Determination of the power deposition of the electron cyclotron resonance heating (ECRH) by its modulation

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Access to the bachelor thesis: https://hdl.handle.net/21.11116/0000-000D-46B9-4

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Agenda

- Idea/ general method

- Automation
  - Preparing the ECE-Data
  - Determine the temperature slope
  - Evaluating particle density profiles
  - Calculating of power deposition profiles

- Application of the automation
  - Modulation at different frequencies
  - Including the zoom system

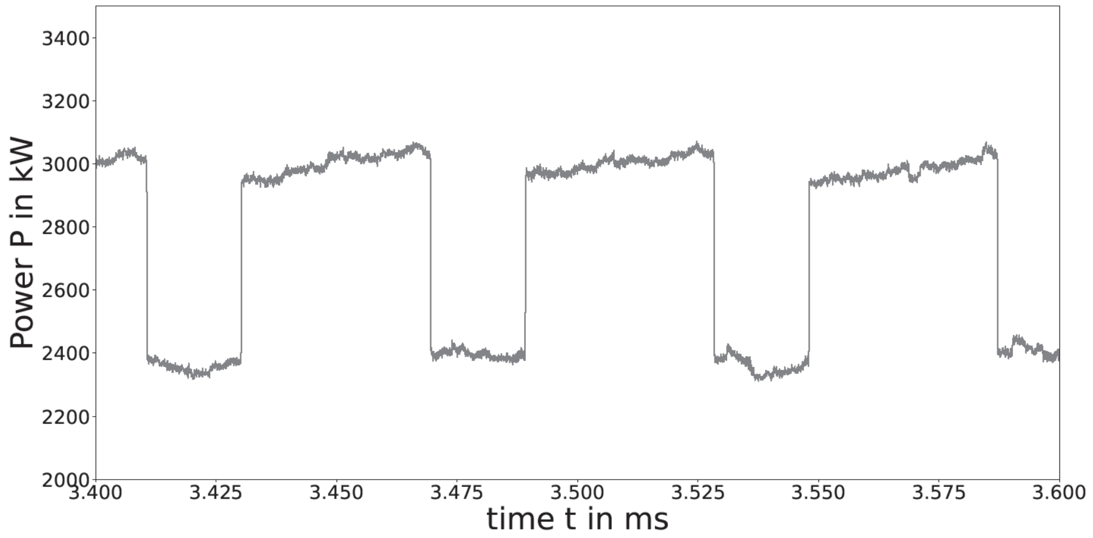
- Final thoughts

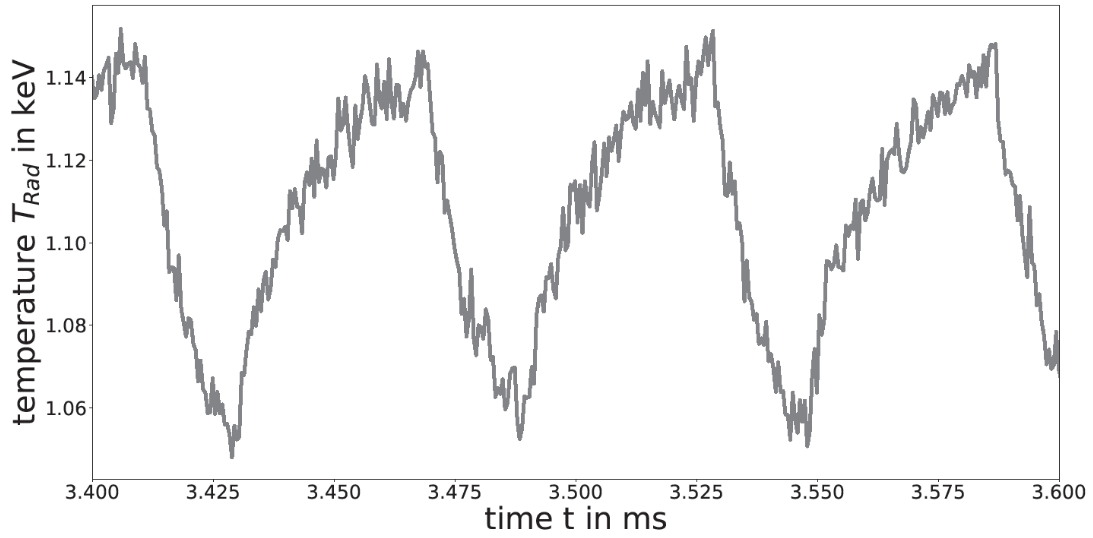
Idea/ general method

- Determination of the ECRH power deposition from modulated data

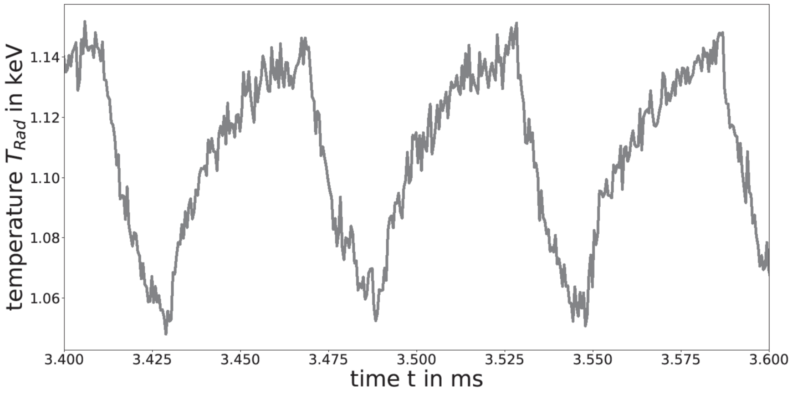
- Step-like progression of power over time from the ECHR

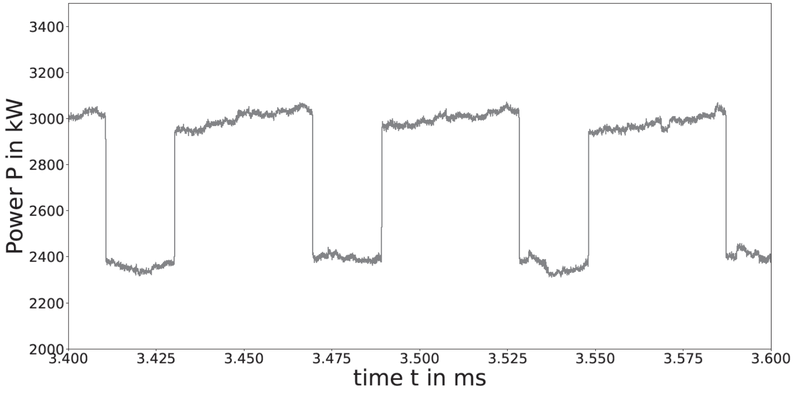
- Temperature of the plasma responses to power change with a time response





Idea/ general method





$$P_{ECRH} = \frac{dW}{dt} + P_{loss} \qquad (1)$$

$$t_1 = t_s - \delta$$
$$t_2 = t_s + \delta$$

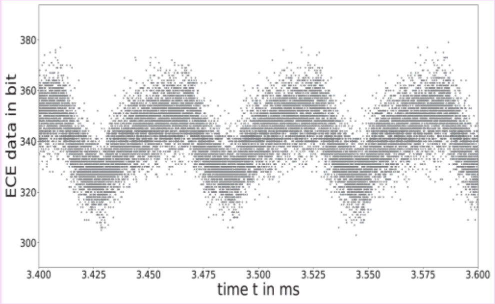
$$\begin{aligned}
\Delta P_{ECRH} &= P_{ECRH}(t_2) - P_{ECRH}(t_1) \\
&= \left(\frac{dW(t_2)}{dt} - P_{loss}(t_2)\right) - \left(\frac{dW(t_1)}{dt} - P_{loss}(t_1)\right) && (2) \\
&= \Delta\frac{dW}{dt} + \Delta P_{loss} && (3) \\
&= \frac{3}{2}k_B N_e\left(\frac{d}{dt}T_e(t_2) - \frac{d}{dt}T_e(t_2)\right) = \frac{3}{2}k_B N_e\left(\Delta(\frac{d}{dt}T_e)\right) && (4)
\end{aligned}$$

$$W = \frac{3}{2}k_B[T_e(r,t)\underbrace{N_e(r,t)}_{\text{const.}} + \underbrace{T_i(r,t)N_i(r,t)}_{\text{const.}}]$$

$$\frac{dW}{dt} = \frac{3}{2}k_B N_e(r)\frac{d}{dt}[T_e(r,t)]$$

Automation

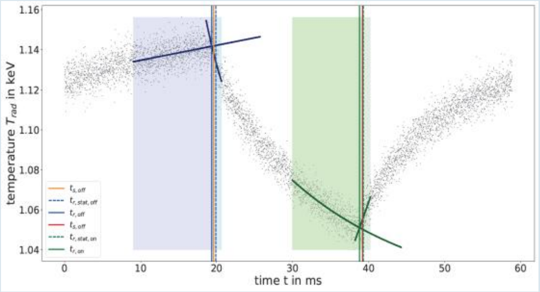
- Data processed in four python subroutines:
- Using ECE radiometer data for temperature change
- only interested in slope relationship not absolute temperature $T_{Rad} \approx T_e$



"DataPrep"

- ECE data pre-rated and averaged

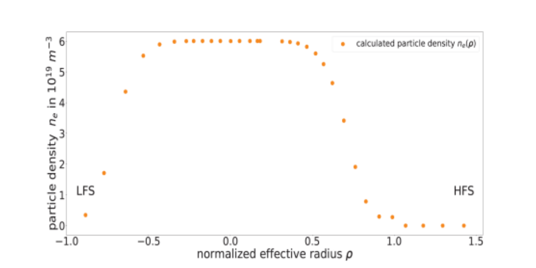
Automation



“Slope“

- Fitting the radiation temperature slope

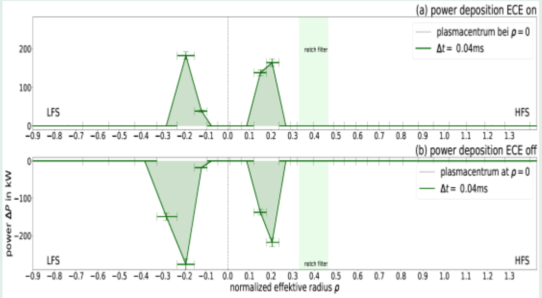
Automation



"Density"

- Determined electron particle density

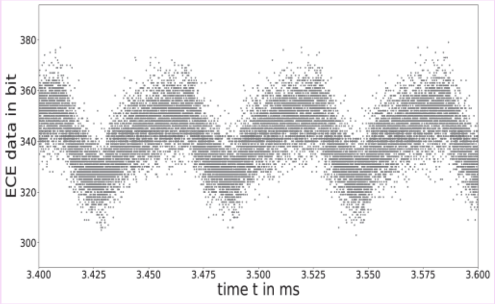
Automation



"PowerProfile"

- Generate spatially resolved power deposition proifle

Automation



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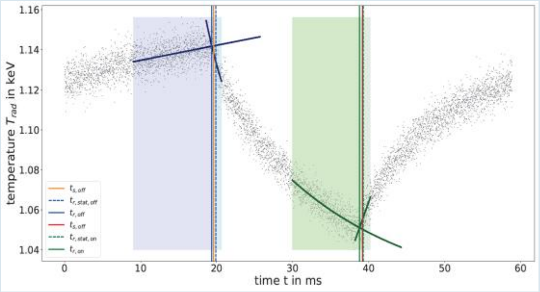
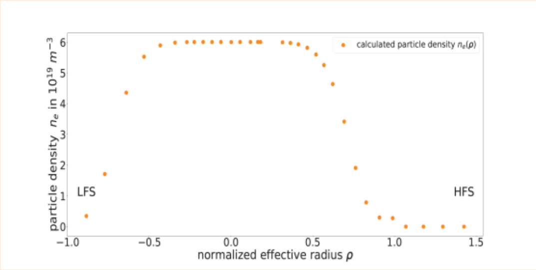


“Slope“

- Fitting the radiation temperature slope



“Density“

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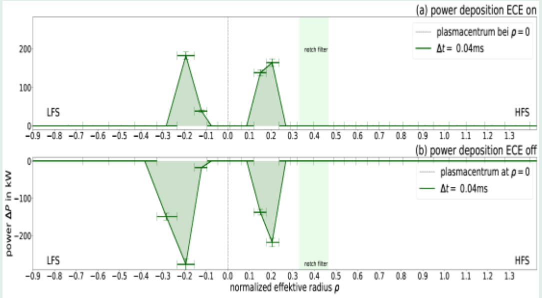


“PowerProfile“

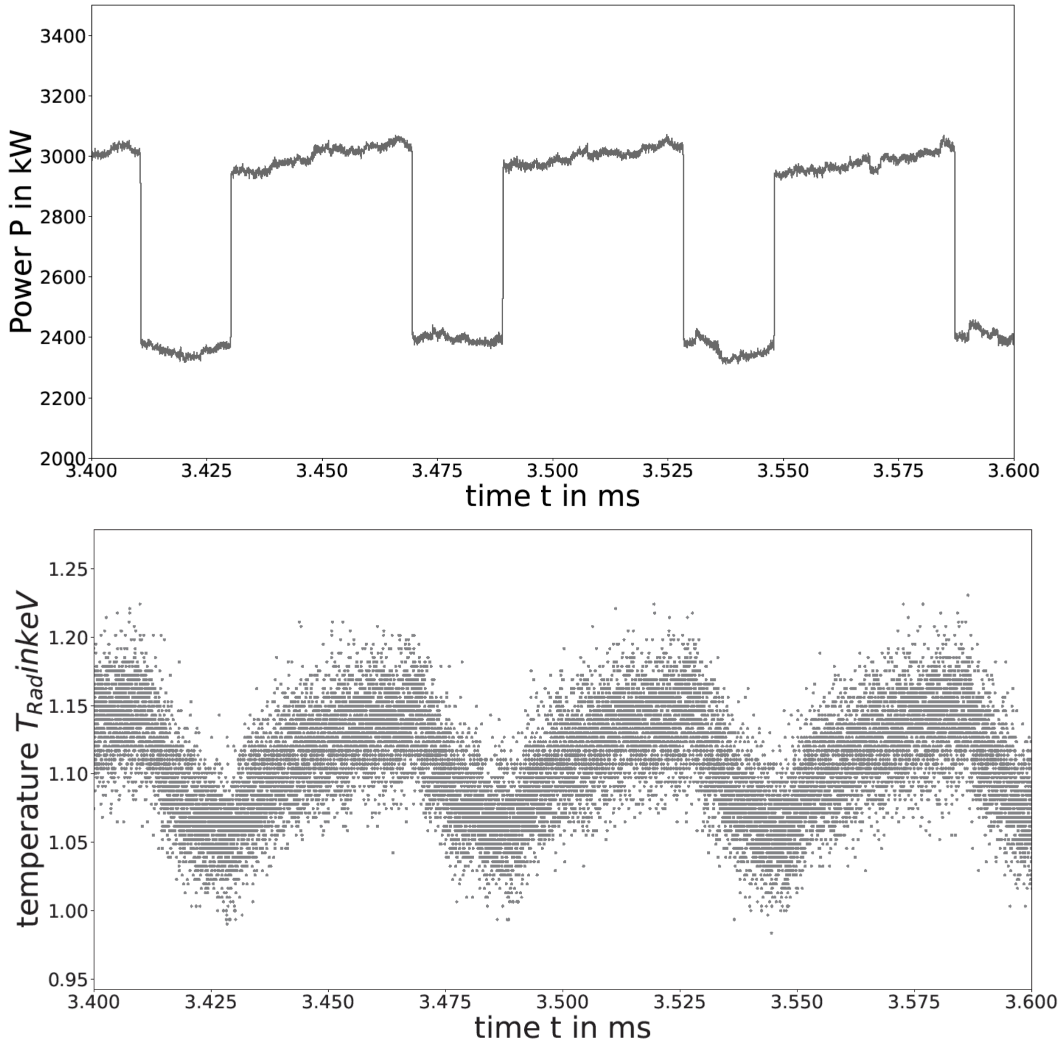
- Generate spatially resolved power deposition proifle

Synchronizing and conversion of the ECE data

- ECE data for each channel synchronized with ECRH data

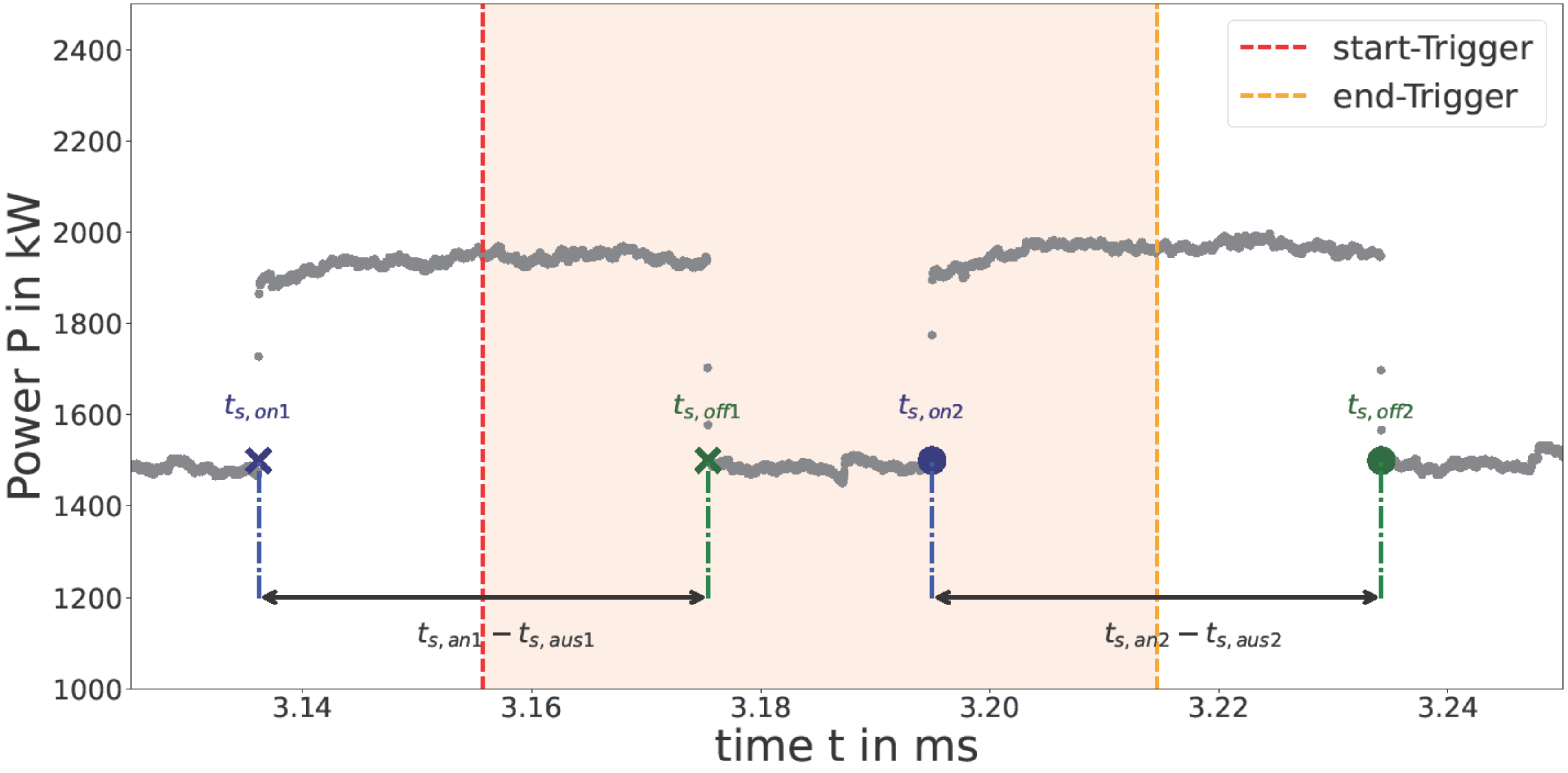
- Conversion of the radiation temperature values from bit to keV

- Using conditional averaging to improve the signal-noise-ratio



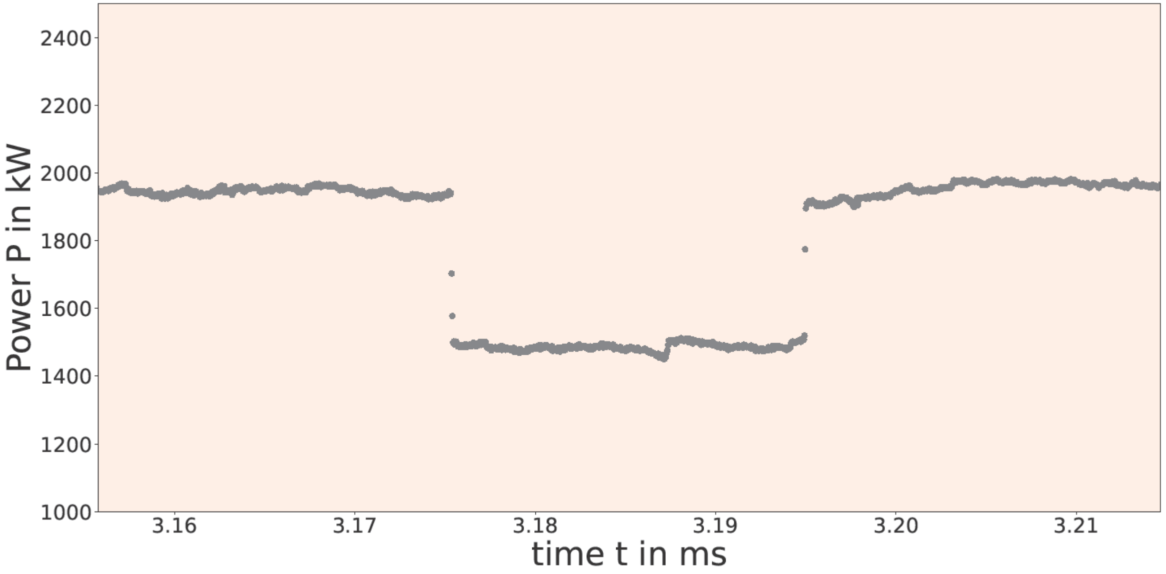
Conditional Averaging

finding the trigger points:

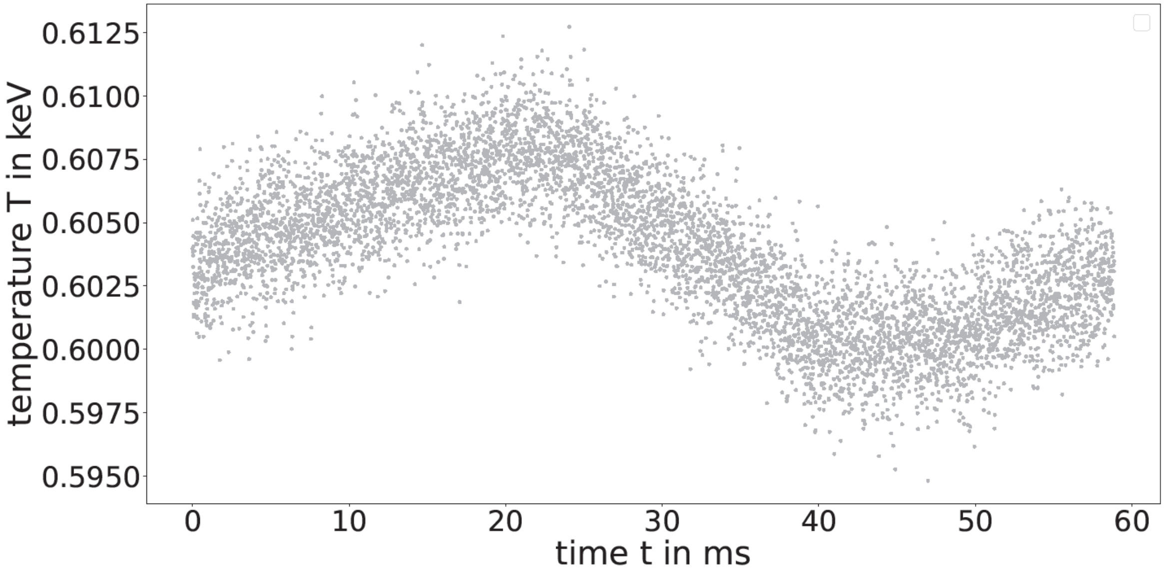


Conditional Averaging

Averaging trigger period:

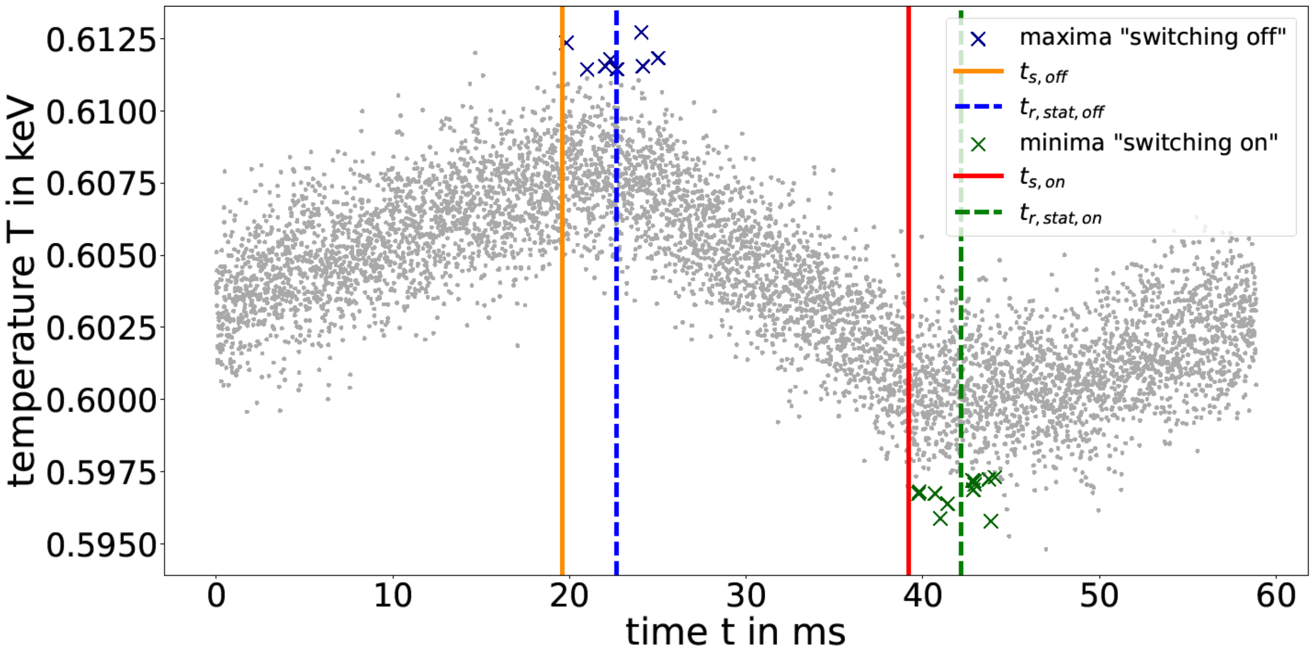


Averaging the ECE data:



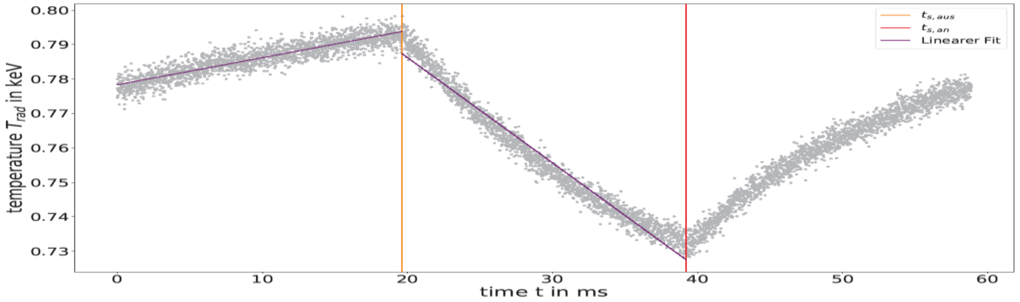
Identify relevant channels

First approach of the response point:

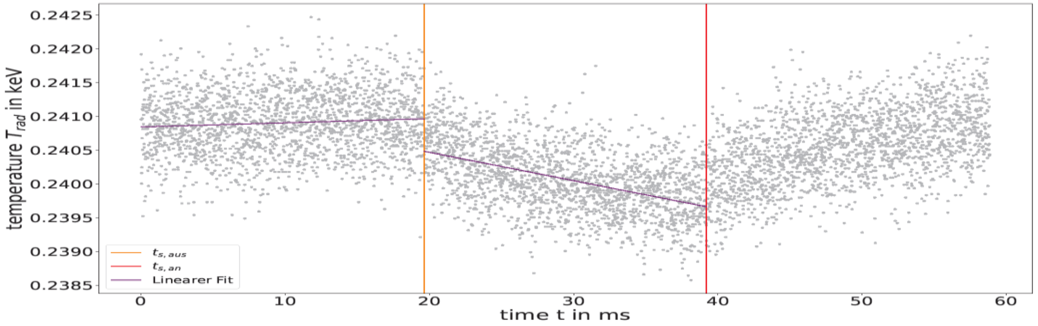


Filtering:

(a) channel 5



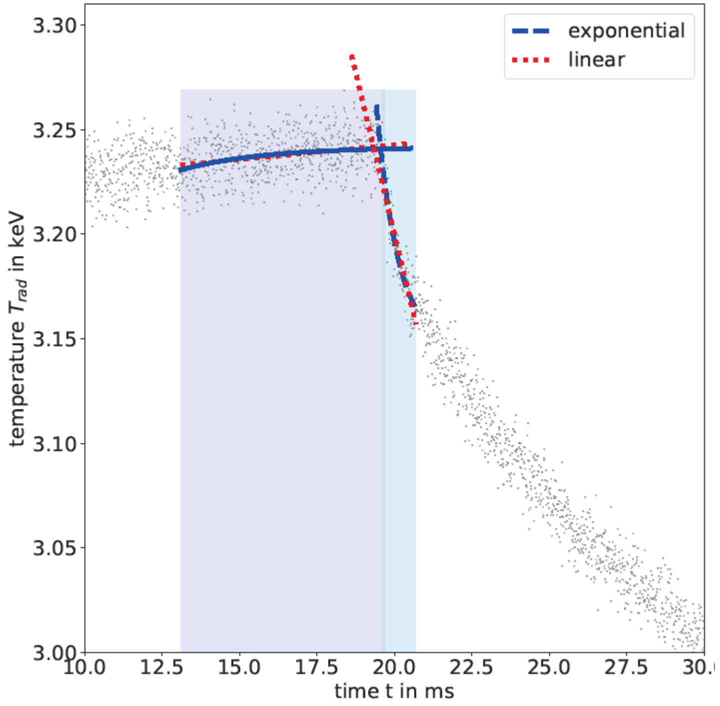
(b) channel 31



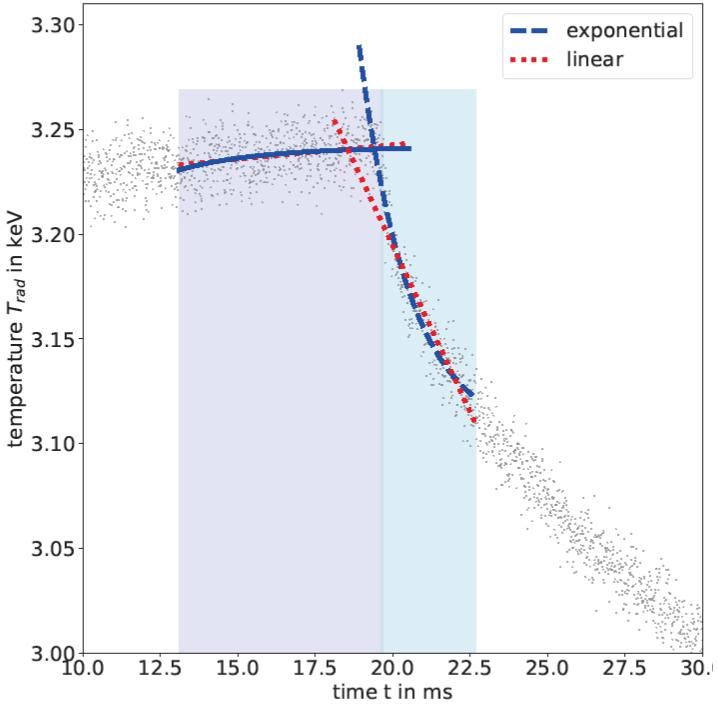
Determine the temperature change

immediate response:

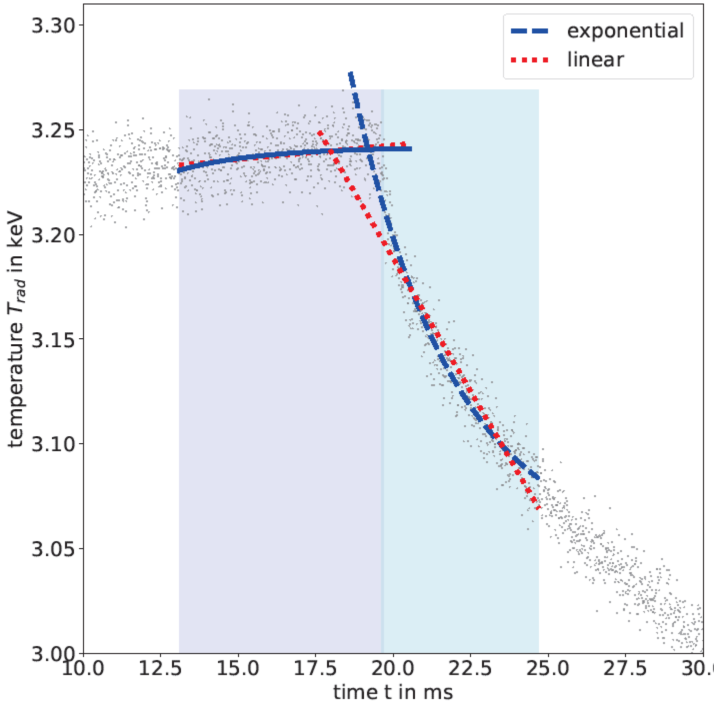
already transport contributions:



(a) $\delta_{post} = 1\ ms$

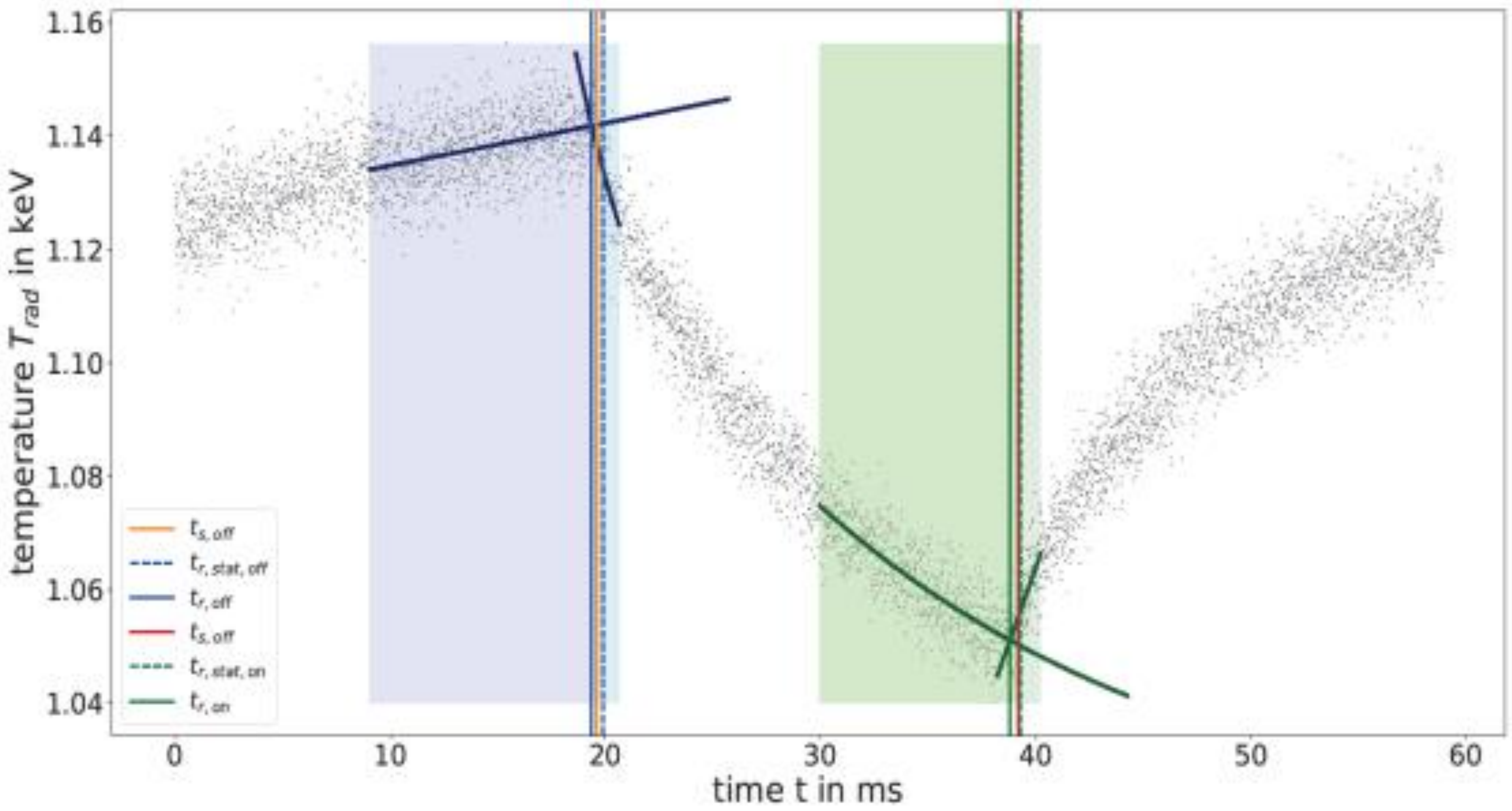


(b) $\delta_{post} = 3\ ms$



(c) $\delta_{post} = 5\ ms$

Finding the response point



- fit range $\delta_{post} \approx 1\ ms$
- Fit functions:

$$f_{e,off}(t) = a_{e,off} + b_{e,off} \cdot e^{-\frac{t}{c_{e,off}}}$$

$$f_{e,an}(t) = a_{e,on} + b_{e,on} \cdot (1 - e^{-\frac{t}{c_{e,on}}})$$

- Intersection delivers response point t_r
- Difference $\Delta t = t_r - t_s$

  important value for automation

- Channel filtered if

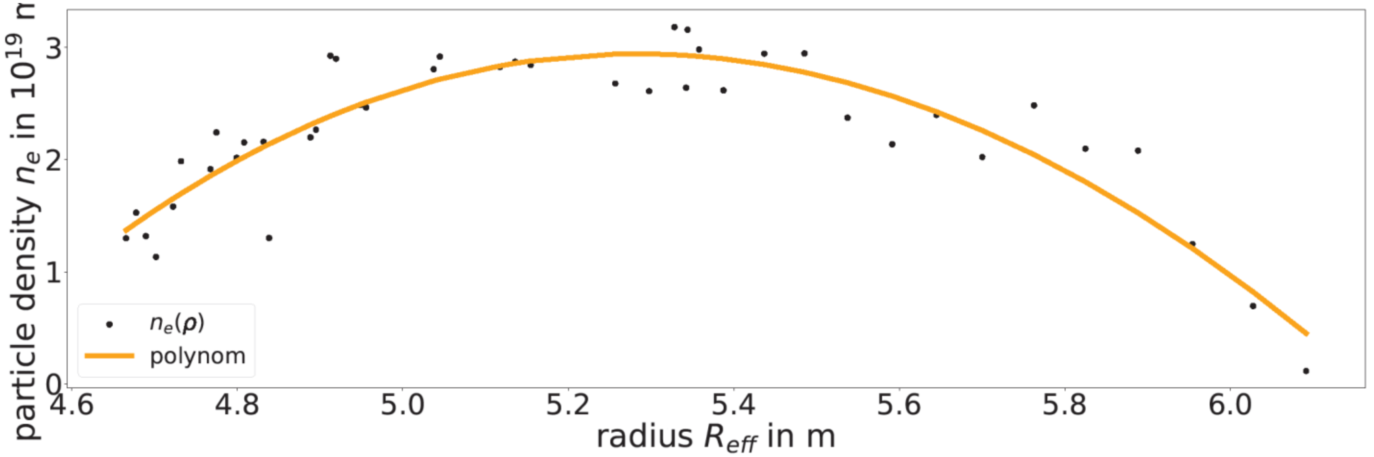
  $\Delta t \leq$ fixed value

Determination of the particle density / Thomson

- Several methods available
- Density n later converted in particle number with $N_e = n_e \cdot V$

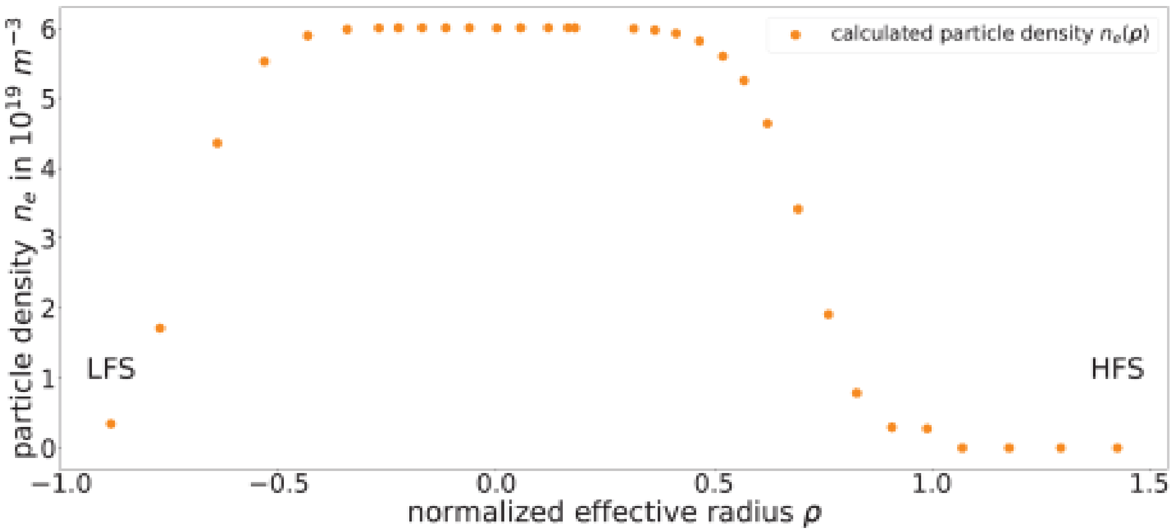
<u>Thomson scattering:</u>

- Design of the diagnostic system allows the detection of the intensity of the scattered light over a discrete scattering volume
- Scattered intensity is proportional to the particle density



Determination of the particle density / ECE-data

- Several methods available
- Density n later converted in particle number with $N_e = n_e \cdot V$

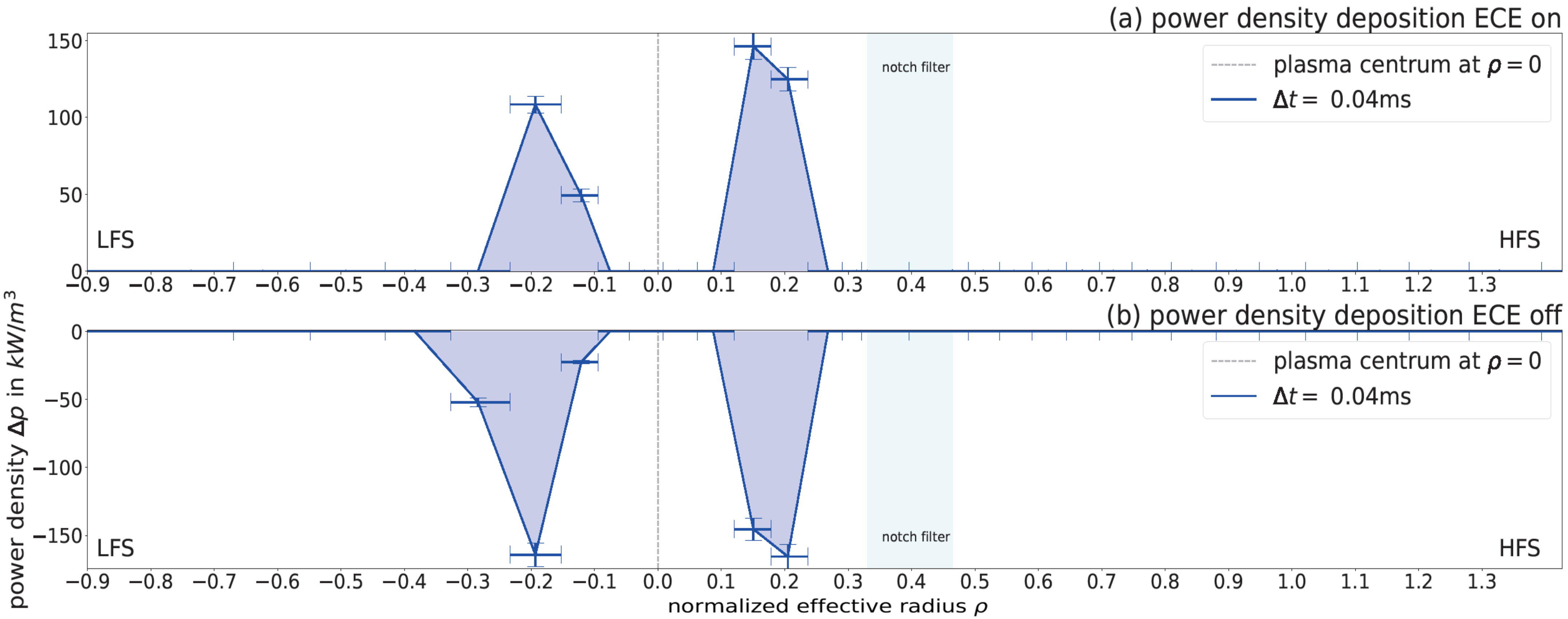


<u>ECE-data + laser interferometer:</u>

- ECE-data provides density at plasma edge due to the optical gray plasma
- Laser interferometer measures average density in plasma
- With Bayesian analysis the parametrization of the density is calculated

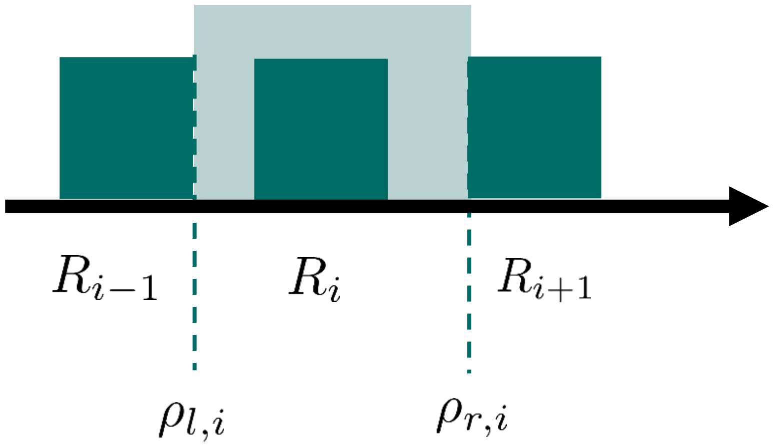
Power density for each radiometer channel

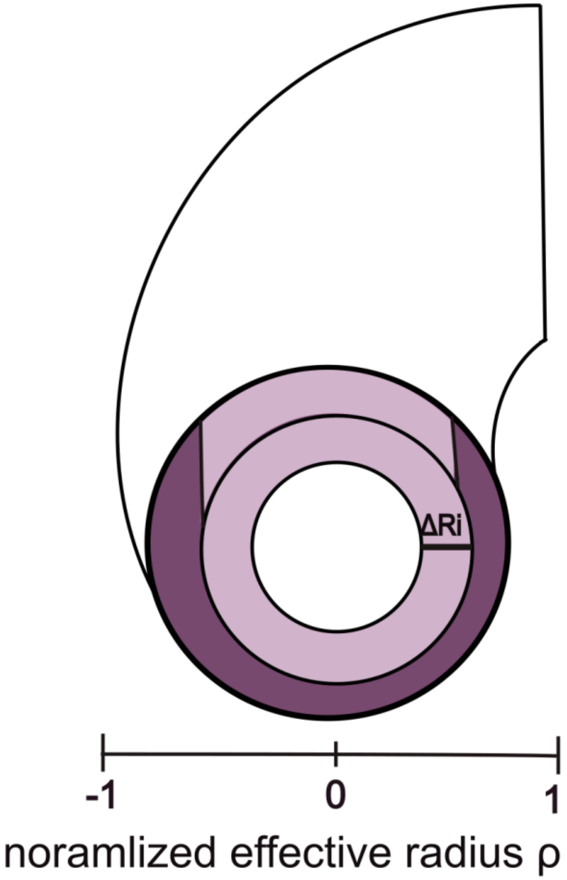
- Calcuating power density with $\Delta p_{ECE} = \frac{3}{2} k_B \cdot n_e(\Delta(\frac{d}{dt} T_{Rad}))$



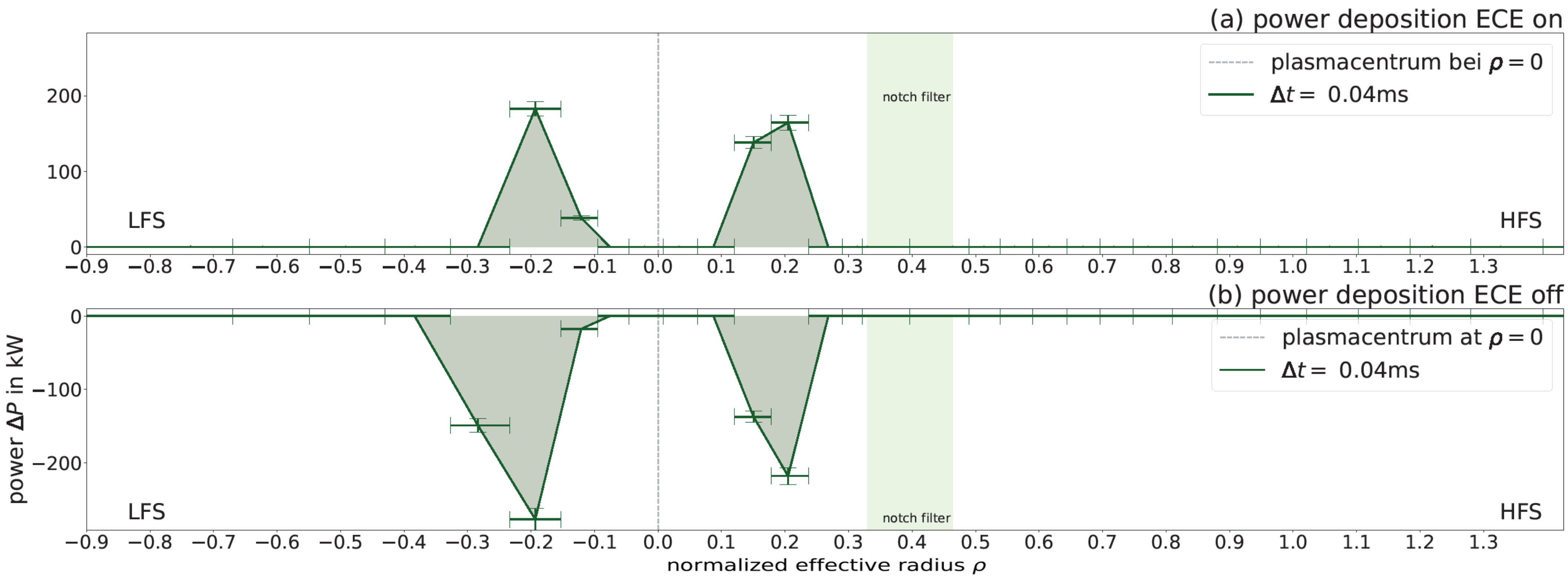
Calculating volume for each radiometer channel

$$\Delta V_i = V_{i+1} - V_i$$
$$= 2 \cdot \pi^2 \cdot R_0 \cdot (|\rho_{l,i}^2 - \rho_{r,i}^2|)$$





Calculating the power deposition profile



ΔP_{ECRH} in kW	$\Delta P_{ECE,on}$ in kW	$\Delta P_{ECE,off}$ in kW
631 ± 2	530 ± 210	-790 ± 260

Application of the automation

Tested based on two special cases:

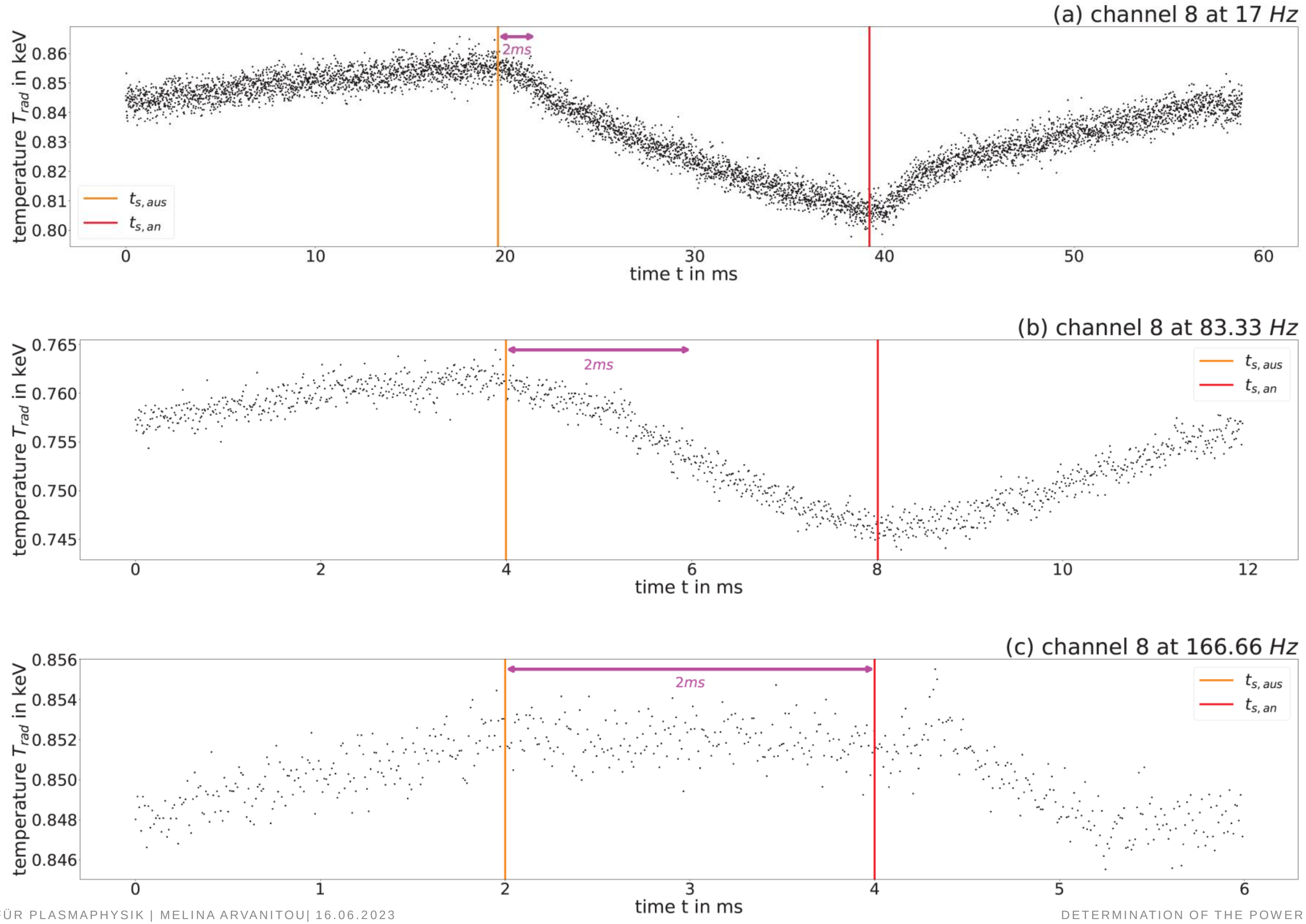
Modulation at different frequencies:

- Signal-to-noise ratio
- Power deposition

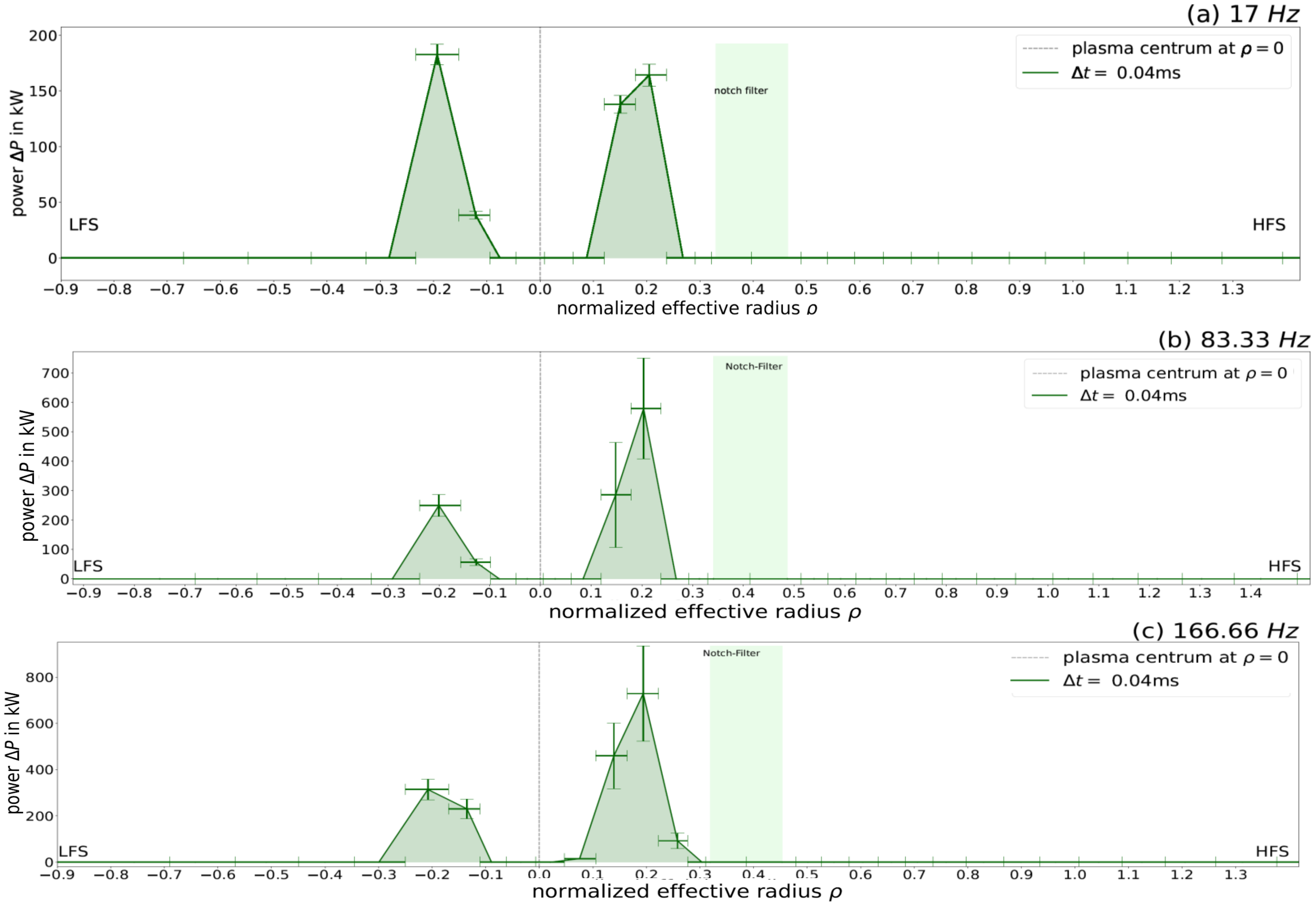
Including zoom system radiometer:

- Availability to gain extra data for power deposition

Modulation at different frequencies: Signal-to-noise ratio



Power deposition is independent of the chosen modulation frequency

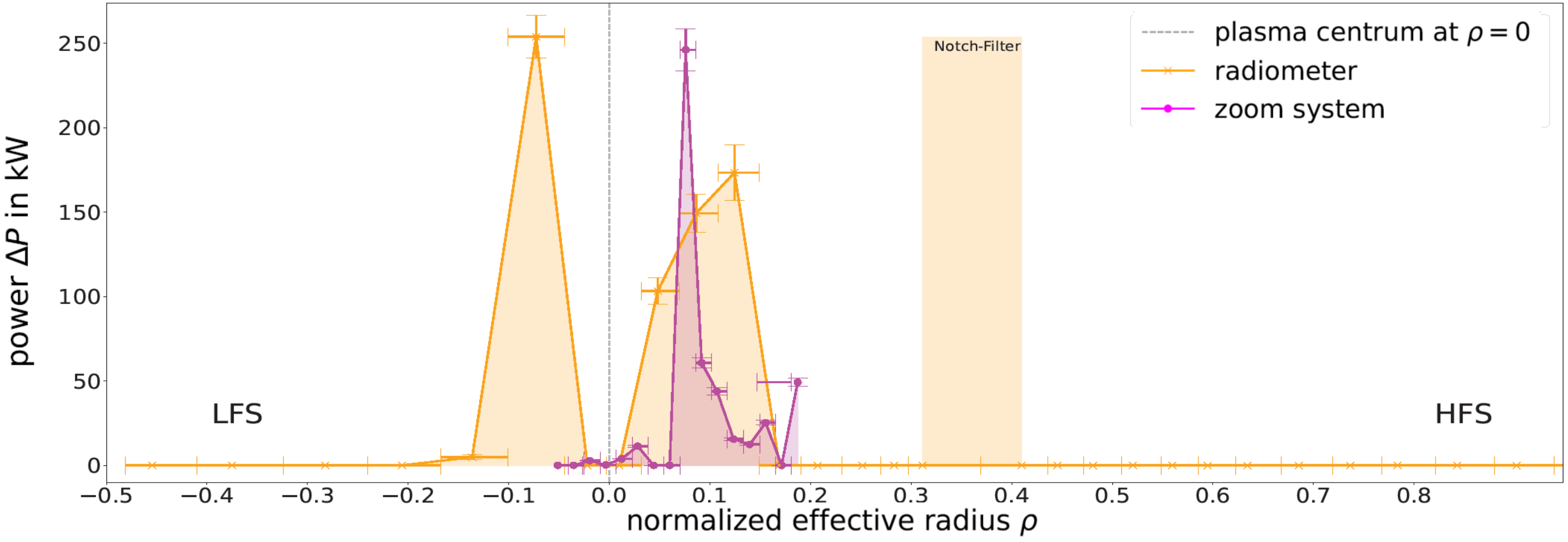


shotnumber	f_{mod}	ΔP_{ECRH} in kW
.014	17 Hz	631 ± 2
.018	83,33 Hz	370 ± 10
.016	166,66 Hz	570 ± 3

$\Delta P_{ECE,on}$ in kW	$\Delta P_{ECE,off}$ in kW
530 ± 210	-790 ± 260
1200 ± 400	170 ± 20
1840 ± 470	-1560 ± 410

Inclusion of the zoom system

- Additional 16 channel radiometer with 4 GHz range and movable location on low field side
- No calibration factors yet
- Location of the power deposition as expected



Final thoughts

- Modulation of the ECRH obtains power deposition profiles with a well-founded statement about the deposited power

- Faster modulation frequencies can lead to a better signal to noise ratio but also affect the resulting value of the total power

- As expected modulation frequency does not have major influence on the power location

- Including the zoom system offers a possiblity to extend the resolution of the profiles if the channels are calibrated

- With the automation a first evaluation for the power deposition can be provided