Automatic injection quality checks for the LHC

L.N. Drosdal, B.Goddard, D. Jacquet, R. Gorbonosov, S. Jackson, V. Kain, D. Khasbulatov, M. Misiowiec, J. Wenninger, C. Zamantzas, CERN, Geneva, Switzerland

Abstract

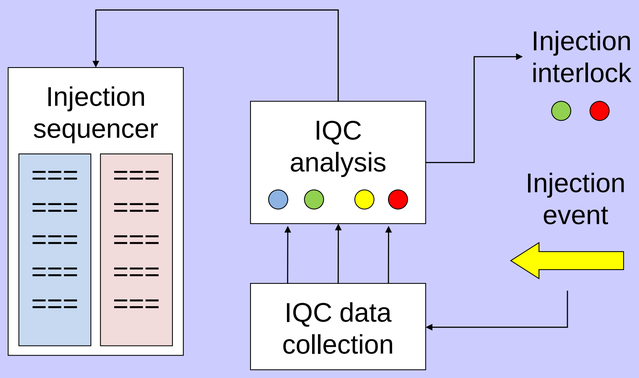
Twelve injections per beam are required to fill the LHC with the nominal filling scheme. The injected beam needs to fulfill a number of requirements to provide useful physics for the experiments when they take data at collisions later on in the LHC cycle. These requirements are checked by a dedicated software system, called the LHC injection quality check. At each injection, this system receives data about beam characteristics from key equipment in the LHC and analyzes it online to determine the quality of the injected beam after each injection. If the quality is insufficient, the automatic injection process is stopped, and the operator has to take corrective measures. This paper will describe the software architecture of the LHC injection quality check and the interplay with other systems. Results obtained during the LHC run 2011 will finally be presented.

Automatic injection system

The LHC is currently filled with 1380 bunches by 12 injection per ring.

The filling pattern is pre-programmed in the injection sequencer which sends requests to the timing system.

At each injection key equipment in the LHC and transfer lines are analyzed in the injection quality check (IQC).



The result is returned to the injection sequencer and the software interlock system (SIS). If the quality is not sufficient the injection process is stopped and the operator has to review the IQC GUI. As long as there are no errors the injection process continues automatically until the machine is filled.

Injection quality checks

Extracted intensity & RF bucket check

The combination of two transfer line BCTs the LHC BQM is used to determine if beam was extracted from the transfer line and injected into the correct buckets.

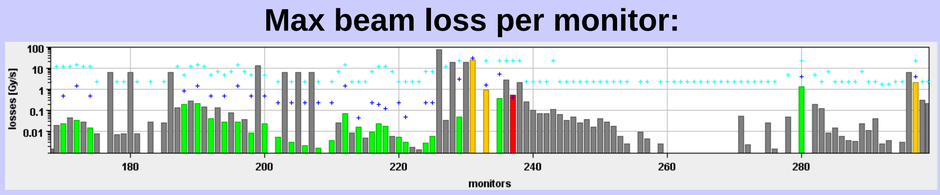
Injection kickers

The four vertical kicker magnets need to have a short kicker rise time of less than 1 ms, little ripple on about 8 ms long flattop and fall times not longer than 3ms. In the IQC tight thresholds are used to pick up any abnormalities.

Beam loss monitors

The beam losses in the transfer line and the LHC provide useful information for diagnosing injection quality. In the case of high losses the beams could even be dumped at injection so it is very important to keep the losses under control.

Max beam loss per monitor:



The pattern of maximum beam loss per monitor can be used to find sources of losses. Plot from IQC BLM panel.

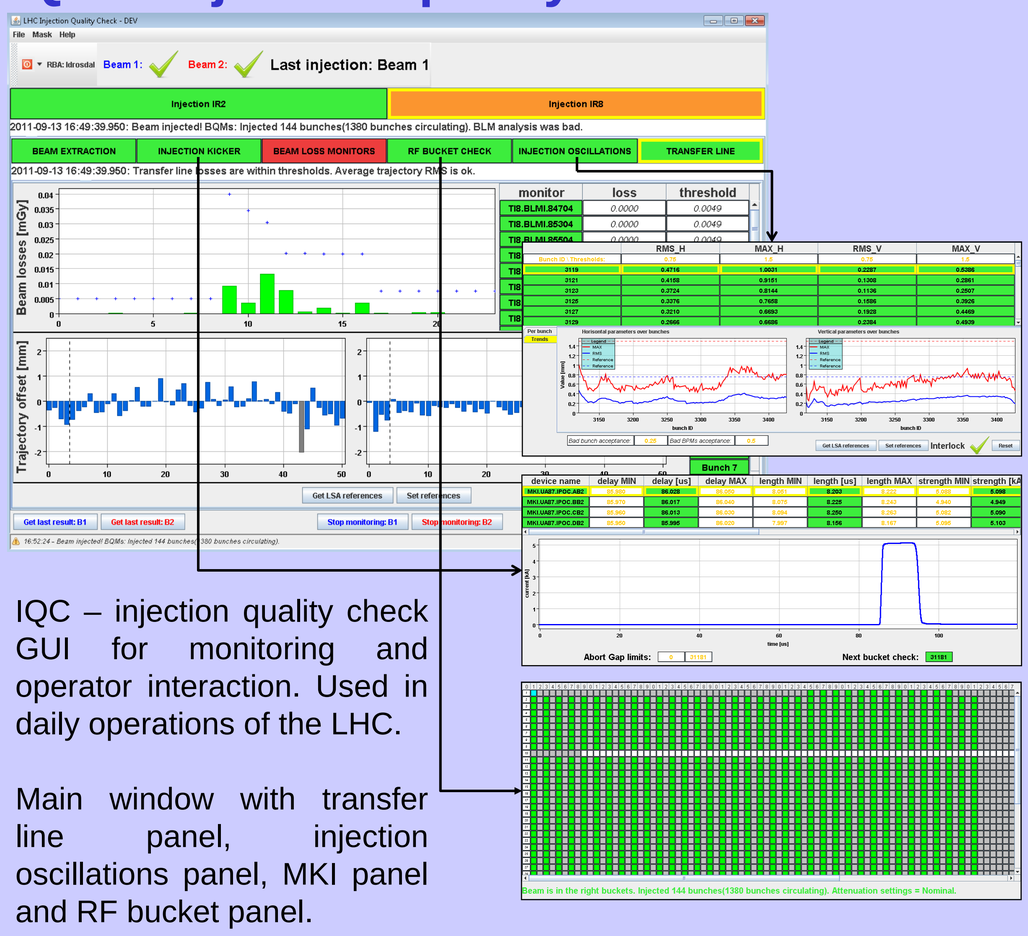
Injection oscillations

If the injection oscillations are higher than tolerances protection against failures can no longer be guaranteed. If the oscillations are too high the IQC will give an SIS interlock on high intensity injections until the orbit has been corrected. The trajectory in the transfer lines (TI2 and TI8) are also analyzed.

IQC result – 6 possible outcomes

Is beam injected?	Quality checks OK?	
NO	REPEAT	No extraction and no beam injected - **continue**
	NO KICK	No MKI pulse, could be errors – **stop (SIS latch)**
UNKNOWN		Missing or ambiguous data, injection cannot be verified – **stop and provide input! (SIS latch)**
YES	SUCCESSFUL	All checks OK - **continue**
	WARNING	Minor errors (for experts to check) - **continue**
	BAD	Module failures – **stop (SIS latch)**

IQC – Injection quality check GUI



IQC – injection quality check GUI for monitoring and operator interaction. Used in daily operations of the LHC.

Main window with transfer line panel, injection oscillations panel, MKI panel and RF bucket panel.

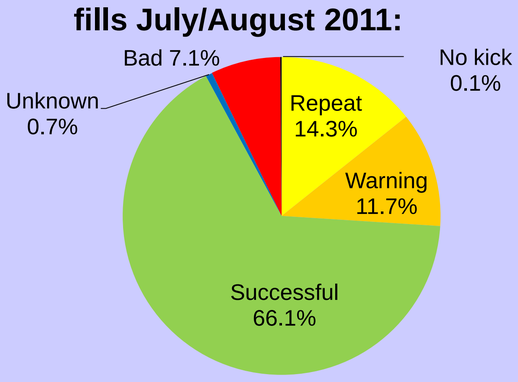
Operational experience

2010 – Commissioning and data quality problems.

2011 – Good performance, only few problems with data quality. Several quality issues were discovered.

Statistics of 60 fills show that the IQC stopped the injections for 7.9% (Unknown, bad, no kick) of the injection events, for the remaining 92.1% the injection process continue.

Distribution of results from 60 fills July/August 2011:

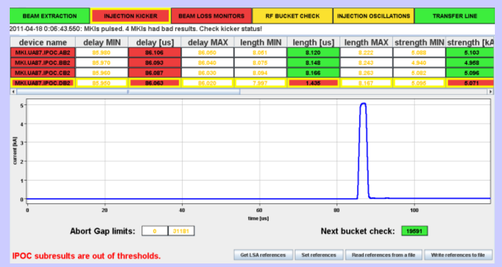


Diagnostics

The IQC has proven to be very useful as a diagnostics tool when reviewing event in the playback mode as well as from the online GUI.

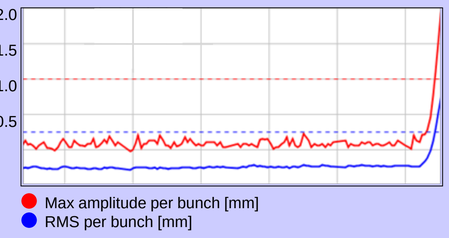
In additional to the general result the IQC can indicate many different quality problems such as:

- Injection into bad buckets
- Bad MKI pulse or MKI failures
- Changes in MKI hardware
- Distribution of beam losses over monitors and time point to sources of problems
- UFOs appearing shortly after injection (within 20 ms buffer)
- High injection oscillations
- Bunch by bunch variations for injection oscillations
- Bad settings or faulty data

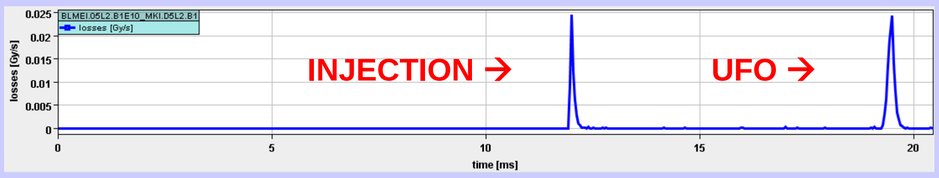


A kicker failure on MKI D caused high beam losses.

Injection oscillations in vertical plane for 144 bunches



When 144 bunches were first introduced higher injection oscillations were discovered in the vertical plane for the last 4 bunches were discovered. The cause was a short MKI waveform.



UFOs appear more frequently around the MKI at injection. In the IQC BLM plot they can be studied if they appear within the 20ms buffer.