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# Observation of quasi coherent modes in W7-X and relation to tokamaks

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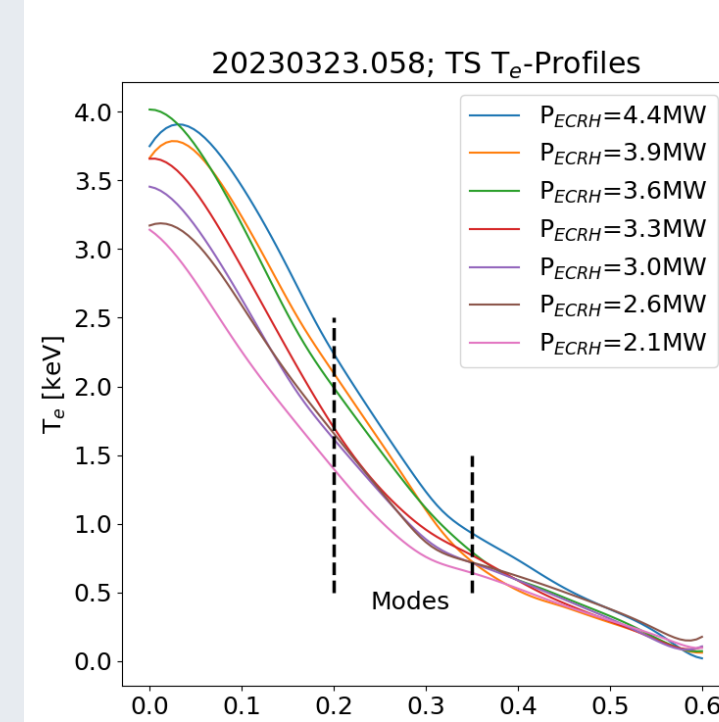
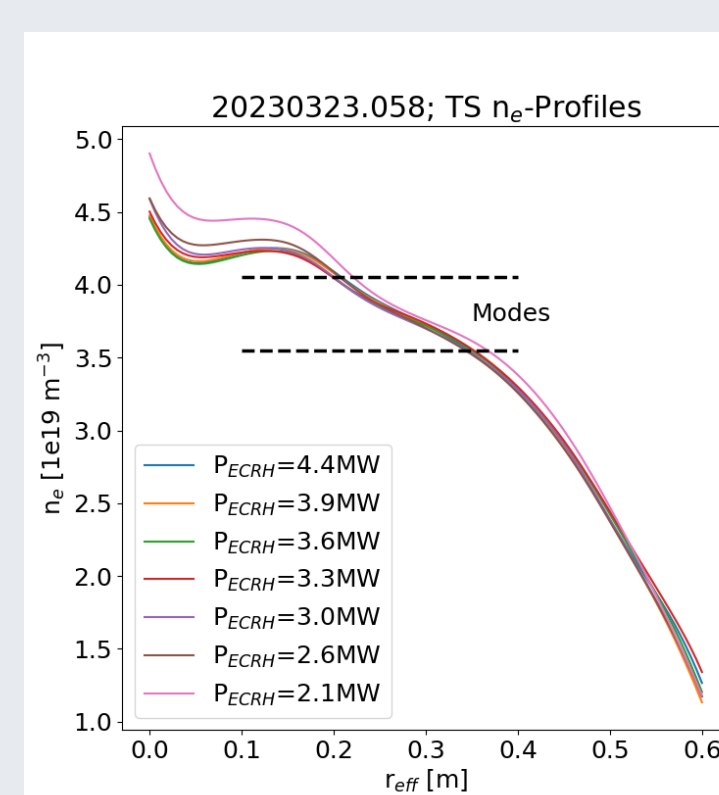
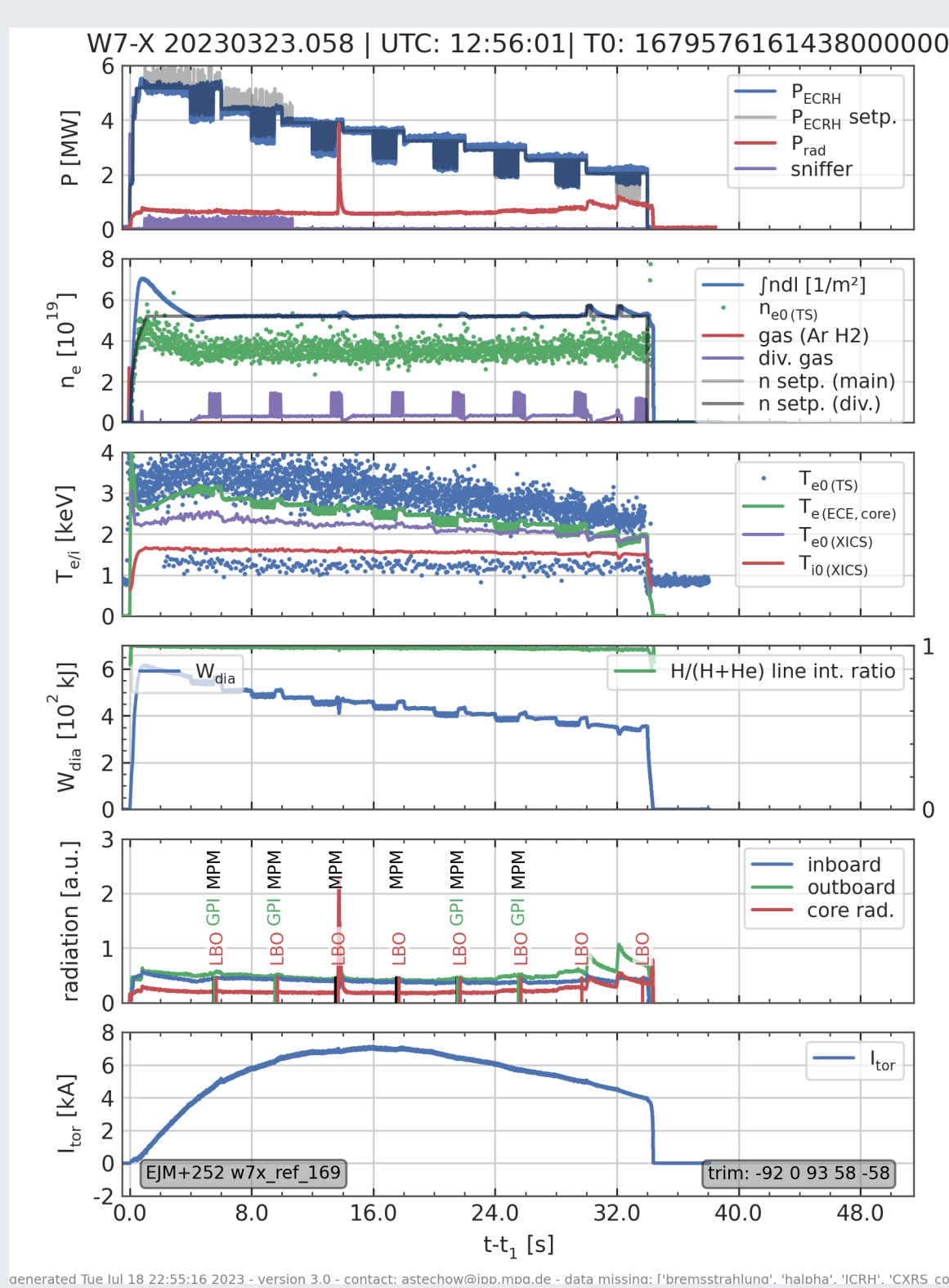
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## Quasi Coherent Modes in fusion devices

**Motivation:** Quasi Coherent (QC) modes with  $k_{\perp} \approx 3 \text{ cm}^{-1}$  are observed in tokamaks as Tore Supra and AUG. The nature is mostly TEM-like. In the stellarator W7-X such modes are observed in the plasma core and as well in the plasma edge. The latter are correlated with an increase in the diamagnetic energy. In all devices they share a similar scaling depending on  $v_{\perp}$

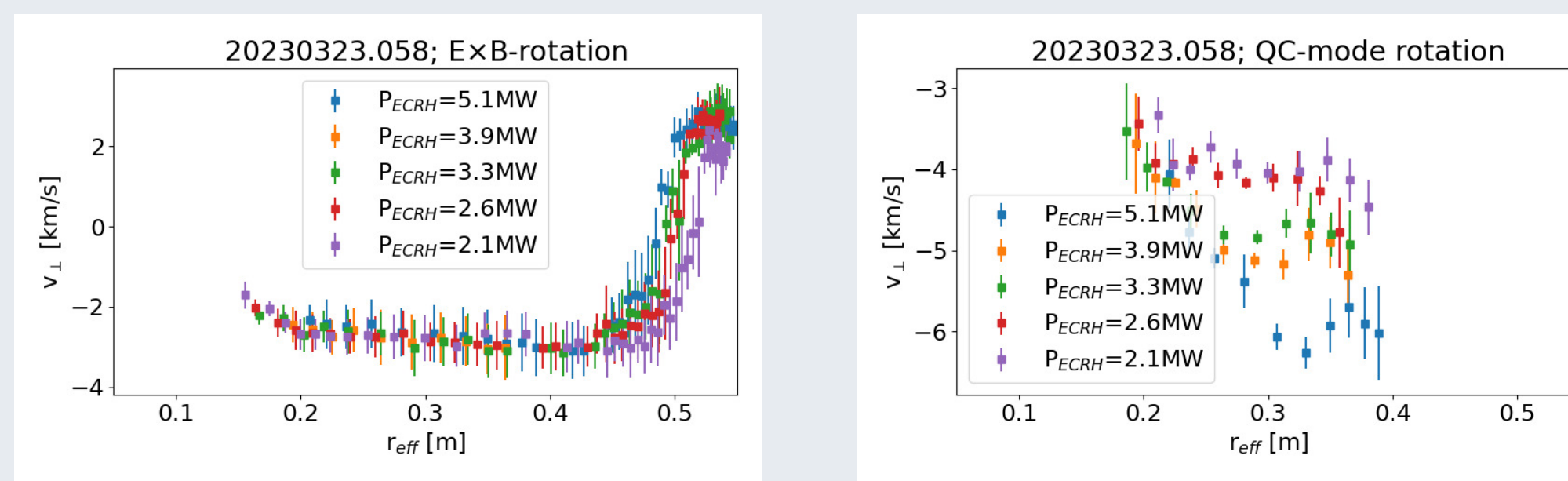
### Observations at W7-X

#### QC-Modes in Standard Configuration (EJM)



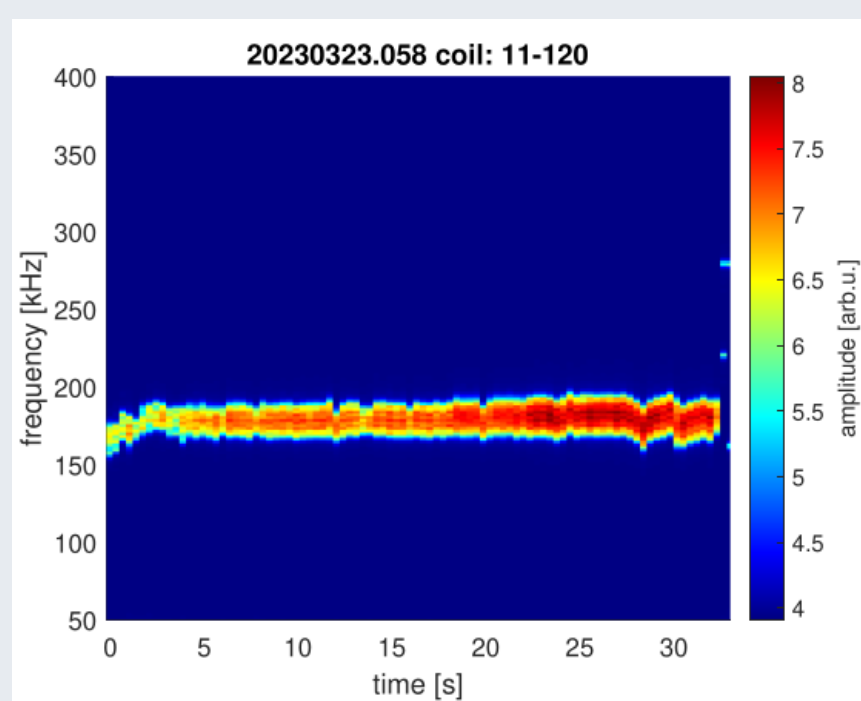
### Observations at W7-X

#### Power Dependence and Mode Velocity



- ▶ Constant  $E \times B$ -rotation of  $-2.7 \text{ km s}^{-1}$
- ▶  $E \times B$ -rotation independent of  $P_{ECRH}$
- ▶ QC-mode rotation more negative than  $E \times B$ -rotation
- ▶ QC-mode rotation increases with decreasing  $P_{ECRH}$
- ▶ Mode rotation is determined by  $P_{ECRH}$

#### Comparison with Magnetics using DMUSIC

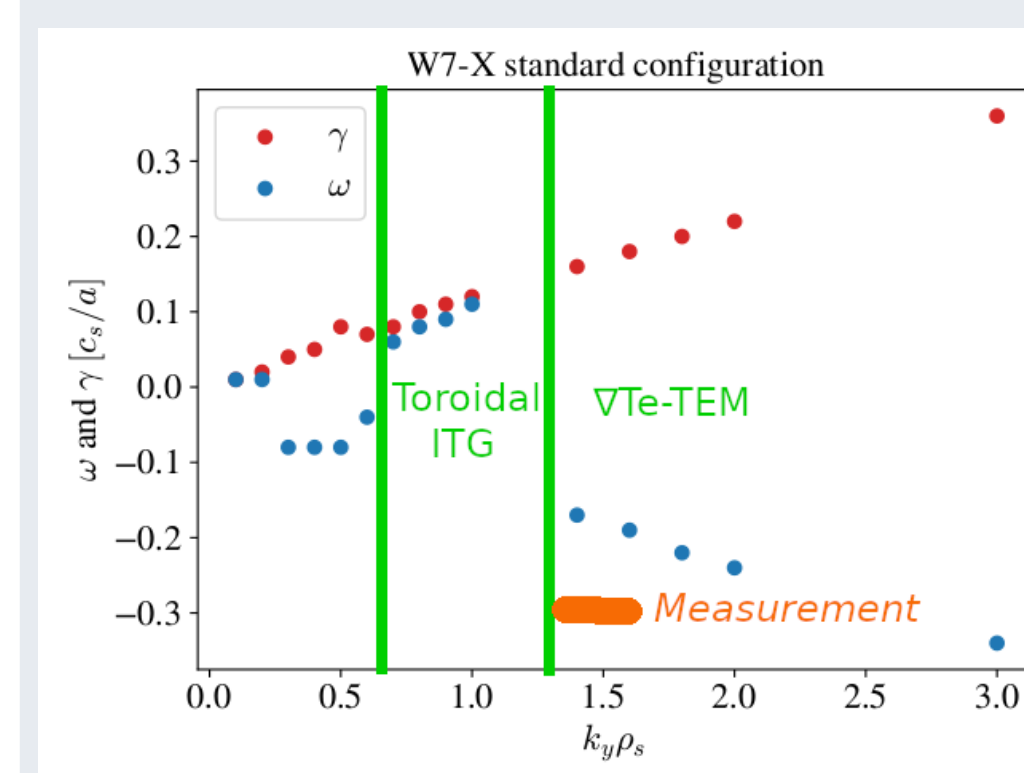


- ▶ Mirnov coils show broad frequency band
- ▶ Center frequency at  $f \approx 180 \text{ kHz}$
- ▶ No correlation between Mirnov and PCR for mode frequency

### Observations at W7-X

#### Estimation of Mode Properties

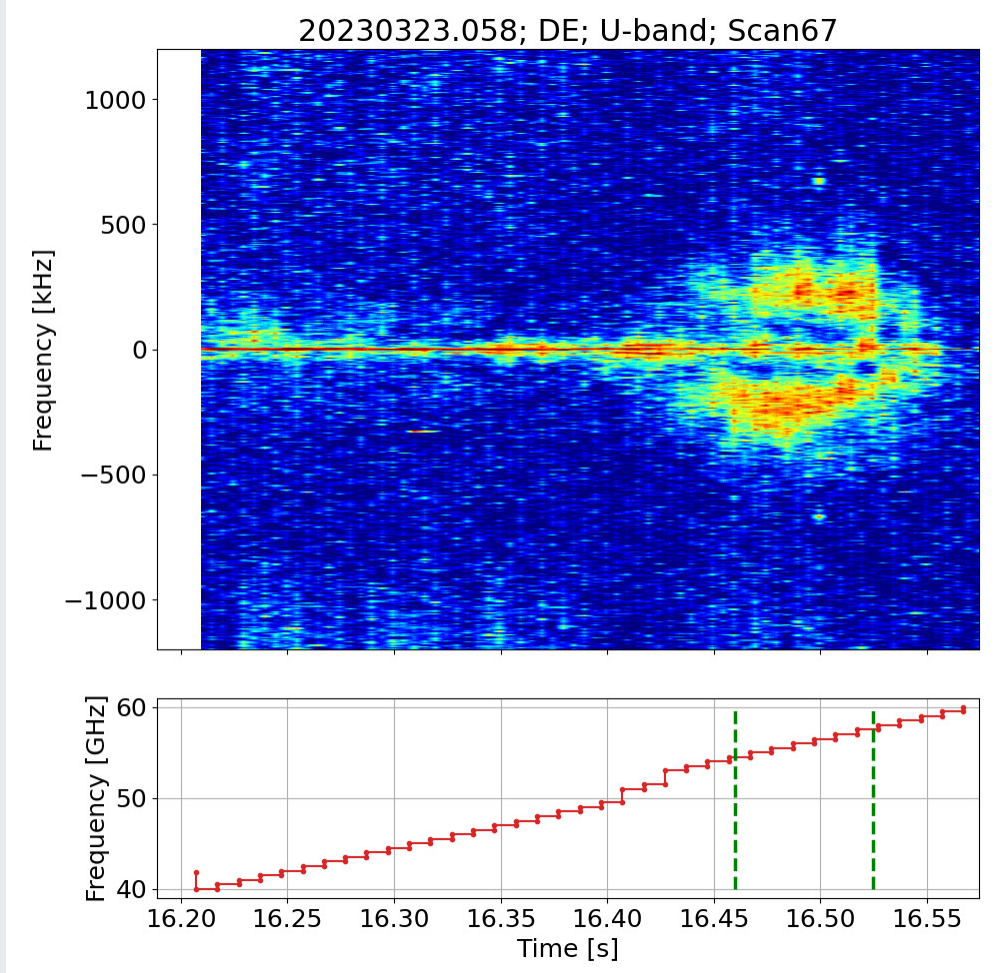
- ▶ Flux surface perimeter  $1.42 \text{ m} \leq s \leq 2.52 \text{ m}$
- ▶ Mode frequency from coherence spectrum:  $f_{QC} \approx 220 \text{ kHz}$
- ▶ Mode velocity:  $-4.7 \text{ km s}^{-1} \leq v_{QC} \leq -4.3 \text{ km s}^{-1}$
- ▶ yields mode number from  $66 \leq m \leq 118$
- ▶ Structure size is constant at  $L=22 \text{ mm}$  yielding  $k_{\perp}=2.9 \text{ cm}^{-1}$
- ▶ QC-modes observed for  $1.2 \text{ keV} \leq T_e \leq 1.8 \text{ keV}$
- ▶ This yields  $1.32 k_{\perp} \rho^* = 1.58$  assuming  $Z_{eff}=1.5$



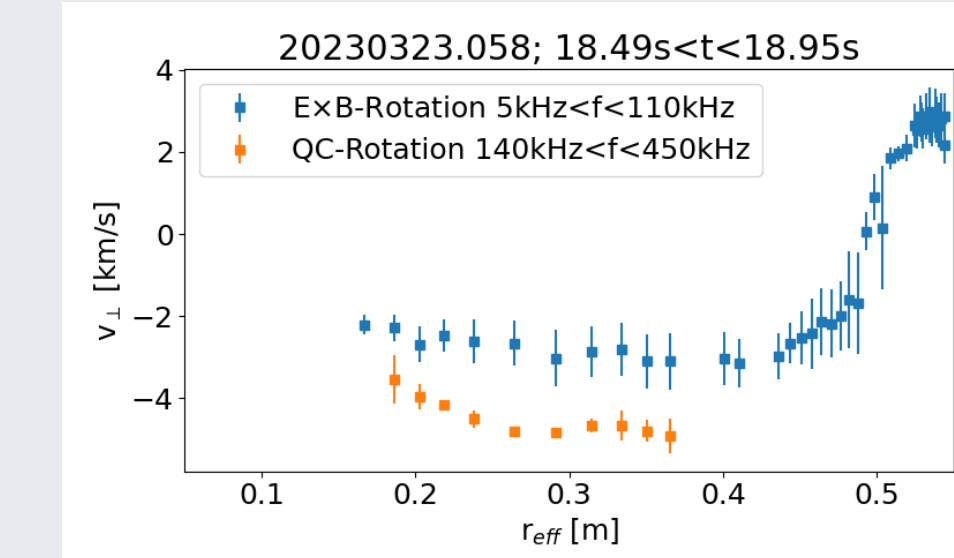
- ▶ Linear gyro-kinetic simulation for EJM
- ▶ Increasing growth rate with  $k_{\perp} \rho^*$
- ▶ Measurement comparable with  $\nabla T_e$  driven TEMs
- ▶ Mode frequency of 220 kHz obtained

- ▶ TEMs are also observed in the plasma edge where they correlate with an increase in  $W_{dia}$
- ▶ In this case they are driven by strong  $\nabla n_e$
- ▶ See also Tu-MCF7; 3-7 July 2023, EPS Conference on Plasma Physics, Bordeaux, France

#### Modes in Coherence Spectra

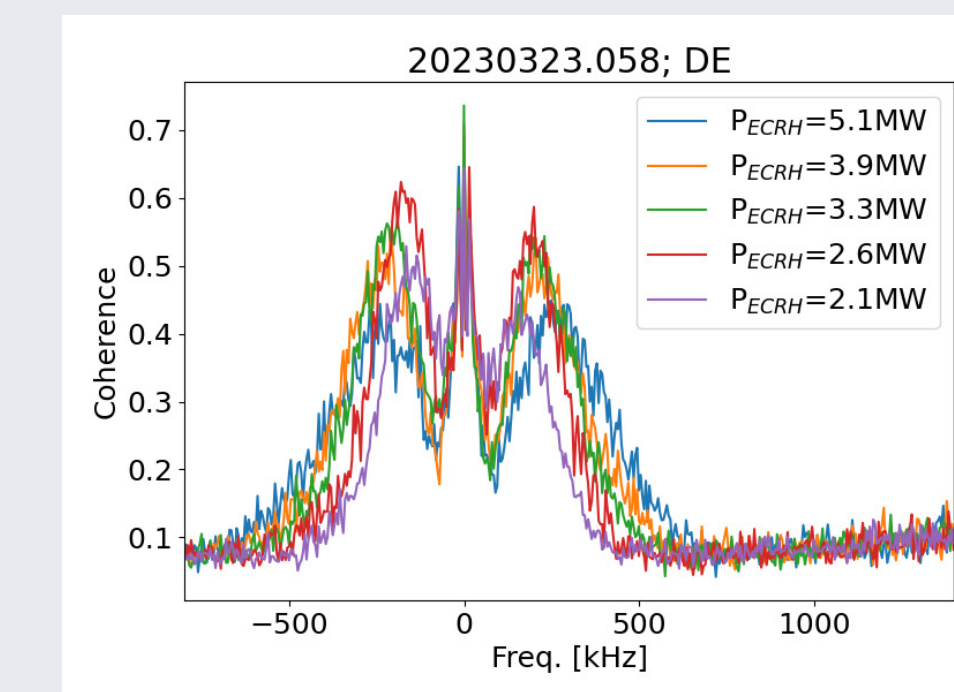


#### E x B- and QC-Rotation



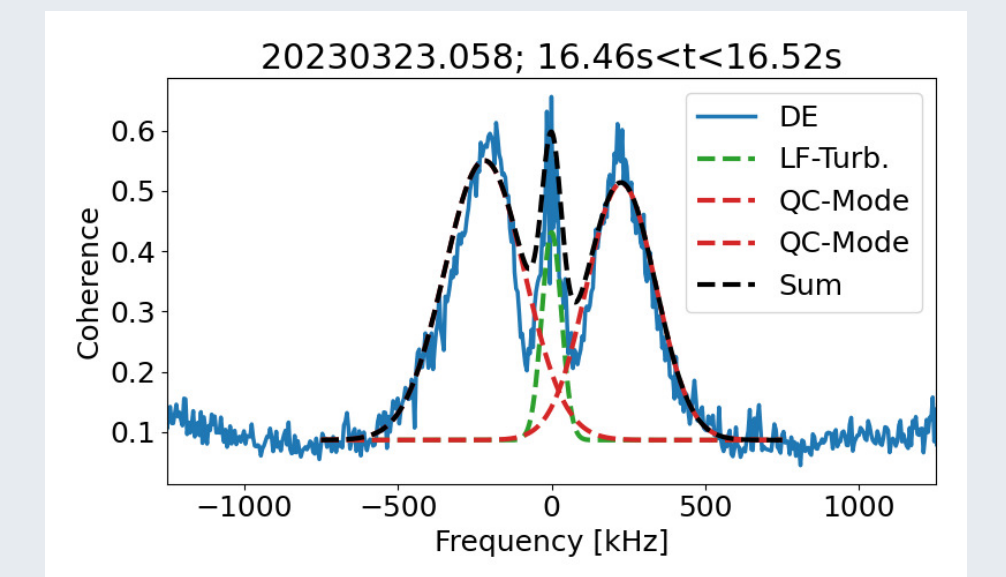
- ▶ QC-mode rotation faster than  $E \times B$ -rotation
- ▶ QC-mode rotation in electron diamagnetic drift direction

#### Power Dependence of $f_{QC}$



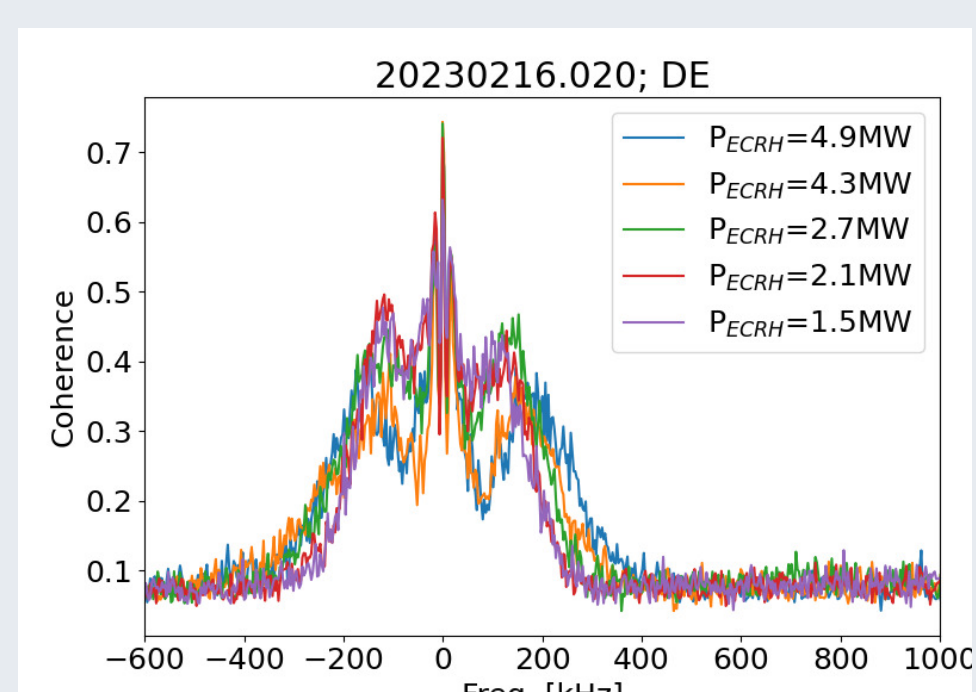
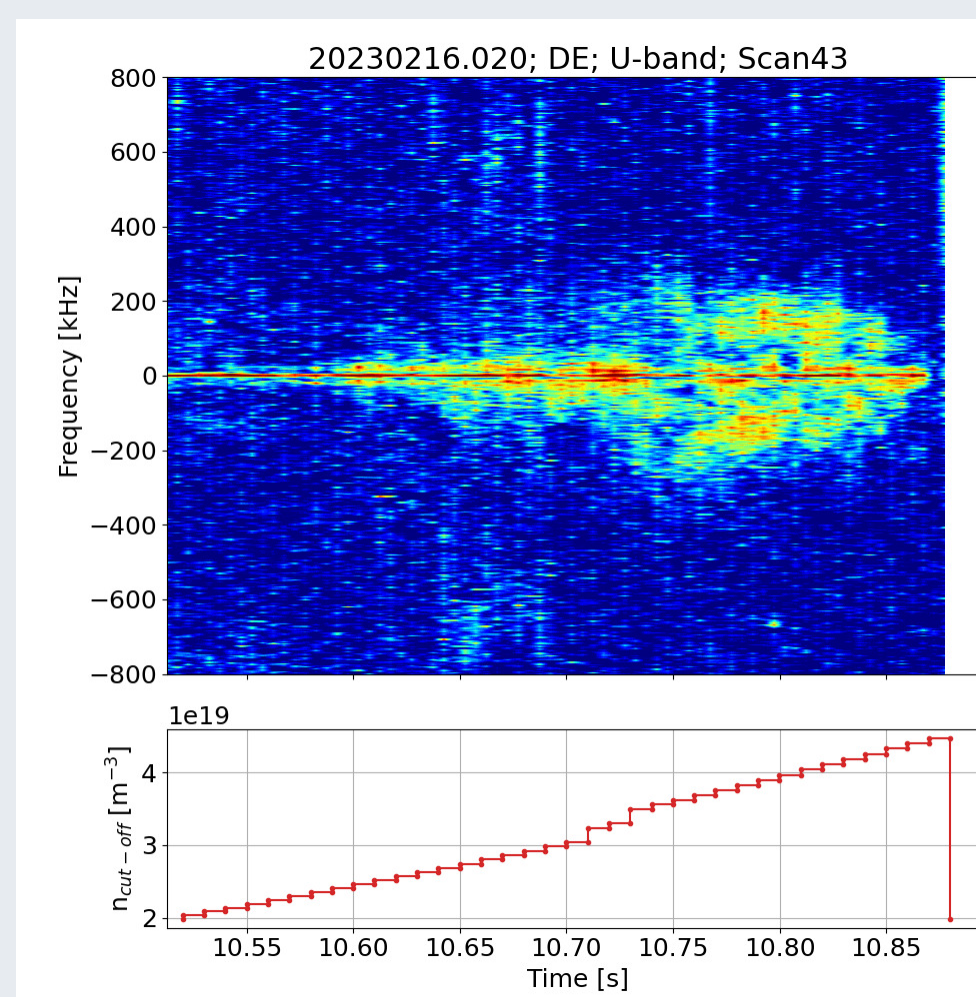
- ▶  $f_{QC}$  decreases with power
- ▶ Largest coherence for  $P_{ECRH}=2.6 \text{ MW}$
- ▶ Low frequency mode at  $f=16 \text{ kHz}$  unaffected

- ▶ Modes located for  $0.2 \text{ m} \leq r_{eff} \leq 0.35 \text{ m}$



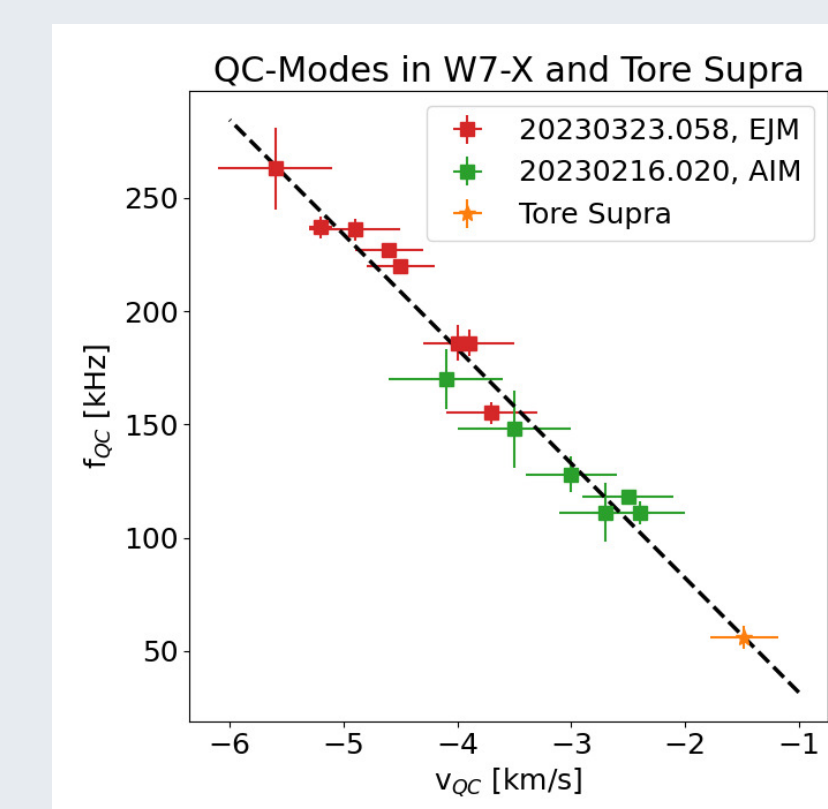
- ▶ 3 distinct components
- ▶ Low frequency component  $5 \text{ kHz} \leq f \leq 110 \text{ kHz}$
- ▶ Quasi coherent Modes:  $140 \text{ kHz} \leq f \leq 450 \text{ kHz}$
- ▶ HWHM of QC-Mode:  $130 \text{ kHz} \leq f \leq 150 \text{ kHz}$

#### QC-Modes in Low Mirror Configuration (AIM)



- ▶ Decrease of  $f_{QC}$  with decreasing power
- ▶ Different  $f_{QC}$  for same power in EJM and AIM

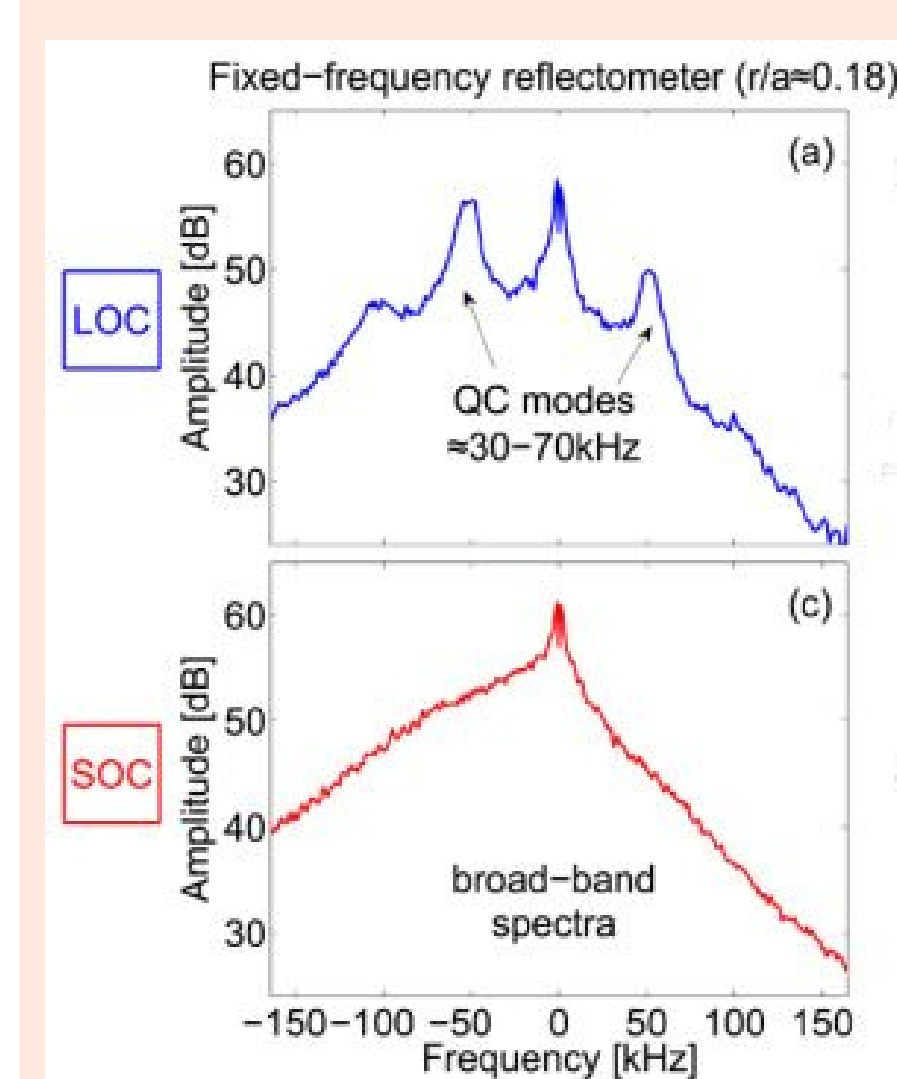
- ▶ Similar program as in EJM configuration
- ▶ Power scan at constant density
- ▶ Power variation from  $5 \text{ MW} \leq P_{ECRH} \leq 1.5 \text{ MW}$
- ▶ Lower mode frequencies observed
- ▶ QC-mode frequency range  $170 \text{ kHz} \leq f_{QC} \leq 90 \text{ kHz}$



- ▶ Scaling of  $f_{QC}$  versus  $v_{QC}$  configuration independent

## Relation to tokamak experiments

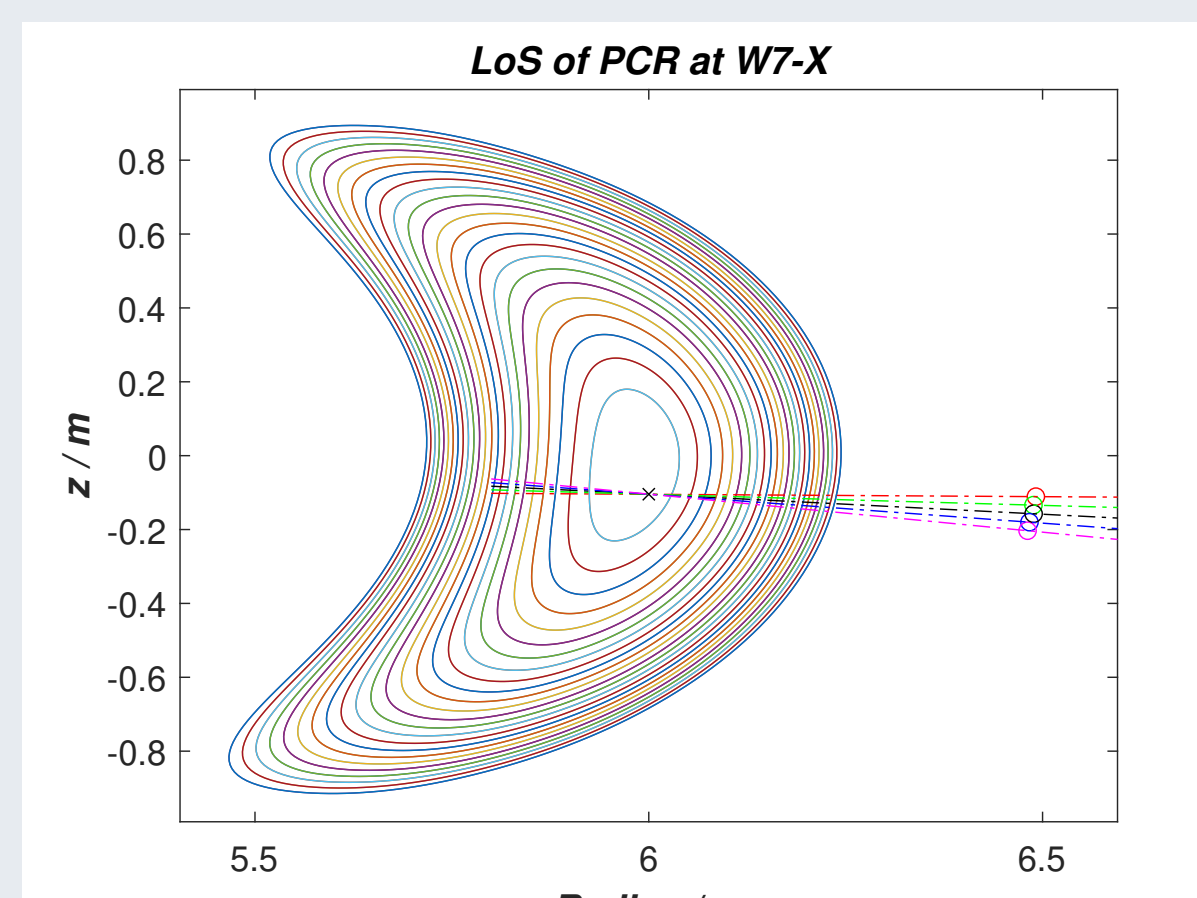
- ▶ TEMs observed in linear confinement regime in Tore Supra



- ▶ QC-modes observed by reflectometry
- ▶ Modes in Tore Supra are of TEM nature
- ▶ Observed in a similar region as in W7-X
- ▶ Assuming  $20 \text{ mm} \leq L_{\perp} \leq 25 \text{ mm}$  yields  $-1.7 \text{ km s}^{-1} \leq v_{QC} \leq 1.2 \text{ km s}^{-1}$
- ▶ Fits with W7-X-scaling for QC-modes
- ▶ See Tore Supra data point in scaling of  $f_{QC}$  with  $v_{QC}$
- ▶ New data analysis tools for extraction of TEM modes developed – See poster 1-11 by L. Salazar
- ▶ Permit the extraction of QC-modes from turbulence spectra
- ▶ Interaction between turbulence components can be analyzed
- ▶ Allows for a multi-machine comparison of QC-modes

## Diagnostic at W7-X and Methodology

- ▶ Poloidal correlation reflectometry (PCR)
- ▶ Sensitive to  $\delta n/n_e$  fluctuations
- ▶ Poloidally spaced receivers measure  $v_{\perp}$ ,  $E_r$
- ▶ Information on modes from coherence spectra
- ▶ Measurement of turbulence wave length
- ▶ Operation in hopping modus to cover large radial range
- ▶ Continuously repeating of scan every 370 ms



- ▶ Location of measurements from TS-profiles
- ▶ Identification of flux surface and poloidal circumference  $s$
- ▶ Calculation of mode numbers as  $m = \frac{s f_{QC}}{v_{\perp}}$
- ▶ Poloidal size of the mode  $L_{\perp} = s/m$

#### Poloidal velocity estimation

$$v_{\perp} = \frac{d \Delta t}{\Delta t^2 + \tau_0^2}$$

- ▶ Elliptical model for  $v_{\perp}$  estimation
- ▶ Taking decay of turbulence in account
- ▶ Depends on the used frequency interval
- ▶ Allows for frequency selective  $v_{\perp}$