Luminosity and Beam Spot Determination Using the ATLAS Detector

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Introduction

We present the algorithms and results of the reconstruction of the luminosity region (also known as the “beam spot”) and measurement of the luminosity in the ATLAS experiment during the first LHC run at center-of-mass energies of $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV.

The spatial distribution of $pp$ interactions is reconstructed both online (in the High-Level Trigger system) and offline (utilizing the full detector precision) using Inner Detector tracks for event-by-event primary vertices [1].

The LHC luminosity is determined in real time, approximately once per second, using a number of detectors and algorithms. These results are displayed in the ATLAS control room and archived every two minutes [2].

Van der Meer or “beam separation” scans provide an absolute calibration of the luminosity measured by ATLAS, that improves the uncertainty by a factor $\times 2$ over Monte Carlo values.

Beam spot evolution with time

Real-time measurements from the trigger and high-precision offline measurements track the LHC beams over time (every $\approx 2$ min).

Beam size measurements

The offline maximum-likelihood fit extracts vertex-resolution corrected luminous sizes ($\sigma_{\ell L}, \sigma_{\ell Y}$), related to the individual beam sizes as:

$$\sigma_{\ell L} = \left( \frac{1}{\sigma_{\ell L}^2} + \frac{1}{\sigma_{\ell Y}^2} \right)^{-1/2}$$

and compare to the expected sizes from $\beta^*$ and beam emittance measurements from LHC.

Luminosity determination at $\sqrt{s} = 900$ GeV and $\sqrt{s} = 7$ TeV

Monte Carlo-based luminosity calibration

$\mathcal{L} = \frac{\mu_{\ell f} n_{\ell f}}{\sigma_{\text{MC}}}$

$\mu$ is the # of $pp$ collisions per bunch crossing, $n_{\ell f}$ the # of colliding bunch pairs, $f_{\ell}$ the LHC revolution freq., $\sigma_{\text{MC}}$ the inelastic $pp$ cross section, $\varepsilon$ the detector eff., $j_{\text{MC}}$ the # of events. The “visible” cross section $\sigma_{\text{vis}}$ is the luminosity calibration constant, measured via van der Meer scans.

Van der Meer (beam-separation) Scans: Absolute $\mathcal{L}$ calibration

The ultimate luminosity calibration is obtained by moving one beam across the other and using machine parameters only to measure the luminosity ($\mathcal{L}$) via the bunch currents ($I_1, I_2$) the overlap integral, and the counting rate at the peak from any of the luminosity detectors.

References

[1] ATLAS, ATLAS-CONF-2010-027

The scans (measured via primary vertex counting (left) and LUCID (right)) provide a direct measure of the absolute luminosity of the LHC, and a factor $\times 2$ precision over Monte Carlo calibrations.