PSI-issues in EAST

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Outline

- Introduction
- EAST experimental setup
- Primary PSI-issues and results
- Next experimental plan
- Summary
- Acknowledgements

Introduction

HT-7/EAST

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Main Parameters of the EAST

	Nominal	Upgrade
B_o	3.5 T	4.0 T
I_P	1 MA	1.5 MA
R_o	1.7 m	1.7 m
a	0.4 m	0.4 m
R/a	4.25	4.25
K_x	1.2-1.5	1.5-2
δ_x	0.2-0.3	0.3-0.5

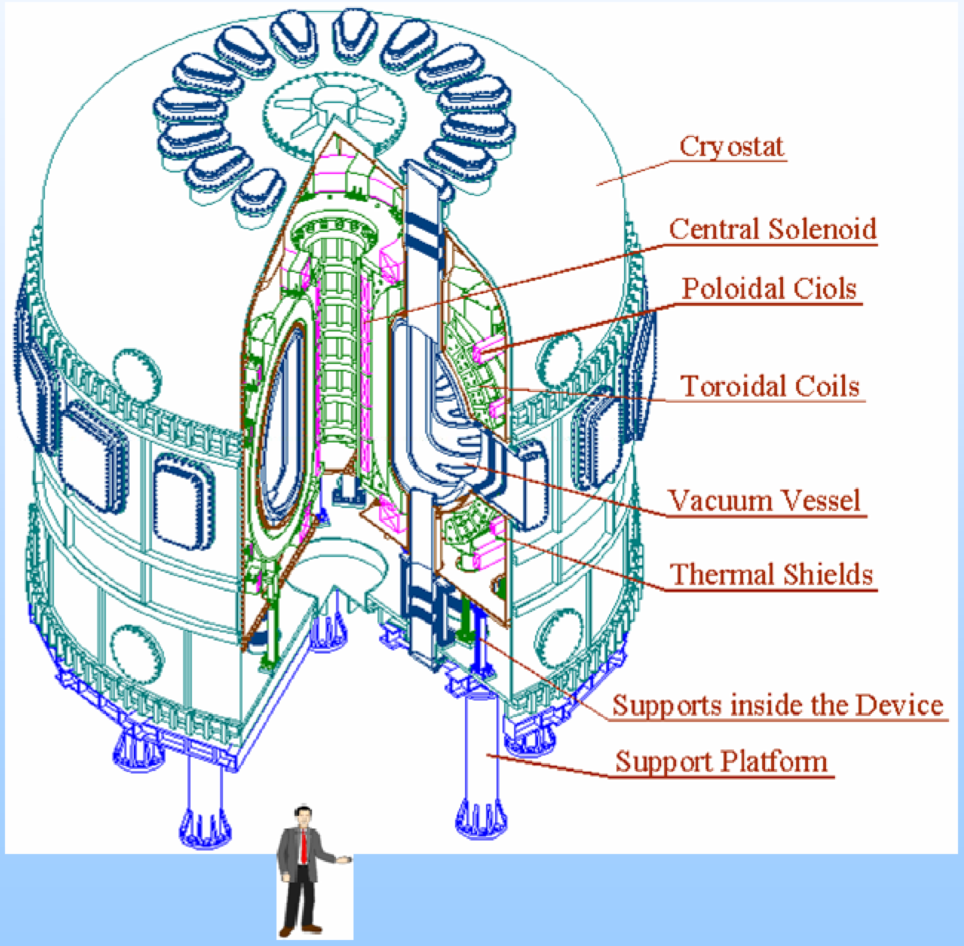
Heating and Driving:

	Nominal	Upgrade
ICRH	3 MW	6 MW
LHCD	3.5 MW	8 MW
ECRH	0.5 MW	1.5 MW
NBI		8 MW

Pulse length 1000 s

Configuration:

Single-null divertor
Double-null divertor

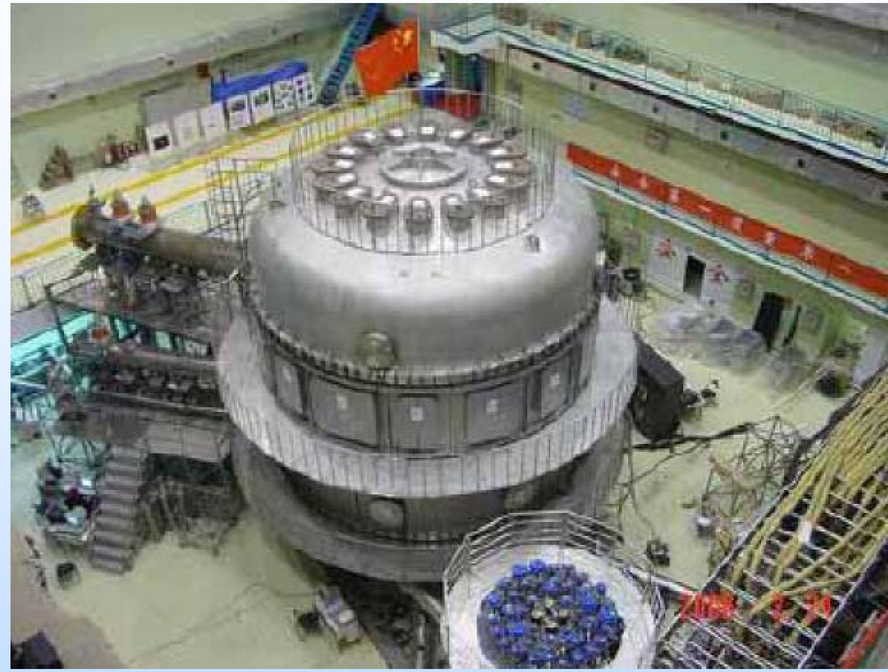


What’s new for the EAST

HT-7/EAST

- Experimental Advanced Superconducting Tokamak (EAST) is one of seven National Maga-Projects of Science Research under construction in China;
- Feb-Mar, 2006, 1st engineering commissioning. From July 25, 2006, on 2nd engineering commissioning and 1st physics experiment started before the last IAEA conference;
- National exammination on the project just passed on Sept. 28, 2006, mainly testing some key design parameters and plasma breakdown;
- Achievements of the device

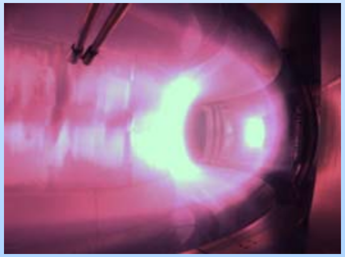
SC coils NbTi CICC-14kA-3.5T-4.5K
Height 10m
Diameter 8m LHCD 2.45GHz, 2MW
Weight 414 ton 2.45GHz, 1.5MW
P_{bg} 10^{-7} Torr ICRH: 30-110MHz 1.5MW



1st experimental campaign in 2006

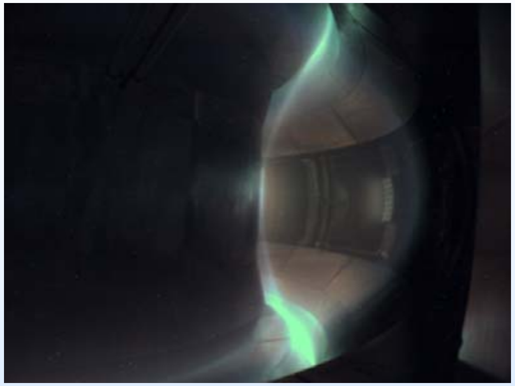
HT-7/EAST

- March 2006: first engineering commission
- Middle of July: accomplishment of in-vessel components installation
- End of July: cooling down (60~80 K)
- 5 August: GDC discharge followed by RF plasmas for wall cleaning
- 20 September: cooling down (magnets 4.5 K)
- 22 September: accomplishment of engineering test (TF –up to 3.55T).
- 23 September : null field configuration, break down with He
- 26 September 2006: 1st boronization, first hydrogen plasma, pre-programming controlled: Ip~220kA, t~2.7s
- 29 September : current feedback control
- 30 September: discharge break for testing spare turbines
- 2 October: 2nd boronization, density feedback control
- 5 October: current and radial position control, followed by Z control
- 8 October: 3rd boronization, Ip ~ 500 kA, (shaping preparation)
- 13 October 2006: elongated plasma (κ~1.28)

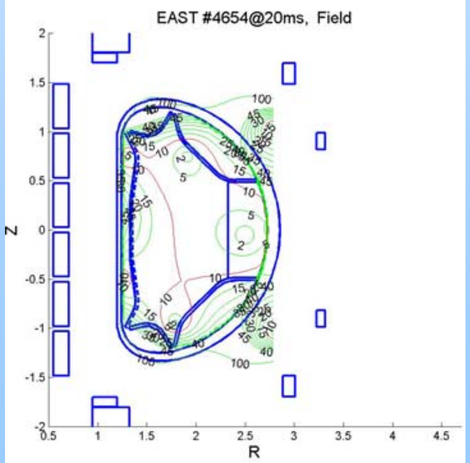


2nd experimental campaign in 2007

HT-7/EAST



- 20 December 2006: vacuum system start up
- 22 December: pumping of in-vessel vacuum
- 24 December: cooling down
- 9 January 2007: cooling magnets to 4.5 K
- 10 January 2007: PF coils & power supply system test
- 11 January: engineering test (TF coils + ICRF cleaning)
- 14 January 2007: break down with LHW (shot number 2729#)
- 17 January: pre-programming controlled: Ip~200kA limiter 3157#
- 18 January: feedback control of Ip~300kA limiter plasma 3231#
- 20 January 2007: IC coil test for vertical instability 3331#
- 22 January: Ip~200kA double-null divertor plasma 3478#
- 8 February 2007: double-null divertor plasma of Ip~500kA shaping during Ip ramp-up 4582#
- 9 February: long pulse 200kA/8.5s divertor plasma 4611#, optimization of low V (~ 3.5V) start-up 4654#
- 10 February: end of plasma experiment 4774#
- 11 February 2007: wall conditioning



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All metal PFCs and arrangements

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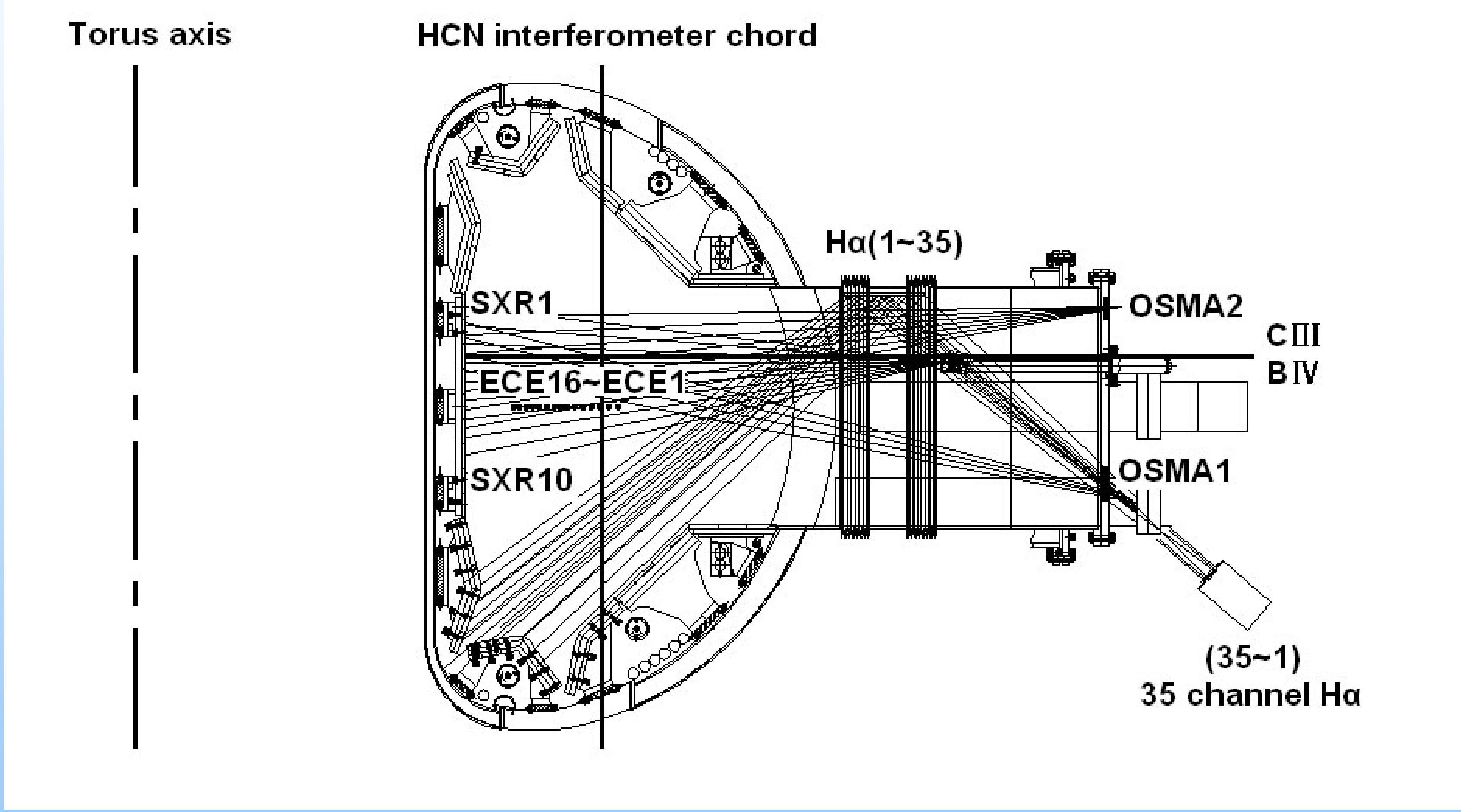
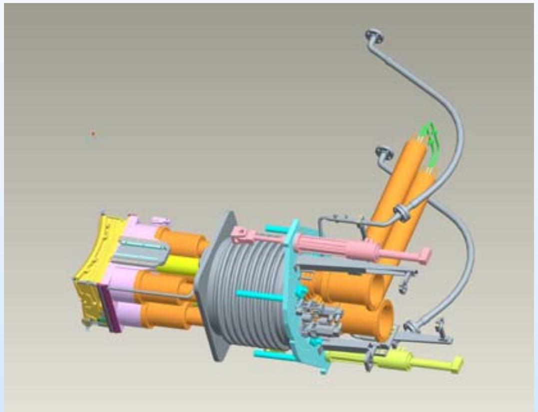
Plasma diagnostics system

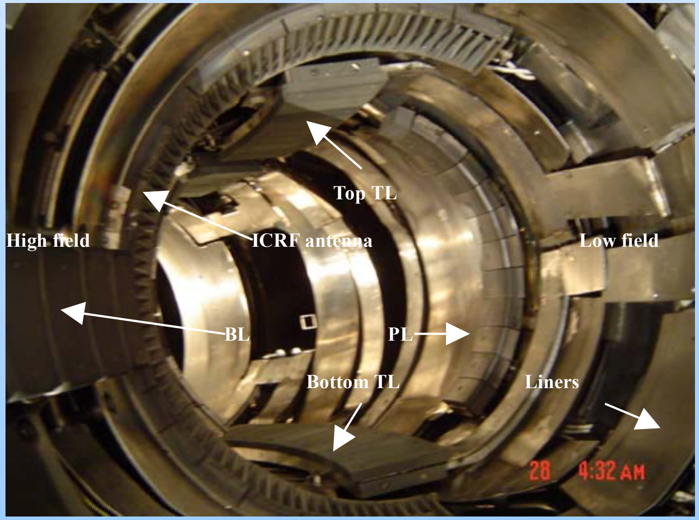


ICRF system (30 kW)

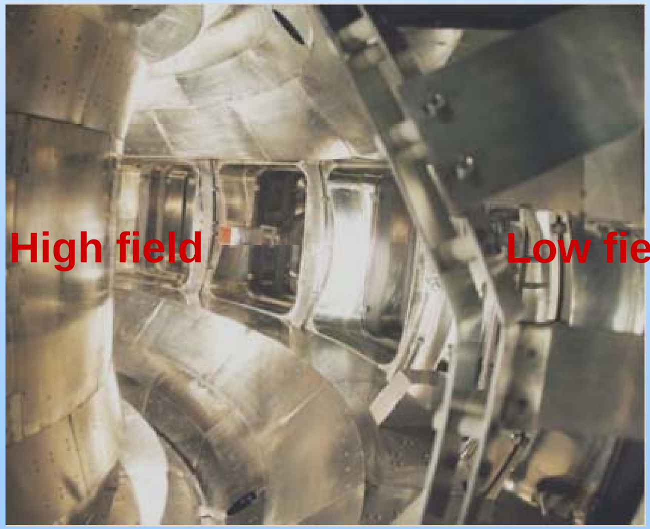
HT-7/EAST

- 5 MW will be available (30~110MHz, first for HT-7);





HT-7



EAST

Exp conditions in 2nd campaign

- **Full metal PFCs, stainless steel in-vessel components, including liners, diverter plates, internal coils, RF antenna;**
- **Two movable molybdenum (Mo) limiters installed at R = 2.235m, with a_{max}= 0.45 m;**
- **About 15 basic diagnostics for plasma study on EAST;**
- **Plasma control system (PCS) built in collaboration with DIII-D;**
- **RF systems at ICRF (30 kW) and at LHF (180 kW) for wall conditioning and discharge pre-ionization;**
- **Wall conditioning: baking, GDC and RF discharges, boronization.**

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HT-7 vs EAST

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HT-7

- Limiter configuration;
- 20% walls are covered by doped graphite with SiC coating;
- D_2 plasma operation;
- Plasma facing areas ~12m^2;
- Low pumping speed;
- RF antenna for both wall conditioning and heating.
- GDC: 2 Mo anodes, ~2A/anodes, Movable.
- Baking: By electric resistance heating.
  - Highest Temp.
    - For liners is 250^{0}C;
    - For limiter is 200^{0}C.

EAST

- Divertor configuration;
- All mental wall (SS+Mo limiter);
- H_2 plasma operation(60-70% H in the RG);
- Plasma facing areas ~50~60m^2;
- High pumping speed;
- Specially designed RF antenna for wall conditioning.
- GDC: 4 SS anodes (use 2 fixed), ~2A/anodes,
- Baking: By hot N_2 interlayer heating; Electric resistance heating.
  - Highest designed Temp. for PFCs is 350^{0}C;
  - Actually used :
    - PFCs ~150^{0}C.
    - Windows <120^{0}C.

Pre-wall conditioning in winter of 2006

- 12/24 start pumping；
- 12/28 start baking, then gradually use cryopumping；
- Baking temperature at interlayer：
  - 12/28~1/2(4.5days) 120~140^{O}C；
  - 1/2 baking temperature reduction;
  - 1/2~ (11days) 80~100^{O}C；
- Baking temperature at pumping ducts;
  - 12/28~1/4(6.5days) 120~150^{O}C;
  - 1/4 ~ 20~30^{O}C。
- Baking temperatures at windows<120^{O}C；
- During He-GDC, stop windows baking, and keep interlayer and pumping ducts baking; He-GDC（ to 1/13 16:00 total 70hours)
- He-ICR （to 1/13 16:00 total 2h45m)

He-GDC and He-ICR in EAST

- He-GDC
  - Dominant before plasma discharge;
  - 3~5h per night before plasma operation.
- He-ICR
  - Between plasma discharges;
  - System experiments

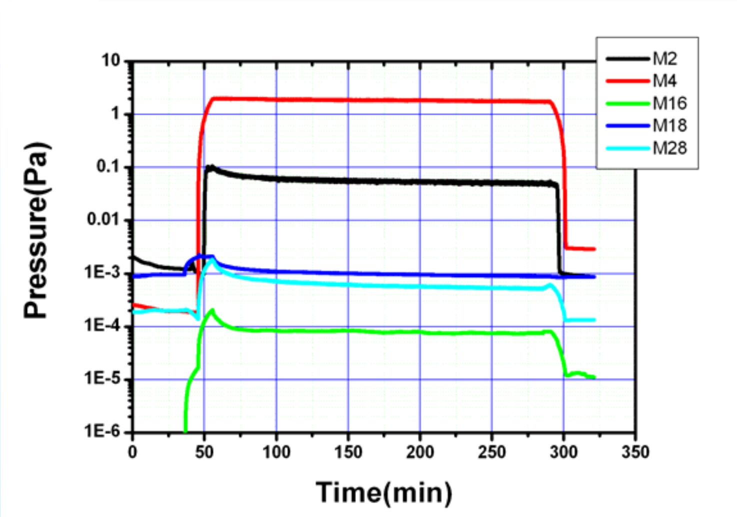
✓ Three times;

✓ Influence factors of power, pressure, magnetic field, pumping speed and wave duty time

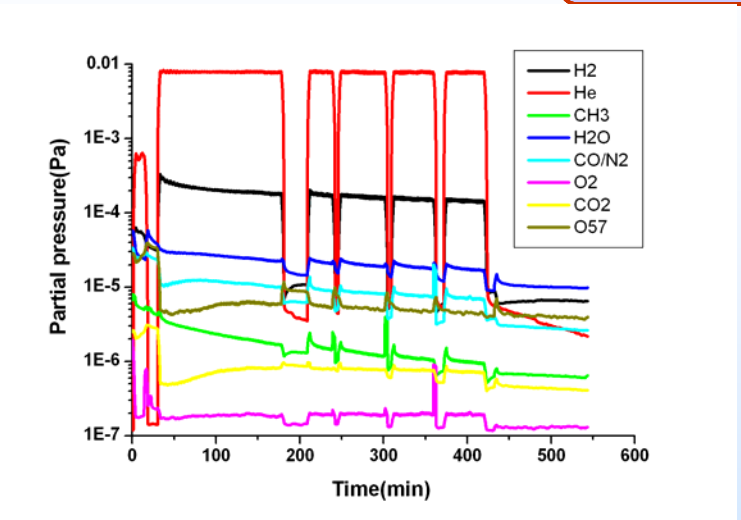
  - Power: 3~20kW
  - Pressure: 4E-3Pa~10Pa

Typical He-GDC and He-ICR

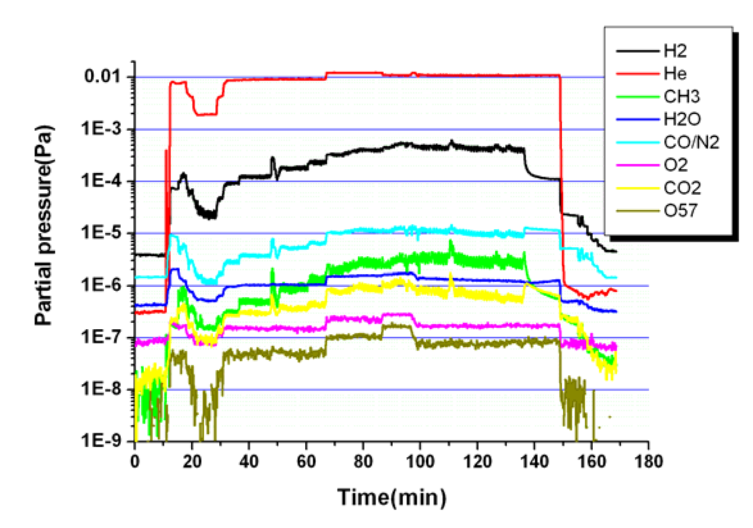
HT-7/EAST



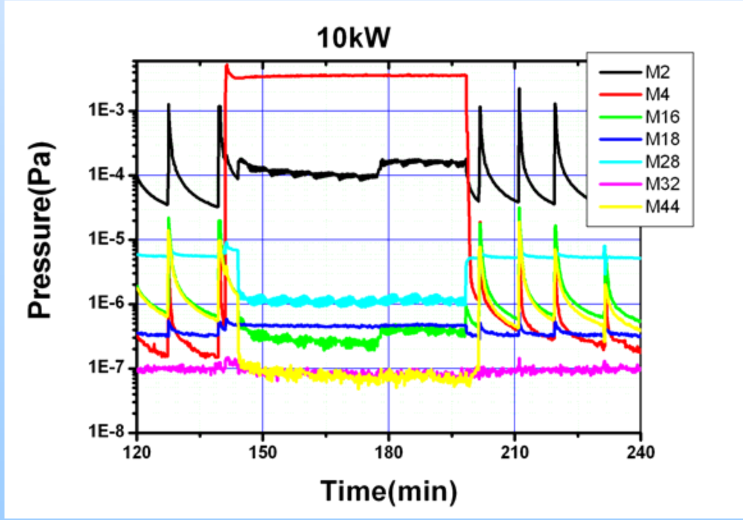
He-GDC(3Pa, 2x2A)



He-ICR at early operation ($1.2*10^{-2}$ Pa, 15kW)



He-ICR with different power and pressure ($4.5x10^{-3}$-$1.8x10^{-2}$ Pa, 3-20kW)



Inter shot He-ICR ($4.5X10^{-3}$ Pa, 10kW)

He-ICR before and after oxidation

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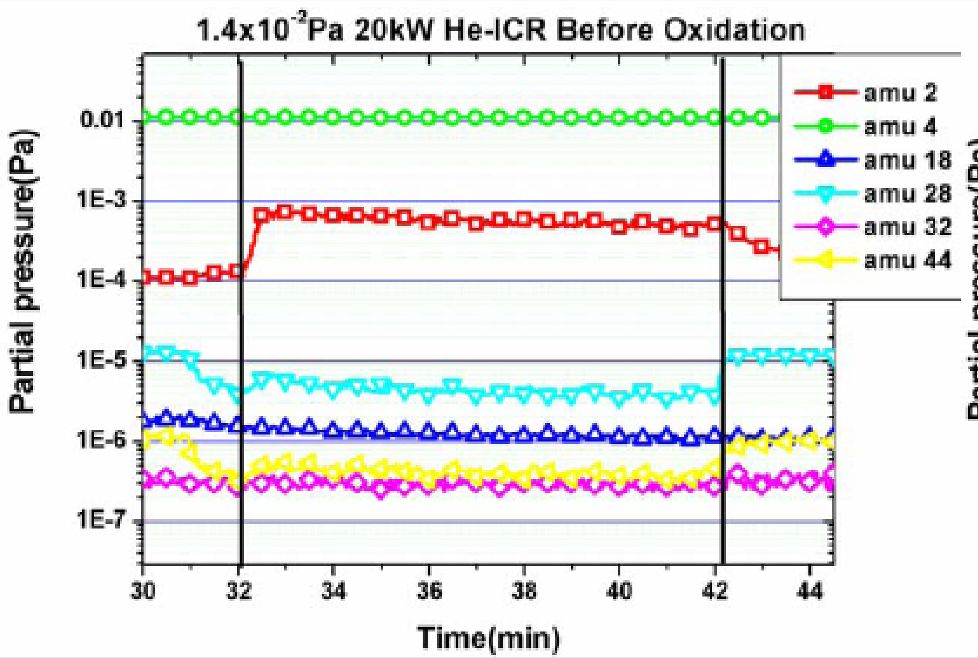

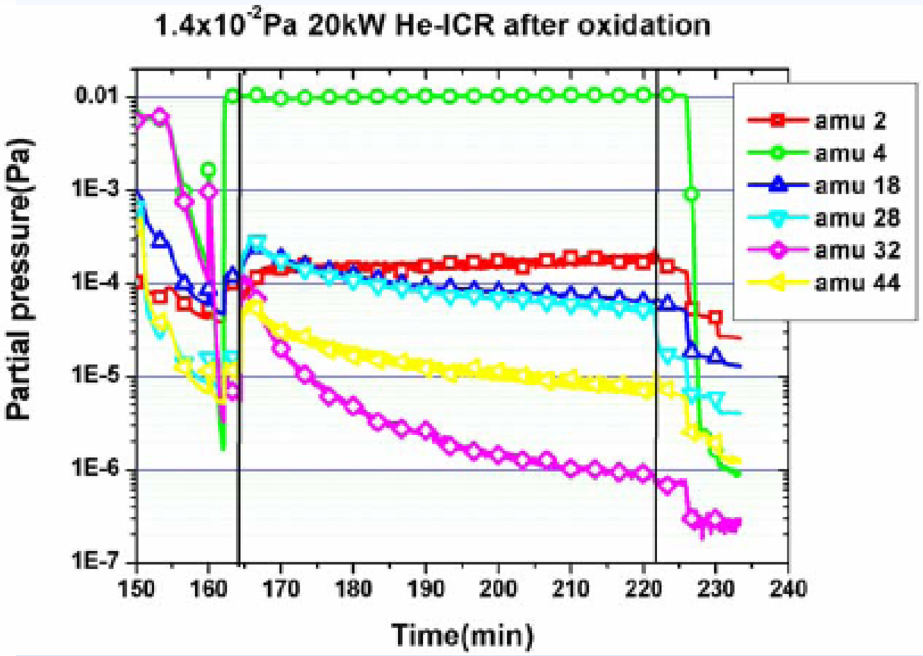

- After He/O-ICR experiments, He-ICR is effective for oxygen removal;
- H and Impurities removal in He-ICR cleanings depended on wall conditions；
- H_2 was effective reduced by He/O-ICR cleanings.

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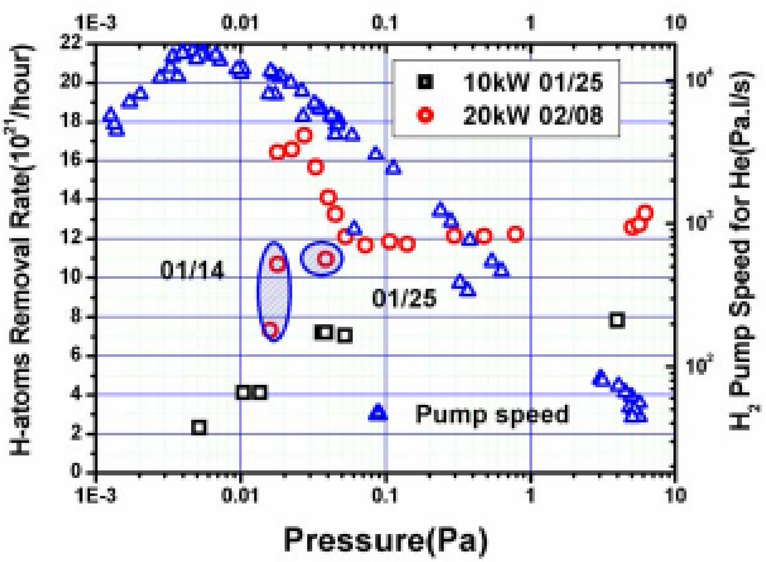
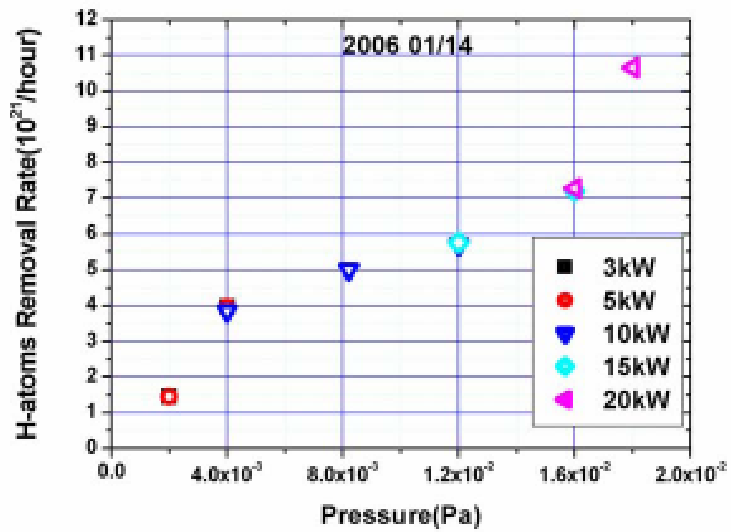
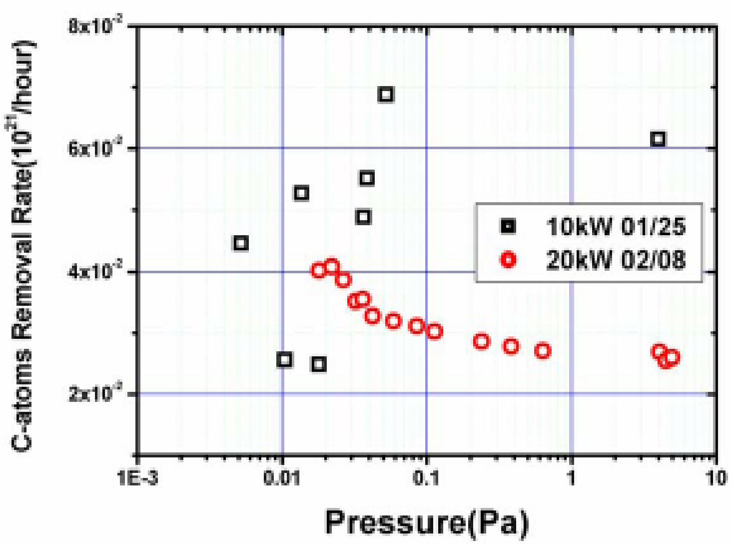
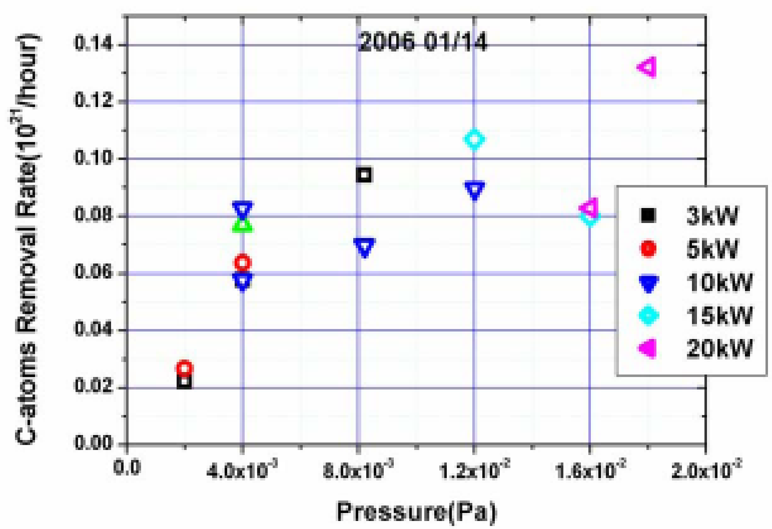
Removal rates of He-ICR

HT-7/EAST









He-ICR in EAST

- Successfully carried out ICRF WC with a specially designed antenna in a divertor machine-EAST；
- The removal efficiency for H in low pressure(4.5E-3Pa) He-ICR is almost as the same as in He-GDC cleaning (2Pa)；
- Factors influence on He-ICR efficiency:
  - Results from partial removal rate and CCD pictures showed that the influence of TF (1-2T) was small；
  - Pulsed RF WC with wave duty time at 0.3s/1.2s,1s/2s is good；
  - High ICRF power promote particles removal；
  - He-ICRF is beneficial for impurities removal in early operation and after oxidation experiments.
- Require to increase pump speed at high pressure in EAST；
- Comparison with HT-7 results
  - Breakdown pressure different: HT-7 limited <0.2Pa, EAST reached ~10Pa;
  - Power different: HT-7 reached 60kW; Highest RF power in EAST was used only 20kW(will be extend to high power in near future.);
  - Highest H removal rate is higher than HT-7 by a factor of 4.

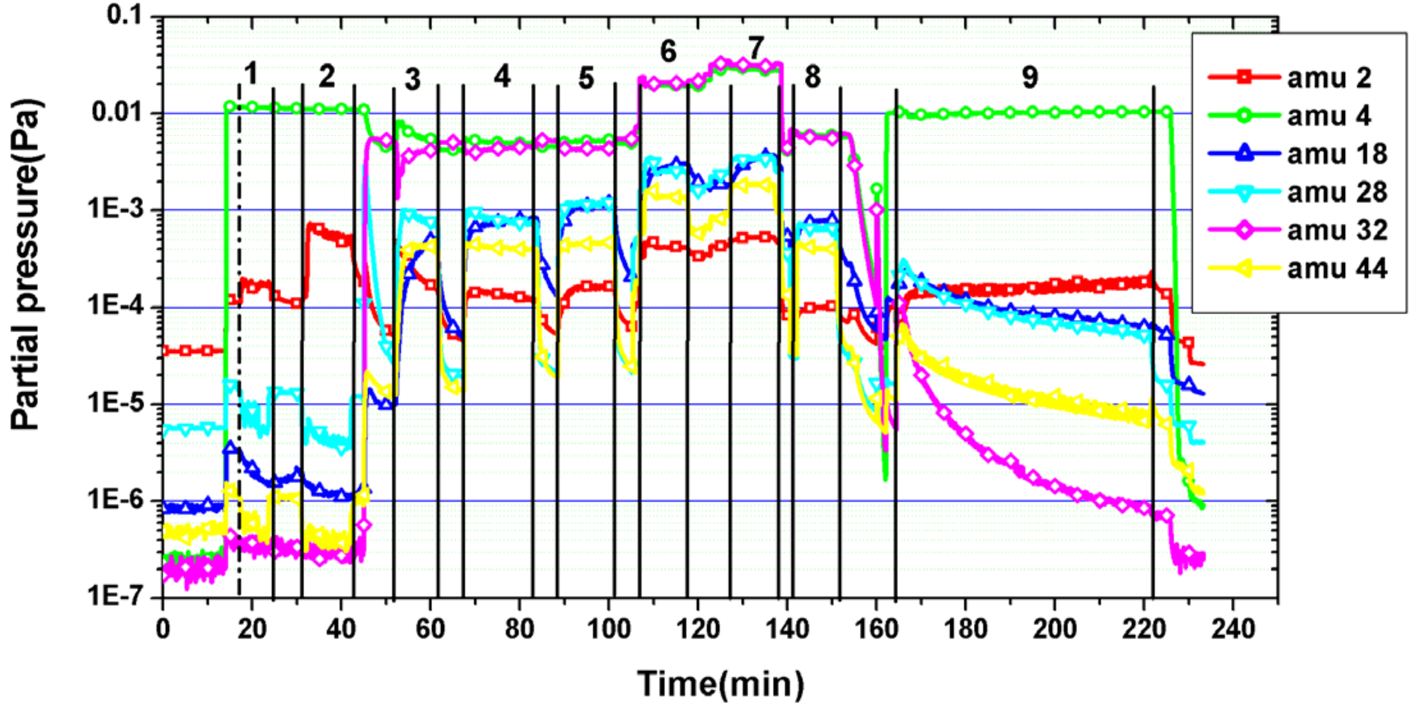
Primary results of oxidation in EAST

Procedures

	Pressure	Power	Gas	Note
1	1.4E -2Pa	20kW	He-ICR	Wall temp.~150^{o}C RF duty: 0.3s on/ 1.2s off B during RF cleaning: 1T; He:O_2~1:1
2	1.4E -2Pa	20kW	He-ICR	
3	1.4E -2Pa	5kW	He/O-ICR	
4	1.4E -2Pa	10kW	He/O-ICR	
5	1.4E -2Pa	20kW	He/O-ICR	
6	5E-2Pa	20-10kW	He/O-ICR	
7	7E-2Pa	10kW	He/O-ICR	
8	1.4E -2Pa	5kW	He/O-ICR	
9	1.4E -2Pa	20kW	He-ICR	
10	0.5Pa	4A*300V	He-GDC	
11	0.5Pa	4A*300V	He/O-GDC	
12	0.5Pa	4A*300V	He-GDC	

He/O-ICR cleaning

HT-7/EAST



1. During oxidation, C was removed by the formation of CO and CO_2 and most of hydrogen released in the form of water molecules;
2. CO, CO_2 and H_2O production after oxygen injection (Thermo-oxidation) only sustained for a short duration.
3. He/O-ICR are beneficial for long removal for C and H.
4. Higher power and/or higher pressuer in He/O-ICR, more CO and H_2O produced.

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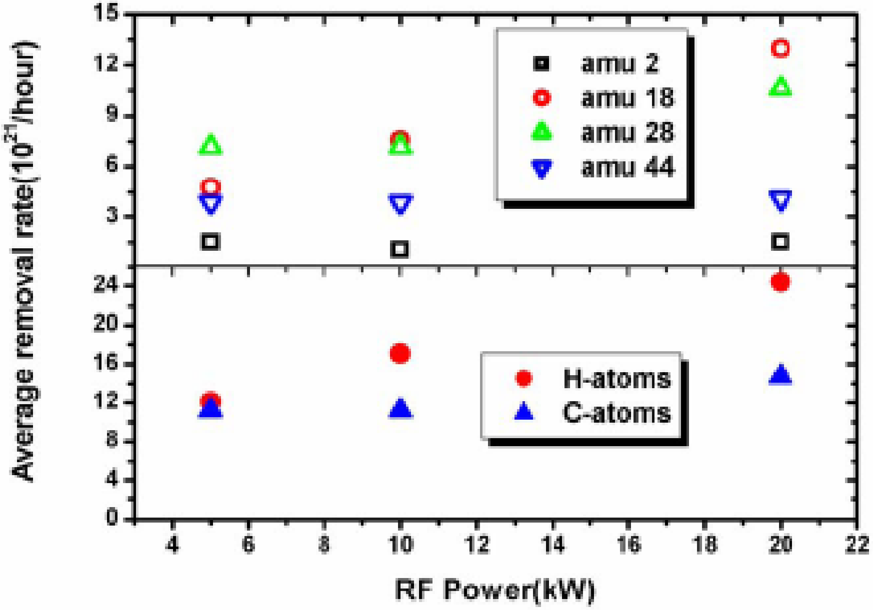
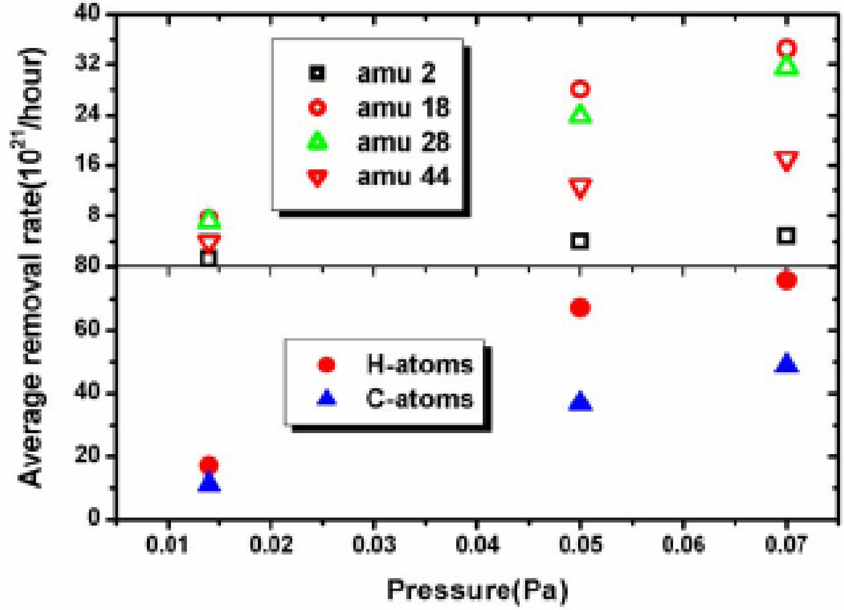
HT-7/EAST

Average removal rates in He/O-ICR



$1.4X10^{-2}$ Pa



10kW

1. O-RF on a SS walls are beneficial for both H and C removal. Highest removal rate are 7.8×10^{22}H-atoms/h, 4.2×10^{22}C-atoms/h (20kW, 7×10^{-2}Pa)
2. Higher than that in He-ICR by a factor of 5 and a few tens respectively.
3. High pressure and conditioning power are favorable for removal of H and C.

Comparison between EAST and HT-7

HT-7/EAST

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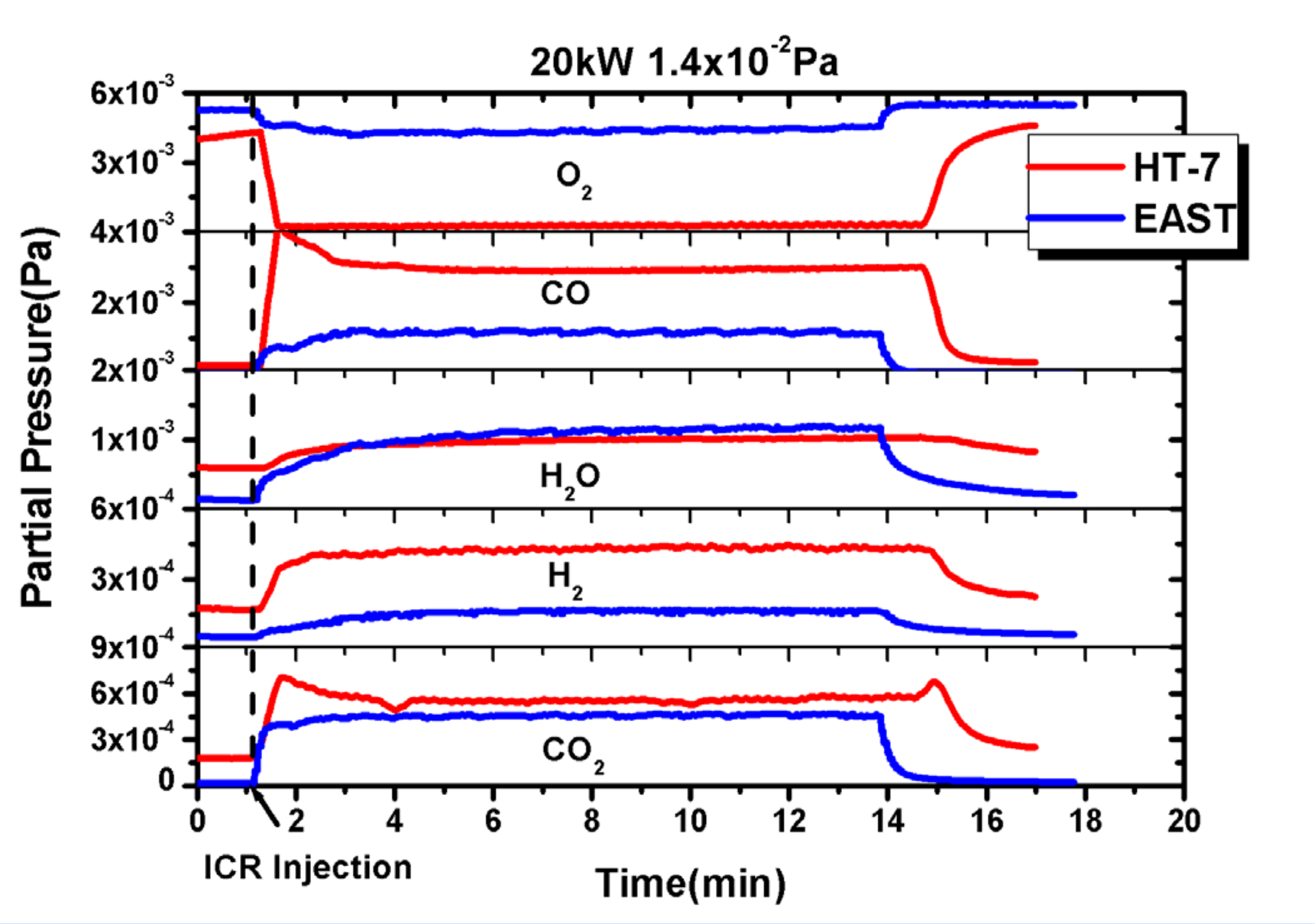

HT-7: More O_2 consumed, relatively more O reacted with C

EAST: Less O_2 consumed, relatively more O reacted with H

He/O-ICR between EAST / HT-7

HT-7/EAST

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- Similar behaviors during oxidation.
- In both devices, H, C removal rates were higher than that in He-ICR by a factor of 4~6 and a few tens.
- Similar influence of power, pressure and wall conditions.
- High removal rates in EAST than in HT-7.
- In EAST, fewer O_2 consumed, higher fraction of O_2 reacted with H.
- Lower O retention rates ($min^{-1}.m^2$) than HT-7 by a factor of >10.
- With the same parameters(20kW, 0.014Pa He/O-ICR)
  - HT-7: ~$2x10^{21}$ H/hour; ~$1.9x10^{21}$ C/hour.
  - EAST: ~$2.5x10^{22}$ H/hour; ~$1.3x10^{22}$ C/hour.
    - Power density (20/40 vs 20/5 kW/m^2)
    - Pumping speed (10^4 l/s vs 850 l/s)
    - Areas facing plasma (50~60m^2 vs ~12m^2)
    - Volume of vessels(~ 40m^3 vs ~ 5m^3)
    - Plasma facing materials (Stainless steels vs doped graphite (or SiC)
    - ICRF antenna (Shape, location…….)
    - Structure of vessels (Divertor vs Limiter)
    - Plasma fuels(H_2 vs D_2)

Breakdown Vloop and dIp/dt ramp-up rate

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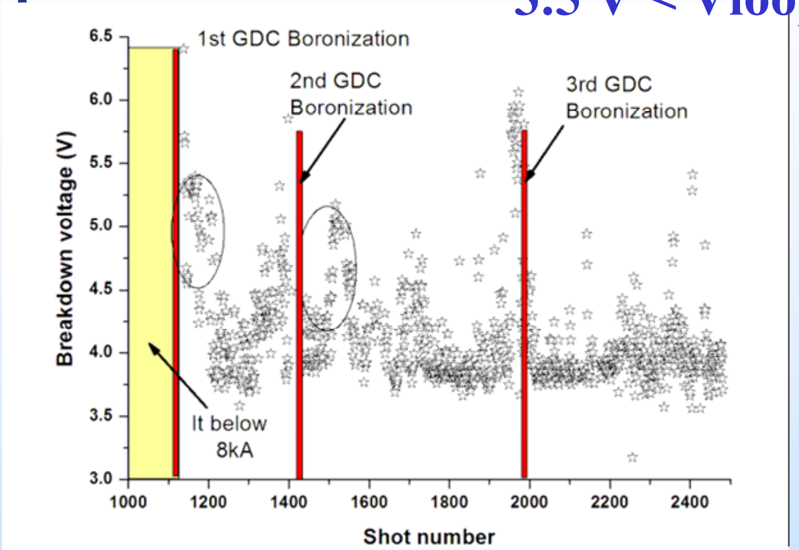
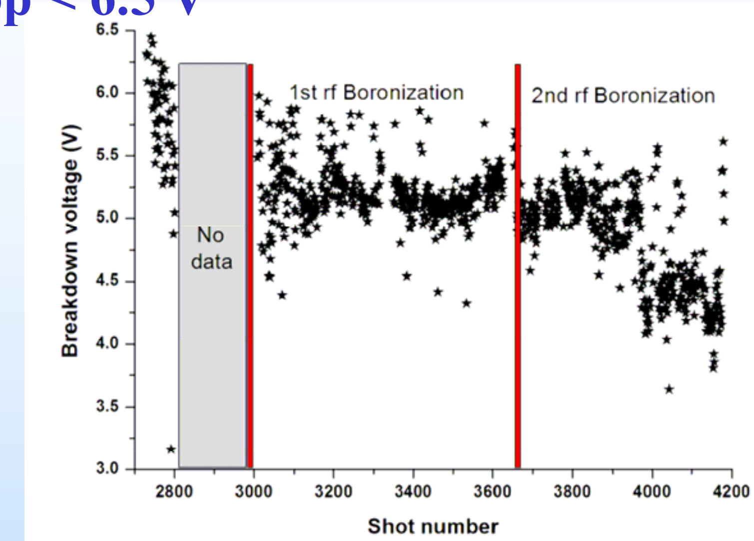
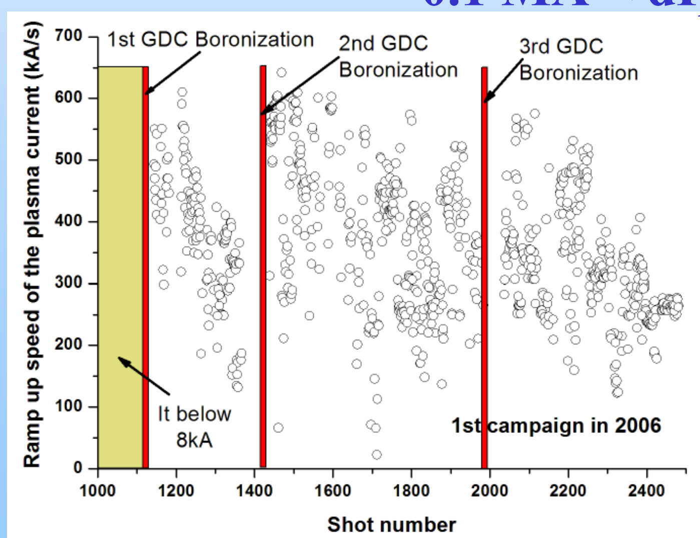
HT-7/EAST

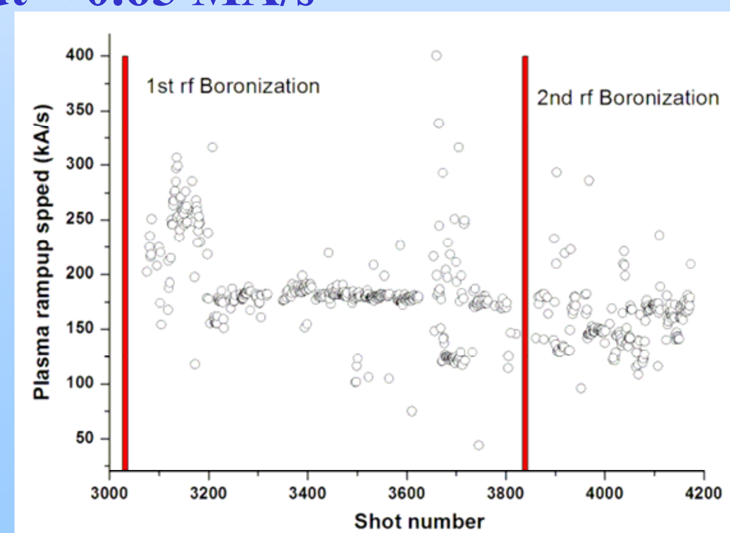
3.5 V < Vloop < 6.5 V





0.1 MA < dIp/dt < 0.65 MA/s





First plasma on EAST

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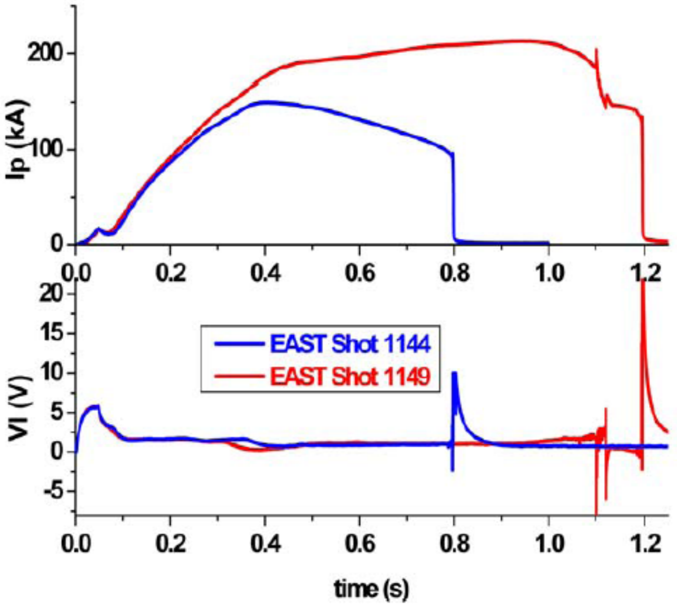
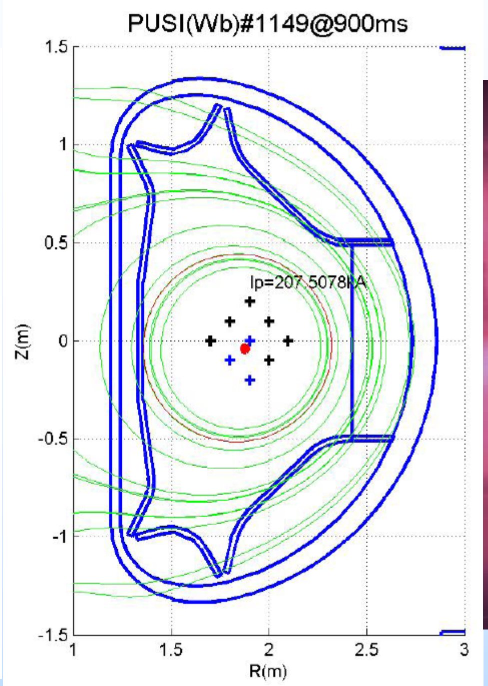
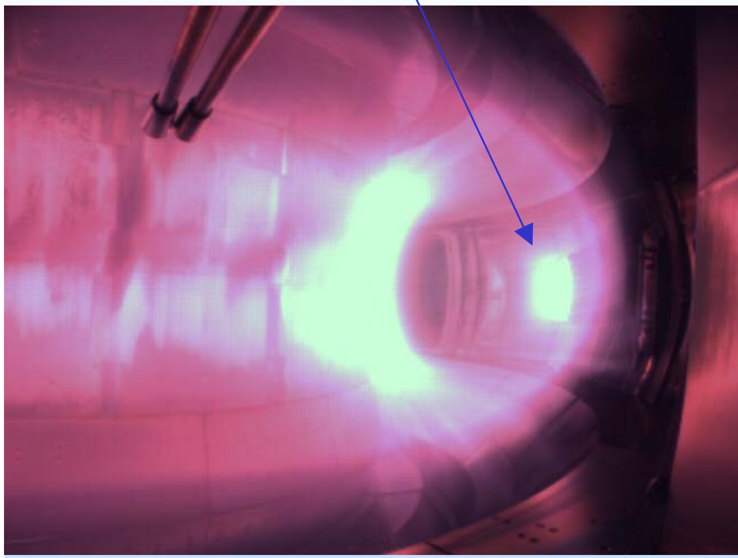
HT-7/EAST





Mo limiter



•After several breakdown shots, plasma current was very smoothly ramped up to 150 kA at a rate of about 0.5MA/s by pre-programmed control and up to 220 kA after only a few more shots. Circular cross-section H plasma with Mo limiter on Sept.26, 2006;

•To avoid impurity burn through, plasma density was relatively low, about $0.4\sim1.0\times10^{19}/m^2$. Strong HXR was observed;

•Most disruptions were due to the shift of plasma position. Even for the worst disruption, the induced voltage at the ends of the PF coils was very low due to the shielding effect of the vessel, safe for PF coils.

Divertor probes

HT-7/EAST

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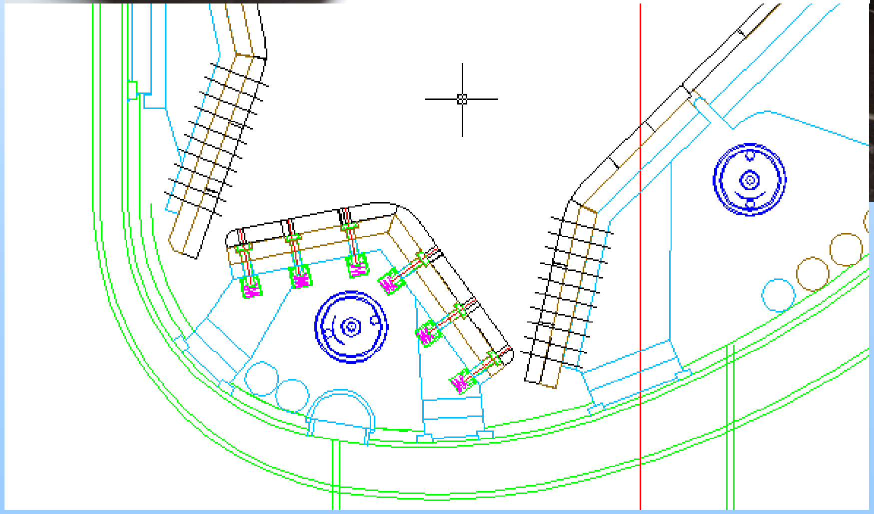
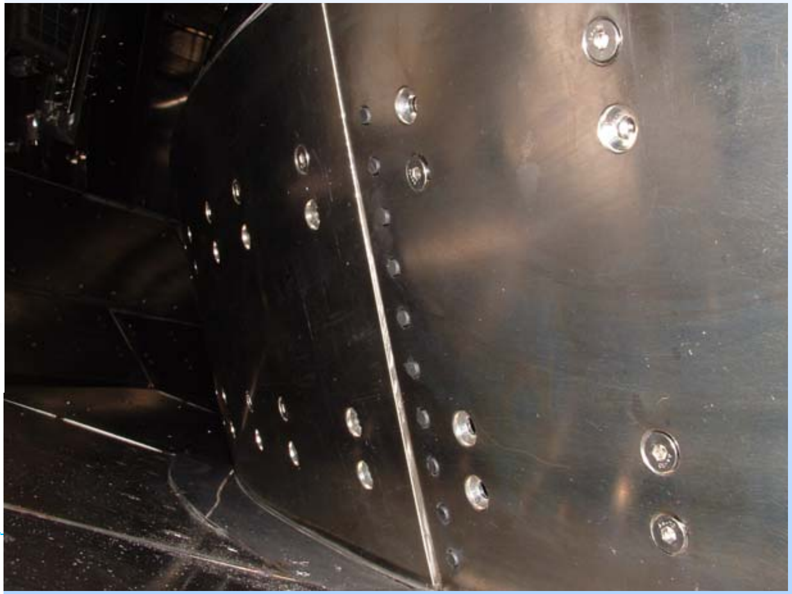
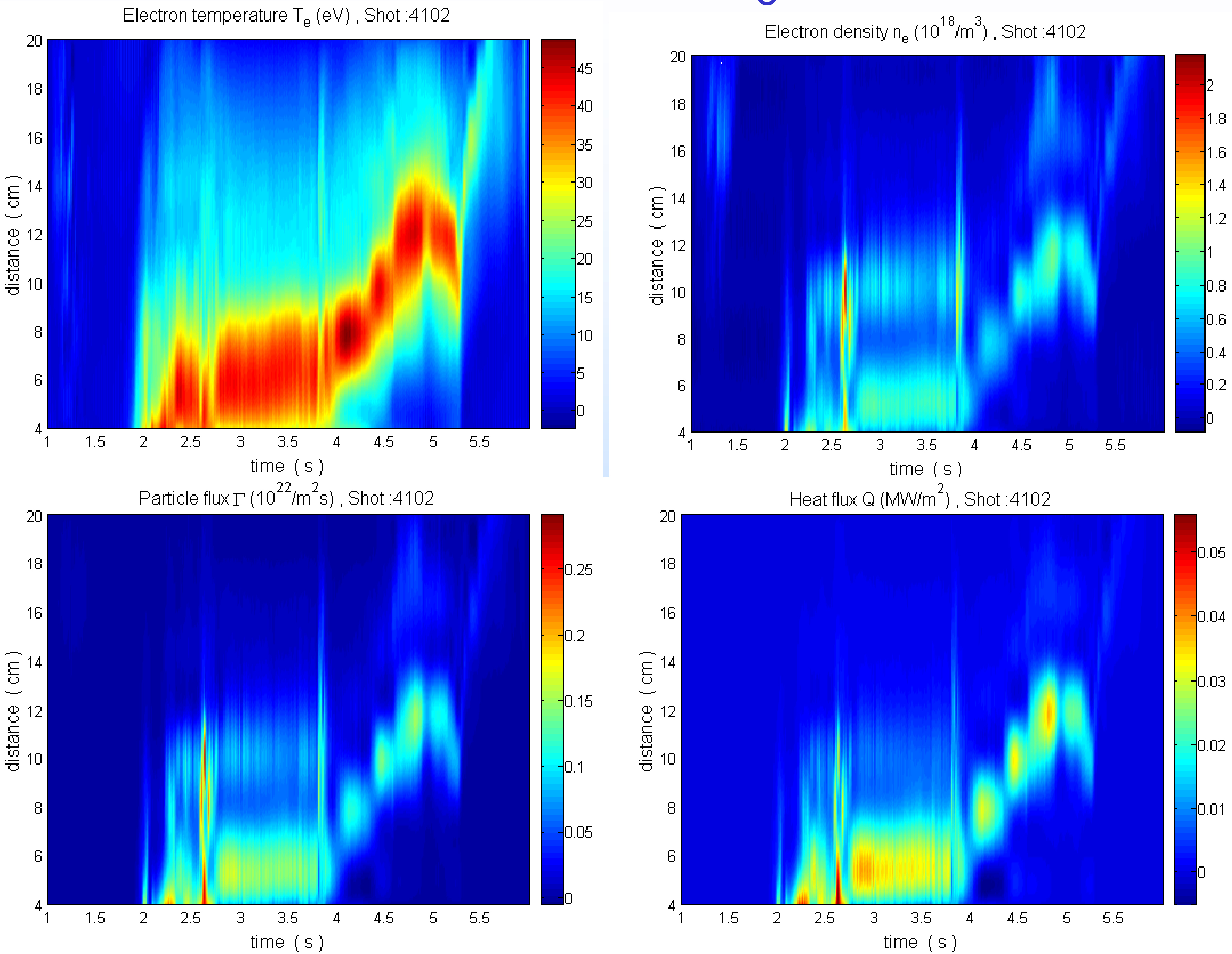
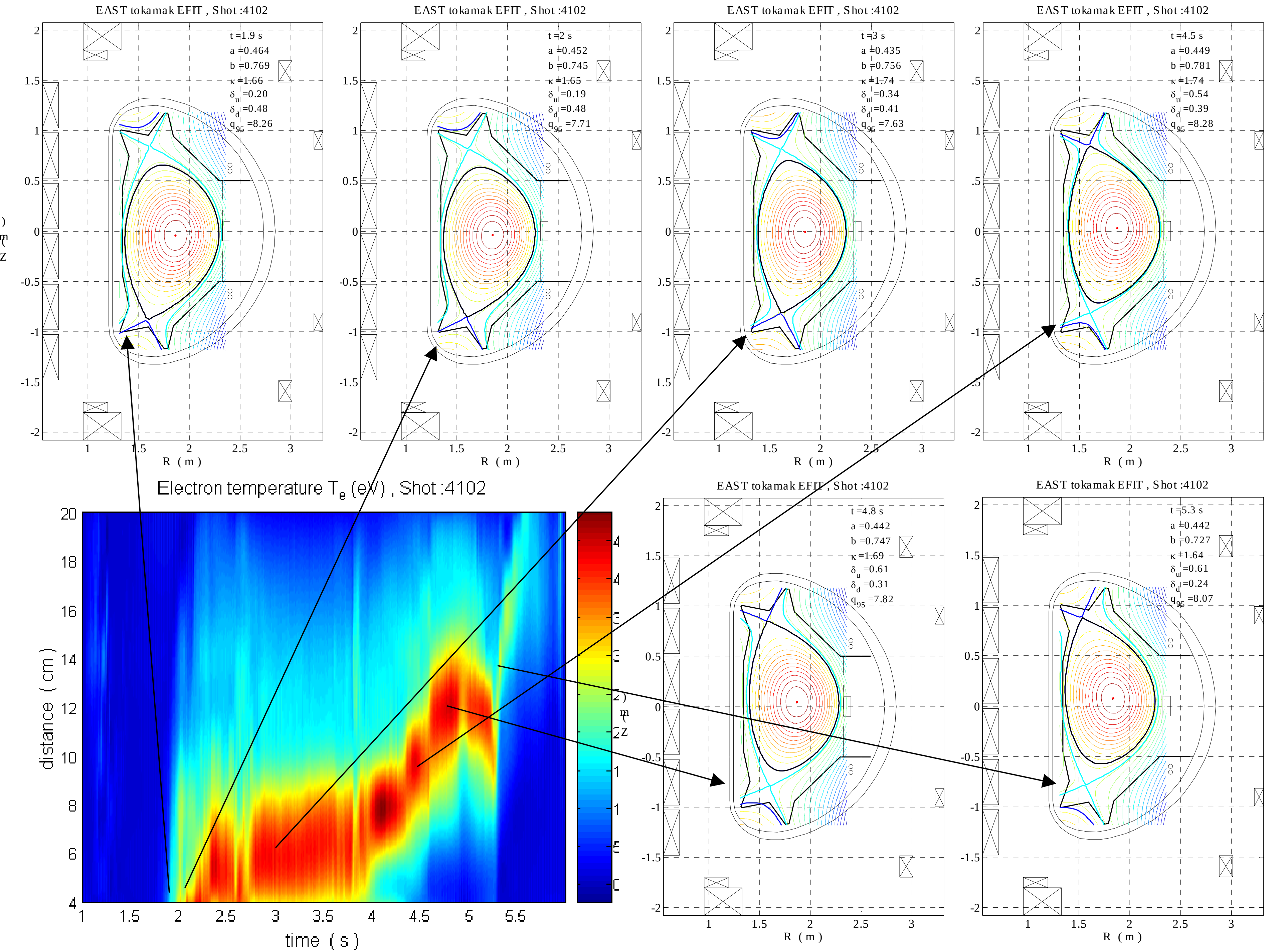


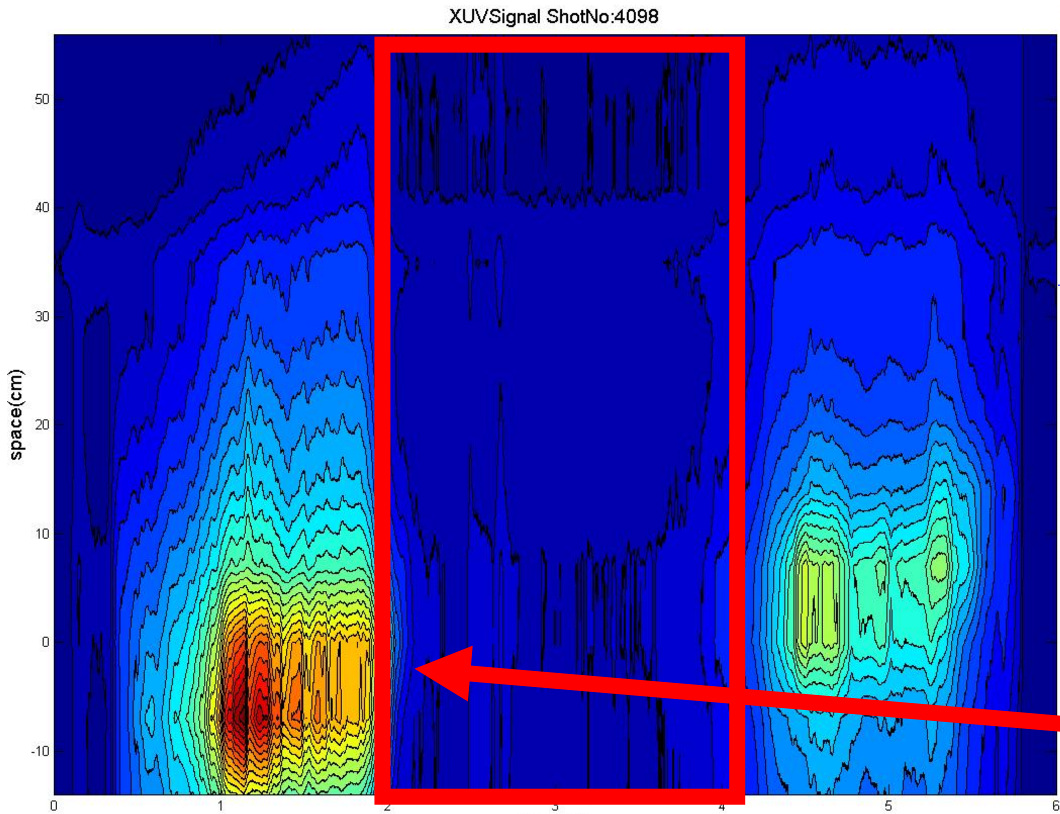


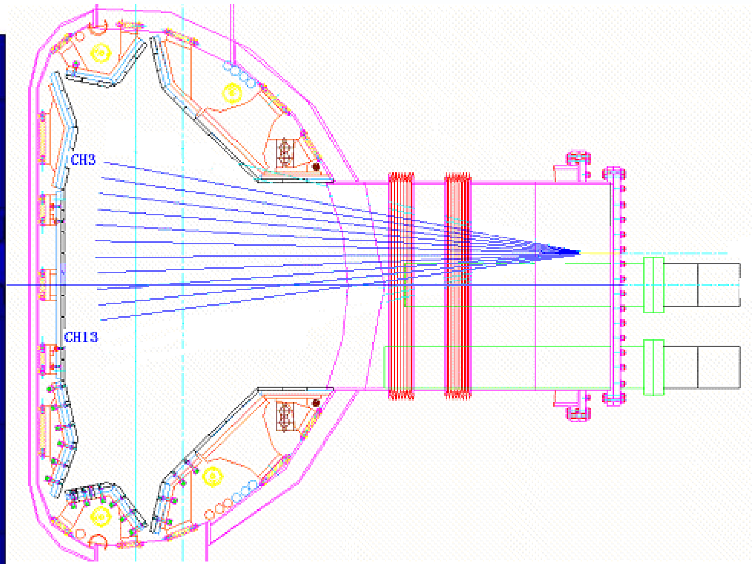
Inner divertor target





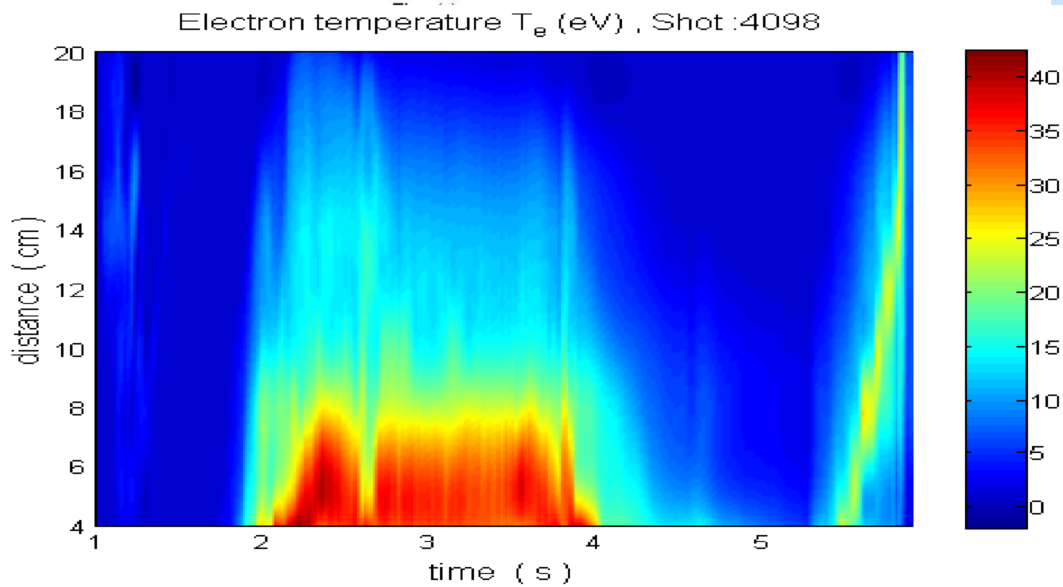
EAST tokamak EFIT , Shot :4102
t =1.9 s
a =0.464
b =0.769
κ =1.66
δul =0.20
δdl =0.48
q95 =8.26
t =2 s
a =0.452
b =0.745
κ =1.65
δul =0.19
δdl =0.48
q95 =7.71
t =3 s
a =0.435
b =0.756
κ =1.74
δul =0.34
δdl =0.41
q95 =7.63
t =4.5 s
a =0.449
b =0.781
κ =1.74
δul =0.54
δdl =0.39
q95 =8.28
t =4.8 s
a =0.442
b =0.747
κ =1.69
δul =0.61
δdl =0.31
q95 =7.82
t =5.3 s
a =0.442
b =0.727
κ =1.64
δul =0.61
δdl =0.24
q95 =8.07
R (m)
Z (m)
Electron temperature Te (eV) , Shot :4102
distance (cm)
time (s)



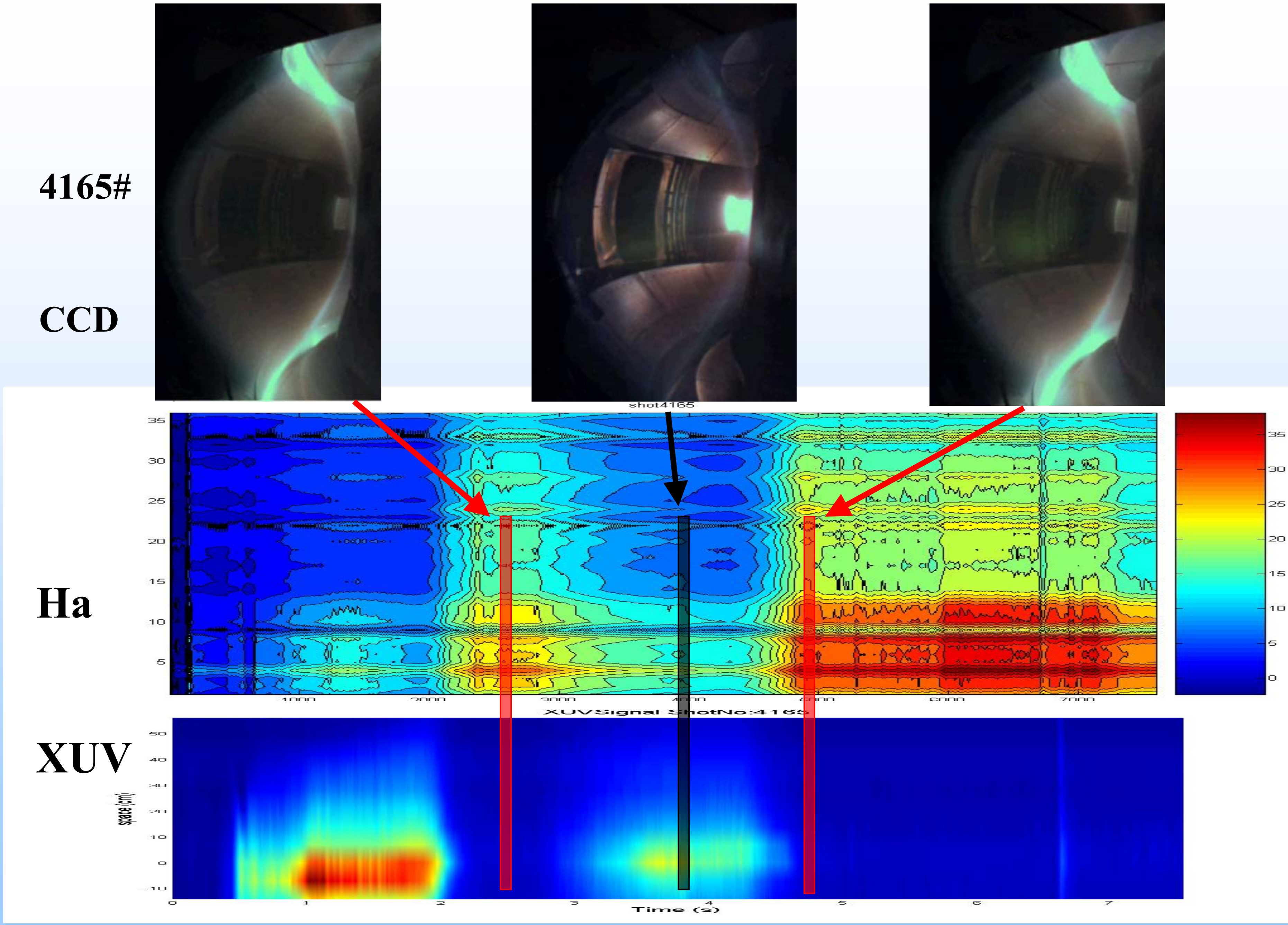


XUV

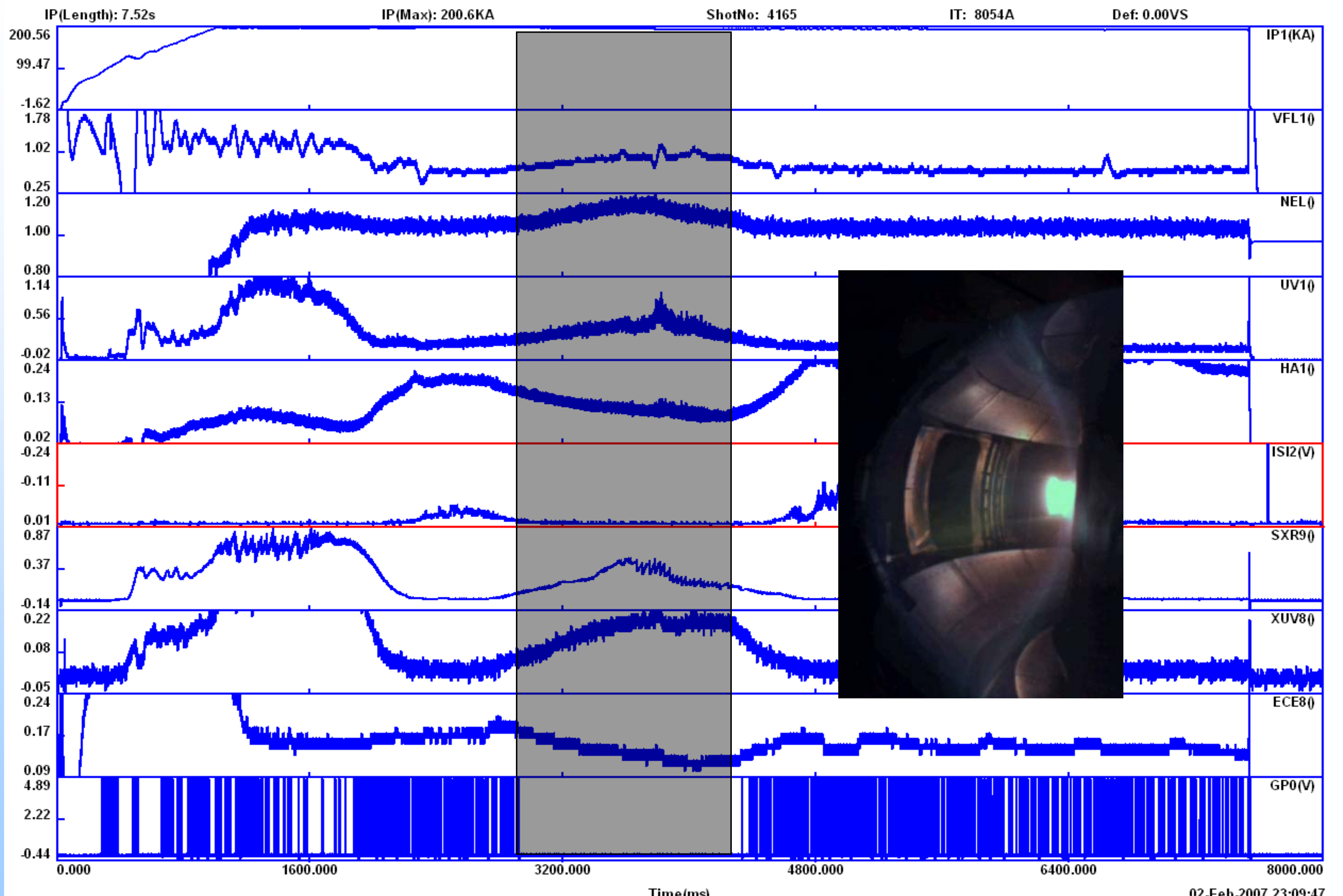
Divertor configuration，
reduction of core radiation of XUV



Down inner diveror target



Limiter configuration，enhancement of XUV radiation



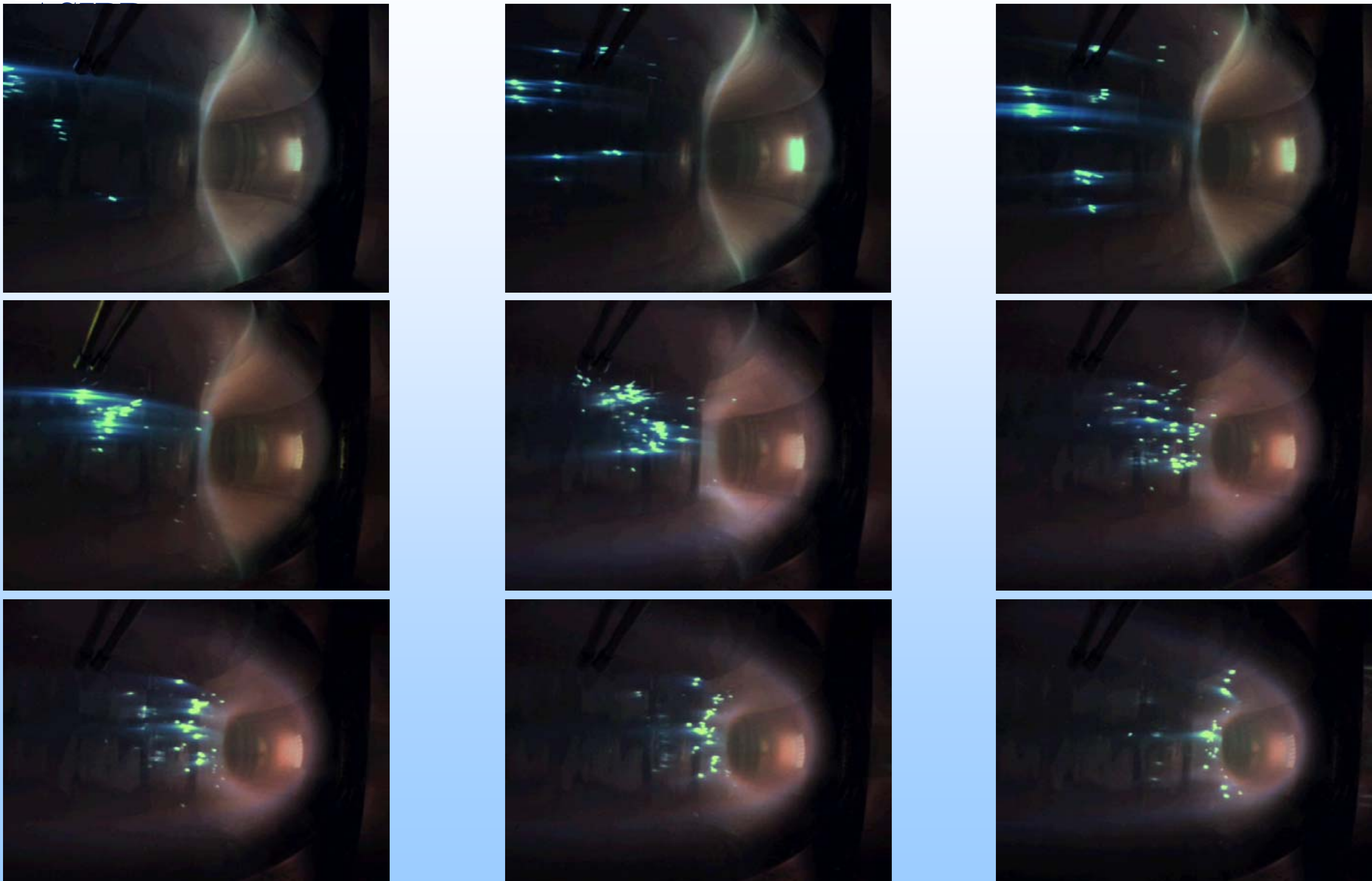
Limiter configuration， enhanced radiation of impurity

Outline

- Introduction
- EAST experimental setup
- Primary PSI-issues and results
- Next experimental plan
- Summary
- Acknowledgement

UFO in vacuum vessel

HT-7/EAST



HT-7/EAST

Strategy for PFM development

All doped graphite with thick SiC coatings as plasma facing materials

Mechanically plus braze joined to heat sink

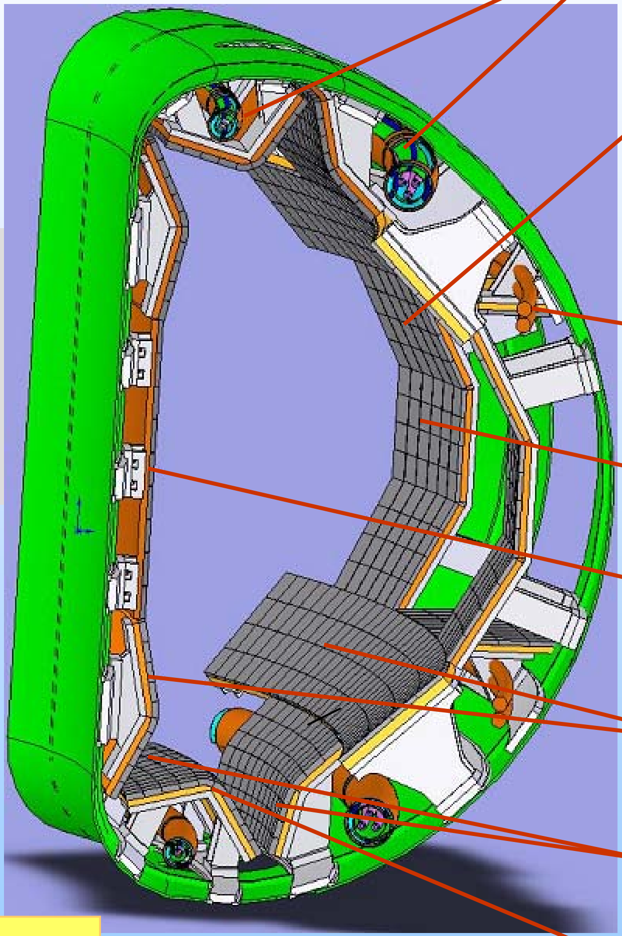
Reliable and convenient for primary plasma discharge and shape control

(1)
Doped graphite (FW) +thick W on copper alloy as HHF PFCs

（2）
All carbon based PFM? Doped graphite(FW) + CFC as divertor target

Change to all tungsten based PFCs

W coatings on CLAM＋W coatings on copper alloy



ICRF wall conditioning

ASIPP

HT-7/EAST

I_T=8.0kA

He-ICRF wall conditioning

1) B_V+B_T

B_V~100-200G; B_T~2T

2) He+H_2

H_2/He ~0.2-0.3

3) f_1+f_2

f_2>f_1

4) B_T- Scan

$f_{Generater}$ scans!!

Summary

- **Divertor plasma has been achieved successfully** in 2007 on the EAST superconducting tokamak with all metal PFCs;
- RF also have been successfully carried out for wall conditioning, recycling control between shots, oxidation and boronization;
- Much better results have been obtained compared with those in HT-7, and the basic date will be compared with **full C** condition;
- ICR conditioning techniques will be carried out in EAST under **full C** and mixed material with **C/W** conditions;
- Towards long-pulse high power plasmas, **full graphite wall and PFC** with **high power** heating (3.5MW LH+IC) and **new diagnostics** will be available in the 3rd experimental campaign;
- For the divertor configuration, RF wall conditioning still need to be further developed.

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