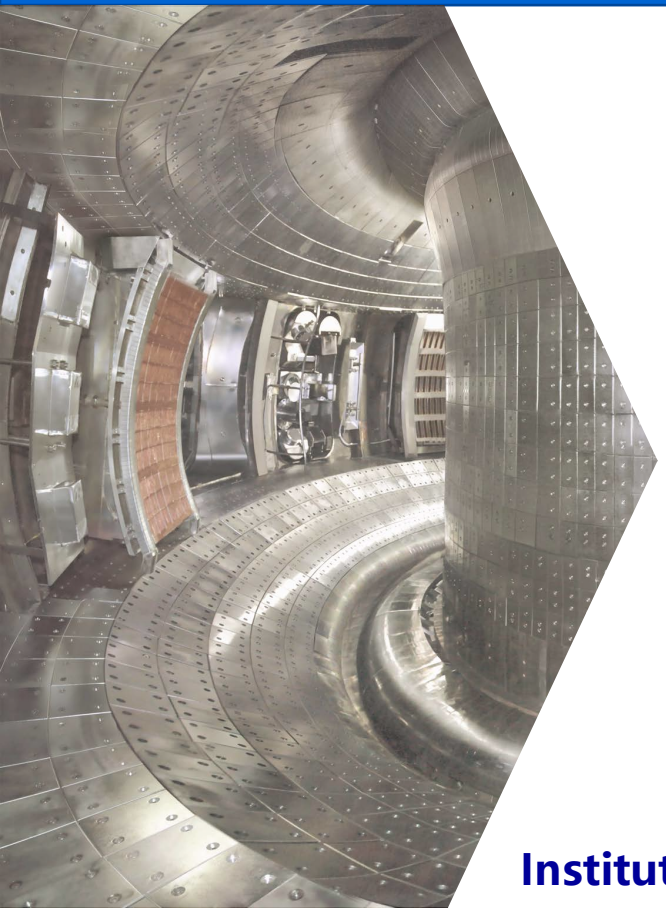


Fusion Strategy and Activities in ASIPP

Yuntao Song

December 7-8, 2022

Institute of Plasma Physics, Chinese Academy of Sciences

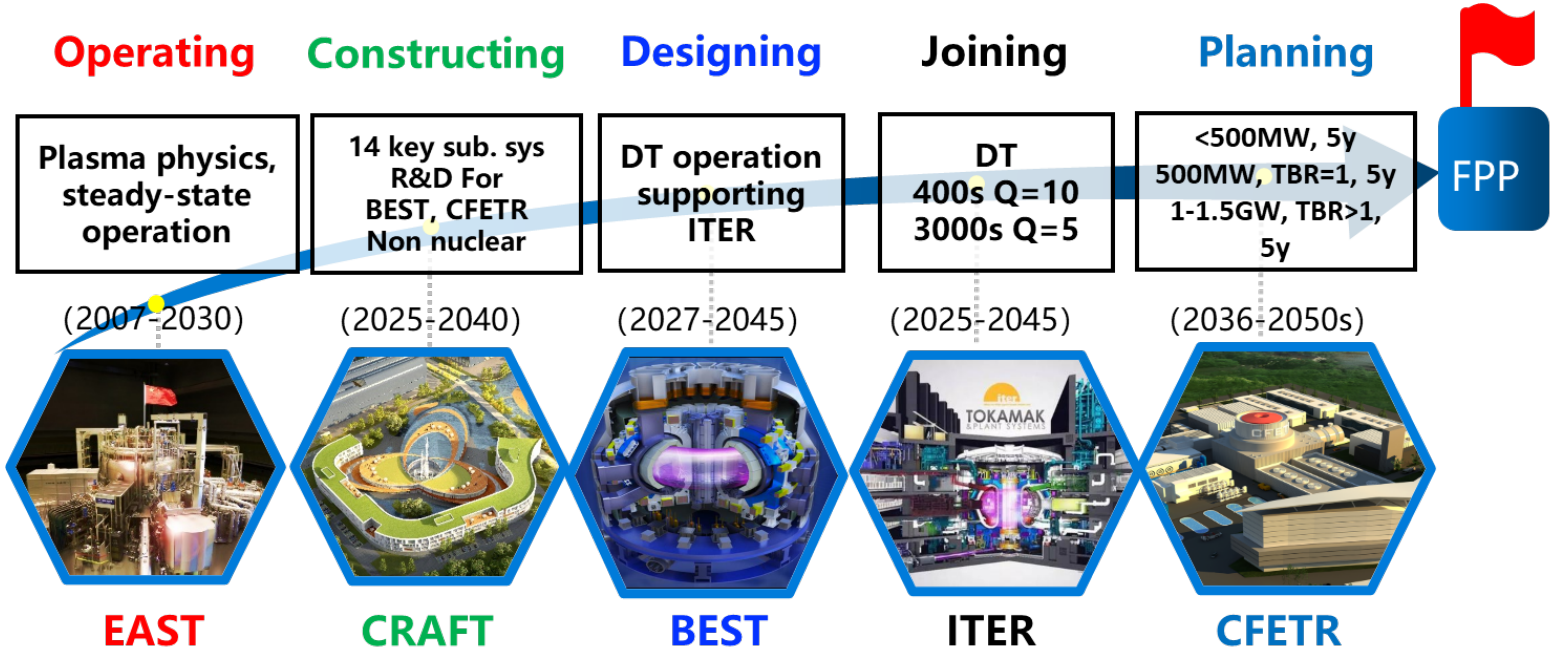
Contents

- **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



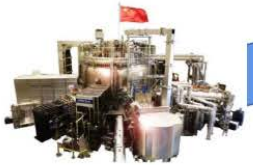
A new planed D-T devices, BEST, to support CFETR with a low risk and cost.

Relationship between devices involved by ASIPP

Earlier burning
& lower cost

Bridge gaps: Burning plasma experiment + FNST

EAST

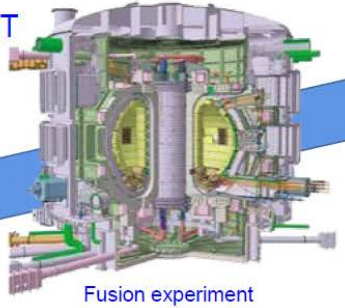


Plasma experiment
~1000s steady state
T_{e0}~10 keV

BEST

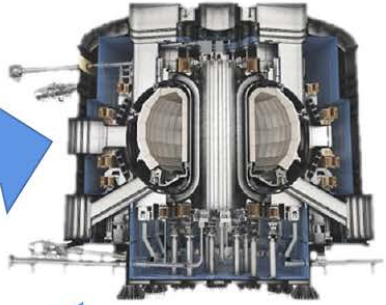
Fusion experiment
2031 D-T operation
P_{fus} = 30-200 MW
Q~1 steady state
Q~5 inductive

ITER



Fusion experiment
2035 D-T operation
P_{fus} = 350-500 MW
Q~5 steady state
Q~10 inductive

CFETR



Power plant demonstration
P_{fus} = 1-2 GW
Q~30 steady state

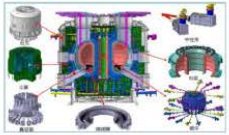
TFTR, JET, JT-60U Q~1 short pulse

Support

Support

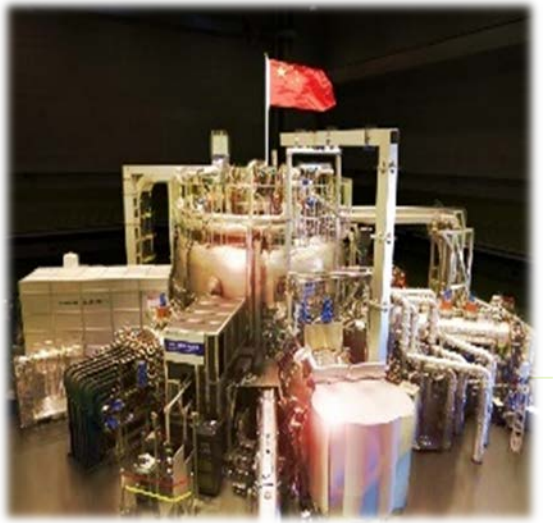
ITER components R&D

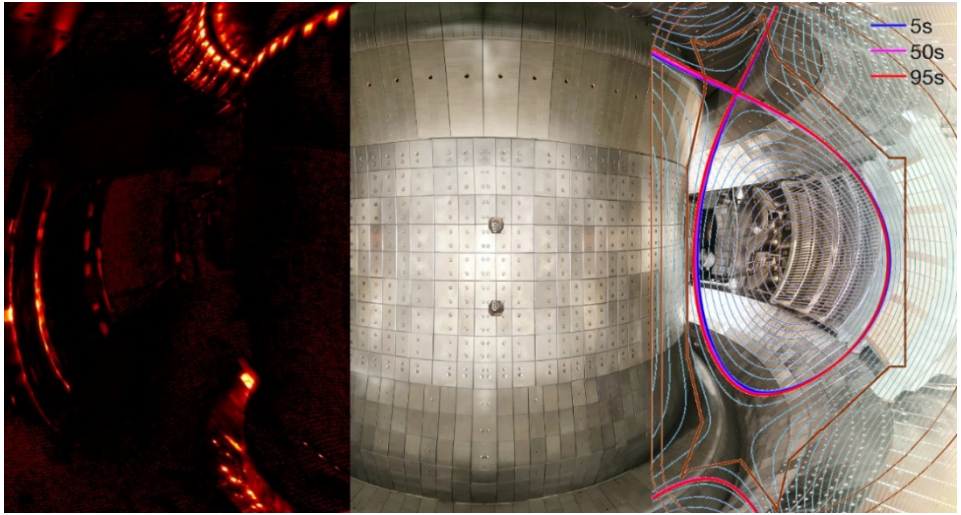
CRAFT
Technology R&D



CFETR design

EAST Mission: Steady state operation and key physics

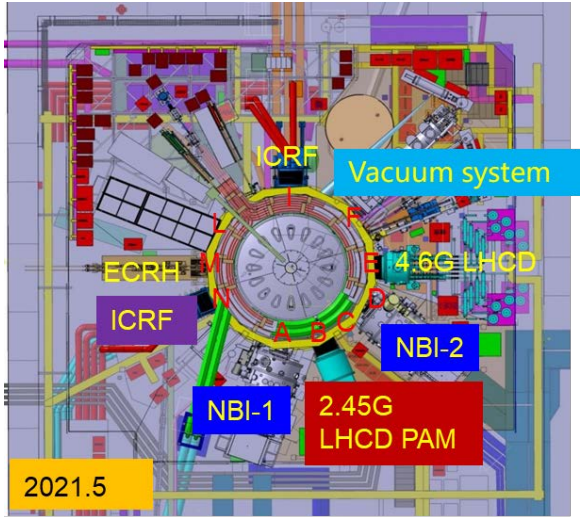


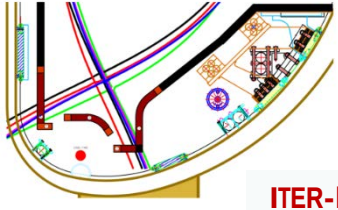


- **Steady state operation scenario** with high performance
- **Experimentally support** of key physics
- **Validation of novel technology** for future devices

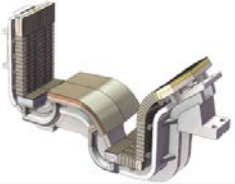
- Advanced scenario development
- Confinement and transport
- MHD and disruption
- Pedestal physics
- Divertor and PWI issues
- Energetic particle instabilities

EAST machine status and capability





ITER-like upper W-Divertor



Upgraded lower W-Divertor

LHCD PAM antenna

ICRF low k antenna

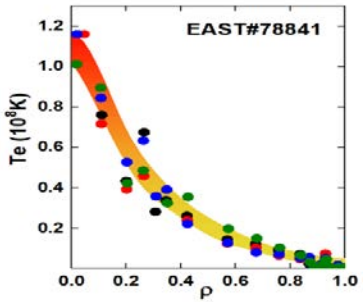
Upgraded vacuum system

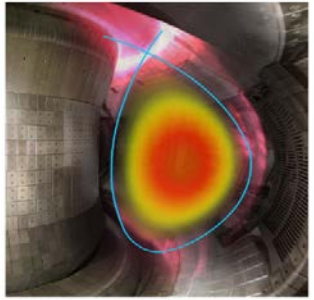
1. **Full metal wall with ITER like W-Divertor**
   - W/Cu structure lower divertor with heat exhaust of **10 MW/m^2**

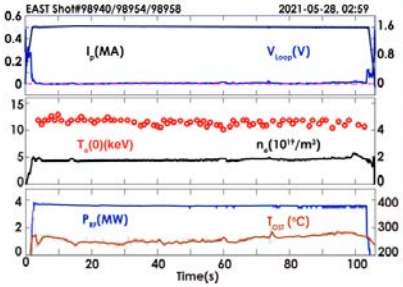
2. **Flexible H&CD combination (with total source power ~30 MW)**
   - LHCD with PAM antenna, ICRF with low k antenna, 4 ECRH systems, 2 co-NBIs

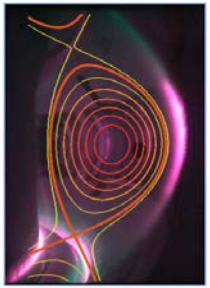
ASIPP

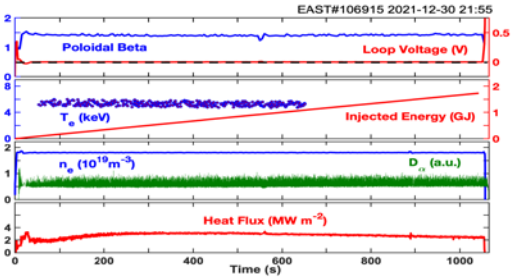
Achieved Long Pulse Operation with High Te(0)











2018
Te0>8.6keV
10s at USN

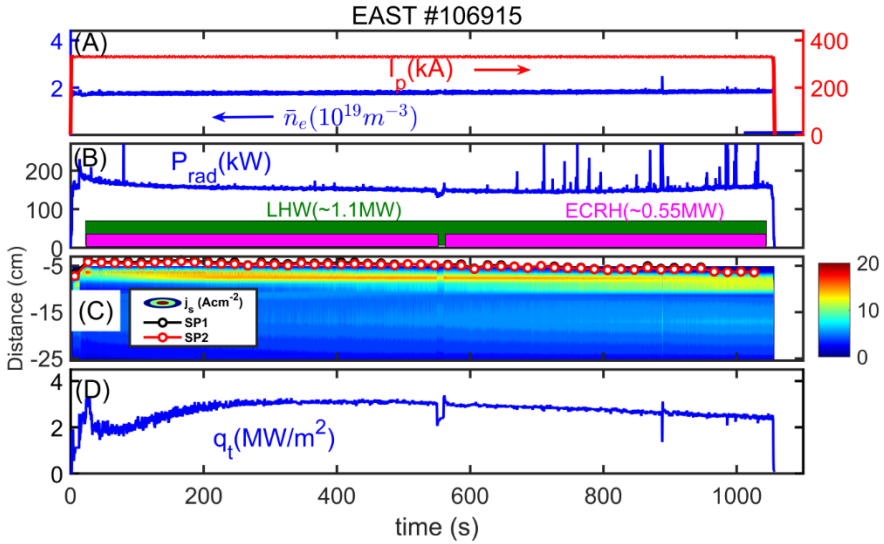
2021 (May)
Te0>10keV
101s at LSN

2021 (Dec.)
Te0>6keV
1056s at LSN

EAST Shot 106915 (Dec. 2021): 1056s pulse length, T_i(0)~1.0keV, n_i(0)~2.2x10^{19}m^{-3}, τ_E~60ms

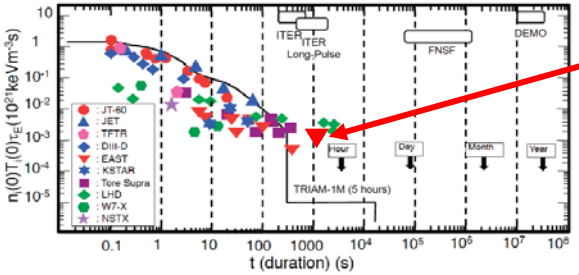
ASIPP

Steady state long Pulse Operation

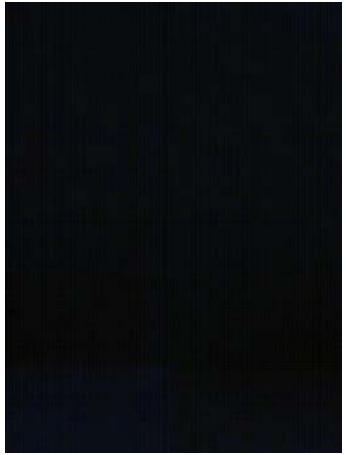


In 1056s long pulse operation:

- **Fully non-inductive plasma with dominant e-heating**
- **Stable control of plasma equilibrium configuration, particle recycling and heat load**



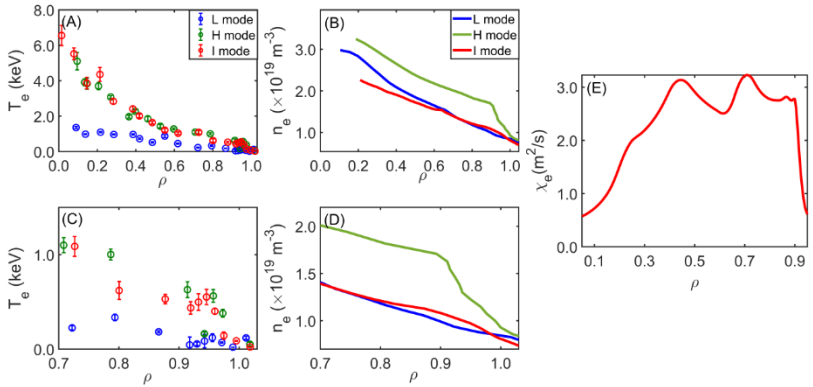
- **EAST 1056s discharge**

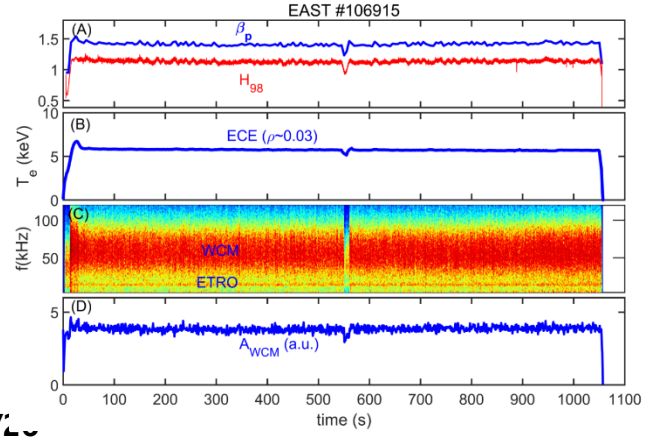


ASIPP

1056s High-confinement Super I-mode

- **Super I mode = I-mode + e-ITB**

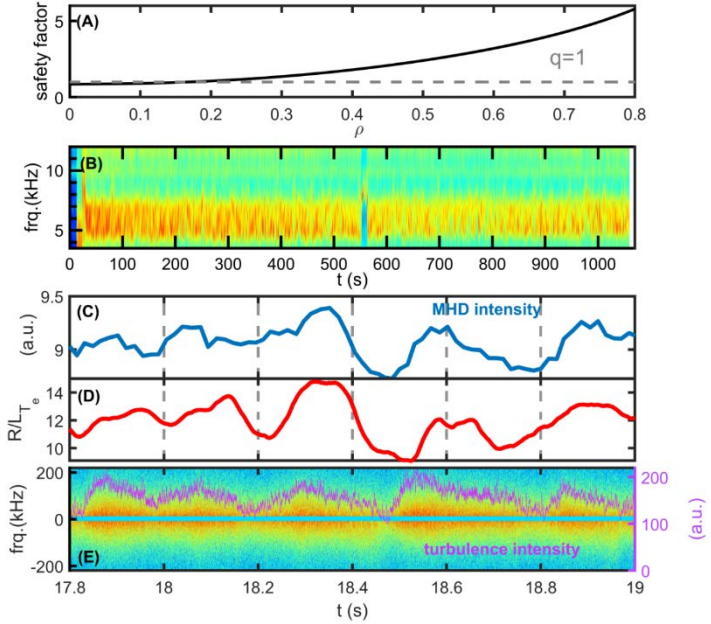




> 1000 s SS I-mode

- **H98 ~ 1.2**
- **WCM and ETRO**
- **no core impurity accumulation**

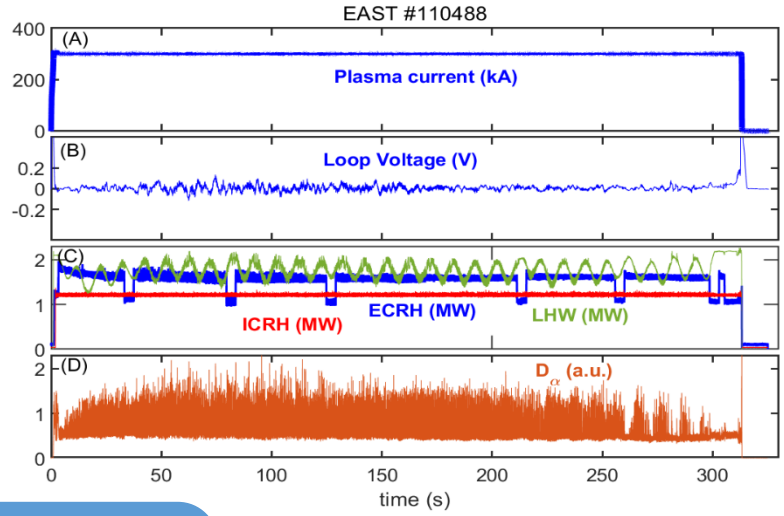
- **Self-organising regime - Interaction between MHD, turbulence and electron heat transport for sustaining stationary ITB**



ASIPP

Long Pulse Operation with H-mode

H-mode in duration of >300s achieved in 2022 (unpublished)**:**



- ✓ $n_e/n_G>0.6$
- ✓ $\beta_P>2.5/\beta_N>1.5$
- ✓ $H_{98y2}>1.2$,
- ✓ $f_{BS}\sim50\%$

2017-07-03
Shot#73999
100s H-mode

2022-05-07
Shot#110488
310s H-mode

ASIPP

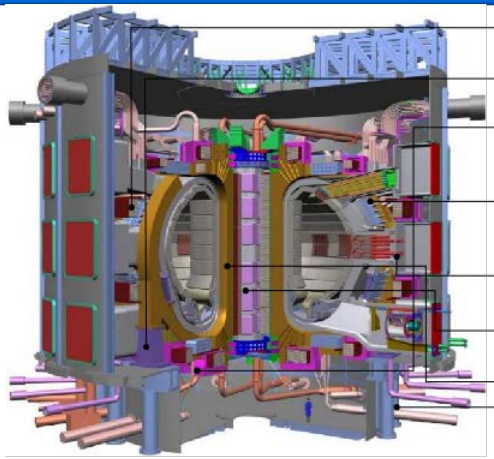
EAST next goal and plan

- **Demonstrations of high power injection (>10MW/100s)**
  - w/o hot spot on guarder limiter for 4.6GHz LHW (➔**4.0-6.0MW ~70%**)
  - New PAM_2.45GHz for long distance coupling (➔**1.0MW ~50%**))
  - Coupling more ICRF power with lower $k_{//}$ antenna (➔**4.0-6.0MW ~50%**)
  - The four gyrotrons of ECRH (➔**2.0MW ~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 operational regime** (High priority)
  - Relevant physics research in support of **400s H-mode** with high performance
    - **Scenarios Development: High Beta SSO / Hybrid /IBS_AT**
    - H&CD, T&C, DSOL physics, dynamic control, EP physics, etc.
  - Exploration of high performance regime relevant to ITER baseline **when more power is available**
- **EAST 2022 schedule :**

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

ASIPP

ASIPP contributions to ITER



A major ITER contributor in China:

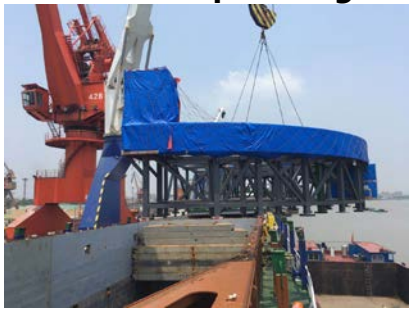
- **Up to 73% ITER procurement packages (PAs) in China**
- **Other ITER contracts like PF6, TAC1, Bellows…**
- **Human resource support to ITER: IPAs, visiting scientists…**

ASIPP contributions to ITER: PAs

Conductors: 100% finished.

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

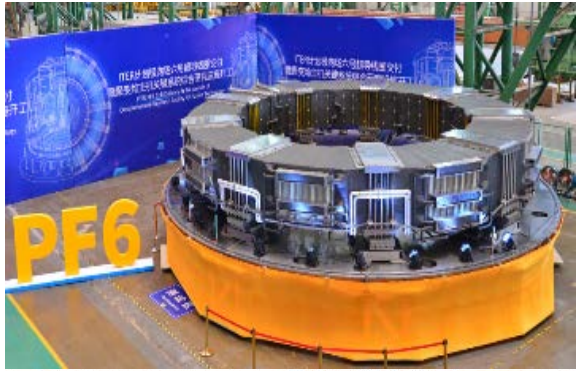
Feeder: R&D finished, 75% produced, planning to finish in 2024.



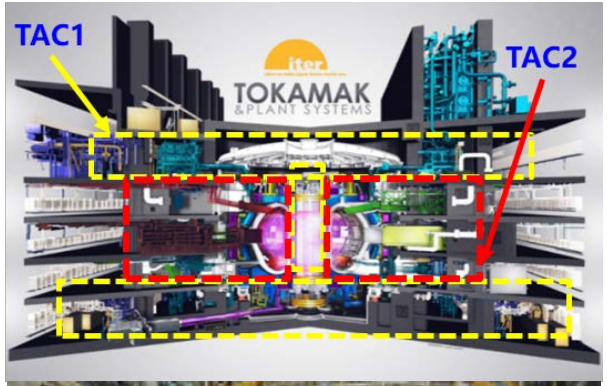
CC : 98% BTCC and 50% SCC Coils produced, planning to finish in 2023.

ASIPP contributions to ITER: Contracts

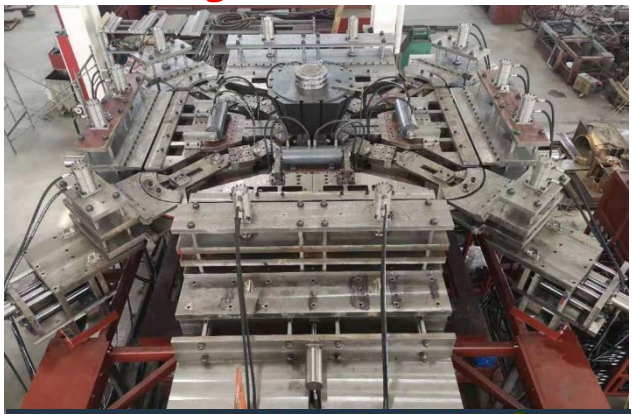
PF6 Coil

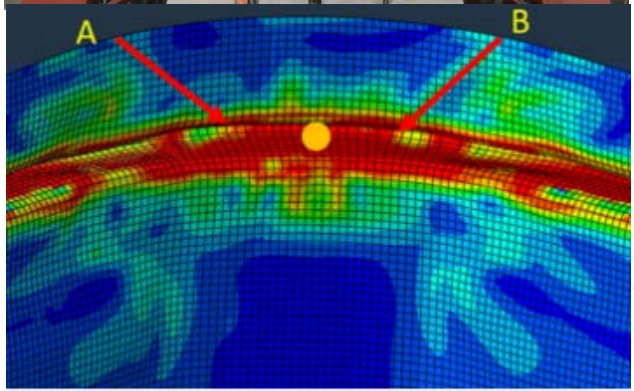


ITER Assembly (TAC1)



Large Bellows





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

Comprehensive Research fAcilities for Fusion Technology

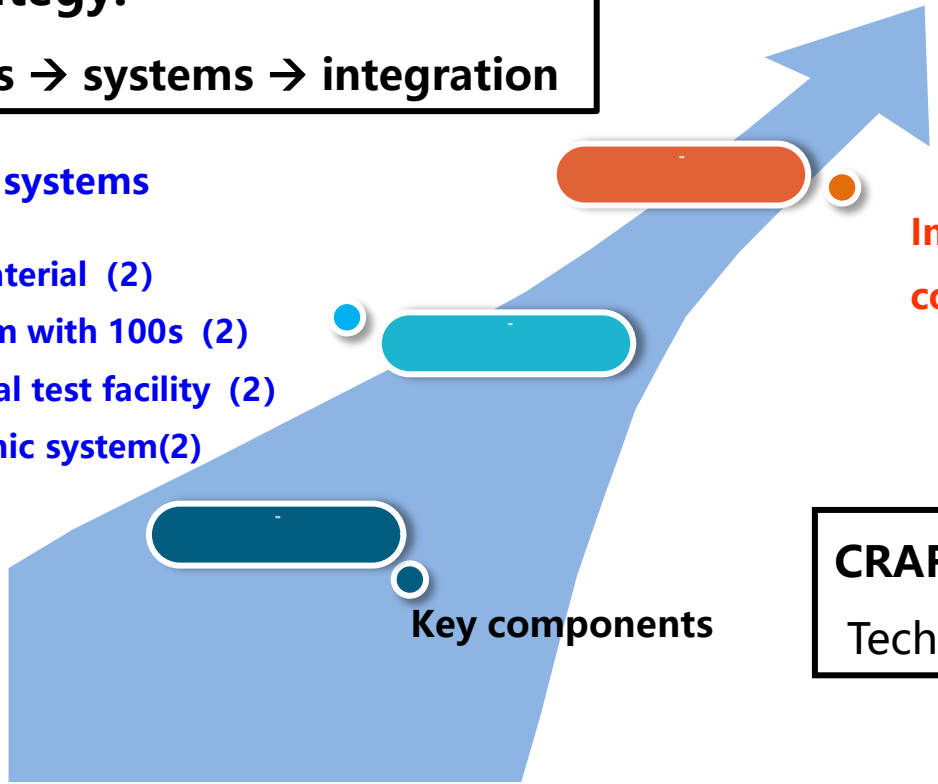
Approved	Chinese **National** Government
Mission	Key research platforms system R&D **in support of future devices (BEST/CFETR)**
Schedule	**2019-2025**
Status	Under construction, campus finished

ASIPP

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

CRAFT Expectation:

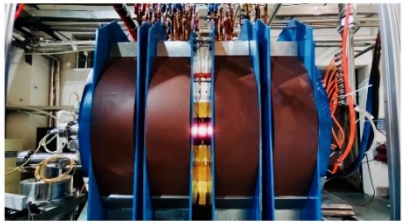
Technically ready for future reactor

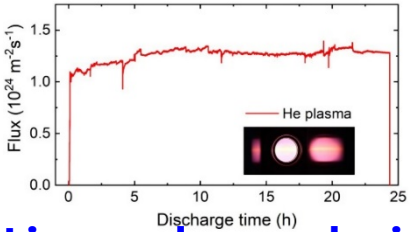
CRAFT Progress (part)

All systems to be ready in 2025

TF coil testing facility for BEST and CFETR

Dimensions: 21m×16m
Winding Speed: 300-500 mm/min
Bearing capacity: > 50t
The contour accuracy: 3mm





Linear plasma device for material study

Particle flux: 10^{24} m^{-2}s^{-1}
Maintained: >24 h

N-NBI system testing platform

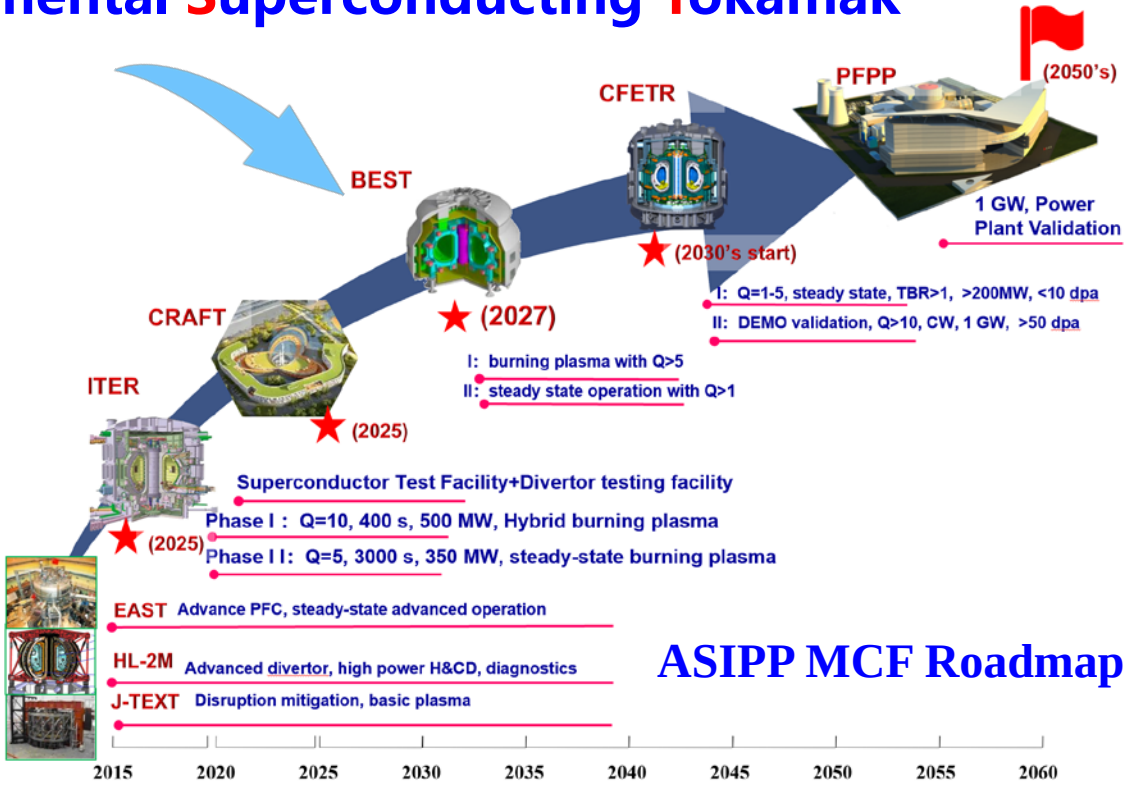
Beam energy: 55keV
Beam current: 3.5 A
Extracted H^- ion density: 160A/m^2

ASIPP

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**

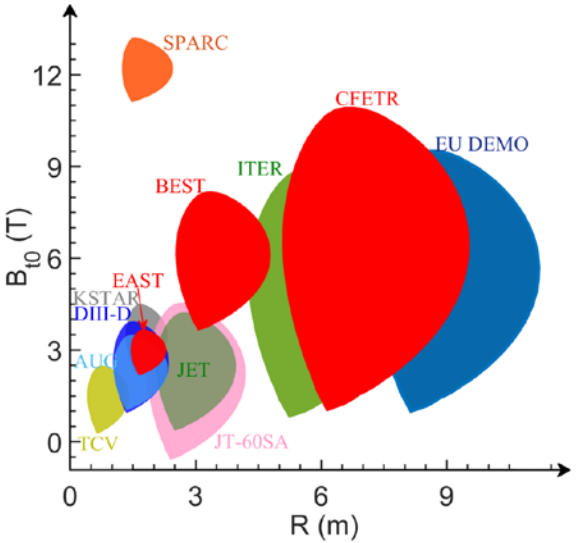


ASIPP MCF Roadmap

Main design parameters for BEST

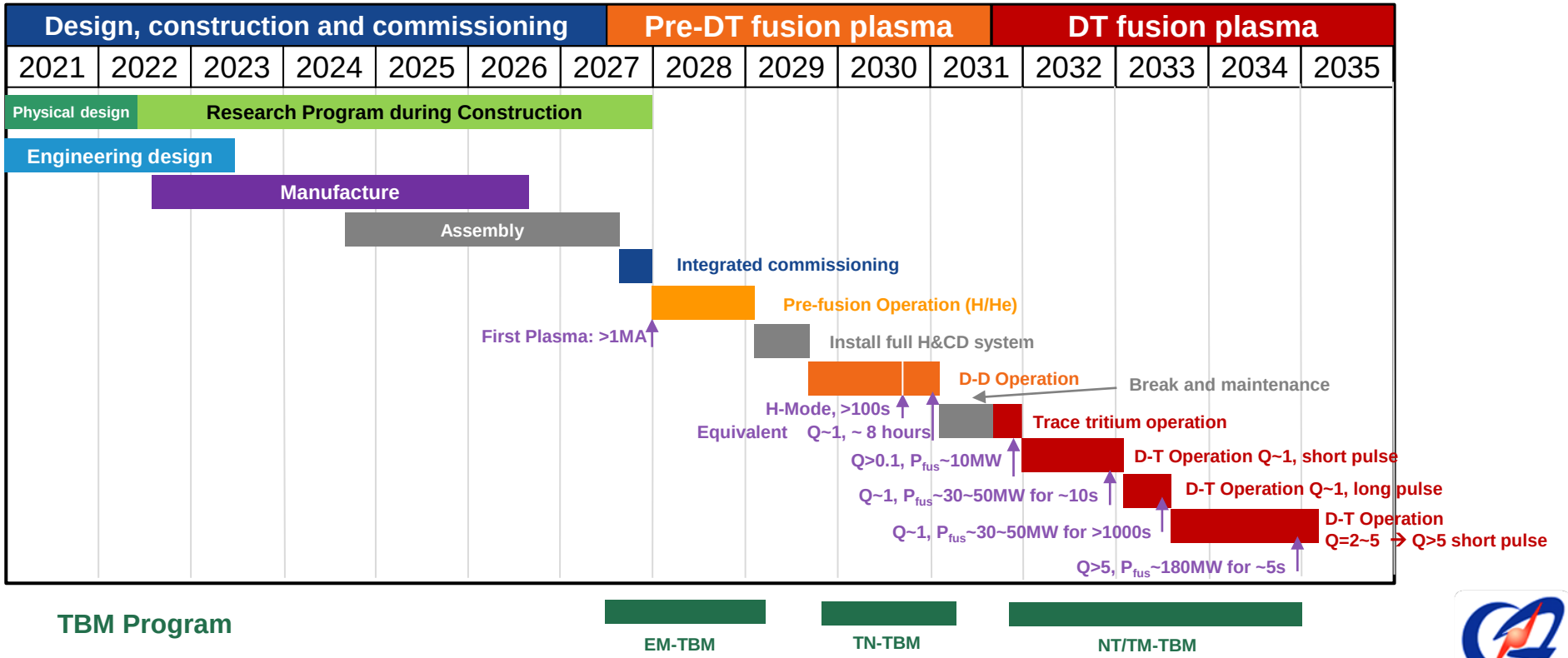
- Burning plasma physics with **Q >5**
- DT plasma in **steady-state at low Q (Q~1)**, with adequate neutron fluence for material, blanket and fuel inventory testing.
- Develop and **explore** methods for achieving **high Q operation** applicable to fusion pilot plants.

Main parameters	
Plasma current	**I_p=3-7 MA**
Major radius	**R=3.6 m**
Minor radius	**a=1.1 m**
Elongation	**K=a/b=1.9**
Toroidal field	**B_T=6.15 T**



ASIPP

Research plan for BEST



TBM Program

EM-TBM

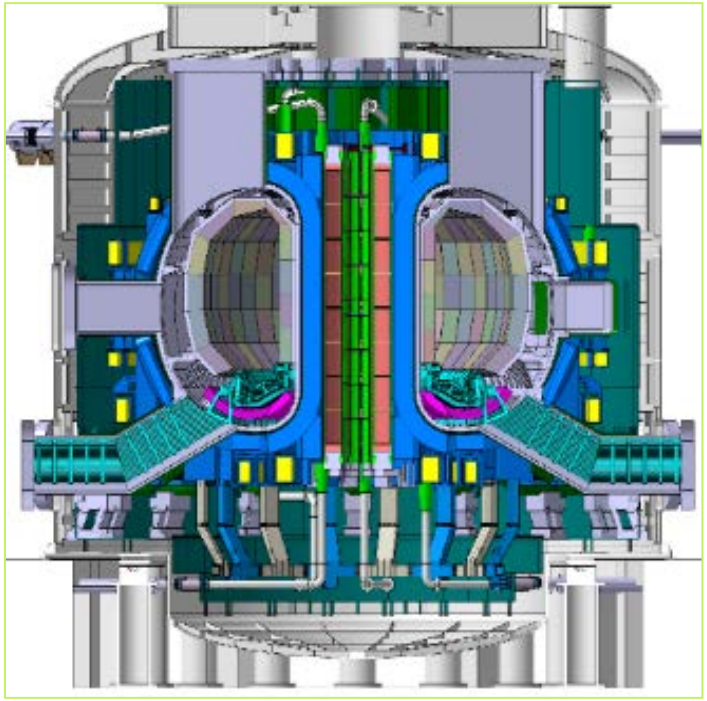
TN-TBM

NT/TM-TBM

ASIPP

CFETR: Chinese Fusion Engineering Test Reactor

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

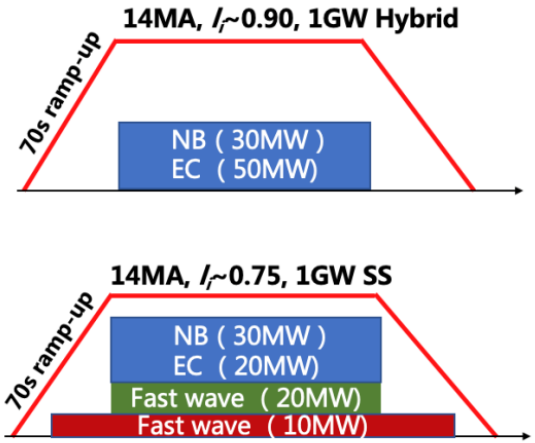


- Self-sustained burning plasma with
  - i) high **fusion power** (200-1500MW),
  - ii) high **duty cycle** (≥0.5),
  - iii) high **fusion gain** (Q=3-30)
- Tritium breeding technology with **TBR≥1**

Domestic Program of CFETR design finished (Dec. 2021)

CFETR design progress: Physics

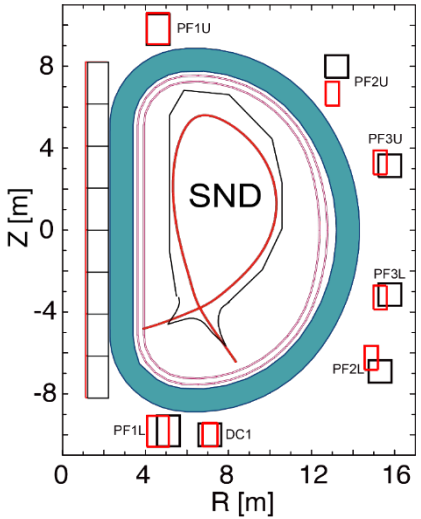
Scenario design

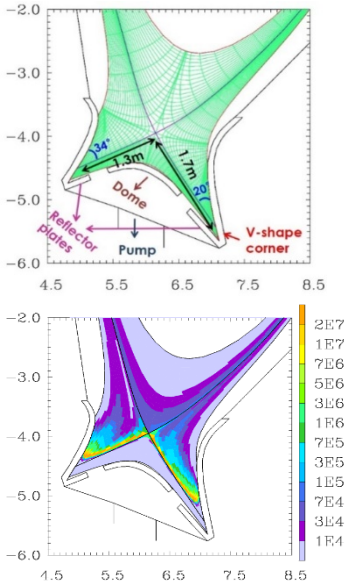


	P_{fus} (GW)	P_{NB}/P_{EC} (MW)	H_{98y2}	β_N/β_P	f_{bs}/I_i	I_p (MA)	$n_{e,line}$ (10^{20}/ m^3)
Hybrid	0.95	30/50	1.14	2.3/1.5	0.45/0.9	13	1.0
SS	1.0	30/55	1.33	3.0/2.5	0.78/0.8	10.5	0.92

Hybrid and Steady State scenarios

Configuration and divertor



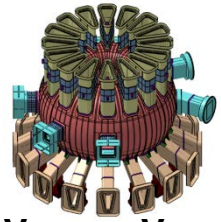


- **Conventional SN divertor**
- **Detachment with Ne injection**
- **Compatible with blanket**

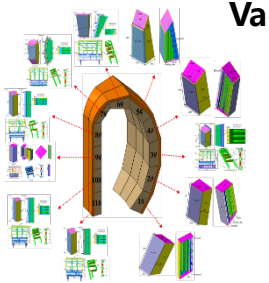
ASIPP

CFETR design progress: Engineering

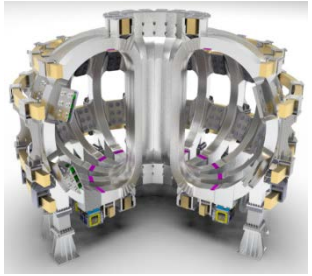
- **Machine engineering and integration design completed**



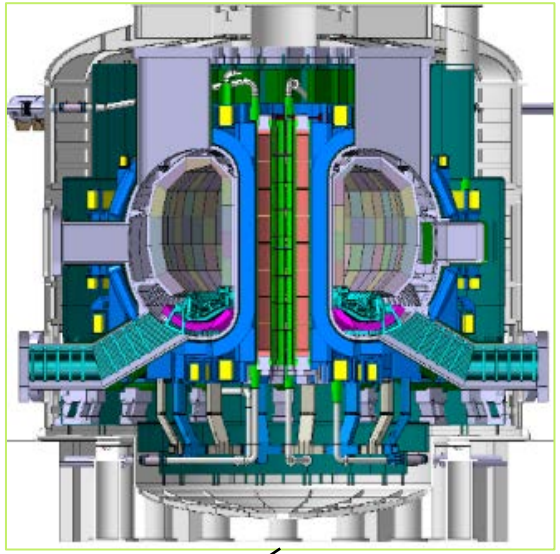
Vacuum Vessel



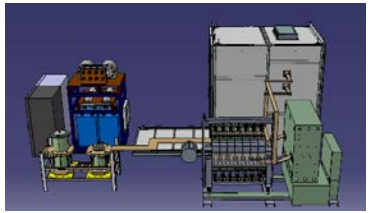
Blanket



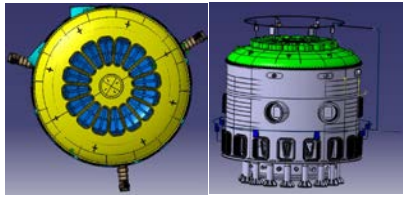
Magnet



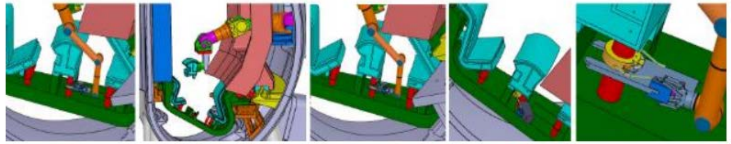
…



Power supply



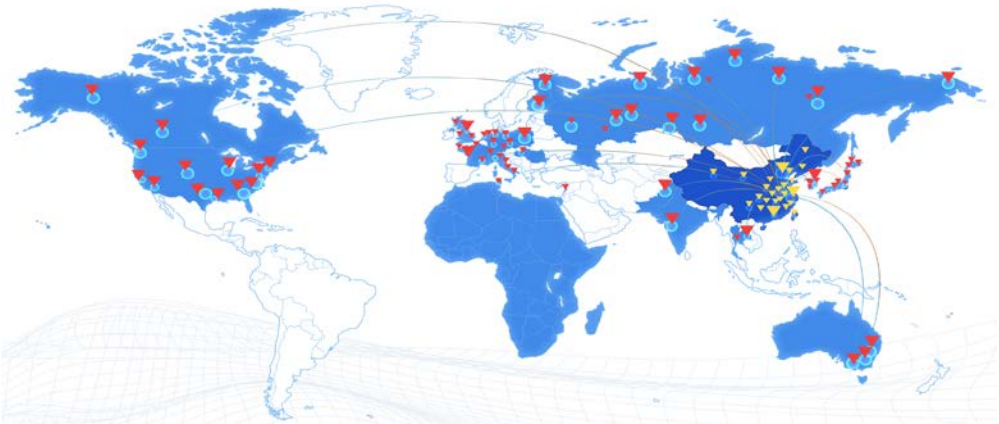
Fueling



Remote Handling

Collaboration: Networks and organizations

Global collaboration networks



Domestic networks

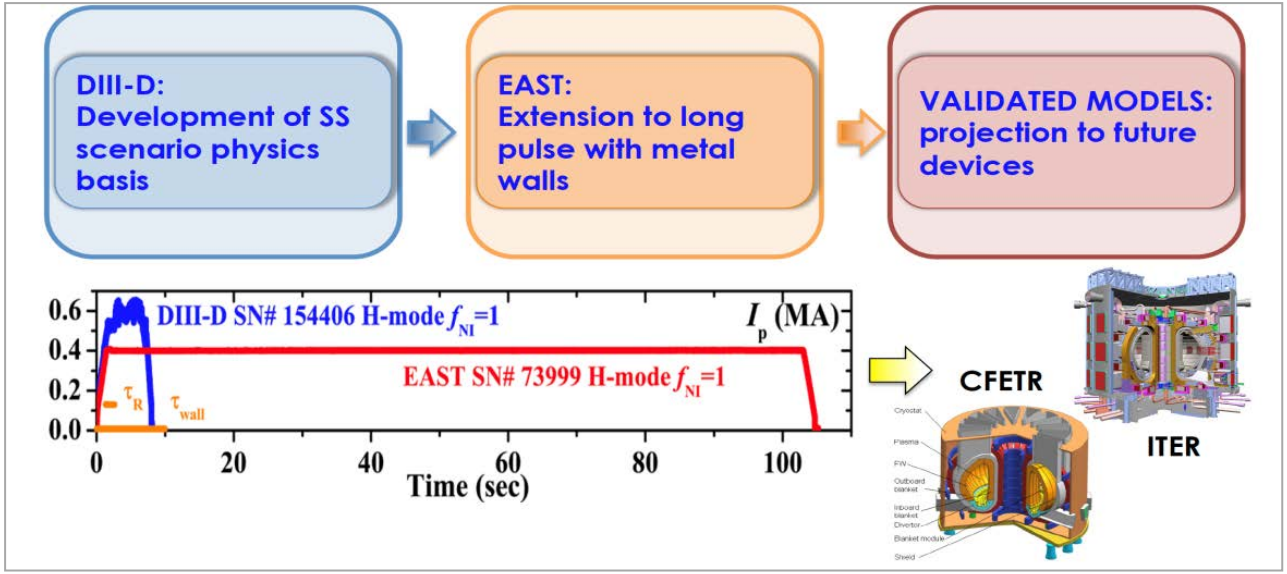
Collaborate with Leading Institutes in US/Germany/French/Korea/Japan…

SPAs: Cooperate on the Integrated Modeling, W-Divertor, ICRH antenna, RMP physics, Infrared diagnostics and so on

Collaboration: Joint Experiments on EAST

EAST: A shared and open platform to the world

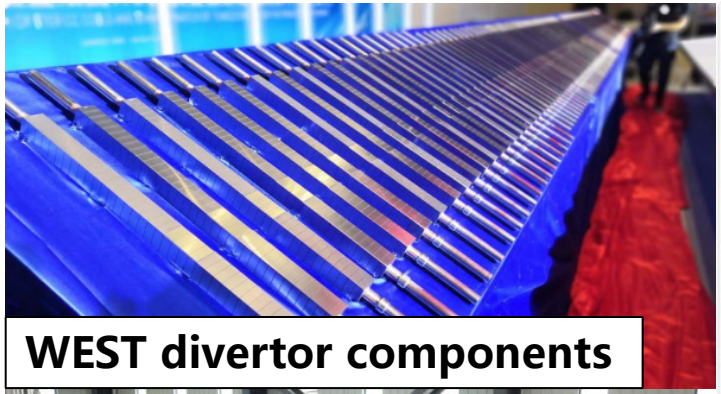
Example: DIII-D & EAST joint experiment



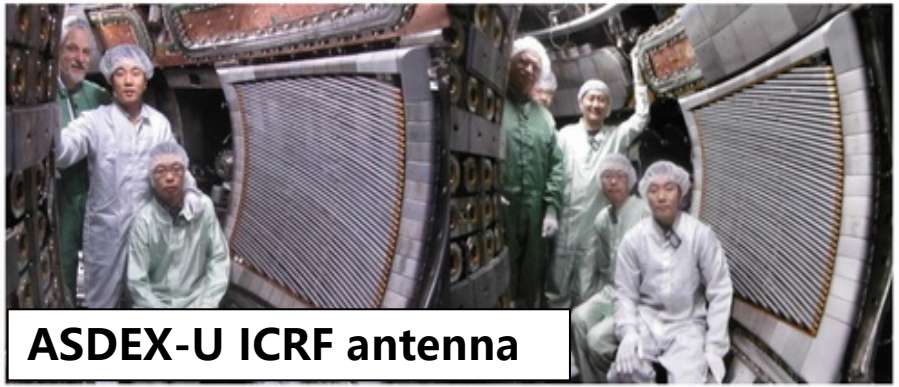
On-site and remote participation

ASIPP

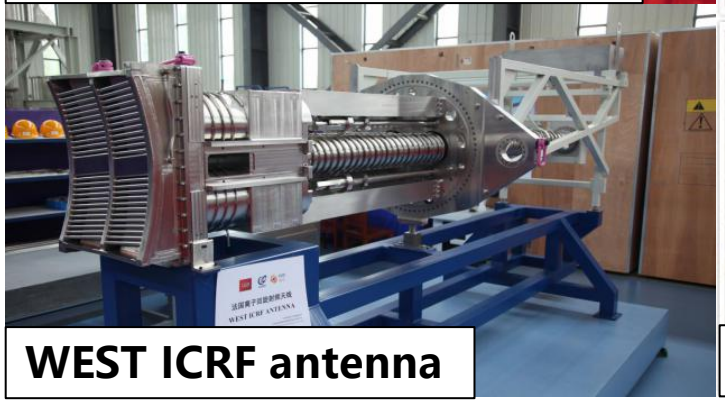
Collaboration: Fusion technology for the world



WEST divertor components



ASDEX-U ICRF antenna



WEST ICRF antenna

Contribution to ITER CS (with GA)

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


Thank you !