PROCEEDINGS OF SCIENCE

LUCID upgrade
ATLAS luminosity monitor for the 2015 LHC

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The upgrade of the ATLAS luminosity monitor, LUCID, is presented. Both the detector and the associated read-out electronics have been improved in order to cope with the LHC luminosity increase foreseen from 2015. The new LHC operating conditions require a careful tuning of the read-out electronics in order to optimize the signal-to-noise ratio. The new read-out electronics will allow the use of digital filtering of the photo multiplier tube signals.

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1. LUCID

The measurement of the luminosity is essential in any high-energy physics experiment for cross-section measurements. Since the start of the Large Hadron Collider, LUCID has been the only dedicated luminosity monitor in the ATLAS experiment [1]. LUCID is and was made of two modules placed around the beam-pipe on both forward ends of ATLAS. Each module of the LUCID is composed of 16 photomultipliers (PMTs) and 4 quartz fiber bundles read by PMTs themselves. The PMTs detect charged particles crossing their quartz window, where Cherenkov light is produced. Light is produced in the fibers, too, and carried to PMTs sitting behind shielding a few meters away. In the old LUCID, the PMT signal was carried on a 100m-long wire to the front-end electronics, that used a constant fraction discriminator to produce a digital "hit" when the signal was over threshold. To measure the per-bunch luminosity LUCID exploited event-counting and hit-counting algorithms [2]. In LUCID II we are replaceing all the PMTs, the fibers are only 1.5 m long and we have developed new front-end electronics, sitting only a few meters from the detectors. Additionally to the old ones, an algorithm based on the measured charge released in the PMTs is foreseen in the upgraded detector.

2. The upgrade

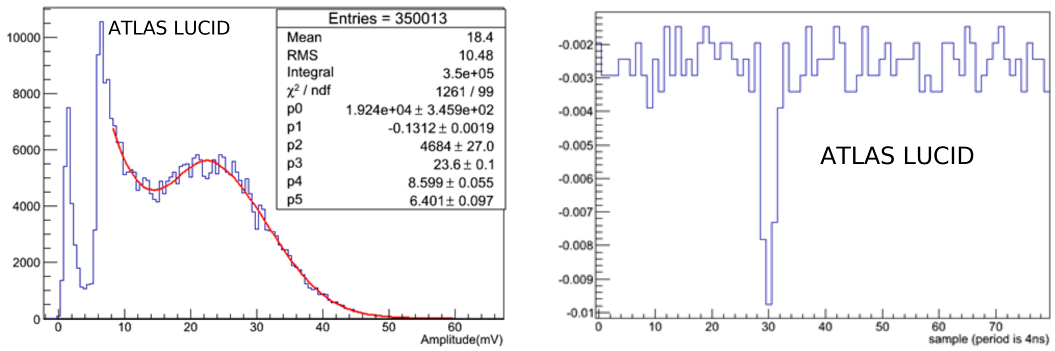
The old LUCID detector could not satisfy the requirements for LHC runs starting in 2015, leading to the development of an upgraded version of both the detector and the electronic system, mainly due to:

- the total integrated luminosity expected for 2015-2018, which will produce a large collected charge in the PMTs, resulting in a fast ageing;
- the 25 ns bunch-spacing, imposing stringent limits to the electronics;
- the increased particle fluxes resulting in the saturation of the PMTs and counting algorithms;

In order to decrease the acceptance and the current drawn by the PMTs, the Hamamatsu R762 PMTs have been replaced with new R760 PMTs, a similar but smaller version. The diameter of the photo cathodes has been reduced from 15 to 10 mm with the new PMTs. For a subset of the PMTs, we are experimenting an innovative acceptance reduction to 7 mm by requring from Hamamatsu the insertion of a thin aluminium layer between the window and the photocathode. The reduced size will limit the ageing, since less light wll be collected, producing a lower current. Moreover the gain of the PMTs will be reduced by an order of magnitude, down to 10^5. Finally, only 4 PMTs will be used at a time in order to reduce the acceptance and have spare PMTs in case of damage. According to MC simulations, the reduction of the detector acceptance also solves the problem of saturation of the luminosity algorithms and allows the luminosity measurement in the full expected range. The old LUCID electronics could not fully cope with the 25 ns bunch-spacing since the electronic front-end system was far from the detector, resulting in tails beyond the 25 ns. Early signal digitization performed by new front-end electronics placed next to the PMTs will avoid this effect, without need for amplification and shaping. The charge integration method performed by the new electronics was proven to be free from the main systematics affecting the old sytem and enables an innovative algorithm based on the total charge collected by the PMTs.

3. PMT Calibration

The new Hamamatsu R760 PMTs that will be installed on LUCID II have been tested for gamma and neutron radiation hardness and proven to be suitable for the expected dose until at least 2018. PMT calibrations have been performed with the goal of finding a good working point at low gain, to reduce the current produced in the PMT, thus reducing their ageing. The calibrations were accomplished using Bi-207 sources, that produce monochromatic electrons from interntal conversion, that produce Cherenkov light close to that expected for particles in ATLAS. Shown in Fig. 1 are the amplitude spectrum of the Bi-207 source and a typical signal, as recorded by the new PMT. A clear separation between signal and noise can be observed. During operation, the PMT



(a) (b)

Figure 1: Amplitude spectrum and typical PMT signal from bismute source

gain calibration will be monitored by a redundant system made of:

- optical fibers carrying LED signals;
- optical fibers carrying LASER signal provided by the Tile calorimeter;
- radioactive sources (feasibility under investigation);

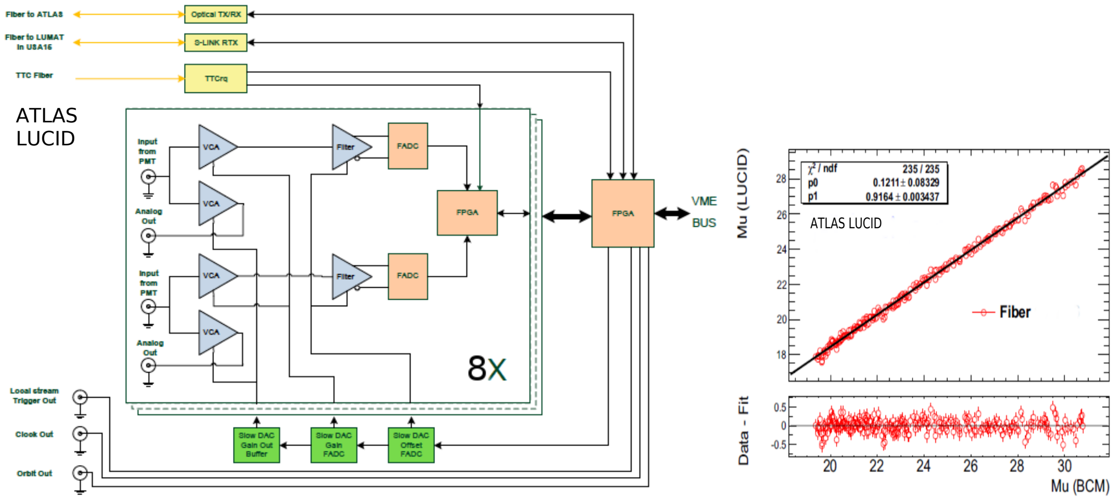
4. The new Electronics

New VME boards (LUCROD), to be placed close to the detector, will perform early signal digitization as well as PMT-charge integration over each bunch crossing time (25 ns). Each board is provided with 16 input channels, each connected to a different PMT. The main components of the LUCROD board are:

- each channel is connected to a low noise amplifier and a 480 MHz FADC which is used both for charge measurement and as a discriminator for hit definition;
- an FPGA for each pair of inputs, integrating the input signals over each bunch crossing;
- an additional FPGA implementing luminosity algorithms and sending hit patterns to the ATLAS stream under reception of an ATLAS level-1 trigger;

- an optical link to dispatch discriminated signals (hits) to an electronic board, implementing luminosity algorithms correlating the two detector modules (LUMAT);
- an analog amplified output for each input, for backward compatibility with the old system;
- possibility to read out samples of the input signals for monitoring purposes.

The scheme of a 2-channel block of the LUCROD is shown in Fig. 2(a), with the optical connections to the LUMAT board. The linearity of the charge-integrating luminosity algorithm is shown



(a) (b)

Figure 2: Scheme of a 2-channel block of the LUCROD board, with connections to the rest of the system, and linearity of the charge integration algorithm using fibers from the old LUCID

in Fig. 2(b), where the average number of interactions per bunch crossing as measured by LUCID using 2012 data is reported as a function of the one measured by the Beam Condition Monitor.

5. Future Developments and Conclusions

Among the possible developments, the implementation of digital filtering in the LUCROD FPGA is under study in order to improve the signal reconstruction for optimal charge measurement. The algorithms for digital filtering will be optimized in an offline analysis of the LUCROD signal shapes. This technique can also be used in other fields to improve detector resolution, for example the energy resolution of X-Ray detectors.
The LUCID II detector is in an advanced stage and will be installed in ATLAS during the autumn of 2014 , ready to be used for an optimal measurement of the luminosity from 2015.

References

[1] [ATLAS Collaboration], "The ATLAS Experiment at the CERN Large Hadron Collider", 2008 JINST 3 S08003

[2] [ATLAS Collaboration], "Updated Luminosity Determination in pp Collisions at root(s)=7 TeV using the ATLAS Detector", ATLAS-CONF-2011-011.