Turbulence and Blob at the boundary of magnetic topology (Edge and SOL)

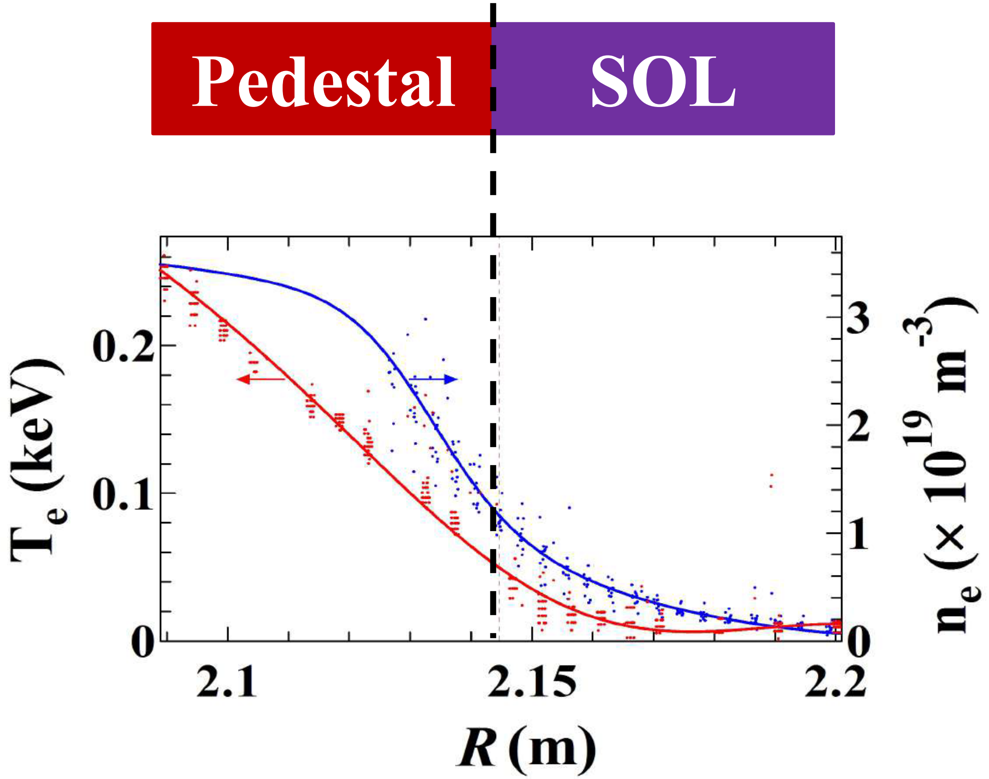
F.D. Halpern, K. Itoh, K. Miki, M.K. Han, D.F. Kong, T. Ming, H. Tanaka, T.T. Tran, Y.W. Cho, B.Y. Zhang, S. Inagaki, J.Q. Dong, C. Moon, M. Kobayashi, H. Hasegawa and all members of Group A

E-mail: dfkong@ipp.ac.cn

7th Asia Pacific Transport Working Group (APTWG) International Conference Nagoya, Japan, 5-8,June, 2017

Key issues of Category A: reduction of the heat load density of Divertor

ASIPP



From C. Moon`s Poster

Lower the heat flow of Divertor

λ_q physics and detachment research

A-PL1: F.D. Halpern
A-P7: H. Tanaka
A-P15: H. Hasegawa
A-P14: M. Kobayashi
A-P13: C. Moon
A-OV1: K. Itoh

ELM mitigation

A-P1: D.F. Kong
A-P12: J.Q. Dong

Basic turbulence study

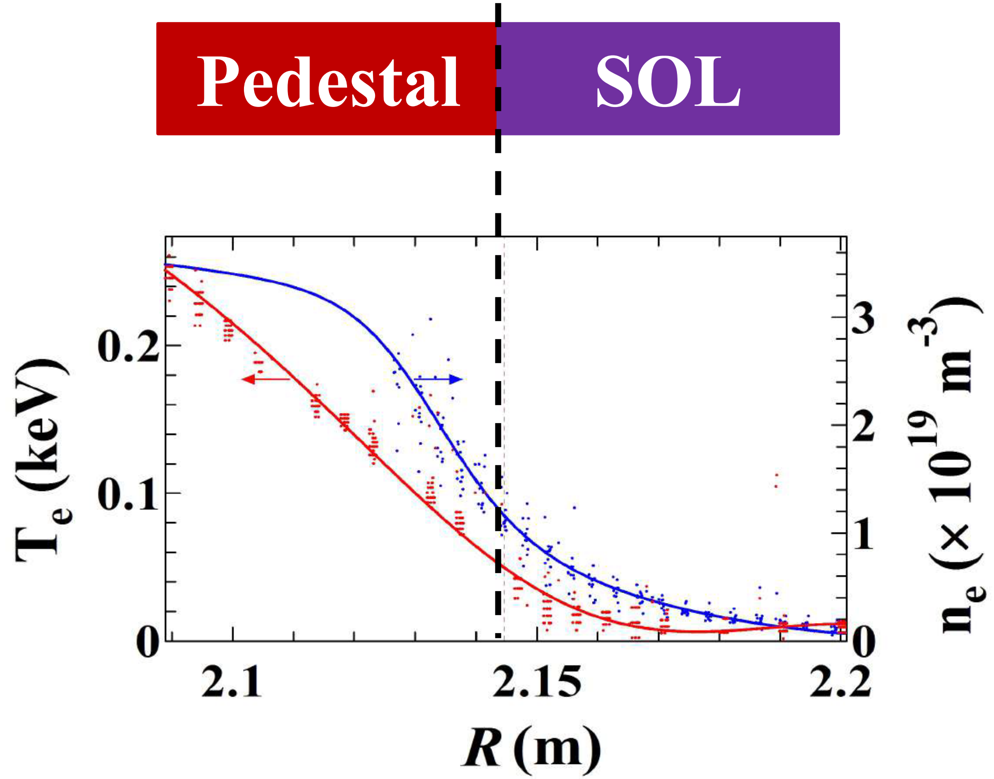
A-P11: S. Inagaki
A-O2: M.K. Han
A-O1: K. Miki

Diagnostic development

A-P2: T. Ming
A-P10: B.Y. Zhang

Key issues of Category A: reducion of the heat load density of Divertor

ASIPP



Lower the heat flow of Divertor

λ_q physics and detachment research

A-PL1: F.D. Halpern
A-P7: H. Tanaka
A-P15: H. Hasegawa
A-P14: M. Kobayashi
A-P13: C. Moon
A-OV1: K. Itoh

ELM mitigation

A-P1: D.F. Kong
A-P12: J.Q. Dong

Basic turbulence study

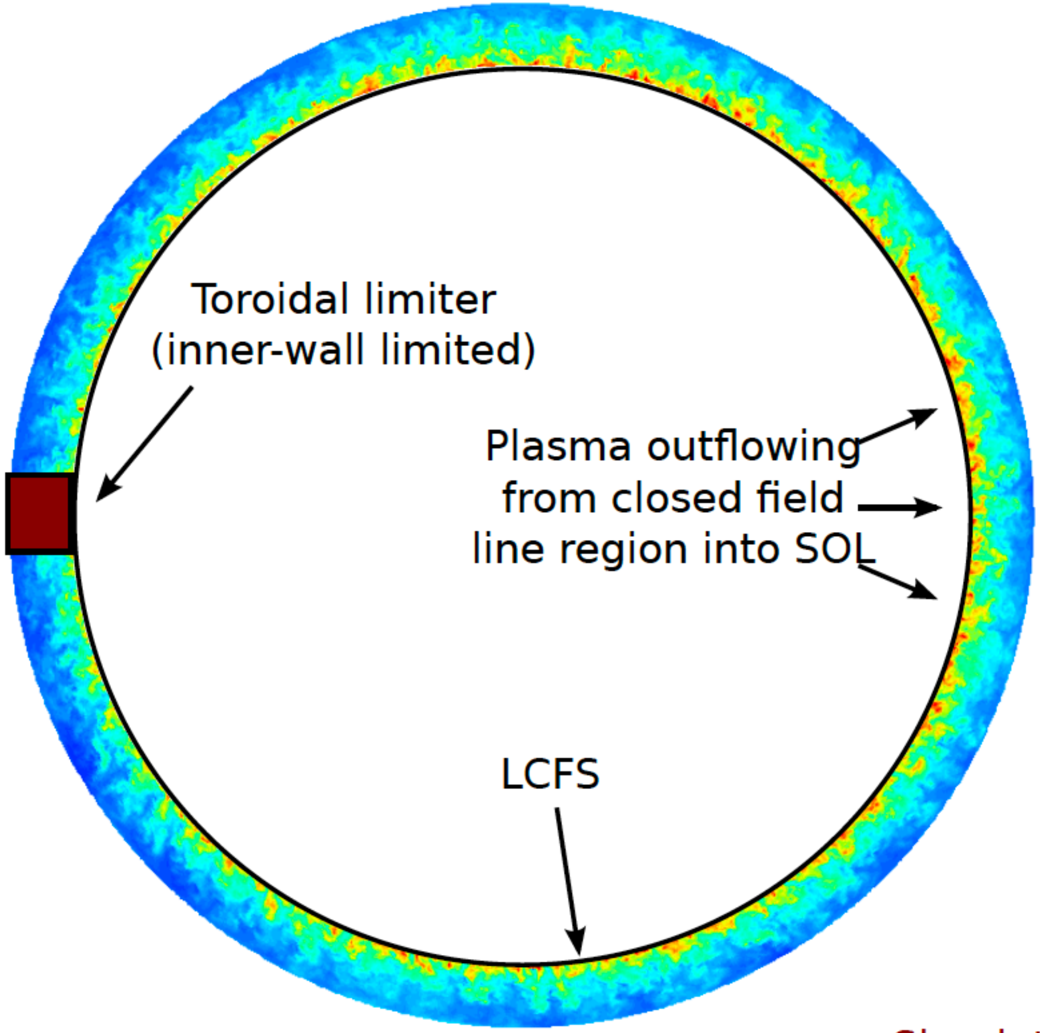
A-P11: S. Inagaki
A-O2: M.K. Han
A-O1: K. Miki

Diagnostic development

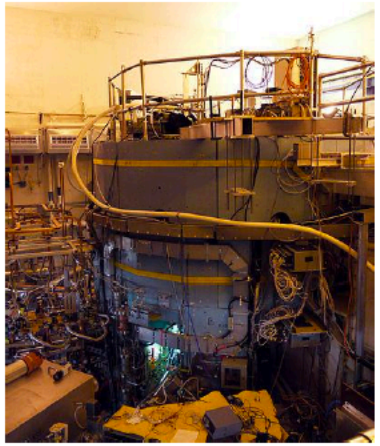
A-P2: T. Ming
A-P10: B.Y. Zhang

Blob dynamics and the tokamak scrape-off layer width

ASIPP



Simulation of Alcator C-Mod inner-wall limited discharge



$B = 4\mathrm{T}$

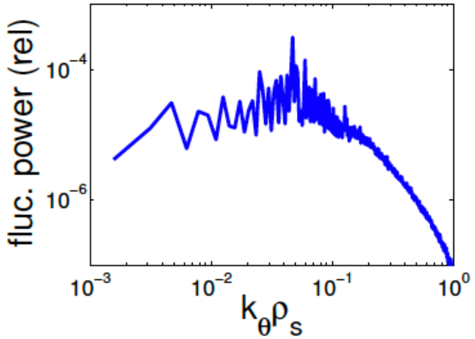
$R = 0.67\mathrm{m}$

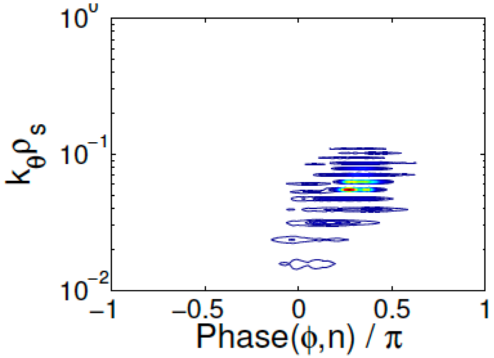
$a = 0.2\mathrm{m}$

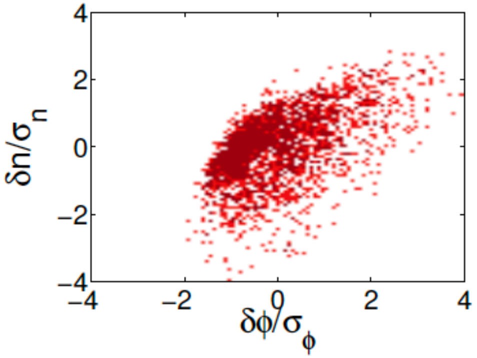
$T_{e,LCFS} \sim 25\mathrm{eV}$

$n_{e,LCFS} \sim 10^{19}\mathrm{m}^{-3}$

Simulation cost: 0.5 million CPU hours







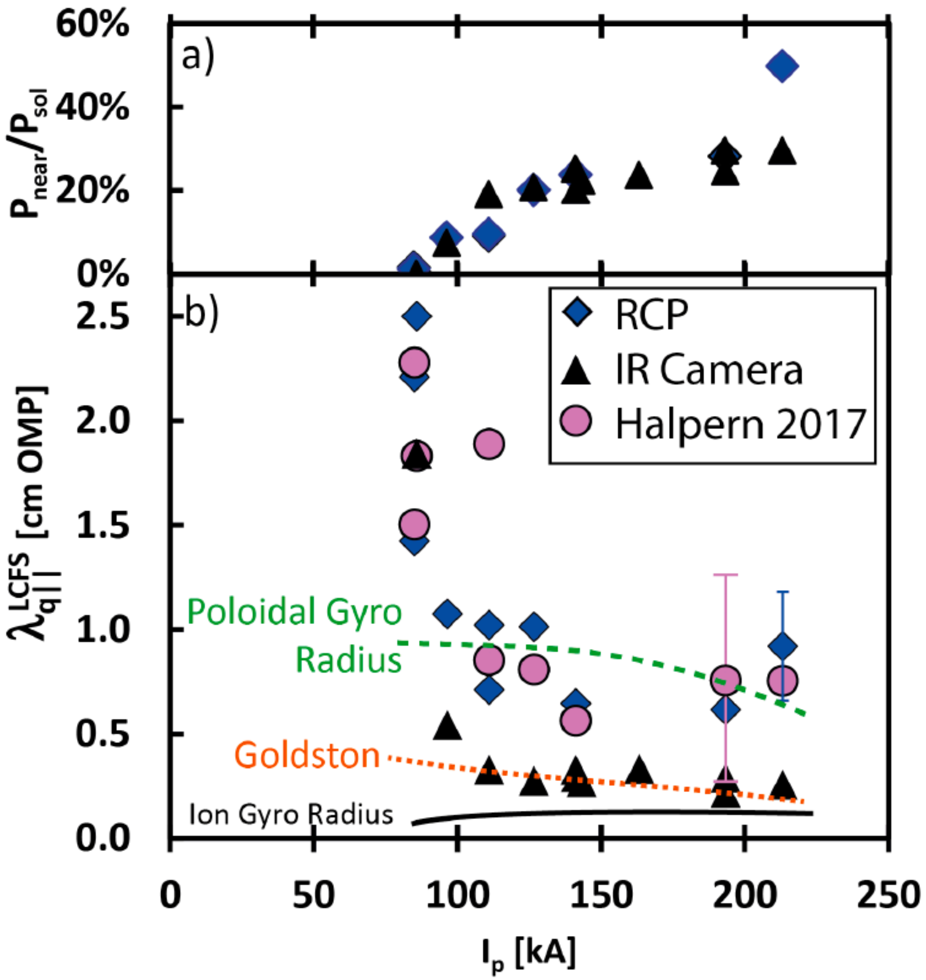
Comparison between theory estimates and TCV LP data shows good agreement for I_p scan discharges

ASIPP

- Model matches variation of measured λ_q even when narrow feature is weak

- Variation of $\lambda_q \sim I_p^{-1}$ captured, likely due to BM turbulence with $L_{rad} \sim q_a \sim I_p^{-1}$

- BM turbulence explains ρ_{pol} scaling sometimes attributed to NC effects



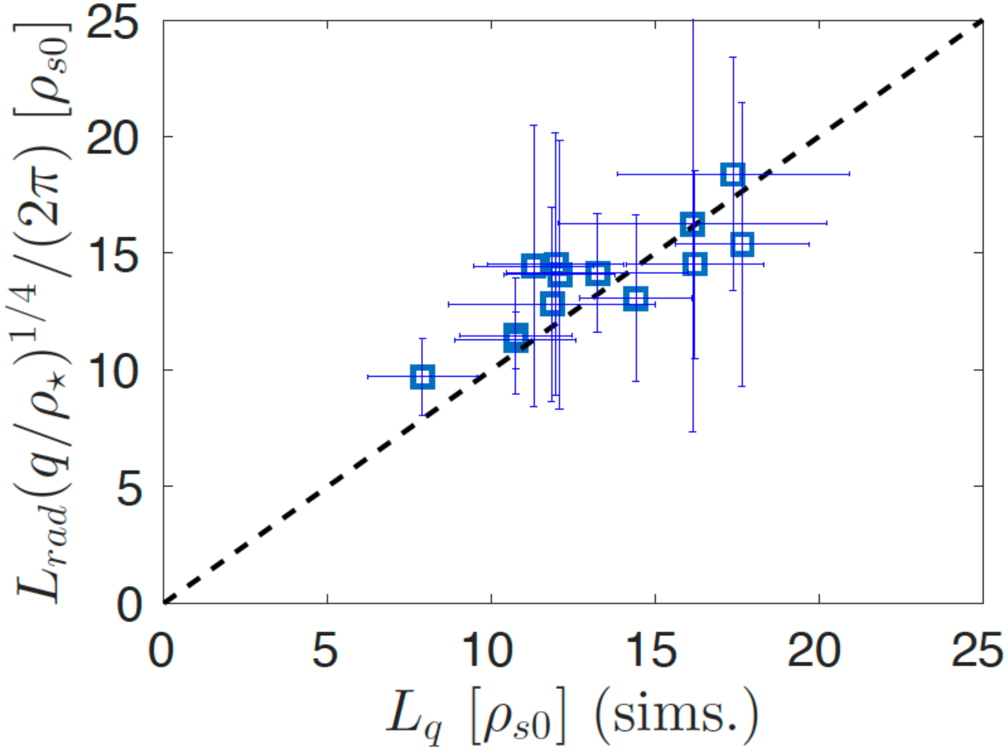
GENERAL ATOMICS

Main result: Narrow feature gradient length λ_q constrained by correlation length L_{rad}

ASIPP

- **Perpendicular turbulent flux** $\Gamma_\perp \approx \tilde{p}\tilde{v}_{\mathbf{E}\times\mathbf{B}}$ **assuming** $\tilde{p} \sim p_0/(k_r L_p)$
- **Balance** $\nabla_\perp \cdot \Gamma_\perp$ **against sheath loss term** $\nabla_\| \cdot \Gamma_\| \sim p_0 c_s / L_\| \approx p_0 c_s/(qR)$

$$\frac{\lambda_q}{\rho_s} = L_q = \frac{L_{rad}}{2\pi}\left(\frac{q_a}{\rho_\star}\right)^{1/4}$$

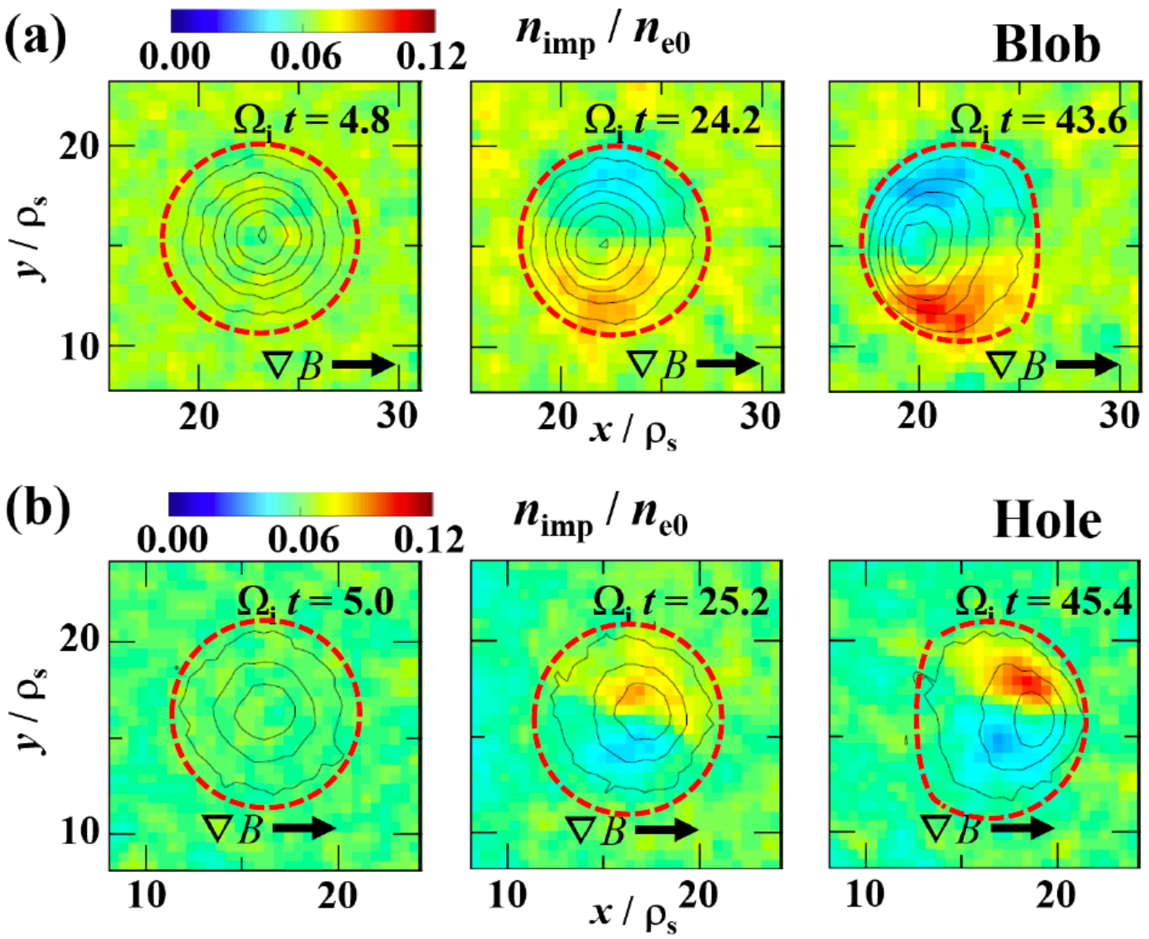


- **Simulation parameters:**
  $q_a = 3$–16, $\hat{s} = 1.5$, $m_i/m_e = 200$–800,
  $\rho_\star^{-1} = 250$–1000, $\nu_{Sp} = 10^{-2}$–1
- **Most of** λ_q **variation stems from** $q_a \sim I_p^{-1}$**, compatible with Eich/Goldston scalings**

GENERAL ATOMICS

Particle-in-cell simulation of non-diffusive plasma transport in scrape-off layer

ASIPP



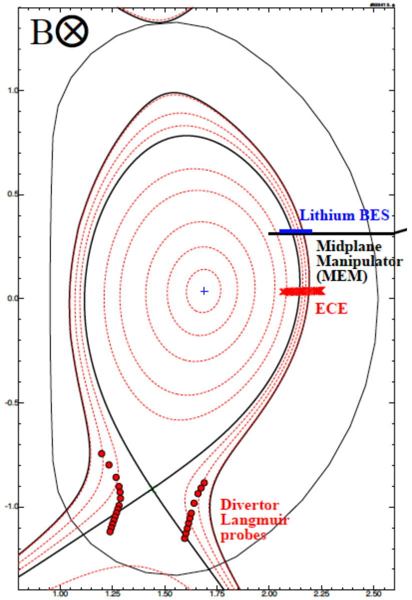
4. Summary and Discussion

- We have developed a 3D-PIC code to study blob / hole dynamics with impurity.
- **Impurity dynamics with the blob / the hole propagation have been demonstrated by the 3D-PIC simulation for the first time:**
  - The dipolar profile of impurity ion density in the blob / the hole is formed by the polarization drift.
  - Such a density profile propagates with the blob / the hole.
  - **The simulations in which the initial impurity density has a radial gradient have shown that the effective radial diffusion coefficient for impurity ions by a single blob / hole is comparable to the Bohm diffusion coefficient.**

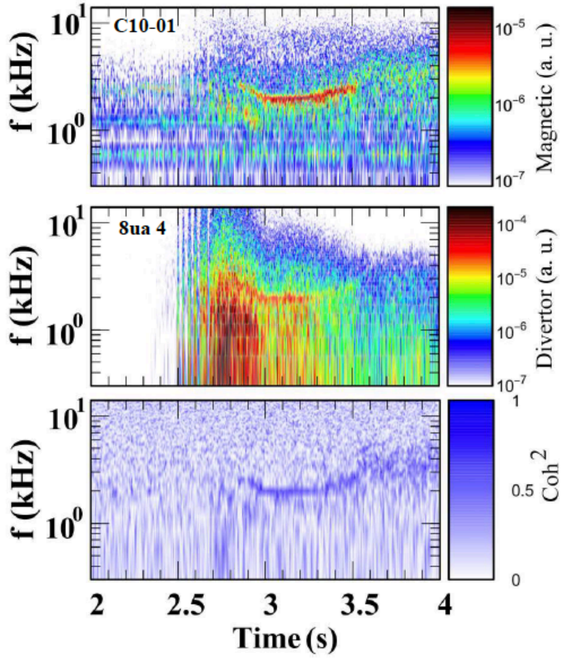
A-P13: C. Moon

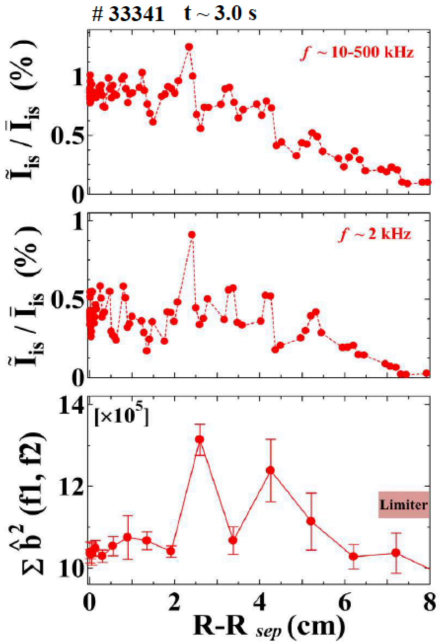
Nonlinear Interaction between Low-Frequency MHD Fluctuations and Turbulence in the Scrape-Off Layer of ASDEX Upgrade

ASIPP

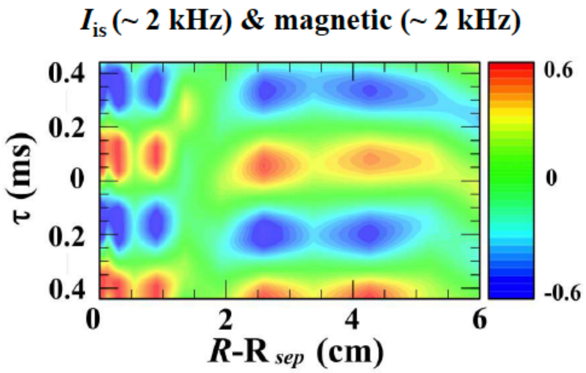


Poloidal diagnostic positions





1. A coherent large scale low-frequency (~2 kHz) fluctuation (CLF) is observed at the separatrix region in ECRH L-mode discharges in ASDEX-Upgrade tokamak.
2. The CLF is localized at the safety factor q ~ 5-6, which is determined by using the lithium beam emission spectroscopy and the electron cyclotron emission diagnostics.
3. The CLF propagates in the electron diamagnetic direction, and is characterized by a toroidal mode number of n = 2.
4. The CLF has significant coherence with the magnetic signal, the divertor fluctuations, and the envelope of the turbulence, which propagates across the SOL.

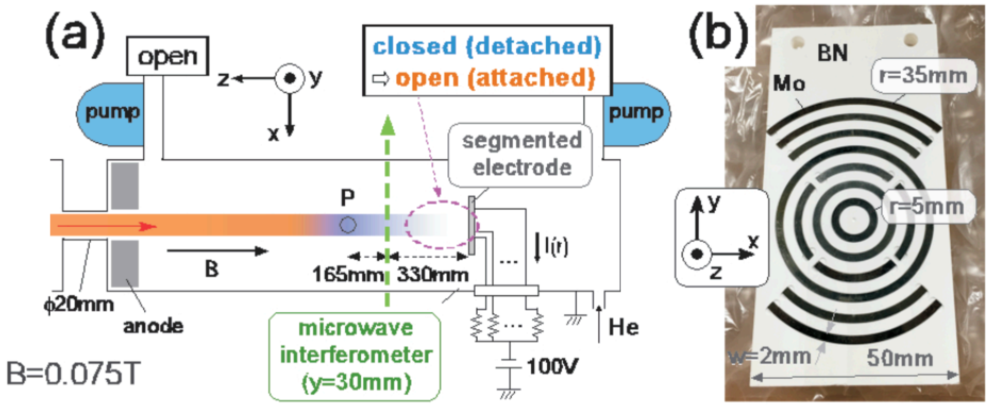


A-P7: H. Tanaka

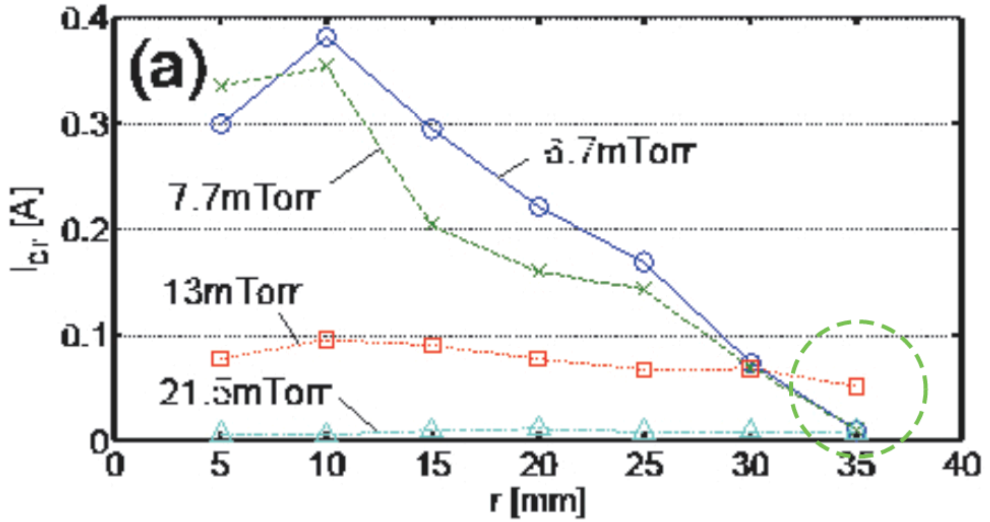
Detachment study in linear device (NAGDIS-II)

ASIPP

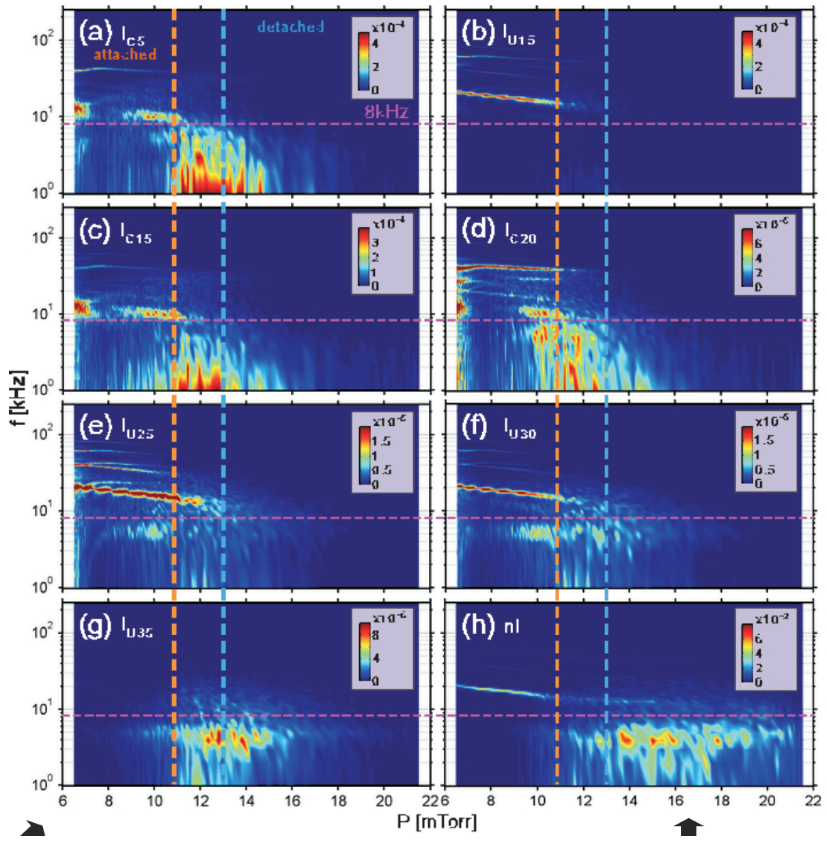
Top view of schematic diagram and segmented electrode



Radial distribution of I_{Cr}



Spectrograms as a function of P



Plasma detachment is the effective solution for reducing heat and particle fluxes into the divertor plate

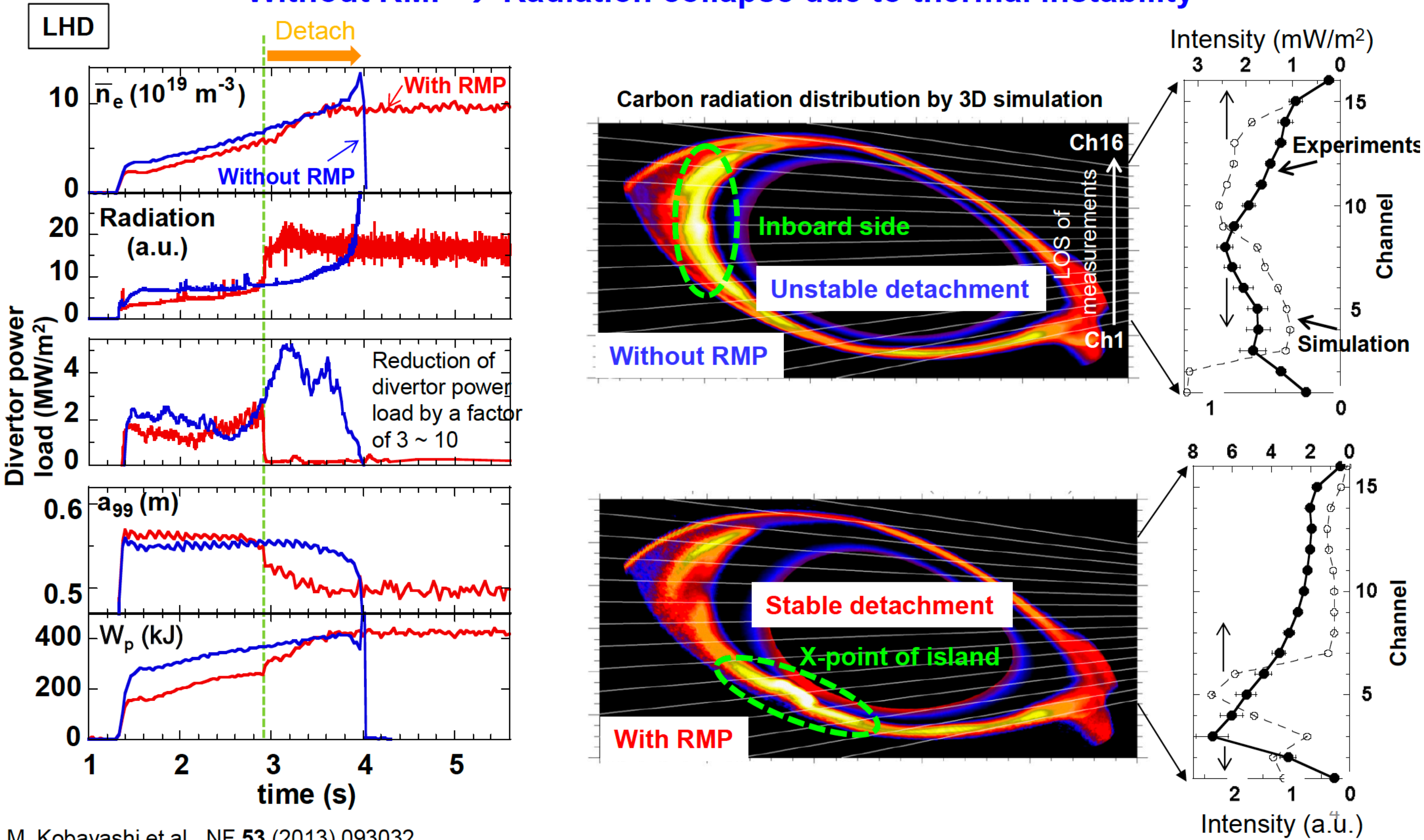
> obtained by increasing plasma density and neutral gas pressure (P) in the divertor region

> resulting from radiation and recombination processes

Control of detachment stability with RMP application

ASIPP

With RMP → Stable sustainment of detached phase (RMP assisted RD)
Without RMP → Radiation collapse due to thermal instability



M. Kobayashi et al., NF **53** (2013) 093032.

Fuelling Fuels Turbulence

ASIPP

Long-Standing Mysteries

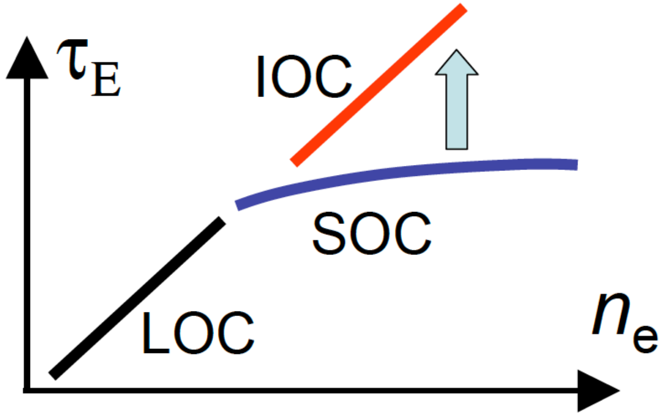
(1) OH confinement: LOC and SOC, then Improved OH Confinement (IOC) is induced buy reducing puff.

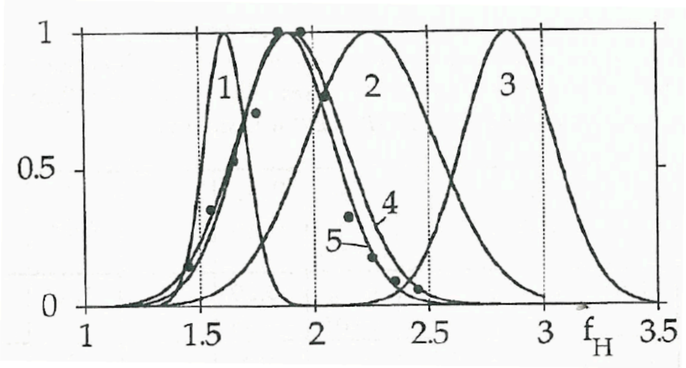
(2) Influence of wall material on the performance of H-mode plasma

W-wall?

(3) Improved confinement modes appear under the condition of ‘degassing of wall’.

(4) ‘ρ > 0.6 Shortfall Problem’





Wagner (1990)

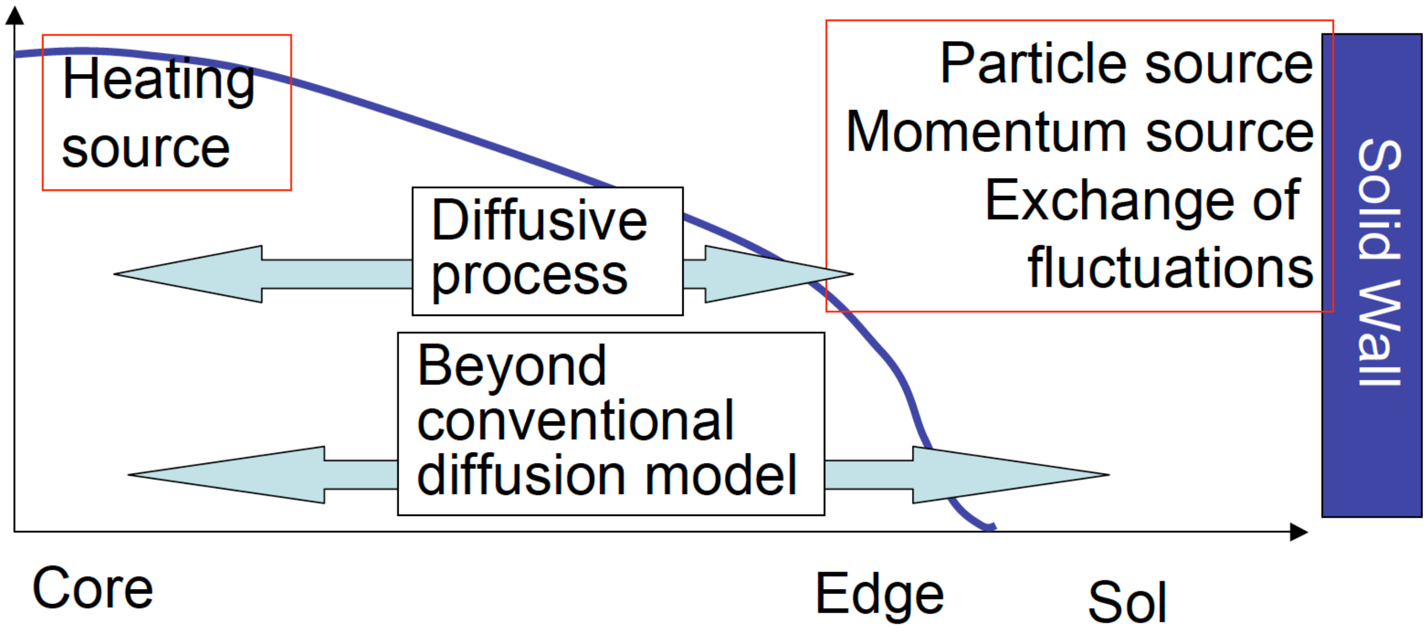
Possible Coupling between Plasma Turbulence and Neutral Particles

Fuelling Fuels Turbulence

ASIPP

Hypothesis

Plasma turbulence directly couples with external sources (heating, particle source, momentum source)



Challenge, with this hypothesis, the problems of hydrogen isotope effect, fast response of core plasma, effects of wall-material/condition on confinement……

Fuelling Fuels Turbulence

ASIPP

Fluctuation driven by fuelling

Fluctuation of particle source in edge plasmas

$$\tilde{S} = \langle S \rangle \left[\frac{\tilde{n}_e(a)}{\langle n_e(a) \rangle} + C \overline{\left\{ \frac{\tilde{n}_e}{\langle n_e \rangle} \right\}}_{SoL} \right]$$

Fluctuation in SoL plasma is printed in the source.

Density fluctuation driven by fluctuation in the source:

$$\boxed{\left| \tilde{n}_e \right| = \frac{\tau_{NL} \left| \tilde{S} \right|}{\sqrt{1 + \omega^2 \tau_{NL}^2}} \approx \frac{\tau_{NL} \langle S \rangle}{\sqrt{1 + \omega^2 \tau_{NL}^2}} \left| \frac{\tilde{n}_e(a)}{\langle n_e(a) \rangle} + C \overline{\left\{ \frac{\tilde{n}_e}{\langle n_e \rangle} \right\}}_{SoL} \right|}$$

$$\frac{\left| \tilde{n}_e \right|}{\langle n_e \rangle} \sim \frac{1}{\rho_i \Delta_n k^2} C \left| \overline{\left\{ \frac{\tilde{n}_e}{\langle n_e \rangle} \right\}}_{SoL} \right| \left[\frac{\left| \tilde{n}_e \right|}{\langle n_e \rangle} \right]_{mix}$$

Mixing length estimate

This can be larger than the one in mixing-length estimate.

Fuelling Fuels Turbulence

ASIPP

1. Problem Definition: Possible Coupling between Plasma Turbulence and Neutral Particles

2. Neutrals in SoL plasma (revisited)

3. Edge turbulence, which is driven by particle fuelling

   Neutral particle density fluctuation is induced by strong SoL turbulence, and drives strong edge turbulence.

   Fuelling fuels turbulence.

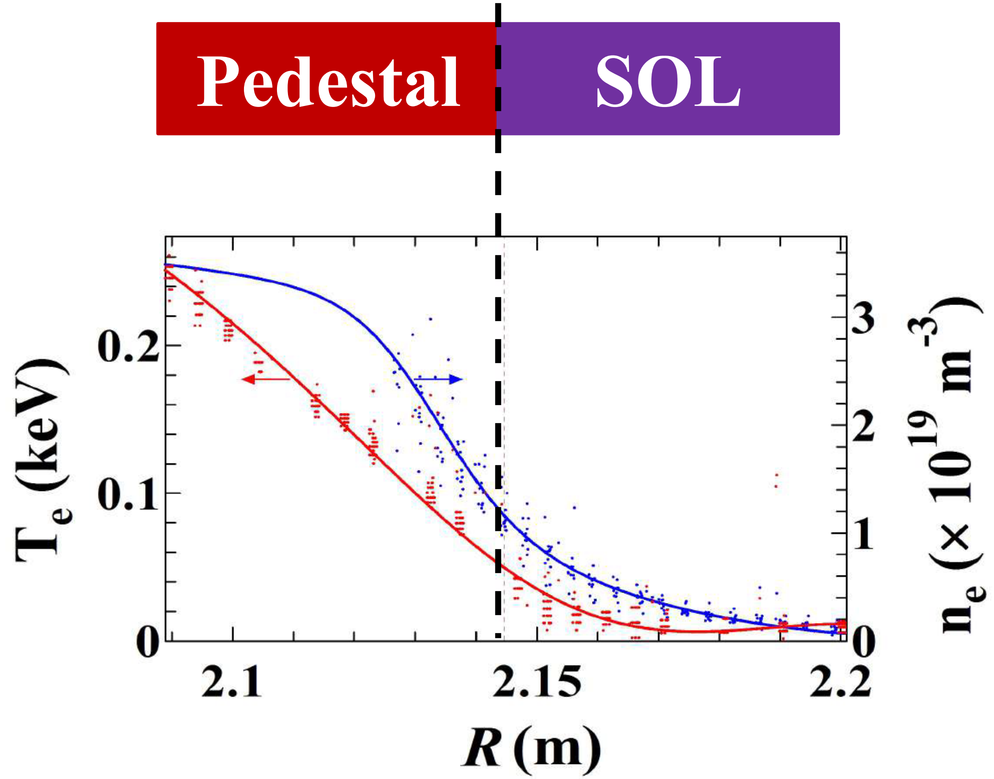
4 On isotope effect of plasma confinement

S.-I. Itoh: C-P5

Acknowledgements Authors acknowledge discussions with Prof. S. Inagaki, Prof. K. Ida, Prof. H. Yamada, Dr. D. Kato, Dr. M. Kobayashi, Dr. T. Kobayashi, Dr. Y. Kamada. This work is partly supported by the Grant-in-Aid for Scientific Research of JSPS (JP15H02155, JP15K17799, JP16H02442).

Key issues of Category A: reducion of the heat load density of Divertor

ASIPP



Lower the heat flow of Divertor

λ_q physics and detachment research

A-PL1: F.D. Halpern
A-P7: H. Tanaka
A-P15: H. Hasegawa
A-P14: M. Kobayashi
A-P13: C. Moon
A-OV1: K. Itoh

ELM mitigation

A-P1: D.F. Kong
A-P12: J.Q. Dong

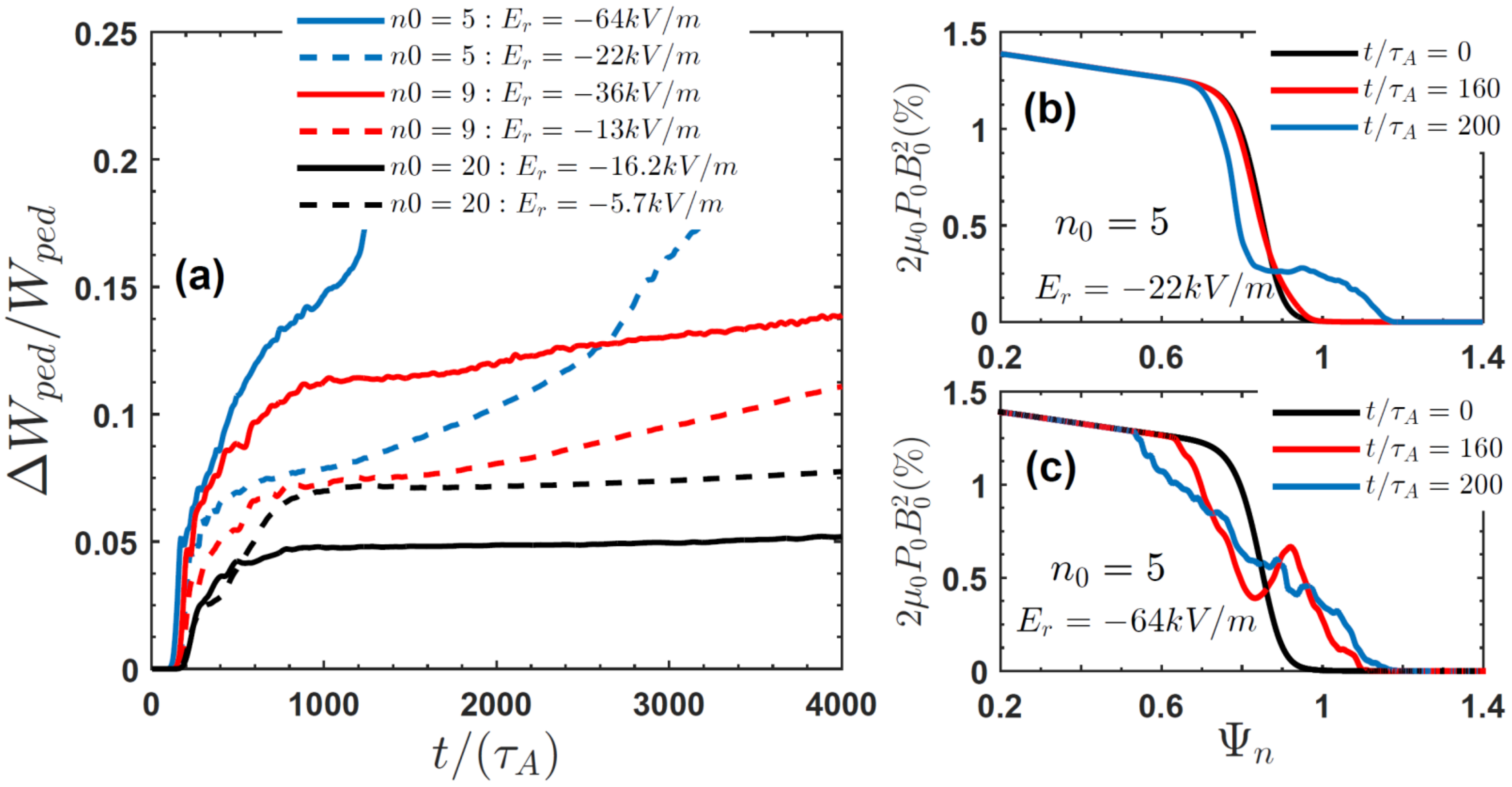
Basic turbulence study

A-P11: S. Inagaki
A-O2: M.K. Han
A-O1: K. Miki

Diagnostic development

A-P2: T. Ming
A-P10: B.Y. Zhang

Impact of Er on ELM size: simulations with BOUT++

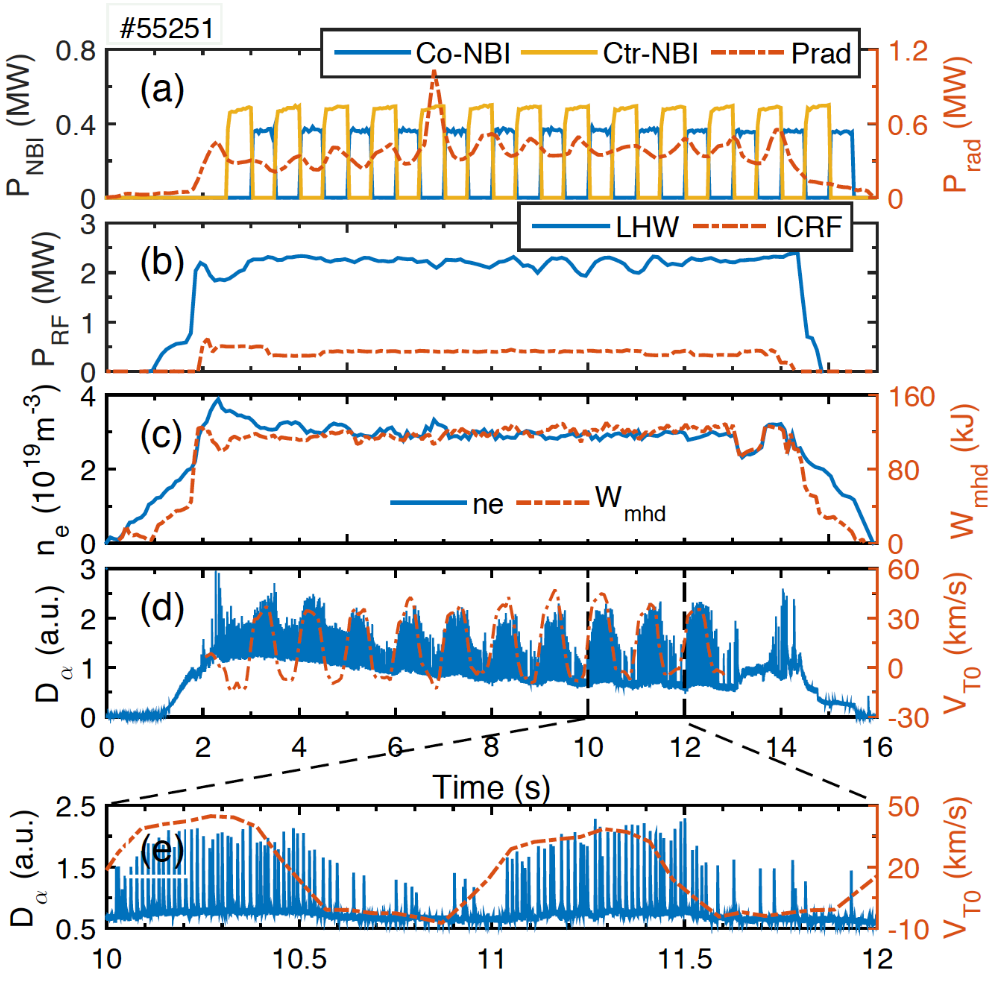


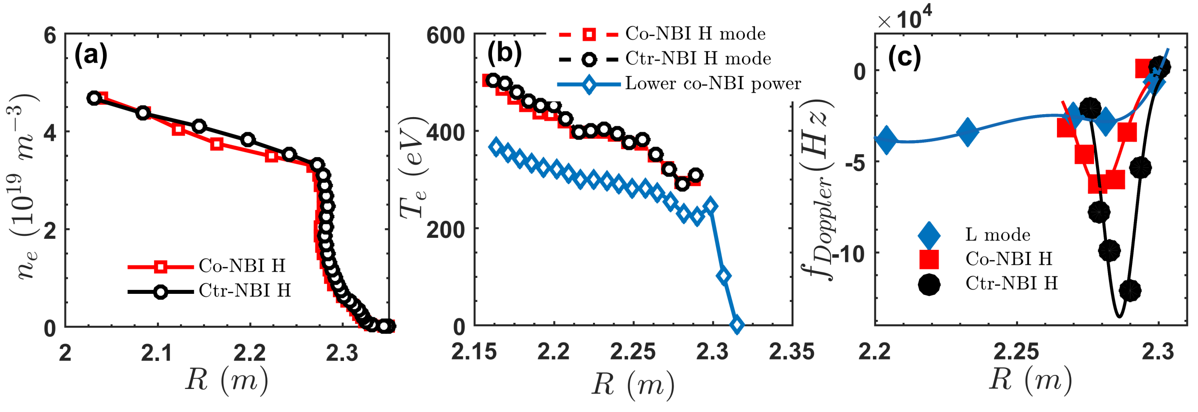
- For low collisionality (n0=5 and n0=9), the increase Er can enhance the ELM size;
- For high collisionality (n0=20), the increase Er would suppress the ELM size and delay the crash of pedestal.

A-P1: D.F. Kong

Impact of Er on ELM size: validations on EAST

ASIPP





◆ **ELM study with co NBI and con NBI:**

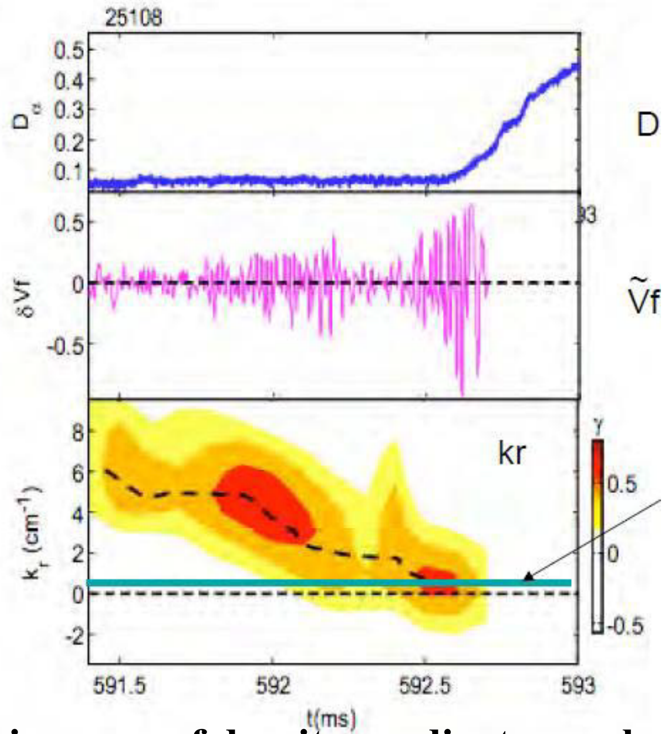
1. **ELM size is modulated by injecting direction of NBI with smaller ELM size at con NBI.**
2. **Stored energy and density profiles remain almost the same (collisionality remains the same?)**
3. **Toroidal rotation (Er) playing an important role in modifying the ELM?**

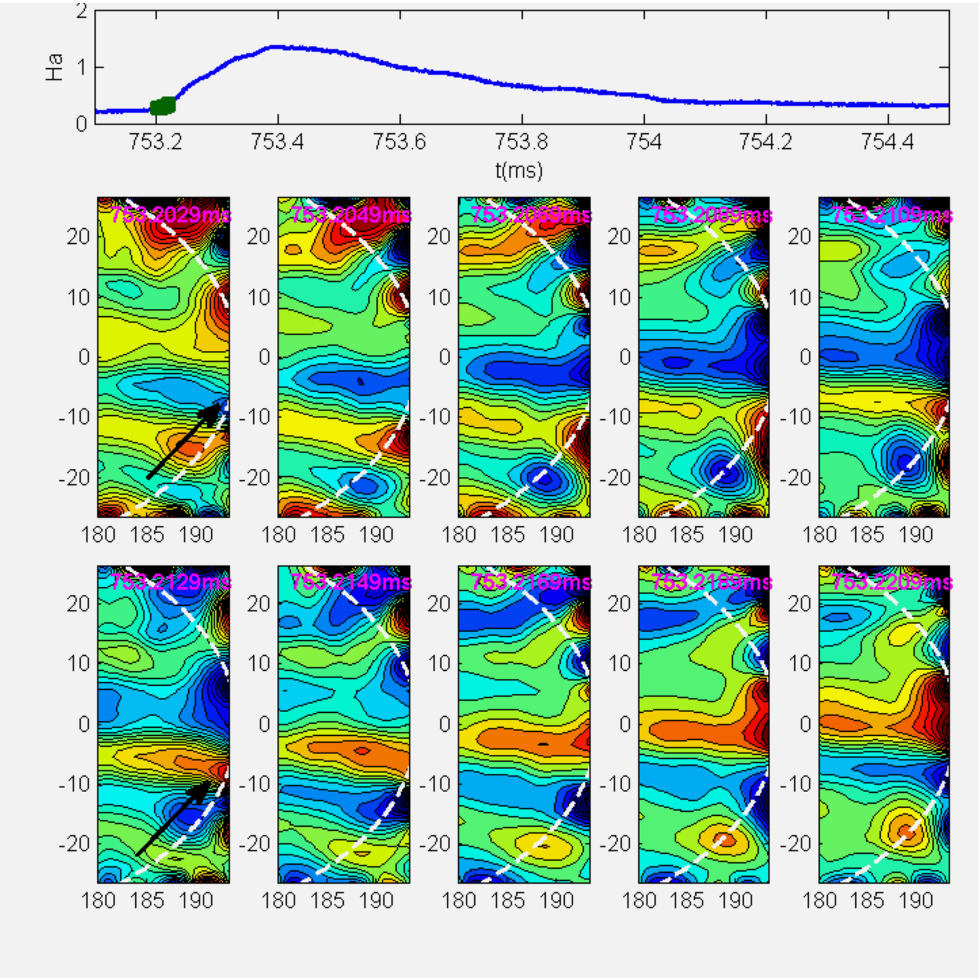
◆ **Those observations on EAST are consistent with the simulation results by BOUT++ mentioned before.**

A-P12: J.Q. Dong

Observation of Streamer as a Trigger for ELMs on HL-2A Tokamak

ASIPP





A dramatic increase of density gradient was observed in the pedestal just before each type-III ELM onset on HL-2A tokamak;

●An inward particle flux inducing quasi-coherent mode (QCM) was found to be responsible for such a change;

●The characteristics of the QCM are identified;

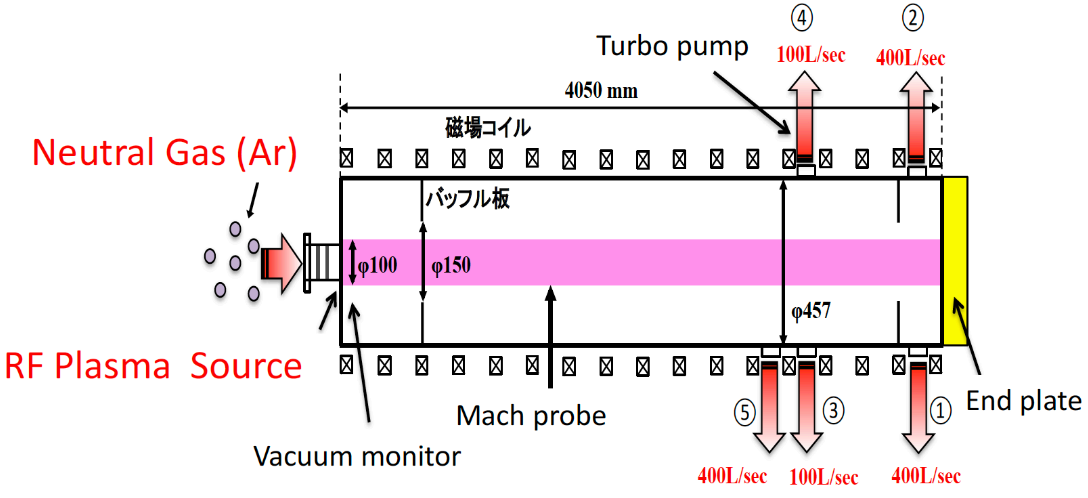
●The QCM has strong nonlinear interaction with the ambient turbulence;

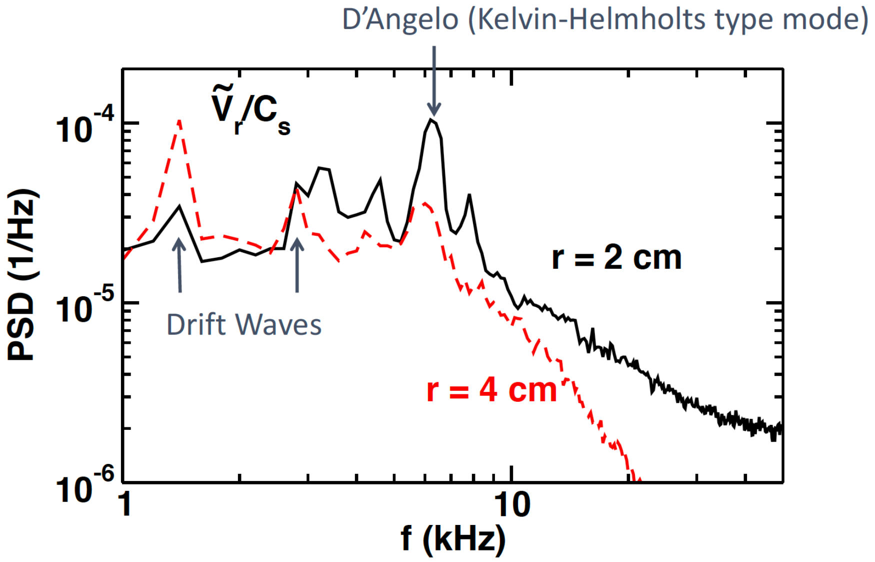
●The QCM is found to transit into streamer which triggers ELM onset;

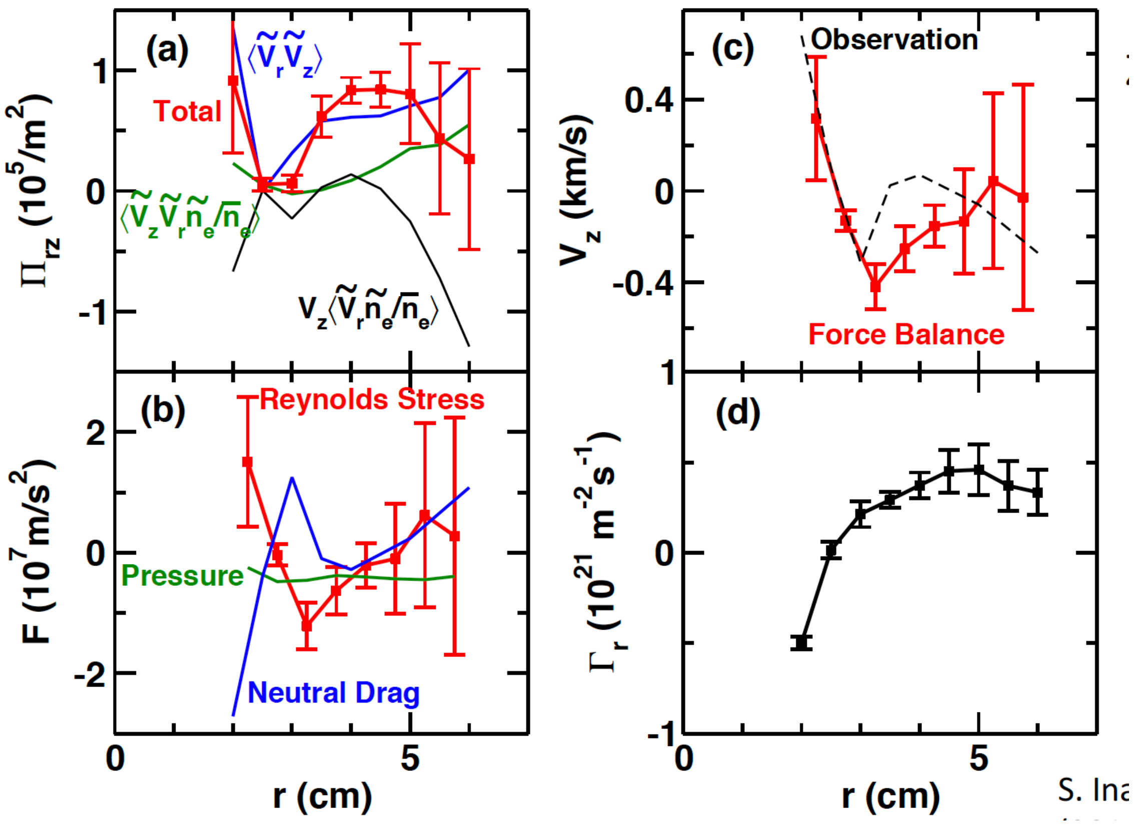
A-P11: S. Inagaki

Axial momentum transport driven by turbulence in linear magnetized plasma (PANTA)

ASIPP







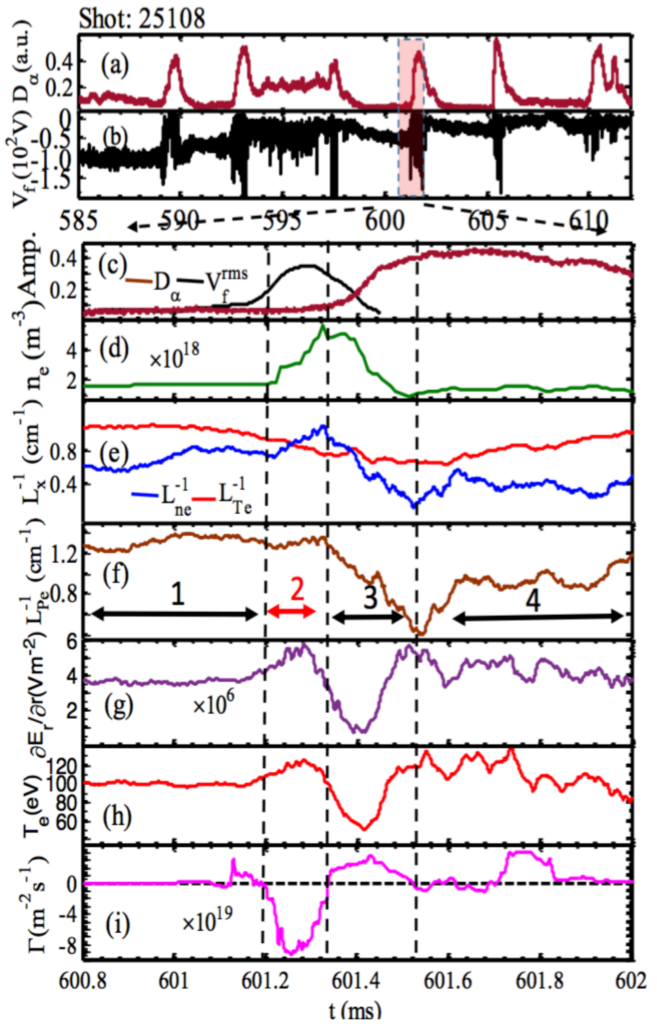
- Reynolds force reverses the axial flow
- D'Angelo mode drives the inward particle flux
- Different instabilities coexist in turbulent plasma

A-O2: M.K. Han

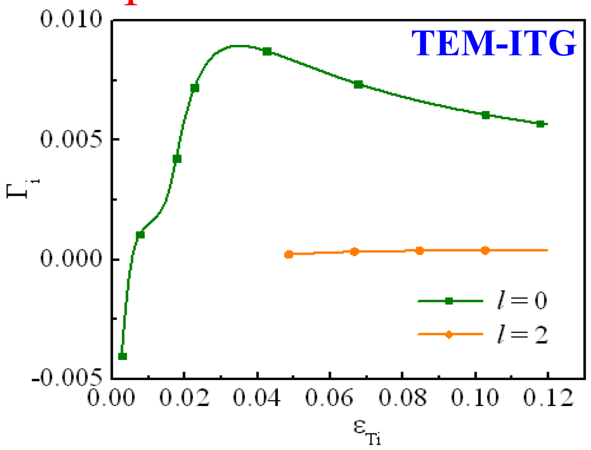
Turbulent particle transport in transport Barriers

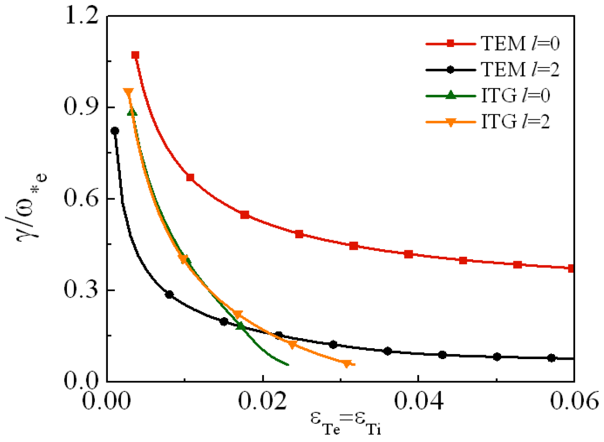
ASIPP

Experimental results from HL-2A



HD7 simulation results based on the typical TB's parameters of HL-2A





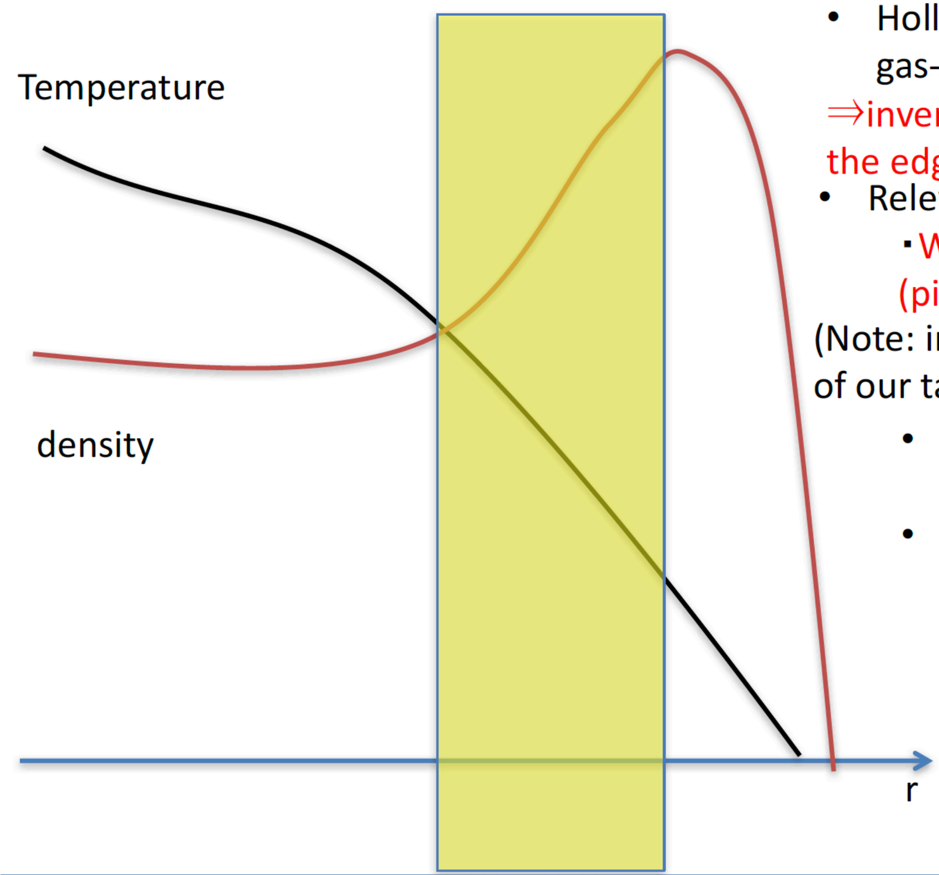
- ✓ **Under the typical TB's parameter, when e_{Ti} is steep enough, ion flux of the TEM-ITG is inwardly.**
- ✓ **Under the typical TB's parameter, the dominant instabilities is TEM and the real frequency is in electron diamagnetic drift direction.**
- ✓ **The typical TB's parameters**

$$\eta_i = 0.80,\ k_\theta \rho_s = 0.6,\ q = 3,$$
$$\hat{s} = 1.6,\ \eta_e = 0.80,\ \varepsilon_n = 0.048,$$
$$\tau = 1.25,\ \varepsilon = 0.23$$

First-Principle Simulation of Particle Transport in the inversed-density-gradient profile

ASIPP

Inversed-density-gradient appears in fueling operations.



- Hollow density profile due pellet or gas-puff injection

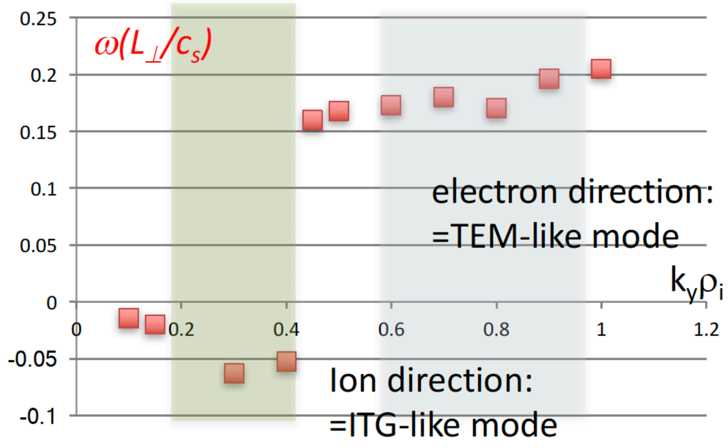
⇒inversed density gradient appears in the edge region.

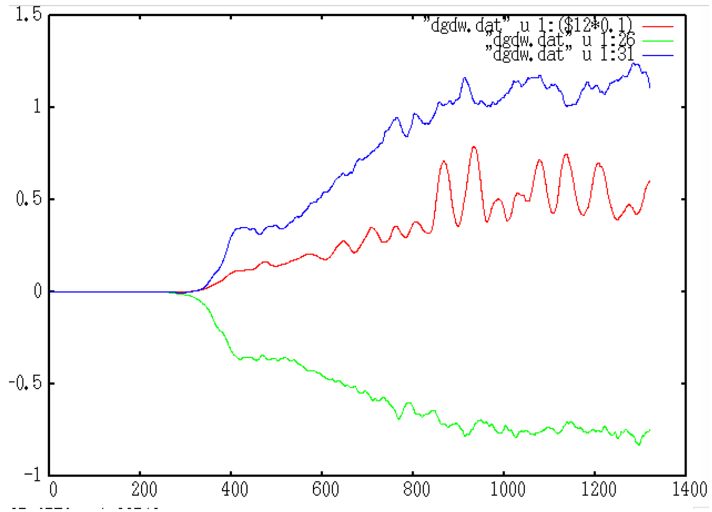
- Relevant to
  - What mechanism of the particle flux (pinch?)

(Note: in this work, profile relaxation is out of our target, due to local approach.)

- Fueling physics contributes ITER/DEMO development.
- Works on validation of particle transport physics. [Angioni '09][Wan '10][Tangered '16]

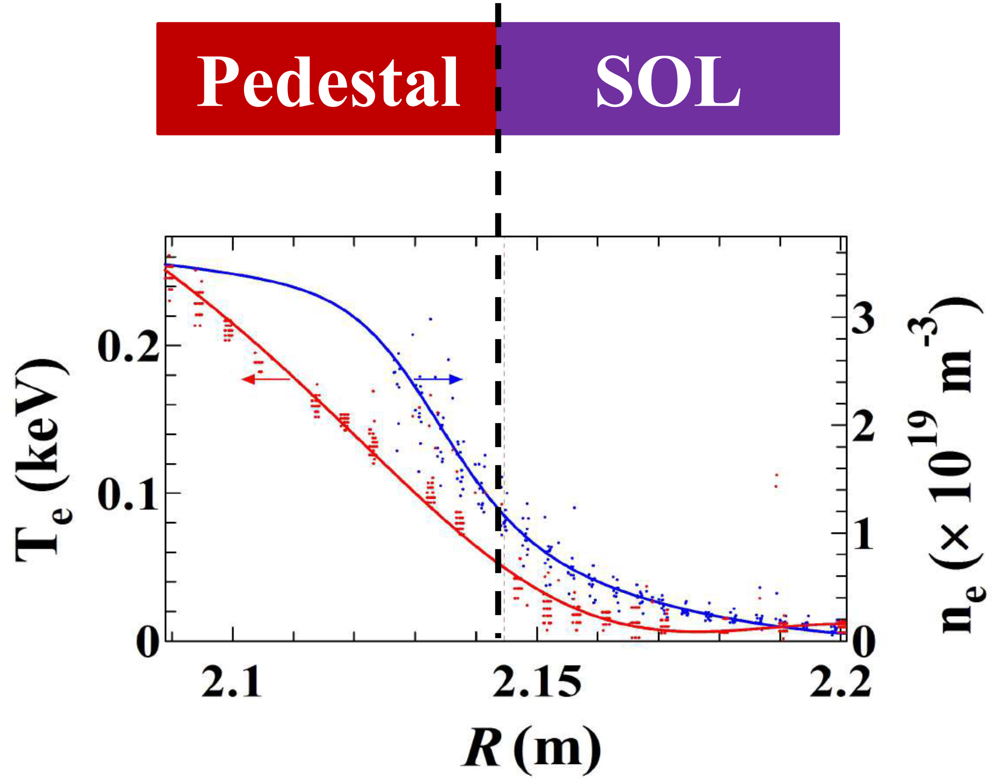
We here undergo the first-principle simulation on the particle transport in the inversed-density gradient region.





Key issues of Category A: reducion of the heat load density of Divertor

ASIPP



Lower the heat flow of Divertor

λ_q physics and detachment research

A-PL1: F.D. Halpern　A-P7: H. Tanaka
A-P15: H. Hasegawa　A-P14: M. Kobayashi
A-P13: C. Moon　A-OV1: K. Itoh

ELM mitigation

A-P1: D.F. Kong　A-P12: J.Q. Dong

Basic turbulence study

A-P11: S. Inagaki　A-O2: M.K. Han
A-O1: K. Miki

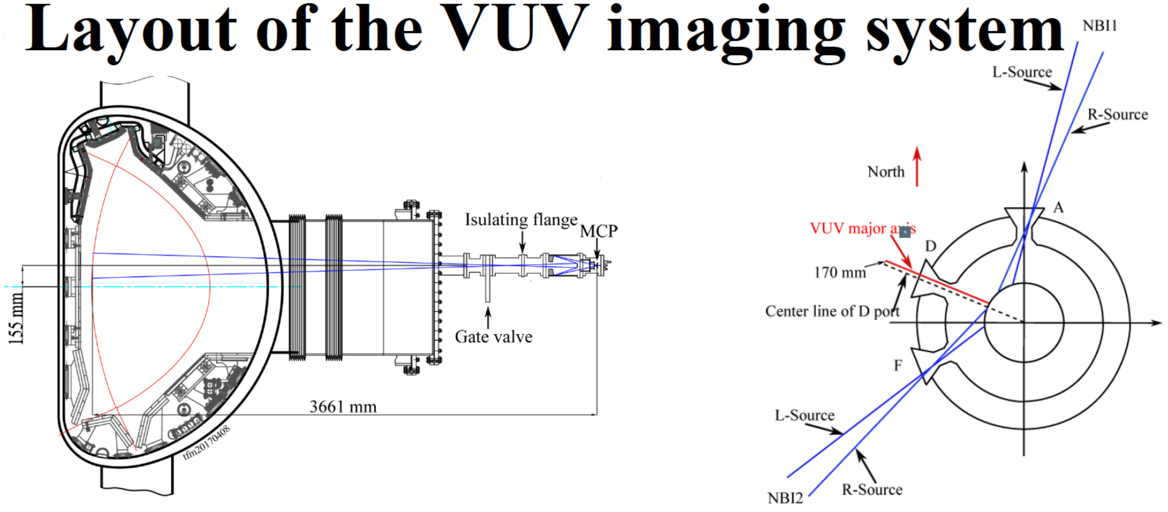
Diagnostic development

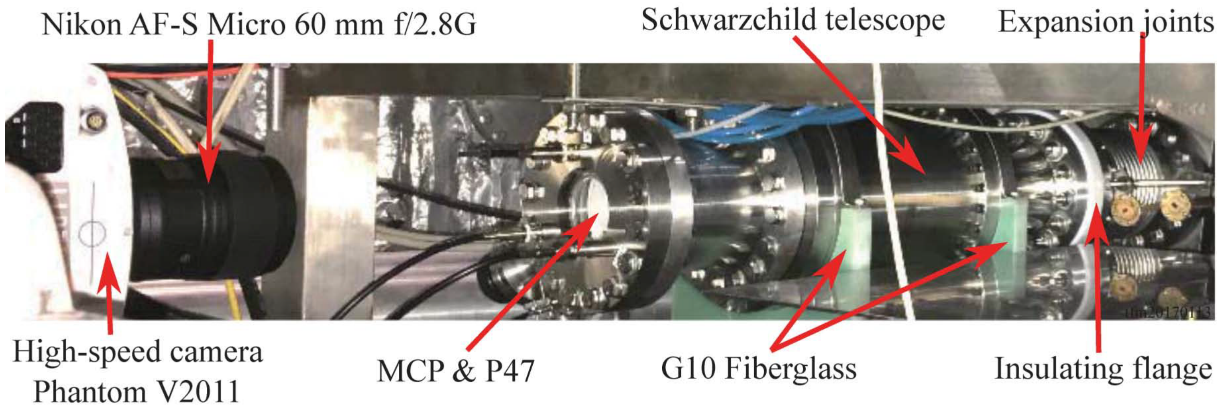
A-P2: T. Ming　A-P10: B.Y. Zhang

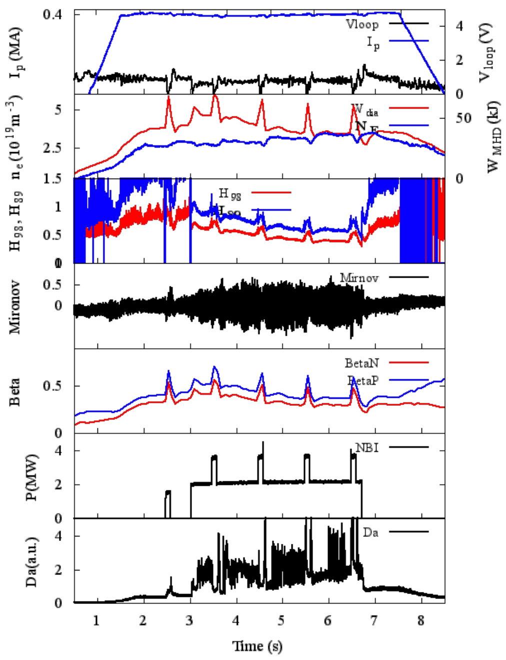
Vacuum ultraviolet imaging of the edge plasma on EAST

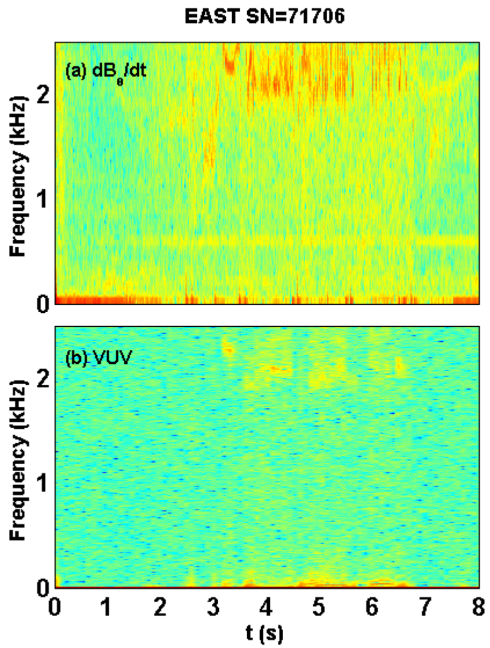
ASIPP

Layout of the VUV imaging system









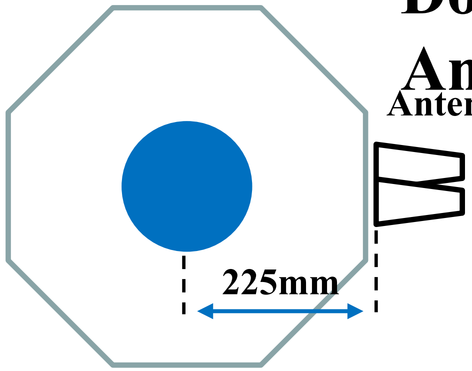
In EAST, a high-speed tangentially viewing vacuum ultraviolet(VUV) imaging system is being developed to derive information on the temporal evolutions of the spatial structure at the edge region.

A-P10: B.Y. Zhang

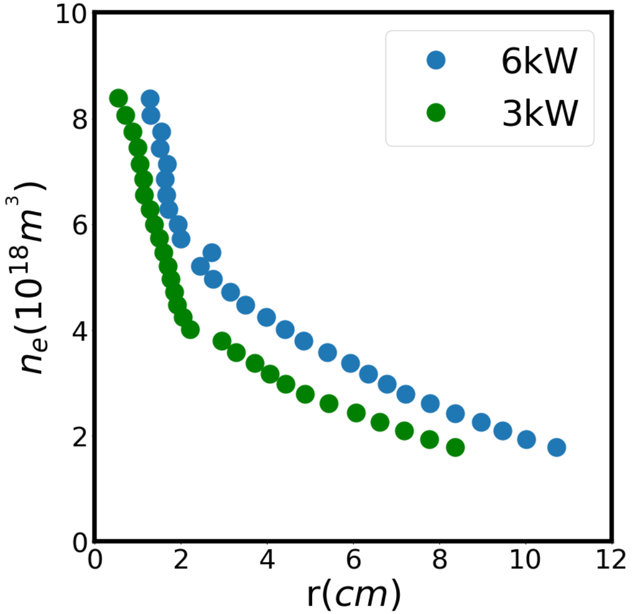
Measurement of electron density profile and perturbation with comb microwave reflectometer in linear magnetized plasma

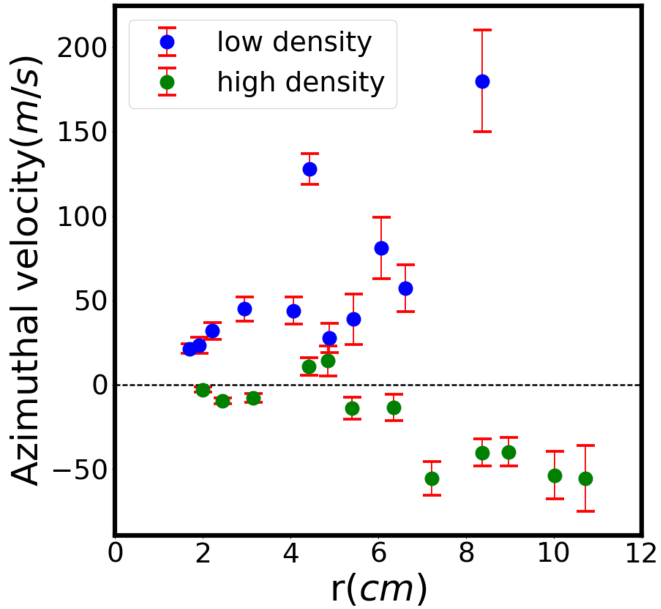
ASIPP

Doppler case:
Angle θ =4°



Cross section of PANTA





1. Comb microwave reflectometer has been used for experimental study in PANTA. The incident frequency ranges from 12GHz to 26GHz, with intervals of 0.5GHz.
2. Density profiles are reconstructed according to the phase delay of reflected wave. The temporal and spatial resolutions are 1μs and 1mm~7mm respectively.
3. The azimuthal velocity is calculated. Plasma rotates in the electron diamagnetic direction at high density, and in ion diamagnetic direction at low density.
4. Medium and high frequency modes are observed at high density case. Harmonic of medium frequency mode is also observed.

ASIPP

Thank you!