Run 3 improvements in the ATLAS online luminosity measurement

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Luminosity

Luminosity measurements are a crucial ingredient in the LHC physics programmes. The **instantaneous luminosity** is given by

$$\langle \mathcal{L}_{\text{inst}} \rangle = n_b \frac{\langle \mu \rangle f_r}{\sigma_{\text{inel}}}$$

- $\langle \mathcal{L}_{\text{inst}} \rangle$ bunch-averaged instantaneous luminosity
- n_b number of colliding bunches
- f_r revolution frequency
- σ_{inel} inelastic pp scattering cross-section
- $\langle \mu \rangle$ bunch-averaged collision rate per bunch-crossing, i.e. **pileup**

Pileup cannot be measured directly, as our detectors have a limited coverage. We thus measure the **visible pileup** μ_{vis}, which is also less sensitive to saturation effects, and rescale according to

$$\mu = \frac{\mu_{\text{vis}} \sigma_{\text{inel}}}{\sigma_{\text{vis}}}$$

σ_{vis} visible cross-section, luminometer dependent, measured with dedicated van der Meer (vdM) scan sessions.

where the cross-section ratio is a measure for the detector efficiency. Pileup is a stochastic process, so a luminometer records some form of raw data x, which is converted to pileup using **luminosity algorithms**, of the form $\mu_{\text{vis}} = f(x)$.

Luminometers & Algorithms

LUCID (ATLAS's main luminometer)

16 photomultiplier tubes (PMTs) on each side of the detector (A and C), at 17 m from the collision point.

Each PMT gives an output every bunch-crossing, if at least one charged particle passed through.

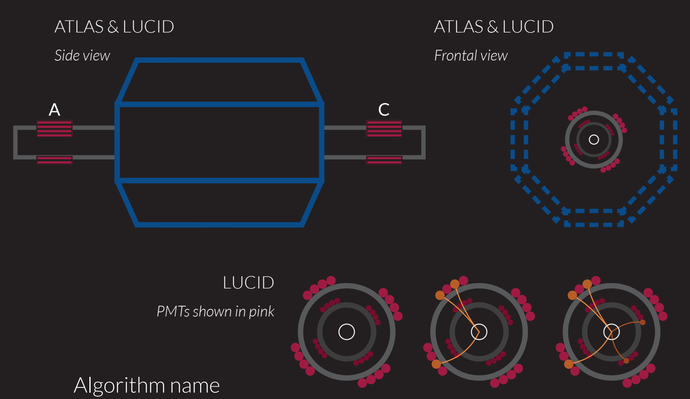
Beam Conditions Monitor (BCM)

4 diamond sensors on each side of the detector at 184 cm from the collision point.

Each side gives an output every bunch-crossing if at least one charged particle passed through one of the sensors.

Calorimeters (FCAL, EMEC, TileCAL)

Electric currents are directly proportional to pileup, and are read out roughly every minute.

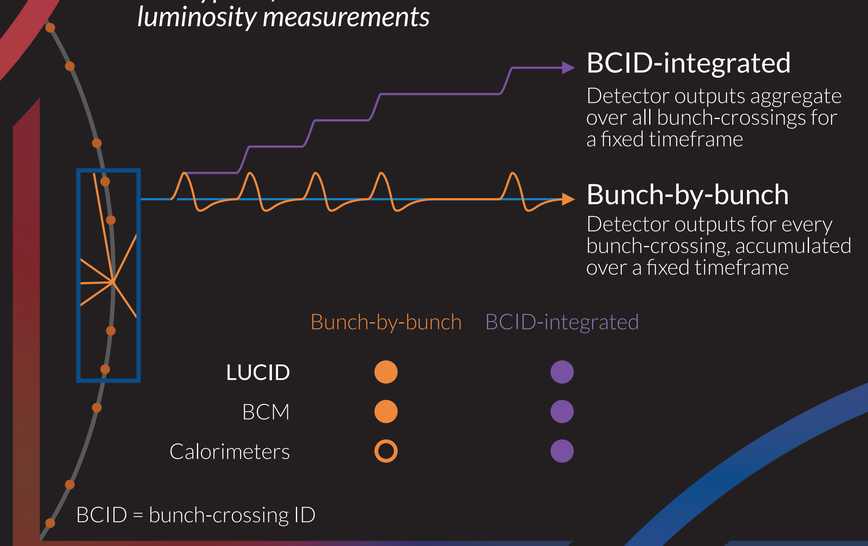


Algorithm name				
Event Counting	`EventOR` *At least 1 hit*	$x = 0$	$x = 1$	$x = 1$
	`EventAND` *At least 1 hit at both A and C sides*	$x = 0$	$x = 0$	$x = 1$
Hit Counting		$x = 0/32$	$x = 3/32$	$x = 5/32$

The different types of collection algorithms for raw luminosity data x, corresponding to different luminosity algorithms

The Online Luminosity Calculator

Two types of online luminosity measurements



The Online Luminosity Calculator (OLC) is ATLAS's online luminosity system. While offline analyses focus on reducing the uncertainties of luminosity measurements, the online systems are a vital aspect of operations. Monitoring the luminosity in real time helps the LHC optimise the beams for collisions, as well as providing the ATLAS trigger systems with vital inputs for pre-scaling. The OLC can also be run separately from ATLAS to provide luminosity outside of normal ATLAS operations. It works as follows:

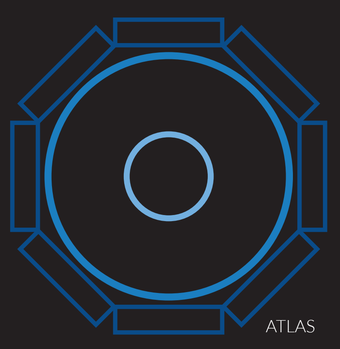
LUCID

Limited functionality in standalone mode, full functionality only accessible when running with ATLAS.

State of the OLC during:
- Run 2
- Run 3

Full functionality available in standalone mode

The long-term goal for the OLC is to have a fully functional "standalone" mode, where it can run without ATLAS needing to be online as well. For Run 3, several important steps were taken towards achieving this.



Bunch masks

Based on bunch group keys in ATLAS systems

New option: bunch masks from BPTX, which is fully independent from ATLAS

Lumiblocks

Luminosity blocks (lumiblocks) are time ranges where the full detector output is assumed stable, while being long enough to measure basic quantities. Usually ~60s.

Sourced from ATLAS online database

New option: independently generated by LUCID

Bunch-by-bunch luminosity

No bunch-by-bunch in standalone mode

With lumiblocks from LUCID and bunch masks from BPTX, **bunch-by-bunch luminosity can now be processed when the OLC runs in standalone mode**

Levelling

Pileup level requested over the phone*

Graphical interface for ATLAS control room shifters

*There was a graphical interface during Run 2, but it could only set a luminosity level, not pileup.

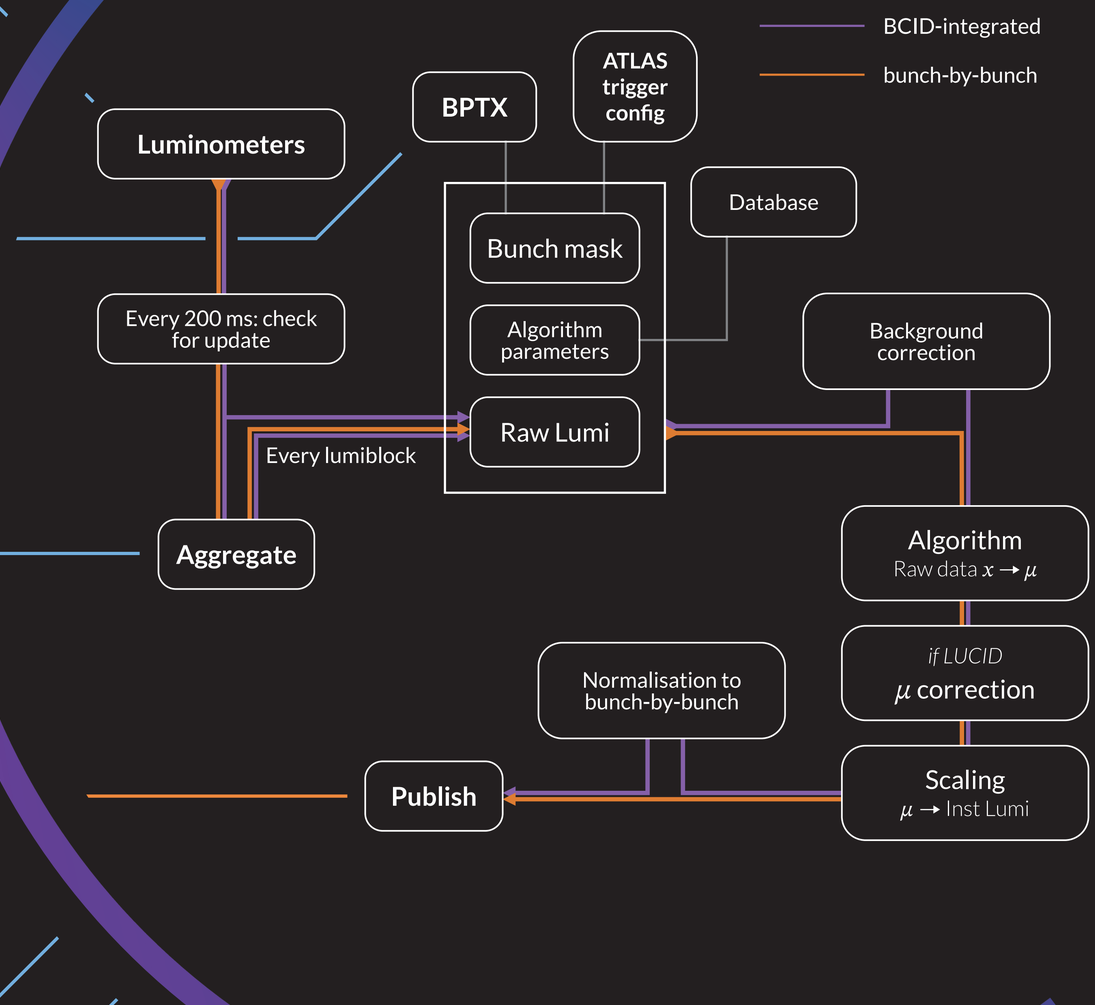
ScanController

Takes over part of the ATLAS data acquisition systems during van der Meer and emittance scans.

Improved interaction protocol with the LHC

Additional improvements *to OLC operations*

OLC *Overview*



Towards HL-LHC with the OLC

The goal for OLC operations is to have a fully functional standalone mode. To achieve this, the following improvements were made to the OLC for Run 3:

- **Full LUCID standalone functionality**
- **BPTX for bunch masks**
- **Lumiblocks generated by LUCID**
- **Bunch-by-bunch luminosity in standalone mode**

As the start of Run 4 and thus the LHC's high-luminosity era draws closer, upgrade work is ramping up all over ATLAS. Both the new High Granularity Timing Detector (HGTD) and the Pixel Lumi Rings in the Inner Tracker (ITk) (replacing the Inner Detector) will be providing new luminosity measurements to the OLC. The Run 3 improvements will be key to the OLC's operations during HL-LHC, becoming even more robust with these new luminometers.

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