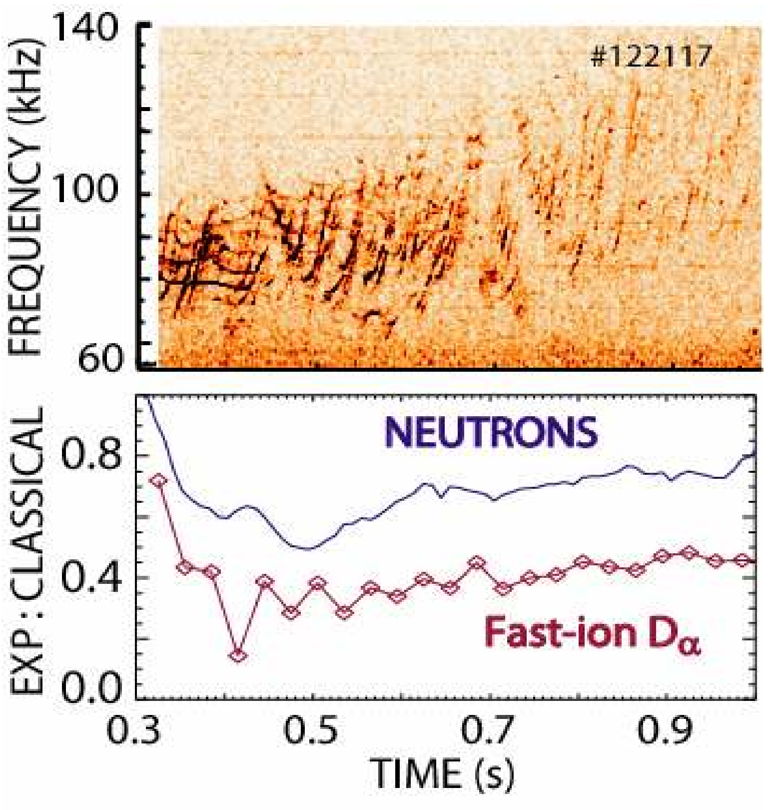
Alfven Instabilities in DIII-D



W. Heidbrink, G. Kramer, R. Nazikian, M. Van Zeeland, M. Austin, H. Berk, K. Burrell, N. Gorelenkov, Y. Luo, G. McKee, T. Rhodes, G. Wang, and the DIII-D Team

Goal: Detailed measurements of fluctuations and fast ions to predict alpha transport in ITER

- Mode structure agrees with ideal MHD theory
- Flattened fast-ion density profile
- Modes on thermal-ion spatial scale

UCIrvine
University of California, Irvine

Alfven Modes are Usually Unstable in Advanced Tokamak (AT) Plasmas

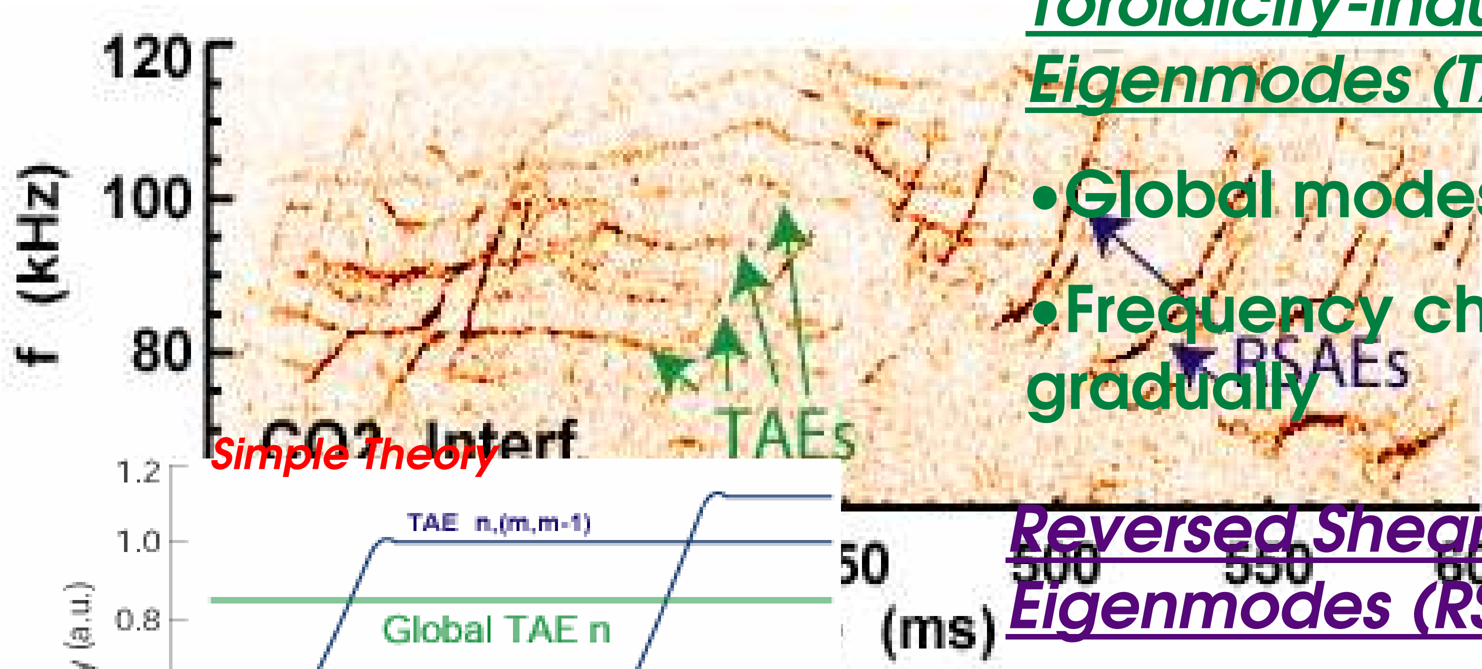
In this talk…

- Reversed shear with early beam injection
- 80 keV Deuterium Co-injection
- Modest density → large beam beta to drive Alfven modes

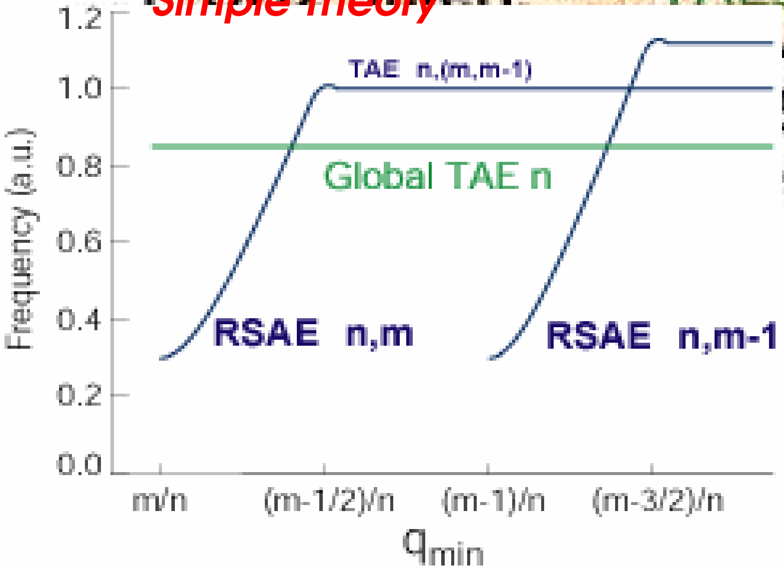
- Qualitatively similar conditions in many plasmas → Alfven modes are common in DIII-D

Toroidicity-induced Alfven Eigenmodes (TAE) & Reversed Shear Alfven Eigenmodes (RSAE)

Data



Simple Theory



Increasing Time →

Toroidicity-induced Alfven Eigenmodes (TAEs)

- Global modes
- Frequency changes gradually

Reversed Shear Alfven Eigenmodes (RSAE)

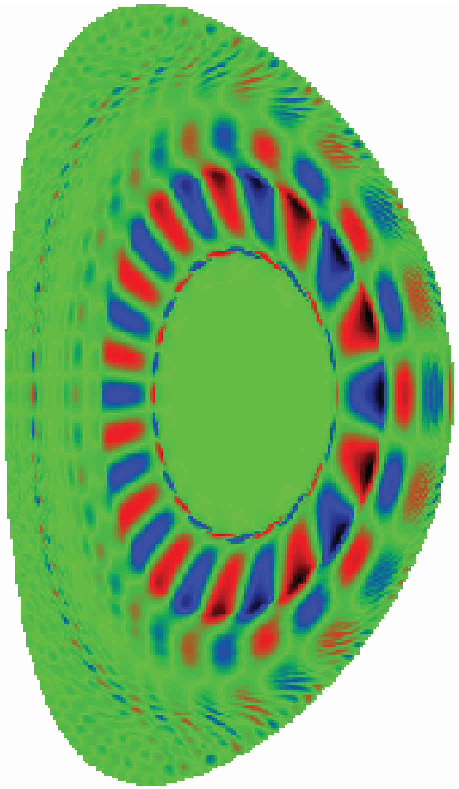
- Localized near q_{min}
- Frequency sweeps upward as q_{min} decreases

Toroidal rotation also shifts frequencies ~ nf_{rot}

Theory: TAEs are Global, RSAEs are Localized

n=3 TAE

δT_e, f = 74 kHz

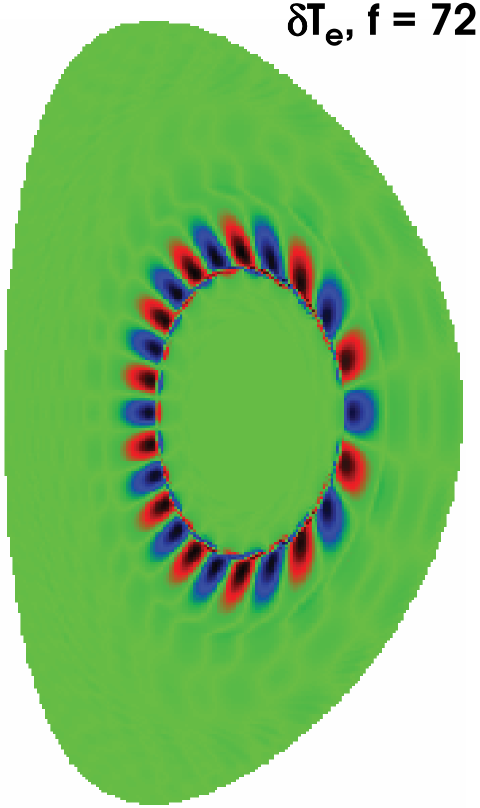


Global mode with many poloidal harmonics

Linear eigenfunctions are calculated by the ideal MHD code NOVA

n=3 RSAE

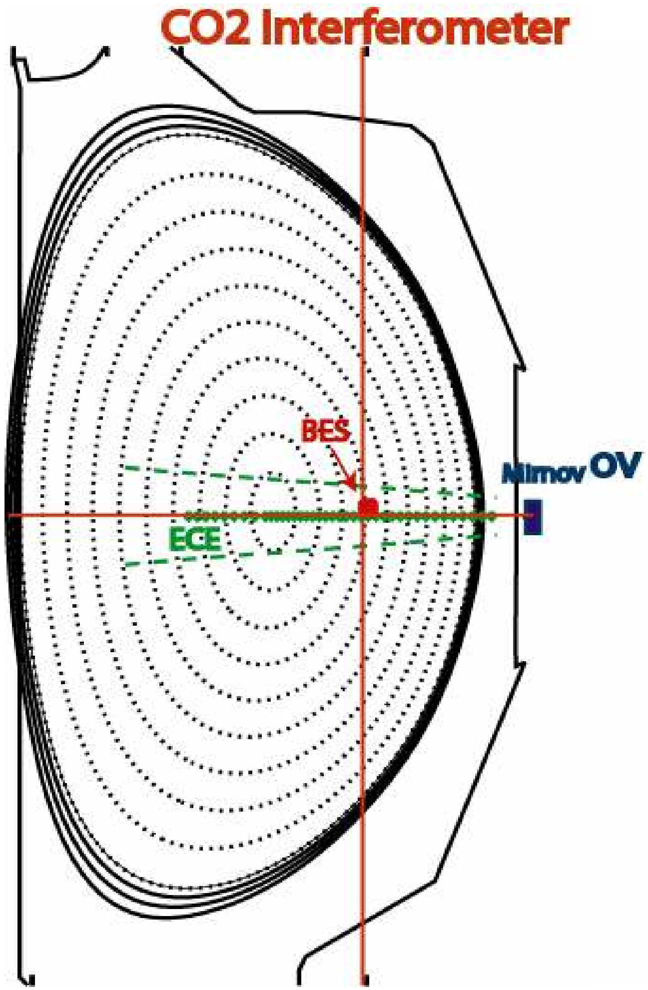
δT_e, f = 72 kHz



Localized mode with one poloidal harmonic

Van Zeeland, PRL 97 (2006) 135001.

Sensitive Diagnostics Measure Fluctuations in n_e, T_e, and B



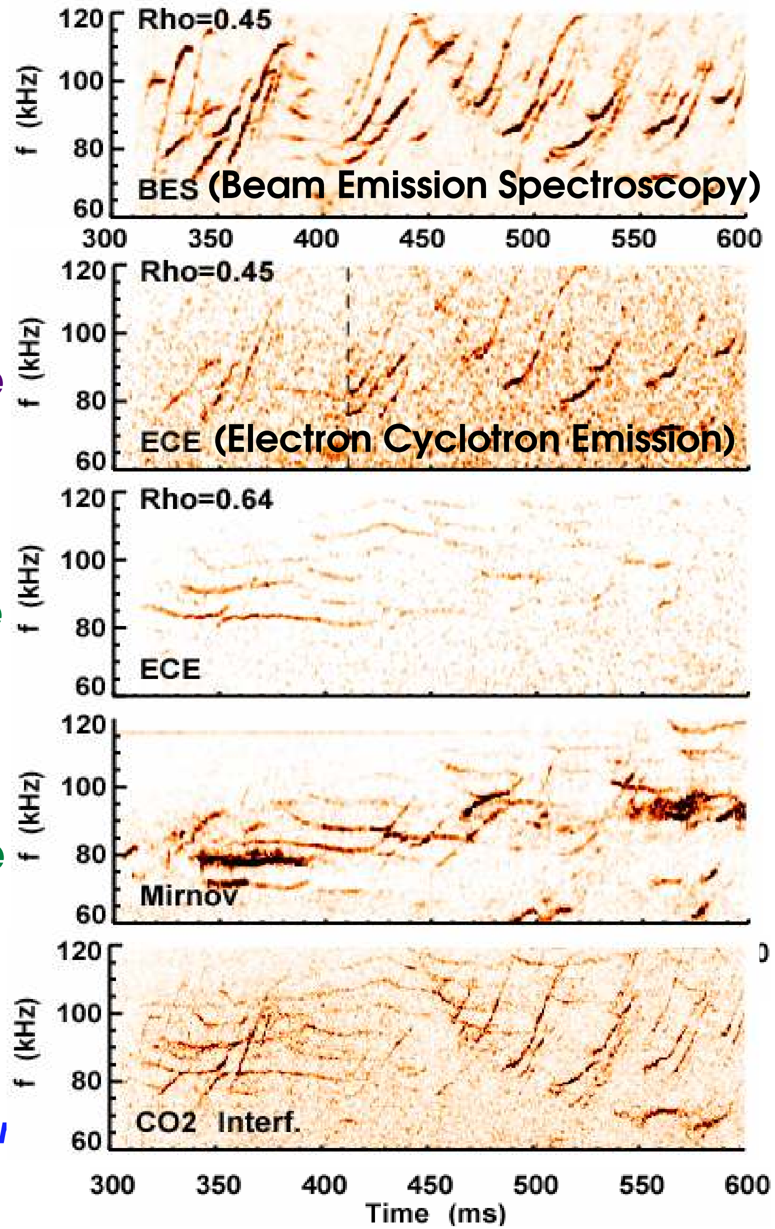
RSAEs dominate

RSAEs dominate

TAEs dominate

TAEs dominate

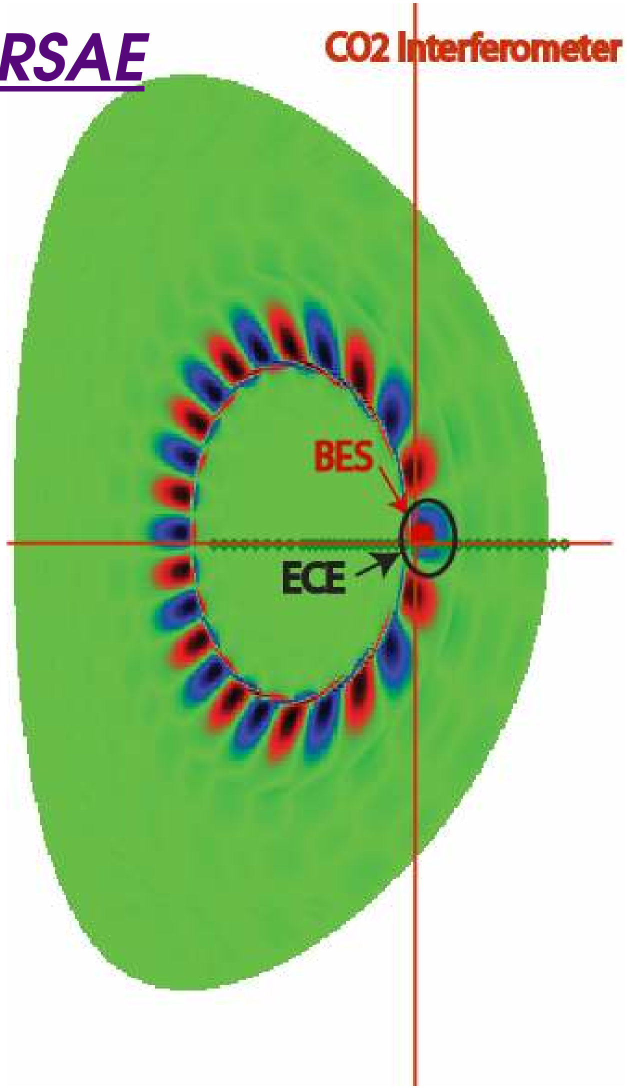
TAEs & RSAEs



Van Zeeland, PPCF 47 (2005) L31; Nucl. Fusio
46 (2006) S880.

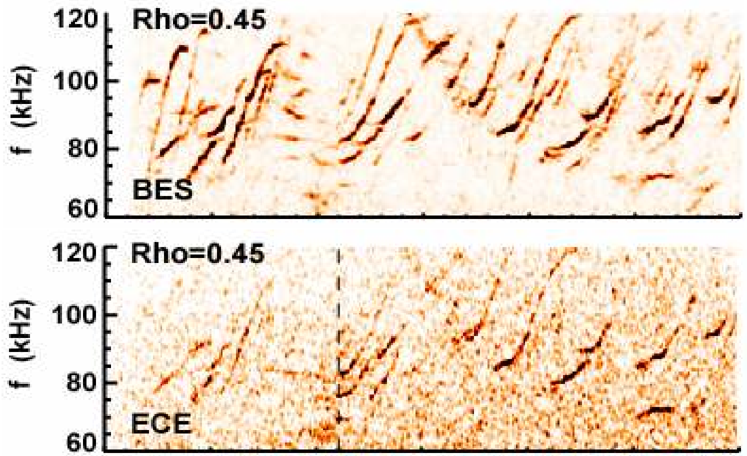
Signals Depend on the Mode Structure: RSAEs are Localized

n=3 RSAE

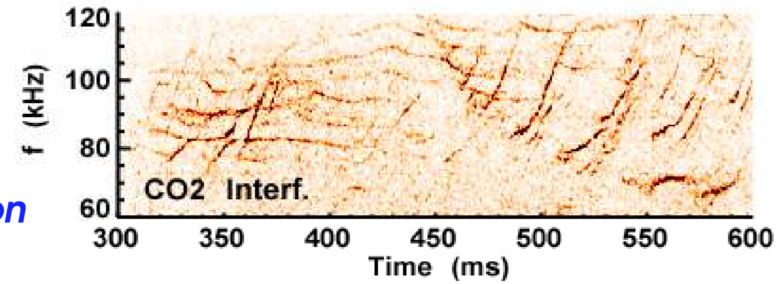


RSAEs dominate

RSAEs dominate



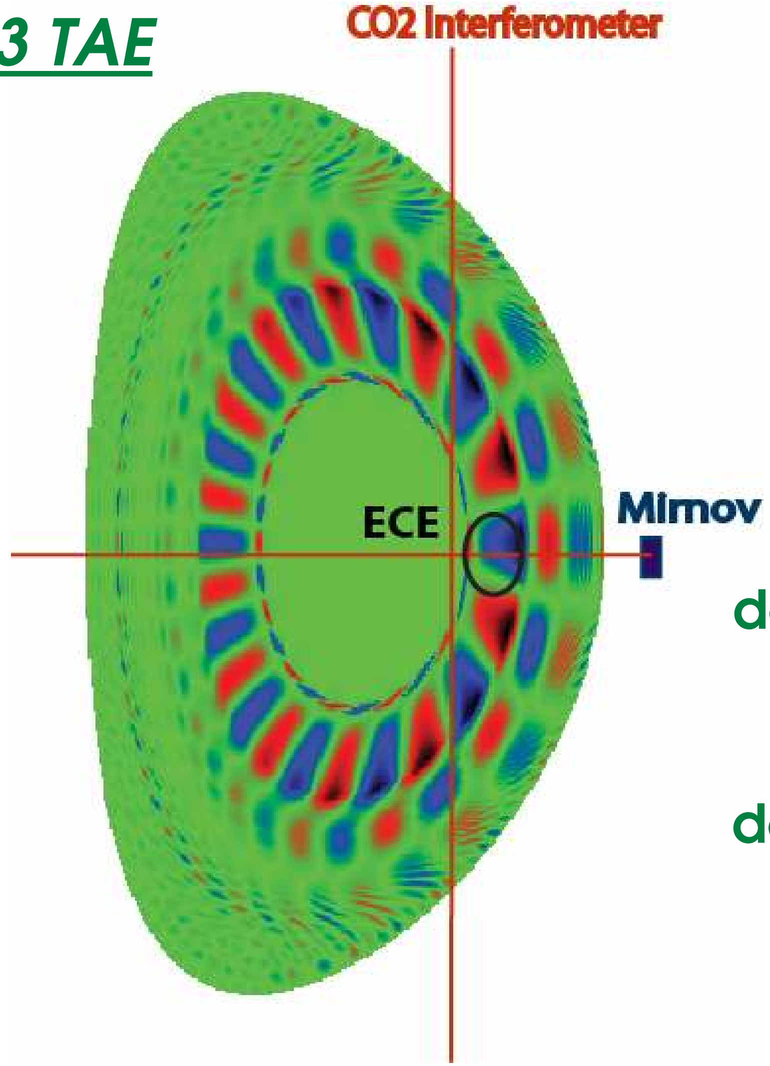
TAEs & RSAEs



Van Zeeland, PPCF 47 (2005) L31; Nucl. Fusion 46 (2006) S880.

Signals Depend on the Mode Structure: TAEs are Global

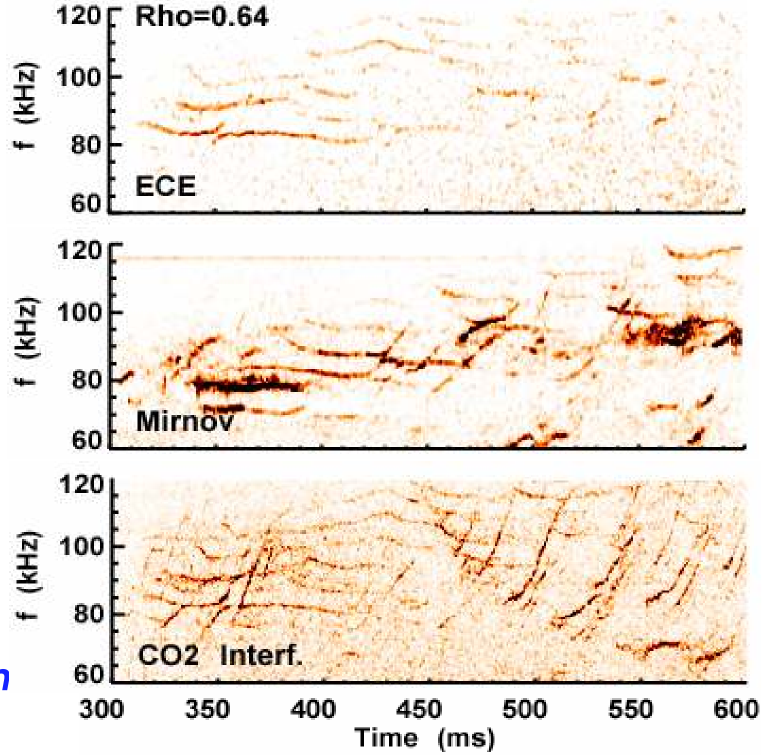
n=3 TAE



TAEs dominate

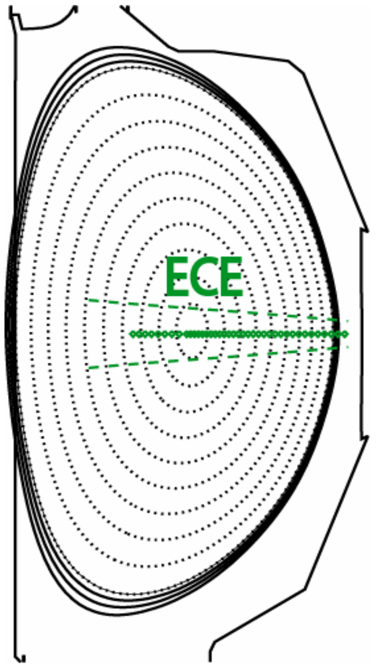
TAEs dominate

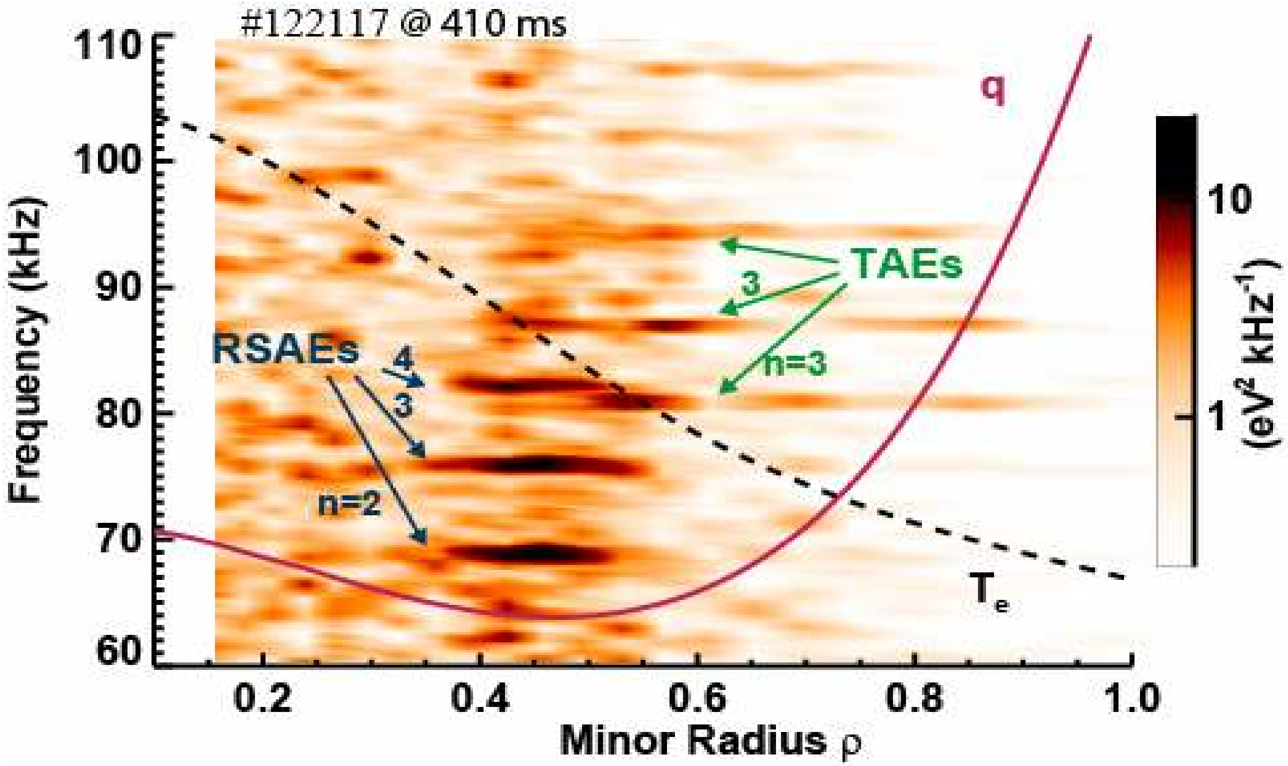
TAEs & RSAEs



Van Zeeland, PPCF 47 (2005) L31; Nucl. Fusion 46 (2006) S880.

The Upgraded ECE Diagnostic Measures the Radial Eigenfunction



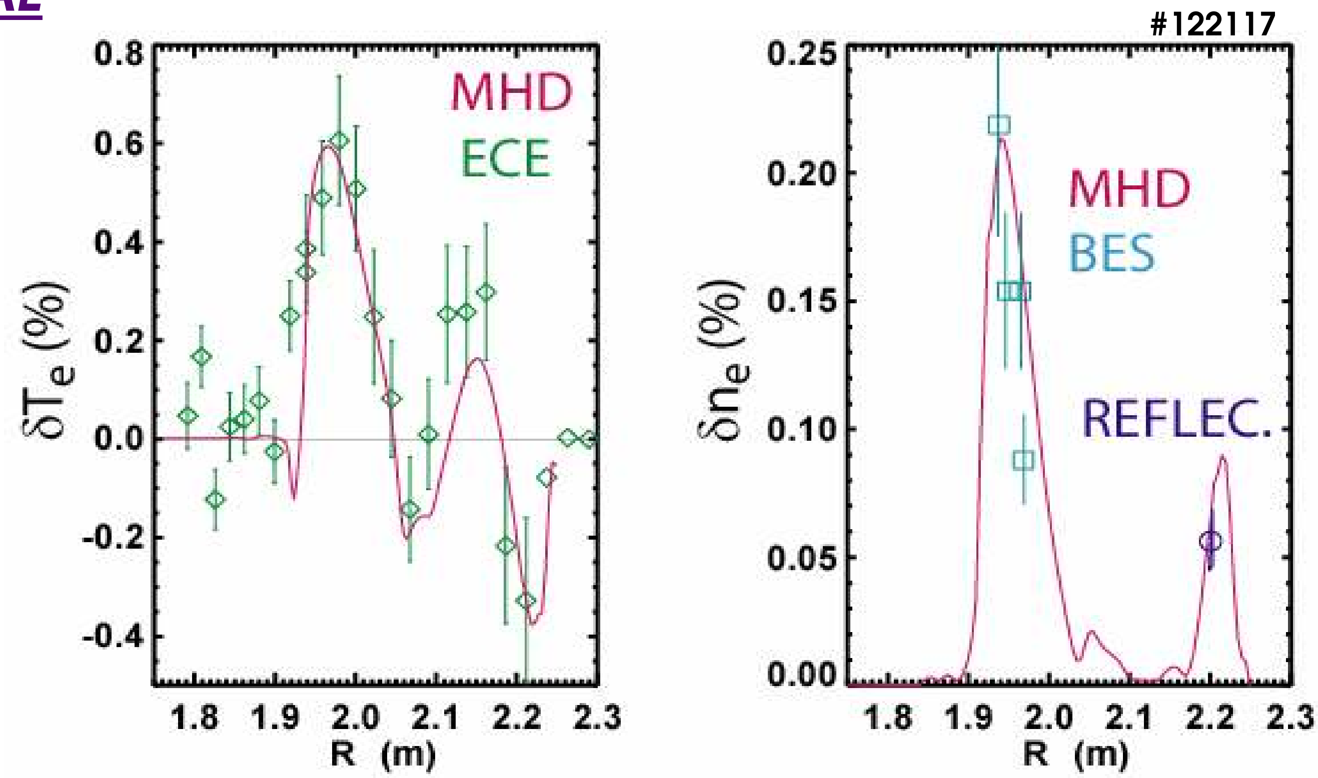


- **RSAEs** are localized at q_{min}
- **TAEs** are globally extended

Van Zeeland, PRL 97 (2006) 135001.

The Mode Structure agrees with linear ideal MHD Theory

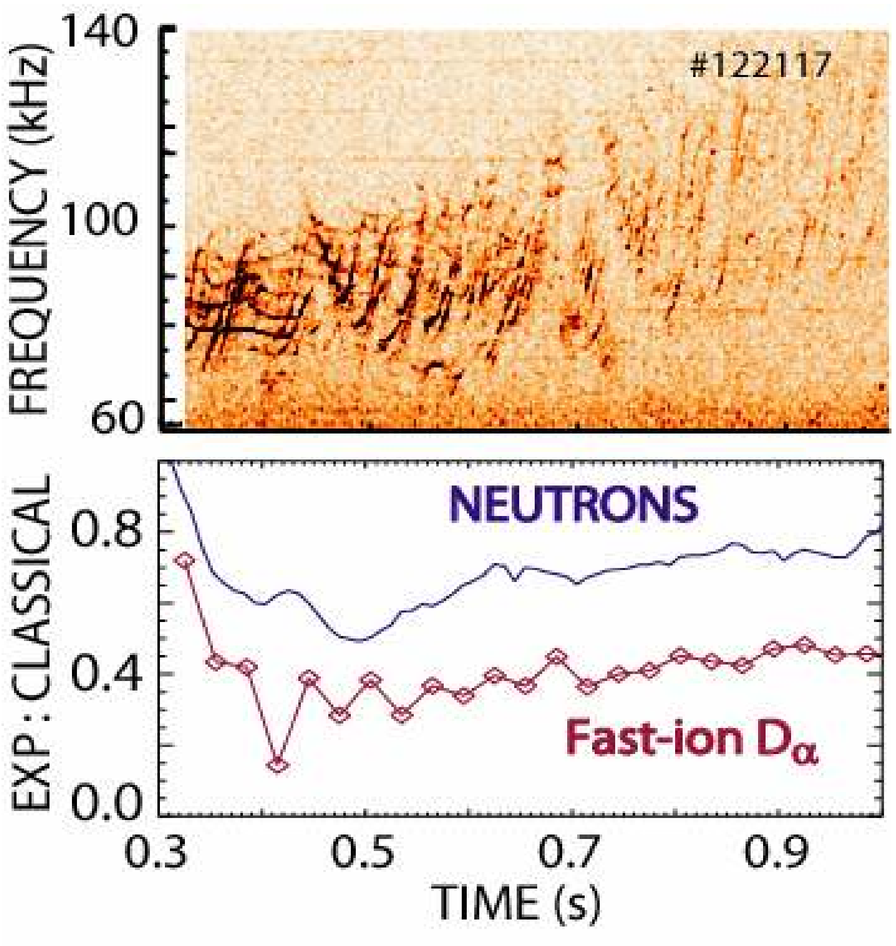
n=3 RSAE



- The MHD δT_e amplitude is scaled to match the ECE data
- No free parameters in the δn_e comparison
- The TAE data also agree well

Van Zeeland, PRL 97 (2006) 135001.

Alfven Modes Degrade Fast-ion Confinement

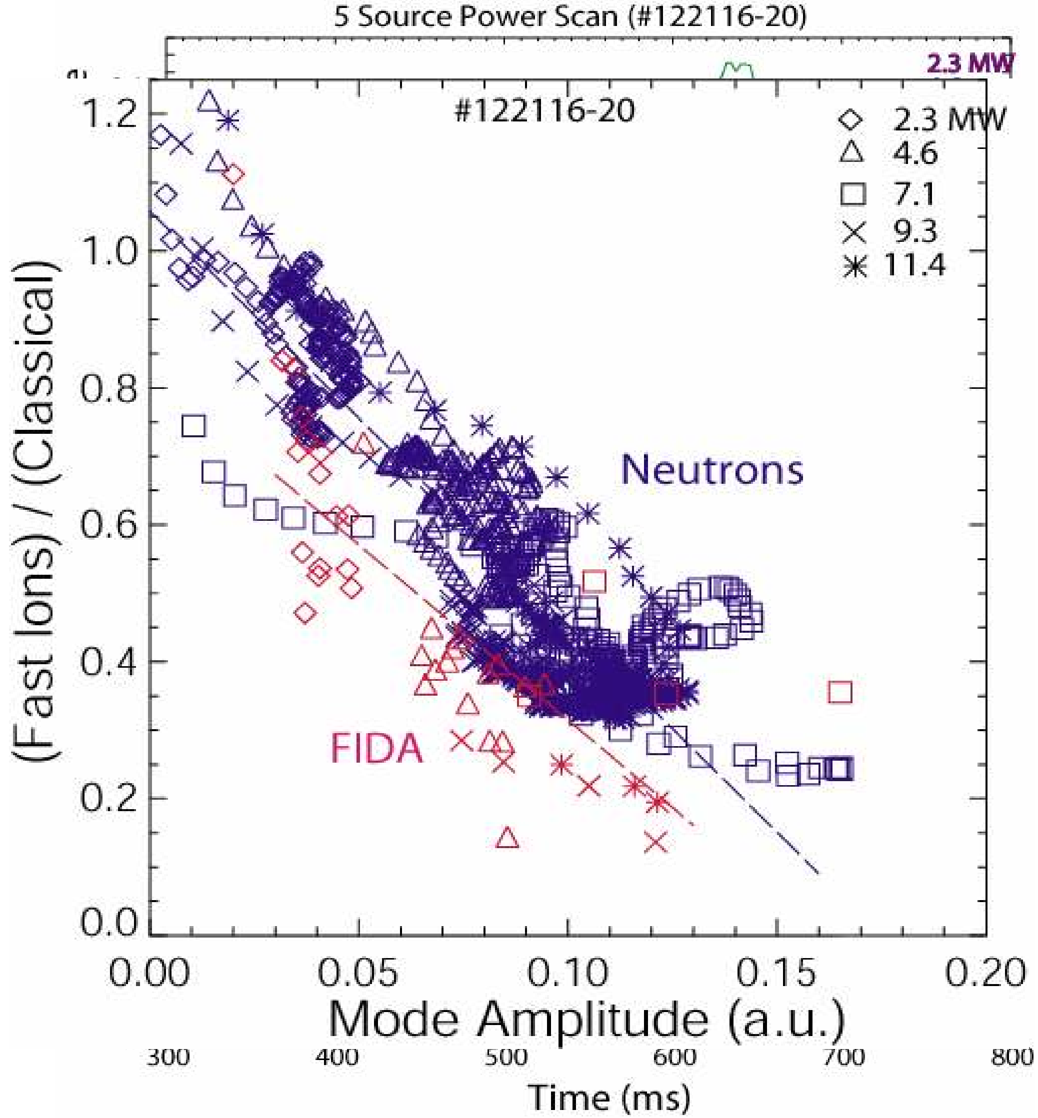


- Volume-averaged neutron rate is below the classical TRANSP prediction during the strong Alfven activity
- Fast-ion D_α (FIDA) diagnostic measures the spectrum of fast ions with 5 cm spatial resolution*
- FIDA "density" near ρ_{qmin} is reduced during the strong Alfven activity

**Heidbrink, PPCF 46 (2004) 1855; Luo, RSI 77 (2006) submitted.*

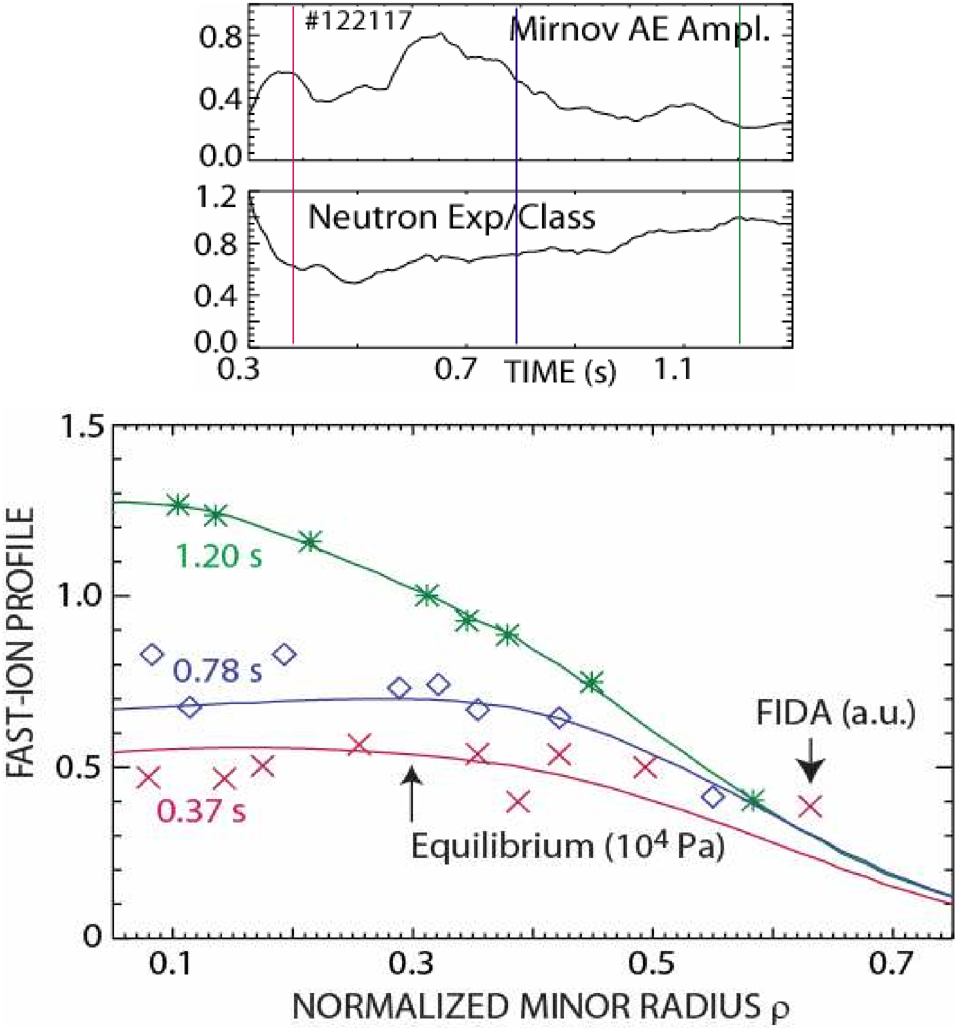
The Fast-ion Deficit Correlates with Alfven Activity

- The strength of the Alfven activity tends to increase with beam power in similar plasmas.
- The discrepancy between the classical prediction and the data is largest when the Alfven modes are strong
- The FIDA deficit is larger than the neutron deficit



For this comparison, the FIDA density and neutron rate are normalized by their values at 2.0 s in the 1-source shot (when Alfven activity is undetectable).

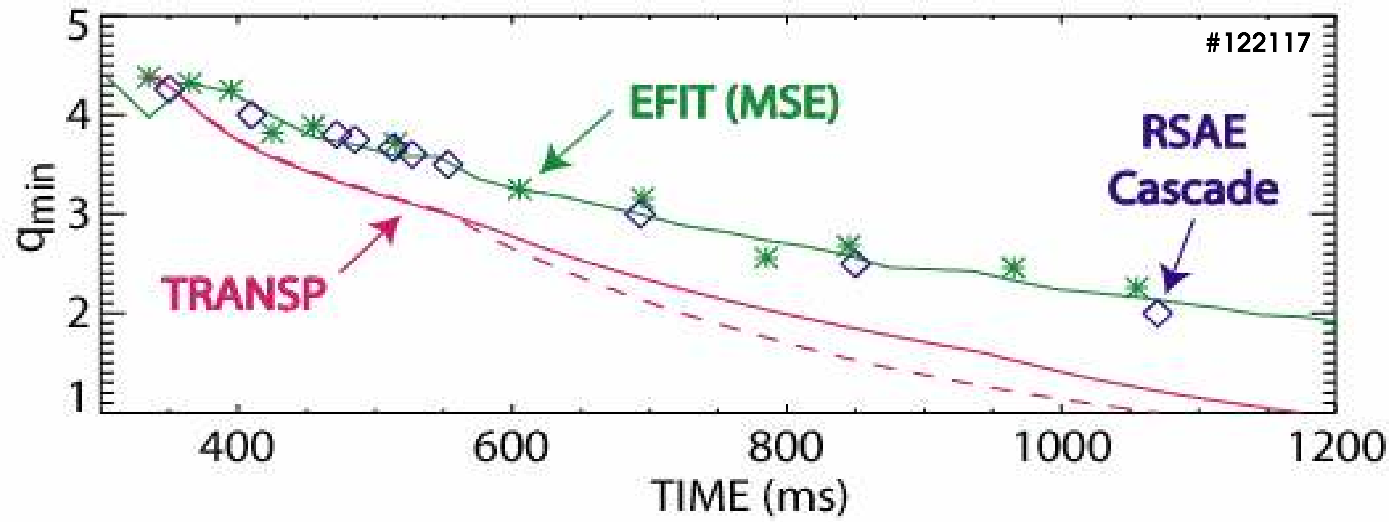
The Fast-ion Density Profile is Flattened



- During the strong Alfven activity, the fast-ion density profile from FIDA is nearly flat
- The fast-ion profile inferred from the equilibrium* is also very flat
- The classical profile computed by TRANSP peaks on axis

***The kinetic EFIT equilibrium uses MSE and magnetics data to compute the pressure profile. Subtraction of the thermal pressure yields the fast-ion pressure.**

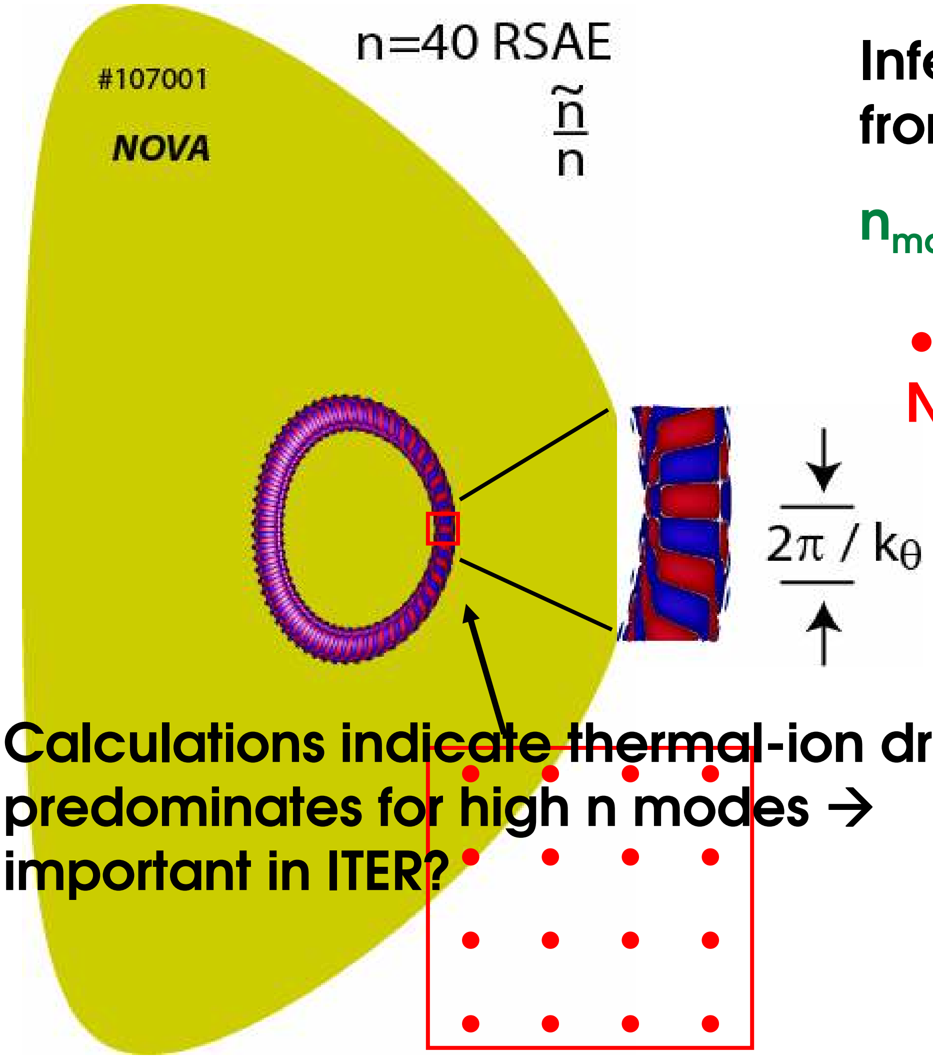
Fast-ion Transport Broadens the Profile of Neutral-Beam Driven Current



- The current diffuses more slowly than classically predicted
- Independent determinations of q_{min} from MSE-based equilibrium reconstructions and from the RSAE integer q crossings agree
- Apparently co-circulating fast ions that move to ρ ~ 0.5 broaden the NBCD profile.*

**Ferron, this conference; Wong, PRL 93 (2004) 085002; Wong, NF 45 (2005) 30.*

Modes also Observed on the Thermal-ion Gyroradius Scale

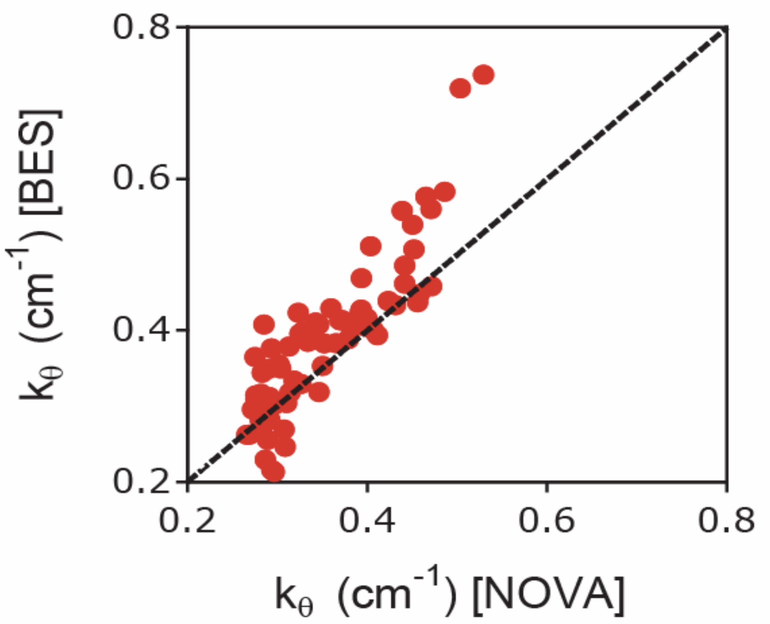


3cm x 3cm BES array

Infer toroidal mode number from Doppler shift →

n_{max} ~ 40

- BES measurements of k_θ agree with NOVA, corroborating n numbers



Calculations indicate thermal-ion drive predominates for high n modes → important in ITER?

Nazikian, PRL 96 (2006) 105006; Kramer, Phys. Pl. 13 (2006) 056104

Diagnostic Advances → Rigorous Tests of Alfven Eigenmode Theory

Diagnostic Advances

Fluctuations: δT_e, δn_e, δB

Fast ions: FIDA, Neutrons, Pressure, Current

Conclusions

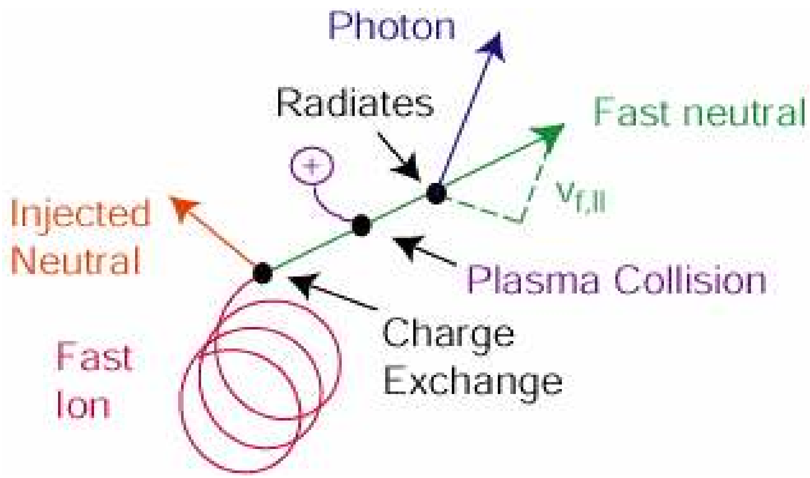
- TAE and RSAE mode structure agree with linear MHD
- Strong Radial Fast-ion Transport
- High n modes on thermal-ion scale

In Progress

- Compute fast-ion transport in validated wave fields & compare with FIDA profile
- Self-consistent nonlinear simulations
- Study excitation threshold of high n modes

Backup slides

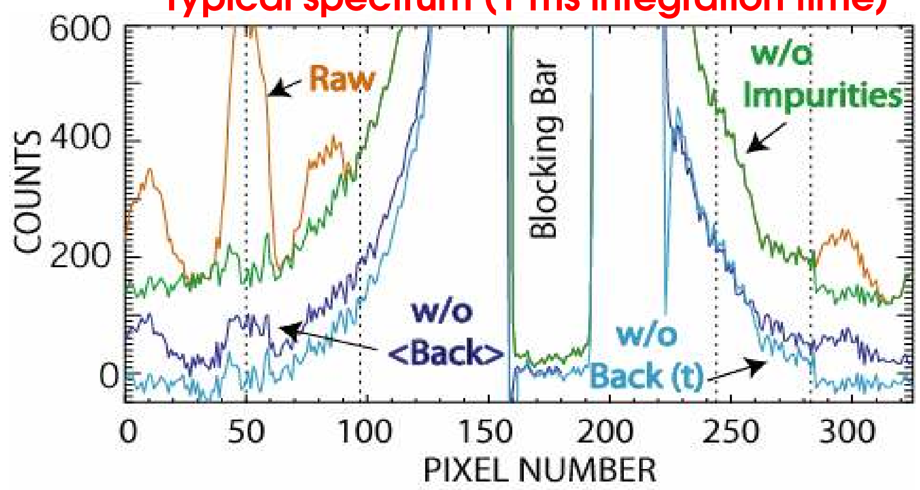
Fast-ion D_α (FIDA) Diagnostic



- A type of Charge Exchange Recombination Spectroscopy
- Use vertical view to avoid bright interferences
- Exploit large Doppler shift (measure wings of line)

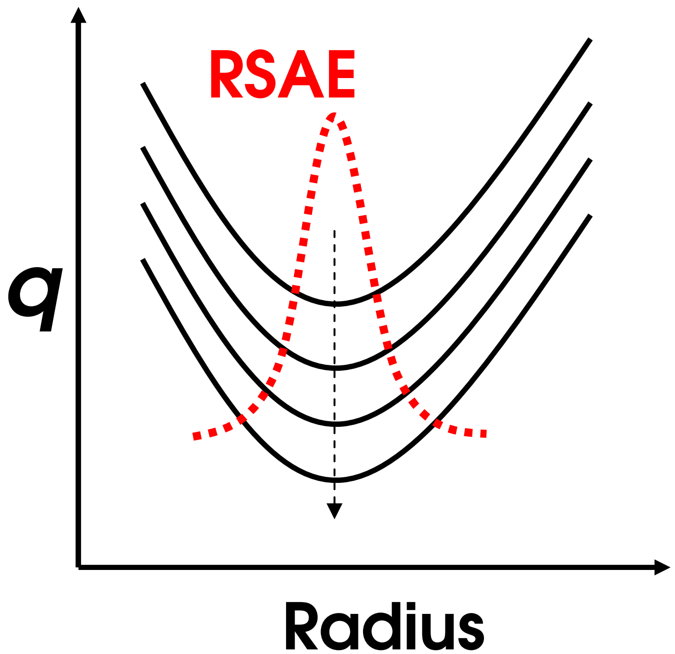
- Background subtraction usually dominates uncertainty
- Achieved resolution: ~ 5 cm, ~ 10 keV, 1 ms.

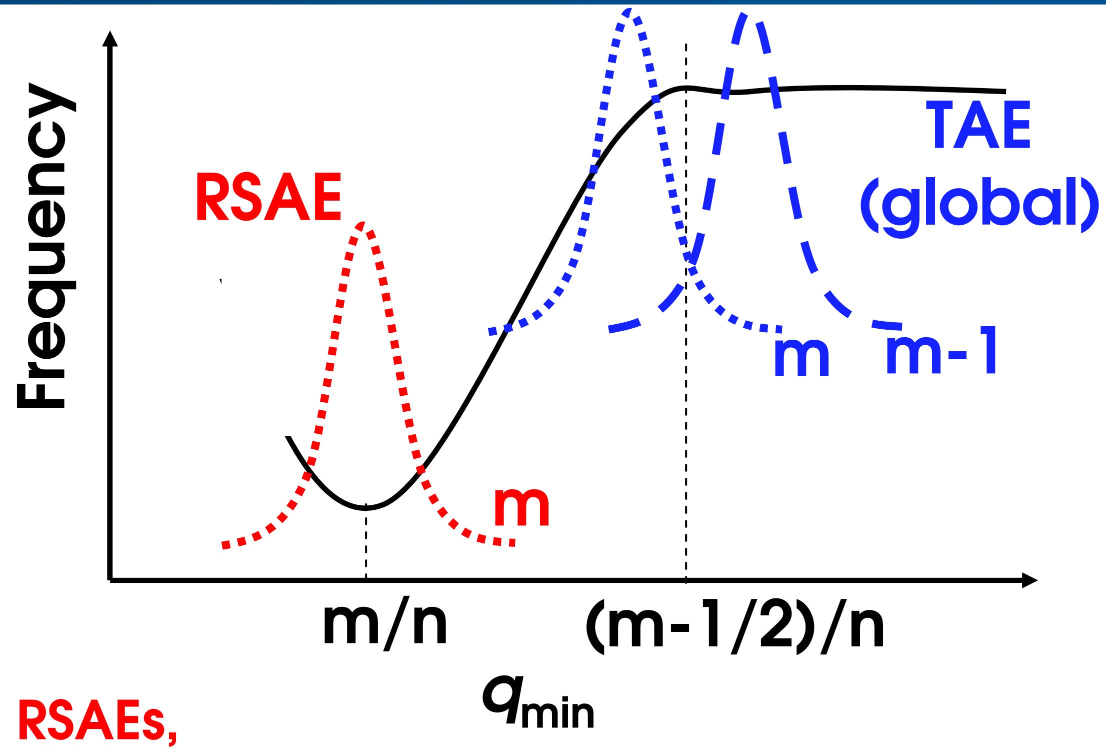
Typical spectrum (1 ms integration time)



Heidbrink, PPCF 46 (2004) 1855; Luo, RSI (2006) submitted.

Theory of Alfvén Eigenmodes in Reverse Magnetic Shear Plasmas :RSAE





- Prediction: Core localized RSAEs, transition to global TAE with a frequency sweep sensitive to q-min

$$\omega = k_{||} V_A = \frac{(m - nq)}{q R} V_A$$

* H.L. Berk *et al*, PRL **87** (2001) 185002

* A. Fukuyama *et al*, IAEA 2002 TH/P3-14