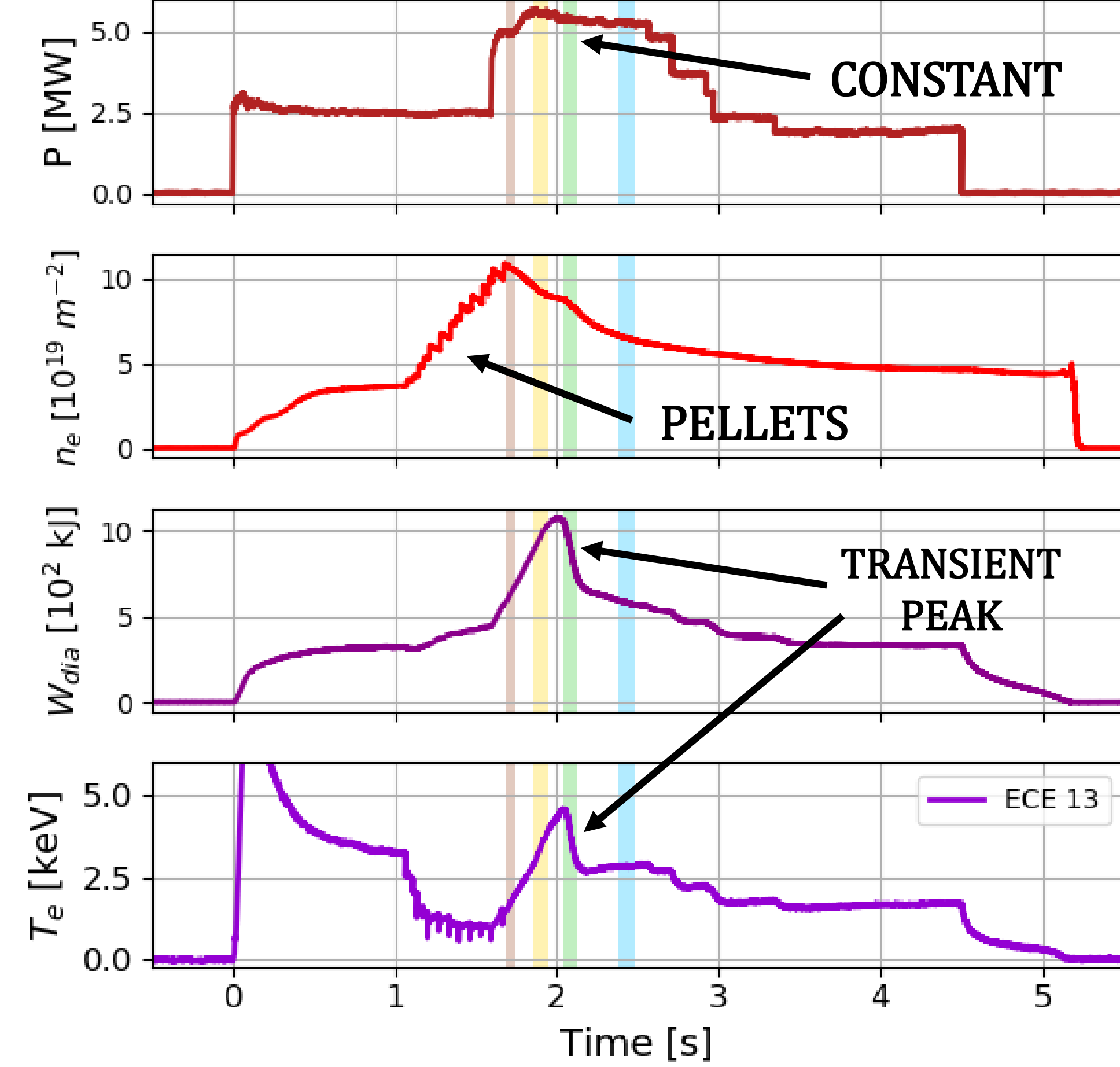


Introduction

In stellarators the radial heat diffusivity and particle exhaust is regulated by transport effects. The W7-X is optimized for neoclassical transport, but turbulent transport is also expected to play a significant role in the regulation. As an example: one of the great surprises of the 2017/18 campaign was that **after the pellet injections (which increases the core plasma density), improved energy confinement was observed.** ⇒ Turbulence studies are of key importance.

Observed phenomenon

After a series of pellet injections, improved energy confinement was observed [1]. This phenomenon is clearly seen on global plasma parameters. #20180904.027 | W7-X



- Density is growing due to the pellet injections
- After pellet injections:
 - Density is slowly decreasing
 - Heating power is constant, but there is a **transient peak** in T_e around 2 s
- Transient peak also appears in diamagnetic energy
- After transient peak of T_e → steady state is developed

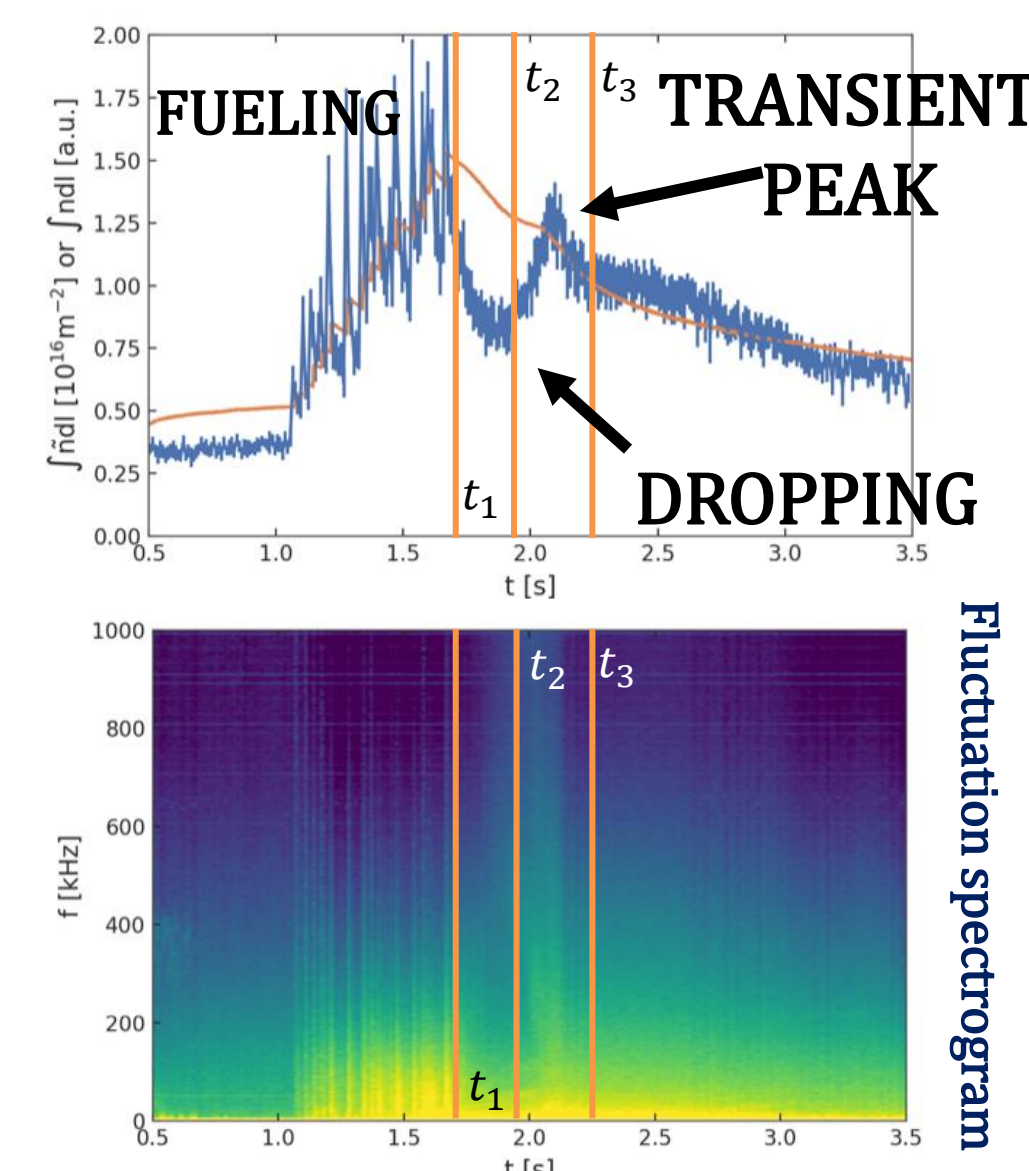
Phase Contrast Imaging (PCI) diagnostic samples plasma density fluctuations along the line-of-sight of an infrared laser beam.

The PCI measured fluctuation amplitude is usually proportional to the line-integrated plasma density **BUT!**

after pellet fueling ($t_1 = 1.7$ s) the fluctuation level suddenly drops and **improved energy confinement** is observed.

Temporary reduction of fluctuation amplitude is observed through the fluctuation spectrogram but **transient growth of fluctuation appears** ($t_2 < t < t_3$). After t_3 the fluctuation is proportional to the density again.

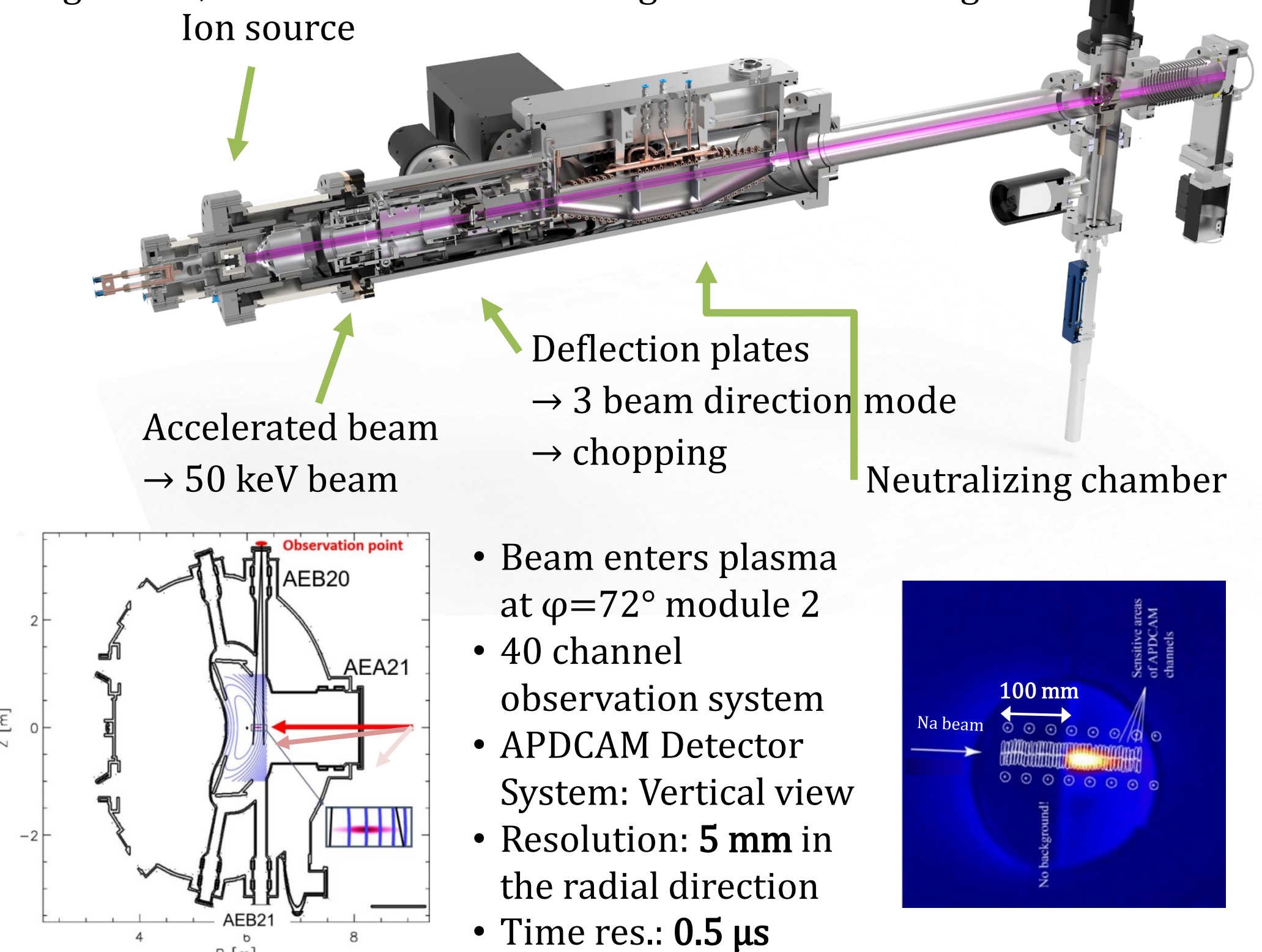
Simulations show that the origin of the changes of the fluctuation is in the core plasma. Whether it has effect on the edge plasma has not been addressed yet in details.



Multi-diagnostics approach

Signals from **PCI, H-alpha, Mirnov coils** were analyzed, alongside with Beam Emission Spectroscopy (BES).

BES: Atomic beam diagnostics that measures the light intensity of the emitted **Na line of the beam atoms** in the edge of the plasma and in the SOL, which is a nonlocal function of the plasma density. BES is a non-perturbative diagnostics, which can measure during the entire discharge.

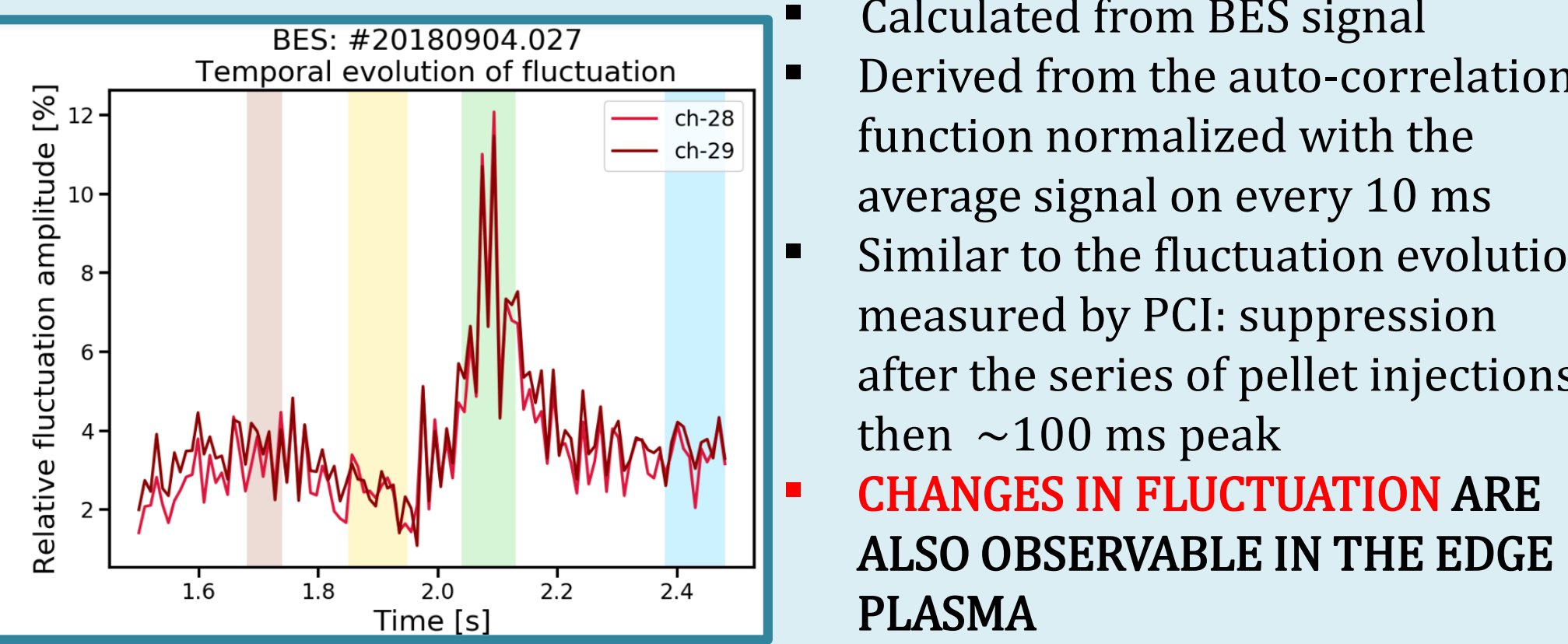


Motivation

PCI : line-integrated signal → **not localized**
BES : **good spatial and temporal resolution** of edge plasma density and its rapid changes.

- Can the changes in fluctuation amplitude be seen in the edge plasma?
- What is the spatio-temporal structure of the measured fluctuation?
- How the fluctuation measured by other diagnostics can be compared with BES observations?

Fluctuation amplitude in the edge plasma



Choosing time intervals

4 time intervals have been chosen for further analysis:

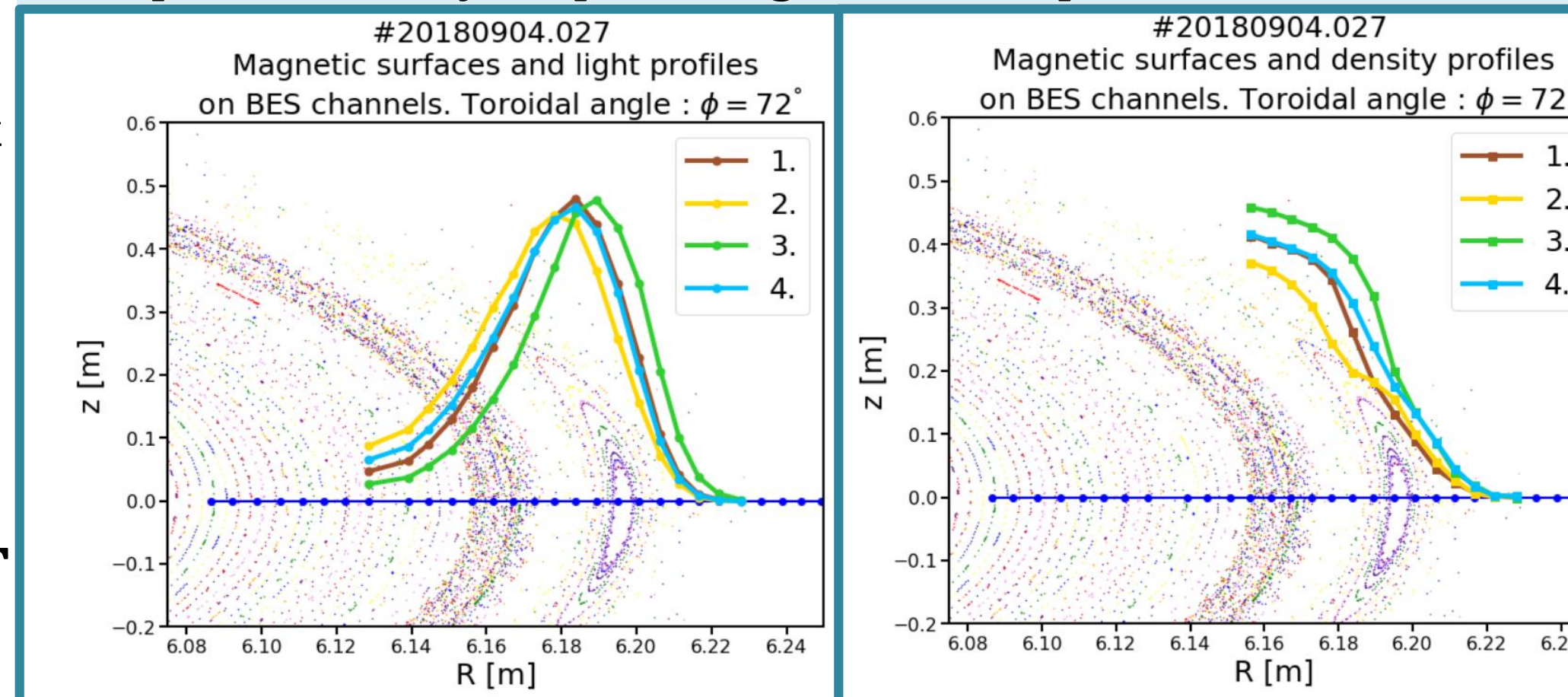
- Right after pellet fueling
- Suppression of fluctuation amplitude
- In the fluctuation amplitude peak
- Steady state

This color code notation will be used in the following parts of the poster.

Density profile

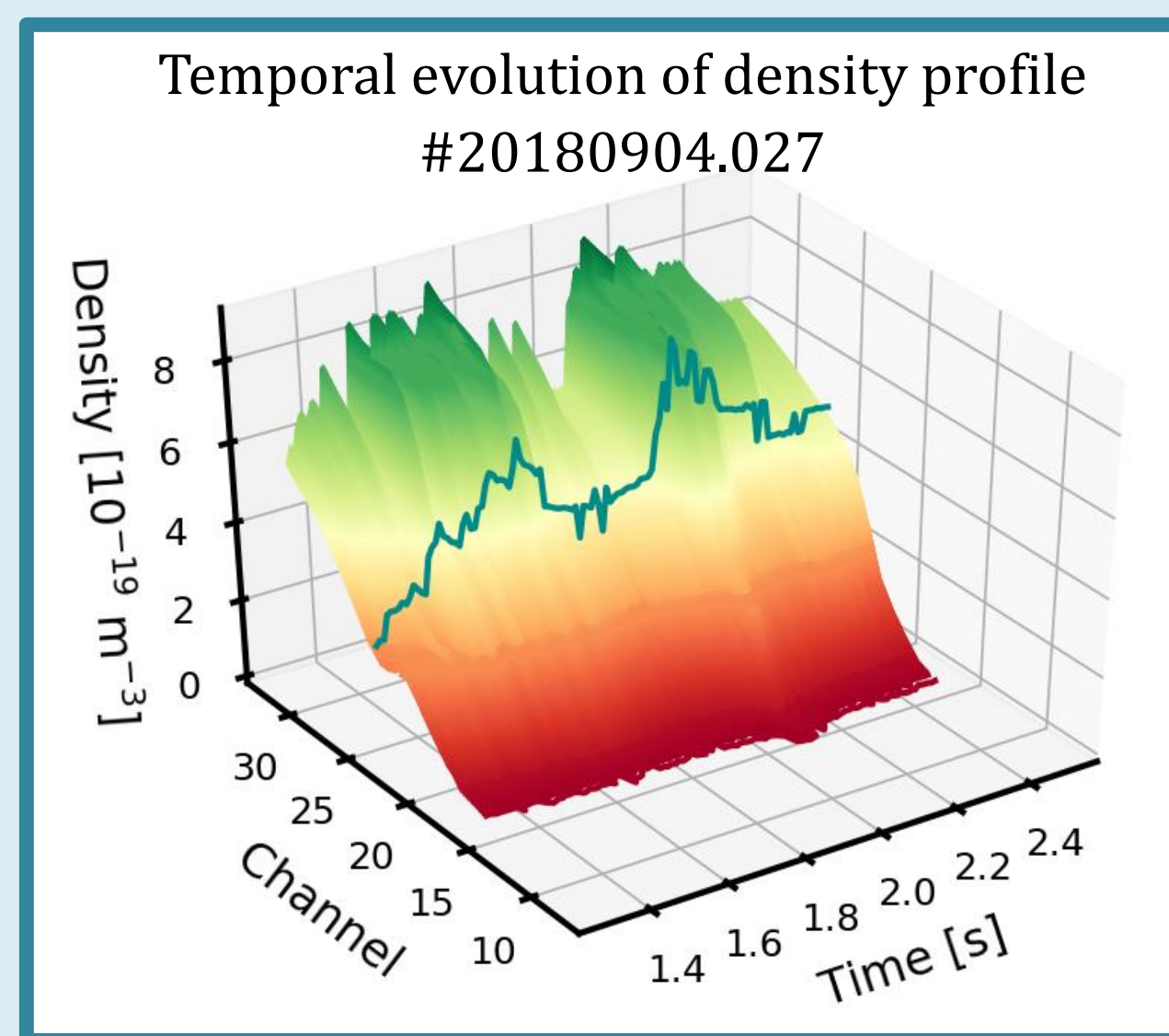
$$I \sim n_{\text{beam}} \cdot n_{\text{plasma}} \cdot \sigma$$

- Density can be reconstructed from BES light profiles
- After pellet injections, during fluctuation suppression the edge plasma density drops, during fluctuation peak it raises



Light intensity

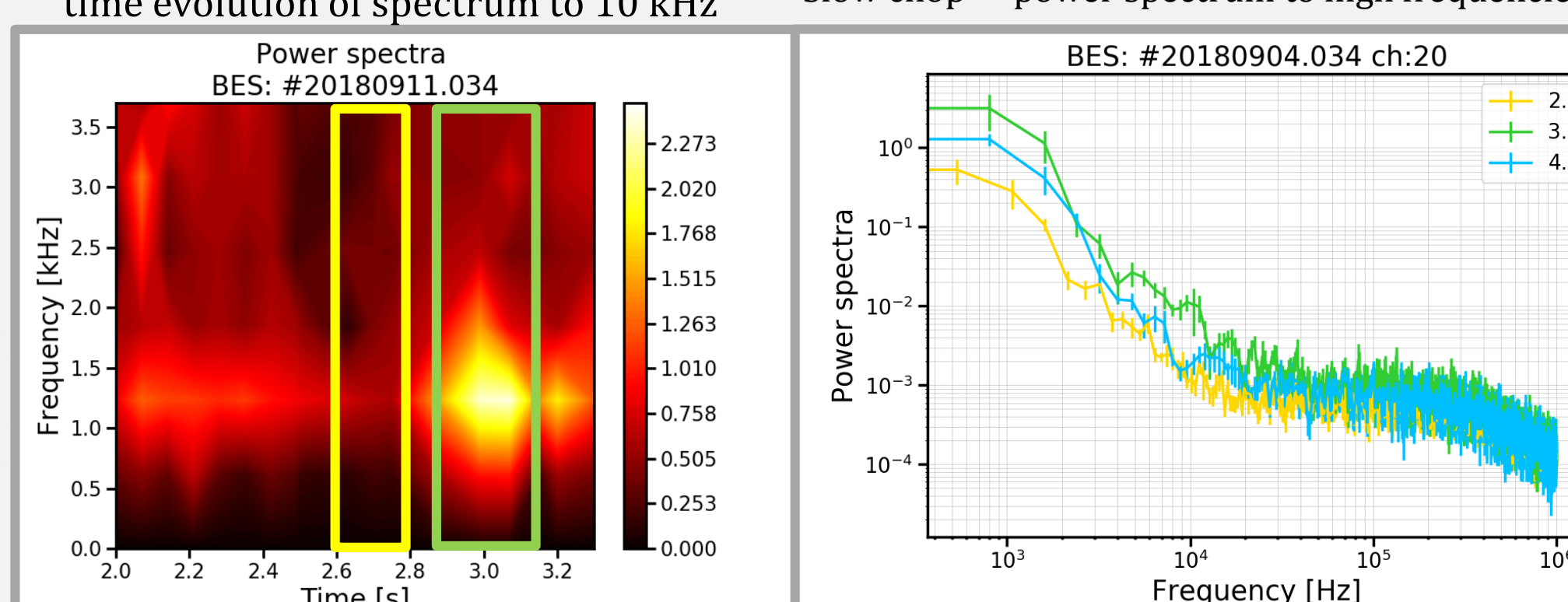
Density



- The line-integrated density continuously drops after pellet injection 11 → $6 \cdot 10^{19} \text{ m}^{-2}$
- At channel 22 ($R = 6.19 \text{ m}$):
- The density drops from 3.4 to $2.9 \cdot 10^{19} \text{ m}^{-2}$ when the energy confinement improves ($\sim 15\%$ drop)
- Then raises during fluctuation peak from 2.9 to $5 \cdot 10^{19} \text{ m}^{-2}$ ($\sim 170\%$ raise)

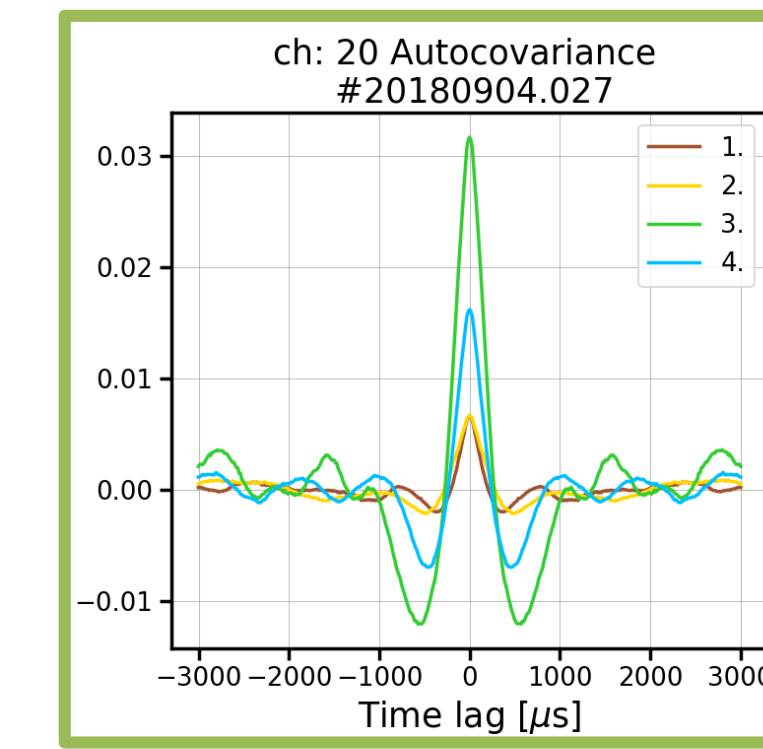
Analysis of edge turbulence from BES

Fast chop → time evolution of spectrum to 10 kHz Slow chop → power spectrum to high frequencies



- Decreasing of few kHz frequencies during fluctuation suppression
- Power of low frequencies up to 10 kHz raise on 3. interval**
- Higher frequencies ($> 50 \text{ kHz}$): the differences, which can be seen on the PCI spectrogram [1], are not visible

Spatio-temporal structure of fluctuations

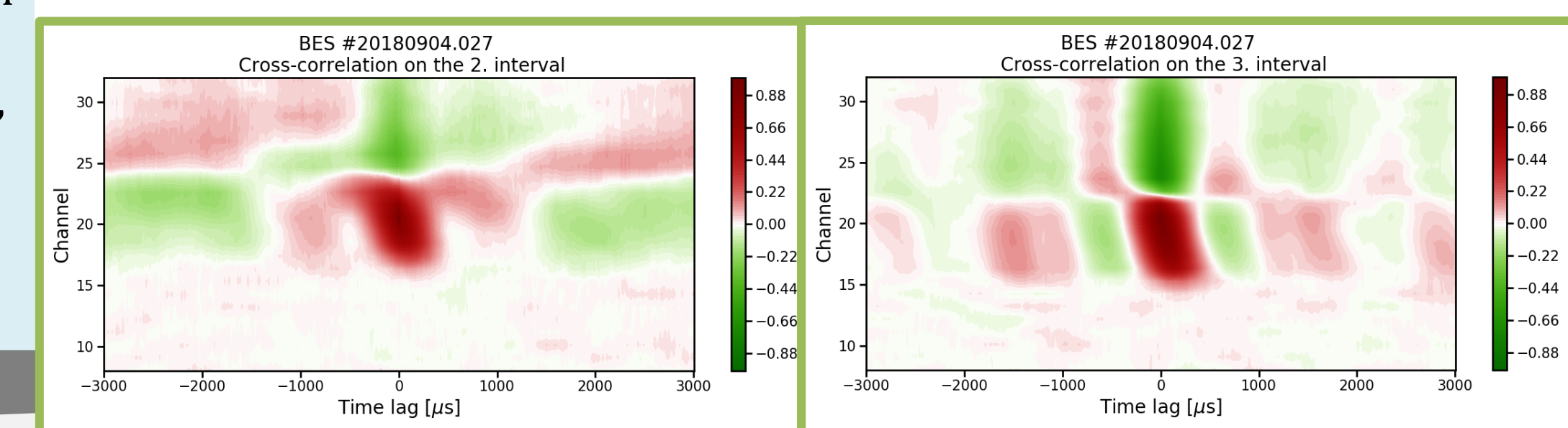


Calculated from the measured light of various channels → anti correlation on the channels after the maximum of light profile

- Higher fluctuation amplitude on 3. interval
- Rapidly decaying 1 ms wavelike structure → this structure changes through the interval fluctuation is not a continuous plasmawave, but a structure with characteristic length

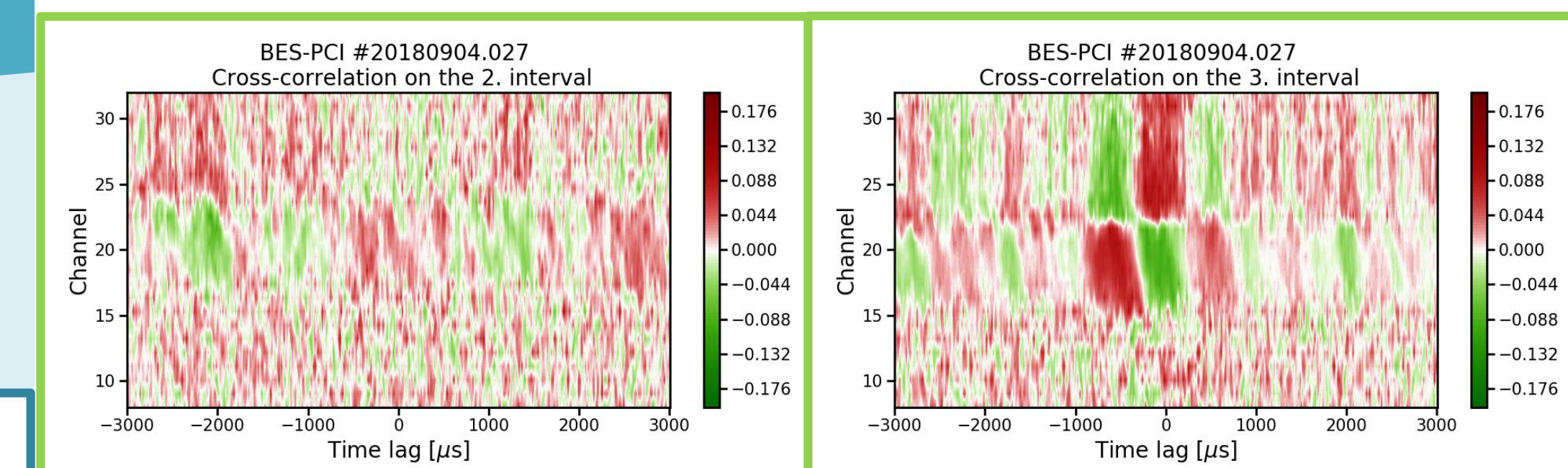
2D Cross-correlation (Reference channel: 20)

- 2. interval: only correlation peak is observed, decays at $300 \mu\text{s}$, radial propagation is less evident
- 3. interval : **increase in radial correlation length**, 1 ms wavelike structures. Slight skew in the position of the correlation peak - **outward propagation** ($\sim 100 \text{ m/s}$ between ch:19-16)



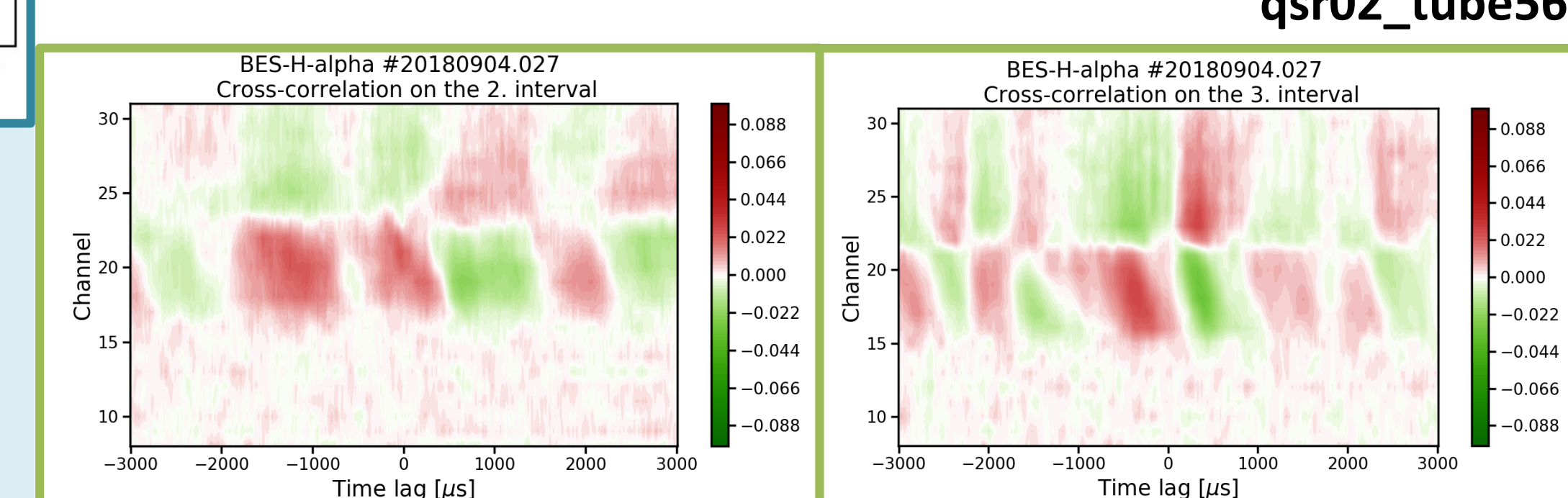
PCI-BES cross-correlation

- During fluctuation suppression (2. interval) no or weak correlation is found
- Strong correlation can be seen on the 3. interval 1 ms wide wavelike structures appearing which was previously observed in BES
- PCI consist useful information at $\sim \text{kHz}$ range frequencies



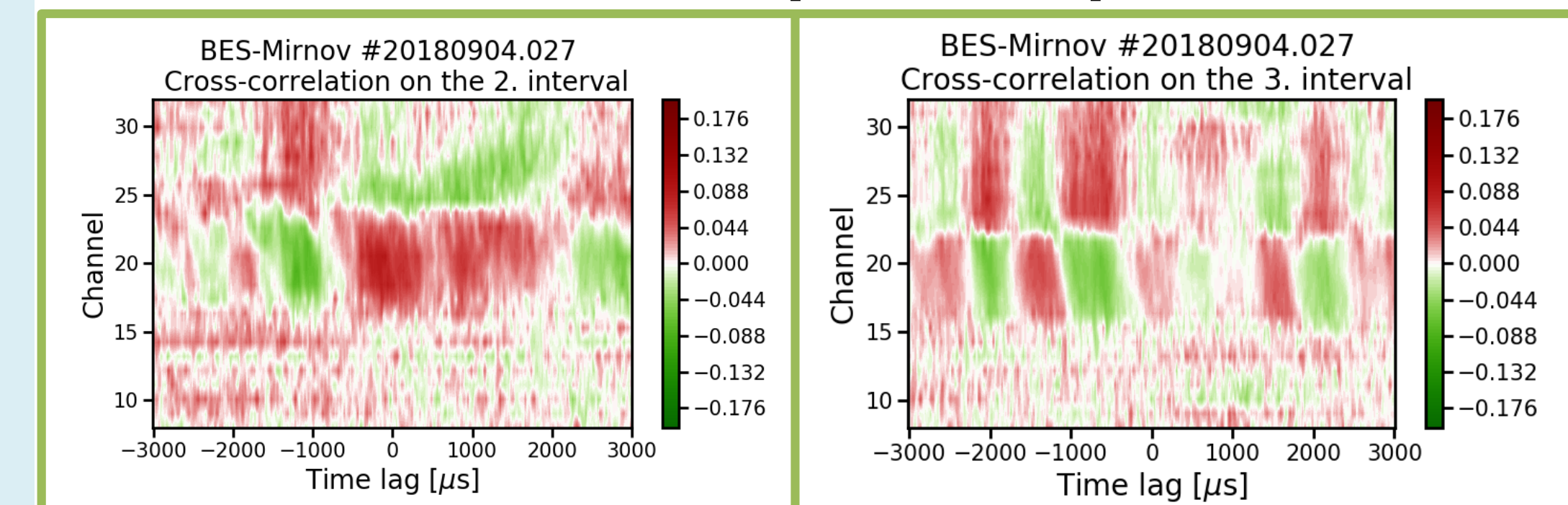
H-alpha-BES cross-correlation

- H-alpha signal indicates the magnitude of the edge plasma transport
- During fluctuation suppression (2. interval) much weaker correlation and lower frequency structures appears
- Stronger correlation can be seen on the 3. interval
- 1 ms wide wavelike structures dominates 3. interval



Mirnov-BES cross-correlation

- Strong correlation is observed between Mirnov and BES signal
- Similar differences are visible between interval 2. and 3. on the temporal behaviors of the correlation map as seen above
- The difference in correlation amplitude is less pronounced



Summary

- Simultaneously to the suppression of core plasma fluctuations the level of edge plasma fluctuation also drops: The fluctuation amplitude measured by BES drops after pellet injection series then it raises transiently and recovers
- The edge plasma density drops during fluctuation suppression, than raises during fluctuation peak
- After pellet injections suppression of $< 10 \text{ kHz}$ fluctuations can be seen in edge plasma, comparing to the steady state
- $\approx 1 \text{ kHz}$ frequency fluctuation are dominant during fluctuation peak, as a 1 ms wavelike structure can be seen in the correlation
- Significant correlation can be seen between PCI, H-alpha, Mirnov and BES signals which provides a coherent observation of edge plasma fluctuation suppression

[1] T. Klinger et al.: Nucl. Fusion 59 (2019) 112004

[2] A. V. Stechow et al.: arXiv:2010.02160v1 [physics.plasm-ph] 5 Oct 2020