Modeling of RMP-Flutter-Induced Transport in DIII-D

by

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With

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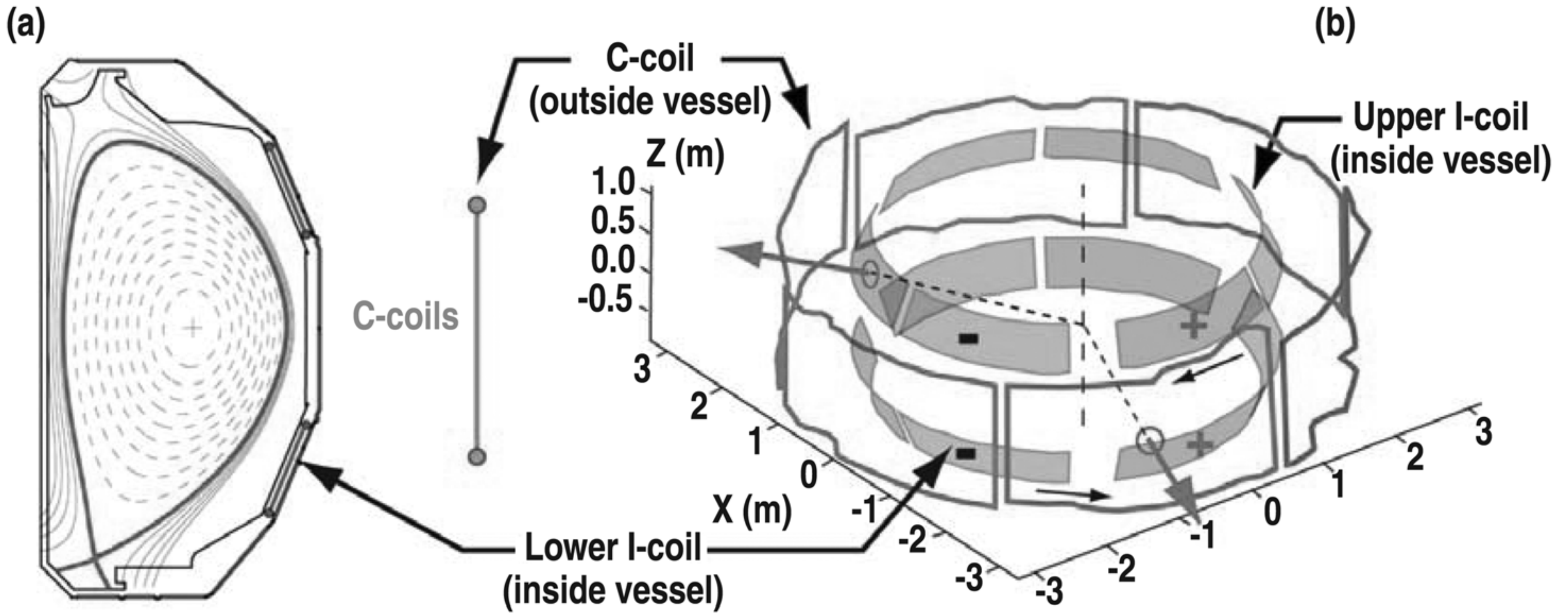
Motivation: Need to Understand Physics of ELM Suppression to Be Able to Project to Future Devices

- **Pedestal grows until ELM hits**
- **RMP coils can inhibit pedestal growth to prevent ELMs**
- **What are possible physics mechanisms that inhibit growth?**
  - Vacuum Islands Picture:
    3D Fields ➔ Overlapping Islands ➔ Stochastic Transport
  - Plasma Islands Picture:
    3D Fields ➔ Flow Screening ➔ Strategically Placed Isolated Islands
  - Magnetic Flutter Picture:
    3D Fields ➔ Flow Screening ➔ Isolated Islands ➔
    Radial Field Line Wiggles Between Islands
- **In this talk, magnetic flutter induced transport is shown to be of an experimentally (DIII-D) relevant level**

Outline

- Experimental Observations
- Vacuum vs Plasma Response
- Magnetic Flutter Equations
- Comparison of Model to Experiment
  - 126006
  - 126440
- q95 Scan Using Model Equilibria
- Summary

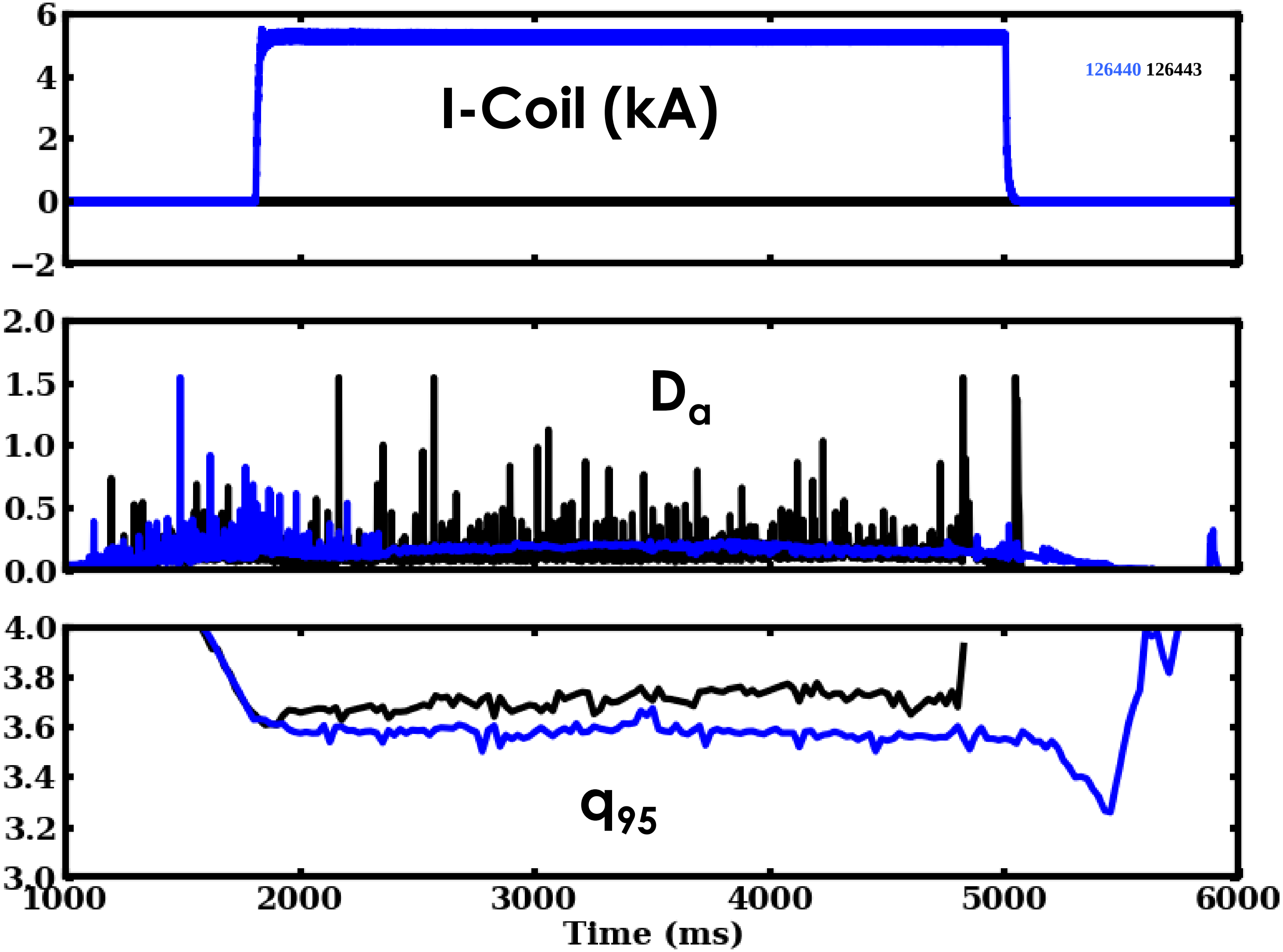
DIII-D has both internal and external magnetic field coils



n=3 I-coil and n=1 C-coil configuration
(with up-down symmetric, even parity, I-coil)

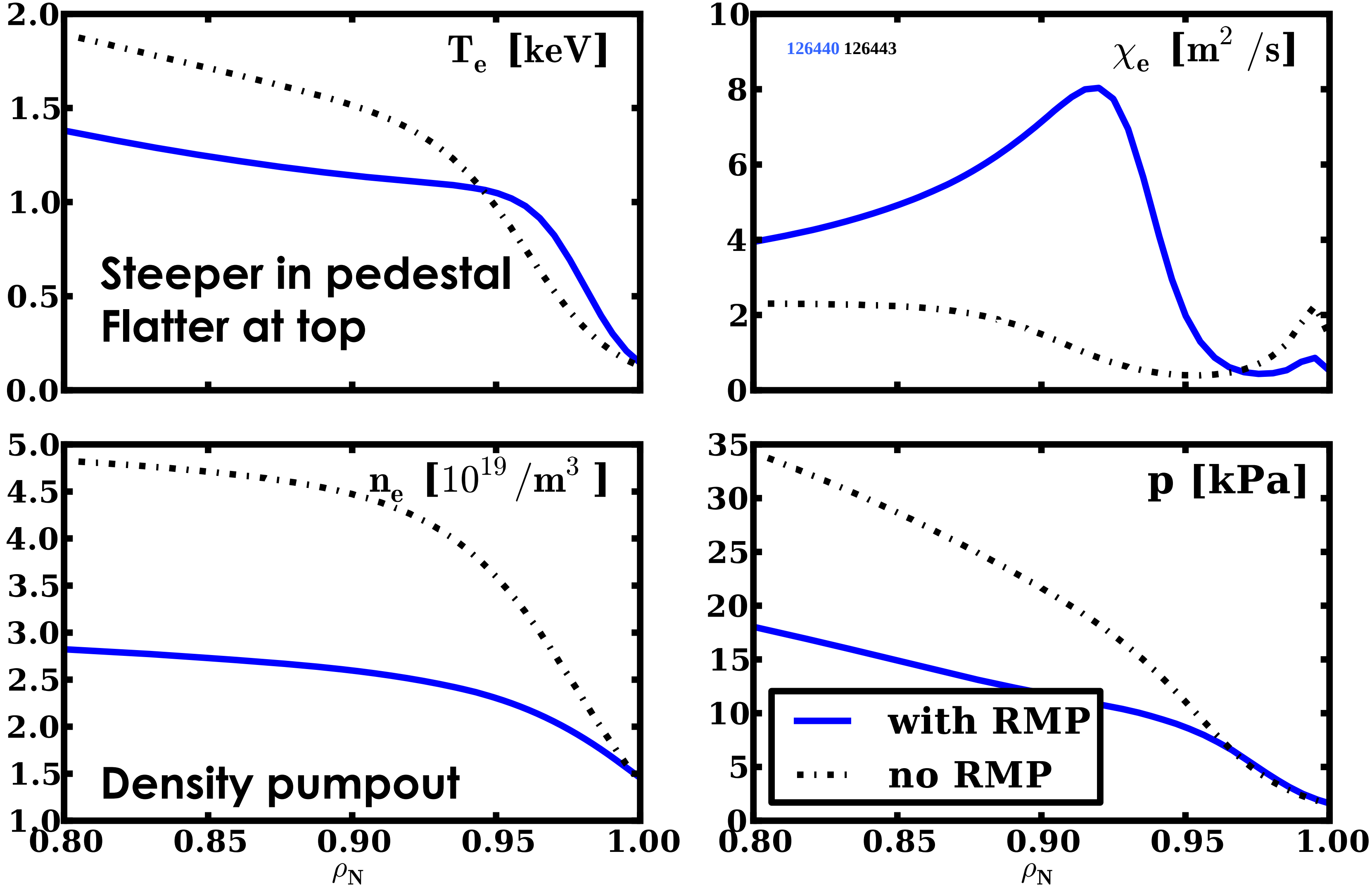
- I-coils are single turn
- For ELM suppression, the I-coils are usually used singly or in odd parity

3D Fields from I-Coils Are Used for ELM Suppression



B_T =2.1 T
I_P =1.6 MA

RMP Fields Have Complicated Effects on the Kinetic Profiles



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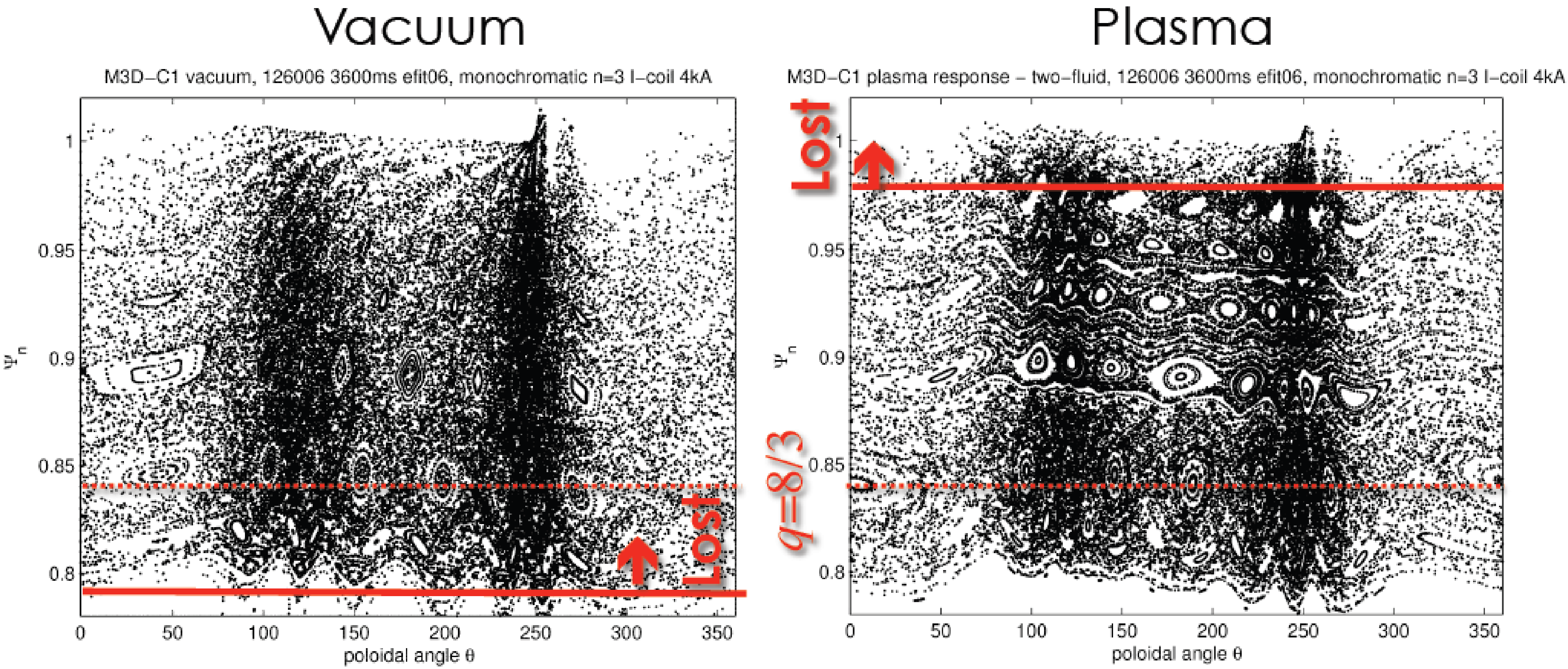
Plasma Response Reduces Region of 3D Fields-Induced Magnetic Stochasticity; Flutter Remains Between Islands



- **M3D-C1 (Two-Fluid MHD) calculates linear perturbations**
- **TRIP-3D calculates Poincaré plots**
- **Shot 126006, Ion Rotation is Carbon Rotation**

Magnetic Flutter Model has Kinetic and Geometric Contributions; Rational Surfaces are Important

Flux ~ electron density * diffusivity * gradient

$$\begin{bmatrix} \delta\Gamma_{\mathrm{et}}^{\mathrm{RMP}} \\ \delta\Upsilon_{\mathrm{et}}^{\mathrm{RMP}}/T_e \end{bmatrix} = -n_e \begin{bmatrix} D_{\mathrm{et}}^{\mathrm{RMP}} & D_T^{\mathrm{RMP}} \\ \chi_n^{\mathrm{RMP}} & \chi_{\mathrm{et}}^{\mathrm{RMP}} \end{bmatrix} \cdot \begin{bmatrix} d\ln \hat{p}_e/d\rho \\ d\ln T_e/d\rho \end{bmatrix}$$

Total diffusivity = sum of the diffusivities at each point induced by each m/n

$$\begin{bmatrix} D_{\mathrm{et}}^{\mathrm{RMP}} & D_T^{\mathrm{RMP}} \\ \chi_n^{\mathrm{RMP}} & \chi_{\mathrm{et}}^{\mathrm{RMP}} \end{bmatrix} = \sum_{mn} \begin{bmatrix} D_{\mathrm{et}}^{m/n} & D_T^{m/n} \\ \chi_n^{m/n} & \chi_{\mathrm{et}}^{m/n} \end{bmatrix}$$

Diffusivity at q ~ (magnetic perturbations)² * Kinetic/Spatial Coefficients

$$\begin{bmatrix} D_{\mathrm{et}}^{m/n} & D_T^{m/n} \\ \chi_n^{m/n} & \chi_{\mathrm{et}}^{m/n} \end{bmatrix} = \frac{v_{Te}^2}{\nu_e}\frac{1}{2}\left(\frac{\langle \delta \hat{B}^{\mathrm{pl}}_{\rho\, m/n}\rangle}{B_{t0}}\right)^2 \begin{bmatrix} K_{00} & K_{01} \\ K_{10} & K_{11} \end{bmatrix}$$

Kinetic/Spatial Coefficients:

$$\begin{bmatrix} K_{00} & K_{01} \\ K_{10} & K_{11} \end{bmatrix}_{\mathrm{tot}} = \frac{B_{t0}/B_{\max}}{\langle v_{\parallel}|_{\lambda=1}/v\rangle}\frac{13}{24\pi}\begin{bmatrix} G_{00} & G_{01} \\ G_{10} & G_{11} \end{bmatrix}$$

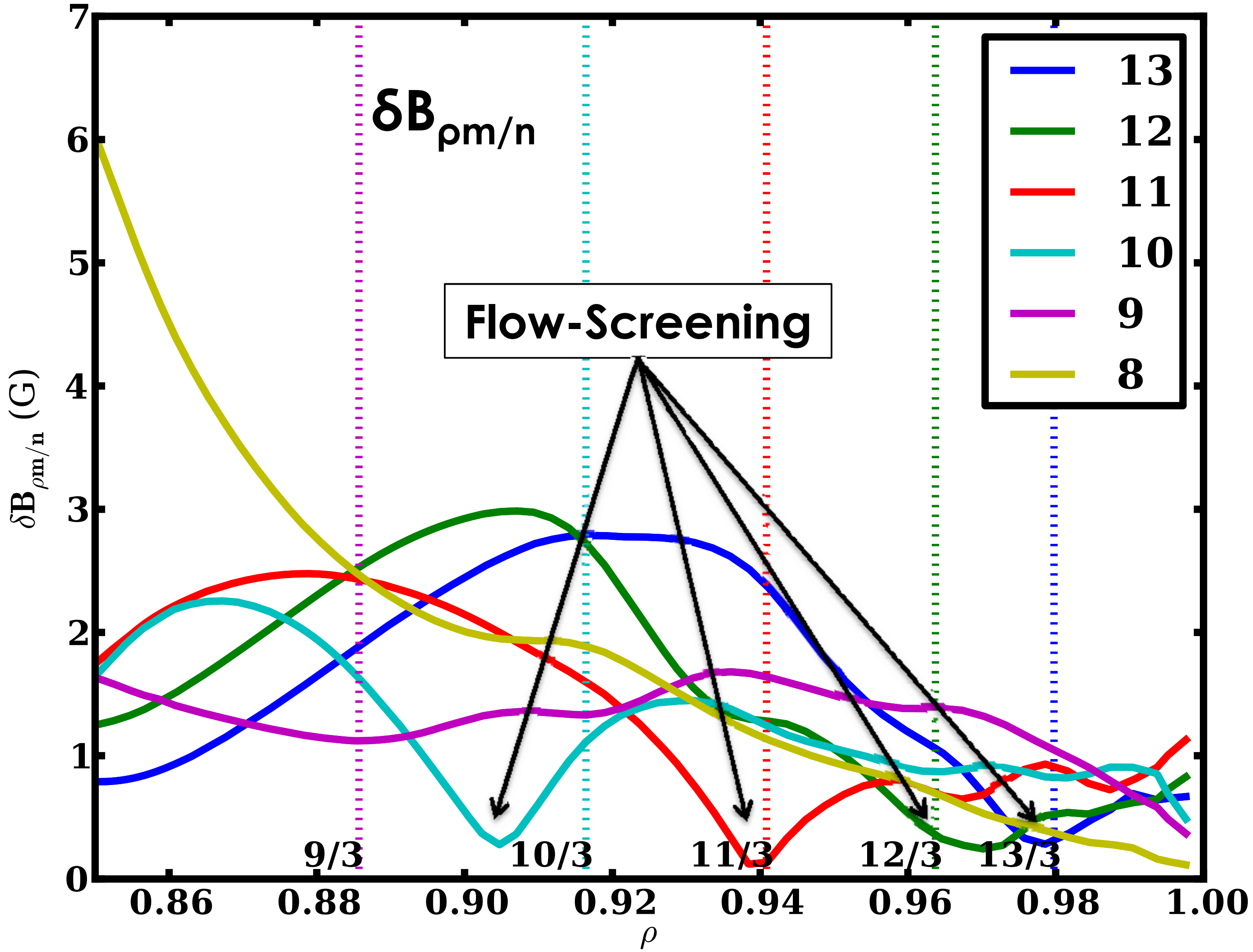
$$\begin{bmatrix} G_{00} & G_{01} \\ G_{10} & G_{11} \end{bmatrix} = \frac{4}{13\,|X|^{3/2}} \times \left(\frac{|X|^{3/2}}{c_{\parallel t}}\int_0^{1/|X|^{1/2}} dy\, y^3 e^{-y} + \int_{y_{\min}}^{\infty} dy\, e^{-y}\right)\begin{bmatrix} 1 & y-\frac{5}{2} \\ y-\frac{5}{2} & (y-\frac{5}{2})^2 \end{bmatrix}$$

- $\chi_e \;\alpha <\delta B_{mn}>^2$
- $<\delta B_{mn}>$ provided by linear M3D-C1 calculations

X – normed distance off a rational surface (X = 0 on the given m/n)

y – normalized electron kinetic energy

126006: $\delta B_{\rho m/n}$ Has Flow Screening at Most Rational



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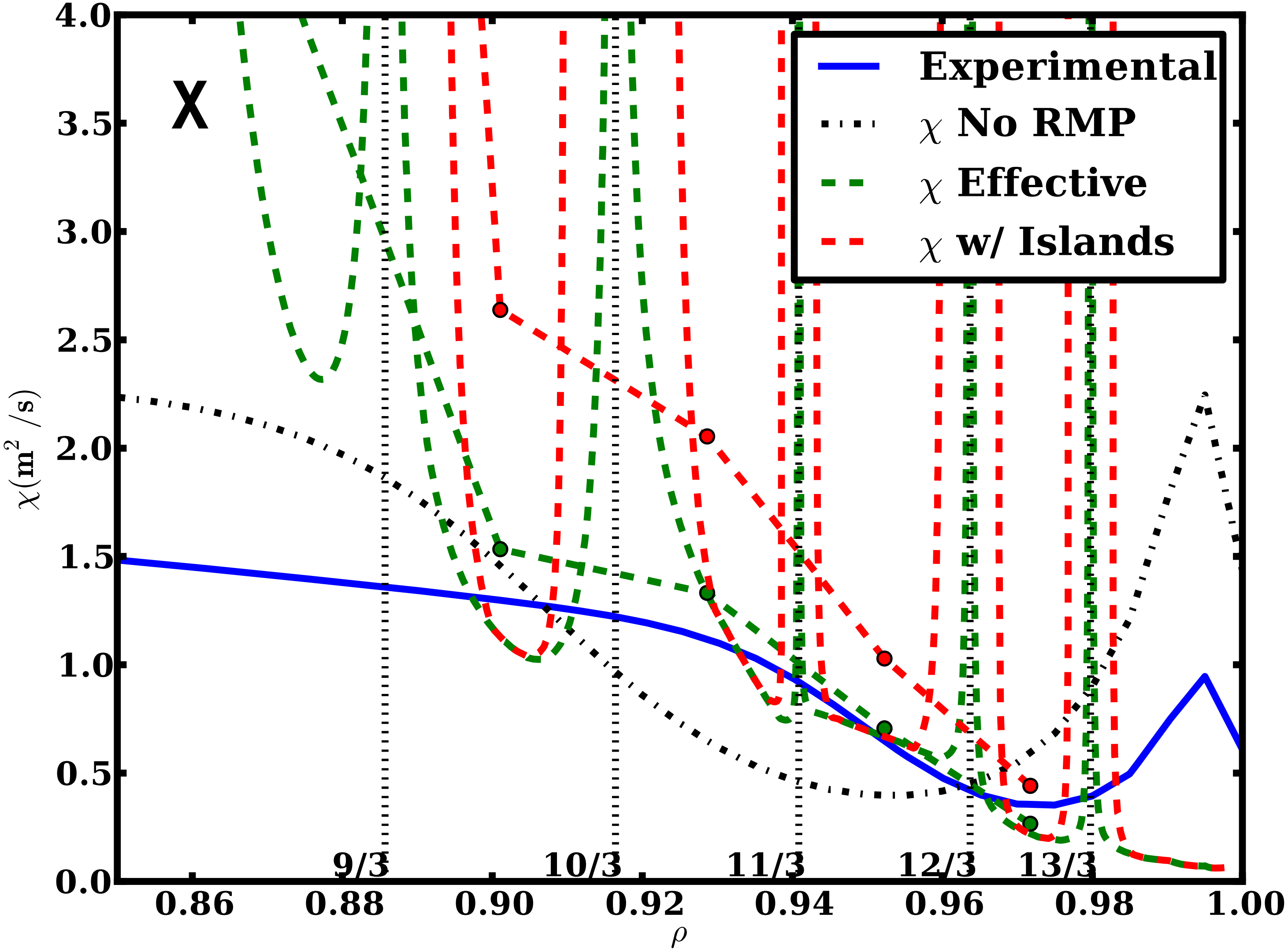
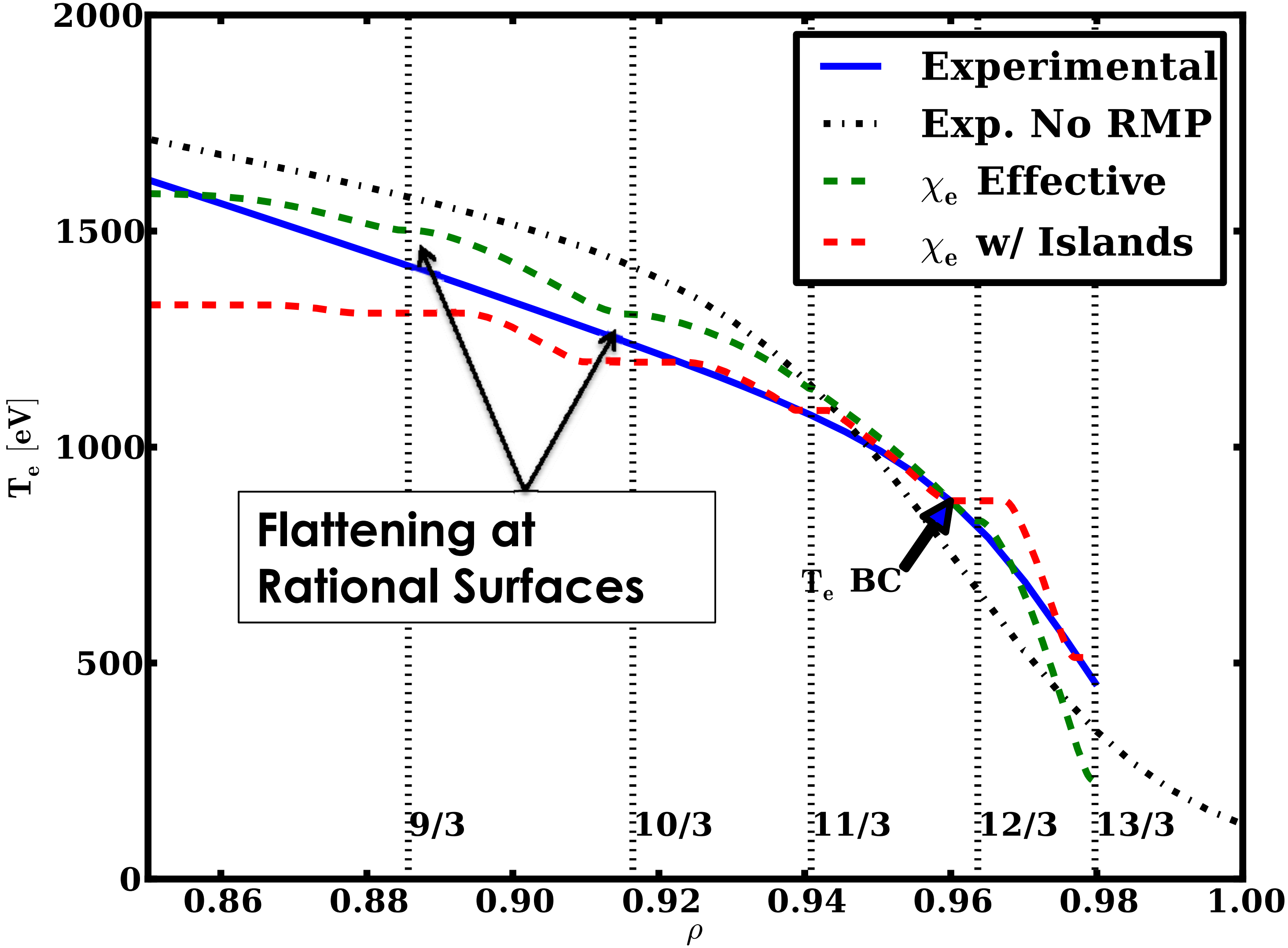
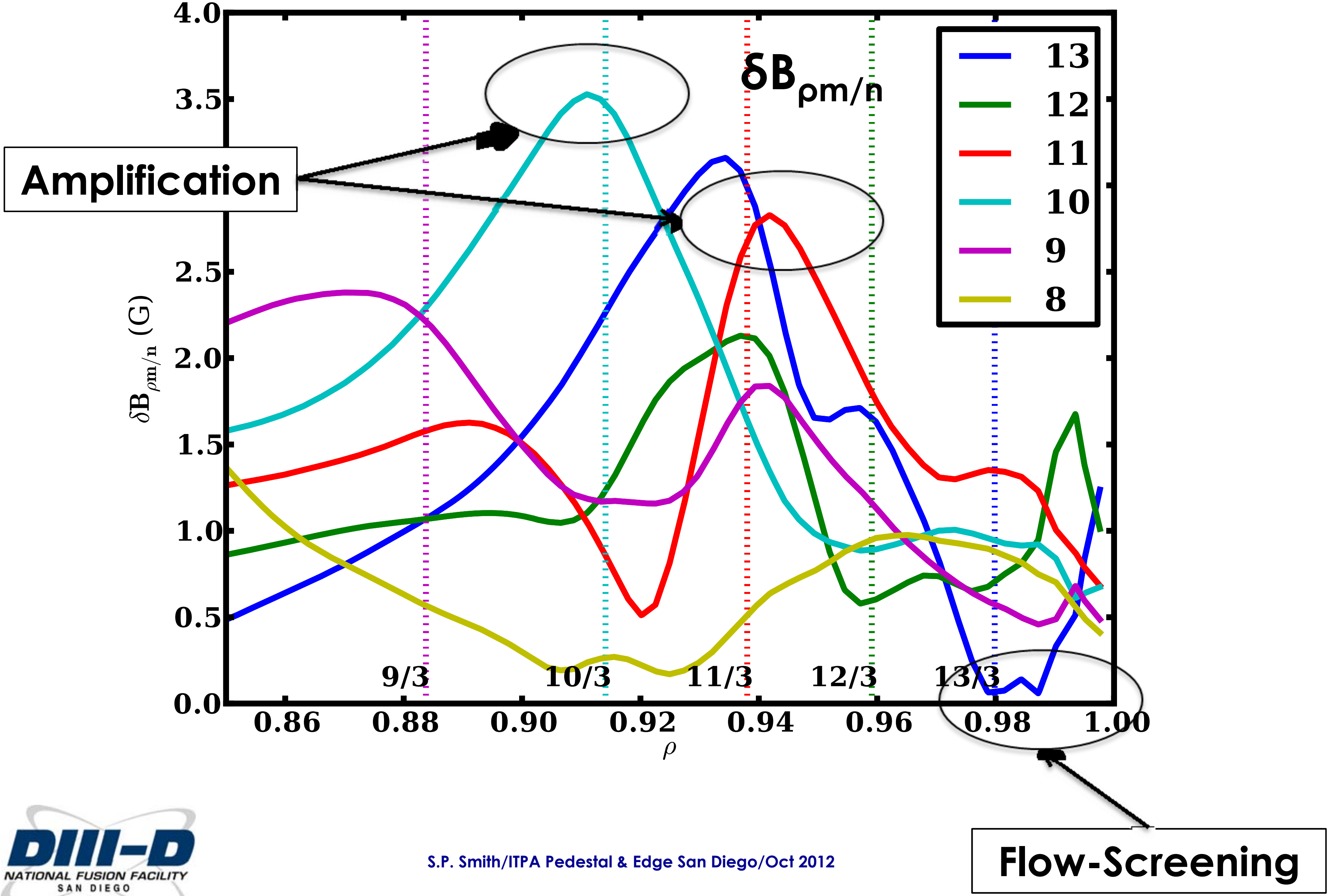
126006: Radially Averaged χ Effective Matches Experimental Diffusivity Reasonably Well



126006: For Judicious Boundary Condition, T_e is Well Matched Across the Top of the Pedestal



126440: : $\delta B_{\rho m/n}$ Has Flow Screening As Well As Amplification



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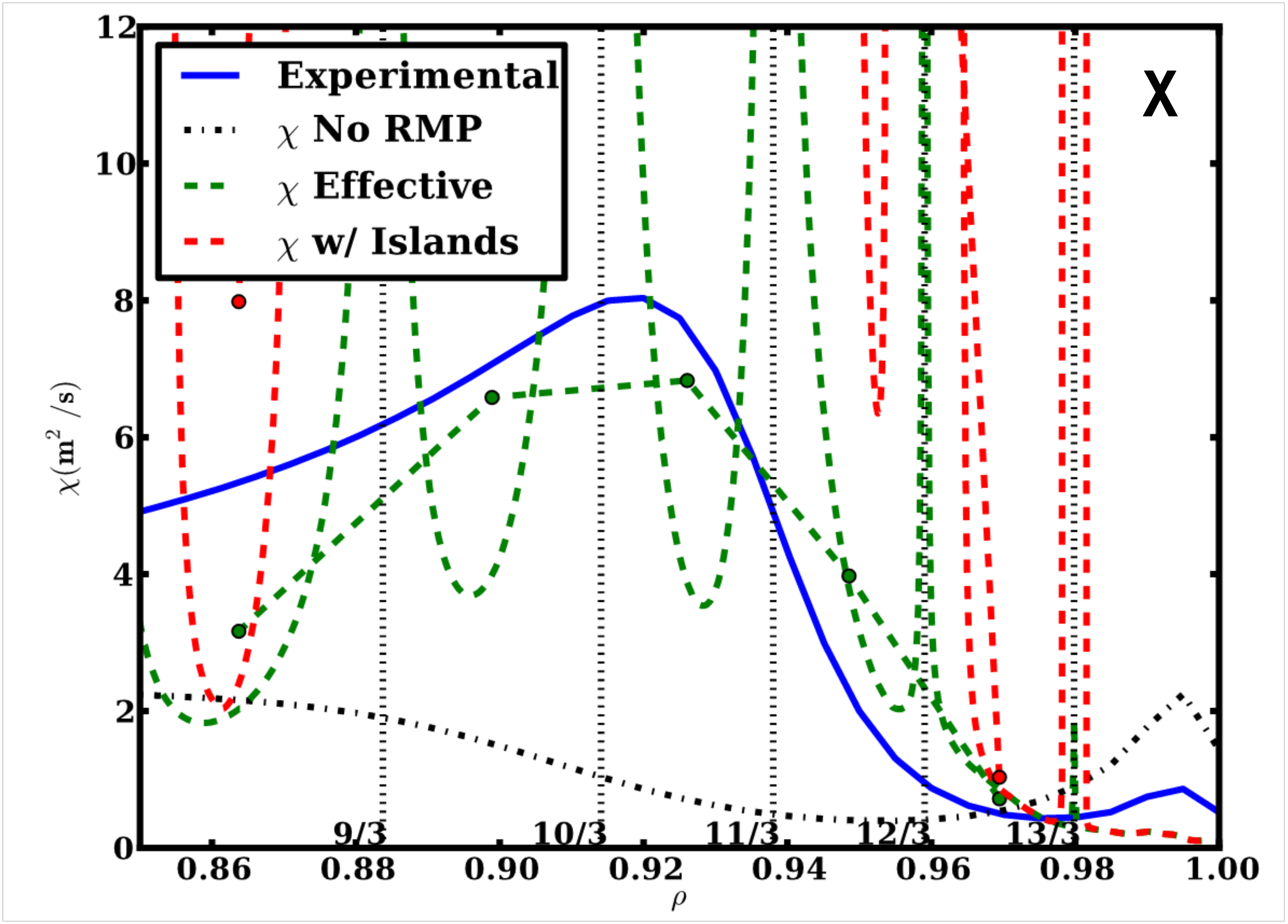
126440: Radially Averaged χ Effective Matches Experimental Diffusivity Reasonably Well



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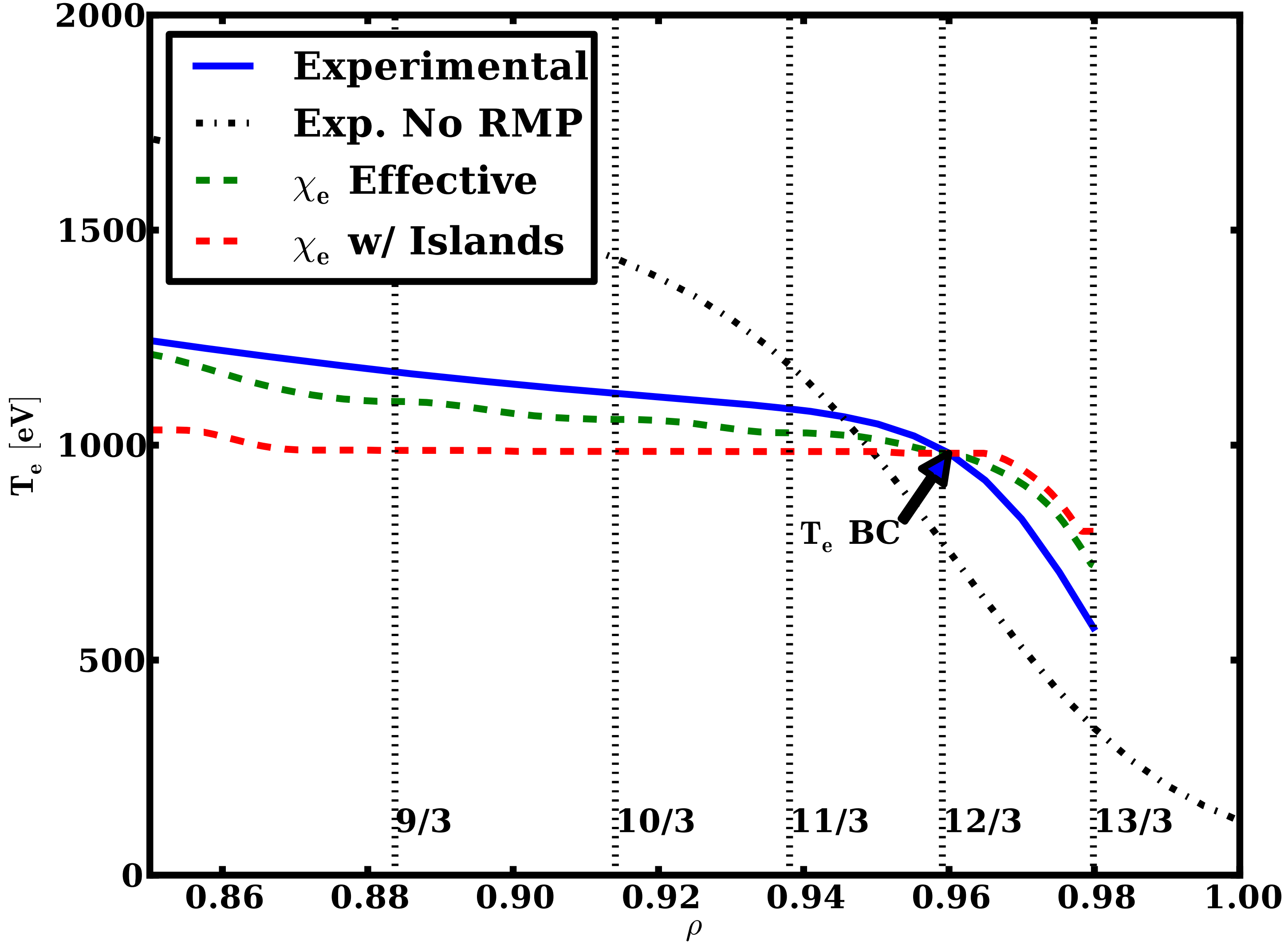
126440: For χEffective, with Judicious Boundary Condition, T_e is Well Matched Across the Top of the Pedestal



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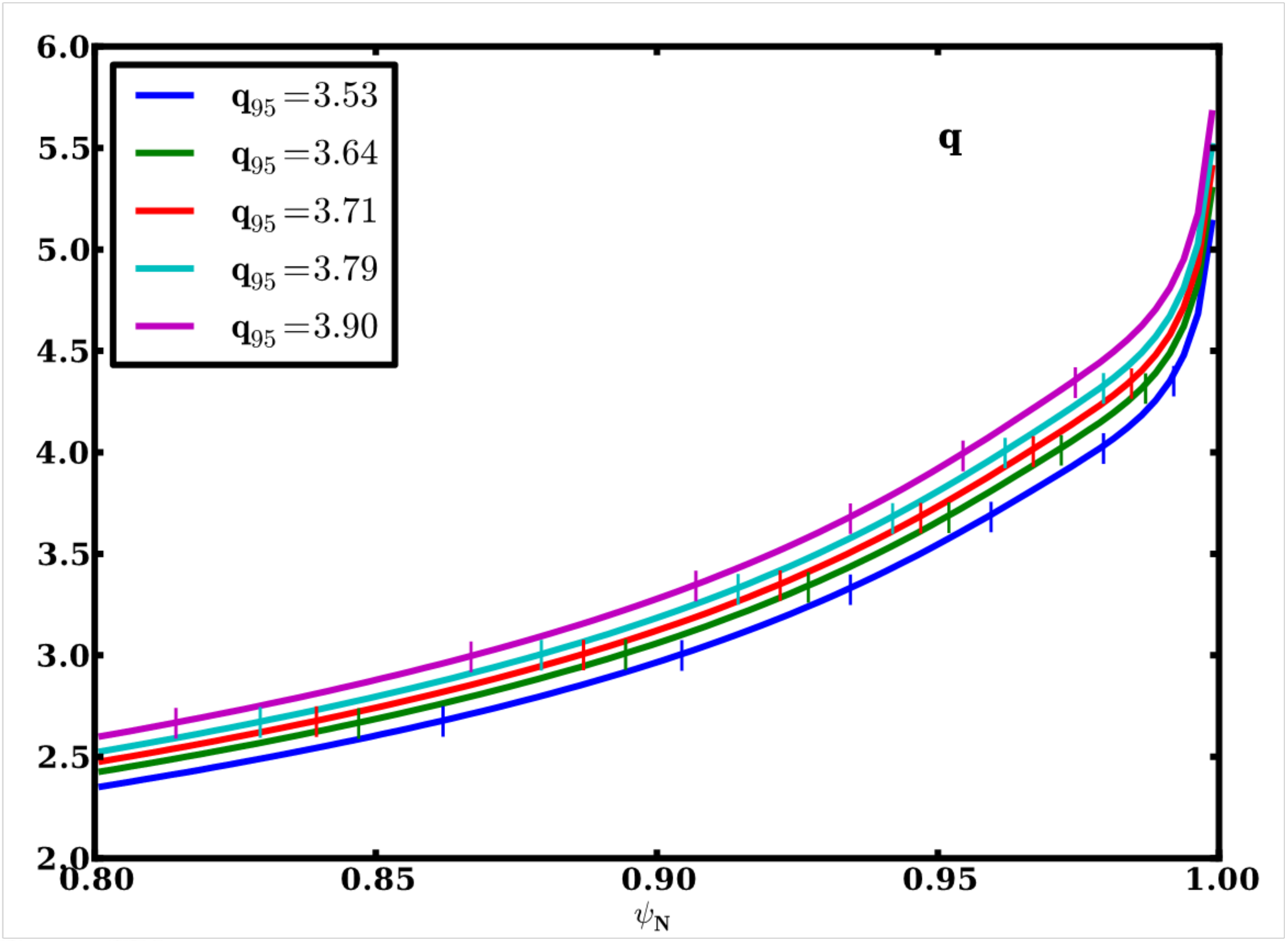
q profile varied by changing B_{T0} ±2%, ±5%; 3.5<q95<3.9



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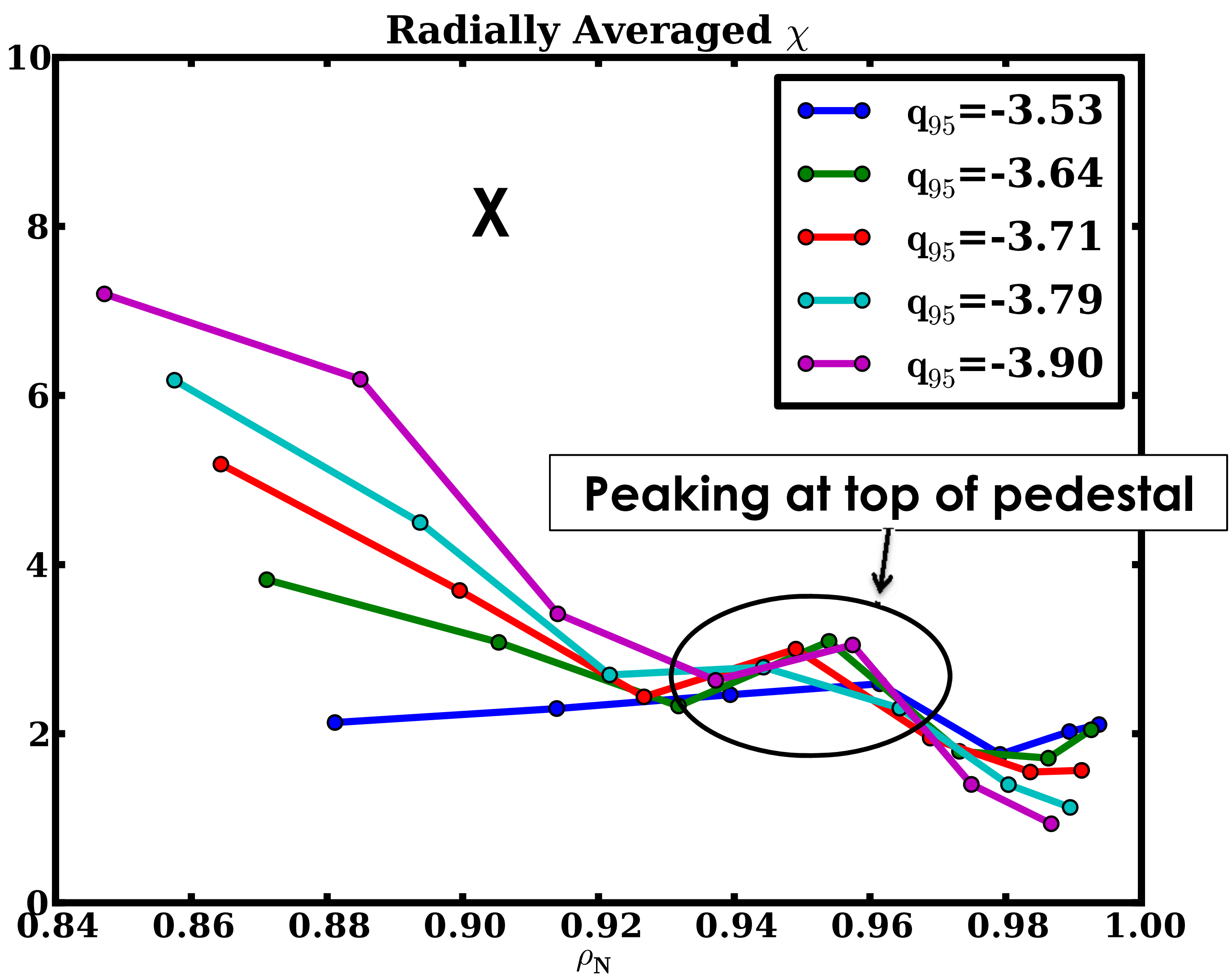
Radially Averaged Diffusivity at Top of Pedestal Might Show Peak When q95 is in Suppression Window



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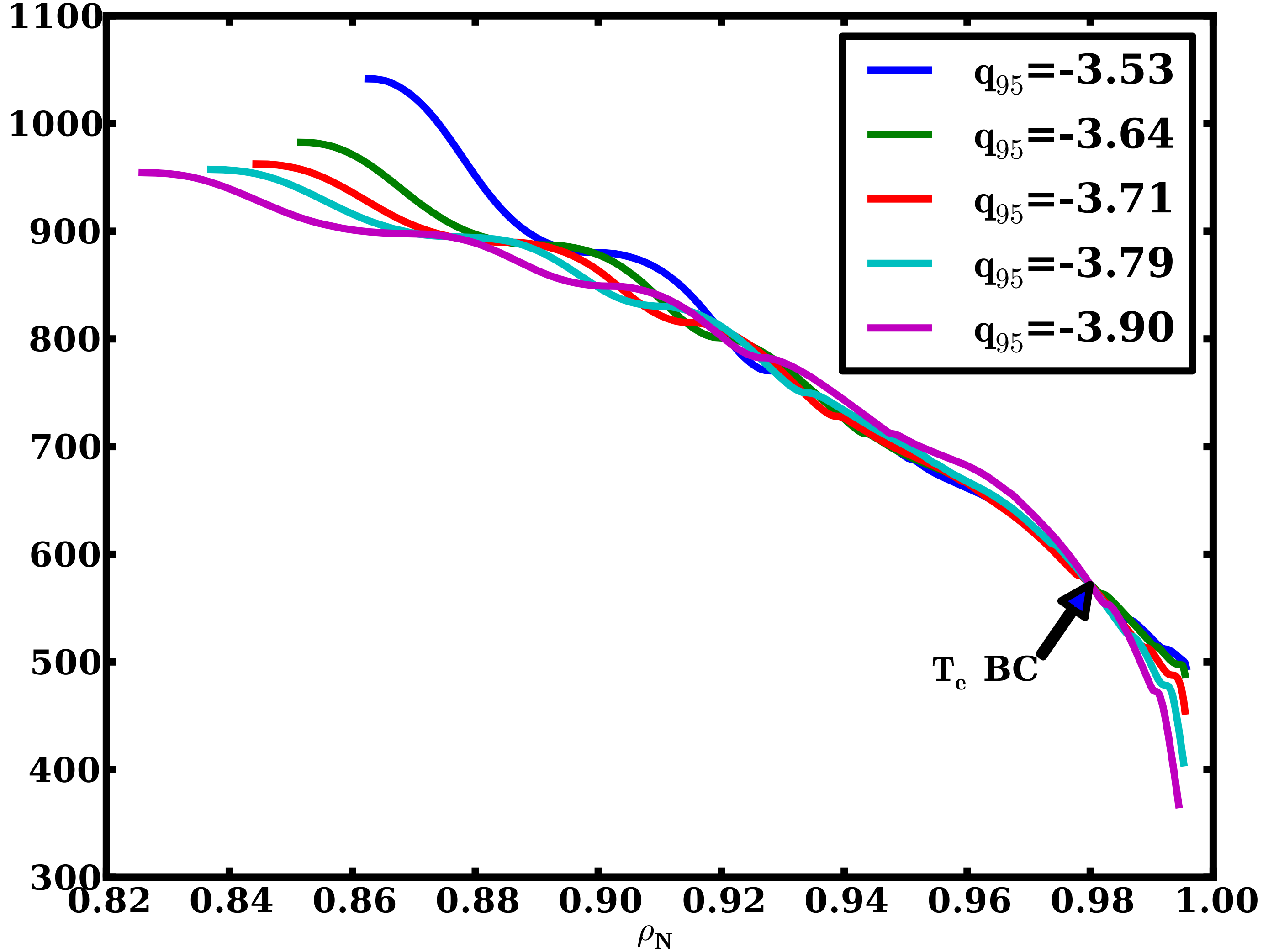
Diffusivity Differences Have Only Slight Effects on the T_e Profile at the Top of the Pedestal



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Summary

- **The Magnetic Flutter Induced Plasma Transport Model has been evaluated for 2 DIII-D discharges where ELMs were suppressed.**
  - The predicted radially averaged diffusivities are of an experimentally relevant magnitude (~m^2/s).
  - The predicted temperature profiles have sub-measurement flattening on rational surfaces.
  - The overall predicted temperature profile shapes generally match experiment.
- **The Model has been used to evaluate a q95 scan to search for a possible explanation for the q95 window seen in DIII-D**
  - Results here are preliminary.
  - The radially averaged diffusivities hint at larger diffusivities around the pedestal top for q95 in the suppression window.

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