Poloidal Rotation and Transport Barrier Formation in the Core of TFTR Plasmas

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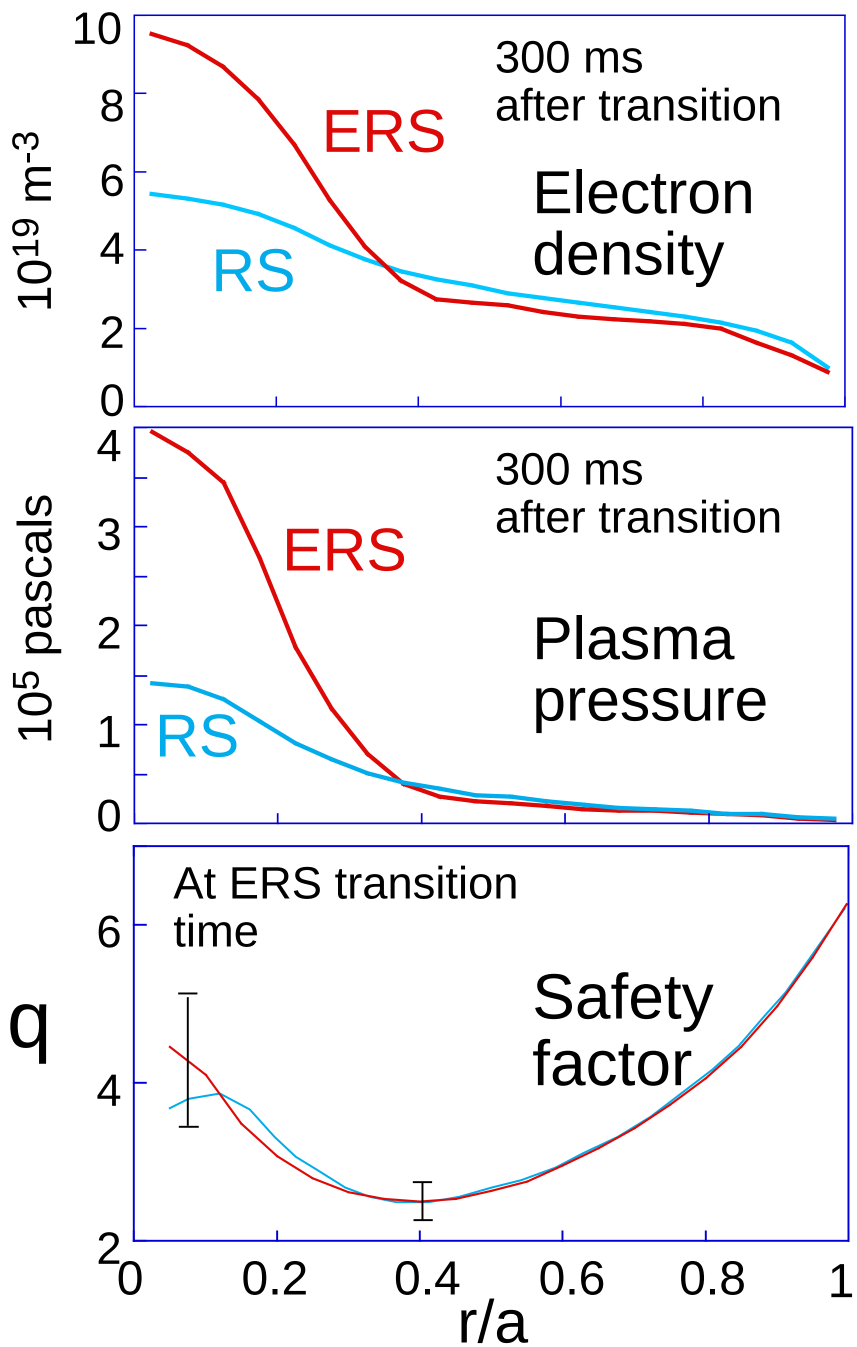
Outline

- Background
- Precursor to ERS transition
- New measurements of $v_\theta(r)$, inversion to provide local values
- E_r measurements
- Shearing rates and transition threshold
- Comparison to Neoclassical predictions
- MHD bursts associated with precursor

Transport Barrier Forms in Plasma Core, Near Minimum in q Profile

TFTR



- Both particle and energy confinement improve inside shear reversal region
- Shear reversal not sufficient for transition

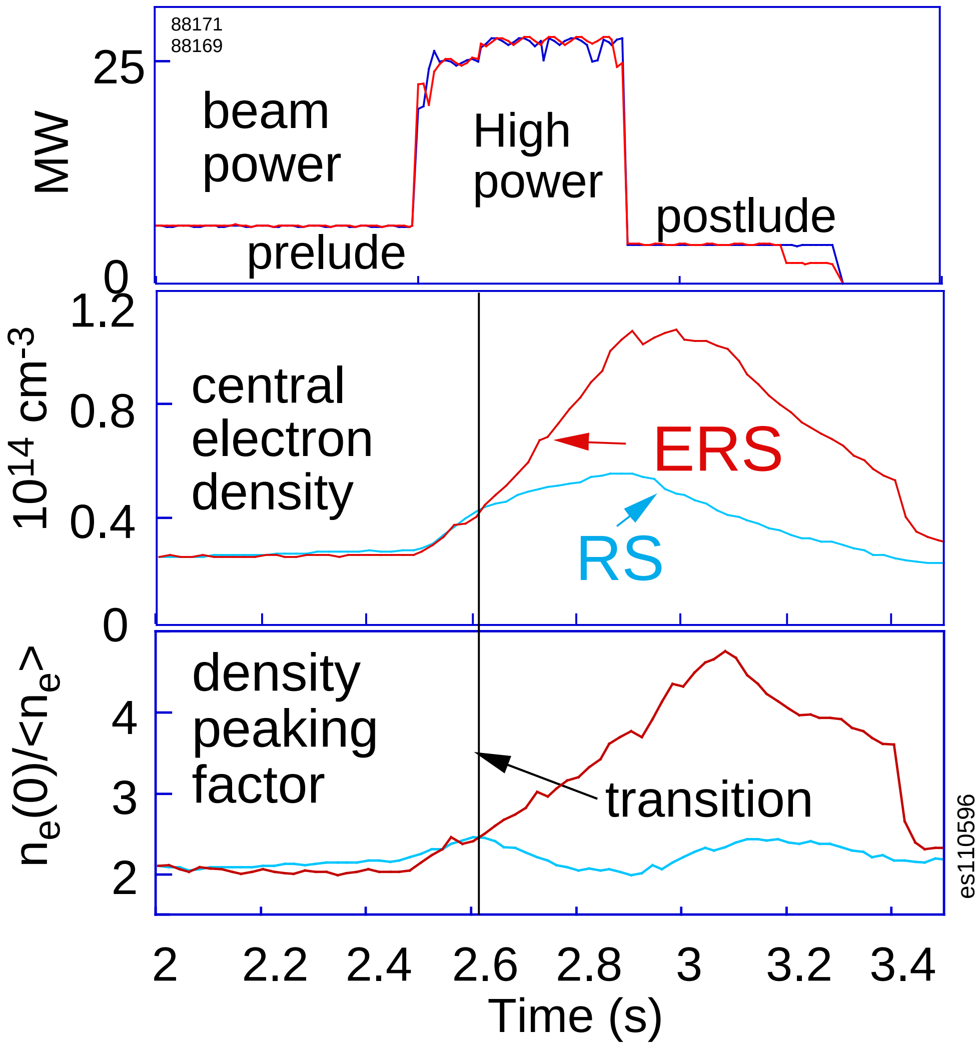
- Model of E×B shear stabilization is fundamental to our present understanding of transport barriers at the plasma edge and in the core.

- Transport barrier formation linked to E_r and a reduction in turbulence due to E×B shear.

- At the H-mode edge, E_r associated with impurity v_θ at time of transition.

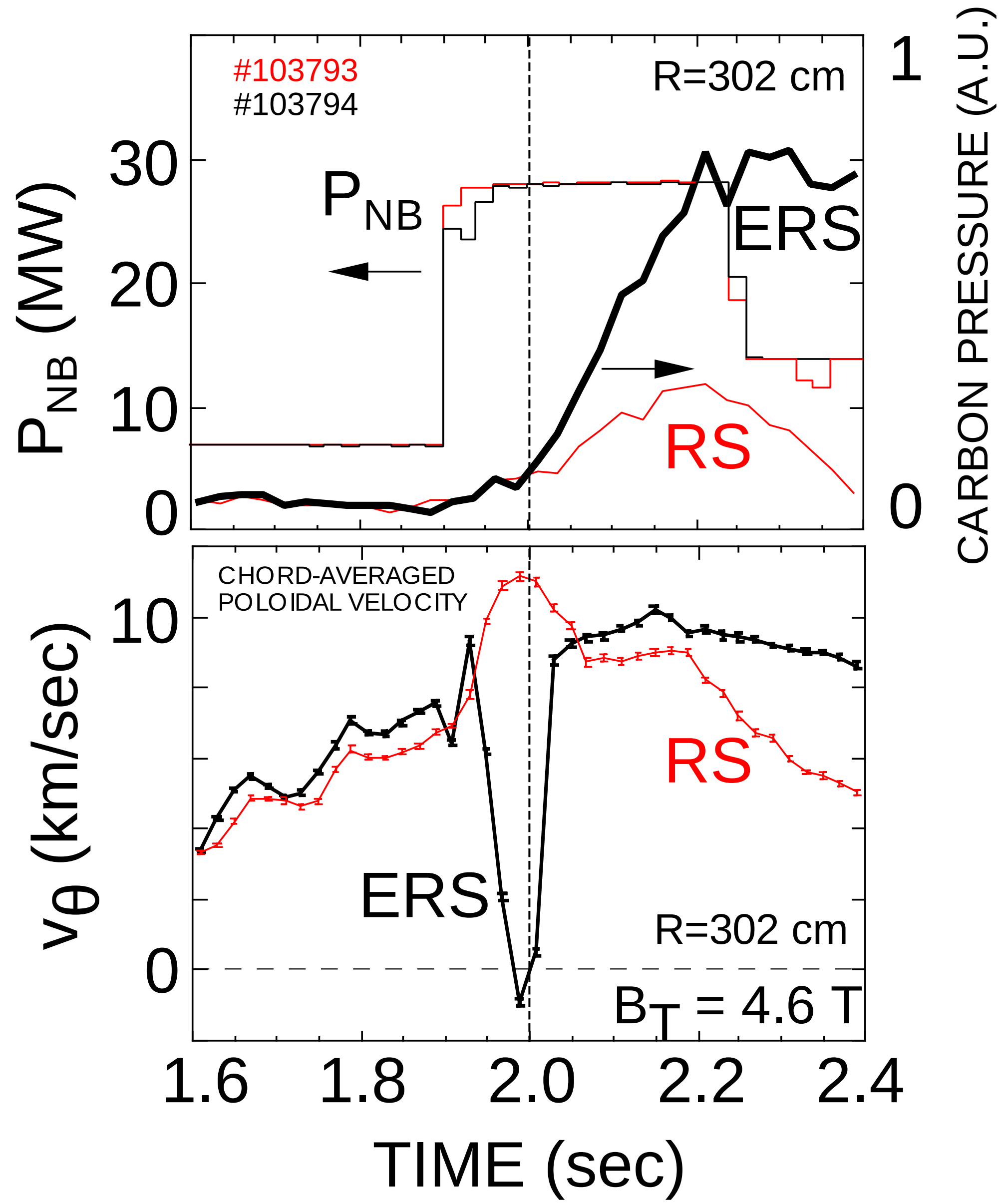
- Recent measurements on TFTR point to the importance of v_θ in core barrier formation in reversed shear plasmas.

The Physics Of Bifurcations Is Central To Understanding TFTR ERS plasmas



- Before transition, n_e, T_e, T_i, V_φ, n_z profiles are indistinguishable
- Key physics must be nonlinear

Bifurcation In Poloidal Velocity Precedes ERS Transition



- Local carbon pressure give earliest indication of the bifurcation in transport, change in $n_e(0)$ ≈50 ms later.

- 50-100 ms before transition, a local change in carbon poloidal rotation is observed for ERS discharge.

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Shearing Rate:

$$\omega_{E\times B} = \frac{(RB_\theta)^2}{B}\frac{\partial}{\partial\psi}\left(\frac{E_r}{RB_\theta}\right)$$

For the outer midplane,

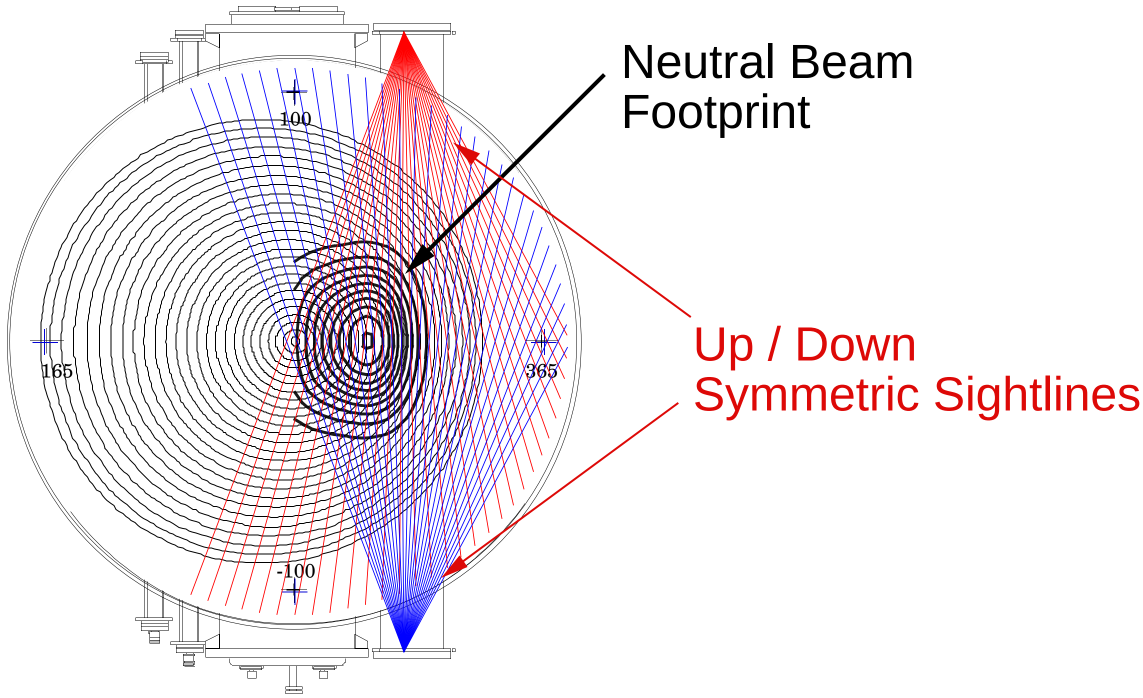
$$\omega_{E\times B} = \frac{E_r}{B}\left(\frac{1}{E_r}\frac{\partial E_r}{\partial R} - \frac{1}{B_\theta}\frac{\partial B_\theta}{\partial R} - \frac{1}{R}\right)$$

Radial Force Balance Equation:

$$E_r = \frac{p}{eZn} + v_\varphi B_\theta - v_\theta B_\varphi$$

- E_r can be affected through each of these terms.
- Evaluation of E_r has typically been to sum terms on right side of equation.
- Core v_θ usually evaluated from neoclassical theory

TFTR Poloidal Rotation Diagnostic Addresses Problems of Core v_θ Measurements



- High Throughput
  - throughput > 2000 × CHERS system
  - Linefits to 1-2 % of pixel width
  - Uses intrinsic and CX emission
- High Spatial Resolution
  - 29 spatial channels (ΔR < 3.5 cm)
- Inversion
  - Recovers local velocity
  - Bell, Rev. Sci. Instrum. **68**,1273 (1997)
- Opposing Views
  - Removes systematic effects
  - Cancels view dependent effects of Charge Exchange Emission
- Strictly Vertical Orientation
  - No toroidal velocity component

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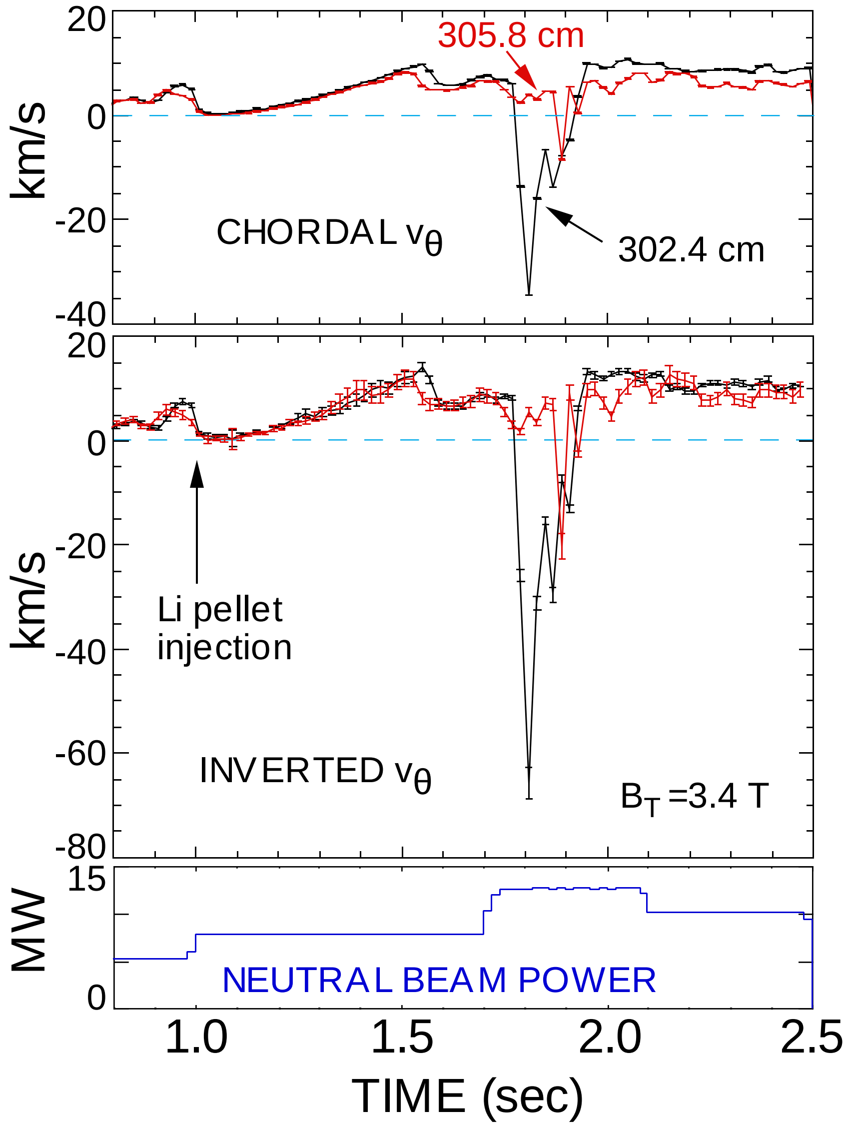
Larger Poloidal Velocity Precursors Often Seen With Lower Toroidal Field



- Poloidal velocity peaks then relaxes with several oscillations
- Transient excursion in poloidal velocity appears on 1 or 2 sightlines only
- Velocity is zero after pellet injection

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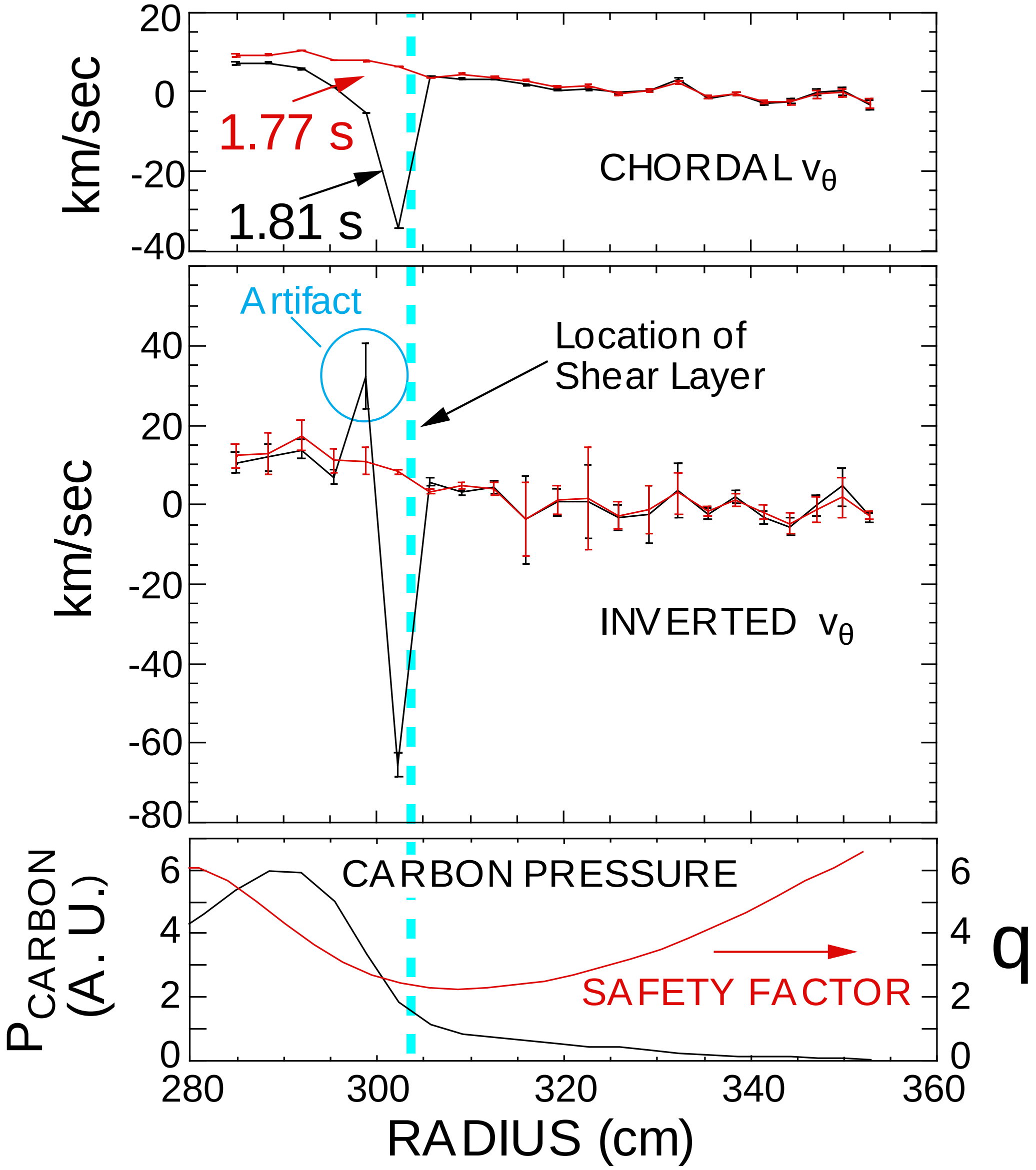
A Narrow Large Poloidal Velocity Shear Layer Located Just Inside q_{min}



- Inversion deepens and narrows apparent shear region
- "Artifact" due to misalignment of shear layer from sightlines
- Shear layer narrower than sightline spacing (3.5 cm)
- Chordal data limits $(\Delta v_\theta)(\Delta r) \approx 220$ km/s - cm
- Location of velocity shear layer, between pressure gradients and low magnetic shear: Reynold's Stress?

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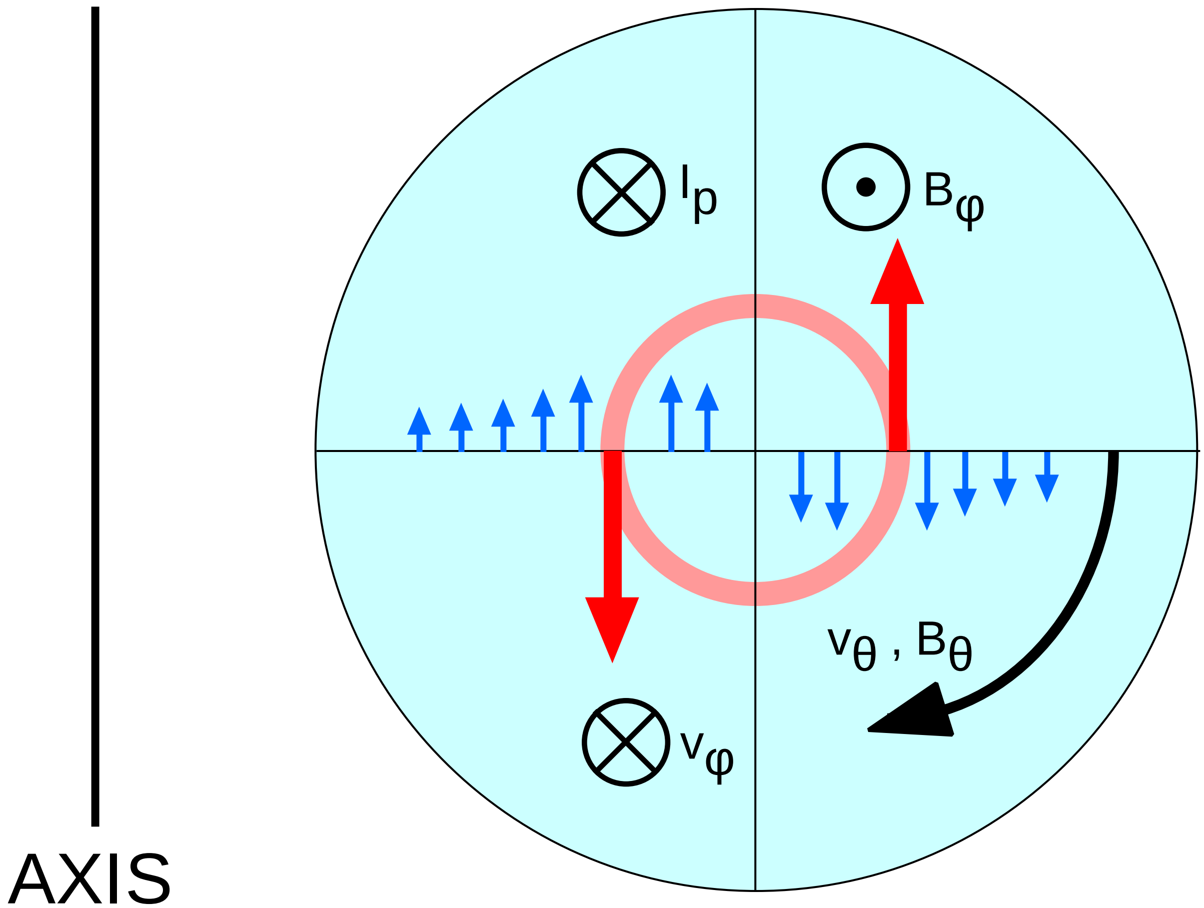
Schematic of Poloidal Rotation in TFTR Reverse Shear plasmas



- Carbon ions generally rotating in the ion diamagnetic direction
- *Transiently*, carbon poloidal flow reverses direction in narrow radial region
- Deuterium ion flow not measured

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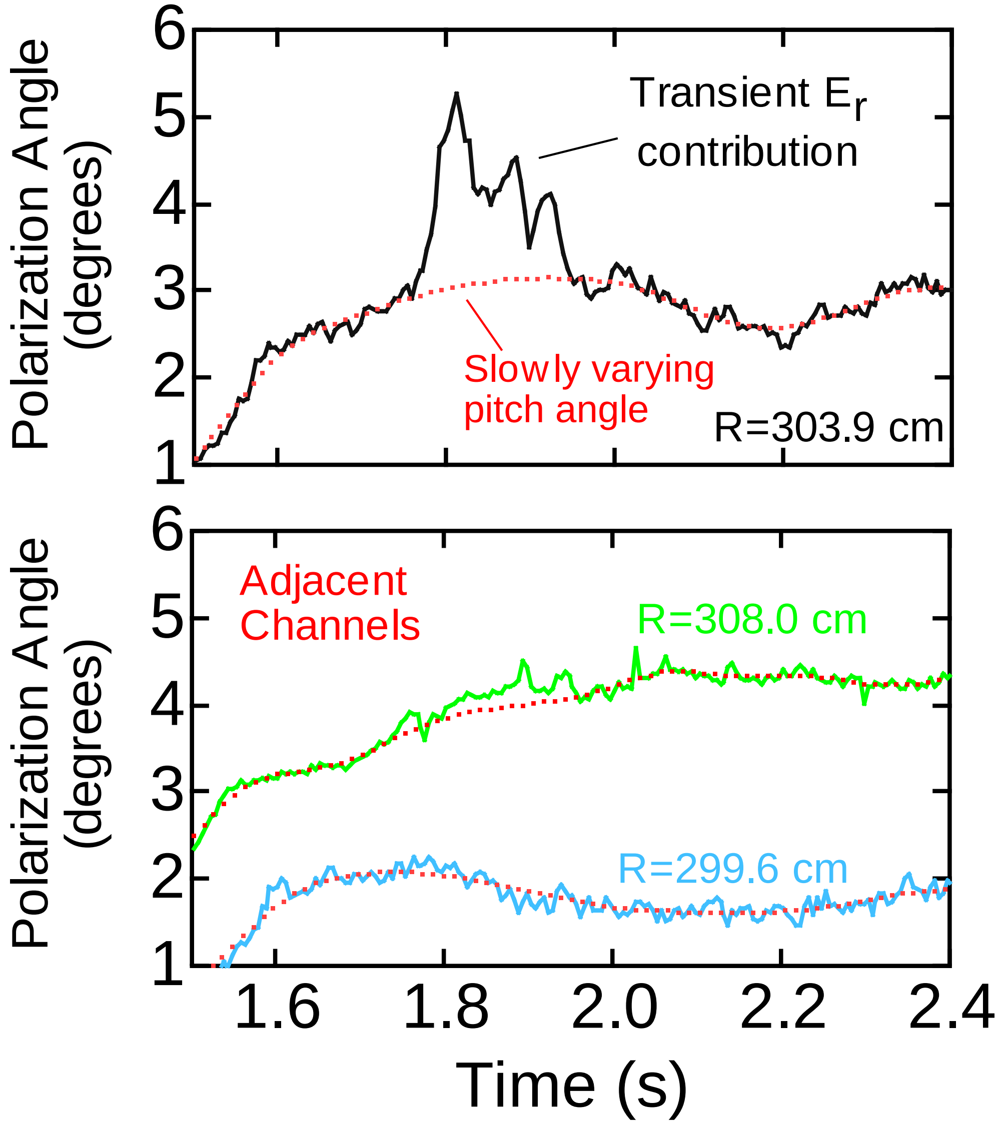
Large E_r Transient Appears on MSE Measurements



- E_r transient easily separated from slowly varying pitch angle
- Adjacent MSE channels detect little or no contribution from transient.

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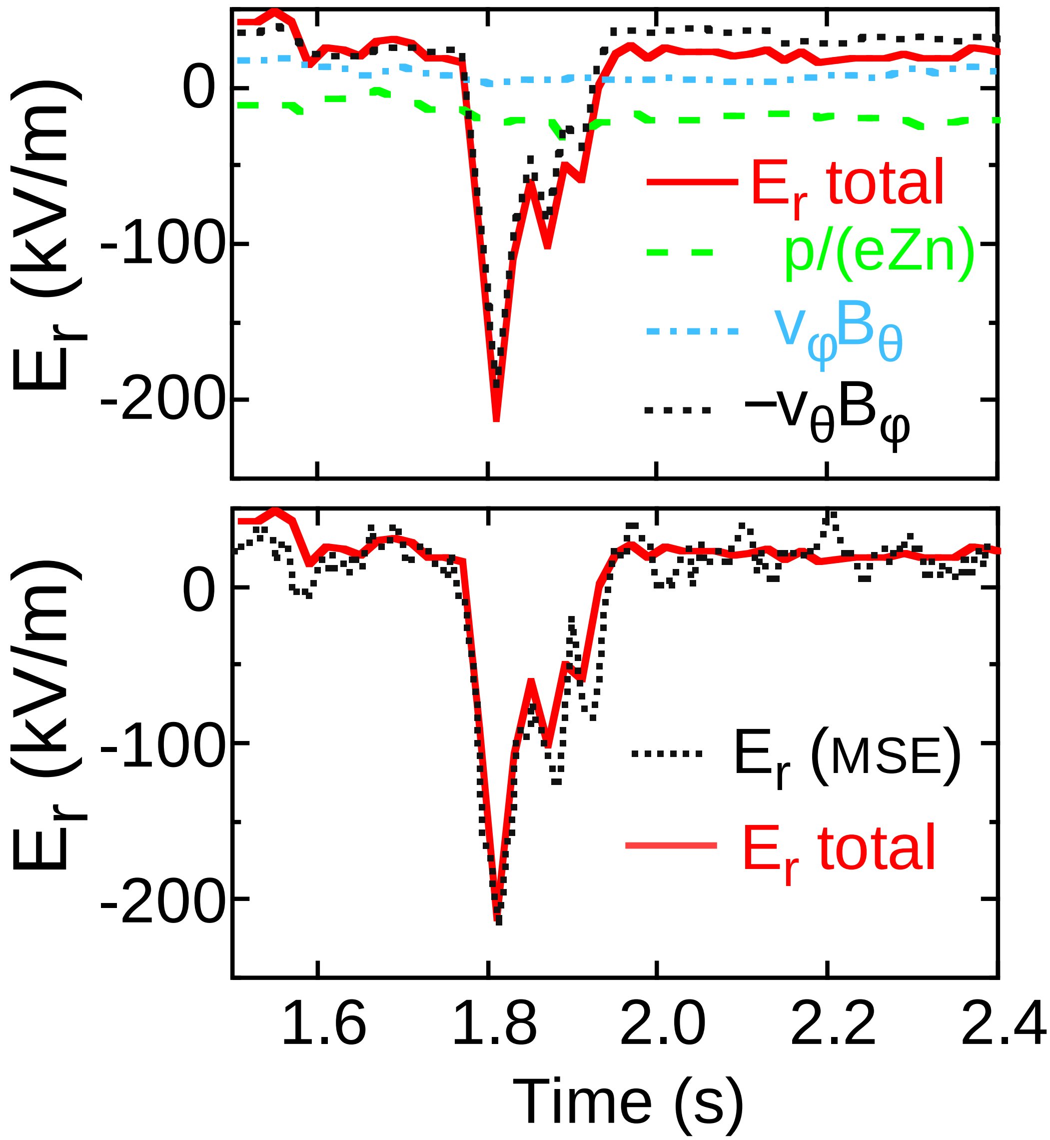
All Terms In Radial Force Balance Equation Measured

$$E_r = \nabla p/(eZn) + v_\varphi B_\theta - v_\theta B_\varphi$$



- E_r measurements agree,
  (averaged over ≈ 3.5 cm)

- E_r transient = poloidal flow

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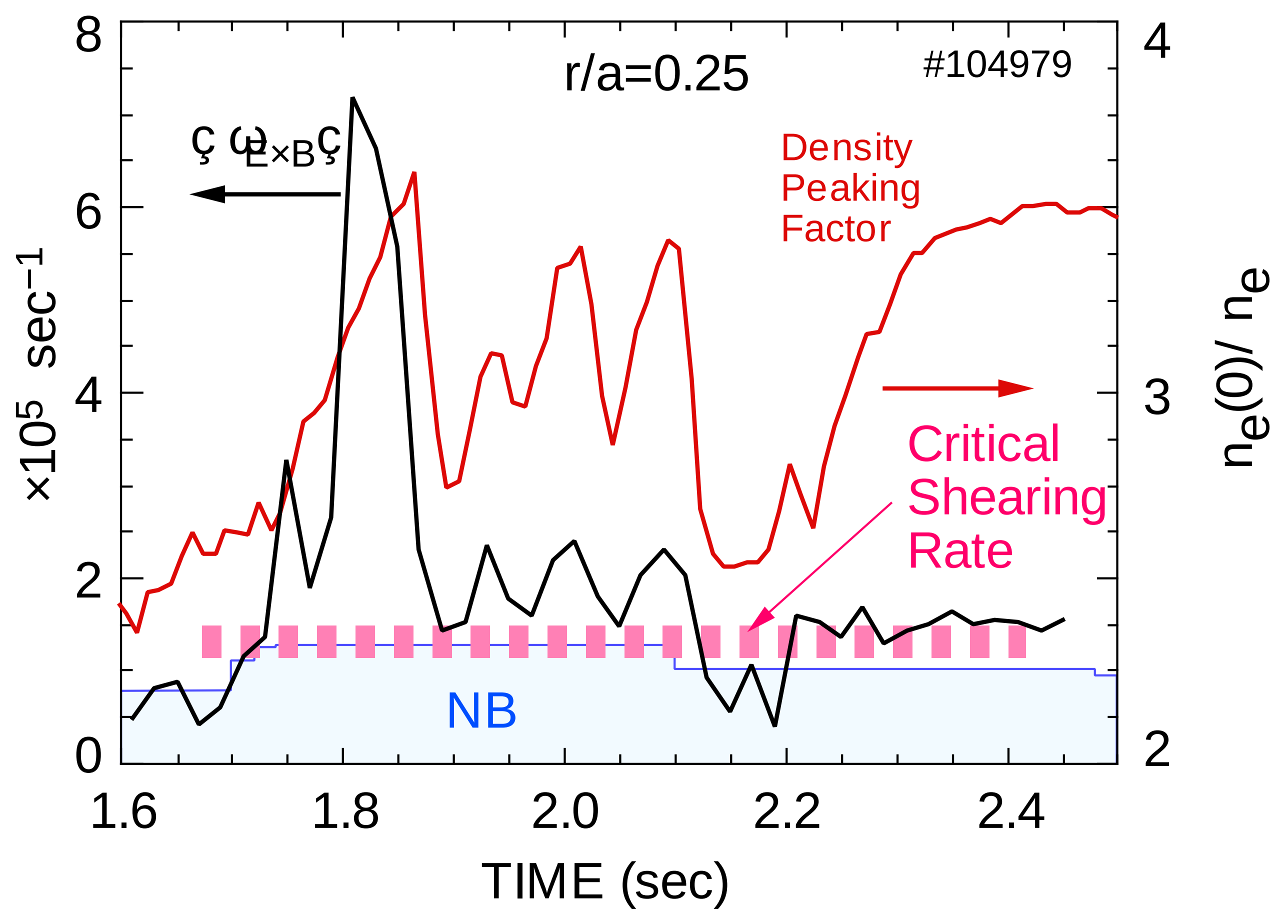
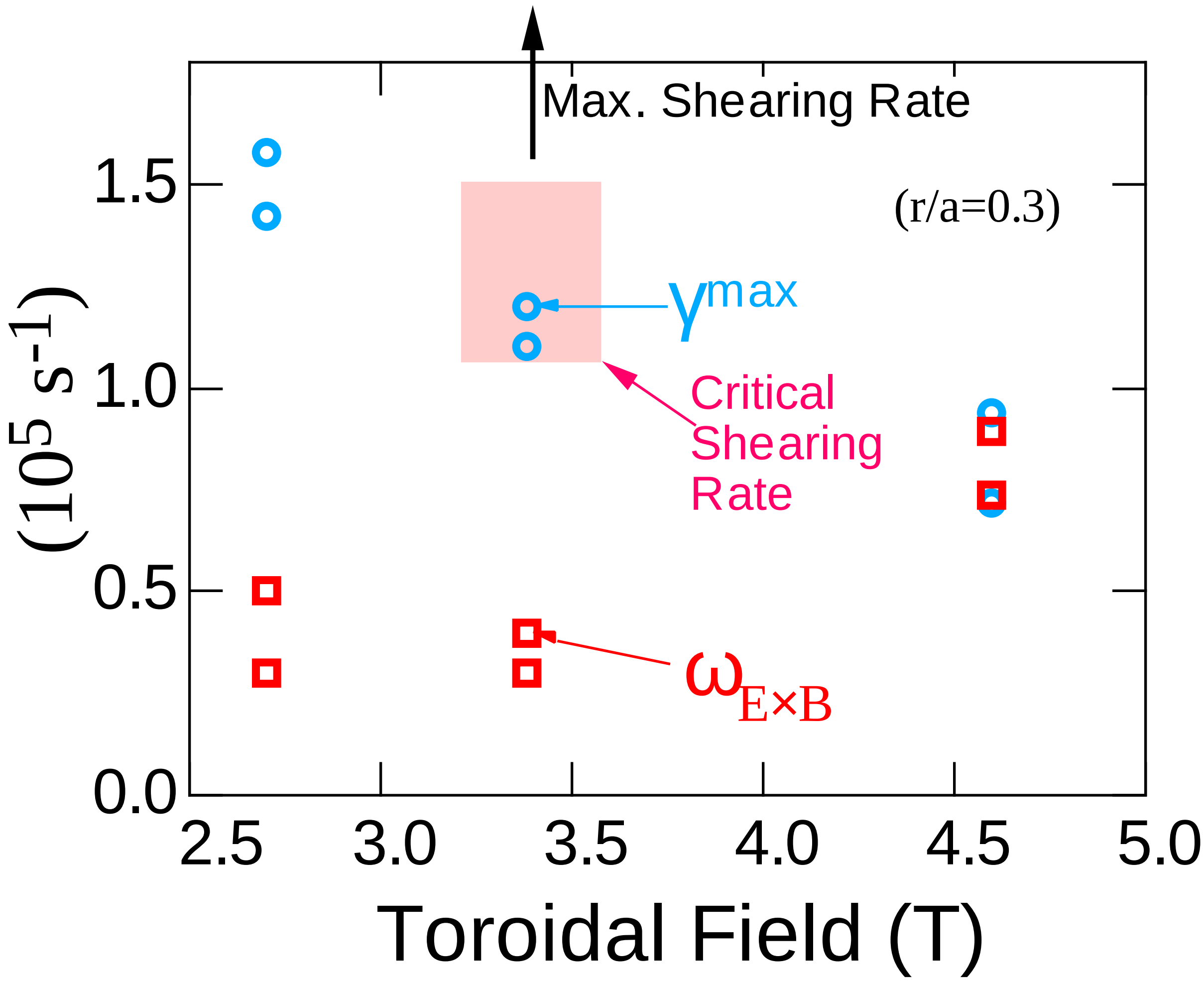
"Dithering" ERS Correlates Shearing Rate With Core Barrier Formation



- Peakedness factor show times of improved confinement
- Marginal conditions for transition indicate nominal transition threshold value for shearing rate
- Precursor spike many times larger than threshold for transition

B_T Variation of Transition Threshold Needs Reevaluation



- Measured threshold $\omega_{E\times B}$ for dithering discharge at 3.4 T near γ^{max} in B_T scan

- With large E_r transients, $\omega_{E\times B} \gg \gamma^{max}$

- Previous threshold for transition was evaluated with neoclassical v_θ

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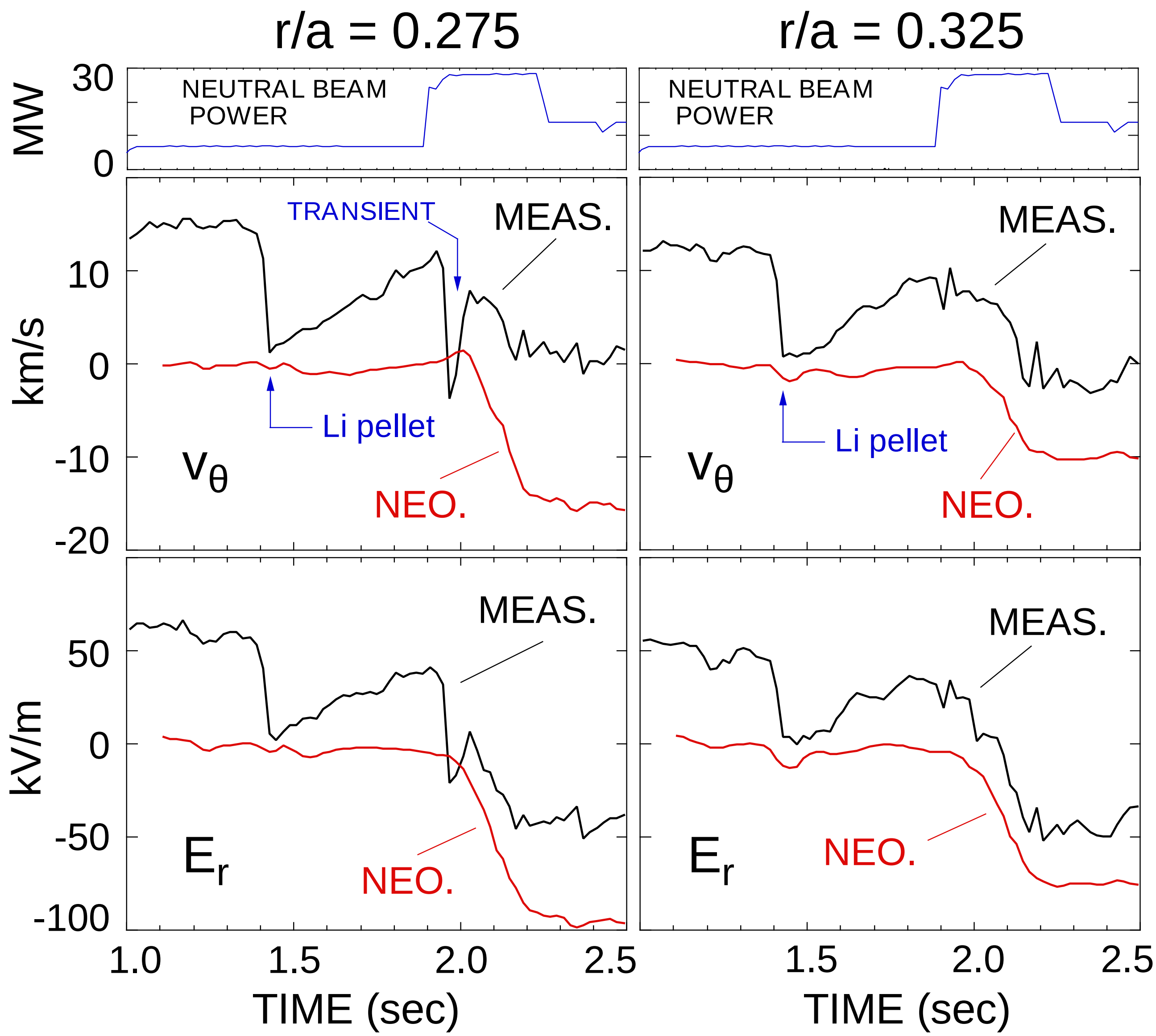
Carbon v_θ, E_r
Offset from Neoclassical Values



- Neoclassical v_θ is near zero prior to ERS transition
- Measured v_θ is zero after pellet injection, then increases
- After transition both neoclassical and measured v_θ decrease with increasing pressure
- Nearly constant difference is maintained during ERS; larger difference at smaller radii

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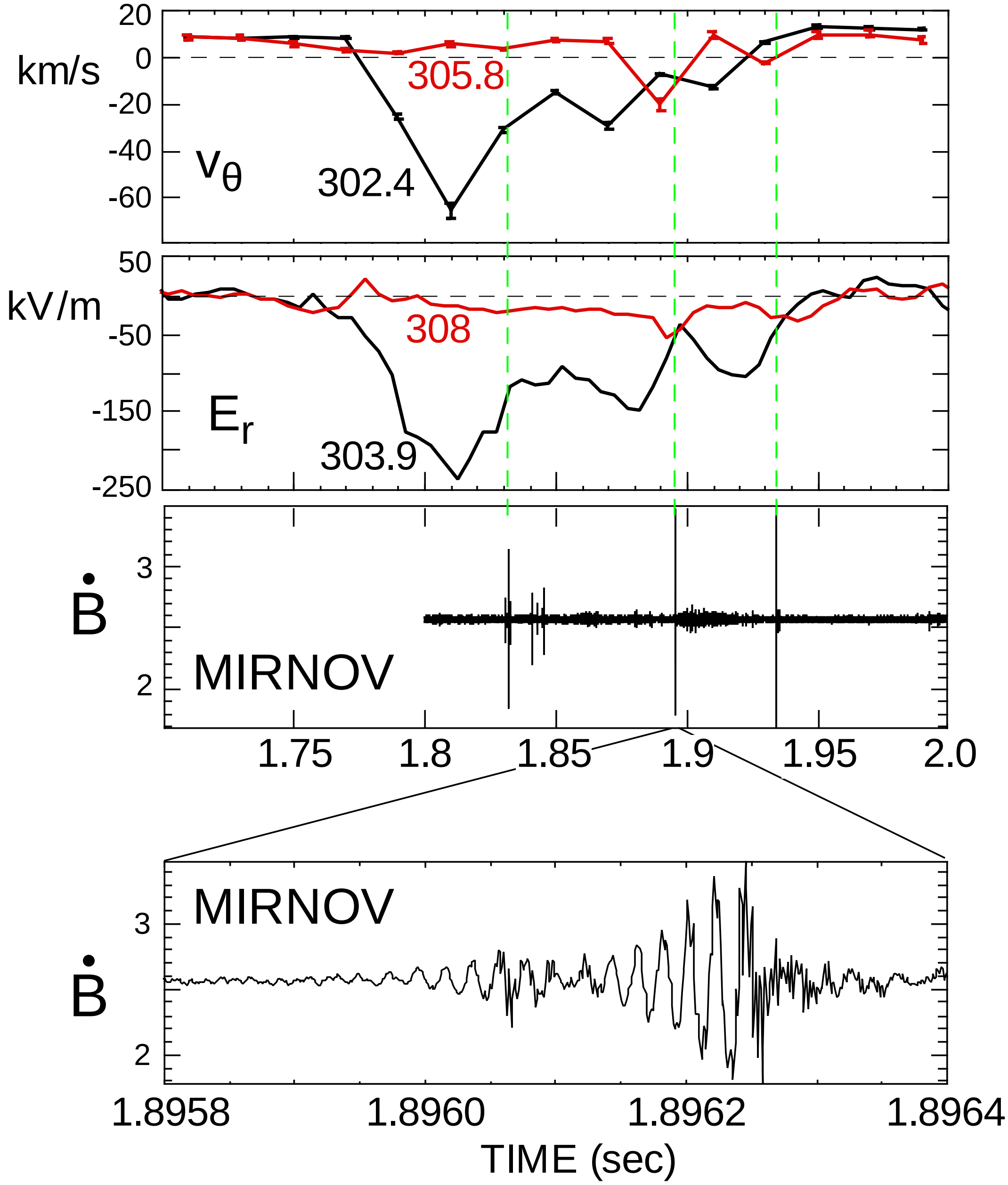
MHD Bursts Occur During Relaxation of E_r/v_θ Excursion



- ECE measures fluctuation at shear layer
- Timing of MHD Burst: Drop in E_r of inner channel with increase in outer channel => during motion of shear layer?

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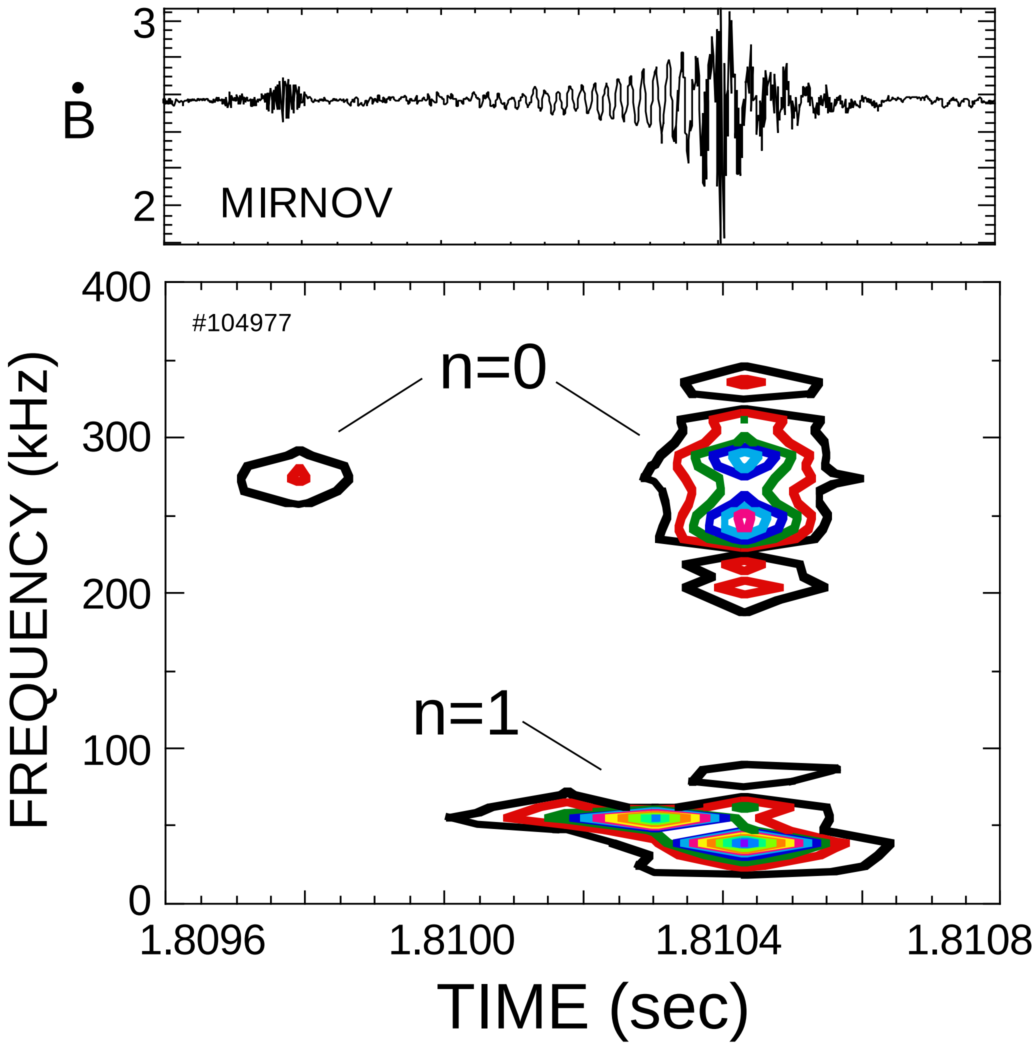
MHD Bursts Occur in Two Frequency Ranges



- Low frequency (≈50 kHz) mode observed by ECE to occur at the poloidal velocity shear layer
- Low frequency mode has toroidal mode number n=1
- Best fit to high frequency mode (≈ 250 kHz) is n=0
- Low frequency mode usually occurs first
- High frequency mode sometimes appears alone

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Summary

- New local v_θ measurements in core plasma
- E_r, v_θ precursor to ERS transition
- Important to measure all quantities in radial force balance equation
- High spatial resolution important, local measurement could "miss" narrow shear region
- For precursor $\omega_{E\times B}$ >> critical shearing rate
- Measured carbon v_θ differs from neoclassical v_θ
- MHD bursts near shear layer
  - 50 kHz, n=1
  - 250 kHz, n=0

CHALLENGES/ PUZZLES:

- What is the cause of the transient poloidal flow? How is the poloidal viscosity overcome?
- What is the source of the discrepancy with neoclassical carbon v_θ?
- What are the MHD modes during v_θ excursion? Clue to understanding dynamics of precursor.

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