3D Full Wave Fast Wave Modeling with Realistic HHFW Antenna Geometry and SOL Plasma in NSTX-U

NSTX-U

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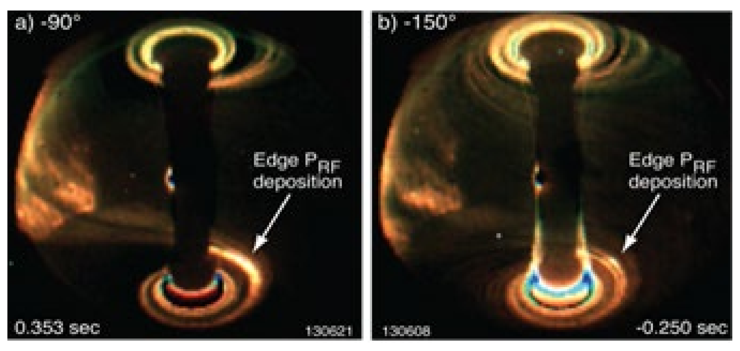
Abstract

- This paper reports the significant advancement of our ability to model and to understand how RF waves interact with the SOL plasma, by realizing for **the first time the full torus 3D SOL plasma simulation together with the antenna and core plasma in NSTX-U device in HHFW frequency regime**.
- The central tool of the present work is the Petra-M code, which is a newly developed state-of-the-art generic electromagnetic simulation tool for modelling RF wave propagation based on MFEM, open-source scalable C++ finite element method library.

Introduction and Motivation

- Previous NSTX studies of HHFW heating efficiency showed large amounts of HHFW power missing from core
- Strong interactions between HHFW and SOL plasma and bright plasma "spirals"

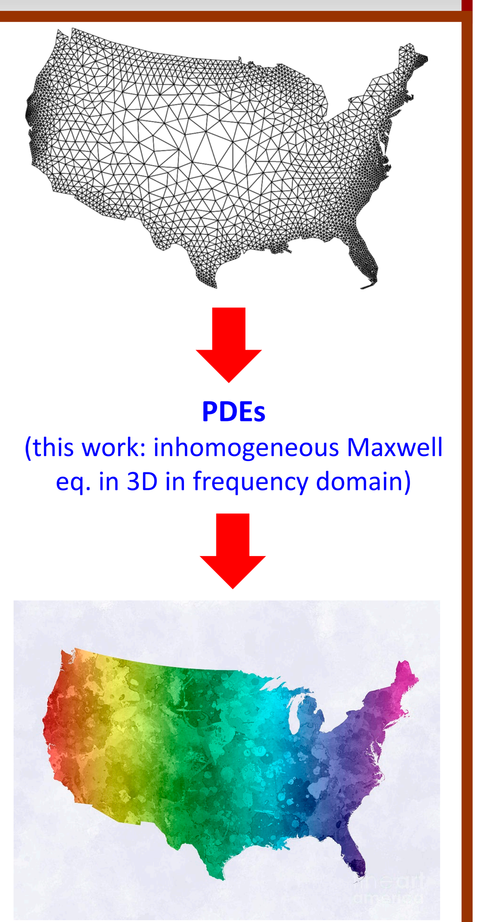


J. C. Hosea, et al., PoP 15 (2008) 056104,
R. J. Perkins, et al., PRL 109 (2012) 045001

- Larger SOL losses for high plasma density in front of the antenna
- 2D AORSA & FW2D simulations shown cavity modes in SOL plasma
  - Green D. *et al, Phys. Rev. Lett.* ***107*** *145001 (2011)*, Bertelli N. *et al, Nucl. Fusion* **54** 083004 (2014), Bertelli N. *et al, Nucl. Fusion* **56** 016019, Kim E.-H. *et al, Phys. Plasmas* **26**, 062501 (2019).
- **Need to further study and understand FW-SOL interaction**
  - 3D HHFW antenna geometry, 3D SOL region
  - to improve HHFW performance in NSTX-U and support future HHFW experiments

Petra-M: integrated multi-physics FEM platform

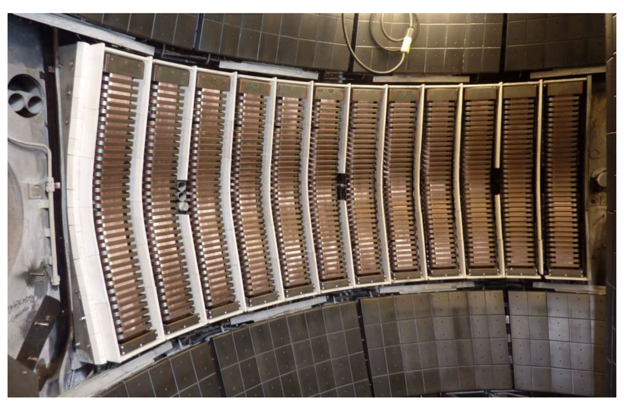
- Geometry/mesh generation
  - Utilize GMSH / Open CASCADE
- FEM assembly and solve
  - FEM interfaces from MFEM (www.mfem.org)
  - Tightly integrated with πScope Python workbench
  - RF Physics module (1D/2D/3D)
  - Weakform module
    - Multiphysics coupling
- Solver/Post-processing
  - Steady State and Time dependent solver
  - MUMPS/Strumpack direct solver
  - Hypre iterative solvers
  - Visualization on πScope
- Scales from laptop to cluster



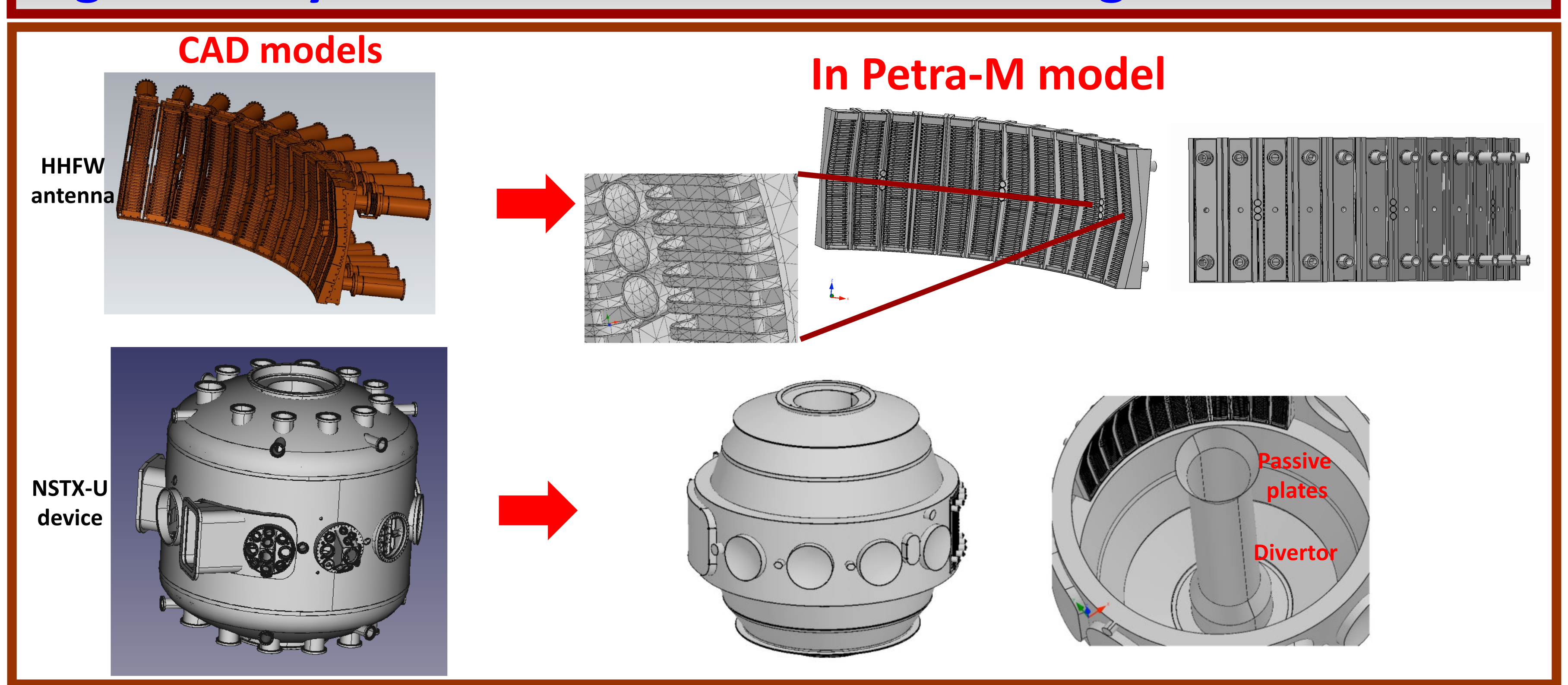
- SHIRAIWA, S. et al, this conference (28th IAEA-FEC). ORAL PRESENTATION
- SHIRAIWA, S. et al., EPJ Web of Conferences 157, 03048 (2017).

High Harmonic Fast Wave System in NSTX-U

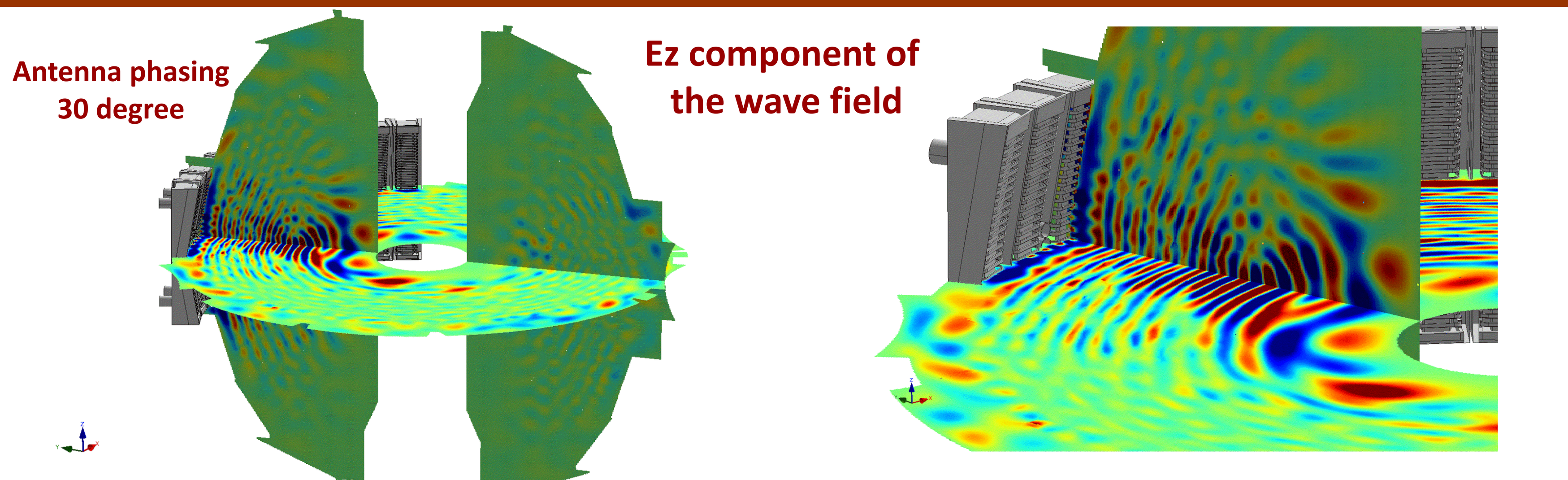
- 12-strap antenna located on the outboard midplane and extends 90º toroidally
- Wave frequency = 30 MHz,
- Up to P_{RF} = 6 MW
- $|k_\phi|$ = 3, 8, and 13 m^{-1} or n_ϕ= 5, 12, and 21 when $\Delta\phi$ = 30º, 90º, and 150º



High Fidelity 3D HHFW antenna and device geometries

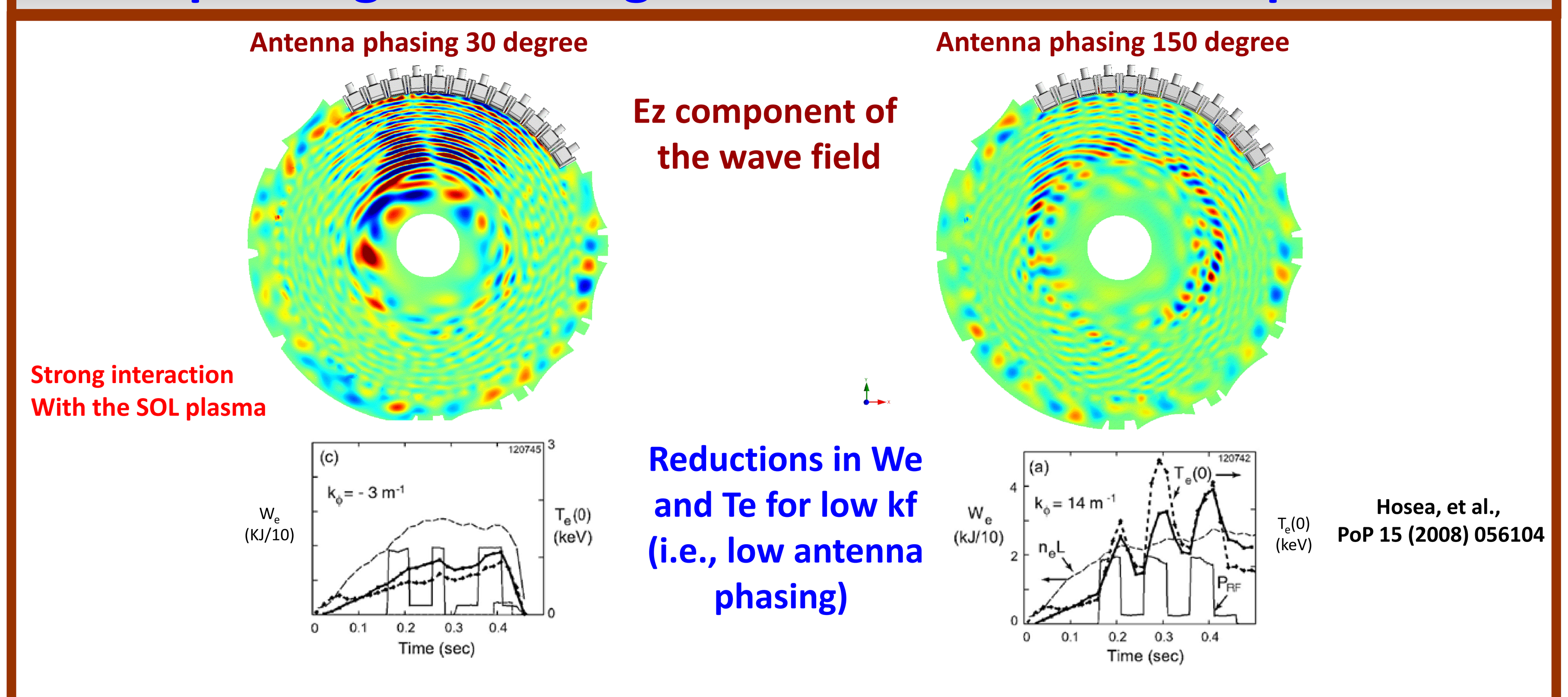


First full 3D torus sim. including realistic antenna geometry

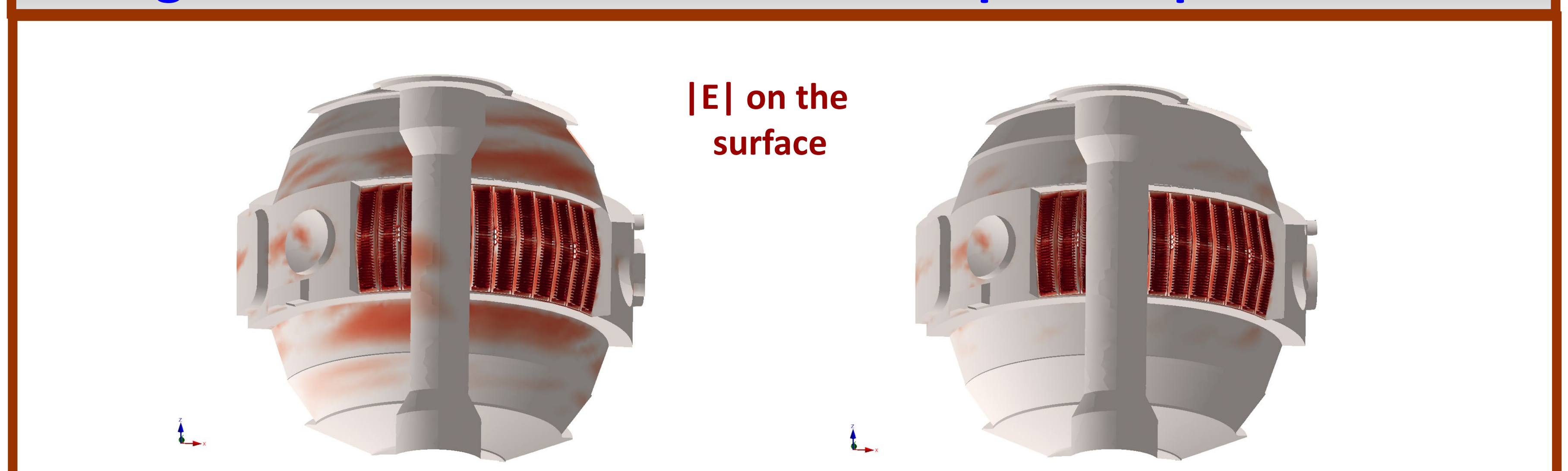


- Equilibrium B field from EFIT as well as the diverted geometry
- Vacuum in the antenna box and anisotropic cold plasma model in the torus with artificial collisions

Lower phasing has stronger interaction in the SOL plasma

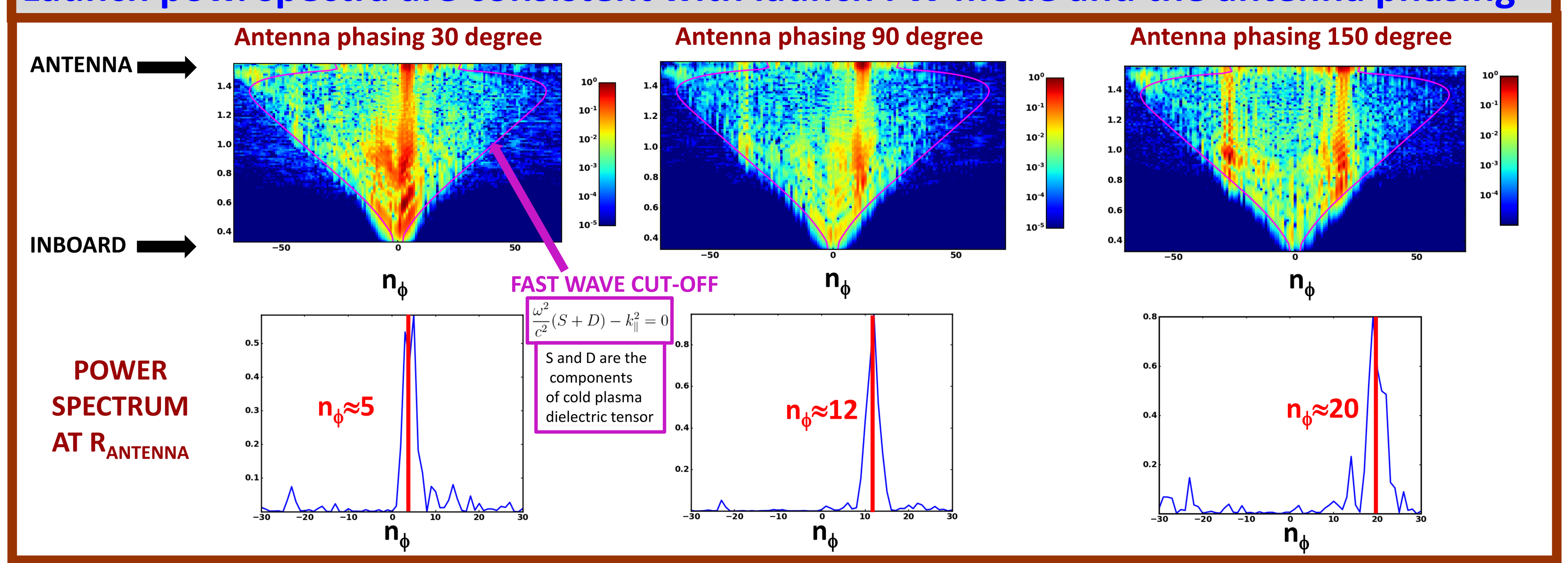


Strong E field on the wall observed on passive plates



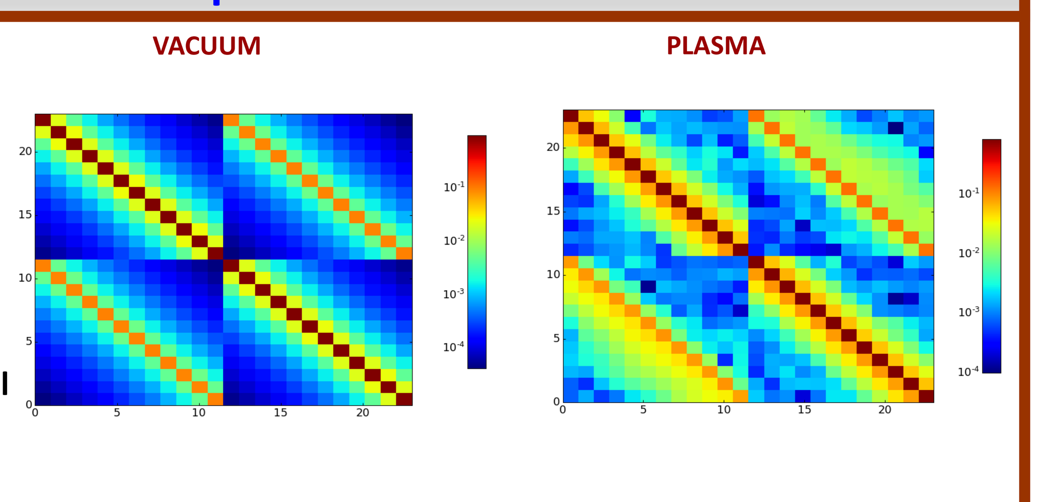
- |E| field stronger for lower antenna phasing
- |E| field on the surface in 3D will be important for studying the antenna impurity generation and RF sheath effects

Launch pow. spectra are consistent with launch FW mode and the antenna phasing



Evaluation of S-matrix in Petra-M: vacuum vs. plasma cases

- S-matrix (24x24) for the front face HHFW antenna
- S-matrix in vacuum is symmetric unlike the plasma case
- Significant improvement w.r.t. the previous modeling efforts done in 2001-2003 with RANT3D [*Swain et al 2001-2003*]
- First step towards the evaluation of experimental coupling resistance in preparation of the HHFW system operation in NSTX-U



Conclusions

- First ever 3D HHFW full wave simulation for NSTX-U plasma including realistic antenna geometry and SOL plasma
  - Strong interaction between HHFW and SOL plasma at lower antenna phasing
  - Strong E field on the wall surface also far away from the antenna
  - Launch power spectra consistent with RF wave theory
  - Evaluation of S-matrix for HHFW 12 strap antenna in NSTX-U (vacuum vs plasma)