Tests of ExB Shear Bifurcation Model for ERS in TFTR

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Outline

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- Brief review of ERS mode phenomena
- Reminder of leading explanation for transition to ERS
- New experimental tests of transition model

Two Confinement Regimes Observed with Reversed Central Shear

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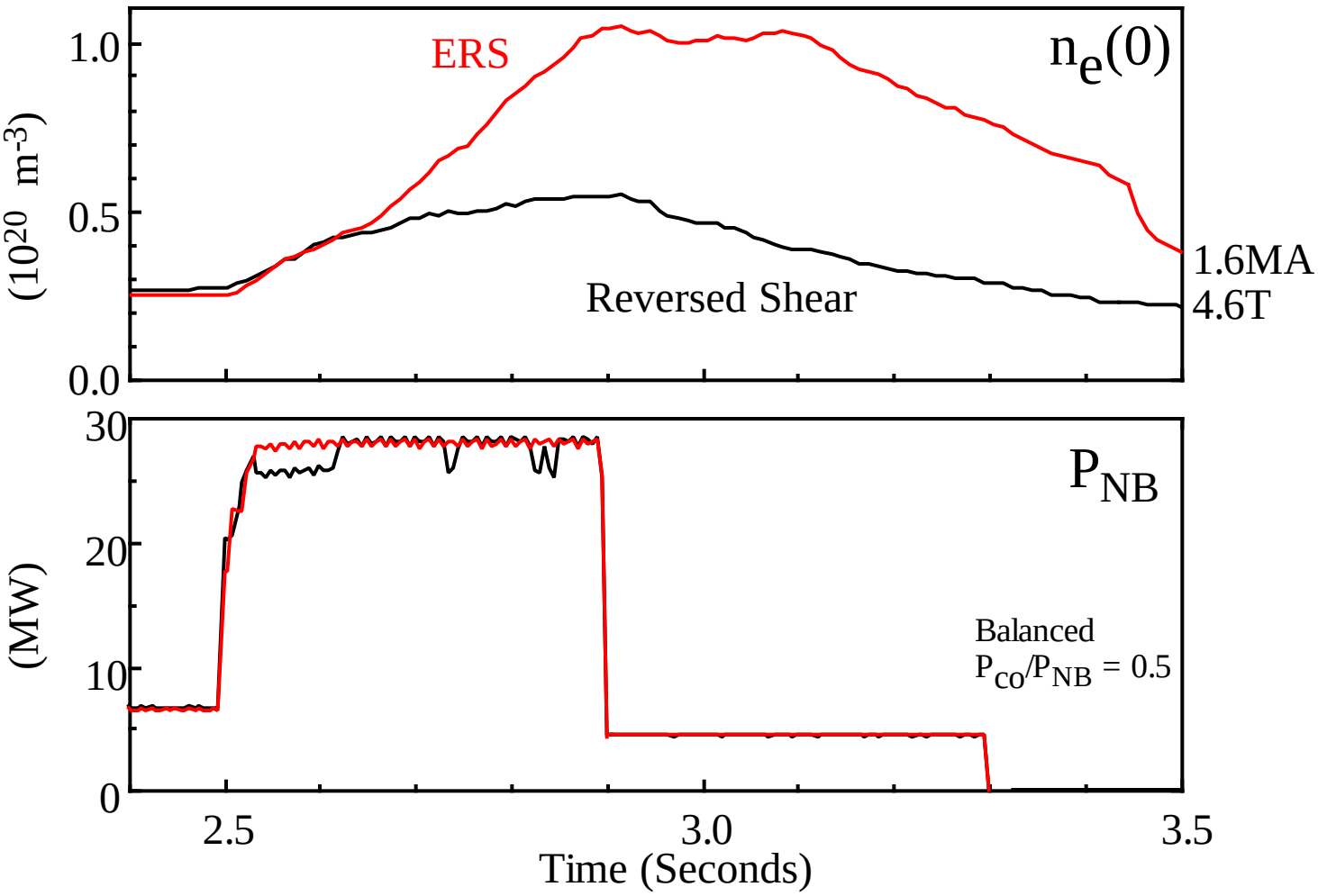
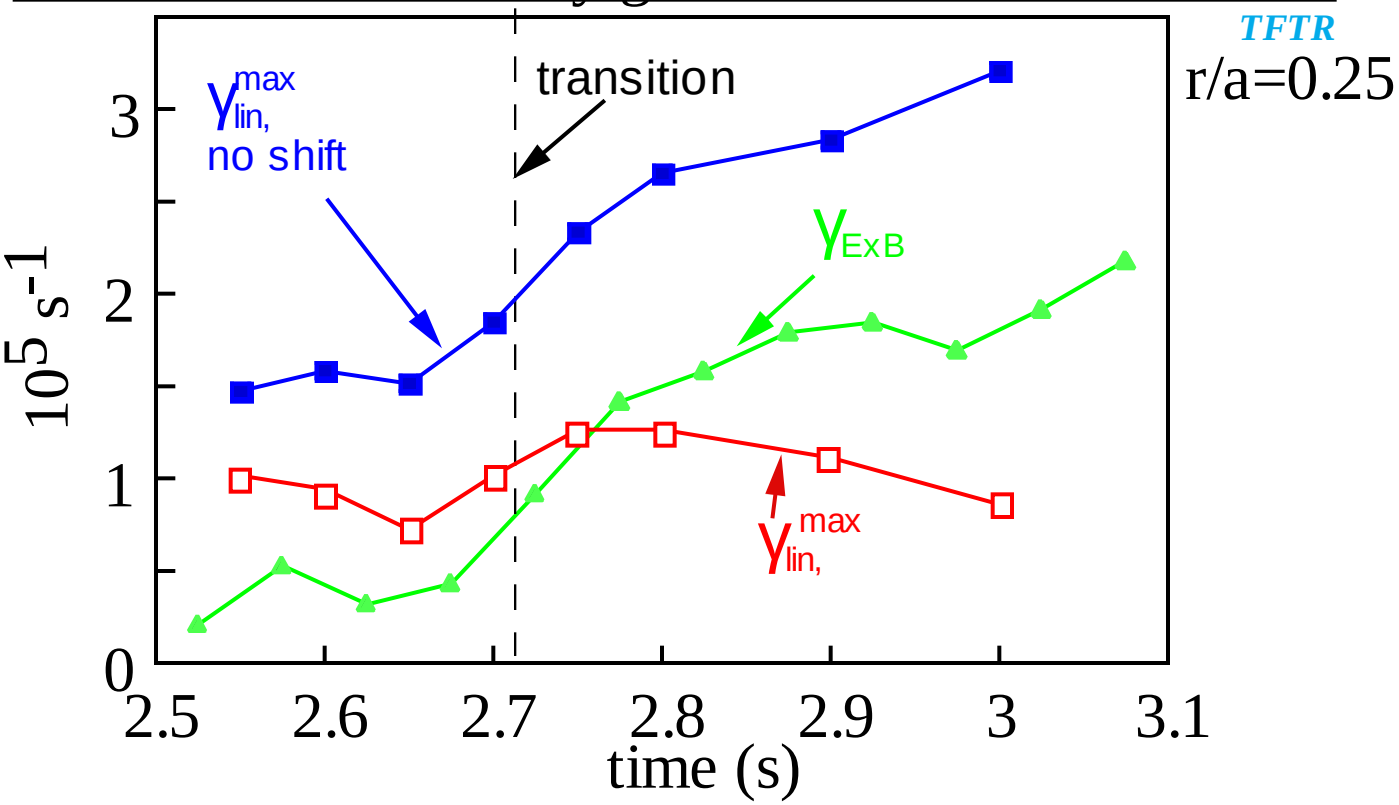


- Both plasmas have reversed shear q-profiles
- Sudden transition to reduced central transport of particles and energy (ERS mode - Enhanced Reversed Shear).
  - D_e ~ neoclassical, χ_i < standard neoclassical
- ERS mode shows extreme hysteresis
  High central density can be maintained with ~5 MW of NBI

Possible Transition Mechanism: p driven increase of shearing rates and decrease of instability growth rates



- Expect turbulence stabilization when $\gamma_{ExB} > \gamma^{max}_{lin}$
  (Biglari, Diamond, Terry 1990; Waltz 1994; Diamond et al 1996)

- $\gamma_{ExB} \quad RB_P / B \ \ d/dR \ (E_r / RB_P)$ (Hahm and Burrell 1996)
  from measured profiles, neoclassical v_θ, and

  $p_i = n_i \ Z_i \ (E_r + v_i \times B)$

- γ^{max}_{lin} is the maximum linear growth rate, from a comprehensive gyro-fluid simulation (Beer and Hammett)
  – includes stabilization due to Shafranov shift
  M. Beer, 2I
- Is observed $\gamma_{ExB} > \gamma^{max}_{lin}$ cause or effect?

Tests of Transition Model

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1) Examine scaling of the threshold power with B

   - tests variation of the different components of the model.

2) Change E_r and γ_{ExB} using co/ctr NBI before transition

   - look for changes in threshold power

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3) Change E_r and γ_{ExB} using co/ctr NBI *after* transition

   - look for changes in back-transition

     – See E. Synakowski, 2IB.01

B Scaling of Transition Power

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Idea

Different Theoretical components to the model have different B scalings: (for fixed pressure profiles)

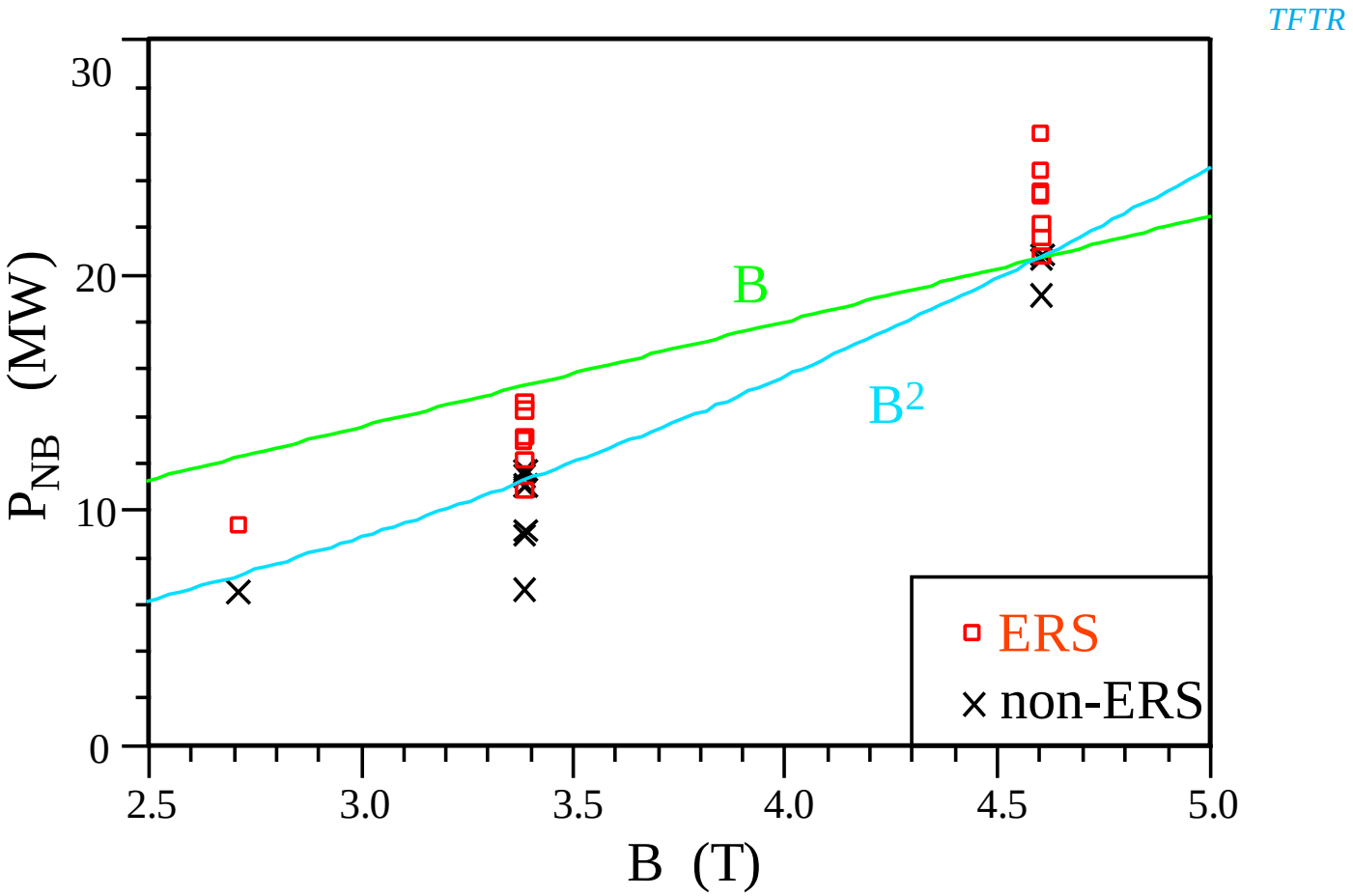
- Shafranov shift effects B_P^{-2}
- γ_{ExB} B^{-1} if driven by p
- γ_{lin}^{max} B^0 at fixed $k_\theta \rho_i$

By varying B we can test whether model varies as plasma does.

Experiment:

- Vary B_T and I_P together attempting to keep q(r) constant
  - does not attempt to separate B_P from B_T

ERS Threshold Power B^2, Nominally



- Measured q-profiles are very similar; r_{min}, q_{min}, q(a)

- At threshold, $P_{NB} \sim B^2$, thus expect
  β, $\beta_P \sim$ constant, Shafranov shift ~ constant
  γ_{ExB} B
  γ_{lin}^{max} B^0 at fixed $k_\theta \rho_i$

- Near-balanced injection
  high-power NBI starts at 1.7 sec
  Li pellet at 1.2 sec for conditioning

Only highest B cases show $\gamma_{ExB} \sim \gamma_{lin}^{max}$ Just before transition

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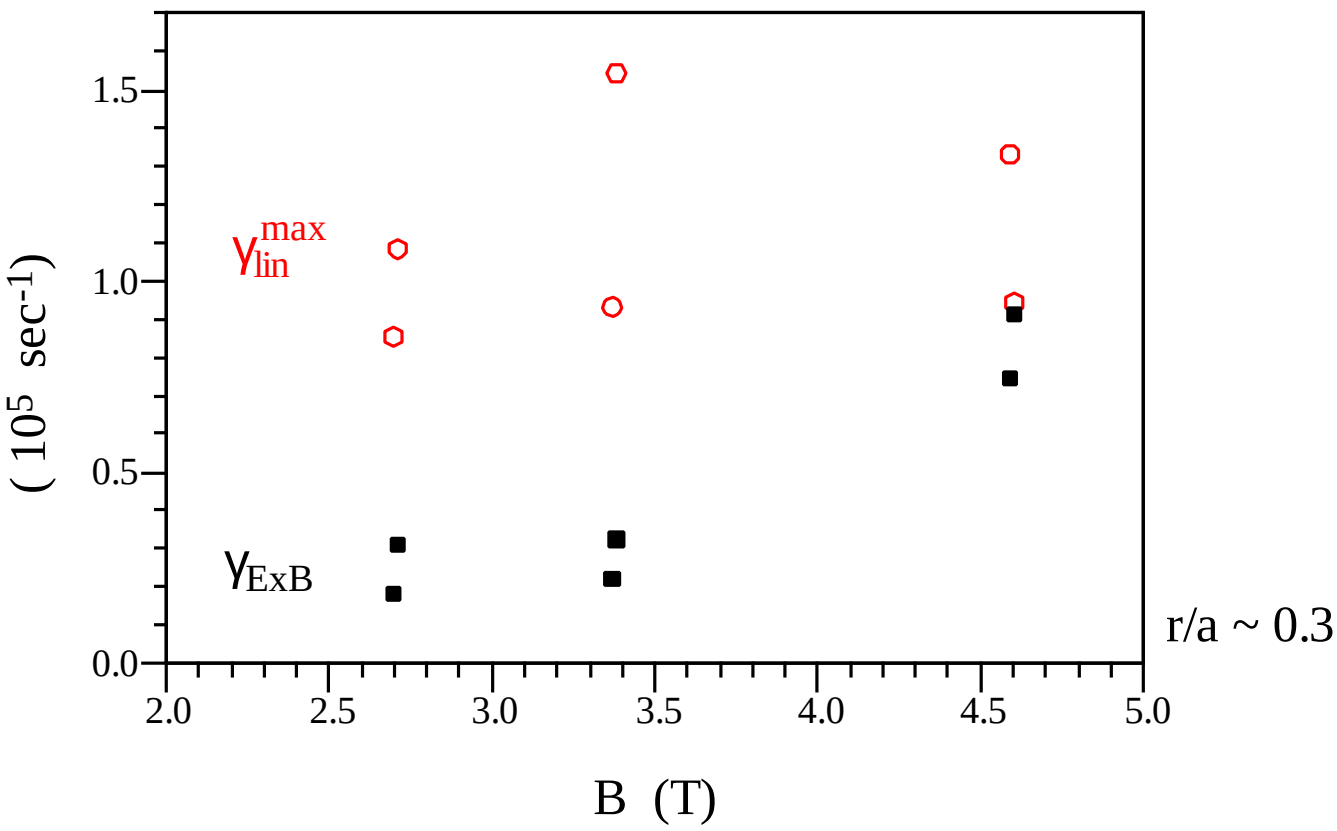
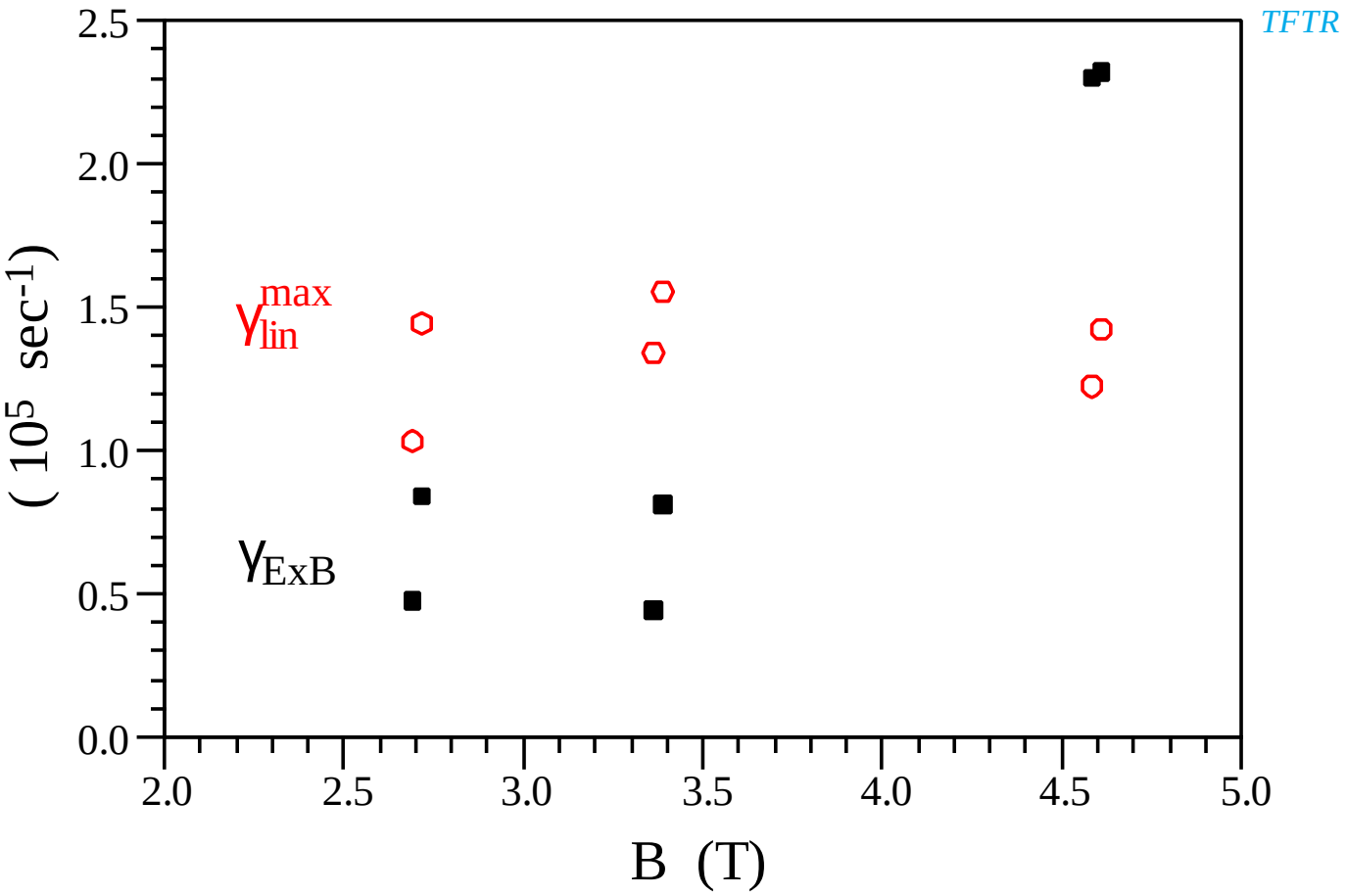


- plasmas undergo ERS transition within ~50 msec
- radius chosen for peak γ_{ExB}
- roughly constant β_P implies
  - roughly constant Shafranov shift−induced stabilization
  - p B^2 => γ_{ExB} B, as observed
- B_T = 2.7 T MSE calibration is problematic
  - nominal analysis gives q-profile in good agreement with B_T = 3.4 T case
  - analysis using q-profiles from 3.4 T and 4.6 T cases shows results are insensitive

Only highest B cases show $\gamma_{ExB} > \gamma_{lin}^{max}$ After Transition



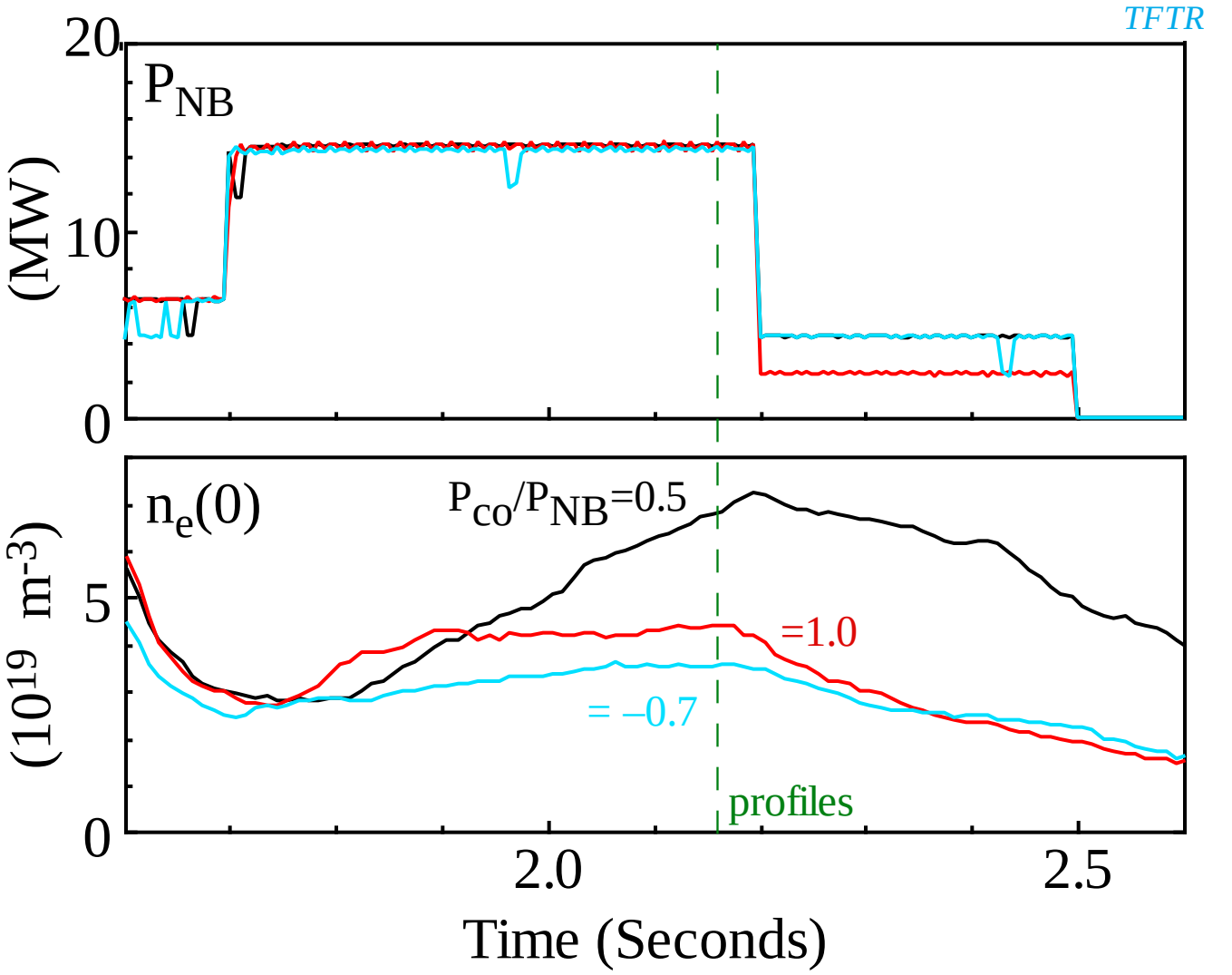
- 50 and 100 msec after transition
- lower B cases appear to disagree with model
  $\gamma_{ExB} < \gamma_{lin}^{max}$ after transition to enhanced confinement.

  $\gamma_{ExB} > \gamma_{lin}^{max}$ at high B is coincidental

– need to compare to fully nonlinear models

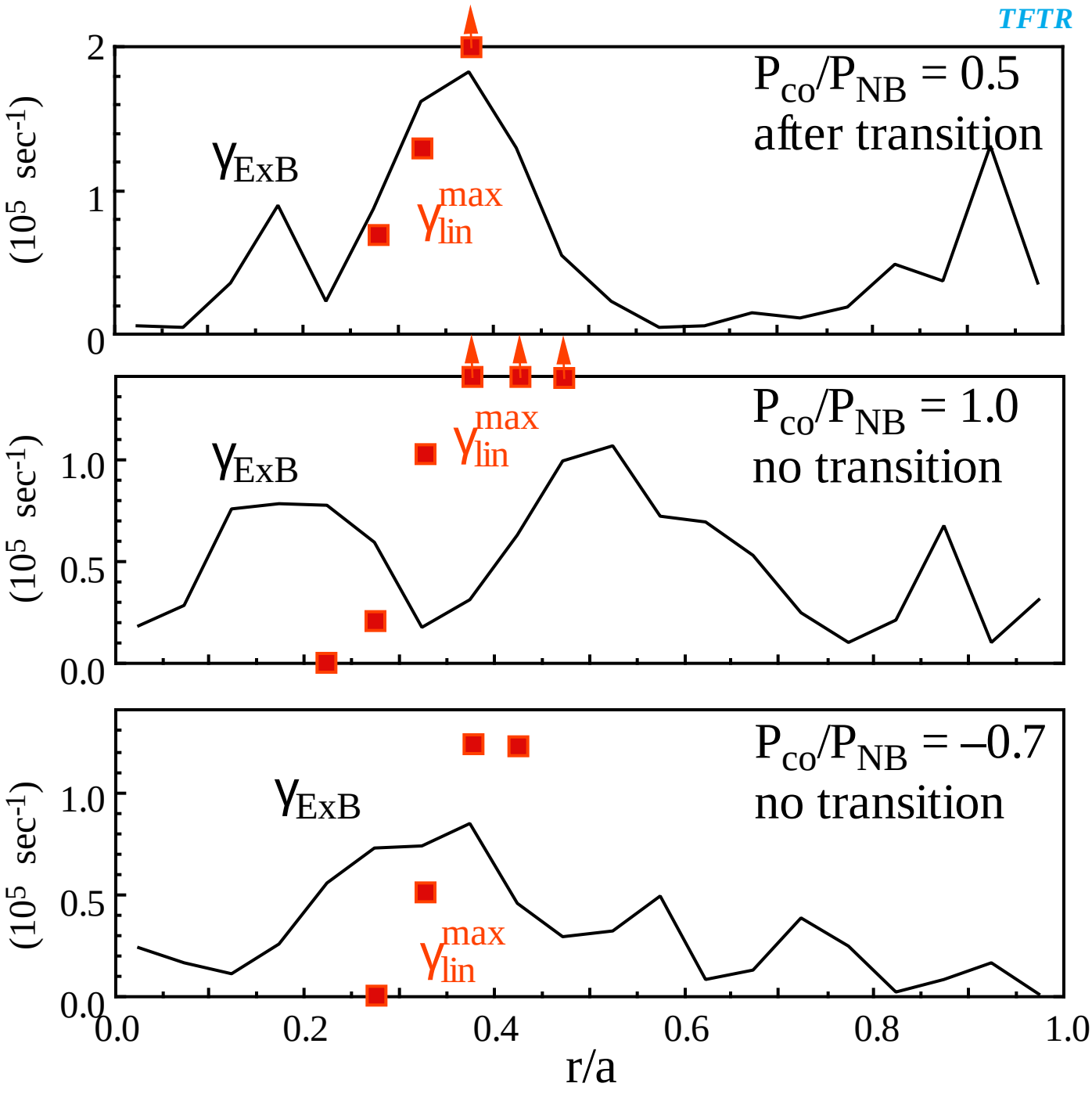
– may imply that some other mechanism causes bifurcation

Strongly Unbalanced NBI Raises Threshold Power



- E_r dominated by imposed rotation
- Transition can be obtained with P_{NB}=16.5 MW and P_{co}/P_{NB} = 0.7
- I_P = 1.2 MA, B_T = 3.4 T

Transitions not observed with strongly unbalanced even though $\gamma_{ExB} > \gamma_{lin}^{max}$



- Not as expected from model
  - indicates bifurcation requires more than $\gamma_{ExB} > \gamma_{lin}^{max}$
- parallel flow destabilization?

Summary

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- ERS bifurcation model of turbulence suppression due to
  - sheared-ExB flow, as characterized by $\gamma_{ExB} > \gamma_{lin}^{max}$
  - Shafranov-shift stabilization

is generally consistent with high-B ERS transitions
  - as discussed by E. Synakowski and M. Beer

- It is inconsistent with
  - observed B^2 dependence of power threshold: γ_{ExB} is not high enough at low B.
  - lack of observed transition in strongly rotating plasmas: γ_{ExB} is high-enough to stabilize.

Need
  - Continue improvement of models e.g. including ExB shear and velocity effects in realistic turbulence simulations.
  - Development of better characterizations than $\gamma_{ExB} > \gamma_{lin}^{max}$