M3D-K Simulation of Beam-driven Alfven Modes in NSTX for Code Validation*

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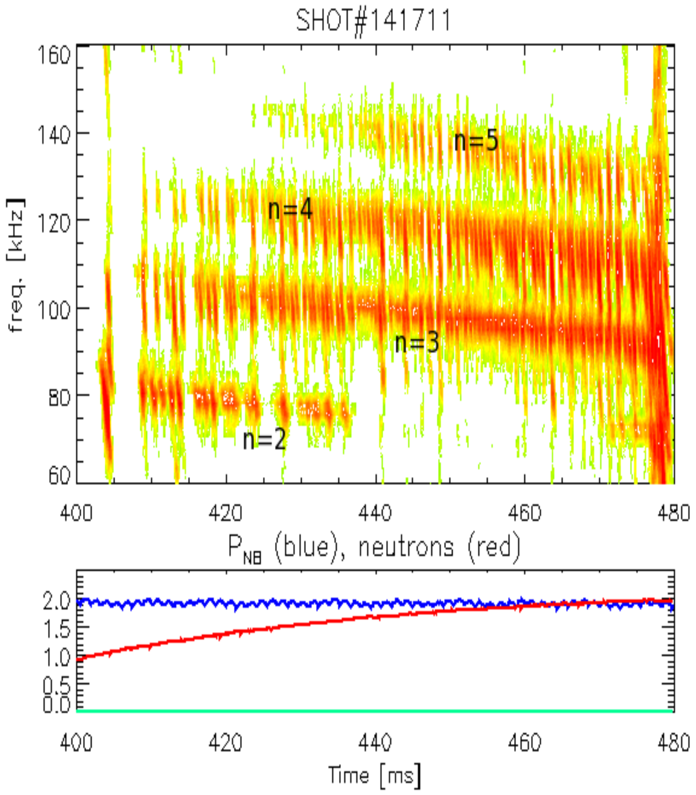
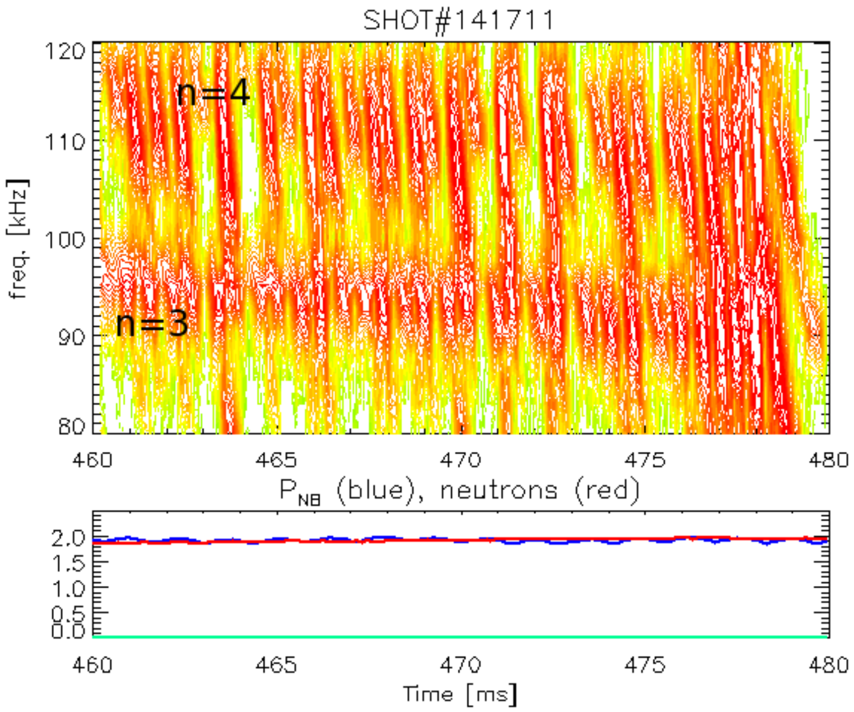
*SciDAC Center CSEP: Center for Nonlinear Simulation of Energetic Particles in Burning Plasmas

Multiple beam-driven TAEs were observed in NSTX (shot #14711)





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Outline

- Introduction
- SciDAC center CSEP
- M3D-K code
- M3D-K results of beam-driven Alfven modes in NSTX
- Discussions

Introduction

- In this work, we have carried out linear simulations of beam-driven Alfven modes in NSTX using the kinetic/MHD hybrid code M3D-K;
- The main goal is validation of M3D-K code for modeling of fast ion-driven Alfven instabilities and fast ion transport.
- This work was done as a part of the SciDAC project CSEP.

SciDAC CSEP: Center for Nonlinear Simulation of Energetic Particles in Burning Plasmas

- The mission is to develop tools for predictive simulations of energetic particle instabilities and transport in burning plasmas.

CSEP team

- PPPL: G.Y. Fu (PI), S. Ethier, J.Y. Lang, N. N. Gorelenkov;
- IFS: H. L. Berk (Co-PI), B. N. Breizman, E. Chen,
- J. W. Van Dam, G. Wang, L.J. Zheng,
- CU: Y. Chen (Co-PI), S.E. Parker;
- ORNL: S.A. Klasky (Co-PI)

CSEP Plan (2011 – 2015)

- Upgrade first principle hybrid codes GKM and GEM: electron physics;
- Code V&V: benchmark between M3D-K, GKM and GEM, analytic theory and reduced models. Validate against experimental data.
- Develop reduced models: nonlinear chirping and quasilinear model;
- Simulation of alpha-driven Alfven modes in ITER;
- Integrated simulations of energetic particle-driven instabilities with MHD modes and micro-turbulence.

CSEP TTF2011 Presentations

- G.Y. Fu: “M3D-K simulations of beam-driven Alfvén modes in NSTX”
- J. Lang: “M3D-K simulation of beam-driven Alfvén modes in DIII-D”
- Y. Chen: “Simulation of Reversed Shear Alfvén Eigenmodes using a gyrokinetic code GEM “
- G. Wang: “Model for spontaneous frequency sweeping of an Alfvén wave in a toroidal Plasma”
- B.N. Breizman: “Modeling of long-range frequency sweeping phenomena”
- E. Chen: “Free-boundary Toroidal Alfven Eigenmodes”

M3D Kinetic/MHD Hybrid Code

$$\rho \frac{d\mathbf{v}}{dt} = -\nabla P - \nabla \cdot \mathbf{P}_h + \mathbf{J} \times \mathbf{B}$$

$$\mathbf{J} = \nabla \times \mathbf{B}, \qquad \frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E}$$

$$\mathbf{E} + \mathbf{v} \times \mathbf{B} = \eta \mathbf{J}$$

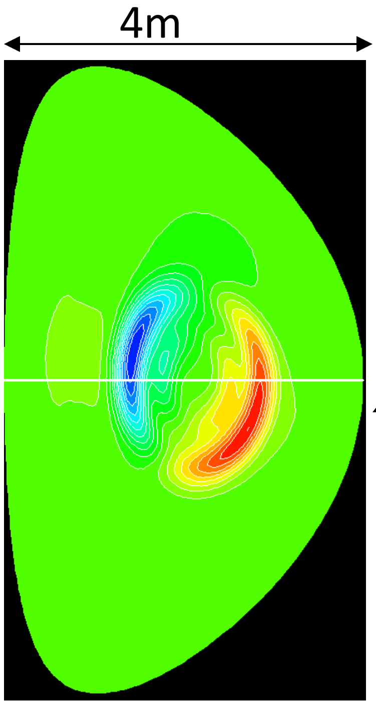
$$\partial P / \partial t + \mathbf{v} \cdot P = -\gamma P \nabla \cdot \mathbf{v} + ...$$

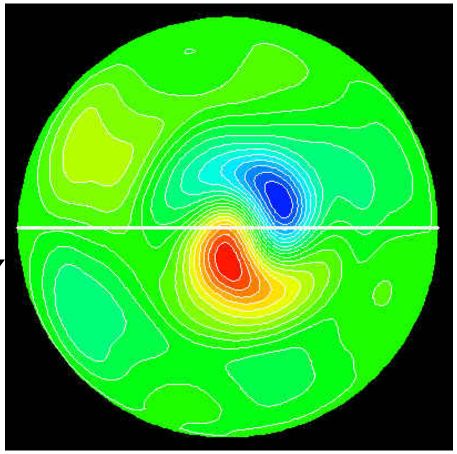
$\mathbf{P}_h$ is calculated using gyrokinetic/drift-kinetic equation (PIC method).

M3D-K Features

- Use realistic geometry (ST!);
- Use experimental parameters and profiles (interface with TRANSP);
- Global;
- Linear and Nonlinear;
- Non-perturbative fast ion effects (i.e., can model EPM);
- Plasma rotation is included;
- Interface with NUBEAM will soon be available.

M3D-K applications:





(1) Alpha particle stabilization of n=1 kink in ITER;

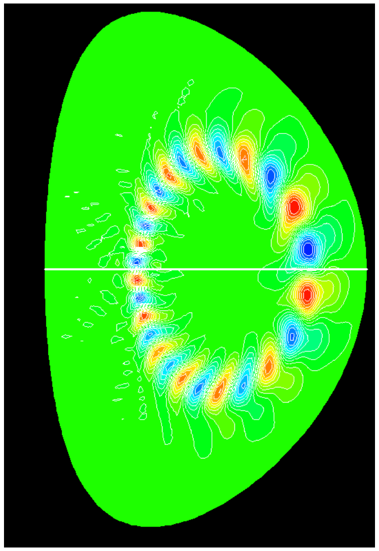
(2) Nonlinear frequency chirping of fishbone;

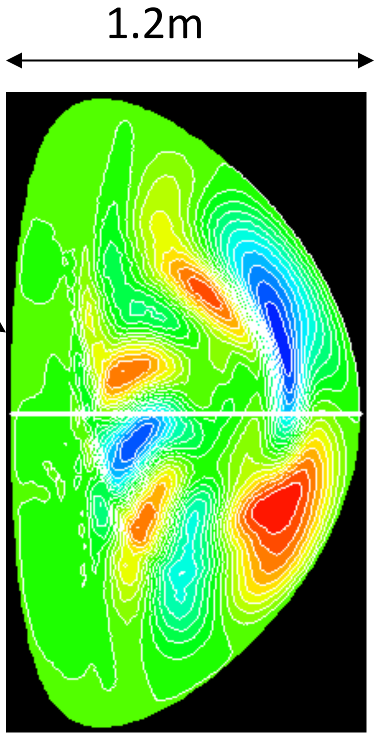
(3) Beam-driven TAEs in DIII-D;

(4) Beam-driven TAEs in NSTX;

(5) Beam-driven GAM in DIII-D

(6) Nonlinear simulation of TAE with energetic particle source and sink





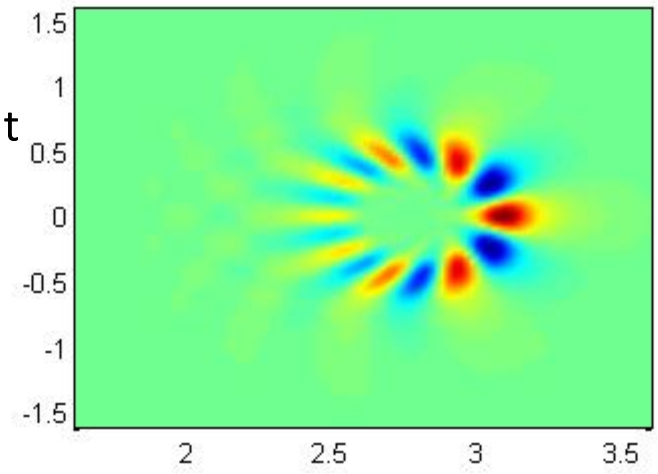
G.Y. Fu, 2004 IAEA Fusion Energy Conference
G.Y. Fu et al., Phys. Plasmas, 2006
G.Y. Fu, invited talk, the 2007 APS-DPP meeting
J.Y. Lang and G.Y. Fu et al, Phys. Plasmas, 2010

M3D-K Verification and Validation

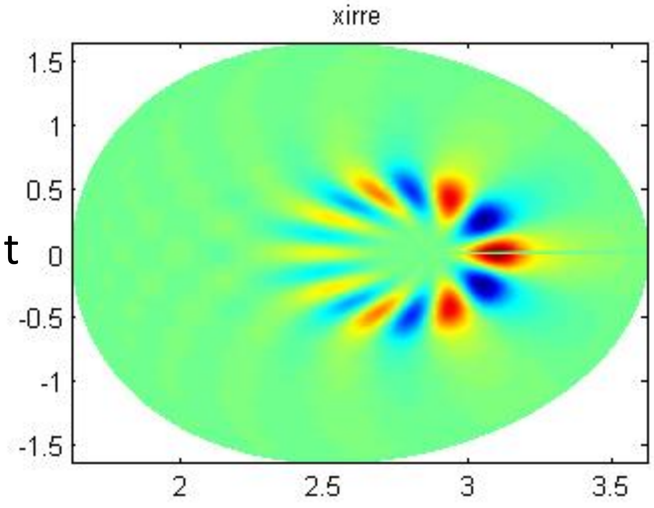
- Good agreement between M3D and NIMROD for CDX-U sawteeth simulations;
- Good agreement between M3D-K and NOVA for RSAE and TAE;
- Good agreement between M3D-K and NOVA2 as well as M3D-K and NIMROD for energetic particle stabilization of internal kink and excitation of fishbone.
- In this work we will compare M3D-K results with NSTX data with respect to beam-driven TAE for code validation.

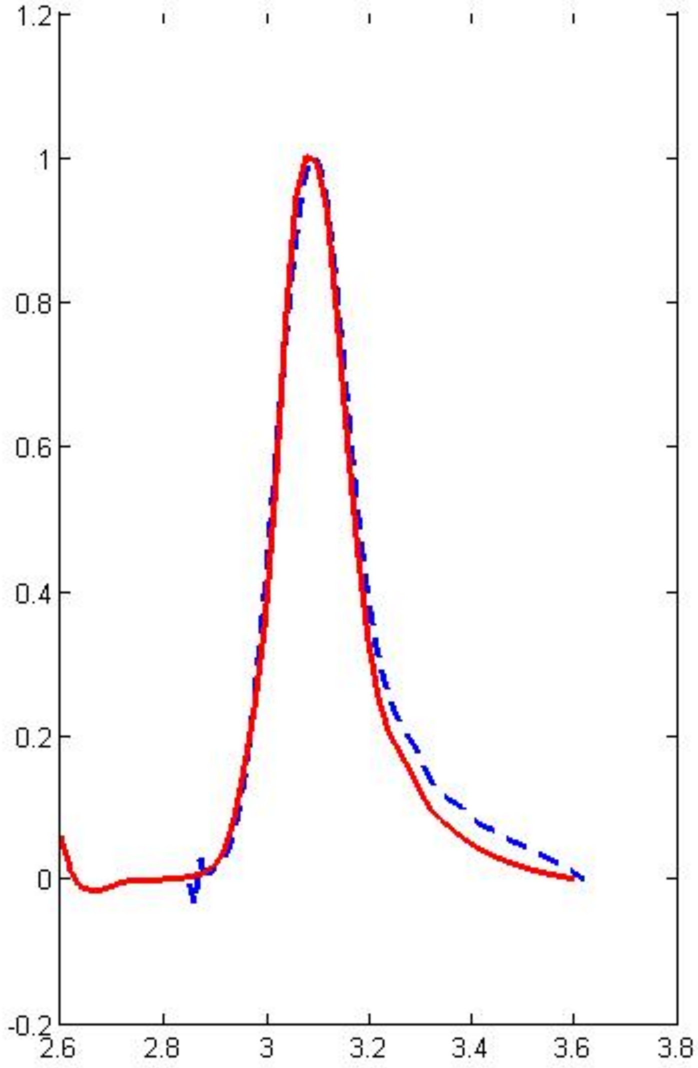
M3D-K results agree with NOVA for a n=2 RSAE in MHD limit

M3D result



NOVA result





J. Lang et al., this meeting.

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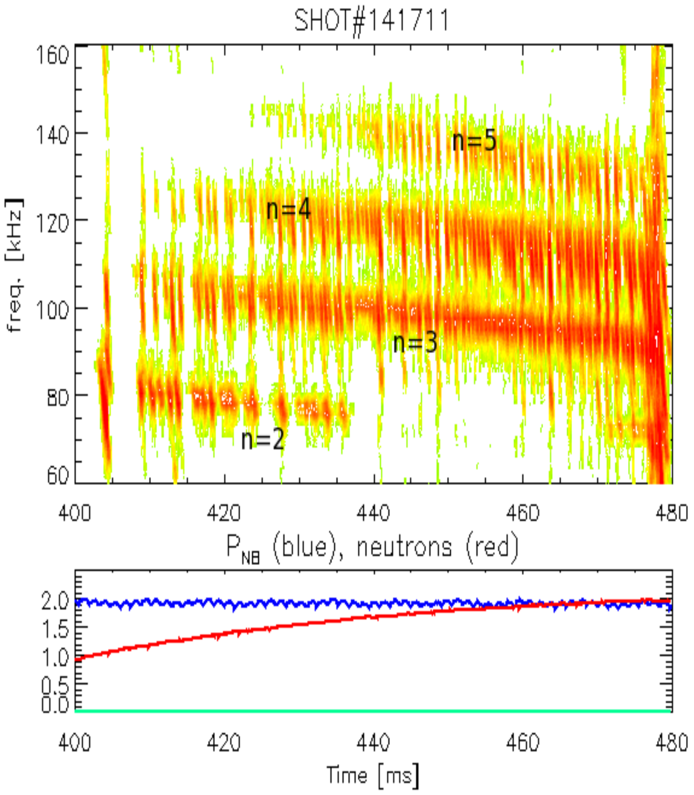

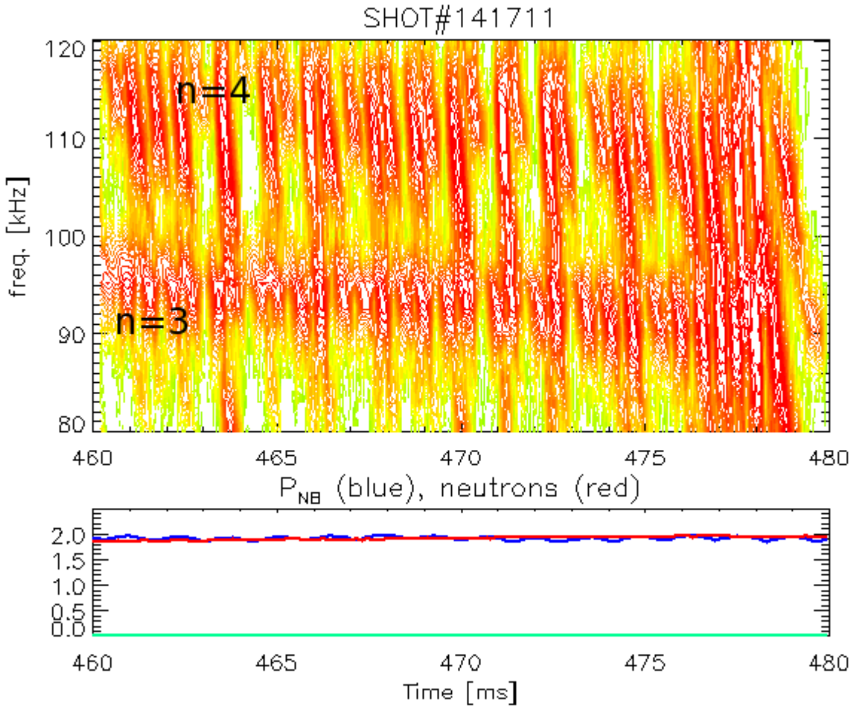

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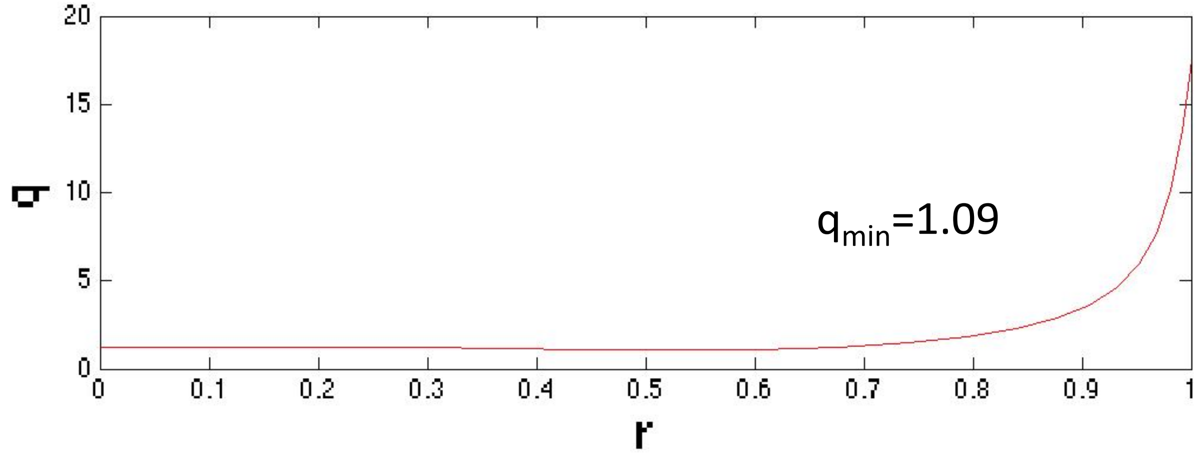
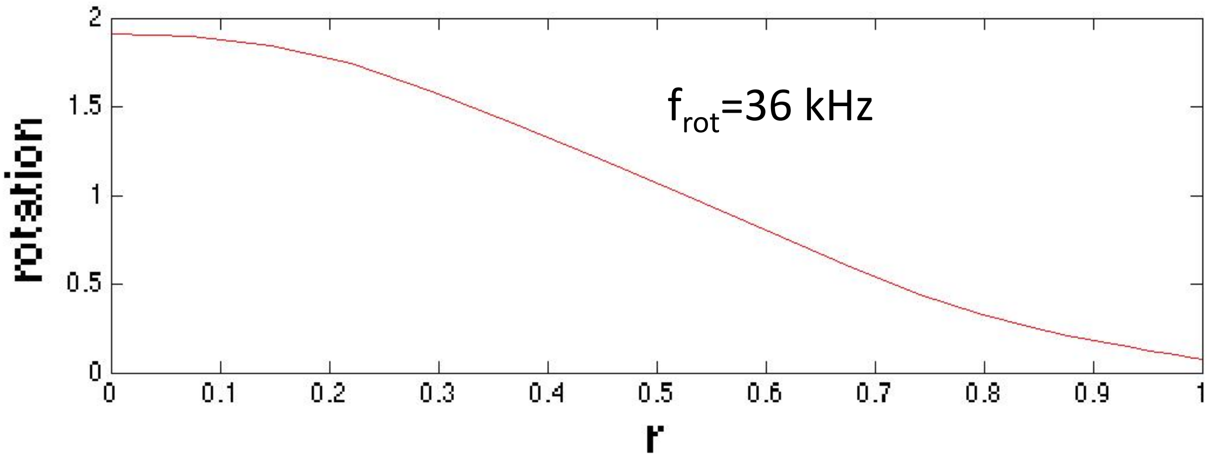
Parameters and Profiles (#141711)





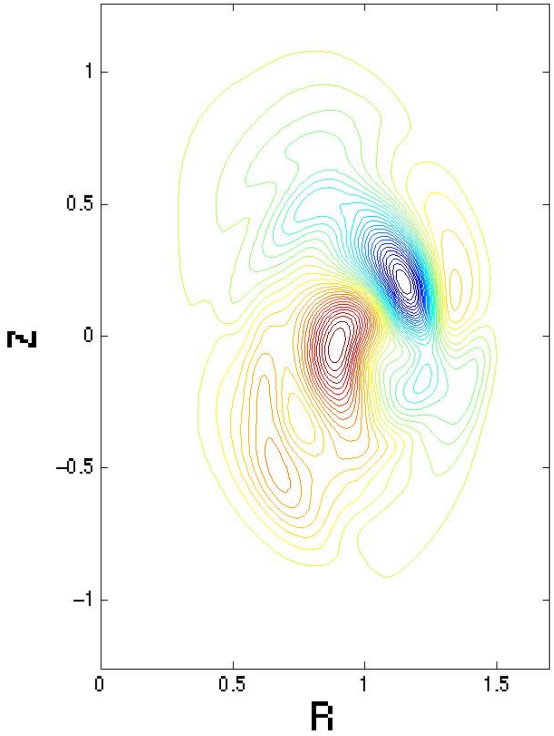
B=0.55T
R=0.85m
a=0.67m

ne(0)=4.4e13/cm^3
Te(0)=1.4 kev
Ti(0)=1.3 kev

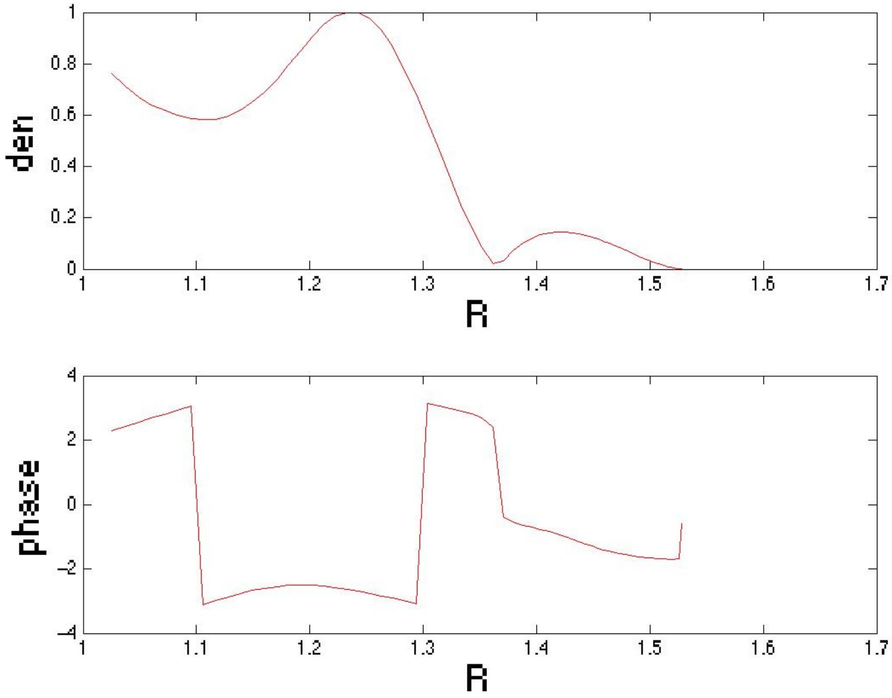
b(0)=24%
b_{beam}(0)=10%

M3D-K results of n=1 mode (kink)

dn_e



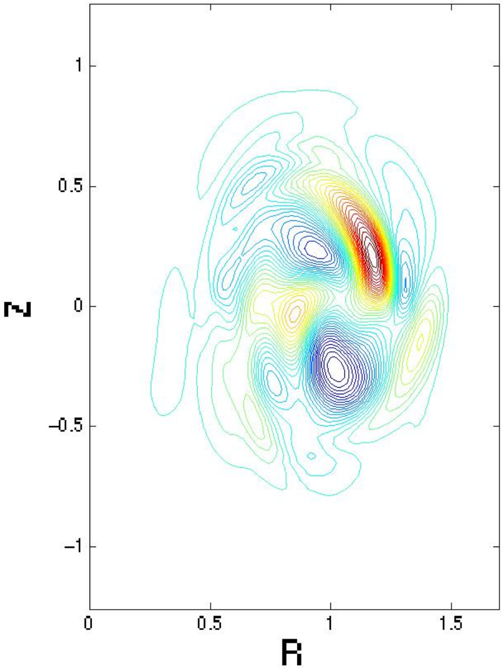
f=36kHz

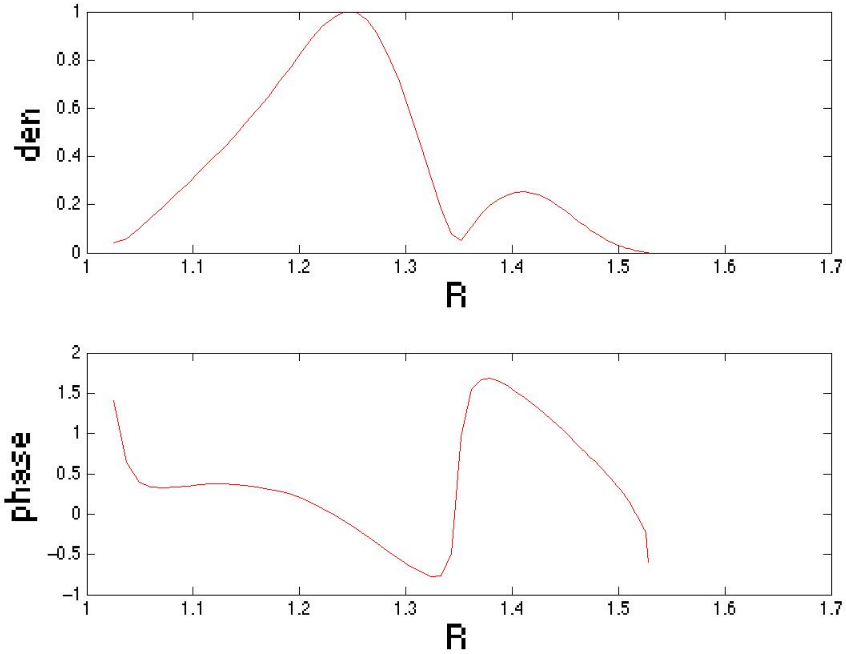


n=2 mode (TAE)

dn_e

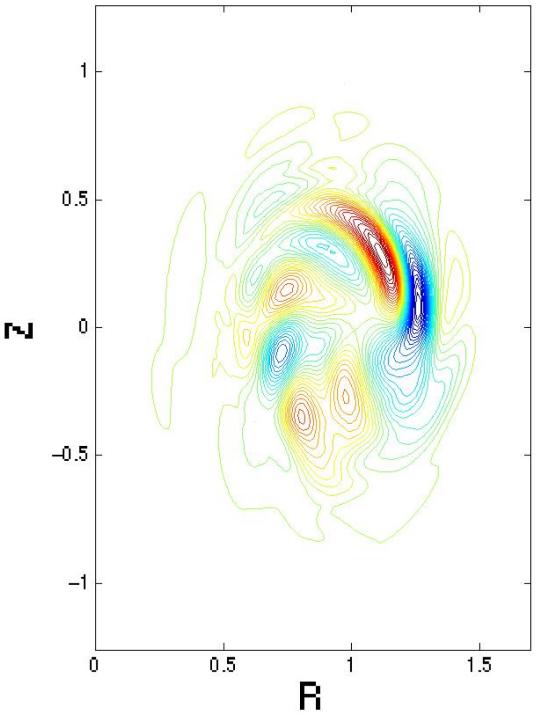
f=65kHz



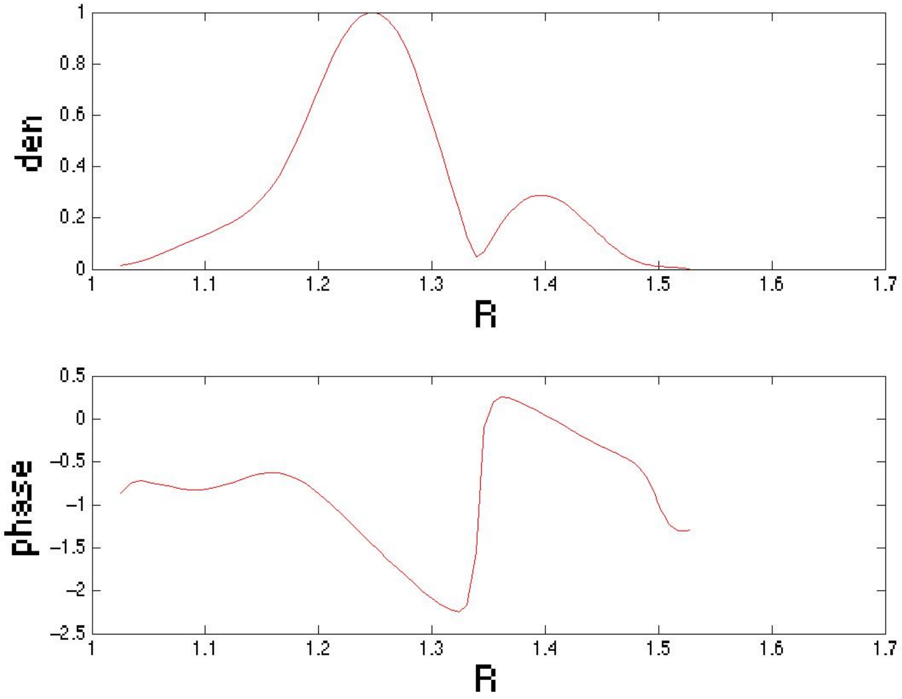


n=3 mode(TAE)

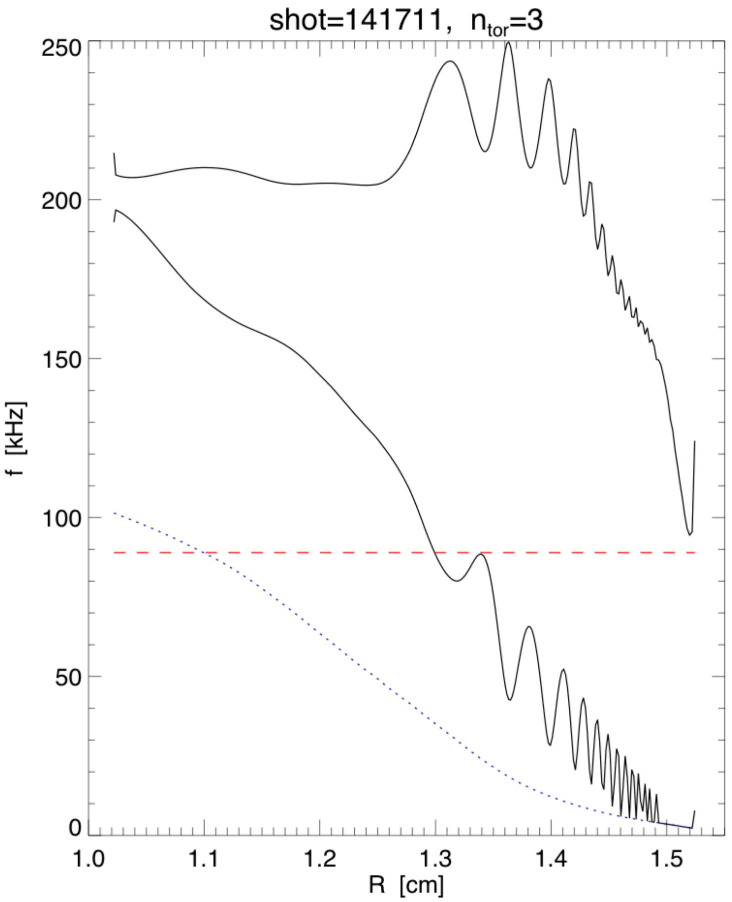
dn_e

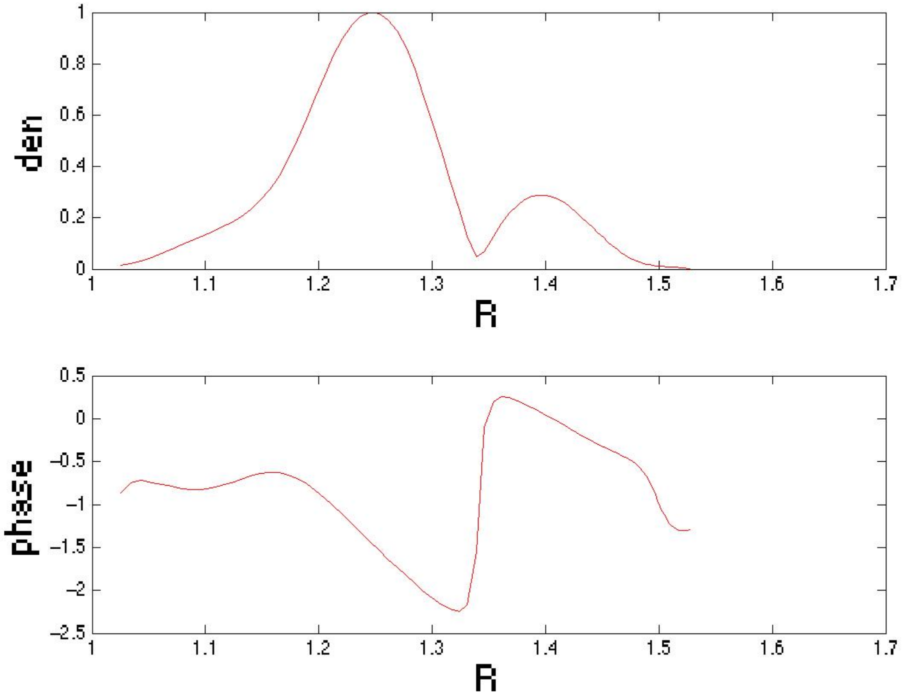


f=97kHz



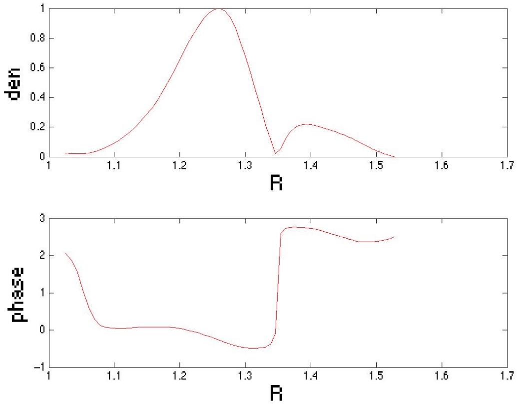
The M3D-K calculated TAE peaks just inside the continuum resonance



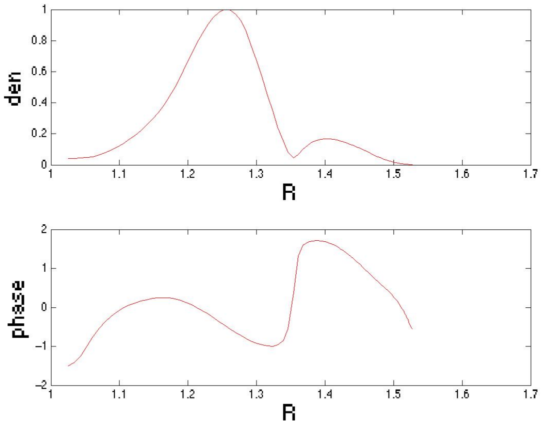


Rotation has little effect on mode structure (n=3 TAE)

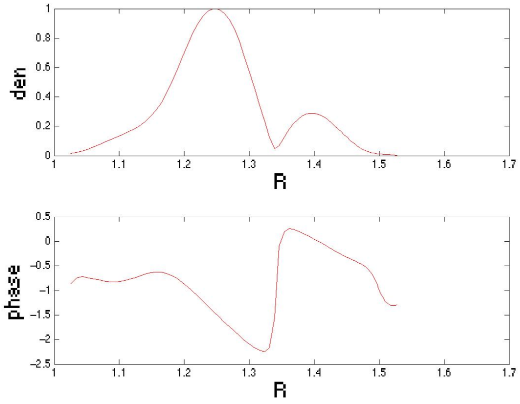
f_{rot}=18 kHz



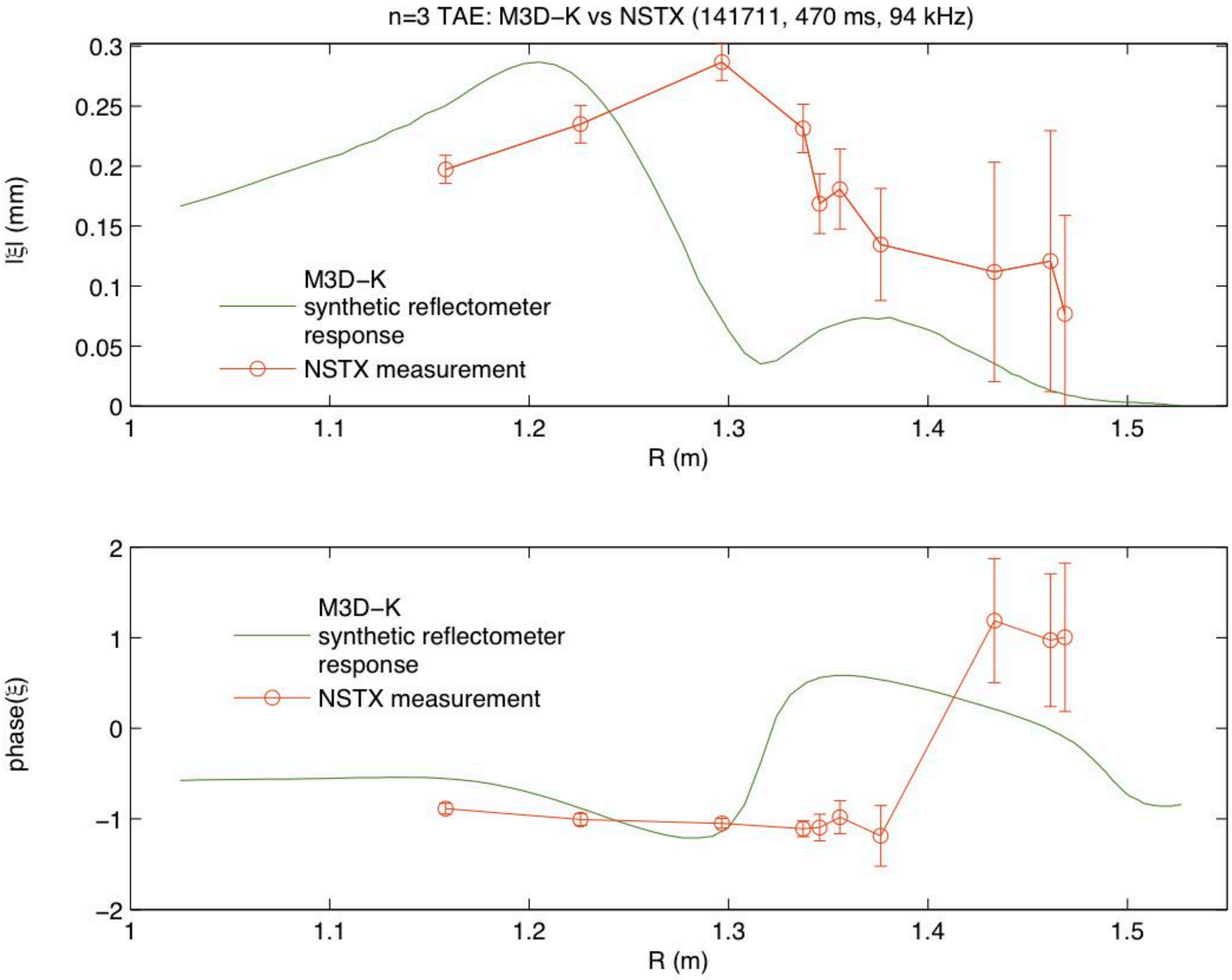
f_{rot}=27 kHz



f_{rot}=36 kHz



M3D-K's mode structure is similar to the measurement. The main difference is a shift in mode location.



f_{exp} = 94 kHz

$f_{M3D\text{-}K}$ = 97 kHz

Discussions

- M3D-K linear results are similar to the measurement with respect to mode frequency, core-localized radial structure, and phase shift.
- The main difference is a significant radial shift between the M3D-K's mode structure and that of measurement.
- The difference in mode location could come from the difference in q profiles, fast ion profiles, or nonlinear modification of beam-driven modes. These possibilities will be investigated in near future.