Online coupling measurement and correction throughout the LHC cycle

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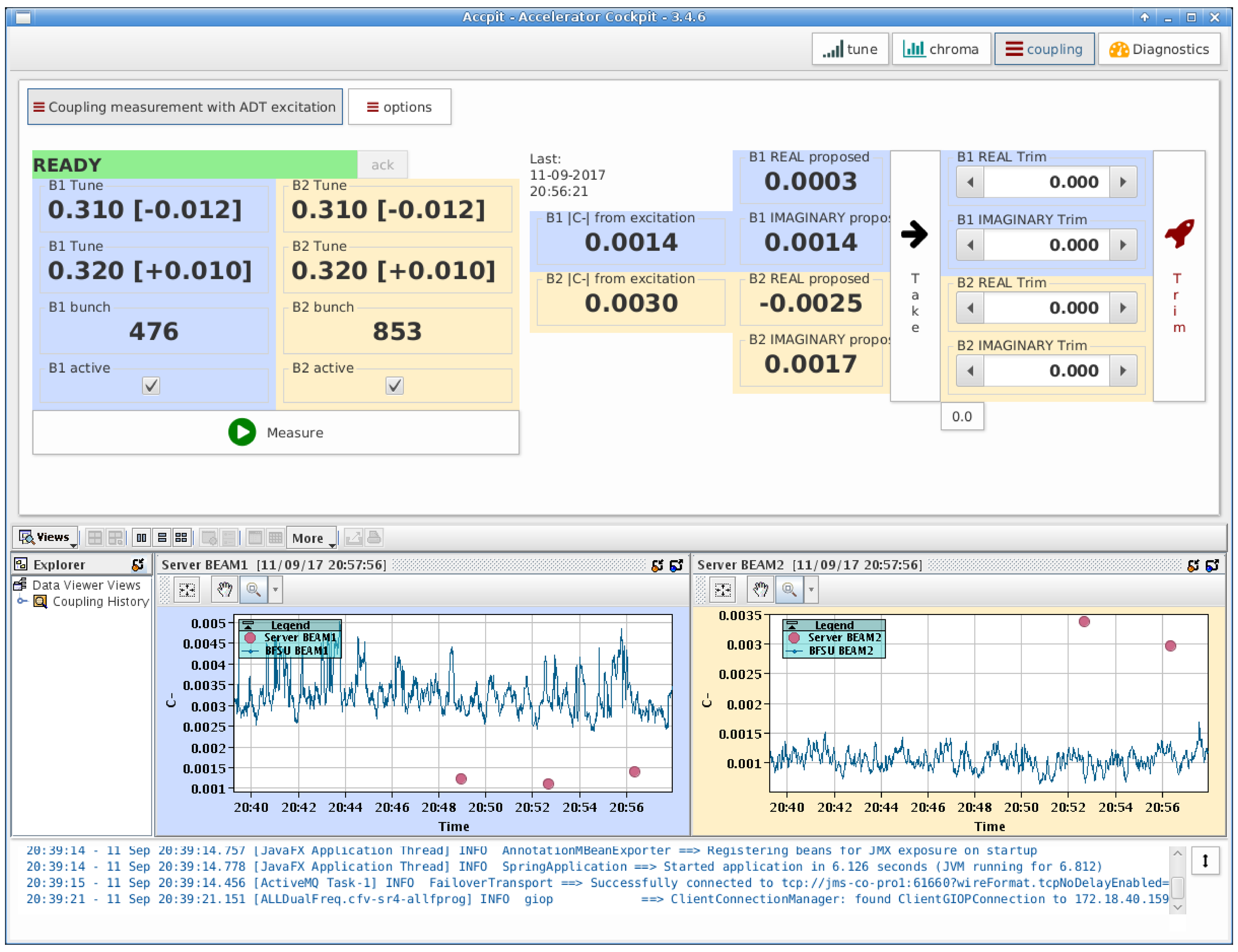
Motivation

A proper tune control requires a machine coupling which is significantly smaller than the tune separation. $C-$, the complex coupling coefficient corresponds physically to closest approach of the 2 tunes, Q_x and Q_y. For the LHC this requirement yields an operational tolerance for the global machine coupling of $|C-| \ll 0.03$ for injection optics and $|C-| \ll 0.003$ for collision optics [1]. The tune feedback, an essential feature for the beam stability, requires that the coupling is as low as possible. Otherwise it is impossible to correct the horizontal and vertical tune independently as a correction in one plane has also an influence on the other one. The transverse coupling has furthermore been linked to cause instabilities and the reduction of dynamic aperture[2].

Application



Technologies

This project integrates several other packages:

- Docker: a container management system
- Grpc: a channel to communicate between python and java
- Spring: application framework
- Reactive Streams: asynchronous stream processing
- Tensorics : tensor data structure for java
- mini-fx : small GUI-composition framework, developed by the LHC operational software team

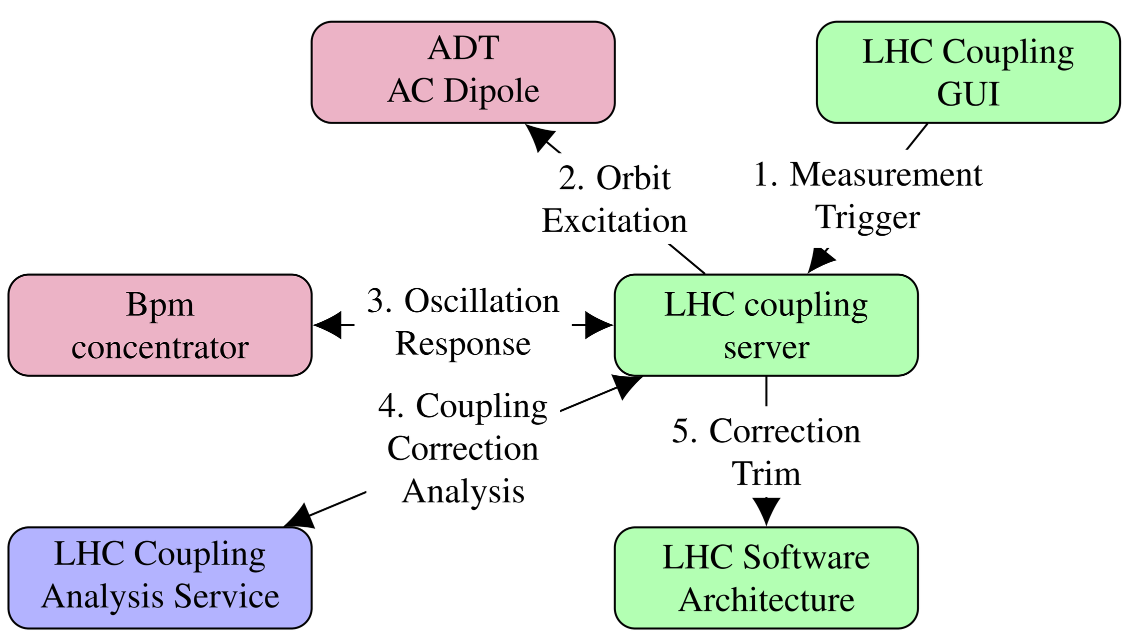
Some of those items were first used at CERN implying testing and market survey to implement correctly those. Others are re-use of software we already use in our applications.

Measurement Principle

The method to measure transverse coupling is to excite the beam with the transverse damper (ADT) used as an AC dipole and record the beam position during 6600 turns. This leads to a coherent beam motion close to the betatron frequency. Unlike kickers, an AC dipole excitation can produce a sustained coherent motion with almost no emittance growth. Turn-by-turn position data of the excited motion from beam position monitors (BPMs) allows prompt measurements of optics parameters. Coupling Resonance Driving Terms (CRDT) due to skew quadrupole fields can be determined from corresponding spectral components of the turn by-turn position [3].

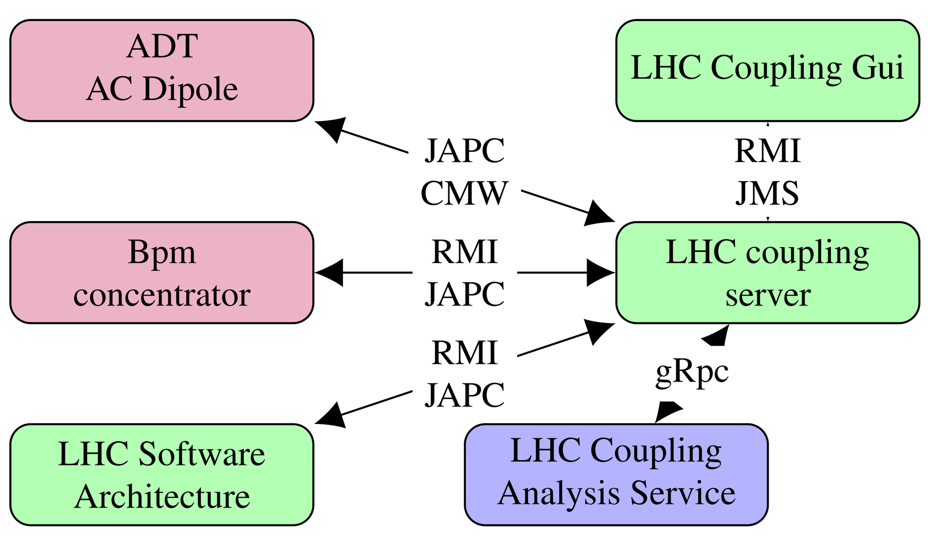
Measurement Flow

- The operator sets the desired parameters and triggers the measurement.
- The timing system triggers the ADT excitation and the recording of the beam position monitors, and when this is done the coupling correction analysis.
- The result of the python script (coupling and correction for both beam) is shown on the panel.
- The operator can decide to send this correction trim to the power supplies.



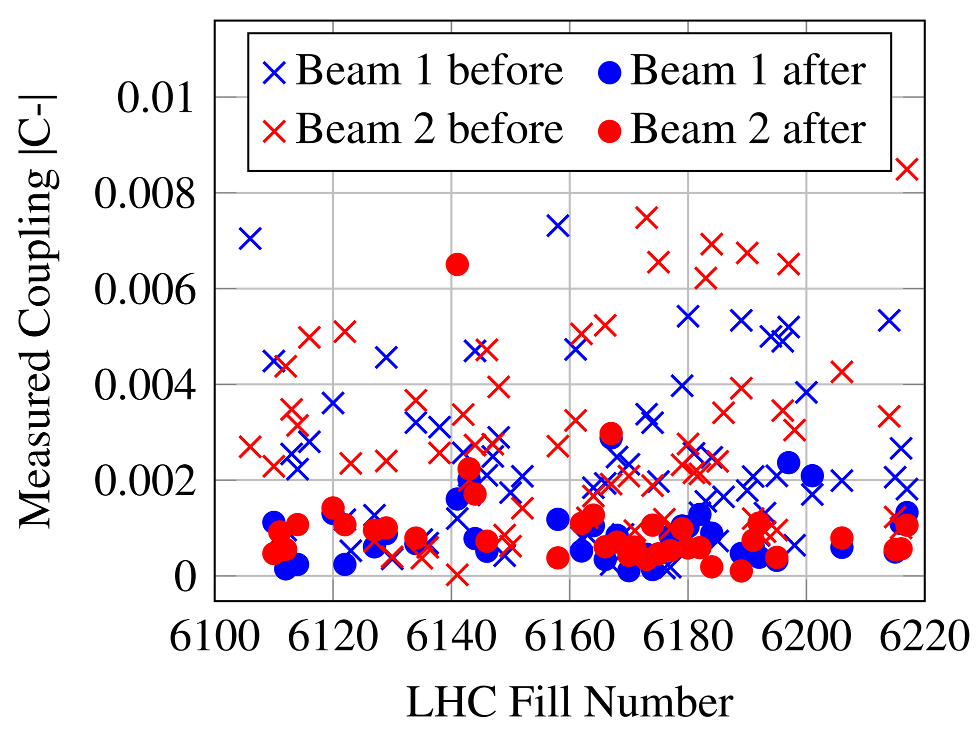
Software Design

The aim of this new software is to simplify the measurement process by allowing the different actors to work together under the supervision of a central server. Different technologies and languages were used. In particular the top layer of the LHC control system is based on Java, while the existing data analysis scripts for LHC optics measurement and correction were implemented in Python.



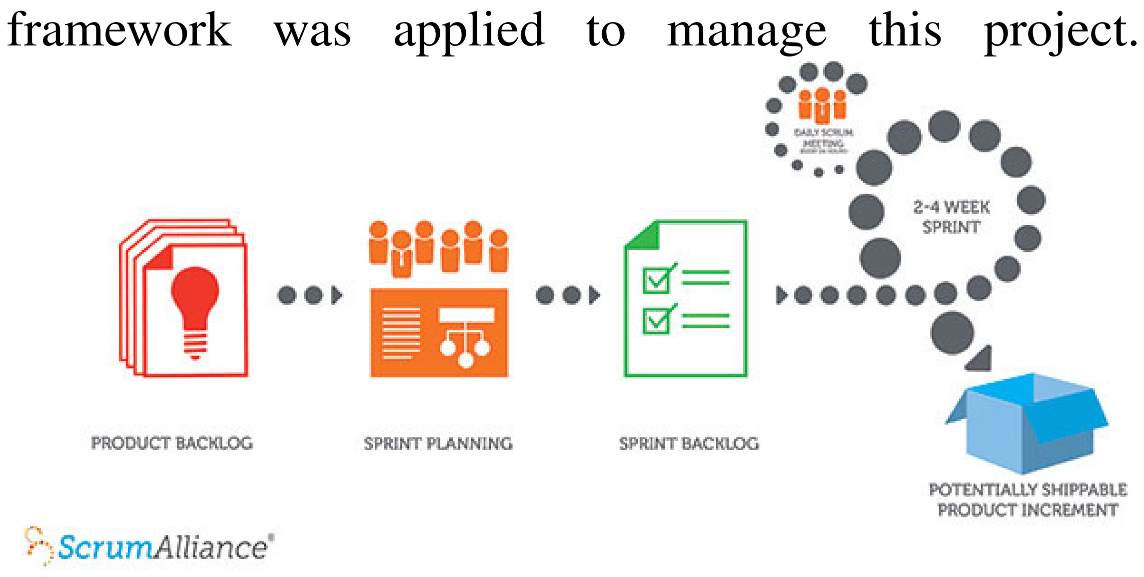
Operationnal experience

The new software allows a coupling correction down to the $|C-| \approx 0.001$ level for most fills, whereas the uncorrected coupling would be up to a factor of 10 higher. This is significantly better than the minimum requirement given in the LHC design report, and provides additional margin for beam stability.



Team Work

Since this project involves four CERN groups working together (BE-CO-APS, BE-OP-LHC, BE-ABP-LAT and BE-RF-FB), it was highly desirable to use agile techniques. In particular, the scrum framework was applied to manage this project.



Conclusions

Concurrently with the Luminosity Control, this software improves the beam quality for the LHC machine. It helps minimizing the time spent at injection and delivers a robust coupling control all around the cycle. Software reuse, Scrum framework implementation and innovative technologies survey were the key of success. The main benefits of this software collaboration are a solid training, an increased attention to the details so that the code remains readable and testable, and a continuous improvement of the working habits.

References

[1] L.R. Carver, et al. "DESTABILISING EFFECT OF LINEAR COUPLING IN THE LHC" Proceedings of IPAC2017, Copenhagen,

[2] E.H. Maclean, and al "Effect of Linear Coupling on Nonlinear Observables at the LHC", Proceedings of IPAC2017, Copenhagen

[3] T. Persson, R. Tomas "Improved control of the betatron coupling in the Large Hadron Collider" Phys. Rev. Spec. Top. Accel. Beams 17 (2014) 051004