FILL ANALYSIS AND EXPERIMENTAL BACKGROUND OBSERVATIONS IN THE LHC

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Abstract

We have developed a fill analysis tool which automatically extracts data and analyses each fill in the Large Hadron Collider. All generated and extracted information is stored in flexible binary formats for outside use. The tool is modular and easily extendable. In this work we make use of the information produced and look at experimental background under different conditions for the 2011 running. We will discuss the observations in the context of the residual gas pressure, beam halo, and cross-talk between experiments, which depend on luminosity at neighbouring experiments.

MOTIVATION

In 2011, the LHC has already produced several fb^{-1} of data, as shown in Figure 1. The peak luminosity has quickly increased, from about 2×10^{32} Hz/cm^2 at the end of 2010, to more than 2×10^{33} Hz/cm^2 as of August this year. The increase in performance means that the machine parameters are quickly changing. The increase in beam intensity can increase beam emittance (growth) and reduce lifetime due to collective effects. The dynamic vacuum pressure can increase, which in turn increases the background levels for the experiments. It is important to monitor and understand these changes in order to optimise the beam conditions and make more accurate predictions for the future.

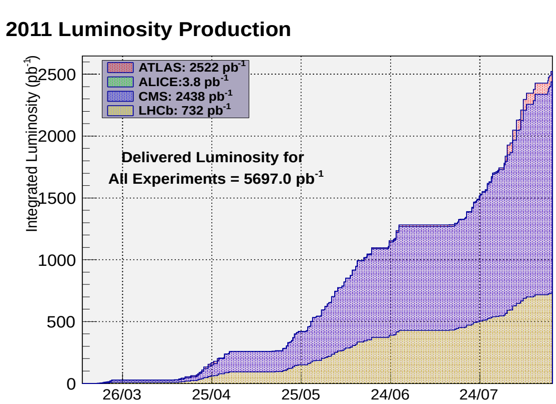


Figure 1: The integrated luminosity delivered for the 2011 running for each experiment in the LHC. This information is continuously updated at [1].

The information available from the LHC monitors can be reached through the TIMBER interface [2], and machine settings can be found in LSA [3]. These databases are highly important for getting the needed information for a proper analysis. There are some limitations however. Due to security, TIMBER can only be used inside CERN, and LSA only on trusted machines in the technical network. Further, manual extraction is time-consuming for large-scale analysis. The amount of information available in TIMBER can be overwhelming to the user, and the knowledge of how trustworthy the data are must be found elsewhere.

We found that a tool which automatically extracts the essential data from the various sources, applies corrections, and/or adds calculated data, would be of value to understand the machine behaviour and to get a better overview. Further, the data should be made available for outside use, in a suitable format for the analysis tools used at CERN.

PROJECT DESIGN

We have written the project mainly in the Python programming language. We have found Python to be simple, efficient, and extendable, suitable for writing the modular code that was needed for this project. Python can be used to work with compiled libraries (e.g. PyROOT), as well as Java libraries through e.g. Py4J. In recent years Python has gained traction as an efficient and flexible scripting language.

Extraction of data from TIMBER is done through the command-line Java interface provided by the Data Management group [5]. Making use of the Online Model [6] is foreseen to retrieve the full TWISS table[1] for the squeezed optics used during stable beams.

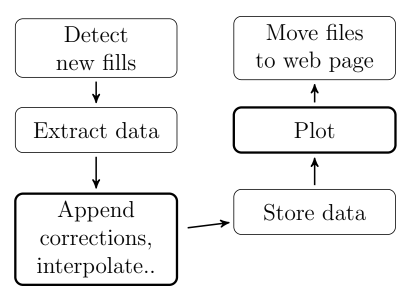


Figure 2: The schematic of the analysis script process. For each fill which goes at least to “injection physics” mode, a selected set of data is extracted, corrections are applied if available (e.g. offline luminosity calculation), and new information is added (e.g. collision pattern). The data are stored and the plotting module is run before all information about the fill is pushed to the web page. Major parts are marked with a thick frame.

In Figure 2 we show the main modules of the project. The project is written so that all new fills are analysed at regular intervals using a ‘cron’ job. The data are read into Python objects that have the needed flexibility for cleaning,

[1] Table of linear beam optics parameters

manipulation and restructuring of data. Empty variables are removed, and all data are time aligned using various interpolation algorithms for different data, making further analysis across all subsystems coherent and flexible. Additional information like collision pattern and time-stamps for various machine state changes is added, and everything is stored to file.

Data that have one value per fill (e.g. delivered luminosity) are written to a JSON formatted ASCII file, an efficient and clean format readable by humans and easily parsable by programming languages. Detailed fill data are provided in a tree structured binary ROOT format. ROOT is an extensive analysis tool package [4], widely used at CERN and elsewhere.

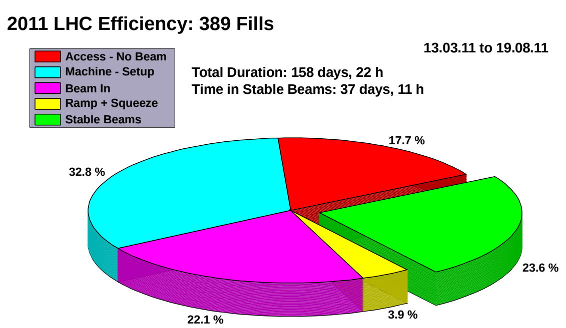


Figure 3: The total machine efficiency so far in 2011. In total, about 25 % of the time has been spent in stable beams. This information is continuously updated at [1].

The second part of the analysis is done in ROOT through the Python interface PyROOT. The ROOT binary file and the JSON file are loaded into memory before the analysis modules are run one by one. This approach allows third parties to contribute with additional analysis modules without the need to know about the internal structure of the project. Templates are provided so that all figures will have a similar look and feel. In Figure 3 we show a good example of useful performance monitoring for the LHC operators, giving a quick overview of the amount of time spent in different beam modes. This information is kept continuously updated on our web page, both for short and long term statistics.

BACKGROUND IN THE LHC

Monitoring background in the LHC is a complex matter. So far the observed background in the LHC has been fairly low, typically below 1 % during proton-proton physics, somewhat higher for ion runs [7]. It is important that we have a good knowledge of what to expect in the future and know what we can do to improve potentially problematic conditions. One should also remember that no matter how low the background is, experiments can always benefit from even better conditions. In LHC we have experiments with vastly different nominal luminosities, which can prove challenging due to background as luminosity further increases for the high luminosity experiments.

The experiments report three main online background parameters back to the machine, which are used as a guideline for online analysis on the machine side. Currently we have an informal guideline as to what these numbers should represent. The first number should be a measure of the total detector background. The second number should be a measure of the beam halo, while the third should measure detector radiation in percentage of dump threshold. Hence, the two first numbers are ideally measurements of background alone, while the third includes collision debris as well in order to measure the total amount of radiation to the experiment.

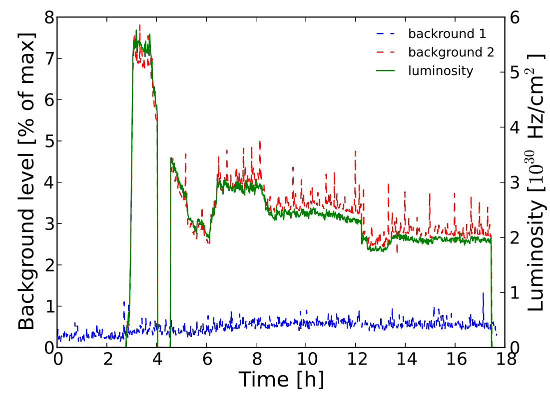


Figure 4: Luminosity and background in ALICE during fill 1901. The luminosity is shown in green, while the background number 1 is in blue and 2 in red. The sudden changes are coming from the automatic luminosity levelling which is applied in ALICE.

The algorithms to calculate the background differ from experiment to experiment, depending on what detectors they have available. It can be difficult to define an algorithm that scales correctly with the background and is independent of the luminosity.

There are some non-colliding bunches for each filling scheme. These bunches are widely used in background algorithms, since they in principle should see no normal collisions, though satellites and debunched beam still can produce some collisions.

In Figure 4, we see an example from ALICE where the algorithm to calculate beam halo background almost exactly follows the luminosity calculation. In this fill ALICE had difficulties because the background was much higher than the luminosity, and the calculation of the luminosity was not successfully excluding the background.

Machine induced background is usually split in three different categories. The beam halo background comes from the halo of the beam interacting with aperture restrictions close to the experiment. The beam-gas background arises from particles in the beam colliding with rest gas molecules in the beam chamber. The final background is interaction region (IR) cross talk, which are residues from collisions in one interaction point (IP) that reach the experimental cavern of another IR. The latter is more relevant when luminosities in different experiments differ by several orders of magnitude.

The aperture restriction which is relevant for the experiments in the LHC are the tertiary collimators, located 70-

140 m upstream of each IP. Their purpose is to protect the final focusing system, which means that they are placed closer to the beam when β^* is reduced. As a result, background originating at the collimators is expected to increase when we go to nominal β^*, which is three times lower than what is used now (1.5 m vs. 0.55 m). This background is lower for ALICE and LHCb, which are operating with higher β^*.

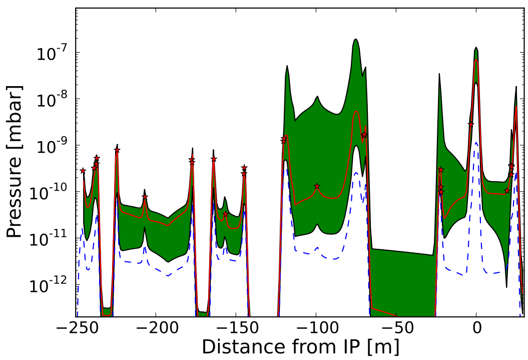


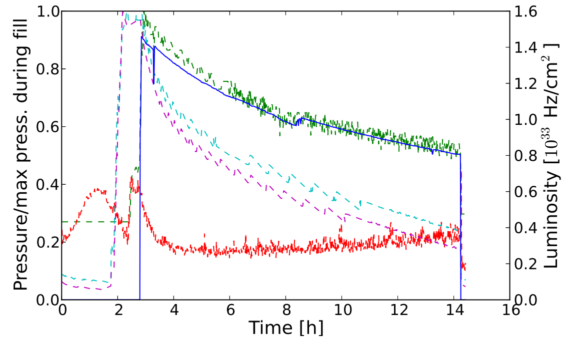
Figure 5: The vacuum distribution for beam 1 in the region around LHCb for fill 2006. In dashed blue we show the simulated static pressure profile provided by the vacuum group [8]. In red the average pressure during the fill is shown, while the green shows the spread during the fill. The relative difference between gauge reading and simulation is assumed to change linearly between pressure gauges. This is a crude assumption since synchrotron radiation will change the profile at top energy. Simulations of dynamic pressure profile will become available later.

The beam-gas component is proportional to the beam current and the vacuum in the beam. However, since the beam current can produce a dynamic vacuum increase, beam-gas can increase faster with beam current if the intensity and energy is above a certain threshold. In Figure 6 we see that the pressure increases due to the energy ramp. In Figure 5 we see the interpolated pressure range during a full fill for LHCb. Here, we have made a linear interpolation of the relative difference between simulated static pressure and measured pressure, which has a dynamic contribution at top energy. The collisions at the IP can also heat the beam-pipe locally, further increasing the local vacuum pressure. We see this in Figure 6, where one gauge is almost exactly following the luminosity level in both ATLAS and CMS.

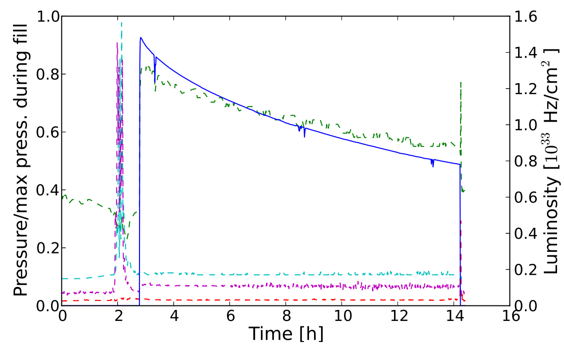
SUMMARY

We have now made available an extensive suite for making data easily available for analysis of each fill in the LHC. The application runs in an automated mode, and data are provided in efficient formats which make extensive analysis possible. It is easily extendable, and it is foreseen to include other sources at a later point.

We have presented some examples regarding background conditions in the LHC for 2011. Having these data readily available for every fill will make it significantly easier and faster to monitor the background conditions, and more generally the machine performance. The statistics



(a) ATLAS



(b) CMS

Figure 6: The luminosity in solid blue, together with a selection of gauges close to the experiment in dashed lines. The pressure is divided by the maximum measured for the gauge during the fill. The gauge presented by the green line is located around 18 m from the IP.

pages already have many users, and we believe it will even prove more useful as the analysis package matures.

ACKNOWLEDGEMENTS

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