Understanding Confinement in Advanced Inductive Scenario Plasmas – Dependence on Gyroradius and Rotation

by

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with

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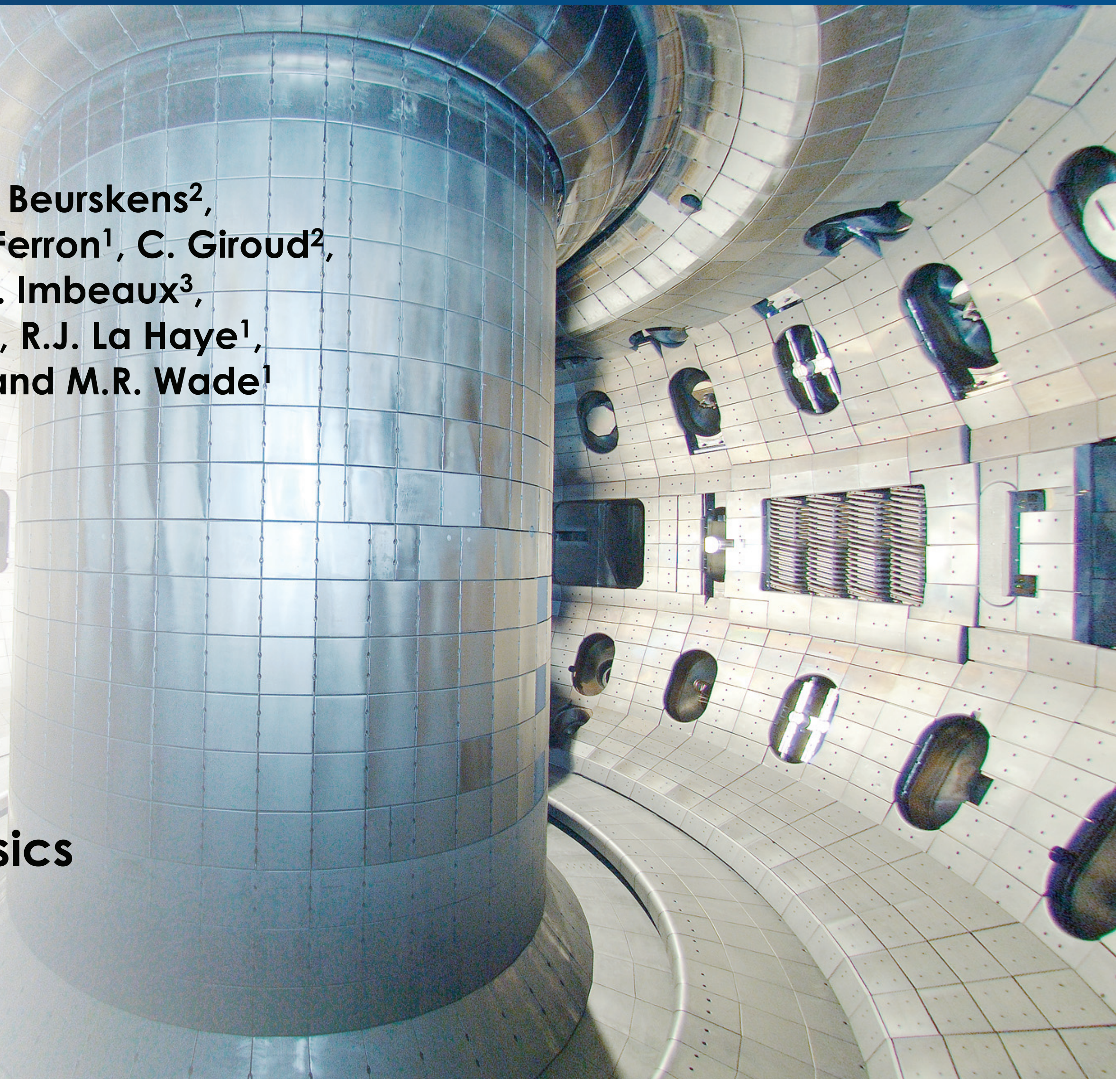


Presented at the 52nd Annual Meeting of the APS Division of Plasma Physics Chicago, Illinois

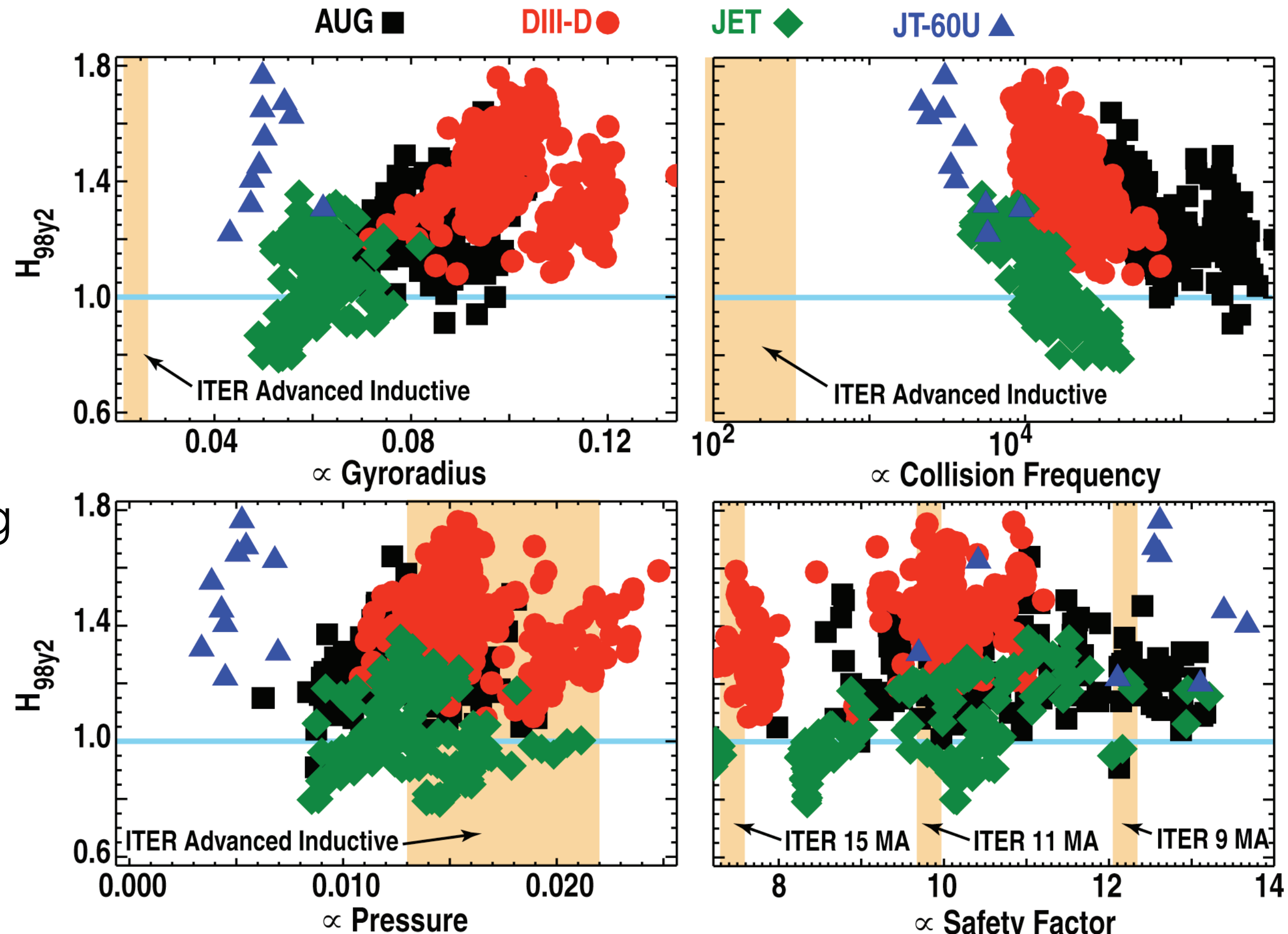
November 8-12, 2010

What Are Advanced Inductive Plasmas?

- **Advanced inductive plasmas are loosely defined as those with $\beta_N \geq 2.4$ and $H_{98y2} \geq 1$ under stationary conditions**
  - 50% higher pressure than ITER baseline scenario at $q_{95} = 3$ (2x fusion power)
  - Same pressure (fusion power) as the ITER baseline at $q_{95} = 4$
- **This suggests possible roles for advanced inductive plasmas**
  - Long-pulse, high-fluence plasmas for limited nuclear testing in ITER
  - Lower current route to meet ITER Q = 10 objective (reduced consequences of disruptions)
  - Alternative means (to 17 MA) of performance enhancement in the event ITER confinement is less than expected
  - Best performance for pulsed energy production

Key Unresolved Issue in Performance Projection is Confinement Scaling

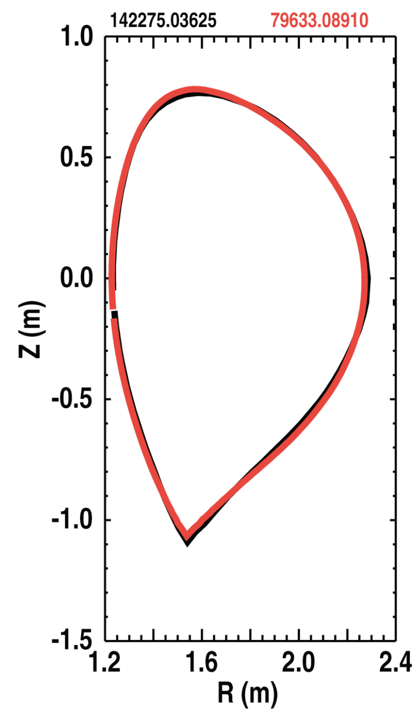
- Standard H-mode scaling does not describe well the international advanced inductive database
- Regression analysis is not likely to succeed (range too small)
- Two approaches being pursued
  - Dimensionless parameter scaling
  - Validation of models of energy transport



Luce, et al., IAEA FEC 2010

Dimensionless Scaling Approach Works Best Using Two Tokamaks In Concert

- **Test the principle by making "identical" plasmas in JET and DIII-D**
  - Dimensionless parameters match with different engineering parameters
  - Match of the profiles and the resulting scaled heat flux indicates the correct parameters have been identified
- **Vary one parameter around this point, holding the other parameters fixed, to isolate the scaling with that parameter**
  - Normalized gyroradius ρ_* was the first parameter varied
  - Strongest variation in the confinement scaling and provides an effective size scaling
  - Combined scan in DIII-D and JET is equal to the distance between JET and ITER

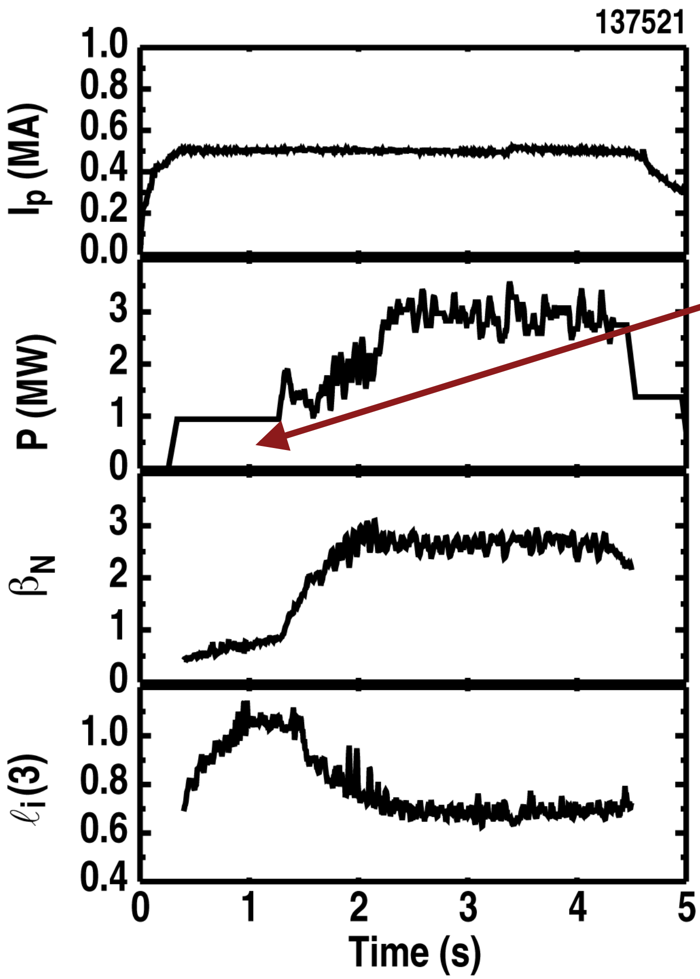


JET shape scaled by 1.675 to match DIII-D

Different Access Schemes Used in DIII-D and JET

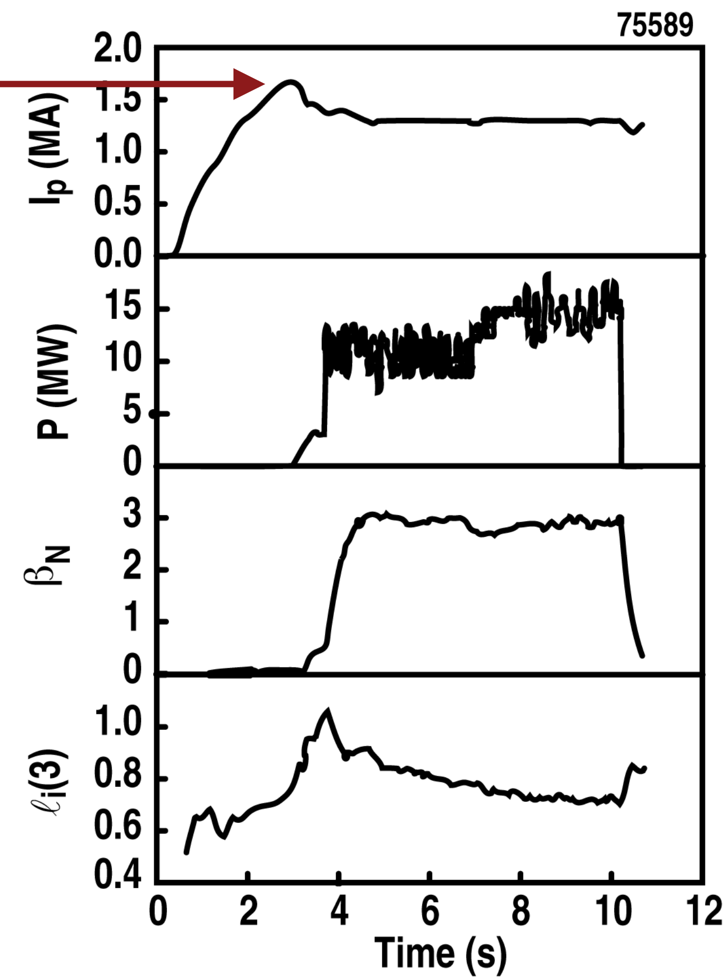
- **Broad current profile thought to be important**

DIII-D



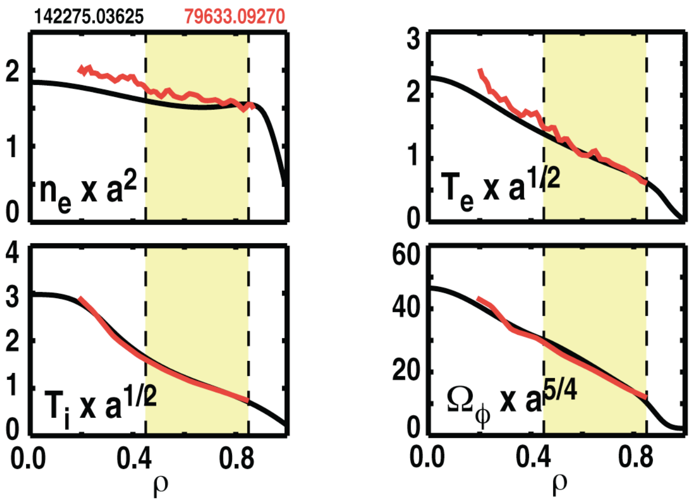
- JET uses current overshoot
- DIII-D uses early heating

JET



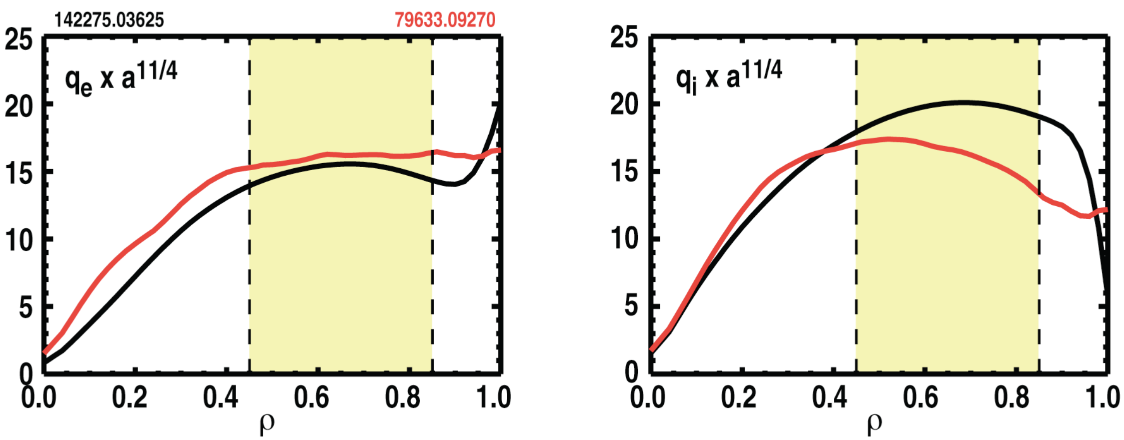
Identical Plasmas Are Found in DIII-D and JET Using the Dimensionless Scaling Approach

DIII-D & JET Measured Profiles Scaled by Plasma Size



- **Scaled kinetic profiles matched well in region indicated**

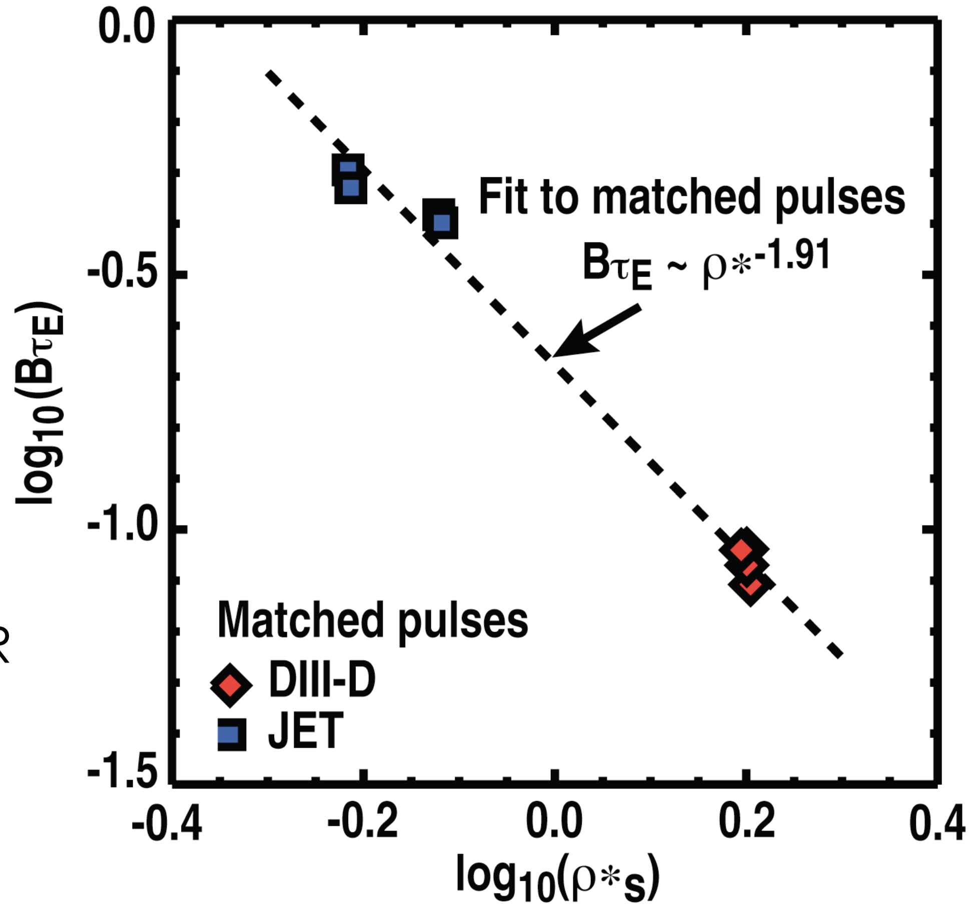
Scaled Electron and Ion Heat Fluxes



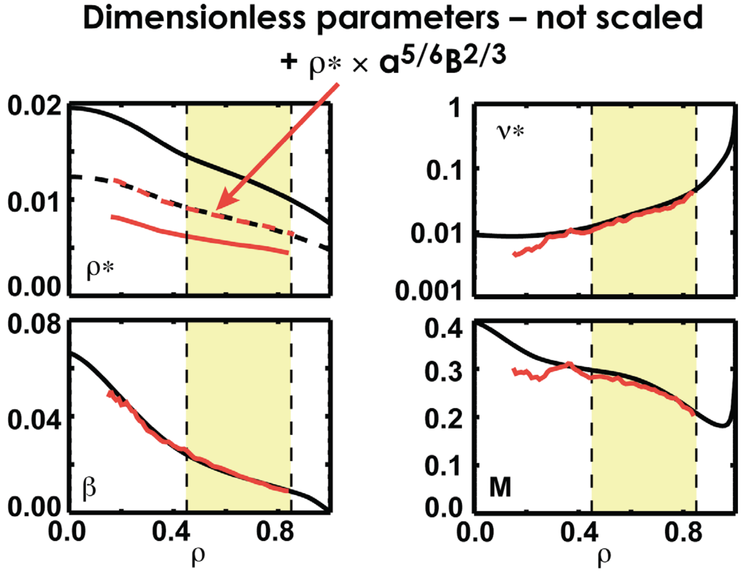
- **Scaled heat fluxes match, giving confidence that:**
  - Dimensionless scaling approach is valid
  - Same regime is attained in both tokamaks

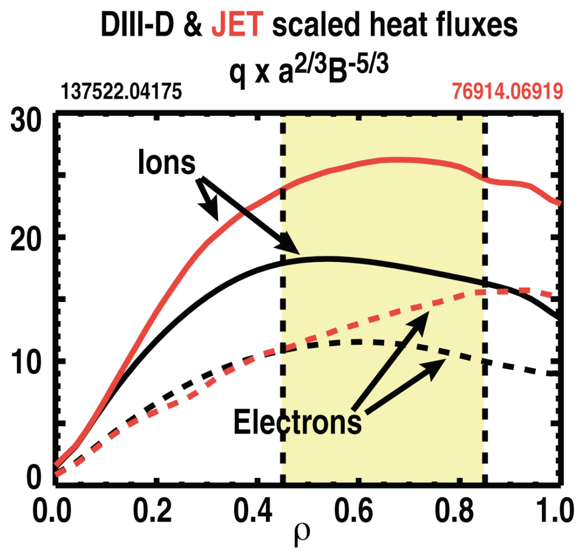
Global Analysis of ρ_* Scan Indicates a Weaker Size Scaling than the Standard H-Mode Scaling

- **Measured scaling is close to Bohm scaling ($B\tau_{th} \propto \rho_*^{-2}$)**
  - Less favorable than ρ_* scaling implicit in H_{98y2} ($B\tau_{th} \propto \rho_*^{-2.7}$)
- **Range spanned in ρ_* between JET and DIII-D is the same as that from JET to ITER**
  - Other parameters not similar to ITER (ν_*, Mach number), so projection is not possible on the basis of this scan alone



Local Transport Analysis Allows Separation of Core and Pedestal Effects



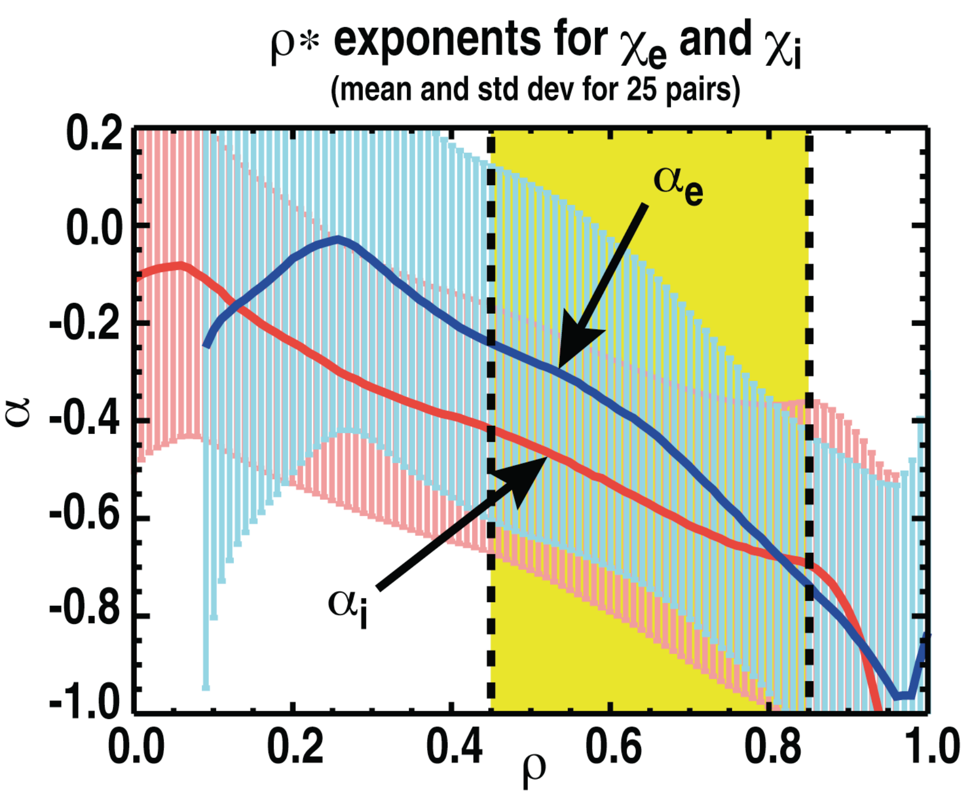


- **Scaled kinetic profiles match well, leading to excellent matches of dimensionless parameters**

- **Scaled heat flux is larger in JET than in DIII-D**
  - Implies weaker size scaling than the Bohm scaling from global analysis

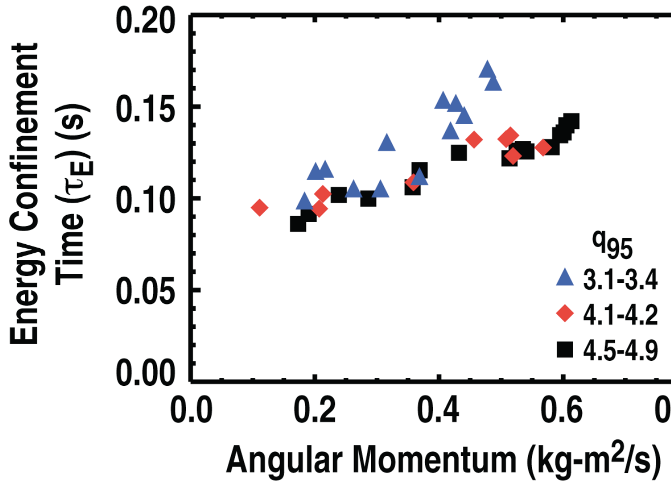
Local Analysis of ρ_* Scan Gives Weaker Size Scaling Than the Global Analysis

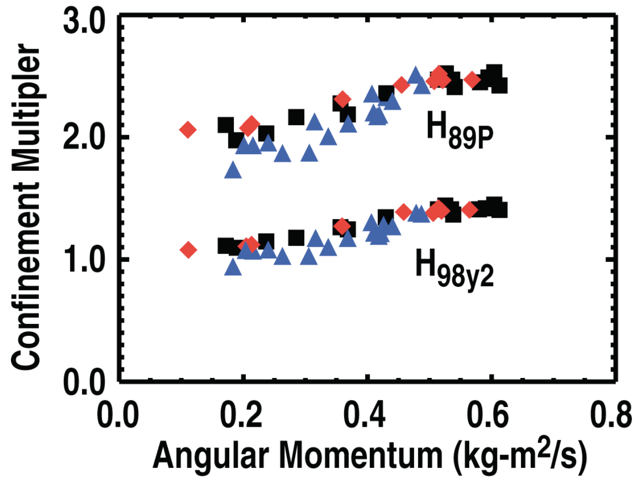
- **Scaling is characterized by:**
  $\chi \propto \chi_B \rho_*^{\alpha}$ or $q \propto a^{-2/3} B^{5/3} \rho_*^{\alpha}$
- **Measured scaling weaker than Bohm (α = 0)**
- **Electron and ion ρ_* scaling similar, unlike the previous L-mode and H-mode results**



Confinement Is Correlated With Plasma Rotation In Advanced Inductive Plasmas

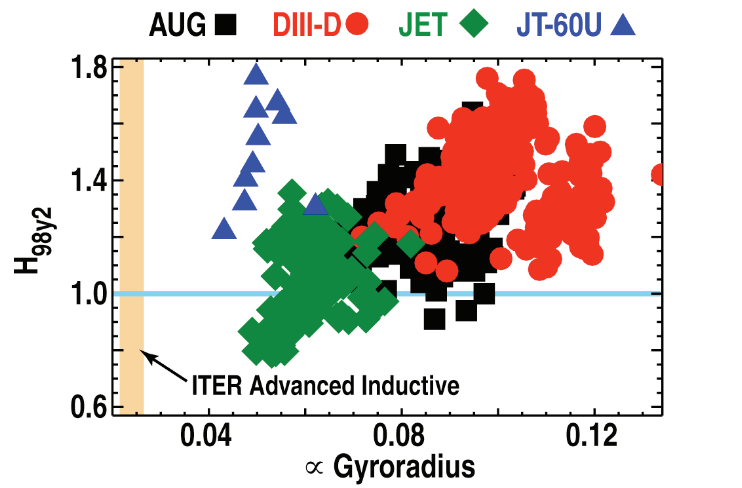
- **Global confinement varies by >50% across the rotation range in DIII-D**
  - Rotation varied by changing the co-/ctr-NBI ratio at fixed stored energy
  - Effect is stronger at low q_{95}
  - Both electron and ion transport are affected
  - Confinement quality still good at low rotation-possibly due to role of current profile
- **Transport modeling suggests that ExB flow shearing effects are responsible**
  - GLF23 and TGLF match data only with flow shear effects included
  - Width of *n*=2 tearing mode correlates with rotation, but impact on confinement is smaller

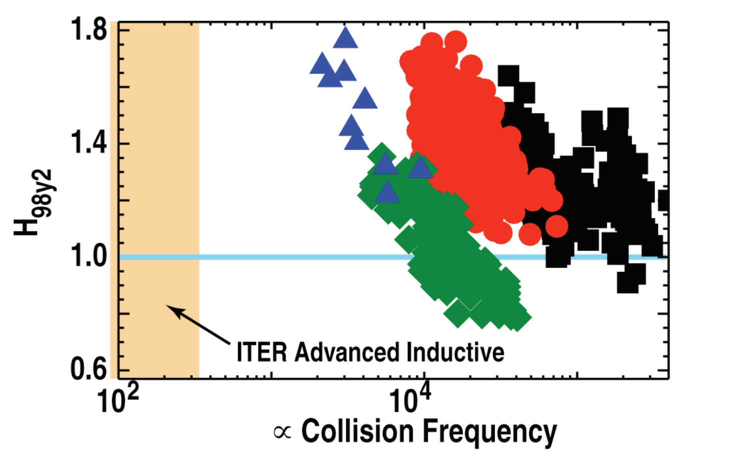




Implications and Outlook for Projections to Future Tokamaks

- **Present H-mode scalings appear to be inadequate for projections**
  - Database work through the ITPA shows the IPB98y2 scaling does not describe the data well
  - Dedicated ρ_* scan shows different scaling
  - Rotation effects not included in the scaling
- **Dimensionless approach yields empirical scaling and key data for validation of theory-based models**
  - ρ_* scan is the same magnitude as the step to ITER
  - Simple extrapolation of ρ_* scan to ITER is not valid — the density in ITER would be above the density limit
  - Scaling with ν_* may be significant





Summary

- **Dimensionless parameter scaling approach applied successfully to DIII-D and JET advanced inductive plasmas**
  - Identical plasmas obtained
  - Size scaling from ρ_* scan is close to Bohm scaling--weaker than standard H-mode scaling
  - Transport scaling with collisionality must be investigated

- **Possible physics mechanisms responsible for the different properties of these plasmas:**
  - Improved confinement in present-day experiments may be due to more favorable current profile in stationary conditions
  - Rotation effects are consistent with theoretical models of ExB flow shear stabilization
  - Can the different current profile lead to a different ρ_* scaling?