LUCID-2 (Luminosity Cherenkov Integrating Detector) is the evolution of the previous detector fully-dedicated to luminosity measurements in ATLAS. The reasons for the upgrade were the increased number of interactions per bunch-crossing and the reduction of the bunch spacing from 50 ns to 25 ns. Since 2015, LUCID-2 is the preferred detector for both the online and offline luminosity measurement.

**LUCID-2 Detector**

LUCID-2 (Fig.1) consists of two modules, placed symmetrically at 17 m from the interaction point, around the beam-pipe. Each module is composed of 16 photomultipliers (PMTs), Hamamatsu R7600, divided in 4 independent groups, plus 4 quartz fiber bundles read-out by PMTs situated 1.5 m away in a lower radiation area. Cherenkov light is produced by charged particles crossing the 20 mm PMT quartz window and the fibers. One set of PMTs has a smaller acceptance (20 mm).

**Calibration System**

The long-term stability of the LUCID-2 detector is ensured by an efficient calibration system, based on:

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

Since 2015, LUCID-2 has successfully used a novel calibration system exploiting 1 MeV electrons from 207Bi internal conversion that produce an amount of Cherenkov light similar to the one caused by particles from collisions, as can be seen in Fig.3. Dedicated calibration sessions are performed before and after each LHC fill to evaluate any PMT gain losses and correct them by an automatic procedure adjusting the PMT high voltage. The mean charges measured in calibration runs are shown in Fig.4 as a function of time. In orange, the mean of 4 tubes for Side A, in red for Side B, and in blue for Side C. A maximum loss of 5% can sometime be observed after long physics fills, resulting in such cases in a maximum luminosity underestimation of about 1.5%, which is corrected for in offline analysis. The stability of the ratio around 1 demonstrates that gain losses do not cumulate but are correctly recovered by the high voltage adjustments.

**Luminosity Algorithms**

LUCID-2 exploits two different kinds of algorithms to provide luminosity:

a) **Hit and Event counting algorithms**: a “hit” is defined as a pulse above a fixed threshold, while an “event” is defined as a particular hit configuration:

\[
L = \frac{1}{\eta} \sum_{i=1}^{N} M_i
\]

\[M_i = 1 \quad \text{detected mean number of interactions}\]

\[\eta = \text{calibration constant obtained by the vdM scan method}\]

b) **Charge integrating algorithms**: measurement of the charge produced in the PMTs, directly proportional to the luminosity.

\[
L = L_{\text{col}} = \frac{1}{K_{\text{cal}}} \sum_{i=1}^{N} Q_i
\]

In Fig.5, an example of a bunch-by-bunch hit distribution is shown. Bunches with collisions can be clearly seen above the 207Bi and beam-induced backgrounds. Unpaired bunches (only one beam filled) are also observed (blue circle), showing LUCID-2’s ability to work also as a non-colliding background monitor.

**Luminosity Measurement and Results**

An accurate and reliable luminosity measurement is fundamental both for physics analysis and for the monitoring of beam stability. ATLAS strategy is based on redundancy: luminosity measurements are performed by many independent detectors and compared. In Fig.6, the percentage difference among LUCID-2, Tile and EMEC calorimeters and Track counting is shown. During the 2015 data taking, a long-term stability of 1% was observed, which is the main source of systematic uncertainty, together with the absolute calibration uncertainty. In 2015, a total systematic uncertainty of 2.1% has been achieved (see Tab.1).

**Read-Out Electronics**

The LUCID-2 electronics (Fig.2 for the scheme) is based on two types of custom-made VME-cards. LUCROD boards are placed at 15 m from the PMTs for immediate signal digitization. LUMAT boards sit about 100 m away. LUCROD’s main components are:

- a) a low noise amplifier, a FADC and a discriminator (hit definition) for each input channel;
- b) an FPGA for each pair of PMTs to evaluate charge integrals for each bunch crossing;
- c) additional FPGAs implementing hit-based as well as charge sums.

Hit patterns are sent, via optical links, to the LUMAT boards which combine signals from the two detector modules. A large number of algorithms is implemented in order to have redundant luminosity measurements.

**Summary of systematic errors in 2015.**

<table>
<thead>
<tr>
<th>Sources</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration error</td>
<td>1.66%</td>
</tr>
<tr>
<td>Error in the calibration transfer correction</td>
<td>0.9%</td>
</tr>
<tr>
<td>Run to run stability uncertainty</td>
<td>1.0%</td>
</tr>
<tr>
<td>Total systematic error</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

A preliminary uncertainty of 3.4% is currently estimated for 2016 but the analysis is still on going.