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Luminosity Monitoring using $Z \to \ell\ell$ events at $\sqrt{s} = 13$ TeV with the ATLAS detector

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During Run 2, the LHC delivered instantaneous luminosities of approximately 10^{34} cm^{-2}s^{-1} at $\sqrt{s} = 13$ TeV in pp collisions. At such high instantaneous luminosities, measuring the decay rate of $Z \to \ell\ell$ provides a powerful tool to monitor the luminosity recorded by ATLAS over time periods as short as 60s. These proceedings present an overview of the method, outlining the event selection, data-driven efficiency determination and corrections derived from simulation, as well as showcasing the robustness of the final results. The absolute luminosities obtained independently in both the $Z \to ee$ and $Z \to \mu\mu$ channels agree to within approximately 1%, with an excellent time stability of around 0.5%, a non-trivial result considering both channels have their own distinct chain of corrections. The difference between the normalised Z-counting luminosity and ATLAS baseline luminosity, where the Z-counting luminosity is normalised to the same integrated luminosity as the ATLAS baseline measurement over the entire data-taking period, is evaluated per LHC fill and found to typically be within 0.5%.

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1. Motivation

The main motivations to pursue the Z-counting method are the monitoring of the long term time stability of the baseline ATLAS [1] luminosity algorithm, providing a comparison between ATLAS and CMS luminosity values (independent of van der Meer scan calibration) and robustness with respect to the mean number of inelastic pp interactions per bunch crossing ($\langle\mu\rangle$) [2].

2. Methodology

Events are reconstructed by selecting two well-identified electrons or muons with transverse momentum (p_T) greater than 27 GeV, pseudorapidity (η) of $|\eta| < 2.4$ and having a dilepton invariant mass of $66 < m_{\ell\ell} < 116$ GeV. To account for detector inefficiencies, data-driven single-lepton trigger and reconstruction efficiencies are determined using the tag-and-probe (T&P) method. These single-lepton efficiencies are combined into an event-level efficiency used to correct the $Z \to \ell^+\ell^-$ production rate,

$$\varepsilon^{\mathrm{T\&P}}_{Z\to\ell^+\ell^-} = (1 - (1 - \varepsilon_{\mathrm{trig},1\ell})^2) \times \varepsilon^2_{\mathrm{reco},1\ell}. \tag{1}$$

Pileup-dependent correction factors are determined from simulation in order to correct for effects which are not accounted for in the tag-and-probe efficiency evaluation. By calculating the tag-and-probe efficiency in Monte Carlo, and comparing to the "true" (generator level) efficiency, the residual non-closure of the data-driven efficiency determination can be evaluated and applied as an additional correction ($F^{\mathrm{MC}}(\langle\mu\rangle)$). Combining the measured production rate with the data-driven and simulated corrections (as well as some other numerical factors), a luminosity can be obtained,

$$\mathcal{L}_{Z\to\ell^+\ell^-} = \frac{\overbrace{N_{Z\to\ell^+\ell^-}(t)}^{\text{Z production rate}} \cdot \overbrace{(1 - 0.005)}^{\text{background correction}}}{\underbrace{F^{\mathrm{MC}}(\langle\mu\rangle)}_{\text{MC correction}} \cdot \underbrace{\varepsilon^{\mathrm{T\&P}}_{Z\to\ell^+\ell^-}}_{\text{data-driven efficiency}} \times \underbrace{A^{MC}}_{\text{acceptance}} \cdot \underbrace{\sigma^{Z\to\ell\ell}_{\text{theory}}}_{\text{theory cross section}}}. \tag{2}$$

The shortest time interval over which this measurement is possible, over which $N_{Z\to\ell^+\ell^-}$ and $\varepsilon^{\mathrm{T\&P}}_{Z\to\ell^+\ell^-}$ are measured, is approximately 60s, a time period known as a luminosity block.

3. Results

Figure 1 shows the single-lepton efficiency corrections and the final luminosity comparison with the baseline ATLAS luminosity [2] for a single LHC fill. These illustrative plots show the electron channel results only, with the procedure and results in the muon channel being very similar. In order to evaluate the stability of the baseline ATLAS luminosity measurement, the $Z \to ee$ luminosity values have been normalised to the same integrated luminosity as the baseline ATLAS measurement. Figure 1 (right) shows the excellent stability of the method over time periods of approximately 20 minutes, where a weighted average over twenty luminosity blocks has been performed to improve the statistical precision.

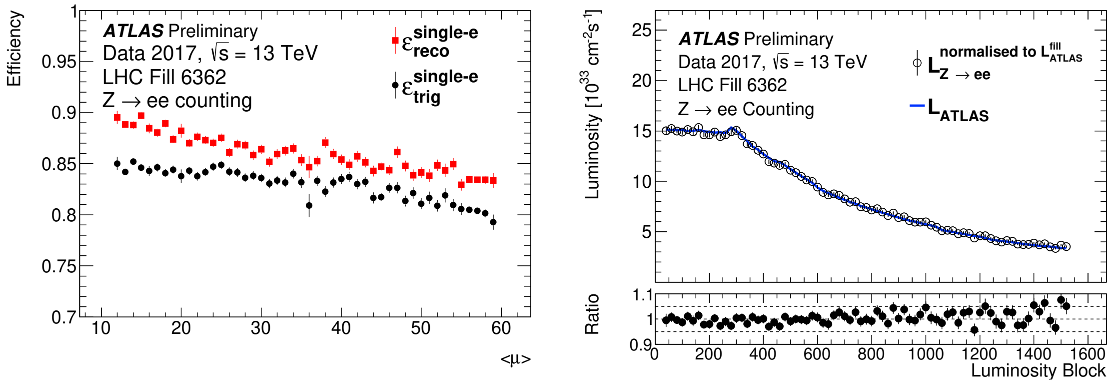

Figure 1: Left: Single-electron trigger and reconstruction efficiencies [3]. Right: Normalised $Z \to ee$ and baseline ATLAS luminosities [3].

Figure 2 (left) shows the ratio of the absolute, i.e. not normalised, $Z \to ee$ and $Z \to \mu\mu$ luminosities. The mean of 0.989 shows that the two channels produce results that are within about 1% of one another, a powerful consistency check. Figure 2 (right) shows the ratio of the fill-integrated $Z \to ee$ and baseline ATLAS luminosities for each LHC fill in the 2017 data-taking period, where the integrated $Z \to ee$ luminosity of the entire data-taking period has been normalised to the ATLAS baseline measurement. The stability of this ratio is evaluated by calculating the RMS, which is approximately 0.5%, a testament to the excellent stability of the method.

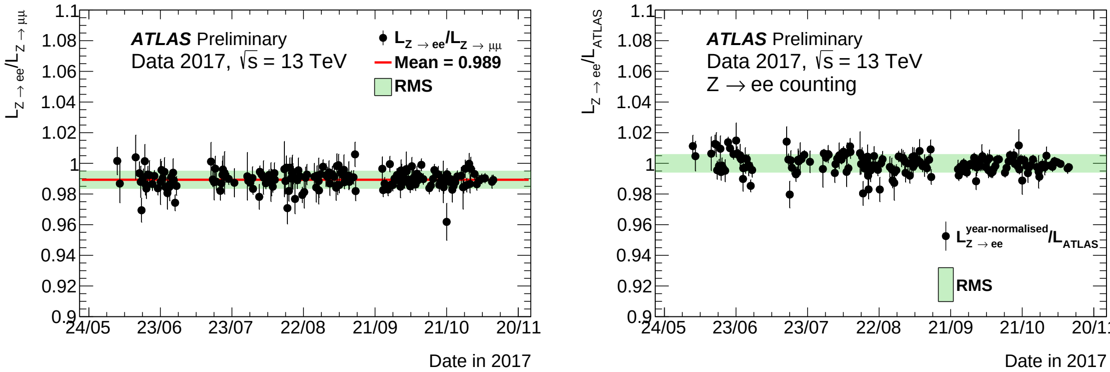

Figure 2: Left: Ratio of absolute $Z \to ee$ and $Z \to \mu\mu$ luminosities [3]. Right: Ratio of normalised $Z \to ee$ and baseline ATLAS luminosities [3].

4. Conclusion

One of the main strengths of the Z-counting method is the data-driven efficiency determination, as detector and pileup dependent effects are able to be accurately modelled and accounted for. Consequently, the Z-counting method is a powerful tool for monitoring the stability of other luminosity measurements at ATLAS.

References

[1] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 S08003, 2008, https://cds.cern.ch/record/1129811.

[2] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021, 2019, url: https://cds.cern.ch/record/2677054.

[3] ATLAS Collaboration, *Luminosity public plots*, http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/LUMI-2020-02/.