Comparison of 3-D Modeling With Experimental Results on Fast Wave Antenna Loading in DIII-D

by

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with

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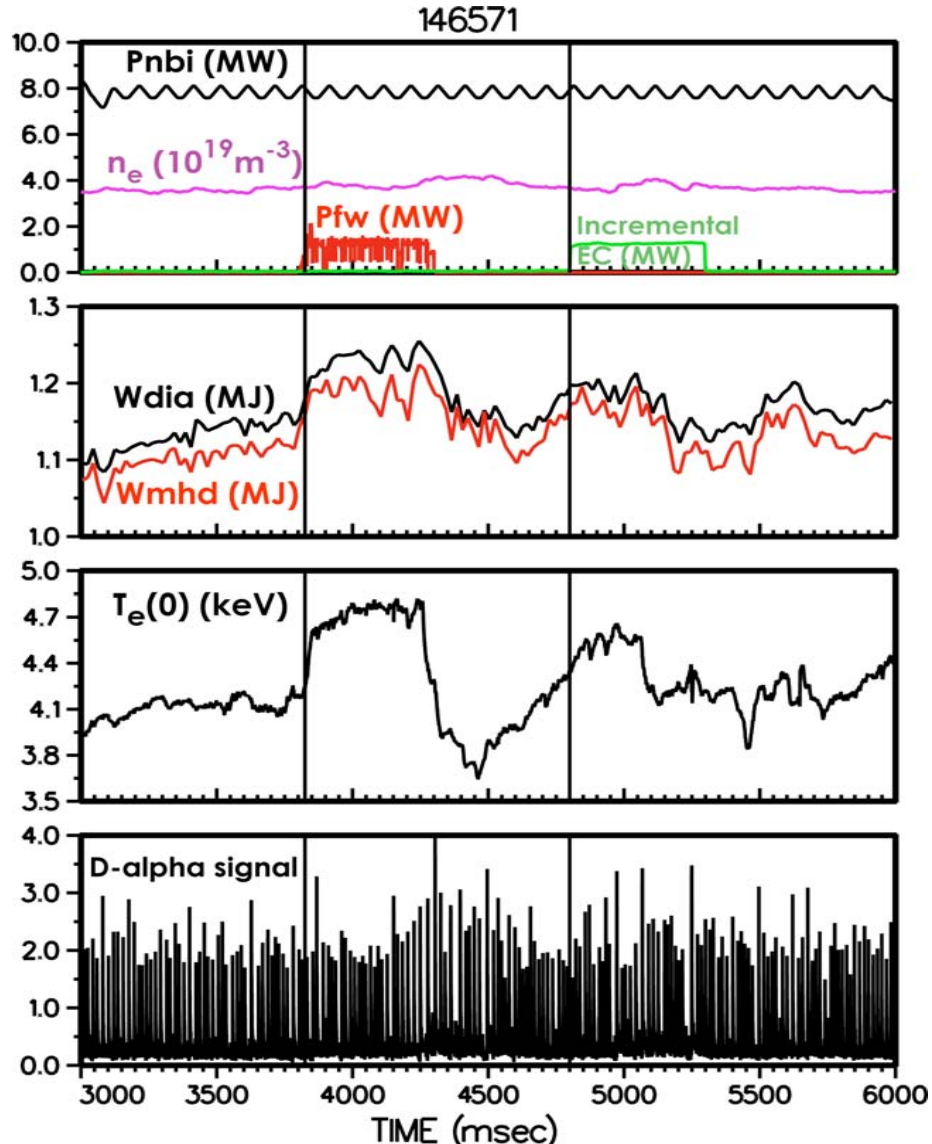
Introduction: DIII-D Fast Wave System Applied to Heating Advanced Tokamak Regimes

- **Important thrust in DIII-D program: advanced tokamak regimes with strong electron heating (ITER, reactor relevant)**
- **Key questions**
  - How much FW power can existing system couple to these discharges?
  - What sets power limit of the system?
  - What can be done to raise those limits?



The Plasma Loading R_L Determines the Power that can be Coupled

$$P_{coupled} \propto \underbrace{\left(\frac{V_{max}}{Z_0}\right)^2}_{} R_L$$

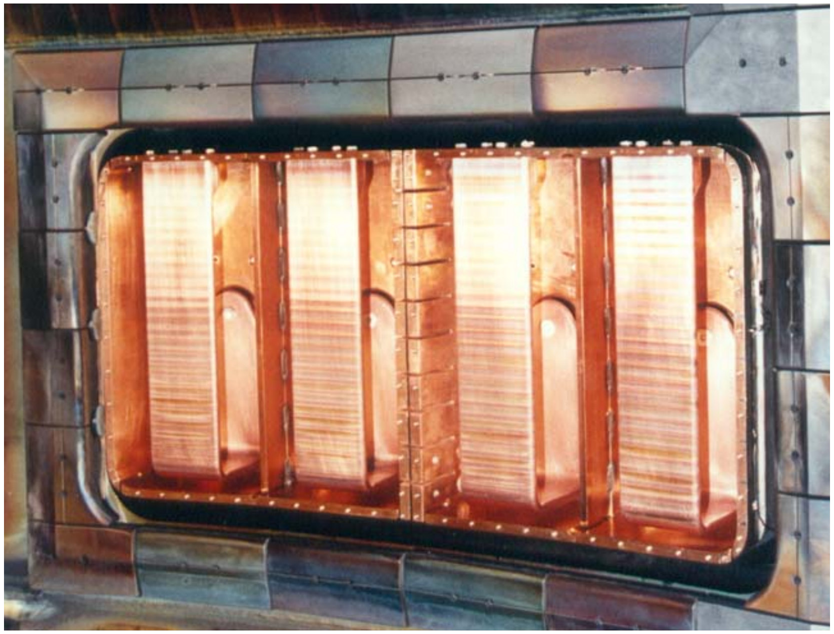
Determined by antenna, transmission line design

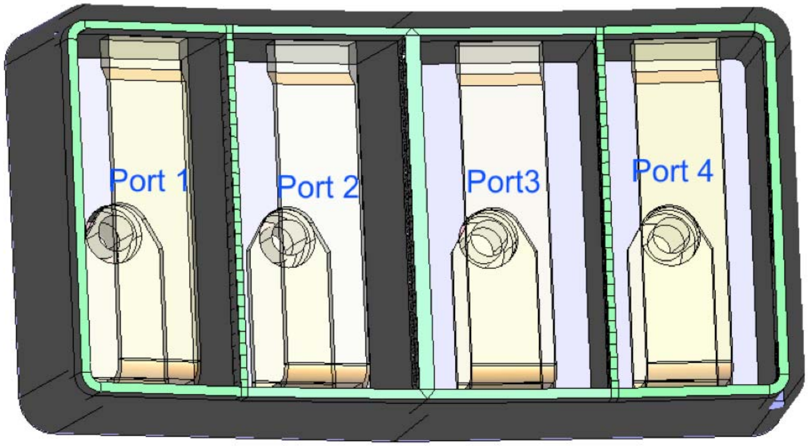
- **Coupled FW power at fixed antenna voltage, impedance proportional to loading resistance R_L**
- **R_L determined by density profile near antenna and other edge parameters**
- **Relation between edge profiles and loading is the subject of this talk**

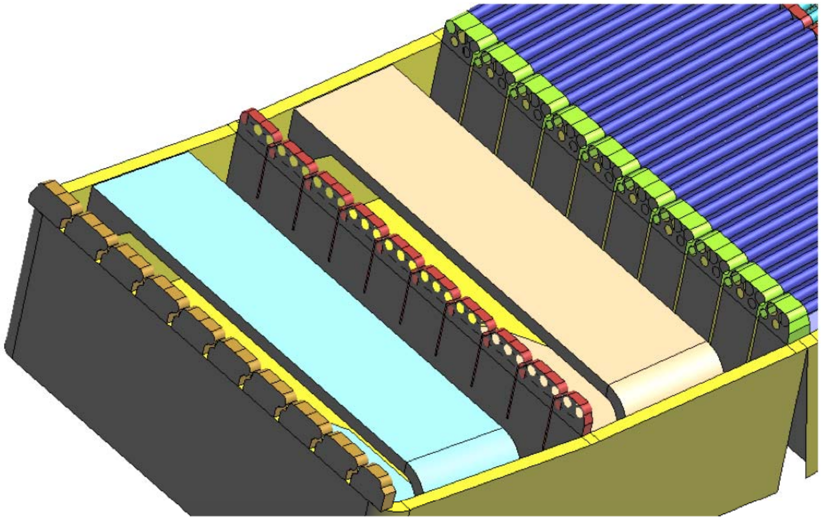
Outline/Summary

- Electrical properties can be precisely predicted with the detailed antenna geometry using 3-D modeling of unloaded antenna array
- The effects of plasma load are quantitatively predicted (no adjustable parameters) given accurate measurements of the profiles near the antenna
- Resistive loading is the most important parameter thus predicted, as it determines peak voltage per watt coupled

Antenna Model Includes All of the Important Details of Faraday Shield, Slotting, etc.



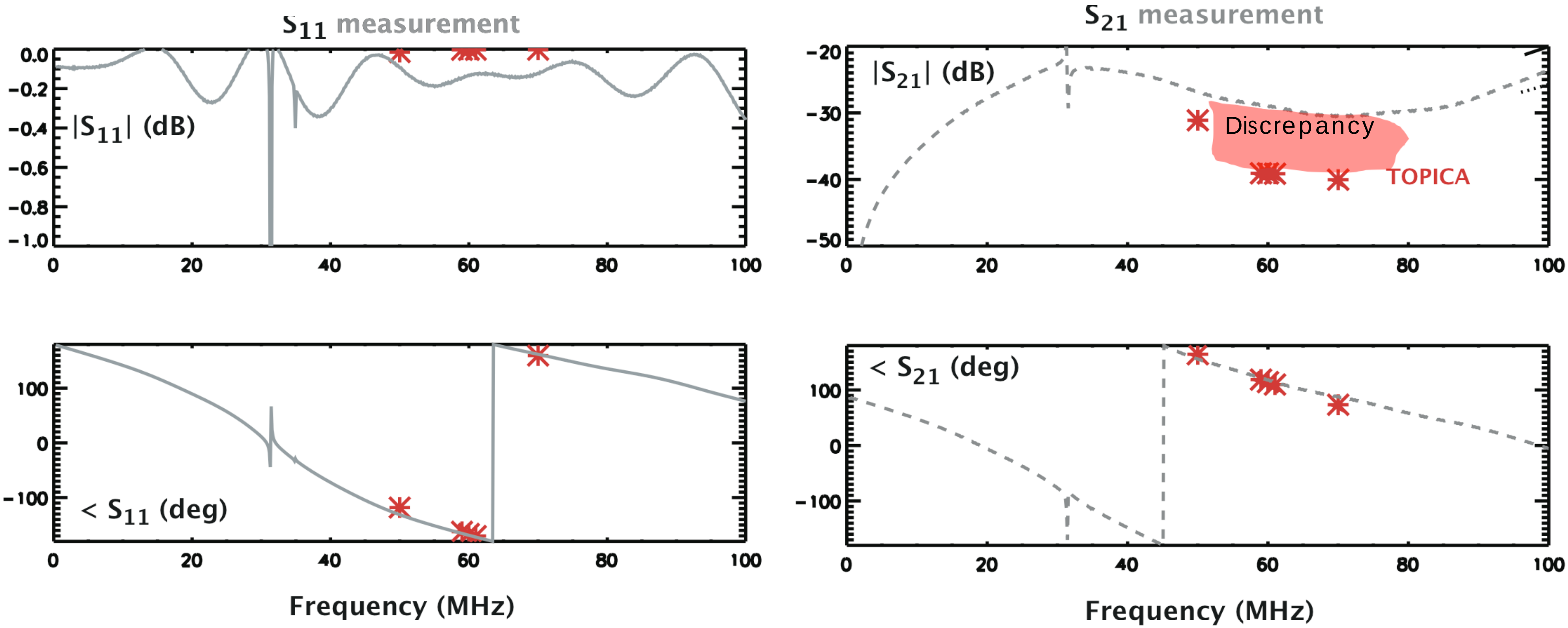




TOPICA Code Used for 3D Modeling of Antenna

- **To attain quantitative understanding of antenna loading:**
- **First, a detailed model of the antenna geometry was constructed based on the CAD drawings of the DIII-D 285/300 antenna array**
- **Next, the model was exported to TOPICA (*T*orino *P*olitecnico *IC A*ntenna)**
  - Code includes a complete plasma wave propagation package
- **TOPICA predicts loading for given measured edge plasma profiles**

With Sufficiently Detailed Model of Unloaded Antenna, Quantitative Agreement Between Code and Measurements Obtained



- **Measurements are gray lines, TOPICA results at a few discrete frequencies are red asterisks**
- **Excellent agreement except for magnitude of reactive strap-to-strap coupling – located omission in model (slots)**

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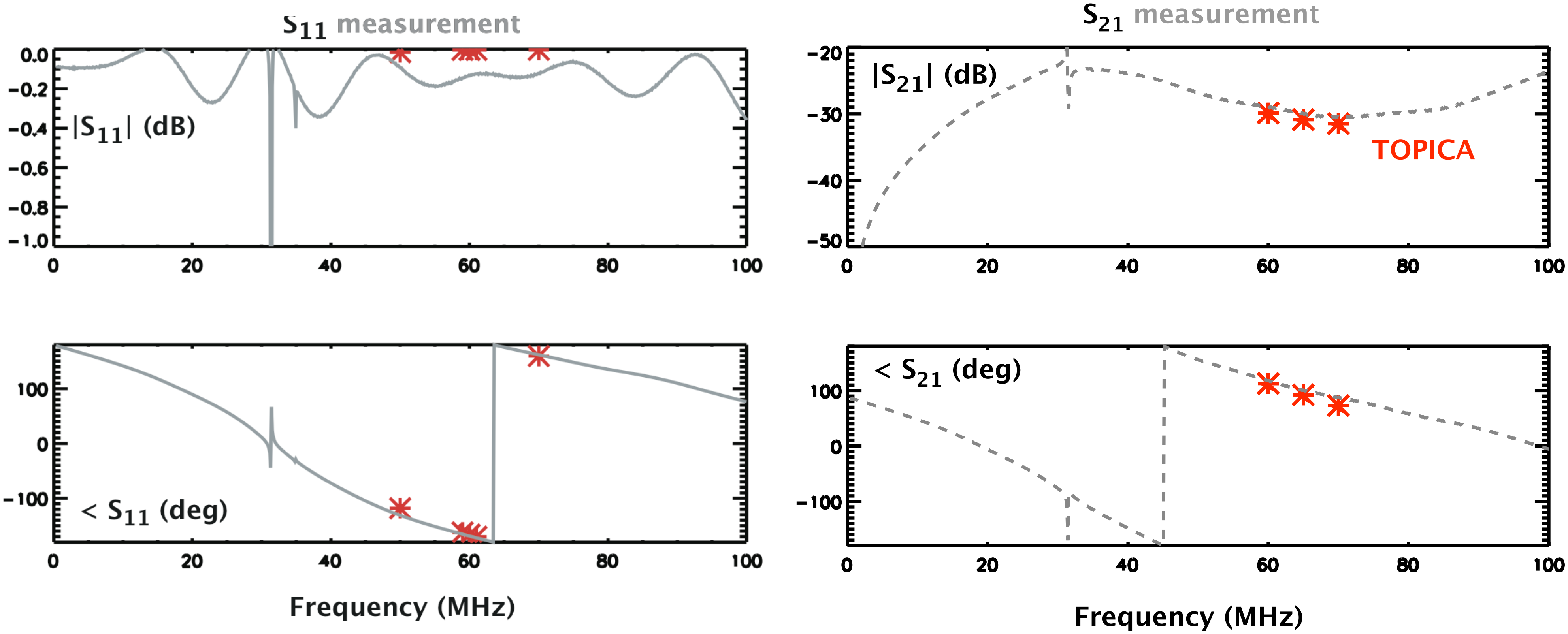


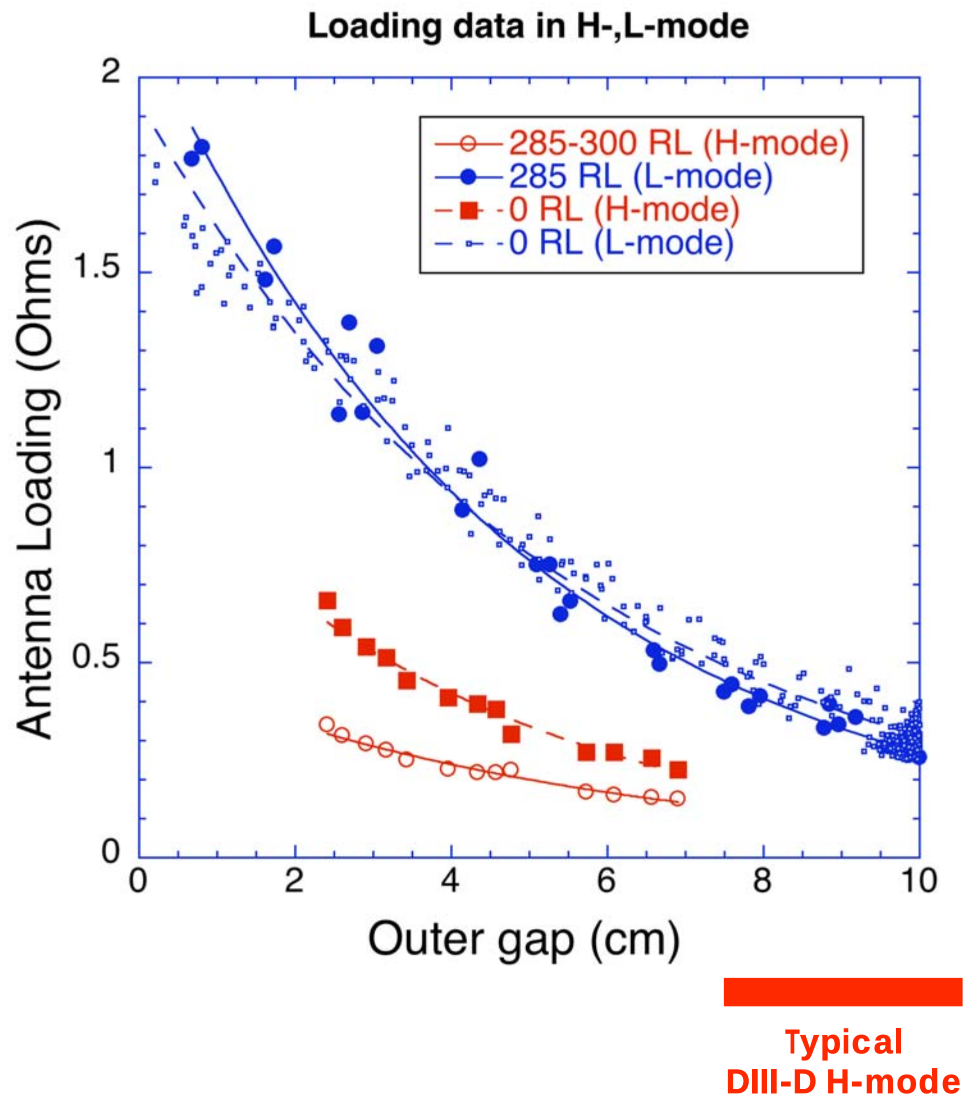
- **Measurements are gray lines, TOPICA results at a few discrete frequencies are red asterisks**
- **Excellent agreement except for magnitude of reactive strap-to-strap coupling – located omission in model (slots)**
- **Recalculation after correlation of model improves agreement**

Having Reached Understanding of Unloaded Antenna, Next Add Plasma Load in TOPICA

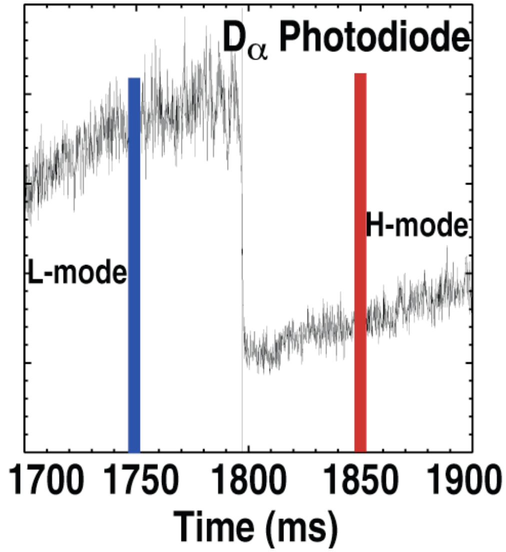
- **Inputs needed: edge parameters (mainly B_T and edge density profiles**
  - Density profiles from both UCLA and ORNL reflectometers
  - ORNL reflectometer adjacent to antenna, UCLA ~1.5 m away toroidally
- **Output is 4X4 impedance matrix ⟶ input to a detailed transmission line model**
- **Final result: compare measured R_L with predicted**
- **Do this for various edge plasma conditions: L-mode, H-mode, QH-mode**

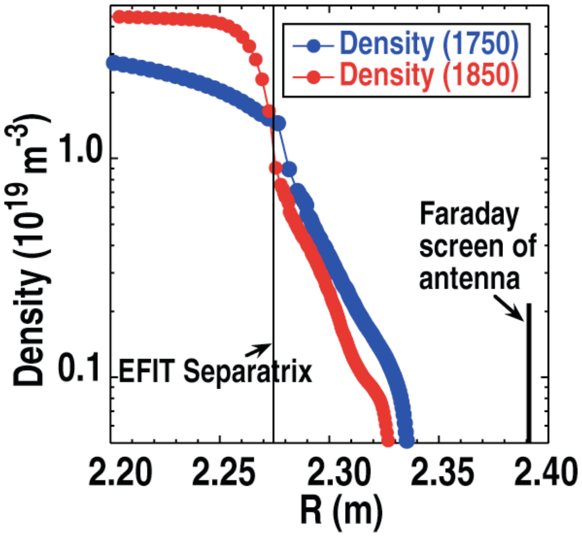
Loading Increases Exponentially as Plasma/Antenna Gap is Reduced; Upgraded Limiters Enable Smaller Gap, Higher R_L

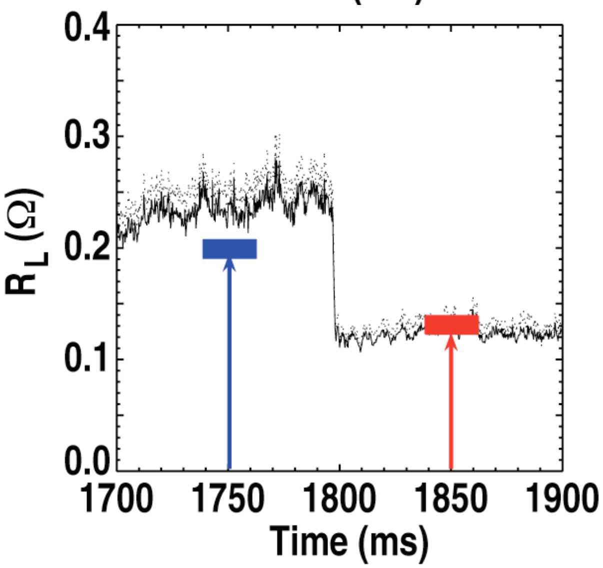
- **Surest way to raise R_L: reduce outer gap**
- **Replaced graphite limiter tiles with CFC (8/09)**
- **Now run 4 cm outer gap or smaller at ~8 MW of NBI successfully**



R_L Agrees With TOPICA Code Using Measured Density Profiles in L- and Standard H-mode at Large Gaps



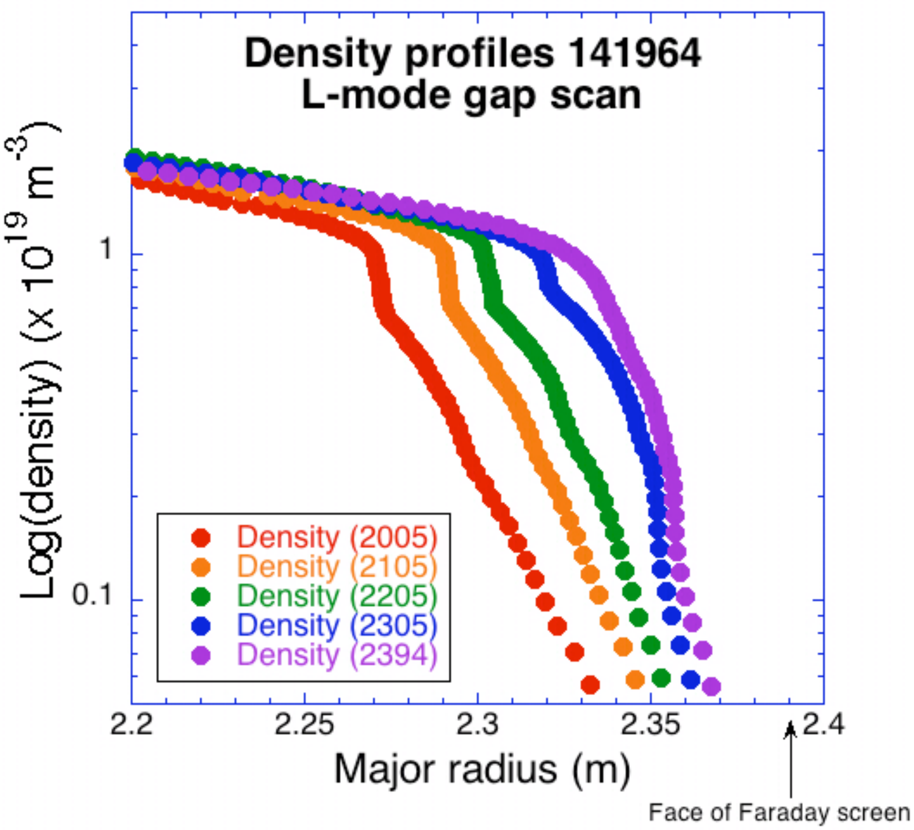




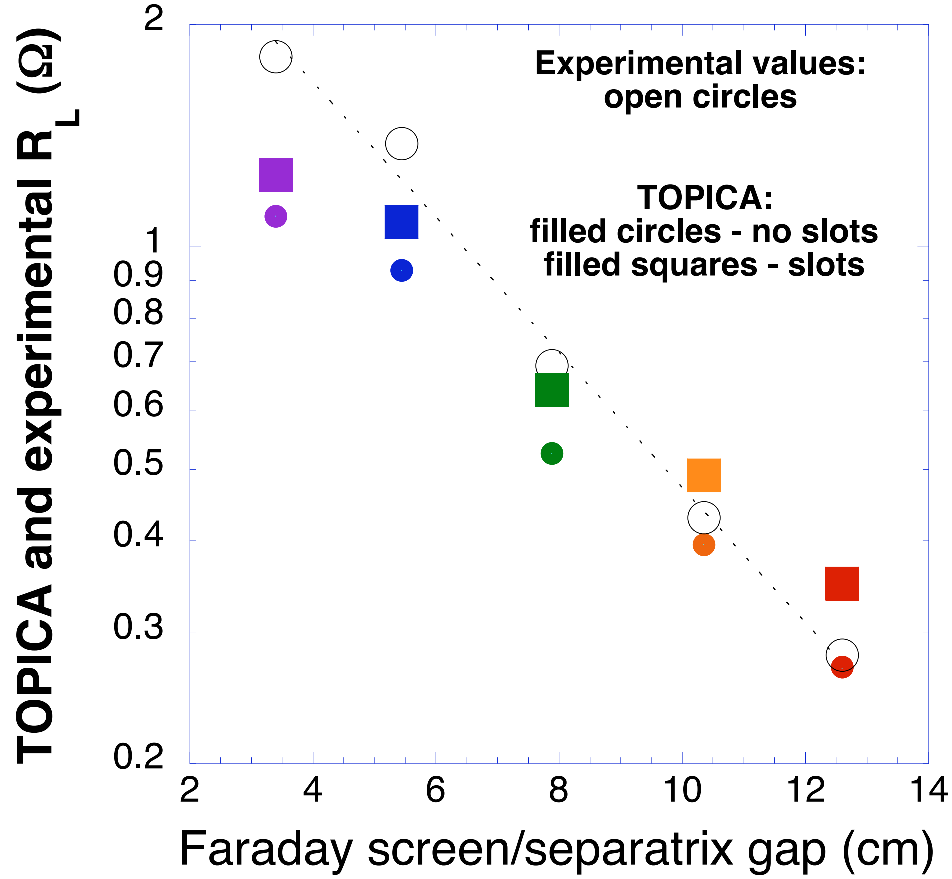
- **R_L drops at L-H transition due to**
  - Increase of evanescence zone thickness (at constant separatrix position)
  - Increase of ∇n_e in propagating zone ("index mismatch" effect)

Edge Density Profiles Measured With Reflectometers Used in TOPICA Modeling of Loading in L-mode Gap Scans

UCLA Reflectometer plus Thomson



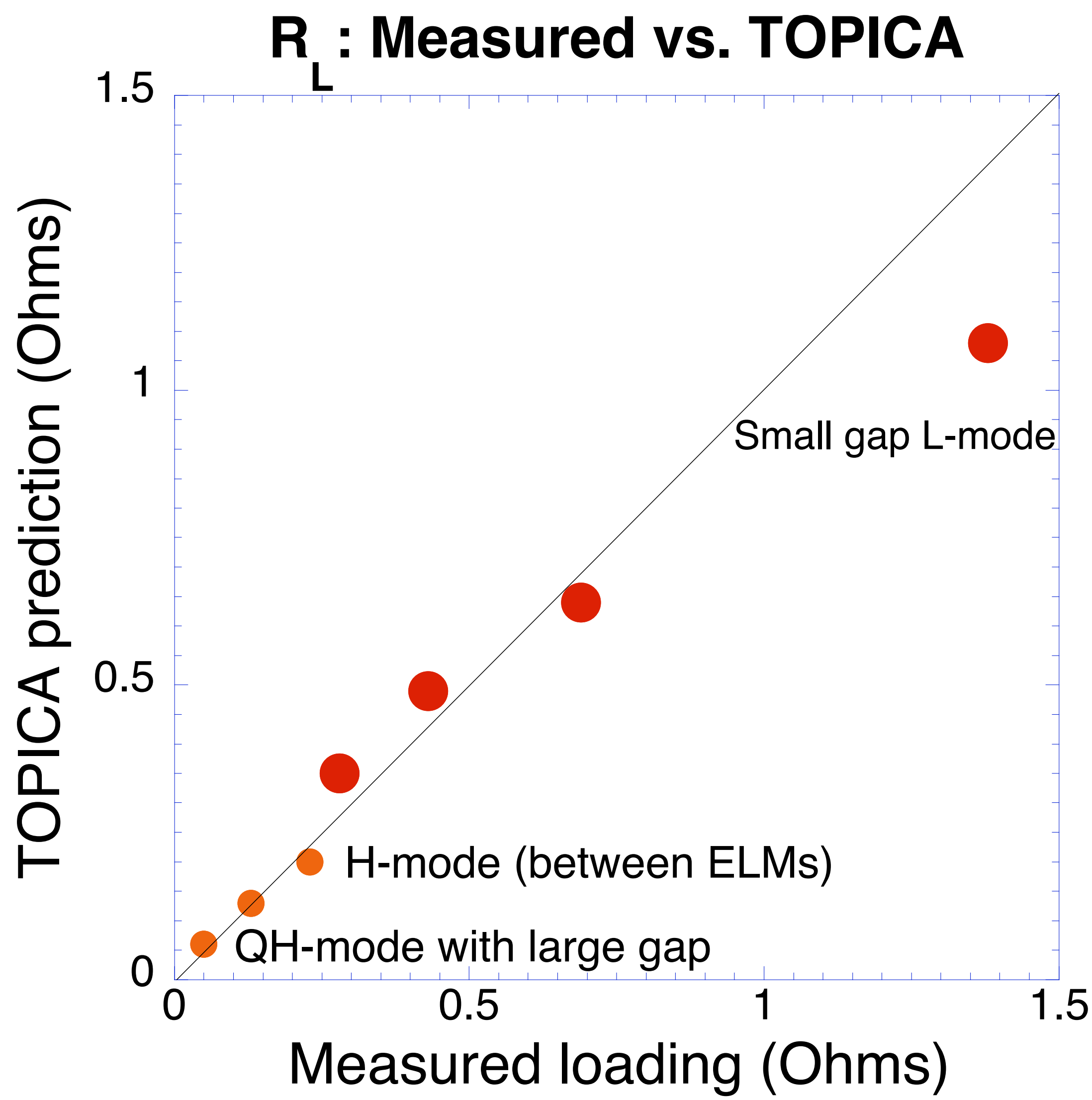
Loading Comparison in L-mode



- **TOPICA in good agreement with data at large gap**
- **Rate of decay with gap is faster than simple expectation**

Summary of Loading Comparisons

- **TOPICA predicts loading accurately in all but the heaviest loading cases**
- **Reason for slight discrepancy at large loading under study**
- ***No adjustable parameters in model***



Conclusion: Loading Well Understood

- TOPICA code accurately predicts the loading that is observed, given accurate measurements of edge profiles (particularly density in far SOL)
- Demonstrates quantitative, predictive understanding of the physics of the coupling process
- Remaining uncertainty for projection to future machines (ITER, DEMO, etc.) is mainly in the prediction of far-SOL density