# MAX IV Operations
# Diagnostic Tools and Lessons Learned


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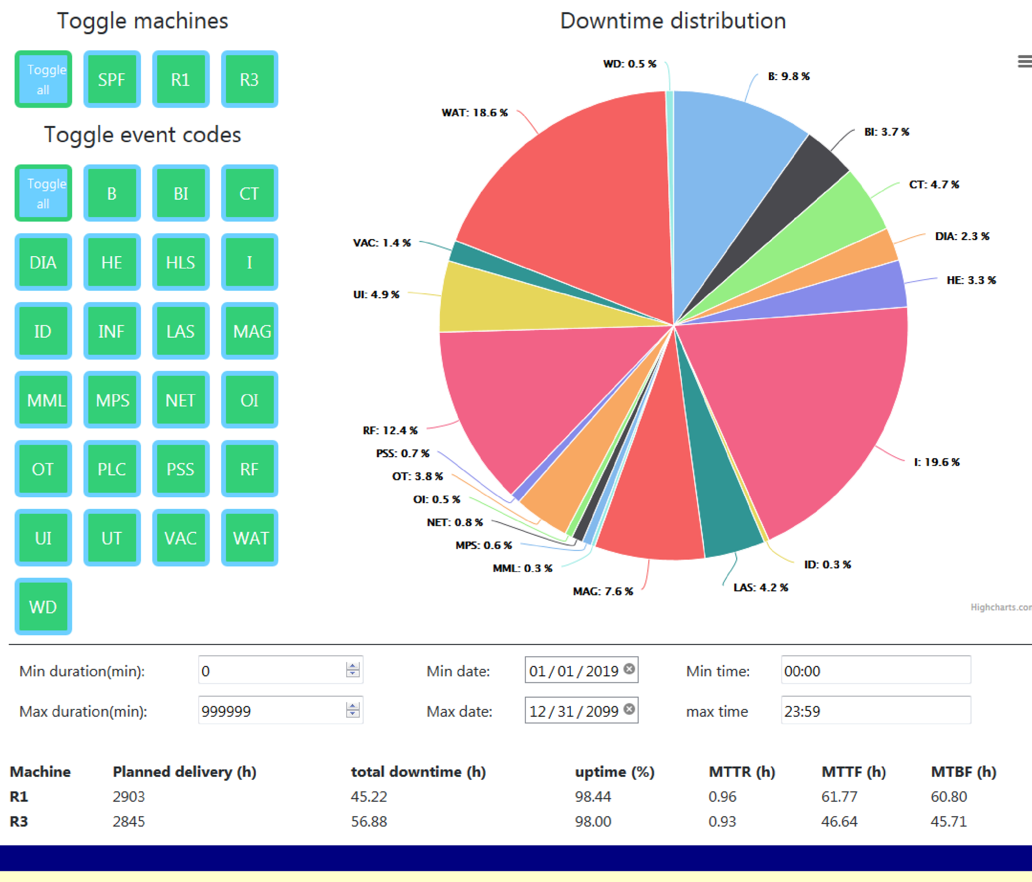
On behalf of the MAX IV Operations Group


## MAX IV Accelerator Operations


The Operations Group is responsible for delivering stable high-quality beams to the beamlines (users). The plot shows the facility status in May 2019, when eleven beamlines had closed undulator gaps and open shutters, indicating that they were actively taking synchrotron light produced at the accelerators, all at the same time. As one can also see from the plot, the linac performed excellently as injector providing beam current top-up every 30 minutes, as well as high bunch charge (100 pC) to the SPF.

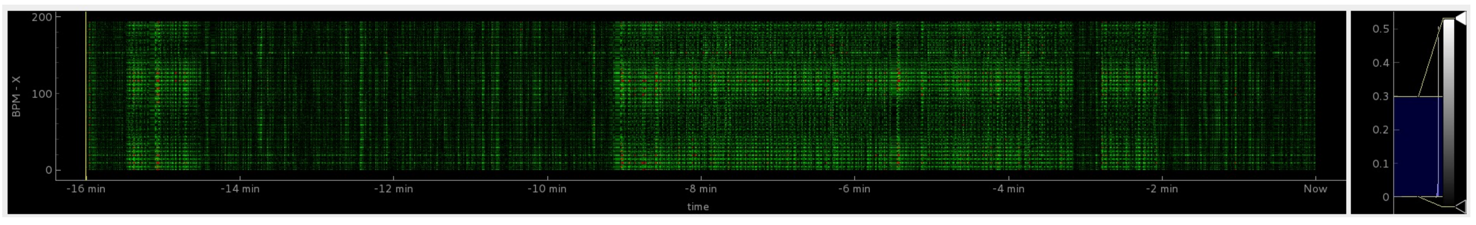
## Downtime monitoring



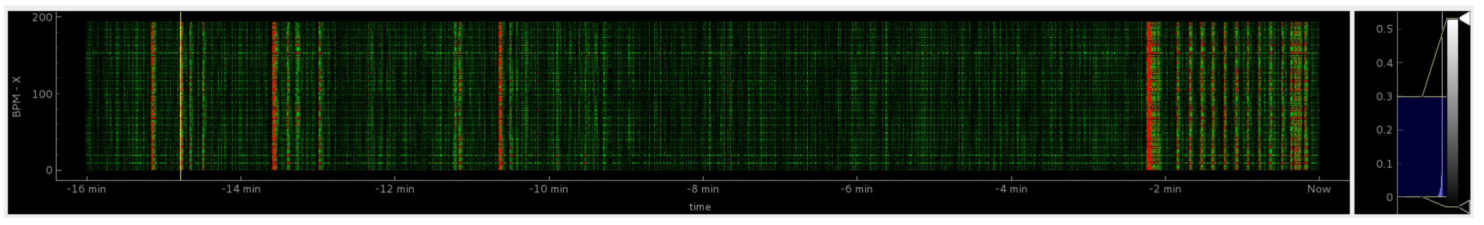

In order to improve the gathering of statistics concerning downtime duration and facilitate reliability studies, a ``downtime web-application" built by the Operations Group was deployed at the start of 2019. The application reports Mean Time Before Failure (MTBF), Mean Time To Failure (MTTF), and Mean Time to Repair (MTTR), on timescales controlled by the user. It allows easy offline analysis of downtime duration by system (beamlines, beam instability, controls, diagnostics, human error, high level software, injector, insertion devices, infrastructure, laser (photo-cathode gun), magnets, machine protection system, network, orbit interlock, programmable logic control (PLC), personnel safety system (PSS), radio frequency (RF), vacuum, water). A beam availability of 98.6% was achieved for the 1.5 GeV storage ring and of 98.0% for the 3 GeV ring during the first half of 2019.

## Beam Position Monitor Time Evolution

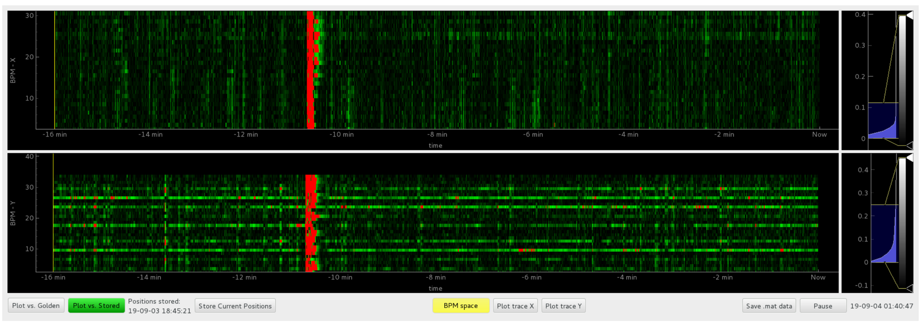
BPM trends shows the BPM positions trends over time. The vertical scale on the left (in micrometers) controls whether there is any deviation within the lower and upper limits set by the scale. In the figure below all points within 0.0 μm to ±0.3 μm are shown in green. If the beam deviates its orbit (vertically or horizontally) within the defined limits, the BPM positions measured are considered "green". If the deviation is above the upper limit (0.3 μm) the points will be shown in red. The plot updates in real time during operations.



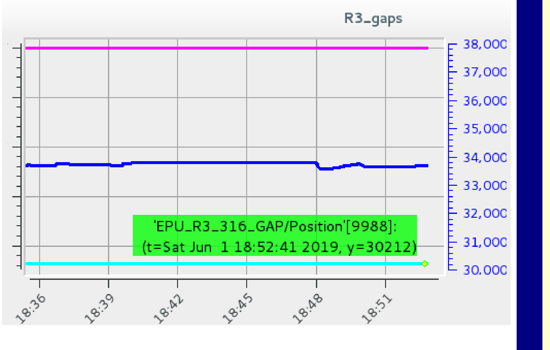
A typical plot for R3 during stable delivery. All BPM readings show the beam is kept within the required limits in the transverse horizontal direction.



Even small changes to one of the beamline's gap, as shown by the figure in the right hand down corner, can cause disturbances to the beam.



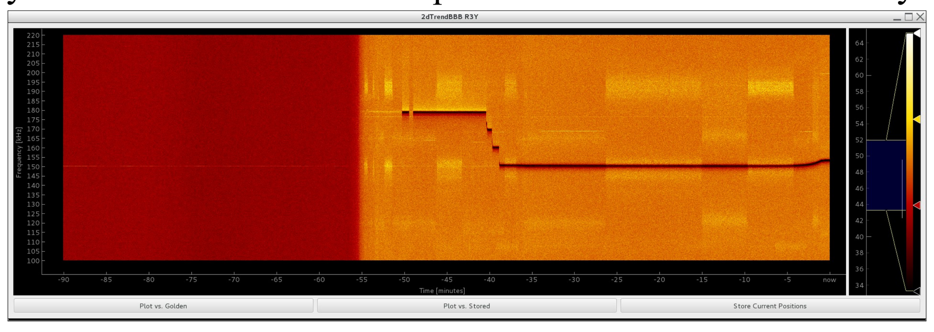
During injections a large vertical line can be observed in the R1 trends. The disturbances are caused by the dipole kicker.




R3 beamline gaps.

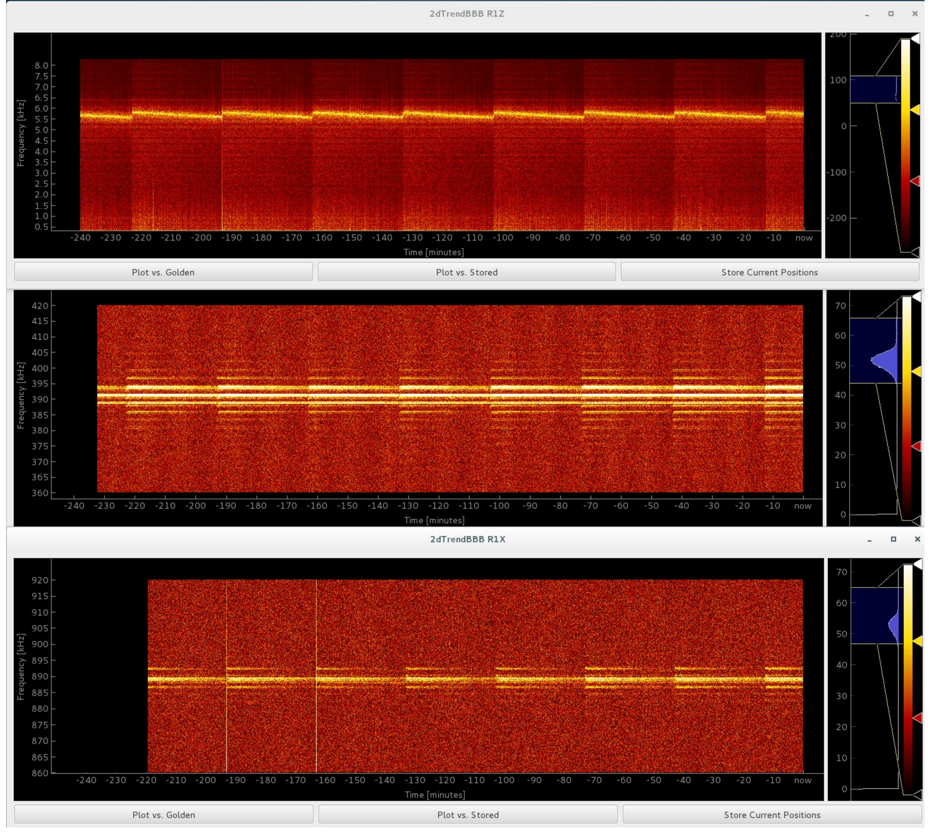
## Accelerator Tunes Visualization

The accelerator tunes visualization makes use of similar concept as the BPM trends, but it monitors the synchrotron and betatron frequencies variations measured by MAX IV's Bunch by Bunch (BBB) system.



Vertical betatron oscillation frequency in R3.

A manual increase of the Master Oscillation (MO) RF of the 3 GeV storage ring in steps of 5 Hz in order to reach a vertical tune tune of 0.265. At -5 minutes a beamline closes its undulator gaps causing the tune to shift.



Synchrotron and betatron frequencies in R1.

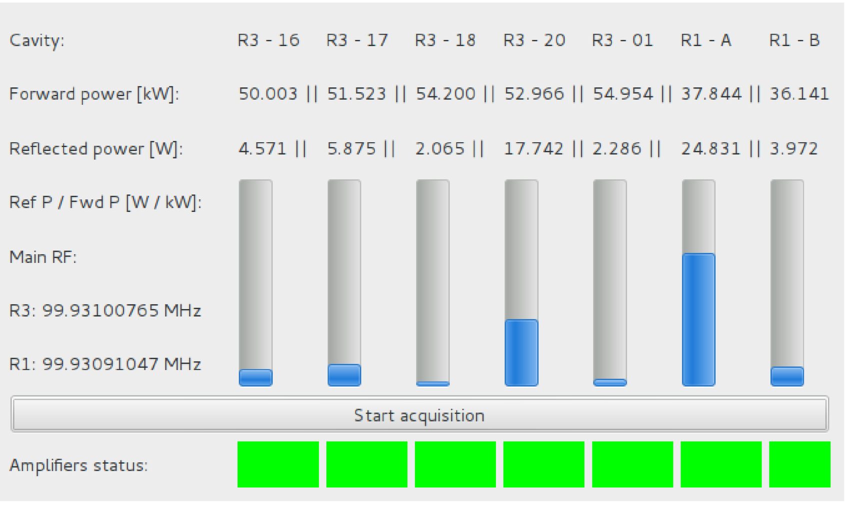
Synchrotron and betatron frequencies in the 1.5 GeV storage ring.

Top: In the longitudinal plane (synchrotron frequency) one can see the effects of the top-up injections done by the linear accelerator every 30 minutes.

Middle: In the vertical plane one can see the signal is strongest around 350 Hz, but lines for higher and lower frequencies, albeit weaker, can be seen for higher and lower frequencies, which is consistent with the lower signal amplitudes measured by the BBB system in those regions.

Bottom: a similar, but less pronounced effect, can be observed in the horizontal plane.

## System Monitor RF (SMoRF) and Alarms

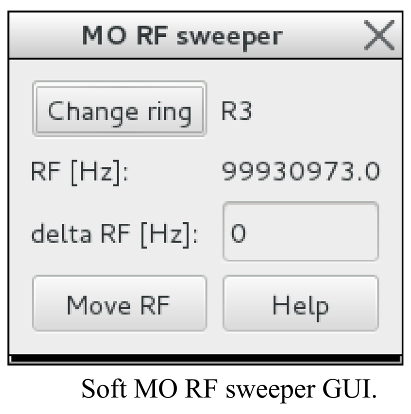



SMoRF (System Monitor for RF) is a software that monitors the RF levels for the two storage rings at MAX IV Laboratory. It shows the forward power, reflected power, and the ratio between the reflected power and forward power and it is useful for detecting e.g. if an amplifier is failing. If the amplifier status is green, all amplifiers are on and working for that cavity whilst orange means that an amplifier is off or failing. Hovering with the mouse above the cavity status reveals which amplifier(s) is/are in fault or off.

The audible alarms tool monitors key components of the storage rings and of the linear accelerator. These include, but are not limited to: current lifetime, beam emittance, water systems, modulators interlock status, total charged delivered to the Short Pulse Facility (SPF), fields in the harmonic (Landau) cavities. All parameters have editable limits. The alarms strive to improve operators' reaction time, reducing beam losses and improving beam quality.

## Soft MO RF sweeper

Beam disturbance is clearly seen when RF is changed directly at 21:05 and 21:07.




Soft MO RF sweeper GUI.

The soft Master Oscillator RF (soft MO RF) sweeper is a tool for changing the MO RF in combination with an orbit feedback system. With this tool, the RF is changed without affecting beamlines that are sensitive to beam instabilities. The simple GUI of this tool shows the current MO RF of the storage ring, and enables users to set the desired change of the MO RF. The tool then moves the MO RF in steps of 0.1 Hz until the defined change has been accomplished. Between each step, at least one 1 second has to elapse and at least 5 iterations of the orbit feedback system has to be carried out. This means that each step does not affect the beam as seen by the beamlines and also gives time for the orbit feedback system to perform minor adjustments to the beam orbit, meaning that the MO RF can be adjusted during delivery. In up right corner figure the difference between when applying a change of 5 Hz directly (at 21:05 and 21:07) and by using the soft MO RF sweeper (at 21:10 and 21:21) is clearly seen.


**This work was done by: B. Meirose, V. Abelin, B.E. Bolling, M. Brandin, , R. Høier, A. Johansson, P. Lilja, J. S. Lundquist, S. Molloy, F. Persson, J. E. Petersson, R. Svärd (MAX IV Laboratory, Lund University).**