Edge Plasma Studies in a Helical-Axis Heliotron Device, Heliotron J

presented by

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Edge Plasma Studies in Heliotron J
– Outline –

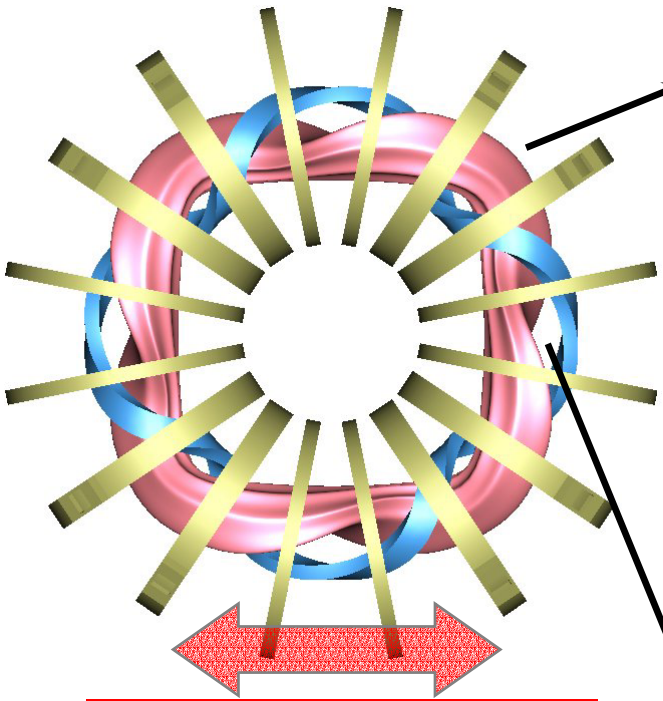
- **The Heliotron J Device**
  - ***A "Helical-Axis Heliotron" Device as a Concept Exploration Facility for an Optimized Helical System in Heliotron Line***

- **Edge Plasma Studies in Heliotron J**
  - ***Distribution of Divertor Plasmas***
    - » ***Asymmetry of Divertor Plasmas***
    - » ***"Spontaneous Shift" of Divertor Trace***
  - ***SOL Plasma Profile and Fluctuations***
    - » ***"H-mode" transition***

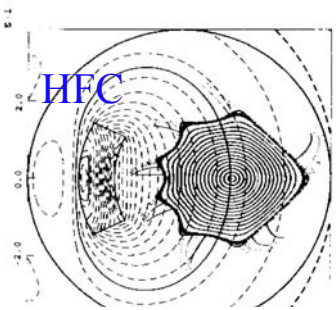
World-Wide Research Activities for Optimized Helical Systems

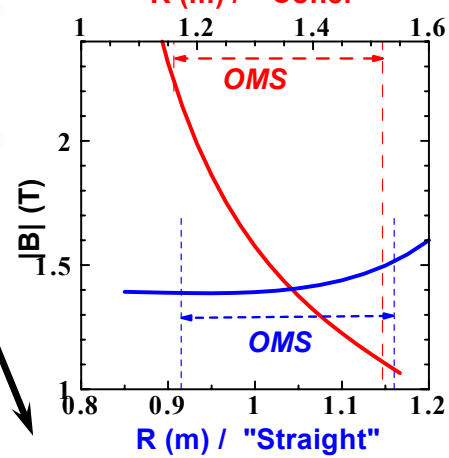
Concept of Advanced Helical system	*Modular Coils*	*Continuous Helical Coils*
Family of currentless **Quasi-isodynamic** (Quasi-Omnigeneous) or **Quasi-Poloidally** Symmetric Devices	*IPP(2010?)* **W7-X** *ORNL(2007)* **QPS**	***helical-axis heliotron*** **Heliotron J**
Family of currentless **Quasi-Helically** Symmetric Devices	*Wisconsin(1999)* **HSX**	***helical heliotron*** **Heliotron E** **LHD**
Family of current-driven Quasi-Axisymmetric (Quasi-toroidal) Devices	*PPPL(2007)* **NCSX** *NIFS* **CHS-qa**	_____
Current-driven Axisymmetric Devices	**tokamaks**	

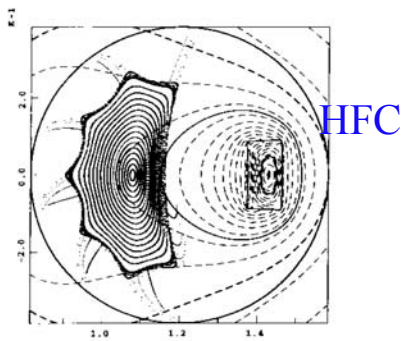
Basic Ideas for Better Confinement in the Helical-Axis Heliotron Configuration

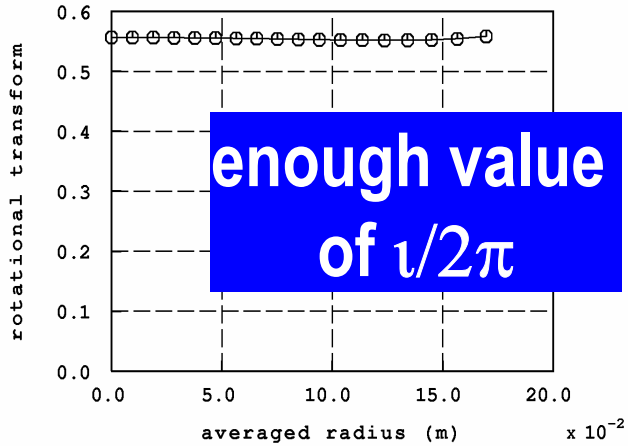


mirror-like region for $v_\perp \gg v_{//}$ particles



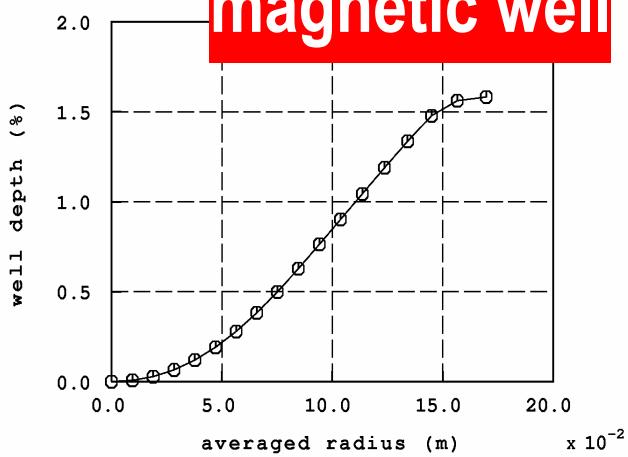




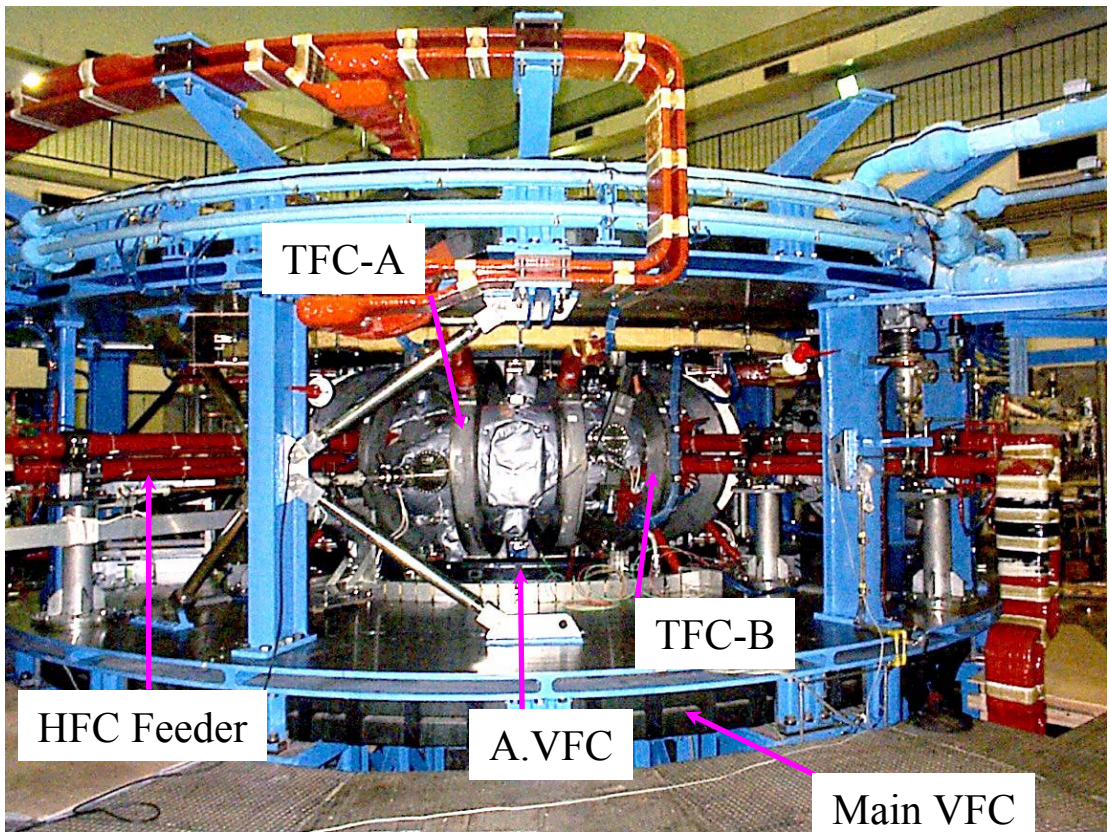


enough value of $\iota/2\pi$

magnetic well



The Heliotron J Device



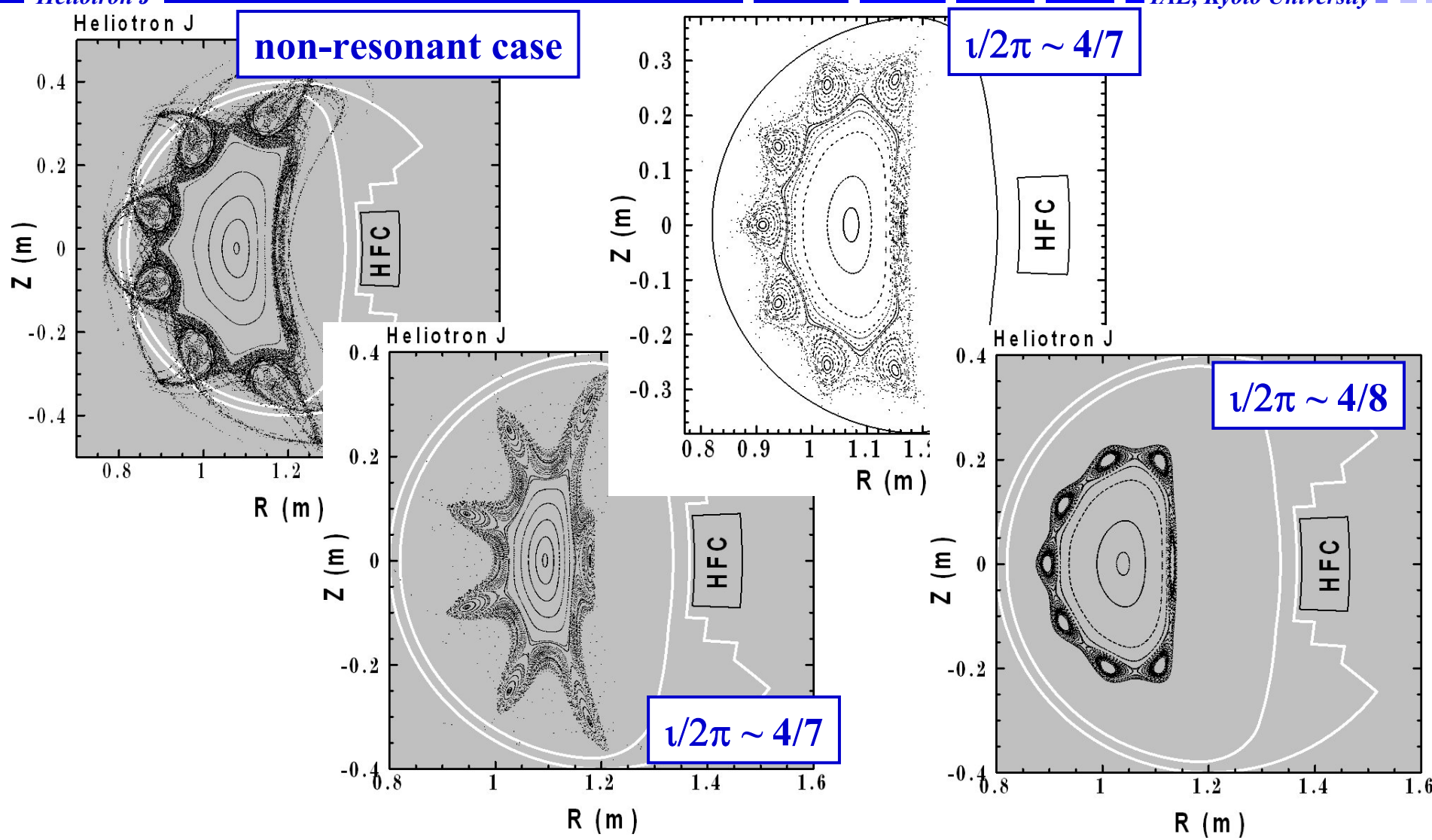
- Coil System
  - Helical Coil
    $\theta = \pi + M/L\times\varphi - \alpha\times\sin(M/L\times\varphi)$
    - » $L = 1$, $M = 4$, $\alpha = -0.4$
    - » Major Radius 1.2 m
    - » Coil Minor Radius 0.22 m
  - (8+8) Toroidal Coils
  - 3 pairs of Poloidal Coils
    (Inner Vertical Coil in the torus center.)
  - Power Source MG 330MVA
- Confinement Field
  - Max. B 1.5 T
  - Flat-Top Time 0.5 sec.

– A_s ~ 15.4 m^2
– V_{CMB} ~ 2.1 m^3

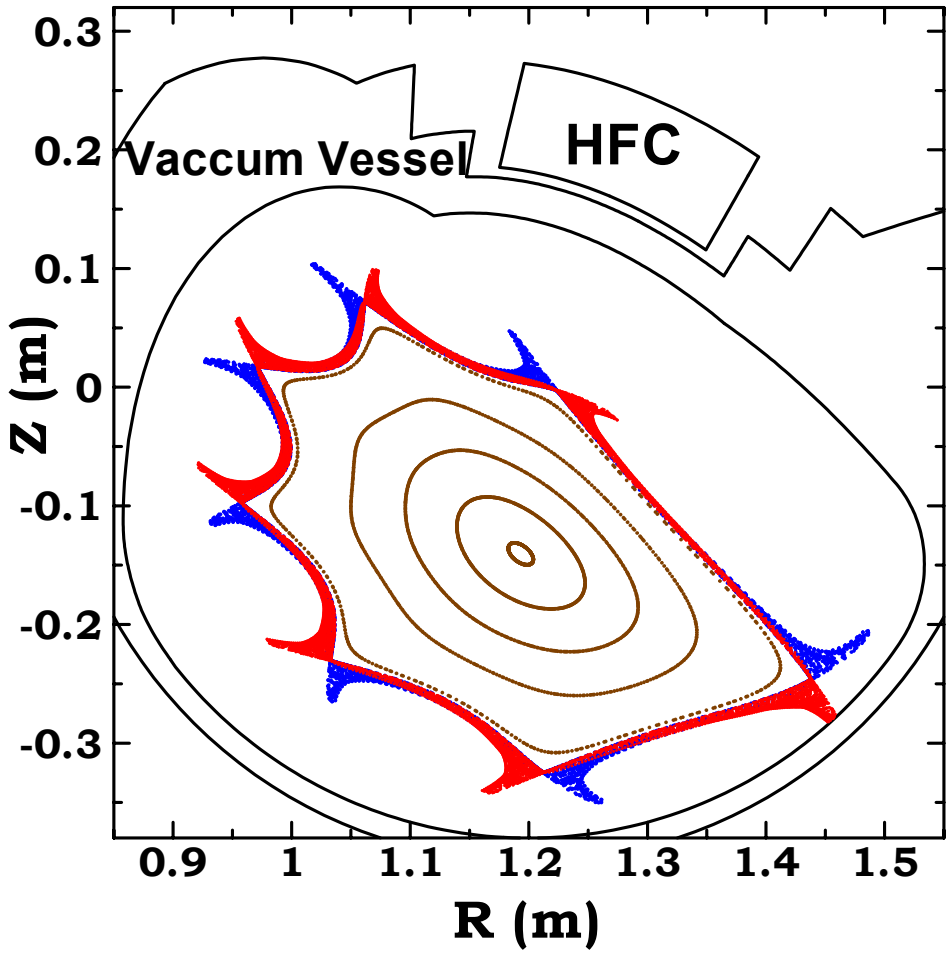
Main Objectives of Heliotron J Experiments

- **As a Concept Exploration Facility;**
  - ***to demonstrate the improved confinement property including edge plasma controllability (divertor scenario) based on the helical-axis heliotron configuration.***
  - ***to establish the design principles for the POP/PE facility based on this concept.***
- **As a Fusion Research Facility in an University;**
  - ***to comprehend the plasma physics in advanced toroidal confinement.***

Heliotron J can produce various edge field configurations.
– Four types of the typical field topology –

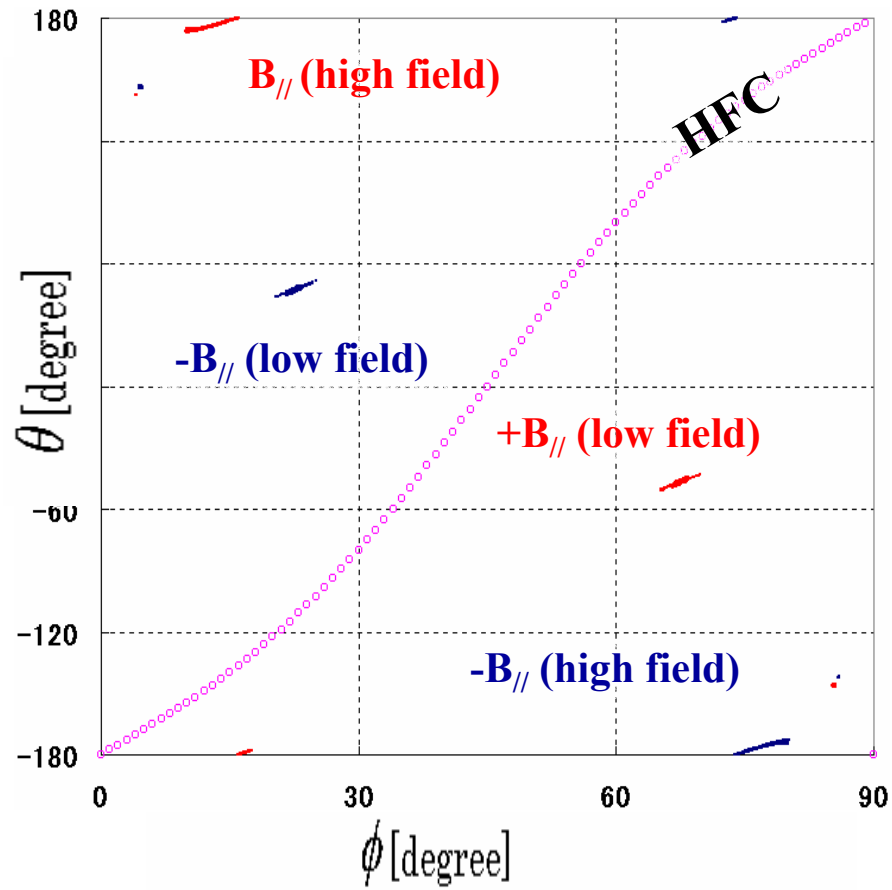


The wall "suppress" the stochastic nature of the edge field lines and makes localized divertor footprints.



Edge Field Structure (ϕ^*=22.5°)

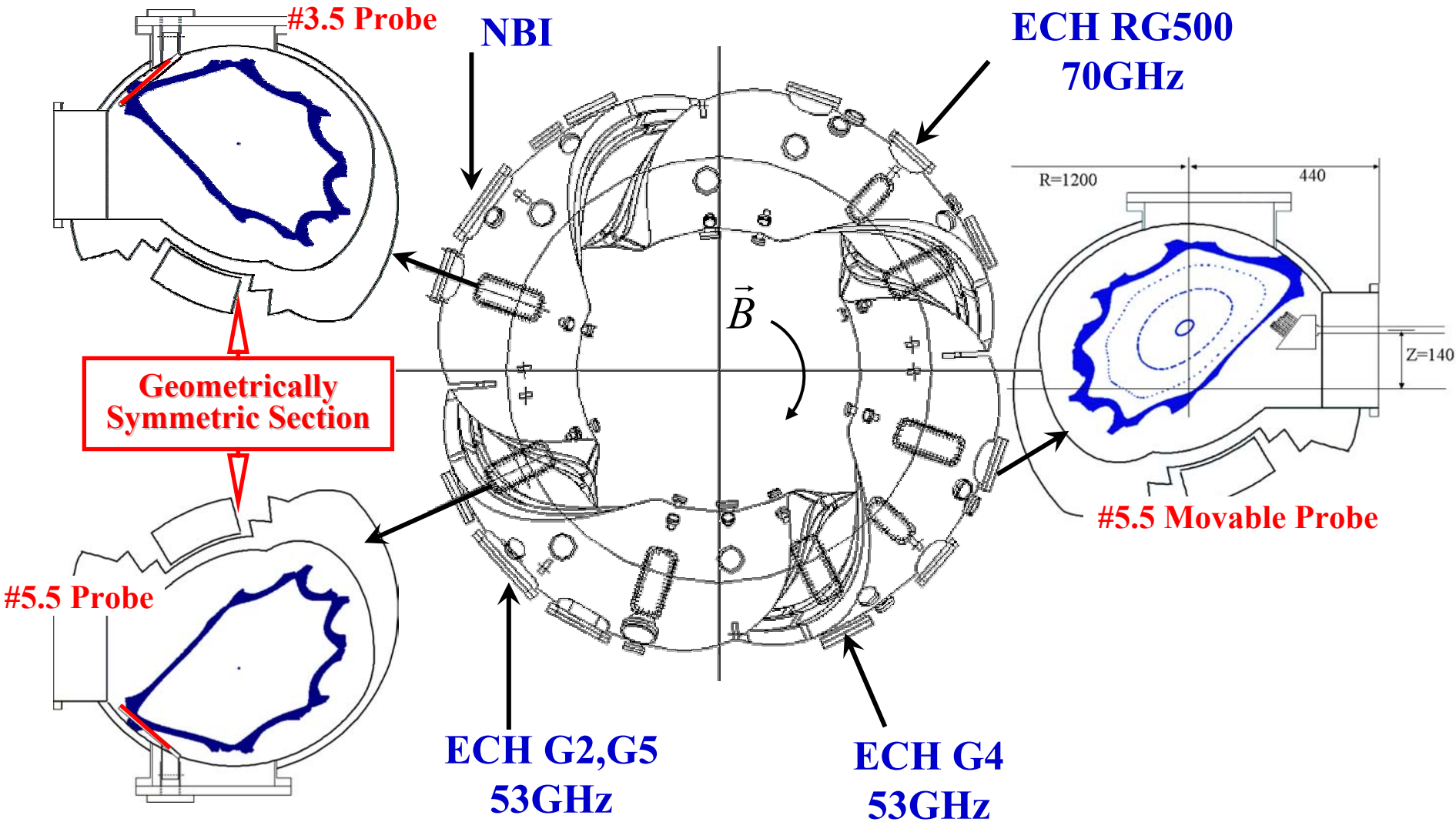
Footprints of the Divertor Field Lines on the Wall



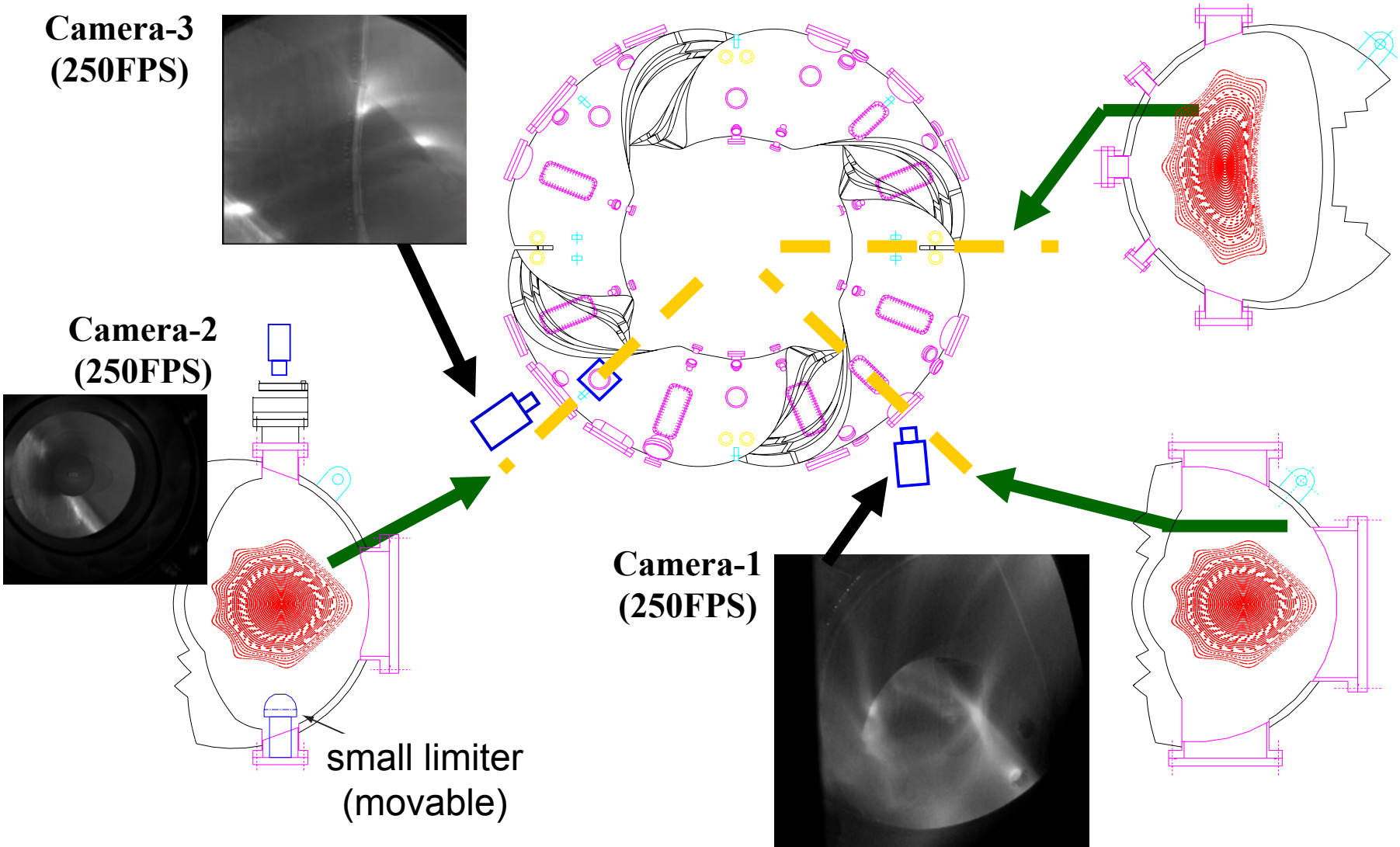
Key Issues to Understand the Edge Plasmas & PSI

- **Near the Wall (or Divertor)**
  - ***localization of the divertor plasmas***
  - ***"divertor asymmetry"***
    - » ***toroidal and poloidal distributions of diverted plasma particle- and heat-fluxes.***
  - ***their dependence on the field topology.***
- **Near LCFS**
  - ***radial and poloidal profiles of the SOL plasma***
  - ***edge turbulence and its effect on the transport***
  - ***their dependence on the field topology.***

Three Langmuir probe systems for edge plasma in Heliotron J.



Edge plasma monitor system with fast CCD video cameras



The existence of the divertor flux asymmetry is a crucial issue for the divertor design.

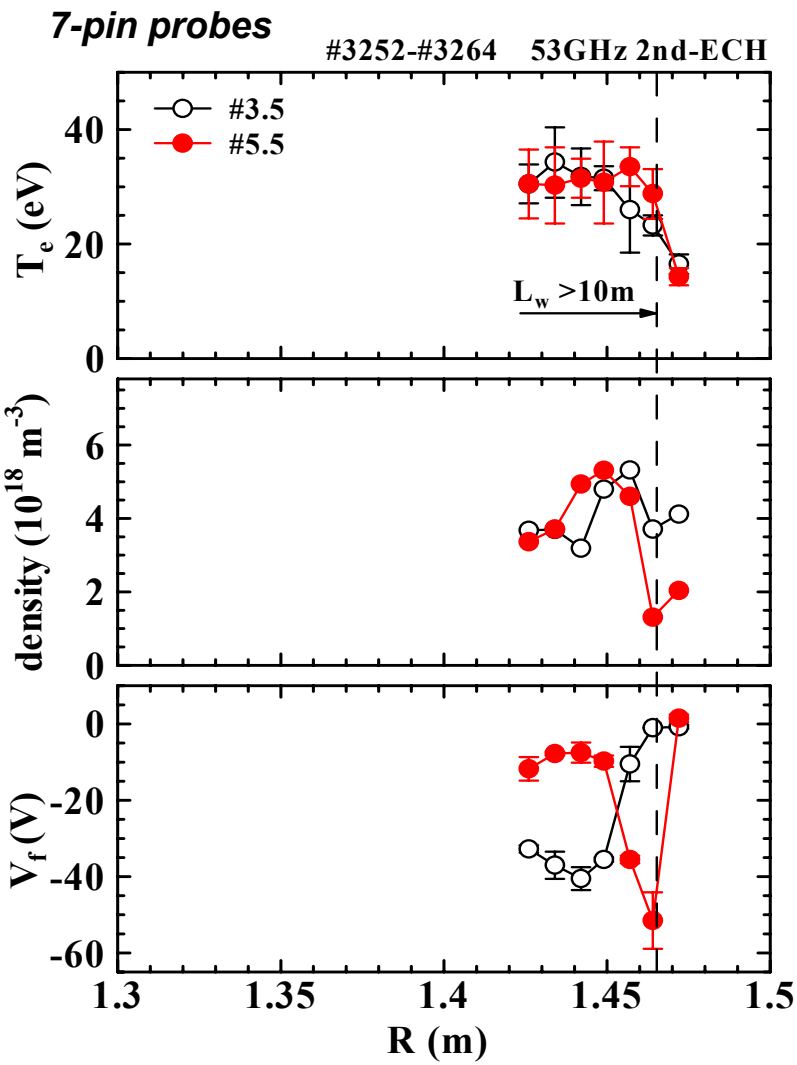
- **tokamaks:** ***the "in-out" and/or "up-down (or vertical)" asymmetries of the divertor flux are observed.***
- **helical devices:** ***asymmetric distributions the diverted plasma were reported in addition to the asymmetry due to the field topology itself.***
  - **In Heliotron E**, a very strong up-down asymmetry was observed for NBI and/or ECH plasmas. This divertor flow asymmetry is **related to convection-like losses of fast particles** and/or to losses enhanced by the **intrinsic vertically asymmetric field ripples**.
  - **In the Uragan-3M torsatron**,
    a strong up-down asymmetry of the divertor flow is also investigated for ICRF plasmas.
    In this case, the asymmetry is simply **related to direct (non-diffusive) losses of charged particles from the core region affected by the ion toroidal $B\times\nabla B$ drift**.

Divertor plasma distribution for ECH plasmas produced by three different heating schemes has been studied since 2000 in Heliotron J.

- 53GHz second harmonic ECH at B ≈ 0.95 T
  - Three non-focused microwaves (TE_{02}).
    $\Delta t \approx$ 40-50 ms, $P_{inj} \leq 0.4$ MW.
- 53GHz high field ECH at B ≈ 1.4-1.5 T
  - No resonance layers for electromagnetic waves in the core region. The EBW heating is supposed as a plausible heating mechanism in this case.
  - The injection launchers and their positions are the same as the 53GHz second harmonic ECH case.
- 70GHz second harmonic ECH at B ≈ 1.25 T
  - A focused single beam (TEM_{00} mode, $P_{inj} \leq 0.4$ MW, $\Delta t \leq$ 200 ms) with a diameter of ≈ 40 mm at the plasma center.

- Typical range of the core plasma
  - $n_e \sim 0.2\text{-}3\times10^{19}$ m^{-3}, $T_e \sim 0.2\text{-}1.0$ keV.

53GHz second harmonic ECH plasmas



Asymmetry in the density profile:

On #3.5 (top) array, the density did not decrease so much even in the private region (R > 1.465m).

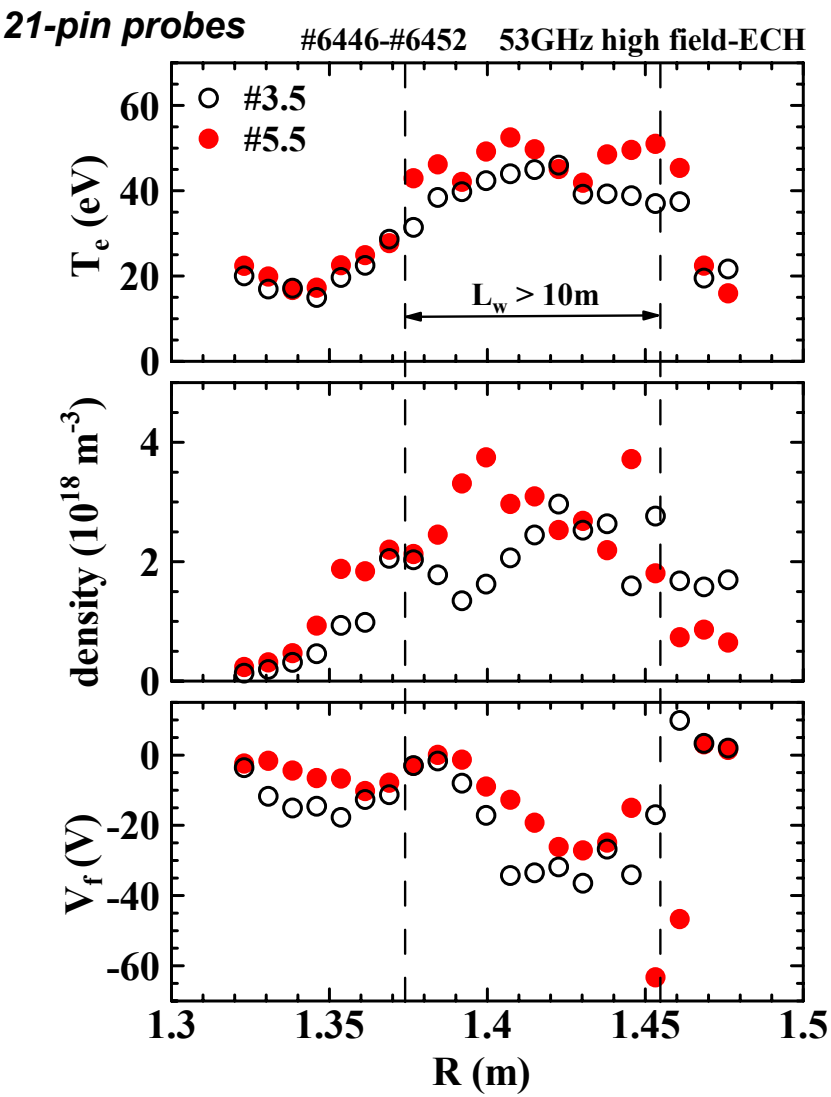
Asymmetry in V_f profile:

On #5.5 array ⇒ a big negative spike (R ~ 1.46 m).
V_f ~ –10 V (R < 1.45m)

On #3.5 array ⇒ no negative spike (R ~ 1.46 m).
V_f ~ –40 V (R < 1.45 m).

These peculiarities of the density and V_f profiles observed on the top (bottom) array came to appear on the bottom (top) as the direction of the confinement field was reversed.

53GHz high field ECH plasmas



Relatively higher density/Te and more negative floating potential were observed for 1.37 m < R < 1.46 m (the footprint zone).

Asymmetry in the density profile

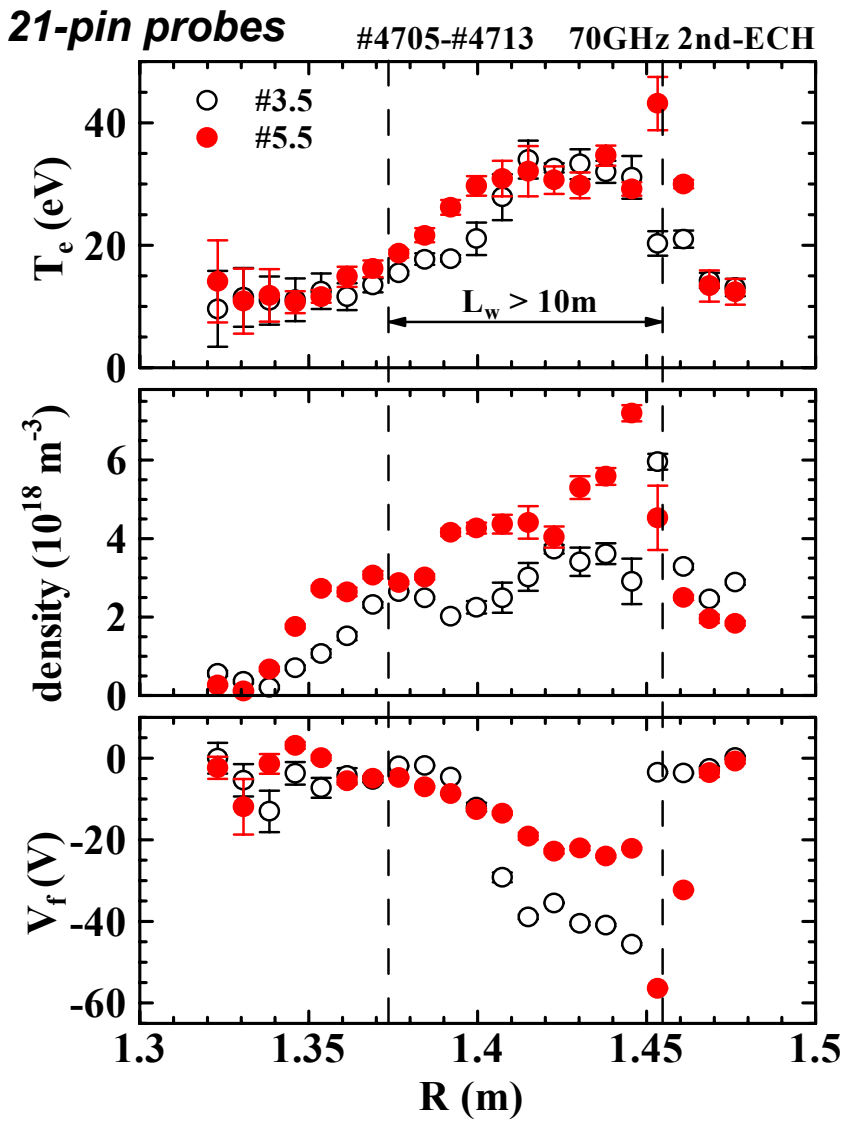
On #5.5 array ⇒ a convex-like profile (1.37 m < R < 1.42 m).
higher density than that on #3.5 probe.
On #3.5 array ⇒ a concave-like profile.

Asymmetry in V_f-profile

On #5.5 probe ⇒ a big negative spike (R ~ 1.45 m).
gradual increase to ~ 0 V (R < 1.43 m).
On #3.5 probe ⇒ no negative spike (R ~ 1.45 m).
large negative (1.14 m < R < 1.45 m).
rapid increase to ~ 0 V (R ~ 1.14 m).

$\Delta V_f \equiv |V_f^{5.5} - V_f^{3.5}| \sim 10$ V (1.42 m < R < 1.45 m) seems small compared to that in the 53 GHz second harmonic ECH case ($\Delta V_f \sim 30$ V).

70GHz second harmonic ECH plasmas



Almost the same asymmetric characteristics observed for the previous case was also observed.

The difference of the density profile in 1.37 m < R < 1.42 m is also observed.

The V_f difference between the two arrays ($\Delta V_f \sim 20$ V) is larger than that for the previous case but smaller than that for the 53 GHz second harmonic ECH.

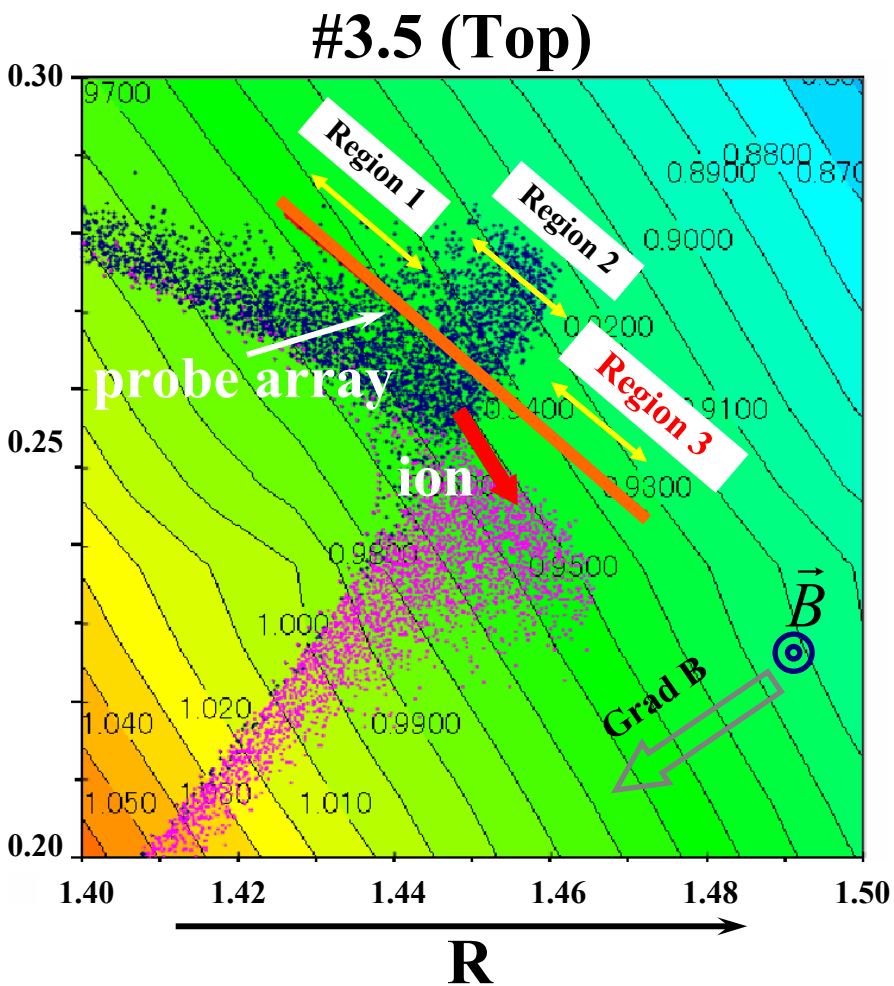
Almost the same asymmetric profiles for three ECH cases.

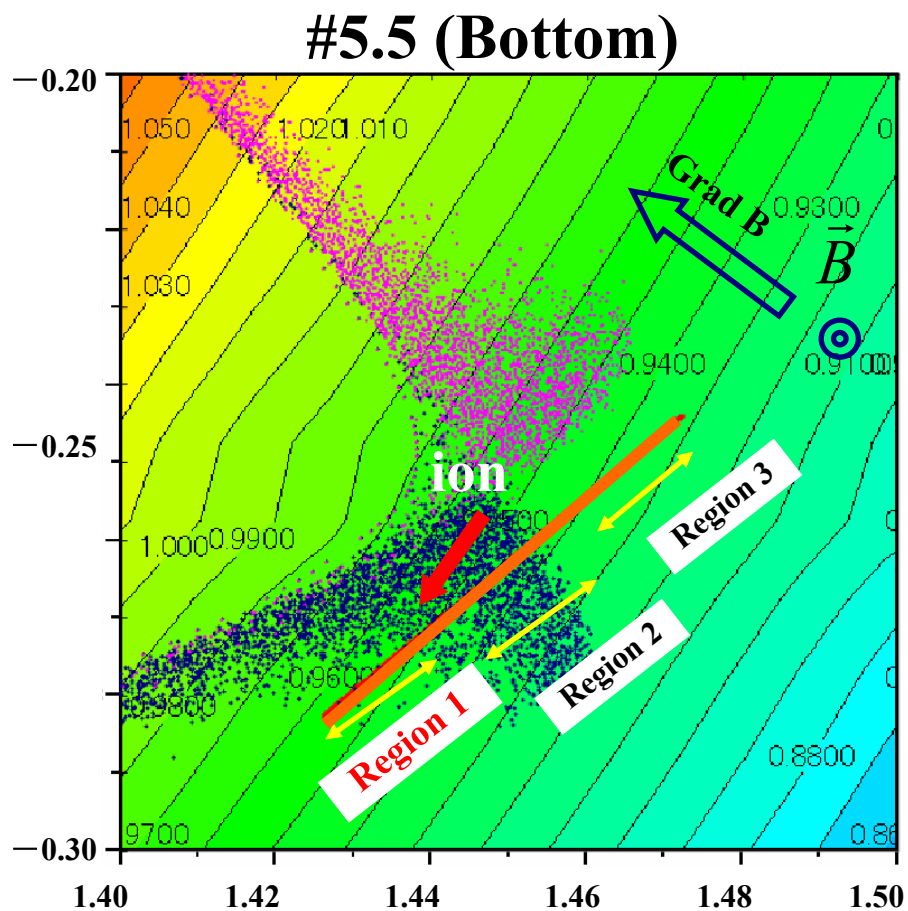
- The asymmetry is rather mild as compared to that observed in Heliotron E.

- **The observed asymmetric profile in the divertor plasma is insensitive to the ECH schemes and the toroidal position of the ECH source.**
  - The two 53GHz case ⇒ the same launching system.
    ⇒ (maybe) different heating mechanism each other.
  - The 70 GHz case ⇒ different the launching position and the injection mode.
- **The up-down asymmetric were turned over when the direction of the confinement field was reversed.**

- ***The distribution for NBI plasmas is under investigation.***

∇B drift effects on the divertor plasma flow – a simple consideration –

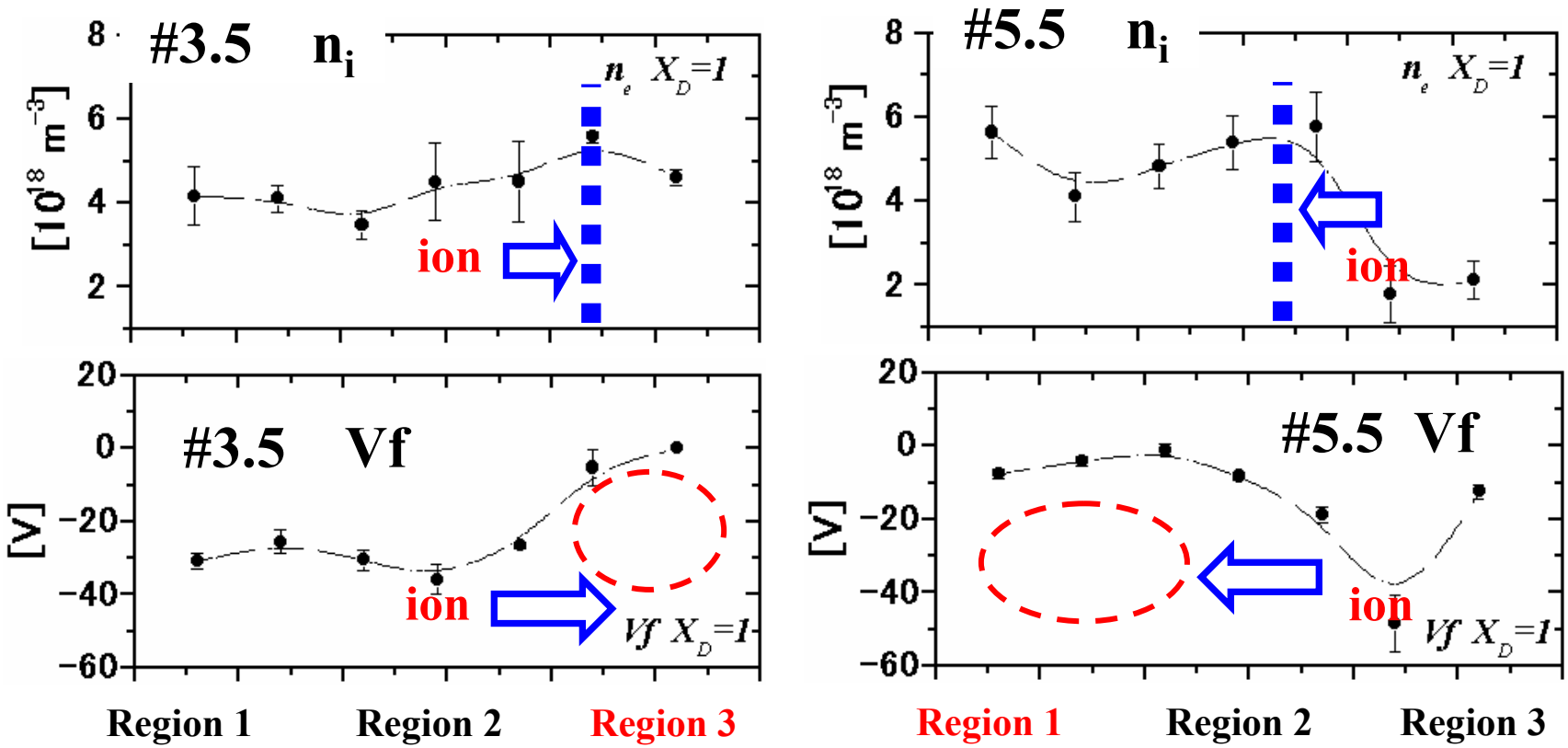




Direction of the ∇B drift of ion : Region 3 **Direction of the ∇B drift of ion : Region 1**

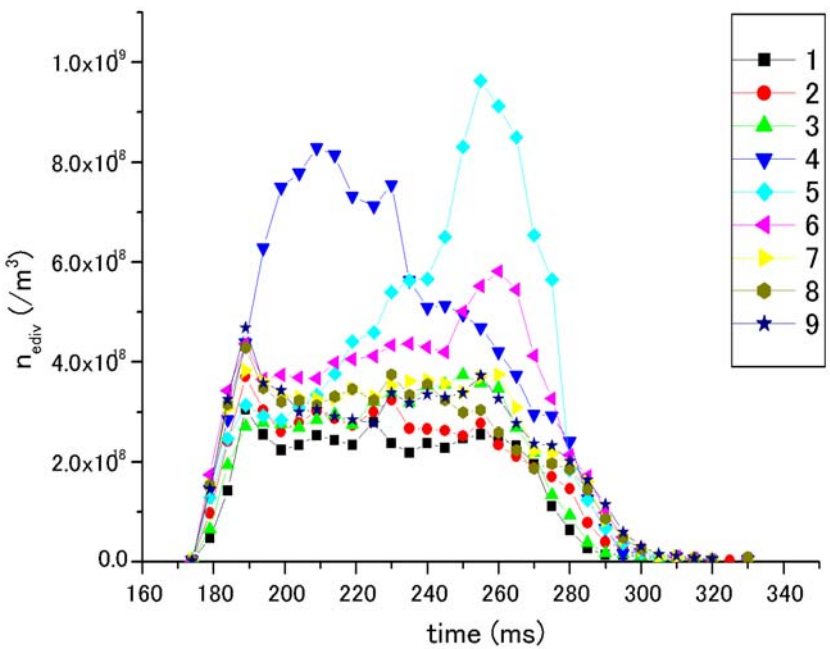
The ∇B drift effects on the divertor plasma flow is qualitatively consistent with the observation.

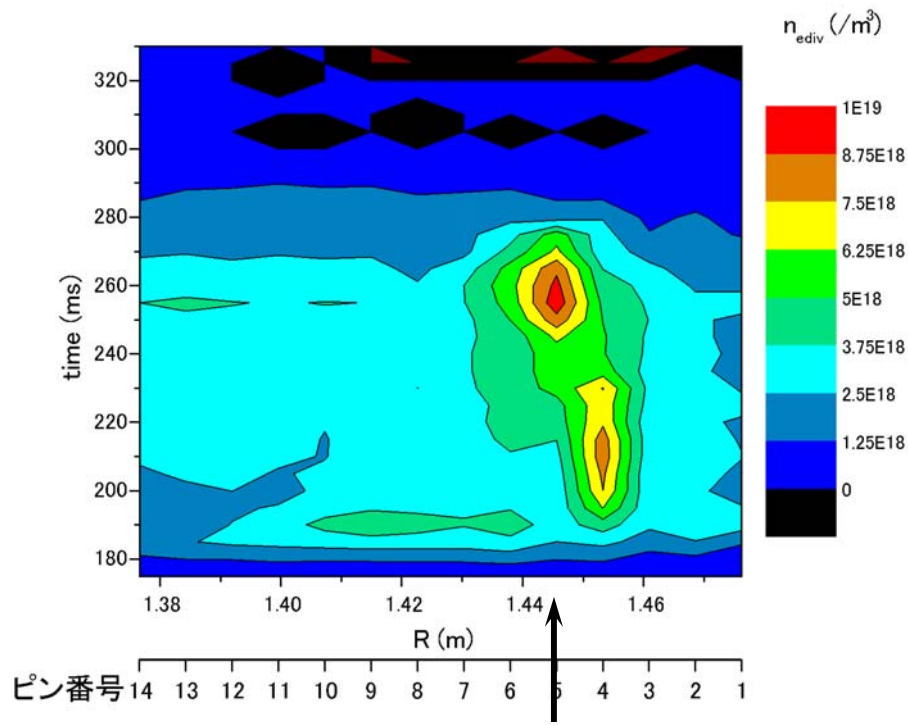
- **The ∇B drift of ions might "shift" the ion density profile.**



- **The excessive ion flux due to the ∇B drift might "lift" the local floating potential.**

The peak position of density profile on the divertor probe array spontaneously shifts during a plasma shot.





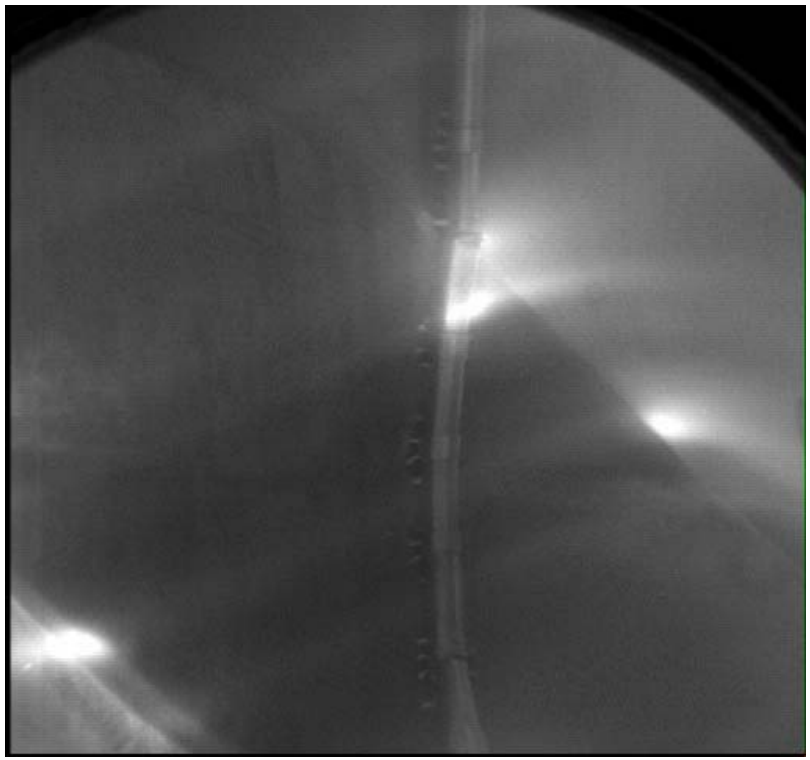
Max. of L_c

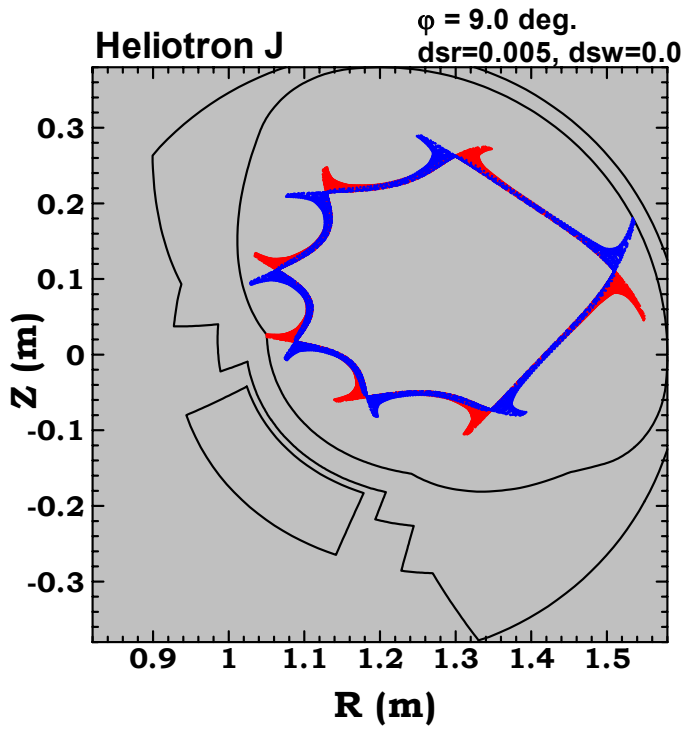
Mechanism(s) of this shift is not clear at present.

$\Rightarrow$ under investigation.

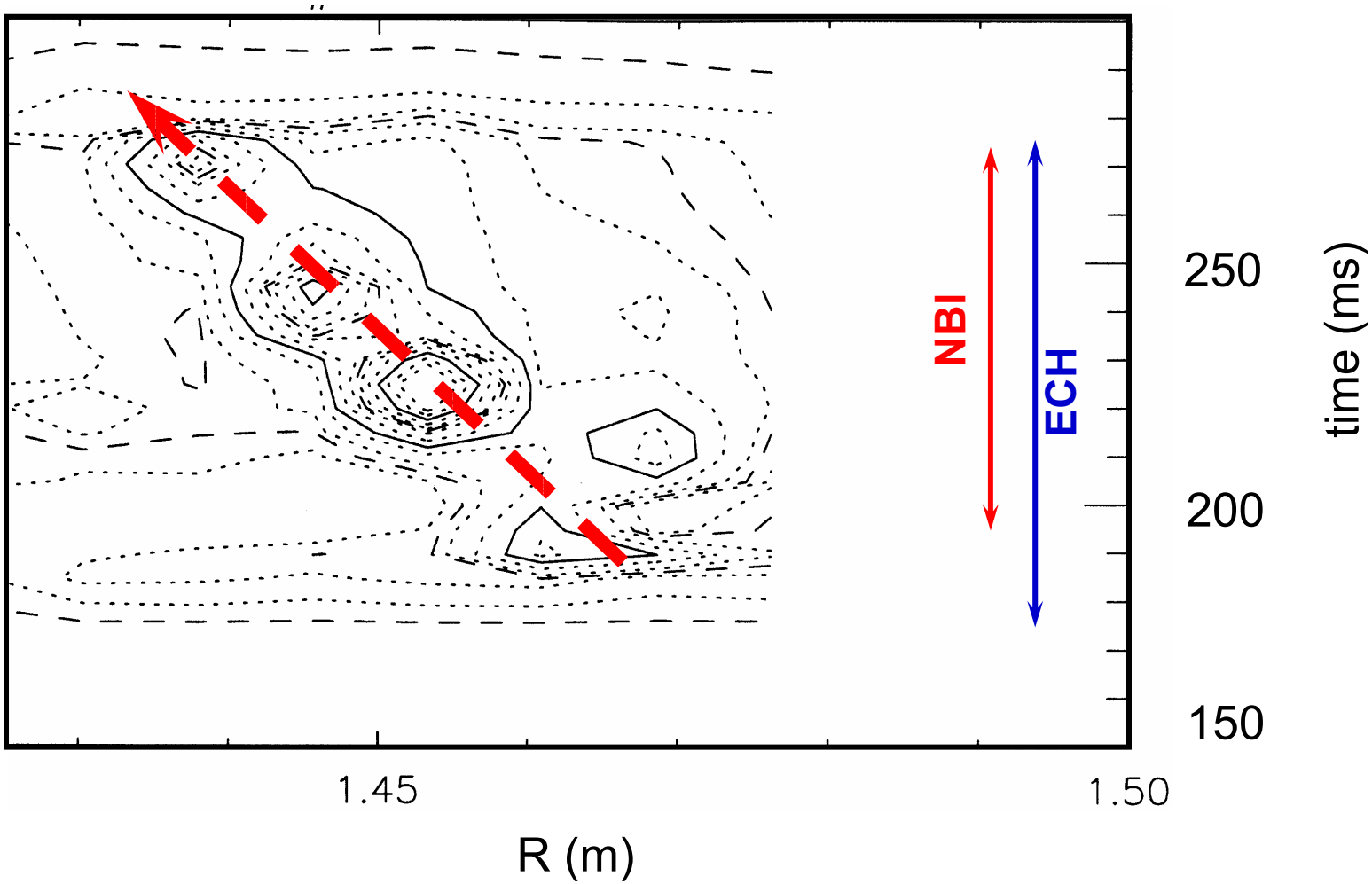
ECH Plasma, STD, #9477

Rather large spontaneous shift was observed in recent ECH+NBI experiments.





Change of I_s profile on the divertor probe #3.5 during an ECH+NBI plasma (#11175).



Summary

- **The existence of the up-down asymmetry in the divertor plasma profile was revealed.**
  - **independent of the heating schemes or the toroidal position of the heating source.**
  - **depend on the field direction.**
  - **The ∇B drift effects on the divertor plasma flow is qualitatively consistent with the observation.**
- **Spontaneous shift of the divertor trace was observed.**
  - **The mechanism of this shift is under investigation.**