The Ratio of Z(→ μμ) + jets to γ + jets production at the ATLAS Detector

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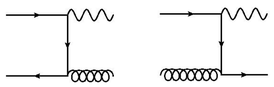
Abstract:
The ratio of Z(→ μμ) + jets to γ + jets events can be used as an excellent test of the Standard Model. At high vector boson p_T (>>M_Z), the event kinematics for the two processes are the same with the difference in cross sections due mainly to the different boson-quark couplings. The theory prediction of this ratio, as described in the JHEP, vol. 2011 no. 10, pp. 058 paper by S. Ask et al, should be insensitive to effects from the event simulation. Furthermore, Z(→ μμ) + jets is an irreducible background for beyond the Standard Model searches at the LHC. Calculating the ratio of Z(→ μμ) + jets to γ + jets allows γ + jets data to be used to calibrate this background. The work of S. Ask et al. is explained and the results summarized. To confirm the theoretical predictions, the 2011 data is analyzed with Release 17 standard cuts and implementation. Full Z inclusive analysis code is written to select Z(→ μμ) + jets events from Run periods D-M of the data. The cuts suggested for the Z inclusive analysis are used. The inclusive photon analysis code from the Argonne National Laboratory ATLAS ASC group is modified to include a γ + jets requirement. Similar jet cuts are applied in both analyses. The ratio of the two results will be taken.

Objectives

Reconstruct the ratio of Z+Jets/γ+Jets ratio in the 2011 ATLAS data and compare with the Standard Model prediction of JHEP, vol. 2011 no. 10, pp. 058

Motivation

Finding a ratio of vector boson production in the ATLAS detector should be a good test of the Standard Model predictions of electroweak boson-hadron production. Such a ratio should depend only on the EWK couplings (see Feynman diagrams below) and therefore provides the advantages of cancelling many systematic effects between the two processes for both the theory and experiment. The PDF uncertainties will cancel as well as luminosity and most of the jet corrections. Furthermore, by using Z + jets and .γ + jets, there is the advantage of having possible background estimation. Z(→νν) is an important background for new physics searches that consider missing Et. By establishing a ratio of Z + jets to .γ + jets events, photon data can be used to estimate this important background. Such a data-driven technique is already in use at CMS.



Introduction

In the Standard Model, the couplings of photons and Z bosons to quarks are:

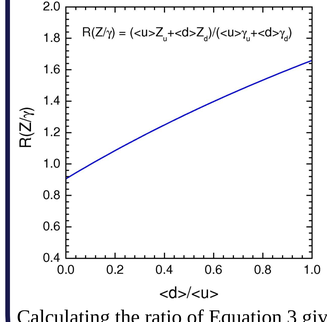
$$-ieQ_q\gamma^\mu \quad \text{and} \quad \frac{-ie}{2\sin\theta_W\cos\theta_W}\gamma^\mu(v_q - a_q\gamma^5) \qquad \text{Eq. 1}$$

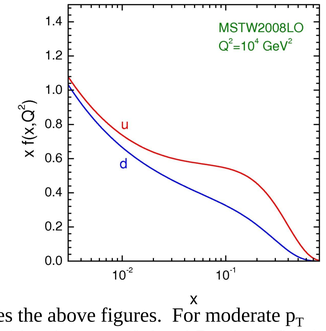
The only other difference in the matrix elements comes from the Z boson mass, which becomes negligible for high vector boson p_T (>> M_Z). Consequently, we expect the ratio of Z to γ cross-sections to be:

$$R_q = \frac{v_q^2 + a_q^2}{4\sin^2\theta_W\cos^2\theta_W Q_q^2} \qquad \text{Eq. 2}$$

Upon substituting numbers, this yields ratios of $R_u = 0.906$ and $R_d = 4.673$
The real ratio will be a weighted average of these two, as it receives contributions from all quark flavors:

$$R = \frac{Z_u\langle u\rangle + Z_d\langle d\rangle}{\gamma_u\langle u\rangle + \gamma_d\langle d\rangle} \qquad \text{Eq. 3}$$

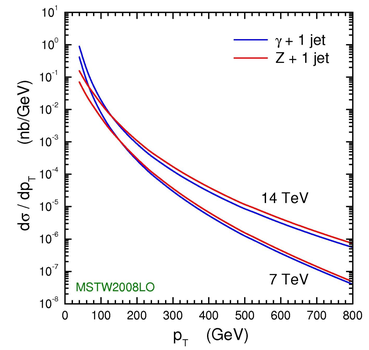


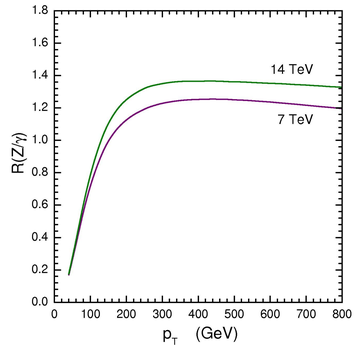


Calculating the ratio of Equation 3 gives the above figures. For moderate p_T values at the LHC, <x> ~ 0.1, which yields <d>/<u> ≈ 0.6 and R ≈ 1.4. This is our expected value of the ratio.

Simulation Predictions

Though 1, 2, and 3 jet cases were considered in the paper, only the 1 jet case is presented here. To simulate these processes, we used a leading-order parton level matrix element program called Gambos. The results are presented below:

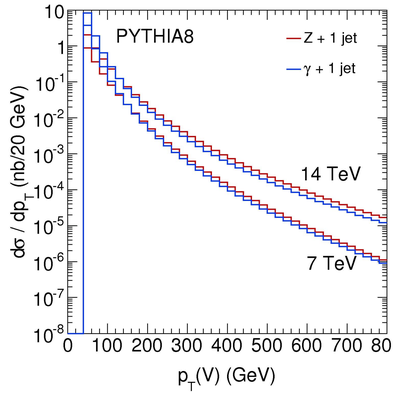


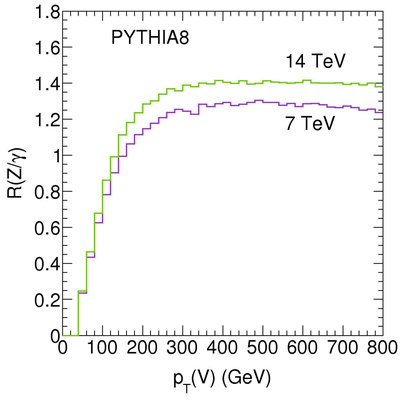


The MSTW2002LO PDF set was used, as well as acceptance cuts of $p_T(V,j) > 40$ GeV and $|y(V,j)| < 2.5$

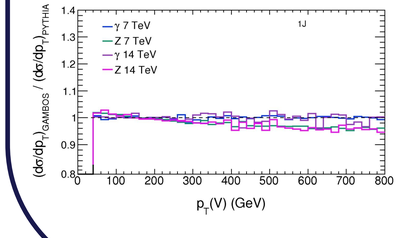
The ratio at √s of 14TeV fits the prediction of 1.4, as expected. At √s of 7TeV, the ratio is suppressed due to the predominance of up quarks in the PDFs at lower energies.

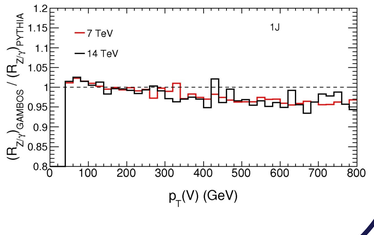
The same calculation was done using the PYTHIA8 LO processes: $q\bar{q} \rightarrow Vg$ and $qg \rightarrow Vq$.





Gambos and PYTHIA8 were compared by taking a ratio of their results, presented below. The programs give remarkably good agreement. The slight difference is due to the way in which the Z boson is treated in each program. The theory program treats the Z as a real particle, while the MC treats it as a resonance. This yields ~5% difference in the Z cross section.





First Steps with Data

Z(→μμ) + jets

Event Selection:
- •GRL: periods D to M
- •Trigger: EF_mu18_EM
- •Primary vertex selection

Good Muon Selection:
- •Muon Selection from W/Z and EWK Common Topics
- •mu_staco_pt > 25 GeV
- •|mu_staco_eta| < 2.4
- •Isolation: mu_staco_ptcone20/mu_staco_pt < 0.1

Jet Selection:
- •AntiKt4TopoEM jets
- •LOOSER jet cleaning cuts
- •Pile-up removal (|JVF| > 0.75 for |η| < 2.4)
- •Overlap removal with muons: ΔR > 0.5
- •pT(Jet) > 80 GeV
- •|y(Jet)| < 1.37

Z Selection:
- •Require two good muons of opposite charge
- •66 GeV < InvMass of two muons < 116 GeV
- •|y(Z)| < 1.37
- •pT(Z) > 100 GeV

γ + jets

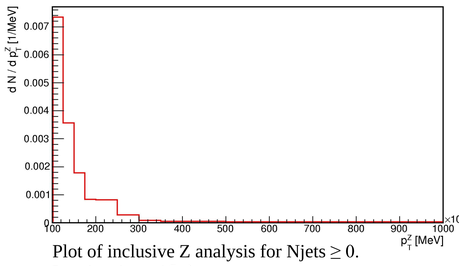
Event Selection:
- •GRL: full data set
- •Trigger:100 GeV photon
- •Primary vertex selection

Good Photon Selection:
- •Require tight photons
- •7 GeV photon isolation
- •Energy correction
- •Background subtraction via ABCD method

Jet Selection:
- •AntiKt4TopoEM jets
- •Standard jet cleaning cuts
- •Overlap removal with photons: ΔR > 0.1
- •pT(jet) > 80 GeV
- •|y(jet)| < 1.37

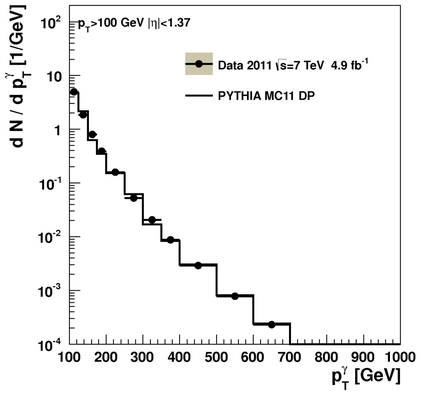
Photon Selection:
- •|y(Z)| < 1.37
- •pT(Z) > 100 GeV

Inclusive dN/dpT Plot for Z Bosons:



Plot of inclusive Z analysis for Njets ≥ 0.
Luminosity ~ 1fb^{-1}

Inclusive dN/dp$_T$ Plot for Photons:



Plot of inclusive photon analysis for Njets ≥ 0.

Notes about these two plots:
- •The Z plot is in MeV and the Photon plot is in GeV
- •They are NOT the same integrated luminosity.

Next Steps: The Z analysis needs to be re-run over the same data set as the Photon analysis. Then a jet requirement (Njets ≥ 1) needs to be put in place. Once the two plots have the same integrated luminosity, a rough ratio can be taken to determine if the shape looks comparable to the theory study. After that, further work on efficiencies and normalization needs to be done to allow true comparison to the theory study. Comparison to MC should also be done.

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