Present State and Future Plan of MCF Research in China

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Outline

HL-2A Tokamak

EAST Tokamak

- Physical engineering capability
- Main experimental results
- Research Plan in next 2-5 years

ITER-CN Activities

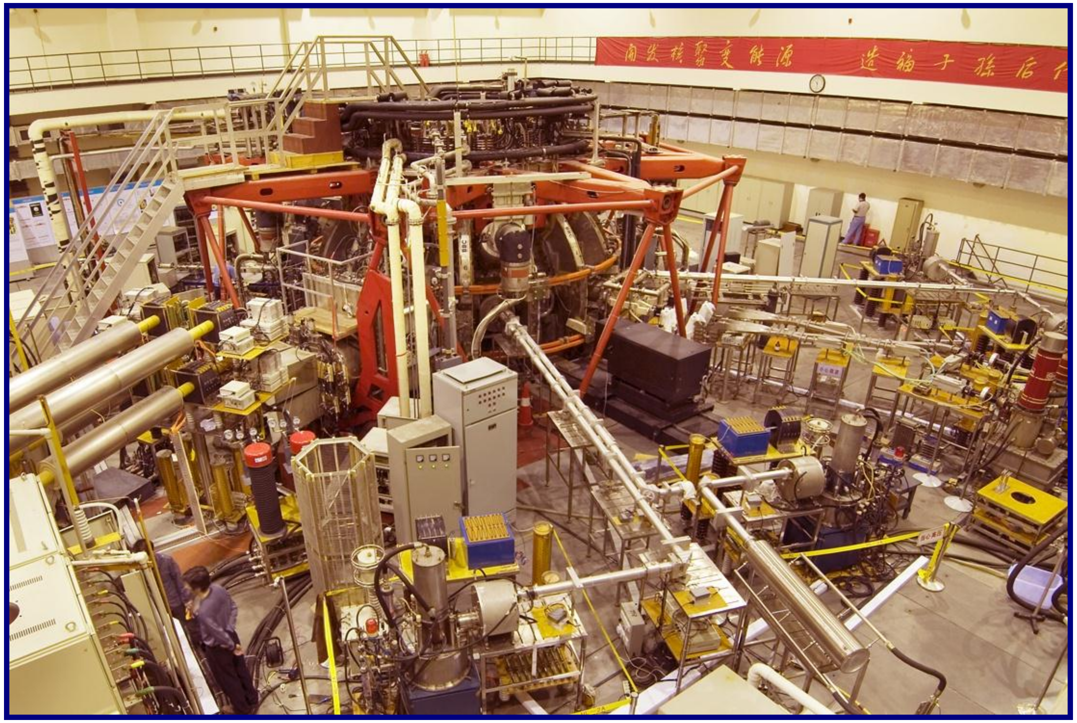
Future Plan of CN-MCF program

Summary

SWIP

Status of HL-2A

HL-2A



- *R:* 1.65 m
- *a:* 0.40 m
- *Bt:* 1.2~2.8 T
- *Configuration:*
  Limiter, LSN divertor
- *Ip:* 150 ~ 480 kA
- *ne:* 1.0 ~ 6.0 x 10^{19} m^{-3}
- *Te:* 1.5 ~ 5.0 keV
- *Ti:* 0.5 ~ 1.5 keV

Auxiliary heating:

ECRH/ECCD: (3+2)MW

(6/68 GHz/500 kW/1 s)

modulation: 10~30 Hz; 10~100 %

NBI(tangential): 1.5 MW

LHCD: 1 MW

(2/2.45 GHz/500 kW/1 s)

Fueling system (H_2/D_2):

Gas puffing (LFS, HFS, divertor)

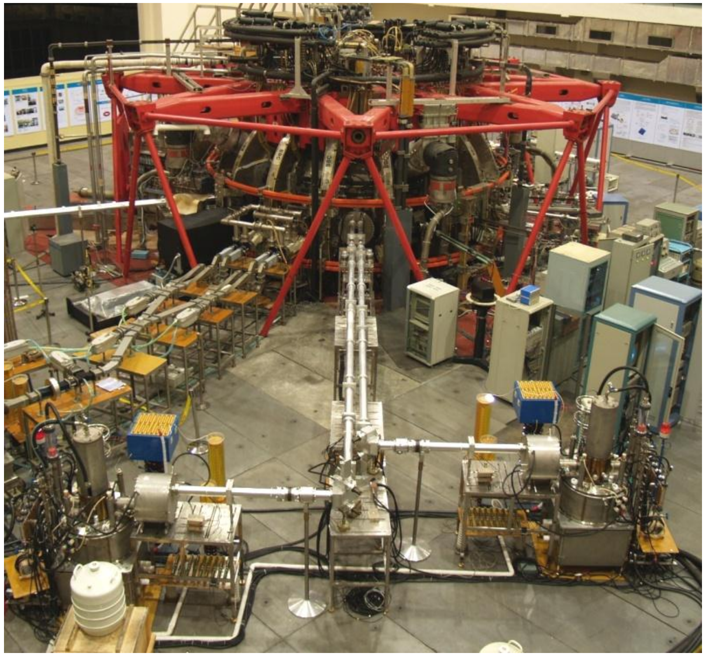
Pellet injection (LFS, HFS)

SMBI (LFS, HFS)

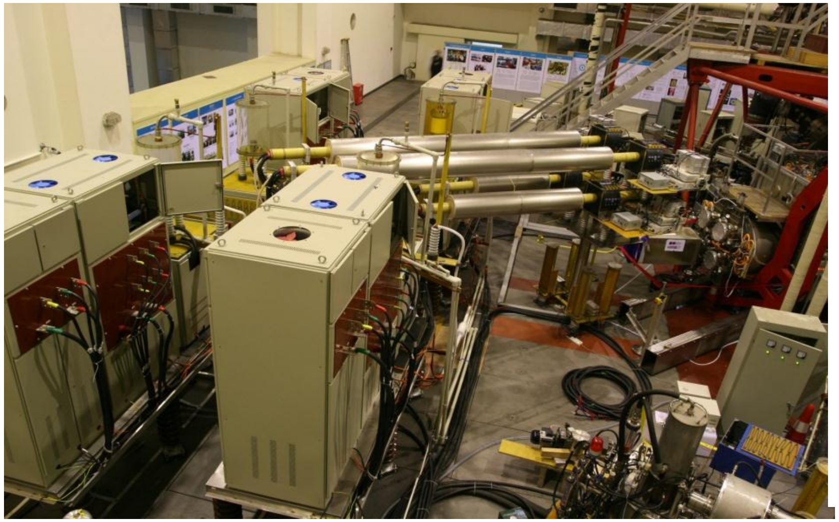
LFS: f =1~80 Hz, pulse duration > 0.5 ms

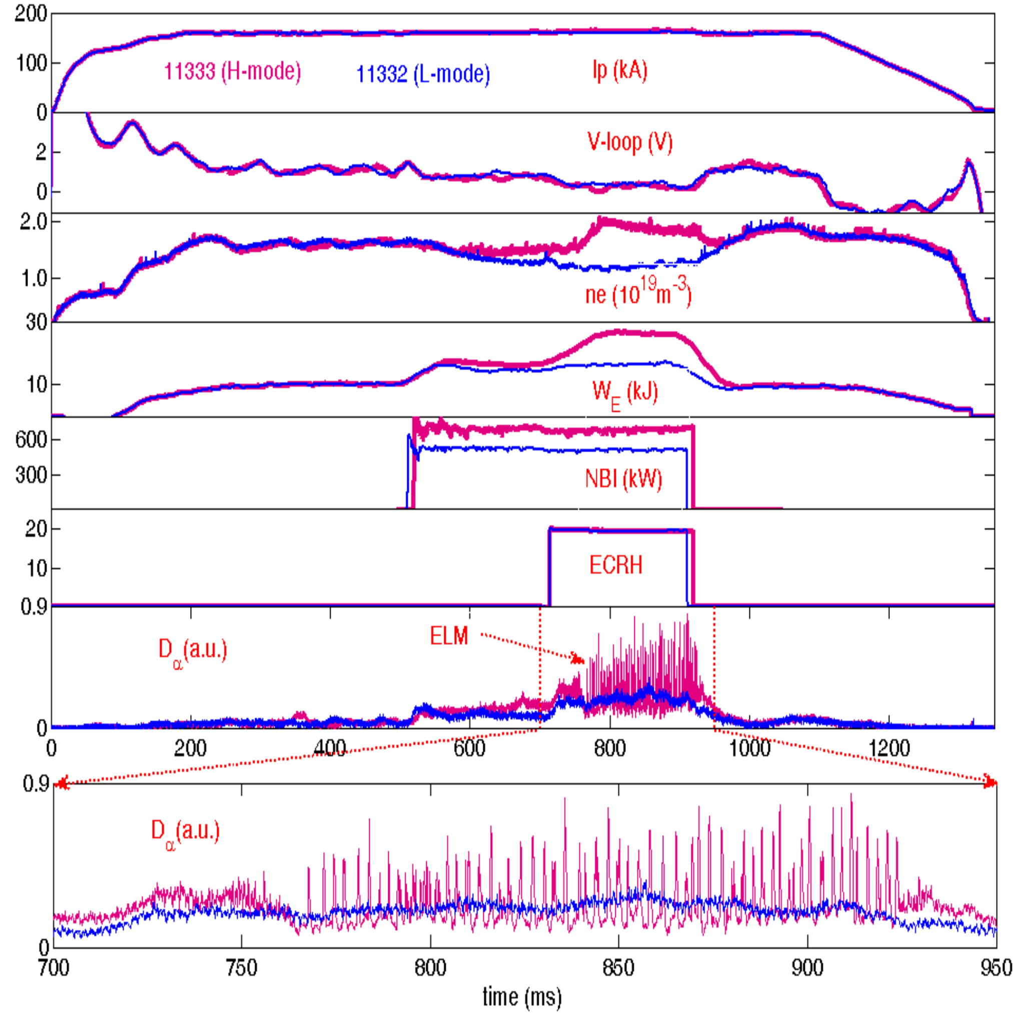
gas pressure < 3 MPa

ELMy H-mode discharges were achieved on HL-2A tokamak



3MW ECRH ,68GHz/1s
NBI :1.5 MW   40-60 keV,





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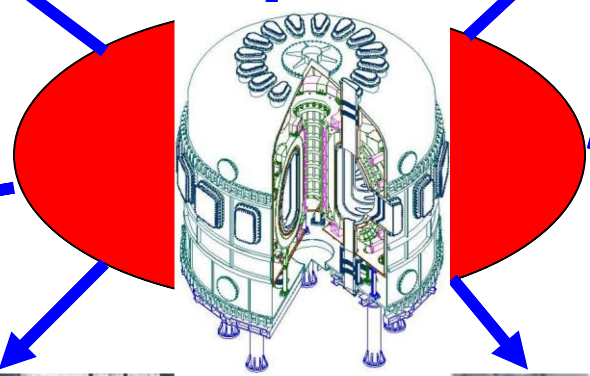
EAST: 5.5 years, 30M$ (TPX)

CICC & magnet design and fabrication

Control system

ICRH & LHCD system

SC magnet test



Vacuum pumping system

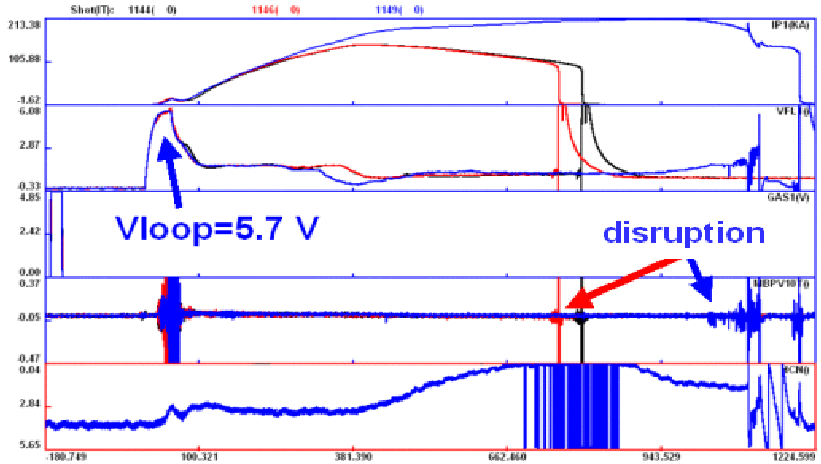
2kW/4.5K Cryogenic & refrigerator system

210MW Power supply system

ASIPP

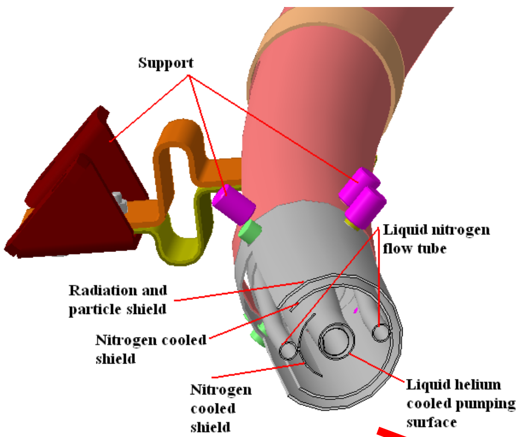
(GA,PPPL)

2006-9-26， 1st Plasma



Key elements in-vessel

Internal Cryo-Pump

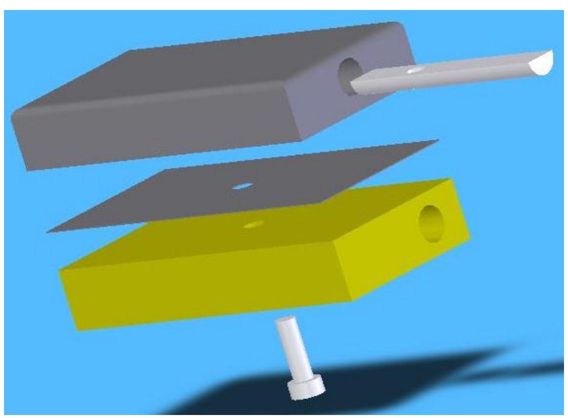


75,600L/S for D2
With DIII-D

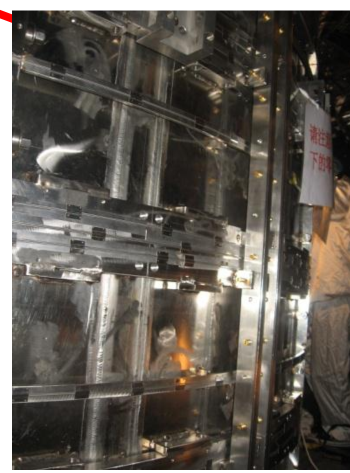
- Actively-cooled PFC
  (~9000 tiles)
- Internal Cryo-Pump
- **LHCD: 2.45GHz, 2MW**
- **ICRF: 30-110MHz,1.5MW**
- Magnetic sensors
- 2 Removable limiter

ICRH antenna

LHCD antenna

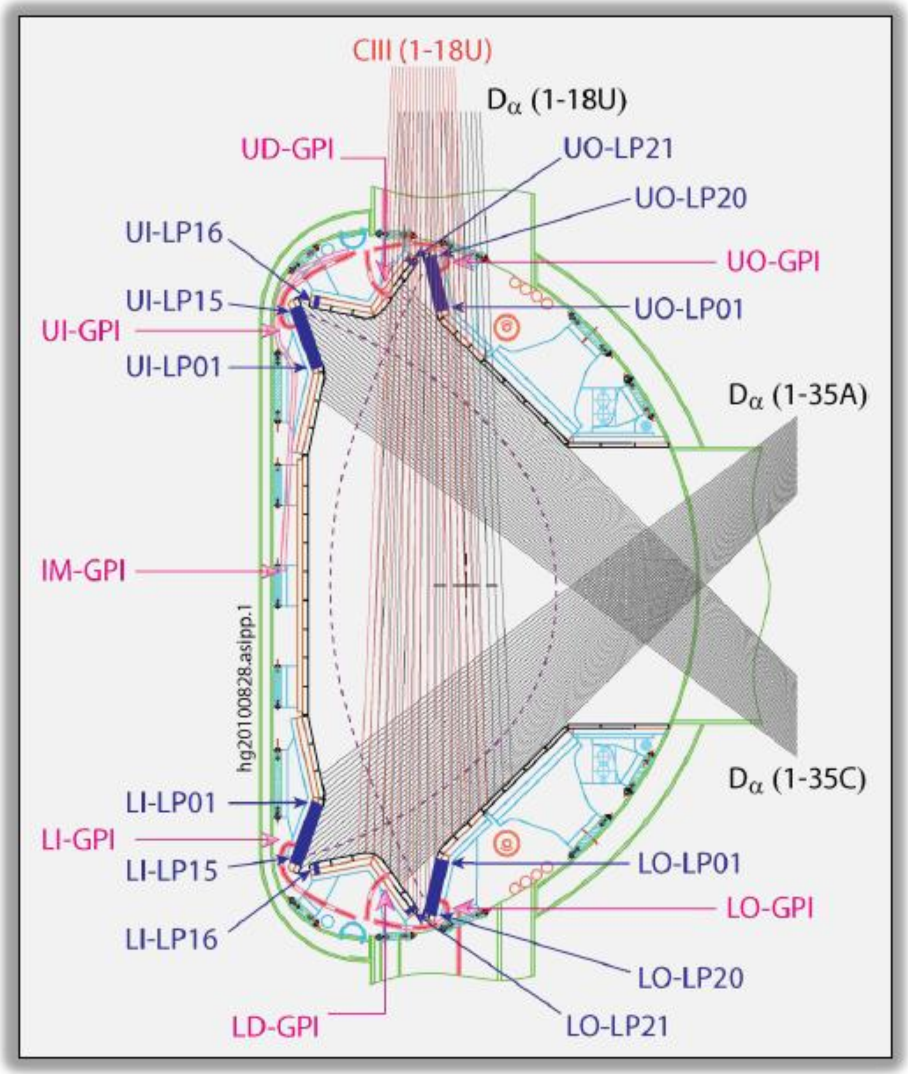


High heat flux region $2MW/m^2$



Total 37 flux loop

Main diagnostics (~50, IFS, GA, PPPL,ORNL)



Key Profiles

Te, Ti, ne, Zeff, Prad, Ha

Advance diagnostics

Thomson scattering (25)

TXCS,

PXCS,

ECEI (384)

Dual-polarization reflectometer

ECE(32)

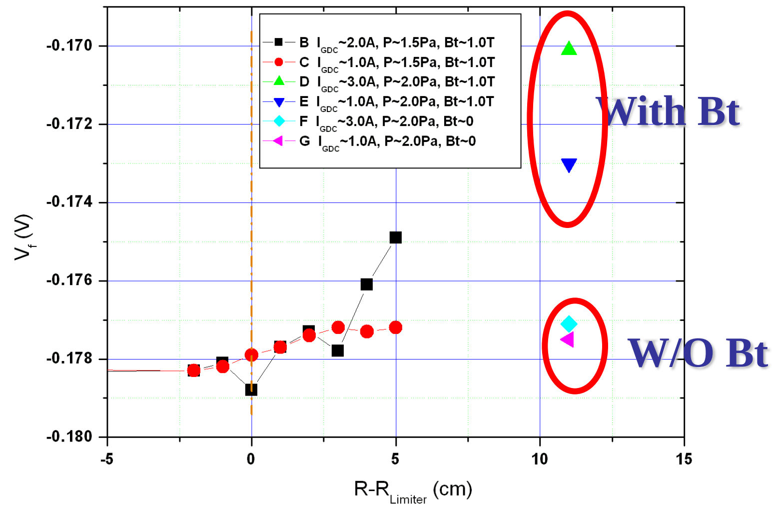
Fast Moving LP

GPI, CO2 scattering

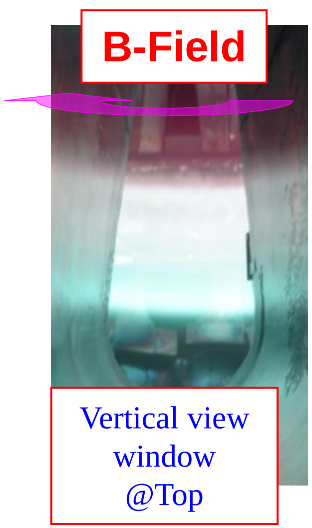
Edge diagnostics

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



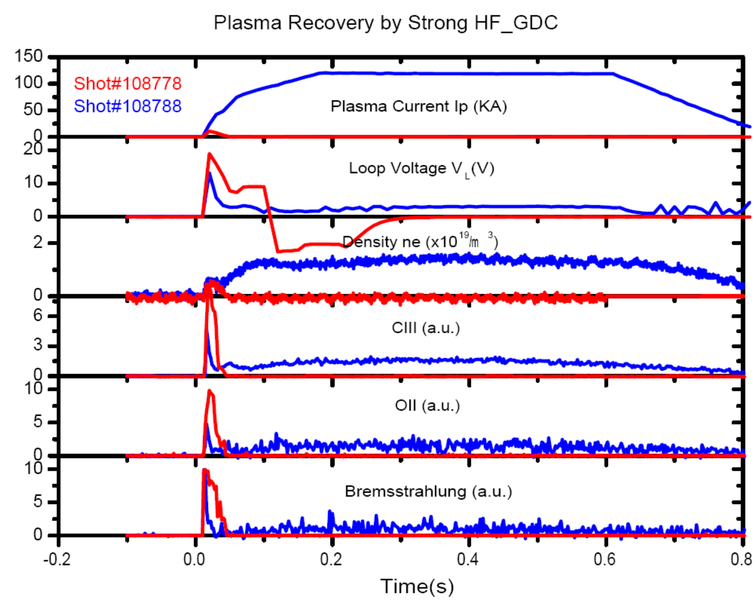
HF-GDC is routinely used in HT-7 for wall conditioning, siliconization and recycling control between shots which shows almost the same effects with RFWC.



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

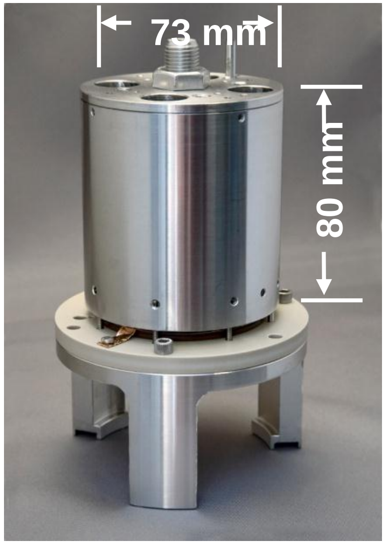
P=5.0E-2Pa, IGD=1.0A, Bt=1.0T, H2

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



Recovery from 10Pa leakage

Li Wall Conditioning (PPPL)



D.Mensfield PPPL

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

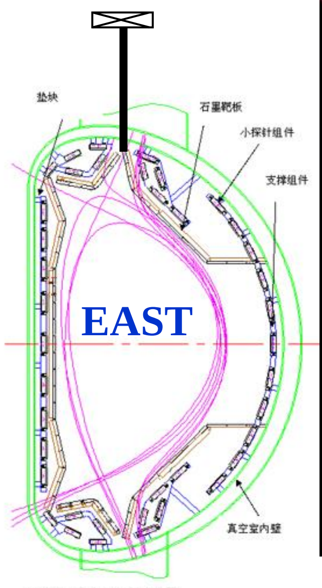
•Main Results:

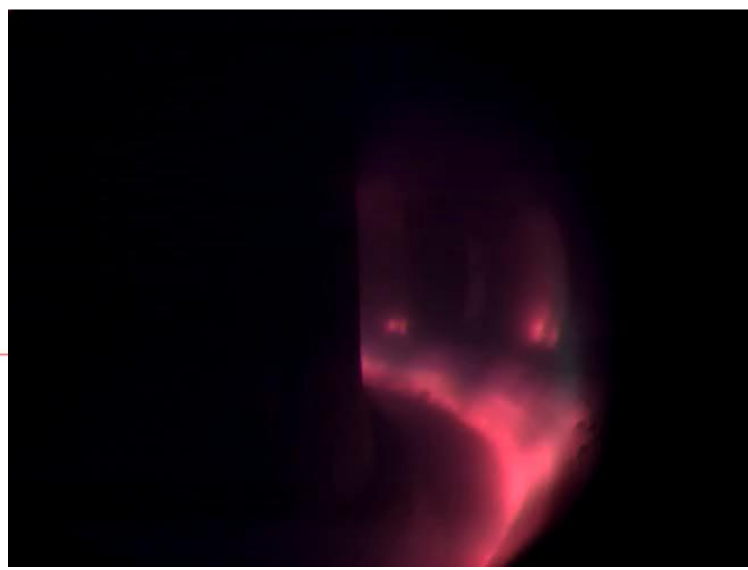
•Very good and quick technique

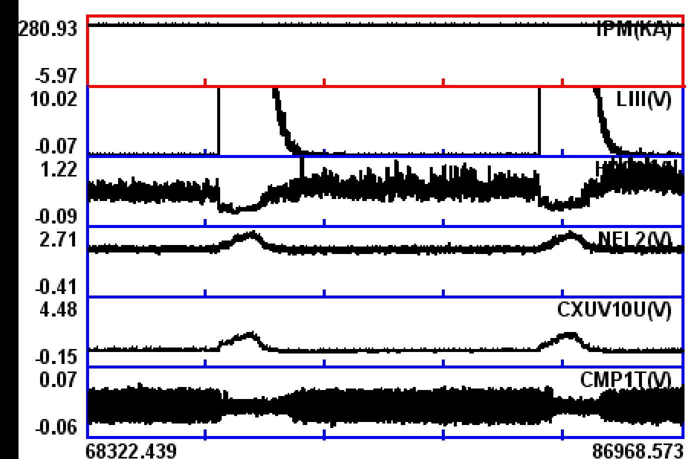
•Z ~ 1.5-2.5

•More broad Te and radiation profile

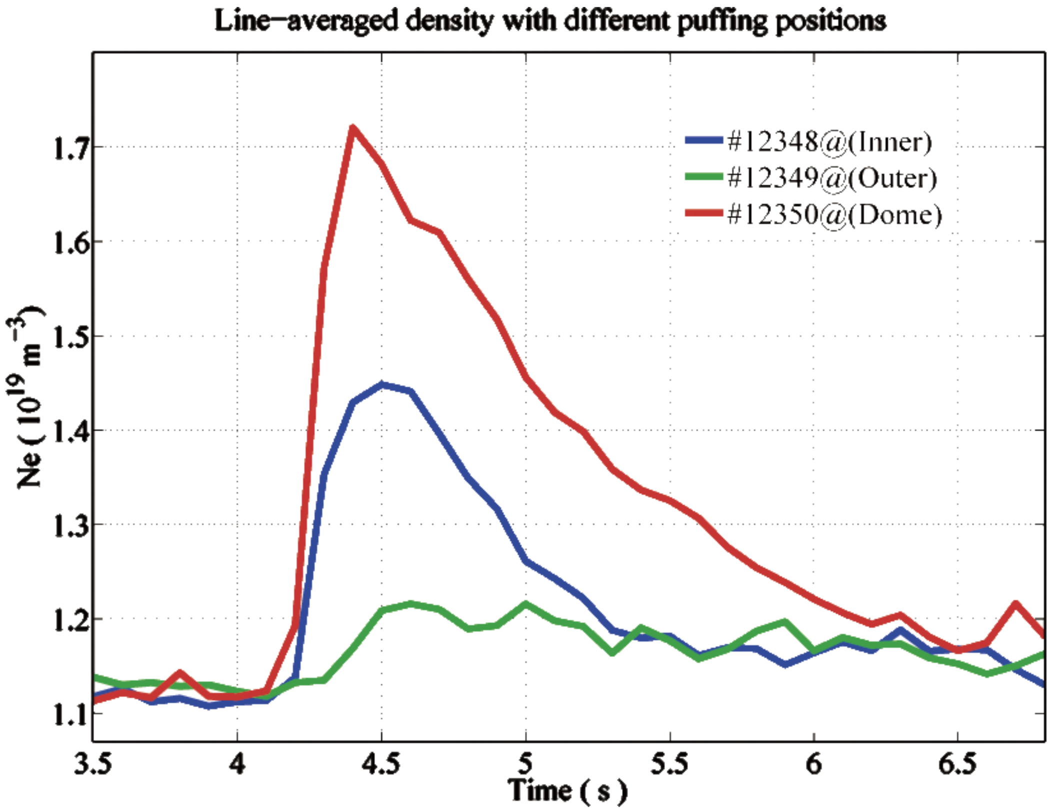
•Low recycling

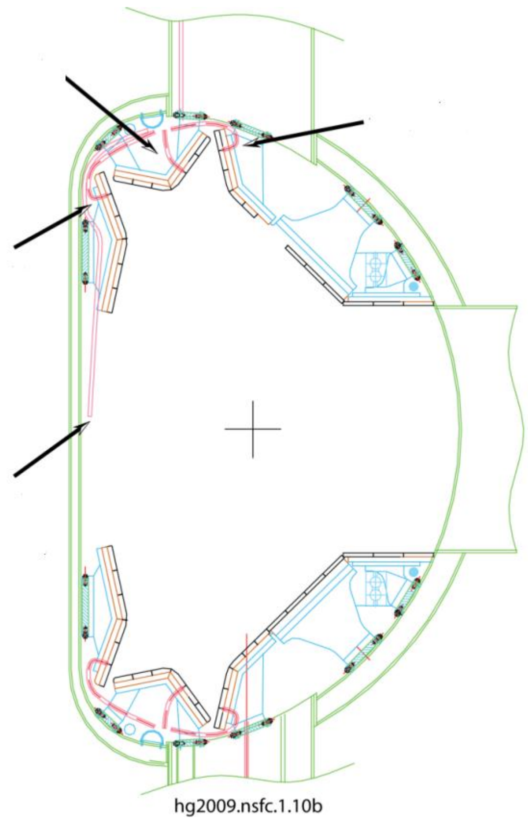






Fueling Effect of Gas Puff Locations



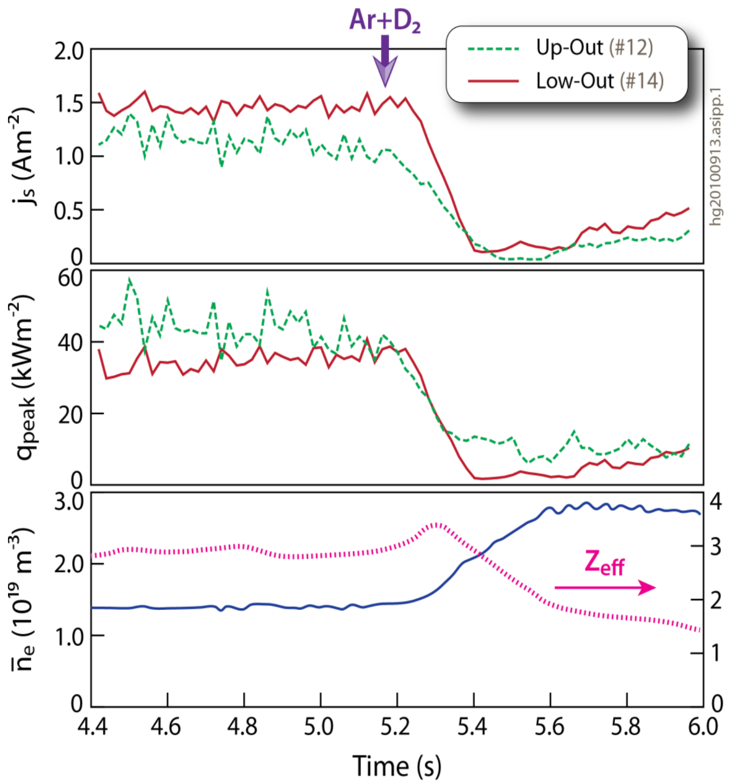


DOME D_2 puffing has highest fuelling efficiency, less from inner target plate, lowest from outer target plate. Compared to SN configuration, DN is more sensitive to gas puffing location.

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

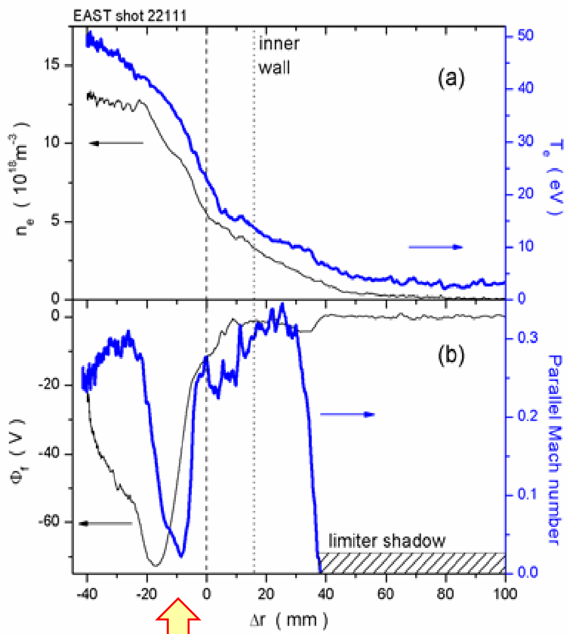
EAST adopted ITER-like vertical target configuration, which promotes detachment near strike point. However, this scenario by density ramping is not fully compatible with LHCD and high confinement scenario, radiative divertor is required.

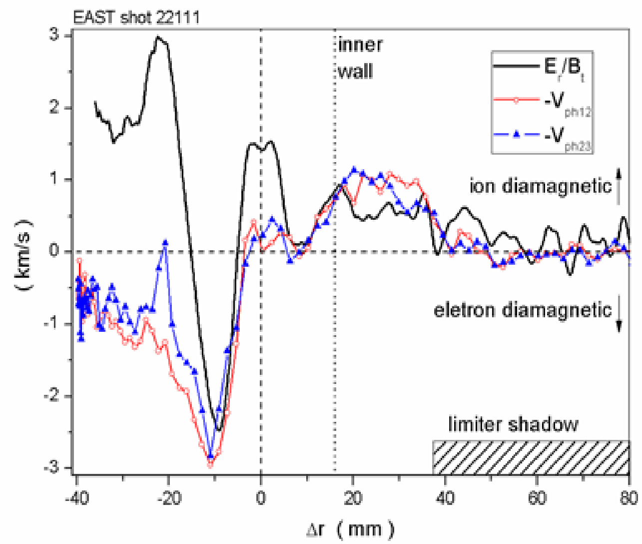
- **D2+5.7% Ar mixture puffing was initiated at 5s led to detachment at both upper and lower outer divertor targets**
- **significantly reducing the peak heat fluxes, q_{peak}, near outer strike points**
- **Zeff is reduced**

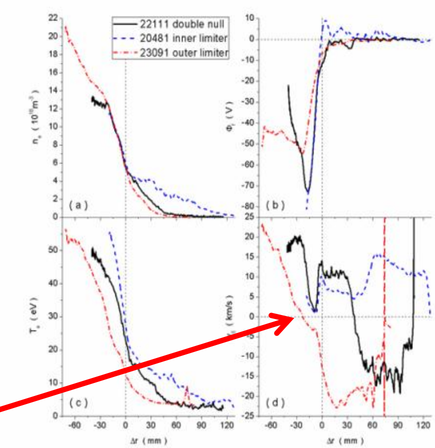


Ar puffing in divertors promote partial detachment and reduce peak heat flux

Toroidal flow at edge



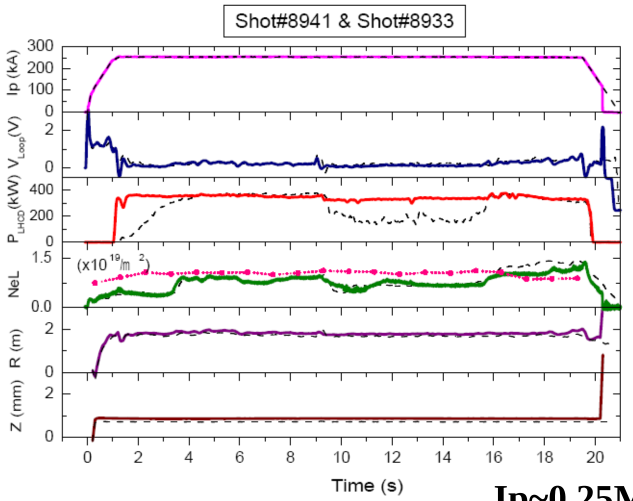




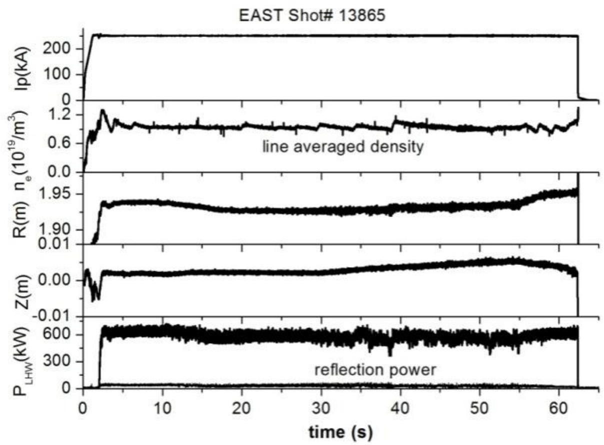
- A minimum (dip) V_ϕ at ~1 cm inside the separatrix.
- Collisionality > 4, in the Pfirsch-Schlüter regime.
- It is situated at the same location of a dip of $E_r(r)$
- But a dip of $V_\phi(r)$ not observed in the discharges that the plasma edge touches the outer limiter

Long Pulse Discharges (With GA)

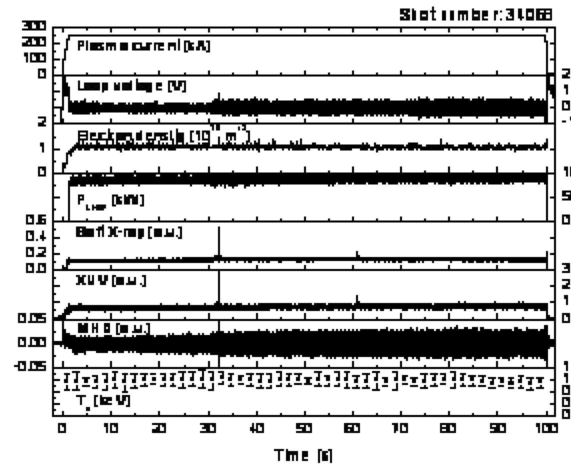
In 2008



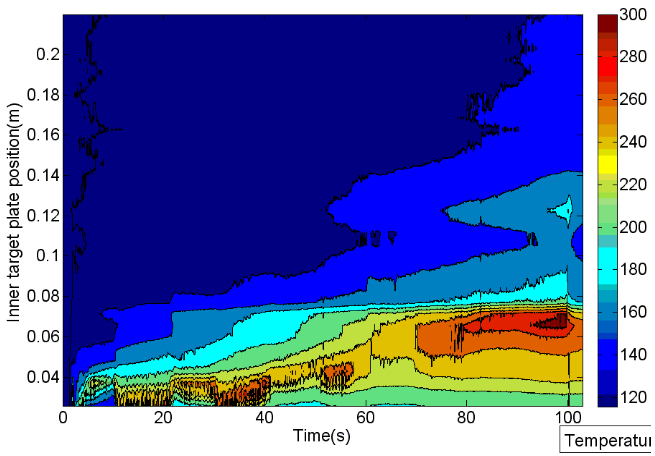
In 2009

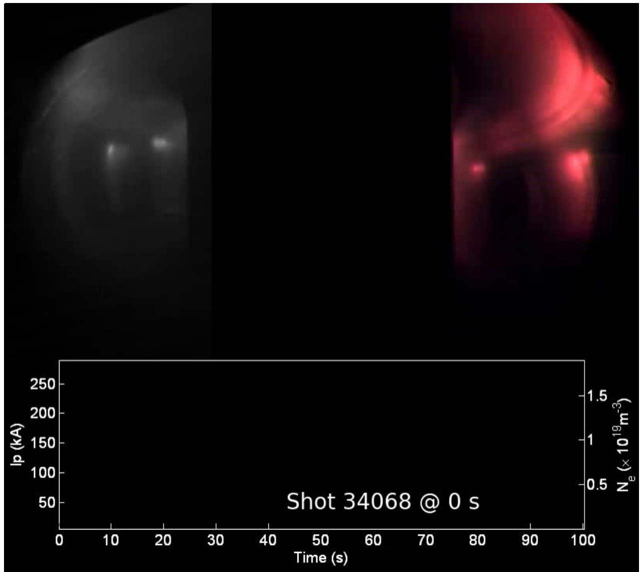


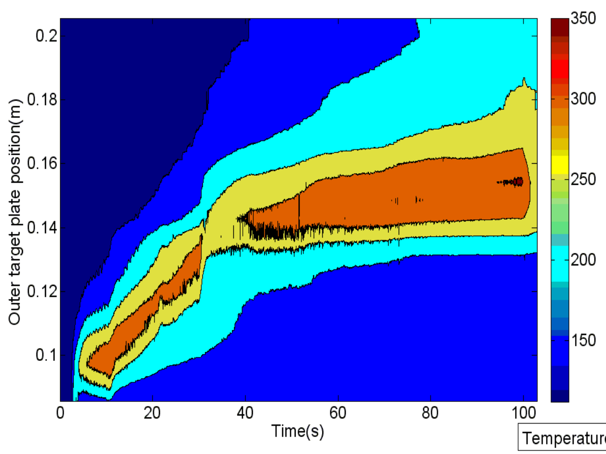
In 2010



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

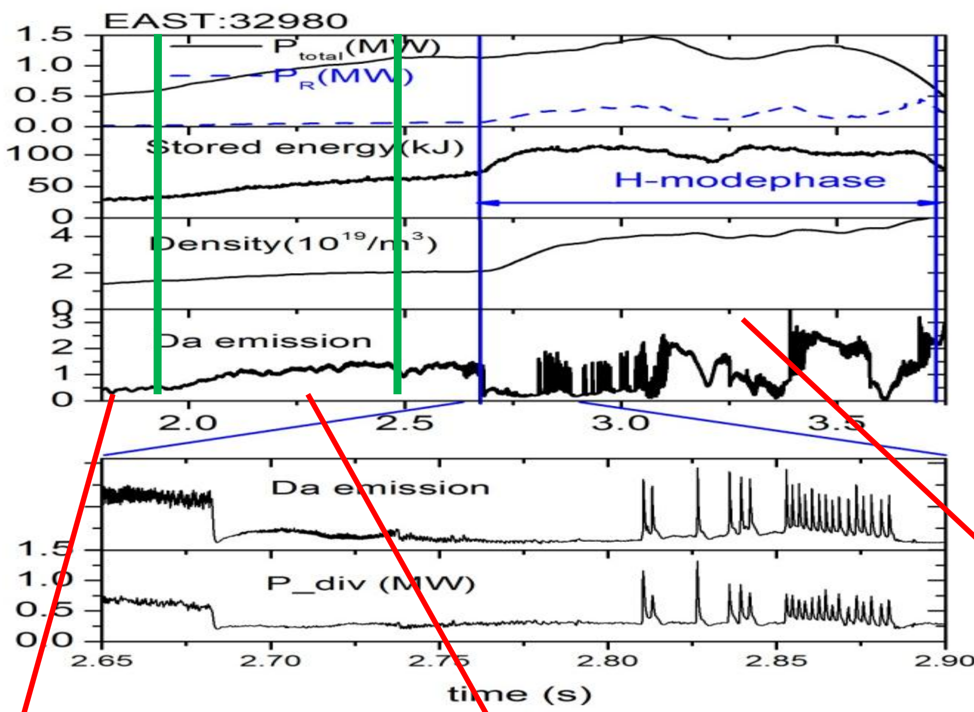


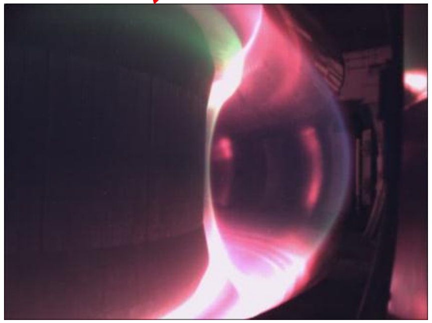


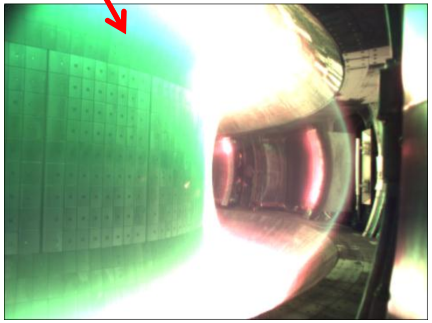


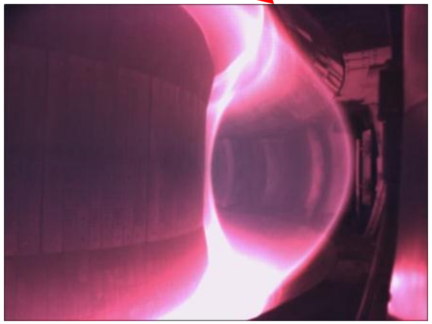
First H mode by Li coating either by oven or by lithium powder injection

EAST

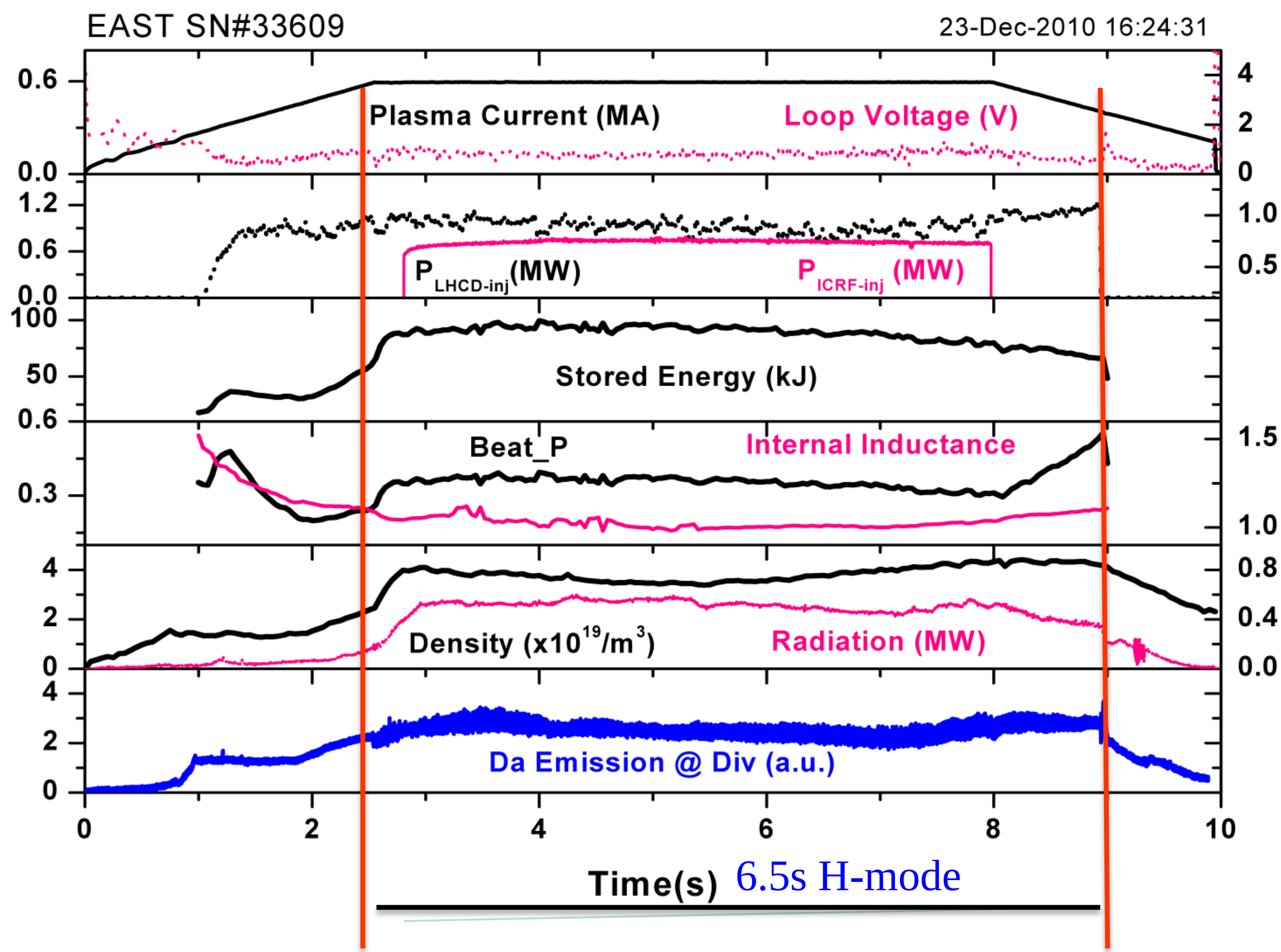






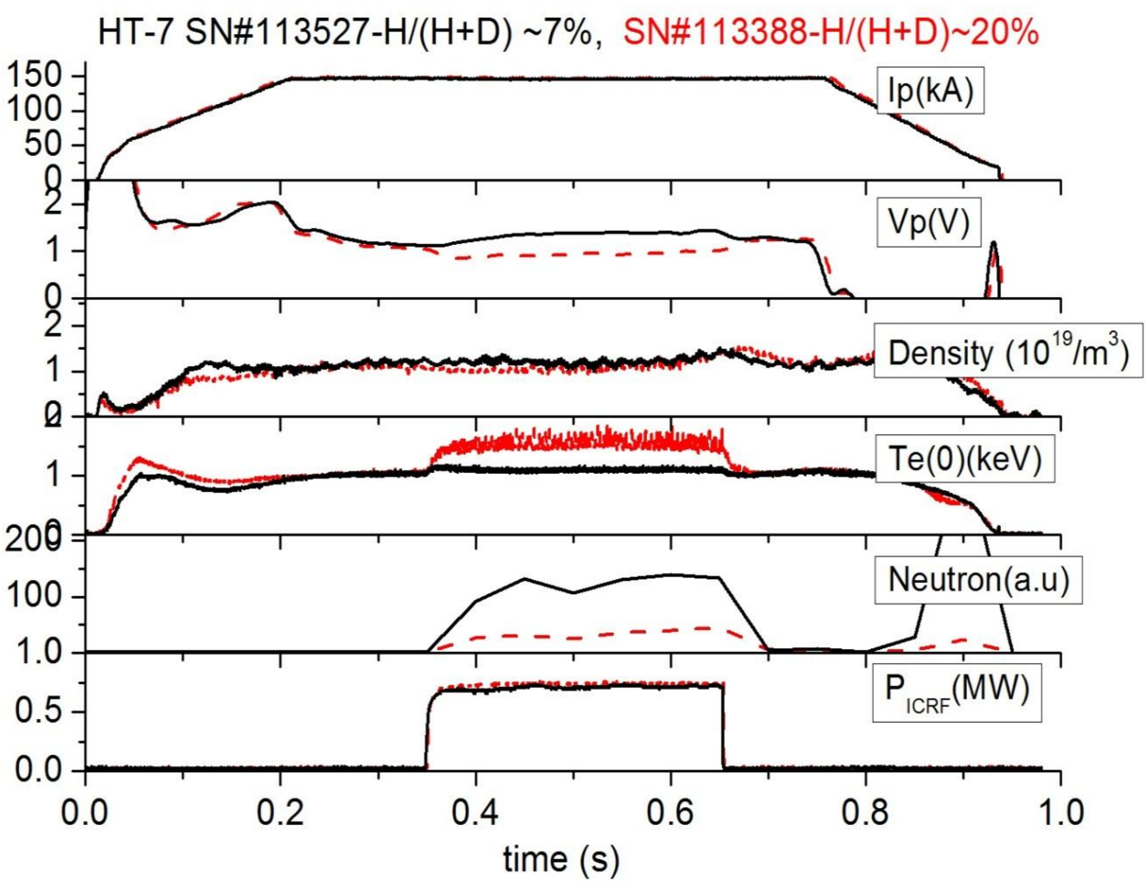


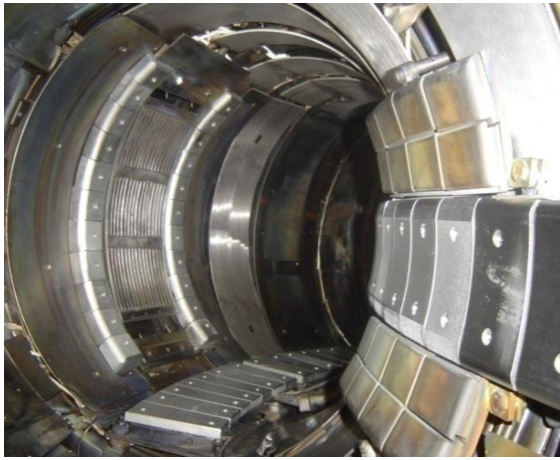
6.5s H-mode by RF+LH (MIT,PPPL)



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

Lithized wall on HT-7





Experiments to support EAST

Recent HT-7 experiments demonstrated the feasibility of Lithized full-metal wall for recycling/impurity control and effective ICRF heating

EAST 2012 capabilities

PF power supply upgrade
SMBI, SS Pellet injector
1/2 C tiles change to Mo tiles
PFC modification for 250^{0}C 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（61）→ 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
200-400s DN

CN-MCF Near Term Plan (2020)

ITER construction

- ASIPP: Feeders (100%), Correction Coils (100%), TF Conductors (7%) , PF Conductors (69%), Transfer Cask System(50%), HV Substation Materials (100%), AC-DC Converter (62%)
- SWIP: Blanket FW (10%) &Shield (40%), Gas Injection Valve Boxes+ GDC Conditioning System (88%), Magnetic Supports (100%),
- Diagnostics (3.3%)

+

Enhance Domestic MCF

Upgrade EAST, HL-2M

ITER technology

TBM(Two options)

T-Plant

University program

DEMO design (Wan)

DEMO Material

Education program(2000)

70-80% of ITER-CN budget

Can start construct CN pilot power plant before 2020

EAST 5 year Plan

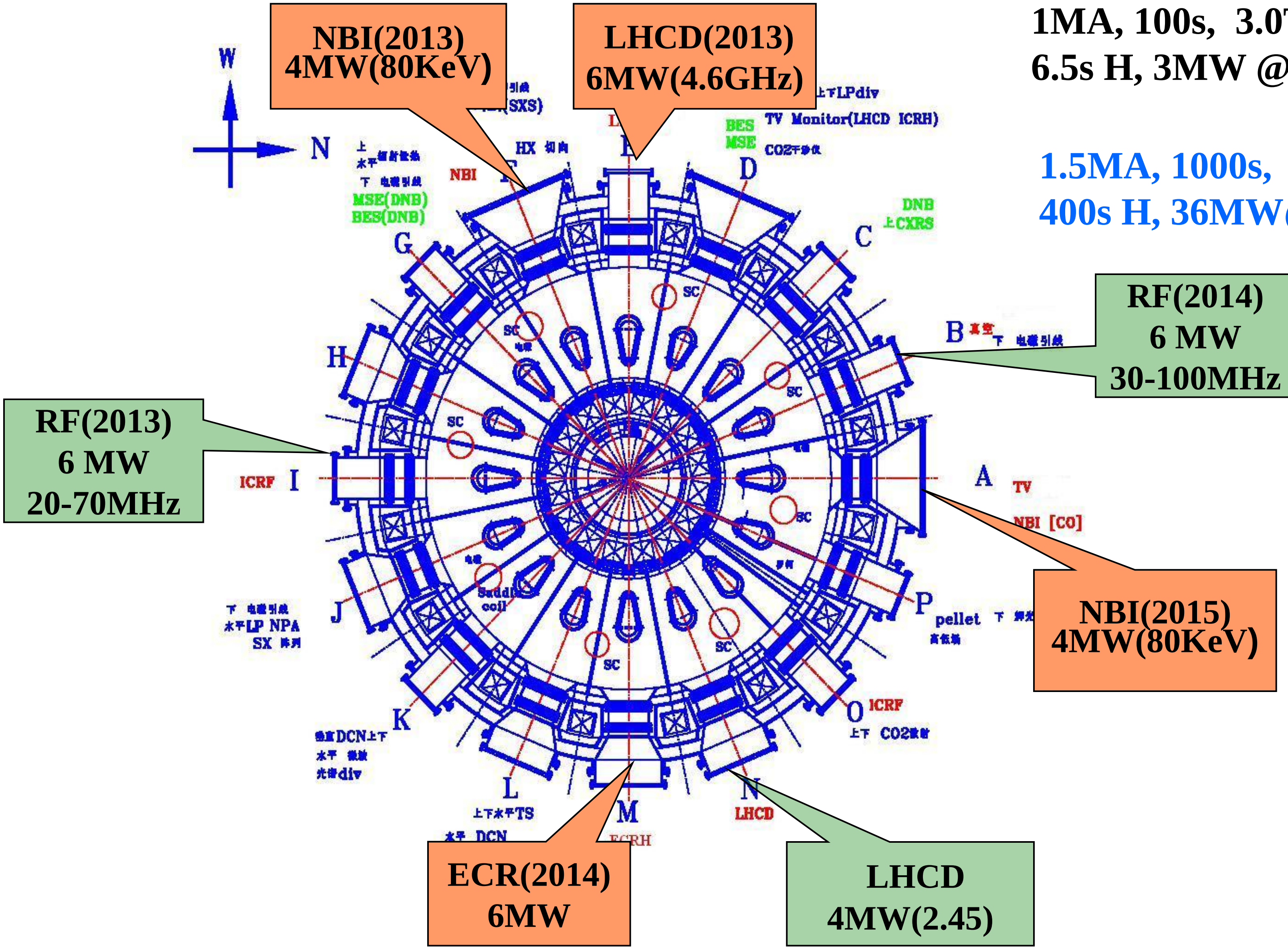
	2011	2012	2013	2014	2015
Ip(MA)	1.0	1.0	1.0	1.5	1.5
LHCD(MW, CW)					
2.45GHz	4.0	4.0	6.0	6.0	6.0
4.6GHz			6.0	6.0	6.0
ICRF(MW,CW)					
20-75MHz	4.5	4.5	4.5	6	6
30-100MHz	1.5	4.5	4.5	6	6
NBI(80keV)			4.0	8.0	8.0
ECRH(140GHz,cw)		1.0	2.0	4	4
Diagnostics	40	45	50	60	60
Duration(s)	100	200	300	400	1000
t-Hmode(s)	10	20	30	100	400

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

Efforts Made- EAST ATSSO

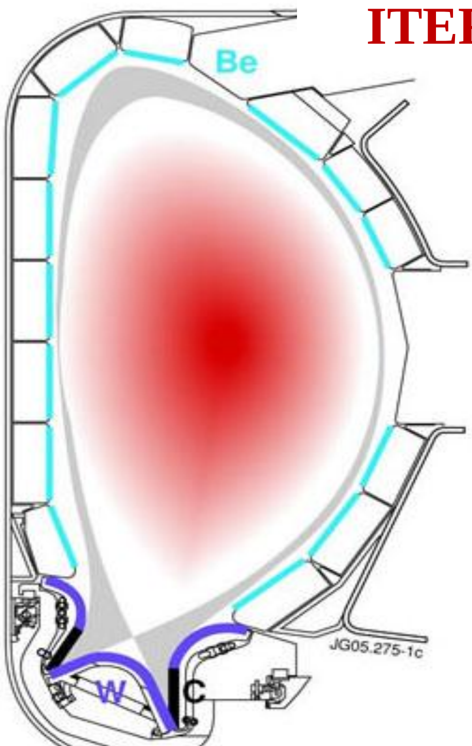
1MA, 100s, 3.0T
6.5s H, 3MW @2010

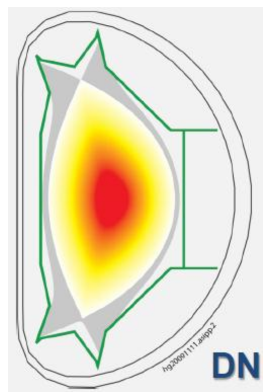
1.5MA, 1000s, 4.0T
400s H, 36MW@2015

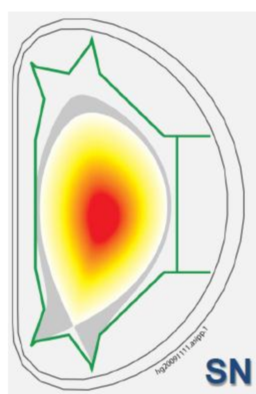


PFC Strategy for ATSSO

ITER







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

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

- **First phase (2008-2012)**

  PFM ⇨ SiC-coated doped C tiles bolted to Cu heat sink ~2MW/m^2

- **Second phase (2013-2016)**

  Full W, Actively-cooled ITER W/Cu divertor , 10MW/m^2.

- **Last phase (2017---)**

  High Tw operation（>400C) by hot He Gas 15MW/m^2.

Edge Simulation under H-mode

With LLNL, ENEA, TS, ITER-IO

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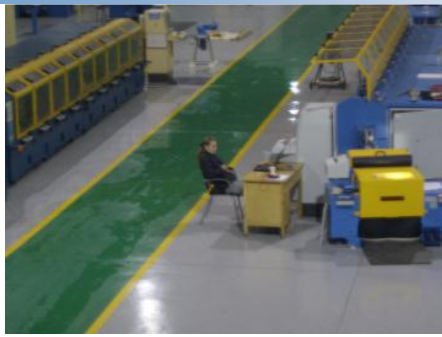
ITER-Conductor: Ready for deliver



Wire: NICNC,Oxford

Coating:Shenghai Ltd

Wire testing:ASIPP

Central tube: Tai Steel,

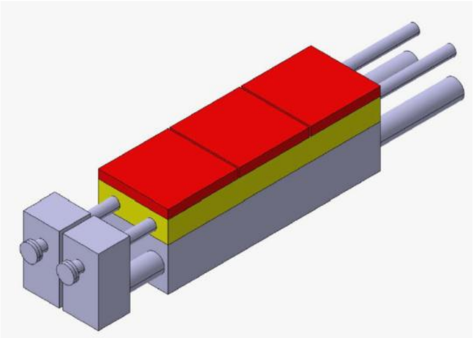
Cabling: Basheng Ltd,

316LN Tube:

Integration:ASIPP

1000m jacketing line
In ASIPP

Shielding Blanket-Ready for sign PA



I. Current Scope of CN procurement

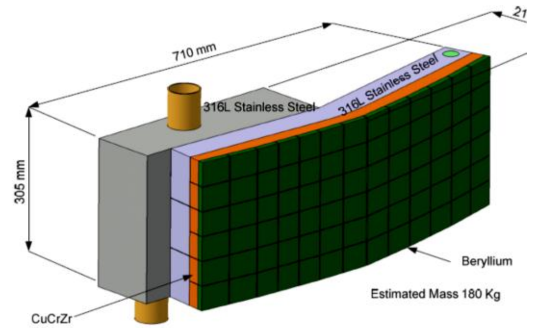
- Current: 10%FW and 40%SB.
- New proposal: 12.6%FW and 50.2%SB.

II. First wall (FW) qualification

Two phases towards manufacturing.

(1) Qualification of Be/Cu/SS joining technology by fabricati & testing qualification mock-ups;

(2) Semi-prototype qualification.

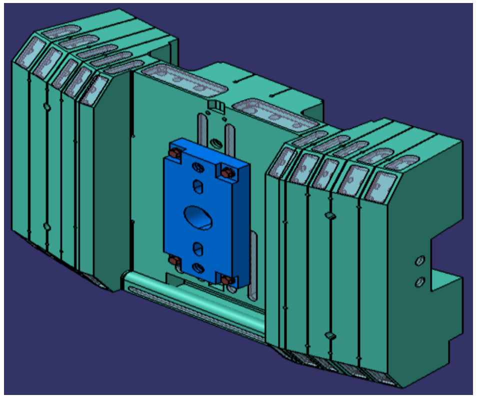


III. Shielding block (SB) analysis and technology

- Modeling, hydraulic, thermal stress, EM analysis;
- 316L(N), deep EB welding and hole drilling.

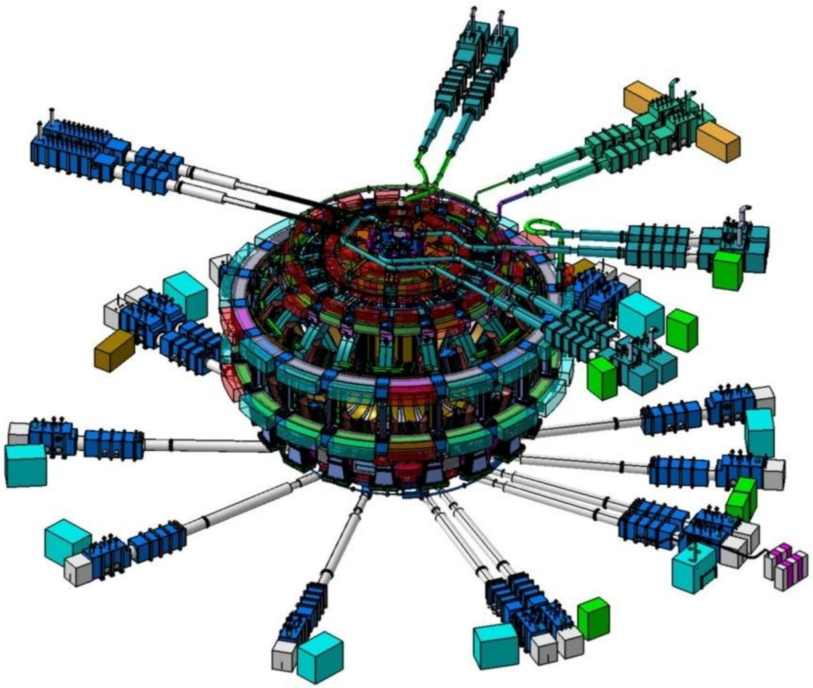
IV. Materials research and qualification

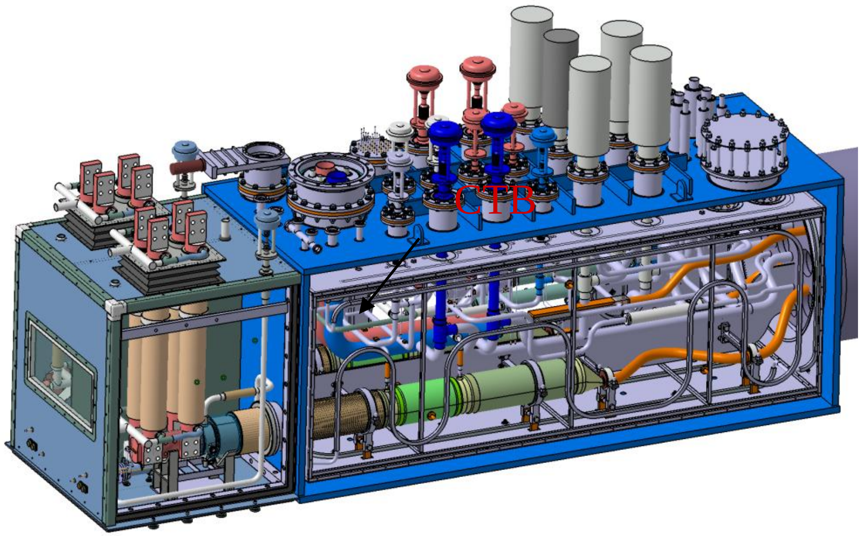
- Qualification of Chinese VHP-Be for ITER FW;
- Post-fabrication property of CuCrZr alloy.

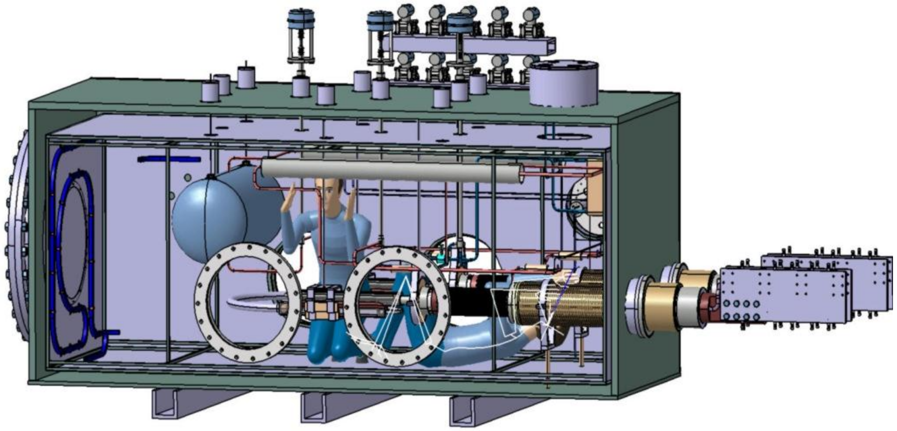


Feeder Team

Feeders: Start Construction







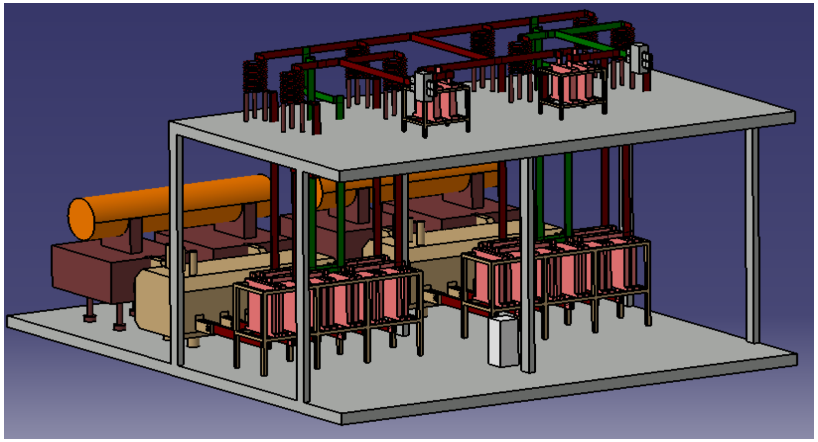
ITER Power Supply: Start Construction

ITER power supply Package in CN

- ★ AC/DC converter (share with KO)

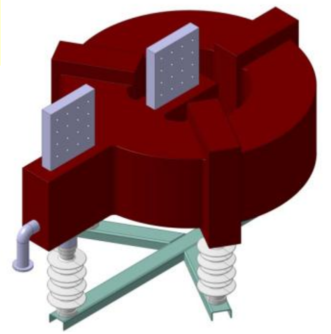
  Tested on EAST

- ★ Reactive power compensation
- ★ HV substation

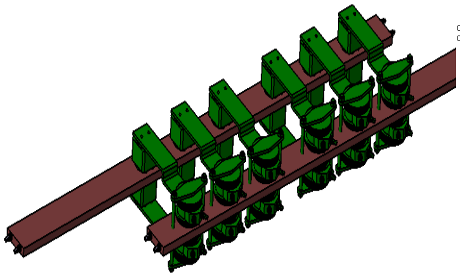


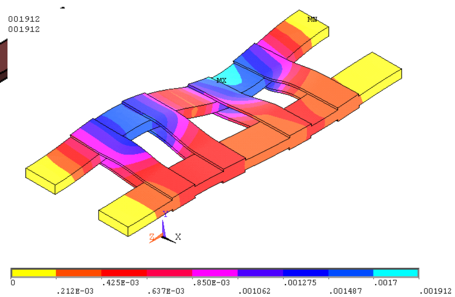
AC/DC Converter structure R&D

Local control R&D



DC inductor R&D





Converter arm displacement in EM force

Outline

HL-2A Tokamak

EAST Tokamak

- Physical engineering capability
- Main experimental results
- Research Plan in next 2-5 years

ITER-CN Activities

Future Plan of CN-MCF program

Summary

Planning for Next Step

- **CN-Design team（18）**

Y.Wan，J.Li，Y.Liu，X.Wang

Phy. Design, 13 sub-groups

2 options within 3 years (ECD1)

- **Eng. Design （4-6 Y）**
- **Key R&D （3-10 Y）**

  Diagnostic

  Blanket (TBM, FFHM)

  Magnet

  T-plant

  RH

- **Education (10 years)**

2016-2025 Construction

Rank No.1 in 2016- 5Y plan

Operation:

5-years, H2, He (D2)

6-8 Y DT-1 operation

6-8 Y DT-2 operation

ITER

2019: 1st Plasma

2027: DT-1, Q=10, 400s

2037: DT-2, Q=5, 3000s

Efforts Made-Education

Present state:

- ASIPP: HT-7/EAST (150 students), ITER (80 students)
- SWIP (60)
- School of Physics (USTC, 25)
- School of Nuclear Science (USTC-ASIPP, >50)
- CN-MOE-MCF center (10 top universities) 50

Total about 450 students, 150/y, 20-30% remain in fusion

Targets and efforts

- 2000 fusion talents in 2020
- MOST, MOE, CAS, CNNC

have lunched a national fusion training program for next 10 years.

Basic training in 10 top univ.

Join EAST/HL-2A experiments

Small facilities in Univ.

Foreign Labs& Univ.

Annual summer school, workshop

Efforts Made- R&D (MOST)

Present state

- 5 year-MCF plan
- 10-year MCF plan

2009

Solid TBM concept design

DCLL TBM concept design

PWI

ITER design

ITER-ICRF

MCF-talent (8, exp.)

2010

Hybrid concept design

TBM-T system design

DEMO-FW(W)

MCF-basic simulation

MCF-talent (9, ITPA)

2011

CN-MCF Reactor design

ITER-W-diverter

High B (Nb3Al,YBCO) magnet

T-plant design

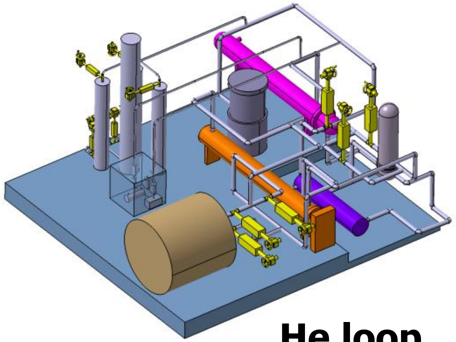
RFP

MCF-talent (5, simulation)

MCF-talent (11, material)

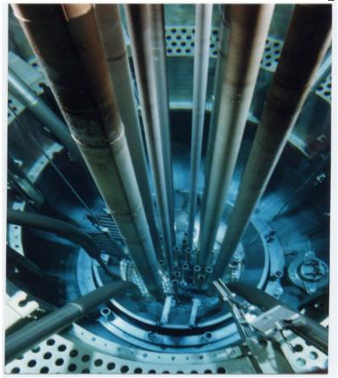
R&D Plans for CN HCSB TBMs

- Fabrication Technology
  - Mockup of U-shape first wall (2010)
  - Mockup of sub-module (2012)
  - Small-size (1:3) Mockup of HCSB TBM (2013)
- Helium Cooling System
  - Design of Test facility for FW
  - Test facility of mockup (2013)
  - Prototype HCS for ITER TBM (2016)
- Breeder Materials
  - Li_4SiO_4 pebble (in-pile 2014-2016)
  - Be pebble in lab. level (2013)
  - Be-irradiation test (2017)
- Structure Materials
  - Fabrication (2011)→ Database for CLF-1under irradiation of 1 dpa (2015)
  - RAFM join by laser solid forming and by diffusion bonding(2010);
  - RAFM HIP join (ongoing);
  - Tritium pemeation barrier (2015).



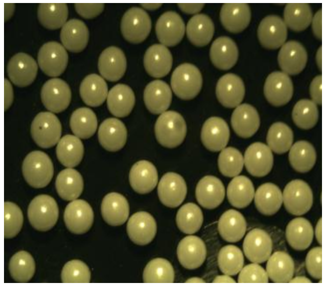
He loop

LSF-III



HFETR

Be Pebble

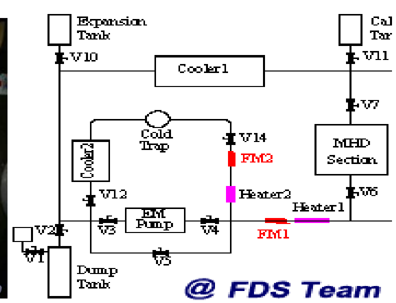


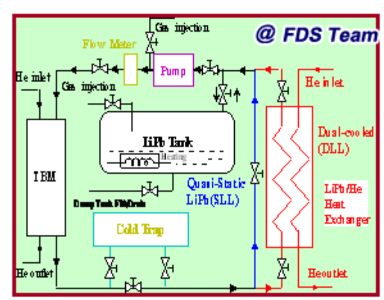
Ceramic Breeder

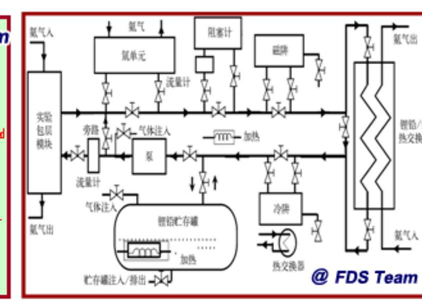
500kg CLF Ingot

Development of DRAGON Series LiPb Loops

Loop name	Type	Function	Temperature	Time
DRAGON-I	TC*	Material Compatibility	420-480^{o}C	2001-2005
DRAGON-II	TC	Compatibility	550~700^{o}C	2004-2006
DRAGON-III	TC	Compatibility	800~1000^{o}C	2007-2009
DRAGON-S^{T}	Static	Compatibility	250~1000^{o}C	2008-2009
DRAGON-R^{T}	Flowing	Compatibility	450~600^{o}C	2009
DRAGON-IV	FC$^{\#}$	Material Compatibility, Thermal-hydraulics, MHD, Purification of LiPb, etc.	480~800^{o}C	2007-2009
DRAGON-V	FC	Dual-coolant test for TBM, MHD test for the complex ducts	300~700^{o}C	2010-2012
DRAGON-VI	FC	Auxiliary system for EAST-TBM	-	2012-2015
DRAGON-VII	FC	Auxiliary system for ITER-TBM	-	2015-2018
DRAGON-VIII	FC	Auxiliary system for DEMO blanket	-	-







Next-step device design: Option 1:

Choice 1: Smaller machine

R=5m; a=1.5m; k=1.75;
T=4.5K, BT=5T; Ip=8MA;
ne=1-4x$10^{20}m^{-3}$;
Step 1:Beta N : 2.5
Pth: 150MW-300MW
Step 2: AT H-mode, Beta N : 3- 4
Pth: 1-1.5GW

Q=2-5 , t> 8 hour, SSO

Material &Component testing,

T breading (TBR>1),

T fuel recycling, RH validation

RAMI validation

FFH blanket testing (SFB, TM)

Choice 2: ITER-like machine

R=6.5m; a=2.5m; k=1.75;
T=4.5K, BT=5T; Ip=8MA;
ne=1-4x$10^{20}m^{-3}$;
Step 1:Beta N : 2.5
Pth: 300MW-500MW
Step 2: AT H-mode, DEMO-like
Pth: 2-3GW

T> 8 hour, SSO

Material &Component testing

T breading (TBR>1),

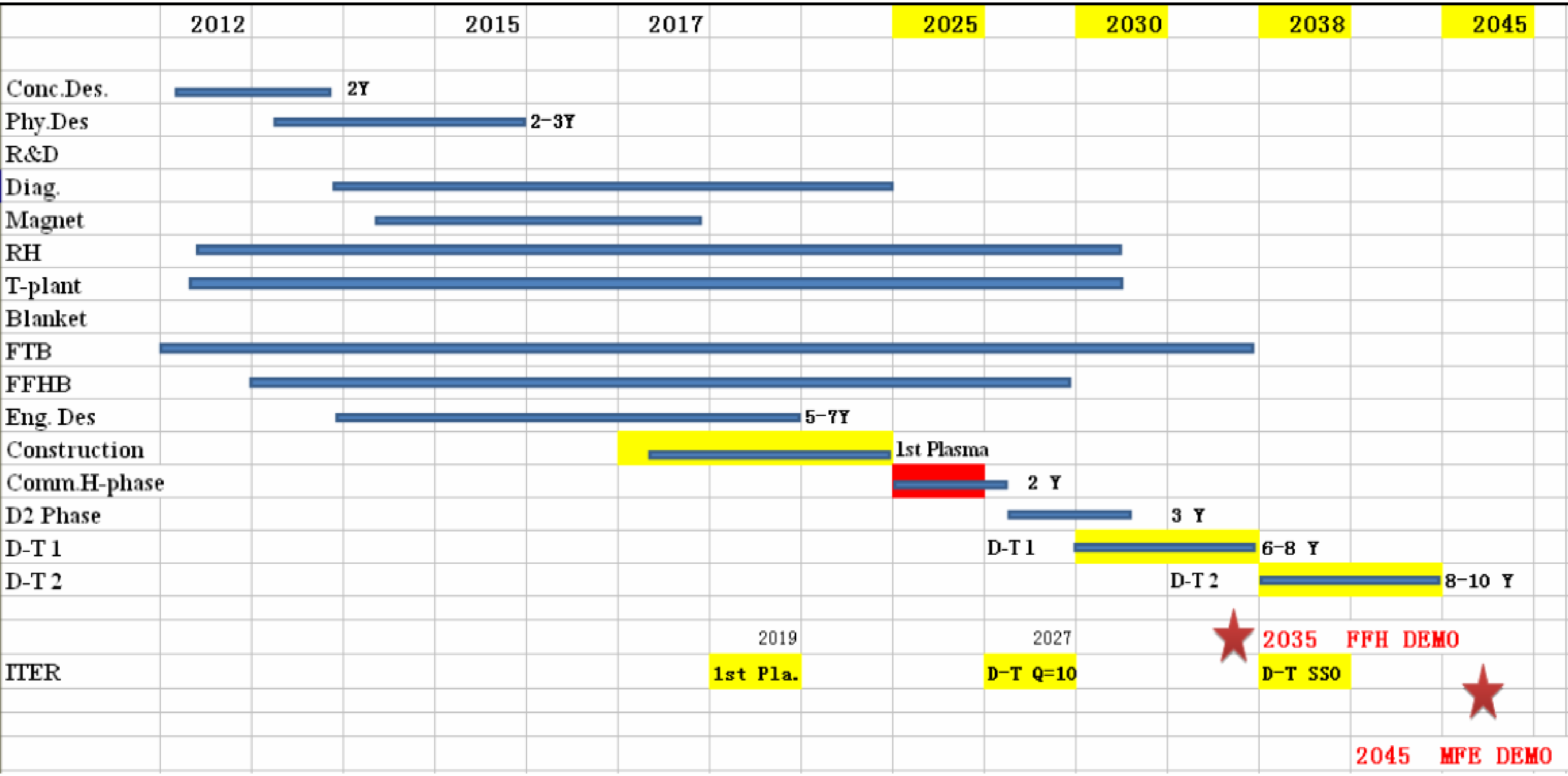
Pure fusion TBM configuration

RH validation, RAMI validation

Close fuel cycle

FFH blanket testing (SFB, TM)

Possible Plan and Schedule



International cooperation

- France, CEA,CADERACHE
- UK, UKAEA, CULHAM
- EU, JET, EFDA
- Germany: IPP, Garching
  KFA, Julich
- Italy, Frascati: ENEA
- USA: UT/IFS, GA,
  PPPL, *U Illinois*
  PSFC/MIT, *SNL*
  ORNL， LLNL
  UCLA， UCSD

ITER-IO、6—DAs

- Japan: NIFS, JAEA,
  JSPS, Tokyo（20M$/y)
  > 30 univ. in each side.

- India, IPR, Bhat
- Korea, KFRI,KBSI
- Russia:Kurchchatov institute
  St. Petersburg, AFIPT
  Troisk: Triniti

Swiss: DRCP

Holland: FOM

Cooperation with US

More than 20 years cooperation

Mutual benefits

Ken obtained 04 state reward

Cooperation with DIII-D

- Wide cooperation for experiments, theory, technology
- good internet connections
- Exchange of Hardware for 5-6M$
- Exchange of personnel 20m/y
- From DIII-D&EAST to ITER

2009 State international cooperation reward

Cooperation with PPPL

- Experiments(>15 Scientists from PPPL)
- Technology (hardware exchange)
- Theory(joint research plan)
- Joint ITER activities
- Future: FSP (simulation EAST,ITERC,FETER)



Very Strong Support from Top Leaders

and Public (10,000 visitors to EAST)

Opportunities and mechanisms for collaboration

- **Opportunities:**

EAST : 400-1000s, full metal, 30MW, hot wall, 3rd shift by US

Joint task forces, detail planning

ITER: sharing resources from both country, joint teams.

Next device: joint teams, 2nd Option, FSP, joint facilities

Education

2011DPP/APS, 64chinese/12from Mainland

- **Mechanisms**

Standard operation found

1-2% of MCF budget from each side

5 years plan

Review, assessment, workshop

Based on present frame

Administration, physics, engineering

"US and China should joint more closely for fusion research which is beneficial for whole human being. I would like to see your successes."

Fusion budget

Fusion research deserve more budget

Contribution to ITER should based on sound demotic program

Joint US-CN ITER teams

- SC PA, 25-35% cheaper
- SS PS, 20% cheaper
- Blanket, 20% cheaper
- RF transmission 40%

Assign sub-contracts to CN

- 25%x145M = 36M $
- ASIPP PA: 2-3 M$

Joint Contracts from IO: 3-4M$

Total: 41-43M$

Non- ITER activities

- CN MCF TFs: 3-4M$

Design, experiments, R&D

US MCF TFs: 5-6 M$

NSTX-Upgrade

DIII-D Upgrade

hardware exchange, sub-contracts

Education

FSP

Total: 8-10M$

40-50M$ saving per year might be possible, need careful and long term planning

Summary

- EAST Starts important experiments with helps from international cooperators, especially from US. EAST is fully open and EAST is also yours.
- By joining ITER project, China will work more closely with other 6 parties for a successful operation of ITER.
- China would do its best to try catching up . Your helps and suggestion are valuable.
- More close cooperation between US and CN will beneficial to us. I am sure we will have more productive outcome in future.

Thanks

Welcome to visit ASIPP