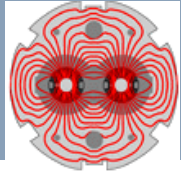
BIS operational experience in a pulsed machine and reliability aspects

the SPS case

J. Wenninger / BE-OP-LHC

BIS at the SPS

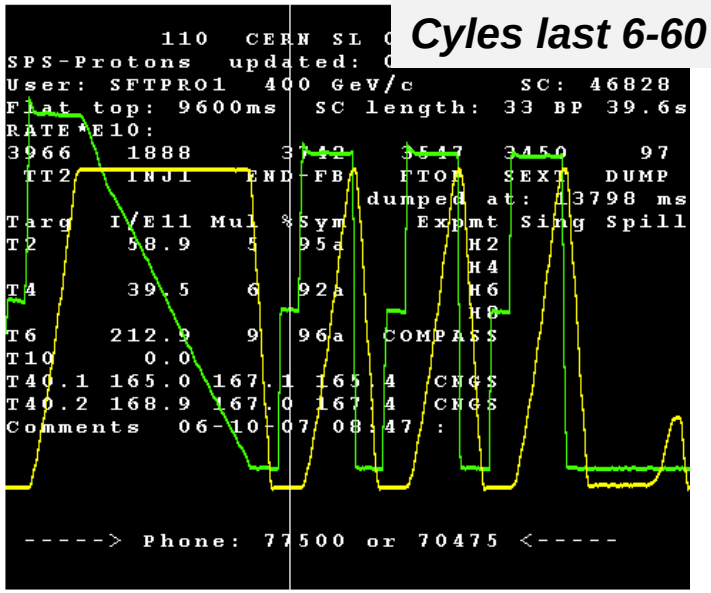


- The initial BIS was foreseen for the LHC – a collider with a slow cycle of many hours.
  - *Infrequent beam dumps with ample time to diagnose interlocks, rearm the interlock system etc.*
- During the period when the LHC BIS was designed (early 2000's) work was initiated to transform the Super Proton Synchrotron (SPS) into a much more flexible machine, able to safely provide beams to various destinations and change the beam mixture on the time scale of a minute or so.
  - *The core control system and many 'auxiliary' systems were not flexible enough to rapidly switch mode and beams.*
    - One of those systems was the interlock system.
- The SPS requirements triggered a study to investigate the possibility to reuse or adapt the future LHC BIS for the SPS.

SPS

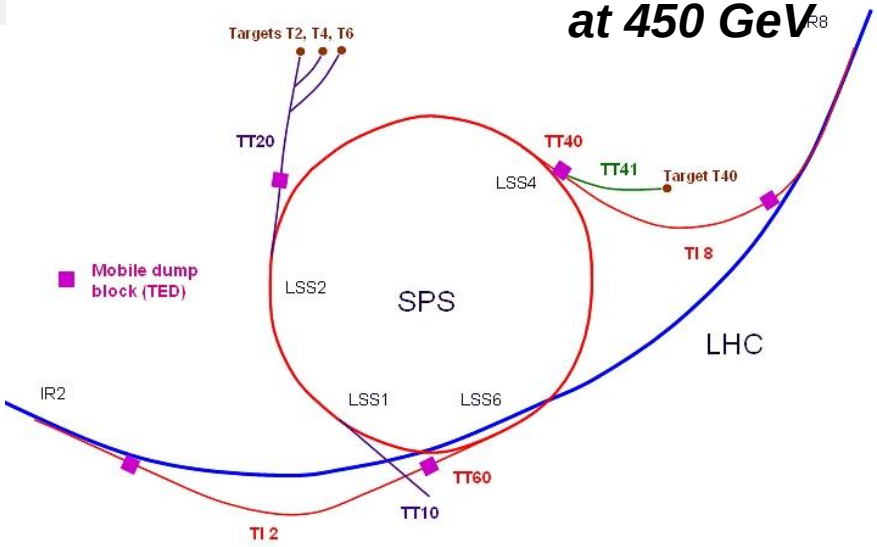
- The Super Proton Synchrotron (SPS) is a 6.7 km long accelerator, injector for the LHC.
  - *In operation since ~1976.*
- In the period 2006-now, it provided beams (protons & ions) to:
  - *The 2 LHC rings (2 extractions),*
  - *The CNGS (CERN Neutrino to Gran Sasso) target,*
  - *The slow extraction experiments,*
  - *The HiRadMat material test facility.*

Typical SPS efficiency ~80%



Cyles last 6-60 s

Stored energy ~3 MJ at 450 GeV



BIS at SPS - outcome

- The outcome:

EUROPEAN LABORATORY FOR PARTICLE PHYSICS
CERN — A&B DIVISION

CERN-AB-2003-010-OP

Architecture of the SPS Beam and Extraction Interlock Systems

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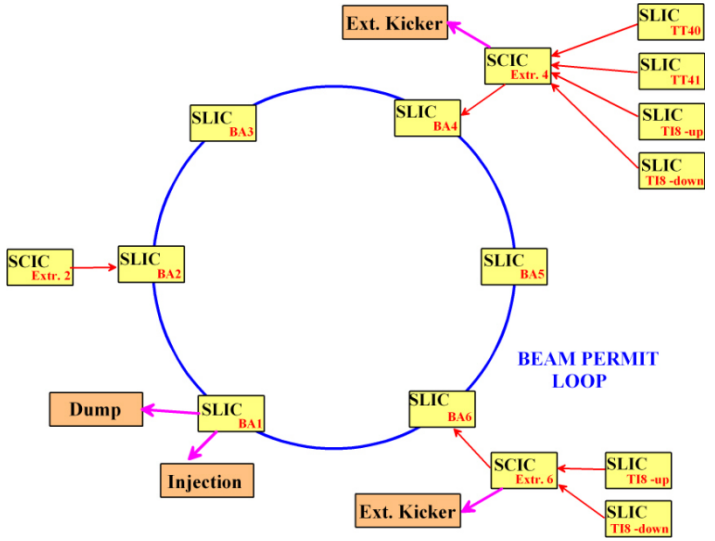
Abstract

For the machine start-up in 2007, the SPS must deliver beams for fixed target experiments, to the LHC and for the neutrino beam to Gran Sasso with the highest possible efficiency. Fast changes of the SPS cycle will be required, which has many implications for the SPS control system. In particular the existing software and hardware interlock systems that protect the SPS machine against beam induced damage due to failures must be upgraded. This report presents the requirements and architecture of the new hardware interlock systems.

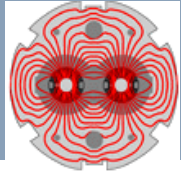
Architecture - all ingredients of current SPS BIS are present.



SLIC (SPS Local Interlock Controller) is now a standard BIC.

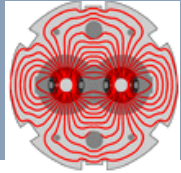
- Decision to use the LHC BIS at the SPS: first controllers (BICs) were installed in 2006 in the SPS → became a test-bed for the LHC BIC/BIS.
  - *Within 2 years the SPS was equipped with new BIS systems.*

Interlock systems at SPS



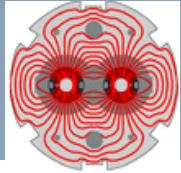
- The SPS has two '**types**' of beam interlock systems.
- The main ring system is similar to the LHC – a permit loop with 6 BICs that acts on a beam dump.
  - *One loop for one beam.*
- The fast extraction (less than one turn [23 us]) interlock systems act on extraction kickers (permit to fire – kick the beam into the transfer line).
  - *They protect the beam transfer path to the destination.*
  - *Permit only when all interlocks associated to the path are TRUE.*
  - *If the permit is not given, the beam remains in the machine and is dumped on the ring beam dump (see above).*
  - *Very similar to a LINAC (but the energy does not change !).*
- The slow extraction is very poorly protected - can only dump the beam in the ring (not a single 'actuator' that can be stopped).

MP is of course not just the BIS



- The BIS provides the interface between clients (interlock providers) and the kickers (dump or extraction).
- The overall machine protection quality depends evidently also on the clients and on the actuators / kickers.
  - *Coverage of failures,*
  - *Reliability and safety of the systems.*
- At the SPS, the protection of the ring and the older transfers is far from optimal. There are a number of known protection loopholes – there are incidents every few years (accepted by the hierarchy…).
  - *Beam loss monitor system for example is too slow (reaction time). A new system is foreseen, but only in a few years from now !*
  - *Between 2006-2013: 2 incidents with damage, 2 near misses.*
- Only the transfers to LHC and to CNGS (stopped) have excellent protection systems with complete failure coverage and appropriate reaction times – designed after 2000 together with LHC.
  - *No incidents in those lines.*

Pulsing or not – just the same?

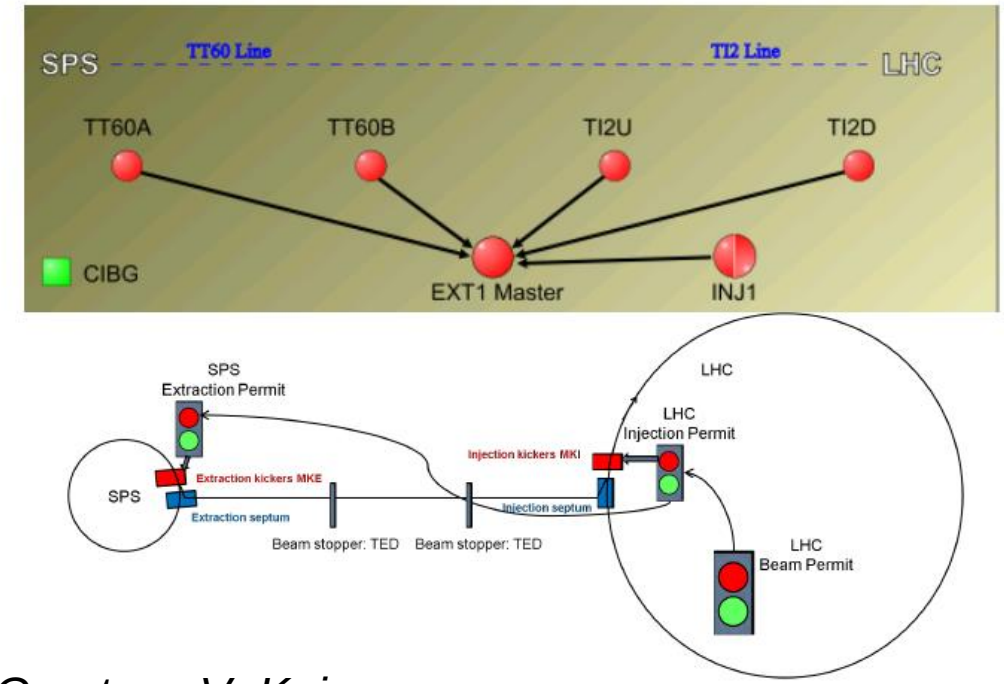


- The hardware of the SPS BIS is essentially the same as the one of the LHC.
- Some differences:
  - *As soon as all interlocks are cleared (inputs back to TRUE) the BIS loop is re-armed automatically to avoid blocking beams that are not affected by a fault (e.g. beam loss).*
    - At the LHC the system is manually re-armed.
  - *The SBF is forced to TRUE for the SPS ring – accepted risk.*
- The pulsing environment is very dynamic:
  - *Different beams every few seconds,*
  - *For extractions the permit given to the kickers lasts ~ 4 milliseconds.*
    - Need a fast post-mortem (end of cycle) analysis as diagnostics.
- The conditions for extractions are more complex than just AND gates – involves movable dumps & beam intensities.

Principle of transfer protection

- Transfer from one machine to another or from a machine to a target are conceptually similar.
- Interlocks are grouped by geographical regions (logical segments of lines or accelerators) – merged at the level of a master controller.

Interlocking hierarchy: LHC ➔ LHC Injection ➔ SPS Extraction

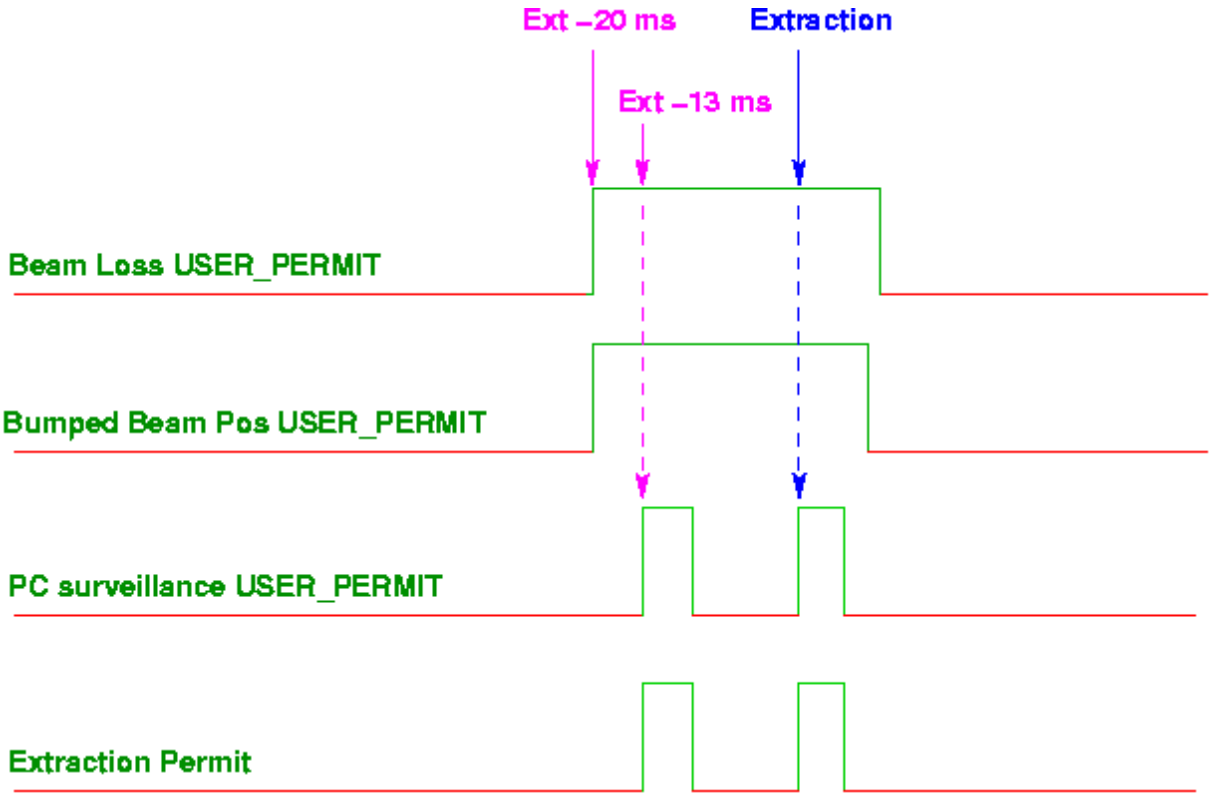


Concept for SPS to LHC transfer protection

Courtesy V. Kain

Extraction permit for LHC - timing

- By the nature of the client inputs, where the conditions are evaluated as close as possible to the time of extraction → the BIS signal to the extraction kickers is very short !

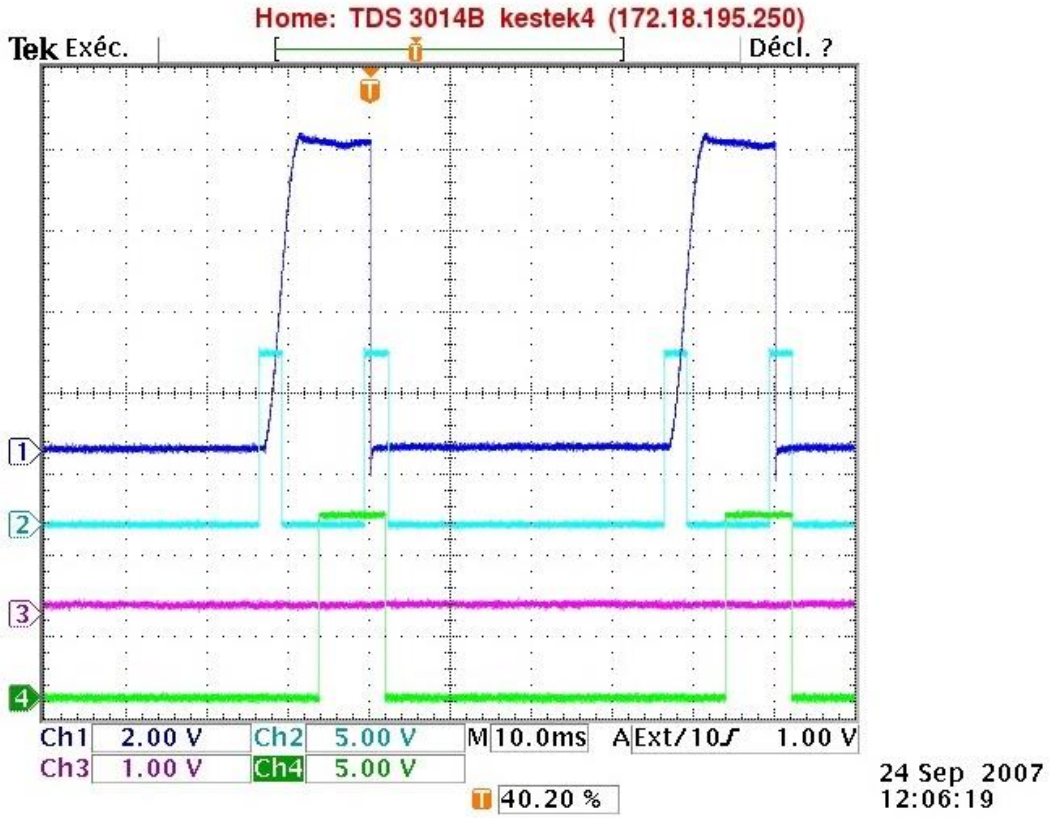


First pulse charges the kicker, the second triggers the current pulse

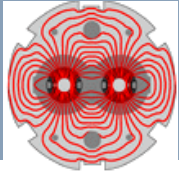
Pulse width ~3-4 ms, 2 pulses spaced by 13 ms

BIS & Kickers

- Signal details for the extraction kickers.
  - *PFN: Pulse Forming Networks (bank of capacitors & inductances to shape the magnet pulse.*
  - *BETS: Beam Energy Tracking System surveying the beam energy (main magnet current) and the voltage on the PFNs.*

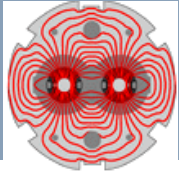


Intermittent failure handling



- The SPS handles multiple beams in parallel and beam loss leading to a dump can occur on one beam and not on the others.
  - *Applies to other beam observables.*
- At the level of the ring such interlocks are reset automatically after the cycle – latched only after 3 consecutive losses on the same beam.
  - *Beam loss is frequent at injection – beam parameters from the injectors !!*
- For the transfer lines such interlocks are latched – require manual reset by the operator.
  - *Transfer are very clean, beam loss triggering an interlock was only observed*
    - twice in 5 years on CNGS beams,
    - never on a LHC beam.
  - *So we can afford to be strict without machine availability issue.*

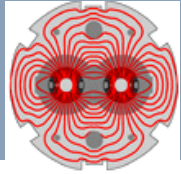
Some statistics – CNGS beam



Year	No. extractions (10^6)	Intensity on T40 (10^{19} p)
2008	0.99	1.78
2009	1.82	3.53
2010	2.14	4.04
2011	2.55	4.84
2012	2.40	3.80
Sum	9.90	17.9

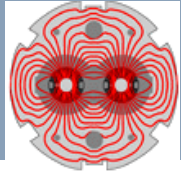
- Close to 10 million beam transfers without damage.
  - *One near miss during an intervention (late evening repair) on the extraction kicker internal protection → combined mistake of the expert and of the operation team (try right away with high intensity !).*

BIS hardware & reliability



- Operational experience with the current BIS hardware is excellent. Interventions and failures are rare – I cannot remember any.
  - *Issues with the BIS account for 'negligible downtime at the SPS.*

Supervision



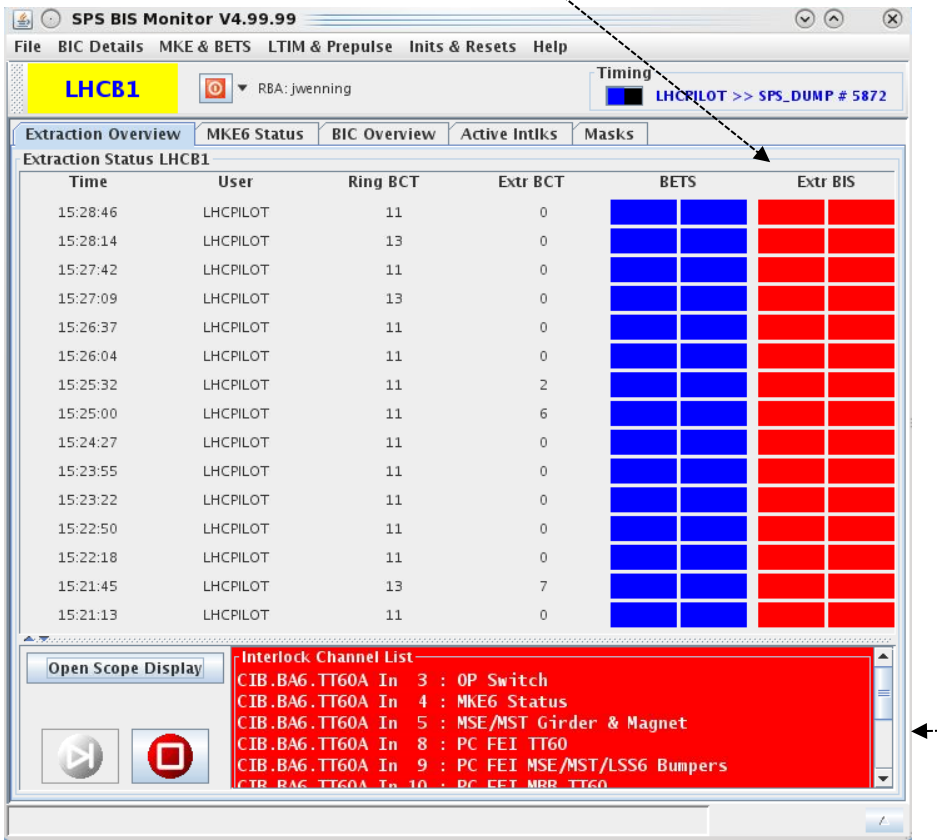
- The standard BIC/BIS supervision, based on a device based approach, proved insufficient for proper diagnostics in operation.
  - *To slow, to complicated to navigate across the screens and plots – want simple diagnostics within second after end of a cycle.*

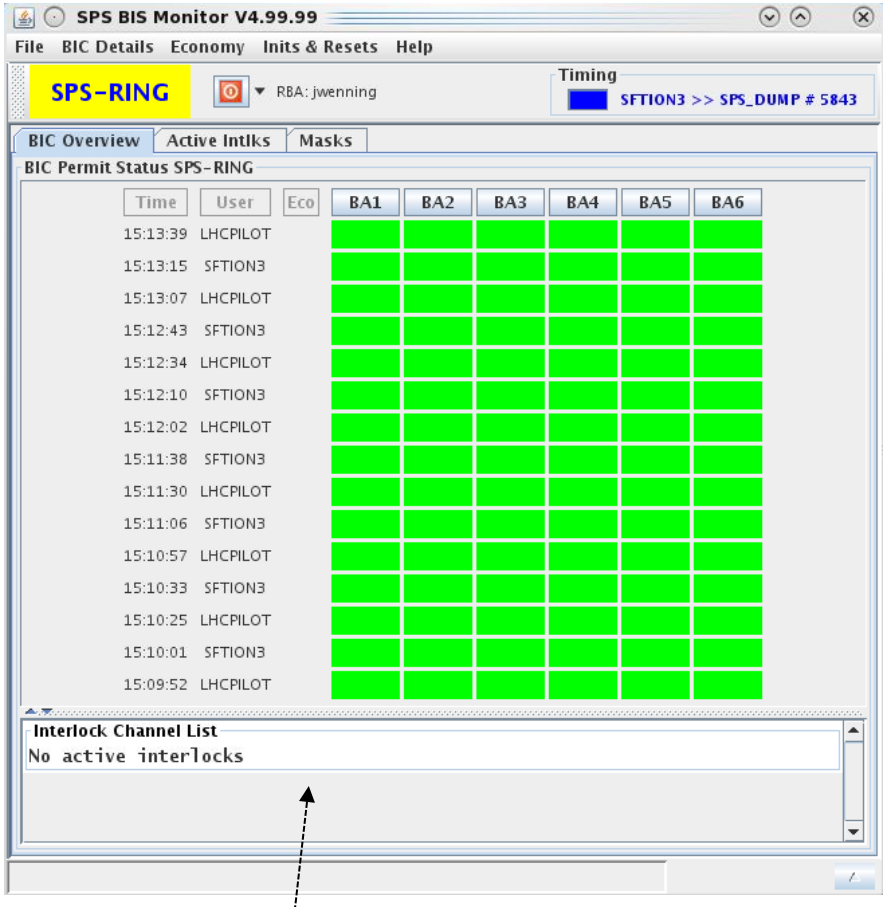
- Dedicated diagnostics software was therefore build by operation for operation with a system approach (system = one extraction or the ring) – top to bottom philosophy !
  - *The same information available in the standard BIS software, but organized to provide a simple view for operation crews.*

Monitoring SW

- Very compact and simple overview for ring and extraction.
- 4 systems fit on one screen.
- History of the last 16 cycles.
  - *With filters on types.*

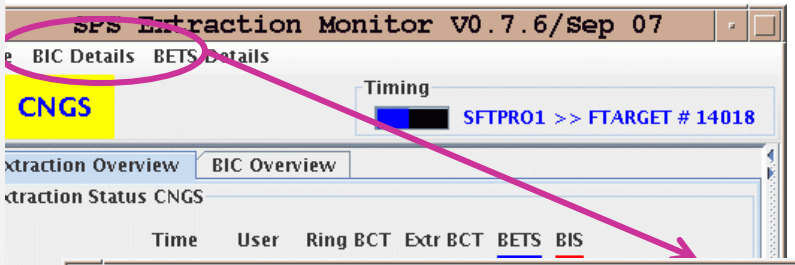
Extraction permit





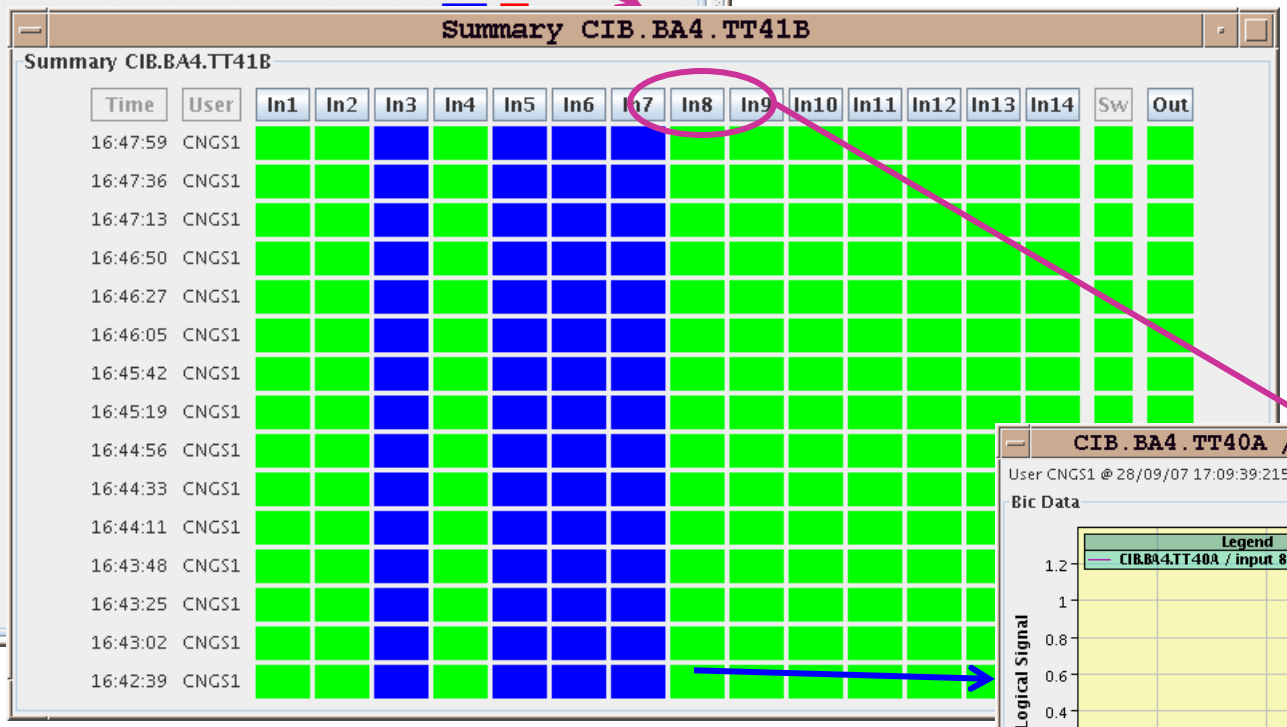
Active interlocks

Details – when they are needed

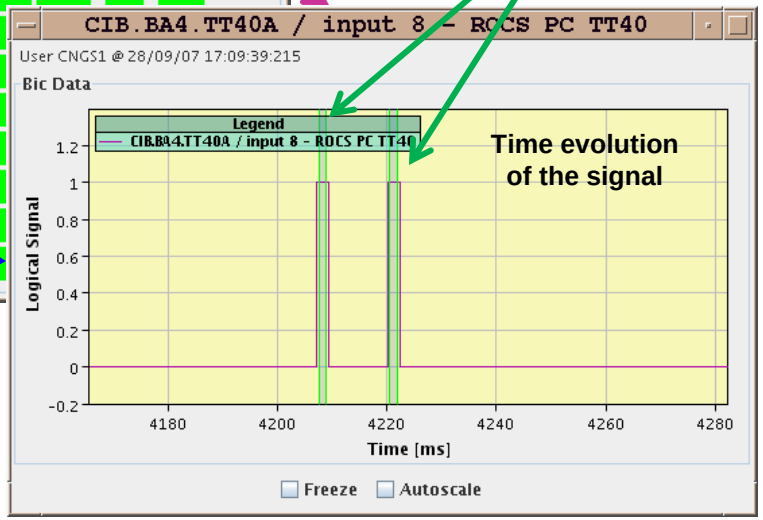


For the extractions the software knows the short windows where the inputs must be TRUE to fire the kickers

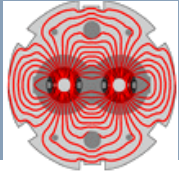
BIC detail



The green/shadowed regions indicate where the signal must be = 1 (TRUE) to be OK (and to give status = green !



Software Interlock System



- Historically the SPS always had many interlocks in software that were applied (summary) to the beam dump once per cycle.
- This concept was modernized and better embedded into the control system (JAVA server) with the 2005 renovation.
- Currently the majority of interlock tests at the SPS are performed in this system – evaluation once per beam cycle (end).
  - *Can handle complex logic involving different system that do not communicate by HW.*
  - *Quick to implement as a fix to cover unexpected issues.*
  - *Anticipation of dangerous configurations of parameters – 'big brother'.*
- The same system exists at the LHC, with 2000 tests evaluated in the SIS software layers.