The LUCID-2 Detector

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LUCID (LUminosity Cerenkov Integrating Detector)

- LUCID is the only dedicated luminosity monitor in ATLAS
- 2 identical modules located around the beam pipe ±17m from the IP
- Quartz used as a radiation hard Cherenkov radiator
- Services exit through monobloc
LUCID in Run 1

- Polished Al tubes surveyed to point to the IP
- Filled with C4F10 as a radiator gas
- PMTs directly viewed gas (16 tubes)
- Aluminum Winston cones focused light on quartz fiber bundle (4 tubes)
LUCID-2: The Run 2 Design

- New design needed for run 2 due to higher luminosity, a new beam pipe and 25ns bunch spacing
- LUCID 1 PMTs and electronics could not function in run 2 conditions
LUCID-2 Sensitive Elements

- 14mm Hamamatsu R762 PMTs replaced with 10mm R760 PMTs (∼1/2 the quartz volume)
- Custom R760 PMTs with 7mm photocathodes (∼1/2 the sensitive area)
- Quartz fiber bundles, 37 PUV800 (800 μm core) per bundle readout by R760 PMTs located in a lower radiation area of the monobloc
PMT Radiation Tests

- PMTs and fibers exposed to $\gamma$ and n at the Casaccia Research Center to simulate run 2 radiation levels
- Run 2 ionizing radiation dose extrapolated from run 1 measurements
- Run 2 neutron level estimated by simulation
- 200kGy $^{60}$Co (CALLIOPE irradiation plant)
- $\approx2.6 \times 10^{14}$ n/cm$^2$ (TAPIO fast neutron reactor)
- PMT gain vs HV tested with a Xe lamp
- Fiber absorption tested with a laser
- No significant effect due to irradiation
LUCID-2 Electronics

- In run 2 the time between bunch crossings (BC) is 25 ns.
- PMT signals sent over 15 m low loss cable to custom LUCROD (LUCid ReadOut Driver) VME boards.
- Signals amplified and digitized by 320 Ms/s 12 bit FADCs.
- A FPGA integrates the output from 2 FADCs as well as measuring amplitude and synchronizing individual channel timing.
- Output of 8 FPGAs are read by a main FPGA which performs BC level calculations.
- LUCROD card on each side sends data over optical link to the LUMAT (LUminosity Monitor and Trigger) card which correlates the results and transmits the results of several luminosity algorithms to the ATLAS TDAQ.
LUCID-2 Calibration

- PMTs aged by integrated current draw
- Accurate PMT gain calibration essential
- 3 different calibrations schemes installed
  - A laser signal from the TileCal calibration system
  - Pulsed LEDs (2 independent systems)
  - $^{207}$Bi source applied directly to the PMT windows
- LED and TileCal laser signals sent to PMTs over optical fiber (with 2nd redundant fiber)
- LED output is independently monitored using a PIN photodiode
- Originally 4 PMTs per side used $^{207}$Bi but in 2017 all PMTs switched to this method
- LEDs are still used to calibrate the PMTs connected to the quartz fiber bundles

PMT HV vs 2016 Luminosity
Bi-207 Calibration

- $^{207}$Bi decays by electron capture and can emit an internal conversion electron of 0.97MeV (7.0%) or 1.05MeV (1.8%)
- This IC electron is above the Cherenkov threshold in quartz
- Source strength tuned to allow measurement in reasonable time when LHC off

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5% gain stability $\iff$ 1.5% luminosity stability

Energy $\sim$ 1 MeV
Absolute Luminosity Calibration

• LUCID provides a relative measurement
• van der Meer (vdM) technique is used to produce an absolute calibration constant
• Beams are scanned across each other on both transverse directions during special runs
• Event rates are measured as a function of position
• Combined with precise beam intensity information
• Allows a calibration constant to be determined for each permutation of detector and algorithm
• $^{207}$Bi rate is low enough to not influence the scan results
LUCID Luminosity Algorithms

- Two basic methods are used
  - Hit/event counting where a hit is defined as a signal above threshold in one PMT and an event consists of at least one hit
  - Charge integration measuring the total PMT charge per bunch crossing
- LUCROD and LUMAT cards generate over 100 luminosity measurements

\[
L = \frac{1}{K_{cal}} \sum_{i=1}^{n_{BC}} Q_i
\]

\[
L = \frac{f_r}{\sigma_{vis}} \sum_{i=1}^{n_{BC}} \mu_{vis}^i
\]

- Charge integration
- Measured PMT charge
- vDM Parameter
- Number of hits/events
- Hit/event counting

Machine revolution frequency
LUCID Luminosity Algorithms 2017

- The current list of algorithm results published by the LUCROD and LUMAT cards
- Individual PMT results as well as logical combinations
- BIM refers to the “modified” PMTs with reduced photocathode size
- FIB are the PMTs reading out the fiber bundles
Luminosity Comparisons

- Comparison of LUCID luminosity results to other ATLAS subsystems
- Fractional differences are normalized to the LUCID_HitOR algorithm

Other detectors normalized to LUCID on Aug 4 run
Calibration error is the uncertainty from the VdM scan

• LUCID luminosity uncertainty 2.1% in 2015
• LUCID luminosity uncertainty 2.2% in 2016
Conclusion

• Integrated luminosity is an essential normalization parameter for collider physics results
• Changes to run conditions in run 2 required a redesign of the original LUCID detector
  • Bunch spacing reduced from 50ns to 25ns
  • Mean number of interaction per bunch crossing, $\langle \mu \rangle$, was 20.7 in 2012 and 34.4 in 2017
  • Beampipe in the region of LUCID changed from SS to Al
• LUCID-2 currently provides the official ATLAS luminosity
• Long term stability of LUCID is $\approx 1\%$ with a total uncertainly of $\approx 2\%$
• Development has started for Run 3