Observation of Ion Tail and Magnetic Fluctuations in ECH/ECCD plasmas

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Background (1)

In some torus devices, such as TCV, FT and W7-A

- **high energy ions have been observed in ECH/ECCD plasmas[A-C].**
- **The phenomena could not be explained by the classical theory of two-body Coulomb collisions.**

Ion energy spectrum obtained in the TCV tokamak

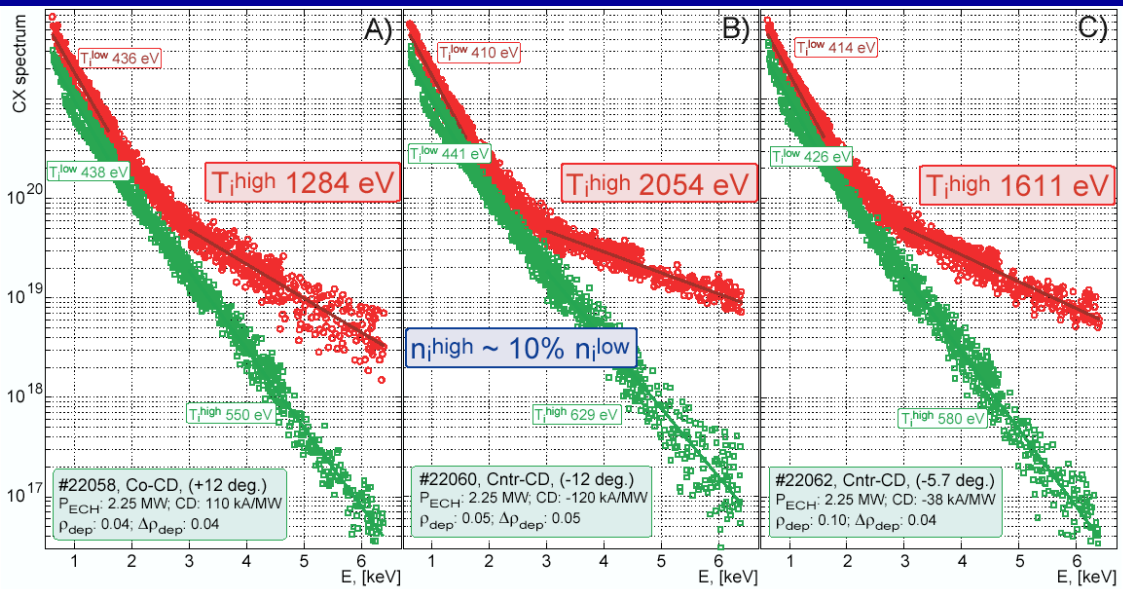


Fig.3: CX-spectrum for EC ON and OFF phases

A) Co-ECCD shot: P_{ECH}:2.25 MW, θ_{tor}:+12°, CD efficiency:110 kA/MW, $\rho_{dep.}$:0.04, $\Delta\rho_{dep.}$:0.04.

B) Cntr-ECCD shot: P_{ECH}:2.25 MW, θ_{tor}:-12°, CD efficiency:-120 kA/MW, $\rho_{dep.}$:0.05, $\Delta\rho_{dep.}$:0.05.

C) Cntr-ECCD shot: P_{ECH}:2.25 MW, , θ_{tor}:-5.7°, CD efficiency:-38 kA/MW, $\rho_{dep.}$:0.1, $\Delta\rho_{dep.}$:0.04.

In TCV tokamak case,

- **Ion tail appears when ECH is turn-on.**
- **Sensitive to the ECH toroidal injection angle and deposition position.**

A.N.Karpushov, *et al*., *30th EPS Conf. Ctrl. Fusion Plas. Phys.*, St. Petersburg, p3-123. (2003).

V.Erckmann and U.Gasparino, *Plasma Phys. Control. Fusion* **36**, (1994) 1896

B.Coppi et al., *Nucl. Fusion* **16**(2) pp.309-328 (1976)

Background (2)

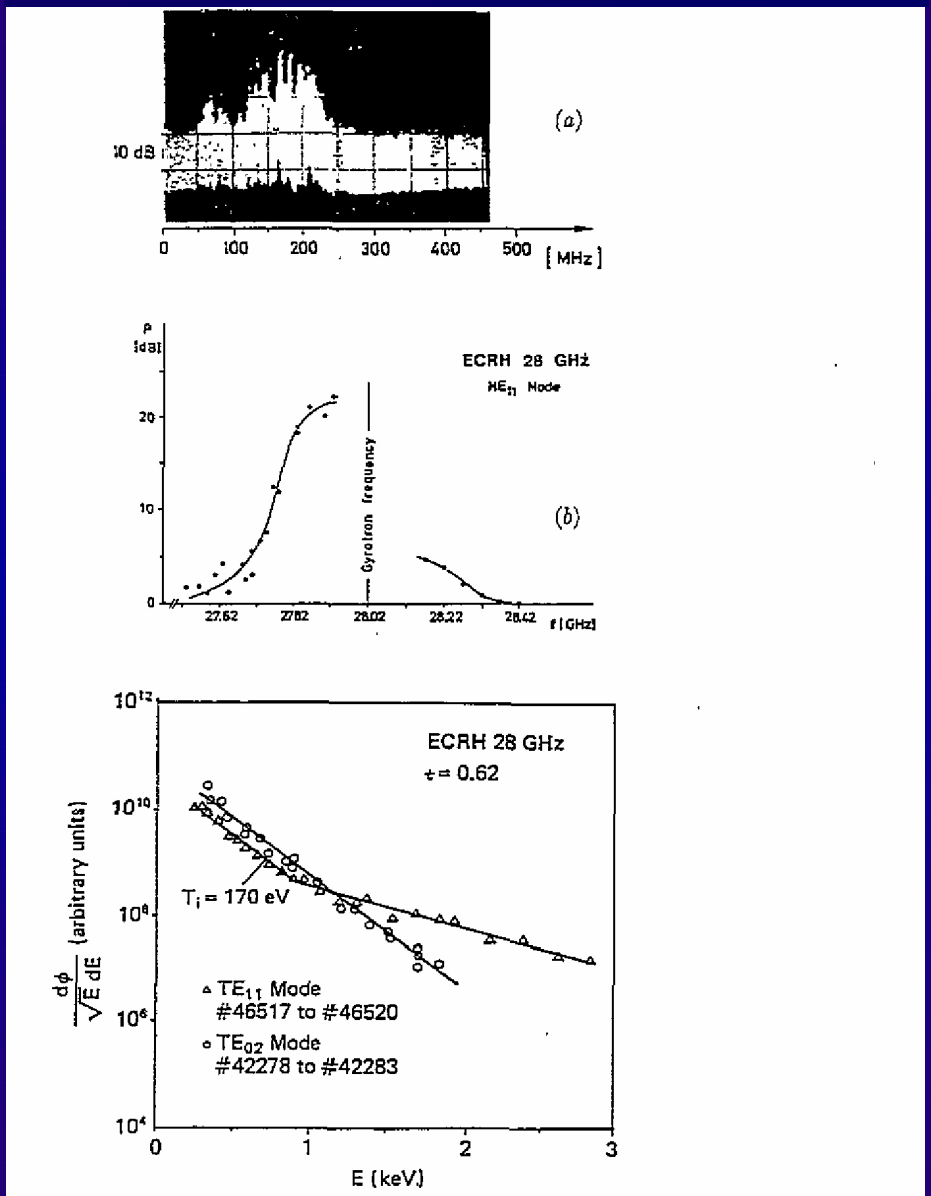


Figure 15. Low- (*a*) and high-frequency (*b*) decay spectra measured at W7-A [86] with X-mode HFS launch (28 GHz, $B_{res} = 1$ T). The ion energy distribution from CX-diagnostics is also displayed for low- (TE02-mode) and high-power density (HE11-mode) of the incident pump wave. The tail formation at high power density is clearly seen.

In the case of W7-A,

- **By using, a polarization twisting mirror at the inner torus wall,**
  -> Reflection in X-mode from HFS.
- **Measurement of the low frequency decay wave.**
  -> LH wave
- **Observation of high energy ion tail in high ECH power density case**

V.Erckmann and U.Gasparino, *Plasma Phys. Control. Fusion* 36, (1994) 1896

Contents

- In the CHS and Heliotron J devices, ECH/ECCD experiments (2nd harmonic) have been carried out.
- Under some conditions, a formation of tail component of high energy ions has been observed.
- In CHS, some magnetic fluctuations has been observed when the ion tail appeard.

In CHS,

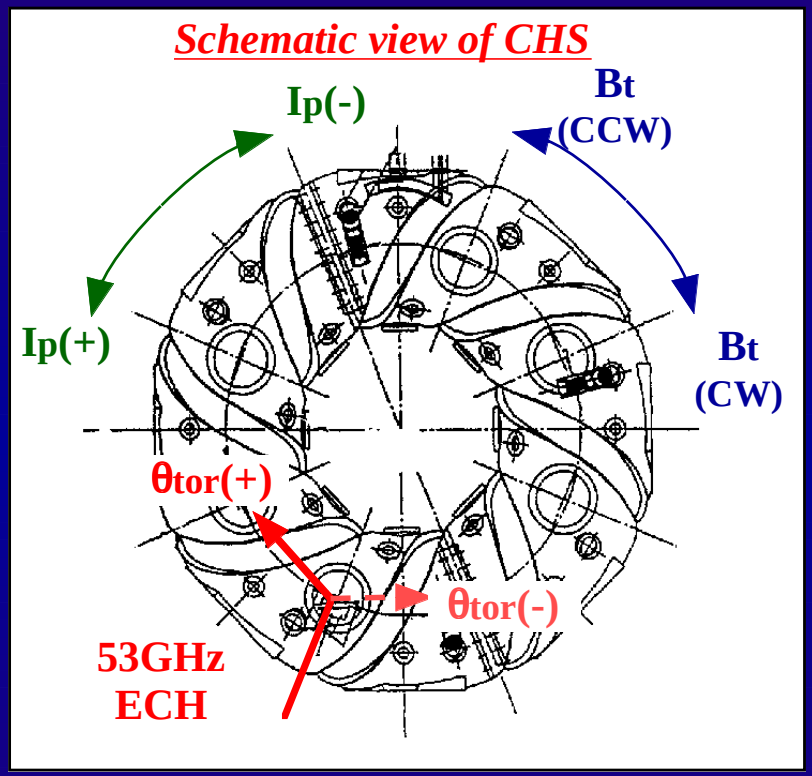
- Property of the ion tail and magnetic fluctuations.

In Heliotron J,

- Property of the ion tail in 70 GHz ECH plasmas.

CHS Device

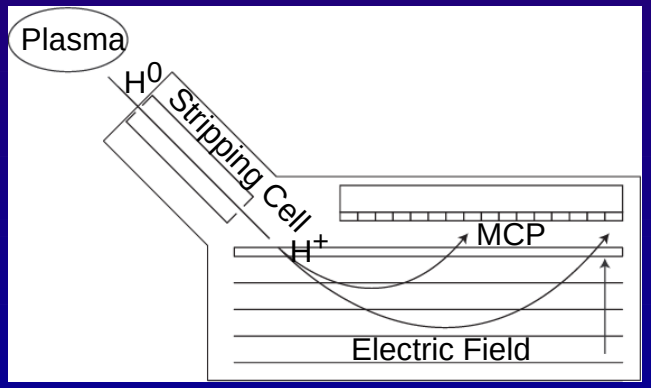
ECH/ECCD experiments using 53GHz ECH system in CHS*



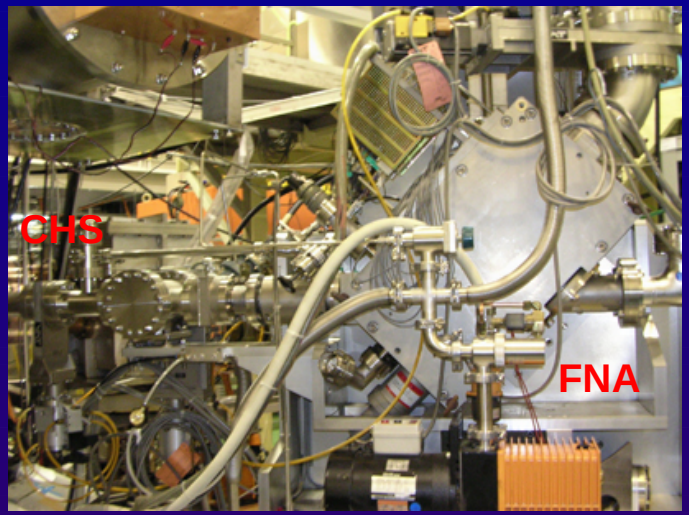
- Injection angle is controllable in toroidal and poloidal direction using three steerable mirrors.
- Polarization is also controllable with polarizer

T. Minami, et al., Nucl. Fusion 44 (2004) 342–349

Fast Neutral Particles Analysis system (FNA)



- Energy range 0.1～50 KeV
- Number of channels 16
- Changeable the toroidal and poloidal angle
- Energy resolution
  First Ch. 3.67% 16th Ch. 1.38%



K. Ida, et al., Nucl. Fusion 39 No 11Y (1999) p1649

M. Isobe, et al., Nucl. Fusion 41 No 9 (2001) p1273

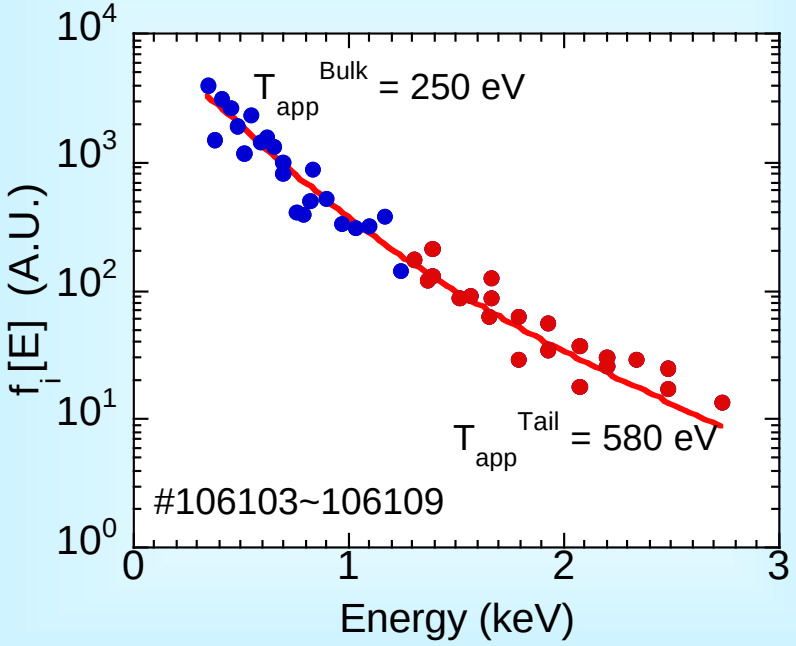
Ion Energy Spectrum of ECH/ECCD Plasmas in CHS

A high energy ion tail was observed in the case of low density

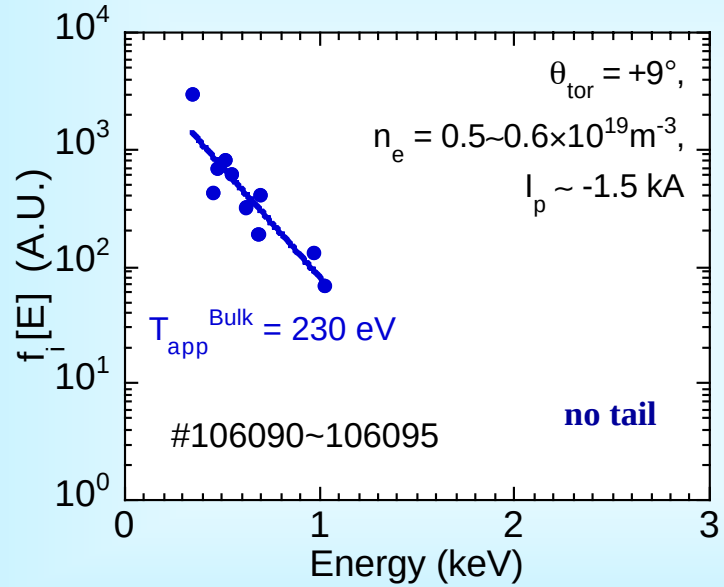
B_t = 0.88T(CW), R_{ax} = 92.1 cm, P_{ECH} = 135 kW

θ_{tor} = -9(deg) ⇒ I_p~-4kA, n_e~0.3x10^{19} m^{-3}

Ion energy spectrum with high energy tail (CHS)



Ion energy spectrum with no tail (Higher density case)

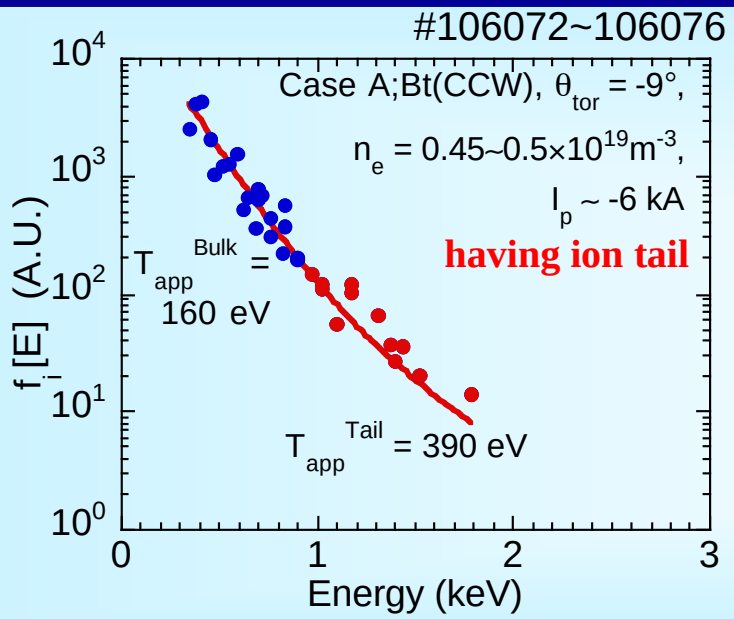


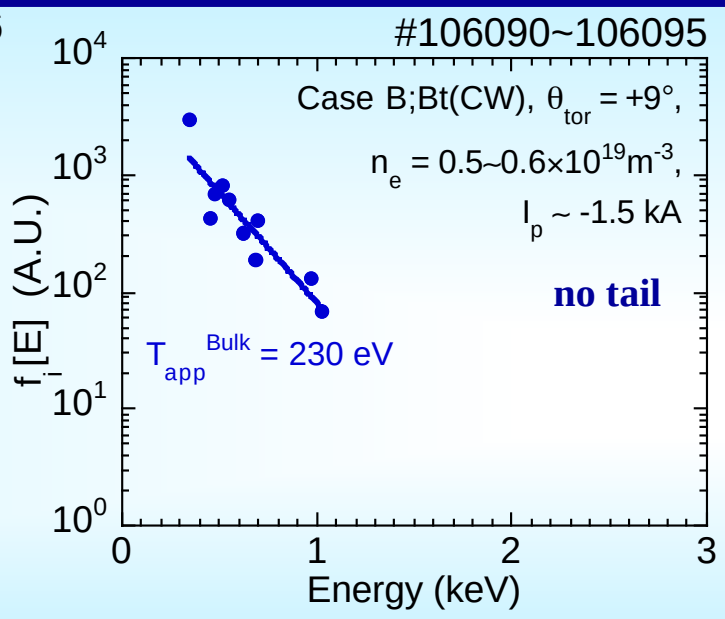
- **A folded spectrum was found**
- **The bulk and tail temperature were to be 250eV and 580eV, respectively.**

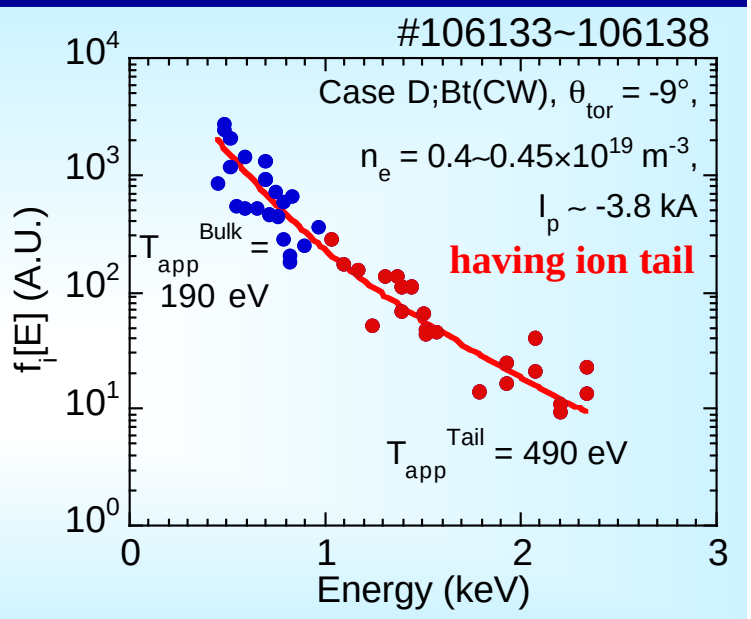
- **No clear ion tails.**

Observation of Ion Tail in ECH/ECCD Plasmas in CHS

	Shot No.	Bt	θtor	Polarization	PEC(kW)	ne(×10^{19} m^{-3})	|Ip|(kA)max	ion tail	fluctuation
A	#106072-076	CCW	-9	RH	135	0.45~0.5	~-6	o	o
	#106077-081	CCW	0	Linear	135	0.5~0.6	-1.7	--	--
B	#106090-095	CW	9	RH	135	0.5~0.6	~+1.5	--	--
C	#106103-109	CW	-9	RH	135	0.3~0.4	~-4	o	o
	#106122-126	CW	-9	RH	135	0.5~0.6	~-2.5	--	--
D	#106133-138	CW	-9	RH	135	0.4~0.45	~-3.8	o	o

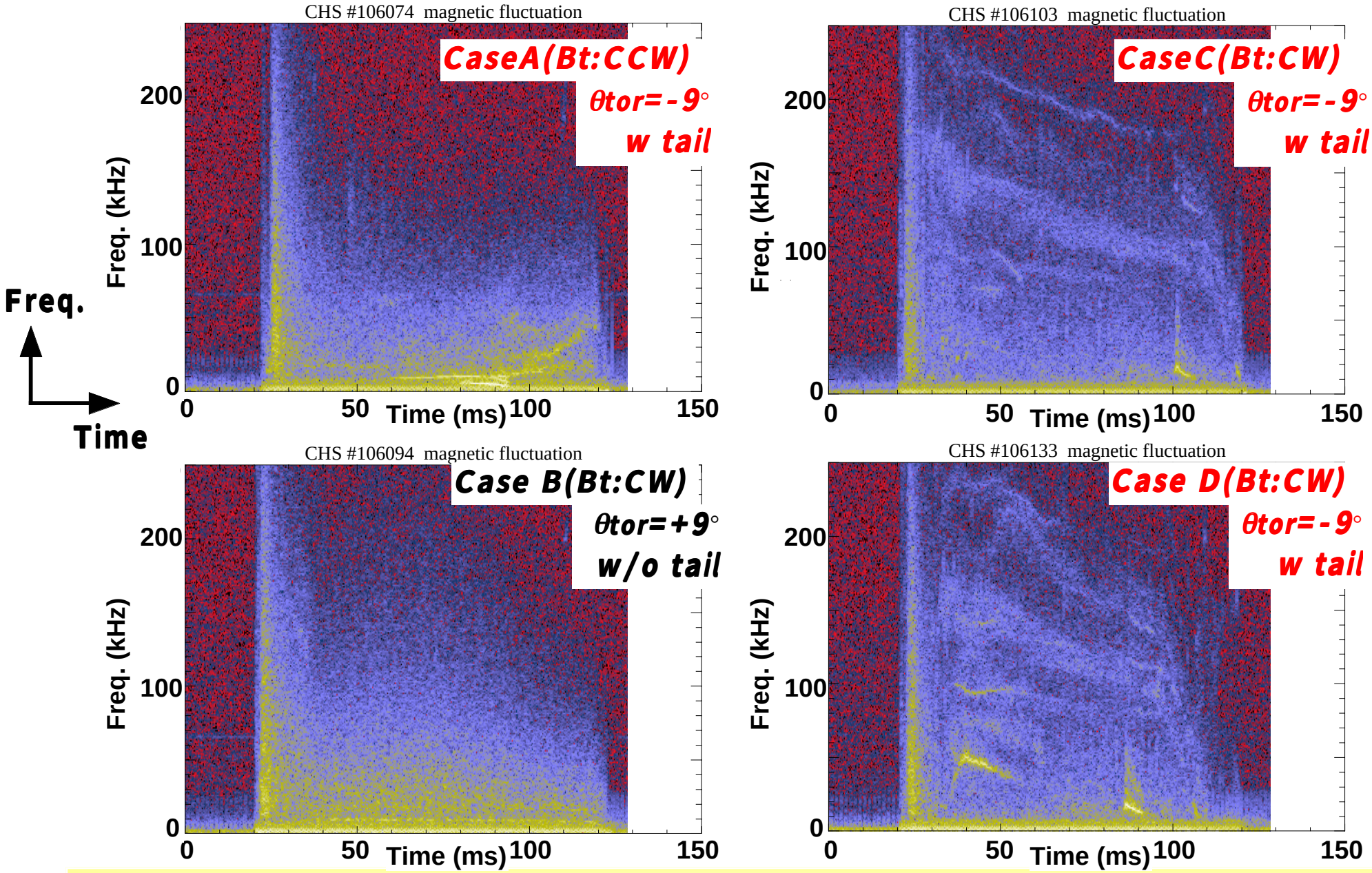






- **Low density condition (< 0.5×10^{19} m^{-3})**

Power Spectrum Density of Magnetic Fluctuations in CHS (1)



- **The magnetic fluctuation in the frequency range of 50 ~ 250 kHz was observed, when the ion tail appeared.**

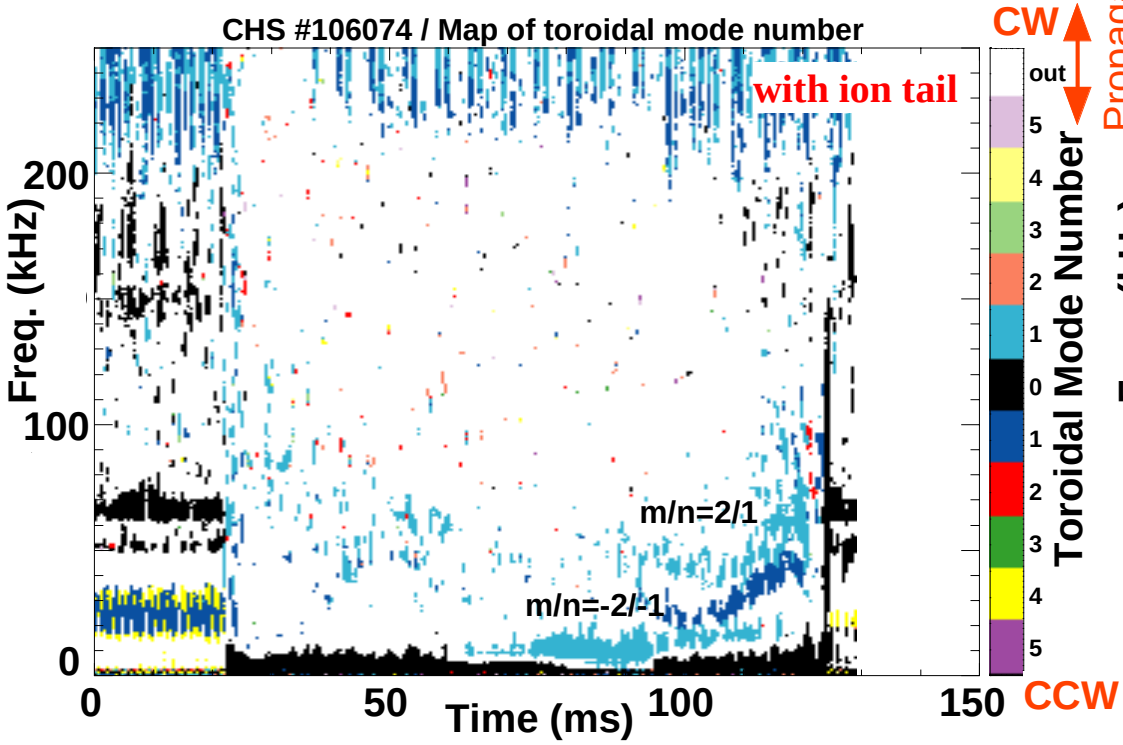
Power Spectrum Density of Magnetic Fluctuations in CHS (2)

Time evolution of the toroidal and poloidal mode numbers having ion tail

Co ECCD

#106074:Case A

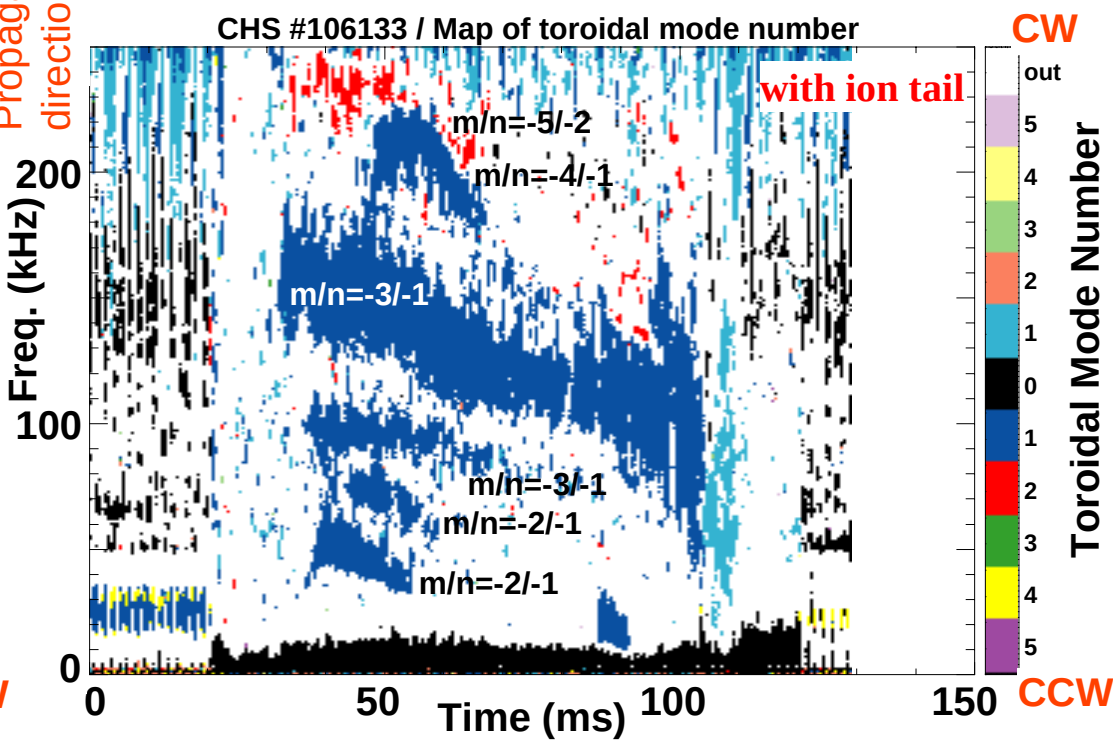
・Bt:CCW ・θtor=-9°(RH) ・Ip=-6 kA・ne=0.5x10^{19} m^{-3}



CTR ECCD

#106133:Case D

・Bt:CW ・θtor=-9°(RH) ・Ip=-3.8 kA・ne=0.4x10^{19} m^{-3}

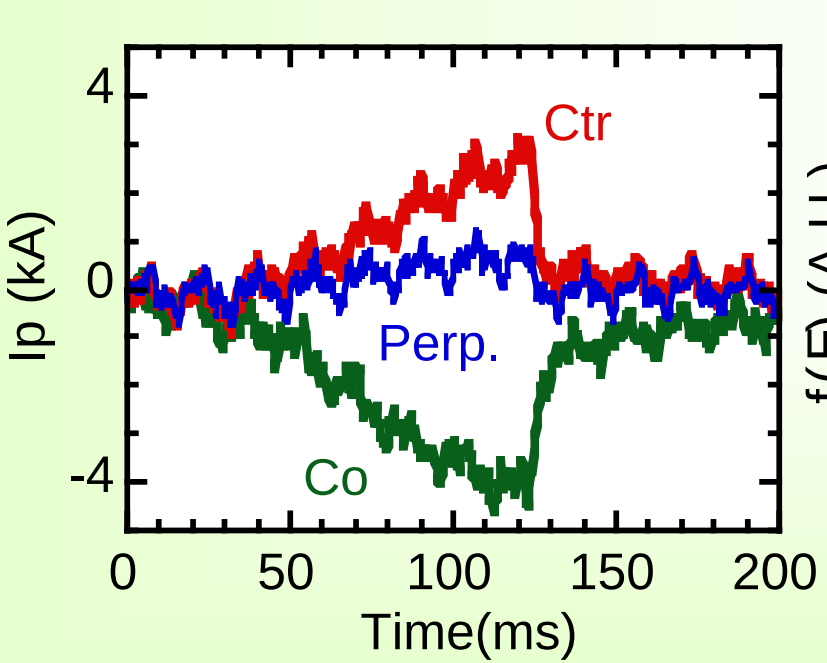


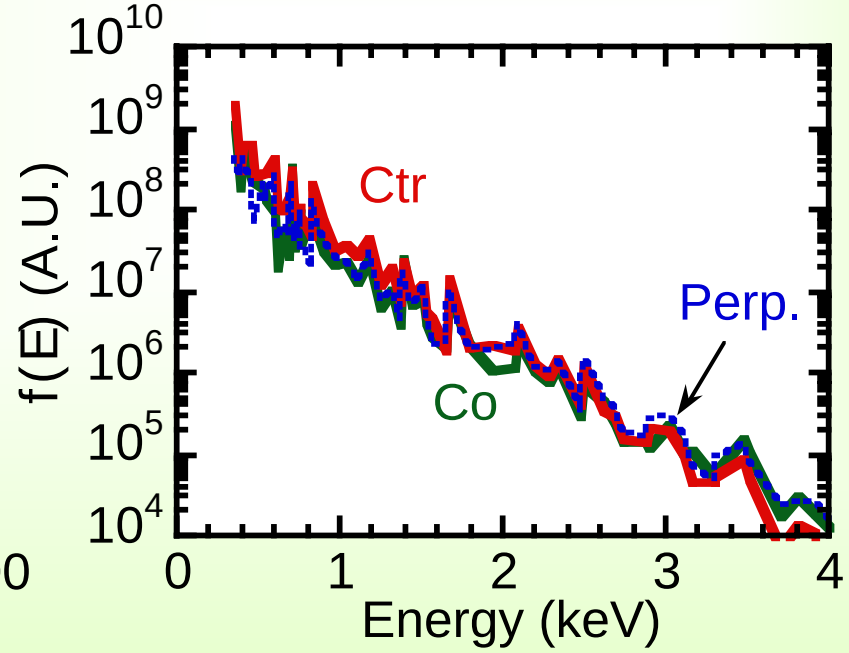
- **Several modes of n=1 and a mode of m/n=5/2 were observed. (depending on current drive direction).**
- **The modes propagate in the ion diamagnetic drift direction and in the counter direction of the magnetic field.**

Ion Tail is Insensitive to ECCD direction

- Three cases of ECH injection angle (Co., Ctr., Perp.)
- Bt = 0.88 T, Rax = 94 cm, $n_e \sim 0.25\times10^{19}$ m^{-3}

Time evolution of the plasma current and energy spectra in ECH/ECCD plasmas of CHS





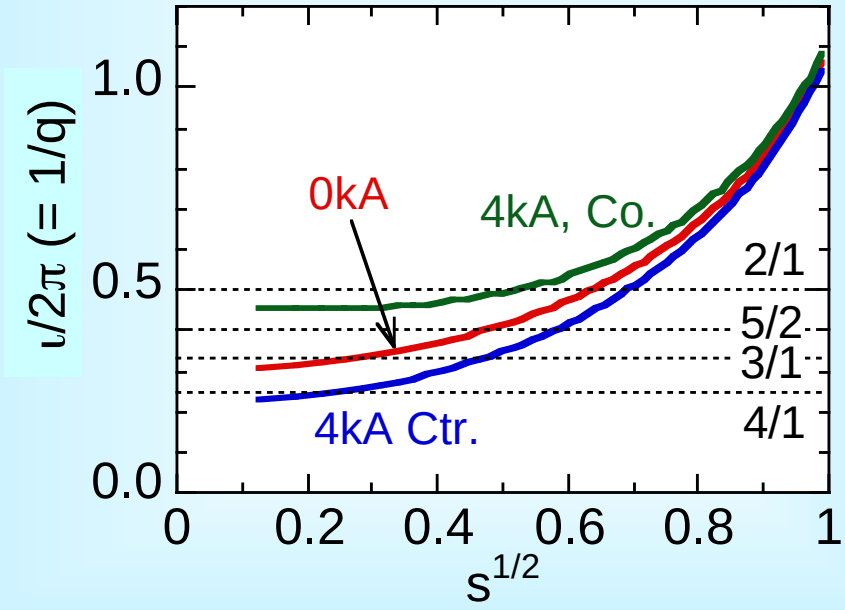
- Observation of the ion tail is not depend on the CD direction.

Iota Profile Calculation with Toroidal Current

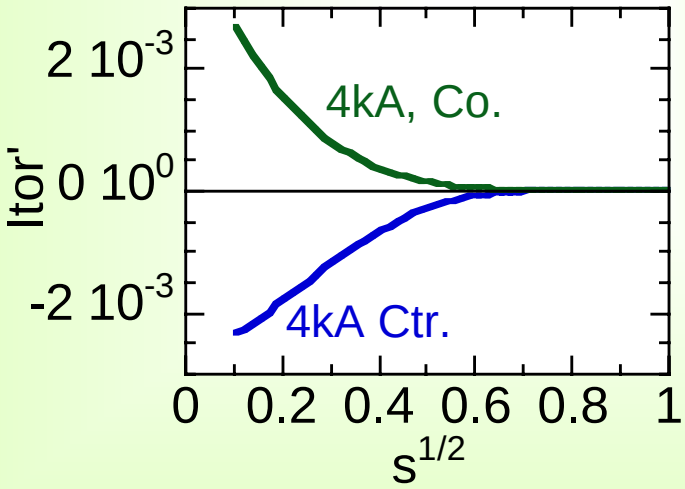
- Calculation of change in iota by a toroidal current (VMEC fixed boundary, zero beta)

  Assumption of peaked current profile, as $j(\rho) = j_0(1 - s)^8$

Iota profile with toroidal current (CHS, Rax =92.1cm Bt = 0.88T)



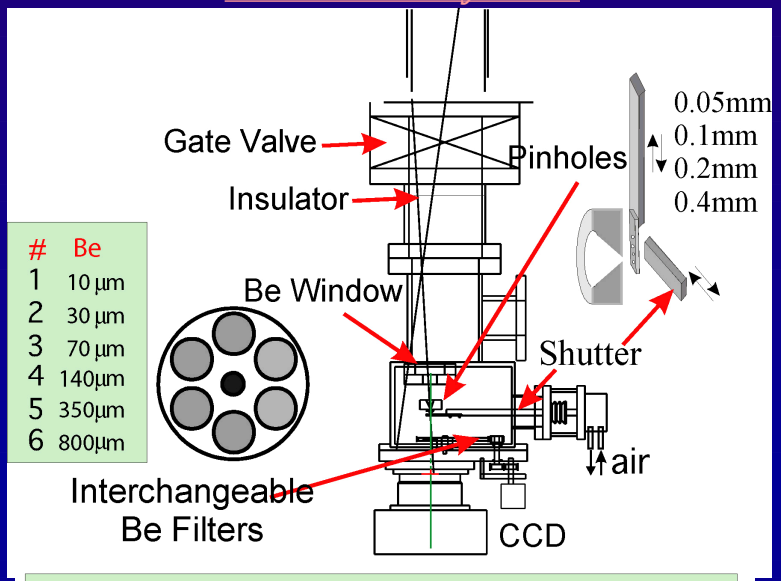
Current profile for calculation



- The peaked current profile has a capability to change the core iota by more than 0.05.
- The change in the mode numbers of the magnetic fluctuation due to the ECCD directions (Co, Ctr) is consistent with the iota profile change.

Measurement of High Energy Electrons with SX-CCD*

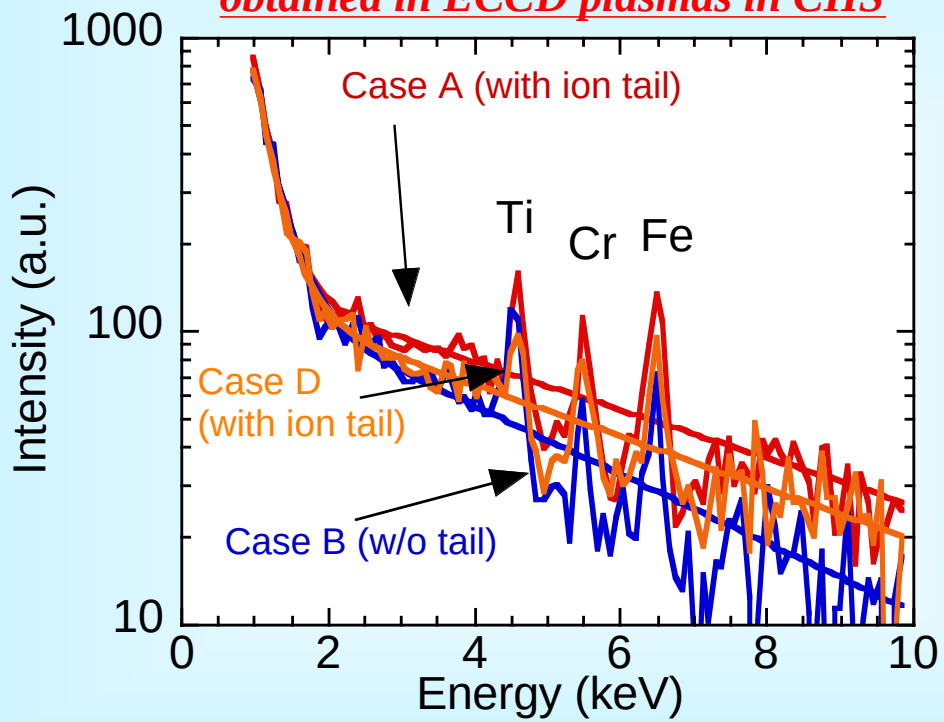
Schematic view of the soft X-ray CCD camera system*



CCD arrays:	TEK 1024x1024DBack CCD illuminated
Spatial resolution:	1024x512 (Frame transfer) 1024x1024 (Full frame)
Energy resolution:	16eV/ADC count (Photon counting mode)
Energy region:	1-10keV
Time resolution: (readout time)	~5.0s(100kHz A/D) ~1.2s(430kHz A/D)

*Y. Liang, K. Ida, S. Kado, *et al*, Rev. Sci. Instru. 72, p717 (2001), http://rd-w3server.nifs.ac.jp/chs/chs_device/diagnostics/sxccd/chssxccd.pdf

Energy spectra of the soft X-ray intensity obtained in ECCD plasmas in CHS



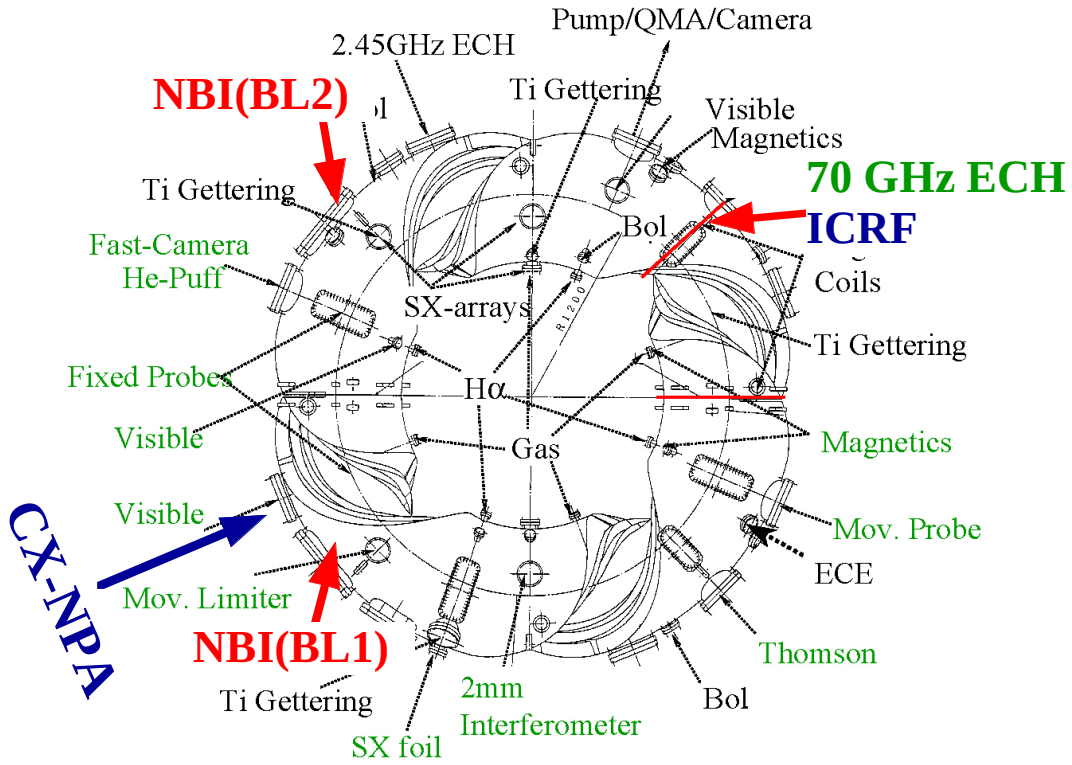
- **An existence of high energy electrons was confirmed in the low density ECH plasmas.**
- **Slope of the electron tail becomes flat when ion tails are formed.**

Effect of high energy electrons?

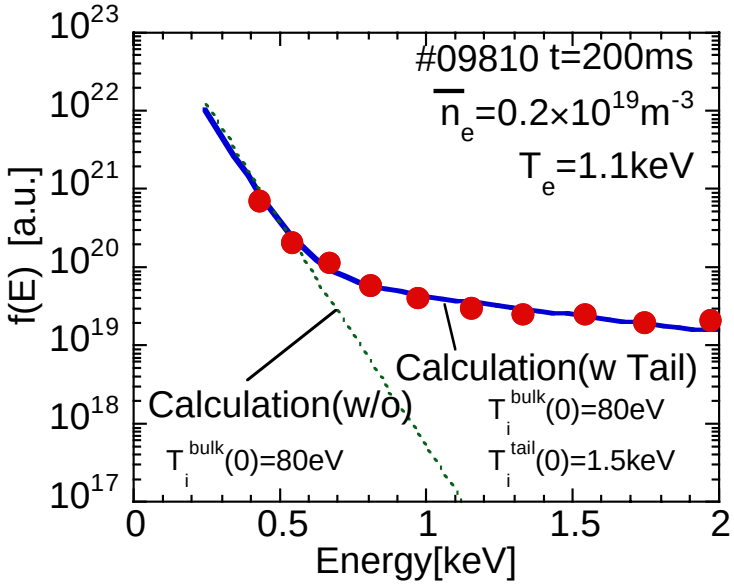
Heliotron J device and 70 GHz ECH Experiment

Heliotron J - **a/R = 0.2m/1.2m, B_t = 1.5 T**
- **ECH(70 GHz) ~ 0.4 MW**
- **NBI ~ 0.7 MW (×2 beam lines)**
- **ICRF ~ 0.4 MW**

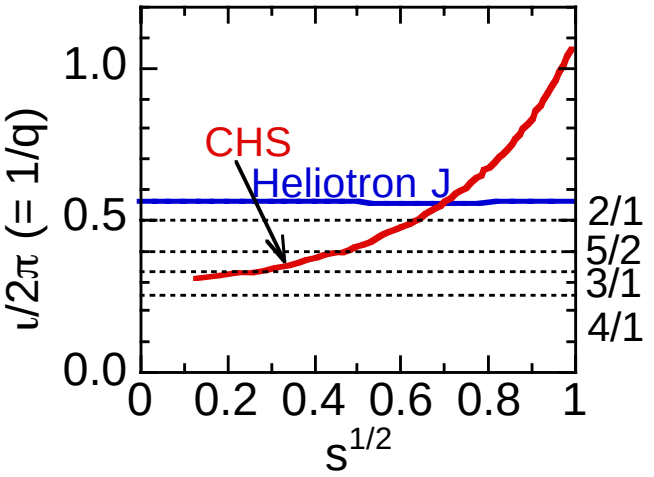
Schematic view of the Heliotron J device



Ion energy distribution obtained in Heliotron J (Lower density case)



In the lower density condition, a folded spectrum is found.

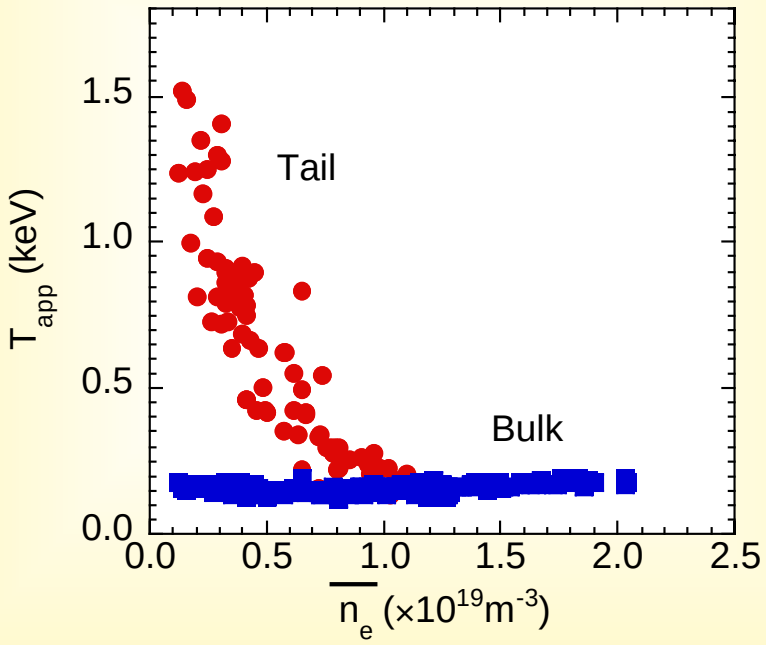


=> No magnetic fluctuation in the standard configuration of Heliotron J

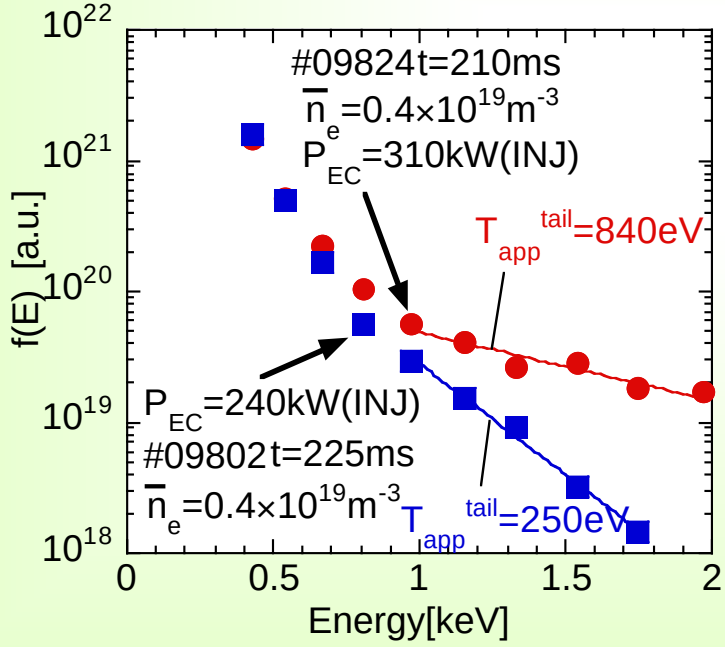
<= Low shear avoiding rational surfaces

Strong Dependence on electron density (Heliotron J)

Dependence of the apparent ion temperature on the electron density



Dependence of the ion energy distribution on the EC injection power

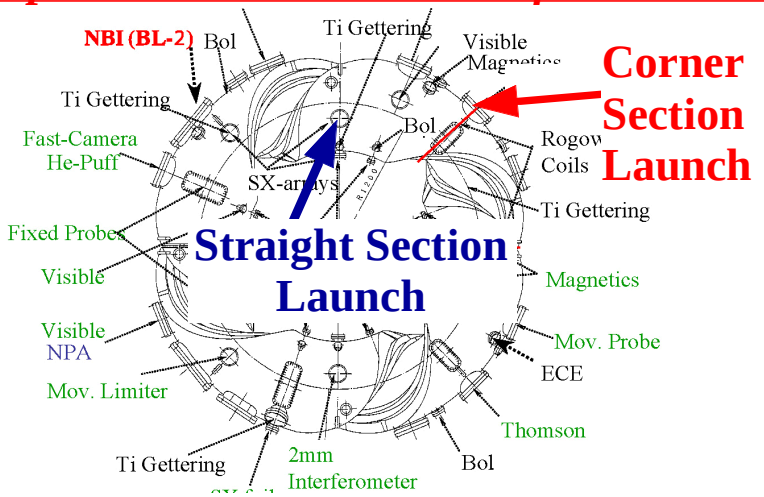


- **Appearance of the tail component in the case of $n_e < 1\times10^{19}$ m^{-3}, (P_{ECH} ~ 300kW)**
- **Increase in the tail temperature with decreasing n_e.**
- **Insensitive of the bulk ion temperature**

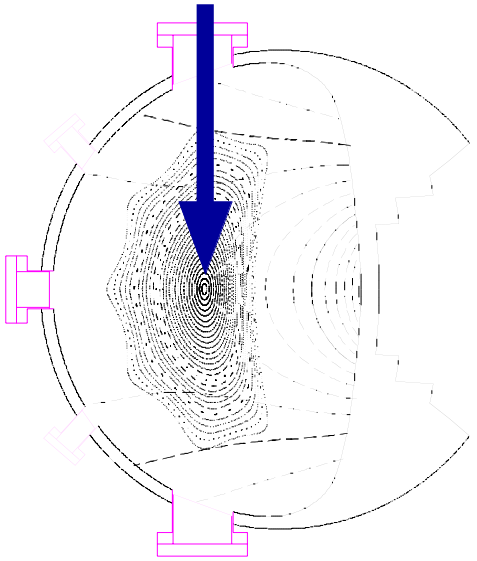
- **The tail temperature in high power case is higher than that in the low power condition, while the bulk ion temperature is almost unchanged.**

Energy Spectra in Two Cases of ECH Launch (Heliotron J)

Top view and cross sections of Heliotron J

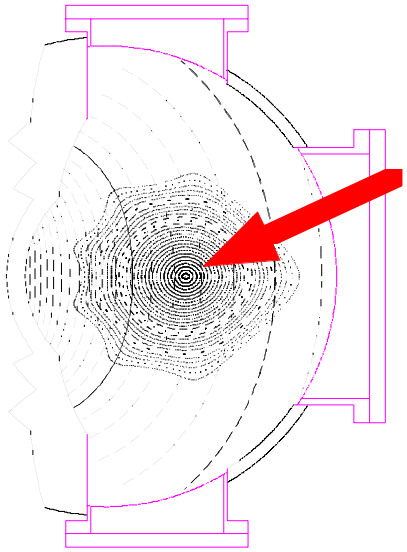


Straight Section Launch



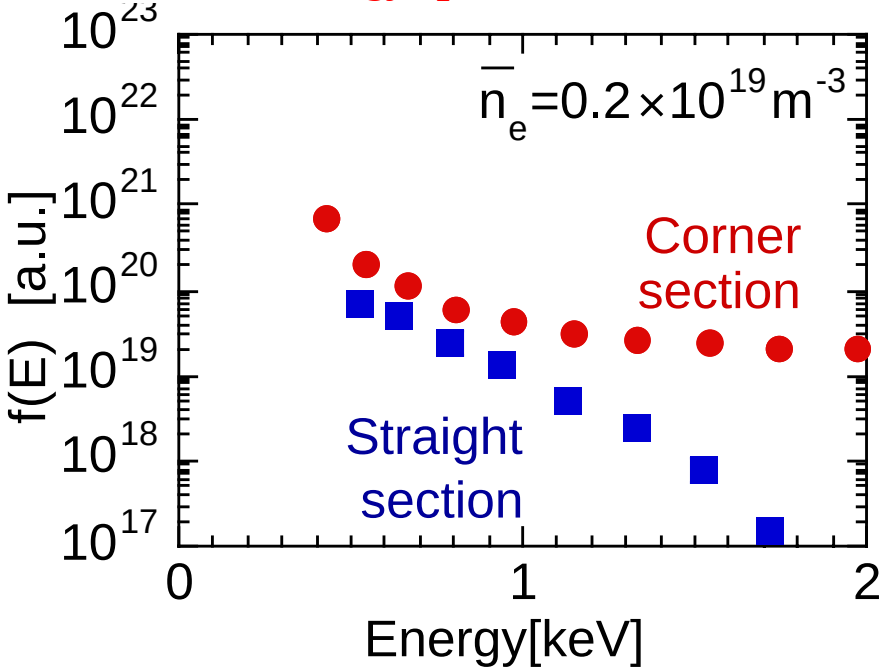
- **Gentle ∇B**
- **Non-focused beam**
- **Long-path absorption**

Corner Section Launch



- **Tokamak like B-contour**
- **Focused beam**
- **Localized absorption**

Ion energy spectra in two cases



- **constant ne**
- **No clear (weak) ion tail in the case of the straight section launch**
  -> difference

Confirmation is needed whether the LH waves are excited or not.

Discussion & Summary

- What type of magnetic fluctuations excite?
  => Trial of configuration acrossing a rational surface with shear in Heliotron J
- Why does the ion tail generate?
  - The density range where the ion tail appears is similar to that of N-ITB (CHS)
  - Effect of Er?
  - Effect of electron tail ?
  - Confirmation whether the LH waves are excited or not.

- In CHS, we observed the following phenomena.
  - The high energy ions appeared only in the cases of low density ECH plasma
  - Formation of the ion tail was not sensitive to the current direction by ECCD.
  - The electron tail temperature was increased when the ion tails were observed.
  - Several modes of n=1 and a mode of n=2 were observed in the case of formation of the ion tail. and the apparent mode numbers depended on the ECCD direction.

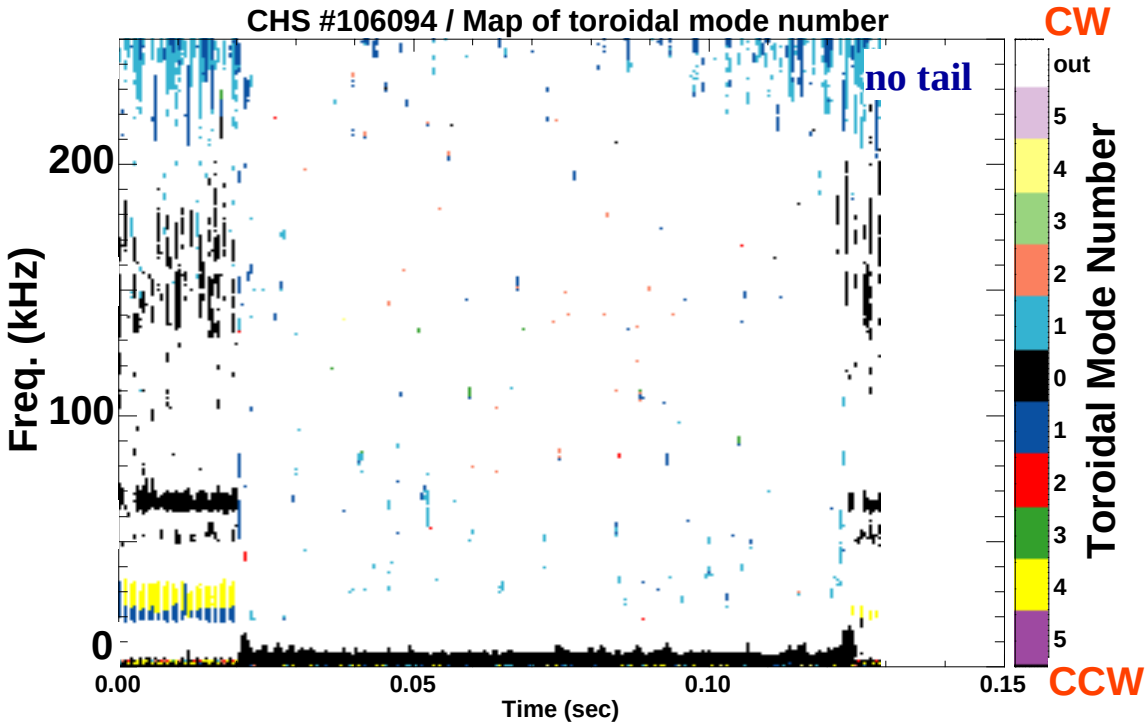
- In the 70 GHz ECH plasmas in Heliotron J...
  - The ion tail temperature dependence on the electron density.
  - No significant modes were observed (low shear configuration avoiding rational surfaces)

Power Spectrum Density of Magnetic Fluctuations in CHS (3)

Time evolution of the toroidal and poloidal mode numbers in case of no ion tail

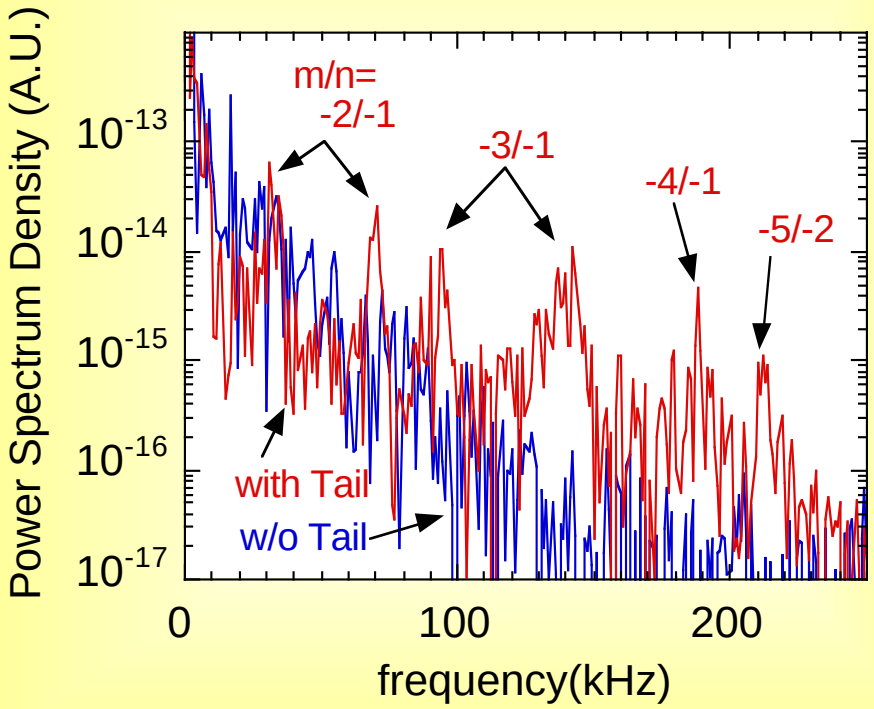
#106094:Case B

・Bt:CCW ・θtor=+9°(RH) ・Ip=+1.5 kA・ne=0.5x10^{19} m^{-3}



Comparison of the power spectrum density

Power Spectrum Density of magnetic fluctuation in CHS



- **No coherent mode was observed when the ion tail did not appear.**