OPERATIONAL EXPERIENCE WITH THE LHC SOFTWARE INTERLOCK SYSTEM

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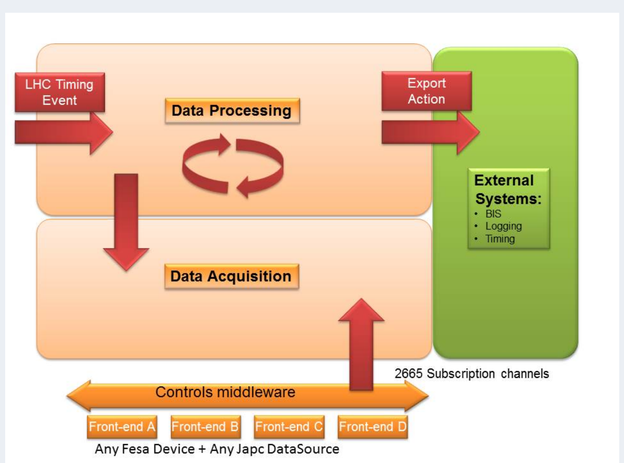
INTRODUCTION

- The Large Hadron Collider (LHC) interlocking strategy rely on the Beam Interlock System (BIS):
  - To prevent injecting or dump the beam whenever a failure of equipment can provoke damage
  - Entirely Hardware implementation
  - Highly reliable
- As a complement of the BIS, the Software Interlock System (SIS) provides further protection
  - by surveying and analyzing the state of various key equipment:
  - All software
  - Highly reliable configurable, fast implementation

SIS ARCHITECTURE

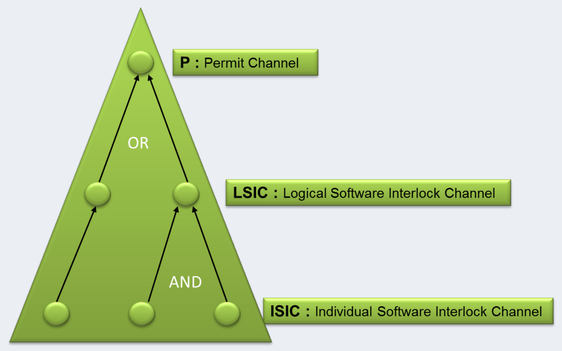
SIS has a layered architecture [1] reflecting the two major tasks of the system, Data Acquisition (2656 subscriptions for LHC) and Data processing (definition of the trees):

- JAVA based software using modern JEE technologies like Spring, RMI, JMS, XML, Velocity scripting.
- Configuration files in XML with the use of Groovy scripting language for **easy and fast configuration**
- Export actions and more complicated logic for data transformation usually stored as Java classes
- Interlock trees evaluated every 2 seconds, triggered from the 1 s clock of LHC timing system.



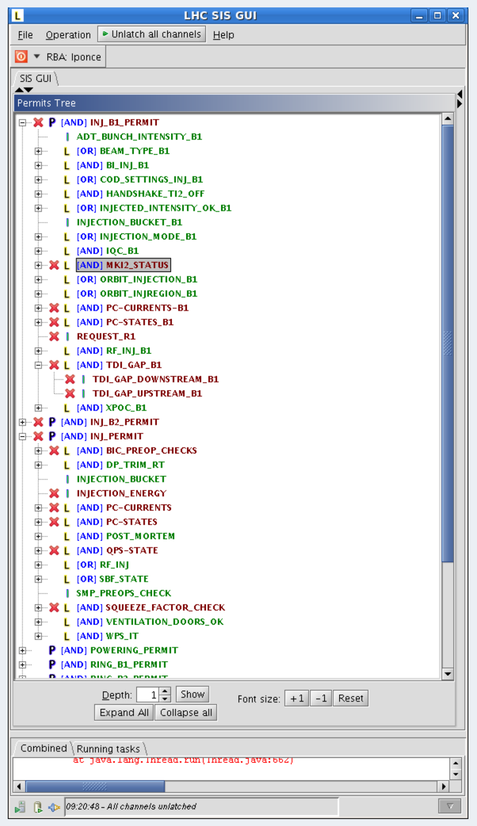
PERMIT TREE STRUCTURE

- The top of the tree is called a "software permit"
  - the fundamental level (ISIC) converts a state into a logical state (TRUE/FALSE)
  - logical states are grouped into intermediate level (LSIC) with OR/AND logic



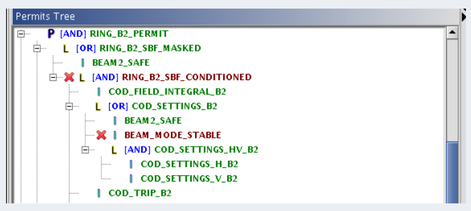
- LHC SIS handles 2665 device/parameter subscriptions equivalent to 5500 checks grouped into 7 permits:
  - **Injection permits** exported to the Beam Interlock Controller to inhibit the beam injection.
  - **Ring permits** exported to the Beam Interlock Controller to inhibit dump the beam .
  - **Powering permit** exported to the Powering Interlock Controller to abort the magnet powering

SIS Swing GUI: Basic functionality will be extended for next run in order to improve interaction with operation



INTERLOCK MASKING

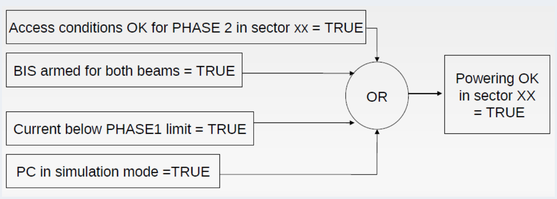
- Masking a channel means overriding individual ISIC or LSIC state to TRUE.
  - Permit signals are not allowed to be masked.
  - Masking is done from the SIS GUI by operators using a role based access control framework to define rights
  - **A mask is always active independent of beam conditions**.
- To make the masking dependent on beam conditions, a ISIC (i.e beam intensity or beam energy) test is added with a OR logic to the channel that should be masked:



- Combination (OR logic) of the 60 A power converter settings LSIC with the BEAM_SAFE ISIC (intensity) and the BEAM_MODE_STABLE ISIC (collision period in the beam cycle): Permit is true as long as the energy is true.

LHC PERMIT EXAMPLES

- Orbit and Corrector Orbit Dipole (CODs) interlocking in Ring Permit:
  - to limit the global orbit excursions of the beams to prevent beam losses and catch un-detected orbit bumps
  - compare dynamically settings of each COD and the reading of each Beam Position Monitor (BPM) with reference/tolerance stored in the LHC settings database (LSA) [2].
  - condition the reference with beam mode or energy within the AND/OR logic.
- Powering permit:
  - implement a link between the powering system and the access system (not foreseen in the BIS) for personal protection to enforce an operational procedure [3].
  - Initially used during the powering test campaign, SIS solution proved to be very reliable and has been kept active during beam operation in combination through a OR logic with the highly reliable signal from the Access Safety System.



SIS PERFORMANCE AND AVAILABILITY

- LHC SIS core runs on dedicate HP server equipped with a CTRI timing card.
- Since the beginning of the operation in 2008, few crashes of the SPS server observed only during the 2009-2010 maintenance period (no beam).
  - problem traced back to a concurrency problem in the timing library
- For the LHC, post mortem (PM) file is produced for each beam abort, tracing first trigger of the beam dump
  - for the 2012 operation period: 77 dumps are flagged to be due to LHC SIS
  - All events are real interlocking conditions, see Table 1
- **none of the dumps are due to SIS failures, the programmed logic was always followed**.

Table : Interlocks channels leading to dump.

SIS DUMP cause	Ratio
Communication problem	20%
Orbit feedback issues	20%
Power converter faults	15%
Beam Position Measurements	10%
Beam Loss Monitors High Voltage	10%
Others (wrong settings, forgotten masks)	25%

AT A GLANCE

- SIS is a reliable solution for different classes of interlocks
  - for injection interlocks: reliability less critical
  - complex interlocks involving multiple system
  - Interlocks for distributed systems like orbit
  - quick solutions for un-expected situations
- Even if it is all software, availability during last years is impressive
- Few interlocks will be moved to hardware after shutdown
- But even more software will come

Some References

[1] J. Wozniak et al., "Software Interlock System", ICALEPCS'07, Knoxville, October 2007, WPPB03, p. 403.

[2] D. Jacquet et al., "LSA - the High Level Application Software of the LHC - and Its Performance During the First Three Years of Operation", ICALEPCS'13, San Francisco 2013, THPPC058.

[3] M. Gruwe et al.,"Access restrictions in LHC and SPS during LHC powering Phase II ", LHC Project Document LHC-OP-OSP-0016, EDMS Number 1010617.