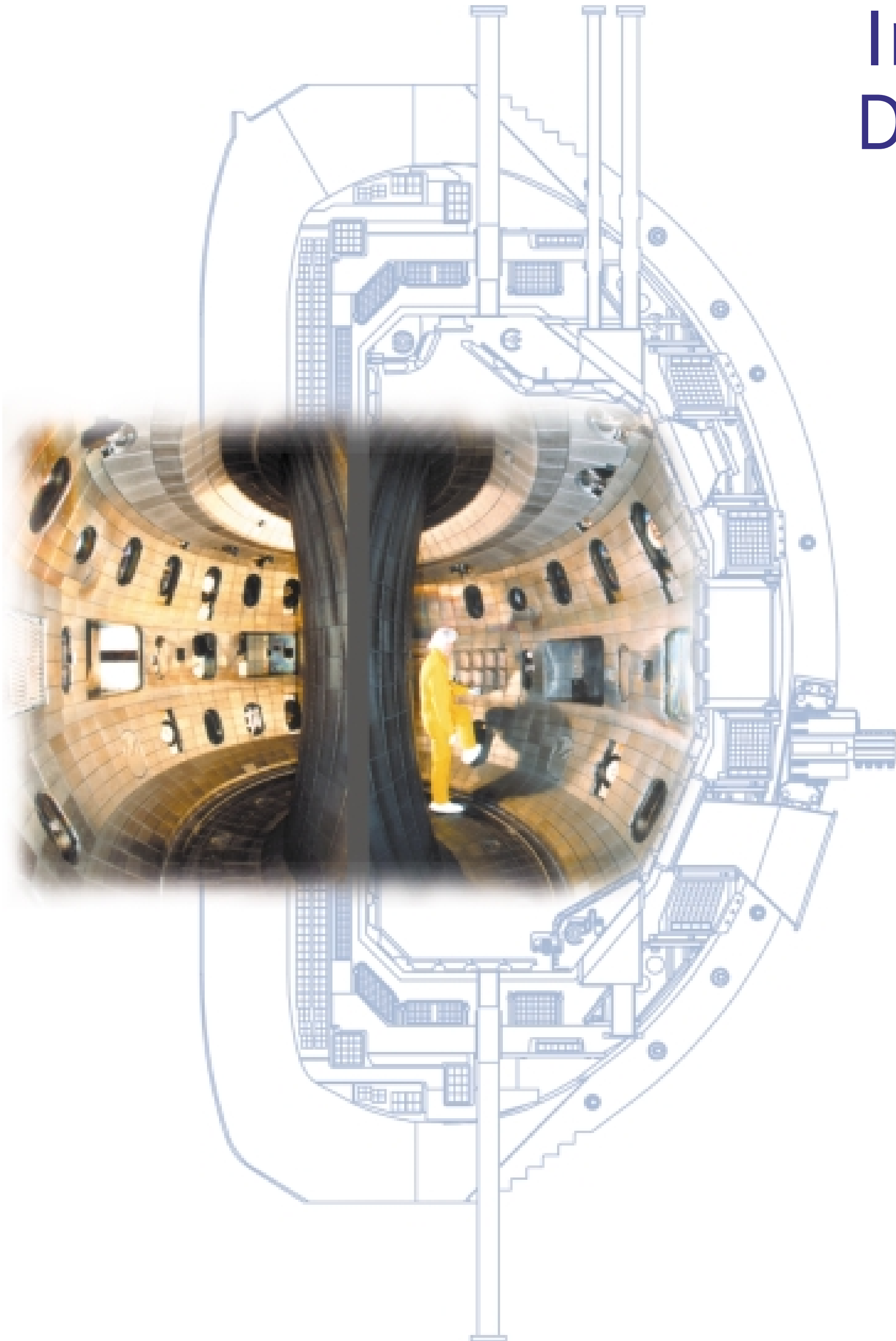


Internal Kink Instability During OFF-Axis Electron Cyclotron Current Drive in the DIII–D Tokamak

by

K.L. Wong*

with L.C. Johnson,* T.C. Luce,[†] M.S. Chu,[†]
C.C. Petty,[†] P.A. Politzer,[†] R. Prater,[†]
R.J. La Haye,[†] R.T. Snider,[†] L. Chen,[‡]
R.W. Harvey,[△] and M.E. Austin[◊]

*Princeton Plamsa Physics Laboratory
[†]General Atomics
[‡]University of California, Irvine
[△]CompX
[◊]University of Texas, Austin

Presented at
the American Physical Society
Division of Plasma Physics Meeting
Seattle, Washington

November 15–19, 1999

DIII–D
NATIONAL FUSION FACILITY

Abstract Submitted
for the DPP99 Meeting of
The American Physical Society

Sorting Category: 5.1.1.2 (Experimental)

Internal Kink Instability during Off-Axis Electron Cyclotron Current Drive in the DIII-D Tokamak[1] K.L. WONG, L.C. JOHNSON, Princeton Plasma Physics Laboratory, T.C. LUCE, M.S. CHU, C.C. PETTY, P.A. POLITZER, R. PRATER, R.J. LA HAYE, R.T. SNIDER, General Atomics, L. CHEN, University of California, Irvine, R.W. HARVEY, CompX, M.E. AUSTIN, University of Texas — Experimental evidence is reported of an internal kink instability possibly driven by barely trapped suprathermal electrons produced in off-axis ECCD experiment on the DIII–D tokamak. It occurs in plasmas with an evolving safety factor profile $q(r)$ when $q_{\min}$ approaches 1. This instability is most active when ECCD is applied on the high-field-side of the flux surface. It has $m/n = 1/1$ with a bursting behavior. In positive magnetic shear plasmas, this mode becomes the fishbone instability. The observation can be qualitatively explained by the drift reversal of the barely trapped suprathermal electrons. This explanation will be compared with calculation of the nonthermal electron distribution function from the CQL3D Fokker-Planck code.

[1]Supported by U.S. DOE Contracts DE-AC02-76CH03073 and DE-AC03-99ER54463, and Grants DE-FG03-94ER54271, DE-FG03-99ER54541, and DE-FG03-97ER54415.

- [X] Prefer Oral Session
- [ ] Prefer Poster Session

King-Lap Wong
wongk@fusion.gat.com
Princeton Plasma Physics Laboratory

Special instructions: DIII-D Contributed Oral Session, immediately following CC Petty

Date printed: July 15, 1999

Electronic form version 1.4

OUTLINE

- Introduction
- Observation of m/n = 1/1 internal kink
  - PCS plasma — fishbone
  - NCS plasma — double-kink if $q_{min} < 1$
- Resonant wave-particle interaction with barely trapped electrons
- Summary

INTRODUCTION

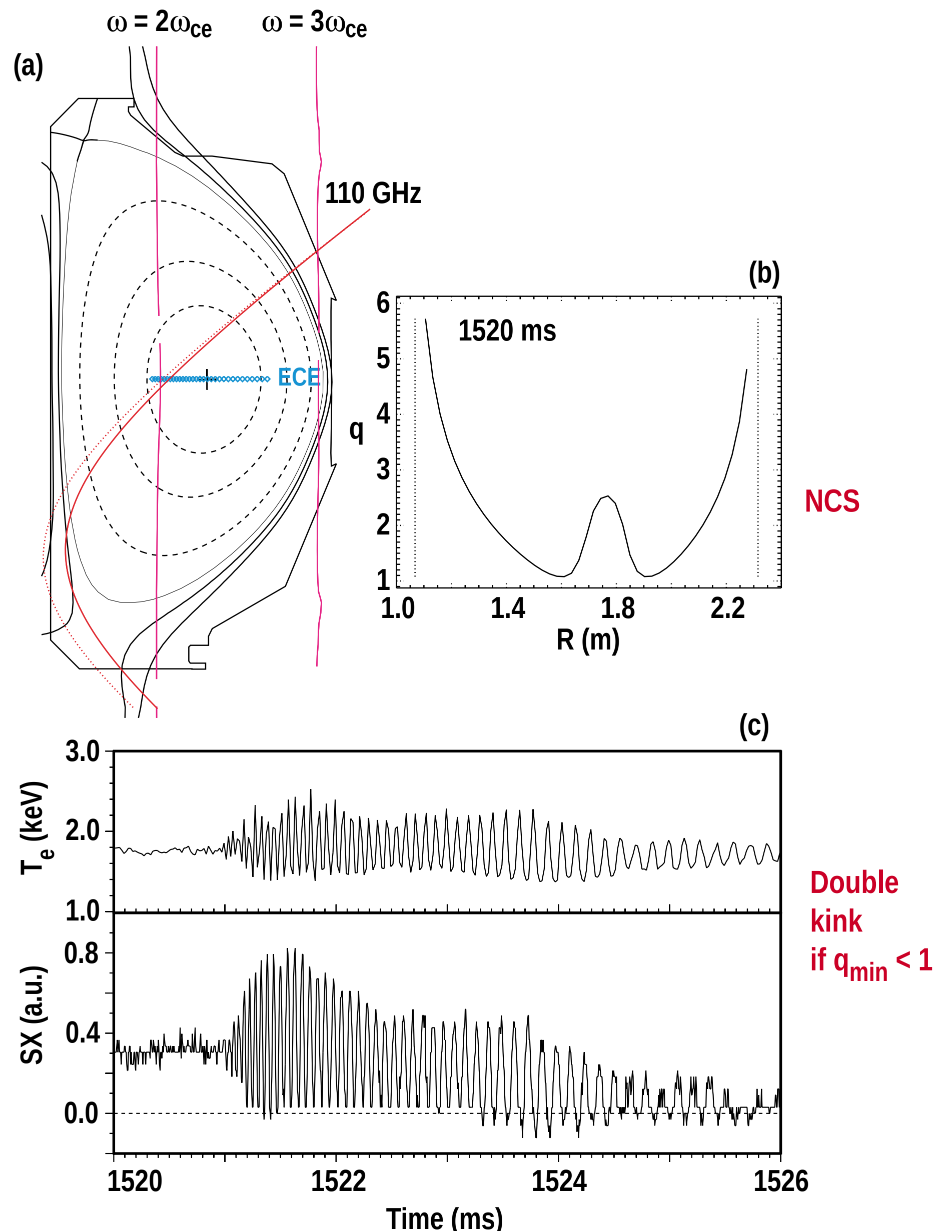
- Electron cyclotron waves (ECH/ECCD) can modify MHD activities through changes in p(r) and j(r)
  - m/n = 2/1 mode: TFR, JFT-2M, TEXT
  - Sawtooth: T-10, DIII–D, TCA
  - Neoclassical tearing modes: ASDEX-U

- Kinetic effects on MHD from energetic ions were observed: fishbones, TAE, etc.

- Similar wave-particle interaction can also happen for electrons

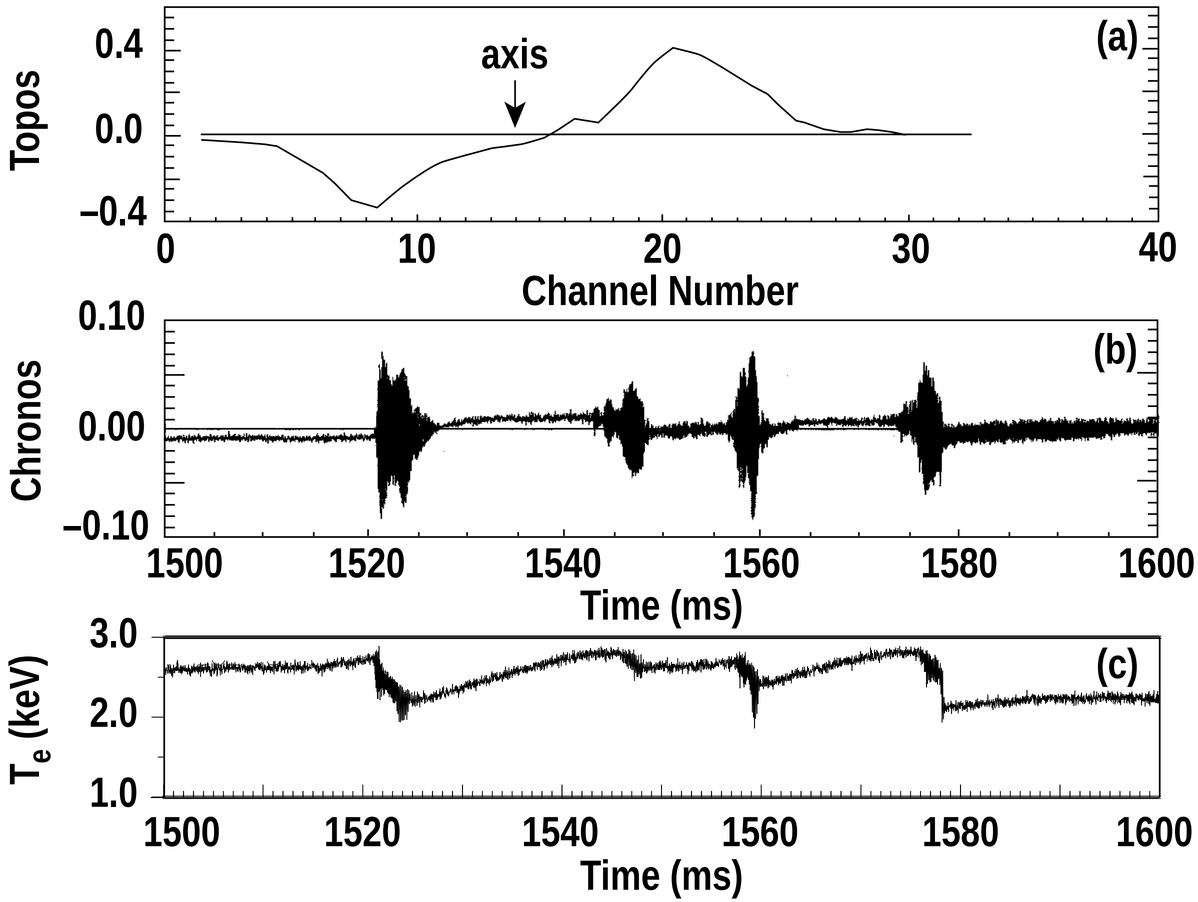
OBSERVATIONS

- Strong MHD activities appear during off-axis ECH with $\omega = 2\,\omega_{ce}$ at $\theta_{res} = \pi$
- Shot 96163: NCS target plasma
- $B_T = -1.77$ T, $I_p = 0.89$ MA
  R = 1.76 m
- a = 0.62 m, $q_{95} = 6.06$, 1.1 MW @ 110 GHz



331-99 jy

TOROIDAL MIRNOV ARRAY SHOWS n = 1
SINGULAR VALUE DECOMPOSITION (SVD) OF δT_e GIVES m = 1



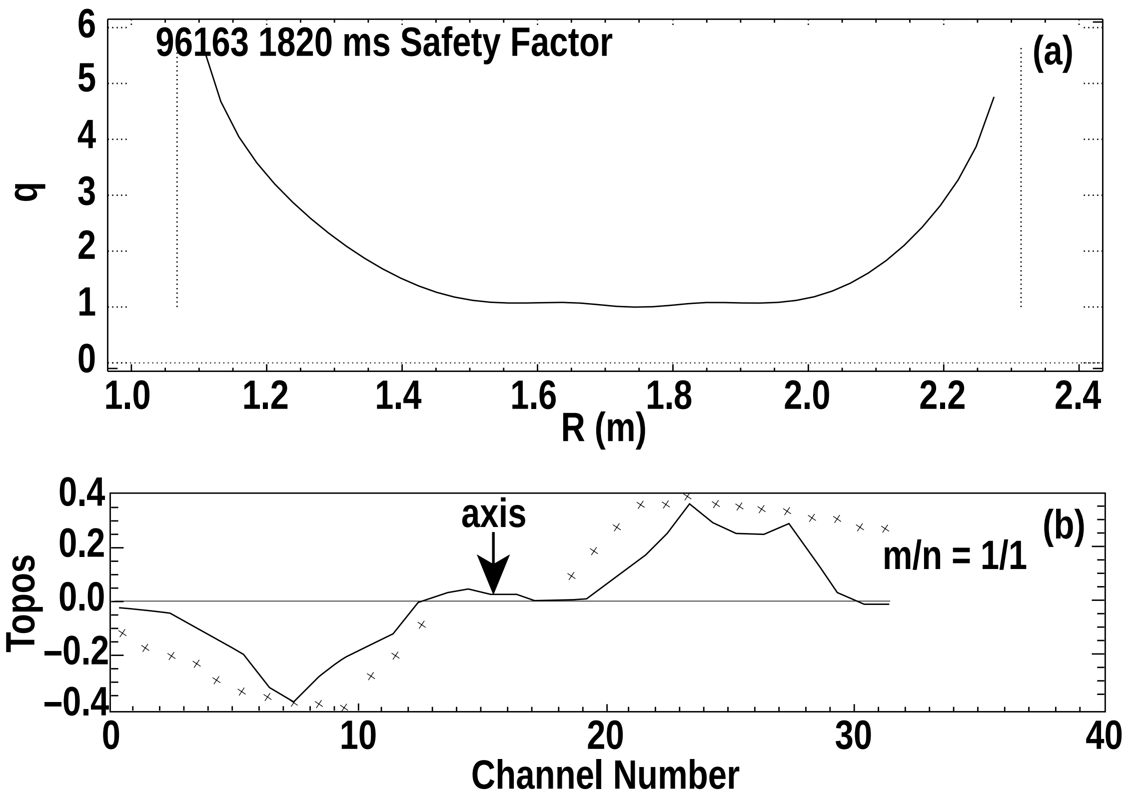
DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

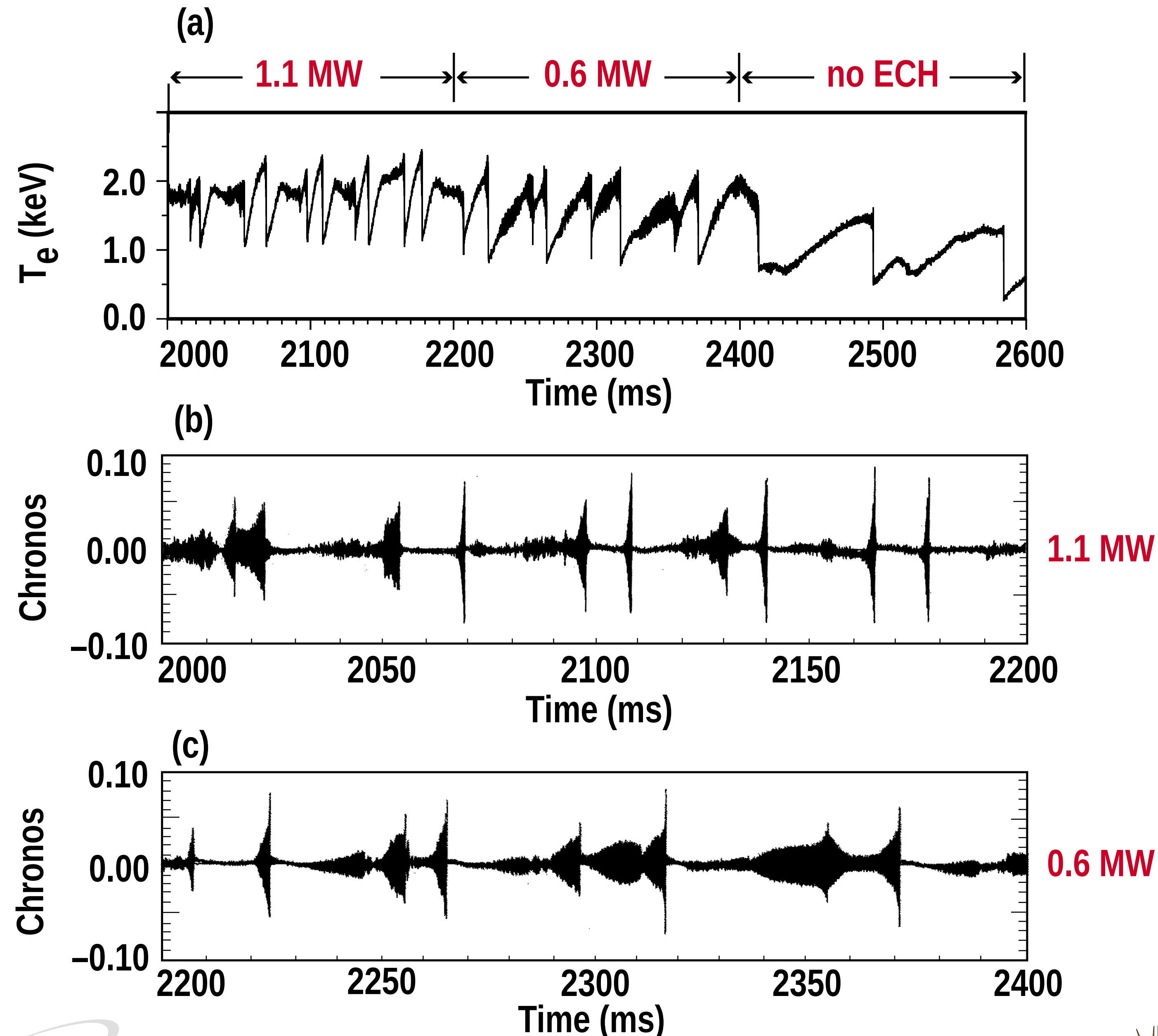
331-99 jy

STABILITY ANALYSIS BY THE GATO CODE

- m/n = 1/1 mode stable at t = 1.52 s, implies energetic particle drive
- Marginally unstable at t = 1.82 s, calculated mode structure agrees with exp't



GROWTH RATE INCREASES WITH ECH POWER



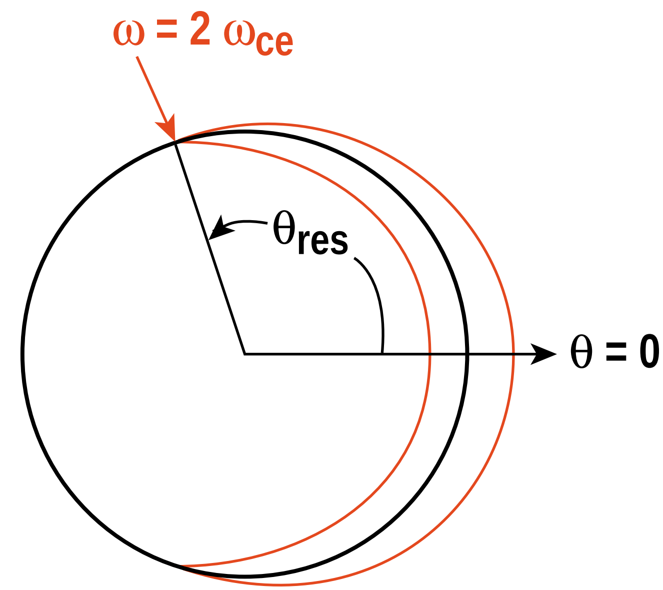
DIII–D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

331-99 jy

PROPERTIES OF SUPRATHERMAL ELECTRONS

- Most suprathermal electrons are trapped with banana tip near the ECH location

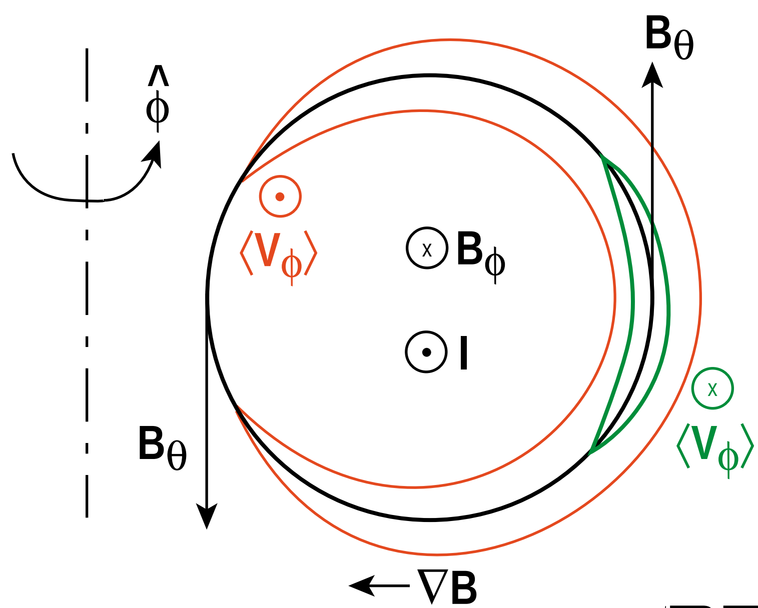


- Drift Reversal

$$V_{\nabla B} = \frac{\mu}{ZeB^2}(B \times \nabla B)$$

$$\sim (B_\phi + B_\theta) \times \nabla B / Ze$$

$$\sim V_y + V_\phi$$



DIII–D
NATIONAL FUSION FACILITY
SAN DIEGO

331-99 jy

PPPL
PRINCETON PLASMA PHYSICS LABORATORY

WAVE-PARTICLE INTERACTION

- 1/1 mode can interact with energetic ions via precessional drift resonance

$$\gamma_{drive} = \gamma_o + \gamma_i + \gamma_e > \gamma_{damp}$$

$$k_\theta \parallel V_{di} \parallel Ze\, B \times \nabla p_i, \quad \omega_{*i} = k_\theta V_{di}$$

$$k_\phi \parallel \langle V_{\phi i} \rangle$$

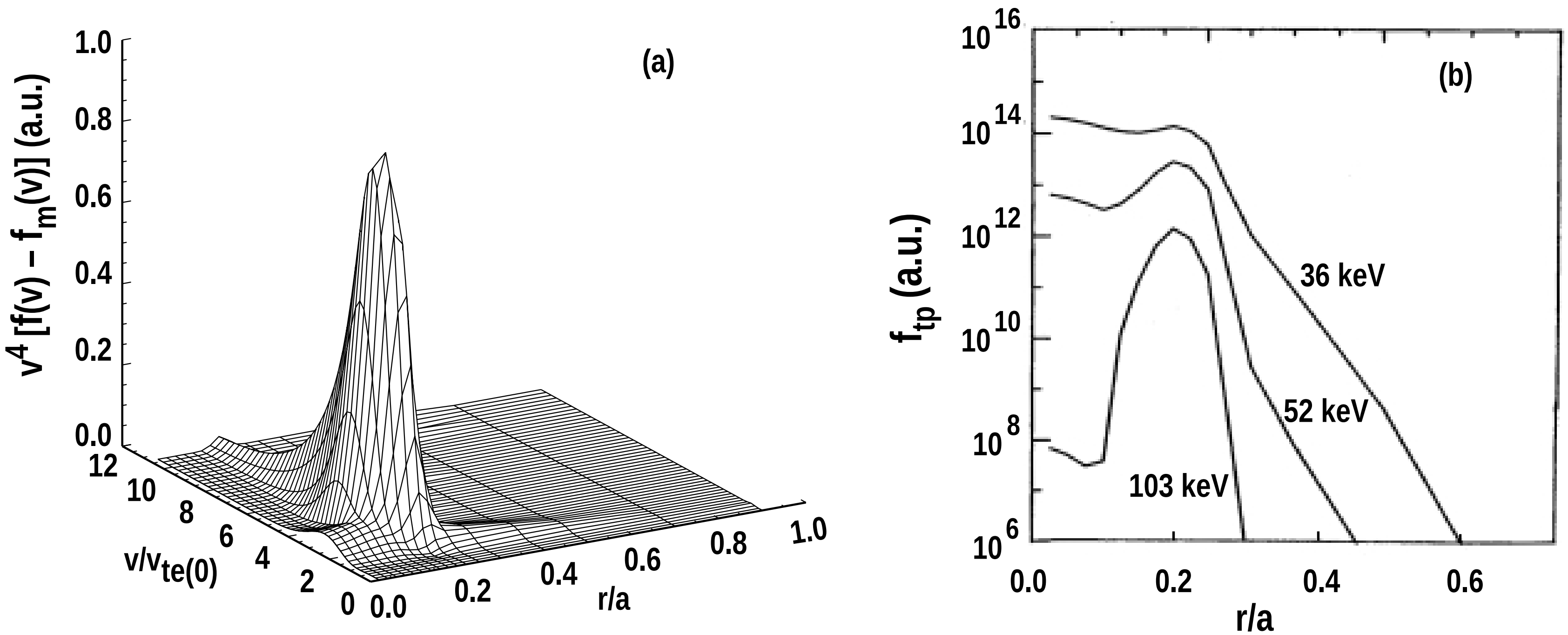
Usually, $V_{de} \parallel -V_{di}, \quad \langle V_{\phi e} \rangle \parallel -\langle V_{\phi i} \rangle$,

- However, fast electrons from off-axis ECH have inverted $p_e(r)$ so that $V_{de} \parallel V_{di}$

- When $\theta_{res} = \pi$, barely trapped fast electrons are produced with $\langle V_{\phi e} \rangle \parallel \langle V_{\phi i} \rangle$ due to drift reversal

- Therefore, energetic ions and energetic electrons can resonate with the same 1/1 mode and assist the drive

SUPRATHERMAL ELECTRON DISTRIBUTION (CALCULATED FROM THE CQL3D CODE)



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

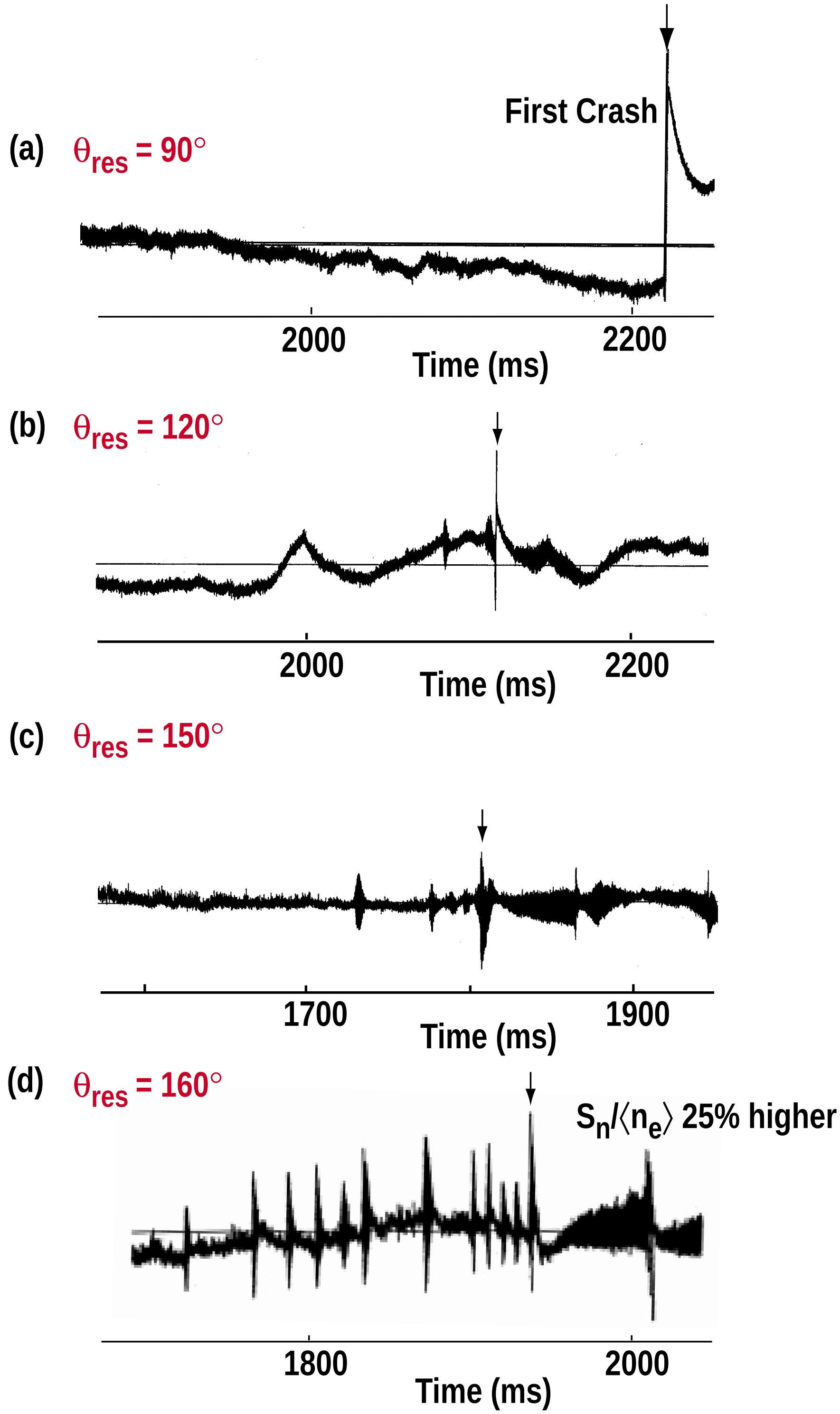
331-99 jy

SEPARATE γ_e FROM γ_i

Correlate variation of 1/1 activity with θ_{res}

- Compare shots with different θ_{res} and 1/1 activities
- Selection criteria
  - The shot with stronger 1/1 has same or smaller $S_n/\langle n_e \rangle$, i.e., same or less fast ions
  - Shots obtained in the same day
- Just before sawtooth crash, q(r) profiles are similar (pcs, $q_0 = 1$)
- Small differences in plasma parameters are uncontrolable, can be treated by statistics
- Get 14 pairs of shots
  - The shot with stronger 1/1 also has larger θ_{res}
    - ★ No exception!

CORRELATION BETWEEN θ_{res} AND 1/1 ACTIVITY (PCS PLASMAS – FISHBONES)



DIII–D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

331-99 jy

SUMMARY

- Active MHD observed during off-axis ECH in DIII–D when $\theta_{res} = \pi$

- They are identified as m/n = 1/1 internal kink modes

  – PCS plasma — fishbone

  – NCS plasma — if $q_{min} < 1$, it would be double kink

- Energetic electrons produced by ECH are found to play a role in driving these modes

- Acknowledgments

  – J. Lohr and DIII–D group — technical assistance

  – DOE contracts DE-AC02-76CH03073, DE-AC03-99ER54463 and Grant DE-FG03-97ER54415

DIII–D NATIONAL FUSION FACILITY SAN DIEGO

PPPL PRINCETON PLASMA PHYSICS LABORATORY

331-99/K. Wong