Recent Progress of EAST Tokamak

P.Fu, J.Li, YT.Song and EAST Team

SOFE, June 27-30, 2011

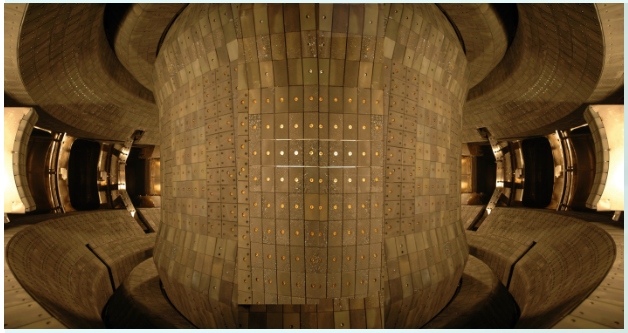
Outline

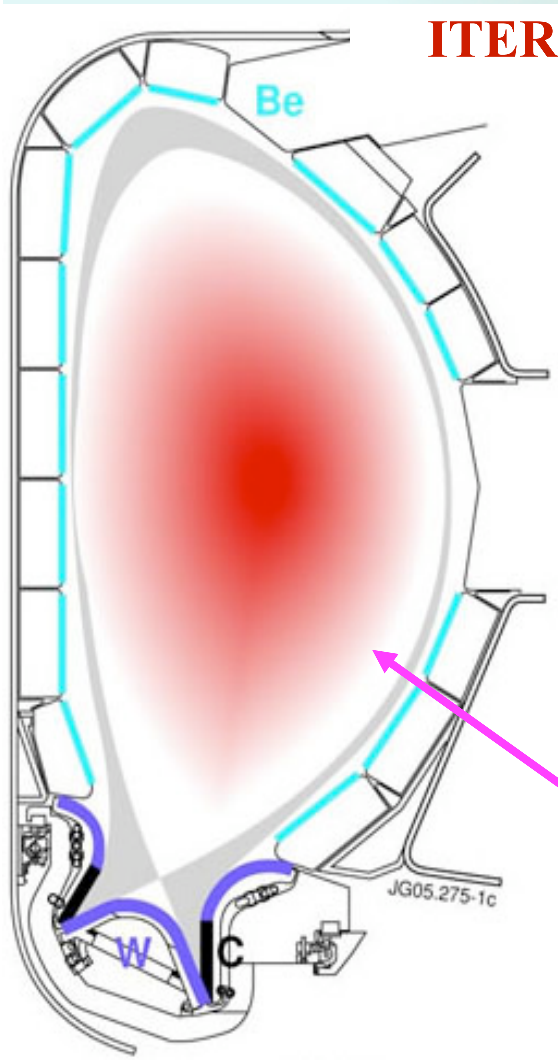
- Technical Improvements
- Current Capabilities
- Physics Achievements
- EAST Research Plan in next 5 years
- Summary

Mission of EAST

- Play the key role for understanding advanced SS plasma physics.
- Provide valuable data bases for ITER and DEMO under SSO condition.

Target: 1MA steady-state operation with 20-30MW CW Heating & CD power and more than 50 diagnostics .



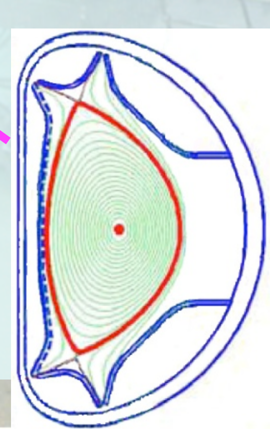


PFC strategy for EAST

Inertial full metal (SS)

Actively-cooled C

Actively-cooled W



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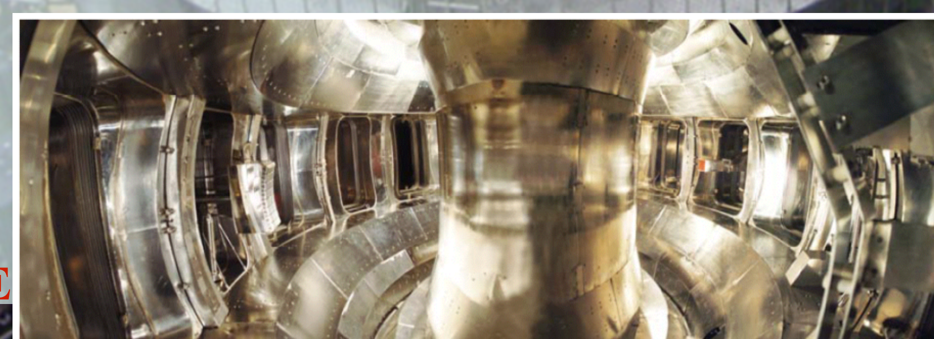
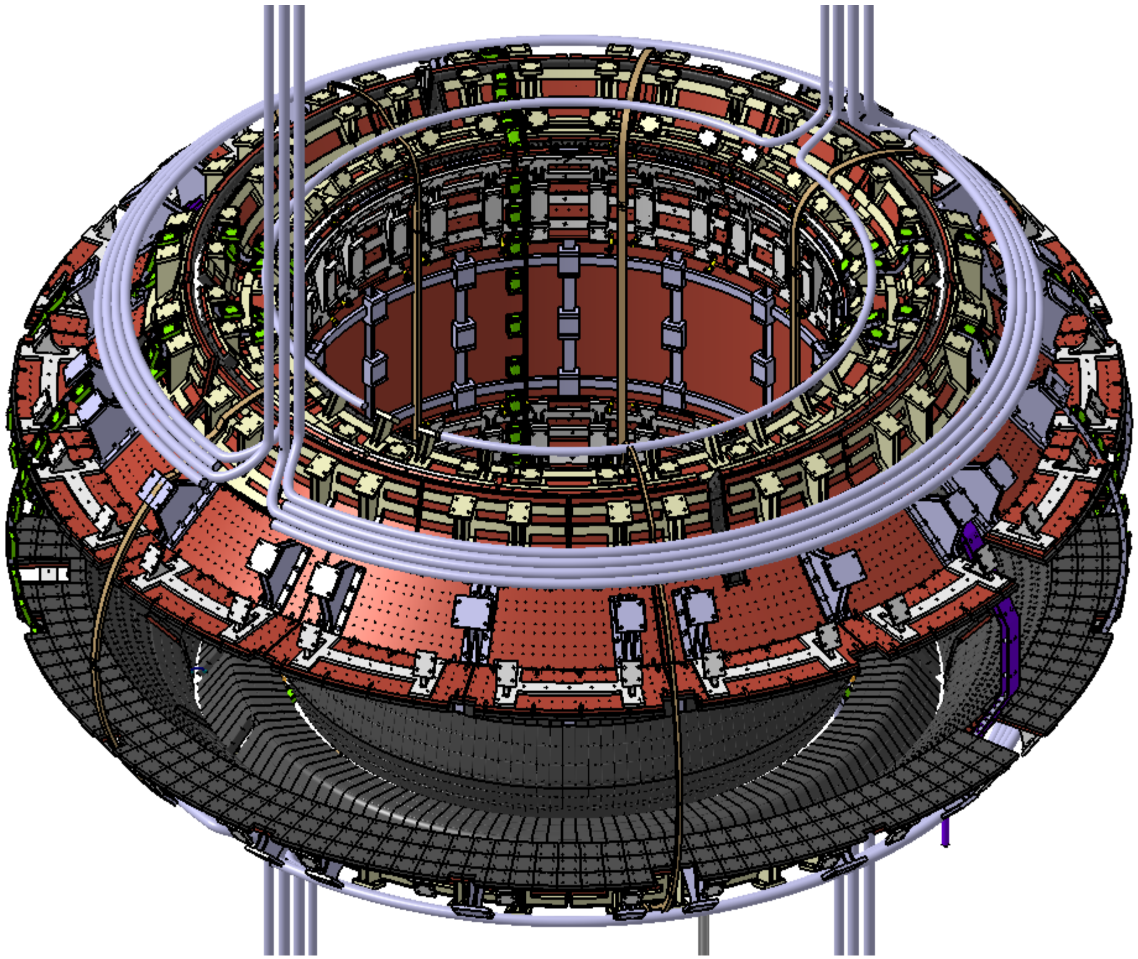


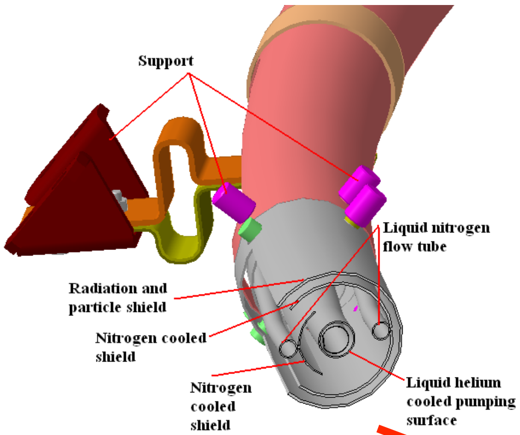
Integration of PFC



- Magnetics
- Cryo-pump
- Thermal couple
- Water cooling
- Anodes of DC GD
- Internal coils
- RF antenna
- Poloidal limiters
- Divertor probes
- Support structures
- Heat sink
- Graphite titles

Key elements in-vessel

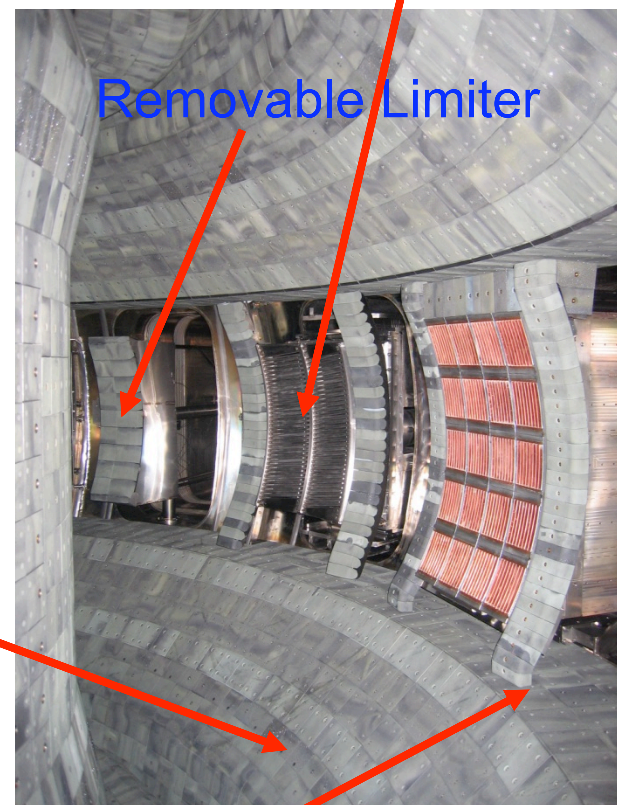
Internal Cryo-Pump



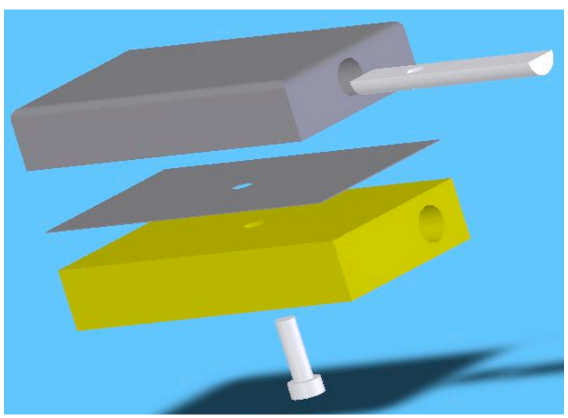
75,600L/S for D2
107,000L/S for H2

- 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

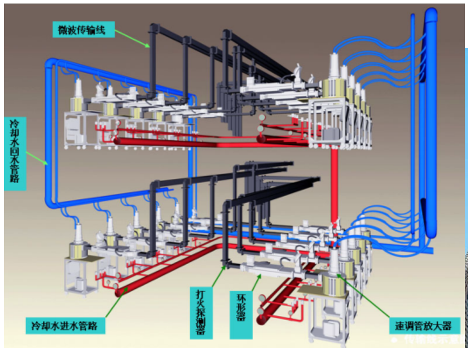


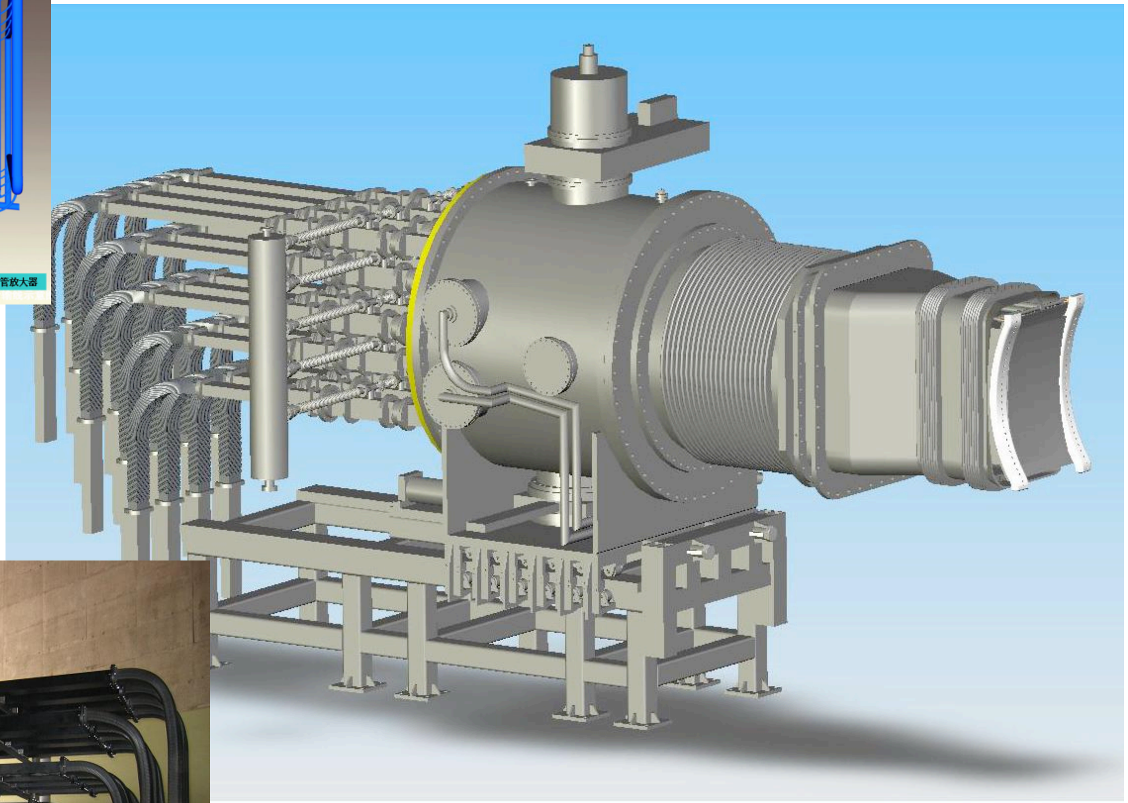
High heat flux region
2MW/m^2

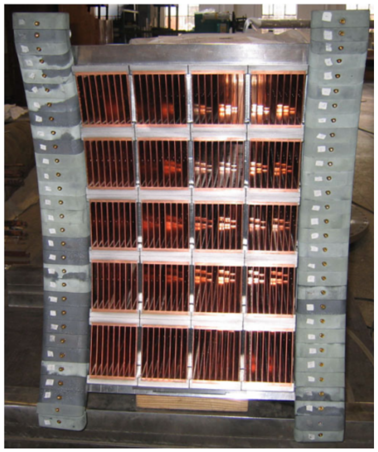
Total 37 flux loop

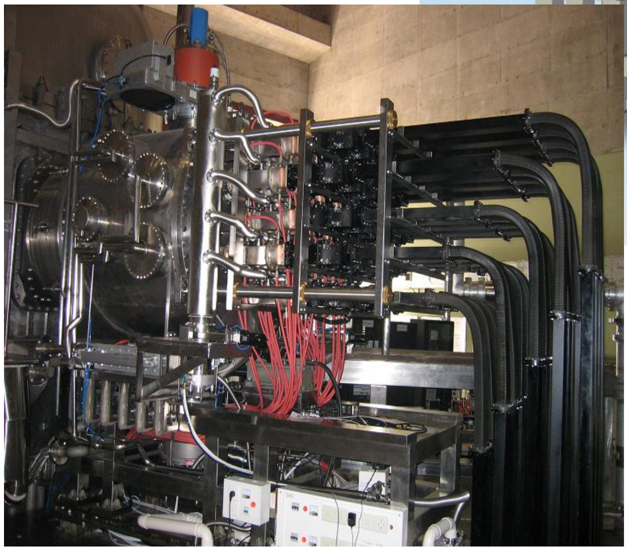
CW LHCD system

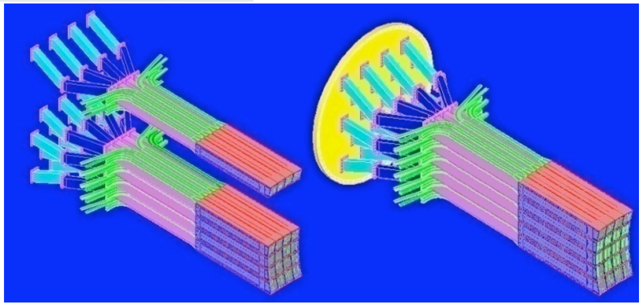
2MW，2.45GHz, n=1.8-2.4





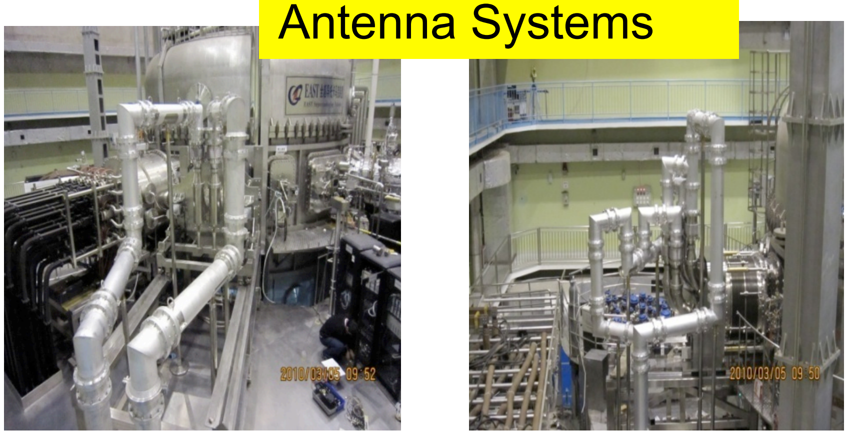






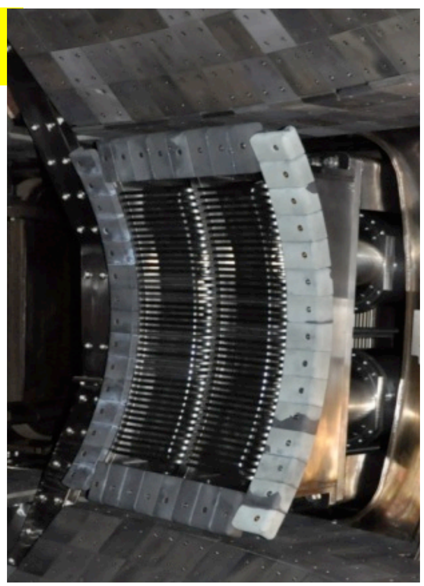
ICRH System On EAST

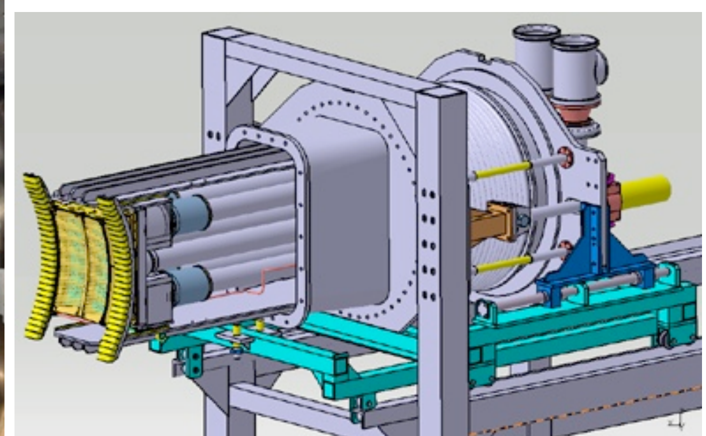
Antenna Systems



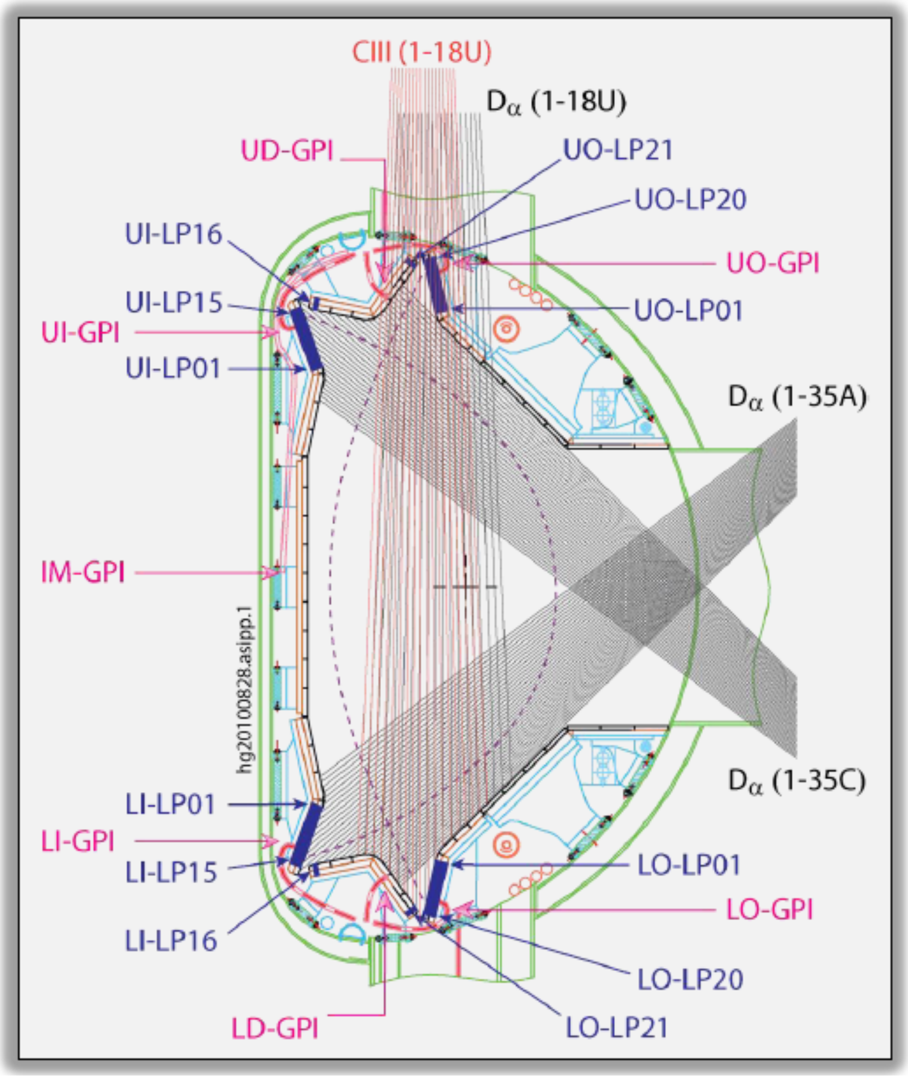
- Total RF Source: 6MW
- 2 antennas, each at 3 MW, 25-70 MHz

RF Systems





Main diagnostics (~40)



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.

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

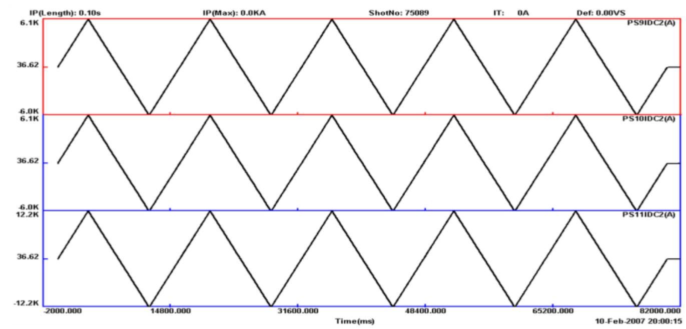
Ipf max = 14.5kA

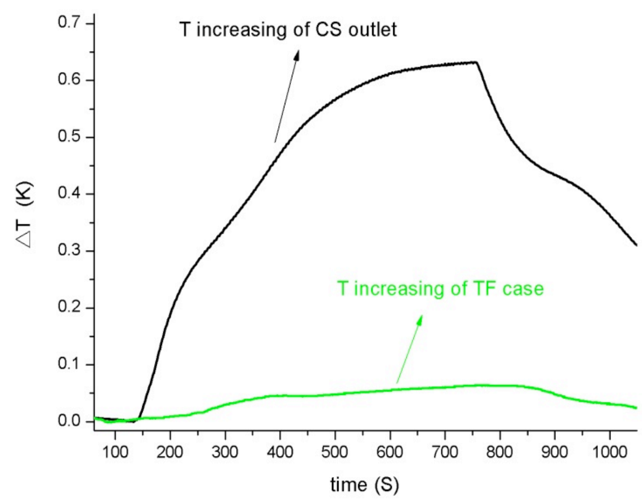
Capable: Ip=1MA, B_T=3.5, 1000s

3.6K: I pf max = 18kA, Tested

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

PFC: 2MW/m2, CW





Simulating 1MA/1000s/4.5K,

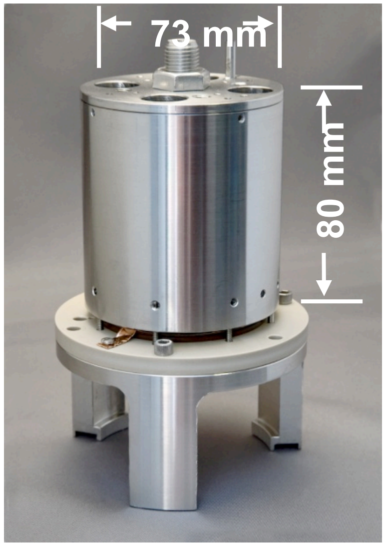
RF Conditioning

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.

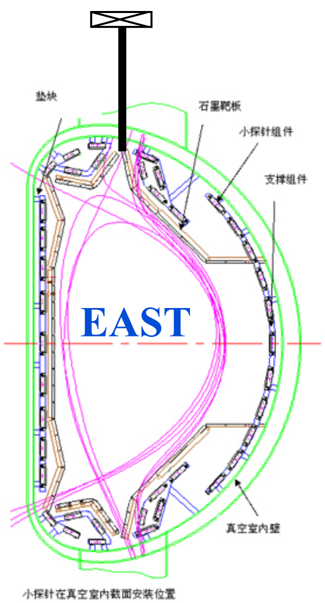
RF C antenna

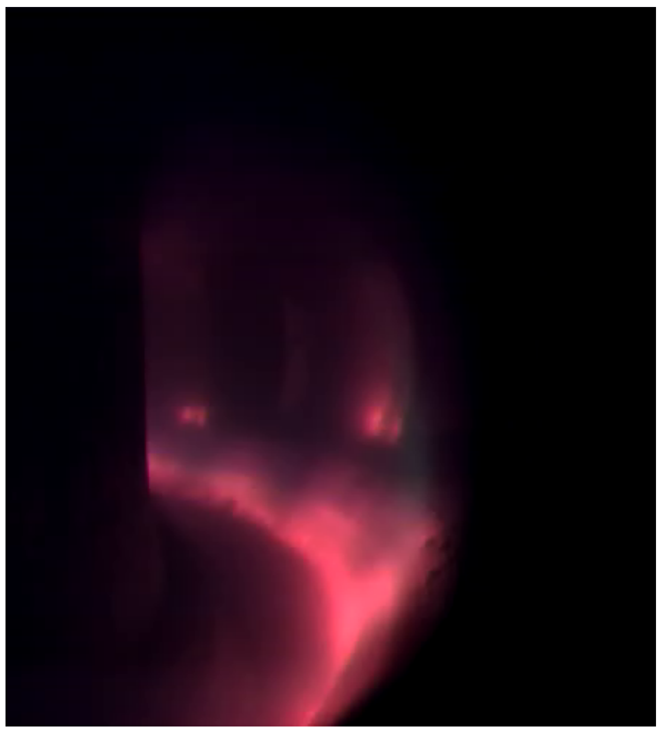
Li Wall Conditioning

EAST



D.Mensfield PPPL





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

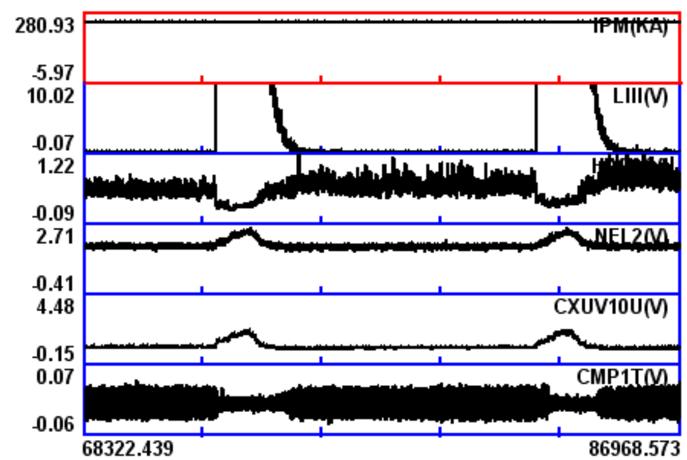
•Main Results:

•Very good and quick technique

•Z ~ 1.5-2.5

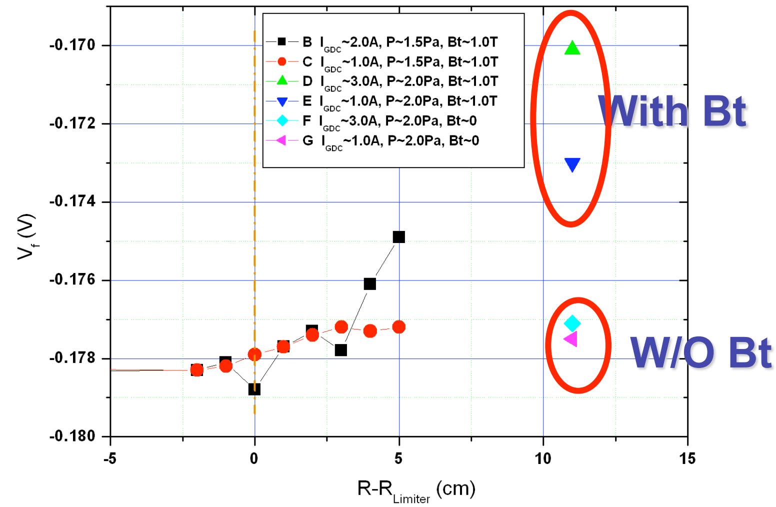
•More broad Te and radiation profile

•Low recycling

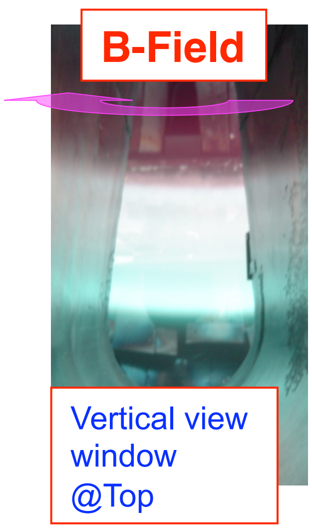


New Method : HF_GDC

•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



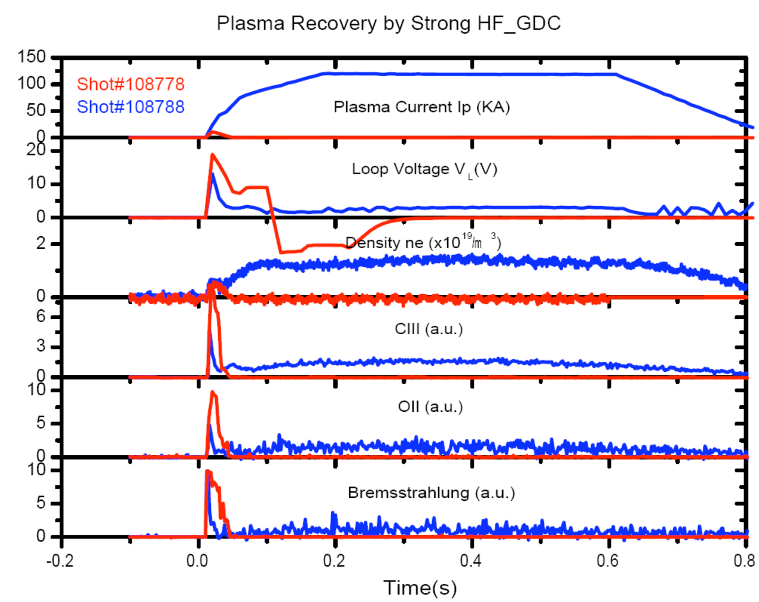
HF-GDC is routinely used in HT-7 for wall conditioning, siliconization and recycling control between shots which shows almost the same effects with RFWC.



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

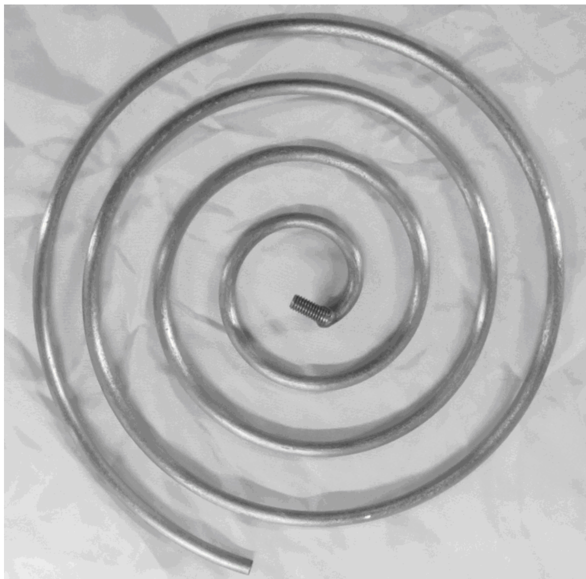
P=5.0E-2Pa, IGD=1.0A, Bt=1.0T, H2

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

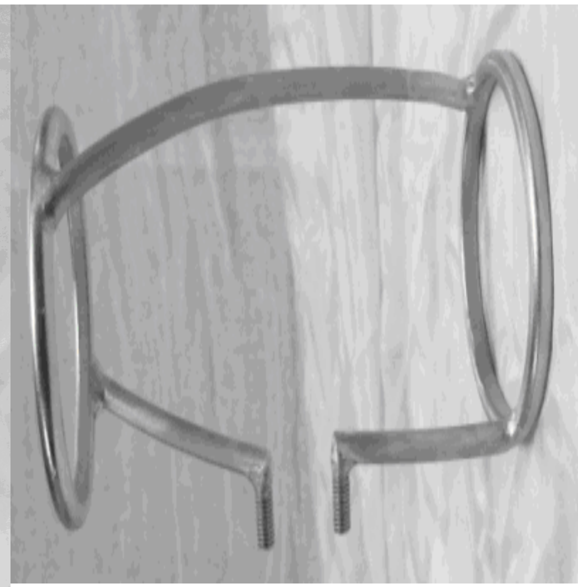


Recovery from 10Pa leakage

Helicon wave conditioning

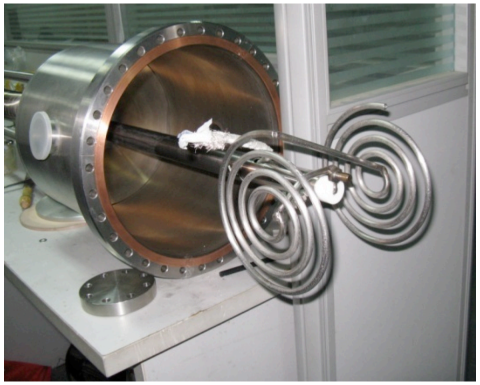


Flat Spiral antenna



Helicon Antenna

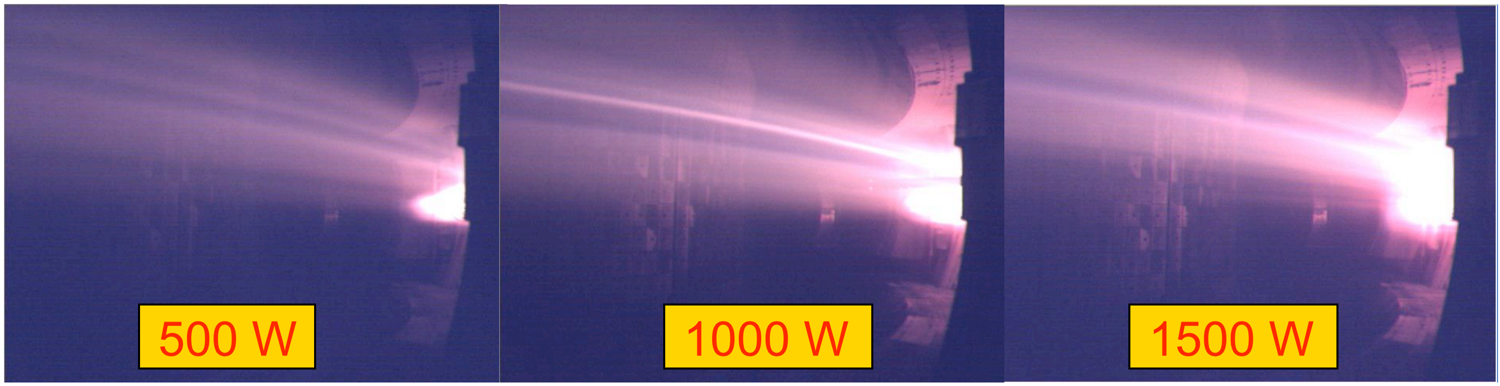
Mixed Antenna



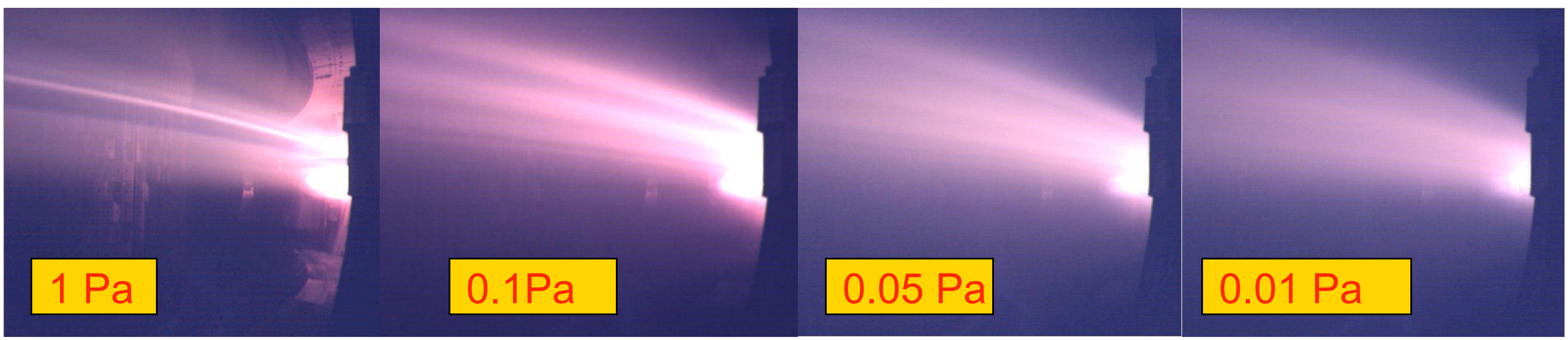
First Try

EAST

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



BT= 2T, P= 0.1 Pa



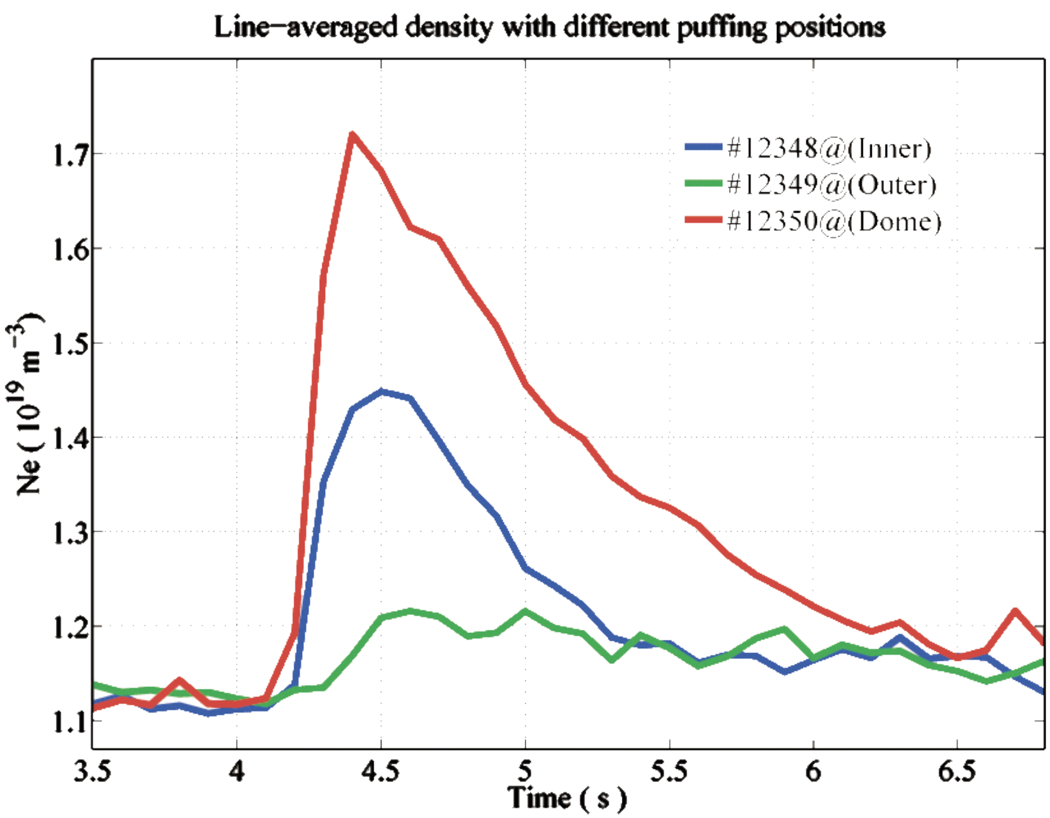
BT= 2T, P= 1kW

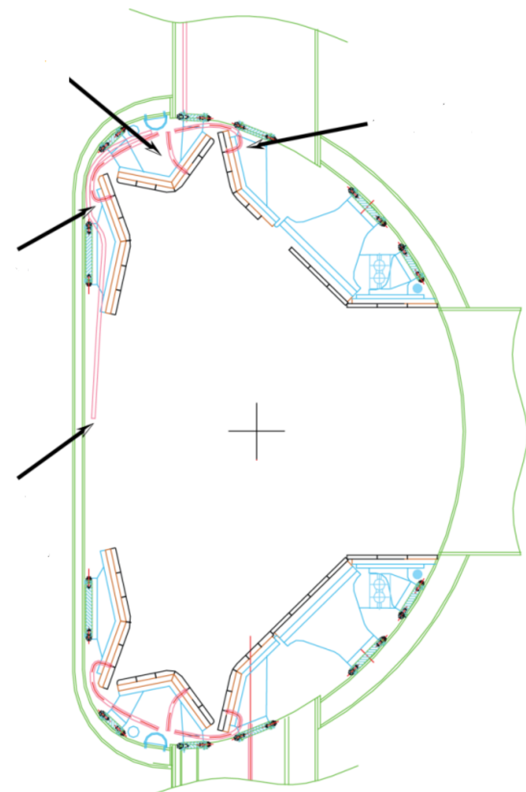
Divertor Physics Experiments

- **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

Effect of Gas Puff Locations



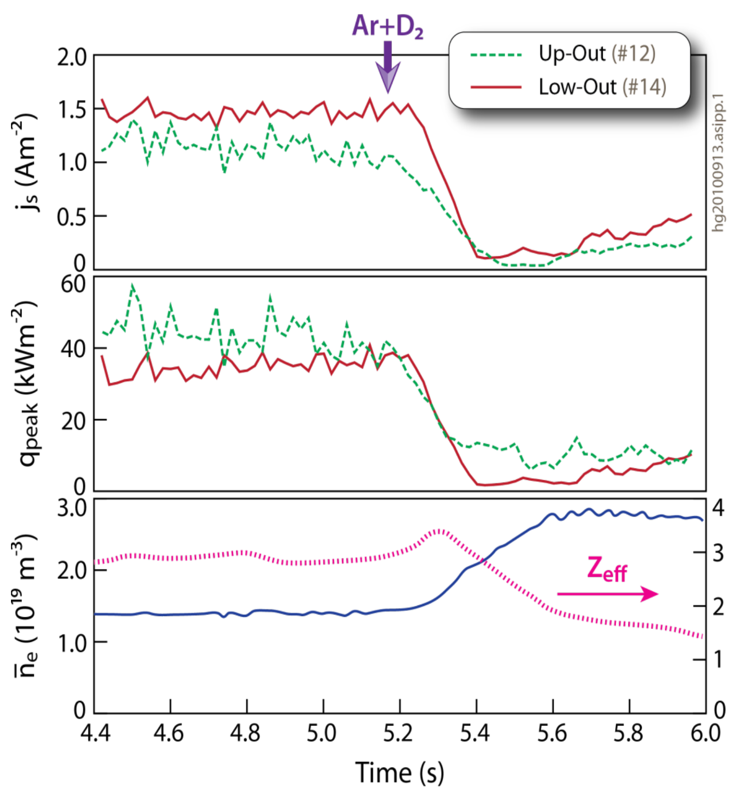


DOME D_2 puffing has highest fuelling efficiency, less from inner target plate, lowest from outer target plate. Compared to SN configuration, DN is more sensitive to gas puffing location.

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.

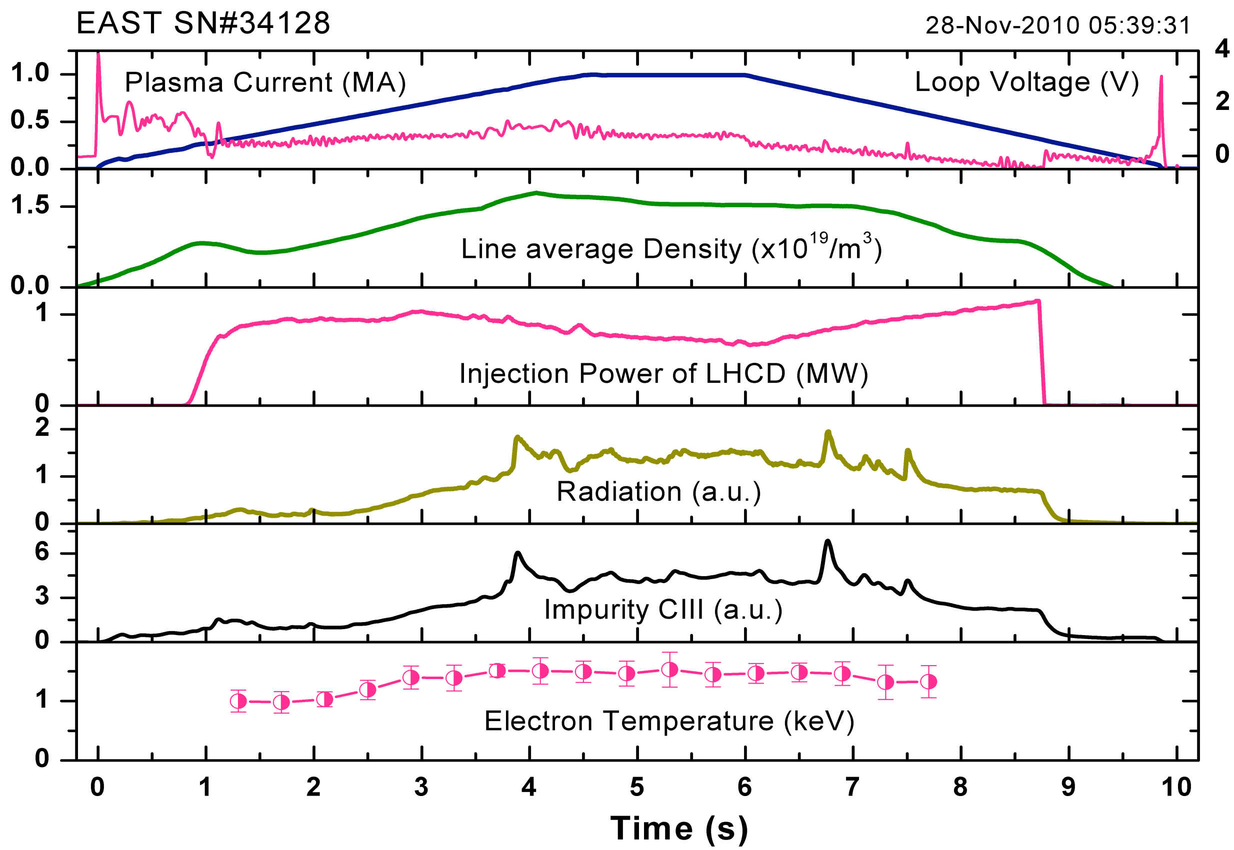
- **D2+5.7% Ar mixture puffing was initiated at 5s led to detachment at both upper and lower outer divertor targets**
- **significantly reducing the peak heat fluxes, q_{peak}, near outer strike points**
- **Zeff is reduced**

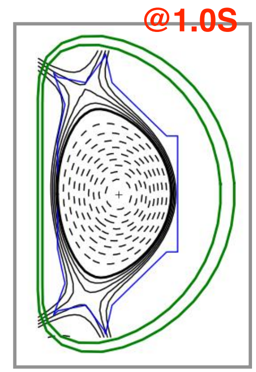


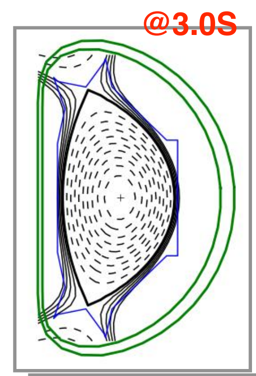
Ar puffing in divertors promote partial detachment and reduce peak heat flux

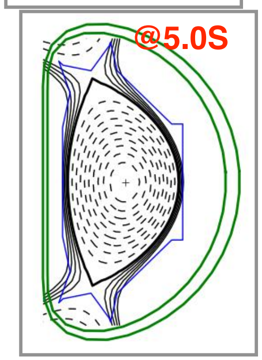
Full Current (1MA) Operation

RTEFIT/Iso-flux control.   LHCD assistance





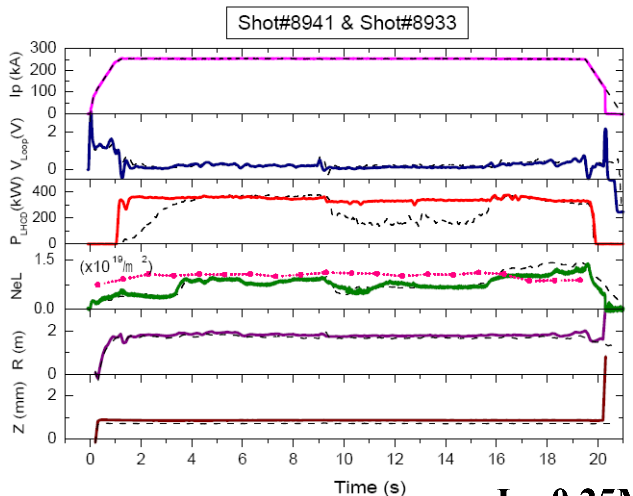




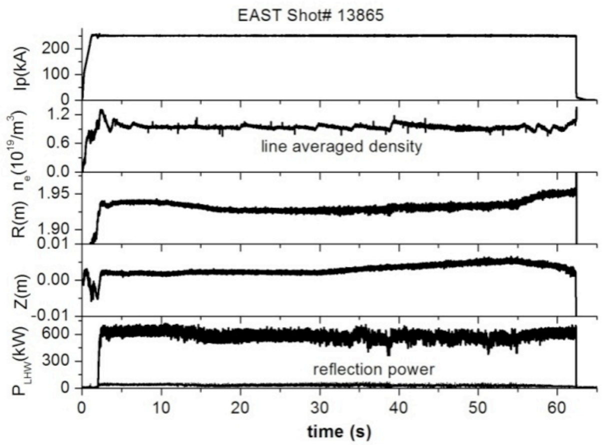
Ip~1.0MA, DN, elongation~1.8, triangurity~0.5,
BT=2.5T ,ne~1.5,P_{LHCD}~0.8-1.2MW

Long Pulse Discharges

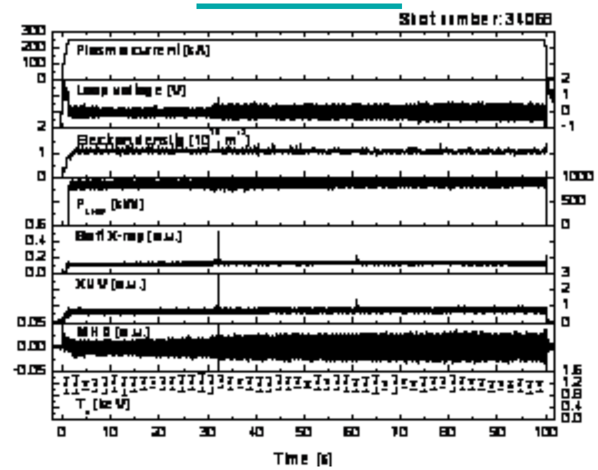
In 2008



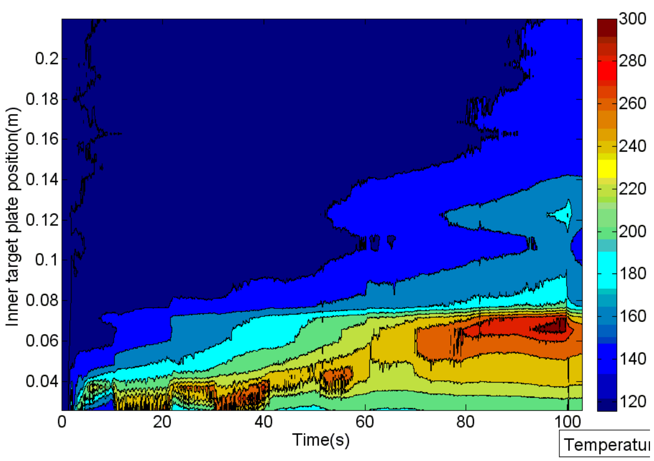
In 2009

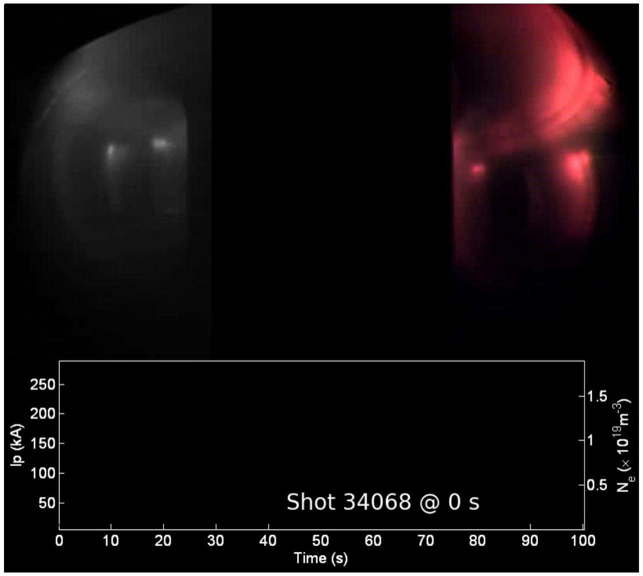


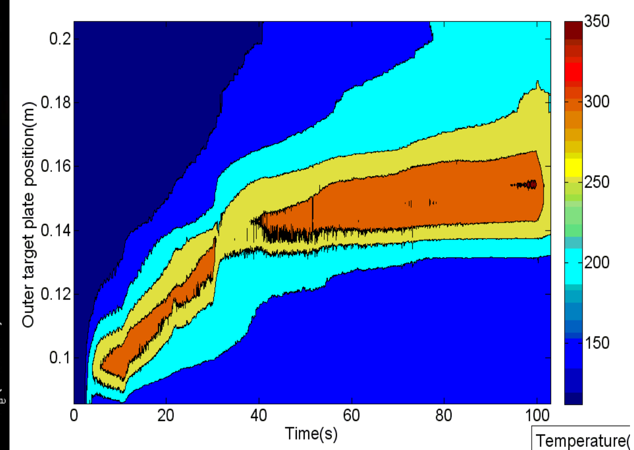
In 2010



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

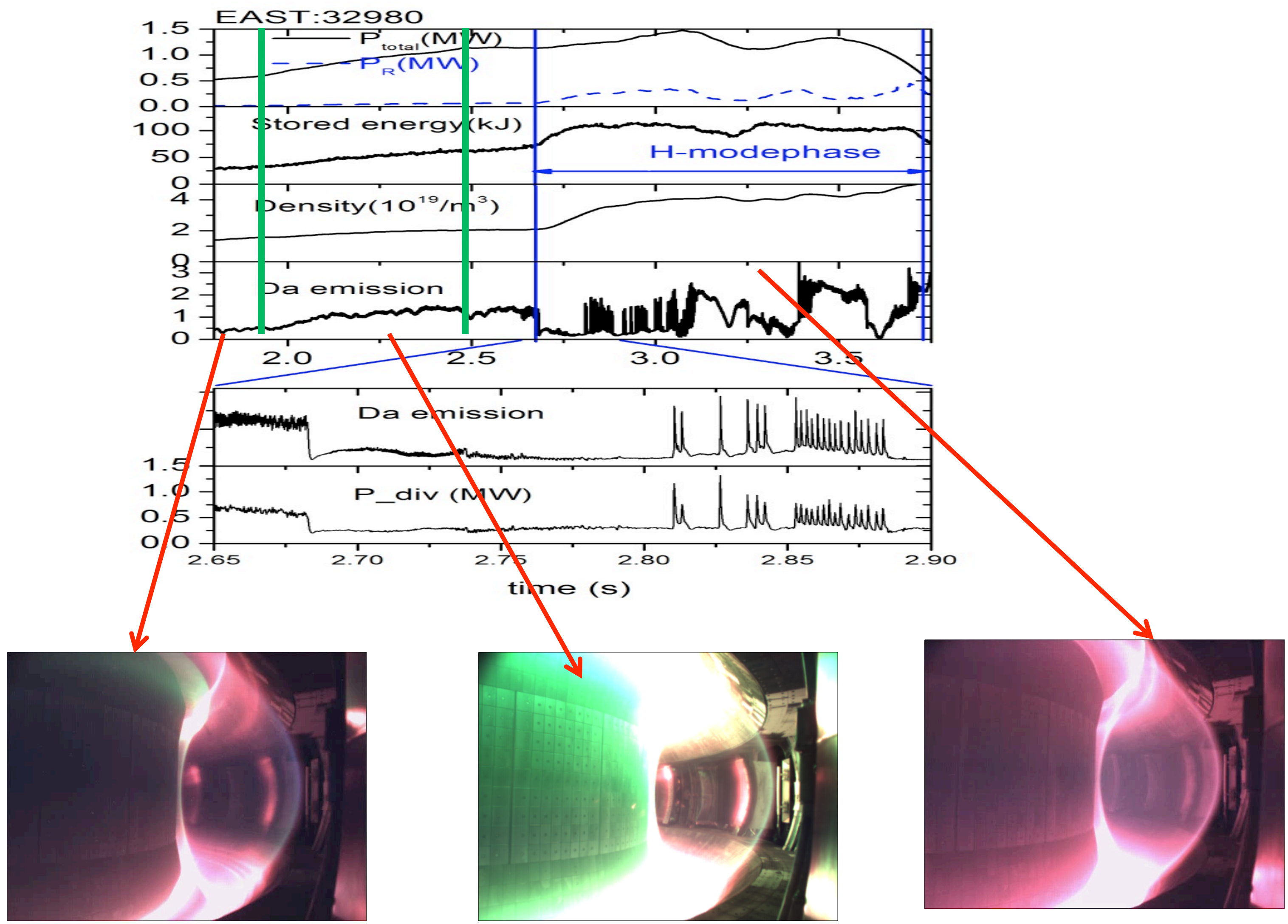




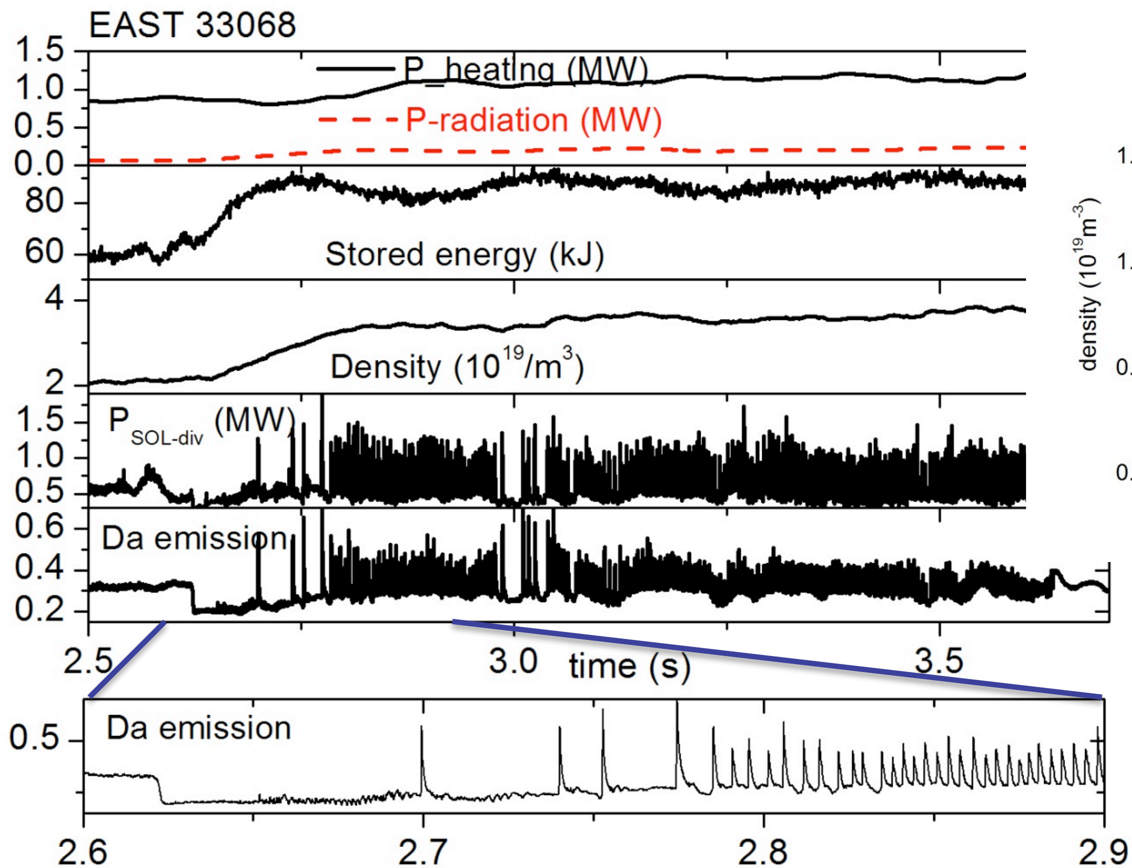


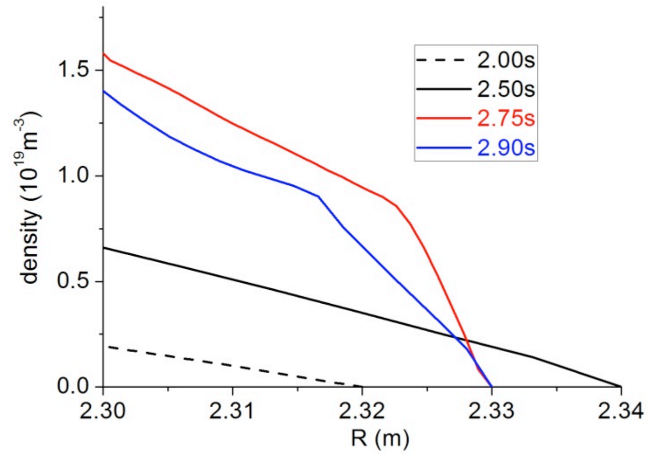
First H mode by Li coating either by oven or by lithium powder injection

EAST



Stationary high density H-mode

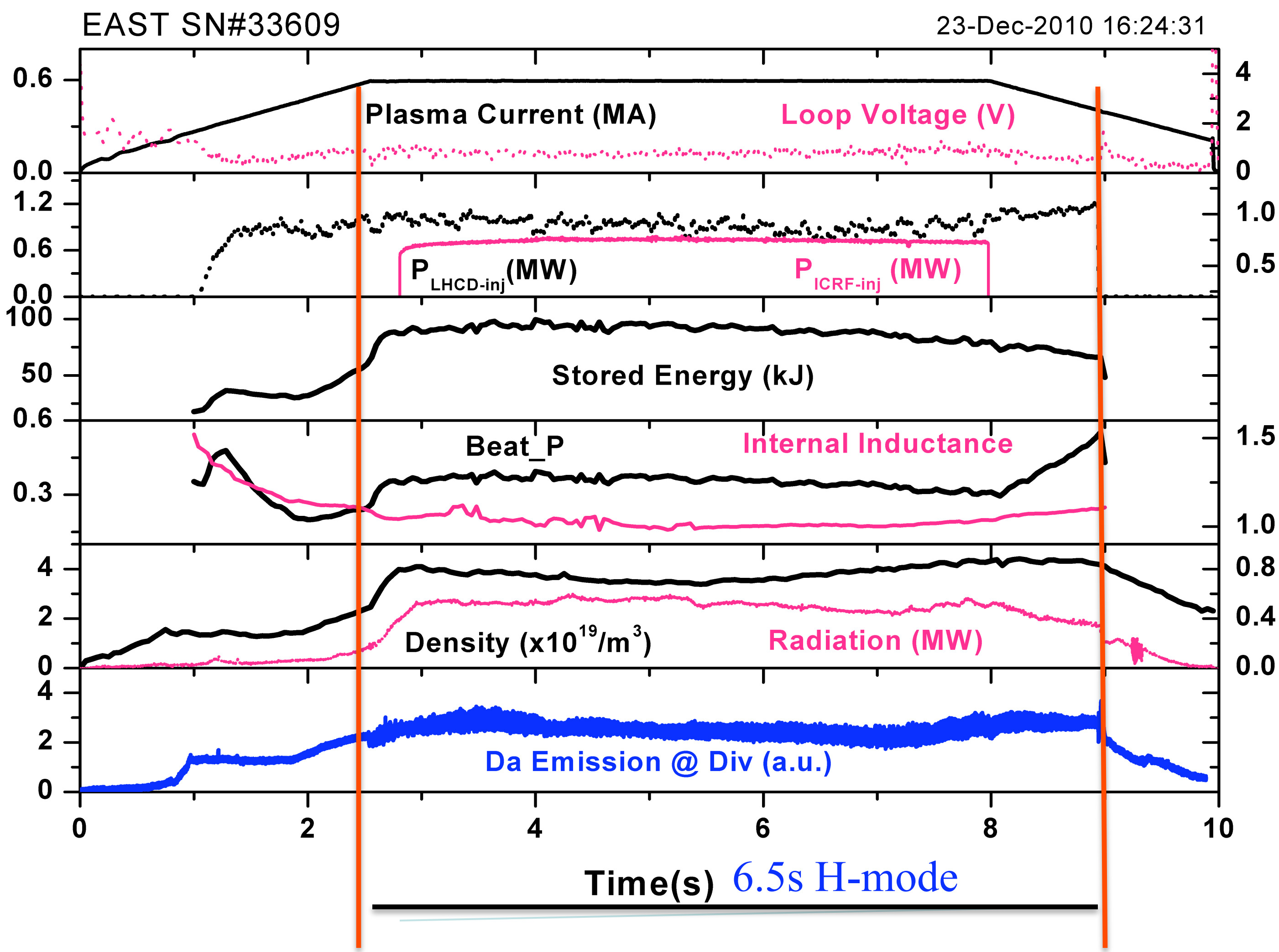




Density pedstal formed after L-H transition
Type I-like phase had more steep gradient than in type III phase

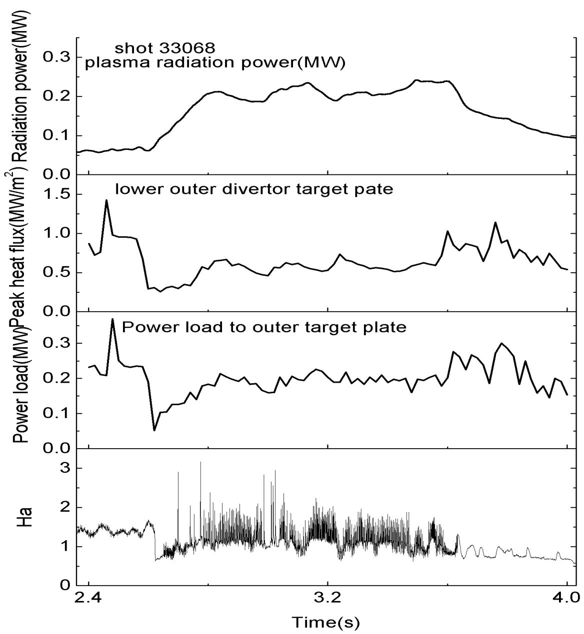
Along accumulation of Lithium in vessel, stationary H-mode has been achieved, Ip~500kA, Bt~1.54T, n_H/n_{GW}~70%

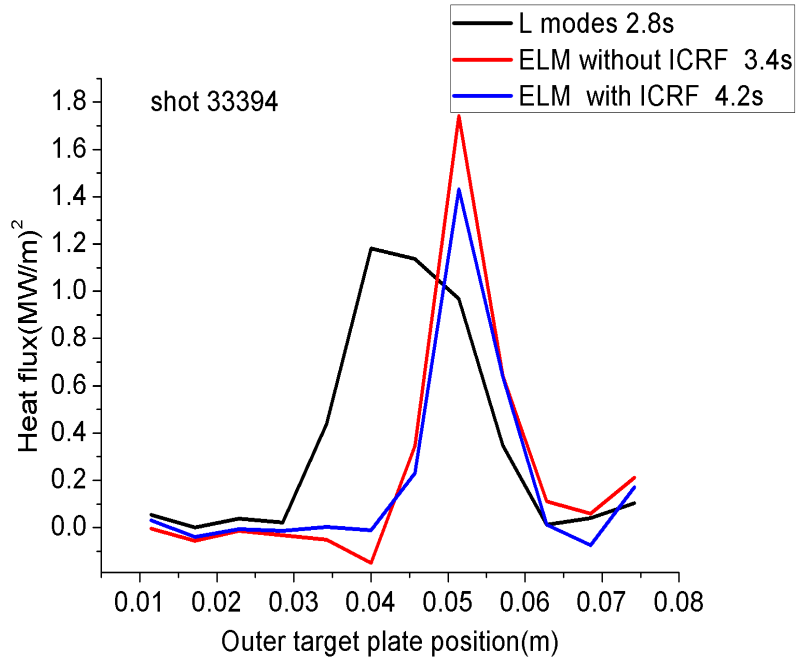
6.5s H-mode by RF+LH

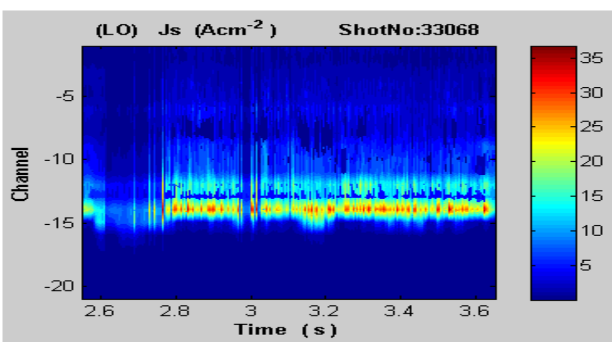


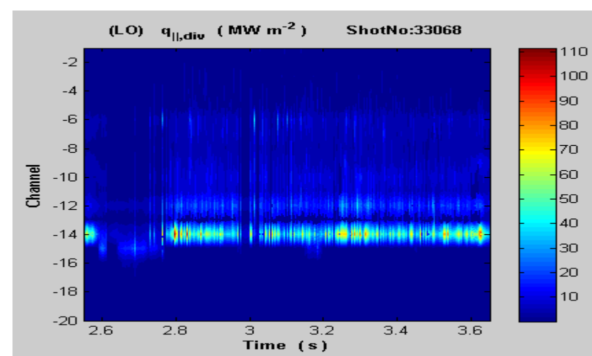
H-mode during ramp-up, flat-top and ramp-down phases, very important for ITER

Heat load for DN Type III ELM









EAST 2011 capabilities

PF power supply upgrade
VDI stabilizer connection

PFC modification for 250^0C and longer pulse with different puffing (place and gases)

- 4 MW LHCD @ 2.45GHz √
- 1.5MW ICRF @ 30-110MHz √
- 4.5MW ICRF @ 25-75MHz ~√

•Diagnostics（2010）→ all key profiles and some of specific measurements for physics understanding

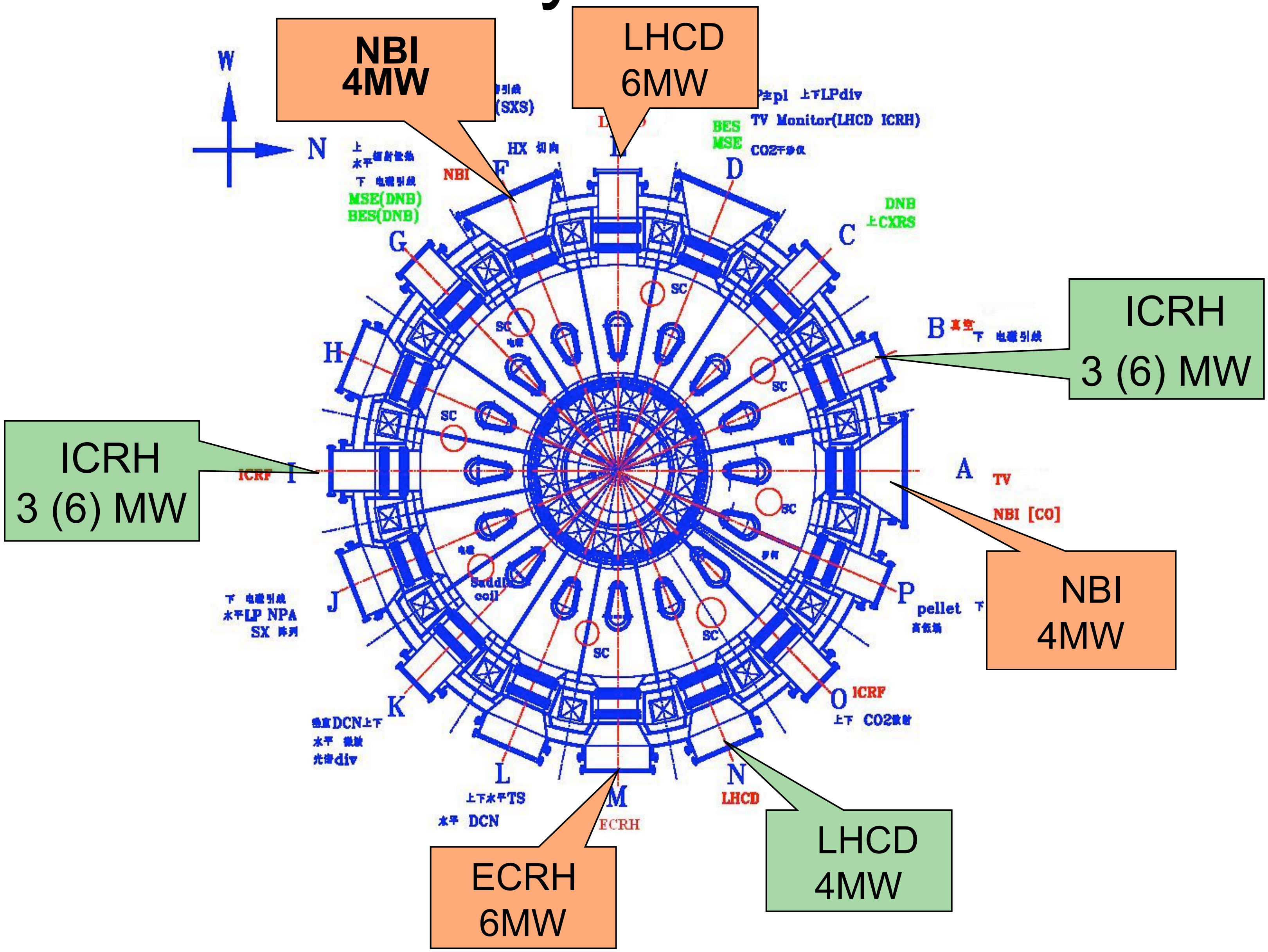
0.6-1MA operation

H-mode operation

For ITER
Safe start-up &termination
VDI
PWI
Fueling
Wall conditioning
ELM control

30s H-mode (~WST)

H&CD systems for EAST

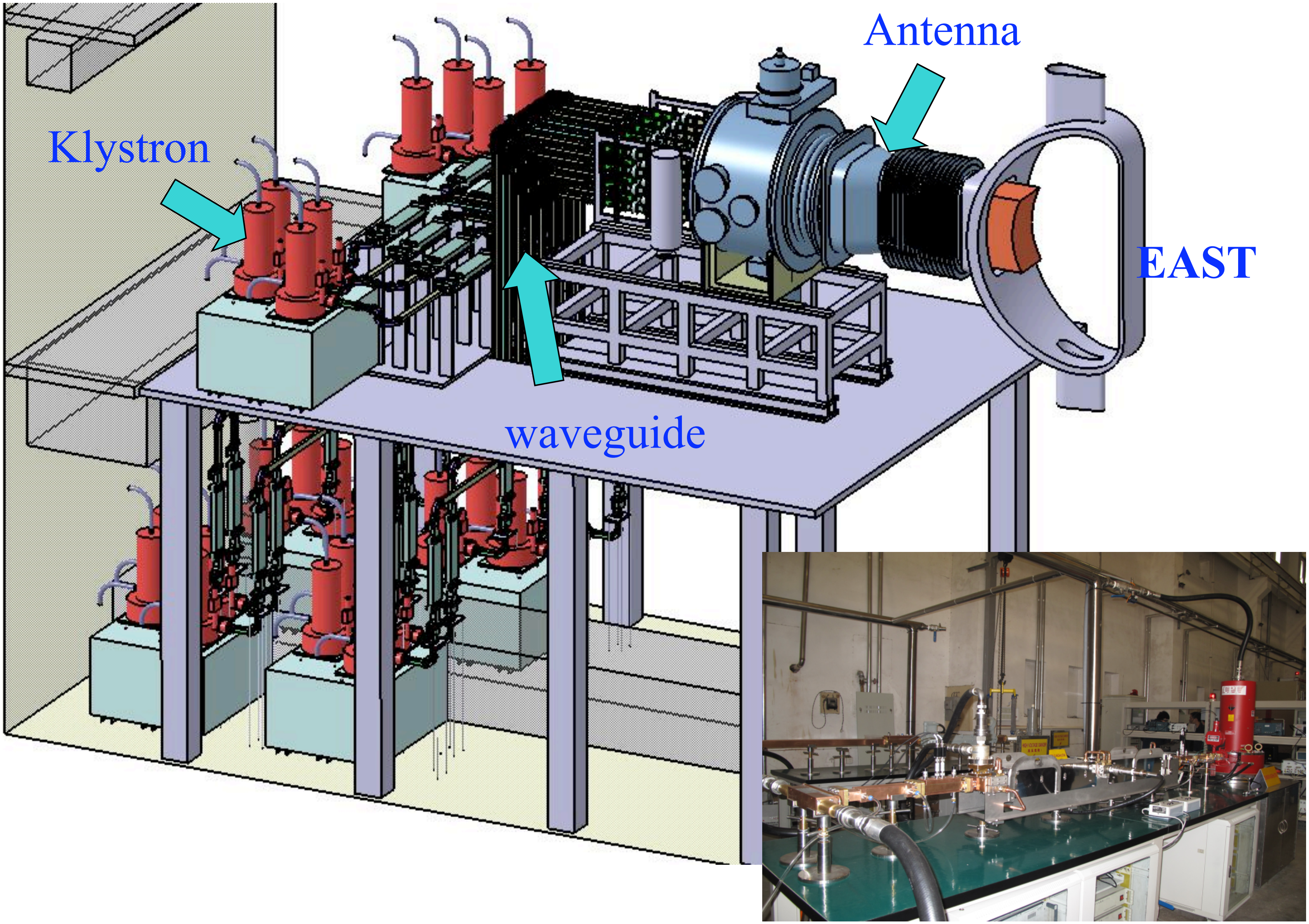


EAST 5 year Plan

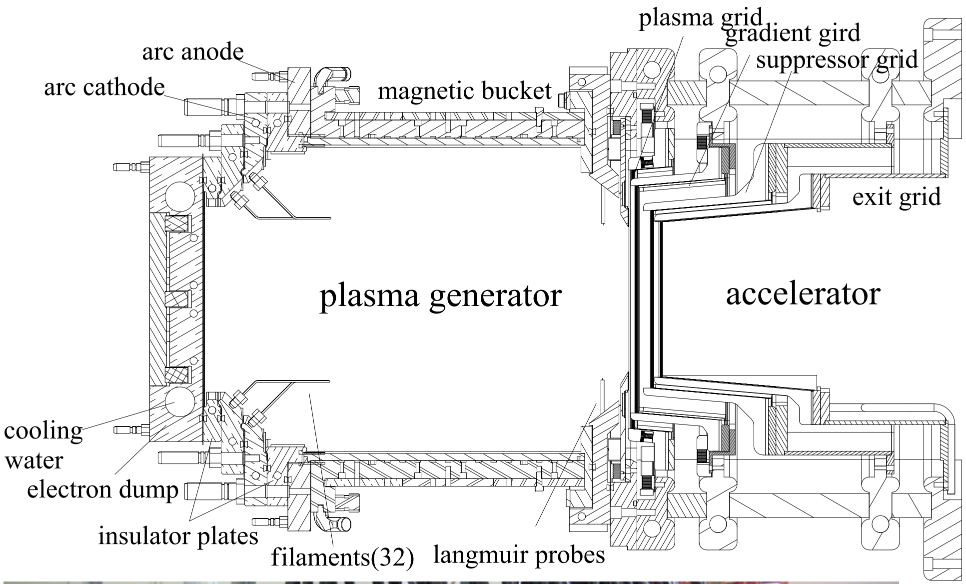
	2011	2012	2013	2014	2015
Ip(MA)	1.0	1.0	1.0	1.5	1.5
LHCD(MW, CW)					
2.45GHz	4.0	4.0	4.0	4.0	4.0
4.6GHz			6.0	6.0	6.0
ICRF(MW,CW)					
20-75MHz	4.5	4.5	4.5	4.5	4.5
30-100MHz	1.5	4.5	4.5	4.5	4.5
NBI(80keV)			4.0	8.0	8.0
ECRH(140GHz,cw)		2.0	4.0	6.0	6.0
Diagnostics	40	45	50	50	50
Duration(s)	100	200	300	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

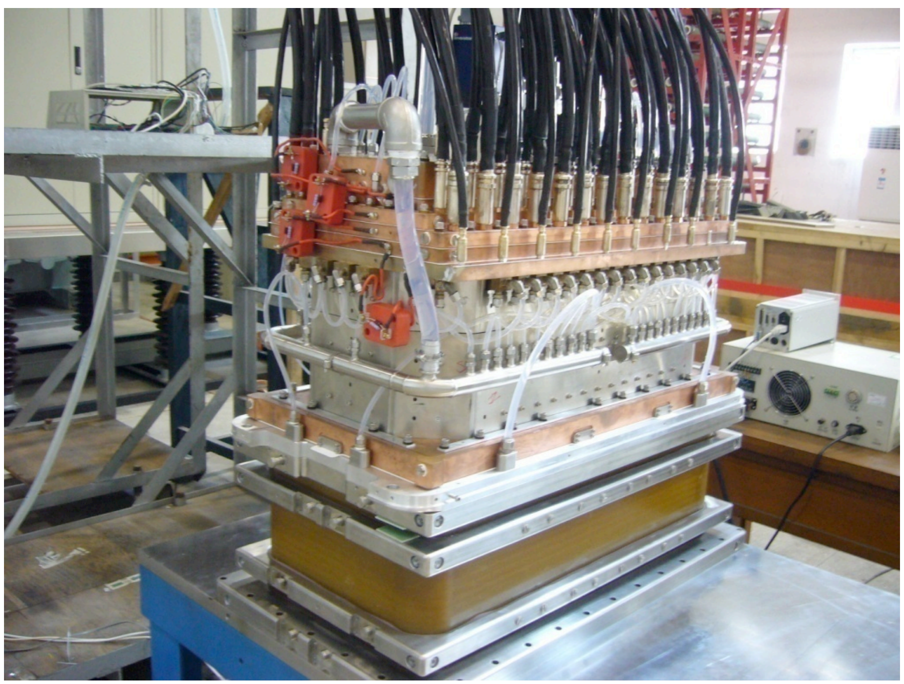
4.6GHz LHCD Microwave System

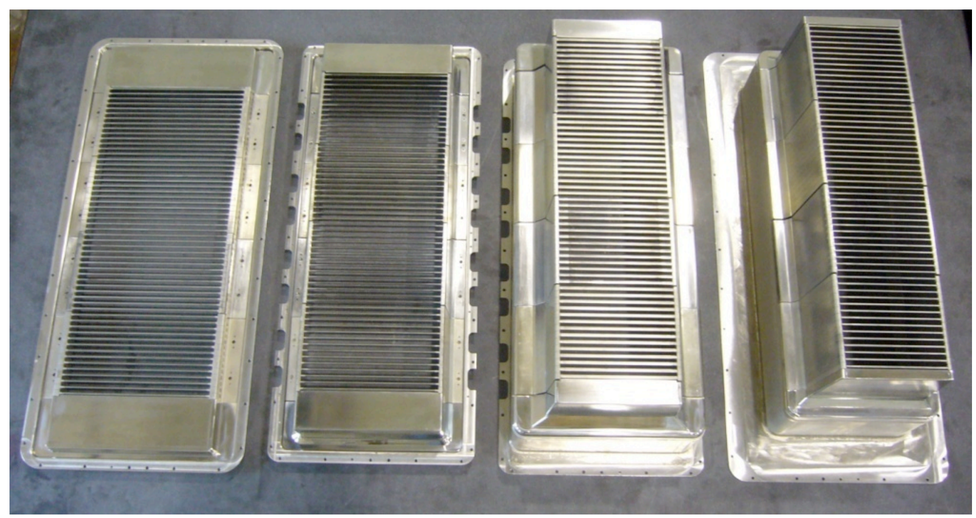


EAST_NBI Ion Source (with cooperation of DIII-D)



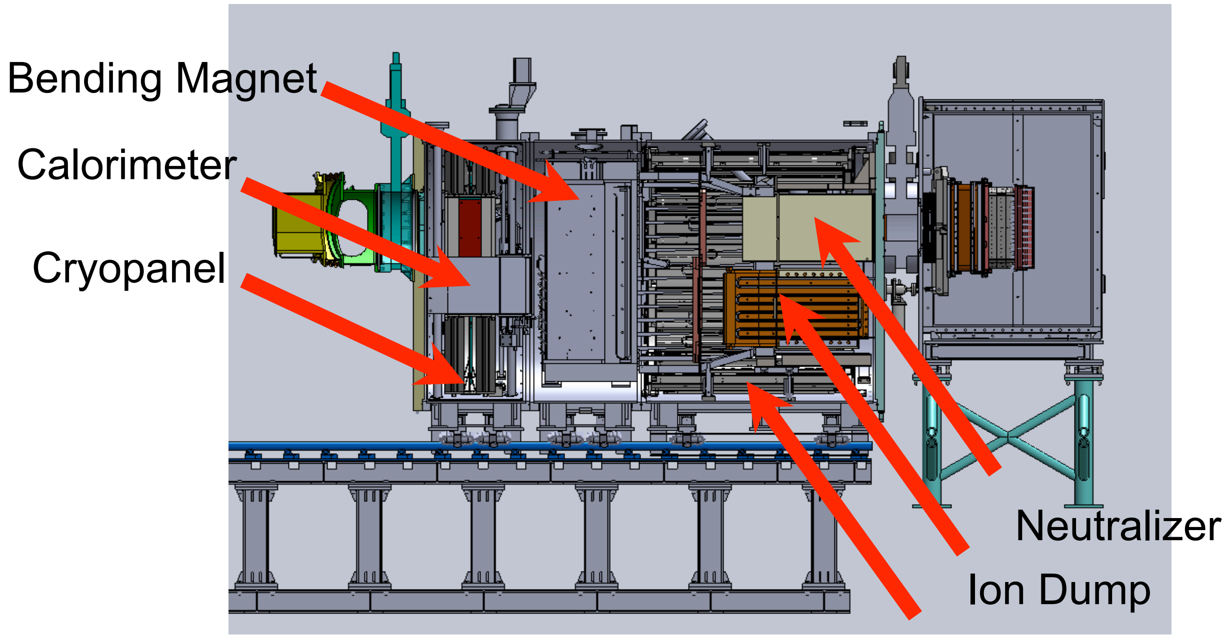
- Ion species: deuterium
- Beam energy: 50-80keV
- Beam current: 40-70A
- Pulse length:10-100s
- Extraction Region: 12cmx48cm
- Composition:
  $D^+:D_2^+:D_3^+ = 80\%:14\%:6\%$
- Divergences: 0.6 (X),1.2(Y)

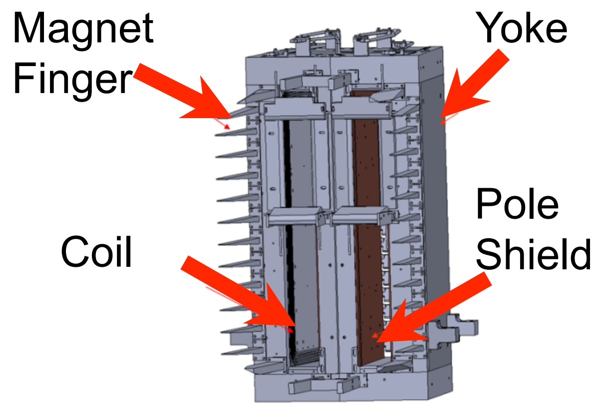




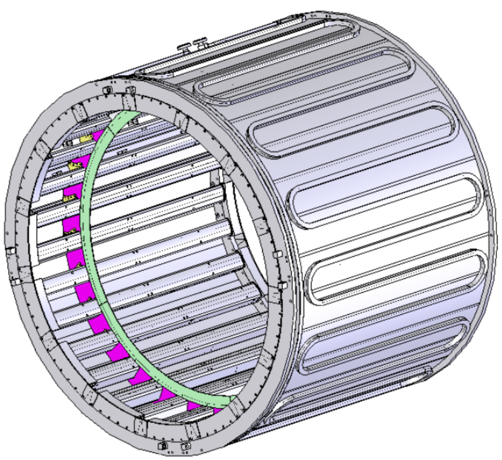
Plasma Grid Gradient Grid Suppressor Grid Exit Gird

Development of EAST_NBI Beam Line

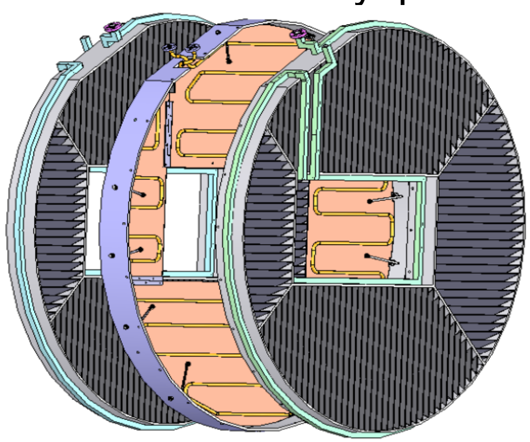


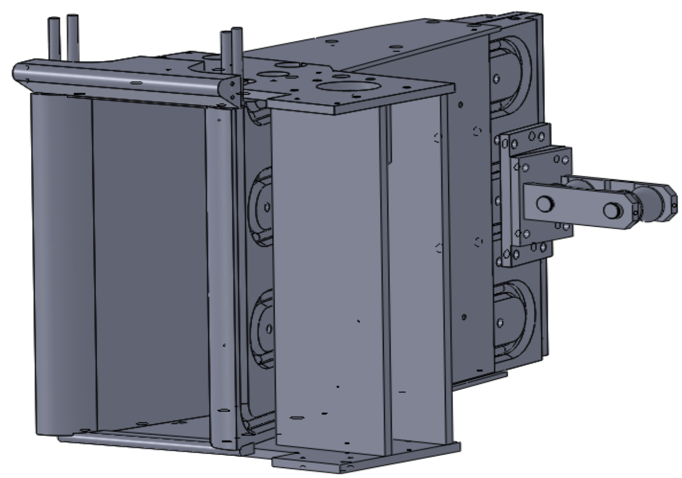


Bending Magnet

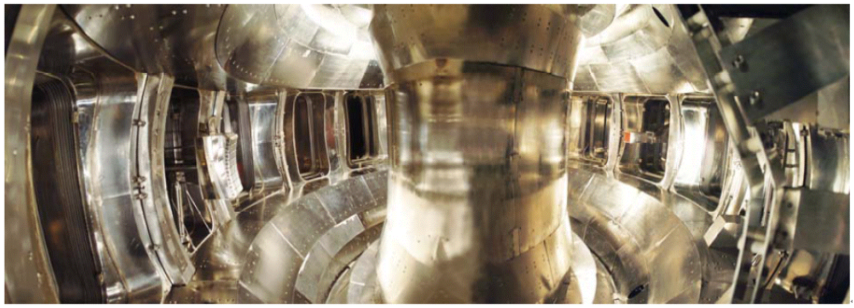

Cryopanel—Spool 1

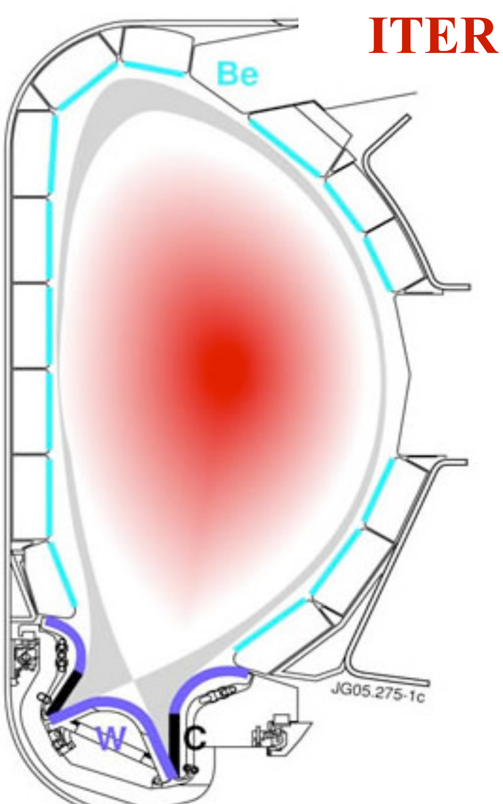
Cryopanel

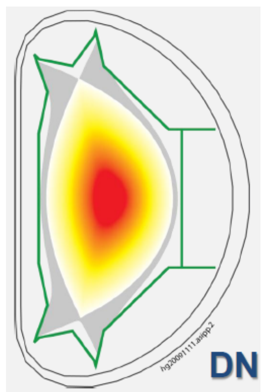

Cryopanel—Spool 3

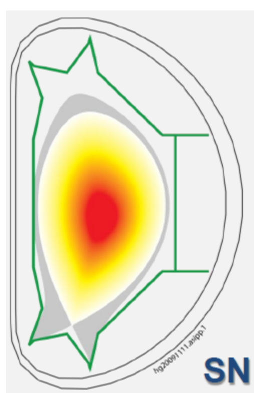

Calorimeter

PFC strategy for EAST









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/m²

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

  PFC ⇨ Actively-cooled W/Cu and partial W/Fe possibly, max. heat flux capability of 7~10MW/m²

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

Summary

- Significant technical improvements have been made since the first plasma in Oct. 2006 which enhance EAST operation capabilities.
- EAST starts high performance long pulse physics experiments and stationary H-mode was obtained.
- It will be very challengeable for 1MA/1000s, H-mode, 10MW/m^2 operation. Suggestions and helps for this goal are most welcomed.
- EAST will be a good facility to test your ideals.

Thanks for colleagues from GA, FRC, PPPL, IRFM-CEA, NIFS, JAEA, KFRI, PSFC, ENEA, IPP, ITER-IO
And all Domestic cooperators