Beam Quality Assessment for LHC beams

Real Time and Post-Pulse

V. Kain, LHC Operation

Special thanks to:

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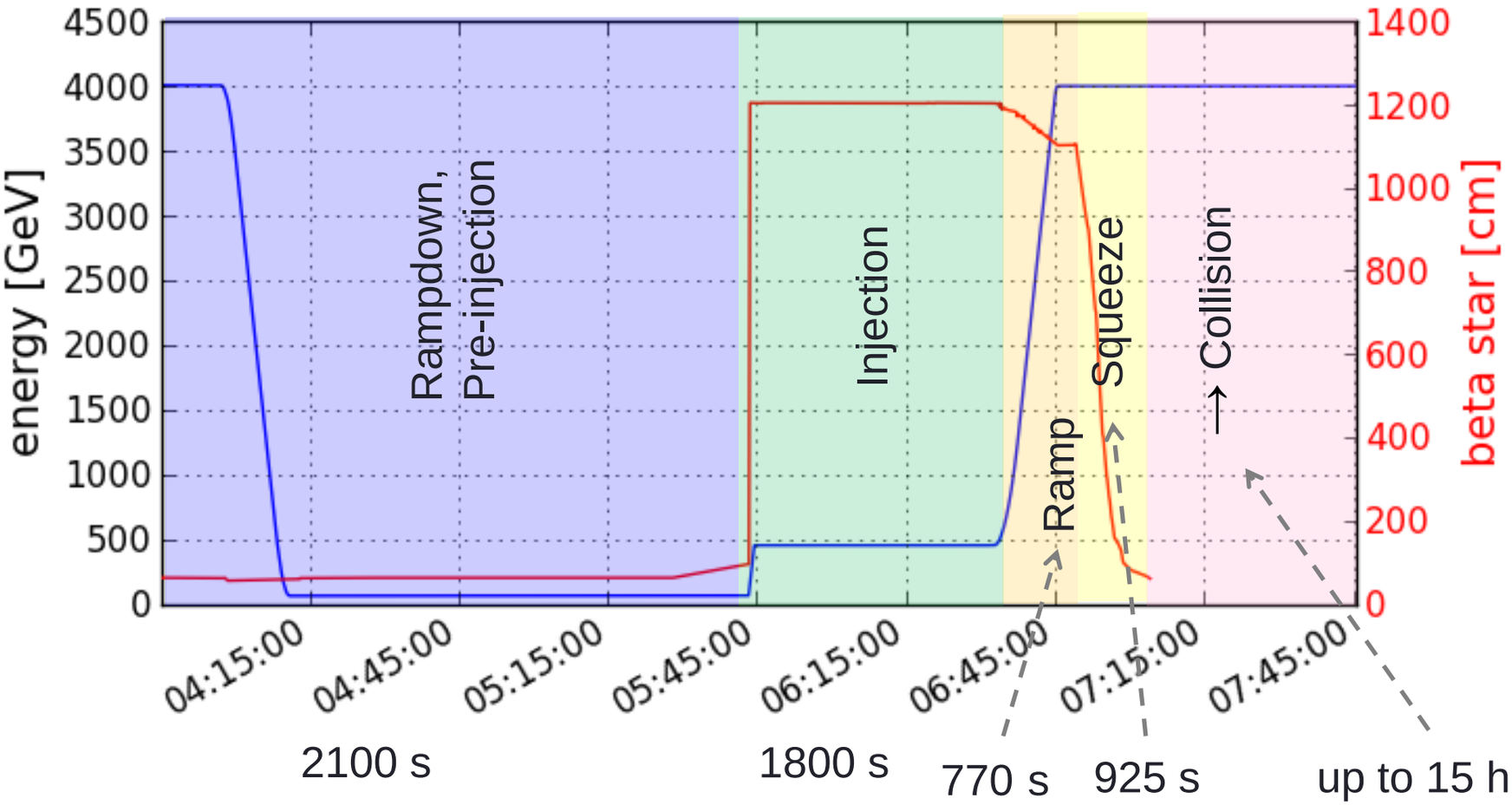
Overview of LHC cycle

LHC cycle is long.

LHC cycle in 2012, 4 TeV collision energy, β* 0. 6 m:



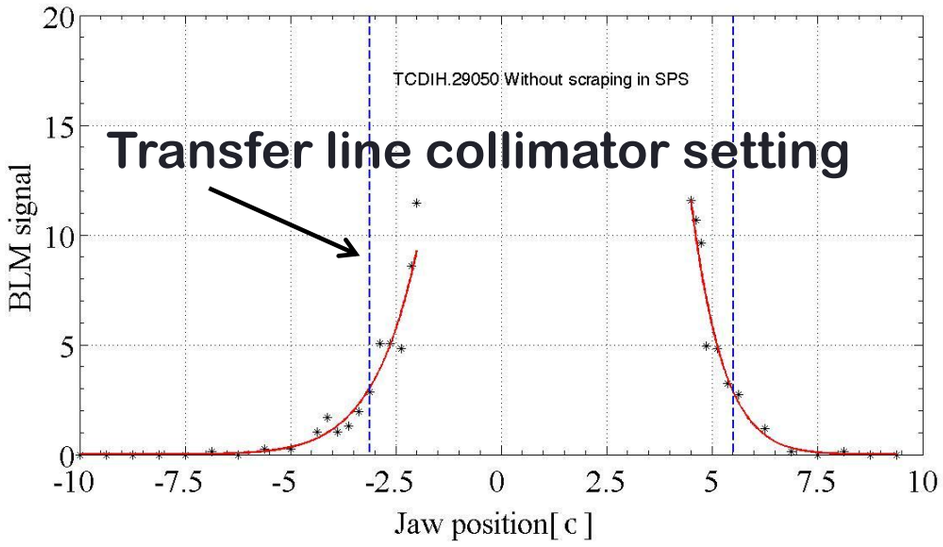
- All parts of cycle except of injection are driven by functions
  - Once execution started cannot/should not be stopped
- Need to go through cycle (e.g. ramp+ rampdown): reproducibility

→ Check beam quality before/at injection. Afterwards: live with it.

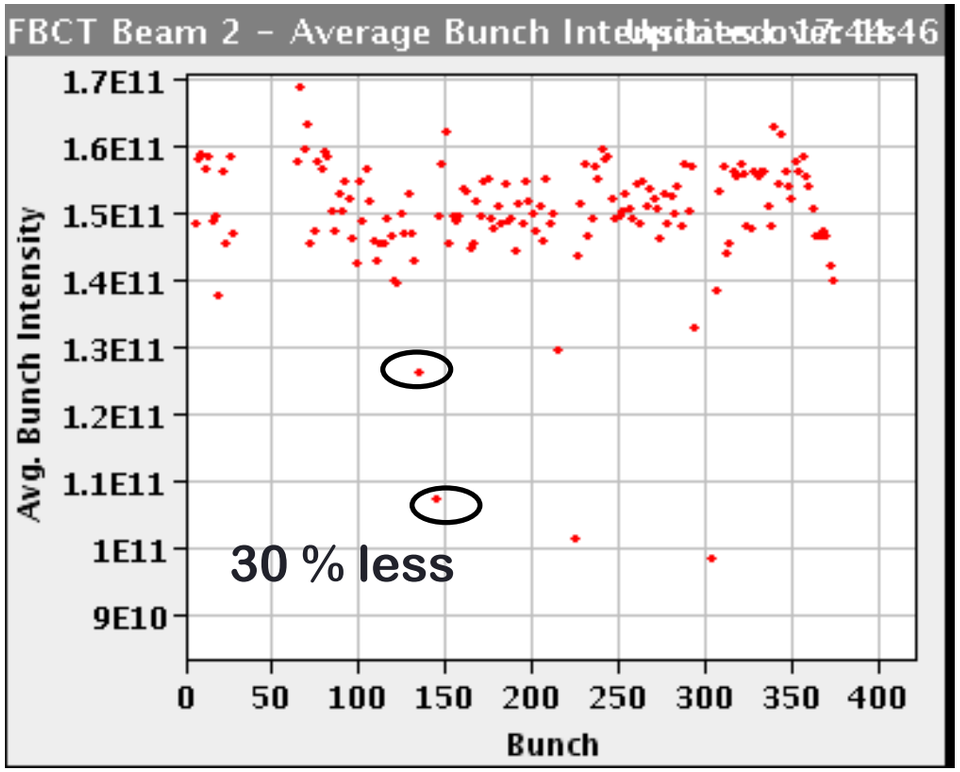
LHC Beam Quality Requirements

Requirements:

- Small emittances: 1.5 x 10^{11}, 1.5 μm
- Uniform bunch intensities (< +/- 10 %)
- Equal beam intensities for beam 1 and beam 2
- Low tail population
- Satellite population reasonable
- Low losses
- Bunches in the correct buckets
- …



Tail population beyond transfer line collimator opening → scraping in the SPS



12 + 144 bunches at injection in the LHC: Problem with injection kicker timing in the SPS

Beam Quality Checks

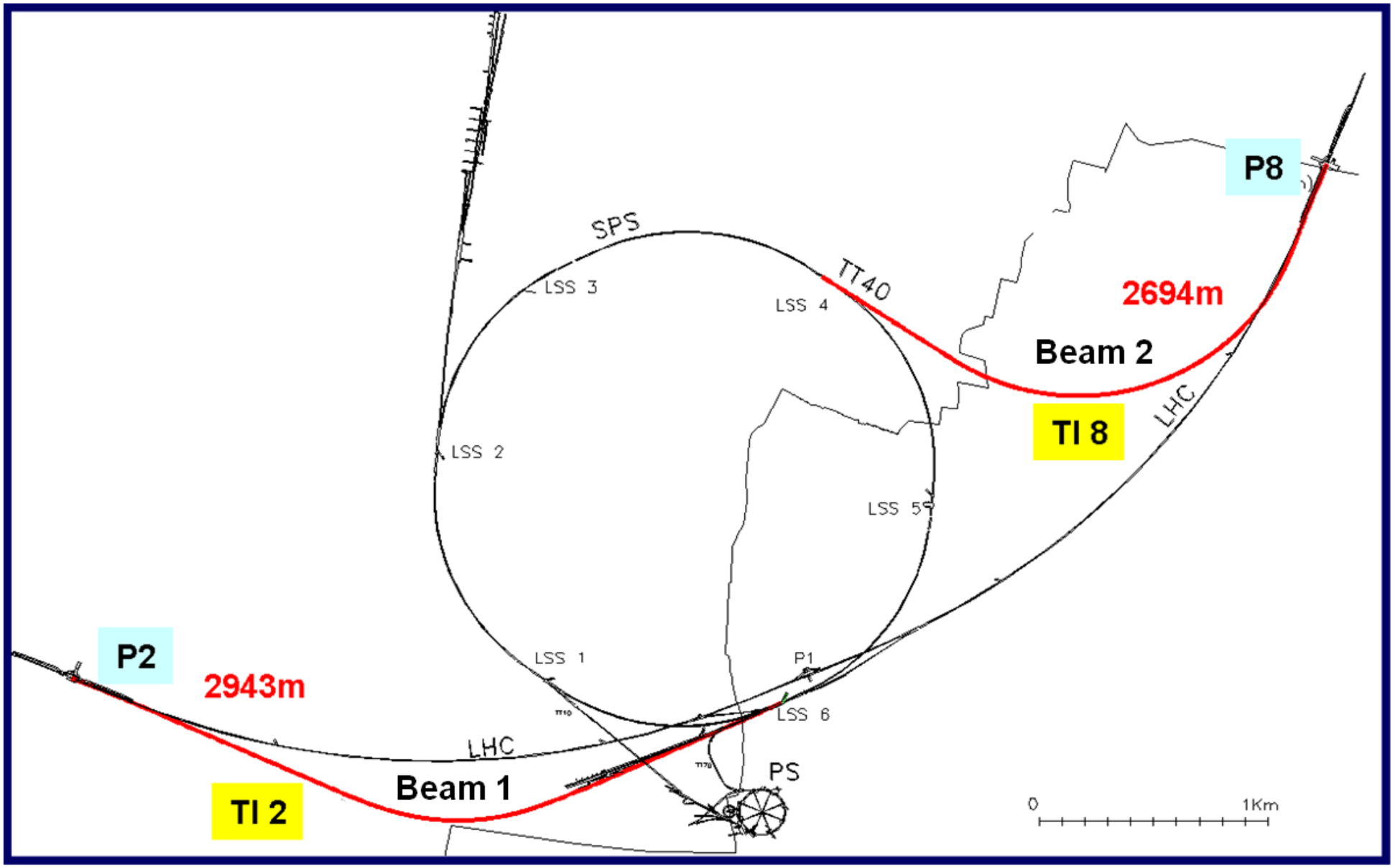
2 types of online active Beam Quality Check Systems:

Beam Quality Monitor (BQM) in the SPS

Injection Quality Check (IQC) in the LHC

Layout SPS to LHC

- 2 3 km long transfer lines to fill the LHC from the SPS

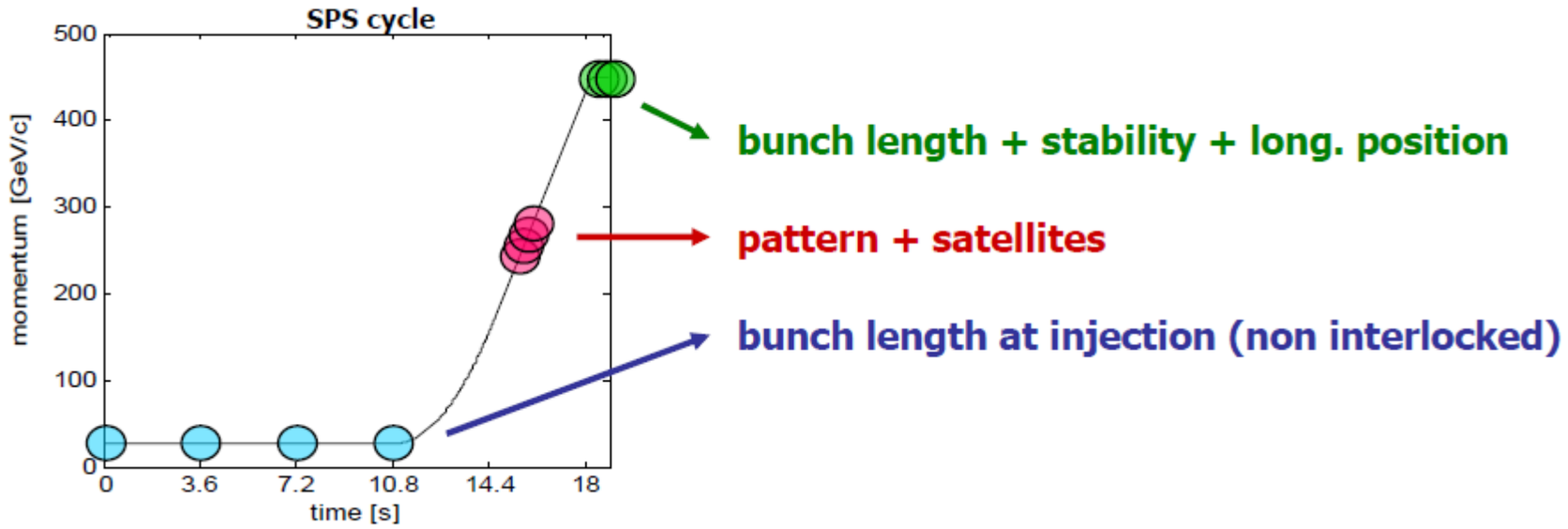


- Need ~ 12 injections per ring to fill LHC; LHC cycle in the SPS ~ 20 s.
- Fast extraction from the SPS
- As soon as extraction launched cannot stop it anymore

Beam Quality Monitor in the SPS

- Beam Quality Monitor (BQM) – checks longitudinal quality of beam in the SPS

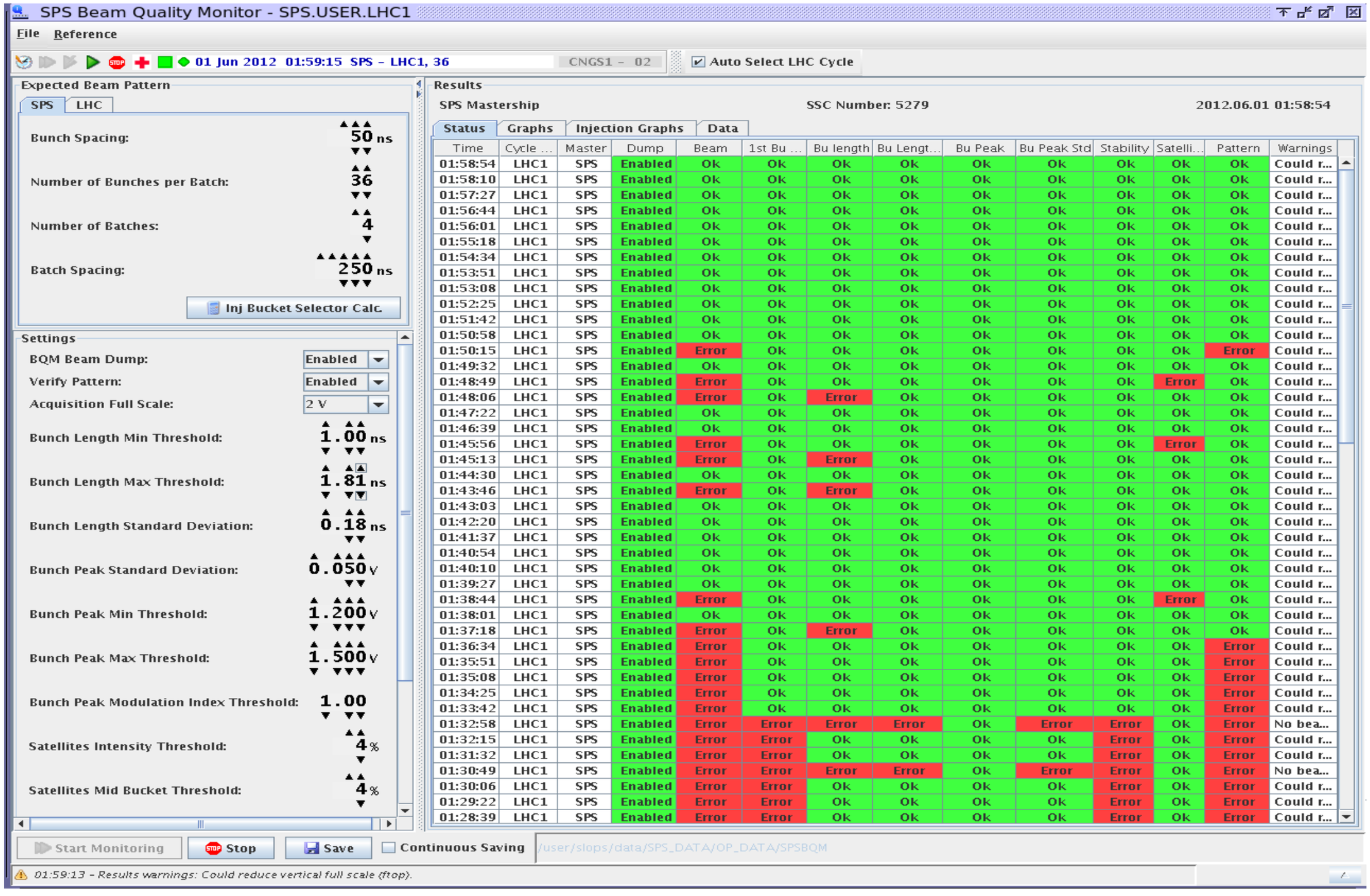
BQM measurements



- Based on Wall Current Monitor Beam Profile. Analysis running on FESA class.
- Dumps beam in the SPS in case of bad quality. Last check ~ 20 ms before extraction.
- Analysis speed: 10 ms data acquisition + 10 ms analysis
- Typical errors caught:
  - Rephasing not working correctly
  - Fully debunched (PS cavity missing)
  - Bad injection phase or bad PS bunch splitting
  - Injections in wrong bucket or missing injections in the SPS
  - Bunch intensity spread too large

Beam Quality Monitor in the SPS

- The BQM analyses each SPS cycle, no matter whether beam requested by LHC or not.



Time	Cycle ...	Master	Dump	Beam	1st Bu ...	Bu length	Bu Lengt...	Bu Peak	Bu Peak Std	Stability	Satelli...	Pattern	Warnings
01:58:54	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:58:10	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:57:27	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:56:44	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:56:01	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:55:18	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:54:34	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:53:51	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:53:08	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:52:25	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:51:42	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:50:58	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:50:15	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:49:32	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:48:49	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Error	Ok	Could r...
01:48:06	LHC1	SPS	Enabled	Error	Ok	Error	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:47:22	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:46:39	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:45:56	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Error	Ok	Could r...
01:45:13	LHC1	SPS	Enabled	Error	Ok	Error	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:44:30	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:43:46	LHC1	SPS	Enabled	Error	Ok	Error	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:43:03	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:42:20	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:41:37	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:40:54	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:40:10	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:39:27	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:38:44	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Error	Ok	Could r...
01:38:01	LHC1	SPS	Enabled	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:37:18	LHC1	SPS	Enabled	Error	Ok	Error	Ok	Ok	Ok	Ok	Ok	Ok	Could r...
01:36:34	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:35:51	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:35:08	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:34:25	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:33:42	LHC1	SPS	Enabled	Error	Ok	Ok	Ok	Ok	Ok	Ok	Ok	Error	Could r...
01:32:58	LHC1	SPS	Enabled	Error	Error	Error	Error	Ok	Error	Error	Ok	Error	No bea...
01:32:15	LHC1	SPS	Enabled	Error	Error	Ok	Ok	Ok	Ok	Error	Ok	Error	Could r...
01:31:32	LHC1	SPS	Enabled	Error	Error	Ok	Ok	Ok	Ok	Error	Ok	Error	Could r...
01:30:49	LHC1	SPS	Enabled	Error	Error	Error	Error	Ok	Error	Error	Ok	Error	No bea...
01:30:06	LHC1	SPS	Enabled	Error	Error	Ok	Ok	Ok	Ok	Error	Ok	Error	Could r...
01:29:22	LHC1	SPS	Enabled	Error	Error	Ok	Ok	Ok	Ok	Error	Ok	Error	Could r...
01:28:39	LHC1	SPS	Enabled	Error	Error	Ok	Ok	Ok	Ok	Error	Ok	Error	Could r...

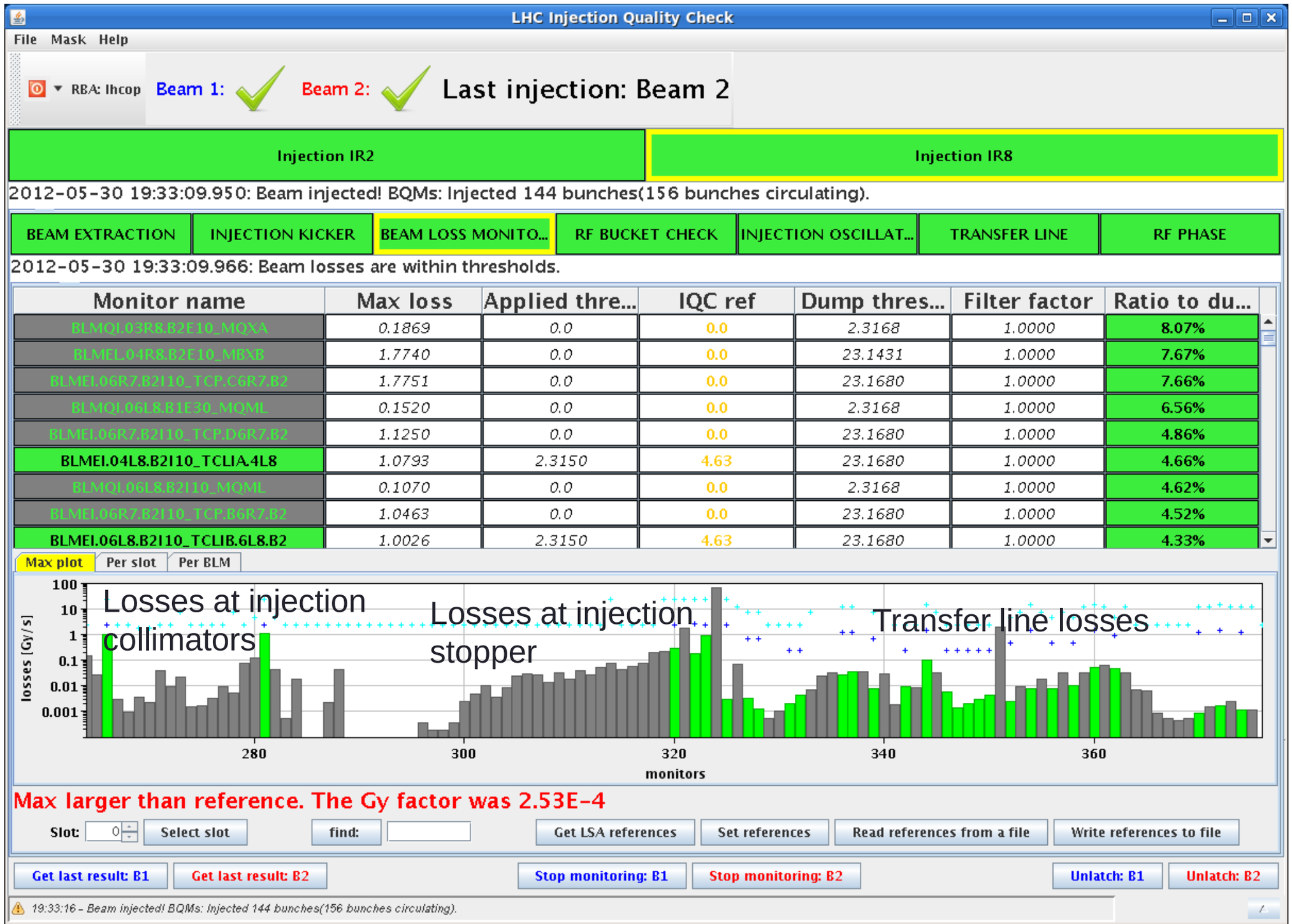
- Logical “AND” of all analysis results, if FALSE beam dumped before extraction

Injection Quality Check in the LHC

- Analysis carried out after each LHC injection – Interlocks next injection in case of bad result
- Collects and analyses data from many systems – BLMs, transfer lines, BPMs, LHC BQM, injection kickers, RF phase error, (SPS scraping)
- Uses LHC Postmortem framework
  - Framework for analysis modules – plugin
  - Partly postmortem push of frontends, partly subscription through CMW
  - All raw data and analysis results stored on Postmortem server
- Running on a JAVA server
- Analysis is triggered by LHC injection event. Data is collected and stored as "Event"
- Modules individually maskable – special LHC modes, tests (e.g. inject & dump)
- Result available after ~ 8 s

Injection Quality Check in the LHC

- 4 possible overall results for injection sequencer: repeat, no kick, bad, success
  - No kick and bad also interlock the injection



IQC GUI:

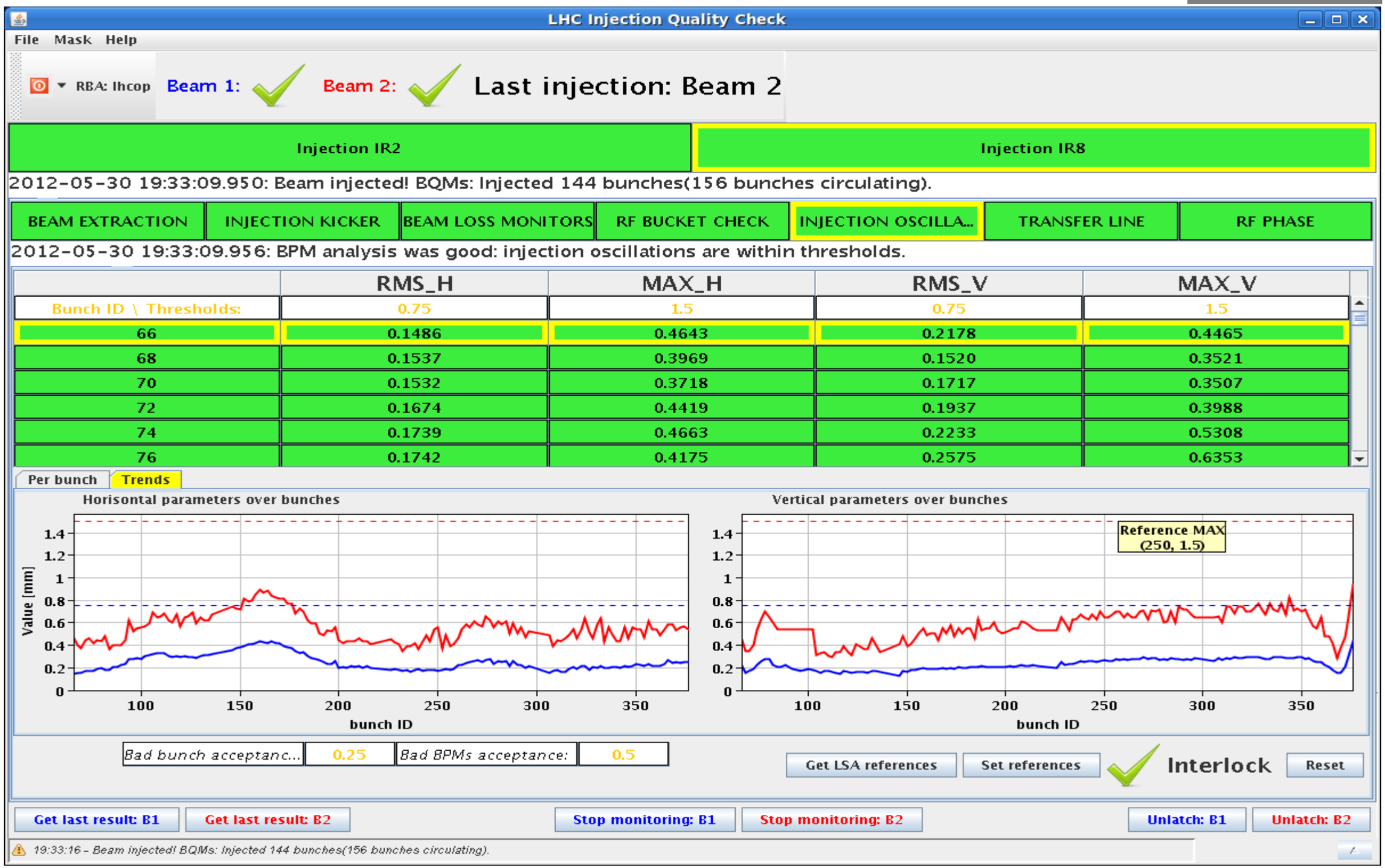
LHC BLM module

L. Drosdal

Injection Quality Check in the LHC

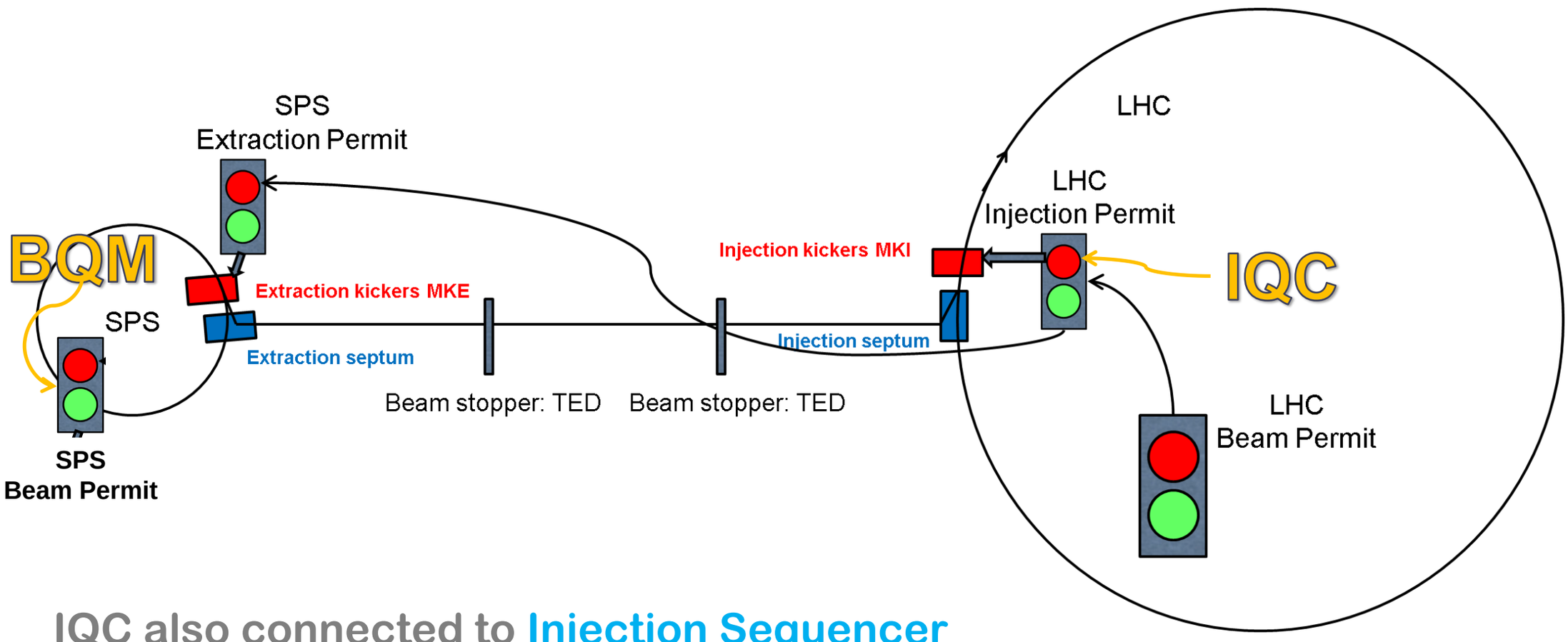
- If injection oscillations are above limit – can only re-inject with maximum 12 bunches. Aperture conservation in LHC and Damper good damping range.
- Injection oscillation injection interlock

L. Drosdal



BQM and IQC signals used online

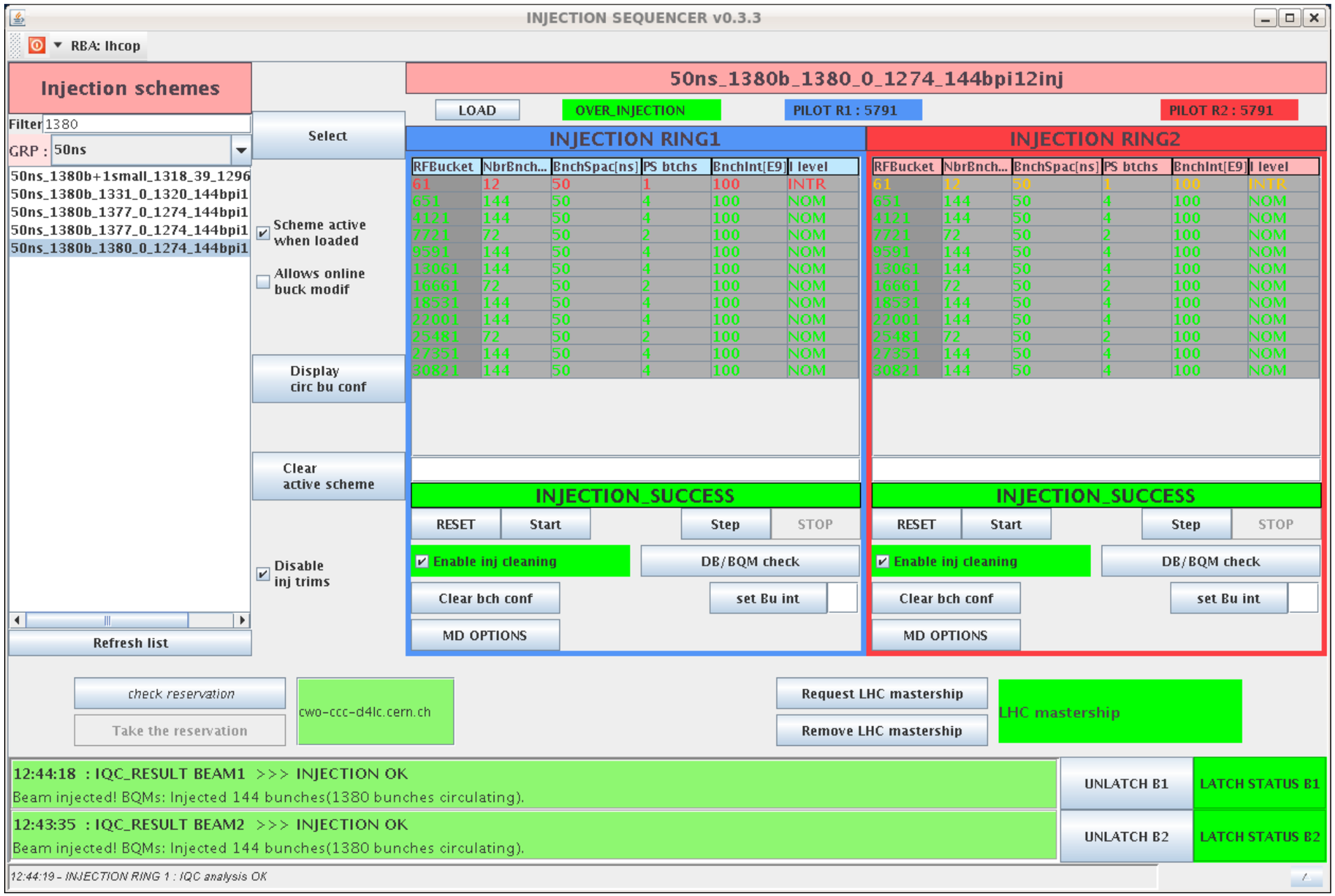
- BQM connected to SPS Beam Permit
- IQC connected to injection Software Interlock System (SIS), the injection SIS is connected to the injection permit



- IQC also connected to **Injection Sequencer**
  - Programs the next injection in the injector timing system
  - Programs all the equipment with required settings for next injection:
    - Pattern of BQM
    - Next injected bunches for bunch-by-bunch measurement systems
    - …

Injection Sequencer and IQC

- Injection sequencer: pre-programmed series of different shots
  - Different number of bunches, different RF bucket, …
- Injection sequencer only plays next request if IQC result was good.



D. Jacquet

What is missing for LHC beams?

1. No **transverse quality monitor** in injectors.

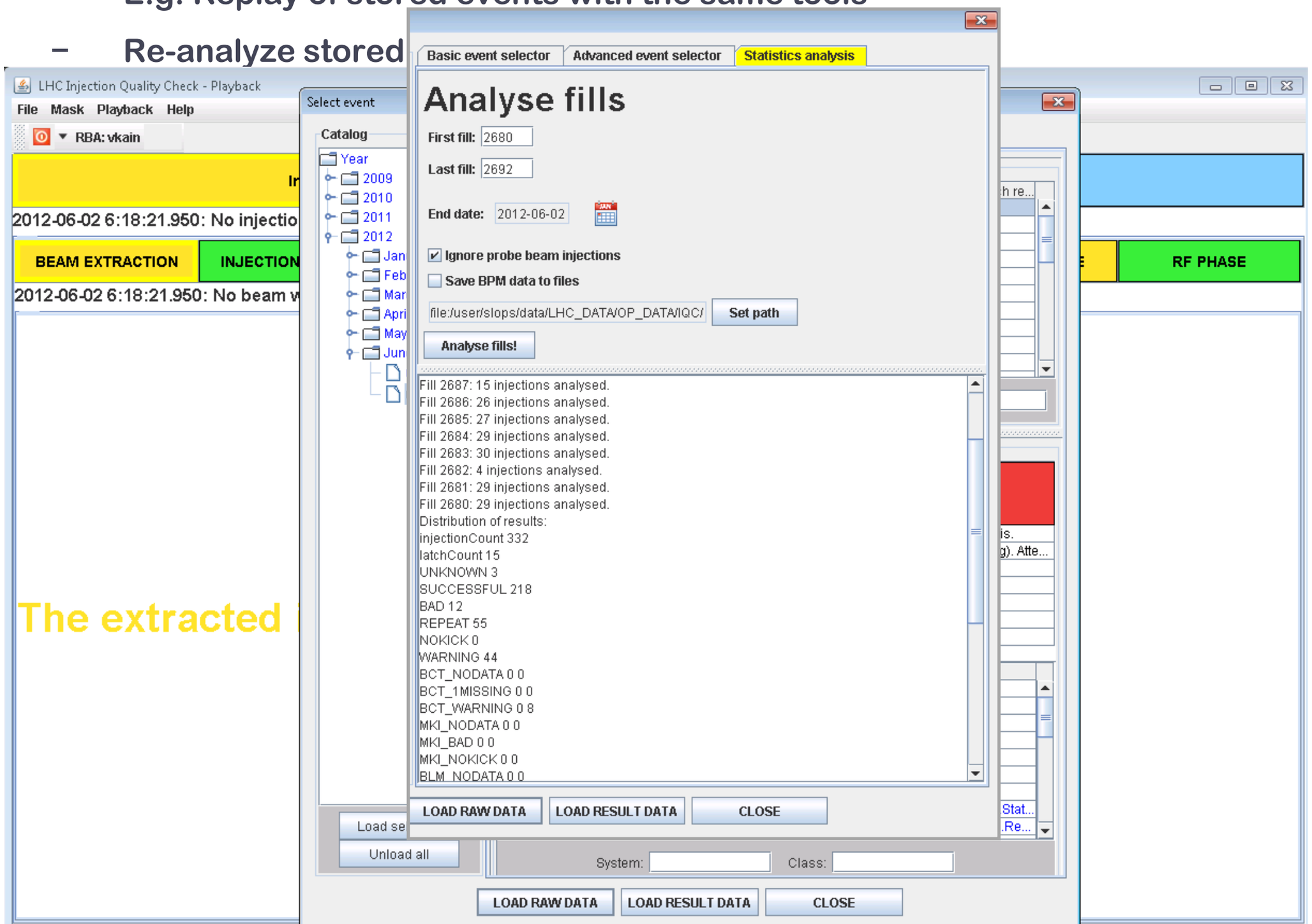
   - Typical issues: **tails and larger emittances**
     - ❑ Noticed due to problem with losses in the transfer lines and later in cycle
     - ❑ Lower peak luminosity
     - ❑ (profile measurements in the LHC have limitations)

   - No continuous emittance measurement in the injectors
     - ❑ Only wire scanners

2. Injector and LHC beam parameter evolution as function of LHC fill number
   - Supertable
   - See trends and catch deterioration
   - We are putting a framework in place

IQC in the LHC – playback, statistics

- The LHC injection process is now well understood due offline analysis
- IQC comes with all the LHC postmortem infrastructure
  - E.g. Replay of stored events with the same tools
  - Re-analyze stored



Summary

- The LHC performance **depends on excellent beam quality** from the injectors and conservation through the LHC cycle.

- Only before or after injection, beam can be rejected due to quality issues because of the LHC cycle length and execution of functions

- The **Beam Quality Monitor in the SPS** stops beam with bad longitudinal quality

- The **Injection Quality Check in the LHC** stops from continuing with injection in case quality is bad

- The LHC online quality checks cover many possible quality issues. Automatic checks of the **transverse emittance and tails** before injection are still **missing**

- Storing of and tools to display all relevant beam parameters in the injectors and LHC as function of fill number is necessary to catch deterioration early or push performance further.