Dynamics of the L-H transition at different densities on MAST

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Thanks to:

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I will talk about …

What motivates the experiment?

How do we measure E_r?

What are the simple dynamics of the L-H transition?

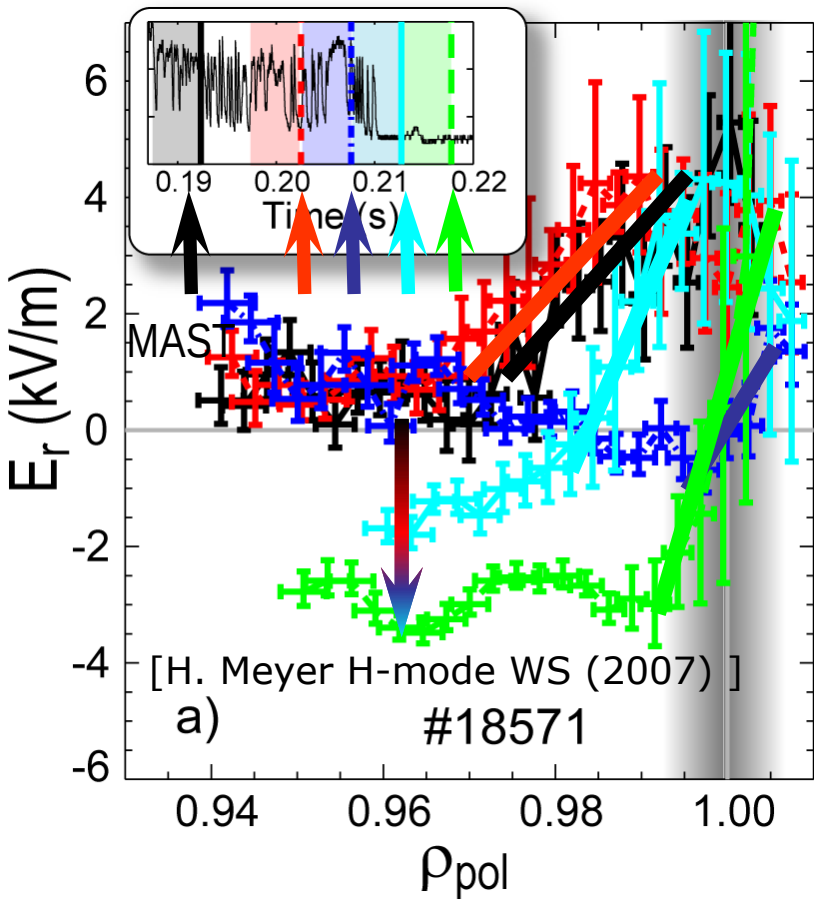
How the flow shear correlates with the turbulence?

What we may learn from this?

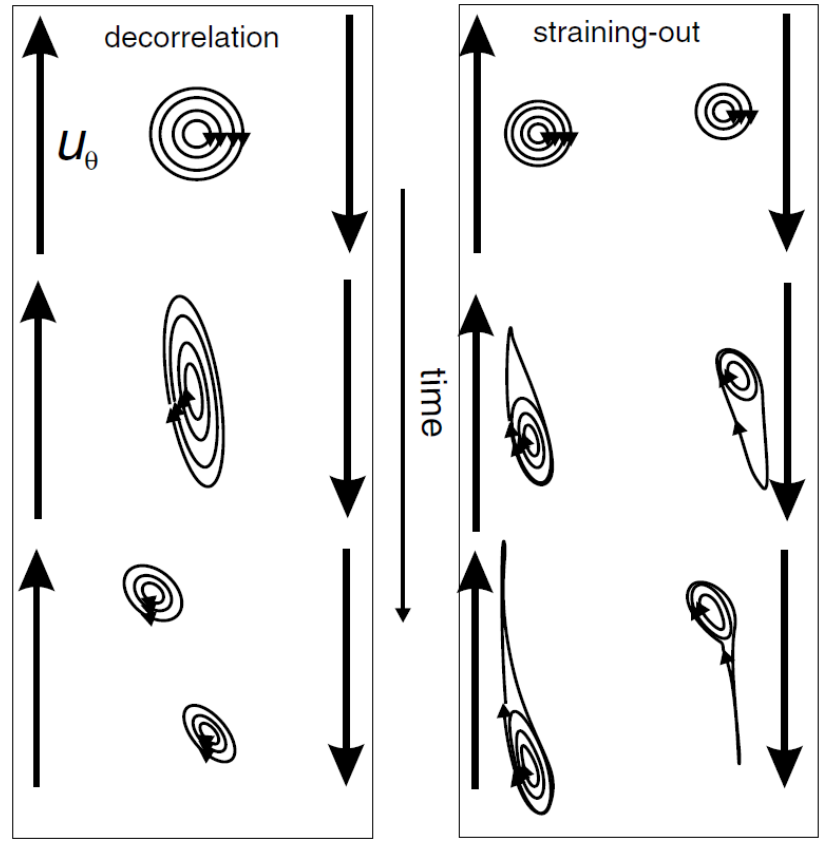
What motivates the experiment?

Zonal flows and GAMs may cause H-mode

- Well known: Edge E_r becomes more negative in H-mode.
- Broad well structure on MAST.
- Mean $|\nabla E_r|$ increases at the LCFS.



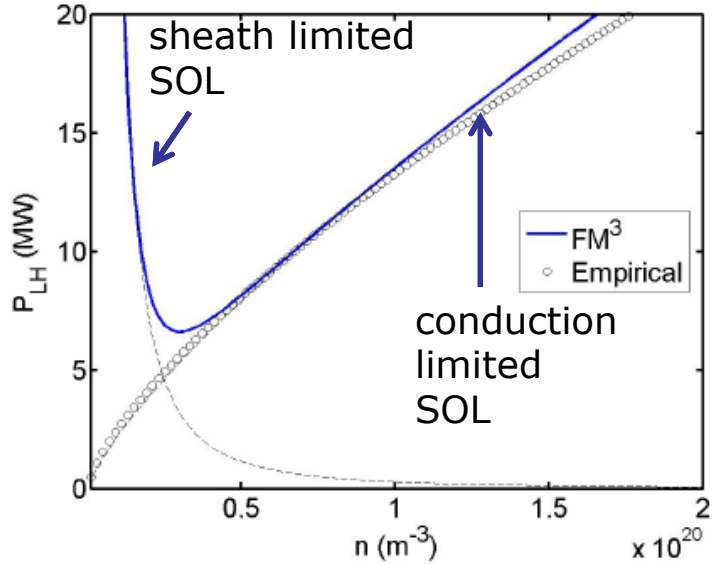
U.Stroth et.al, PPCF, **53** (2011) 024006

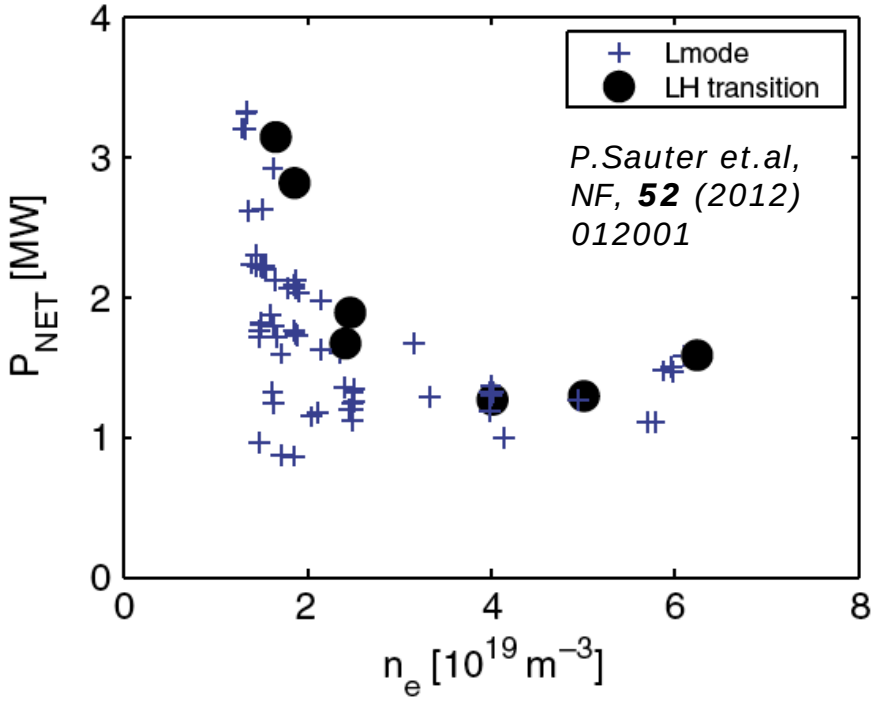


- Sheared E×B flow stretches large eddies and strains small eddies.
- Stretching ⇒ decorrelation.
- Straining ⇒ energy transfer.

L-H physics may change with density

- Non monotonic threshold behaviour.
  - Below $n_e^{crit.}$ P_{L-H} decreases sharply with n_e.
  - Above $n_e^{crit.}$ $P_{L-H} \propto n_e^{0.7}$.





Fundamenski et.al:

- H-mode when moving from 2D to 3D turbulence.

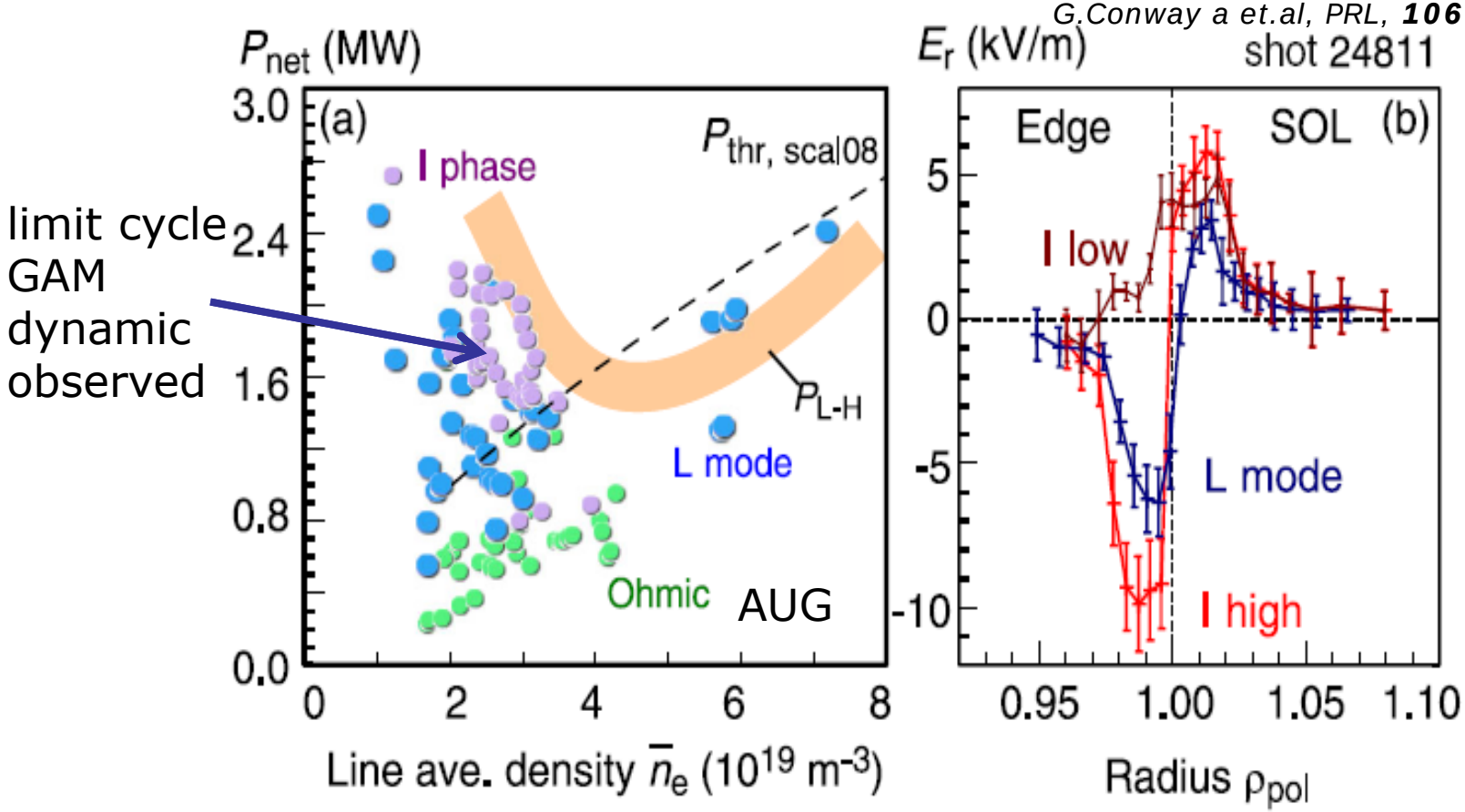
$$\tau_{\parallel}^{A}/\tau_{\perp}^{Q} \equiv Wa > Wa_{\mathrm{L-H}}$$

- Different behaviour due to different SOL conditions.

$$P_{\mathrm{L-H}} \approx 0.083 \frac{\sqrt{n_{\star 19} B L_{p\star}}}{L_{\parallel\star}} S_{\perp} \hat{T}_{\star}^{\frac{5}{4}}$$

GAM limit-cycle dynamics al low n_e

G.Conway a et.al, PRL, **106** (2011) 065001



- Fluctuating E_r around 15 kHz
  - GAM frequency $\propto T_i^{1/2} \Rightarrow$ probably lower on MAST.
- On AUG this is called I-phase.

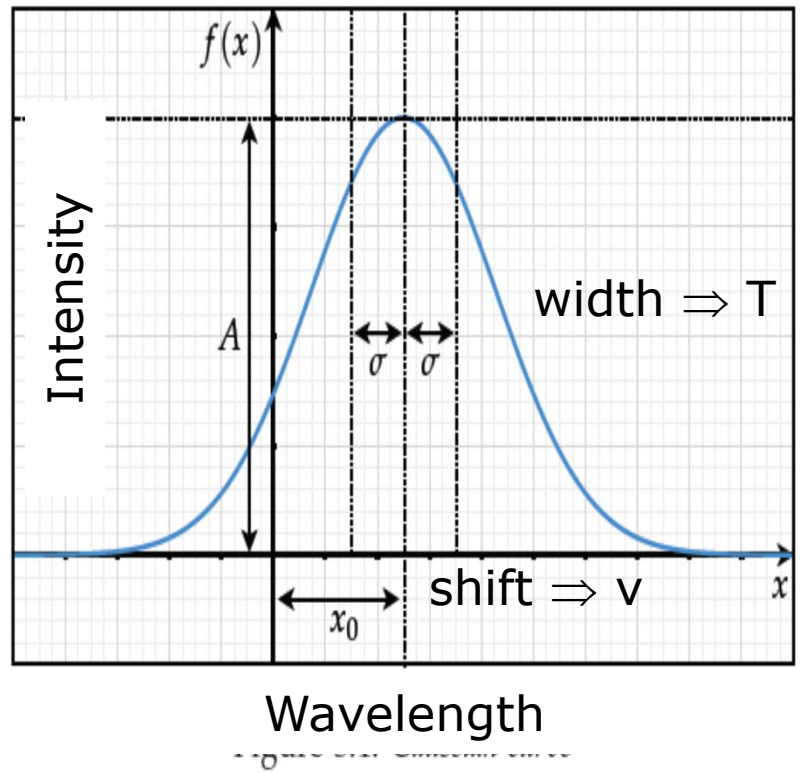
How do we measure E_r?

Solving the force balance $\Rightarrow E_r$

$$E_r \approx \frac{\nabla p_\alpha}{eZ_\alpha n_\alpha} + v_{\alpha,\phi} B_\theta - v_{\alpha,\theta} B_\phi + \cdots$$

$$\frac{\nabla p_\alpha}{eZ_\alpha n_\alpha} = \frac{T_\alpha}{eZ_\alpha}\{L_{T_\alpha}^{-1} + \underbrace{L_{n_\alpha}^{-1}(T_e, n_e)}_{\approx L_\varepsilon}\} \text{ with } L_f = \nabla \ln f$$

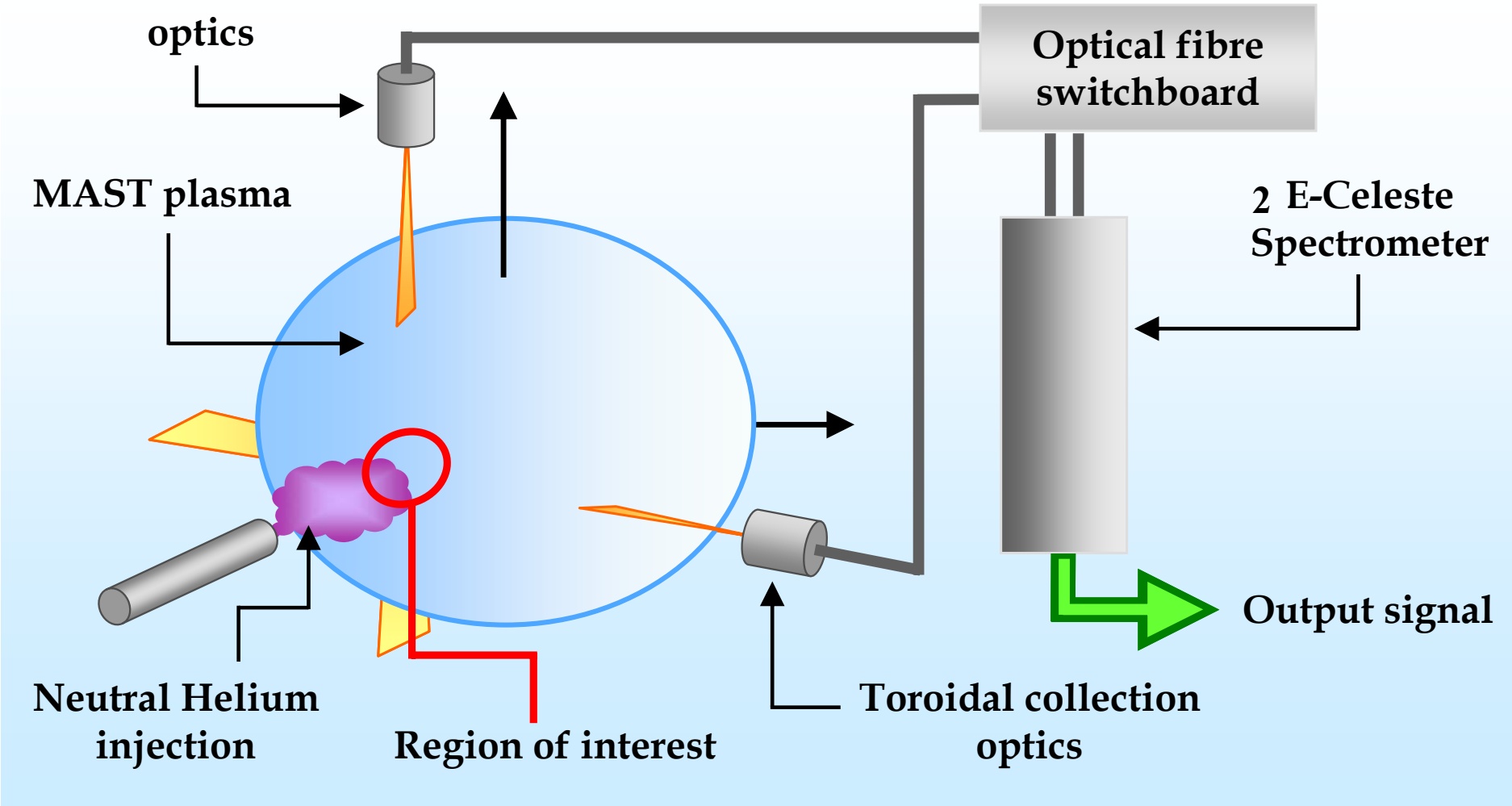
- E_r can be calculated from the force balance of any impurity ion.
- He^+ has peak emission in pedestal and simple spectrum, but $T_{HeII} \neq T_i$.
- Spectrum is projection of $f_\alpha(\mathbf{v})$ onto the observation direction.
  - Maxwell $\Rightarrow$ Gaussian profile!
- Doppler spectroscopy $\Rightarrow$ $v_{\alpha\phi}$, $v_{\alpha\theta}$, T_α and $I(n_\alpha, n_e, T_e)$
  - Need n_e and T_e (TS) to calculate L_n from the intensity profile.
- Locally inject He^+



9 Radial positions at 50 kHz

$\Delta t = 20\mu s$ (f=50kHz)
$\Delta R \sim 3$ mm (4.5 mm pitch)

20 fast chords
240 slow chords

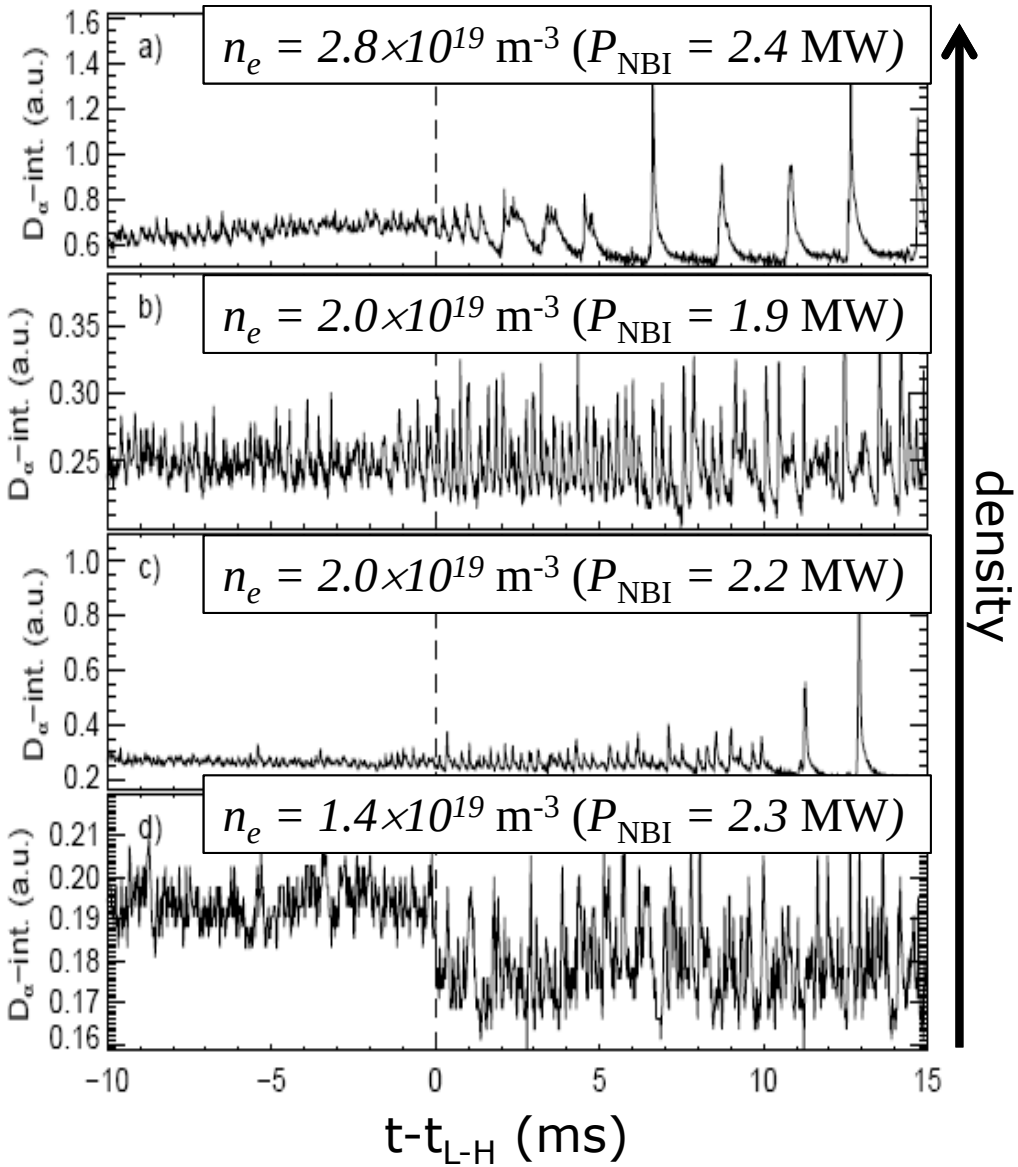


What are the simple dynamics of the L-H transition?

Really two types of transition

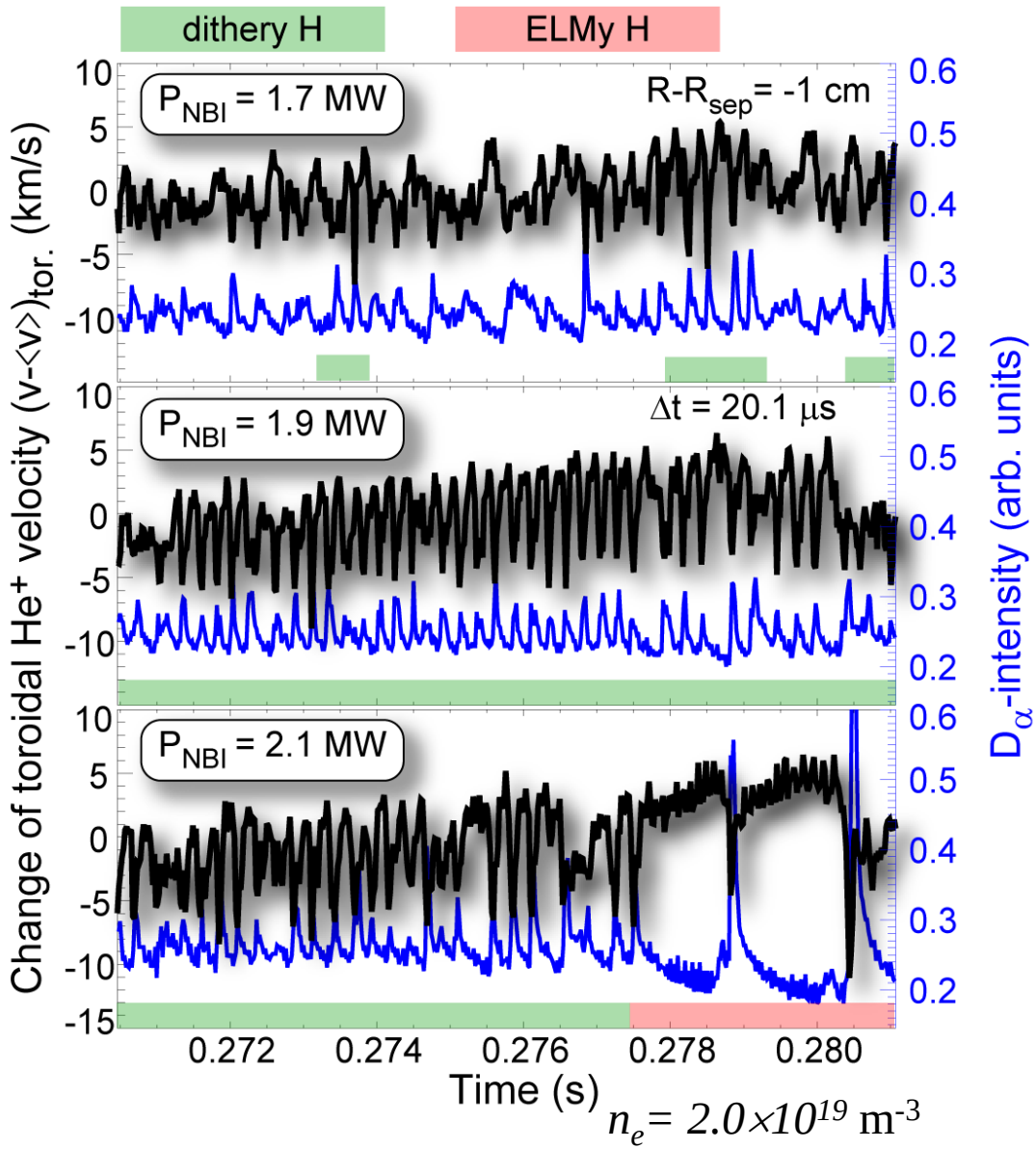
1. L-mode to dithery phase
   - $P_{NBI} \uparrow n_e$
   - Similar to AUG I-phase.
   - ETB forms transiently.
2. Dithery phase to ELMy
   - $P_{NBI} \uparrow n_e > 2e19\ m^{-3}$
   - $P_{NBI} \downarrow n_e < 2e19\ m^{-3}$

- Dithering H-mode operational region widens with decreasing density.
  - Wider power range.
  - Longer duration before 2nd transition.
  - $n_e < 2e19 m^{-3}$: 2nd transition not observed.



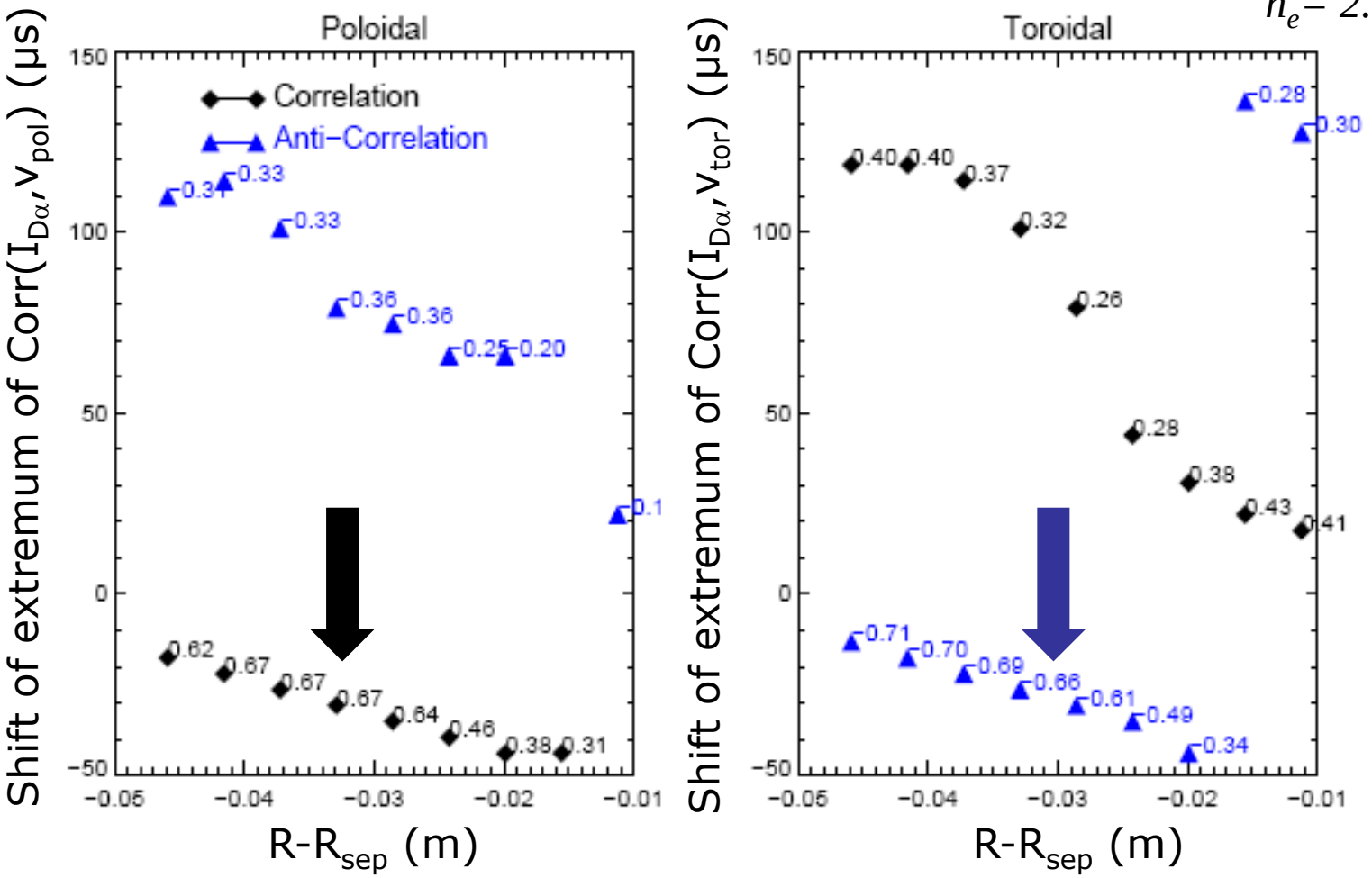
V_{HeII} correlated with dithers

- Duration of dithery phases increase with power.
- Change of toroidal He^+ flow is well correlated with D_α dithers.
- Velocity becomes more positive with time.
  - More positive v_{tor} $\Rightarrow$ more negative E_r



First change close to LCFS

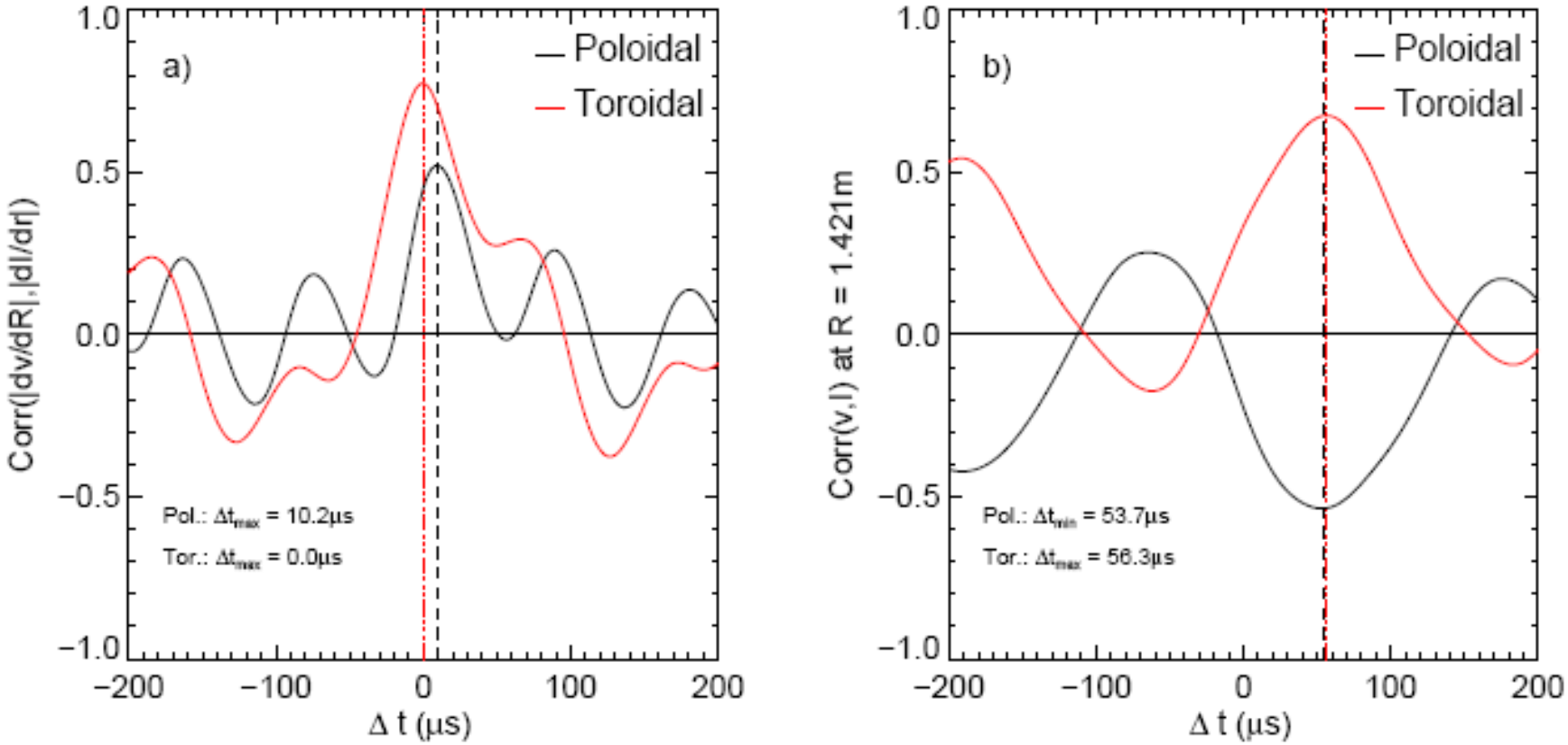
$n_e = 2.0 \times 10^{19}$ m^{-3}



- Cross correlation of D_α-int. with v: Corr(D_α,v_{HeII})
- For typical E_r dynamics expect correlation for v_{pol} (black) and anti-correlation for v_{tor} (blue)

v_{HeII} changes before I_{HeII}

$n_e = 2.0 \times 10^{19}$ m^{-3}

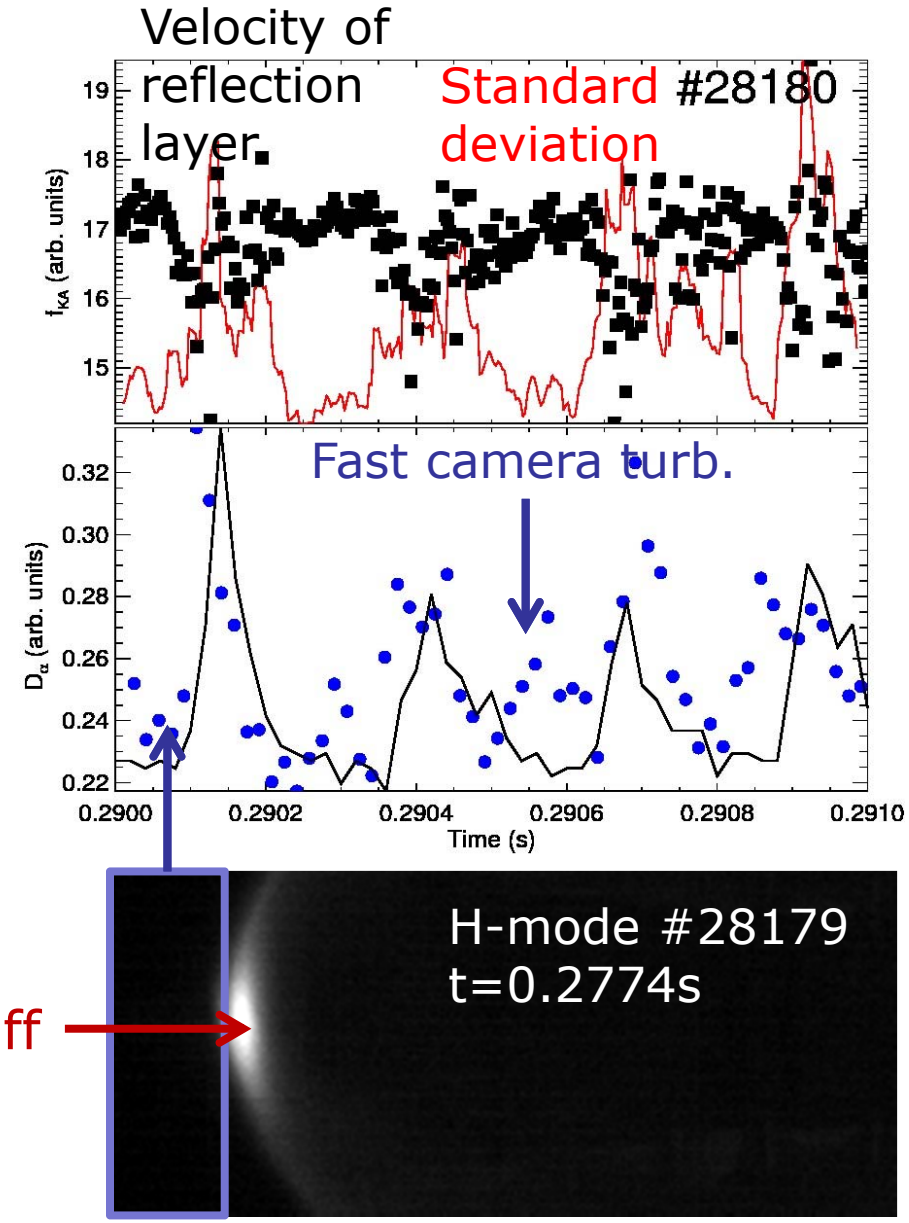


- Linear approximation of dI/dr and dv/dr.
- Gradients in I and V change simultaneously, but …
- V changes before I.

How the flow shear correlates with the turbulence?

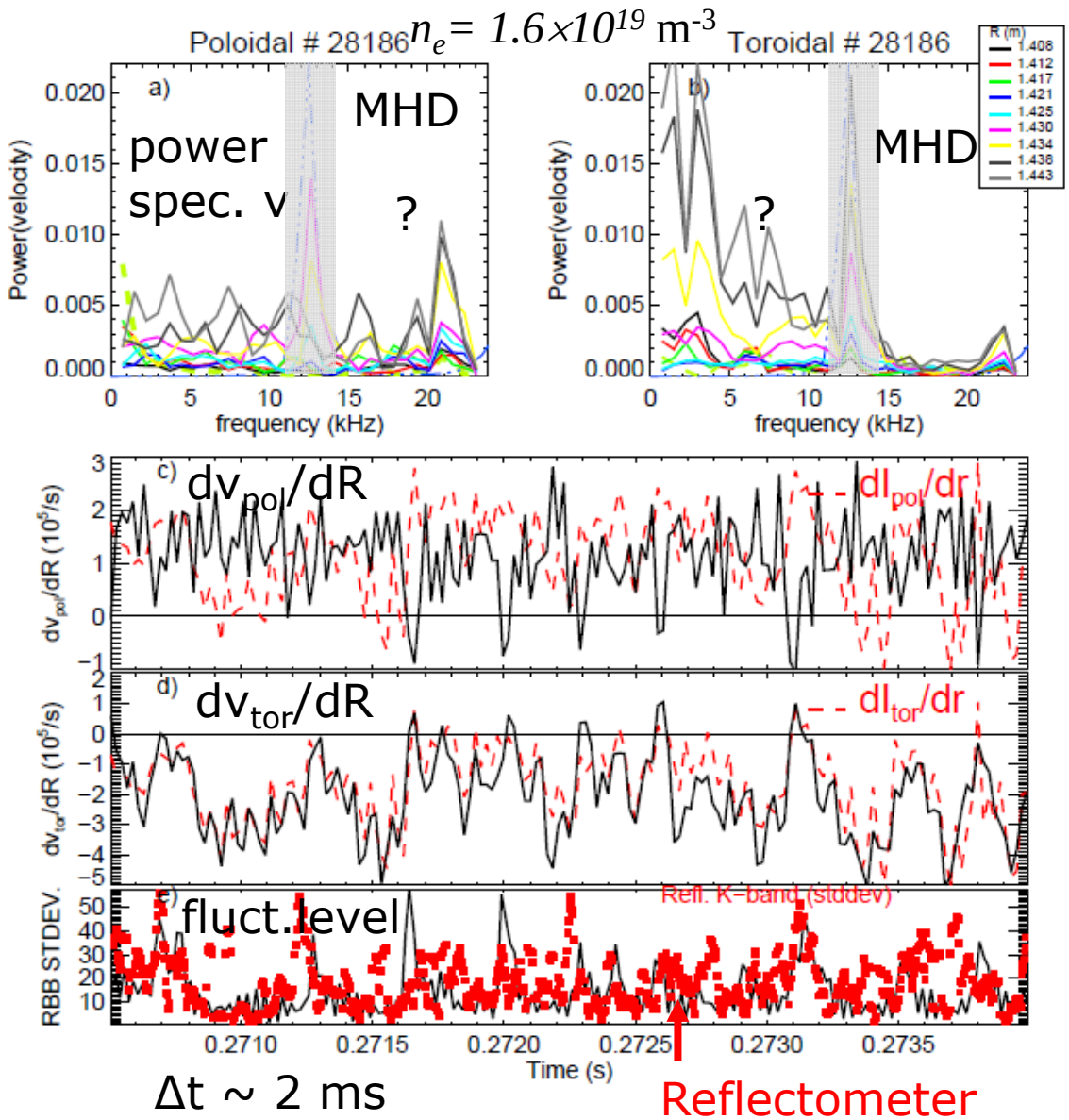
Fast imaging ⇒ filamentary turb.

- Fast camera images same region as ECELESTE measurement.
- Filaments are highlighted by the gas puff.
- Fast imaging runs on internal clock ⇒ compare with D_α



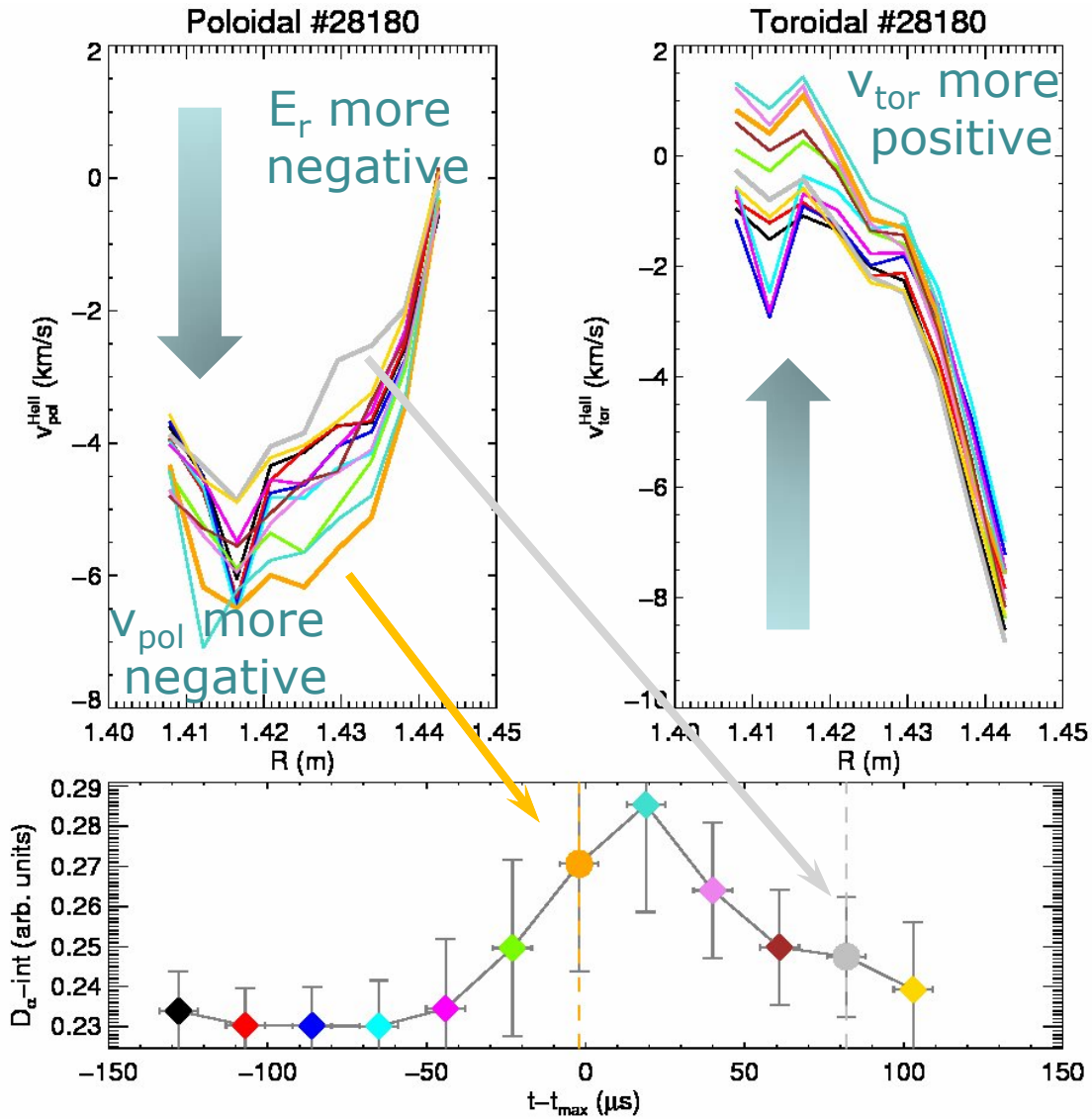
High $|\partial_r V| \Rightarrow$ low turbulence

- Power observed at low frequencies at low density
  - Zonal flows? GAMs (~10-15 kHz)?
  - Gradients approximated by linear fit (underestimate).



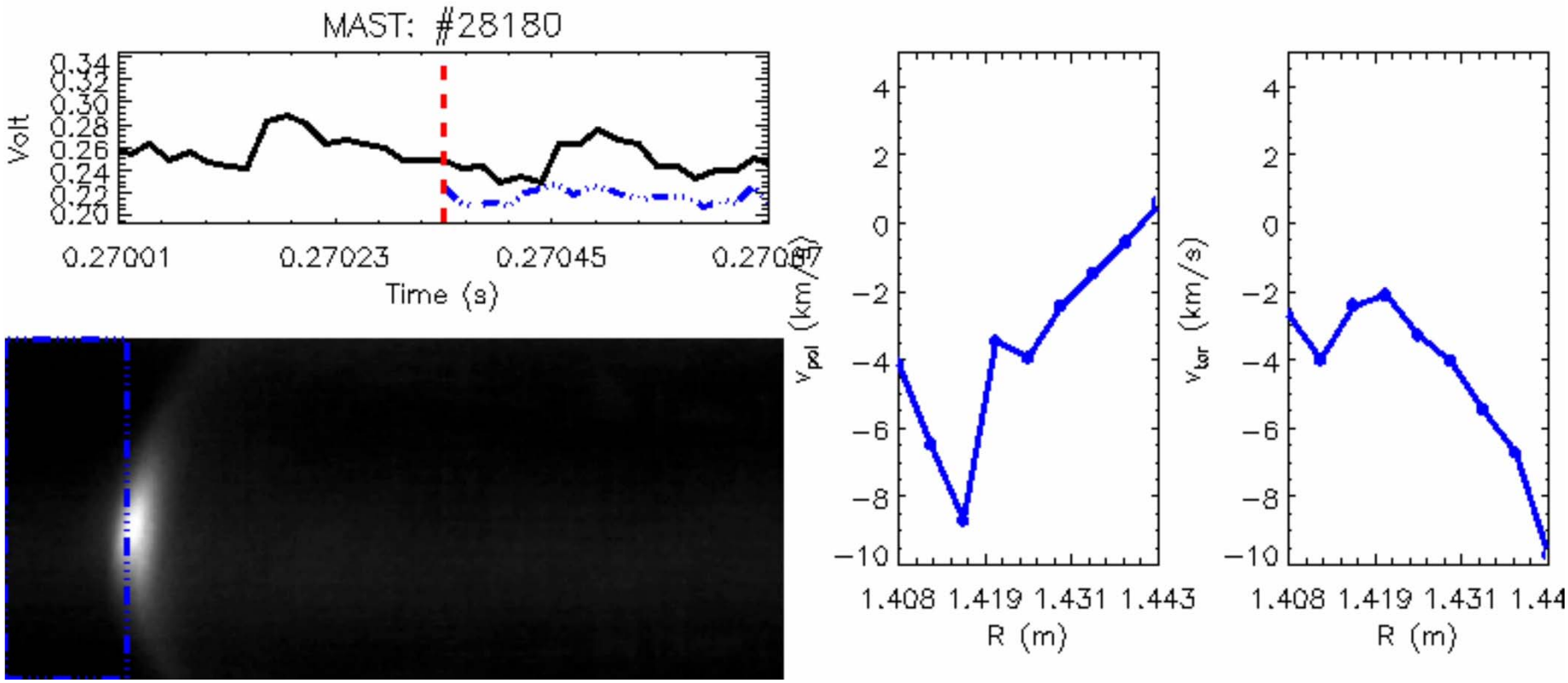
E_r most negative at max(D_α)

- Sustained dithery phase at medium density.
- Boxcar analysis of He^+ flows with respect to maximum D_α peak.
- Periodicity ~ 4-5 kHz.
- Strongest He^+ flow shear corresponds to max(D_α)
  - limit-cycle?
  - Predator-Prey?

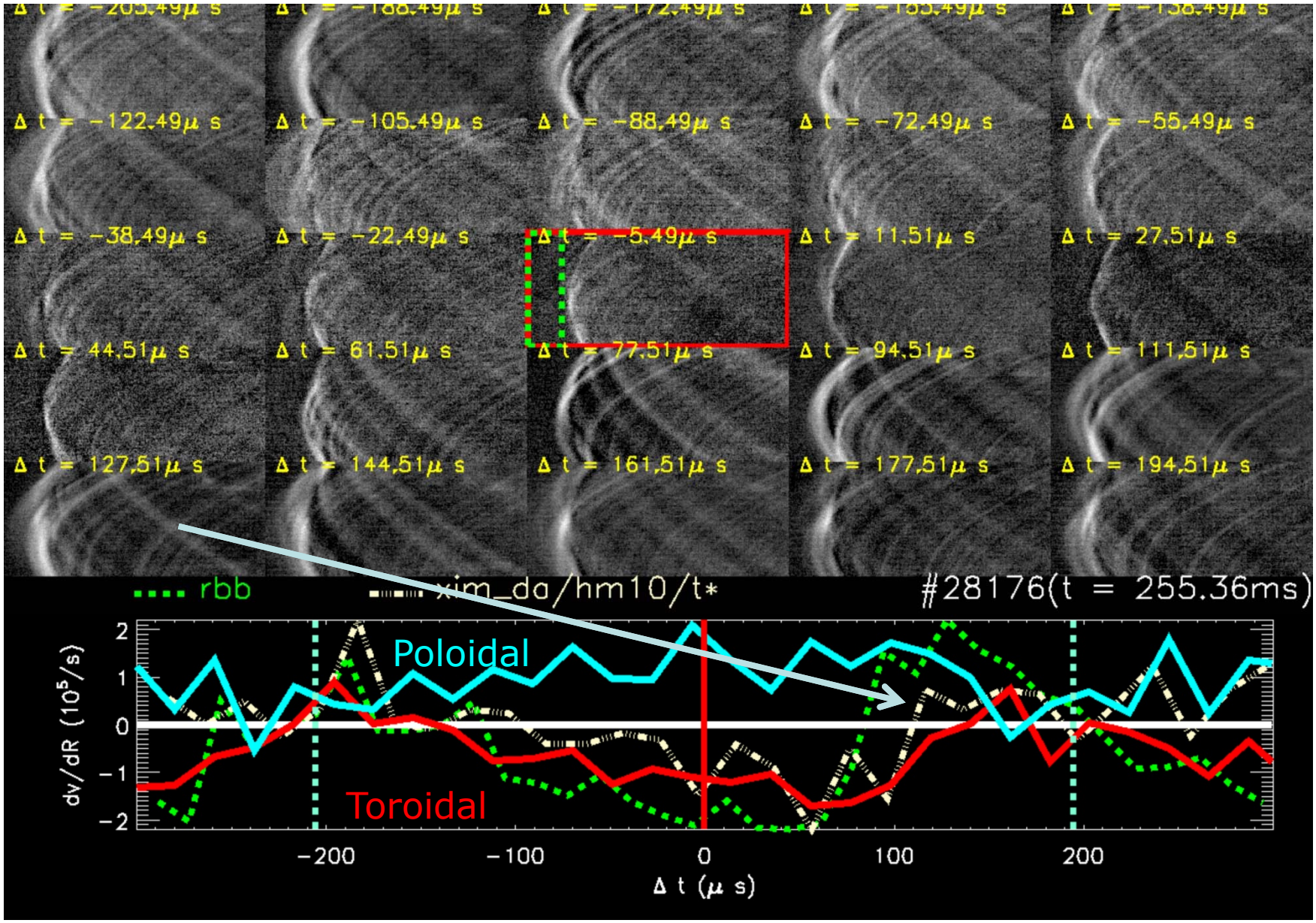


$n_e = 2.0\times10^{19}$ m^{-3}

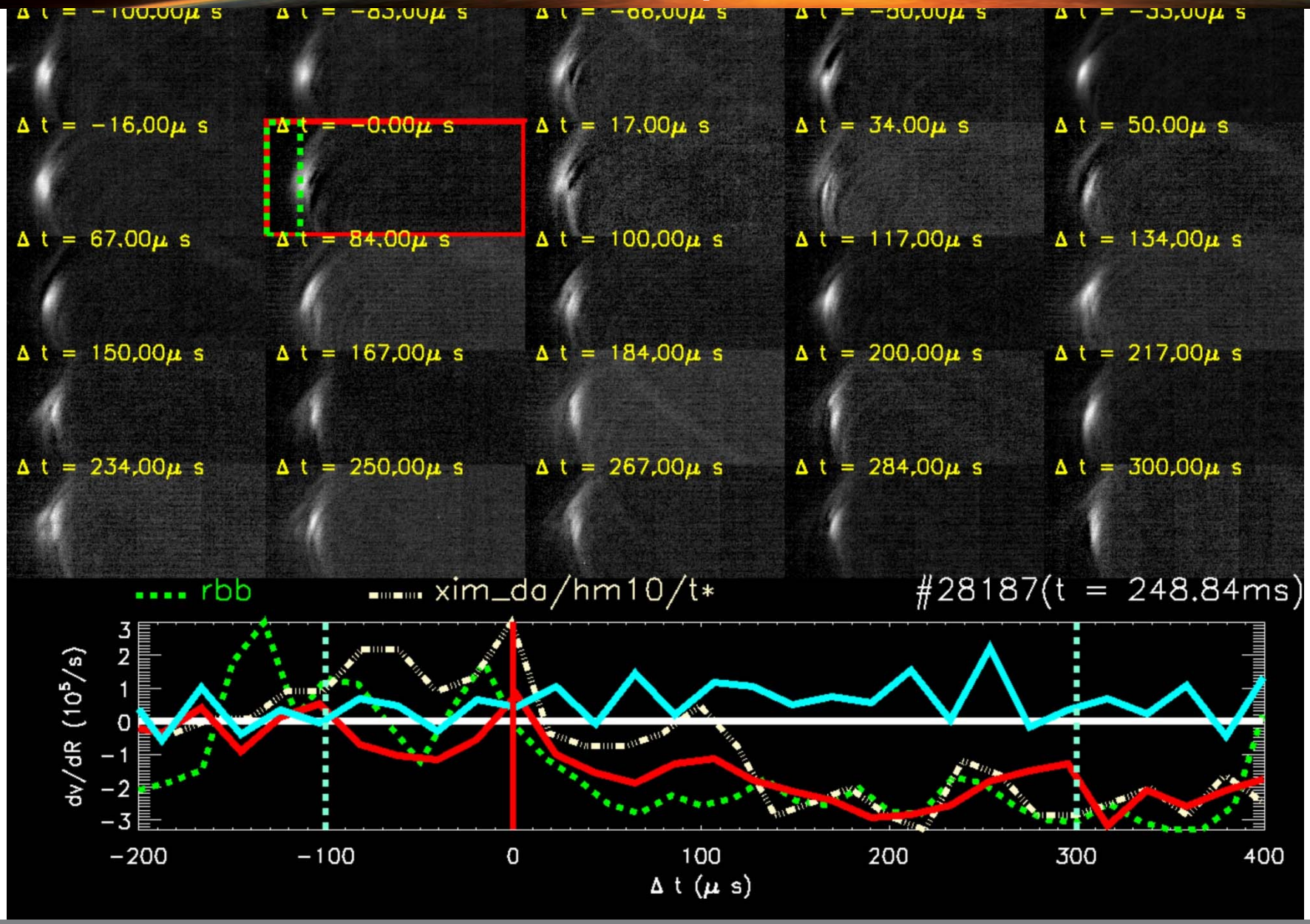
Velocity fluctuation level is high



Clear filaments with $\partial_r v$ present



No change of $\partial_r v$ prior to L-H trans.



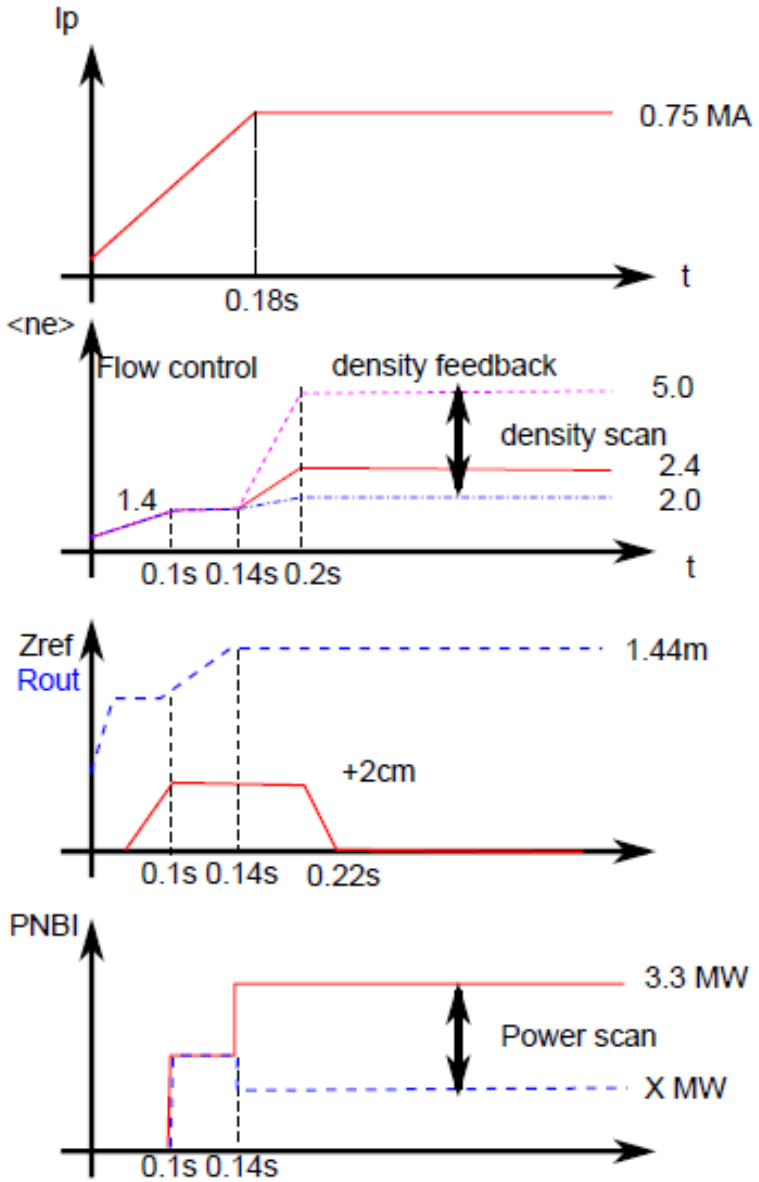
What we may learn from this?

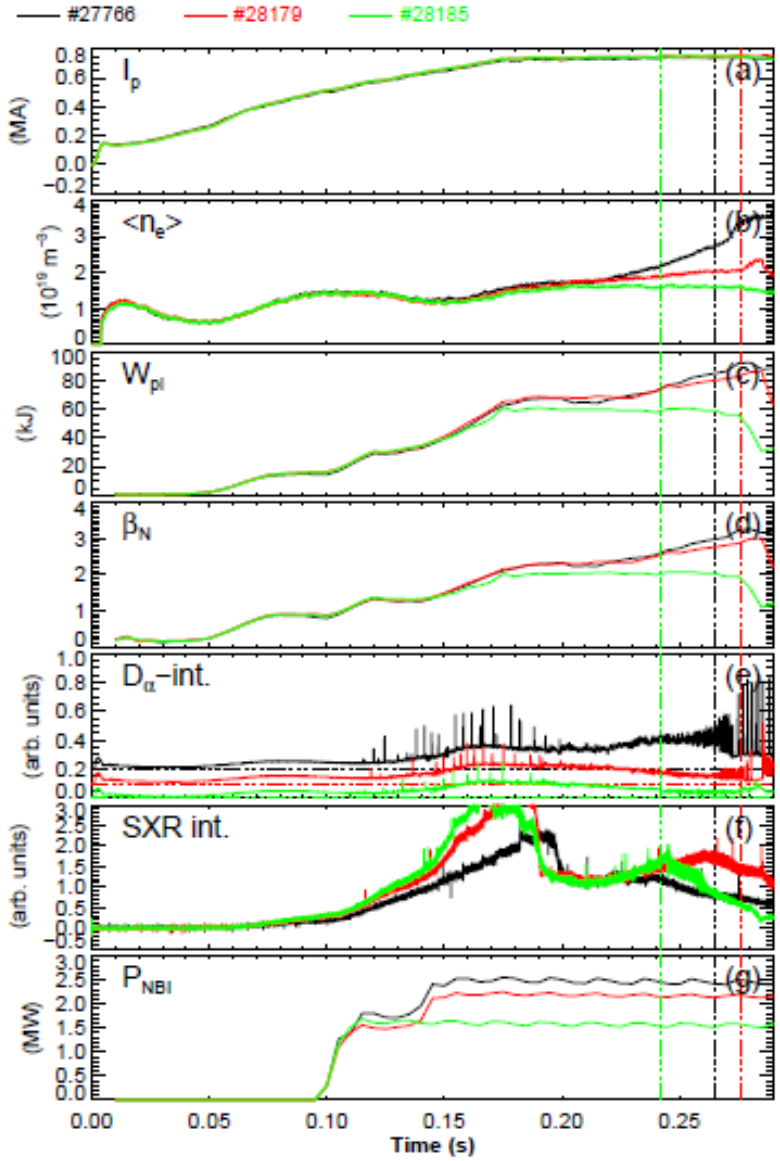
Filaments erupt before reduction of $|E_r|$

- Fast (50 kHz) visible Doppler spectroscopy on He^+ to measure E_r dynamics resolves transient ETBs.
- Clear correlation between flow, and flow shear with turbulence behaviour.
- Shear evolves simultaneous with reduction in turbulence, but …
- Strong filaments observed with full ∇E_r present.
  - Not compatible with simple predator-prey model?
  - What about multiple predators (Zonal flow, Mean flow, GAMs)?
- Is the ETB destroyed by "super L-mode"?
  - Steeper gradient $\Rightarrow$ turbulence pushes through $E \times B$ shear.

The End

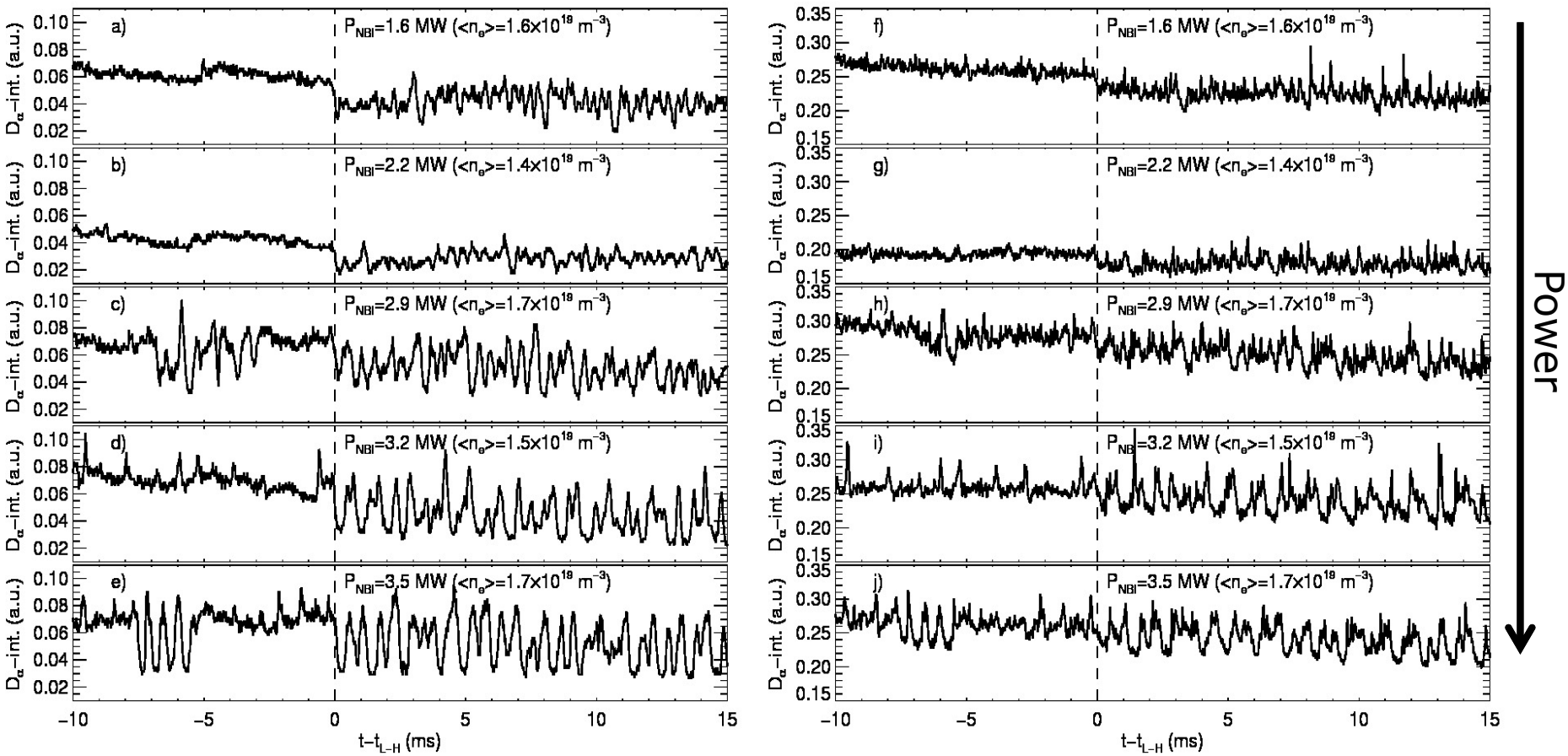
Plasma evolves ⇒ same ramp-up!





No ELMy H-mode below $n_e < 2e19\ m^{-3}$

Divertor $n_e = 1.6\times10^{19}\ m^{-3}$ mid-plane



- Dithers become more pronounced with power, but no clear ELMs with available power P_{NBI} < 3.5 MW.