Energy Exchange Dynamics across L-H transitions in NSTX

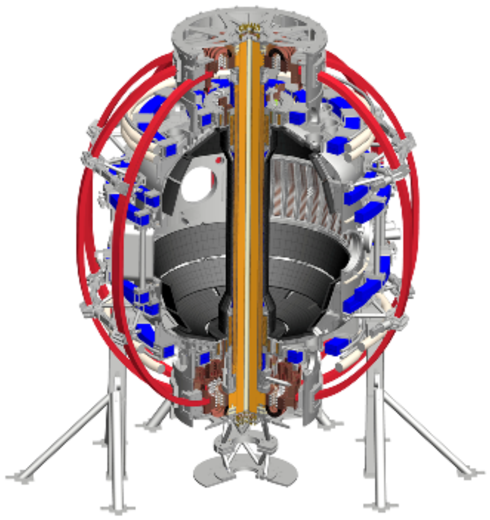
A. Diallo, S. Banerjee*, S. Zweben, and T. Stoltzfus-Dueck

Princeton Plasma Physics Laboratory, Princeton NJ, USA.

*Institute for Plasma Research, Bhat, Gujarat, India.

Result Review

September 22nd 2016



Supported by U.S. DoE under contract DE-AC02-09CH11466

GPI diagnostic is central to the analysis

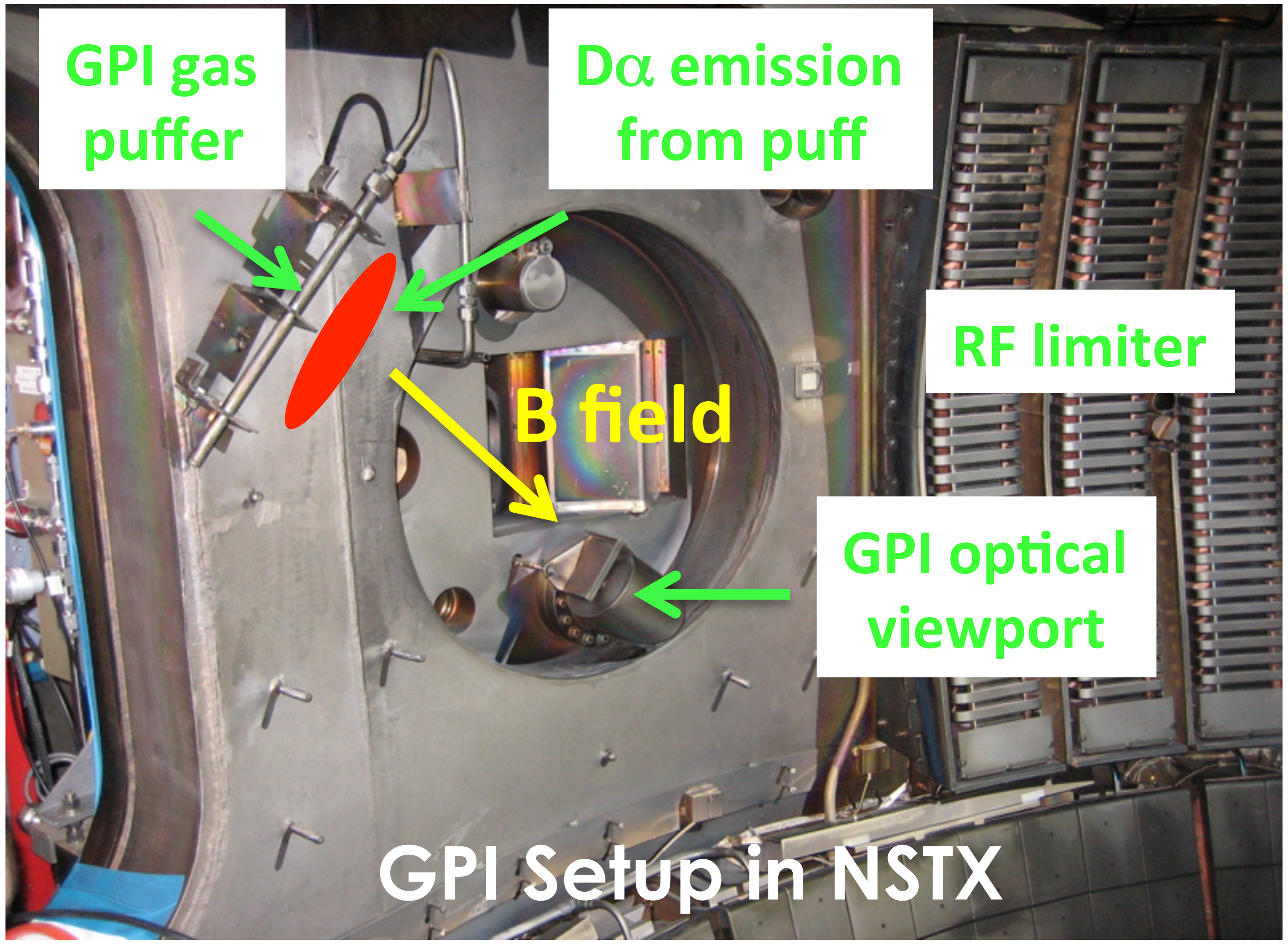
- GPI data taken at ~400 kHz frame rate;
  - Image size 24 x 30 cm
  - Spatial resolution ~ 1 cm

See Zweben et al. NF 44 134 (2004) for detailed description

- GPI gas has minimal effects on the plasma parameters

Zweben et al. PPCF 56 095010 (2014)

- Analysis included RF, Ohmically, and NBI heated plasmas

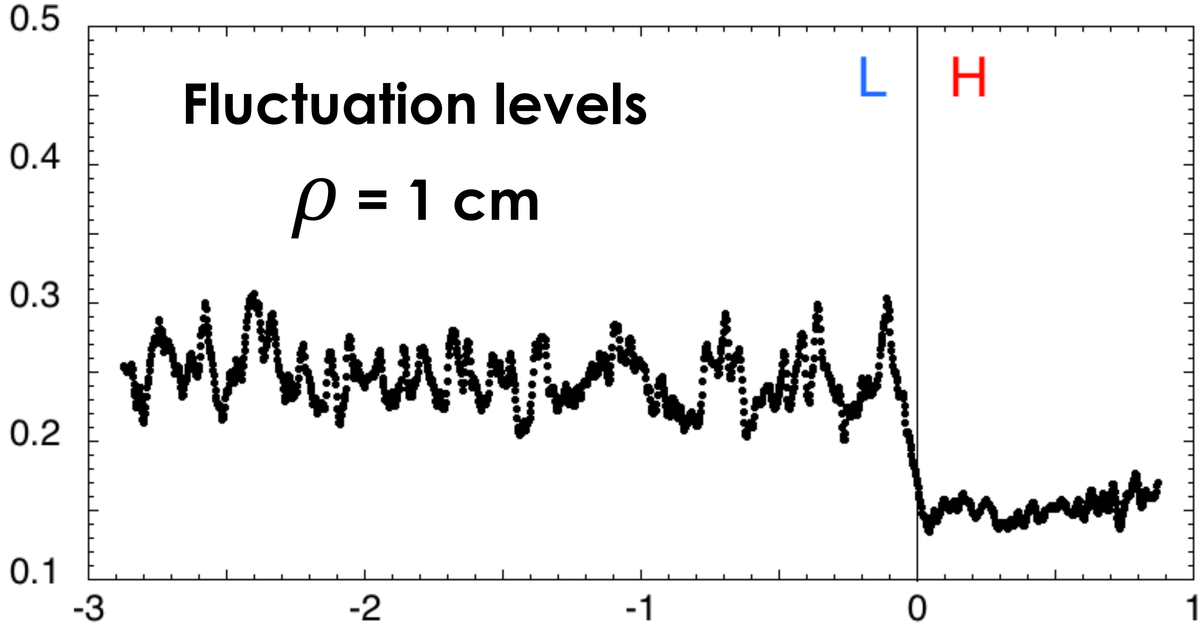


Discharges characteristics (total of 17):

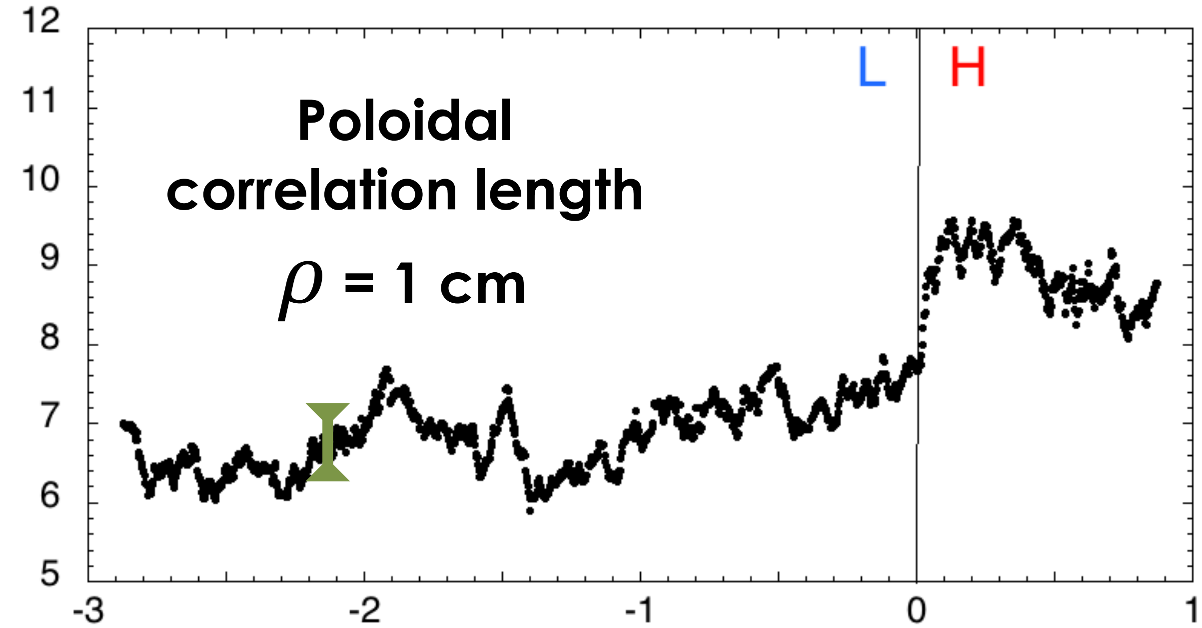
NBI-Heated: 138113:138119
Ohmically-Heated: 141745:141751 (not shown here)
RF- Heated: 141919:141922, 142006

There is no significant change of turbulence quantities *preceding* the L-H transition but clear drop in fluctuation levels (~100 μs) across the L-H transition as expected

Averaged over all the 17 discharges

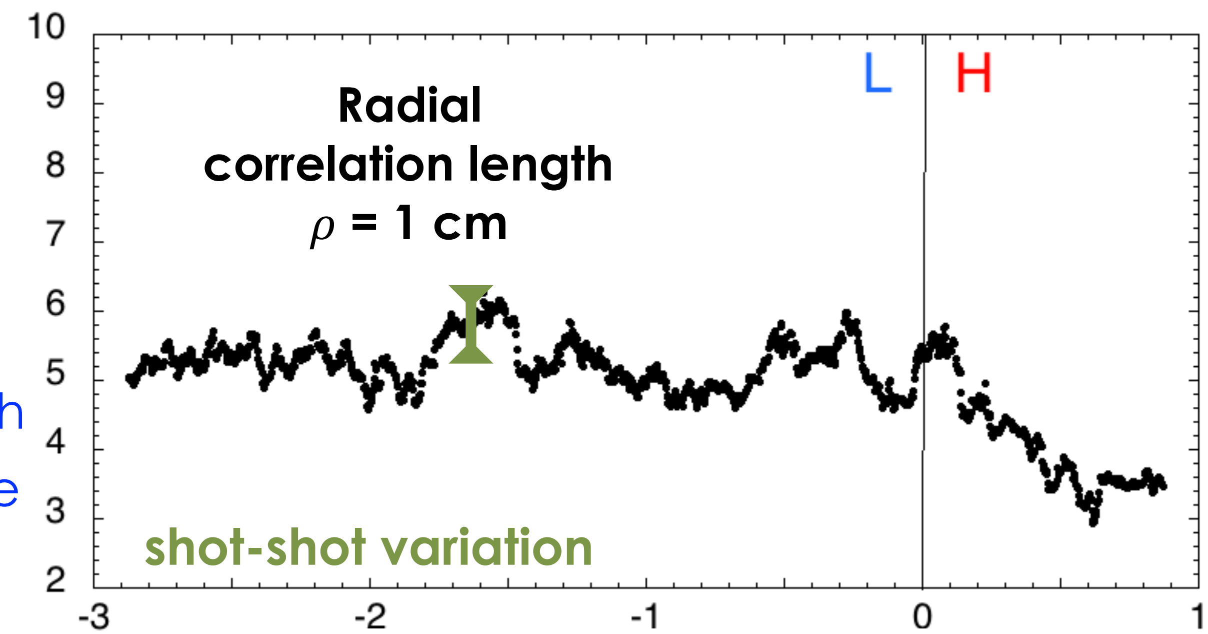


Time rel. to L-H transition [ms]



Time rel. to L-H transition [ms]

- **The turbulence quantities are averaged over multiple discharges (1cm inside LCFS)**
  - note zero suppressed in all plots.
- **Across the L-H transitions:**
  - Slight increase in the average poloidal correlation length
  - Loss of radial correlation is translated in a slight decrease in the radial correlation length.



Time rel. to L-H transition [ms]

Approach for the decomposition of the velocity field components

- Reynolds decomposition should be applied to the whole flux surface.
- However, GPI view is limited to a 30 x 24 cm patch of the flux surface.
  - The flux-surface average is replaced by a temporal average.

- For each velocity component,

$$v_i = \bar{v}_i + \tilde{v}_i, \ \ i \in [r, \theta]\,, \ \ \forall t$$

$$\text{High-pass filter of } v(r,\theta,t) \text{ at 1 kHz} \longrightarrow \tilde{v}(r,\theta,t)$$

$$\text{Low-pass filter of } v(r,\theta,t) \text{ at 1 kHz} \longrightarrow \bar{v}(r,\theta,t)$$

This cutoff frequency was chosen to include the poloidally oscillating flow (2 - 5 kHz) described in ref. Zweben et al. PoP (2010) into the non zonal component.

Variations (1 - 2 kHz) around this cutoff do not qualitatively change the results presented here.

The analysis relies on this energy balance between flows and turbulence including the electron parallel dynamic

Stoltzfus-Dueck, PoP, **23** 054505 (2016)

(see next talk for discussion)

Turbulence fluctuations

Thermal free energy

non-zonal ExB energy

Zonal ExB energy

$$\partial_t \left(\frac{T_{e0}}{2n_{e0}} \tilde{n}_e^2 + \frac{n_0 m_i \left\langle \tilde{v}_E^2 \right\rangle}{2} + \frac{n_0 m_i \langle \bar{v}_E \rangle^2}{2} \right) = \text{sources} + \text{sinks}$$

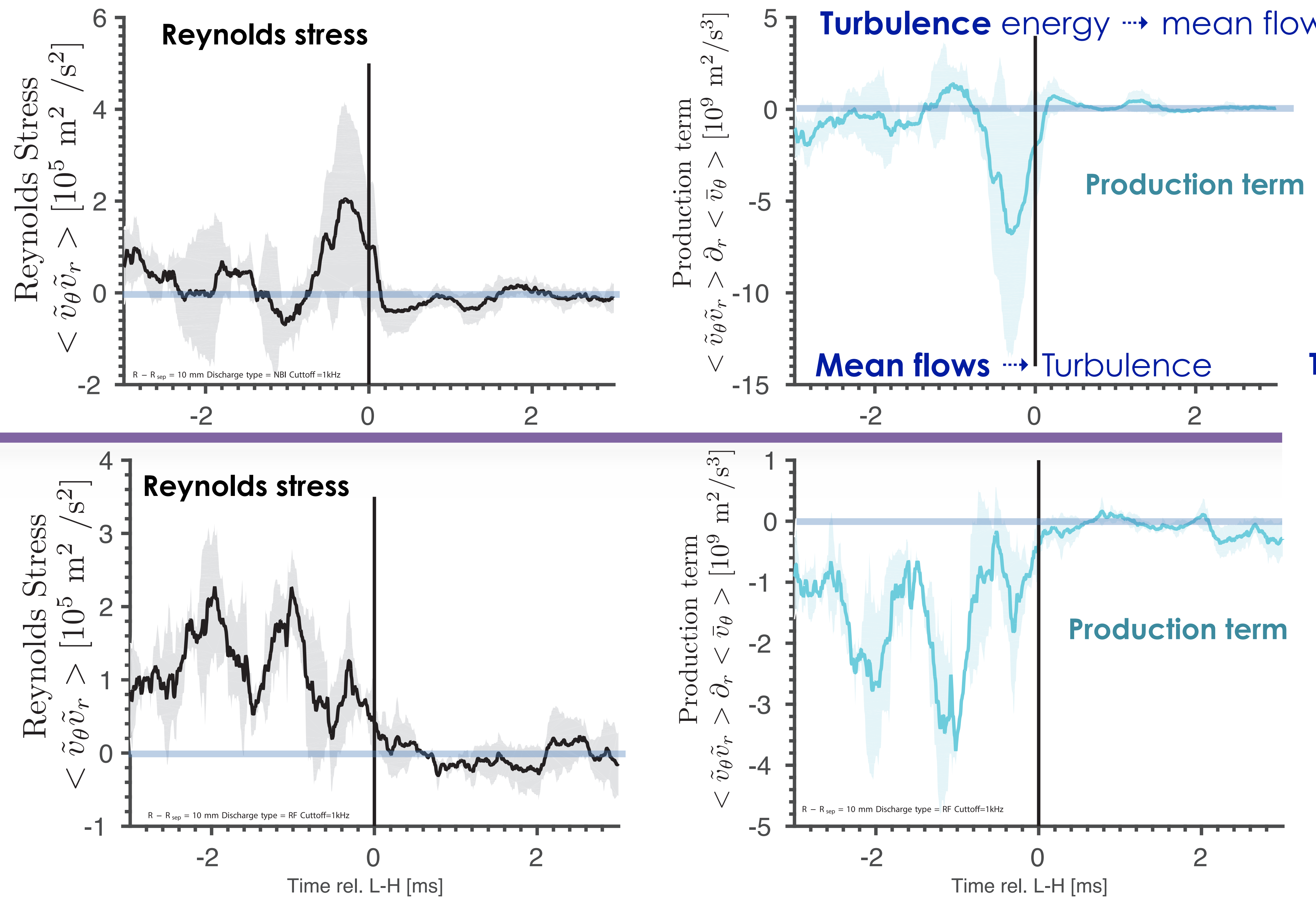
$$n_0 m_i \left\langle \tilde{v}_r \tilde{v}_\theta \right\rangle \partial_r \left\langle \bar{v}_\theta \right\rangle$$

Production term = P

$P > 0 \Rightarrow$ energy is transferred from **turbulence** to mean flows.

$P < 0 \Rightarrow$ energy is transferred from mean flows to **turbulence.**

For all heating schemes, we observe that the energy is transferred from mean flows to turbulence 1 cm inside the separatrix



NBI

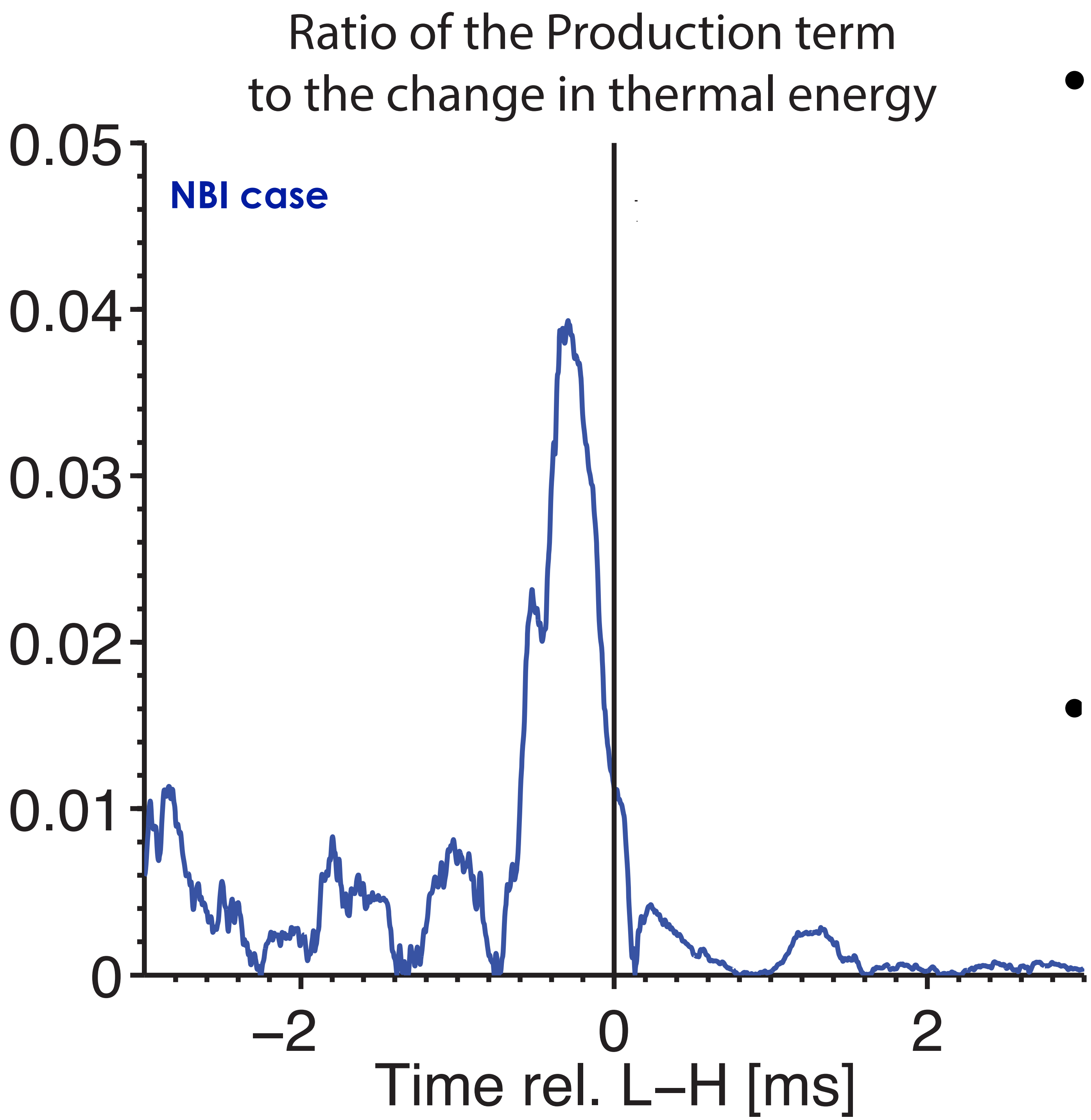
The shaded area represent the std over multiple discharges

RF

- **This is inconsistent with the turbulence depletion hypothesis prior to the L-H transition.**
- **Such negative production term has previously been observed in JET ohmic discharge.**

Sanchez JNM **337** 296 (2005)

Even the absolute value production term cannot account for the L-H transition duration



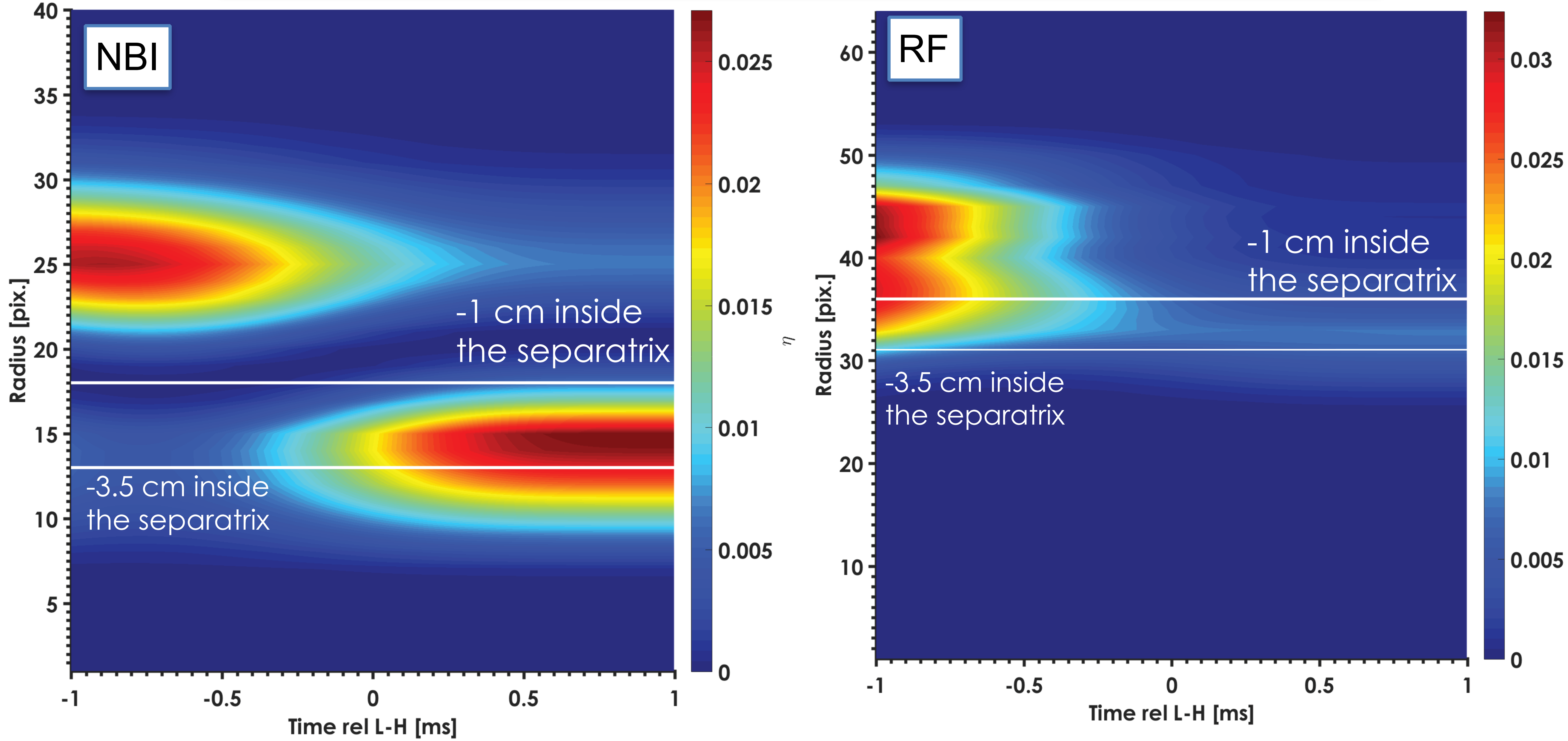
- We compare the change in the free energy into a thermal portion between the L and H mode phases to the production term

$$\frac{P}{P_0} \doteq \frac{n_0 m_i (\tilde{v}_E^x \tilde{v}_E^y)\partial_x \left\langle v_E^y \right\rangle}{(\tau_{L-H}^{exp})^{-1}(E_{\tilde{n}}|_L - E_{\tilde{n}}|_H)}$$

- Using the computed production term, the L-H transition duration yields 25 ms much slower than our observation.
  - Note the results are qualitatively similar for RF and Ohmic cases (not shown here)

The kinetic energy in the mean flow is much smaller than the thermal free energy

$$\eta \doteq \frac{\langle \bar{v}_\theta \rangle^2 / c_s^2}{(\tilde{n}_e / n_{e0})^2} \Longrightarrow \frac{\langle \bar{v}_\theta \rangle^2 / c_s^2}{\left(< \tilde{I}^2 >_{[L]} / \bar{I}^2 \right)}$$



- The radial structure is not yet understood.

Results in previous experimental investigations motivated the examination of the energy exchange dynamics on NSTX

- We consider the following energy balance to evaluate the turbulence depletion:
  - Most experimental results neglected the thermal free energy

Thermal free energy non-zonal ExB Zonal ExB

$$\partial_t \left(\frac{T_{e0}}{2n_{e0}} \tilde{n}_e^2 + \frac{n_0 m_i \left\langle \tilde{v}_E^2 \right\rangle}{2} + \frac{n_0 m_i \langle \bar{v}_E \rangle^2}{2} \right) = \text{sources} + \text{sinks}$$

- We evaluated this energy transfer dynamics and possible links with the L-H transition on NSTX edge using the gas-puff-imaging for three heating schemes (**NBI**, **RF**, and *Ohmic*)
  - The edge turbulence using GPI showed no consistent changes preceding the L-H
  - These turbulence quantities change from before and after the transition but this does not help to identify the L-H transition mechanism.
  - Using a velocimetry approach ODP, we show that turbulence depletion is not necessarily mediated by the perpendicular Reynolds stress.
  - The turbulence energy transfer to mean flow is not key to the L-H transition, contrary to the predator- prey model.
  - Non negligible contribution to the poloidal flows by the Reynolds stress, however, is plausible.

Future work will attempt to better quantify the uncertainties in 2D velocimetry in H-mode by making quantitative comparison with turbulence simulations.