– Overview of Heliotron J –

Recent Results and Near-Future Plan of Heliotron J Project

Heliotron J Team

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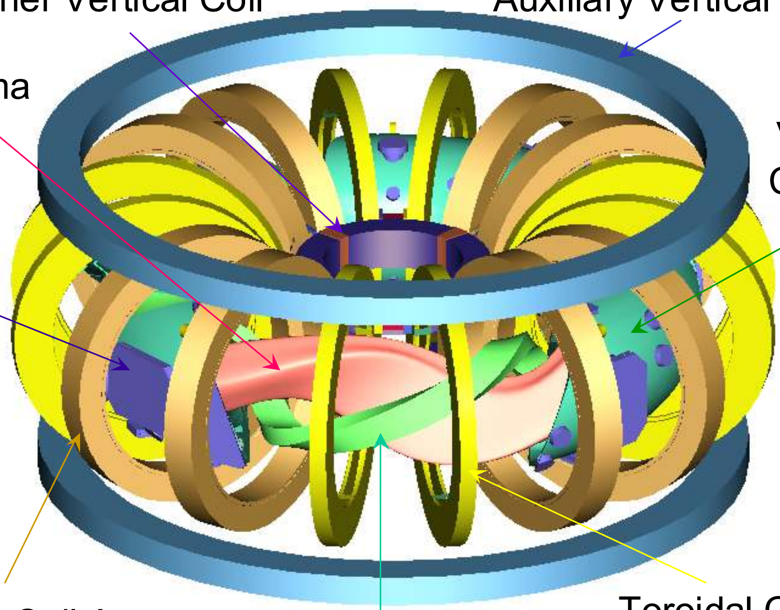
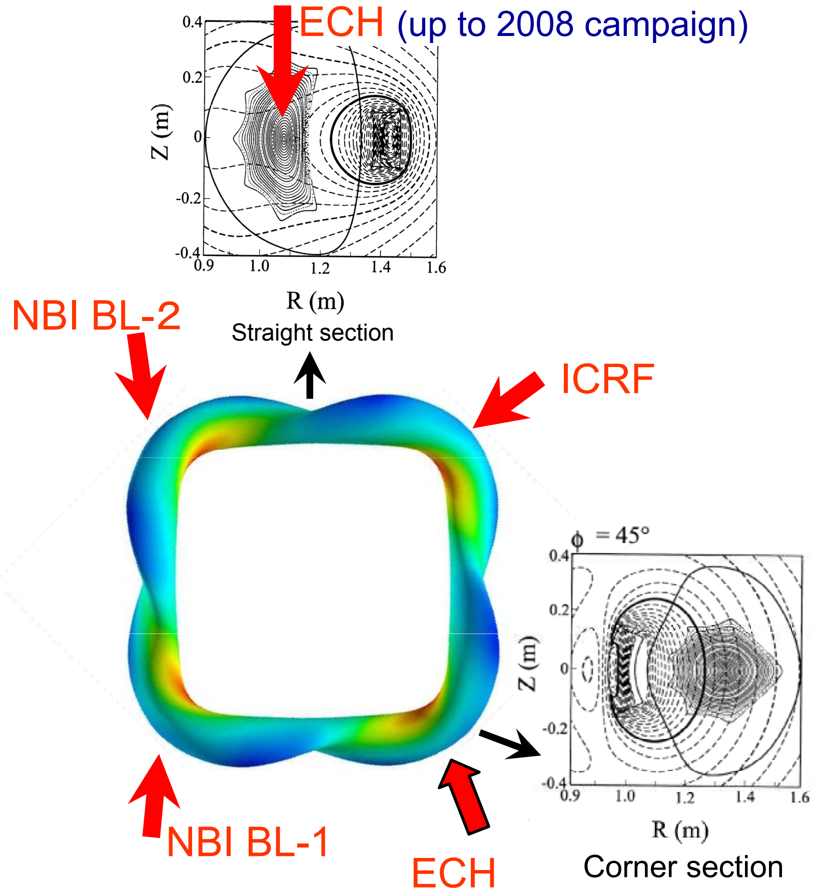
Heliotron J

L/M = 1/4 helical coil
$\langle R_0 \rangle / \langle a_p \rangle$ = 1.2m/0.1-0.2 m
B_0 < 1.5T, $\iota/2\pi$ = 0.4 ~ 0.65
$\Delta\iota/\iota(a) \approx$ 1.4 % for STD configuration.
Magnetic well ≈ 1.3 %

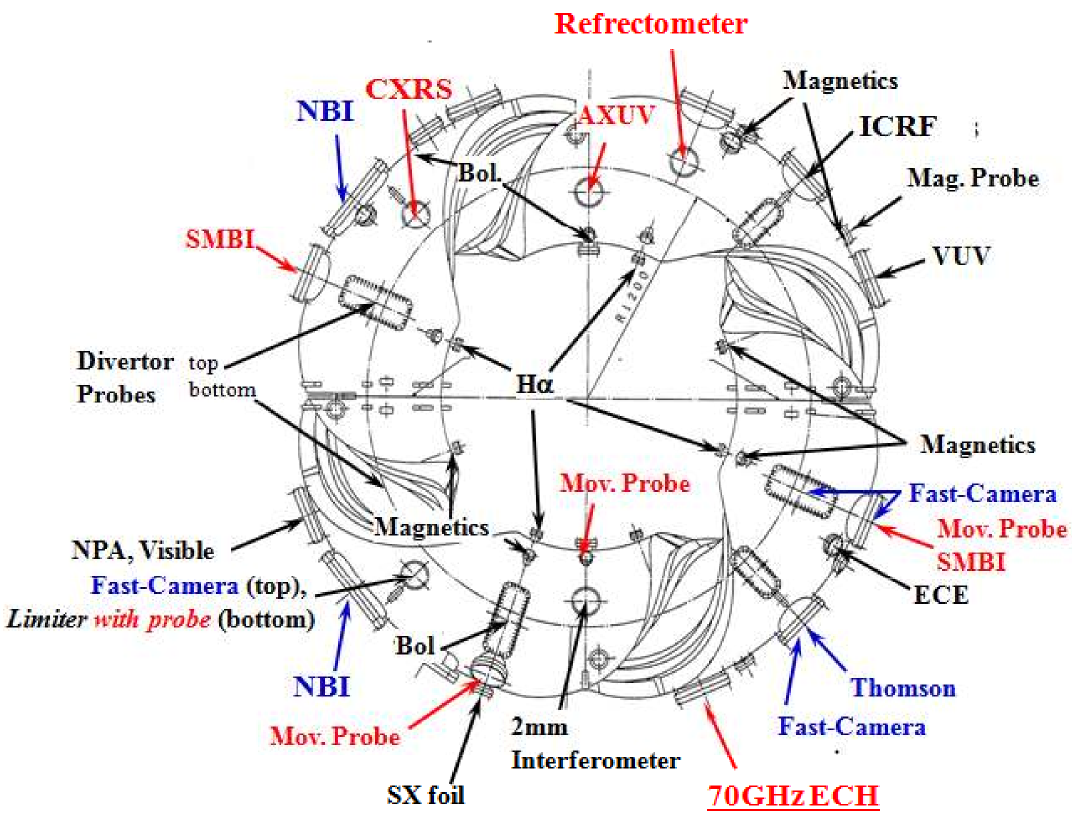
ECH : 70GHz (2nd X, ≤ 0.45 MW)
NBI : 30kV, 0.7MW × 2 beam-lines
ICRF : 19~23MHz (≤ 0.4 MW × 2 units)





Experimental studies of improved confinement are in progress.

Proposals for collaboration studies are welcome!



- Upgrade of heating and diagnostic equipments for FY2009 campaign
  - Focusing/steering ECH launcher
  - Reflectometer for density profile measurement
  - Combination Langmuir probes at 3 positions
  - Two SMBI systems
  - CXRS system

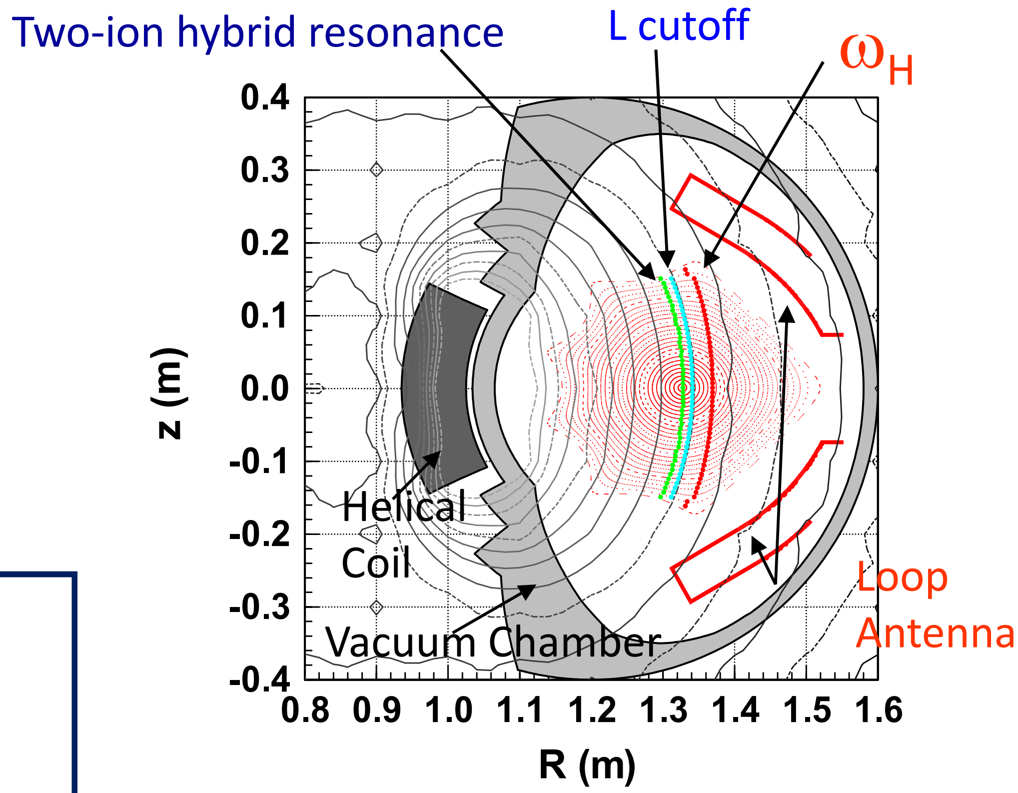
- Confinement Studies
  - Configuration effects
    - » Iota (incl. I_p-effects)
      - *Iota-control by ECCD/NBCD*
    - » ε_h, ε_t, ε_b
    - » Resonance perturbation fields
  - Plasma profile control
    - » *Accumulation of profile database*
    - » Fueling/recycling control
      - SMBI and Li-coating (under discussion)
  - Plasma rotation control
    - » Co/CTR NBI
    - » Electrode Bias (low field exp.)
  - Plasma turbulence
  - Transport of energetic particles
    - » NBI, ICRF
- ECCD/ECH Studies
- Application of the data-mining method for MHD studies

Bumpiness Control Experiments (1)
– Fast Ions –

- To study the effect of the magnetic configuration on the generation and confinement of fast protons generated by ICRF minority heating, fast ion velocity distribution has been investigated.
- The high energy tail component extended to ~ 30 keV is observed near the pitch angle of 120° only in the high-ε_b case, where the observation range is 111° - 128°.

A Schematic View of ICRF Heating Antenna

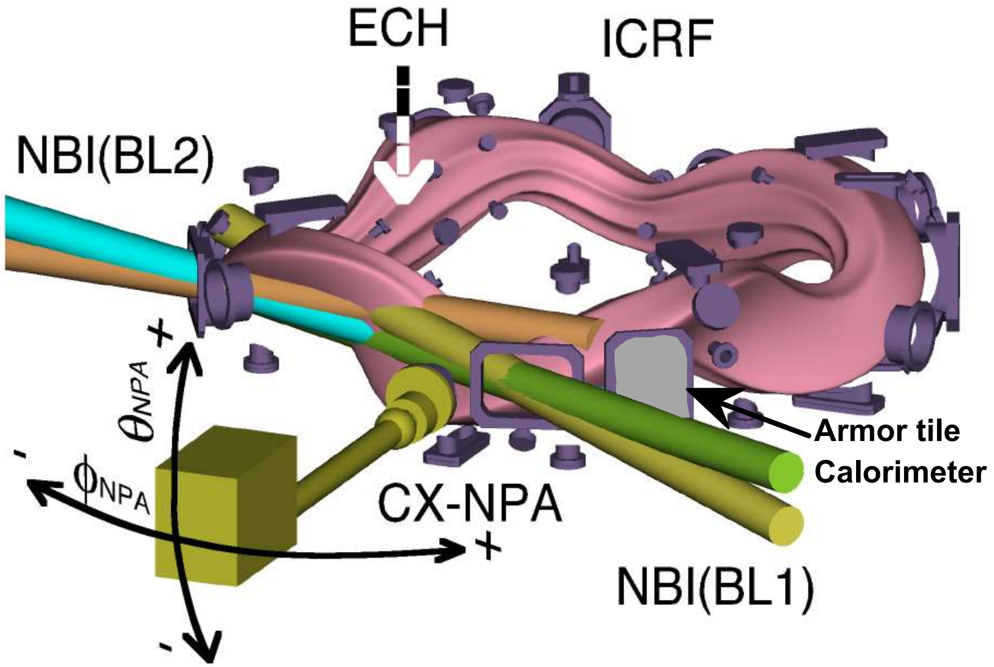
- **Two loop antennas are installed at the corner section (#14.5) of Heliotron J.**
- **The mod-B structure is tokamak-like in this section.**
- **Antennas are located on the weaker field side.**



RF Frequency	19 MHz、23.2 MHz
ICRF power	< 0.4 MW X 2
Magnetic Field	1.26 T
Majority D and Minority H	
Electron Density	0.2-0.6 X 10^{19} m^{-3}

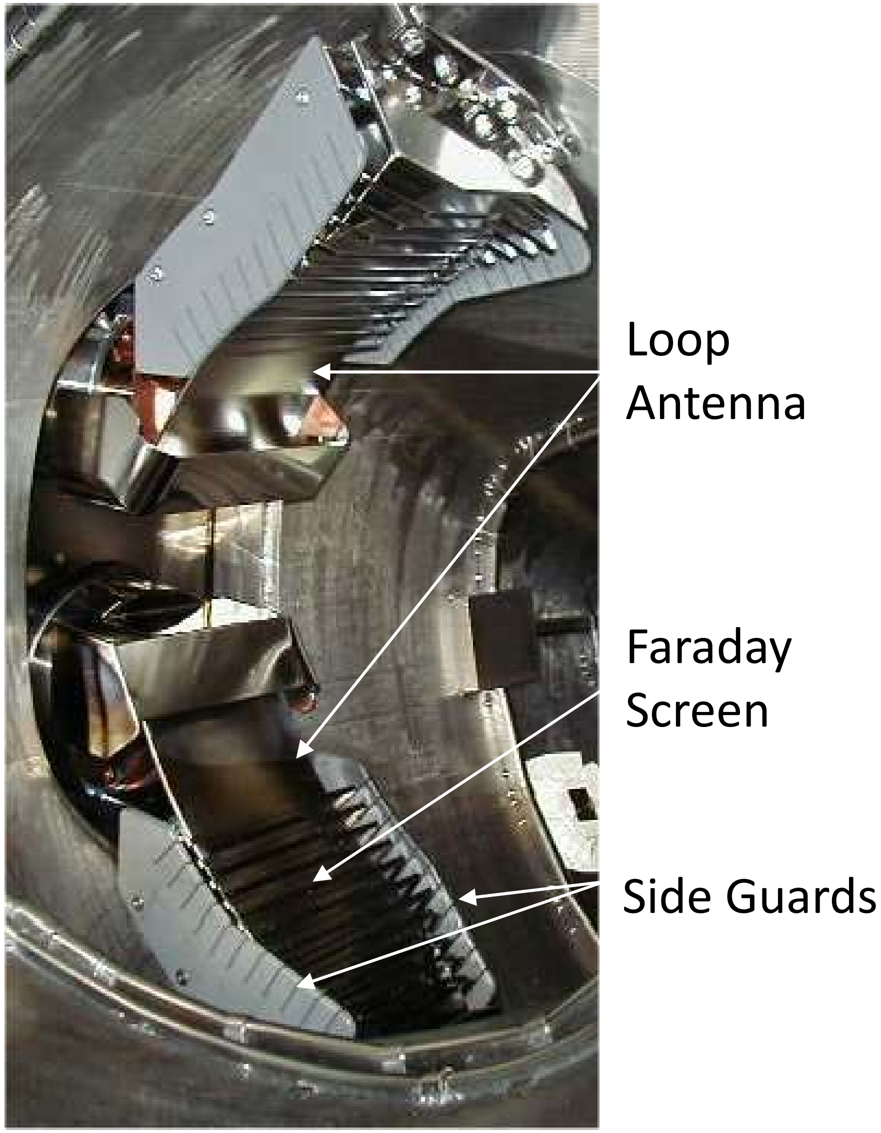
CX-NPA System and ICRF Antennas

Bird's eye view of Heliotron J plasma, ECH, NBI and ICRF systems and CX-NPA



CX-NPA system

Type	: E//B type
Energy range	: 0.4 - 80 keV (Hydrogen)
	: 0.2 - 40 keV (Deuterium)
Energy resolution	: 5% (typical)
Toroidal angle	: $-10^{o} < \phi_{NPA} < +18^{o}$
Poloidal angle	: $-3^{o} < \theta_{NPA} < +10^{o}$

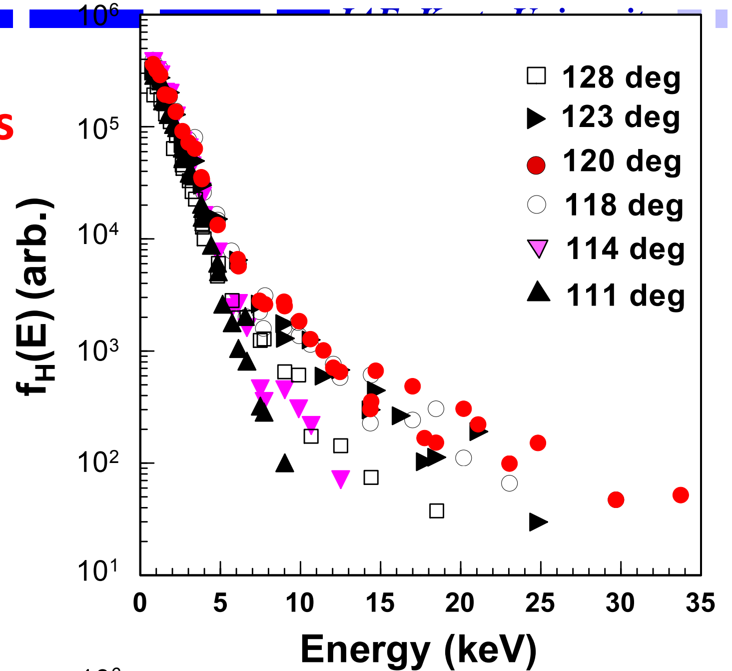


Pitch Angle and Bumpy Dependence

- An ICRF pulse of 23.2 MHz or 19 MHz is injected into an ECH target plasma.
  $T_i(0) = 0.2$ keV, $T_e(0) = 0.8$ keV and = 0.4×10^{19} m^{-3}.
  ICRF injection power is 250-290 kW.
- In high bumpy case, the ion flux is measured up to 34 keV at the pitch angle of 120°.
- In the medium case, the change in energy spectrum is small.
- In low bumpy case, the fast ion flux is increased continuously towards 90°.

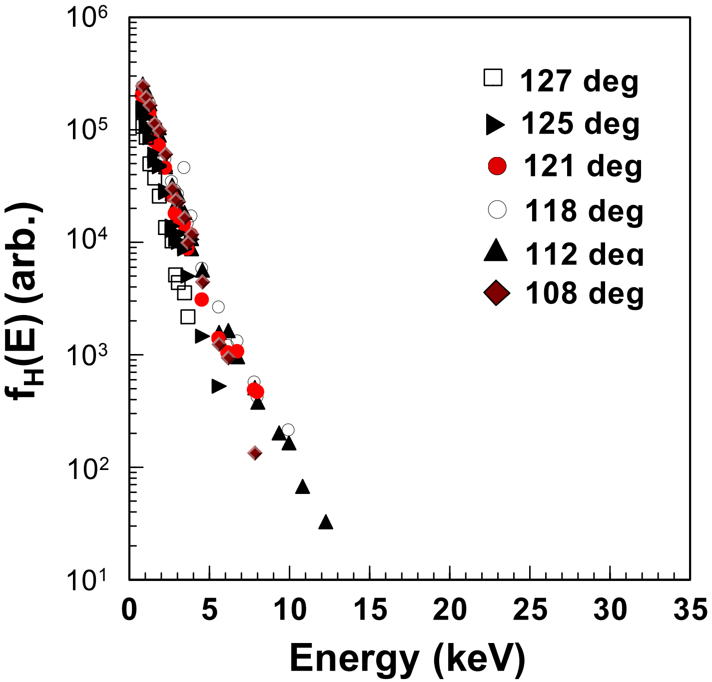
High Bumpiness

23.2 Mhz



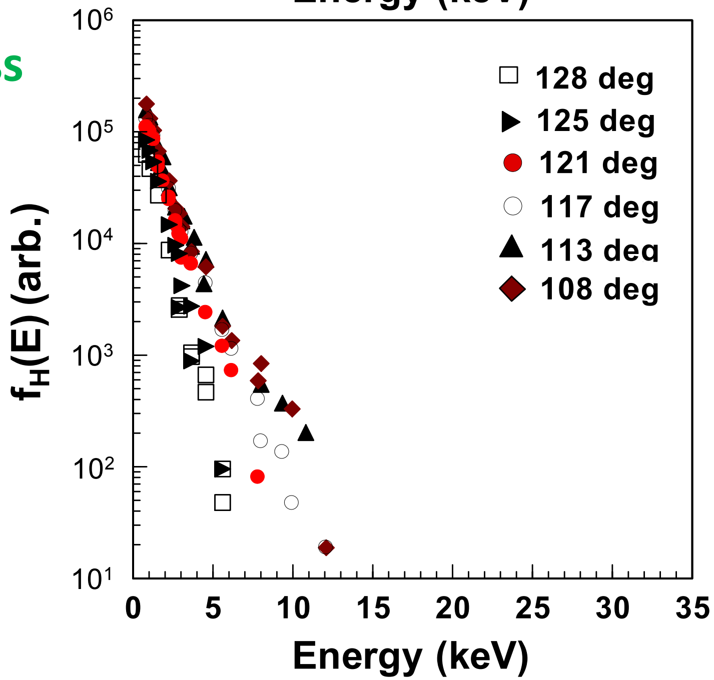
Medium Bumpiness

19 MHz



Low Bumpiness

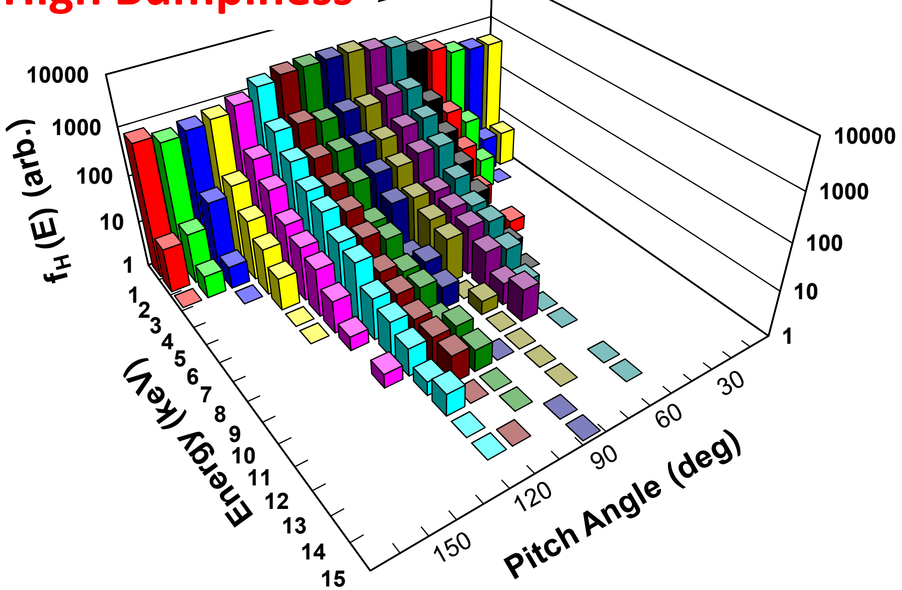
19 MHz



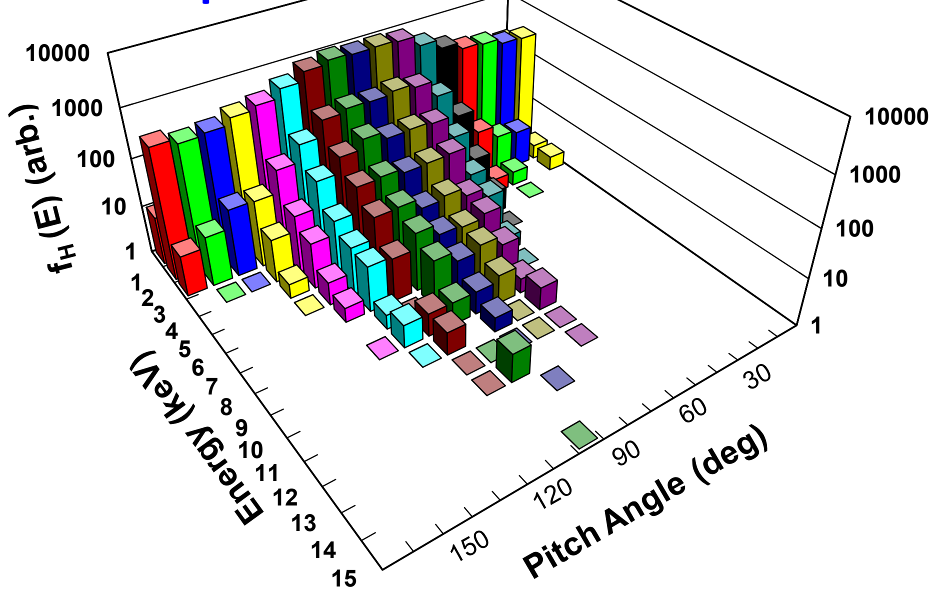
Calculated Pitch Angle Distributions

- **The high energy ions are generated near 60° and 120° in pitch angle.**
- **The higher energy flux can be observed in the high bumpy case in comparison with other cases.**
- **In the medium and low bumpy cases, the high energy component is smaller than that in the high bumpy case.**
- **One of the reasons of these tendency is the orbit loss structure near the perpendicular direction.**

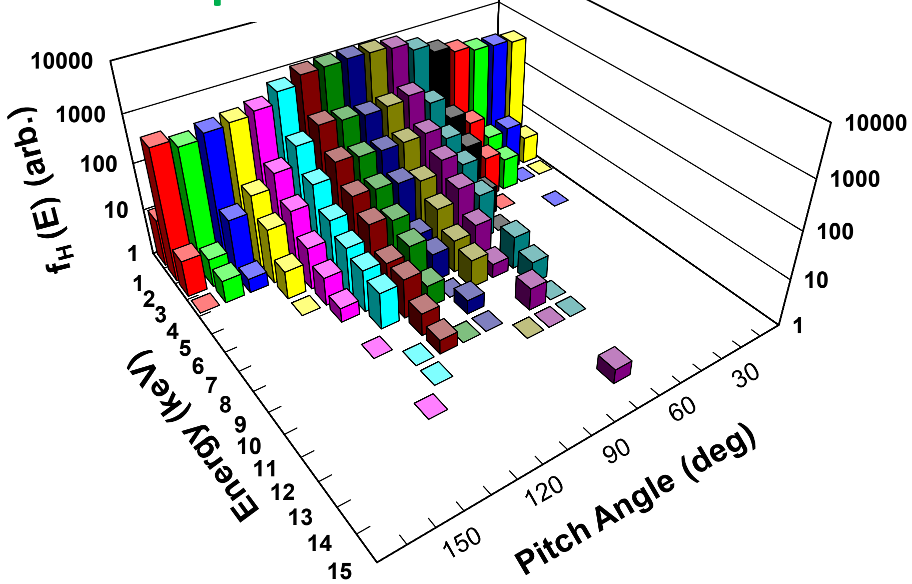
High Bumpiness



Medium Bumpiness



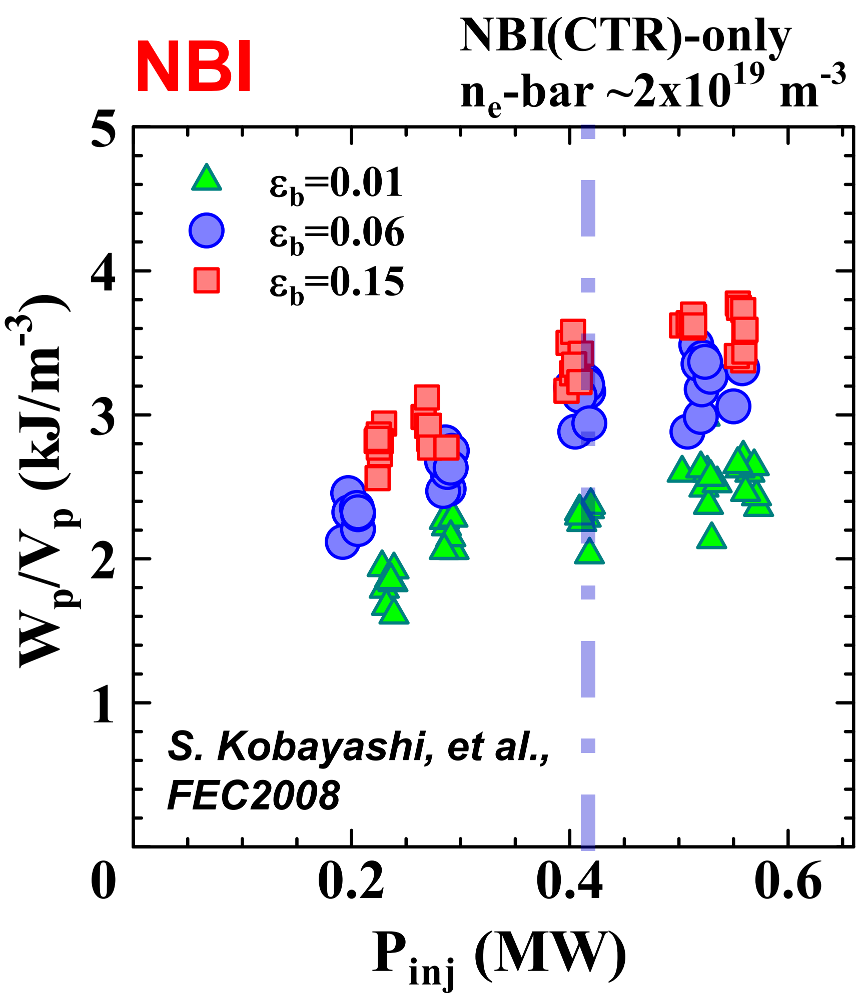
Low Bumpiness



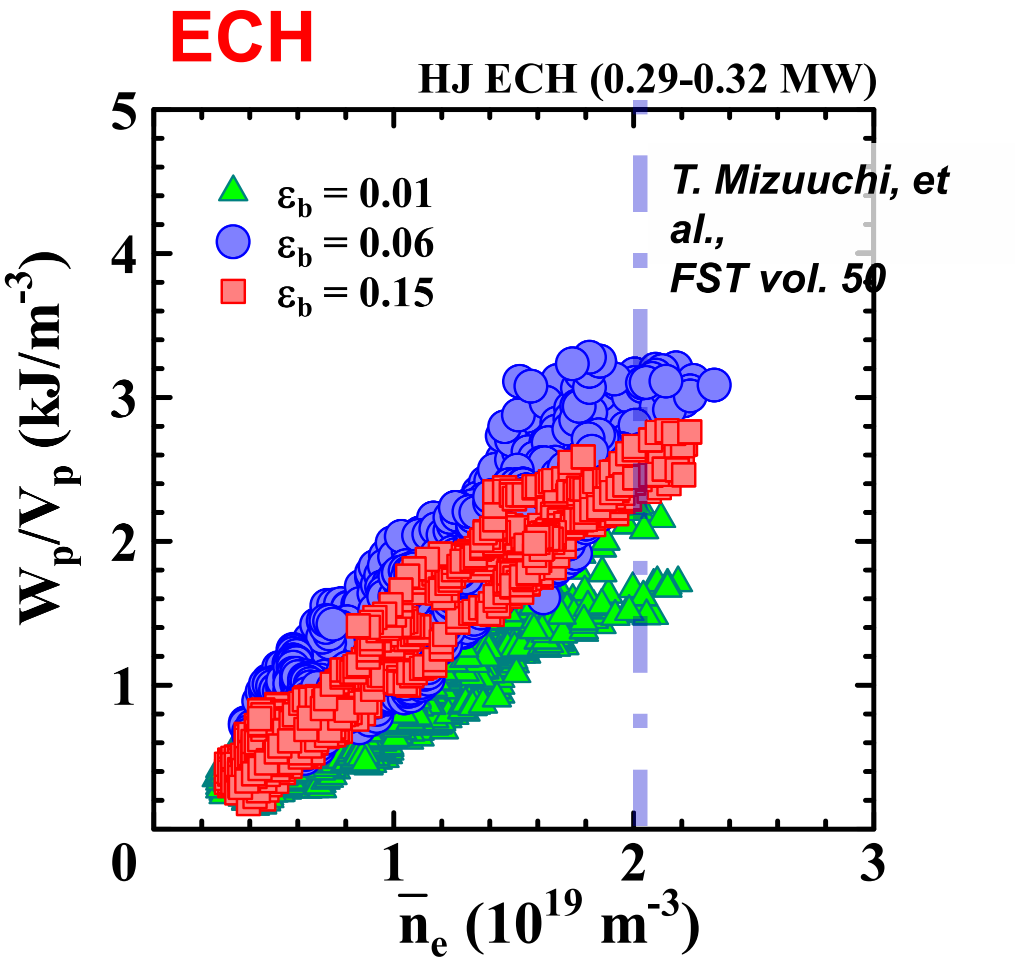
Bumpiness Control Experiments (2)
– *Global Energy Confinement* –

- **Following to the pervious study for ECH-only plasma, the global energy confinement has been compared among the three configurations for NBI-only plasma.**
- **The better plasma performance in W_p/V_p has been obtained in the high- and medium-ε_b cases compared to that in the low- ε_b case.**
  - **The improvement in T_i and T_e contributes to the higher plasma performance in these configurations.**

Bumpiness Effects on Plasma Performance: W_p in the high- and medium-ε_b configurations is clearly higher than that in the low-ε_b case.



- Power scan experiments
  0.2 MW < P_{NB} (CTR) < 0.6 MW
  @ ~2×10^{19}m^{-3}

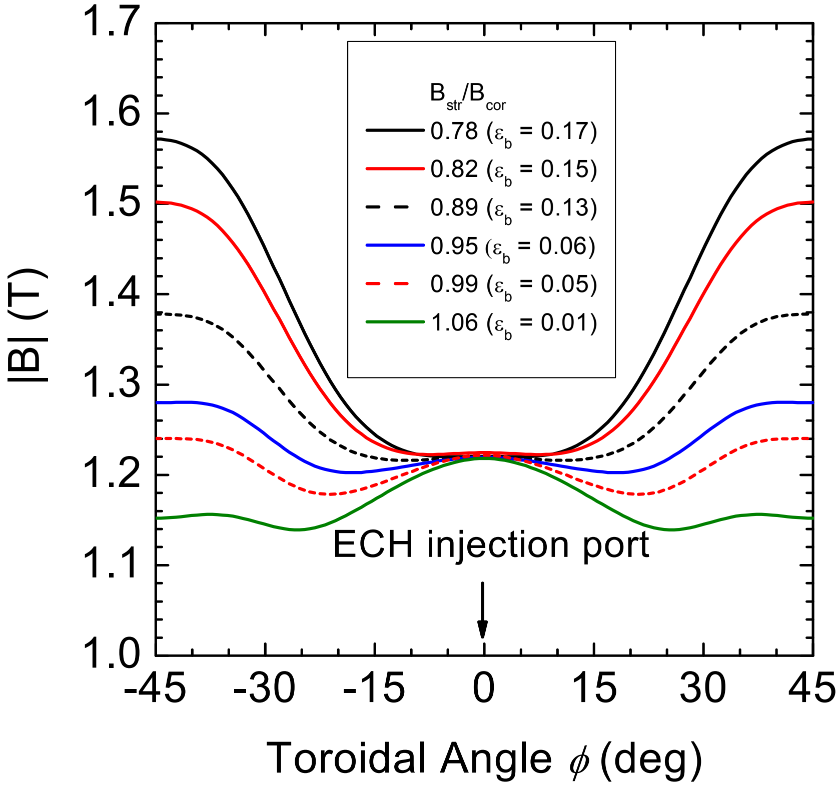


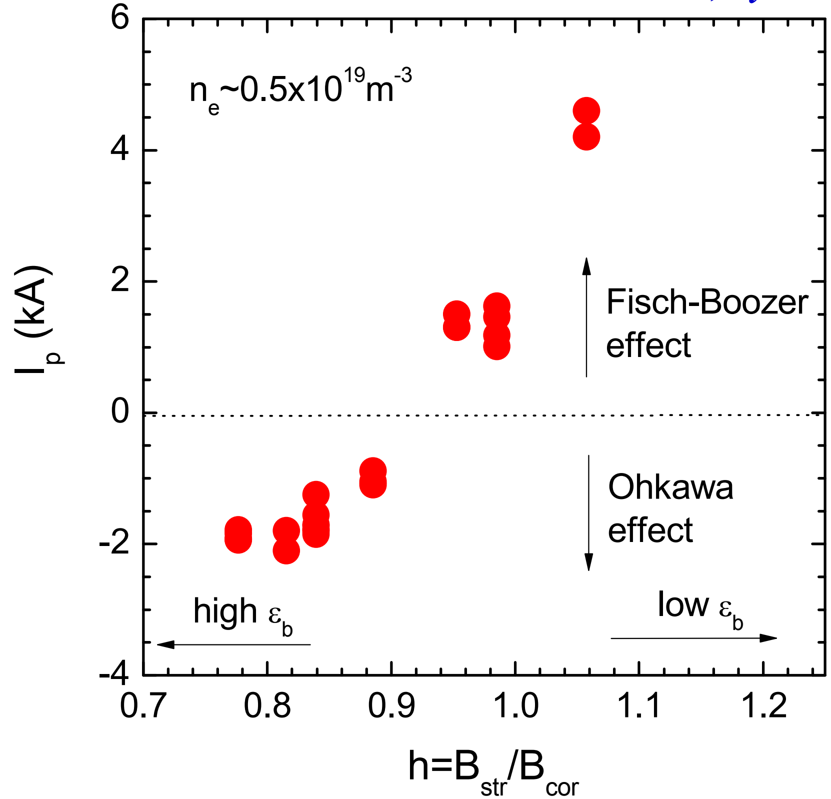
- Density ramp-up experiments
  X-mode 2nd ECH @ 70 GHz
- W_p increases with density up to ~2.5x10^{19} m^{-3} (close to the cut-off).

Bumpiness Control Experiments (3)
– ECCD –

- **A wide configuration scan shows that the EC driven current strongly depends on the magnetic ripple structure where the EC power is deposited.**
- **As the EC power is deposited on the deeper ripple bottom, the EC driven current flowing in the Fisch-Boozer direction decreases, and the reversal of directly measured EC driven current is observed.**
- **The normalized ECCD efficiency is found to be independent of the absorbed EC power for both ripple top and bottom heating cases.**
- **In order to increase the controllability of ECCD, the launching position and system has been changed.**

Effect of Magnetic Ripple on ECCD



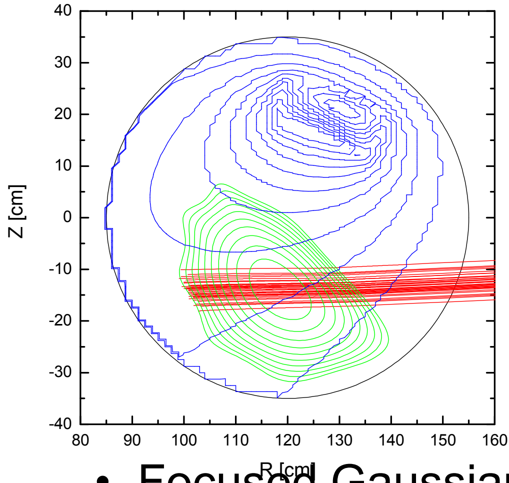


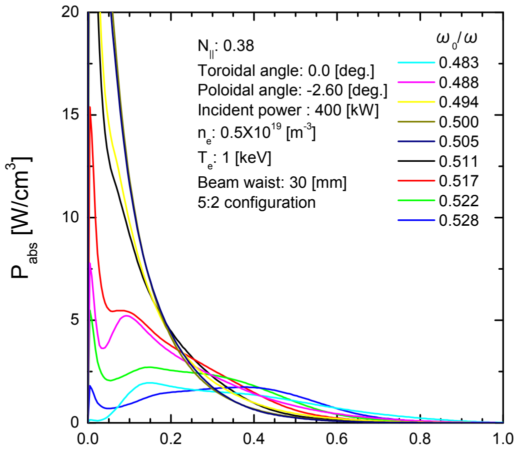
- **The bumpiness control causes the change in ripple structure.**
- **The toroidal current changes its flowing direction depending on the ripple structure.**
- **The current direction is explained by the balance between the Fisch-Boozer effect and the Ohkawa effect.**

K. Nagasaki, FEC2008, submitted to NF

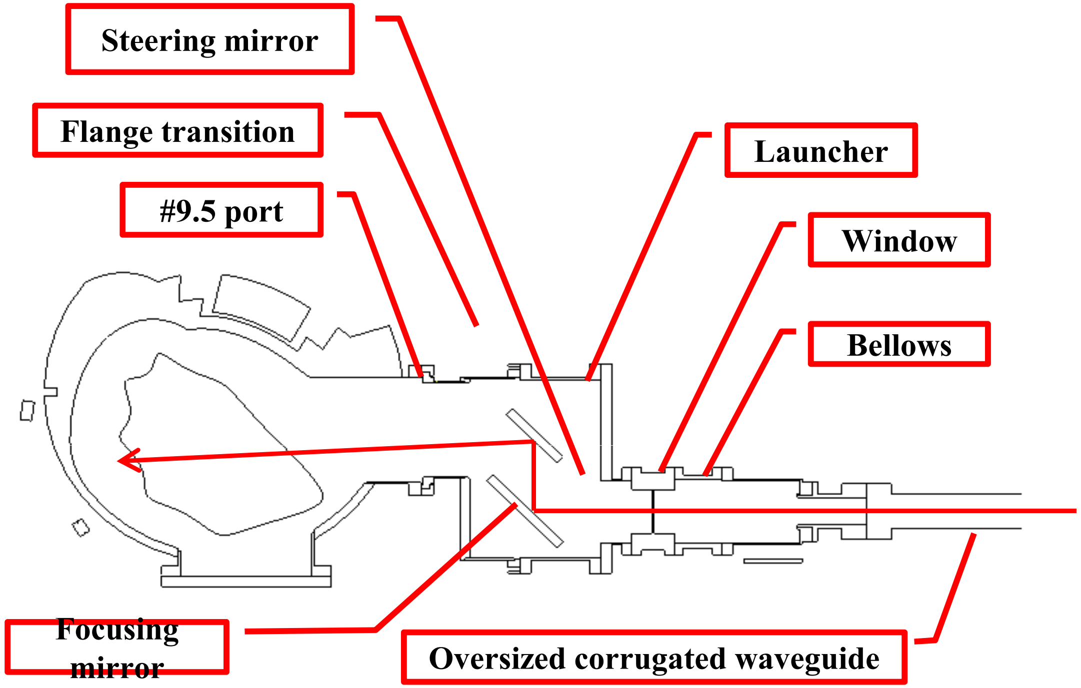
Upgraded Launching System

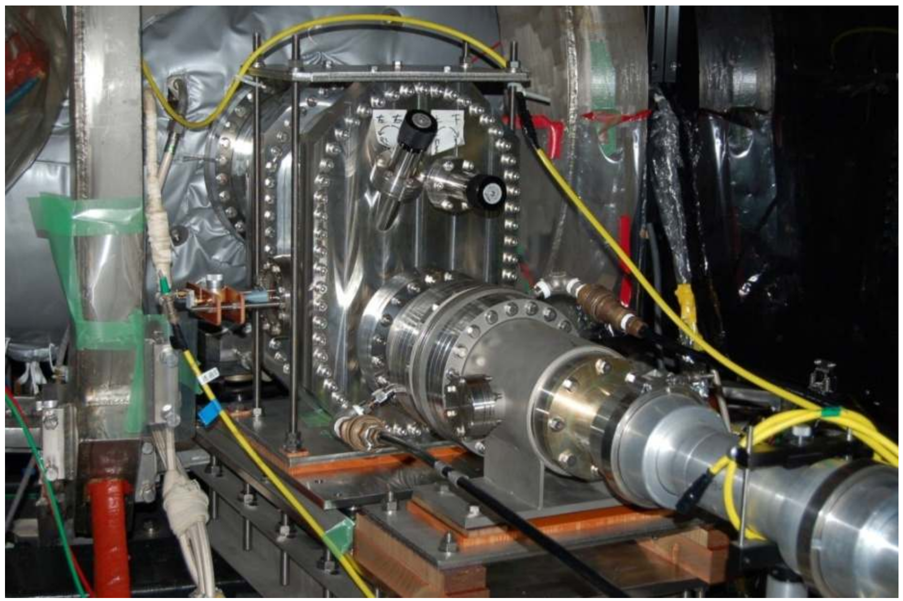
- **A launching system with a focusing mirror and a steering mirror has been installed in Heliotron J for the 2009 experimental campaign.**
- **The main purposes are to localize the power absorption profile and to control ECCD by changing $N_{||}$.**





- Focused Gaussian beam, w=30mm
- $-0.1<N_{||}<0.6$
- Possible to Inject along magnetic axis

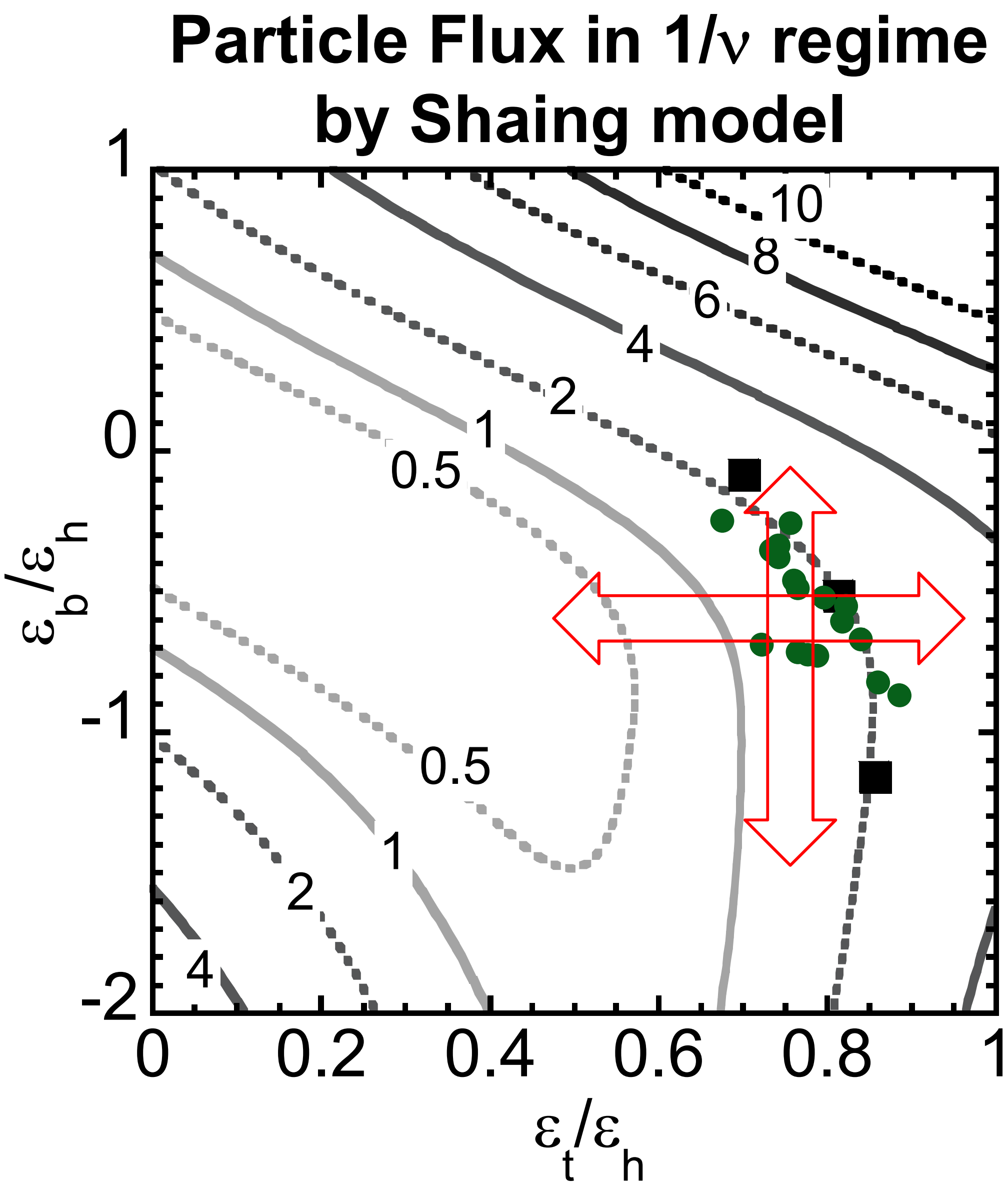




To deepen the understanding of configuration effects on the plasma performance & enhanced confinement physics,

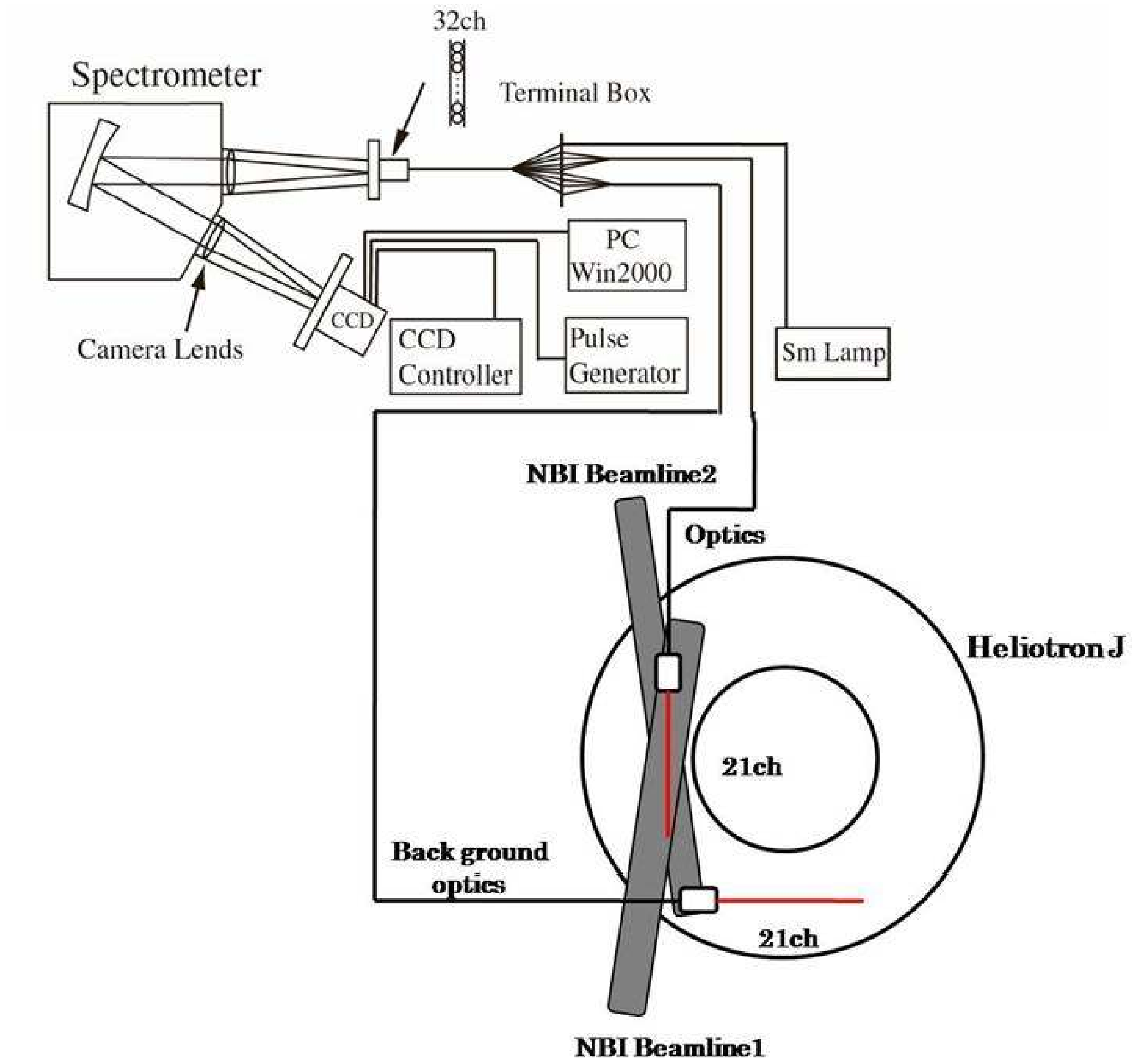
- **Expansion of investigation range in ($\varepsilon_t/\varepsilon_h$, $\varepsilon_b/\varepsilon_h$)-space with different iota values,**
- **Build-up of profile database by upgrading the diagnostic system,**
- **Expansion of achievable plasma parameter range by fueling and PWI control,**
- **Increase of the plasma current controllability,**
- **Comprehensive study of plasma turbulence.**

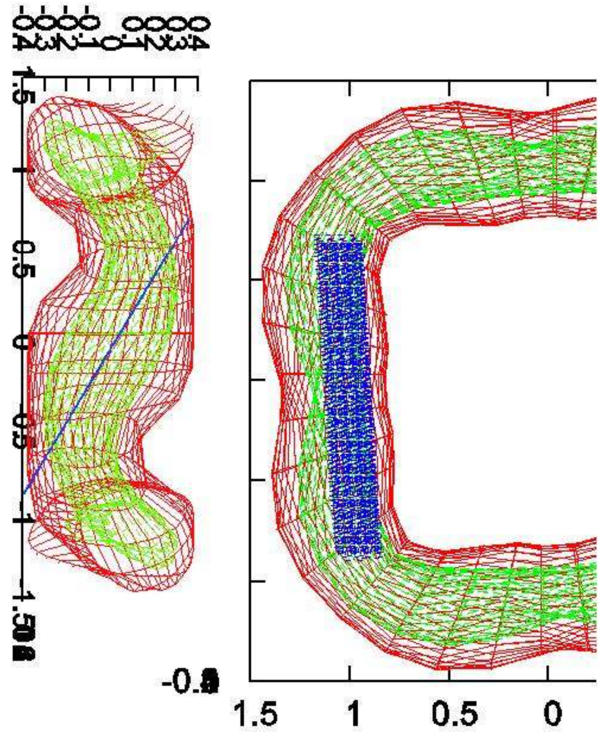
Expansion of investigation range in ($\varepsilon_t/\varepsilon_h$, $\varepsilon_b/\varepsilon_h$)-space with different iota values



- **The configuration parameter ($\iota/2\pi$, ε_b) range, which has been surveyed so far, is limited.**
- **Experiments in the expanded investigation range in ($\varepsilon_t/\varepsilon_h$, $\varepsilon_b/\varepsilon_h$)-space with different iota values are proposed.**

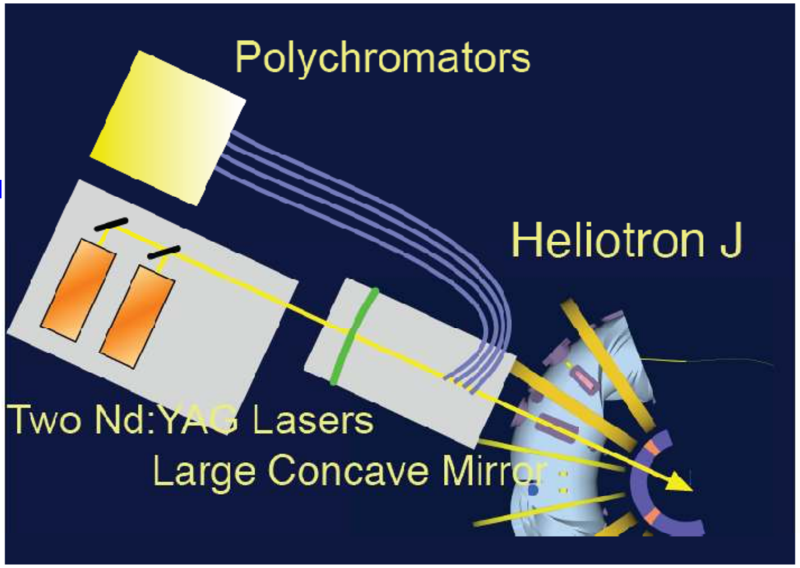
Upgrade of CXRS System (scheduled)

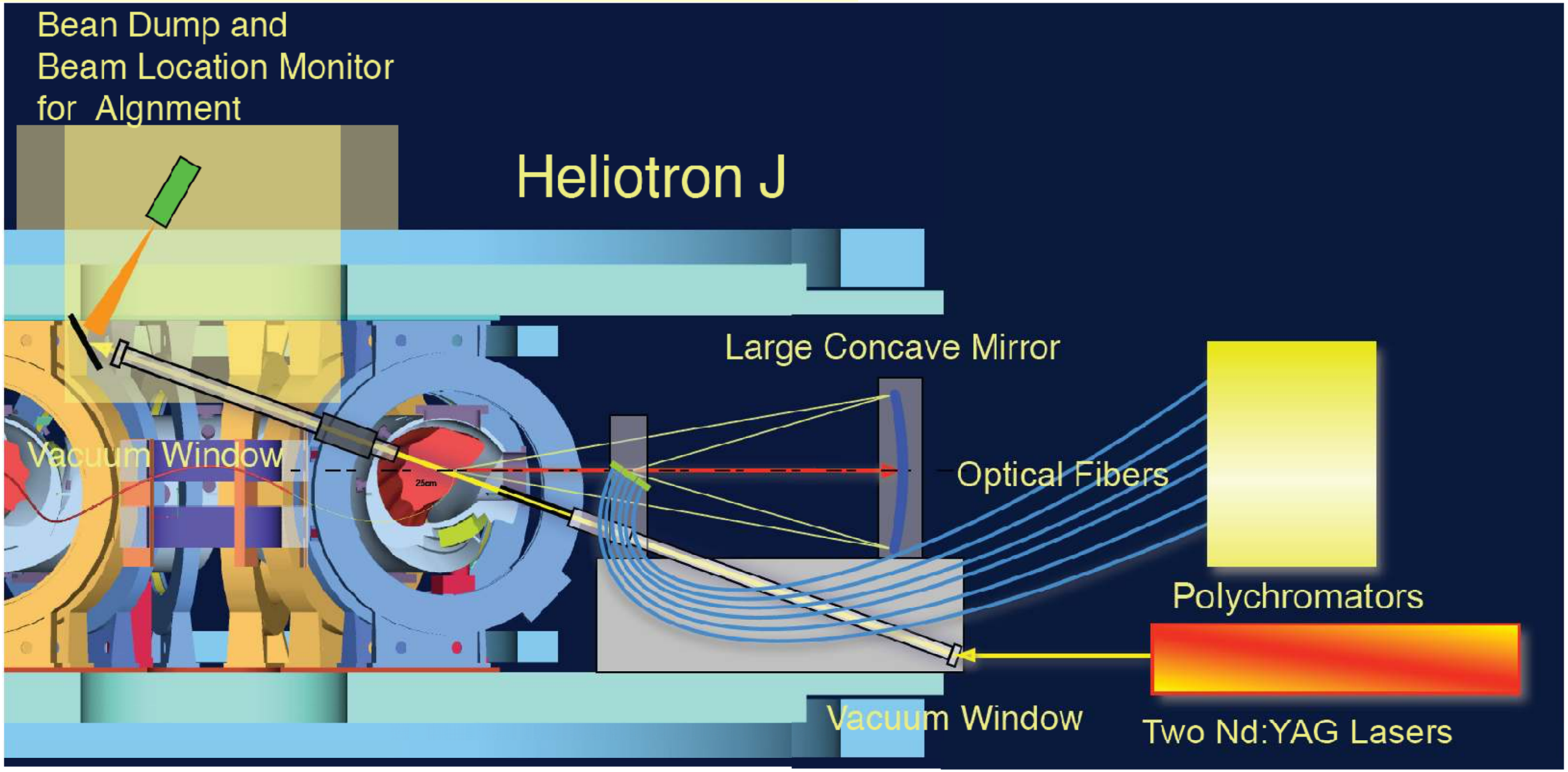




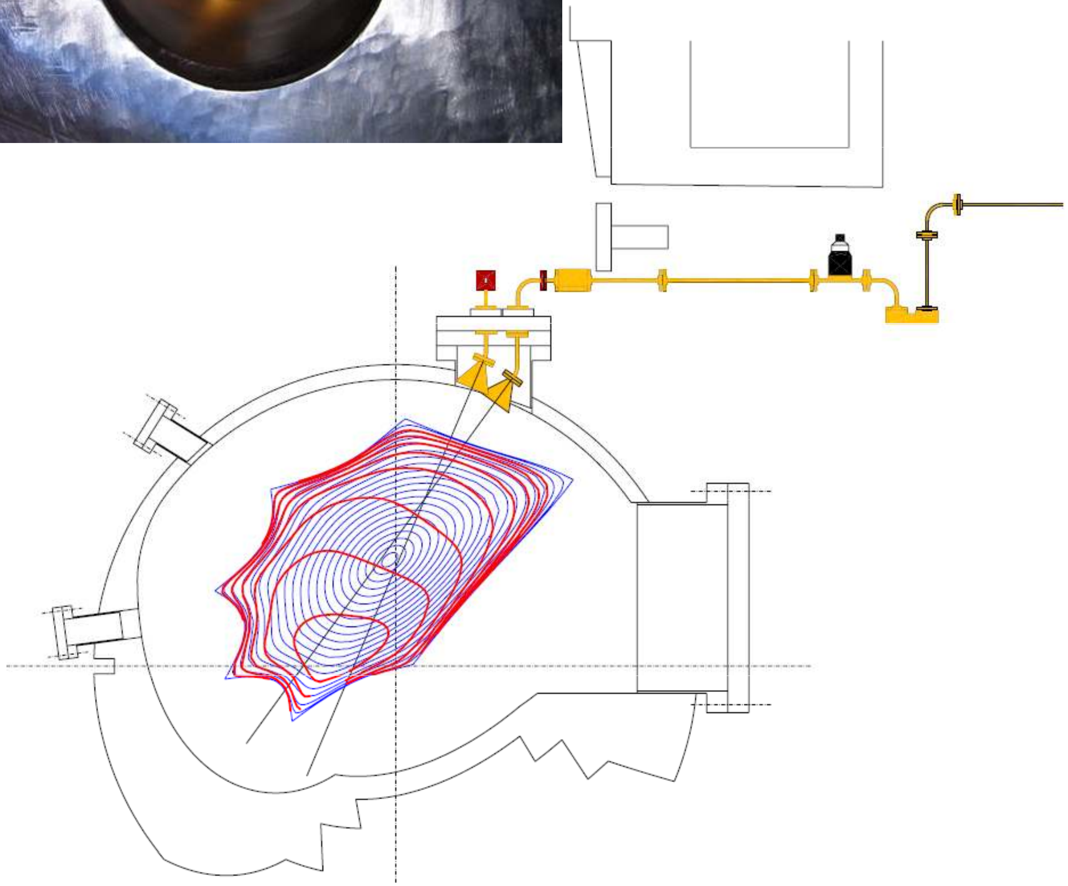
New Nd:YAG Thomson Scattering System

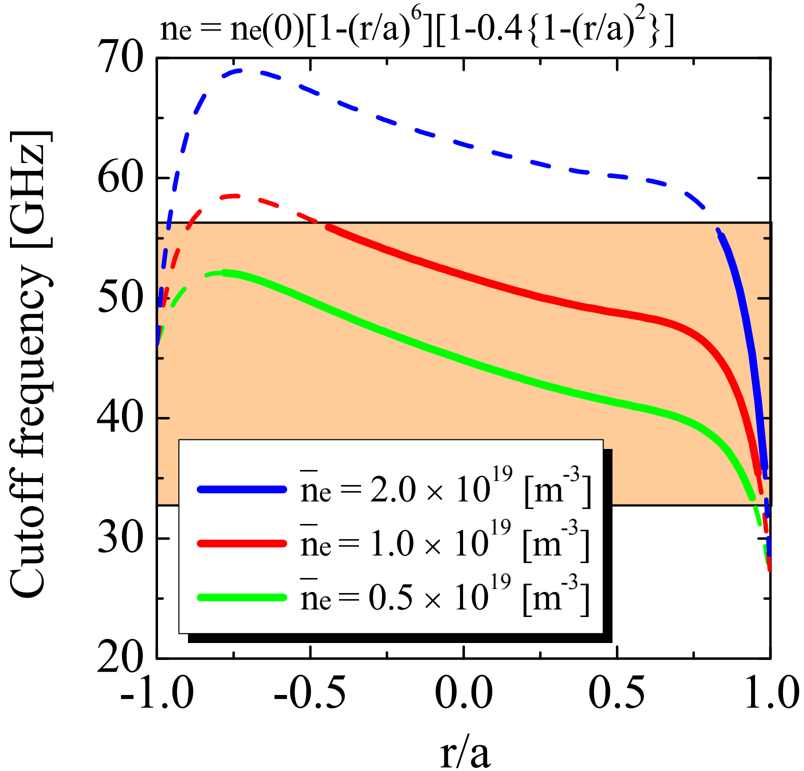
- Purpose:
  Measurement of temporal evolution of the profile of the Heliotron J plasma for the study of the improved confinement by the profile control.
- Two 50Hz Nd:YAG lasers (550mJ):
  The plasma profiles can be measured with 10ms interval.
- High photon count:
  Obliquely back scattered light is collected with large concave mirror (R=800mm).
- The system have 25 polychromators that have 5 wavelength channels: Spatial resolution is ~1cm.





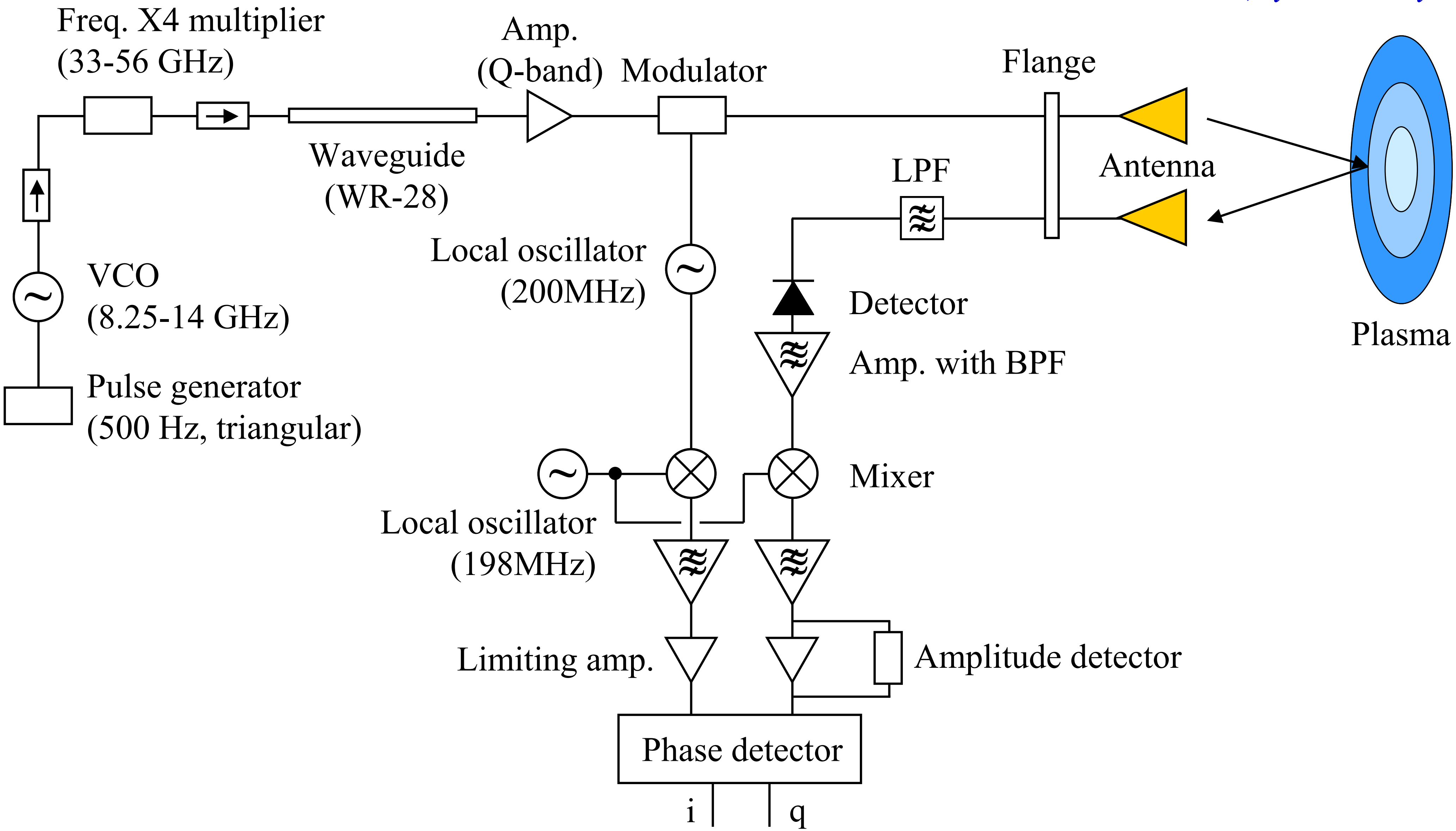
AM reflectometer
for electron density profile measurement



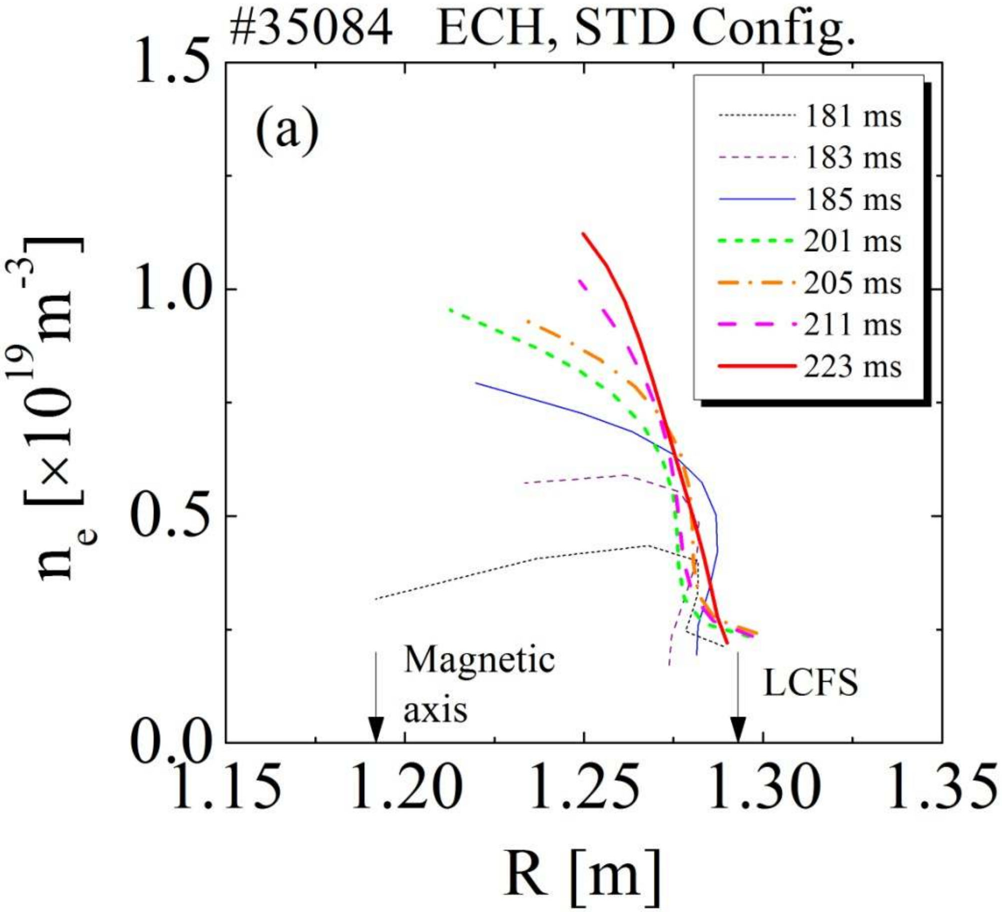


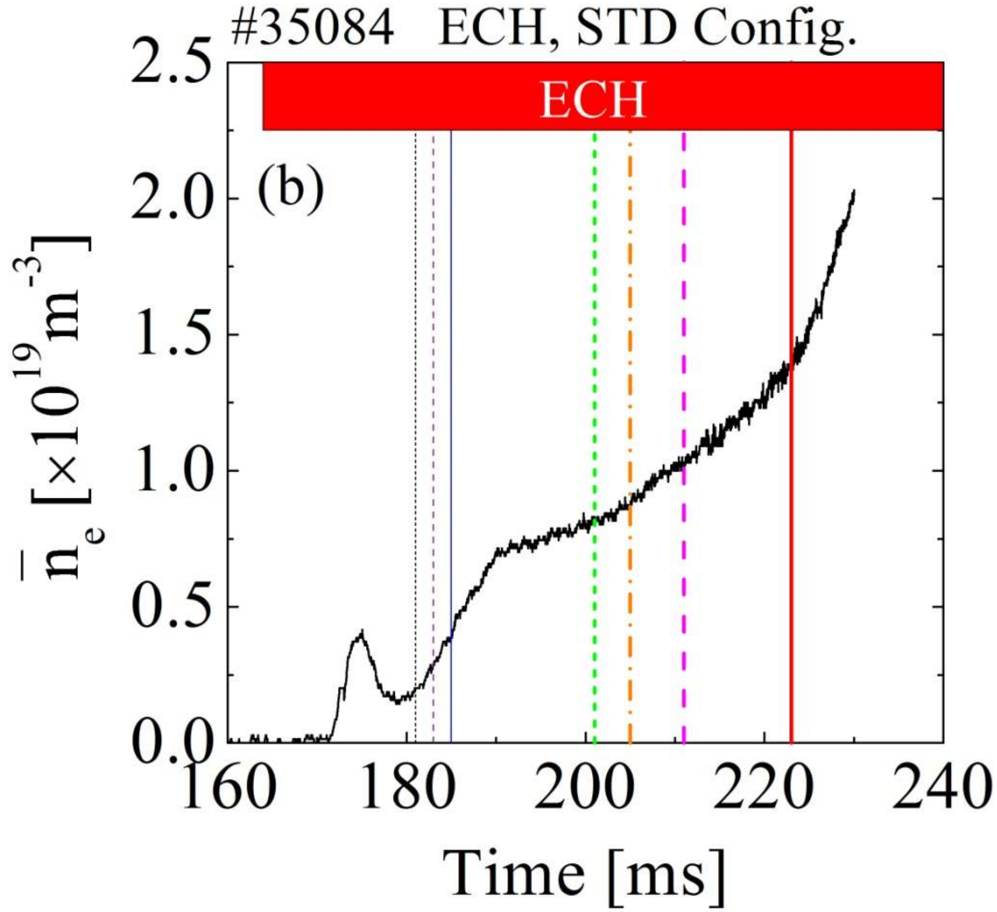
X-mode cutoff frequencies at given electron densities

Schematic of AM reflectometer

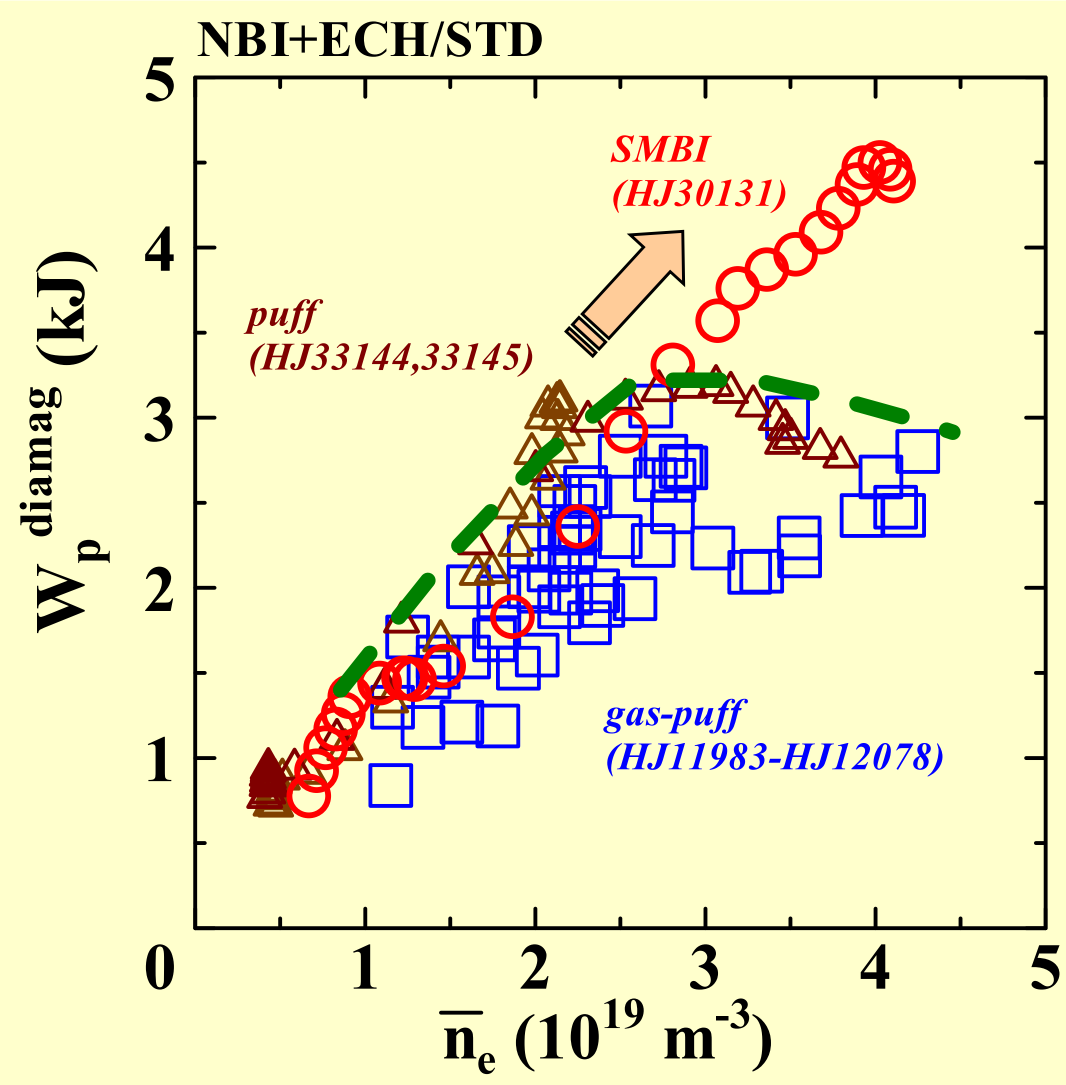


Preliminary Result of Reflectometer Measurement





Fueling/PWI control can be an important factor to obtain the improved confinement.



- SMBI can expand the operation region of Heliotron J.
- The stored energy reached ~ 4.5 kJ, about 50 % higher than the max. one achieved so far under the normal gas-puff in Heliotron J.
  - ECH (~ 0.35 MW) and NBI (~ 0.6 MW)
- Effective pumping or recycling control should be combined.

Comprehensive Study of Plasma Turbulence

- **MHD Activities**
  - **GAE**
  - **MHD Study with Data Mining Technique**

- **Edge Turbulence**
  - **Relation of the edge (inside/outside the LCFS) turbulence with the transition**
  - **Difference between O- and X-points of the Flux Surface**
  - **"Long Distance Correlation"**

- **Biasing Experiment**

New Langmuir Probe Systems (proposed)

Objective

- Simultaneous measurement of δE_r and δE_θ.

$$\delta E_r = (\varphi_{s1} - \varphi_{s2}) / \Delta r$$

$$\delta E_\theta = (\varphi_{s2} - \varphi_{s3}) / \Delta\theta$$

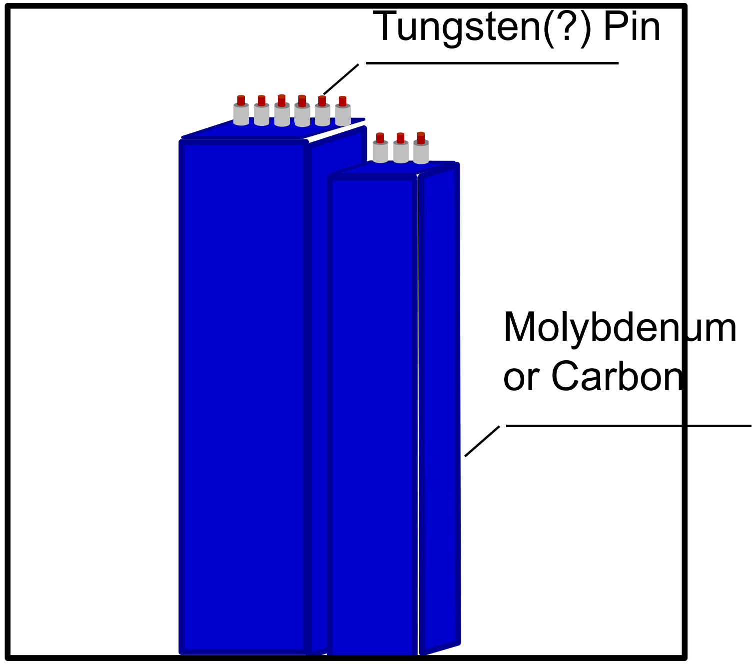
- Evaluation of turbulence driven transport.

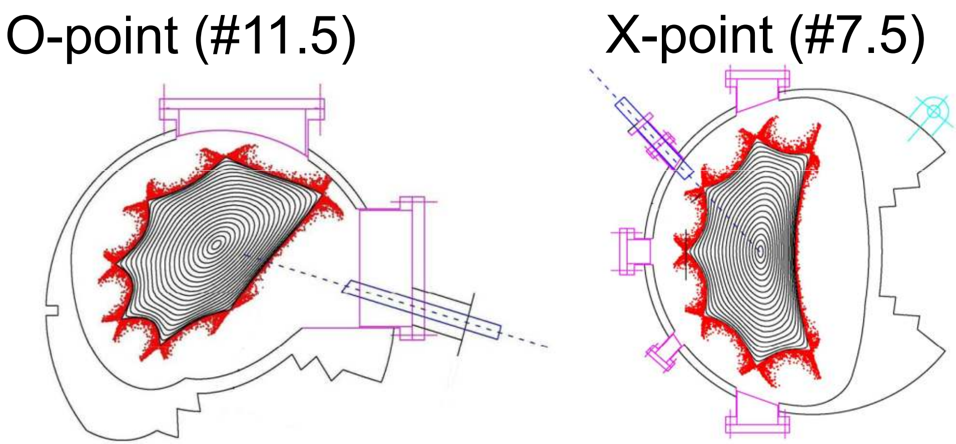
$$\Gamma_{turbulence} = \langle \delta n_e \cdot \delta E_\theta \rangle / B_T$$

- Investigation of nonlinear relationship between Reynolds stress and turbulence.

$$\langle \delta v_r \cdot \delta v_\vartheta \rangle \sim \langle \delta E_\vartheta \cdot \delta E_e \rangle / B^2$$

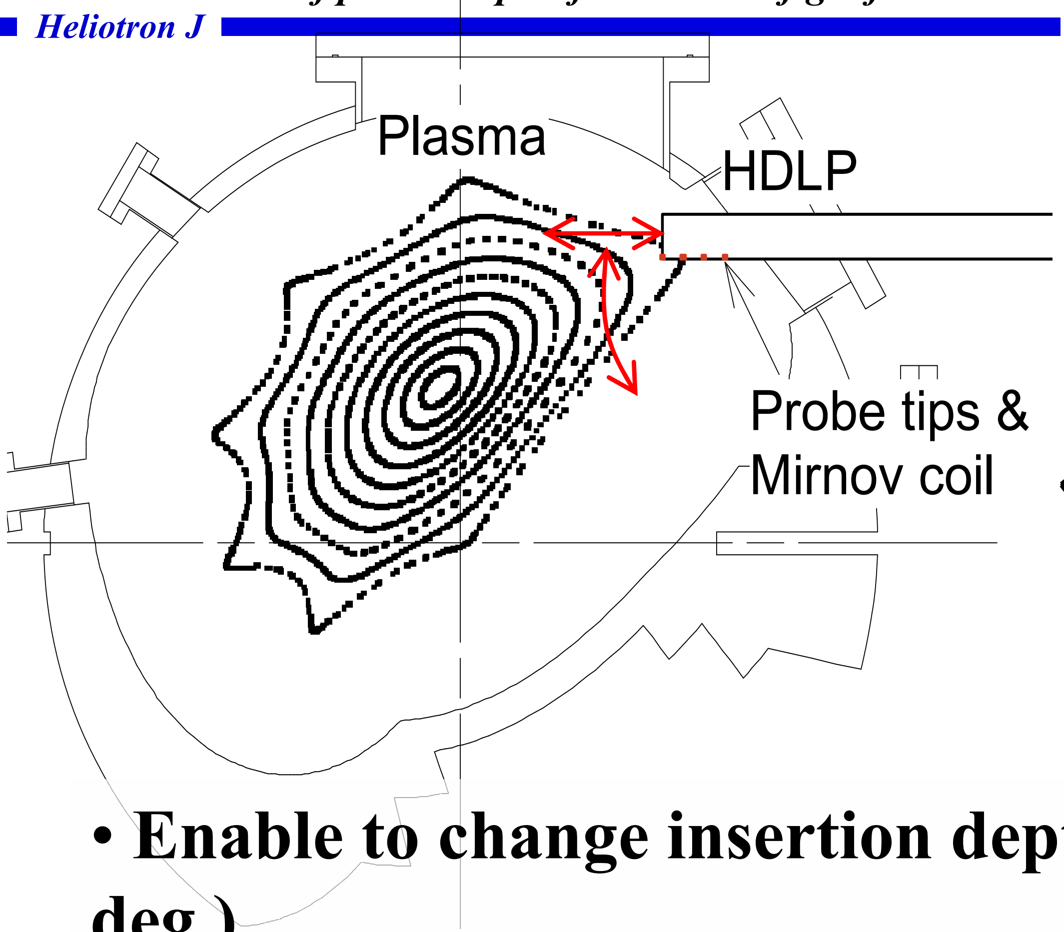
- Correlation of fluctuations at different toroidal sections.



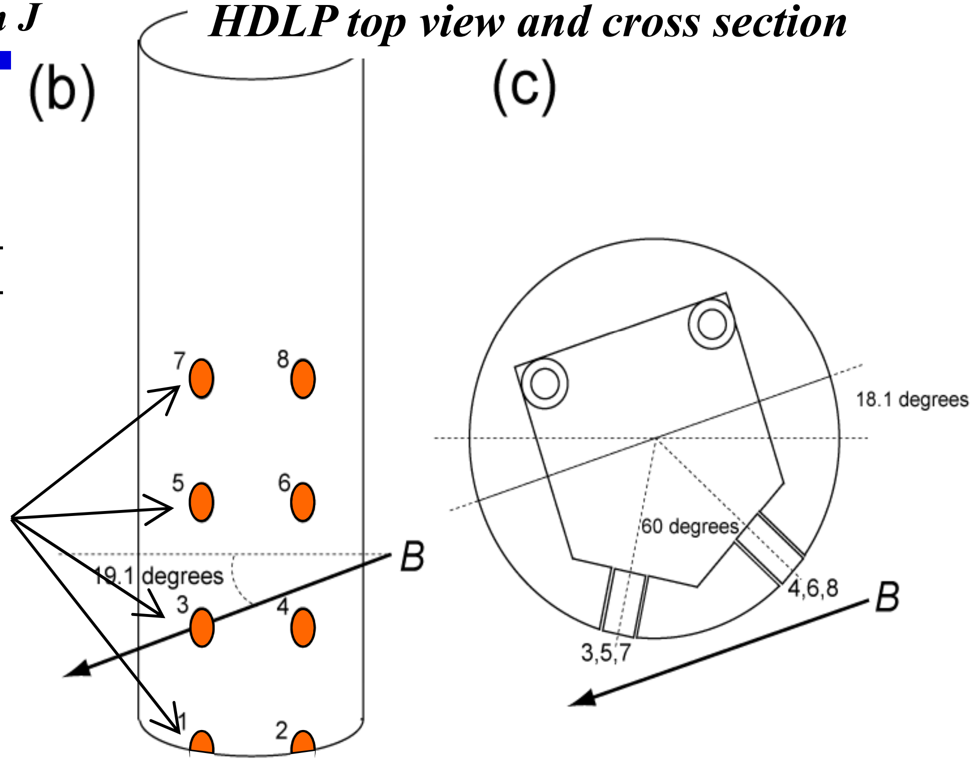


HDLP installation into Heliotron J

Cross section of poincare plot for STD config. of Heliotron J



HDLP top view and cross section



- Enable to change insertion depth and poloidal angle (0 to -5 deg.)
- Probe angle in z-ϕ plane is flexible (20 degrees in this experiment).

  ← To align HDLP probe tips to magnetic field
- Almost separate Co- and Ctr-going ion fluxes, however, some highly and vertically accelerated particles are still

*K. Nagaoka, et al., Plasma Fusion Res.1, 005 (2006), **K. Nagaoka, et al., Proc. ICPP2008, P2-156

Studies of MHD in Heliotron J

✓ Topics of MHD equilibrium/stability of Heliotron J

- ➢ Effect of magnetic configuration with a low magnetic shear in combination with a magnetic well on MHD stability, in particular, pressure driven interchange and ballooning modes.

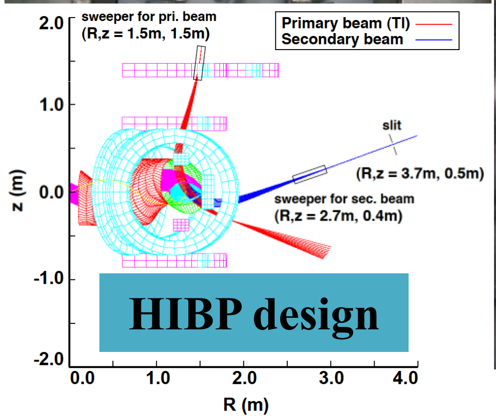
  ➔ To apply the data mining technique to build MHD database for getting unified understanding of a helical plasmas.
- ➢ Effect of finite beta and plasma current on MHD equilibrium for high beta plasma operation.
- ➢ Effect of magnetic island on confinement and external control of magnetic island by resonant magnetic perturbation (RMP) in a low magnetic shear configuration.
- ➢ Energetic-ion-driven MHD instabilities including global Alfvén eigenmode (GAE), helicity-induced AE (HAE) and mirror-induced AE (MAE) and their effect on energetic ion transport.

✓ Diagnostics for MHD studies in Heliotron J

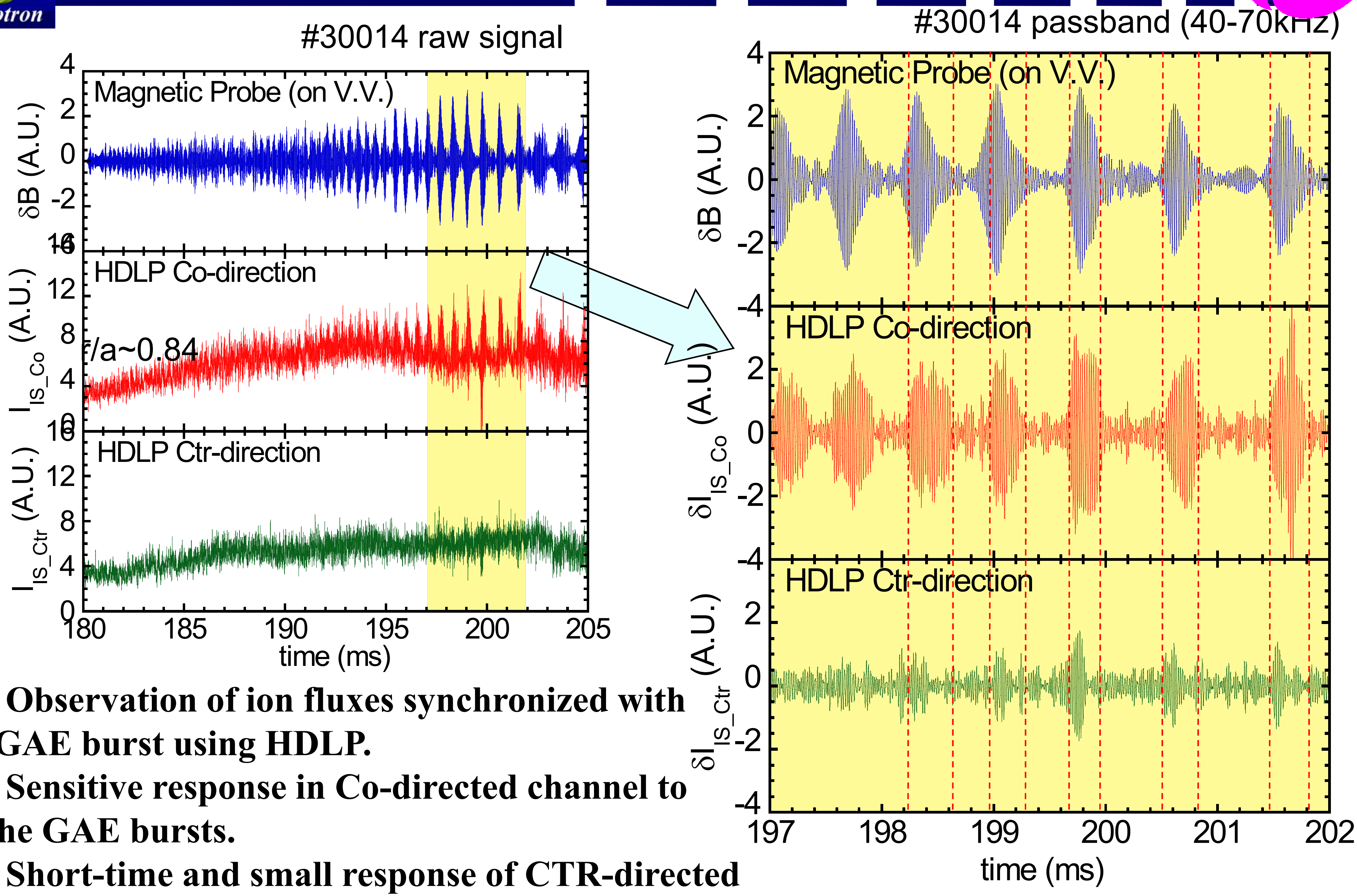
- ➢ Toroidal (4ch) /Poloidal (14ch) array of magnetic probe (B_θ)
- ➢ Soft-X ray and AXUV diode array (16ch)
- ➢ Poloidal array of saddle coil (Br)
- ➢ ECE radiometer
- ➢ Movable Langmuir probe array

✓ Future Plan of diagnostics

- ➢ Upgrading magnetic probes and saddle coils
- ➢ Soft-X ray computer tomography (SX-CT)
- ➢ Heavy ion beam probe (HIBP)



Bursting GAEs in Heliotron J ($\iota(a)/2\pi = 0.54$)



- **Observation of ion fluxes synchronized with GAE burst using HDLP.**
- **Sensitive response in Co-directed channel to the GAE bursts.**
- **Short-time and small response of CTR-directed channel in earlier phase of burst, (disappeared after the peak of magnetic fluctuation)**

Expansion of achievable plasma parameter range by fueling and PWI control

- **Fueling Control**
  - Conventional Gas-Puff
  - SMBI (Supersonic Molecular Beam Injection)
  - Pellet Injection (under discussion)

- **PWI Control**
  - Lithium Coating (or Boron Coating)
    (under discussion)