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FORMATION, EVOLUTION AND DEGRADATION OF THE TRANSPORT BARRIER IN TFTR REVERSED SHEAR DISCHARGES

G. Taylor, R.E. Bell, C.E. Bush, H.K. Park,
E.J. Synakowski, S.D. Scott

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ABSTRACT

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Enhanced reversed shear (ERS) plasmas in TFTR exhibit a transition to improved core confinement within a transport barrier located near the minimum magnetic shear radius. This transport barrier has been sustained for over 350 ms in a quasi-stationary state by 14 - 15 MW of neutral beam power. With counter-dominated or balanced neutral beam injection, the ERS phase is terminated by a large, off-axis, magnetic reconnection which can occur up to 100 ms after the end ofneutral beam heating. Controlled back transitions from the ERS regime have been induced by predominantly (80 - 100%) co-injected beam heating, resulting in a relatively gradual degradation of the transport barrier. This paper will discuss the behavior of the electron and ion profiles (n_e, T_i, T_e, etc.) and other inferred quantities (D_e, χ_i, etc.) as the transport barrier forms and evolves.

OVERVIEW

- Abrupt transition to enhanced core confinement in TFTR plasmas with reversed magnetic shear - Enhanced Reversed Shear (ERS).
- ERS plasmas exhibit steep transport barriers near region of minimum magnetic shear (r/a ~ 0.3 - 0.5).
- ERS transitions obtained with beam power ~ 28 MW and low applied beam torque:
    - Transport barrier evolution studied during subsequent 14 MW "postlude" heating phase.
    - Beam torque varied at constant beam power during postlude.

- Transport barrier evolution in postlude sensitive to beam torque:
  - Postludes with counter-dominated or balance beam injection terminated by off-axis MHD.
  - Postludes with predominantly co-injection exhibit gradual back transition from ERS regime.
- By varying beam torque, can change toroidal velocity and hence radial electric field:
  - Can separate ExB shear and Shafranov shift as cause of enhanced core confinement.
  - Find transport levels remain low over a wide range of radial electric field.
  - Changes in ExB shear clearly precede changes in core confinement.

REVERSED SHEAR PLASMA GENERATED BY BEAM HEATING DURING CURRENT RAMP

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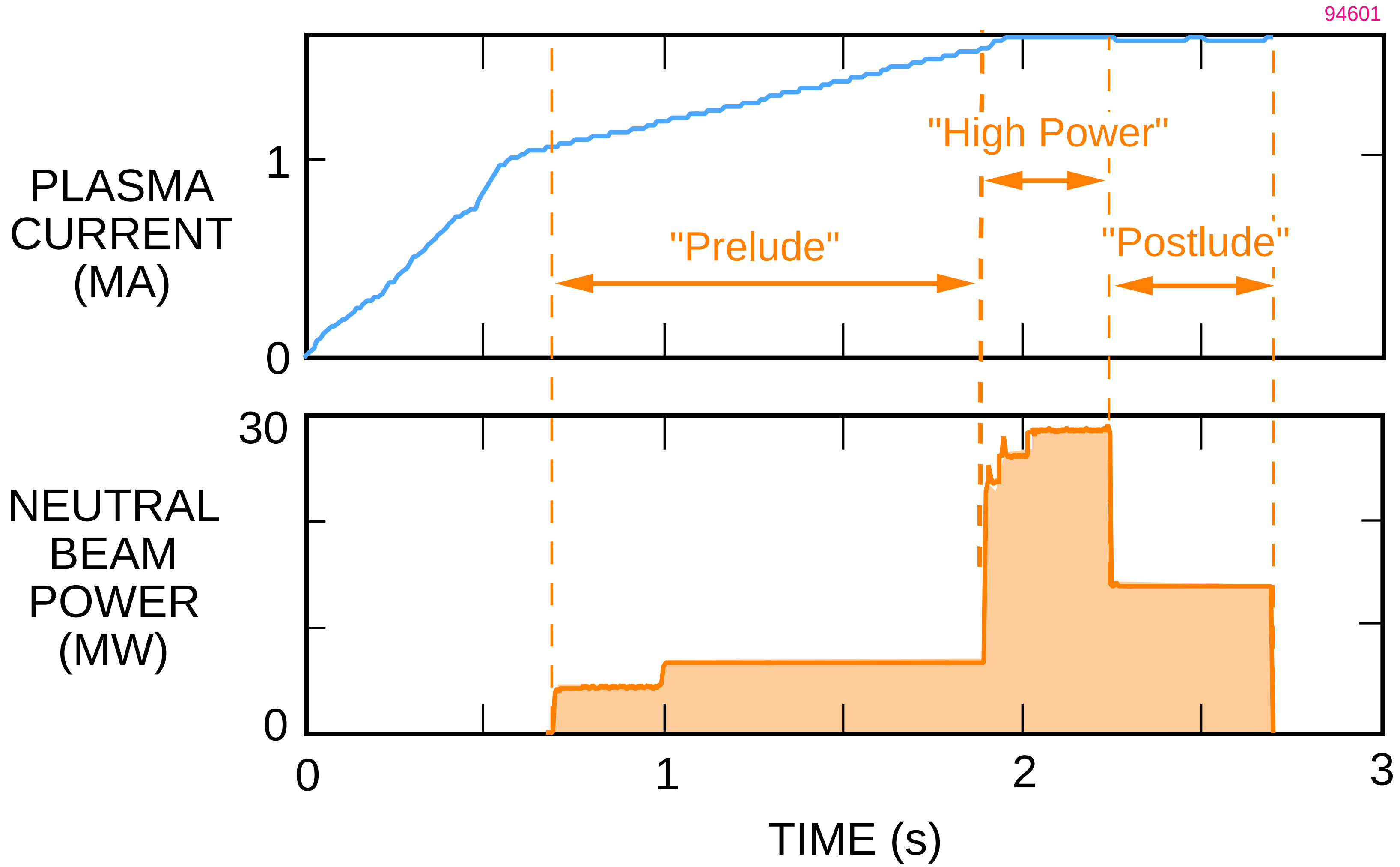
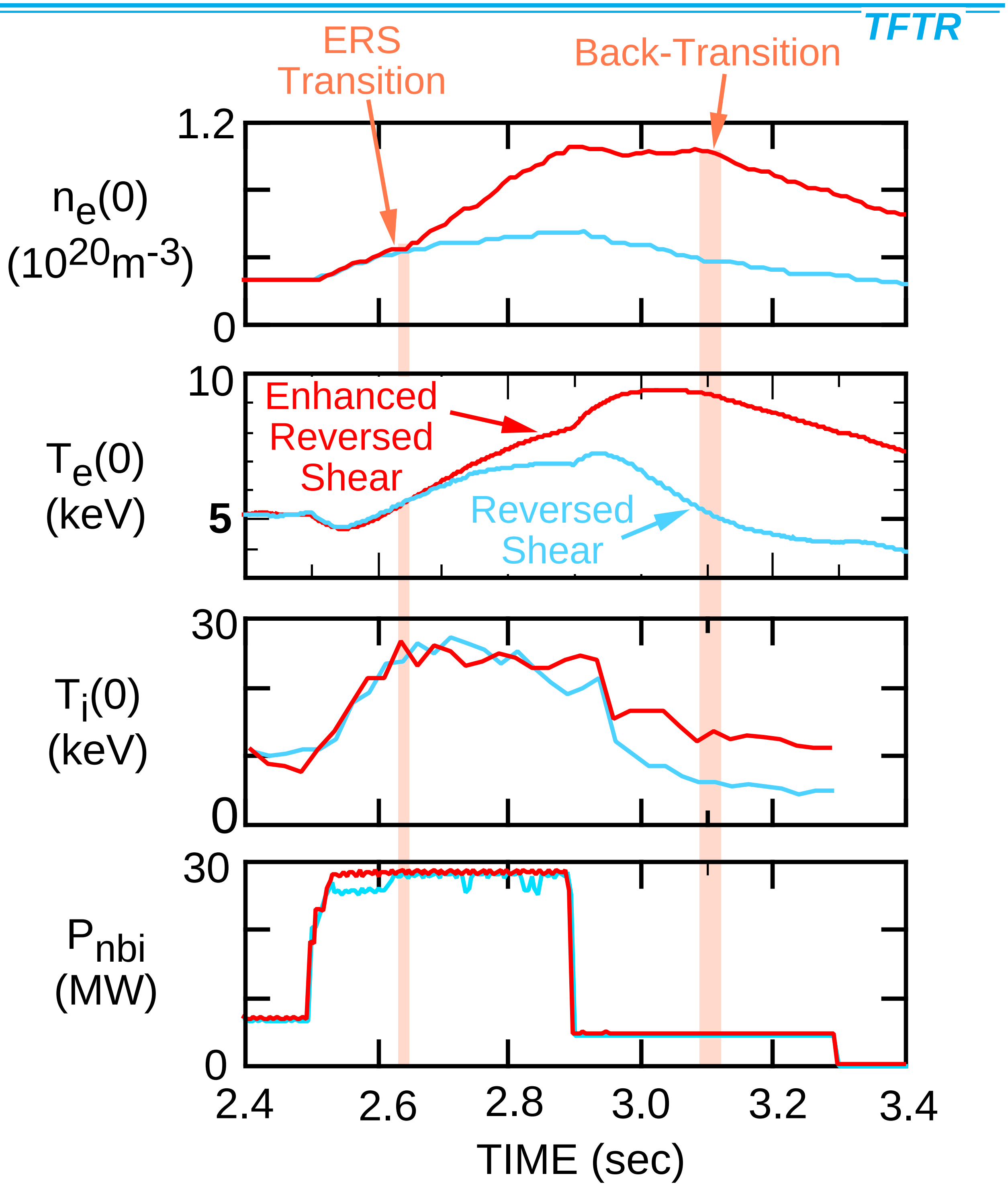


NEW CONFINEMENT REGIME OBSERVED ON TFTR WITH REVERSED SHEAR



- Abrupt transition to reduced particle and thermal transport in Enhanced Reversed Shear (ERS) discharge.

STEEP GRADIENTS IN ELECTRON TEMPERATURE AND DENSITY INDICATE TRANSPORT BARRIER IN ERS PLASMAS

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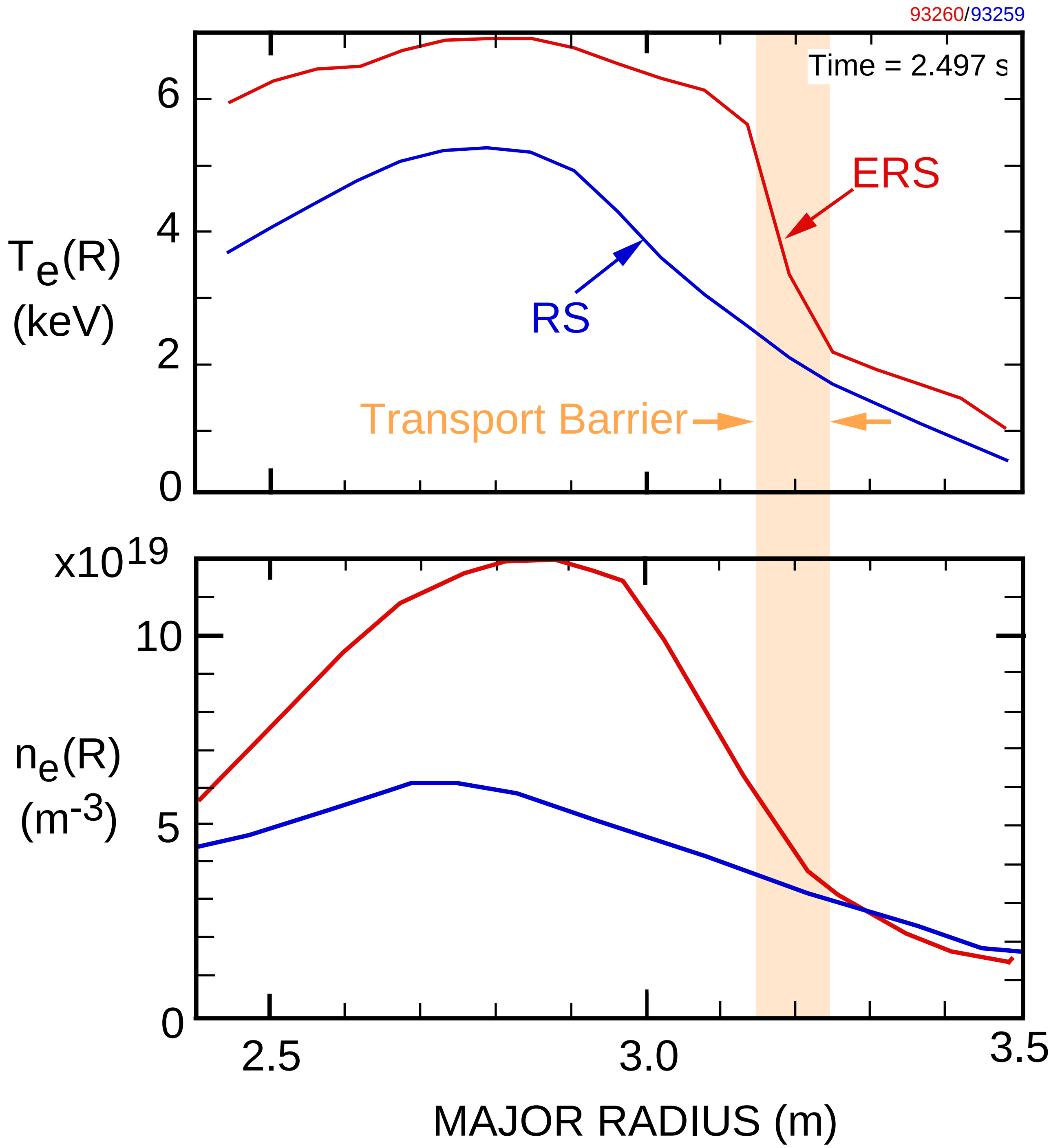

5. Te(R), ne(R) RS/ERS

STEEP ELECTRON TEMPERATURE GRADIENT MEASURED BY ECE IN ERS PLASMAS WITH SMALL RADIAL JOG

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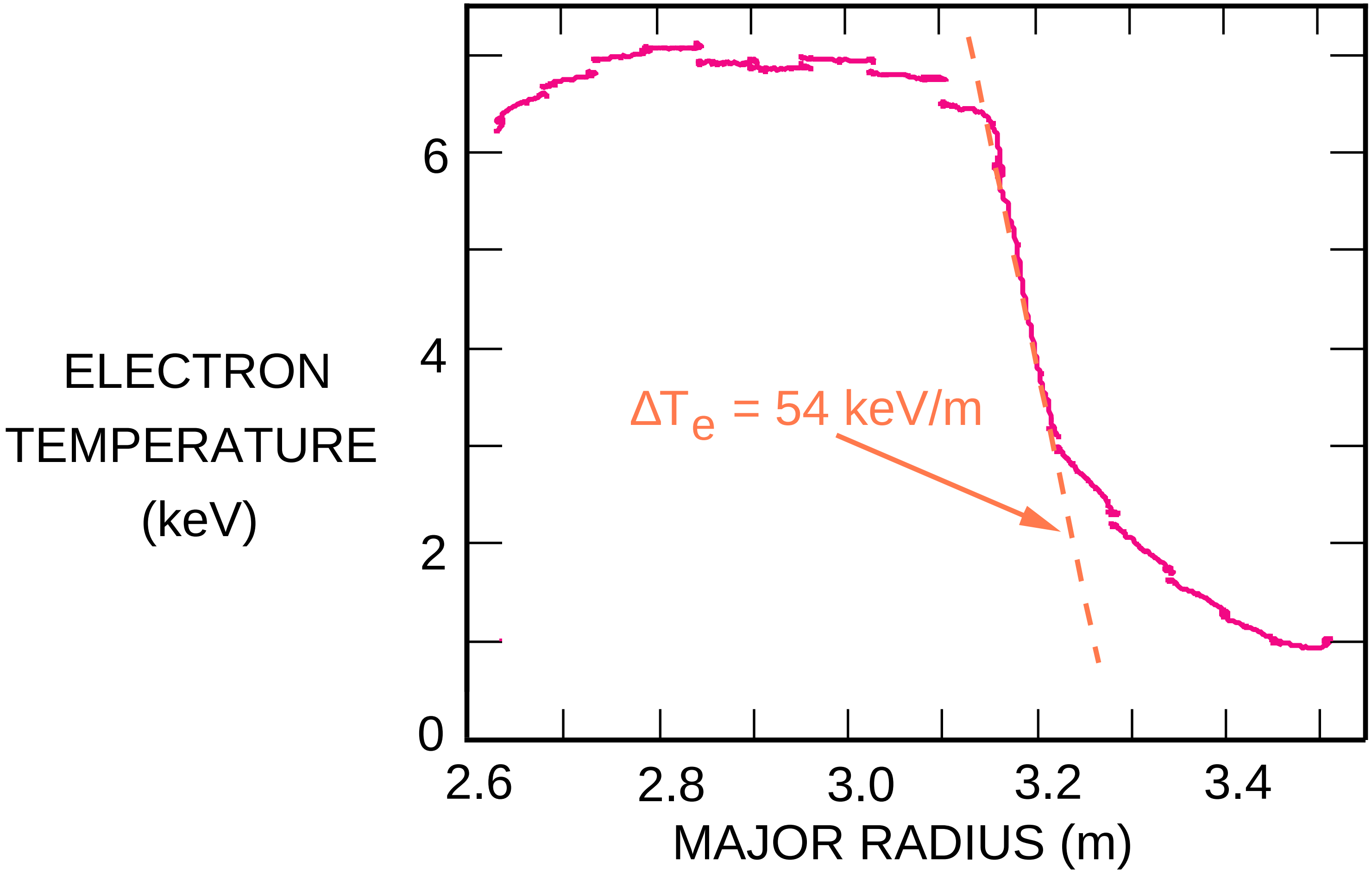

- ERS plasma jogged outwards 0.06 m in 25 ms.
- ECE measured by 20-channel grating polychromator with effective channel spacing ~ 0.05 m.

VARY BEAM CO-FRACTION DURING POSTLUDE TO CHANGE TOROIDAL VELOCITY

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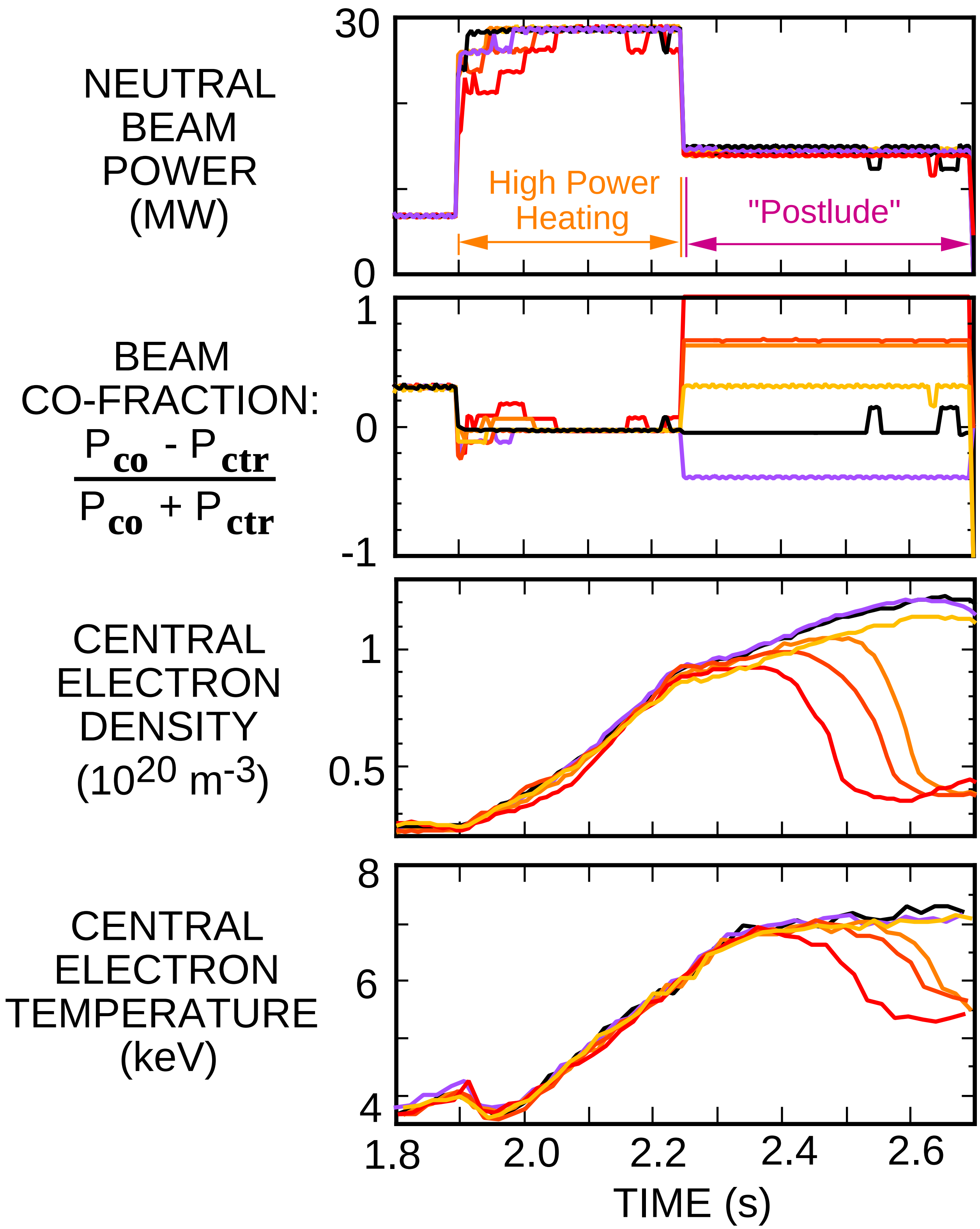

DEGRADATION FROM ERS REGIME OCCURS BEFORE THE END OF CO-DOMINATED POSTLUDE

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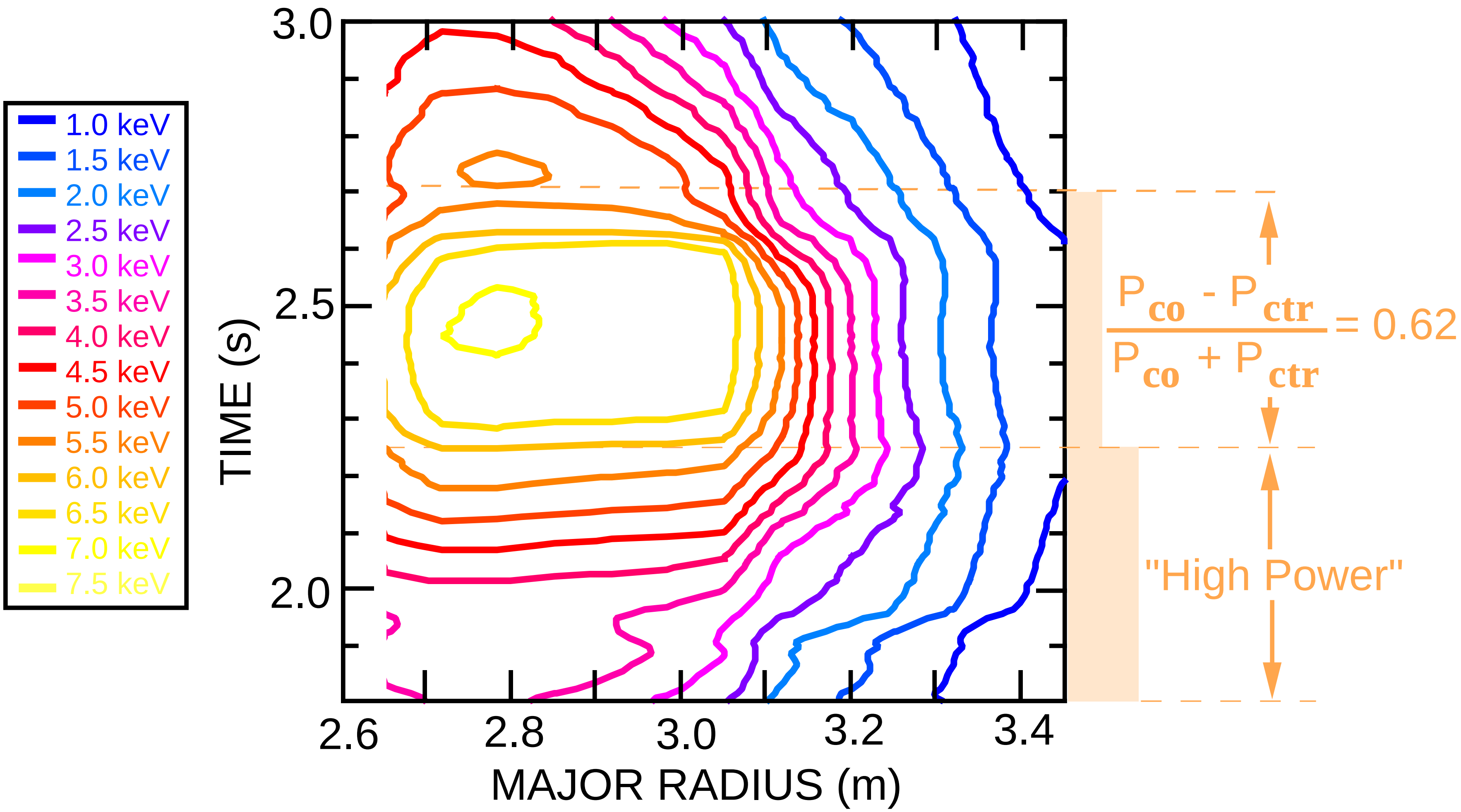
ELECTRON TEMPERATURE CONTOURS



8. 94601 Te Contour

CORE DENSITY RAPIDLY DEGRADES DURING CO-DOMINATED POSTLUDE

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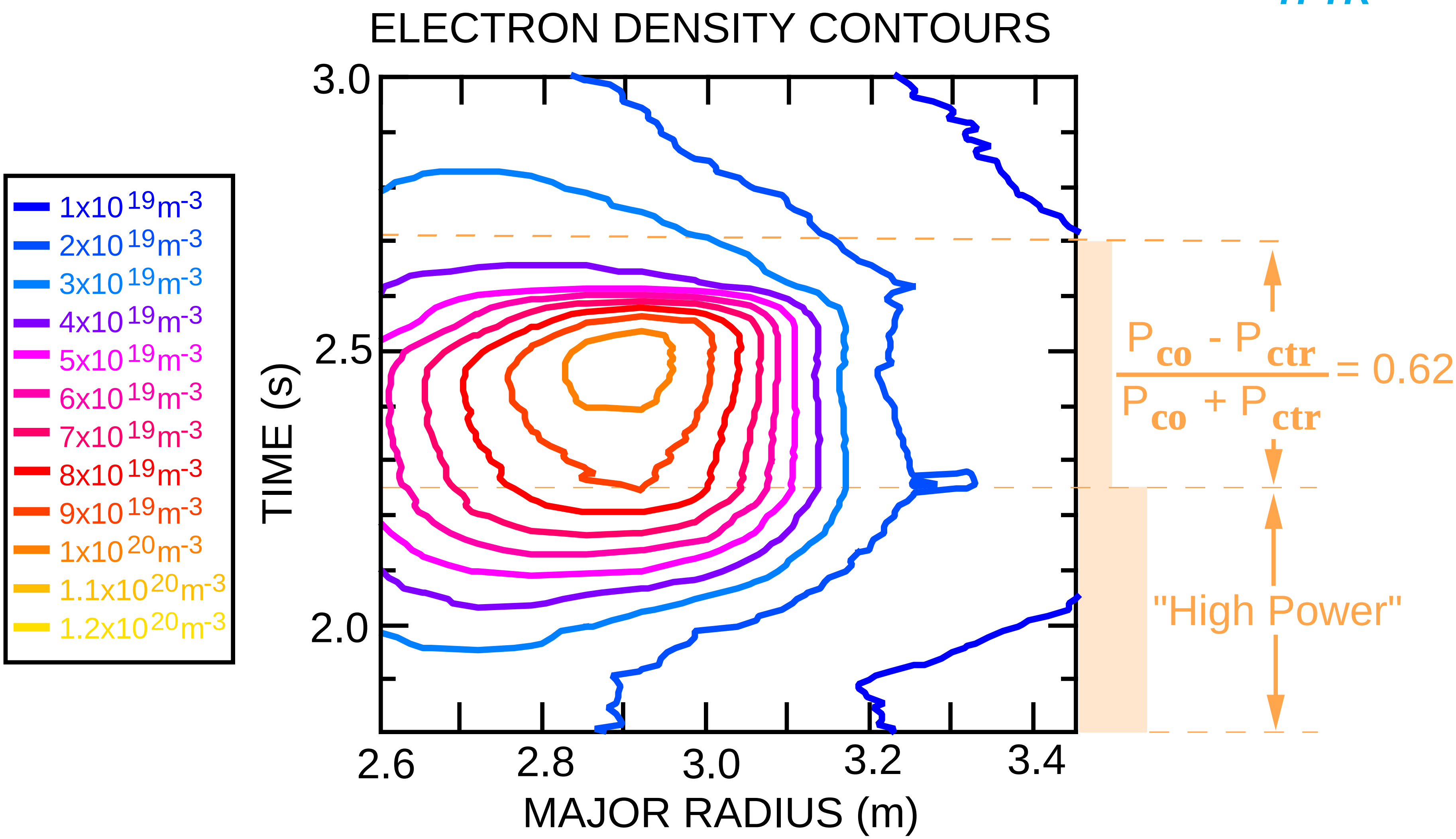

- Electron density degrades before electron temperature during co-dominated postlude.

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CO-DOMINATED POSTLUDES EXHIBIT CONTROLLED BACK-TRANSITIONS FROM ERS REGIME

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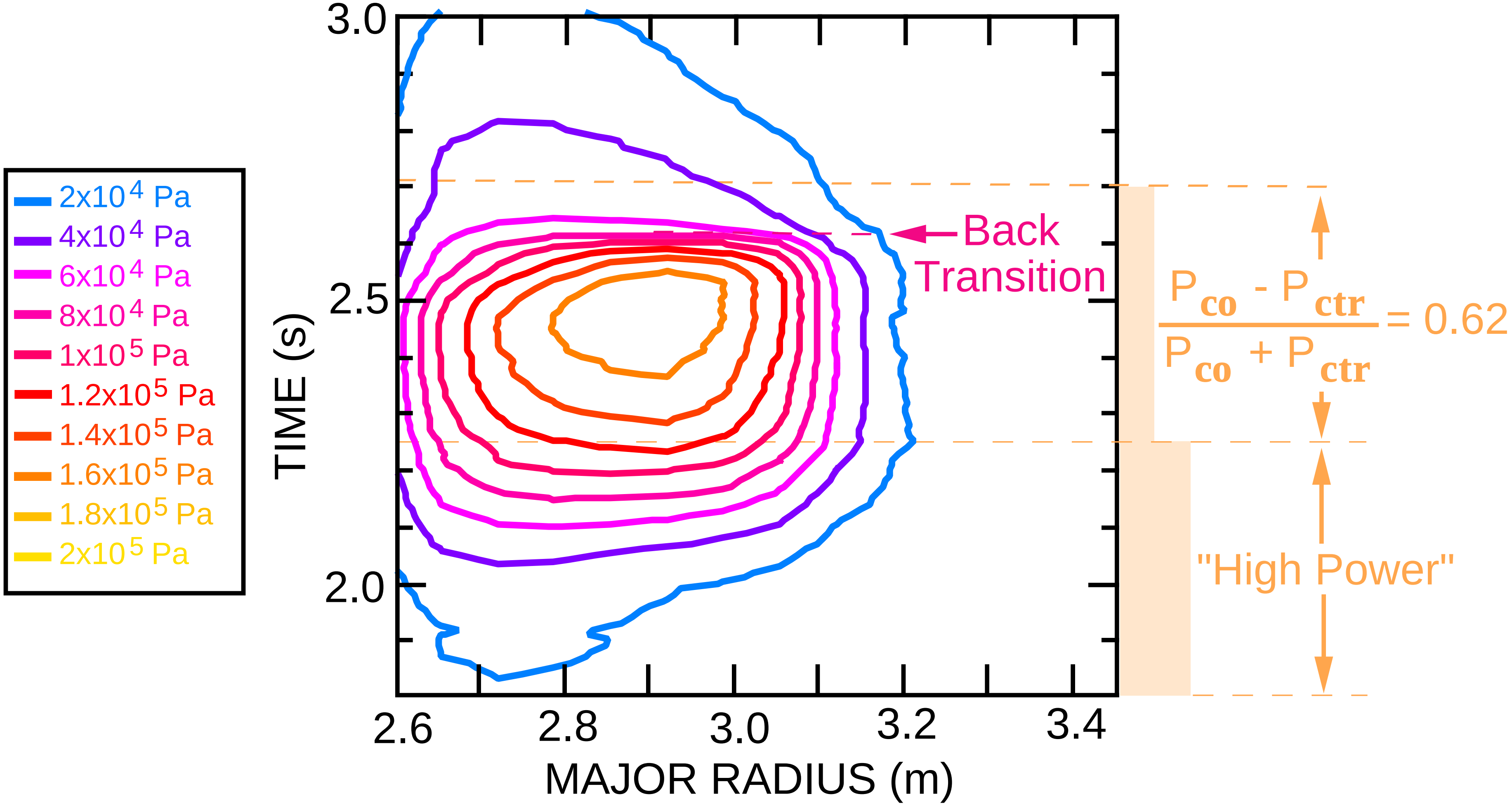
ELECTRON PRESSURE CONTOURS



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ERS MODE PERSISTS BEYOND BALANCED INJECTION POSTLUDE

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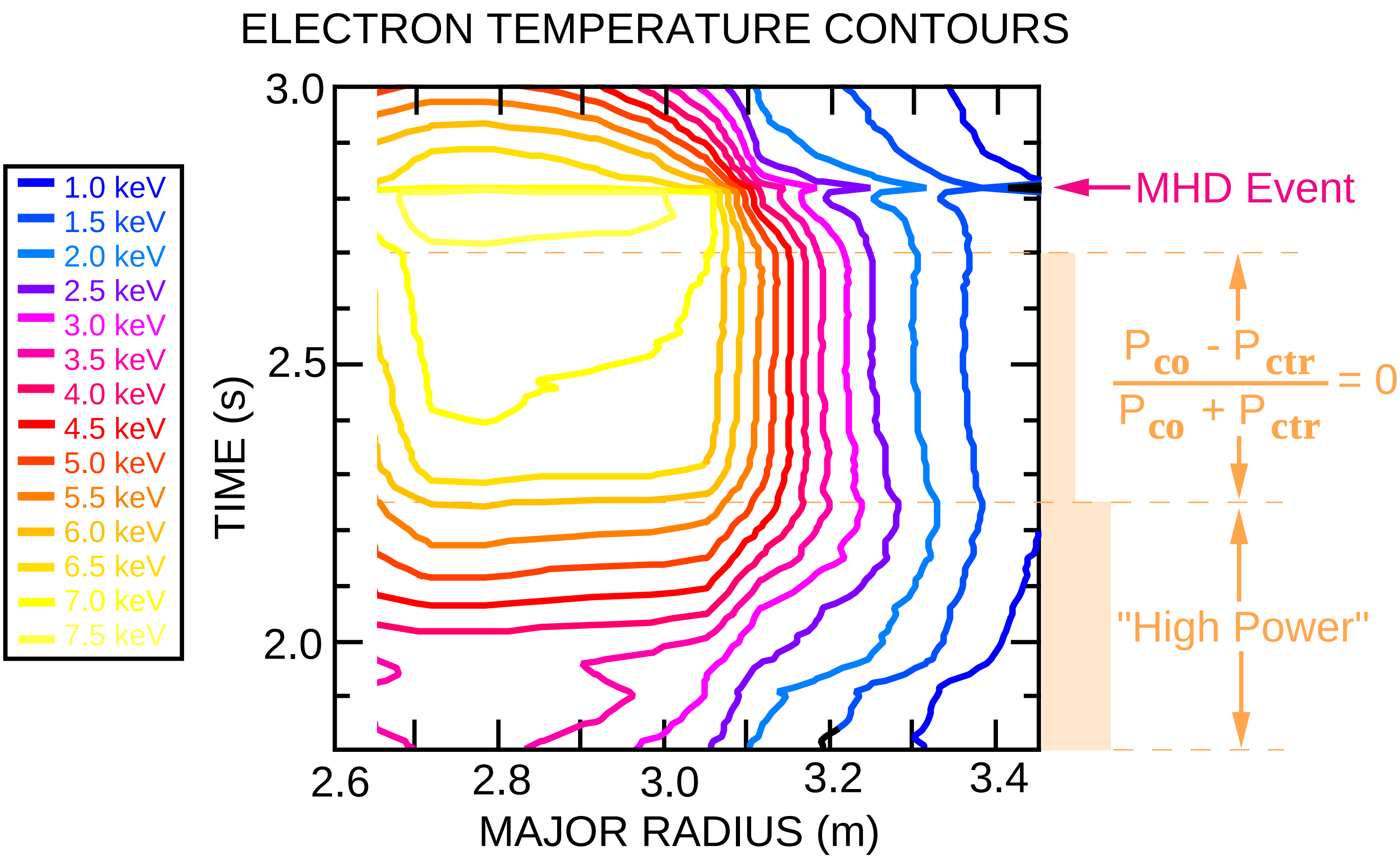

• ERS mode terminated by off-axis MHD event.

CORE ELECTRON DENSITY RISES THROUGHOUT BALANCED INJECTION POSTLUDE

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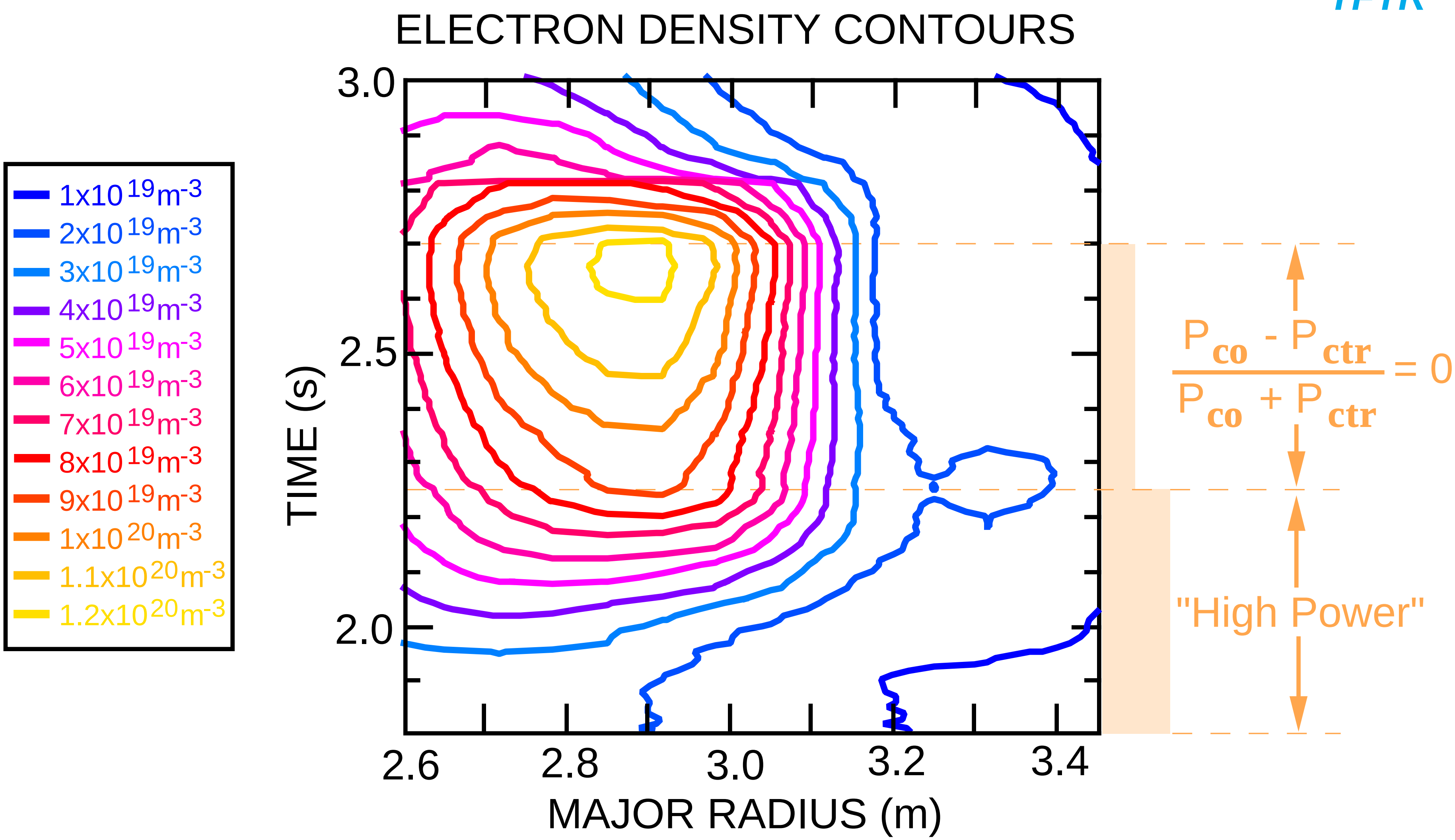

12. 94603 Ne Contour

CORE ELECTRON PRESSURE RISES TROUGHOUT BALANCED INJECTION POSTLUDE

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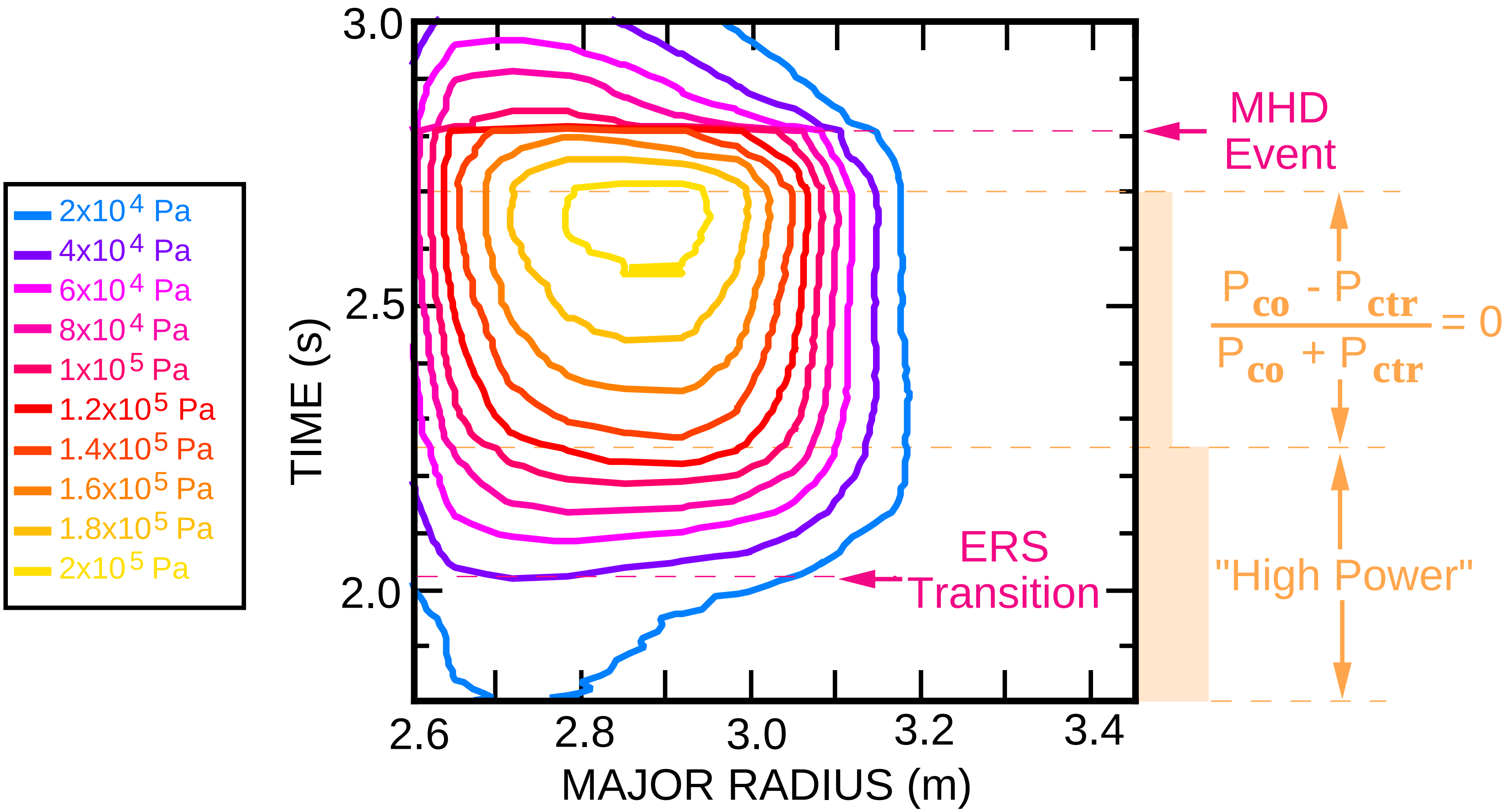
ELECTRON PRESSURE CONTOURS



- Steep electron pressure gradient at R ~ 3.05 m persists throughout balanced injection postlude.

OFF-AXIS MHD OBSERVED WITHIN THE TRANSPORT BARRIER 200μS BEFORE CORE TEMPERATURE COLLAPSE

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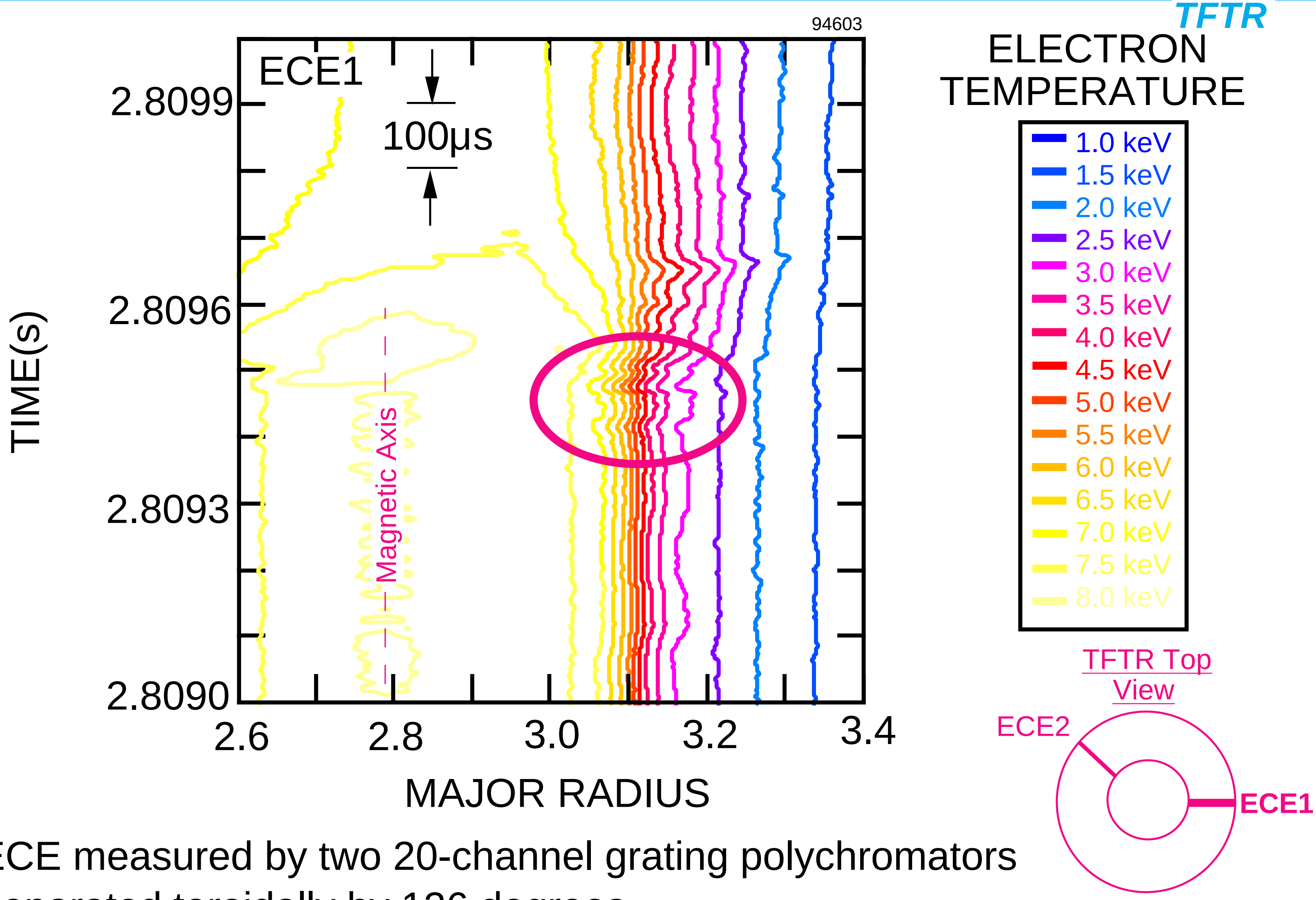

- ECE measured by two 20-channel grating polychromators separated toroidally by 126 degrees.

TRANSPORT BARRIER DEGRADES DURING POSTLUDE HEATING PHASE WITH CO-DOMINATED INJECTION

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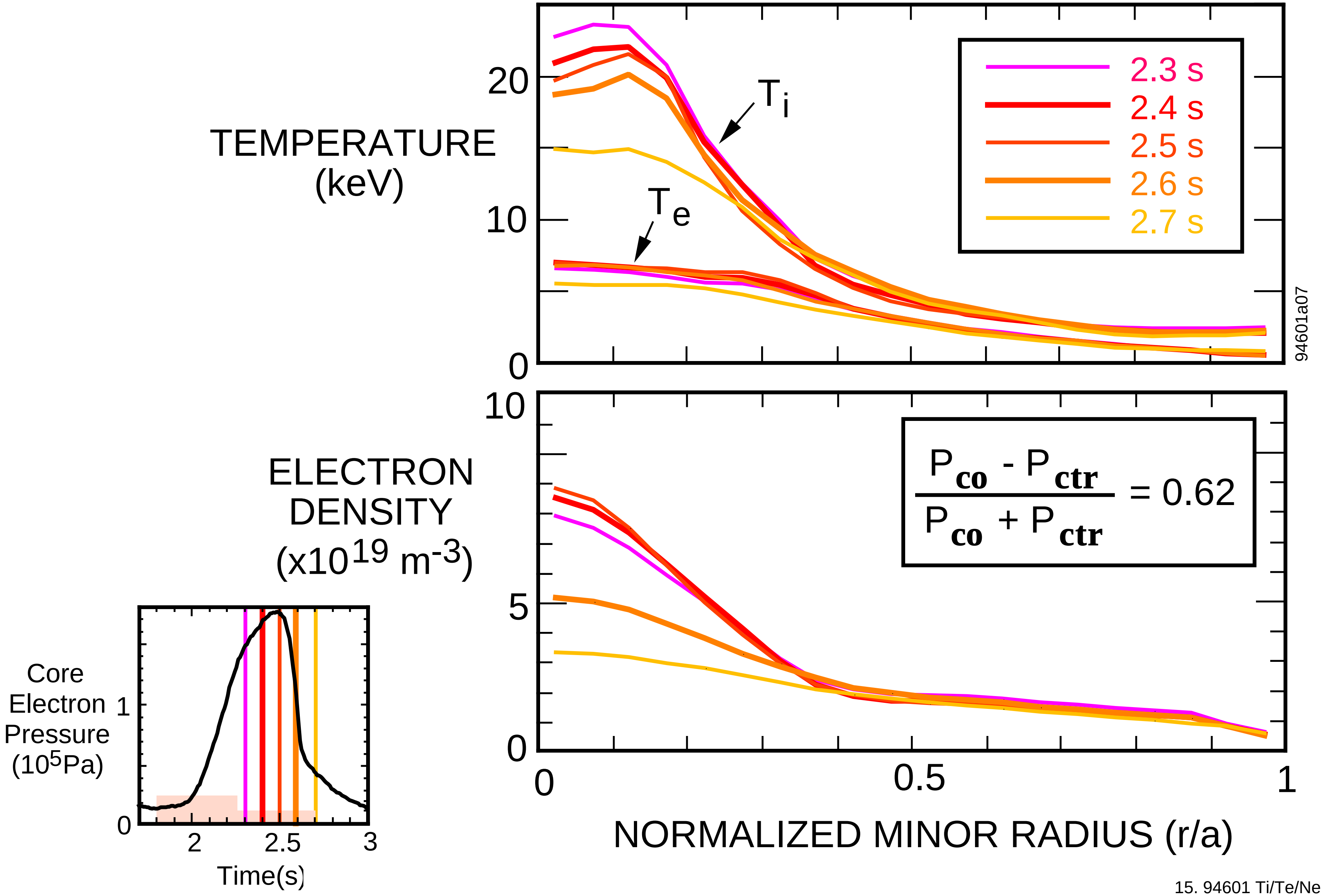

15. 94601 Ti/Te/Ne

TRANSPORT BARRIER DEGRADES DURING CO-DOMINATED POSTLUDE EVEN THOUGH REVERSED SHEAR PROFILE PERSISTS

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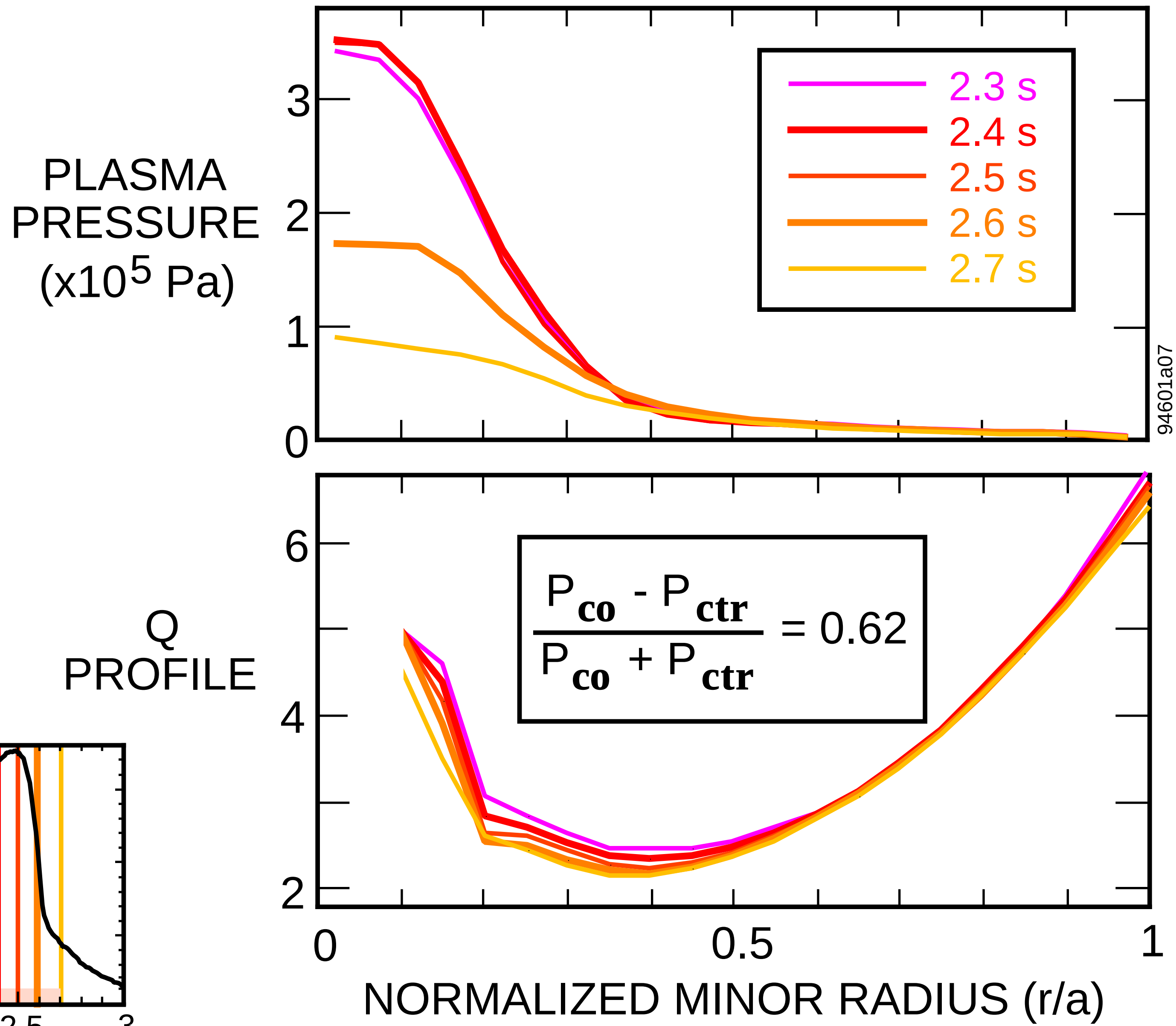

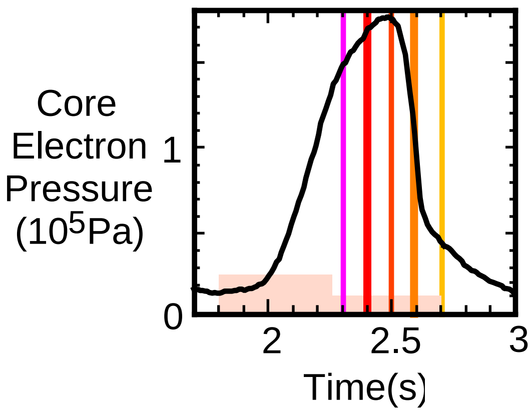

16. 94601 Pres/q

TIME DEPENDENT KINETIC ANALYSIS

- Analysis of ERS plasmas performed with the TRANSP time dependent kinetic code.
- TRANSP used direct measurement of current density profile during prelude heating phase measured by motional Stark effect (MSE) diagnostic:
    - TRANSP used to extrapolate current density profile during high power heating phase
- Carbon density profile measured by charge exchange recombination spectroscopy (CHERS).

AS TRANSPORT BARRIER DEGRADES LARGE INCREASE IN ION HEAT DIFFUSIVITY NEAR CORE

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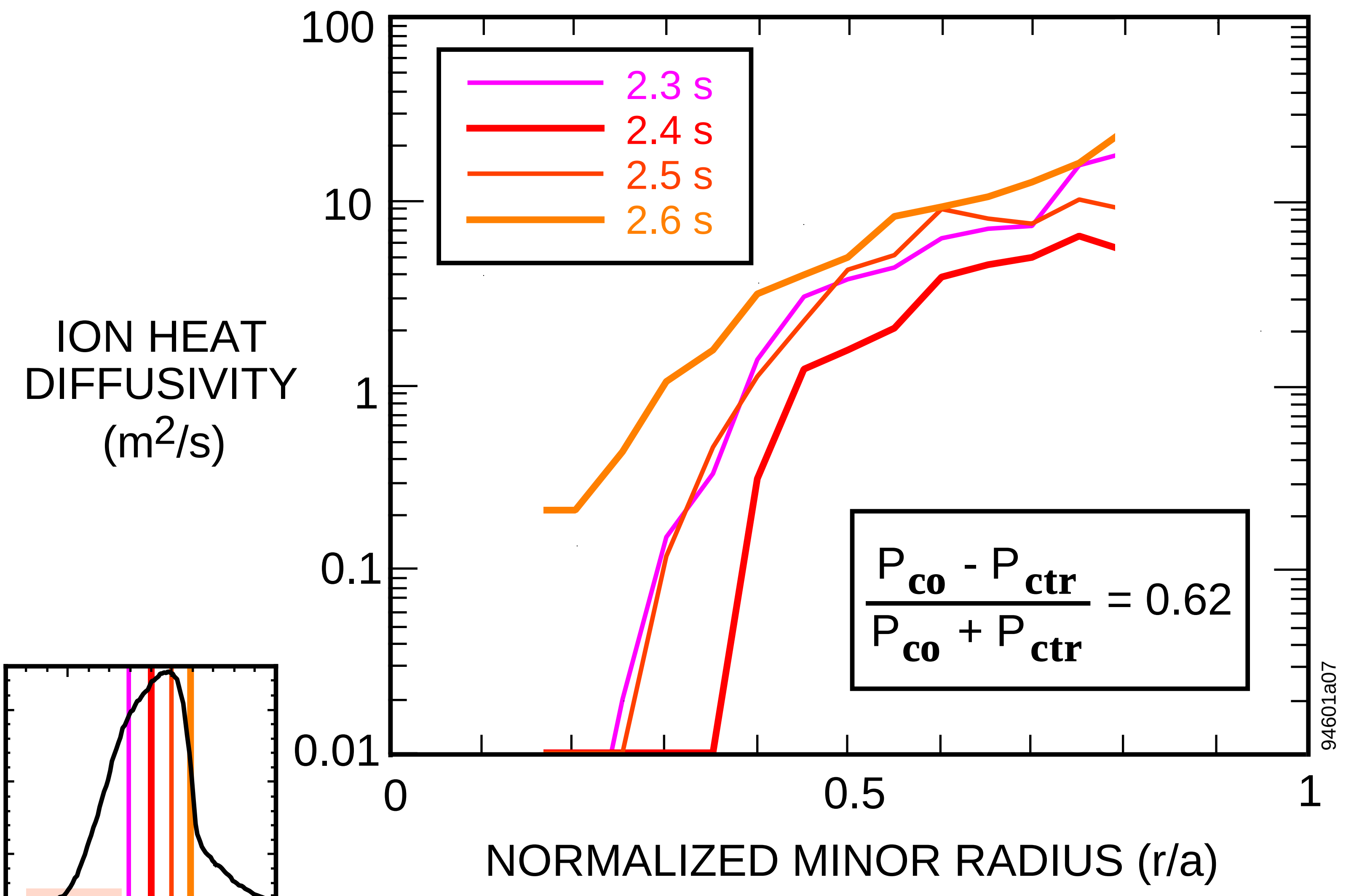

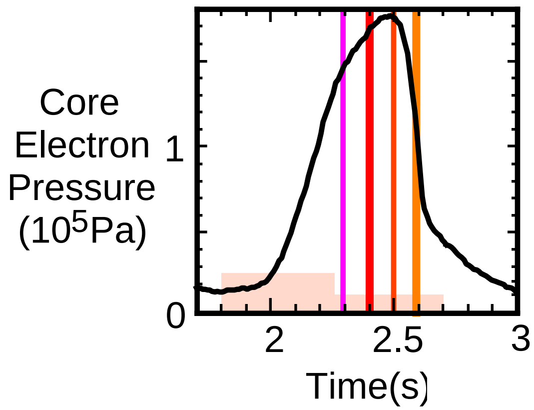

ELECTRON HEAT DIFFUSIVITY SHOWS NO INDICATION OF THE TRANSPORT BARRIER

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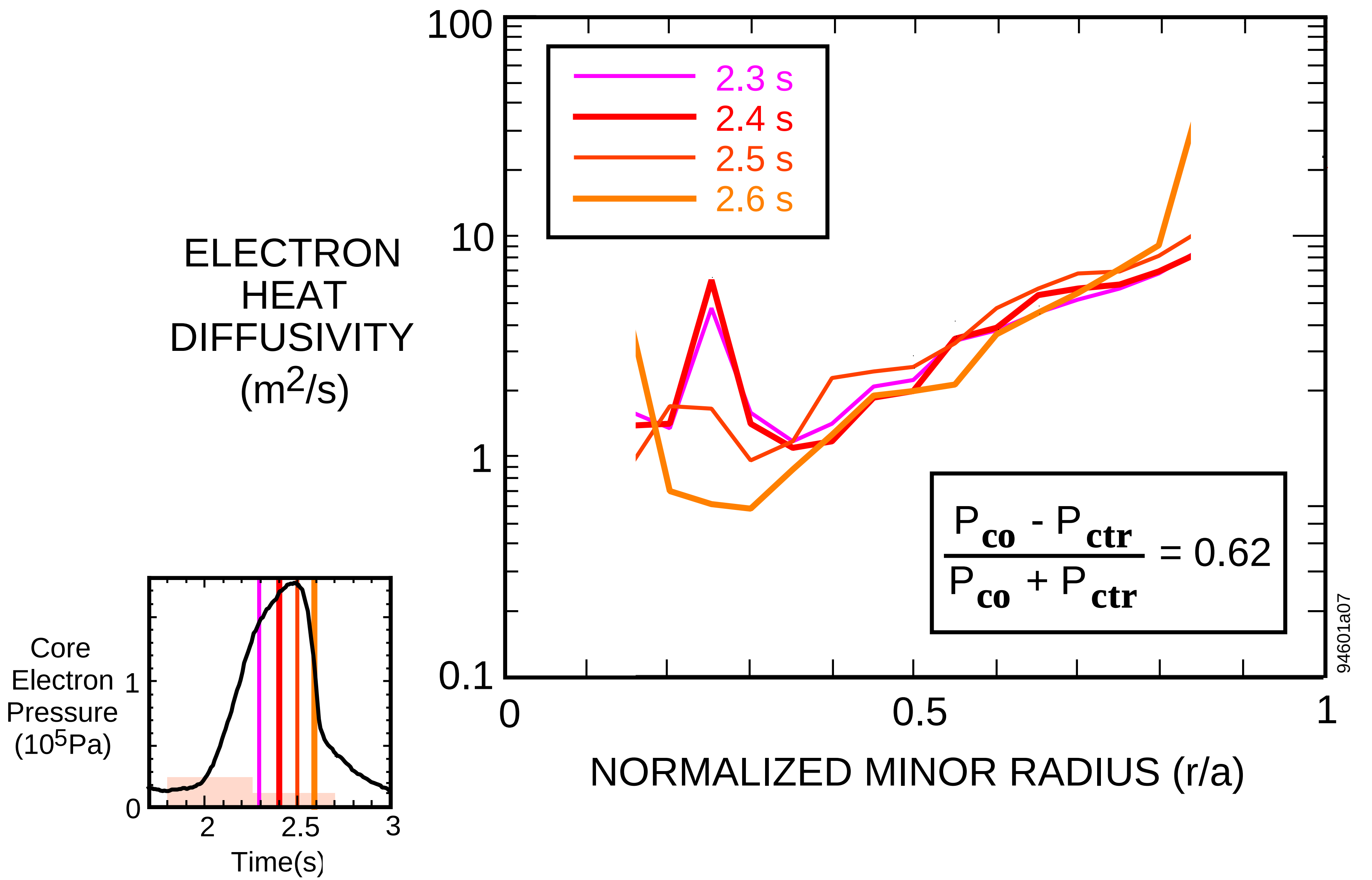

CORE PARTICLE DIFFUSIVITY INCREASES SIGNIFICANTLY AS TRANSPORT BARRIER DEGRADES

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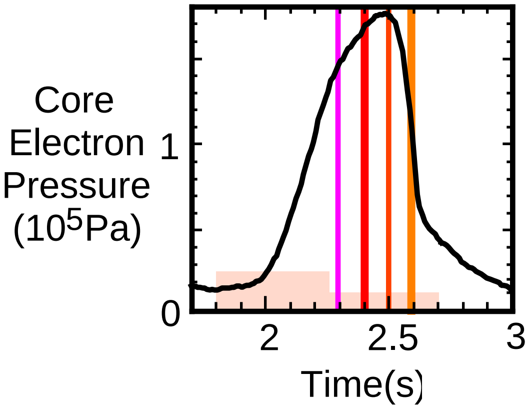

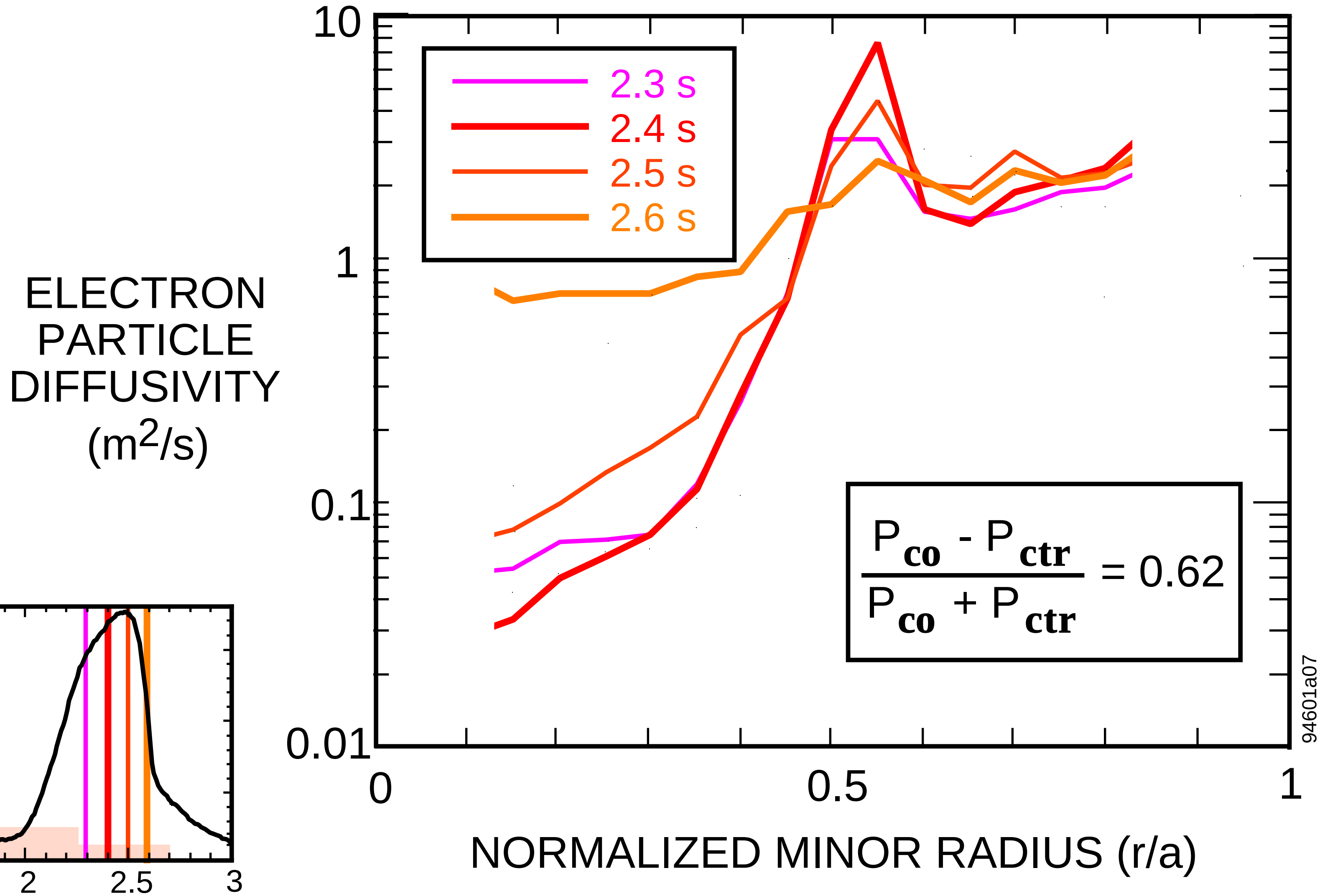

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E_r CAN BE VARIED BY CHANGING THE TOROIDAL VELOCITY (V_φ)

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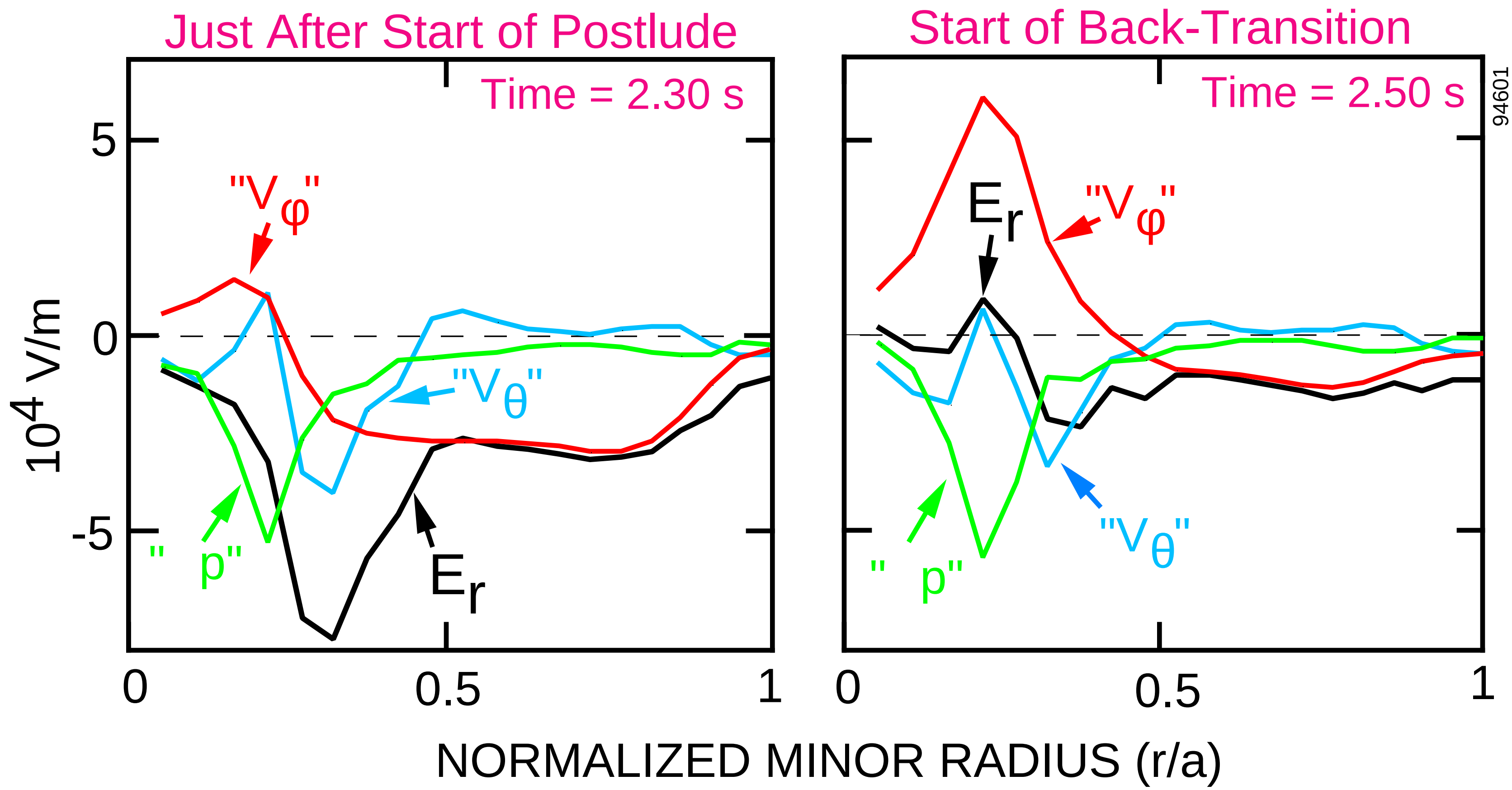

$$E_r = 1/(n_c Z_c)\ \ p_c + V_\varphi B_\theta - V_\theta B_\varphi$$

$$\frac{P_{\mathbf{co}} - P_{\mathbf{ctr}}}{P_{\mathbf{co}} + P_{\mathbf{ctr}}} = 0.62$$

CHANGES IN ExB SHEAR CLEARLY PRECEDE CHANGES IN CORE CONFINEMENT

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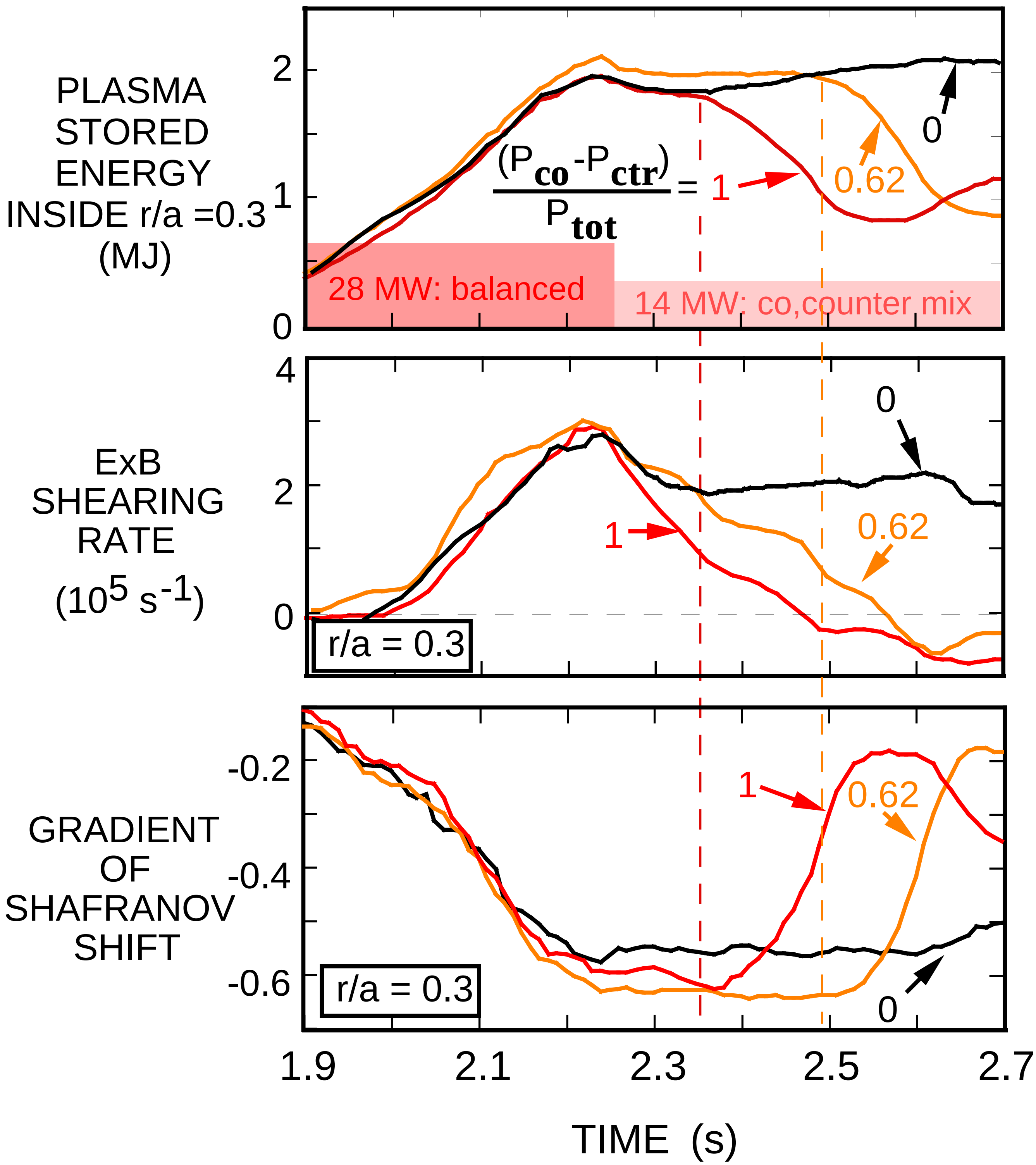

ExB SHEAR, NOT SHAFRANOV SHIFT PLAYS FUNDAMENTAL ROLE IN DEGRADATION OF TRANSPORT BARRIER

- Loss of core confinement occurs at similar values of ExB shear.

- ExB shear, not toroidal velocity shear, plays fundamental stabilizing role:

    - toroidal velocity shear actually maximum at back-transition.

- No change in Shafranov shift or heating and pressure profiles before back-transition.

See Invited Paper 2IB.01, ***"Local Transport Barrier Formation and Relaxation in Reversed Shear Plasmas on TFTR"*** **- E.J. Synakowski**

SUMMARY

- Reversed shear plasmas can exhibit a steep internal transport barrier.

- Transport barrier evolution depends on applied beam torque:
    - Terminated by off-axis MHD with counter or balanced beam injection.
    - Gradual degradation with co-dominated beam injection.

- Can vary beam torque to separate ExB shear from Shafranov shift.

- Change in ExB shear precedes barrier degradation.