Plasma Fluctuation measurements in Ion Stiffness Experiments using Phase Contrast Imaging

by

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In collaboration with:

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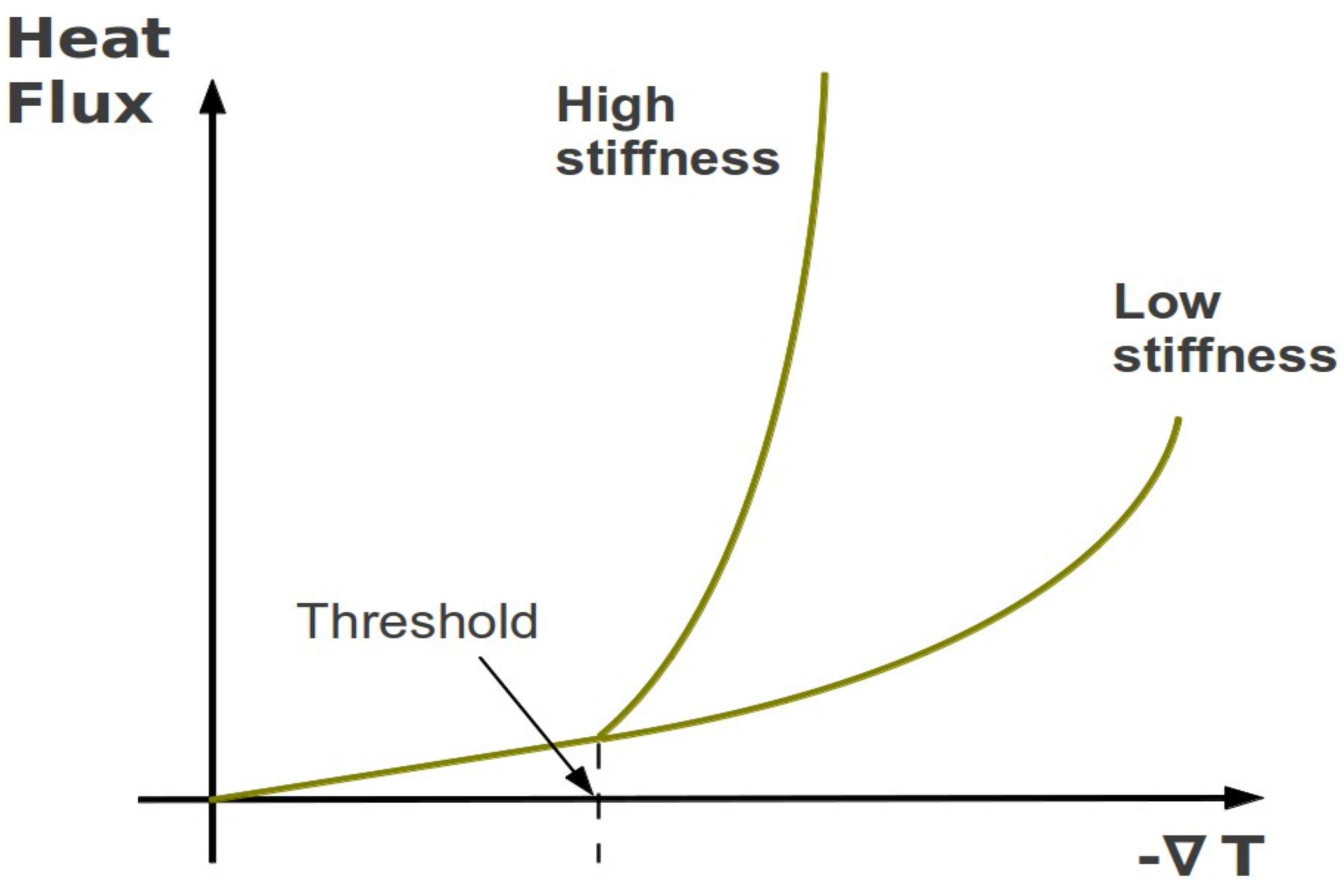
What is stiffness ?

The profile's resistance to change with the addition of heating power



High stiffness may affect ITER performance

- **TGLF modeling of ITER base case scenario suggest very stiff transport at fixed pedestal beta and no ExB shear**
  [J. Kinsey at al., *Nucl. Fusion* **51**, 083001 (2011)]

- **Recent JET experimental results indicate that, at low magnetic shear, ion stiffness significantly increases with lowering toroidal rotation, and thus ExB shear**
  [P. Mantica et al., *Phys. Rev. Lett.* **107**, 135004 (2011)]

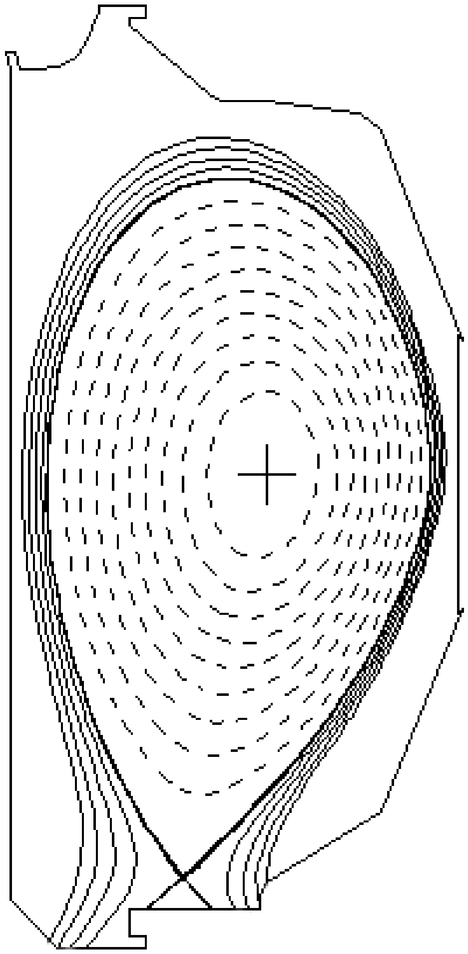
- **ITER is expected to rotate slowly due to low external torque and high inertia, thus stiff profiles are predicted**

How will the fusion power scale with the coupled power ?

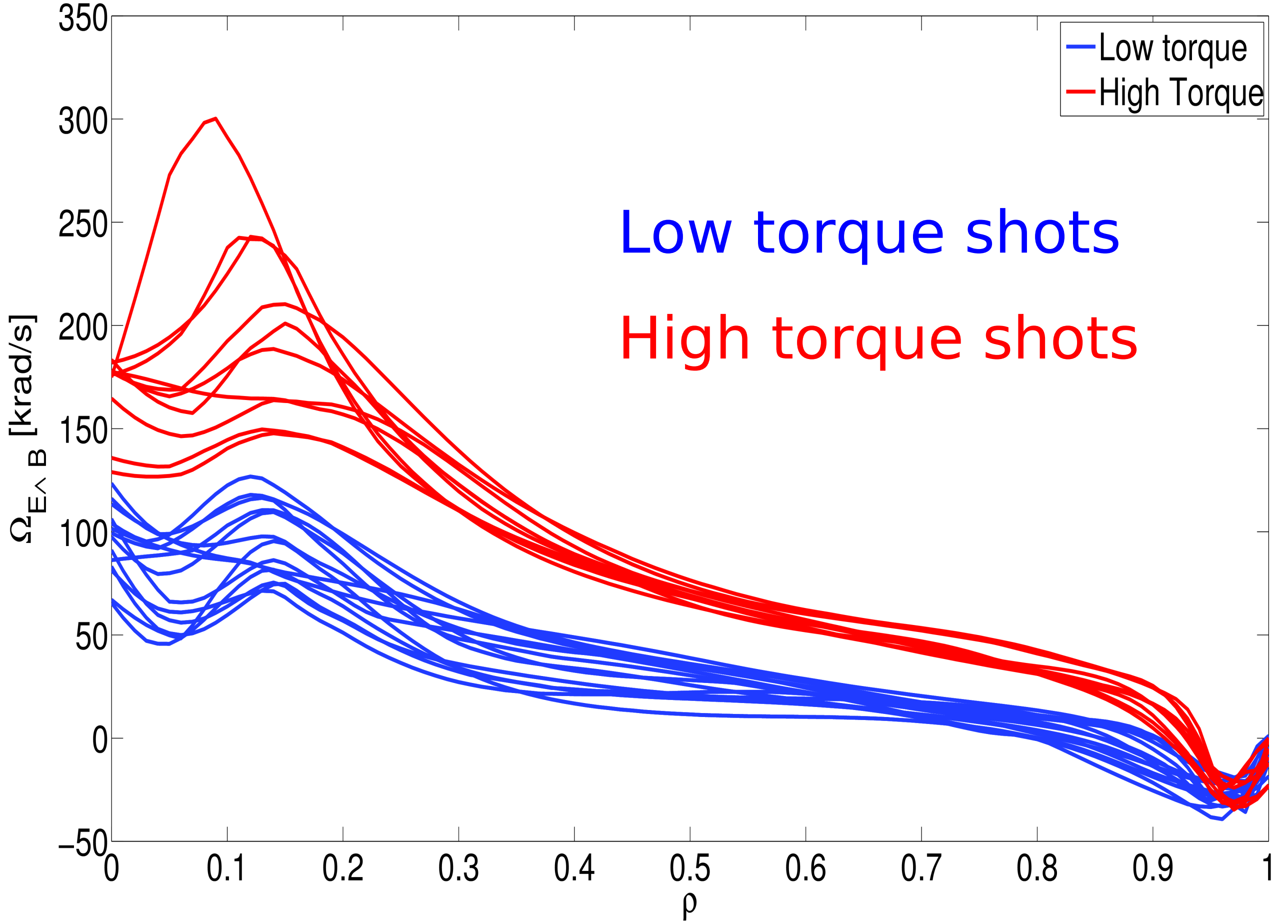
Dedicated experiments were performed on DIII-D to test the impact of rotation on ion stiffness

- **Goal: vary heat flux at fixed β_{ped} in ITER relevant scenario**
- **Co and balanced beams provided low and high rotation**
- **NBI power varied by a factor of 3 at low and at high rotation**

  - n_{e0} ~ 5-6 10^{19} m^{-3}
  - T_{e0} ~ 3.5-5 keV
  - T_{i0} ~ 4-8 keV
  - B_T = 2.1 T
  - q_0 ~ 1.2
  - q_{95} ~ 4
  - P_{NB} ~ 3-9 MW
  - β_p ~ 0.6-1.2



ExB velocity depends primarily on torque



Little dependence is observed on input power in the entire dataset

Does a larger ExB (shear) reduce transport and fluctuations?

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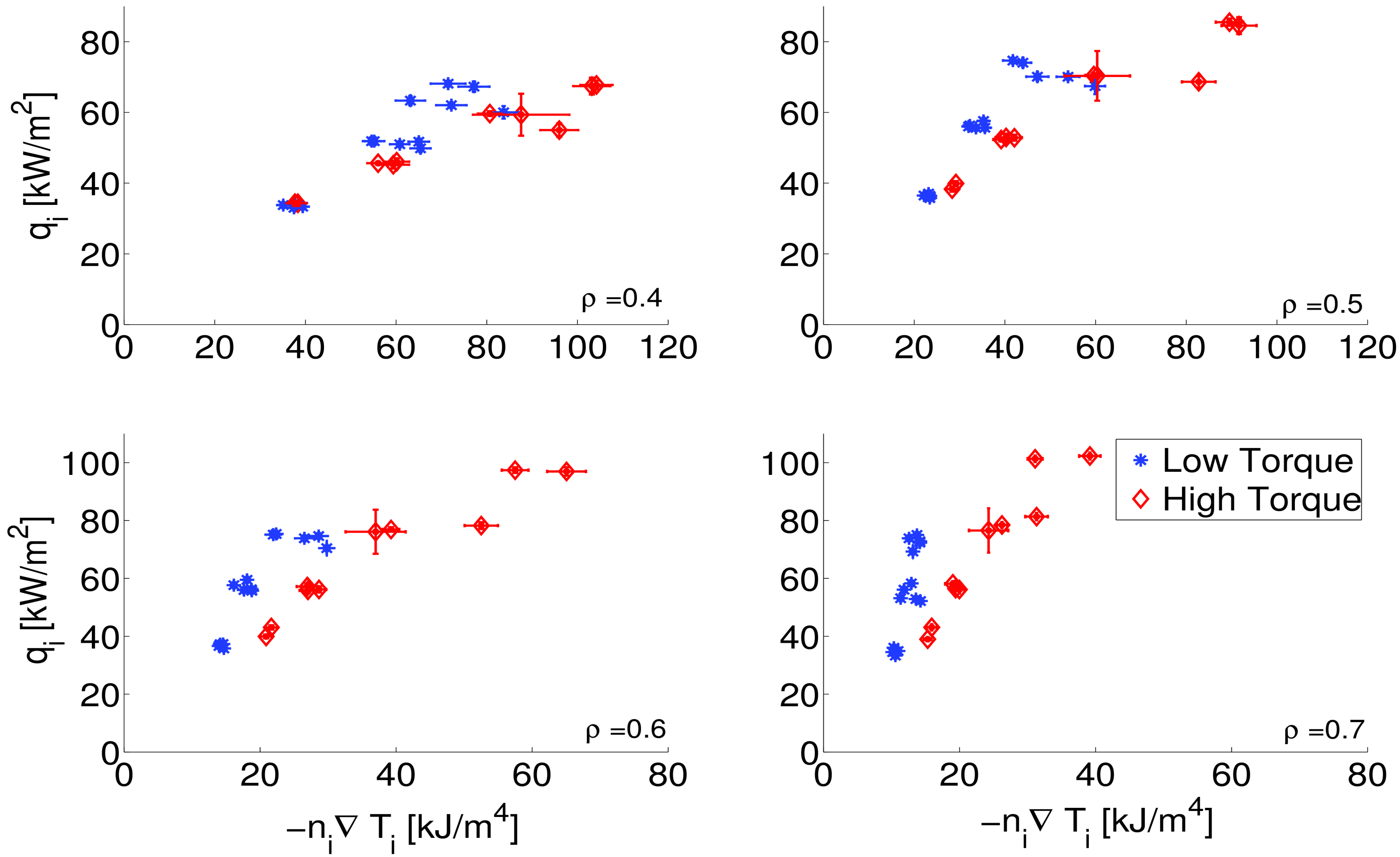
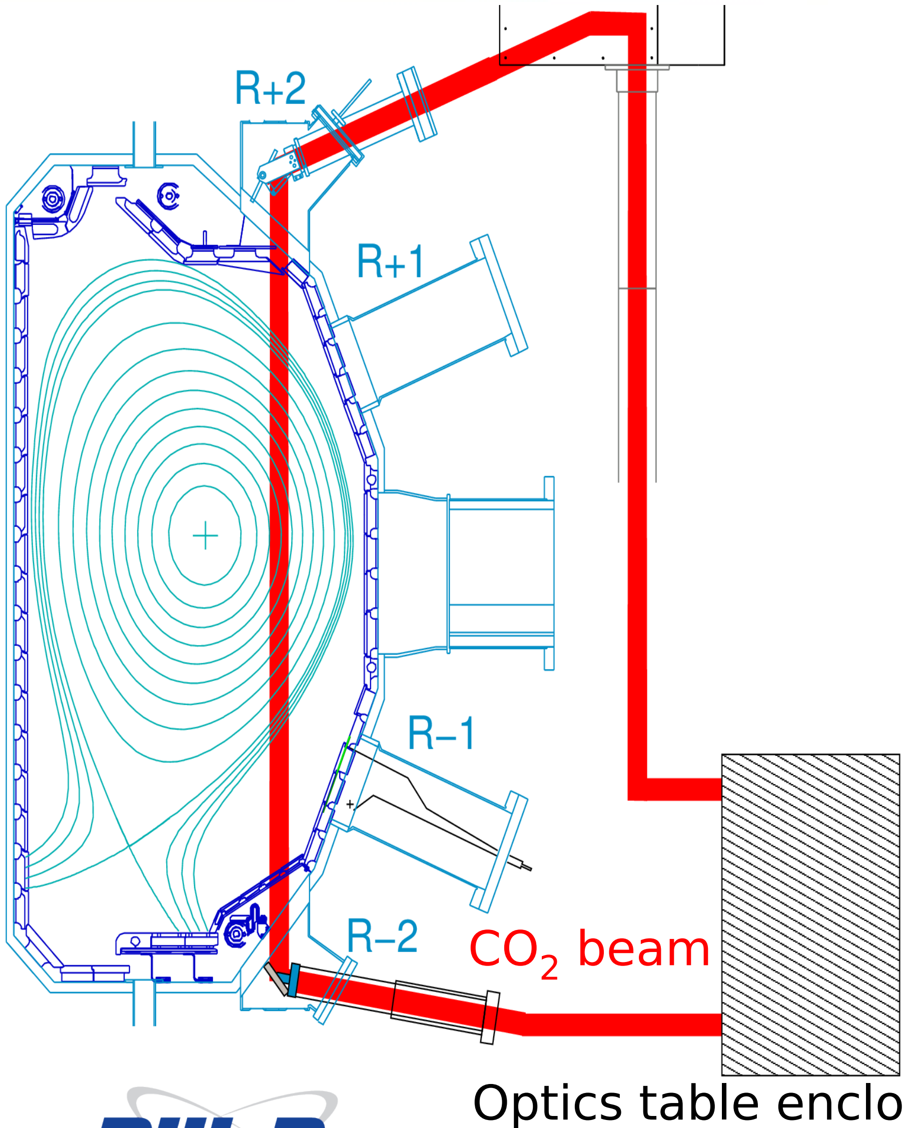
Plasmas at high rotation show lower transport consistent with a larger ExB shear quench



Larger difference between the two scenarios at outer radii

Linear relationship between fluxes and gradients

Fluctuations were measured by the Phase Contrast Imaging diagnostic



Details on the system:
J.C. Rost, GP8.00090

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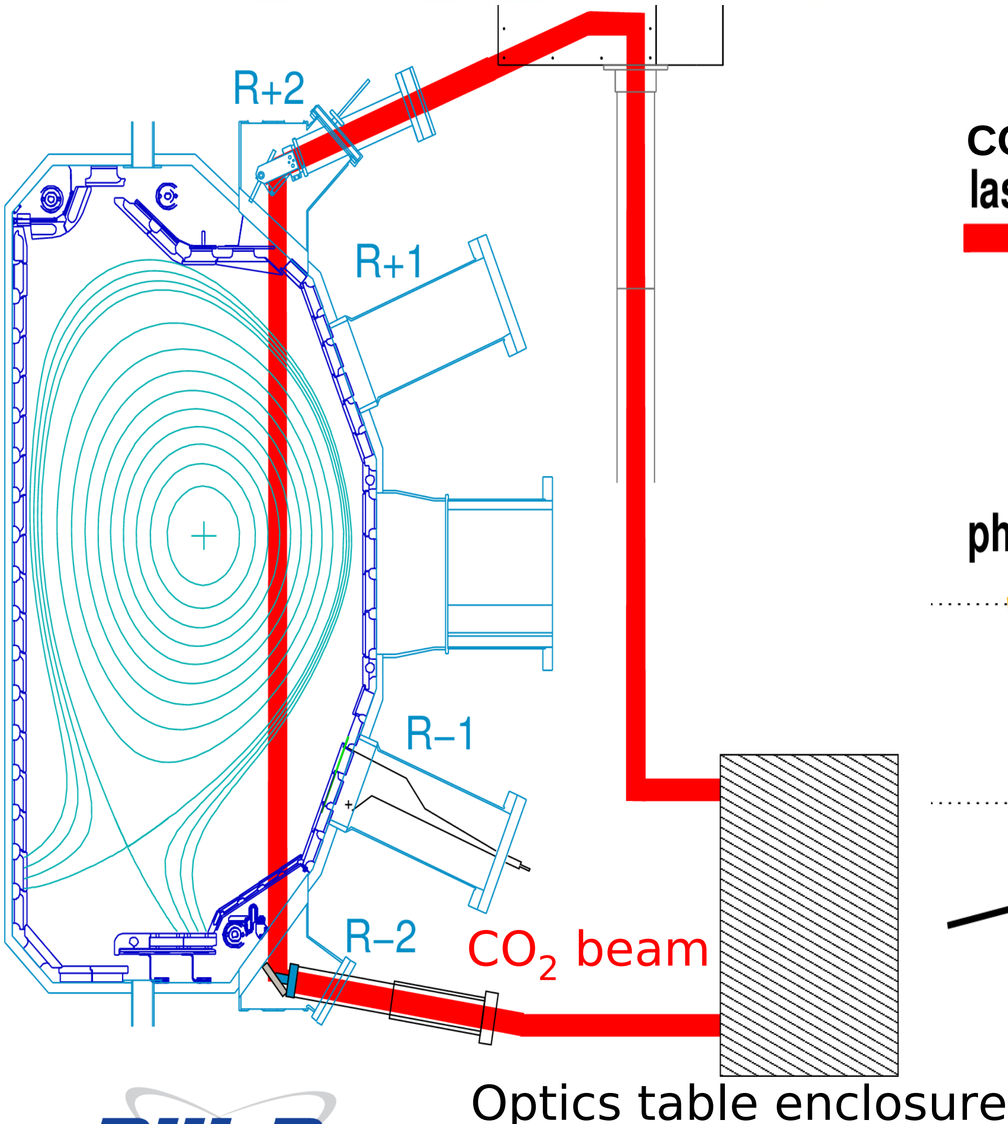

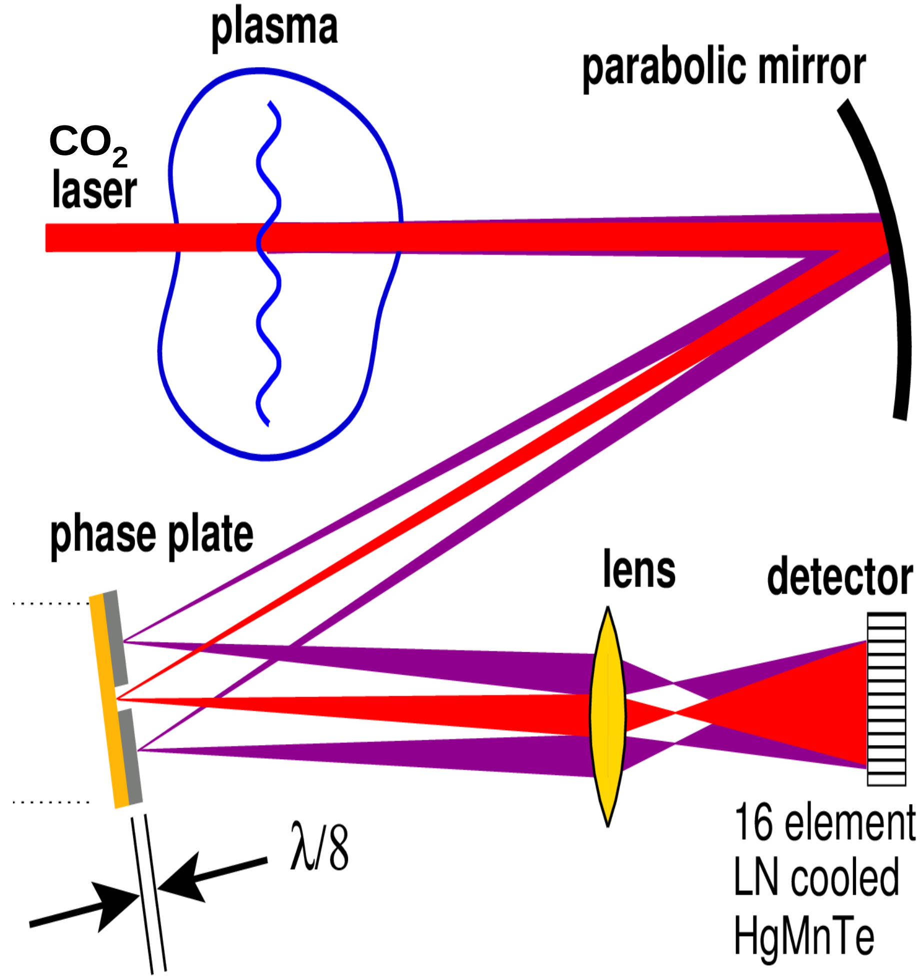

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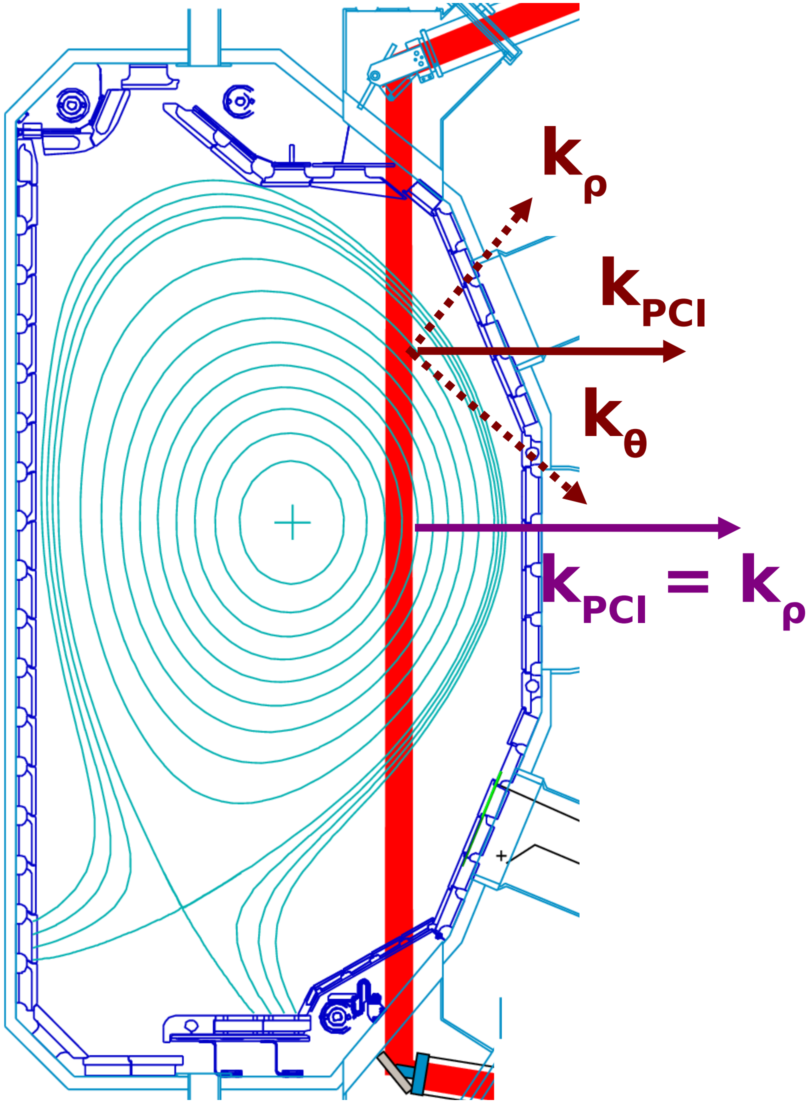
Fluctuations were measured by the Phase Contrast Imaging diagnostic

- **Sensitive to the line integral of density fluctuations**
- **Large bandwidth**
  - f: 10 kHz - 10 MHz
  - k: 1 - 20 cm^{-1}
- **Sensitive to horizontally directed wave-vectors:**
  - k_ρ-k_θ components change along the beam-path
- **k_θ induces a net Doppler shift**



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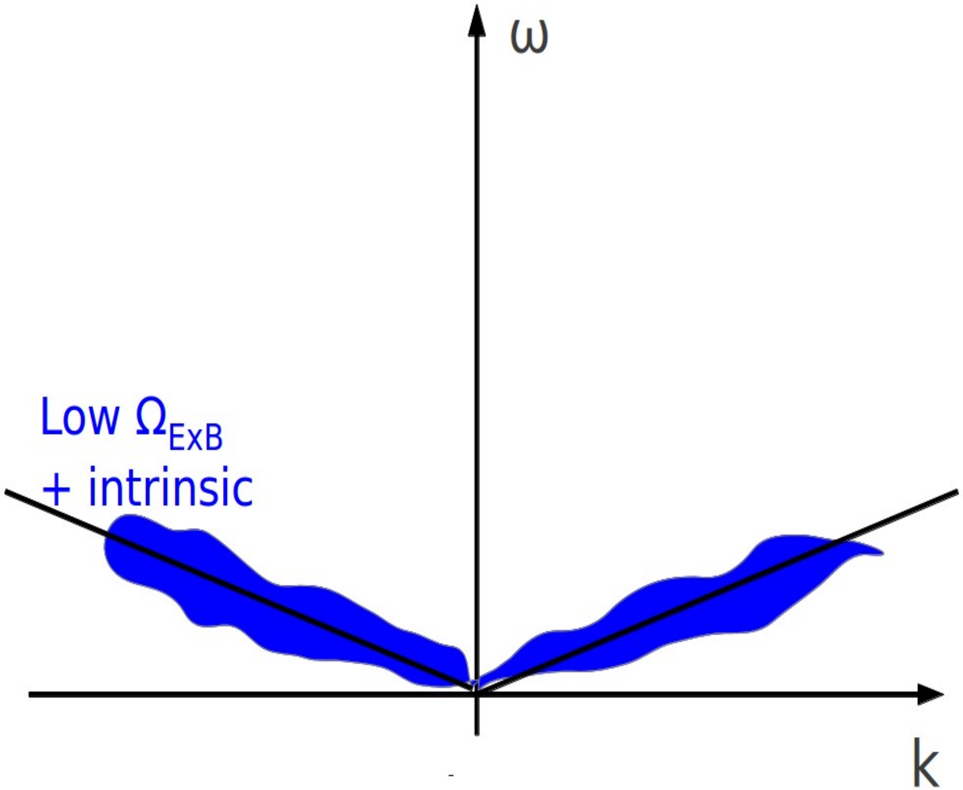
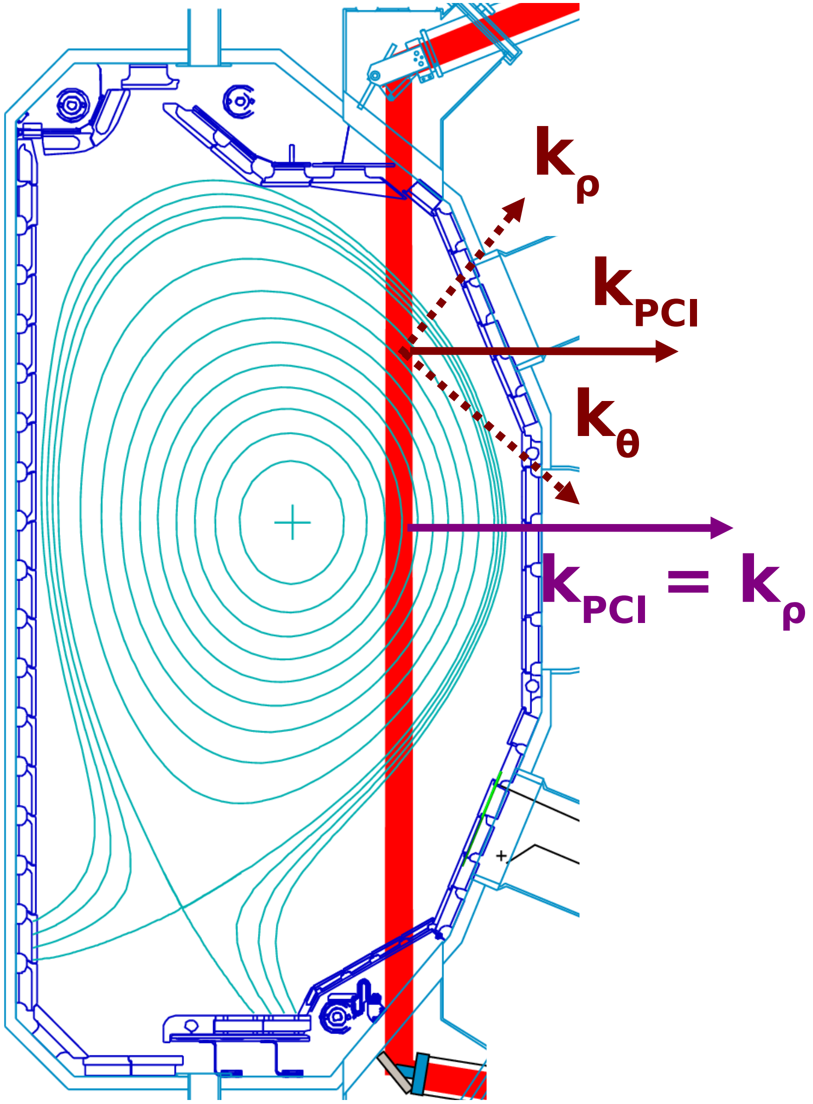
Intrinsic frequency and Doppler shifts are captured by the PCI





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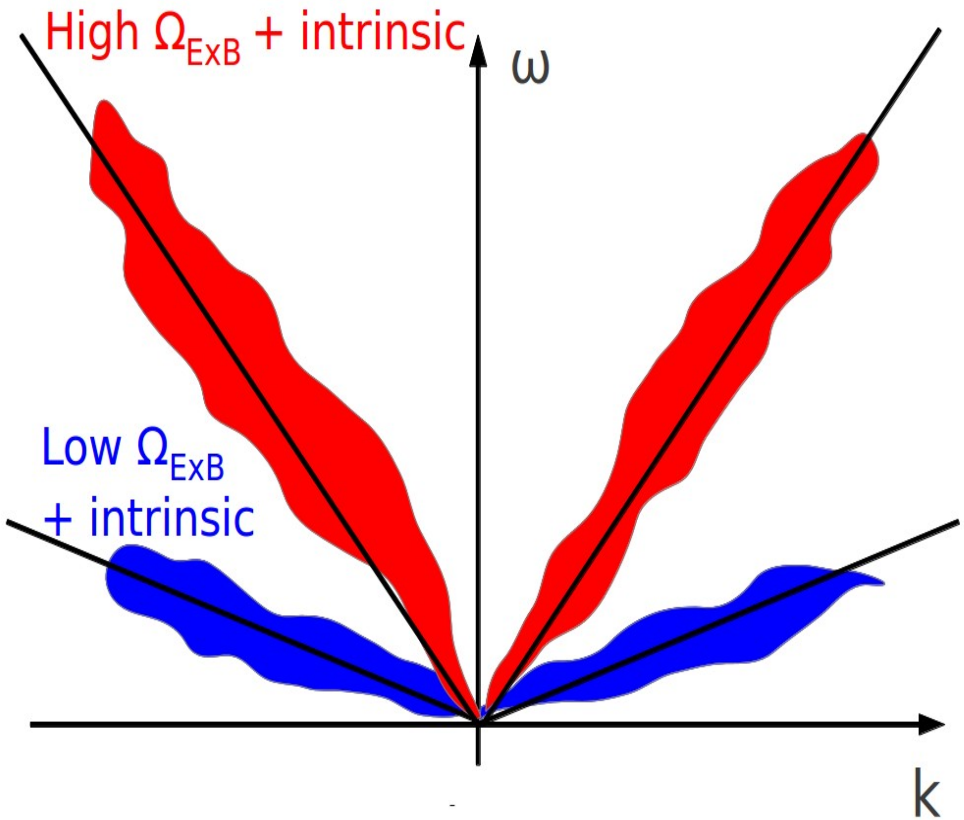
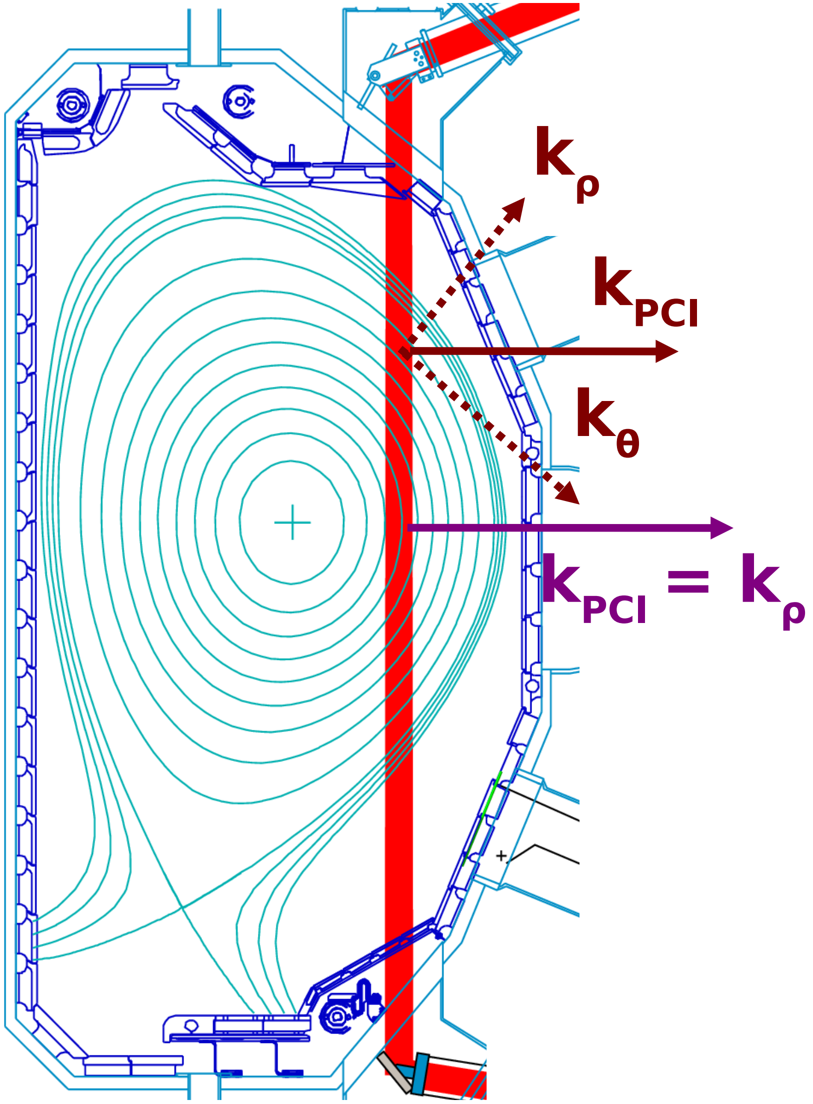
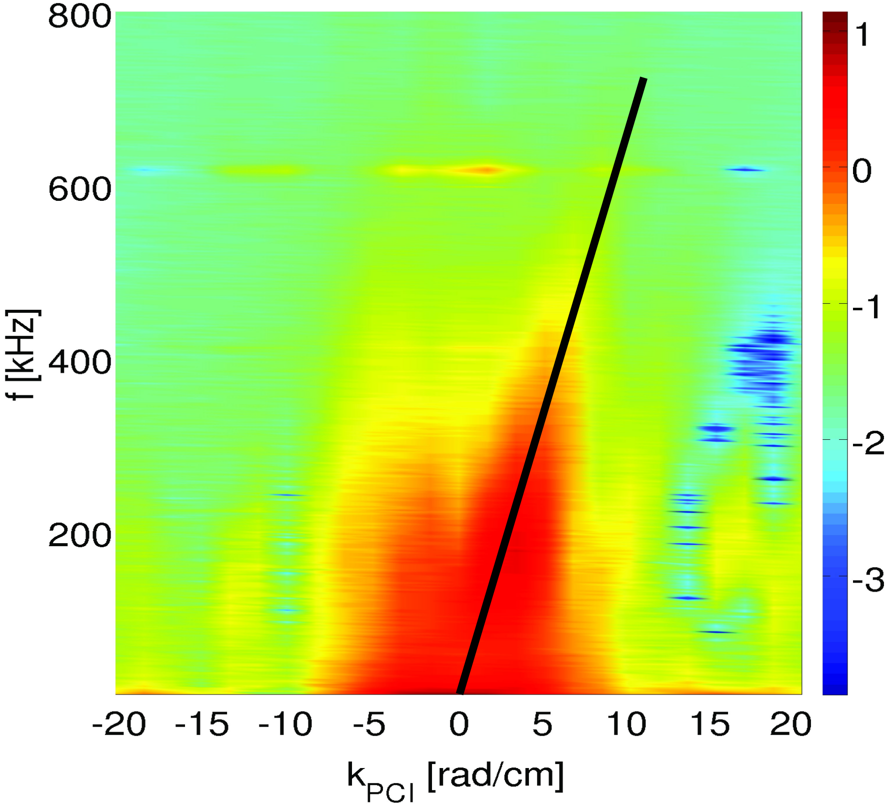




Doppler shift in PCI spectra is consistent with CXRS measurements

Low Torque -3.3 MW



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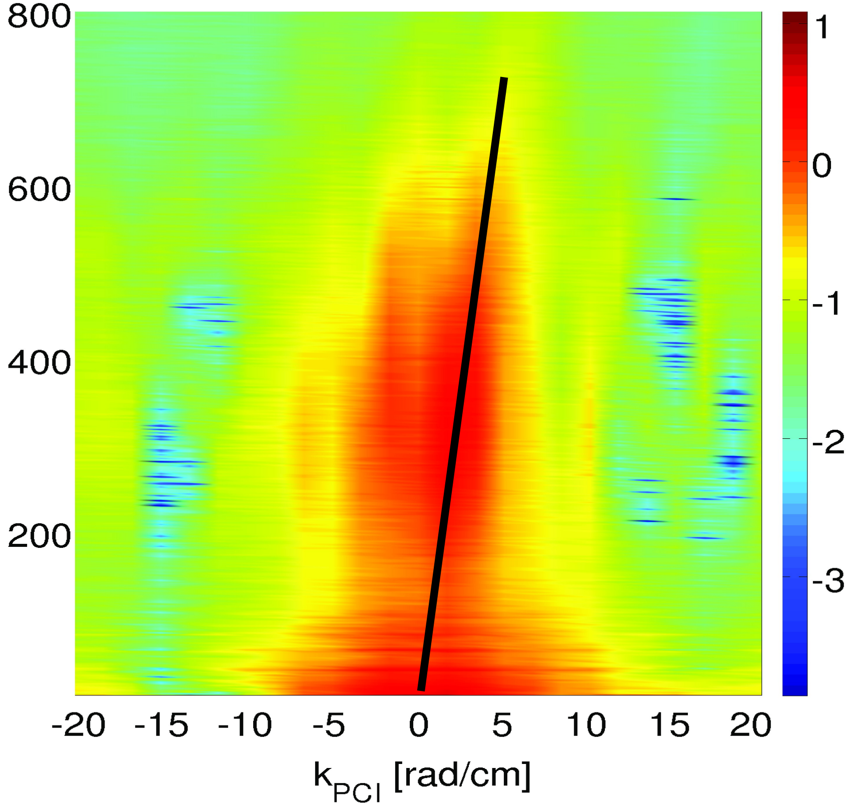
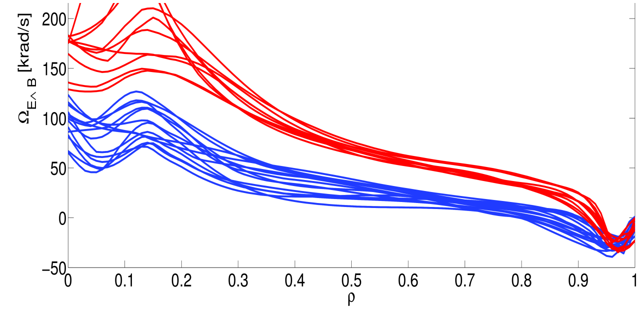
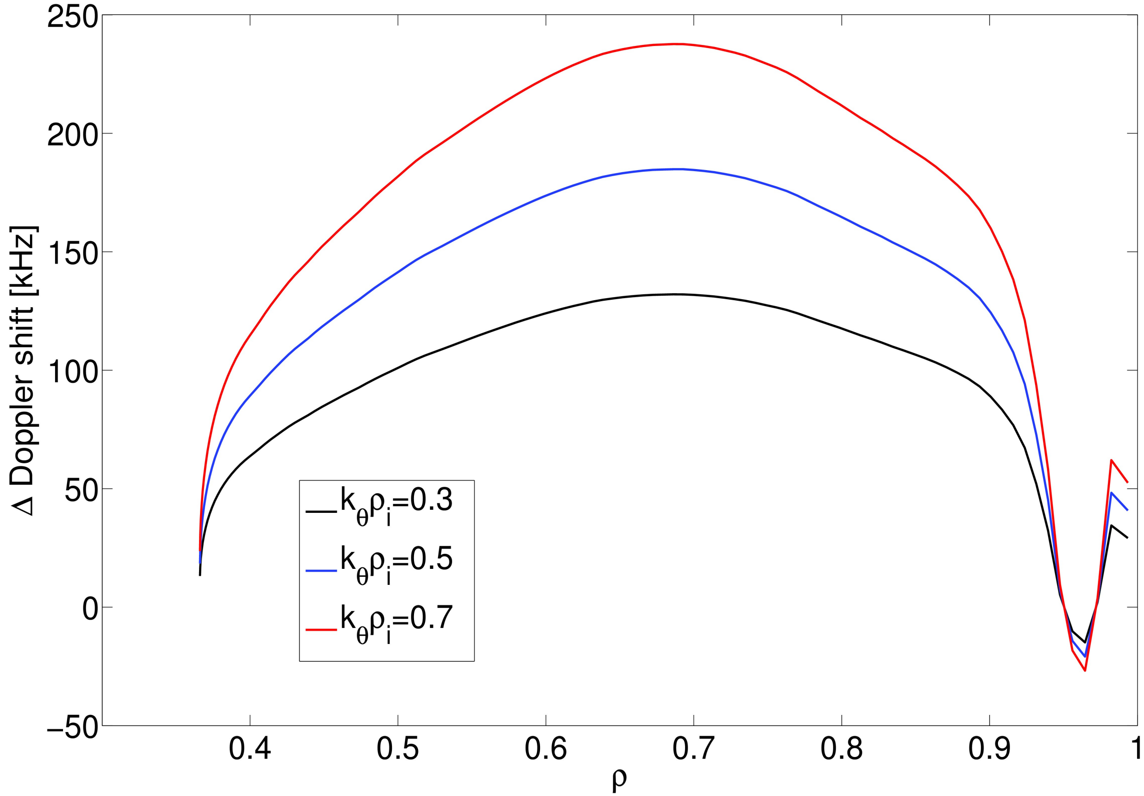


Primary dependence is observed on coupled torque



Difference in Doppler shift localizes the signal in the region 0.5 < ρ < 0.8



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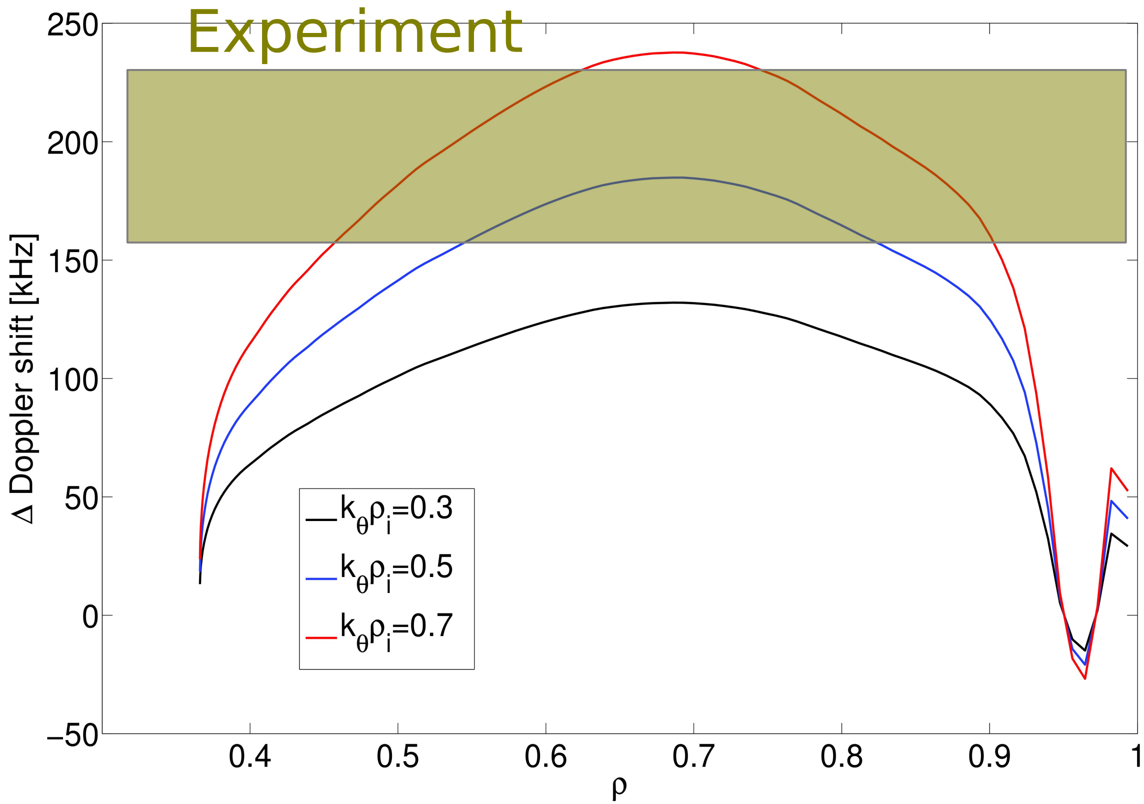
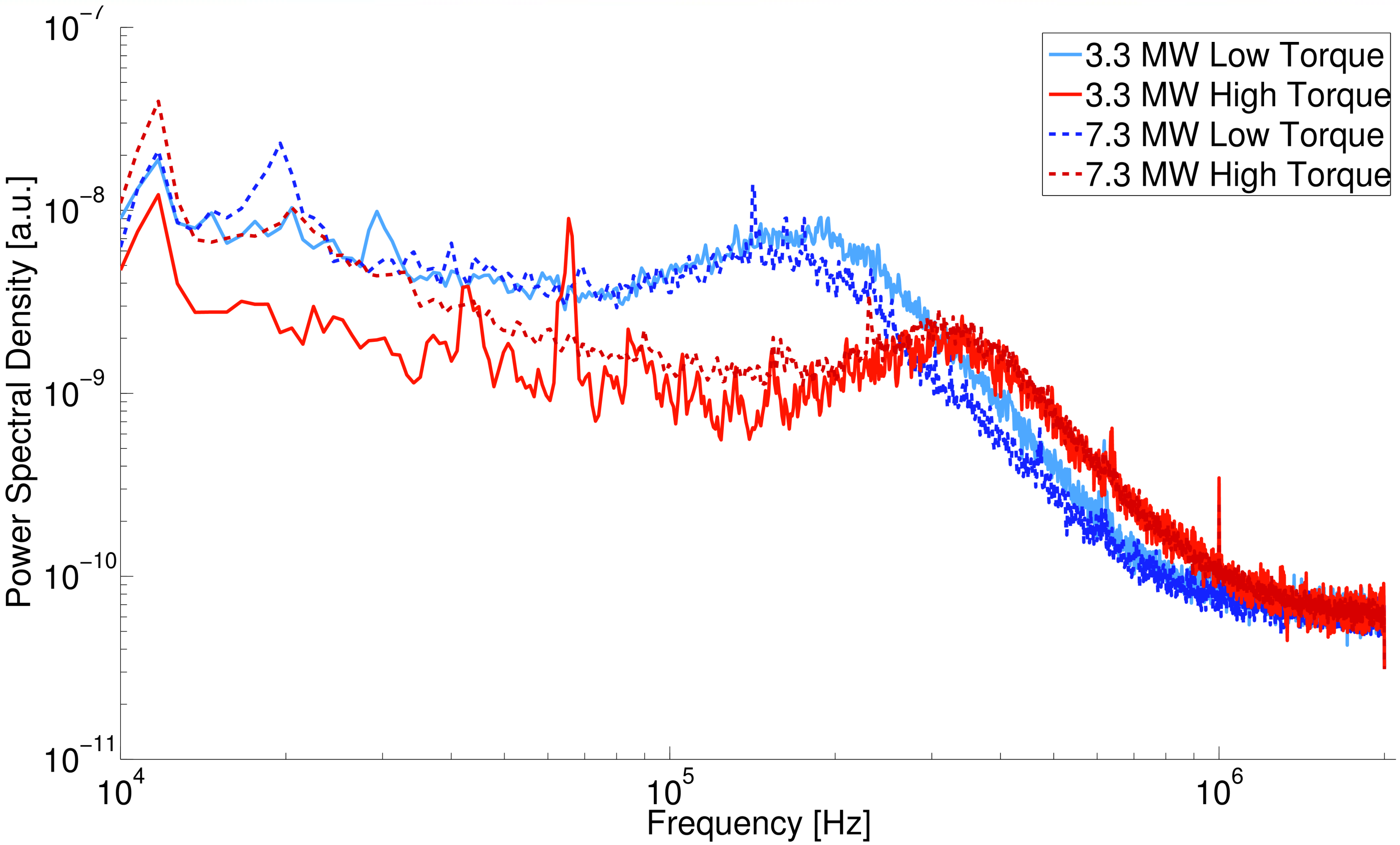


A difference in Doppler shift of 200 kHz is compatible with standard turbulence spatial scales in 0.5 < ρ < 0.8

Innermost radii and the pedestal are to be excluded

The intensity of fluctuations decreases at high rotation

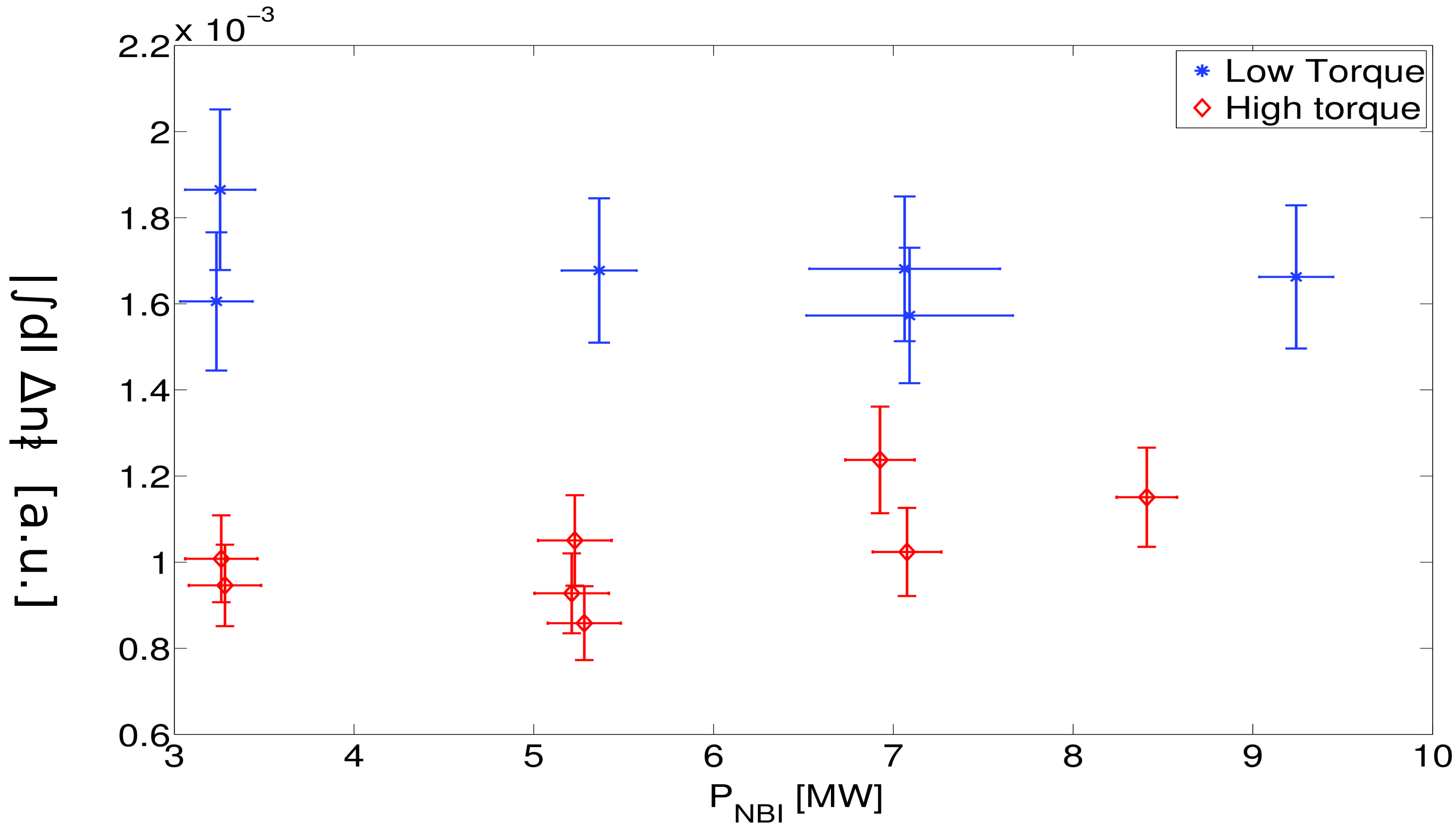


Spectra are coherently averaged in inter ELMs phases

Comparable intensities at same torque and different power

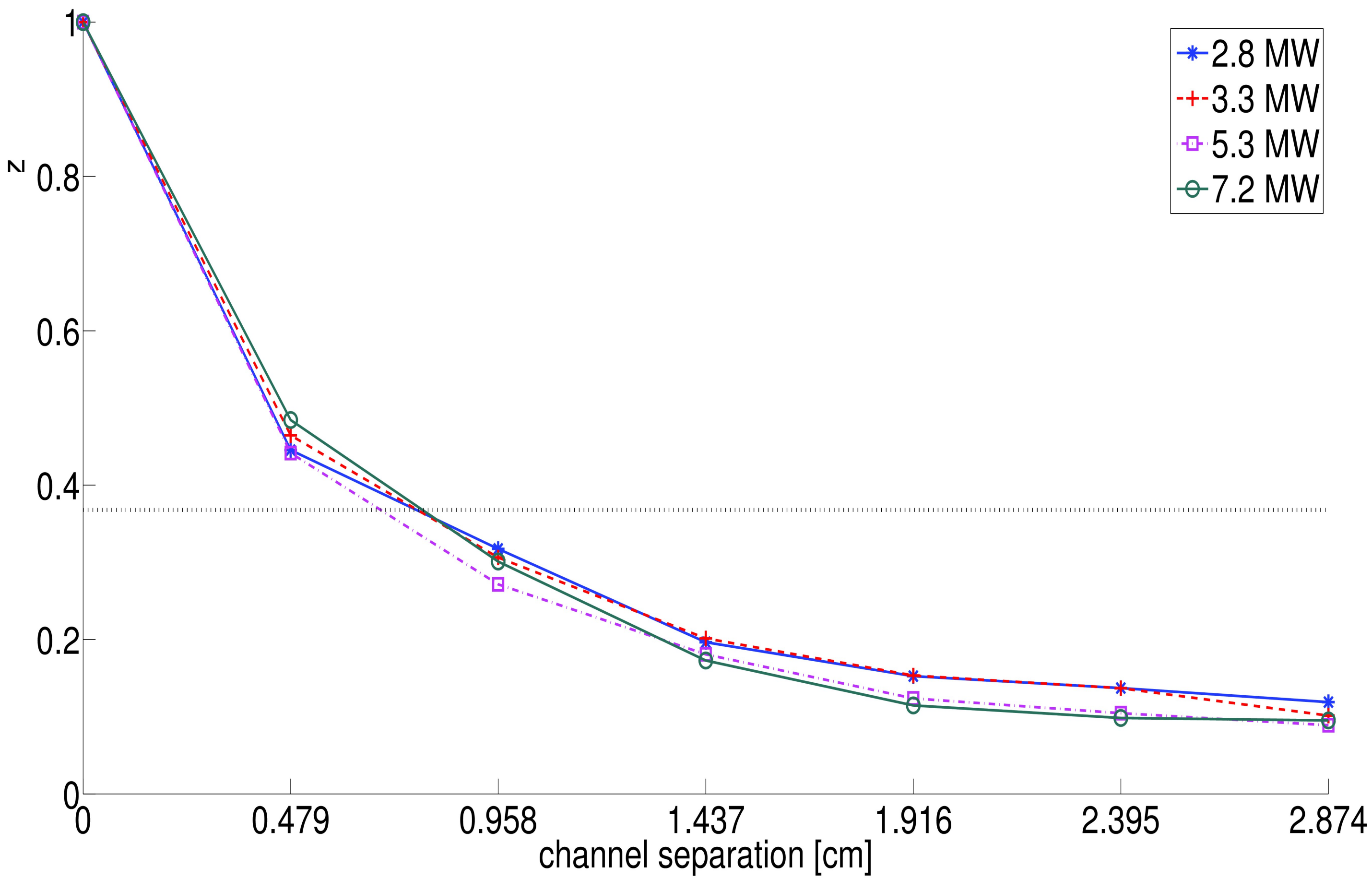
High torque plasmas show similar Doppler shifts

The intensity of fluctuations decreases at high rotation



Comparable intensities at same torque and different power

Correlation lengths do not seem to depend on either torque or power



Correlation lengths are coherently averaged in inter ELMs phases

The impact of torque is within the PCI resolution

Conclusions and future work

Intensity of fluctuations:

- **Strong torque** dependence
- **No power** dependence

Correlations lengths:

- **Independent** of **torque** and **power**

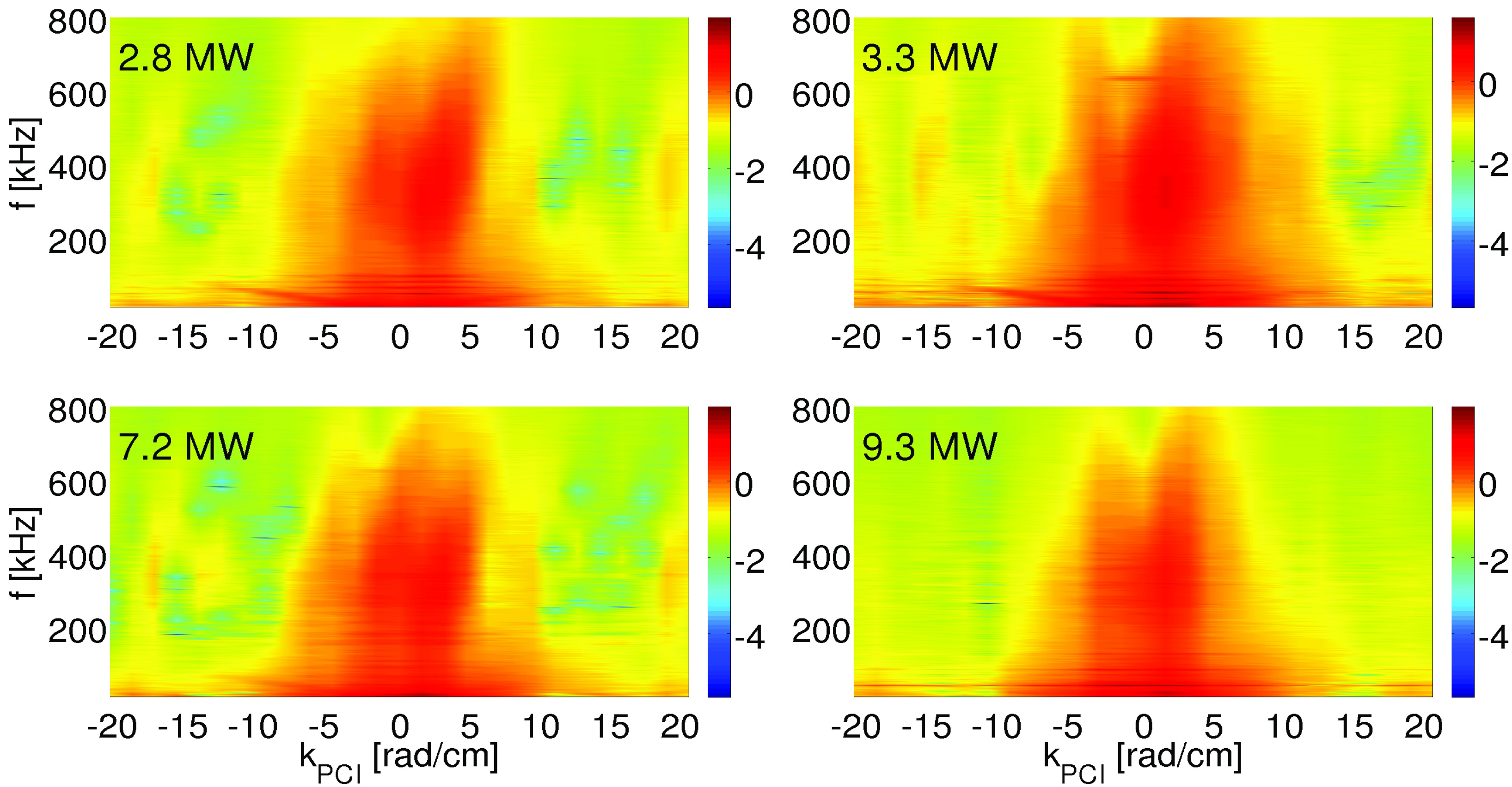
Based on Doppler shifts, the bulk of the signal comes from the region $0.5 < \rho < 0.8$, where the effect of torque on transport is the largest

Nonlinear GYRO simulations and comparisons via a synthetic diagnostic are **in progress**

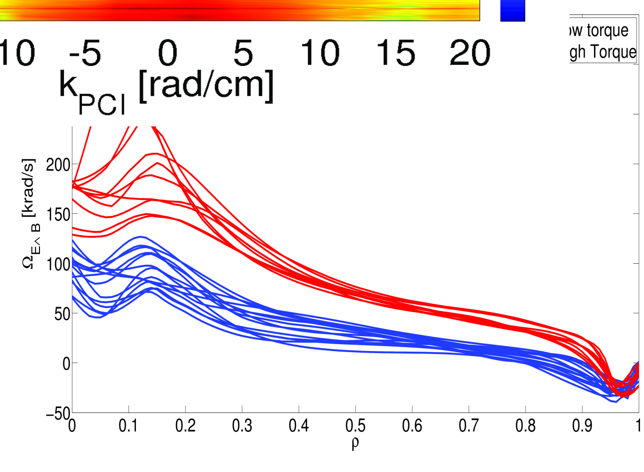
What is stiffness ?

- **The sensitivity of the gyro-Bohm normalized ion heat flux to the driving R/LTi. [J.Citrin, ITPA 2012]**
- **The ratio between the diffusivity and the difference between the logarithmic gradient of the temperature and its critical value, using an appropriate normalization. [X.Garbet, PPCF 2004]**
- **Marginal stability, i.e. profiles whose gradients are close to the instability threshold everywhere**
- **The profile's resistance to change with the addition of heating power... i.e. the fractional increase in the diffusive heat flux divided by the fractional increase in the temperature gradient [J.De Boo, PoP 2012]**

Doppler shift in PCI spectra is consistent with CXRS measurements



Little or no dependence is observed on input power at same torque



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