LUCID-2 – ATLAS Luminosity Monitor (Luminosity Cerenkov Integrating Detector)

- LUCID is a Cerenkov detector sensitive to particles from the LHC-collisions. It is composed of two modules around the beam-pipe at ±17m from the ATLAS IP.
LUCID-2 Sensors

All PMTs calibrated with Bismuth for 2017

- Sensors – 4 groups of 4 PMTs
  - 4x10 mm window PMTs (calib. $^{207}$Bi)
  - 4x10 mm window PMTs (calib. with $^{207}$Bi)
  - 4x7mm reduced window (calib. with $^{207}$Bi)
  - 4x10 mm spare PMTs (calib. with $^{207}$Bi)
  - 4 quartz fibre “calos” readout by PMT in low radiation area (CALIB. WITH LEDS)
• 4 custom-made VME boards (LUCROD) placed ±17 m from the PMTs provide hit counting and charge measurement (insensitive to pile-up & prop. to lumi.) at each bunch crossing.
  – FPGAs integrate PMT signals over each bunch crossing

• 2 LUMAT boards correlate hits from each side of LUCID to produce online and offline lumi measurements based in 12 algos
• PMTs test to 200 kGy using the CALLIOPE $^{60}$Co source and...
• PMTs tested up to $\sim 2.6 \times 10^{14}$ n/cm$^2$ using the TAPIRO facility
• This is the radiation dose expected for LHC RUN-2
• No obvious radiation effects on the PMTs
• All PMTs now calibrated with ~1 MeV electrons from 207-Bi internal conversion
• Fibres Calos: now calibrated with LED pulses (stability monitored by Pin Diode)
• $^{207}$Bi now deposited on the window of all PMTs
  – Intensity of source is small compared to expected event rate but enough to calibrate in a few minutes when there are no interactions in ATLAS
**Absolute Luminosity Calibration**

![Graph and Diagram]

*Bi-207 dies not spoil the precision of the VdM scan*

- **Calibration:**
  - The absolute calibration constant is measured for each algorithm and sensor type during dedicated LHC fills
  - The Van der Meer (VdM) scan technique is used (sweeping beams transversely across each other in a simple x/y scan (RH diagram)*
Luminosity Algorithms

- **LUCID-2 Exploits 2 Different kinds of algorithm:**
  - Hit and event counting algorithms e.g. EventOR (\( n_{hit} \geq 1 \) in detector)
    
    \[
    L = \frac{f_{vis}}{\sigma_{vis}} \sum_{i=1}^{n_{BC}} \mu_{vis} 
    \]

    Detected mean number of hits/events
    Calibration constant obtained from The VdM scan

  - Charge Integrating algorithms: measurement of the charge in the PMTs - proportional to luminosity.
    
    \[
    L = \frac{1}{K_{cal}} \sum_{i=1}^{n_{BC}} Q_i 
    \]

    Charge measured by PMT
• **LEFT - Comparison of methods of lumi determination in ATLAS**
• **RIGHT - Ratio of μ the <#inelastic pp collisions/bunch crossing> from different ATLAS luminometers, to that reported by the forward (A) arm of the LUCID detector:**
  – The backward arm of LUCID (LUCID-ORC),
  – The LUCID coincidence algorithm (LUCID-AND)
  – The luminosity determined by the TILE calorimeter (consistent within ±0.4% or better).
  – The BCM detector underestimate the luminosity by as much as 2 % early in the fill.
Precision of Luminosity Measurement

**Error on ATLAS luminosity in 2015**

<table>
<thead>
<tr>
<th>Error</th>
<th>50 ns</th>
<th>25 ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration error</td>
<td>1.66%</td>
<td></td>
</tr>
<tr>
<td>Error in the calibration transfer correction</td>
<td>0.8%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Run to run stability uncertainty</td>
<td>1.0%</td>
<td></td>
</tr>
<tr>
<td><strong>Total systematic error</strong></td>
<td><strong>2.1%</strong></td>
<td></td>
</tr>
</tbody>
</table>

VdM Calibration

LUCID uncertainty

Preliminary estimate of lumi. error in 2016 ~ 2.2%
Final Words

• An accurate determination of the luminosity is essential in any high-energy physics experiment providing cross-section measurements.

• The change of LHC running conditions for 13 TeV running has required a complete LUCID redesign of detector & electronics – hence LUCID-2.

• Currently, LUCID-2 provides the official luminosity figures for ATLAS.
  
  – Preliminary results of the analysis shows a long-term stability of the LUCID at the level of ~1% and a total systematic uncertainty on luminosity measurement of ~2%

• Thanks to the different detection methods implemented, LUCID-2 is expected to provide important inputs for the luminosity detector for Hi luminosity LEP.