Automation in the SPS and LHC and its effect on operator skills

The past 20 years have seen great advances in the CERN accelerator control systems. Low level operation skills have been largely replaced by sophisticated sequencers and feedback loops. At the same time, a drive for greater efficiency, a tendency for more complex accelerator operations and a need to reduce the risk of "human error" have rendered these tools essential. The effect of this controls evolution on operator skills will be analyzed in the context of SPS and LHC accelerator operations at CERN.

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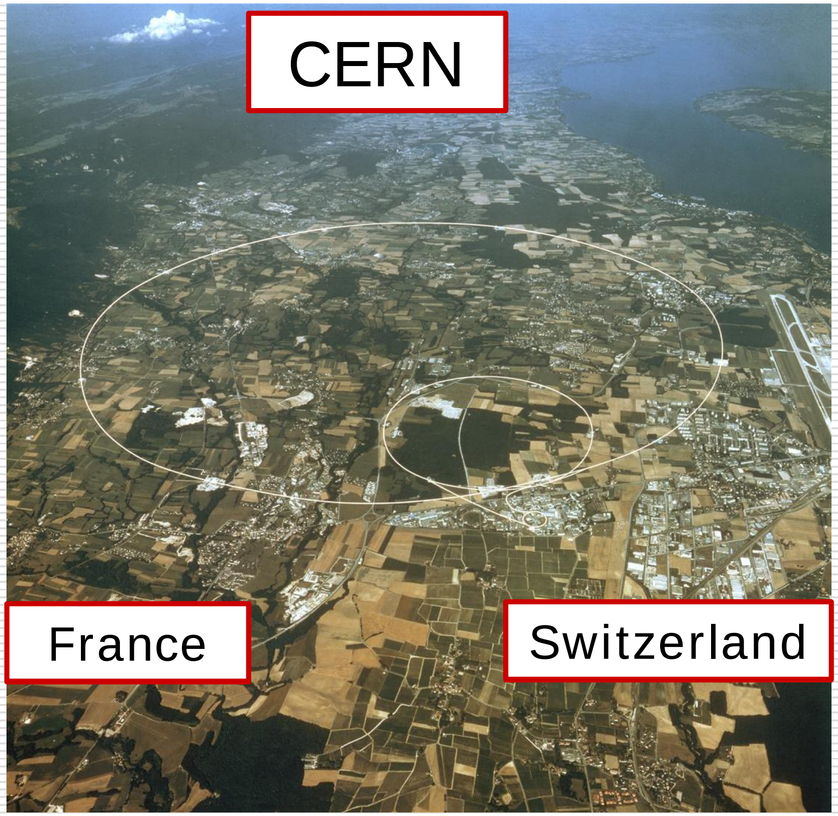
Talk Content

- The CERN Accelerator complex
- Brief history of accelerator controls at CERN,
  A progressive evolution towards greater automation
- Automation tools in the SPS and LHC
- How to manage automation tools without eroding operator understanding



The CERN Accelerator Complex

Proton Synchrotron (PS)

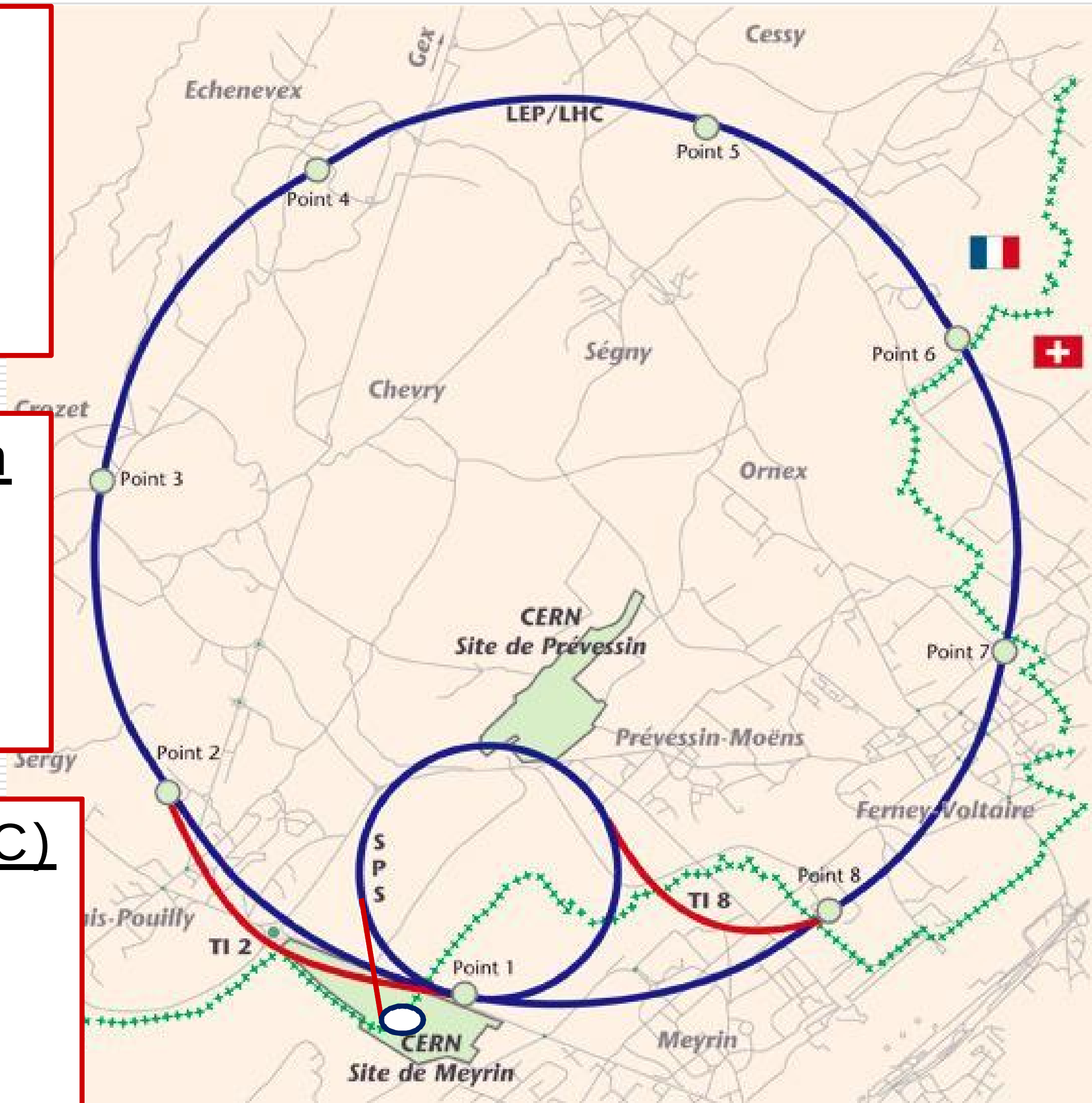
- Circumference 628m
- Energy 26 GeV
- Since 1959

Super Proton Synchrotron (SPS)

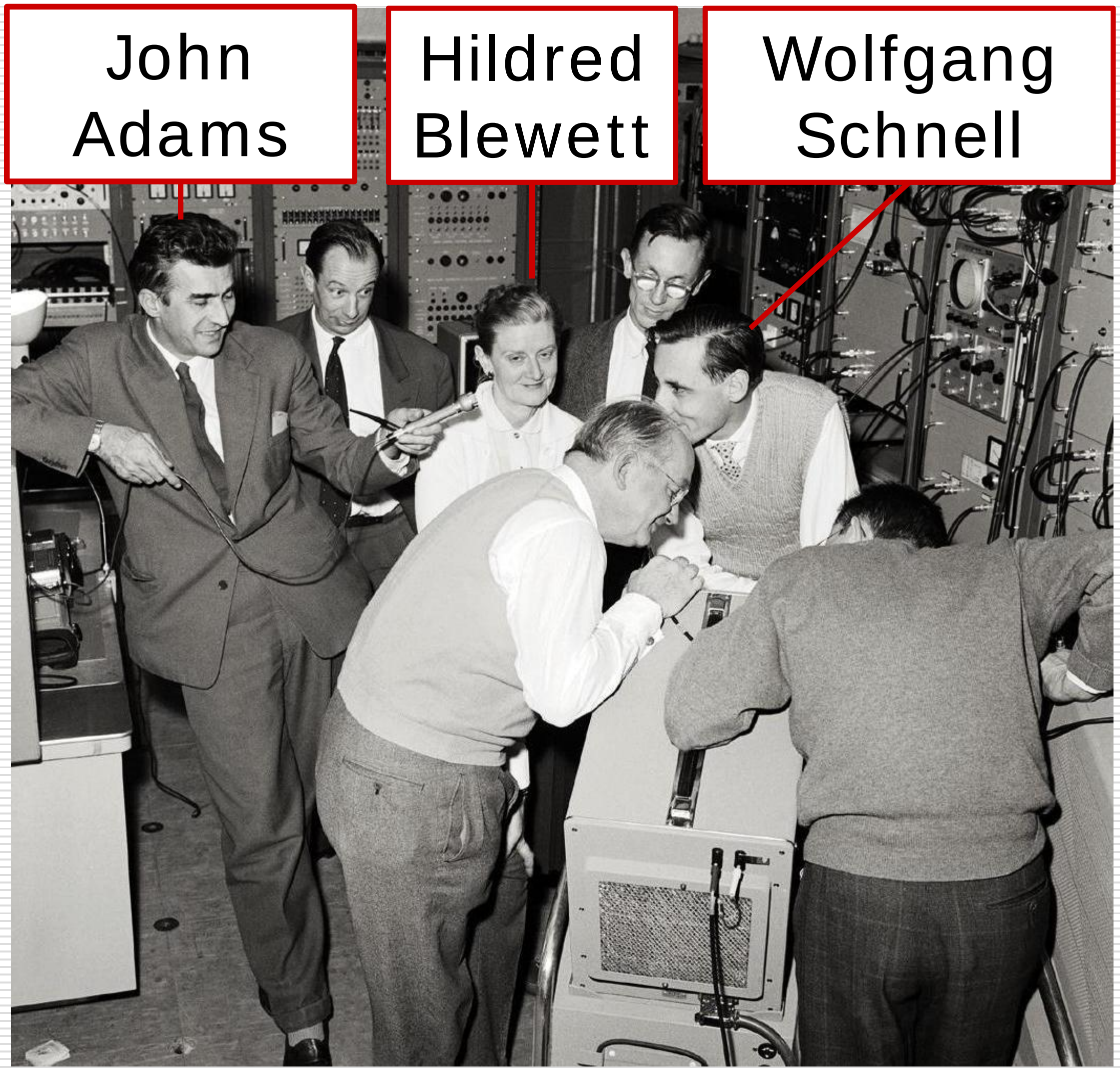
- Circumference 7km
- Energy 450 GeV
- Since 1976

Large Hadron Collider(LHC)

- Circumference 26km
- Energy 4 TeV / beam
- Since 2008



1959 PS commissioning



Synchrotron design based on strong focusing theory

Radial position pickup feedback on RF phase

Key to passing transition energy and on to a brief world record 25 GeV

Beaten 6 months later by the 33 GeV AGS at Brookhaven

1976 SPS Startup, 400 GeV

- First fully distributed control system.
- Front end mini computers joined in a network to the control room.
- Application software written with “Nodal” interpreter.
- Operations Group taking an active role in application software development.

1983 SPS P-Pbar collider. W, Z Boson

Simon van der Meer

Carlo Rubbia

Nobel prize 1984

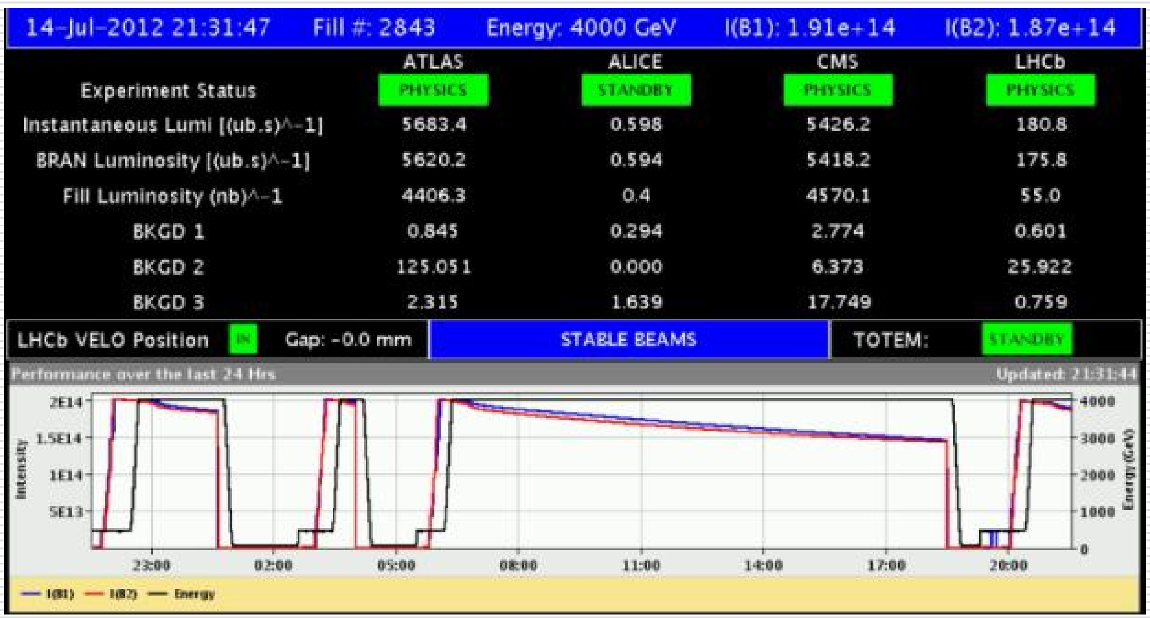
- Stochastic cooling key to producing intense antiproton beams
- Need for automatic countdown sequence of checks before extracting the precious Pbar stack
- 1988: prepare the SPS as the injector for the future Large Electron Positron collider, LEP
  - •UNIX workstations running "C" code application software
  - •High level software, physics parameter trims with full trim history

1990s LEP operation up to 200 GeV

- Huge progress in control system
- Database driven settings management, trim incorporation
- Greatly improved reproducibility of the machine

2012 LHC operation at 4 TeV / beam

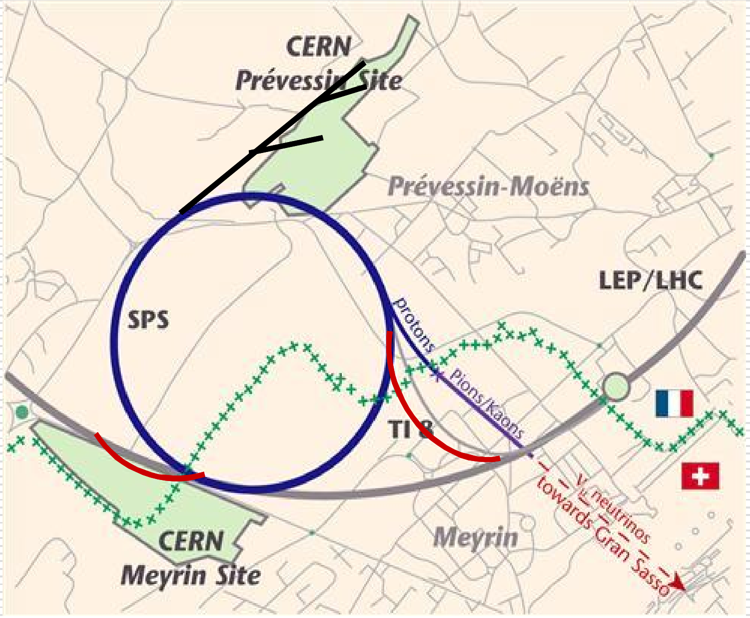
- Intensities ~$4x10^{14}$ @ 4TeV. Automation tools essential for safe beam control and fast turnaround between physics fills.
- Big advances in computing power and application software by now written in Java language.
- Well established sequence of tasks to drive the machine via Sequencer tool.

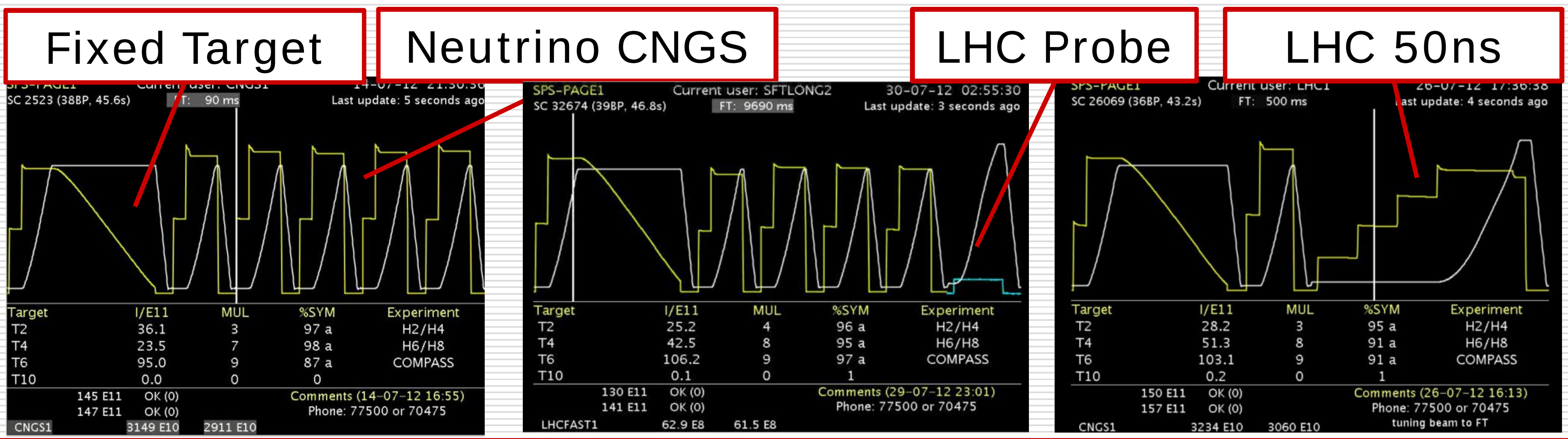


Achieve 10 fb^{-1} Integrated luminosity by 4th August 2012

Automation today in the SPS

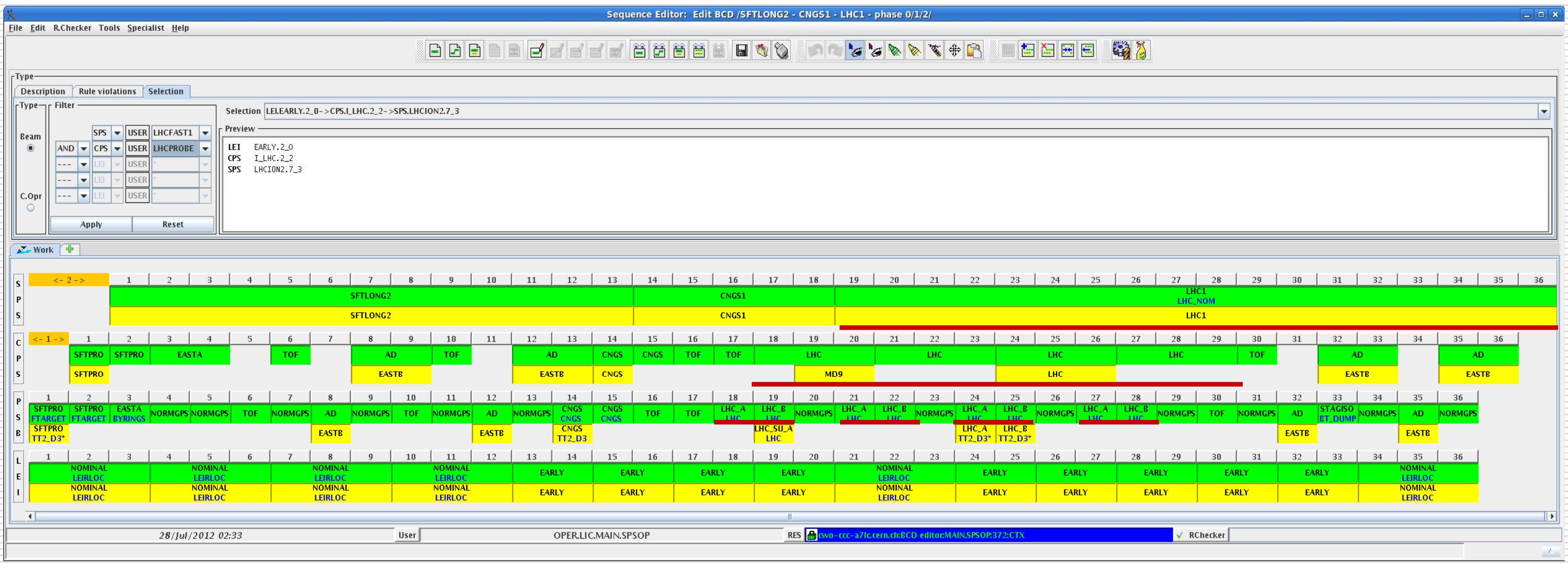
- SPS providing beams to many users
  - Fixed Target, Neutrino, various MD cycles, beams to LHC
- Need for frequent and rapid cycle changes (LHC fills).
- Tools to quickly check and optimize beams.





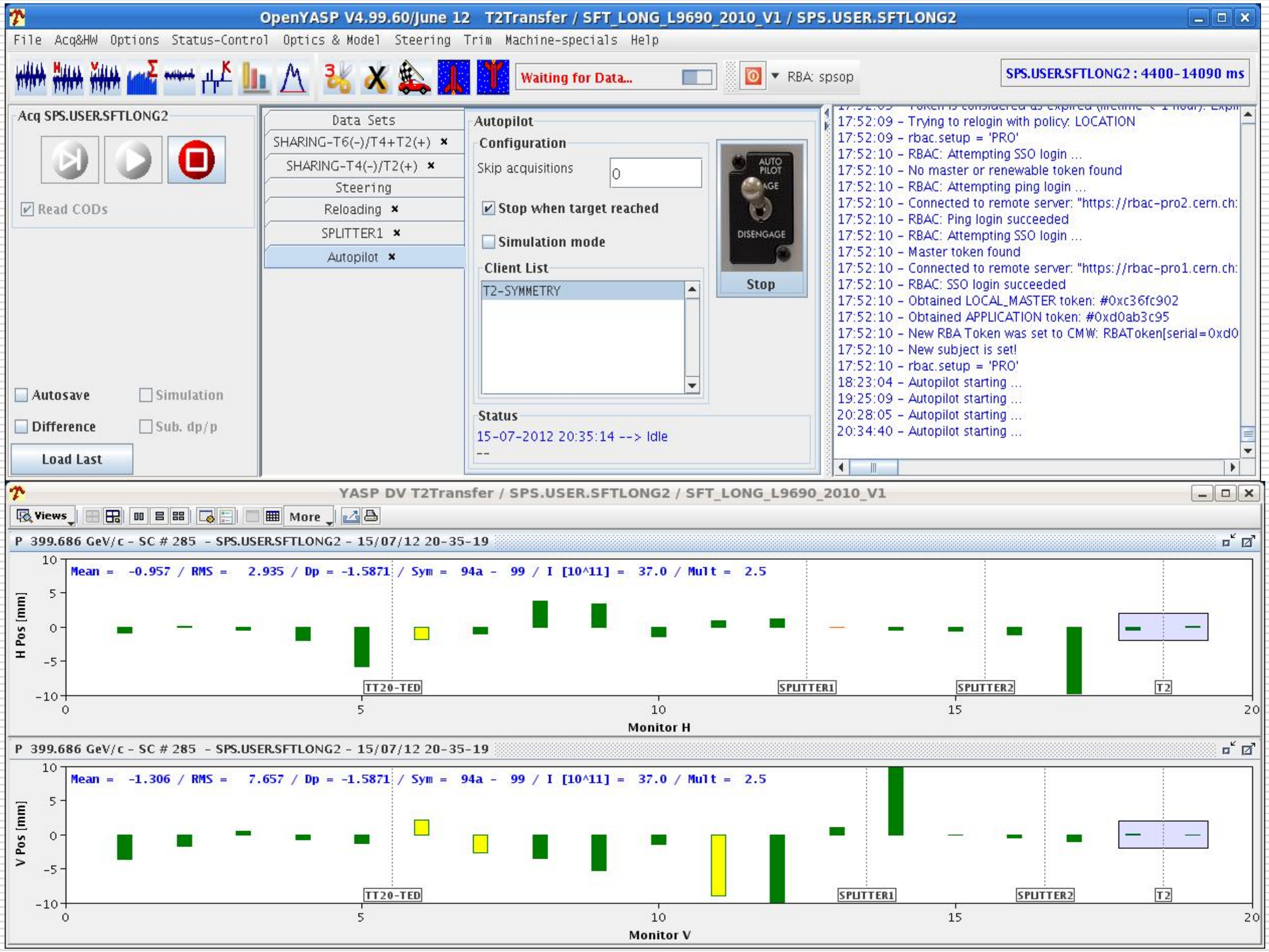
Injector Chain: Cycle Management

- Allows rapid cycle editing through timing tables
- All machines linked together through same timing system
- Around 30 cycles resident in front end, ready to be “played”
- 20 years ago, an SPS cycle change would take at least 2 hours



SPS: Automatic Steering (Autopilot)

- Automatic steering of beam on fixed target
- Injection oscillations
- Convenient but may erode operator ability to make a fully manual transfer line steering



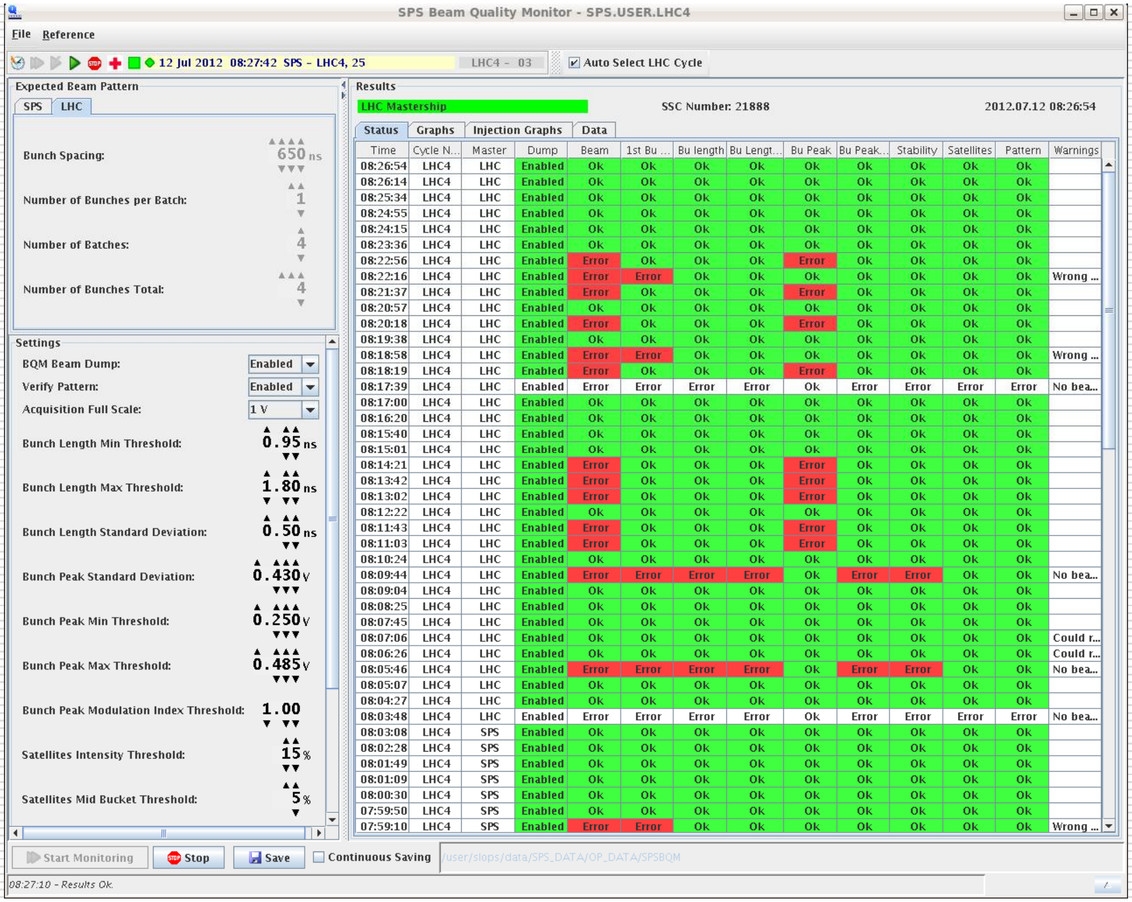
SPS: Beam Quality Monitor

- Check of key beam parameters before extraction to LHC

- Check on batches of up to 144 bunches

- Avoids bad quality beam reaching the LHC

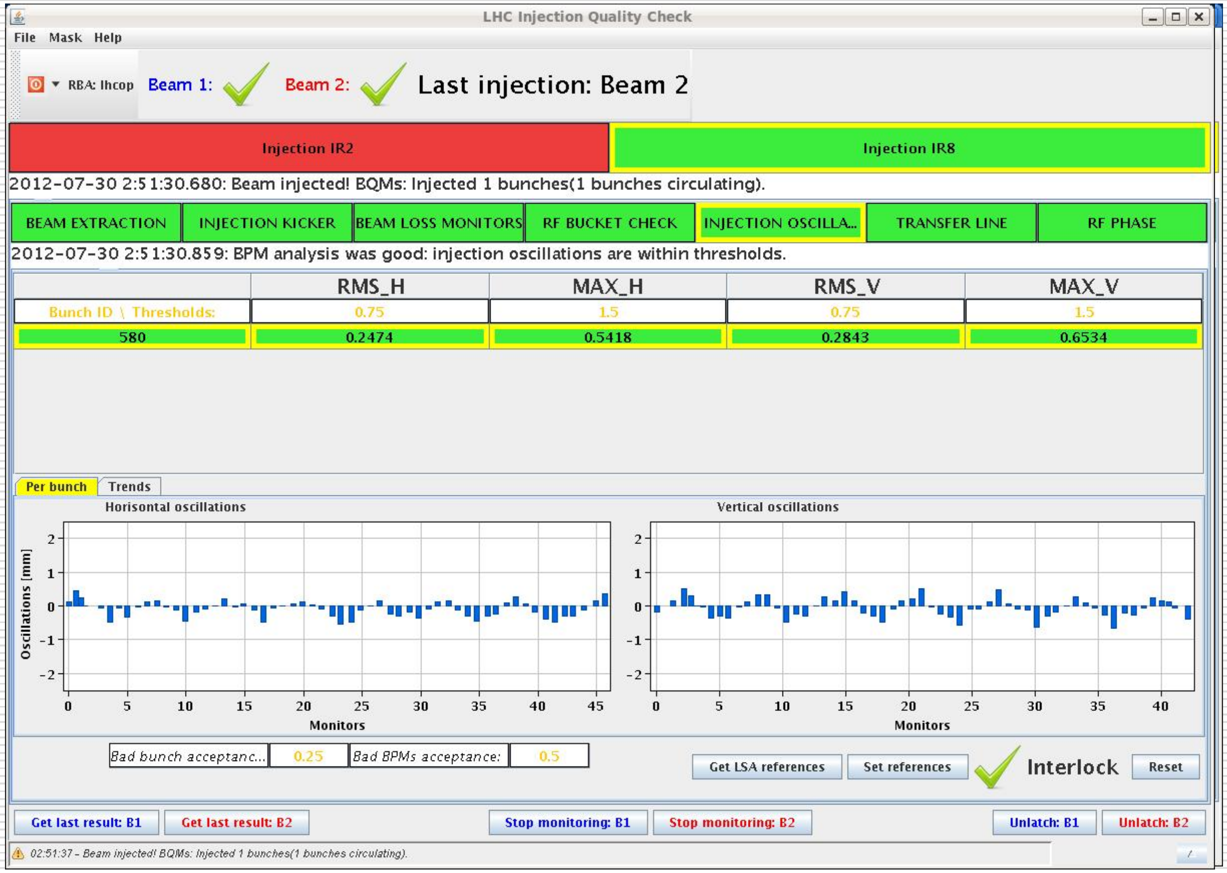
- Important fixed display snapshot of each extraction



LHC Injection Quality Check

2x10¹³ per batch @ 450 GeV from SPS

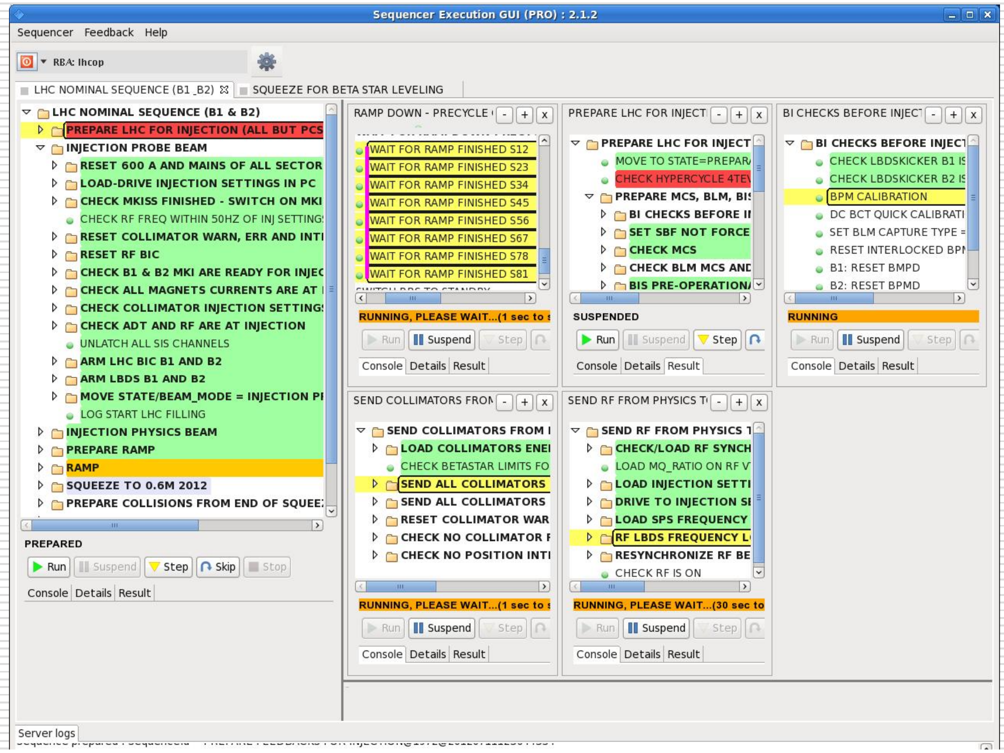
Automatic check of each batch of beam as it is injected



- Kicker pulse
- Beam loss monitors
- RF Bucket and phase check
- Injection oscillations and transfer line beam position

The LHC Sequencer

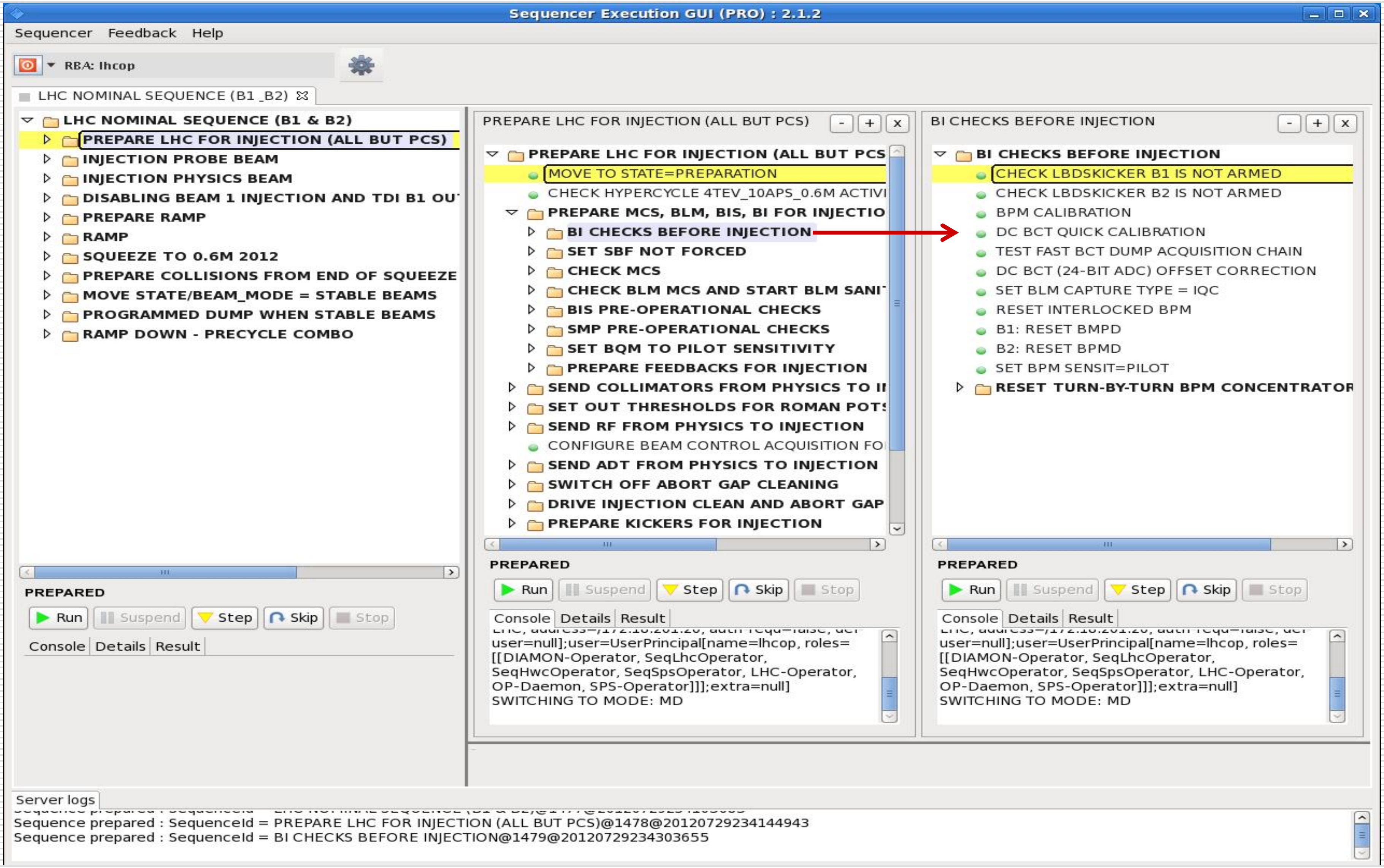
- Drive machine through a clear predefined set of sequences.
- Allows for parallel task execution.
- Can run sequences automatically, or manually step through.



•Clear execution status and error reporting.

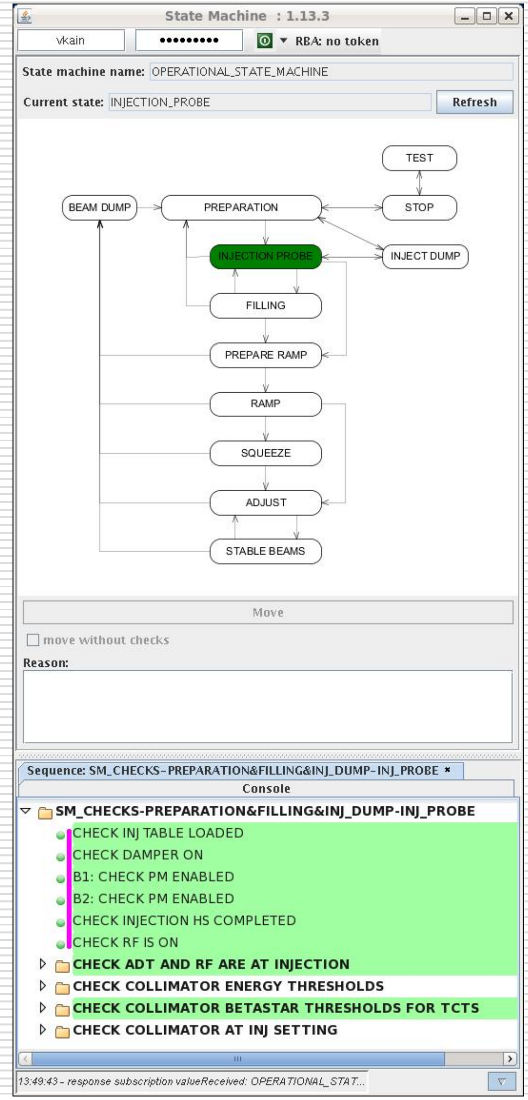
•Sequences fully maintained by operations group. Convenient sequence editing tool.

The LHC Sequencer



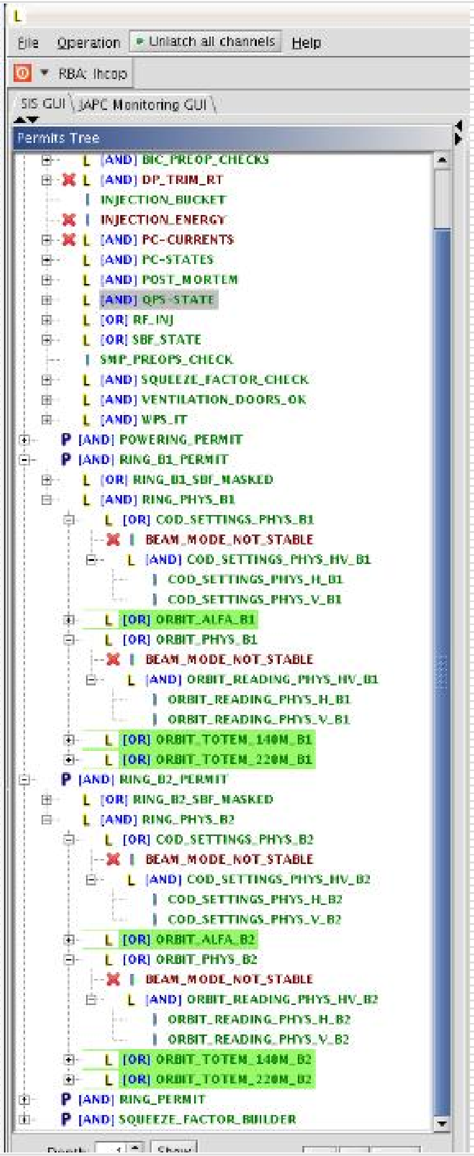
LHC: The State Machine

- Checks that all mandatory tasks have been performed at key break-points in the sequence
- Gives "green light" before proceeding to a new BEAM MODE
- Handshake with experiments

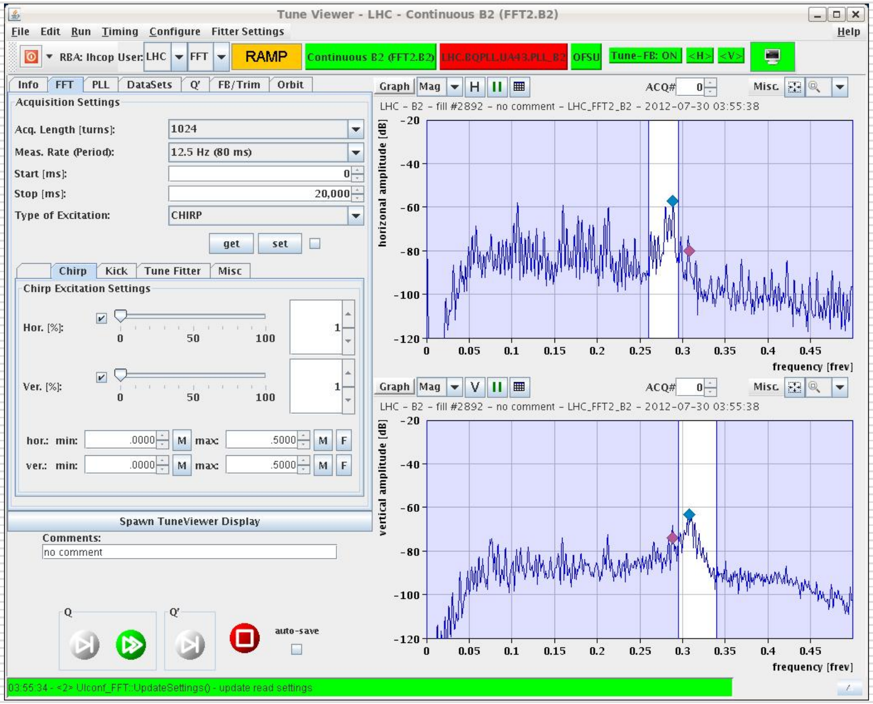


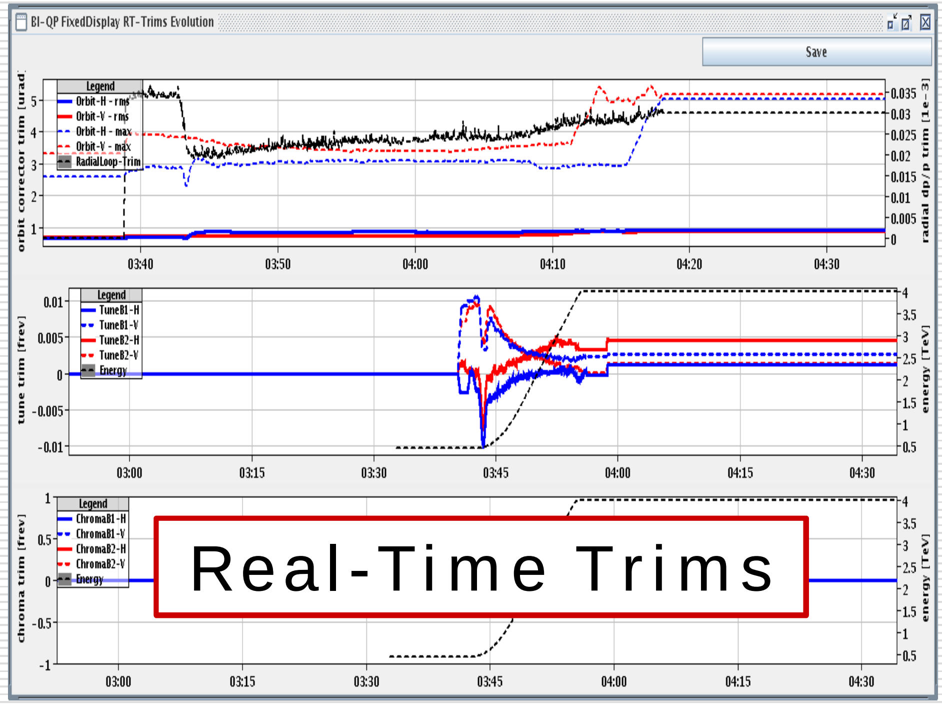
LHC Software interlock + Announcer

- Software surveillance and interlock on machine critical systems and states.
- Latches an interlock beam dump or injection kicker inhibit.
- Compliments hard wired beam interlocks.
- Same system in both SPS and LHC.
- The Announcer is separate system based on the same software (separate logic tree).
- Monitors various systems to announce warning messages according to equipment state.



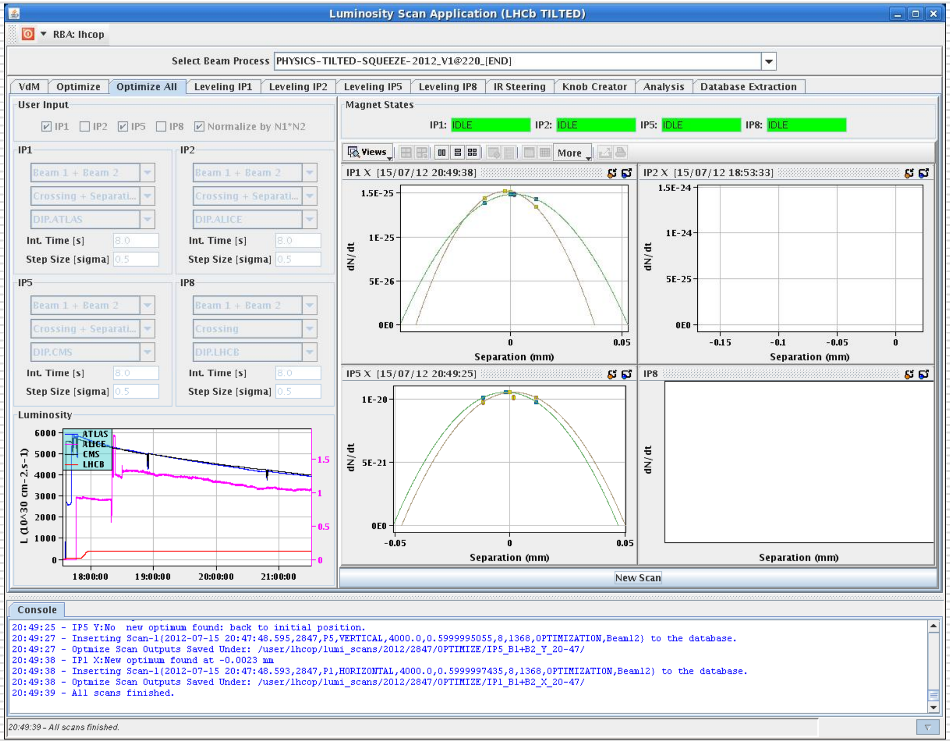
LHC Tune Feedback





- Tune (and orbit) feedback essential on LHC ramp
- Care needed to achieve a reliable measurement
- Real-time trims need to be checked carefully and end ramp

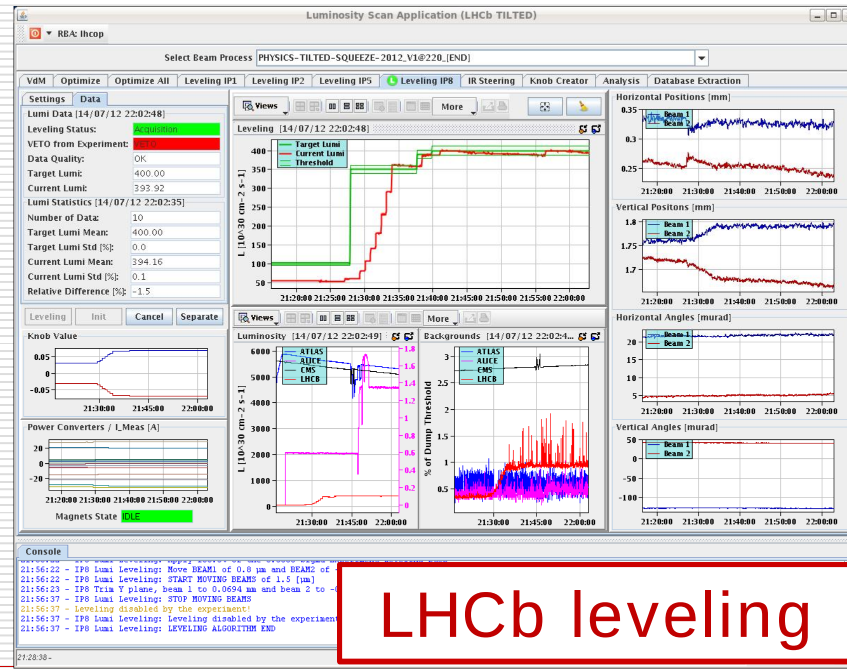
LHC Luminosity scan and leveling



Automatic process to quickly optimize collisions before declaring

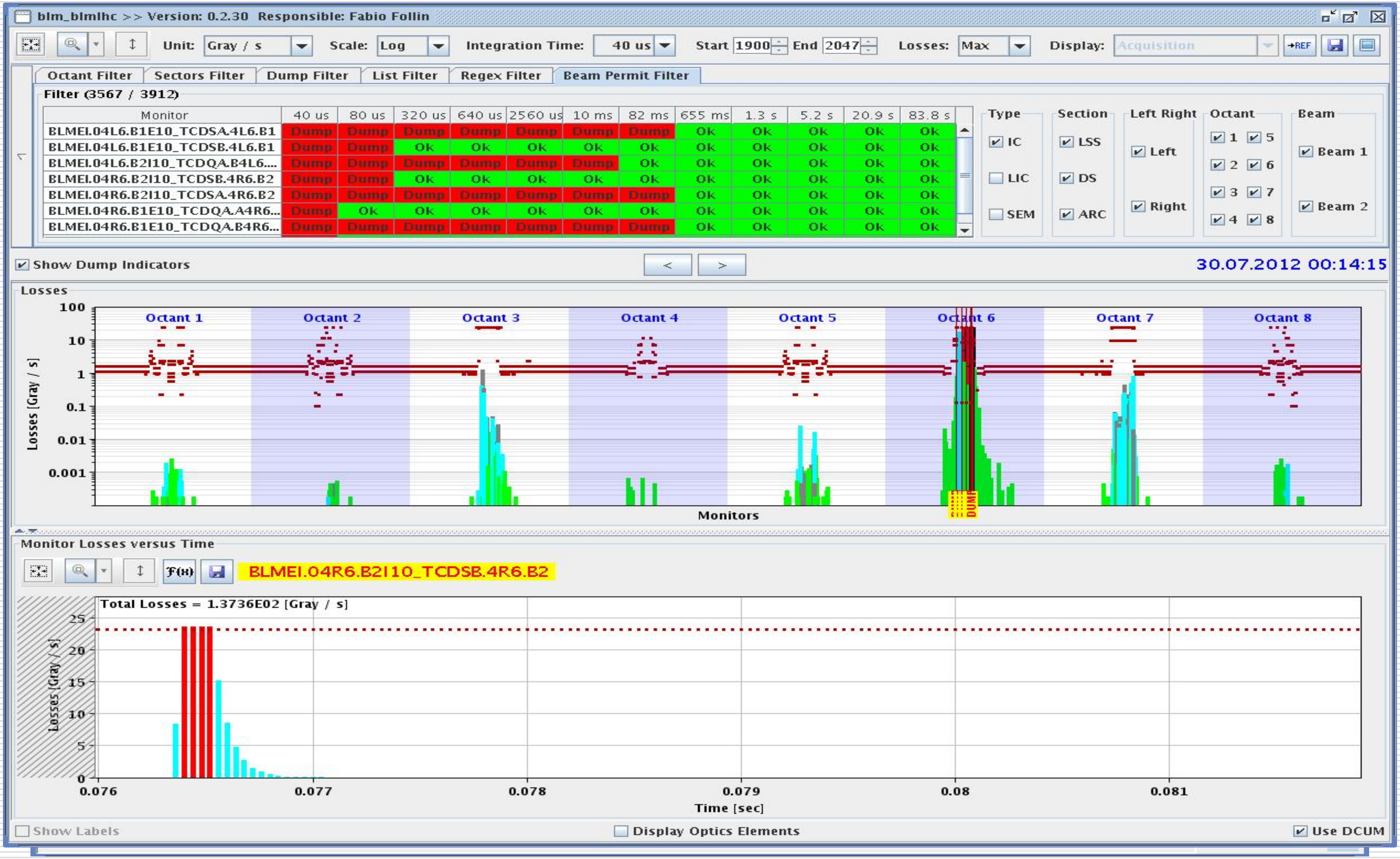
** Stable Beams **

Lower luminosity experiments require automatic “leveling” to limit their luminosity within a certain range



LHCb leveling

LHC: Post mortem viewer



Coping with Automation

- Train new operators on beams where they have freedom to make trims and optimize
- Involve crews in non-standard operations and MD studies (which involve switching back to manual operation) where ever possible
- Make crews the stakeholders in automation processes. Software development and sequence maintenance
- Avoid “Black Box” systems.
  Provide a display and interface

Conclusions

- Automation today in the SPS and LHC has evolved over many years through the experience gained from various accelerator projects, and made possible by technical advances in computer controls.
- Ever more ambitious and technical accelerator projects require a larger degree of automation to operate safely and efficiently.
- Operator workload today implies a higher degree of *multi-tasking*. A larger number of tasks must be performed both quickly and efficiently.
- Operations should also be involved in automation process development and maintenance.
- Handling intense beams at high energy in the LHC leave no room for *operator error*. Automation becomes an imperative.

Thanks for your attention!