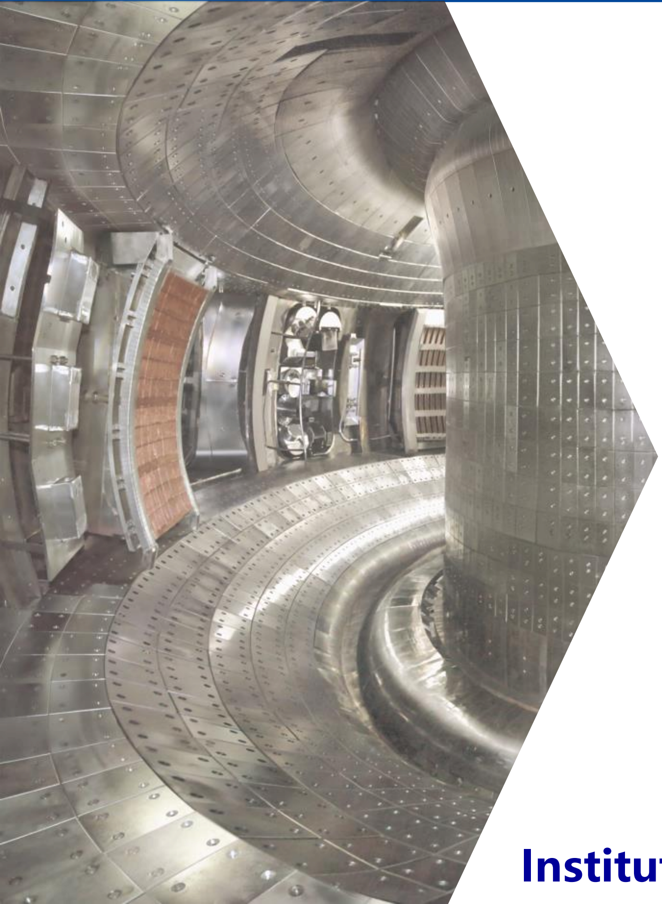
FUSION POWER ASSOCIATES: 42nd Annual Meeting and Symposium



Fusion Research and Activities in ASIPP

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December 15, 2021

Institute of Plasma Physics, Chinese Academy of Sciences

ASIPP

Contents

- **ASIPP strategy towards Fusion Power Plant**
- **Devices/Programs ASIPP involved in and related progresses**

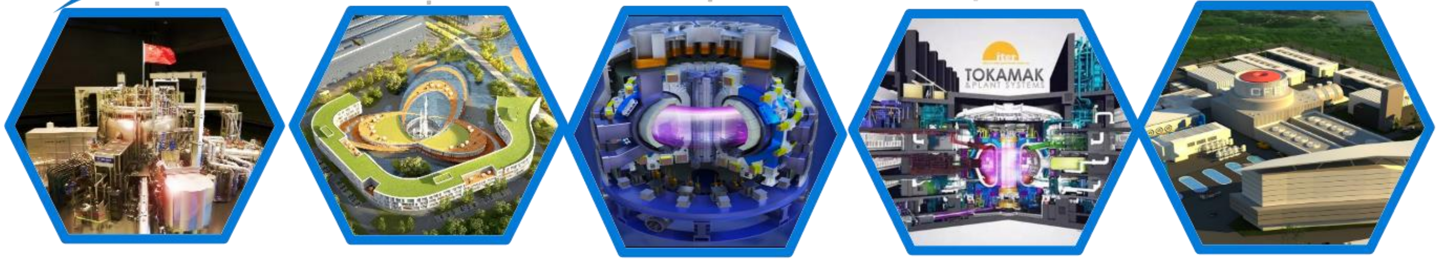
  - EAST
  - ITER
  - CRAFT
  - BEST
  - CFETR

- **Summary**

New strategy of ASIPP towards FPP

Operating	Constructing	Designing	Joining	Planning
Plasma physics, steady-state operation	14 key sub. sys R&D For BEST, CFETR Non nuclear	DT operation supporting ITER	DT 400s Q=10 3000s Q=5	<500MW, 5y 500MW, TBR=1, 5y 1-1.5GW, TBR>1, 5y
(2007-2030)	(2025-2040)	(2027-2045)	(2025-2045)	(2036-2050s)
EAST	CRAFT	BEST	ITER	CFETR

FPP



A new planed D-T devices, BEST, to support CFETR with a low risk and cost.

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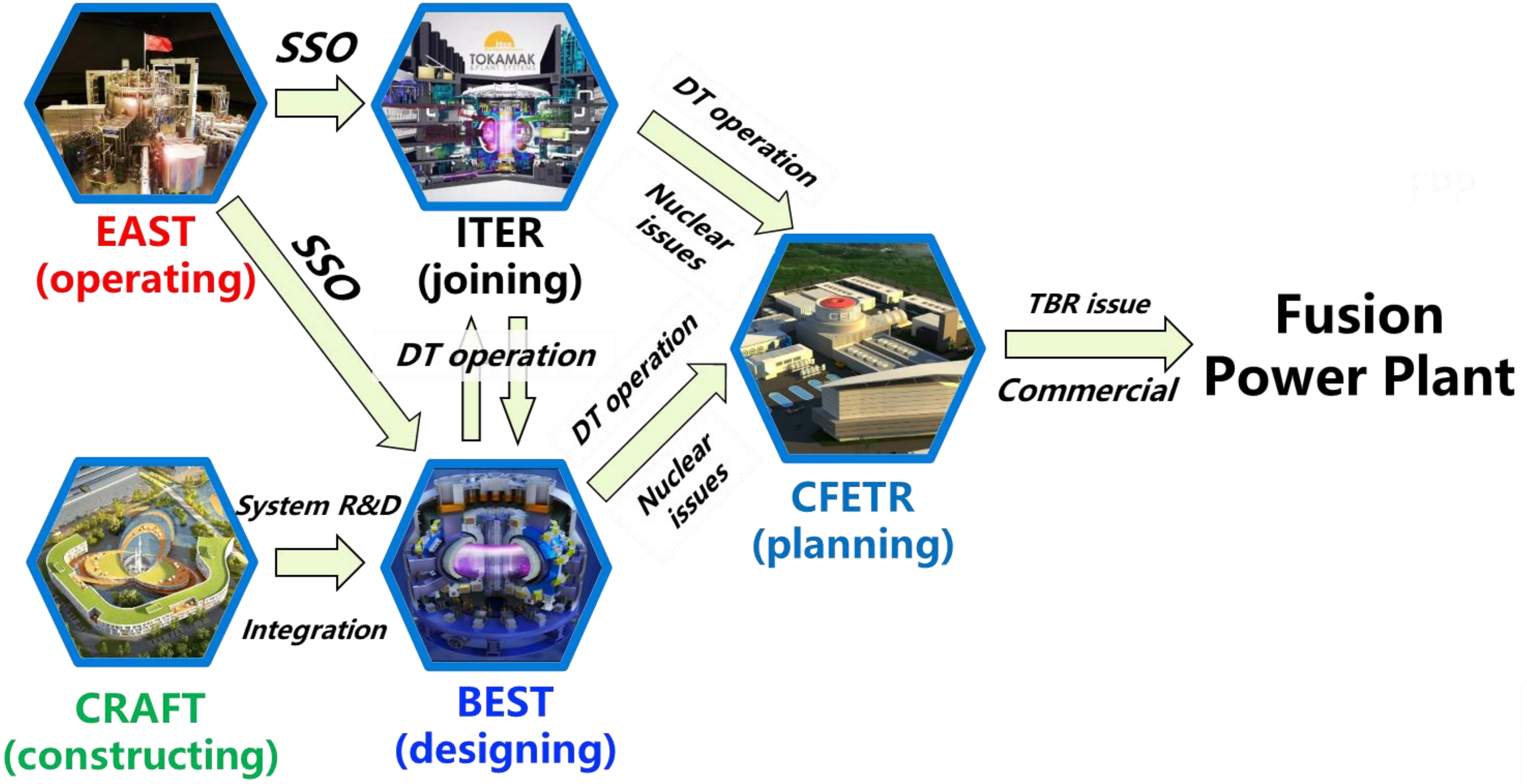
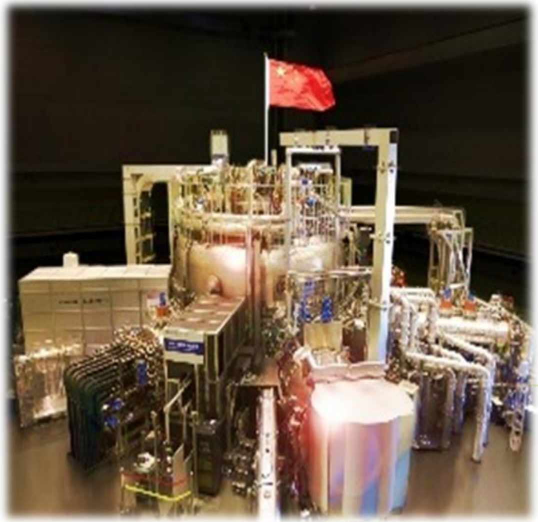
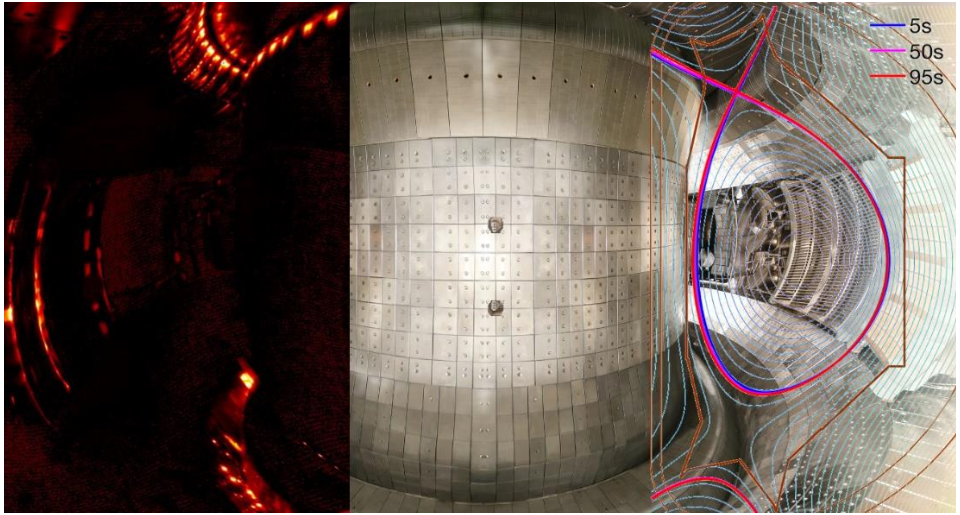
Relationship between devices involved by ASIPP



EAST Mission: Steady state operation and key physics

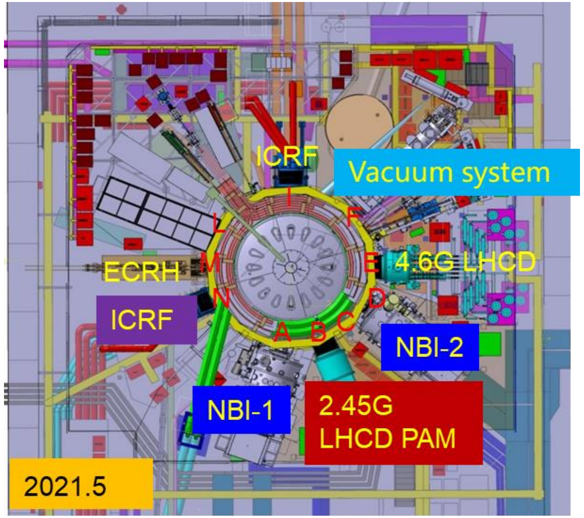


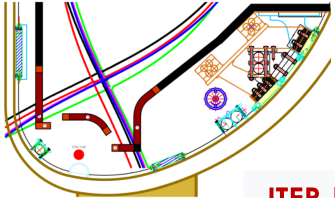


- **Steady state operation scenario** with high performance
- **Experimentally support** of key physics
- **Validation of novel technology** for future devices

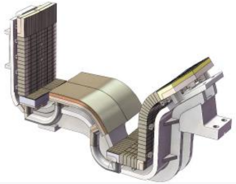
- Advanced scenario development
- Confinement and transport
- MHD and disruption
- Pedestal physics
- Divertor and PWI issues
- Energetic particle instabilities

EAST machine status and capability





ITER-like upper W-Divertor



Upgraded lower W-Divertor

LHCD PAM antenna

ICRF low k antenna

Upgraded vacuum system

1. **Full metal wall with ITER like W-Divertor**
   - W/Cu structure lower divertor with heat exhaust of **10 MW/m²**

2. **Flexible H&CD combination (with total source power ~30 MW)**
   - LHCD with PAM antenna, ICRF with low k antenna, 4 ECRH systems, 2 co-NBIs

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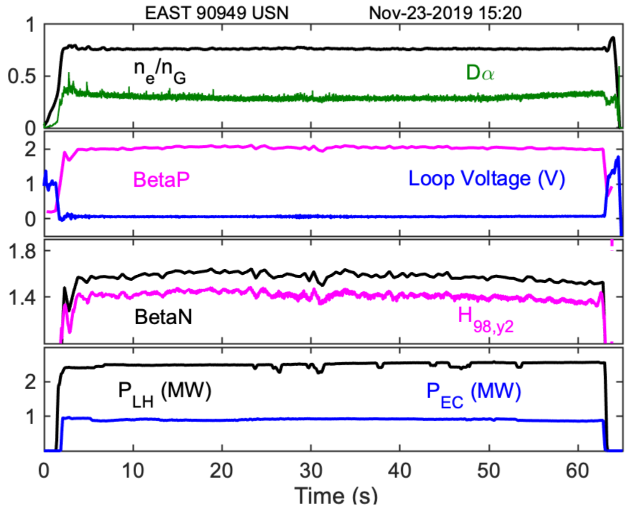
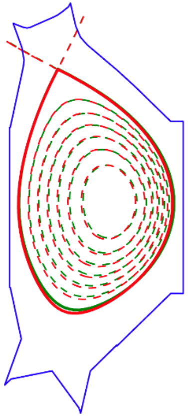
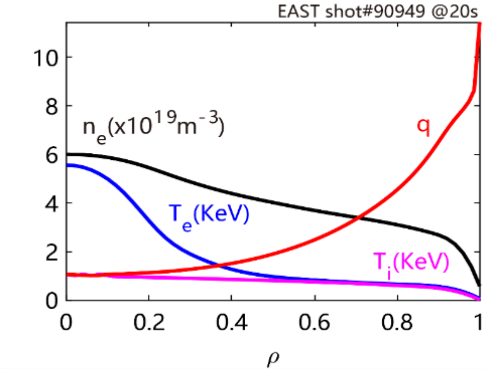
Steady-state high βp scenario development

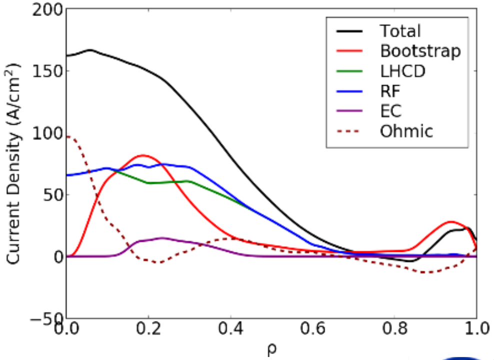




@ 30/60s

ITER-like
Tungsten divertor

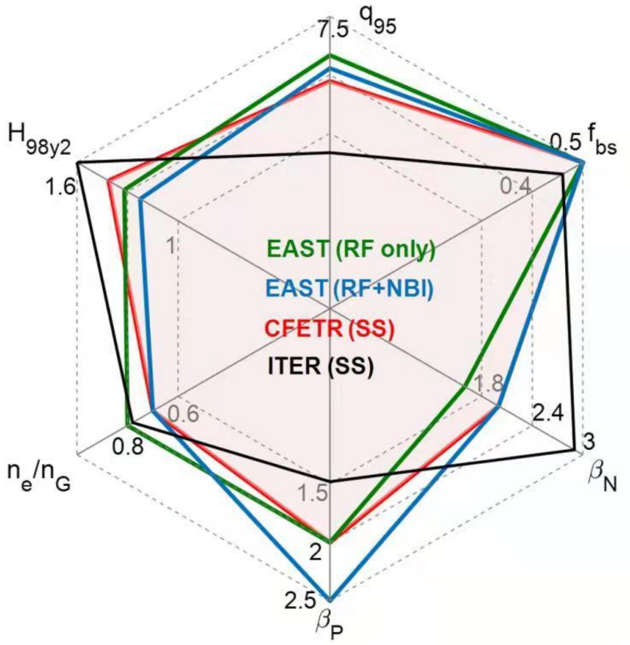




- **61.2s H-mode sustained with enhanced RF-heating**
  - **H_{98y2}~1.2, f_{GW}~0.7, β_p~2.1, β_N~1.7,V_{loop}~0**
  - Robust iso-flux control with Strike Points to W-divertor
- **101s H-mode in 2017**
  - **H_{98y2}~1.1, f_{Gr}~0.6, β_p~1.2, β_N~1.0,V_{loop}~0**

Fusion performance extended on EAST

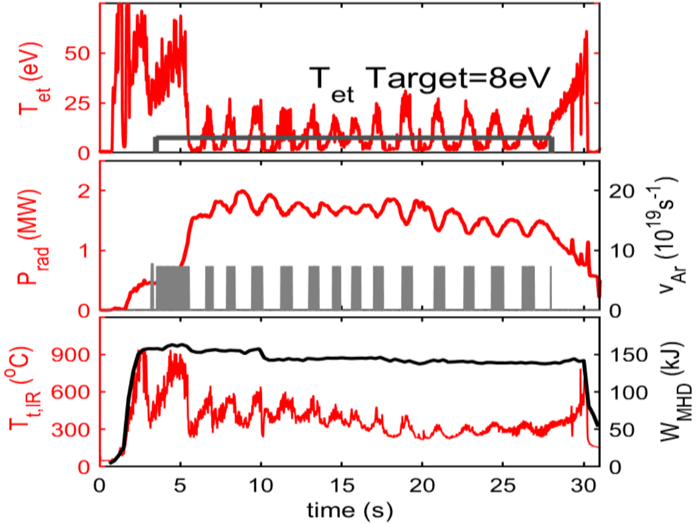
- **Fully non-inductive plasma with q95~6.0-7.0**
- **Extended operational regime**
  - High density f_{GW}~0.8
  - f_{BS} ~ 50%
- **Dominant e-heating，zero torque**
- **Small ELMs with well impurity control**
- **Improved confinement**
  - H_{98y2}~1.4
  - e-ITB inside r<0.4



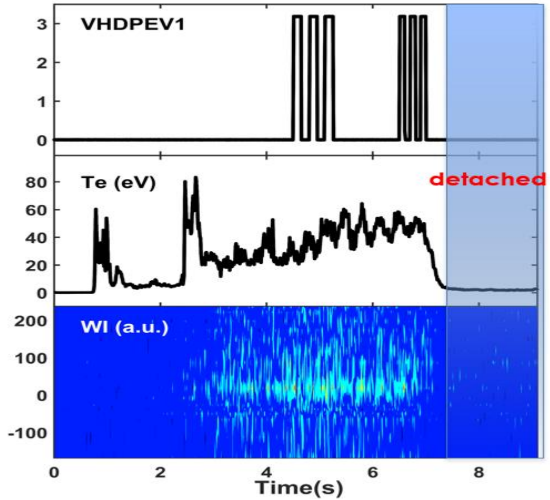
Close to 1GW CFETR Performance

Active detachment & W erosion control on EAST

➢ **EAST successfully demonstrates the active control scheme of detachment, addressing a key issue of ITER**



- Divertor T_{et} feedback control > 25 s
- H_{98y2}>1, good core-edge integration



- W erosion at the new divertor totally suppressed in detached condition
- Relative large ELMy H-mode with Neon

A significant progress on PWI control for long pulse core-edge integration

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EAST next goal and plan

- **Demonstrations of high power injection (>10MW)**
  - w/o hot spot on guarder limiter for 4.6GHz LHW (4.0-6.0MW **~70%**)
  - Coupling more ICRF power with new coating antenna (4.0-6.0MW **~50%**)
  - The three gyrotrons of ECRH (1.5MW **~50%**)
  - Favorable NB operational regime with less fast ion loss (4.0-6.0MW **~75%**)
  - Compatibility and synergy effect with different heating schemes
- **Extension of plasma operation with Available & Reliable 6.0-10MW (High priority)**
  - Relevant physics research in support of future long pulse H-mode with high performance
    - Scenarios Development: High Beta SSO / Hybrid /AT
    - H&CD, T&C, DSOL physics, dynamic control, EP physics, etc.
  - Exploration of high performance regime relevant to ITER when more power is available
- **EAST 2021 timeline**

Months	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Physics Exp.	Upgrade and Preparatory			1st Campaign						2nd Camp.	

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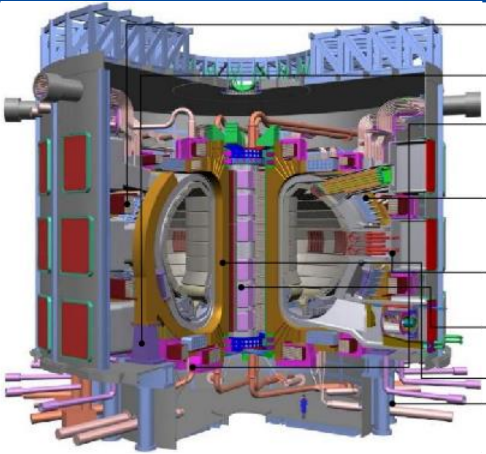
ASIPP contributions to ITER



A major ITER contributor in China:

- **Up to 73%** ITER procurement packages (PAs) in China
- Other ITER contracts like **PF6, TAC1, Bellows…**
- Human resource support to ITER: **IPAs, visiting scientists…**

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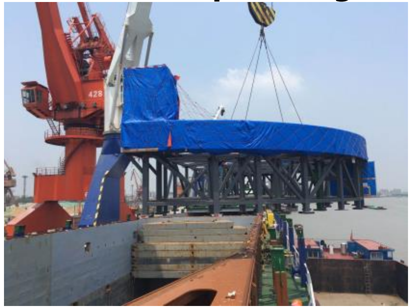
ASIPP contributions to ITER: PAs

Conductors: 100% finished.

AC/DC: All components were delivered to ITER site in Sept, 2021; **PPEN**: on-site installation support is going on.

Feeder: R&D finished, 62% produced, planning to finish in 2024.



CC : 72% produced, planning to finish in 2023.

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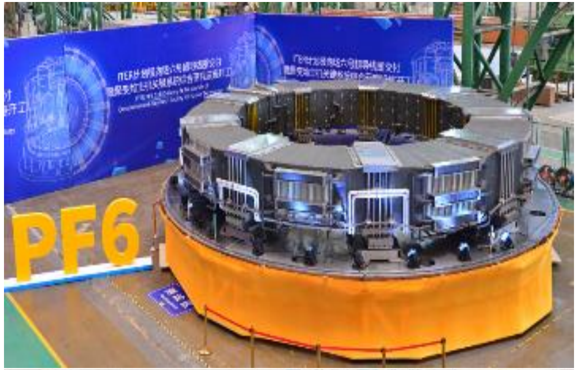
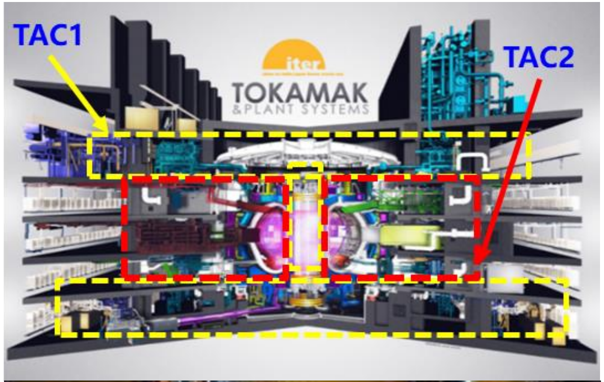
ASIPP contributions to ITER: Contracts

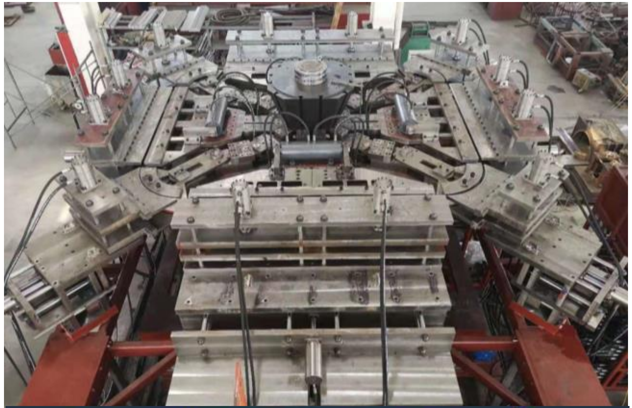
PF6 Coil

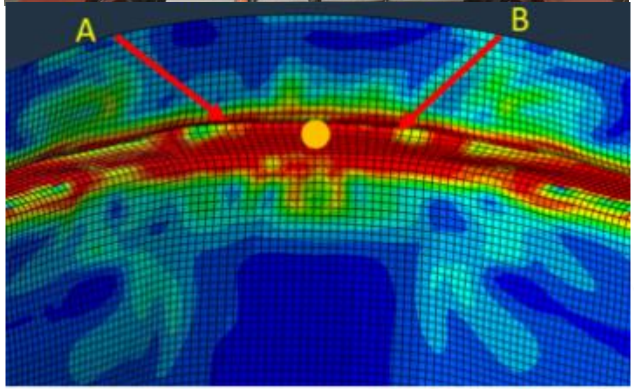


ITER Assembly (TAC1)



Large Bellows





CRAFT national project, supporting future devices (BEST/CFETR)

Comprehensive Research fAcilities for Fusion Technology

Approved	Chinese **National** Government
Mission	Key research platforms system R&D **in support of future devices (BEST/CFETR)**
Schedule	**2019-2025**
Status	Under construction, campus nearly finished

CRAFT national project, supporting future devices (BEST/CFETR)

CRAFT strategy:

Components → systems → integration

Future devices

Key systems

SC material (2)

NNBI system with 100s (2)

Linear material test facility (2)

Cryogenic system(2)

Integrated system design, commission and operation

Key components

Tetrode (2)

Gyrotron (4)

NNBI source (3)

CRAFT Expectation:

Technically ready for future reactor

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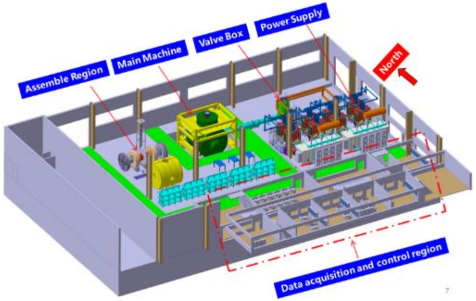
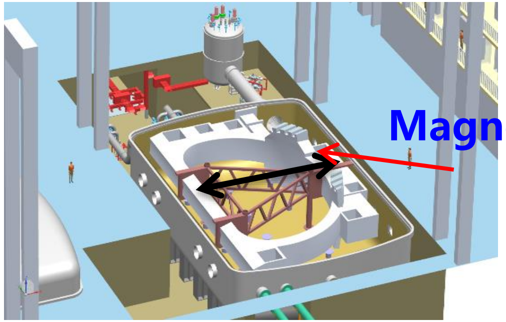
CRAFT Progress (part)

To be ready in 2025

Superconductor Test Facility (16.5T, 100KA)

Evaluation of Conductor and joint performance





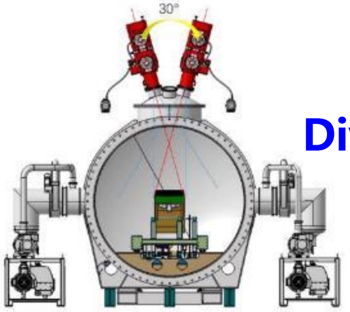
Magnet

Superconducting magnets test facility

Large-scale magnets performance (safety, stability, reliability…)

Large linear plasma facility (~3 T, 10^{24} -10^{25} $m^{-2}s^{-1}$)

For plasma-facing materials and components

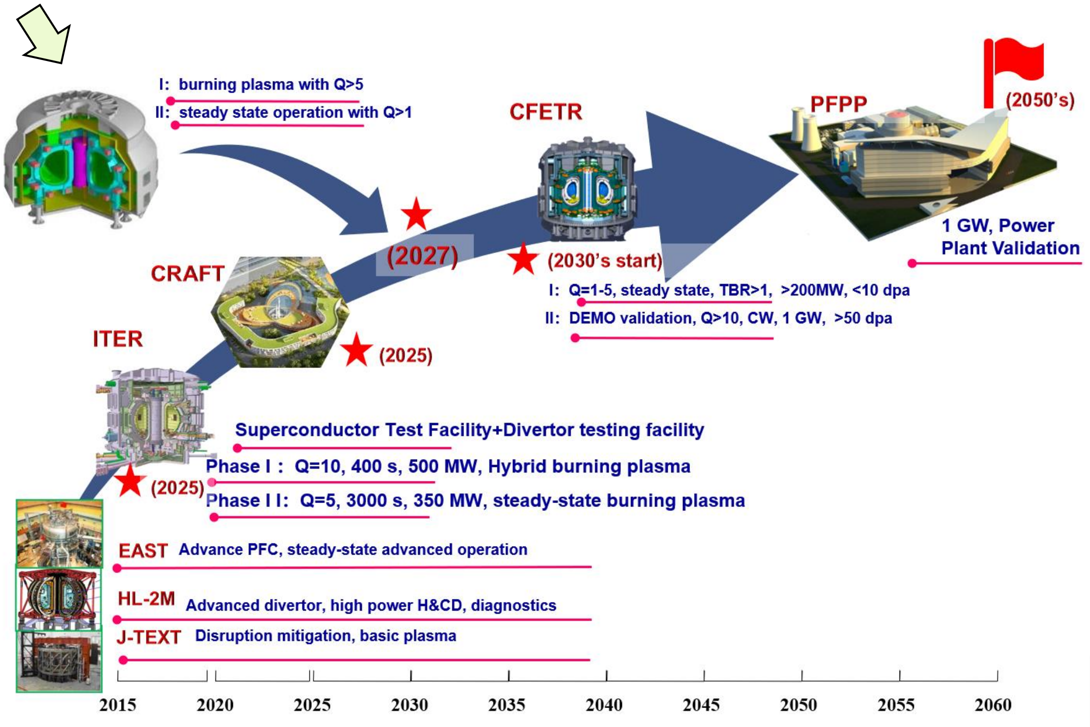


Divertor test facility ($20MW/m^2$)

BEST facility (under design)

Burning plasma Experimental Superconducting Tokamak

- **Burning plasma** with lower cost (construction and operation)
- To **understand Alpha particle** behavior and its control
- To develop the integrated control of a **fusion steady state scenario**



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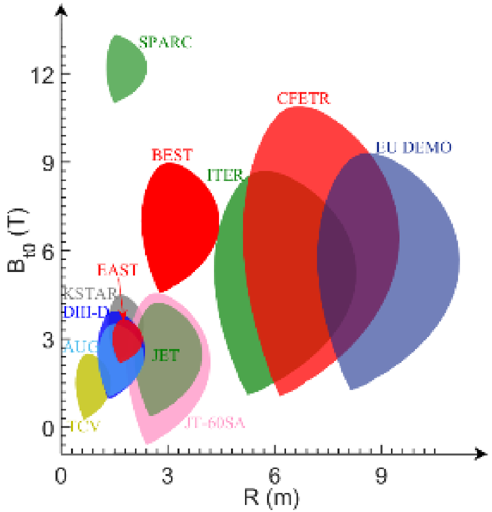
Main design parameters for BEST

- Burning plasma physics with **Q >5 as baseline**
- DT plasma in **steady-state at low Q (Q<1)**, with adequate neutron fluence for material, blanket and fuel inventory testing.
- Develop and **explore** methods for achieving **high Q operation** applicable to fusion pilot plants.

Main parameters	
Plasma current	**I_p=4-7 MA**
Major radius	**R=3.6 m**
Minor radius	**a=1.1 m**
Elongation	**κ=a/b=1.9**
Toroidal field	**B_T=6.15 T**



"In general, **we fully support the concept** of a device of this size and objectives as a critical step in the Chinese program to lead to CFETR"

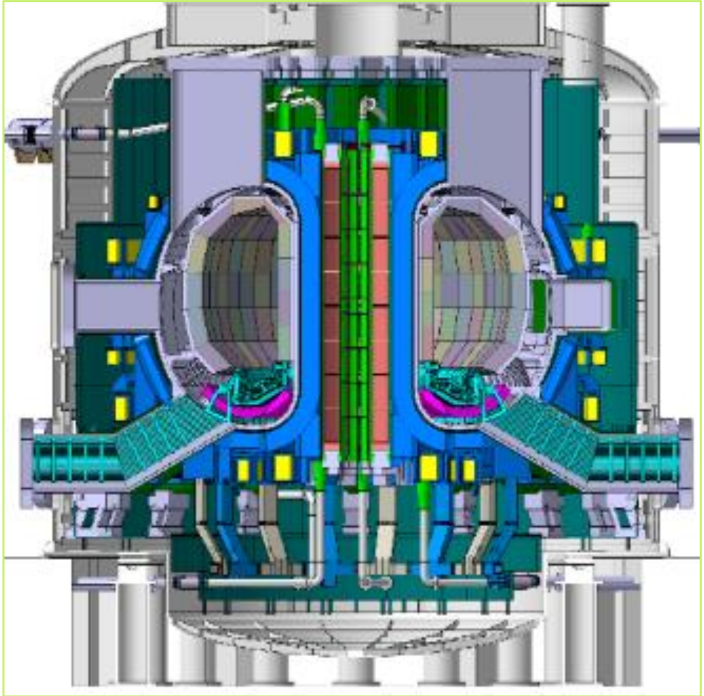
——BEST PAC 2021(July 29-30)

CFETR: Chinese Fusion Engineering Test Reactor

- **CFETR**: A **DEMO** facility before FPP in China

- Self-sustained burning plasma with
  - i) high **fusion power** (200-1500MW),
  - ii) high **duty cycle** (≥0.5),
  - iii) high **fusion gain** (Q=3-30)

- Tritium breeding technology with **TBR≥1**



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CFETR design project completed in 2021

CFETR design Project

MOST

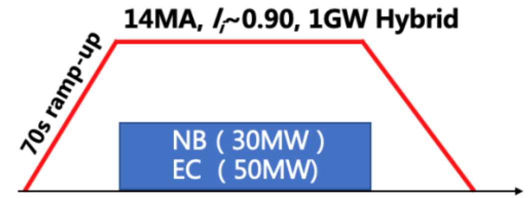
1. Physics design
2. Nuclear safety system
3. Engineering and integration design
4. Auxiliary system design
5. Database and management system

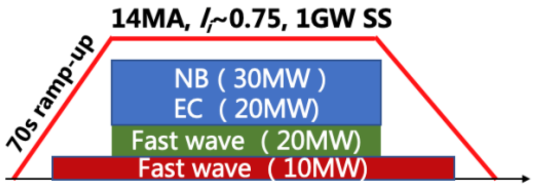
87 tasks, >800 people involved

Main parameters	
Plasma current	I_p=14 MA
Major radius	R=7.2 m
Minor radius	a=2.2 m
Toroidal field	B_T=6.5 T
Fusion power	P_{fusion}=200-1500 MW

CFETR design progress: Physics

Scenario design

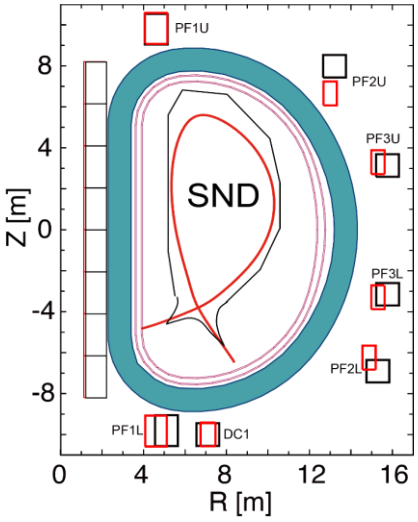


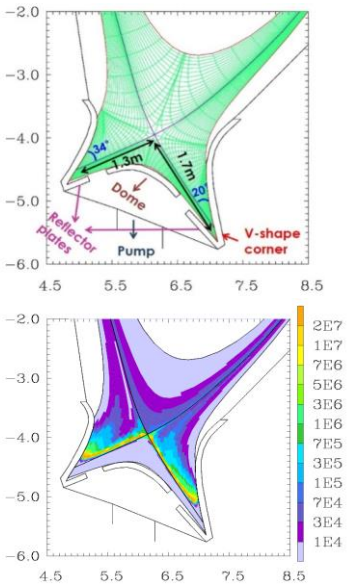


	P_{fus} (GW)	P_{NB}/P_{EC} (MW)	H_{98y2}	β_N/β_P	f_{bs}/l_i	I_p (MA)	$n_{e,line}$ ($10^{20}/m^3$)
Hybrid	0.95	30/50	1.14	2.3/1.5	0.45/0.9	13	1.0
SS	1.0	30/55	1.33	3.0/2.5	0.78/0.8	10.5	0.92

Hybrid and Steady State scenarios

Configuration and divertor





- **Conventional SN divertor**
- **Detachment with Ne injection**
- **Compatible with blanket**

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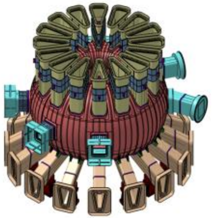
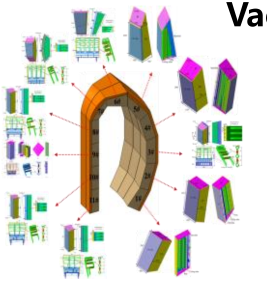
CFETR design progress: Engineering

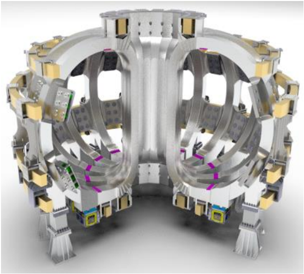
- **Machine engineering and integration design completed**



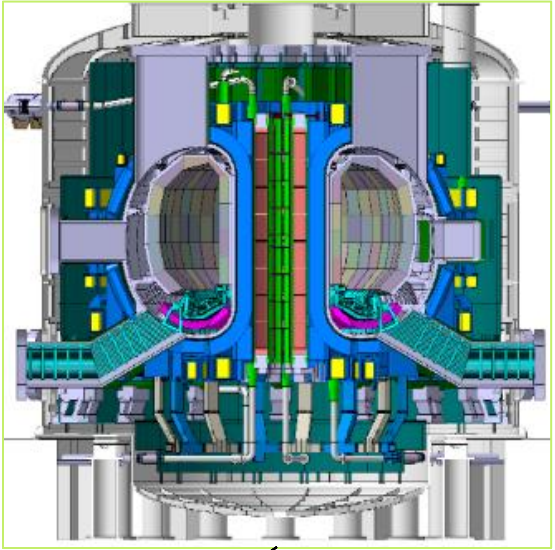
Vacuum Vessel

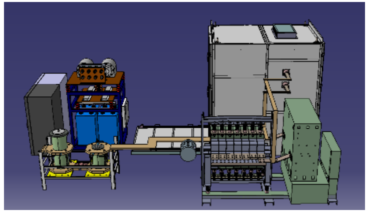


Blanket

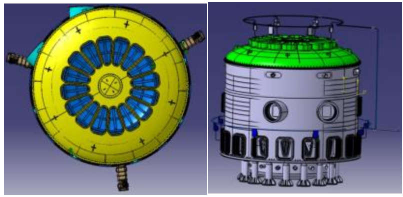


Magnet

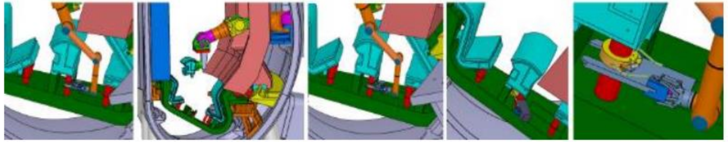




Power supply



Fueling



Remote Handling

…

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Collaboration: Networks and organizations

Global collaboration

Fusion for Energy (F4E)
EURO fusion
York University
Plasma Research Laboratory
General Atomics (GA)
Princeton Plasma Physics Laboratory (PPPL)
MIT Plasma Science & Fusion Center (PSFC)
Lawrence Livermore National Laboratory (LLNL)
Queensland University of Technology (QUT)
The Culham Center for Fusion Energy of the United Kingdom Atomic Energy Authority (CCFE)
Joint Institute for Nuclear Research (JINR)
The Nuclear Research Center "KURCHATOV INSTITUTE" (NRC KI)
Lappeenranta university of technology, Finland
University of Saskatchewan
French Alternative Energies and Atomic Energy Commission (CEA)
The Institute of Plasma Physics of the Italian National Research Council (IFP-CNR)

Max-Planck Institute of Plasma Physics (IPP)
Forschungszentrum Juelich GmbH (FZJ)
National Institute for Fusion Science (NIFS)
National Fusion Research Institute of Korea (NFRI)
Thailand Institute of Nuclear Technology (TINT)

Pusan National University
Air Liquide
Institute of Plasma Research (IPR)
Denmark Technical University
University of Twente
General Fusion

Academy of Sciences of the Czech Republic
National Institutes for Quantum and Radiological Science and Technology (QST)
National Council for Scientific and Technological Development (CNPq)
iThemba LABS
National Agency for Atomic Energy (ENEA)

Domestic networks

Example: SIFFER (SIno-French Fusion Energy centeR)

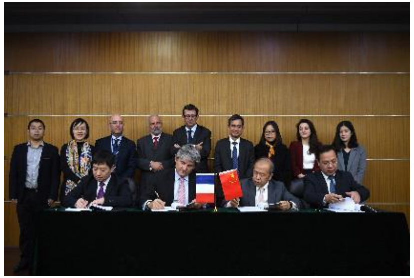
SIFFER
FUSION TOGETHER
irfm
SWIP
ITER CHINA

Members:

IRFM (FR)
ITER CNDA (CN)
ASIPP (CN)
SWIP (CN)

SPAs:

Integrated Modeling
W-Divertor
ICRH
Infrared monitoring

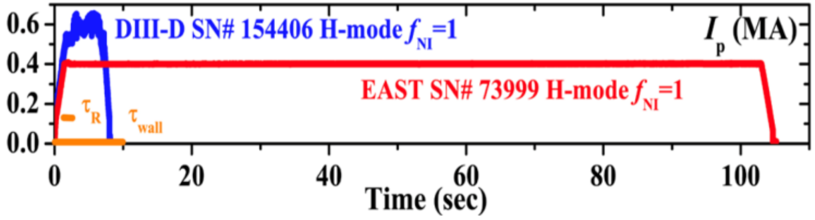


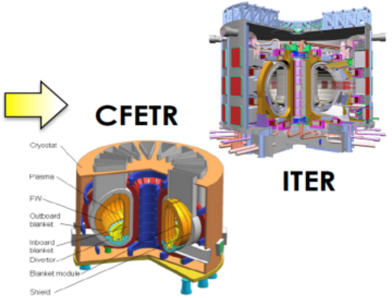
Collaboration: Joint Experiments on EAST

EAST: A shared and open platform to the world

Example: DIII-D & EAST joint experiment

DIII-D: Development of SS scenario physics basis → EAST: Extension to long pulse with metal walls → VALIDATED MODELS: projection to future devices





On-site and remote participation

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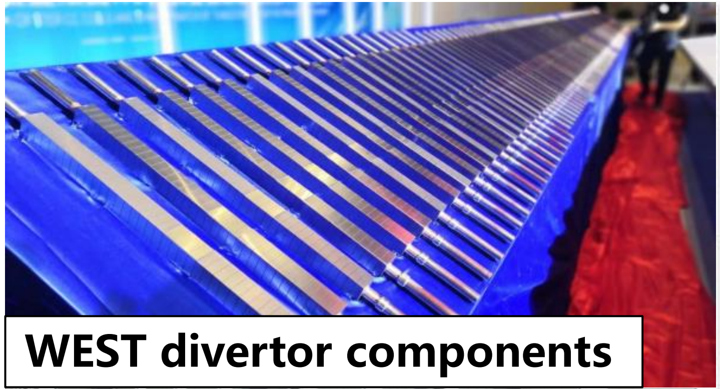
Collaboration: Fusion technology for the world



WEST divertor components

ASDEX-U ICRF antenna

WEST ICRF antenna

Contribution to ITER CS

Summary: ASIPP Fusion Research Strategy

- **Fasten application of clean, safe, non-carbon fusion energy**

- **EAST:** Continually exploring SSO and other critical physical issues in support of ITER/BEST/CFETR.
- **ITER:** Actively participating in construction and operations in support of BEST/CFETR
- **CRAFT:** Developing of key techniques/materials for BEST/CFETR with innovations and ITER reference.
- **BEST:** Fusion reactor related D-T burning plasma with low cost and risk in support of CFETR
- **CFETR:** a planed China DEMO FPP with supports from EAST/BEST/CRAFT

- **Strengthen global collaboration and train young generation to support this strategy**

Thank you !