Characterization of pedestal modes through fast vertical oscillations at DIII-D

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with

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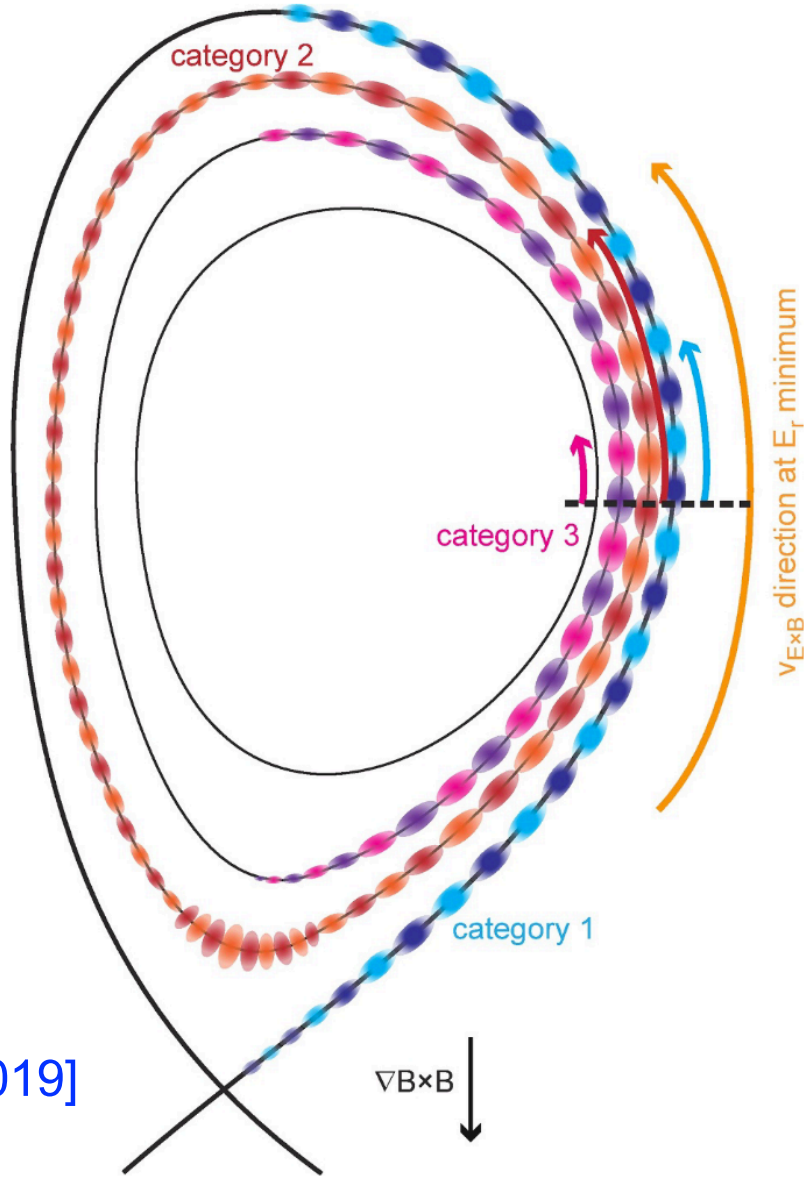
INTRODUCTION

Three general pedestal mode categories exist

- **Instabilities at the plasma boundary** have been observed on a large number of machines
  - **MHD-like modes** expected to play a major role in regulating the profile gradients
  - **Microinstabilities** are highly correlated with inter-ELM profile recovery phases
  - Consistent physical picture does not yet exist



[Laggner NME 2019]

Vertical oscillations induce extra edge current

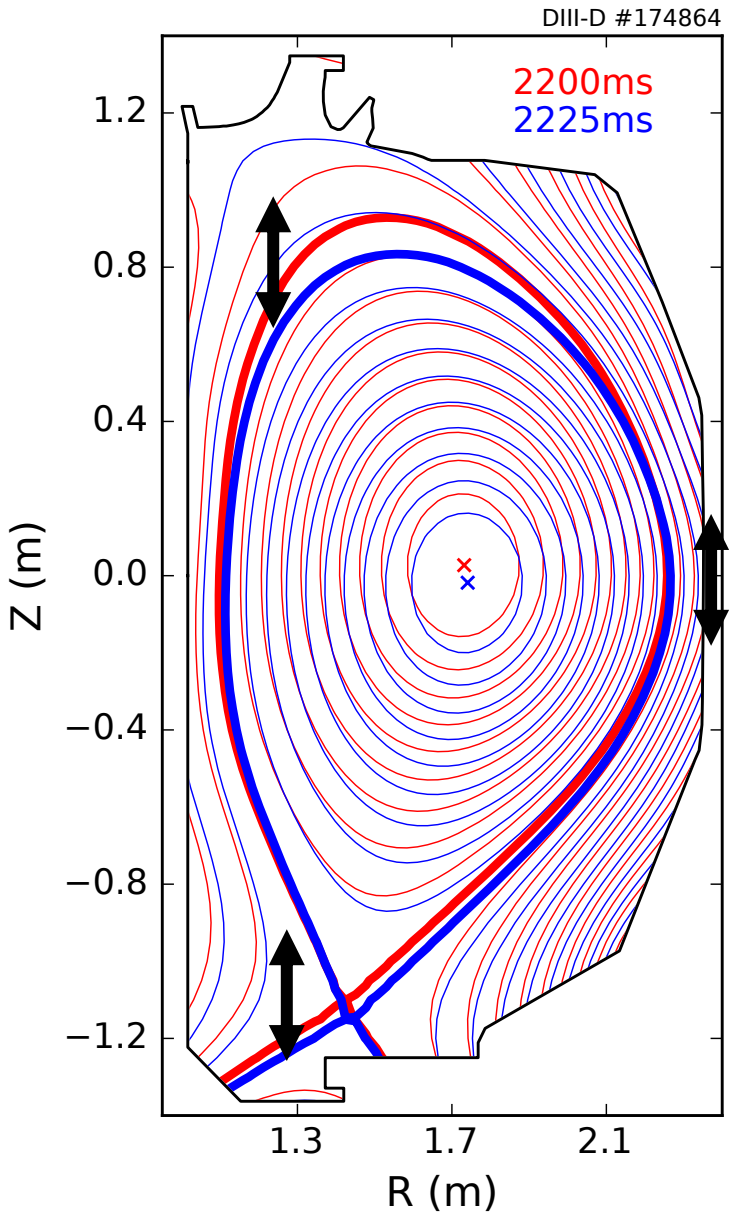
- Vertical oscillations have been used to trigger ELMs
  - **Perturbed edge current destabilizes PB modes**

- Change in current density from two effects:
  - Change in total current
  - Redistribution of current

$$\delta J_\phi = \frac{1}{2\pi r_0 w_r}\left(\delta I_\phi^{w_r} - I_\phi^{w_r}\frac{\delta w_r}{w_r}\right)$$

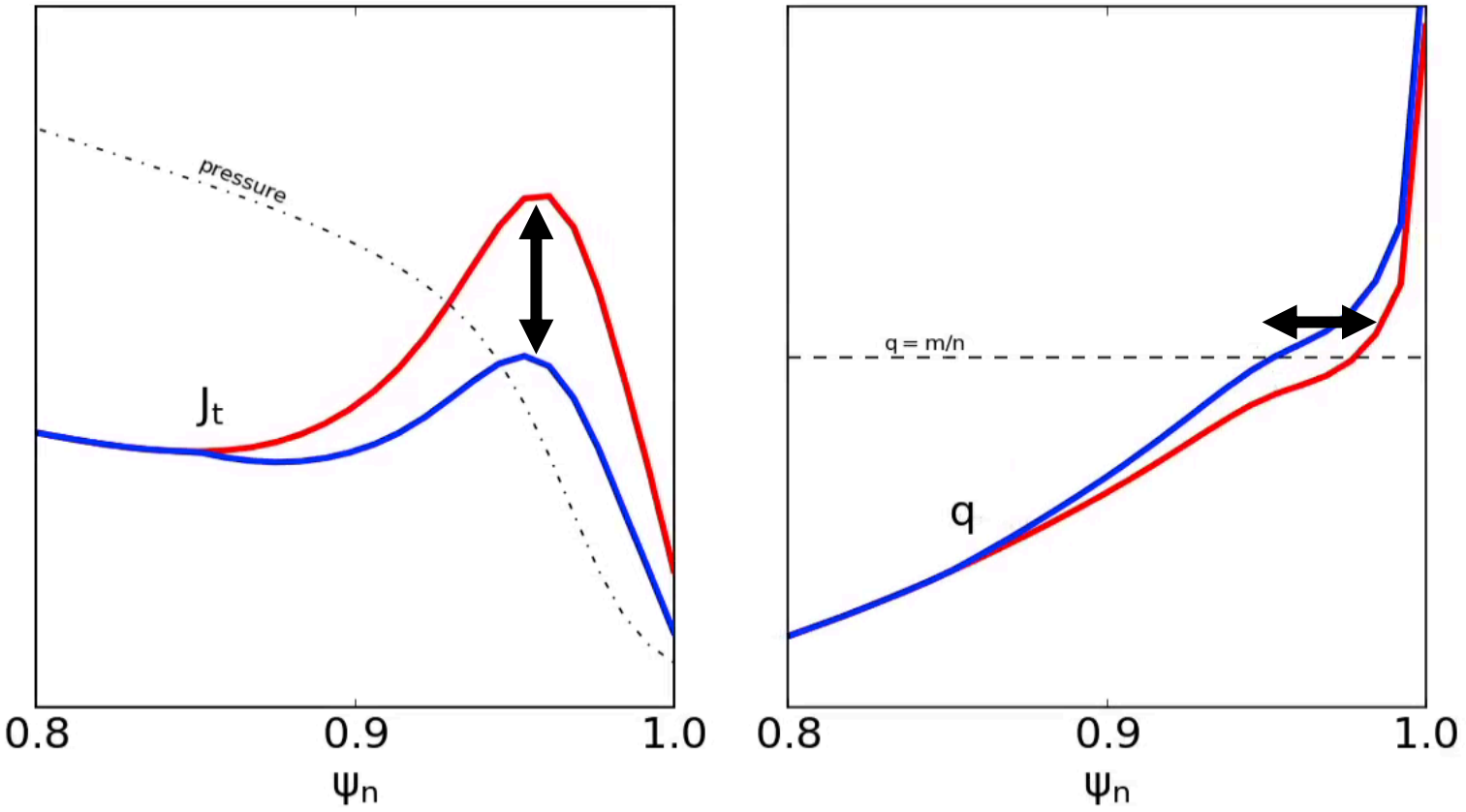
[Artola NF 2018]

- In JET and ITER, increased edge current drives ELMs
- In AUG, ELMs still driven with deceased edge current



Expected effect: shift q-profile to probe modes

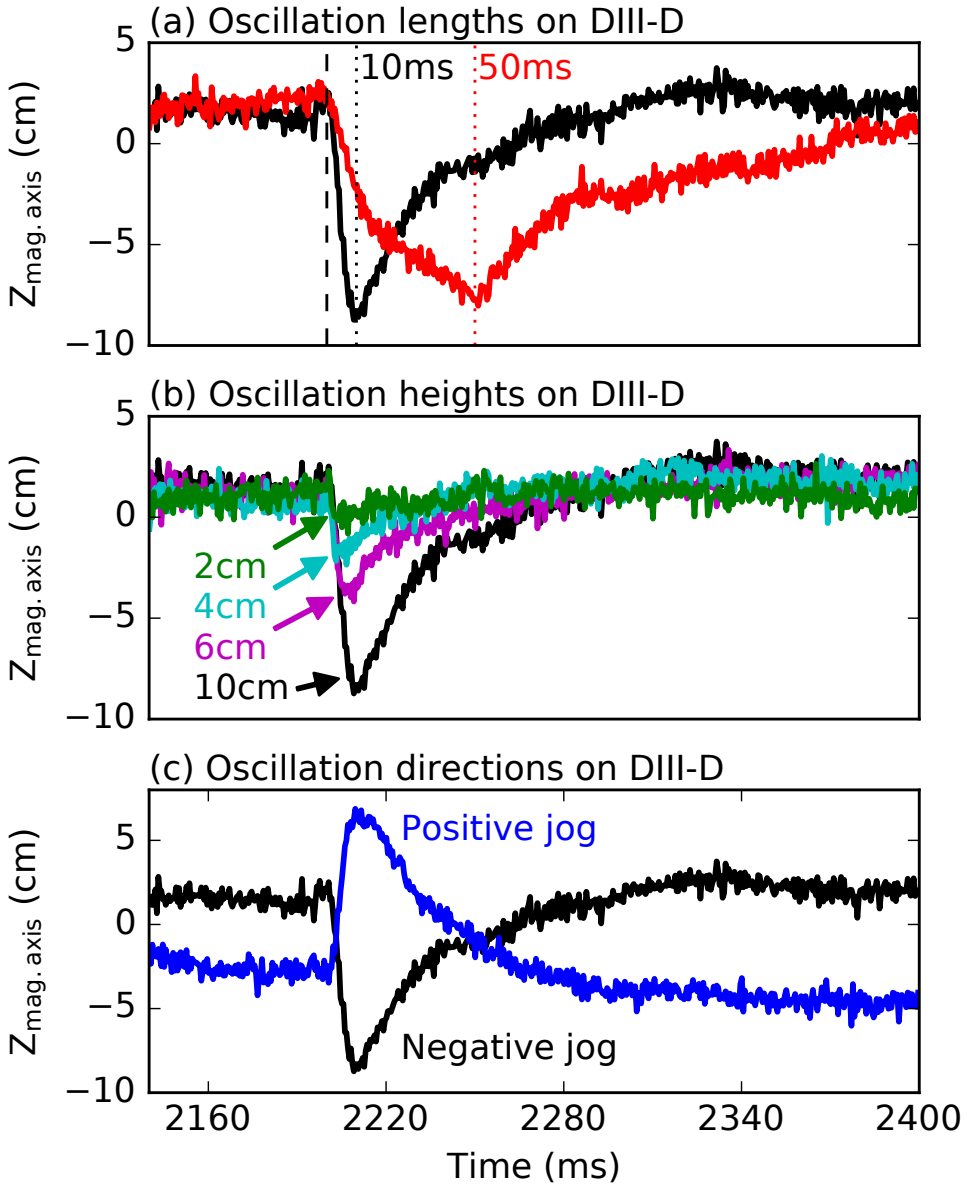
- Experimental strategy: **use vertical oscillations to probe edge modes**
- Hypothesis:
  - Decreased edge current moves q-profile inwards
  - MHD-like modes trapped to q-profile also move inwards



METHODS

Flexible oscillations creates parameter scan

- Explored jogging parameter space with three scans:
  - Jogging **duration** scan (10ms – 50ms)
  - Jogging **height** scan (2cm – 10cm)
  - Jogging **direction** scan (up and down)
- Jogging events either with either **controlled magnetics** or **"release and catch"**
- **Only the largest, fastest jumps led to inverted mode chirping**

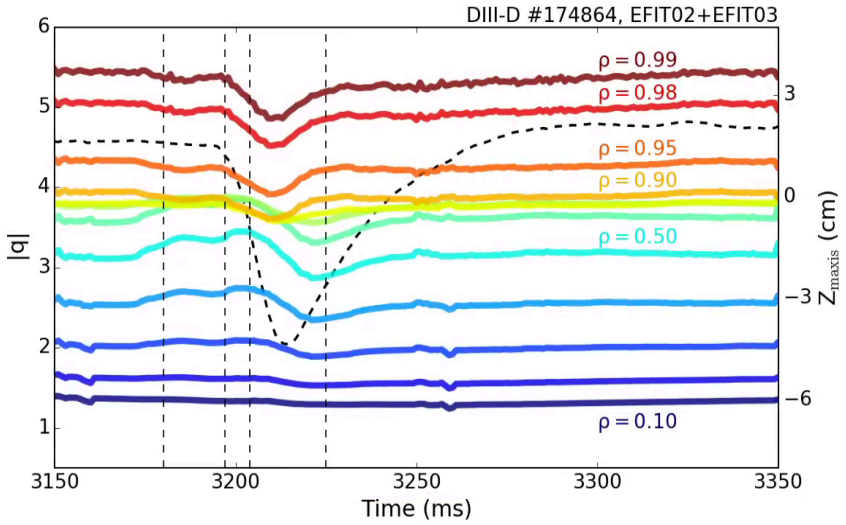


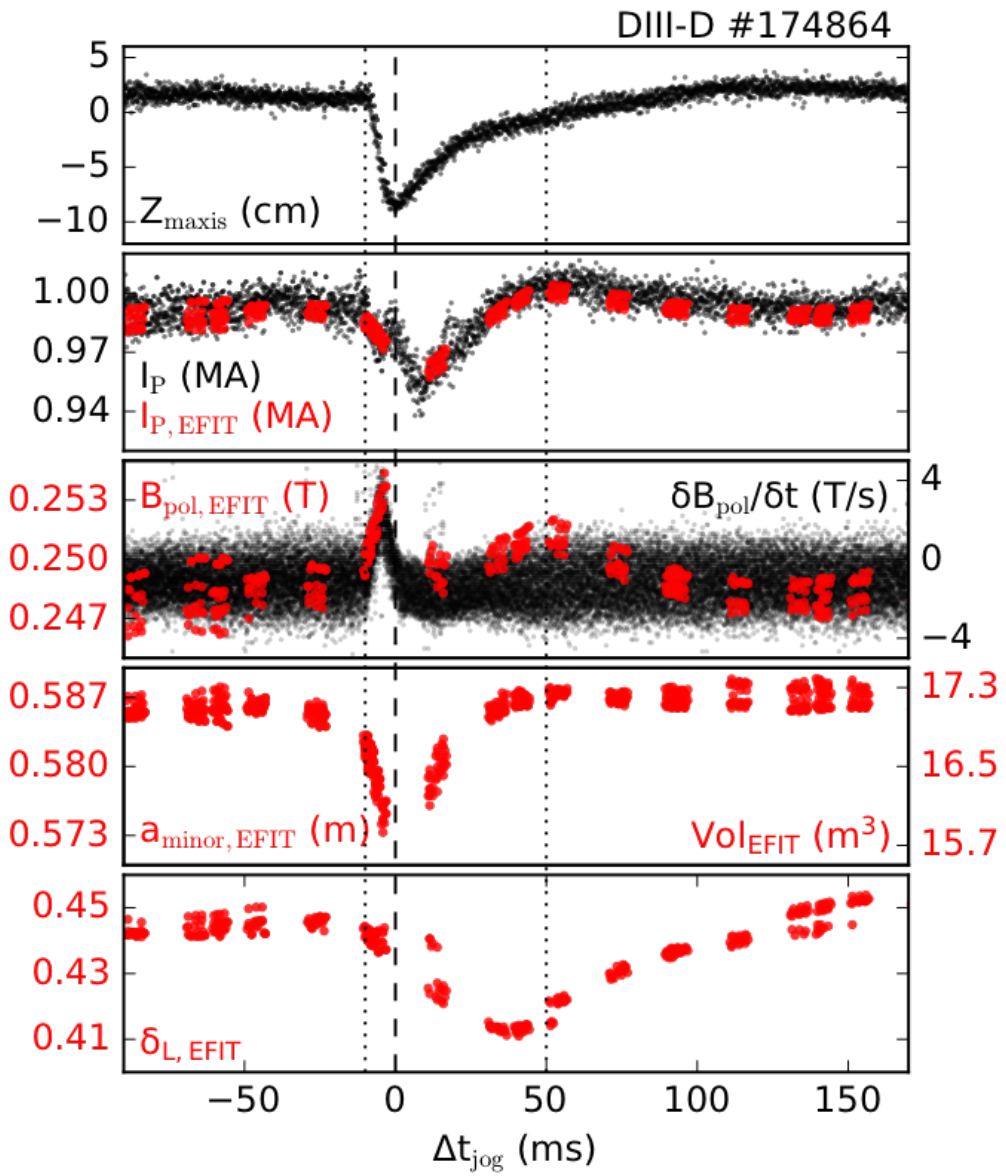
Shape change not negligible and modifies q

- The **plasma minor radius decreased** during jog

$$B_p \sim \frac{I_p}{a_{minor}} \qquad q = \frac{r\,B_T}{R\,B_p}$$

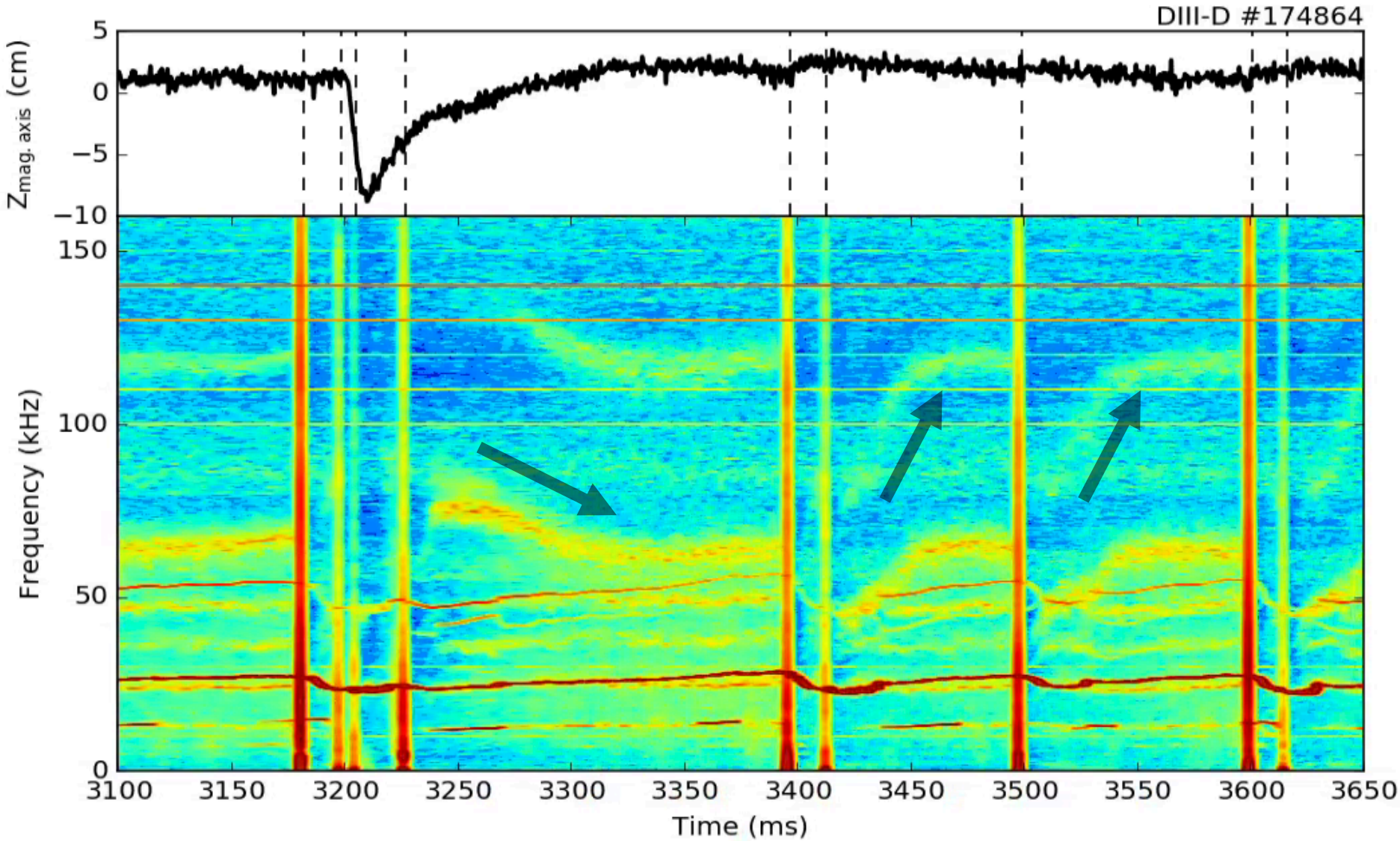
- Non-negligible Δa_{minor} leads to increase in B_p, **reducing q at the edge**





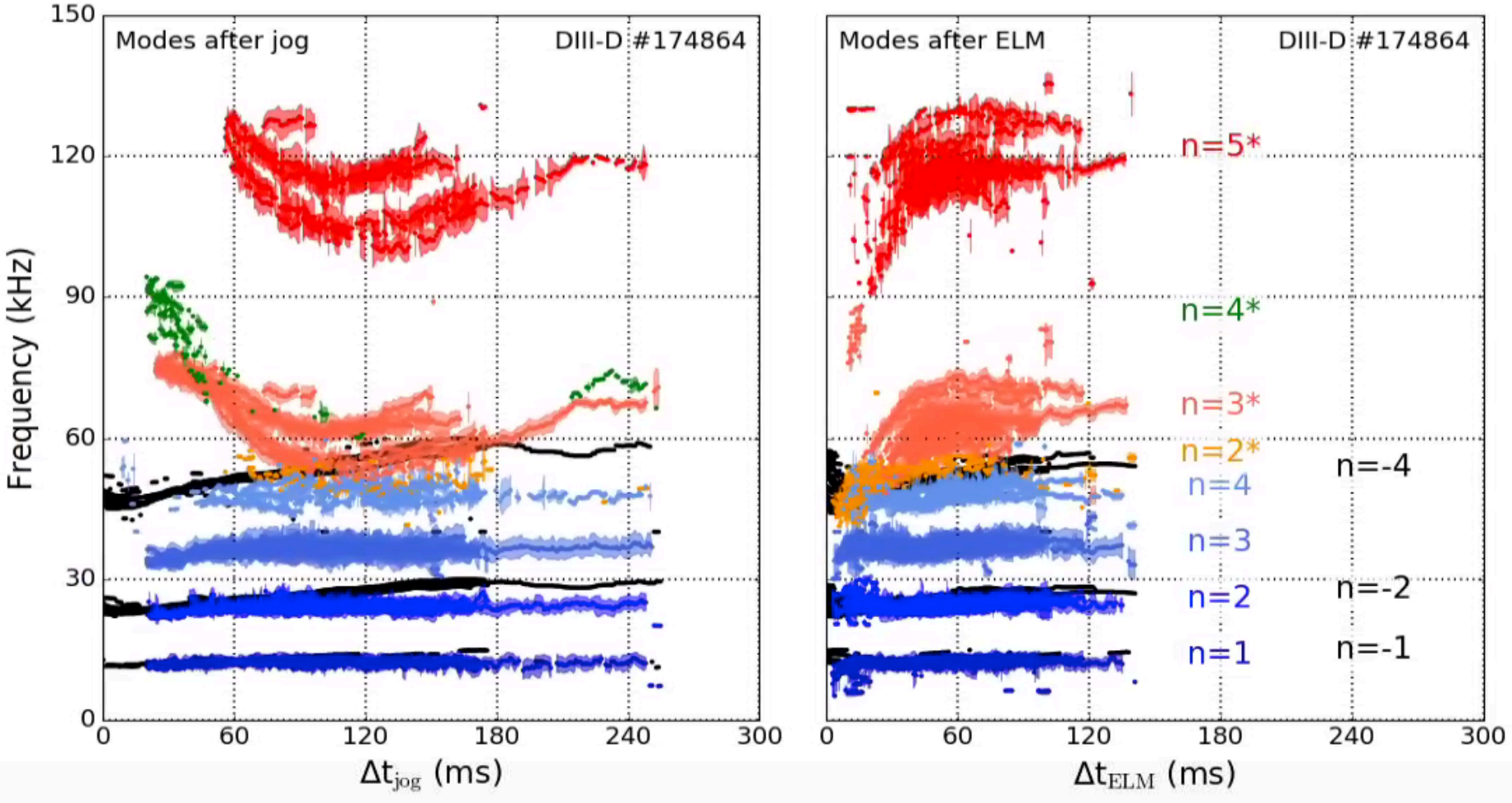
EXPERIMENTAL OBSERVATIONS

Largest jogs lead to inverted mode chirping



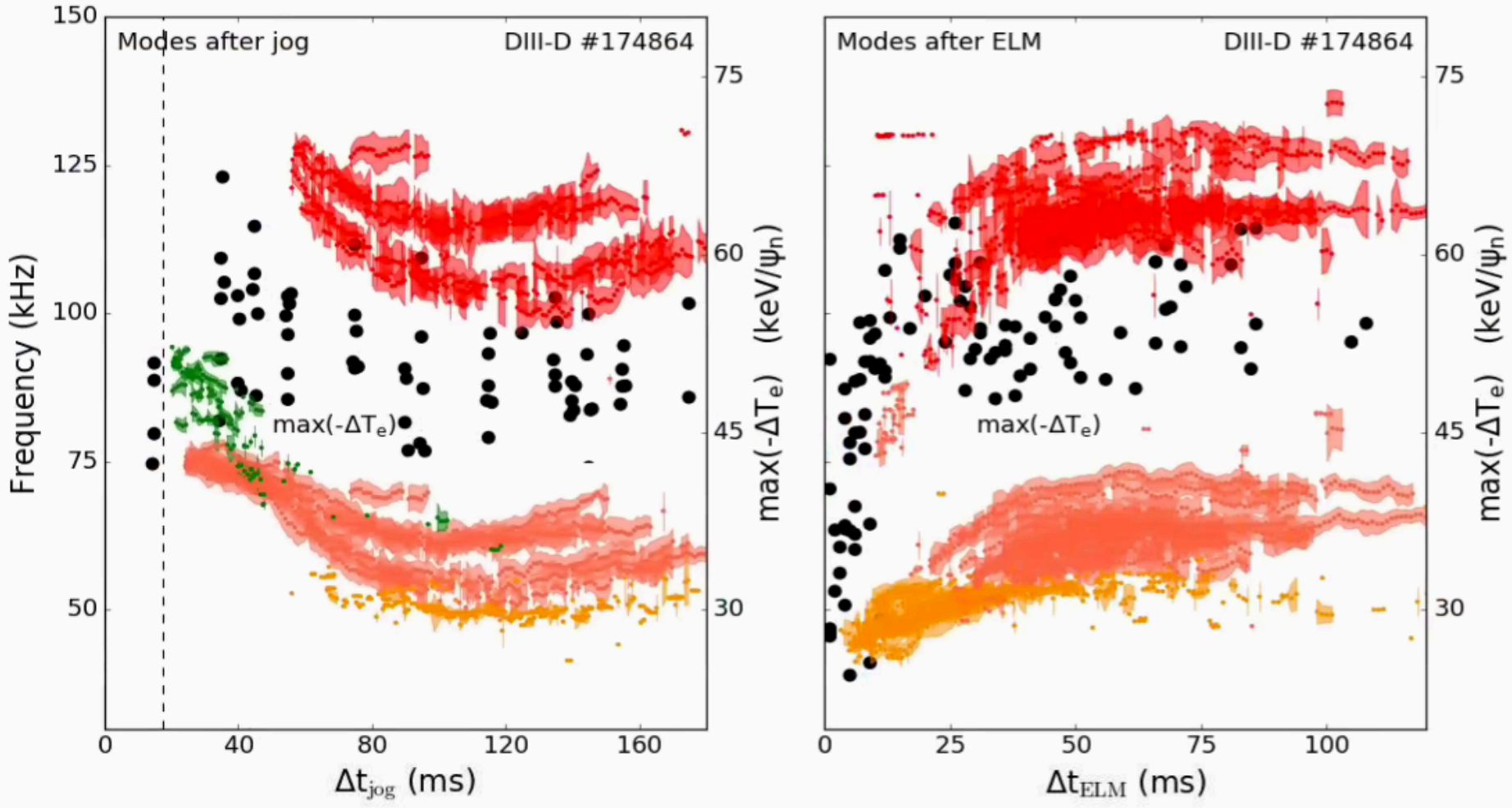
$n = 3$ and $n = 5$ modes chirp, others don't

- After jog, plasma experiences longer ELM-free period
- $n = 3$ and $n = 4$ modes merge during chirp-down



Saturation of ΔT_e correlated with mode onset

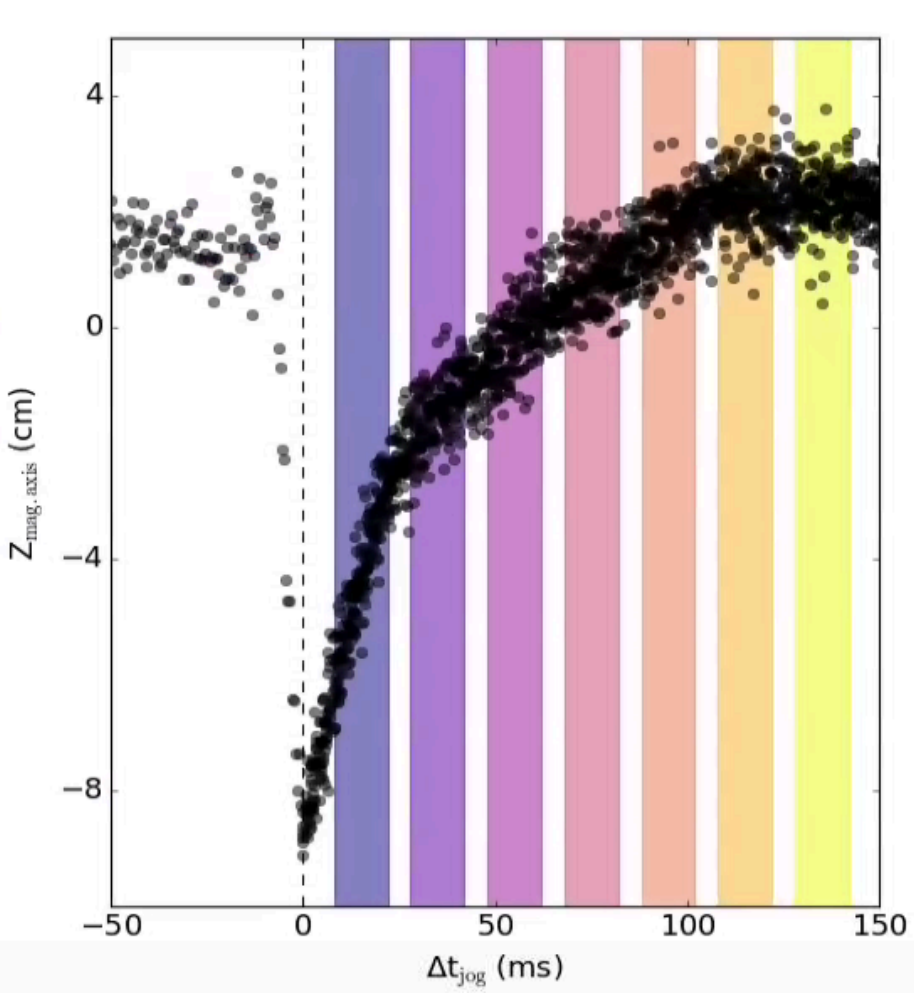
- Gradient recovery aligned with high-frequency mode onset in AUG
- Mode induces transport to limit pedestal [Laggner PPCF 2016]

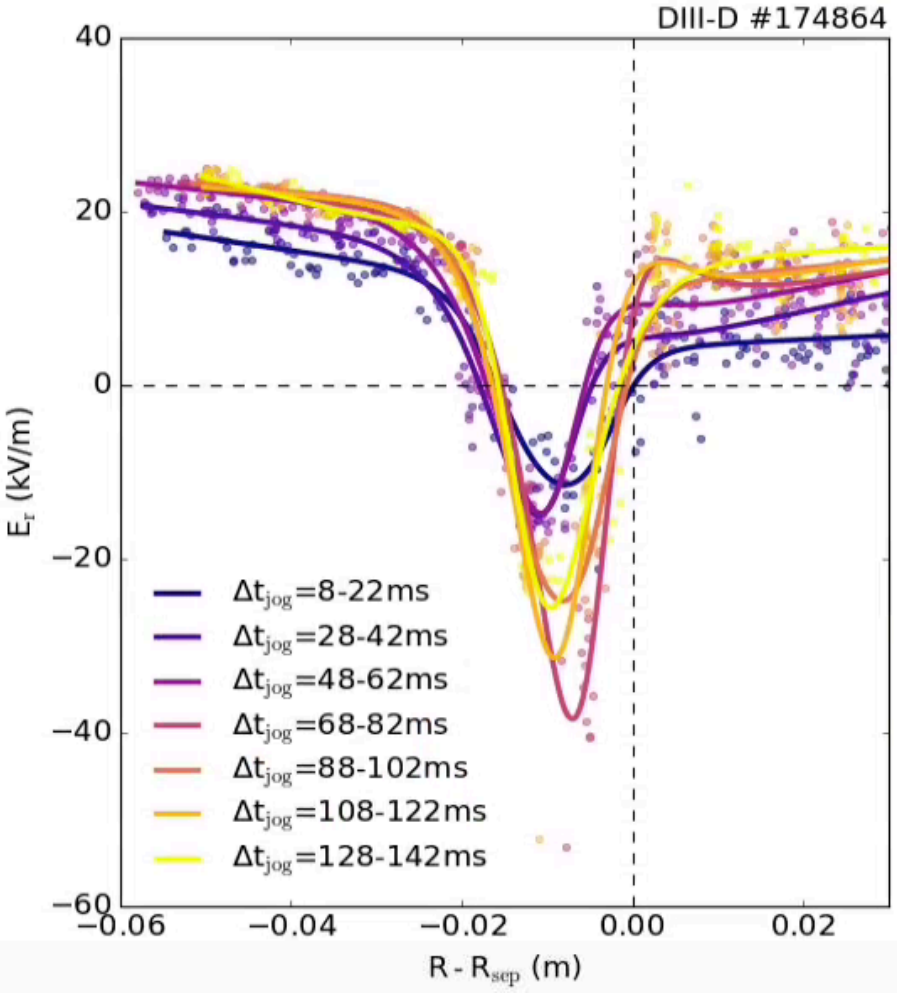


ANALYSIS

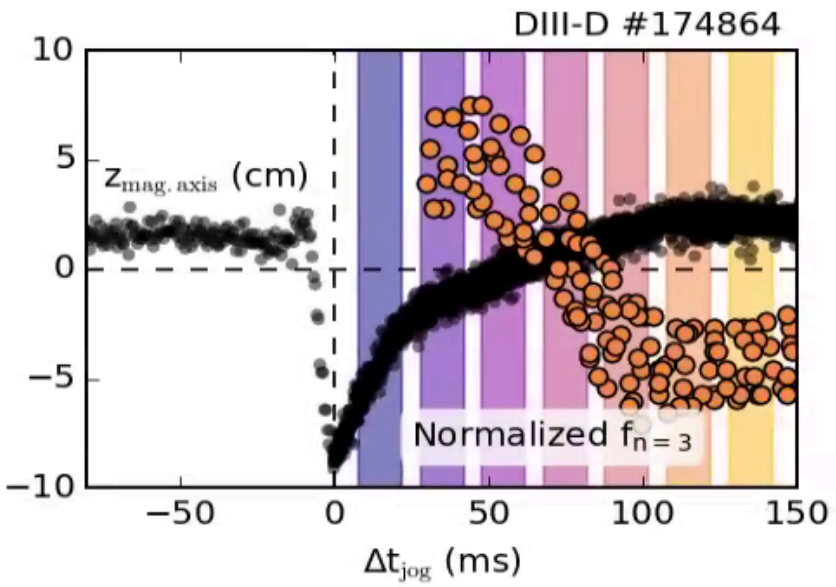
Large jogging events correlate with dip in E_r

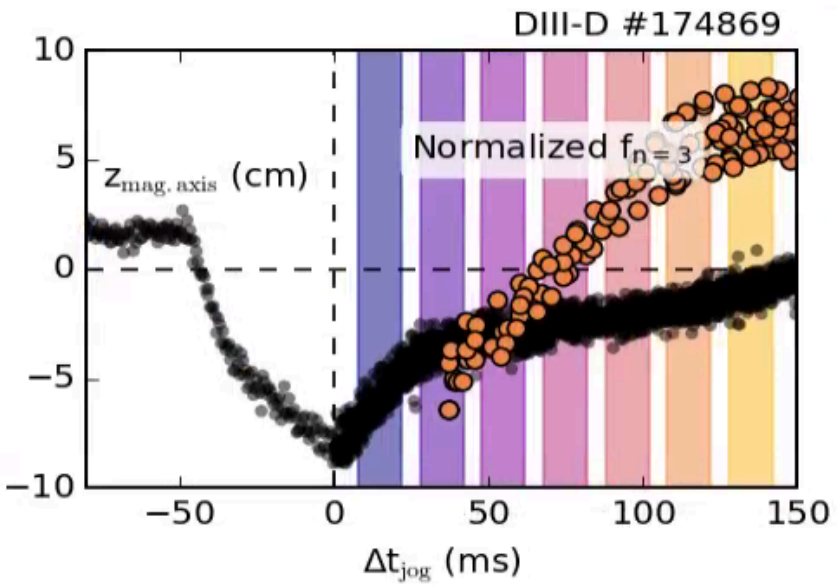
- Deep E_r observed during drop in mode frequency
- Behavior not observed after normal ELM

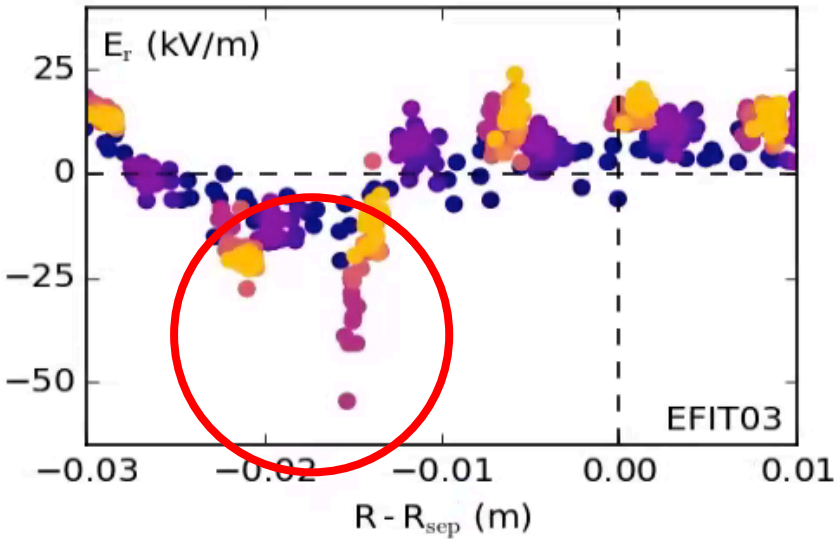


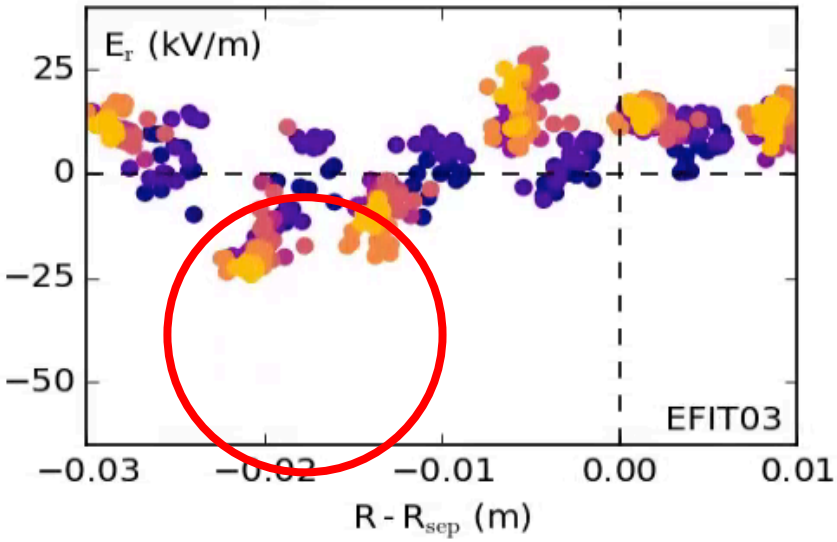


E_r dip only seen in shots with inverted chirping

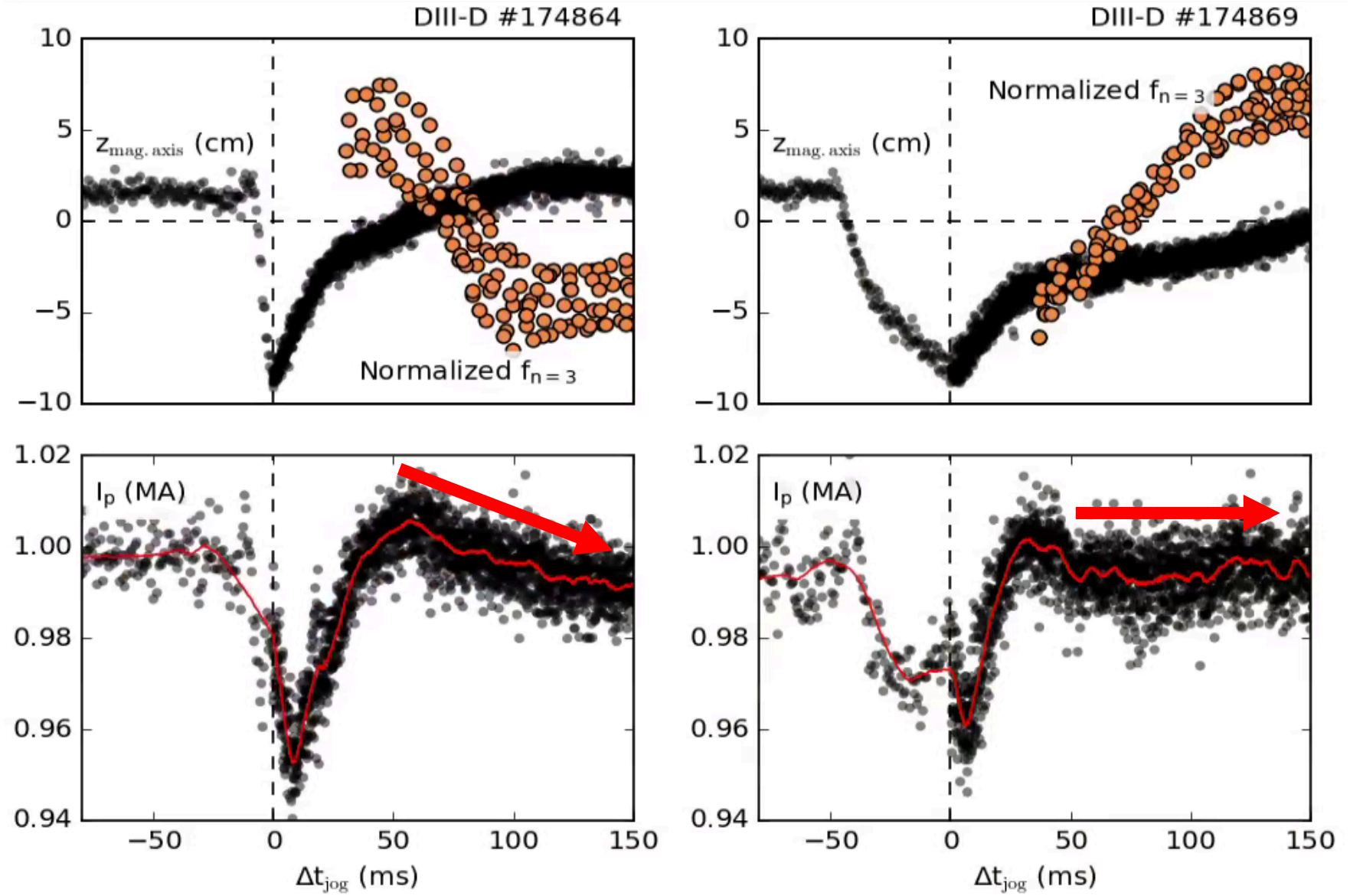








Inverted chirping correlated with current reduction



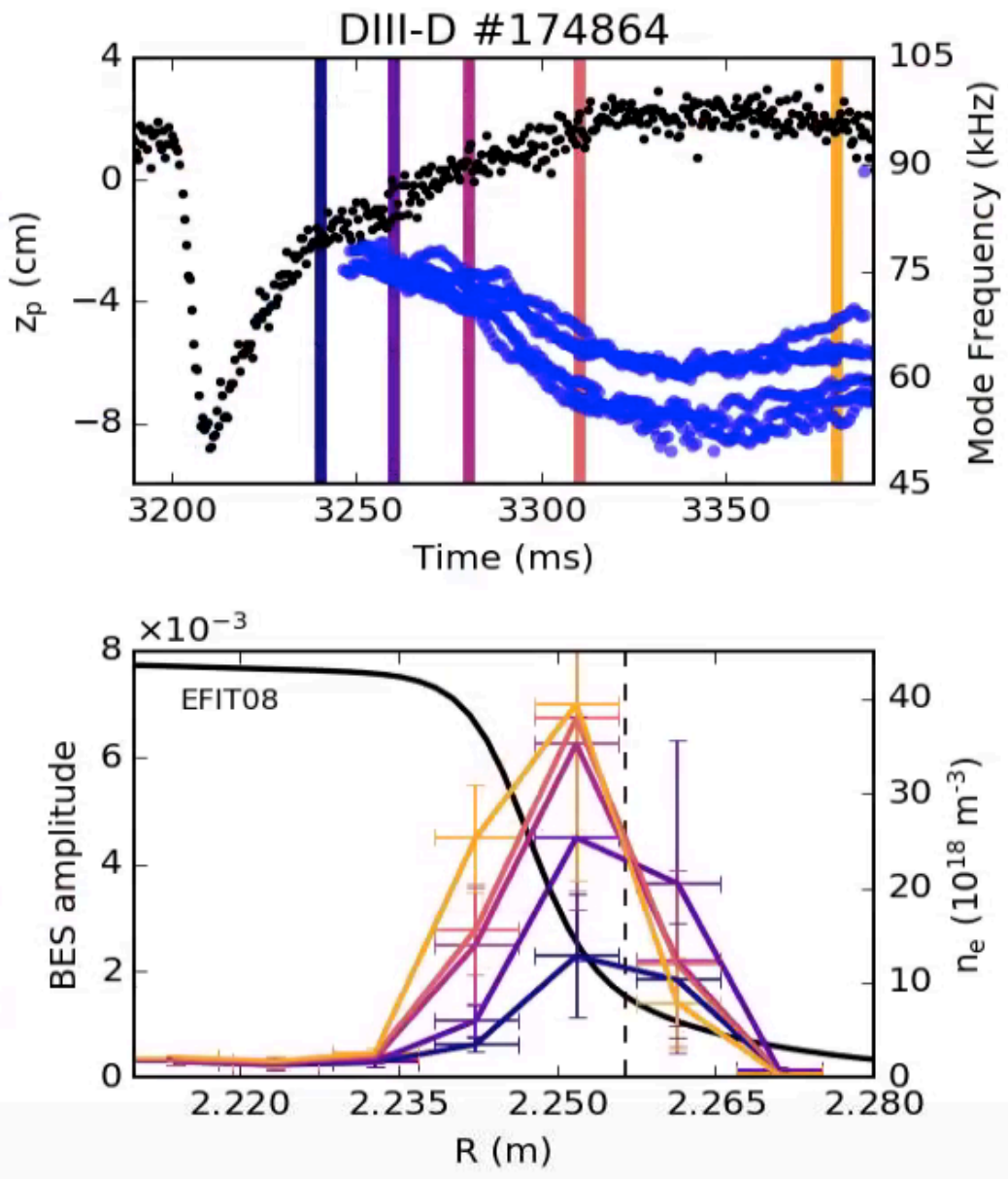
Chirped modes sit just inside the separatrix

1. **From BES k_θ:**
   - $k_\theta = 0.14$ /cm
   - $q = \frac{m}{n} \sim \frac{70}{5} = 14$

2. **From BES amplitude:**
   - mode only exists in edge channels

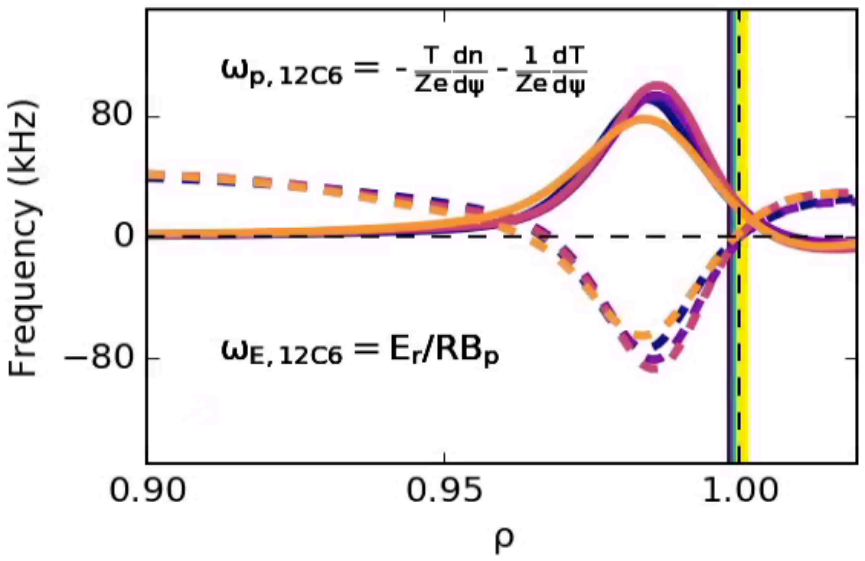
3. **From magnetics:**
   - $q = \frac{m}{n} \sim \frac{42}{3} = 14$

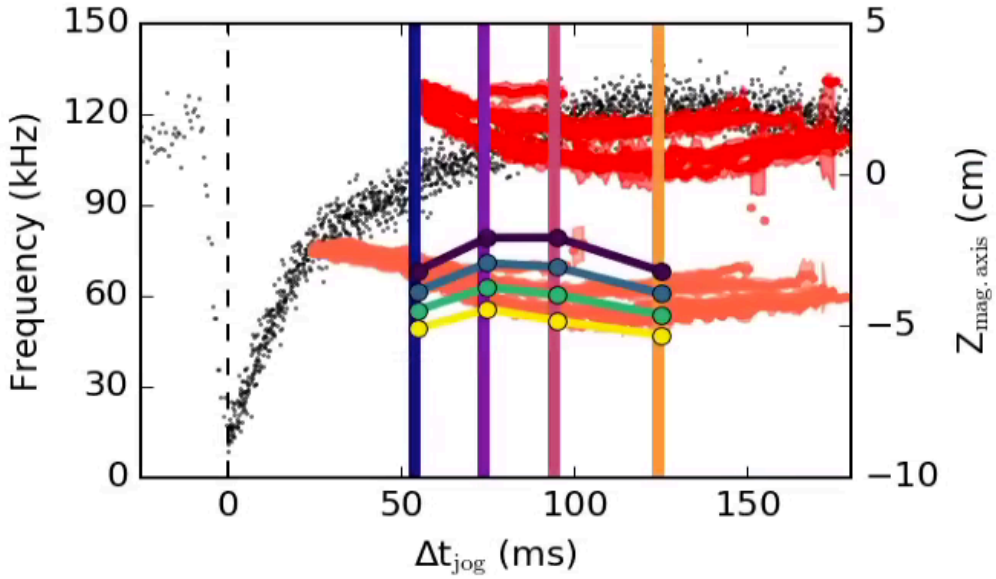
Other modes located at:
- Core $(n = -1 \rightarrow -4)$
- Pedestal top $(n = 1 \rightarrow 4)$



Mode frequency agrees with plasma rotation

- Mode frequency agrees with **edge rotation** derived from CER data
- Mode propagates in electron diamagnetic direction
- There is, however, significant uncertainty in this method

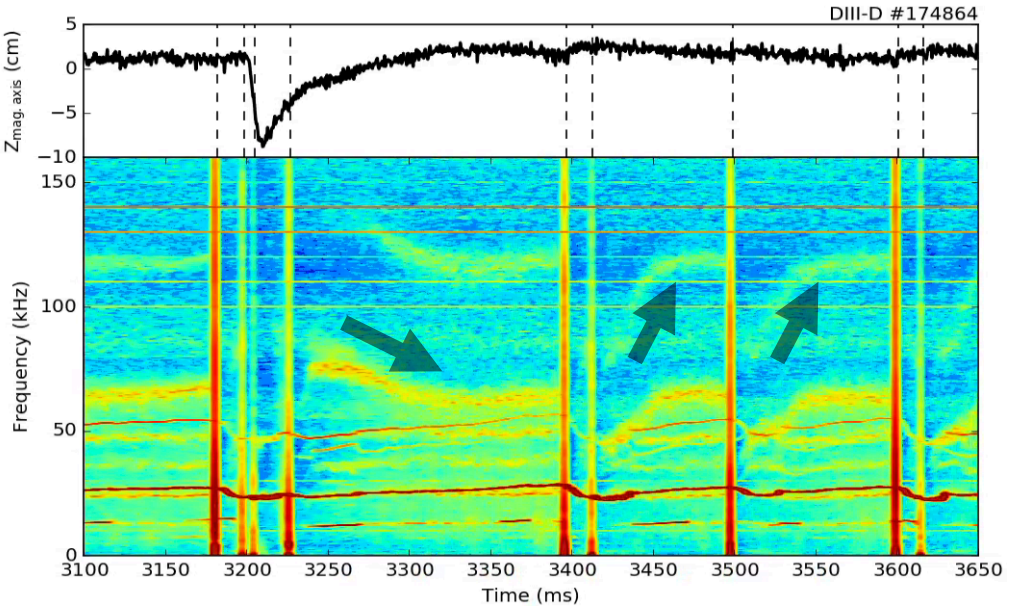




DISCUSSION/CONCLUSION

Large vertical oscillations change inter-ELM mode behavior through induced edge current

- Through a series of discharges at DIII-D, vertical oscillations were used to **induce current** in the plasma edge
- Reduced current during largest chirps **inverts chirping behavior** of edge-localized modes
- Inverted chirping behavior correlated with E_r **overshoot** and **current recovery**



- Potential to directly diagnose turbulence type in H-mode pedestal

Edge modes are probably MTMs

- High-frequency magnetic modes observed **near the edge** in a series of DIII-D discharges
  - Similar to category 1 modes from [Laggner NME 2019]
    - Medium frequency range (30 kHz to 150 kHz)
    - Localized close to the separatrix
    - n in the region from 3 to 8
  - Similar to washboard modes on JET [Perez PPCF 2004]
  - Similar to other QCFs on DIII-D [Diallo PoP 2015]

- **Inverted chirping** after vertical oscillations shows correlations between modes and q-profile + E_r well
  - Mode is probably MHD-like
  - Mode is probably not turbulence driven

- From fingerprints method, MTM and ETG modes are expected to dominate energy loss [Kotschenreuther NF 2019]
  - Most likely, **these modes are MTMs**

Future work to determine mode type

- **Gyrokinetic modeling with GENE**
- **Potential modeling with JOREK-STARWALL**
- **Analysis ideas:**
  - Calculate initial conditions for modes based on drive height?
  - Non-linear mode interaction from magnetics spectrum?
  - What happens to the core modes at the jogging event?
  - Can we calculate the SOL E_r?
  - Does the SOL E_r modify/control the edge E_r?
  - Do the core modes respond behave as expected?

BACKUP SLIDES

Plasma current decreases towards x-point

- When moving towards the nearest X-point, a significant **negative current** is induced

[Artola NF 2018]

$$\delta I_{\phi}^{w_r} = \frac{4\pi}{\mu_0 R_0}\left[\delta\psi_{ext}(a) - B_\theta(r_0)R_0\delta w_r - \eta J_\phi \delta t\right]$$

Total toroidal edge current

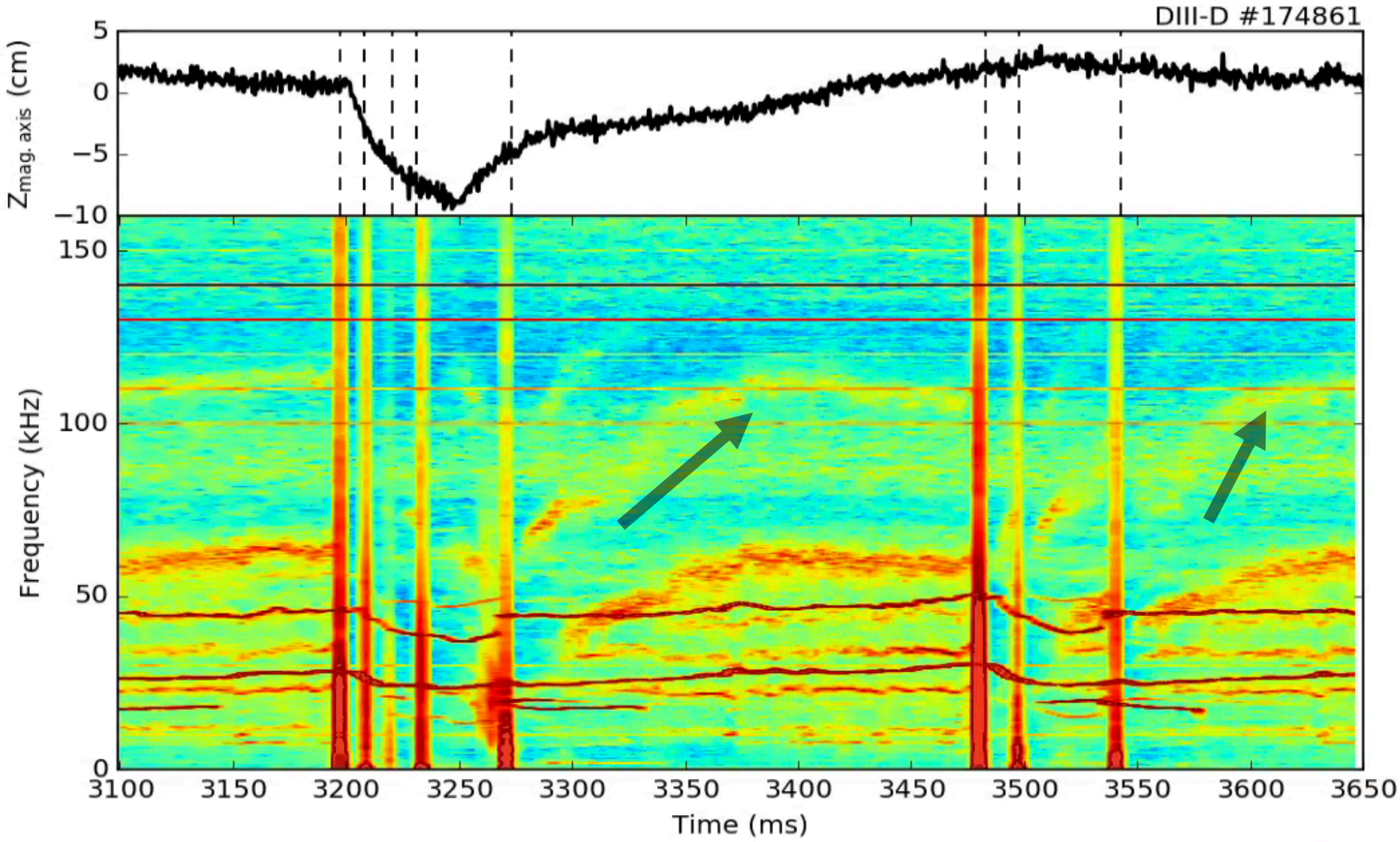
Local change in external flux (from PF coils/walls)

Motion of plasma through inhomogeneous field $(\delta \boldsymbol{r}\cdot\boldsymbol{\nabla}\psi_{ext})$ and Plasma compression or expansion (δw_r)

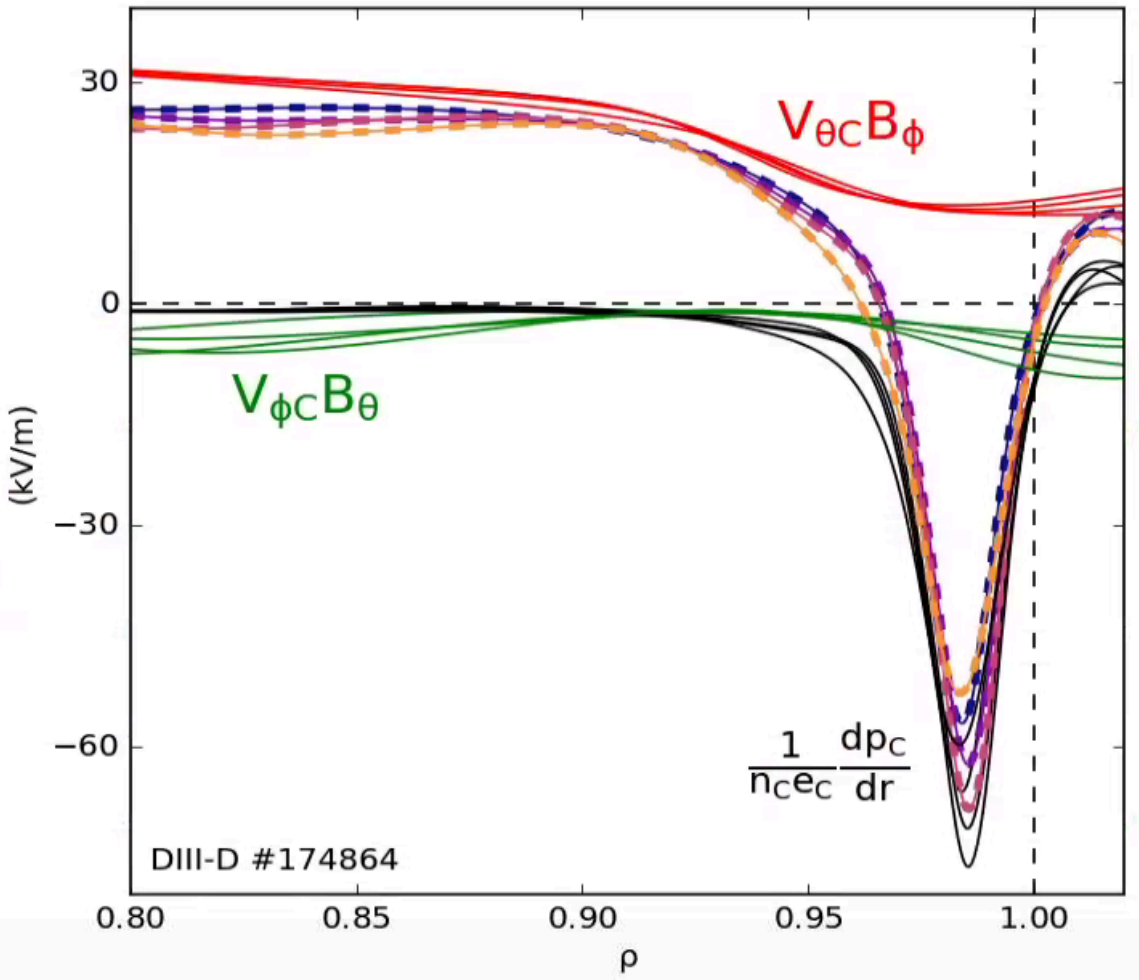
Small resistive decay term (only speed dependence)

- Magnetic field gradient is larger in the lower position $(\delta \boldsymbol{r}\cdot\boldsymbol{\nabla}\psi_{ext} > 0)$
- In JET and ITER, a reduction of the plasma volume leads to an increase in the positive current

Controlled oscillations do NOT invert chirping behavior



Change in E_r comes from Δp_C term

- E_r primarily determined through CER measurements of intrinsic Carbon
- Largest effect on E_r in the pedestal region comes from Δp_C term
- Measurement limited by spatial (~ 0.8cm) and temporal (~ 10ms) resolution of CER diagnostic

$$E_r = V_{\phi C} B_\theta + V_{\theta C} B_\phi + \frac{1}{n_C e_c} \frac{dp_c}{dr}$$