OV/P-1203: Advances in physics and applications of 3D magnetic perturbations on J-TEXT

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* See the Appendix of *Liang Y. et al 2019 Nucl. Fusion 59 112016*

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1. Summary

Over the last 2 years, the J-TEXT researches has contributed to the impacts of 3D MP fields on MHD instabilities, disruptions.

- Three major achievements have been made on J-TEXT in supporting for the expanded operation regions and diagnostic capabilities, i.e. the 105 GHz/500 kW/1 s ECRH system, the poloidal divertor configuration and upgrades of several new diagnostics.
- The locked mode (LM) threshold are observed to vary non-monotonically on electron density on q = 2 and 3 surfaces. LM has been unlocked from the RMP field by electrode biasing (EB). Three kinds of standing wave (SW) structures have been observed to share a similar connection to the 2/1 island structure.
- The massive gas injection (MGI) can suppress the runaway electron (RE) generation, if it arrives at the plasma edge before TQ. MGI can dissipate RE current with a saturated rate of 28 MA/s on J-TEXT.
- Both the phase and width of the RMP induced 2/1 LM are found to influence the MGI shutdown dynamics and RE generation.

2. Introduction

A. J-TEXT tokamak

- Main parameters

Ohmic plasma in limiter conf.

ECRH 500 kW, Poloidal Divertor.

R = 1.05 m, a = 0.255 m (limiter)

I_p < 240 kA, B_T = 1.2 ~ 2.5 T

n_e = 0.5~7 x10^{19} m^{-3}

T_{e0} ~ 1 ~ 1.5 keV, T_{i0} ~ 0.5 keV

- Auxiliary Systems

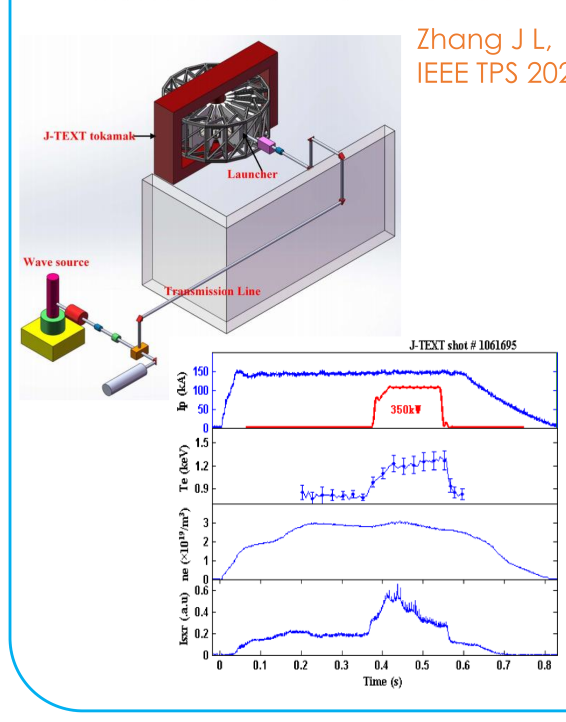
RMP, EB, SMBI

MGI, SPI

B. Successful operation of ECRH systems

- 105 GHz/0.5 MW/1s, successfully commission in 2019/06
  - ✓ X2 mode
  - ✓ Poloidal and toroidal angle is around ±20°
- 0.4 MW injection: T_{e0} increases from 0.9 keV to ~**1.5 keV**

Zhang J L, IEEE TPS 2020

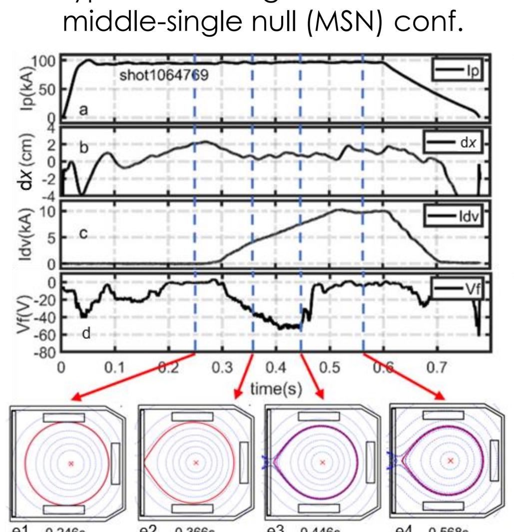


C. Operation of the poloidal divertor configuration

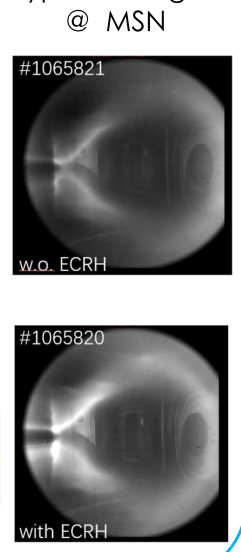
(Chen Z P, P5-1199, *Thur. 8:30*)

- The poloidal divertor configuration with an X-point in the HFS has been achieved from the end of 2018
- The 400 kW ECW has also been successfully injected into the diverted plasma.

typical discharge in the HFS middle-single null (MSN) conf.



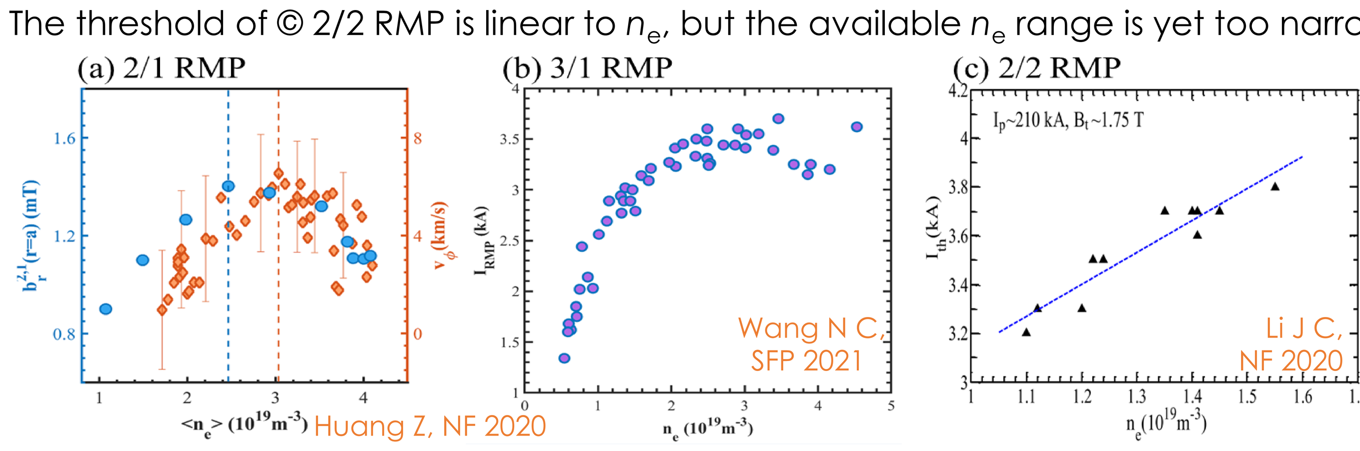
typical images @ MSN



3. Progress on MHD researches

A. Density scaling of the RMP penetration threshold

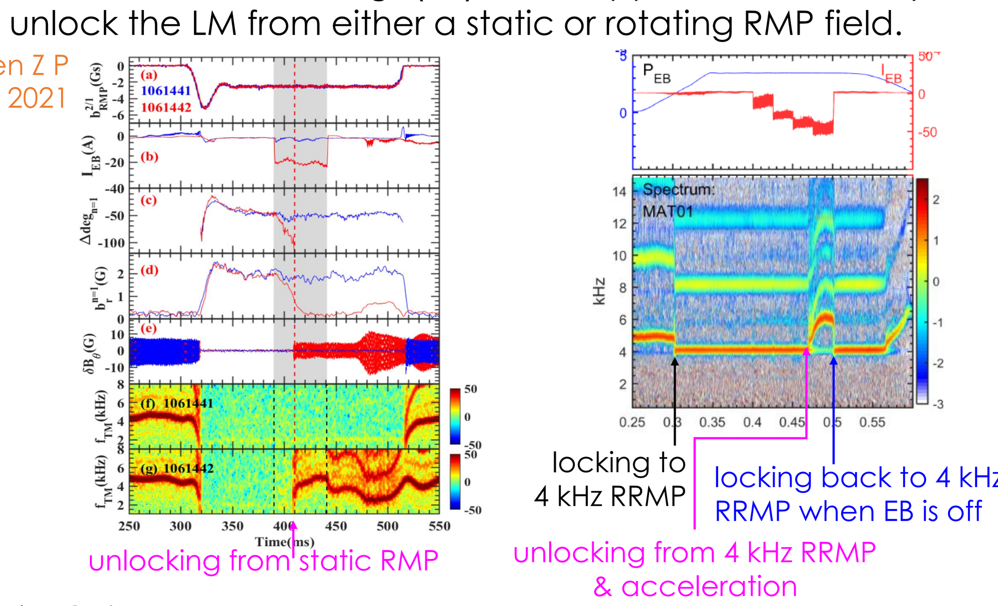
- Both the thresholds of (a) 2/1 and (b) 3/1 LM are observed to vary non-monotonically on electron density.
  - ✓ The toroidal rotation @ $r_{s,q=2}$ also vary non-monotonically on n_e
  - ✓ Scaling includes rotation shows little density dependence $b_{r,th}^{2/1} \propto n_e^{-0.18\pm0.04} f_0^{1.04\pm0.25}$
- The threshold of © 2/2 RMP is linear to n_e, but the available n_e range is yet too narrow.



B. Locked mode control via electrode biasing

- The electrode biasing (EB) was applied successfully to unlock the LM from either a static or rotating RMP field.

Chen Z P NF 2021

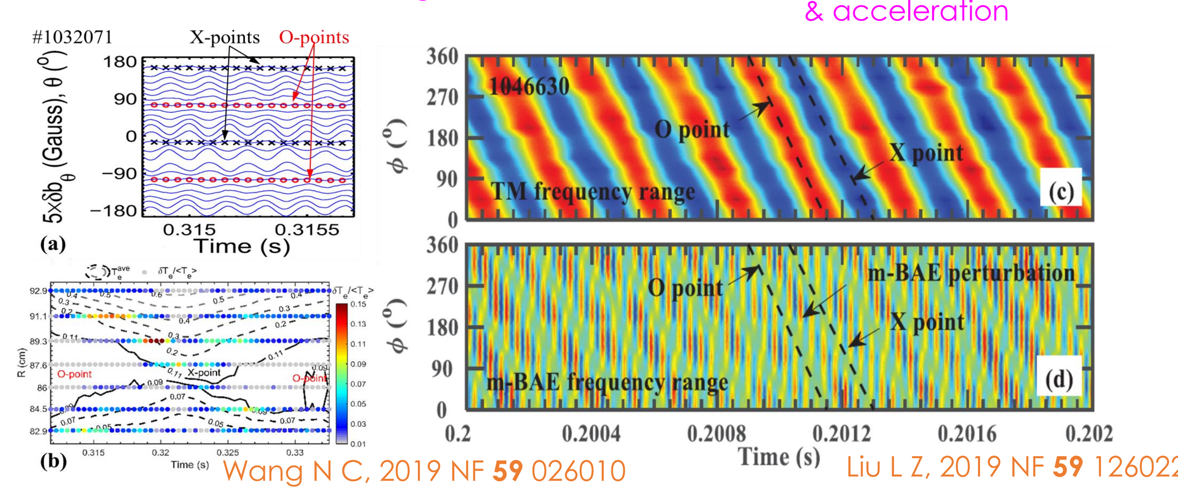


C. Standing waves in the presences of magnetic islands

- In the presence of 2/1 LM, three kinds of standing wave (SW) structures have been observed to share a similar connection to the island structure, i.e.

the **nodes** of the SWs locate around the **O- or X- points** of the 2/1 island.

  - ✓ the forced oscillation of the island phase due to rotating RMP (1~6 kHz) [a, b]
  - ✓ BAE(Beta-induced Alfvén Eigenmodes) at 20 ~ 50 kHz [c,d]
  - ✓ A SW appearing spontaneously at ~ 3 kHz without any external 3 kHz RMP field
- Future comparison between the second SW, i.e. BAEs, and the third SW would be important to reveal the mechanism of their formation.



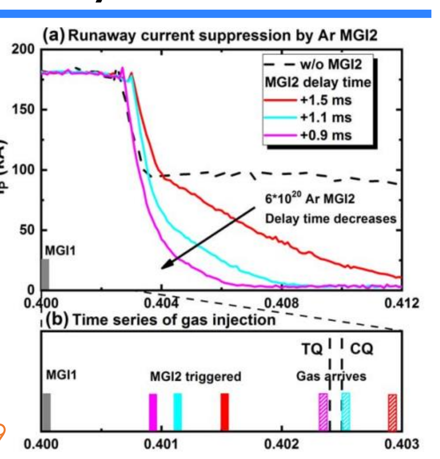
4. Progress on the Disruption Control

See [Chen Z, P5-1202, *Thur. 8:30*] for dual-SPI results

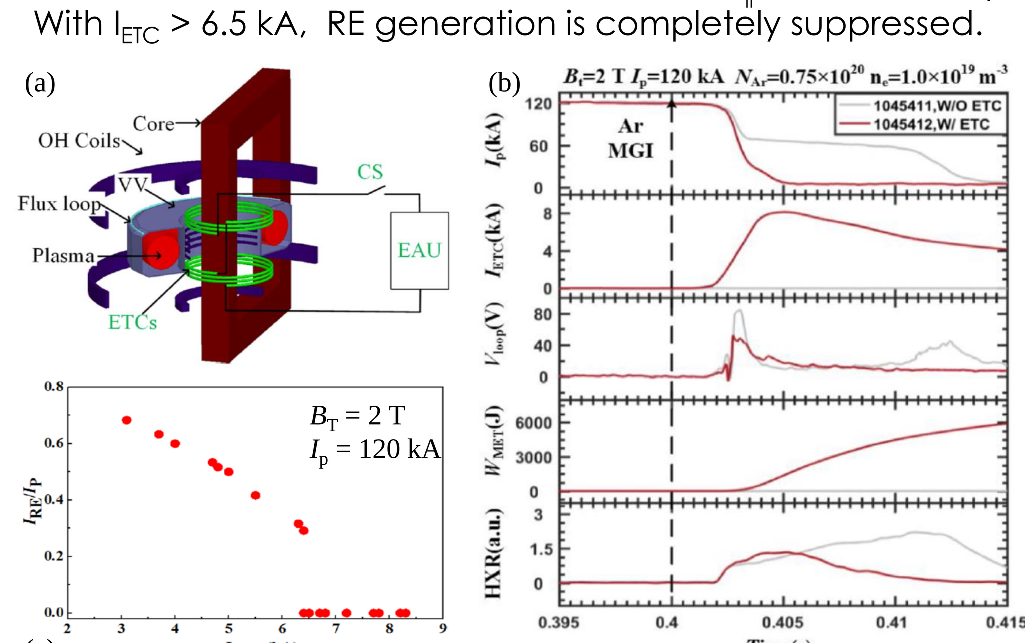
A. Suppression of runaway current by MGI and MET

- If the time when the additional high-Z impurity gas arrives at the plasma edge, $t_{arrival,MGI2}$, is before the thermal quench (TQ), the runaway current (I_{RE}) can be significantly suppressed (magenta) by weakening the primary RE generation, leading to a 90% reduction of the final formed I_{RE}.

Wei Y N, PPCF 2019



- Transfer magnetic energy using well I_p-coupled coils (ETC) can accelerate the CQ rate and reduces $E_{||}$ simultaneously. With I_{ETC} > 6.5 kA, RE generation is completely suppressed.

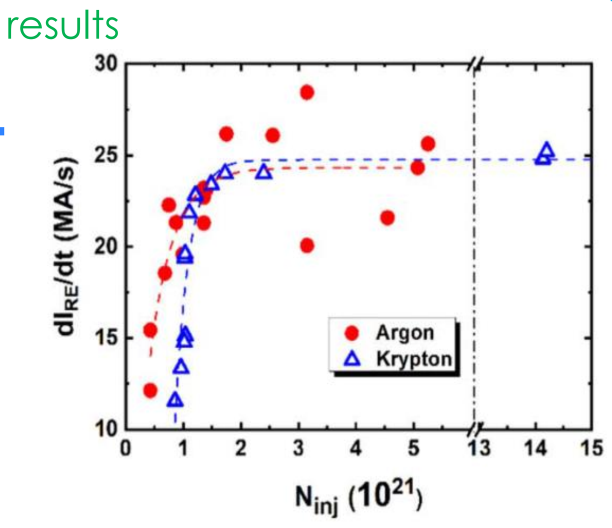


Cai N H, FED 2021

B. Dissipation of runaway current

- When the secondary MGI has been applied after the formation of RE current plateau, the RE current can be dissipated, and the dissipation rate increases with the injected impurity quantity, but saturates with a maximum of 28 MA/s.

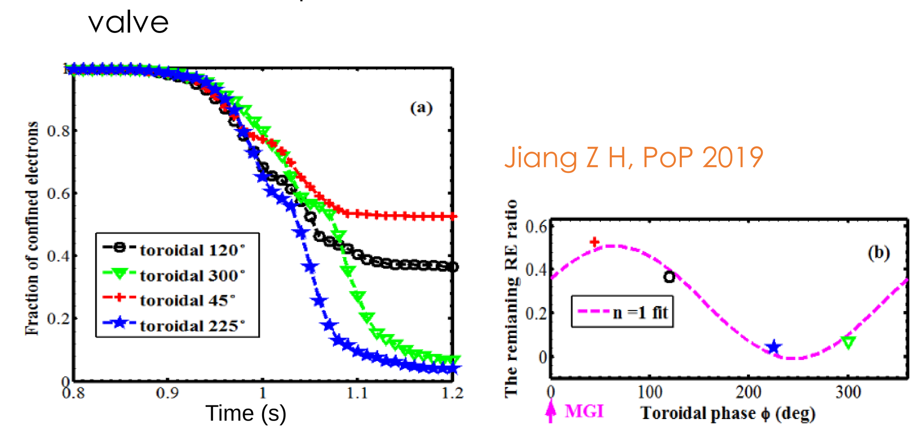
Wei Y N, PPCF 2020



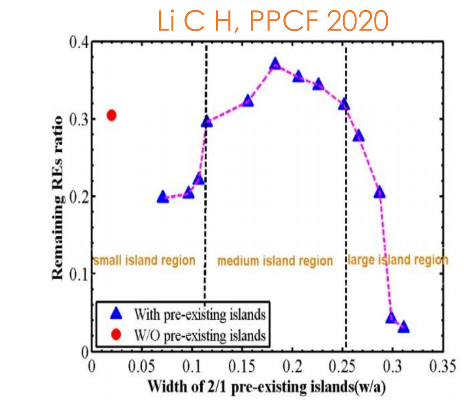
C. Impact of RMP on the MGI triggered disruption

- When the RMP induced 2/1 LM is larger than a critical width, the MGI shutdown process can be significantly influenced. If the phase difference between the O-point of LM and the MGI valve is +90° (or -90°), the penetration depth and the assimilation of impurities can be enhanced (or suppressed) during the pre-TQ phase and result in a faster (or slower) thermal quench. Tong R H, NF 2020
- NIMROD modelling shows:
  - ✓The remaining RE ratio shows an n = 1 dependence on the relative toroidal phase between the pre-seeded 2/1 island and the MGI valve
  - ✓ The RE confinement is also found to vary with the width of 2/1 locked island non-monotonically

Jiang Z H, PoP 2019

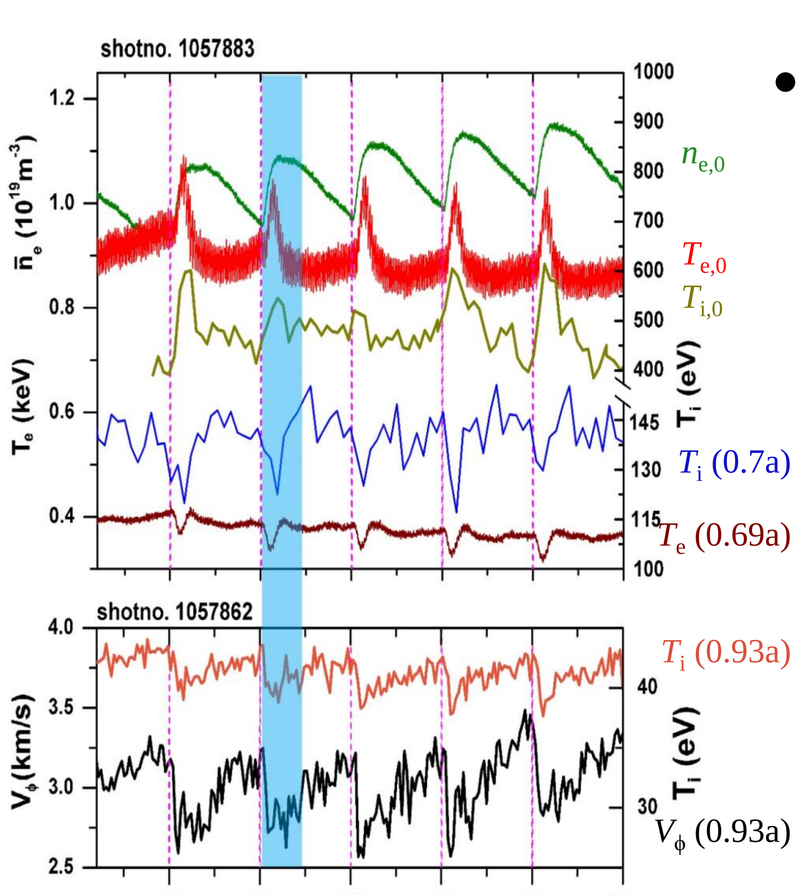


Li C H, PPCF 2020



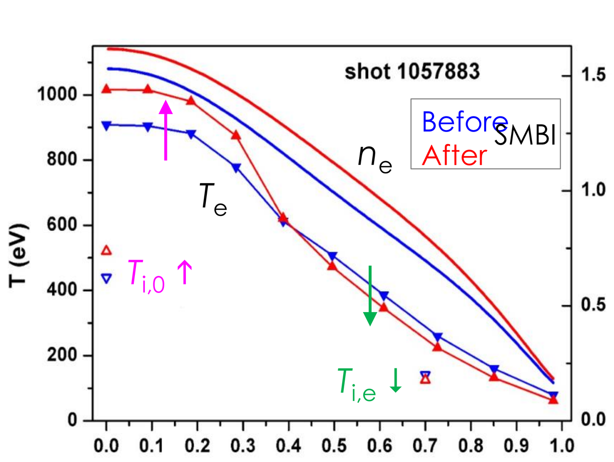
5. Turbulence and Transport Study

A. Observation of non-local effects in ion transport channel



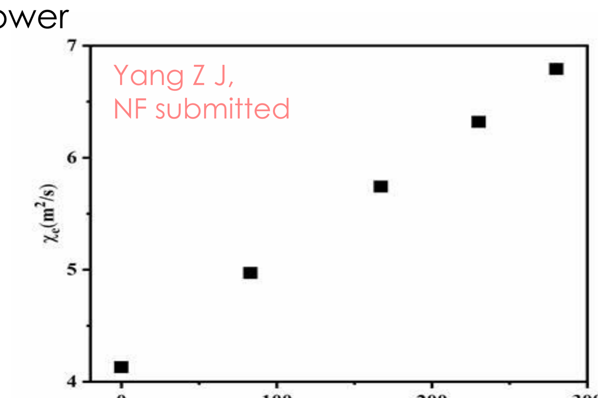
- In cold pulse experiments in J-TEXT, the ion transport shows similar non-local response as the electron transport channel (electron temperature, particle, and momentum)

Shi Y J, NF 2020



B. Electron thermal transport with ECRH

- the electron thermal diffusivity χ_e increases almost linearly with the ECRH power



- The χ_e is also found to decrease as plasma density increasing in ohmic plasma, but almost no change for ECRH plasma.

C. Theoretical study on the turbulence

(Wang L, P7-1170, *Fri. 8:30*)

- **Intrinsic current** driven by EM turbulence in pedestal
  - ✓ Mean parallel current equation (He W, PPCF 2019)

$$\frac{\partial\langle J_{\parallel}\rangle}{\partial t} + \nabla\cdot\langle\delta v_{E\times B,r}\delta J_{\parallel}\rangle - \nabla\cdot\langle\frac{e}{m_e}\delta b_r\delta P_{\parallel}\rangle$$

$$= -\frac{e^2}{m_e}\langle\hat{b}\cdot\nabla\delta\phi\delta n_e\rangle - \frac{e^2}{cm_e}\langle\frac{\partial\delta A_{\parallel}}{\partial t}\delta n_e\rangle$$

  - ✓ Scaling for the ratio of the intrinsic current to the BS current:
    - Turbulent flux (source) driven: $\frac{J^{\Gamma}_{turb}}{J_{BS}} \propto \frac{T_e^{3/4}T_i}{n_e}, \frac{J^{S}_{turb}}{J_{BS}} = \propto \frac{T_eT_i}{n_e}$
  - ✓ Electrostatic contribution is strongly cancelled by the EM effects
- **Combined effects of RMP E_r on drift loss of fast ions in pedestal**
  - ✓ Non-asymmetric perturbed field results in net radial drift
  - ✓ Strong E_r in pedestal significantly reduces the toroidal precession frequency of deeply trapped FIs → key mechanism for the drift loss
  - ✓ The loss time of deeply FIs (tens of μs) could be much smaller than the slowdown time (tens of ms) in DIII-D pedestal → drift loss is an important mechanism for the loss of deeply FIs. [Huang H T, PST 2020]

6. Outlook

In the following two years, detailed researches with those newly developed diagnostics and auxiliary systems, e.g. ECE-imaging, VUV spectrometer, and Doppler reflectometry, will be beneficial for the study of MHD activities, turbulence and transport.

The plasma operation with ECRH or poloidal divertor configuration will become more mature and it will inspire further researches on plasma heating, current drive, MHD and disruption control, boundary physics, etc.

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