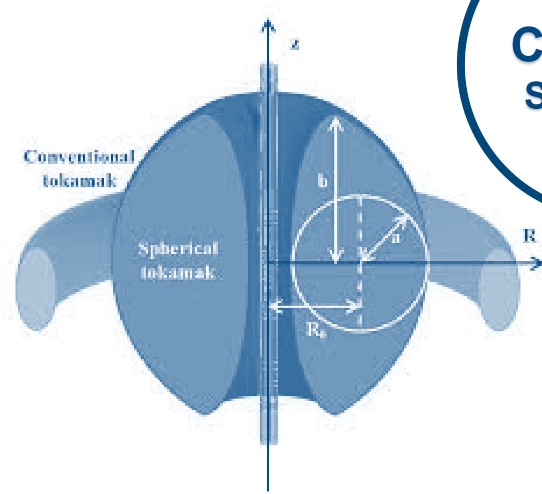
ENN 新奥

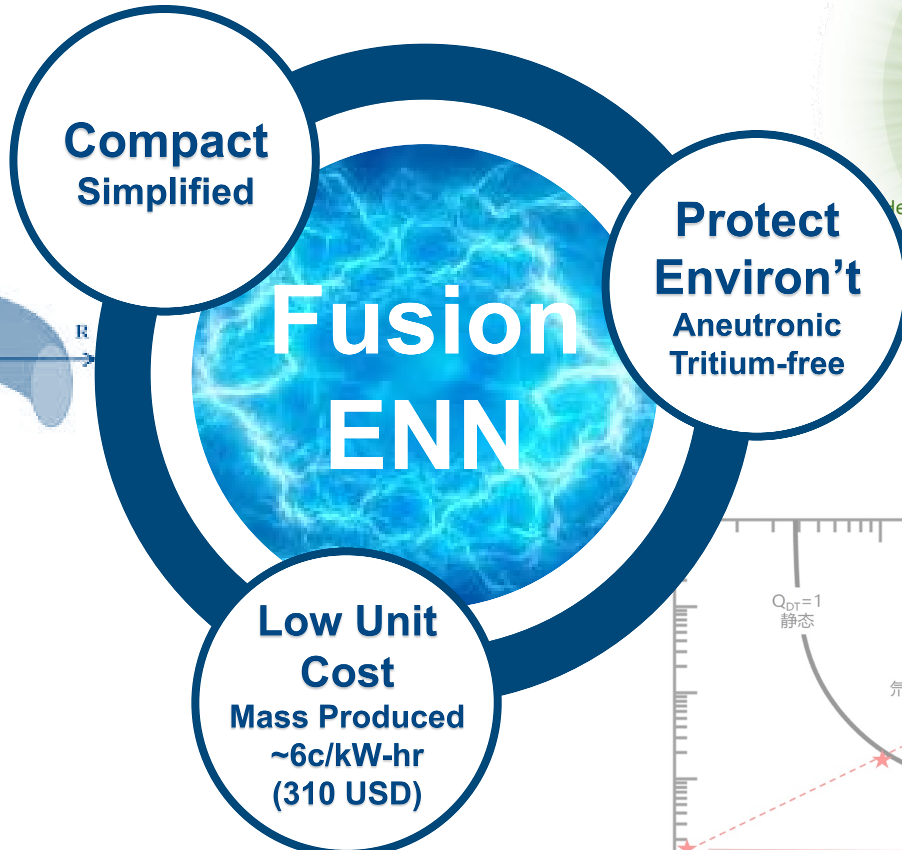
EXL Fusion Power Technology R&D

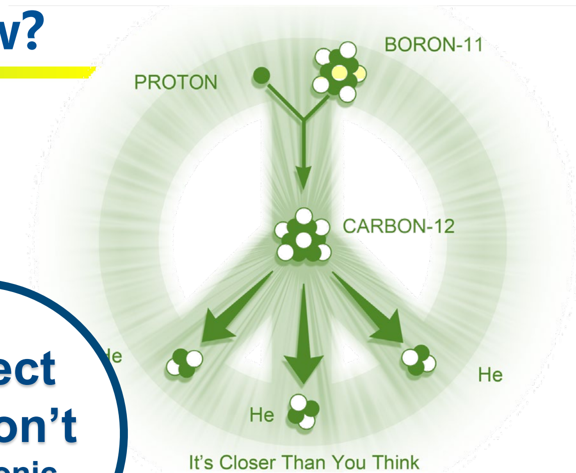
ENN Energy Research Institute
Hebei Key Laboratory of Compact Fusion

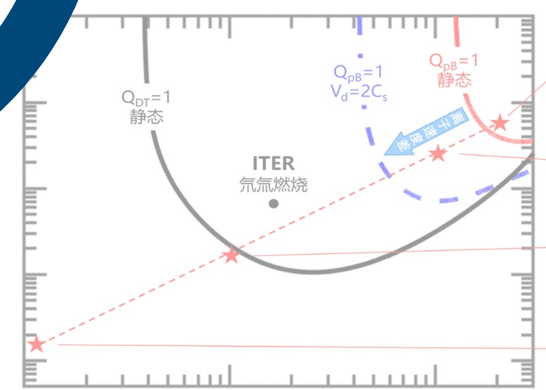
March 26, 2021

ENN Fusion R&D Mission — Compact Clean Commercial (Low Unit Cost) Power. But How?

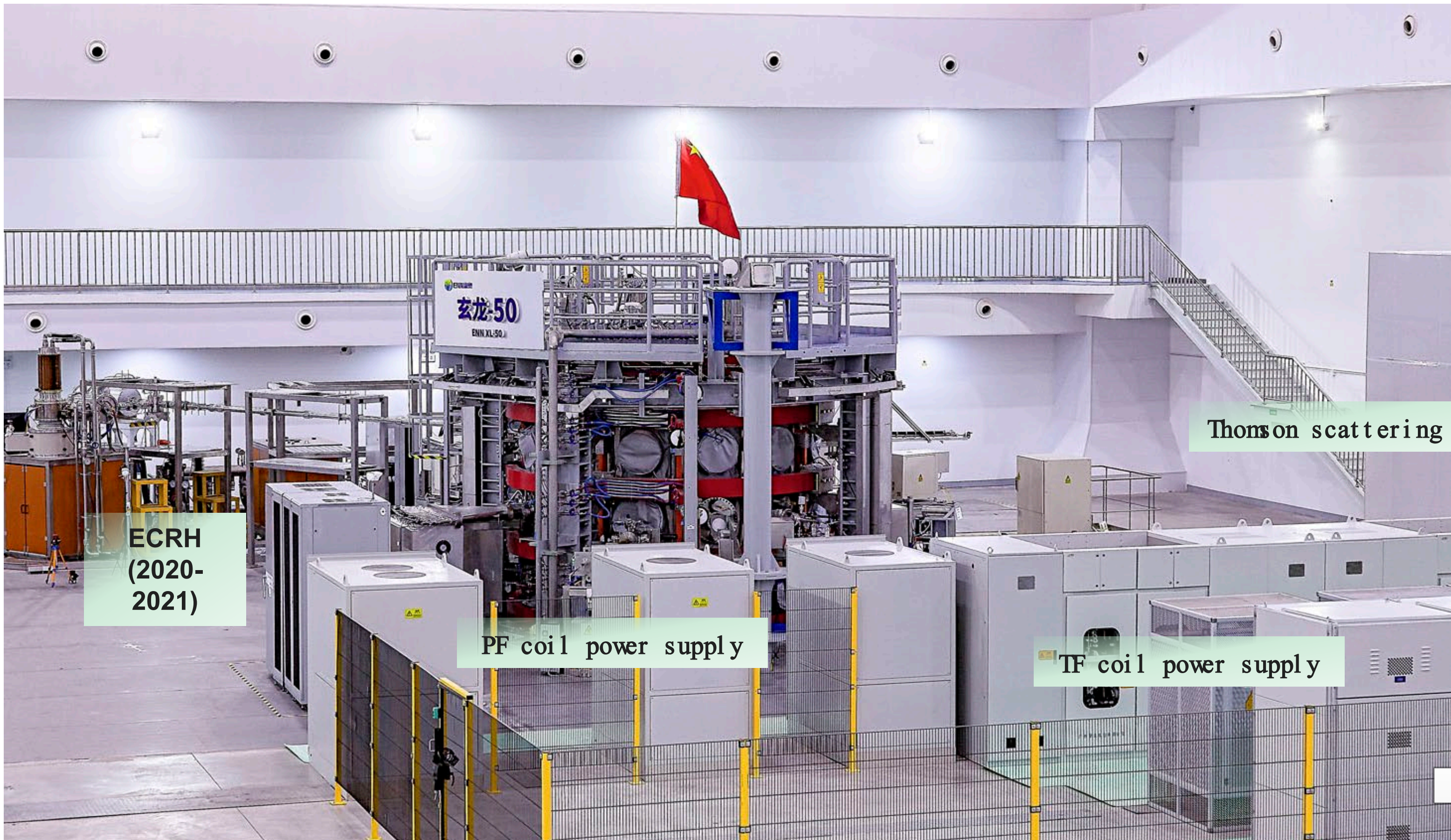








EXL-50 facility layout

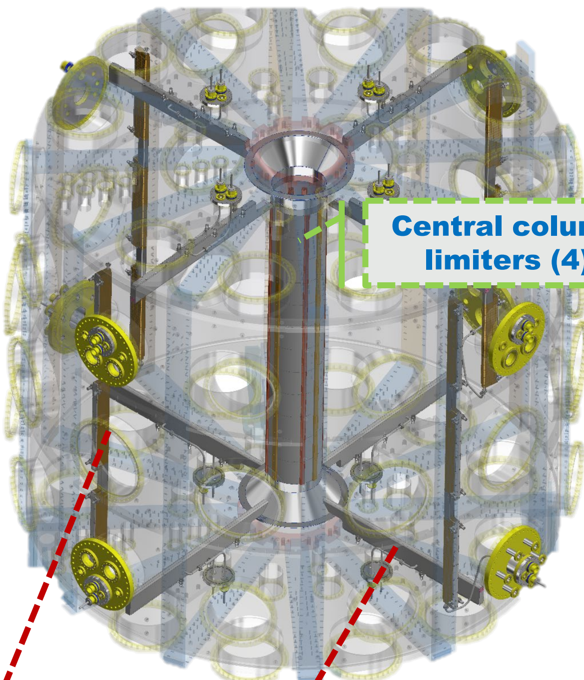


Main design parameters of EXL-50

Parameters	Values
Plasma current	⩽0.5 MA
Thermal ions major radius R_i	0.48 m
Energetic electron cloud radius	0.7m
Thermal ions aspect ratio (LCFS)	1.5
Energetic electron cloud aspect ratio	1.3
Toroidal magnetic field (at R_i)	⩽0.5T
Elongation	≈2
Thermal ions temperature	⩽1 keV
Energetic electron temperature	0.23 MeV
Electron density	$2 \times 10^{19}/m^3$
ECRH power (28GHz)	1.6 MW
LHCD power	1 MW
ICRH power	1 MW
NBI power	1.5 MW
Discharge TF flattop duration	⩽5 s

- No CS coil
- No divertor
- No first wall
- Fully welded vacuum vessel
- Drive plasma current with ECRH

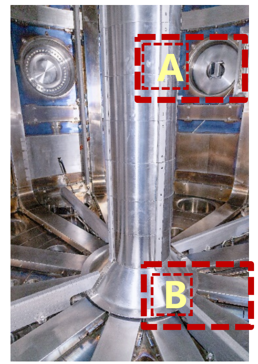
Tungsten-coated copper limiters

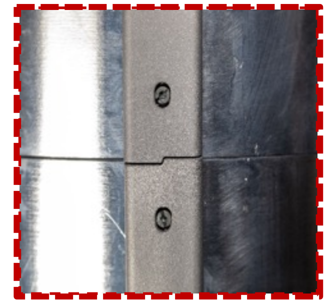


Central column limiters (4)

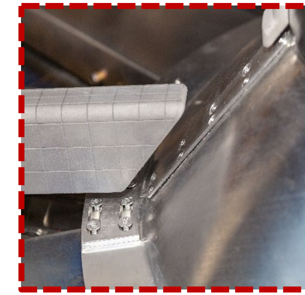
Vertical limiters（12）

Upper and lower limiters （8）



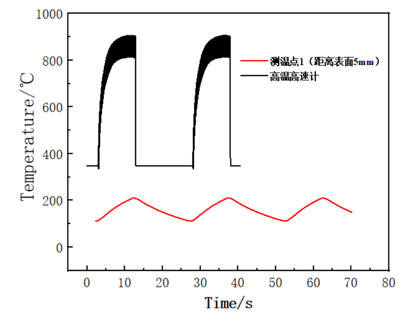


A. Central column limiter

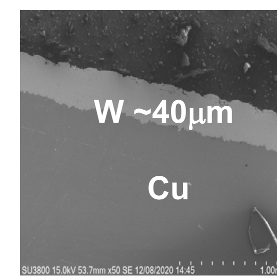


B. A lower limiter

e-Beam test sample



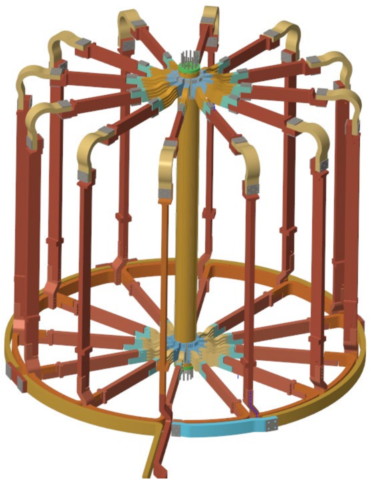
Surface and base metal temperatures of NO.640-642

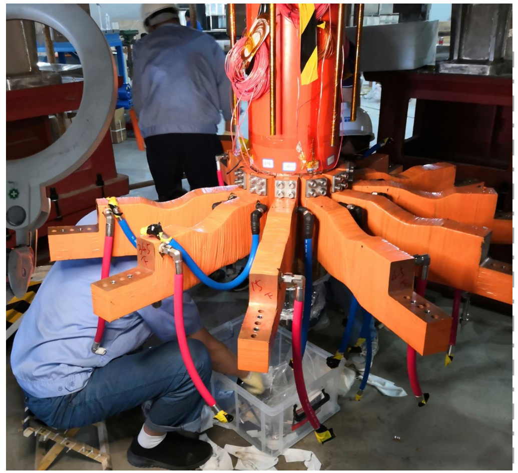


Section observation of tungsten coating by EM

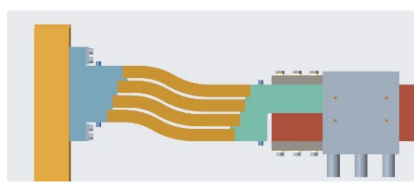
Tungsten coating has been shown to survive incident heat fluxes of 10 MW/m² for 1,000 cycles in testing at SWIP, showing shallow surface cracks.

Magnet coils



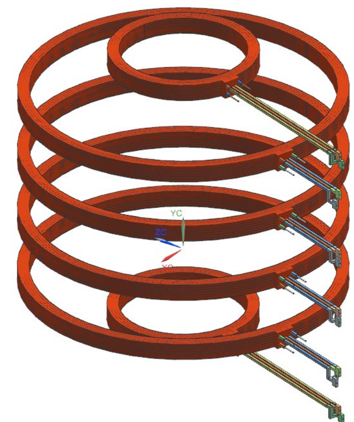


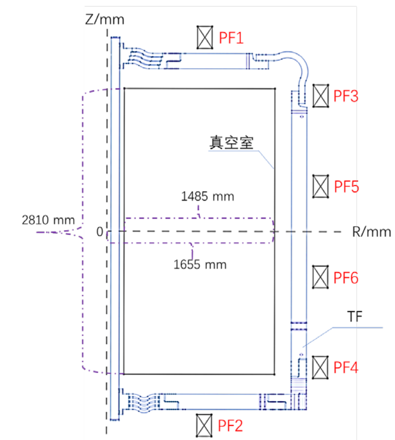
Parameter	Value
Turn	12
Current	100 kA
Magnetic field	0.41 T (at R=0.58m)
Materials	CuZr,CuAg
Weight	13 t
Cooling	water
Ripple	<1.6% (at R=1.51m)
Temperature rise	70 ℃
Pulse flattop time	5 s



Central column flexible joint

Poloidal field coils

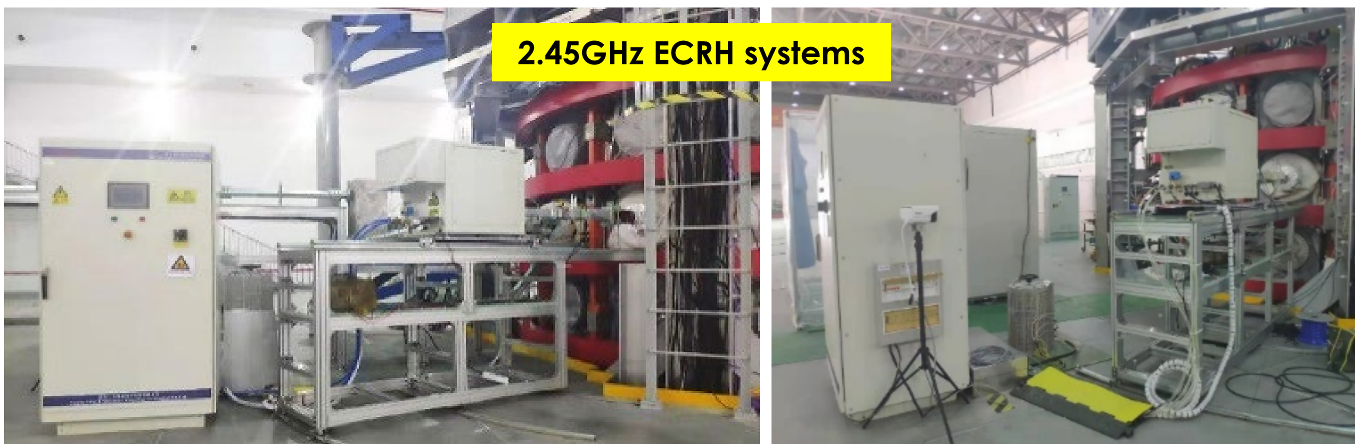




Coils	R,m	Z,m	dR,m	dZ,m	Turns	Current,kA
PF1 PF2	1.908	± 0.963	0.147	0.224	22	17.3
PF3 PF4	1.335	± 2.107	0.147	0.224	22	17.3
PF5 PF6	0.445	± 2.107	0.147	0.224	22	17.3

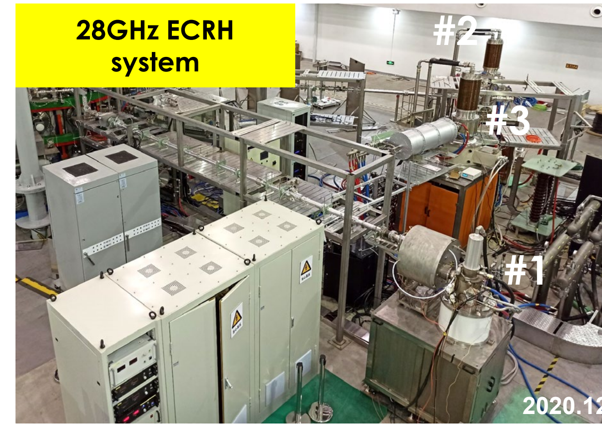
2 X 2.45-GHz/15kW/CW systems

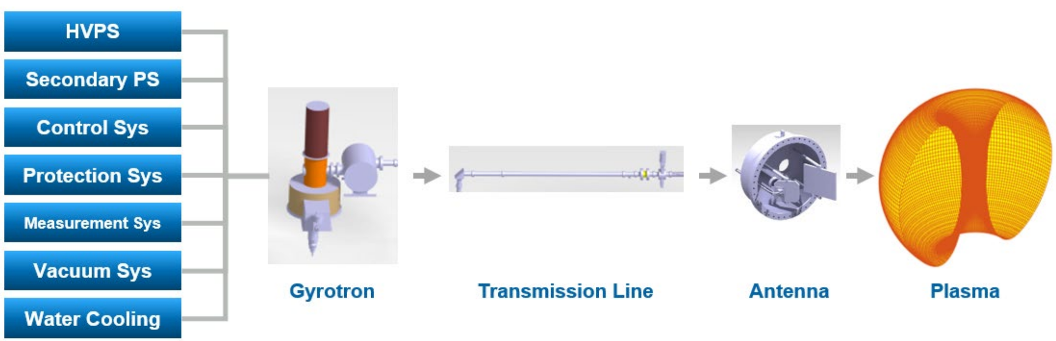
- **Produced first plasma in 2019.**
- **ECRH startup to ~7kA plasma current at low field.**
- **Used for discharge cleaning, ECR boronization, and pre-ionization at full field.**



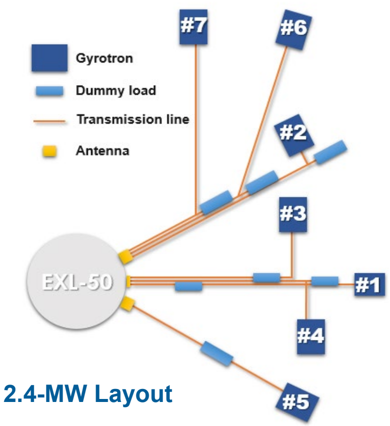
1 X 28-GHz/50kW/30s, 2 X 28-GHz/400kW/5s systems

- Electron Cyclotron Resonance Heating (ECRH) alone is used for plasma start-up, heating and current drive during 2020.
- Consist of gyrotron, S/C magnet, MOU, transmission line, antenna, high-voltage power supplies, control and protection system, vacuum, monitor and protection, water cooling systems.
- Installed systems delivered up to ~300kW/4.5s.
- Three antenna systems: toroidal injection angle from -44°to 48°(midplane). Upper antenna injection angle from 0°to 30°(vertical), and from 15° to -30°(toroidal).
- A total gyrotron power of 2.4 MW is planned.



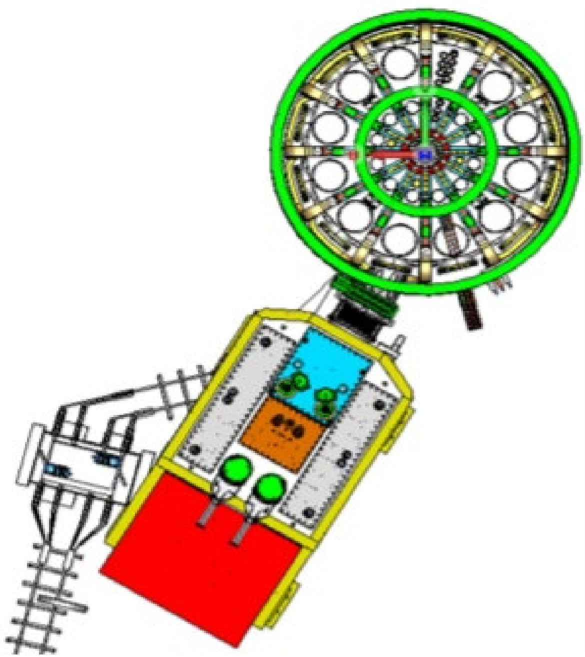


Architecture of the ECRH System



2.4-MW Layout

1.5MW neutral beam injection system



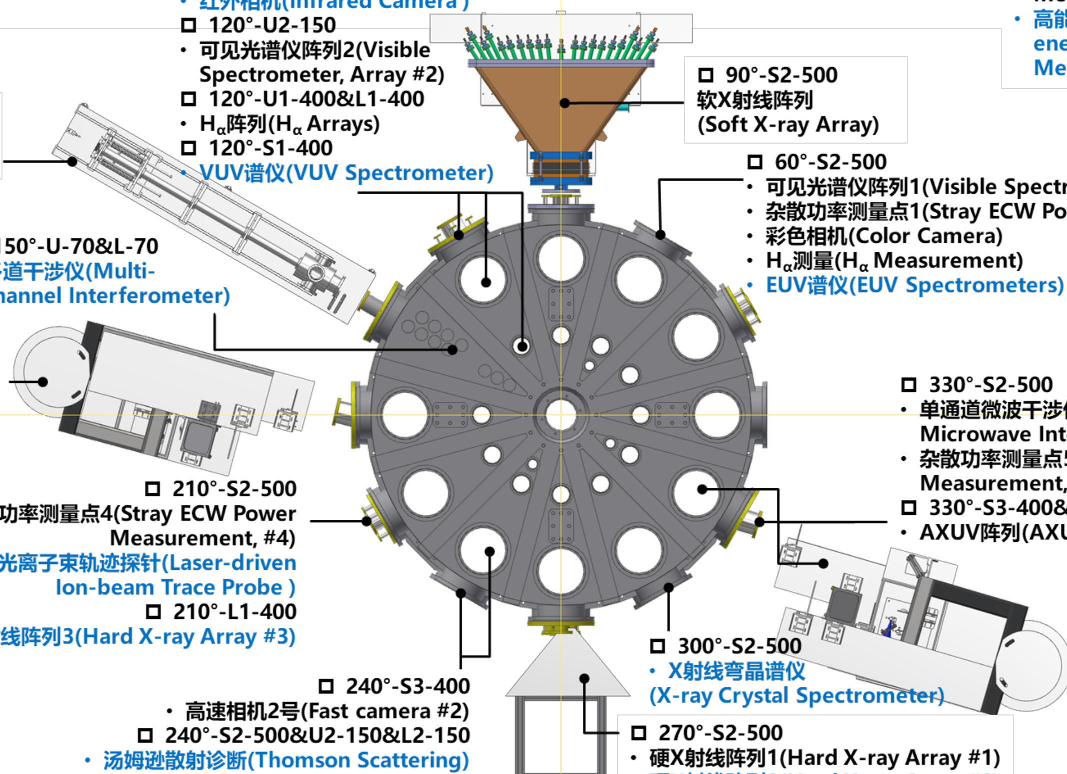
Top View of NBI on EXL-50

Main Parameters of 1.5MW NBI for EXL-50 Tokamak

- Ion source type: Multi-cusp bucket ion source;
- Number of grids: 3;
- Number of ion sources: 2;
- Acceleration parameters: 50kV/40A/5s;
- Beam Convergence angle: 2×3.2°;
- Grid convergence angle: 178°;
- Beam focal length: 5366mm;
- Neutralization efficiency: ＞55%;
- Proton ratio: ＞70%;
- Pumping speed: 1×10^6 l/s;
- Residual ion deflection: magnetic deflection;
- Injection angle: 55.3 °;
- Number of filaments: 16

Present and planned diagnostics on EXL-50

- 黑色(Black)：已安装(Installed)
- 蓝色(Blue)：建设中(Under Construction)



□ 120°-S2-500
- 高速相机1号(Fast Camera #1)
- 杂散功率测量点2(Stray ECW Power Measurement, #2)
- 红外相机(Infrared Camera)

□ 120°-U2-150
- 可见光谱仪阵列2(Visible Spectrometer, Array #2)

□ 120°-U1-400&L1-400
- H_α阵列(H_α Arrays)

□ 120°-S1-400
- VUV谱仪(VUV Spectrometer)

□ 位置可移动(Portable)
- 两道硬X射线测量(2-channel Hard X-ray Measurement)
- 高能硬X射线测量(High-energy Hard X-ray Measurement)

□ 90°-S2-500
软X射线阵列
(Soft X-ray Array)

□ 150°-S2-500
- 静电探针
(Langmuir probe)

□ 60°-S2-500
- 可见光谱仪阵列1(Visible Spectrometer, Array #1)
- 杂散功率测量点1(Stray ECW Power Measurement, #1)
- 彩色相机(Color Camera)
- H_α测量(H_α Measurement)
- EUV谱仪(EUV Spectrometers)

□ 150°-U-70&L-70
- 多道干涉仪(Multi-channel Interferometer)

□ 180°-S2-500
- 单通道微波干涉仪发射端(Single-channel Microwave Interferometer, Transmitter)
- 杂散功率测量点3(Stray ECW Power Measurement, #3)

□ 330°-S2-500
- 单通道微波干涉仪接收端(Single-channel Microwave Interferometer, Receiver)
- 杂散功率测量点5(Stray ECW Power Measurement, #5)

□ 330°-S3-400&U1-400
- AXUV阵列(AXUV Arrays)

□ 210°-S2-500
- 杂散功率测量点4(Stray ECW Power Measurement, #4)
- 激光离子束轨迹探针(Laser-driven Ion-beam Trace Probe)

□ 210°-L1-400
- 硬X射线阵列3(Hard X-ray Array #3)

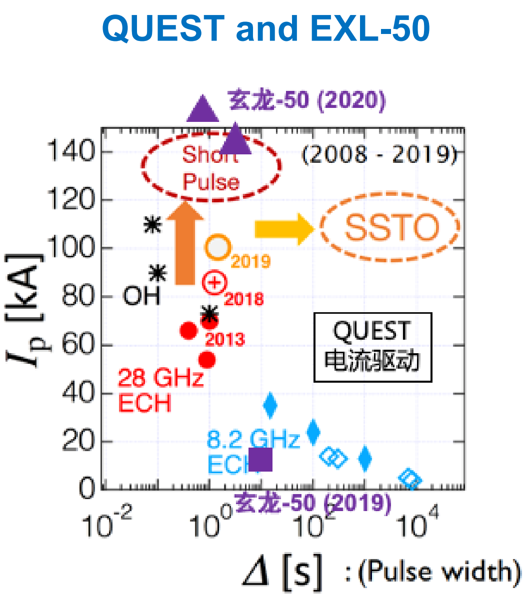
□ 300°-S2-500
- X射线弯晶谱仪
(X-ray Crystal Spectrometer)

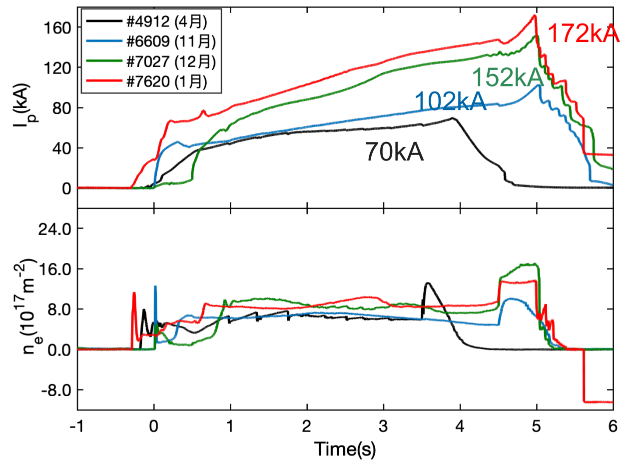
□ 240°-S3-400
- 高速相机2号(Fast camera #2)

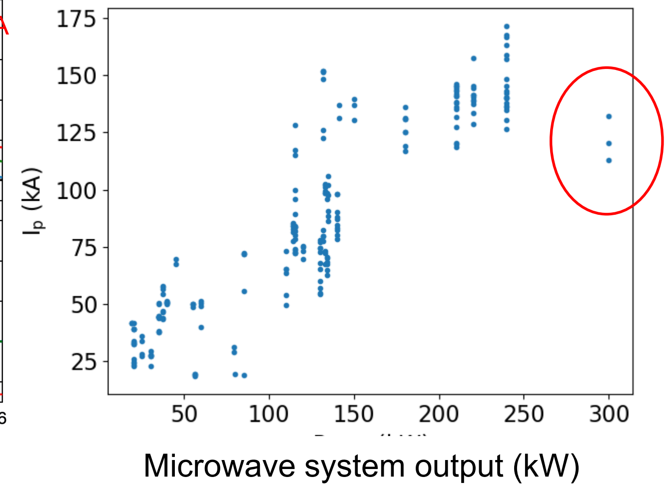
□ 240°-S2-500&U2-150&L2-150
- 汤姆逊散射诊断(Thomson Scattering)

□ 270°-S2-500
- 硬X射线阵列1(Hard X-ray Array #1)
- 硬X射线阵列2(Hard X-ray Array #2)

2020 progress in driven current







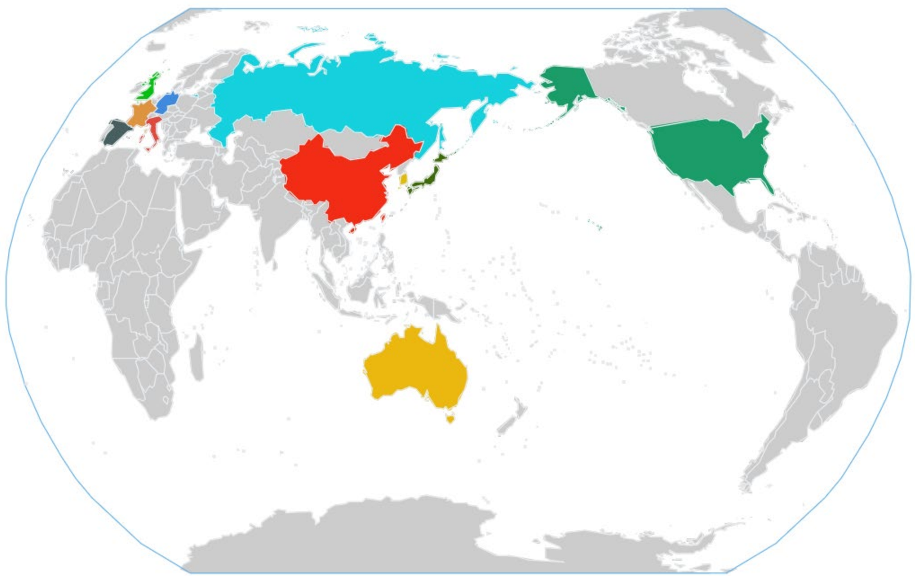
- Transient 172kA, quasi-stationary 140-150kA
- A new record, as far as we know
- Power absorbed by the plasma unknown

ENN Fusion Technology R&D Center （2021）

Founding time	Our people	Honor
Feb. 2018	Around 100 researchers with 40% holding PhD degree	Authorized as Hebei Key Laboratory of Compact Fusion

Cooperation, Contribution, Moving Fusion Energy R&D Forward

- **Promote an efficient and agile p-B fusion R&D effort，be a member of fusion community**
- **Learning by doing, drawing from expertise in fusion, high-energy particles, laser, materials**
- **Engage experts from schools, laboratories, industries, power companies, private enterprises**



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Institute of Modern Physics, Chinese Academy of Sciences

"Develop Fusion Energy, Benefit Mankind for Generations!"