7th APTWG 2017 International Conference   5th – 8th June 2017, Nagoya University, Japan

Summary of Working Group D:

Mechanism determining plasma flows and their impact on transport and MHD

On behalf of Group D

Won-Ha Ko (NFRI, Korea)
M. Leconte (NFRI, Korea)

Presentations : Total 11

- **Plenary (1)**
- **Oral (4)**
- **Poster (6)**

- **Categories**

– Intrinsic torque and rotation (2)
– Toroidal rotation and momentum(3)
– Zonal flows (3)
– Turbulent transport (3)

Intrinsic torque and rotation

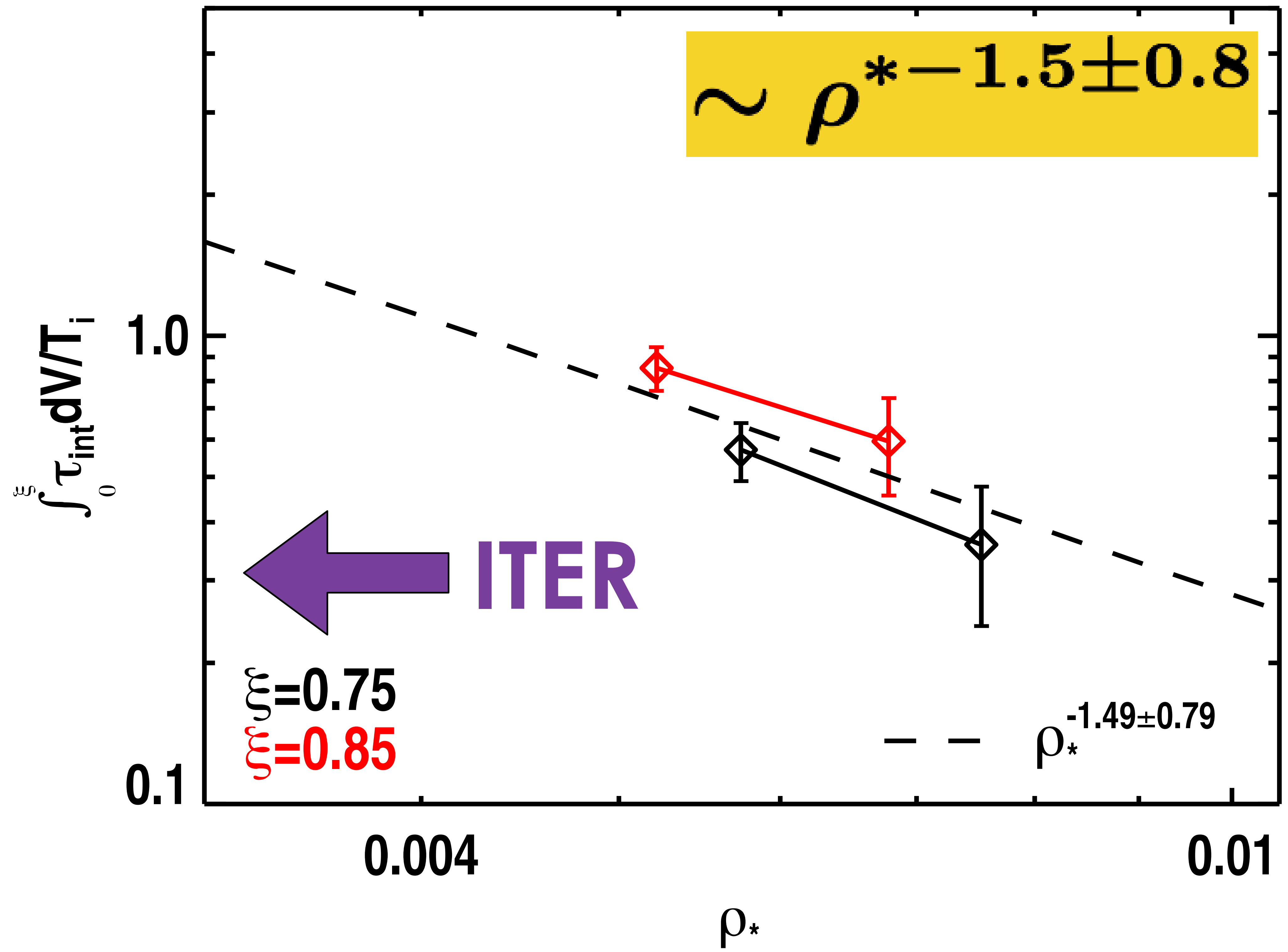
1. The influence of plasma rotation on burning performance in Tokamak (C. Chrystal - GA)

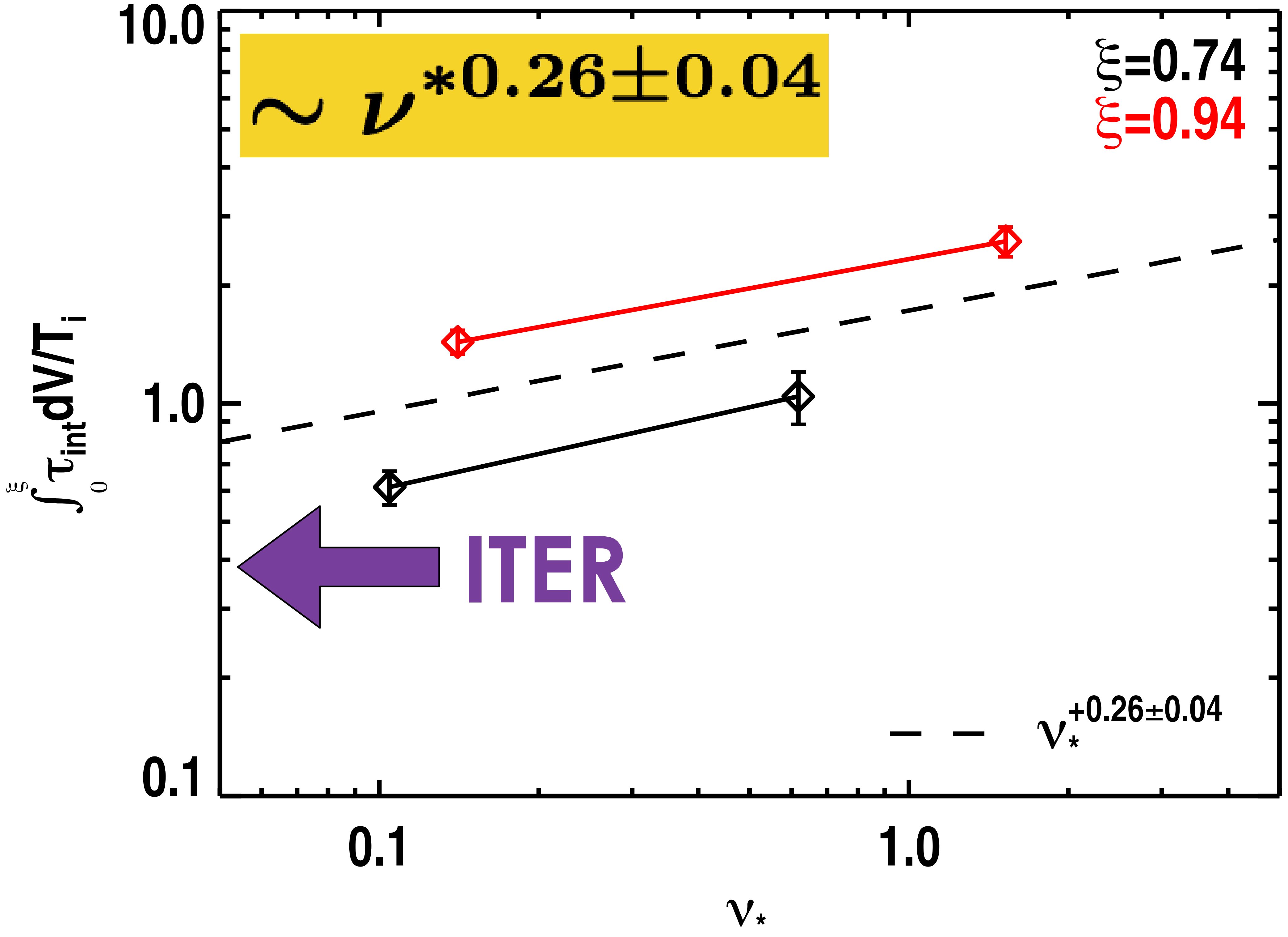
2. Empirical investigation of spontaneous rotation under co- and counter-NBI heated H-mode plasma in KSTAR* (Won-Ha Ko - NFRI)

The influence of plasma rotation on burning performance in Tokamak

(C. Chrystal - GA)

Normalized Intrinsic Torque Increases with Decreasing ρ^* and Decreases with Decreasing ν^*





- Intrinsic torque is ~1 Nm, in agreement with previous measurements
- Must work with dimensionless parameters to determine scaling, normalize intrinsic torque with T_i (simplest quantity with same units, discussed more later)
- Net scaling is unexpectedly "favorable": increases for ITER's (~33Nm) lower ρ^*, ν^*

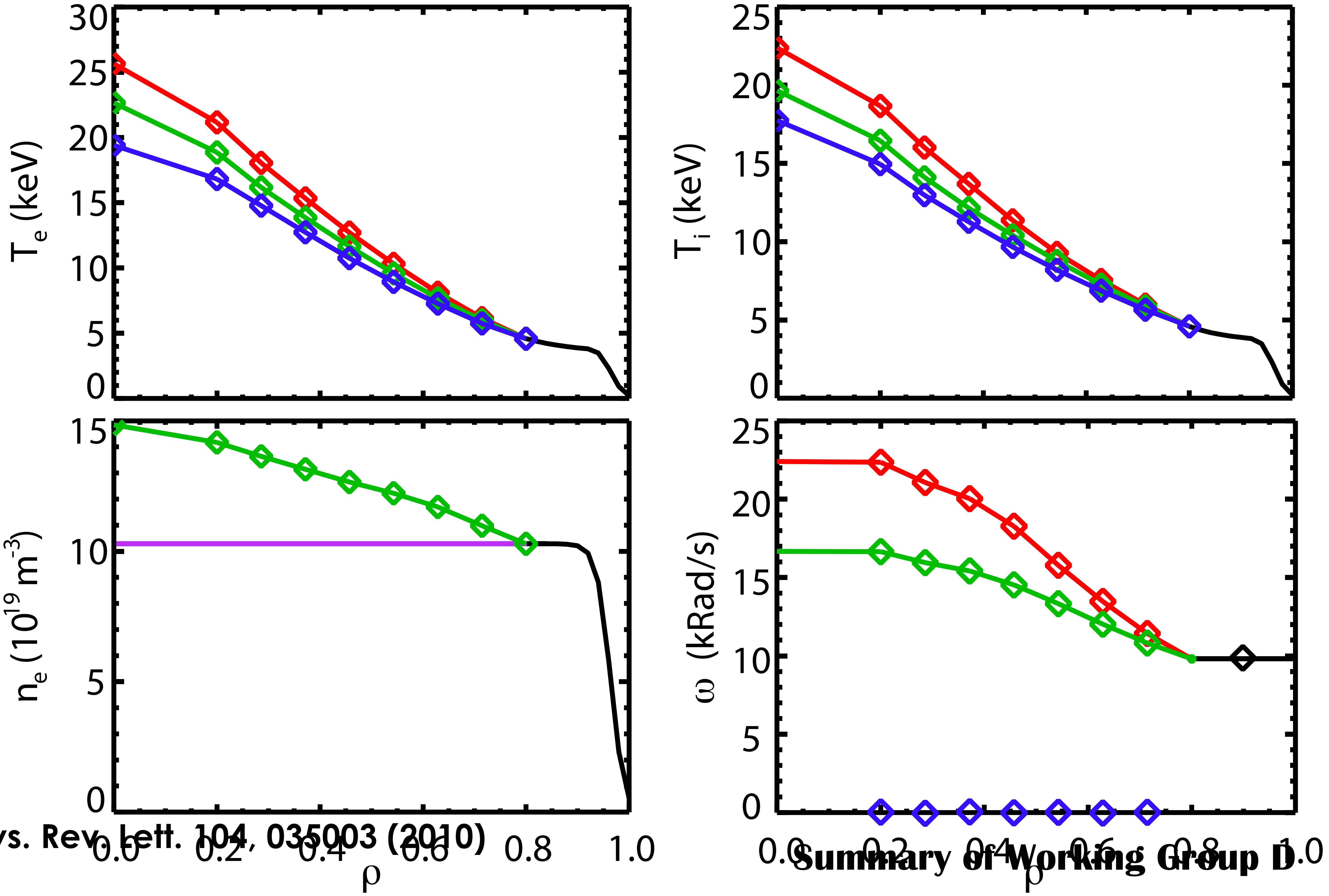
The influence of plasma rotation on burning performance in Tokamak

(C. Chrystal - GA)

Rotation Profile Predicted for ITER with Edge Intrinsic Torque Boundary and TGLF Transport Increases Performance

- **10 krad/s B.C., TGLF/TGYRO used to predict core rotation from NBI**
  - Previous comparisons increase confidence
- **Flat density has higher rotation, self-consistent particle transport has lower rotation, higher Q_{DT}**
  - This rotation yields ~35 kV/m Er, 3X grad-pressure term[1], simulations used high ExB ordering
- **Alfvén Mach number=0.01, further study needed to determine RWM stability[2,3]**

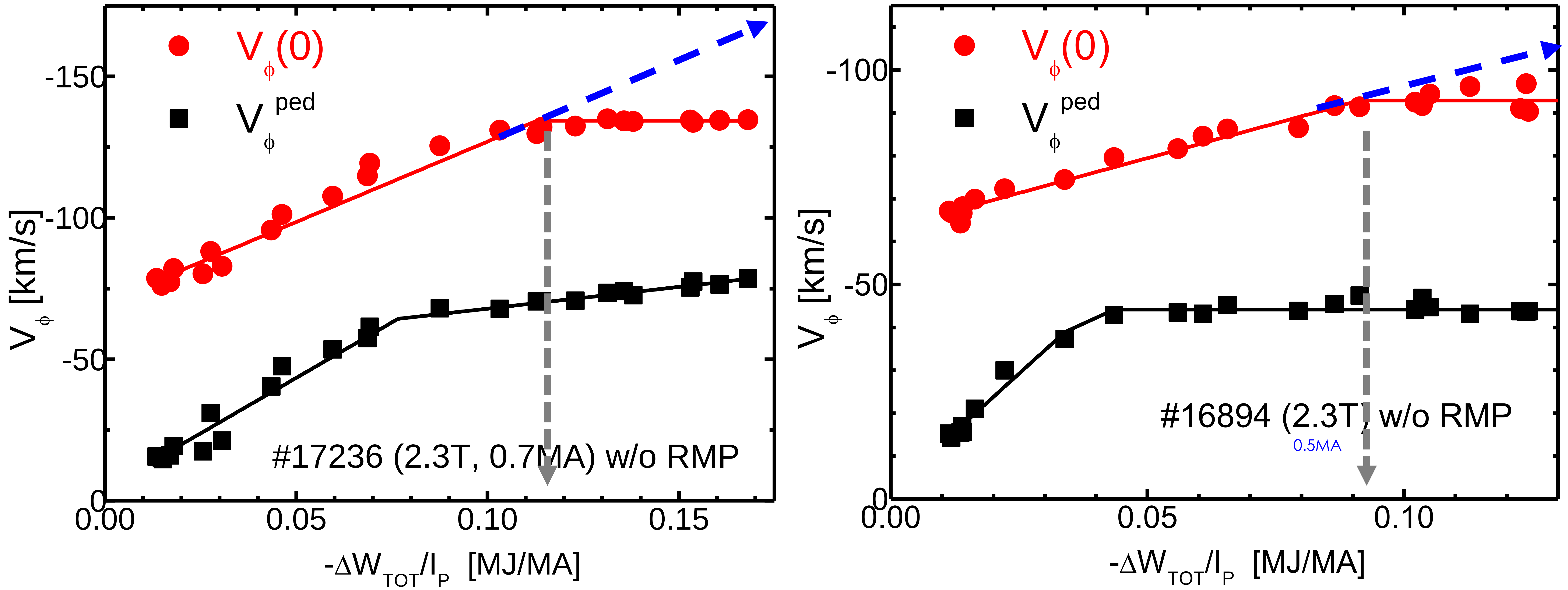
Flat Density No ExB => Q=5 | Flat Density +ExB => Q=8 | +Density Evolved +ExB => Q=11



[1] Budny , Nucl. Fusion 48, 075005 (2008)

[2] Liu, Nucl. Fusion 49, 035004 (2009) [3] Berkery, Phys. Rev. Lett. 104, 035003 (2010)

Empirical investigation of spontaneous rotation under co- and counter-NBI heated H-mode plasma in KSTAR* (Won-Ha Ko - NFRI)



- RMPs strongly reduces rotation from pedestal to core region but is not saturated core rotation by ΔW/Ip and removes a modest pedestal structure and edge counter rotation in co-NBI heated plasma while V_ϕ has a edge co-rotation in counter-NBI heated plasma in spite of RMPs. → indirect evidence of the edge intrinsic rotation with co-direction
- Core rotation saturated in counter-NBI heated H-mode and amount of core intrinsic torque can estimate from blue line → indirect evidence of the core intrinsic rotation with co-direction

Toroidal rotation and momentum

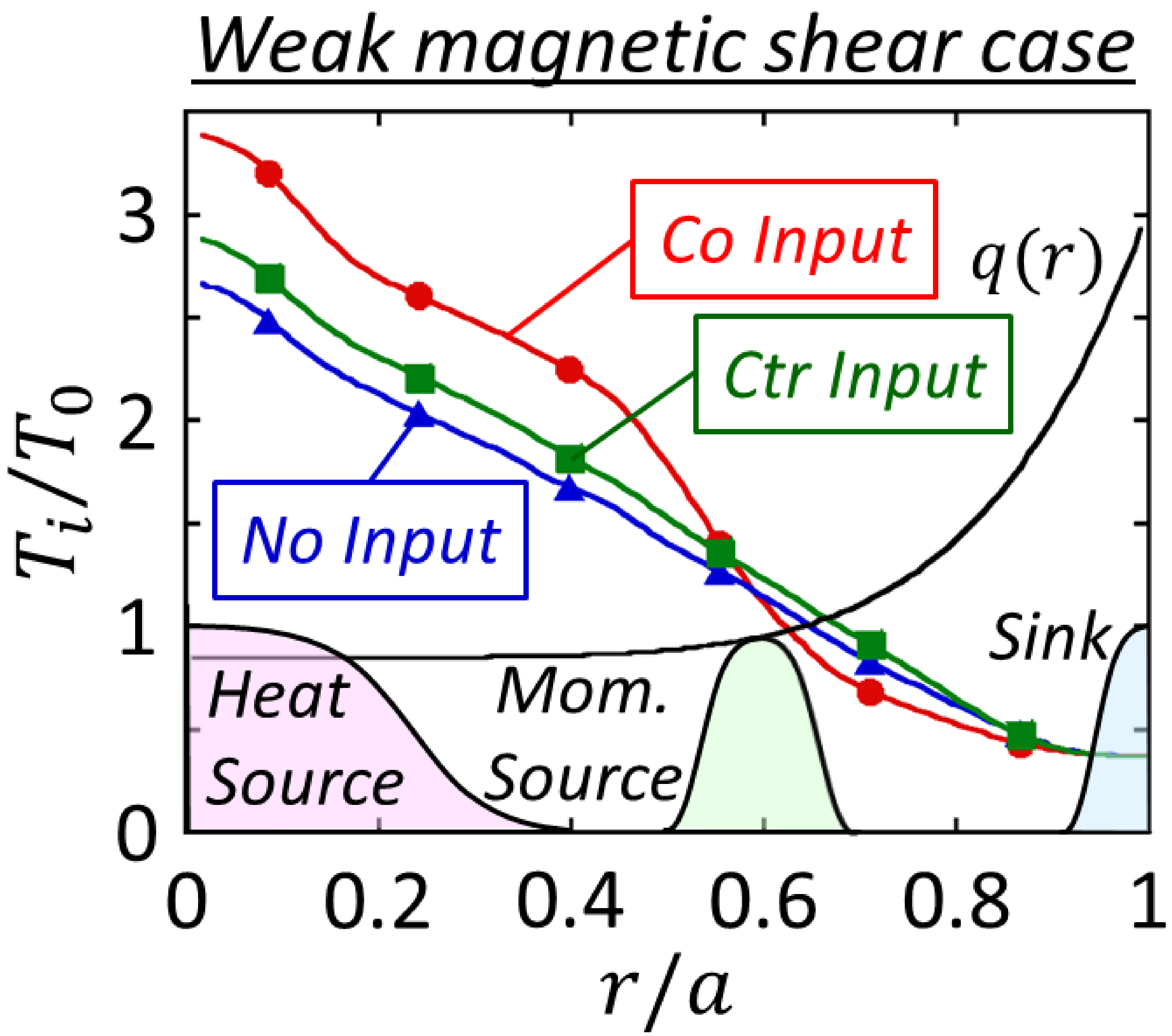
1. ITB formation by toroidal momentum injection in flux-driven GK turbulence (K. Imadera - Kyoto Univ.)

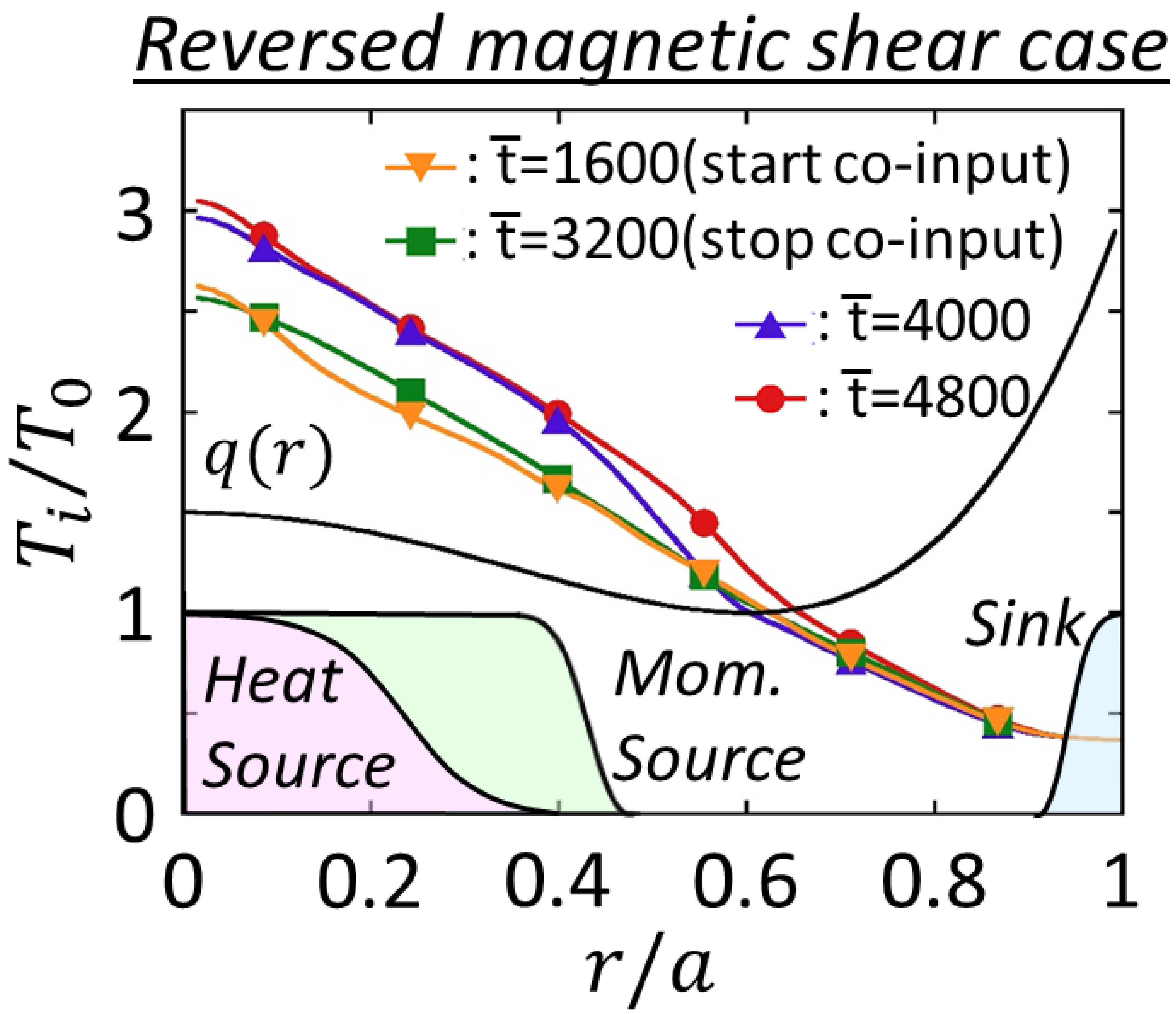
2. How turbulence fronts induce plasma spin-up (Y. Kosuga - Kyushu Univ.)

3. Finite orbit width effect on the neoclassical toroidal viscosity in the superbanana-plateau regime (S. Matsuoka - JAEA)

ITB formation by toroidal momentum injection in flux-driven GK turbulence

(K. Imadera - Kyoto Univ.)





- ✓ **Co-current toroidal rotation in outer region can benefit the ITB formation in weak magnetic shear plasma** **(Left Figure)** showing a qualitative agreement with the observations in the JET experiment. **The underlying mechanism is identified to originate from a positive feedback loop between mean E_r shear and resultant momentum flux.**
- ✓ **Such a mechanism can also benefit the ITB formation around q_{min} surface in reversed magnetic shear plasma (Right Figure).**

How turbulence fronts induce plasma spin-up

(Y. Kosuga - Kyushu Univ.)

- **Flux of fluctuation || mom. by the triplet correlation is calculated**

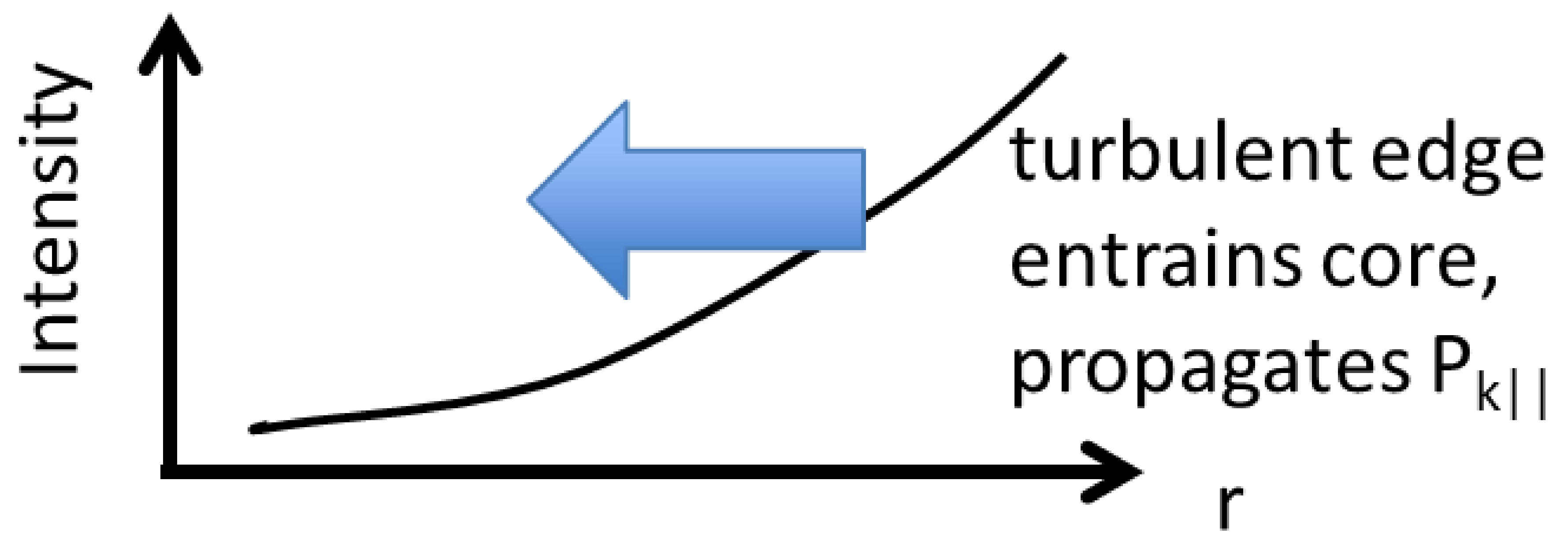
$$\langle \tilde{v}_x \tilde{n} \tilde{v}_\parallel \rangle = \sum_{\mathbf{k_1}} (V_{\mathbf{k_1}} P_{\parallel \mathbf{k_1}} - D_{\mathbf{k_1}} \partial_x P_{\parallel \mathbf{k_1}}) \sim -v_* \frac{L_n^2}{\rho_s L_I} |\hat{\phi}|^2 P_{\mathbf{k}\parallel}$$

Convection **Diffusion** **Inward flux of turbulence momentum density**

- **Fusion application:**

In L-mode, induce edge-core coupling of toroidal flows

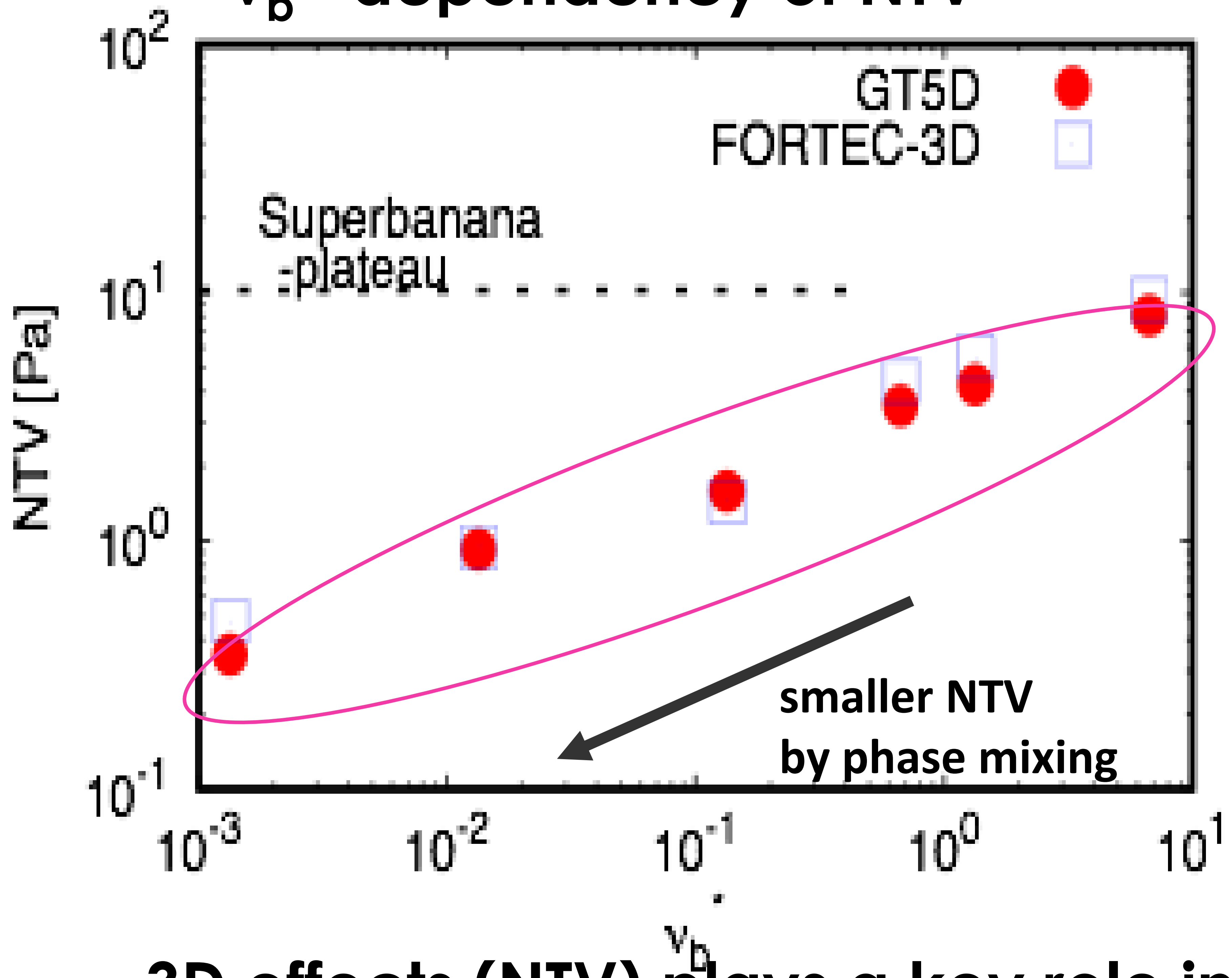
A possible origin of LSN/USN asymmetry



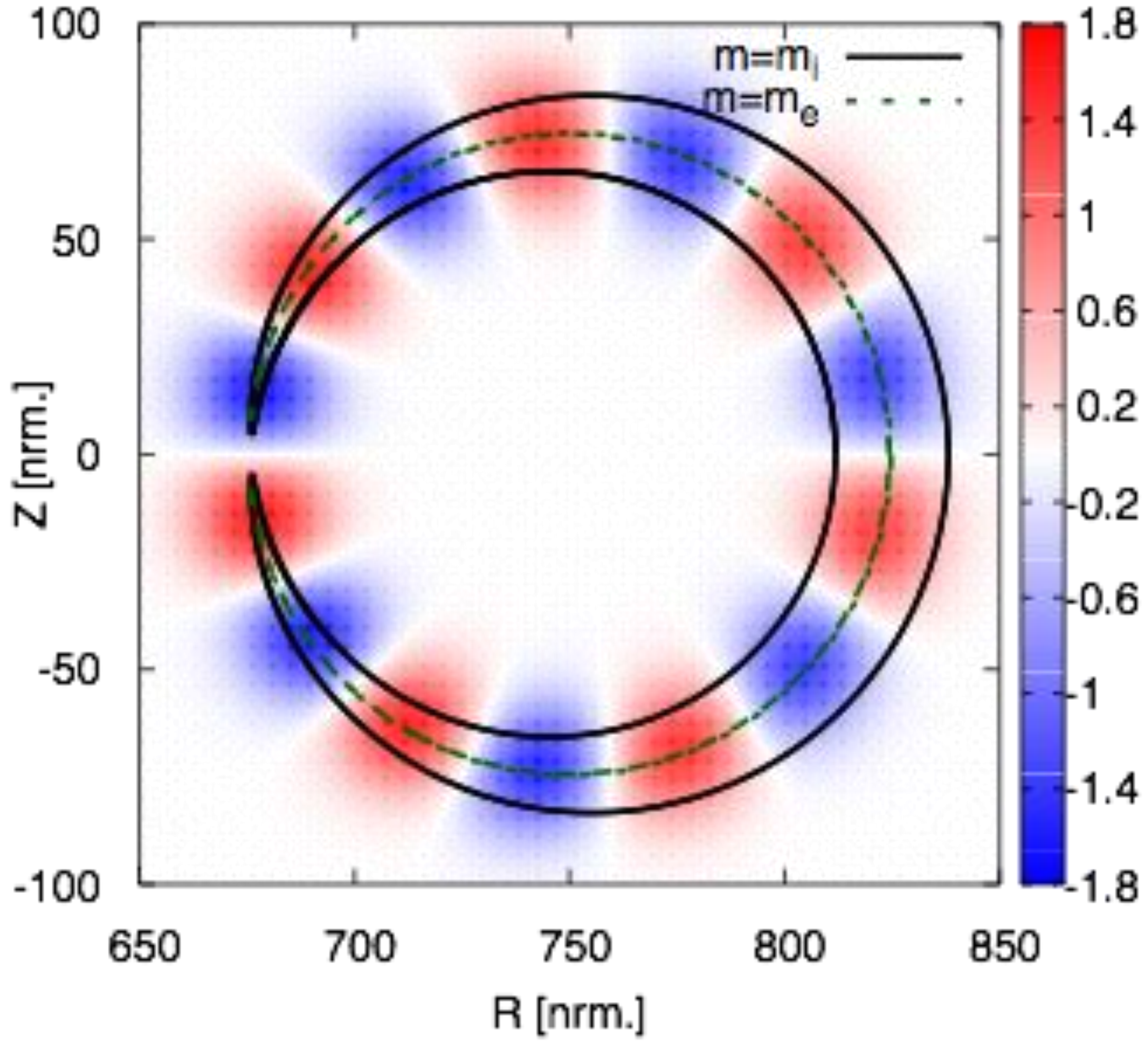
- **Rotation drive is linked to spatial dynamics of turbulence. Several extension possible and merit further investigation.**

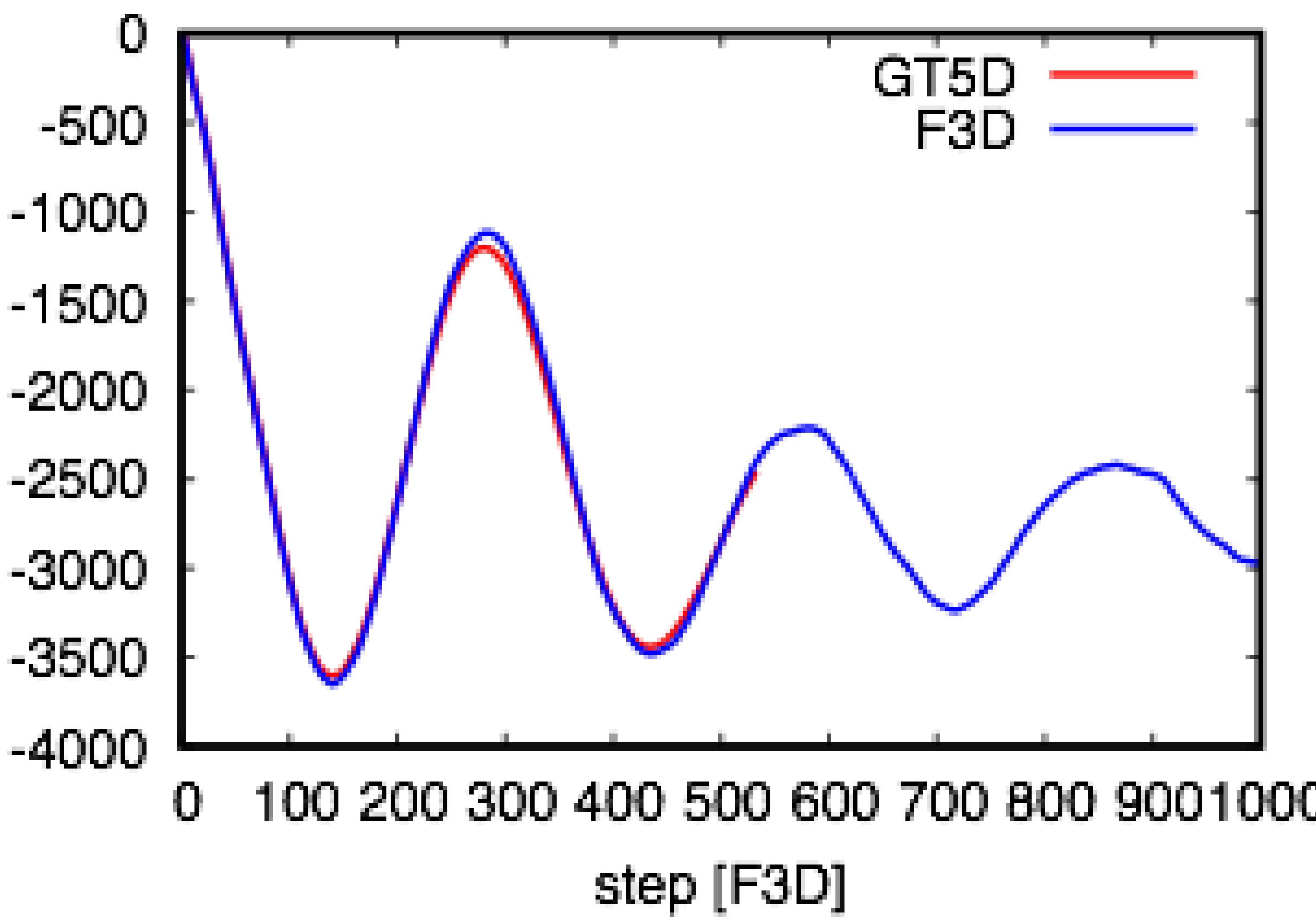
Finite orbit width effect on the neoclassical toroidal viscosity in the superbanana-plateau regime (S. Matsuoka - JAEA)

- ν_b*-dependency of NTV



Typical trapped orbit and δB





→ Er and Γi shows fairly a good agreement with FORTEC-3D.

→ GAM oscillation and its damping are observed.

- **3D effects (NTV) plays a key role in predicting the rotation/transport.**
- **Two global kinetic simulations show ;**
  NTV has different ν_b*-dependency from the standard Superbanana-plateau theory .
- **Finite orbit width effect significantly changes the NTV.**

1. Effective magnitude of the perturbation decreases. —> Smaller NTV.
2. Bounce phase mixing caused by the finite mode structure. —> ν_b*-dependency.

Zonal flows

1. Effects of Parallel Flow Fluctuation on Zonal flow (Sumin Yi - NFRI)

2. Residual zonal flows with finite radial wavenumber revisited, and effects of initial parallel flow and electromagnetic potentials in tokamaks (O. Yamagishi - NIFS)

3. Helical electric potential modulation via Zonal-Flow coupling to Resonant Magnetic Perturbations (M. Leconte - NFRI)

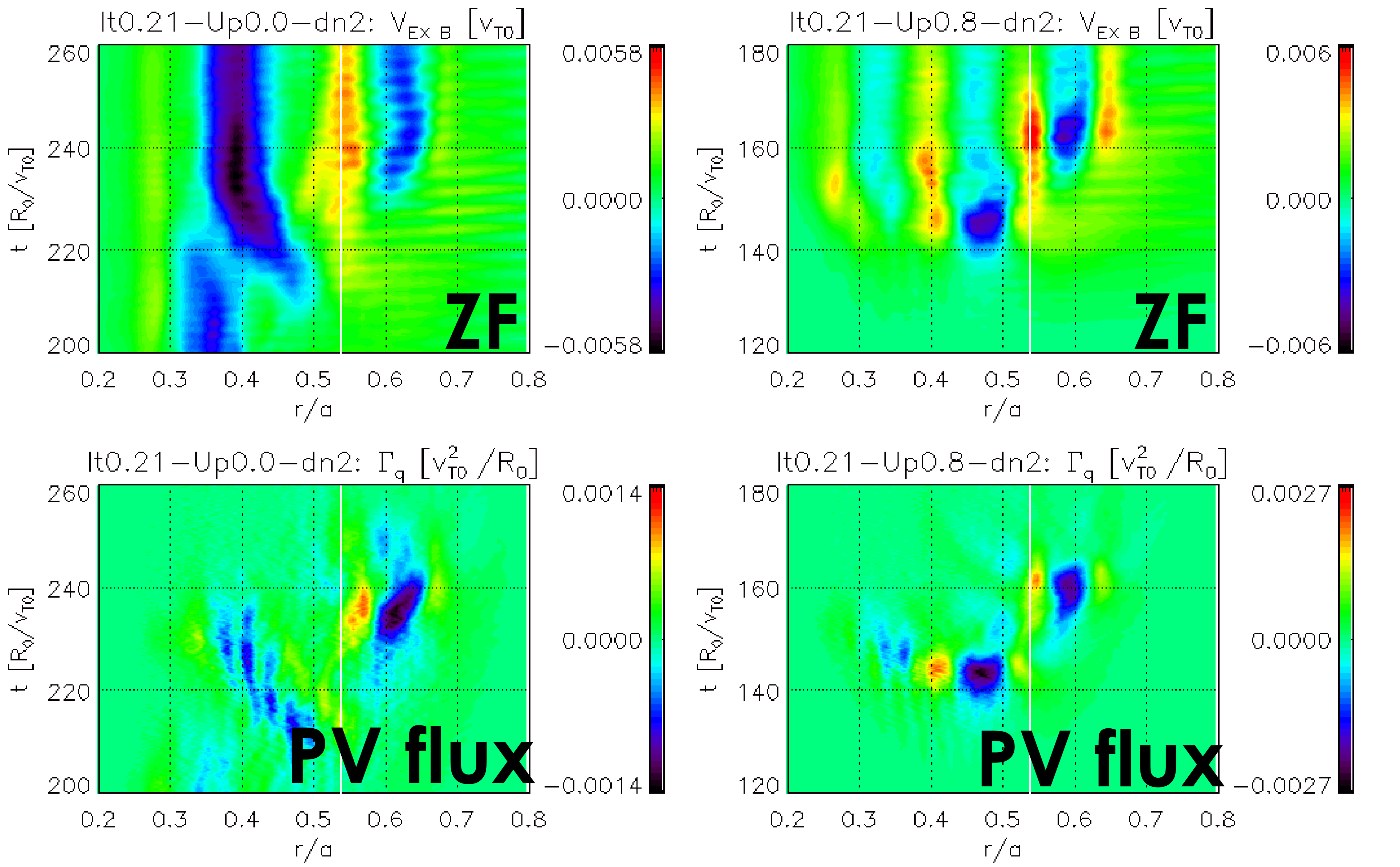
Effects of Parallel Flow Fluctuation on Zonal flow (Sumin Yi - NFRI)

- ***How does parallel dynamics affect the generation of zonal flow?***
- Gyrokinetic simulations
- An analysis of poloidal momentum transport in the framework of the potential vorticity(PV) mixing theory.

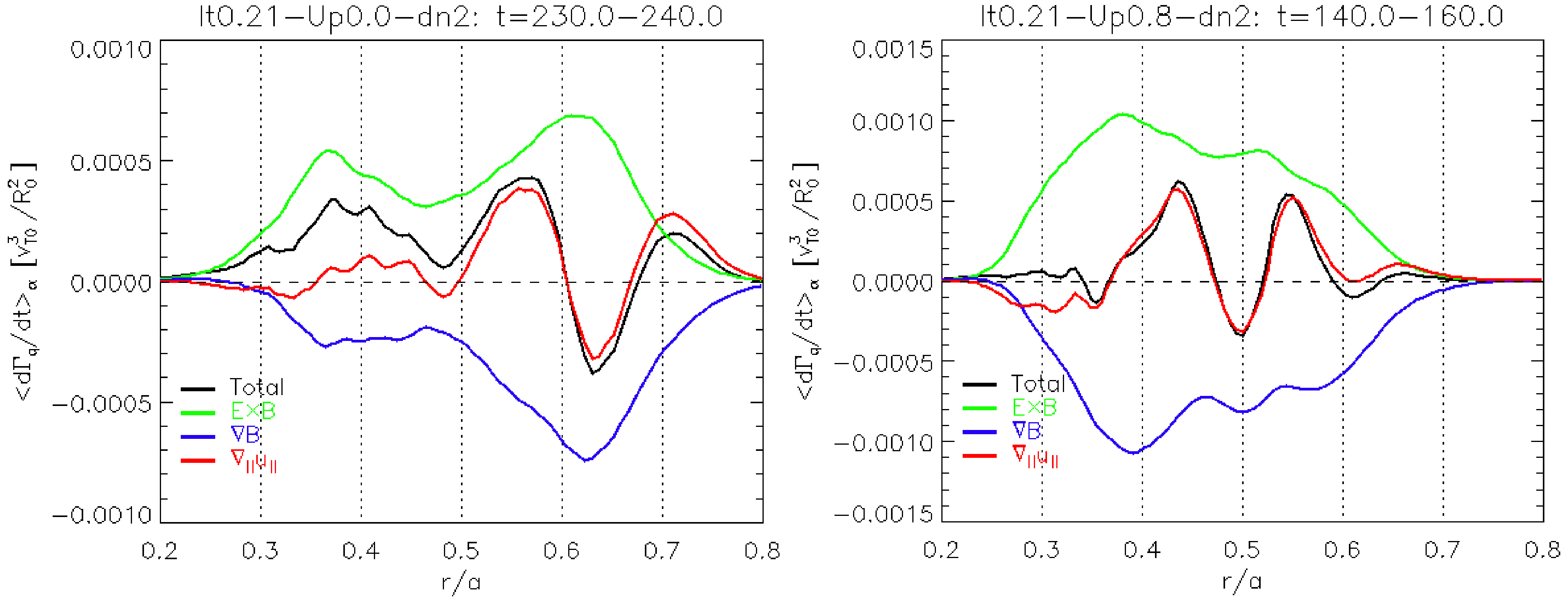
→ Radial profiles of zonal flow show clear differences when the equilibrium parallel flow shear is applied. The difference in the zonal flow structures is well described by that of PV flux.

- **The contribution of the parallel flow fluctuation on the PV flux is smaller than the other perpendicular mechanisms in absolute amplitude. But, the perpendicular contributions, the ExB diffusion (green curves) and the thermoelectric pinch (blue curves), are largely cancelled each other.**
- **So, The compression of the parallel flow fluctuation shows a substantial contribution to the total PV flux evolution.**

$dU_{||}/dr=0.0$ $dU_{||}/dr=0.8$



Decomposition of the PV Flux Mechanisms

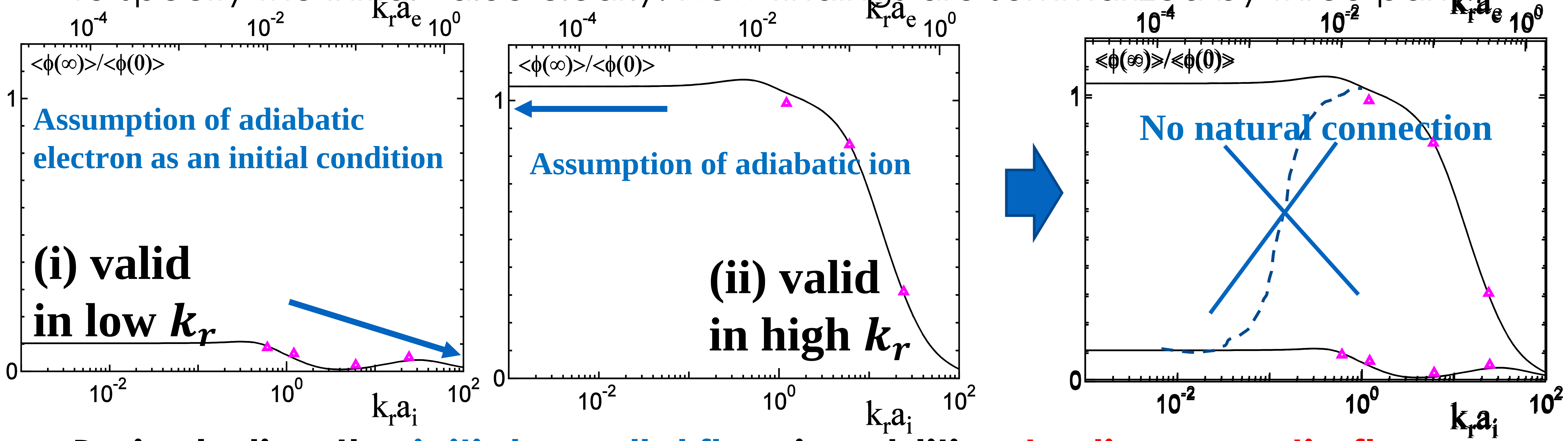


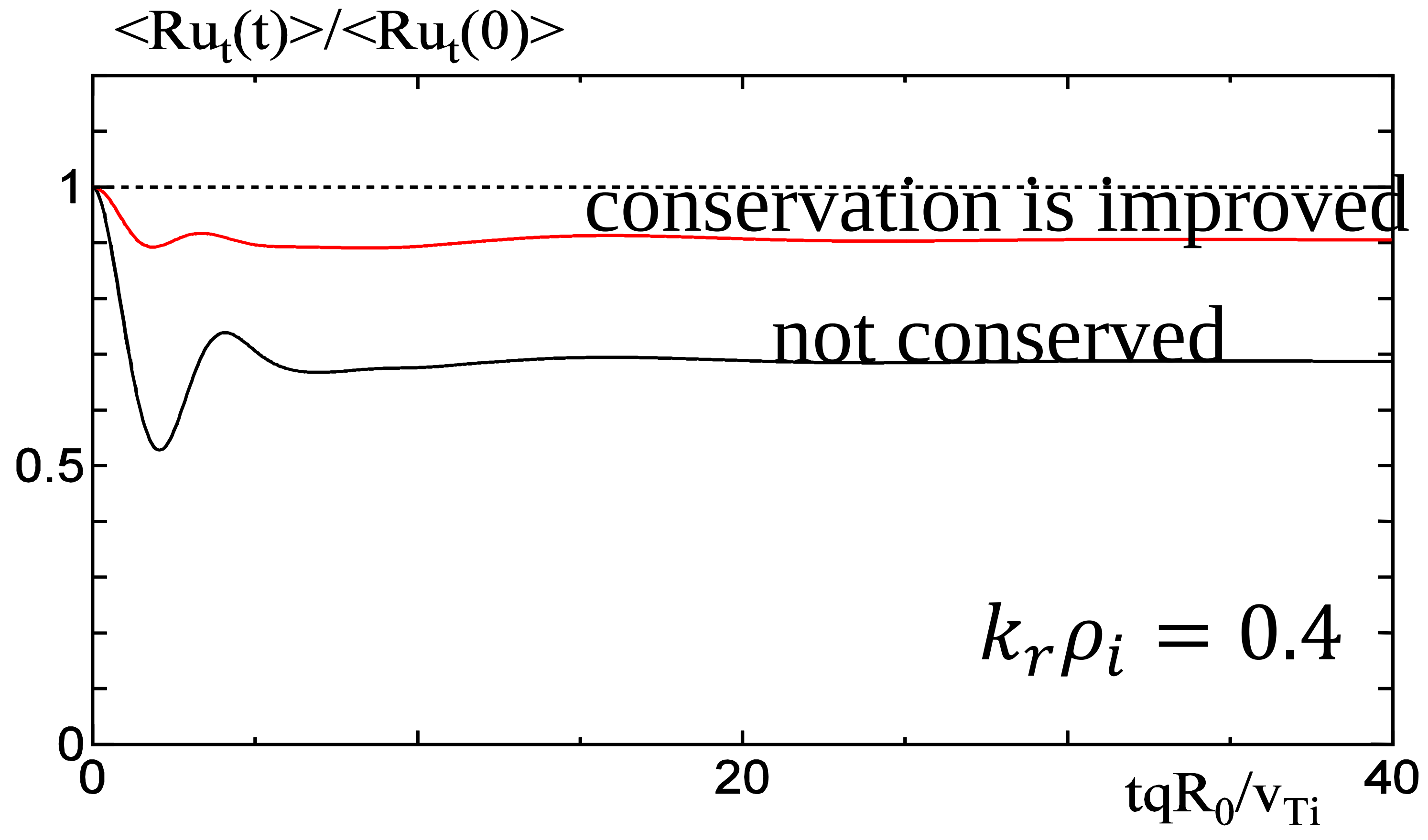
$dU_{||}/dr=0.0$ $dU_{||}/dr=0.8$

Summary of Working Group D

Residual zonal flows with finite radial wavenumber revisited, and effects of initial parallel flow and electromagnetic potentials in tokamaks (O. Yamagishi - NIFS)

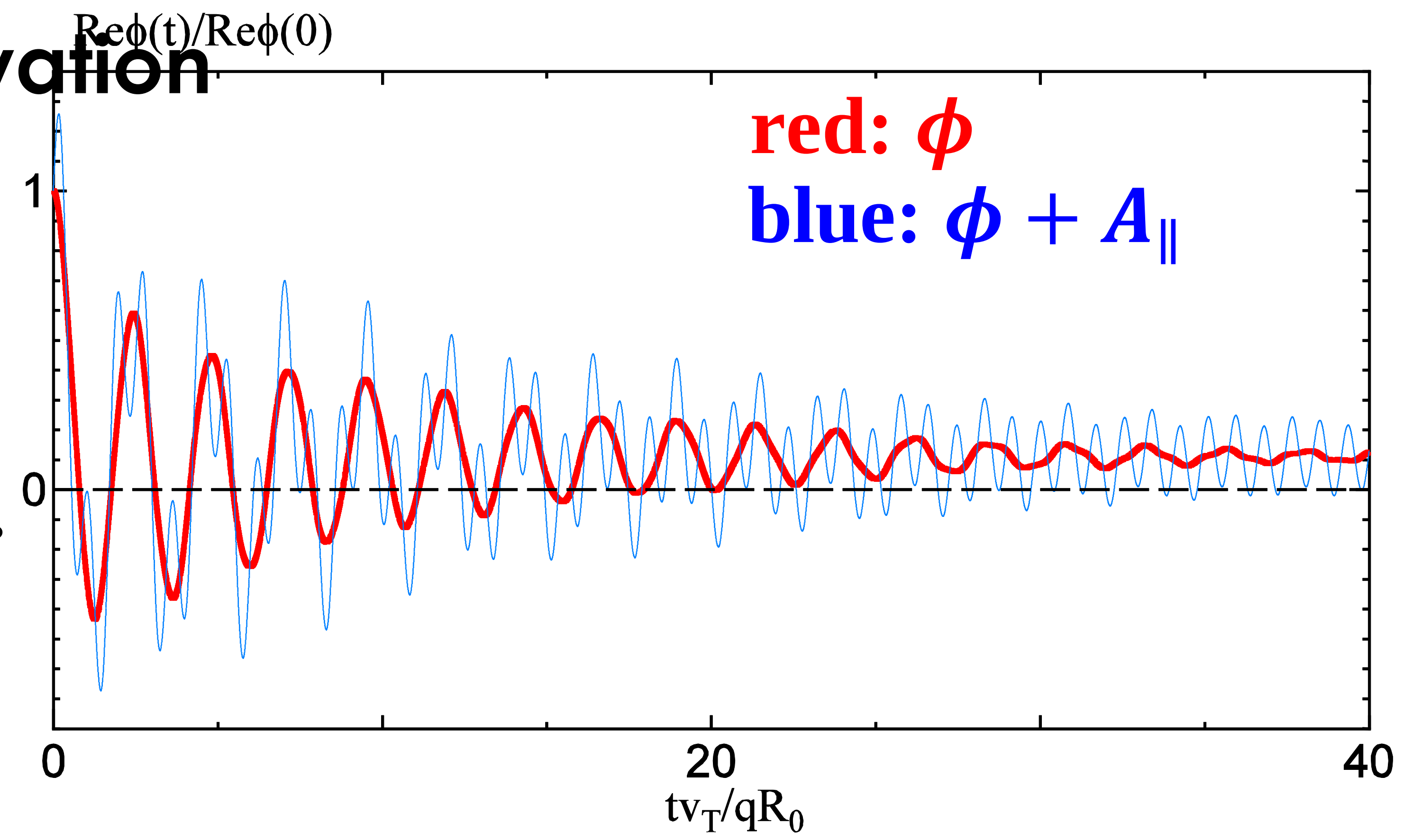
- The Rosenbluth-Hinton test by the direct gyrokinetic simulation and semi-analytical approach, to investigate the radial wavenumber dependence of the residual zonal flows. Since the Rosenbluth-Hinton test is initial value problem, it is important to specify the initial value clearly. New findings are summarized by three parts.





- **By including the initial parallel flow in addition to diamagnetic flow as a first order perpendicular flow, check the conservation of toroidal angular momentum ~ Ru$_{tor}$ in the Rosenbluth-Hinton test. → toroidal momentum conservation**

$$J_0 F_{1i}(0) = F_{0i}\left[\frac{\delta \bar{n}}{n_0} + \frac{m}{T_0} v_\parallel u_\parallel + \frac{\delta \bar{T}_\perp}{T_0}\left(\frac{v_\perp^2}{v_T^2} - 1\right)\right]$$



- **In addition to the conventional electrostatic potential ϕ in the Rosenbluth -Hinton test, the electromagnetic potential $A_\parallel$ is included as an initial condition.**
- Fast oscillation is introduced in the usual decay phase of GAM (f~ Alfven freq).
- Although the resulting residual level seems not to be changed, the time to reach to the stationary zonal flow becomes longer. Thus this electromagnetic effect may weaken the suppression effect of turbulence moderately.

Helical electric potential modulation via Zonal-Flow coupling to Resonant Magnetic Perturbations (M. Leconte - NFRI)

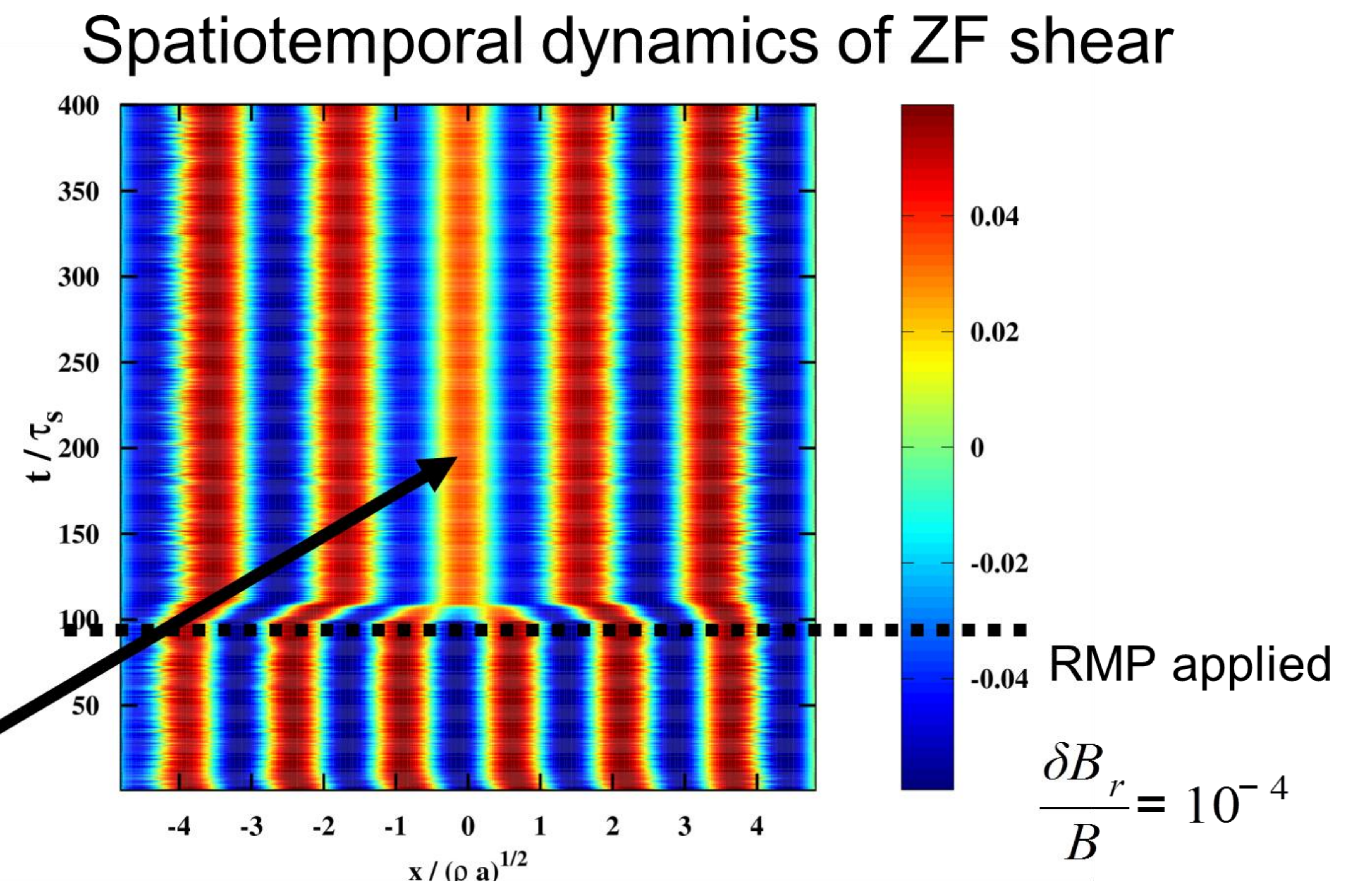
- Study of RMP impact on Zonal Flow saturation
- Based on phenomenological 1D nonlinear model

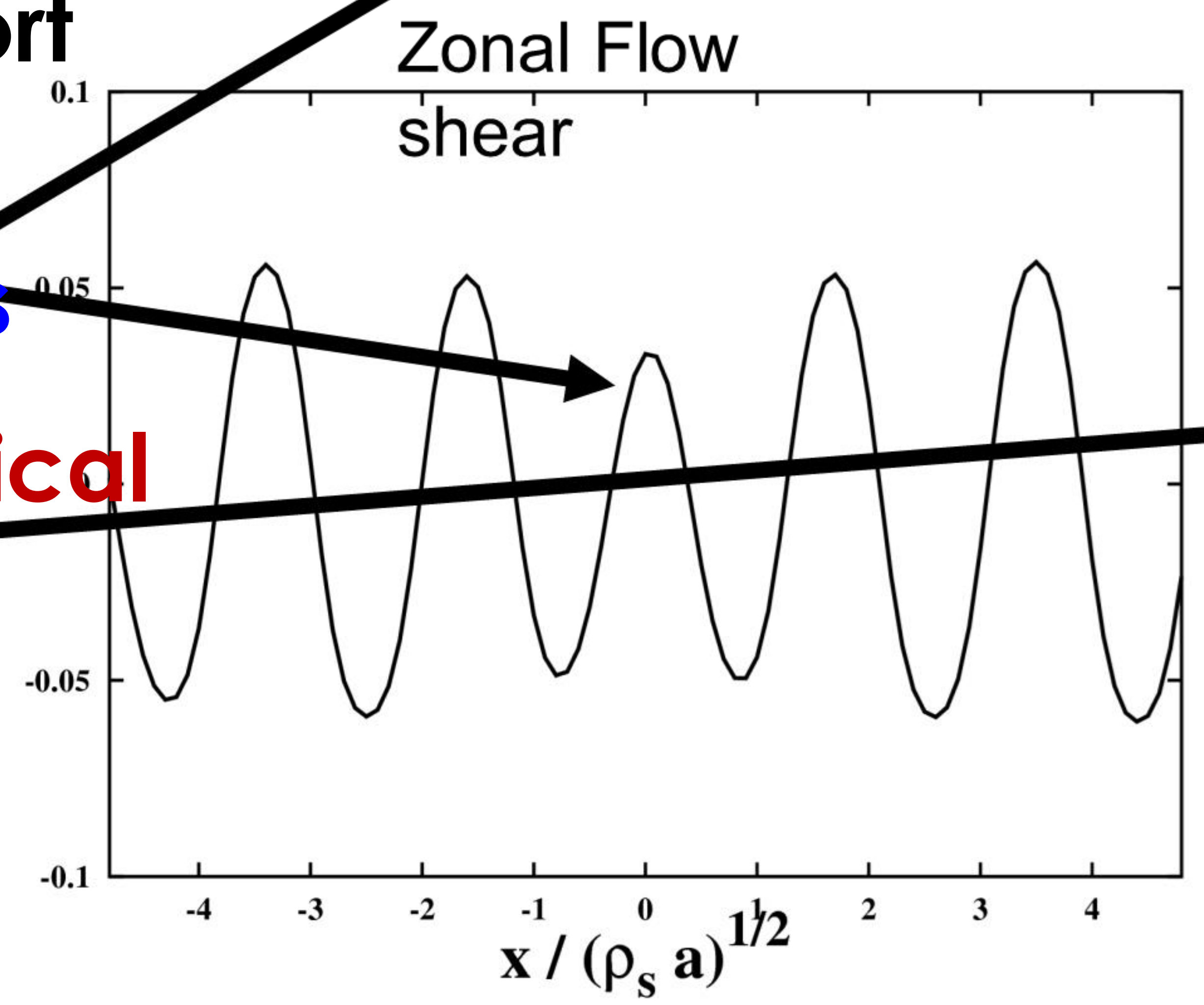
around single resonance surface x=0

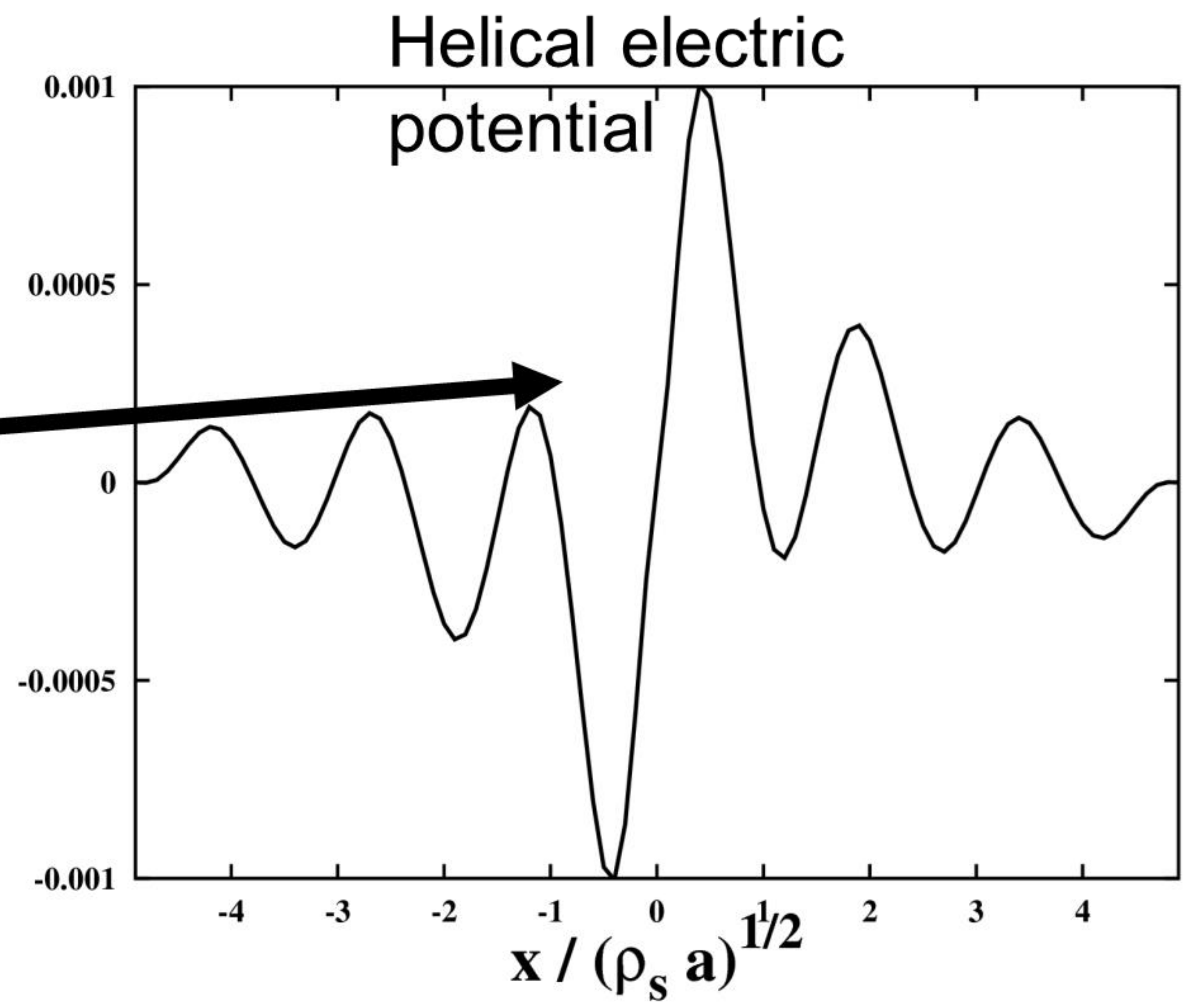
- Key question: given an initial saturated state of co-existing turbulence and Zonal Flows, How do RMPs modify it, and what is the final new saturated state?

Main results [M.Leconte and J.H. Kim, accepted in NF'17]:

- 1) The modification takes the form of a transport bifurcation.
- 2) new saturated state has weaker Zonal Flows
- 3) The new state has a 3D topology, with a helical modulation of the electrostatic potential.







Turbulent transport

1. Observation of solitary and mono-cycle shaped flow structure associated with the TESPEL injection (T. Tokzawa - NIFS)

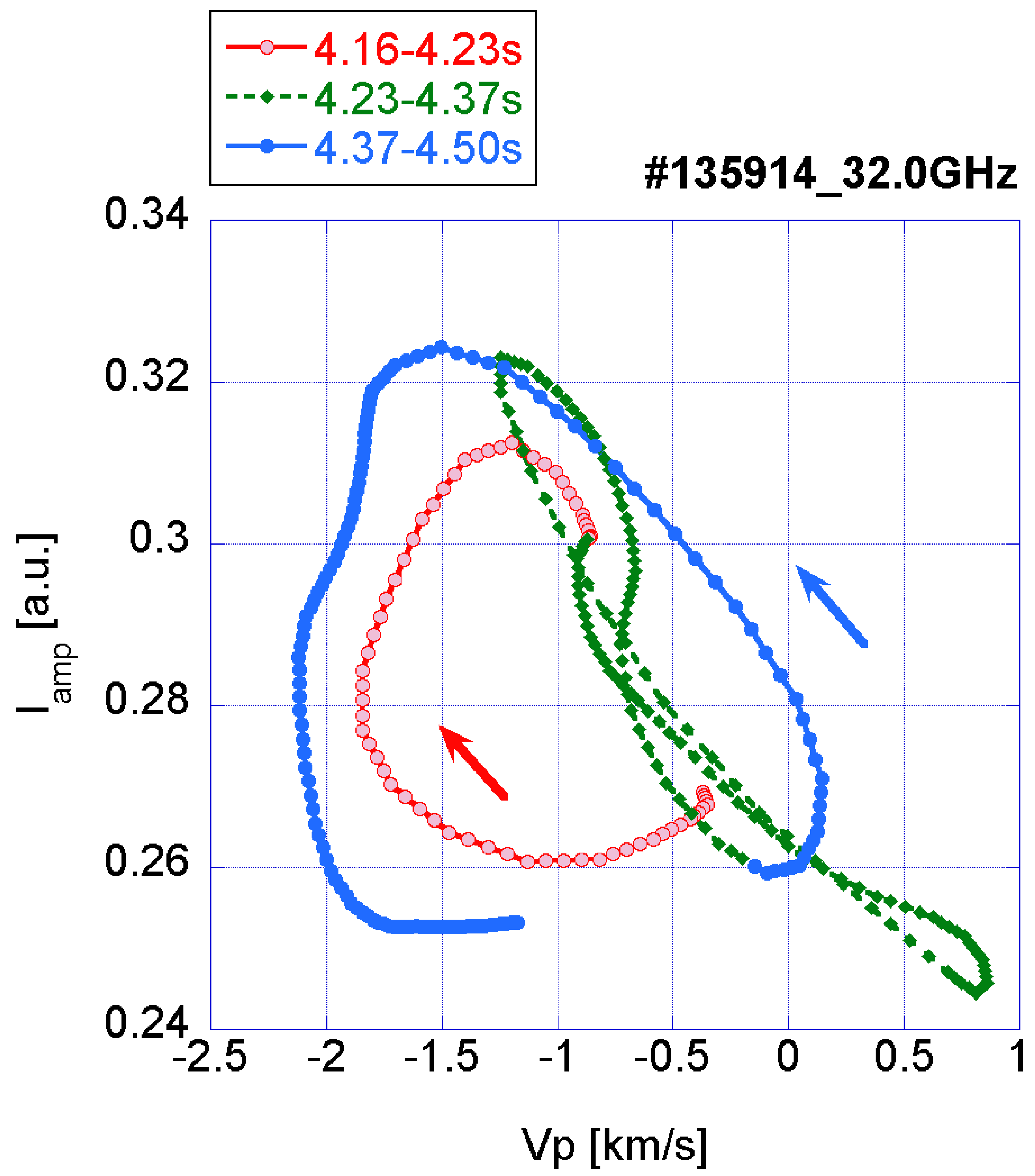
2. Impact of end-plate biasing on plasma fluctuations in PANTA (Y. Nagashima - Kyushu Univ.)

3. Gyrokinetic formulation to derive conservation laws for collisional and turbulent transport of particles, energy, and toroidal momentum (H. Sugama - NIFS)

Observation of solitary and mono-cycle shaped flow structure associated with the TESPEL injection

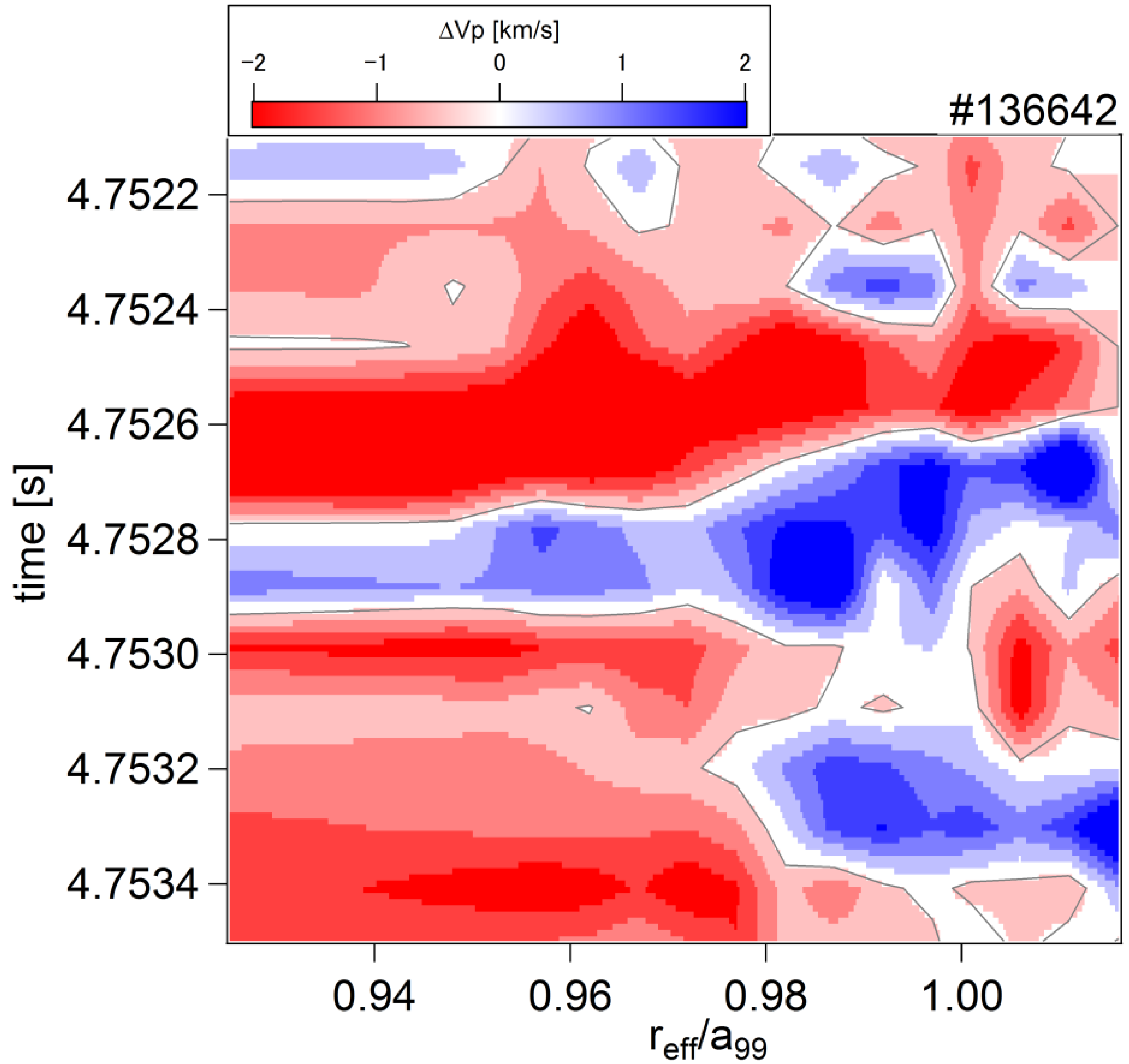
(T. Tokzawa - NIFS)

1. Oscillation near the transition threshold



- **Reversed relationship (Linkage of Vp(~Er) and turbulence) is observed during the oscillation**
- **Inversion position moves outward.**

2. Propagation of Vp structure



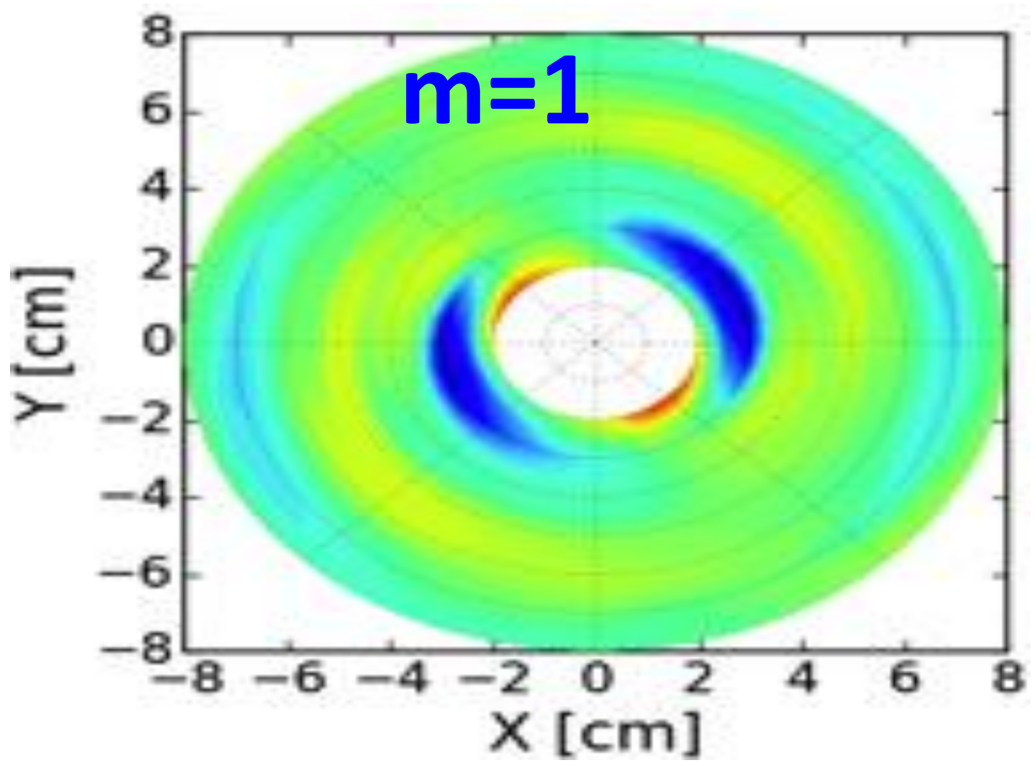
- Precise Vp measurement shows
- There are two time scale of propagation
- Edge Vp structure changes very fast (< 0.1ms)
- Oscillation between negative and positive

Summary of Working Group D

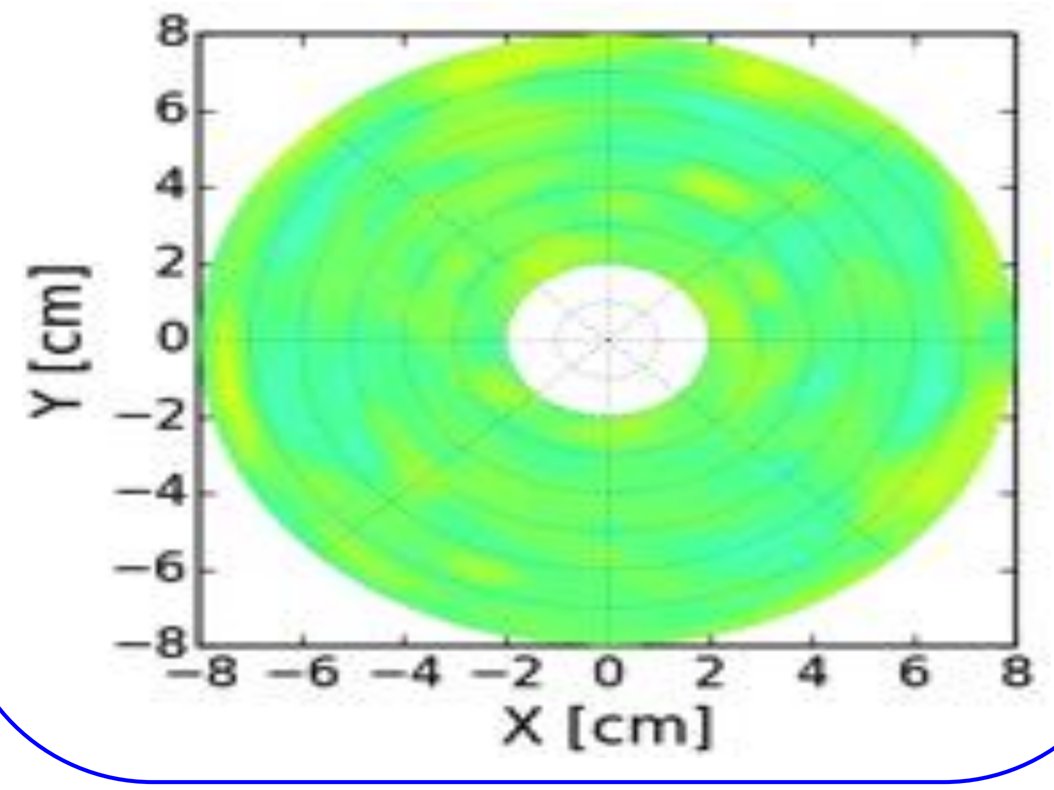
Impact of end-plate biasing on plasma fluctuations in PANTA

(Y. Nagashima - Kyushu Univ.)

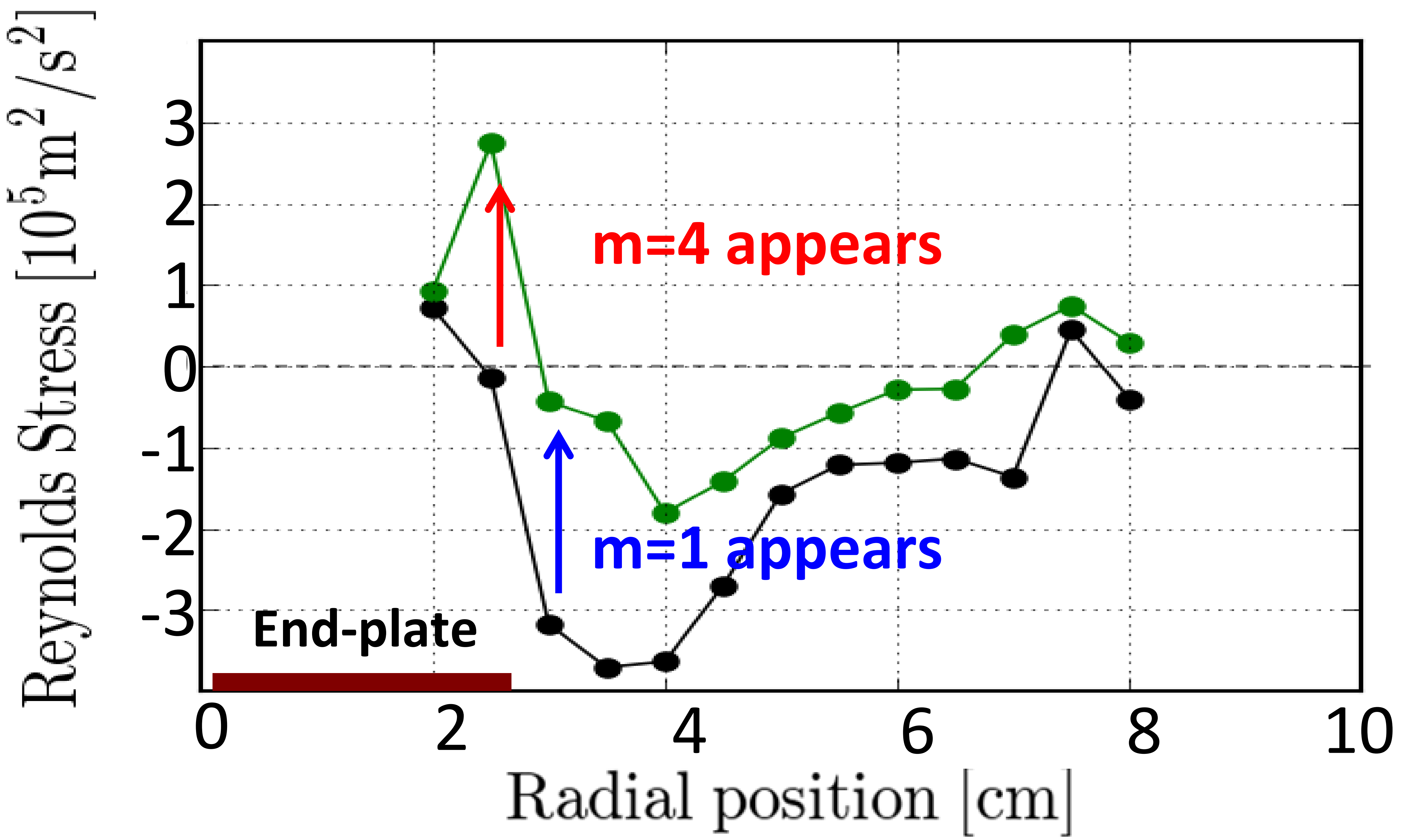
0 V



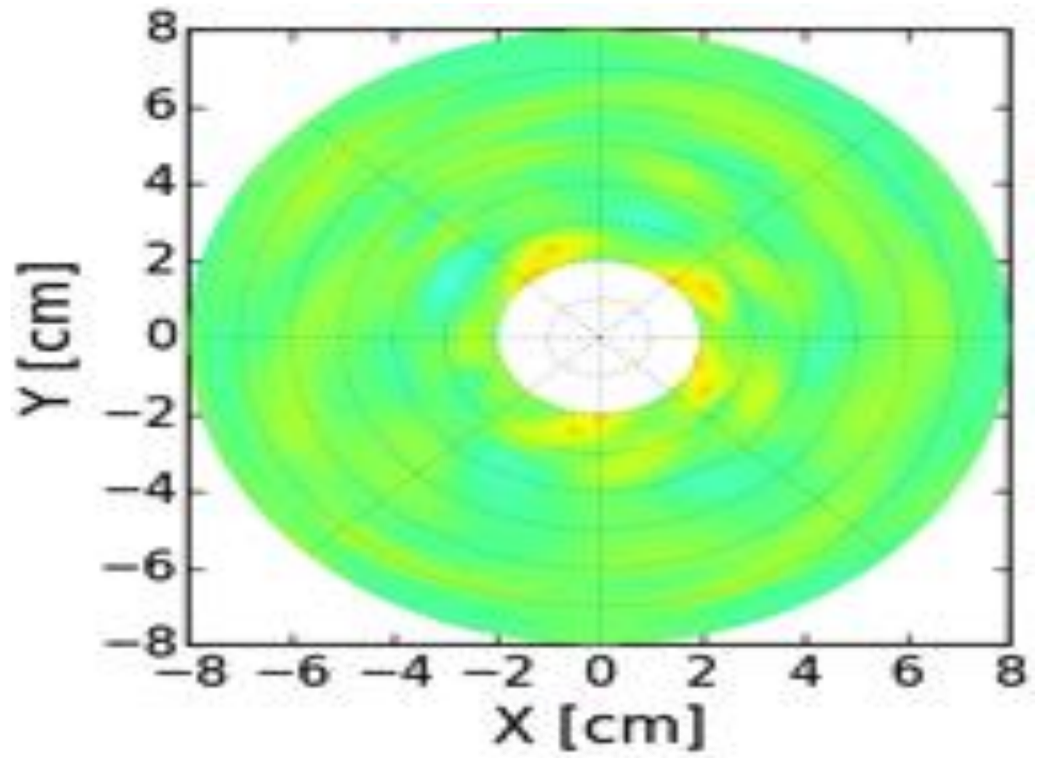
30 V **disappear**



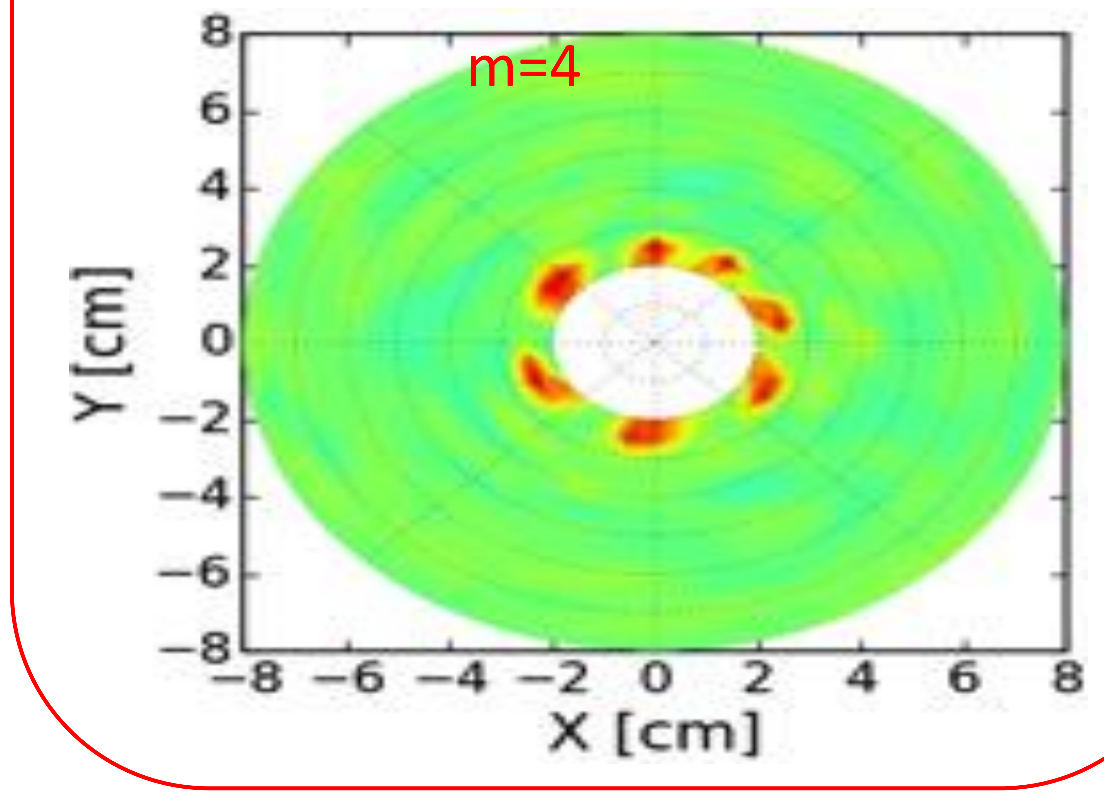
Change in RS Profiles by the Biasing



0 V



30 V **appear**



Inside the end-plate：m=4 appears → RS increases.
Outside the end-plate：m=1 disappreas→ RS decreases.

- Turbulence Reynolds stress profile is mainly composed of 2.8 kHz m=1 mode (probably drift wave) before biasing. However, during the biasing, the m=1 mode disappears and RS decreases. On the contrary, during the biasing, new m=4 mode appears and the mode mainly contribute RS increase.

Gyrokinetic formulation to derive conservation laws for collisional and turbulent transport of particles, energy, and toroidal momentum (H. Sugama - NIFS)

Expansion in $\delta = \rho / L$

Radial flux of toroidal momentum
$$\left(\Pi_a\right)^s = \left(\Pi_a^{ncl}\right)^s + \left(\Pi_a^{H}\right)^s + \left(\Pi_a^{(E)}\right)^s + \left(\Pi_a^{turb}\right)^s + \left(\Pi_a^{cl}\right)^s = O(\delta^2)$$

Neoclassical flux
$$\left(\Pi_a^{ncl}\right)^s = \frac{m_a c}{2 e_a \chi'} \left\langle \int d^3 v\, g_{a1} U \mathbf{b} \cdot \nabla_{\varepsilon_0} \left[m_a (U b_\varsigma + V_\varsigma)^2 + \mu \frac{|\nabla \chi|^2}{B} \right] \right\rangle$$

Turbulent flux
$$\left(\Pi_a^{turb}\right)^s = -\left\langle \int d^3 v\, \hat{h}_a \frac{c}{B} \left(\nabla \hat{\psi} \times \mathbf{b} \cdot \nabla s \right) \left(U b_\varsigma + V_\varsigma + (v'_\perp)_\varsigma \right) \right\rangle$$

Classical flux
$$\left(\Pi_a^{cl}\right)^s = -\frac{m_a^2 c}{e_a \chi'} \left\langle \int d^3 v\, C_a \left[(U b_\varsigma + V_\varsigma)(v'_\perp)_\varsigma + \frac{1}{2} \left\{ (v'_\perp)_\varsigma (v'_\perp)_\varsigma - \frac{R^2 B_P^2}{2 B^2} (v'_\perp)^2 \right\} \right] \right\rangle$$

$O(\delta^2)$ toroidal momentum transport equation

$$\frac{\partial}{\partial t} \left(V' \left\langle (\Sigma_a n_{a0} m_a) \left(1 + \frac{v_{PA}^2}{c^2} \right) V_\varsigma \right\rangle \right) + \frac{\partial}{\partial s} \left(V' \left[\sum_a \left\{ (\Pi_a)^s - \left\langle (\Sigma_a n_{a0} m_a) \left(1 + \frac{v_{PA}^2}{c^2} \right) V_\varsigma \mathbf{u}_s \cdot \nabla s \right\rangle \right\} - \frac{1}{4\pi} \left\langle \left\langle \nabla s \cdot \left(\mathbf{E}\mathbf{E} + \hat{\mathbf{B}}\hat{\mathbf{B}} + \frac{4\pi}{c} \hat{\mathbf{j}} \hat{\mathbf{A}} \right) \cdot \mathbf{e}_\varsigma \right\rangle \right\rangle \right] \right) = 0$$

V_ς : angular toroial flow velocity

- The Lagrangian variational principle and the **collision operator** represented in terms of Poisson brackets are combined for **presenting the new gyrokinetic formulation** to derive governing equations of background and turbulent electromagnetic fields and gyrocenter distribution functions for toroidally rotating plasmas.
- The governing equations satisfy the particle, energy, and toroidal momentum conservation laws which are desirable for long-time global transport simulation to pursue evolutions of the background density, temperature, and E x B flow profiles.
- The **transport equations** of particles, energy, and toroidal momentum derived here include, in a unified way, classical, neoclassical, and turbulent transport fluxes which **agree with those derived separately from the conventional recursive formulations.**