SYSTEM'S PERFORMANCES IN BI

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Abstract

In this talk, the dependability of CERN's Beam Instrumentation (BI) in 2017 is presented. All faults which contributed to LHC downtime are analysed, categorised and compared to previous years to isolate recurrent failures and evaluate trends. Special attention is given to the Beam Loss Monitoring system and its System Sanity Checks which was the highest contribution to the BI downtime in 2017. Finally, actions taken to remedy the situation as well as on-going reliability analysis and upgrade efforts to improve the overall performance in the future are discussed.

INTRODUCTION

In 2017, BI systems reduced their downtime both in absolute numbers as well as when normalised per operational day. In comparison to the total 650h of LHC downtime in 2017, BI systems caused 32h. This is distributed mainly amongst three systems, from which the Beam Loss Monitoring (BLM) system is responsible for 18 faults and 30h of downtime, i.e. 94% of total availability loss, whilst the Beam Position Monitor (BPM) and the Beam Current Transformer (BCT) systems account for 3% and 1% respectively. Since the BPM and BCT systems have achieved and maintained sufficiently high availability, the focus for future improvements is set to the BLM system.

In the next chapters, a fault analysis breaks down the issues and illustrates the individual impact and relation of a fault. The faults are split in four main categories and the performance is analysed with data from two different tools, i.e. the Accelerator Fault Tracker (AFT) [1] and the section's internal issue tracking. To recognize trends and analyse the performance, the data are tracked back since 2012.

Special attention is given to single faults with a high availability impact as well as the luminosity impact of different faults.

For all BI systems past upgrades and planned future efforts to enhance the performance are pointed out.

BI SYSTEMS PERFORMANCE

AFT tracks faults of the LHC systems, since 2010, which influence the operation mainly in terms of availability. With the start of the second LHC Run, the procedure to record and assign the faults have been streamlined and provides consistent data.

Observing this period only, the absolute yearly downtime of all BI systems significantly decreased year to year (see Fig. 1).

Nevertheless, when the data are normalised per day of operation, it can be seen the decrease of the downtime remains true but the step is smaller (see Fig. 2).

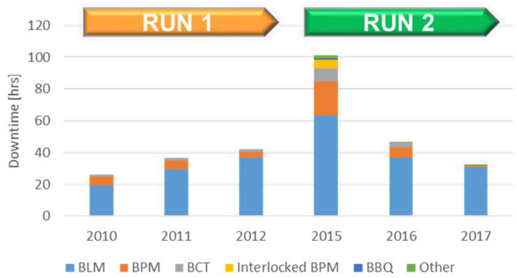

Figure 1: Raw Fault Time by System.

During 2017, the BLM system maintained the same availability level as in 2016. Because of the Extended Year-End Technical Stop, the LHC lacked 50 days of operation compared to 2016. An operational day is herein defined as a day where the storage ring was filled.

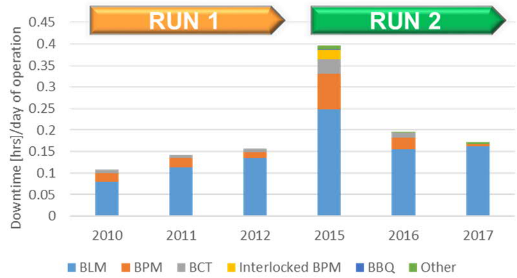

Figure 2: Normalized Raw Fault Time by System.

For the remaining BI systems, 2016 and 2017 show a large reduction on their downtime. This can safely be contributed to the effort and the targeted upgrades done.

Table 1 summarizes the major upgrades for those BI systems in preparation for the 2017 operational period:

Table 1: 2017 BI system upgrades

System	Upgrade(s)
DCCT	- Software optimisation to eliminate issues with calibration and flickering of safe beam flag - System B front end electronic modification to reduce noise level by a factor of 3
FBCT	- New digital acquisition system with enhanced measurement precision which improves the instrument availability
BPM	- Continuous analysis of "dancing BPMs" with interventions to change front-end cards - New rack monitoring system
Wire Scanner	- Split of Beam1 and Beam 2 electronics - Architecture change from LynxOS to Linux

BLM FAULTS ANALYSIS

To understand better the nature and the causes of the occurred BLM faults, a deeper analysis was performed. The faults were sorted into 13 distinct categories. In addition to the AFT as a data source, the BLM system's issue tracking complements the statistics. This more comprehensive and detailed logging serves as an additional instrument to identify degrading system parts and to be able to react earlier. Further to quantifying a fault by its availability impact, effort is put to evaluate the related luminosity impact by using an operational example. This luminosity impact in many cases seems to differ from the availability measure.

2017 Faults

The 18 BLM faults, which lead to downtime in 2017, are categorised in Table 2. The majority of downtime is assigned to the system failing the Sanity Checks [2], to one single VME power supply fail, and the SEUs on the surface reprogrammable electronics.

Table 2: Categorised AFT BLM system faults in 2017

Issue	2017			
	#	%	downtime	%
SEU (surface)	4	22%	04h 40m	15%
VME Power Supply Fail	1	6%	07h 47m	25%
Connection Lost: FESA/VME/CPU	1	6%	00h 04m	0%
HV Power Supply Drop				
HV Power Supply Noise				
Sanity Error: Communication/VME	4	22%	01h 23m	5%
Sanity Error: IC	1	6%	00h 29m	2%
Sanity Error: LIC				
Sanity Error: SEM	3	17%	13h 54m	46%
BLECF optical link issues	4	22%	02h 13m	7%
BLETC optical link issues				
Other optical link issues				
Other				
	18		1d 06h 32m	

To test the system's functionality the Sanity Checks are performed each time before filling the machine with new beams. The three events, which contributed a downtime of 14h, were caused by the degradation of the Secondary Emission Monitors (SEM) and their cabling positioned inside the dump blocks. Each of these events lasted more than 4h. Such a failure and the inability to access the location of the detectors required each time a manual reset of the tunnel acquisition card and await for the recovery period. Therefore, it was decided, and finally executed during the third intervention, to disconnect those detectors.

Another 25% of 2017's BLM downtime results from a transformer failure in one of the tunnel electronics power supply. The resolution of the issue itself is quite complex, but many other factors contributed to the 8h availability loss. Additional delays were due to the access permission by Radiation Protection, the availability of spare parts, and the event happening outside of usual working hours were more support could be available.

The four issues on the surface part of the system were spread over a total of 350 processing cards. The term Single Event Upset (SEU) is used here for any alteration in the configuration of the FPGA's firmware. This can be caused by either an impact of an ionizing particle or spurious bit flips in the device's fabric. Estimates based on the neutron fluence indicate an average of three per year to be expected for the BLM surface electronics [3]. Unfortunately, the failure data lack sufficient information to further investigate the root causes.

Previous Years Faults

To project the failures of 2017 to previous years, AFT data from the year 2012 on was extracted. In addition to this, Jira data of an already available failure analysis [4] was taken, updated and extended.

Table 3: Categorised AFT and Jira BLM system faults for the four last operational years, *2012 AFT data not fully consistent

Issue	2012		2015		2016		2017	
	AFT*	Jira	AFT	Jira	AFT	Jira	AFT	Jira
SEU (surface)	3	3	2	3	1	1	4	3
VME Power Supply Fail	1	1					1	1
Connection Lost: FESA/VME/CPU	5	6	7	7	1	1	1	2
HV Power Supply Drop		4		1				1
HV Power Supply Noise			3	5	2	2		
Sanity Error: Communication/VME	3	9	6	20	2	3	4	6
Sanity Error: IC		3	1	5			1	3
Sanity Error: LIC		6		1				
Sanity Error: SEM	5	10	5	8	4	4	3	4
BLECF optical link issues	1	7				2	4	7
BLETC optical link issues	3	11	1	1	4	9		7
Other optical link issues	2	10		12				1
Other	2		2		2			
	25	70	27	63	16	22	18	35
	1d 12h 28m		2d 15h 16m		1d 12h 36m		1d 06h 32m	

The yearly amount of AFT issues confirms the decrease until 2016. The same applies to logged Jira issues where from 2016 to 2017 more incidents occurred throughout all categories. This trend has to be monitored in the future, however the fact that all categories increased does not yet indicate wear-out of a specific system part.

Overall, the different power supplies fail at a rather constant low rate. The same applies for firmware faults on the surface. Errors due to lost connection in fact decreased their failure rate. For sanity errors, especially the SEMs at the dump block, a constant high failure rate with many Jira issues in 2012 and 2015 is registered. For the optical fibre links, which connect the tunnel to the surface electronics, showed a high failure rate at the beginning and decreased towards the end of Run 2. Since the optical links caused 17 false beam dumps during 2012, several actions were successfully performed to minimize their impact. In the framework of a big campaign during the first Long Shutdown (LS1), the tunnel and the surface installation were maintained and upgraded. This included changes to the acquisition electronics, the processing electronics and the associated firmware as well as changes of the supporting applications [4].

Availability vs Luminosity

To draw conclusions from past faults and to improve the system for the future it is essential to understand the full nature of a fault. Associated to this, it is the similarly important to be aware of the individual impact of a fault. To define such an impact on the LHC system level, availability is a useful measure.

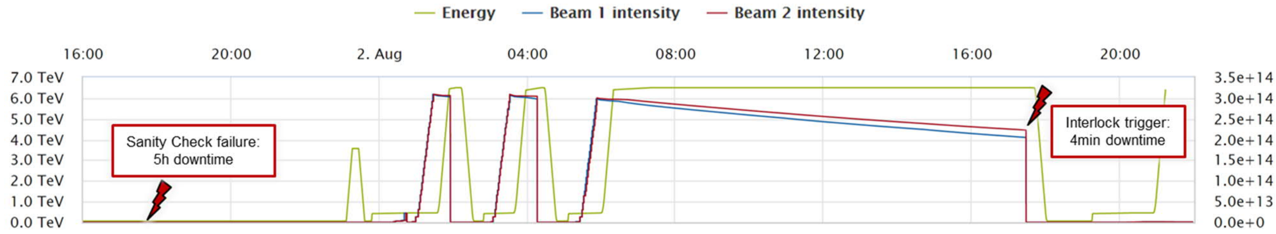

Figure 3: AFT extract of the 02.08.2017. Two distinct BLM failures with different availability and luminosity impact.

However, by only taking availability, the main output of the LHC, luminosity, cannot always be scaled proportionally. Especially for the extensive BLM system additional fault information such as if a fault causes a false beam dump is of great value to enhance future performance and LHC luminosity output.

To illustrate the different impact Fig. 3 displays two BLM system faults within 30 hours of operation in August 2017. The first was a problem with the dump block SEMs and caused 5h of LHC downtime. The issue was discovered while performing the Sanity Checks before a new fill and prevented this fault to happen during physics operation and therefore avoided to unnecessarily fill the machine in a fault state. The second fault is an interlock, which triggered due to incorrect BLM system voltage values. It accounts for 4 minutes of downtime, but happened during the flat top and dumped the beam. For this example, this clear contradiction between availability loss and associated luminosity loss requires special attention when drawing conclusions for future improvements. It is hard to quantify precisely the lost luminosity related to a false beam dump because of many parameters, which vary depending on different operational scenarios. This can be the time of the dump at either injection or at a specific time on the flat top, the optimum fill length, the energy, degraded operation and many more to name only a few. Nevertheless, future efforts need to aim at reducing the amount of false dumps by reliably discovering fault states of the system before injecting the beams. This increases the luminosity production when furthermore the availability impact of these fault states is mitigated.

BLM DEPENDABILITY EFFORTS

Past Efforts

Being a protection system, a lot of effort was already invested to enhance the BLM system performance. During the development a reliability prediction, using the Failure Mode, Effects, and Criticality Analysis and a Fault Tree Analysis model, was performed to enhance the design and assess the system's reliability [3]. After installation the process of constantly improving the system commenced. The redesign of the backend mezzanine [5], preventive system fault analysis and failure logging from 2012 on and the before mentioned maintenance campaign during LS1 are only a few actions being executed. Starting in the end of 2016, the previous dependability analysis was updated. Outcomes of this analysis strongly influence the future strategy for enhancing the system performance.

Future Efforts

In the framework of updating the dependability analysis, a methodology for dependable PCB design, production, installation and operation was developed [6]. Following this guideline, a test strategy for the upgrade of the surface processing card is prepared. This new VFC-HD card [7] comprises an improved design with a more powerful FPGA which replaces the currently used mezzanine card by four standard SFP+ transceiver modules [8]. The additional processing resources offer the possibility to facilitate different processing and to improve the most critical part of the code by using redundancies.

To provide a high level of reliability upon installation of the VFC-HD cards various tests are foreseen:

- Power supply component test
- Functional production test
- Burn-In
- Validation tests
- Destructive temperature test

Two test benches were designed to execute the power supply and the module's functional testing by the PCB manufacturer. To perform burn-in a climatic chamber of the type Binder MKF 240 is available. It will also be used for validation tests to qualify the system in different temperature and humidity environments as well as to test at elevated temperature to trigger related failure mechanisms.

Other future improvements concern the Sanity Check. Currently the check takes around 20 minutes and performs a sequence of five steps to check different crates. It is planned to merge the check of the injection crates and the extra crate in LHC point 7 into a single step. This saves 20% of time for each execution of the check. Another improvement would be to enable checking a single sequence step. Up until now every time there is a problem with the Sanity Check, the whole sequence has to be run no matter if the erroneous crate is identified and time could be saved by only testing this one crate.

For the already disconnected SEM detectors in the dump region positions a plan is under preparation to install six new detectors per Dump which will include high radiation tolerant cabling.

SUMMARY

In 2017, BI systems achieved a better availability than in previous years with very strongly performing BCT and BPM systems. The BLM system performed better than in previous years but still can improve its availability. The detailed faults analysis of the BLM system aiming to further reduce the downtime proposes to focus on improving the intervention time and to better prepare for rarely occurring failures. In addition, the various measures like constant maintenance, preventive system fault analysis and system upgrades with related testing seem to have already a large positive effect and should be kept in place. A comparison of two distinct BLM system failures showed that besides the system's availability, also the luminosity impact of faults is important to be weighted. It remains difficult to quantify the associated luminosity loss of different faults and to scale these two different measures. This highlights the importance of diagnostics to prevent false beam dumps.

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