Barrier dynamics studies in different experimental configurations and implications for advanced tokamak research

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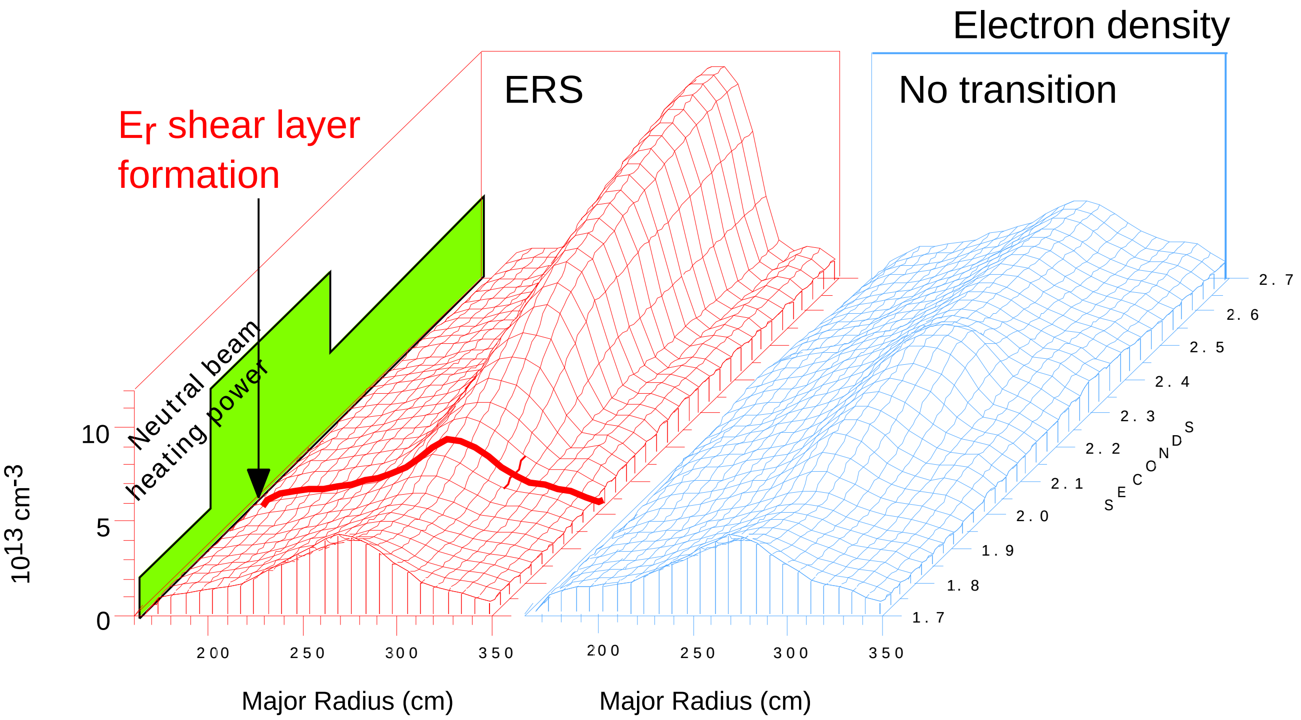
Three points:

1. In AT modes, particle confinement is in danger of being *intolerably good,* demanding control tools
   - helium ash? other impurities?

2. How experiment generates E×B shear has a profound influence on barrier dynamics
   - barrier control is possible
   - need to ensure experiment is best aimed at AT goal

3. Models with E×B shear reproduce many of the dynamics
   - fluctuations character, transition time scales

Dramatically reduced particle and energy transport in core follows narrow E_r shear layer formation



- Particle transport improves with energy transport

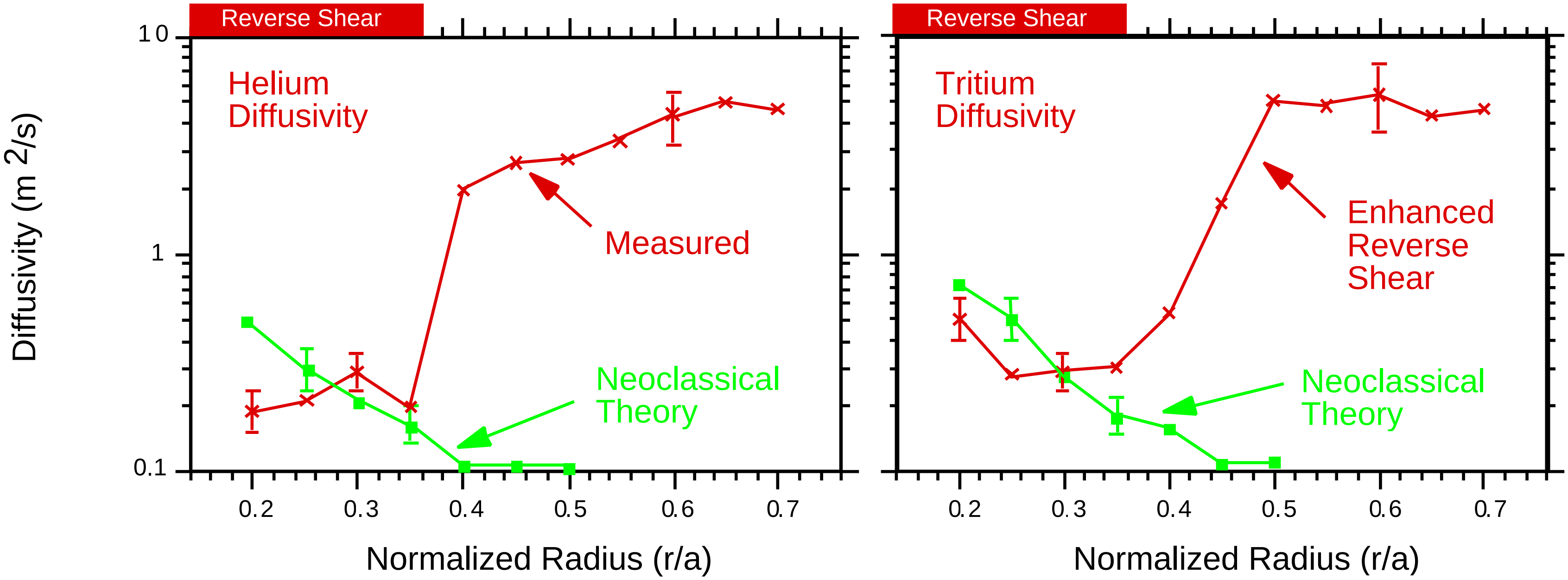
  may need barrier control to exhaust impurities

- Trigger event is E_r shear layer formation about 2 cm wide

  small scale events unrelated to device size can fundamentally alter core confinement

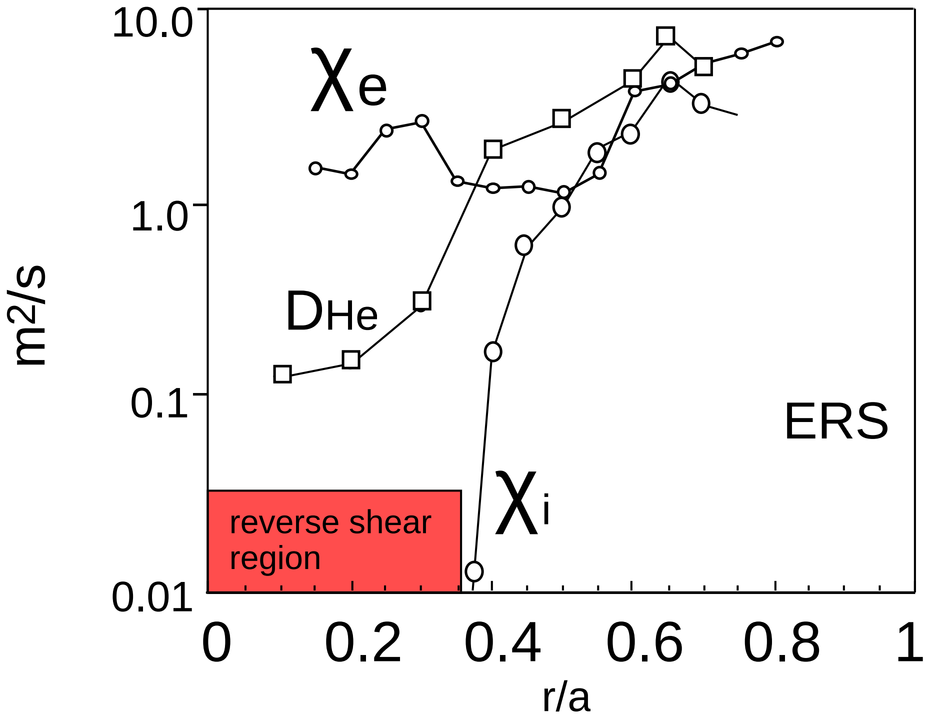
In ERS Core, Helium & Tritium Diffusivities are Similar and Agree with Neoclassical Theory

TFTR



- Neoclassical helium & tritium diffusivity calculated by NCLASS using measured profiles

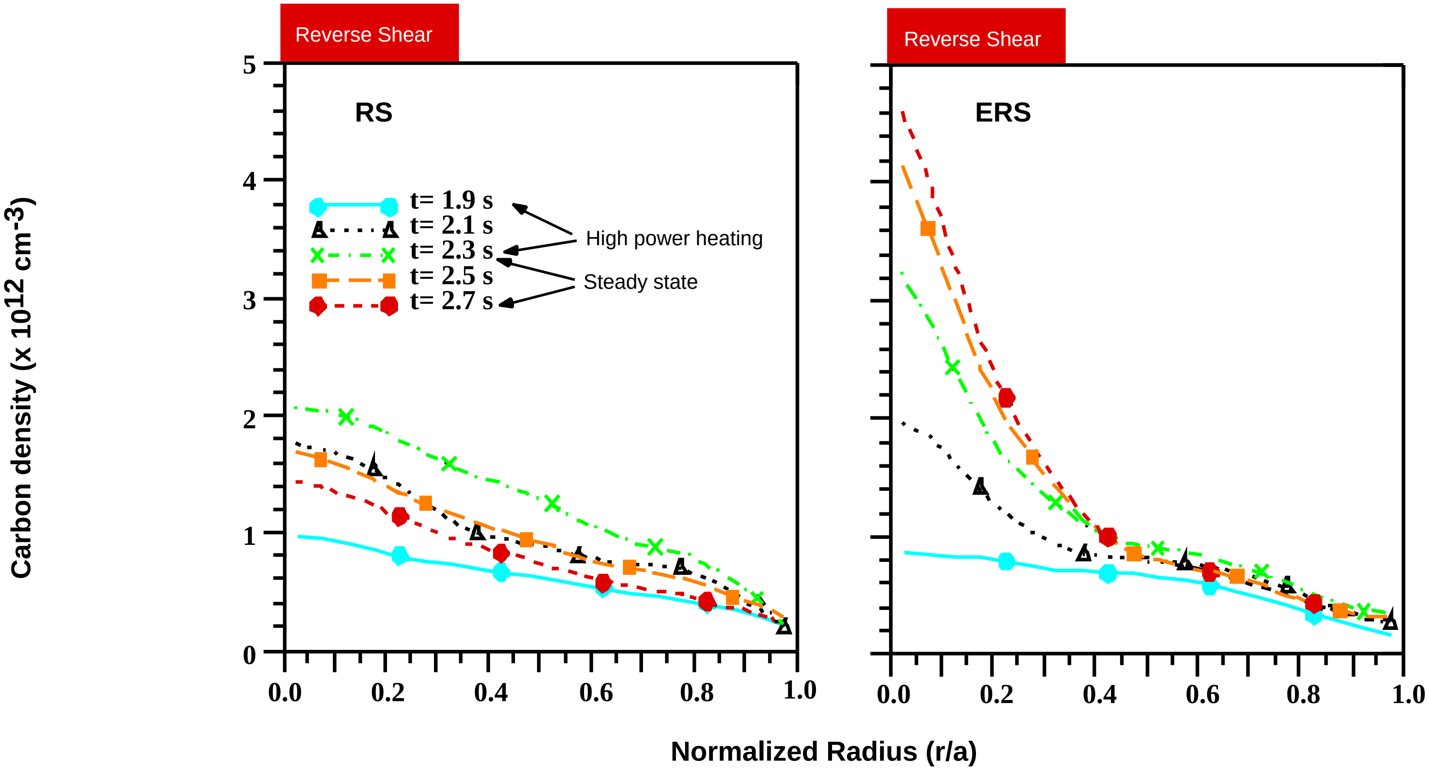
Assessing the helium ash problem requires understanding the observed behavior of different transport channels



- On TFTR, D_{He} ~ χ_{fluid}, which would to be acceptable for ash removal - BUT
- This may be an accident of having a very low χ_i and high χ_e

ERS Carbon Profile Peaks Due to Inward Pinch within Reverse Shear Region

TFTR



- ERS carbon profile continues to peak along with Ne after reduction in carbon source.
- RS carbon density decreases at all radii after reduction in carbon source.

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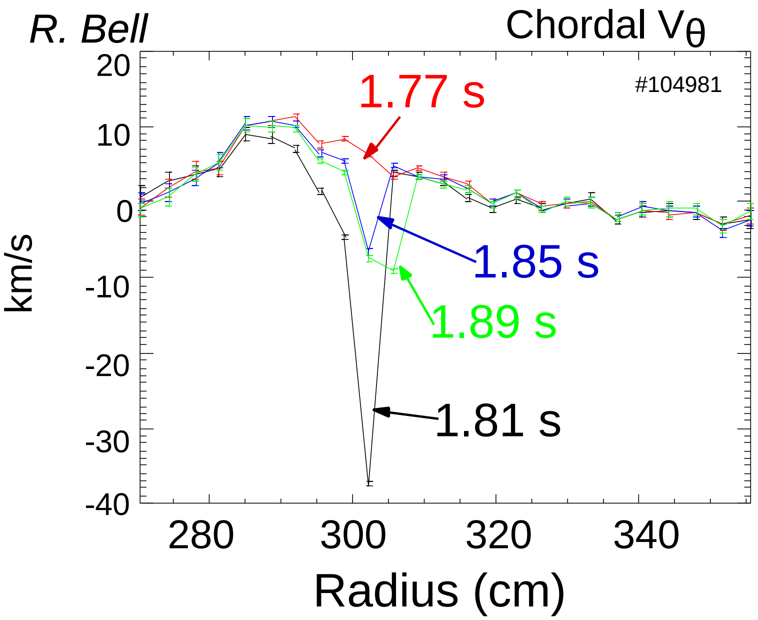
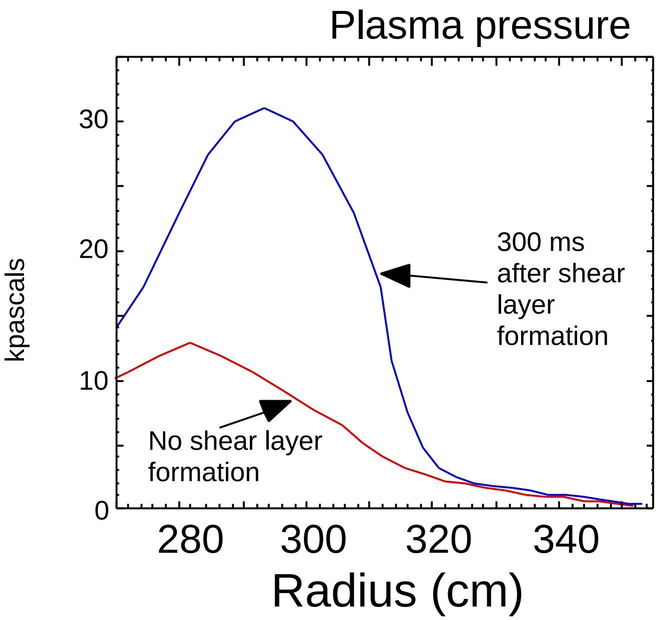
E_r shear layer formation on a small scale can have large-scale consequences





- shear layer narrower than chordal profile suggests
- plasma will respond to manipulation of E_r shear on a small scale

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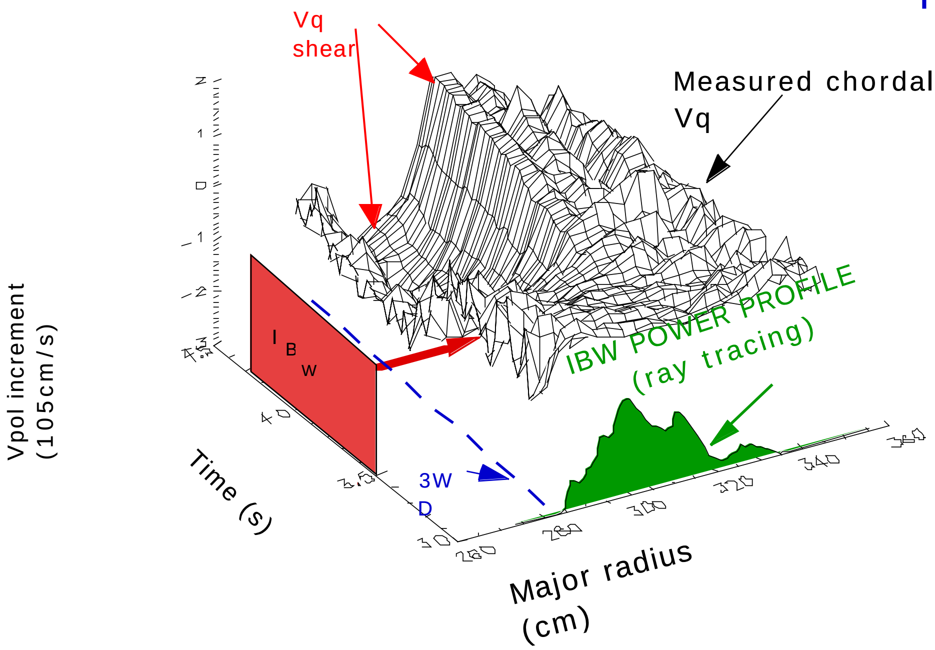
Poloidal Velocity Shear Produced by Ion Bernstein Waves (IBW)

TFTR



- ~150 kW of IBW was coupled into TFTR out of 400 kW launched.
- Coupling may be improved with poloidal ` phasing or waveguide coupler. Problems likely due to surface waves.
- Calculations indicate need ~1.5 MW to form barrier

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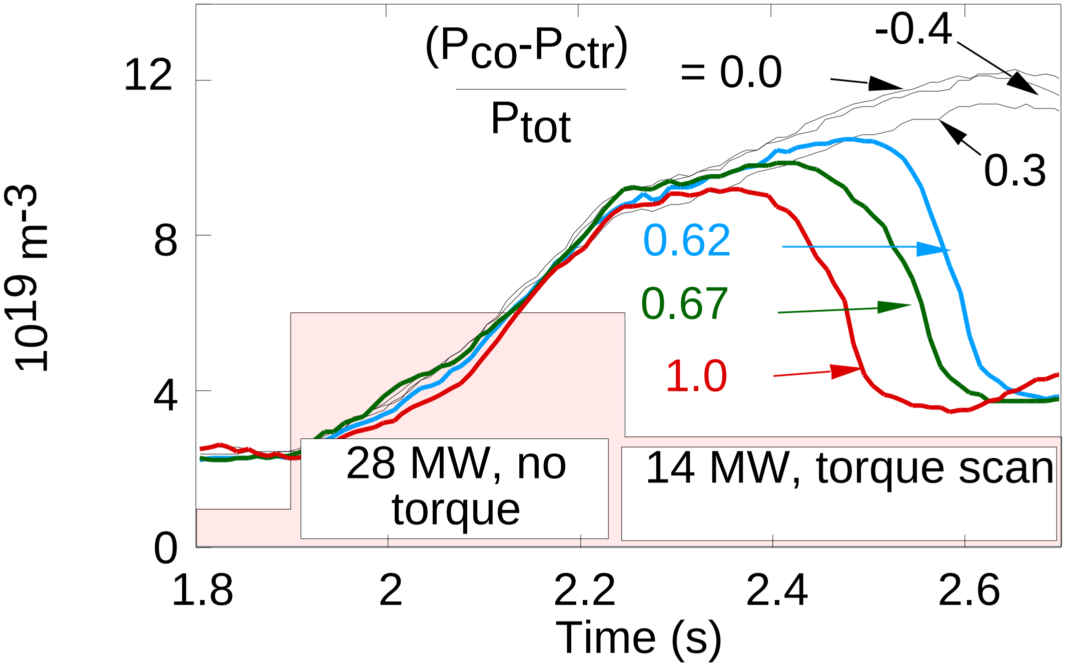
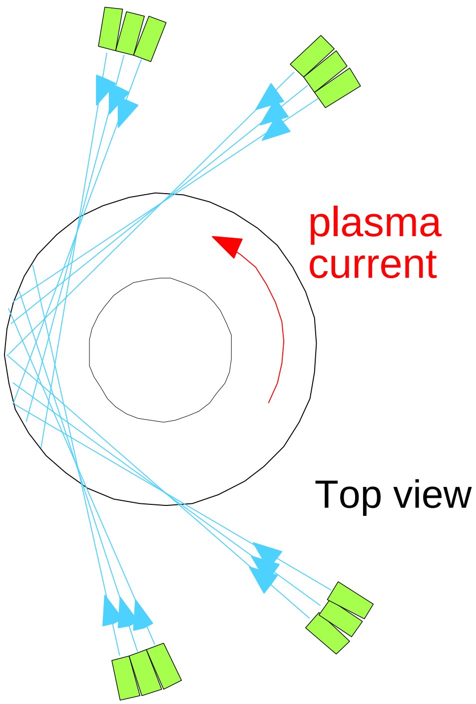
Coarse barrier control was found by varying the applied torque

TFTR

Maximum electron density





- larger fractions of injected power parallel to the current   earlier losses of core confinement
- small or negative fractions antiparallel to the current   no losses of core confinement

Synakowski, Phys. Rev. Lett. **78** (1997)

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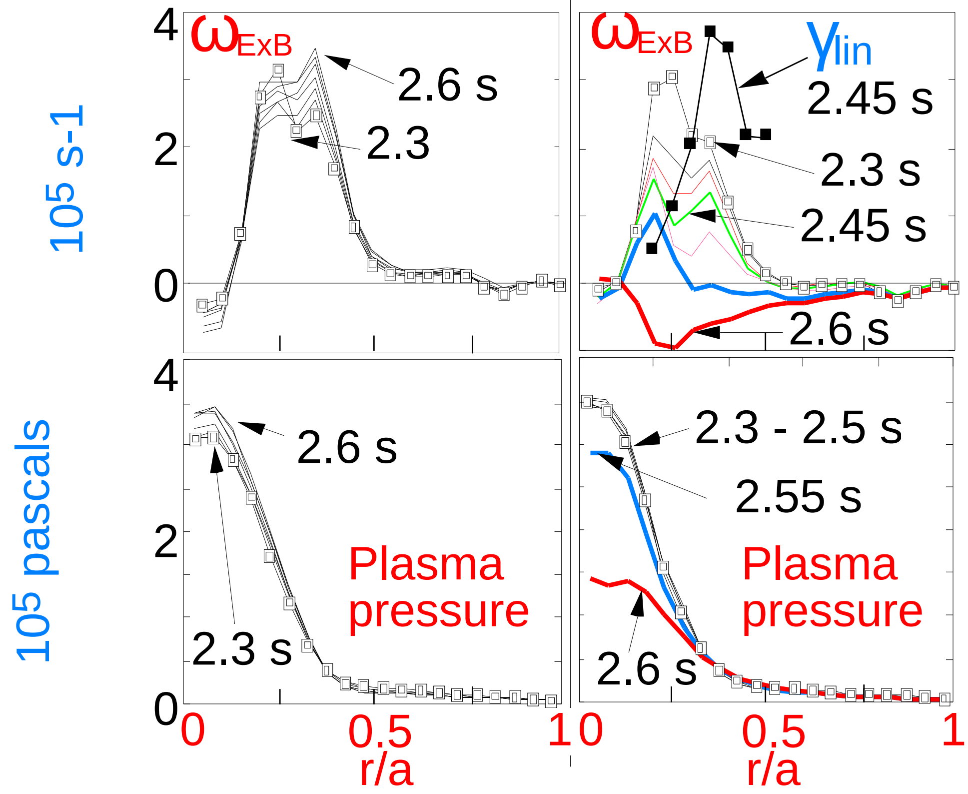
ejs030798, ERS Ne(0), B.T.

Pressure profile collapses only when shearing rate is forced to small values

$$\frac{(P_{co}-P_{ctr})}{P_{tot}} = -0.4 \qquad \frac{(P_{co}-P_{ctr})}{P_{tot}} = 0.62$$



$$E_r = p/(nZe) + V_\varphi B_\theta - V_\theta B_\varphi$$

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

- Quantities central to η_i , η_e, and Δ'-induced stabilization are held constant
- Core barrier collapses wher $\gamma_{ExB} \sim 1/2\gamma_{lin}$

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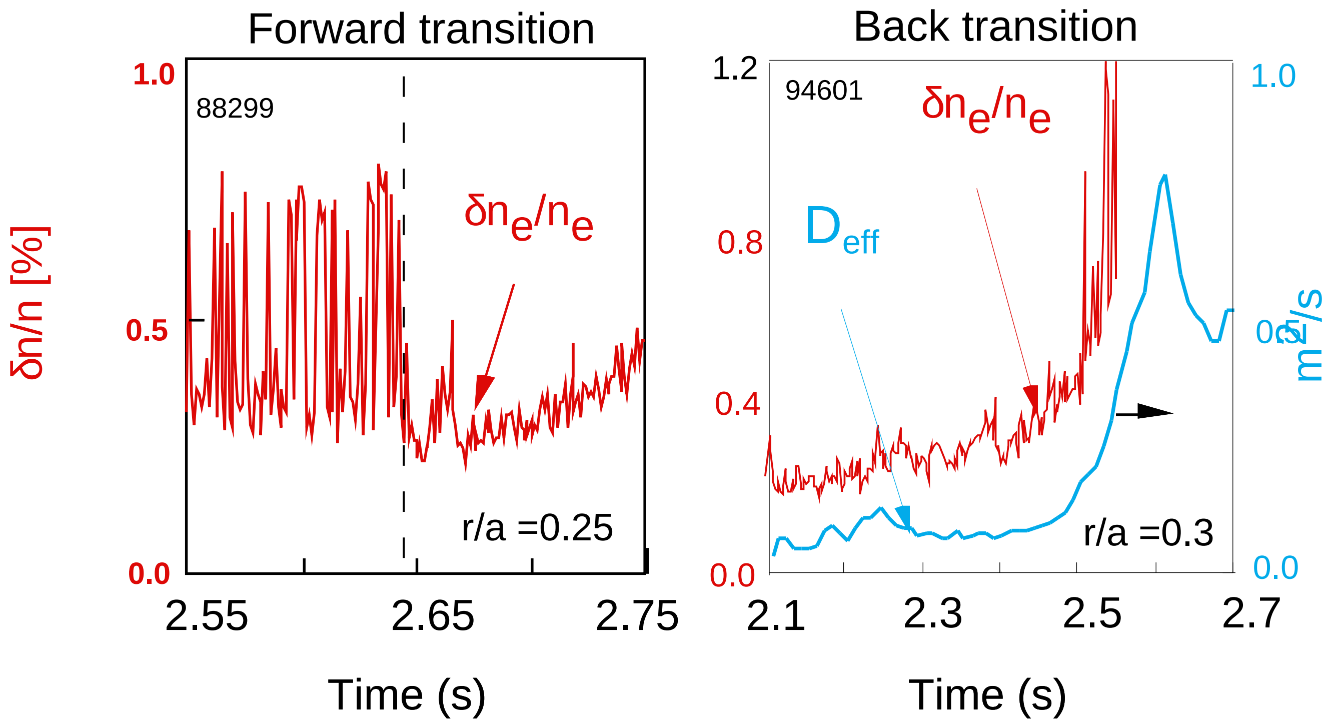
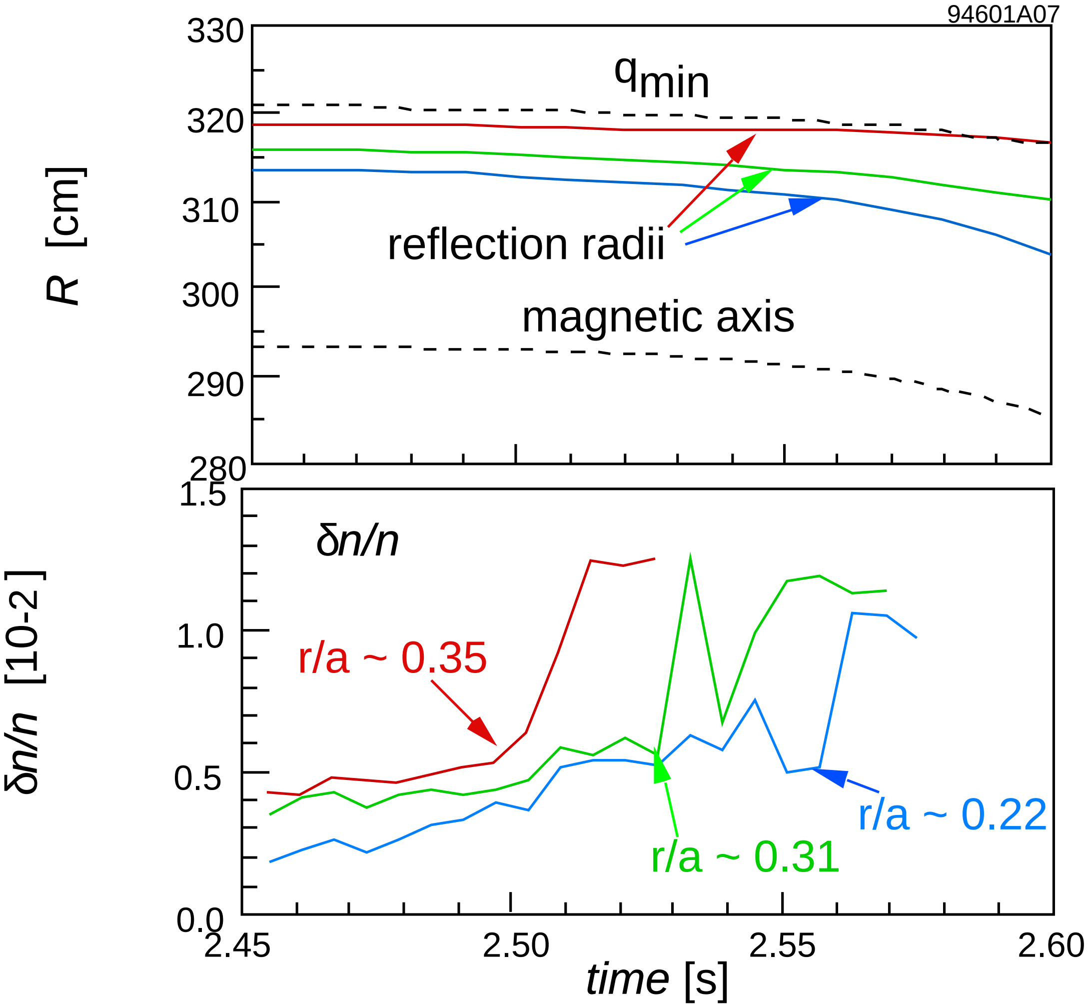
Change in fluctuation level is fastest for forward transition



- Note difference in time interval
- *Formation*: positive feedback with p *quick quench* of fluctuations
  Collapse: As barrier peels away, core is continually accessed, propping up p and $\gamma_{E\times B}$ *slow degradation*

Measured fluctuations return from the outside in



- Fluctuations provide measure of barrier location

Calculations have been used to examine dynamics of turbulence and profiles

David Newman, University of Alaska at Fairbanks

- 1-D turbulence calculation: envelope model, poloidally and toroidally averaged, coupled with multimode transport model

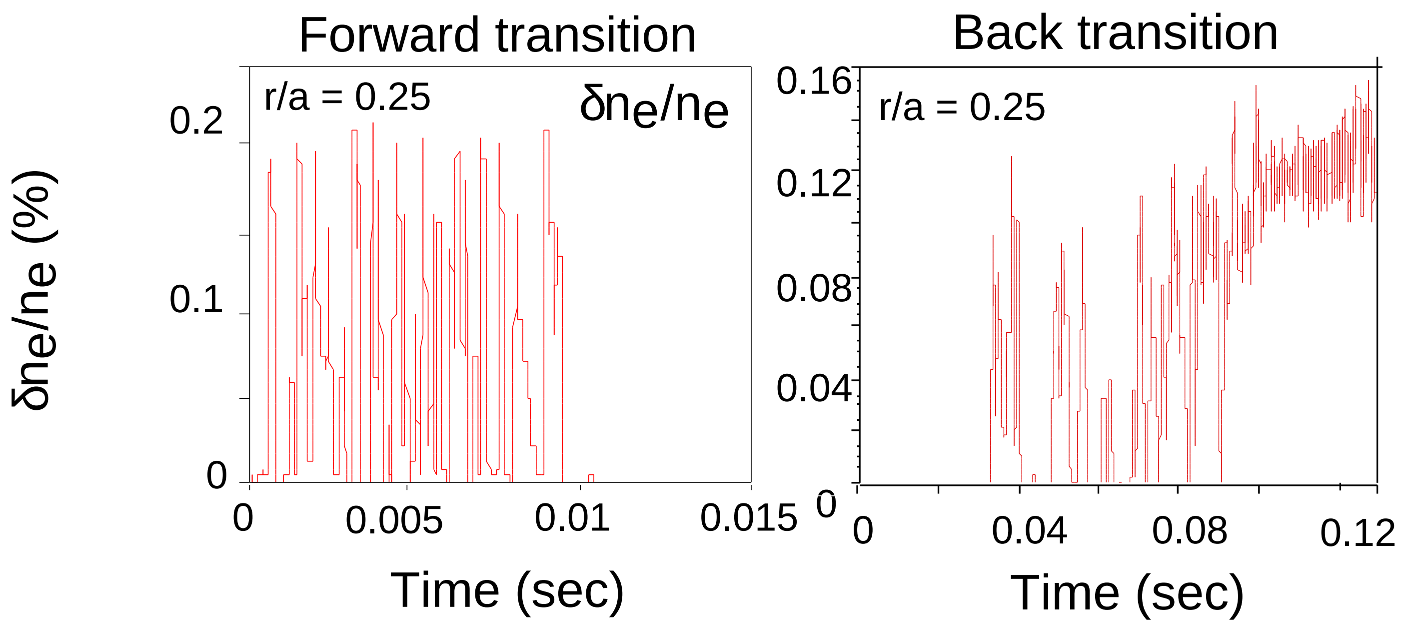
- E×B shear explicitly included in growth and saturation of fluctuation amplitudes; phase information absent

- feedback loop between gradients, instability drive, E×B shear

Key elements for bifurcations:

a. growth rate reduction inside q_{min} due to reverse shear
b. central particle and power deposition

Calculated time scale of fluctuation change is fastest for forward transition

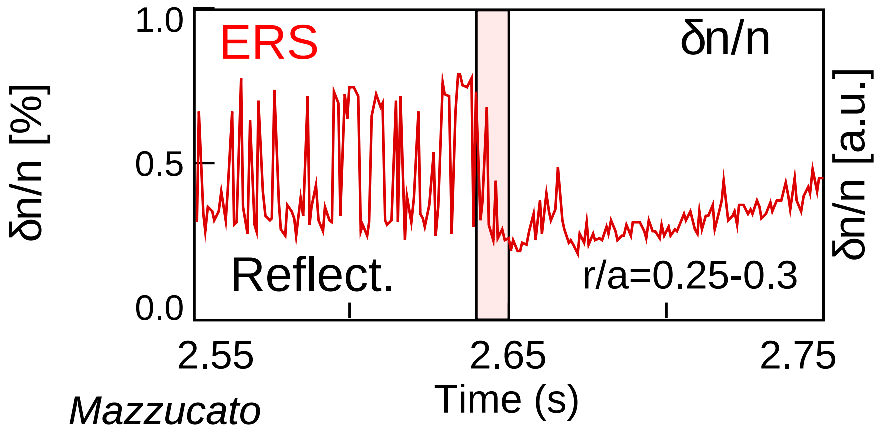


- Note difference in time intervals
- Bursting is predicted:
  a consequence of interplay between instability drive and E×B shear

Core transport and fluctuation reduction can have very different time scales

Fast

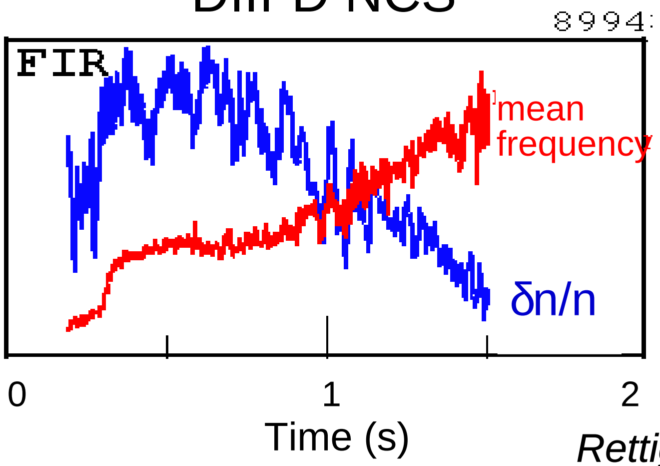
High power ERS Core (TFTR)



Mazzucato

Slow

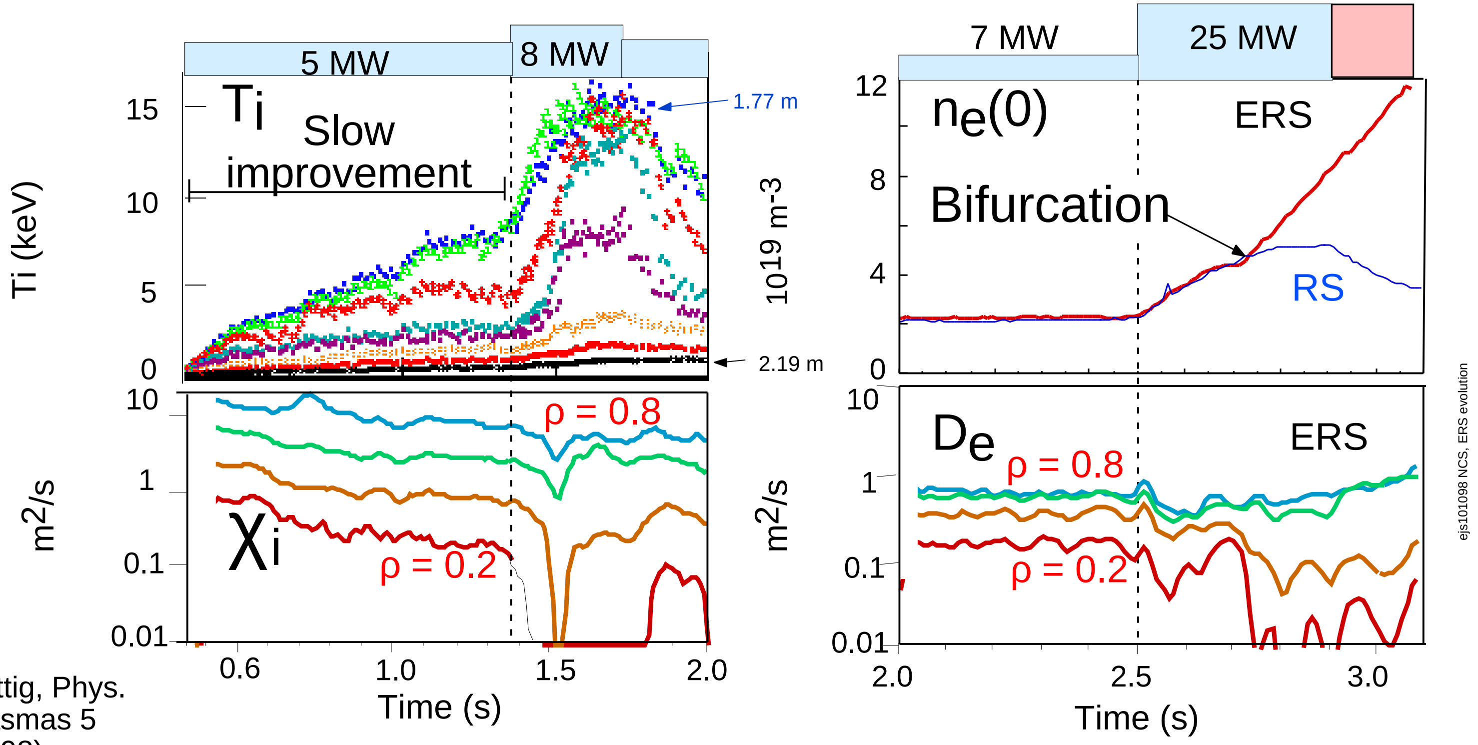
DIII-D NCS



Rettig

- Difference in time scale may be due to fast boostrap with p-dominated bifurcation vs. competition between p and V_φ in DIII-D case
- DIII-D: fluctuation, transport reduction during time when V_φ shear is slowly increasing
- TFTR: fluctuation, transport change is “single step” in character

DIII-D NCS develops more slowly than TFTR ERS plasmas



Rettig, Phys. Plasmas 5 (1998)

- DIII-D NCS: Gradual improvement early in time
  Faster improvement as V_φ' increases with power ste
- TFTR ERS: Rapid bifurcation at V_θ excursion

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

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Conclusions:

1. Particle confinement provide another incentive for transport barrier control
   - neoclassical ion particle confinement in TFTR ERS
   - spotty behavior of electron thermal channel makes it even harder to predict severity of problem
2. Models with E×B shear reproduce many of the dynamics
3. Our AT programs should take advantage of flexibility in E×B shear generation if it is available
   - need to be in the configuration nearest the AT target
   - plasmas will respond to local flow shear: push RF control tools
   - flexibility of varying momentum input would enhance understanding of barrier dynamics