

Quasi-Coherent Fluctuations Limiting the Pedestal Growth on Alcator C-Mod: Experiment and Modeling

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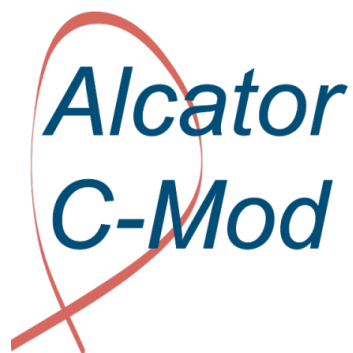
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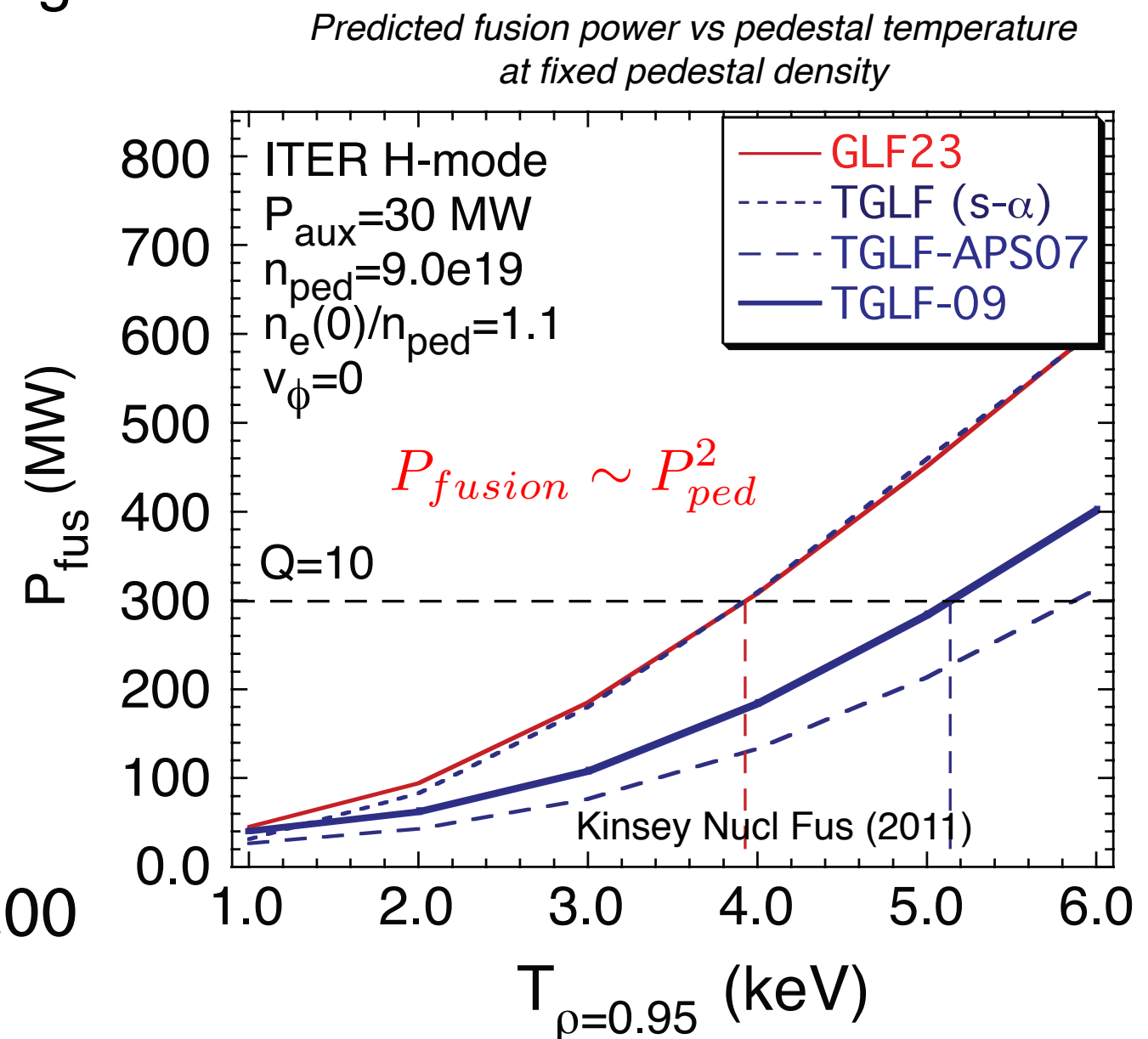
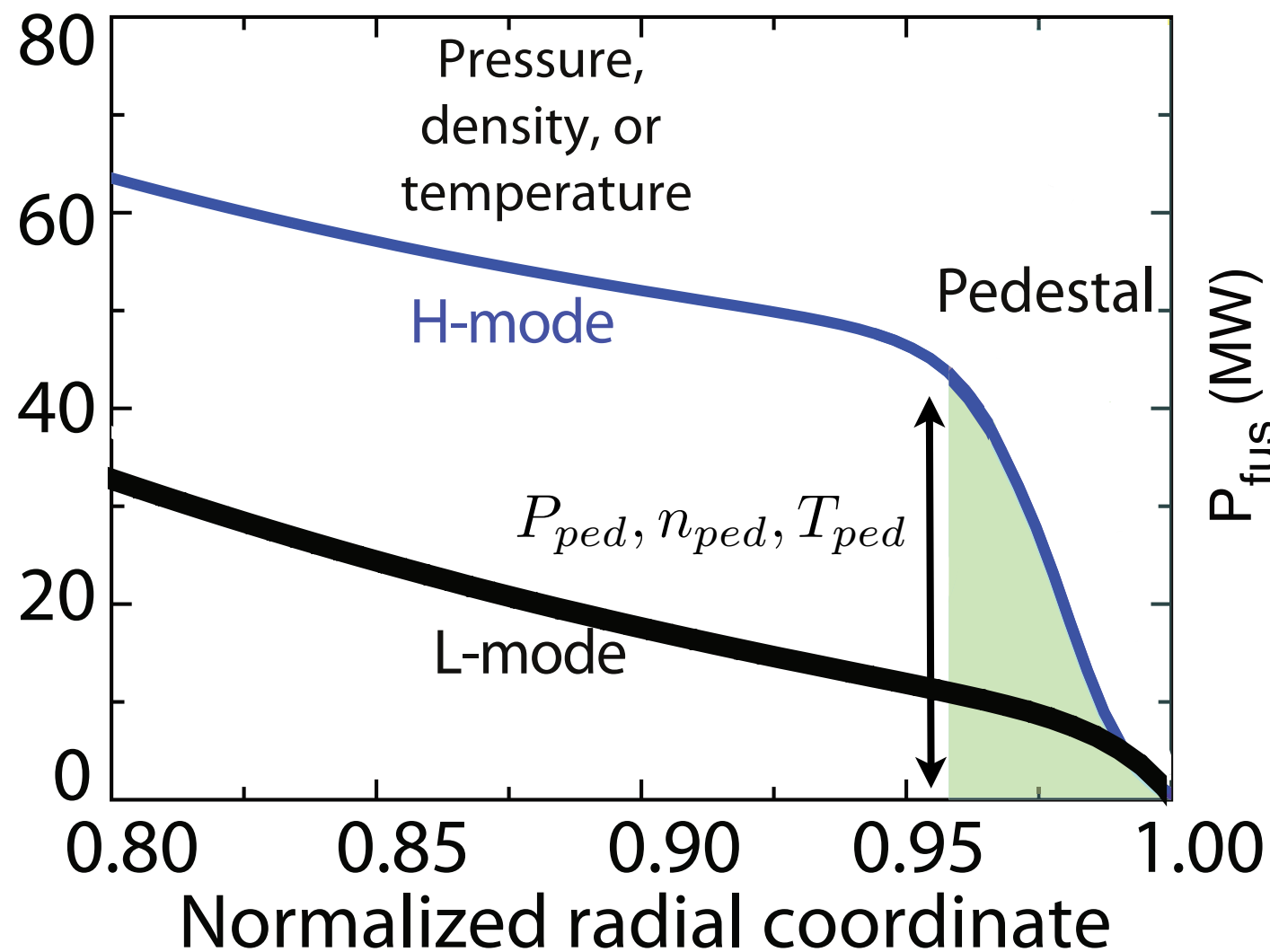


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Objective: Understanding the pedestal structure is crucial for performance prediction of fusion devices

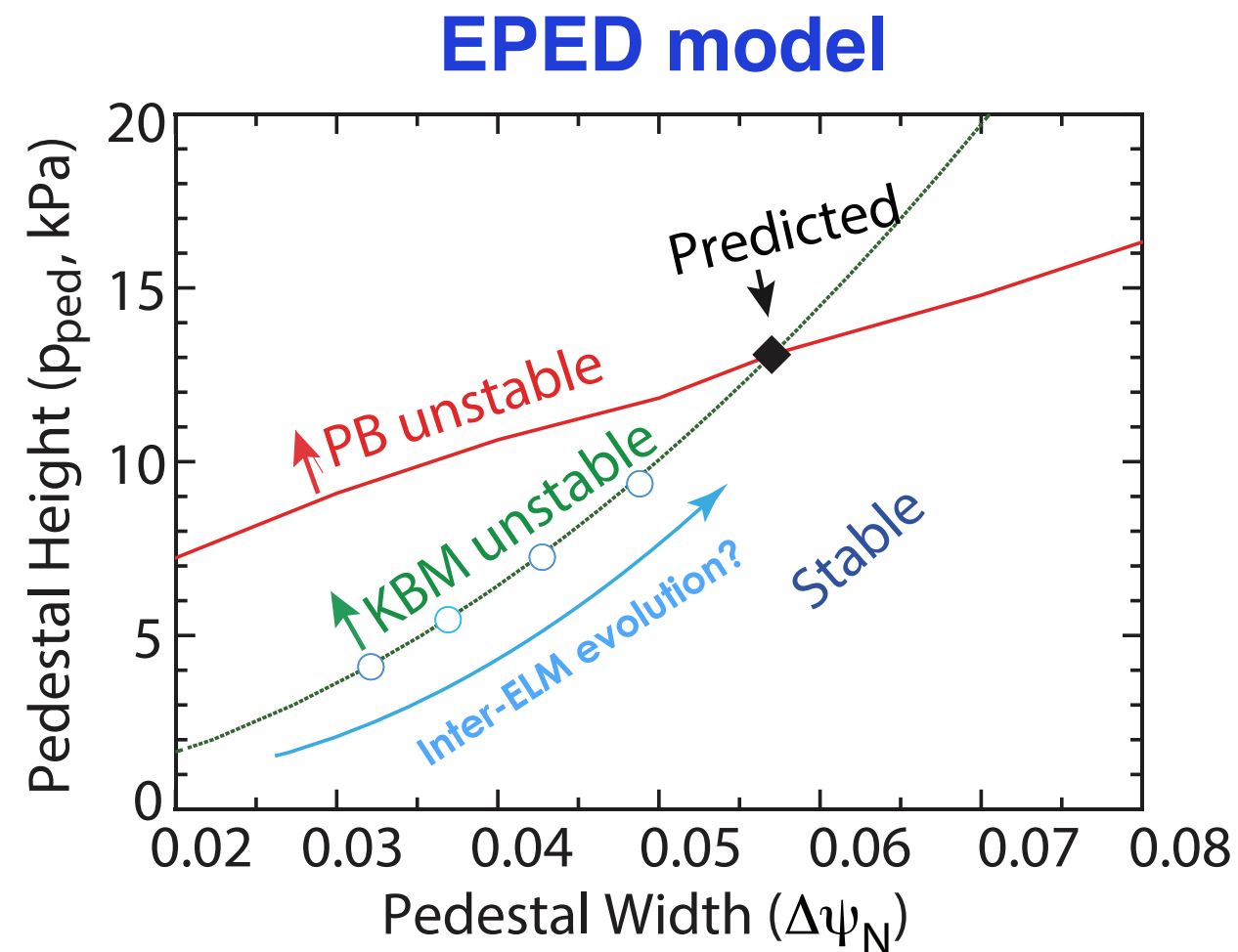
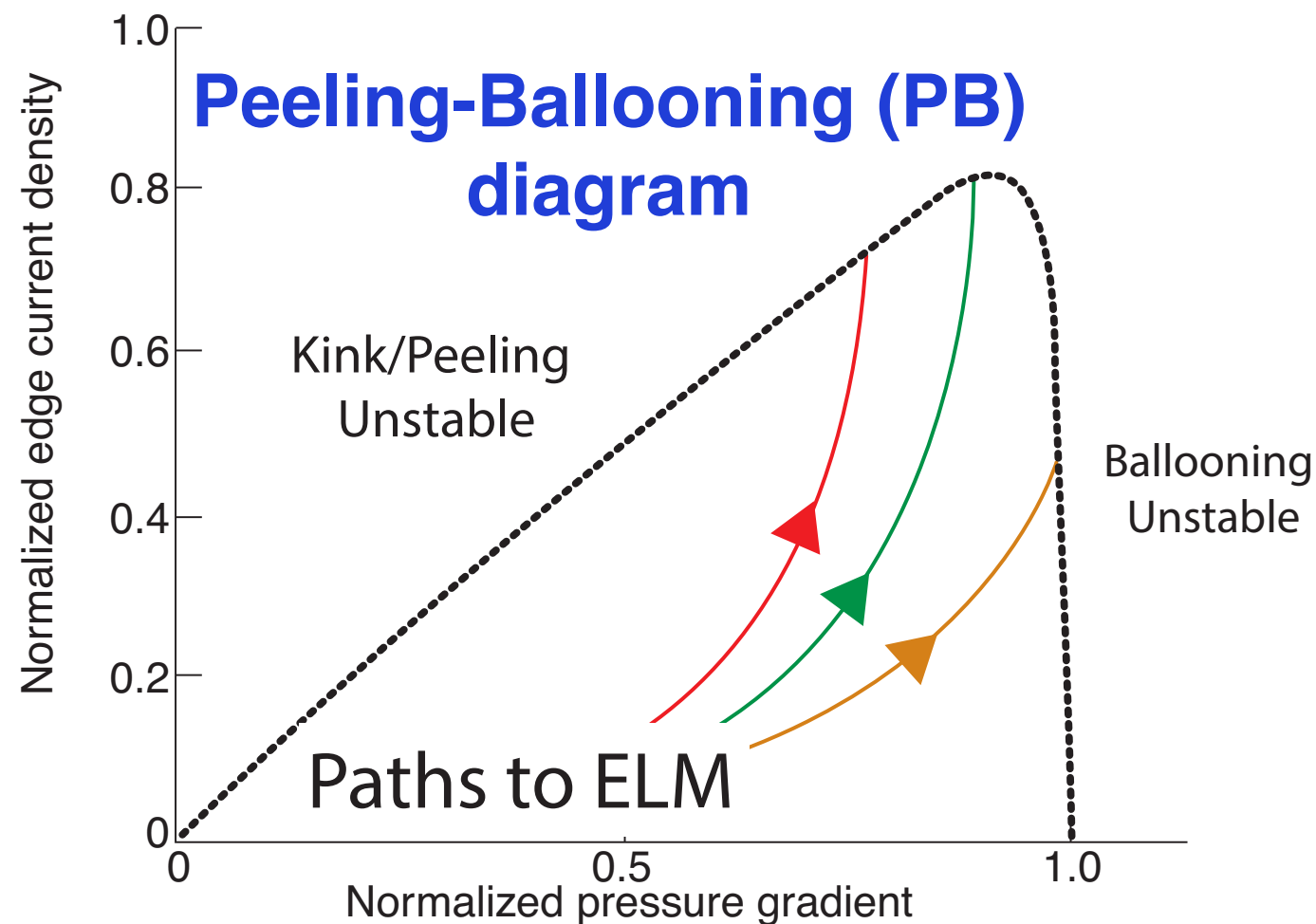
- Substantial pedestal heights are critical for achieving high fusion power in ITER
- Link between pedestal height and global confinement well established by current experiments, transport modeling



EPED predictive model provides a candidate mechanism for pedestal formation

- EPED: pedestal structure set by two key limiting instabilities:
 - non-local peeling–ballooning modes (PBM) — trigger for edge-localized mode (ELM)
 - nearly local kinetic ballooning modes (KBM) — regulates transport between ELMs
- Combining these two constraints allows prediction of two unknowns, the pedestal height and width.

Connor, PoP (1998); Wilson, PoP (2002);
Snyder, PoP (2001); Snyder, NF (2011)

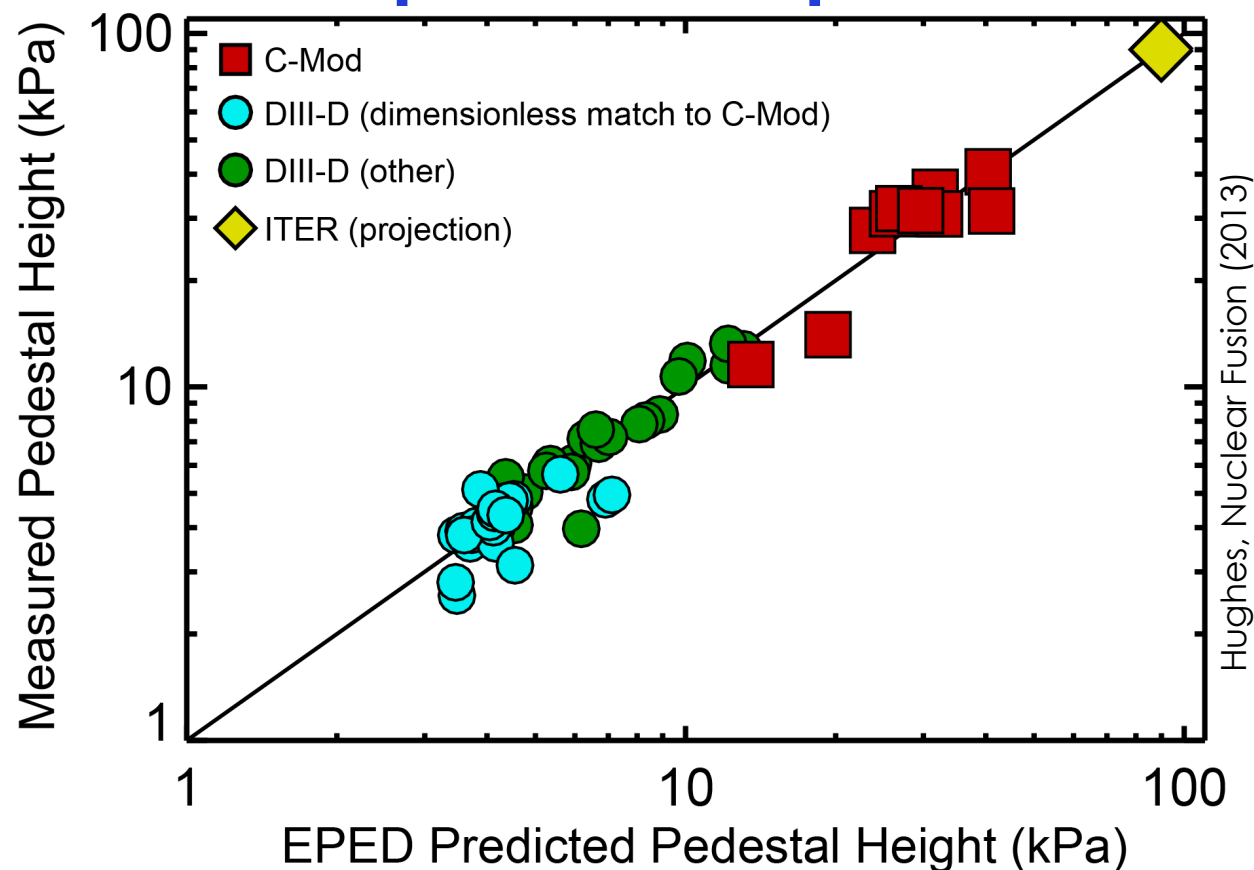


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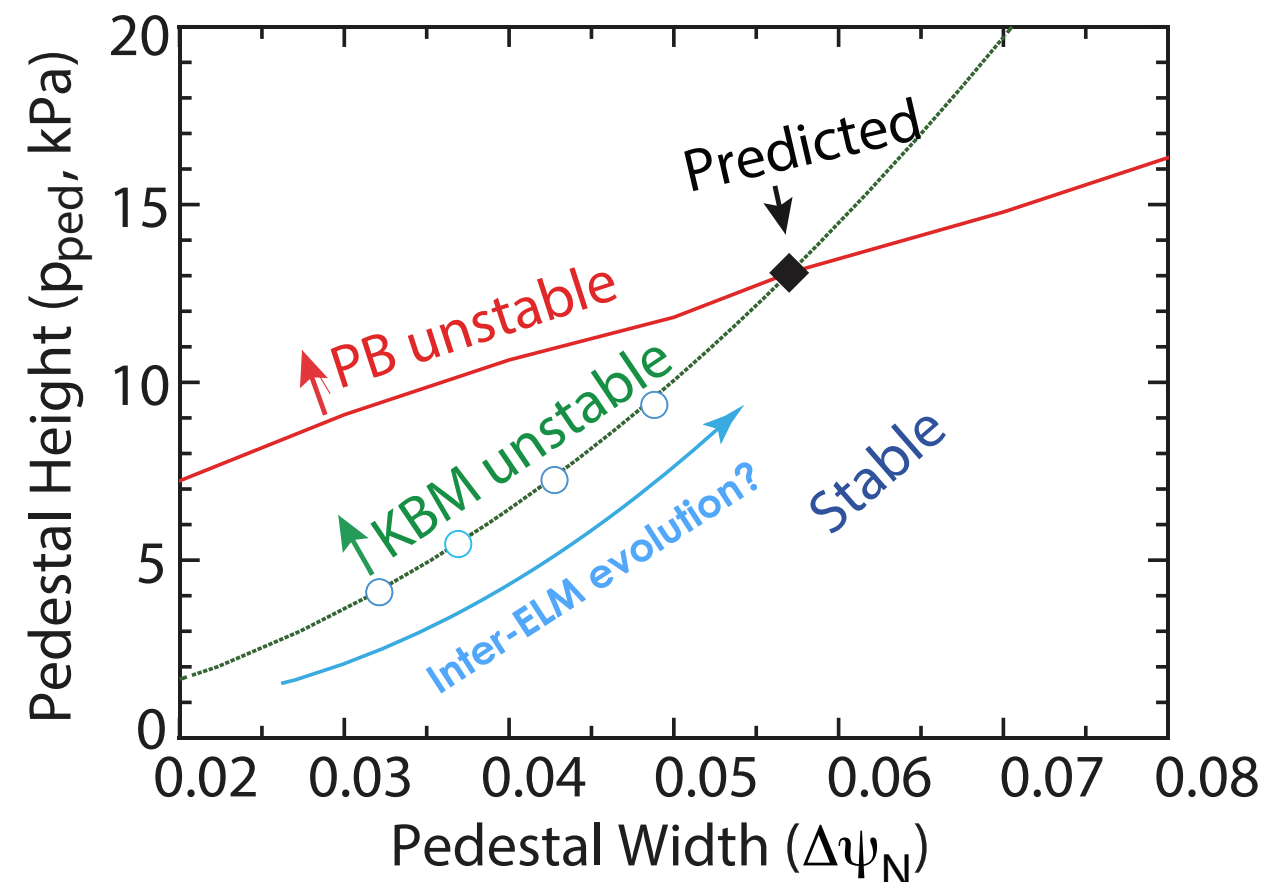
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EPED predictions compared to experiment



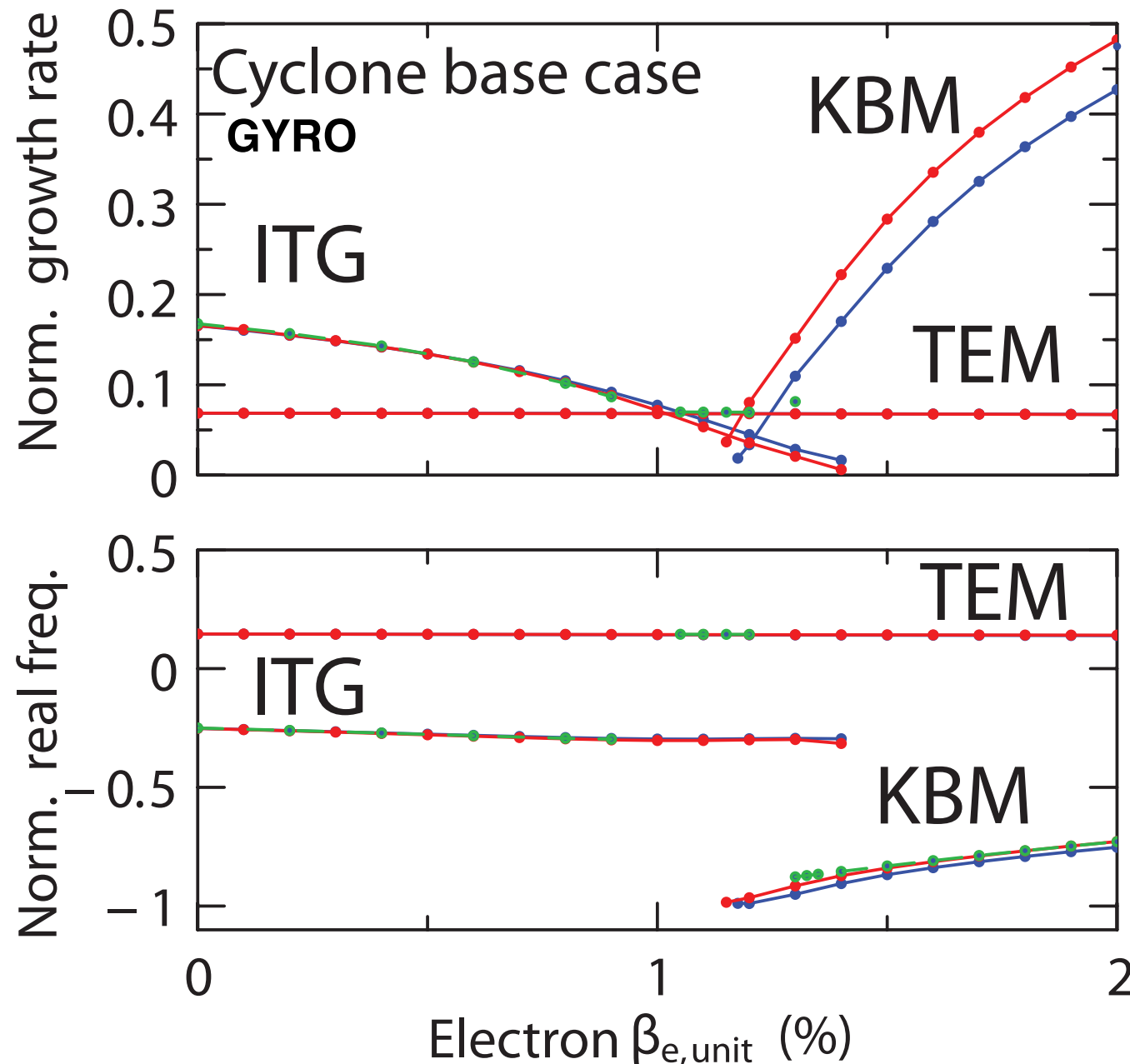
EPED model



Can we find signatures of pedestal-limiting mechanisms between ELMs?

Theory predicts a sensitivity of KBM growth rate to β — observable between ELMs?

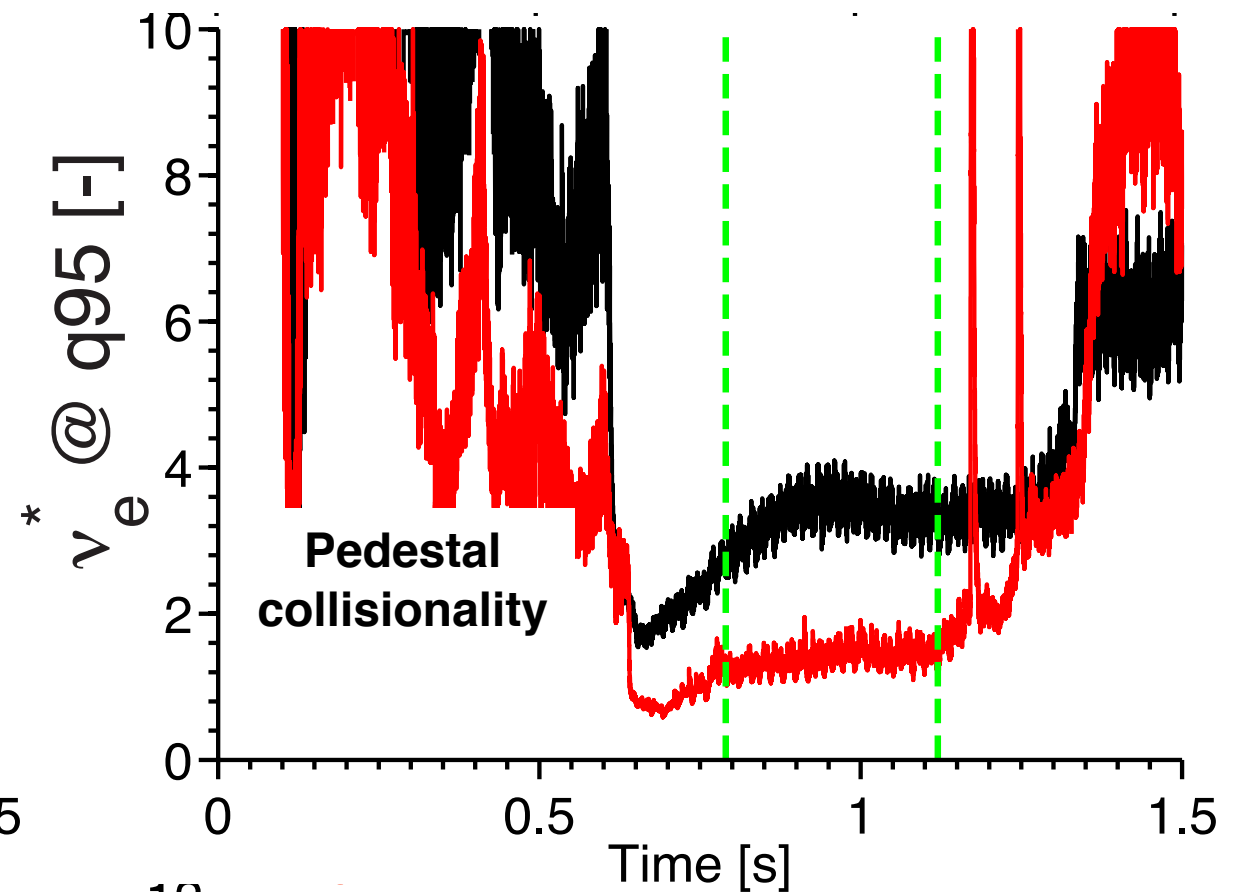
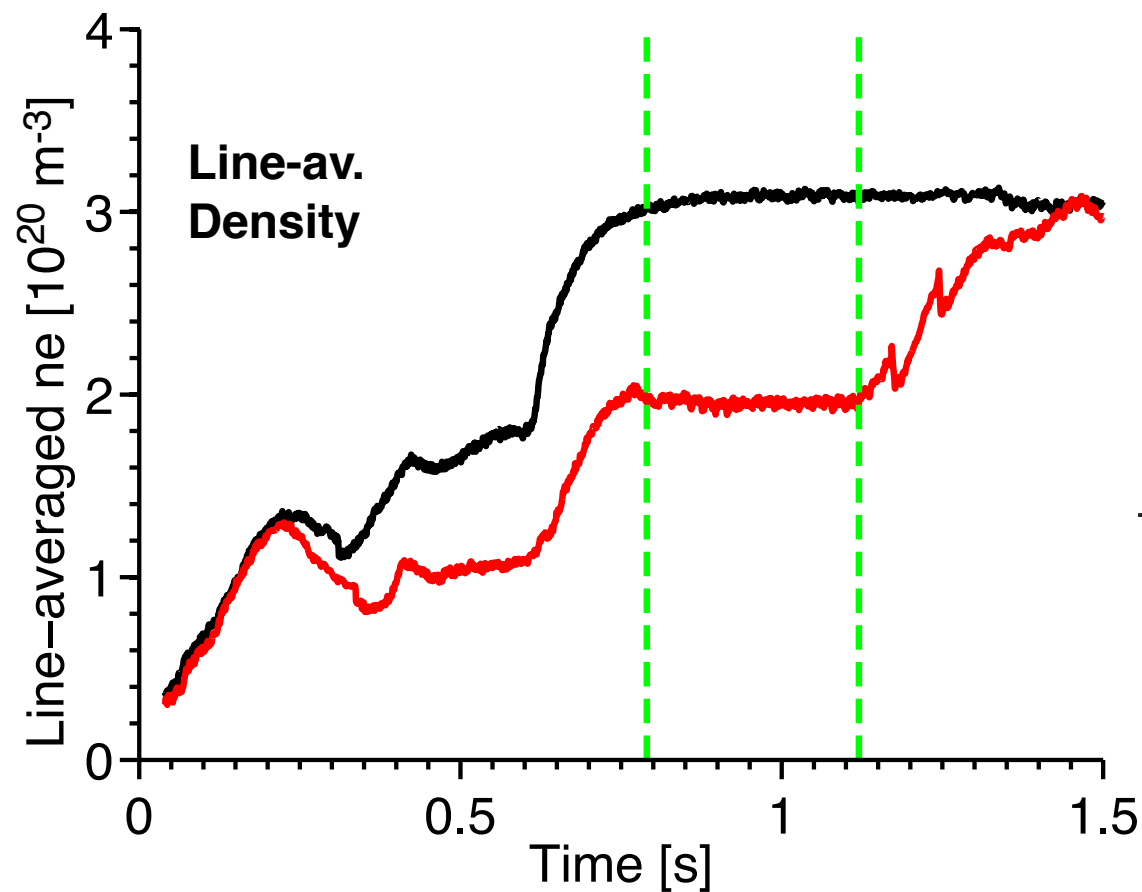
Belli and Candy Phys. Plasmas 17, 112314 (2010)



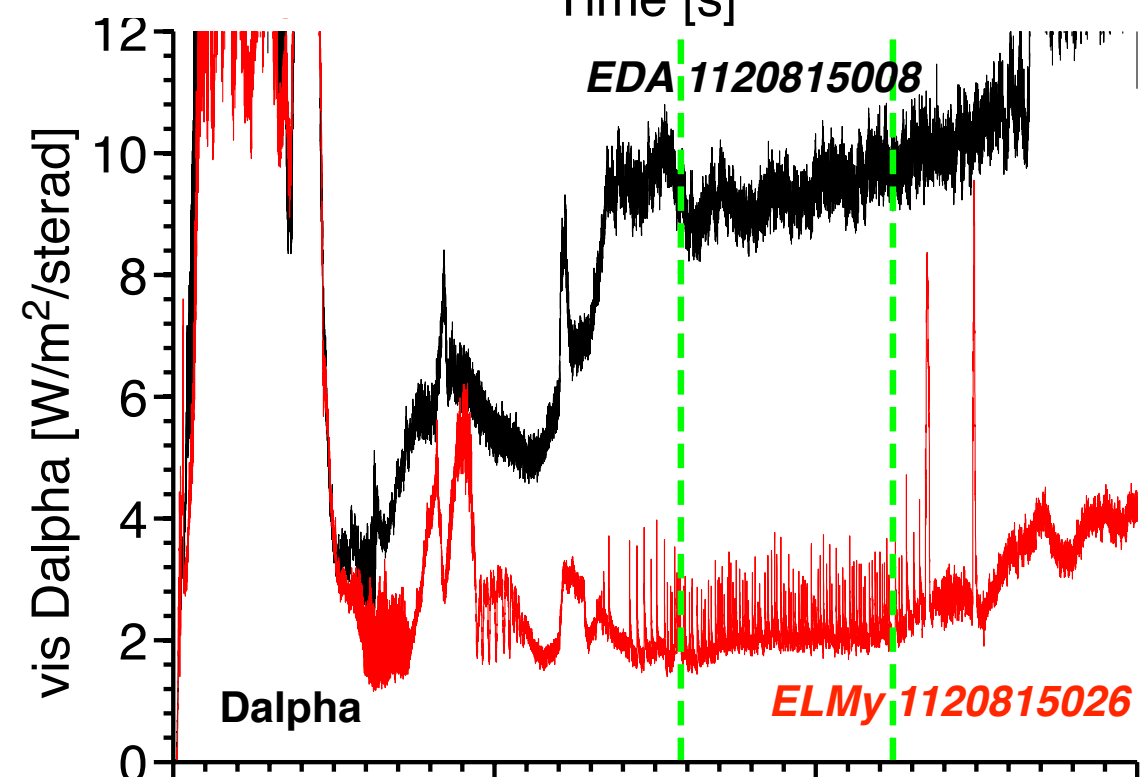
Variations can be captured between ELM cycle

- Experimental goal: Identify and characterize *turbulent fluctuations* during the ELM cycle
- Expected measurable characteristics
 - Pedestal localized
 - Intermediate- n and electromagnetic mode
 - Sudden change in growth rate
 - Ion spatial scale ($k\rho_s < 1$)
 - Propagates in ion diamagnetic direction.

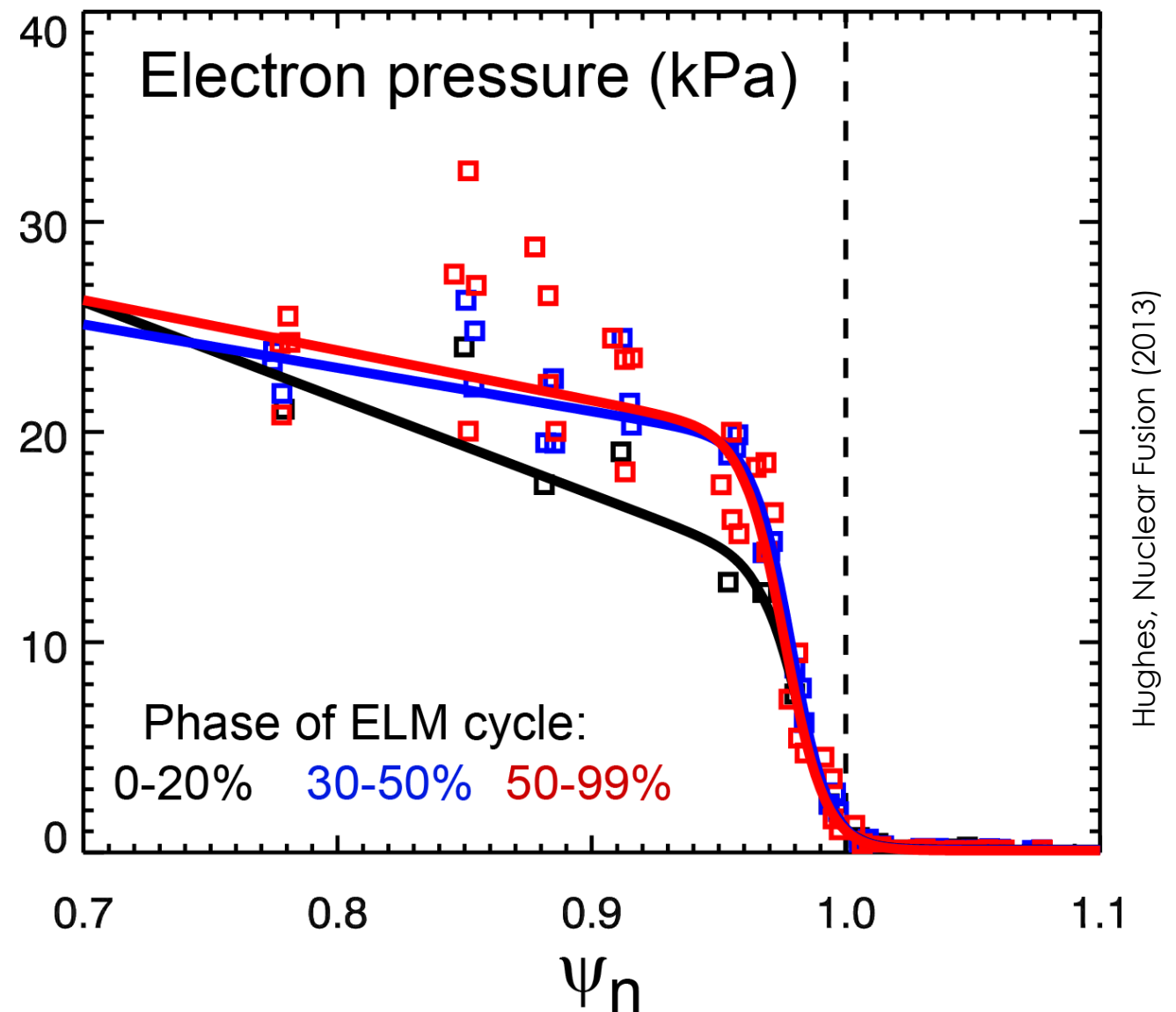
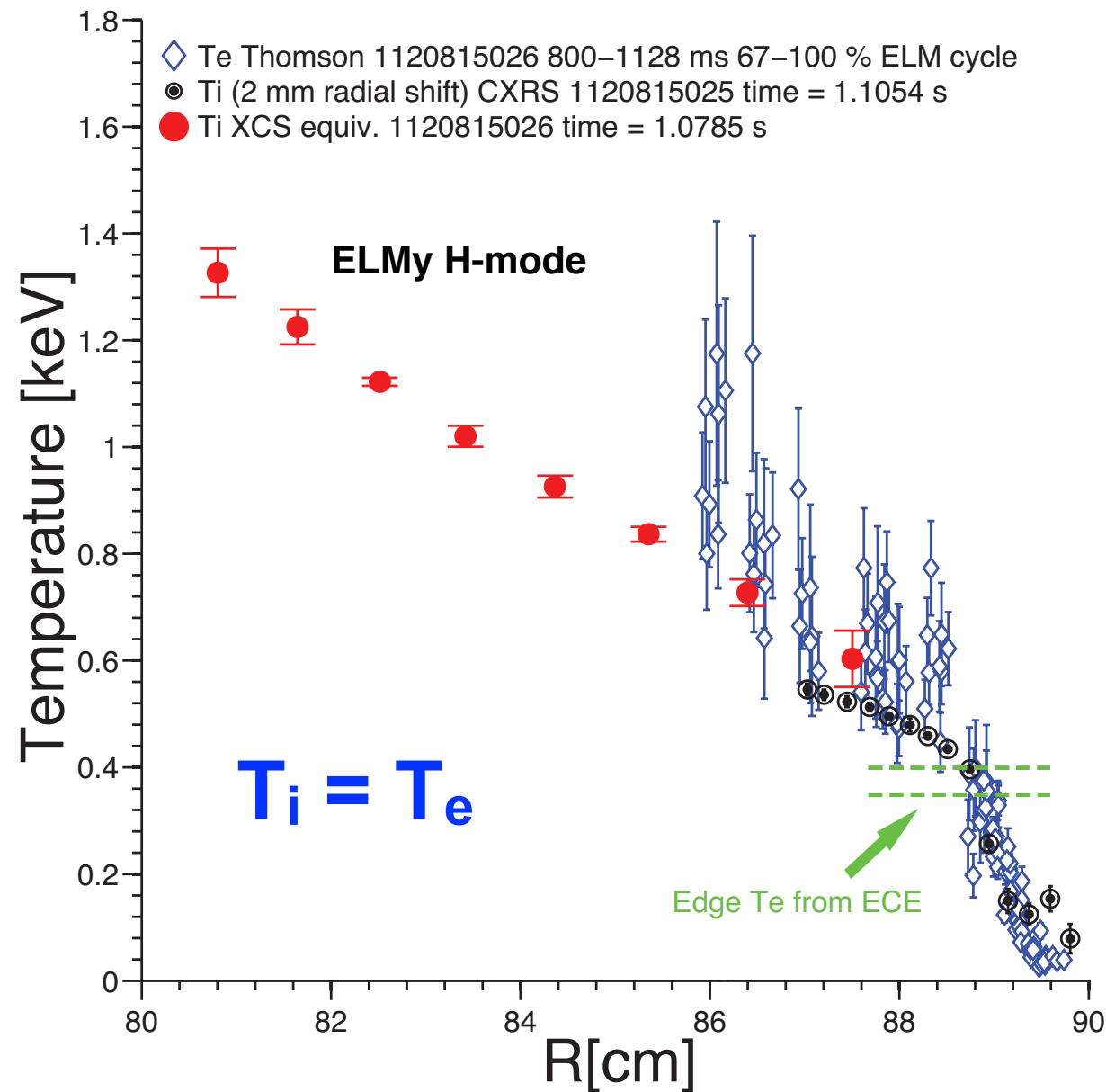
Experimental collisionality scans are used to access Type I ELMy H-mode



Transition from enhanced D_α (EDA) H-mode to **ELMy H-mode** occurs around $\nu^* \sim 1$



Radially resolved profiles may be either averaged over ELMs or binned by phase of ELM cycle

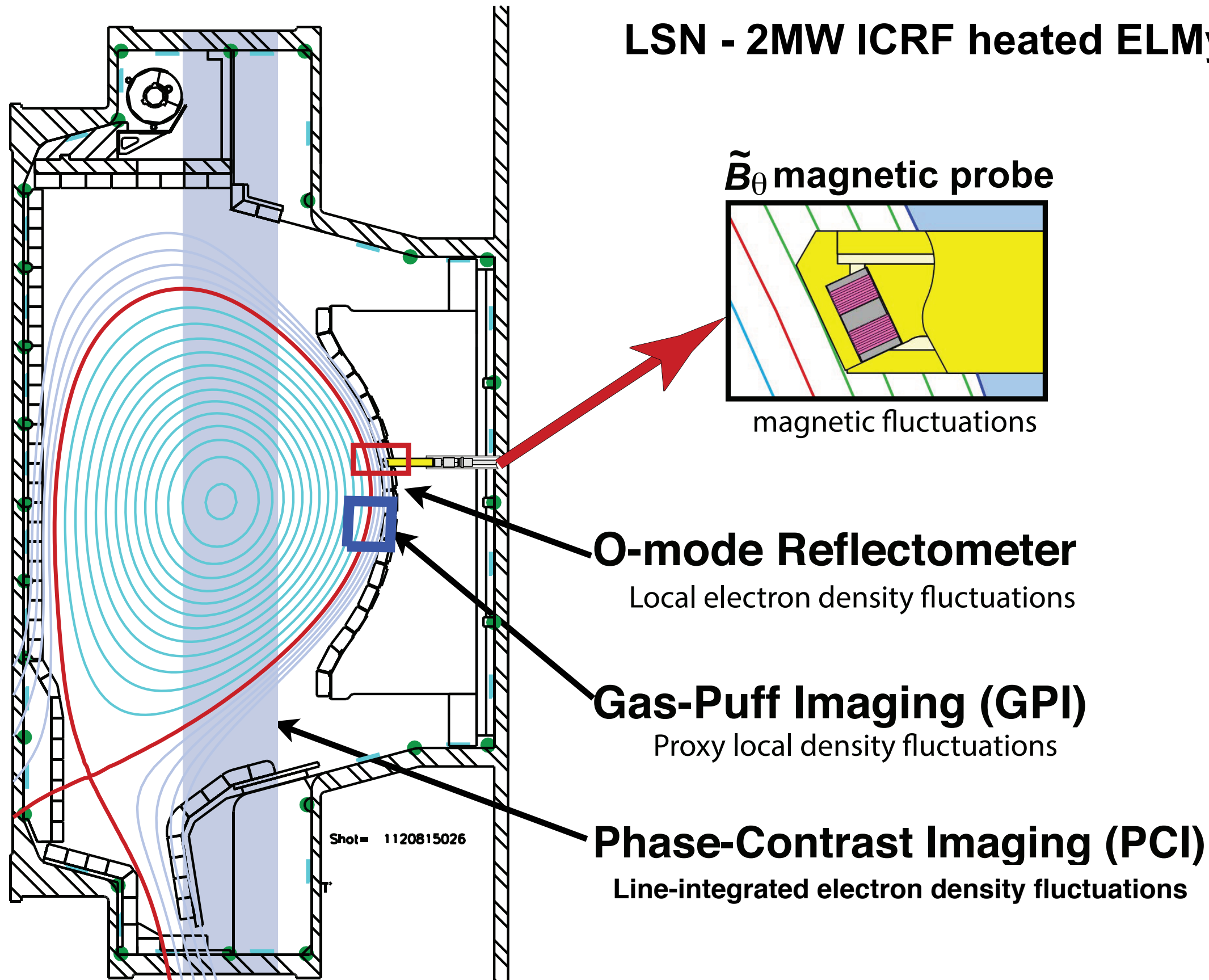


- ELM crash induces fast drop in T_e and measurable rebuild time
- ELM perturbation to density is weaker

Pressure evolution is a test bed for KBM onset

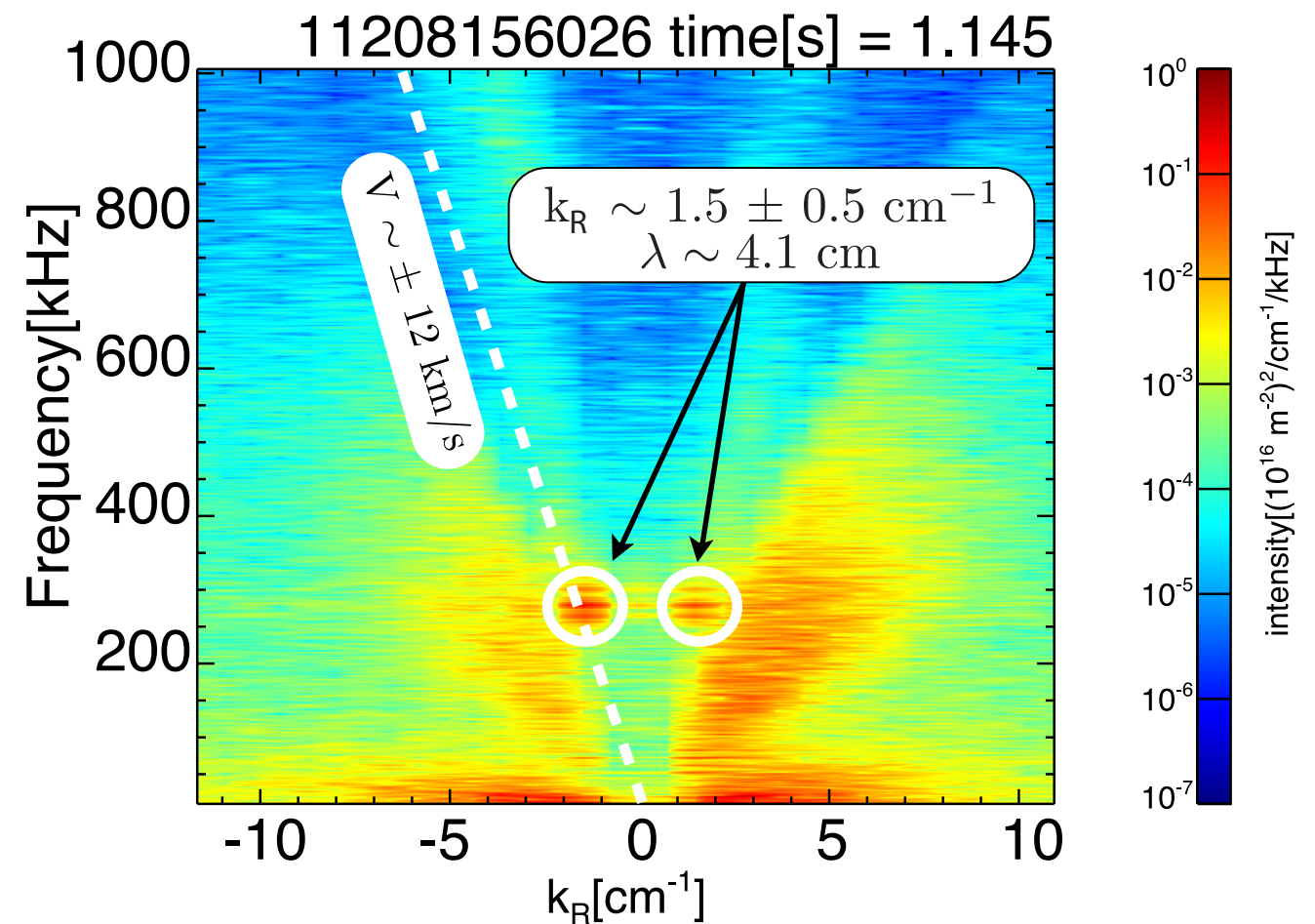
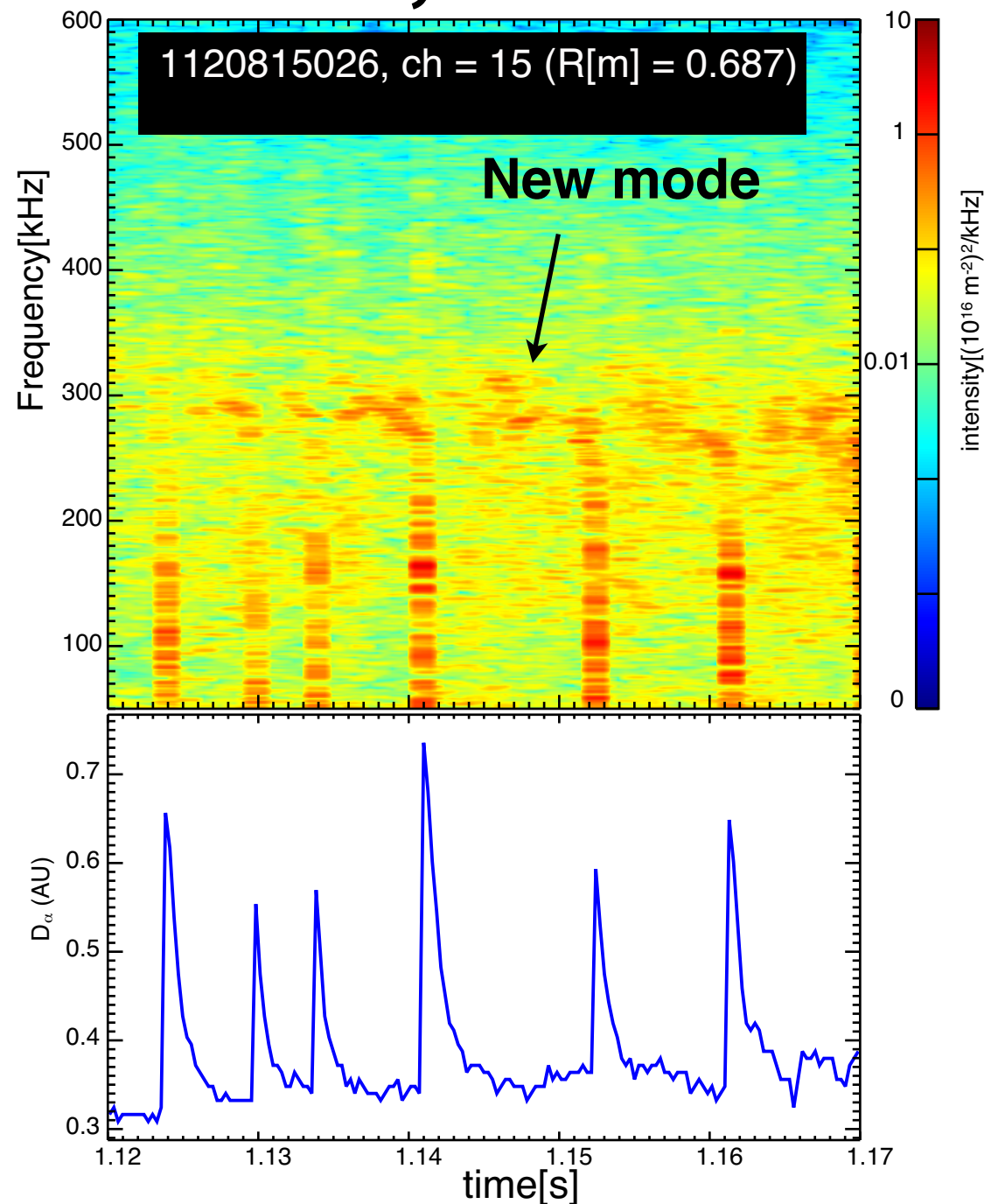
Various poloidally separated diagnostics provide edge fluctuation measurements between ELMs

LSN - 2MW ICRF heated ELMy discharges



Quasi-coherent fluctuations (QCF) are observed on phase contrast imaging (PCI) spectrogram

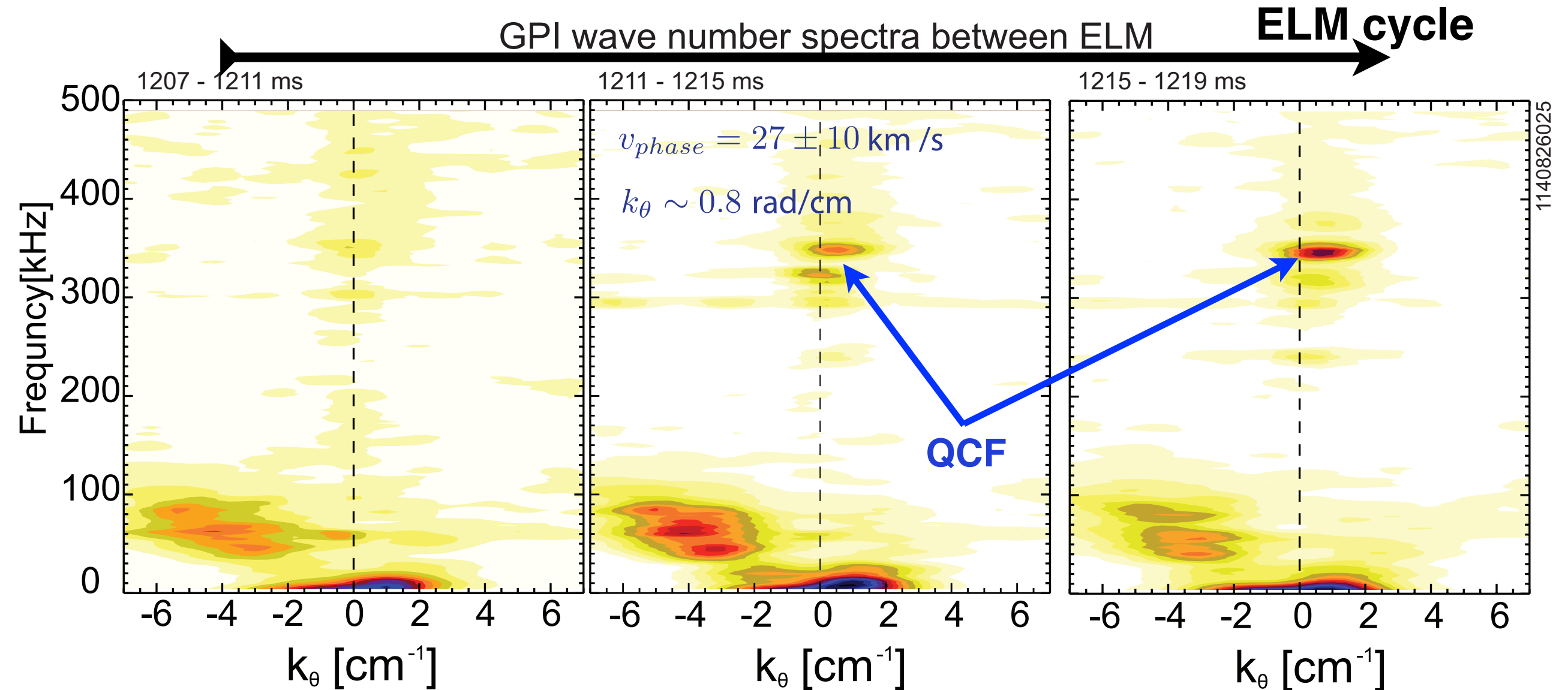
ELMy H-mode



PCI provides an estimate the radial component wavevector

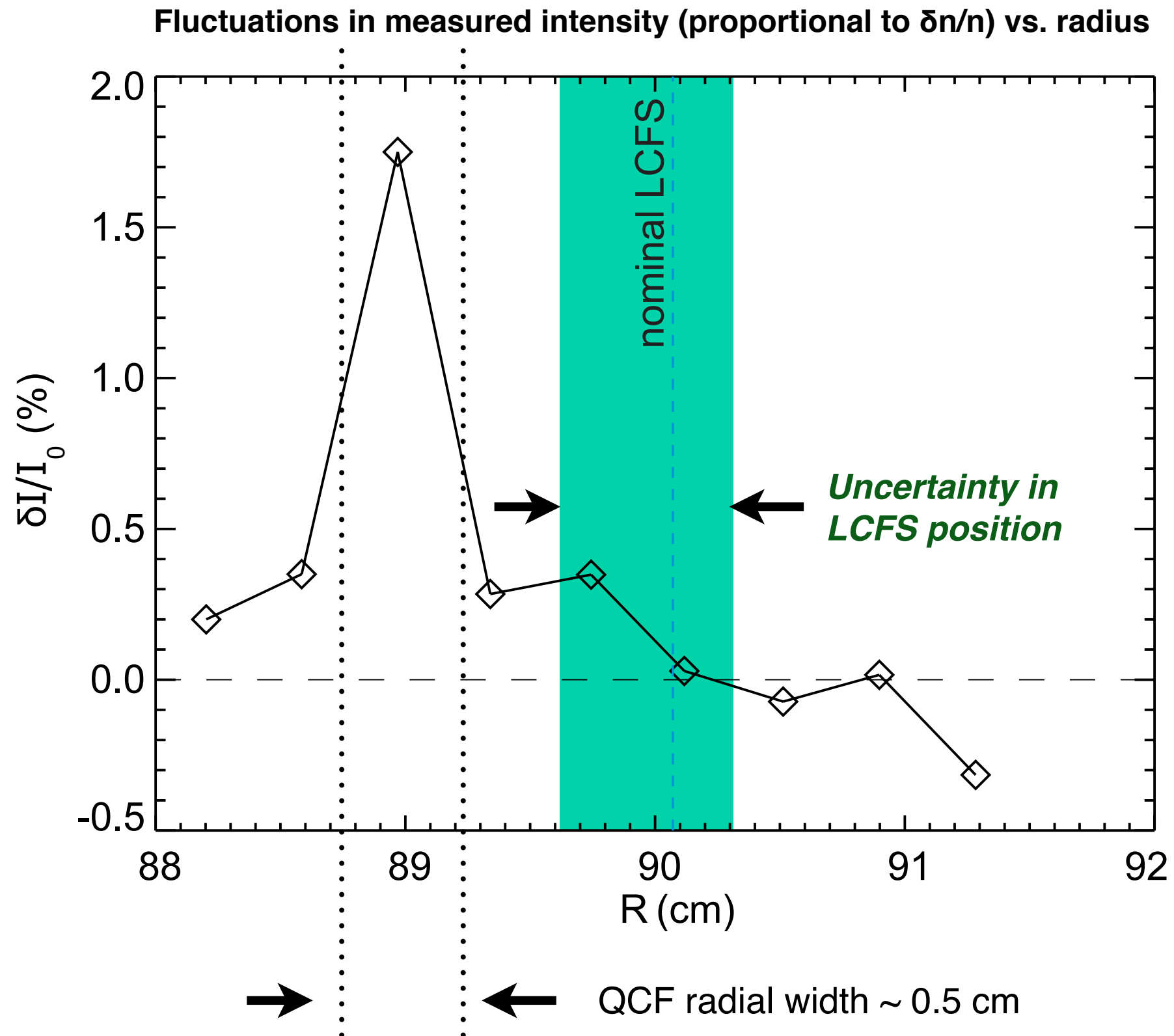
$k_R \Rightarrow k_\theta$ when mode is edge localized

Signatures of the QCF have been observed on gas puff imaging (GPI) between ELMs

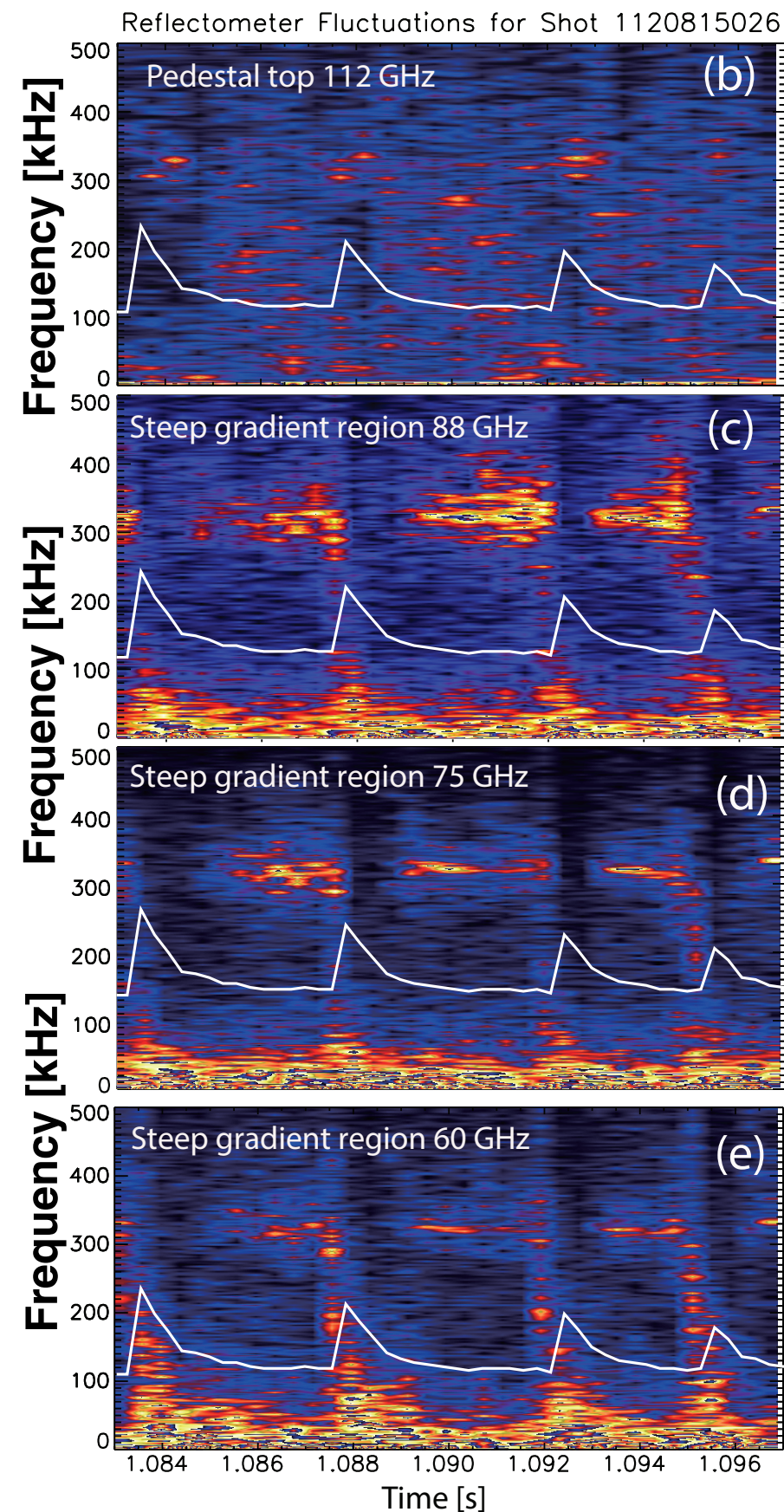
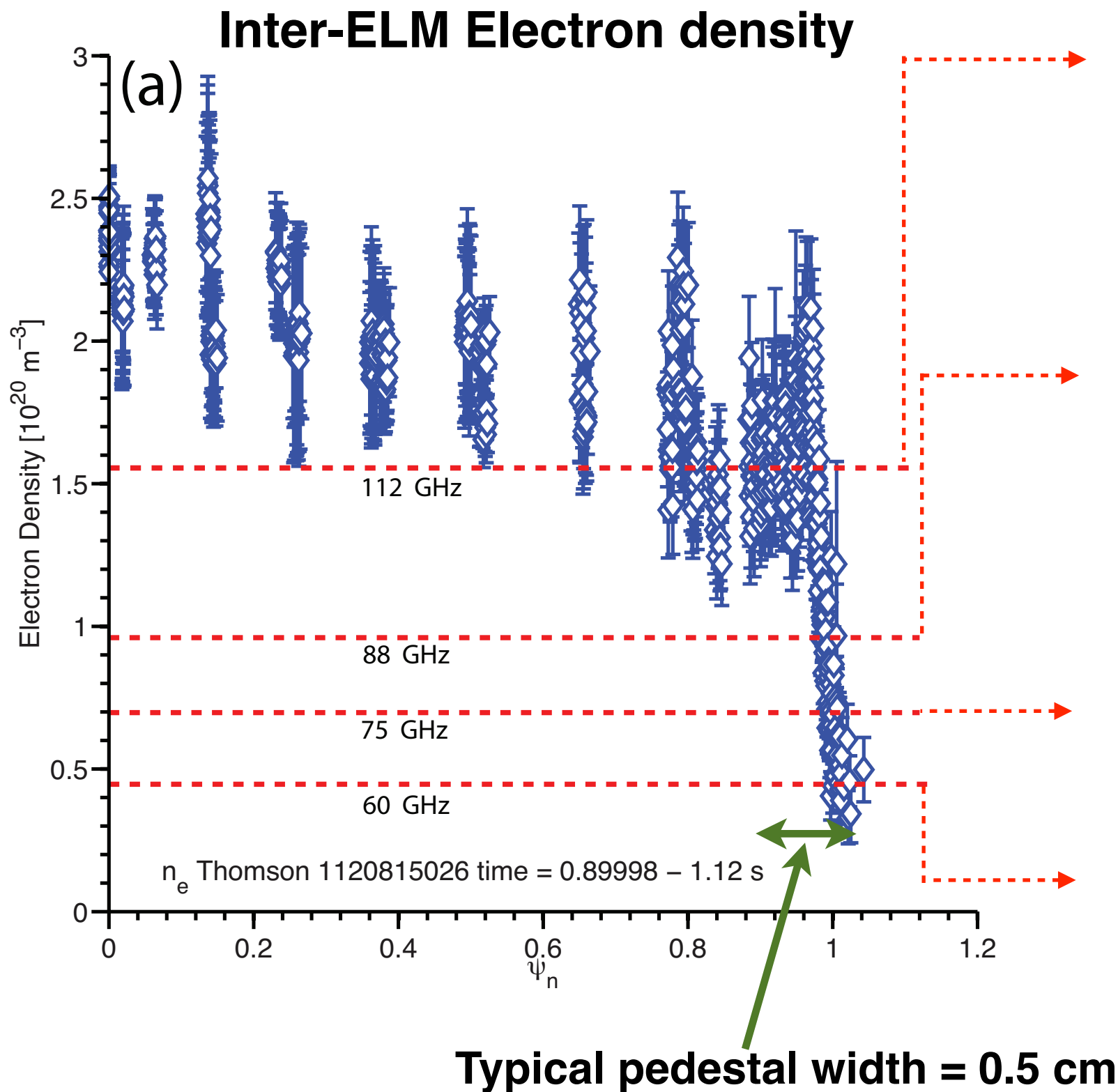


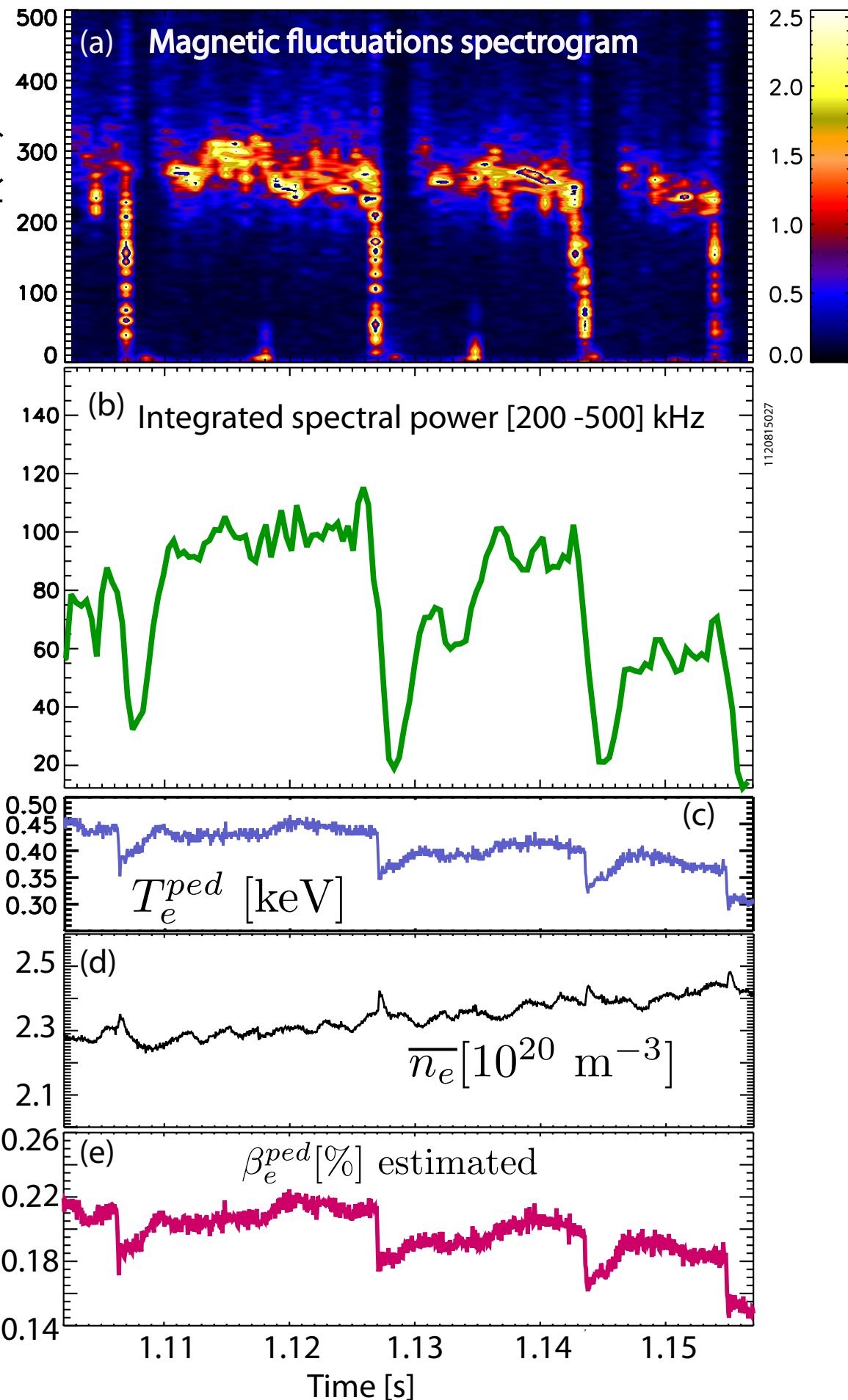
- QCF is coherent in frequency and wavenumber
- Propagates in the electron direction in the lab frame

GPI indicates strong radial localization of QCF



O-mode reflectometry localizes the QCFs to the sub-centimeter scale density pedestal





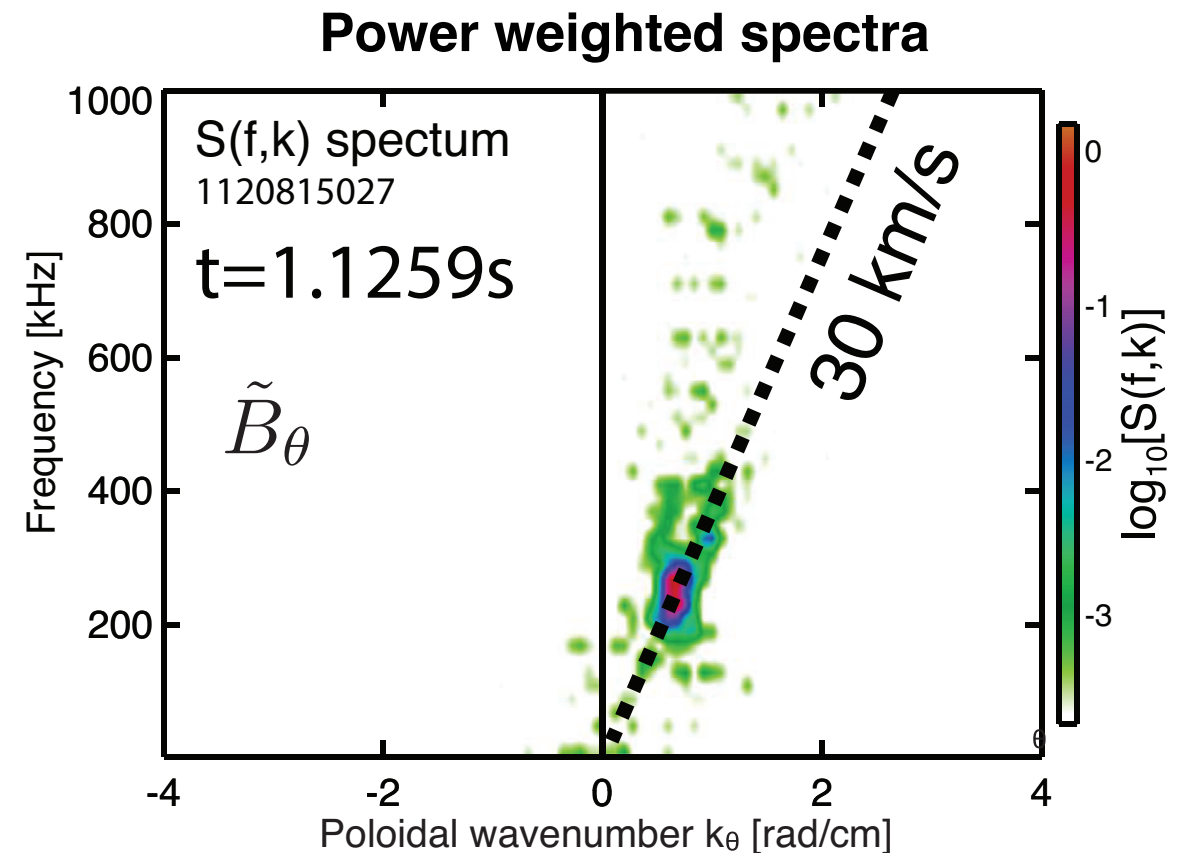
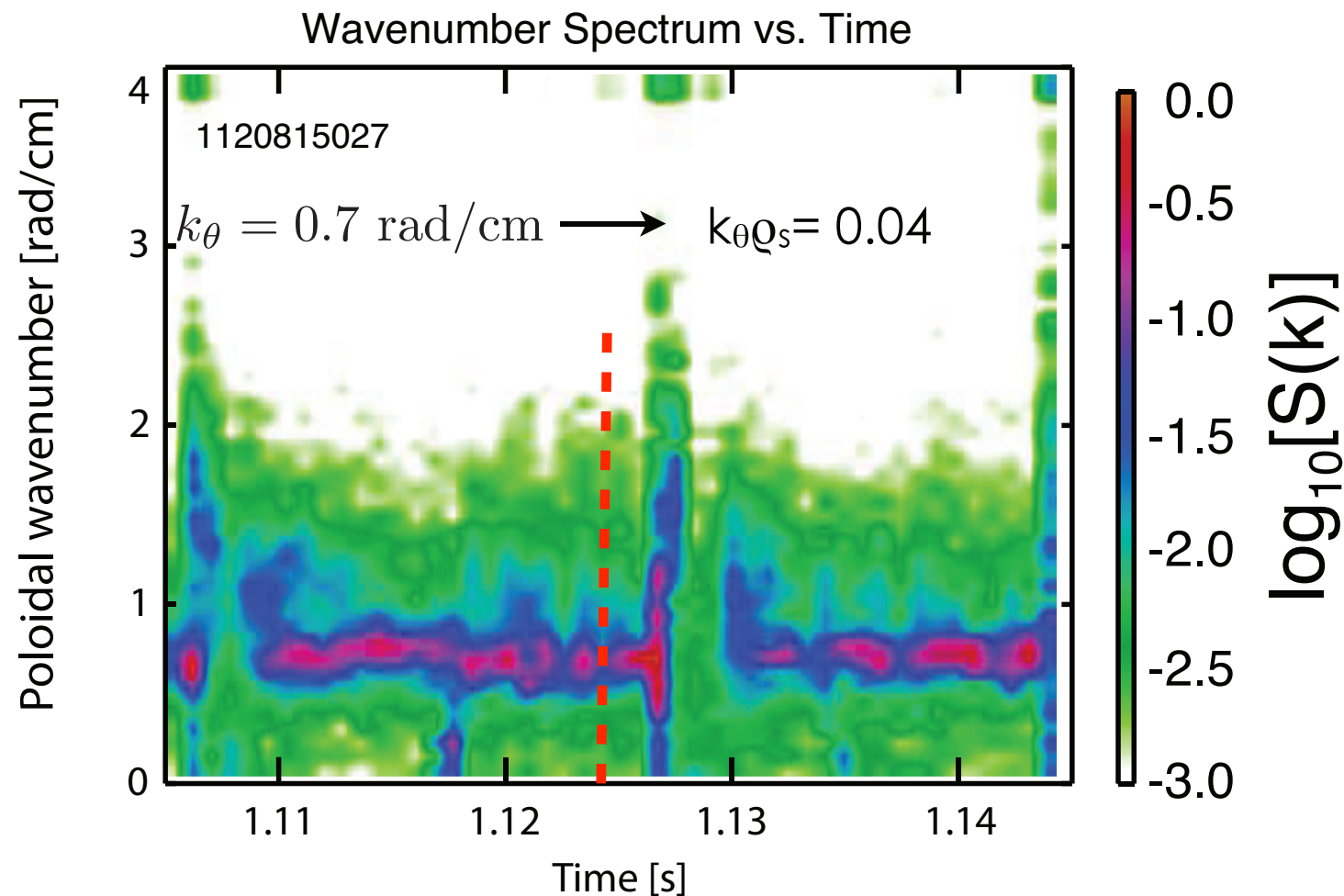
Inter-ELM magnetic fluctuations track the edge electron temperature

- ECE shows prompt drop in T_e .
- Each ELM event is followed by period of the pedestal- T_e increase and then saturation
 - Similar T_e dependence with washboard modes on JET
- Mode *turn on* is correlated with the pedestal saturation
- β -limit is consistent with the expected *KBM* or *microtearing* growth rate dependencies

Perez, PPCF 2004

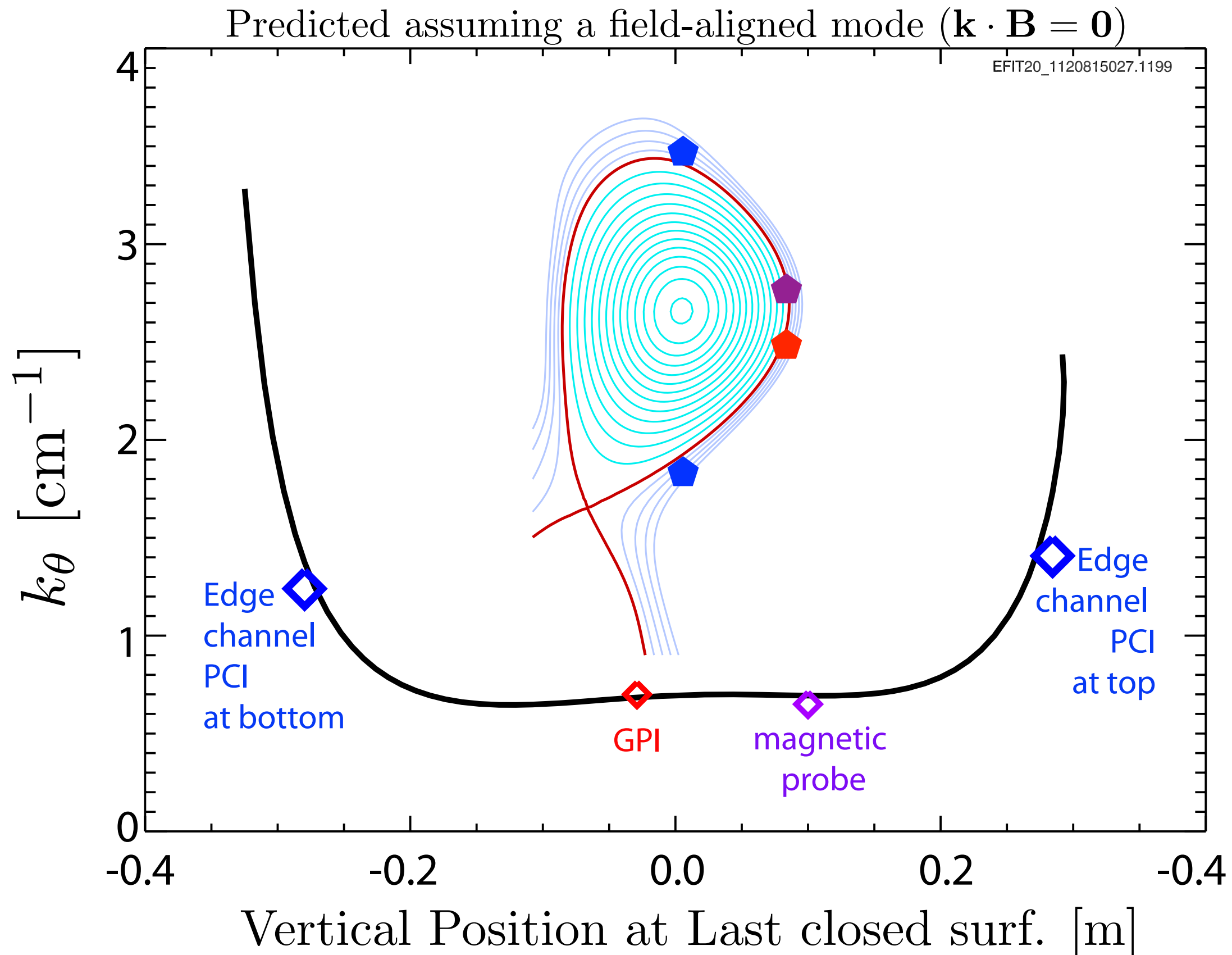
Diallo, PRL (2014)

Quasi-coherent fluctuations are low k_θ and propagate in electron diamagnetic direction (lab frame)

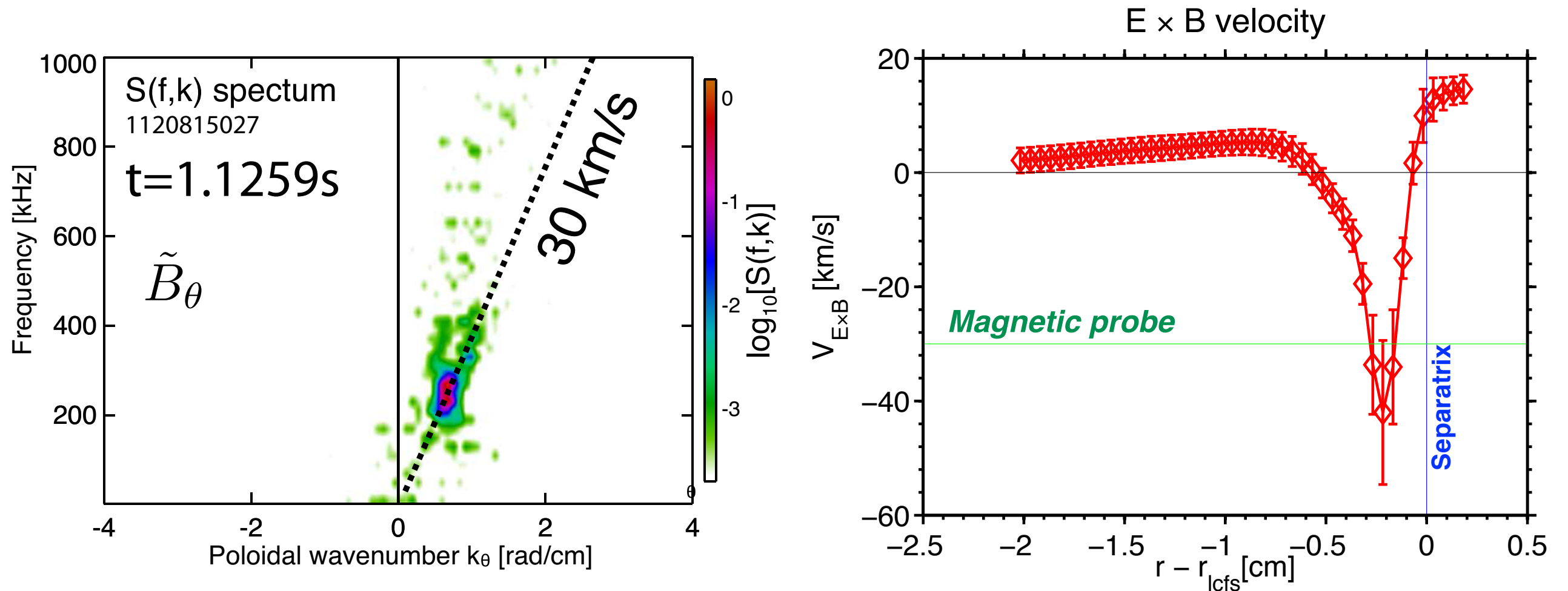


- $k_\theta \rho_s = 0.04$, $n=10$
- Two-point correlation using a double-head magnetic provides the wavenumber and propagation direction

Wavenumbers from various diagnostics consistent with field-aligned perturbation

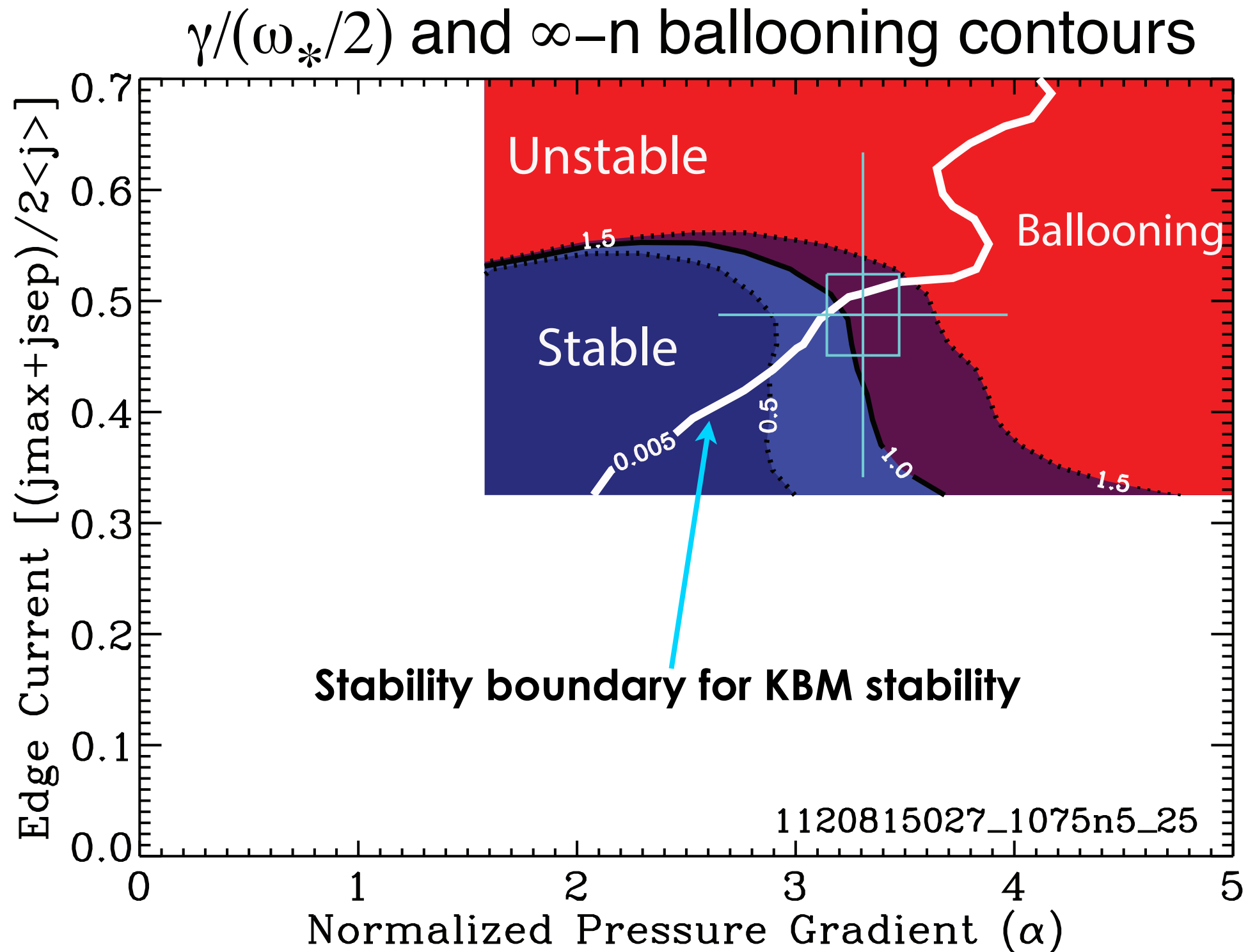


Pedestal-localized fluctuations are consistent with an ion mode, localized to E_r well

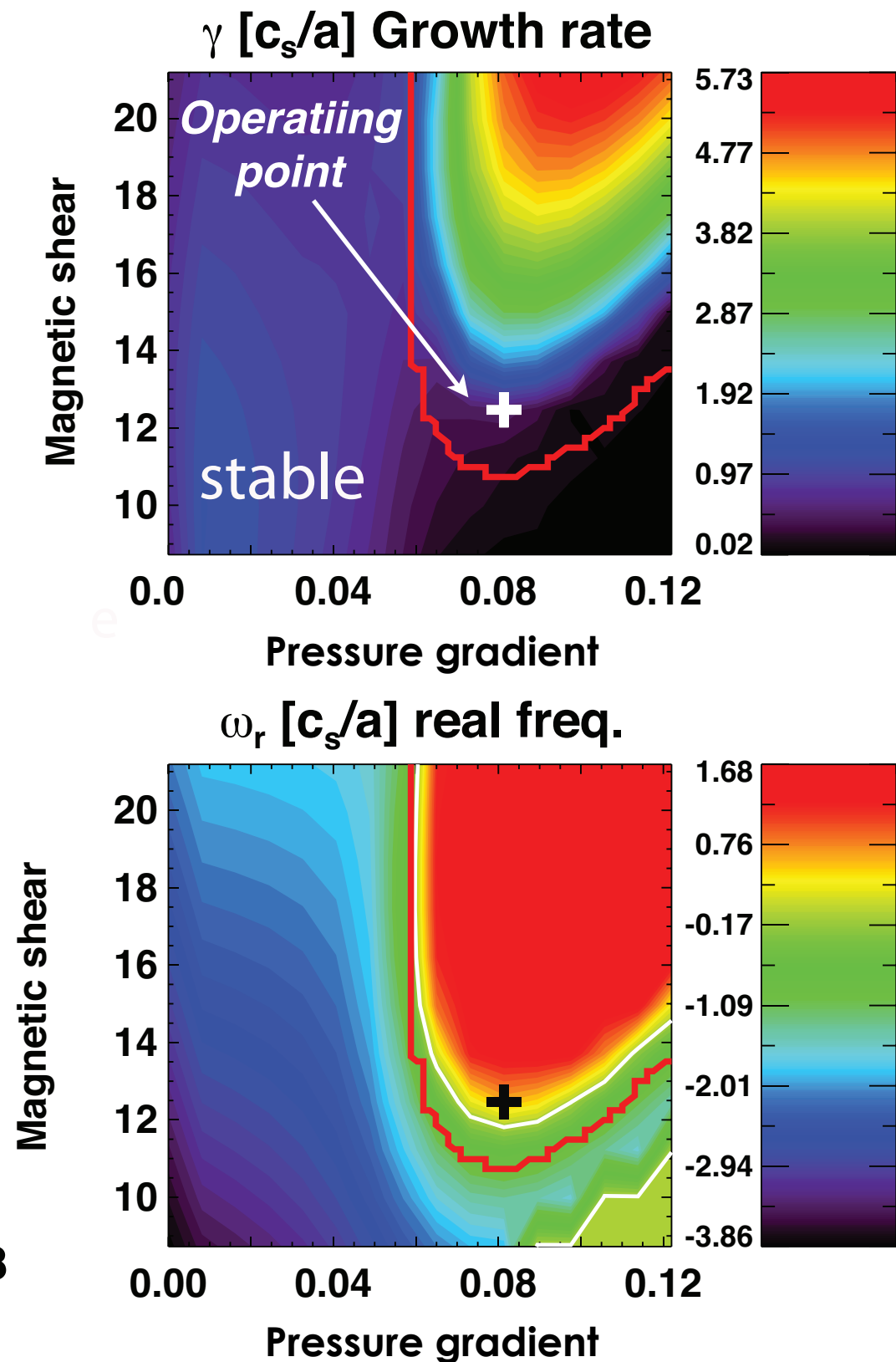
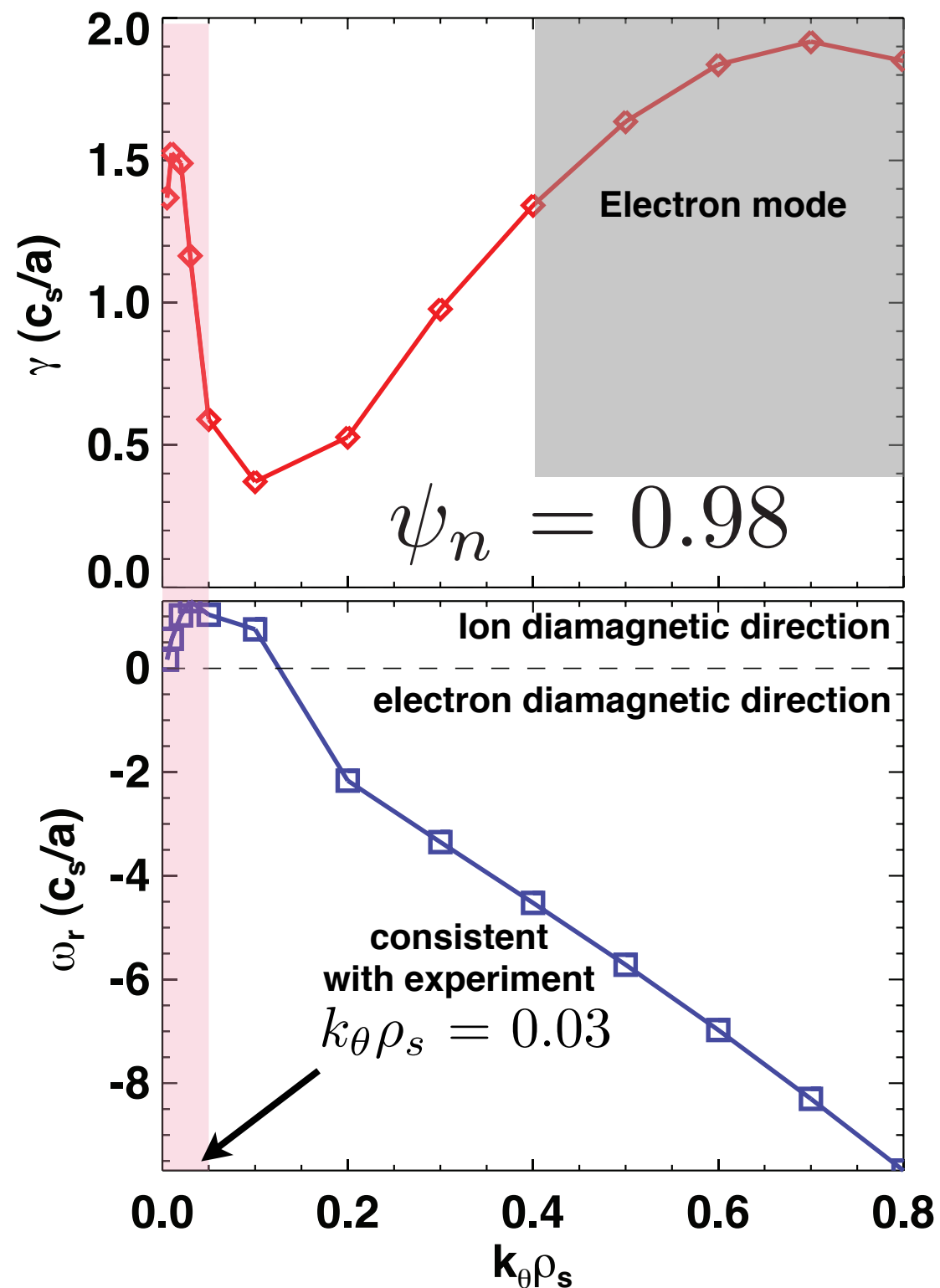


- Width of pedestal, width of well in radial electric field $\sim$ millimeters
- Uncertainty in flux surface mappings between poloidally separated diagnostics is of similar scale!
- Ongoing work to obtain accurate mapping of fluctuation radial location onto plasma flow profile
- *Localization in the deepest part of the E_r well would imply fluctuations propagating in the ion direction*

ELITE calculations indicate that the experimental point is near both the nominal PBM and KBM thresholds



GS2 linear stability predicts low $k_\theta \rho_s < 0.2$ mode propagating in the ion diamagnetic direction (plasma frame)



Experiments on C-Mod show evidence of QCF contributing to the pedestal dynamics between ELMs, suggestive of

- Inter-ELM fluctuation measurements on C-Mod show onset of quasi-coherent density and magnetic fluctuations, *localized to pedestal*
 - frequency of approximately 300 kHz and spatial poloidal scale $k_{\theta}\rho_s \sim 0.04$
 - electron diamagnetic propagation in lab frame; possibly ion-directed in plasma frame
- Results clearly show that the QCF is pedestal localized; its **onset** at a critical edge pressure (or ∇p) is suggestive of the kinetic ballooning mode (KBM)
 - onset and saturation of this mode simultaneous with plateau in pedestal T_e
- Linear GS2 calculations indicate the most unstable mode is edge localized with $k_{\theta}\rho_s = 0.03$ and has KBM characteristics, consistent with experiment
- Open questions and further investigations
 - Why the relative coherence of the fluctuations?
 - Can we get at the transport driven by these fluctuations?
 - Can we improve our understanding with time-resolved profile evolution?