Investigation of Global Momentum Confinement Times on DIII-D

By Wayne Solomon

In collaboration with

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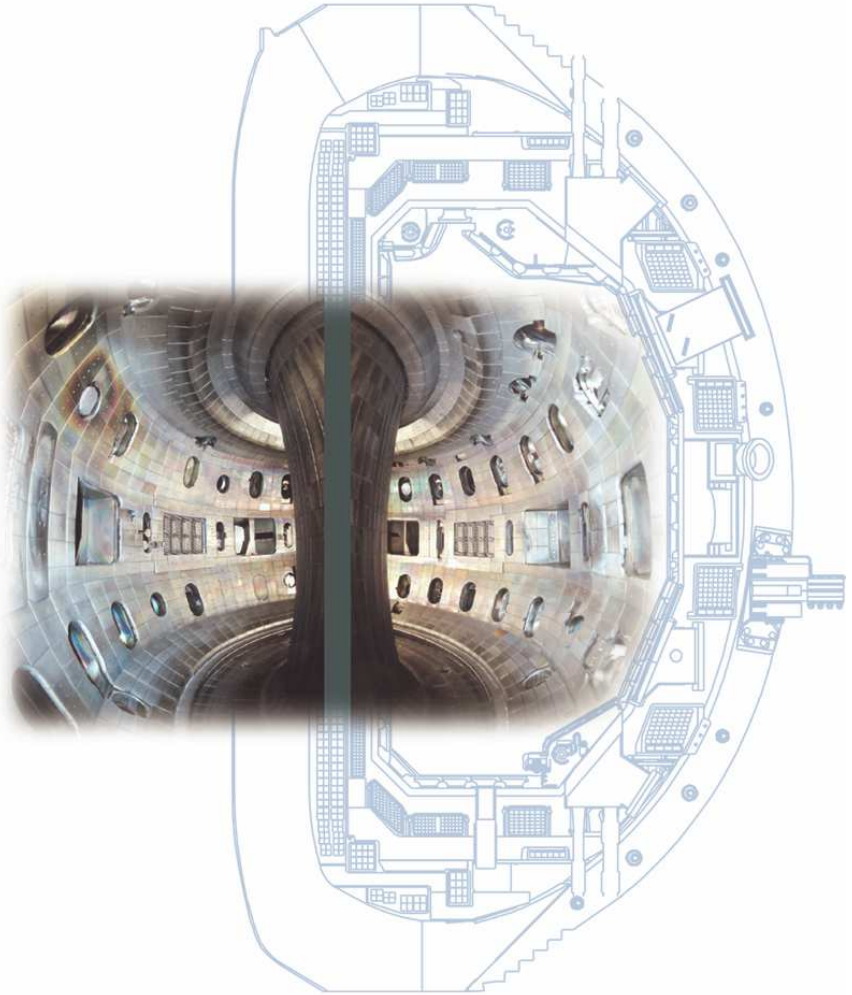

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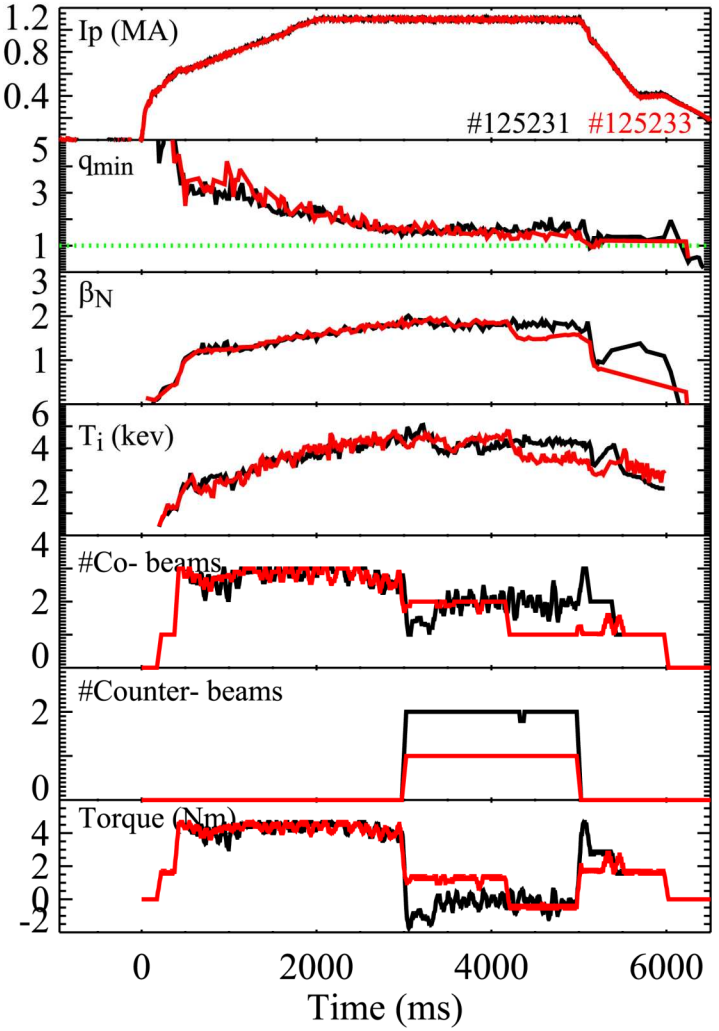
PPPL PRINCETON PLASMA PHYSICS LABORATORY

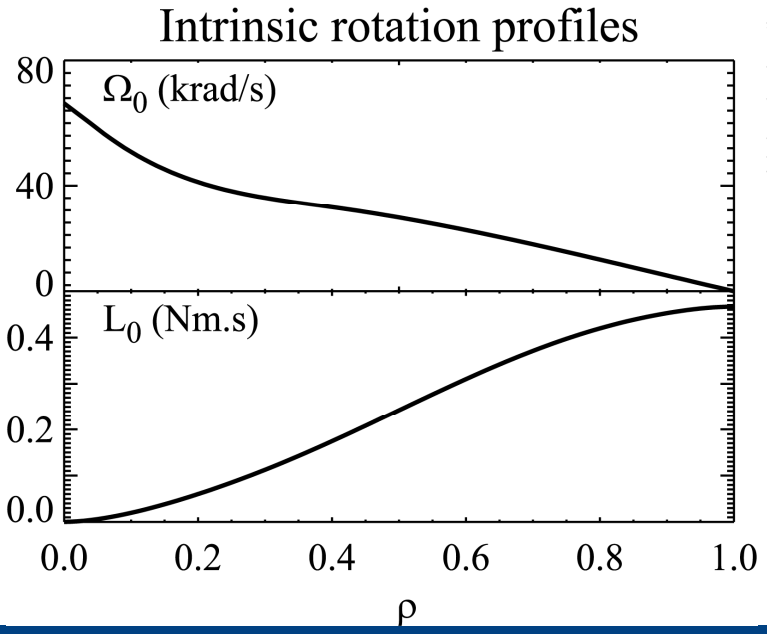
Momentum Transport Was Investigated in ELMing H-mode plasmas

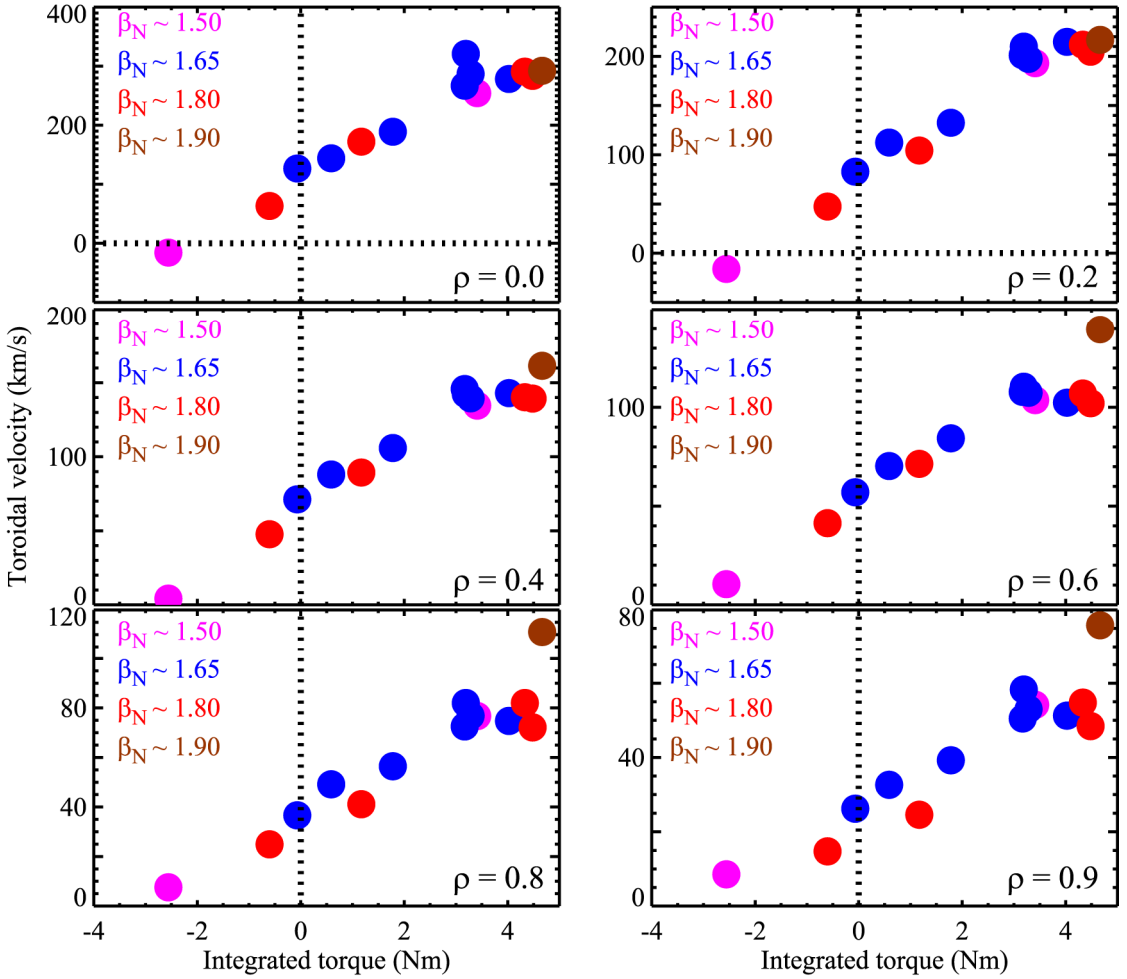
- **Elevated q_{min} conditions stay above 1 for ~ 5 s**
  - no sawteeth
- **Torque scans performed at constant β_N**
  - Use plasma control system (PCS) beta feedback control
  - Beta feedback as proxy for T_i
- **As vary number of counter sources, PCS adjusts number of co-sources to maintain requested beta level**



Intrinsic Rotation Profile Can Be Interpolated From the Torque Scan Data

- **Very large intrinsic rotation on axis**





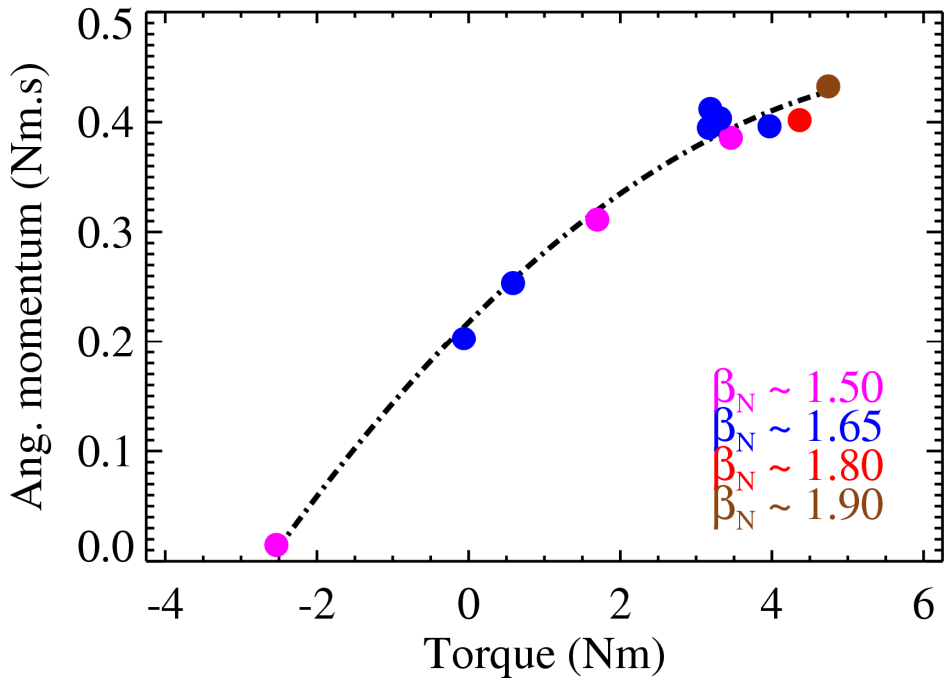
Total Mechanical Angular Momentum Reveals Non-Linear Response to Total Neutral Beam Torque

- **Non-linear response of angular momentum to applied torque suggests momentum confinement time is dependent on torque**

- **Simple quadratic fits data well, implying a linear degradation of momentum confinement with torque**

$$L = AT - BT^2$$

$$\tau_\phi \sim L/T = A - BT$$



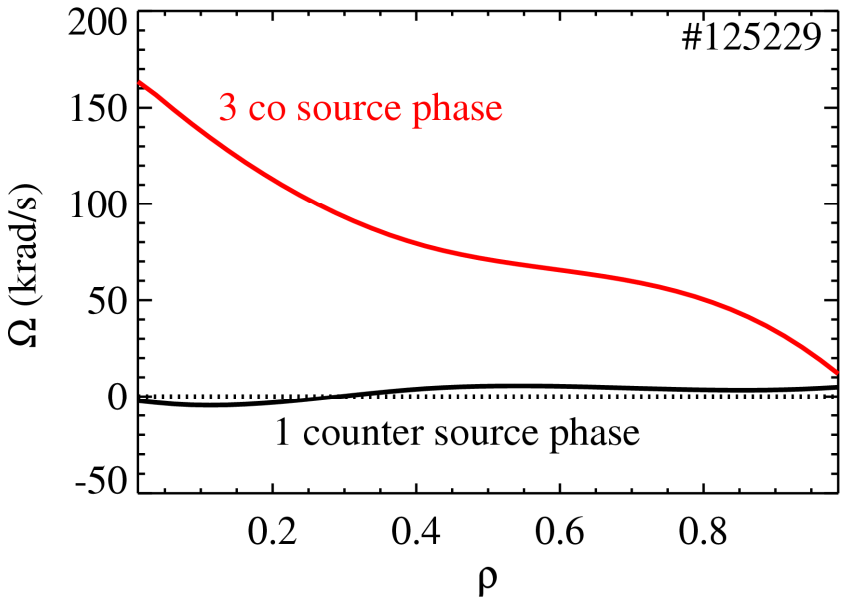
Near Zero Rotation Profile With Net Neutral Beam Torque Suggests an Anomalous Torque Source

- **From momentum balance equation**

$$mnR\frac{\partial V_\phi}{\partial t} = T + \nabla \cdot \Gamma$$

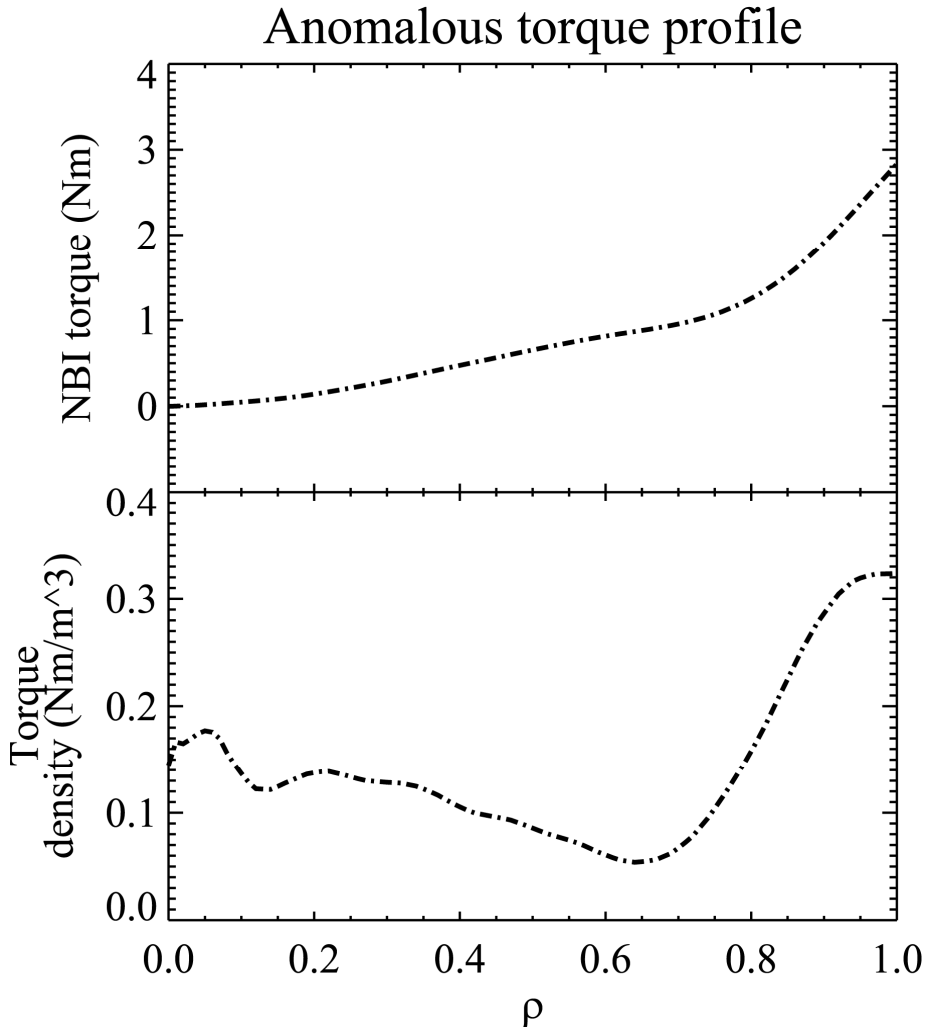
$$\Gamma \sim mnR\left(\underbrace{\chi_\phi \frac{\partial V_\phi}{\partial r}}_{diffusion} + \underbrace{V_\phi V_{pinch}}_{convection} \right) + \ldots$$

  - If V_ϕ is zero everywhere and constant, then net torque to the plasma must be zero
  - This situation is nearly realized in this example, but there is one net counter source on
  - "Anomalous" torque source



Precise Anomalous Torque Profile Can Be Inferred From Torque Scan Data

- Torque scan provides opportunity to interpret "anomalous torque" corresponding to the intrinsic rotation profile.
- Anomalous torque closely matches torque from approx one net co-source
- Plasma rotates as if there was an extra co-source worth of torque!

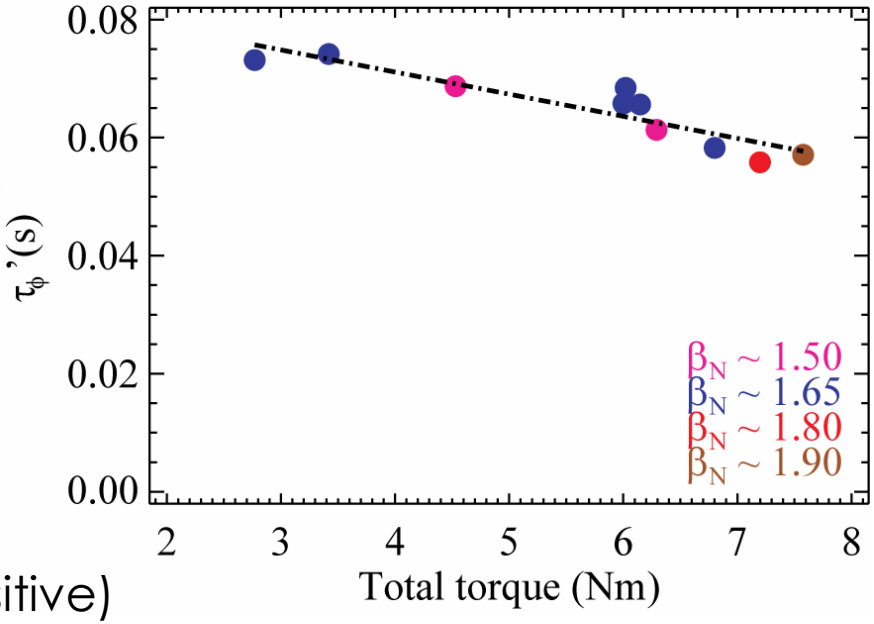


Global Momentum Confinement Time Can Now Be Computed With Knowledge of Anomalous Torque

- **Equation for momentum confinement time becomes**

$$\tau_\phi \sim \frac{L}{T_{NBI}} \quad \rightarrow \quad \tau_\phi' \sim \frac{L}{T_{NBI} + T_{an}}$$

- **Assumes anomalous torque constant**
- **Clear improvement in momentum confinement time as total torque to plasma is reduced.**
- **Values on x-axis shift significantly due to large anomalous torque**
  - never really reach counter torque (consistent with rotation always positive)



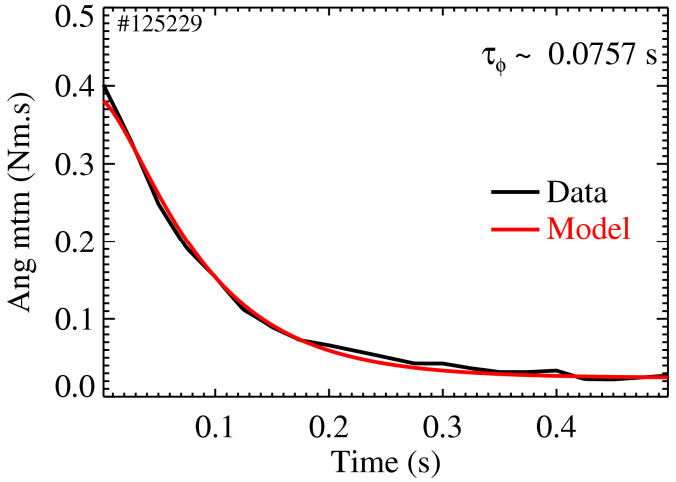
Angular Momentum Relaxation Time Comparable to Global Momentum Confinement Time

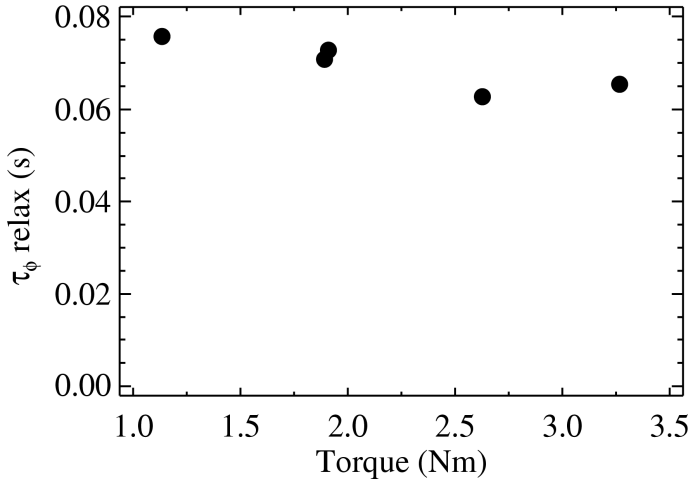
- **Can also analyze the dynamic behavior when step torque from one value to another**

$$\frac{dL}{dt} = T(t) - \frac{L(t)}{\tau_\phi^{relax}}$$

  - Torque deposition occurs over collisional slowing down time

- **Integrate model and solve for τ_ϕ^{relax}**
- **Model fits momentum decay adequately**
- **Relaxation time reproduces similar trend as global momentum confinement time**





Momentum and Heat Diffusivities Show Different Dependence on Toroidal Rotation

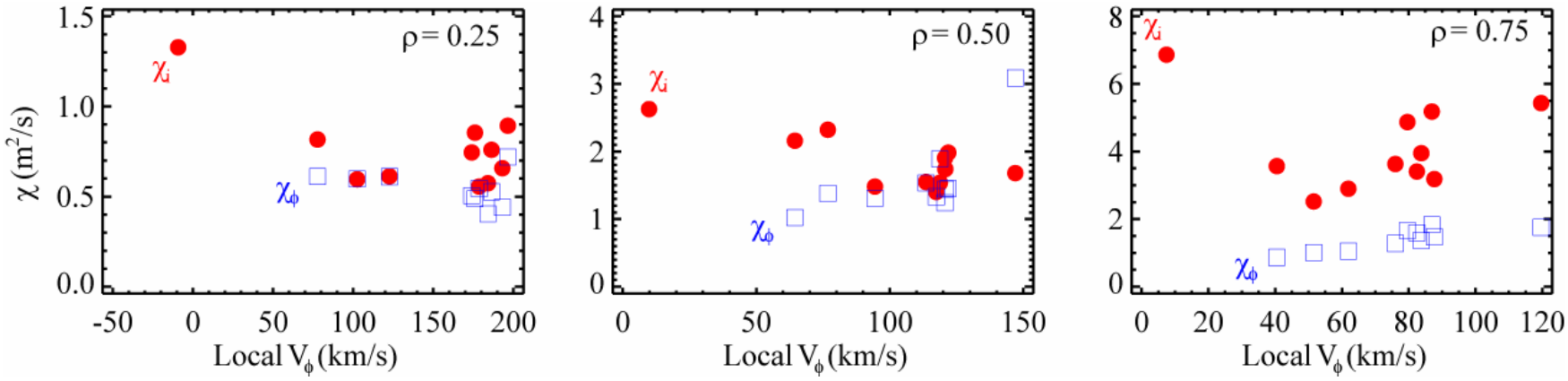
- **Momentum diffusivity solved by TRANSP from momentum fluxes**

$$\Gamma_\phi = mnR\chi_\phi \frac{\partial V_\phi}{\partial r}$$

- **Correct for intrinsic rotation / anomalous torque**

$$T' = T + T_{an} \Rightarrow \chi_\phi' = \left(1 + \frac{T_{an}}{T}\right)\chi_\phi$$

- **Momentum diffusivity increases with rotation at all radii**
- **Momentum and heat diffusivities comparable at large rotation**
- **Possible optimal rotation at edge for heat diffusivity**



Summary

- **At moderate β_N in H-mode discharges, plasma shows significant "intrinsic" co-rotation, near balanced NB injection**
  - Central rotation under such conditions >100 km/s
  - Maintain co-rotation even with significant net counter NB injection
  - Must be considered for momentum confinement studies

- **Momentum confinement degrades with increase to net torque**
  - Comparable to degradation in energy confinement with power

- **Momentum relaxation time comparable to momentum confinement time**
  - Also shows similar dependence on torque

- **Momentum and heat diffusivities exhibit different responses to changes in toroidal rotation**