Overview of PWI Activities on EAST

Jiangang Li for ASIPP-PWI Team

2nd Sino-Germany PWI workshop, Garching, 2010-12-6-9

Outline

- Present state of EAST
- PFC strategy for EAST
- Studies on Plasma-Wall Interaction
- Future Plan

Provide a valuable information for ITER

Mission of EAST

- A good facility for 1MA steady-state operation with 20-30MW CW Heating & CD power and more than 50 diagnostics .
- Play the key role for understanding advanced SSO plasma physics.
- Provide valuable data bases for ITER and DEMO under SSO condition.

Physical Engineering Capability

Evaluation of superconducting magnets and related systems for steady-state plasma discharges.

Key issue→AC loss

Magnets, power supply, cryogenic systems

4.5K: TF: B_T = 3.5T, B_T=4.0T individual

PF: 20-50kA/s~ 1s, 3kA/s~1000s

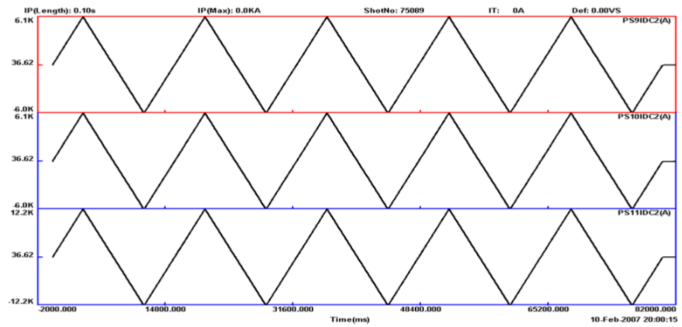
Ipf max = 14.5kA

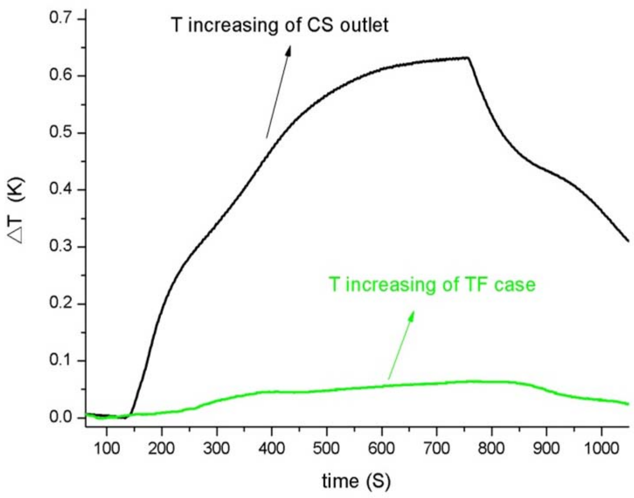
Capable: Ip=1MA, B_T=3.5, 1000s

3.6K: I pf max = 18kA, Tested

Capable: Ip=1.5MA, B_T=4T, >1000s

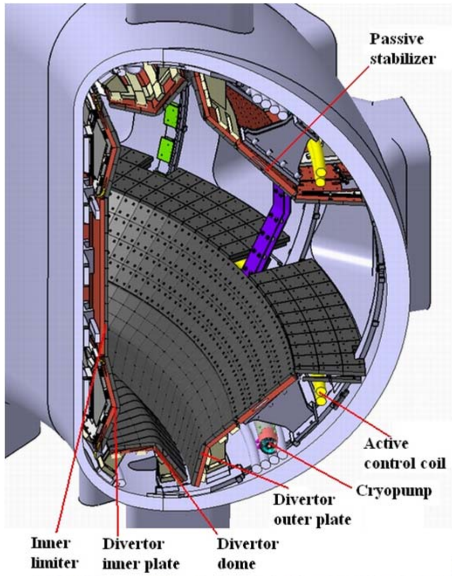
PFC: 2MW/m2, CW





Simulating 1MA/1000s/4.5K,

Present Status and System Capabilities



•Graphite PFC (tiles with 2MW/m^2)

•Internal Cryo-Pump, Removable limiter

•RTEFIT/Isoflux control, limiter, SN, DN

•Plasma: Ip~1.0MA, Bt~3T, Plhcd~1.2MW, Picrf~2.6MW, Td>100s (DN)

•Shaping: kappa~1.9, delta~0.65

•System Capabilities:

•LHCD: 2.45GHz, 2MW

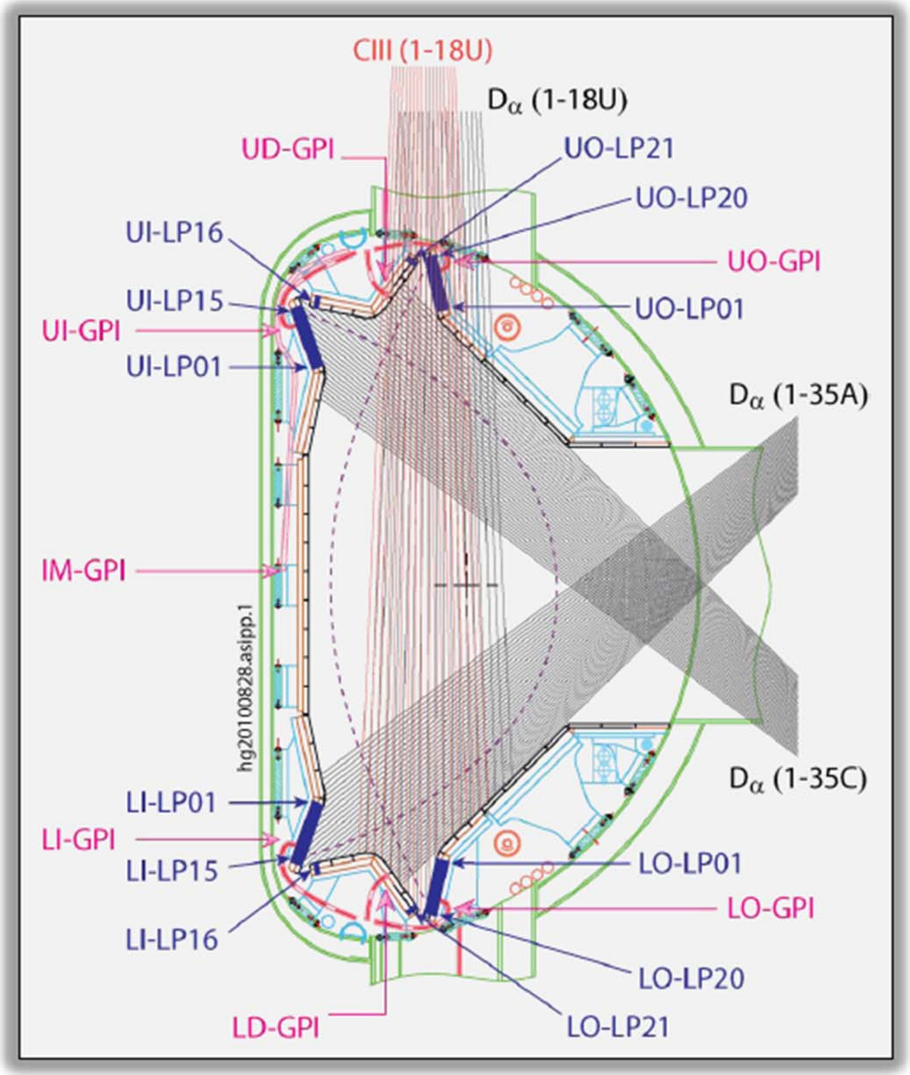
•ICRF: 30-110MHz,1.5MW

•ICRF: 20-70MHz, 4.5MW

•Diagnostics: >40, in 2010 for all key profiles

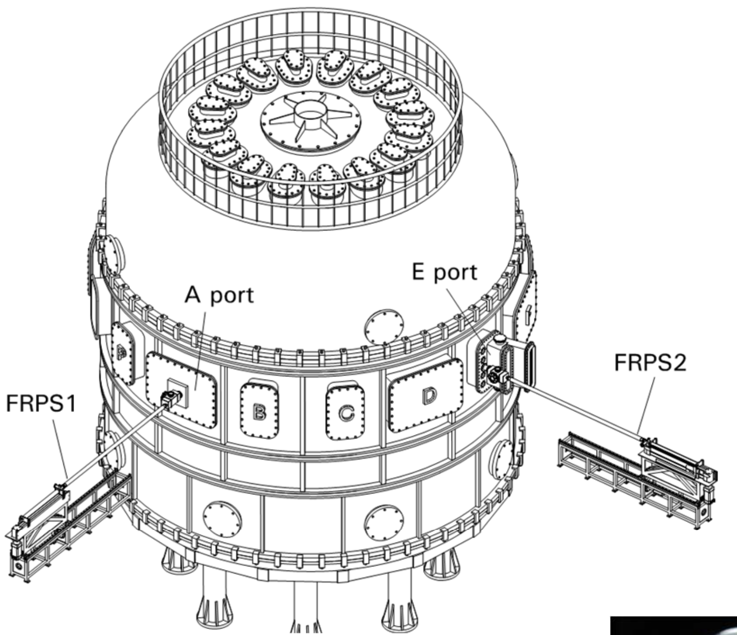
•Multi-purpose gas injection at different location for various gas (D2, CD4, Ar, N2 …)

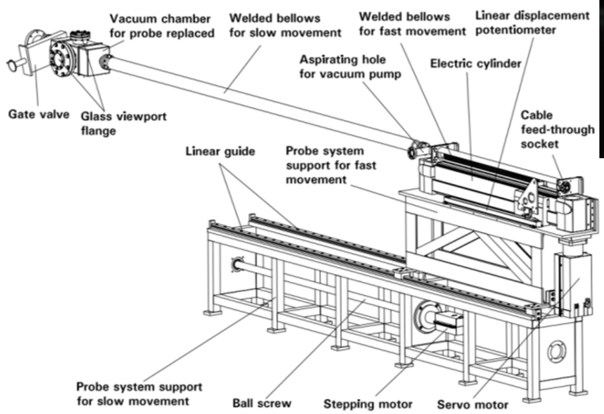
Main Edge diagnostics

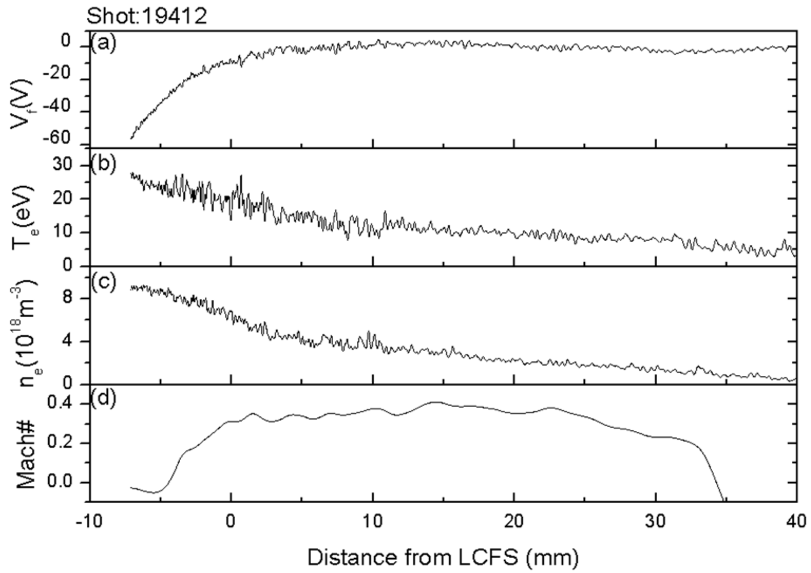


- **Langmuir Probe System**
  - 222 divertor target embedded graphite probes, configured as 74 triple or single probes.
  - 2 sets of reciprocating probes from the opposite sides of the mid-plane.
- **Spectroscopy**
  - 18-channel D_α/CII/CIII, viewing the lower outboard divertor from the top of the machine.
  - 2 arrays of 35-channal D_α, viewing inner target and dome of both upper and lower divertors from outer midplane through in-vessel reflection mirrors.

Fast reciprocating probe system





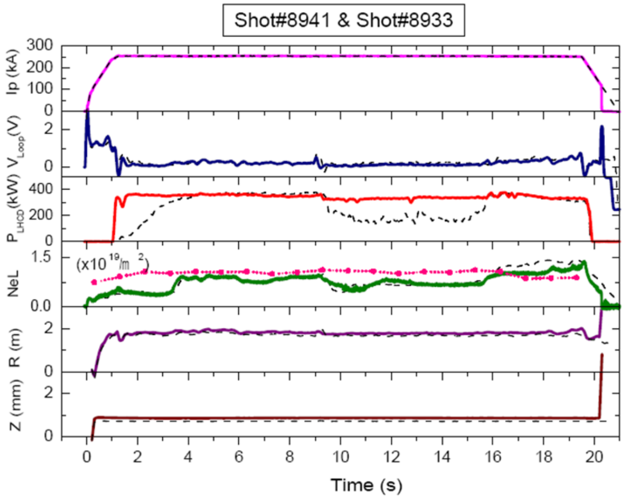


Allow edge profile and turbulence measurements at multi time slices in one shot

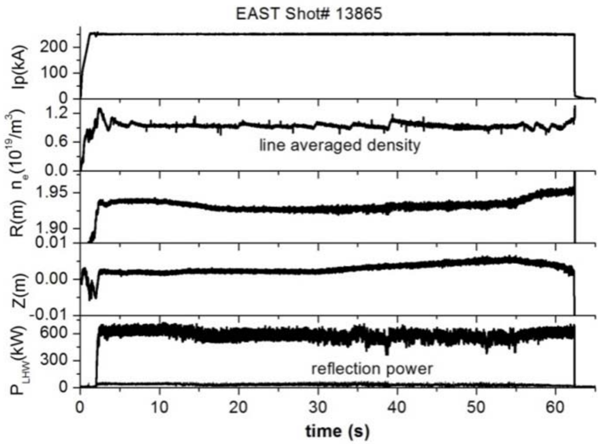
- **Two probes toroidally separated by 90°**
- **Scanning rate up to 2m/s**
- **Multi scanning in one shot**
- **Radial scanning up to 20cm**
- **Exchangeable probe head**

Long Pulse Discharges

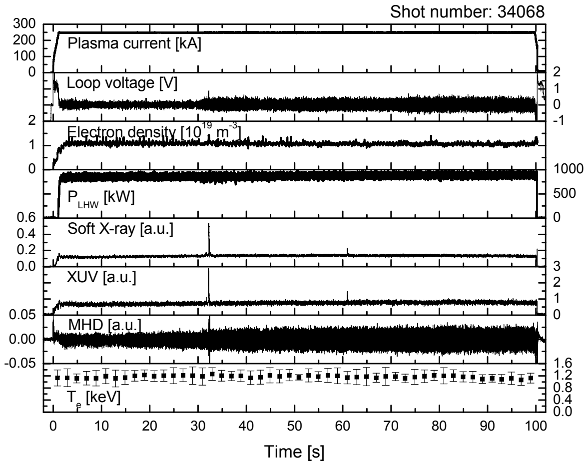
In 2008



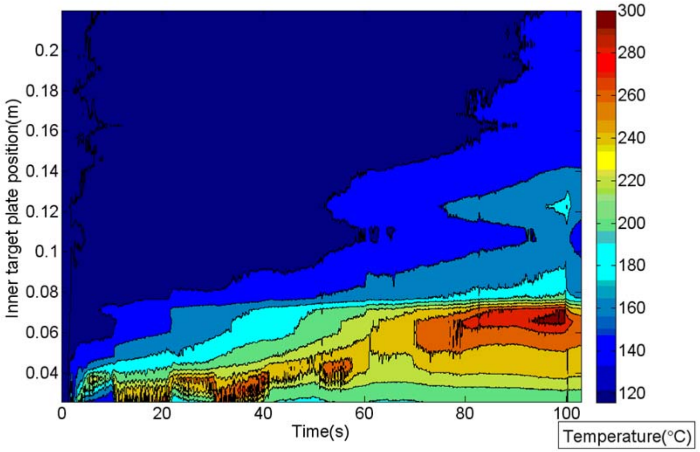
In 2009

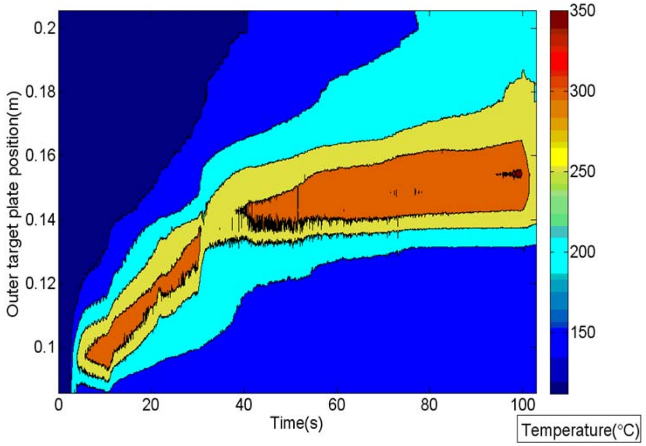


In 2010

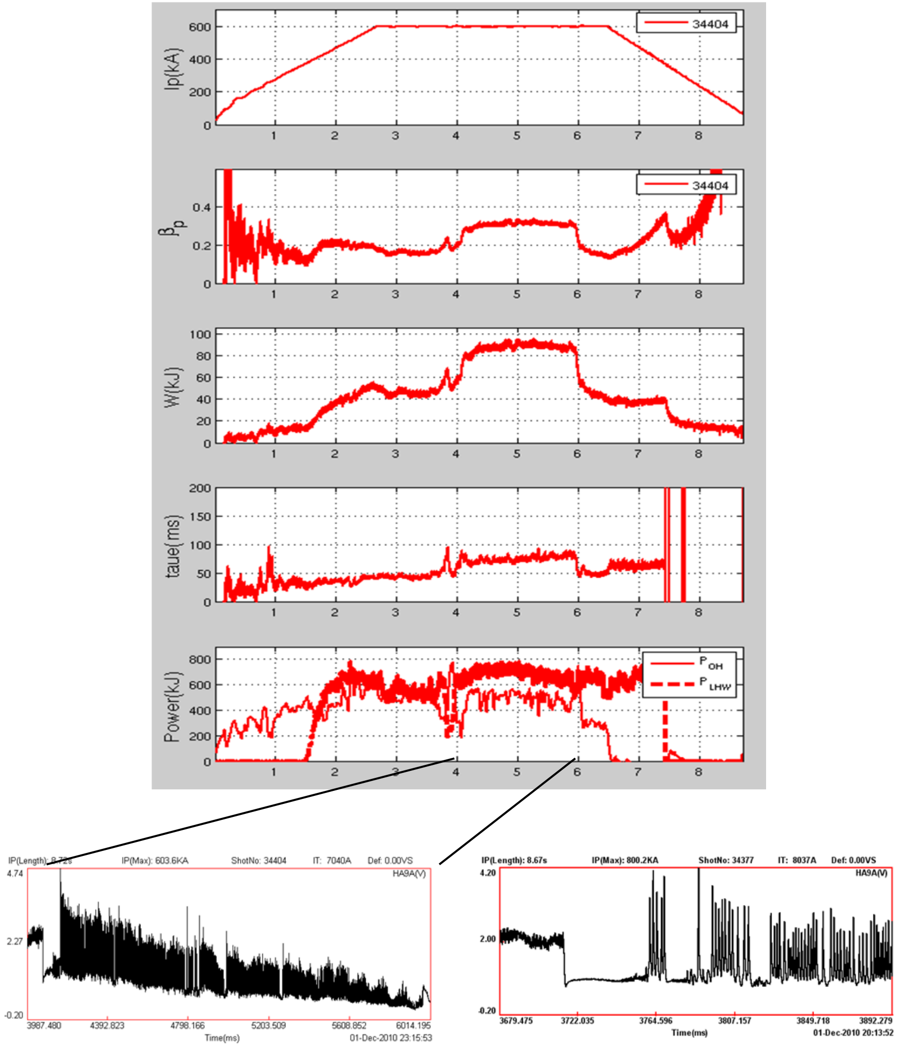


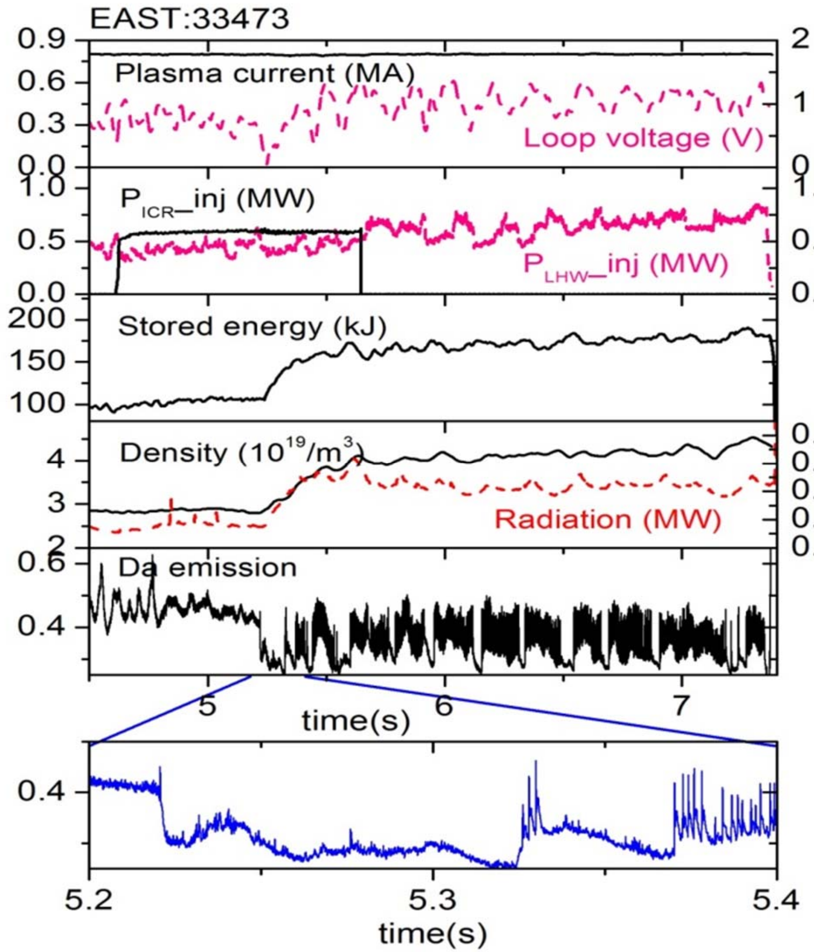
Ip~0.25MA, DN, elongation~1.8, tranigurity~0.5, It=9000A,Ne~1.2,Te~1.3keV, PLHCD~0.8MW





Stationary H-mode





I_p=0.6MA, B_T =1.55T, P_{LHW}^{inj} =1MW.
H_{89}~1.5 or $H_{IPB98,y2}$~0.9.

Ip=0.8MA, BT =1.78T, PLH=0.5~0.7MW, PRF =0.63MW@f = 27MHz, H/(H+D)~6%

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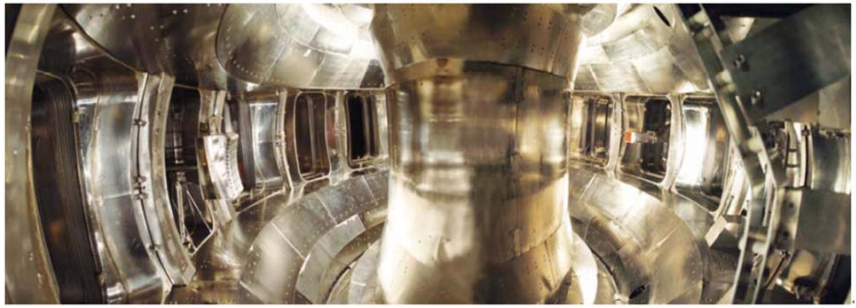
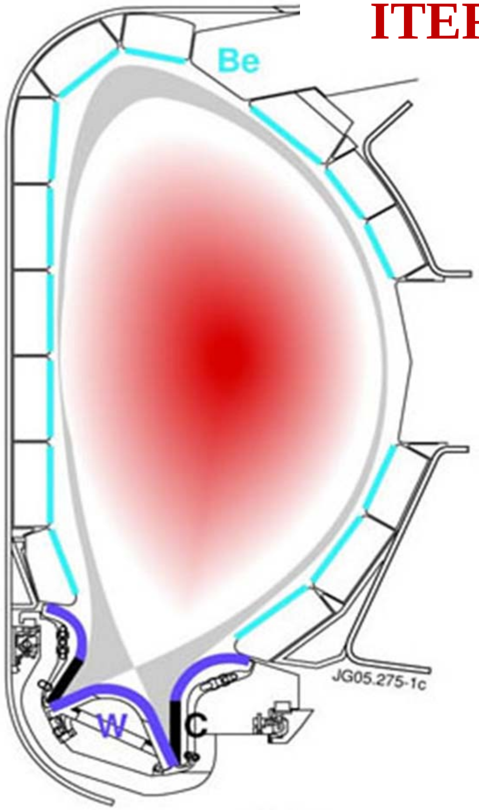
- PFC strategy for EAST
- Studies on Plasma-Wall Interaction
- Future Plan

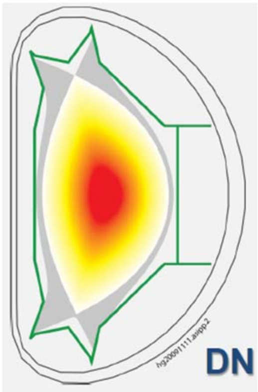
Provide a valuable information for ITER

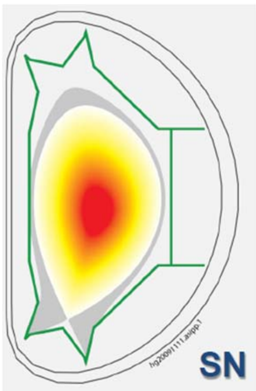
PFC strategy for EAST



ITER







Plasma-facing Materials and Components (PFMC)

- **Initial phase (2006-2007)**

  PFM ⇨ SS plates bolted directly to the support without active cooling

- **First phase (2008-2013)**

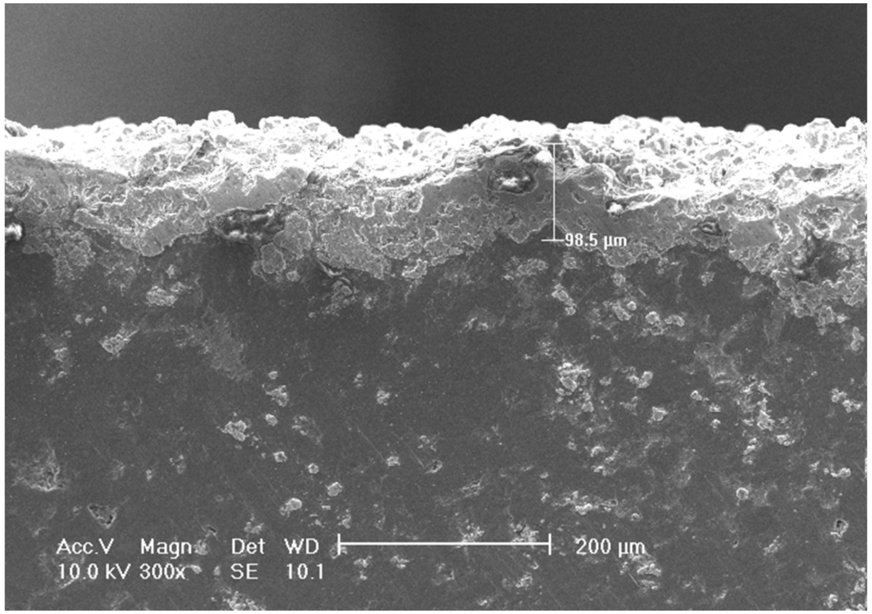
  PFM ⇨ SiC-coated doped graphite tiles bolted to Cu heat sink cooled actively, max. heat flux capability ~2MW/m^2

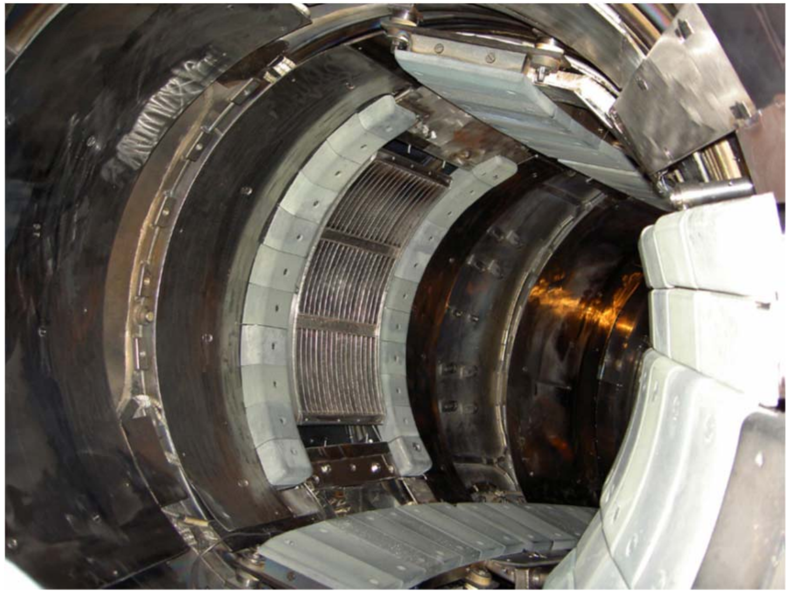
- **Second phase (2014-2016)**

  PFC ⇨ Actively-cooled W/Cu and partial W/Fe possibly, max. heat flux capability of 7~10MW/m^2

  - **Actively-cooled W/Cu divertor project launched recently at ASIPP**

SiC coatings on doped graphite



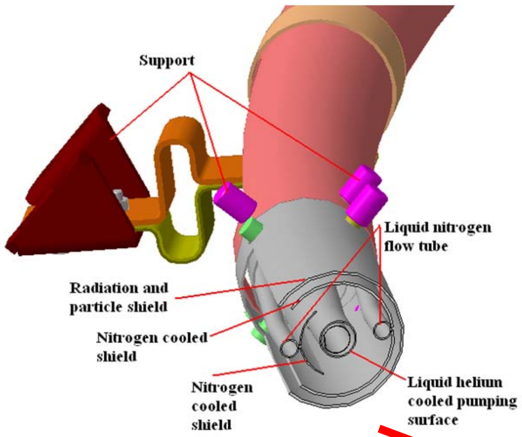


- **Thick SiC coatings**
  - **A new SiC coating technique of CVR combined with CVI**
  - **Gradient SiC coatings by the infiltration of reaction gas through open pores**
  - **Sufficient resistance against exfoliation**
- **The coatings exhibit superior surface characteristics and satisfactory thermal shock resistance**

Q. G. Guo et al., *J. Nucl. Mater.*, 290–293 (2001) 191
J. L. Chen. et al., *Phys. Scr.*, T111 (2004) 173

Key elements in-vessel

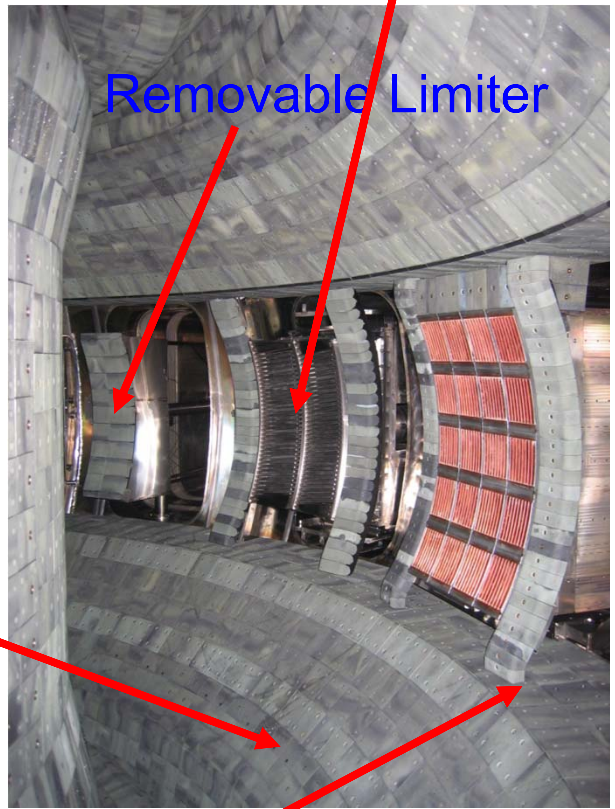
Internal Cryo-Pump



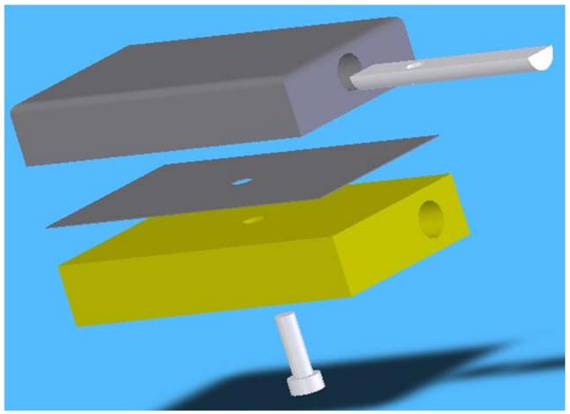
75,600L/S for D2
107,000L/S for H2

- Actively-cooled PFC (~9000 tiles)
- Internal Cryo-Pump
- **LHCD: 2.45GHz, 2MW**
- **ICRF: 30-110MHz,1.5MW**
- Magnetic sensors
- 2 Removable limiter

ICRH antenna



LHCD antenna



High heat flux region 2MW/m²

Total 37 flux loop

W/Cu-PFMC Project

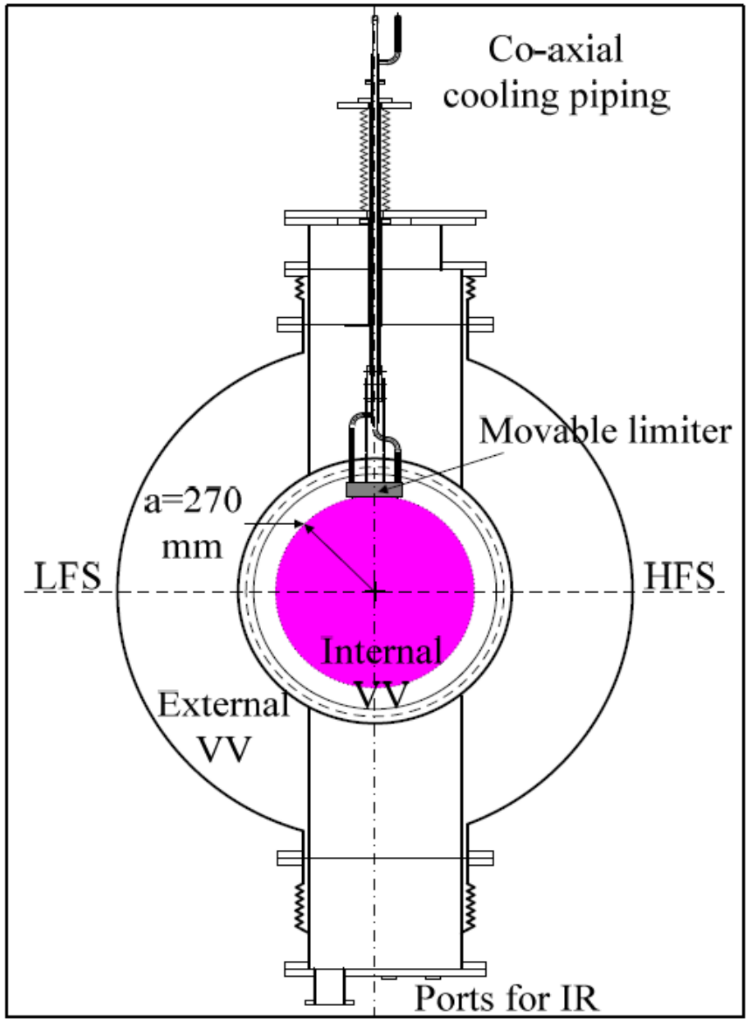
W/Cu divertor operation starts in 3-5 years
R & D issues listed below to be addressed

- **Space limitation in EAST and availability of W/Cu joining technique**
- **VPS-W coatings: thickness, microstructure, porosity, impurities**
- **W/Cu-PFC: structure design, W/Cu bonding**
- **High heat flux (HHF) testing for evaluation of PFC integrity and lifetime, validation of NDTs**
- **Non-destructive testing (NDT) for manufacturing and reception examination, e.g., IR-thermography, ultrasonic**
- **Plasma-wall interaction (PWI) studies on tokamaks/in laboratories: H/He/n radiation effects, e.g., surface modification and bulk damage, and impact on retention/recycling and service life**
- **Simulation efforts needed to get insight into the PWI effects**

Cooling and castellation structures

- PFC = W coating + Cu heat sink + support
- Cooling structure (heat sink and support)
  - Heat removal capability up to $10 MW/m^2$
  - Compatibility with available space in EAST
  - Robust structure design to achieve expected service life
- Castellation structure (PFM consideration)
  - To relieve the constraints so as to reduce thermal stress and also to prohibit spreading of cracks in the tungsten coatings
  - Compatibility with the coating processing
  - Testing of mock-ups with the structures

VPS-W/Cu PFC testing in HT-7



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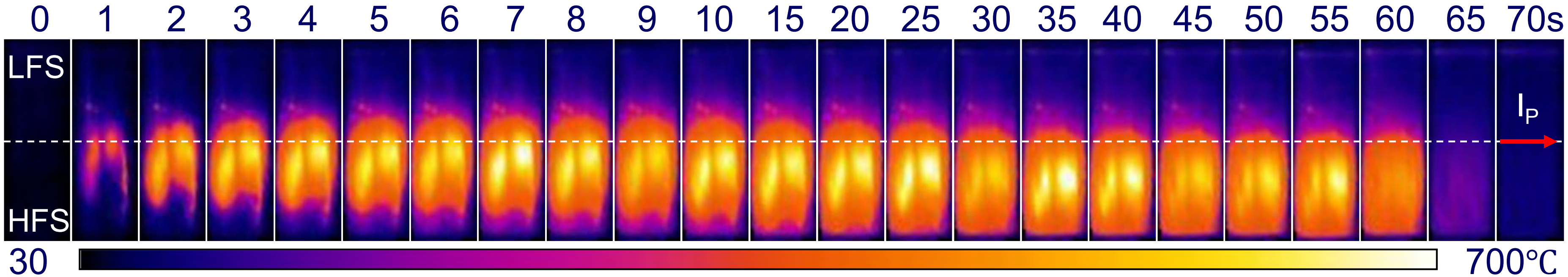
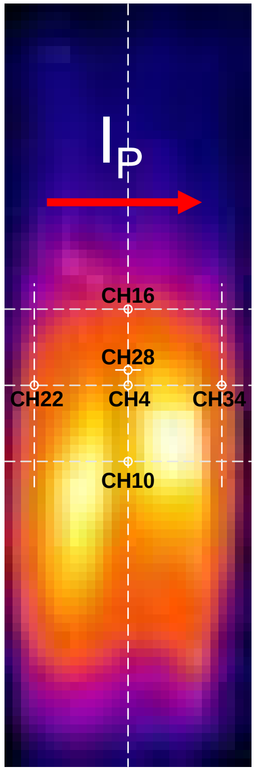
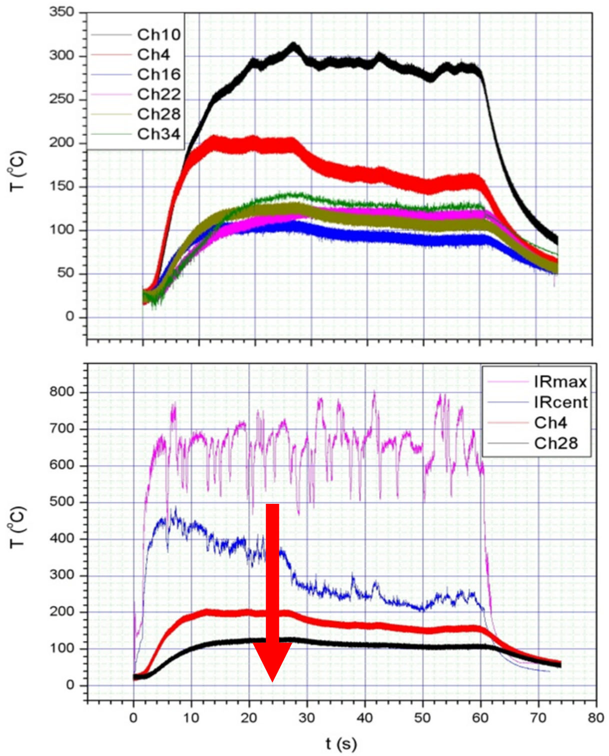
G. -N. Luo, et al., *Phys. Scr.*, T128 (2007) 1
Q. Li, et al., *Fus. Eng. Des.*, accepted

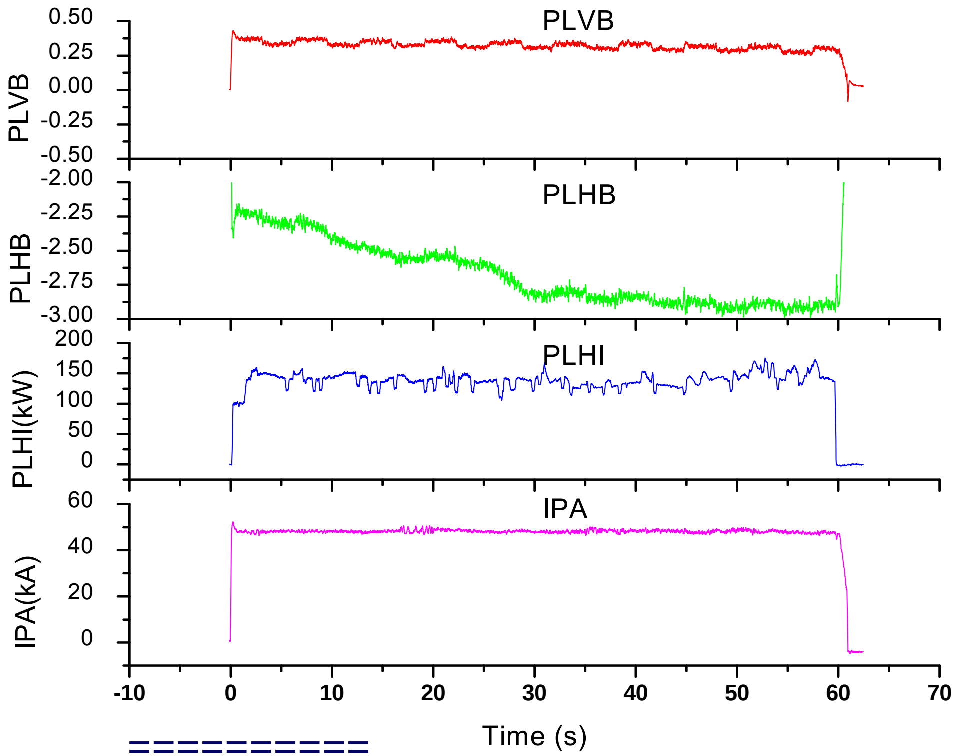
- **The limiter was inserted to the different positions of *r<a* and exposed to more than 20 pulses of OHCD and LHCD plasmas, respectively**
- **The surface and substrate temperatures monitored by an IR camera and thermocouples, respectively**
- **OHCD plasma:**
  - **I_P~140kA, n_e~$1.5\times10^{19}/m^3$,T_e~500eV,t ~0.7s**
  - **Modeling is consistent with the IR measurements: max. temperature ~65℃, a peak heat flux ~ 0.8MW/m^2,**
- **LHCD plasma:**
  - **I_P~50 kA, n_e~0.5×1019m-3, P_{LHCD} ~130kW *t*=61s**
  - **The calculated heat flux is too low to reproduce the IR data, ~700℃ and 7MW/m^2, due possibly to the fast particles driven by LHCD**

Long pulse discharge









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Provide a valuable information for ITER

RF Conditioning

1. ICR conditioning were successfully carried out in EAST, a divertor SC tokamak with metal/C walls.
2. ICR cleaning, recycling control, boronization and oxidation have been carried out and compared with GDC.
3. High pressure and RF power are favorable for removal of hydrogen and impurities.
4. Wider operation widows (EAST: 15-30kW, 10^{-4}-10Pa) and higher removing rate were obtained.
5. RF-Boronization has been routinely used for all campaigns with about 200nm thickness. 30-60 min. He RF conditioning was used for control recycling. Very good plasma performance can been easily obtained.

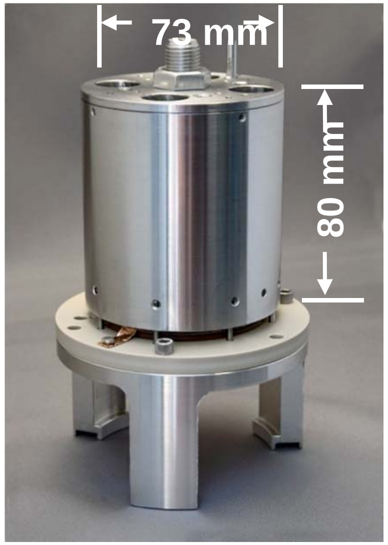
RF C antenna

He/O-ICR in EAST

1. **He/O-ICR were successfully carried out in EAST, a divertor tokamak with metal walls. O-GDC would lead arcing, and it is difficult to be controlled.**
2. **High pressure and conditioning power in He/O-ICR are favorable for removal of hydrogen and impurities.**
3. **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), which were higher than that in He-ICR by a factore of 5 and a few tens respectively.**
4. **During oxidation, C was removed by the formation of CO and CO_2 and most of hydrogen released in the form of water molecules.**
5. **Both He-ICR or He-GDC are effective way to remove oxygen.**
6. **Both O-RF and O-GDC could lead contamination on various materials (W\Pure Graphite\Deposits\SS\Silicon).**

Li Wall Conditioning

EAST



- Li Oven: RF coating (10-60g)
  - •Evaporating
- Li power dropper

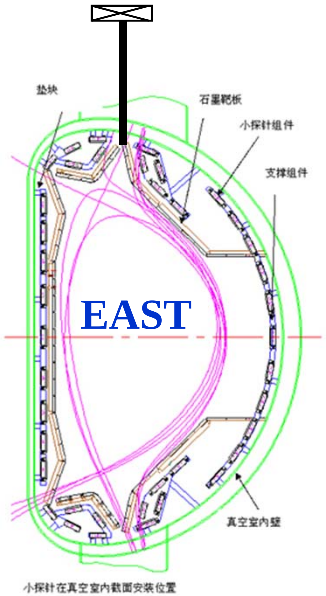
•Main Results:

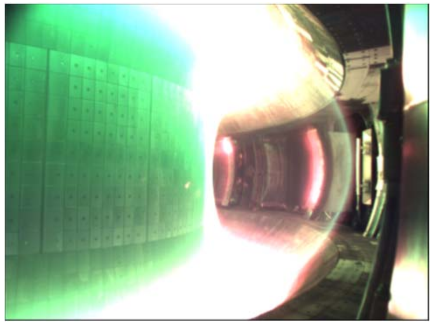
•Very good and quick technique

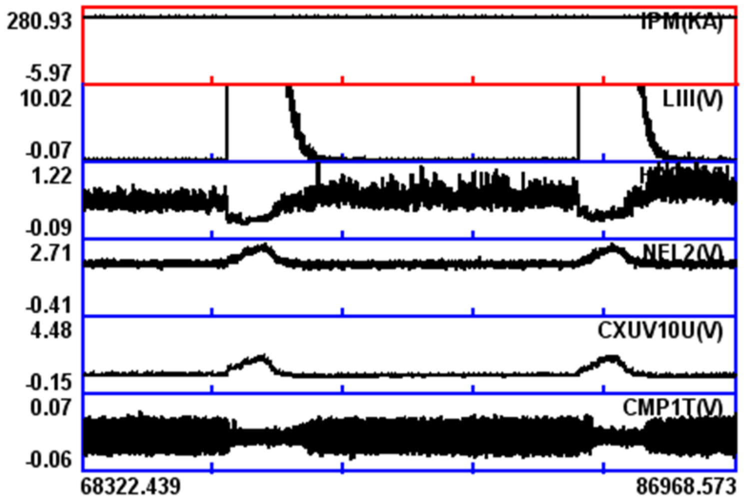
•Z ~ 1.5-2.5

•More broad Te and radiation profile

•Low recycling



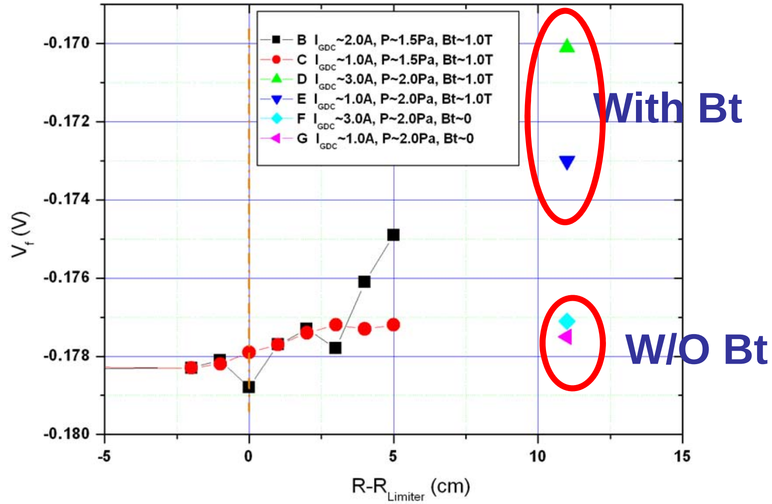




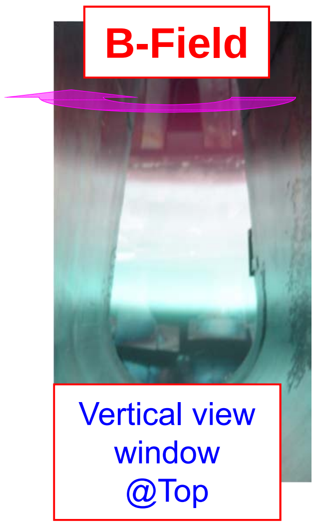
MHD was suppressed, Lower recycling.

New Method : HF_GDC

•Power Supply : U=1.0KV , f=100KHz , I~0.5-1.0A
•Work Gas : Ar , He , H2.
•GDC electrode
•HT-7: 5x10-4Pa-0.5Pa, Bt=0.5-2



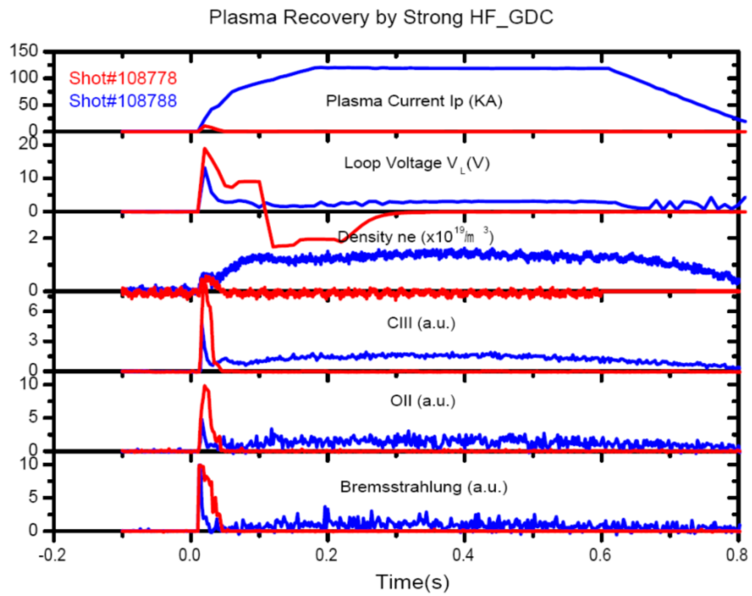
HF-GDC is routinely used in HT-7 for wall conditioning, siliconization and recycling control between shots which shows almost the same effects with RFWC.



P=5.0E-2Pa, IGD=1.0A, Bt=1.0T, He

P=5.0E-2Pa, IGD=1.0A, Bt=1.0T, H2

P=5.0E-4Pa, IGD=1.0A, Bt=1.0T, He



Recovery from 10Pa leakage

Helicon wave conditioning

Flat Spiral antenna

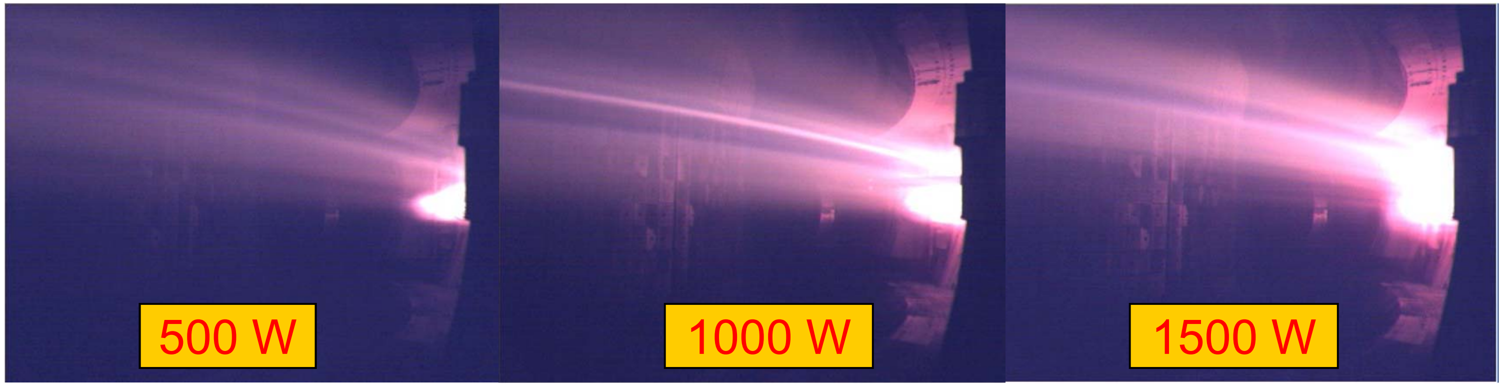
Helicon Antenna

Mixed Antenna

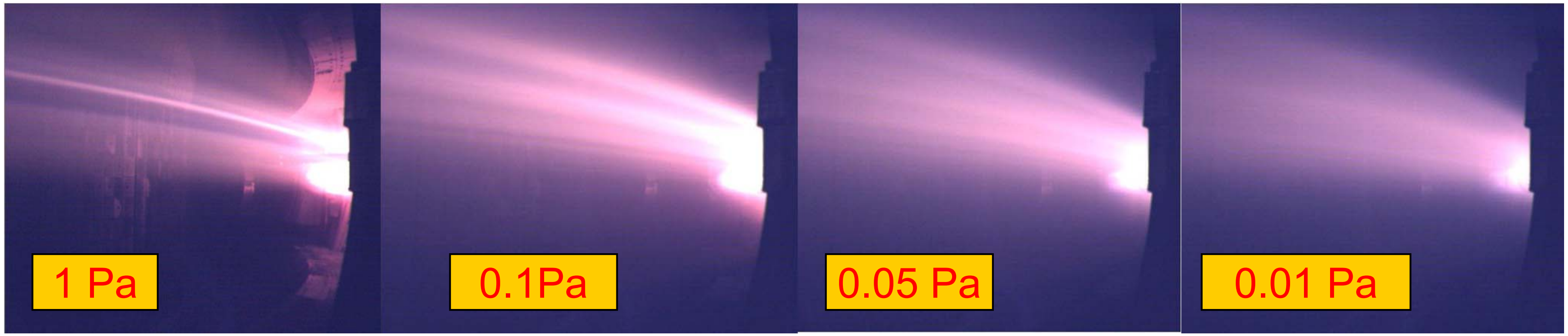
First Try

EAST

F=13.6MHz, P=0.5-2kW, Bt =0.5-2T



BT= 2T, P= 0.1 Pa



BT= 2T, P= 1kW

Divertor Physics Experiments

- **Assessment of basic divertor plasma behavior**
- **Effect of divertor configurations *– Comparison between single null and double null***
- **Divertor asymmetry and drift effects *– Comparison between normal and revered toroidal fields***
- **Effect of gas puff locations on divertor asymmetry and fuelling efficiency**
- **Divertor screening for intrinsic carbon by CH_4 puffing**
- **Active control of divertor heat flux by Ar puffing**
- **Effect of divertor cryopump**

Search for div. operational scenarios relevant to SSO

Divertor Plasma Detachment Was Clearly Demonstrated on EAST by density ramp-up

Sheath-Limited

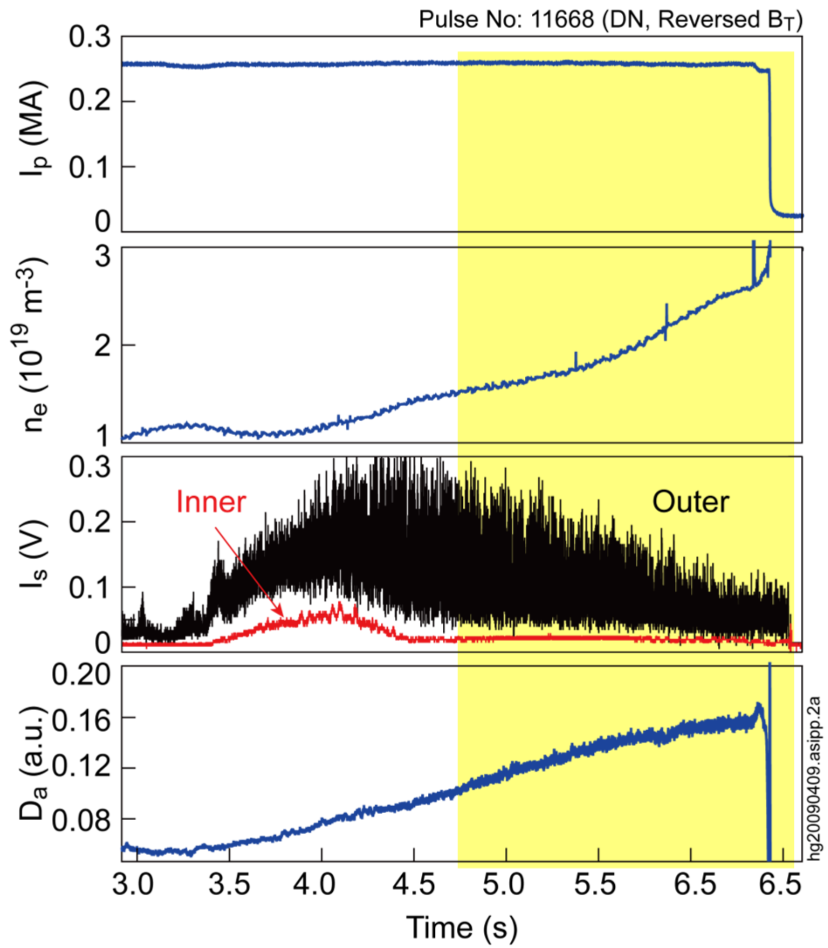
- **Ion saturation current I_s (particle flux) increases with density n_e**

Conduction-Limited

- **I_s further increase until roll over**

Detachment

- **Particle flux starts to decrease as n_e increases**

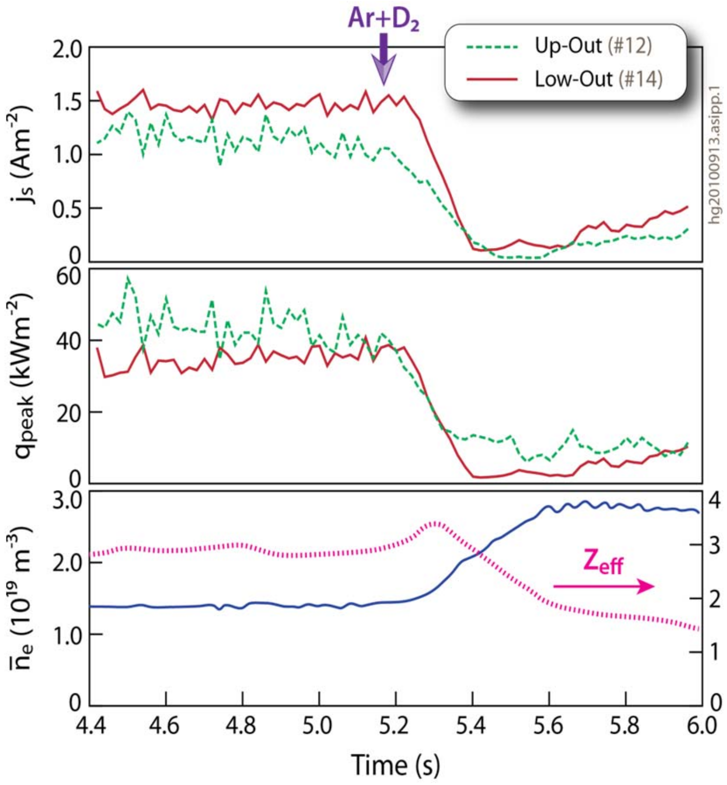


Plasma detachment reduces peak particle & heat fluxes, as well as associated material damage, essential for steady-state operations.

Effect of Ar:D2 mixture gas injection into upper and lower outer divertors

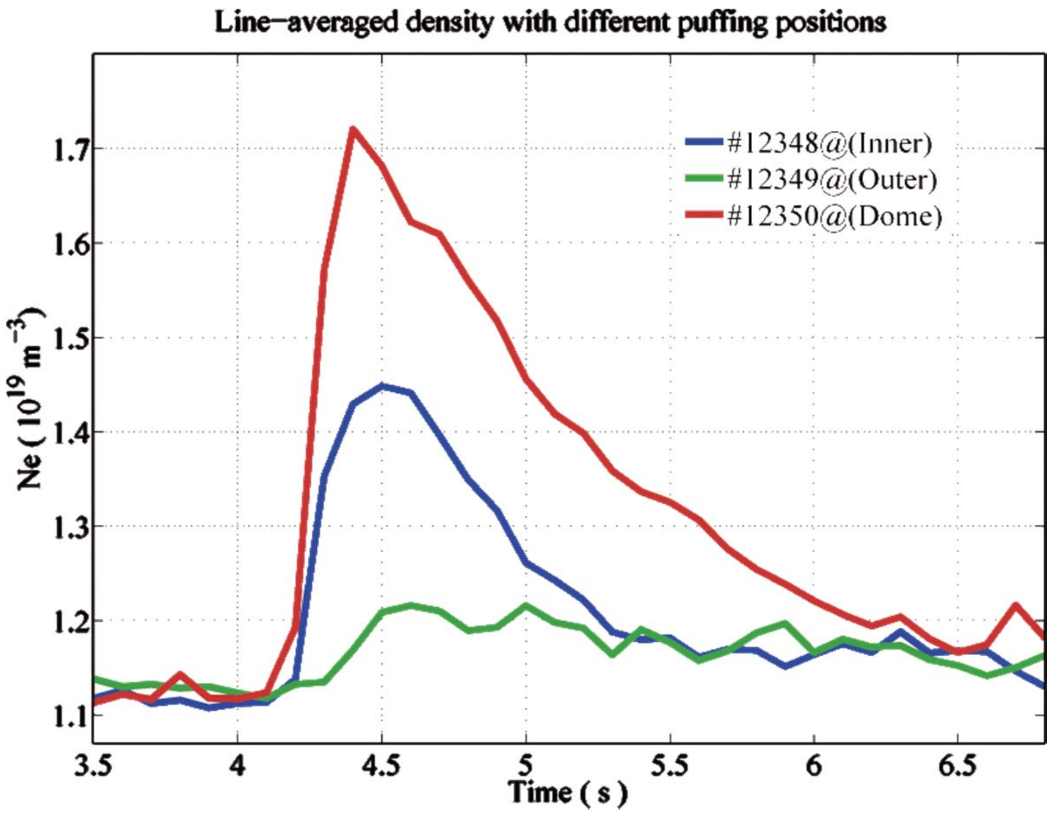
EAST adopted ITER-like vertical target configuration, which promotes detachment near strike point. However, this scenario by density ramping is not fully compatible with LHCD and high confinement scenario, radiative divertor is required.

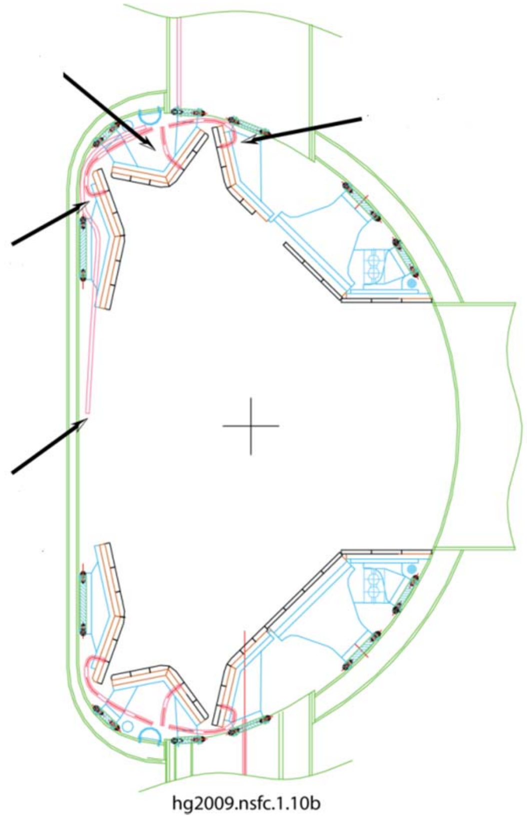
- **D2+5.7% Ar mixture puffing was initiated at 5s led to detachment at both upper and lower outer divertor targets**
- **significantly reducing the peak heat fluxes, q_{peak}, near outer strike points**
- **Zeff is reduced**



Ar puffing in divertors promote partial detachment and reduce peak heat flux

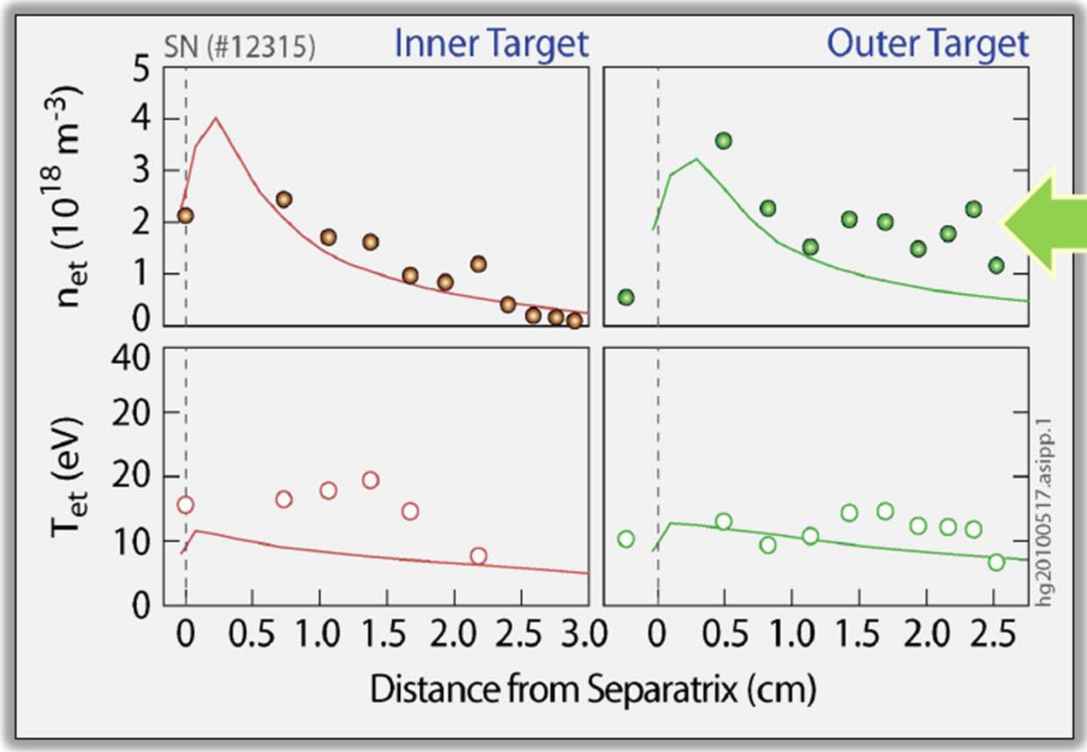
Effect of Gas Puff Locations





DOME D_2 puffing has highest fuelling efficiency, less from inner target plate, lowest from outer target plate. Compared to SN configuration, DN is more sensitive to gas puffing location.

Comparison with Initial SOLPS-B2/EIRENE modeling

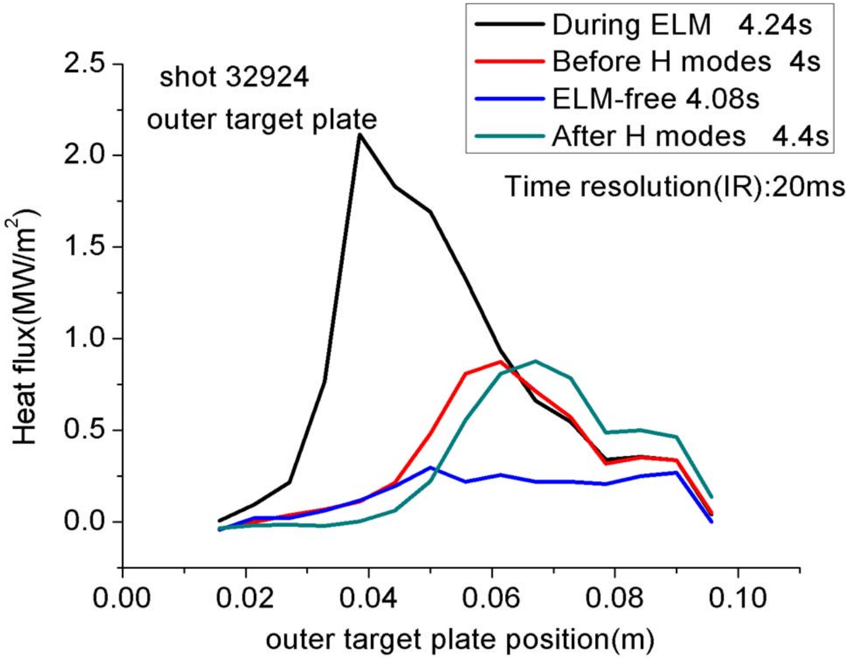


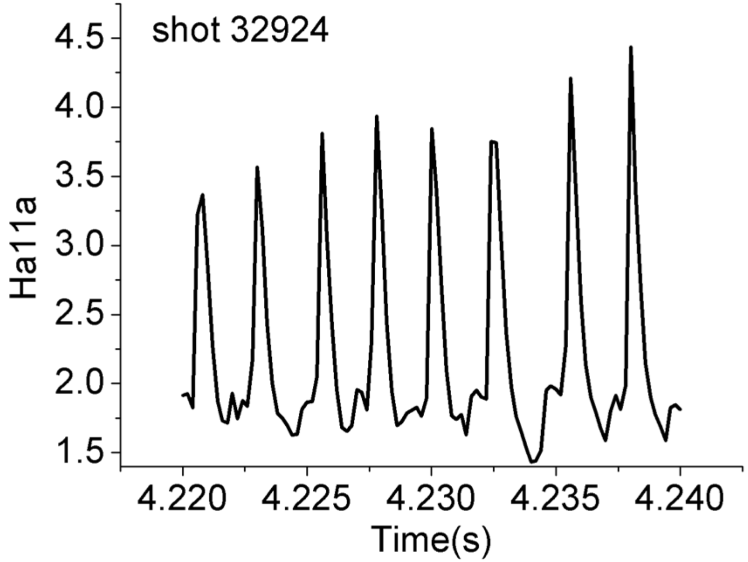
Density decays much slower in outboard SOL, possibly arising form enhanced radial transport by turbulence

- SN – Normal B_T, P_s = 0.25 MW with $P_i = P_e$, $n_s = 5\times10^{18}$ m^{-3} ~ ½ $<n_e>$
- $D_\perp$ = 0.5 m^2/s, $\chi_i = \chi_e$ = 1 m^2/s
- Carbon: Phys. + Chem @ 0.5eV, w/ Y_{ch} = 2%

Target heat load during ELM

ASIPP

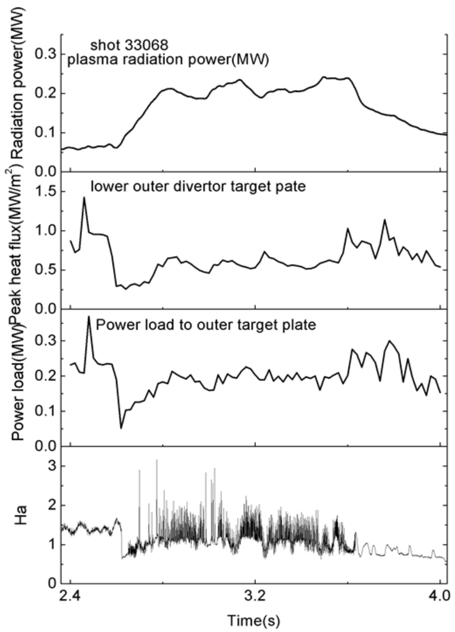


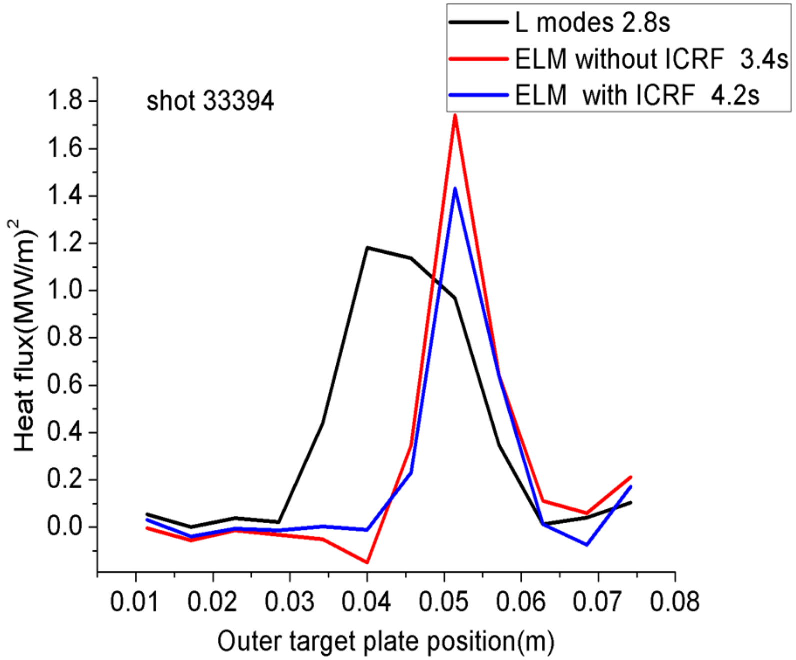


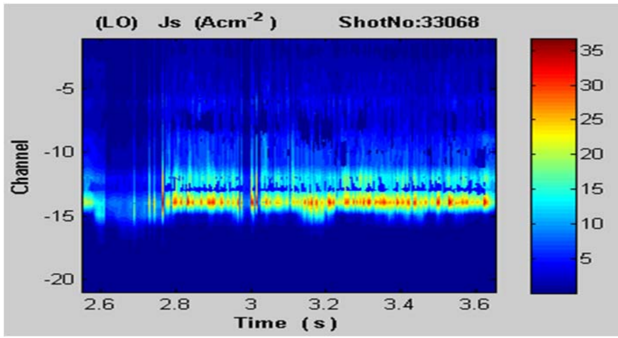
For Type I ELM, ΔWj is about 2KJ

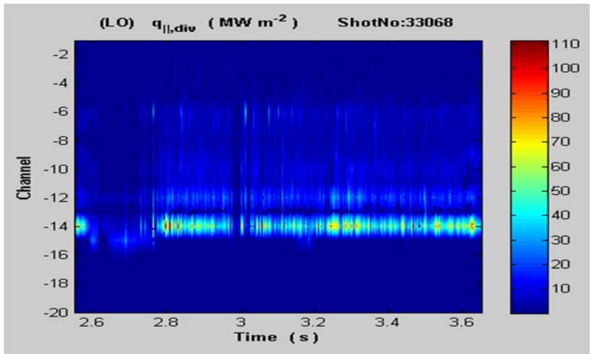
ASIPP

DN Type III ELM









Dust during plasma discharges

EAST

•Dusts were observed by CCD camera due to unfavorable position control.

•Most dust in tile gaps, SOL zones at low field sides, windows tubes…

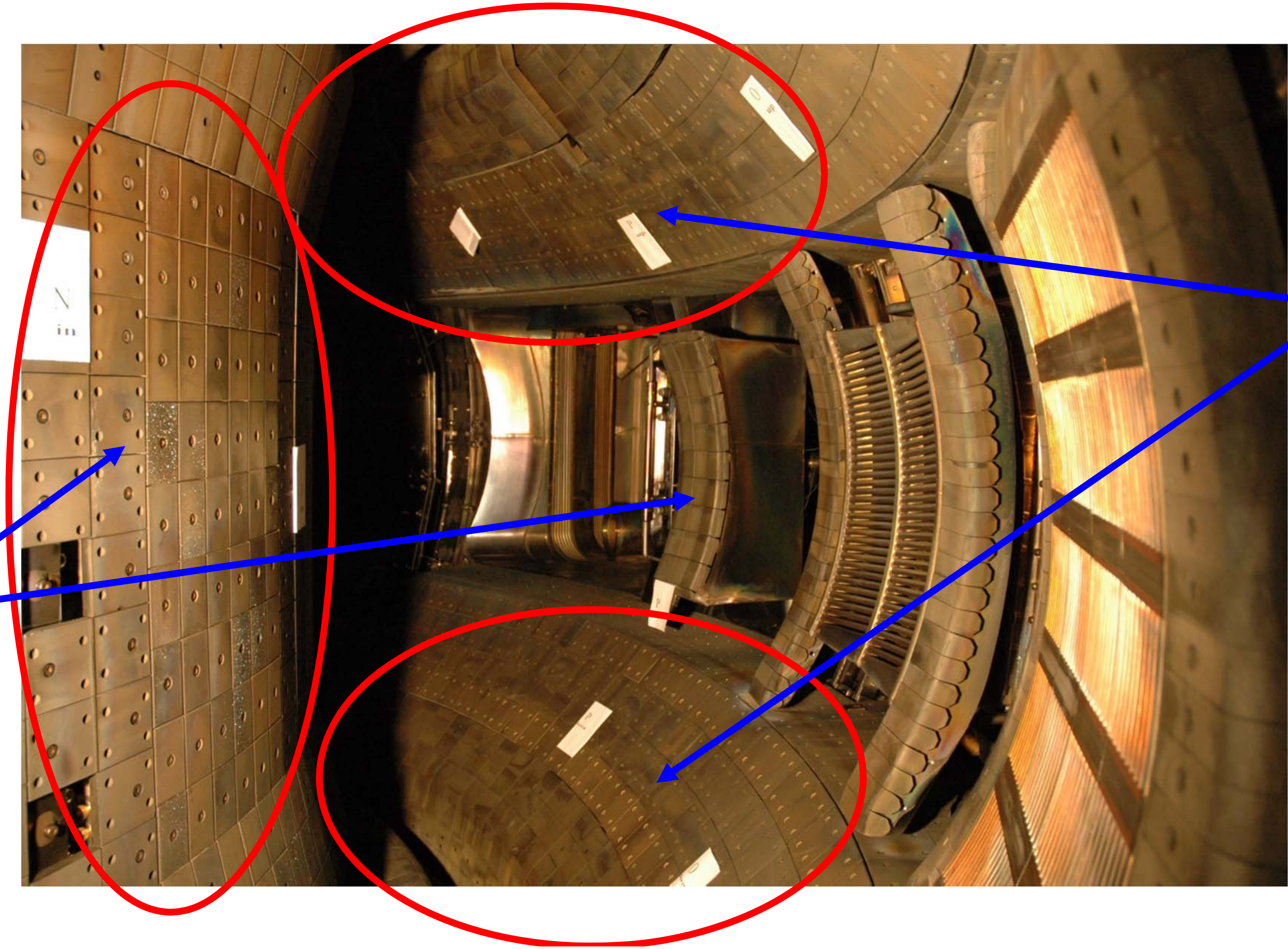
•Total collected dust was 4.05g.

•~1mg/shot.

Erosion/Deposits on walls

EAST

erosion on tiles



deposition on some tiles

A first wall migration study on EAST

R. A. Pitts, S. Carpentier-Chouchana, X.Gong, P. C. Stangeby, W. R. Wampler

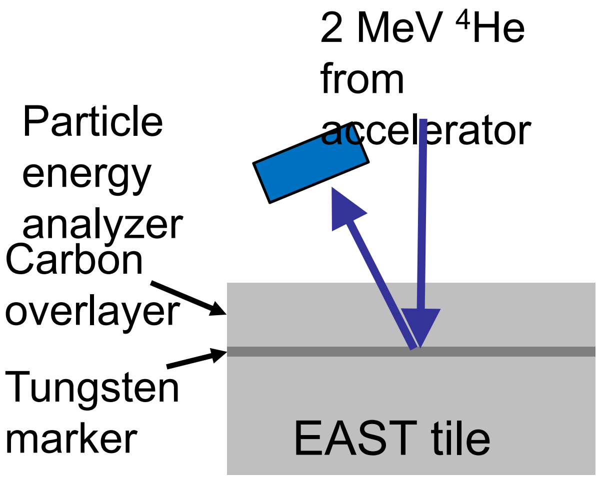
4 spare tiles available for start-up limiters

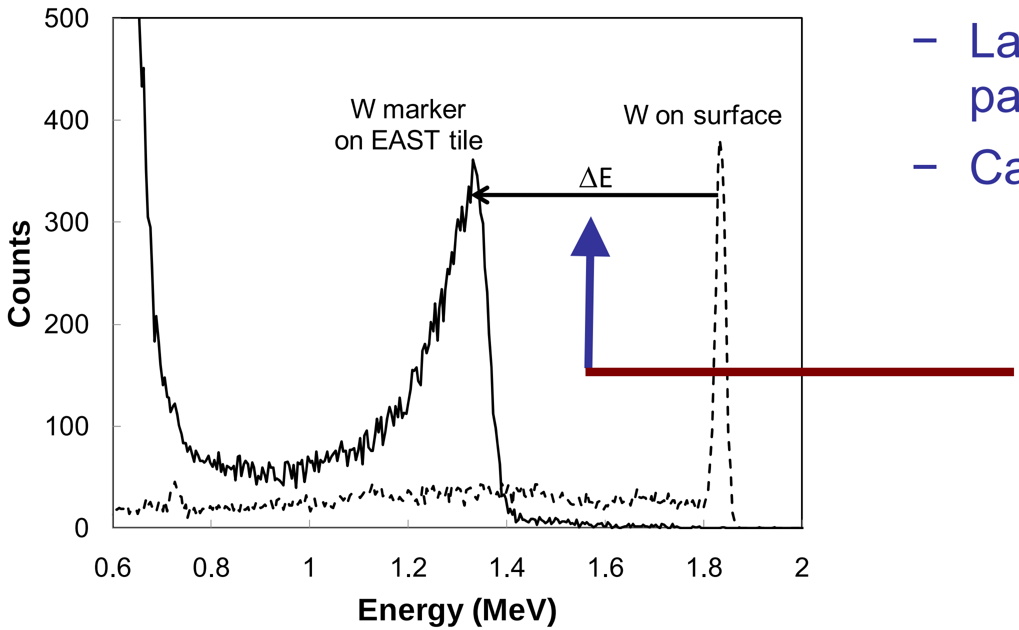
- Never been exposed in the tokamak
- Doped polycrystalline graphite with SiC surface layer (GBST1038, 1%B, 2.5% Si, 7.5% Ti))

Proposal by W. R. Wampler to try wide area W depth markers for erosion/re-deposition study

- Thin W layer (~2 nm)
- Covered with ~1-2 μm deposited C layer
- Some testing required because of SiC layer
- Work performed at Sandia
- Dedicated, later experiment will use new manufactured graphite without SiC

Erosion/deposition EAST tiles will be measured by RBS



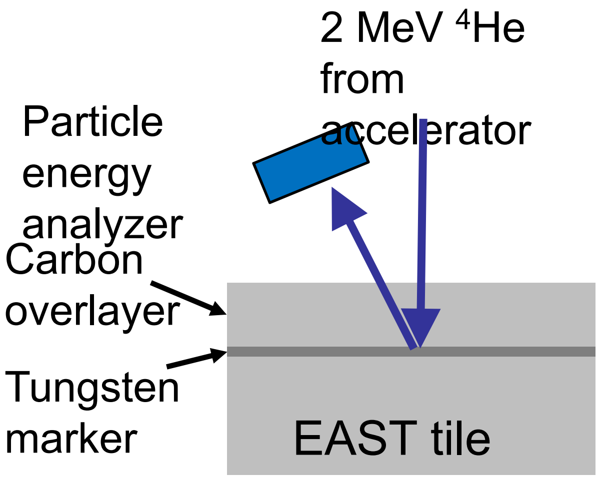


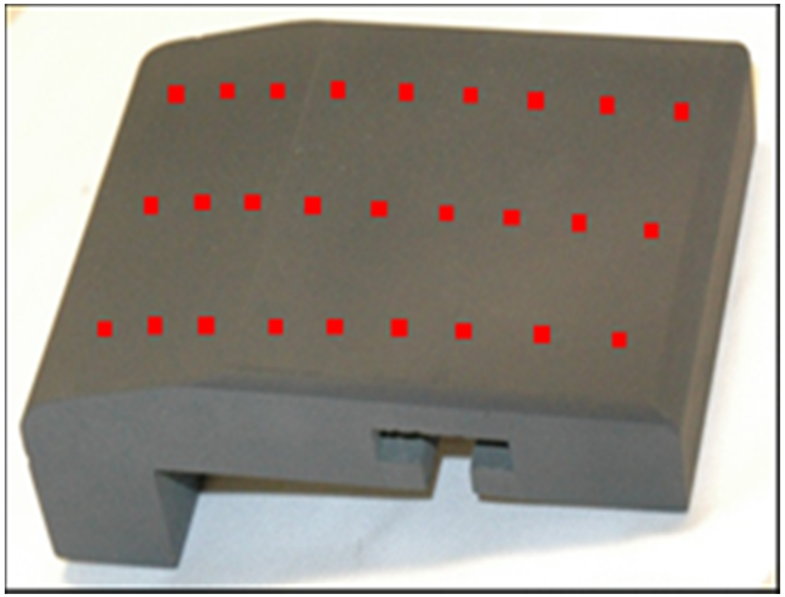
Vapour deposition → W depth marker ~1 nm thickness then C layer ~1 μm

- Tiles annealed at 500°C prior to deposition (to ensure clean surface) then to 700°C afterwards
- 2 tiles treated at once
- Layers less thick than requested on one pair
- Can use Si as depth marker if required

Carbon thickness determined from energy loss

Erosion/deposition EAST tiles will be measured by RBS





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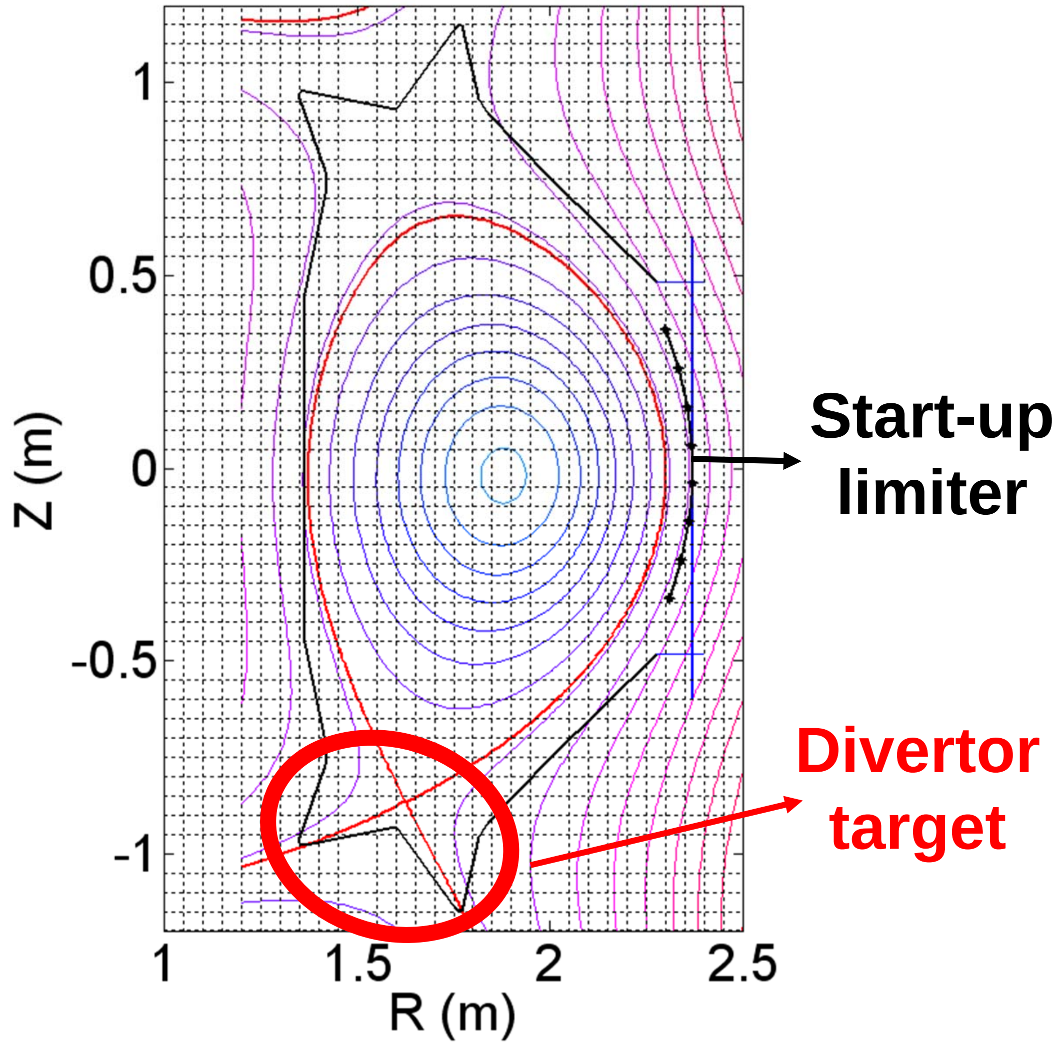
RBS spectra taken at 27 points on each tile

- Erosion/deposition determined from change in depth of W marker to resolution of 50 nm

ERO for EAST Tokamak

EAST geometry implemented into ERO ➡ ERO-EAST code



ITER-like configuration

Erosion & Deposition

ITER Prediction :

Target lifetime &

Tritium retention

Outline

- Present state of EAST
- PFC strategy for EAST
- Studies on Plasma-Wall Interaction
- **Future Plan**

Provide a valuable information for ITER

EAST 5 year Plan

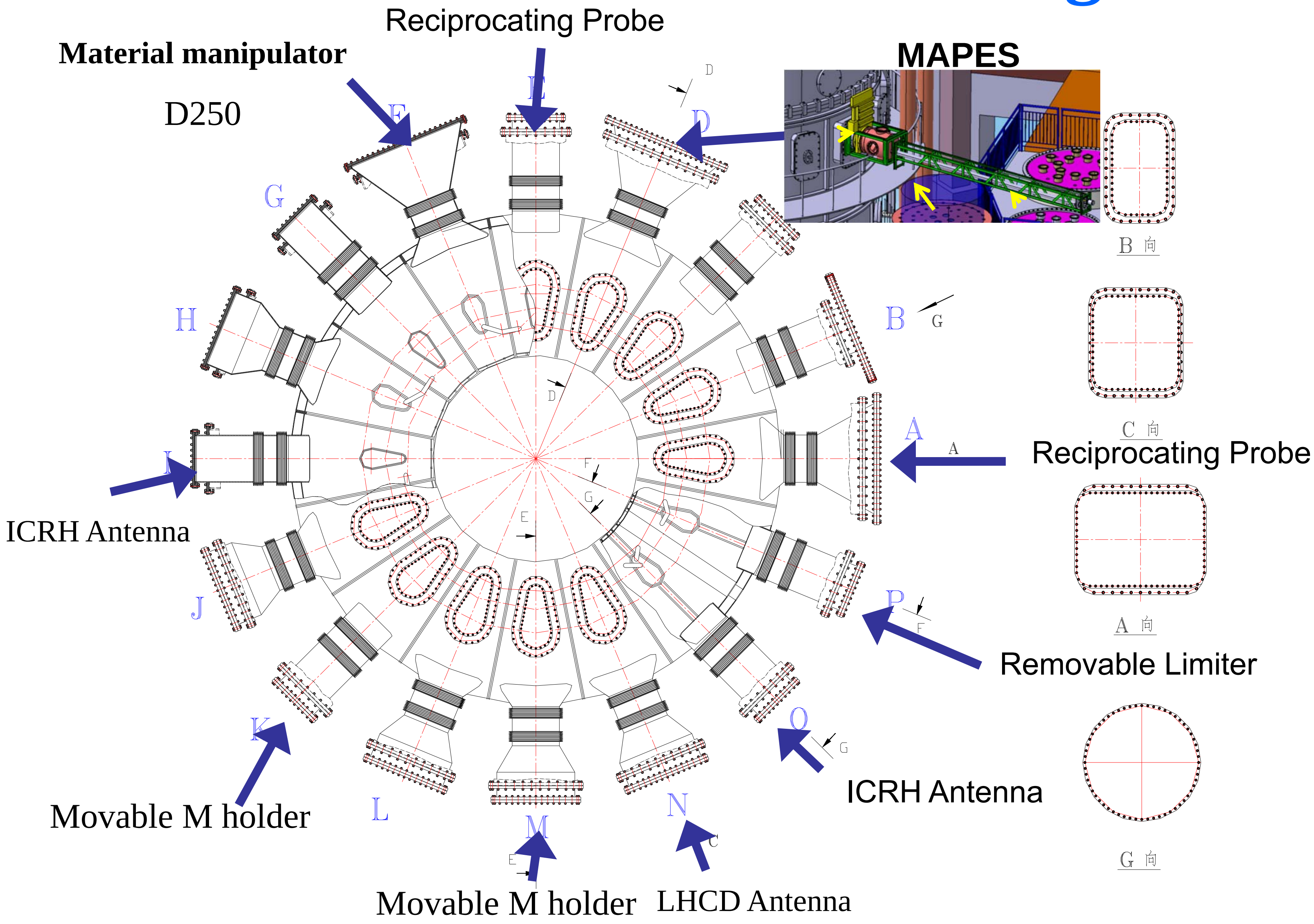
	2011	2012	2013	2014	2015
Ip(MA)	1.0	1.0	1.0	1.5	1.5
LHCD(MW, CW)					
2.45GHz	4.0	4.0	4.0	4.0	4.0
4.6GHz			6.0	6.0	6.0
ICRF(MW,CW)					
20-75MHz	4.5	4.5	4.5	4.5	4.5
30-100MHz	1.5	4.5	4.5	4.5	4.5
NBI(80keV)			4.0	4.0	4.0
ECRH(140GHz,cw)		2.0	4.0	6.0	6.0
Diagnostics	40	45	50	50	50
Duration(s)	100	200	300	400	400
t-Hmode(s)	10	20	30	60	100

With over 20MW CW power and 50 diagnostics, EAST could play a key role for long pulse advanced high performance plasma for ITER within next 5 years

Plasma wall interaction in Long Pulse AT operation

- **Understand flows and exchanges of fuel and impurity particles between plasma and facing materials for fuel and impurity control.**
- **RF wall conditioning techniques in divertor devices for ITER (cleaning, isotopic control, boronization).**
- **Develop RF Tritium removal techniques that could be applicable to ITER.**
- **Steady-state erosion and redeposition.**
- **In-situ control of T-codeposition and migration by surface temperature control.**
- **Life time of graphite and W under SSAT operation.**

Plan For Material testing



Summary

- EAST starts operation after successfully completing the construction and commissioning.
- It will be very challengeable for 1MA/1000s 10MW/m2 operation. PWI under steady-state will play a the key role.
- Helps and suggestions are welcomed and highly appreciated.
- EAST will be a good facility to test your ideals.

Thanks