Separation of Momentum Diffusion and Pinch Using n=3 Non-Resonant Braking Perturbations on NSTX

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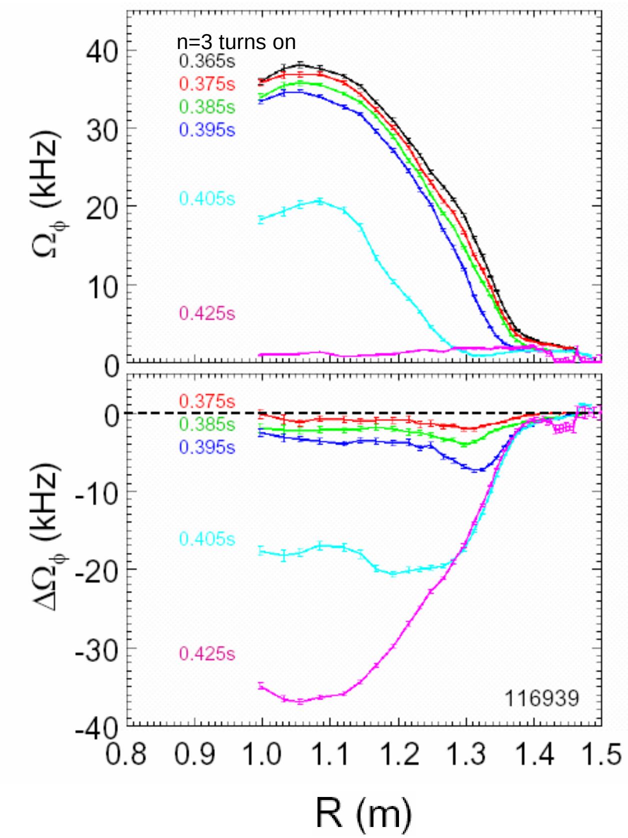
Motivation

- Rotation plays an important role in fusion plasmas
  - Turbulence suppression
  - RWM and NTM stabilization
- Hence, predictive understanding of rotation and momentum transport desirable
  - Predictions for ITER and future devices
- Usually, momentum transport considered diffusive
  - Recent studies on JT-60U suggest role of convection
- Perturbative studies made on NSTX to investigate role of momentum pinch at low aspect ratio

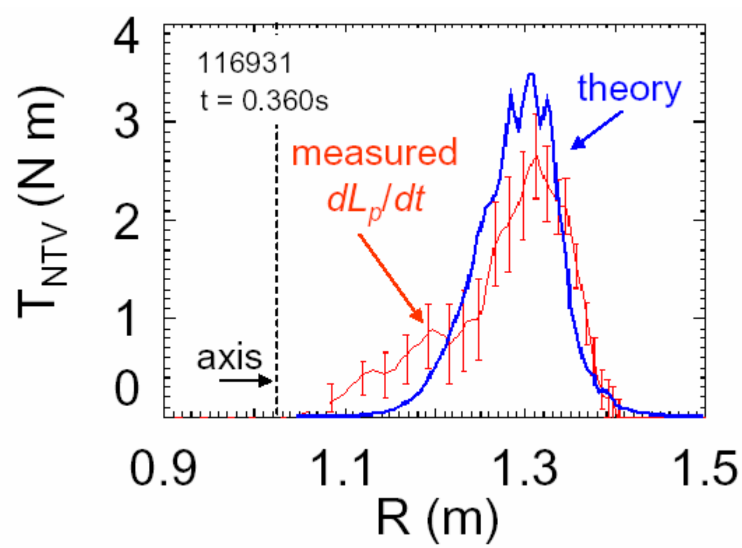
Momentum Transport Studied Using Non-Resonant n=3 Magnetic Perturbations

NSTX

- Previously been used to slow plasma rotation for ITER-relevant RWM stabilization experiments
  Zhu et al. PRL (2006)



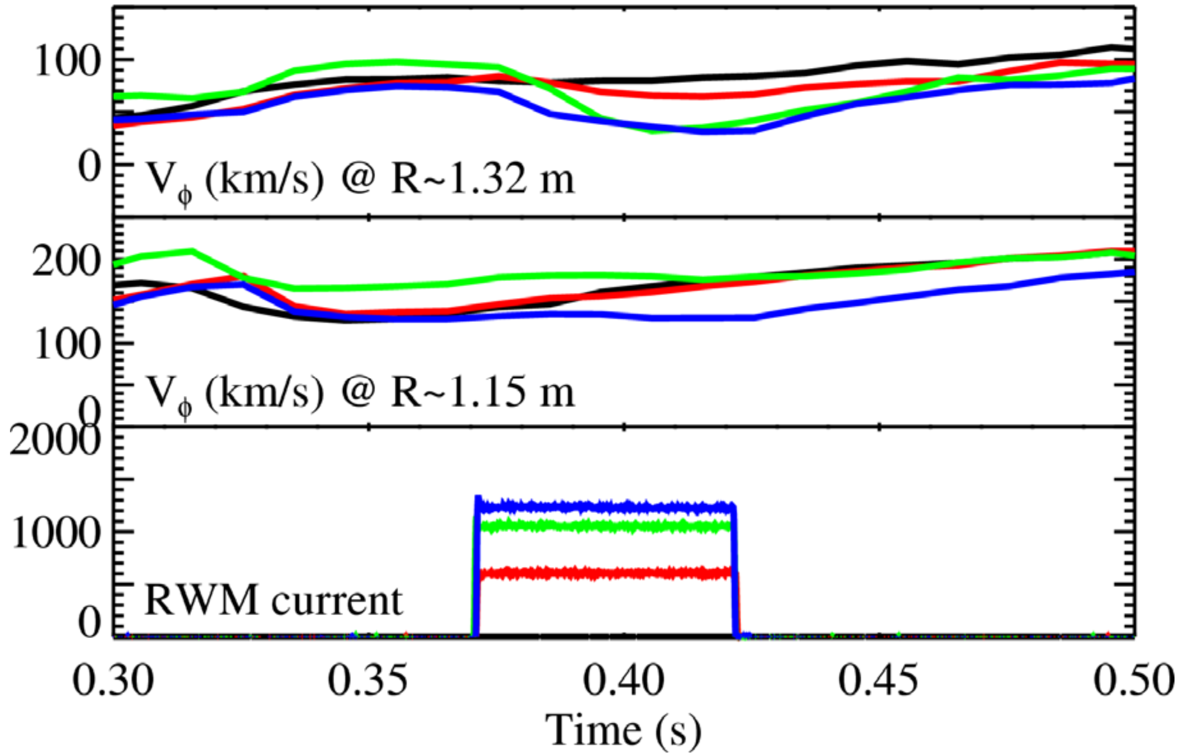
Observed rotation damping consistent with neoclassical toroidal viscosity (NTV) theory



Steady-state & transient application

Perturbative τ_ϕ, χ_ϕ Can be Obtained from Transient Application of n=3 Braking

NSTX



- Rotation responds rapidly to nRMP braking at edge
- Effect on central rotation less pronounced

Momentum Confinement Time Several Times Larger than Energy Confinement Time

NSTX

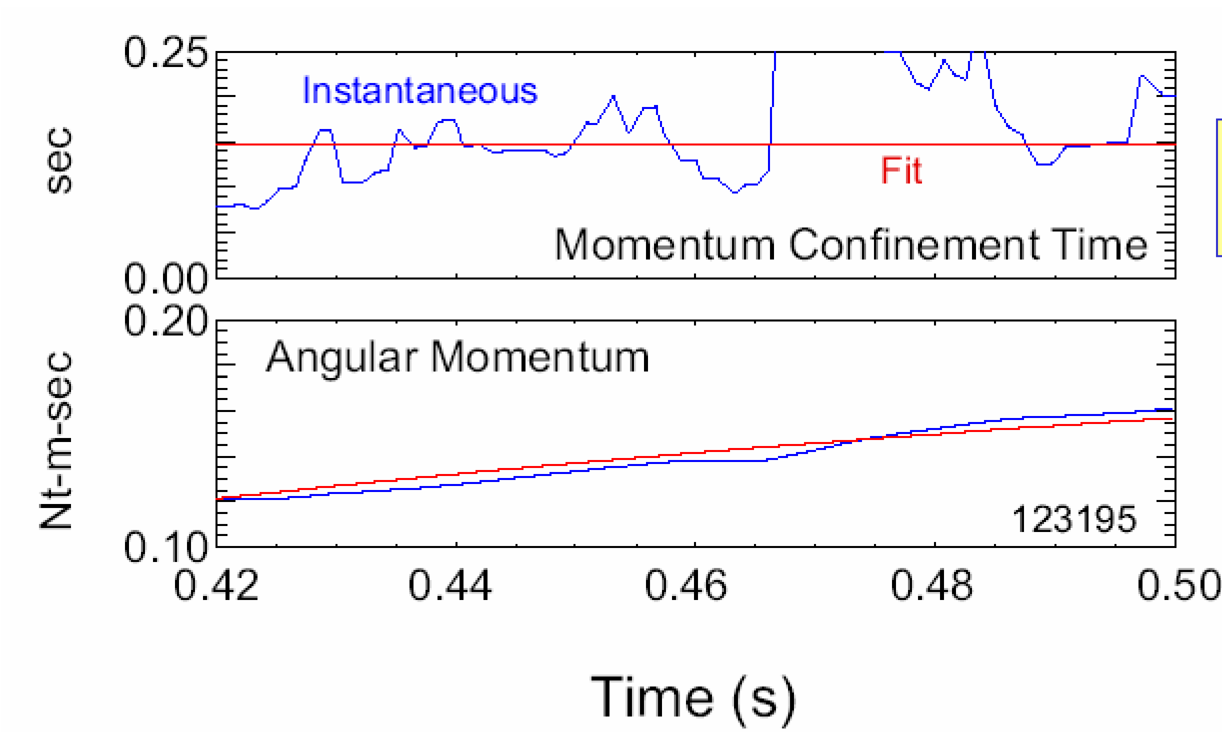
- Use $dL/dt = T – L/\tau_\phi$ relation to determine instantaneous τ_ϕ
- Model rotation recovery following perturbation to determine perturbative τ_ϕ

  $L(t) = \tau_\phi * [T – (T-L_0/\tau_\phi) * \exp(-t/\tau_\phi)]$, where

  L = Angular momentum

  T = Torque (NB torque only)

  L_0 = Angular momentum at time of nRMP turn-off



τ_E ~ 30-50 ms
$< \tau_\phi$

Local Momentum Transport Investigated During Spin Up After Perturbation

NSTX

- Toroidal rotation evolves according to momentum balance equation

$$mnR\frac{\partial V_\phi}{\partial t} = \eta + \nabla \cdot \Gamma_\phi$$

where

η = Torque density, m = mass, n = density, V_ϕ = toroidal rotation, Γ_ϕ = momentum flux

- TRANSP calculation of torque coupled with CHERS rotation measurement → Γ_ϕ well determined

- Model Γ_ϕ evolution to determine diffusive and convective contributions

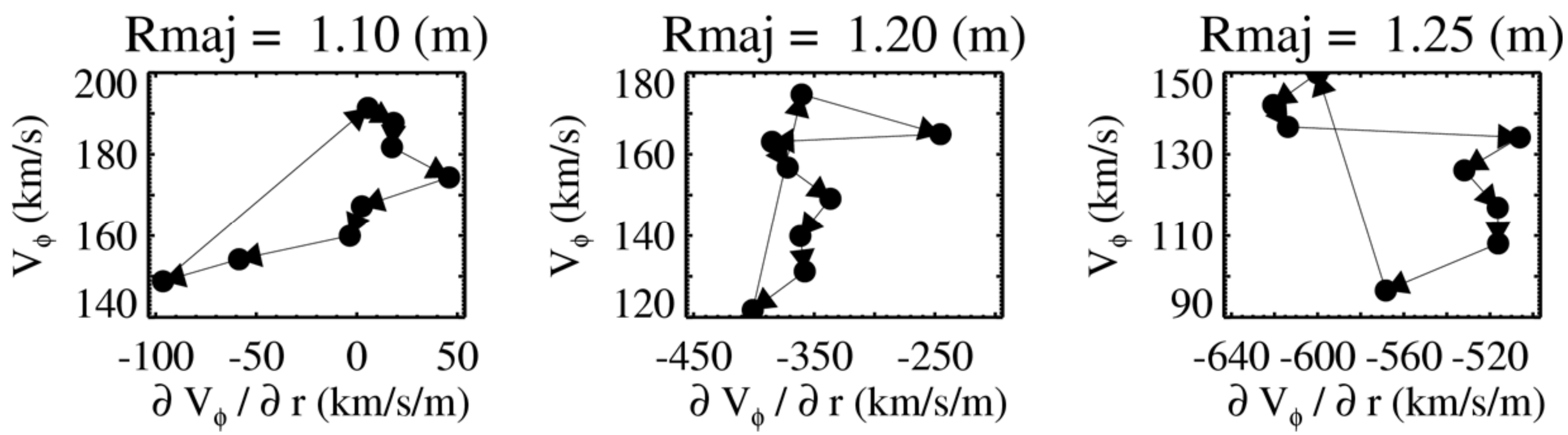
Successful Distortion to Rotation Profile Allows Separation of χ_ϕ and V_ϕ^{pinch}

NSTX

- Use simple model for momentum flux

$$\Gamma_\phi = mnR\left(\underbrace{\chi_\phi \frac{\partial V_\phi}{\partial r}}_{diffusion} - \underbrace{V_\phi V_\phi^{pinch}}_{convection}\right)$$

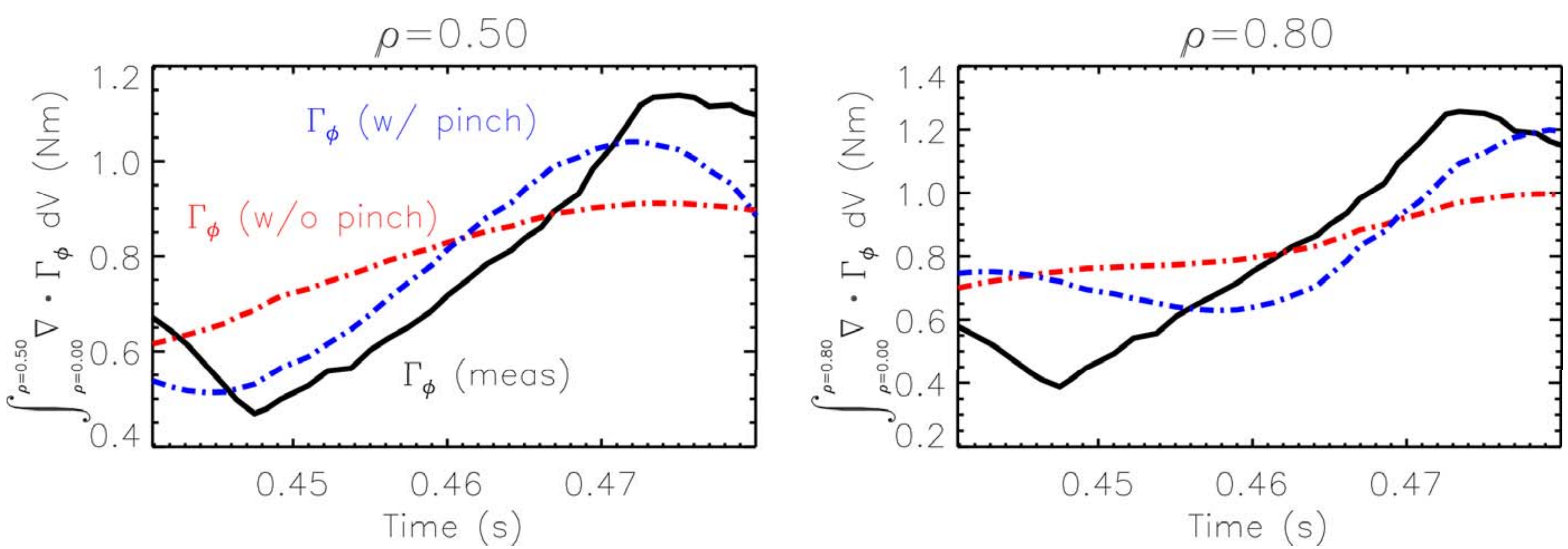
- Must change V_ϕ independently of dV_ϕ/dr
  - can unravel relative contribution of χ_ϕ and V_ϕ^{pinch}



Including Momentum Pinch Improves Fit to Momentum Flux

NSTX

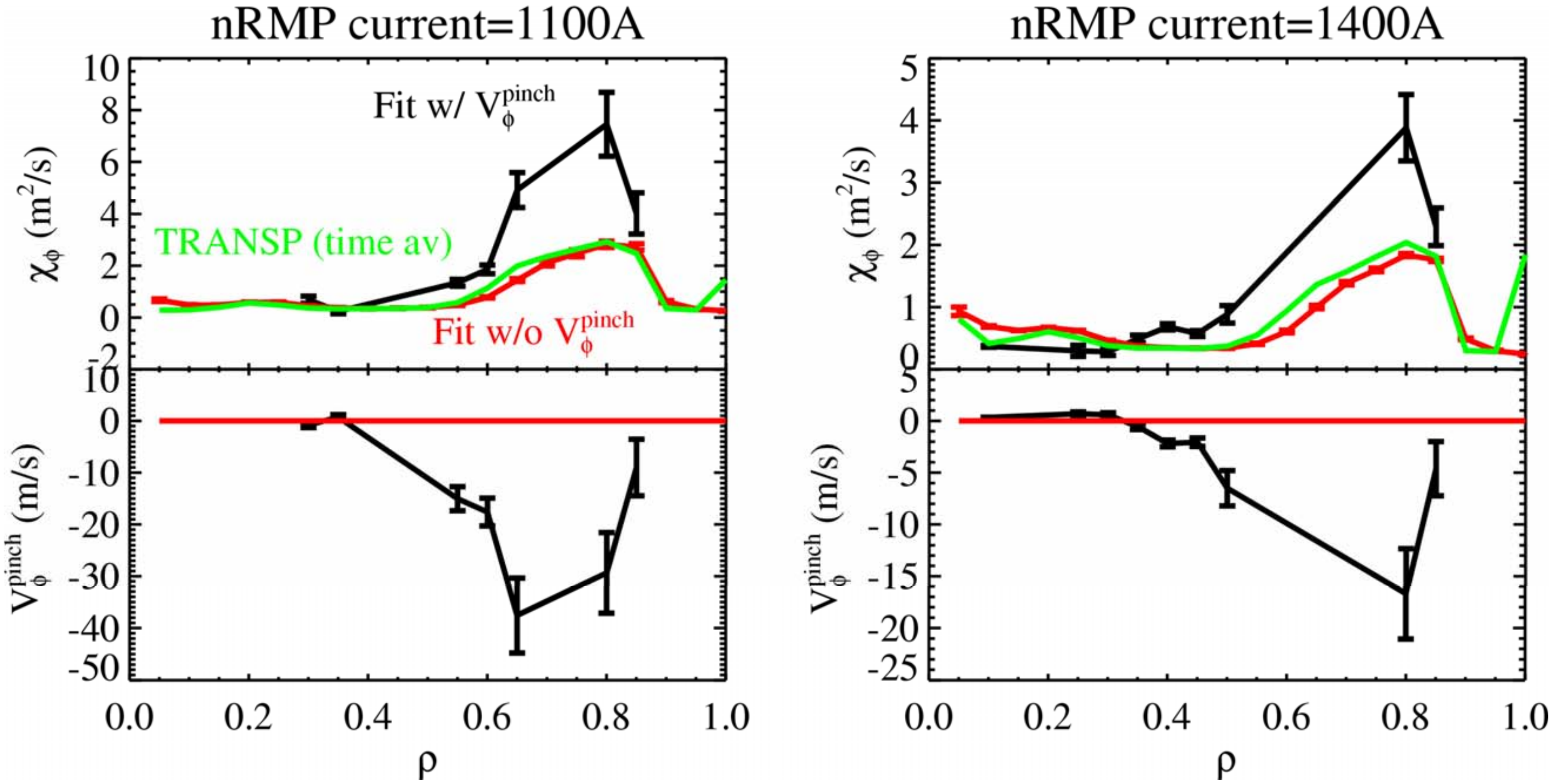
- Non linear least squares fit of χ_ϕ, V_ϕ^{pinch} profiles
  - Assumed constant in time
- Inclusion of pinch improves reconstruction of momentum flux at some radii
  - Not perfect → Other off-diagonal terms? χ_ϕ, V_ϕ^{pinch} changing…?



Perturbative Momentum Transport Reveal Significant Inward Pinch

NSTX

- Relatively consistent result from different sized perturbation
  - Within factor of 2
    decoupling of V_ϕ, dV_ϕ/dr not ideal → trade-off between χ_ϕ and V_ϕ^{pinch}
  - Smallest nRMP pulse did not produce sufficient distortion to analyze



Inferred Inward Pinch Scales with Theoretical Predictions

NSTX

- Theoretical consideration of low-k turbulence drive of momentum pinch

  $v_{Peeters} = \chi_\phi/R\ [-4-R/L_n]$

  (Coriolis drift)

  Peeters et al. PRL (2007)

  $v_{Hahm} = \chi_\phi/R\ [-3]$

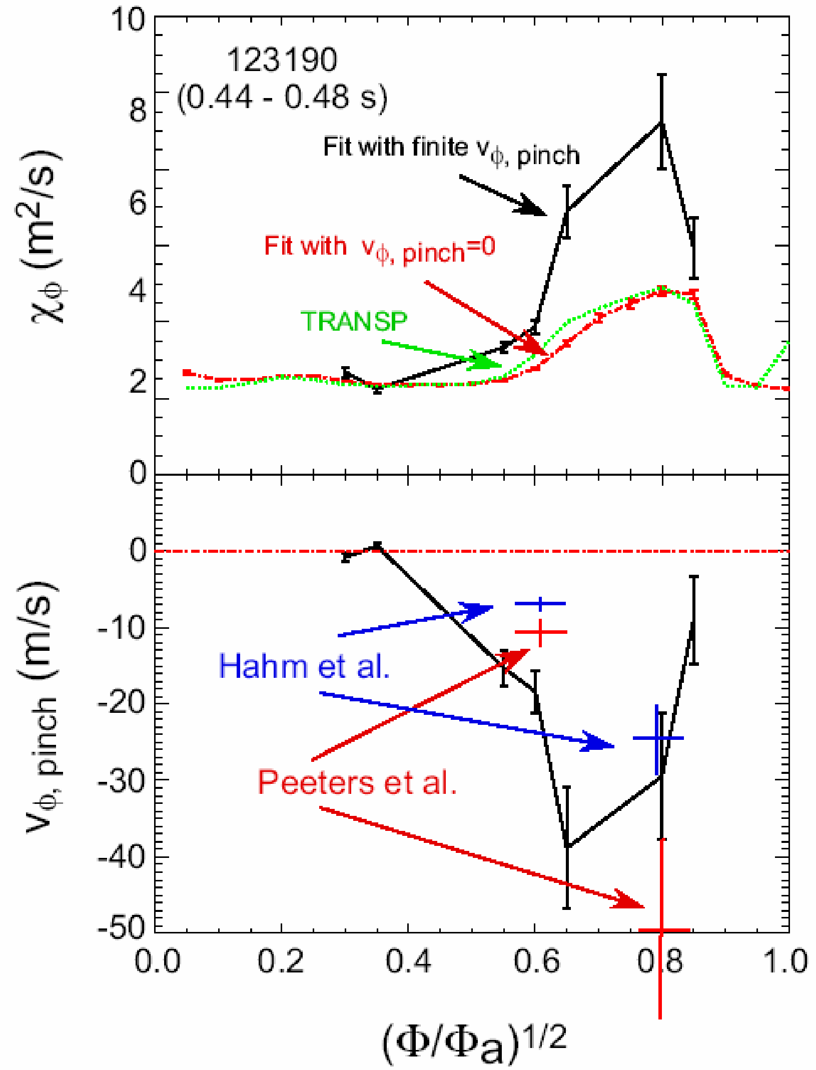
  (∇B, curvature drifts)

  Hahm et al. PoP (2006)

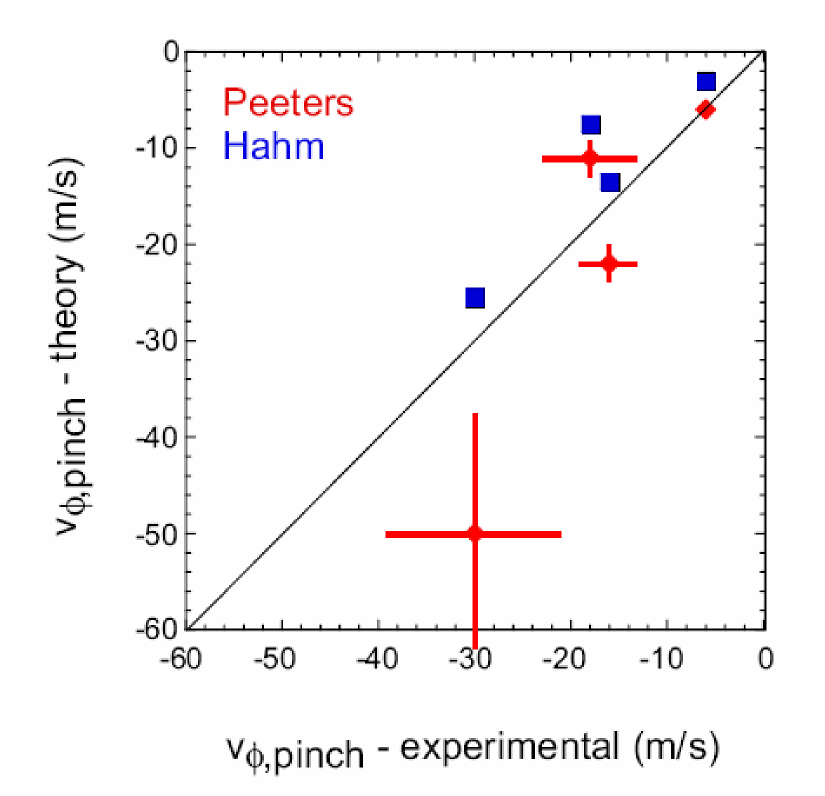
  – Effect of off-diagonal terms ($\propto \nabla T_e$, ∇n_e)?

  – $\chi_\phi^{ss} < \chi_\phi^{pert}$ with pinch

- Important to consider when comparing χ_ϕ to χ_i



Reasonably Good Agreement Between Theory and Experiment in Limited Comparison

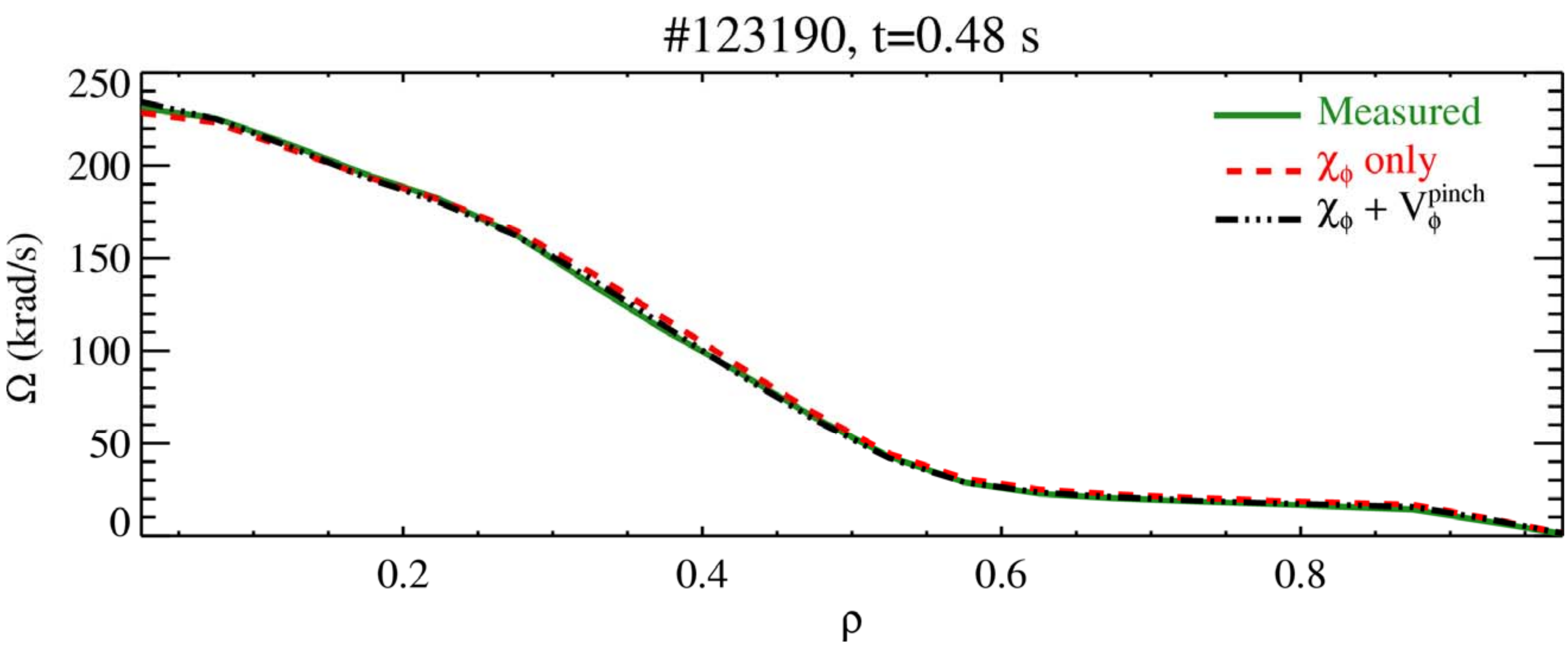


Can comparisons with large variations in L_n be used to discriminate between theories?

Is a Momentum Pinch Really Needed to Describe Rotation Evolution?

NSTX

- Perform predictive TRANSP run specifying momentum transport to look at expected rotation evolution
  - Compare χ_ϕ only with χ_ϕ + V_ϕ^{pinch}
- Over relatively short evolution time, cannot distinguish rotation profiles from measurement



Summary

- n=3 non-resonant magnetic braking successfully used for perturbative momentum transport studies

- Perturbative momentum confinement time several times greater than energy confinement time
  - Avoids issues of intrinsic rotation

- Braking caused adequate distortion to rotation profile
  - Enabling separation of χ_ϕ and V_ϕ^{pinch}

- Momentum flux suggests significant inward pinch
  - Comparable to theoretical predictions

- Rotation evolution period too short to definitively illustrate need for pinch
  - Repetitive perturbations + Fourier analysis probably needed to improve this