Deuterium-Tritium Plasmas in Novel Regimes in TFTR[1]

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Topics

- Enhanced Reversed-Shear (ERS) regime
- High internal-inductance (High-l_i) plasmas at high current
- Scaling of fusion reactivity and confinement between D and D-T
- Alpha-particle physics

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Increased Stability Can Extend D-T Performance and Studies of Alpha-Particle Physics

- TFTR D-T experiments:
  - Effects of tritium on plasma confinement
  - Validating ability to project D-T performance in future
  - Alpha-particle physics

  Require high T concentrations and high fusion reactivity.

- TFTR supershot regime is limited by stability

- Two routes to increased stability by modifying current profile:
  - Reversed shear in core, $q_0 > 1$
  - Increase internal inductance, $q_0 < 1$

Experiments in 1996 Have Explored Two Advanced Regimes With High Confinement

Reversed-shear

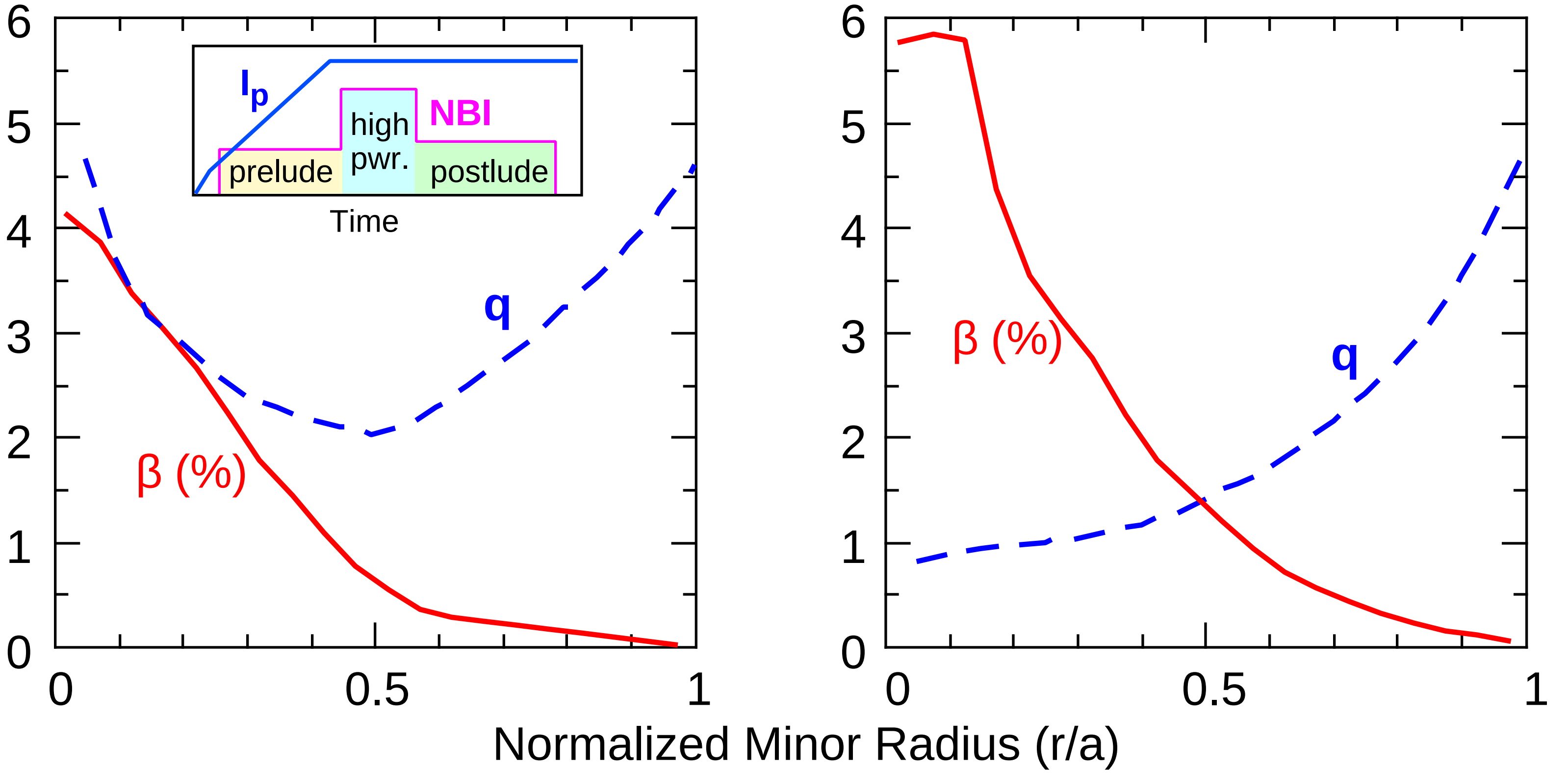
$\tau_E = 0.23\text{s}$

NBI heating during current ramp in large plasma

High-l_i

$\tau_E = 0.23\text{s}$

Low-q startup in small plasma followed by expansion



- Both regimes have NBI fueling, low edge recycling, peaked profiles and $T_i > T_e$

Lower q_a and Higher Current Ramp Rate Increased Region of Shear Reversal and ERS Confinement

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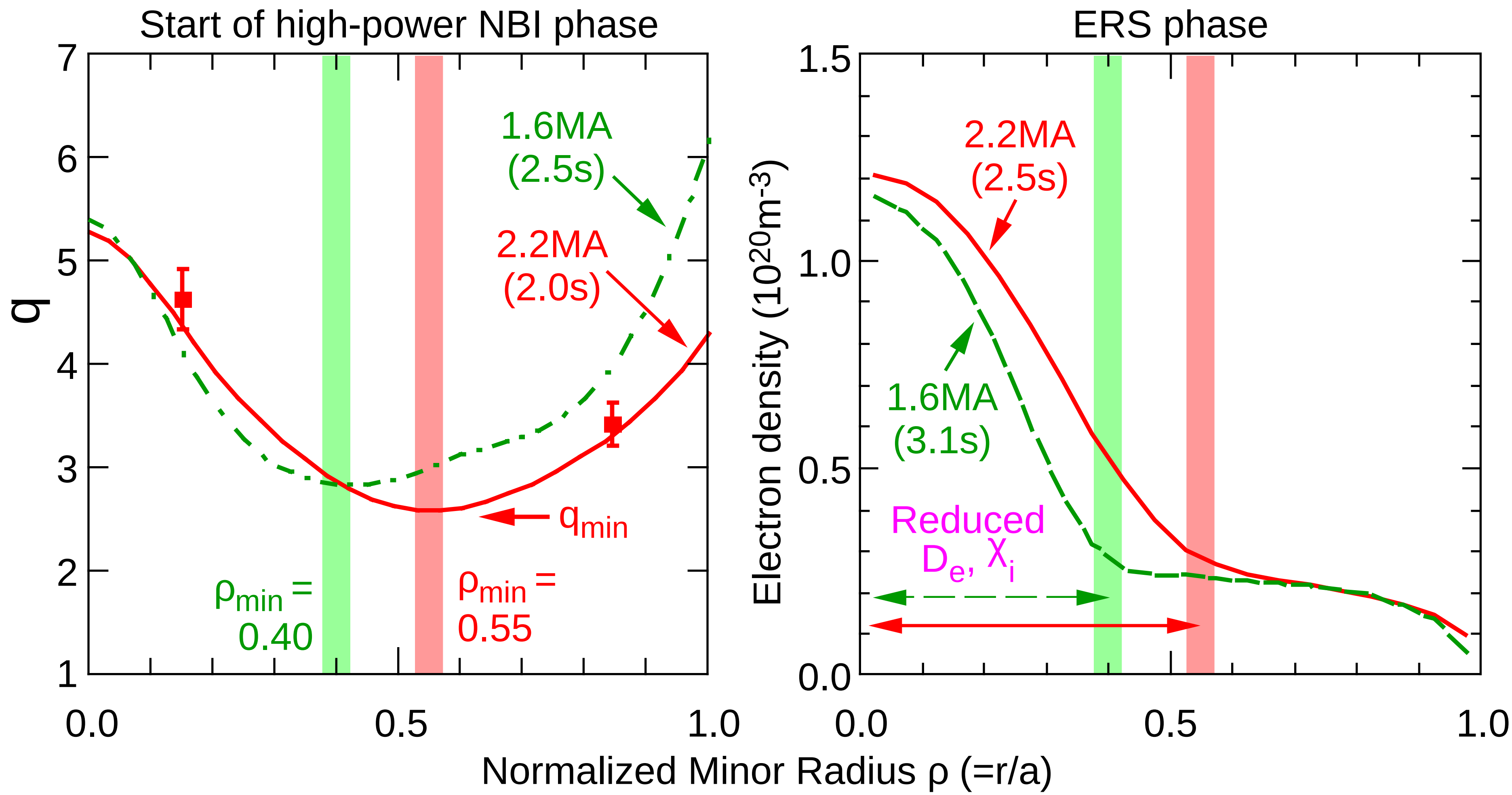

- Location of transport barrier in ERS phase moves with ρ_{min}

Natural Evolution of Pressure and q Profiles Reduces β-Limit During ERS Phase at High Current

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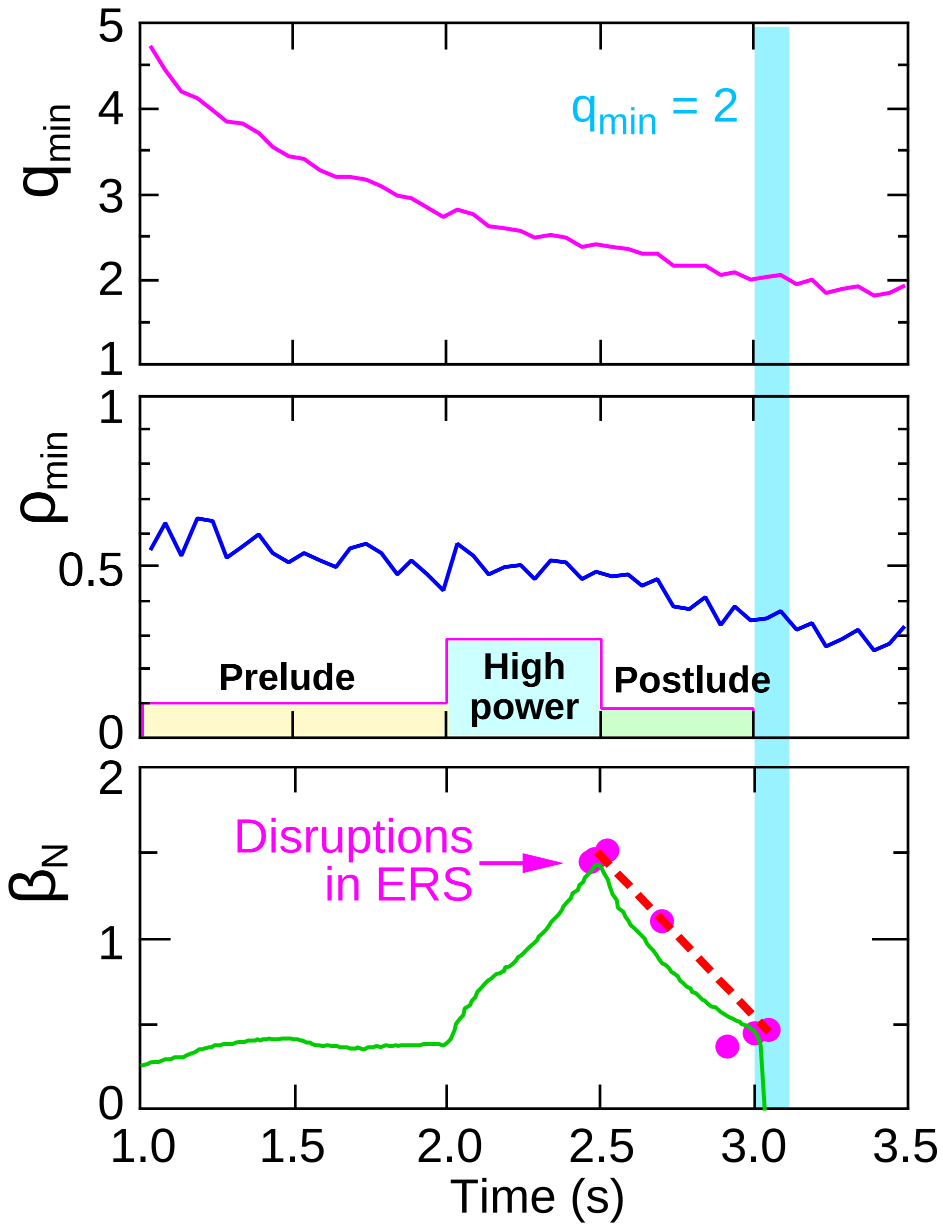

- Large pressure gradient inside ρ_{min} persists even in "postlude" phase
- q_{min}, ρ_{min} both decrease with time
- β-limit is reduced as $q_{min} \rightarrow 2$
- $\beta_N = 2.0$, $\beta^*_N = 4.1$ achieved at 1.6MA
- **Challenge**: control barrier location and shape of q-profile near ρ_{min}

S. Batha, 4F.04; E. Fredrickson, 6IB.01

Injected Lithium Trapped Within Transport Barrier after ERS Transition

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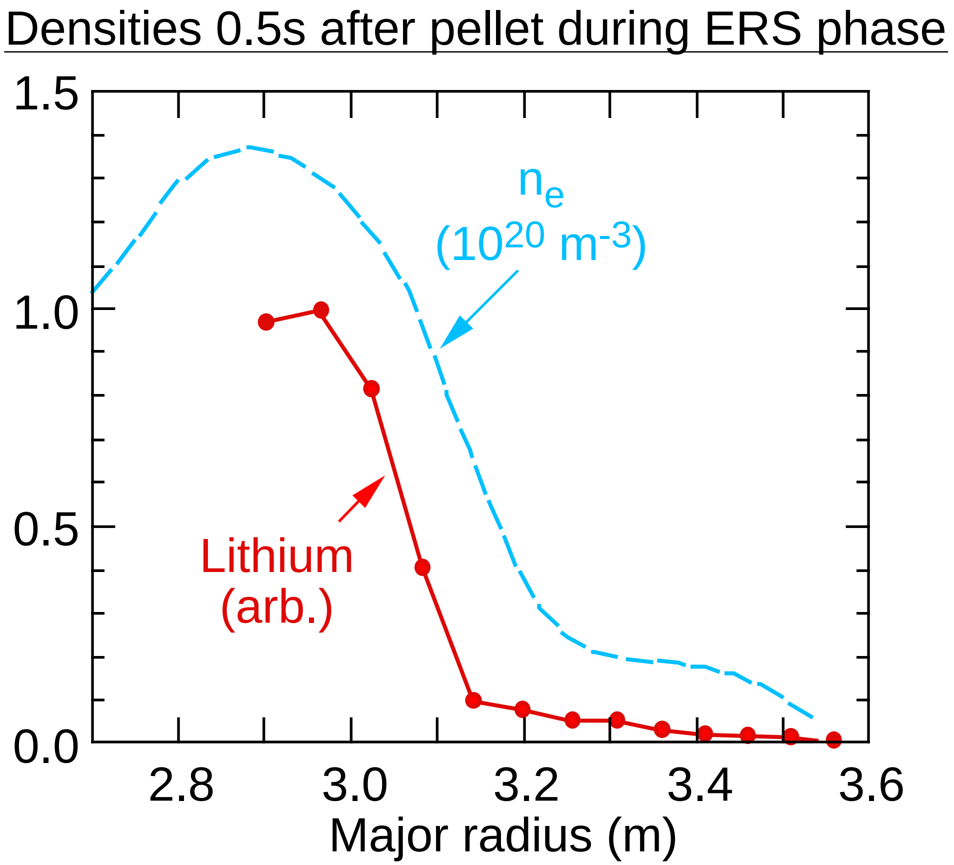
- Power threshold for ERS appears to increase with plasma current
- Lithium pellet at start of HP-NBI necessary to stimulate ERS at 2.2MA



- Suggests an issue for helium ash transport in ignited ERS plasmas

E. Synakowski; A. Ramsey, 1S.12

Higher NB Power Required for ERS Transition in D-T

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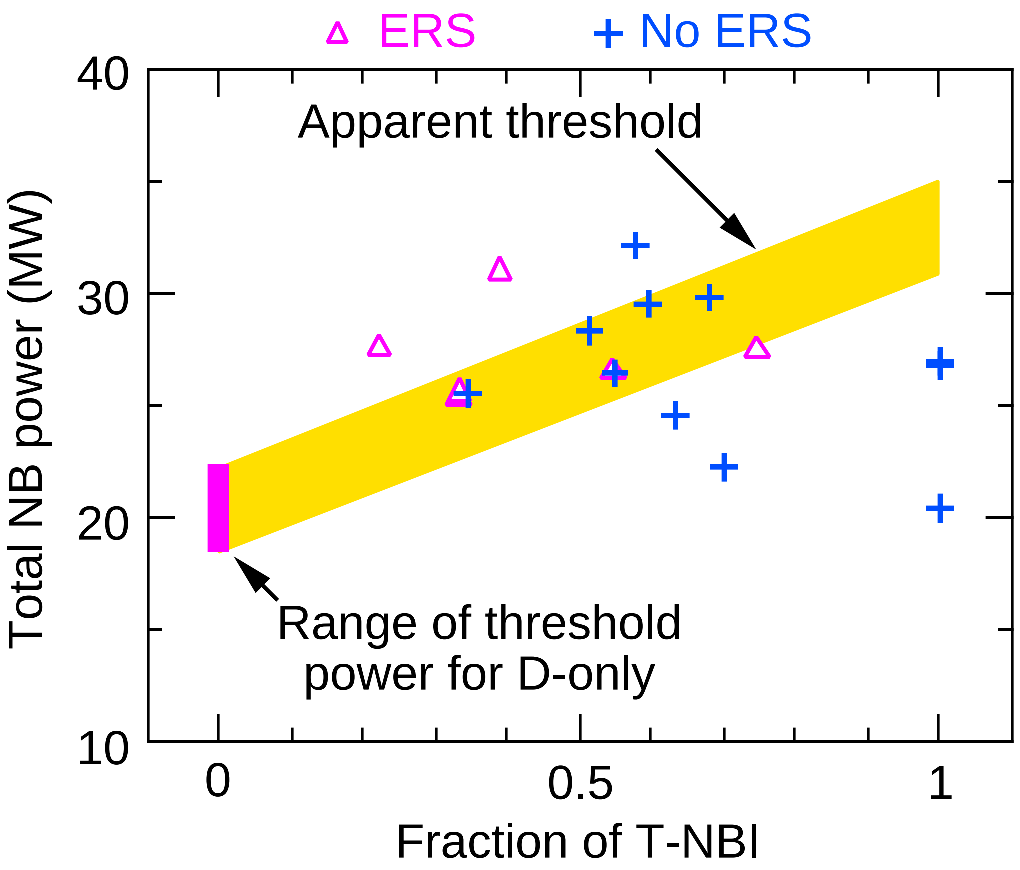

- Transition threshold also depends on wall conditioning
- Challenge for theory: same or lower threshold expected
- Experiment: develop tools to trigger and control at lower power

S. Scott, 1S.13

Expansion of Ultra-Low-q Discharge Reliably Produces High-l_i Plasma

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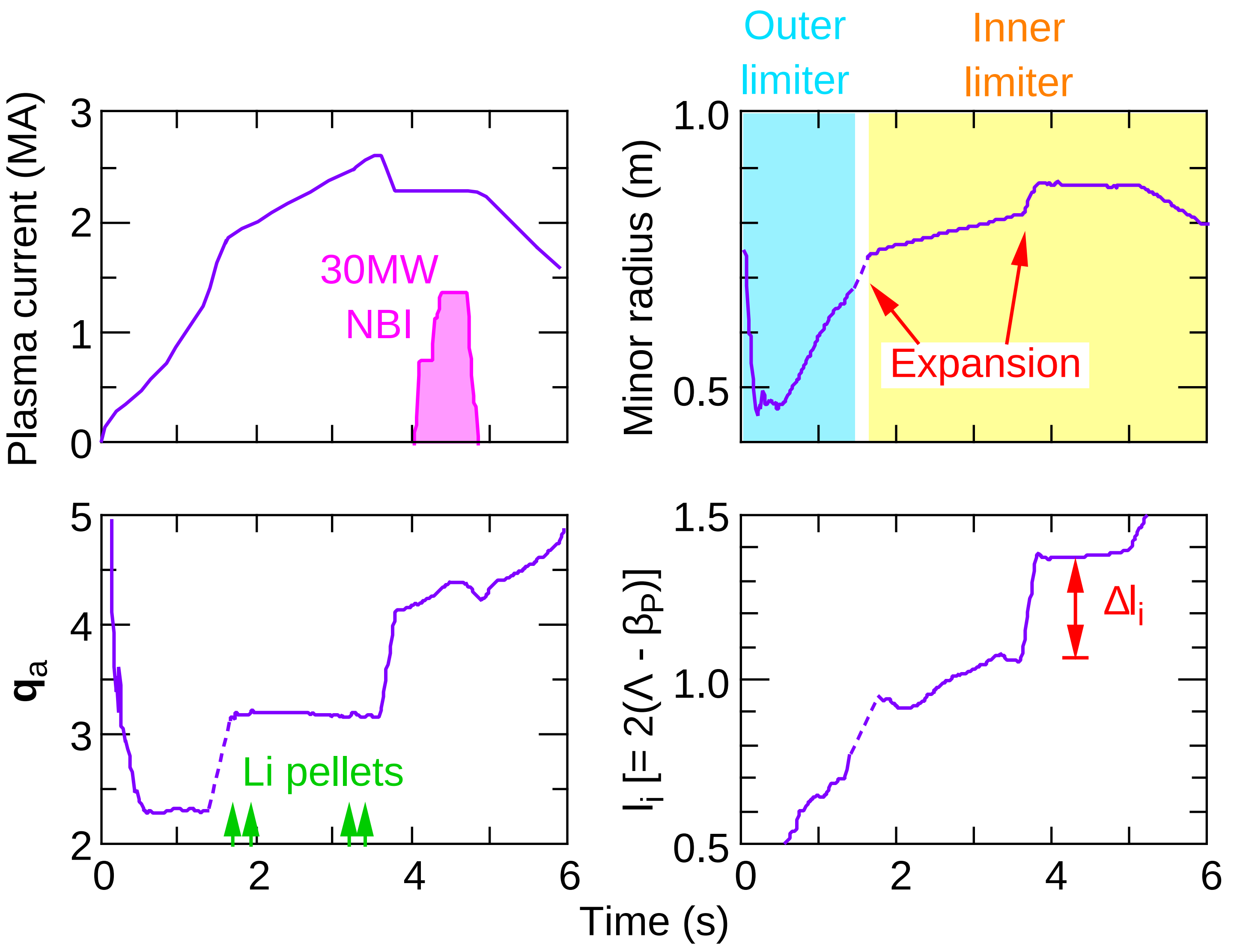
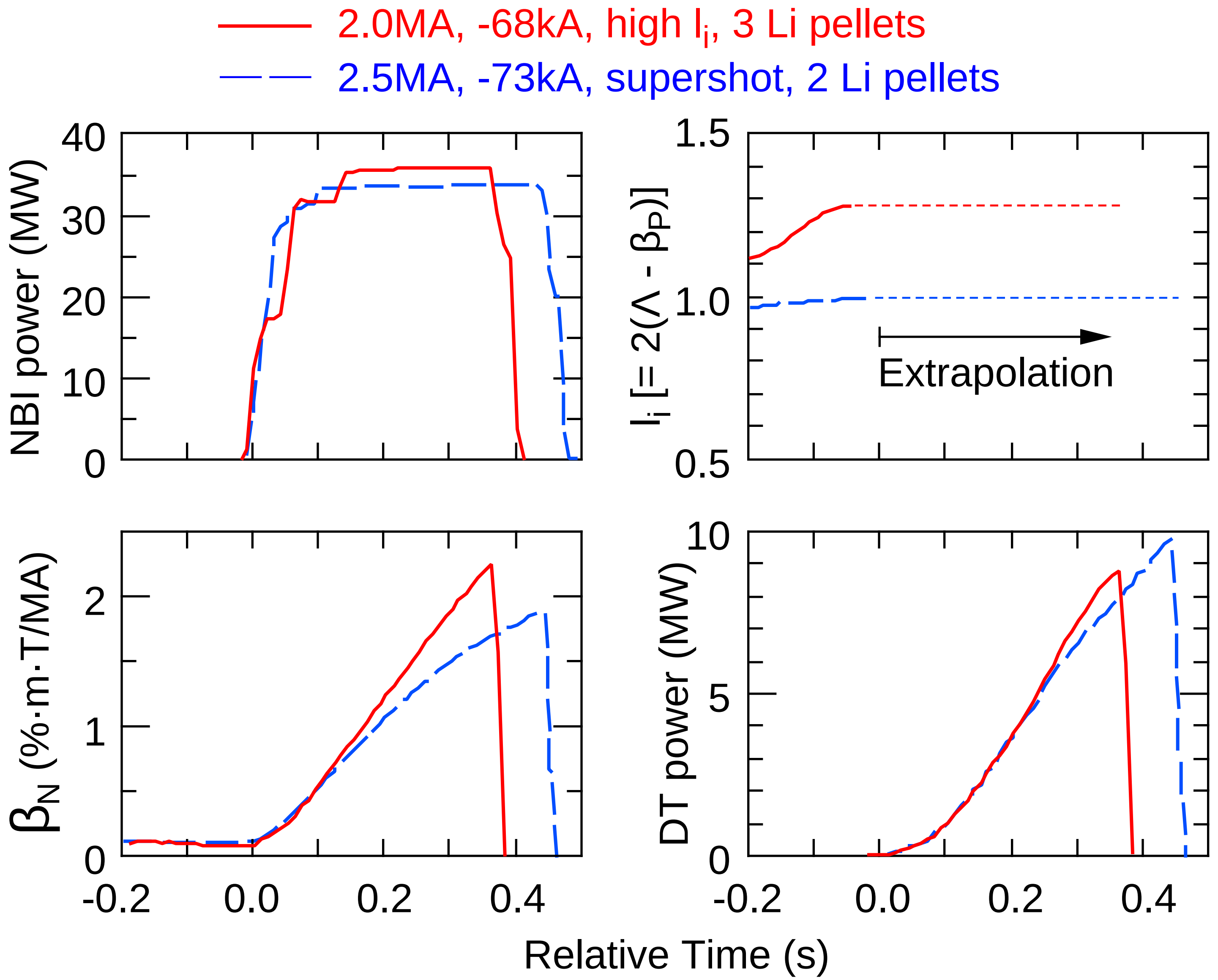


- Confinement during NBI increased by lithium pellet conditioing

S. Sabbagh, 4F.02; E. Fredrickson, 6IB.01

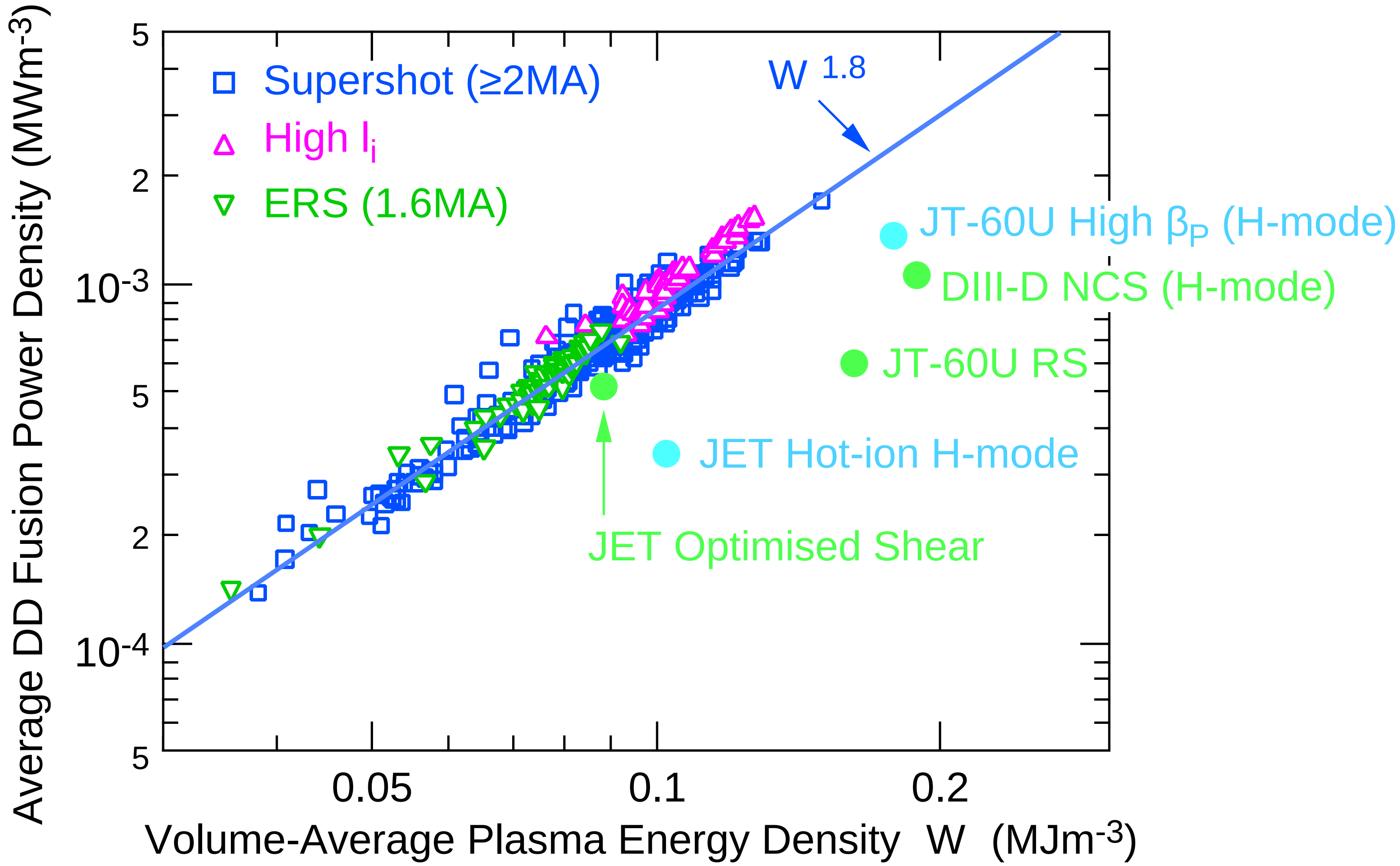
Normalized β-Limit Scales ∝ l_i in Expansion Plasmas



- β-limit was not reached with available NBI power in 2.3MA high-l_i plasmas

S. Sabbagh, 4F.02; E. Fredrickson, 6IB.01

DD Fusion Power Density is Closely Related to Plasma Energy Density Over Range of Regimes in TFTR

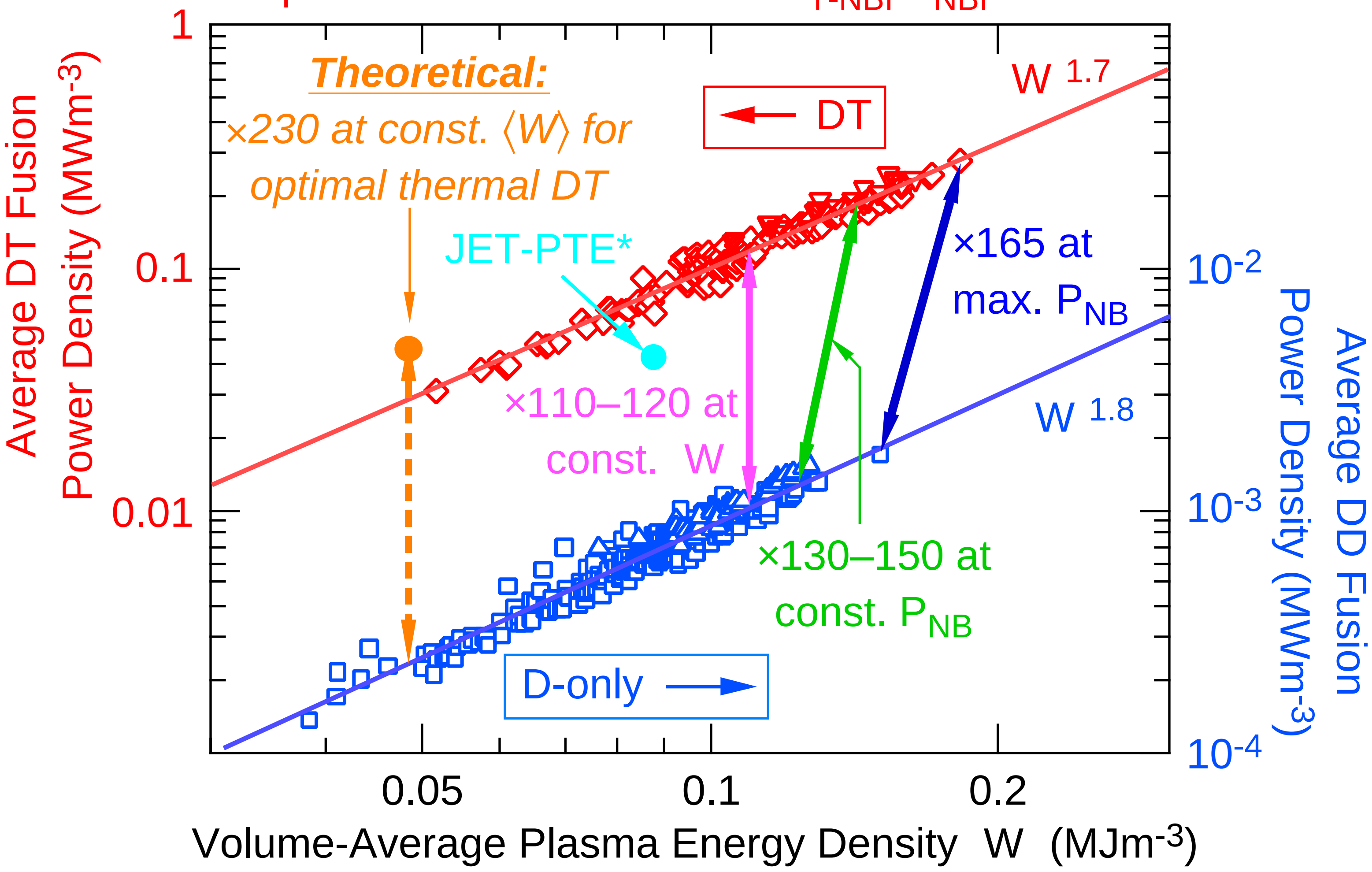


- Axes are "universal": independent of plasma size or configuration
- H-mode increases plasma energy without significantly contributing to reactivity

Reactivity Ratio Between D and D-T Plasmas Depends on Plasma Regime and Operational Constraints

High-current supershots and high-l_i plasmas

Optimal D-T mixture: $0.35 \le P_{T\text{-}NBI}/P_{NBI} \le 0.85$



- Higher I_p, B_T were needed to exploit higher P_{NB} and τ_E in D-T

50:50 D:T projection [Nuclear Fusion **32 (1992) 187]*

Energy Confinement Scales $\propto A^{1/2}$ In D-T With H-Minority ICRF Heating

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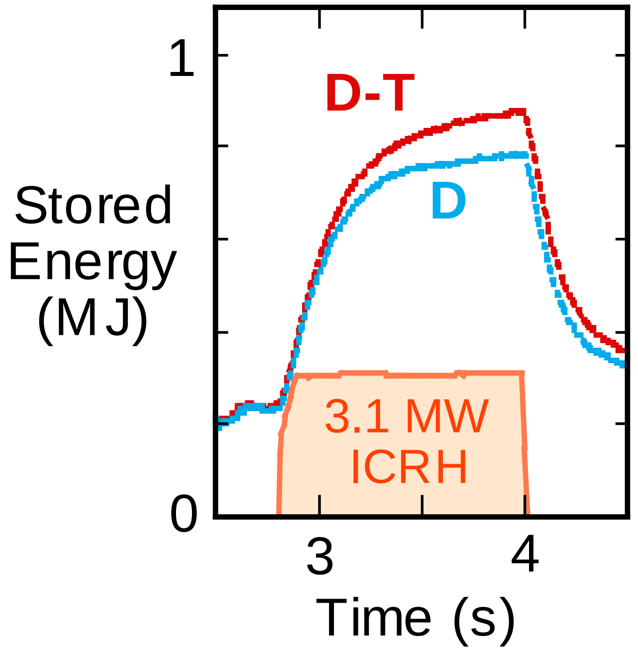
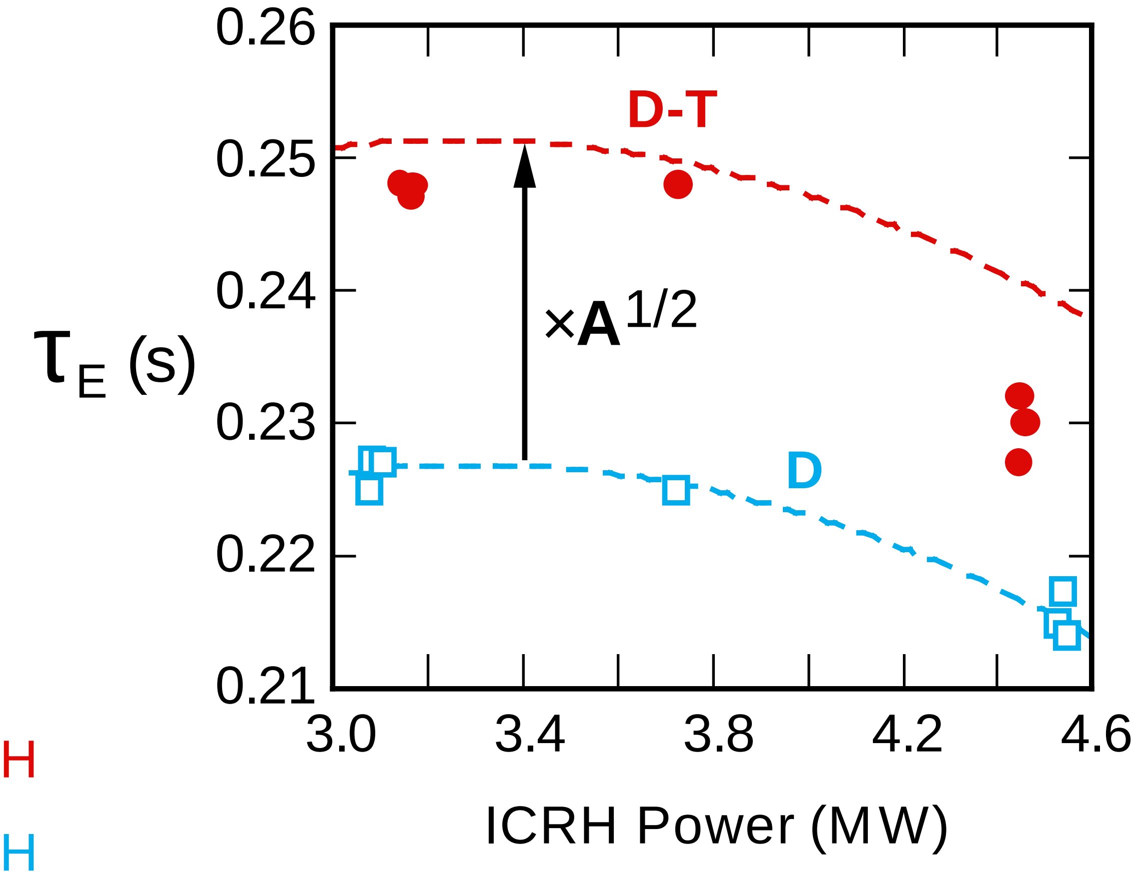


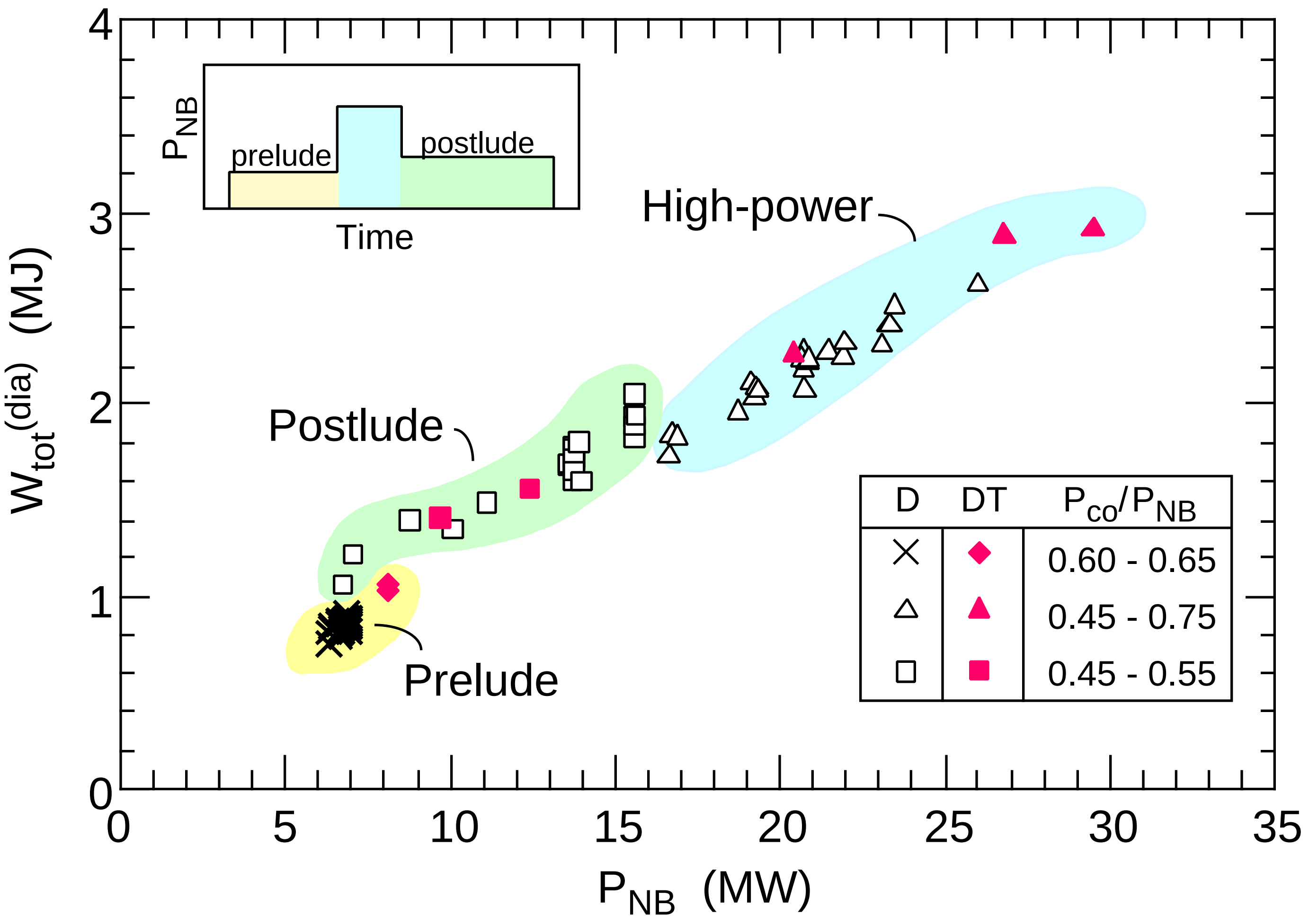


D-T: 40%T, 40%D, 5% H

D: 1%T, 78%D, 8% H

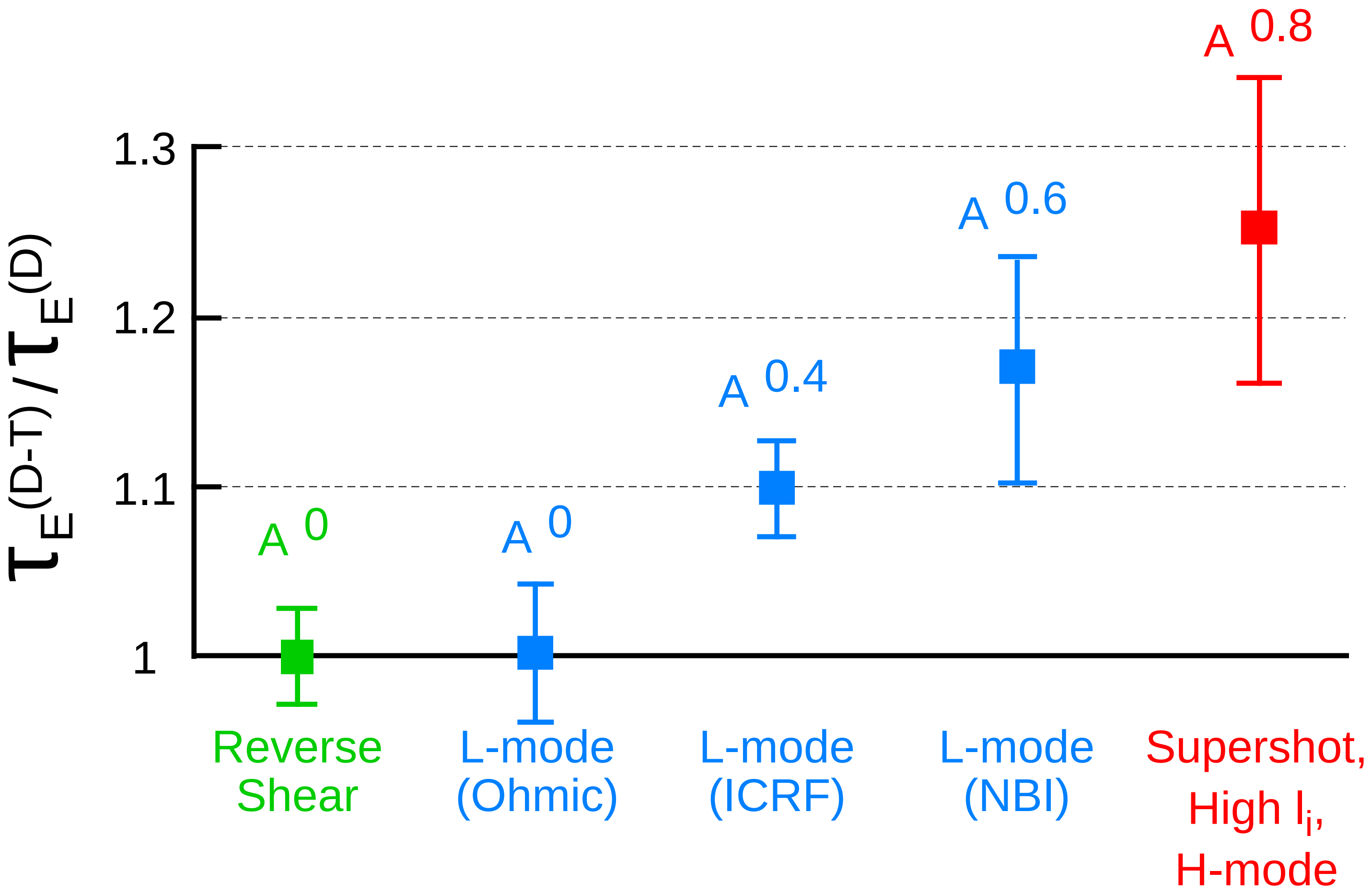
- H-minority ICRF heating only:
  - Heating and change in transport only through electrons.
  - No energetic D or T tails.

No Isotope Effect on τ_E in Reverse Shear Plasmas



- **Challenge**: plasma profiles (n_e, T_e, T_i) are similar to supershots

D-T Isotope Effect Depends On Operating Regime



- Average ion mass (amu): ~1.9 (D), ~2.5 (D-T)
- Challenge for theoretical interpretation and to gyro-Bohm scaling

First Observation of Toroidal Alfvén Eigenmode Driven by Fusion Alpha Particles in Weak-Shear Plasmas

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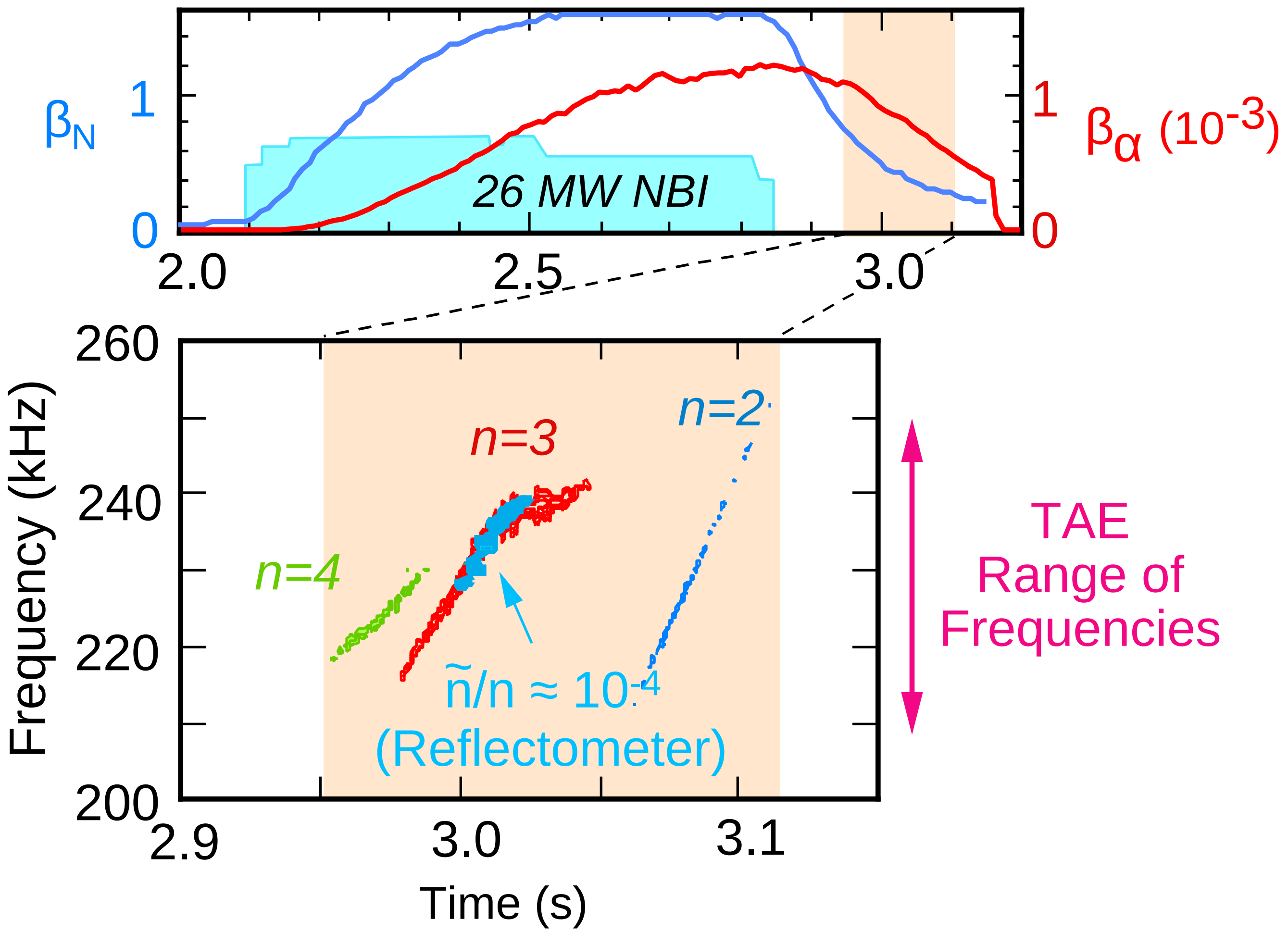
- "Core localized TAE" predicted by theory (Fu, Spong) for weak shear with $q_0 > 1$



- Mode becomes unstable for very low β_α (<< ITER)

R. Nazikian, 4F.08; Z. Chang, 8IB.02

Summary

- ERS physics:
    - Requires controlling transport barriers and q profiles for improved stability
    - Power threshold higher in D-T
    - Impurity retention: potential helium ash problem
- High-l_i regime:
    - Extended to high current by new technique
    - β_N l_i continues to hold
    - Substantial D-T fusion power: 8.7MW
- D-T physics
    - Reactivity ratio DT:DD depends on complex constraints
    - Isotope effect different in reversed-shear plasmas
    - Isotope effect in ICRF heated L-mode
- First observation of the alpha-driven TAE in D-T plasmas

TFTR Has Operated Safely and Productively through an Extensive D-T Campaign

- Since first D-T operation in December 1993:
  - 1.2 GJ D-T fusion energy (4.2 × 10^{20} D-T neutrons)
  - 841 D-T shots for wide range of experiments
- D-T operation routine
  - Recently completed vacuum vessel opening *(first in 3 years)*
  - Installed new ICRF antennas
- Tritium technology issues for fusion
  - Retention and removal of tritium
  - Commissioned Tritium Purification System for closed-loop tritium cycle
- *Future operation is not limited by technical constraints of D-T*

Plans

- Exploit new ICRF capabilities
  - Ion Bernstein Wave launcher for triggering and controlling transport barriers
  - 4-strap FW launchers for control of current drive by mode-converted IBW
- New diagnostic capabilities for physics of confinement enhancement
  - poloidal rotation
  - improved MSE measurement
- New techniques for lithium conditioning
  - extend enhancements already achieved with pellets
  - use ^{6}Li for less interference with ICRF heating
- "Radiating plasma mantle" for improved performance at high power
- Alpha particle physics
  - Elements of "alpha-channeling" scheme