Effects of Resonant Magnet Field Perturbations on Density Profiles, Particle Transport, and Turbulence in DIII-D

by

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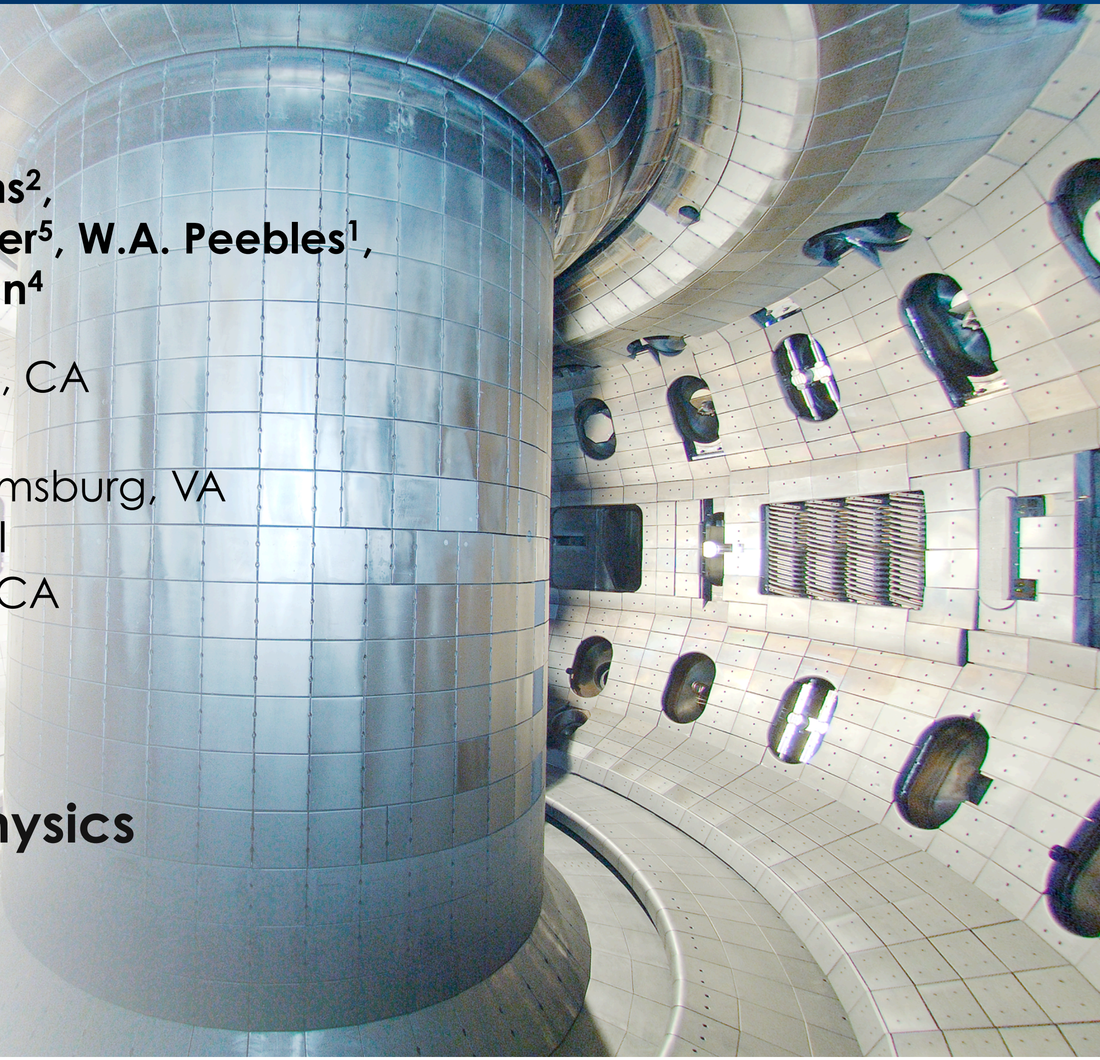

Presented at the

53rd Annual Meeting of the APS Division of Plasma Physics Salt Lake City, Utah

November 14-18, 2011

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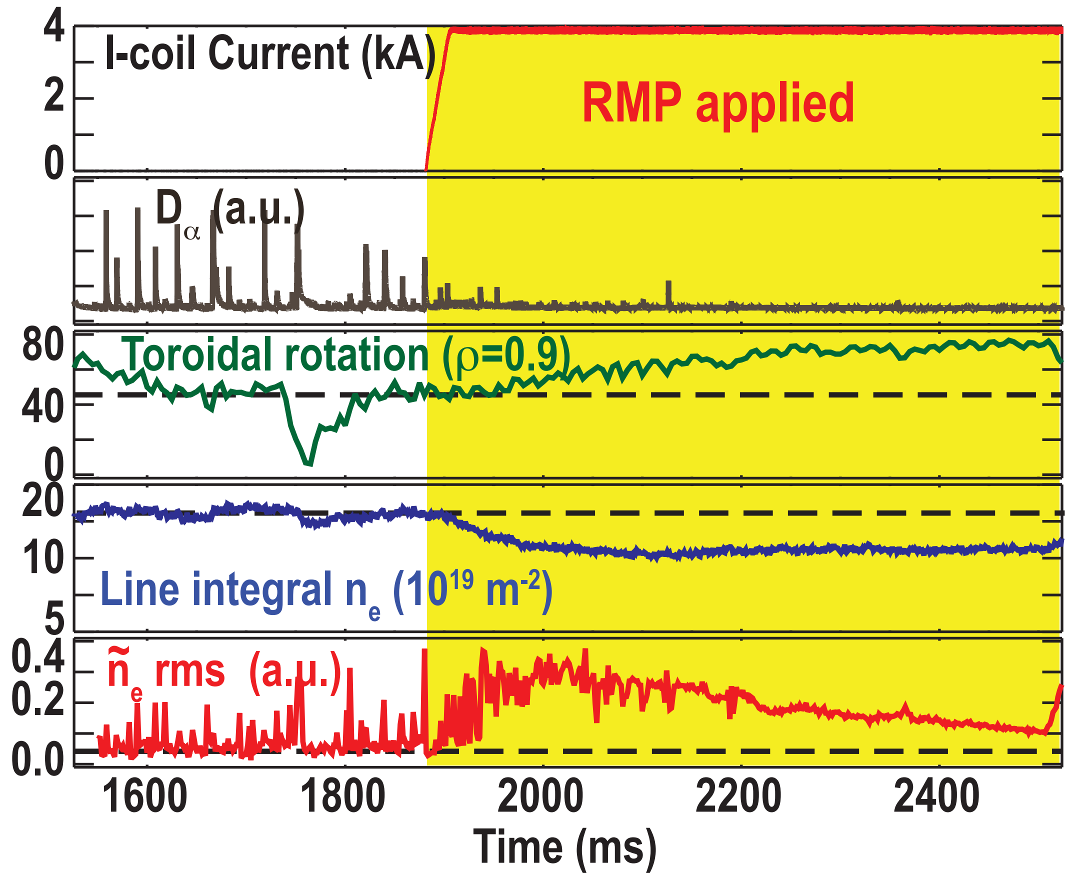
Motivation: Understanding Transport Changes with RMP is Important for Optimizing ELM Suppression in ITER

- **Resonant magnetic perturbations (RMP) affects plasma in multiple ways**
  - ELM suppression
  - Rotation changes
  - Density "pumpout"
  - Turbulence changes



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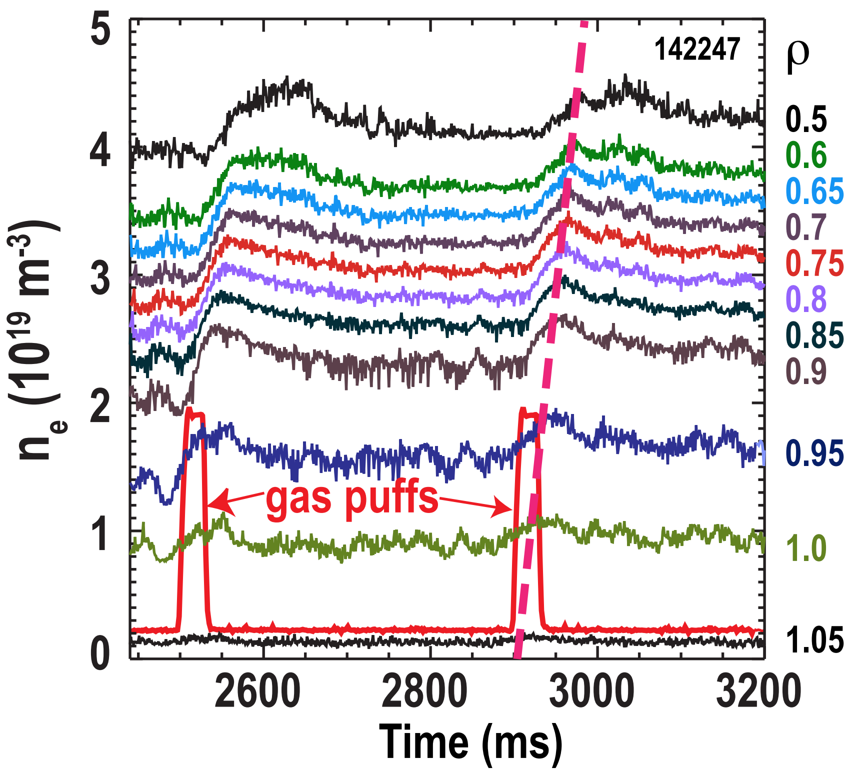
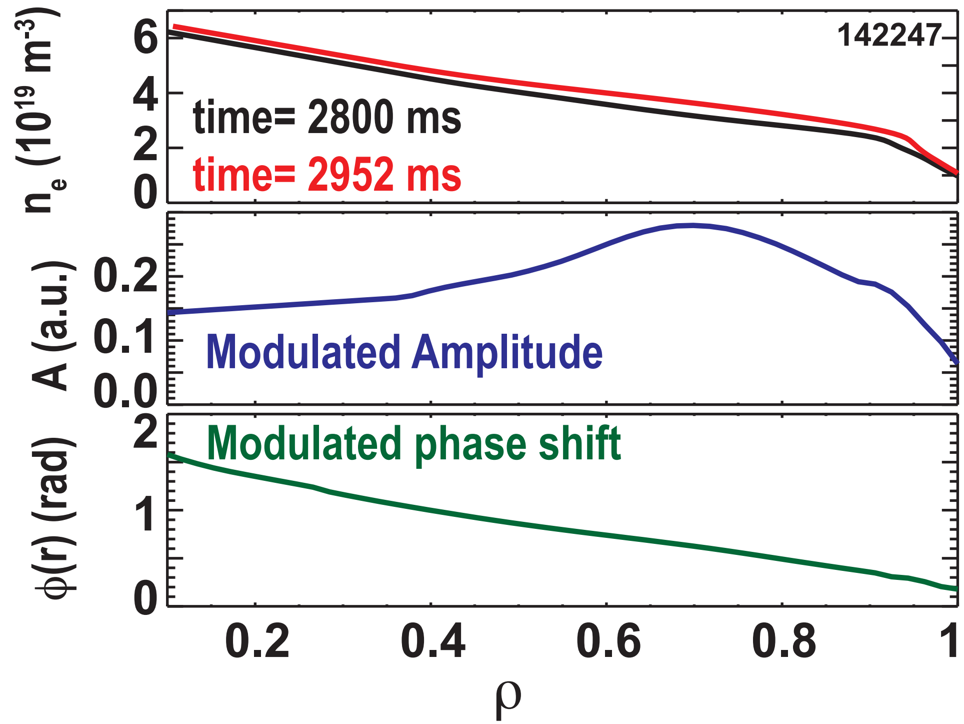
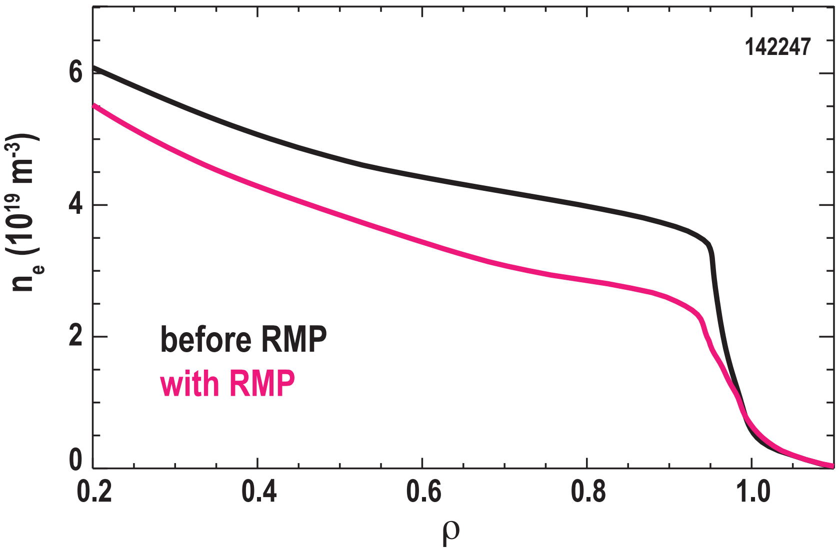
Particle Transport Measured Using Perturbation Technique — D_2 Main Gas Puff Modulation

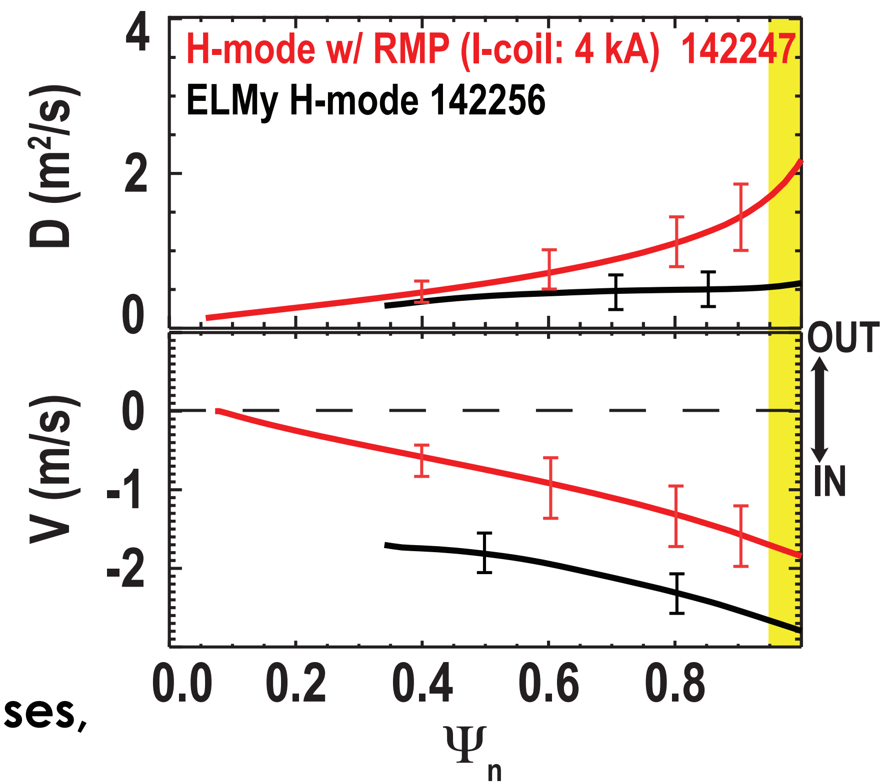




- Propagation of D_2 gas puffs from edge to core clearly observed
- Reflectometer provides density profiles with high temporal resolution, 0.1 ms
- Analytical expressions exist for perturbed diffusion coefficient (D) and pinch velocity (V) from modulated amplitude and phase shift profiles - see E. J. Doyle, poster Thursday PM, UP9.00055

First Direct Measurement of Increase in Perturbed D and Reduction in Pinch V with n=3 RMP Application (H-mode)





- **Diffusive transport (D) clearly increases, while inward pinch (V) decreases**
  - Consistent with observed density pump out
- **Note: modulated edge neutral source is not considered, which may affect analysis for ρ > 0.95**

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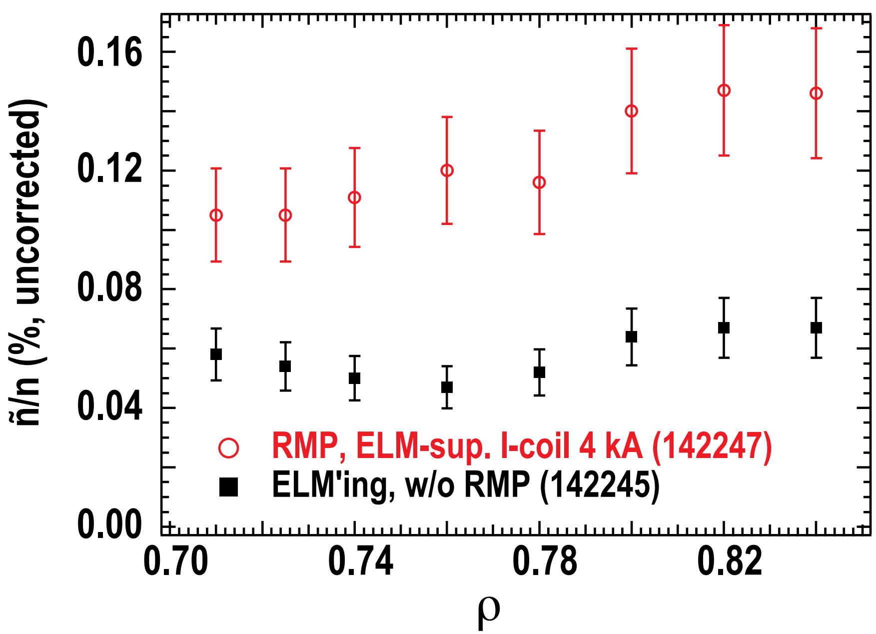
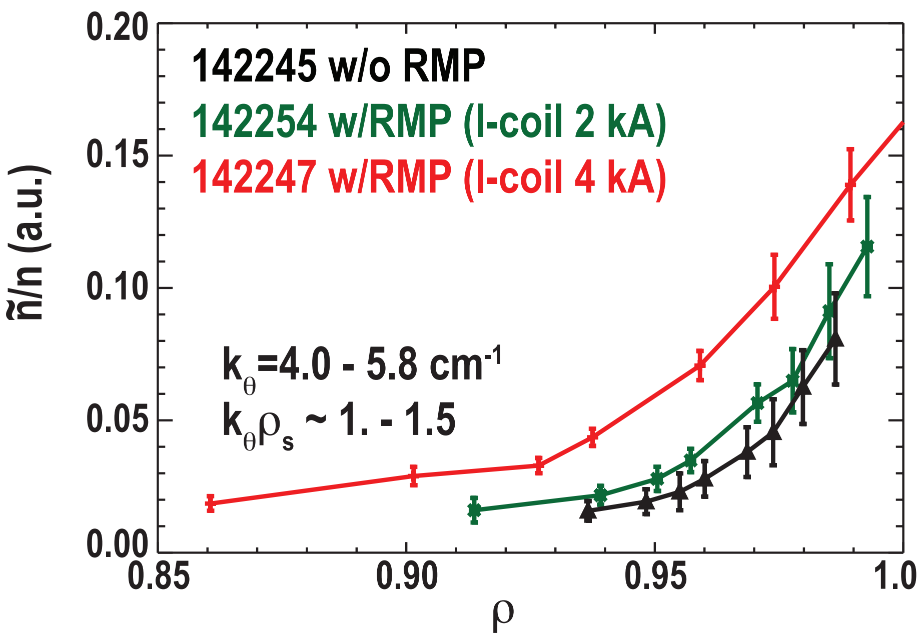
Turbulence Increases with RMP Application in These H-modes, Observed with Multiple Diagnostics

BES measurement $k_\theta < 3\ cm^{-1}$



DBS measurement, intermediate k



- Beam Emission Spectroscopy (BES) data show low-k turbulence increases in the core
- Doppler backscattering (DBS) data show intermediate-k turbulence increases in the core and edge

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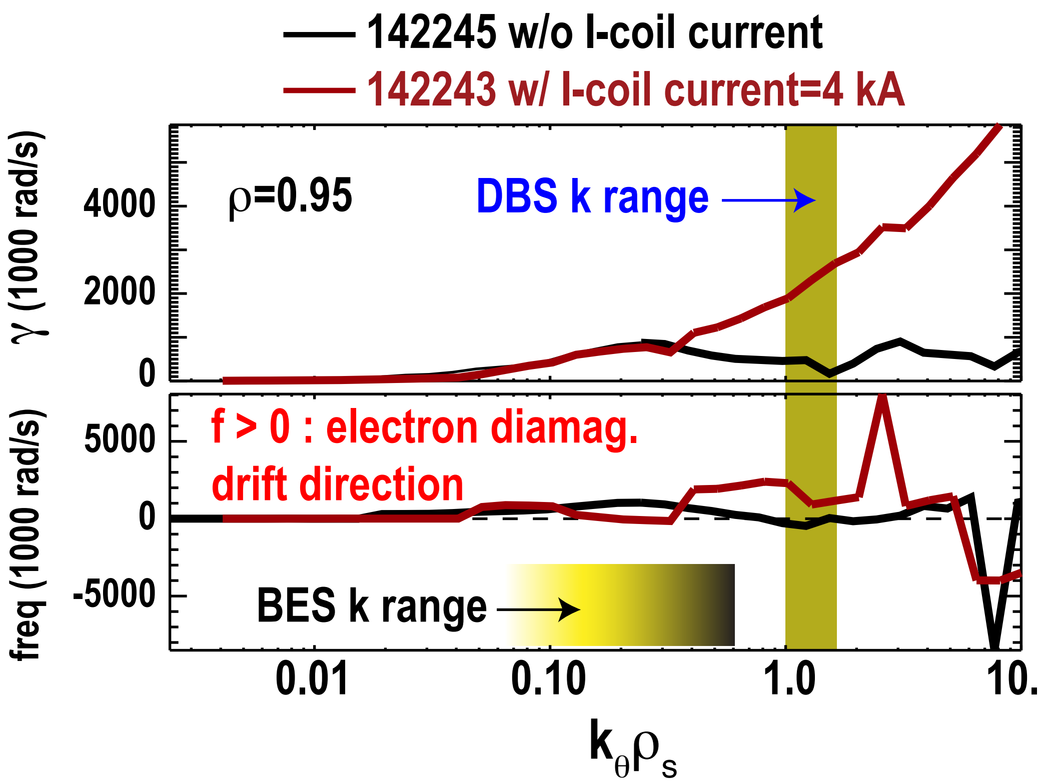
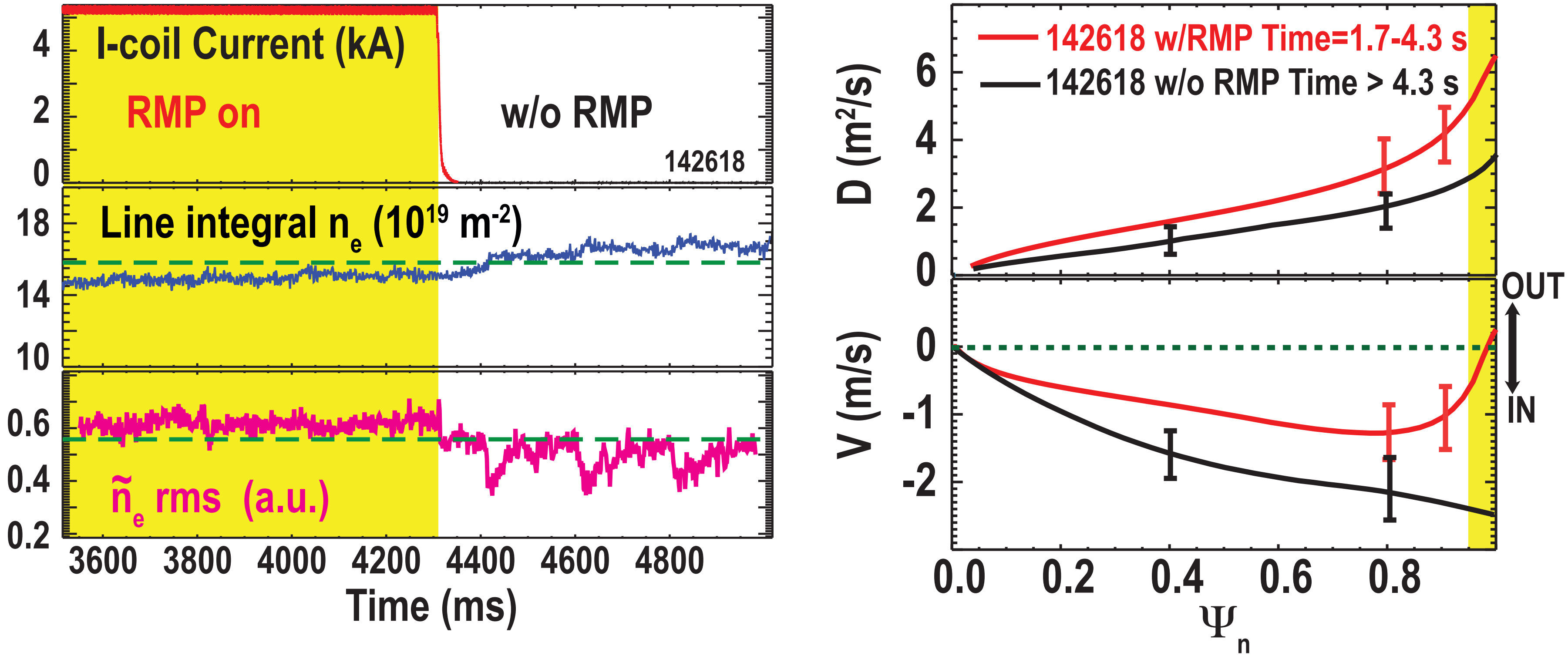
Turbulence Changes with Application of n=3 RMP are Consistent with TGLF Analysis



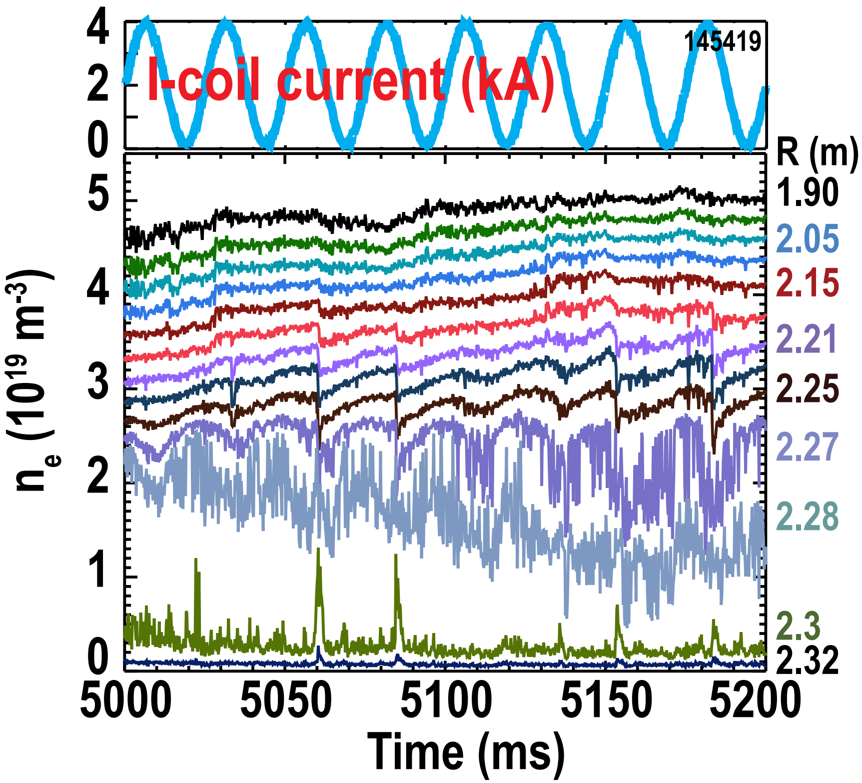
- **TGLF: Trapped particle gyro-Landau-fluid model**
- **Growth rates increase for $k\rho_s$ > 0.5 with RMP**
- **Possible change in turbulence propagation direction**
  - Electron diamagnetic drift direction mode with RMP, ion direction without RMP, for $k_\theta\rho_s$=0.3-3

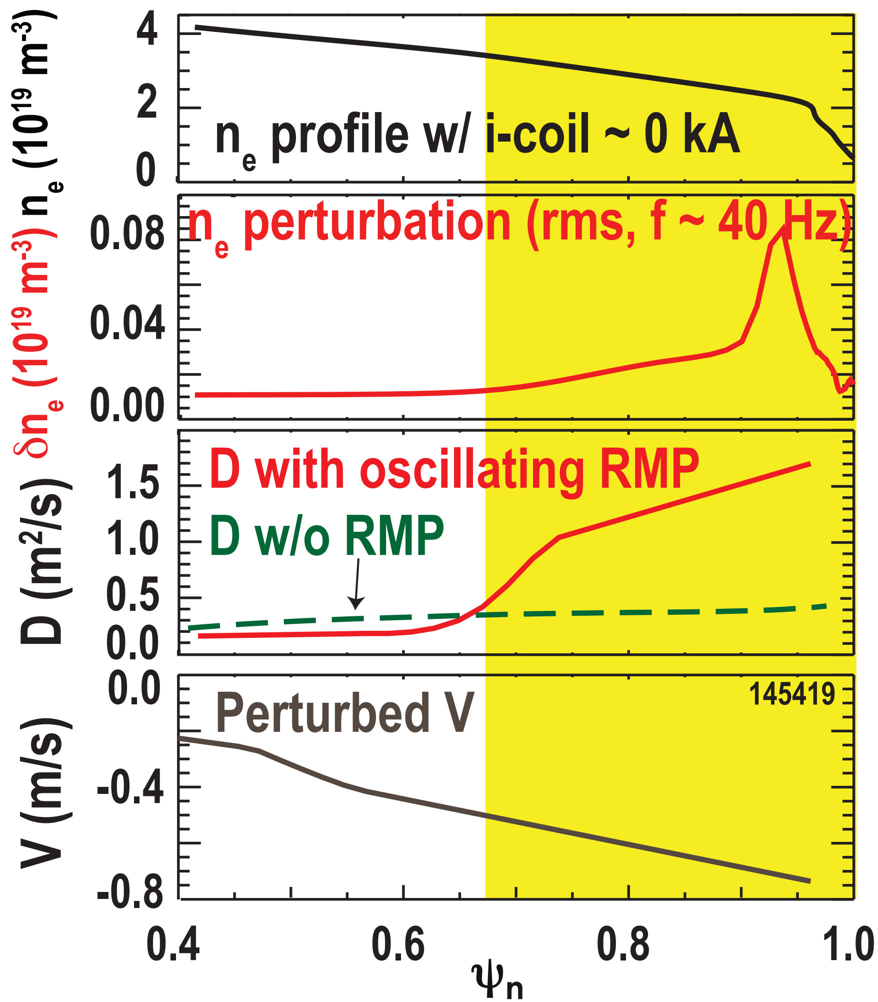
L-mode Plasmas Also Respond to RMP, Again with Measured Increase in D and Reduction in V



- **Measurements confirm that n=3 RMP application also increases particle transport in L-mode**

Perturbed D Significantly Increases in Stochastic Area, Via Transient Analysis with Oscillatory n=3 RMPs





- Measure perturbative particle transport rates (D and V) by using oscillating RMP, instead of gas puff

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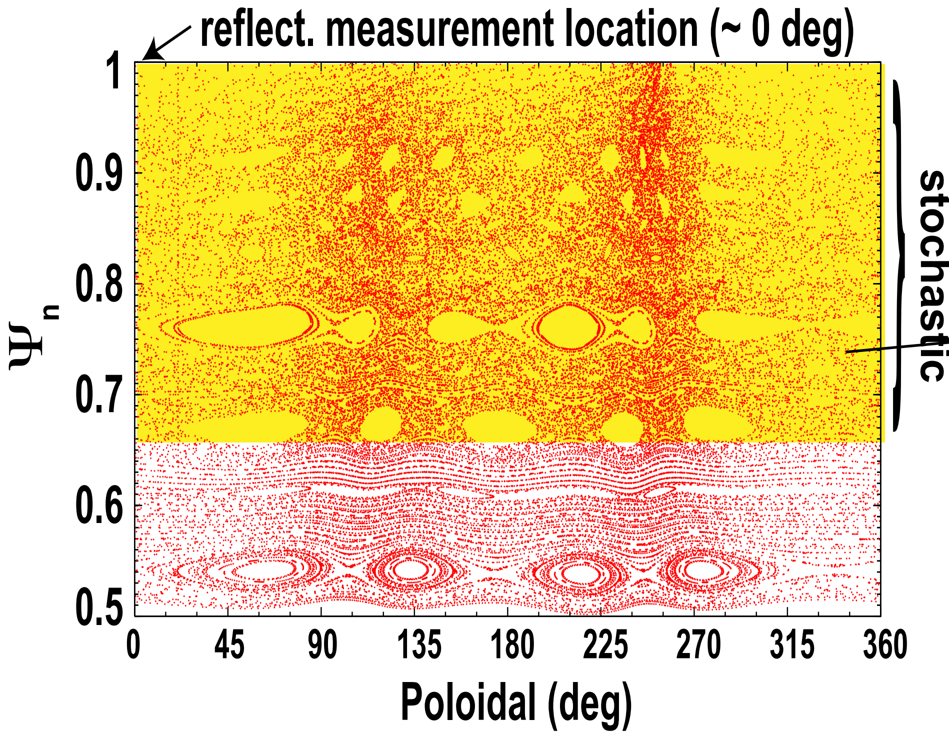

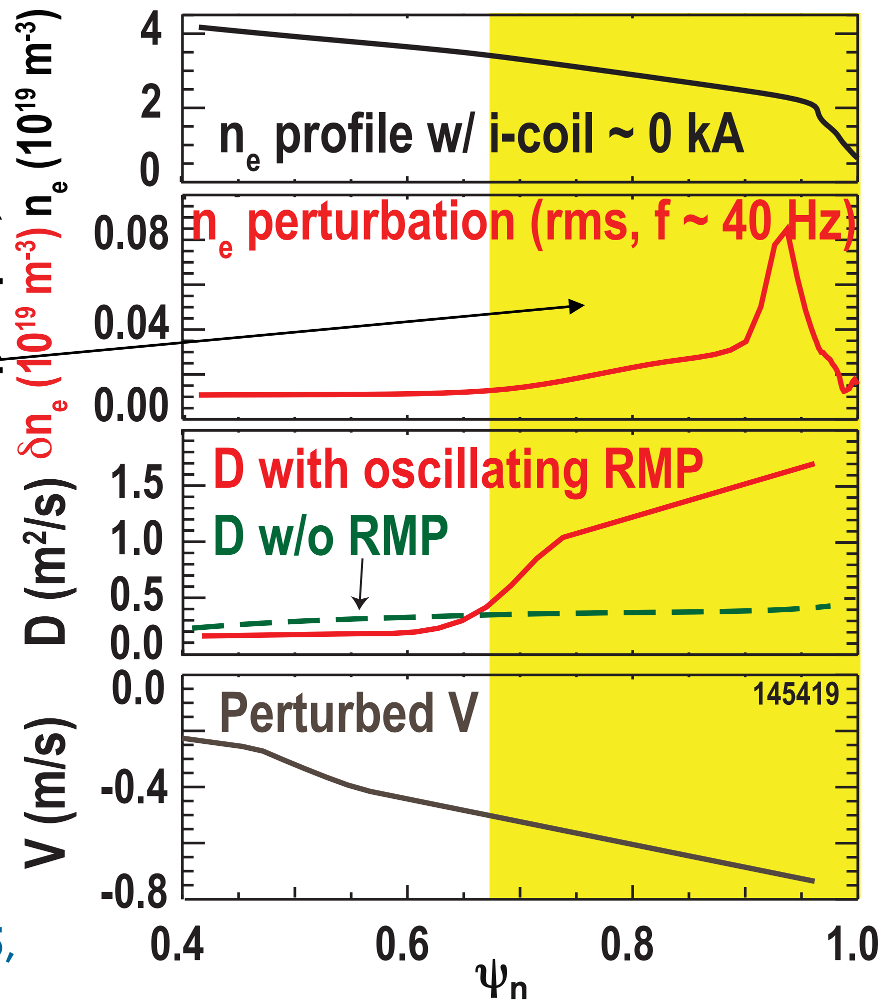

- Poincare plot generated by TRIP3D (a vacuum field line code) for shot 145419 with 4 kA of I-coil current
- The plot shows stochastic layer in $\Psi_n > 0.65$, where perturbed D significantly increases

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Summary

- **Two modulation techniques successfully used to measure perturbative particle transport rates (D, V)**
  - Gas puff modulation
  - Oscillating resonant magnetic perturbations

- **First direct measurement of increase in D and decrease in V with RMP application**

- **In these H-mode plasmas, turbulence levels increase substantially with RMP application**
  - Consistent with TGLF calculations
  - Potential explanation for observed changes in core transport

- **Oscillating n=3 RMP field generates increased particle transport in stochastic edge region**

With Some Assumptions, Analytical D_{pb} and V_{pb} are Obtained

Approach based on Takenaga et al., *Plasma Phys. Control. Fusion* 40, 183 (1998). Modulated particle transport equation is as follows:

$$\partial\tilde{n}/\partial t = (\frac{1}{r}\frac{\partial}{\partial r}r)(D\frac{\partial\tilde{n}}{\partial r} - V\tilde{n}) + \tilde{S}$$

1. **Assume the local modulated density as:**

   $$\tilde{n}(r,t) = A(r)\exp[i(\omega t - \phi(r))]$$

2. **Cylindrical geometry**
3. **Assuming the modulated particle source is negligible, then an analytical expression for D and V can be obtained as follows,**

$$D = -\frac{\omega(Y\sin\phi + X\cos\phi)}{r(\partial\phi/\partial r)A}$$

$$V = -\frac{\omega((\partial A/\partial r)Y - (\partial\phi/\partial r)AX)\sin\phi + ((\partial\phi/\partial r)AY + (\partial A/\partial r)X)\cos\phi)}{r(\partial\phi/\partial r)A^2}$$

Where ω is gas puff modulation frequency, and $X = \int rA\cos\phi dr, Y = \int rA\sin\phi dr$