Max-Planck-Institut für Plasmaphysik

Consistently calculating the radiated power in near real time at the stellarator Wendelstein 7-X

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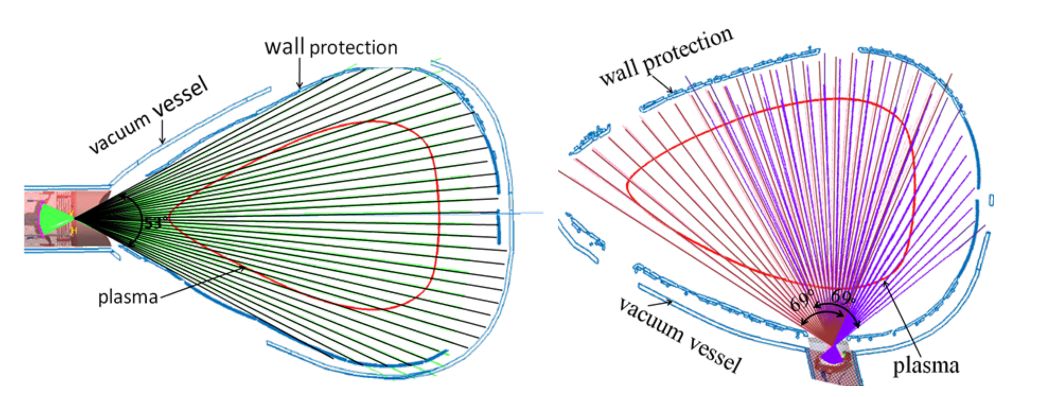
Motivation

- averaged thermal load on in-vessel components expected to be up to 100 kW/m^2 mainly by radiation and non-absorbed heating power
- calculating the temporal and spacial evolution of the radiation loss previously only after the plasma has been terminated
- dynamically adjust heat loads on components and investigate radiation regimes of high temperature plasmas with possibility of improved detachment experiments.
- possibly find gas puff-radiation scaling law for purposes of extensive plasma control, i.e. density, power and radiation

Recap

Design

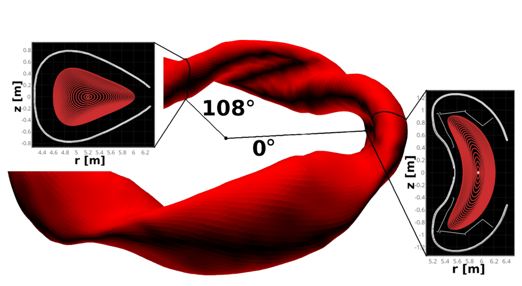
- multi-device system: horizontal bolometer camera (HBC, 32 channels) and vertical bolometer camera (VBC, 20 channels for each of two subdetectors) $\Rightarrow$ more detectors with different filters/coatings available, e.g. for investigation of soft x-ray radiation
- fan-shaped lines of sight provide full plasma coverage at 5 cm spatial resolution
- steady state operation at discharges with up to 30 min of 10 MW heating power ensured by cooling system with graphite elements and water cooling structures



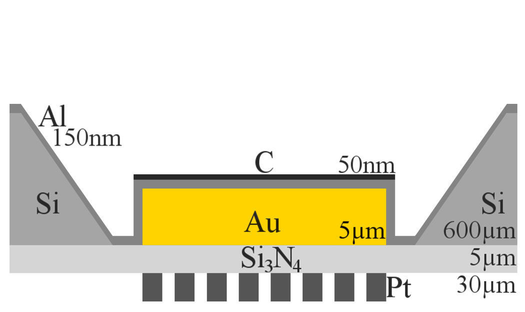
LOS for HBC (32 ch.) and VBC (two 20-ch. subdetector arrays) with individual apertures, retracted into the vacuum vessel behind wall elements; located in the triangle-shaped plane at W7-X.[1]

Performance

- VBC/HBC detector arrays with carbon coated, 5 µm thick gold-foil absorbers for maximum absorption at sensitivity of 200 nW and minimum reflectivity (visible light to SXR between 600 nm to 0.2 nm)
- Au-foil on 5 µm Si_3N_4 substrate, backed by a 30 µm platin meander with a 0.25 ms response time
- temporal resolution in range of 0.08 ms to 6.4 ms, depending on experiment and data economy
- impact of electron cyclotron resonance heating (ECRH) stray radiation (several 10 kW m^{-2} at 140 GHz) reduced down to 3% microwave transmission, opt. transmission factor 53%

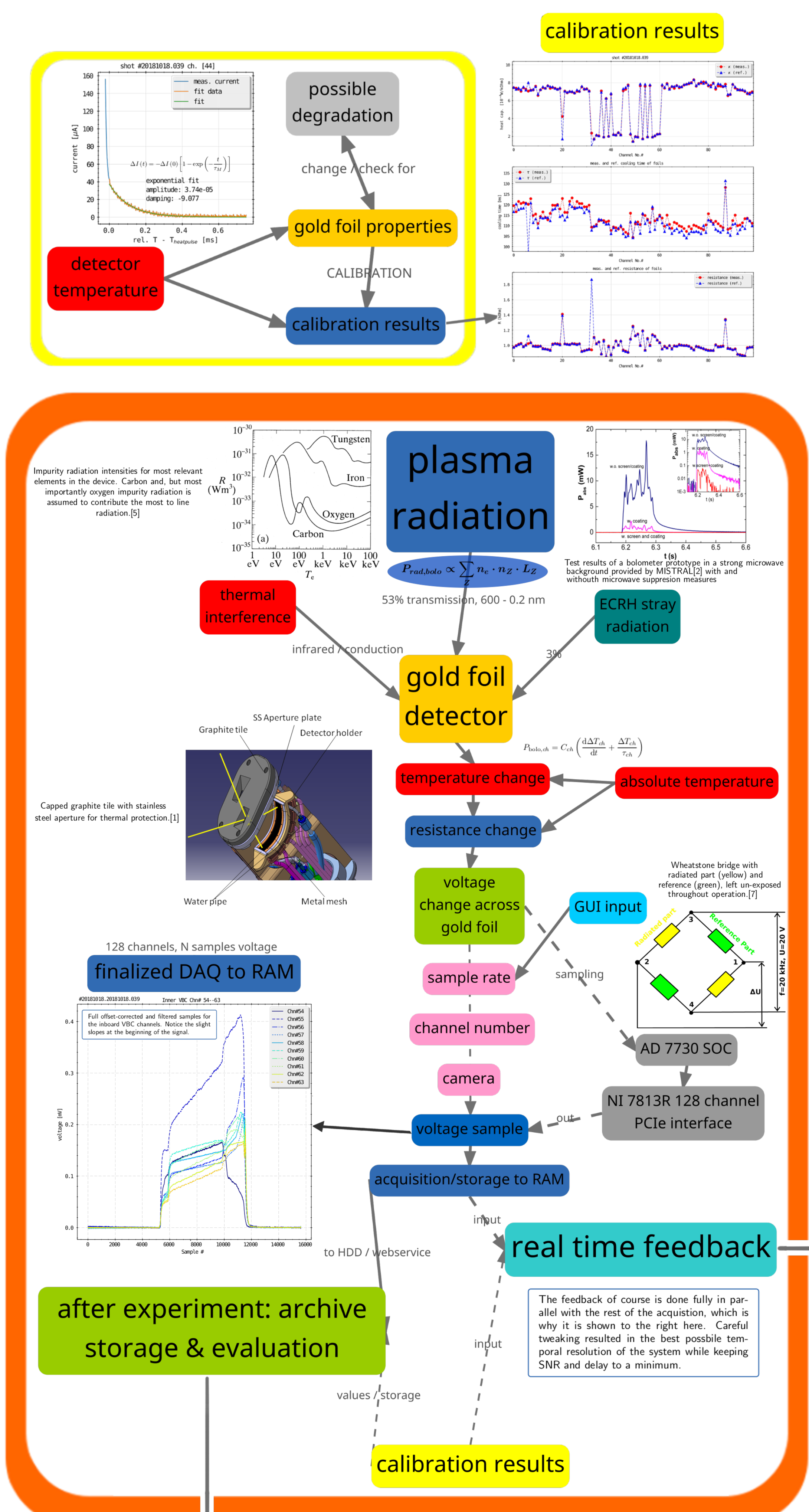


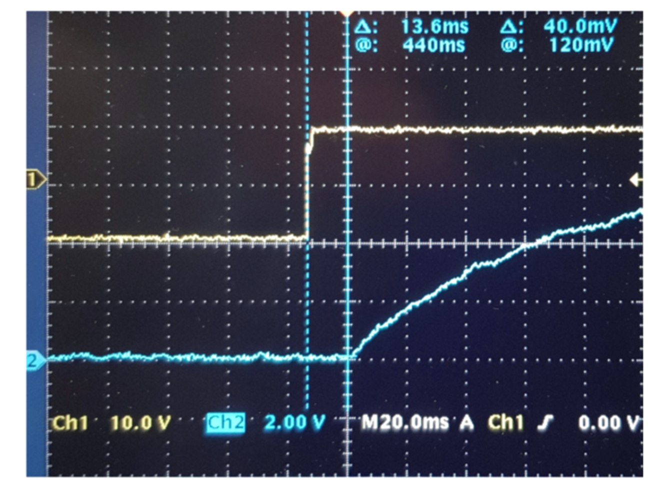
W7-X plasma vessel (torus, center) with equilibrium fluxsurfaces (red), calculated by VMEC[4] at triangle- (top-left, 108°) and "bean"-shaped (bottom-right, 0°) planes.



Scheme of a single detector channel with housing/holder, absorption foil, substrate and meander.[7] Layer dimensions are noted.

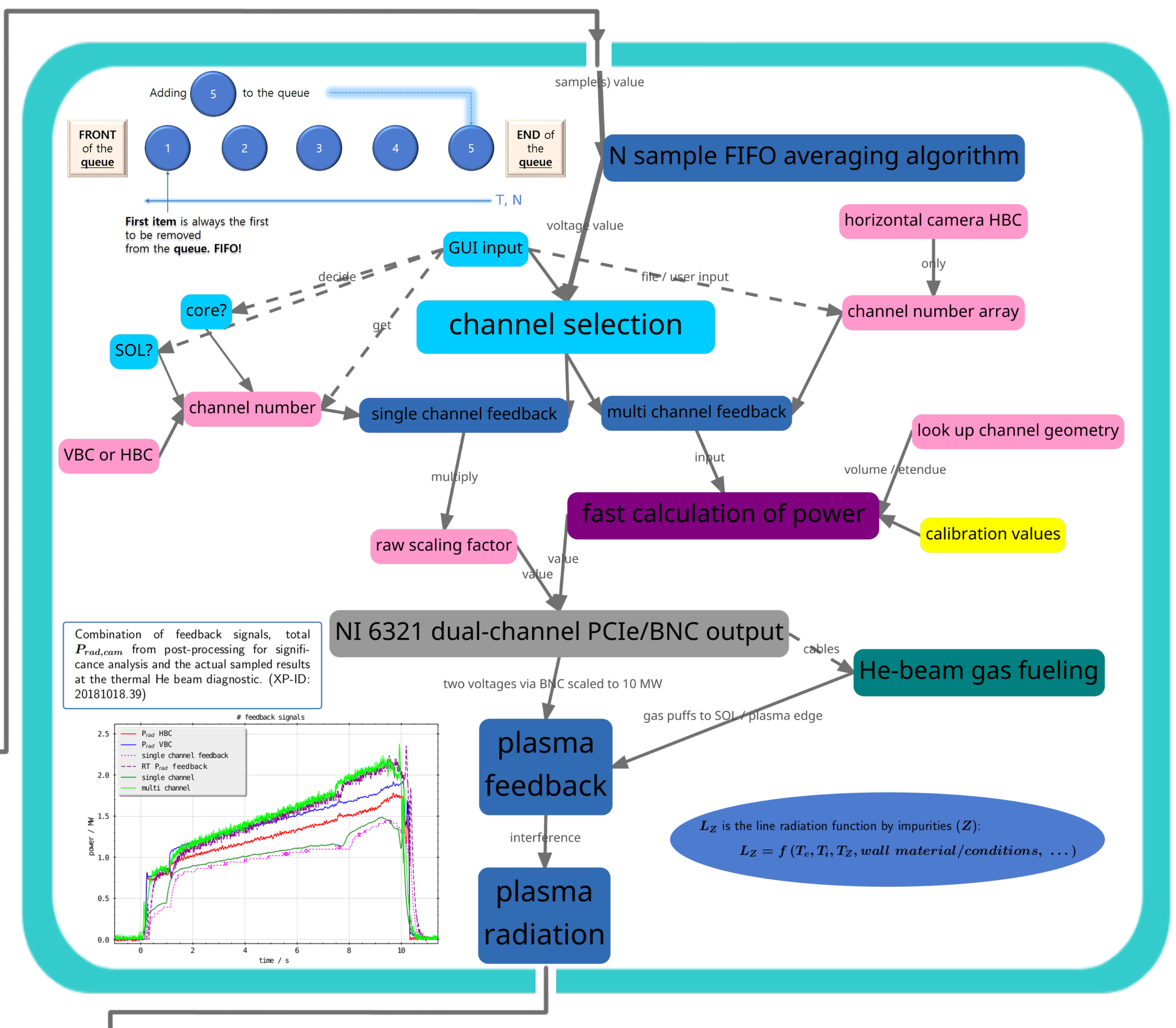
Setup

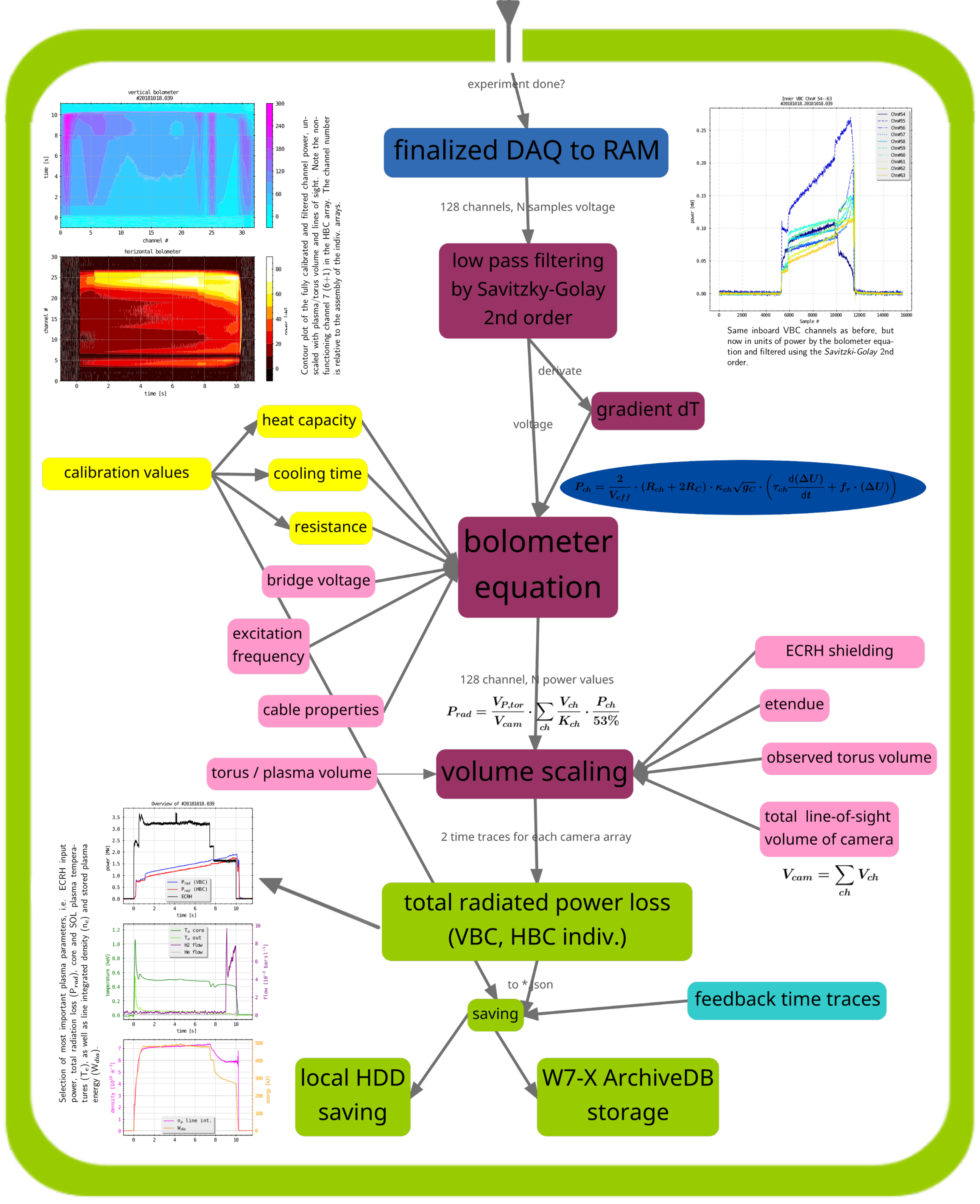




Capture from an oscilloscope, showing in Ch1 (yellow) the laser cycle pulse and in Ch2 (cyan) the detector response. The vertical lines (cyan) measure the time delay.

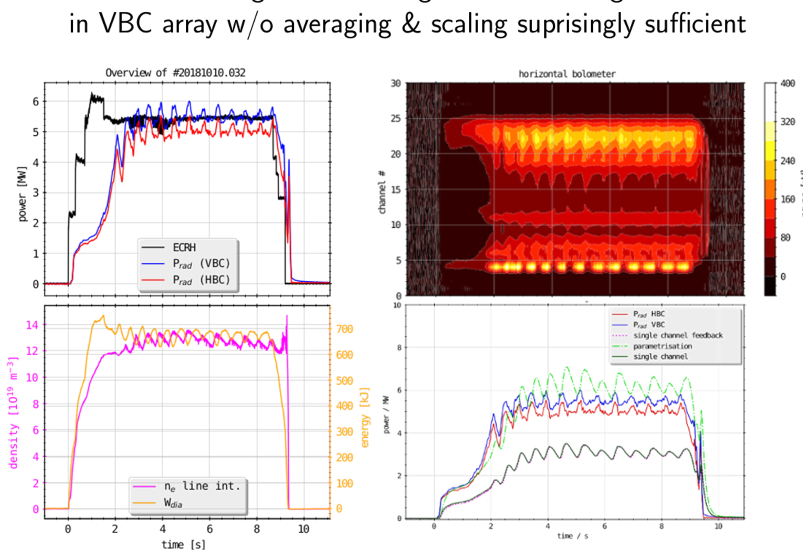
- testing feedback system internally prior to implementation/usage
- defined solid-state laser pulses with cycle frequency 1 Hz - 1 kHz and 7 mW power onto detector
- feedback loop and calculation algorithm limit the system to a temporal response of $\geq$14 ms
- mainly due to $F \cdot \Delta t$ where Δt is the sample rate and F the number of *FIFO* array elements to average
- shallow slope of rising edge in feedback is result of detector response and neglected dynamic (see bolometer equation [7])





Prelimanary results

- feedback signals have been successfully commissioned and provided nearly for all experiments throughout the previous campaign OP1.2b
- focused tweaking of raw scaling factor for a single SOL channel in VBC array w/o averaging & scaling suprisingly sufficient



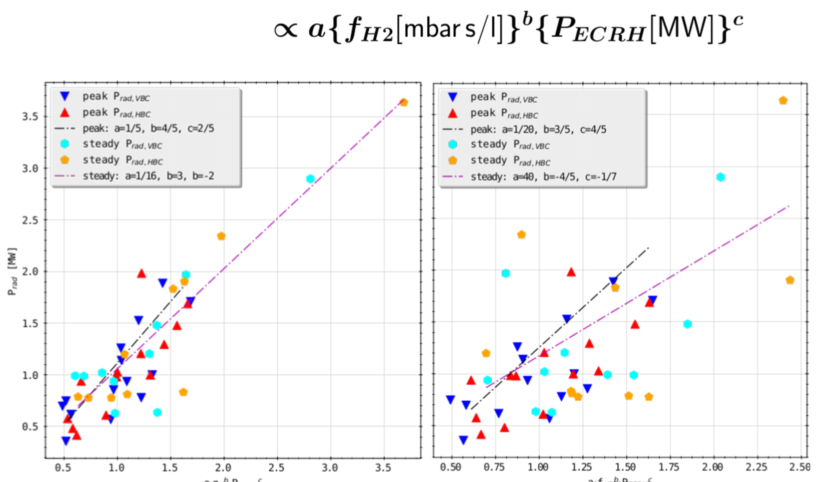
XPID: 20181010.32; the thermal helium beam diagnostic fueled H_2 according to the parametrisation (lime, bottom right) to dial in the radiated power loss - implicitly given through the feedback P_{rad} - at $\geq 0.9 P_{ECRH}$. The oscillations are a result of the feedback control via the bolometry signal. The goal was to achieve stabilized detachment from the divertor elements. Note how the radiation front along the SOL (observed by čh. 3-6 & 21-26) oscillates as well.

- trying to find possible scaling between input power, density, gas fueling and radiated power loss, e.g. for plasma control
- making simple 3 parameter $\{a, b, c\}$ intereference assumption like:

$$P_{rad}[\mathrm{MW}] \propto a\{n_e[10^{19}\mathrm{m}^{-3}]\}^b\{P_{ECRH}[\mathrm{MW}]\}^c$$

or

$$\propto a\{f_{H2}[\mathrm{mbar\,s/l}]\}^b\{P_{ECRH}[\mathrm{MW}]\}^c$$



Attempt of finding a possible scaling between input power, density/main gas fueling in H_2 and radiation loss in arbitrary magnetic configurations. Seperated however are the stages after the fueling, i.e. right at the peak of P_{rad} and when equilibriated (steady).

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Outlook

- for the upcoming campaign OP2, starting early/mid 2020, the system has to be technically improved to account for longer discharges & more accurate predictions, by e.g. automatic channel and scaling selection based off of configuration or programing
- extensive analysis of impact of helium beam gas fueling on radiation loss in comparison to the main valves, since it is located closer to the divertor/SOL

On the horizon:

Implemented until next campaign will be a setup for bayesian & non-bayesian systems to calculate poloidal tomography profiles. This will also aid the developement of the introduced feedback alogrithm, since one might be able to weight the different lines of sight individually given the configuration & plasma shape.

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