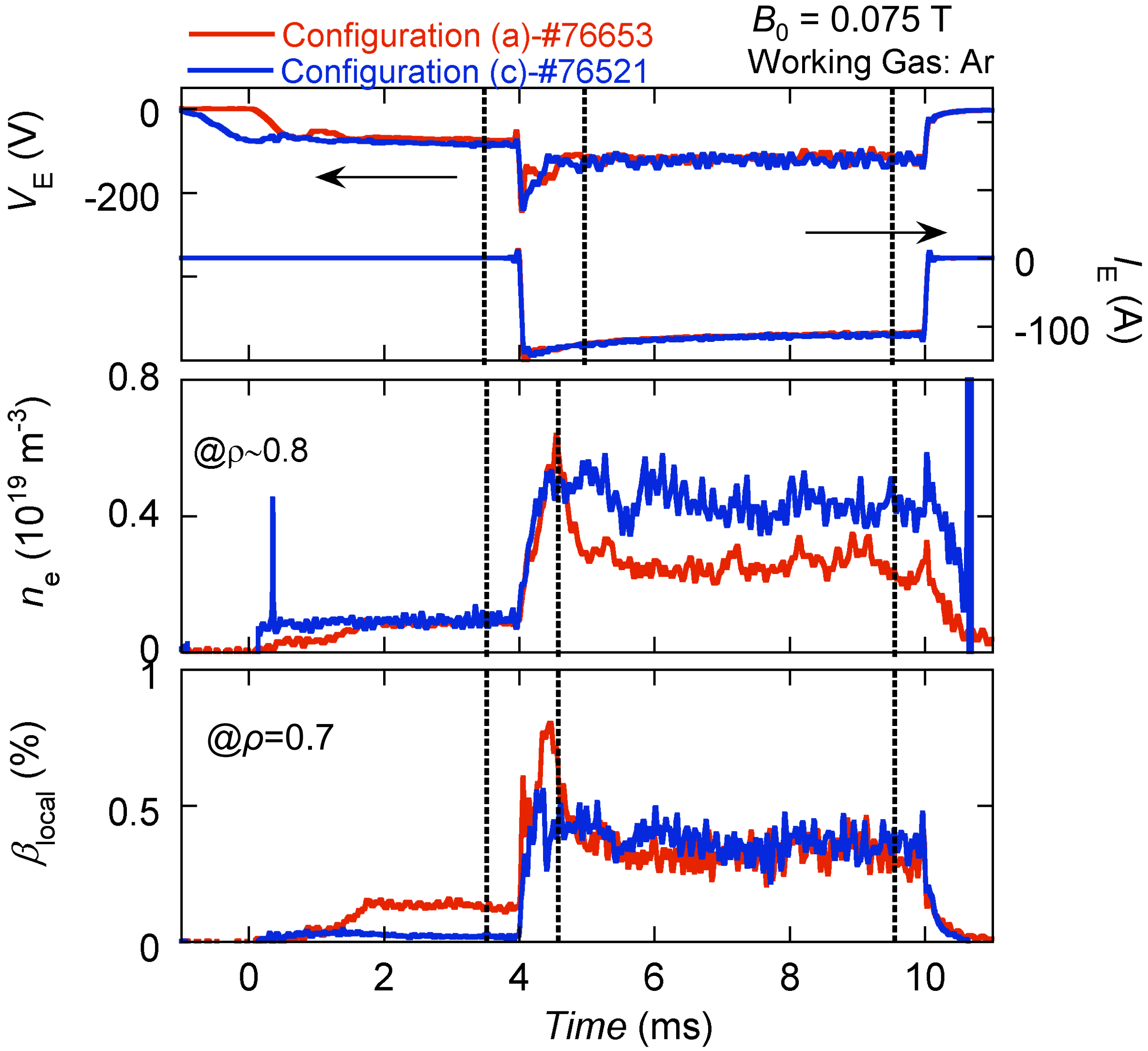
The bursting fluctuation frequency tightly depends on the high speed *E*×*B* poloidal flow.

New Type Electrode made of Hydrogen Storage Metal

For the development of a new field in biasing experiments, we have fabricated the **new type electrode made of hydrogen storage metal** for the particle injection (electron, ion and neutral particle).



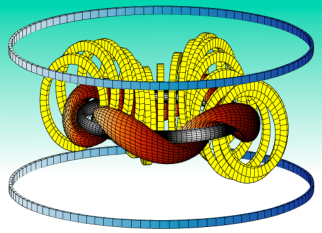




Beta value increased up to about 0.5 % using the electrode made of gold (Au)-coated palladium (Pd) under the low magnetic field (~ 0.08T).

This type electrode is useful to realize a new field of high-beta experiments in small-sized devices.

New Method for the Rotating Magnetic Islands by the External Perturbation Fields

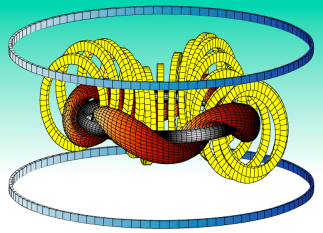


Study of magnetic island effects on the transport is important, because it leads to the **advanced control method for a plasma periphery** in a fusion reactor. The perturbation fields effects on the transport have been surveyed widely in LHD and DIIID *etc*.

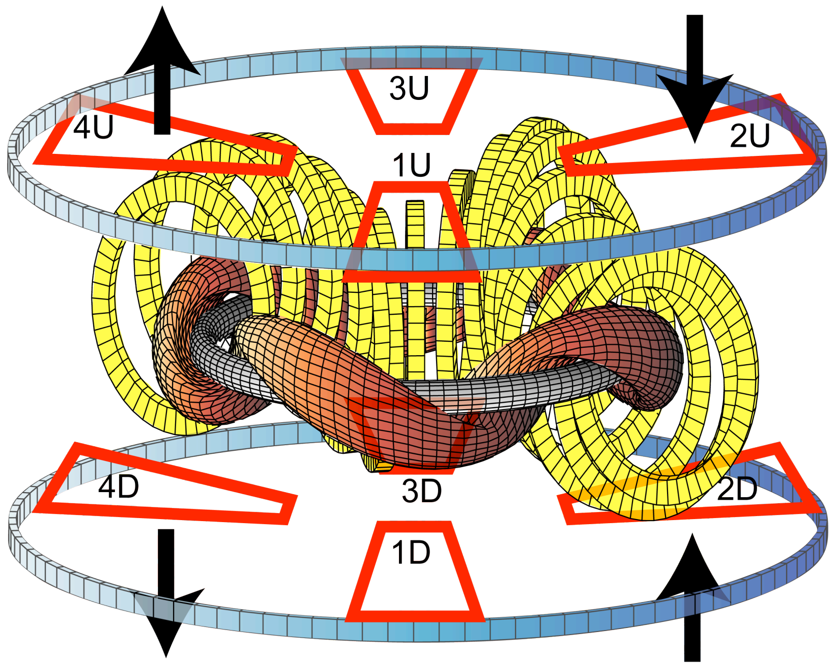
- For the research on island effects on confinement modes, TU-Heliac has advantages that (1) the position of a rational surface is changeable by selecting the ratio of coil currents, (2) the island formation can be controlled by external perturbation field coils, (3) a radial electric field and particle transport can be controlled by the electrode biasing.
- In TU-Heliac the ion viscosity for the *plasma with islands* was roughly estimated from the $\boldsymbol{J} \times \boldsymbol{B}$ driving force using the electrode biasing. It suggested that the ion viscosity increased according to the increase in the magnetic island width [5].
- Therefore it is expected that plasma poloidal rotation will be driven by the poloidal rotation of the island. The purposes of this experiment are, to propose the **new method for rotating islands by the external perturbation fields**, to survey the ability of the plasma poloidal rotation driven by rotating islands and, to study the rotating island effects on confinement modes in TU-Heliac.

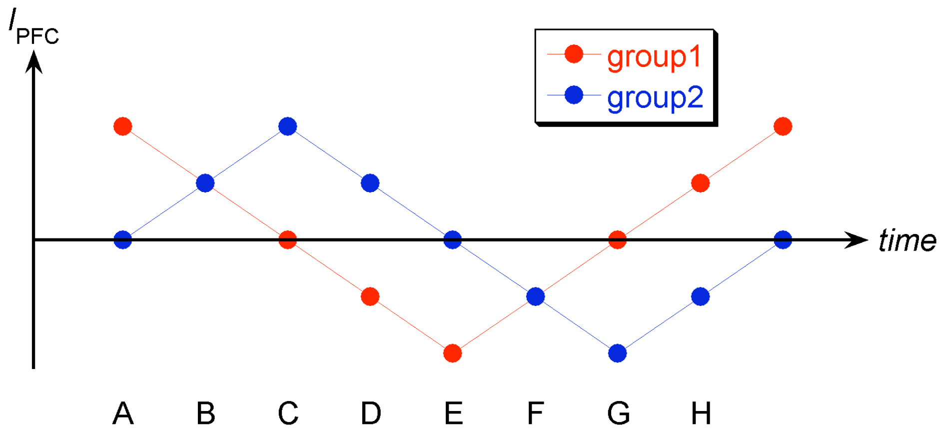
[5] S. Kitajima *et al*., Fusion Sci. Technol. **50**, 201 (2006).

Rotating Magnetic Islands

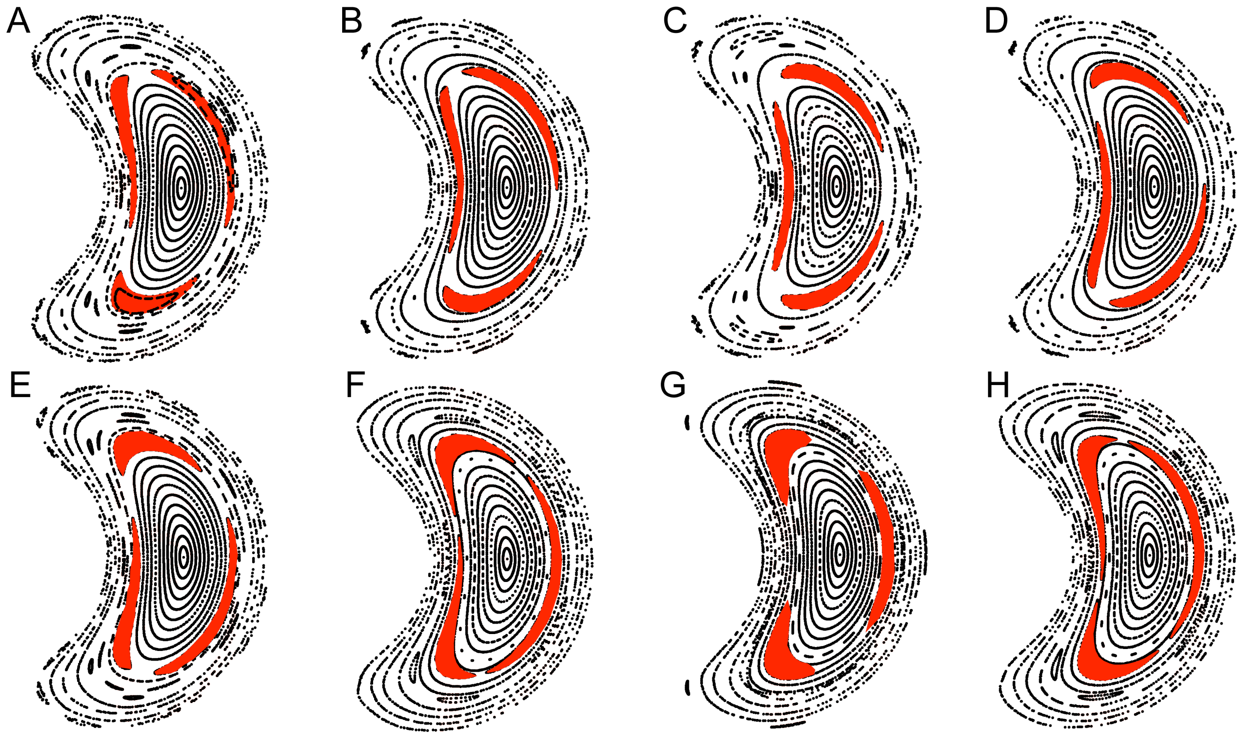


- The efficient configuration of perturbation coils for generating islands ($m = 3$) has been searched.
- We decided 4 pairs of upper and lower external perturbation field coils, which located at the toroidal angle φ = 0°, 90°, 180° and 270°, and generated cusp field at each toroidal angle.





group1 = {1U, 1D, 3U, 3D}
group2 = {2U, 2D, 4U, 4D}

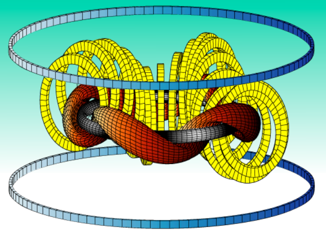


The velocity of the poloidal rotation $\boldsymbol{V}_{\textbf{island}}$ is proportional to the frequency ω of the perturbation coils.

$V_{\text{island}} = \langle r \rangle \omega / m$

$\langle r \rangle$: the average radius of the rational flux surface
m: poloidal mode number

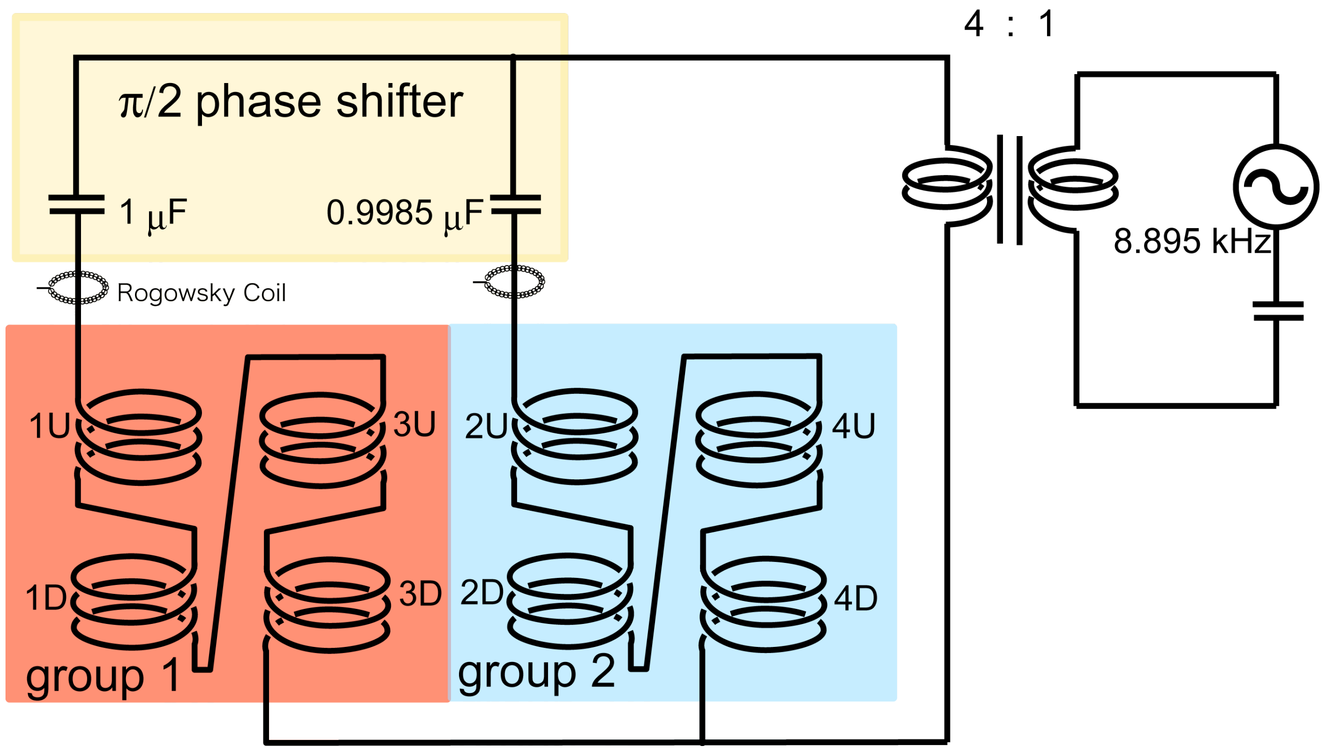
Phase Shifter for Perturbation Coils

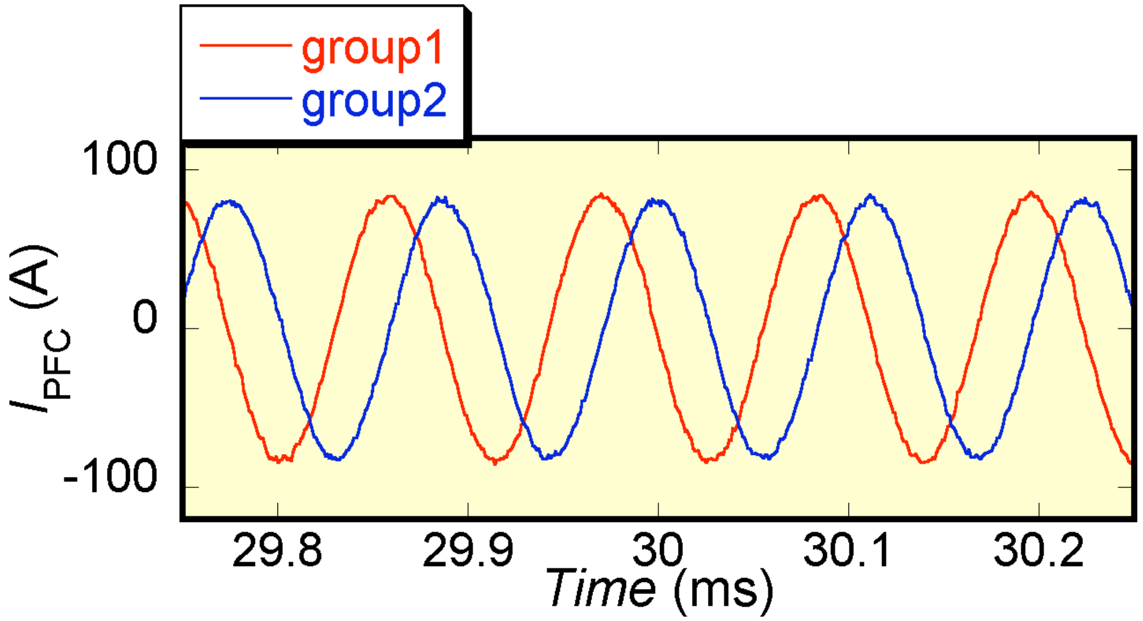


In the experiment we adopted the phase shifter, which consisted of **precisely tuned capacitors**.

$I_{group1} = I_{PFC}\sin(\omega t-\pi/4)$
$I_{group2} = I_{PFC}\sin(\omega t+\pi/4)$

- $I_{PFC} = 85$ A
- $f_{PFC} = 8.895$ kHz
- $V_{island} \sim 0.7$ km/s at $R = 112$ mm (island location)

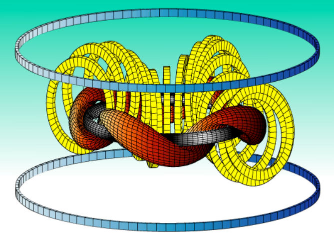




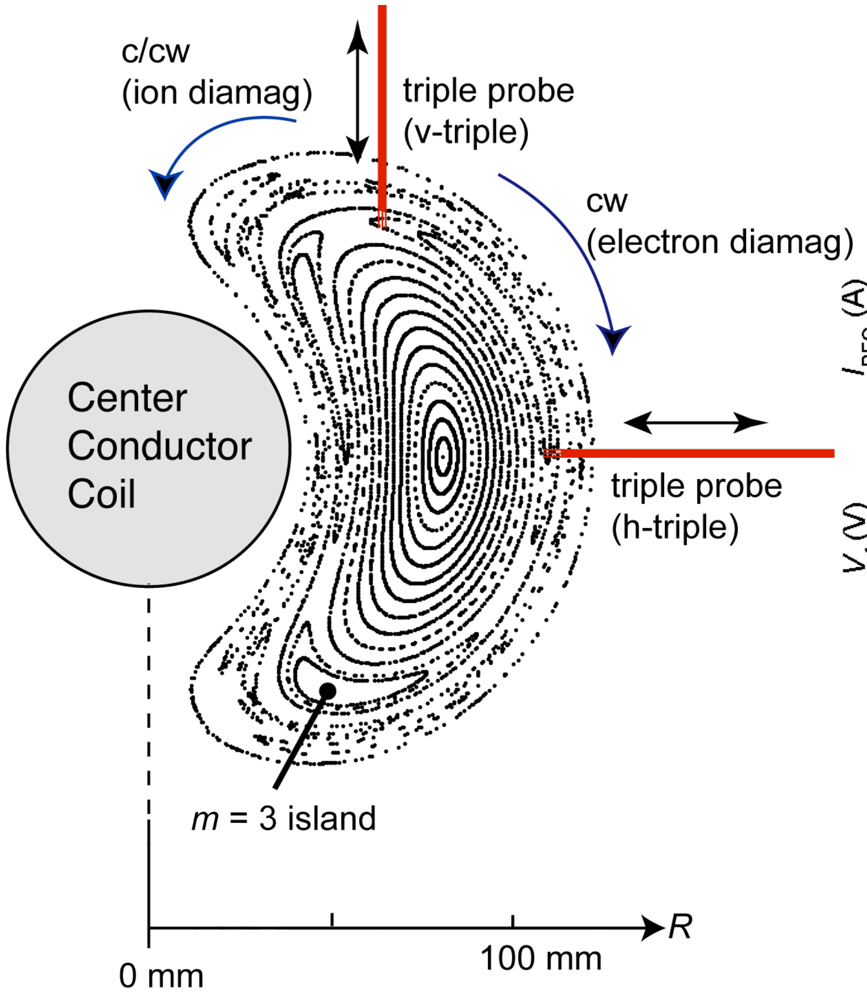
perturbation coil currents measured by the Rogowski coils. Two group coil currents have $\pi/2$ phase shift and same values.

$f = 8.895$ kHz, phase shift = $\pi/2$

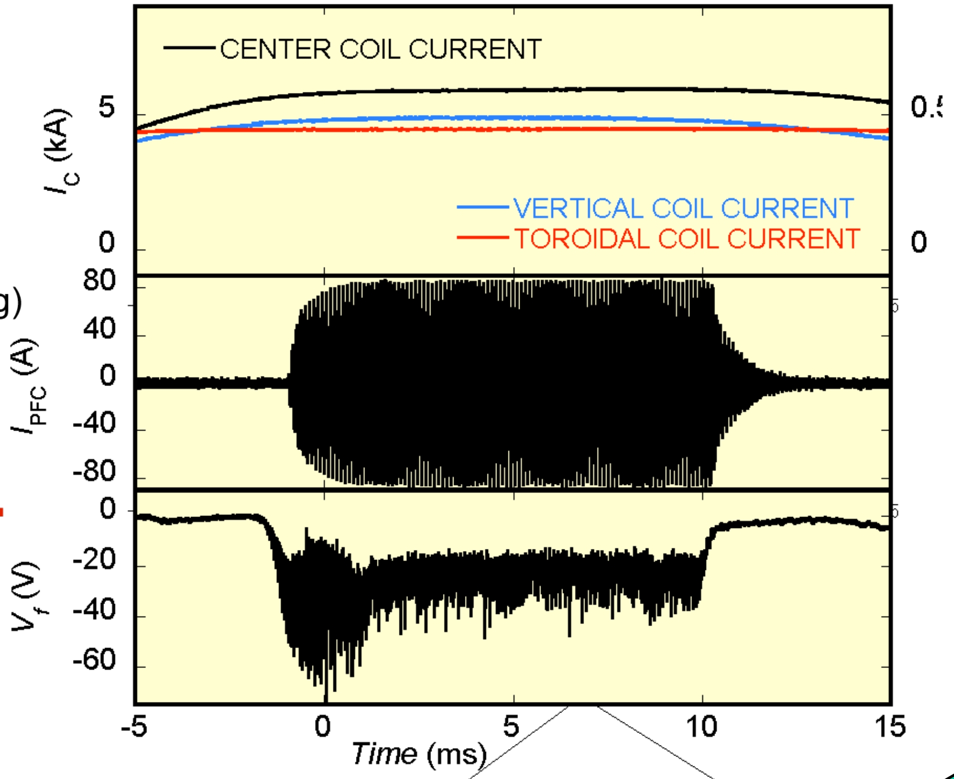
Floating Potential Measurements

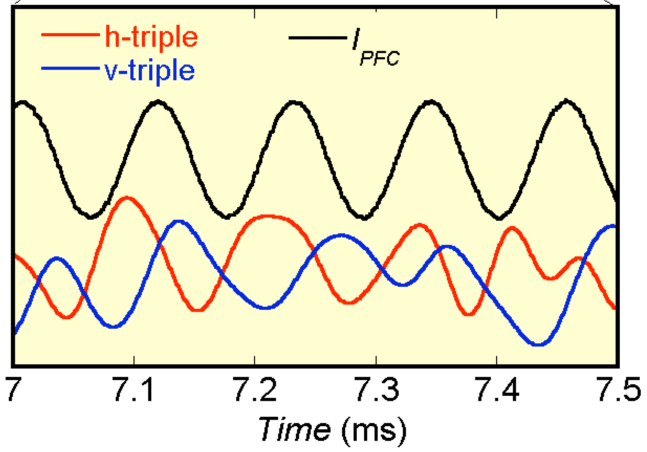


To check experimentally the effect of the external perturbation field, we measured the floating potential by a Langmuir probe (high speed triple probe).

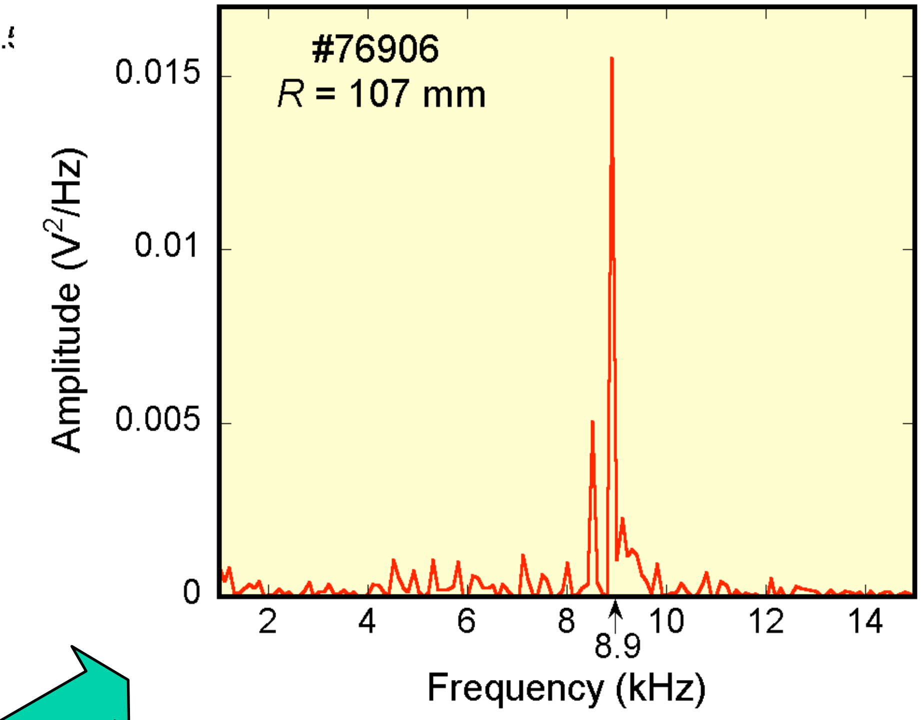


cross section of magnetic surfaces with *m* = 3 magnetic island Two Langmuir probes are set on the magnetic surface at the positions which were separated about a half of the poloidal length of the island.



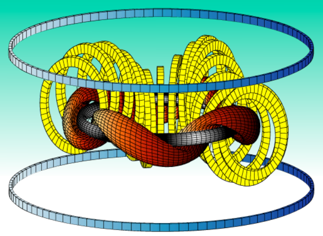


Phase shifts between two signals

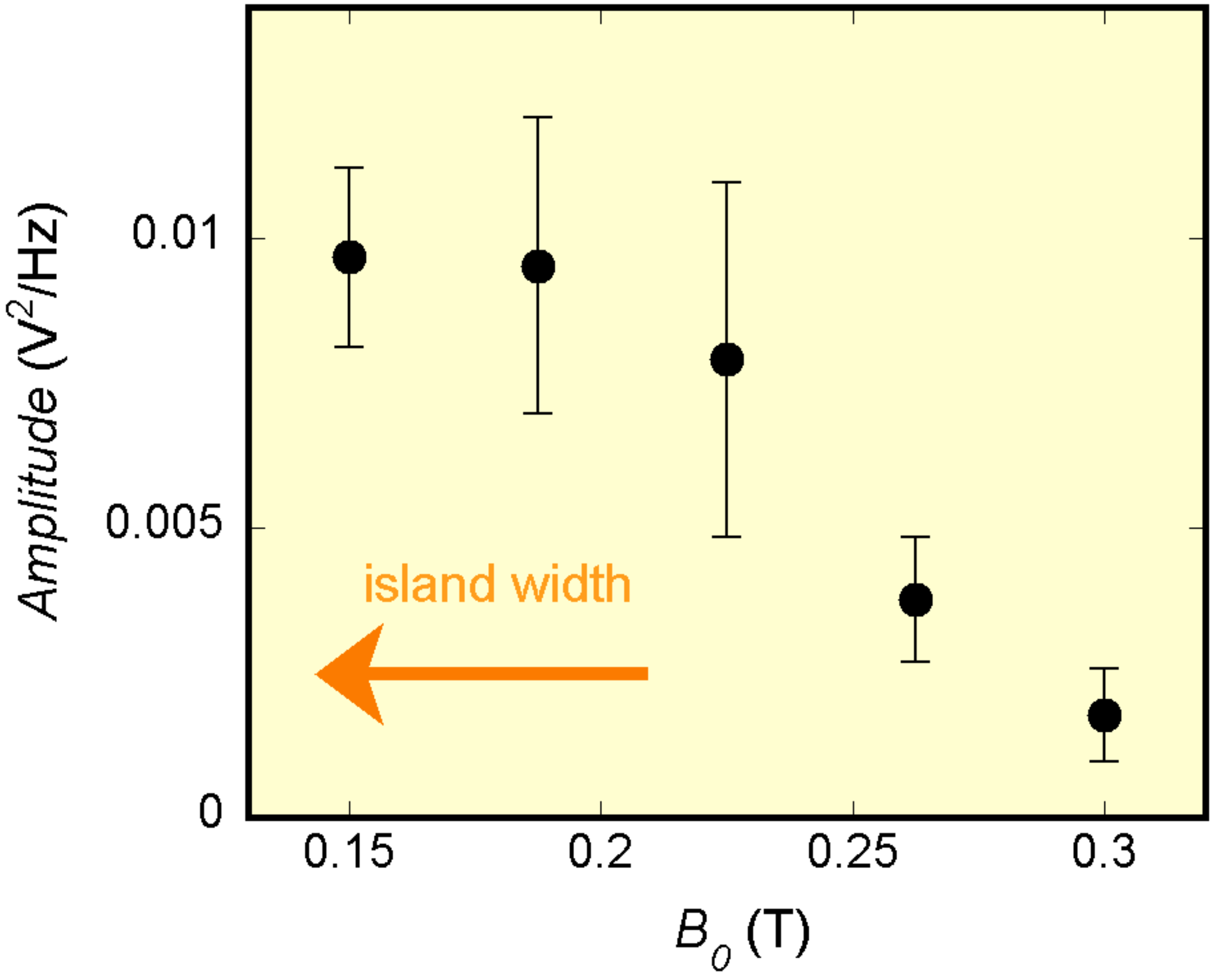


FFT power spectrum of floating potential

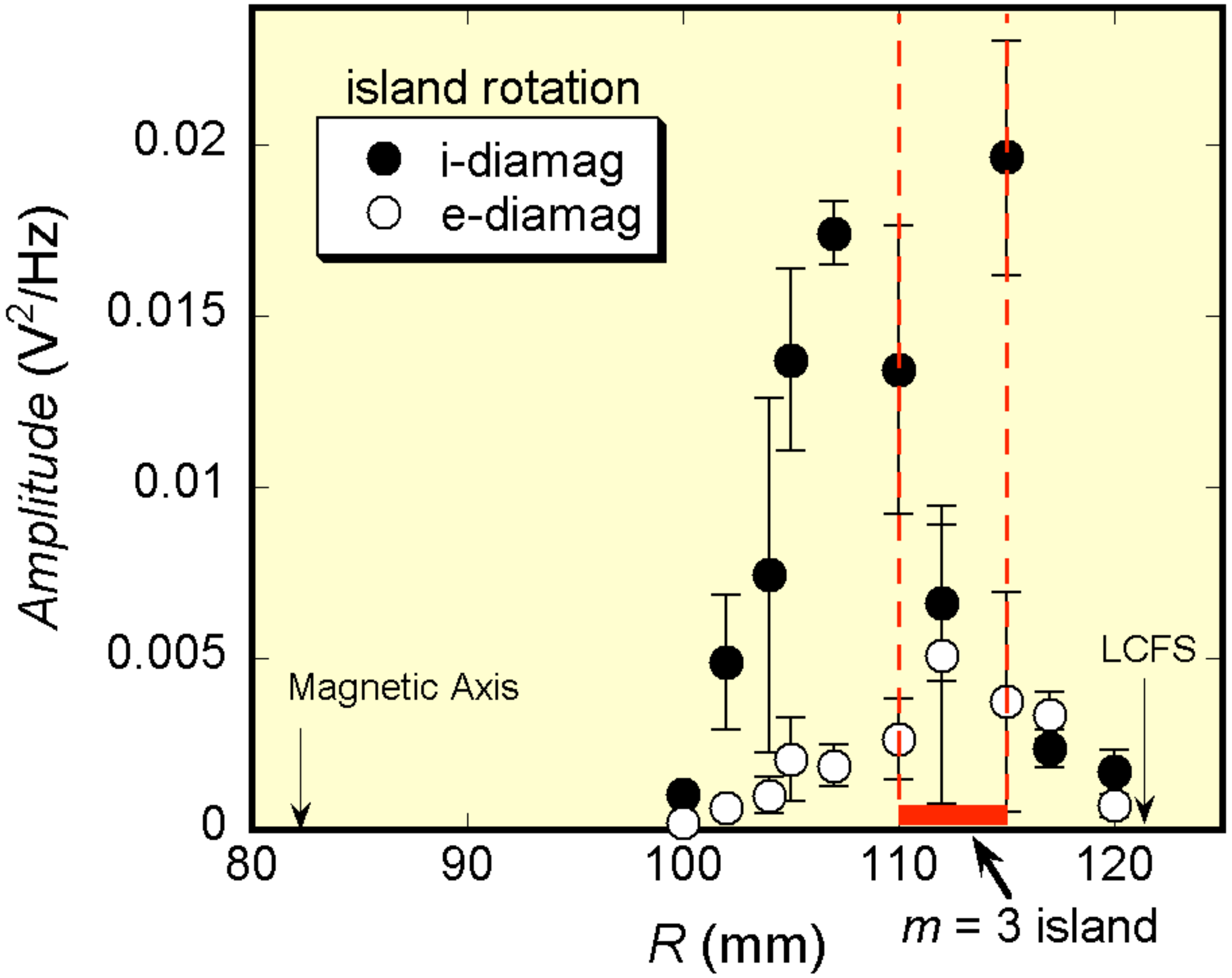
FFT Power Spectrum of Floating Potential



We surveyed the relation between FFT power spectrum of the floating potential and the island width and the radial profile of FFT power spectrum at the frequency of the perturbation coil current.



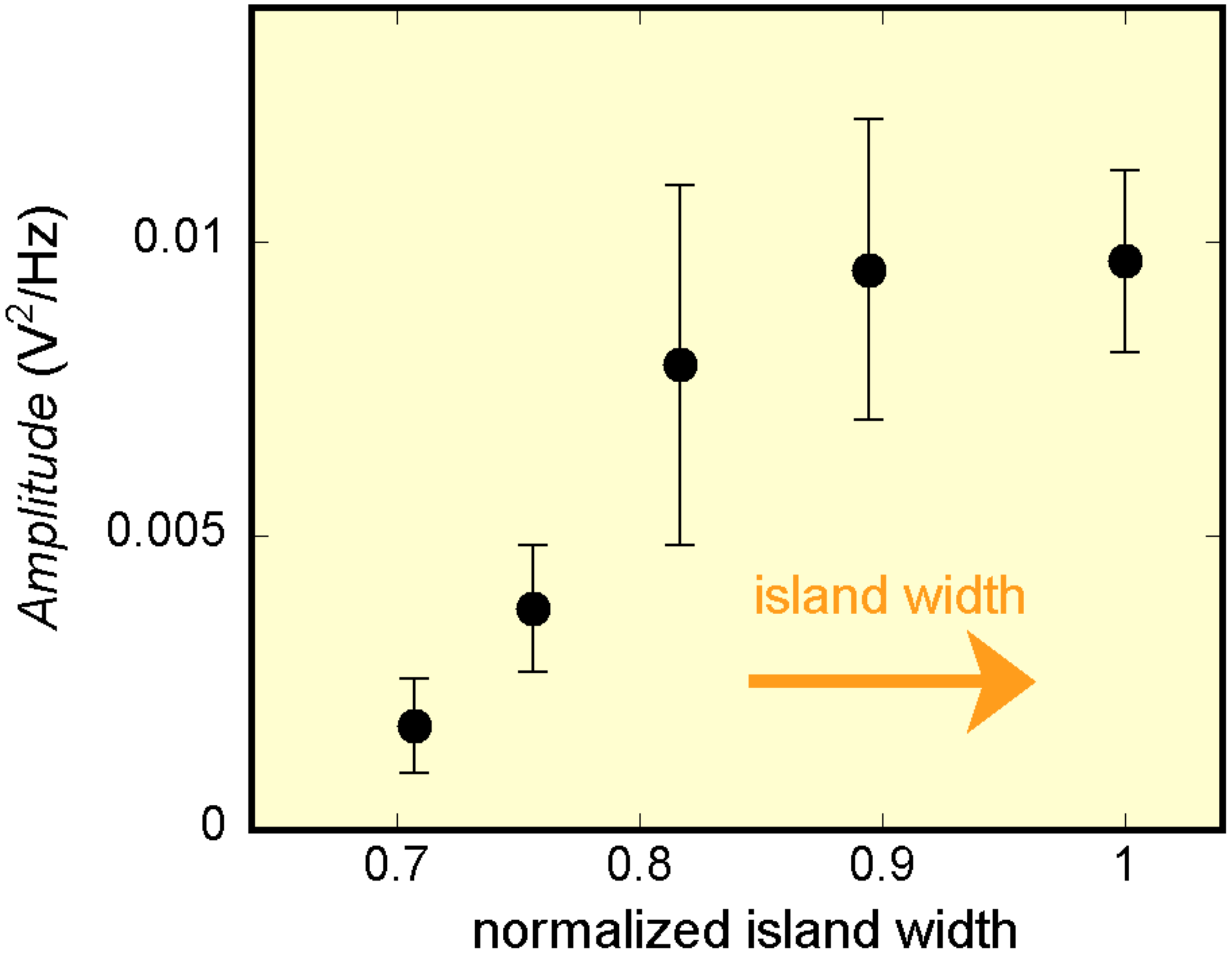
- relation between the FFT power spectrum(@f=8.895kHz) of floating potential and the island width



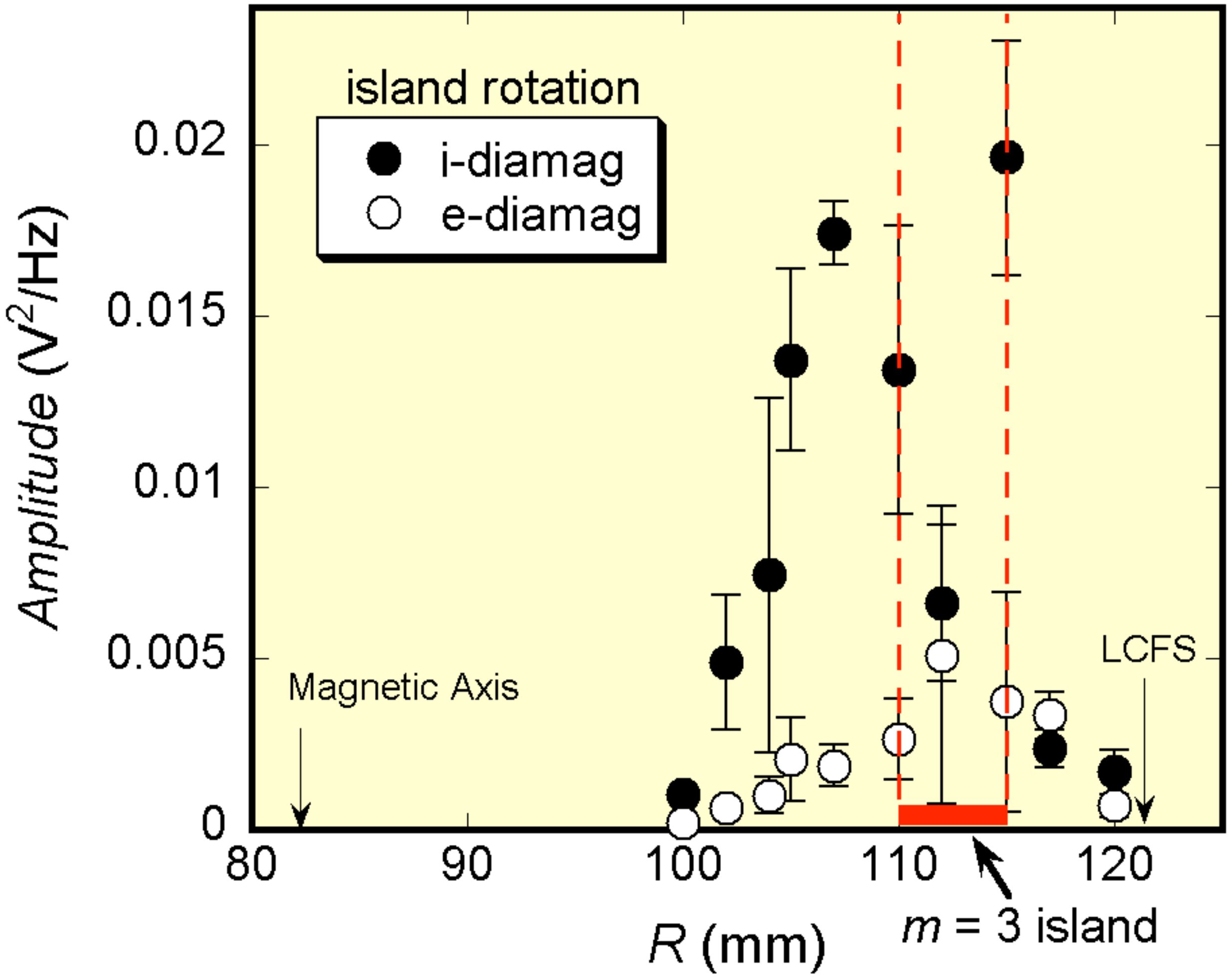
- relation between the FFT power spectrum (@f=8.895kHz) of floating potential and the radial position of the Langmuir probe
- Power spectrum have the maximum around the m = 3 magnetic island.

FFT Power Spectrum of Floating Potential

We surveyed the relation between FFT power spectrum of the floating potential and the island width and the radial profile of FFT power spectrum at the frequency of the perturbation coil current.



- relation between the FFT power spectrum(@f=8.895kHz) of floating potential and the island width

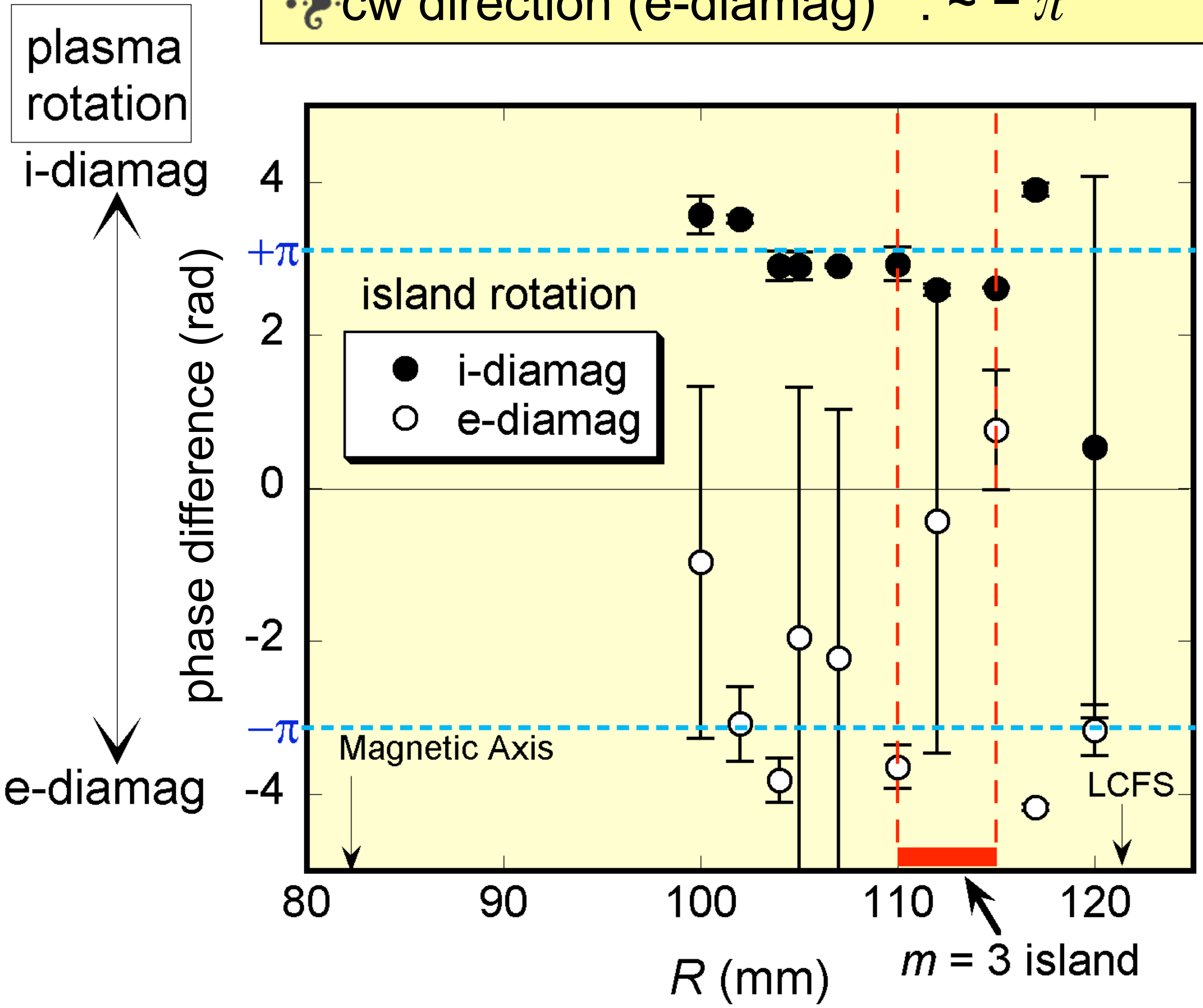


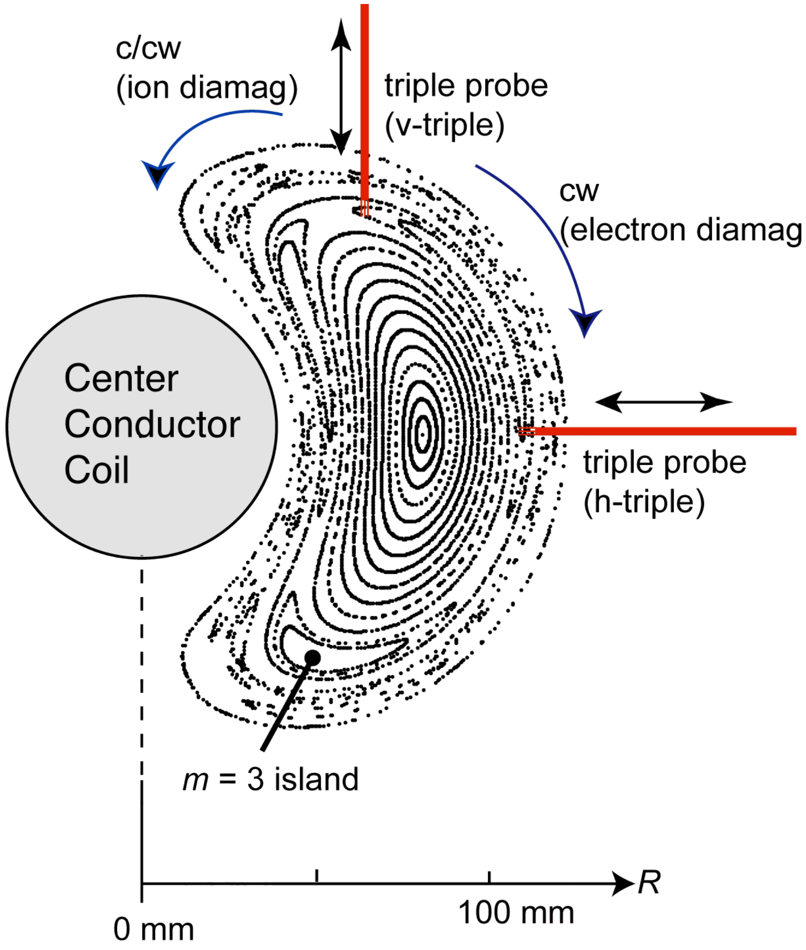
- relation between the FFT power spectrum (@f=8.895kHz) of floating potential and the radial position of the Langmuir probe
- Power spectrum have the maximum around the m = 3 magnetic island.

Phase Difference in Probe Signals

Expected phase difference was calculated from the probe positions

- c/cw direction (i-diamag) : ~ π
- cw direction (e-diamag)   : ~ − π

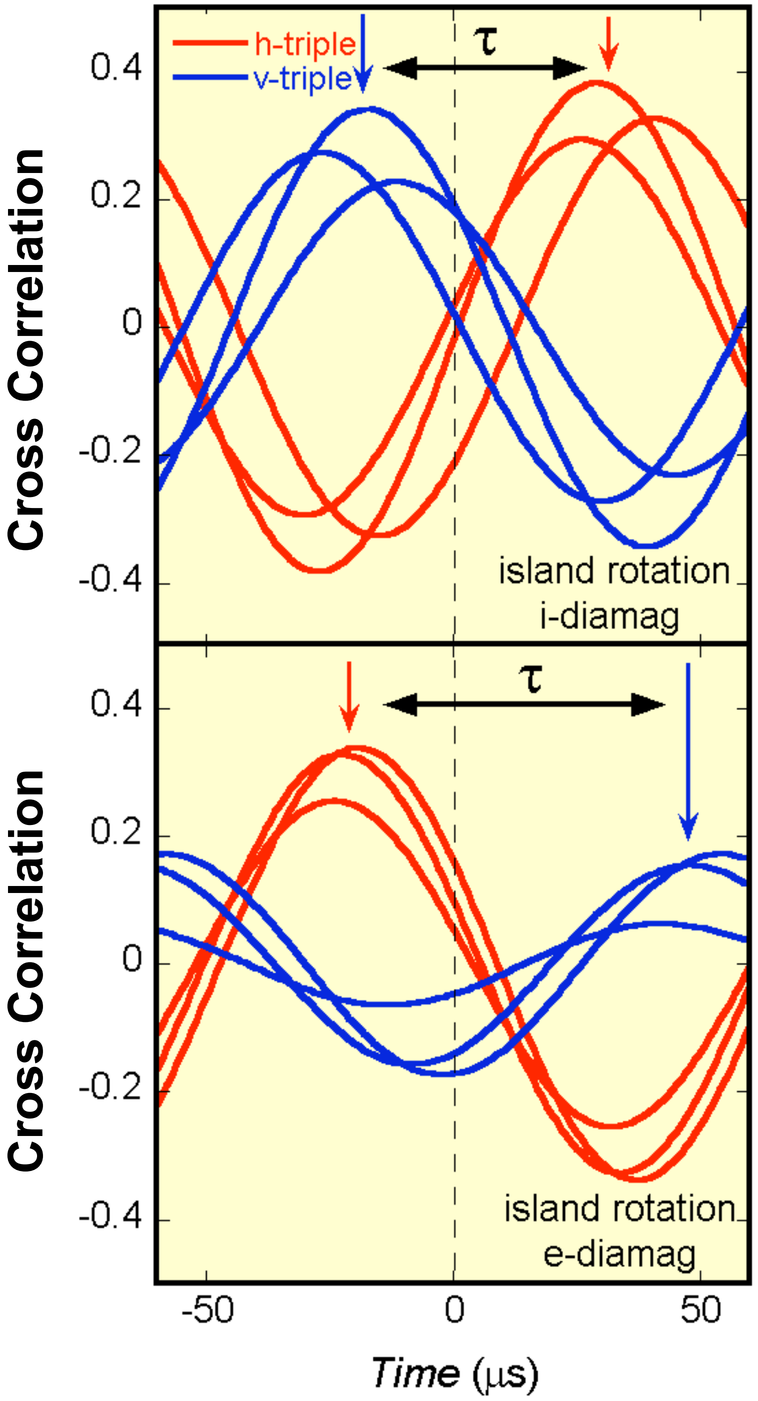




- Phase difference in the floating potential signals by two Langmuir probes agreed well with the expected value π in the c/cw rotation (i-diamag).
- Phase difference in the cw rotation (e-diamag) had large error.
  → Target plasma had the weak positive radial electric fields (E_r ~ 2 kV/m), thus the bulk plasma rotated in the c/cw direction by the ***E*** x ***B*** rotation.

Cross Correlation between Probe Signals

We calculated the **cross correlations** from two floating potential signals measured by a Langmuir probe (high speed triple probe).



Expected time difference was calculated from the probe positions:

c/cw direction (i-diamag) : ~ 50μs;

cw direction (e-diamag) : ~ −50μs.

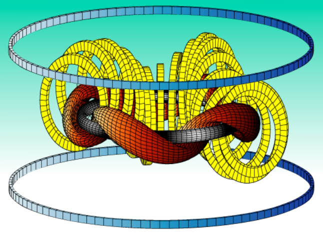
measured time difference between two probes

c/cw direction (i-diamag) : ~ 50μs

cw direction (e-diamag) : ~ −70μs

- Time difference in the floating potential signals by two Langmuir probes agreed well with the expected value in the c/cw rotation (i-diamag).
- Time difference in the cw rotation (e-diamag) had large value.
  → There are some restrictions on the rotation of the islands in the direction which is opposite to the natural direction of the ***E*** x ***B*** bulk plasma rotation (c/cw direction).

Summary of Rotating Magnetic Islands



We proposed a **method for the rotating magnetic islands** by the external perturbation fields which were produced with 4 pairs of cusp field. The alternating currents for the perturbation coils have the π/2 phase shift.

- We designed and constructed the phase shifter for the coil currents .
- The phase difference in the floating potential signals by two Langmuir probes confirmed that the rotation of the magnetic islands in the ion-diamagnetic direction.
- These experimental results suggest the ability of producing plasma poloidal rotation driven by rotating islands, though the island rotation was affected by the natural rotation of the target plasma.

We can expect the higher poloidal rotation velocity by increasing in the frequency of the perturbation coil current.

In future works we will study the effect of the rotation of the target plasma by the hot cathode biasing, which can reduce the natural $\boldsymbol{E} \times \boldsymbol{B}$ bulk plasma rotation (ion-diamagnetic direction).