Physics objective of EAST

- **Long sustainment of inductive high performance plasma (~ t_{wall}) at Te>10keV, $n_e>10^{20}m^{-3}$**
- **Long sustainment of Full CD hot plasma (1000s) at Ip=1MA.**
- **Realization of advanced mode of operation with reasonably high performance (β_N>2, H_{89}>2) for the pulse length up to 1000 seconds.**
- **Long sustainment of high beta (β_N~3) plasma.**

  (high k & d, Mode-control-coil for RWM)
- **Divertor optimization**

  (compatibility with high δ and β, Doped C and metallic PFC, forced cooling Divertor, long particle exhaust)
- **Reduced Activation Ferritic steel, low radioactive SS and ODS W of PFC**

Three phases of the operation

	phase I	phase II	phase III
B_o	3.5	3.5	3.5(4.0)
I_P(MA)	1	1	1(1.5)
R_o(m)	1.95	1.95	1.75
a(m)	0.5	0.46	0.4
R/a	4.1	4.2	4.25
K_x	1.2-1.5	1.2-1.7	1.5-1.9
δ_x	0.2-0.3	0.3-0.7	0.3-0.5
ICRH(MW) CW	1.5(30-110)	1.5(30-110MHz) 1.5(20-50MHz)	3(20-50MHz) 3(30-110MHz)
LHCD(MW) CW	2(2.45GHz)	2(2.45GHz) 1.5(3.7GHz)	2(2.45GHz) 3(4.6GHz) 3(3.7GHz)
ECRH(MW) 0.2-5s	0.2(60GHz)	0.5(60GHz) 0.5(110GHz)	0.5(60GHz) 1.0(110GHz) 100s
NBI(MW) >100s	0	4(40-80keV)	8(40-80keV)
pulse length(S)	1-60	10-1000	10-1000
Configuration:	limiter,DN	DN, SN	Internal cryo-pump, DN,SN

1MA D Operation

(B_t = 3.5 Tesla, Ip = 1 MA; q* = 3.4, q_{95} = 5.1)

	H = 1.5	H = 2	H = 3
τ_E (ms)	95	127	191
n T(10^{19} m^{-3}keV)	23	31	46
W (MJ)	0.58	0.77	1.2
β_p	0.76	1.0	1.5
f_b (I_b / I_p)	0.18	0.25	0.37
β_N	1.0	1.4	2.1
β (%)	0.74	0.98	1.5

1.5MA D Operation

(B_t = 4.0 Tesla, Ip = 1.5 MA; q* = 2.6, q_{95} = 3.9)

	H = 1.5	H = 2	H = 3
τ_E (ms)	149	199	298
n T (10^{19} m^{-3}keV)	35	46	69
W (MJ)	0.89	1.2	1.8
β_p	0.52	0.69	1.0
f_b (I_b / I_p)	0.13	0.17	0.25
β_N	0.93	1.2	1.9
β (%)	0.87	1.2	1.7

EAST Advanced Tokamak Program

2006 2007 2008 2009 2010 2011 2012

Hardware and tool Development

RF 1.5MW 30-110MHz 1.5MW 20-50MW 1.5MW 20-50MHz 1.5MW 30-110MHz

LH 2.0MW(2.45GHz) 1.5MW(3.7GHz) 1.5MW(3.7GHz) 2MW(4.6GHz)

EC 0.2MW(0.2s) 0.5MW(1s) 1.0MW(110GHz, 10s)

NBI 4MW 4MW

Plasma shape

Density, Temperature & Impurity control

Integration & Sustainment Performance Optimization

SSO Demonstration $\beta_N H_{89}$>2-4 $\beta_N H_{89}$>4-6

Scenario Development NI Ip >70% NI Ip >90% (~100%)

Ip =1 MA, t= 60s t_{pulse} >100s t_H >30s, t_{pulse} ~1000s t_H >60s,

Current profile control:LHCD, IBW, ECRH, MCCD

Pressure & Transport control: IBW, LHCD, RF, NBI

Challenges and opportunities

- **Challenges :**

  Superconducting techniques.

  Continuous heating and current driven techniques.

  Steady-state operation and real-time control.

  Heat and particle removal in Steady-state condition.

  Neutron shielding

- **Opportunities:**

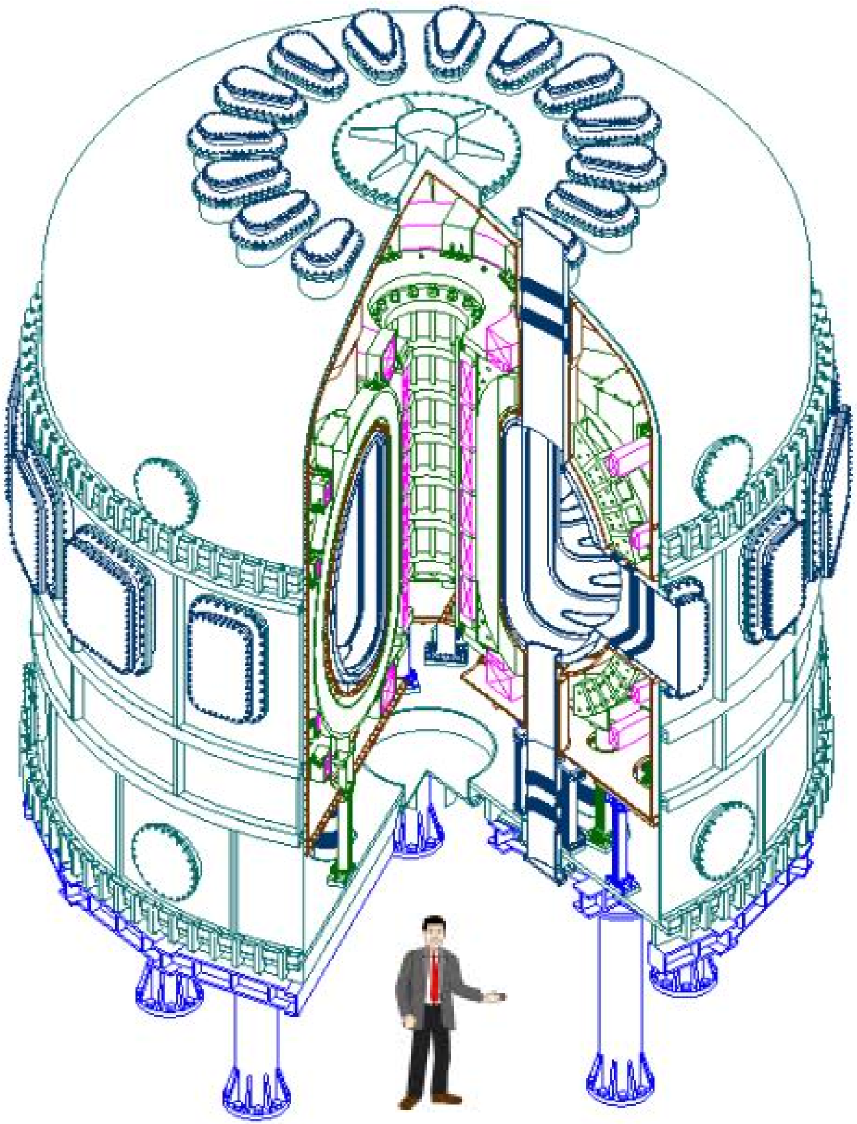
  Evolution of the current profile on the time scale much longer than the resistive time in fusion-relevant tokamak plasma.

  Behavior of the transport barriers in steady-state operation mode

  MHD stability on the steady-state base .

  Test bench for ITER.

  A key device for steady-state operation in the fusion community .



Major Radius R_o 1.75 m

Minor Radius a 0.4 m

Toroidal Field B_o 3.5 T

Plasma Current I_P 1 MA

Elongation K_x 1.6 - 2

Triangularity d_x 0.4-0.8

Pulse length 1000 s

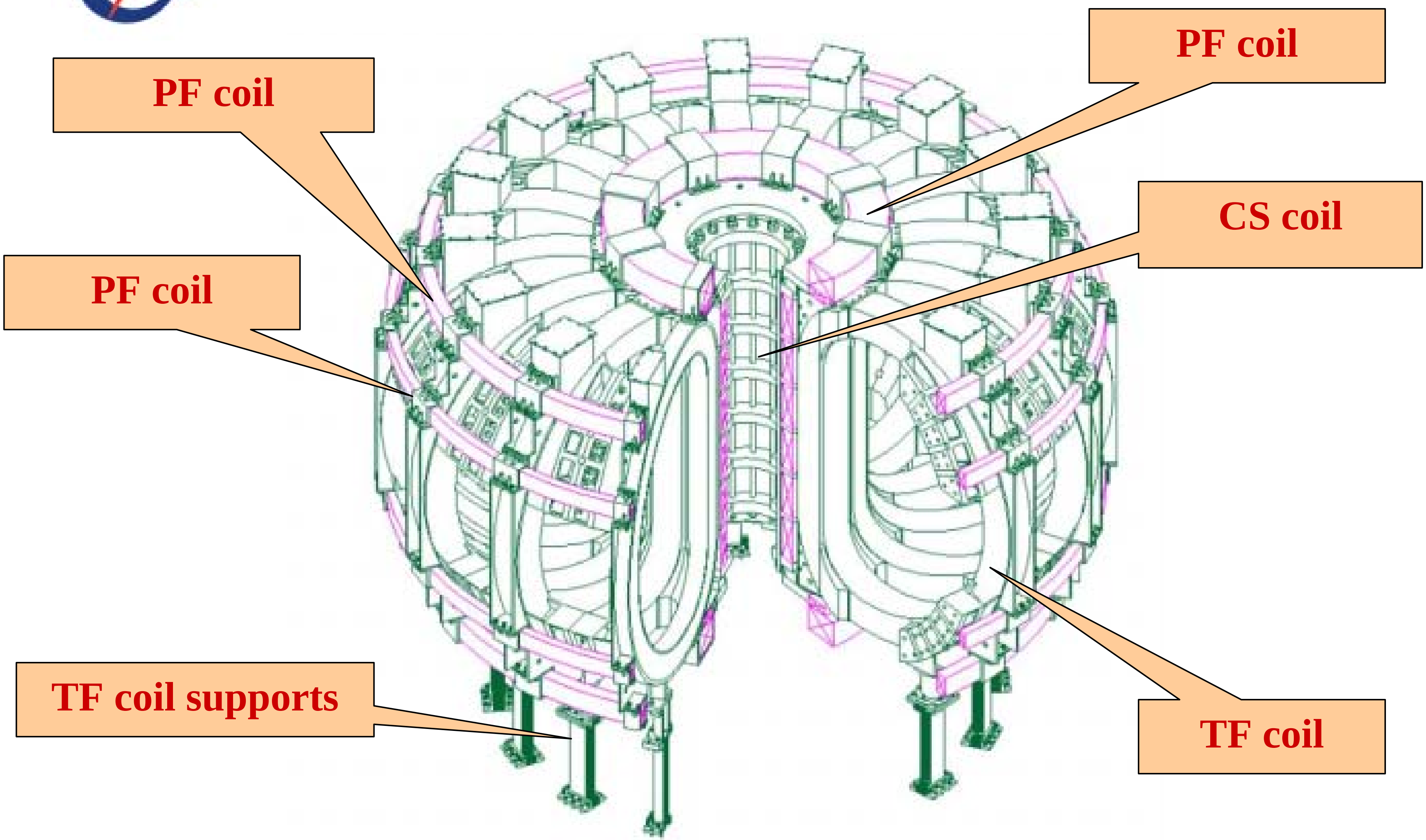
Heating and Driving:

(first phase)

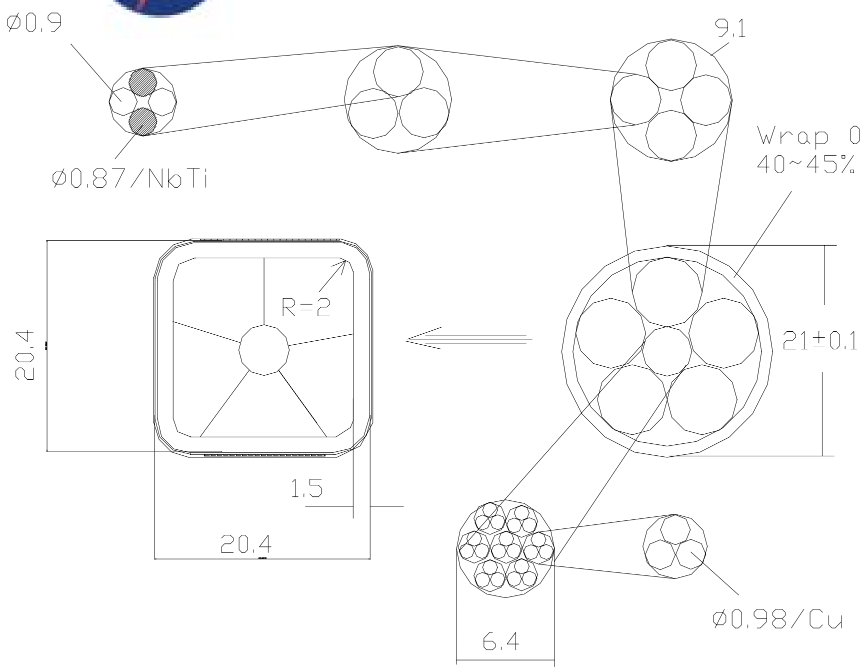
ICRF	3 MW
LHCD	3.5 MW
ECRH	0.5 MW

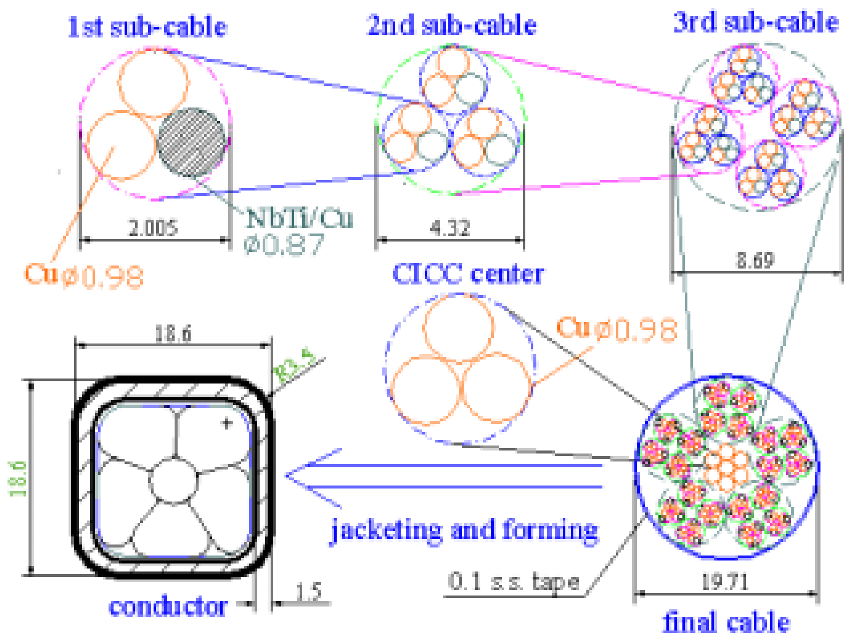
Configuration:

- Single null divertor
- Double-null divertor
- Pump limiter



EAST magnets





Large proportion of segregated cooper in conductor (68%)

Different surface coating for TF and PF respectively

CICC for EAST TF & PF magnets

CICC jacketing line

TF Parameters

Maximal field at coil	5.8T
Total turns	16×130
Coil size (D Shape)	3.52×2.51 m
Winding type	6 pancakes
Conductor size	20.4×20.4 mm
Length of each coil	2×593.5 m
Length of cooling channel	201 m
Operating current	14.3 kA
Operating temperature	3.8 K
Total storage energy	298.5 MJ

PF Parameters

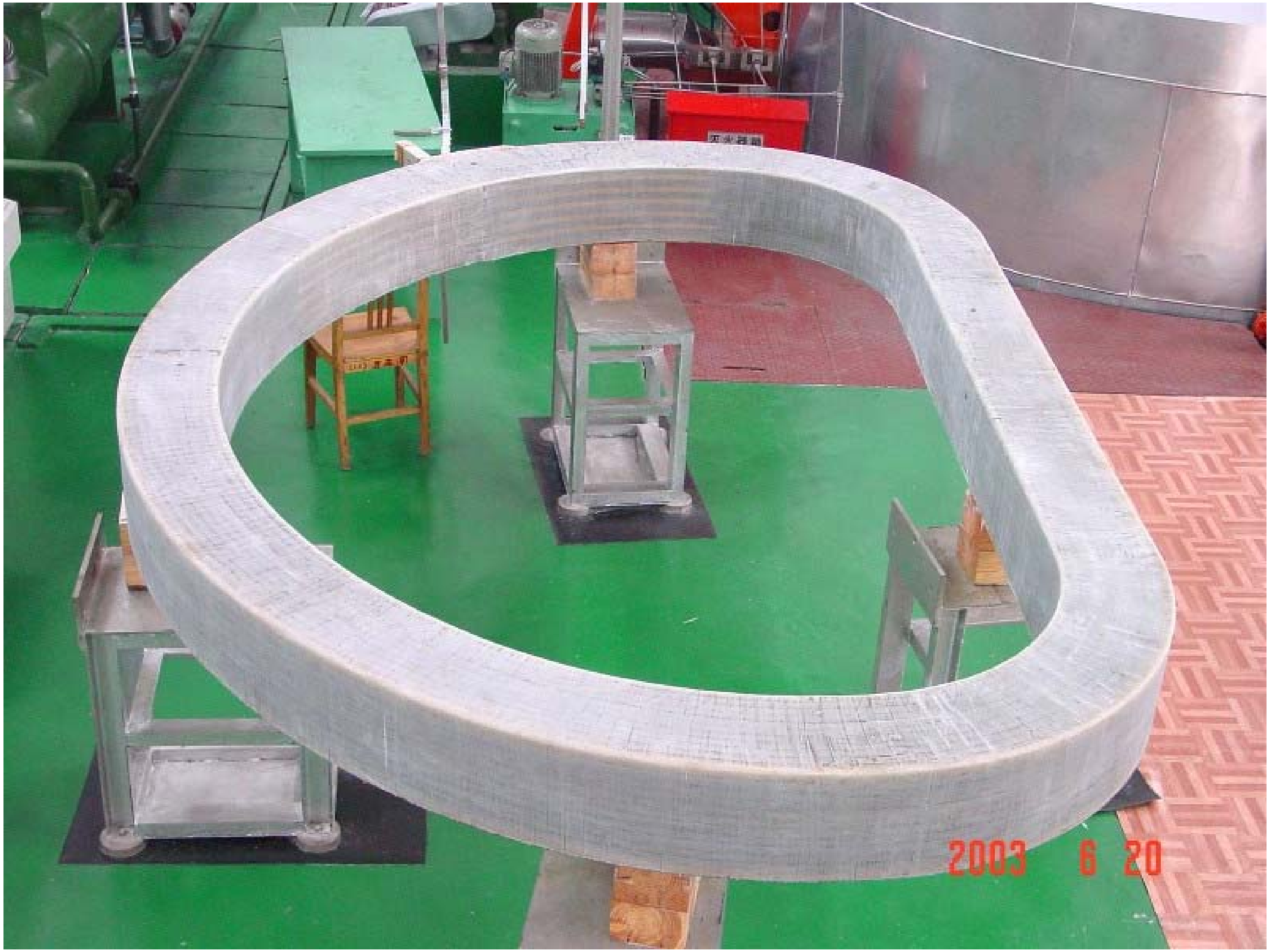
		PF1- 6	PF 7- 8	PF 9-10	PF 11-12	PF13-14
Out diameter	mm	1418	2401	2670	6054	6650
Inner diameter	mm	1085	1889	1889	5779	6468
Height	mm	476	103	289	221	179
Turn		140	44	204	60	32
Conductor	mm	20.8×20.8			18.6×18.6	
B_{max}	T	4.3			1.5	
I_{max}	kA	14.5				
dB/dt_{max}	T/s	6.8				
Operating temperature	K	3.8				
Total flux swing	VS	10				

TF coil case machining

TF prototype coil winding

PF coil winding

Vacuum pressure impregnation equipment (VPI) for TF and PF coils



TF coil after VPI

Diameter available 3.1 m

Height available 4.7 m

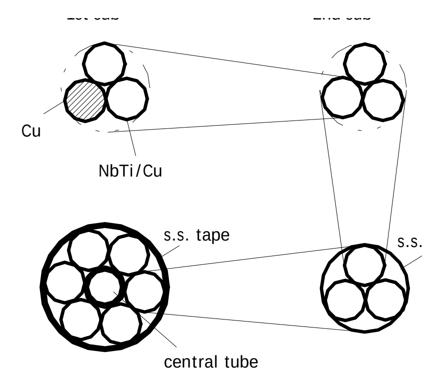
Vacuum 1×10^{-5} τ

Maximal current 30 kA

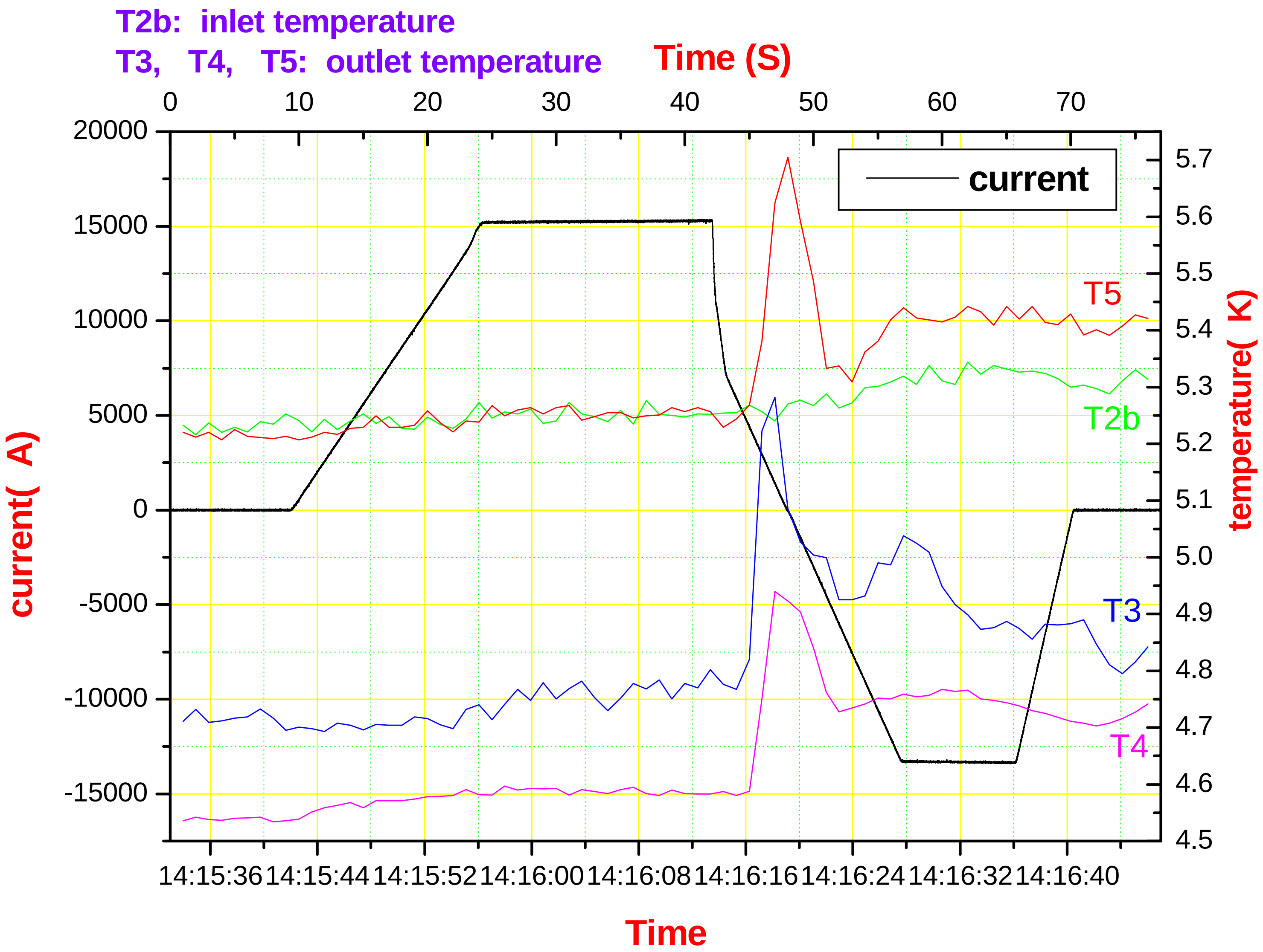
Refrigerator 500W/4.5 k

The prototype of TF and PF magnet will be tested in the facility this year

Superconducting magnet test facility

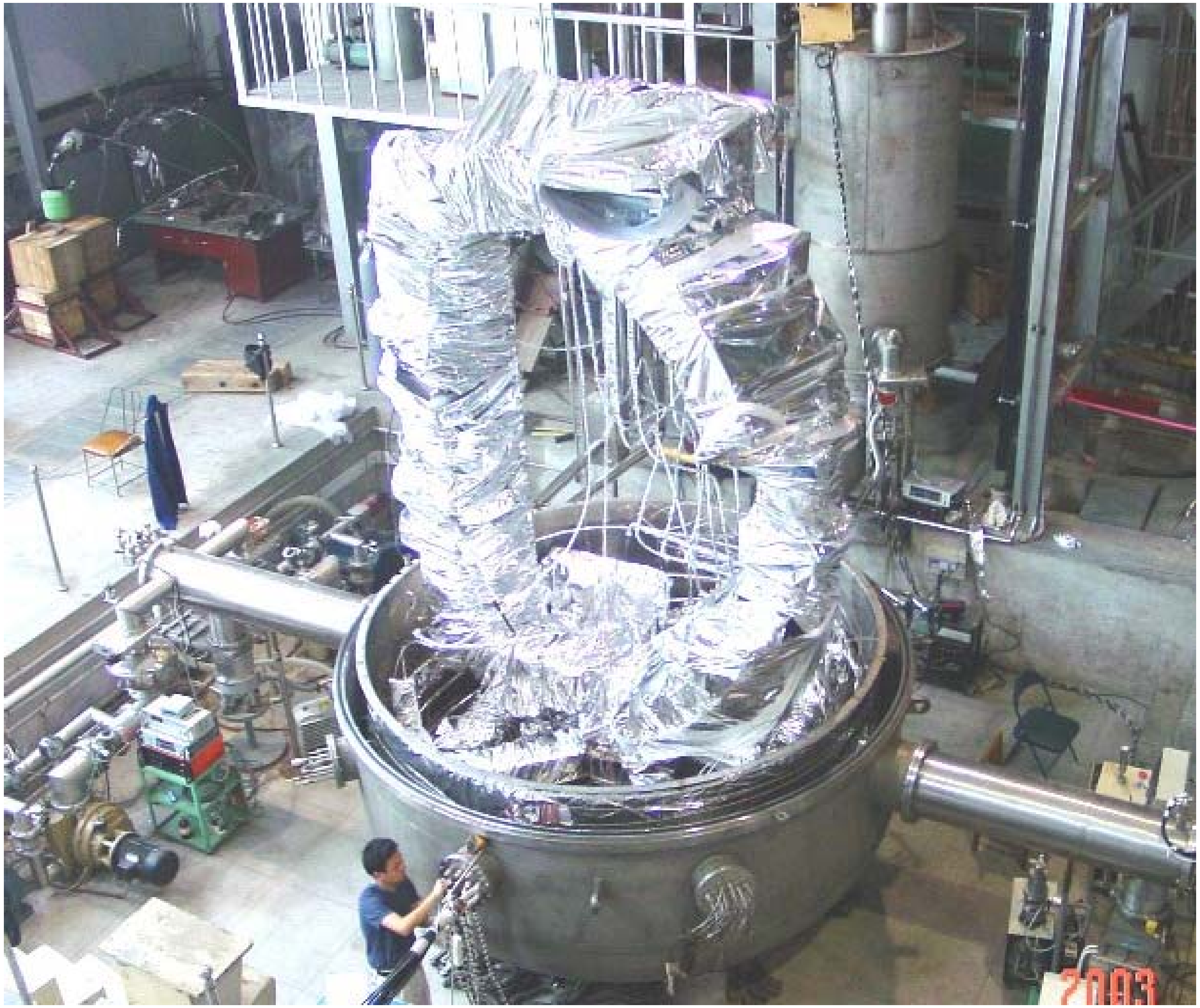


CS model coil installed in test facility

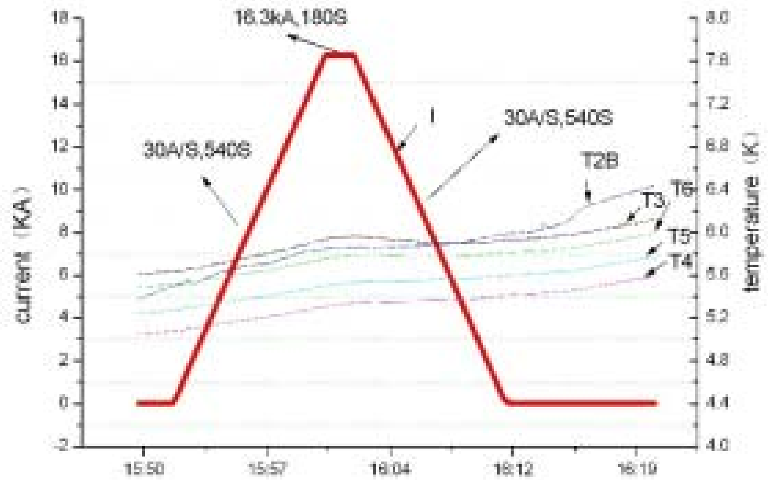


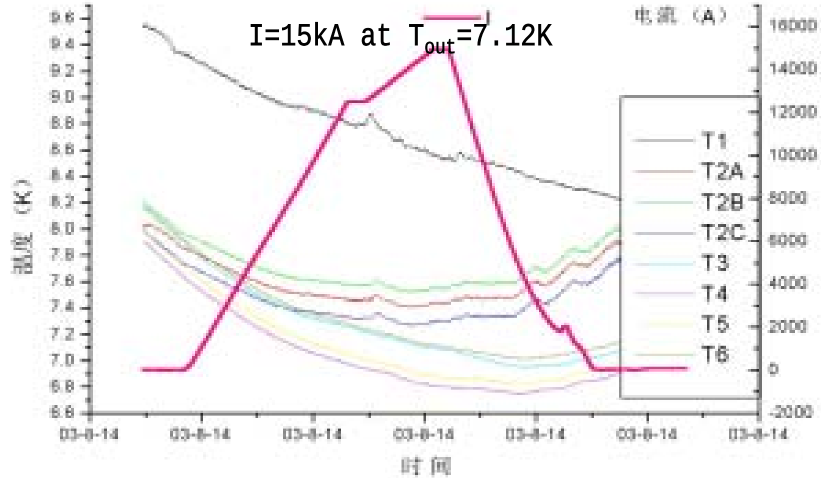
Outlet temperature rise due to coil fast discharge

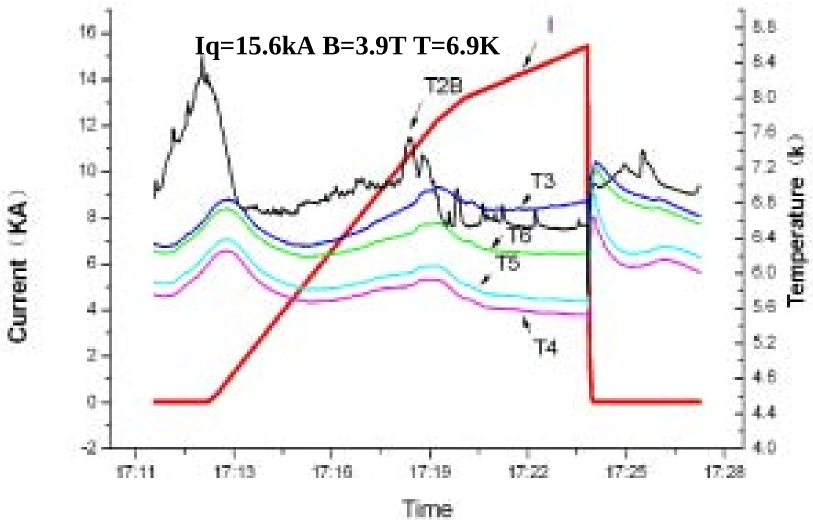
ΔT max ~ 0.3 K

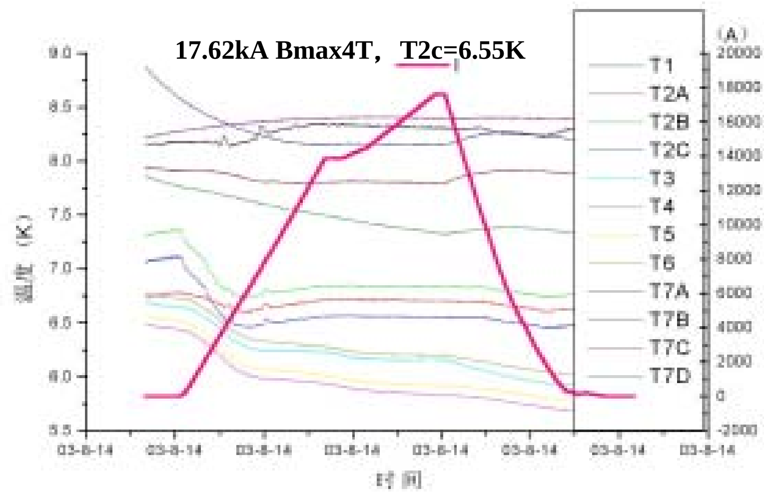


TF prototype coil in test facility









Extrapolated Iq from the test results =55-65kA at Bmax=5.8T,T=3.8K

TF coil exciting

Vacuum Vessel & in vessel components

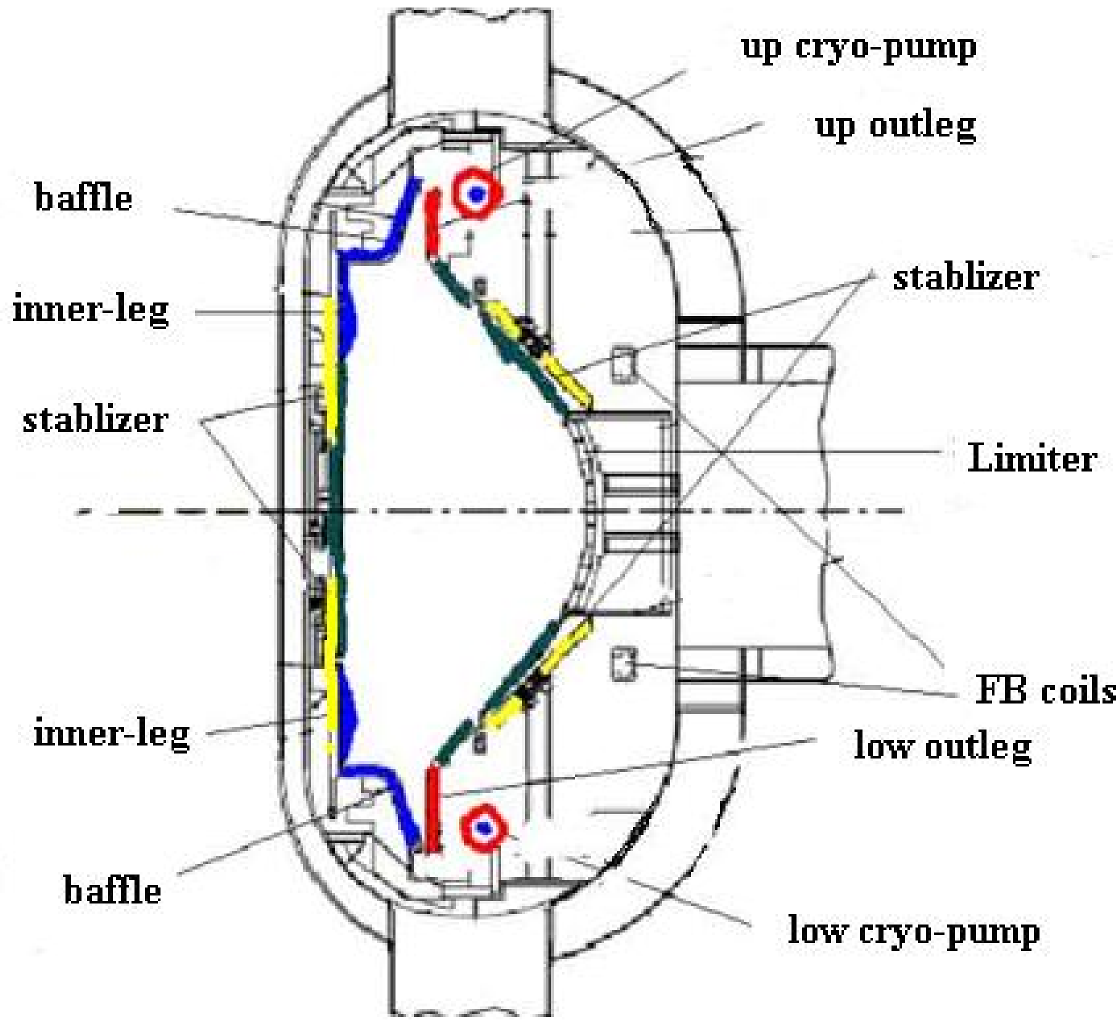
- Full welded double wall structure.
- Sixteen horizontal ports and thirty two vertical ports for Diagnostic, auxiliary heating and current drive
- Divertor and limit armed by graphite and CFC tiles
- Passive stabilizers and fast feed back control coils.
- The vessel and first wall can be back up to 200 º C and 350 º C respectively.
- Active cooling for first wall components and vessel wall.
- Flexible gravity supports are adopted to compensate thermal expansion.

Structures of Divertor and internal components

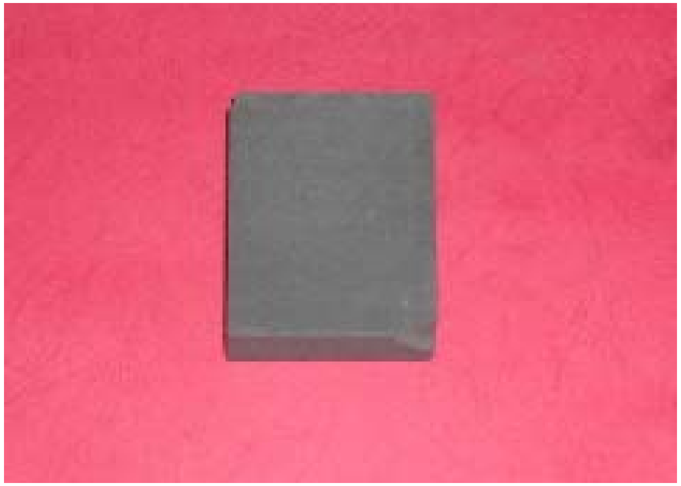
FM:2-3MW/m^2,doped C with SiC coating, Bolted type heat sink.

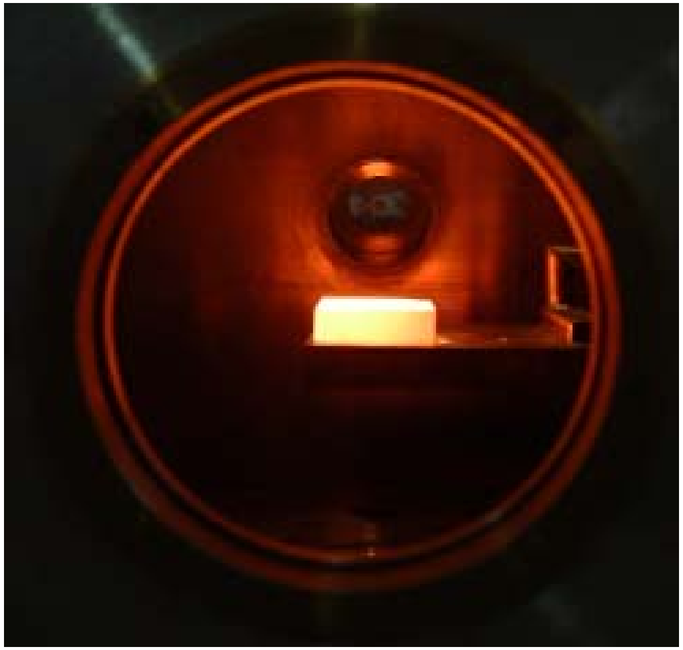
Divertor legs: 8-10MW/m^2, W coating on high performance C, C brazed to Cu heat sink

- Poloidal limiters;
- Divertor cassette modules, easy to change and alignment.
- Internal fast feedback coils for VDI control
- Using internal cry-pump in later phase.



First wall material testing facility





Plasma Control

- **Equilibrium, shape and position**

  PF coils+ internal fast feedback coil, Develop state-of-the-art simulations and models for real-time and steady-state condition

  Real time data collection for SSO profile control
- **Error field :correction coils(*Br/B*~ 5-8x10^{-5})**
- **Toroidal field ripple and fast particle losses :**

  The ferromagnetic material :ripple 2.7% to less than 1-1.5% .
- **MHD Instabilities (NTM,RWM)**

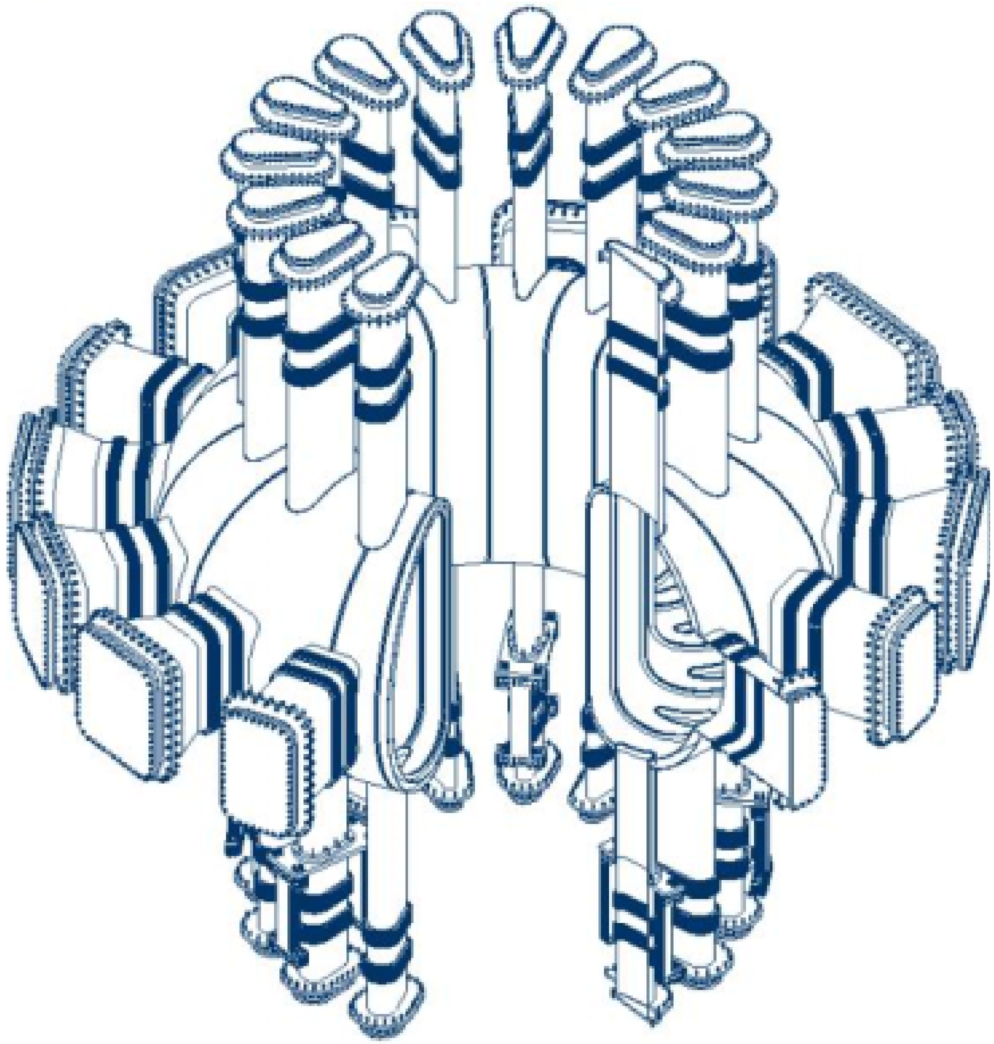
  Tailoring J(r) by LHW,IBW, NBI, RFC coils
- **Disruption mitigation: Ar,Ne puff(GP, MBI), killer pellets**
- **Profile controls**

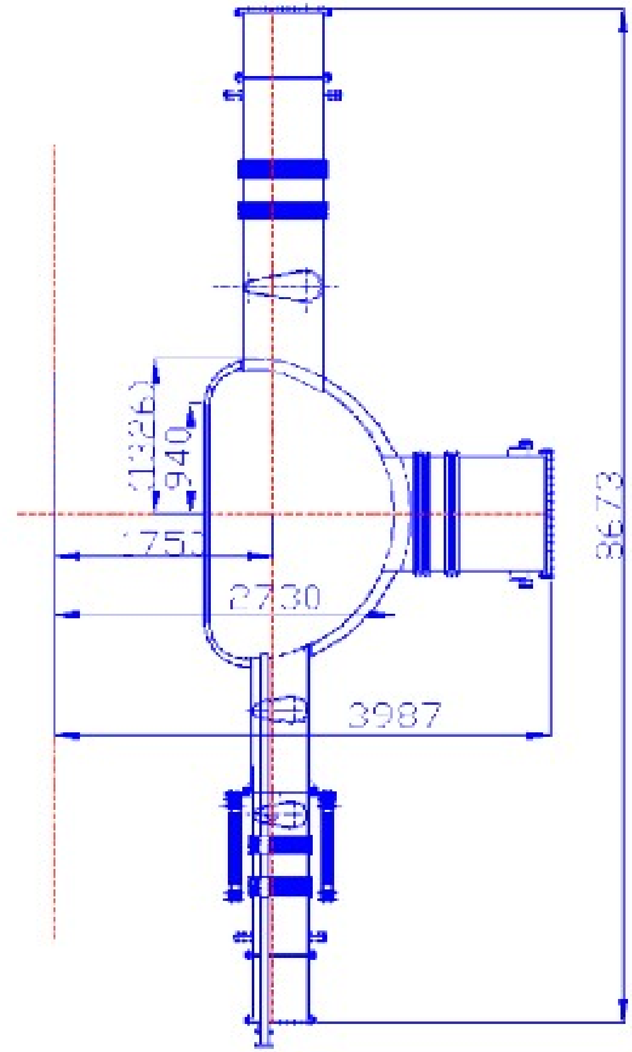
  Ne: NBI, ICRF, IBW, pellet, SMB

  Te(Ti): LHCD, IBW, NBI, ECRH, MCCD, ICRF

  Transport and turbulence: IBW, LHCD, ECRH

  ITB: IBW+LHCD, IBW+ECRH





Vacuum Vessel

Prototype of Vacuum Vessel Sector manufacture

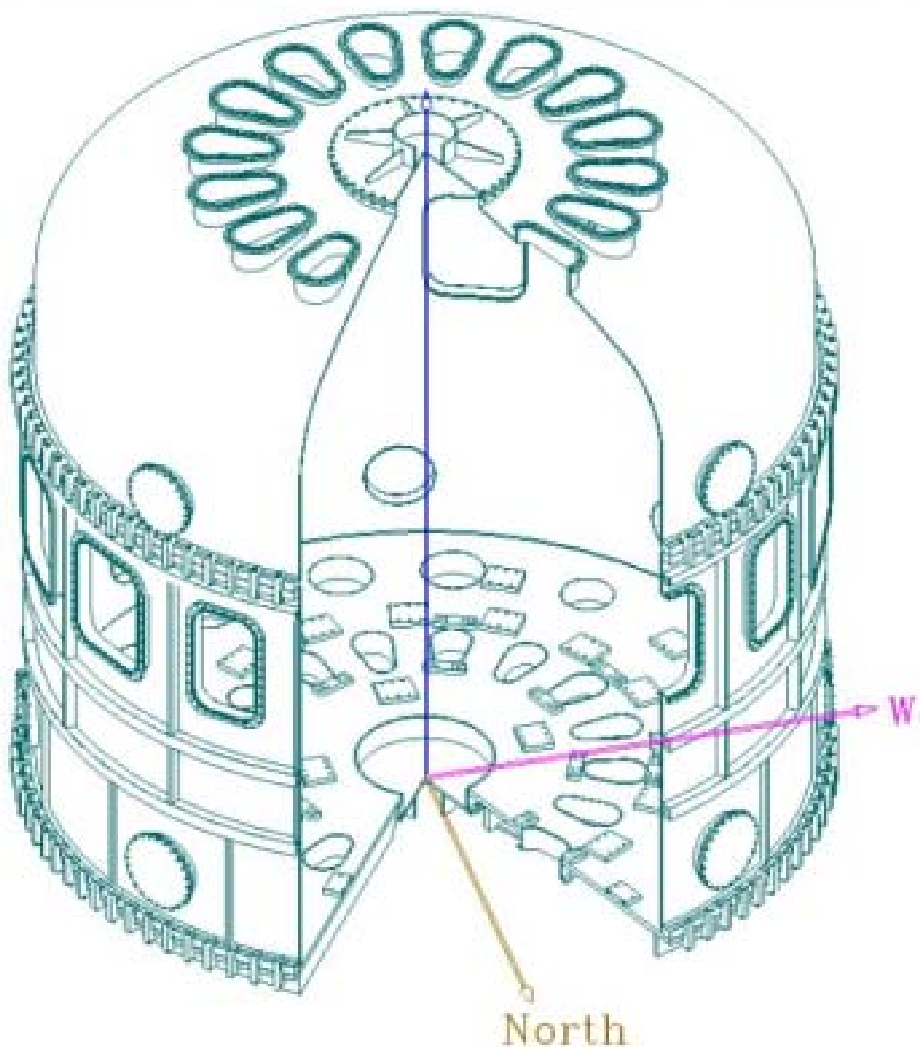
Vacuum Vessel port Bellows

Stress measurement of Vacuum Vessel ports and support

1/16 prototype vacuum vessel

Accuracy inspection of 1/16 prototype VV on A NC milling machine

Cryostat



Cryostat consists of upper head, middle cylindrical section and flat bottom section,

The main functions of the cryostat is to provide the vacuum insulation environment for the operation of the superconducting coils, all of magnets, vacuum vessel and thermal shield are supported on the flat bottom section. Except 48 penetrations for the vacuum vessel ports extention, there are 19 penetrations on the cryostat for cryo-feeder line, access to the cryostat interior for repair or inspection.

Thermal Shield fabrication

The main building for EAST

Bottom cryostat installed on the support

Cryogenic Systems

- **The cooled mass is around 165 tons at 3.8-4.5K and 20 tons at 80K. The heat load estimated is about 890W/4K +7.5g/s and 30kW/80K for normal operation.**
- **110g/s-3.8K supercritical Helium flow for the PF coils cooling, 260g/s-3.8K supercritical Helium flow will be used for TF windings and coil cases cooling. 110g/s-60K Helium flow will be used for thermal shield.**
- **The cryogenic system consists of 2kW/4.4K+11kW/80K refrigerator, 260g/s-4bar He pump, 1000L-3.8K sub-cooler and 10000L-4.5K liquid He tank, gas storage system and compressor station.**

Compressor station &
Helium gas storage system

One set of PF power supply of EAST is under testing

ICRF & LHCD System

The LHCD System

- **2.45 GHz existing system, which is used for HT-7 tokamak now, consists of 20 klystron amplifiers with CW output power of 2 MW in total.**
- **3.7 GHz system consists of 2 klystron amplifiers with 1.5 MW output power and 1000s pulse length.**

The ICRF System

Two subsystems, each one has 1.5 MW output power and the frequency range is from 30MHz to 110MHz. The first 1.5MW RF generator has been prepared and in bench test now.

1.5MW/30-110MHz RF generator

1MW 2.45GH LHCD launcher

2MW LHCD power supply

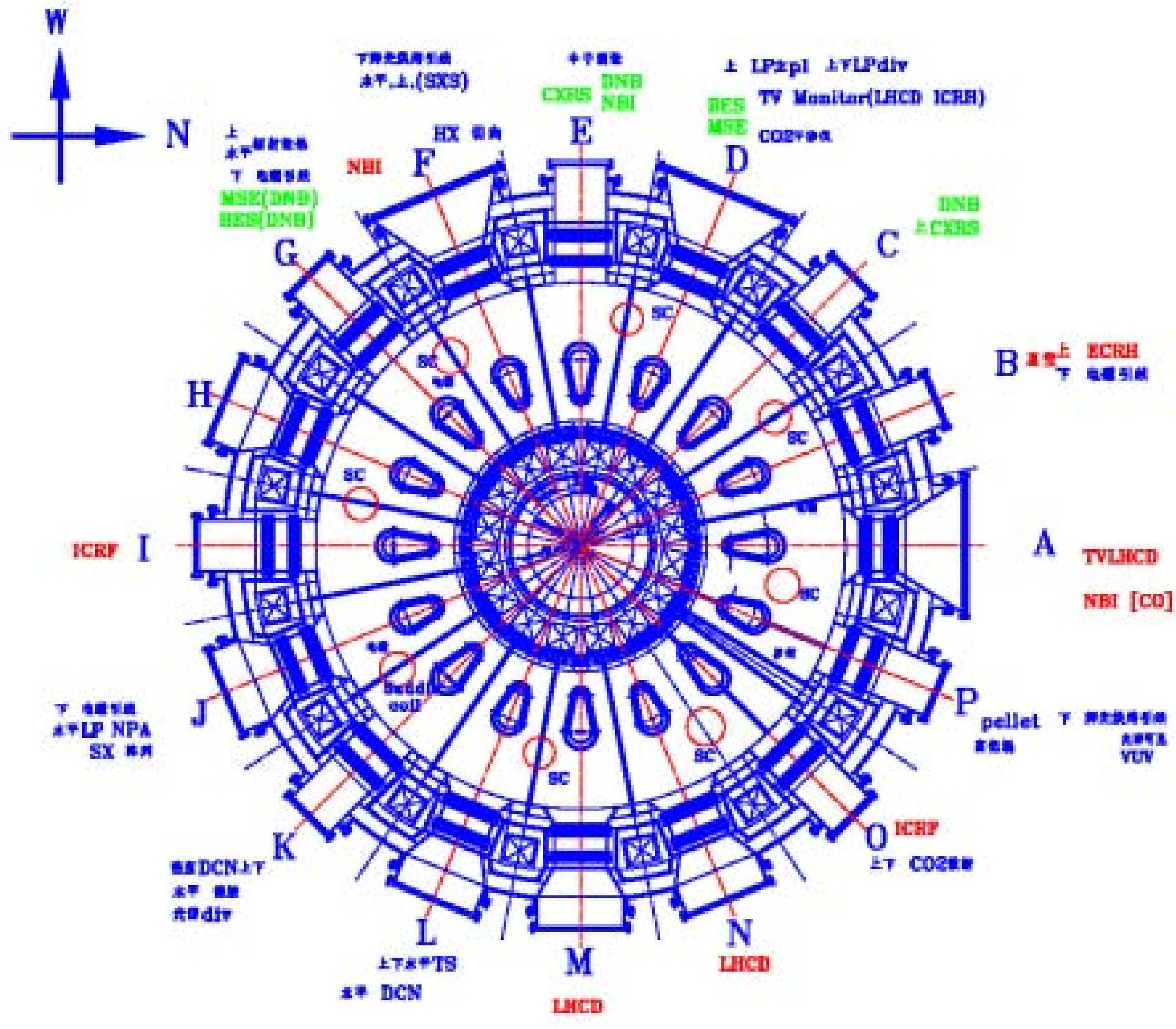
Basic Diagnostics

- Mainly for machine operation
- Electro-magnetic coils (for EFIT and control)
- Te: (ECE,SX-PHA) 、Ne (FIR interferometer, DCN)
- FW&Divertor（Langmuir probes,Visible spectroscopy,Visible and IR CCD ）;
- Bolometer、impurity monitors、 HX-ray, H_α array;
- MHD: Magnetic probes, SX array
- Vacuum Gauge,RGA

Advanced diagnostics

for physics understanding

- FIR Polarimetry
- MW Reflecmeter.
- TS
- DNB MSE
- MW Image
- CO_2 scattering
- Lp Array
- CXRS
- High resolution ECE
- Material Station



Schedule of EAST Project

- 1995 Submitting the proposal and begun the conceptual physics design
- 1996 Begun the preliminary engineering design
- 1997, 1998 The project approved by government finally and continue the conceptual engineering design
- 1998 -1999 Final conceptual engineering design and R&D
- 2000 - 2001 Engineering design and fabrication begun
- 2001 - 2002 Fabrication, some pre-assembly and test
- 2003 - 2004 Fabrication and assembly
- 2005 Complete assembly and get the first plasma
- 2006 - 2010 The first phase operation
- 2010- 2020 The second phase operation
- Around 2020 The proposal for a test reactor may be submitted