SWIP Tokamak Programme and Collaborations

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Outline

- Status of HL-2A& HL-2M
- Collaborations on tokamak programs (HL-2A & HL-2M)
  - Diagnostics development
  - Experiments
  - Theory and modeling
- ITER Procurement in SWIP and Collaborations
- Collaboration opportunities

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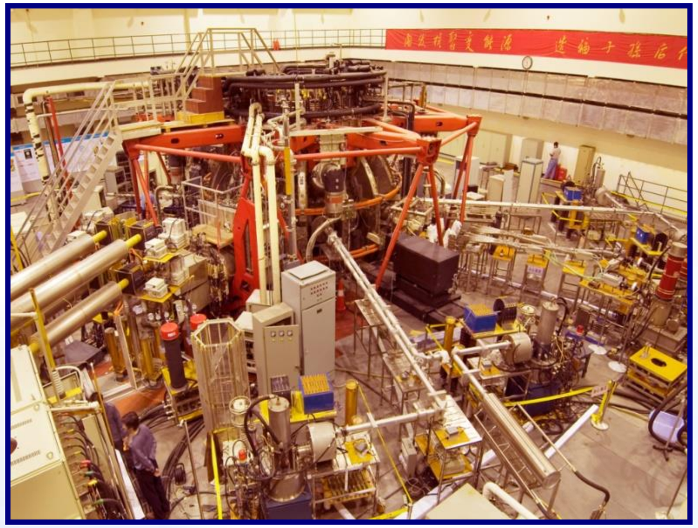
Status of HL-2A& HL-2M

CNNC China National Nuclear Corporation

HL-2A tokamak-status



- *R:* 1.65 m
- *a:* 0.40 m
- *Bt:* 1.2~2.7 T
- Beta_N: up to 3
- *Ip:* 150 ~ 480 kA
- *ne:* 1.0 ~ 6.0 x 10^{19} m^{-3}
- Limiter, LSN divertor

Auxiliary heating (10MW):

ECRH/ECCD: 5 MW

(6 X 68 GHz/500 kW/1 s,
2 X 140 GHz/1000 kW/1 s)

NBI (tangential): 3 MW

LHCD: 2 MW (4/3.7 GHz/500 kW/2 s)

Fueling system (H_2/D_2):

Gas puffing (LFS, HFS, divertor)
Pellet injection (LFS, HFS)
SMBI (LFS, HFS)
LFS: f =1~80 Hz, pulse duration > 0.5 ms
gas pressure < 3 MPa

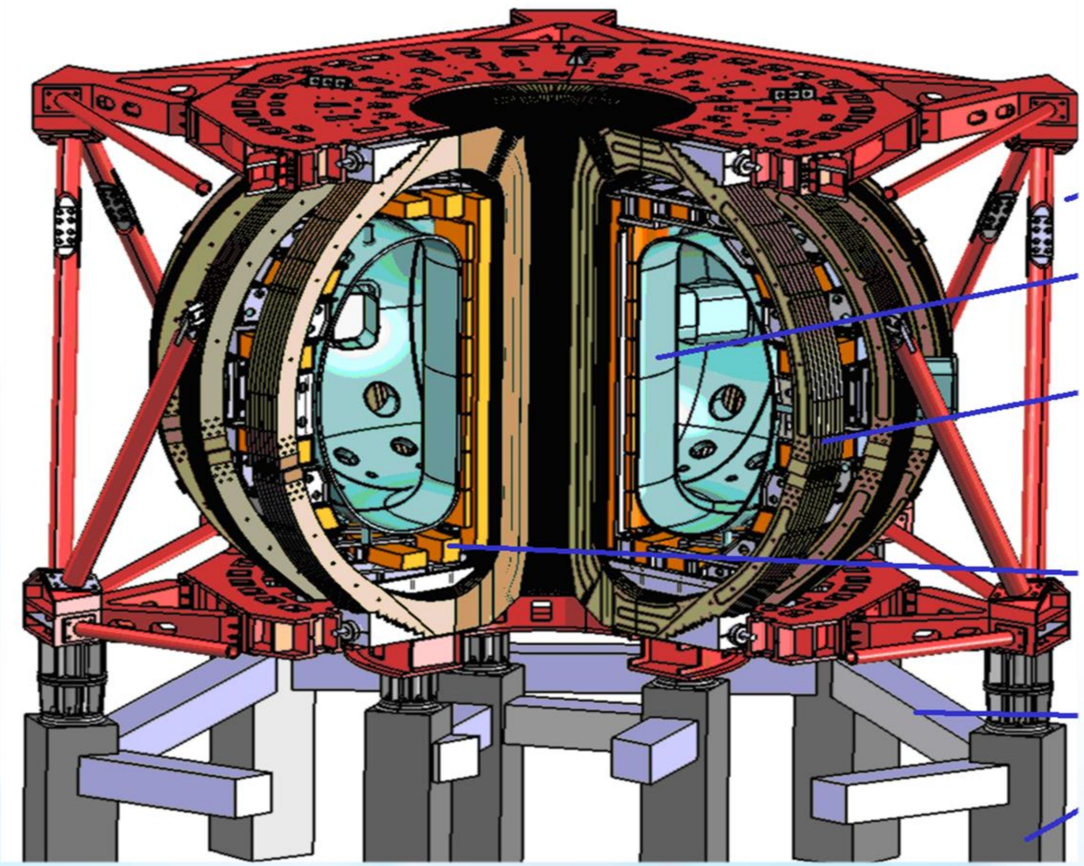
More than 30 physics diagnostics with good spatial-temporal resolution: CXRS, MSE, ECEI …

HL-2M tokamak-status

Mission: high performance, high beta, and high bootstrap current plasma; advanced divertor configuration (snowflake, tripod), PWI at high heat flux.

Main parameters

Plasma current	I_p = 2.5 (3) MA
Major radius	R = 1.78 m
Minor radius	a = 0.65 m
Aspect ratio	R/a = 2.8
Elongation	K = 1.8-2
Triangularity	δ > 0.5
Toroidal field	B_T = 2.2 (3) T
Flux swing	ΔΦ= 14Vs
Heating power	25 MW



HL-2M tokamak

Auxiliary Heating Systems & Diagnostics:

Total power ~ 25 MW

developed 2MW LHCD + 2 MW ECRH

under developing 5MW NBI + 2MW ECRH + 2MW LHCD

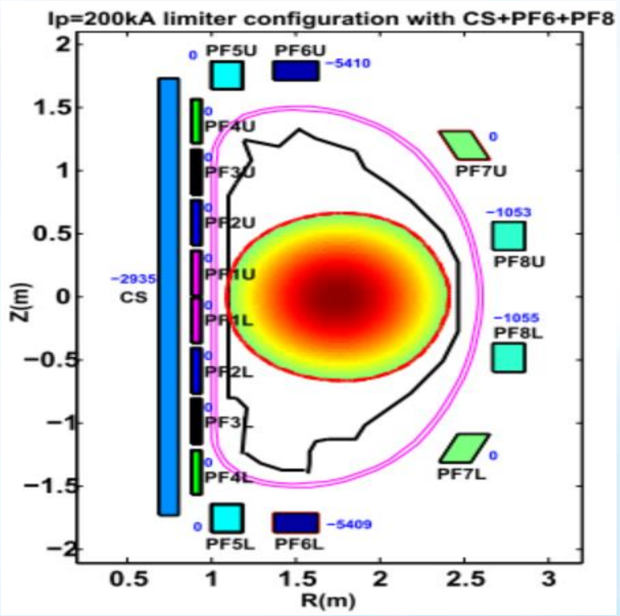
First plasma scenario development for HL-2M

- 3 people visited GA ,worked with **DIII-D control group** (Humphreys) for **plasma control and device operation** in 2016.

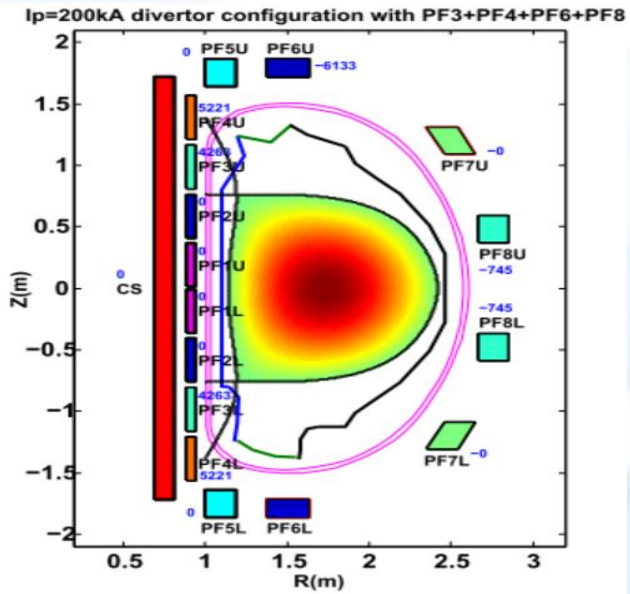
limiter (Case I) and divertor (Case II) plasma with Bt=1.4T, Ip= 200kA, k≈1, no VDE expected.

For sake of simplicity and safety, only small part of PF coils will be used, these scenario will lead to successful commissioning in first plasma campaign.

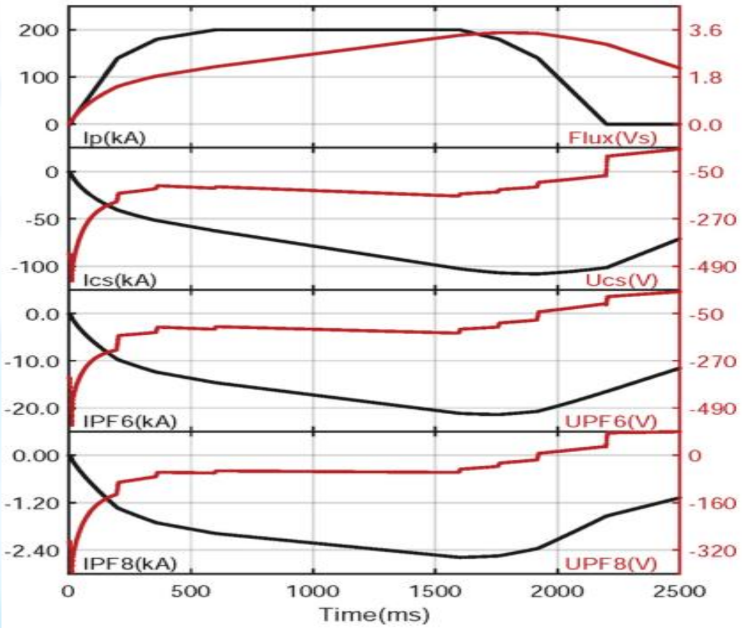
Case I: PF6+ PF8+CS



Case II:PF3+PF4+PF6+ PF8+CS

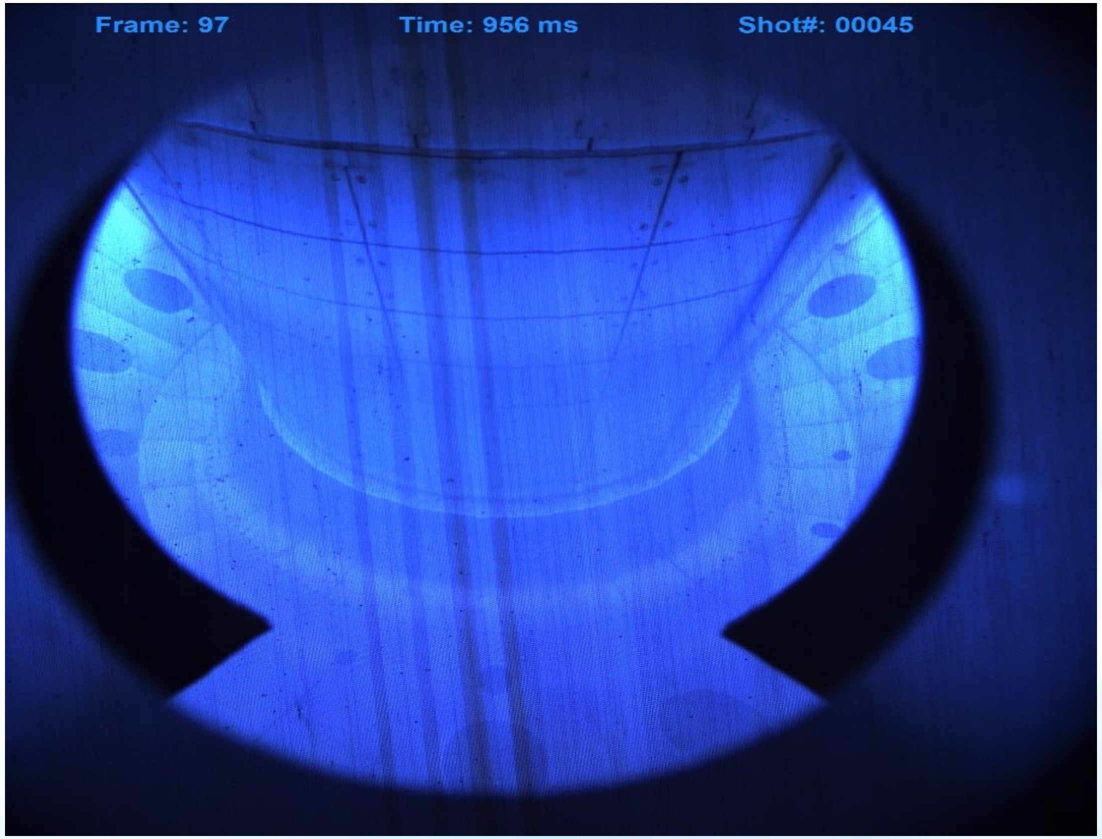


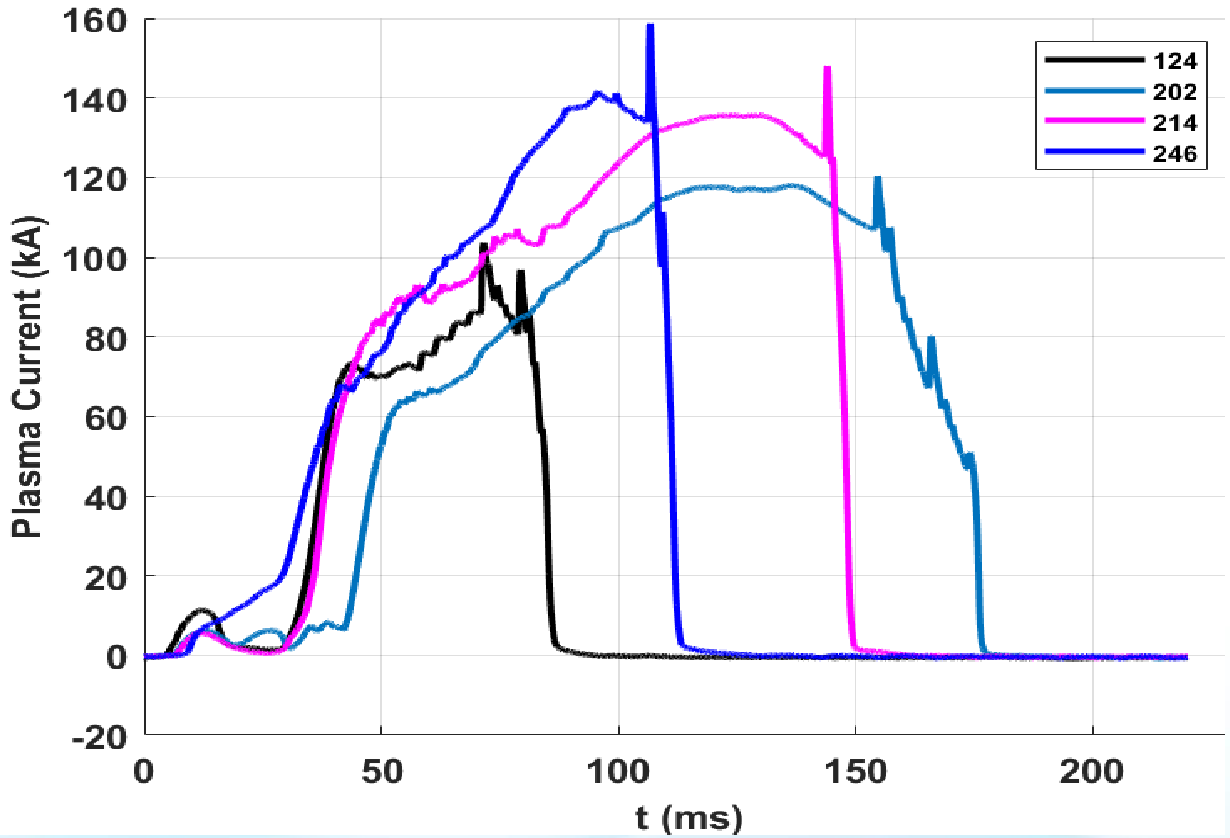
Voltage and current waveform(Case I)



Song, X. M., et.al., (2019). FED, 147, (2019), 111254.

HL-2M realized fist plasma discharge in Dec. 2020





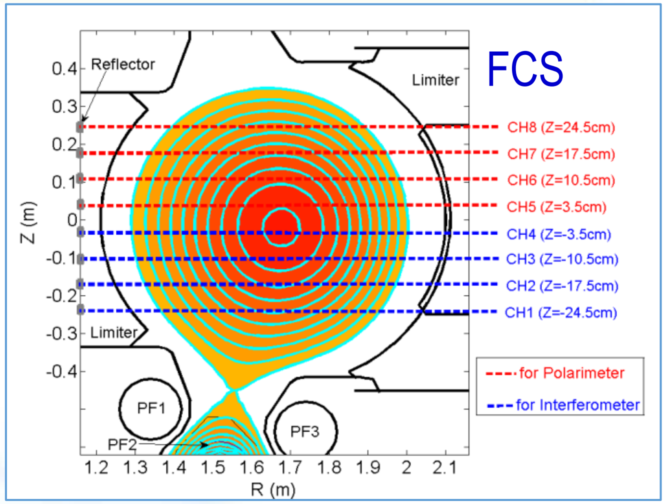
- Maxmum current: 140kA， pulse:180ms

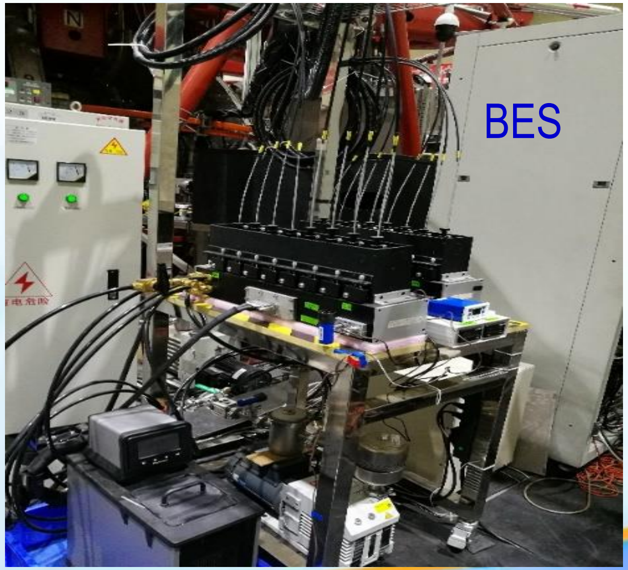
Collaborations on tokamak programs (HL-2A & HL-2M)

Diagnostics development

Summary of collaborations on diagnostics

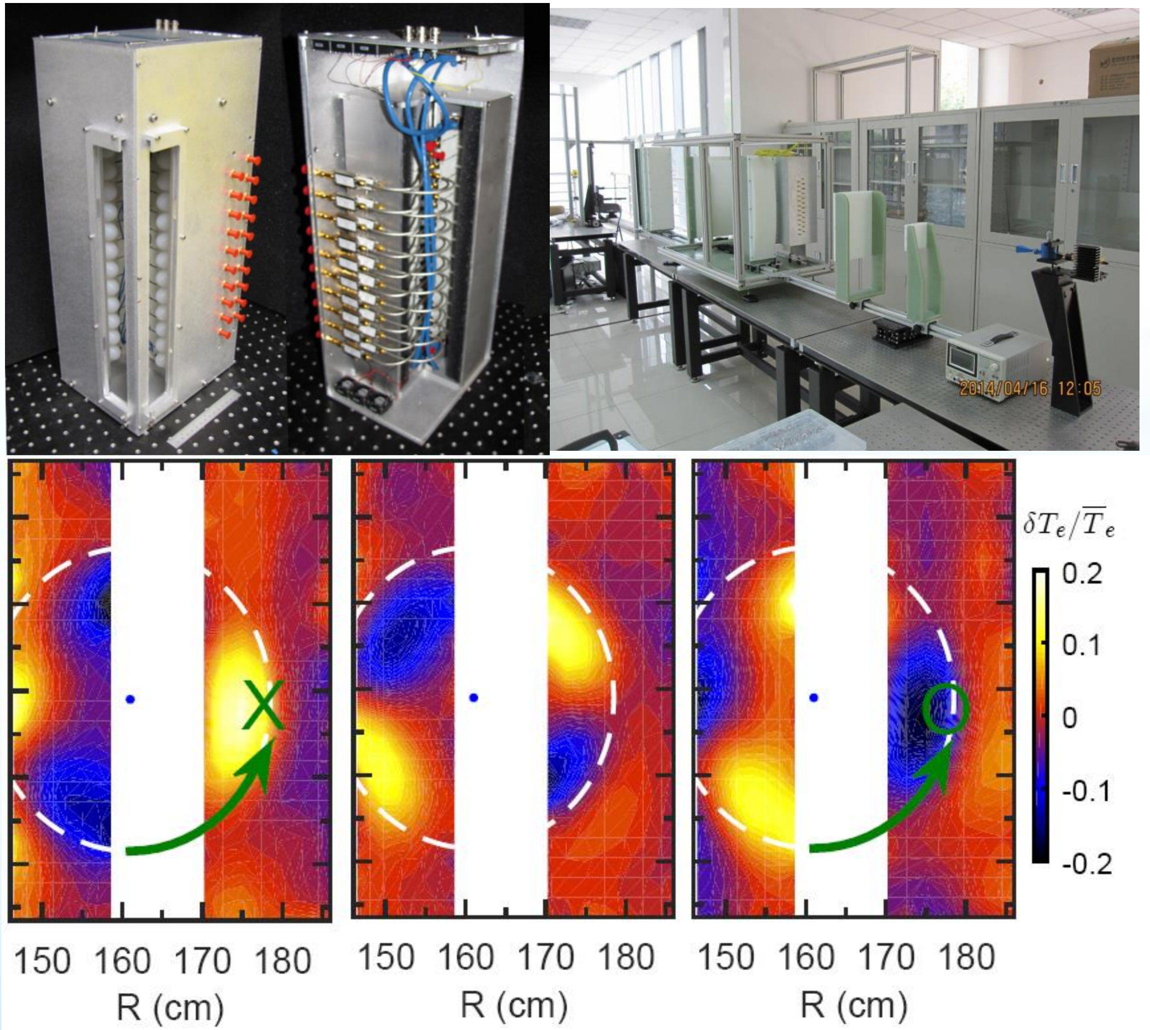
		Collaborators
Basic diagnostics	FIR laser Polarimeter-Interferometer improvements	Dr. W.X. Ding, UCLA, USA
	Far-forward Collective Scattering (FCS) diagnostic	Dr. W.X. Ding, UCLA, USA
Advanced diagnostics	Beam Emission Spectroscopy (BES)	Dr. George McKee, Dr. Z. Yan, UWM, USA.
	Electron cyclotron emission imaging (ECEI)	N. C. Luhmann, Jr. and Dr. Y. L. Zhu, UC Davis
	Phase Contrast Imaging (PCI)	Dr. J.C. Rost, MIT
	Gas Puff Imaging (GPI)	Dr. R.J Hong, UCSD, USA
	CO2 CTS diagnostic system	Dr. R.Y.,PPPL, USA
	Fast ion Dα diagnostic (FIDA),SSNPA	Prof. W. W. Heidbrink, , UCI, USA.





Electron Cyclotron Emission Imaging (ECEI)

(With **N. C. Luhmann, Jr. and Dr. Y. L. Zhu, UC Davis)**



- 2D imaging for electron temperature fluctuations
- Two 24 (vert.)x8 (rad.) arrays, LFS and HFS imaging simultaneously
- Work frequency: 60-90 GHz (Bt>1.3T)，75-140GHz (Bt>1.6T)
- View of field:53 cm in the vertical direction, and 35 cm in the radial direction.
- Wide zoom pattern (large scale MHD measurement) and narrow zoom pattern (fine structure measurement of small scale MHD, like ELMs)
- Resolution: 2.5 μs, 1-3 cm

Gas Puff Imaging (GPI)

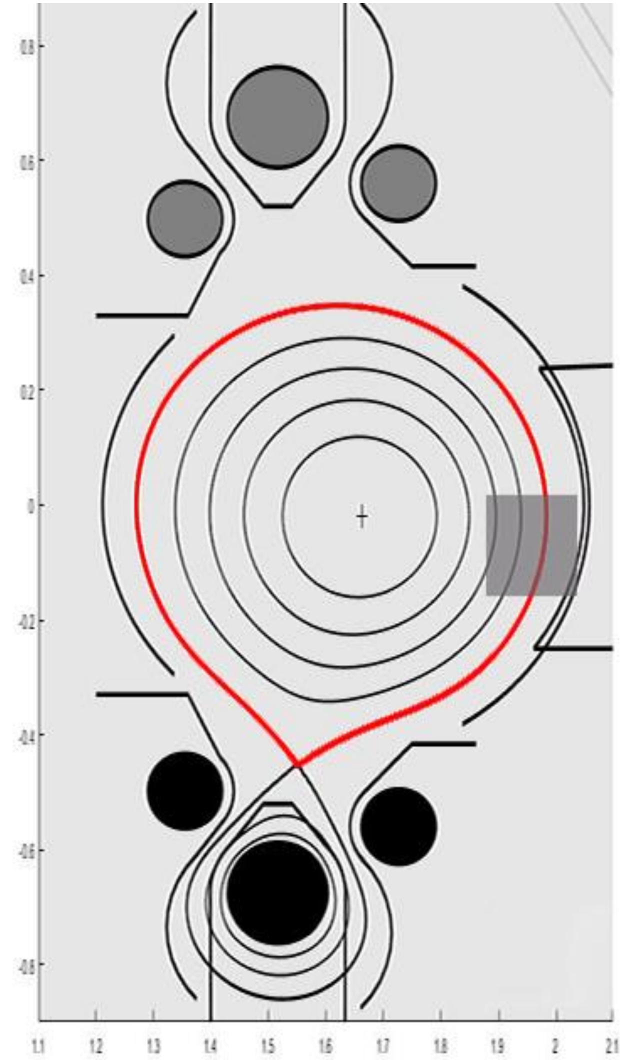
with Dr. R.J Hong, UCSD, USA.

View of field: 15 cm×15cm.

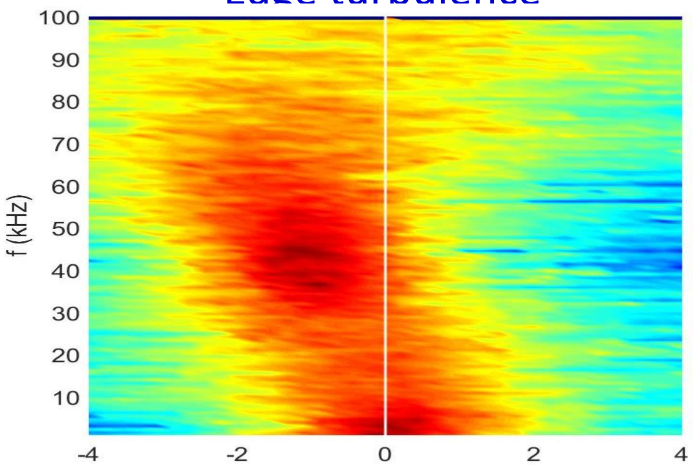
Measure: edge turbulence、blobs.

Resolution: 5-10 μs, 1.25 mm×1.25mm

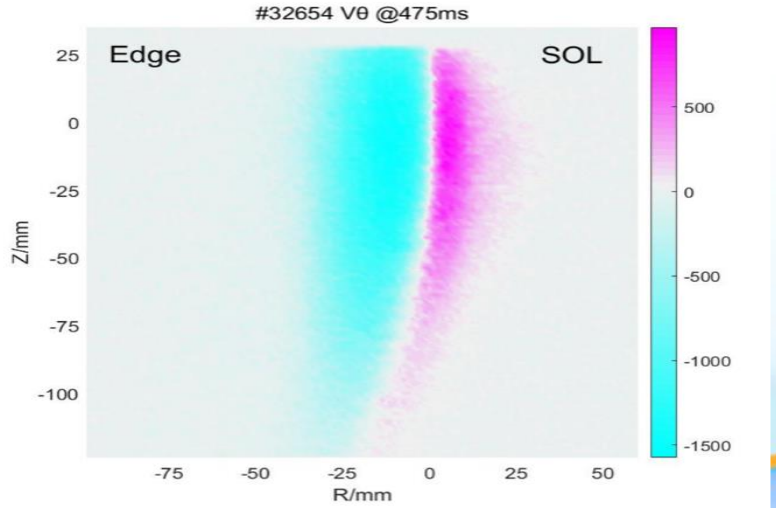
GPI installation in HL-2A



Edge turbulence

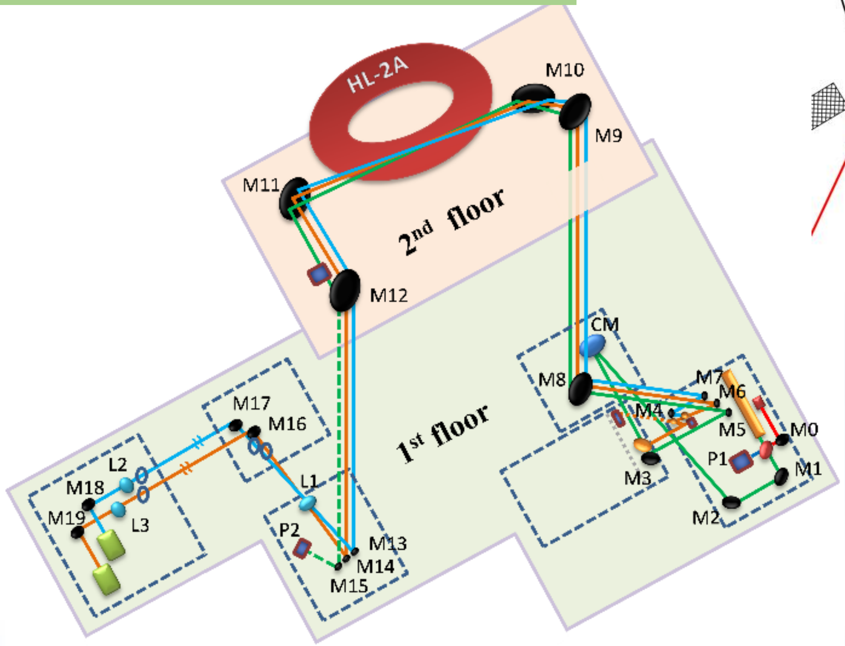


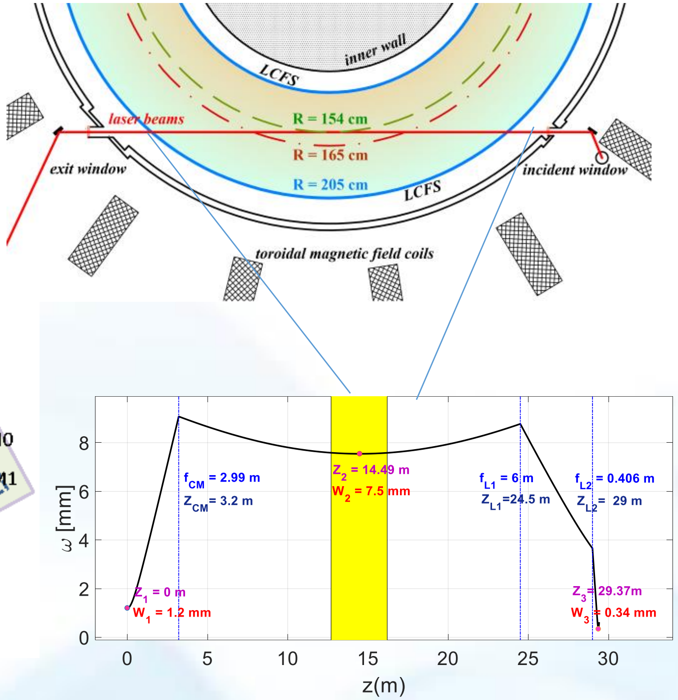
V_θ map calculated



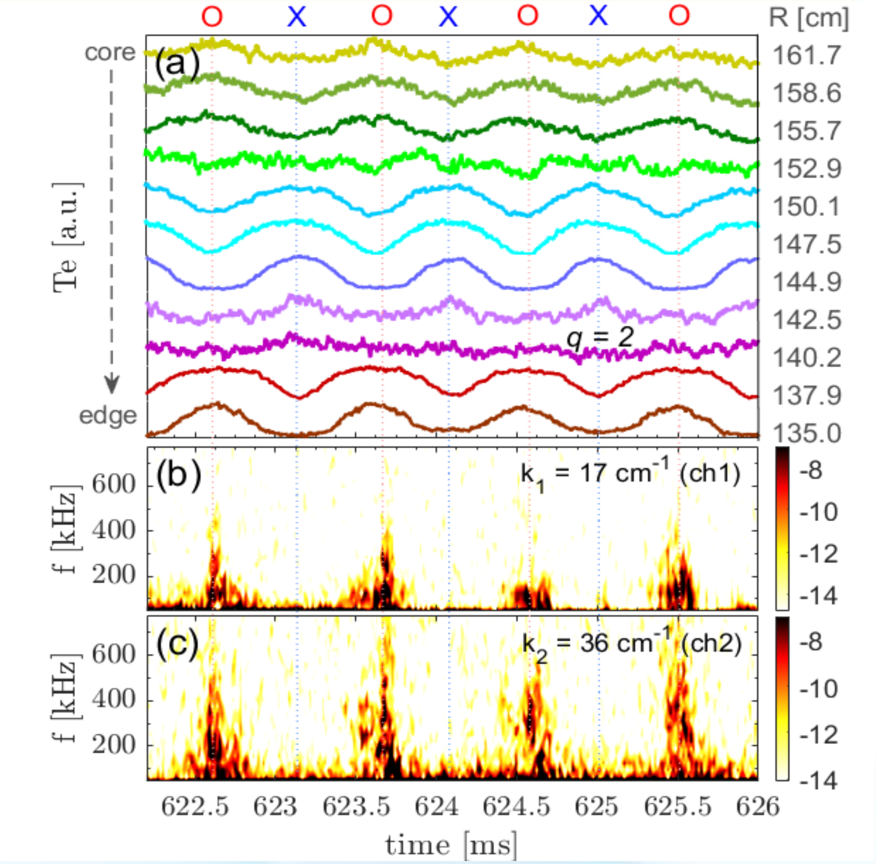
CO2 Collective Thomson Scattering (CTS)

(with Dr.Y. Ren, PPPL, USA.)





layout of the CO_2 CTS diagnostic system



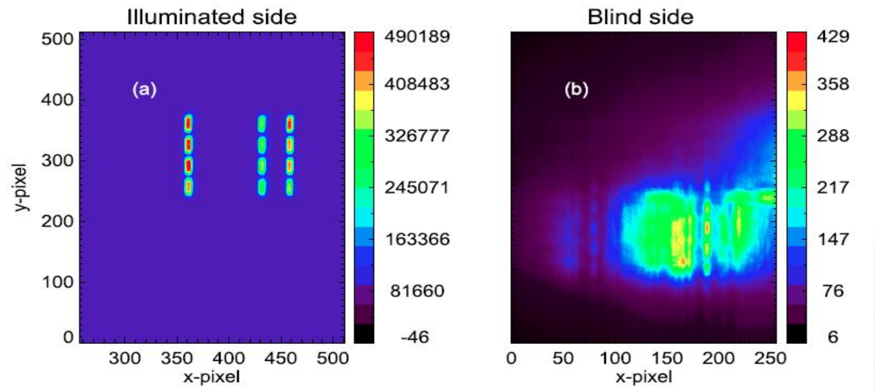
More collaborations are proposed, such as upgrade of the CO2 CTS system, role of short-scale turbulence on transport.

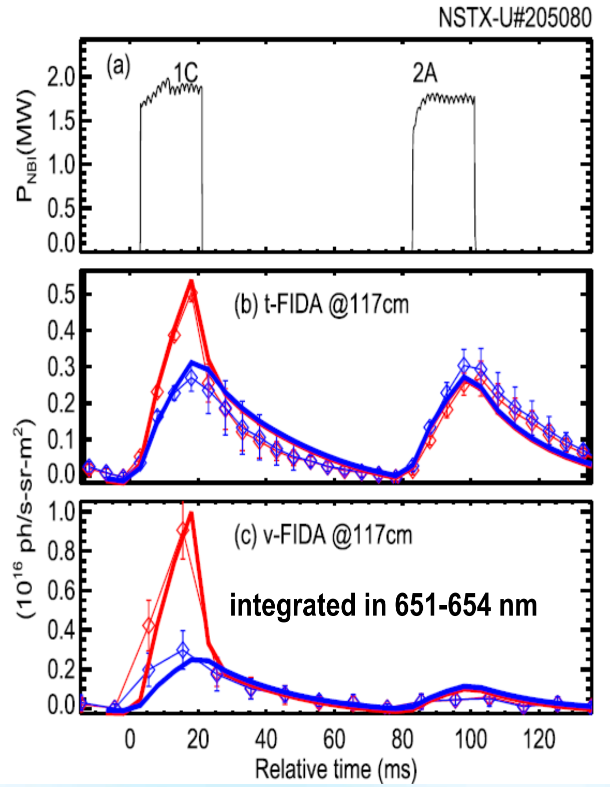
- Both the fluctuations of k = 17 cm^{-1} turbulence and the k = 36 cm^{-1} turbulence are suddenly enhanced at the O-point moments.

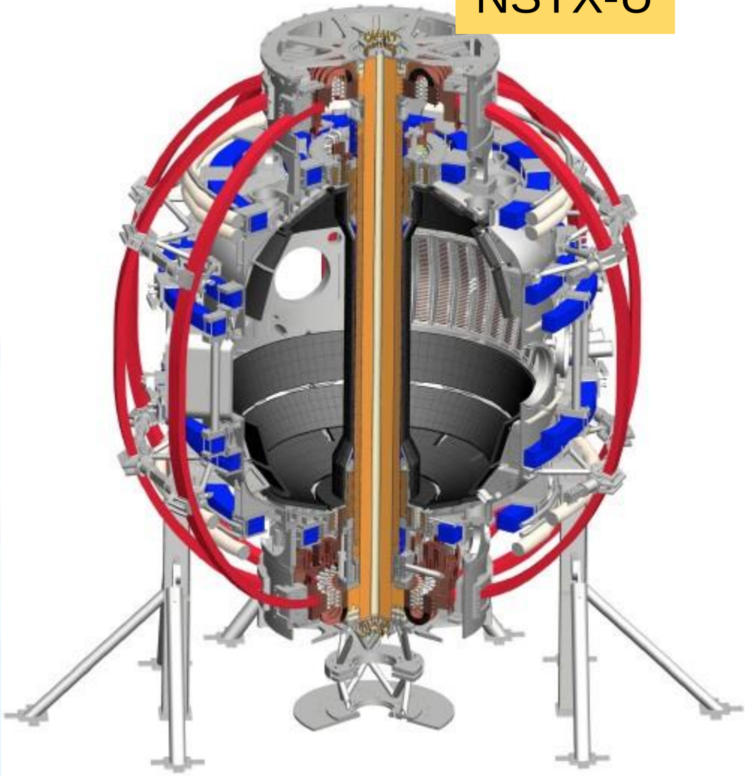
FIDA signals agree well with FIDASIM modelling

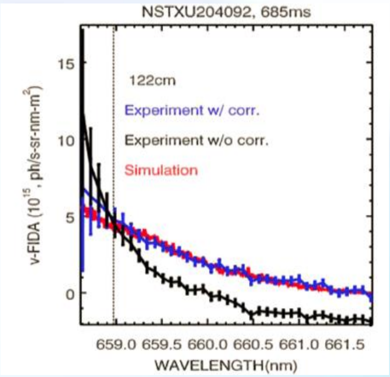
with Prof. W.W.Heidbrink (UCI), M.Podeta(PPPL)

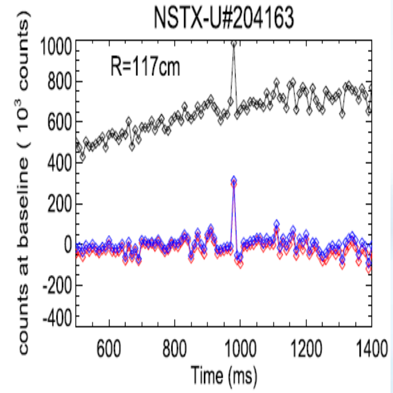
NSTX-U









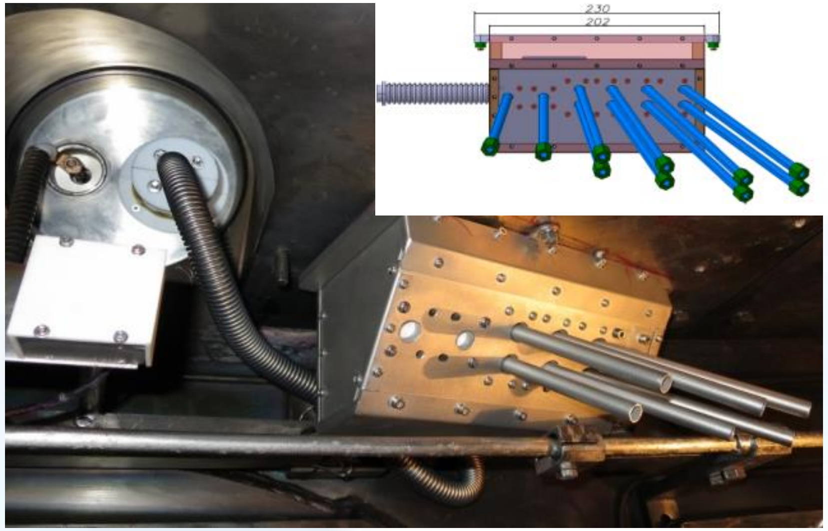


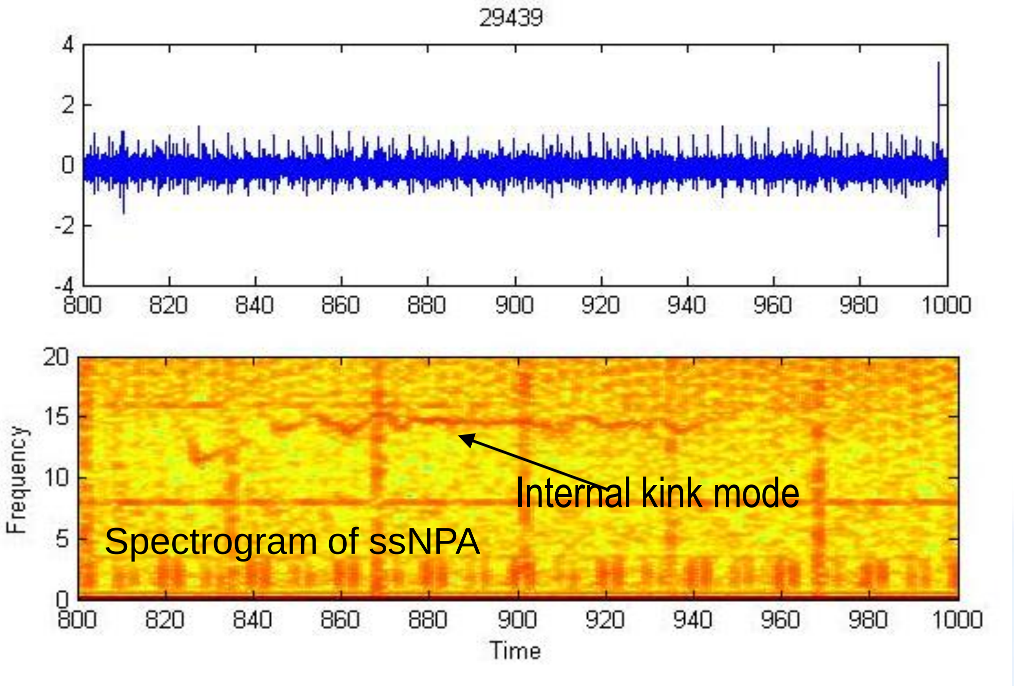
- P-FIDA light makes a relatively large contribution to the total FIDA signal in NSTX-U. The p-FIDA signal is detectable for fast ions in the edge region

G.Z.Hao, et al. PPCF,(2018)
G.Z.Hao, et al. RSI,(2018)

Solid-state Neutral Particle Analyzer (ssNPA)

with W.W. Heidbrink, UCI





A 6-channel ssNPA had been installed on HL-2A in2016, and rough data are obtained by ssNPA.

◆L.M. Yu et al., Investigation, Survey, Calculation and Rrimary Design of SSNPA for HL-2A/M Tokamak. GF-A0100062G, *internal report* 2015.
◆L.M. Yu et al., Design and Primary Data of ssNPA on HL-2A,*Western Nuclear Society*, 21st-24th, 9, 2016, Sichan.

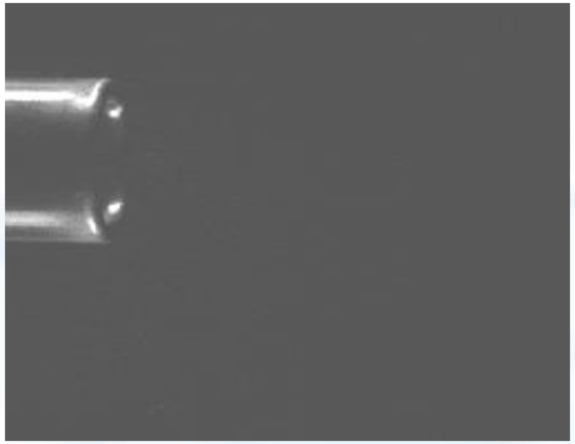
Development of shattered pellet injector on HL-2A

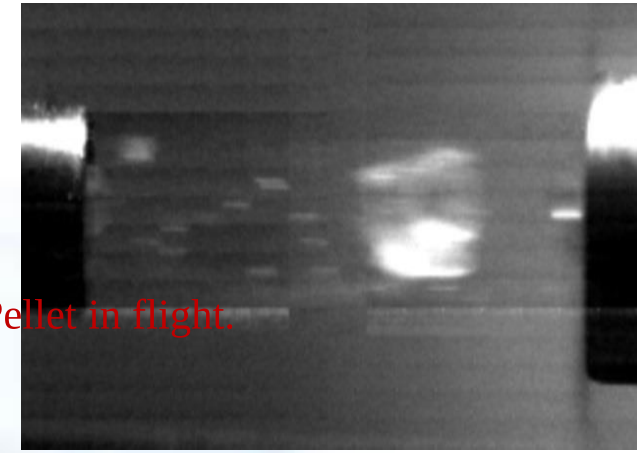
with Dr. Larry R. Baylor Fusion Energy Division ,Oak Ridge National Laboratory.

A shattered pellet injector (SPI) based on the in-suit technology has been developed for HL-2A with the cooperation of Southwestern Institute of Physics and Oak Ridge National Laboratory.

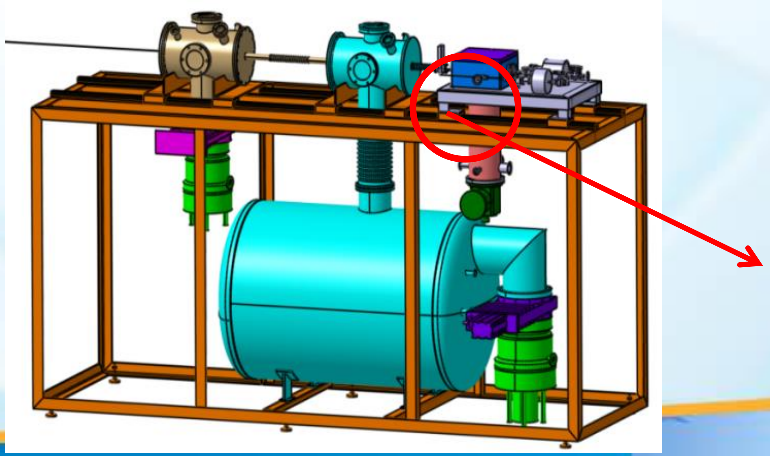
Technical characteristics of the HL-2A SPI

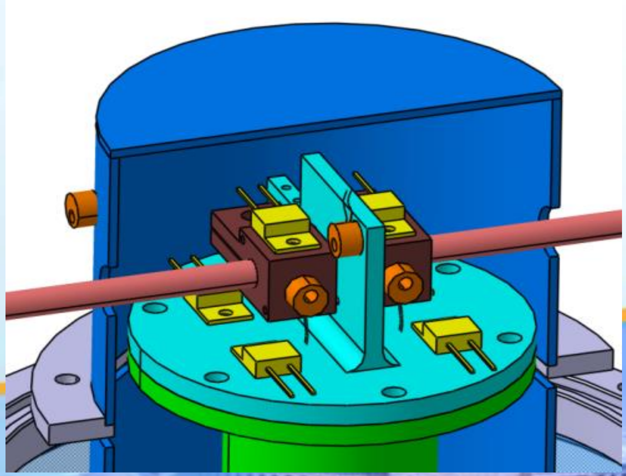
Pellet material	Ar and Ne	
Number of pellets in one injection cycle	1	
Pellet size	Diameter: d =3.5mm	Length L=4 mm
Pellet speed	Variable from 100 to 300 m/s	





Pellet in flight.





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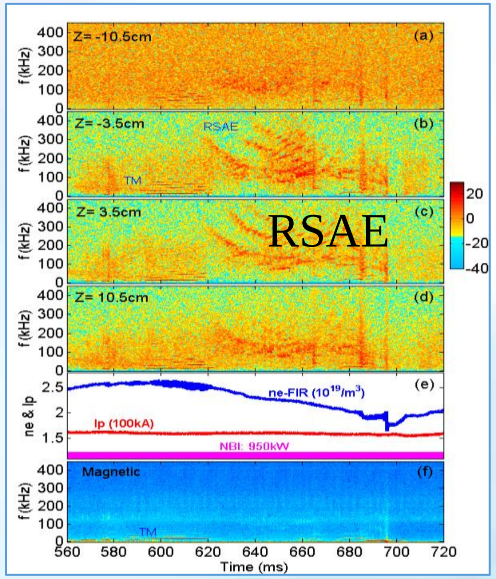
Far-forward Collective Scattering (FCS) & Beam emission system (BES)

FCS (with Dr. W.X. Ding, UCLA, USA.)

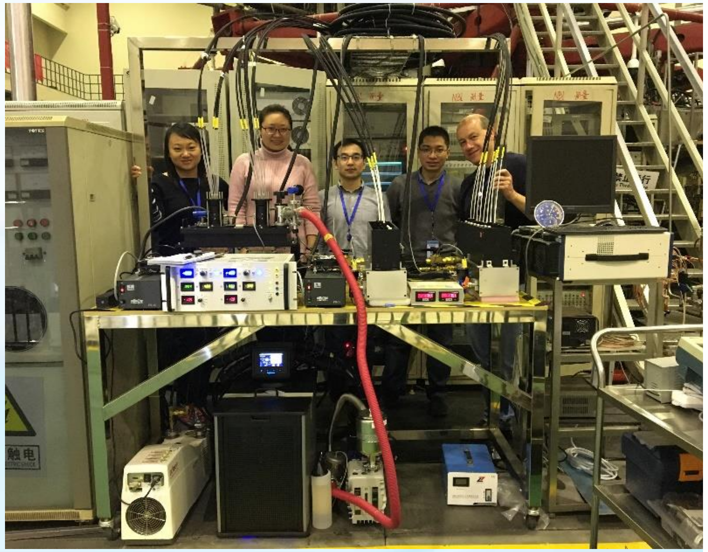
An eight-channel Far-forward Collective Scattering (**FCS**) diagnostic has been successfully developed from the formic-acid (HCOOH, λ=432.5μm) laser Polarimeter and Interferometer on HL-2A tokamak, measuring the electron density fluctuations ($k<1.6cm^{-1}$).

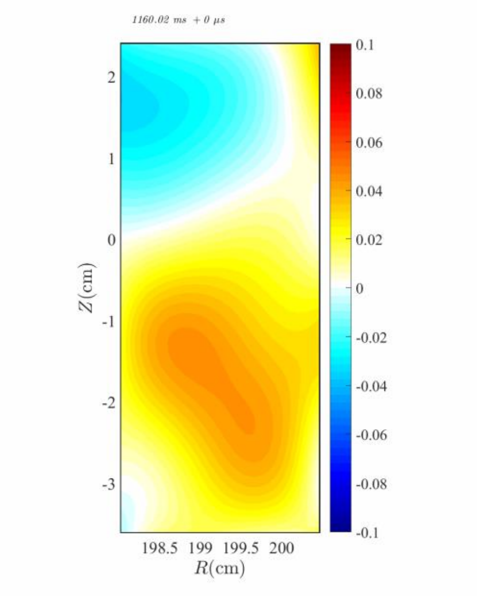


Figures: RASE perturbations measured by FCS diagnostic on HL-2A.

BES, (with Dr. George McKee, Dr. Z. Yan, UWM, USA.)

- 48 channels (2×24 array) are available. Covering r/a = 0.43~1.03.
- Spatial resolution: Δr = 0.7 (edge) ~ 1.2 (core) cm, ΔZ = 1.2 cm;
- Temporal resolution: Δt = 0.5 μs (2 M/s).
- Flexible configuration by rearranging fiber bundles on the fiber mount.

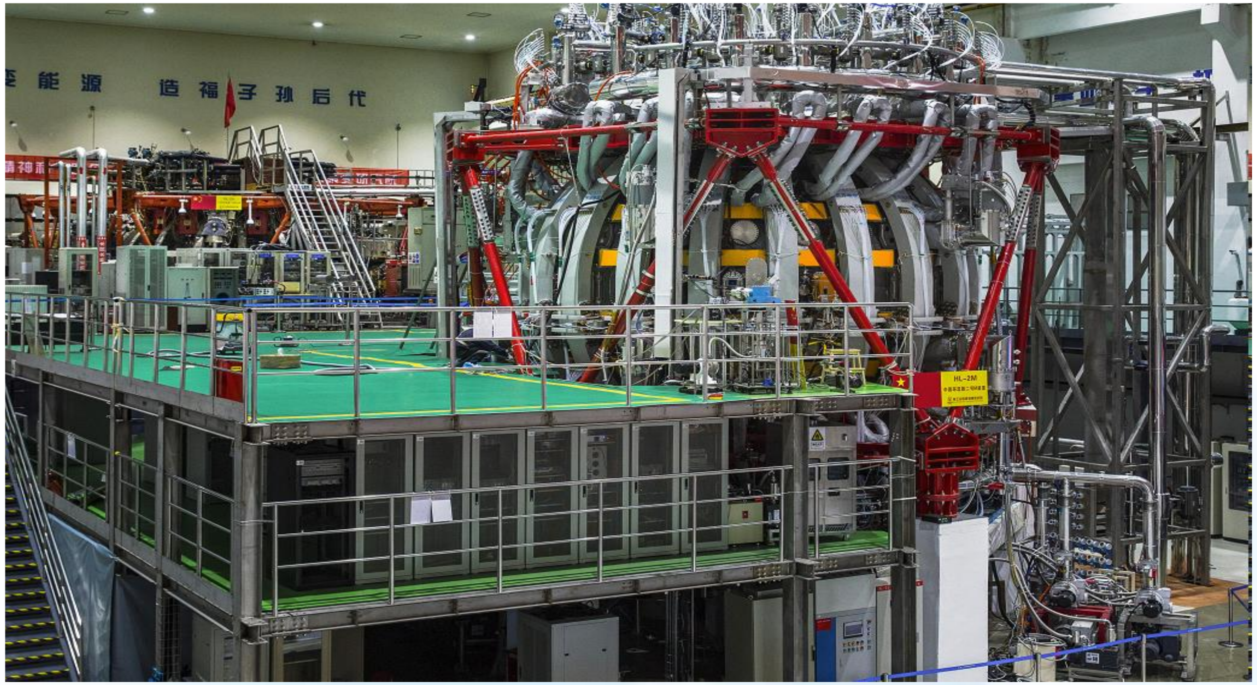




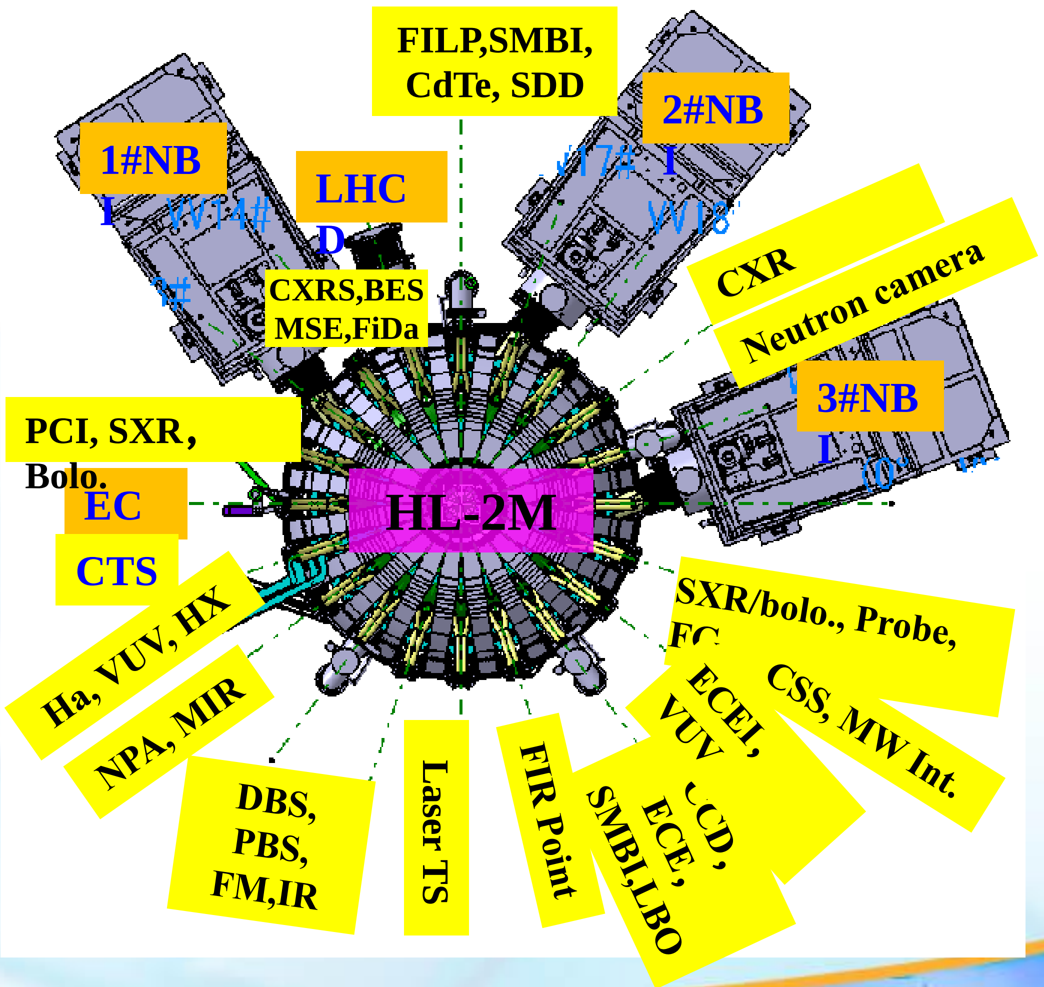
Y.G. Li et.al,, ***Rev. Sci. Instrum***, 90(5): 053502, (**2019**).
Journal of Instrumentation, 14: C120202, (**2019**) .

Collaboration opportunity on HL-2M diagnostic developement

HL-2M commissioned on Dec.4,2020



Five-year plan of HL-2M diagnostics development



■Magnetic diagnostic systems
— 400 channels: Integrator, filter ciruits,...
—800 detectors: magnetic probe, flux loop, Rogowski coils,...
■density and temperature profile: POINT(15ch) ,Thomson (100ch)
■Current profie: MSE (11ch), FIR POINT(15ch)...
■turbulence and plasma rotation: CXRS (64h), BES (64 ch), ECEI (384ch) ...
■Energetic particles : SLIP, FIDA, Neutron camera(10ch)...
....

Collaborations on tokamak programs (HL-2A & HL-2M)

Experiments

Highlights of collaborations on the HL-2A experiments

Topics	Achievements	Collaborators
Turbulence &Transport	L. Wang et al Phys. Plasmas 26 (2019) 092303, W. Liu et al Phys. Plasmas 28(2021) 012512 L. Nie et al NF 58 (2018) 036021 R. Hong et al NF 58 (2017) 016041	Prof. George Tynan, UCSD, USA
	T. Long et al 2019 Nucl. Fusion 59 106010 D. Guo et al. Nucl. Fusion 58 (2018) 026015	Prof. Patrick. H. Diamond, UCSD, USA
	61st APS-DPP meeting	Dr. George McKee, UW-Madison, USA
MHD related physics	N. Wu et al, POP 25 102505(2018)	Prof. X Q Xu, LLNL, USA
	Dong Li et al Nucl. Fusion 60 (2020) 076005, T. F. Sun et al Nucl. Fusion 61 (2021) 036020 T. F. Sun, et al. FED, 148, (2019), 111301	Prof. Yueqiang Liu, GA

MHD physics: ELM control by vertical swing plasmas

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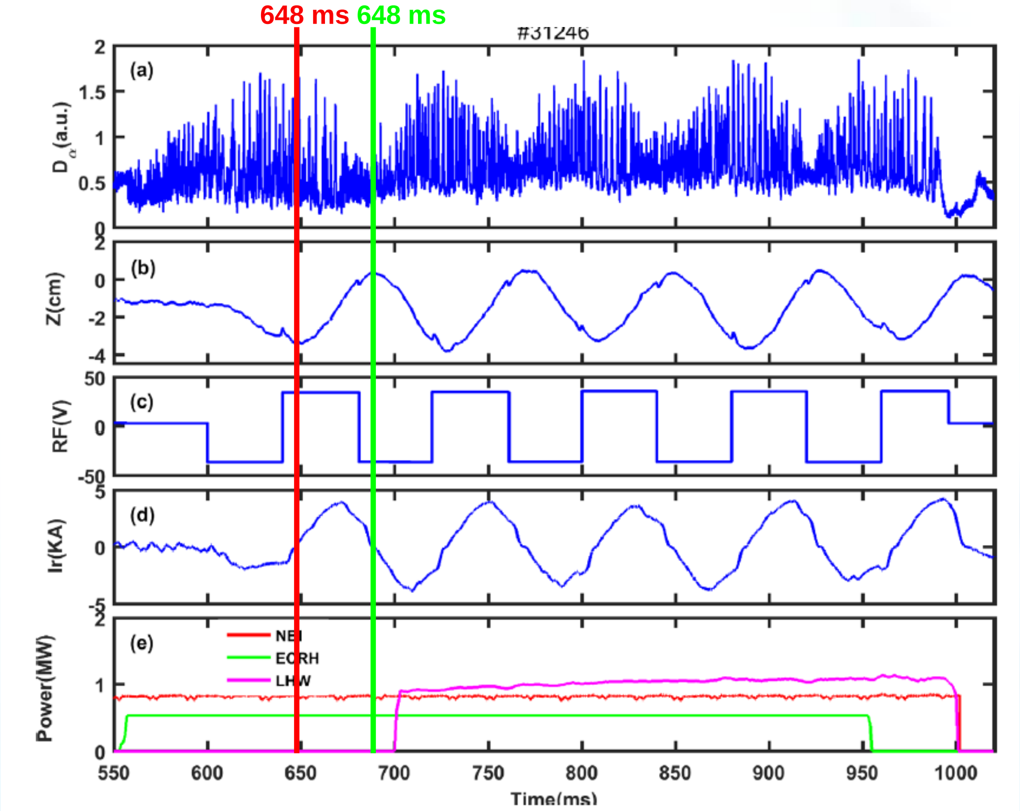
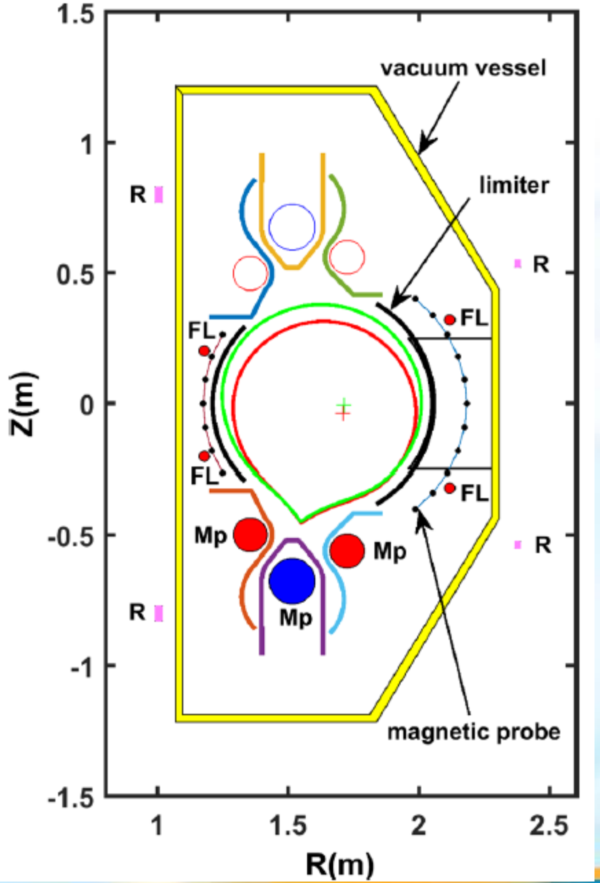
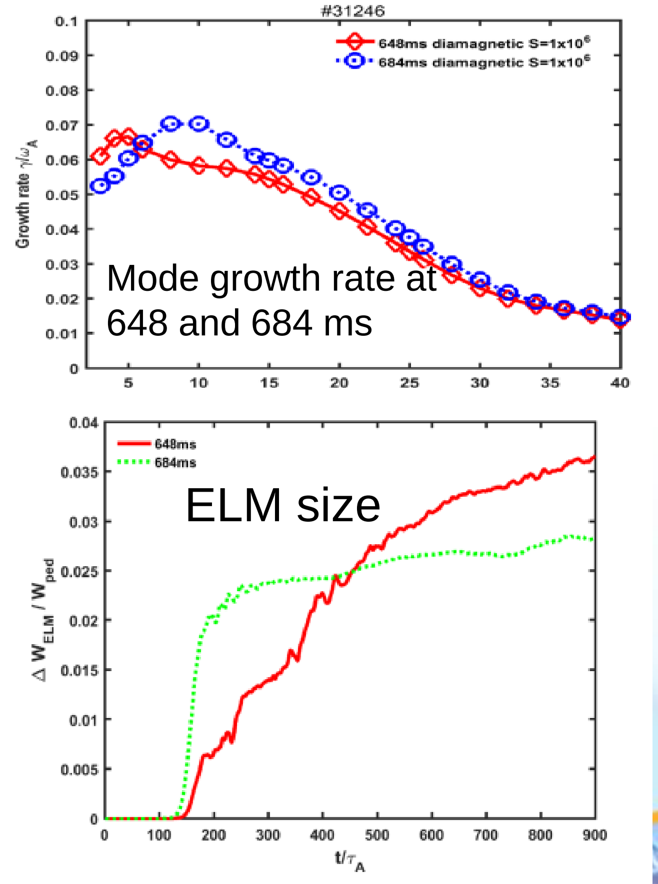
with **Prof. X Q Xu, LLNL**

- The weak ion diamagnetic effect induces the ELM mitigation during vertical swing of plasmas
- BOUT++ simulation results supporting HL-2A experiments



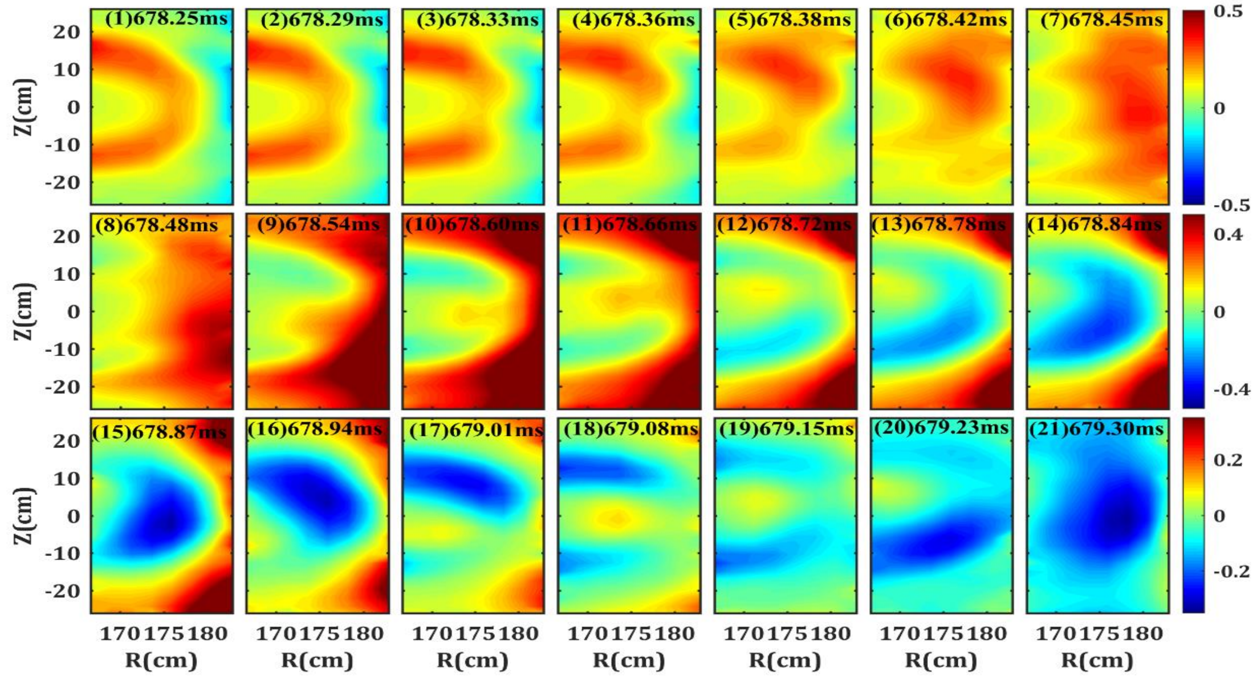


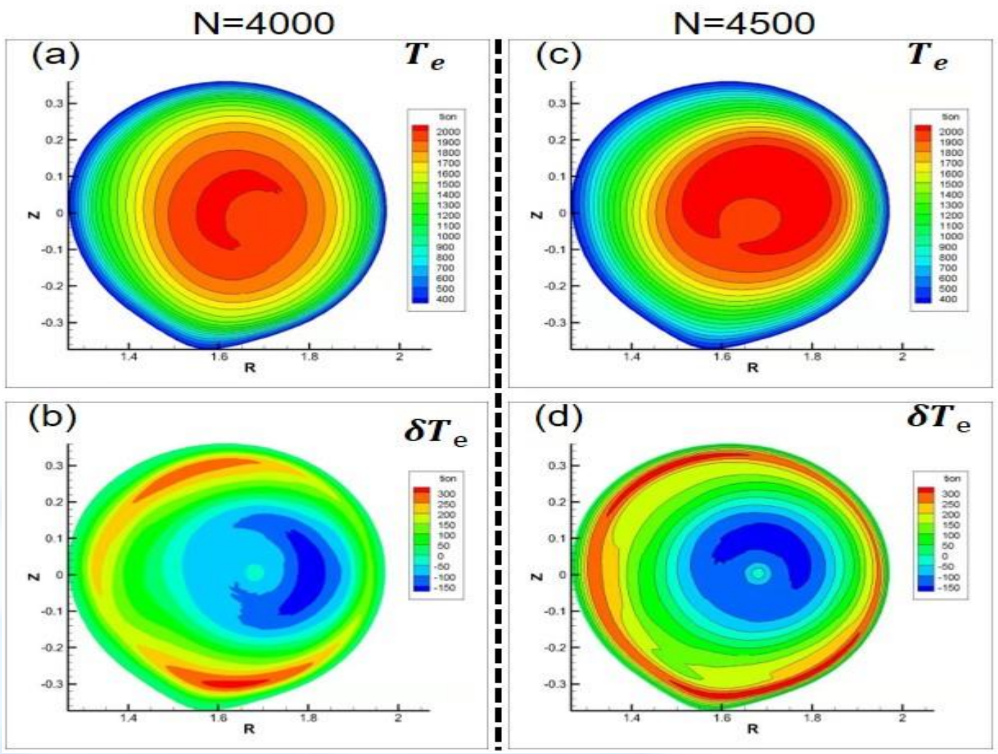


N. Wu et al, POP 25 102505(2018)

MHD physics: evolution of quasi-interchange mode

(With **Dr. Y. L. Zhu, UC Davis)**





Experimental observations given by ECEI:

- Formation(frame 8-14): colder core temperature fluctuation distorts to a crescent shape while a hot bubble becomes bigger gradually and draws into concave side of the crescent.
- Evolution(frame 15-21): the mode propagates in electron diamagnetic drift direction with m=1

Simulation given by NIMROD

- 2D structure of T_e show a hot crescent and a cold bubble, consistent with physics picture of Q-I model given by theory;
- 2D temperature perturbation is in agreement with ECEI results.

P. W. Shi, Phys. Plasmas (2018)

MHD physics: MHD control and modulation on turbulence

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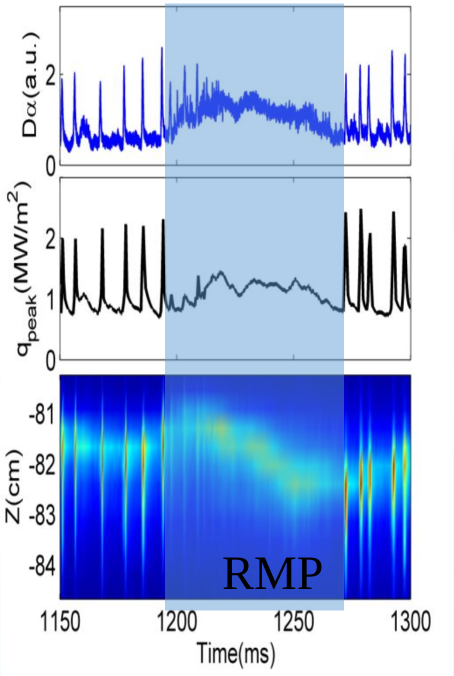
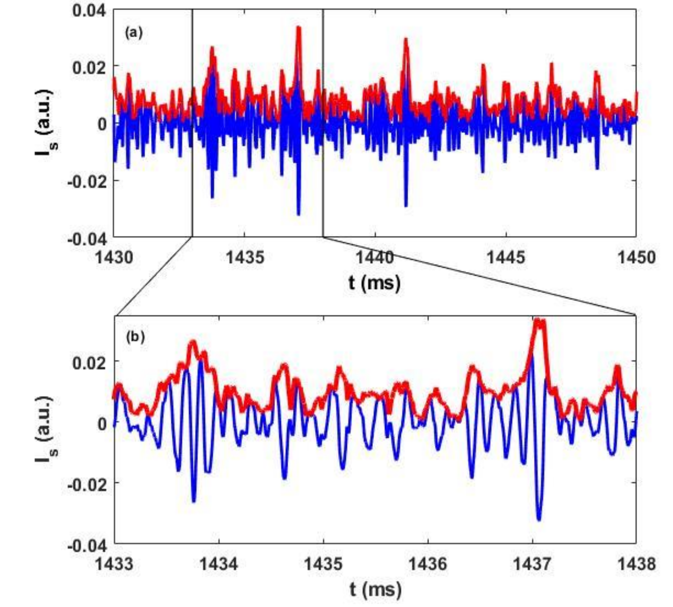
(with **Prof. Y.Q. Liu, GA, USA)**

- Suppression of Type I ELM with RMP



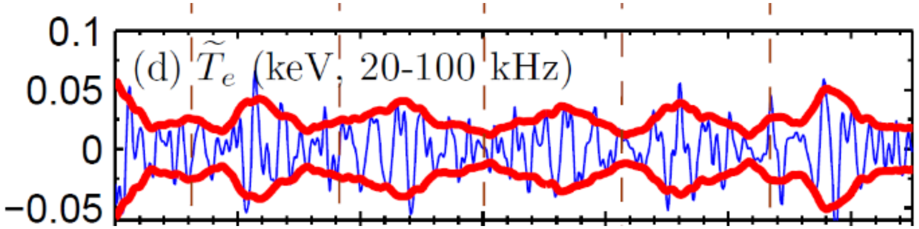


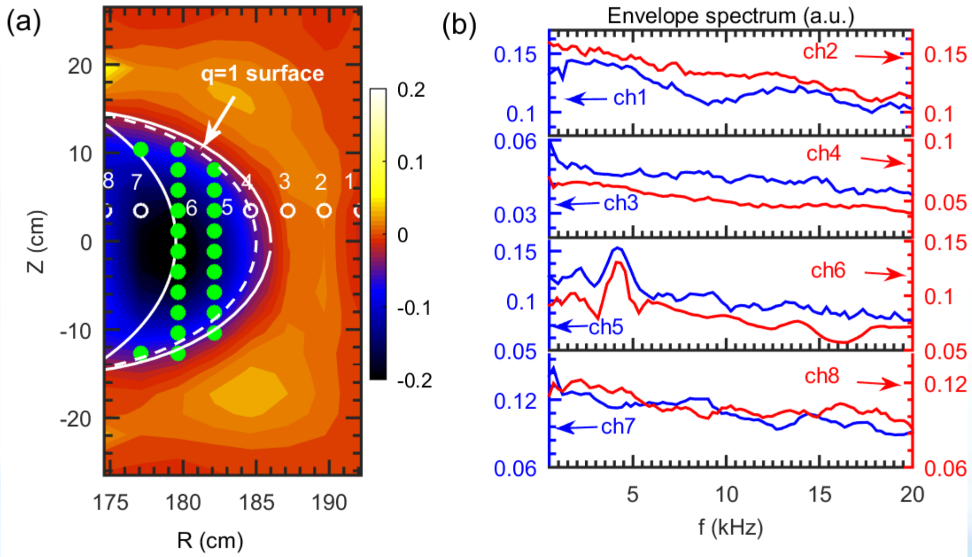
- The edge coherent mode induces the continuous particle transport across the pedestal during the mitigation of ELM.

T. F. Sun et al Nucl. Fusion 61 (2021) 036020, FED,148 (2019)，111301

(With **N. C. Luhmann, Jr. and Dr. Y. L. Zhu, UC Davis)**

- Modulation of Te fluctuations by TM



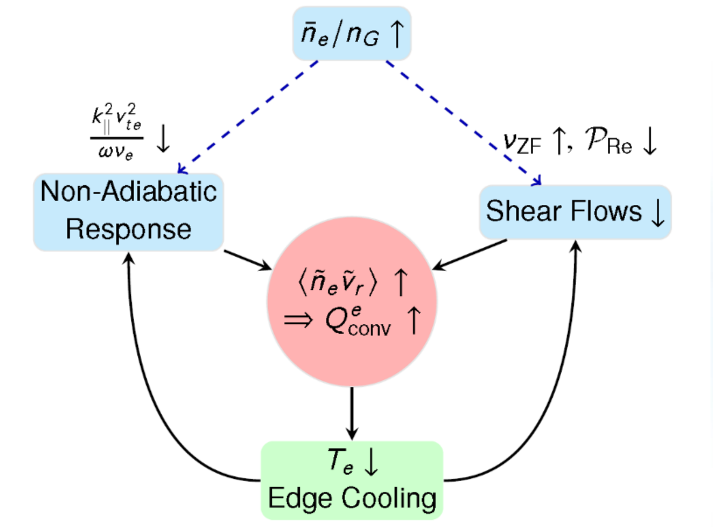


- Modulation only occurs inside the TM island, due to the drastic change ot Te gradient between X-point and O-point.

M. Jiang, Nucl. Fusion (2019)

Turbulence & Transport

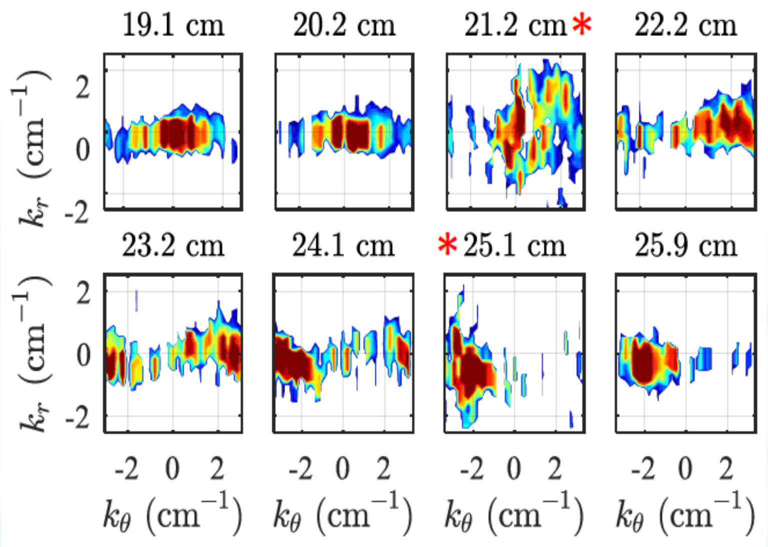
(With **Prof.** George Tynan**, UCSD**）



turbulent particle transport increases + shearing rate of the mean poloidal flow drops

onset of MHD instabilities that limit plasma density

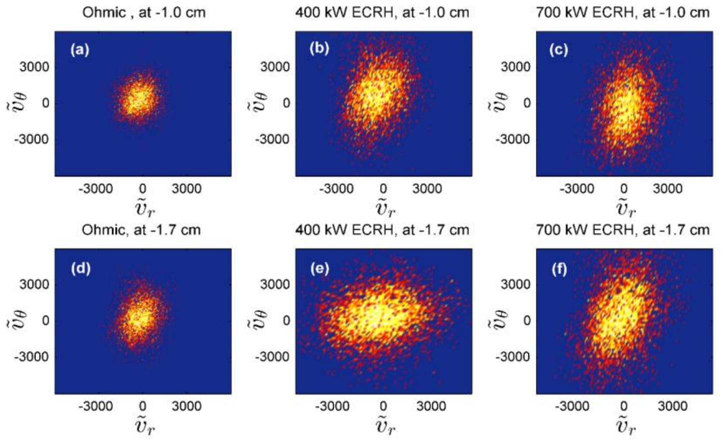
(With **Prof.** George Tynan**, UCSD,**）



k_r/k_θ from BES data

Found the vidence of ExB staircase on HL-2A

(With **Prof. P. H. Diamond, UCSD)**



ECRH power → spectral symmetry breaking →the intrinsic poloidal flow.

R. Hong et al NF 58 (2018) 016041

W. Liu et al PoP 28 (2021) 012512

T. Long et al NF 59(2019)106010

Collaborations on tokamak programs (HL-2A & HL-2M)

Theory and modeling

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Highlights of collaborations on theory & modelling

Topics	Achievements	Collaborators
Scientists training	1st Chengdu Theory Festival Joint PhD >5(T.Long, R.Ke, B.D.Yuan, Y.F. Wu, Q.H.Yan,…..)	Prof. Patrick. H. Diamond, UCSD, USA
Turbulence physics	Qinghao Yan and P H Diamond, to be submitted,	Prof. Patrick. H. Diamond, UCSD, USA
	M.K.Han, 2021, Nucl. Fusion (accepted)	Prof. Horton, Univ. of Texas, Austin
MHD	G.Q. Dong, et al, NF 59 (2019) 066011 G.Q. Dong et al, PoP,24, 112510 (2017) G.Q. Dong, et al,2021, NF (accepted) W. Xie, et al., AIP-Advances, in press Xue Bai, PoP, 2020, 27(12): 124502. Xue Bai, PoP 2020, 27(7): 072502. Xue Bai, PoP, 2018, 25(9): 090701. Xue Bai, PoP, 2017, 24(10): 102505. N. Zhang,, et al., PoP, 24, 063006(2017) N. Zhang,, *et al*., PoP, 25, 092502 (2018) N. Zhang,, *et al*., NF, 60, 096006 (2020) N. Zhang,, *et al*., NF, (2021), in press	Prof. Yueqiang Liu, GA,USA
Divertor physics	Houyang Guo et al. NF, 59 (2019) 086054 H.L. Du, H.Y. Guo, et al. NF, 60 (2020) 126030	Prof. H.Y. Guo, GA,USA
Integrated modelling	Design of HL-2M discharge scenarios	Prof. Orso Meneghini, GA, USA
	Integrated simulation of ELM and transport	Prof. X. Q. Xu, LLNL, USA

The 1st Chengdu Theory Festival (August 20-31, 2018, China)

Leading by **Prof. P. H. Diamond, UCSD, USA**

Lecturers includes: **Prof. P. H. Diamond, UCSD; Prof. G. Tynan, UCSD; Dr. W. X. Wang, PPPL; Dr. X. Q. Xu, LLNL**

Scientific Organizing Committee
Patrick H. Diamond (Chairman, UCSD); Xuru Duan (SWIP); Min Xu (SWIP); Zhibin Guo (PKU); Lu Wang (HUST)

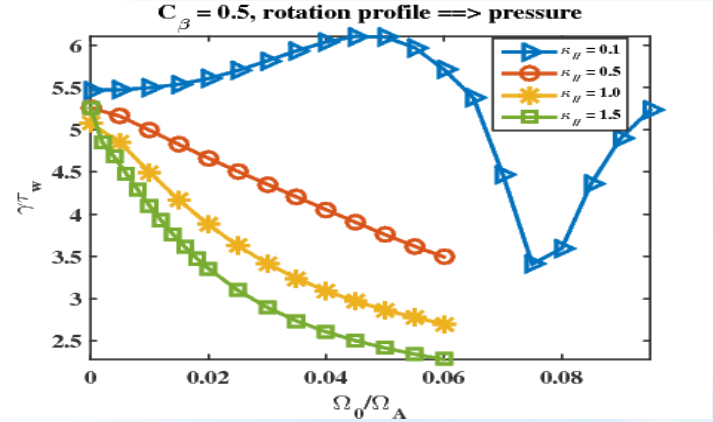
Local Organizing Committee
Xuru Duan (Chairman, SWIP); Min Xu (SWIP); Jiquan Li (SWIP); Ting Long (SWIP); Shaobo Gong (SWIP); Qinghao Yan (SWIP); Ruirui Ma (SWIP); Yang Li (SWIP); Wei Che (SWIP); Guangzhou Hao (SWIP); Zhanhui Wang (SWIP); Xuping Xiao (SWIP); Chen Lin (SWIP); Rui Zhang (SWIP)

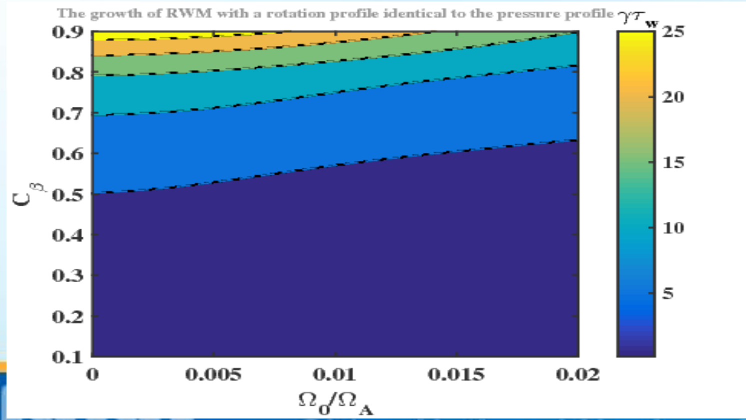
- Aiming to promote advanced research dialogue and education at the cutting edge of research in theoretical fusion plasma physics and related fields. Young scientists, postdocs and PhD students were in contact with leading researchers worldwide, in a collaborative and informal environment in which new ideas were discussed in depth.

MHD instabilities

with Prof. Y.Q. Liu, GA, USA

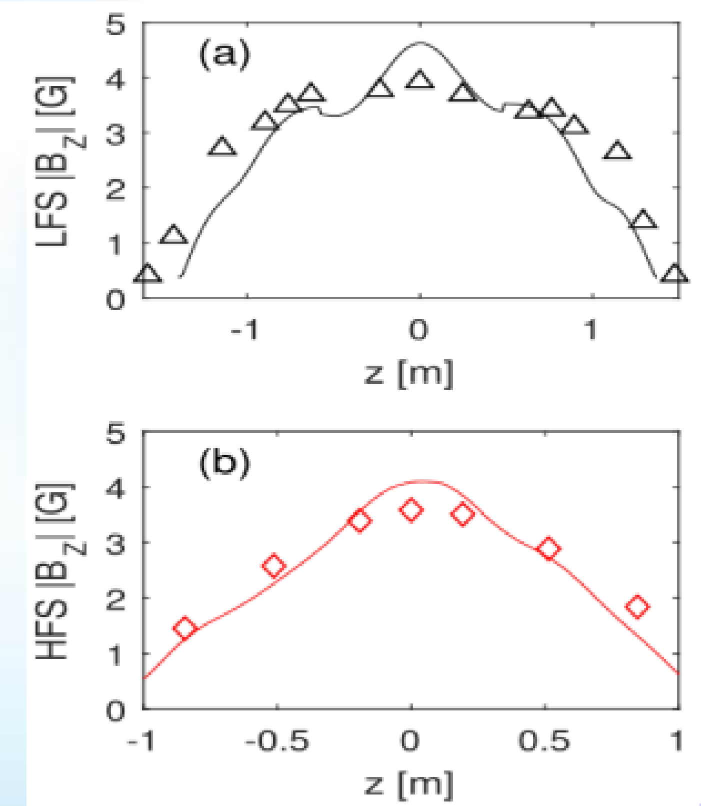
- **Resistive wall mode can be stabilized rotation, with stong parallel damping. (CFETR)**





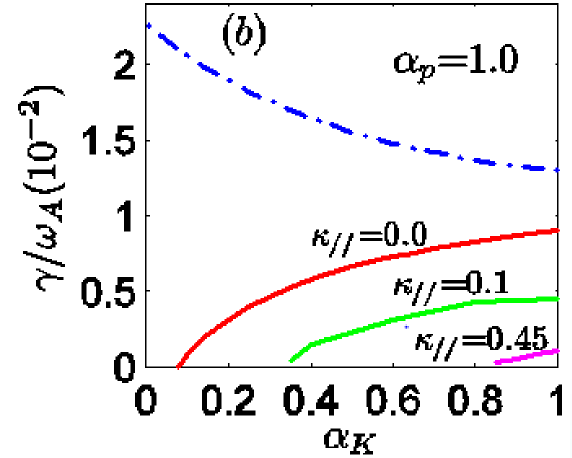
- **Modelling results support the EHO experiments on DIII-D**

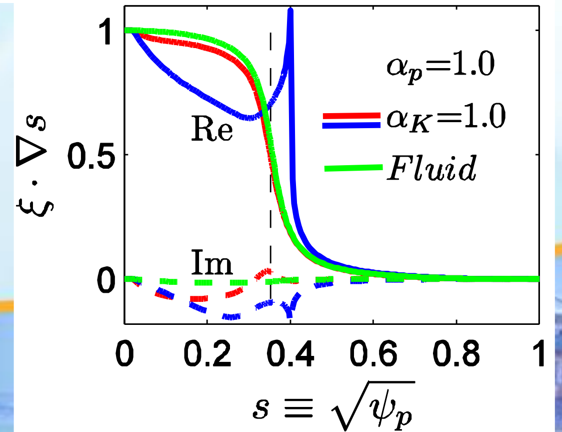
G.Q. Dong et al, PoP,24, 112510 (2017)
G.Q. Dong, et al,2021, NF (accepted)



- **Fishbone like mode driven by trapped thermal ions**

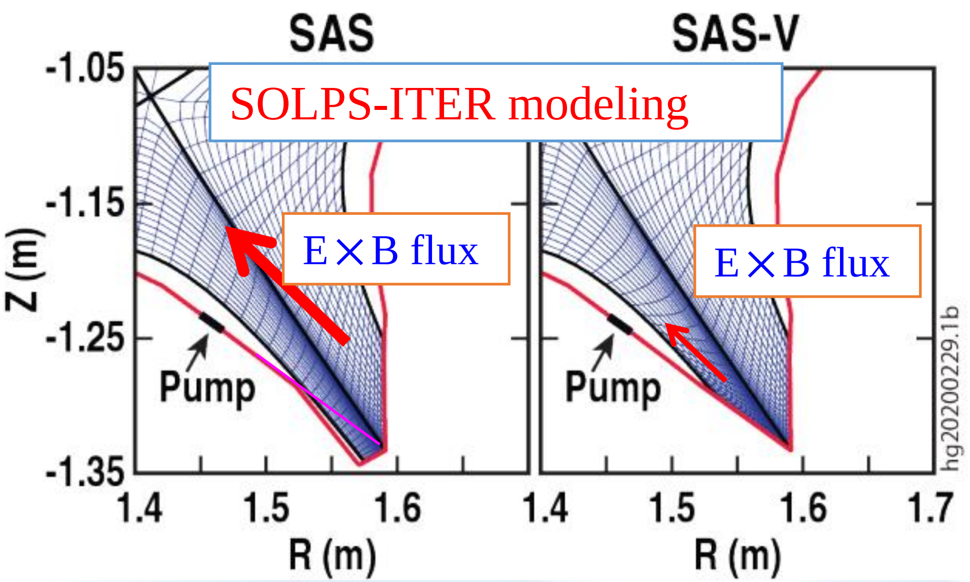
W. Xie, et al., AIP-Advances, in press





Divertor & edge physics

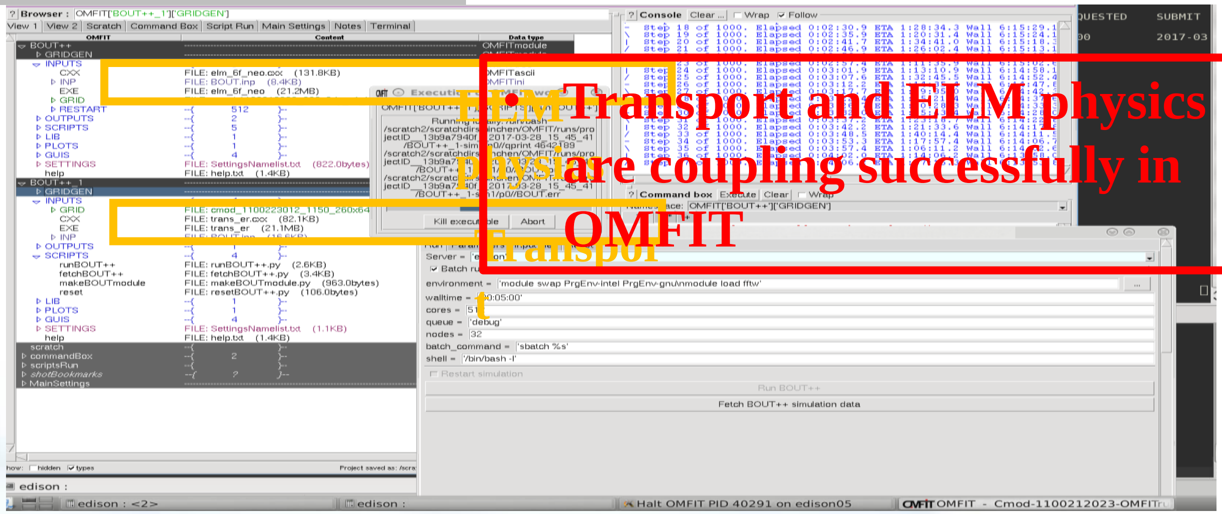
with **Prof. H.Y.Guo, GA, USA**



- The E×B drift effect on detachment can be mitigated by adding extra reflecting baffle in PFR region. As a result, the detachment can be achieved easily with relative low upstream density.

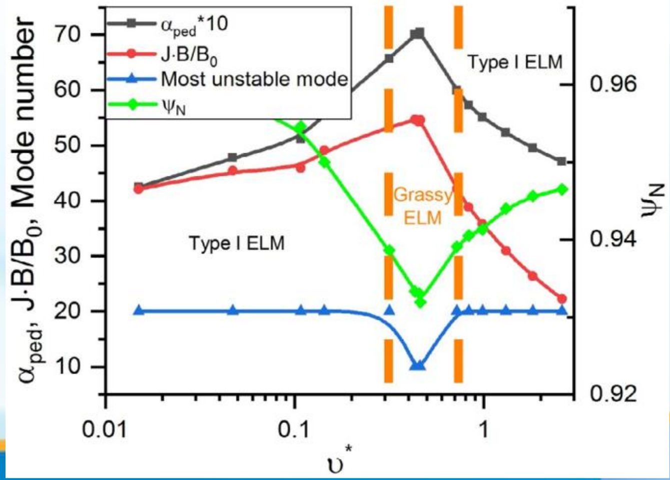
H.L. Du, et.al., NF 60 (2020) 126030

with **Prof. X Q Xu, LLNL, USA**



- ELM Transport and ELM physics are coupling successfully in OMFIT

with **Prof. V.S. Chan, GA, USA**



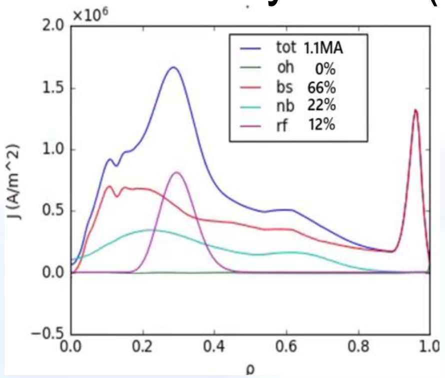
- ELM operation regimes and their distinguishing features along the marginal stability boundary of CFETR.

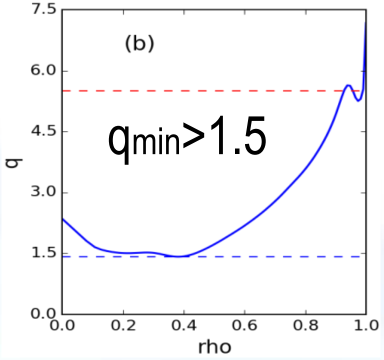
Y.R.Zhu et al. NF, 60,(2020), 046014

Integrated modelling : design of HL-2M discharge scenario

with **Prof. Orso Meneghini, GA, USA**

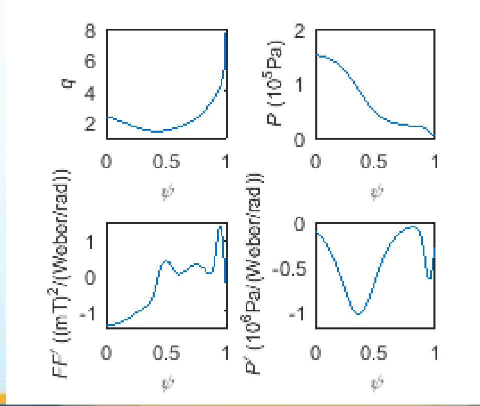
◆HL-2M steady-state (SS) scenario

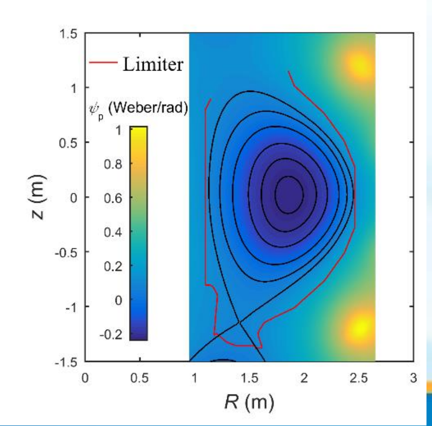




◆HL-2M high β_N scenario

I_p: 1.5MA， B_{T0}: 2.2T， β_N: 3.2384





HL-2M parameter list for SS scenario

Plasma Current Ip (MA)	1.1
Central magnetic field B_T/T	2.0
Electron temperature Te(0) (keV)	6.8
Ion temperature Ti(0) (keV)	13.0
Electron density $n_e/10^{19}m^{-3}$	4.4
Poloidal beta βp	1.75
Normalized beta β_N	3.1
Power of NBI / MW	10.0
Power of ECW / MW	3.0
Bootstrap current fraction	66%
Non-induction current fraction	100%
Pedestal density $n_{e\_ped}/10^{19}m^{-3}$	2.0
Zeff(0)	2.2
l_i	0.86
$H_{ITER98y2}$	1.57

Turbulence physics

(with **Prof. Patrick H. Diamond, UCSD, USA)**

- A model for turbulence spreading was derived from a simplified kinetic equation:

$$\frac{\partial}{\partial \hat{t}}\hat{I} = \mathcal{G}\otimes\frac{\partial}{\partial \hat{r}}\left[2\hat{D}_0\hat{I}\frac{\partial}{\partial \hat{r}}\left(\hat{I}-\frac{\delta_{b*}^2}{2}\frac{\partial}{\partial \hat{r}^2}\hat{I}\right)\right]+\mathcal{G}\otimes\hat{I}-\hat{I}^2$$

$$t \to \hat{t}/\gamma_L\,, \qquad r \to \hat{r}L_T, \qquad \langle\tilde{\phi}^2\rangle \to \hat{I}\,\gamma_L/\gamma_{NL}$$

It contains the nonlocal effects, which are in the form of the convolution with nonlocal kernel:

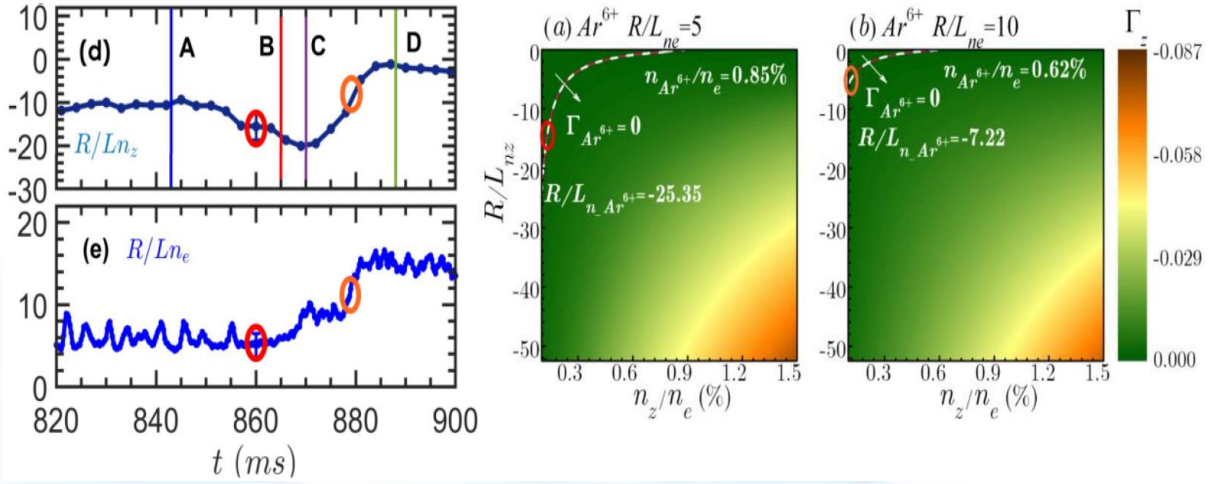
$$\mathcal{G}(x) \propto \exp(-|x|/\delta_{b*})$$

Nonlocal effects thicken the turbulence spreading front and increase the speed of front propagation.

Q.H. Yan and P H Diamond, to be submitted.

(with **Prof. Horton, Univ. of Texas, Austin)**

- **Physics of turbulence and impurity transport**

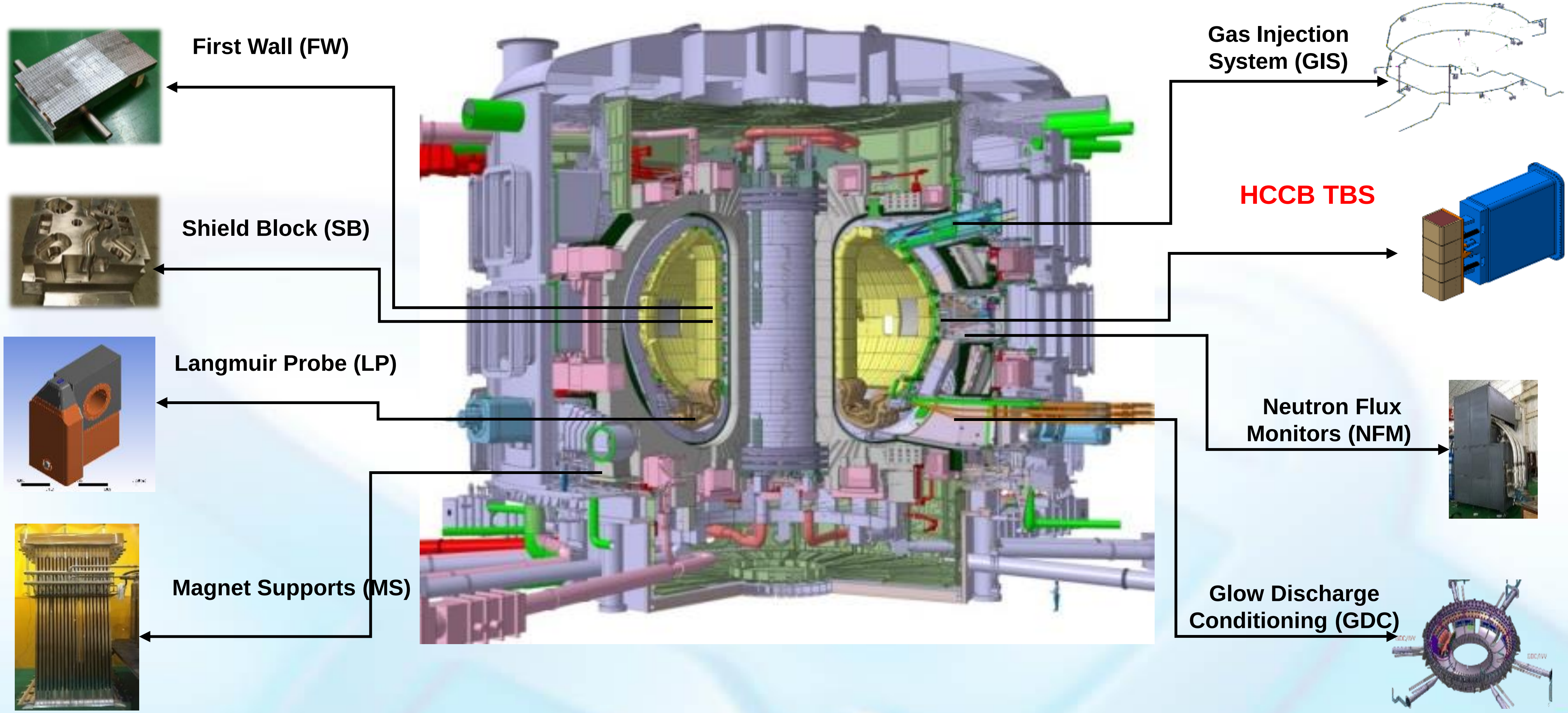


- The reduction of peaking factor of impurity HDPs induced by increase of electron density gradient observed in the IM decay phase of the experiment.
- This observation stimulated the theoretical verification of another significant physics element, that is, R/Lne effects on IM turbulence induced flux and resulting PFz.

M.K.Han, 2021, Nucl. Fusion (accepted)

ITER Procurement in SWIP and Collaborations

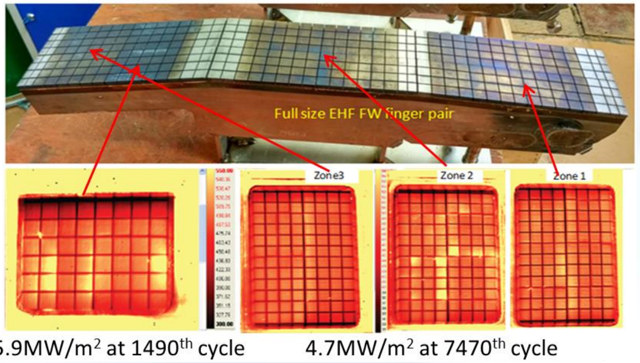
ITER Procurement in SWIP



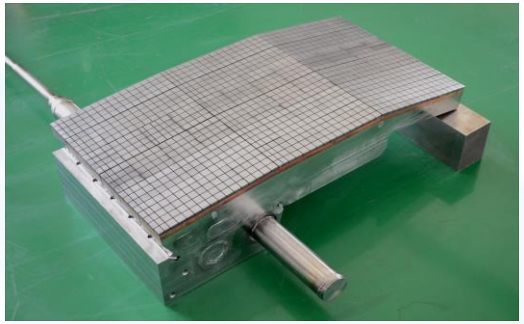
ITER FW getting into series production phase I

- ✓ **Semi-prototype qualified by IO with success in high heat flux test of the fingers.**
- ✓ **Be/Cu bonding by HIPing reached to a success rate of 90%.**
- ✓ **FW Procurement arrangement issued in 2016.**

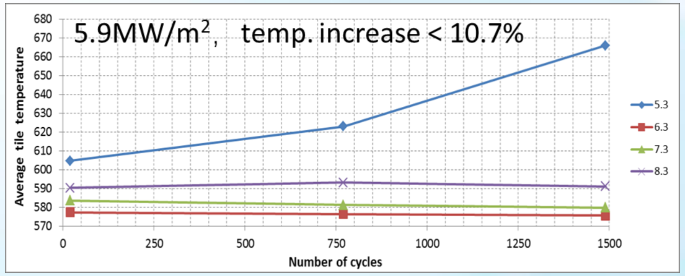
- ✓ **Building-up 16kW laser welding machine, phase-array UT, Be contamination and CMM facilities.**
- ✓ **Completing detail design change of FW04 and the welding assembly testing.**
- ✓ **Completion LFC and insulation coating qualification.**



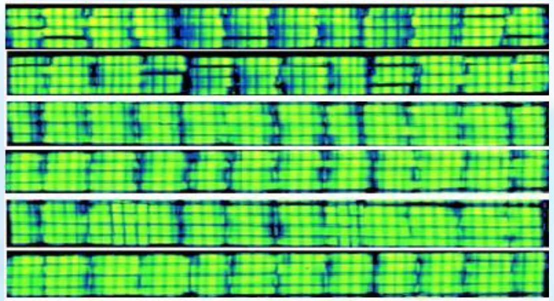
（1）Perfect finger pair and surface temp. after and during HHFT.



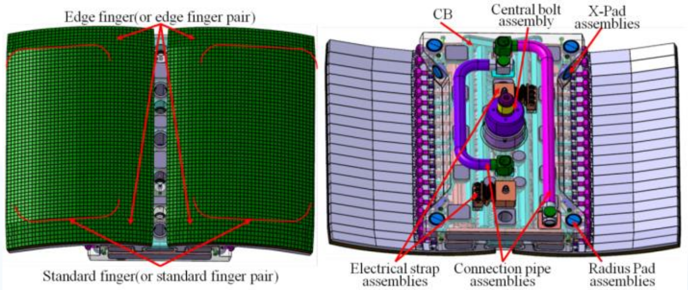
（3）EHF FW semi-prototype with 6 fingers mounted on a beam.



（2）Temperature rising meets < 20% criteria during HHFT at power density high than design by 25%.



（4）No UT indications of defect at Be/Cu joining interfaces



（7）Updated FW04 design, better manufacturability & less water leak risk

（8）Assembly 12 dummy fingers with a central beam

（5）16kW laser welding into use, realizing full-penetration welding without back sputtering

（6）Phase-array UT, developing creep-wave technique

Series production of ITER Shield Blocks

Variants	SB03	SB04	SB05	SB09	SB10	SB11	SB14	SB17	SB18	Total
Quantity	18	18	18	18	18	36	22	36	36	220

Progress：SB10, SB17 and SB09 in manufacturing, 5 products completed.

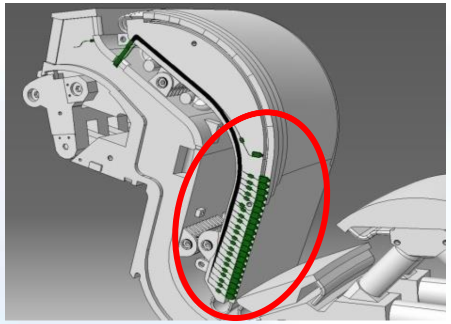
Key technologies：

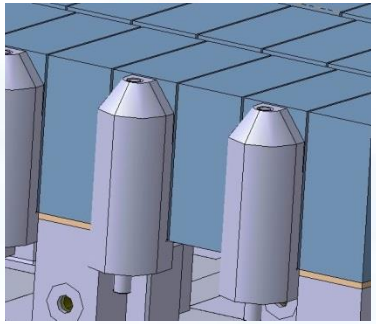
➢ Deep drilling, welding deformation control, vacuum tightness.

Job No.	SN	Forging cutting	Datum machining	Deep Drilling	Mid-Machining	Welding	Heat Treatment	UT RT on welds	Final Machining	Hydro-Presssure	HHLT	Final DT
14074	01	√	√	√	√	√	√	√	√	wait		
14075	02	√	√	√	√	√	√	√	√	wait		
14076	03	√	√	√	√	√	√	√	√	√	√	wait
14077	04	√	√	√	√	√	√	√	√	√	√	wait
14078	05	√	√	√	√	√	√	√	on-going			
14079	06	√	√	√	√	√	√	√	√	√	√	on-going
14080	07	√	√	√	√	√	√	√	√	√	√	on-going
14081	08	√	√	√	√	√	√	√	√	√	√	wait
14082	09	√	√	√	√	√	√	√	on-going			
14083	10	√	√	√	√	√	√	√	wait			
14084	11	√	√	√	√	√	wait					
14085	12	√	√	√	√	√	√	√	wait			
14086	13	√	√	√	√	√	√	√	wait			
14087	14	√	√	√	√	√	√	√	wait			
14088	15	√	√	√	√	√	√	√	on-going			
14089	16	√	√	√	√	√	√	√	on-going			
14090	17	√	√	√	√	√	√	√	on-going			
14091	18	√	√	√	√	√	√	√	on-going			

Development Progress for Langmuir Probe

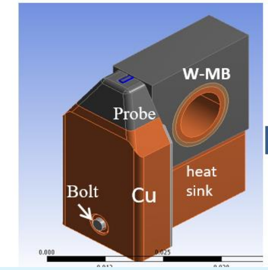
- The Divertor Langmuir Probe (DLP) system measures the plasma parameters at the divertor targets
  - Advanced control: signal of whether the plasma is *detached* or not
  - Physics: Plasma temperature and density @ target



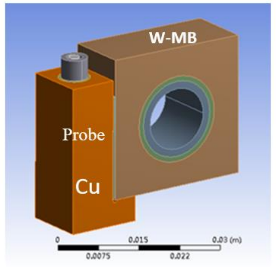


Progress 1: Finished the thermal analysis and preliminary probe design

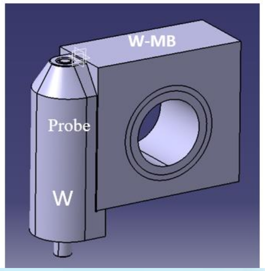
First version



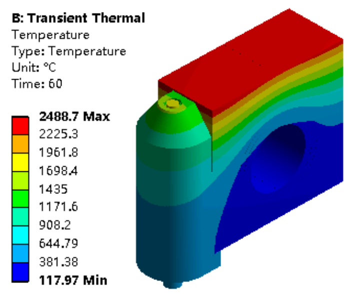
second version



final version

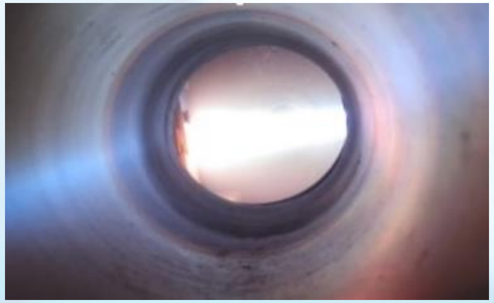


Thermal analysis



Progress 2: Developed 3 versions of power supply, and finished the preliminary power supply design work

Progress 3: finished the prototype manufacture and thermal test



Progress of Magnet Supports

- Since 2018, SWIP has successfully delivered 17 batches of fabricated supports to ITER Organization, FE4, JA DA and RF DA.
- So far, all PFCS-2,5,6 supports, all Gravity Supports, and some of CCS have been handed over to receiving Parties, and some even installed on ITER site.
- Series manufacturing of rest supports is ongoing, and the rest to be delivered by the end of 2021

Delivery Ceremony for the 1st batch of MS

Delivery Ceremony for the 1st batch of MS

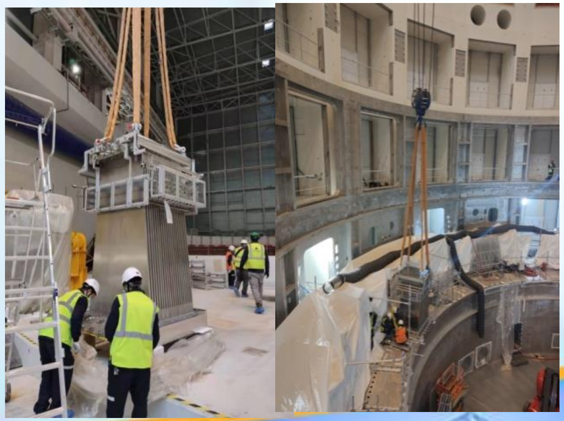

Handover of PFCS6 cooling clamps


First batch of CCS


Delivery of PFCS5


Delivery of 1st batch of GS


Delivery of 2nd batch of GS

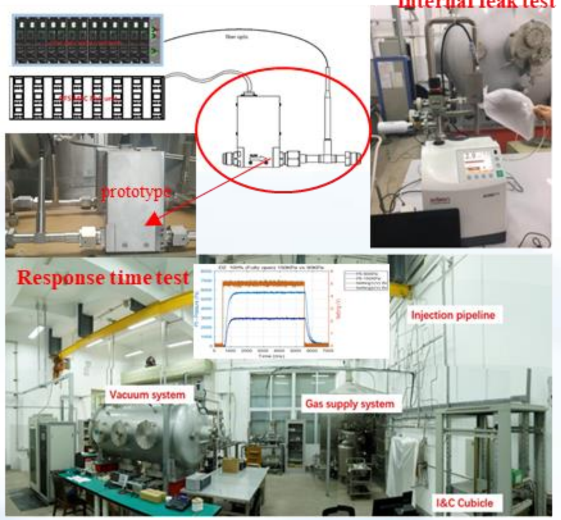

GS installed on site

Progress of ITER Gas Injection System

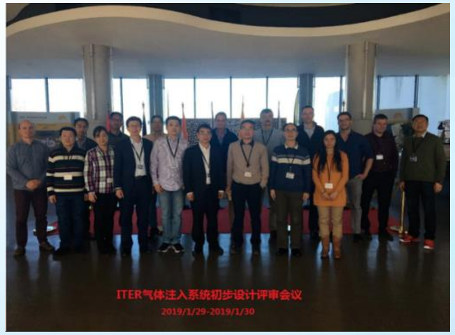
核工业西南物理研究院
Southwestern Institute of Physics
中核集团 CNNC

- **GDS manifolds delivery** was begun in April of 2020, the last batch has been fabricated and is waiting for delivery.
- **GIS dosing valve** has been developed and the performance is under test together with gas injection line.
- **GVB and I&C PDR** was closed and FDR is under preparation.

MRR of the GIS Manifold (2017)

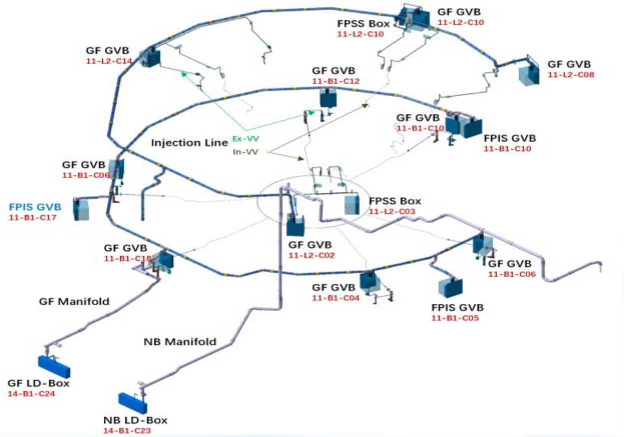


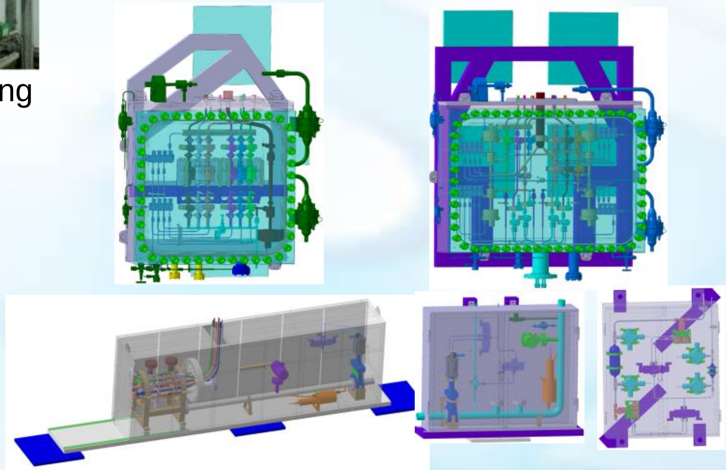
Prototype of all-metal GIS dosing valve and performance test



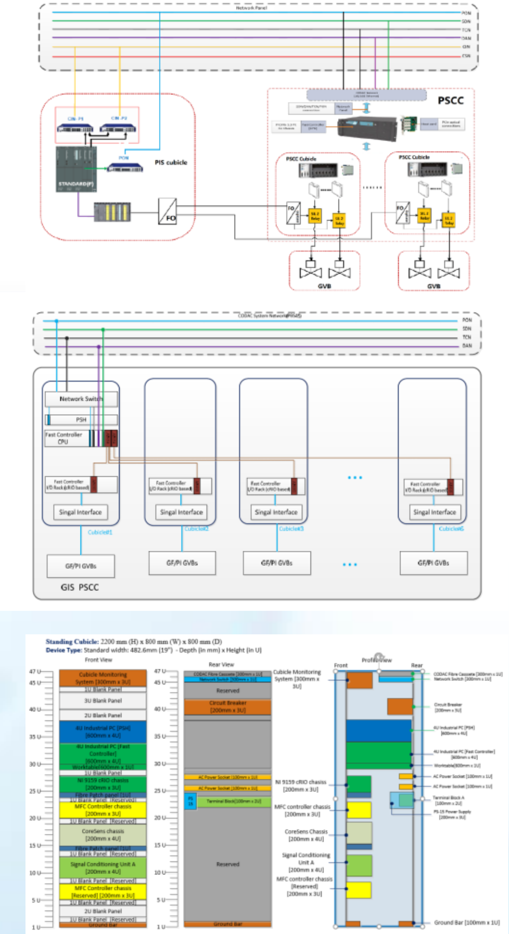
Passed PDR of the GVB and I&C

GF GVB shell trail-manufacture and design conformity tests.





Detailed design of the GIS GVBs



Detailed design of GIS I&C system

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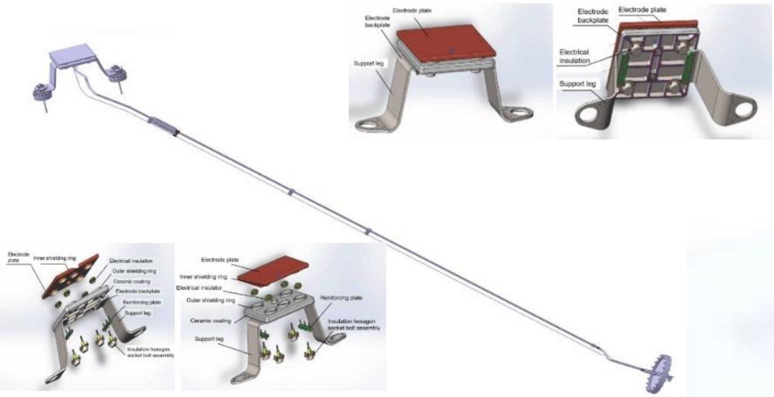
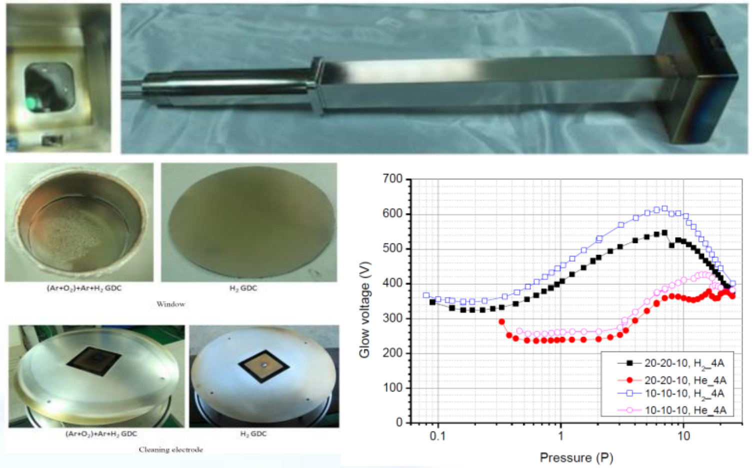
Southwestern Institute of Physics
中核集团 CNNC

Progress of ITER Glow Discharge Conditioning

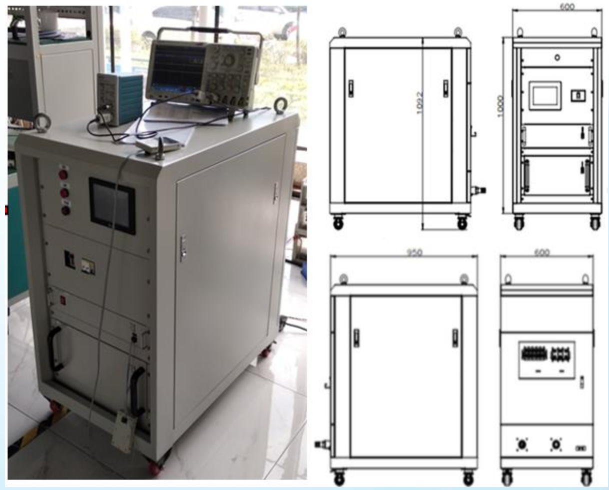
- PDR of GDC system for ITER 1st plasma was closed and the final design is ongoing.
- Experiment Research on ITER Glow Discharge Cleaning was performed in SWIP.
- New concept of permanent GDC electrode is under design.

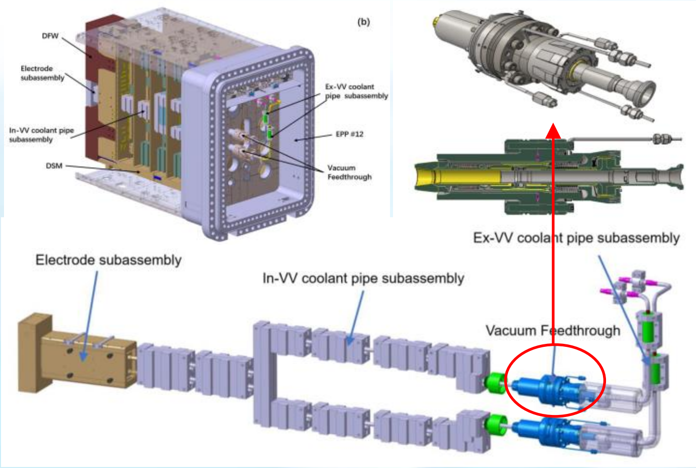
Passed GDC TE PDR (2019)


Temporary Electrode for 1st Plasma

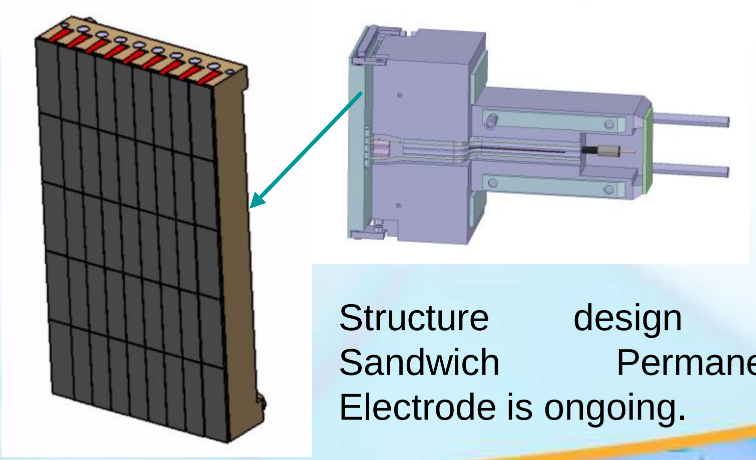


Test on glow initiation, gap insulation for ITER GDC design and operation


Mock-up of GDC Power Supply

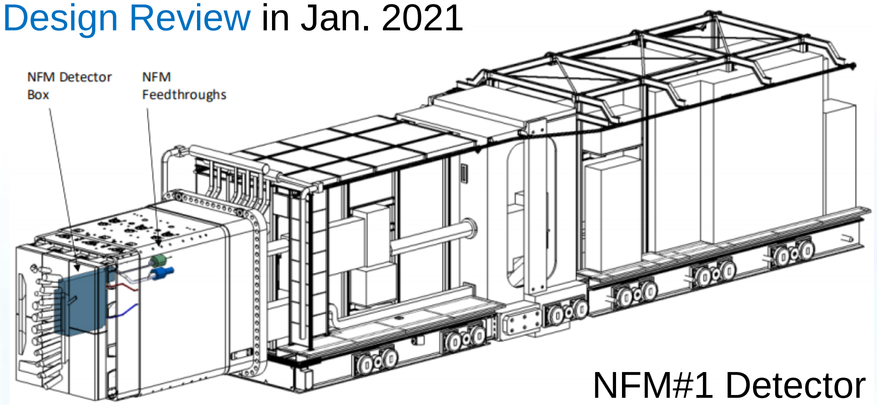


Permanent electrode structure design

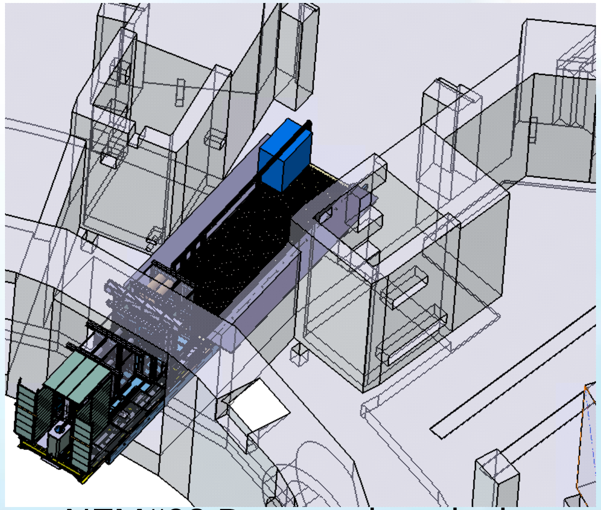

Structure design of Sandwich Permanent Electrode is ongoing.

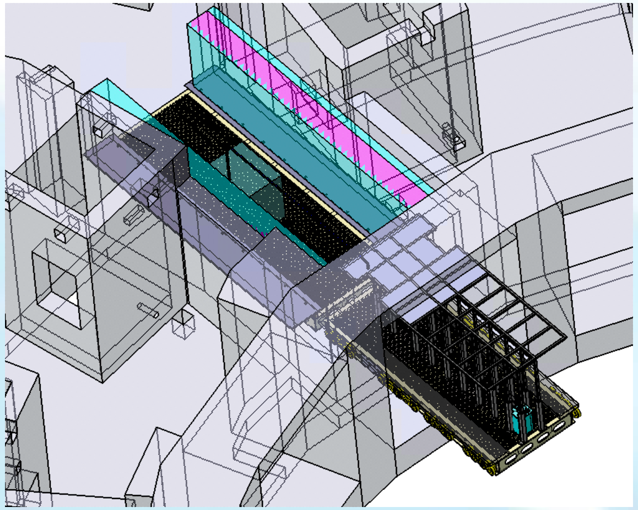
Progress of ITER Neutron Flux Monitors Diagnostics

- ITER Neutron Flux Monitors shall measure the time-resolved total neutron emission for both DD and DT plasmas, providing the evaluation of the fusion power.
- NFMs are located at 4 locations in ITER Equatorial Ports #1, #7, #8 & #17 to cover the whole toroidal view.
- NFM in ITER Equatorial Ports #1, #8 & #17 carried out Preliminary Design Review in Jan. 2021

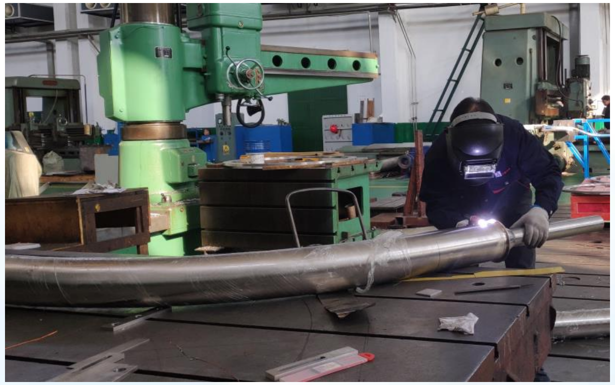


NFM#1 Detector box design


NFM#08 Detector box design

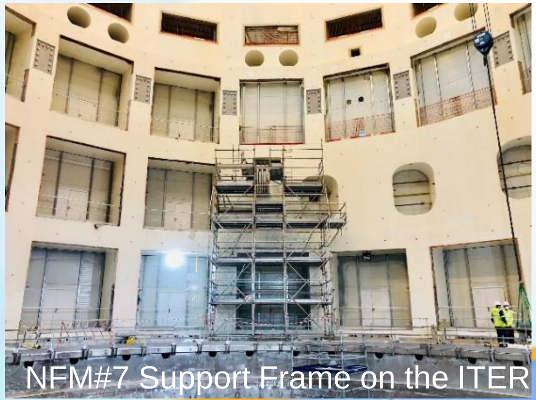

NFM#17 Detector box design

- The Support Frame of the ITER NFM#07 system has been installed in 2020. It is one of the first diagnostic devices installed by ITER.


NFM#7 Support Frame Manufacture


NFM#7 Support Frame transport

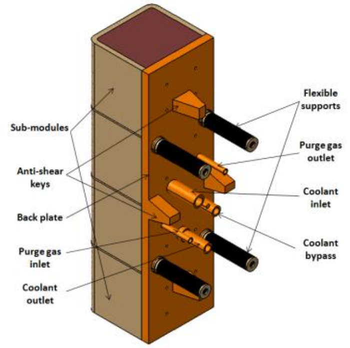

NFM#7 Support Frame Installation


NFM#7 Support Frame on the ITER

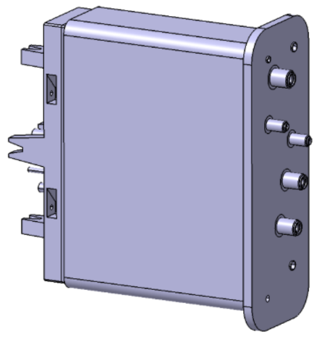
Design and R&D Progress on HCCB TBS

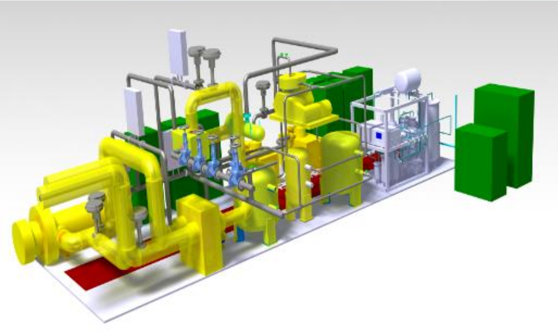
Design of HCCB TBS, including TBM-set and its ancillary system have been improved since Conceptual design was approved in 2015. And now preparation of PDR of HCCB TBS is in-progress.

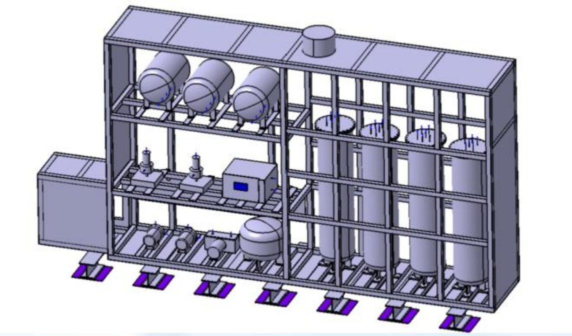
- Improved design of HCCB TBM-set taking into account fabrication manufacturability and engineering performance, including nuclear performance;
- Improved ancillary system design, including key processes and system performance;
- Design verification calculation and analysis have been iterated several times and verified the design evolution;
- HCCB TBS Design for PDR is almost frozen, and preparation work is in progress, including design verification and documentations.

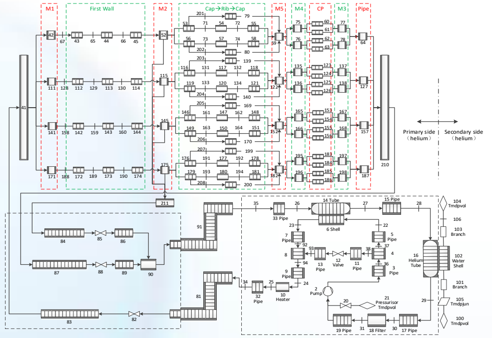


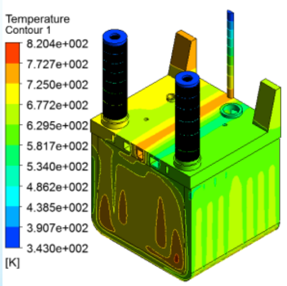
HCCB TBM


TBM Shield

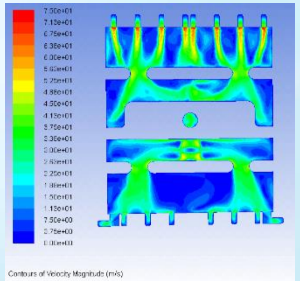

HCS

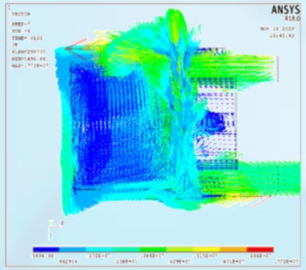

TES


Accident analysis model

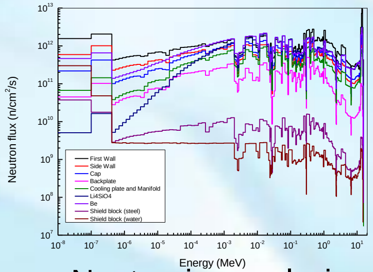


Thermal analysis

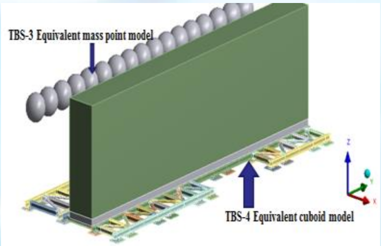

Hydraulic analysis



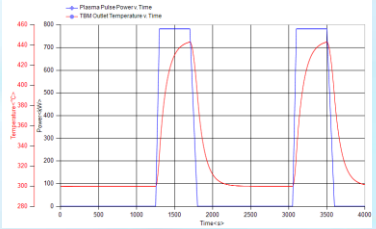
EM analysis

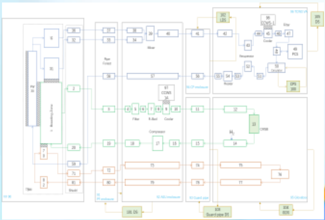


Neutronics analysis



Seismic analysis model


Operation simulation

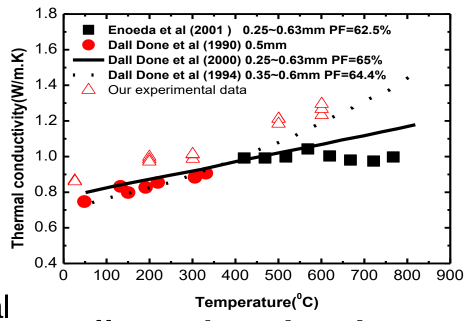

Tritium analysis model

Collaboration on HCCB TBS

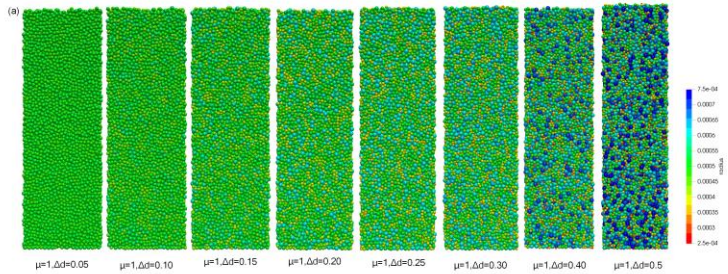
In collaboration with **Dr. Alice Ying, UCLA, USA.**

- R&D of Advanced tritium breeder
  - Composite Li_4SiO_4-Li_2TiO_3 pebble，
  - New cellular solid breeder
- Pebble bed technology (Experimental measurement and numerical simulation)
  - Thermo-mechanical properties: thermal mechanical, thermal expansion and creep, deformation modulus, crushed load and crush characteristics, etc.
  - Heat transfer performance: effective thermal conductivity, interface conductance, etc.
  - Flow characteristics of purge gas: Pressure drop, velocity distribution, etc.

Thermal mechanical measurement



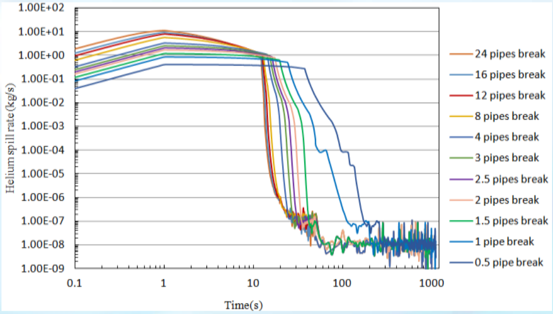
Effective thermal conductivity



DEM simulation of pebble bed

In collaboration with **Dr. Brad Merrill, Idaho National Laboratory (INL), USA.**

- Safety analysis
  - Benchmark of RELAP and MELCOR
  - Accident analysis cooperation for CN HCCB TBS
- Tritium simulation technology
  - TMAP workshop for tritium simulation technology exchange
  - Tritium simulation benchmark



Accident analysis of CN HCCB TBS

Outline

- Collaborations on tokamak programs (HL-2A & HL-2M)
  - Diagnostics development
  - Experiments
  - Theory and modeling
- ITER Procurement in SWIP and Collaborations
- Collaboration opportunities

Collaboration opportunities

Impressive progress of collaborations in last 5 years

- > 8 advanced diagnostics
- >30 publications
- Training PhDs >5
- 1st Chengdu Theory Festival
- Scientists visiting, >20

Topics	Achievements	Collaborators
Turbulence &Transport	L. Wang et al Phys. Plasmas 26 (2019) 092303, W. Liu et al Phys. Plasmas 28(2021) 012512 L. Nie et al NF 58 (2018) 036021 R. Hong et al NF 58 (2017) 016041	Prof. George Tynan, UCSD, USA
	T. Long et al 2019 Nucl. Fusion 59 106010 D. Guo et al. Nucl. Fusion 58 (2018) 026015	Prof. Patrick. H. Diamond, UCSD, USA
	61st APS-DPP meeting	Dr. George McKee, UW-Madison, USA
MHD related physics	N. Wu et al, POP 25 102505(2018)	Prof. X Q Xu, LLNL, USA
	Dong Li et al Nucl. Fusion 60 (2020) 076005, T. F. Sun et al Nucl. Fusion 61 (2021) 036020 T. F. Sun, et al. FED, 148, (2019), 111301	Prof. Yueqiang Liu, GA

		Collaborators
Basic diagnostics	FIR laser Polarimeter-Interferometer improvements	Dr. W.X. Ding, UCLA, USA
	Far-forward Collective Scattering (FCS) diagnostic	Dr. W.X. Ding, UCLA, USA
Advanced diagnostics	Beam Emission Spectroscopy (BES)	Dr. George McKee, Dr. Z. Yan, UWM, USA.
	Electron cyclotron emission imaging (ECEI)	N. C. Luhmann, Jr. and Dr. Y. L. Zhu, UC Davis
	Phase Contrast Imaging (PCI)	Dr. J.C. Rost, MIT
	Gas Puff Imaging (GPI)	Dr. R.J Hong, UCSD, USA
	CO2 CTS diagnostic system	Dr. R.Y.,PPPL, USA
	Fast ion Dα diagnostic (FIDA),SSNPA	Prof. W. W. Heidbrink, , UCI, USA.

Topics	Achievements	Collaborators
Scientists training	1st Chengdu Theory Festival Joint PhD >5(T.Long, R.Ke, B.D.Yuan, Y.F. Wu, Q.H.Yan,.....)	Prof. Patrick. H. Diamond, UCSD, USA
Turbulence physics	Qinghao Yan and P H Diamond, to be submitted,	Prof. Patrick. H. Diamond, UCSD, USA
	M.K.Han, 2021, Nucl. Fusion (accepted)	Prof. Horton, Univ. of Texas, Austin
MHD	G.Q. Dong, et al, NF 59 (2019) 066011 G.Q. Dong et al, PoP,24, 112510 (2017) G.Q. Dong, et al,2021, NF (accepted) W. Xie, et al., AIP-Advances, in press Xue Bai, PoP, 2020, 27(12): 124502. Xue Bai, PoP 2020, 27(7): 072502. Xue Bai, PoP, 2018, 25(9): 090701. Xue Bai, PoP, 2017, 24(10): 102505. N. Zhang,, et al., PoP, 24, 063006(2017) N. Zhang,, *et al.*, PoP, 25, 092502 (2018) N. Zhang,, *et al.*, NF, 60, 096006 (2020) N. Zhang,, *et al.*, NF, (2021), in press	Prof. Yueqiang Liu, GA,USA
Divertor physics	Houyang Guo et al. NF, 59 (2019) 086054 H.L. Du, H.Y. Guo, et al. NF, 60 (2020) 126030	Prof. H.Y. Guo, GA,USA
Integrated modelling	Design of HL-2M discharge scenarios	Prof. Orso Meneghini, GA, USA
	Integrated simulation of ELM and transport	Prof. X. Q. Xu, LLNL, USA

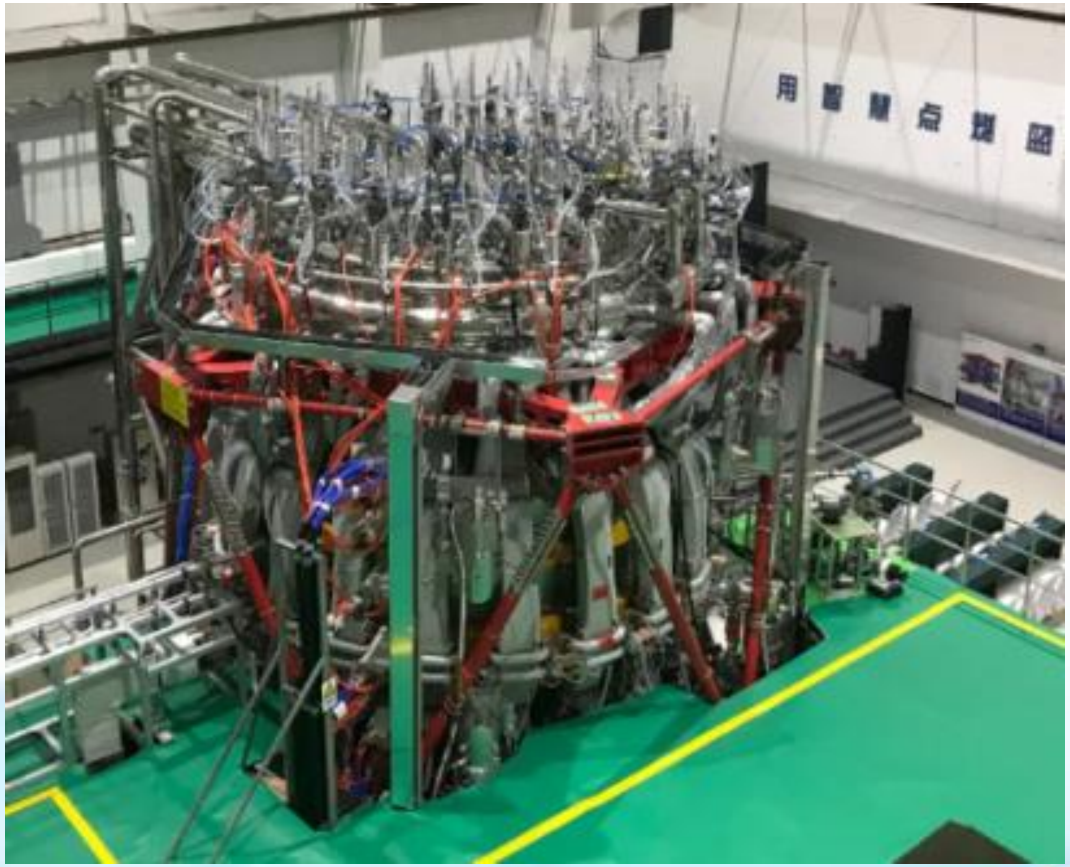
Time	Visit	Personnel	Collaboration details
2015/09-2016/06	SWIP→UCD	Dr. M. Jiang	Optical simulation, microwave imaging technology
2016/08	UCD→SWIP	Prof. Luhmann	Novel and advanced technology in ECEI
2017/09	UCD→SWIP	Prof. Luhmann Dr. M. Chen	SoC application in ECEI, QH-mode study on DIII-D
2019/03, 2019/12	Video conferences	UCD, SWIP, HUST, USTC	Data analysis, OMFIT module, synthetic ECEI diagnostic

Date	Visitor	Host	Purpose or Report
Apr. 8th, 2015	V. S. Chan	SWIP	Establishing the Physics Basis for Designing the Next Step Fusion Nuclear Science Facility
Oct. 26th to 31st, 2016	V. S. Chan	SWIP	CFETR physics group workshop
Sep. 12th to Nov. 13th, 2016	Clement Wong	SWIP	A New Development Path for Controlled Fusion A Briefing on Selected Fusion Materials
Feb. 28th, 2017	Hou Yang GUO	SWIP	A New Small Angle Slot (SAS) Divertor Concept
July 6th, 2017	Hou Yang GUO	SWIP	DIII-D Boundary/PMI Research Plan Development of Advanced Divertor Concepts for Steady-State Fusion
Aug. 20th to 24th, 2018	Lang Lao, Orso Meneghini	SWIP	OMFIT training

Collaboration opportunities in future

- **Key physics and techniques on HL-2M with supporting for ITER and future reactors**
  - Development of advanced diagnostics
    - Thomson，MSE, FIR POINT, CXRS， BES, ECEI, FIDA,…
  - Accessing and real time control of the high performance plasma
    - MHD control: ELM, RWM, EPM, disruption,…
    - Edge physics: H-mode detachment, advanced divertor configuration,…
    - Design of advanced scenarios,….
  - Plasma physics: core-edge coupling, edge plasma physics, fast ion physics, turbulence & transport, MHD physics

HL-2M



Great thanks

for all the dedicated support for SWIP!