Instantaneous luminosity measurement of the ATLAS experiment with $Z \to \mu^+\mu^-$

Harish Potti, Peter Onyisi

2017 Division of Particles and Fields meeting

July 31, 2017

TEXAS

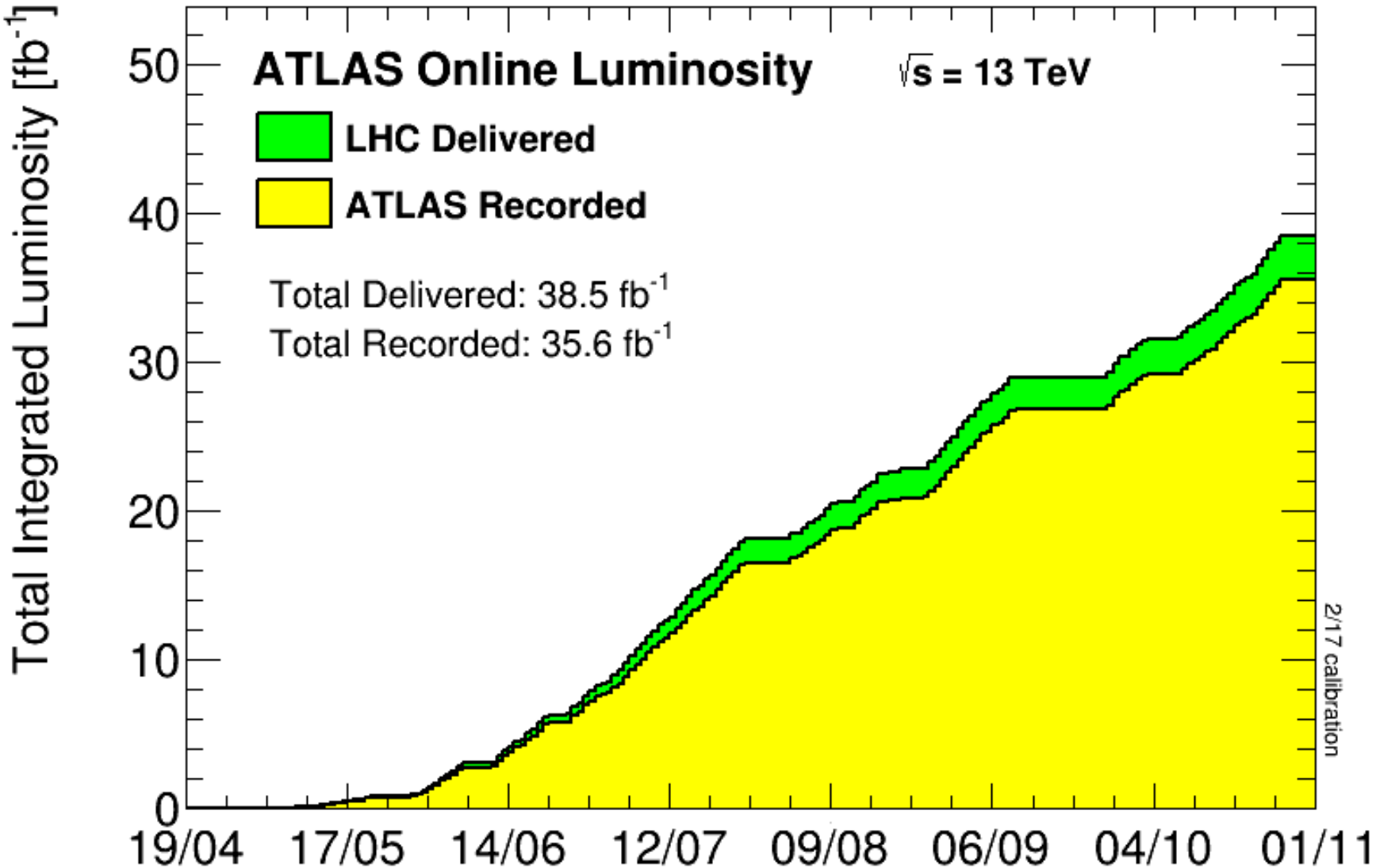
The University of Texas at Austin

ATLAS EXPERIMENT

Introduction

- Precise luminosity measurement is a crucial ingredient for almost all measurements at the Large Hadron Collider
- ATLAS experiment uses many different algorithms and sub-detectors to measure luminosity
- Absolute calibration of these algorithms is performed using van der Meer (vdM) method
- For more details on these measurements, see this document arXiv : 1608.03953
- For the 2016 data, total uncertainty on the ATLAS luminosity measurement $= \pm$ 2.2%

Luminosity recorded by the ATLAS experiment in 2016



Motivation

- For a long time, collider physicists have wanted to calibrate luminosity using a common, well-understood physics process
- This can be achieved with $Z \rightarrow \mu\mu$ process as it has following advantages
  - Very small background
  - high yield - O(1k events)/minute at the design luminosity of LHC
  - cross-section for the process is known at the level of NNLO

Features of the luminosity measurement from Z counting

- Leading systematic uncertainties on the Z luminosity measurement are completely distinct compared to the ones on official ATLAS luminosity measurement
- Process is self-calibrating; efficiencies for muon detection and triggering are obtained from the same Z sample used for luminosity measurement
- Measurements can be obtained in short time scales with reasonable statistical uncertainties
- Yields of $Z \to \mu\mu$ events in a fiducial region could be used as a cross check to luminosity measurements between ATLAS and CMS experiments

Method - 1

Number of reconstructed $Z \to \mu\mu$ events (N_{rec}) is given by

$$N_{rec} = \sigma(Z \to \mu\mu) \times A \times \int C(t) \times \mathcal{L}(t) \times F(t)\, dt$$

where,

- σ = cross-section
- A = Acceptance = Fraction of $Z \to \mu\mu$ events satisfying kinematic selections of the analysis at the truth level
- C = efficiency correction factor (accounts for trigger and reconstruction efficiencies)
- $\mathcal{L}$ = Instantaneous luminosity
- F = fraction of the time the detector is ”live”

Method-2

- On smaller time scales, all factors other than F are approximately constant $\Longrightarrow$

$$\mathcal{L} = \frac{N_{rec}}{\sigma \times A \times C \times \bar{F}\Delta t}$$

  Where, $\bar{F}$ = mean live fraction over the time interval Δt

- Rate of $Z \to \mu\mu$ events produced in a fiducial phase space =

$$R_{fid} \equiv \mathcal{L} \times \sigma \times A = \frac{N_{rec}}{C \times \bar{F}\Delta t}.$$

- Fiducial yield rate (R_{fid}) can be measured without any theoretical uncertainties and can be compared directly between ATLAS and CMS experiments

Fiducial region definition

Fiducial region definition

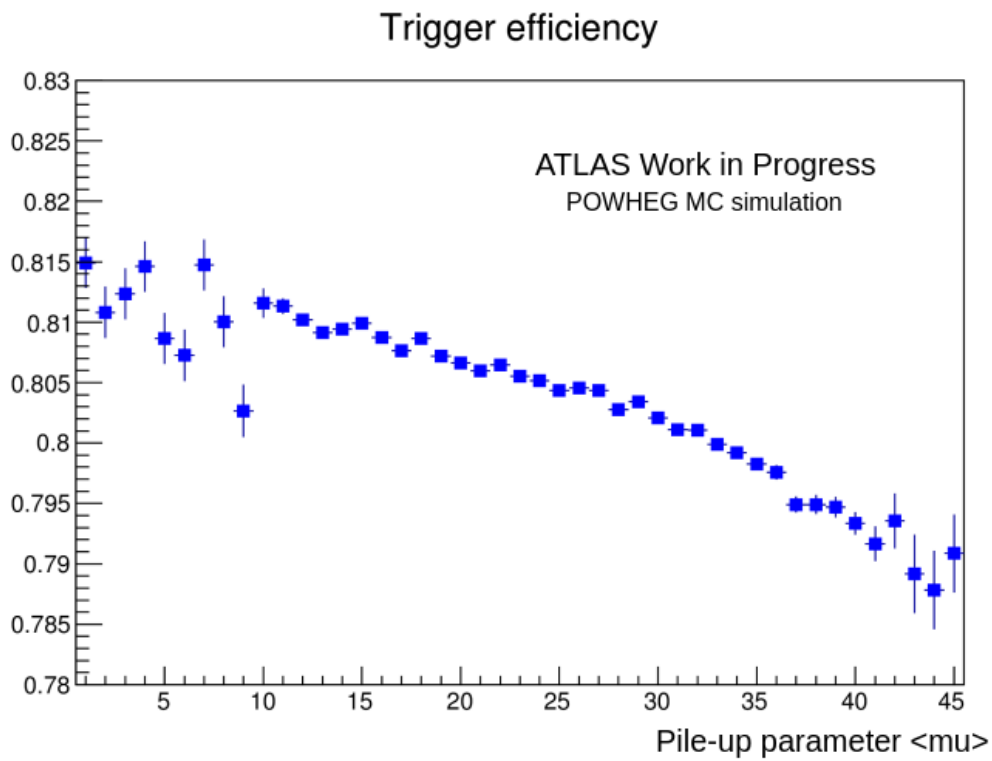
- $p_{\mathrm{T}}(\mu) > 27$ GeV, motivated by the plateau of single muon trigger turn-on curves
- 66 GeV $< m(\mu^+\mu^-) <$ 116 GeV, the same window used by the Zboson cross-section measurement
- $|\eta_\mu| < 2.4$, motivated by the coverage of the ATLAS muon trigger detectors

Acceptance (A) for the fiducial region is calculated using the PowHeg Monte Carlo simulation.
A = 33.2%

Trigger efficiency ϵ_{trig} measurement

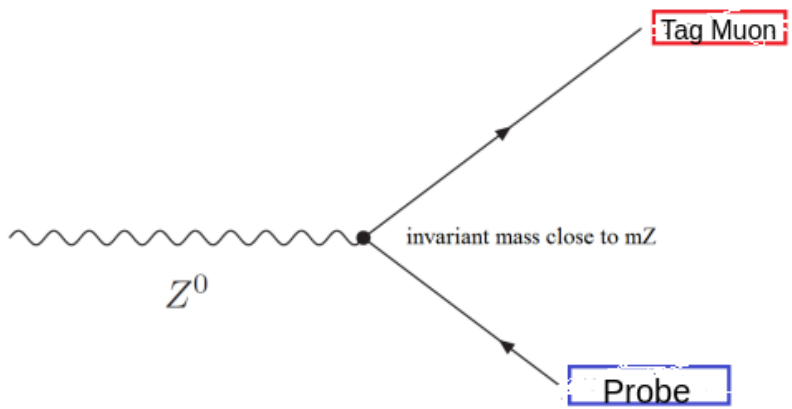
Description	Total Number
Total $Z \rightarrow \mu\mu$ events produced in Data	N (Unknown)
only one muon fired trigger events (N_1)	$2 \times N \times \epsilon_{trig} \times (1 - \epsilon_{trig})$
Both muons fired trigger events (N_2)	$N \times \epsilon_{trig}^2$

- Per muon trigger efficiency = $\epsilon_{trig} = \frac{1}{N_1/2N_2+1}$
- Event trigger efficiency = $C_{trig} = 1 - (1 - \epsilon_{trig})^2$



Reconstruction efficiency

- Reconstruction efficiency (ϵ_{reco}) is the efficiency that a muon is identified by the ATLAS detector
- In ATLAS experiment, muon tracks are independently reconstructed in the Inner Detector(ID) and Muon Spectrometer(MS), which are then combined
- ϵ_{reco} is measured with these independent track reconstructions with a method called "Tag and Probe"

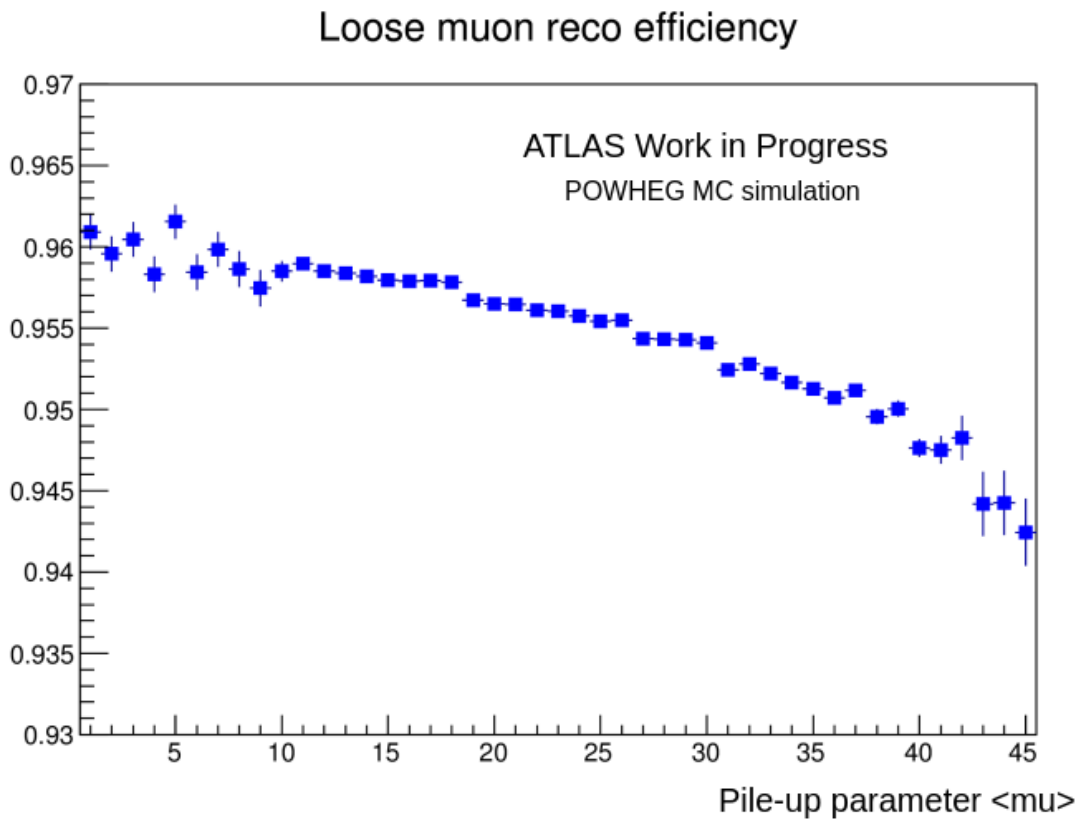


Reconstruction efficiency - 2

- Tag : Muon reconstructed by both the ID and MS and fires trigger
- Probe is an ID track such that invariant mass of Tag Muon + ID track $\in$ (86,96) GeV
- MS efficiency = $\dfrac{\#\ probes\ with\ a\ matching\ track\ in\ MS}{Total\ number\ of\ Probes}$
- Events with same-sign tag and probe pair are used for estimating the background in the ID
- Efficiencies for isolation and muon quality are calculated in a similar way using Tag & Probe method
- Event reconstruction efficiency = $C_{reco} = \epsilon^2_{reco}$

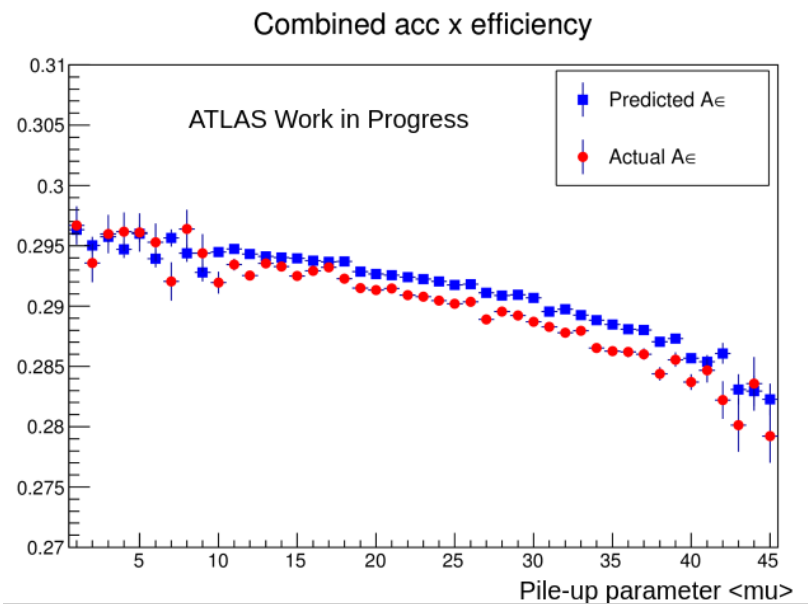
Reconstruction efficiency - 3

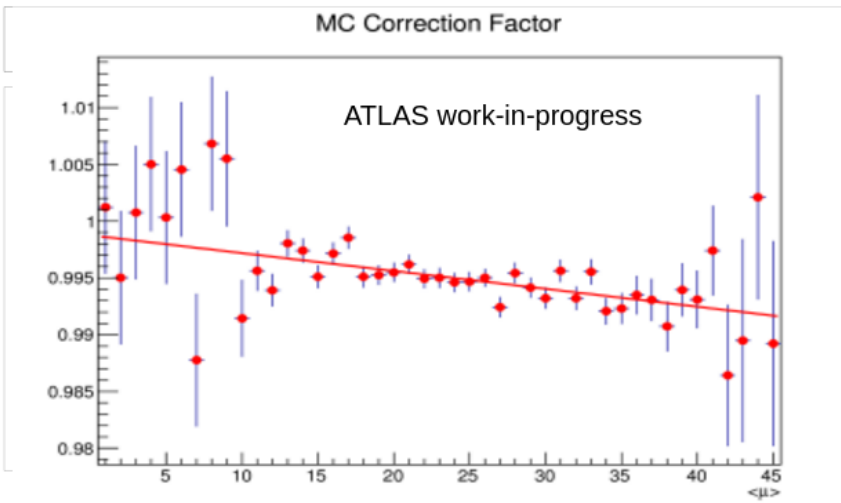
- Muon reconstruction efficiency as a function of pile-up is shown here for POWHEG MC simulation



Monte Carlo closure

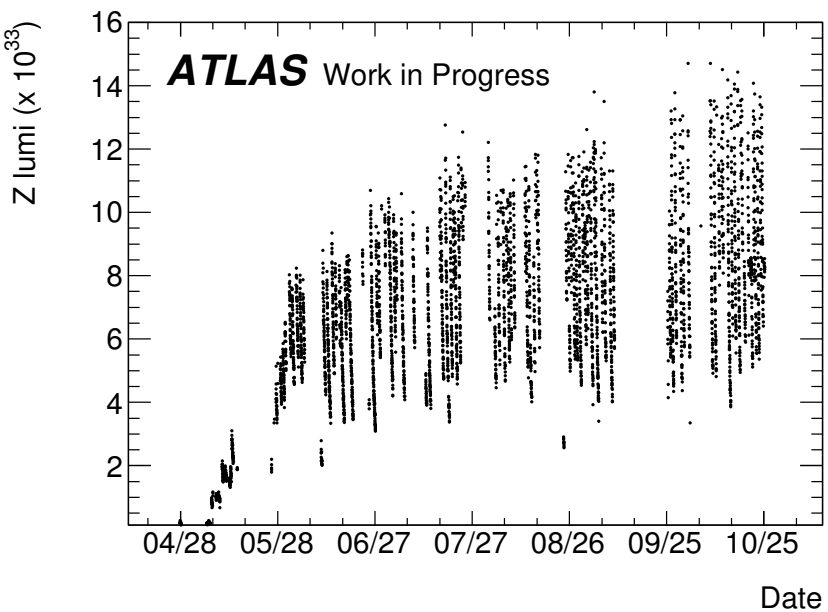
- Product of Acceptance and efficiency correction factor is plotted for direct measurement from MC (actual) and T&P measurement (predicted)
- Ratio between the two is applied as a correction factor to tag-and-probe measurement

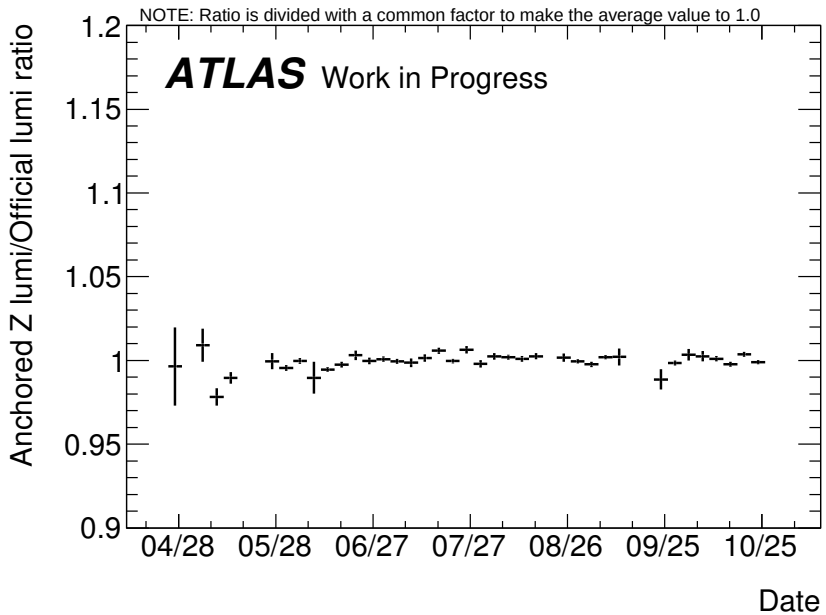




Results

- Z luminosity results for full 2016 ATLAS data are presented here
- Results are in good agreement with the official ATLAS luminosity





Summary

- Preliminary results of luminosity measurement from $Z \to \mu\mu$ has been presented
- We are running this analysis on the standard reconstruction chain of ATLAS experiment. People are using this measurement for validation of 2017 results
- Work in progress : Finalize systematic uncertainties on the current measurement