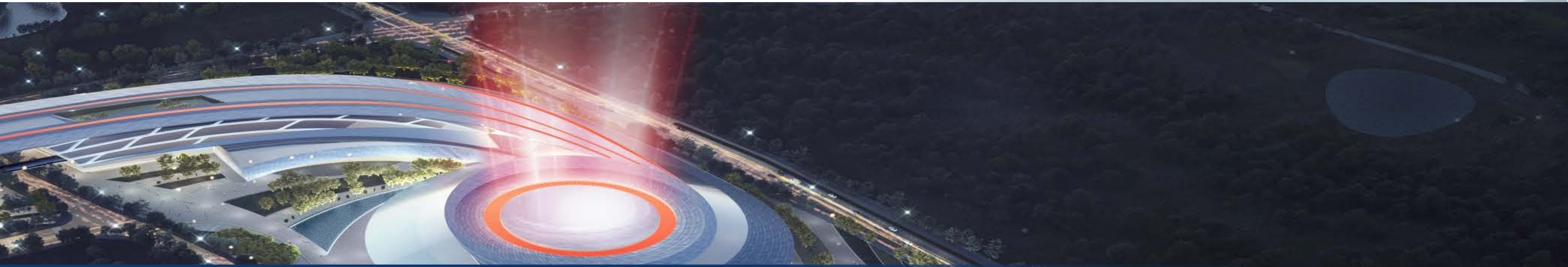
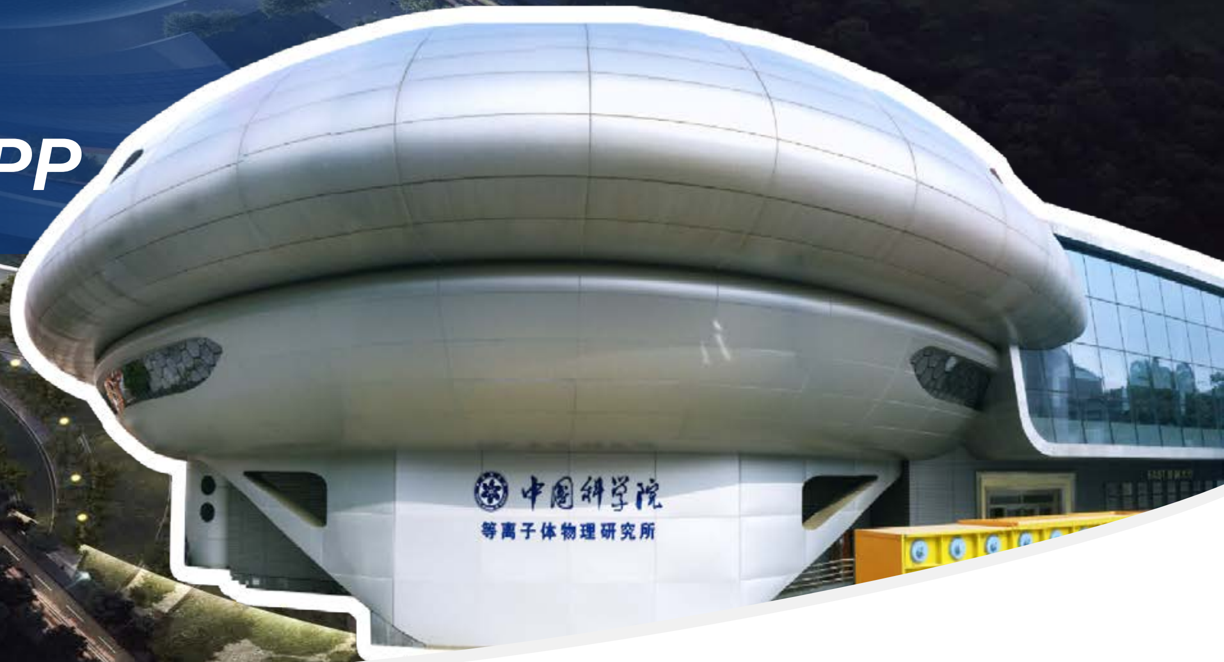


All for Fusion Energy

overview and updates of R&D at ASIPP



Yuntao SONG

on behalf of Institue of Plama Physics,
Chinese Academy of Sciences(ASIPP)

songyt@ipp.ac.cn

2024.12.03

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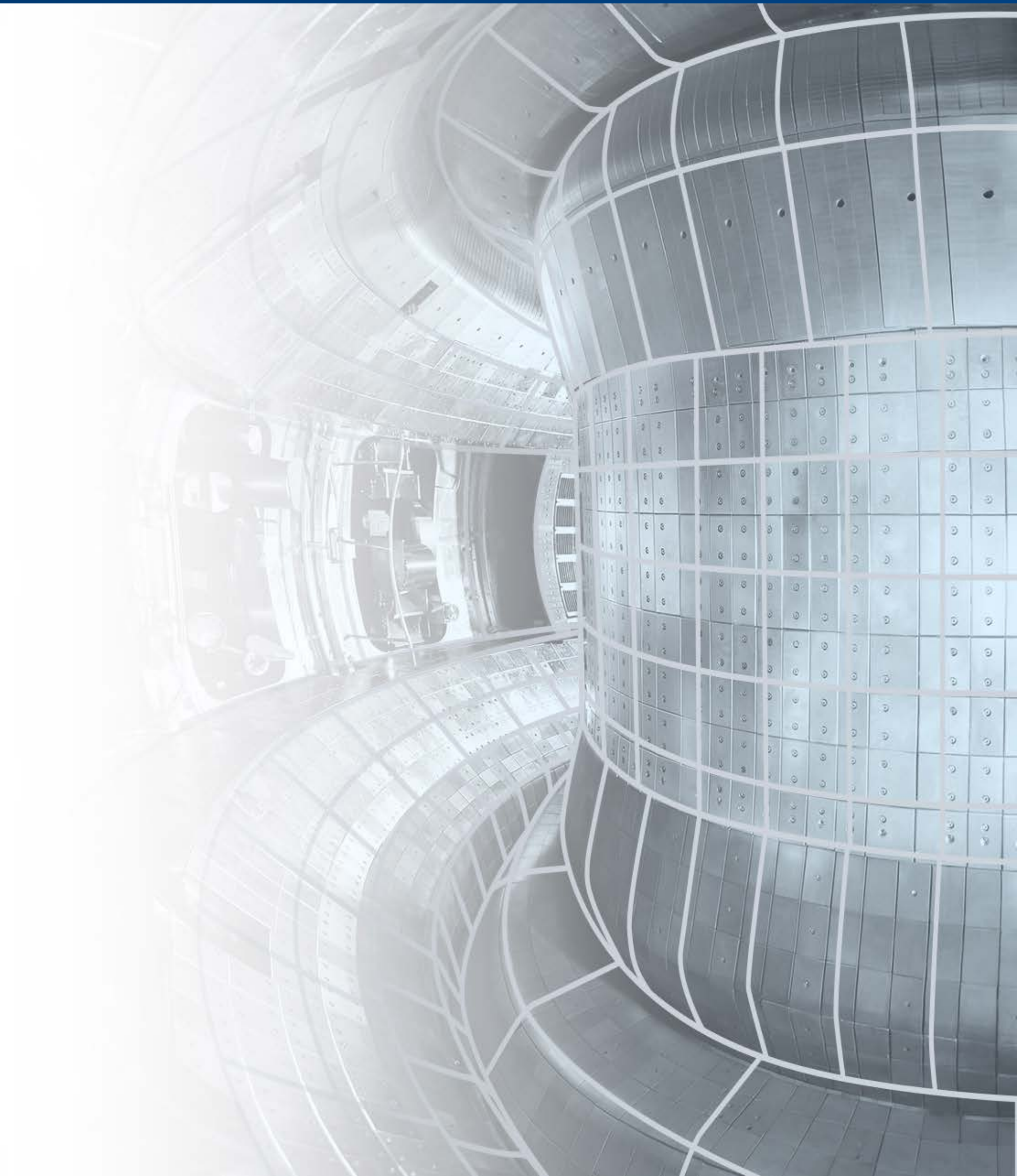
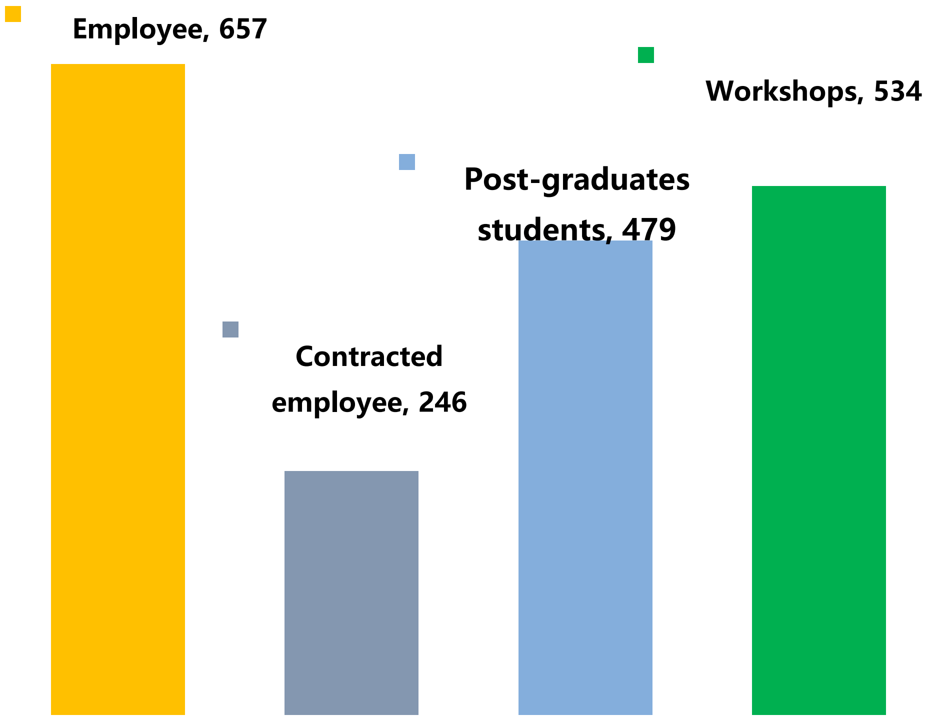


About ASIPP

- **ASIPP**: Institute of Plasma Physics, Chinese Academy of Sciences, founded in **Sept. 1978** in Hefei, Anhui Province.
- **Mission**: research of **fusion energy** based on the **tokamak approach**.
- **Organization**: **14** Divisions, **3** Research Centers.
- **Human resource: ~2000**



Main Campus

New Energy Research Center

CRAFT(New Campus)

Four Generations of Tokamak at ASIPP

HT-6B

1978 - 1992

HT-6M

1985 - 2002

HT-7

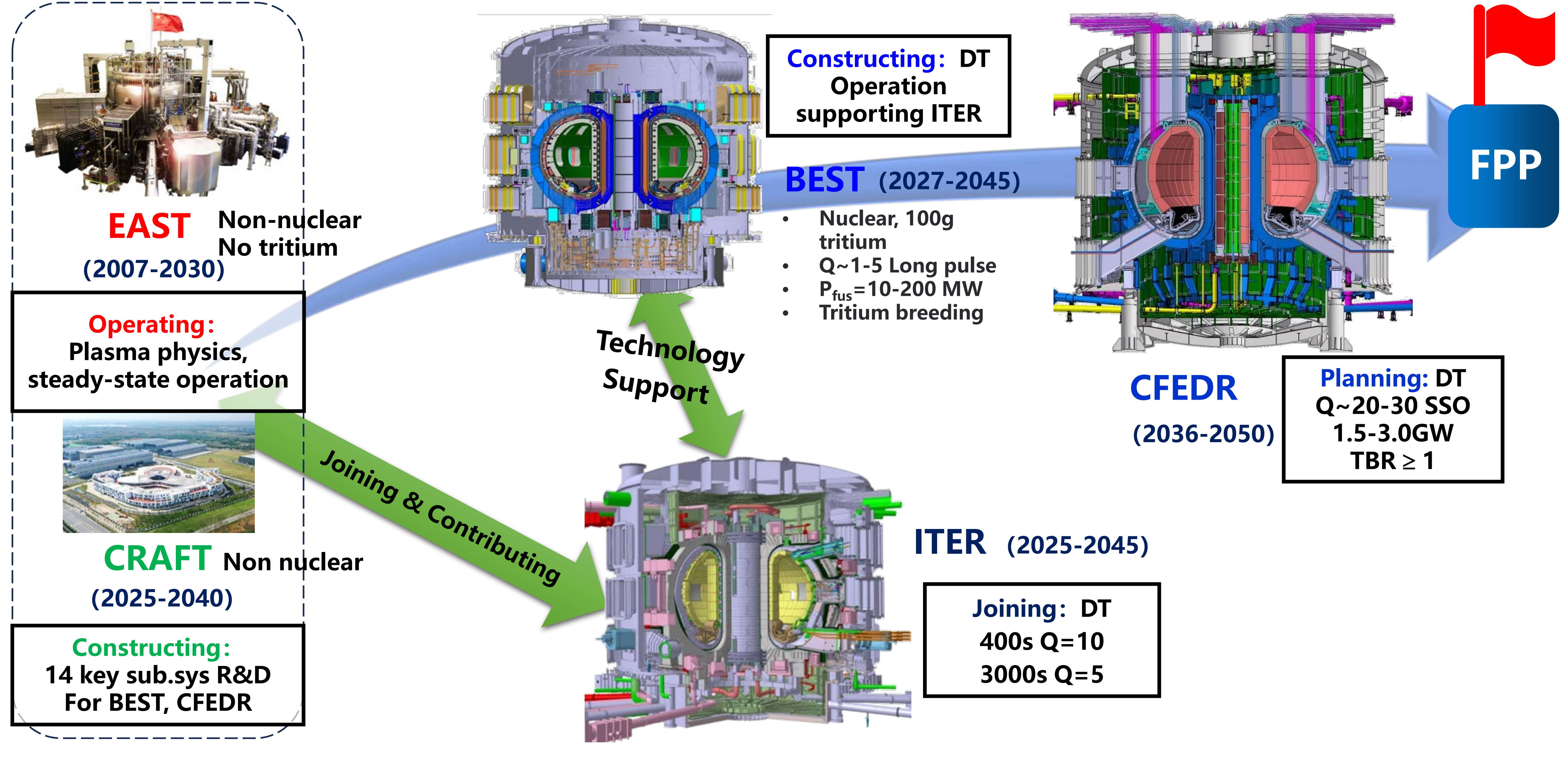
1994 - 2012

EAST

1998 - present

- **HT-6B & HT-6M:** Conventional non–superconducting tokamak
- **HT-7: Chinese first superconducting** tokamak
- **EAST (Experimental Advanced Superconducting Tokamak):** Non-circle cross-section **full superconducting** tokamak

ASIPP Fusion Roadmap



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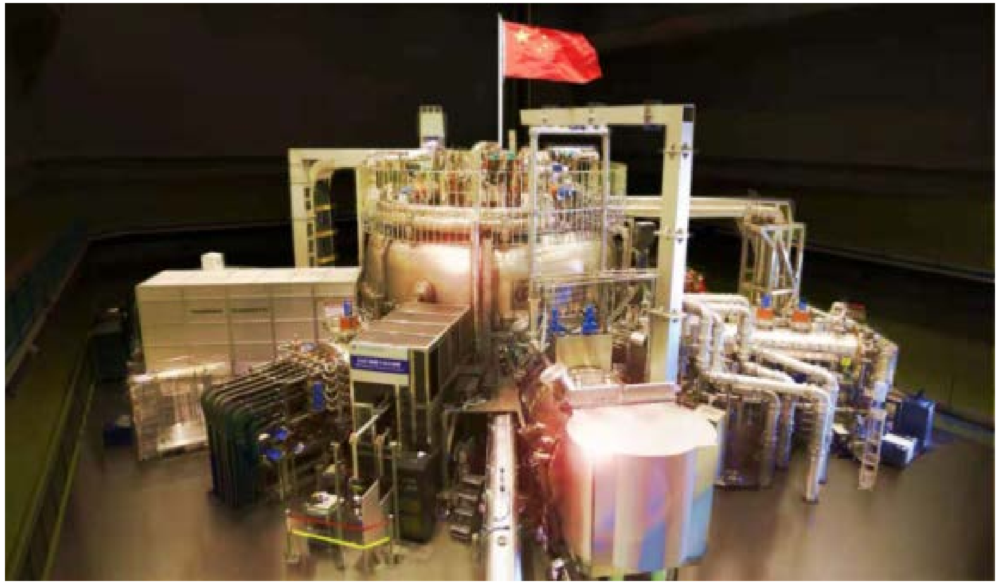
EAST: Full Superconducting Tokamak

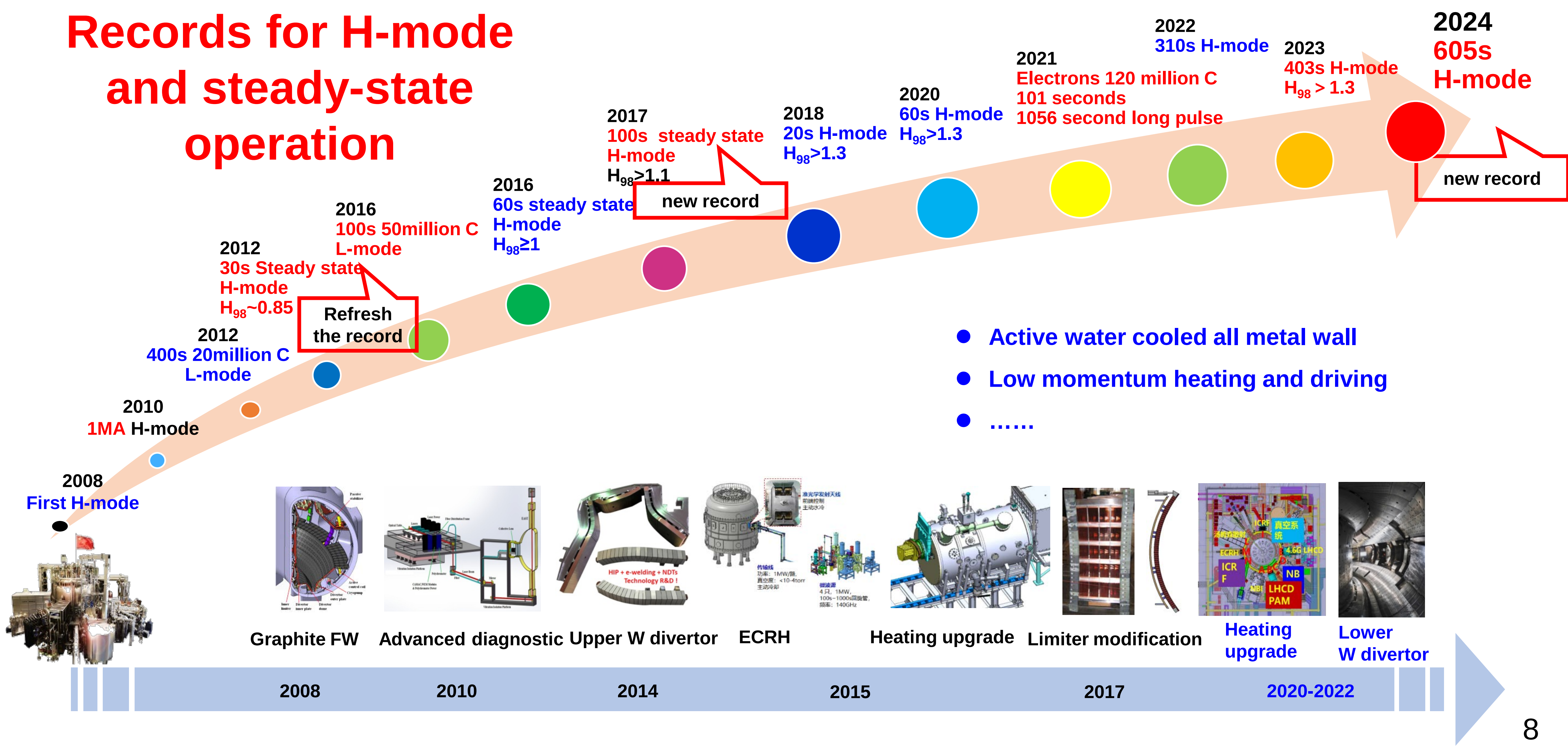


To realize the advanced long pulse steady-state operation and provide scientific basis for the design, construction and experimental operation of ITER, BEST and CFETR.

1996	2000	2006	2024
Proposal	Start of construction	First plasma	140000th discharge

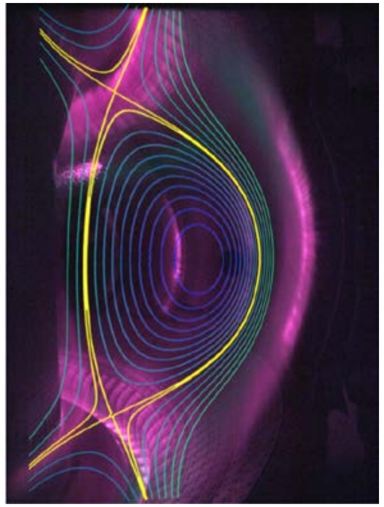
- An **open platform for steady-state** high performance plasma operation.
- It could be operated in **3 shifts** for experiment proposals from the world.

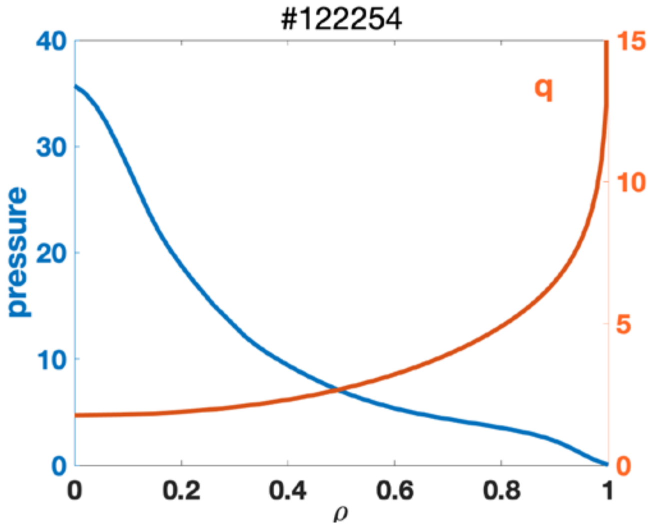
EAST Achievements



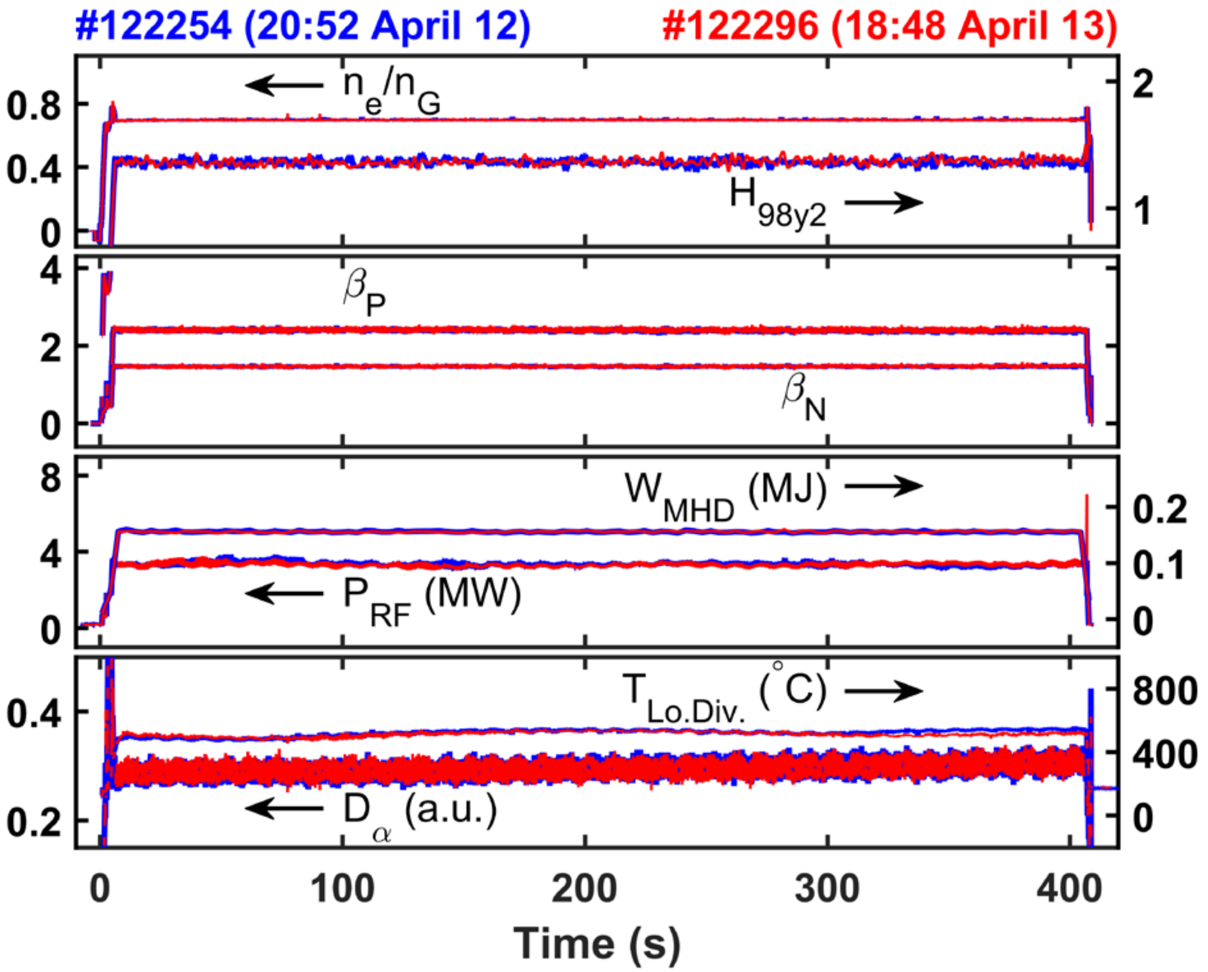
EAST Recent Highlights (I)

403 s reproducible H-mode





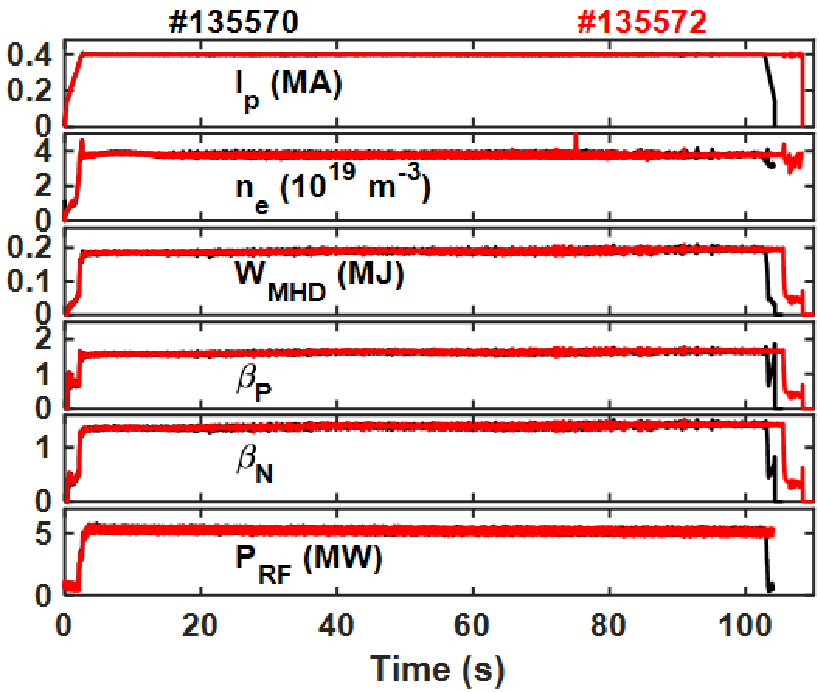
- A full non-inductive at f_{GW}~0.7 with f_{BS}>50% by RF heating with zero torque injection
- $H_{98,y2}$ ~1.35 with ITB by electron dominant heating
- Stationary control on particle exhaust and heat load with actively cooling W-divertor
- Small ELMs throughout discharges with high core performance

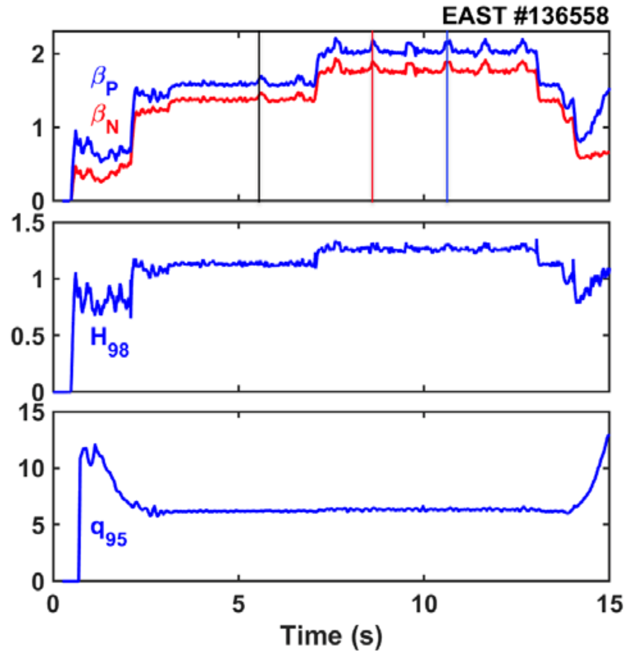


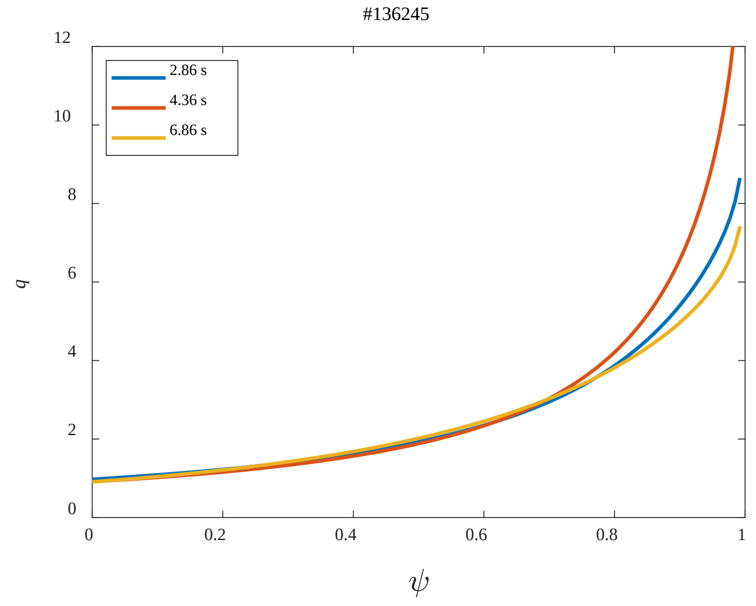
New Milestone and Big Step Forward

EAST Recent Highlights (II)

● Steady state H-mode with Boron coating metal wall



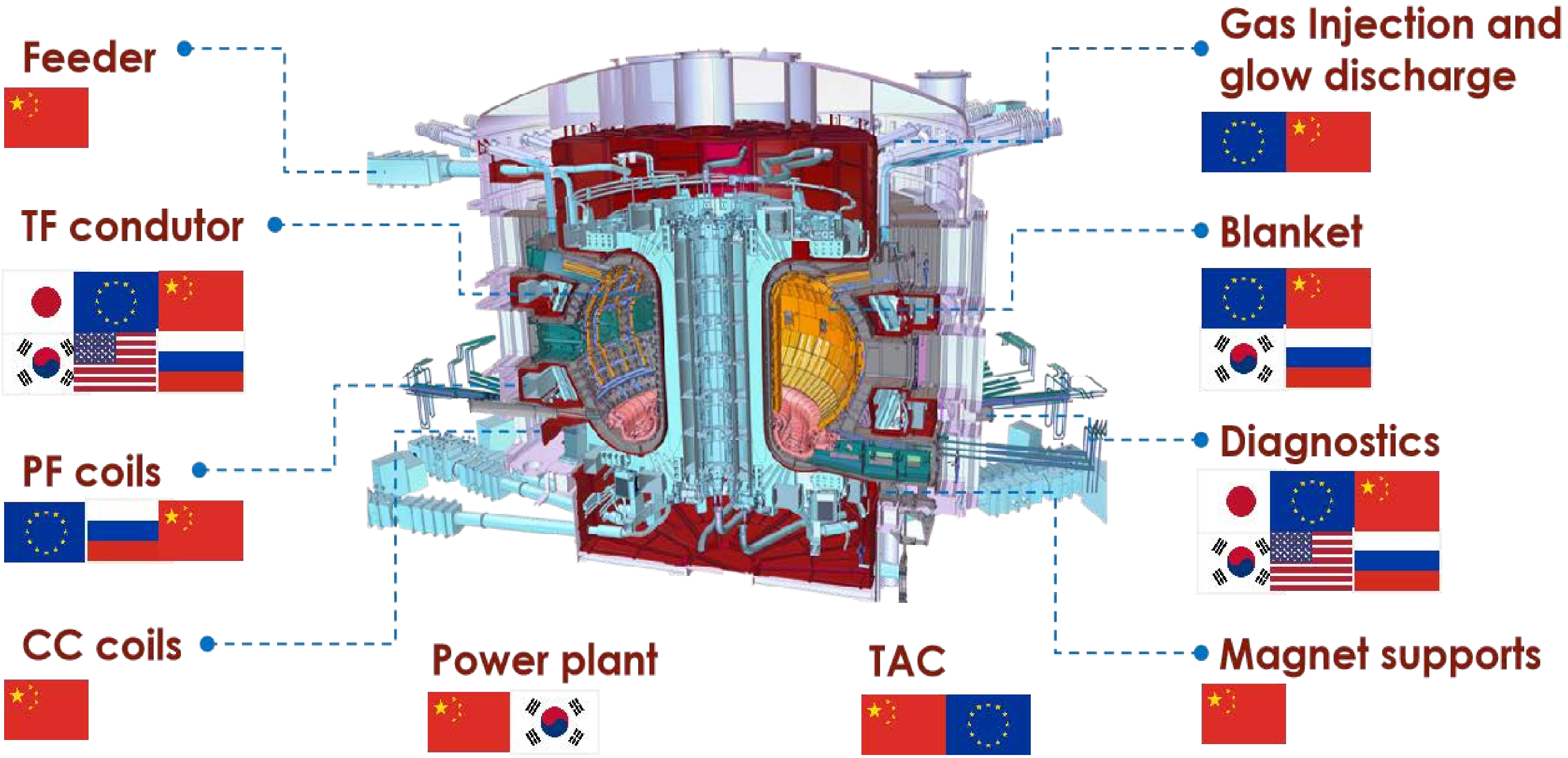




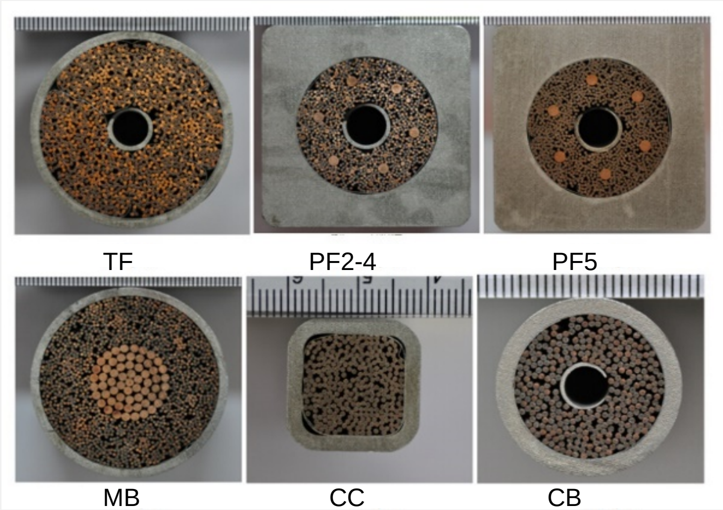
- ✓ **Reproducible H mode in 100s scale, tokamak metal wall with Boron coating**
  - I_p ~ 0.4MA / n_e ~ 4 / $H_{98y,2}$ ~ 1.1 , P_{EC} ~ 3MW, P_{LH} ~ 2.2MW
- ✓ **ITER baseline scenario with Q>10 and moderate q_{95}~6.0**
  - β_P~2.0, β_N~1.8, H_{98y2} ~ 1.25， P_{LHW}~2.3MW, P_{EC}~2.4MW, P_{IC}~2.8MW
- ✓ **Hybrid scenario development with Boronization; sawtooth instability suppressed by flat current profile (q0>1)**

Technology Towards Fusion Pilot Plant

ASIPP undertakes more than 80% of ITER Procurement Package in China

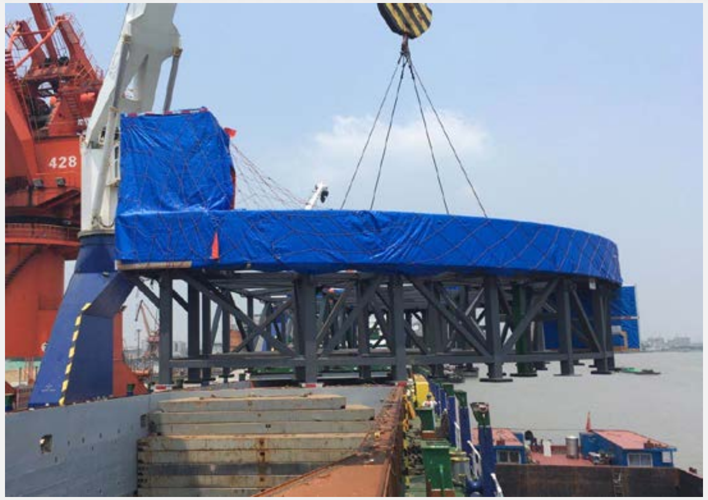


ITER Procurement Packages



Conductors:100% finished

AC/DC Converter & PPEN:100% finished, test supporting



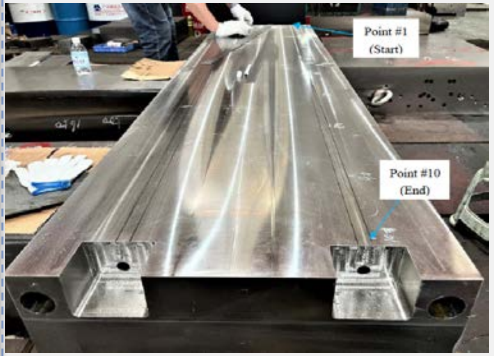
Feeder:82% produced

BCCs&TCCs:100%, SCCs:95%

X-ray Camera

LVIC prototype

Diagnostics Integration



DSM gun-drilling sample

ITER International Contracts

- PF6： 100% completed， In cash procurement from EU F4E
- As CNPE consortium member, implemented the installation of major components of ITER.

Installation of coil

>95% in PIT

>50% Feeder

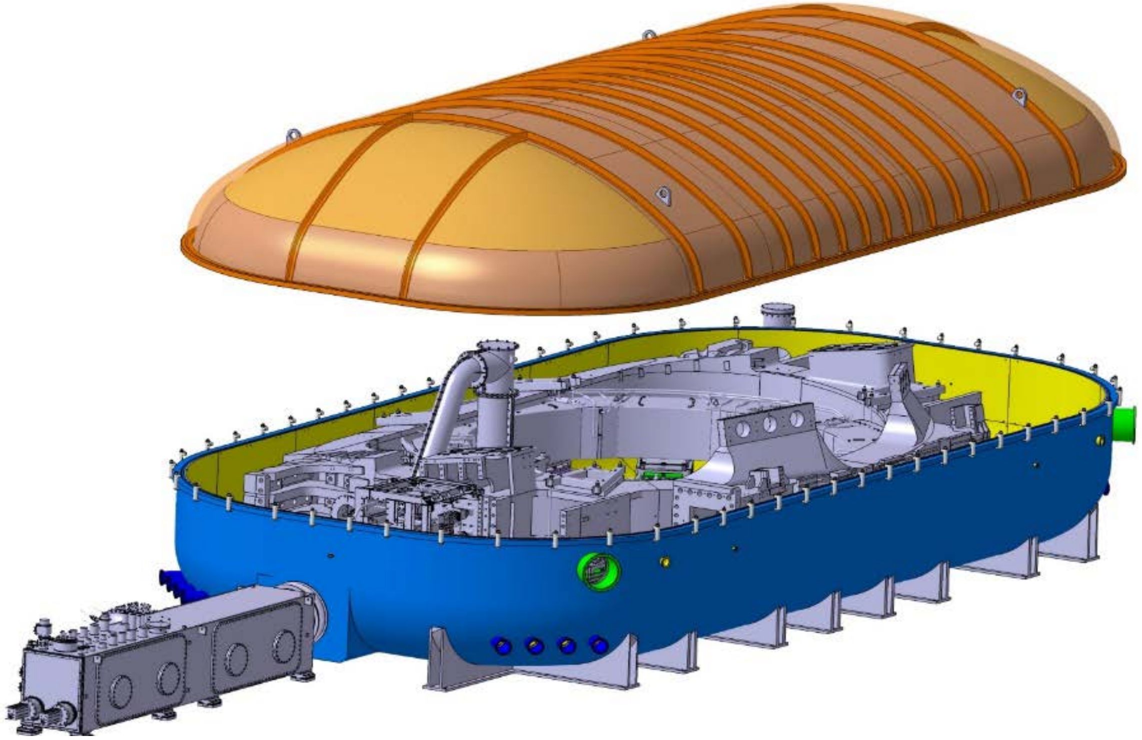
Placement have been finished.

ITER International Contracts

- Developed and manufactured ELM-IVCF Mock-ups
- FDR for Cryostat have been completed

In-Vessel ELM-IVCF Prototype&Tooling

Mock-ups: ELM standard bracket assembly, In-port feeder bracket assebly, ELM coil corner bracket assembly , Feeder with sleeve

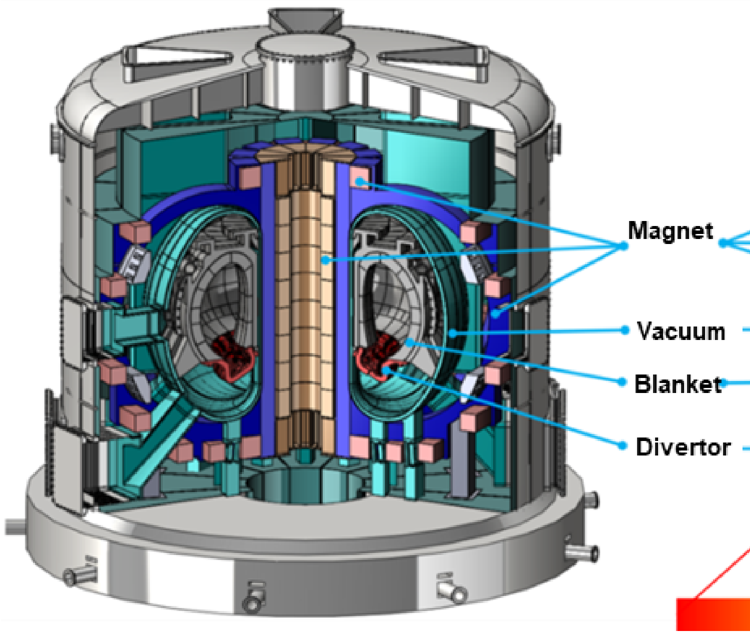


Cryostat Design for Magnet Test Platform

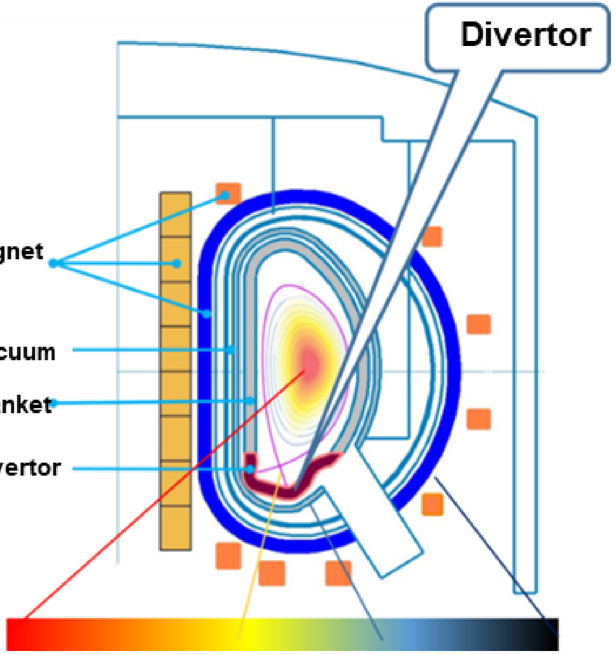
CRAFT: Comprehensive Research Facility for Fusion Technology

Explore and master fusion DEMO level key technologies

Establish the method and standard for manufacture the key material, components and system for fusion pilot plants



Large complex superconducting magnet system



Divertor system under extreme conditions

project duration: 5 years and 8 months

CRAFT Facilities

- Two main Platforms and related R&D works, will be finished in 2025.
- External users/collaborators are warmly welcome to use these testing facilities

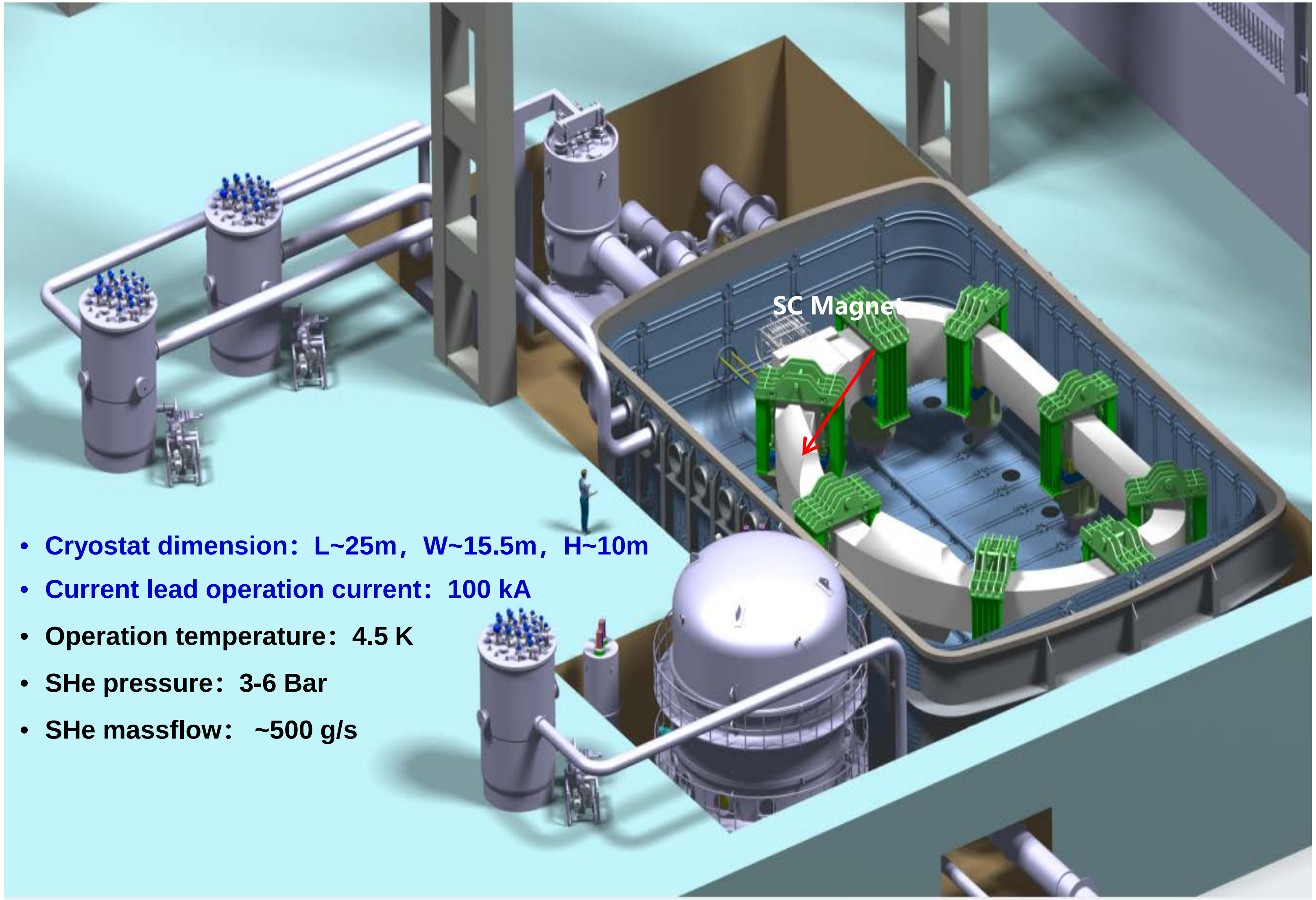
Superconducting magnet research system

- 1. SC Material testing facility
- 2. SC Conductor testing facility
- 3. SC magnets testing facility
- 4. CFETR CSMC and testing facility
- 5. CFETR HTS coil and testing
- 6. CFETR TF coil and testing
- 7. Cryogenic system
- 8. Power supply system

Divertor research system

- 9. Large Linear plasma testing facility
- 10. CFETR divertor development
- 11. CFETR divertor testing facility
- 12. EAST divertor upgrade
- 13. NNBI system
- 14. ECRH system
- 15. LHCD system
- 16. ICRF system
- 17. RH testing facility
- 18. VV and installing testing facility
- 19. Central Control facility

CRAFT: SC Magnets Testing Facility



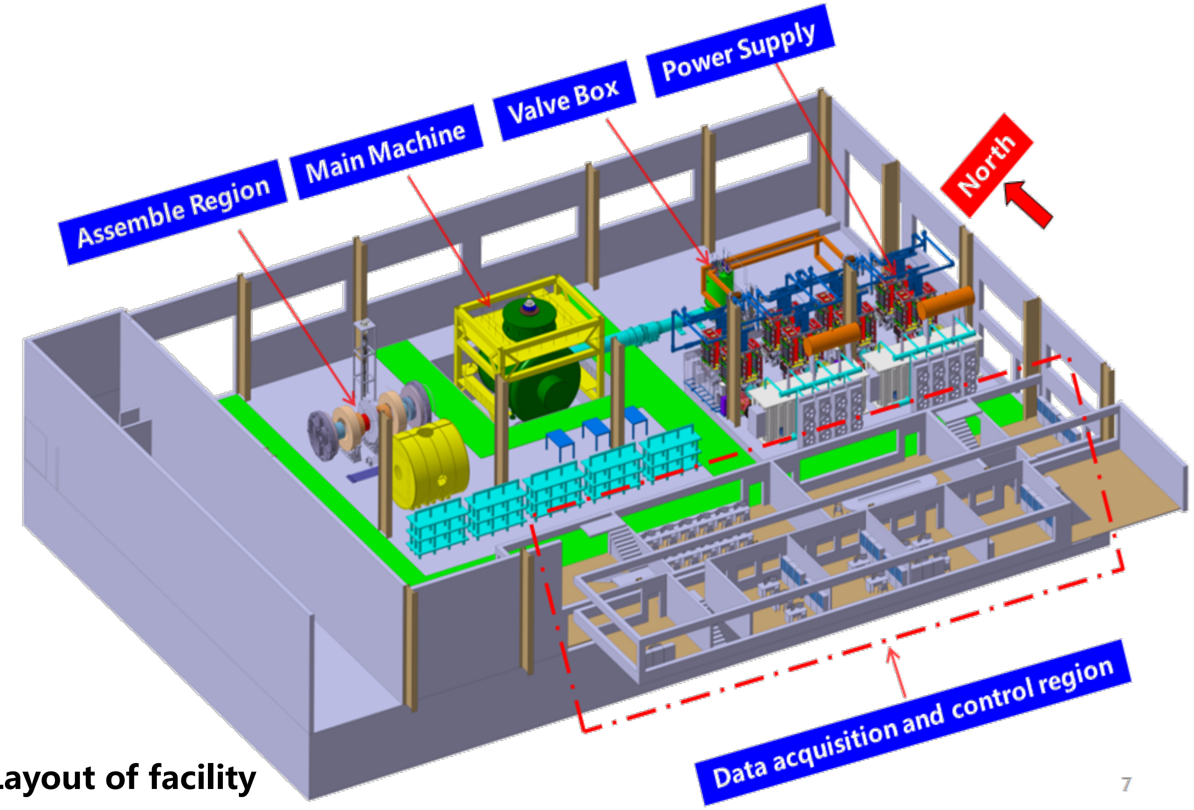
- Cryostat dimension：L~25m，W~15.5m，H~10m
- Current lead operation current：100 kA
- Operation temperature：4.5 K
- SHe pressure：3-6 Bar
- SHe massflow： ~500 g/s

- **Large-scale SC magnet experiment (mechanics, thermo-hydraulic, electromagnetics)**
- **Magnet performances evaluation (safety, stability, reliability)**

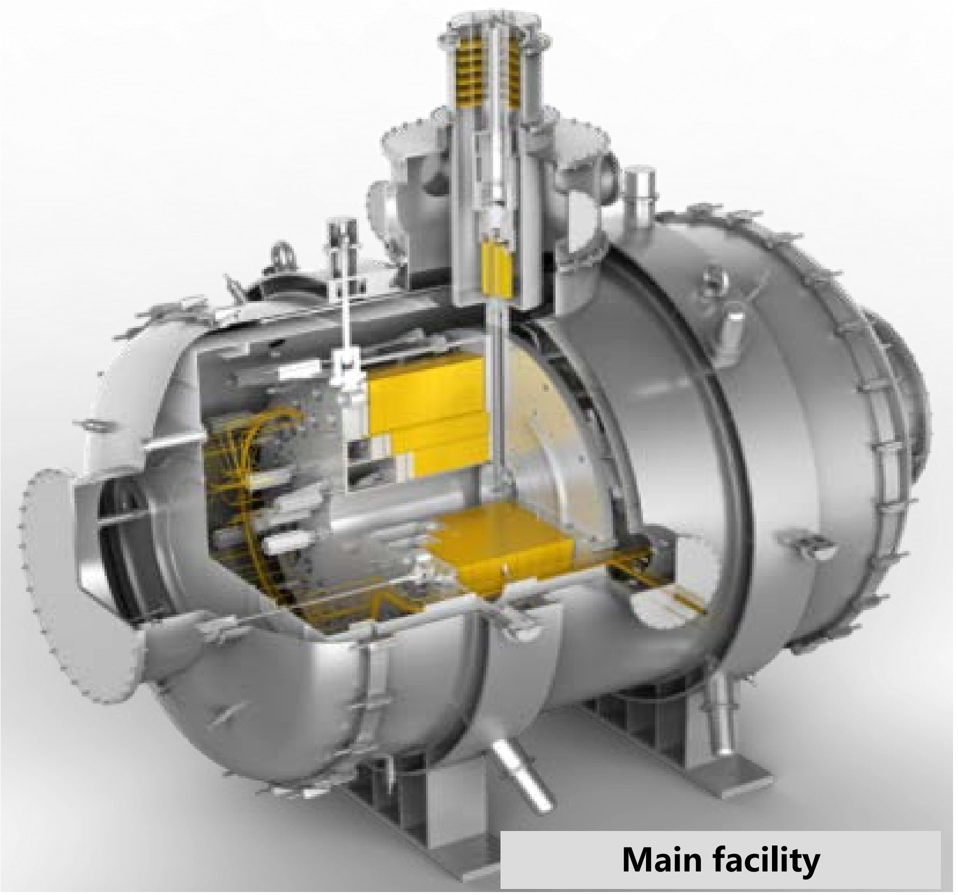
Test dewar

100kA HTS CL

CRAFT: SC Conductor Testing Facility



Layout of facility



Main facility

Max. test field	15T
Test aperture	100X160X550mm
Field homogeneity	≥ 95%
Max. test current	100 kA

Production line

CRAFT: SC Material Testing Facility

Back field for Ic test: **19 T&70mm@4.2K**

Temperature for Ic test: **4.2-80 K**

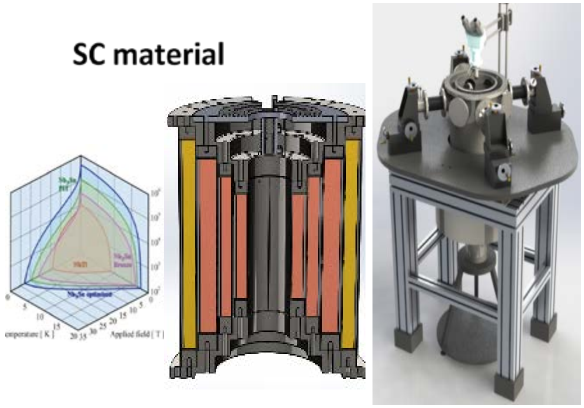
Temperature Accuracy: **30 mk@10 K**

HiPot test voltage: **0-100 kV**

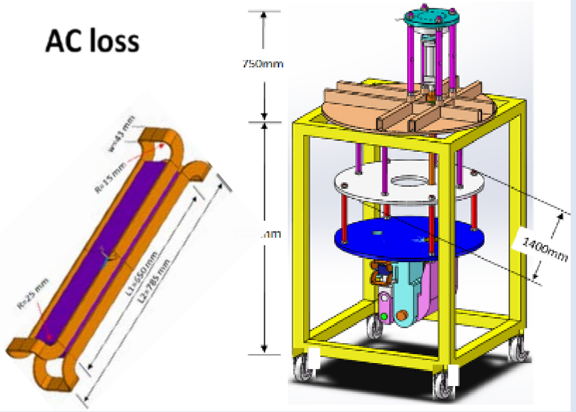
Paschen test gas pressure: **0.01-10^4 Pa**

Max loading for Mechanical test: **2500 kN**

SC material

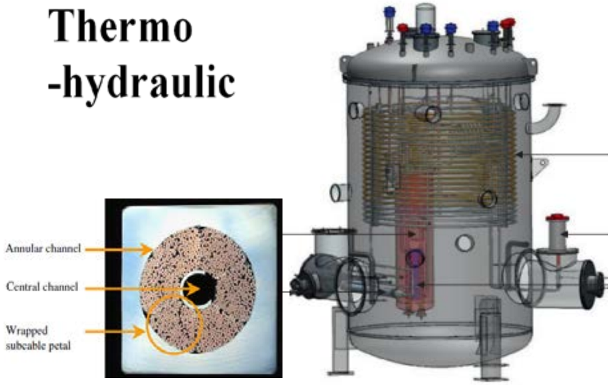


AC loss

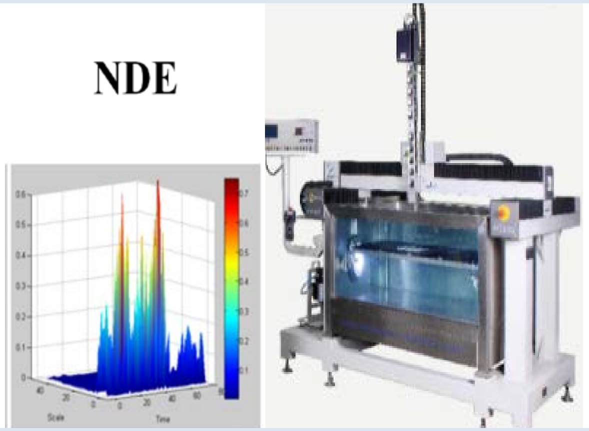


Structure material

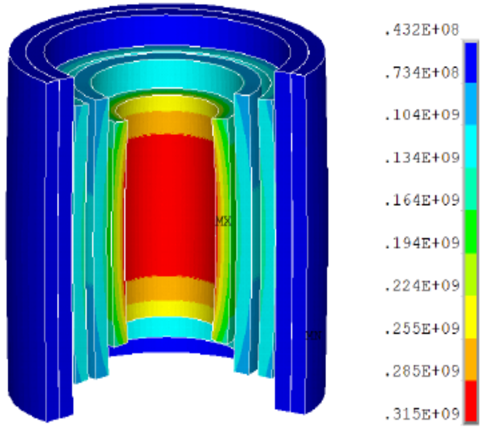
Thermo -hydraulic



NDE

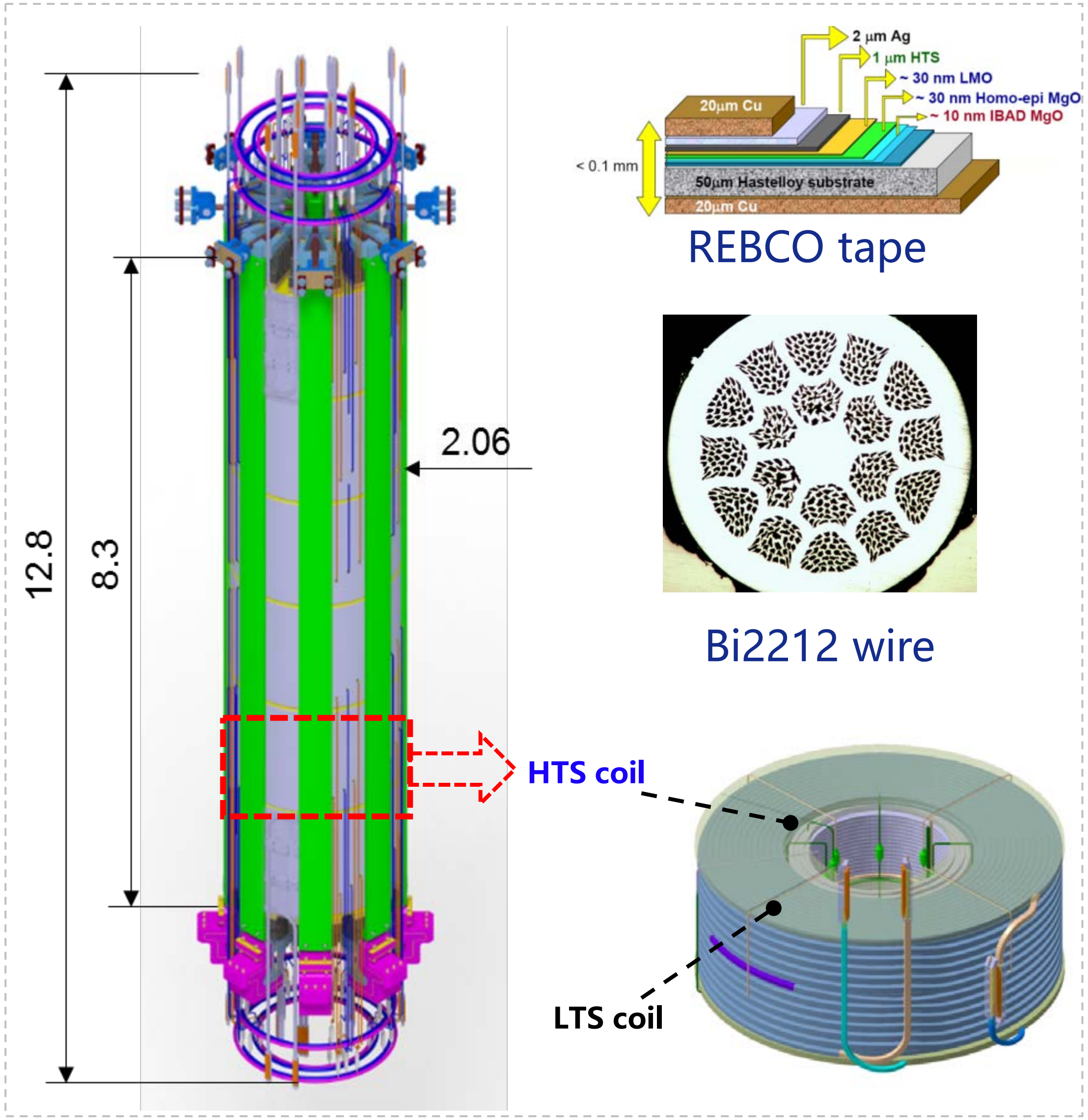


High voltage

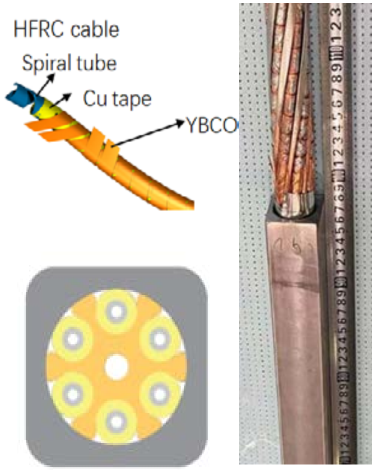


19T&70mm magnet

CRAFT: HTS Coil and Testing



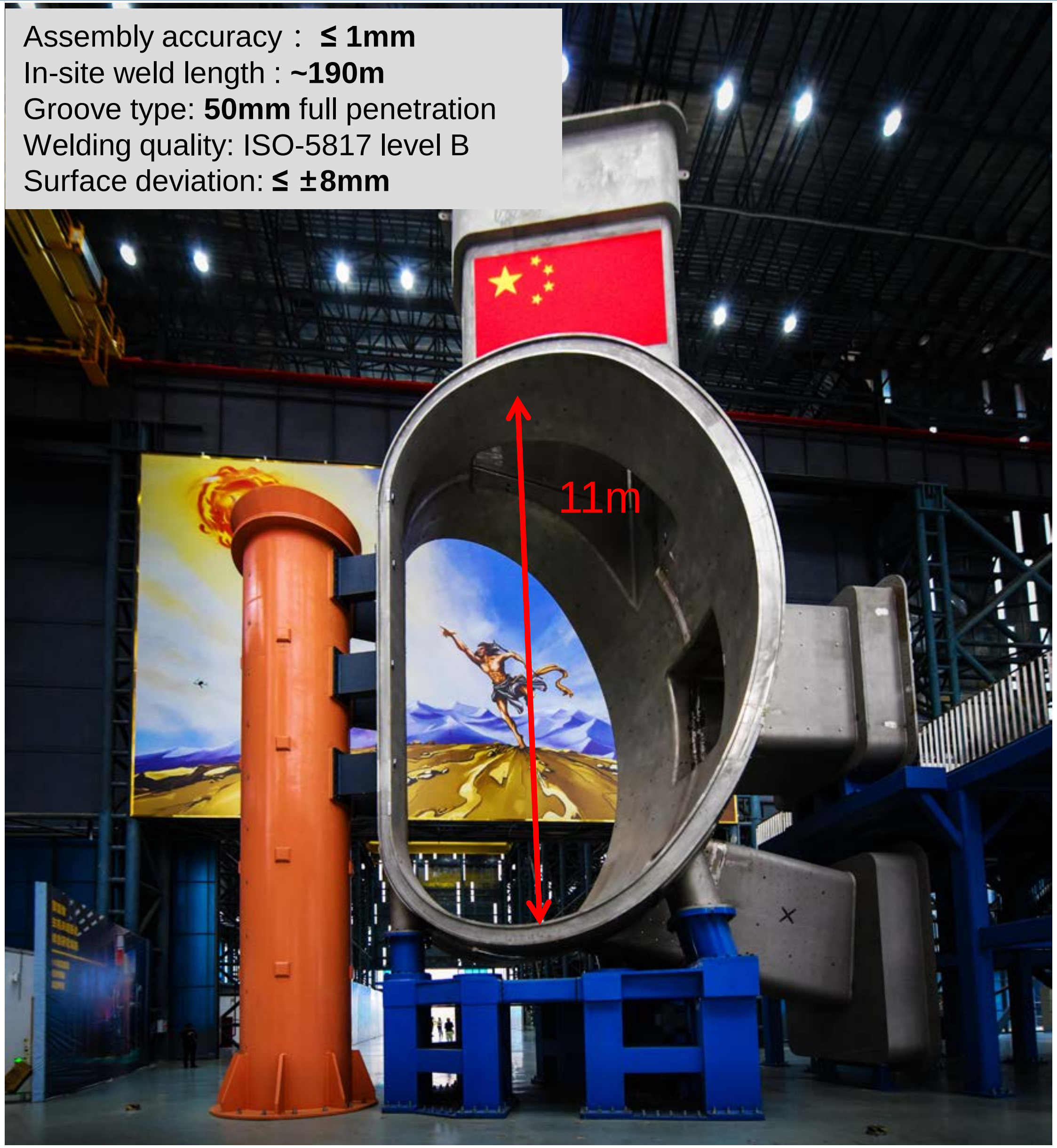
Hybrid CS coil design concept

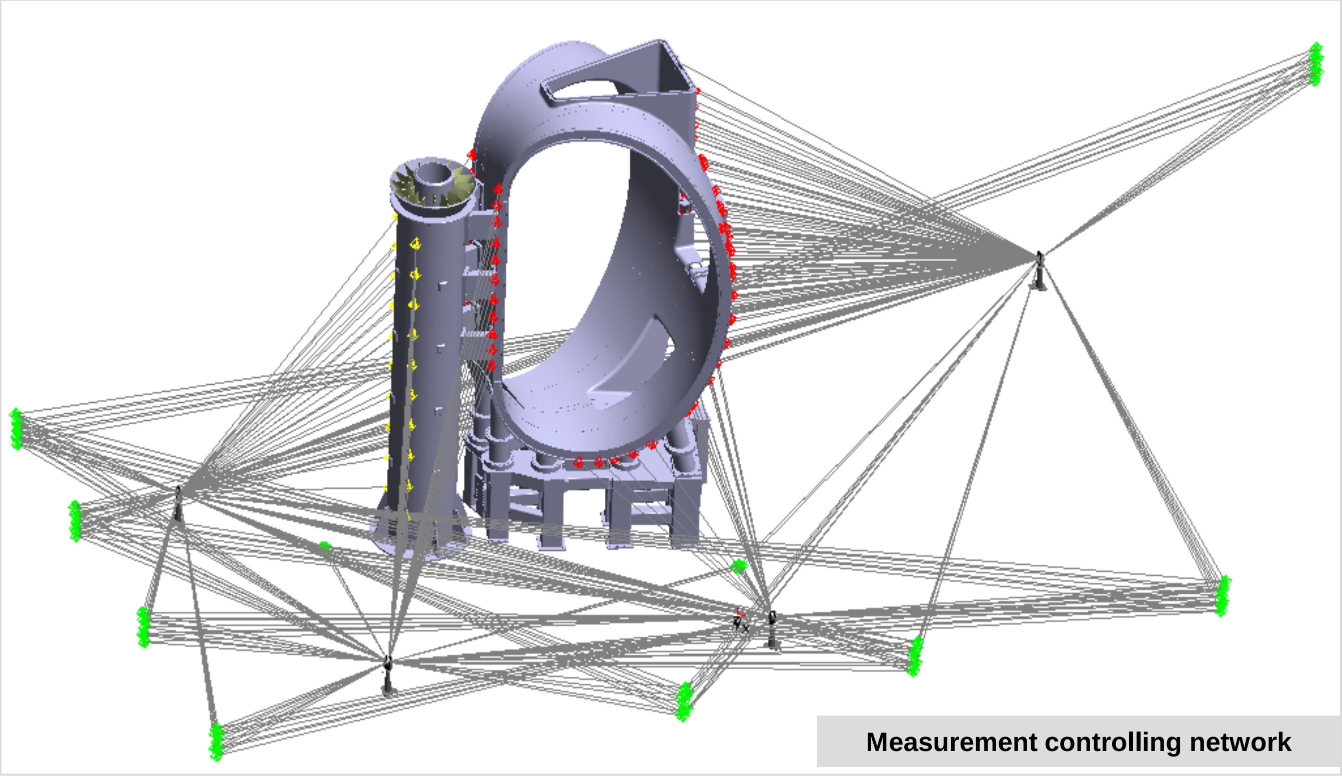


Cabling and coil winding line

CRAFT: 1/8 VV and Assembly Test Platform

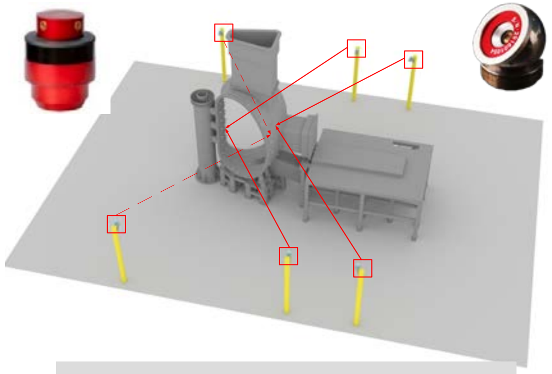
Assembly accuracy： **≤ 1mm**
In-site weld length : **~190m**
Groove type: **50mm** full penetration
Welding quality: ISO-5817 level B
Surface deviation: **≤ ±8mm**





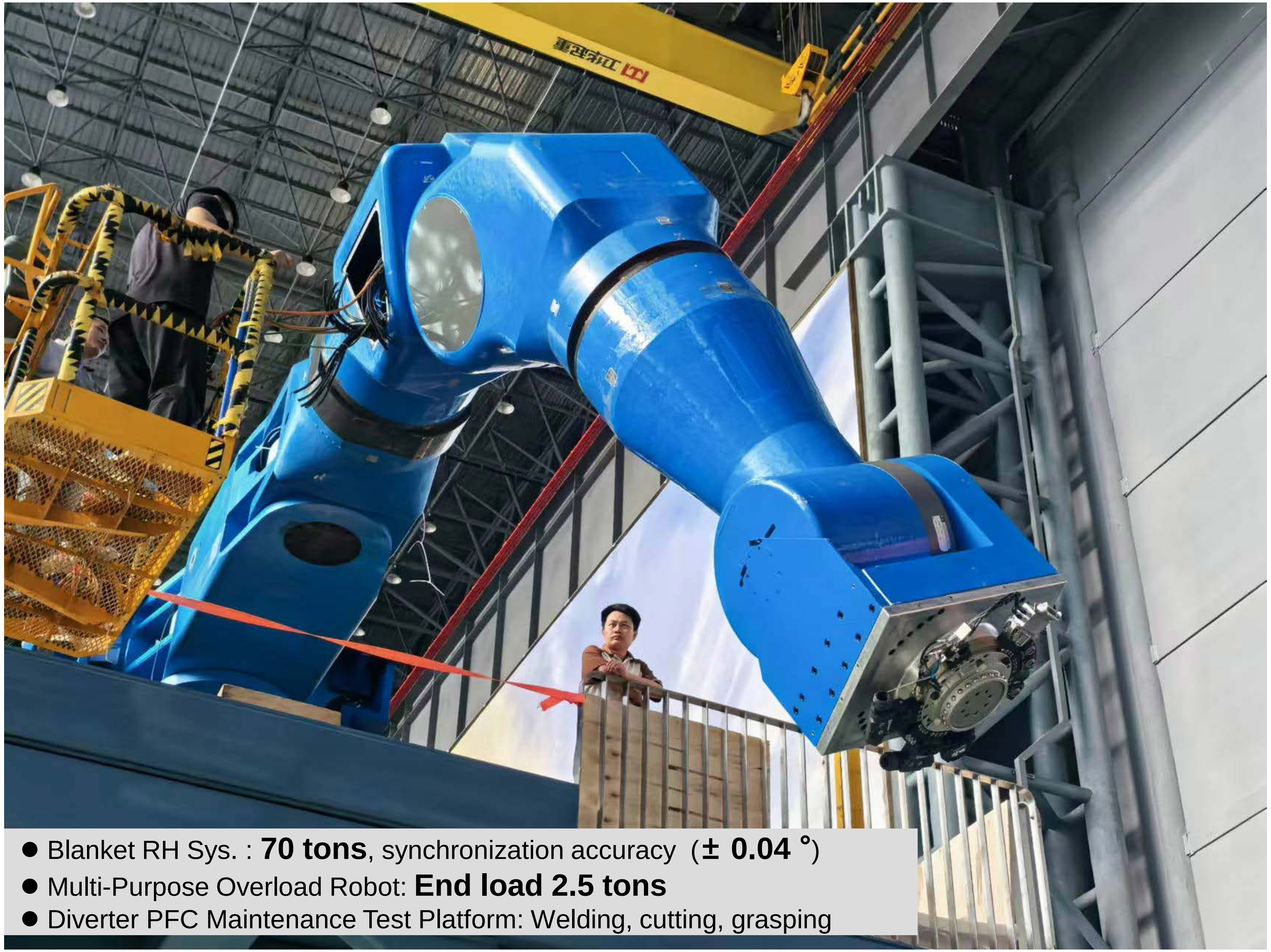
Measurement controlling network

In-site machining system



iGPS dynamic measurement

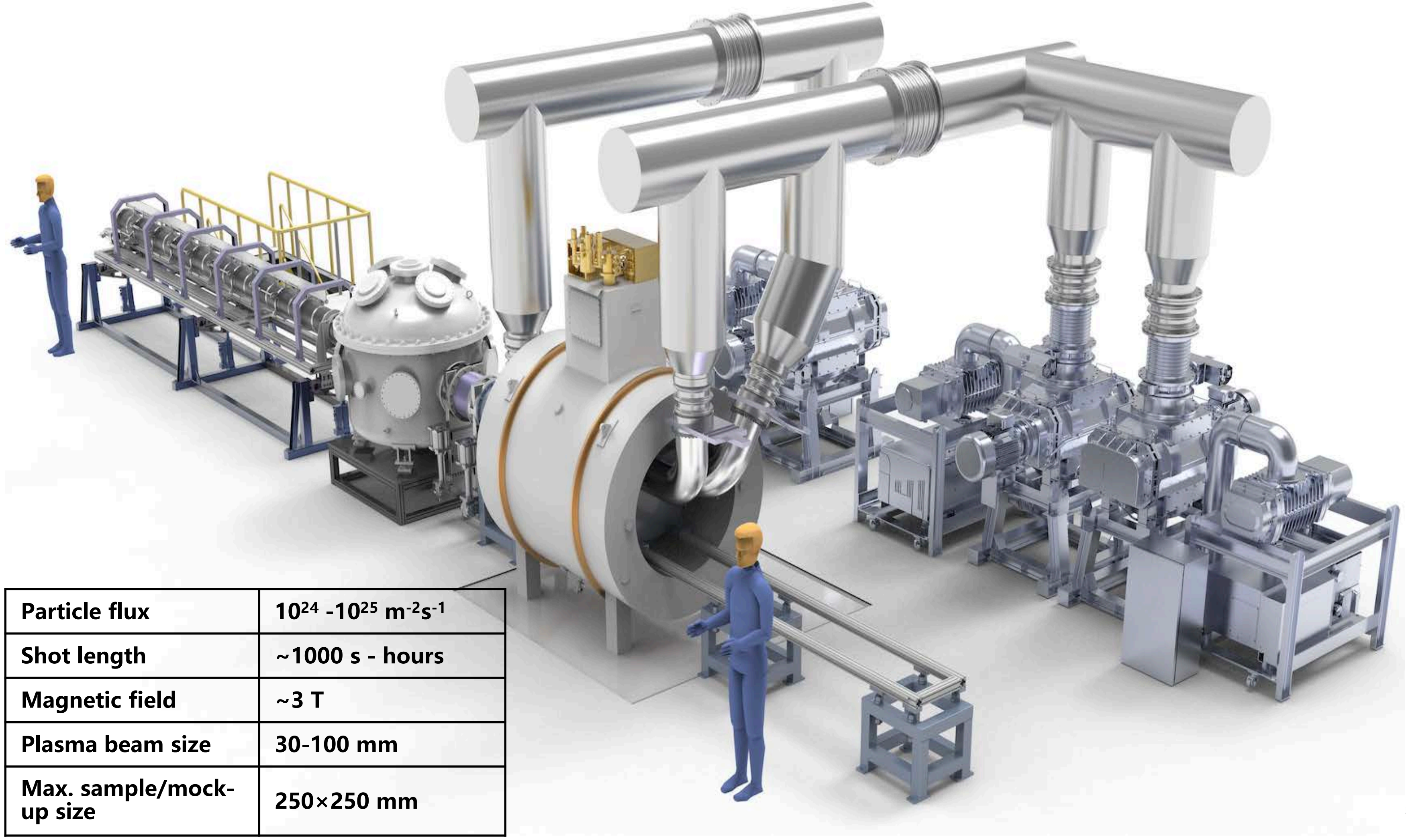
CRAFT- RH Testing Facility



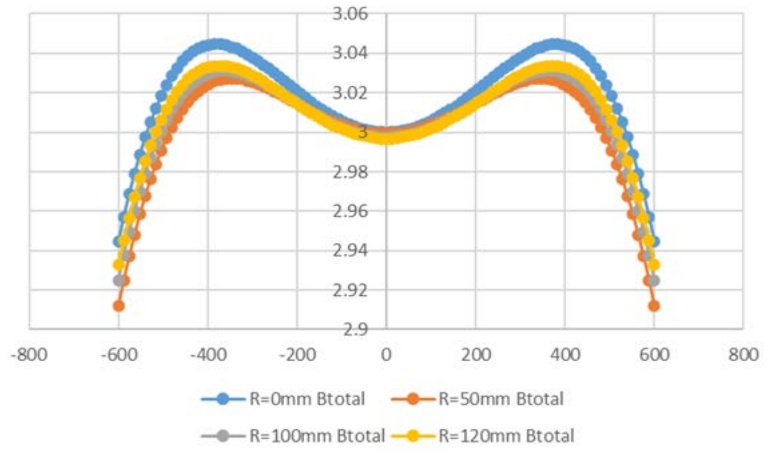
- Blanket RH Sys. : **70 tons**, synchronization accuracy (**± 0.04 °**)
- Multi-Purpose Overload Robot: **End load 2.5 tons**
- Diverter PFC Maintenance Test Platform: Welding, cutting, grasping

Integrated testing platform

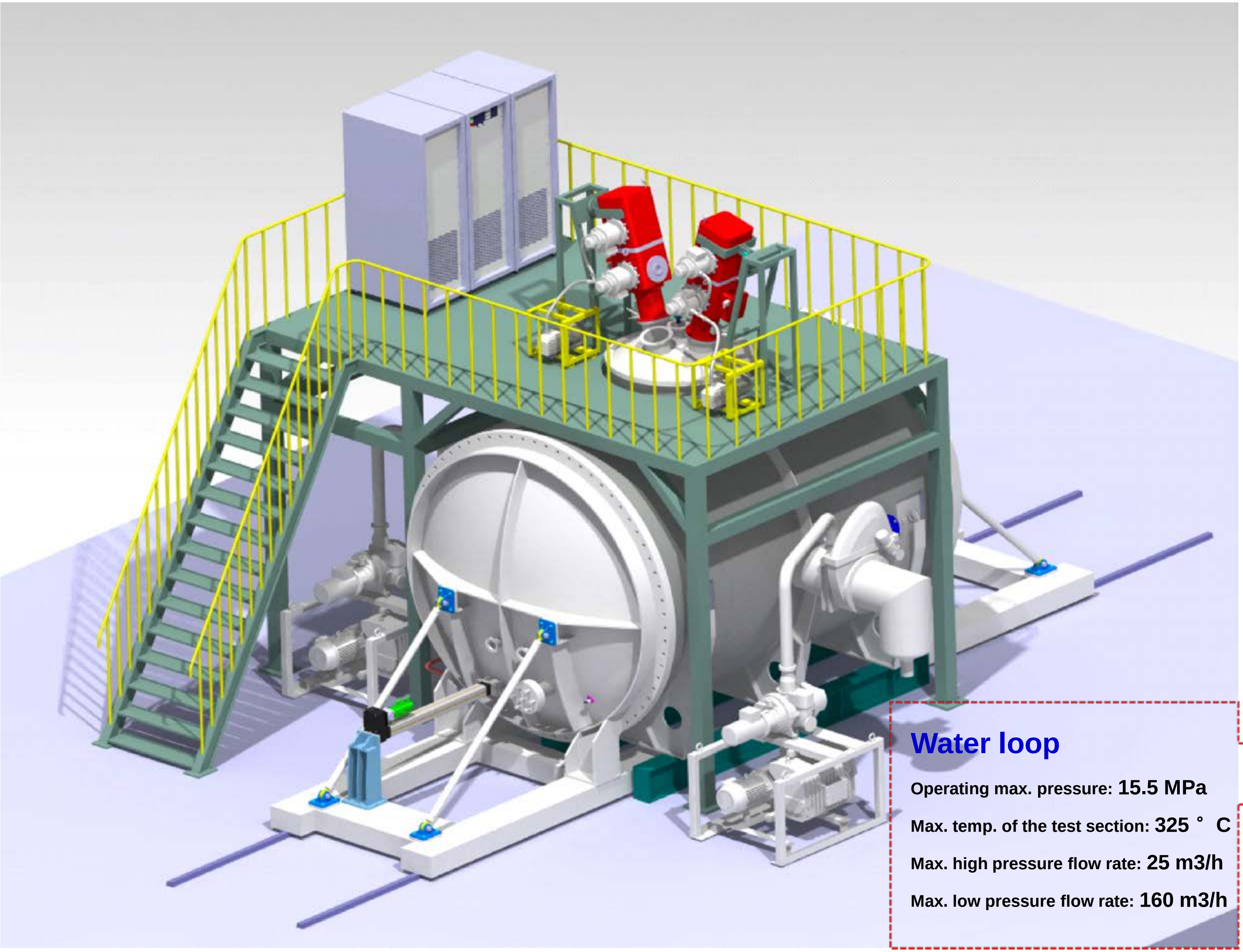
CRAFT- Large Linear Plasma Testing Facility



Particle flux	10^{24} -10^{25} $m^{-2}s^{-1}$
Shot length	~1000 s - hours
Magnetic field	~3 T
Plasma beam size	30-100 mm
Max. sample/mock-up size	250×250 mm



CRAFT: Divertor/Blanket Test Facility



Water loop

Operating max. pressure: **15.5 MPa**

Max. temp. of the test section: **325 ° C**

Max. high pressure flow rate: **25 m3/h**

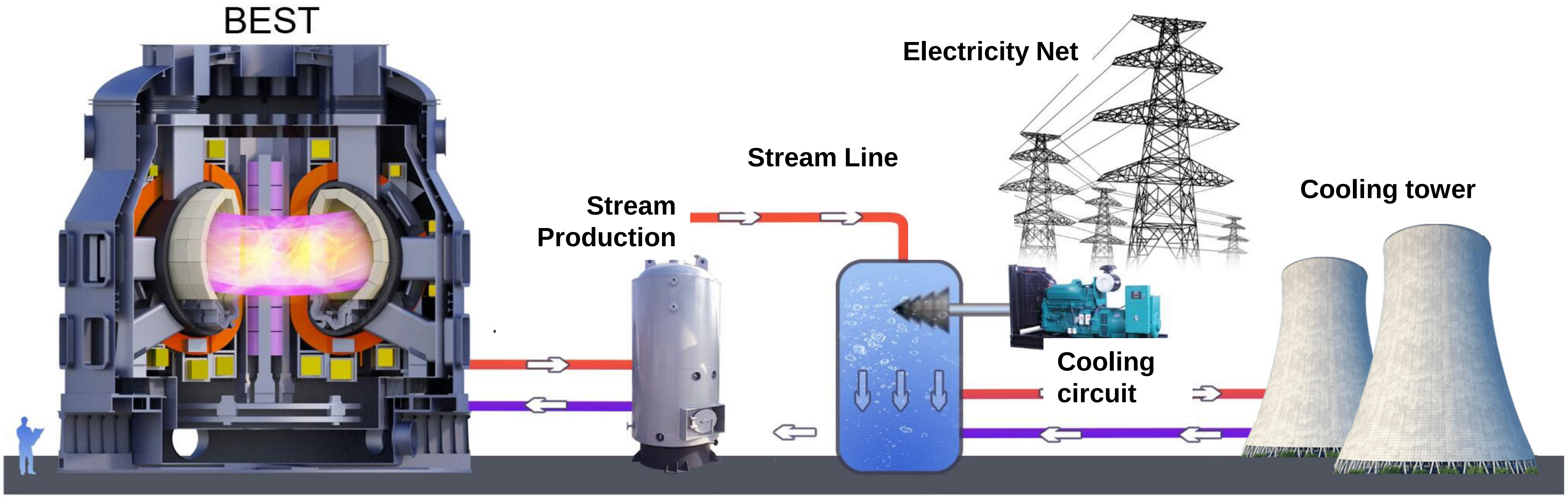
Max. low pressure flow rate: **160 m3/h**

- **The construction and commissioning of the main machine and water loop was finished.**
- **20MW/m2 heat load, Water/CO2 cooling, components acceptance test or accident test.**

Burning plasma Experimental Superconducting Tokamak（BEST）

Scientific objective

- Fusion power of 20-200 MW, Q=1-5, alpha particle heating and the burning plasma confinement and transportation
- Long pulse steady state safe control of burning plasma
- Realization of real-time T production, extraction and cycling



High Performance BEST Q>1 and Q>5 Scenarios

- Steady-state scenario is obtained by **reversed-magnetic-shear** enhanced-confinement ITB with high β_P and high bootstrap fraction.

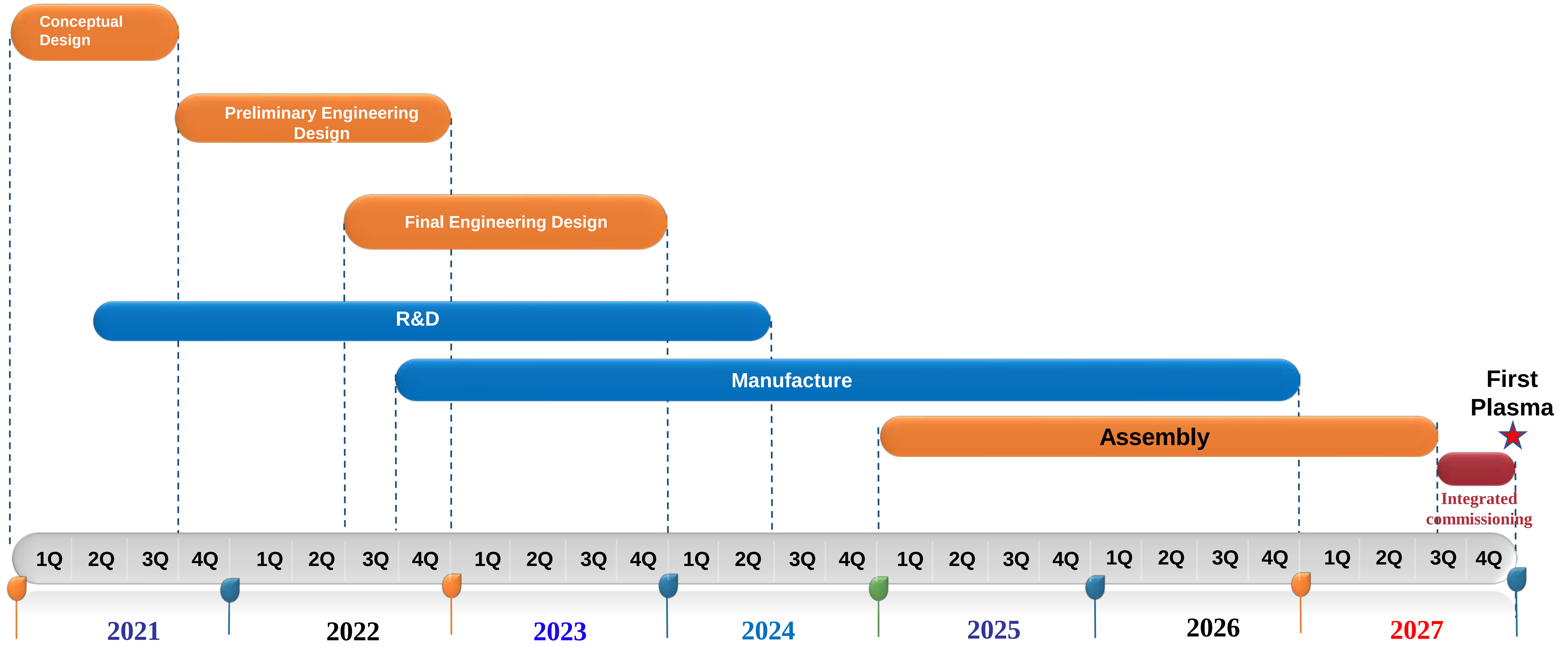
- Long-pulse inductive hybrid scenario with Q ≥ 1 can be obtained by several H&CD combinations. **BEST would serve as a good platform for the study of DT hybrid scenarios.**

- **Q>5** is obtained by a second ramp-up of plasma current and density as demonstrated by a preliminary time-dependent simulation.

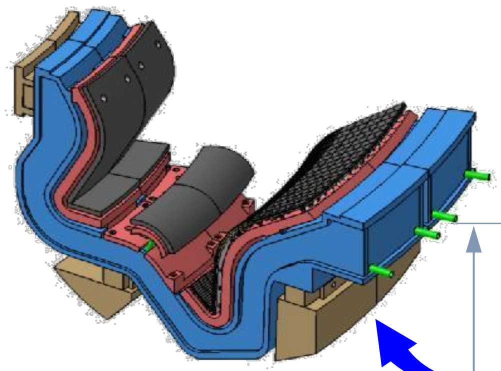
	Steady state	**long-pulse induct/hybrid**	burning
Fusion Gain	Q ≥ 1	Q ≥ 1	Q>5
Flattop duration	≥ 1000 s	≥ 100 s	5~10 s
P_{fus} (MW)	52	20	181
Q_{fus}	1.2	1.0	5.5
I_p (MA)	3.85	5.3	6.05
q_{95}	8.5	5.9	5
NBI (MW)	10	10	10
ICRF (MW)	10	4	10
ECRF (MW)	13	6	13
LHRF (MW)	10	0	0
$f_{bs}\|f_{ohm}$	0.83|0	0.3|0.54	0.81|0.15
$\beta_N\|\beta_P$	2.7|2.6	1.4|0.98	3.0|1.8
H_{98y2}	1.69	1.33	1.59
$n_{e,line}$ ($10^{19}/m^3$)	12.7	7.2	16.7
Z_{eff}	2	1.9	2

BEST Planning and Schedule

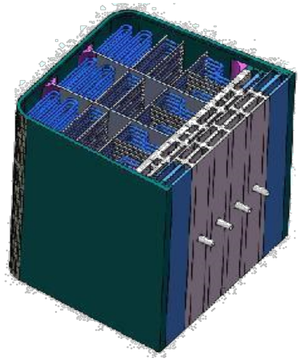
Overview of BEST Schedule



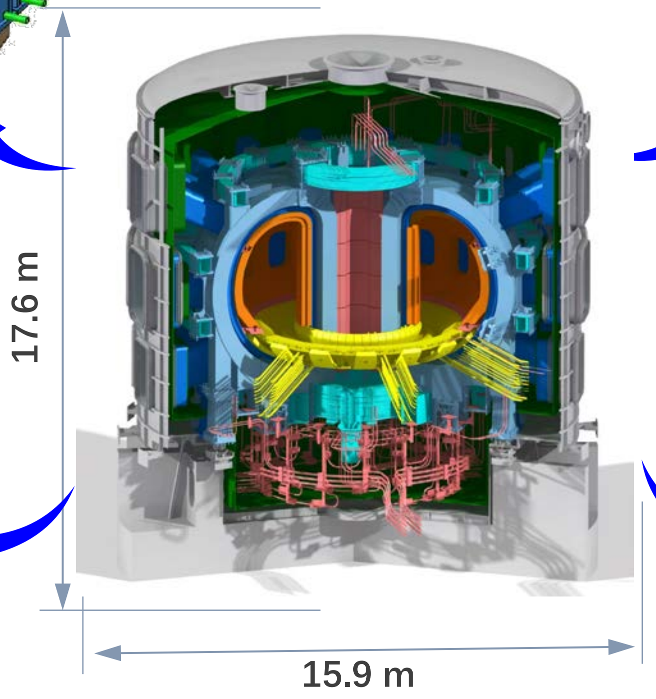
BEST Engineering Design

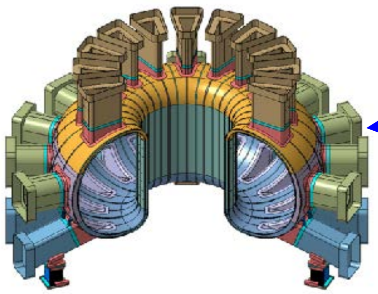


Divertor

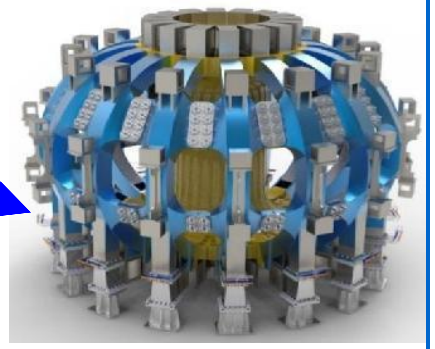


Blanket





Vacuum Vessel



Magnet
TF: 1000 t
Bt: 6.15T

Key Parameters

- **Major radius: R=3.6m**
- **Minor radius: a=1.1m**
- **Toroidal Bt: B_T=6.15T**
- **Plasma Current: I_P=4~7MA**
- **Power: P_{fusion}=20~200MW**
- **Elongation: κ = 1.7- 1.9**

BEST System Fabrication

Three TF coil production lines

Conductor Production line

TF Winding Test

Superconducting Cable

BEST Campus

The construction of the BEST campus started on 30th June 2023.

CFEDR: Chinese Fusion Engineering DOME Reactor

Aiming 1.5-3.0 GW net electrical power generation
Achieve steady-state self-sustainable burning with Q=20-30
Systematic R&D works for the Engineering Verification based on CRAFT

- ✓ **R&D works are being carried out**
  - TF magnet
  - Divertor
  - 1/8 vacuum vessel
  - NBI system
  - RH system
- ✓ **Large-scale testing facility under constructed**
  - Magnet Performance Research facility
  - Linear plasma testing facility

CFEDR: Chinese Fusion Engineering DOME Reactor

Chinese DEMO reactor to build up the science and technology basis for DT fusion power plant

	CFEDR
R_0 (m)	7.8
a (m)	2.5
κ	1.8
P_{fus} (GW)	1.5-3.0
Q	20-30
TBR	≥1

Obtained burning Plasma for fusion power →

1. P = 1.5-3.0 GW
2. Q = 20, physics and technology SS
3. Q = 20-30 hours FPP long pulse/SS
4. High energetic α heating

Steady-state operation for fusion energy →

5. SSO (Ext H&CD + Higher f_b)
6. Long pulse inductive (OH+BS+CD)
7. PSI on the first wall
8. Heat & particle exhaust on Div.

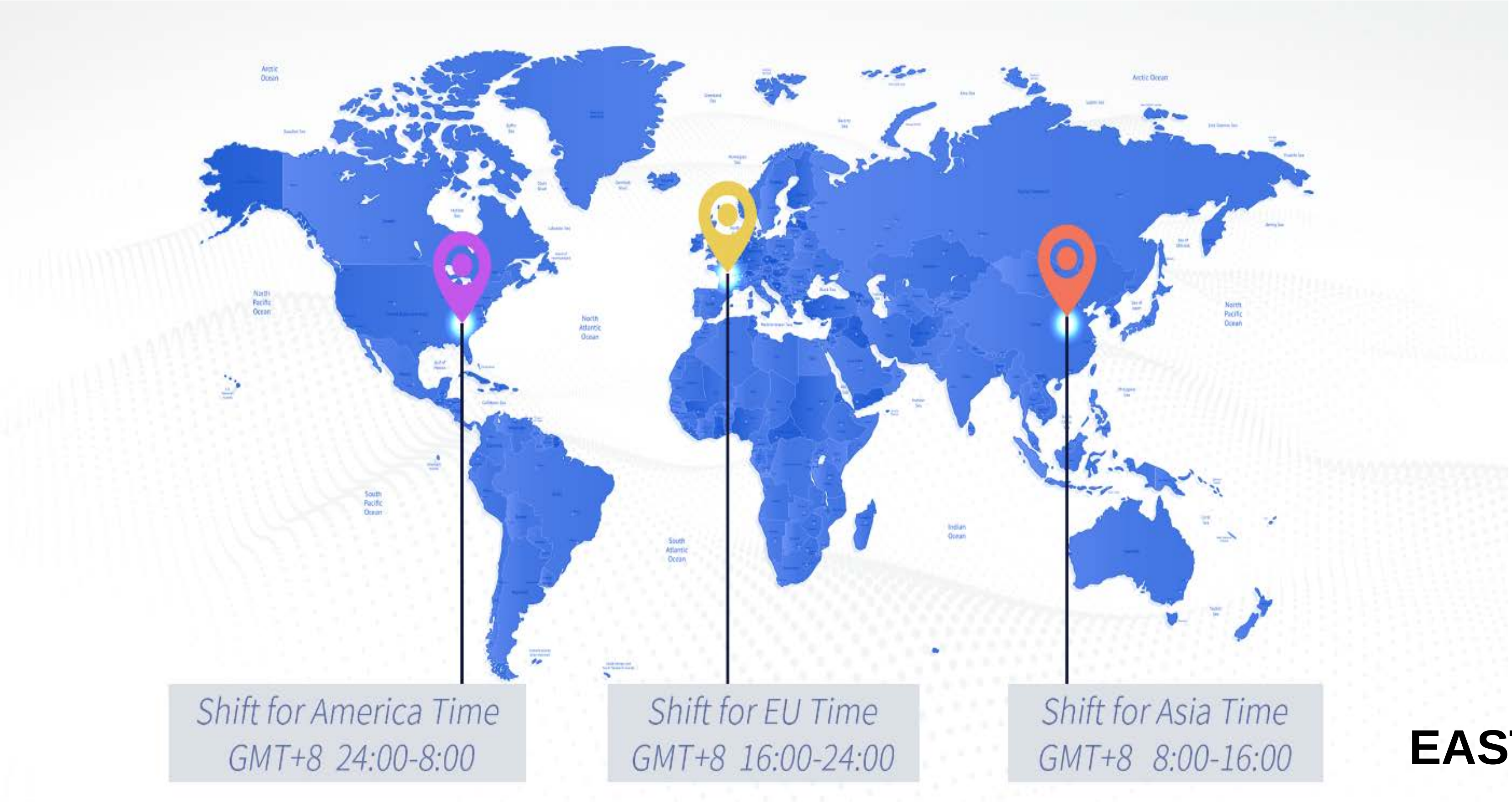
Breeding tritium for T self-sustained →

9. T-breeding by blanket
10. T-plant: extract & reprocessing
11. Materials & components
12. Reliable and quick RH
13. Licensing & safety

Worldwide Collaboration

EAST is an open platform dedicated Three-Shift joint experiments for worldwide collaborators.

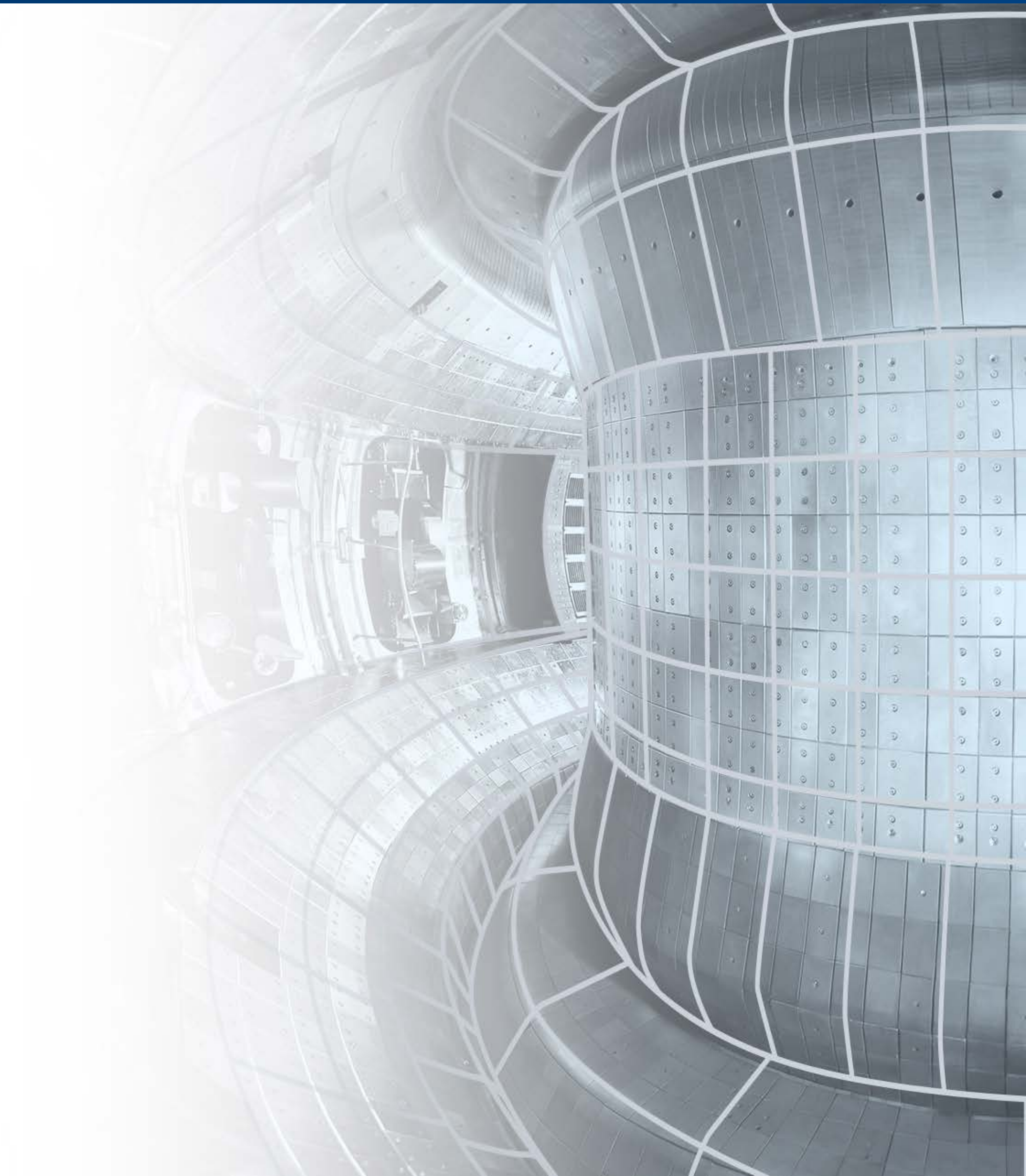
- **Established cooperative relations with 120+ key fusion research institutions in 50+ countries and regions.**



- **EAST data fully shared with all collaborators.**
- **Over 40% international proposals was carried out in recent 3 years**
- **On-site and remote participation are welcomed.**

EAST website: http://east.ipp.ac.cn/

Contents

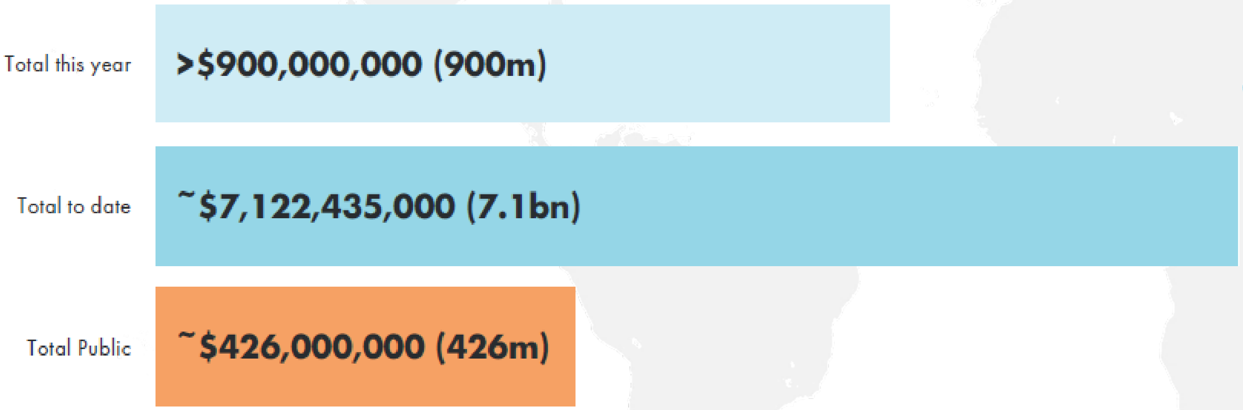


Summary and Outlook

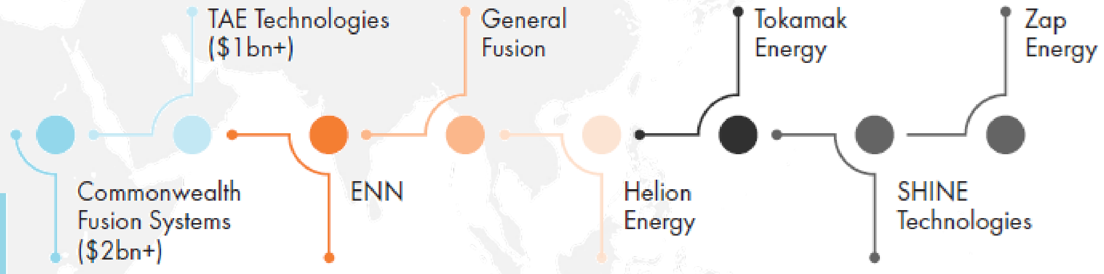
Fusion has become a globally recognized future energy source.

- **Public and private investment in the fusion industry keeps growing.**

- **The ambitious targets to achieve fusion need ambitious resources.**



Total Funding in 2024



Companies with $200M investment or more

Risks and difficulties are huge in achieving fusion ...

Sourced by "The global fusion industry in 2024, FIA"

Summary and Outlook

- ASIPP **dedicates to the fusion research and development** based on EAST-CRAFT-ITER/CN-BEST-CFETR facilities.
- Strong efforts have been made to **support R&D** towards **Fusion Pilot Plants**.

Opening and sharing,

- ASIPP will continue to strengthen the **collaboration with the world fusion community** in exploring the ultimate energy source for humankind.

Thank you! See you in Hefei!

ASIPP