PROGRESS OF HL-2A EXPERIMENT AND HL-2M PROGRAM

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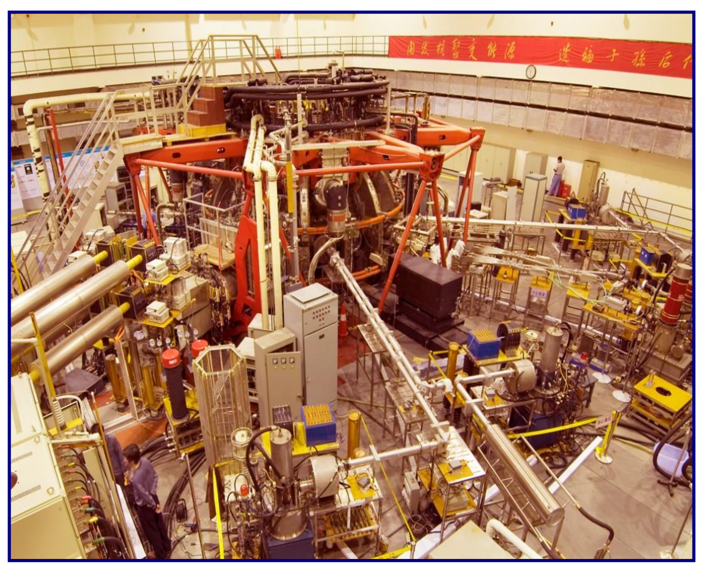
ABSTRACT

During the recent two years after the last IAEA FEC conference, HL-2A has made significant progress in the high parameter related research areas, such as a high-β_N scenario with DTBs. Statistical analysis has shown that there is a critical velocity shear value for the L-H transition. The ELM control with RMP has been both achieved in HL-2A. Besides, the impurity seeding with different external actuators has been successfully used to actively control the plasma confinement and instabilities as well as the plasma disruption with the aid of the disruption prediction on HL-2A. In addition, the turbulent transport result from a wide range of phenomenon such as the energetic particles and the magnetic island has been investigated. Finally, the status about the completion and the first plasma discharge of the new tokamak HL-2M with the plasma current of the megampere level are presented.

HL-2A TOKAMAK

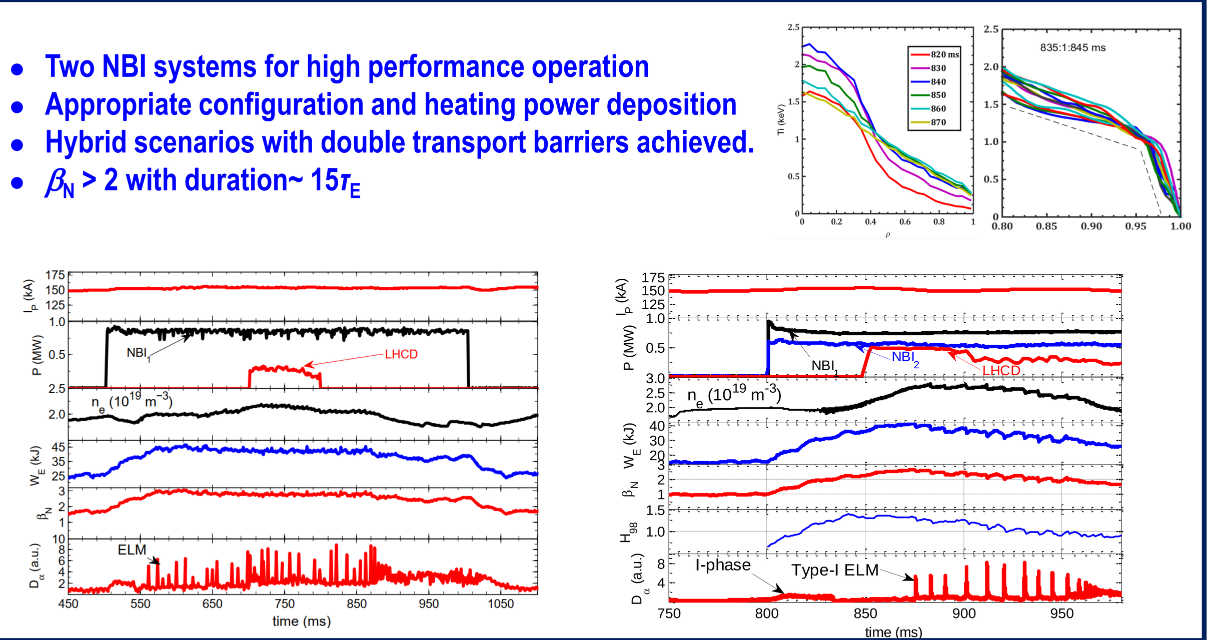


R: 1.65 m
a: 0.40 m
B_T: 1.2~2.7 T
Configuration: Limiter, LSN divertor
I_p: 150 ~ 480 kA

ECRH/ECCD: 5 MW (6 X 68 GHz/0.5 MW/1 s, 2 X 140 GHz/1 MW/1 s)
NBI (tangential): 3 MW
LHCD: 2 MW (4/3.7 GHz/0.5 MW/2 s)

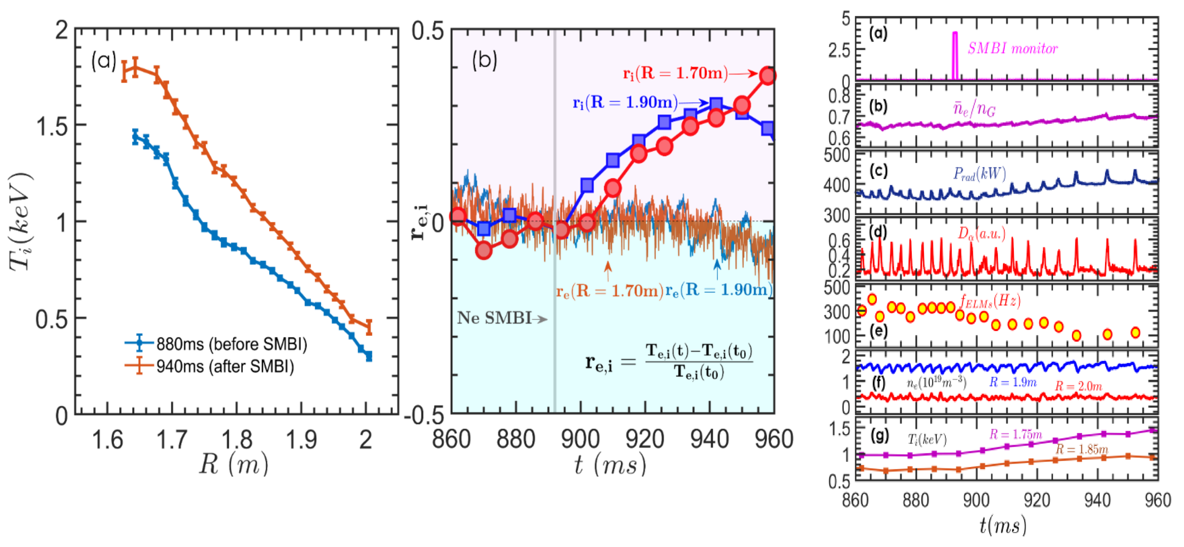
HIGH-β_N OPERATION

- Two NBI systems for high performance operation
- Appropriate configuration and heating power deposition
- Hybrid scenarios with double transport barriers achieved.
- $\beta_N > 2$ with duration~ $15\tau_E$



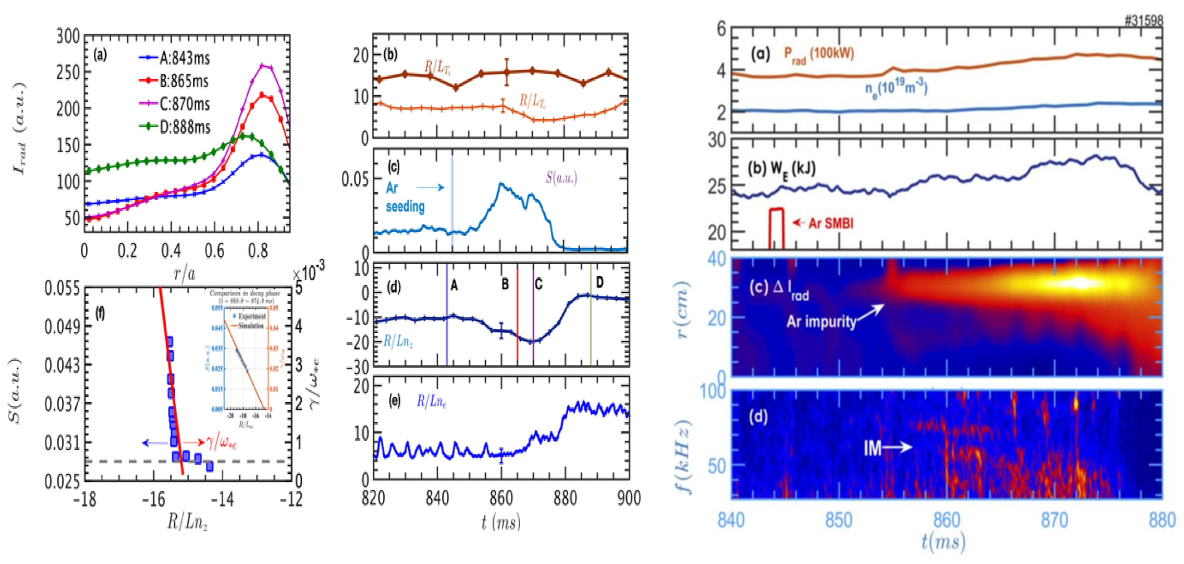
CONFINEMENT ENHANCEMENT WITH IMPURITY SEEDING

- H-mode confinement is improved by neon impurity seeding in the ELMy H-mode
- Ion and electron heat flux exhibits distinct responses to the impurity seeding.
- Electron and ion thermal transports are decoupled by the impurity seeding.
- Decoupled ion thermal transport contributes to an improved energy confinement.



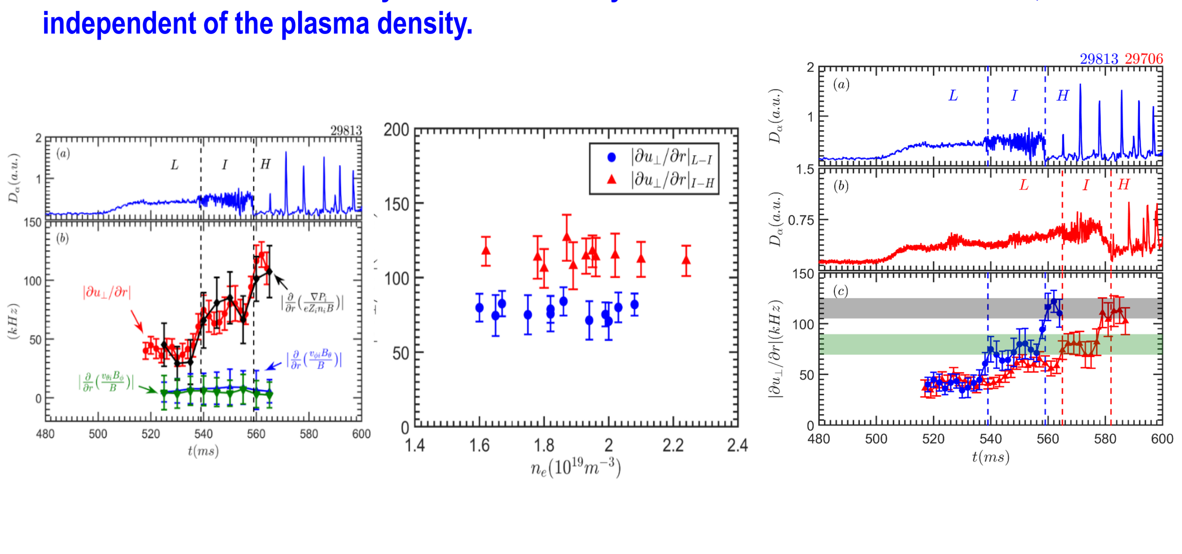
IMPURITY TRANSPORT & TEMPERATURE SCREENING EFFECT

- The evidences of impurity mode induced transport such as impurity density peaking factor (PF) are observed in argon injection experiment for the first time.
- Theory predicted ITG screening effects on the transport are evidenced in the experiment.
- The increment of R/L_{ne} plays a key role in the decrement of PF and sustainment of slightly hollow profile of impurity ions.



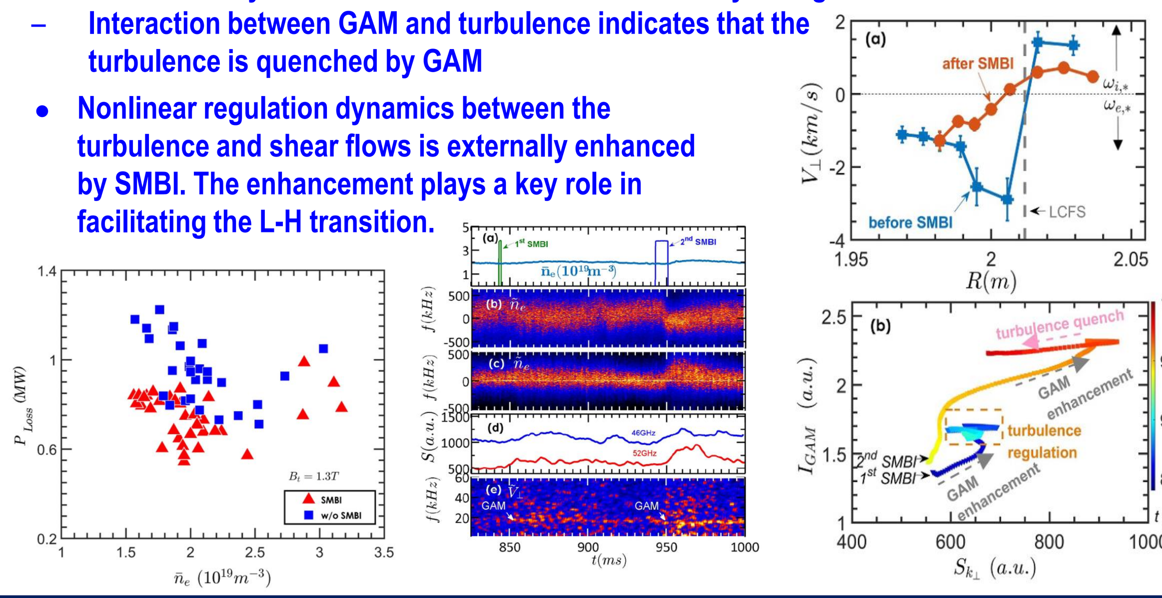
EDGE VELOCITY SHEAR FOR L-I-H TRANSITION

- Velocity shear increases before the L-I and L-H transitions. Significant decrease of turbulence and increase of density gradient were observed at the L-H transition, mainly due to the pressure gradient term
- L-H transition occurred only when the velocity shear exceeded some threshold, which is independent of the plasma density.



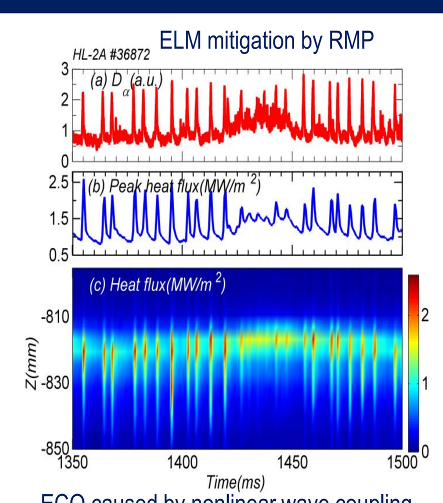
EFFECT OF SMBI ON L-H TRANSITION

- Mechanism of SMBI on L-H transition is demonstrated.
  Two dynamic processes:
  - GAM intensity increases with the turbulence intensity owing to SMBI
  - Interaction between GAM and turbulence indicates that the turbulence is quenched by GAM
- Nonlinear regulation dynamics between the turbulence and shear flows is externally enhanced by SMBI. The enhancement plays a key role in facilitating the L-H transition.



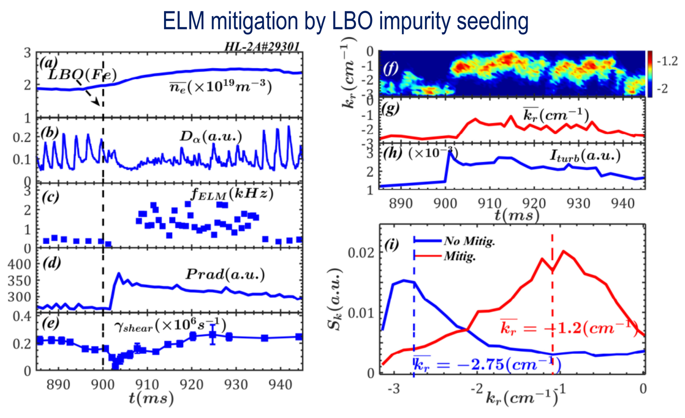
ELM MITIGATION

- Edge coherent oscillation (2–25 kHz), caused by the three-wave interaction of turbulence enhanced by RMP, is observed in the steep-gradient pedestal region of ELM mitigated H-mode plasmas.
- ELM mitigation and suppression has also been achieved by impurity seeding via laser blow off. Dual effects, including the turbulence enhancement via the turbulence wavenumber shift, and the turbulence suppression via the impurity dilution, play a key role in the ELM mitigation and ELM suppression, d.



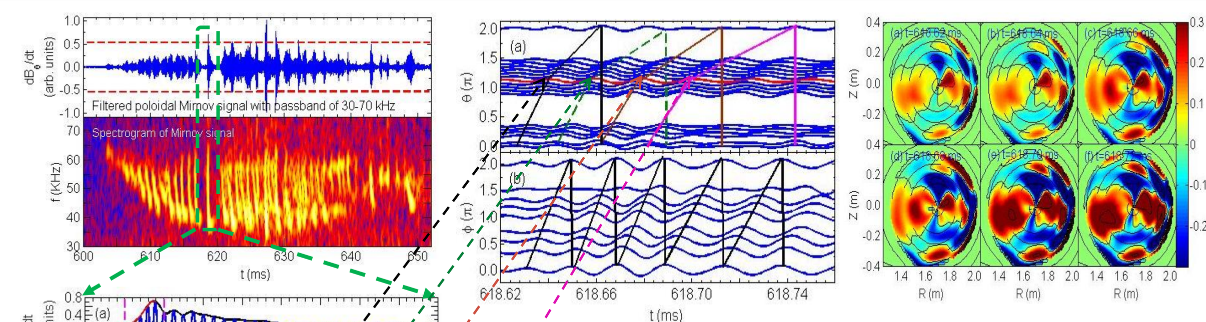
ELM mitigation by RMP

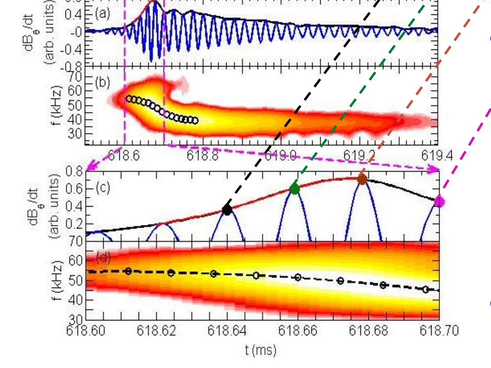
ECO caused by nonlinear wave coupling among turbulence



ELM mitigation by LBO impurity seeding

EVIDENCE OF EPM AVALANCE DYNAMICS



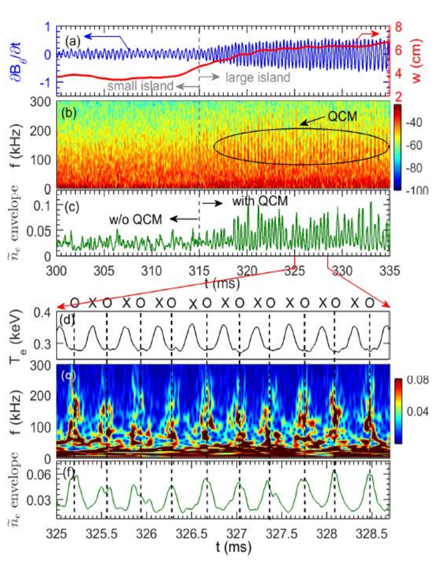


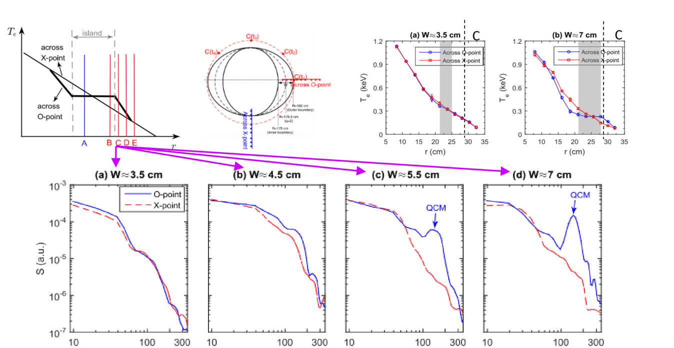
- In a successive chirping process (a strong single burst) t=618.60-618.76 ms:
  - The frequency of the mode sweeps down from 55 to 43 kHz;
  - Poloidal mode number changes from m=2 to 3, and then from 3 to 4.
  - Toroidal mode number keeps at n=1.
- Additionally, radial propagation of EPM can also be proved by:
  - m=2 elements are dominant at first, then the mode propagates in outward. At last, the m=4 elements are dominant.

INFLUENCE OF LARGE MAGNETIC ISLAND

The influence of the rotating m/n = 2/1 magnetic islands:

- Both the QCM (100–175 kHz) and broadband turbulence (40–100 kHz and 175–300 kHz) outside the island are significantly enhanced during the O-point phase in comparison with that of the X-point.
- The QCM magnitude increases with the island size.

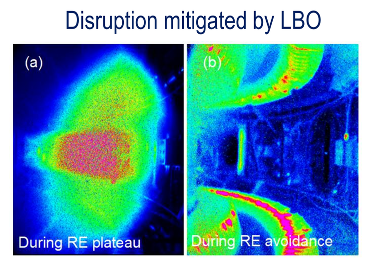




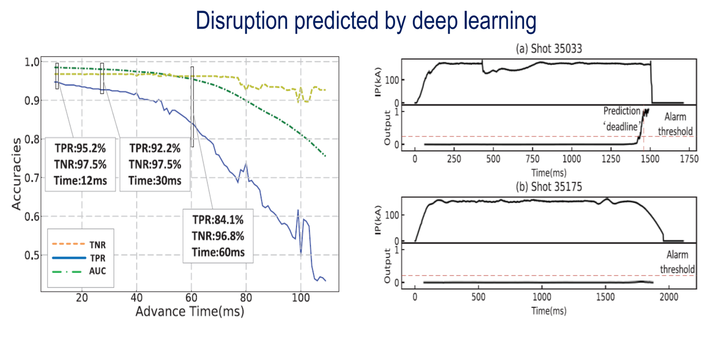
DISRUPTION MITIGATION & PREDICTION

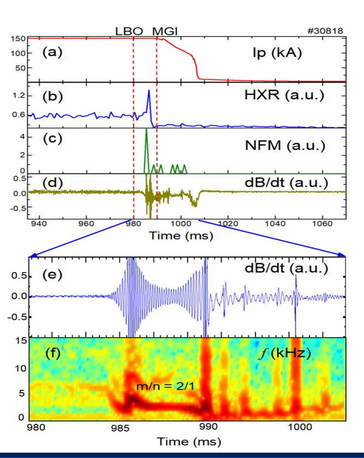
- With LBO system, the avoidance of runaway current generation during disruptions has been successfully achieved.
- Disruption prediction algorithms developed based on deep learning.
  - Accuracy: 96.8%, by assembling convolutional neural network (CNN) and long short-term memory (LSTM) neural network.
  - Disruption alarms : 30 ms before current quench.

Disruption mitigated by LBO

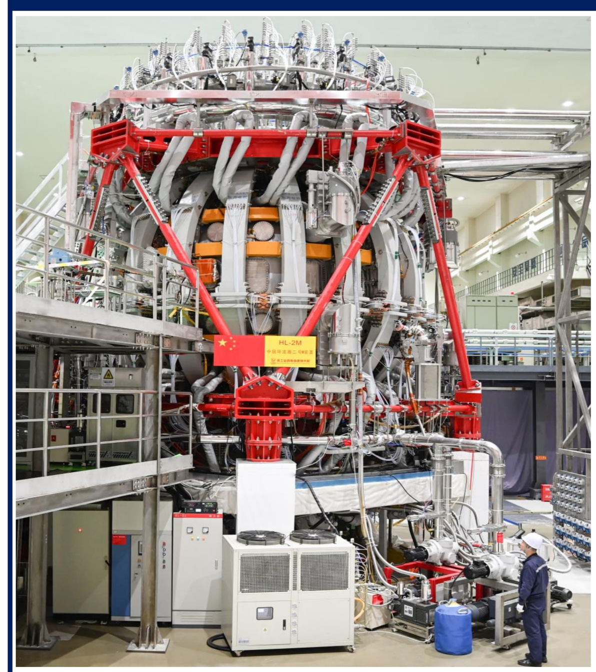


Disruption predicted by deep learning





HL-2M TOKAMAK

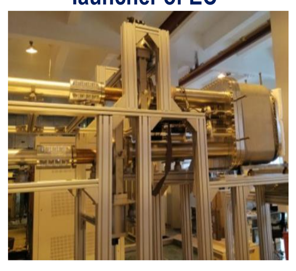


R = 1.78 m
a = 0.65 m
I_p = 2.5 (3) MA
R/a = 2.8
K = 1.8-2
δ > 0.5

B_T = 2.2 (3) T
$\Delta\Phi$= 14Vs

NBI	5MW / 15MW
ECW	5MW /8MW
LHW	2MW / 4MW

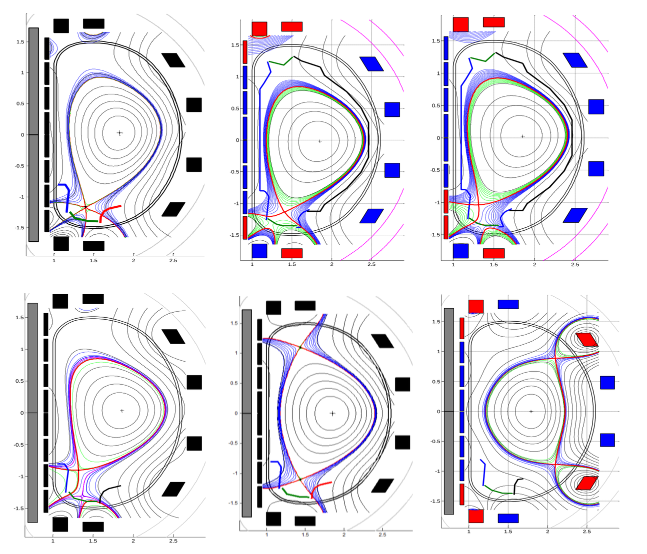
Outer structure of the plug-in unit and equatorial launcher of EC

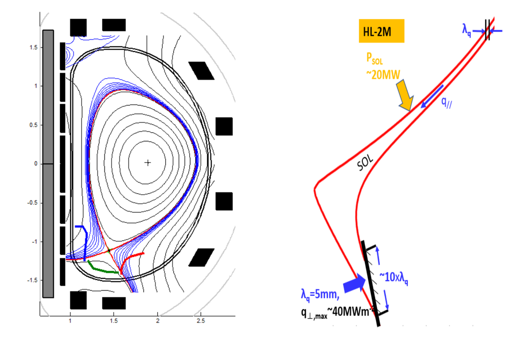


Power supply and control system for 5MW beam

FLEXIBLE CONFIGURATIONS

- Standard divertor with 14 MW/m^2 heat flux
- Advanced divertor configurations with Mega-Ampere plasma
- Heat flux width λ_q : 1~10mm





SCENARIO FORESEEING

In support of ITER pre-fusion phase operation (Hybrid and Steady State) :

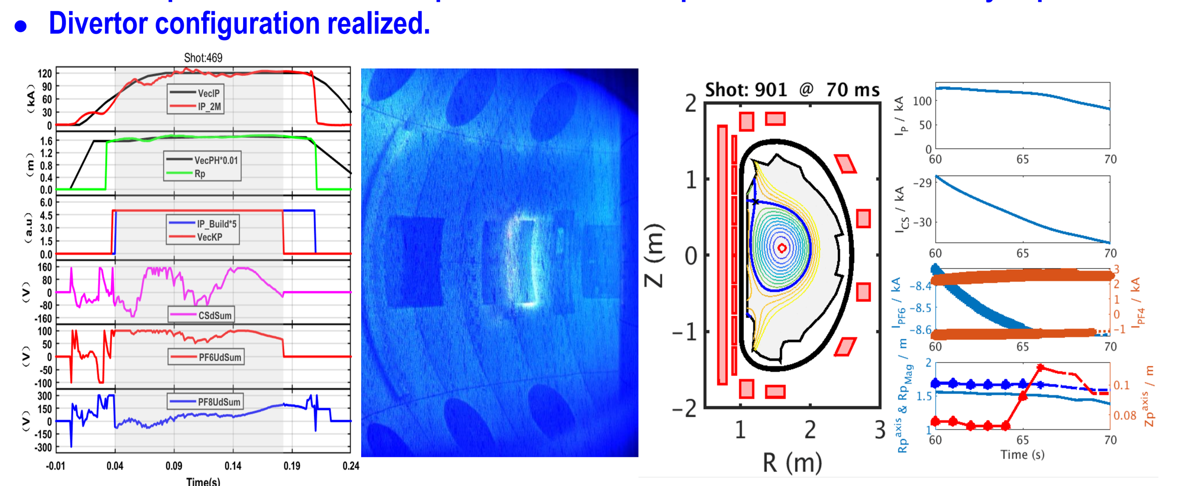
- Hybrid scenario : I_p=1.0~1.4MA, f_G~0.5 by combining NBCD with ECCD or ECCD+LHCD
- In Hybrid regimes, the fractions of bootstrap current f_{BS} and total non-inductive current f_{ni} are between 30%~45% and 70%~90%, respectively; β_N can reach 2.5 with $H_{98(y,2)}$~1.1
- Full non-inductive regimes, such as the hybrid steady state regime and the regime with a reversed magnetic shear, can reach 1MA plasma current with f_{BS}>60% , $H_{98(y,2)}$~1.3, β_N >3.

High performance operation with I_p = 2.5MA / B_T = 2.2T, P_{heat} = 27MW :

- High performance operation with β_N ~ 3
- $n(0)\ \tau\ T_i(0)$ can reach about 10^{20} m^{-3}skeV
- Central plasma temperature can reach around 10keV, with f_G=0.5

FIRST PLASMA

- First plasma achieved in 2020.
- Close-loop feedback control of plasma current and position was successfully implemented
- Divertor configuration realized.



SUMMARY

HL-2A experiment:

- High β_N operation with DTB;
- Impurity effect on transport and confinement (H-mode enhancement, impurity mode, TEM);
- L-H transition and ELM mitigation (Velocity shear and SMBI on L-H, RMP and LBO on ELM mitigation)
- Energetic particle and MHD instability (Interaction EP, MHD and turbulence, Disruption prediction and mitigation)

HL-2M tokamak, with R=1.78m, a=0.65m, B_T=2.2~3 T, Ip=2.5~3MA, achieved its first plasma in 2020;

Aiming at critical physics and technology issues for ITER & fusion reactors, provide the platform for:

- High performance plasmas study for next-step fusion devices;
- Flexible divertor configuration (snowflake, tripod, etc.);
- Test and validation of PFC under high heat and particle flux;
- Key issue such as mitigation of ELM, disruption, VDE, etc.

OTHER FUSION RESEARCH ACTIVITIES AT SWIP

- Fusion reactor design
- Fusion technology relevant activities:
  - Fusion reactor materials
  - R&D of key components (advanced divertor,….)
  - R&D of ITER Procurement Packages at SWIP
    - Helium-cooled solid breeder test blanket module (TBM)
    - First Wall & Shielding Blanket
    - Gas Injection & Glow Discharge Cleaning System
    - Magnet Support
    - Neutron Flux Monitoring
    - Langmuir Probe

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