Local Turbulence Suppression and Flow Shear Dynamics During q-Triggered Internal Transport Barriers on DIII–D

by
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Overview

- **<u>Motivation</u>: Understand the effects of low-order rational *q* surfaces on turbulence and flow shear at low magnetic shear.**
  - Integer q's in Negative Central Shear (NCS) can trigger ITBs (Austin, et. al.).
  - Why? ...Zonal Flows (Waltz, et. al.),
    ...Convective Cells (Diamond & McDevitt)

- **<u>Work</u>: Examine turbulence and turbulence flow via Beam Emission Spectroscopy (BES).**
  - Data at both high and low toroidal rotation, v_ϕ.

- **<u>Results</u>: Turbulence tied to rational surfaces in Negative Central Shear (NCS).**
  - Local turbulence reduction observed at time q_{min} crosses low-order rational.
  - Local turbulence poloidal velocity, v_θ, shear develops after q_{min}=2.
  - Outward radial propagation, roughly following q=2 surface.

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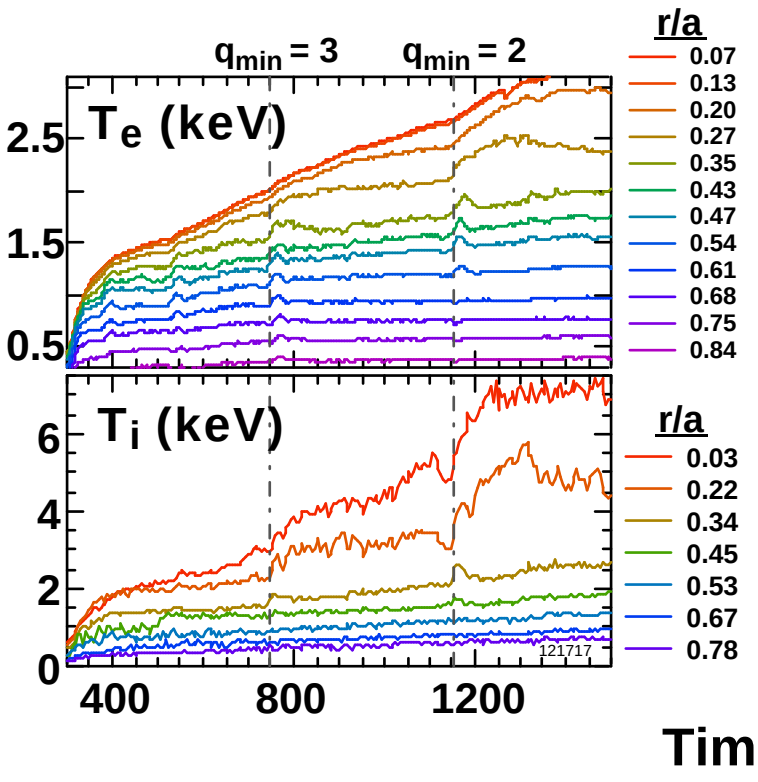
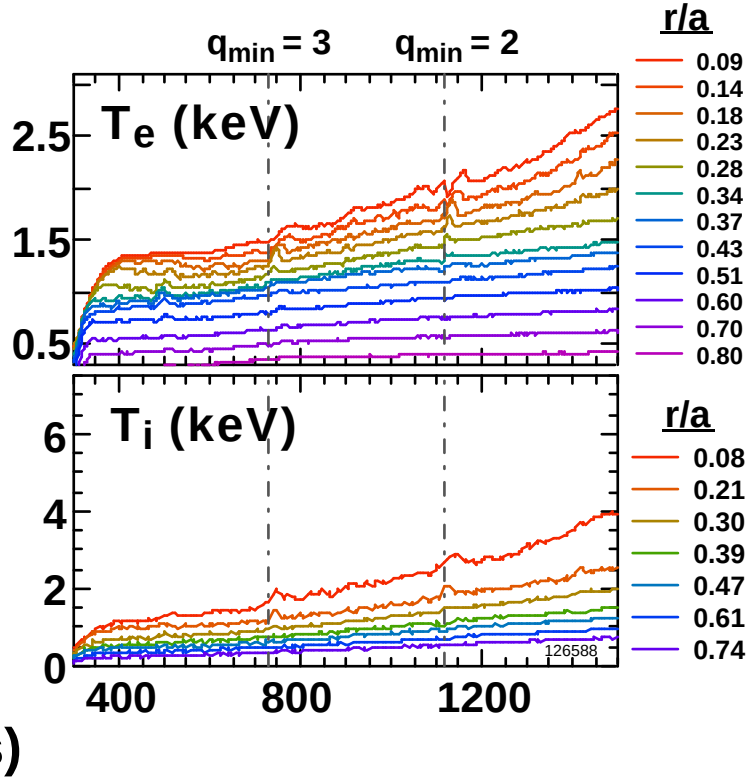
Integer *q*'s Linked to ITB Formation in NCS Discharges on DIII-D

- **ITB forms with sufficient background *ExB* shear when q_{min}=2.***
  - Sudden changes in confinement at low-order rational q_{min} surfaces.
  - Background *ExB* shear controlled via Neutral Beam Injection (NBI).

High Toroidal Rotation
5 MW Co-current NBI



Low Toroidal Rotation
5 MW Balanced NBI



Time (ms)

***See Poster UP8.00059, M. Austin, Thursday Afternoon**

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Sheared Flows Predicted Near Low-Order Rational *q* Minima

- **GYRO simulations suggest zonal flows (*m*=0, *n*=0)**
  - Explained by a resonance of turbulence modes at low-order rational surface.
  - Enhanced turbulence at lowest-order surface.
  - Radial divergence drives zonal flows.

R.E. Waltz, et. al., Phys. Plasmas, ***13*** *052301 (2006).*

- **Secondary Convective Cells theorized**
  - Energy transfer from drift waves to low-*m*,*n* convective cell, resonant at *q*=*m*/*n*.
  - Can drive radial transport.
  - Damped by magnetic shear.

C.J. McDevitt, et. al., Phys. Plasmas ***13*** *032302 (2006).*

P. Diamond, et. al. IAEA 2006.

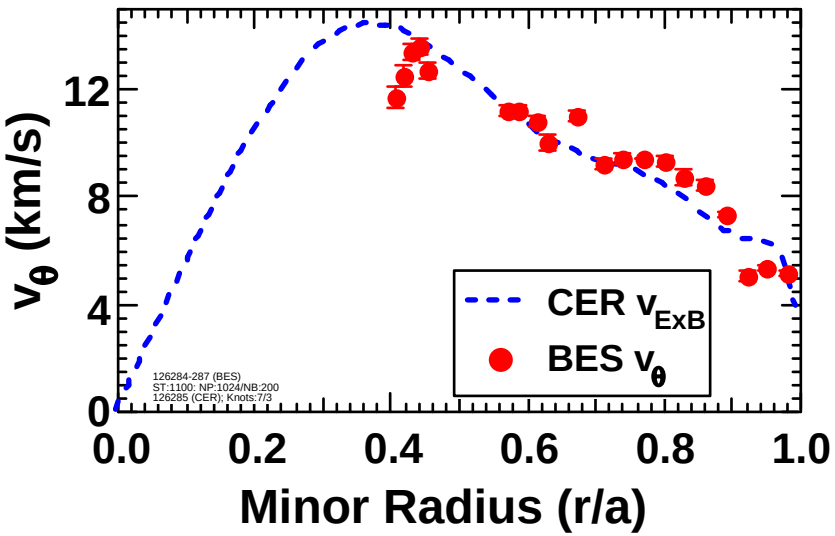
2D BES Array Measures Local Turbulence and Poloidal Flow

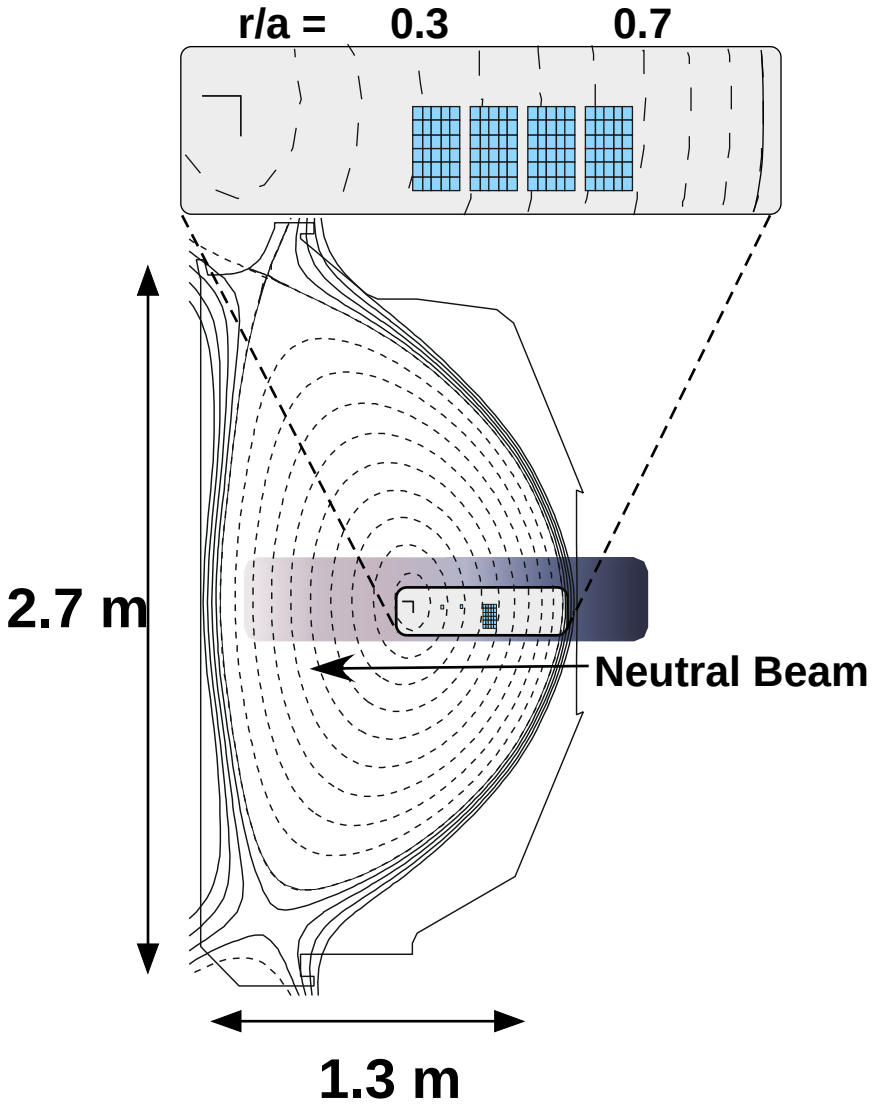
- **5x6 BES array scanned radially shot-to-shot**

- **Turbulence advection measured via Cross Correlation Time Lag ⇒**

$$v_{\theta,turbulence} = v_{ExB} + v_D$$

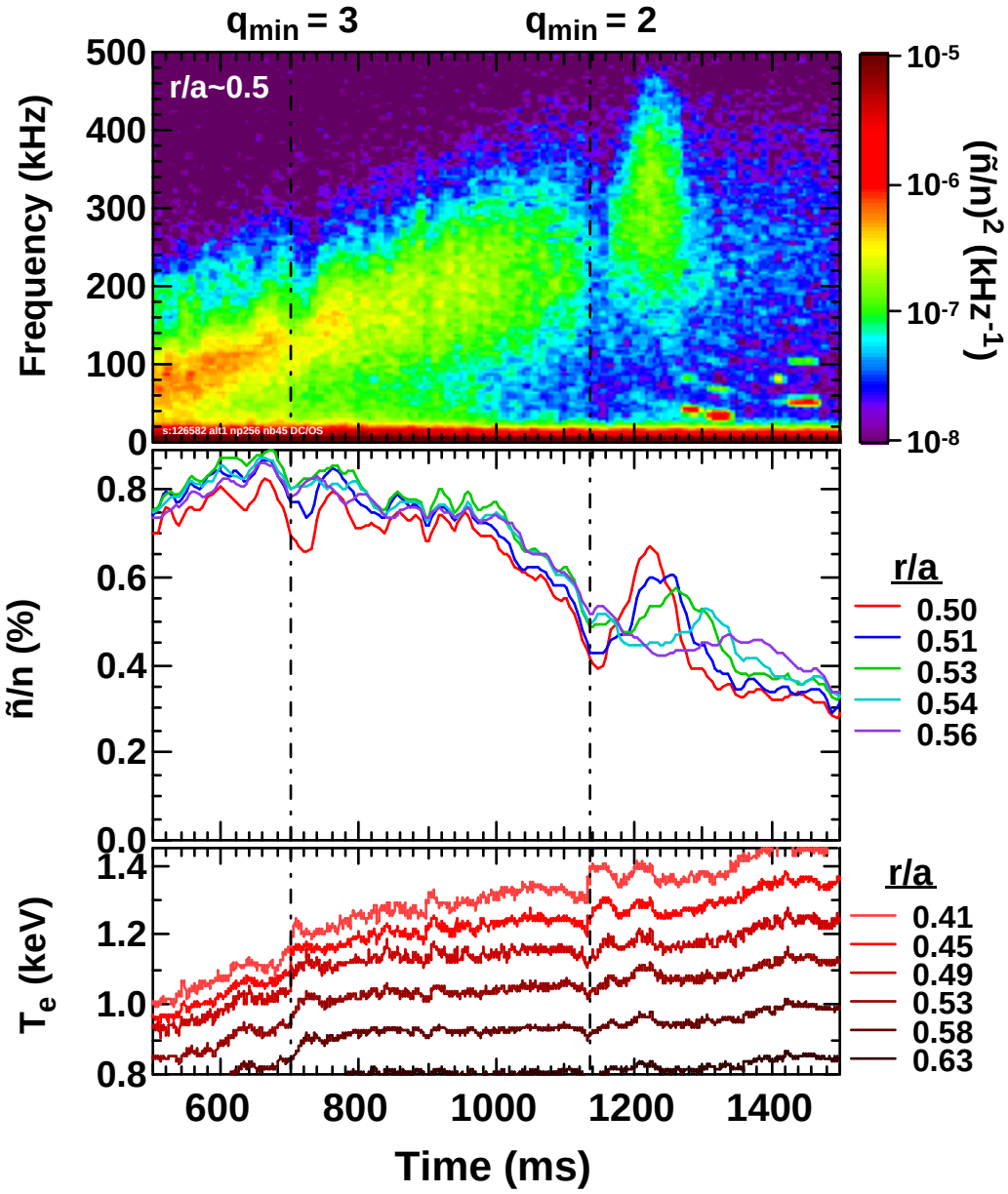
  - Typically, $v_D << v_{ExB}$
  - Compares well to CER-measured E_r.





Localized Turbulence Reduction w/ Low-Order Rational *q* Minima

- **ITB triggered by q_{min}=2 inside r/a~0.4 at high rotation**
- **Turbulence reduction when low-order rational q minima appear.**
  - Measurements outside q_{min}.
  - Fluctuation spectra dominated by RSAE's inside q_{min}.
- **Largest turbulence reduction observed nearest q_{min},** ~30 %
- **Radial outward propagation.**
  - Front velocity ~ 0.4 m/s
- **Increased transient turbulence levels following suppression.**
  - Possible mode resonance?



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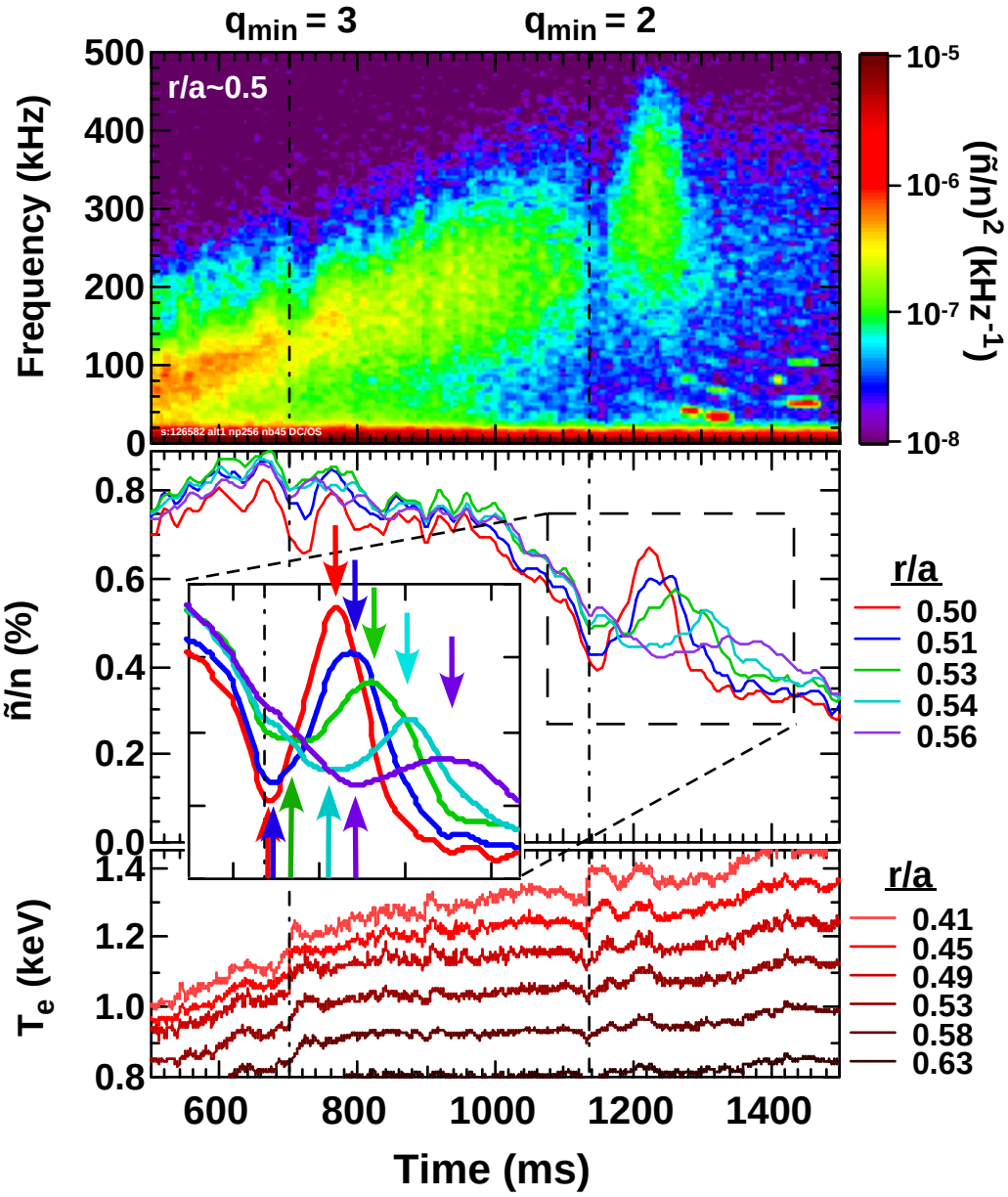
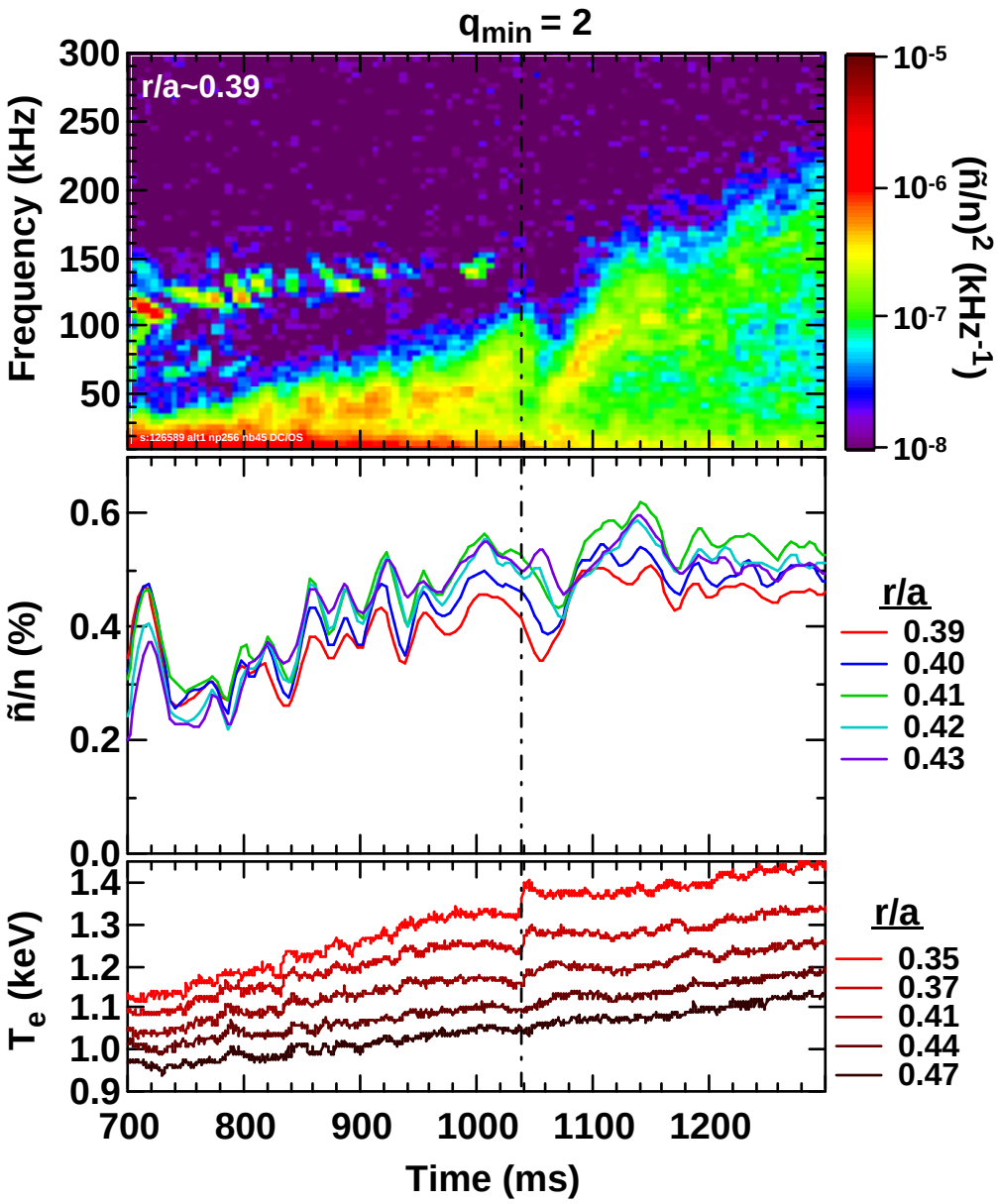


Turbulence Suppression Also Observed in Balanced Injection

- **No ITB formed w/o sufficient equilibrium E_r.**
  - q_{min} at r/a ~ 0.30-0.4
- **Suppression observed when low-order rational q minima appear.**
  - Measurements outside of q_{min}=2.
- **Again, largest reduction found observed closest to q_{min} surface.**
  - < 30%
- **Outward radial propagation of suppression.**
  - Front ~ 1 m/s
  - Comparable to q=2 surface

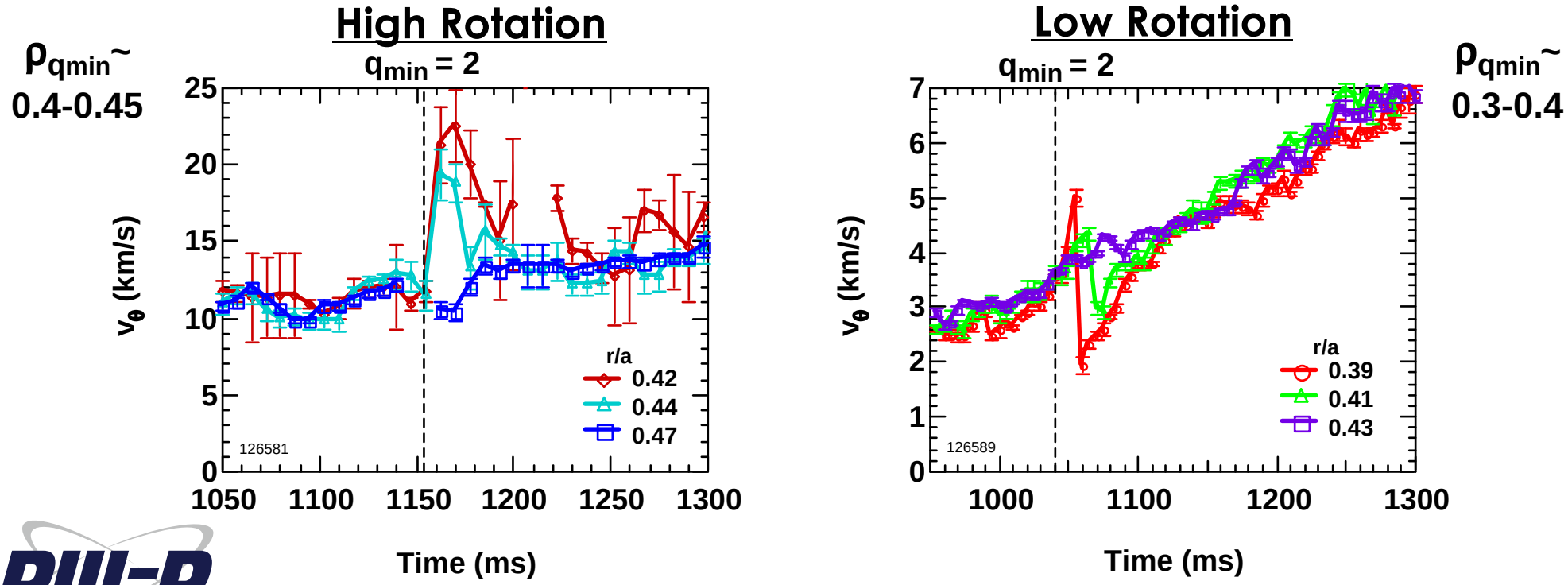


Localized v_θ Shear Measured Near q_{min}=2 Surface

- **Transient v_θ excursion ⇒ flow shear develops following q_{min}=2.**
  - at highest, dv_θ/dr exceeds 500 kHz at high rotation, 150 kHz at low rotation.
- **Shear rate transiently exceeds measured turbulence decorrelation rate,**

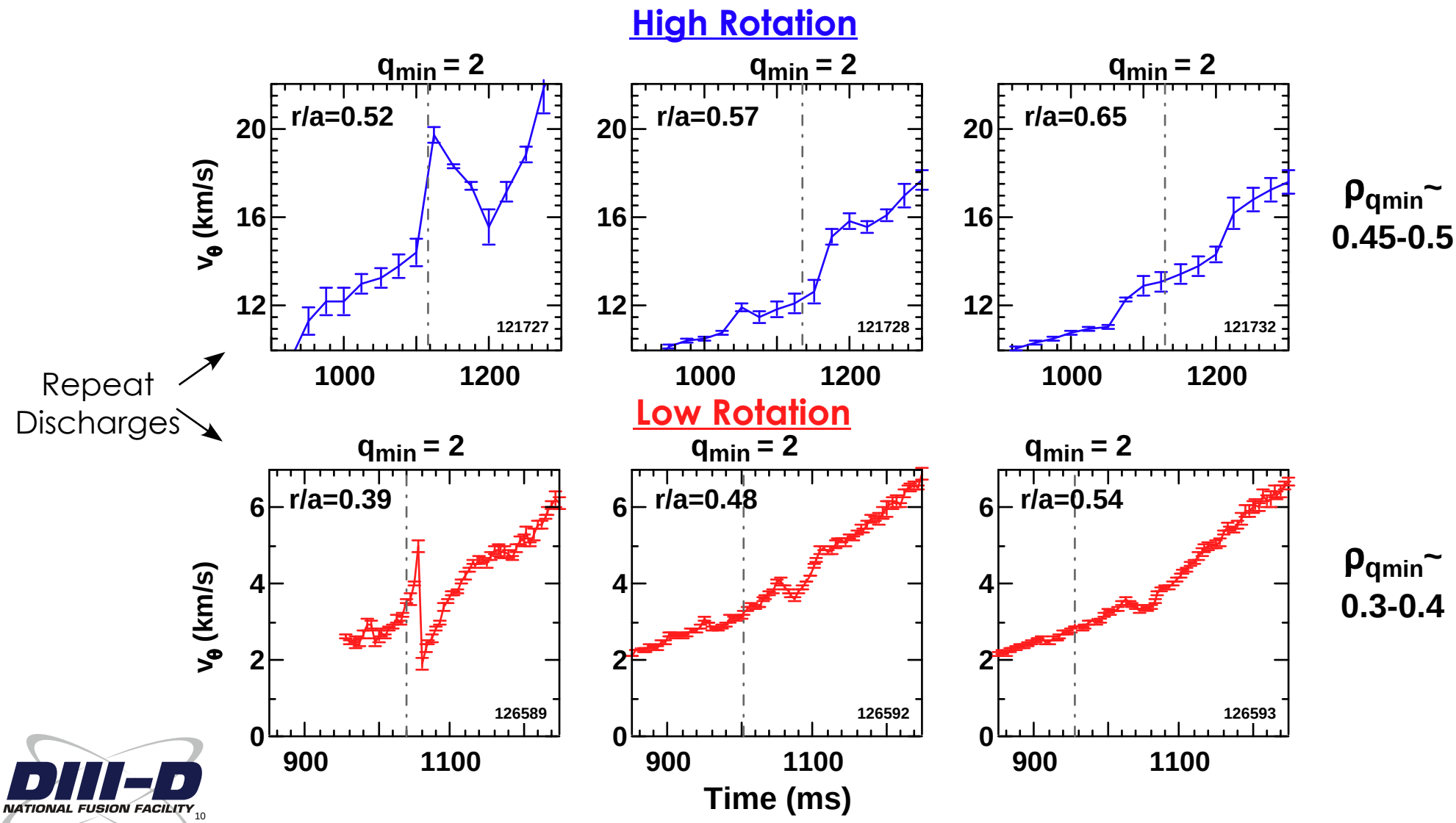
$$dv_\theta/dr < \tau_c^{-1}.$$

  - τ_c^{-1} ~ 70 kHz at high rotation, τ_c^{-1} ~ 100 kHz at low rotation.
- ***Low frequency Zonal-Flow-like structure.***



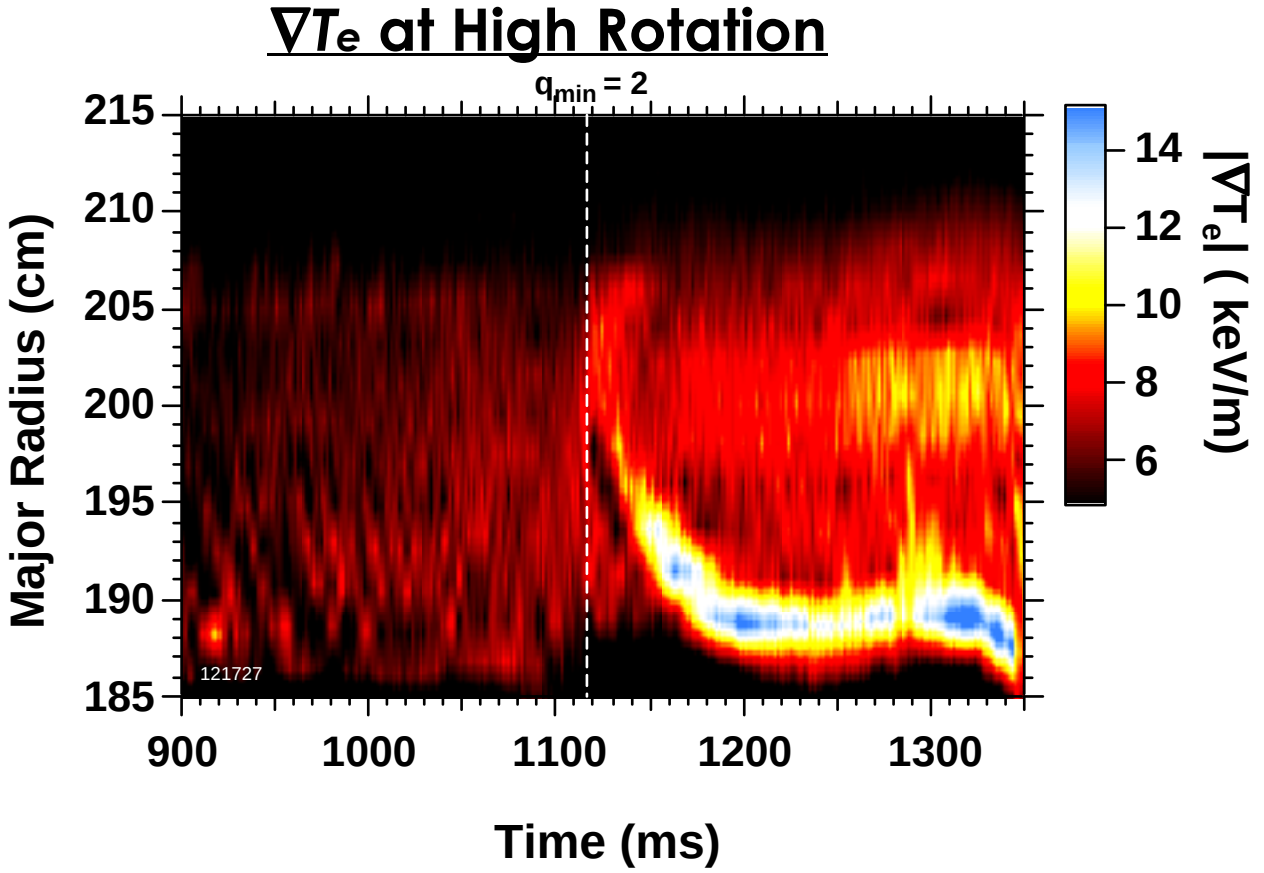
Localized v_θ Excursion Propagates Radially Outward

- **Propagation independent of toroidal rotation, ~1m/s.**
- **Weakens with increasing radius, i.e. magnetic shear.**



Velocity Excursion Follows q=2 Surface

- ∇T_e corrugations follow q=2 surface.
- v_θ excursion tracks/follows ∇T_e corrugation.



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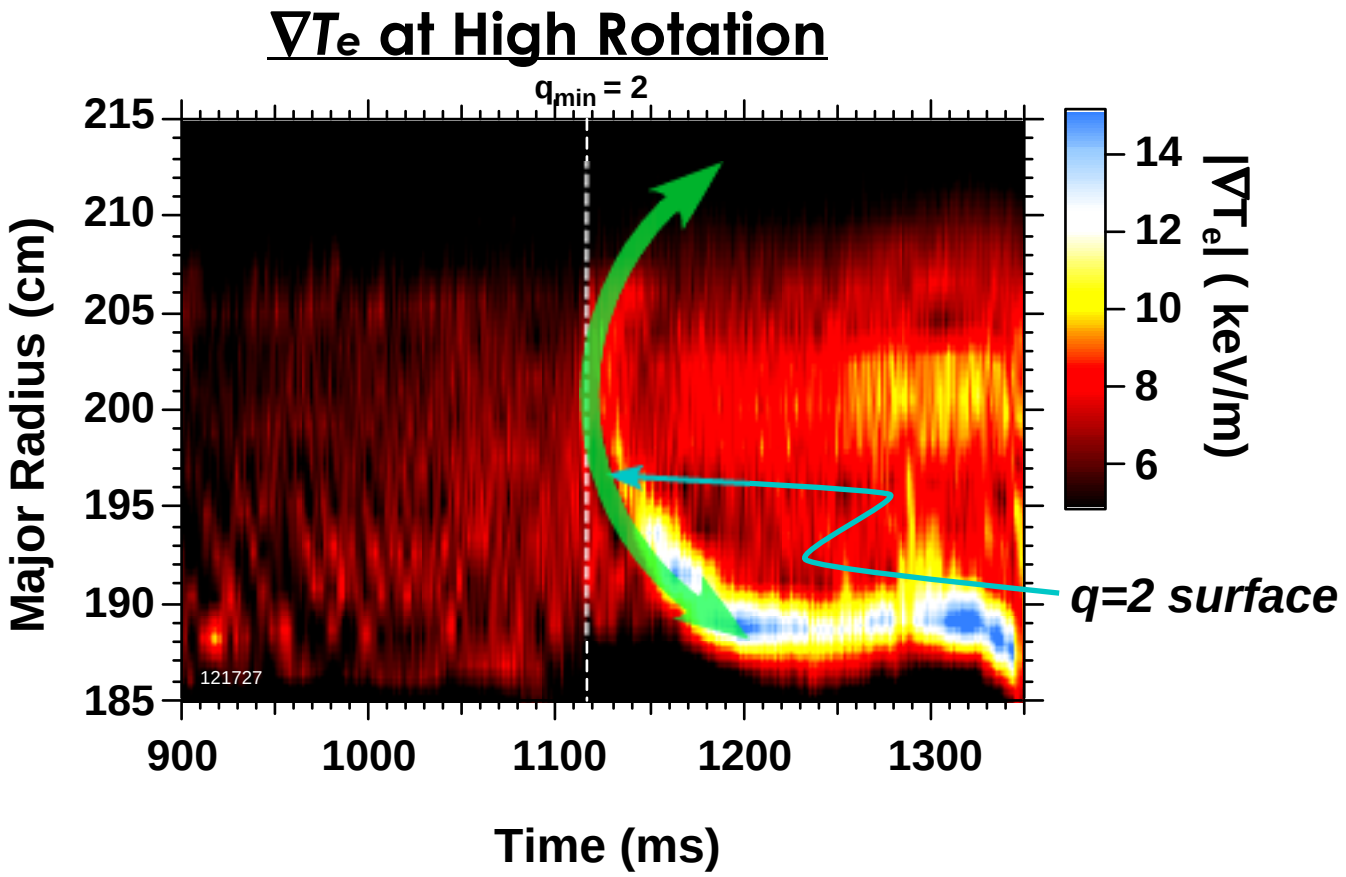

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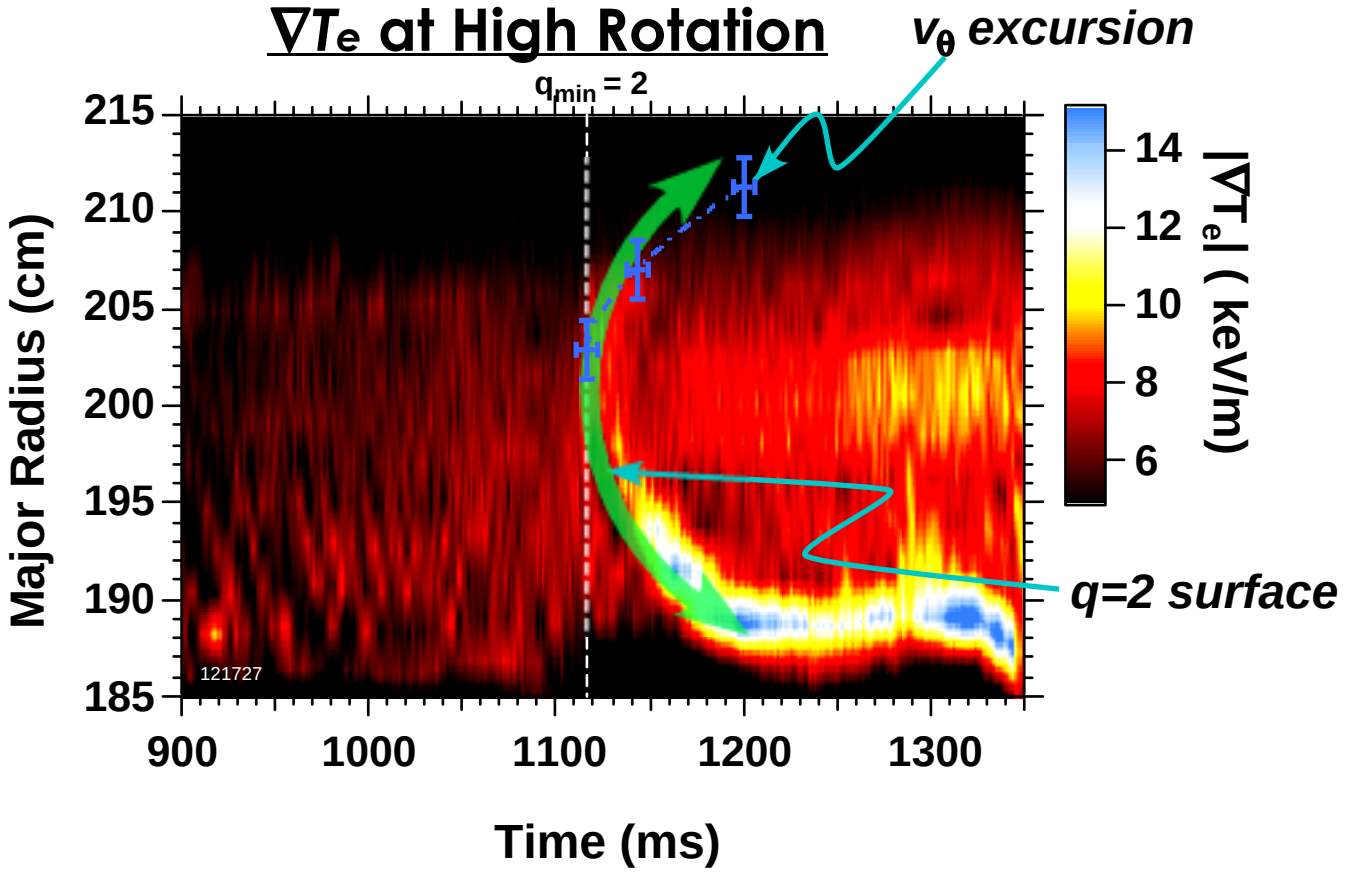
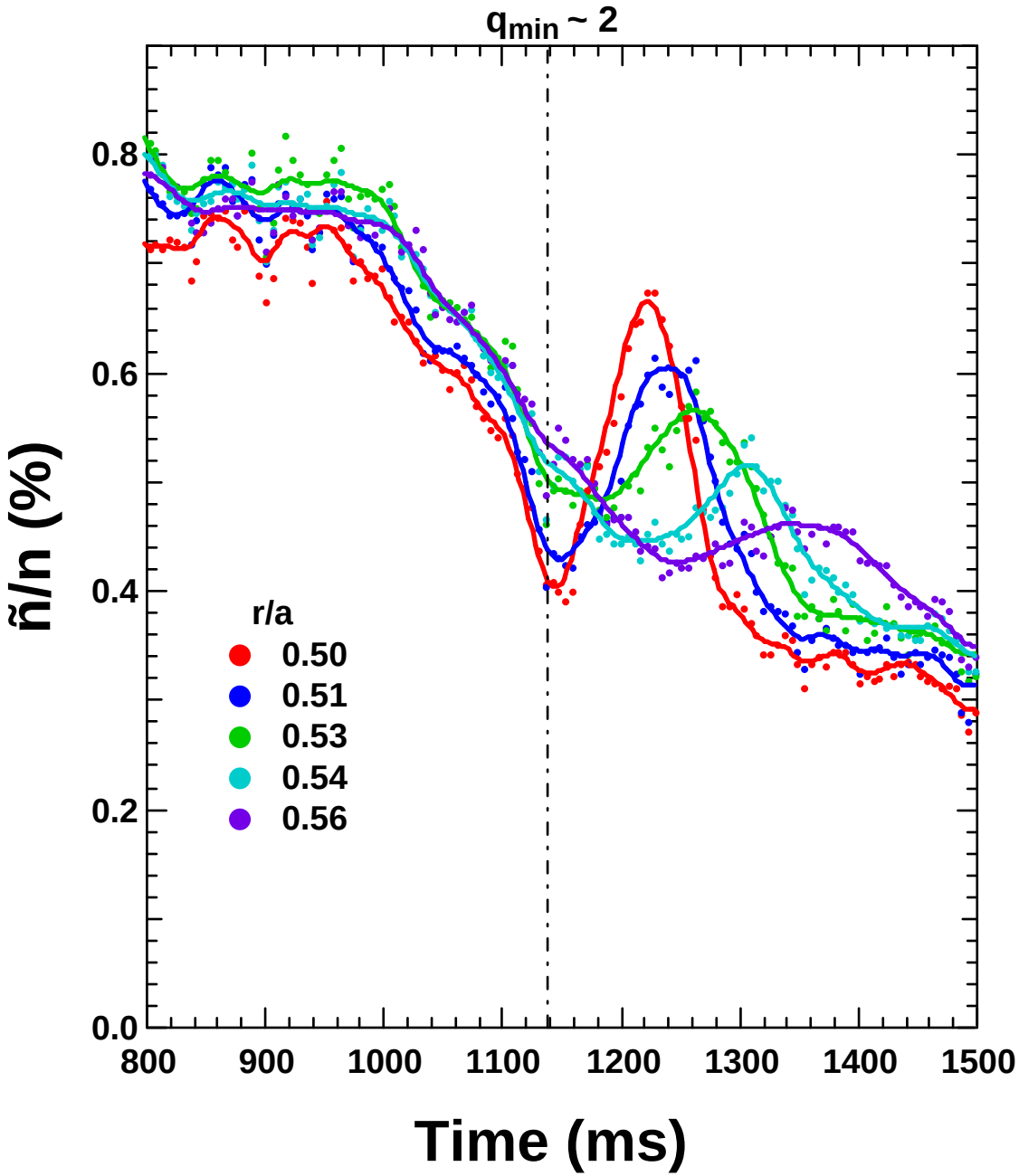


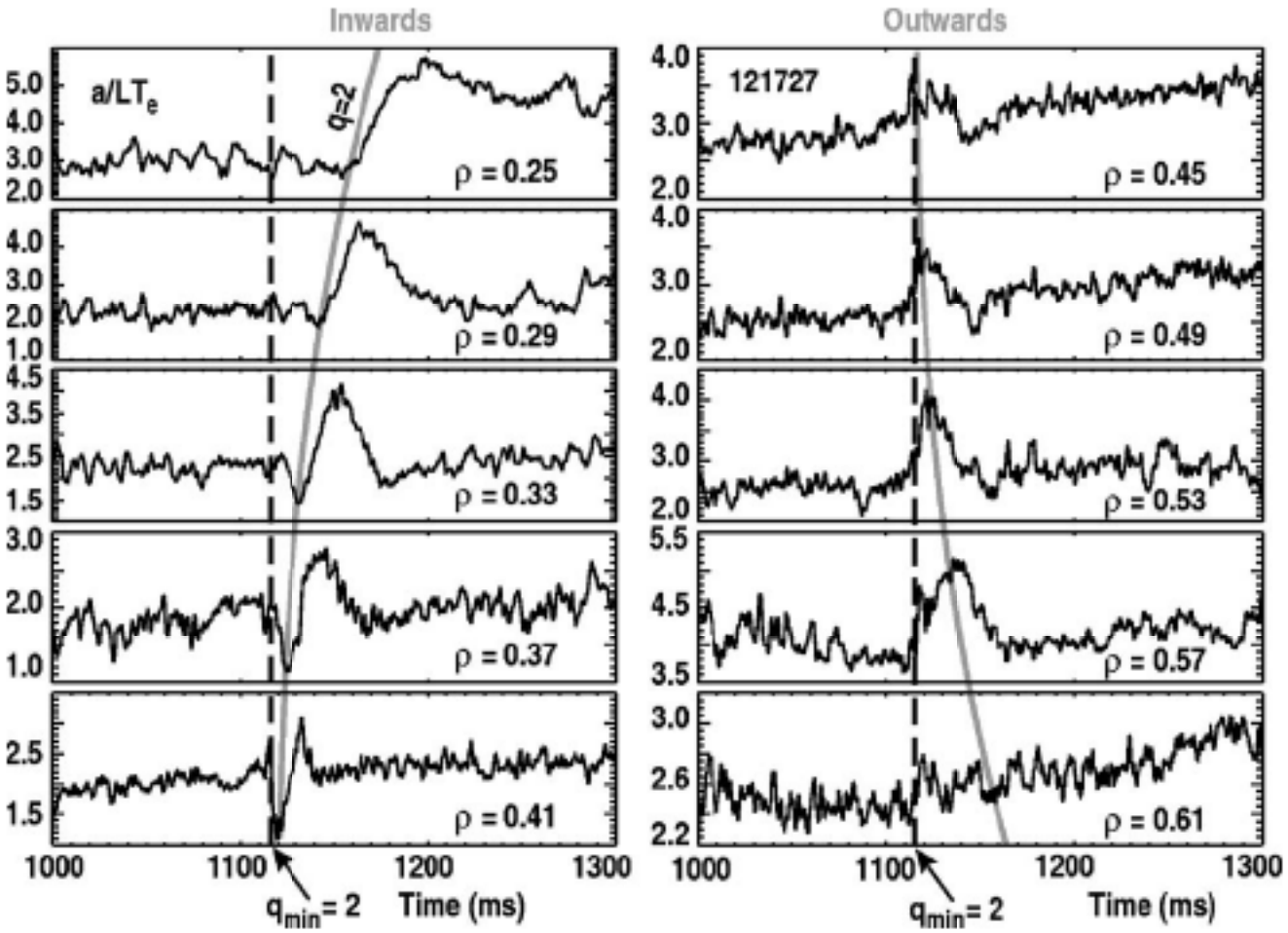
Summary and Conclusions

- **Spatio-temporal turbulence dynamics examined during NCS q_{min} events via localized BES fluctuation measurements.**
- **Transient turbulence suppression correlates with low-order rational q minima.**
- **Low frequency zonal-flow-like velocity shear develops immediately after q_{min} reaches 2.**
  - Weakens with increasing magnetic shear
- **Outward radial propagation observed, approximately tracking q=2 surface.**
- **Supports theories of shear flow tied to integer surfaces at low magnetic shear, i.e. zonal flows or convective cells.**

Turbulence Suppression Propagates Radially Outward



Te Gradient Corrugation Propagates with Integer Surface



M.E. Austin, et al., Phys. Plasmas **13**, 082502 (2006).

Sheared Flows Predicted Near Low-Order Rational Surface

- **GYRO simulations suggest zonal flows (m=0, n=0)**
  - Resonance of turbulence modes at surface.
  - Enhanced turbulence in at lowest-order surface.
  - Radial gradient drives zonal flows
  - R.E. Waltz, et. al. Phys. Plasmas, **13** 052301 (2006).*

- **Secondary Convective Cells theorized**
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GYRO Simulations*