Influence of magnetic configuration on edge turbulence and transport in the H1 Heliac

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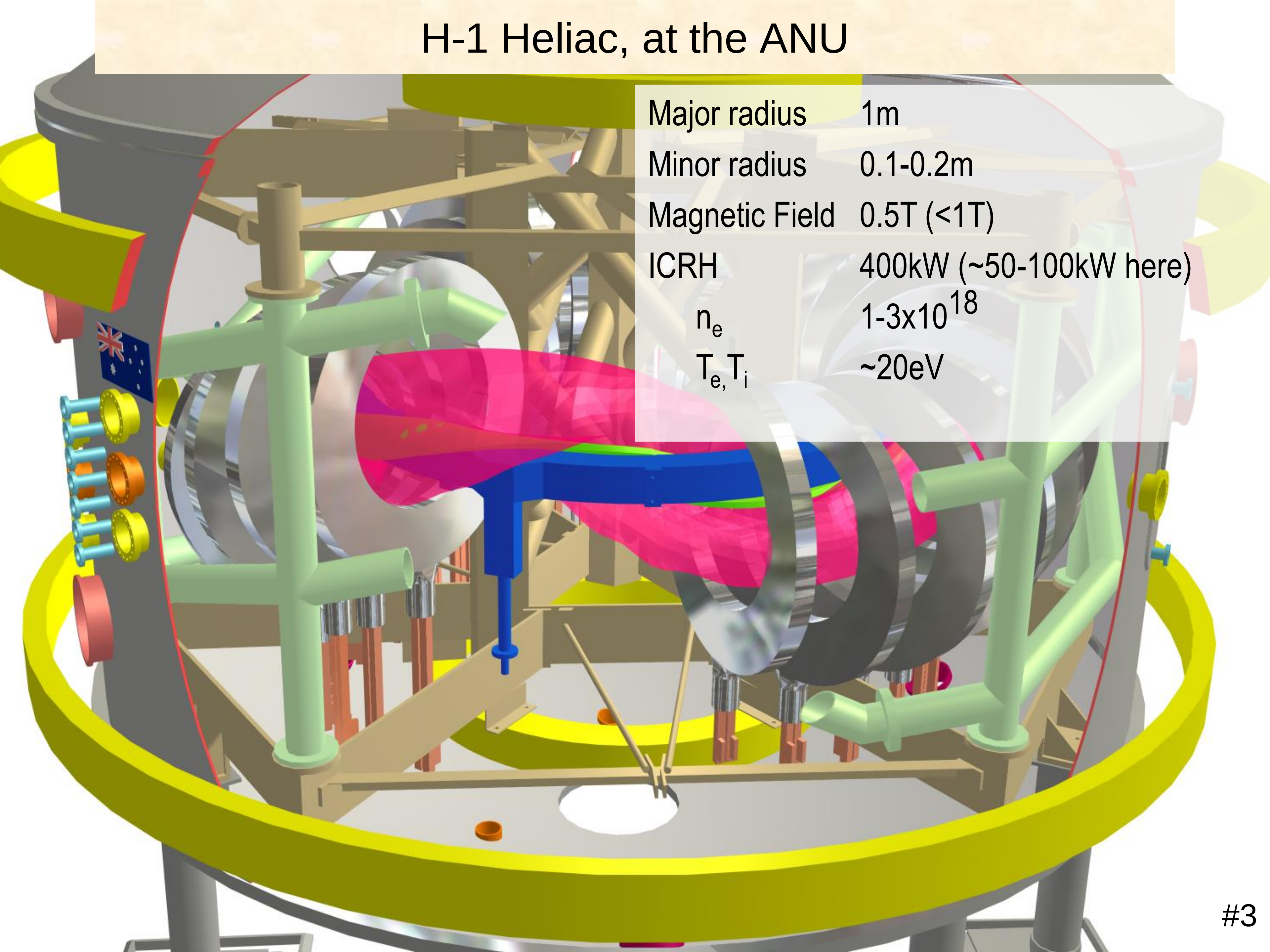
Outline

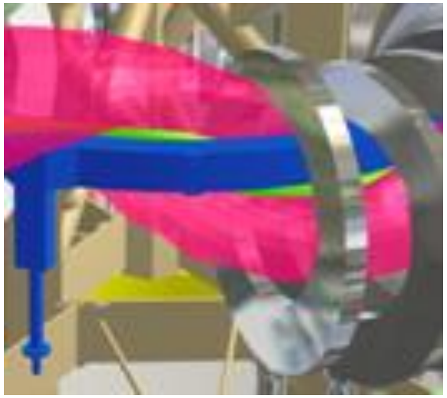
- Magnetic properties of H-1 Heliac
- Confinement & turbulence changes with rotational transform
- Turbulence structure & flux
- Directions for analysis

H-1 Heliac, at the ANU

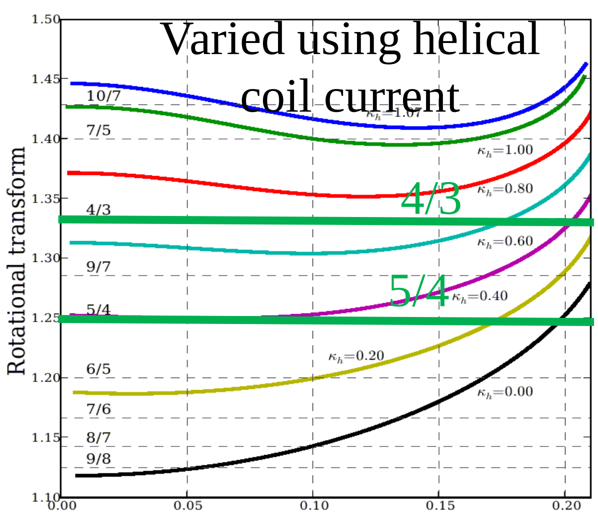
Major radius	1m
Minor radius	0.1-0.2m
Magnetic Field	0.5T (<1T)
ICRH	400kW (~50-100kW here)
n_e	$1\text{-}3\times10^{18}$
T_e, T_i	~20eV

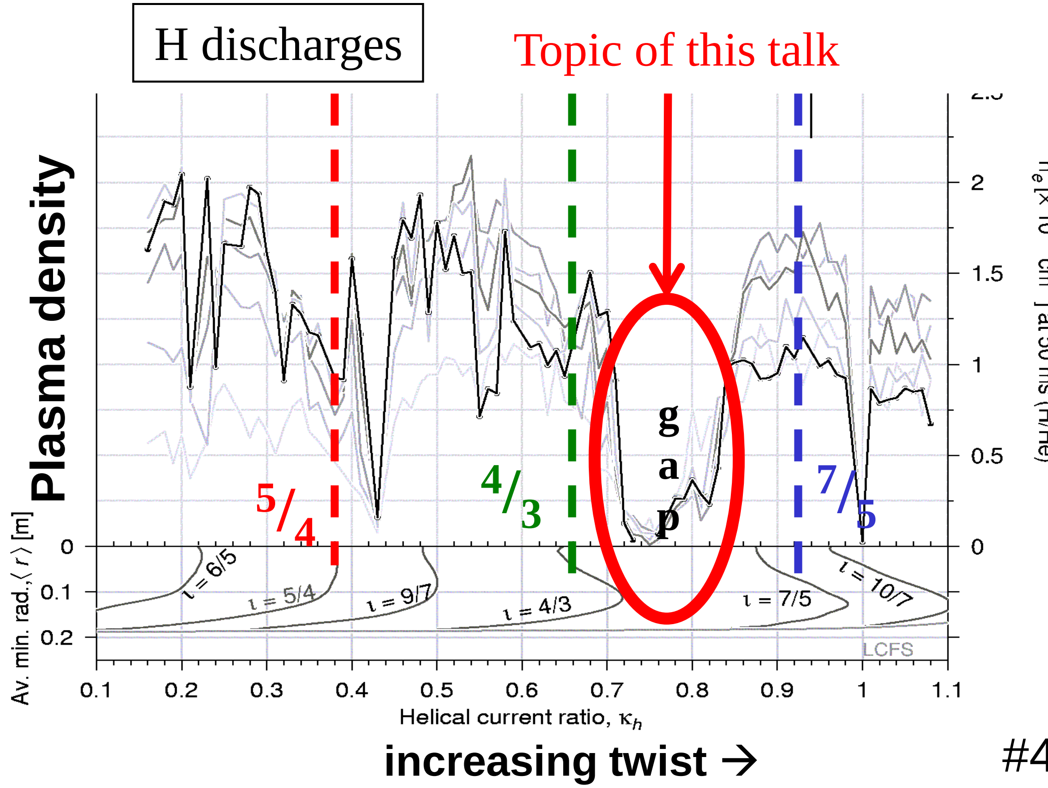


Control of rotational transform: effect of islands on confinement?

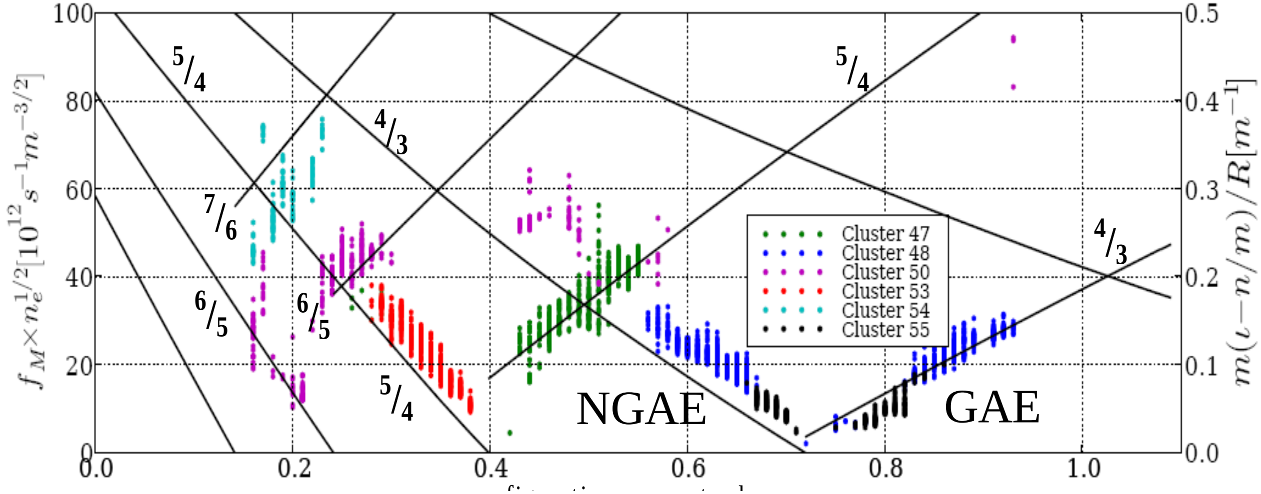


- Helical coil produces “rotational transform”
- When rotational transform is rational and its radial shear is small, magnetic islands may be formed
- Low order rationals are also likely localization points for fluctuations – MHD theory
- Island may be “stone in the river” forcing mean flow to zero, reducing electric field and enhancing transport?

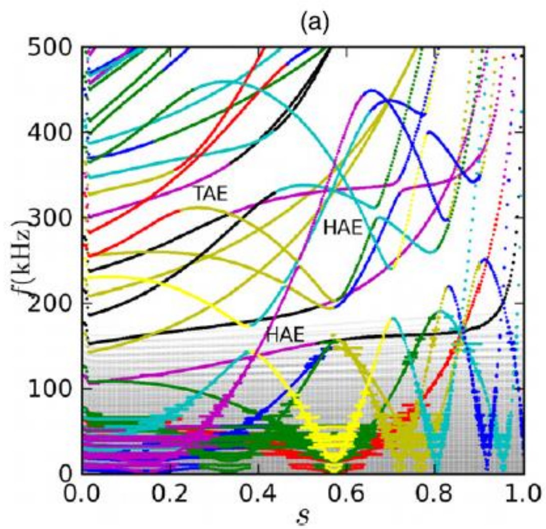




Alfven waves and continuua



(k_H) Increasing ɨ (twist per turn) →



- *Shear Alfvén modes:*
- $\omega = V_A(n - ɨm)/R_0$.
- Modes cluster in V-shapes when plotted against rotational transform c.f. "Alfvén cascades"
- Complex MHD gap structure, with "sound-mode" coupling (BAE)

Blackwell, B.D., et al.,. ArXiv e-prints, 2009, IAEA proceedings 2012.
J Bertram et Al. PPCF **54** (2012) 055009

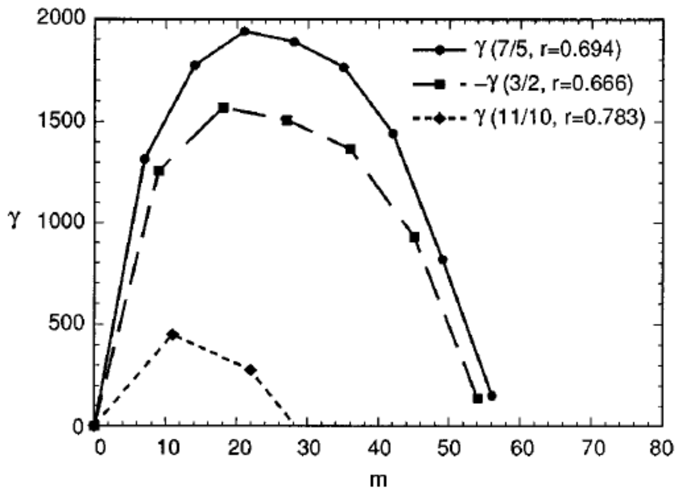
Resistive interchange turbulence drive

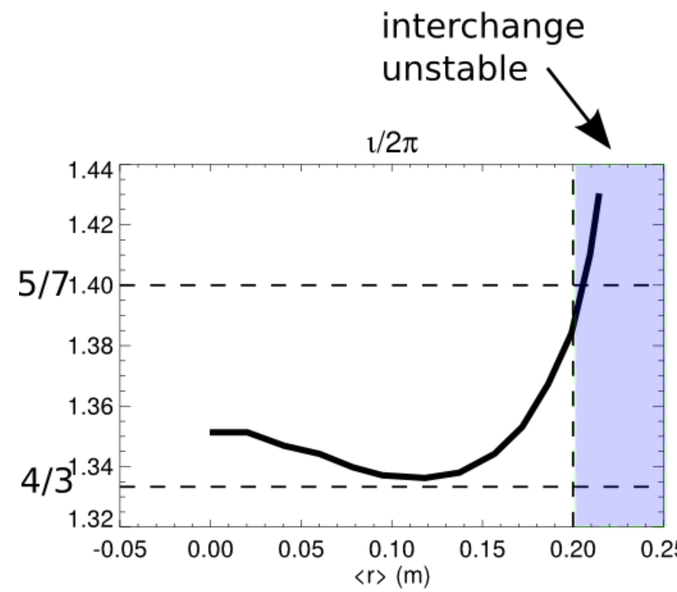
Analytic theory developed (Carrerras 1987/1989), verified by simulation

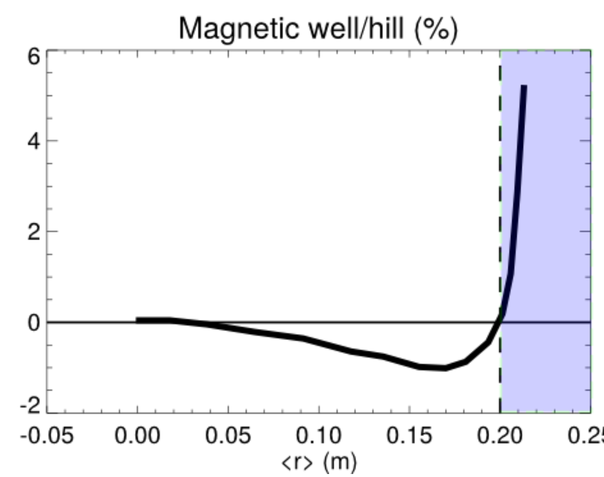
growth rate $\gamma \sim S^{-1/3}\left(\nabla\beta \frac{R_0^{\ 2}\kappa_n}{2} m \frac{2\pi d\rho}{d\iota}\right)^{2/3}\tau_{hp}^{\ -1}$

H-1: κ_h = 0.72 (where density is low)

Instability of resistive interchange
(Garcia, 1997)

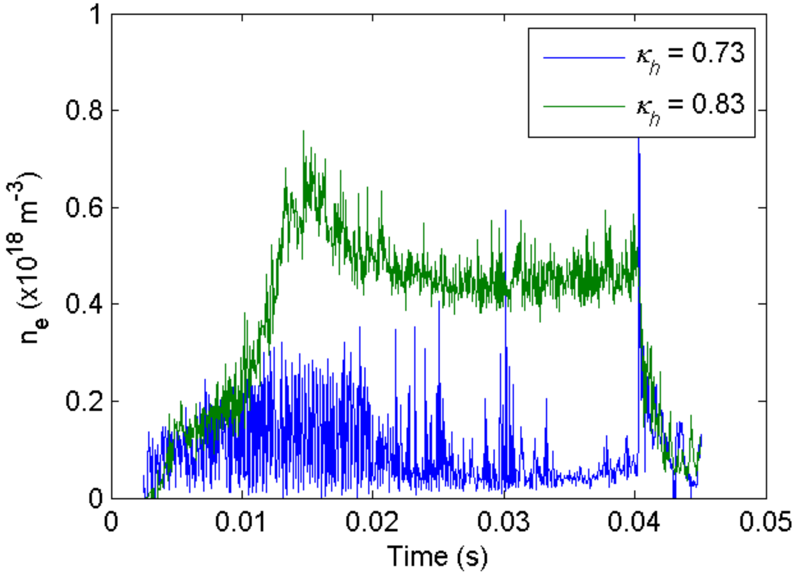


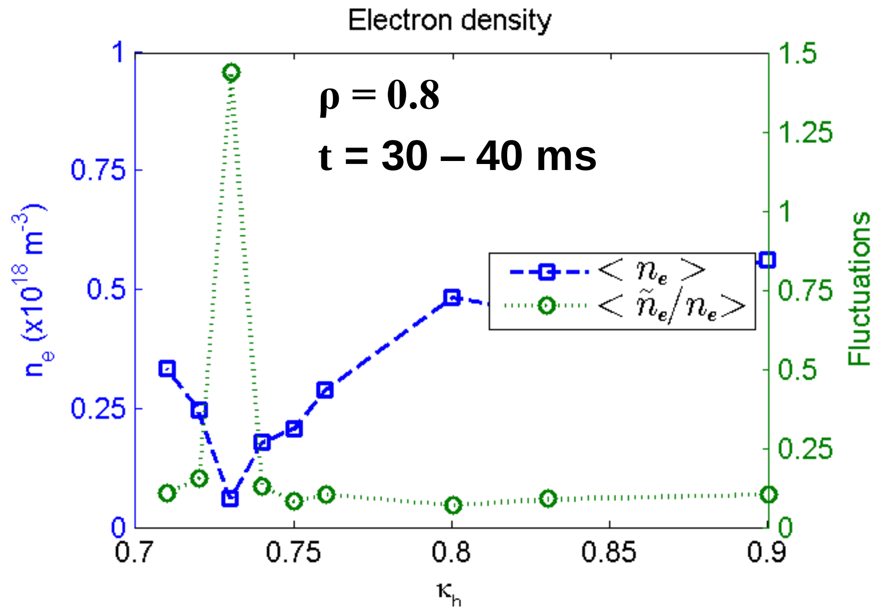


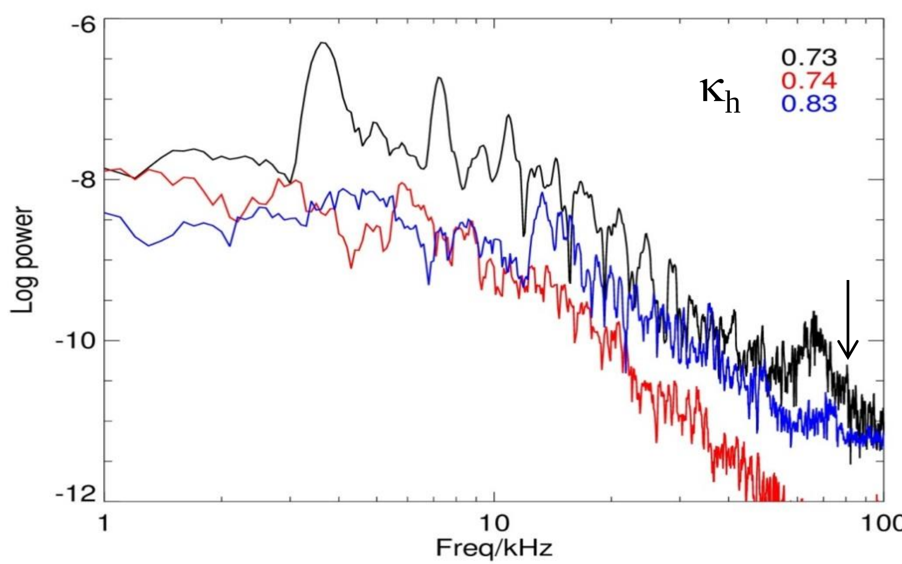


- Can drive medium-high scale fluctuations
- Requires low shear-> H1 is low shear machine
- Requires pressure gradient -> edge has that naturally
- Seed rational needs to coincide with hill region
- Relationship to open field line region?

Probes: confinement & fluctuations for varying rotational transform

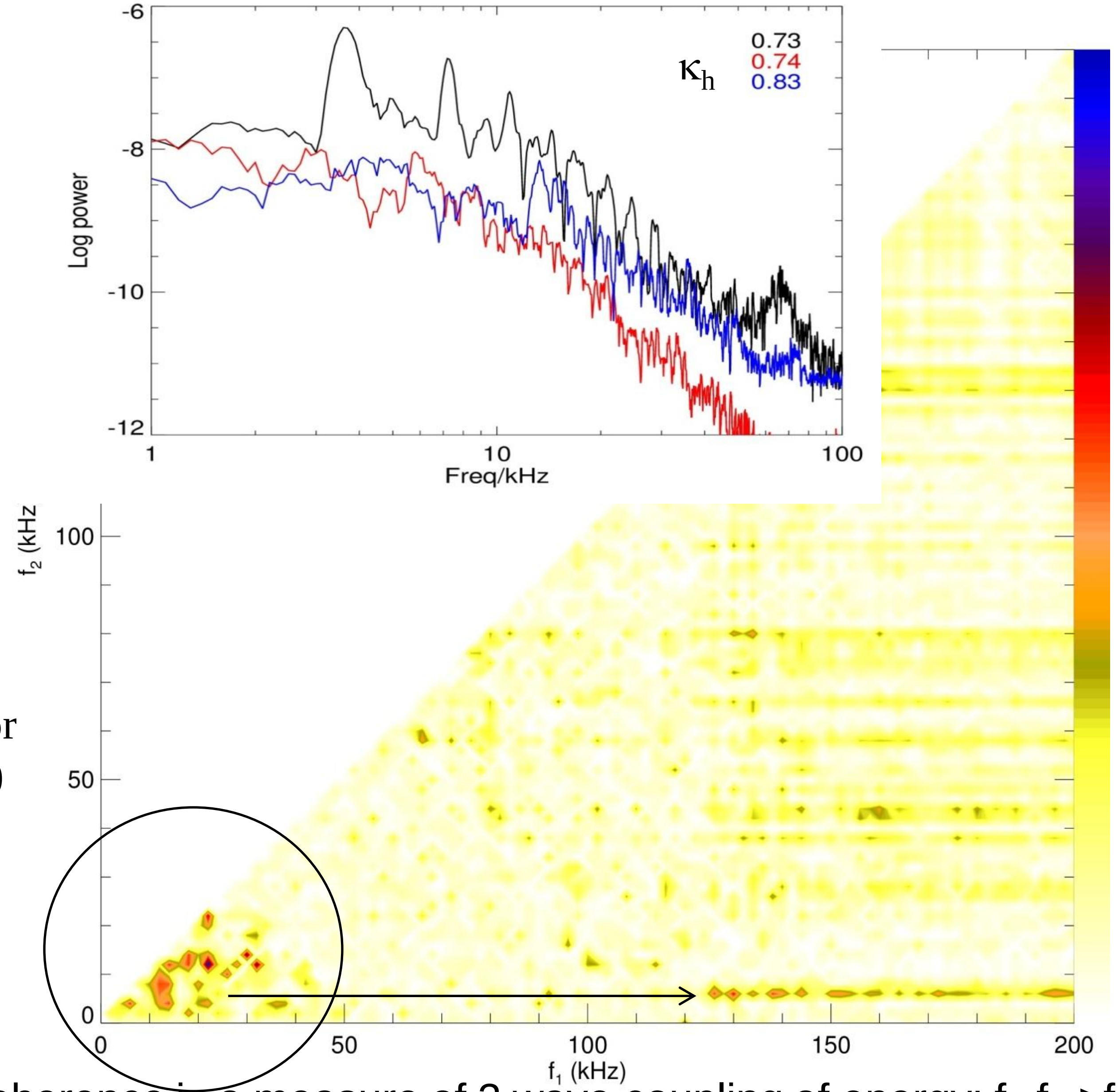






- Langmuir probes show density collapse more clearly
- κ_h ~ 0.73: Low density, large coherent modes
  - ~70kHz mode

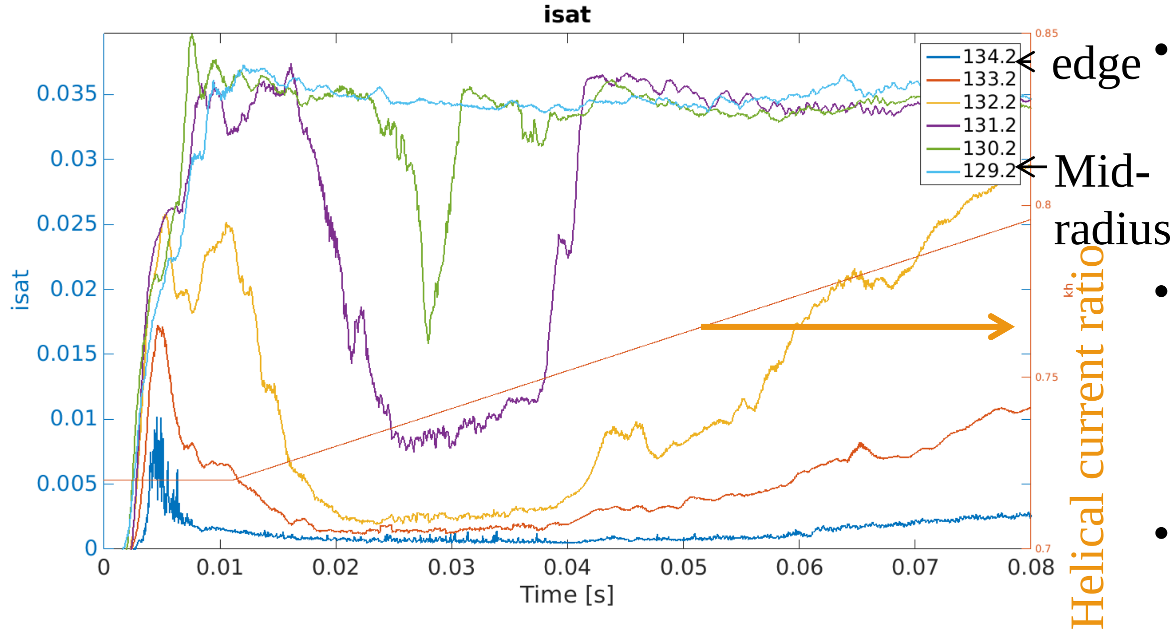
Interaction amongst modes: bicoherence

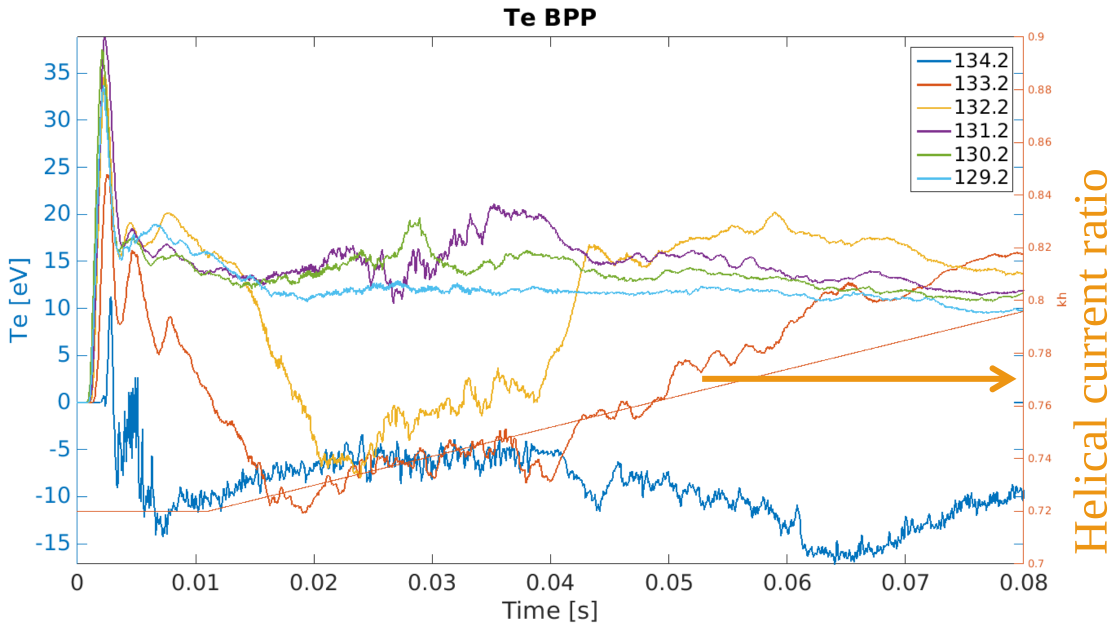


I_{sat}, r=1.33m, κ_h=0.73 (poor confinement)

- Bicoherence is a measure of 3 wave coupling of energy: $f_1, f_2 \rightarrow f_1 + f_2$

Helical current scan: profile response

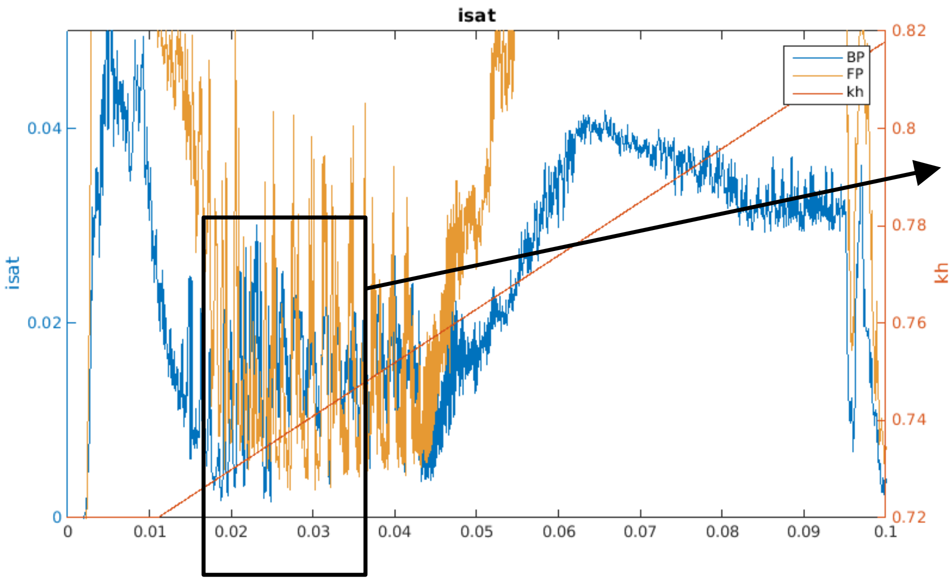


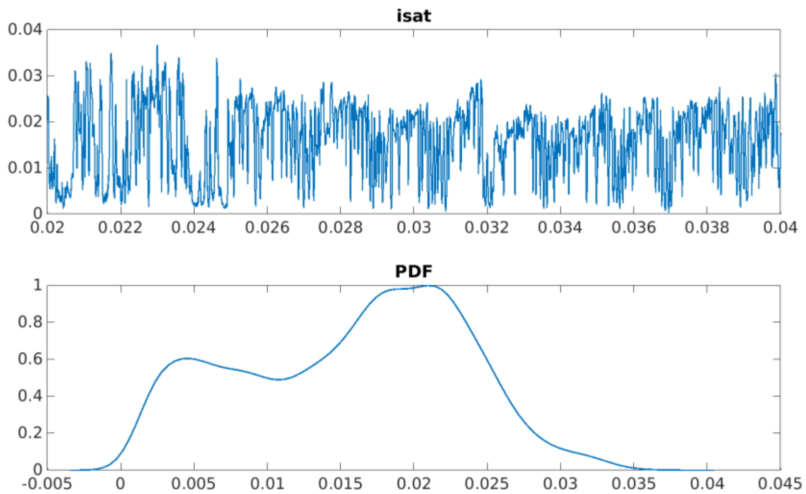


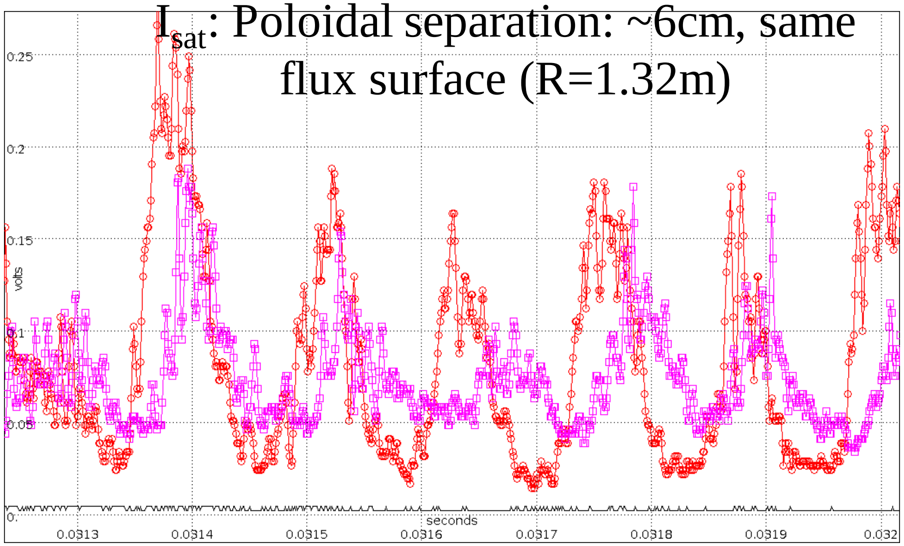
- Helical current ratio k_h scanned in time from 0.72 to ~0.83 in 100ms
- Density and temperature (smoothed) drops near k_h=0.73
- T_e from Ball-pen probe: negative value near edge due to RF pickup (improved recently with RF choke)

Ball-pen probe: Adámek, J et al. Czechoslovak Journal of Physics 54 : 95–99.

Density dithering near edge



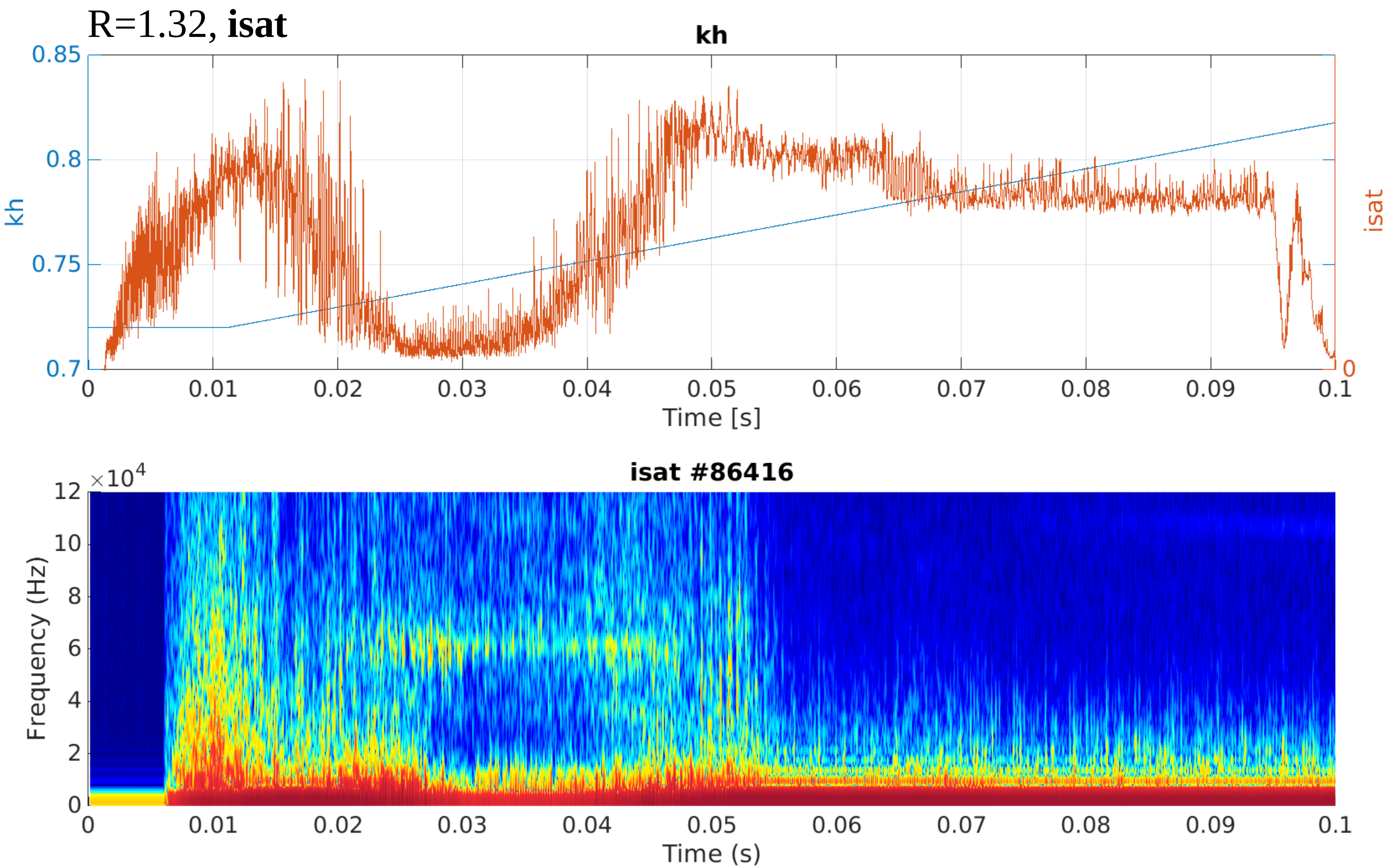




I_{sat}: Poloidal separation: ~6cm, same flux surface (R=1.32m)

- In low confinement region, density “dithers” between two states: temporal history and PDF resemble limit cycles?
- But, there is a poloidal variation -> relationship to blobs

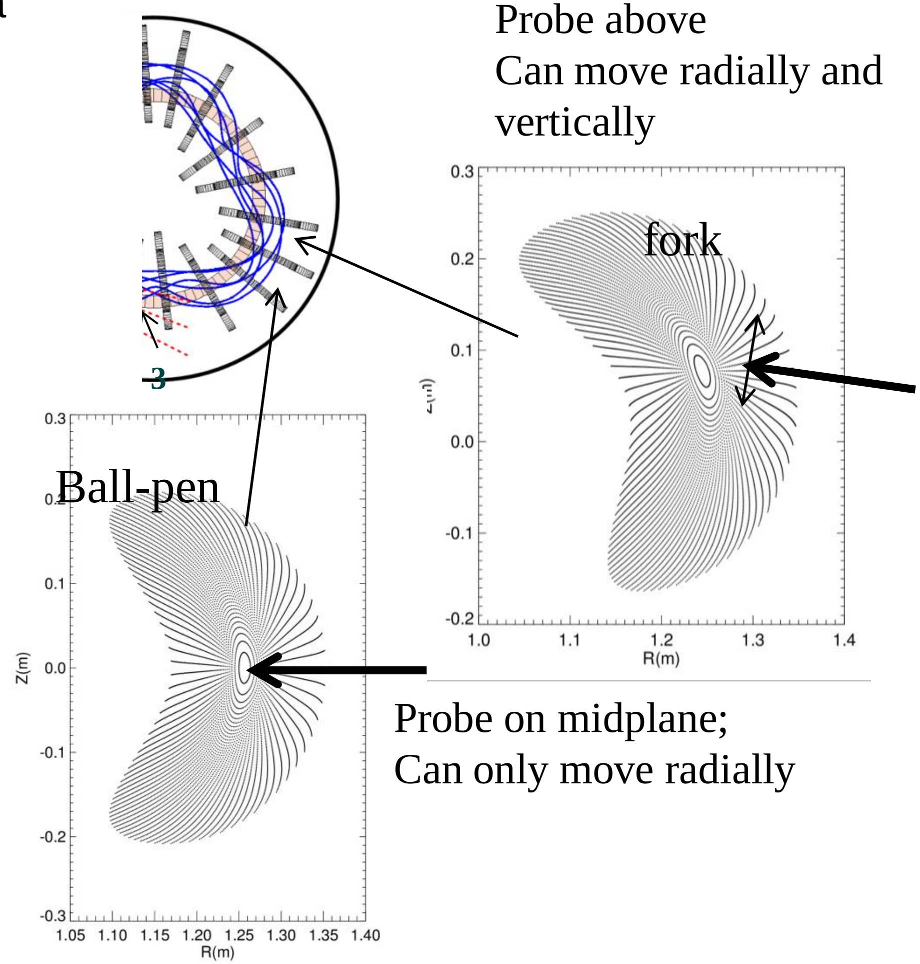
High frequency coherent mode during density collapse



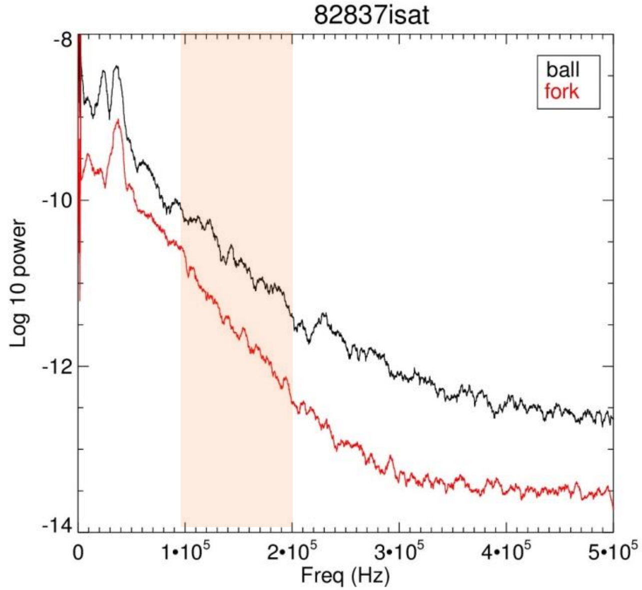
- 80kHz mode may be related to fluctuation induced flux? Non-alfvenic scaling.

Principle of Cross-correlation of 2 probes

- Ball-pen probe can be moved to plasma centre with only slight perturbation (at kh=0.83)
- Fork probe perturbs plasma more than ball-pen probe
  - *can only measure near the edge*

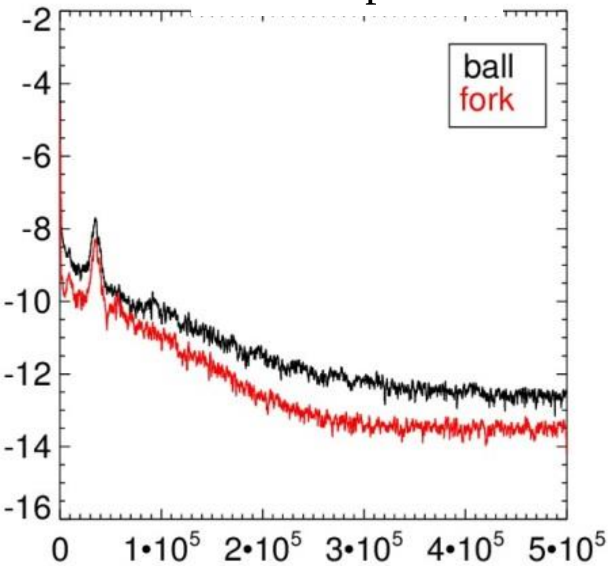


Power spectra; ballpen r/a=0.8



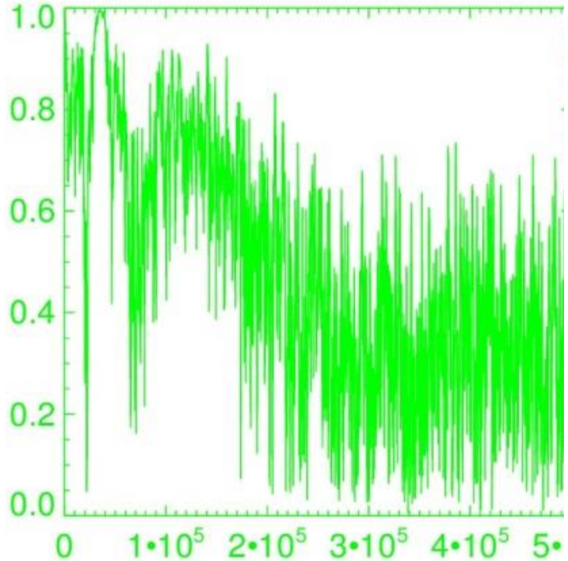
Frequency dependent cross-correlation

Power spectra



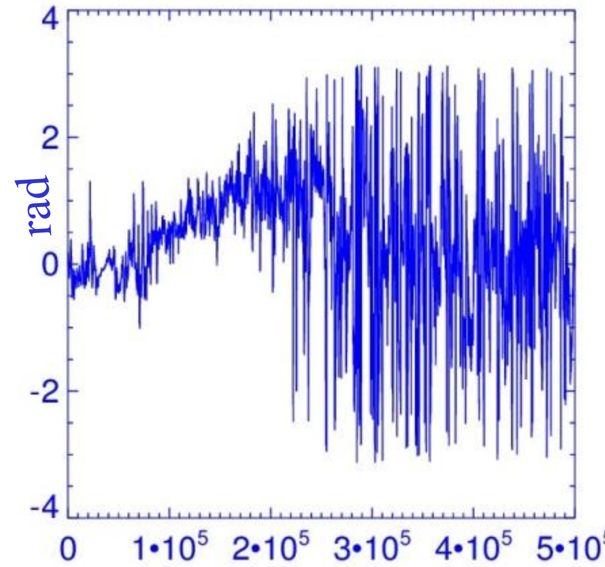
f/Hz

coherence



f/Hz

Cross-phase vs freq

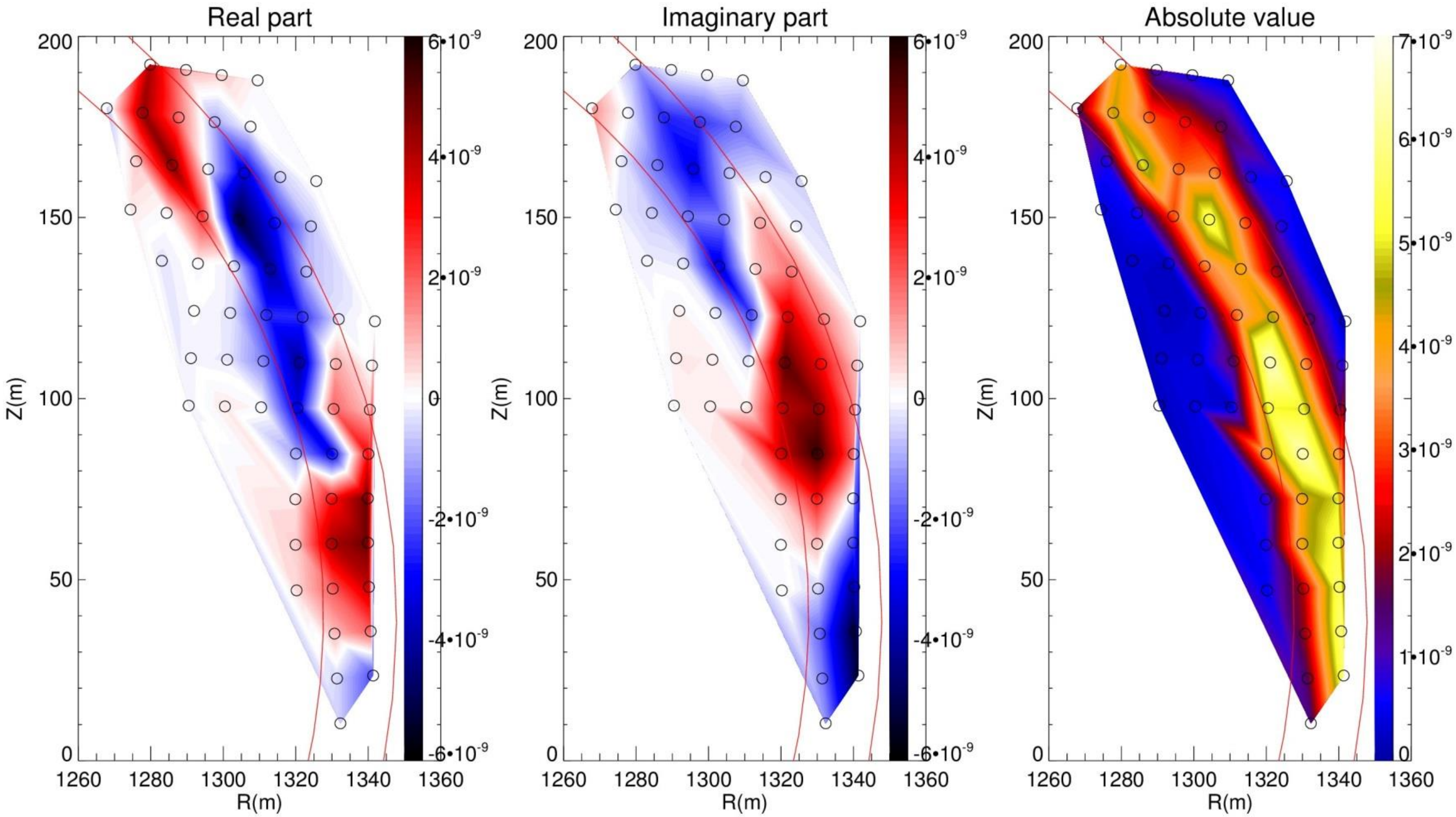


$$\gamma = \frac{\langle s_1 s_2 \rangle}{\sqrt{\langle s_1 s_1 \rangle \langle s_2 s_2 \rangle}}$$

- Turbulence has broad spectrum (~<200kHz)
- Cross-correlation between two poloidal locations
- Cross-phase conveys propagation speed

Cross-correlation: 100-200kHz (κ_h=0.83,high density)

- Cross-correlation shows narrow radial structure 0.8<r/a<1; poloidal elongation and detailed phase pattern

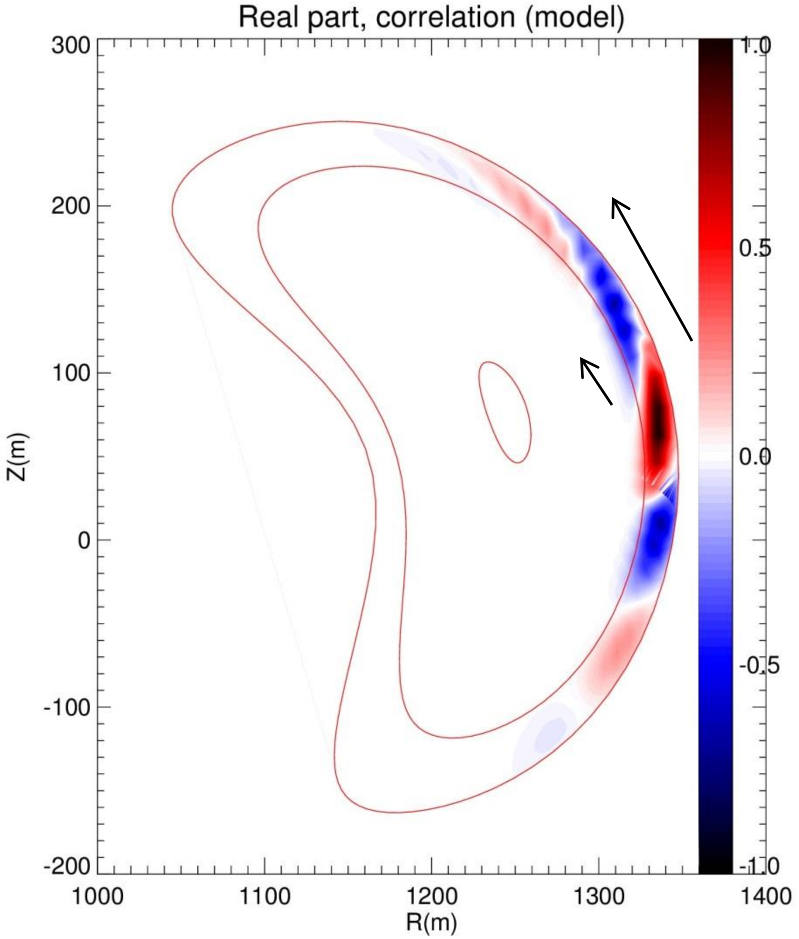


Model function fit

$$\Gamma = \exp\left(-\frac{(\rho-\rho_0)^2}{\Delta\rho^2} - \frac{(\theta-\theta_0)^2}{\Delta\theta^2} + ik_r(\rho-\rho_0) + im(\theta-\theta_0) \right)$$

- k_r=-10.
- m_0=10.
- $\Delta\rho$=0.1
- $\Delta\theta$=0.5
- Eddy tilt, in direction of shear flow

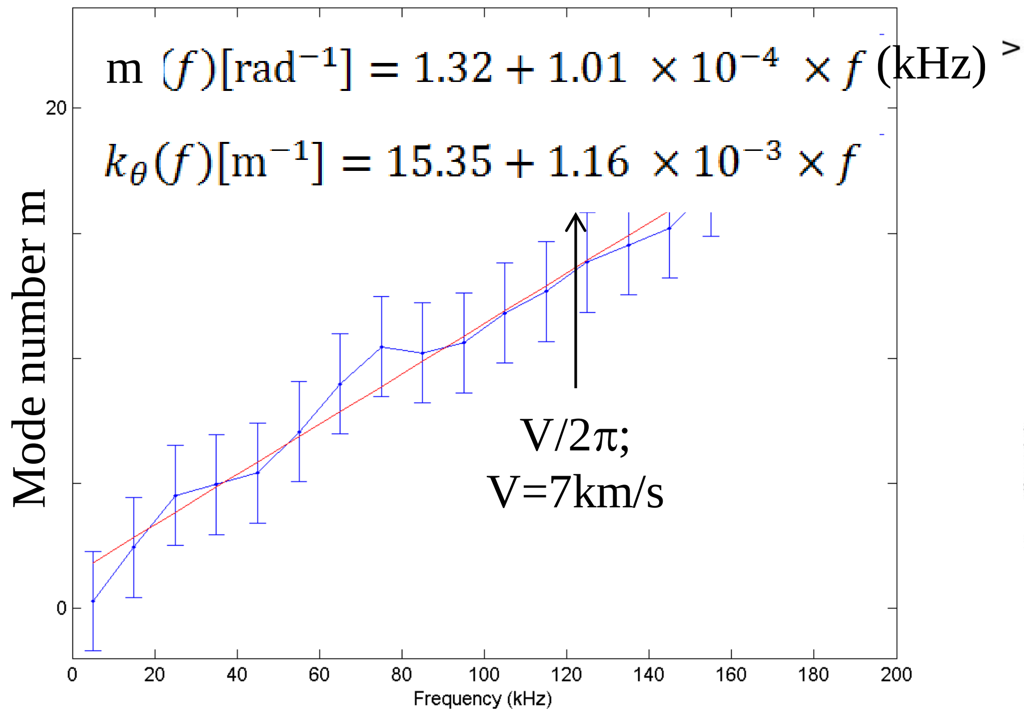
- k_θ = 0.83cm^{-1}
- ρ_g = 0.1cm
- $k_\theta \rho_g$ ~ 0.1 (for ~100kHz)

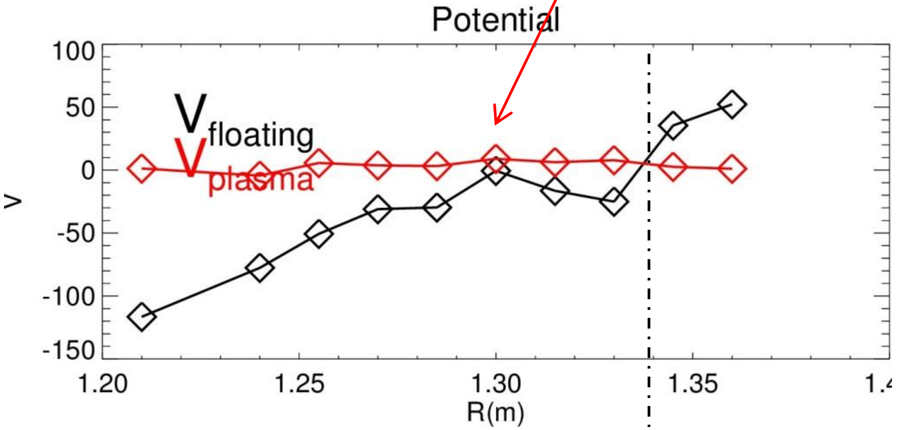


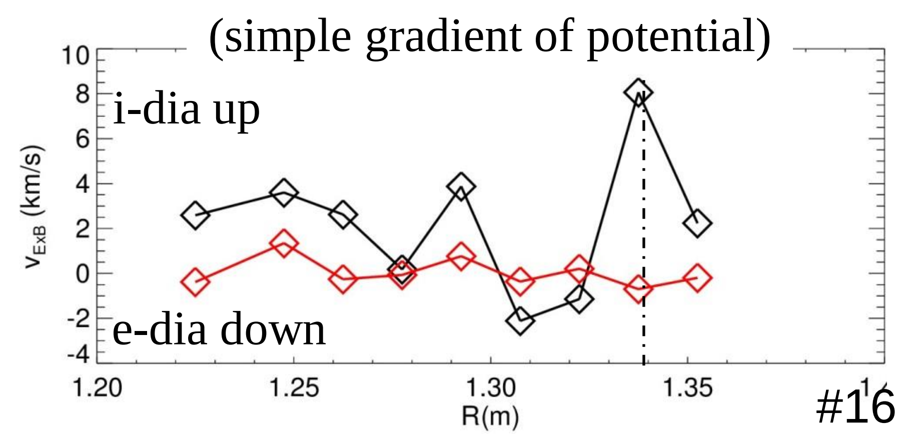
Poloidal phase velocity

- V_θ =7km/s up (ion dia direction). Compare this with v_{ExB}?
- Is probe potential profile reliable to calculate E? ($V_{fl} = V_{pl} + 2.54\ T_e$)
  - Which 'V' to Use?
- Need more careful measurements in edge.
  - Peak V_{ExB}~7km/s (idia)
- For drift wave, $V_\theta = V_{ExB} + v_{dia}$, for MHD type mode, $V_\theta = V_{ExB}$

V_{plasma} from BPP was incorrectly measured







Fluctuation induced flux

$$\Gamma_{\perp}^{fl} = \frac{k_\theta}{B}\langle\tilde{n}\tilde{V}_p\rangle = \int_0^\infty T(\omega)\, d\omega$$

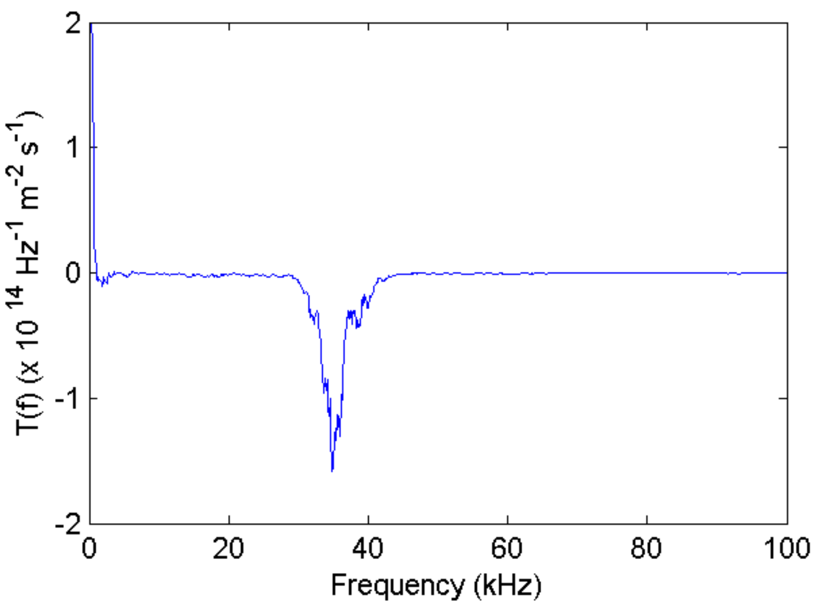
- **Transport spectral density function [1]:**

$$T(\omega) = \frac{k_\theta(\omega)}{B}\sqrt{P_{nn}(\omega)P_{VV}(\omega)}\ |\gamma_{nV}(\omega)|\ sin[\alpha_{nV}(\omega)]$$

Using
Ball-pen probe
To obtain V_{pl}

$$\Gamma_{\perp}^{fl} = \int_0^\infty T(\omega)\, d\omega = -\,5.2\ \times 10^{17} m^{-2} s^{-1}$$

Γ_{total}~1-5x$10^{18}$$m^{-2}s^{-1}$

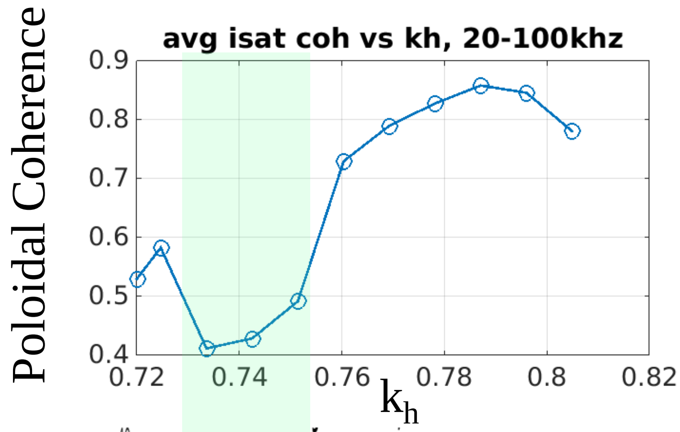


Fluctuation driven flux is similar to total flux

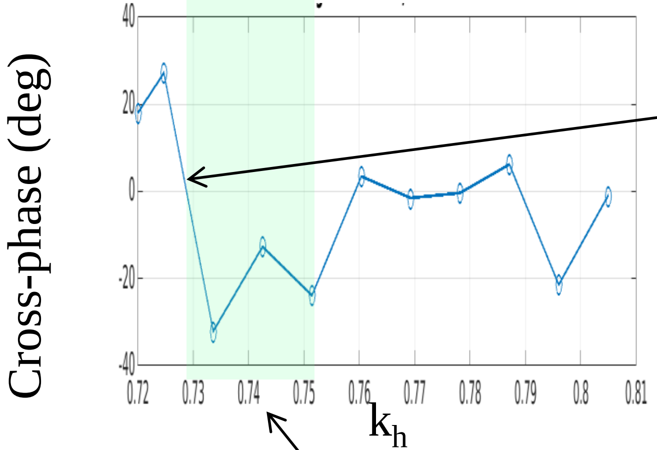
Dominated by coherent modes
Not broadband turbulence

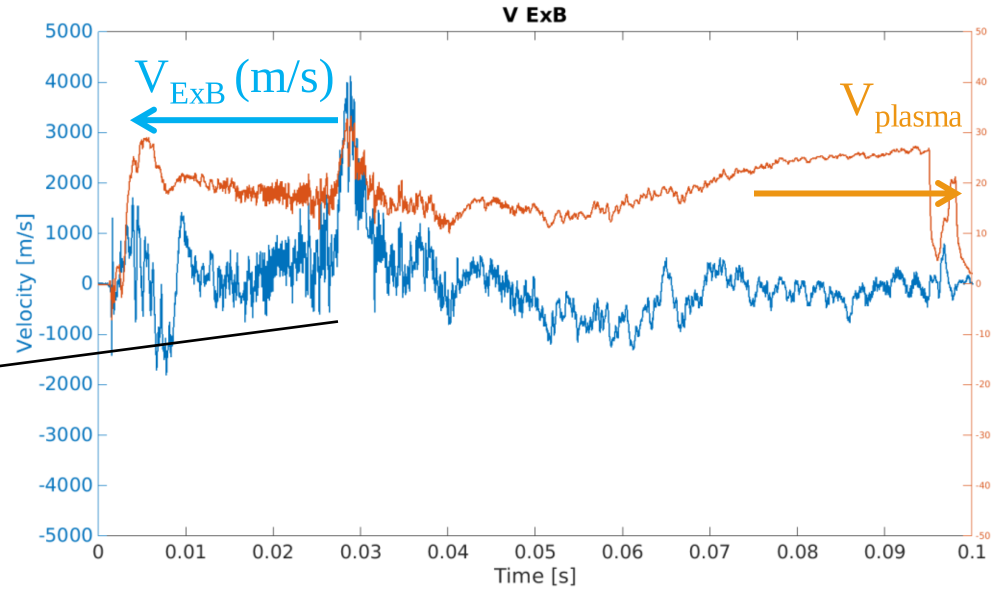
[1] E.J. Powers , Nucl. Fusion, vol. 14 (1974)

New dataset showing reversal of fluctuation direction upon loss of confinement



Probe separation: ~60mm poloidally





Density decreases

- “Transition” linked to burst in plasma potential
- Ambition: Calculated fluctuation induced flux, nonlinear parameters, examine transition in more detail

Conclusions

- Coherent mode amplitude increases with poorer confinement (κ_h=0.73) :
  - 7/5 resonance near edge in region of magnetic hill: interchange instability
  - Inverse turbulence cascade pumping low frequency modes
- Dithering between two states analogous to transition phenomena in the pedestal
- Edge turbulence structure:
  - Poloidal propagation near ExB velocity
  - Eddy tilt ~ 45^0: surprisingly large
  - Long range correlation not found so far
- Coherent modes <100kHz drive most of the fluctuation-induced-flux at k_h=0.83
  - Modes may be related to Alfven / sound continuum (BAE)
  - How can electrons & ions be "decoupled"?
- Plans:
  - k_θ spectrum measured as function of iota: fluctuation-induced flux to be calculated (and compared with net flux)
  - Reynolds stress, transition dynamics (more probe tips)
  - Other diagnostics: 21ch interferometer, C II emission tomography
  - Island healing/growing, relation to flow shear