

EAST Overview: Recent Progress & Future Plans

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and EAST Team**

PPPL, April 20, 2012



Outline

- **Introduction of EAST**
(Experimental Advanced Superconducting Tokamak)
- **Progress on Technology Front**
- **Highlights of Scientific Achievements**
- **5-Year Research Plan**
- **Summary**

Outline

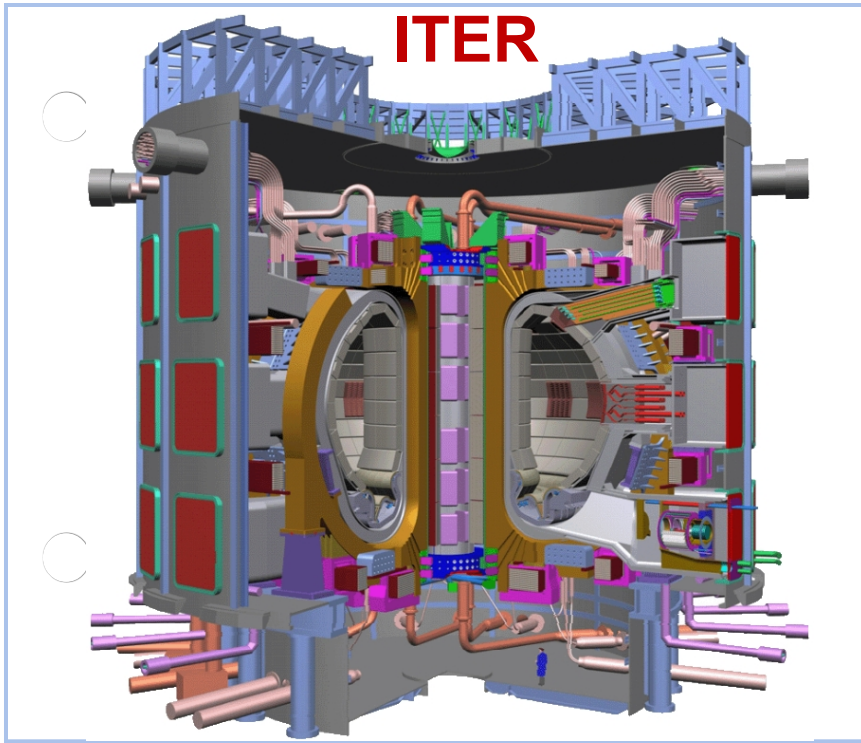
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Mission of EAST

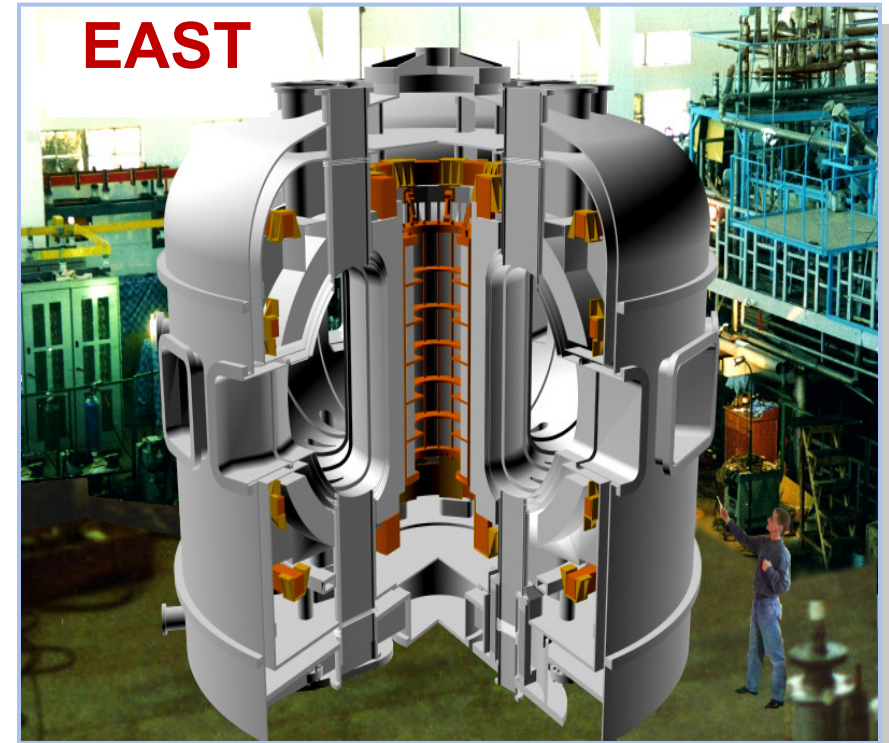
- Investigate advanced Steady State (SS) high performance plasma physics.
- Provide a valuable technology and physics basis for ITER and DEMO under steady-state operation (SSO) conditions.

Target: 1 MA SSO with 20-30 MW CW CD&H with advanced diagnostic capabilities

EAST Has ITER-Like Configuration and Heating Scheme (RF)



$R = 6.2 \text{ m}$, $a = 2 \text{ m}$, $t = 400 \text{ s}$
 $I_p = \sim 15 \text{ MA}$, $B_T = 5.3 \text{ T}$
Single null

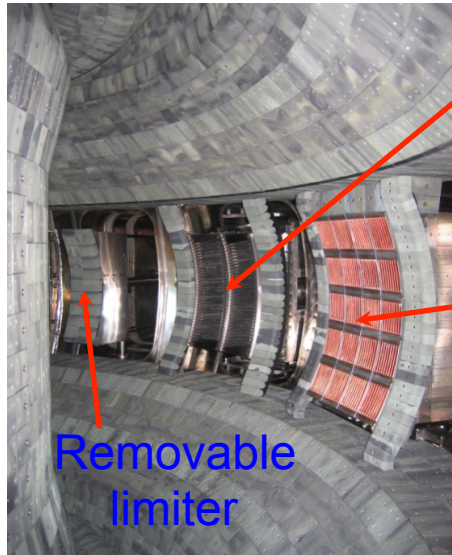


$R = 1.9 \text{ m}$, $a = 0.5 \text{ m}$, $t = 1000 \text{ s}$
 $I_p = 1 \text{ MA}$, $B_T = 3.5 \text{ T}$
Single /Double null

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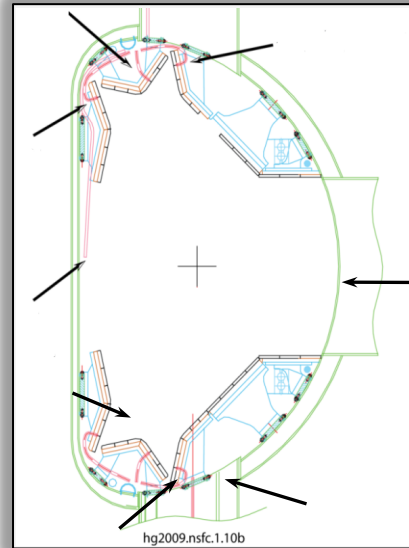
Key Internal Components



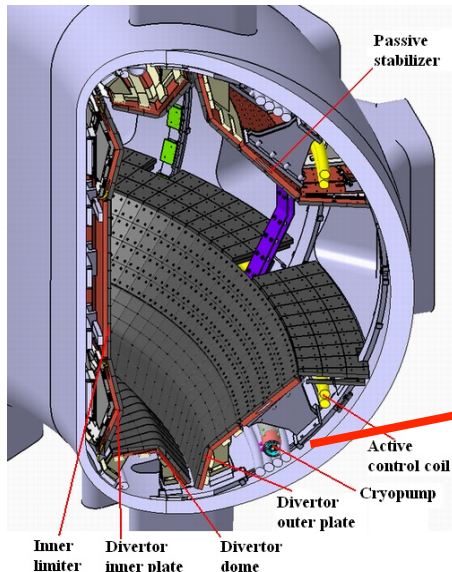
**ICRF
antenna**

**LHCD
launcher**

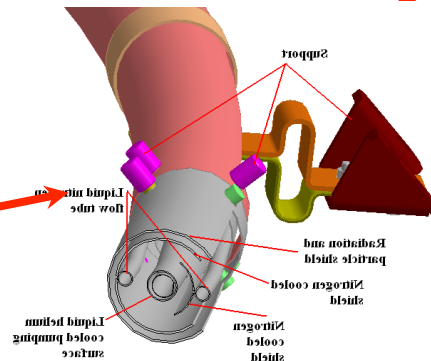
**Removable
limiter**



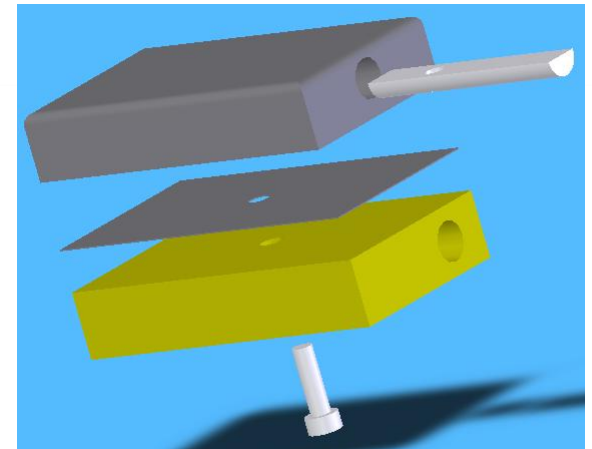
**Multi-purpose gas
injection system
@various locations**



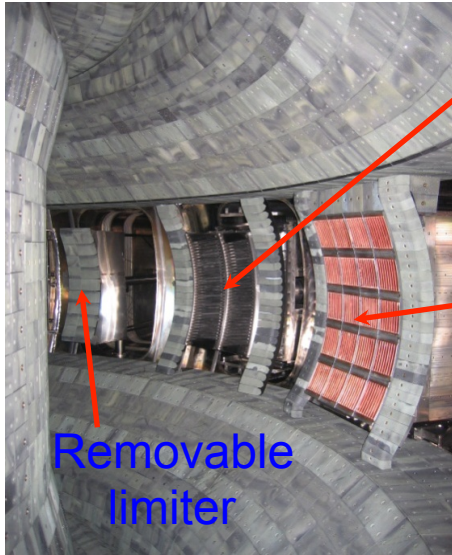
**Internal cryopump
~75.6 m³/s for D₂**



**Actively water-cooled PFC
(Tolerable heat flux 2MW/m²)**

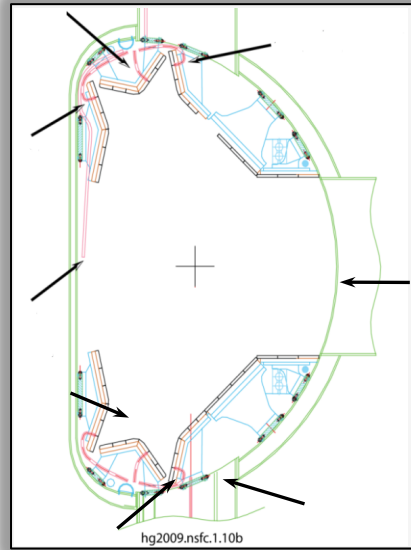


Key Internal Components

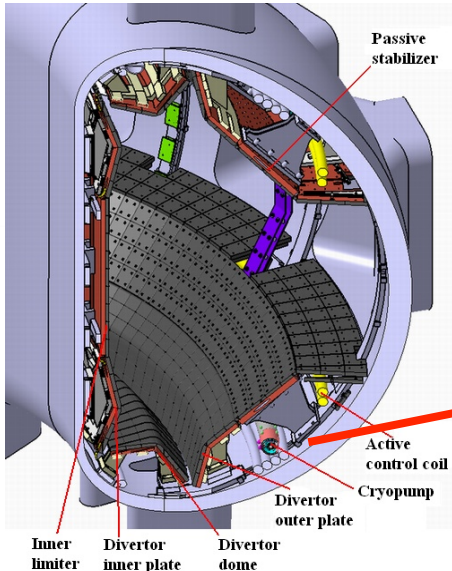


ICRF
antenna

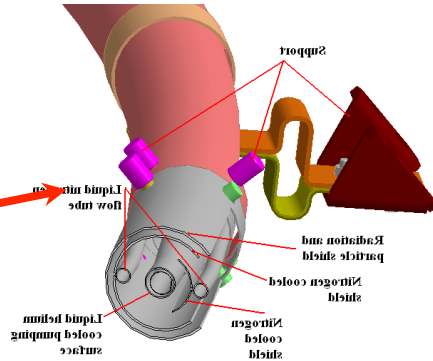
LHCD launcher



Multi-purpose gas injection system @various locations



Internal cryopump
~75.6 m³/s for D₂

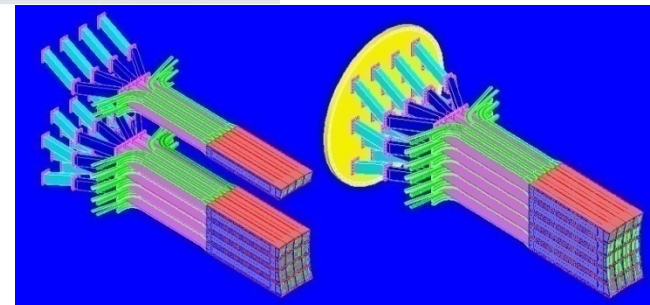
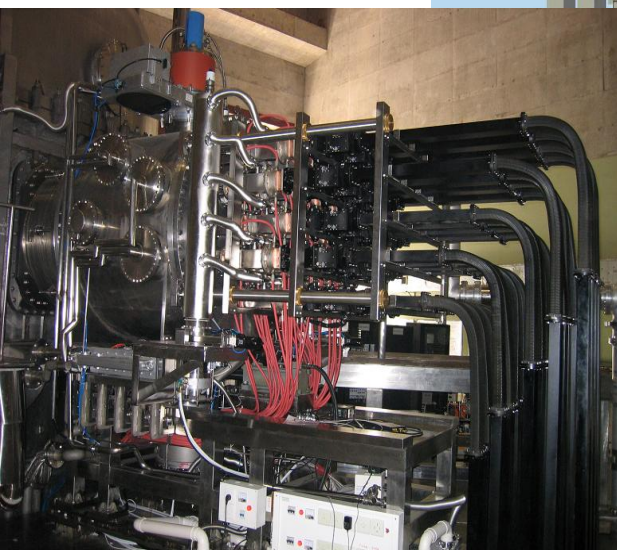
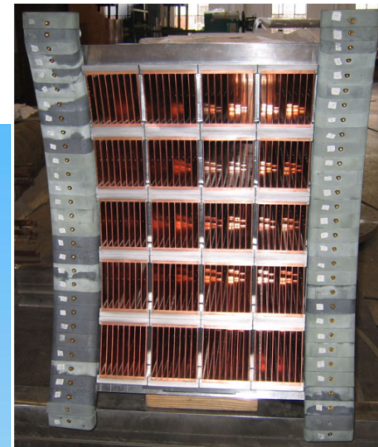
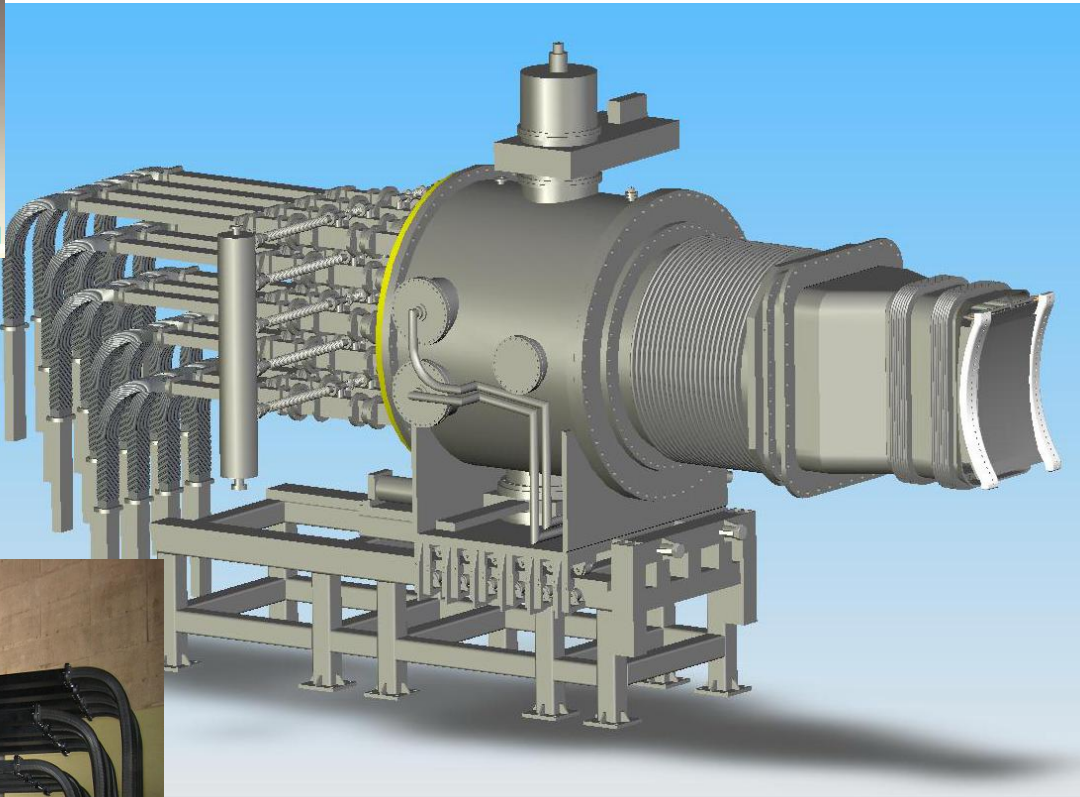
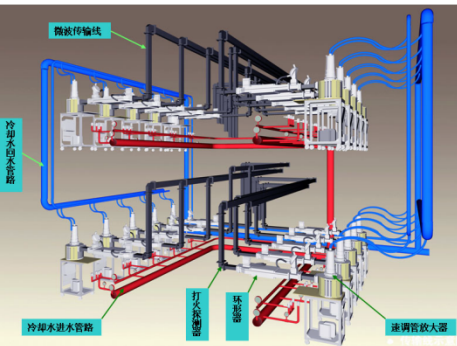


Actively water-cooled PFC
(Tolerable heat flux 2MW/m²)



Graphite tiles have now been replaced by Mo tiles except those at divertor target plates

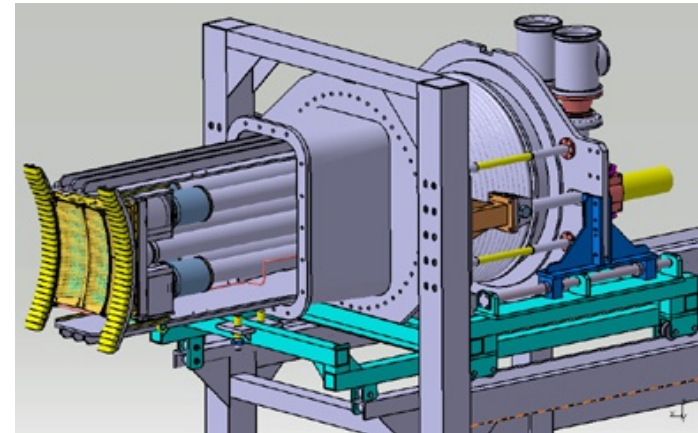
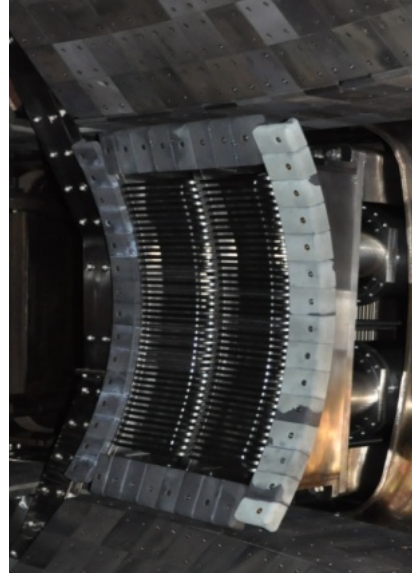
CW LHCD System (2.45 GHz, 4MW)



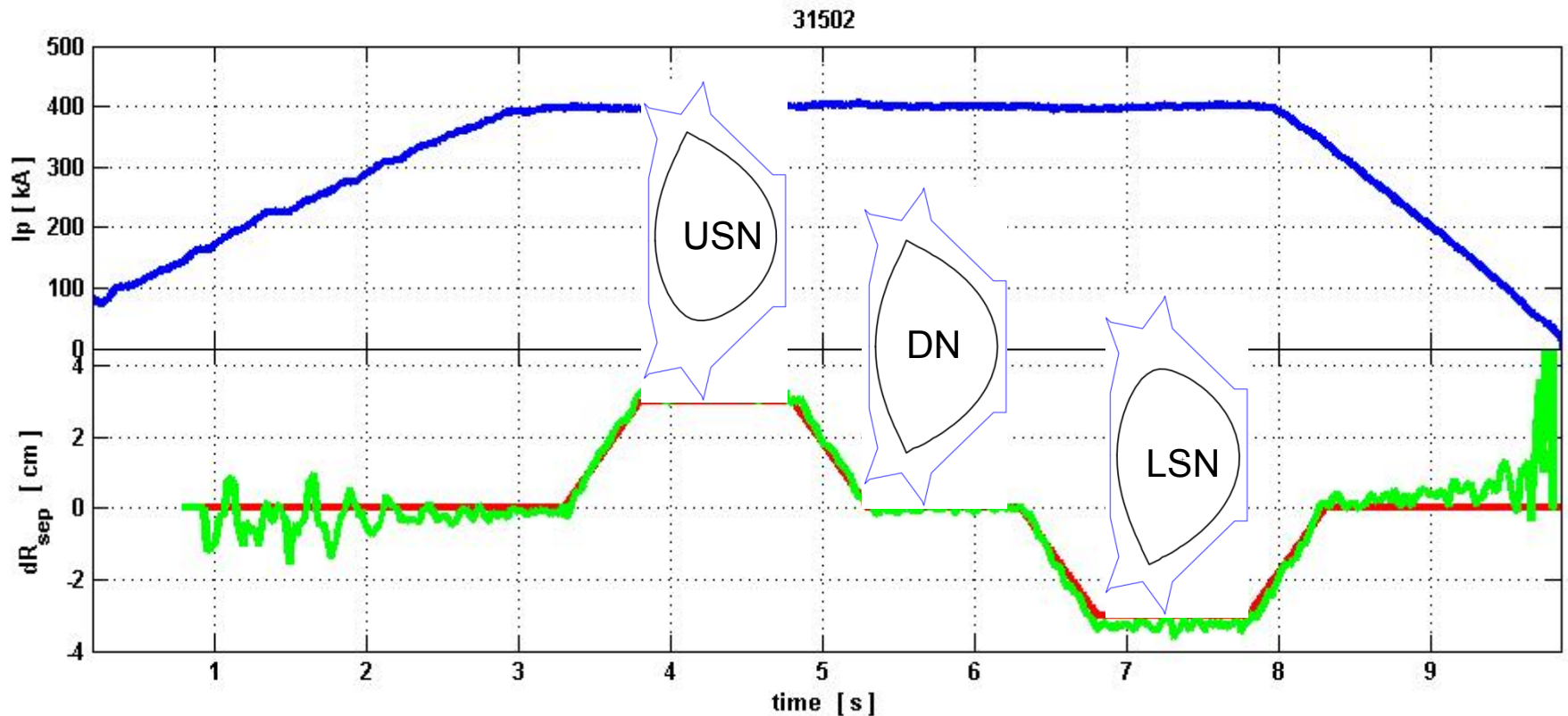
ICRH System On EAST



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

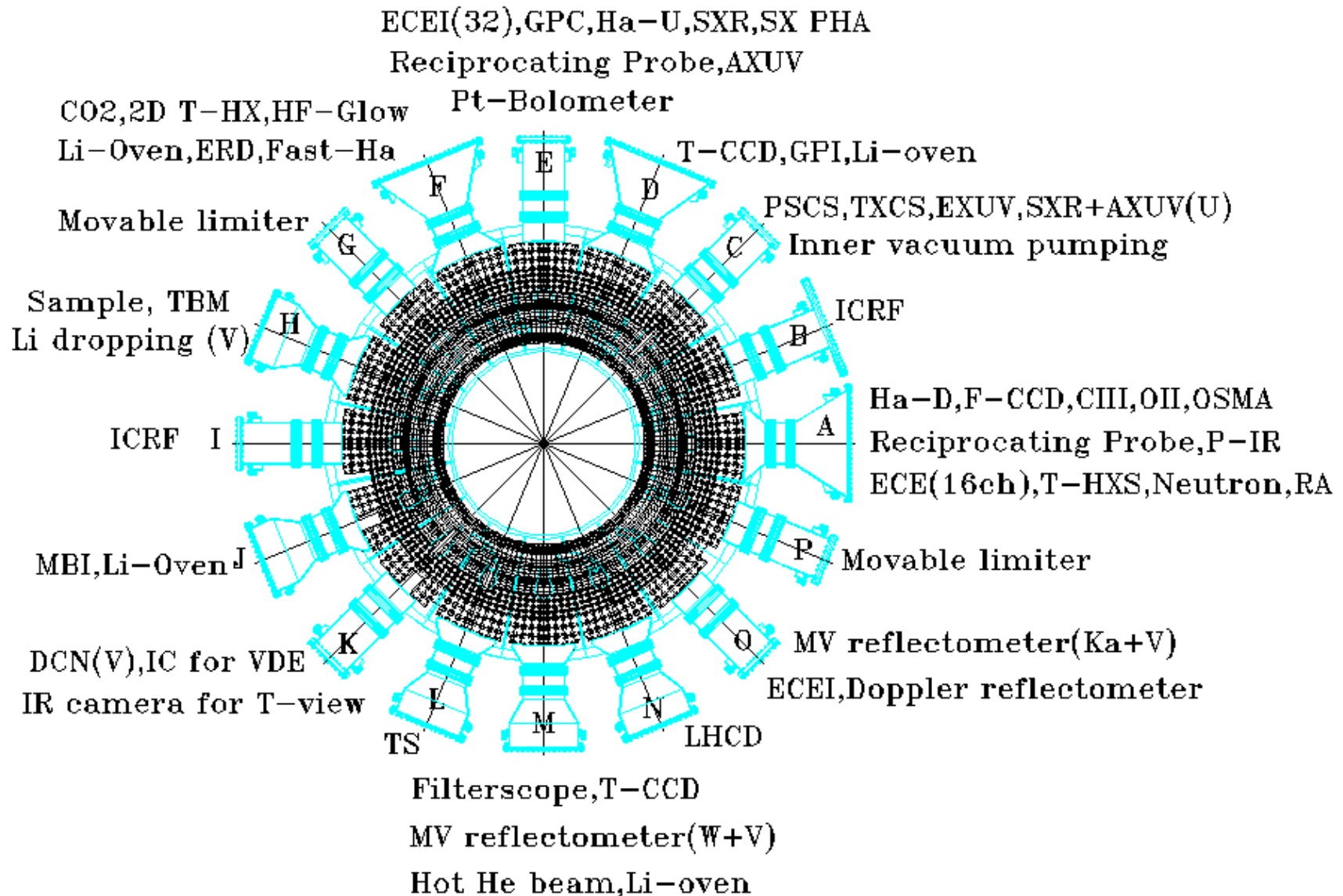


Developed Flexible Plasma Control and Feedback System



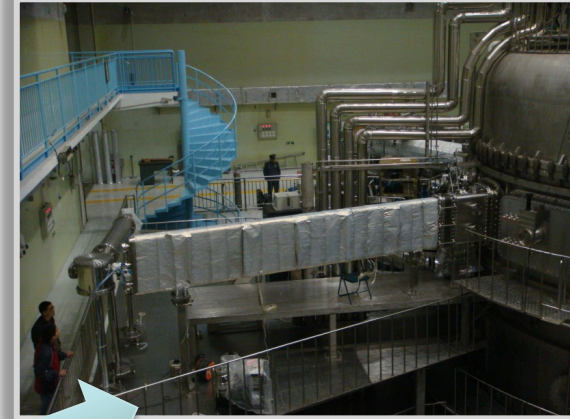
DN and SN were realized by control dR_{sep} & strike points

Matured Diagnostics for Key Profiles & Specific Physics Studies (~ 40)



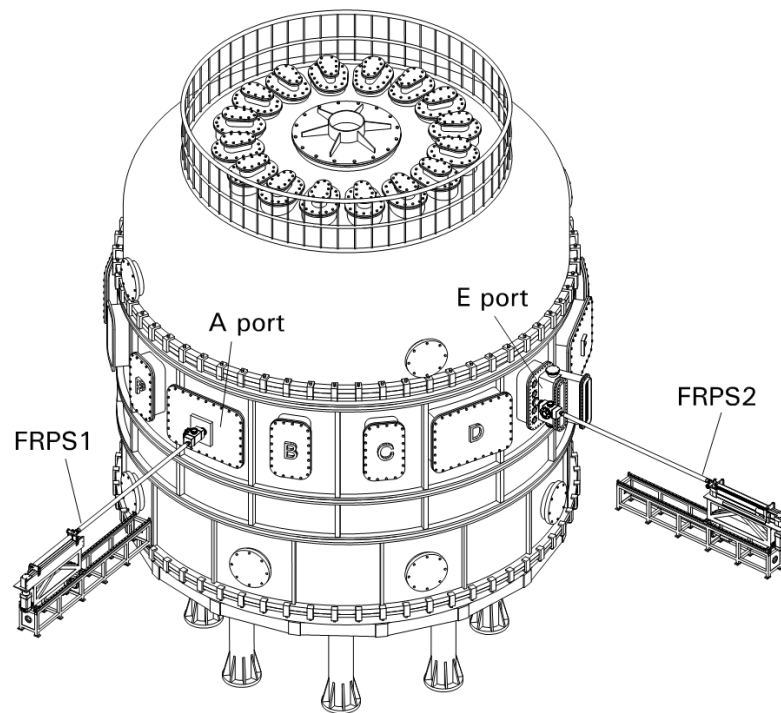
Key Plasma Profile Diagnostics

- The FIR Interferometer System
- Thomson Scattering Diagnostic
- Two X-ray Crystal Spectrometers
- Two ECE Heterodyne Radiometer Systems
- FM V&W Band Microwave Reflectometry
- Microwave Profile Reflectometer
- Edge Rotation Diagnostic
- Thermal Helium Beam Diagnostic (being built)

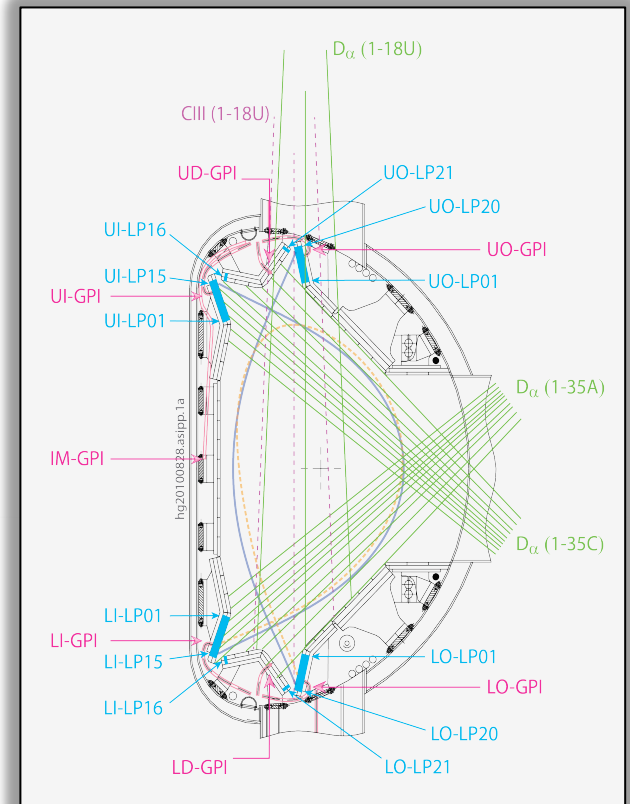


Edge Spectroscopy & Langmuir Probes

Two Fast Reciprocating Probes allow edge profile and **turbulence measurements**

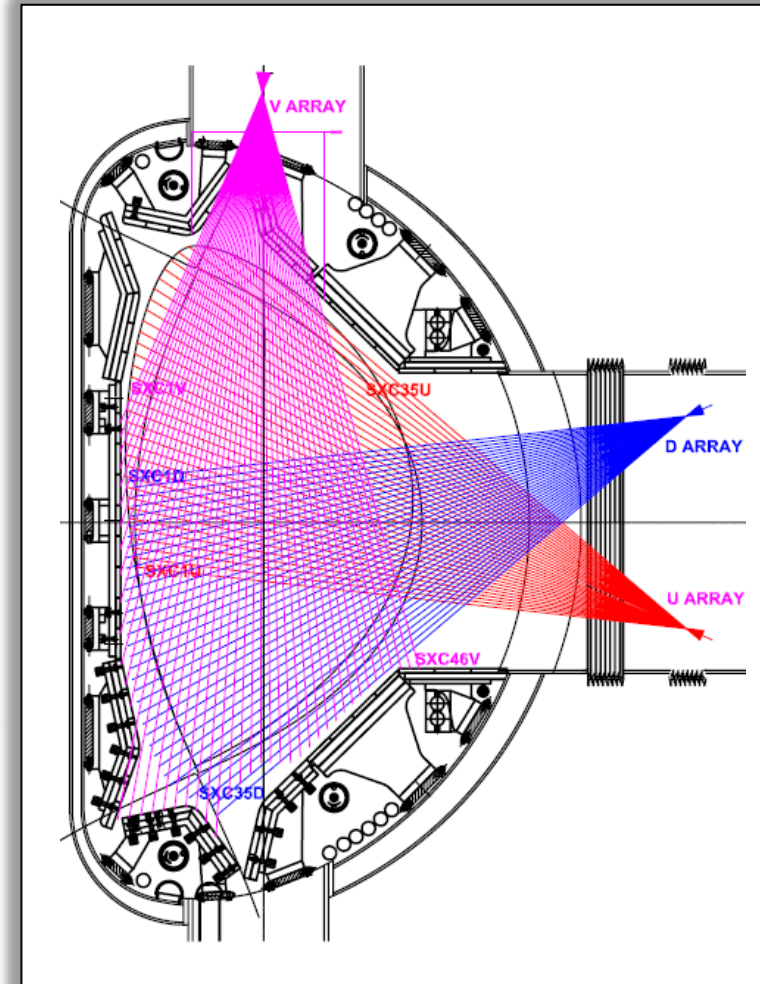


Target Probes & Edge Spectroscopy

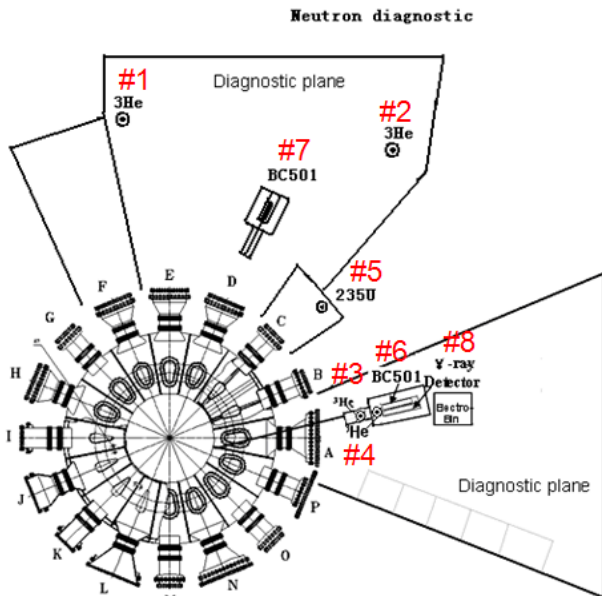


Impurity Radiation Measurements

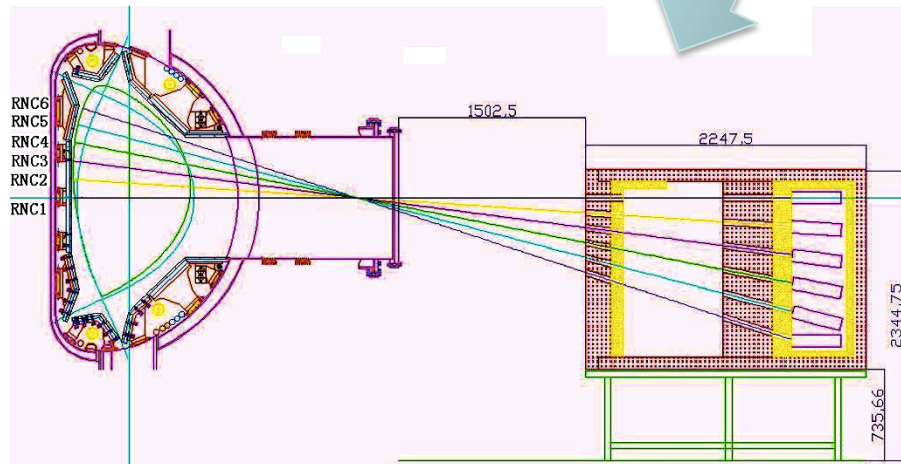
- Extreme Ultraviolet Spectrometers
- Soft X-ray PHA System
- Bolometer diagnostic System
- Soft x-ray imaging system



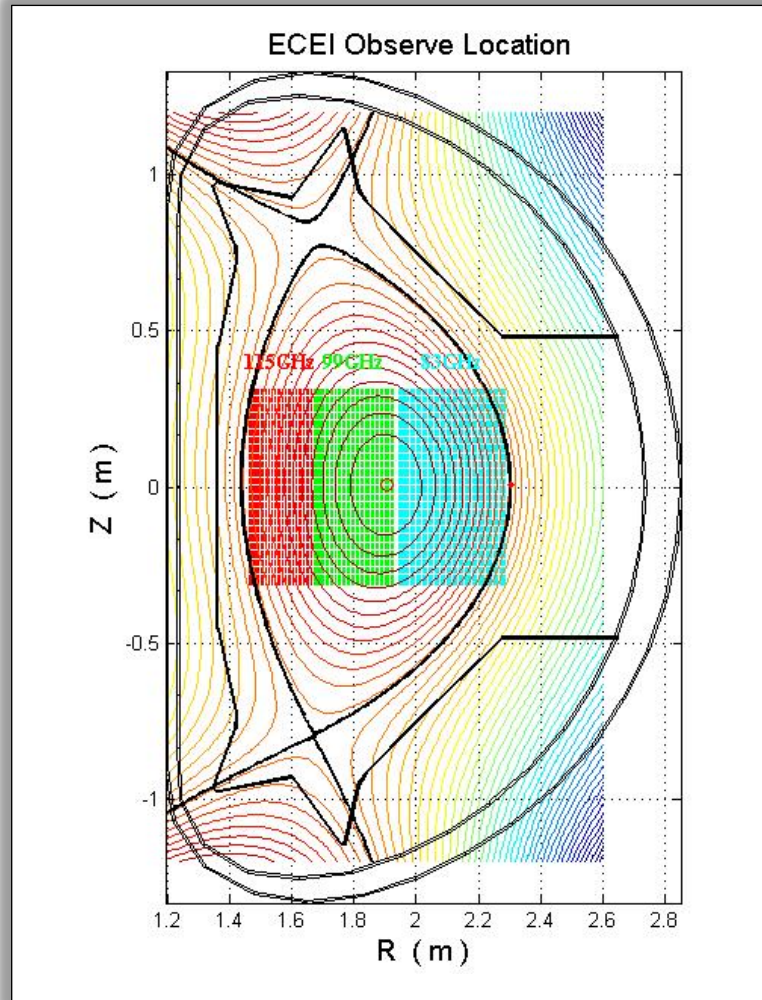
Energetic Particle Measurements



- Hard x-ray Diagnostics
- Runaway Electron diagnostic System
- Neutron measurements

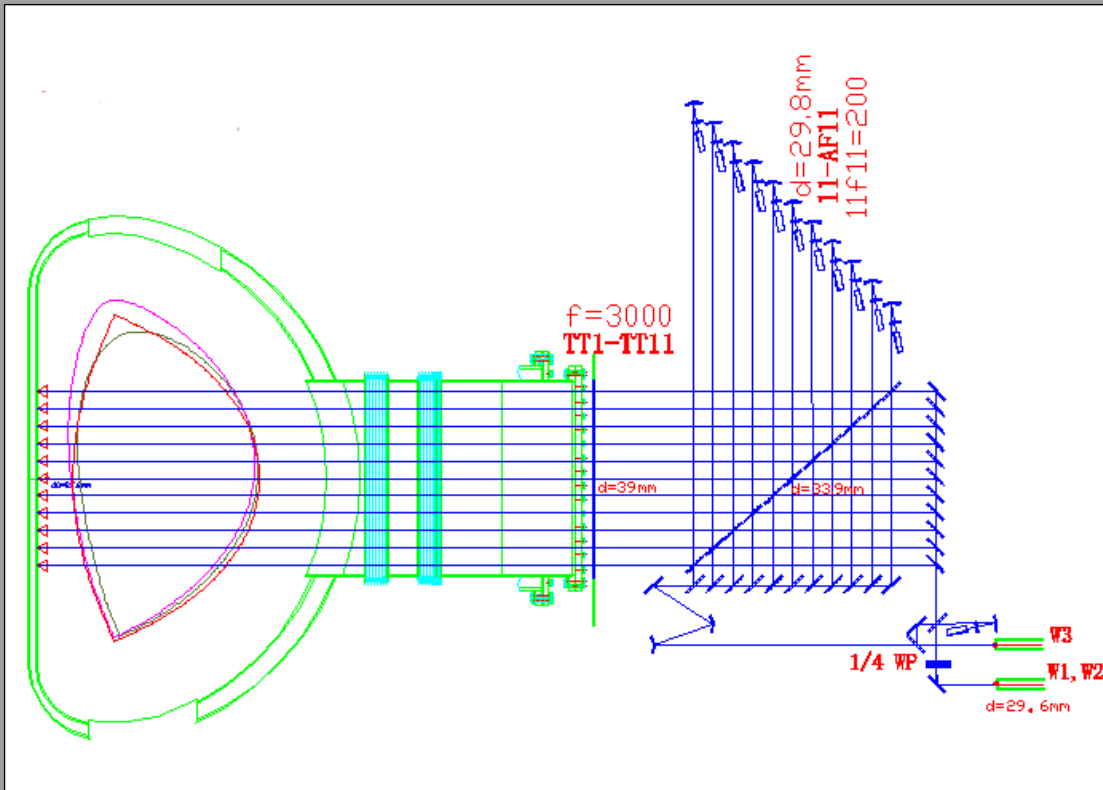


Fluctuations



- ECEI System
- Tangential CO₂ Laser Collective Scattering System
- Gas Puff Imaging System

Many Advanced Diagnostics Are Being Developed, e.g.,



EAST Faraday Rotation System

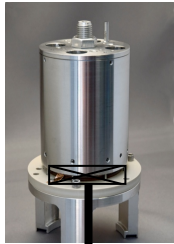
- 3-beam FIR laser (694 GHz) [Coherent Inc.]
- R-, L-wave technique used on C-Mod and MST
- High-speed, low-noise planar diode mixers
- time response $\sim 1 \mu\text{s}$
- Low phase noise: ability to see small equilibrium changes and fluctuations

in collaboration with UCLA (Brower/Ding)

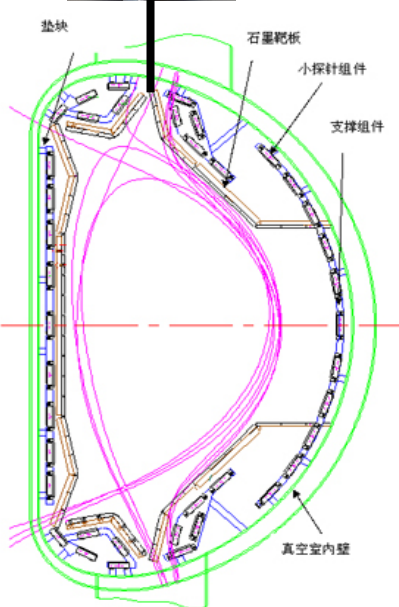
Developed Advanced Wall Conditioning for Recycling & Impurity Control

Li Coating

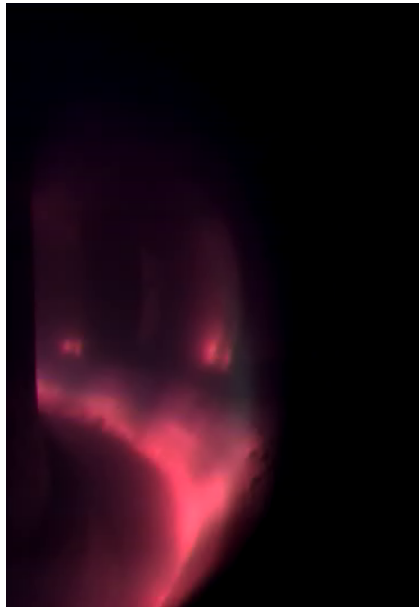
- RF Li coating
- Li evaporating
- Li droplets



In collaboration
w/ PPPL



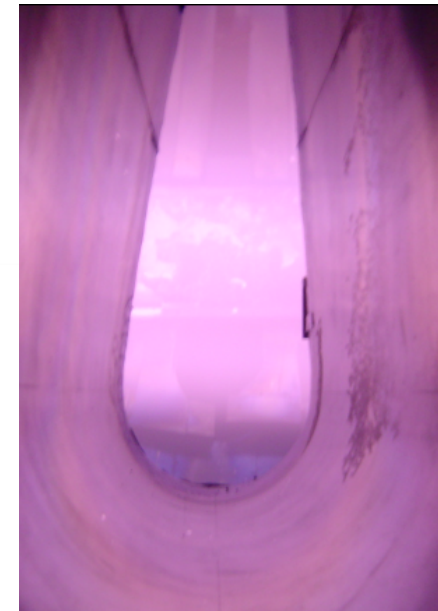
小探针在真空室内截面安装位置



ICR Conditioning



HF GDC

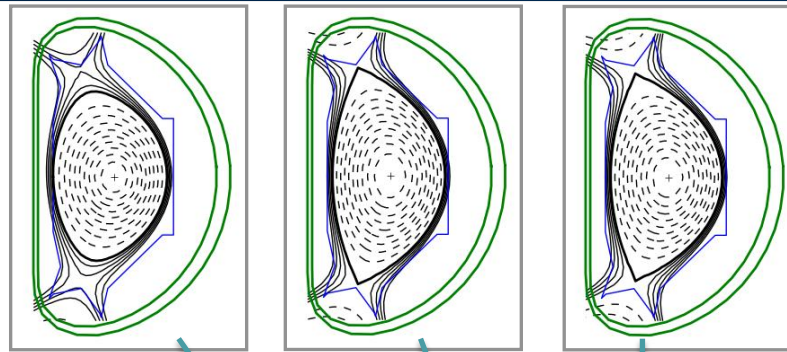


Outline

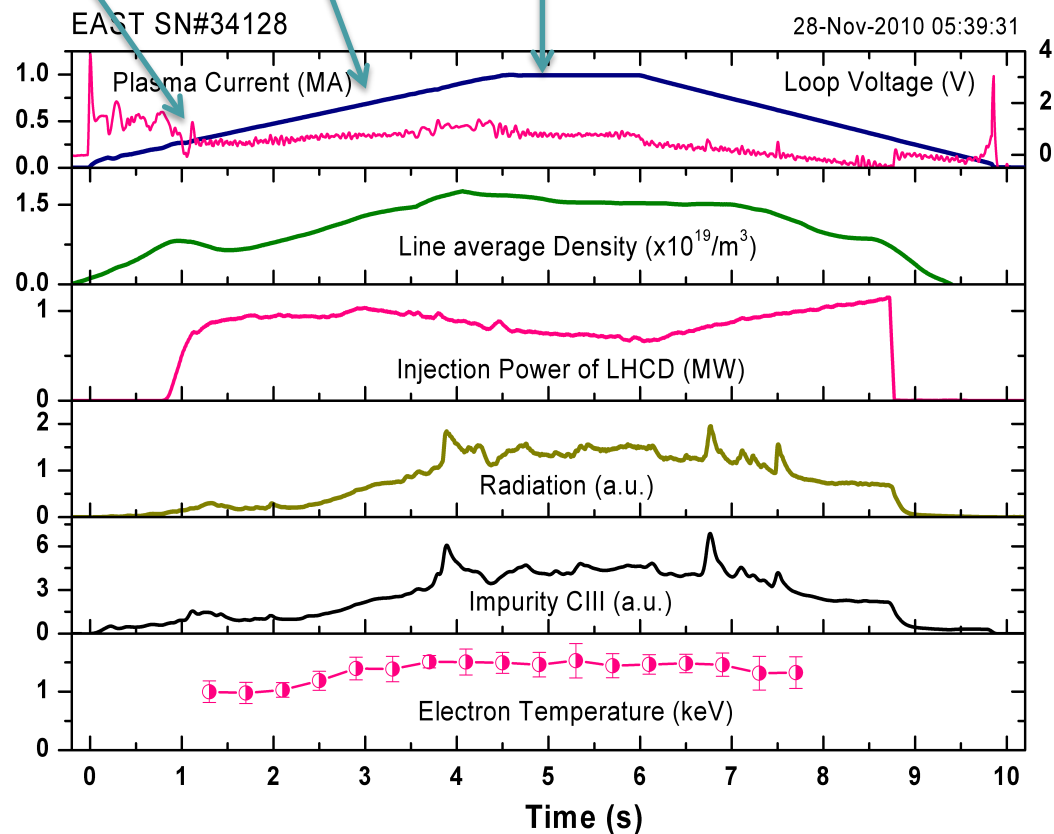
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Approaches to Full Current 1 MA Plasma Operation

- Increased initial magnetization currents: 8→12 kA
- HFGDC preionization for reliable break down
- Well conditioned wall w/ Li to reduce impurity radiation
- Current ramping up assisted w/ LHW



**Well
controlled
configuration**



Demonstrated Long Pulse Plasma Operation up to 100 s

Heat load control:

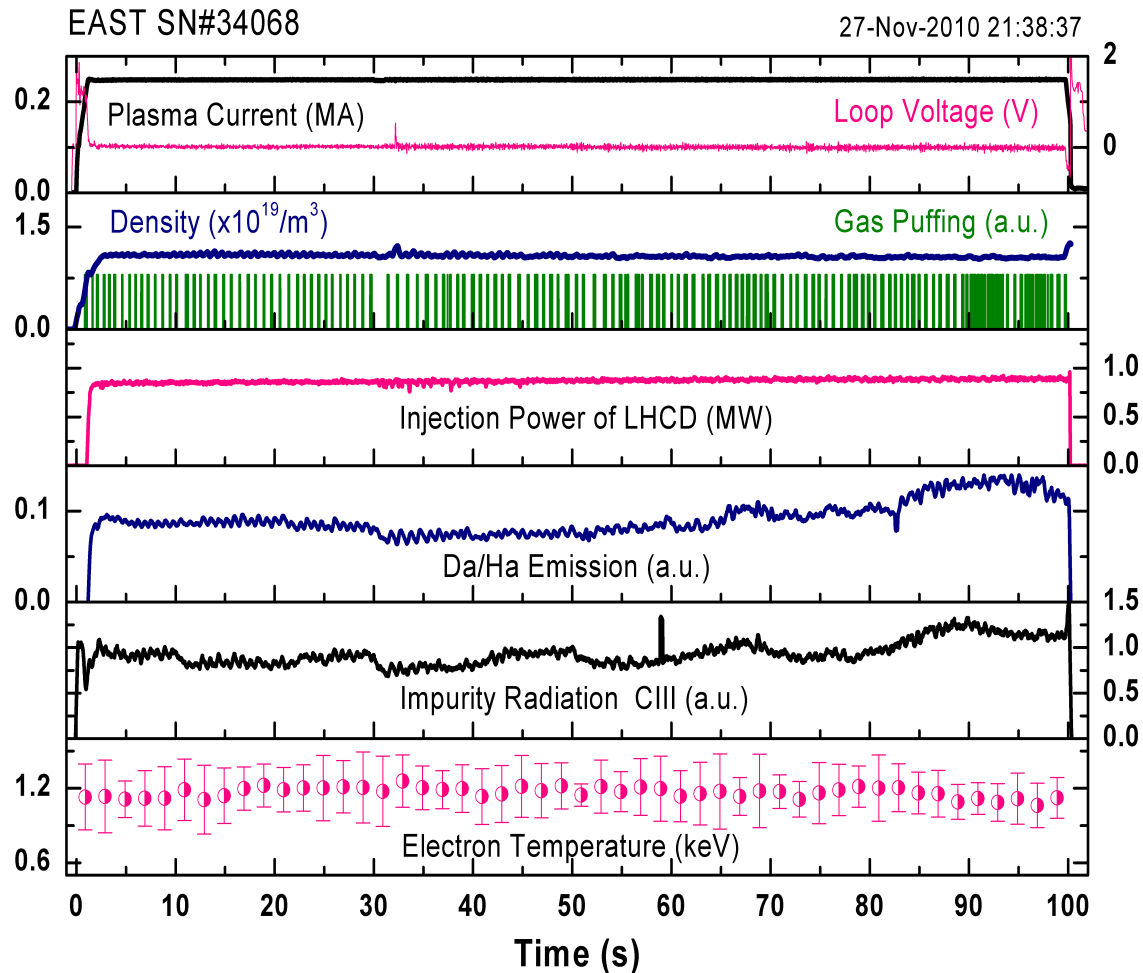
- sweeping strike points
- divertor gas puffing.

Recycling control:

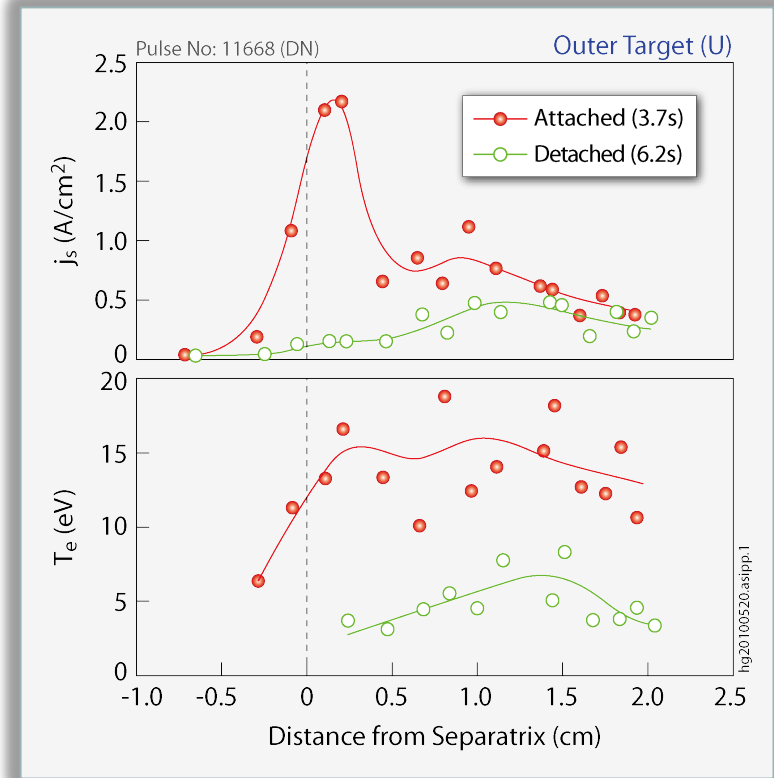
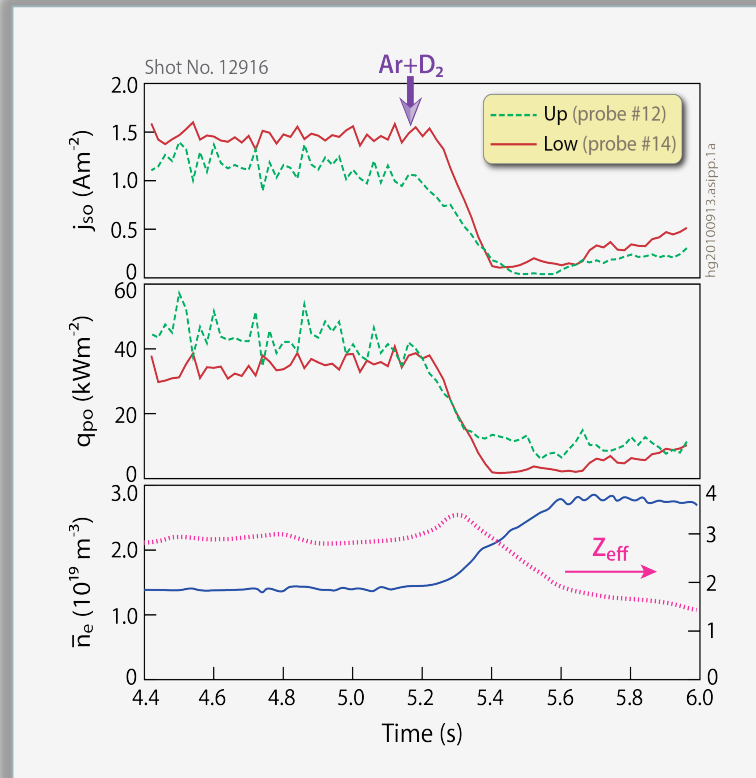
- internal cryo-pump
- RT wall conditioning w /Li powder injection.

LHW coupling:

- optimized by controlling plasma position and shape.

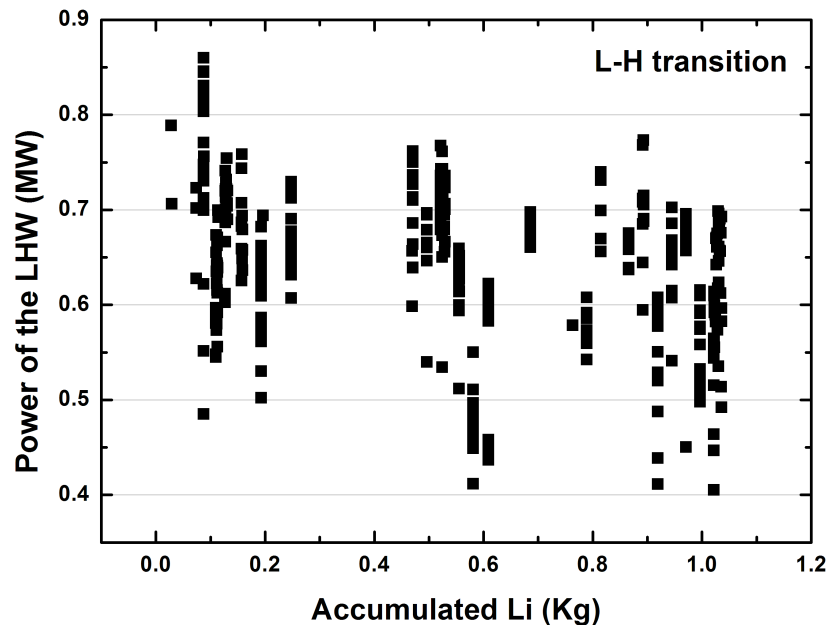


Active Control of Heat Load by Divertor Ar Puffing for Long Pulse Operation

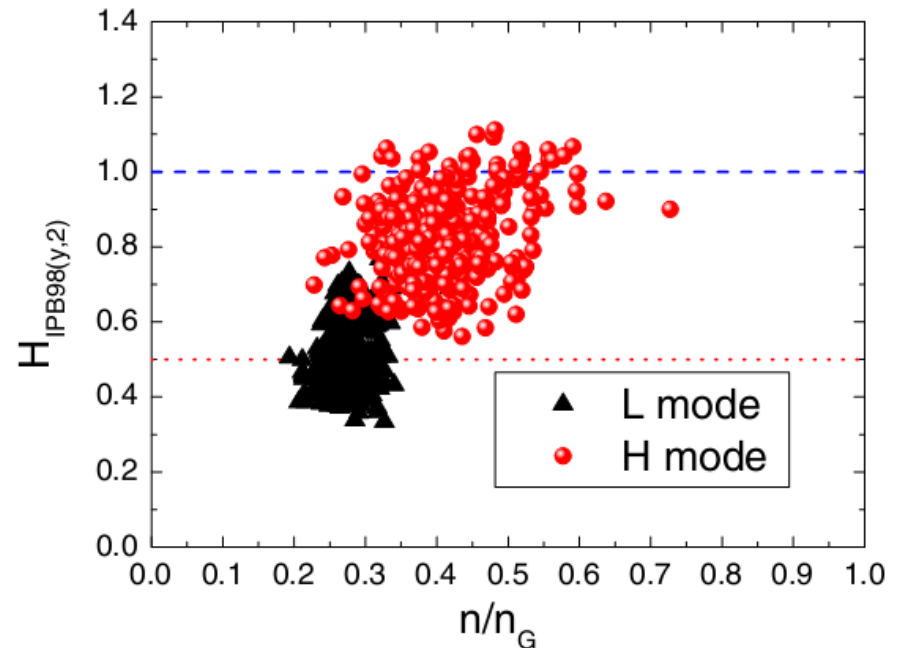


- Ar puffing promotes detachment, reducing peak heat flux.
- Detachment is needed for high power long pulse operation.

Achieved First H-mode with Li Coating at Marginal Heating Power

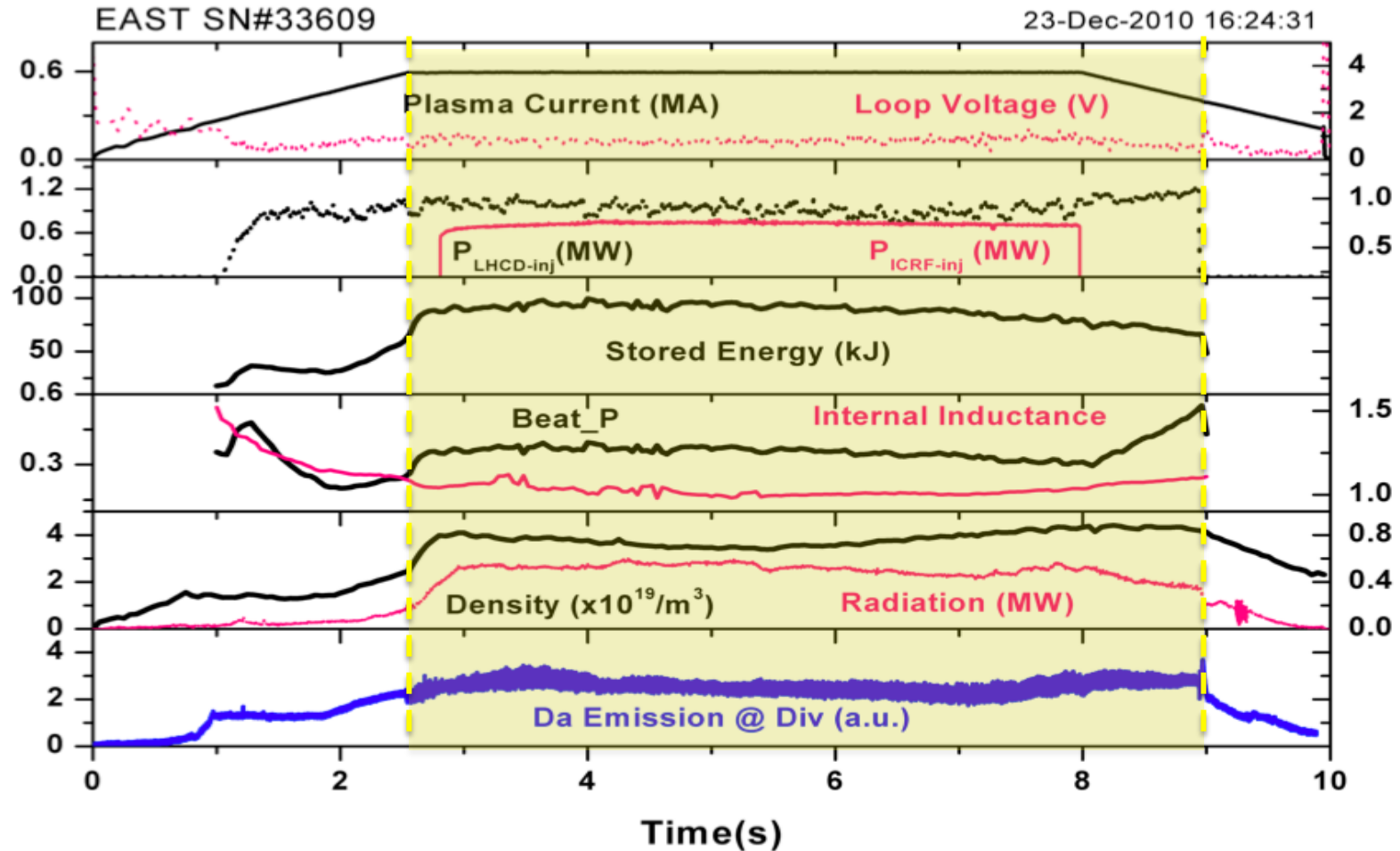


LHW input power required for H-mode access decreases at increasing Li accumulation.



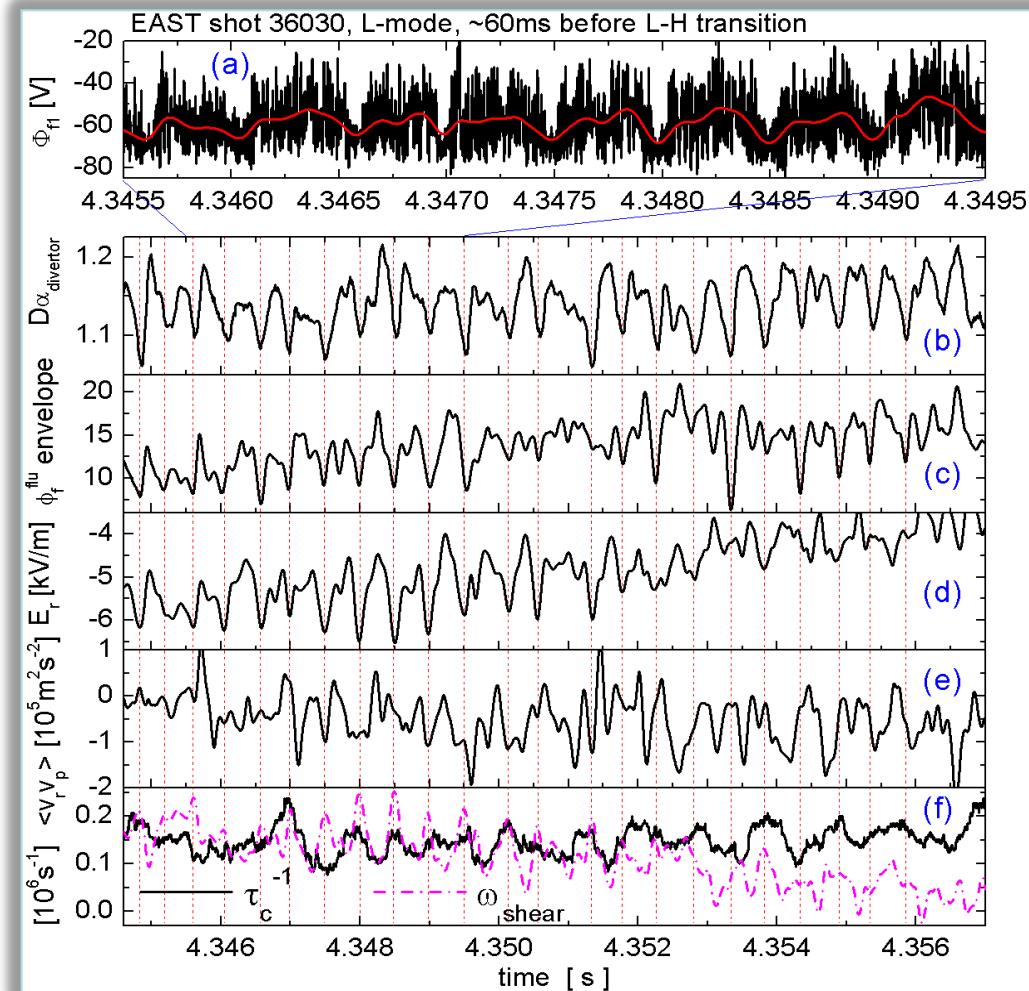
Obtained relatively good confinement, despite low input power w/ $H_{98} \sim 0.8$.

Achieved Stationary H-mode up to 6.4 s w/ Combined LHCD & ICRH



- H mode has just been extended to 10 s during the present campaign.
- Achieving H-mode during ramp-up, flat-top and ramp-down phases is important for ITER.*

Identified Important Role of Turbulence Driven Zonal Flows at L-H Transition



- Energy transfer rate from turbulence to zonal flows

$$\gamma \equiv \langle v_p \rangle \langle \tilde{v}_r \tilde{v}_p \rangle / (\Delta r \langle \tilde{v}_p^2 \rangle)$$

$$\sim 2 \times 10^4 \text{ s}^{-1}$$

- Zonal flow damping

$$\tau_{ii}^{-1} \sim 1 \times 10^4 \text{ s}^{-1}$$

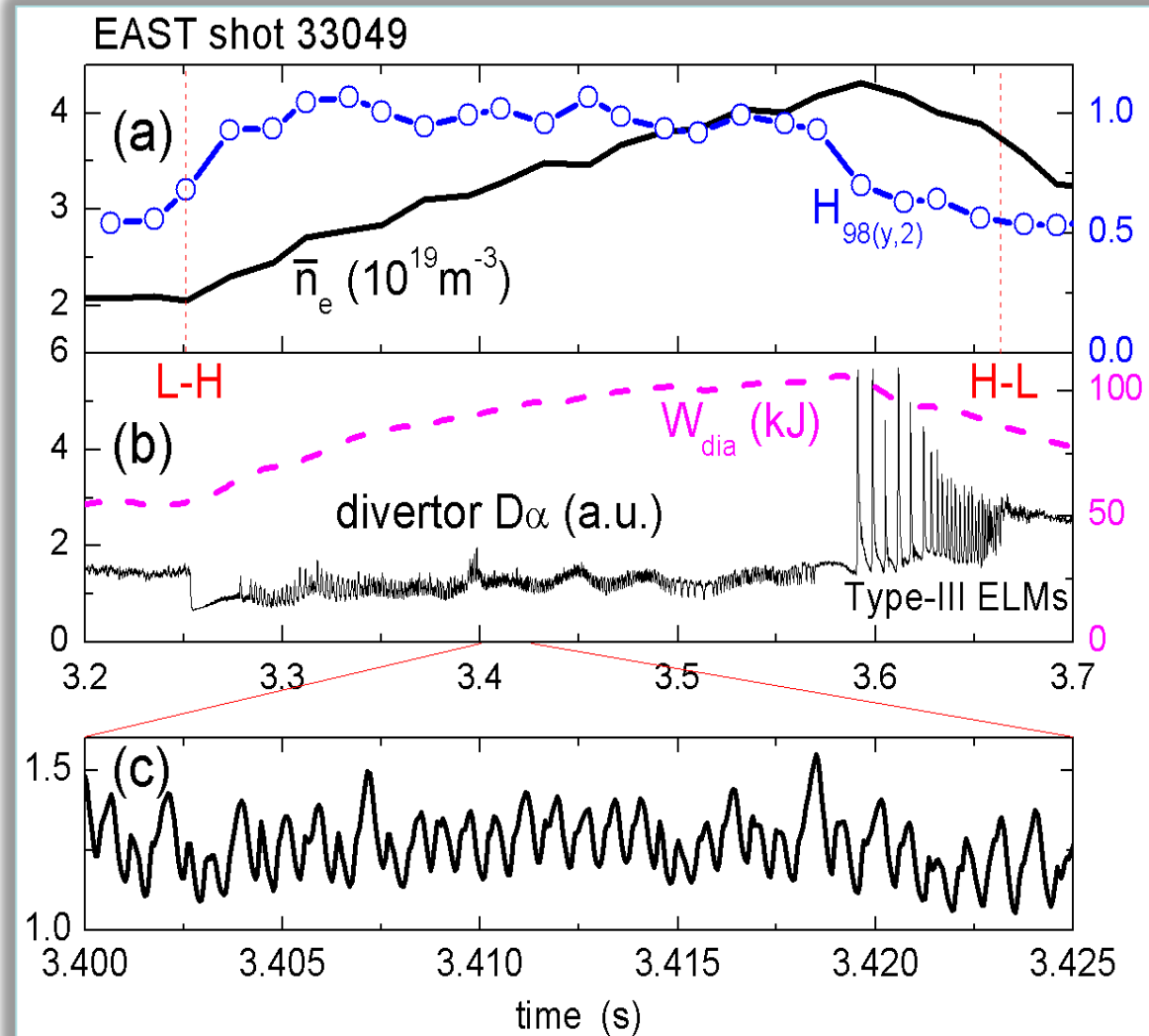
This indicates that the turbulence force is strong enough to overcome the damping force, thus driving the oscillating zonal flows.

G.S. Xu et al., PRL107, 125001 (2011).

Zonal-flows Also Appear at H-mode Pedestal Associated with Small ELMs

A new small-ELM at H-mode pedestal appears with excellent confinement.

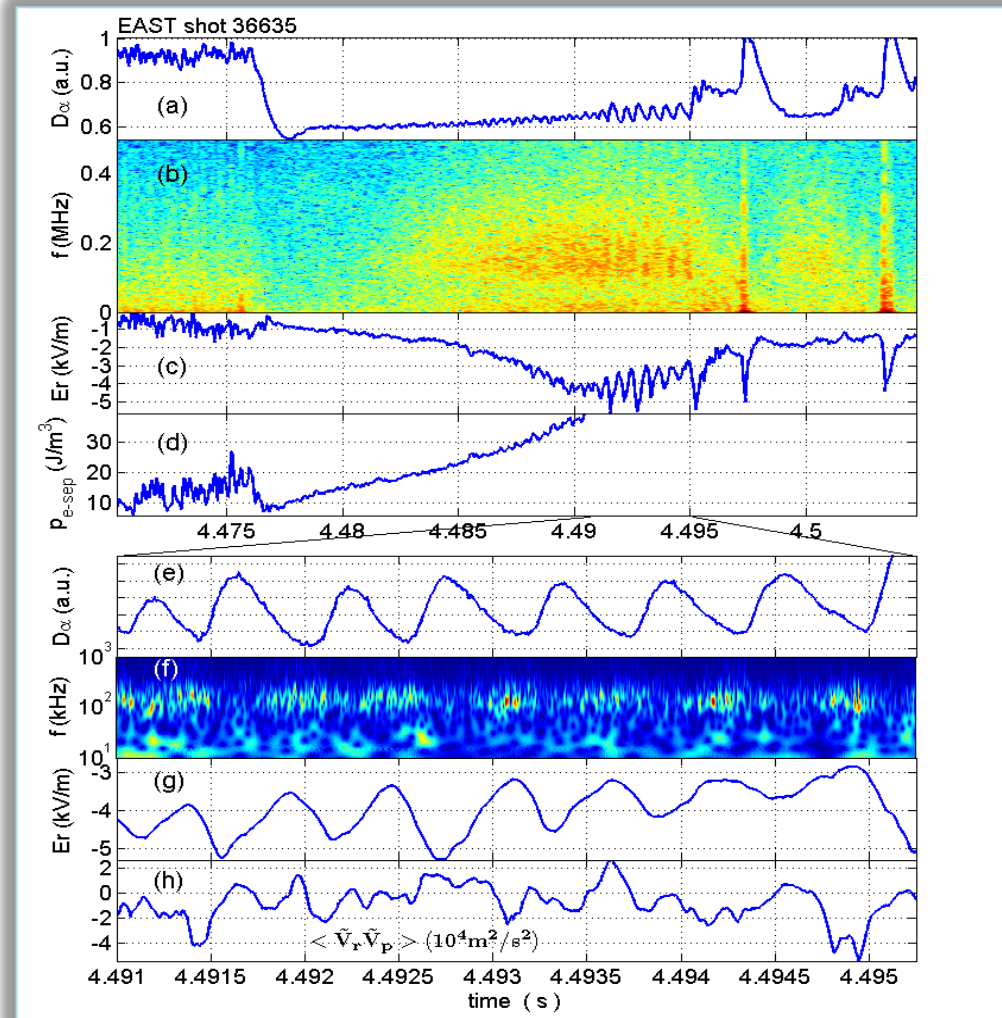
Concomitant with oscillating zonal flows & a high-frequency broad-band turbulence



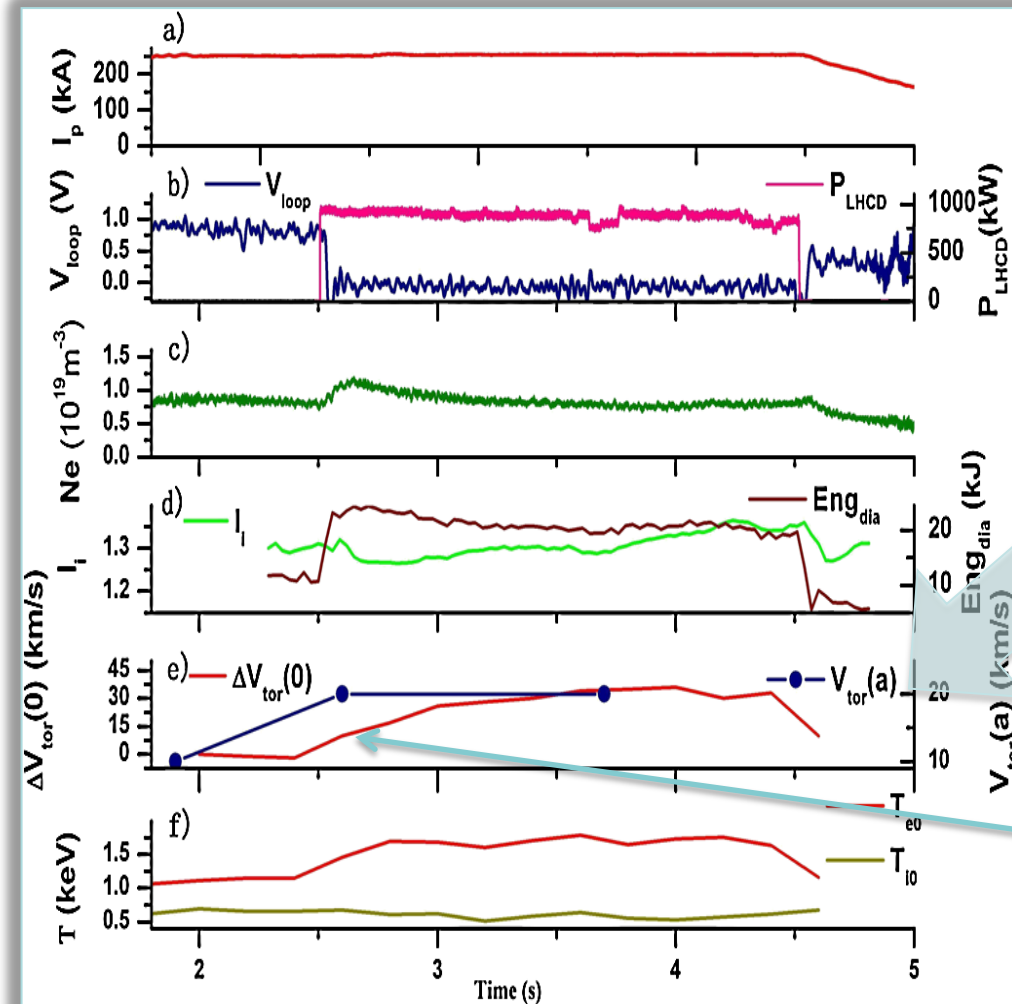
High-frequency Broad-band Turbulence at Edge Concomitant w/ Zonal Flows

- High-frequency turbulence (50-500 kHz) and Reynolds stress is modulated by zonal flow oscillations.
- Suppressed when local E_r becomes more negative, i.e. w/strong shear.

This strongly suggests that small ELMs may be produced by the interactions between high frequency turbulences & zonal flows.



Co-current Toroidal Rotation Driven by LHCD at both Core and Edge in L-mode



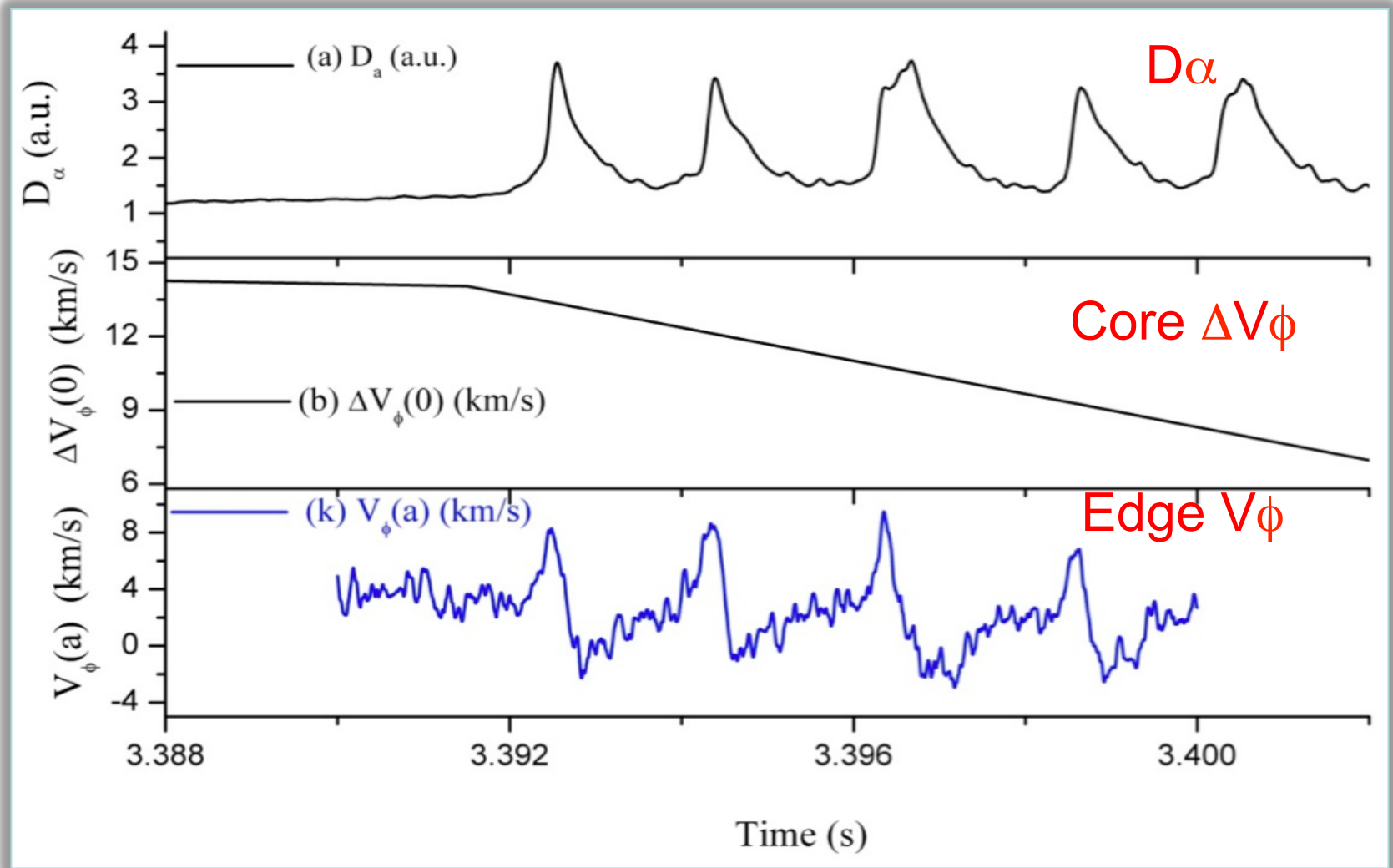
Co-current toroidal rotation Speed:

- 40 km/s in core plasma
- 20 km/s at edge

Edge spins up first, indicating momentum source from edge.

Y.J. Shi et al., PRL106, 235001 (2011).

Evidence of Toroidal Rotation Breaking by ELMs



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Recent Enhancements to EAST

- Upgraded PF power supply, control & VDI stabilization systems
- Upgraded PFC for 250°C baking & Li coating system for longer pulse
- New CW pellet & SMBI for ELM control & deeper fuelling.
- Augmented auxiliary heat capabilities
 - ✓ 4 MW LHCD @ 2.45GHz
 - ✓ 1.5MW ICRF @ 30-110MHz
 - ✓ 4.5MW ICRF @ 25-75MHz
- Enhanced diagnostic capabilities

0.6-1 MA

**Long pulse
H-mode**

For ITER

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

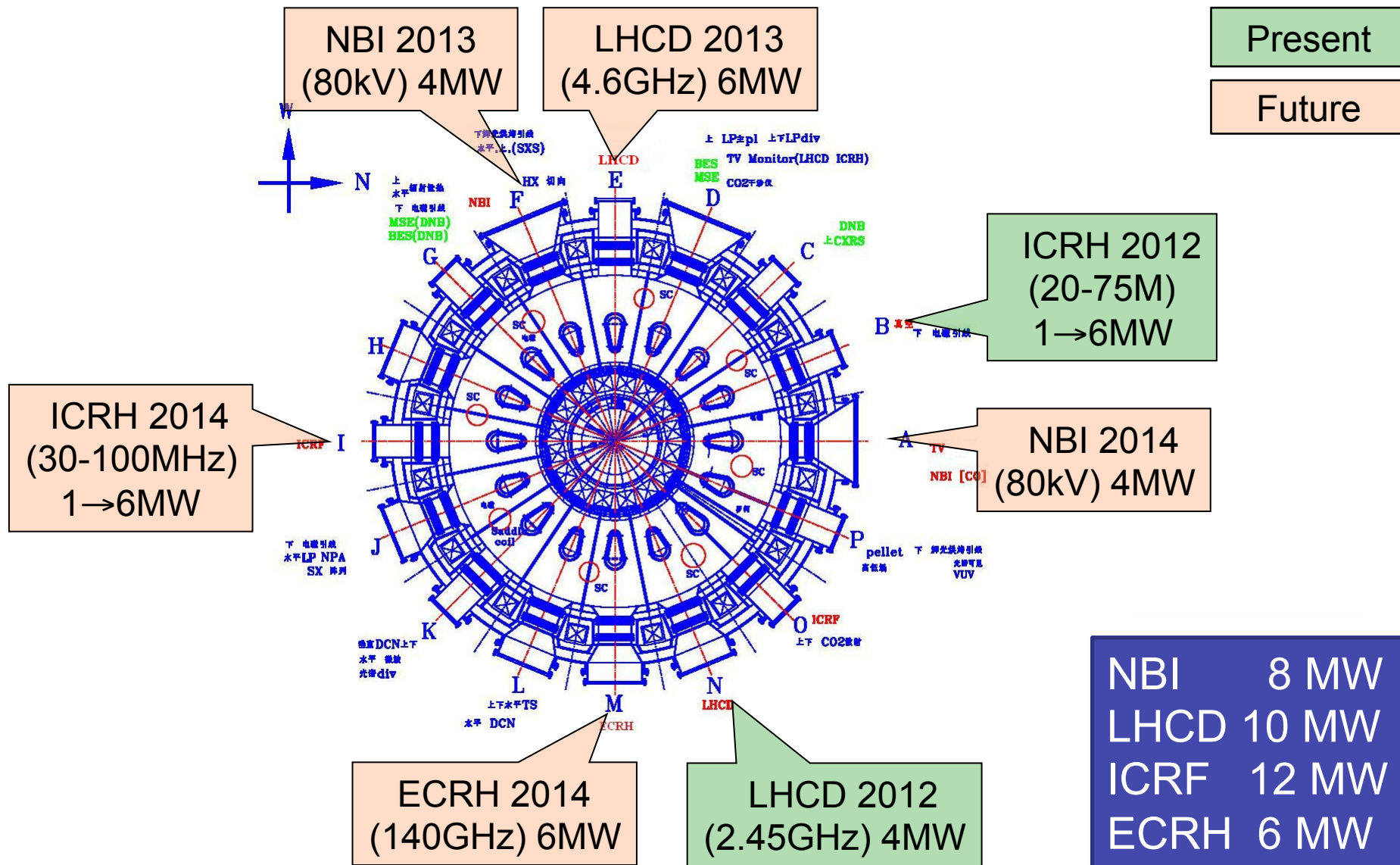


EAST 5-Year Plan

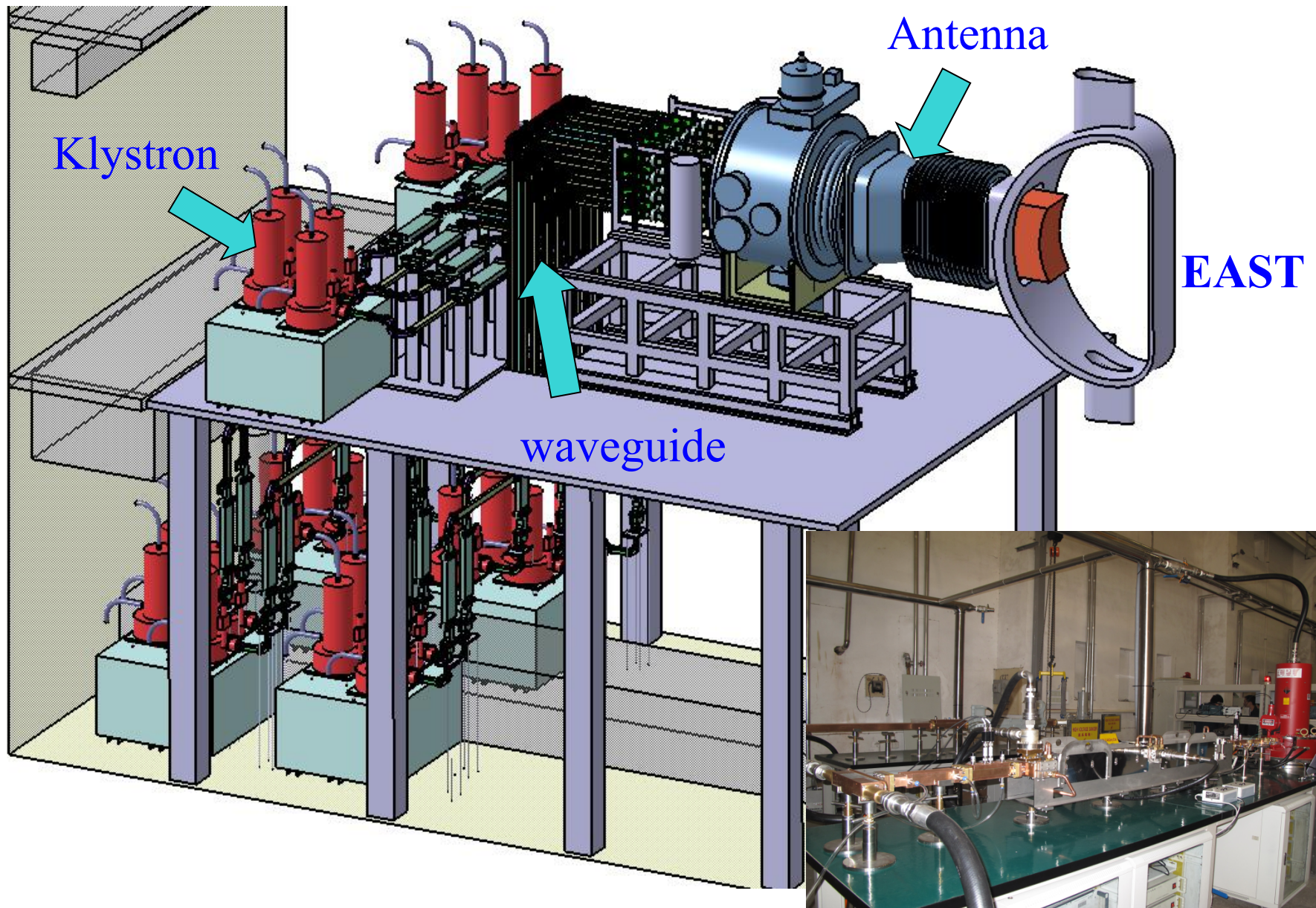
	2011	2012	2013	2014	2015
Ip(MA)	1.0	1.0	1.0	1.5	1.5
LHCD(MW, CW)					
2.45GHz	4.0	4.0	4.0	4.0	4.0
4.6GHz			6.0	6.0	6.0
ICRF(MW,CW)					
20-75MHz	4.5	4.5	4.5	4.5	4.5
30-100MHz	1.5	4.5	4.5	4.5	4.5
NBI(80keV)			4.0	8.0	8.0
ECRH(140GHz,cw)	2.0	4.0	4.0	6.0	6.0
Diagnostics	40	45	50	50	50
Duration(s)	100	200	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 plasmas for ITER within next 5 years

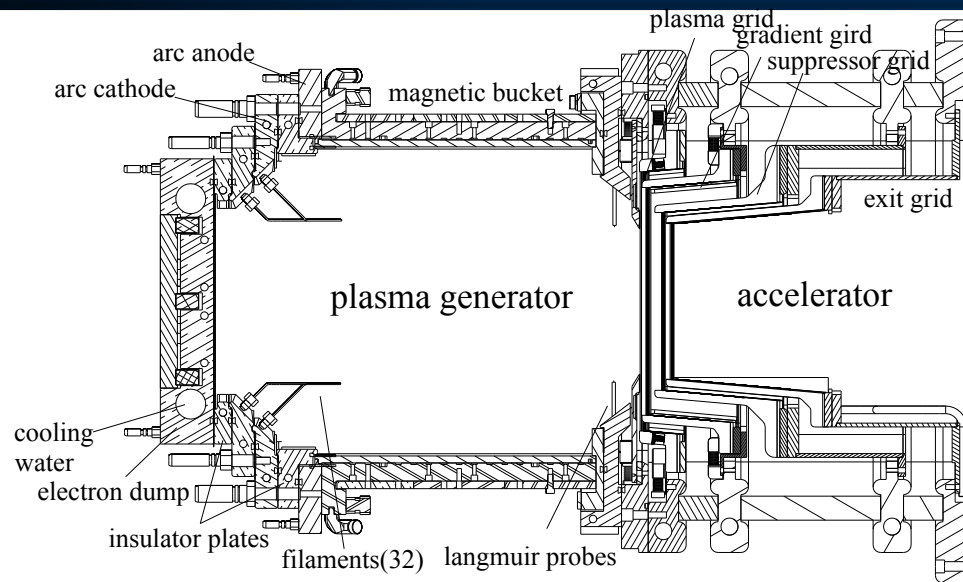
H&CD Systems for EAST



4.6 GHz LHCD Microwave System

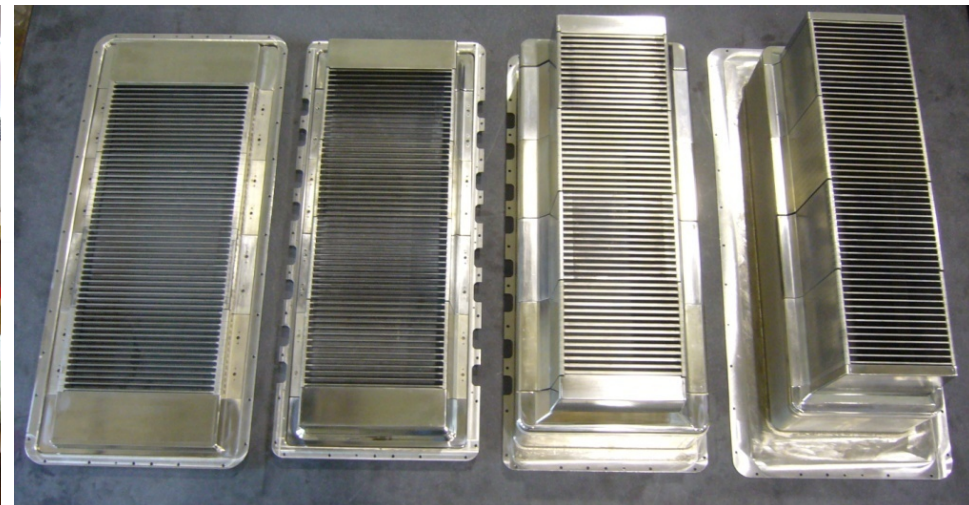
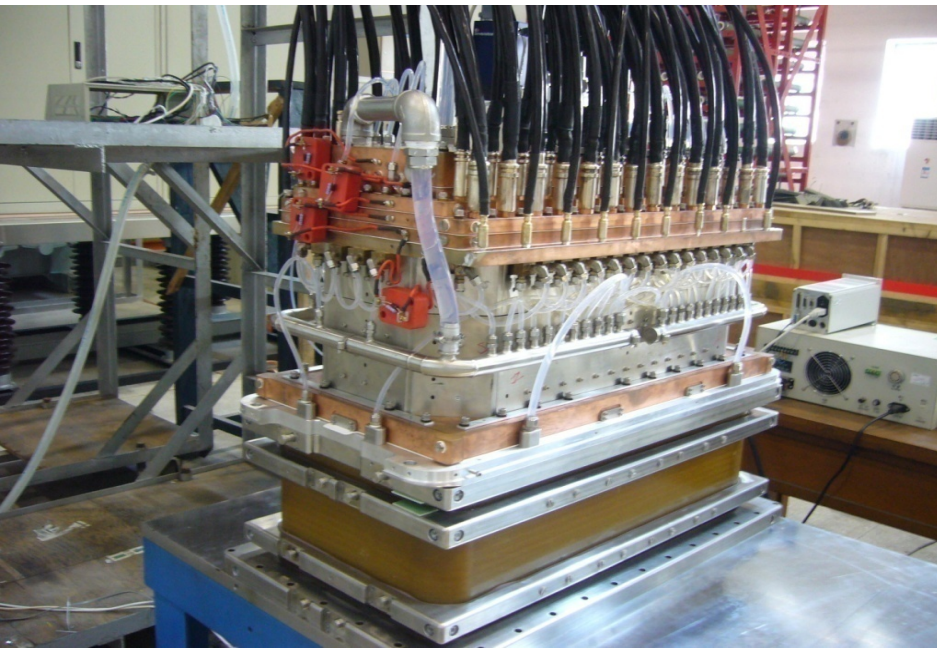


Development of NBI Ion Source



- 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)



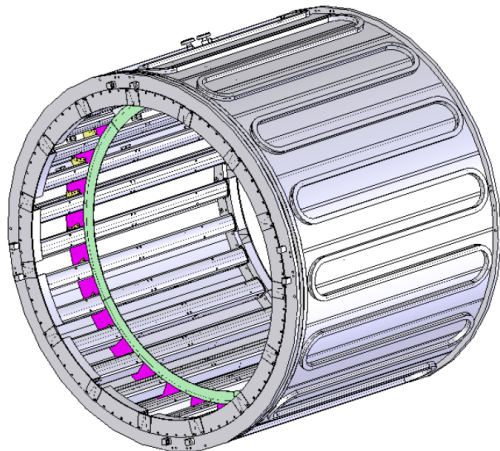
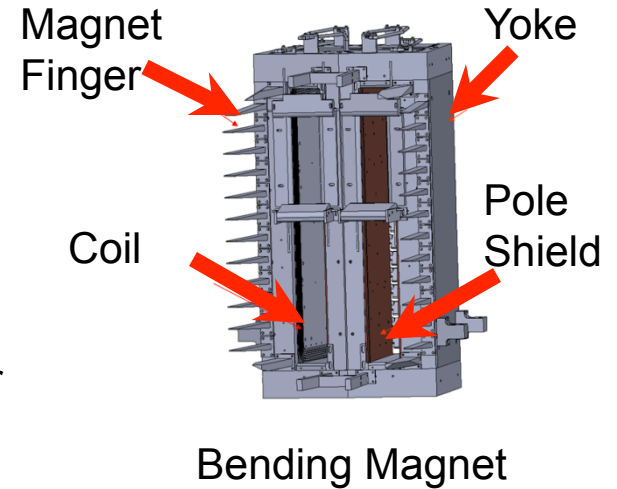
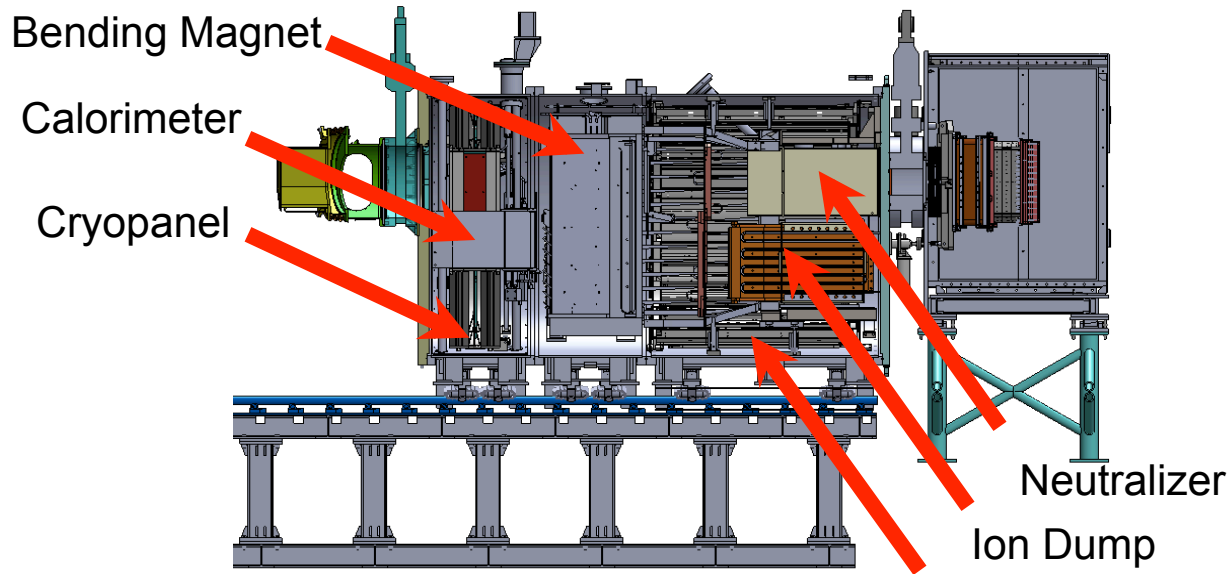
Plasma Grid

Gradient Grid

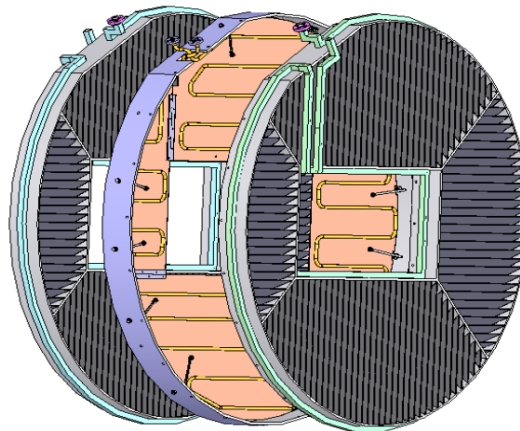
Suppressor Grid

Exit Grid

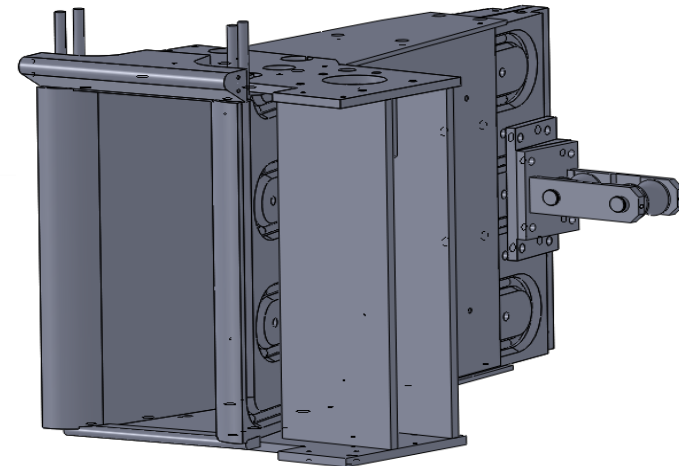
NBI Beamline Components



Cryopanel—Spool 1

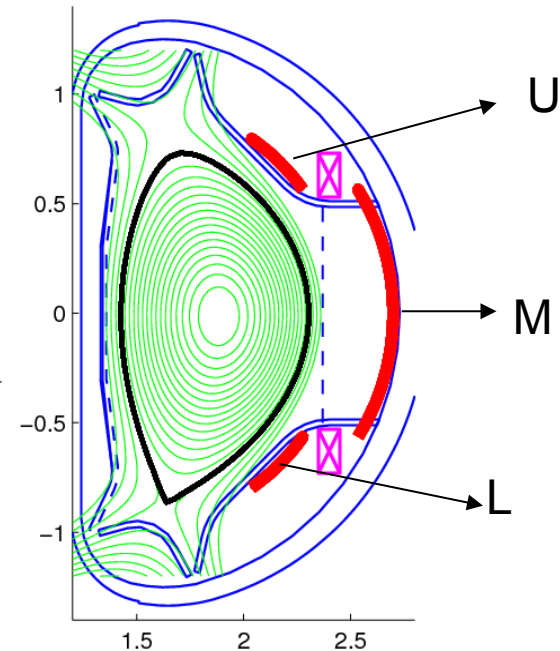
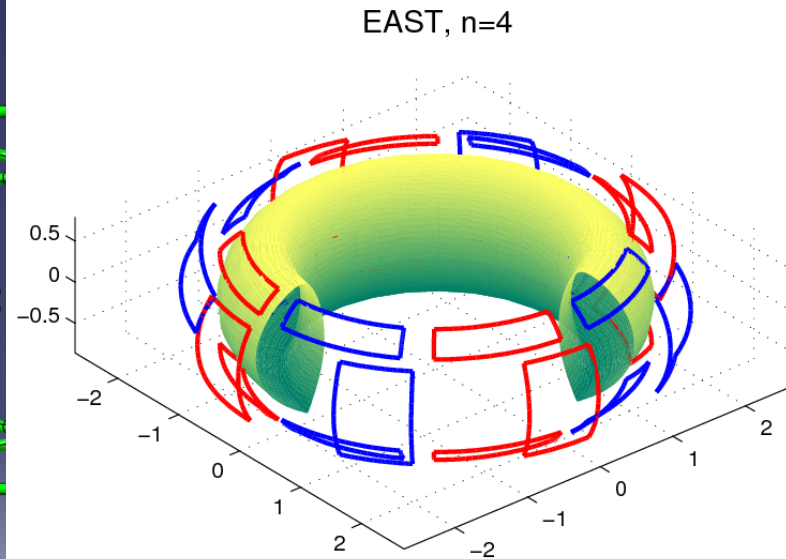
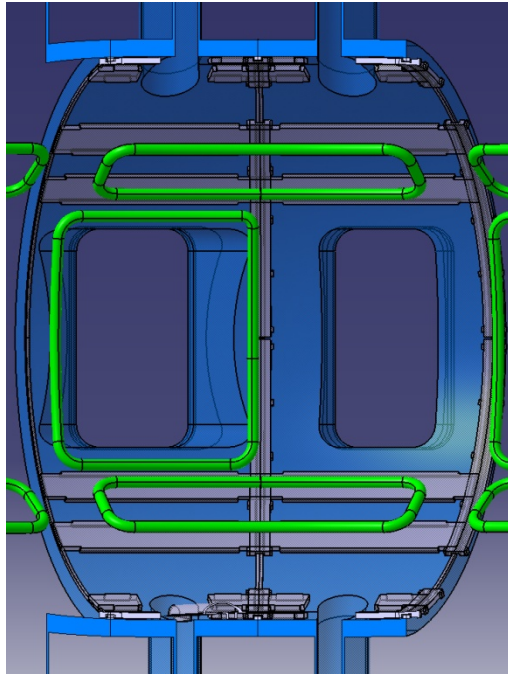


Cryopanel—Spool 3



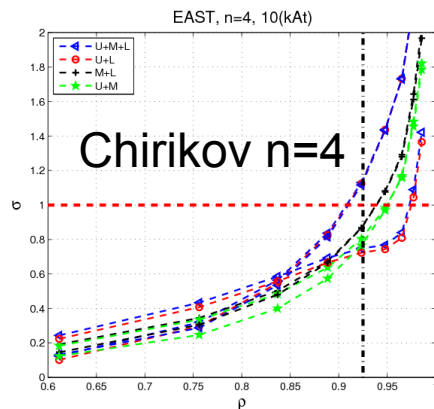
Calorimeter

Design of RMP Coils for ELM Control



$$8(U) + 8(M) + 8(L) = 24$$

8 coils can produce the spectrum
with $n = 1, 2, 4$ and quasi 3.
 $I_{\text{coils}} = 10 \text{ (kA*turns)}$



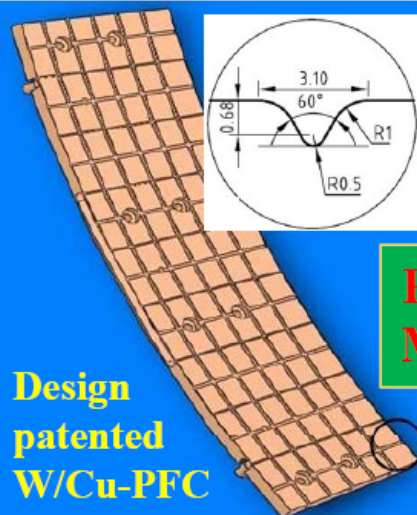
PFC Strategy for EAST:

$SS \rightarrow C \rightarrow Mo/C \rightarrow W \rightarrow$

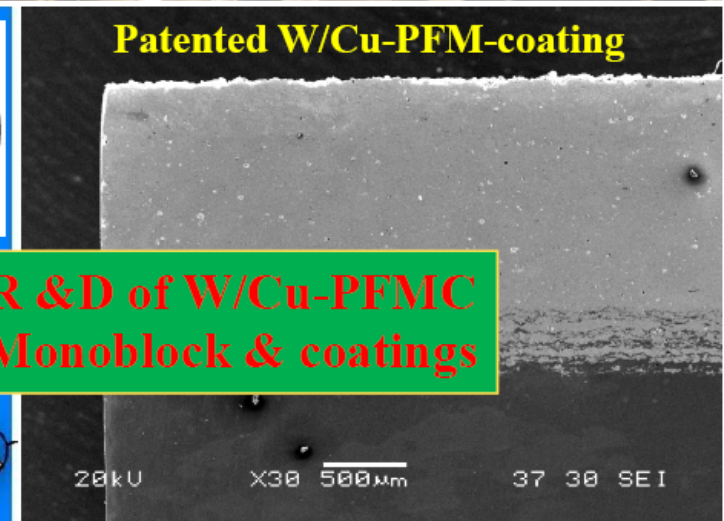
SS-PFM (2006-07)



SiC/C-PFM (2008-)



Patented W/Cu-PFM-coating



**R & D of W/Cu-PFMC
Monoblock & coatings**

Summary

- EAST has made significant progress on both technology and physics fronts since first plasma in Oct. 2006.
- Achieved stationary H-modes and made many innovative observations on H-mode physics.
- EAST is now starting a new campaign for high performance long pulse physics studies.

It will be a great challenge for 1MA/1000s H-mode 10MW/ m^2 operation. Your participation in EAST program to achieve these goals are most welcome.

Acknowledgements

Domestic

1. Hefei Institute of Physics Science, CAS
2. Hefei University of Technology
3. Donghua University, Shanghai
4. South West Institute of Physics, Chengdu
5. Tsinghua University, Beijing
6. USTC. Hefei,
7. Tianjin University, Tianjin
8. Thermal Power Research Inst. Co., Ltd, Suzhou
9. Jialong Co.,Ltd, Shanghai
10. Wuhu Shipyard,China State Shipbuilding Co.,Ltd
11. Wuhu Boiler Works
12. Shanghai Boiler Works Co.,Ltd.
13. Shanghai No.5 Steel Co.,Ltd .
14. Nuclear Non-Destructive Testing Centre

International

1. General Atomic, USA
2. FRC, UT at Austin, USA
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4. Washington University, USA
5. IPP_Garching, Germany
6. FZJ_Juelich, Germany
7. NIFS, Toki, Japan
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