A first look at Z + jet events in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the CMS detector

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Abstract

An initial phase of data analysis was conducted to find Z + jet events using the $Z \rightarrow \mu\mu$ channel in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. Various cuts were used to select the Z + jet events from the data. From the Z + jet events, the ratio of transverse momentum between the Z and the jet was calculated to search for jet quenching. As the analysis is still in the initial phase and uses confidential data from the CMS Collaboration, my supervisors and I decided not to include any detailed results.

Introduction

The research goal of the Heavy Ion Group in CMS is to better understand a state of matter called the quark-gluon plasma (QGP). This state of matter is created at extremely high temperatures and densities, and is experimentally accessible in relativistic heavy ion collisions. QGP was also present in the early universe, milliseconds after the big bang. Currently, there are theories that explain the interactions in the QGP, but there are still aspects that are not quite well understood [1, 2]. In the LHC, it was shown through the suppression of high-p_T hadron production relative to a proton-proton (pp) baseline [3], and by other means [4], that QGP was created in lead-lead (PbPb) collisions.

My summer project at CERN focused on analysing proton-lead (pPb) collision data from early 2013. The aim was to have a first look at Z + jet events, with the Z bosons reconstructed from the dimuon channel, pPb $\rightarrow Z$ + jet and $Z \rightarrow \mu\mu$. In the analysis, Z + jet events from data and simulation were selected using various kinematic cuts. For the Z + jet events, the transverse momentum ratio of the Z boson and the corresponding jet was calculated. A systematic deviation of the ratio between data and simulation would indicate the presence of QGP.

Note: This project has gone through an initial phase of data analysis. As the results are preliminary, and may be included in a future publication, my supervisors and I have decided to omit the detailed event selections and the analysis plots. Please consult Lamia Benhabib, Krisztian Krajczar or Gabor Veres from the CMS Heavy Ion Group for further information.

Motivation for Z + jet events in pPb

The QGP is a medium where quarks and gluons have sufficiently high temperatures and densities that they become deconfined. Since the medium contains asymptotically free quarks, colour charged partons that traverse the medium are affected by the QGP via the strong interaction. As the partons subsequently hadronise into jets, we see the jets also being modified relative to a reference sample where no QGP effects are present. Experimentally the modification manifests itself as a suppression of high-p_T jet production, which is usually referred to as jet quenching. The Z + jet event is hailed as one of the golden channels to study jet quenching, because the jet is affected by the medium and the electroweak Z boson is not. The ATLAS experiment had confirmed a preliminary result on jet quenching in the Z + jet and $Z \rightarrow \ell\ell$ channel in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV [5].

It was demonstrate, through jet quenching studies and other means, that QGP is formed in PbPb collisions in the LHC. However, due to the smaller interaction volume in pPb collisions, it is not clear if any QGP effect would be seen. Preliminary studies of dijet events [6] and isolated photon and jet events [7] in pPb collisions with CMS indicate that there is no jet quenching. We are motivated to search for pPb $\rightarrow Z$ + jet with $Z \rightarrow \mu\mu$ because the dimuon channel provides a clean signal for the Z. A drawback, however, is the lack of statistics in the 2013 pPb dataset. The analysis procedure could be applied to the next pPb run when the LHC is up and running again in early 2015.

Data and simulation

The analysis was performed on the pPb data taken in the early 2013. The dataset corresponds to an integrated luminosity of (34.6±1.2) nb^{-1}. The beam energies were 4 TeV for protons and 1.58 TeV per nucleon for lead nuclei, giving a centre of mass energy per nucleon pair of $\sqrt{s_{NN}} = 5.02$ TeV. The direction of the proton and lead beams were reversed during the run, giving two comparable sized datasets. The data analysed is the combination of the two samples.

The PYTHIA + HIJING Monte Carlo (MC) simulation for pPb $\rightarrow Z$ + jet with $Z \rightarrow \mu\mu$ was used to give a comparison to data. Z + jet signal events from PYTHIA were embedded into HIJING minimum bias pPb background, giving a total of 250,000 events. The simulation served as a benchmark as it did not contain any QGP effects.

Both the data and the simulation were processed into the Forest (ROOT TTree) data format. The analysis was then conducted using the ROOT data analysis package.

Event selection

The overall event selection procedure for pPb $\rightarrow Z$ + jet with $Z \rightarrow \mu\mu$ is outlined in Figure 1. Due to the confidential nature of the unpublished material, the Z + jet event selection procedure is not outlined in detail.

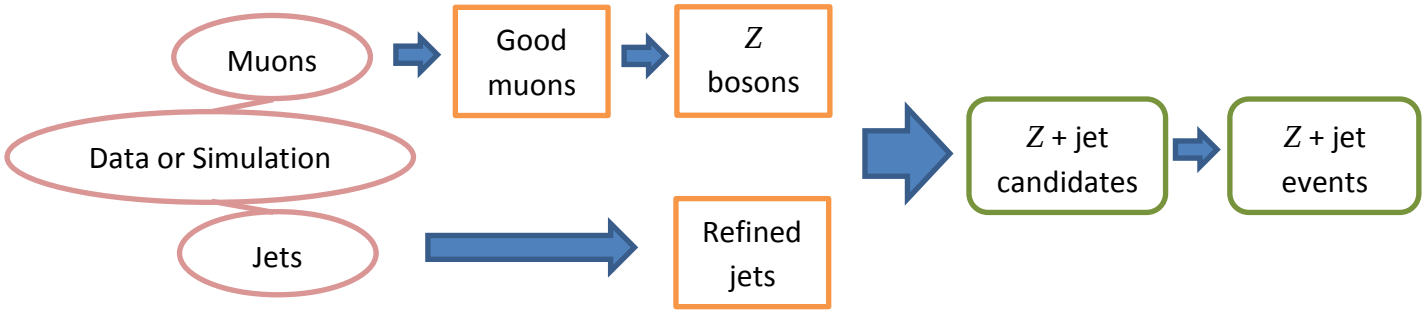

Figure 1. Flow diagram of analysis procedure for pPb $\rightarrow Z$ + jet and $Z \rightarrow \mu\mu$.

Firstly, the Z boson was reconstructed from two oppositely charged muons from the same event. Each of the muons had to pass the standard "Good Muon" selection[1]. Further transverse momentum, $p_{T,\mu} > 20$ GeV, and pseudorapidity, $|\eta_\mu| < 2.4$ cuts were applied. The Z candidate was reconstructed by combining the two muons, and accepted if it had an invariant mass between 60 GeV and 120 GeV.

Since the only high-p_T products of the collision are the Z boson and the jet, the Z and the jet is expected to exhibit back-to-back correlation in the transverse plane. The jets are processed from the events that contain a Z. Before the selection of correlated Z + jets, a cut on jet $p_{T,J}$ and $|\eta_J|$ were applied. A selection using the azimuthal angle between the Z and the jet, $\Delta\phi_{J,Z}$, was used to search for back-to-back correlated Z and jets candidates. Further improvements to reduce the background and to find the Z + jet events were implemented by imposing additional cuts on Z and $\Delta\phi_{J,Z}$.

Results

The invariant mass distribution of the dimuons is plotted in Figure 2. Data and simulation correspond and both peak at the around 90 GeV. There is seemingly no background contribution to the Z bosons. The total number of Z bosons and its invariant mass distribution is in agreement with the previous analysis done on the current pPb dataset [8].

[1] "Good Muon" selections are validated by the muon Physics Object Group for Z in pPb.

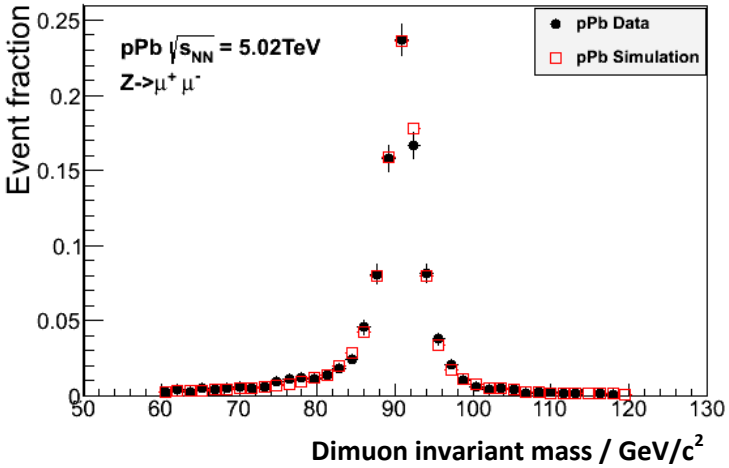

Figure 2. Dimuon invariant mass distribution.

Here we only outline the results for the selection of back-to-back Z + jet events. To motivate our selections for back-to-back Z + jet events we looked at various $p_{T,Z}$, $p_{T,J}$ and $\Delta\phi_{J,Z}$ distributions. Cuts were applied accordingly to select a clean Z and the jet sample. Furthermore, we tried to quantify the loss of statistics in the selection procedure by looking at fraction of Z bosons with a jet partner against bins of $p_{T,Z}$. Finally the p_T imbalance distributions, $p_{T,J}$ / $p_{T,Z}$ were visualized for different jet reconstruction cone sizes. It was found that the cone size did have a significant effect on the mean of the p_T imbalance ratio.

Conclusions

An initial phase of data analysis was conducted to find Z + jet events with $Z \rightarrow \mu\mu$ in pPb at $\sqrt{s_{NN}} = 5.02$ TeV. Z + jet events were selected from the data and simulation, and their p_T imbalance distributions calculated to see if there was any jet quenching relative to a simulated reference.

Currently, as the analysis is still in the initial phase, there are still several aspects in which we can improve our analysis procedure. In the short term, the goal should be validating the simulation. Potential issues in vertex matching in the embedding process and the jet energy scale should be checked. Furthermore, improvements to the Z + jet selection process could be investigated. These include elimination of high p_T muons that are misidentified as jets and considering systematic uncertainty in muon selection, jet energy scale corrections, etc.

Acknowledgements

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