Application of Ideal Perturbed Equilibrium Code to Magnetic Diagnostic Designs in DIII-D

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April 24, 2012

1. Background
   - IPEC
   - 3D Magnetics in DIII-D
2. Application of IPEC in Sensor Design
   - Motivation for HFS Arrays
   - Basic Constraints
   - Demonstrate Adequate Signal Reconstruction
3. Summary
   - Summary

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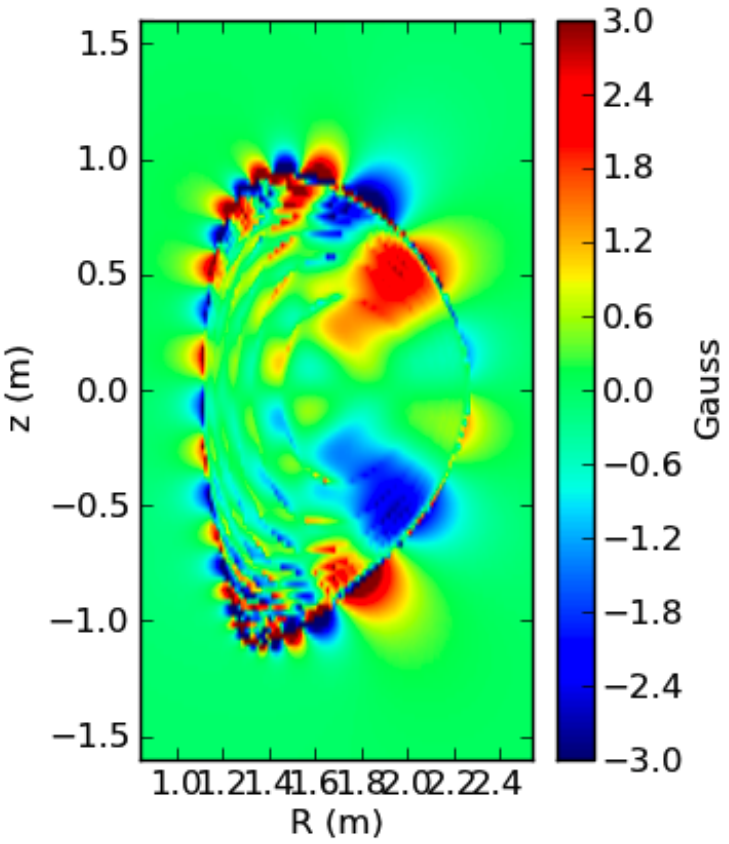
- The Ideal Perturbed Equilibrium Code (IPEC) calculates the linear equilibrium equations

$$\nabla \delta p = \delta \vec{J} \times \vec{B}_0 + \vec{J}_0 \times \delta \vec{B}$$

- Fully 3D, with free boundary
- Virtual casing technique on control surface: solve $F(\xi)$
  - Input: Fourier components of external error field on boundary
  - Output: 3D plasma response (one toroidal mode per run)



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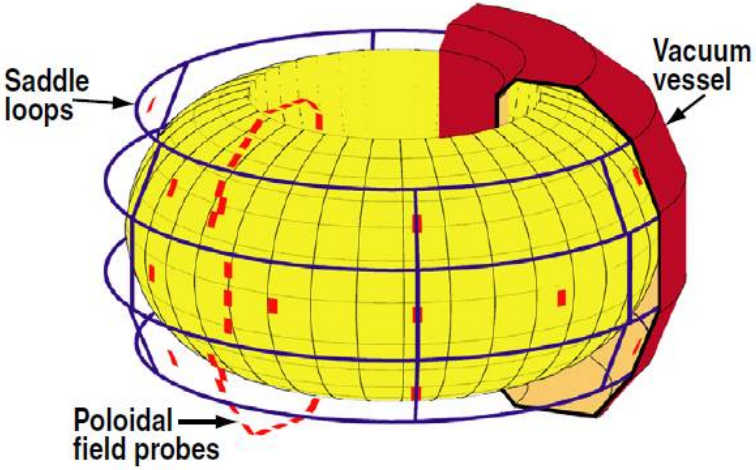
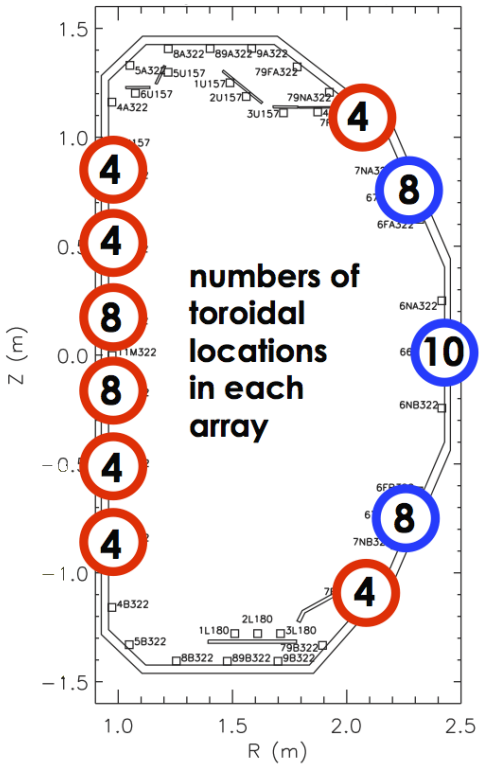
- DIII-D currently sports full toroidal arrays of poloidal field and radial field sensors at the 3 outboard segments



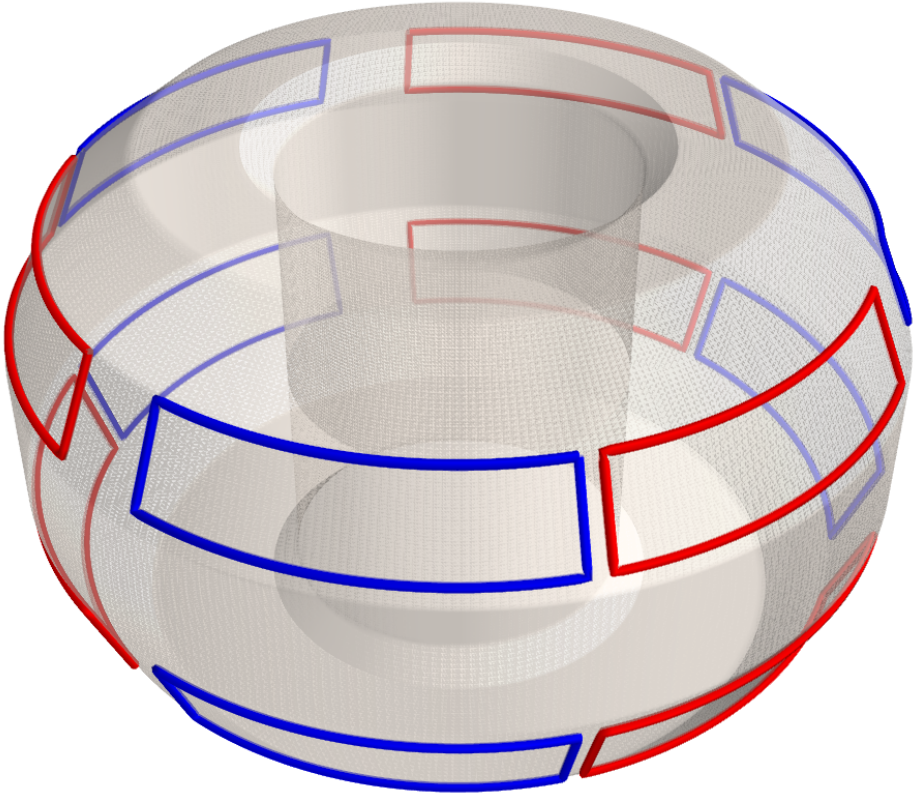
- Upgrade to 3D magnetic diagnostics is motivated by broad range of physics goals
  - Plasma response to external 3D fields
  - EM Torque measurements
  - Equilibrium reconstruction
  - Unstable plasma modes: low n, low frequency
  - Unstable plasma modes: low n, high frequency

- Proposed upgrade of 3D sensor set include ~107 new sensors



- Toroidal Array Approach (resolve $\delta B/B \sim 10^{-2} - 10^{-4}$ by hardware differencing)
  - 6 new toroidal arrays on High Field Side (red)
  - 2 new toroidal arrays on Low Field Side (red)
  - Extension of existing arrays to measure n=1,2,3 (blue)
- High spatial resolution array at mid-plane for ELM precursors
- This has been a large effort: T. Strait, D. Battaglia, J. Hanson, J. King, L. Lao, A. Sontag

- All results in this presentation will be for plasma response to applied error field using up-down symmetric I-Coils with 1 kA



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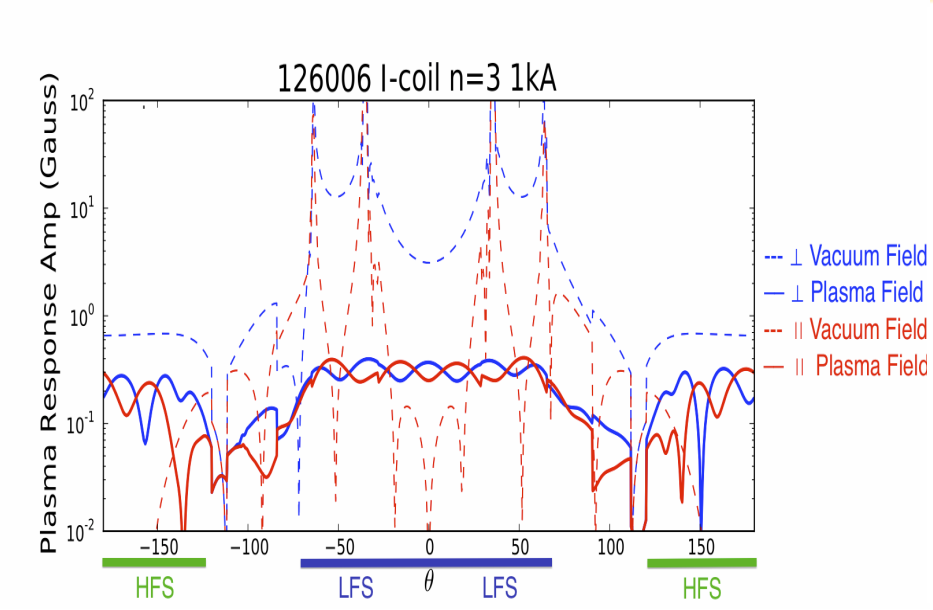

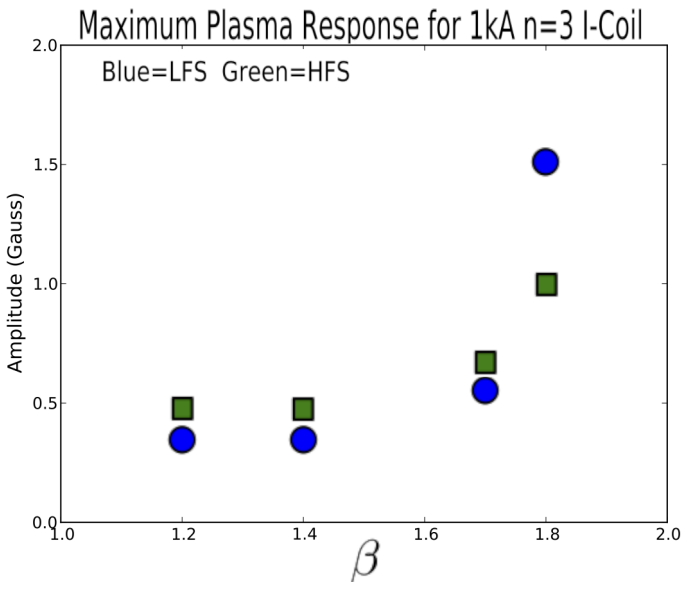

- Raw Signal of same order at both mid-planes
- HFS offers large plasma response to applied error field ratio

- Plasma becomes more ballooning as β increases, but LFS increases as well
- Sensors in both locations needed to test predictions

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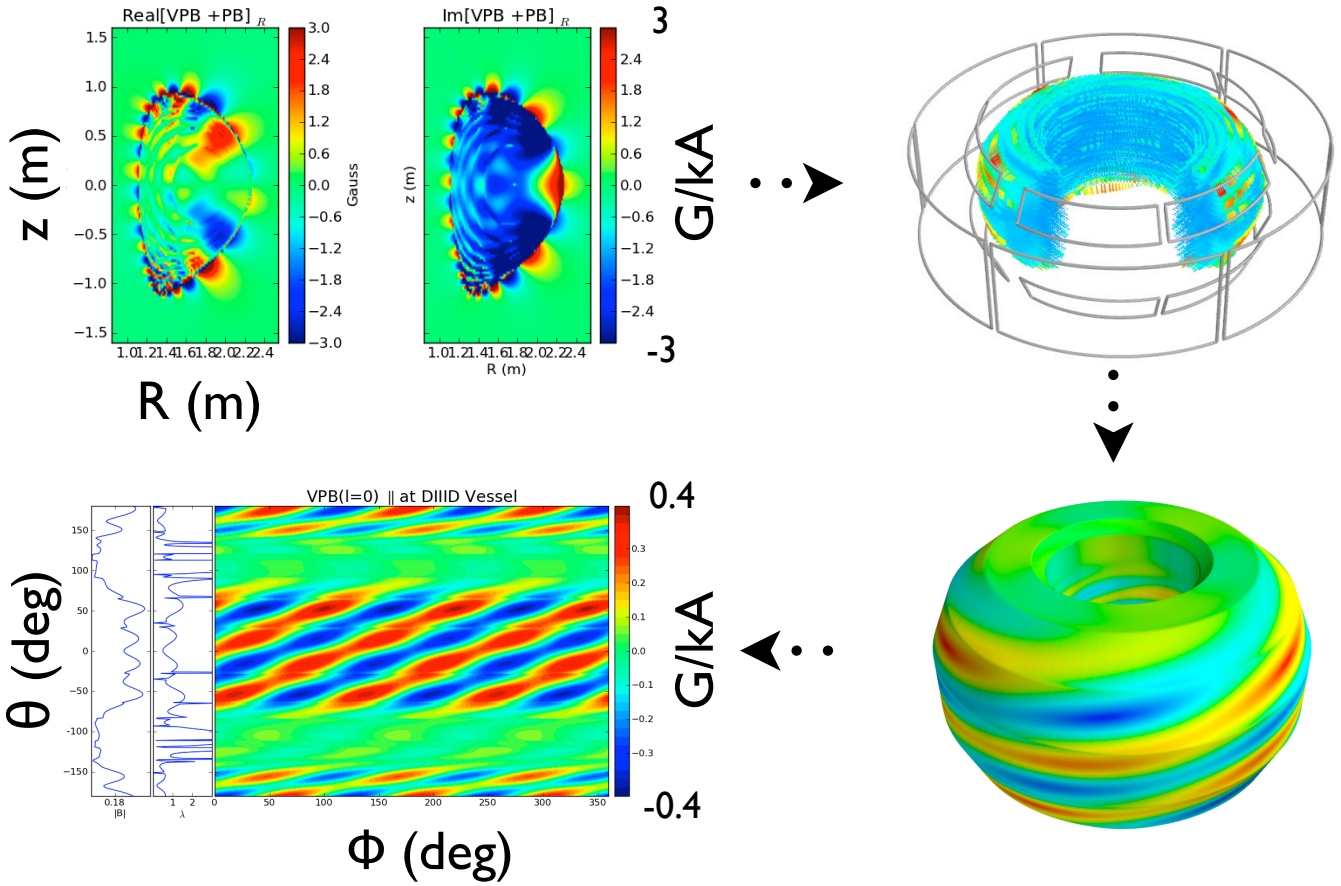
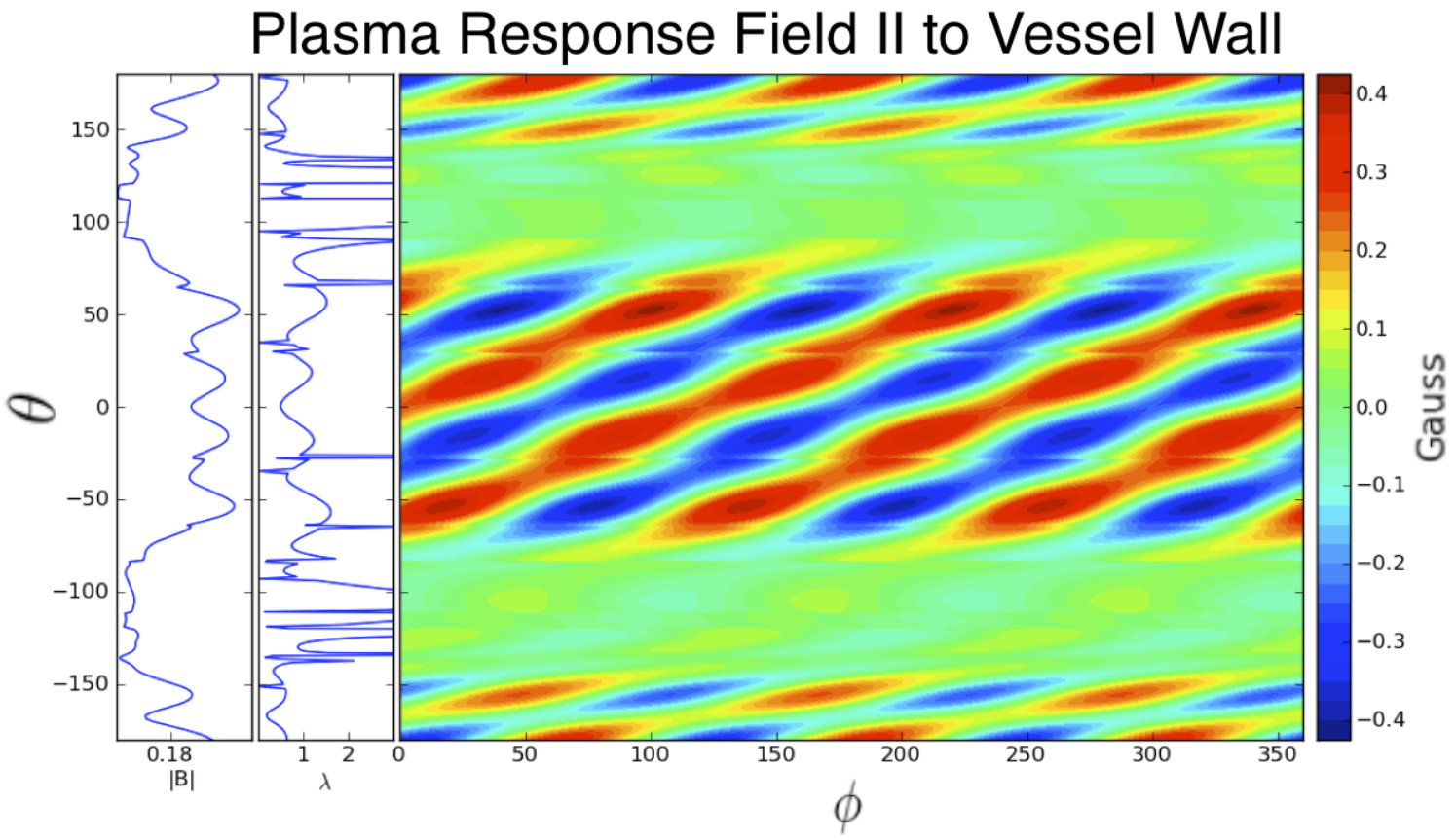
- Python intuitive visualization post-processing for IPEC has played a major role in supporting the design of sensor locations



- IPEC model of fields at the vessel wall immediately identifies constraints: dead zones, spacing, and signal amplitude



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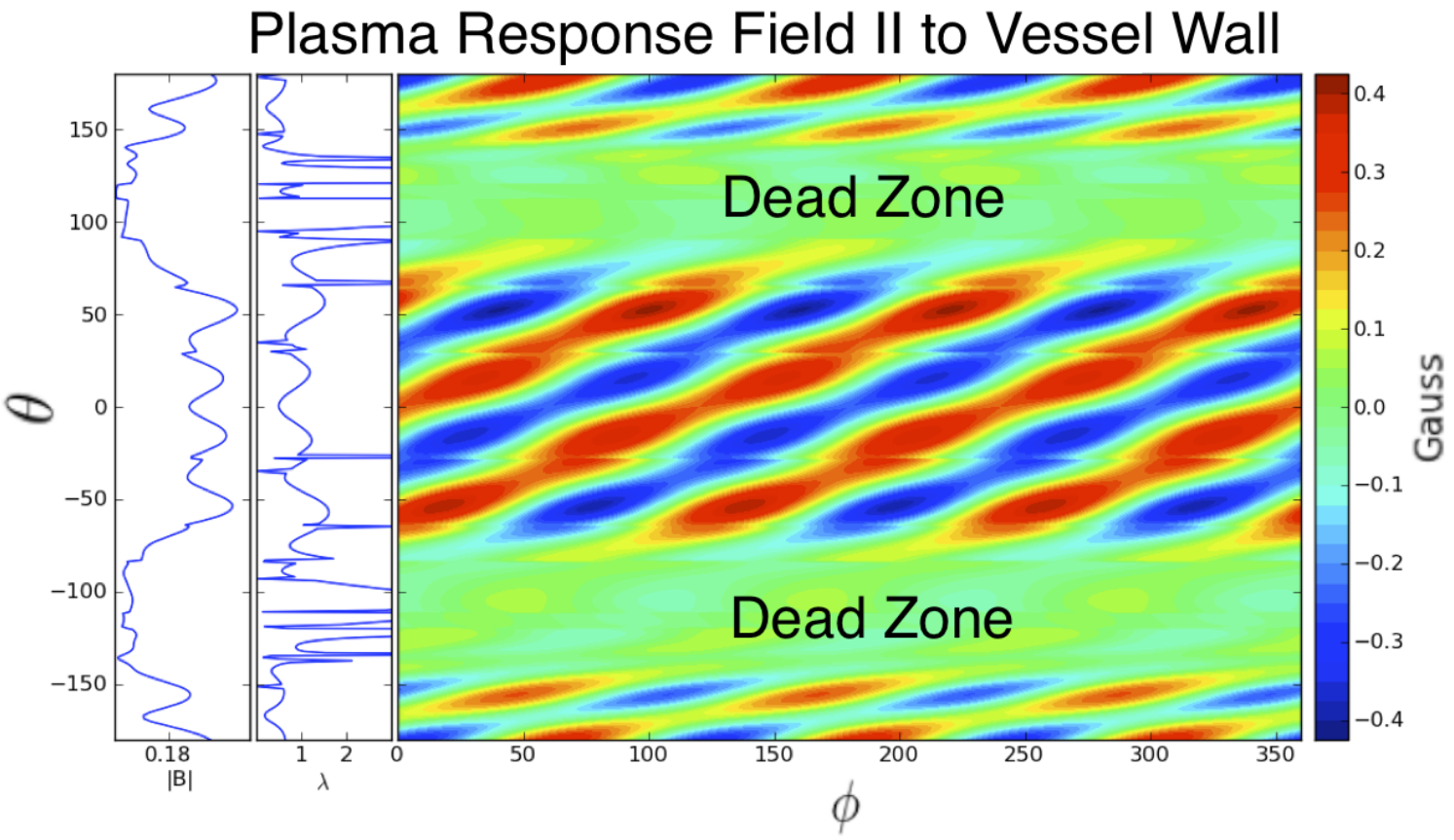

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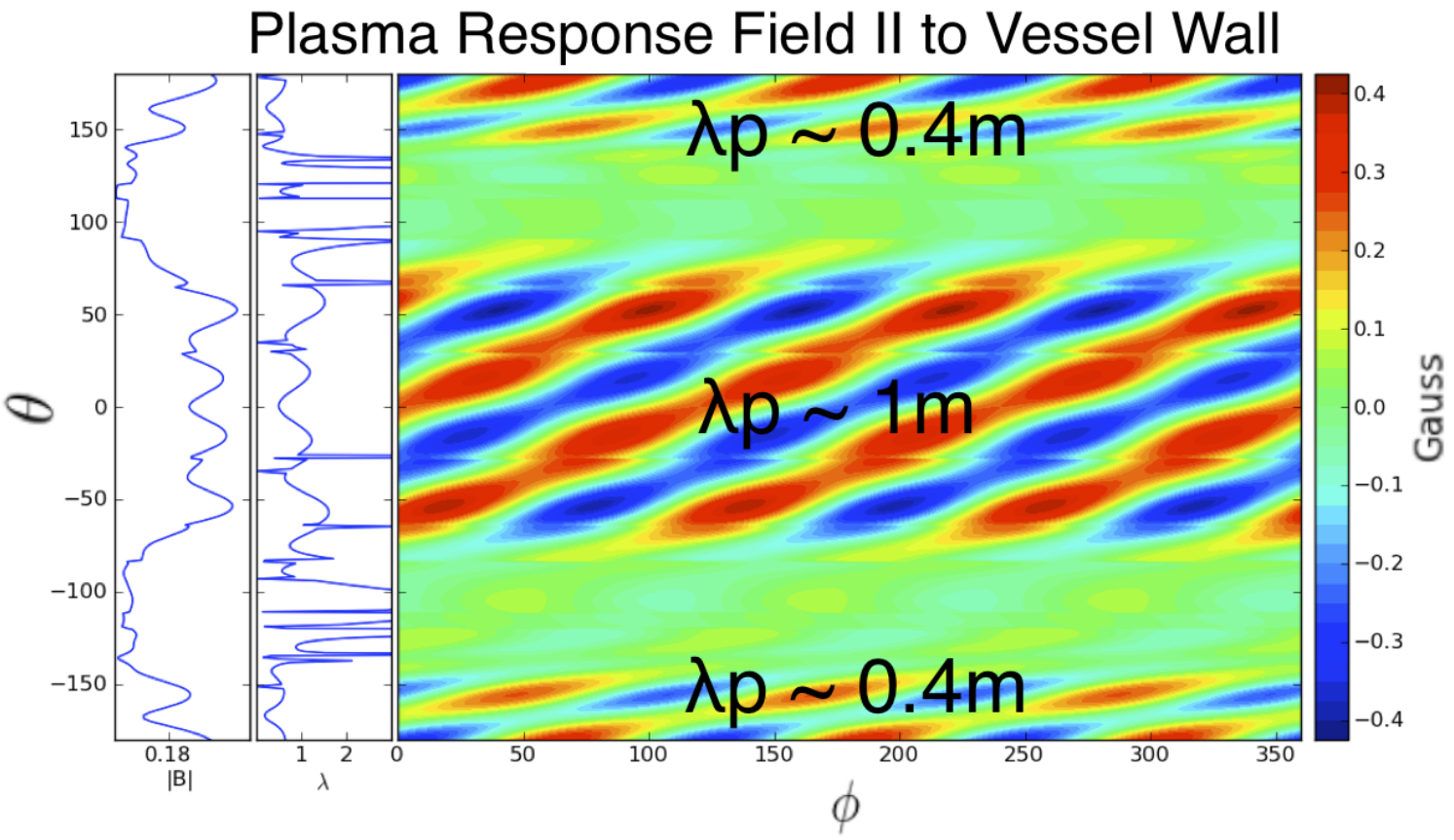

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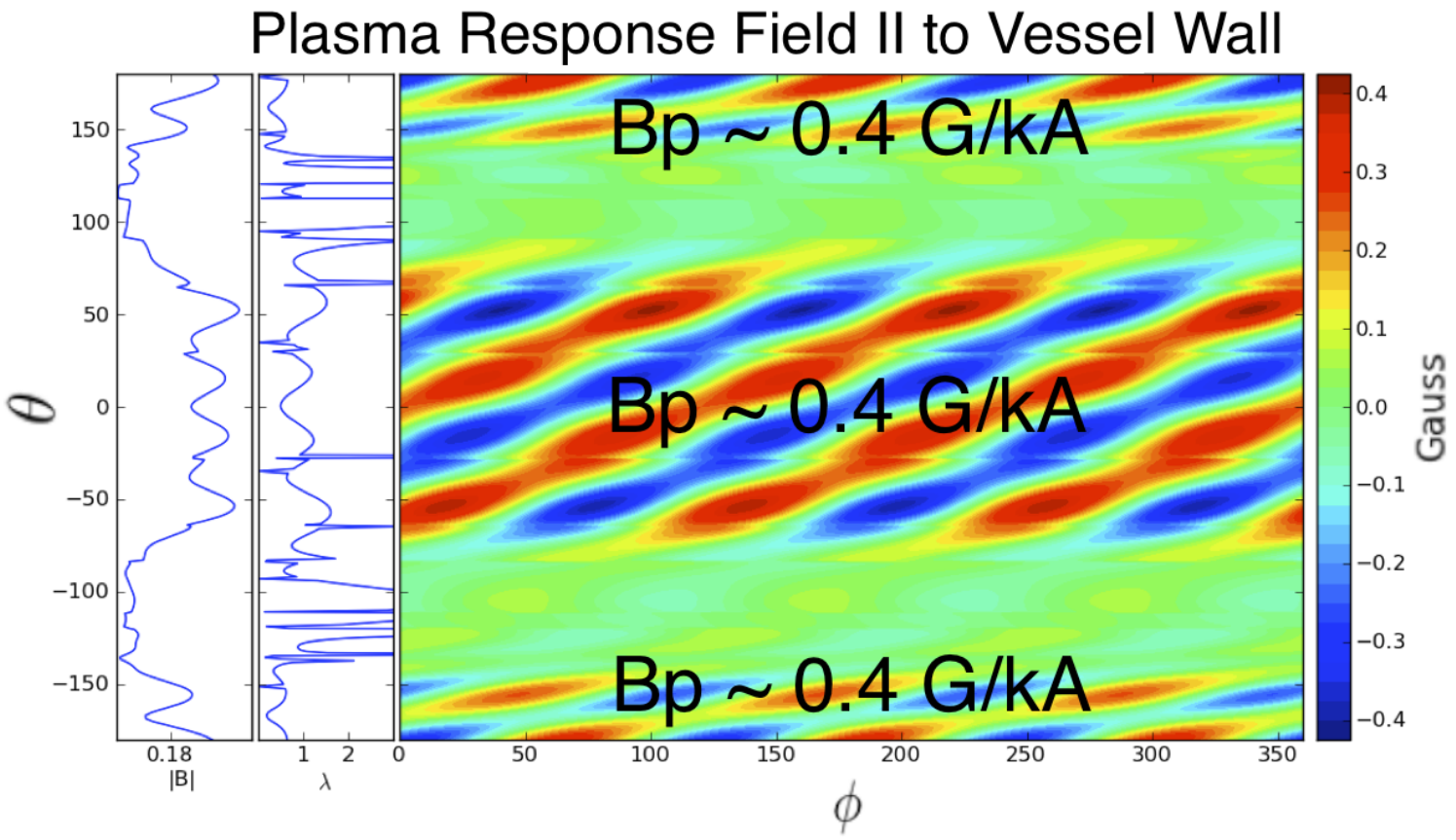

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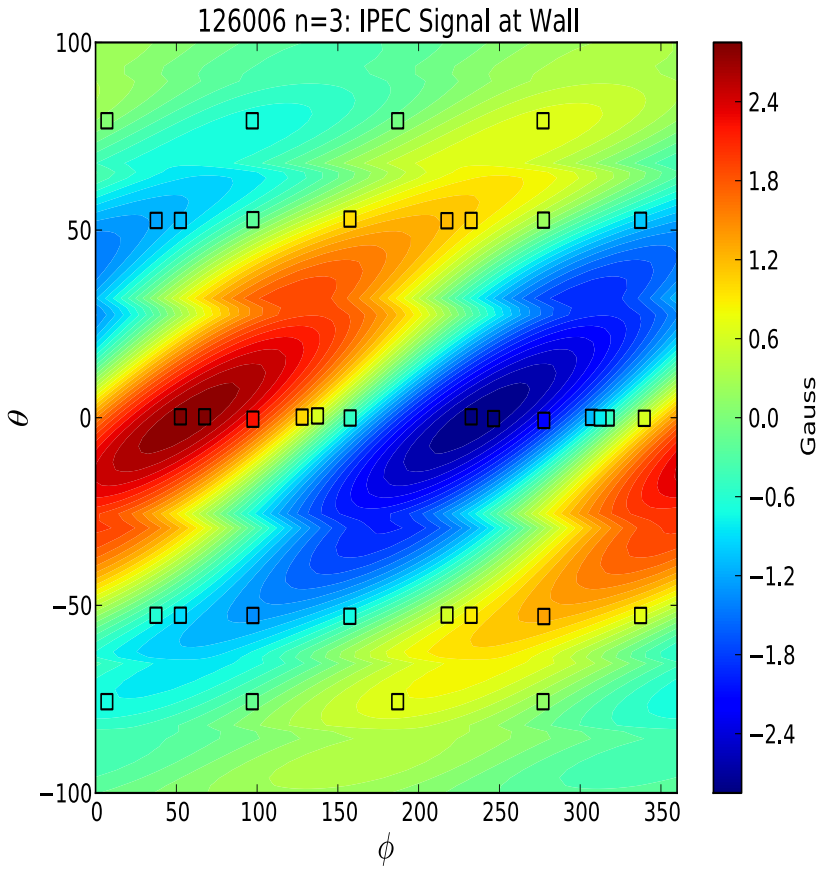
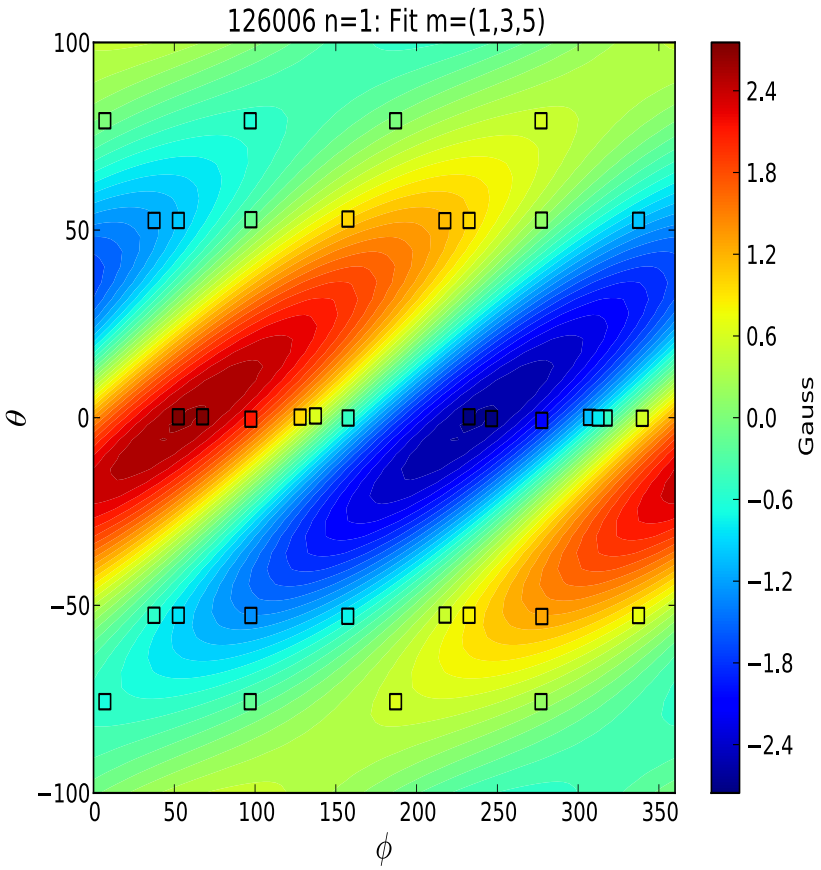
- Are sensors positions adequate to properly diagnose signal?
  - 2D synthetic diagnostics used to reconstruct signal at wall
  - Intuition from previous visualizations suggest dominant helical mode with sidebands for variation in poloidal amplitude

$$B \approx \sum_{m=\mu-2,\mu,\mu+2} A e^{i(n\phi - m\theta)}$$

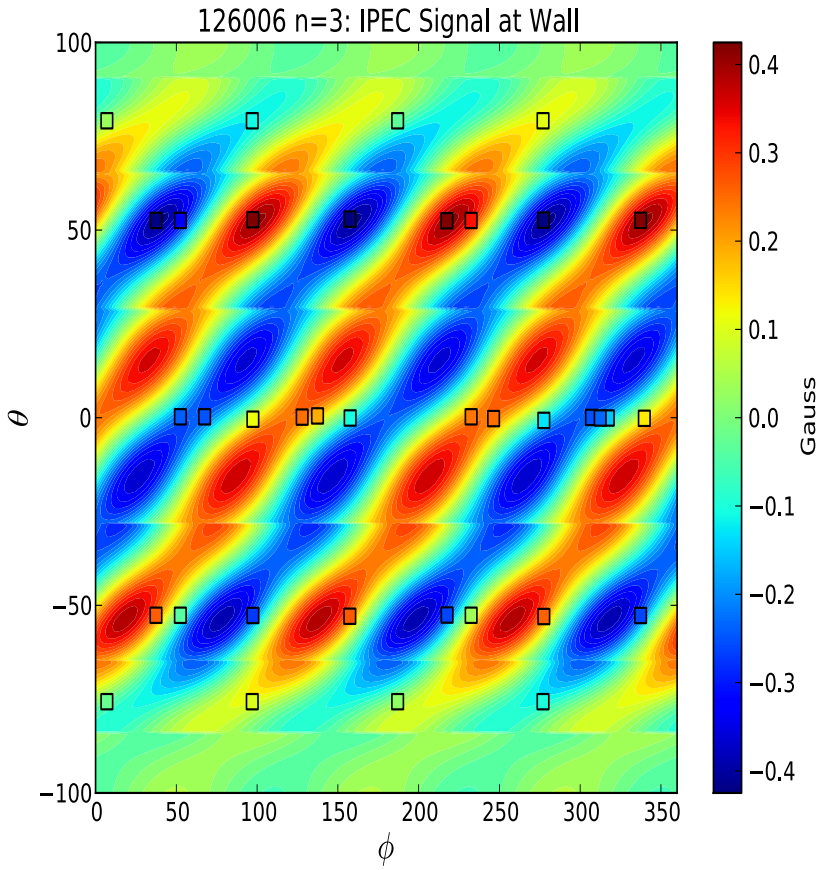
    - 6 degrees of freedom
- Positive results for large scale mode structure
  - Still some challanges to be addressed on HFS

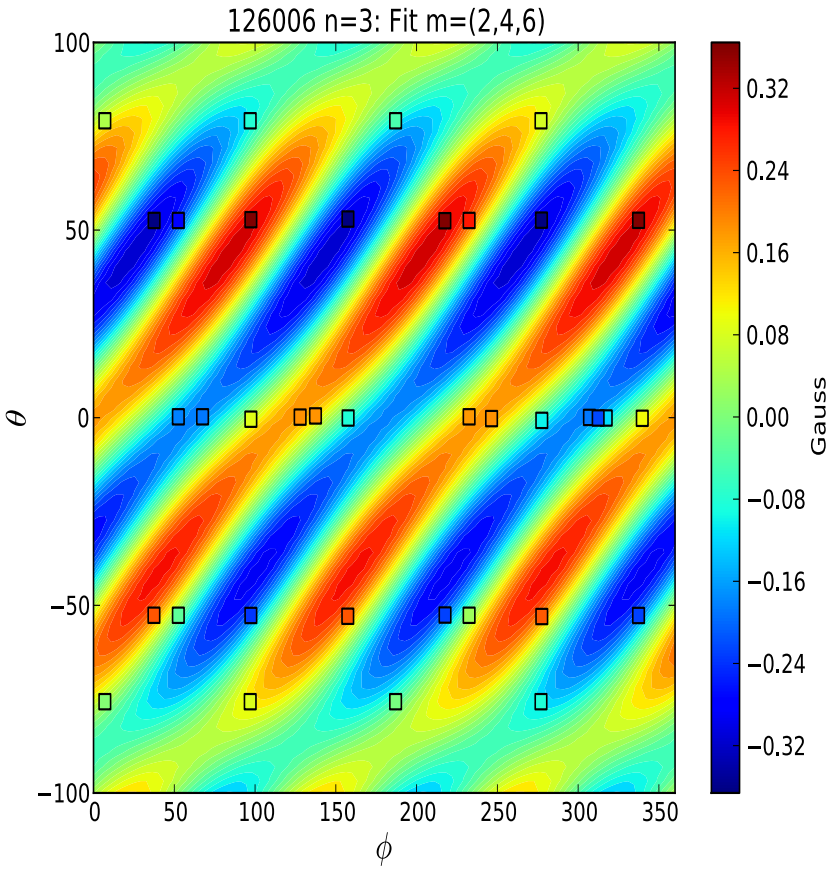
- LFS: n=1 very well matched



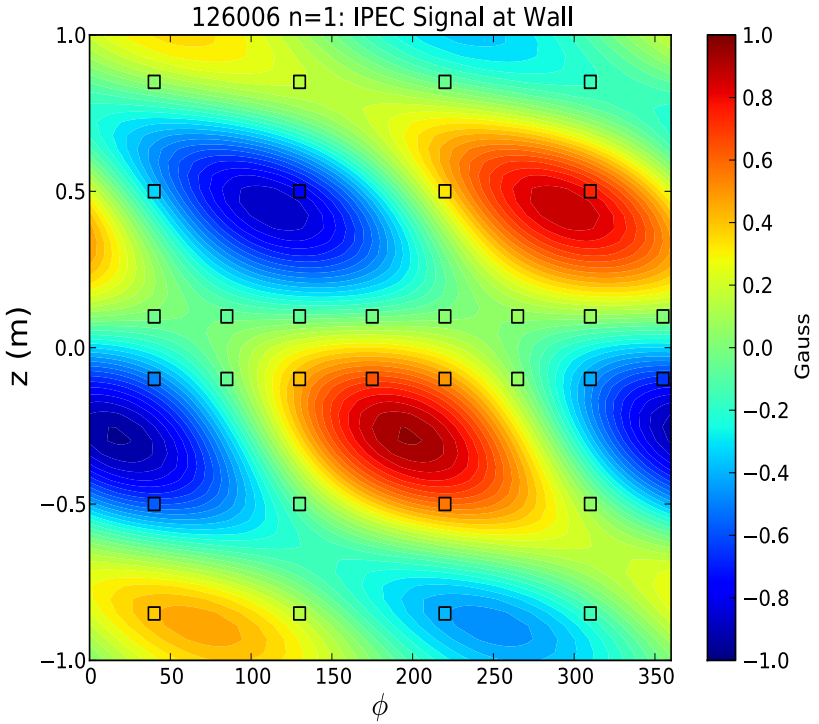


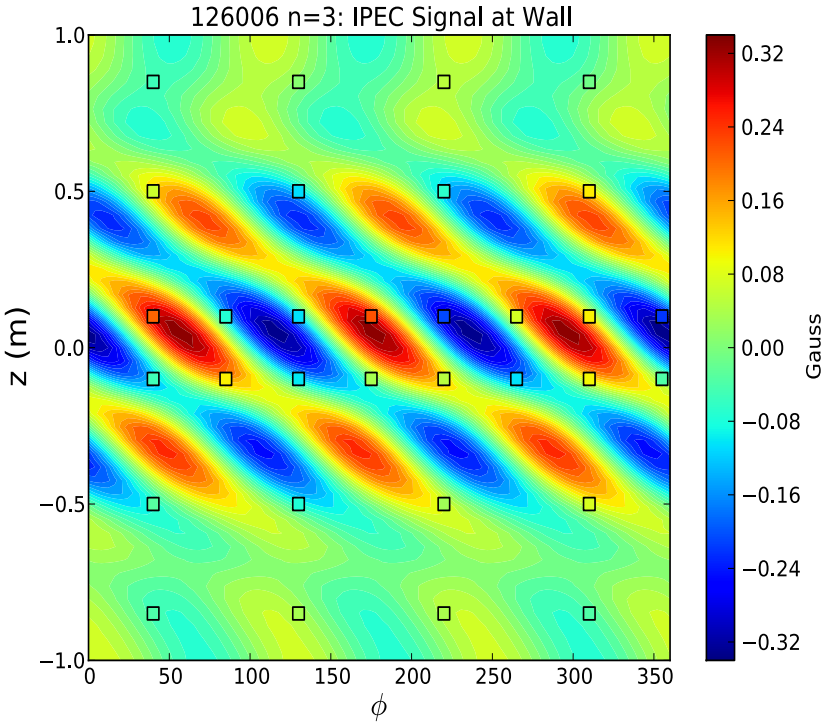
- LFS: n=3 large scale mode structure matched





- HFS is more challanging
  - Wide variety of structures observed, including various null positions - Optimization of design is still in progress





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- IPEC represents a powerful tool for fully 3D free boundary perturbed equilibrium
  - Post processing now takes full advantage of intuitive visualization tools and synthetic diagnostics to relate IPEC modeling directly to the experimental measurement
- Application to DIII-D 3D magnetic diagnostic design has proven the versatility of this tool
  - Physics validation and motivation
  - Sensor constraints based on detailed machine geometry
  - "Full circle" validation of diagnostic reconstruction
  - Many challanges still to be addressed
- Much more is and will be made possible with direct comparison between synthetic and experimental diagnostics.

- The author would like to acknowledge the hard work of T. Strait, D. Battaglia, J. Hanson, J. King, L. Lao, A. Sontag and all contributors to the 3D Magnetics PVR effort as well as R. Nazikian for his support of this collaboration.
- Research supported by the DOE Office of Science Graduate Fellowship administered by the Oak Ridge Institute for Science & Education.