Transport barrier formation and relaxation in TFTR reverse-shear plasmas

presented by

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for the
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There are two dominant viewpoints regarding the cause of low transport in ERS

1. E×B shear stabilization of turbulence

2. Shafranov shift gradient (Δ') stabilization

   Both pictures exhibit a threshold quality

   Both predict bifurcations and sustained high confinement with increasing p

<u>On TFTR, both effects are important</u>

- E×B shear is necessary to keep confinement high, fluctuations low
  - With Δ' effects alone, ERS is lost

- E×B shear beats out instability drives only if Δ' effects are present

- Variability in a shear suppression threshold criterion is found

Two plasmas nearly identical early in time can follow very different paths

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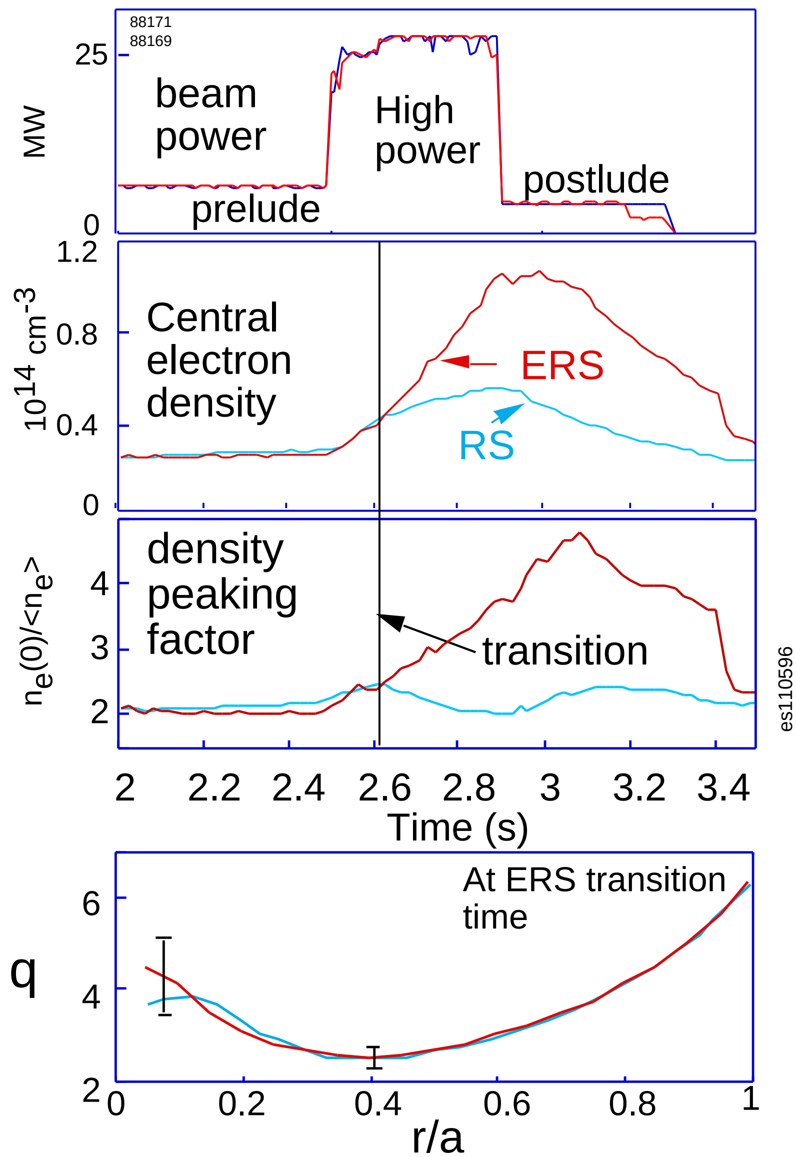

Transition yields good core confinement, strong peaking of density and pressure

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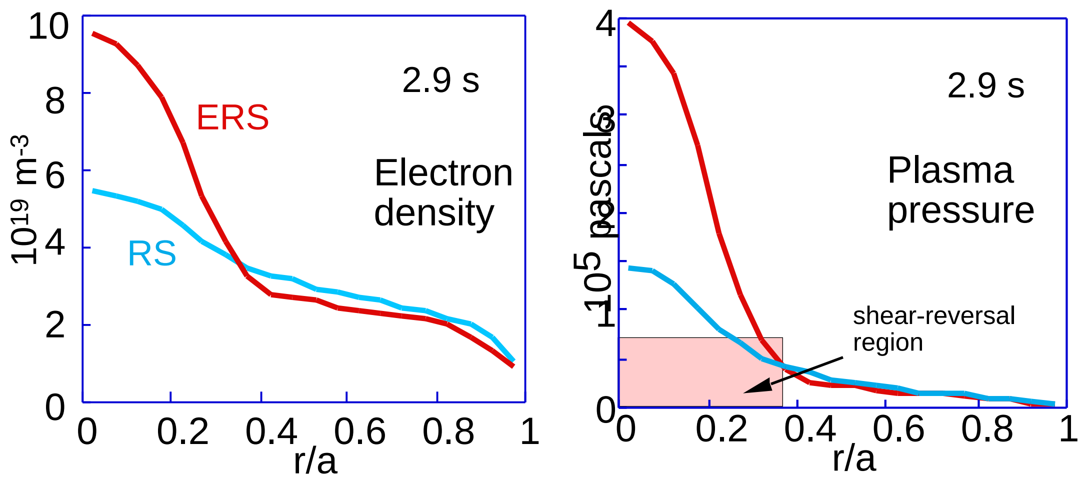


- Analysis for barrier physics studies done near r/a = 0.3, where gradients are large and well documented

E×B shear, Shafranov shift are candidates for transition model

I. E×B shear stabilization (Diamond)

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

increasing p larger E_r and E_r shear

Shearing rate:

$$\gamma_{E\times B} \equiv \frac{(RB_\theta)^2}{B} \frac{\partial}{\partial \psi} \frac{E_r}{RB_\theta} \quad \text{(Hahm and Burrell)}$$

On outer midplane,

$$\gamma_{E\times B} = \frac{E_r}{B} \left[\frac{1}{E_r} \frac{\partial}{\partial R} E_r - \frac{1}{B_\theta} \frac{\partial}{\partial R} B_\theta - \frac{1}{R} \right]$$

Threshold criterion:

$\gamma_{E\times B} \sim \gamma_{lin}^{max}$ *no transport* (Waltz *et al.*)

II. Low J(r) in core   large Δ'

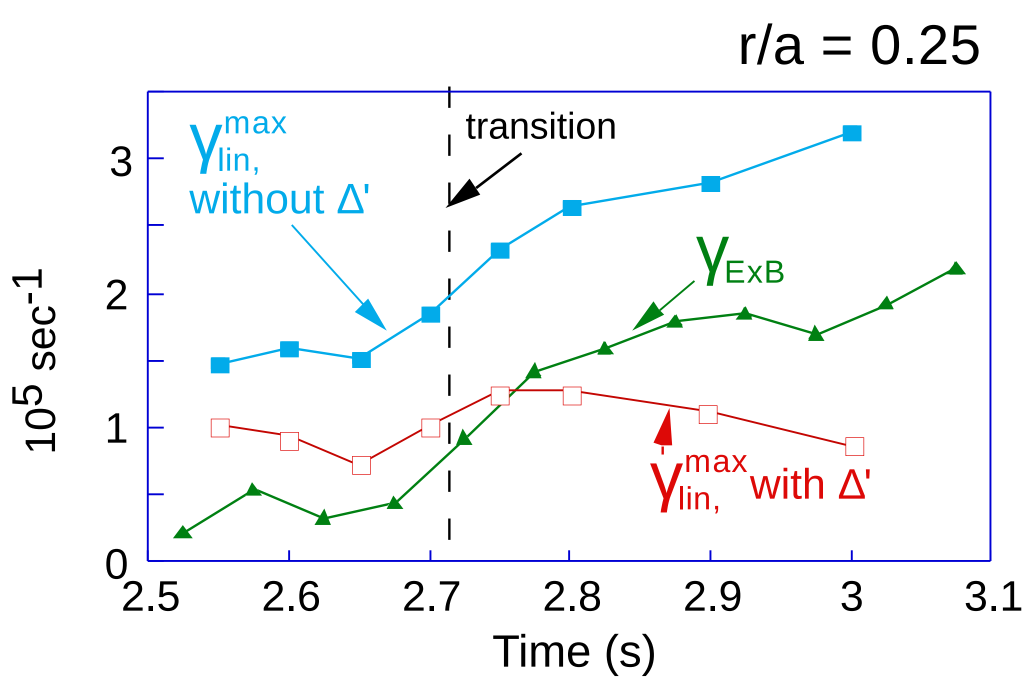
favorable precession of trapped particles

fluxes *reduced* with p increase

may lead to a bifurcation on its own

(M. Beer: next talk)
(J. Drake, edge ballooning modes, PRL)

Both suggest a combined picture:



Bursting fluctuation levels fall when ExB shearing rate exceeds maximum linear growth rate

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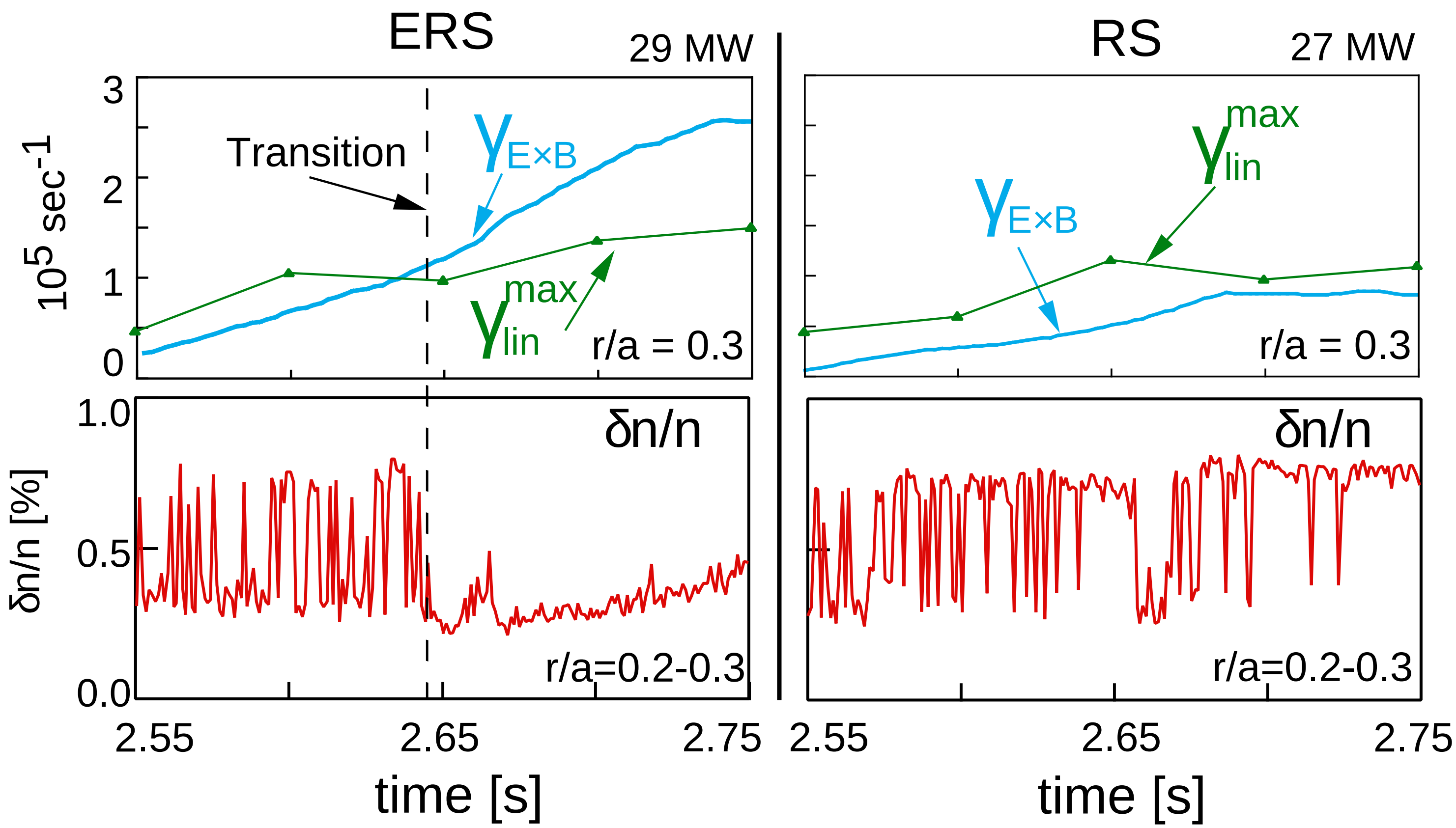

- Reduction in turbulence is at ERS transition time
- δn/n measured from reflectometry (Mazzucato, 4F.06; PRL 77, 3145)

Separation of E_r and Δ' effects aided by develpment of nearly steady-state ERS

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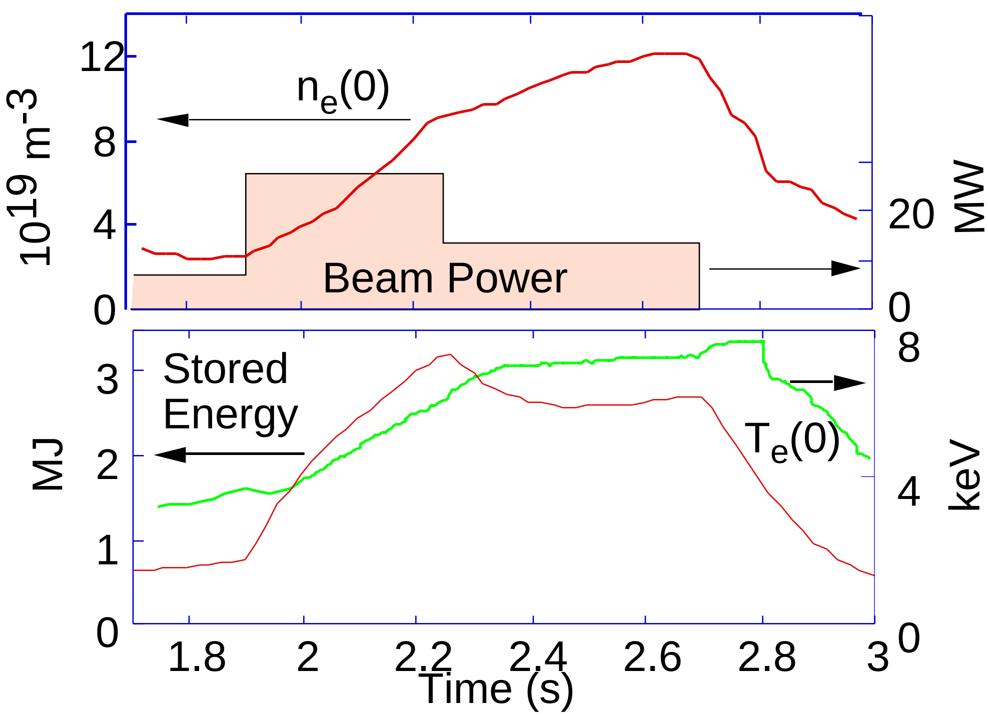

- Plasma pressure profile nearly constant in postlude
- Steady-state with half of available power allows E_r variations with co, counter beams in postlude

Back-transitions are correlated with applied torque at constant power

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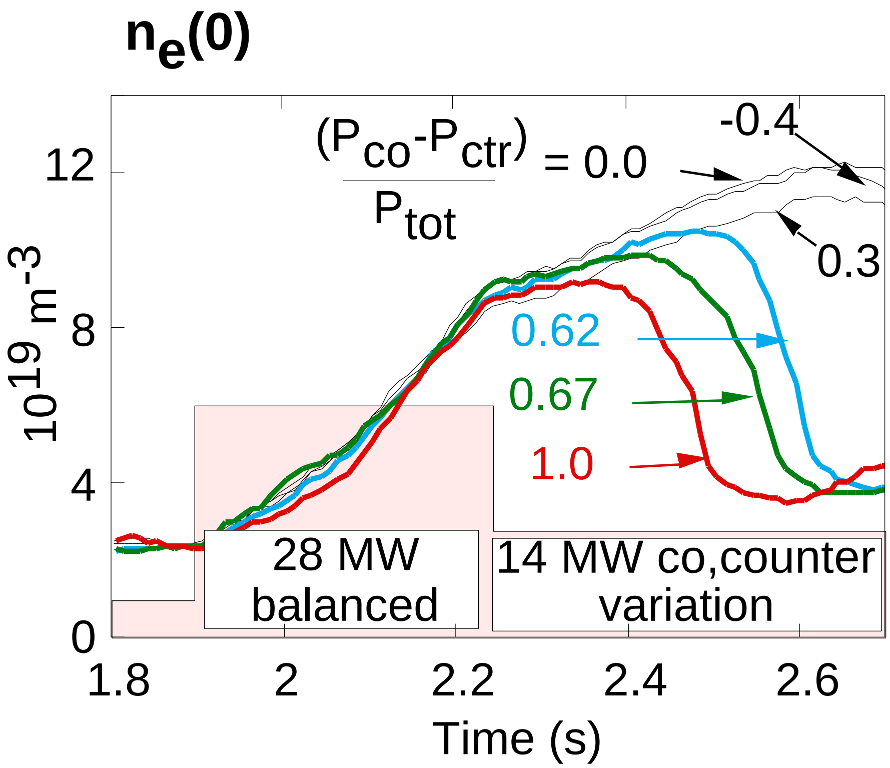

- Strong co-injection leads to loss of ERS confinement
- nearly balanced had sustained ERS
- toroidal rotation drive of instabilities expected to be small (Rewoldt,1S.15)

E_r was varied during the postlude by changing V_φ with co, counter neutral beams

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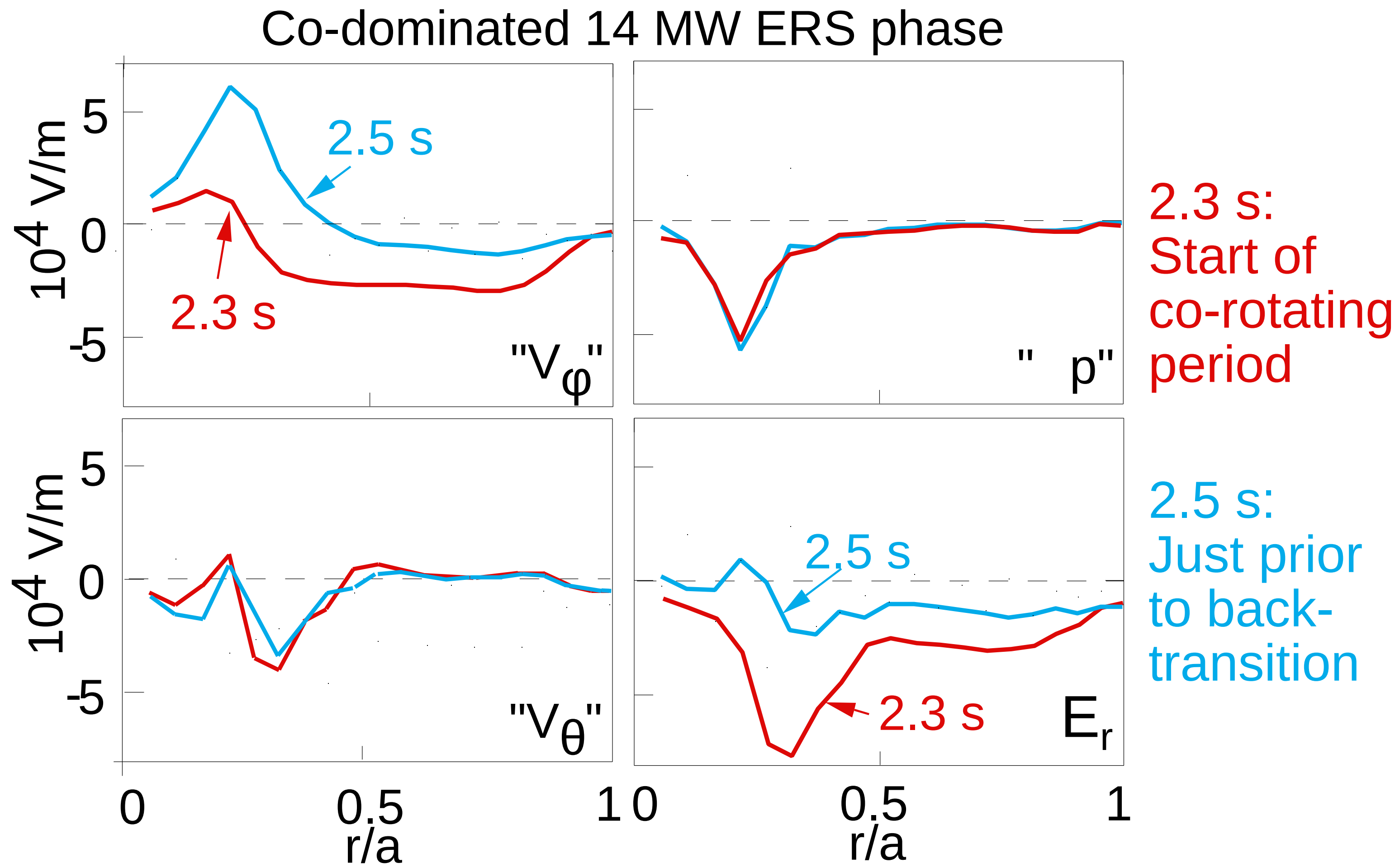
Carbon force balance: $E_r = \nabla p/(nZe) + V_\varphi B_\theta - V_\theta B_\varphi$



Core stored energy collapses when $\gamma_{E\times B}$ is driven to small values by co-rotation

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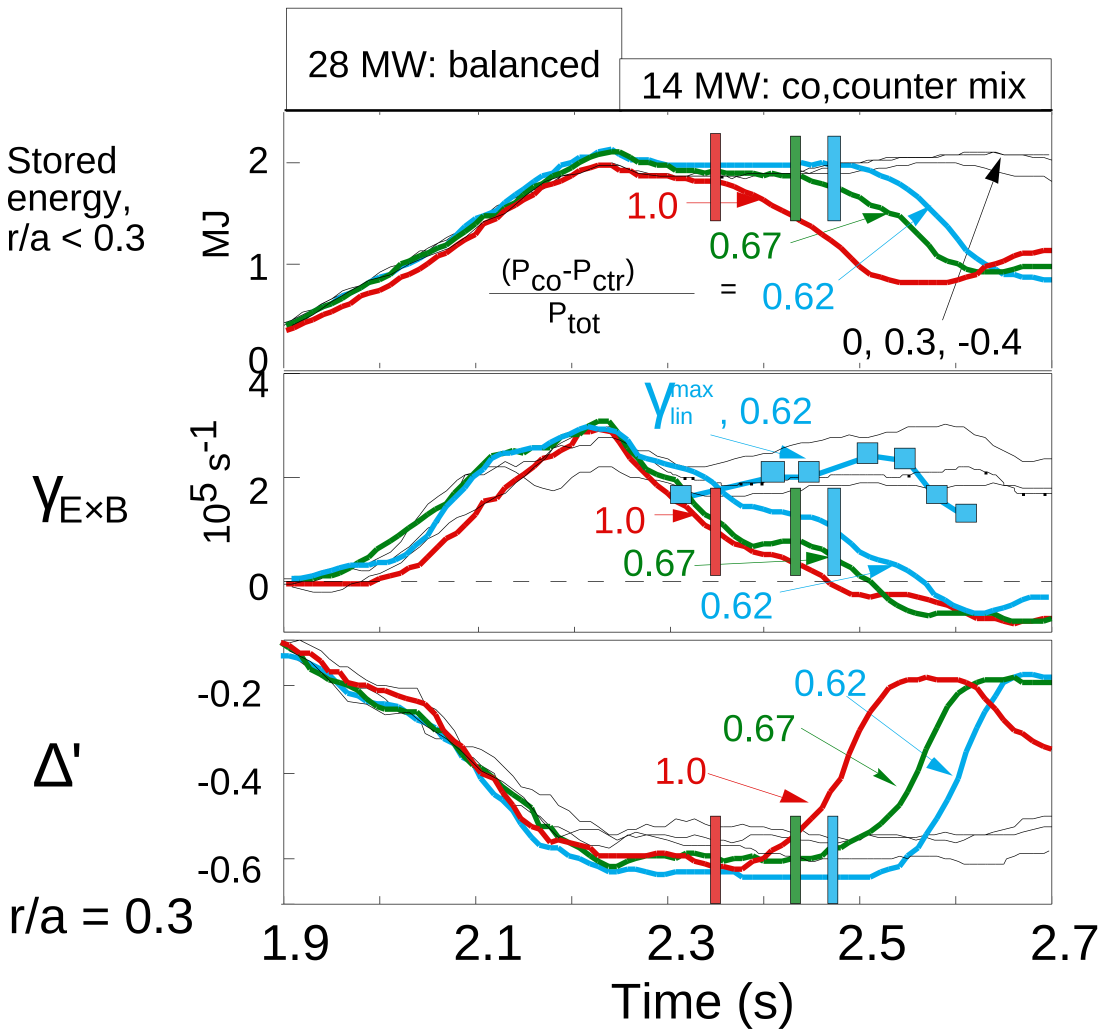

- Change in $\gamma_{E\times B}$ precedes back-transition
- Back-transitions at similar values of $\gamma_{E\times B} \sim \gamma_{lin}^{max}$
- Δ' unchanged until loss in confinement

Core fluctuation levels are correlated with local transport

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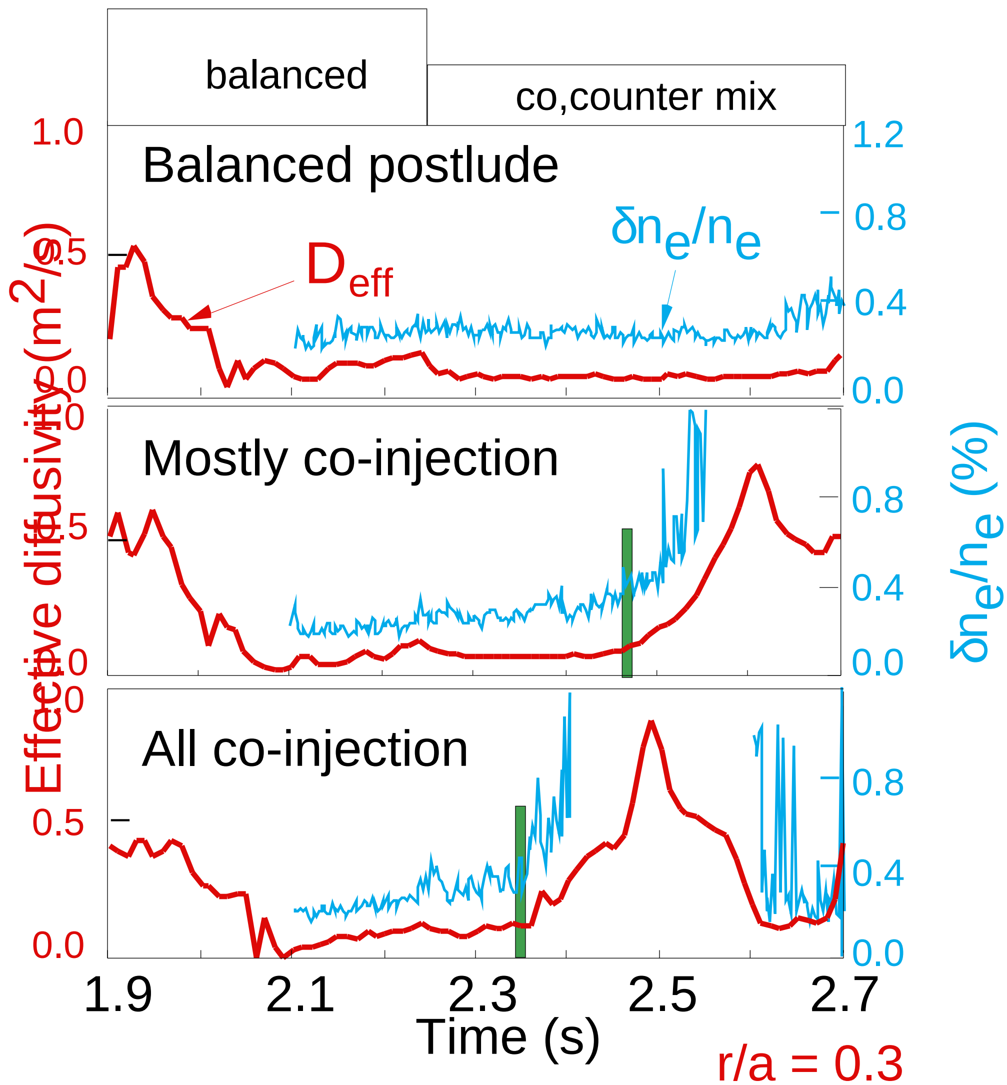

- Fluctuations measured with reflectometry (Mazzucato)

Applying high power early in the current evolution makes ERS more likely

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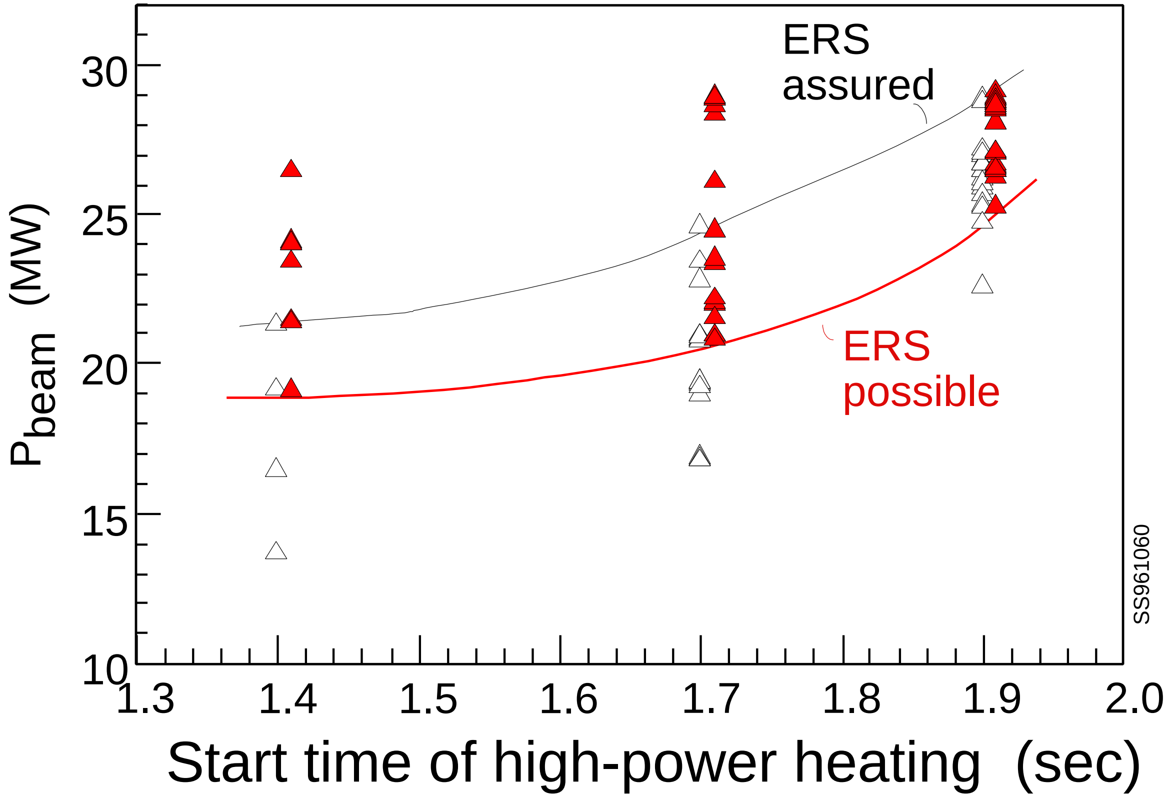

- I_p flat-top not reached until 2.0 sec.
- Early   larger q(0), q_{min}, Shafranov shift,   p

Heating earlier in current evolution increases $\gamma_{E\times B}$ and Δ', consistent with lower power threshold

Before transition, time of same global β_p

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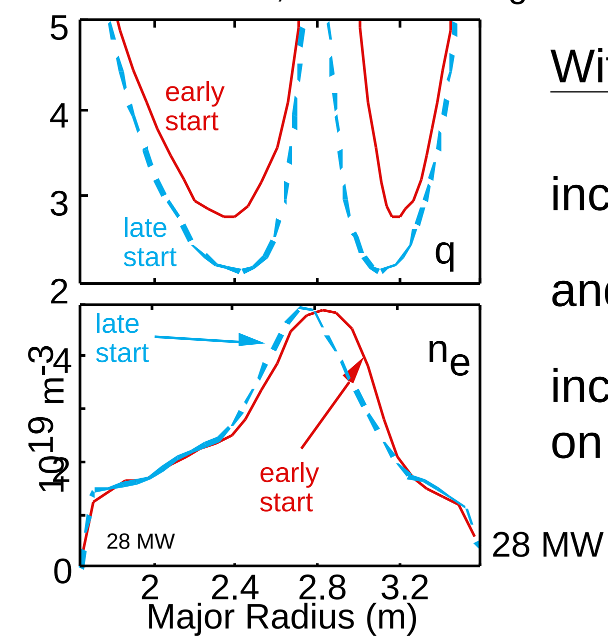
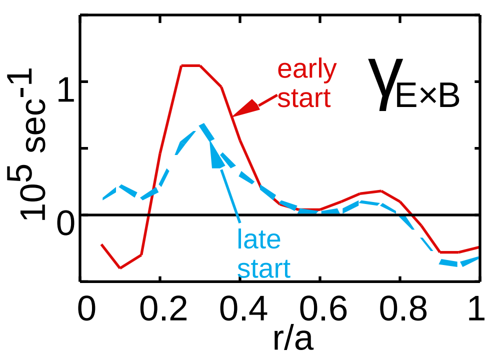


With early start:

increased $\left|\frac{1}{B_\theta}\frac{dB_\theta}{dR}\right|$

and

increased p
on outer midplane



Both combine to

give larger $\gamma_{E\times B}$

$$\gamma_{E\times B} = \frac{E_r}{B}\left[\frac{1}{E_r}\frac{dE_r}{dR} - \frac{1}{B_\theta}\frac{dB_\theta}{dR} - \frac{1}{R}\right]$$

B field scan reveals strong scaling of power threshold and variations in E ×B shear stabilization criterion

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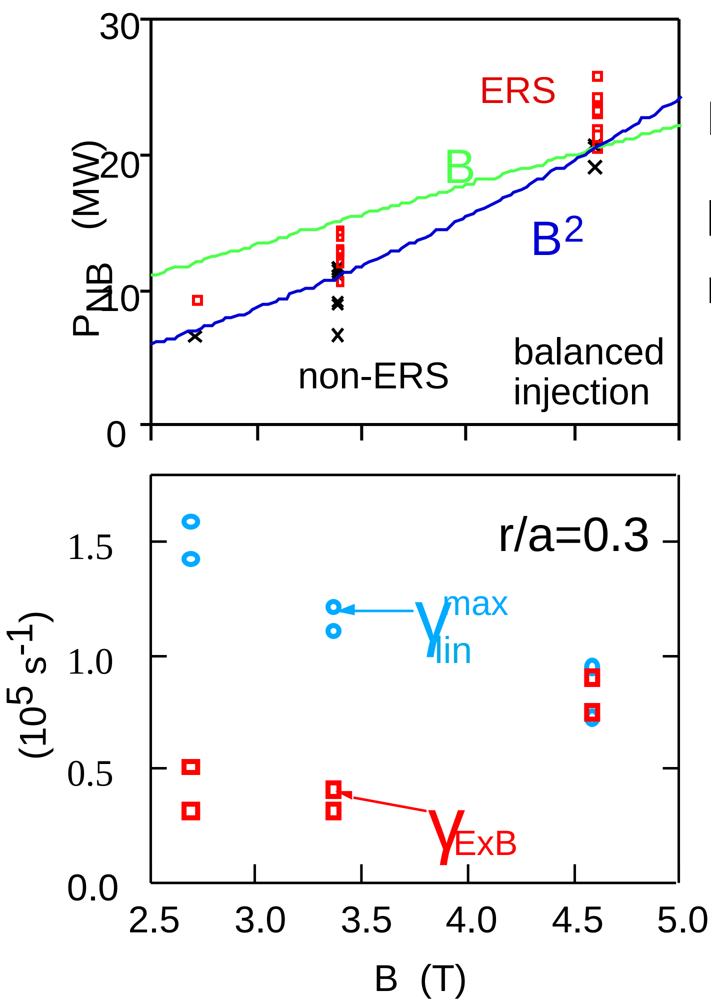

ERS threshold power B^2, nominally

Zarnstorff, 4F.03

- similar q profiles
- Rates shown just prior to ERS transition .
- Radius chosen for peak $\gamma_{E\times B}$.

Strongly Unbalanced NBI Raises Threshold Power

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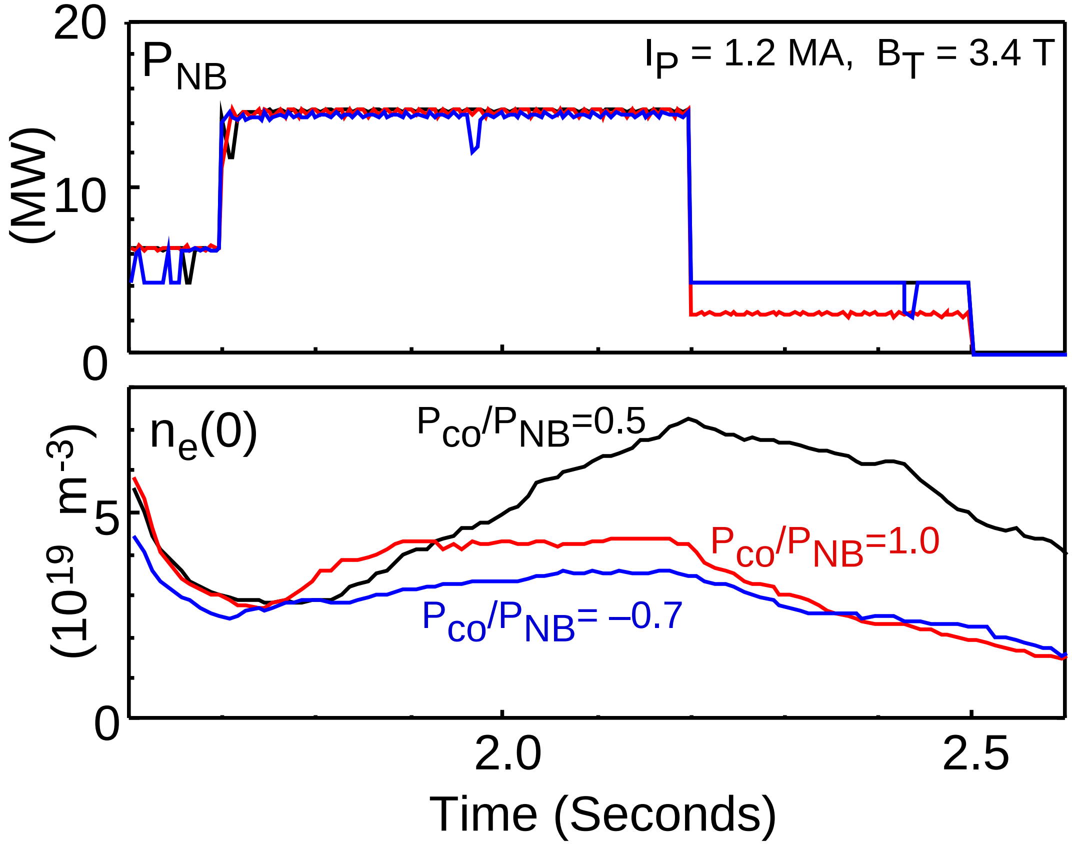

- With co-injection p increases oppose V_φ increases
- Transition can be obtained with P_{NB}=16.5 MW and P_{co}/P_{NB} = 0.7
- Counter rotating case more difficult to explain

Summary

1. Combined transition picture is consistent with ERS transition and reduction in turbulence

2. E×B shear is necessary to keep high confinement

   With Δ' effects alone, ERS is lost

3. Δ' effects required for sustained E×B shear suppression with increasing p

4. Challenges

   In B scaling experiment, $\gamma_{E\times B}/\gamma_{lin}^{max}$ at transition varies by factors of two or more

      need to find where the dependencies are

      Δ' more important at low B?

   Power threshold higher with strong rotation

Transport barriers with naturally occurring E_r shear may not scale favorably to a tokamak reactor

It may be energetically unfavorable to generate enough rotation on ITER to create a barrier.

Scaling of p drive to ITER-like machines is unfavorable if profile scale lengths increase with system size

smaller machines, like spherical tokamaks, may be better suited for transport barrier formation

IBW may be needed to act as a low-power trigger mechanism