Poster 16

Radial electric field formation and its effect on the electron thermal transport in LHD high T_e plasmas

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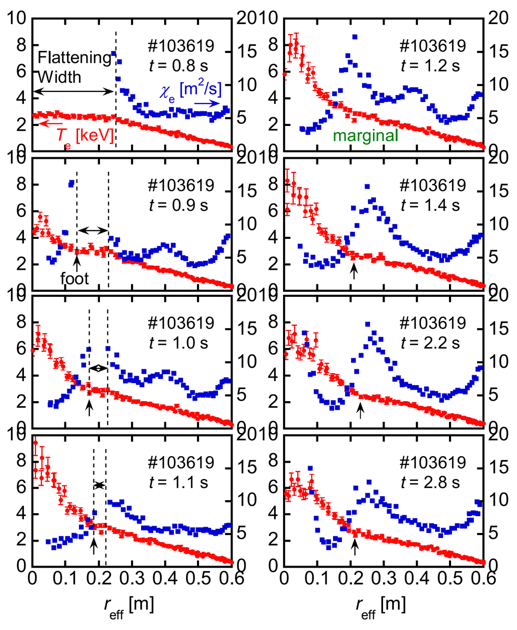
Motivation

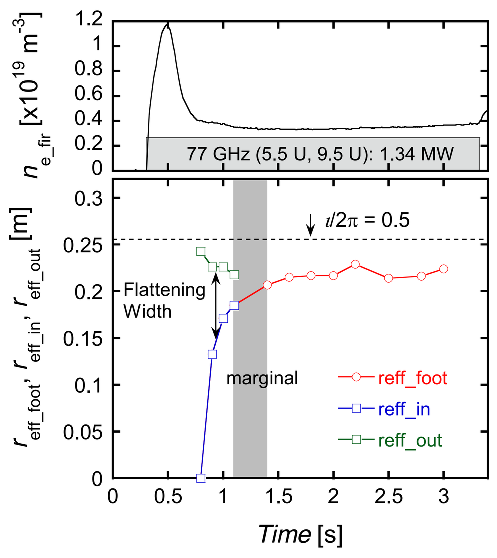
CERC plasma in LHD

High electron temperature plasmas with eITB are experimentally observed in LHD.

These includes features;
Steep T_e gradient
Electron-root E_r w/ strong E_r shear
Only ECH heating (in recent experiments)
T_e at the core exceeds 15 keV

called **CERC** (Core Electron-Root Confinement)





Local flattening

The eITB foot point of inside/outside approaches each other during the formation of CERC eITB (see figure above).
T_e at the core increases as the width of the flattening becomes narrower.
Foot point of eITB ends up at approx. ι/2π = 0.5[1,2].

Motivation

How are the E_r and its shear formed in CERC plasmas?
The E_r reduces the NC and/or turbulent transport??
What determines the eITB foot point?
It has been suggested that the close relationship b/w the foot point and the magnetic island or a low order rational[2]. However, it remains unclear.
In addition, the flow along the surface has a close relationship to island healing, which occurs the low collisional plasmas.

SInce the ambipolar E_r strongly affects the particle orbit, the ambipolar E_r, the parallel flow, and the NC thermal transport should be investigated at the same time.

FORTEC-3D[3] code, which includes the electron FOW effect is appropriate for such NC transport simulations in high T_e plasmas as CERC.
To clarify the eITB formation in CERC plasmas, NC simulations have been initiated using FORTEC-3D; the ambipolar Er and thermal diffusivity are compared to those experimental values.

FORTEC-3D

FORTEC-3D solves the DK eq. with δf Monte-Carlo method.
distribution function : $f = f_M + \delta f$
two weight scheme : w_i and p_i

$$\delta f(\boldsymbol{R},K,\mu) = \int dw dp\, w F(\boldsymbol{R},K,\mu,w,p;t)$$

$$f_M(\boldsymbol{R},K) = \int dw dp\, p F(\boldsymbol{R},K,\mu,w,p;t)$$

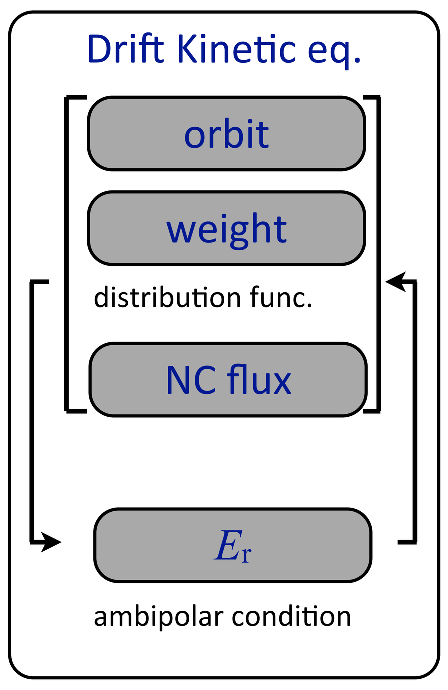
$$F(\boldsymbol{R},K,\mu,w,p;t) = \Sigma\delta(\boldsymbol{R}-R_i)\delta(K-K_i)\delta(\mu-\mu_i) \times \delta(w-w_i)\delta(p-p_i)$$

$$\dot{w}_i = -\frac{p_i}{f_M}\left[\boldsymbol{v}_d\cdot\nabla - K\frac{\partial}{\partial K} + C_{FP}\right] f_M$$

$$\dot{p}_i = \frac{p_i}{f_M}\left[\boldsymbol{v}_d\cdot\nabla - K\frac{\partial}{\partial K}\right] f_M$$

$$\epsilon_0\epsilon_\perp\frac{\partial E_r}{\partial t} = -e\left(\Gamma_i - \Gamma_e\right) \to 0$$

Γ_i is referred to DGN/LHD



The orbit and weights of each marker particle are followed with including collision in longer time step.
→ δf at the steady state determined.

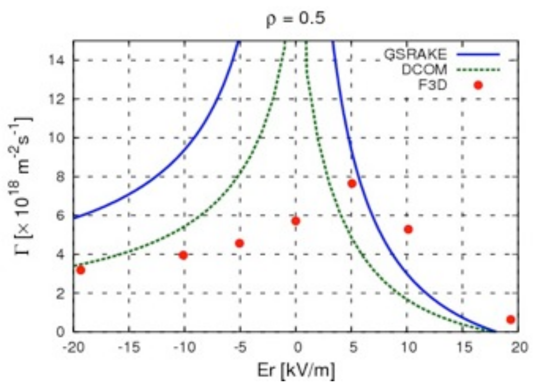
Note:
Ion particle flux Γ_i of DGN/LHD[4] are determined by locally and mono-energetically since T_i of CERC plasma is usually low.

FORTEC-3D includes;
1. Electron finite orbit width (FOW) effect
2. Like-particle collisions of both pitch angle and energy scatterings, satisfying the conservation laws
3. Unlike-particle collisions of only pitch angle scattering.

Finite orbit width effect

FOW effect is important for high T_e plasmas in LHD as CERC;
finite orbit width (FOW) effect for electrons becomes large.

Previous benchmark calculations b/w FORTEC-3D code for electrons[3,4] and local codes show that this arises due to the collisionless detrapping and the poloidal rotation.



$T_e(0)$ = 5.0 keV low collisionality

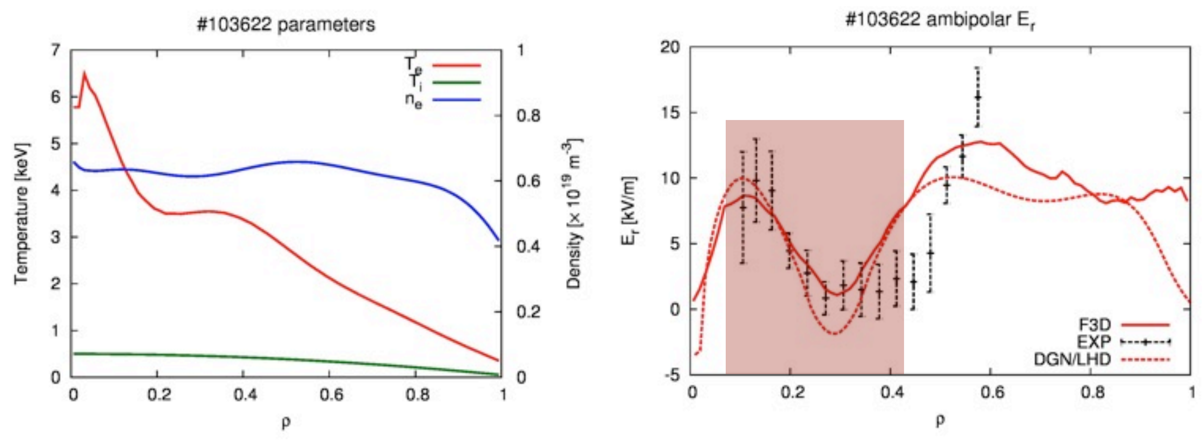
Estimated radial drift of helical trapped electrons ≅ 4 - 5 cm.

NC transport should be calculated with the electron FOW effect.

Numerical analyses

FOW effect on LHD CERC plasma

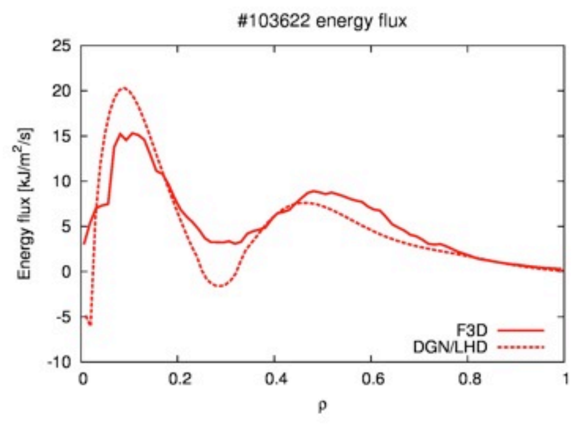
E-root E_r is formed in high T_e CERC plasmas in LHD



The ambipaor E_r is compared to both DGN/LHD and the experiment.
Results of FORTEC-3D agrees well with E_r evaluated by the potential profile observed by HIBP.
Quite similar values are obtained b/w FORTEC-3D and DGN/LHD.

FOW effect does not influence so much on the steady-state ambipolar E_r.

NC energy flux w/ and w/o FOW effect is compared to each other.

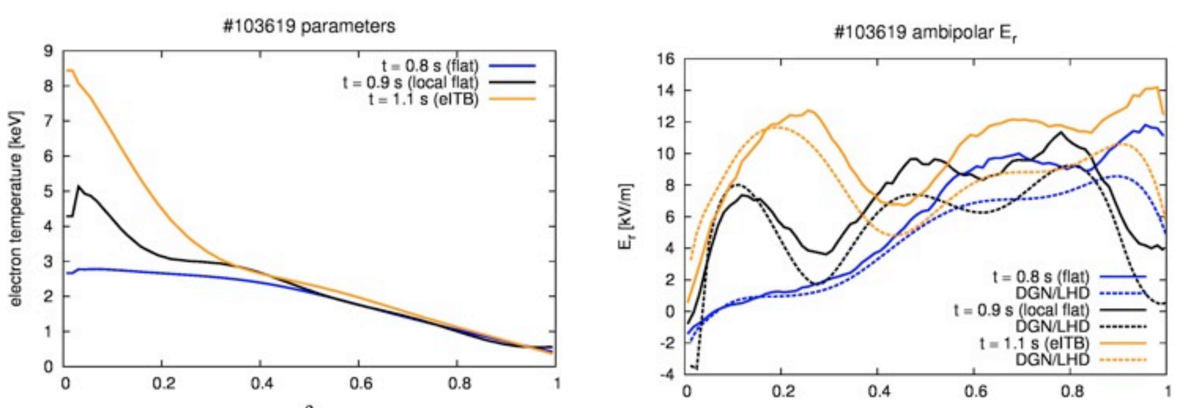


NC energy flux is 30 - 40 % reduced compared to that w/o the electron FOW effect.

FOW effect rather important for the NC thermal transport.

The E_r formation and the thermal transport

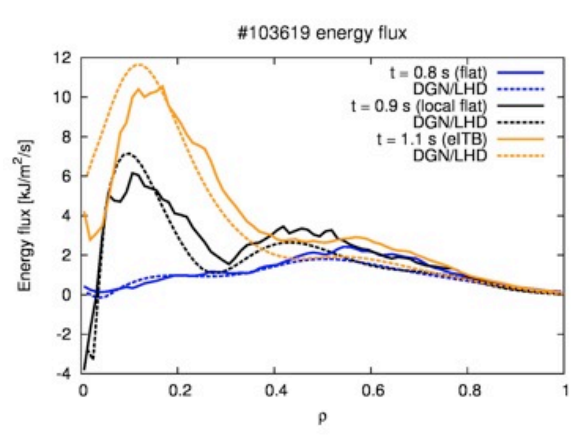
The ambipolar E_r and the NC energy fluxes are also investigated for #103619.



Along with the eITB formation, the ambipolar E_r gradually grows to the electron root with steep shear.

The region of the sheared e-root E_r moves outward.
→ qualitatively agrees to the movement of the eITB footpoint.

E_r goes to zero locally.
→ corresponds to the position where the local flattening of T_e gradient (eITB footpoint).



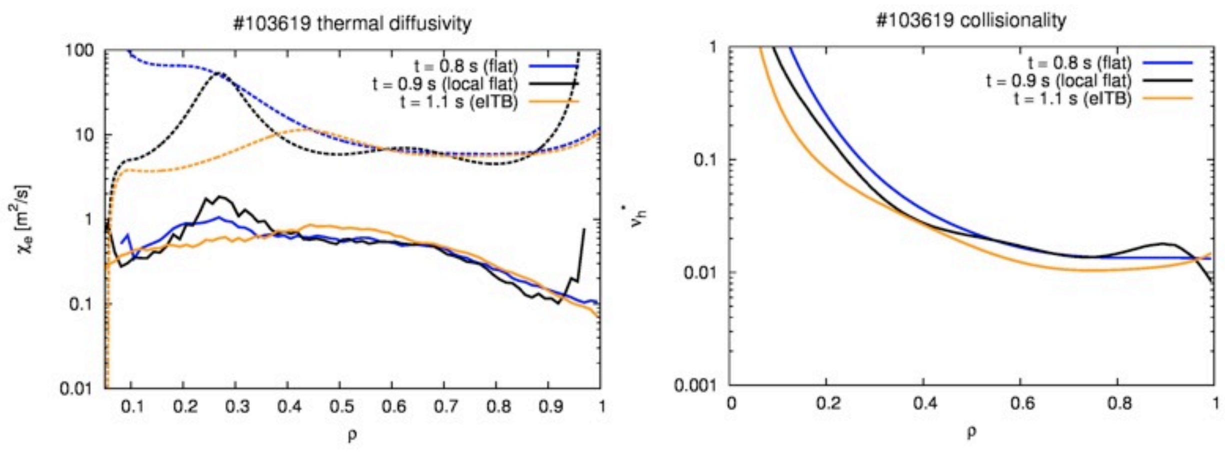
The total energy flux increases as the temperature increases.

NC thermal transport increases due to the formation of the steep T_e gradient in CERC plasmas.

Numerical analyses

Thermal diffusivity

Large E_r at the core reduces the electron transport.



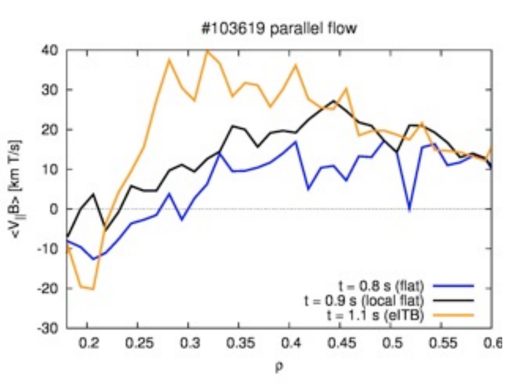
Although T_e increases in the CERC formation, χ_{NC} (solid) remains low.
→ $1/\nu$ dependence ($\propto T_e^{7/2}$) does not appear due to the formation of the e-root E_r even in the $1/\nu$ region.
This indicates that the e-root E_r forms to rather compensate the increase in the NC thermal transport in the eITB formation process in the CERC plasma.
First, the thermal diffusivity reduces at the core (t = 0.9 s), then it reduces approximately at ρ < 0.4 region (t = 1.1 s), where E_r has the shear.
The comparison of the χ_{NC} to χ_{exp} (dashed) suggests that the main reduction of the thermal transport is attributed to the reduction of the turbulent transport, since χ_{NC} is kept low.
→ GK simulations for ETG turbulence are required.

NC thermal diffusivity is still slightly large in the flattening region due to the absence of the large e-root E_r.

Electron parallel flow (tentative results)

In general, the eITB formation in LHD tends to take place for a plasma with counter NBI injection (w/ plasma current in the ctr-direction) than that with co-injection[2].
On the other hand, all the CERC plasmas calculated by FORTEC-3D in this work are made by ECH only.
Is there any relation b/w the parallel flow in ECH plasmas and the momentum input in NBI plasmas??

Electron parallel flow is obtained by FORTEC-3D for #103619.



Results show the parallel flow in the co-direction generated at the flattening region.

This corresponds to the bootstrap current of electrons in the ctr-direction. The current density is approximately up to 10 kA/m³.

Current in the ctr-direction in the CERC formation qualitatively reproduces the tendency of the eITB formation in past LHD experiment[2].

Summary

Summary

Experimental analyses of CERC plasmas have been carried out.
We have found;

- The electron FOW effect is still important for the NC energy flux and thus the thermal diffusivity rather than for the ambipolar E_r.
- Strong shear of E_r, leading to the improved confinement, is formed in the inner region of local flattening region when the eITB forms in a CERC plasma.
- The NC thermal diffusivity remains low level during the eITB formation, and no $1/\nu$ dependence appears. Formation of the e-root E_r compensates the increase in the NC thermal transport.
- The direction of the electron parallel flow is qualitatively the same as that of the previous experimental study.

Discussions

To elucidate the mechanism of eITB formation;

- The turbulent transport level will be evaluated by GKV-X[5].
- Effect of the island, or perturbation field will be included.
- The parallel flow should be evaluated with the momentum conserving collision operator b/w electrons and ions.
- Effect of the ECH heating on the NC transport and the E_r formation should be investigated.

References

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