Luminosity calibration at ATLAS in 2011

M. J. Tibbetts, LBNL, Berkeley, CA 94720, USA
on behalf of the ATLAS Collaboration

Abstract

An overview is provided of absolute luminosity calibrations of dedicated luminosity detectors and algorithms at ATLAS for different LHC physics conditions. Emphasis is placed on their precision calibration in $\sqrt{s}$=7 TeV proton-proton collisions. Details of systematic uncertainties associated both with this calibration and its subsequent application to typical running conditions in 2011 are presented. A preliminary estimate of the total uncertainty is shown to approach a precision of $\sim 2\%$. Potential correlation of this uncertainty with that expected in 2012 proton-proton collision data is discussed.

INTRODUCTION

Precision luminosity determination is an essential part of the ATLAS [1] physics program as it directly impacts both Standard Model cross-section measurements and background estimations in searches for new physics signatures. The monitoring of luminosity is primarily achieved by continuously recording the response of two independent detectors for all 3564 slots of 25 ns in the nominal LHC fill pattern:

- LUCID is a Cerenkov detector consisting of sixteen polished aluminum tubes surrounding the beampipe on each side of the interaction point (IP) with pseudorapidity range $5.6 < |\eta| < 6.0$.
- The Beam Conditions Monitor (BCM) consists of four diamond sensors on each side of the IP arranged around the beampipe in a cross pattern at $|\eta| = 4.2$. The sensor readouts are paired horizontally (BCMH) and vertically (BCMV) providing a two-fold redundancy for luminosity monitoring. Each pair is calibrated independently.

As discussed in detail elsewhere [2, 3, 4], the application of Poisson statistics can be used to derive event counting algorithms. These allow detector response to be interpreted as a measurement of the number of visible interactions per bunch crossing, $\mu_{\rm vis} = \epsilon_{\rm alg}\mu$, where μ is the average number of inelastic interactions per bunch crossing (directly proportional to the luminosity) and $\epsilon_{\rm alg}$ is the efficiency of a detector algorithm. Inclusive event counting (EventOR) requires at least one signal on either side of the IP for a given detector to be over a predefined threshold. Coincidence event counting (EventAND) places the tighter requirement that there be at least one signal over threshold on both sides of the IP for that detector. Table 1 shows preliminary efficiencies measured in 2011 7 TeV proton-proton collisions [4] for various detector algorithms, assuming a proton-proton inelasitic cross-section of 71.5 mb. It can be seen that a significant range of efficiencies are available. Low efficiency can be advantageous for high μ running as such algorithms are less likely to suffer from saturation (so-called zero starvation). However, they suffer in their ability to evaluate systematic uncertainties at lower μ, such as in calibration scan data, due to statistical limitation. For such studies higher efficiency algorithms are preferential. In 2011 7 TeV proton-proton data BCM algorithms provided the central value for both monitoring of instantaneous luminosities (EventAND) and the integrated luminosity measurement used in physics analyses (EventOR).

Table 1: Preliminary efficiencies [4] for various detector event counting algorithms measured in 7 TeV proton-proton collision data.

Algorithm	$\epsilon_{\rm alg}$ [%]
LUCID_EventOR	59.5
LUCID_EventAND	18.8
BCMH_EventOR	6.6
BCMH_EventAND	0.2

LUMINOSITY CALIBRATION

The luminosity, $\mathcal{L}$, for a detector algorithm is given by the sum of $\mu_{\rm vis}$ over all luminous bunch-crossings, n_b:

$$\mathcal{L} = \frac{f_r}{\sigma_{\rm vis}} \sum_{i=0}^{n_b} \mu^i_{\rm vis}, \quad (1)$$

where f_r is the LHC revolution frequency and $\sigma_{\rm vis}$ is the so called 'visible cross-section' for that detector algorithm. It follows that in order to determine the luminosity from a given algorithm its associated $\sigma_{\rm vis}$ must be known. At ATLAS measurement of the various $\sigma_{\rm vis}$ is performed through analysis of data from dedicated beam separation scans [5]. These provide an absolute calibration of luminosity through direct measurement of the beam-beam convolved profile by scanning the LHC beams across each other in both the horizontal and vertical planes. In a given plane the characteristic convolved beam width, Σ_δ, is given by,

$$\Sigma_\delta = \frac{1}{\sqrt{2\pi}} \frac{\int \mu^{\rm sp}_{\rm vis}(\delta){\rm d}\delta}{\mu^{\rm sp}_{\rm vis}(\delta = 0)}, \quad (2)$$

where $\mu^{\rm sp}_{\rm vis}$ at beam separation $\delta = x, y$ is $\mu_{\rm vis}$ normalised to the bunch current product, $n_1 n_2$ for a given luminous bunch crossing. It can be shown [2] that $\sigma_{\rm vis}$ is given by

$$\sigma_{\rm vis} = 2\pi\mu^{\rm sp}_{\rm vis}(\delta = 0)\Sigma_x\Sigma_y. \quad (3)$$

Table 2: Summary of beam separation scans taken at ATLAS for various LHC running conditions from November 2010 until the end of 2011. The current analysis status of each scan is shown; a publication updating the May 2011 proton-proton (7 TeV) preliminary result in [4] is under preparation.

	Nov 2010 PbPb	Mar 2011 pp (2.76 TeV)	May 2011 pp (7 TeV)	Dec 2011 PbPb
LHC Fill(s)	1533	1653 & 1658	1783	2337
n_b	113	64	14	344
Peak μ	1.4×10^{-4}	0.36	2.3	6×10^{-4}
β^* [m]	3.5	11.0	1.5	1.0
Analysis Status	Ongoing	Ongoing	Preliminary result [4]	Ongoing

Furthermore the Σ_δ should be physical properties of the LHC beams and hence algorithm independent. This allows a consistency check when calibrating multiple algorithms though comparison of their measured specific luminosity, $\mathcal{L}_{\rm spec}$, which is defined as,

$$\mathcal{L}_{\rm spec} = \frac{f_r}{2\pi\Sigma_x\Sigma_y}. \quad (4)$$

Table 2 summarises beam separation scans taken at ATLAS for various LHC running conditions from November 2010 until the end of 2011. In 2011 ATLAS has focused on precision understanding of systematic uncertainties in the May 2011 7 TeV proton-proton scan as well as the long term stability and pileup dependence of this calibration. Preliminary results of this analysis are available in [4]. The present report gives detail of some progress in this analysis since the preliminary result; however, results presented here are subject to change with the final submission of the analysis to a scientific journal, the manuscript of which is currently under preparation.

MAY 2011 7 TeV PROTON-PROTON LUMINOSITY CALIBRATION SCAN

The beam separation scan in LHC fill 1783 was the only precision 7 TeV calibration at ATLAS in 2011. The scan sequence consisted of a horizontal then vertical scan (together labelled scan VII) followed by a second horizontal then vertical scan (together labelled scan VIII) in the same LHC fill. Beam recentring after the first pair of scans was found to be unnecessary. The second pair of scans allows cross-checks on the reproducibility of key luminosity variables which is essential for evaluation of beam dependent systematic uncertainties. The fill consisted of 14 luminous bunch-crossings at the ATLAS IP with bunch currents and beam-beam overlap profiles varying by 10–20%. This can be seen in Figure 1 which shows preliminary measurements of Σ_x for two BCM algorithms in scans VII and VIII. Also visible is a moderate emittance growth between scans which is characterised here by a larger Σ_x in scan VIII relative to scan VII for a given luminous bunch. The bunch by bunch response of both the BCM and LUCID detectors results in 14 independent measurements of their various $\sigma_{\rm vis}$ which can be checked for consistency.

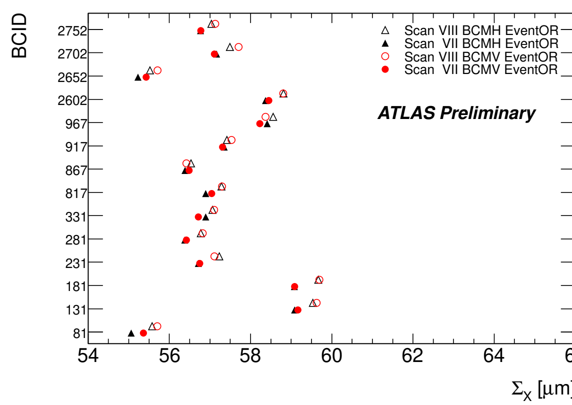


Figure 1: Measurements of Σ_x determined from various BCM event counting algorithms in beam separation scans VII and VIII for each luminous bunch crossing in LHC fill 1783.

Beam Profile and Fit Function

In 2010 it was found that beam separation profiles were well described when fitted by the sum of two Gaussians and a constant term, with the constant term interpreted as background from beam gas interactions [3]. The data in fill 1783 tend to favour a single Gaussian component only. Furthermore they are corrected for the main sources of background:

- Local activation (proportional to instantaneous luminosity) and detector noise the combined rate of which can be inferred from empty crossings adjacent to the luminous bunch and then subtracted from each point of the scan curve under consideration. The dominant contribution of this component is local activation.
- Beam gas background which is proportional to bunch charge but independent of instantaneous luminosity. The relative contribution from each LHC beam can be inferred from crossings of isolated non-colliding bunches in ATLAS during the scan. Again the inferred rate is then subtracted from the luminous bunch scan curve.

After background subtraction fits to data often still exhibit a statistically significant constant term which must therefore be interpreted as luminosity and included in the integral of

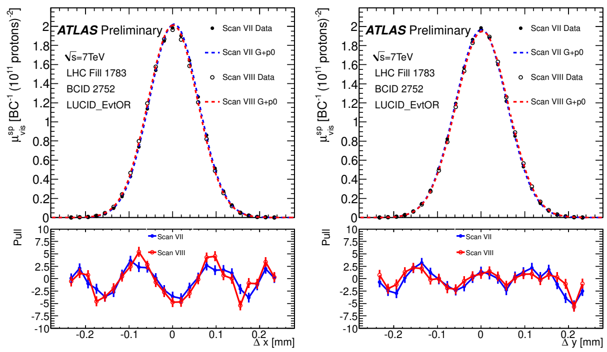


Figure 2: Fitted beam convolved profiles in the horizontal (left) and vertical (right) planes. The fitted scan curves for scan VII (blue) and VIII (red) are overlaid. Pull distributions of the scan curve relative to data at each separation point in the respective scans are shown (bottom).

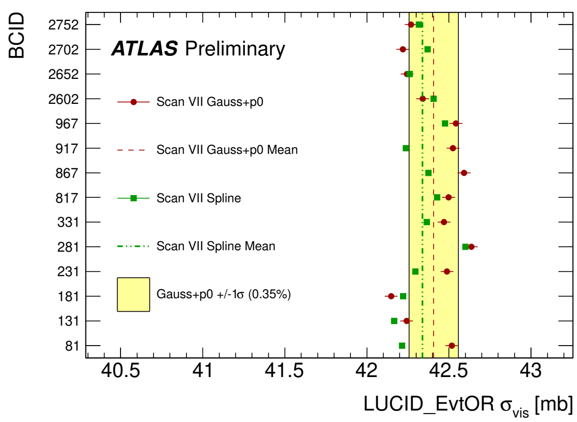
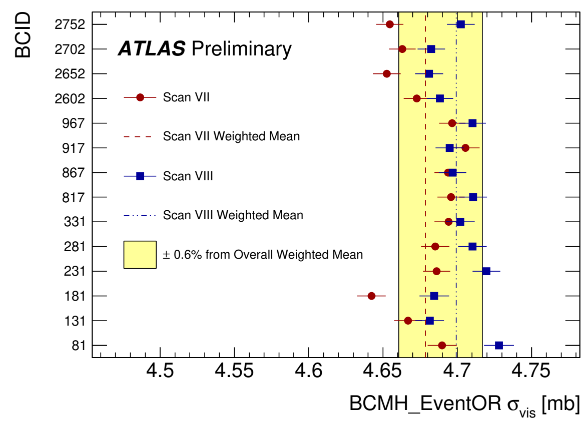


Figure 3: Comparison of preliminary σ_{vis} measurements for LUCID_EventOR in scan VII, determined from an analytical fit of Gaussian plus constant (red) and the interpolation of data points using a cubic spline (green).

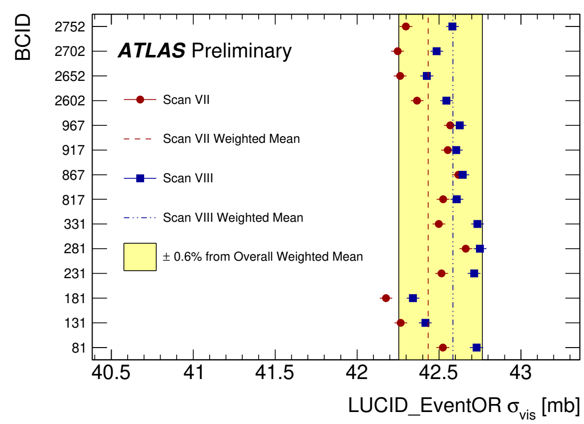
equation 2. The difference in fitting non-background subtracted data with constant term interpreted as background and then background subtracted data with constant term interpreted as luminosity is found to be no more than 0.3% for any one algorithm.

Figure 2 shows an example of a fitted scan curve to LUCID_EventOR data where the fit quality of Gaussian plus constant term particularly suffers. In particular the horizontal fit pull for both scans VII and VIII shows a clear non-Gaussian modulation not accounted for by the fit model. To address potential systematic uncertainties arising from such mismodelling all scan curves are refitted with a cubic spline extrapolation between measured points on the scan curve. This method for modelling the profile by definition passes through each scan point and hence provides a robust alternative to the analytical fit function when it deviates from data. Figure 3 shows the difference in σ_{vis} for LUCID_EventOR in scan VII when measured using the cubic spline method or the analytic Gaussian plus constant fit to data. The largest difference in the average σ_{vis} of any one detector algorithm from each of these methods in a given scan is taken as a systematic uncertainty associated with the choice of fit model of 0.3%.

Bunch by Bunch Consistency



(a)



(b)

Figure 4: Preliminary measurements of σ_{vis} for each luminous bunch crossing in scans VII and VIII for (a) BCMH_EventOR and (b) LUCID_EventOR.

Figure 4 shows a bunch by bunch comparison of preliminary σ_{vis} measurements for both LUCID_EventOR and BCMH_EventOR for both scans VII and VIII. It can be seen that the independent detectors (with same fit method) show similar bunch by bunch systematic trends relative to the average σ_{vis} in a given scan. These variations are considered as contributing two components of systematic uncertainty. Firstly the largest bunch by bunch spread of measured σ_{vis} within a given scan for any one algorithm is assigned as a systematic uncertainty of 0.55%. Secondly the largest difference in average σ_{vis} between scans VII and VIII for any one algorithm is taken as a systematic uncertainty of 0.8% due to emittance growth and other non-reproducibility between scans. In principle the increase in beam-beam overlap due to emittance growth should com-

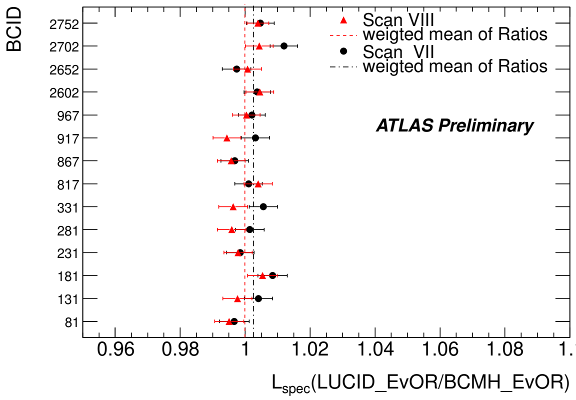


Figure 5: Comparison of $\mathcal{L}_{\rm spec}$ values for scans VII and VIII measured with BCMH_EventOR and LUCID_EventOR for each luminous bunch crossing. The average deviation from unity is shown as a vertical line for scans VII (black) and VIII (red) respectively.

pensate the decrease in $\mu_{\rm vis}^{\rm sp}$ at zero beam separation when calculating the corresponding $\sigma_{\rm vis}$; however, the difference in average $\sigma_{\rm vis}$ observed between scans suggests a residual non-linear component in this expected cancellation.

An additional consistency check is provided by comparison of $\mathcal{L}_{\rm spec}$ bunch by bunch between algorithms for each scan. Figure 5 shows the ratio of $\mathcal{L}_{\rm spec}$ for LUCID_EventOR and BCMH_EventOR. The largest deviation from unity in the average ratio for any one scan is taken as a systematic uncertainty of 0.3%.

Beam Recentering

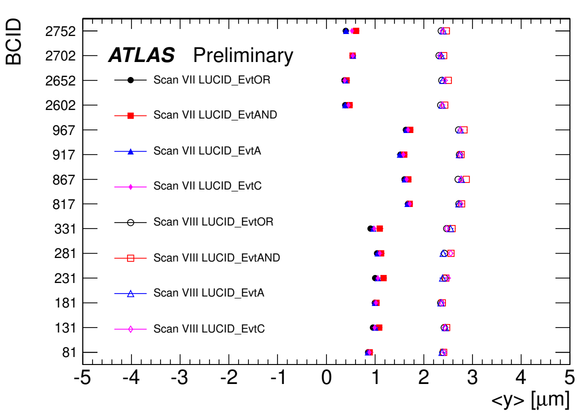


Figure 6: Nominal separation of the maximum of the fitted beam convolved profile measured in the vertical plane for various LUCID algorithms for each luminous bunch crossing. A residual non-reproducibility is observed between scan VII (closed points) and scan VIII (open points).

The LHC beams were not recentred between scans VII and VIII; however, there is a residual 2 micron non-reproducibility in the separation at peak $\mu_{\rm vis}^{\rm sp}$. This is shown in Figure 6 which compares the fitted peak position in the vertical plane for various LUCID algorithms in each scan. Any such offset in a given plane will lead to an underestimate in the peak $\mu_{\rm vis}^{\rm sp}$ in the scan profile of the orthogonal plane. This is found to contribute a systematic uncertainty on the measured $\sigma_{\rm vis}$ of 0.1%.

Figure 6 also shows a visible systematic difference for the 6 lowest bunches (81–301) relative to both the middle four (817–967) and the upper four (2602–2752). This is attributed to orbit cross-talk induced by beam-beam deflections at other IPs around the LHC ring. Bunches 81–301 were private to ATLAS and CMS, whereas the other groups of four also has the bunch from one beam colliding at LHCb and the bunch from the other beam colliding at ALICE.

μ Dependence

During both scans VII and VIII the measured μ ranges from close to zero at maximum beam separation to a maximum of 2.6 at zero separation. Uncertainties on the relation between detector response and μ in this range can directly affect the determination of $\sigma_{\rm vis}$. Figure 7 shows the consistency of μ measurements relative to BCMH_EventOR for various algorithms for the duration of the luminosity scan fill. They are consistent across the entire range to within $\pm 0.5\%$ which is taken as a systematic uncertainty due to algorithm μ dependence within the calibration LHC fill.

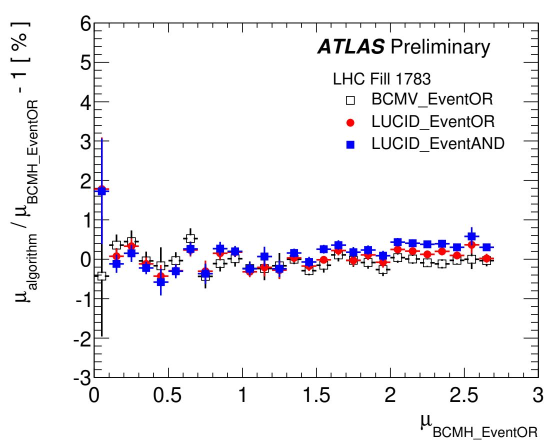


Figure 7: Relative deviation in measured μ between various algorithms and BCMH_EventOR as a function of μ for beam separation scan data in LHC fill 1783.

Non-Linear Correlations

An essential assumption of the luminosity scan technique of fitting independent functions in the horizontal and vertical planes is that the beam overlap profile transversely factorises. In 2010 when data were well described by the sum of two Gaussians a 'pessimistic' correlated fit model was applied to evaluate the associated systematic uncertainty due to this assumption [3]. This technique is arbitrary and given that the data from fill 1783 are not well described by the double Gaussian it is not clear whether its application is still appropriate. Comparison of the resulting uncertainty in different luminosity scans in 2010 and 2011, given in Table 3, shows at the very least that the value is highly fill dependent. There is potential in future scans to use vertex imaging of the luminous region to analyse this effect in more detail; however, this would require $\beta^* \sim$11 m so that measurement of the observed beam width will not be limited by the resolution of vertex reconstruction.

Table 3: Uncertainty derived from applying a transversely correlated double Gaussian model to luminosity scan data in various LHC fills.

Luminosity Scan	**Uncertainty [%]**
April 2010	3
May 2010	2
October 2010	0.9
May 2011	0.5

Length Scale Calibration

The determination of Σ_δ relies on the LHC 'nominal separation' determined by four closed orbit bumps; one for each beam and each transverse plane. This scale is cross-calibrated with a dedicated length scale scan at identical β^* to that in the calibration scan but in a different LHC fill. The length scale calibration scan at ATLAS proceeds as follows:

- One beam is moved by a nominal amount.
- It is followed by the other beam which is then scanned around the first beams to find the point of optimal beam-beam overlap.
- The beamspot position at this point calibrates the nominal movement of the first beam.
- This is repeated and a linear fit of the nominal separation as a function of the ATLAS length scale extracts the calibration constant for each bump.

In the luminosity scan itself the beams are scanned simultaneously in opposite directions, hence the overall separation scale is the average of the two beams in a given plane. The calibration yields a systematic uncertainty of 0.3% on $\sigma_{\rm vis}$. Non-linear residuals at the $\sim$0.2 micron level are observed in the calibration fits; however this provides a negligible additional uncertainty.

ATLAS Beam Separation Scan Systematic Uncertainties

Table 4 shows the summary of systematic uncertainties in the May 2011 luminosity scan which are measured directly by ATLAS. Comparison is made of the preliminary numbers in [4] to the current projected uncertainties for the full $\sim$5fb^{-1} 7 TeV proton-proton dataset from 2011. Additional sources of uncertainty compared to the preliminary result have been considered, as described above. The only additional contribution not described here is the effect of dynamic beta which is discussed elsewhere [6]. The dynamic beta uncertainty assigned in Table 4 assumes a contribution from collisions at ATLAS only. This turns out to be a dominant uncertainty for the scan. Another dominant uncertainty is inconsistency between BCMH and BCMV of 0.7%. This is observed in routine physics running and the cause is not currently understood. Overall the uncertainty has increased slightly compared to the preliminary result, mainly due to the additional contribution of dynamic beta uncertainty.

Table 4: Summary of systematic uncertainties from beam separation scan luminosity scale calibration in LHC fill 1783. Preliminary values [4] are compared to the projected uncertainty on the full $\sim$5fb^{-1} 2011 7 TeV proton-proton dataset. Projected numbers are currently being finalised and subject to change. Uncertainties not discussed in the text are described in [4]. Not shown here are the bunch current uncertainties for the calibration scan fill which are given in Table 5.

	Prelim. [%]	5fb^{-1}Proj. [%]
Beam Centring	0.1	0.1
Beam Jitter	0.3	0.3
Non-Reproducibility	0.4	0.8
Bunch Consistency	0.4	0.5
Fit Model	0.8	0.3
Background Subtraction	–	0.3
Reference $\mathcal{L}_{\rm spec}$	–	0.3
Dynamic Beta [6]	–	0.8
Non-Linear Correlations	0.5	0.5
μ-Dependence	0.5	0.5
Length Scale Calibration	0.3	0.3
Inner Detector Scale	0.3	0.3
BCM H/V Consistency	0.7	0.7
Total ATLAS	1.5	1.75

MONITORING OF LUMINOSITY CALIBRATION STABILITY

The luminosity calibration for 7 TeV proton-proton running at ATLAS in 2011 is determined using data from a single LHC fill with peak $\mu < 2.6$ and relatively few colliding bunches. It is therefore necessary to confirm the calibration is stable for all 2011 proton-proton LHC fills, and that detector response as a function of μ is stable for all ranges observed in 2011: $2.5 < \mu < 18$. The ATLAS strategy for evaluating these potential sources of uncertainty is to partially separate the two effects and monitor the consistency of luminosity measurements from independent detectors to evaluate the magnitude of each.

Luminosity from Calorimeters

For redundancy, detectors whose response is proportional to luminosity, other than BCM and LUCID, are desirable for cross-checks of the luminosity calibration stability. To this end in 2011 ATLAS has made use of both the PMT current drawn in the Tile Calorimeter (TileCal) and the current drawn across liquid argon gaps in the Forward Calorimeter (FCal) [1, 4]. Both detectors are cross-calibrated to a known luminosity algorithm at a specific time; TileCal is calibrated to LUCID_EventOR at peak μ in LHC fill 1783; FCal is calibrated to BCMH_EventOR for a wide range of μ in LHC fill 2086 (discussed below). These calibrations are then extrapolated to other LHC fills allowing stability monitoring. It should be noted that unlike BCM and LUCID the TileCal and FCal do not have bunch by bunch capability and hence only measure $\langle\mu\rangle$, the average μ across all luminous bunches in a fill.

μ Dependence

Physics running in 2011 covered a large range of $\langle\mu\rangle$ which means in principle the stability of luminosity calibration as a function of μ can be determined from examination of all 2011 data. However, this approach is ambiguous if one wants to decouple effects due to detector stability in time, such as aging, from those explicitly related to the μ correction itself. In order to remove this ambiguity a dedicated analysis is made at ATLAS in LHC fill 2086, which is a regular physics fill consisting of 873 colliding bunches colliding at ATLAS with peak $\mu \sim 12$. During this fill the LHC beams were separated and then brought back into collision at the ATLAS IP, therefore effectively scanning a wide range of μ.

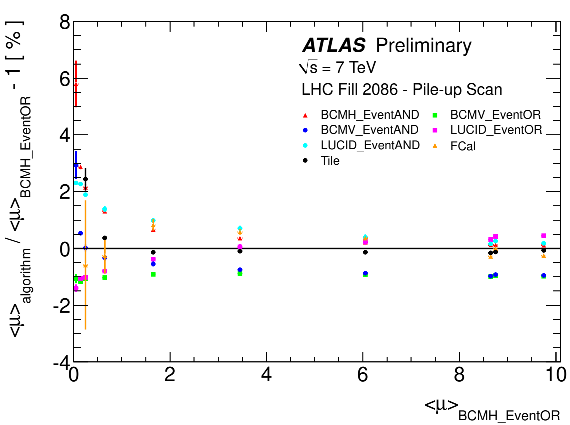


Figure 8: Fractional comparison of $\langle\mu\rangle$ measured with various detectors and algorithms to BCMH_EventOR as a function of $\langle\mu\rangle$ in a single physics fill. For $\langle\mu\rangle > 2$ all algorithms are consistent within $\pm 1\%$.

Figure 8 shows a comparison of the relative deviation of measured $\langle\mu\rangle$ relative to BCMH_EventOR for various detectors and algorithms. The FCal is calibrated to BCM in this fill so observed deviations are due to residual non-linear effects in its luminosity response. The discrepancy of BCMH and BCMV of 0.7% discussed above is clearly visible. It can also be seen that for $\langle\mu\rangle < 2$ EventAND algorithms diverge by up to 2% in contrast to their response at higher $\langle\mu\rangle$ which is flat. This is currently the subject of further investigation. The limit in understanding of luminosity scale at low $\langle\mu\rangle$ during physics running is not discussed here; however, ongoing analysis is underway to improve understanding, particularly in the context of luminosity uncertainty for the ALFA experiment [7]. In the range of $\langle\mu\rangle$ of interest for the majority of 2011 proton-proton physics running the consistency between algorithms is observed to be no worse than $\pm 1\%$ which is assigned as a systematic uncertainty due to μ dependence.

Long Term Stability

The long term stability of detectors and algorithms can be determined through investigation of their consistency through the entire 2011 7 TeV proton-proton running period.

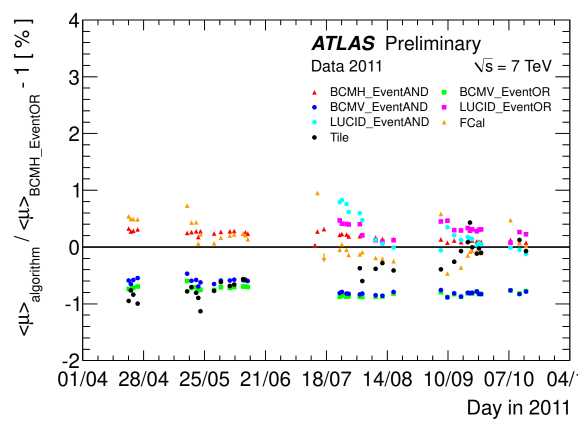


Figure 9: Fractional comparison of $\langle\mu\rangle$ measured with various detectors and algorithms to BCMH_EventOR as a function of day in 2011. Each point represents a single ATLAS data acquisition run and all algorithms are consistent to within $\pm 1\%$.

Figure 9 shows the relative deviation in $\langle\mu\rangle$ of various algorithms compared to the $\langle\mu\rangle$ measured by BCMH_EventOR, with each point representing the average luminosity from a single ATLAS stable data acquisition period (run). It can be seen that all algorithms and detectors are consistent within $\pm 1\%$. Although the deviations here are not strictly independent of the μ dependence discussed above, the observed deviation is treated as an additional independent uncertainty. The 0.7% offset between BCMH and BCMV algorithms is seen to be stable across the course of the year.

Collision Induced Radiation

Figure 10 shows the response of LUCID_EventOR and BCMH_EventOR for a physics fill in June 2011 as a function of bunch crossing. It can be seen that non-colliding bunches in a bunch train have a response of 0.5% (1%)

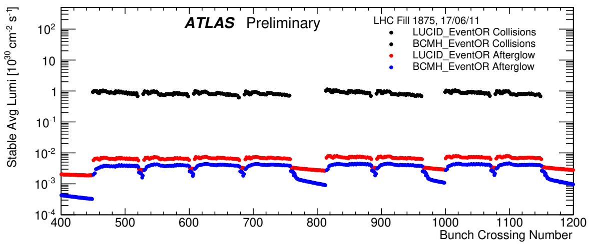


Figure 10: Observed luminosity averaged over LHC fill 1875 as a function of the bunch crossing number for the LUCID_EventOR and BCMH_EventOR algorithms. The small "afterglow" luminosity present in crossings where no bunches are colliding is the result of induced activity seen in the detectors.

relative to bunches with collisions for BCMH_EventOR (LUCID_EventOR). The activity is proportional to instantaneuos luminosity, stable across the train and decays exponentially between trains, suggesting it is dominated by collision induced radiation; it is subtracted from colliding bunches in physics running to a precision of 0.2% by inferring its level from adjacent empty crossings.

OVERALL 2011 7 TeV LUMINOSITY CALIBRATION UNCERTAINTY

The overall luminosity scale uncertainty at ATLAS is derived from the quadrature sum of the uncertainty due to the beam separation calibration and the uncertainty related to luminosity monitoring in physics running conditions over the course of 2011. Table 5 summarises the current status of the luminosity scale uncertainty for 2011 7 TeV proton-proton data and compares it to the preliminary results in [4]. It can be seen that the expected uncertainty has been reduced, primarily due to improvement in the determination of beam currents during the beam separation scan which is discussed in detail elsewhere [8]. Consequently uncertainties from both the ATLAS analysis of calibration data and monitoring of calibration stability now dominate the

Table 5: Summary of all systematic uncertainties for the ATLAS luminosity scale in 2011 7 TeV proton-proton data. Preliminary values [4] are compared to the projected uncertainty on the full ~5fb^{-1}dataset. Projected numbers are currently being finalised and subject to change.

	Prelim. [%] Apr-Aug 2011	5fb^{-1} Proj. [%] Apr-Oct 2011
Bunch Current [8]	3.0	0.35
ATLAS Calibration	1.5	1.75
μ-Dependence	1.0	1.0
Long Term Stability	1.0	1.0
Afterglow	0.2	0.2
Total	3.7	2.3

projected uncertainty with almost equal contribution. The final uncertainty is approaching a level of $\sim 2\%$; however, it is again stressed that the numbers presented here are not final and subject to change.

PROSPECTS FOR 2012 LUMINOSITY CALIBRATION

There is no reason to expect the current improvement in accuracy of bunch current measurements to deteriorate in 2012 hence the calibration uncertainty in 8 TeV collision data is again likely to be dominated by calibration scan analysis and long term monitoring. In 2012 ATLAS expects to calibrate additional detector subsystems for long term monitoring such as the muon spectrometer resistive plate chambers [1], thus improving the available monitoring redundancy. Collision data in 2012 is projected to have significantly higher $\langle\mu\rangle$ values; preliminary analysis of data from a dedicated high pileup LHC fill with $\mu > 30$ in 2011 suggests that current algorithms will remain consistent to within 1% for this increased range. The commissioning of so called 'hit-counting' algorithms for LUCID will allow their use where current event counting algorithms saturate due to zero-starvation at higher μ.

To a large extent it is expected that the luminosity scale uncertainty for ATLAS in 2012 with be uncorrelated with the final 2011 uncertainty. This is because the majority of uncertainties in the calibration scan are completely dependent on the beam conditions in the associated fill and thus independent between different calibration fills [3]. Furthermore luminosity monitoring uncertainties only apply to the data under consideration so no correlation between monitoring uncertainties in 2011 and 2012 will exist.

CONCLUSIONS

In 2011 ATLAS has focused on obtaining a precision luminosity scale calibration for 7 TeV proton-proton data. Recent improvement by an order of magnitude in the LHC bunch current uncertainty has resulted in the uncertainty on luminosity scale at ATLAS approaching $\sim 2\%$. This value is driven almost equally by calibration uncertainties from analysis of a beam separation scan LHC fill in May 2011 and by the uncertainty in applying that calibration to physics running throughout the year. The precision of luminosity calibration in 2012 is expected to be comparable to 2011; however, the uncertainty on luminosity scale in the respective datasets will be largely uncorrelated.

REFERENCES

[1] ATLAS Collaboration, JINST **3** (2008) S08003.

[2] ATLAS Collaboration, Eur. Phys. J. **C71** (2011) 1603.

[3] ATLAS Collaboration, ATLAS-CONF-2011-011 (2011), `http://cdsweb.cern.ch/record/1334563`

[4] ATLAS Collaboration, ATLAS-CONF-2011-116 (2011), `http://cdsweb.cern.ch/record/1376384`

[5] S. van der Meer, CERN-ISR-PO-68-31 (1968).

[6] W. Herr, LHC Lumi Days 2012, these proceedings.

[7] K. Hiller, LHC Lumi Days 2012, these proceedings.

[8] LHC Bunch Current Normalisation Working Group, LHC Lumi Days 2012, these proceedings.