Nonlinear Evolution and Radial Propagation of the Energetic Particle Driven GAM

by
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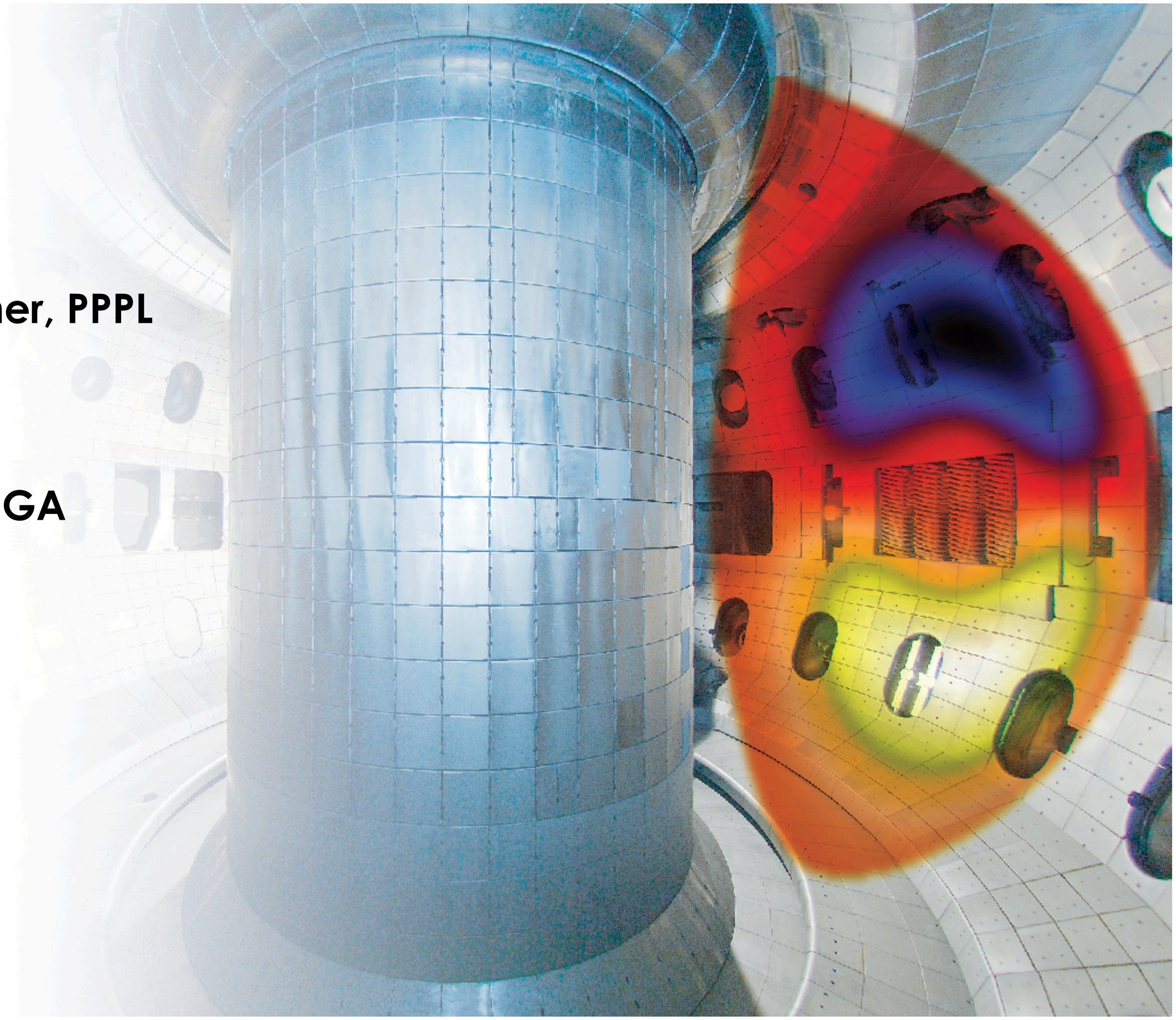

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April 8, 2011

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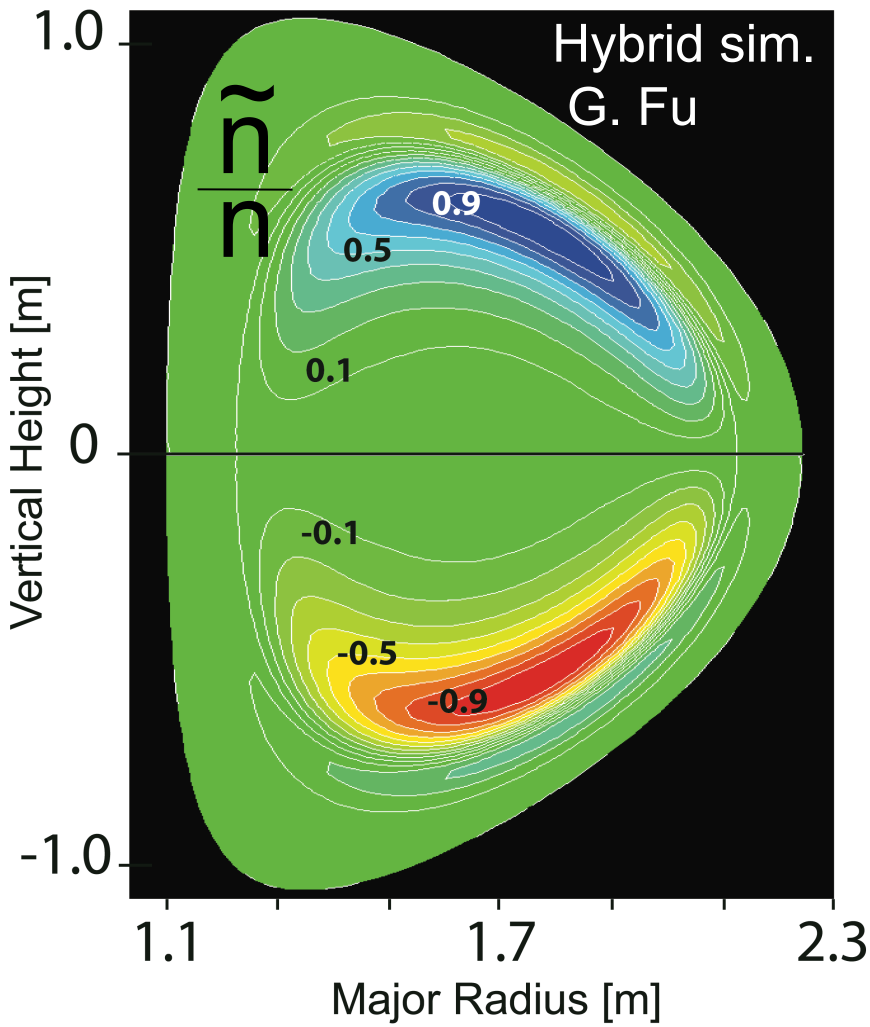
PPPL PRINCETON PLASMA PHYSICS LABORATORY

Outline

- Mode excitation/structure
- Comparison to linear E-GAM theory
- Nonlinear E-GAM evolution



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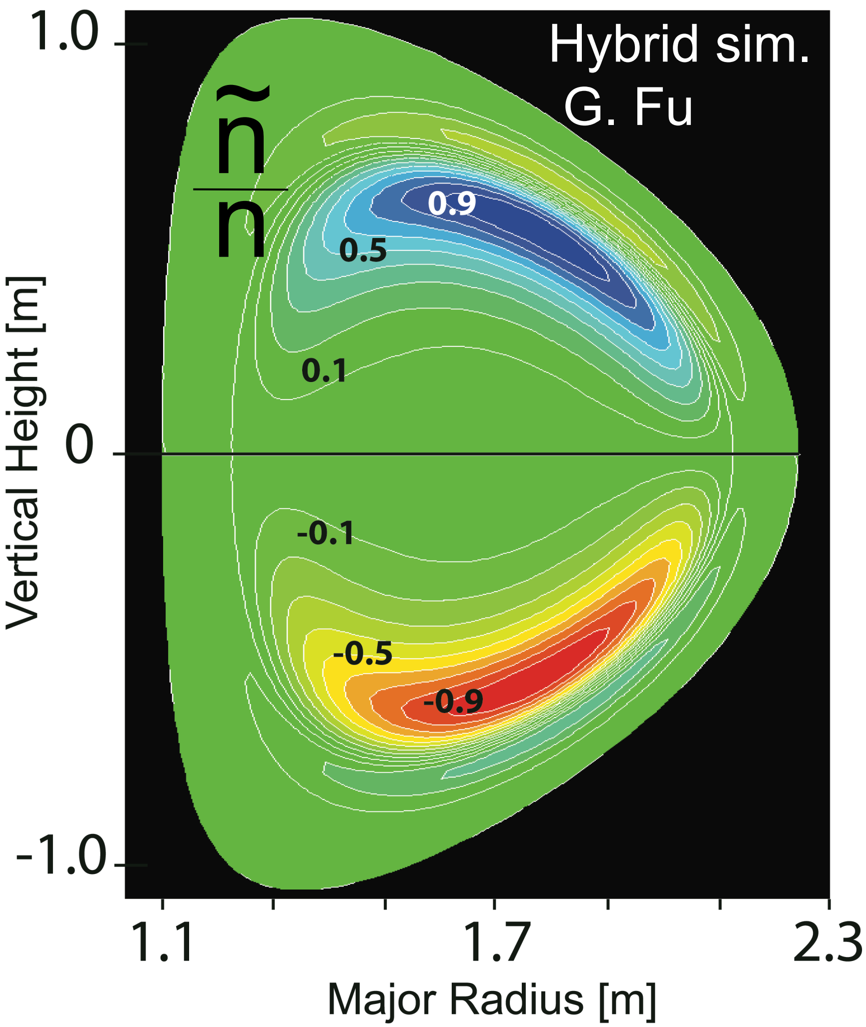
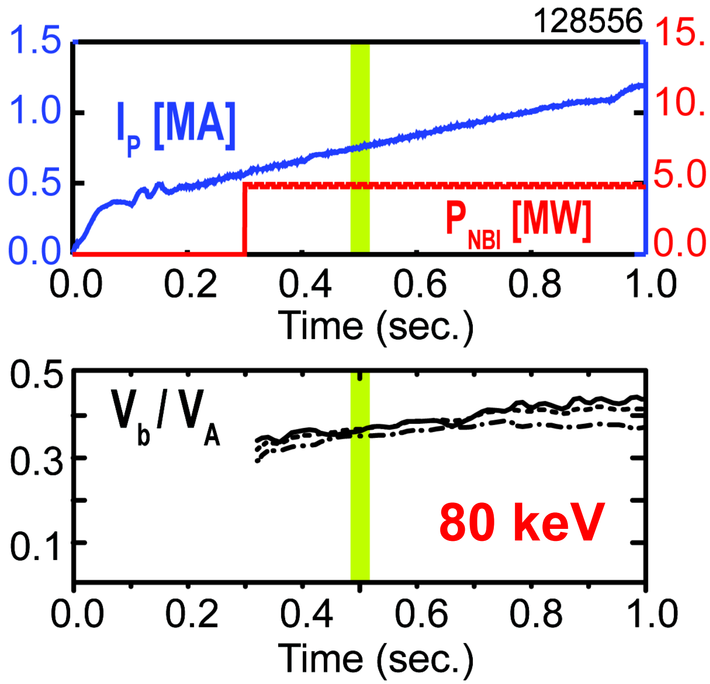
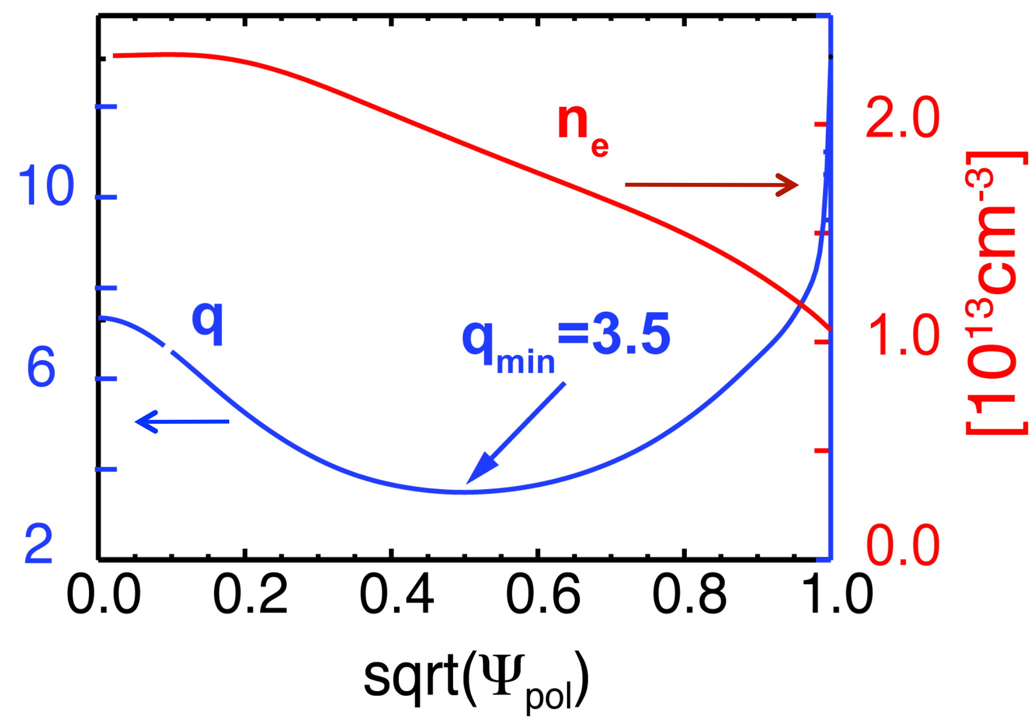


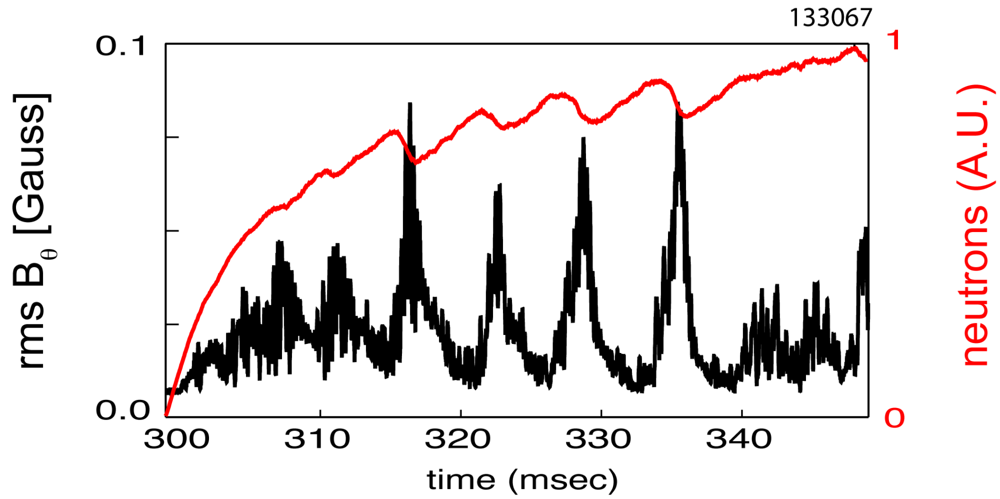
Recipe for E-GAM Excitation in DIII-D: Counter Tangential Beam Injection with High q_{min}

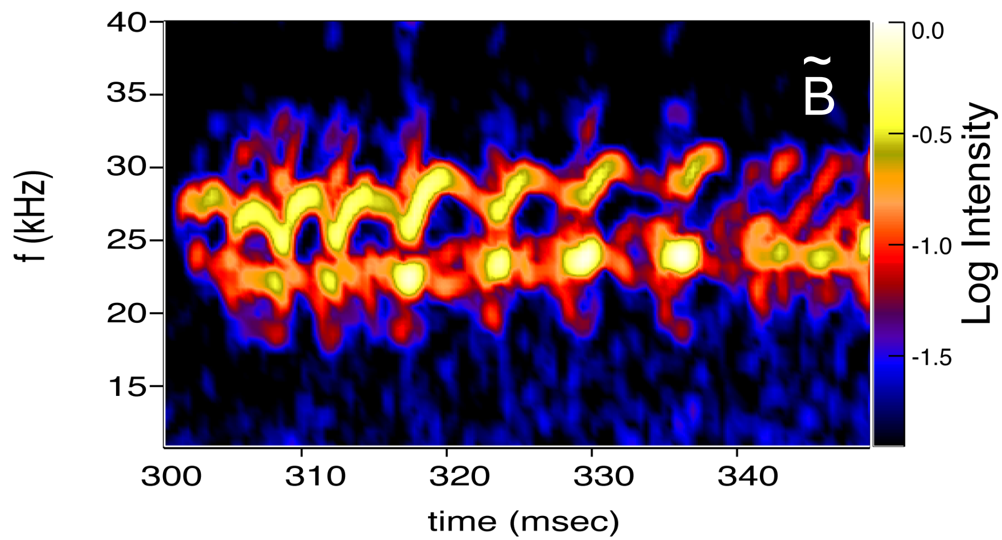




- 80 keV beam ions, $\beta_{fast} \sim \beta_{thernal} < 1\%$

Intense Bursting observed with Counter beam injection in DIII-D



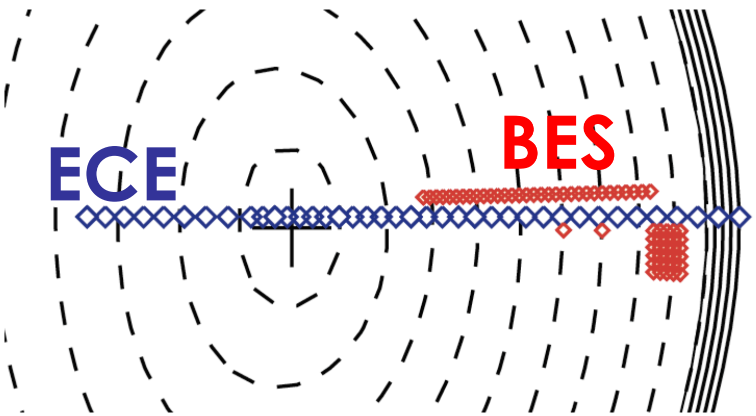


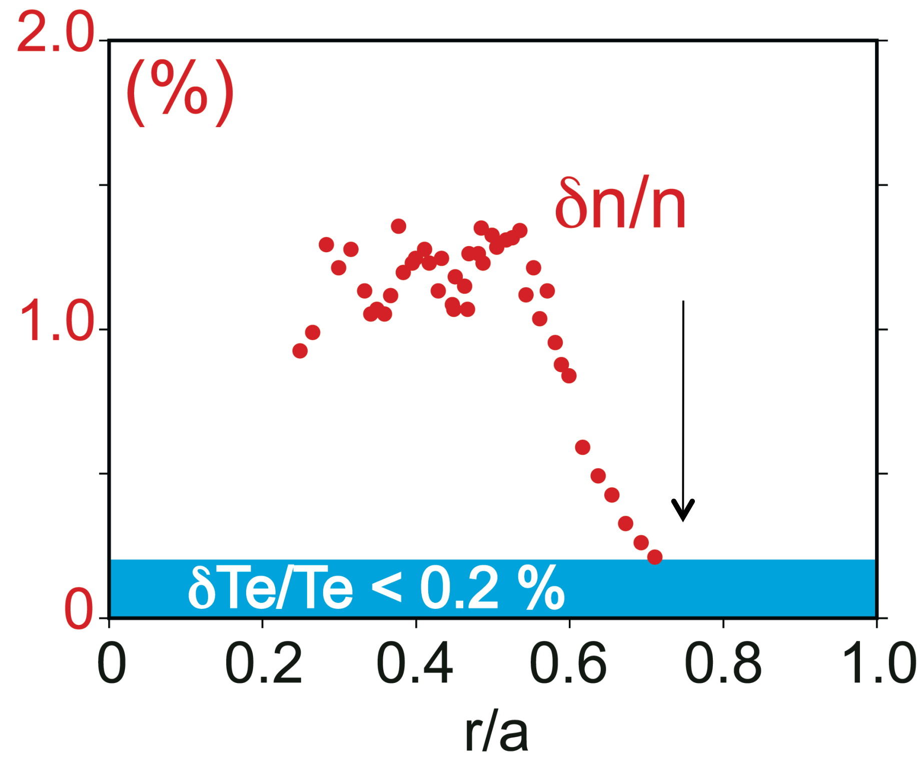
- 10-15 % neutron drops with each mode burst
- Possible evidence for hole/ clump formation

(H.L. Berk and B. Breizman)

Radially Resolved BES Measurements Reveal Global n=0 mode, no Te fluctuations

ECE array measures ΔT_e
BES array measures Δn_e





- **Peak density mode amplitude near midplane can be as high as 5-8 %**
- **upper bound on temperature fluctuation set by ECE photon noise**

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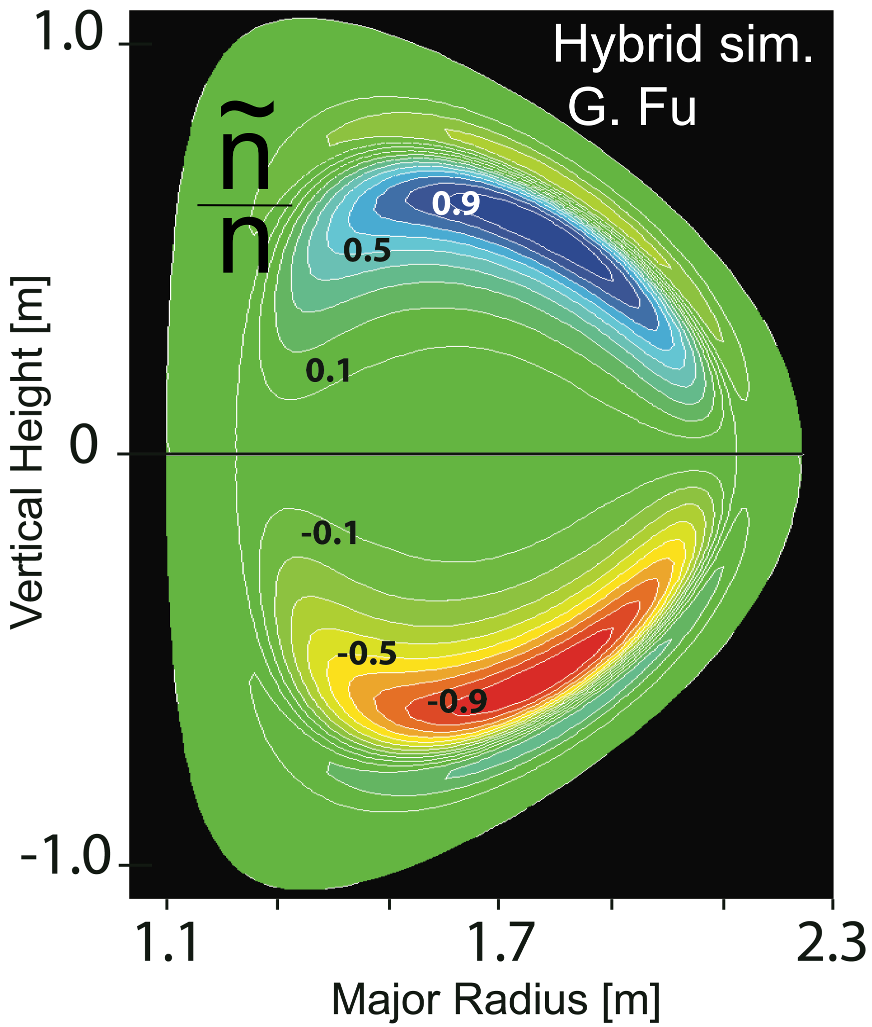

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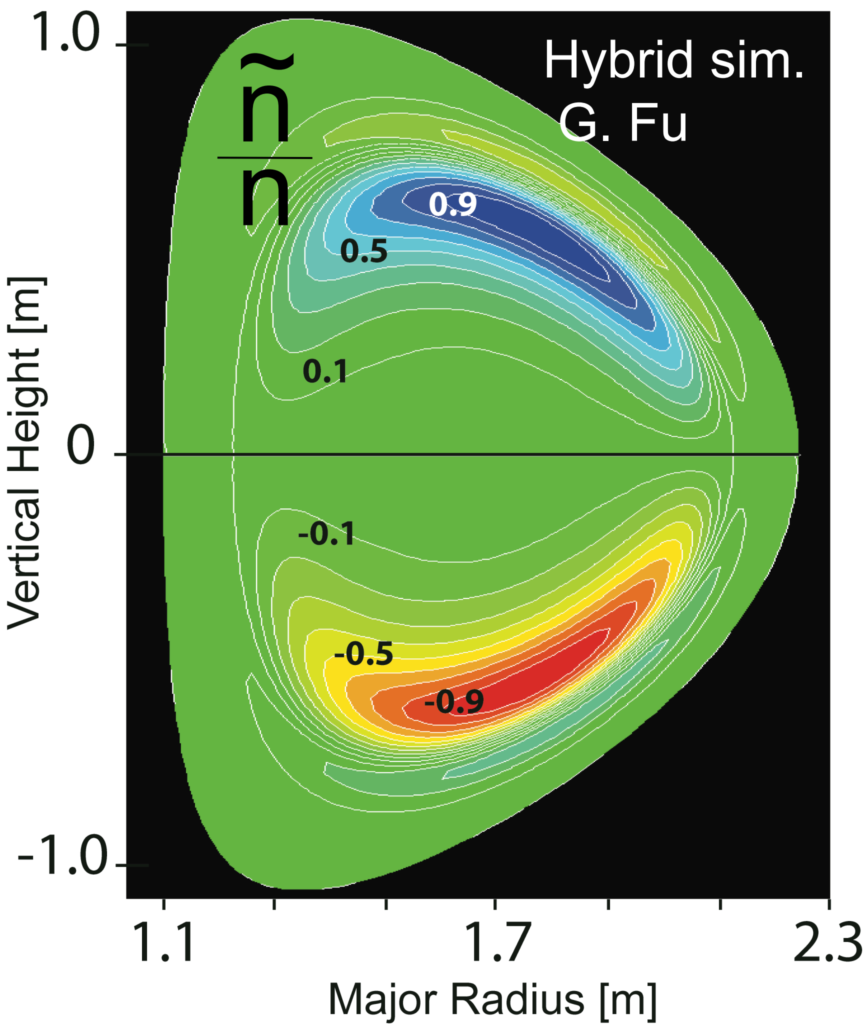
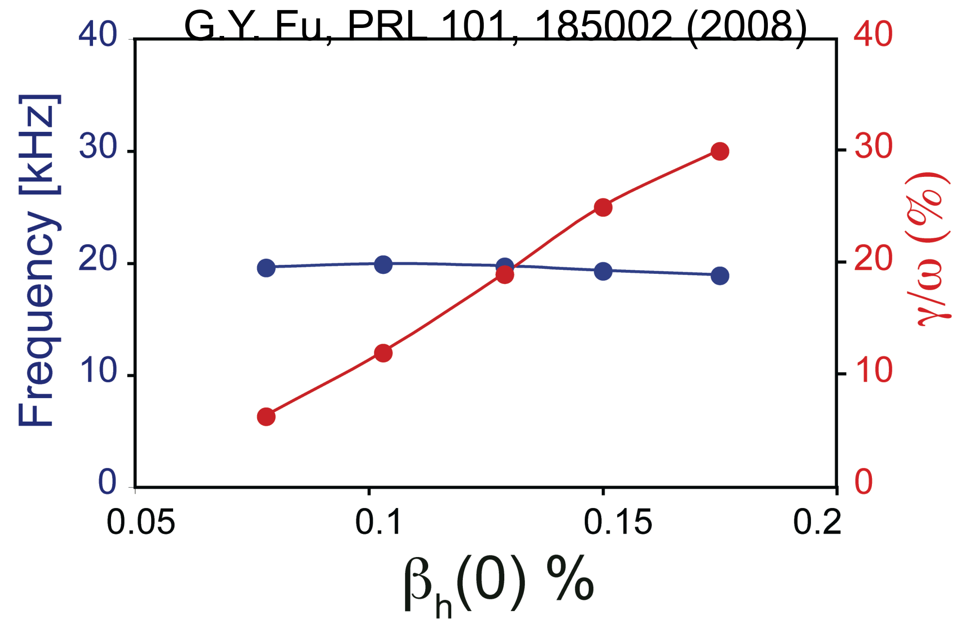
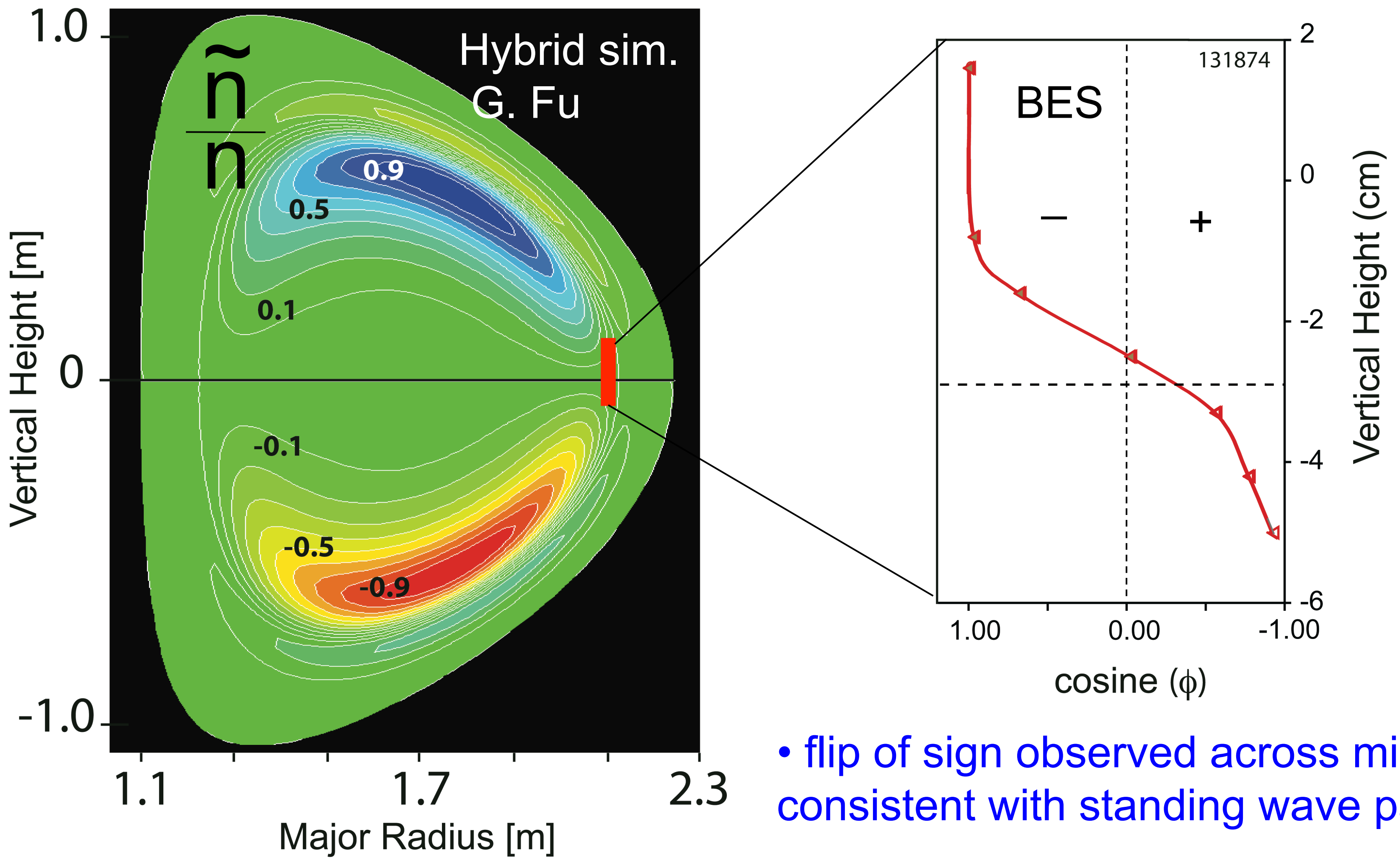
Theory Predicts Global nonperturbative GAM Driven via Beam Ion Bounce Resonance





- Mode exists for $\omega_b \sim \omega_{GAM}$
- pure zonal flow, no T_e component
- Large linear growth rate (30%) consistent with bursting/chirping

Up/Down Standing Wave Prediction Confirmed Using Vertical BES Detector Array



• flip of sign observed across midplane, consistent with standing wave pattern

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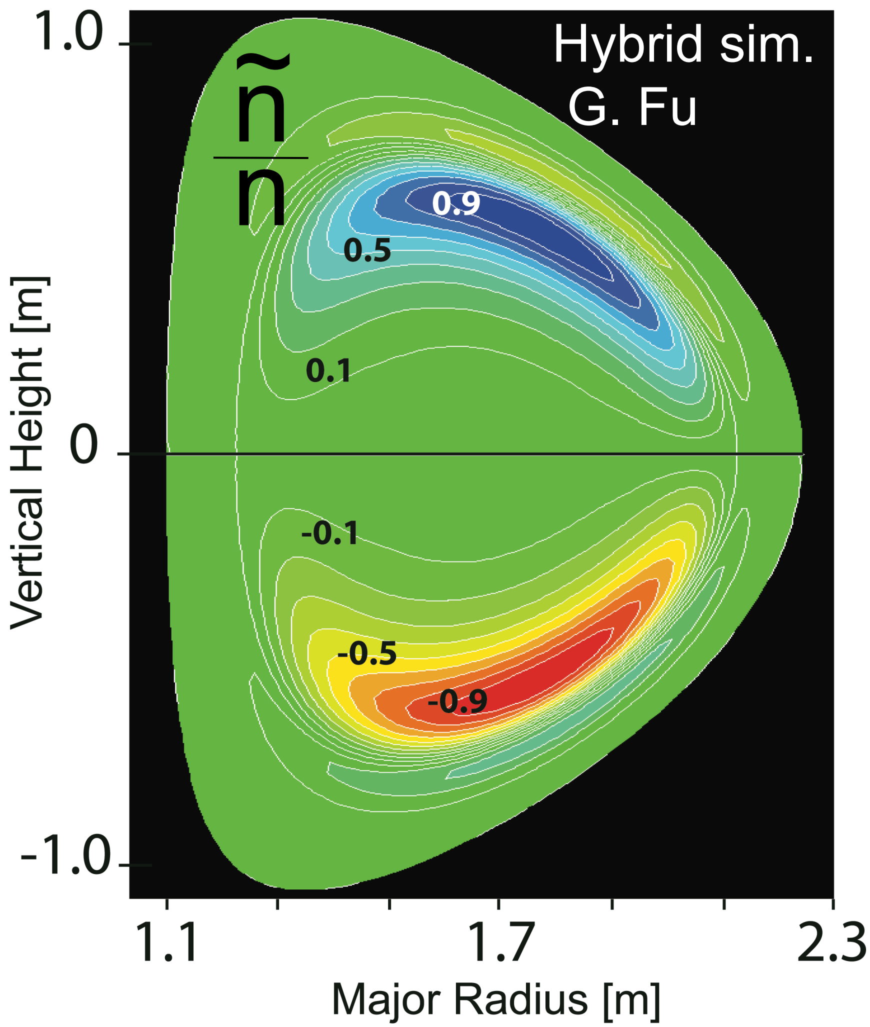


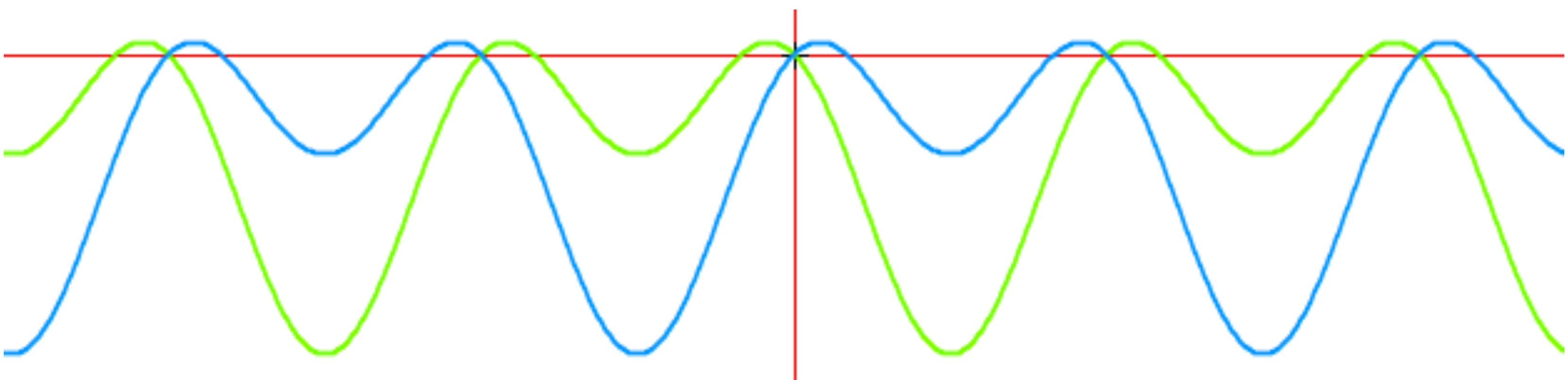
Nonlinear Perturbed Density Associated with the E-GAM

G. Fu, J. Plasma Phys. 2010

$$\frac{\delta\rho}{\rho} = -\frac{r}{R}[2\hat{E}_r \sin(\theta)\sin(\omega t) + \frac{1}{2}\hat{E}_r{}^2 \cos(\theta)(1-\cos(2\omega t))]]$$

- Where E_r is the normalized radial electric field.

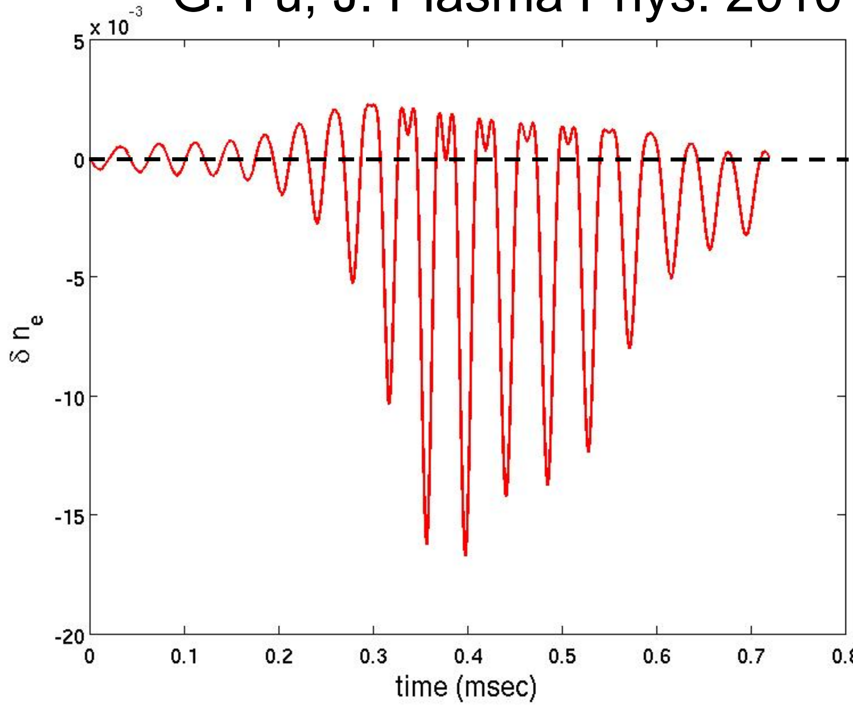
- Note that the second term is always negative and the first term can have either sign.



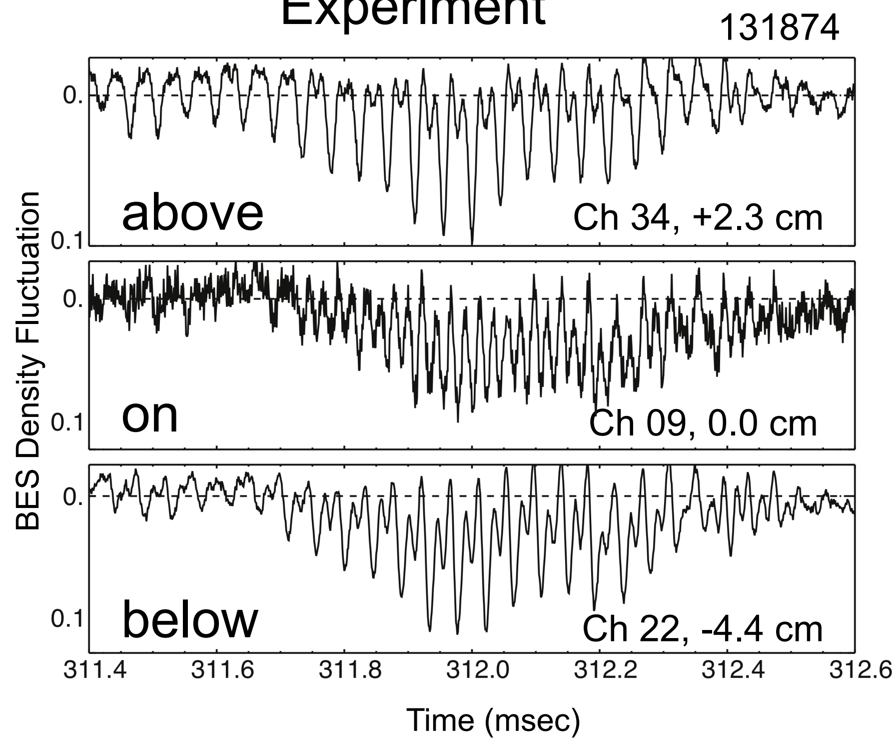
sin(θ)>0; above midplane   sin(θ)<0; below midplane

Hybrid Simulation of E-GAM Burst Consistent with Observation on DIII-D

G. Fu, J. Plasma Phys. 2010



Experiment



- DC density component is negative on midplane
- Second harmonic peaks on midplane, while fundamental goes through zero

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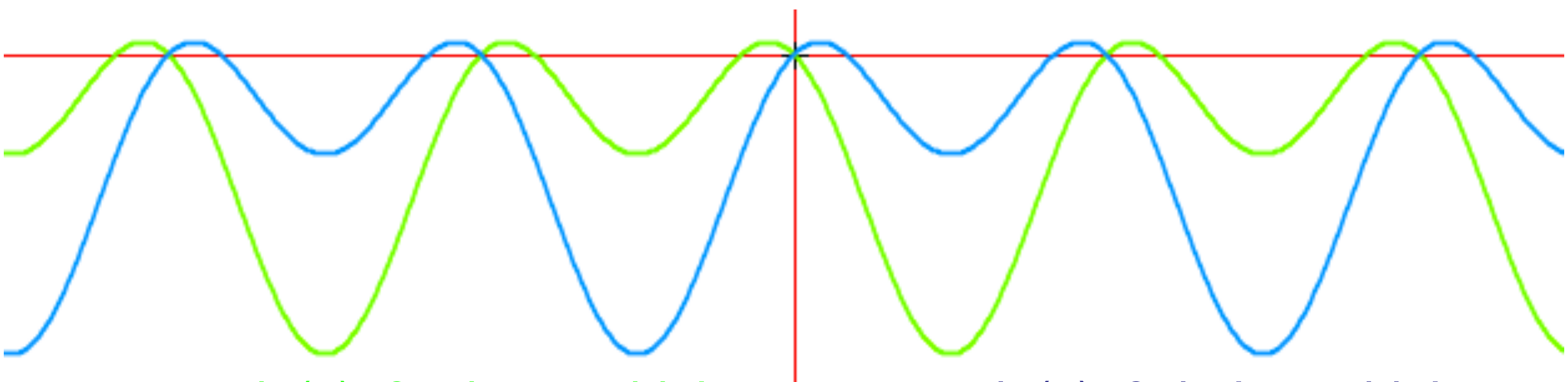
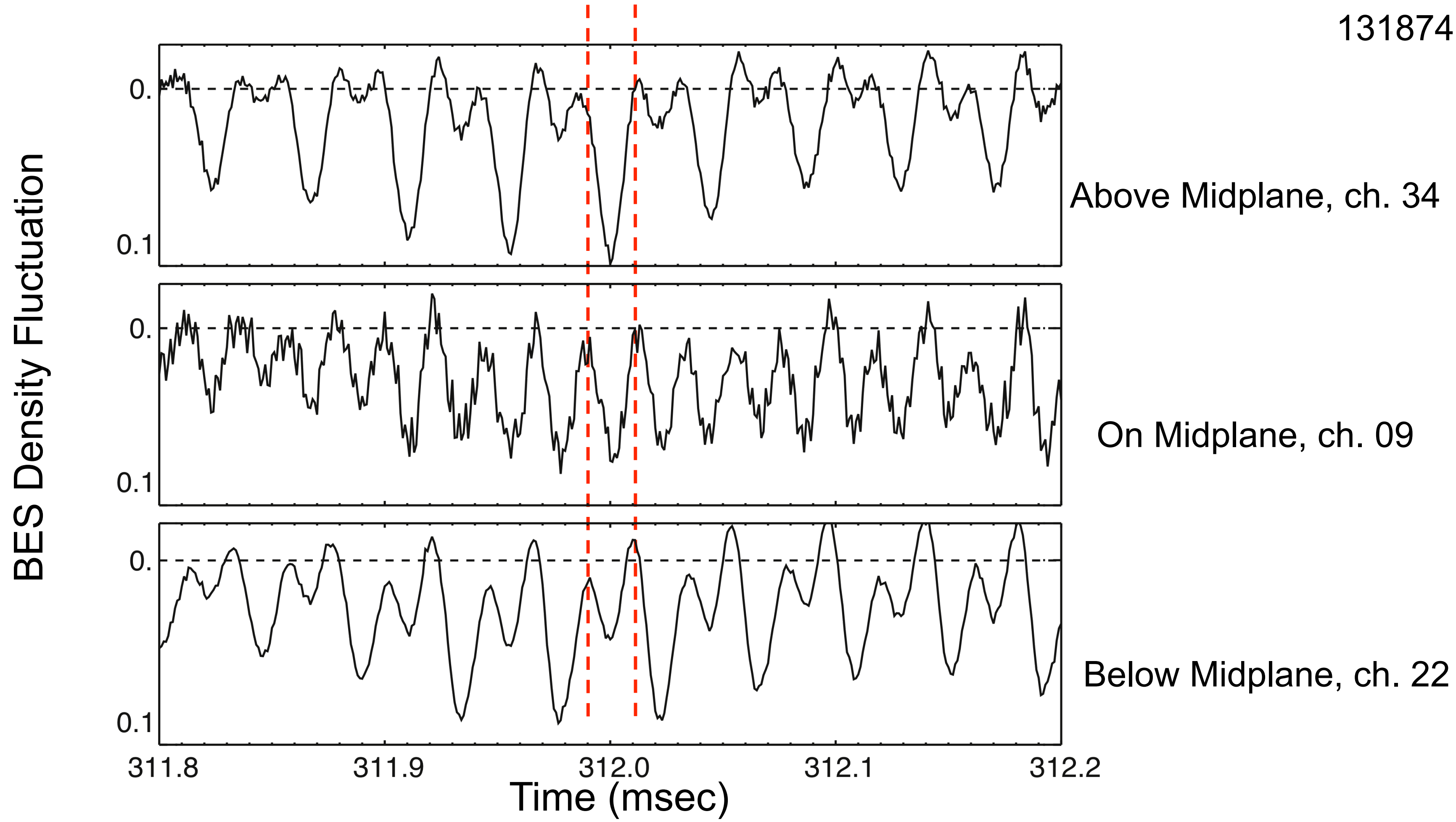


sin(θ)>0; above midplane   sin(θ)<0; below midplane

DC and Second Harmonic Stay in Phase, Fundamental Flips Phase, Across Midplane



- Some third harmonic is also contributing

Nonlinear Model Predicts Amplitude of Electric Field Fluctuation and peak density fluctuation

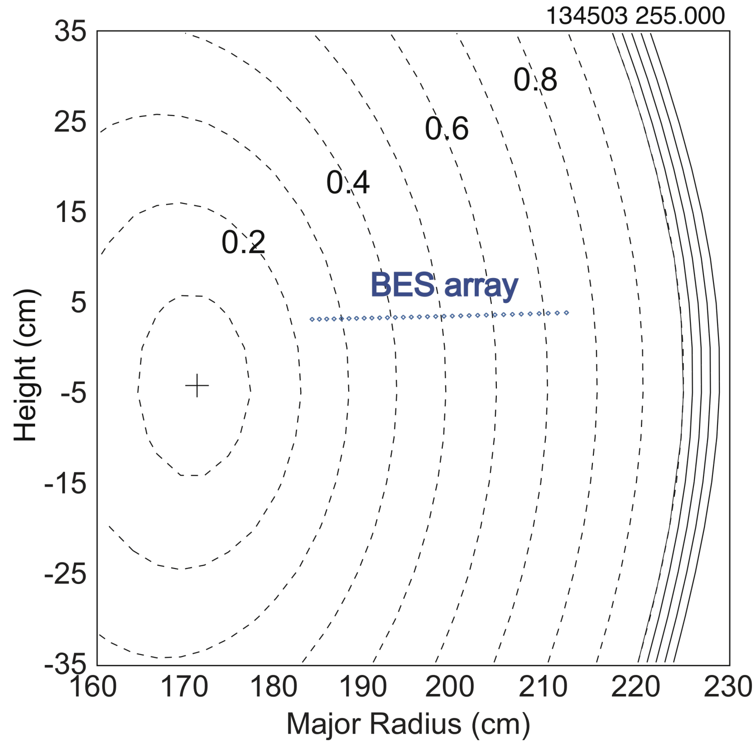
$$\frac{\delta\rho}{\rho} = -\frac{r}{R}[2\hat{E}_r \sin(\theta)\sin(\omega t) + \frac{1}{2}\hat{E}_r^{\,2}\cos(\theta)(1-\cos(2\omega t))]$$

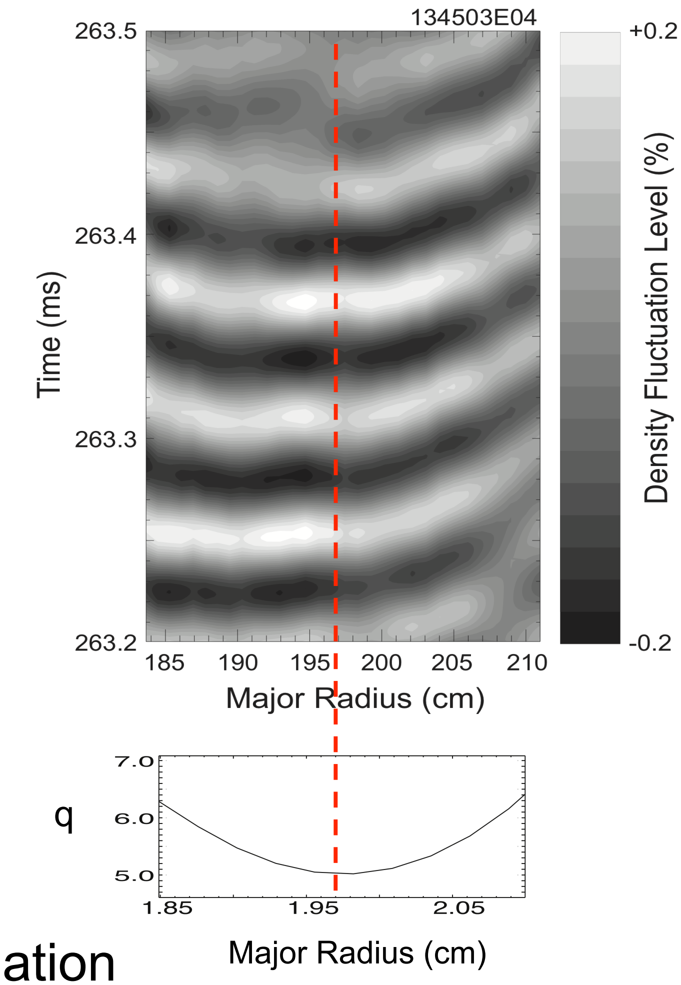
$$\left(\frac{\delta\rho_{2\omega}}{\rho}\right)_{\theta=0} = \frac{r}{2R}\hat{E}_r^{\,2}$$

$\hat{E}_r$: normalized radial electric field

- Next step is to infer E_r
- In principle can compare with BES measured advection of microturbulence

Outward and Inward Radial Propagation of E-GAM Observed in Reverse Magnetic Shear Plasmas





- q_{min} is not aligned with reversal of propagation

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Outward Radial Propagation Predicted Analytically, Inward Propagation Needs Understanding

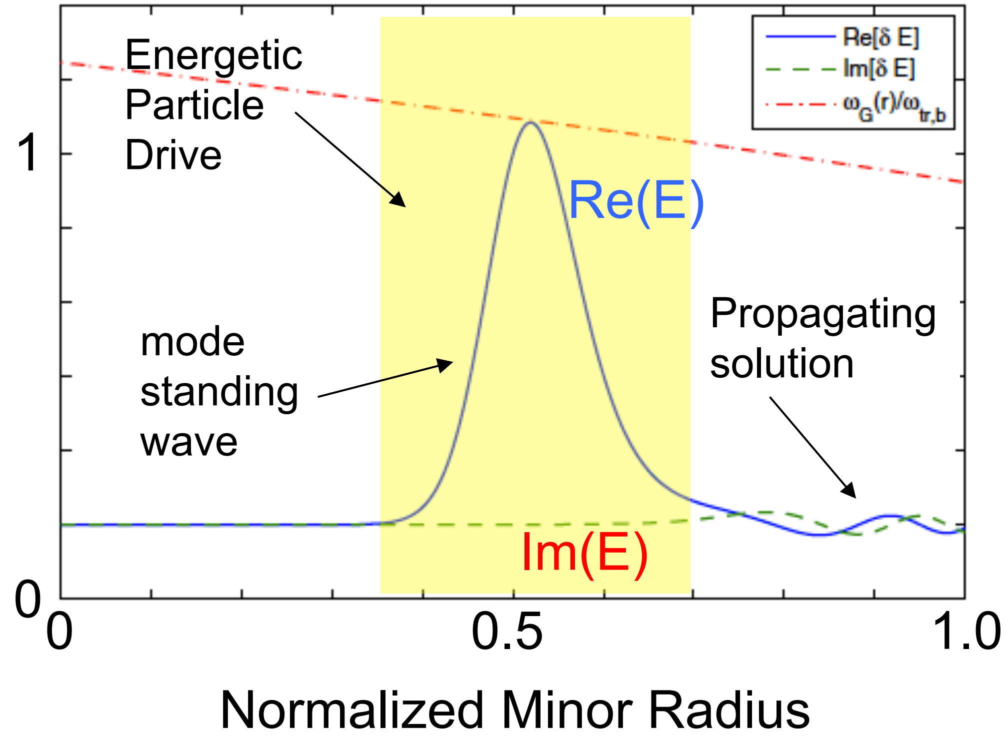
Plasma Phys. Control. Fusion 52 (2010) 095003
Zhiyong Qiu[1,3], Fulvio Zonca[2,4] and Liu Chen[2,3]

- Theory predicts GAM standing wave in region of energetic particle induced potential well

- Outward propagating solution due to tunneling out of well

- Does reverse magnetic shear induce inward propagation?

- More realistic model required.



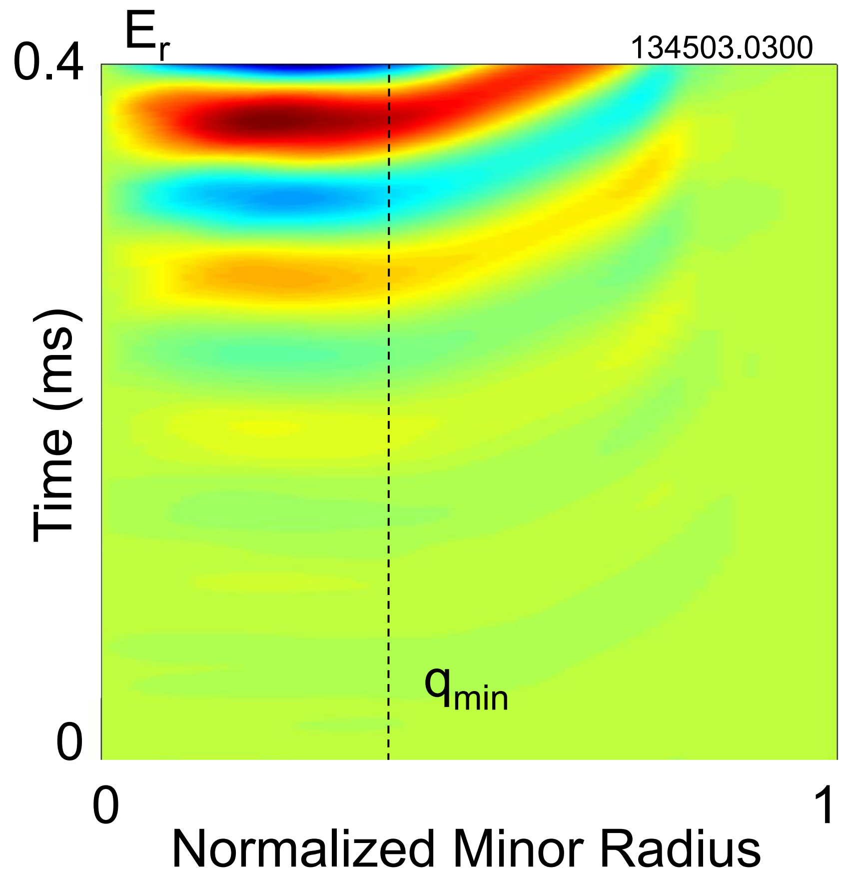
Recent Electrostatic Hybrid Full-f Simulation Reveals Outward Propagation Consistent with Experiment – G. Fu

- Mode exists at 15 kHz, close to experimental value

- Outward propagation and increasing k_r with radius consistent with experiment

- No inward propagation seen in simulation
  - note, inward propagation comes late in experimental data

- More realistic simulation required using actual beam deposition profile
  - currently using analytic beam



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Summary

- Key nonlinear predictions on E-GAM structure validated with experiment

  - DC, second harmonic coupling

  - outward radial propagation

- Nonlinear theory and simulation can help infer E_r from second harmonic amplitude

  - compare to turbulent advection due to ExB

- Outstanding issues:

  - is inward propagation a property of strong negative magnetic shear?

- More realistic analytic and numerical modeling required

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