Gyrokinetic analysis of turbulent transport in helical systems with different magnetic shear

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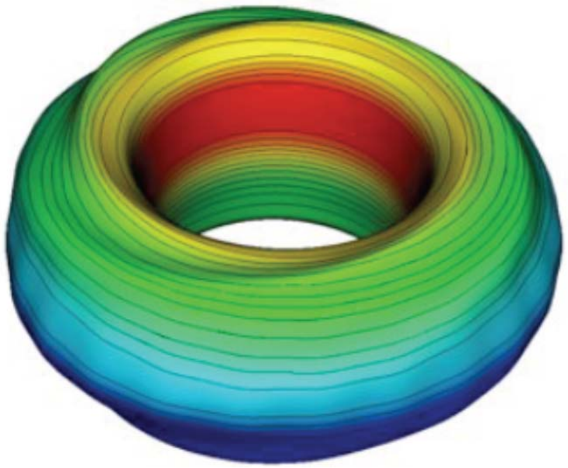
Motivation

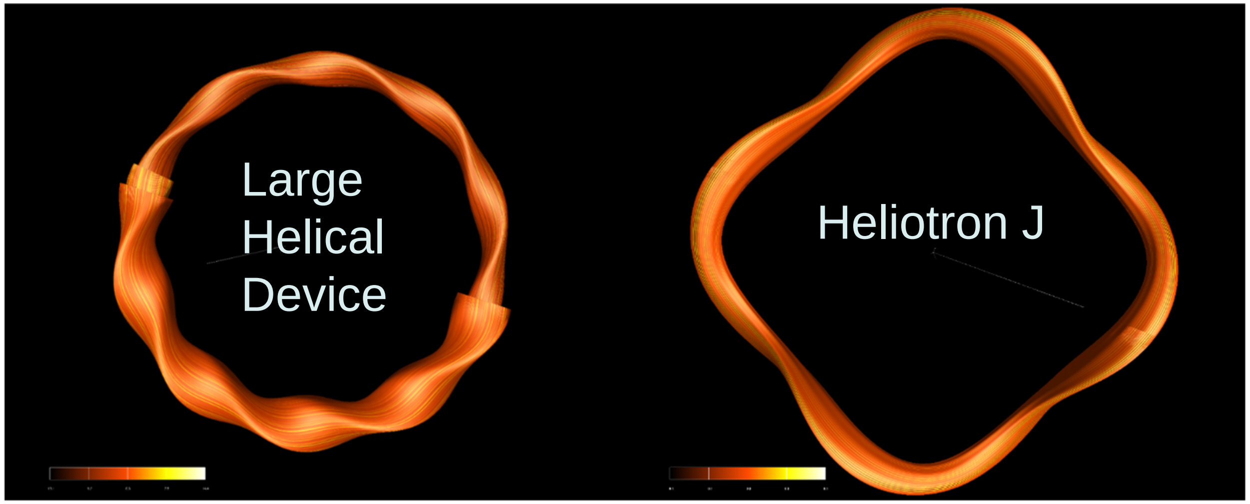
– Approximate degrees of deviation from axisymmetry
  - **3D tokamak** ($\delta B_{n\neq0}/\delta B_{n=0}$ = 10^{-3} to 10^{-2})
  - **Helical reversed field pinch state** ($\delta B_{n\neq0}/\delta B_{n=0}$ = 0.03 to 0.05)
  - **Stellarator** ($\delta B_{n\neq0}/\delta B_{n=0}$ = 0.1 to 0.3)

D. Spong, APS 2014

Tokamak with RMP

Resonant fields - ELM coil





D. Spong, APS 2014

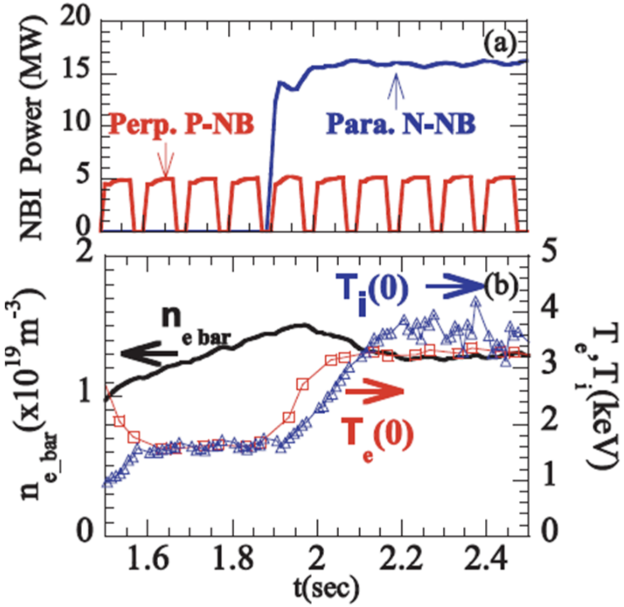
Outline

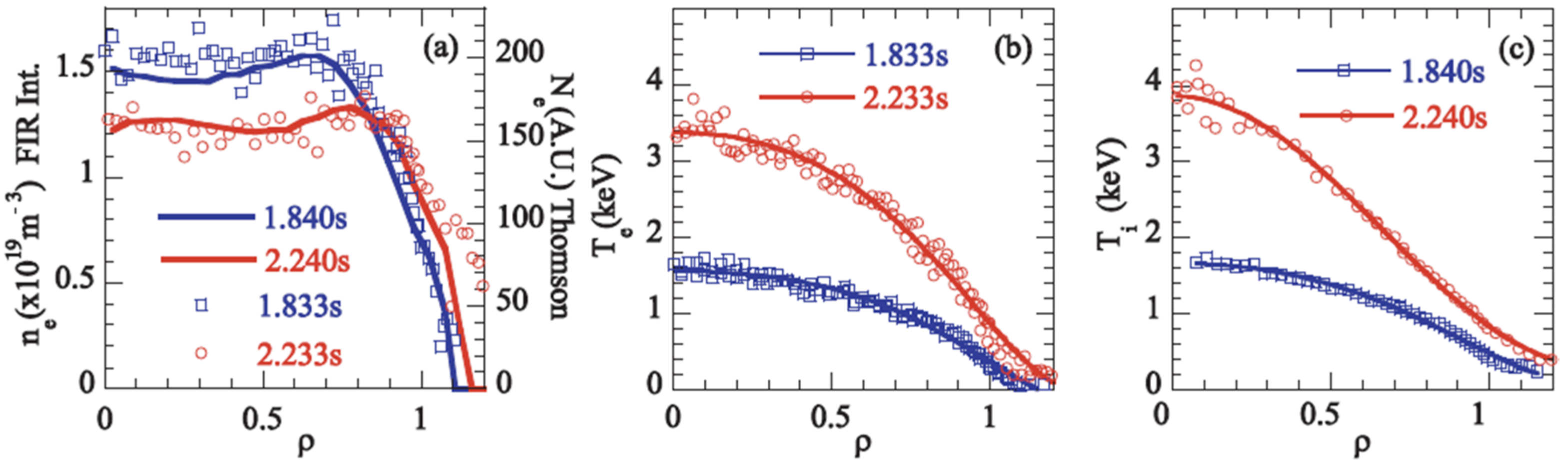
- Introduction
- Large Helical Device (LHD)
- Heliotron J (HJ)
- Comparison
- Summary

	LHD-L	HJ-ST
R_0/a	6.2	7.3
$\rho = r/a$	0.68	0.5
q	1.5	1.7
$\rho_*[10^{-3}]$	2.	4.5
ν_i^*	0.083	3.2
$\beta\,[\%]$	0.2	0.05
T_e/T_i	0.96	1.3
R_0/L_n	2.7	9.3
R_0/L_{Ti}	8.7	13.
R_0/L_{Te}	9.1	17.
$\hat{s}$	1.2	0.023
$D_{\rm well}$	-0.01	0.74

LHD discharge #88343

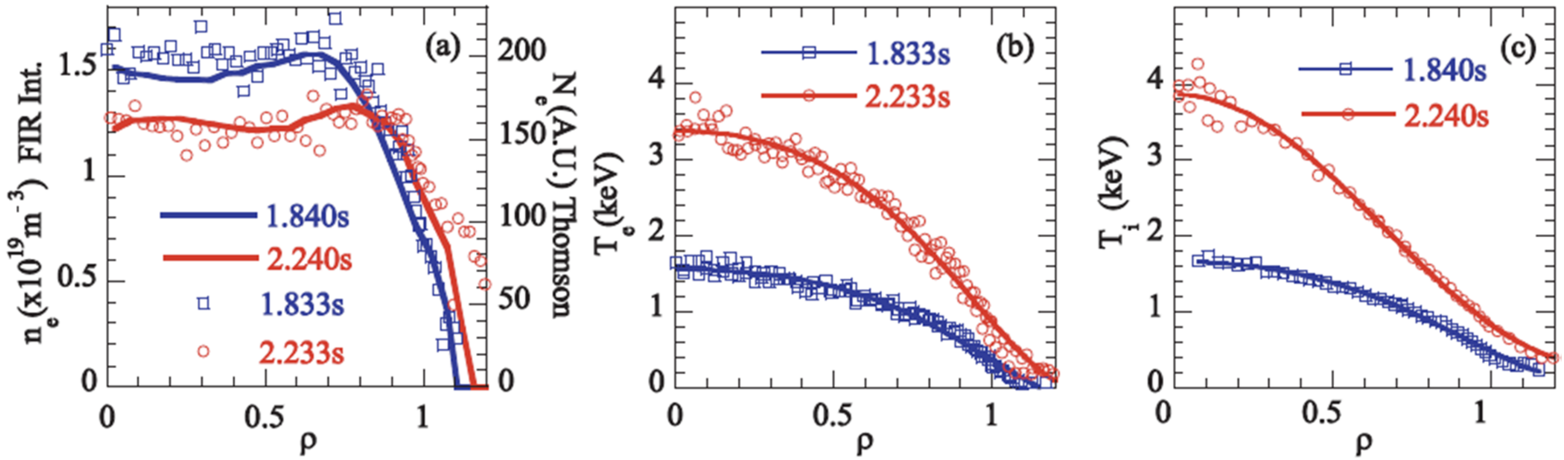
- B=2.75T, R=3.6m (shifted to 3.75m)
- Low-Ti phase: Ti=1.6keV t=1.8s
- High-Ti phase: Ti=3.9keV t=2.2s
  - Beta(r/a=0.65)=0.3%
  - Collision: 1/nu

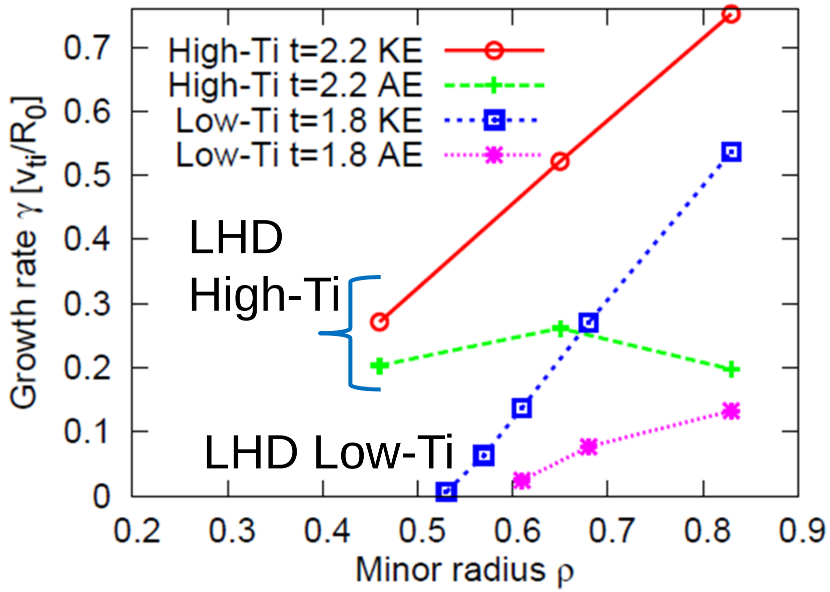




Tanaka, PFR 2010

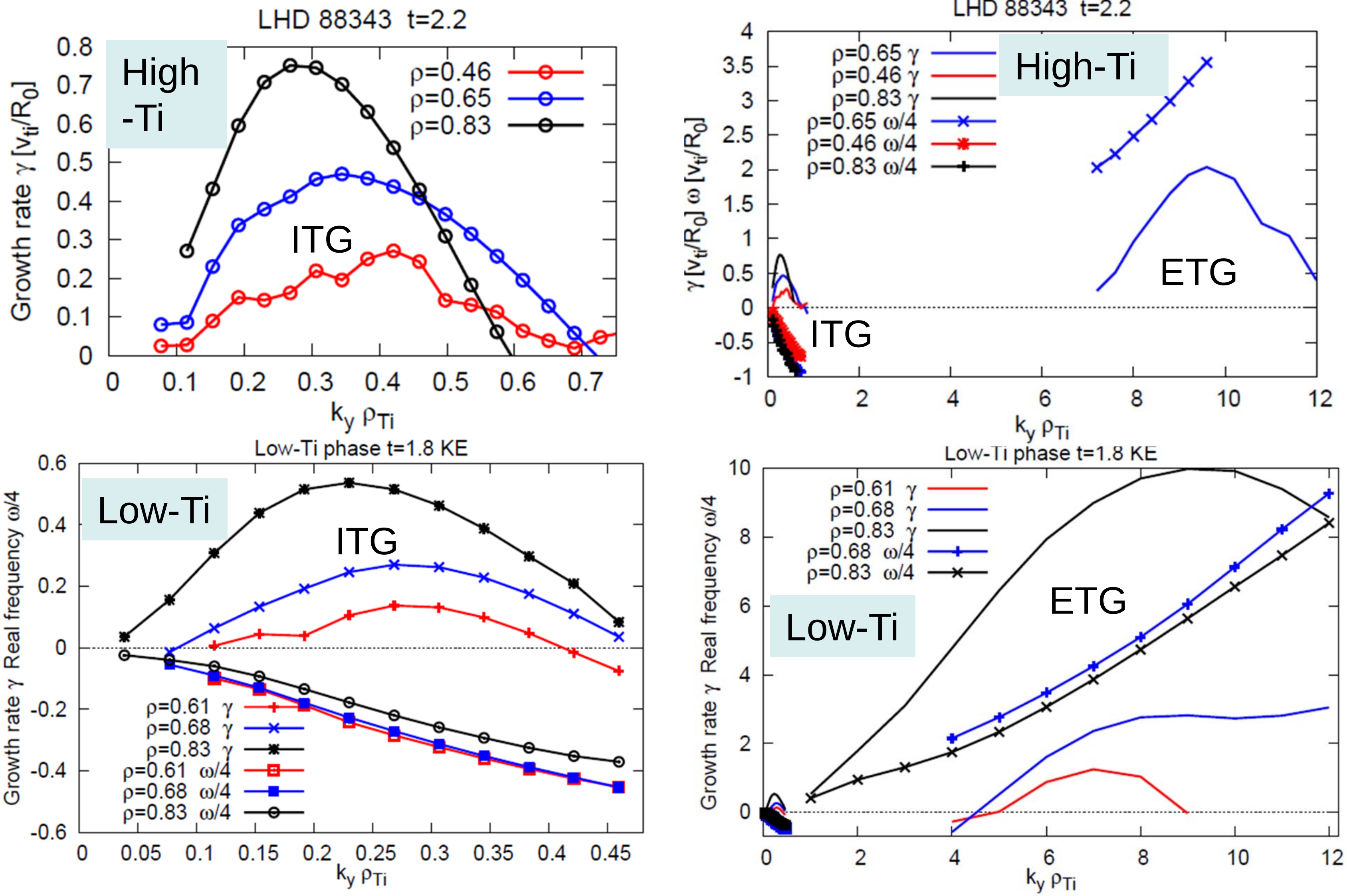
Linear analysis of LHD





- Ion temperature gradient (ITG) modes are unstable.
- Kinetic electron effects enhance the instability.

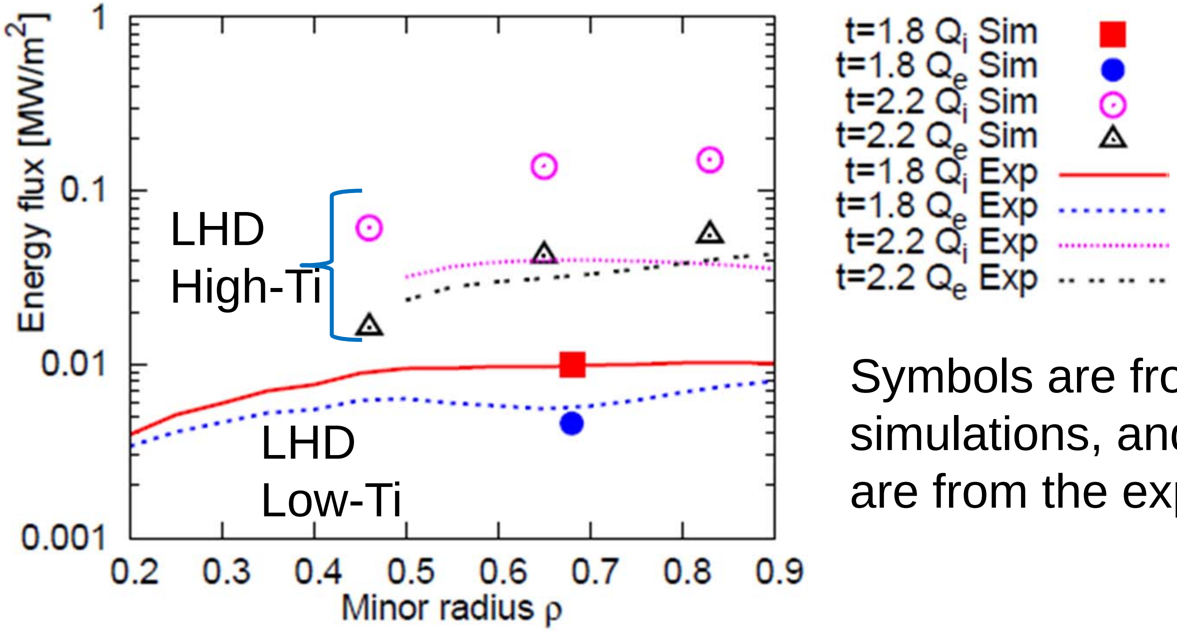
Linear growth rate



- ITG and ETG modes are unstable.

Turbulent energy flux of LHD

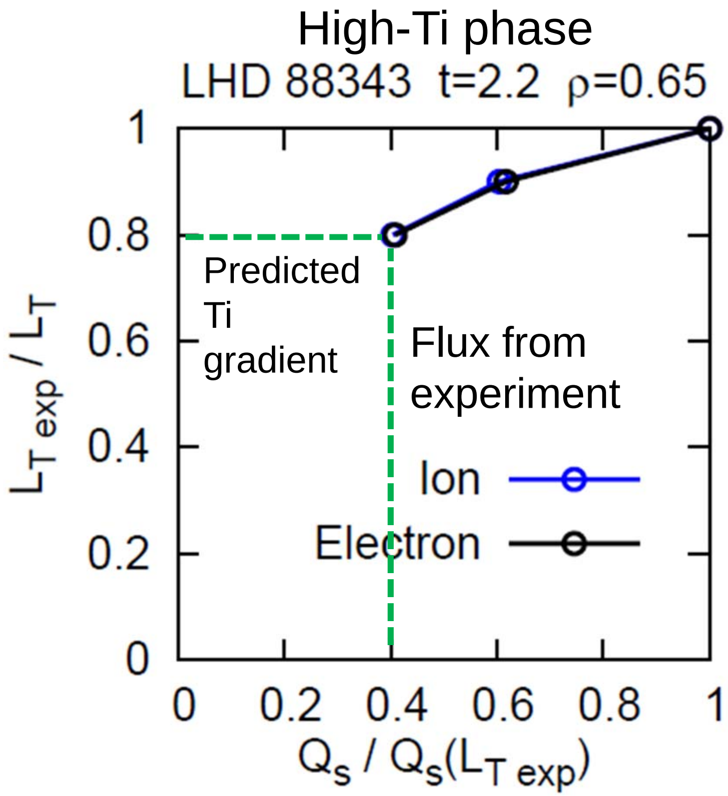
Ion and electron energy fluxes due to turbulence, Qi and Qe.



Symbols are from the simulations, and curves are from the experiments.

- The transition of the energy flux from the low-Ti phase (t=1.8, Ti=1.6keV) to the high-Ti phase (t=2.2s, Ti=3.9keV) in the experiment is reproduced.
- There is no short-fall problem, which suffers the GK analysis of some tokamaks.

Prediction of profile by flux matching



L_T : Temperature gradient length

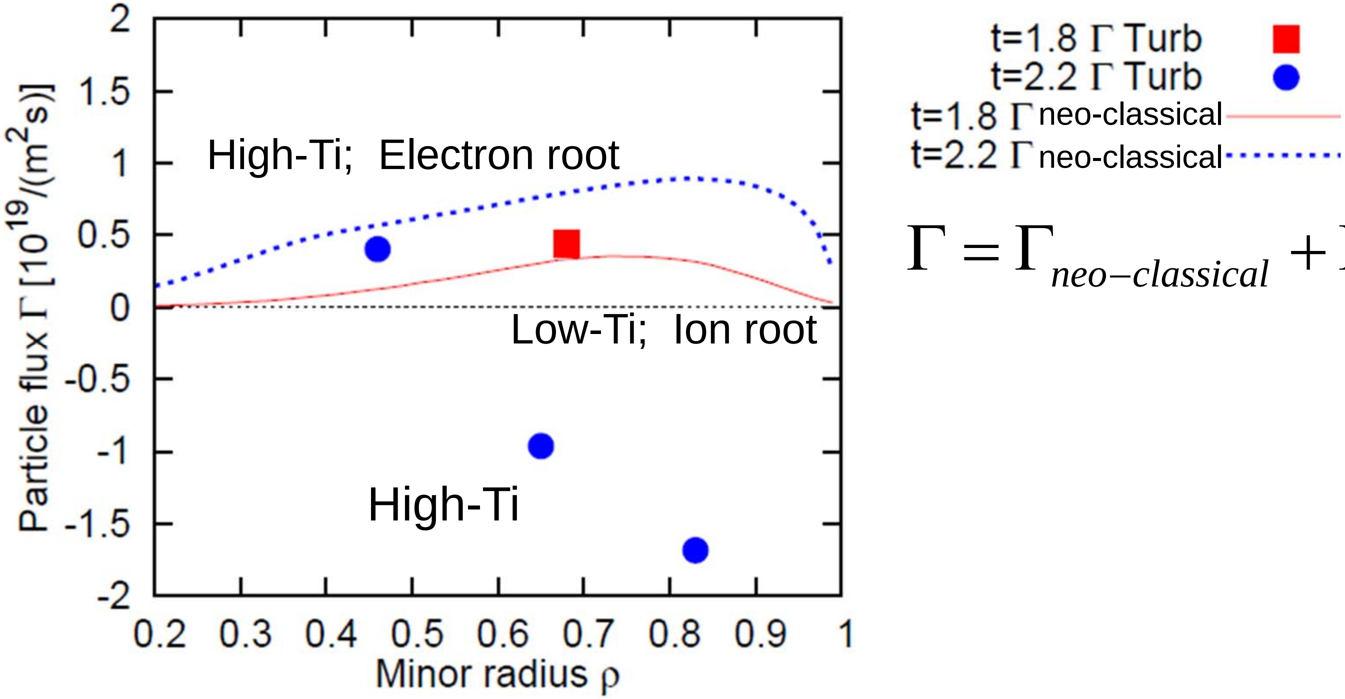
$L_{T\,\mathrm{exp}}$: Experimental observation of LT

Q_s : Heat flux of “s” species

$Q_s(L_{T\,\mathrm{exp}})$: Experimental observation of Qs

- The predicted temperature gradient length deviates from experimental observation about 20%.

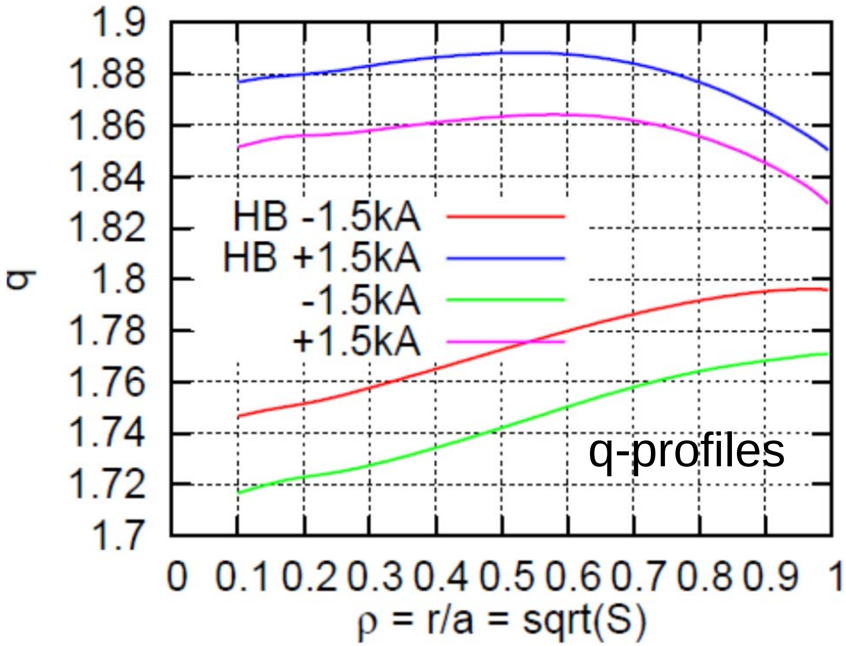
Turbulent particle flux

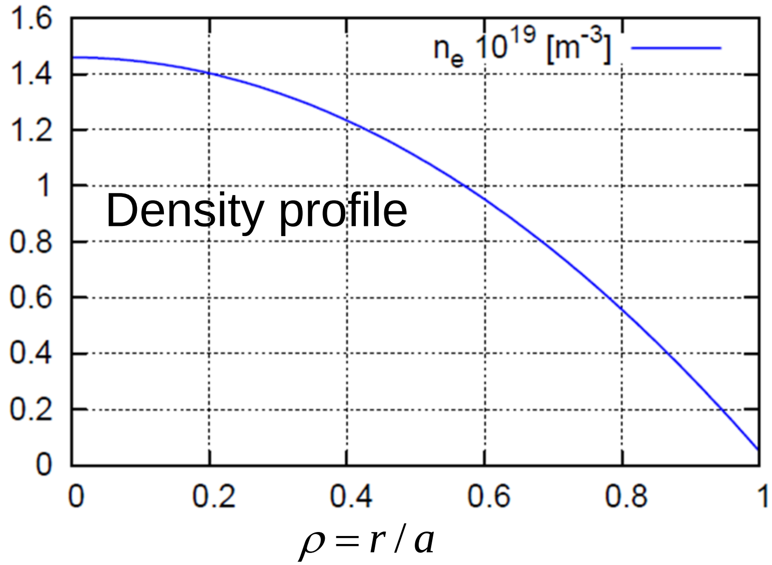


$$\Gamma = \Gamma_{neo-classical} + \Gamma_{turbulence}$$

- The turbulent particle flux directs to the magnetic axis, and its direction is opposite to the neo-classical particle flux.

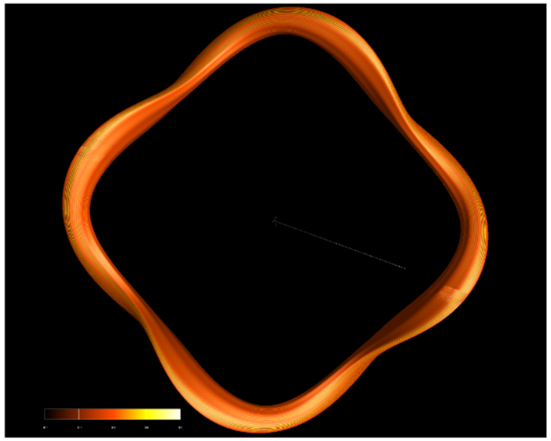
Profiles of HJ plasma

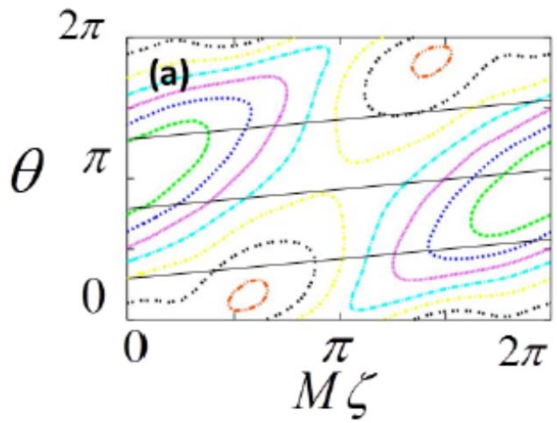


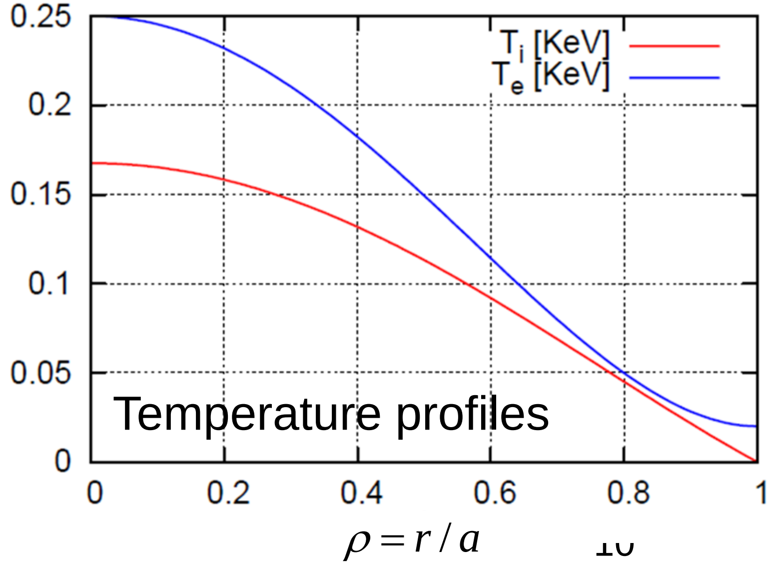


HJ-ST: standard configuration

HJ-HB: High-toroidal ripple configuration







Nishioka, PFR 2014

Simulation results

- The ITG mode is unstable
  - The LHD is the inner shifted configuration, so it is magnetic hill with a moderate shear.
  - The HJ is magnetic well with a very weak shear.
  - The LHD has an advantage compared with HJ from the linear aspect of drift wave instability.

	LHD-L	HJ-ST
R_0/a	6.2	7.3
$\rho = r/a$	0.68	0.5
q	1.5	1.7
$\rho_*[10^{-3}]$	2.	4.5
ν_i^*	0.083	3.2
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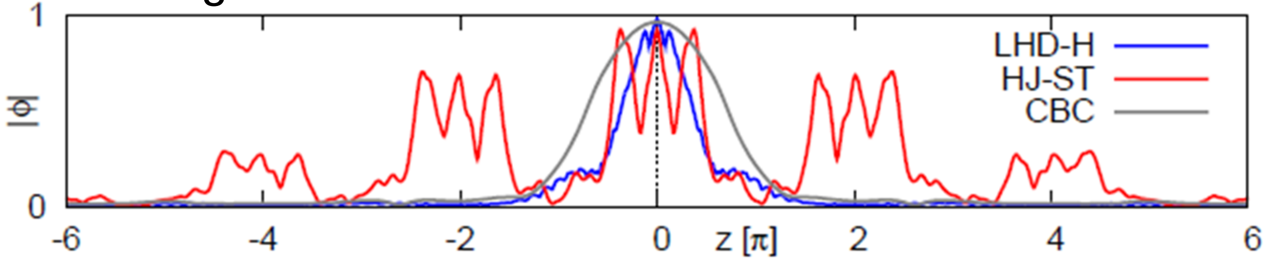
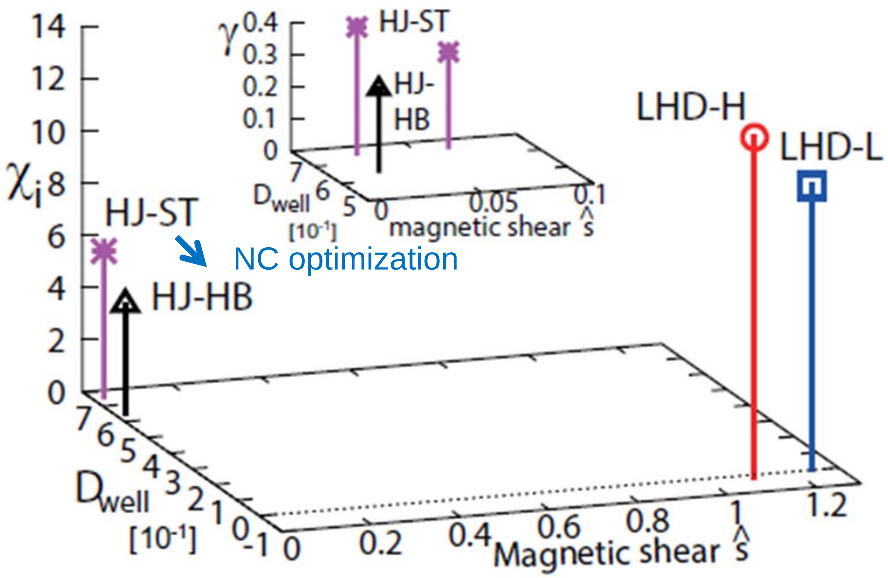
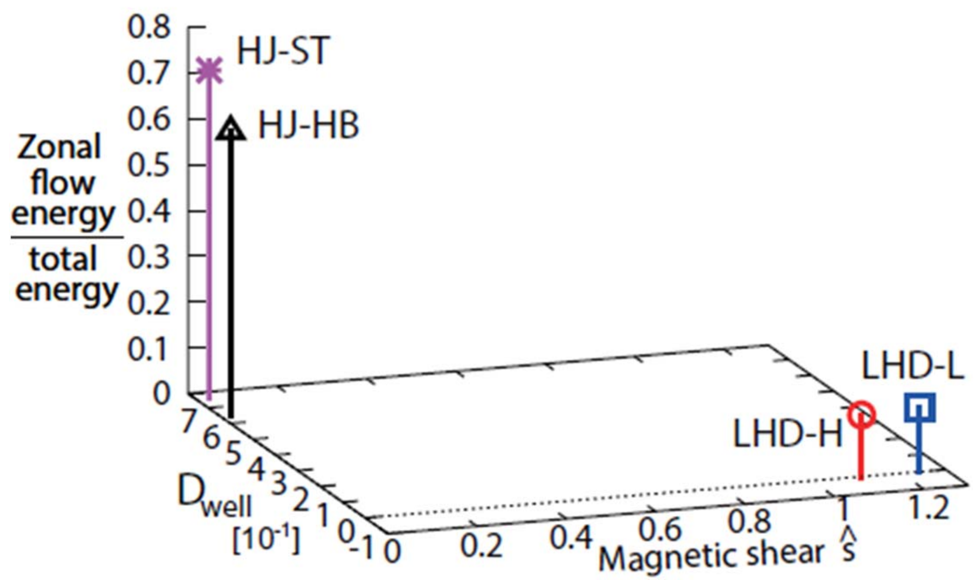
$D_{\rm well}$	-0.01	0.74
Instability	ITG	ITG
$\gamma\,[v_{Ti}/R_0]$	0.27	0.4
$R_0/L_T - R_0/L_{T\rm crit}$	2.6	5.2
$\chi_i\,[v_{Ti}\rho_{Ti}^2/R_0]$	11.	5.9
$\chi_e\,[v_{Ti}\rho_{Ti}^2/R_0]$	4.8	2.4
$E_{\rm ZF}/(E_{\rm ZF}+E_{\rm ITG})$	0.14	0.72

Eigen function of the ITG mode



Comparisons in (s_hat, Dwell) space





- The stabilizing effect of the magnetic shear is confirmed by the reduction of the growth rate by increasing the shear.
- The neoclassical optimization improves turbulent transport in HJ.
- Weak magnetic shear of HJ does not lead to high turbulent transport because of nonlinear interactions including zonal flow production.

Summary

- Comparisons of turbulent transport in helical systems including the LHD and the Heliotron J
- LHD analysis
  - The simulations reproduce the temperature gradients before and after the additional NBI within 20% error.
  - There is no short-fall problem.
- HJ analysis
  - The neoclassical optimization (high-toroidal ripple) suppresses the turbulent heat transport.
- Comparison reveals that the regulation of turbulence by zonal flows is more efficient in HJ which has very weak magnetic shear.