ヘリオトロンJにおける Nd:YAGトムソン散乱計測装置を用いた 電子内部輸送障壁の計測

第18回　若手科学者によるプラズマ研究会
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N. Kenmochi,[1] T. Minami,[2] C. Takahashi,[2] S. Tei,[1] T. Mizuuchi,[2] S. Kobayashi,[2] K. Nagasaki,[2] Y. Nakamura,[2] H. Okada,[2] S. Kado,[2] S. Yamamoto,[2] S. Ohshima,[2] S. Konoshima,[2] G. M. Weir,[2] Y. Ohtani,[1] and F. Sano[2]

[1]*Graduate School of Energy Science, Kyoto University, Gokasho, Uji, 611-0011, Japan*
[2]*Institute of Advanced Energy, Kyoto University, Gokasho, Uji, 611-0011, Japan*

Contents

Introduction

Background

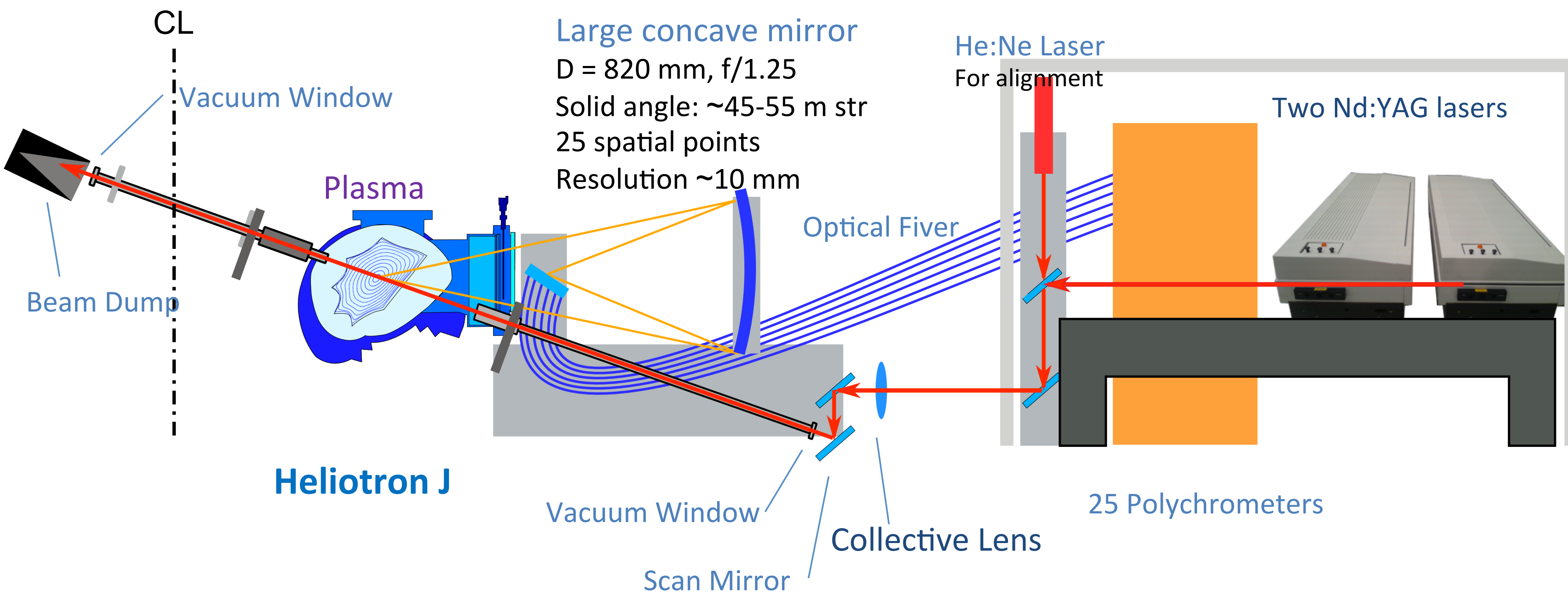
- ✓ Temporal measurements of plasma density and temperature profiles provide crucial information on the physics of transition phenomena, such as L-H transition.
- ✓ In Heliotron J, spontaneous transition phenomena to an improved confinement mode, which is similar to the H-mode, have been observed experimentally.

Purposes

- ✓ To measure the time evolution of electron density (n_e) and temperature (T_e) profiles in Heliotron J.
- ✓ To investigate the structure of plasma profiles in confined improvement modes.

A Nd:YAG Thomson scattering system with high time/spatial resolution has been developed in Heliotron J

Overview of the Nd:YAG Thomson scattering system

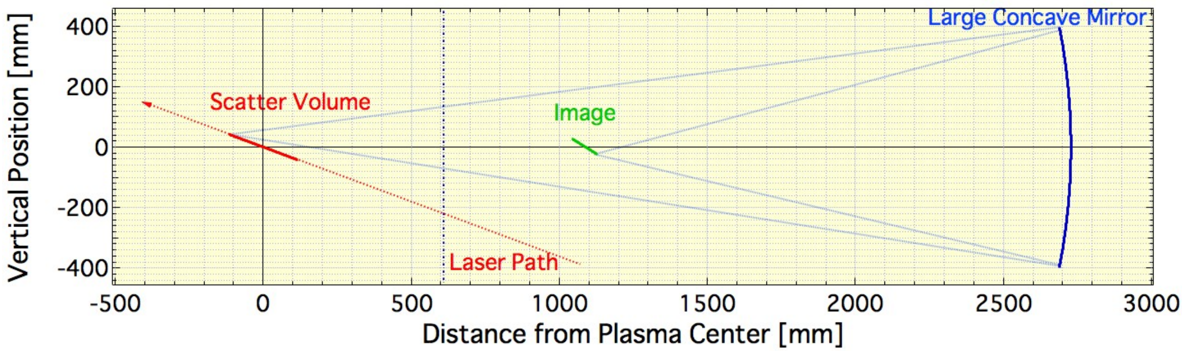


Performance (1 shot)

- Spatial Resolution : ~ 1 cm
- Measurement Point : 25
- Time Interval : 10 μs ~ 10 ms
- Range of T_e : 10 eV - 10 keV
- Range of n_e :> 0.5×10^{19} m^{-3}

Imaging optical system

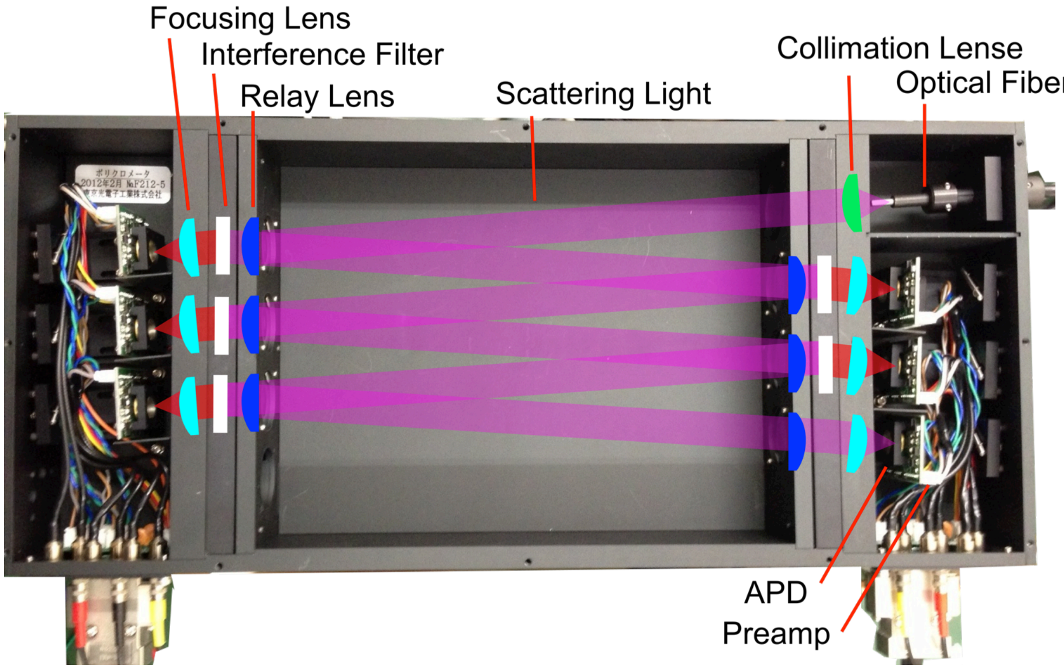
- ✓ The scattered light is collected with a large concave mirror.
  D = 820 mm
  f = 1.25
  solid angle: ~45-55 msr
  aberration: 0.7–1.5 mm
- ✓ The structure of fiber bundles is optimized to reduce loss on a coupling between the fiber and the scattered light from the collected mirror.



Optical Fiber Bundle

Large Concave Mirror

Polychromator



25 Polychromators on Rack

Scattered lights are detected by 25x6ch. interference polychromators which have cascaded structure.

5 channels

for the scattering light measurement and

1 channel

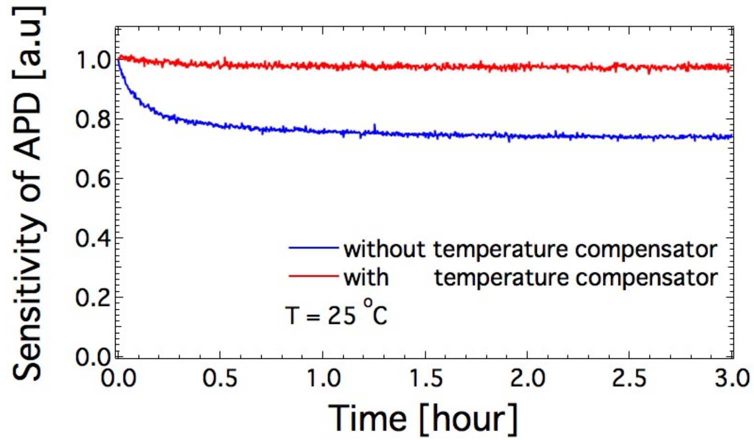
for the density calibration by the Rayleigh scattering method.

Avalanche photo diode (APD): Hamamatsu Photonics S8890-30

Temperature compensator of APD

A sensitivity of APD depends on its own temperature.

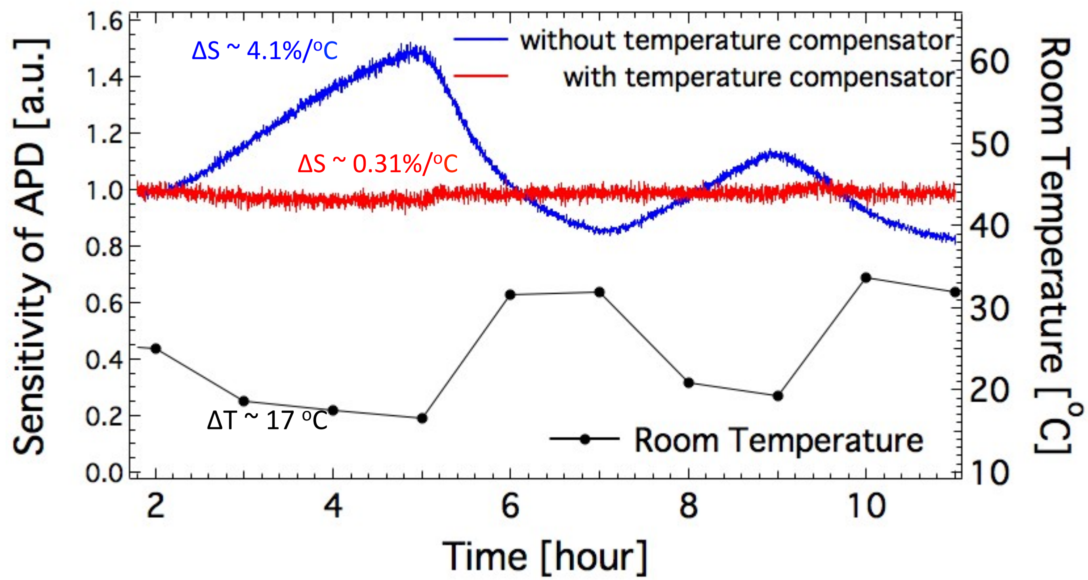
- ✓ To reduce thermal variation, temperature compensators are installed into APDs of the polychromators.



High Voltage Power Supply
Matsusada Precision inc.
HAPD-0.8PT

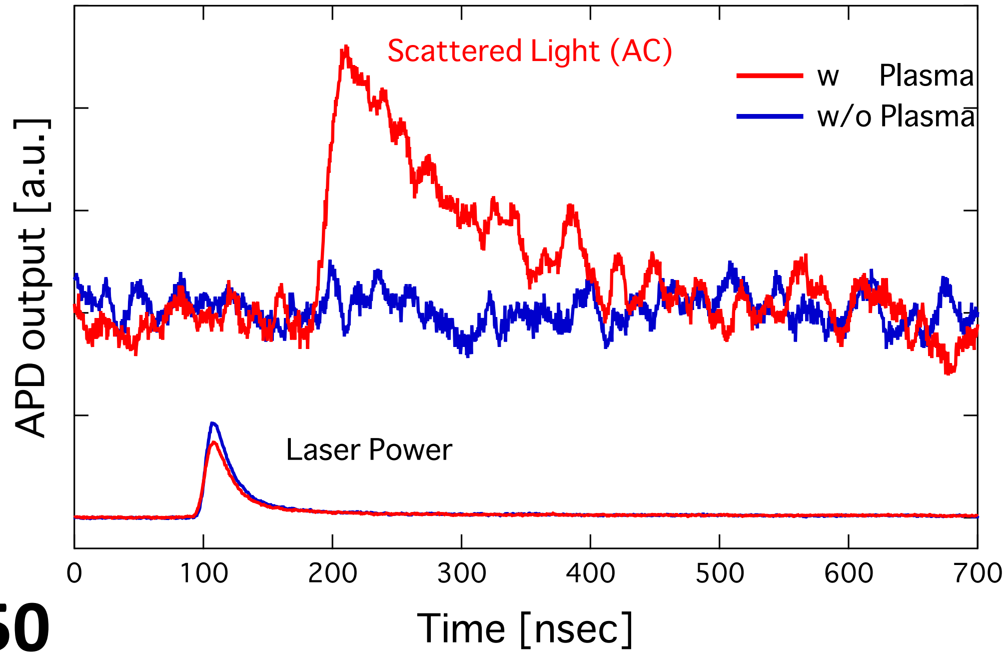
- ➢ **The quick stabilization enables us to start the measurement after short time warming up the APD.**

- ➢ **We can measure T_e and n_e stably without being affected by the experimental room temperature of Heliotron J.**



Result of Performance Test

To confirm the S/N ratio of the system for low density and low scattered light plasmas, **we measured Thomson scattering signals for the plasma n_e~ 0.5×10^{19} m^{-3}**



S/N ratio ~ 50

✓ Though the laser is injected into the vacuum vessel, no remarkable changes are observed.

→The system successfully suppresses a stray light.

First Observation of Internal Transport Barrier in Heliotron J

Introduction: First observation of electron internal transport barrier in Heliotron J

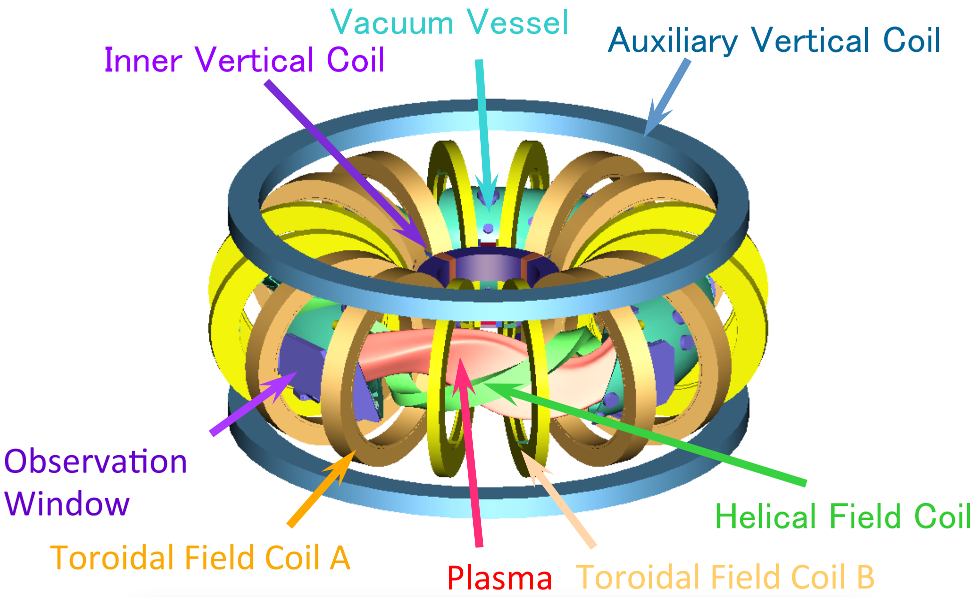
✓ Peaked electron temperature profiles have been observed with on-axis ECH in Heliotron J.

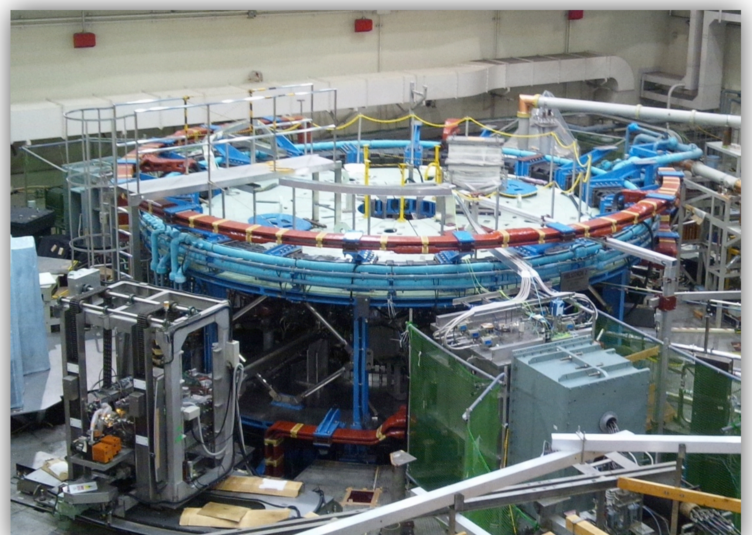
✓ Peaked profiles have been observed in relation to electron ITB in many helical devices, through Core Electron-Root Confinement (CERC), where radial electric field shear reduces the transport in the core region [1].

✓ Heliotron J is suitable for the study of ITB characteristics against flexible magnetic configuration.

[1] M. Yokoyama *et al*., Nucl. Fusion **47** (2007) 1213

Heliotron J device





- Major Radius : R = 1.2 m
- Plasma Minor Radius : a = 0.1-0.2 m
- Magnetic Field : B ≤ 1.5 T
- Vacuum iota : 0.3-0.8

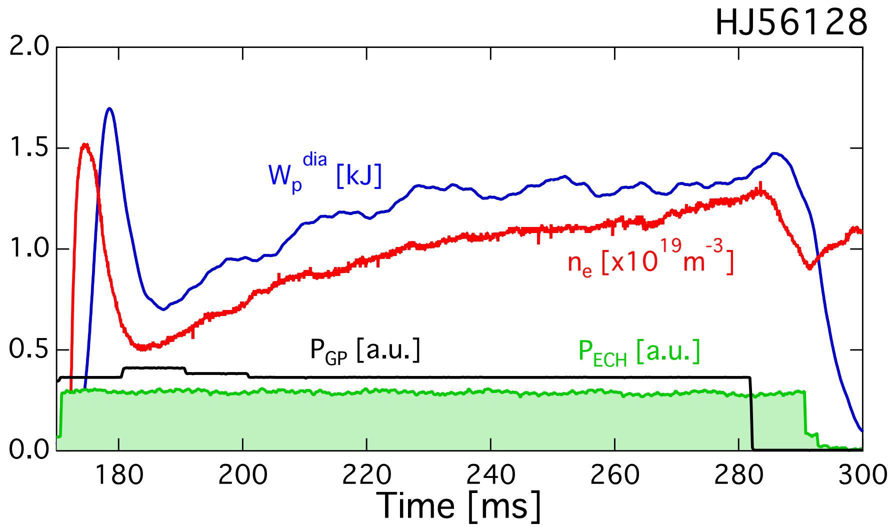
  with low magnetic shear, ($\Delta\iota/\iota < 0.04$)

- Coil System
  - One helical coil (l/m=1/4)
  - Two sets of toroidal coils (TA and TB)
  - Three pairs of vertical field coils (main V, AV, IV)
- Heating System
  - ECH 70 GHz 0.4 MW
  - NBI 30 kV 0.7 MW × 2 (Co & Ctr.)

Experimental set-up of density ramp-up control plasma with center-focused ECH

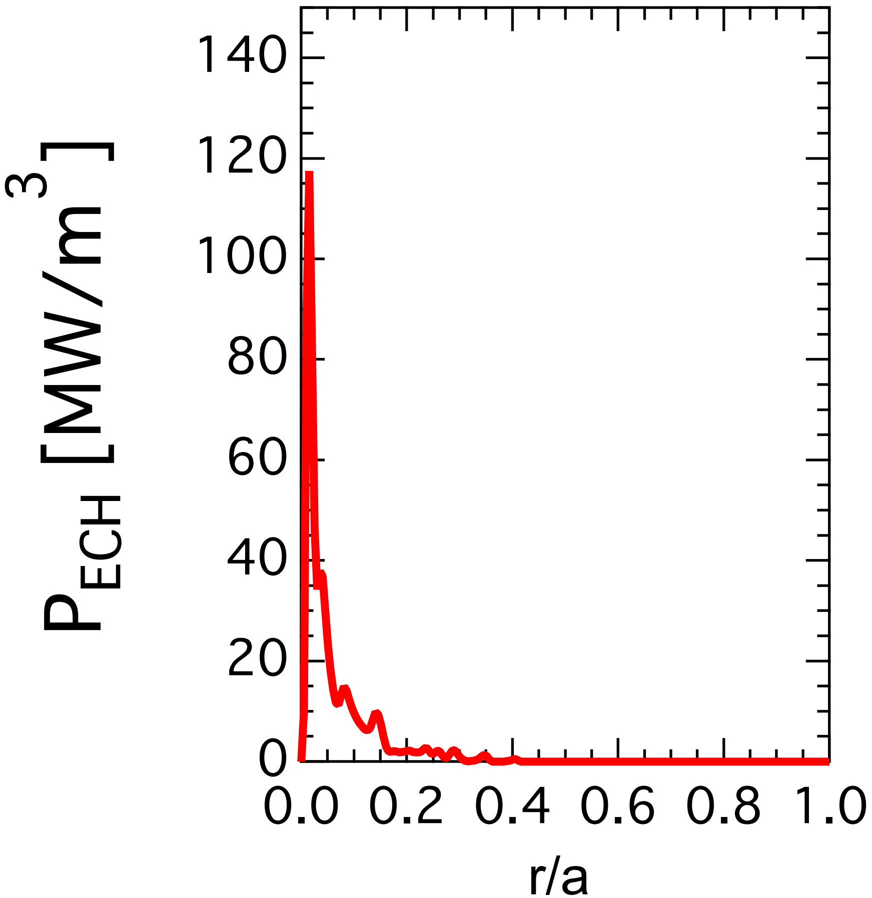
Electron Cyclotron Heating

- Located on the magnetic axis
- Injection Power: 330 kW
- Absorption Power: ~90%



Electron density is controlled to increase from $0.5 \times 10^{19} m^{-3}$ to $1.2 \times 10^{19} m^{-3}$ with constant power of ECH

Power Absorption Density of ECH (X-mode) calculated by TRAVIS

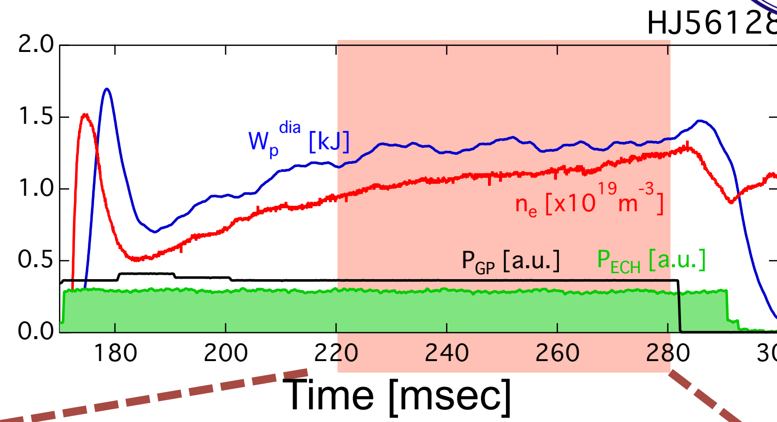


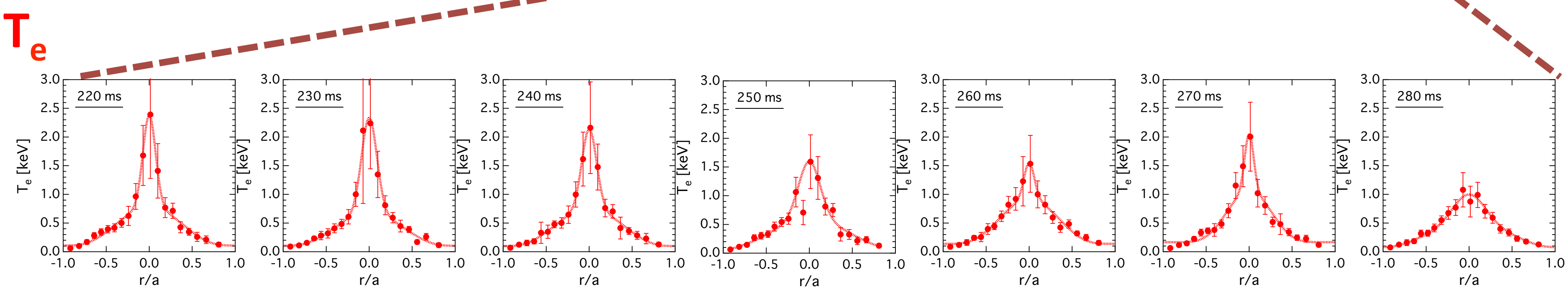
Profile changes of density ramp-up control plasma with center-focused ECH

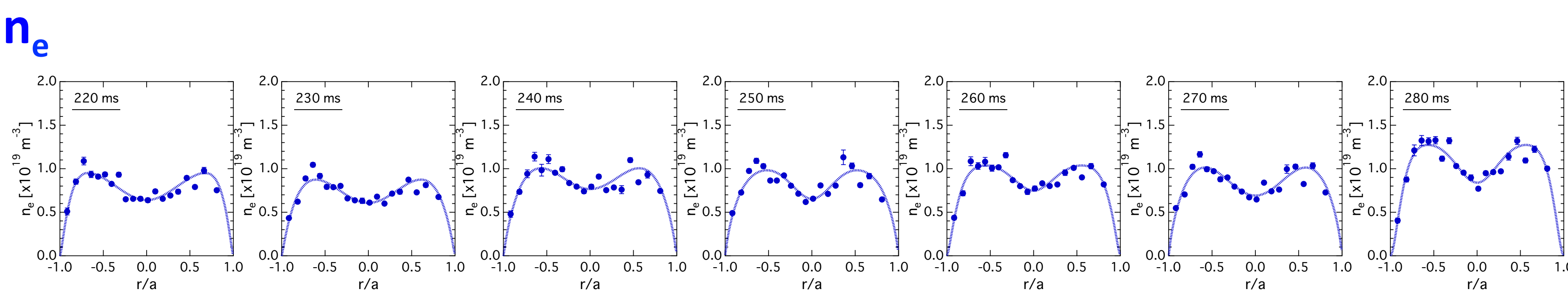
Profiles of T_e and n_e for NBI-sustained plasma

Electron Cyclotron Heating

- Located on the magnetic axis
- Injection Power: 330 kW
- Absorption Power: ~90%



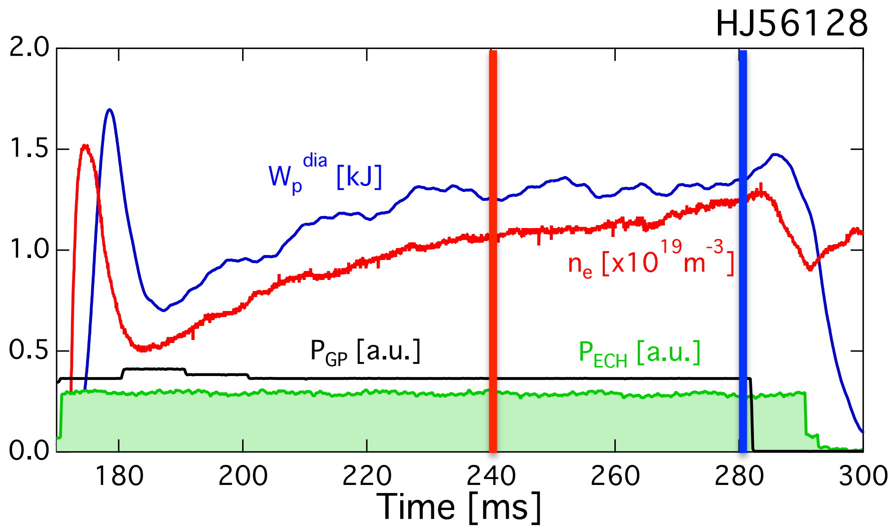


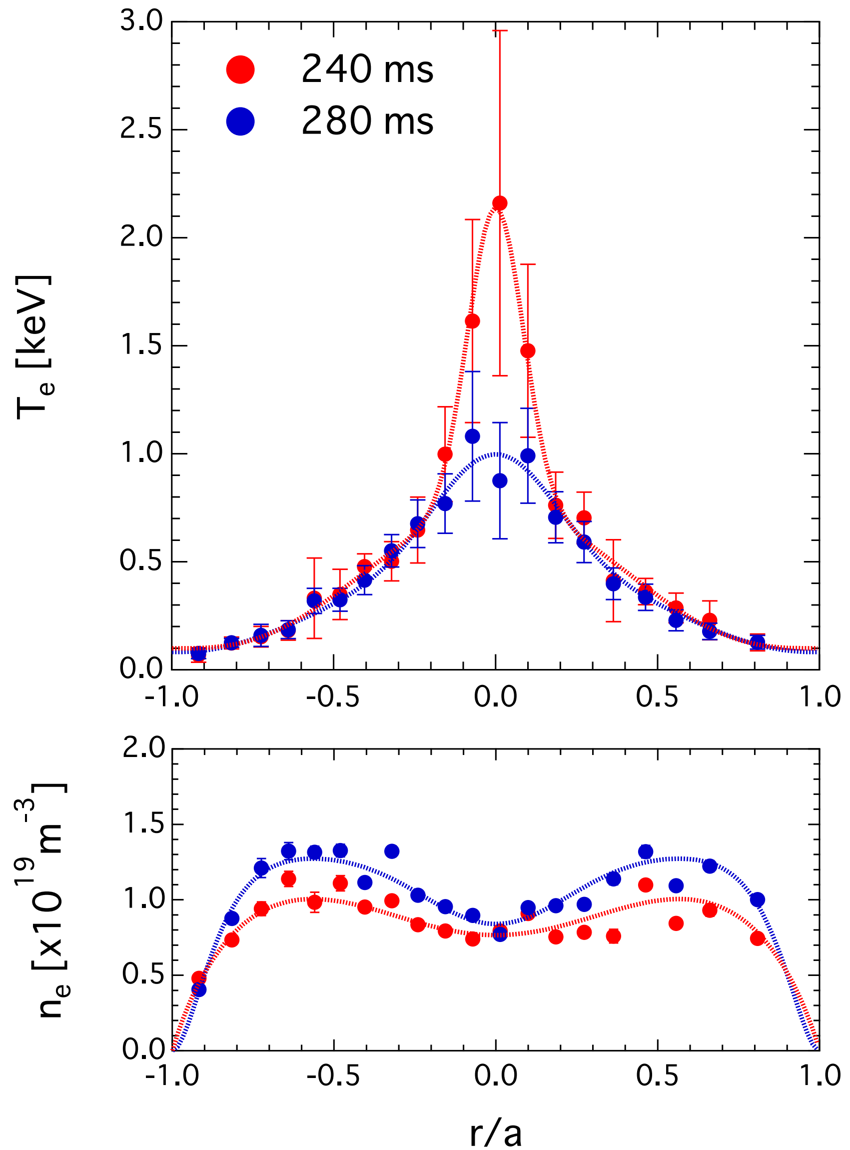


Formation of electron ITB with center-focused ECH

Electron Cyclotron Heating

- Located on the magnetic axis
- Injection Power: 330 kW
- Absorption Power: ~90%

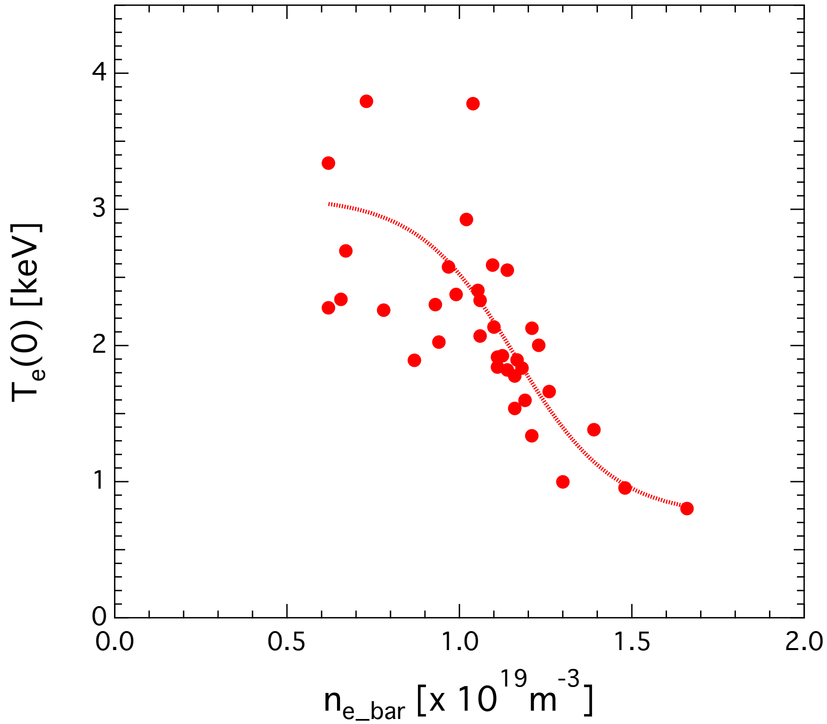




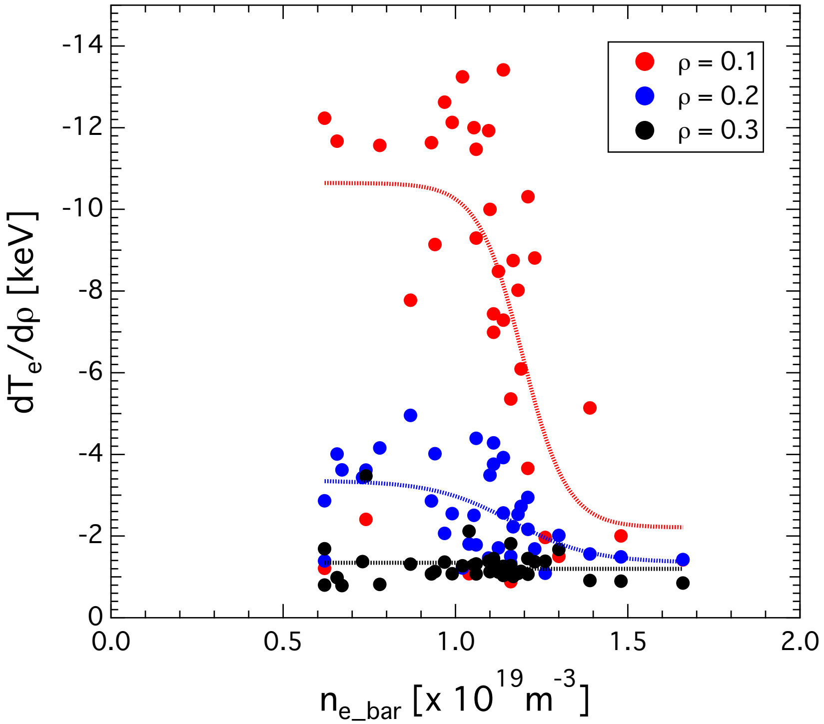
In the density scan experiment,
the peaked electron temperature profiles are observed with center focused ECH during the period of lower density.

Density dependence of ITB formation

Core T_e vs. line average density



T_e gradient vs. line average density



When the electron density becomes less than ~1.2 x 10^{19} m^{-3},

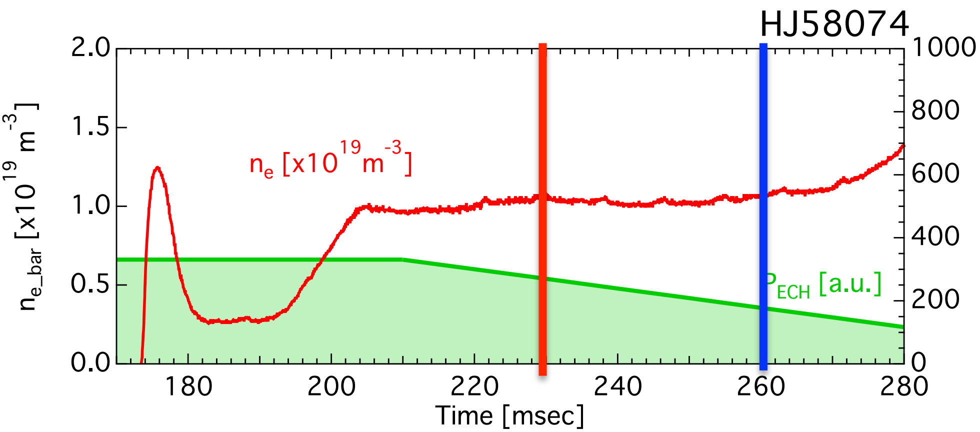
✓ Electron temperature of plasma center increases

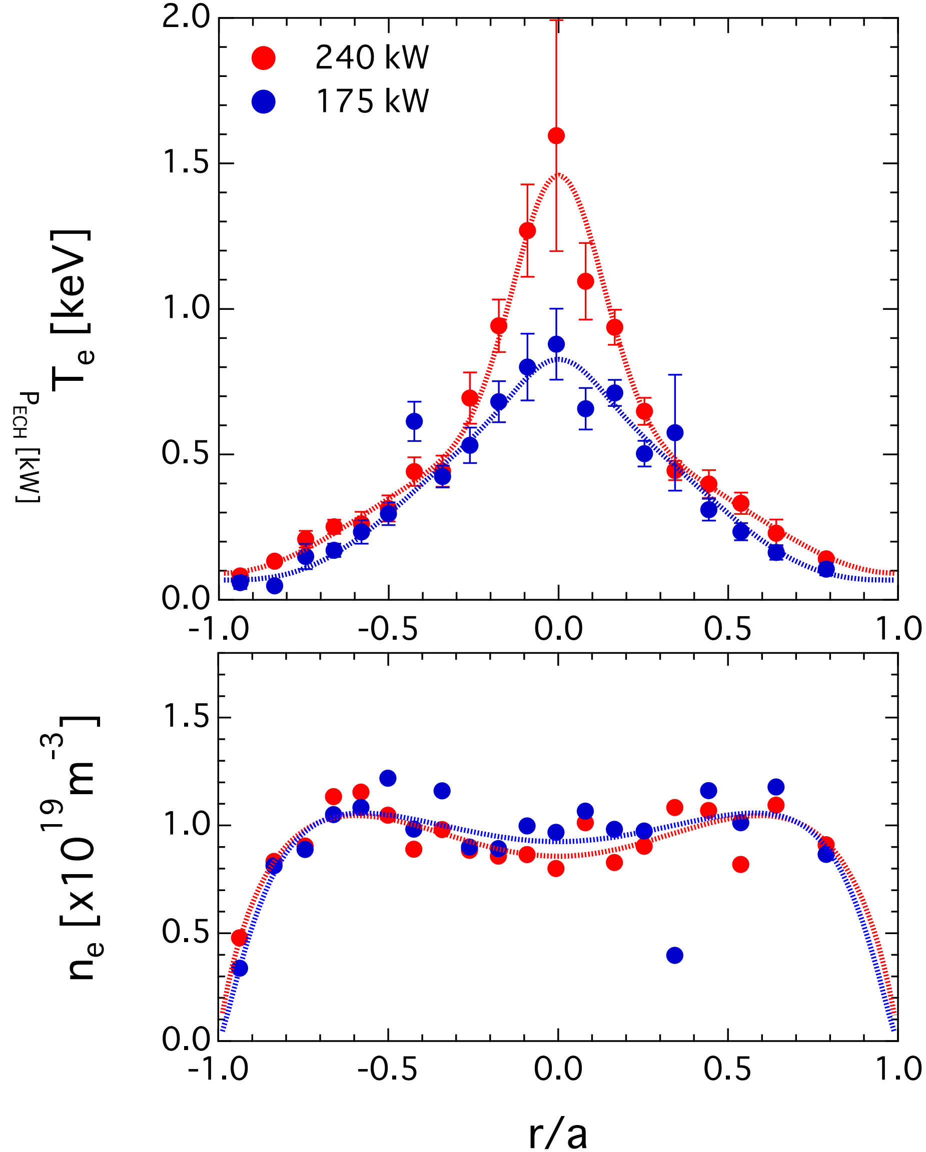
✓ The steep gradient is formed in the core region

Formation of internal transport barrier (ITB) with center-focused ECH

Electron Cyclotron Heating

- Located on the magnetic axis
- Injection Power: 330-120 kW
- Absorption Power: ~90%





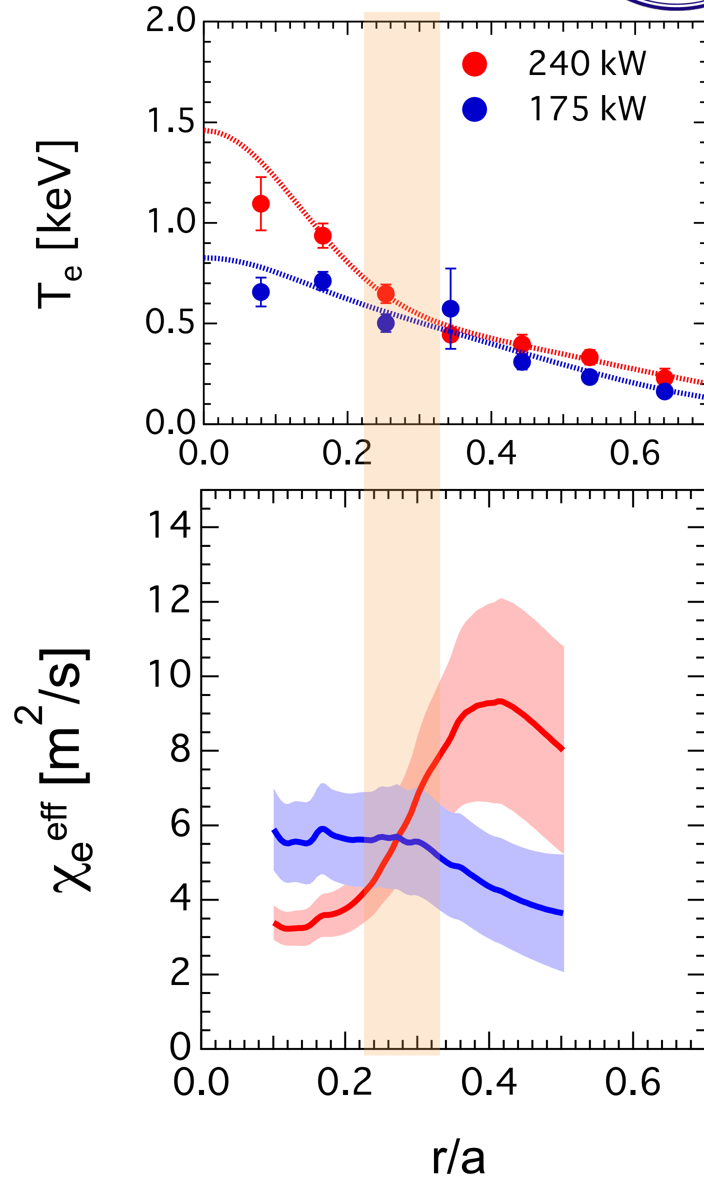
In the ECH power scan experiment, the peaked electron temperature profiles are observed with center focused ECH during the period of higher ECH power.

Analysis of effective heat transport

- ✓ Quantitative comparison of electron effective thermal diffusivity χ_e^{eff} has been calculated in ITB and non-ITB plasma.
- ✓ χ_e^{eff} is defined as follows.

$$\chi_e^{eff}(\rho) = \frac{\frac{1}{\rho}\int_0^{\rho} P_{ECH}\,\rho\, d\rho}{-n_e \frac{\partial T_e}{\partial \rho}}$$

- ✓ The clear reduction of χ_e^{eff} associated with the formation of the ITB at $\rho<0.3$.



Summary

Development of a Nd:YAG Thomson scattering system

To reveal the mechanism of transition phenomena, a high time resolution Nd:YAG Thomson scattering system is developed

- Spatial Resolution: 1 cm (25 points), Range of n_e: >0.5x10^{19} m^{-3}, Range of T_e: 10 eV – 10 keV, which are adequate to clarify the structure of transport barriers in Heliotron J

- **Polychromator**
  - ✓ The APDs provided with temperature compensation circuits enable to detect the scattering light at a constant sensitivity independently of their own temperature
- **Beam Dumper**
  - ✓ Carbon beam dumper, which has conical hole structure, attenuates the laser beam
- **Imaging Optical System**
  - ✓ The large concave mirror (D = 820 mm, f/1.25) collects the scattered light on the optical fiber bundle in stair case form

First Observation of ITB on Heliotron J

- ✓ Peaked electron temperature profiles have been observed with on-axis electron cyclotron heating (ECH) in Heliotron J
- ✓ Reduction of effective thermal diffusivity is confirmed associated with ITB formation in the core region

Future Plan

✓ Measurement of E_r with CXRS

✓ Comparison with the thermal diffusivity of the neoclassical transport calculation

✓ Investigation of magnetic configuration dependence on ITB formation