Progress of J-TEXT on RMP and Disruption Physics

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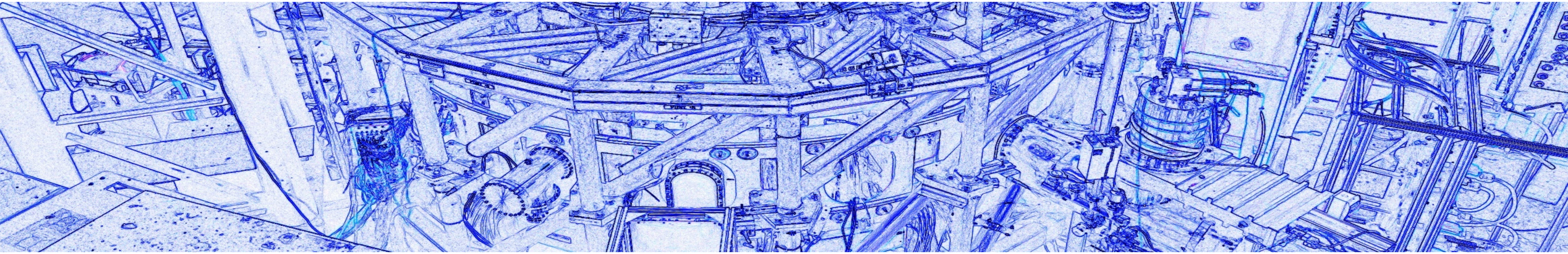


10th US-PRC Magnetic Fusion Confinement Workshop, LLNL, March 23-26, 2021

Outline

I. J-TEXT overview

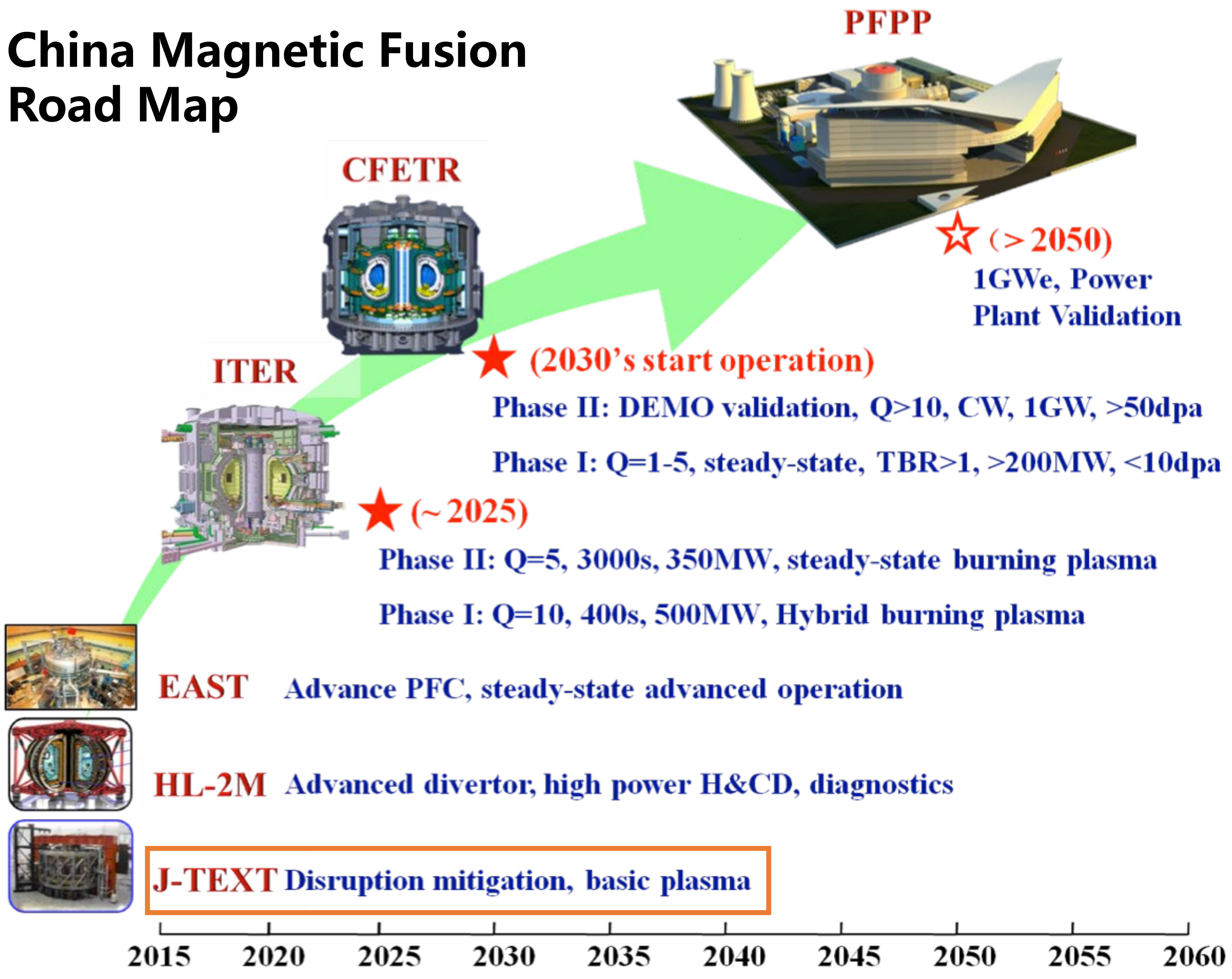
II. RMP and disruption mitigation

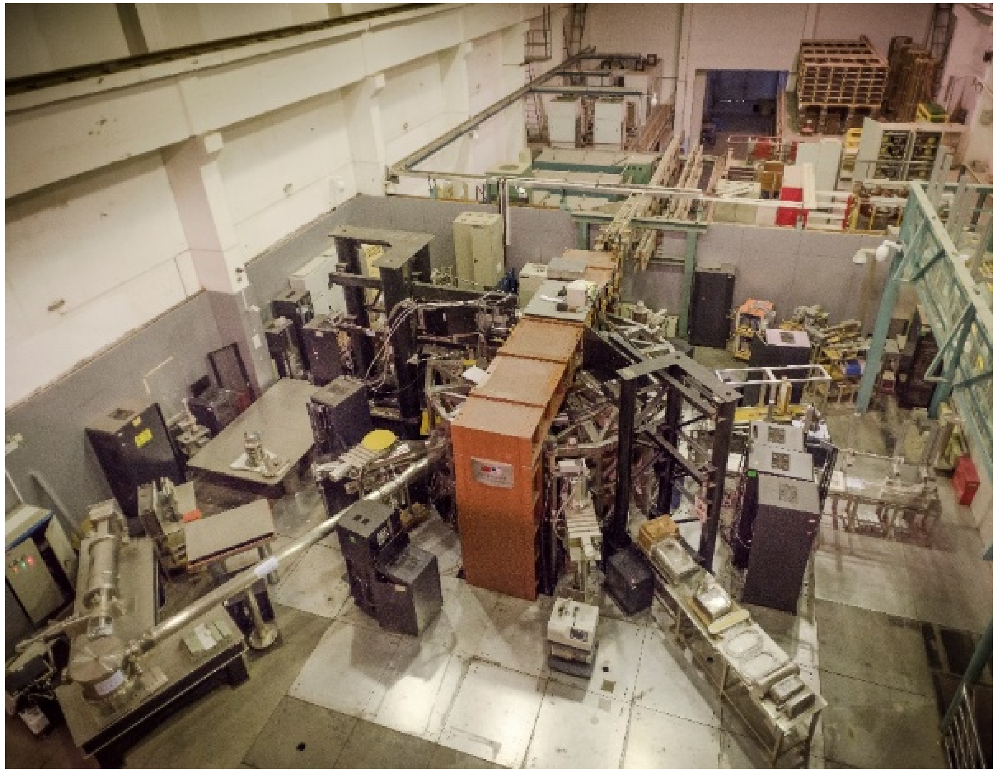
III. Runaway electron control

IV. Summary and future work

J-TEXT status in magnetic fusion program

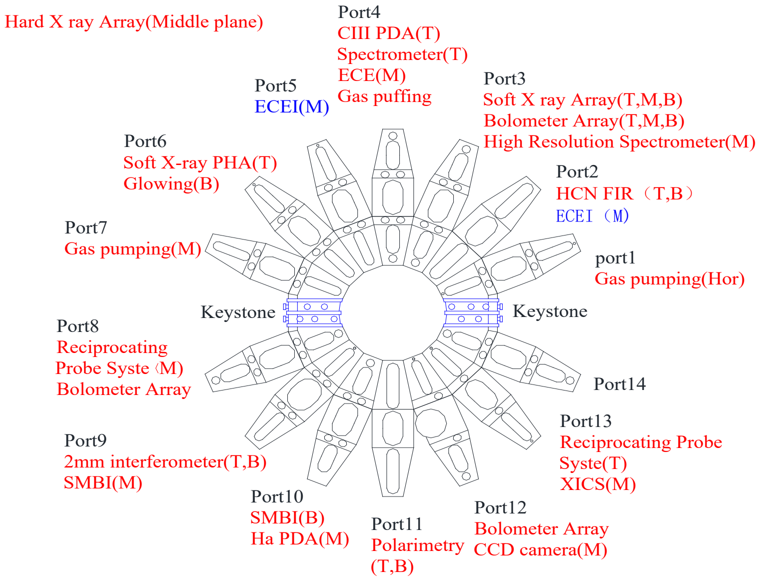
China Magnetic Fusion Road Map

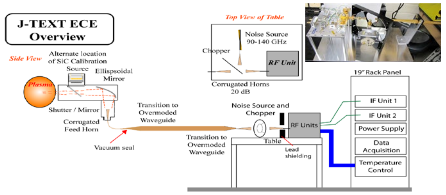


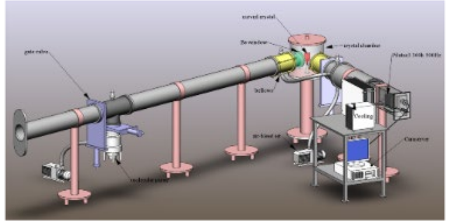


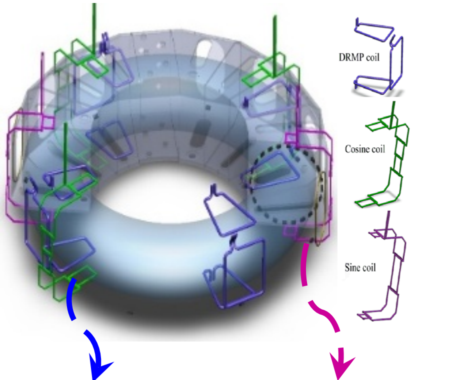
Recent J-TEXT system upgrade

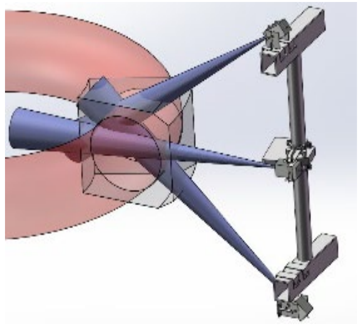
- **30+ diagnostic systems, including first polarimeter for tokamak in China**
- **First high frequency DRMP system and dual SPI system in China**
- **ECRH system and midplane divertor**

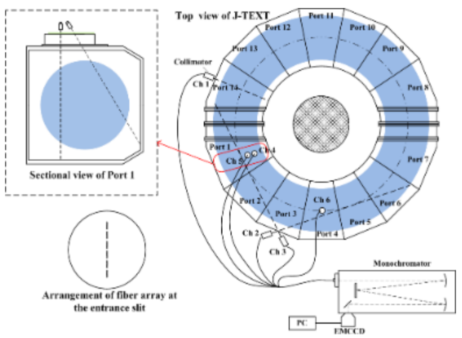




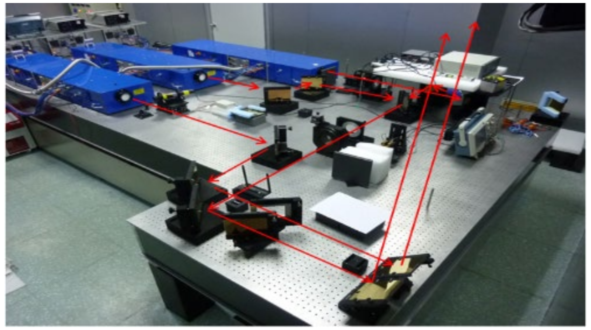


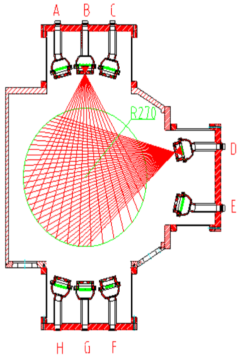


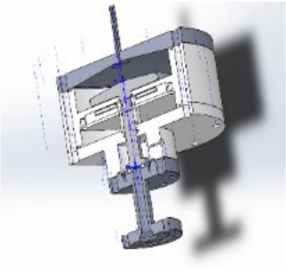




Toroidal arrangement : flux loops , 2D Mirrov Pick-up coils
——Blue developing

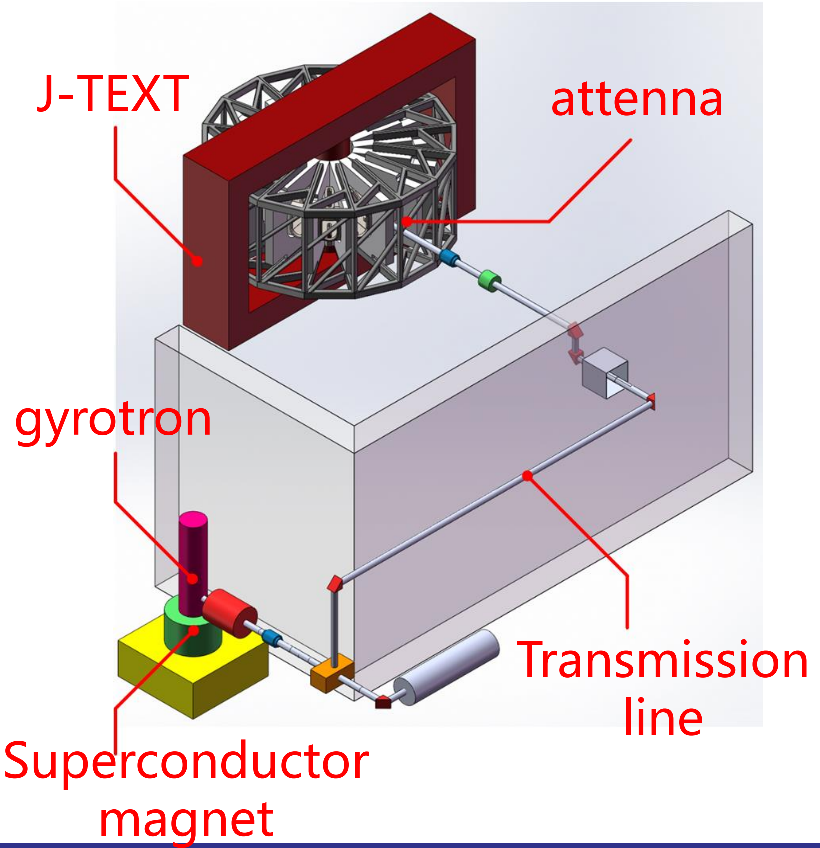


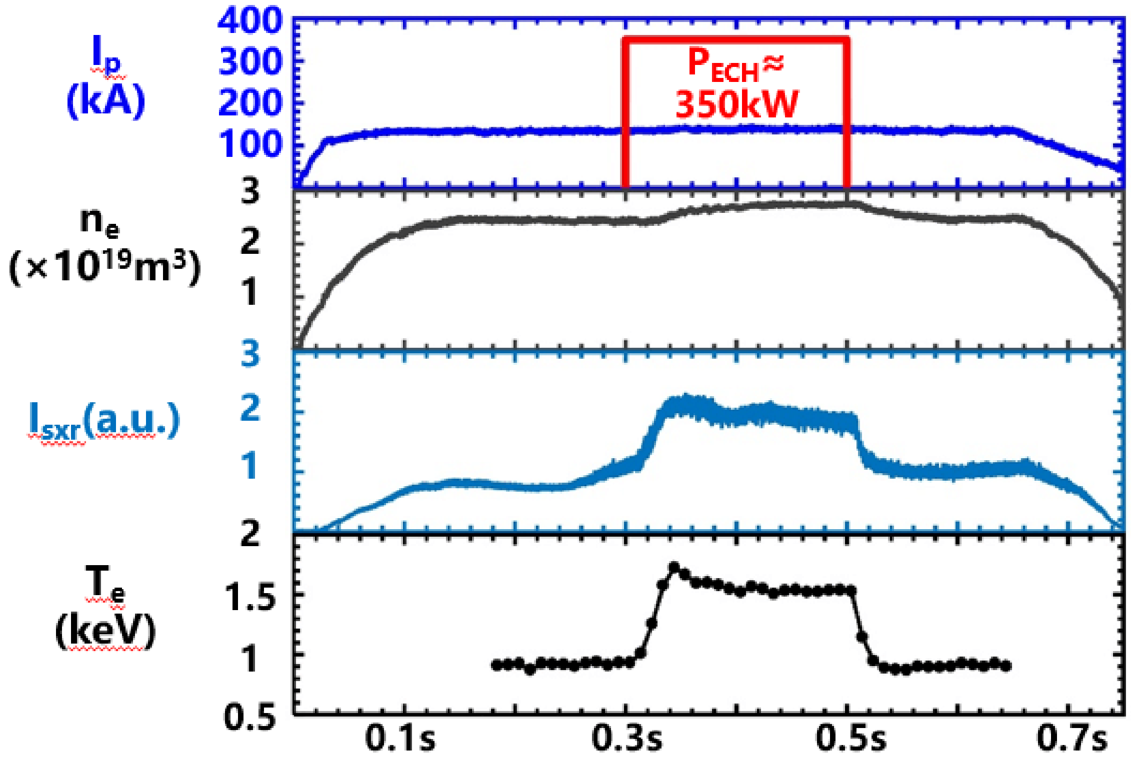




ECRH on J-TEXT reaches Te above 1.5keV

ECRH system parameters on J-TEXT: 105GHz/500kW/1s
Enhanced J-TEXT plasma performance (Te > 1.5keV)
To conduct localized heating and ECCD experiments on J-TEXT





2019 spring campaign

J-TEXT high-field-side divertor configuration

- **Successful discharges in HFS single-null and double-null divertor configurations**
- **Extended operation space of J-TEXT**

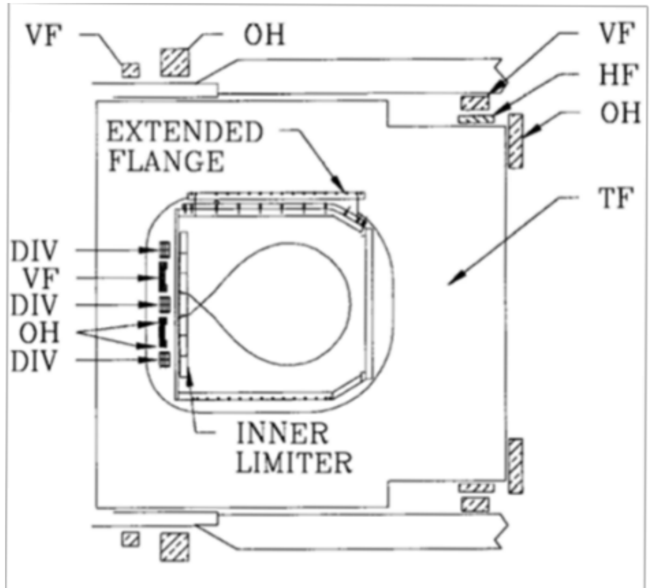


FIGURE 1
Cross-section of TEXT Upgrade showing last closed flux surface for the 200kA/200kA single null diverted discharge.

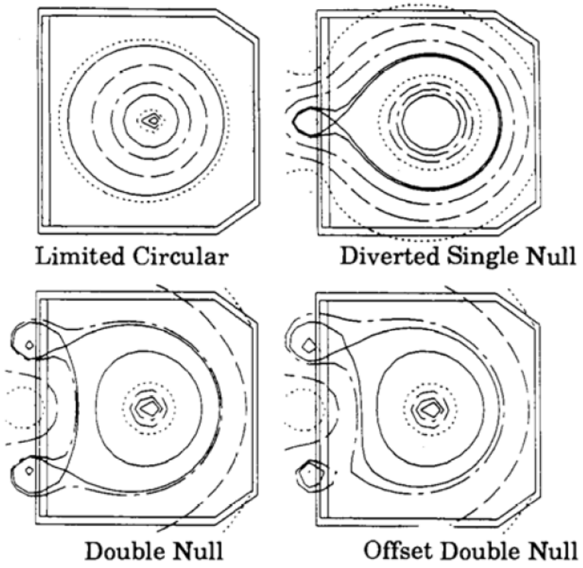
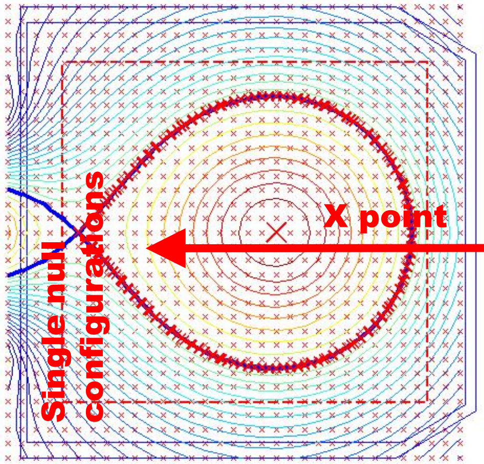
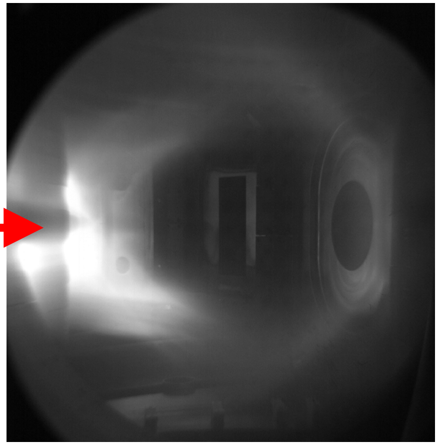


FIGURE 2
Base line configurations for TEXT Upgrade. For 200kA plasma and divertor current; Rp=1.05m.

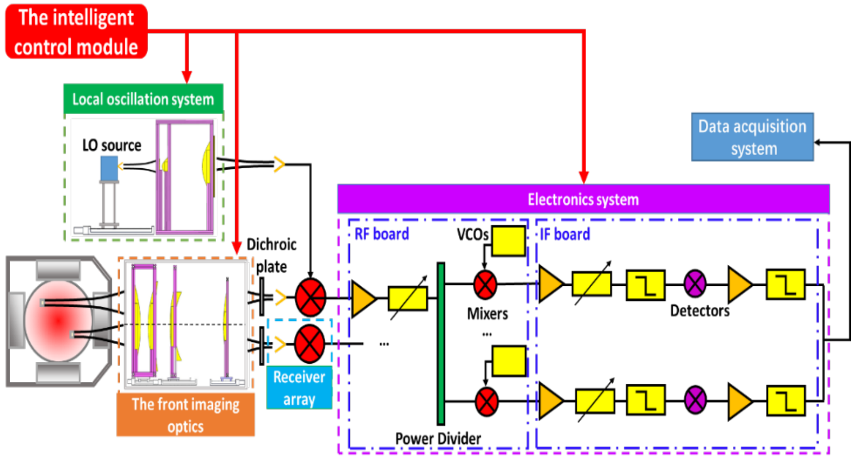




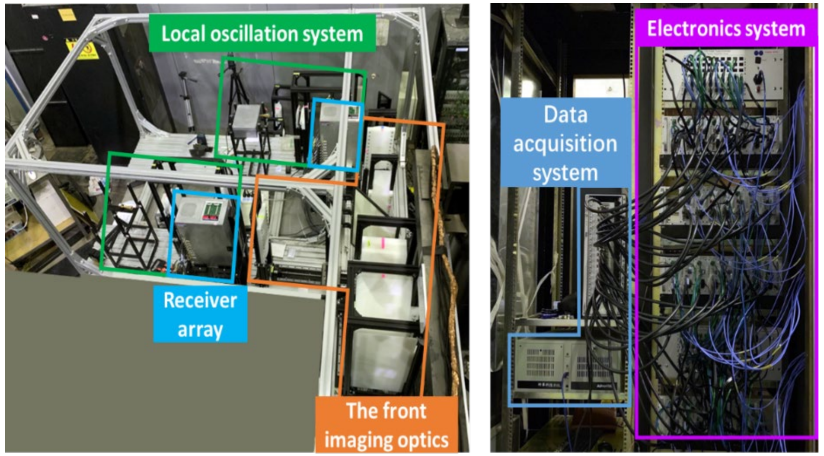
- **Major US collaborators: UT Austin**

Development of the first digital control ECEI system

- A new 256-channel ECEI system has been developed on J-TEXT tokamak.
- It is the **first full-function digital control** ECEI system which can remotely set and control the diagnostic.



Simplified schematic of J-TEXT ECEI system



The layout of the J-TEXT ECEI system

- **Major US collaborators: UC Davis**

Publications：

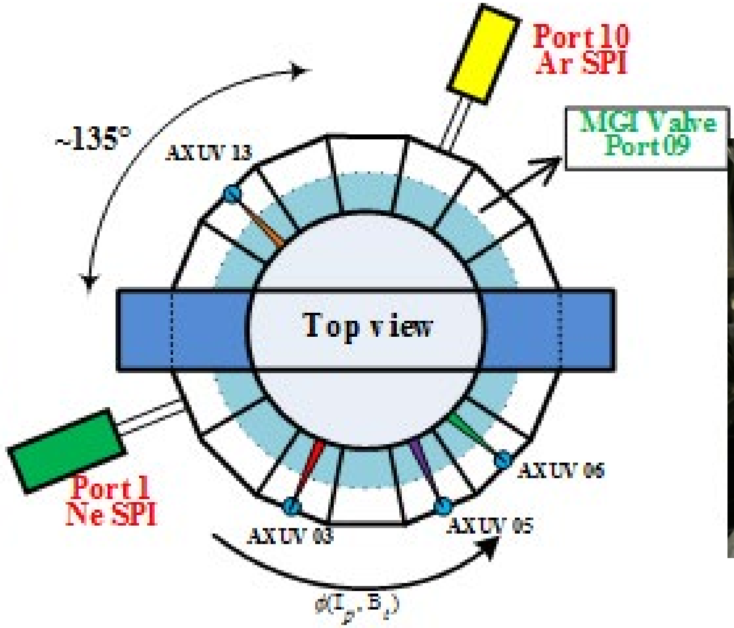
Yang, Z.J., et al., FED, 2020. 153,111494.

Xie, X.L., et al., FED, 2020. 155,111636.

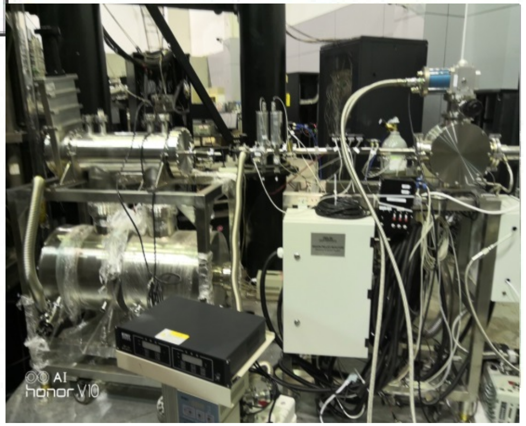
Dual SPI system installed on J-TEXT

	Ar	Ne
Port	10	1
Propellant gas	Ar	He
Pellet diameter (mm)	5	5
Pellet length (mm)	2-8	2-8
quantity	$1-4\times10^{21}$	$1.7-6.7\times10^{21}$
Velocity (m/s)	130-300	150-350

Ne SPI



Ar SPI



- SPI disruption mitigation: Collaboration with GA in the frame of ITPA MHD task force

J-TEXT focuses on key ITER physics areas

Ensuring the success of ITER

- TBM effects
- ELM control
- Disruption mitigation
- Runaway electron control
- Non-activated operation
- Hydrogenic inventory control
- Scenario demonstration discharges
- Neoclassical tearing modes
- Divertor heat transport
- Startup and rampdown

J-TEXT focus areas:

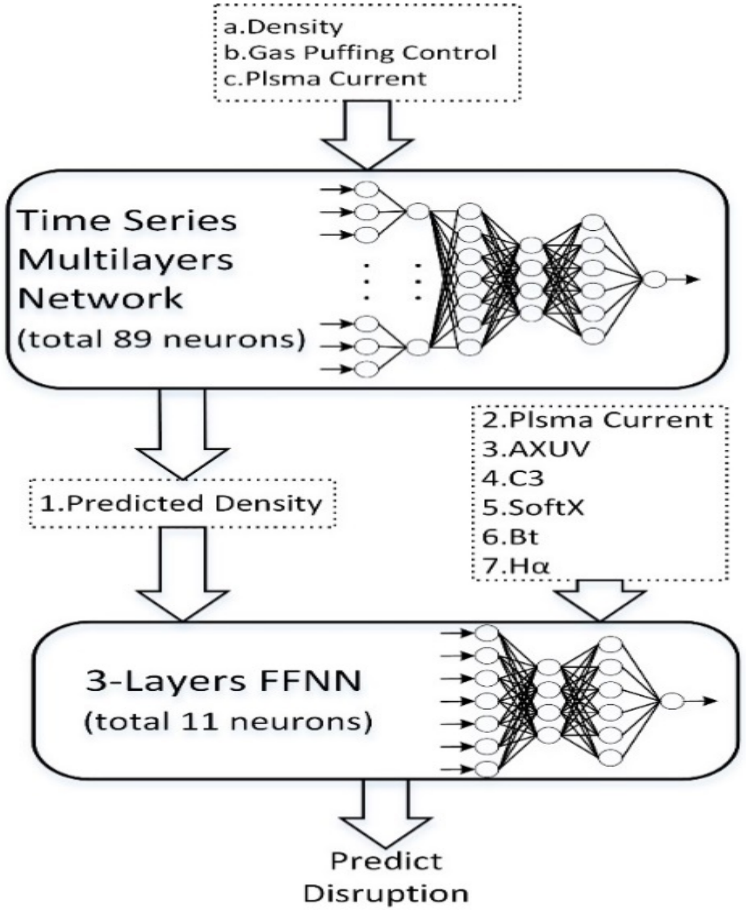
MHD instability control

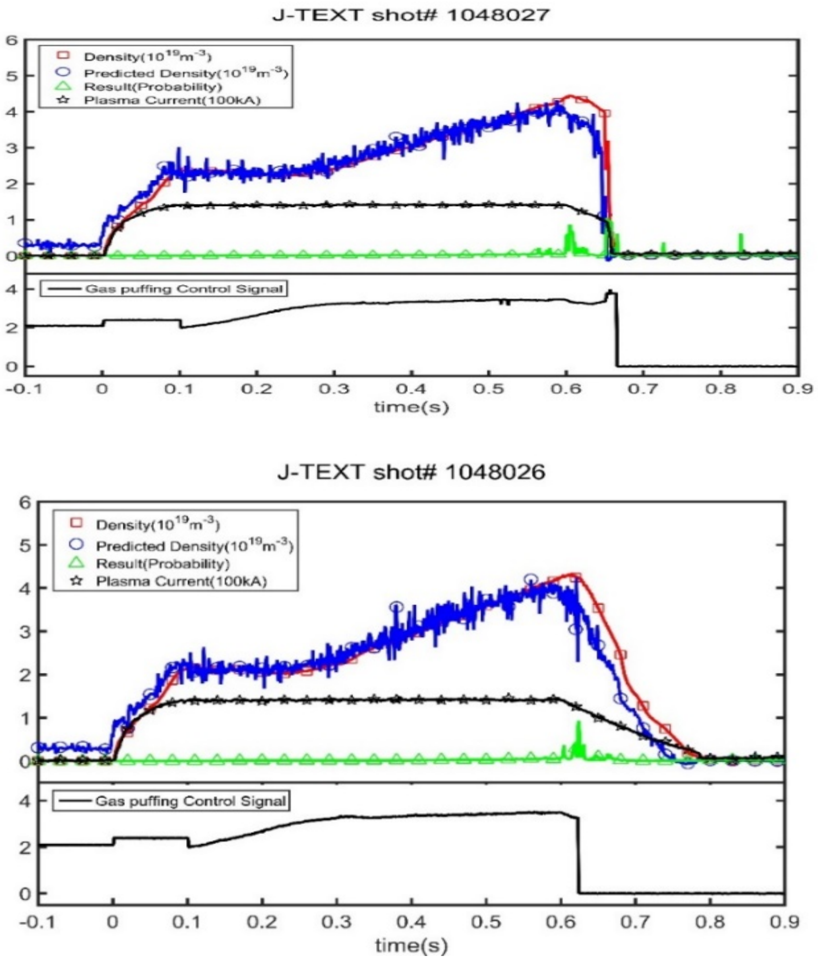
Disruption avoidance

RE suppression & dissipation

Neural network developed for disruption prediction

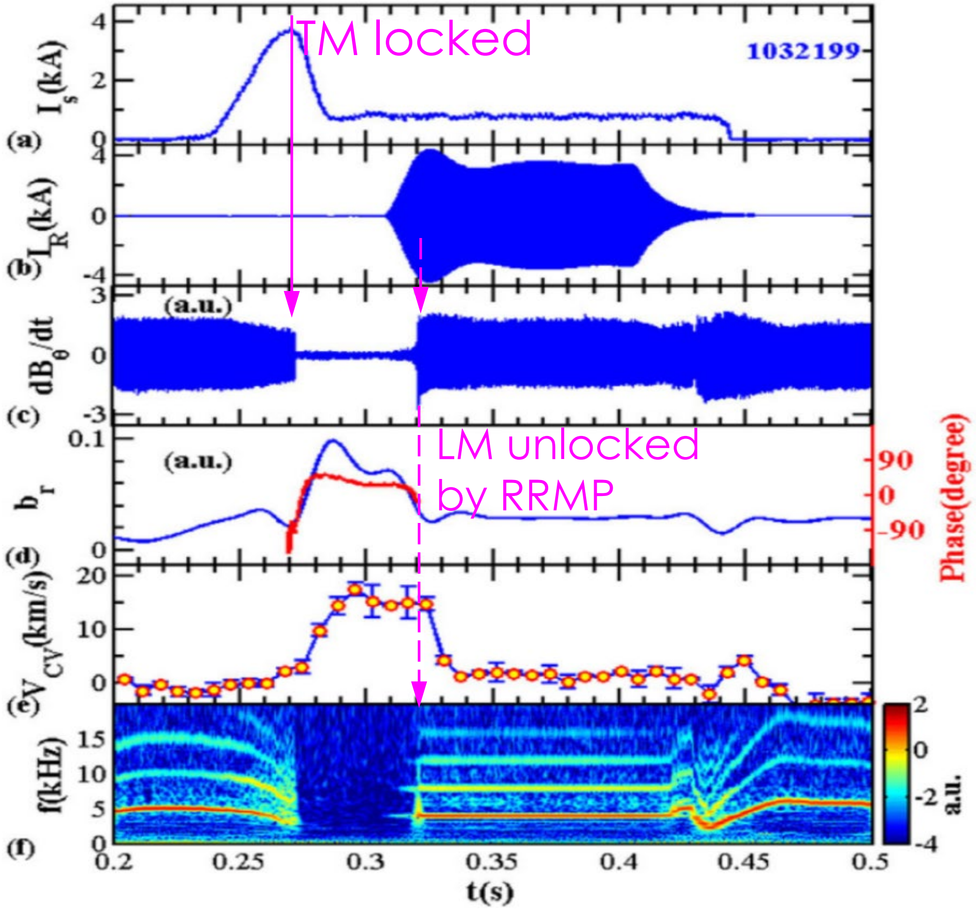
Hybrid neural network for density limit disruptions prediction and avoidance





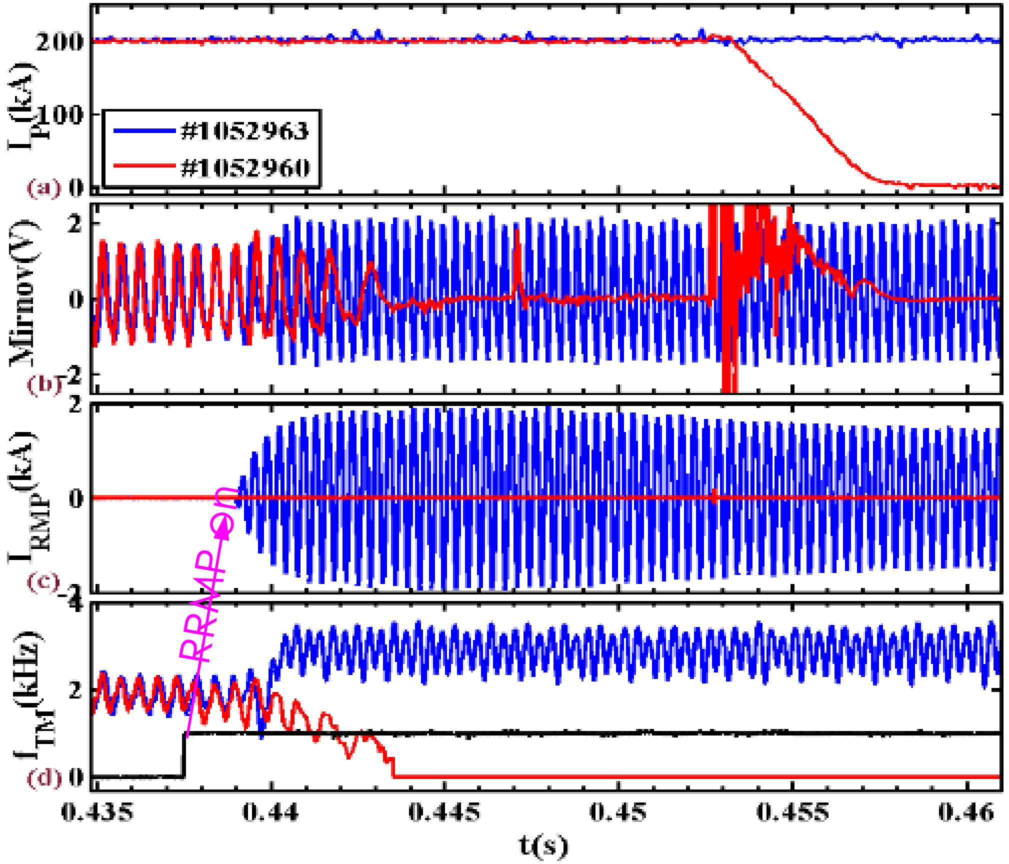
Zheng W, et al., Nuclear Fusion, 58 (2018) 056016

DRMP TM control avoids disruption onset



Rotating RMP unlocks TM and drives island rotation

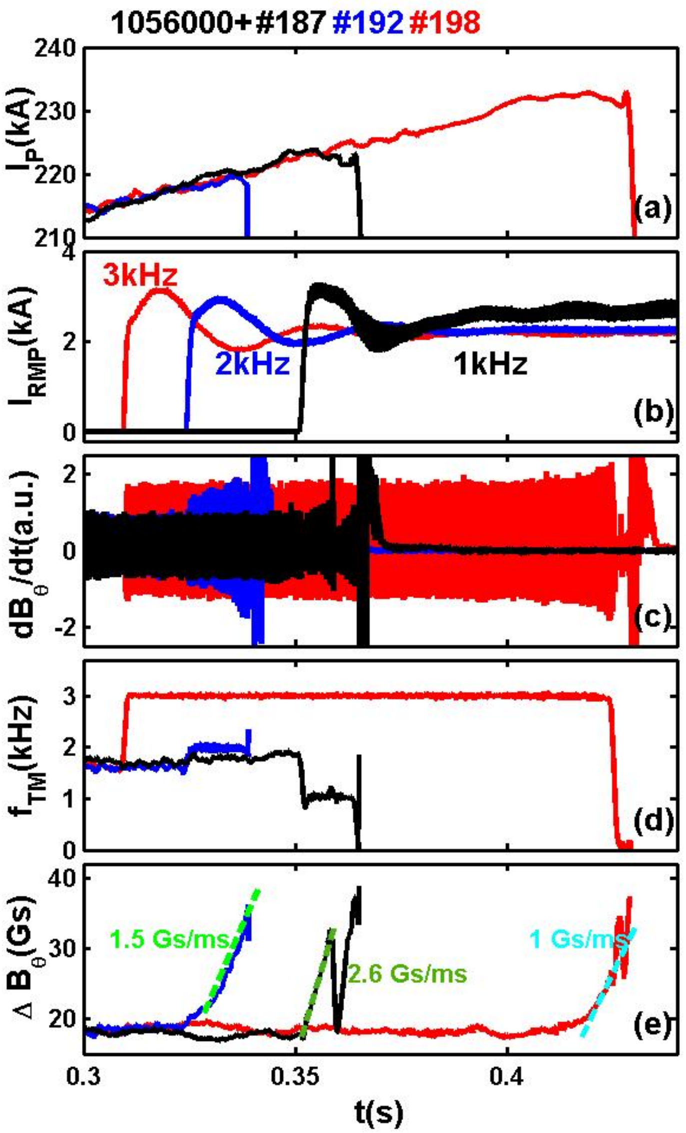
Jin H, PPCF 2015，Wang N, NF 2019

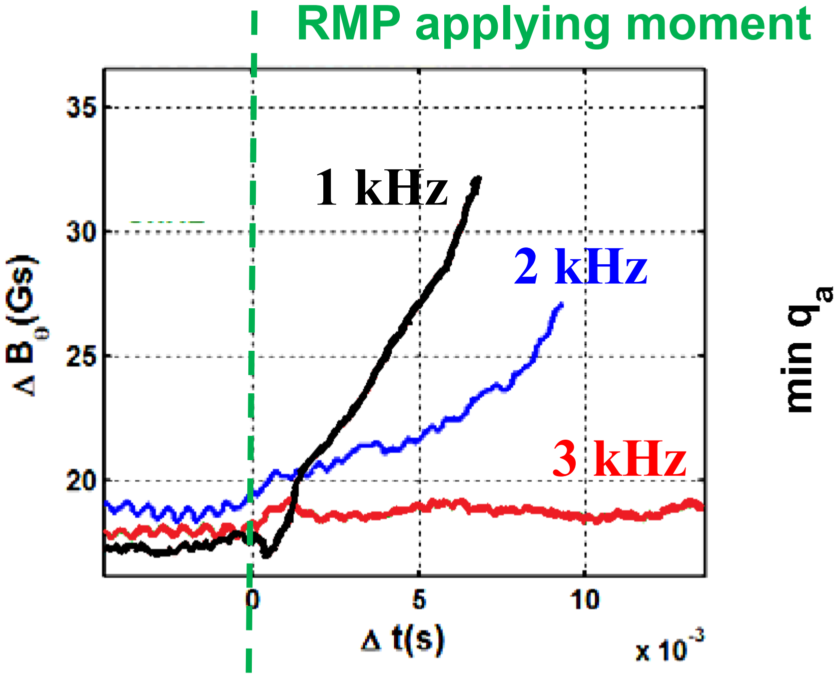


Rotating RMP accelerates rotation and avoids disruption

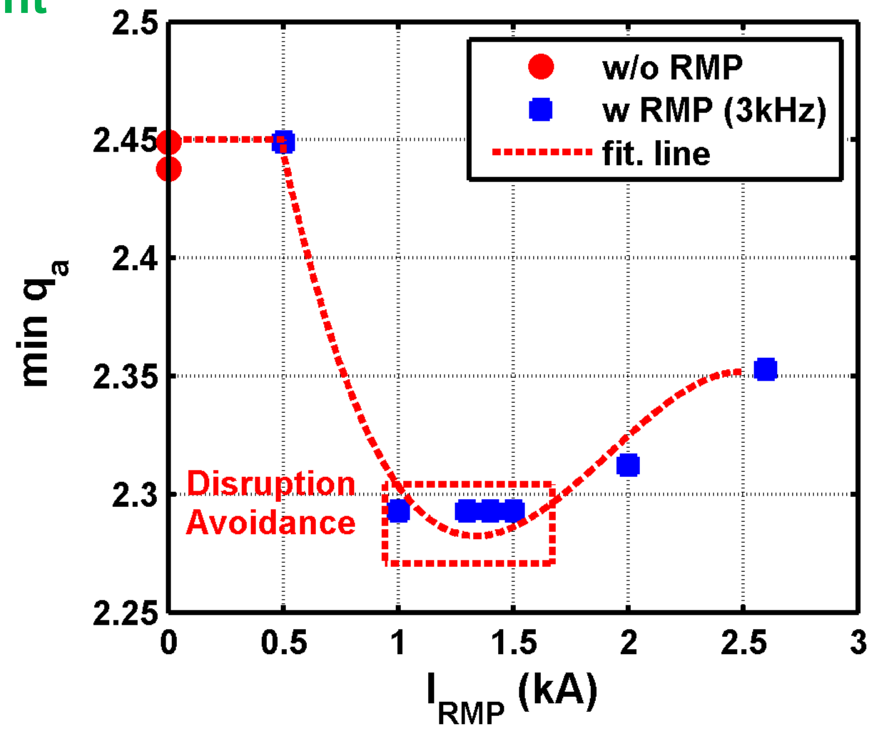
Ding Y H, IAEA FEC 2018

DRMP regime optimized for disruption control





Higher frequency rotating RMP more effective on suppressing LM amplitude



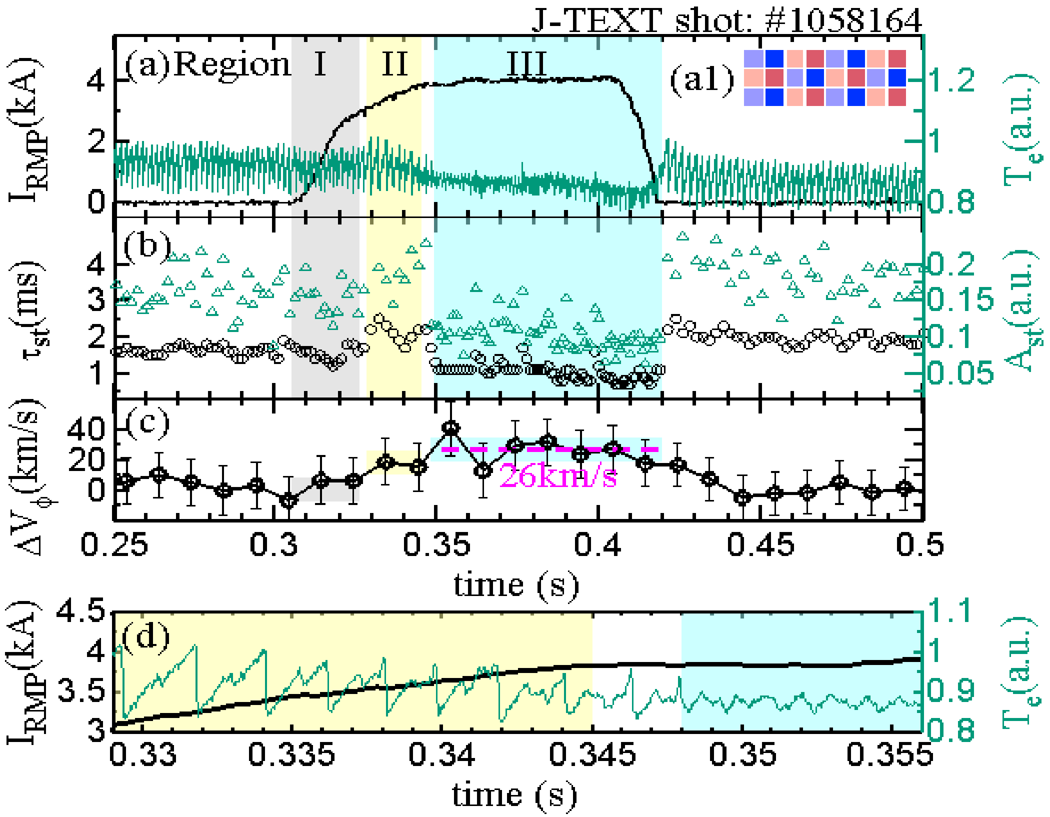
Nonlinear RMP effects on q profile allow disruption avoidance

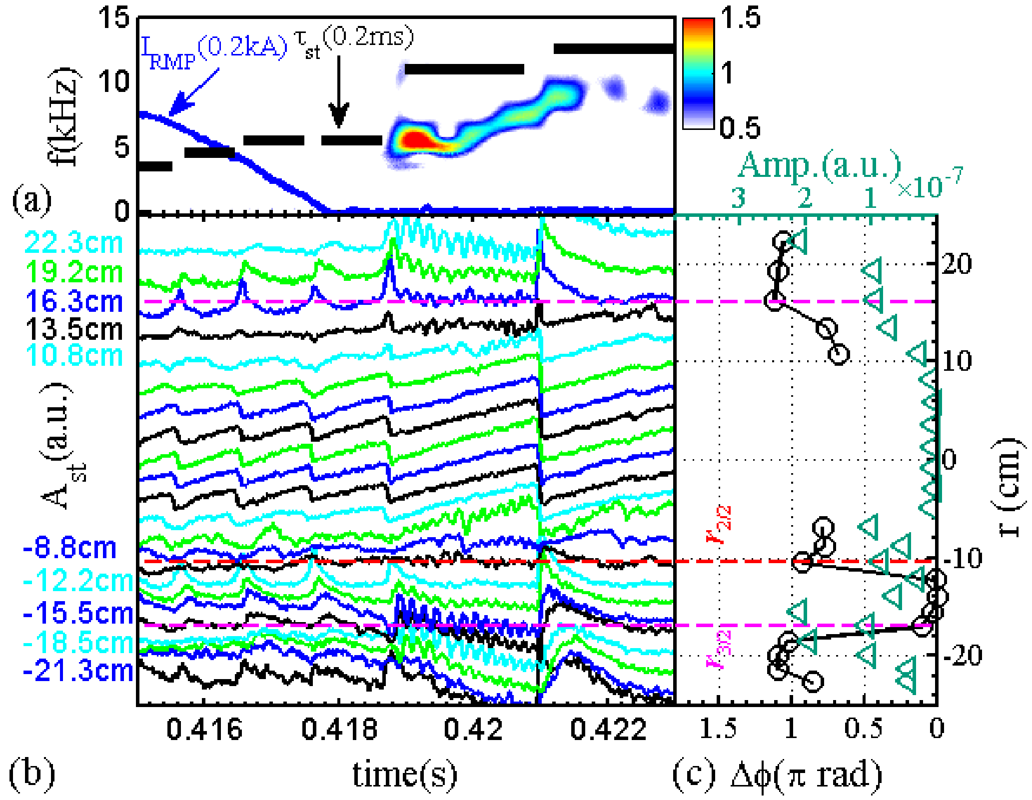
Li D, NF 2020

Effects of 2/2 RMP on sawteeth

- Mitigation of sawteeth by 2/2 RMP in region with qa < 2.8 and ne < 2×1019m-3 in J-TEXT (Irmp=4 kA)
- Core rotation driven in co-Ip direction
- Reduction of sawteeth is highly related with trigger of 2/2 island

Nuclear Fusion, 60 (2020) 126002





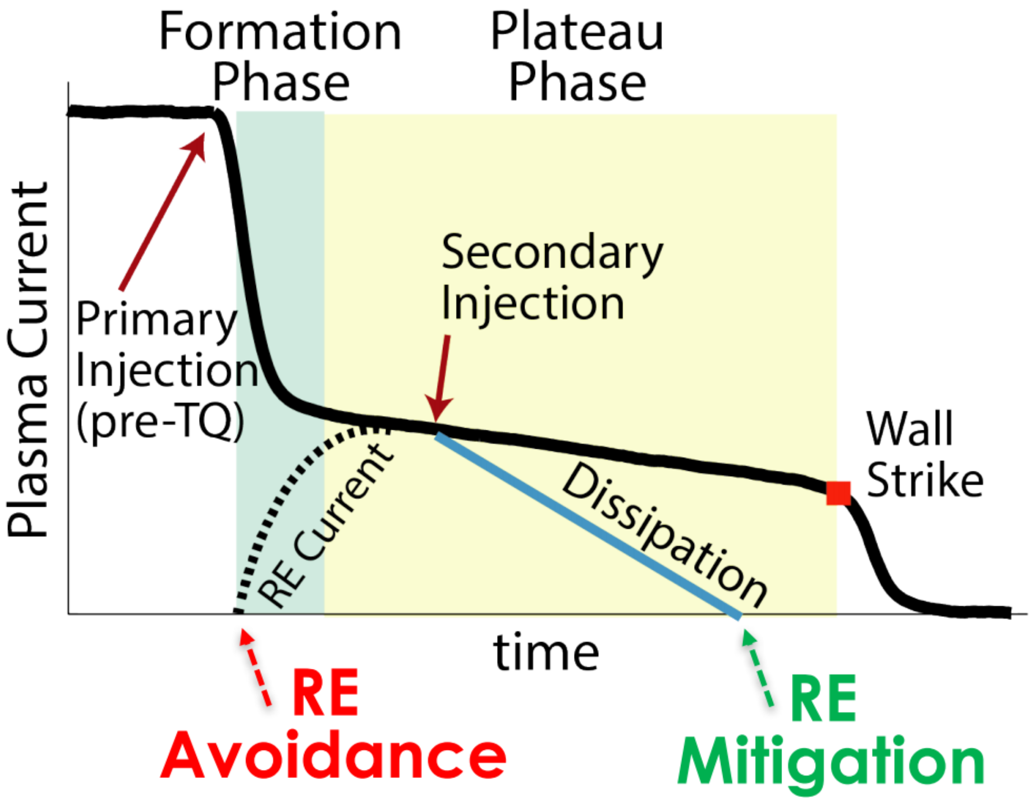
- New scheme for sawteeth control using RMPs with m/n = 1 but m, n > 1

Novel schemes developed for RE control

Ensuring the success of ITER

- TBM effects
- ELM control
- Disruption mitigation
- Runaway electron control
- Non-activated operation
- Hydrogenic inventory control
- Scenario demonstration discharges
- Neoclassical tearing modes
- Divertor heat transport
- Startup and rampdown

Disruption mitigation: RMP and electrode biasing control LM and avoid disruption onset



Runaway electron current control schemes

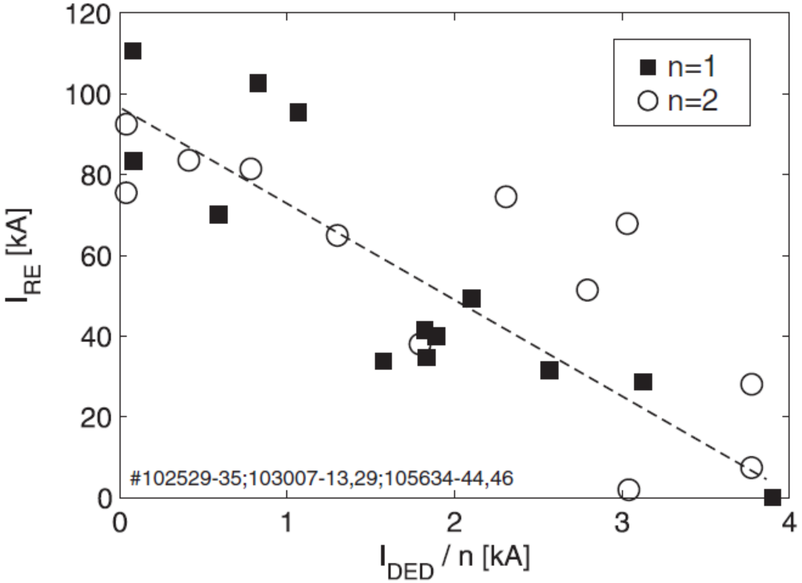
◆ **Schemes-I:**

RE suppression via RMP/SMBI/MGI/ETC

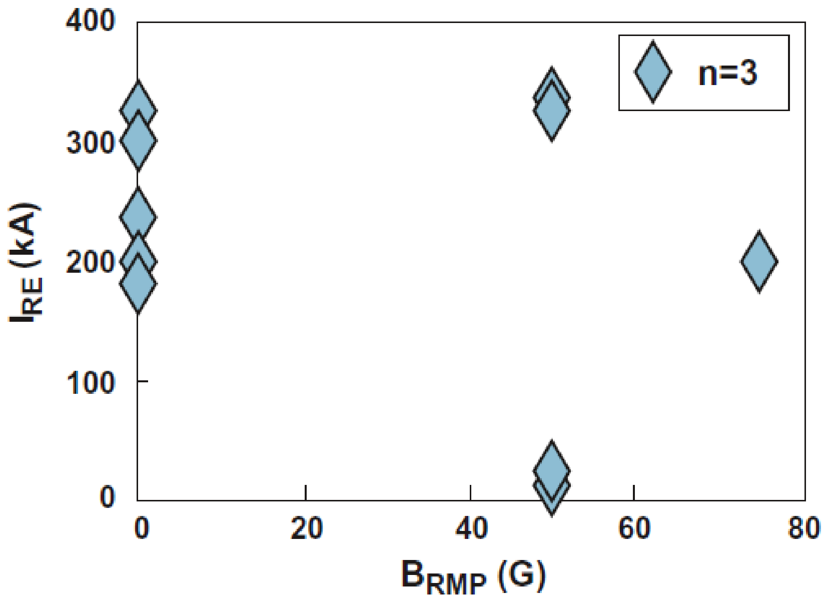
◆ **Schemes-II:**

RE dissipation via MGI and SPI

Schemes-I: RE suppression (RMP)



RE suppression in TEXTOR;
Lehnen, M. PRL 2008



RE suppression in DIII-D;
Hollmann E. M. 2011 J. Nucl. Mater.

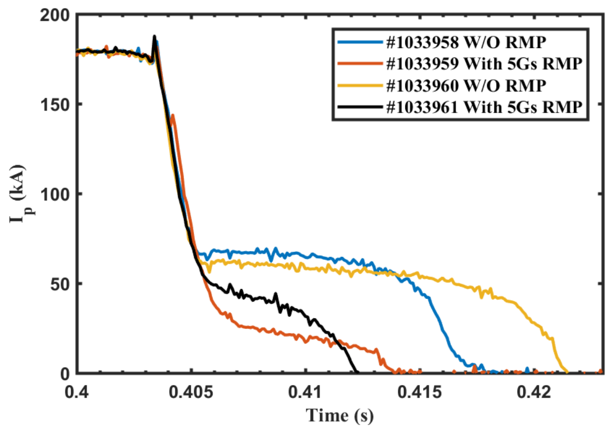
3 RE control regimes found on J-TEXT:

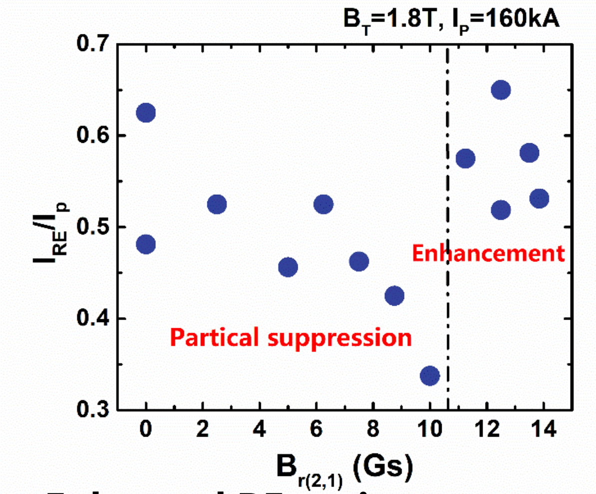
1. Partial suppression

2. Enhanced RE

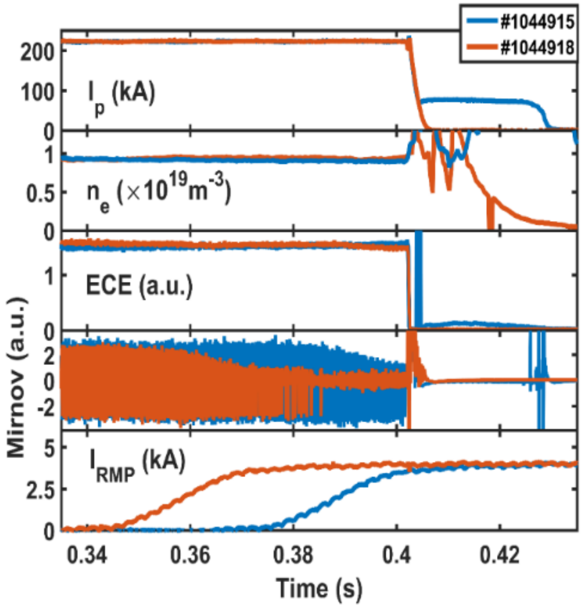
3. Full suppression by (a) Mode locking; (b) RMP penetration

Full RE suppression achieved via RMP mode locking & penetration

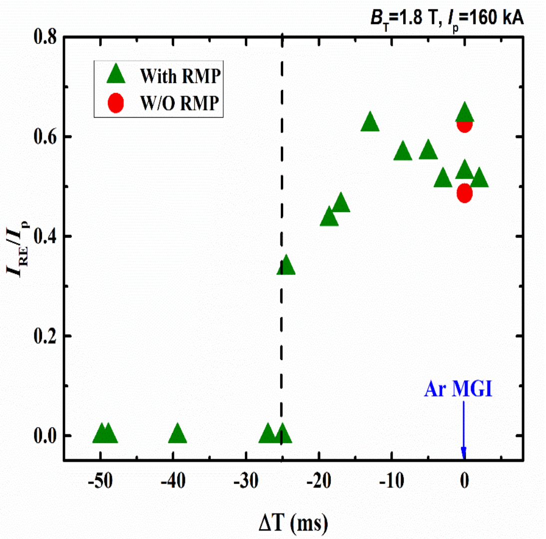




Partial RE suppression – Enhanced RE regimes

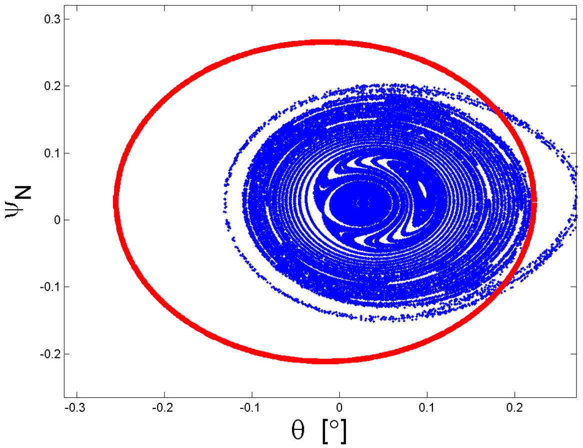


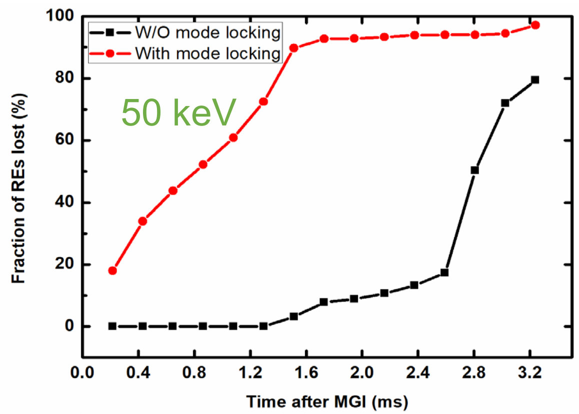
Full RE suppression due to mode locking



Full RE suppression due to RMP penetration

$E=18MeV; I_{DRMP}=6kA$



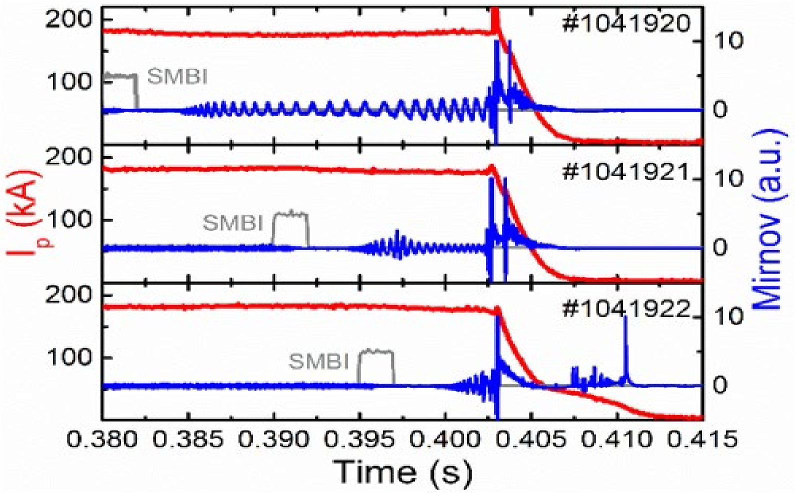


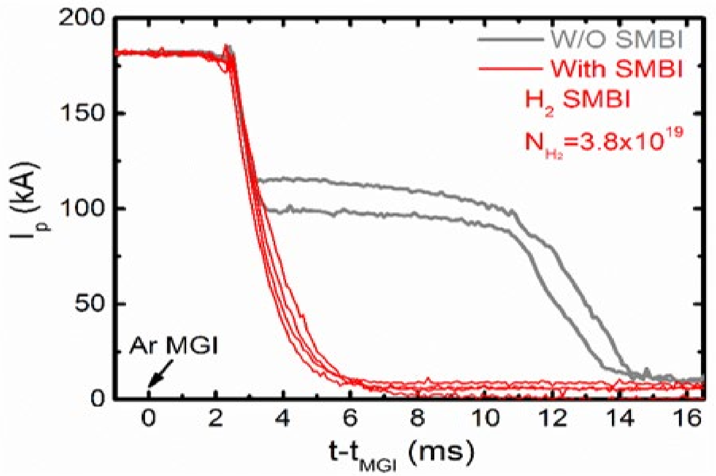
NIMROD simulation show RE loss enhancement in presence of islands

- **Major US collaborators: NIMROD team (US)**

Jiang, Z. H., et. al., Nuclear Fusion 56(2016) 092012.
Chen, Z. Y., et al., Nuclear Fusion 56(2016) 112013.
Chen, Z.Y.,et al., Nuclear Fusion 56 (2016) 074001 Letter.
Z. F. Lin, Z.Y.Chen et al., Nucl. Fusion 58 (2018) 126024.
Z. F. Lin, Z.Y.Chen et al., PPCF 61 (2019) 024005.
Z. F. Lin, et al., PPCF 61 (2019) in press.

Schemes-I: RE suppression (SMBI)

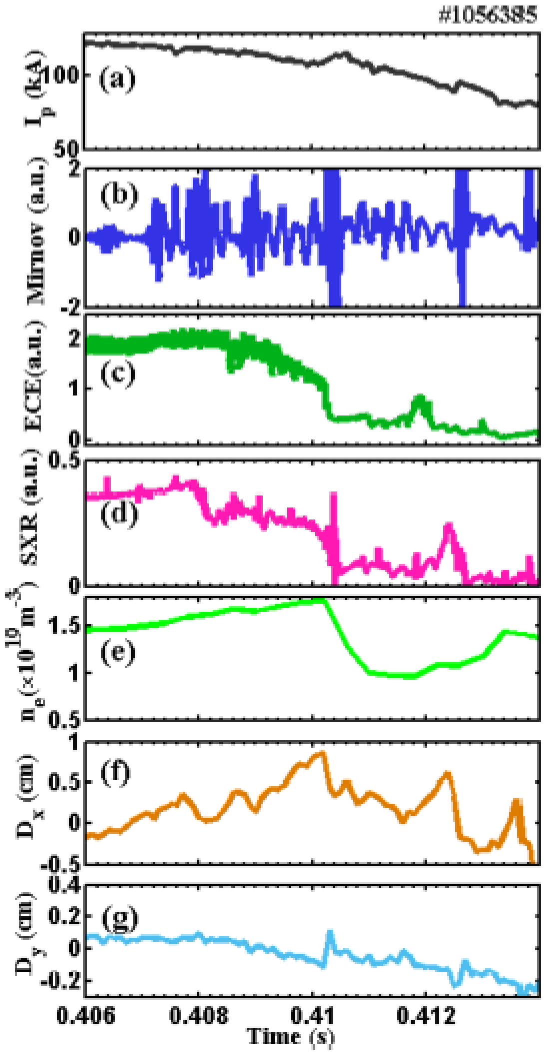


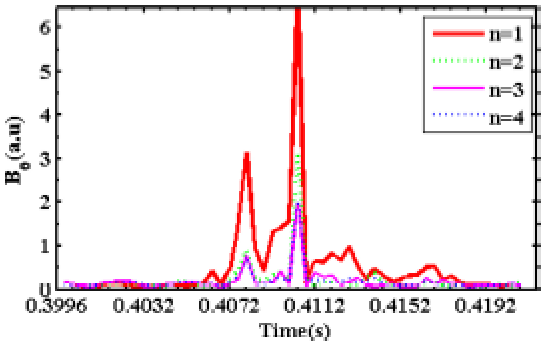


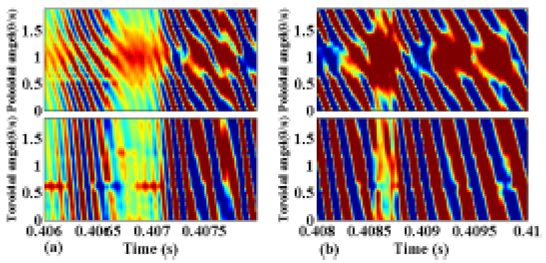
- Developed novel RE suppression scheme based on SMBI induced magnetic perturbations.
- Combined MGI+SMBI scheme enhances magnetic perturbations during disruption and enable RE suppression.

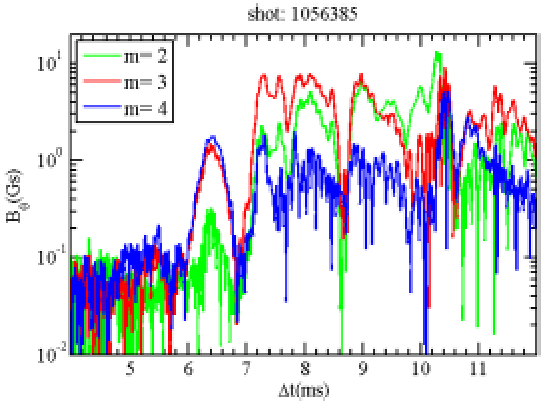
Plasma Phys. Control. Fusion 59 (2017) 085002
Nucl. Fusion 60, 066004 (2020)

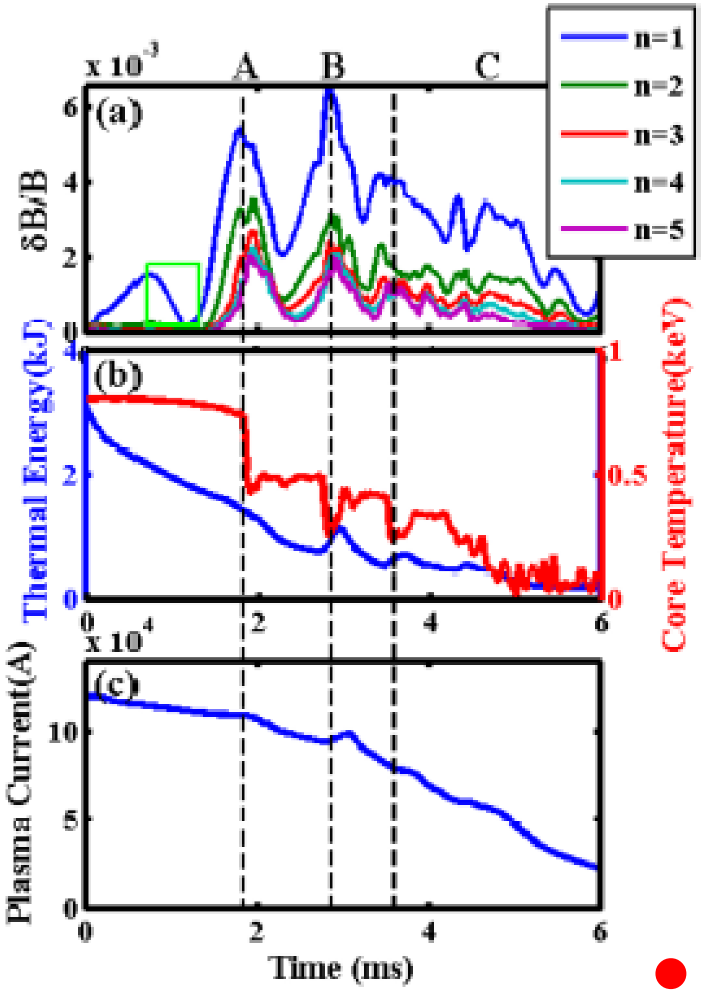
Minor disruptions triggered by supersonic molecular beam injection (SMBI) on J-TEXT tokamak









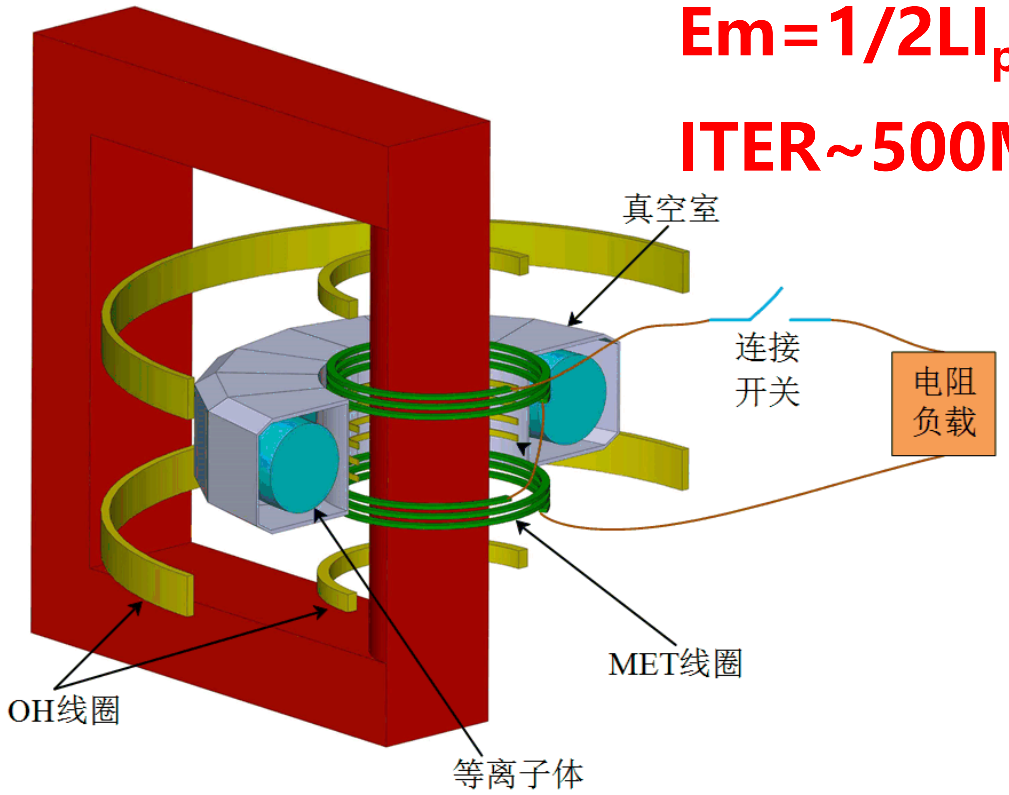


Nucl. Fusion 60, 066004 (2020)

- The core plasma temperature decreases to less than tens of eVs after a relatively long period of multistage thermal collapse.
- Different MHD modes appear as impurity cold front propagates toward the *q* = 2 surface.

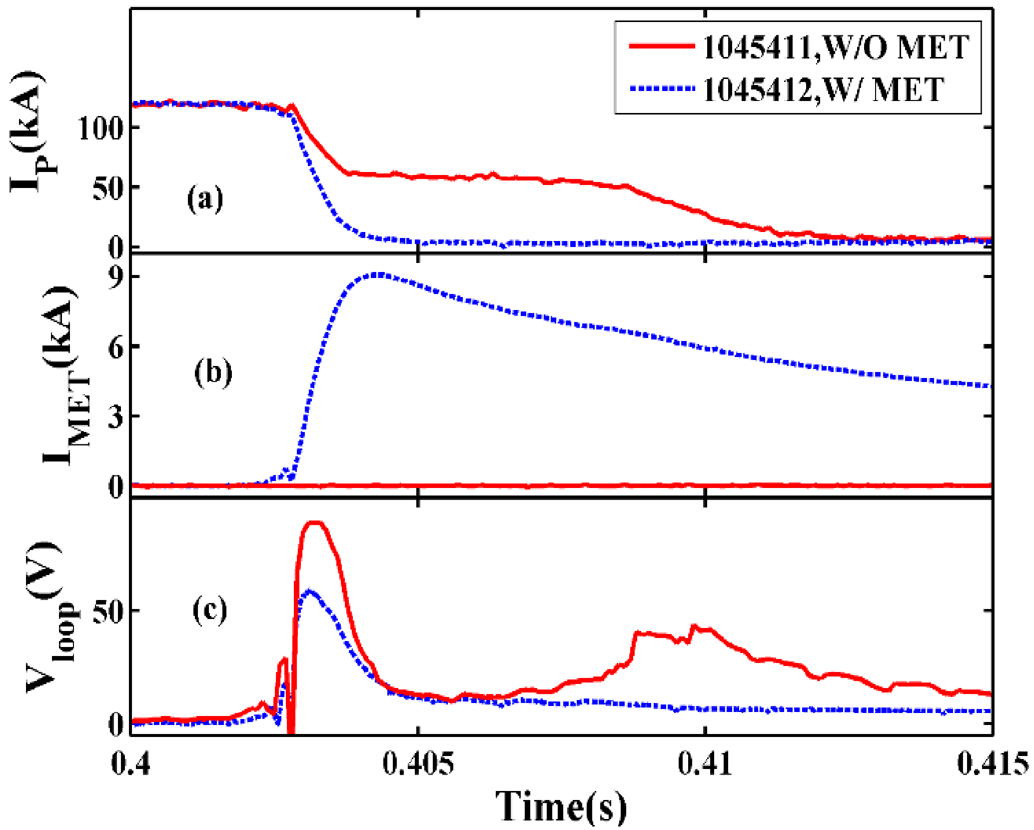
- **Major US collaborators:** **NIMROD team (US)**

Schemes-I: RE suppression (ETC-Energy Transfer Coil)



$Em=1/2LI_p^2$

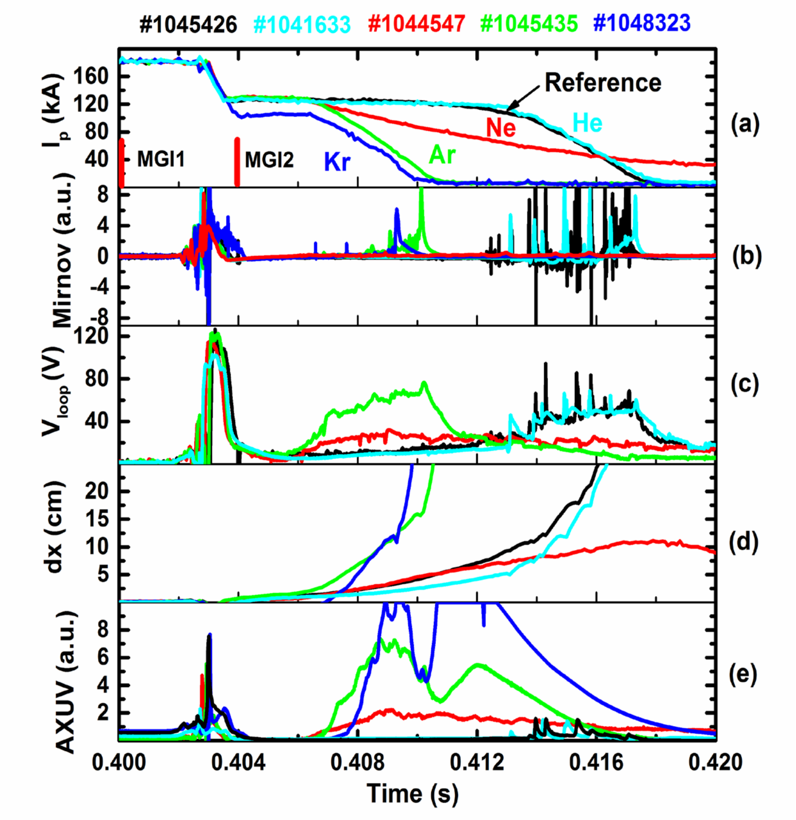
ITER~500MJ



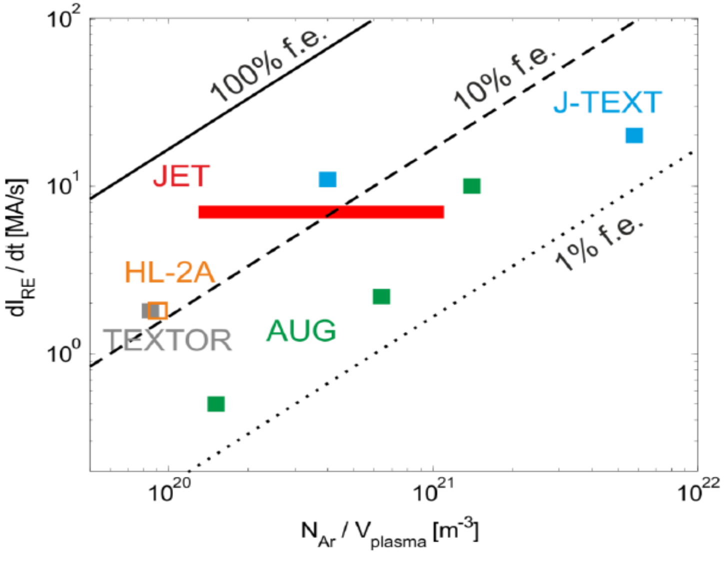
Novel ETC system provides a new scheme for disruption mitigation

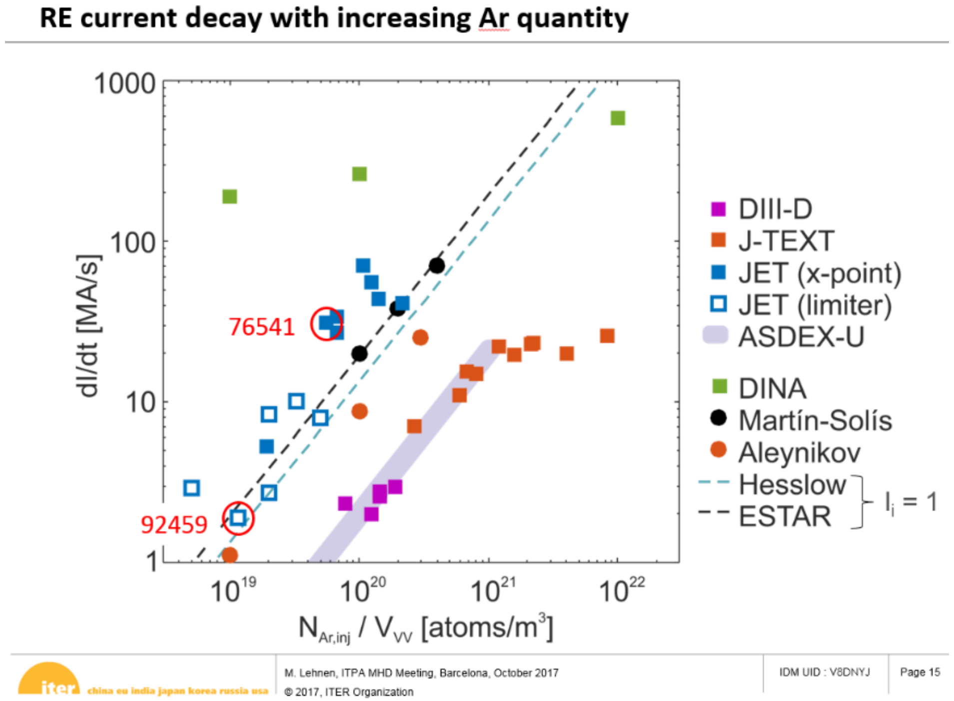
ETC can effectively reduce loop voltage during disruption, thus enable RE suppression.

Schemes-II: RE dissipation (MGI) -ITPA



RE current decay rate as function of Ar density



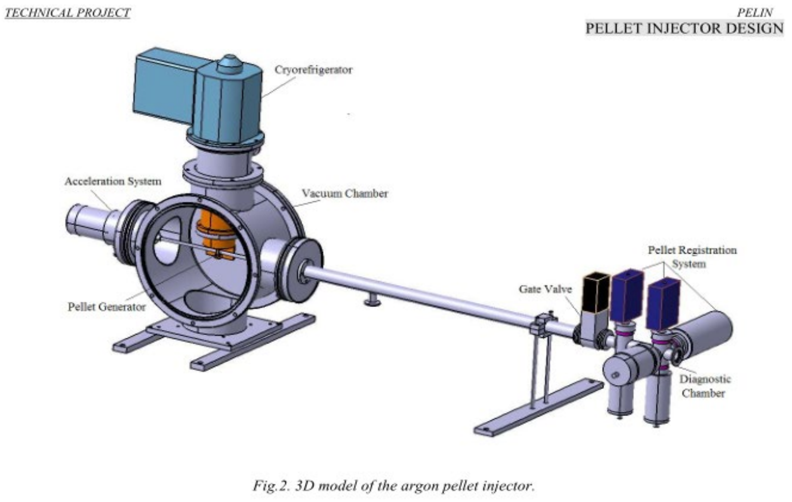


ITPA WG11: Control of Locked Modes

ITPA MDC-19 Error Field Correction for ITER

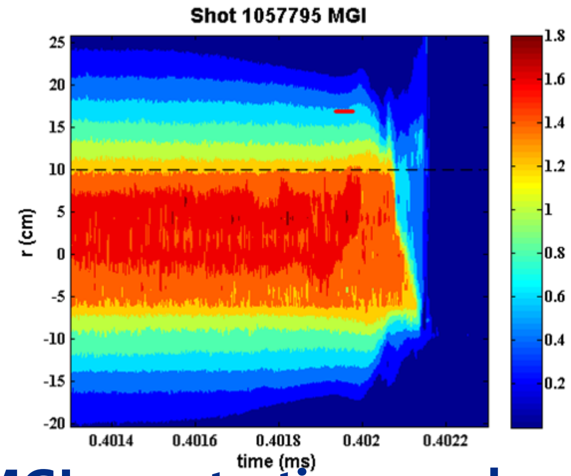
- **Dissipation rate ~ 26MA/s, highest so far in world;**
- **Dissipation rate saturation found and confirmed on DIII-D**

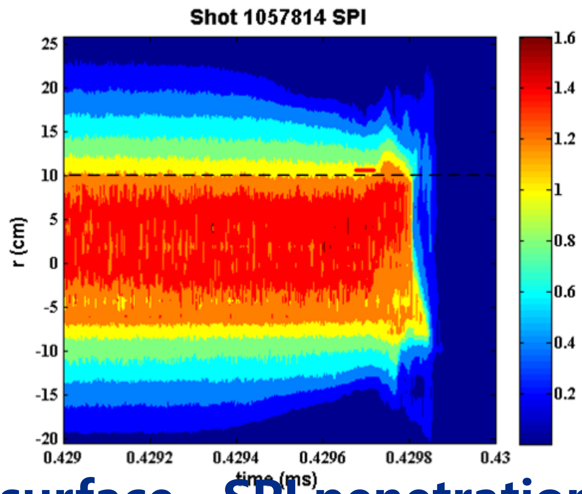
Schemes-II: RE dissipation（SPI）-ITPA

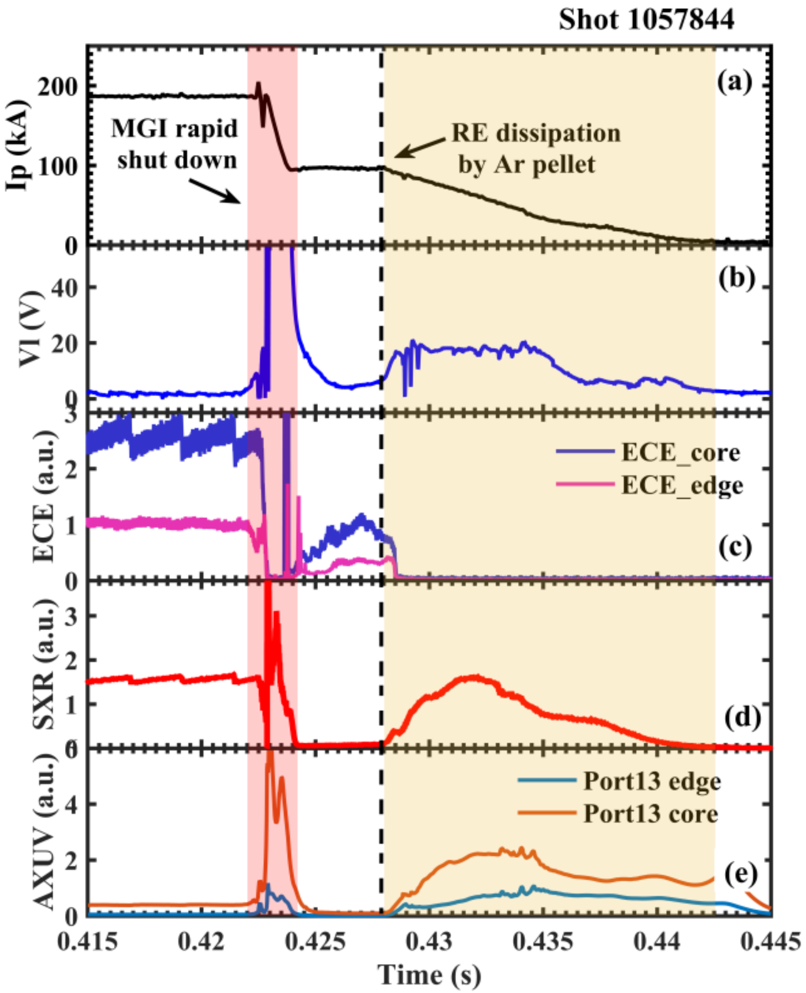


SPI adopted as top option for disruption mitigation on ITER

Dual SPI system installed on J-TEXT，and successfully applied to disruption mitigation experiments.





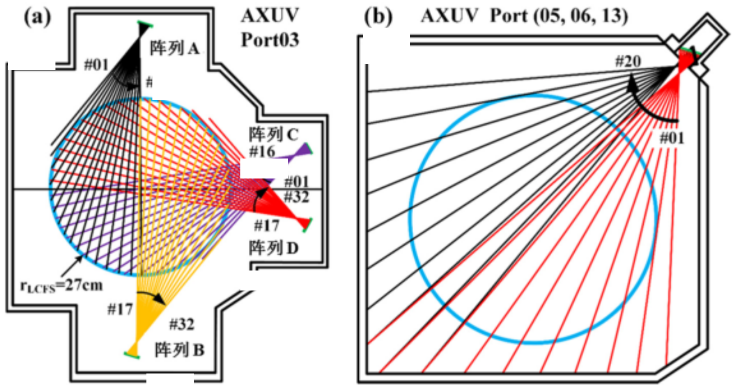


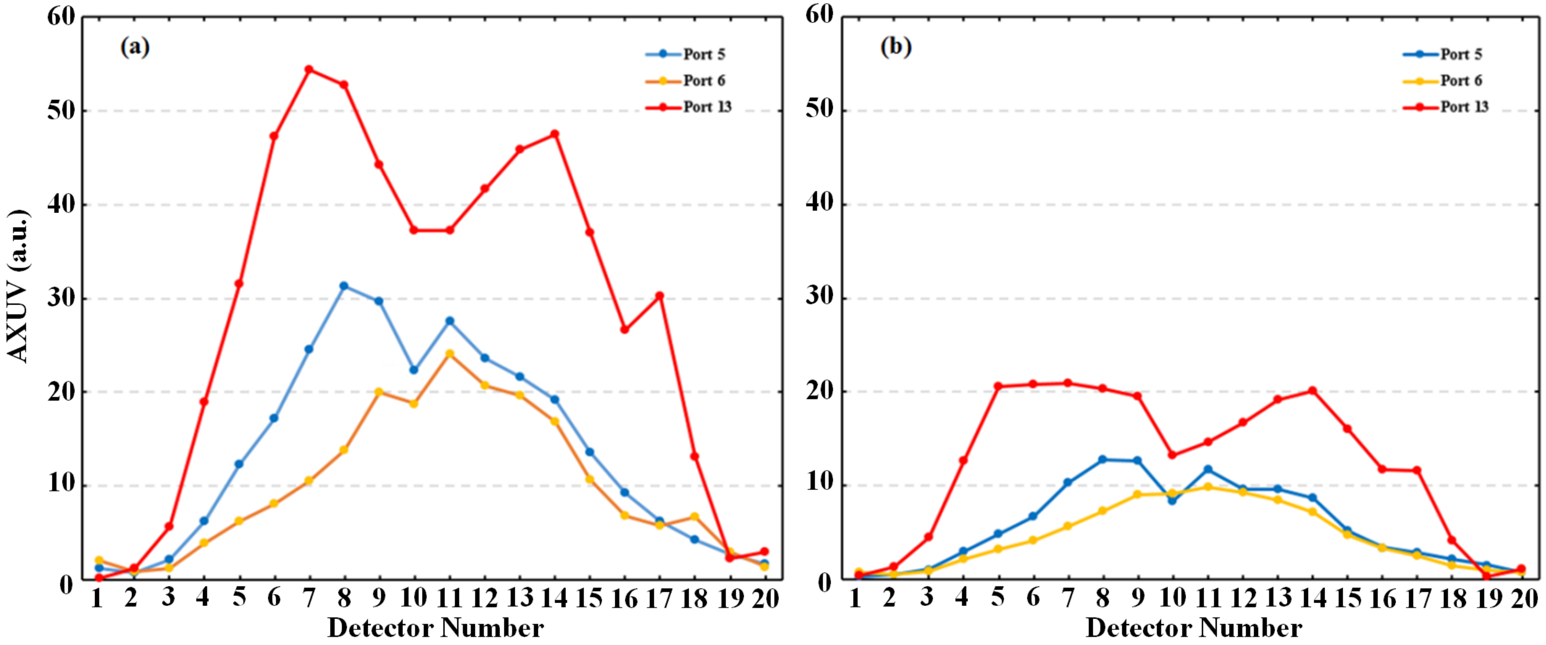
MGI penetration reaches q=2 surface，SPI penetration reaches q=1 surface and enhances mitigation efficiency

SPI dissipation of RE current

Radiation asymmetry reduced by dual SPIs

- In single SPI, **there is a strong radiation asymmetry**. The radiation in Port 13, which is closed to the injection port, is much stronger than that in Port 5 and 6.
- The localized thermal radiation is **reduced** by dual SPIs.





The thermal radiation in TQ phase, (a) single Ne SPI; (b) dual SPIs

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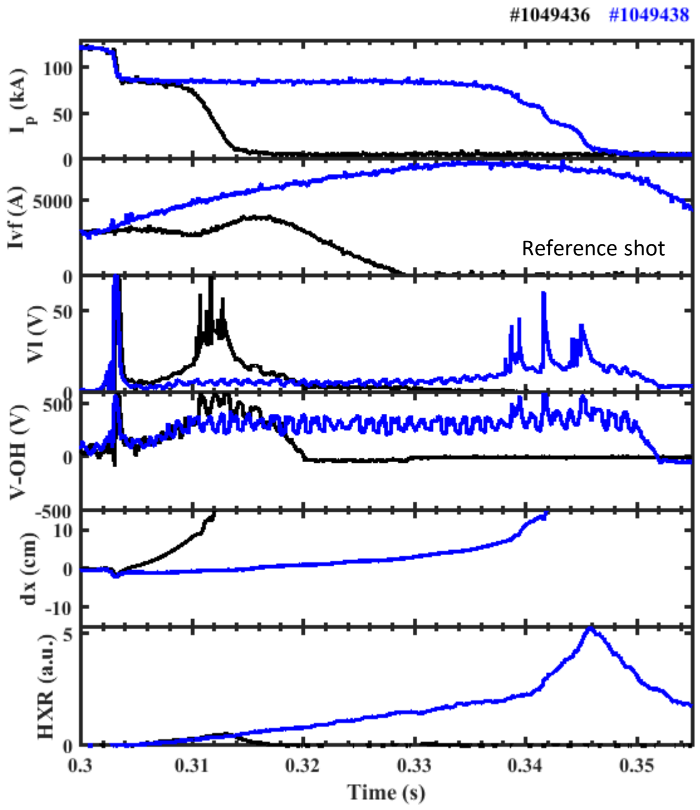
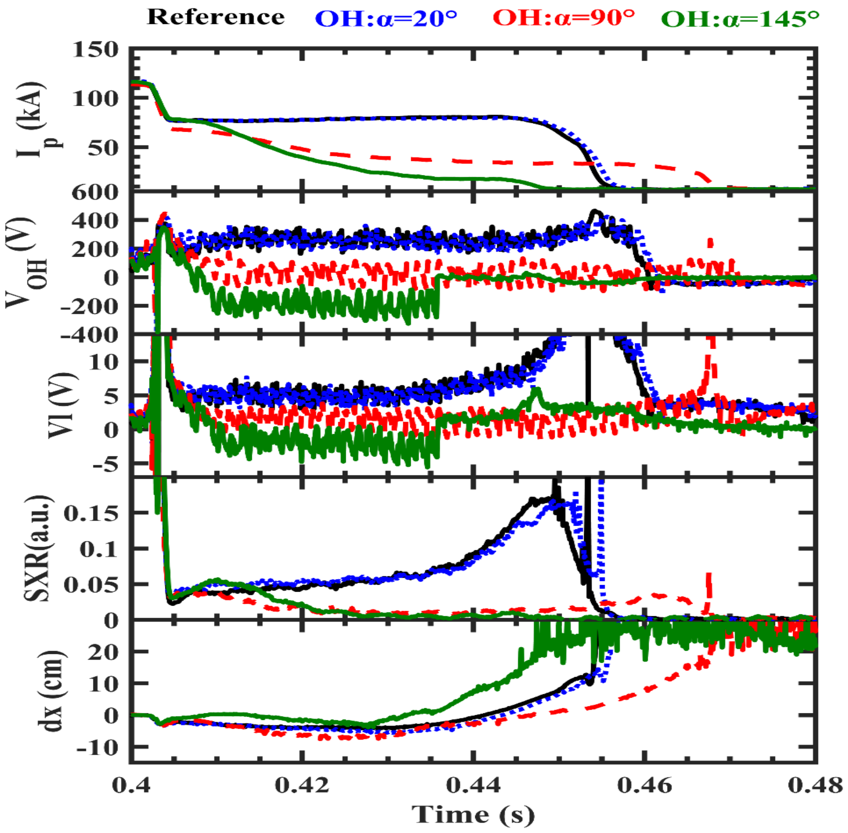
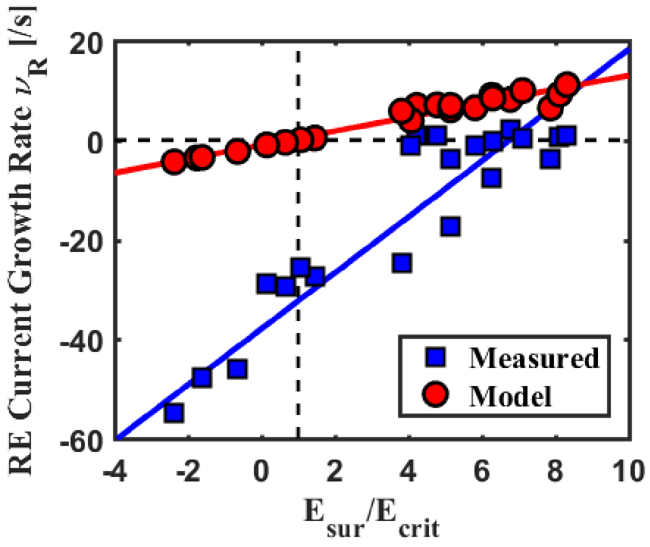
Schemes-II: RE dissipation (E field reversal – soft landing)



- Active RE current control extends plateau duration to 30-80ms.



- Electric field reversal dissipates RE current (-4MA/s), leads to soft-landing.



Critical electric fields for zero RE current growth rate, where measured value 6 times of theory prediction.

Dai A. J. et al., Plasma Phys. Control. Fusion 60 (2018) 055003

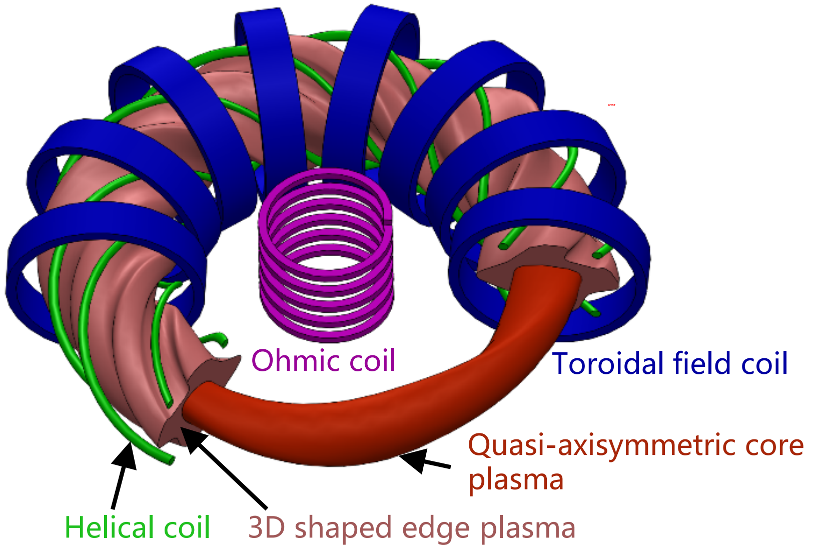
Summary and future work

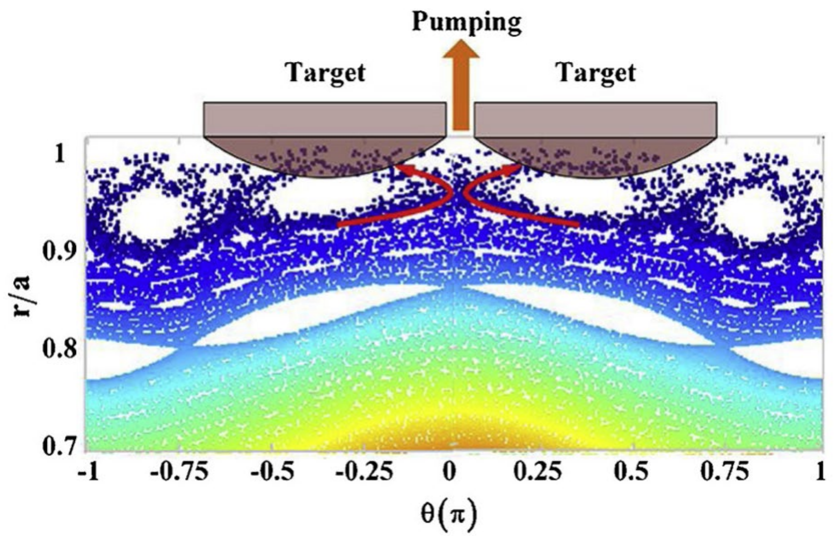
J-TEXT has made major progresses on

- **RMP-aided disruption mitigation**
- **Runaway electron current suppression and dissipation**

Future work continues ITER-relevant physics on:

- **3D configuration optimization for disruption and thermal transport control**
- **Novel divertor design study for fusion reactor**





2021-23 J-TEXT-US MFC collaboration plan

J-TEXT	PRC > US	US > PRC
UT-Austin	High-field side diverter operation and control	Study impurity transport in presence of RMP; ECE upgrade and CECE development
UC-Davis		High resolution visualization diagnostic; Smart feedback control development for diagnostics; Joint experiment for plasma disruption avoidance
General Atomics	Study of dual SPI on radiation and electron density asymmetry during fast shutdown	
UC-San Diego	Mean field model of the L→H transition in a stochastic magnetic field	
UW-Madison	MHD theory and simulation for: tokamak plasmas in Q>5 and B>10T regimes; FRC and stellarator plasmas	Disruption physics collaboration