Simulation of MSE signals, as a diagnostic tool for MHD instabilities

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Abstract

Mode identification of MHD instabilities is often based on external signals, typically, by Mirnov loops placed at some distance from the plasma. With a sufficient number of coils it is possible to identify the dominant poloidal and toroidal harmonics at the plasma boundary. The internal structure can be determined from the electron cyclotron emission[a]. Recently[b], the motional Stark effect, MSE, diagnostic has proved to be a complementary alternative, as it measures the local field perturbation within the discharge. The predicted mode structure for global instabilities is easily obtained from codes, such as PEST, from which, we can simulate the expected MSE signal. We examine a variety of plasma pressure and safety-factor profiles and geometry to determine the expected MSE signal. Comparisons with experiment will be presented.

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[a]Okabayashi et al. Nuclear Fusion Vol. 38, (1998) 1149

[b]Jayakumar et al. BAPS Vol. 48(2003) QP1.045

Approach

- Equilibrium from EFIT/TRANSP
  - Best fit to experiment
- Stability analysis using ideal MHD model
  - PEST : Determine eigenvalue and eigenfunction

$$\omega^2 , \xi(\mathbf{x})$$

- Determine perturbed field

$$Q = \nabla \times x \times B$$

- Determine MSE signal

The fluctuation in the MSE signal is determined using the equilibrium field, *B*, and perturbed field, *Q*.

$$Q \equiv \nabla \times (x \times B) = \tilde{B}$$

$$Q_q \equiv \frac{Q \bullet \nabla q}{|\nabla q|}$$

$$Q_y \equiv \frac{Q \bullet \nabla y}{|\nabla y|}$$

$$Q_f \equiv \frac{Q \bullet \nabla f}{|\nabla f|}$$

$$\text{Pitch} \equiv P = \frac{B_z}{B_f} = \frac{B_q \ (\text{mid-plane})}{B_f}$$

$$\text{Pitch perturbation} \qquad dP = \frac{B_q + Q_q}{B_f + Q_f} - \frac{B_q}{B_f}$$

Normalizing the Signal-I

- PEST provides a linear solution with an arbitrary scale factor – to fix its value:
- Determine the magnetic scalar potential in the vacuum region
- Use the plasma surface value and apply Green's 2^{nd} identity to compute the solution at the Mirnov probe location
- Match the field to the experimental measurement to normalize the amplitude of the perturbation

Normalizing the Signal-II

- A crude approximation
- Use the cylindrical solution

$$B(r) = B(r_s)\left(\frac{r_s}{r}\right)^{(m+1)}$$

$$r_s = R(surface) - R(axis)$$

$$r = R(loop) - R(axis)$$

$$m = \text{poloidal mode number}$$

Reference to work presented at APS DPP'03

Observation of MHD modes using the Motional Stark Effect Diagnostic

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Summary

- An MHD instability has been observed using the Motional Stark Effect (MSE) diagnostic on the DIII-D tokamak.
  - -Possibly for the first time, the local oscillating poloidal field component in a hot plasma device has been measured.
  - - First measurement of oscillating poloidal field component using MSE.
- The oscillating poloidal field component associated with a Resistive Wall Mode (RWM) has been measured in a plasma where the mode was rotated using internal field coils.
- The radial profile of the amplitude of oscillation poloidal field is in general agreement with profile of the Electron Cyclotron Emission (ECE) oscillation amplitude.
- The peak flux surface displacement obtained from MSE observations is in agreement with expectation.

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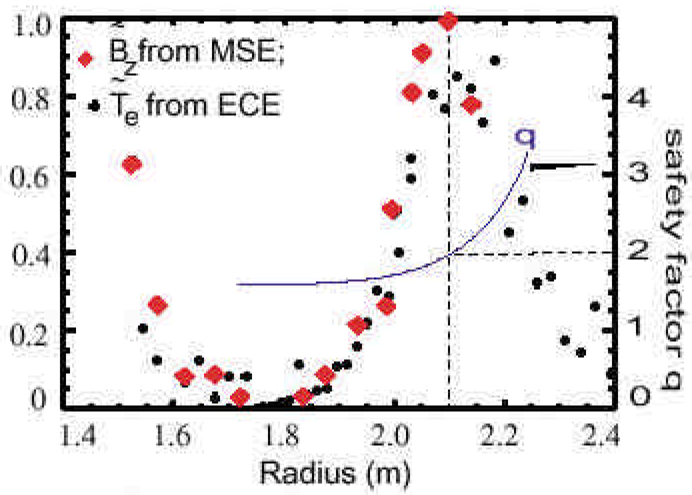
Mode structure reconstructed from MSE

PROFILE OF THE OSCILLATION AMPLITUDE OF
Bz (MSE) AND Te(ECE) ARE SIMILAR



(Normalized to peak values)

The oscillations are sum of n=0 and n=1 components. (not separable)

T̃e ~85 eV; B̃z ~55 gauss (RMS)
Correspond to a peak flux surface
Displacement of ~0.55 cm

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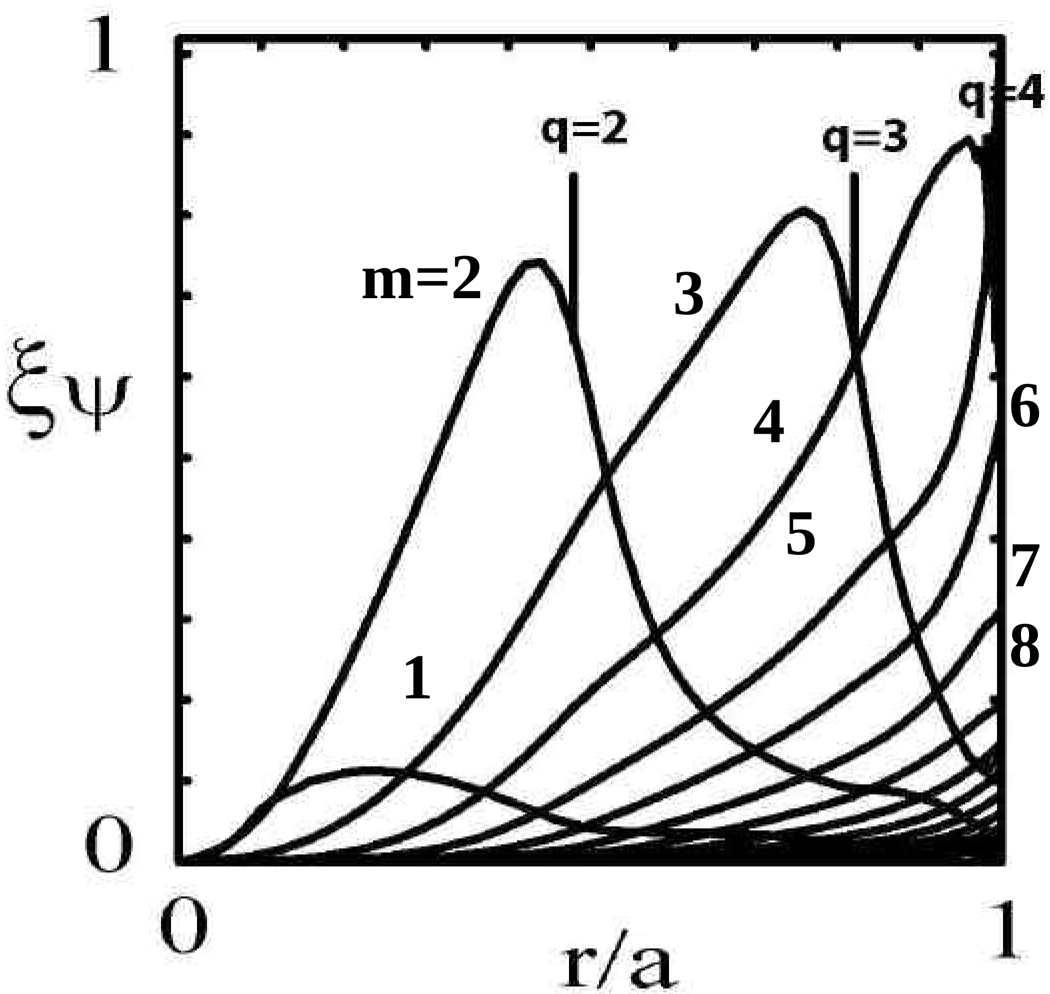
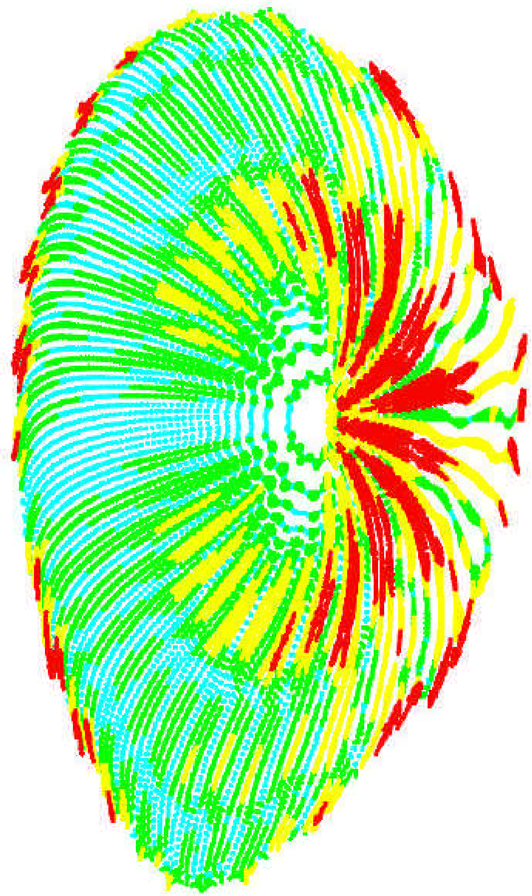
Peak location is at the q~2 radius.

Outstanding issues for comparison of theory with experiment

- Theory
  - Normalization
  - Linear mode structure – nonlinear effects?
  - Accuracy of equilibrium reconstruction
  - Modeling of external boundary
- Experiment
  - Separation of n=0 and n=1 components
  - Noise level as high as ~ 30-40%
  - Poloidal mode number identification
  - Radial resolution
  - Rotation

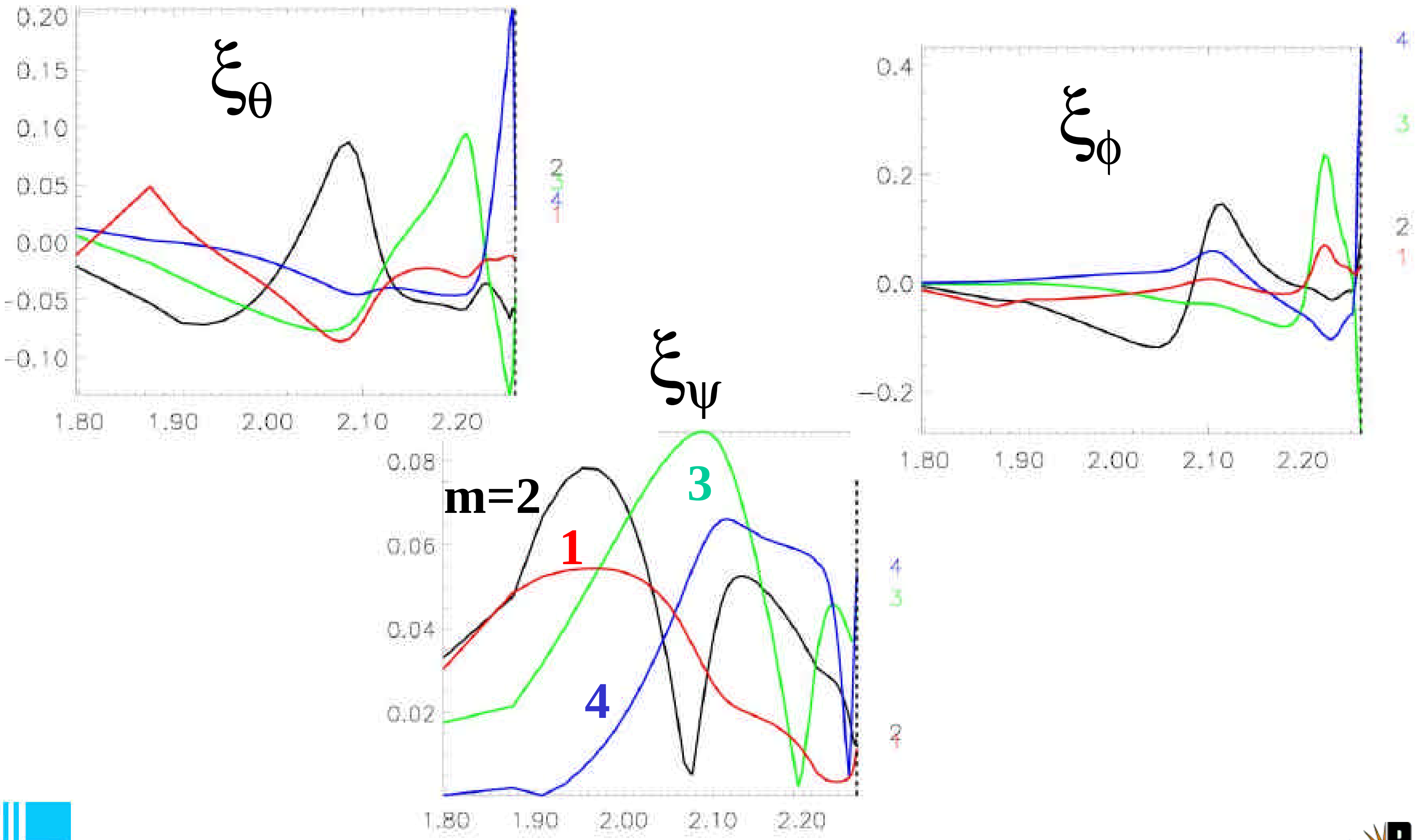
Unstable eigenfunction of displacement vector for DIIID Shot:113550 at 1725 *ms*.



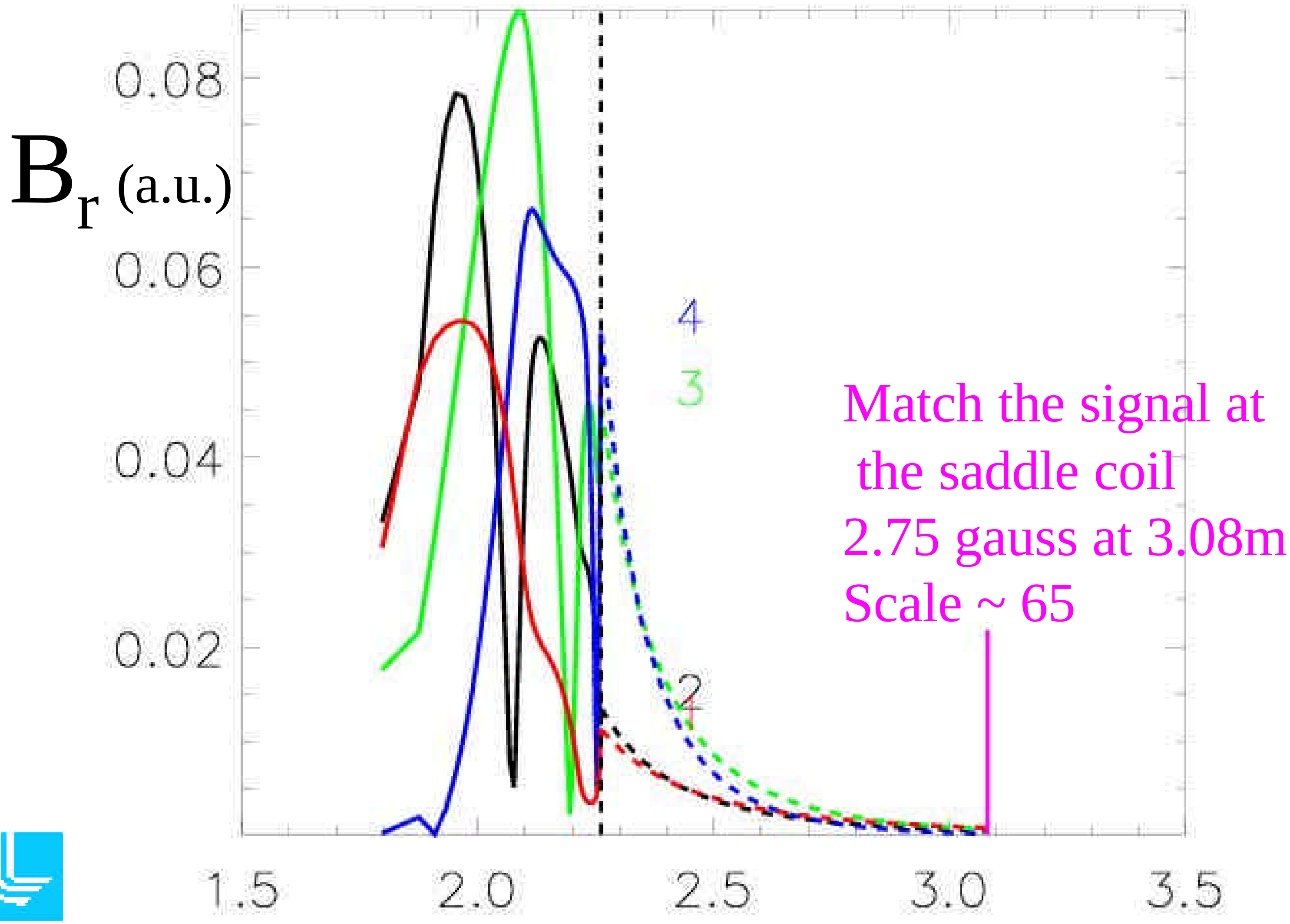


Unstable eigenfunction of perturbed field

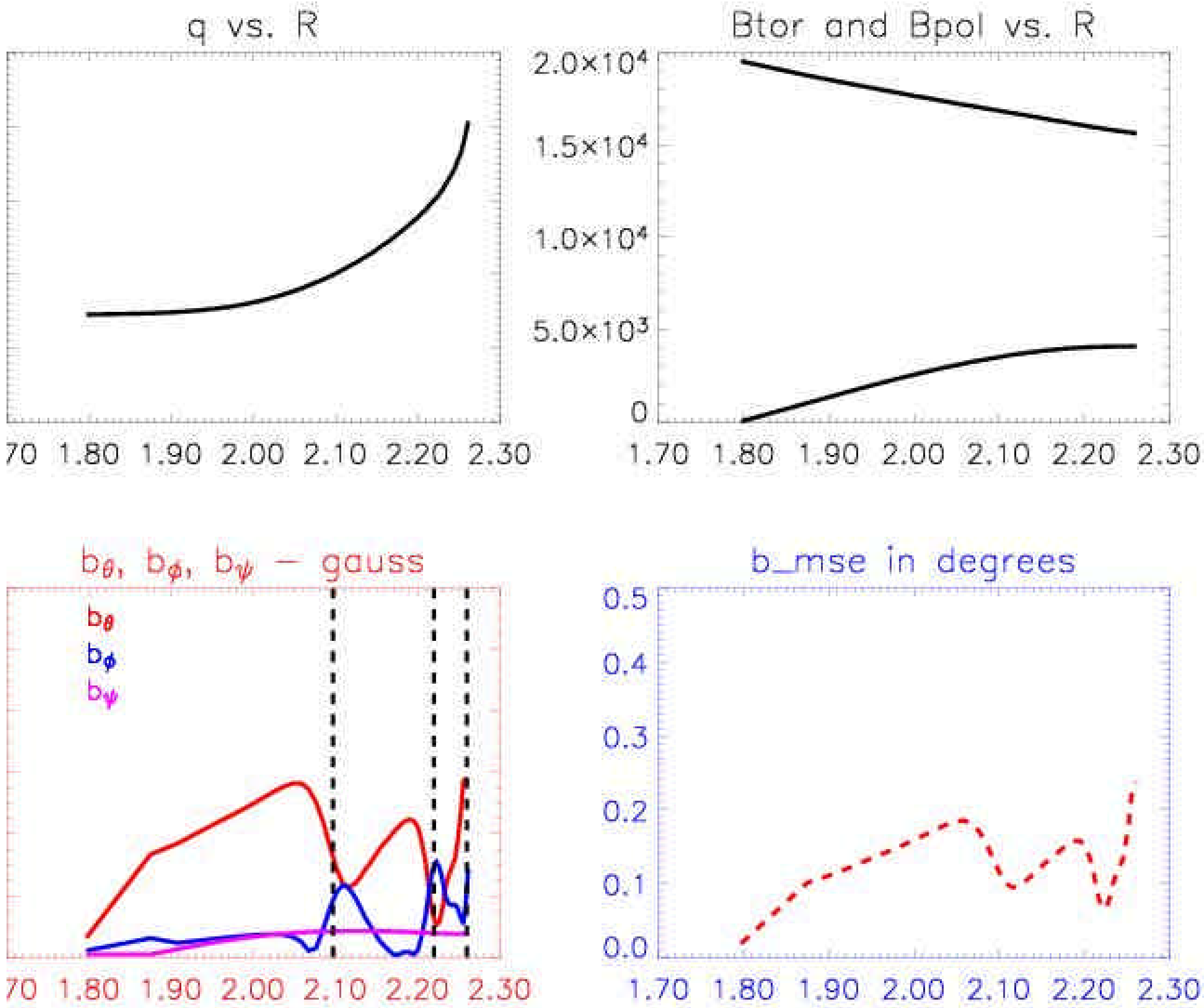
(higher harmonics not shown)



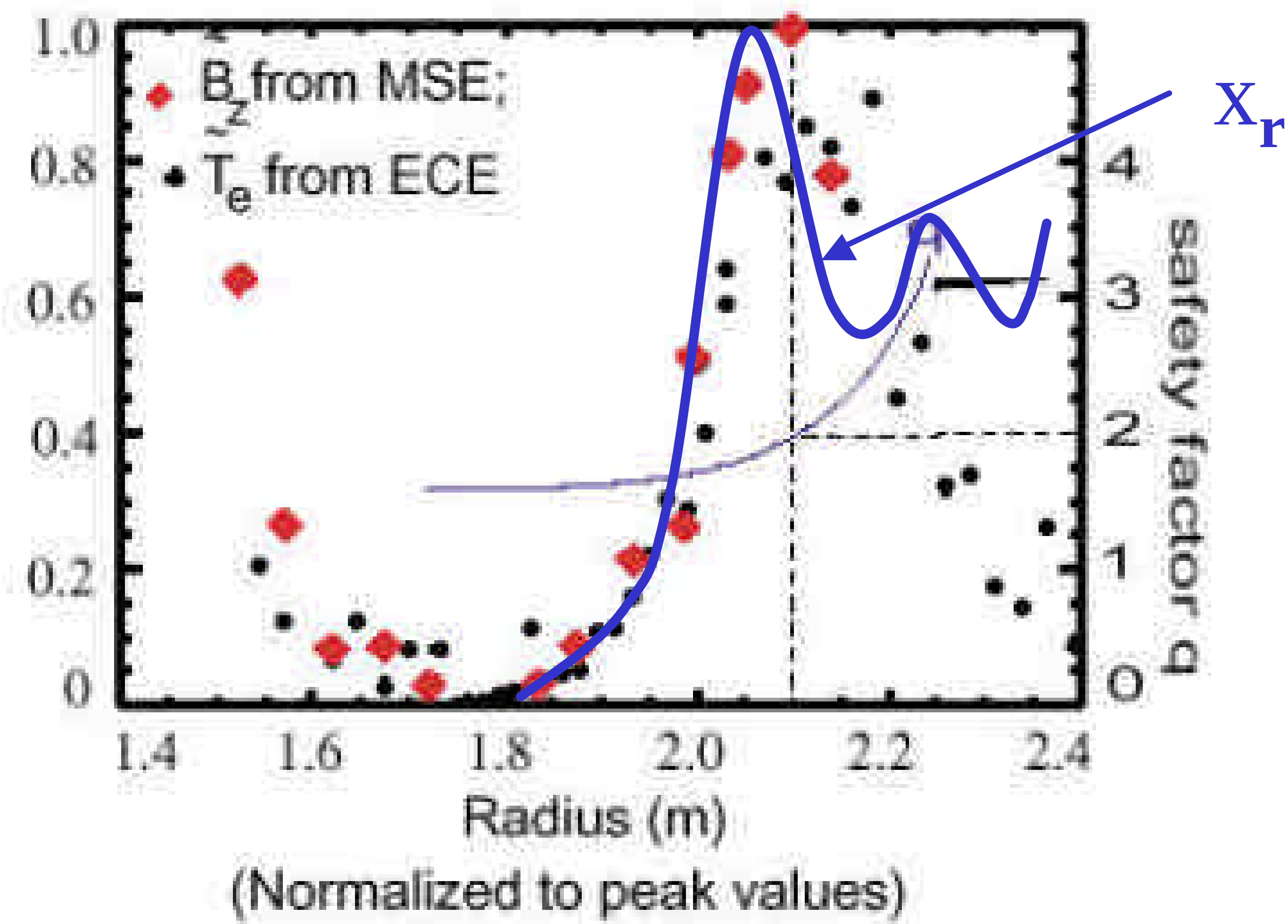
Normalizing the Signal-III



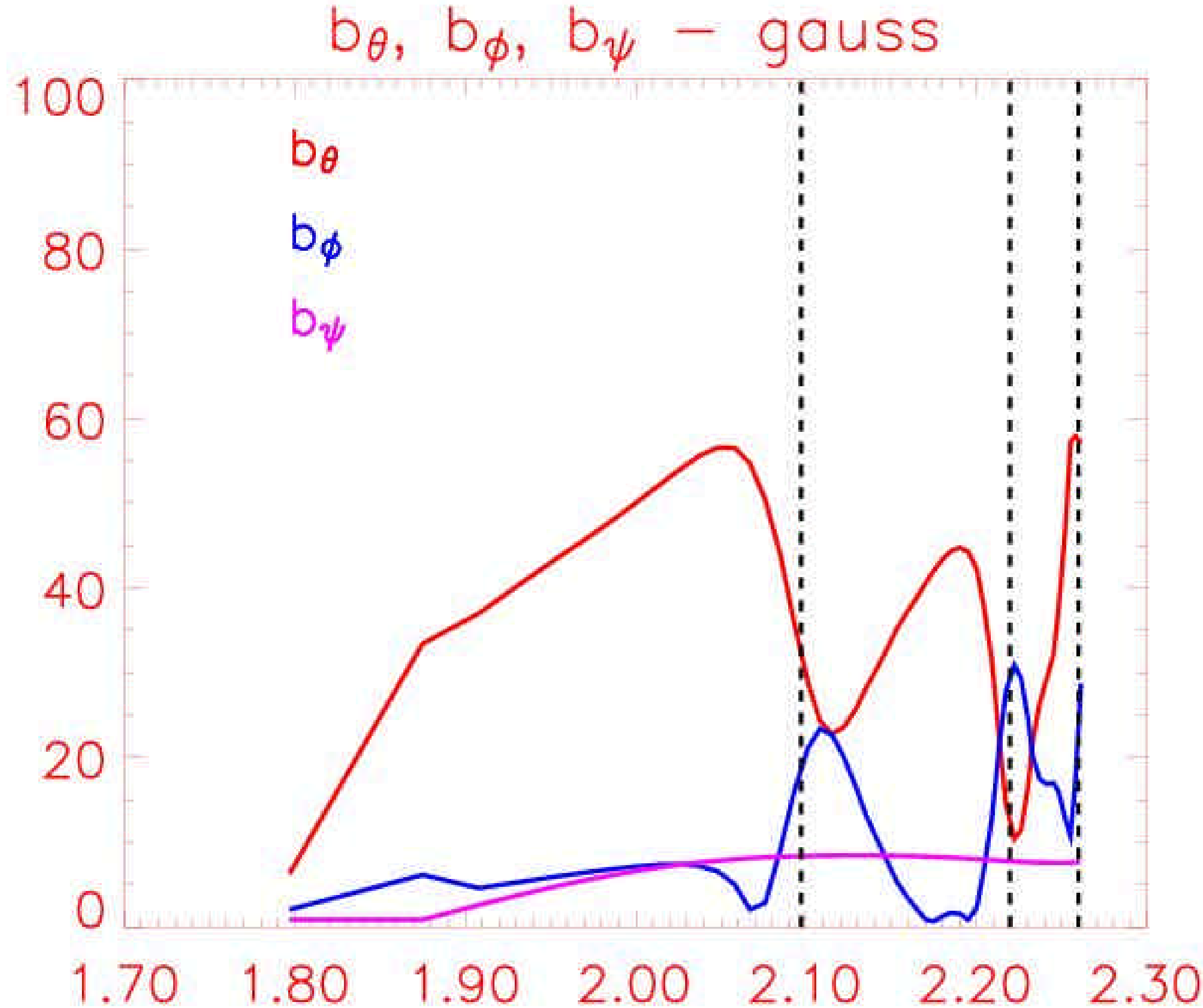
Predicted MSE signal



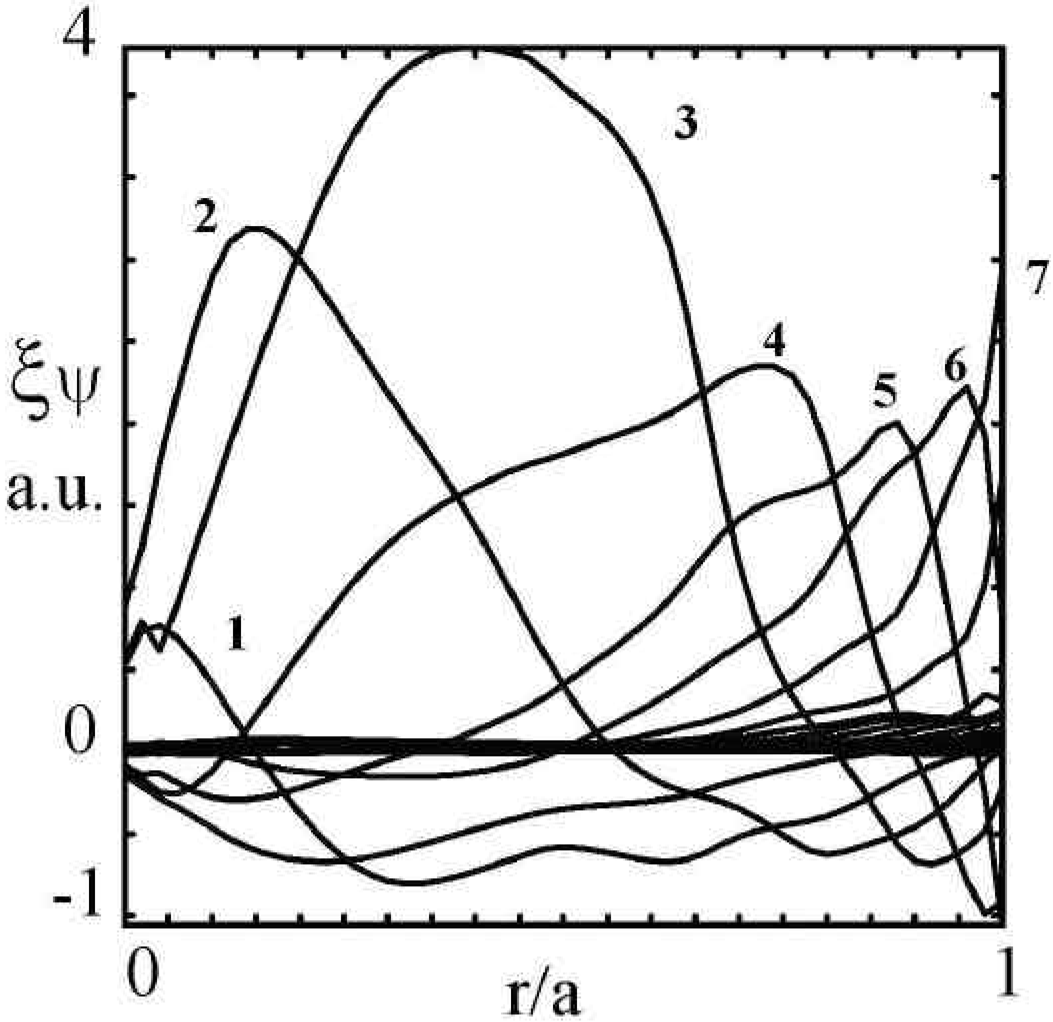
Predicted Displacement

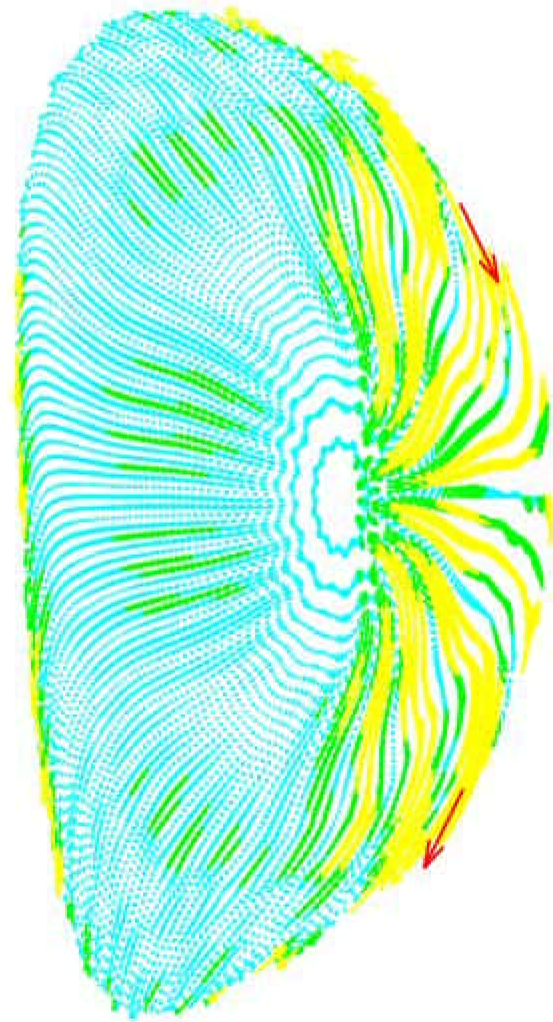


Radial distribution of perturbation

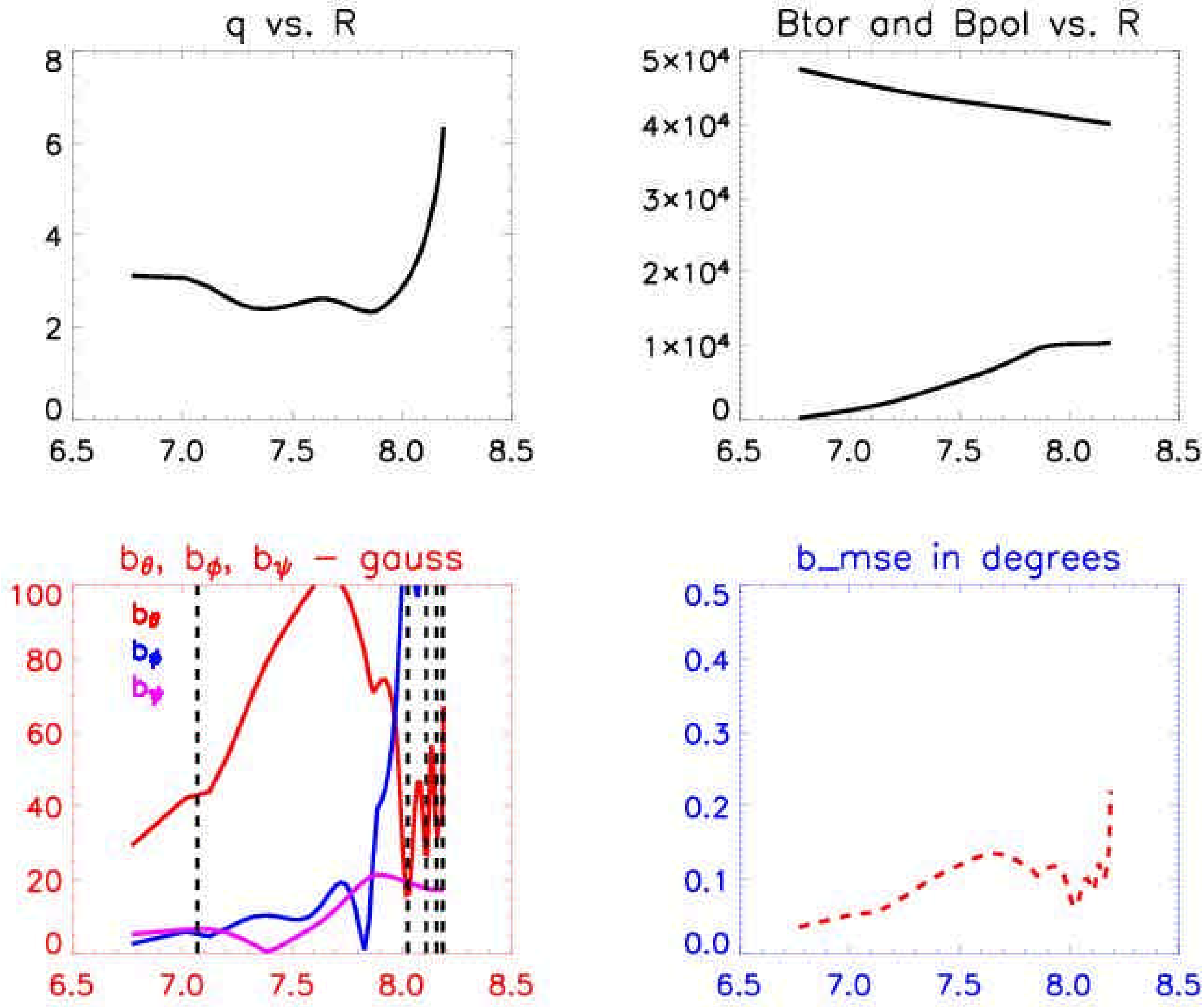


Unstable eigenfunction of displacement vector for ITER – $b_N = 3.4$

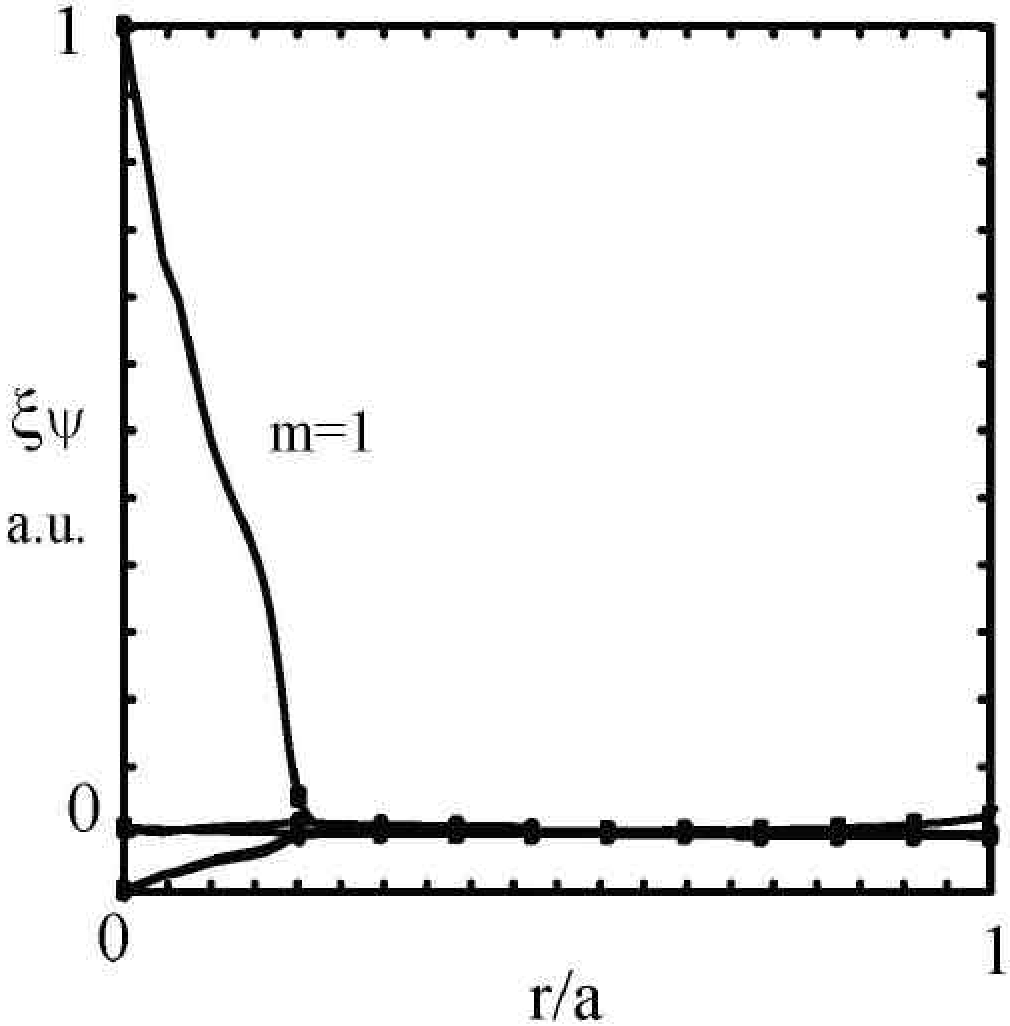


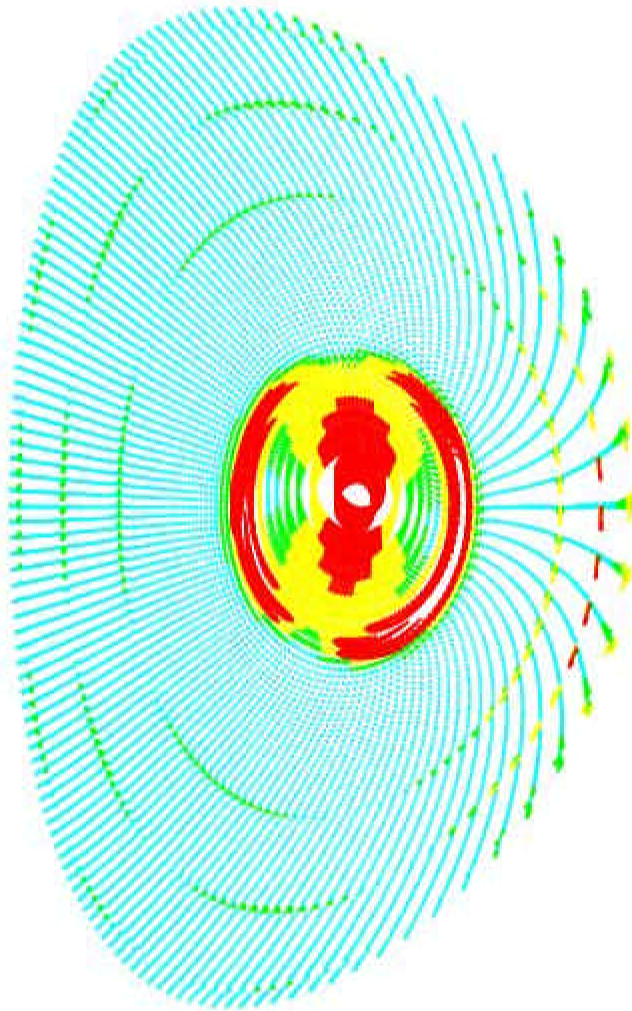


Predicted MSE signal - ITER

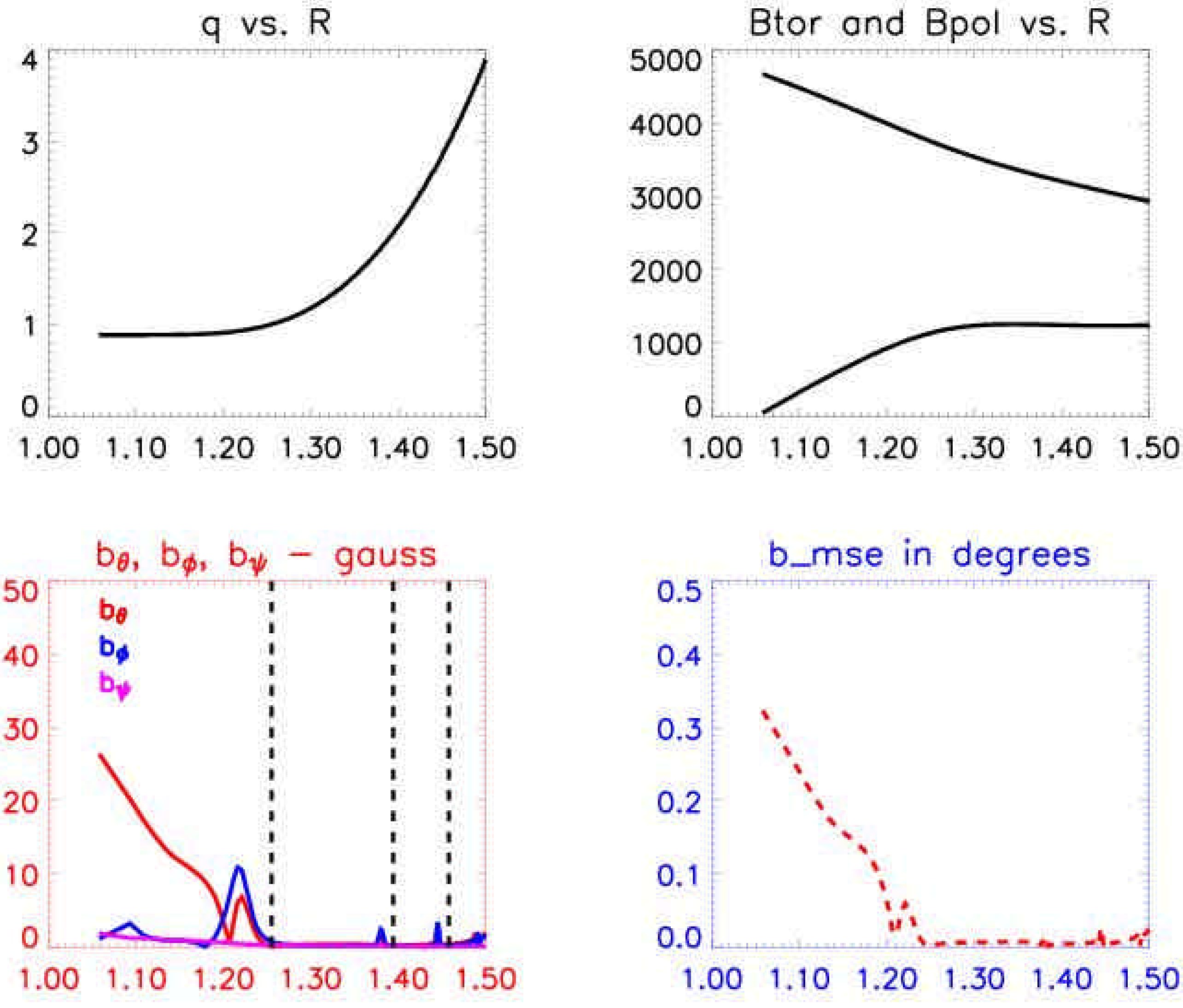


Unstable eigenfunction of displacement vector for internal kink R/a=2

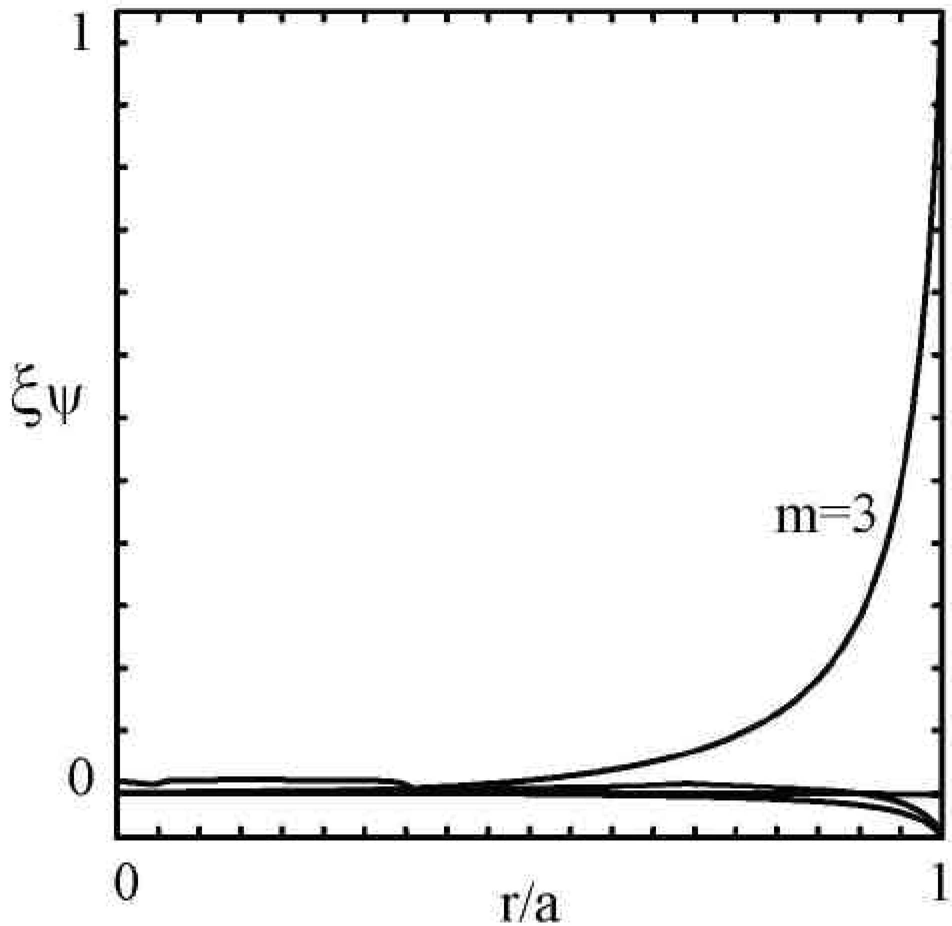


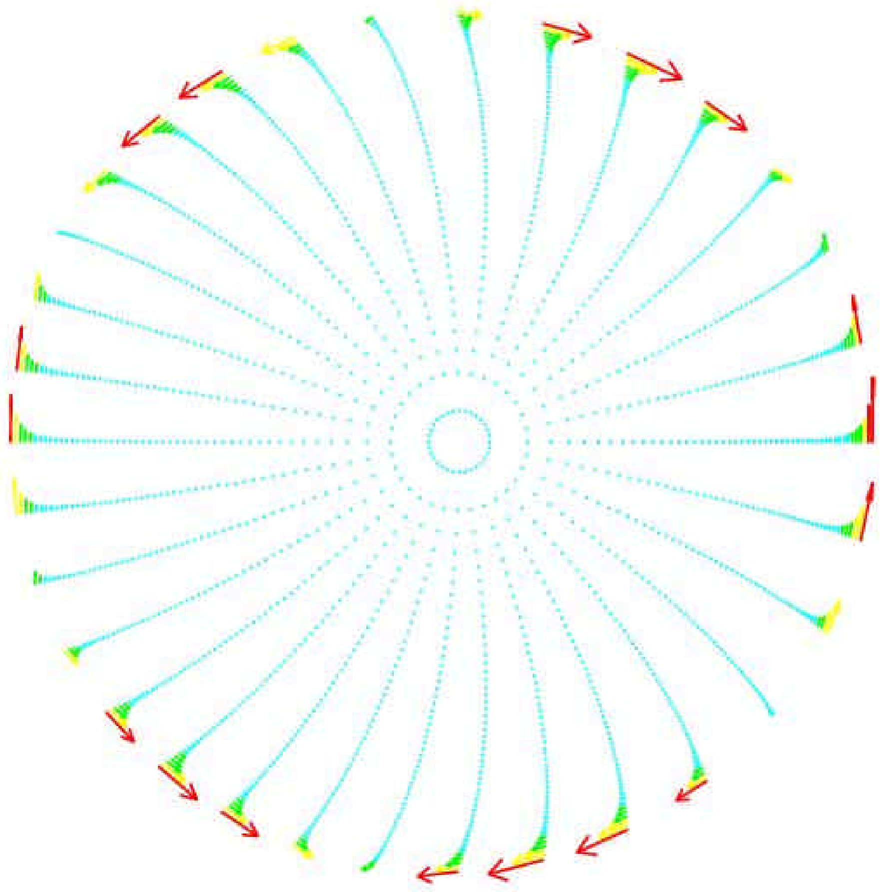


Predicted MSE signal for internal kink R/a=2

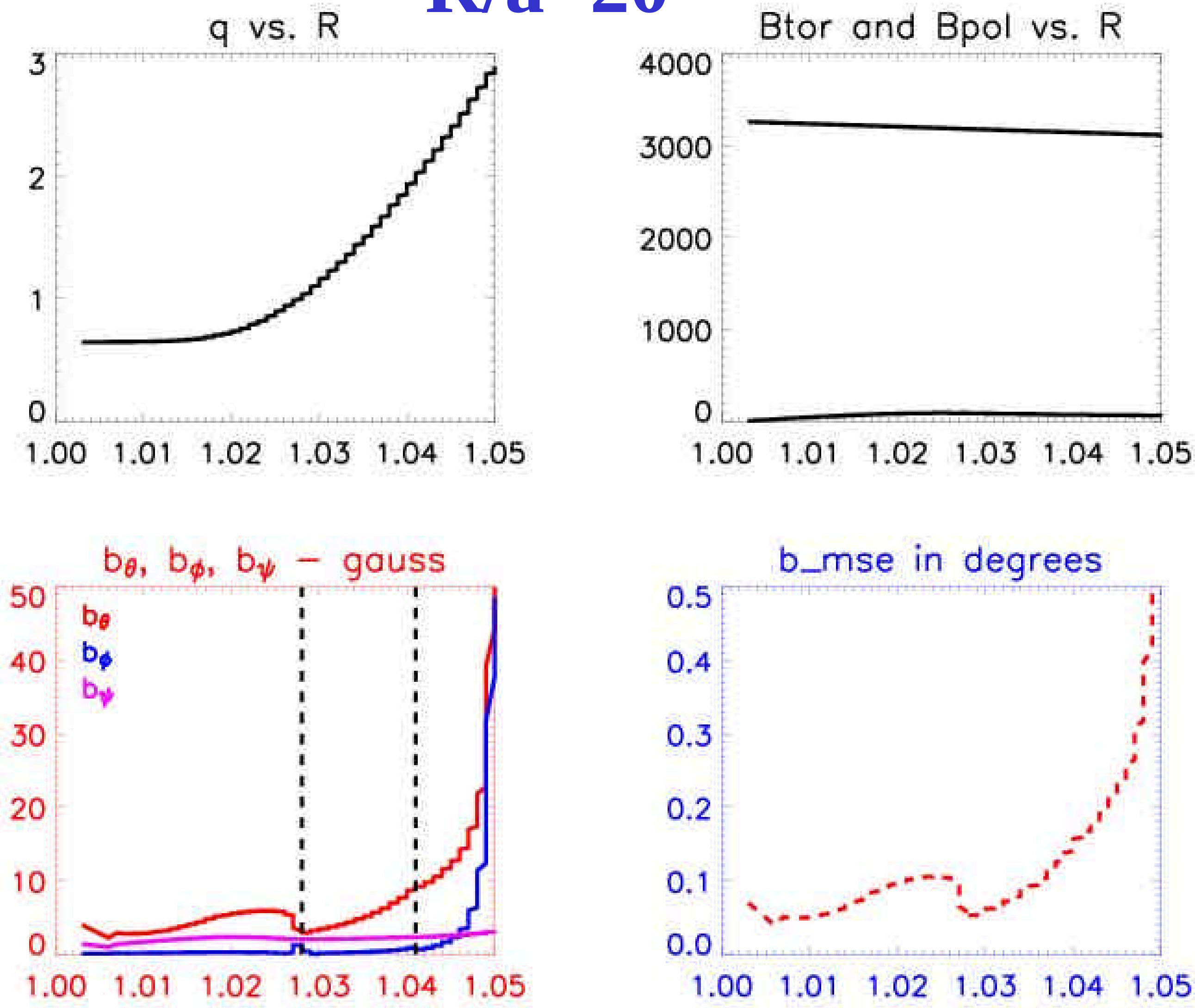


Unstable eigenfunction of displacement vector for external kink R/a=20

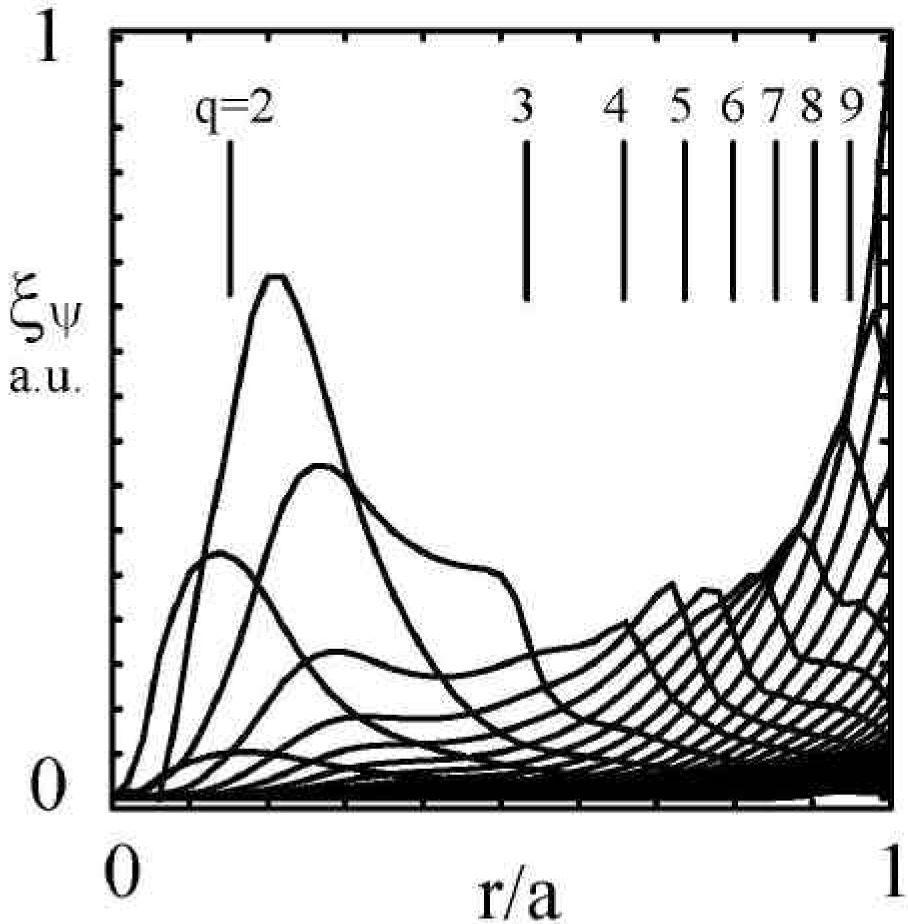


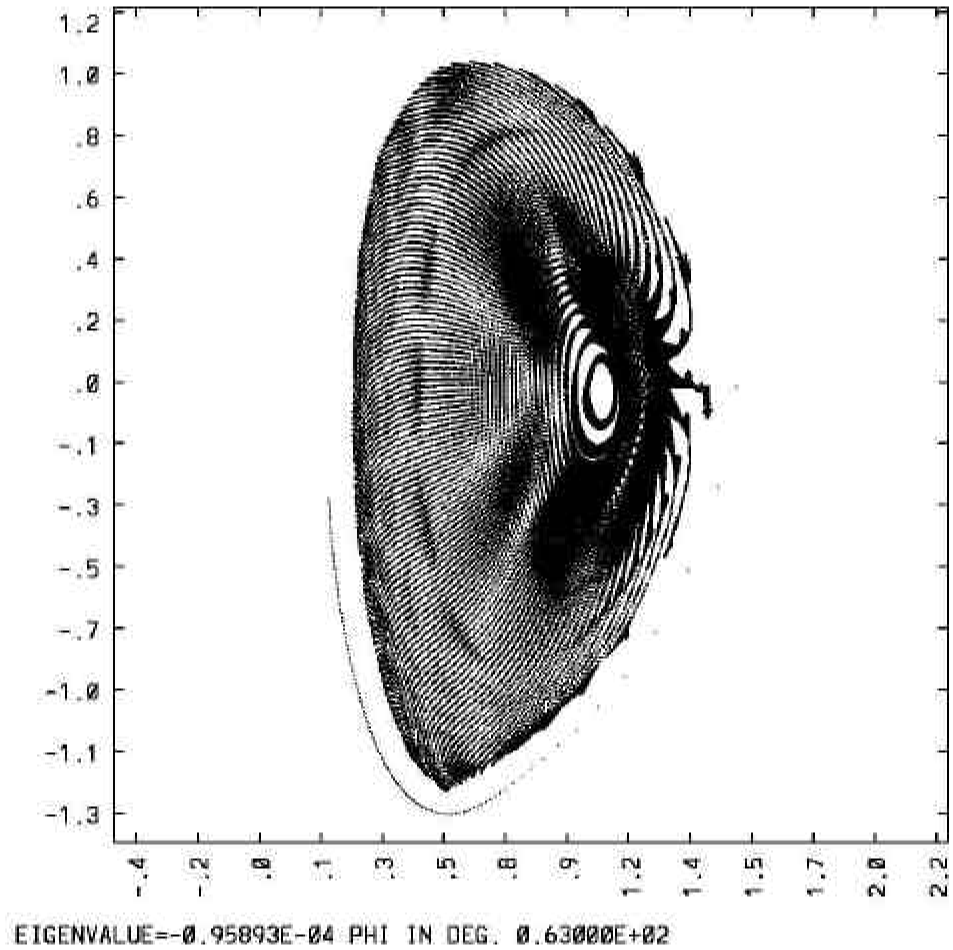


Predicted MSE signal for external kink R/a=20

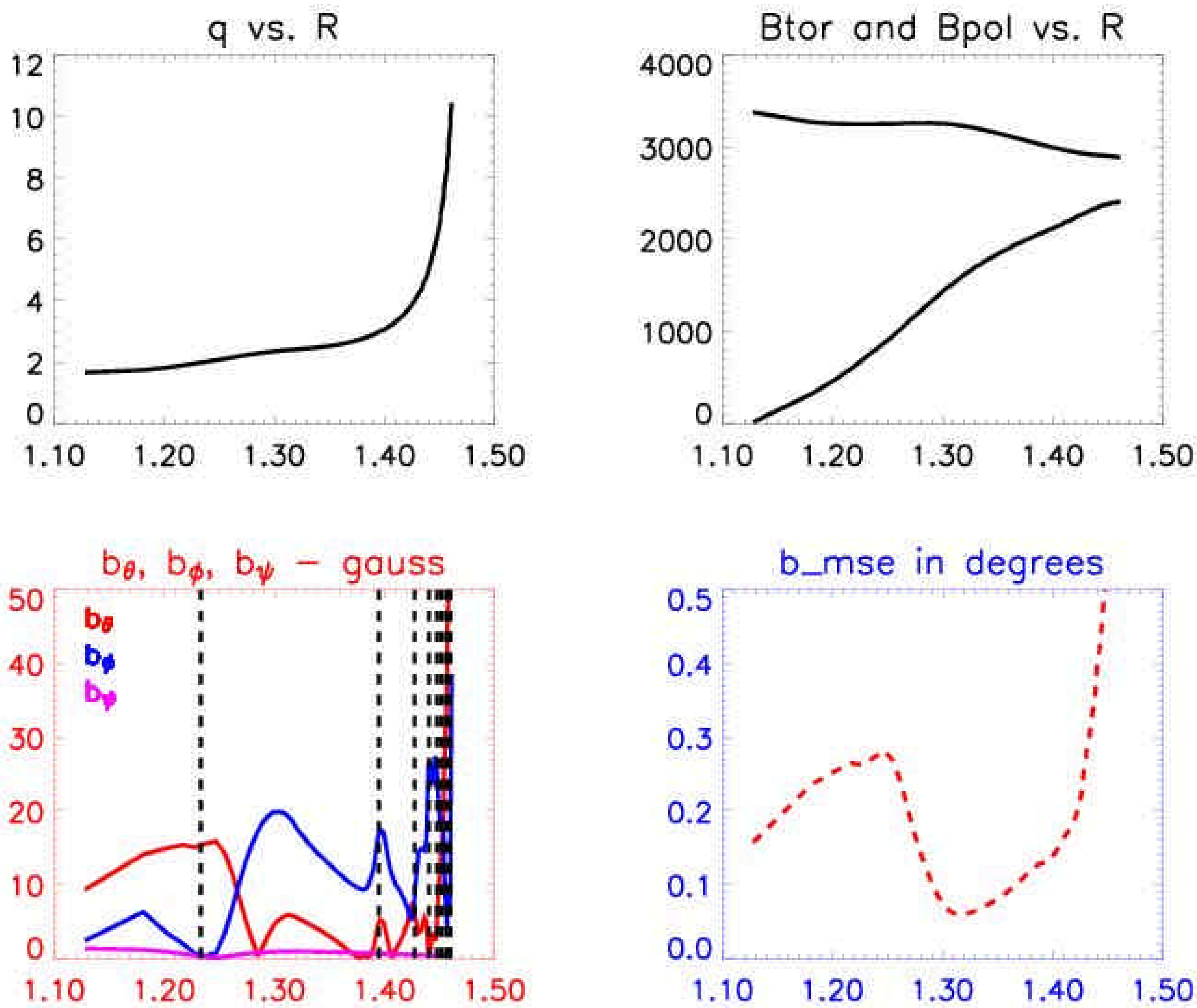


Unstable eigenfunction of displacement vector for NSTX –b$_N$ ~ 6





Predicted MSE signal for NSTX – b_N ~ 6



Summary

- Investigated the use of the MSE signal as a diagnostic tool for internal MHD activity
- Developed a post-processor for the PEST code to predict radial profile of MSE fluctuations
- Started benchmarking with experimental data
- Need to refine the external model for predicting MHD signal at Mirnov loop location
- Applied procedure to a variety of geometries and instabilities