Observation of Toroidal Flow on LHD

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Introduction

The stabilizing and destabilizing of the magnetic confinement plasma is considered to be sensitive to the profile of flow velocity.

A moderate shear of poloidal flow can suppress turbulence and reduce the transport, although a large velocity shear causes instabilities such as Kelvin-Helmholtz instabilities.

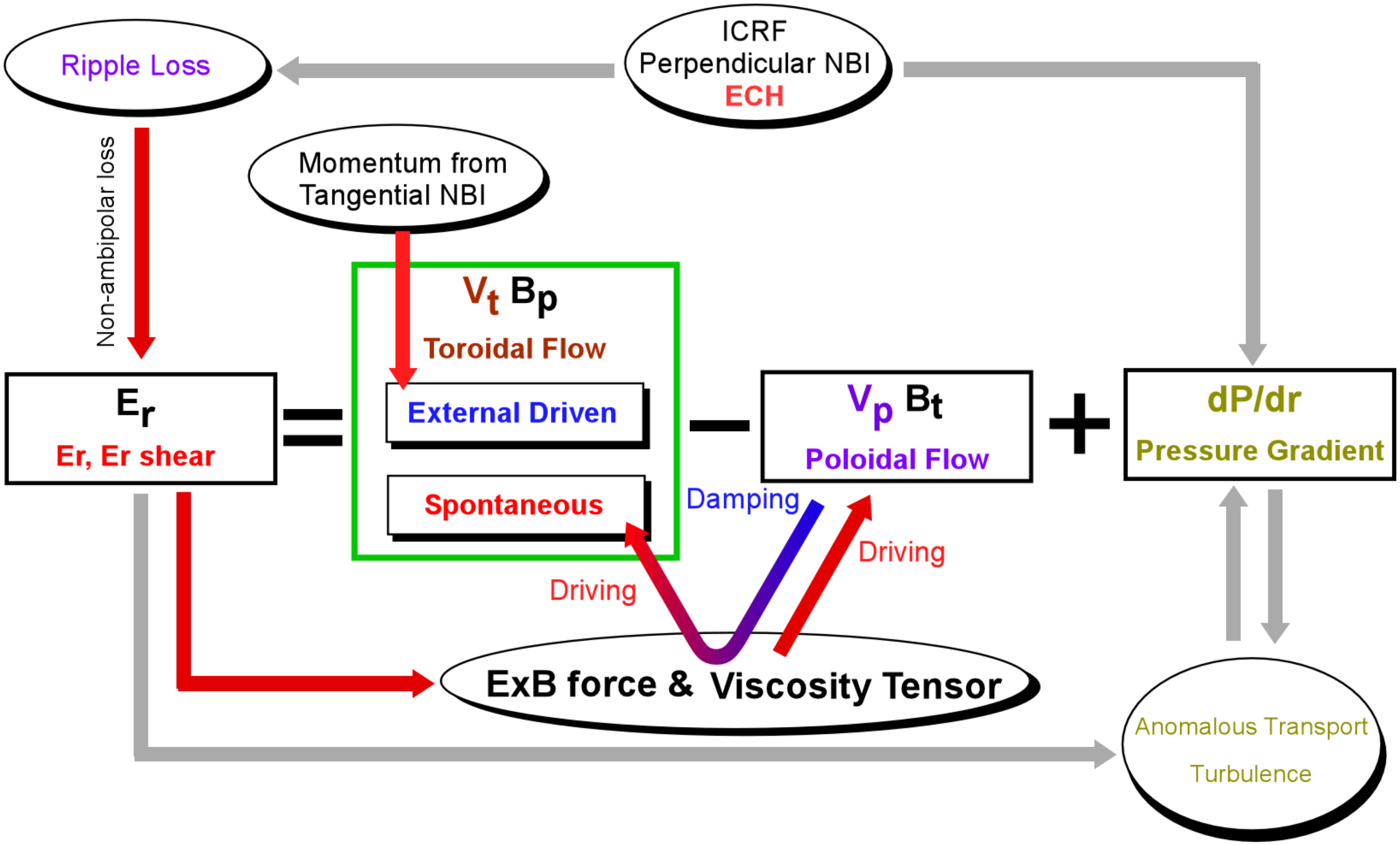
It has been pointed out that the toroidal flow contributes the stabilization of resistive wall mode in tokamaks. Therefore the spontaneous troidal flow becomes important in the next fusion device such as ITER, where the toroidal flow velocity driven by external momentum is expected to be not enough to stabilize the MHD mode.

The mechanism of driving the spontaneous troidal flow has a great interests in the momentum transport physics.

In this presentation, we will report observations of toroidal flow and discuss the mechanisms of spontaneous flow in helical plasma.

Spontaneous and External Driven Toroidal Flow

Radial Force Balance : $E_r = V_t B_p - V_p B_t + 1/(Zen)\ dp/dr$



The radial electric field is determined by the non-ambipolar loss or pressure gradient and the coupling of ExB force and viscosity tensor drives spontaneous toroidal rotation.

Observation of Toroidal Flow on LHD

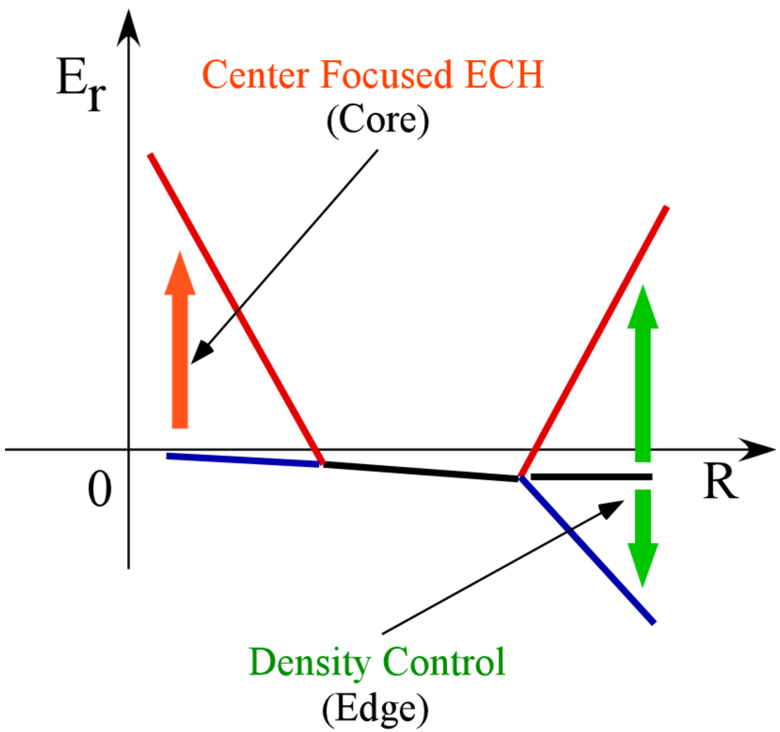
LHD

Control of NBI injection
(external momentum input)

Control of radial electric field by changing collisionality.
Density can change edge E_r
Local ECH can change center E_r

Measurement of both Toroidal and Poloidal flow with charge exchange spectroscopy

E_r control by changing collisionality

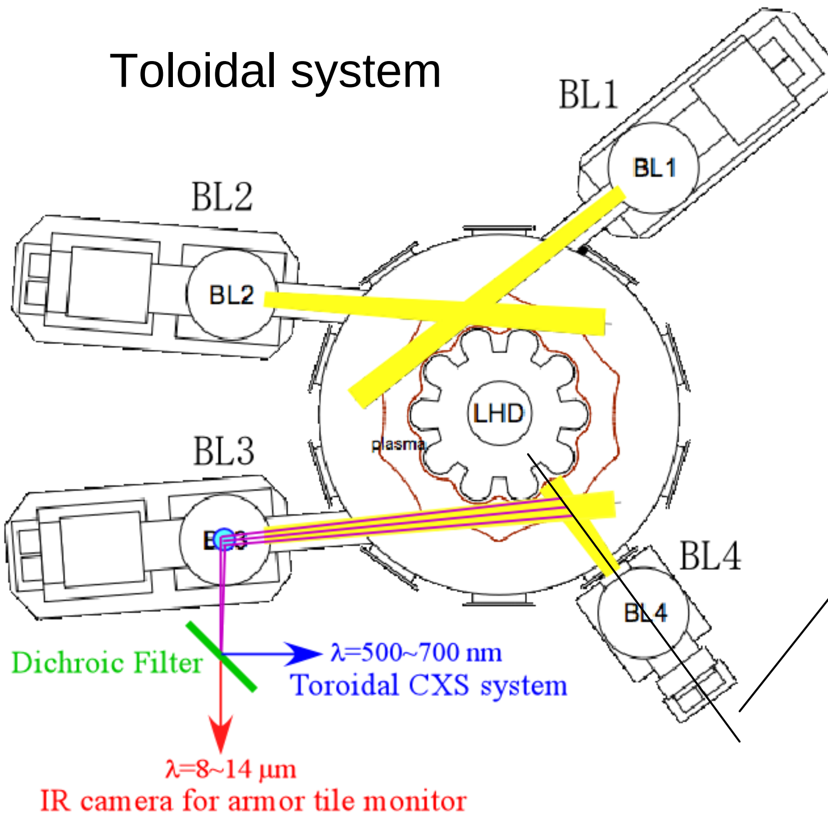


Both NBI driven toroidal flow and spontaneous toroidal flow depended on Er have been observed in LHD.

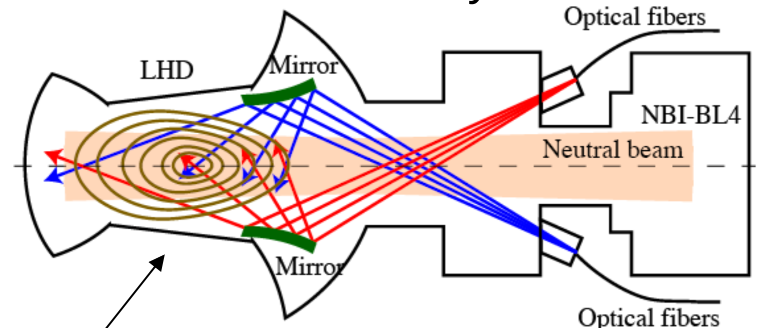
Line of Sights of CXS on LHD

Charge exchange spectroscopy measurement can be performed both with poloidal and toroidal line of sights.

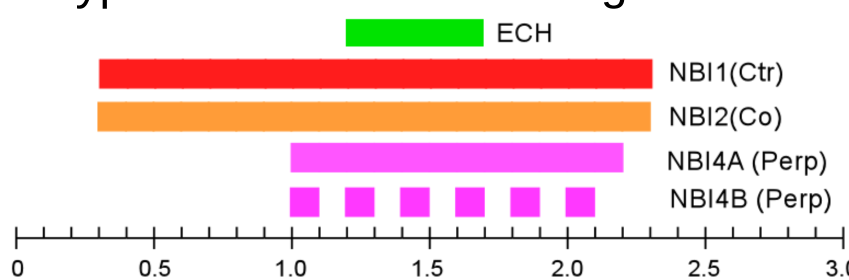
Toloidal system



Poloidal system



Typical scheme of discharge for CXS

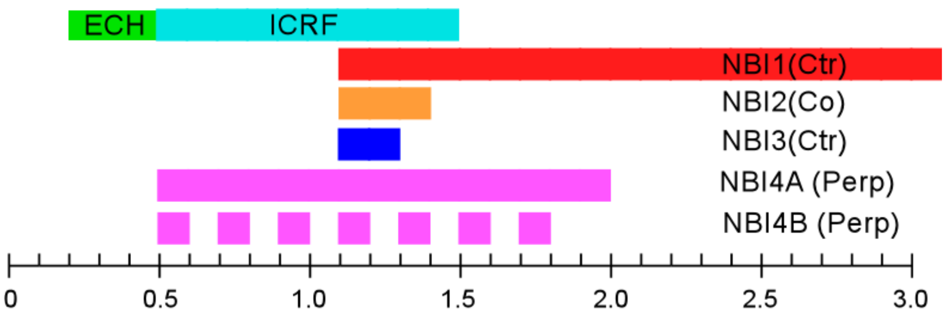


40keV perpendicular injection NBI with positive ion source

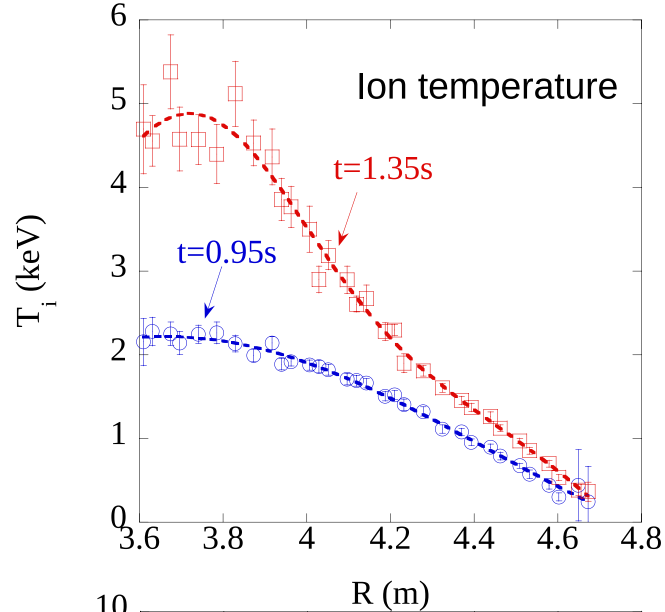
To acquire the background signal, the p-NBI is modulated with 100msec ON and 100msec OFF.

Profiles in the case of Counter Injection

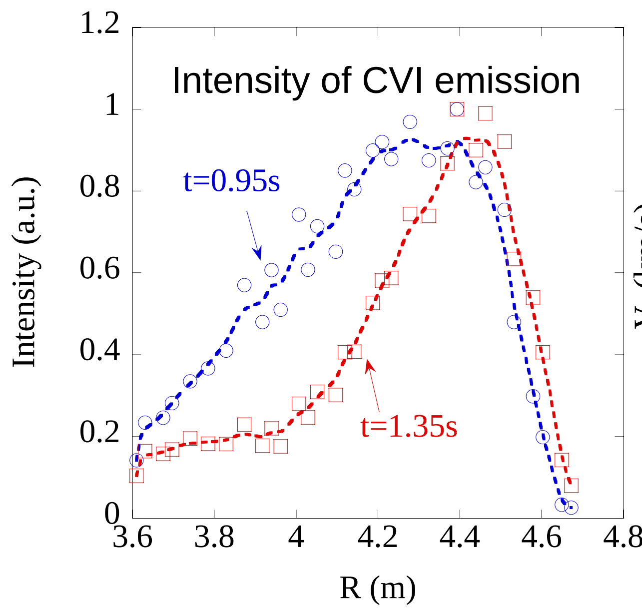
B_t=2.85T R_{ax}=3.6m γ=1.254 Bq=100%

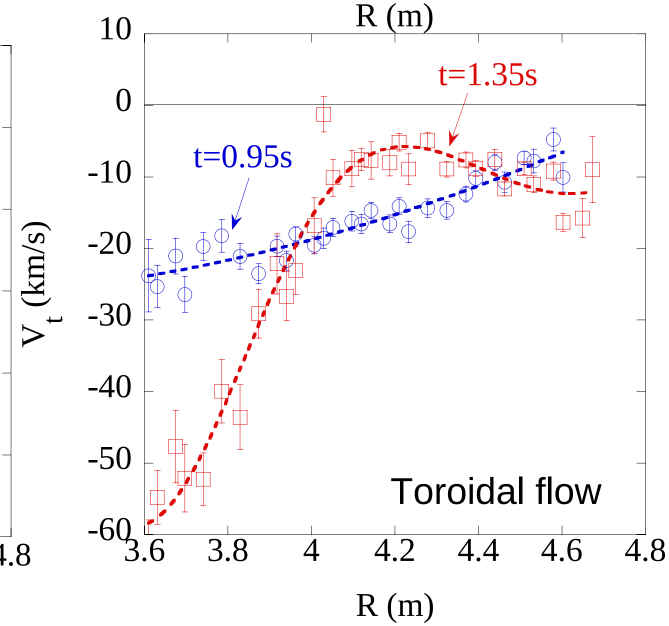


High Ion temperature (~4.5keV) obtained in NBI sustained plasma with electron density n_e~1.5x$10^{19}$$m^{-3}$.



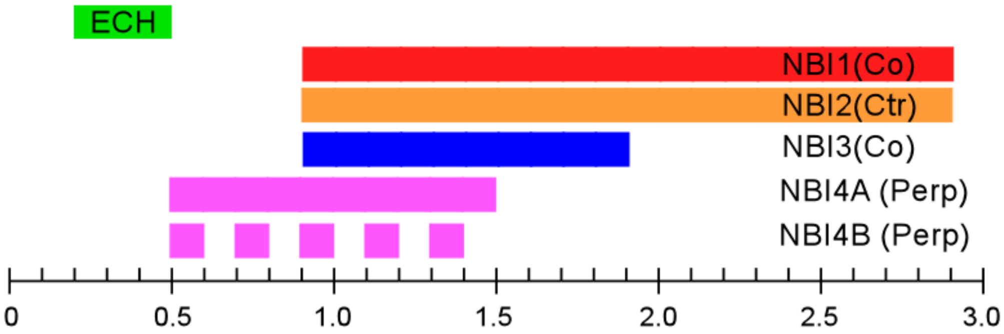
Strong toroidal flow is observed in the core region of the plasma and its direction is consistent with the direction of the NBI.

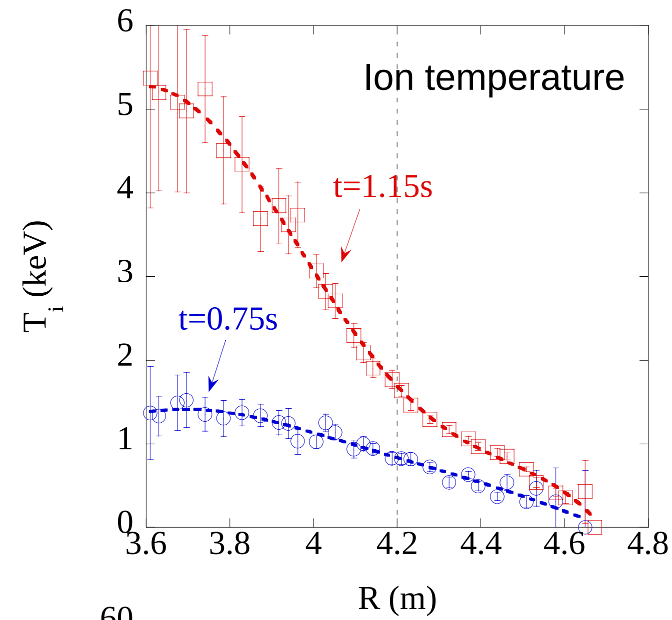




Profiles in the case of Co Injection

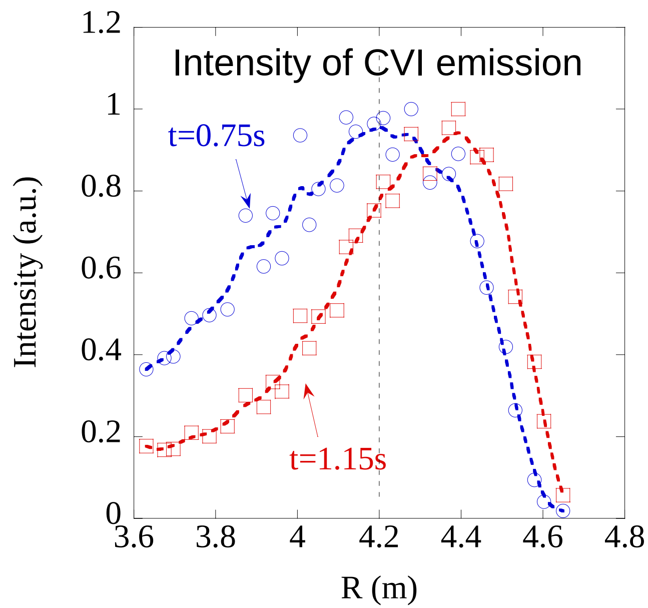
B_t=-2.769T R_{ax}=3.575m γ=1.254 Bq=100%

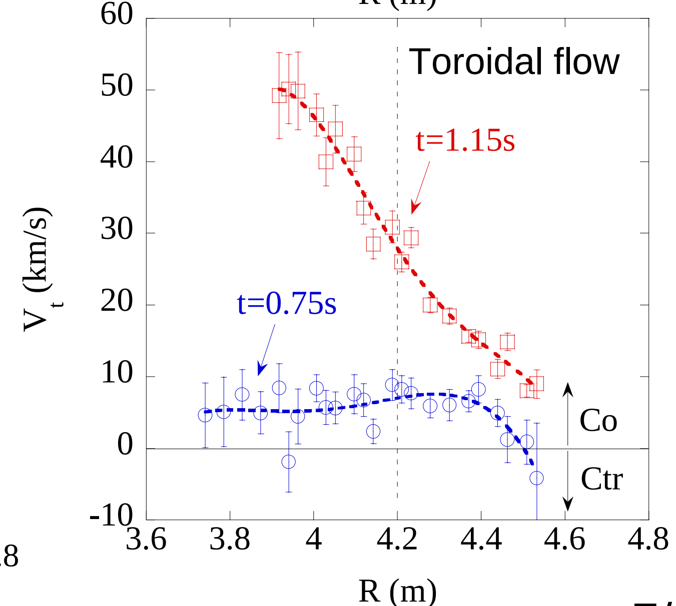




High Ion temperature (~5keV) obtained in NBI sustained plasma with electron density n_e~1x10^{19}m^{-3}.

The CXS intensity profile shows that the profile of carbon impurity is strongly hollowed when the T_i becomes high.





Toroidal Flow driven with NBI

Toroidal Flow driven by Externally Injection of Momentum

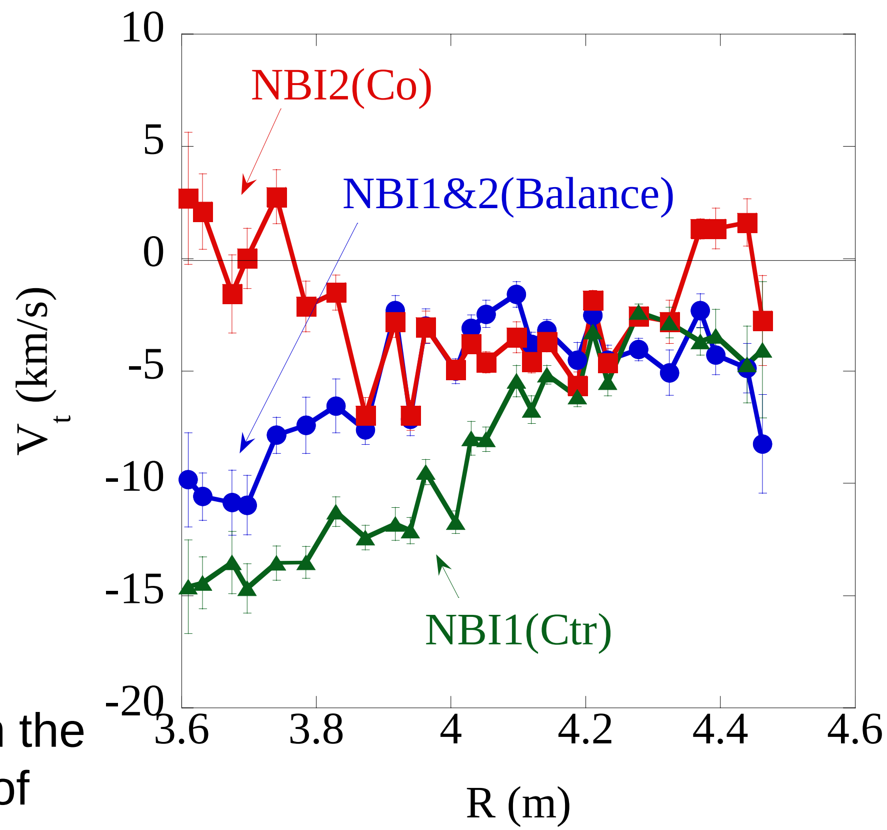
Toroidal flow is observed with in the case of co-injection, counter-injection, and balanced injection to see the NBI driven component.

The NBI dominantly drives the toroidal flow near the plasma center.

Co-injection case (NBI2) :
Toroidal flow drive inside the R of 3.9m

Counter-injection case (NBI1) :
Toroidal flow drive inside the R of 4.1m

Balanced-injection case :
Spontaneous component is observed.



The NBI driven component is small at the plasma edge.

It is considered to be the result come from the strong helical ripple and small deposition of the NBI power at the plasma edge.

B_t=1.5T R_{ax}=3.6m γ=1.174 Bq=100%   75488,75489,75493

Toroidal Flow driven by Radial Electric Field

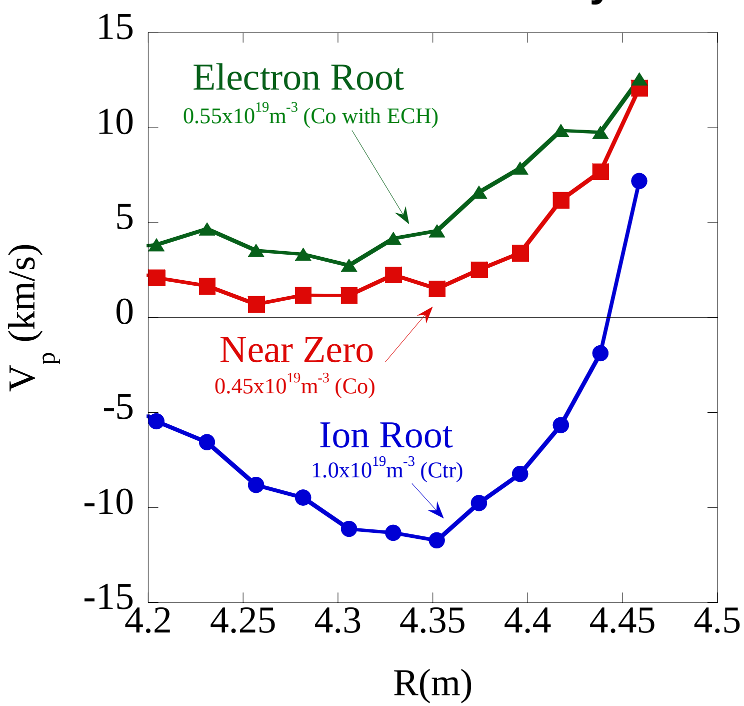
Positive and negative Er can be formed at the plasma edge by controlling the density and input power.

Toroidal flow at the plasma edge changed associated with the changing the radial electric field.

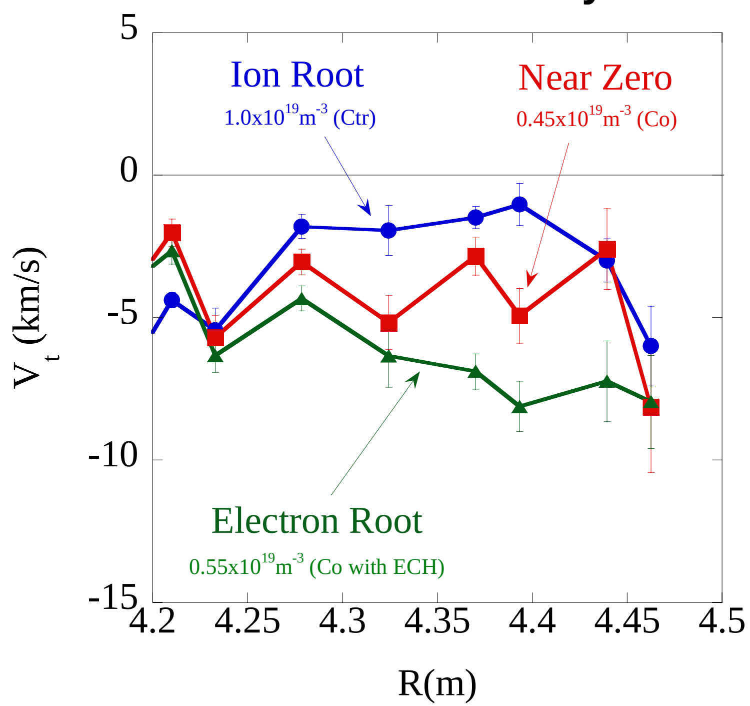
Vp < 0 (Ion root) ⇨ Drives Vt in co-direction.

Vp > 0 (Electron root) ⇨ Drives Vt in counter-direction.

Poloidal flow velocity



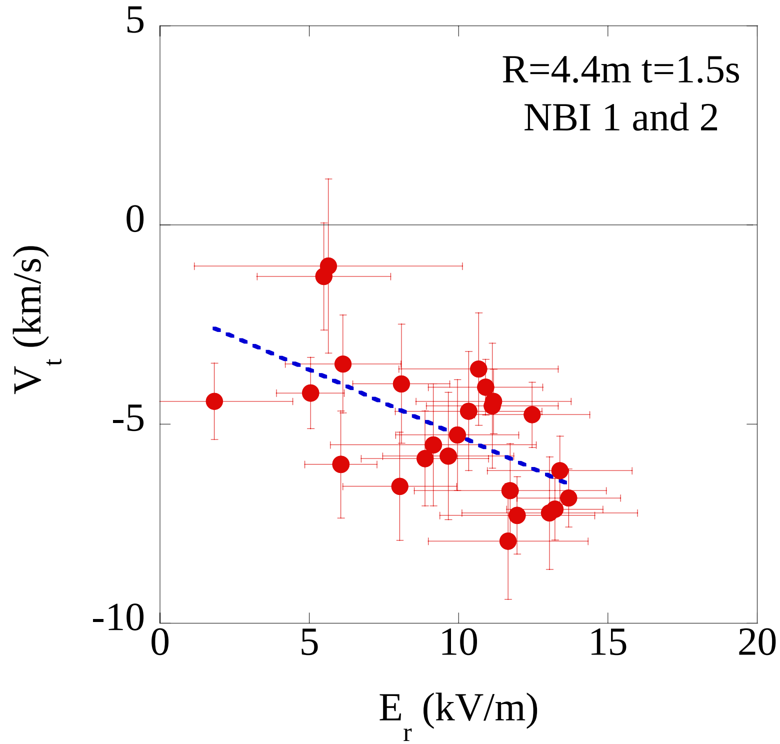
Toroidal flow velocity

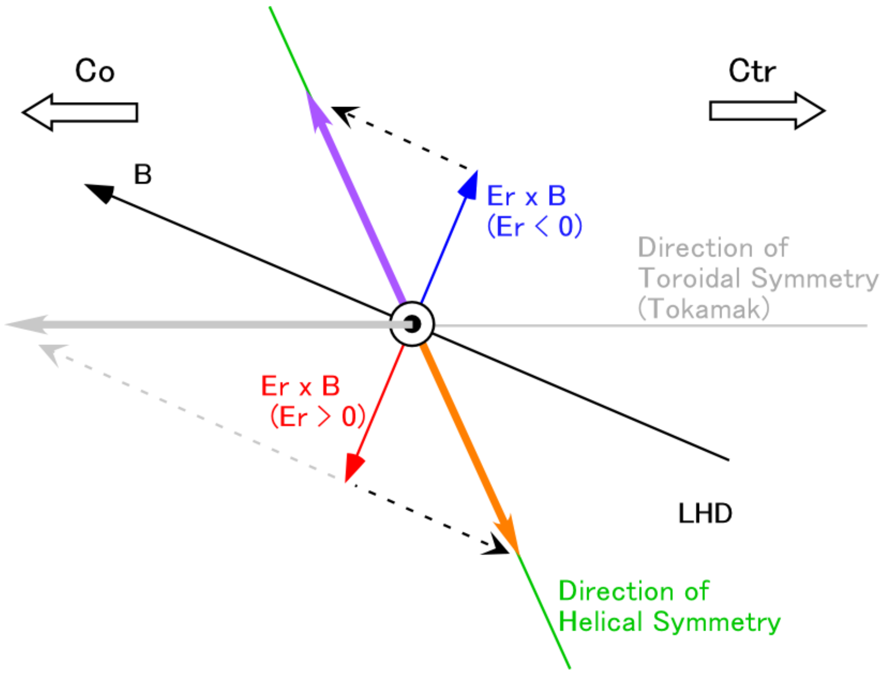


B_t=1.5T R_{ax}=3.6m γ=1.174 Bq=100%

Toroidal Flow driven by Radial Electric Field

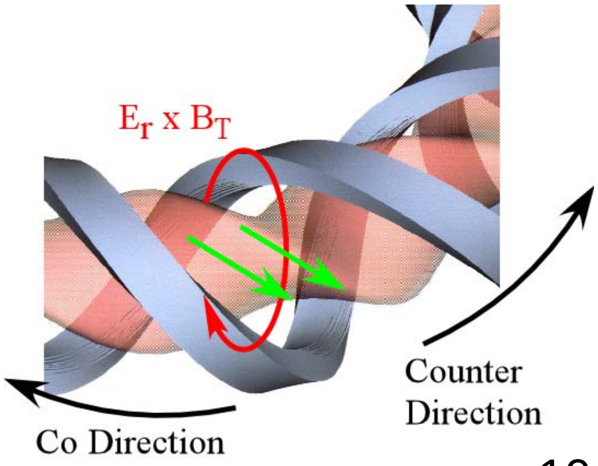
Dependence of toroidal flow velocity on radial electric field





ΔEr=15kV/m => ΔVt=5km/s

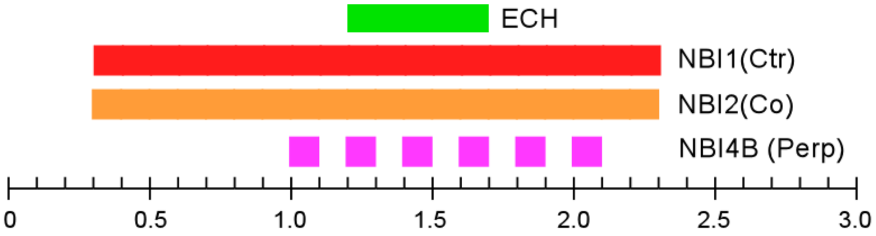
Counter flow is increased associated with growing up the positive E_r (electron root)

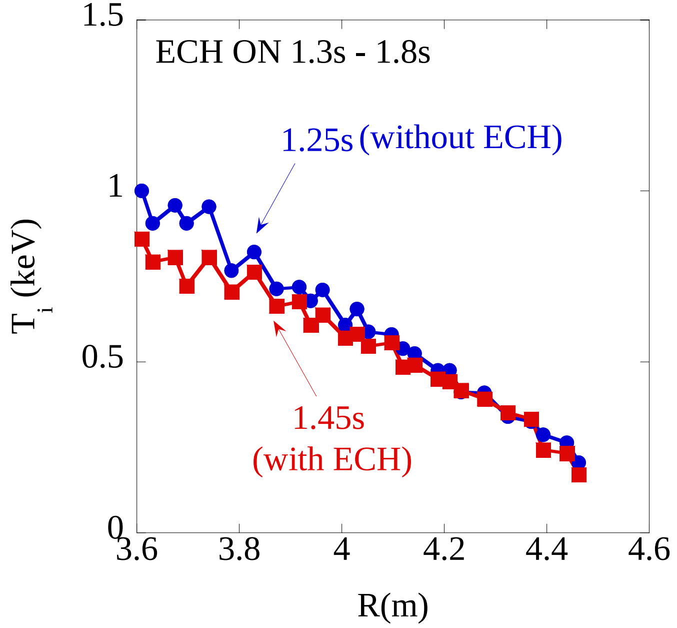


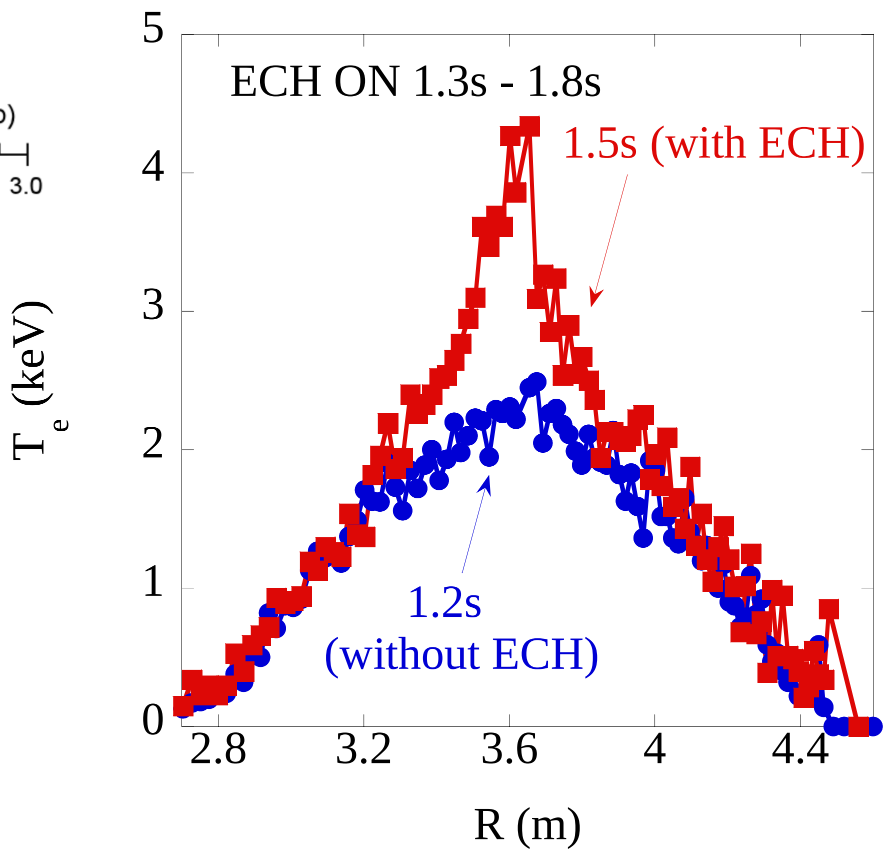
The direction of the poloidal flow driven by E_r x B is changed to the direction of helical pitch which has minimum gradient of magnetic field strength.

Toroidal Flow driven by ECH (1)

ECH is injected into the NBI sustained plasma (<ne>~0.4×10^{19} m^{-3}).
The NBI is injected with balanced combination to make the NBI driven flow small.
Modulated injection of NBI4 is just used for CXS measurement.

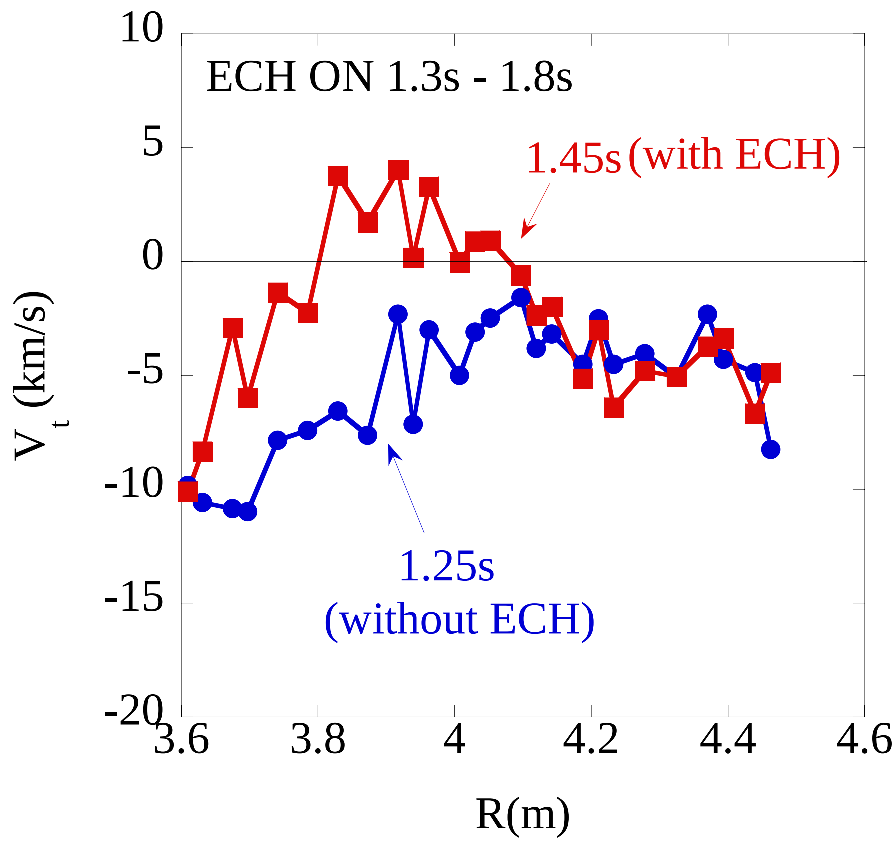


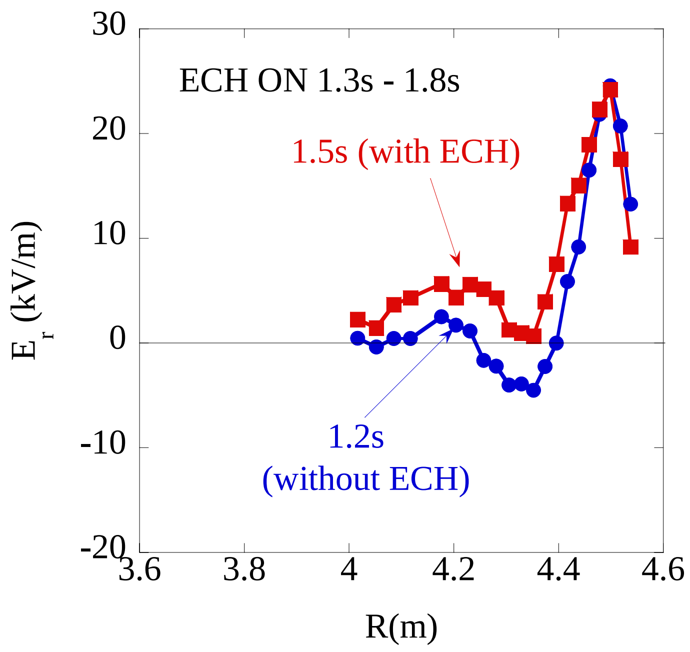




The CERC (Core Electron Root Confinement) profile is observed in the electron temperature, while the ion temperature has no significant change with the ECH.

Toroidal Flow driven by ECH (2)





Toroidal flow is driven into co-direction near the plasma core (ΔVt~10 km/s) during the ECH.

During ECH, the positive radial electric field appears associated with the formation of the CERC.

⇨ Positive Er drives the flow in the co-direction near the plasma core.

B_t=1.5T R_{ax}=3.6m γ=1.174 Bq=100% #75493

Summary

(1) The profiles of ion temperature, toroidal flow velocity and carbon impurity are measured with charge exchange spectroscopy using the charge exchange line of fully ionized carbon.

(2) **Toroidal flow driven by external momentum**

Strong toroidal flow parallel to the momentum input of NBI is observed in the core region of the plasma.

(3) **Spontaneous flow**

(3-1) At the plasma edge

The relation between the spontaneous toroidal flow and radial electirc field is investigated and the positive radial electric field drives spontaneous rotation in the counter direction (anti parallel to the $<ExB_p>$) at the plasma edge.

(3-2) In the plasma core

Toroidal flow driven in the co direction is observed when the ECH is injected. This observation shows the spontaneous rotation at the plasma core is opposite to that at the plasma edge (parallel to the $<ExB_p>$).

(3-3) The differences between core and edge can be explained by the differences in the ratio of $\varepsilon_t/\varepsilon_h$.