The Status of ECRH System on HL-2A

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Outline

3MW ECRH system on HL-2A

- 3 MW ECRH system
- Launchers
- Operation of ECRH system

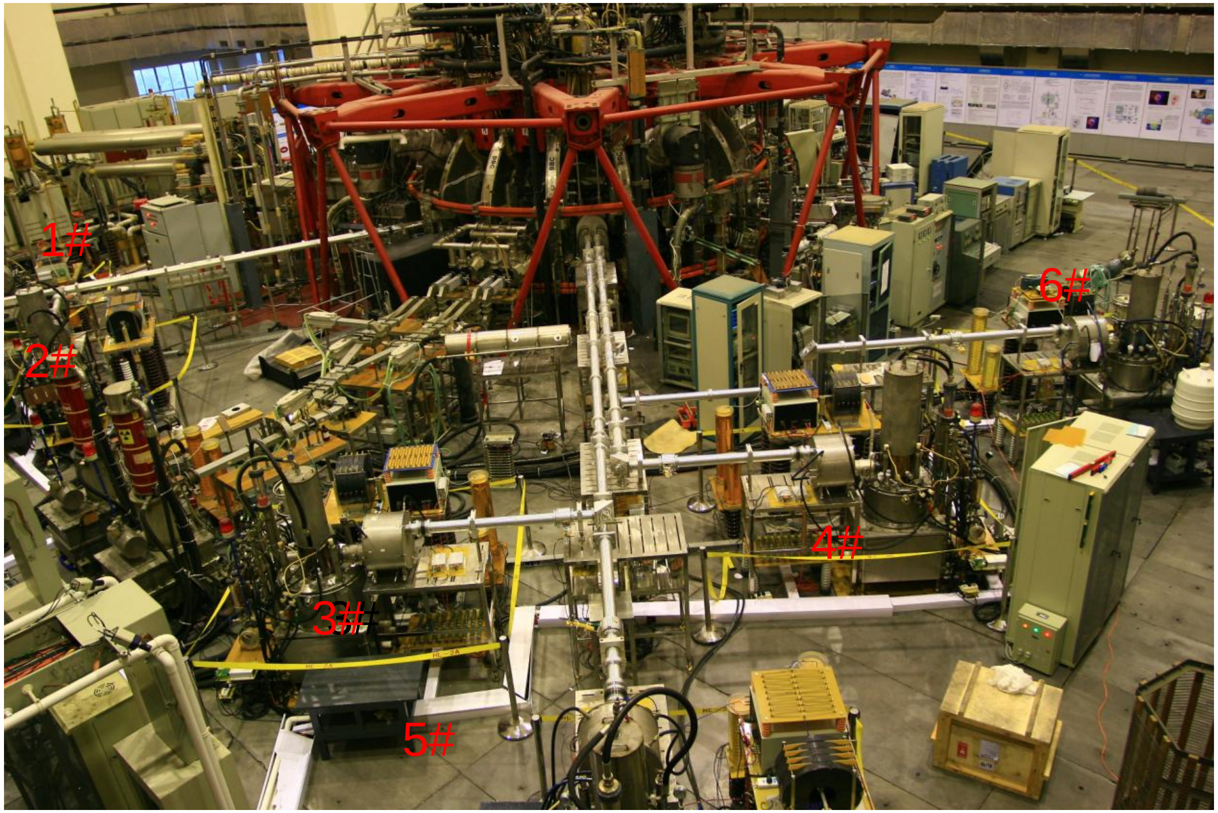
High powerful ECRH experiments on HL-2A

- **ELM H mode realization**
- **ITB triggered by far off-axis ECRH switch-off**
- **Observation of NTM**
- **Influence of SMBI on NTM**
- **Stabilization of TM with ECRH**
- **Sawtooth Control with ECRH**
- **Runway electron suppression**

Summery

ECRH system on HL-2A Tokamak

HL-2A



Main parameters R=1.65 m and a=0.4 m

- **B_T: 2.8 T 2.7 T** **I_P: 480 kA 430 kA**
- **Duration: 3.0 s** **Plasma density: 6.0 x 10^{19} m^{-3}**
- **Electron temperature:~5 keV** **Ion temperature: >1 keV**
- **Fuelling system: GP, SMBI, PI** **Heating system: ECRH , NBI, LHCD**

3MW/68GHz ECRH system

HL-2A

ECRH: 3 MW

4/68 GHz/500 kW/1 s

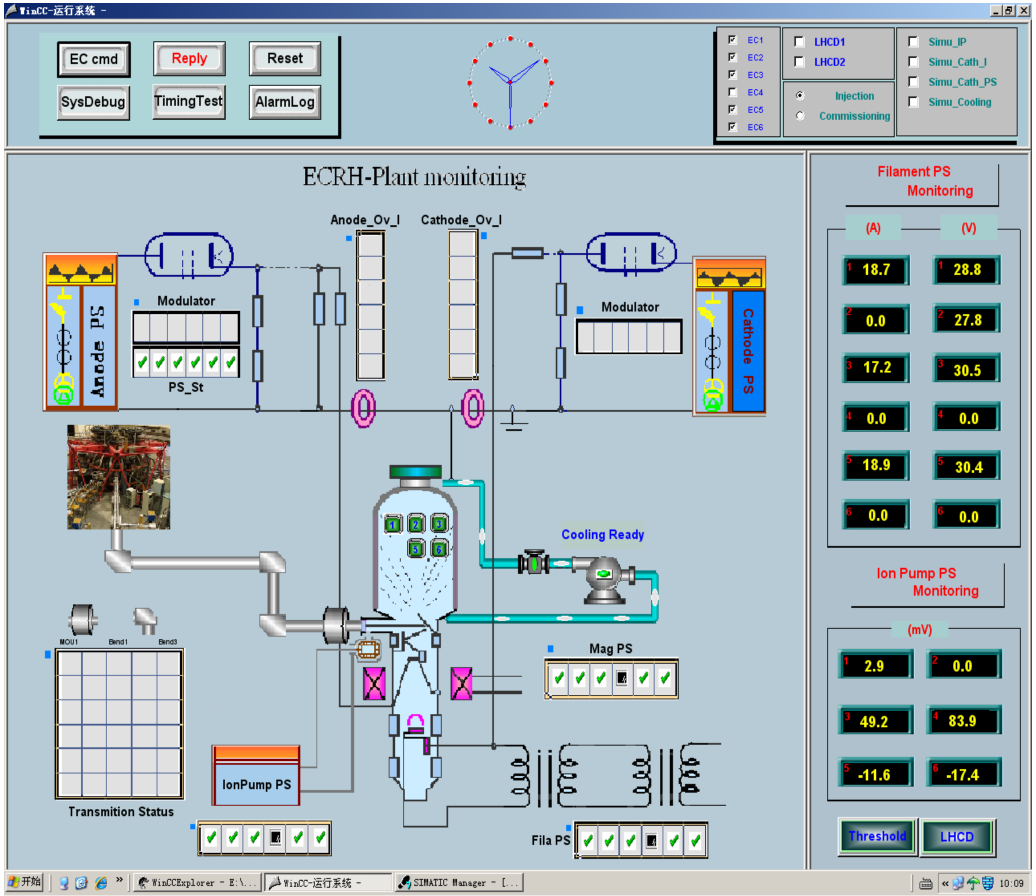
+ 2/68 GHz/500 kW/1.5 s

gyrotrons from GYCOM

modulation:

10~30 Hz; 10~100 %

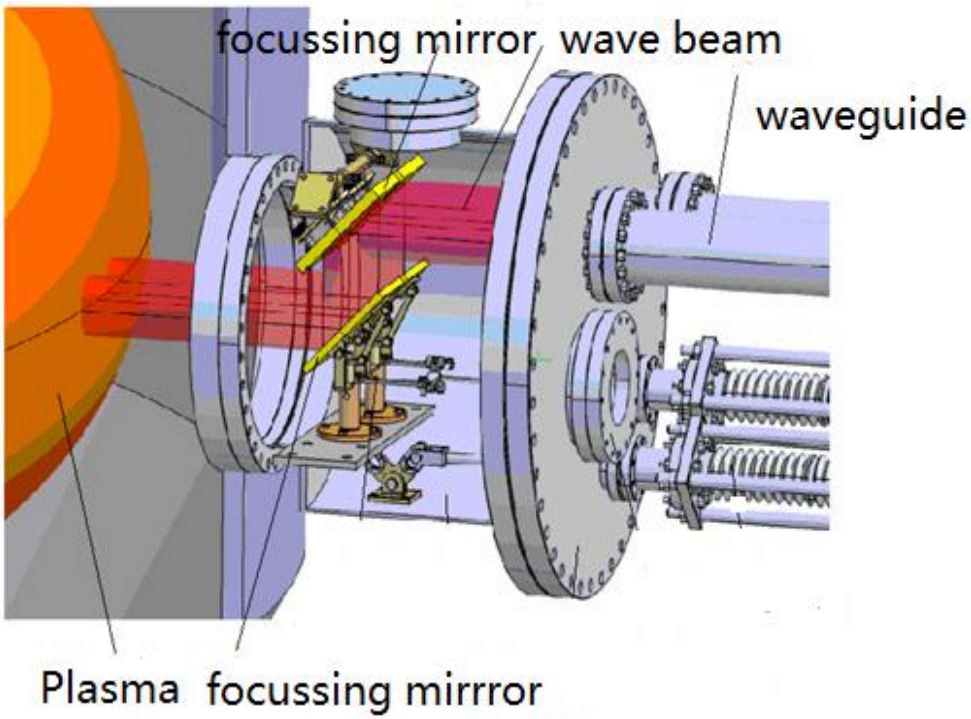
Wave beam radius: 21mm (center)



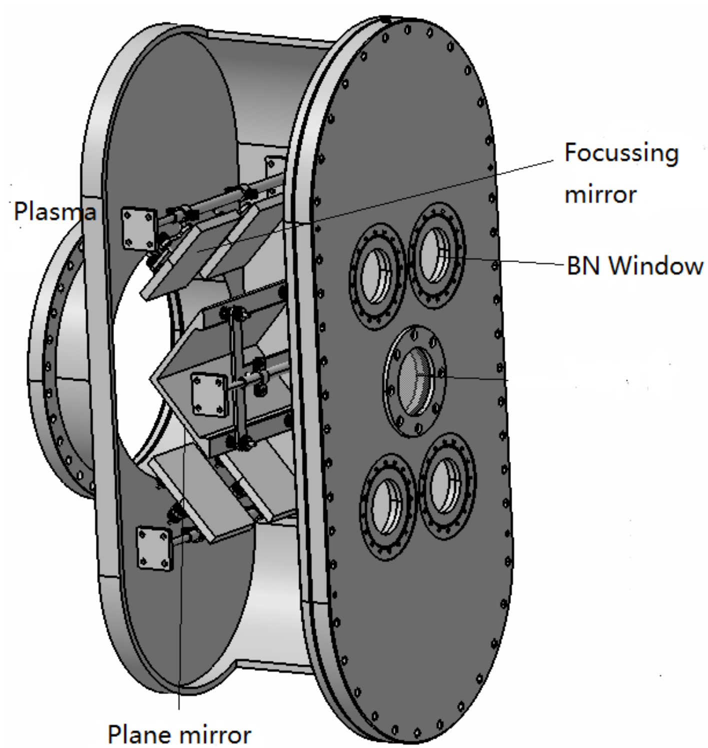
3MW 68GHz ECRH system has been developed on HL-2A basis on the gyrotrons from GYCOM.

Two launchers for six beams

HL-2A



Launcher for No.1,2



Launcher for No.3,4,5,6

One launcher is used for two beams, which can be steered .The other is used for 4 beams. The diameter of tokamak port is only 350mm.

Operation of ECRH system

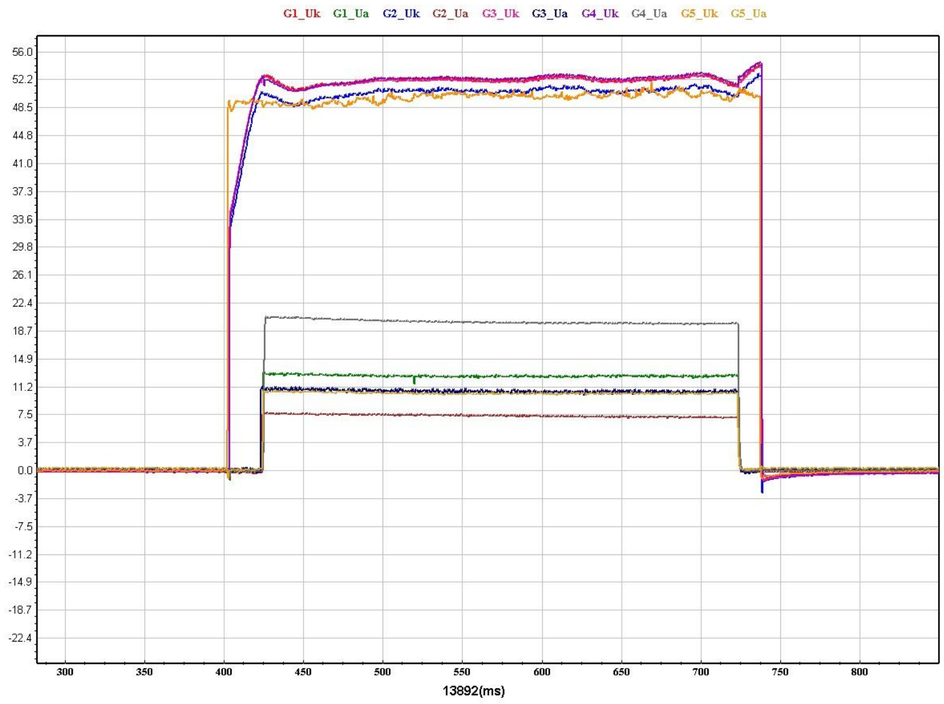
- **With the polarizer, EC waves in ordinary and extraordinary mode were injected into HL-2A at different magnetic field.**
- **ECRH system operated under high output power reliably and stably during HL-2A experiments.**

Operation for four sub-systems		Parameter
For One Day	Maximum effective shots	34 shots
	Protection shots	1 shot
	Successive Shots for P>1.2MW	20 shots
	Successive Shots for P>1.4MW	15 shots
	Successive Shots for P>1.5MW	8 shots
Maximum Pulse Duration		0.82MW/900ms
Maximum Average Output Power		1.71MW/400ms

Operation of ECRH system

HL-2A

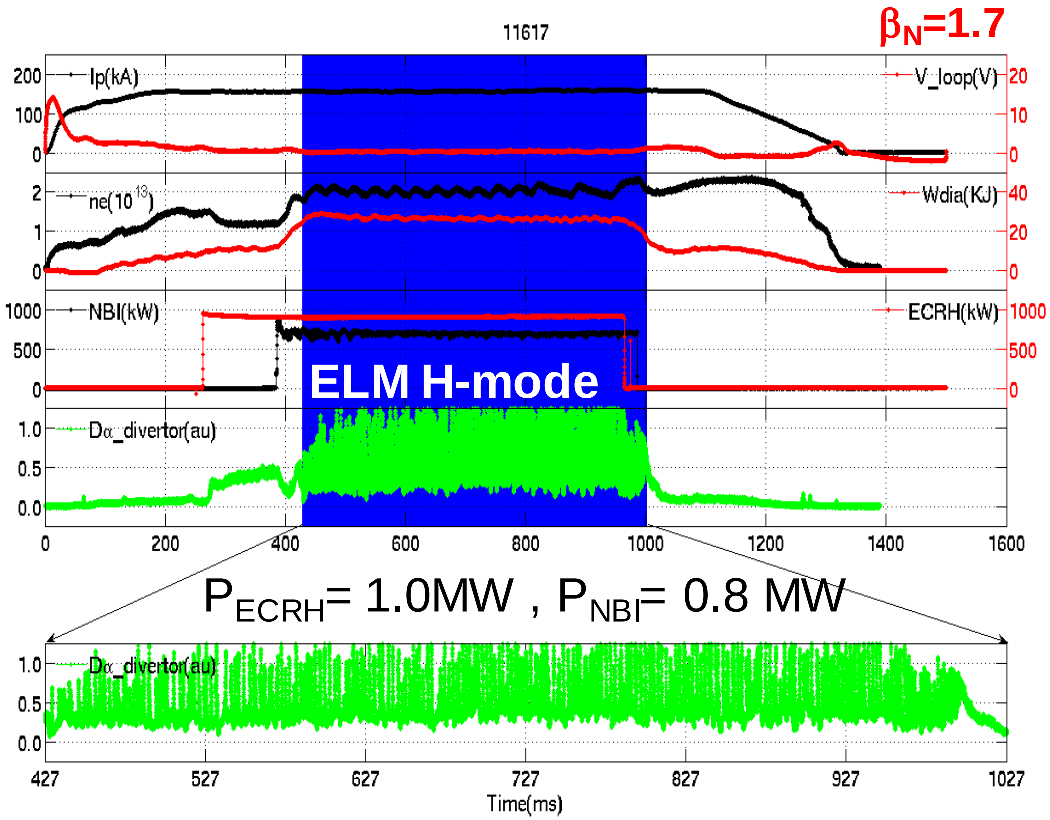
ECRH Sub-system	Pulse Duration (ms)	Output Power P(kW)
1#	300	310
2#	300	380
3#	300	330
4#	300	360
5#	300	270



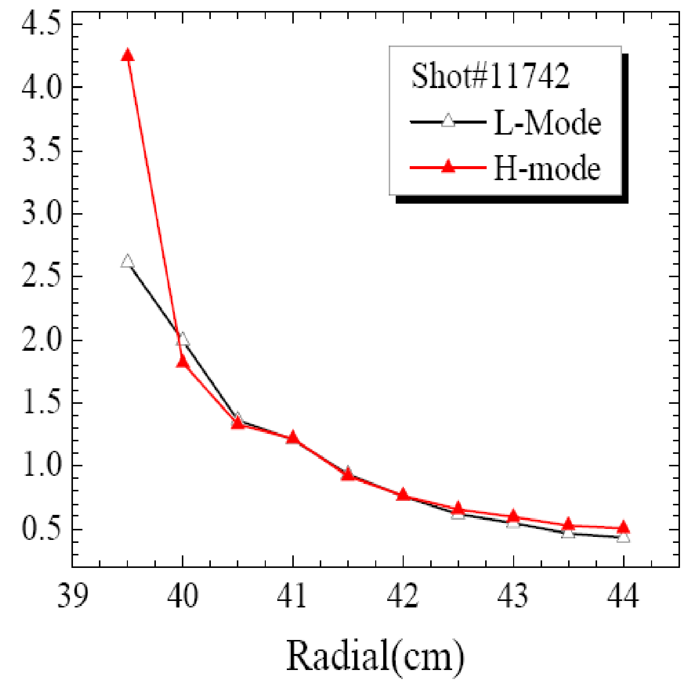
With the development a PSM power supply (80kV/100A/long pulse) ,5 subsystems have been operated together and No.6 subsystem is conditioning now.

ELM H mode realization

HL-2A

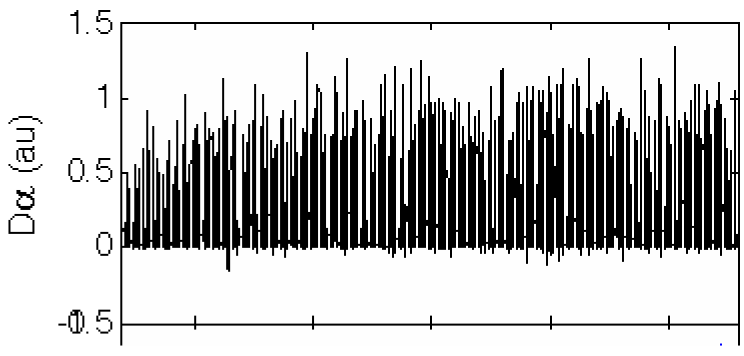


Steep edge density gradient



Ip~180KA,Bt~1.3T, Ne~2.2x10^{13}/cm^3

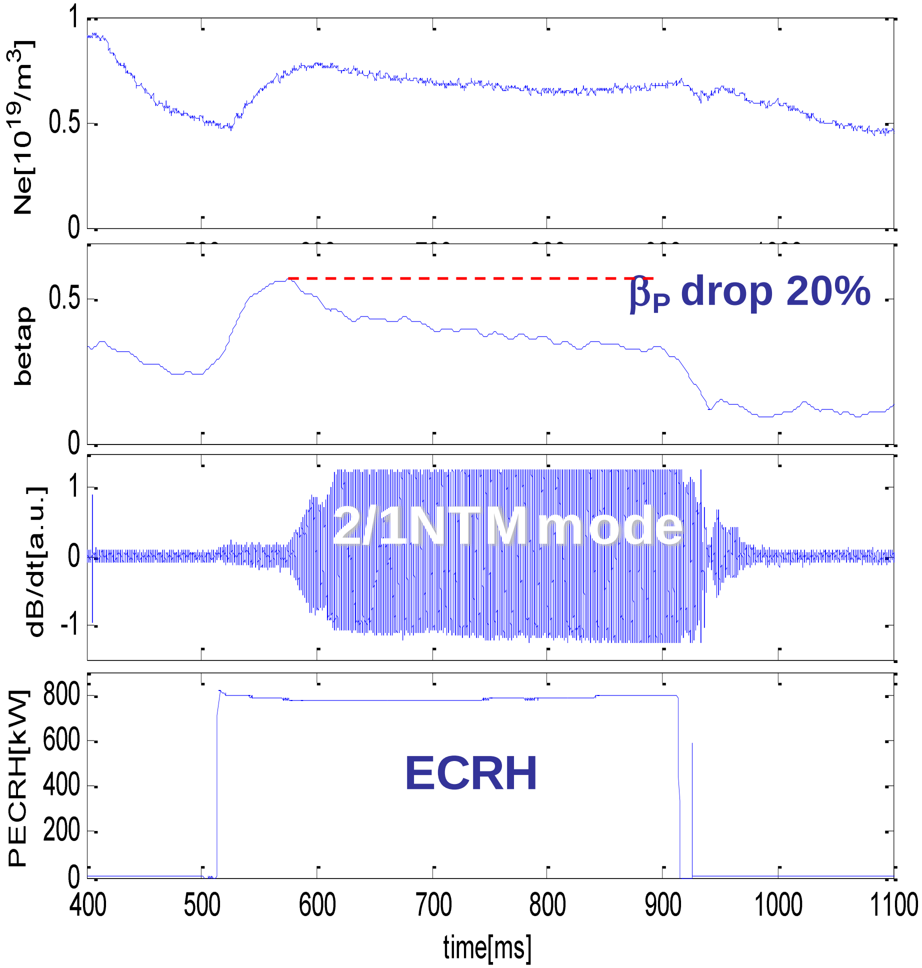
- Energy, particle and impurity confinement improve simultaneously;
- Impurity accumulation in H* inspite of broad n_H-profiles;
- Steep edge gradient was observed;
- Type III ELMs was driven with f~500Hz.



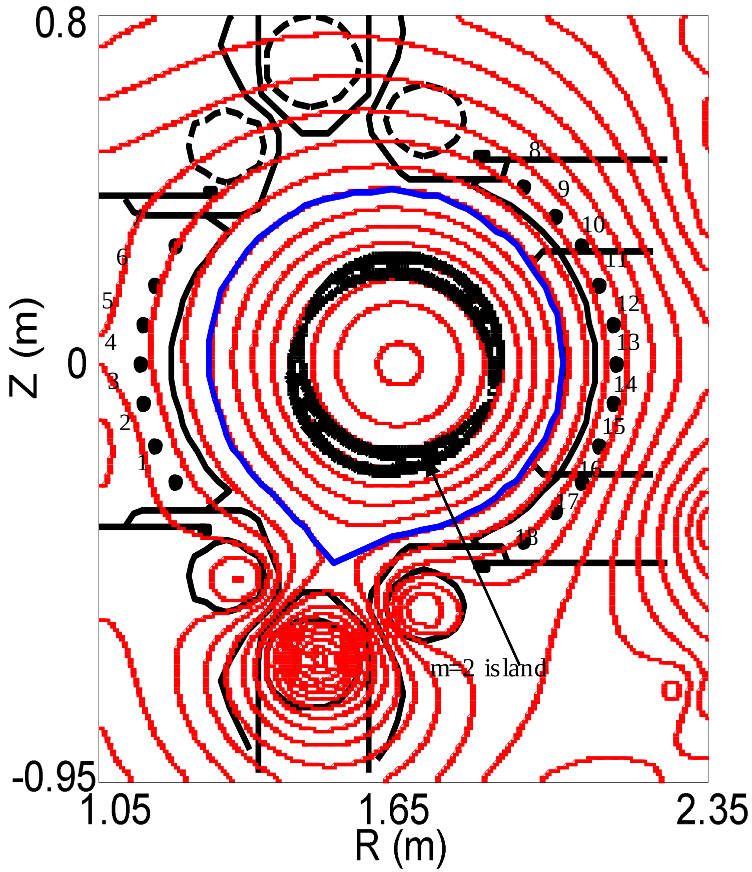
Type III ELM(300~500Hz)

Observation of NTM on HL-2A

The m/n=2/1 NTMs were observed in a single null divertor discharge with low density and low beta plasma heated by ECRH, leading to a fall of 20% in β_P



m=2 magnetic island structure



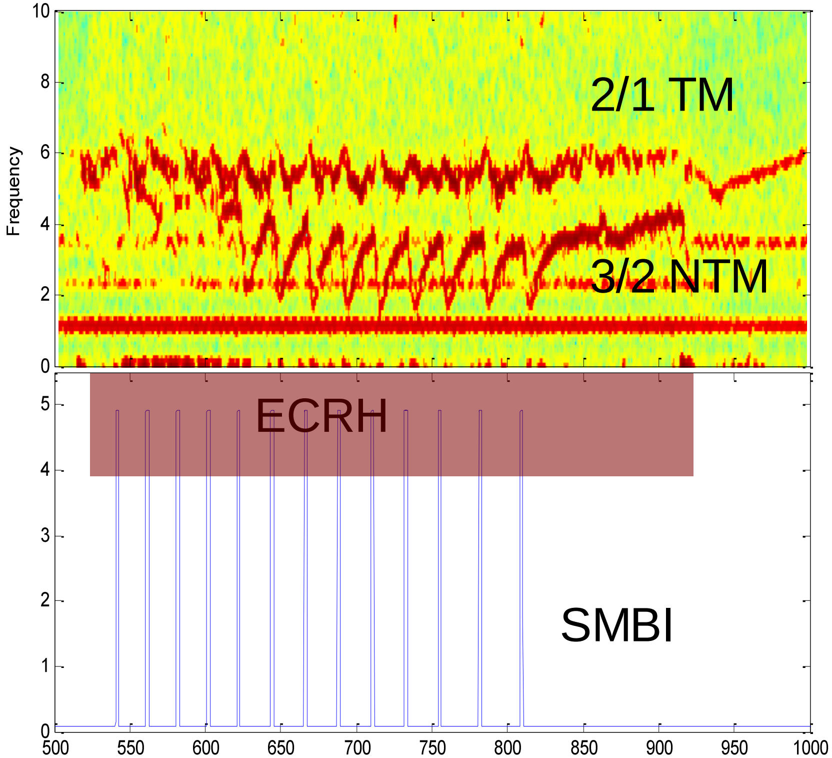
I_p~160 kA, P_{ECRH}~1MW, q_a~4,
$n_e = 0.8 \times 10^{19} m^{-3}$, β_N =0.5-0.7

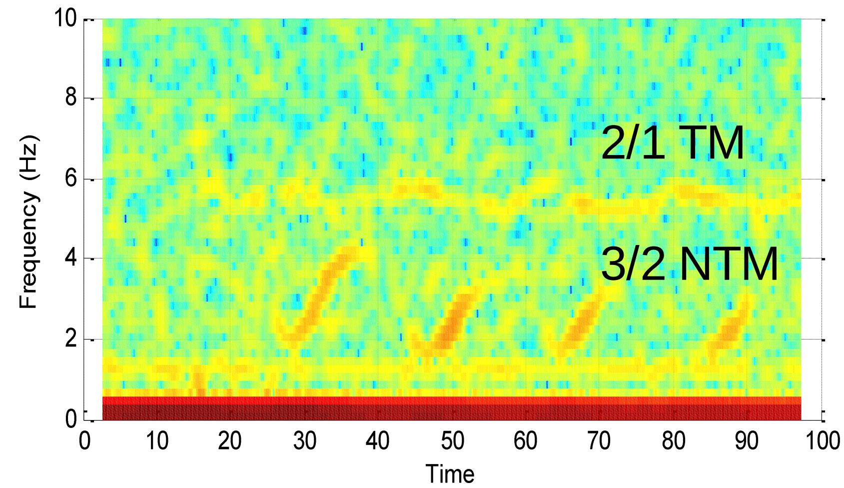
Low collisionality: $\nu_i / \varepsilon\omega_{*e} \approx 0.07 << 1$

Influence of SMBI on NTM

HL-2A

Triggering of 3/2 NTM by SMBI





I_p=160kA,B_t=1.29T,n_e~1.52

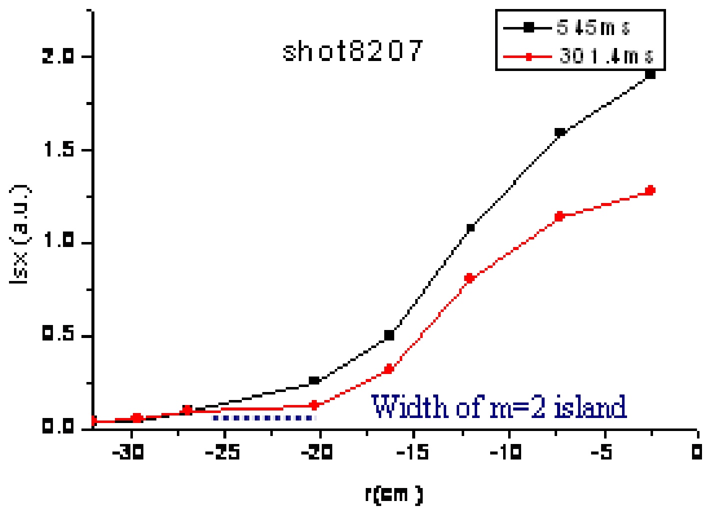
β_N~0.9

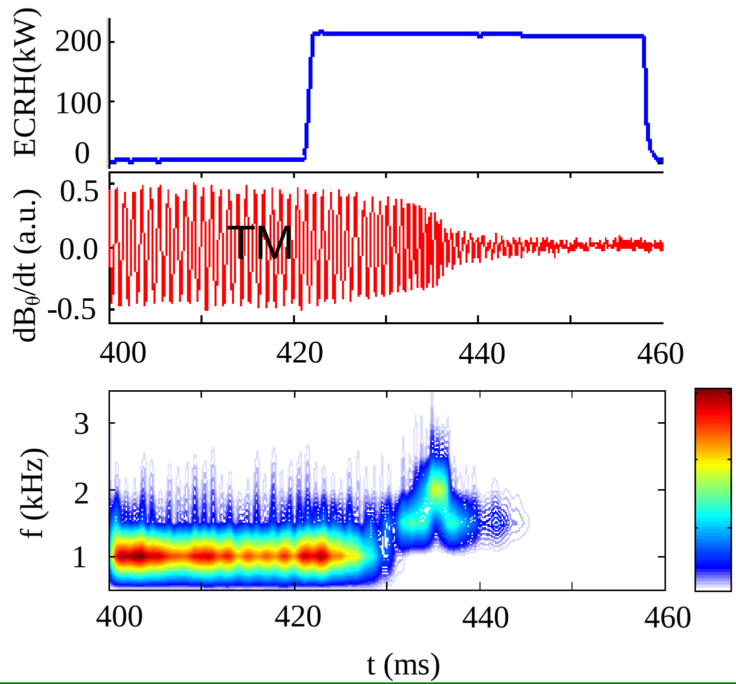
P_{ECRH}>1MW

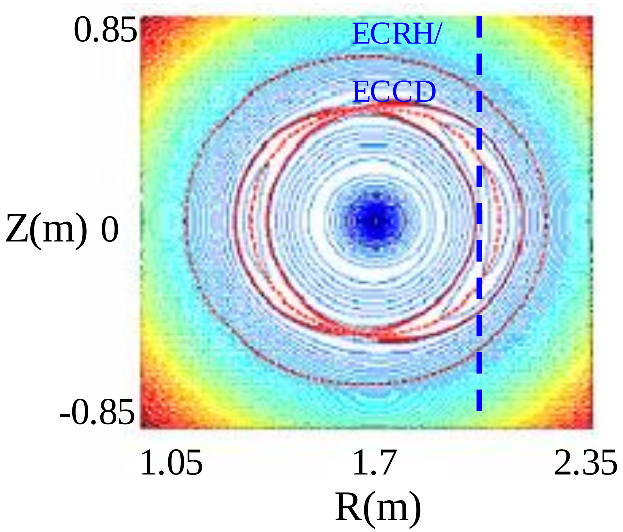
- 3/2 NTM could be triggered by SMBI during ECR heating.
- The high power ECRH makes the low density plasma into lower collisional regime while the SMBI change the pressure gradient near the rational surface, triggering the NTM perturbation.

Stabilization of Tearing mode with ECRH

HL-2A







- Off-axis heating near q=2 surface can stabilize the m=2 tearing mode
- With tearing mode stabilization, the plasma density as well as stored energy keep increase.

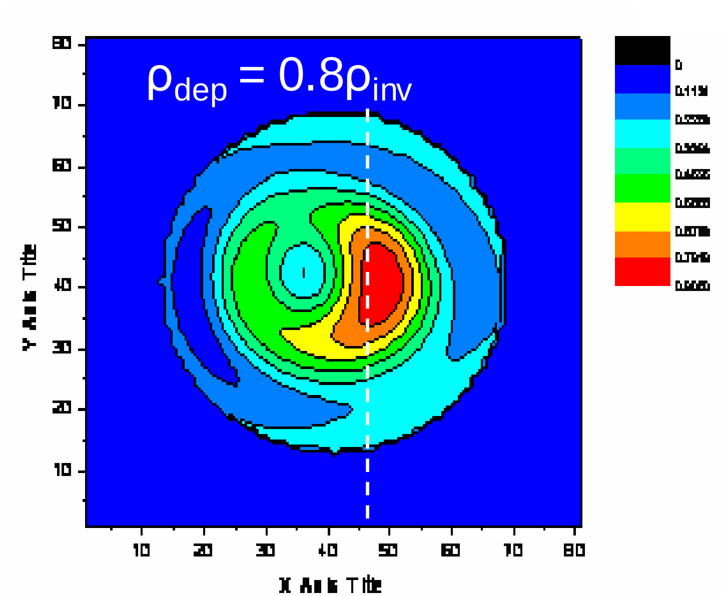
■Further study will focus on NTM stabilization with ECCD/ECRH.

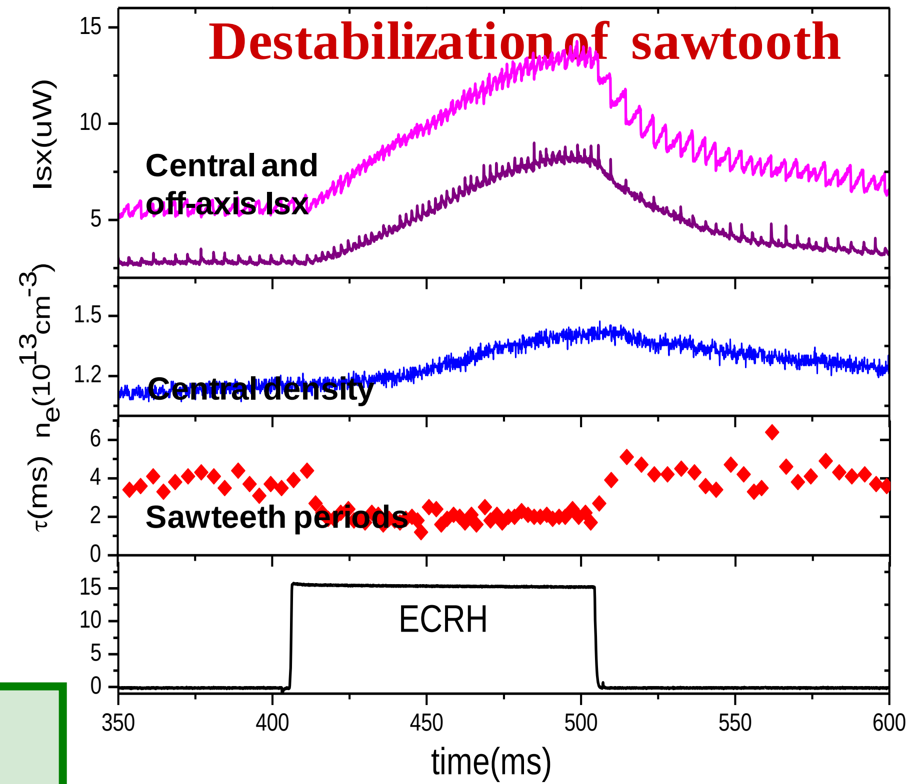
IAEA/ITPA MDC-8

Sawtooth Control with ECRH on HL-2A

HL-2A

Heating just inside the q=1 surface





- Off-axis heating just inside q=1 surface can destabilize the sawtooth

- Heating just near or outside q=1 surface can stabilize the sawtooth.

Bt=1.28T, $\rho_{dep} = 0.8\rho_{inv}$

r_{EC}=10cm, r_s=12cm, 4ms->2ms,

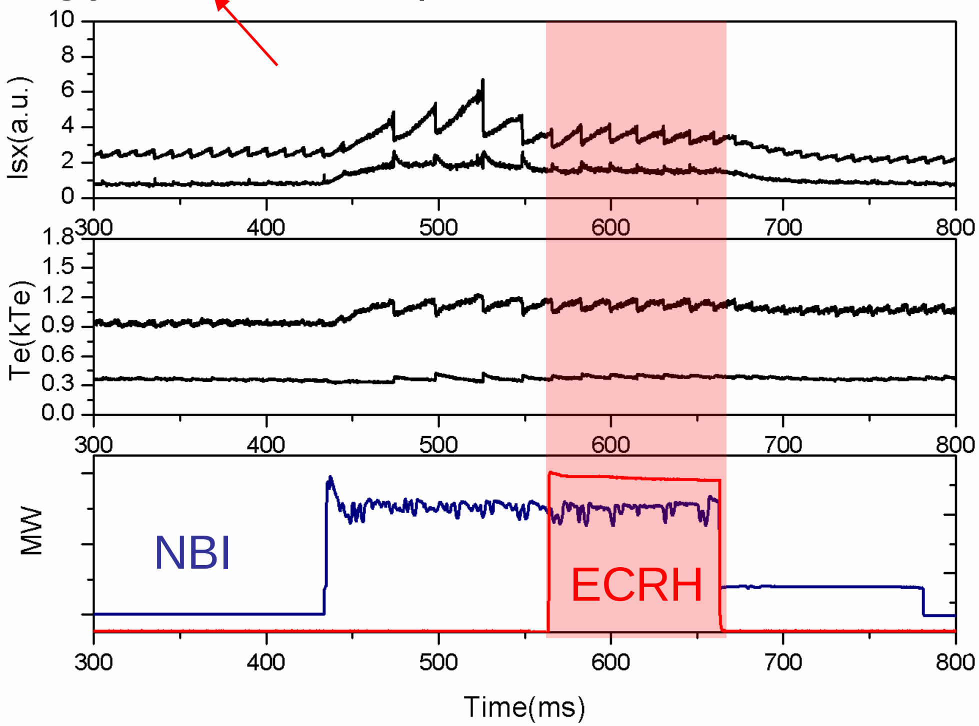
Ip=148kA, P_{EC}=530kW

Sawtooth control with ECRH on HL-2A

Destabilization of long sawtooth stabilized by high energetic ions induced by NBI

- **NBI+ECRH**
  - **770kW NBI: τ_{saw} = 27ms**
  - **Add 300kW ECRH τ_{saw}=15ms**
  - **The long sawtooth produced by NBI can be destabilized.**

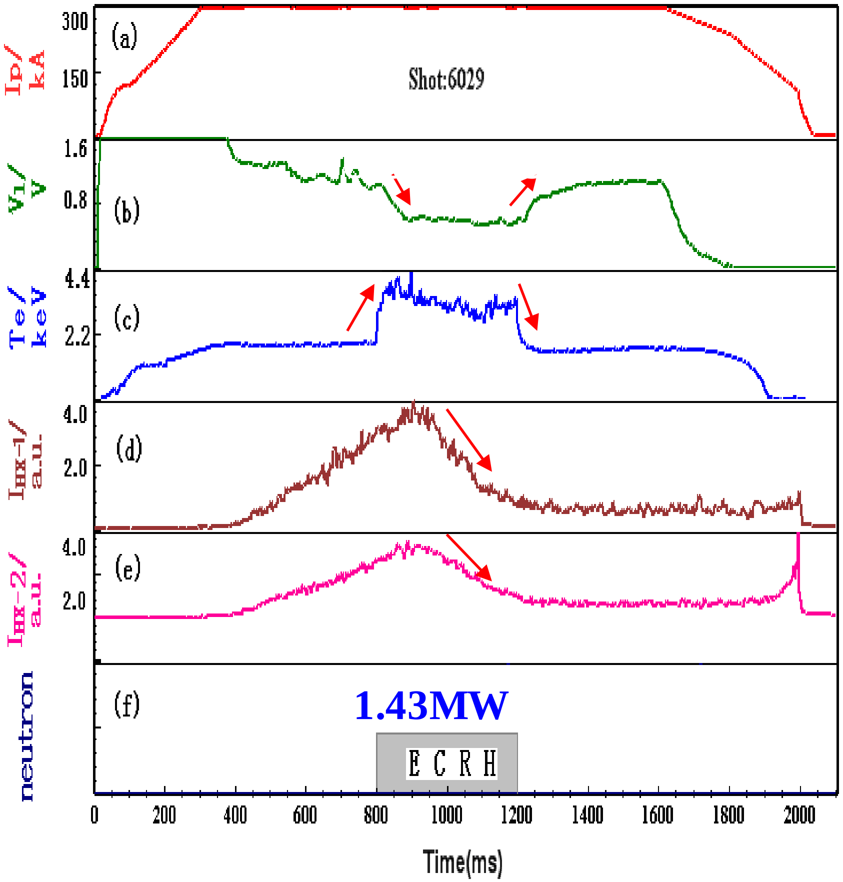
Heating just inside the q=1 surface



- Further study will focus on control with ECCD.

Suppression of RE

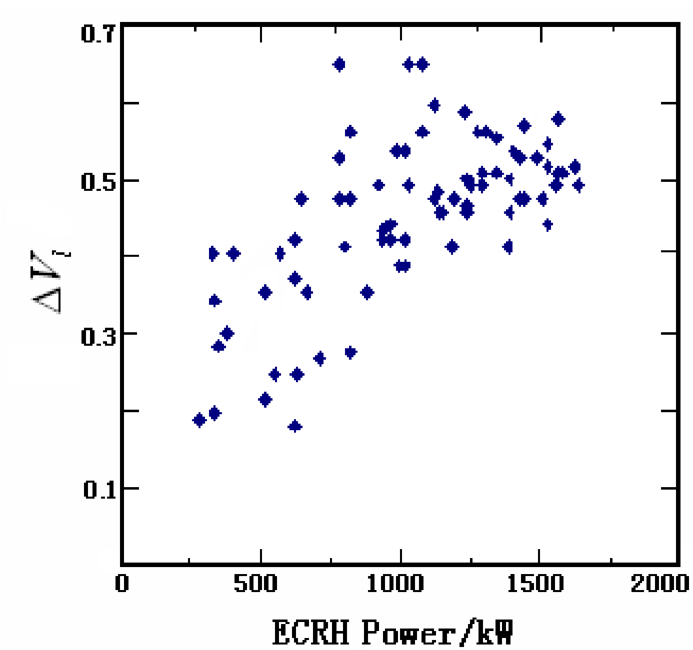
Suppression of runaway with ECRH



Typically, runaway electrons are created in the core of the plasma when the density is low and the electric field is high.

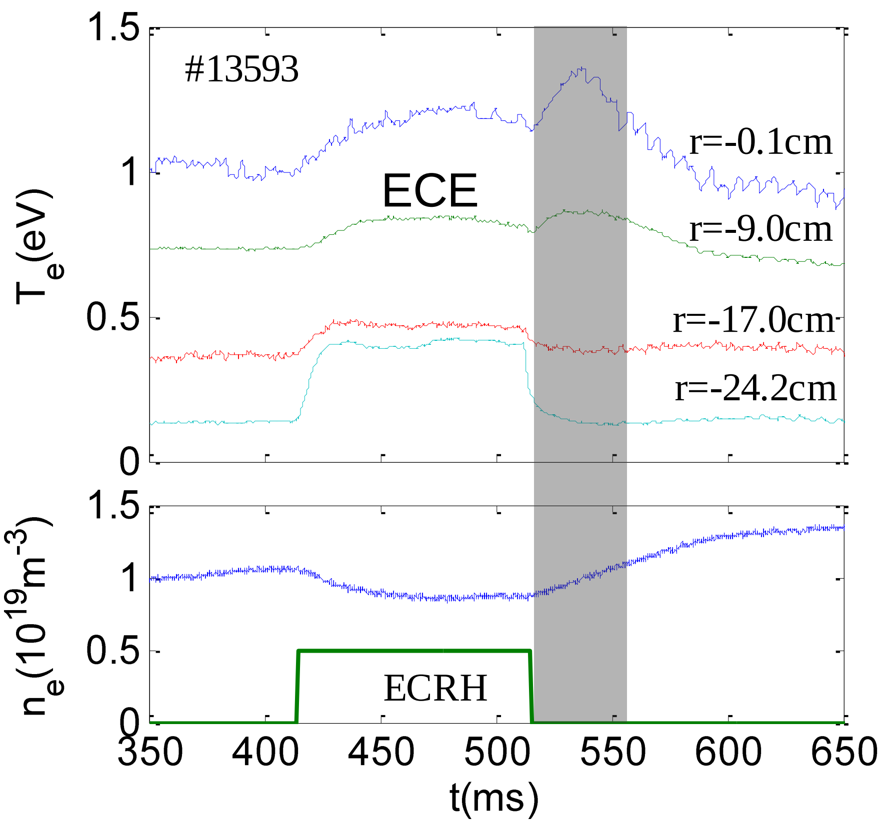
Te increase leads to a decrease in the plasma resistivity. Hence, the value of loop voltage Vl fall during ECRH.

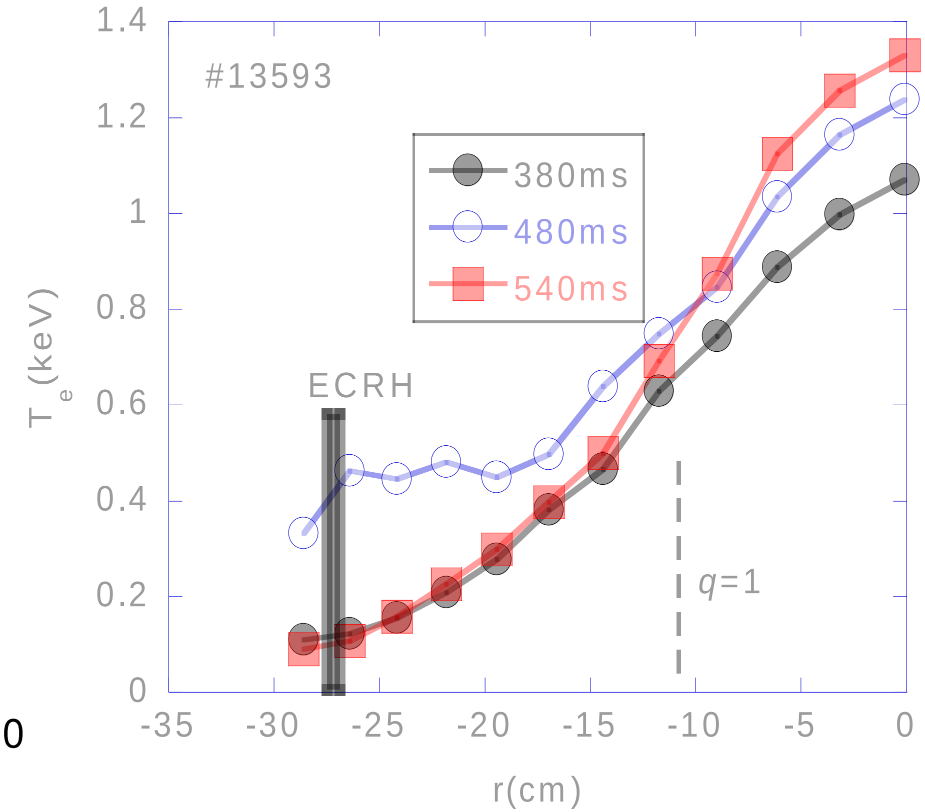
$$\eta = 2.3 \times 10^{-9} \frac{Z_{eff} \ln \Lambda}{T_e^{3/2}}$$



Statistic analysis of Vl fall with the ECRH power.

ITB triggered by far off-axis ECRH switch-off

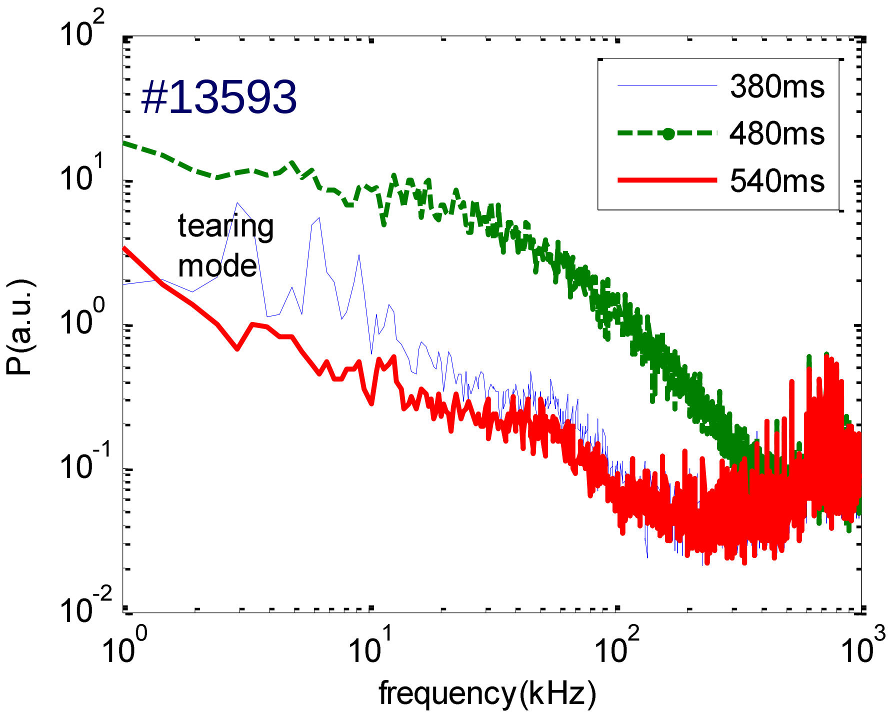


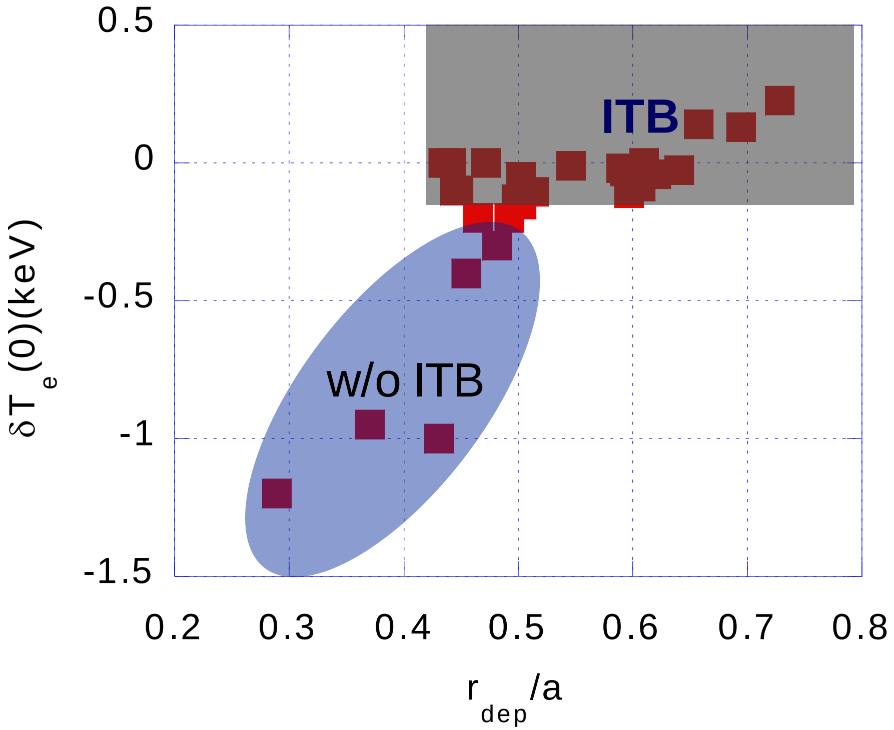


Bt=1.44T, Ip=165kA, P_{EC}=740kW in X2 mode

Reduced core turbulence after ECRH switch-off

HL-2A





Power spectrum of core density fluctuation by reflectometry

Statistic of the δT_e after ECRH switch-off as a function of power deposition

Summery

- Six 68GHz/500kW ECRH system has been developed. Up to now five subsystem are operated together.

- 140GHz/500kW/2s ECRH system are under discussion.

- High power ECRH experiments has been explored.
  - NTM has been observed on HL-2A;
  - ELM H mode has been realized;
  - Transient ITB after far off-axis ECRH switch-off has been explored.
  - Stabilization of TM and sawtooth Control with ECRH has been studied.

Thank You!