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Roland Sabot, Luigui Salazar, Stéphane Heuraux, A. Krämer-Flecken, Alberto Gallo, et al.. Systematic analysis of turbulence: component extraction of the density fluctuations and study of their dynamics for different regimes. 29th IAEA Fusion Energy Conference (FEC 2023), Oct 2023, Londres, United Kingdom. cea-04566218

HAL Id: cea-04566218

<https://cea.hal.science/cea-04566218>

Submitted on 2 May 2024

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SYSTEMATIC ANALYSIS OF TURBULENCE: COMPONENT EXTRACTION OF THE DENSITY FLUCTUATIONS AND STUDY OF THEIR DYNAMICS FOR DIFFERENT REGIMES

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Introduction

Data driven approach: database digging for systematic analysis of experiments → trend, universality

Two approaches to reduce the dimensionality of density fluctuation measurements → database

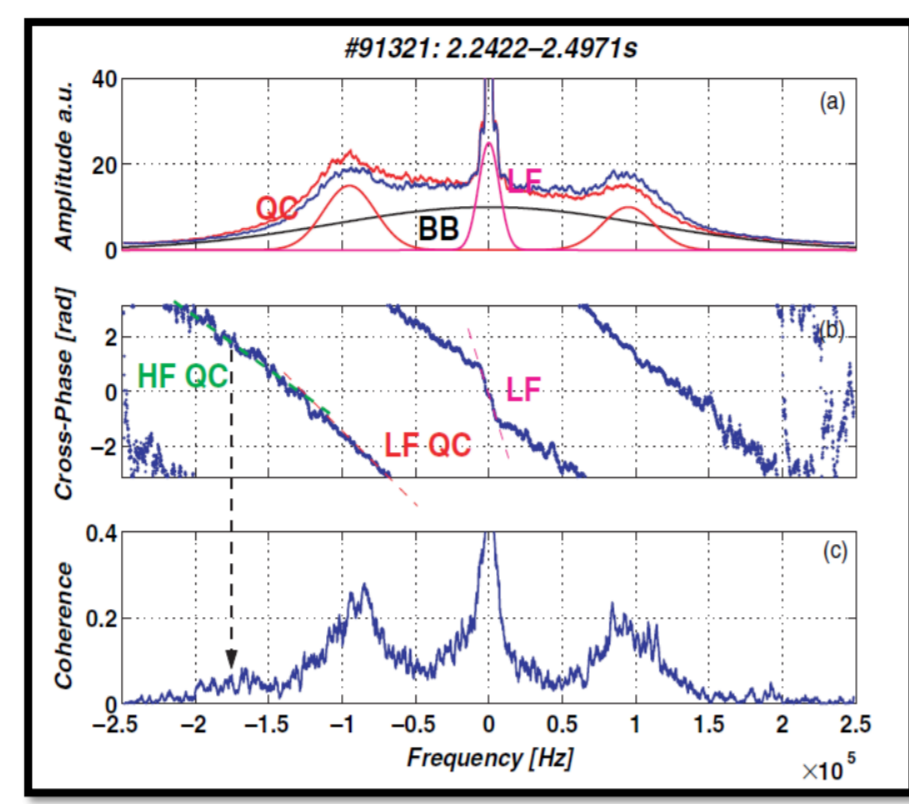
- **Parametrization:** the reflectometry frequency spectrum is reduced 3 components [Sun 18 & 19]
- **Component extraction** by combining signal processing with machine learning [Salazar 22 & 23]

Both rely on the decomposition of the frequency spectrum in components.

Reflectometry spectrum components

Using correlation reflectometry, the frequency spectrum was shown to be the superposition of several components [Vershkov04, A. Krämer-Flecken05]:

- **Low Frequency (LF) components**
- **quasi coherent modes (LFQC & HFQC)**
- **broadband component (BB)**
- Noise level
- + MHD modes



(a) Amplitude, (b) cross-phase and (c) coherency spectra for an Ohmic plasma [Krämer-Flecken04]

Turbulence in LOC and SOC regimes

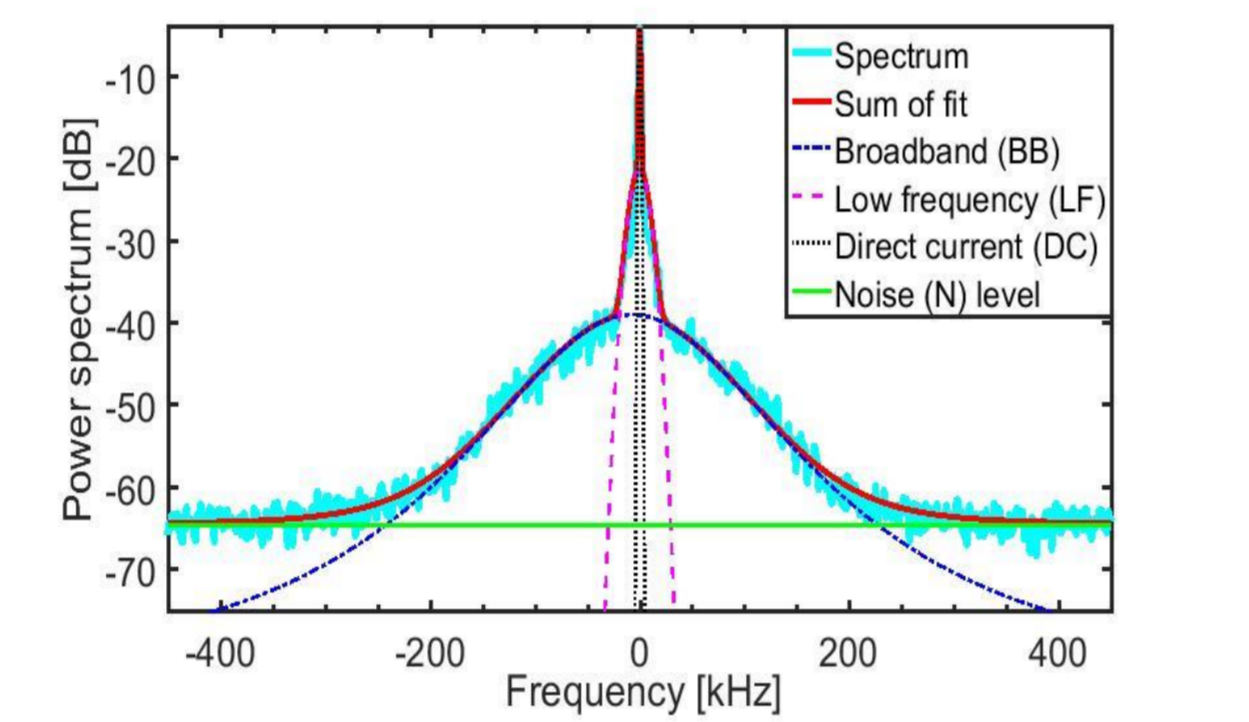
Parametrization method

The frequency spectrum is fitted by **3 components**:

- narrow (± 1 kHz) wavecarrier (DC): Gaussian
- low frequency (± 10 kHz) fluctuations (LF): Gaussian
- The BB is fitted by the Taylor function (Hennequin99) or generalized Gaussian: 4 parameters
- + noise level = 11 parameters

Assumptions:

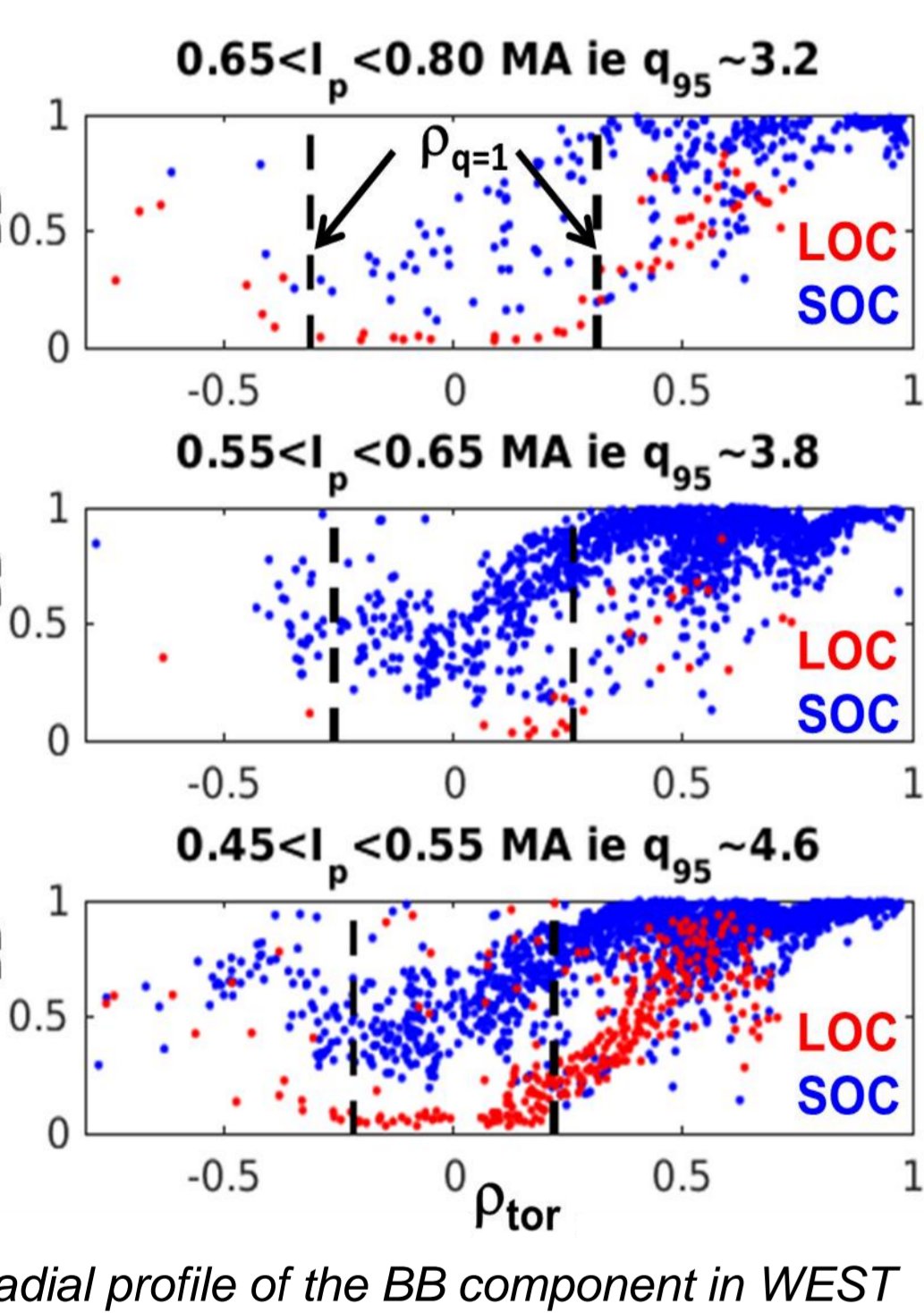
- ad-hoc separation of components
- Narrow modes like quasi-coherent modes neglected
- Stationarity during the measurement (frequency spectrum)



Frequency spectrum and fitting components [Sun18]

Tore Supra Database: 300 000 spectra from 6000 discharges } Core X-mode reflectometer [Sabot06]
WEST Database: 75 000 spectra from 800 discharges }

Radial evolution of the BB contribution in Ohmic regimes



radial profile of the BB component in WEST

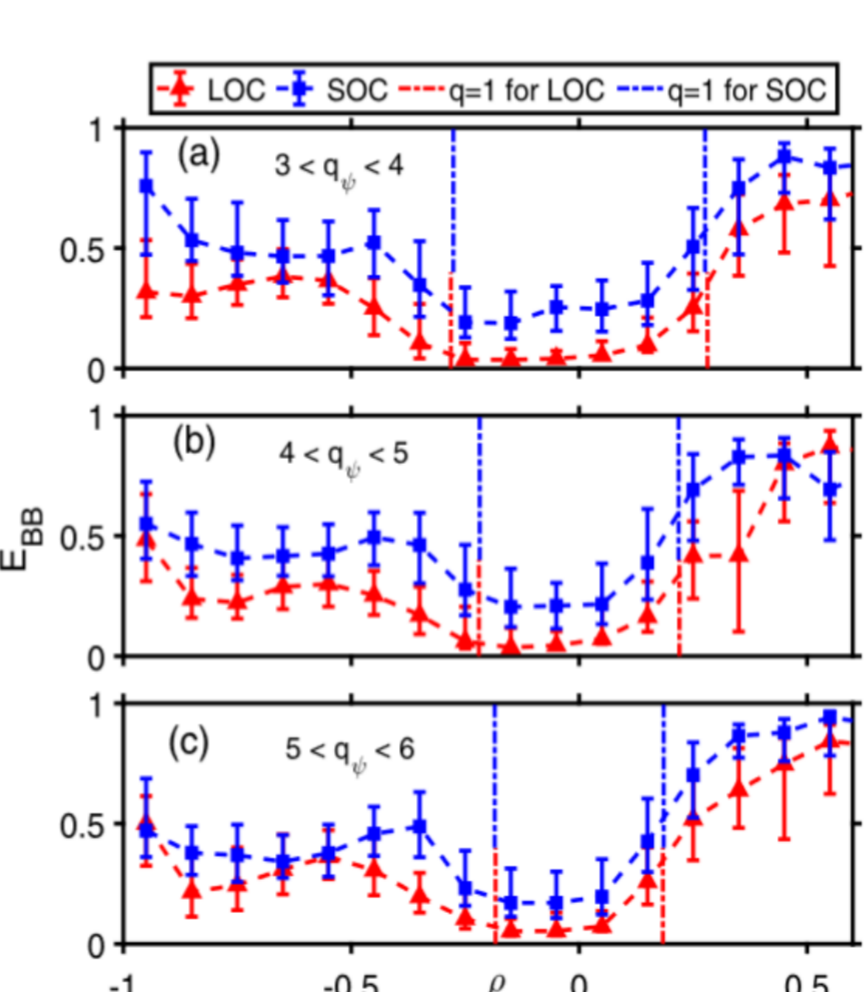
LOC-SOC critical density n_e^{crit}

• WEST: $n_e^{crit} = 5.3 I_p$ (from Ostuni22 reduced database)

• Tore Supra: $n_e = 2.6 I_p$ [Sun 19]

LOC-SOC discrimination

- LOC: $n_e < 0.9 n_e^{crit}$
- SOC: $n_e > 1.1 n_e^{crit}$
- Threshold $0.9 n_e^{crit} < n_e < 1.1 n_e^{crit}$



BB component in Tore Supra, Sun19

E_{BB} in SOC > in LOC over the whole cross section for all q_{ρ}
 E_{BB} very low inside $q=1$ in LOC, shallower basin in SOC in WEST
 Beyond $q=1$ on LFS in SOC, most spectrum energy is in the BB

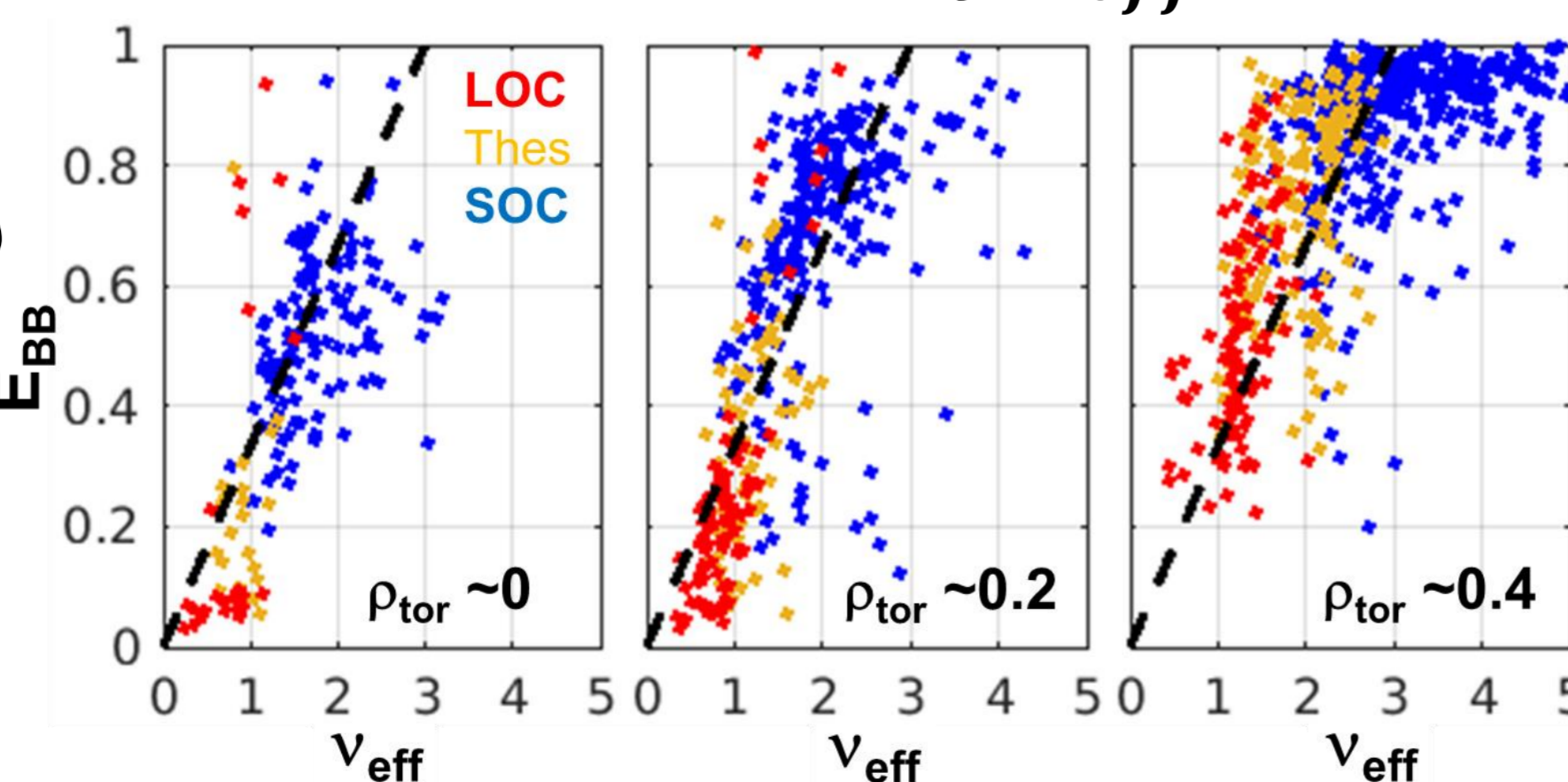
BB contribution with the effective collisionality ν_{eff}

Similar linear evolution inside & outside $q=1$

$$E_{BB} \sim \frac{1}{3} \nu_{eff} (\nu_{eff} \sim 1.2 R \nu_{eff} n_e T_e^{-2} \text{ [Angioni03]})$$

while $\langle E_{BB} \rangle$ increases with ρ

- $\rho \sim 0 \rightarrow \langle E_{BB}^{LOC} \rangle \sim 0.1$ ($E_{BB}^{Thres} \sim 0.2$)
- $\rho \sim 0.2 \rightarrow \langle E_{BB}^{LOC} \rangle \sim 0.2$ ($E_{BB}^{Thres} \sim 0.4$)
- $\rho \sim 0.4 \rightarrow \langle E_{BB}^{LOC} \rangle \sim 0.6$ ($E_{BB}^{Thres} \sim 0.7$)



E_{BB} values for $\nu_{eff} \sim 1$ similar across the plasma core whereas $\langle E_{BB}^{Thres} \rangle$ increases with ρ
LOC-SOC transition is global phenomena but turbulence depends on local parameters

References

Angioni05 C. Angioni, et al, Relationship between density peaking, particle thermodiffusion, Ohmic confinement, and microinstabilities in AUG L-mode plasmas, PoP 12 040701 (2003)
 Arnichand14 H. Arnichand et al Quasi-coherent modes and electron-driven turbulence Nuclear Fusion 54 123017 (2014)
 Citrin17 J. Citrin et al, Comparison between measured and predicted turbulence frequency spectra in ITG and TEM regimes Plasma Phys. Control. Fusion 59 064010 (2017)
 Hacquin16 S. Hacquin et al, Simulation of core turbulence measurement in Tore Supra ohmic regimes Physics of Plasmas 23 092303 (2016)
 Hennequin99 P. Hennequin, et al., 26th EPS Conference on Control. Fus. and Plas. Phys. (EPS, Petit-Lancy, 1999), Vol. 23J, pp. 977-980.
 Kaiser02 A. Kaiser and Y. Schreiber Information transfer in continuous processes, Physica D: Nonlinear Phenomena 166 43-62 (2002)
 Krämer-Flecken04 A. Krämer-Flecken, Turbulence studies with means of reflectometry at TEXTOR, Nuc. Fus. 44 1143-57 (2004)
 Krämer-Flecken23 A. Krämer-Flecken, Observation of quasi coherent modes in W7-X and relation to tokamaks, 27th Joint EU-US TTF Meeting, 2023, Nancy (France)
 Sabot06 R. Sabot et al, A dual source D-band reflectometer for density profile and fluctuations measurements in Tore-Supra, Nuclear Fusion 46 S685-92 (2006)
 Salazar22 L. Salazar et al, Extraction of quasi-coherent modes based on reflectometry data Plasma Phys. Control. Fusion 64 104007 (2022)
 Salazar23 L. Salazar et al, Modes extraction in reflectometry signals using data processing tools and machine learning methods, 27th EU-US TTF, 2023, Nancy (France)
 Sun18 Y. Sun et al Parametrization of reflectometry fluctuation frequency spectra for systematic study of fusion plasma turbulence, RSI 89 073504 (2018)
 Sun19 Y. Sun et al, Experimental trends of reflectometry frequency spectra emerging from a systematic analysis of the Tore Supra database, Physics of Plasmas 26 032307 (2019)
 Vershkov05 V. A. Vershkov et al Summary of experimental core turbulence characteristics in ohmic and ECRH discharges in T-10 tokamak plasmas, Nucl. Fusion 45 S203-26 (2005)

Quasi-coherent modes

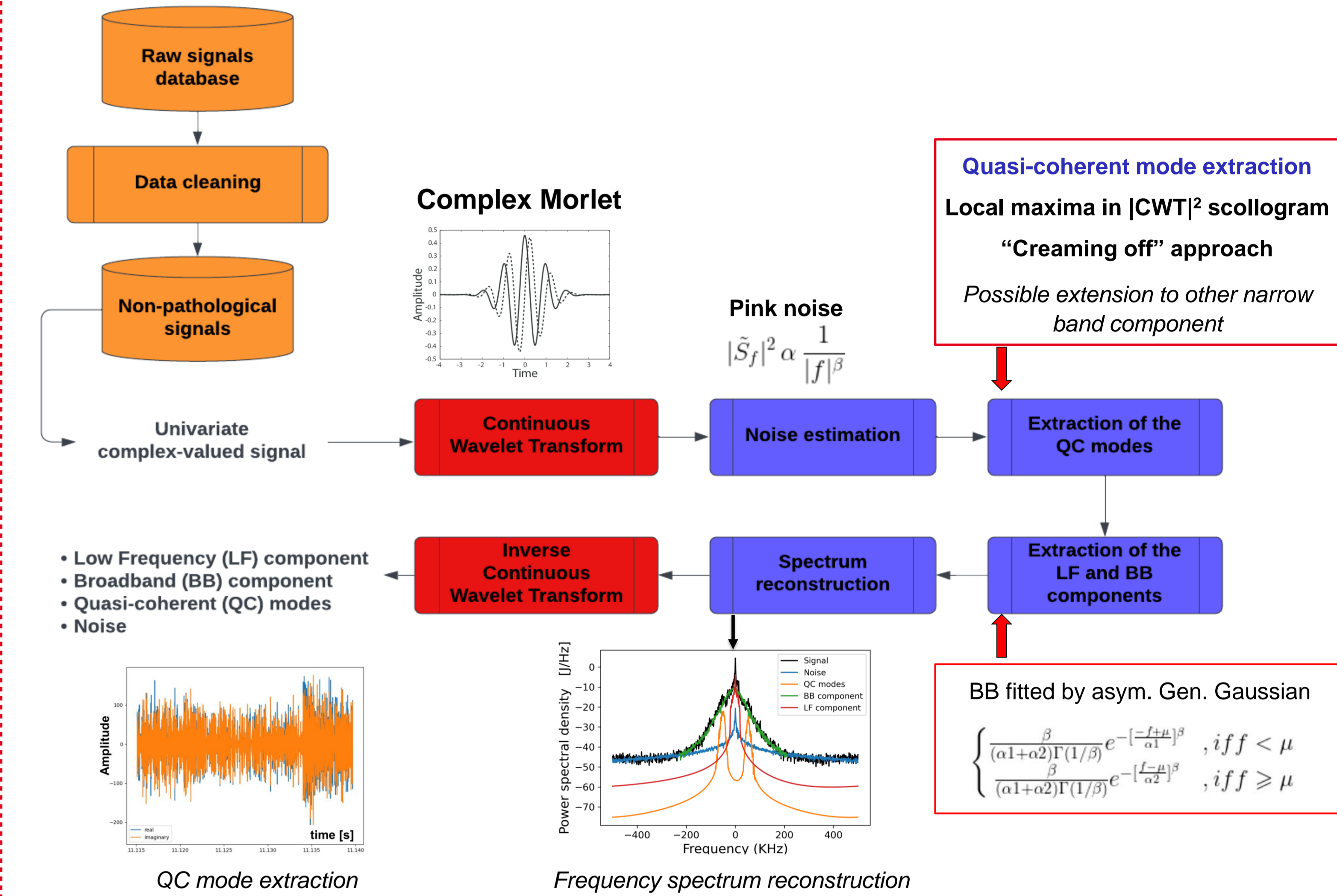
Experiment analysis of several devices and gyrokinetic simulations showed the QC mode are associated to TEM (Trapped Electron Mode) dominated regimes like LOC [Arnichand 14, Hacquin 16, Citrin 17].

Components extraction method

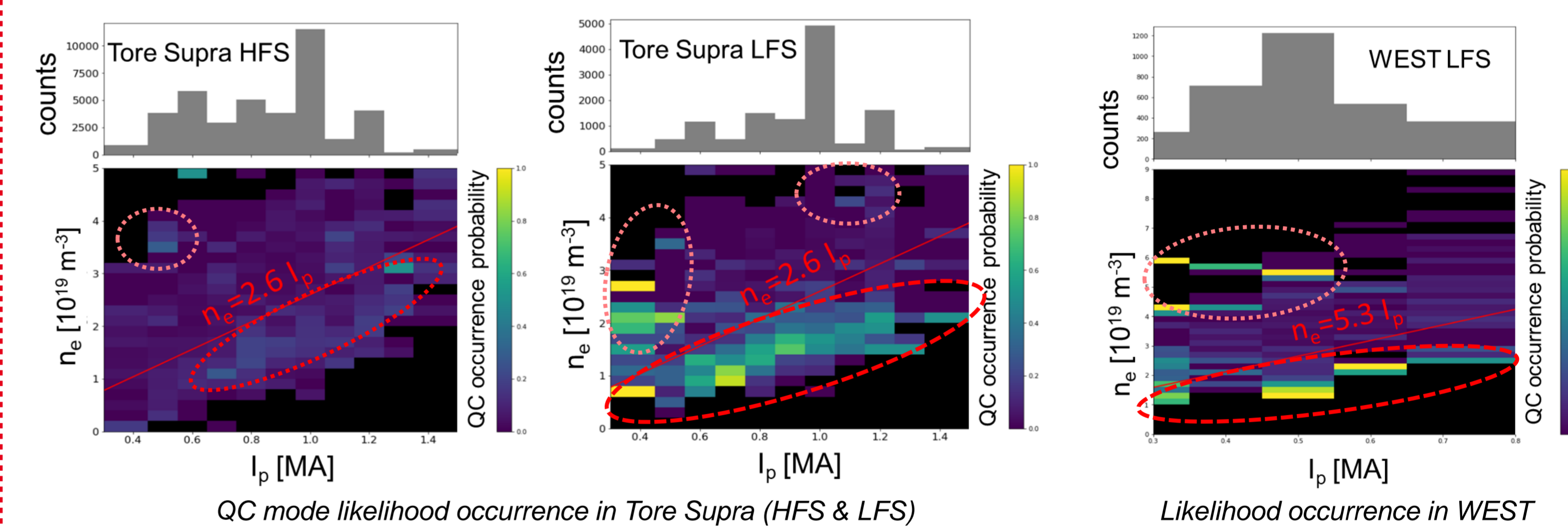
The method born out of the necessity to remove the limitation of the parametrization method:

- Shift from ad-hoc component separation to automatic identification
- Enabling the extraction of neglected components as the QC modes
- Transition from averaged spectrum to instantaneous quantities

Advanced Signal Processing & Machine Learning

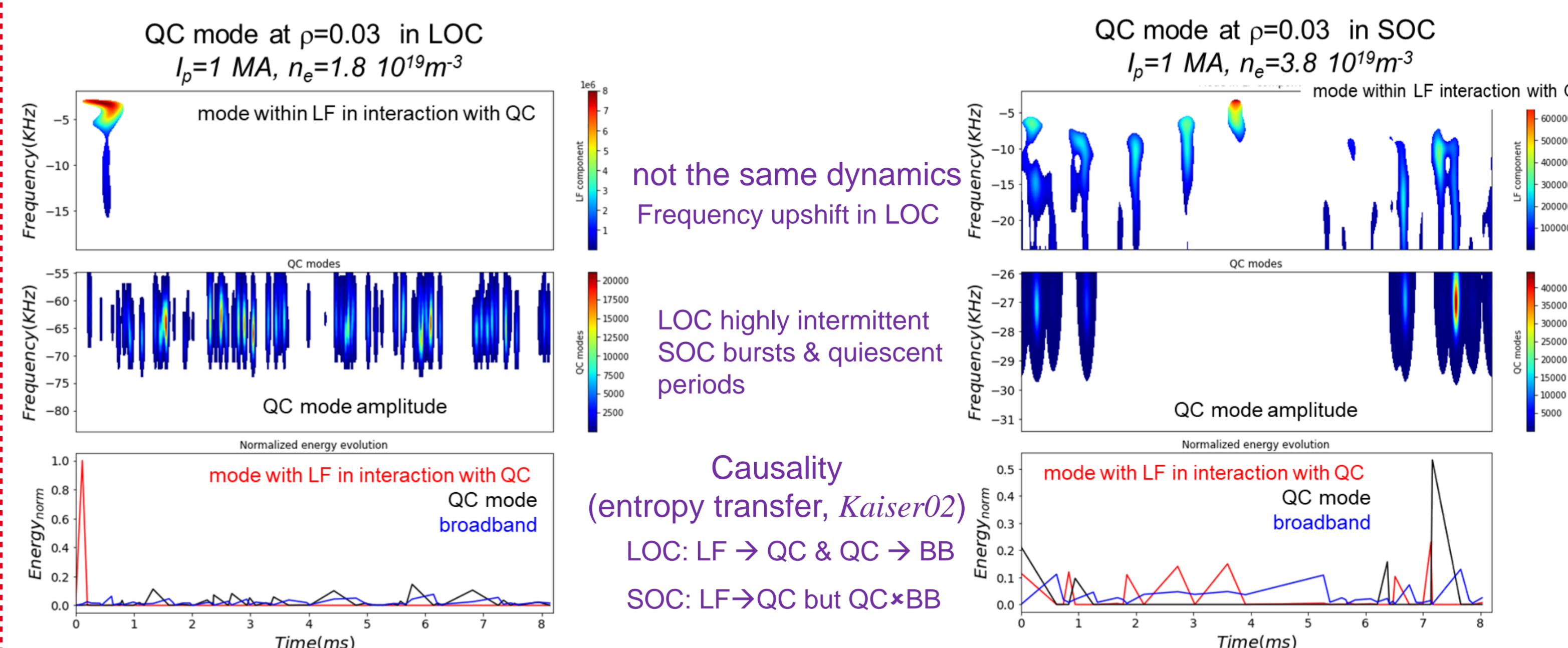


Likelihood occurrence of quasi-coherent modes



- QC overwhelmingly observed on the LFS below LOC-SOC threshold
- 2 clusters in SOC regime on LFS: at low current & moderate density & high current, high density
- Occurrence likelihood on HFS low in LOC and SOC regimes

Interactions between QC modes and other modes



Multi-machines, multi-magnetic configurations (Tore Supra, WEST, Textor, W7X) studies have consistently demonstrated the common occurrence of LF component bursts preceding QC generation [Salazar23, Krämer-Flecken23]

Main results :

- ✓ Profile evolution of the BB contribution in LOC and SOC
- ✓ BB turbulence more dependent on local parameters than global Ohmic confinement regime
- ✓ Expected cluster QC mode below the LOC-SOC threshold confirm the link with LOC and TEM
- ✓ Time-dependent methods have revealed evidence of transient energy exchange
- ✓ Observation of energy exchange among components has provided evidence of causal links among them
- ✓ Different properties of LOC QC modes (intermittency, energy transfer) require further investigations