LUCID-2 Detector: The ATLAS Luminometer

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Abstract

After the long shut-down, the LHC Run2 has started with new running conditions with respect to Run1: in particular the centre of mass energy has reached 13 TeV and the bunch-spacing is now 25 ns. In order to cope with these changes, the ATLAS luminosity monitor LUCID and its electronics have been completely rebuilt. This note describes the new detector and electronics, the new luminosity algorithms and the new calibration systems, with a brief review of the first results about the stability of the measurement and evaluation of systematic uncertainties for the 2015 data.

Key words: *luminosity; photomultipliers; lhcb detector; bismuth 207; ATLAS detector.*

LUCID-2: El luminómetro ATLAS

Resumen

Después de una larga parada, el LHC Run2 comenzó con nuevas condiciones de funcionamiento con respecto al Run1: en particular, el centro de masa energía ha alcanzado los 13 TeV y el espaciamiento entre los grupos es de 25 ns. Para hacer frente a estos cambios, el monitor de luminosidad ATLAS LUCID y su electrónica se han reconstruido por completo. Esta nota describe el nuevo detector y la electrónica, los nuevos algoritmos de luminosidad y los nuevos sistemas de calibración, con una breve revisión de los primeros resultados sobre la estabilidad de la medición y evaluación de incertidumbres sistemáticas para la toma de datos de 2015.

Palabras clave: *luminosidad; fotomultiplicadores; detector lhcb; bismuto 207; detector ATLAS.*

Introduction

LUCID (LUminosity measurement using a Cherenkov Integrating Detector) is the dedicated luminosity monitor of the ATLAS experiment [1] at LHC. Run2 new running conditions called for a redesign of the old LUCID detector and its electronics.

The LHC peak luminosity increase by a factor 2 with respect to Run1 has resulted not only in the increase of the number of interactions per bunch-crossing but also in the detector occupancy, leading to saturation of the luminosity algorithms and affecting the photomultipliers (PMT) lifetime. The solution has been to decrease the detector dimensions, using PMTs with smaller quartz window exploited as Cherenkov radiator. Hamamatsu R760 PMTs, ϕ=10 mm, had been selected to meet the challenges of Run2.

LUCID-2 consists of two modules (A and C) placed around the beam-pipe and symmetrical with respect to the interaction point, at 17 m from it. Each module consists of 16 PMTs, grouped by 4: 3 groups with ^{207}Bi radioactive sources deposited on the windows for calibration purpose (one of them is not turned on and to be used as spare) and another group of PMTs (with ^{207}Bi) with even more reduced acceptance, ϕ= 7 mm. In addition, there are also 4 bundles of quartz fibers, used as Cherenkov radiators, readout by PMTs situated 1.5 m away, in a lower radiation area.

In order to cope with the 25 ns bunch separation time, the electronics has been redesigned. LUCID- 2 new readout system is based on a custom-made VME-card, LUCROD (LUCid ReadOut Driver), which is placed close to the detector in order to avoid the signal deterioration before digitization. After the amplification, the signal is fed into a FADC, sampling at 320 MS/s. The output of two FADCs are input to a FPGA, which integrates the pulses and measures the amplitudes. Each LUCROD board contains 8 FPGAs and their outputs are fed into a main FPGA, which adds up the charge from different PMTs and calculates hit-patterns. Hit-patterns are then sent via optical links to the LUMAT (100 m away) which combines the information from the two detector modules.

Materials and methods

TThe LUCID-2 long-term stability is ensured by an efficient calibration system based on:

- ^{207}Bi radioactive sources deposited on PMT windows
- LED light, monitored by PIN diodes, for the fiber detectors

Since 2015, LUCID-2 has successfully used an innovative calibration system exploiting 1 MeV electrons from ^{207}Bi internal conversion. The reason for using radioactive sources deposited on quartz window is that it is intrinsically more stable and unaffected by radiation like more stable standard systems as LED light injected by optical fibers. The electrons produces an amount of Cherenkov light similar to the one caused by particles from collisions, as can be seen in figure 1.

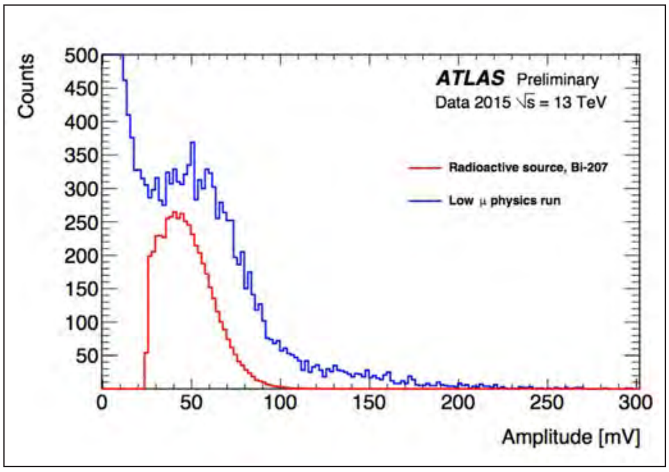

Figure 1. Pulse-height distributions from LUCID PMT recorded in 13 TeV run (blue) and in a calibration run.

The intensity of the source is large enough to provide a sufficient statistics to allow a calibration run, but not too large in order to not interfere with the luminosity measurements during data- taking. Dedicated calibration sessions are performed before and after each LHC fill in order to monitor PMT gain losses and correct them with an automatic procedure, adjusting the high-voltage provided to PMTs. Figure 2 shows the measured mean charge of 4 tubes, on each side of the detector, in the calibration runs, normalized to a reference run at the beginning of the data-taking. The stability of the measurements demonstrates that gain losses do not cumulate but they are correctly recovered by high voltage adjustments. Gain losses up to 5% are visible after long physics runs, corresponding to ~1.5% underestimation of the measured luminosity, which is corrected for in offline analysis. LUCID-2 exploits two different types of algorithms to measure luminosity. The first method relies on counting hits or events. A hit is defined as the presence of a pulse amplitude above a preset threshold in a LUCID readout channel, while an event is defined as a particular hit configuration. The second method is completely new with respect to Run1 and its implementation has been possible thanks to the new electronics. The so-called charge integrating algorithm is based on the measurement of the total charge (Q) produced bunch-by-bunch by the PMTs, which is pro- portional to the luminosity (L). The relation between Q and L does not depend on a particular statistical model, and consequently this algorithm does not suffer from non-linearities. On the other hand, it is more sensitive to photomultiplier gain variations with respect to hit event rate countings.

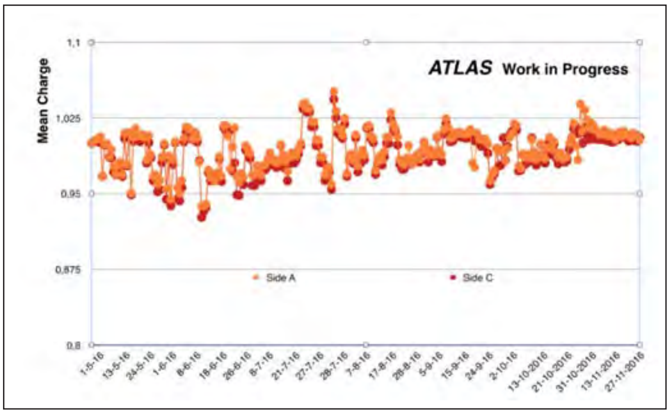

Figure 2. ^{207}Bi signal mean charge, normalized to a reference value for LUCID Side A and Side C.

Discussion and results

An accurate and reliable luminosity measurement is fundamental both for physics analysis and for the monitoring of beam stability. The ATLAS strategy is redundant [2]: luminosity measurements are performed by many independent detectors, exploiting different technologies and sensitivities to backgrounds. In figure 3, LUCID-2 percentage difference with respect to Tile, EMEC calorimeters and Track Counting is shown for 2015. Run to run stability at the level of 1% is the main source of systematic uncertainty together with absolute calibration. A total systematic uncertainty of 2.1% has been evaluated for the 2015 data-taking (table 1).

Table 1. Summary of systematic errors in 2015.

Source	Error
Calibration error	1.66%
Error in the calibration transfer correction	0.9%
Run to run stability	1.0%
Total systematic uncertainty	2.1%

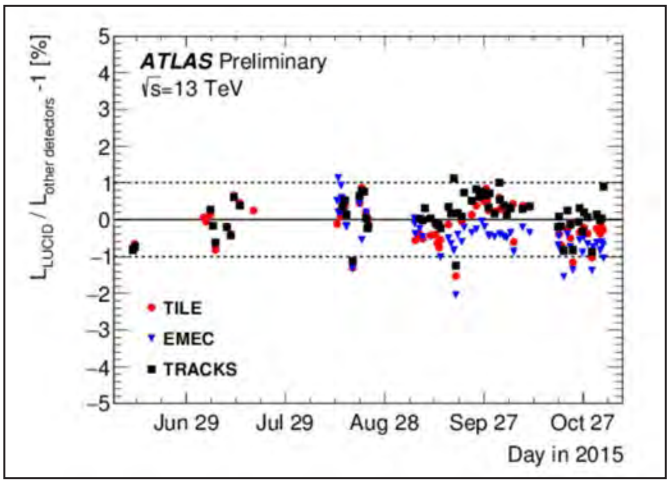

Figure 3. Run to run stability in 2015

Conclusions

LUCID-2 is the reference luminosity provider for ATLAS. The decision of using quartz win- dows as Cherenkov radiator and the new calibration system based on ^{207}Bi radiactive sources (directly applied on the window) to monitor the gain of the photomultipliers led to a very stable luminosity measurement. The new electronics installed allows the implementation of a new algorithm based on the charge integration in parallel to the standard counting algorithms. The results of 2015 analysis show a stability of the measurement at a level of 1% and a total systematic uncertainty of 2.1%.

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