Eur. Phys. J. C 49, 19–22 (2007)
DOI 10.1140/epjc/s10052-006-0114-5

THE EUROPEAN
PHYSICAL JOURNAL C

Regular Article – Experimental Physics

Dilepton tagged jets

C. Mironov[a], P. Constantin, G.J. Kunde

Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Received: 3 August 2006 /
Published online: 8 November 2006 –

Abstract. We present simulation studies of a possible jet measurement at LHC using the leptonic decay of a high transverse momentum virtual photon/Z^0 in association with a quark/gluon jet. The interested production channels are $q+\overline{q} \to Z^0/\gamma^* + g$ and $g+q \to Z^0/\gamma* + q$ with the subsequent $Z^0/\gamma* \to \mu^- + \mu^+$ decay. The total energy of the jet is highly correlated to that of the dilepton coming from the Z^0/γ^* decay. The jet can be considered in this case as tagged (i.e. a dilepton-tag) with a known energy. Based on momentum balance between the dilepton (whose energy is not modified by the medium) and the jet (which does suffer energy loss in the medium), the angular correlation analysis that we plan to perform can shed light on the properties of the medium traversed (e.g. density) and parton fragmentation functions.

1 Introduction

With the advent of the large hadron collider (LHC), the field of relativistic heavy ion collisions will enter a new era – the detailed study of the novel form of matter discovered at lower collision energies at RHIC [1]. An important tool in the study of this medium will continue to be the measurement of dijets via leading hadron correlations [2]. In particular, two hadron *azimuthal* correlations allow the study of back-to-back hard scattered partons that propagate in the medium before fragmenting into jets of hadrons [3]. While traversing the medium, the hard-scattered partons lose energy through collisions and radiation and thus the properties of the final jet is modified. By measuring these modifications, we gain information about the properties of the medium.

In hadron–hadron analyses both jets are affected by the medium. This means the *initial* energy of the jets is unknown and any attempt of measuring jet fragmentation functions will have large uncertainties. To try to solve this issue, another measurement was suggested in late 1990's by Wang and collaborators [4, 5]: study the hadron momentum fraction distribution $z = p_{\mathrm{T}}^{\mathrm{hadron}}/p_{\mathrm{T}}^{\gamma}$ in $\gamma+$jet processes. Replacing on one side the hadronic probe by an electromagnetic probe, which propagates through the medium undisturbed, a measurement of the p_{T} of the initial hard scattering is possible since $\overrightarrow{p}_{\mathrm{T}}^{\mathrm{jet}} \approx -\overrightarrow{p}_{\mathrm{T}}^{\gamma}$. The relation is valid up to k_{T} effects, where k_{T} is the intrinsic transverse momentum of the partons that enter the hard scattering. The jet can be considered in this case as tagged (i.e. a γ-tag) and its further evolution can be easier to determine. The direct photon couples weakly with the medium and conserves its initial kinematics, while on the other side the hadronic jet loses energy (by collisions, gluon radiation) and will be attenuated. This allows for the determination of the momentum fraction distribution of the far side jet hadrons (i.e. the fragmentation function).

Though the $\gamma+$jet process has its virtues, the main problems arise from misidentification of the background. Several such scenarios can take place depending on the collision centrality, detector performance and momentum of the photon. Direct photon clusters can combine in the calorimeter to an invariant mass of the π^0 and hence be rejected. A photon from $\pi^0 \to 2\gamma$ can be lost due to detector inefficiency and the other one misidentified as a real direct photon. At high p_{T} π^0s, the two photon clusters merge and leave just one cluster in the calorimeter faking a single direct photon signal. Additionally, photons can be produced in the collinear fragmentation of a hard quark or gluon [6]. These fragmentation photons can be misidentified as direct photons.

One measurement that overcomes the drawbacks of the $\gamma+$jet analysis is the leptonic decay of high transverse momentum virtual photon (γ^*) or Z^0-bosons, in association with a hadronic jet [7, 8]. The production channels we are interested in are $q+\overline{q} \to \gamma^*/Z^0 + g$ (annihilation process) and $g+q \to \gamma^*/Z^0 + q$ (Compton scattering) with the subsequent decay $\gamma^*/Z^0 \to \mu^- + \mu^+$ and the fragmentation $q/g \to$ jet.

In order to fully understand the medium created in nucleus–nucleus collisions, a comparison to the elementary nucleon–nucleon collisions is used as a reference. Since not only the final states influence the final AA measurement but also the initial states phenomena (within the incoming nuclei), it is of most importance that the reference process is not sensitive to the final state nuclear interactions effects. Production of the lepton pairs seems to be an obvious candidate.

[a] e-mail: cmironov@lanl.gov

An additional advantage of the γ^*/Z^0+jet is that its production mechanism is well known. The particular aspect we are interested in is that the Compton process requires a gluon in the initial state while the annihilation process requires an anti-quark, which has a harder fragmentation function than the gluon. Therefore, a larger percentage of recoil gluon jets will appear at lower p_T (from Compton) whereas higher p_T will be dominated by the recoil quark jets (from annihilation). This gives an unique opportunity to distinguish between quark and gluon jets on the basis of their overall recoil jet energy on the away-side of a given γ^*/Z^0 [7].

2 Rates at LHC

The large hadron collider is built to provide nucleon–nucleon, nucleon-nucleus and nucleus–nucleus collisions. Proton and ion beams have the same rigidity which imposes a further limit on the maximum center of mass energy that can be achieved with a particular colliding particle species.

The following discussion is built on the assumption of lead ion beams colliding at their maximum center of mass energy possible at LHC, $\sqrt{s} = 5.5$ TeV. The luminosity considered is $L = 0.5\,\mathrm{mb}^{-1}\mathrm{s}^{-1}$, the average value for the first year of heavy ion run at LHC. A runtime of (10^6 s) is used, corresponding to one month of collisions and considering 50% efficiency. The rates for PbPb collisions are obtained using pp collisions at the same energy and $\sigma_{AA} = A^2 \times \sigma_{pp}$ dependence between σ_{AA} and σ_{pp}.

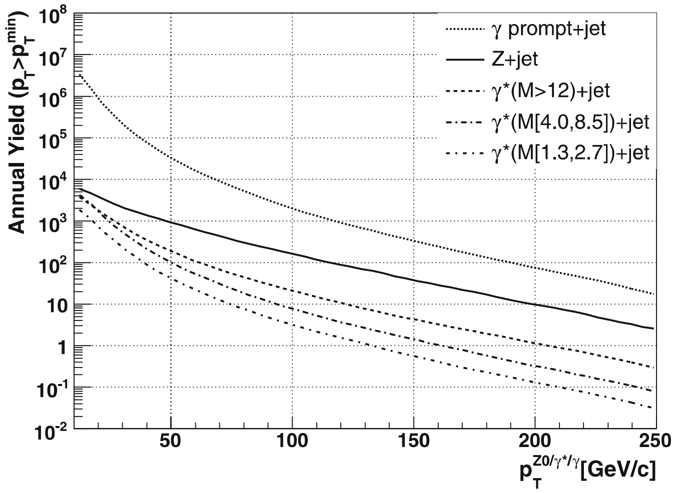

Fig. 1. Boson + jet integrated yields above a certain minimum value of p_T^{boson}

Table 1. Integrated Z^0/γ^*+jet yields above different p_T of the boson

p_T (GeV/c)>	10	20	30	50
Z^0 ($M = 91.19$ MeV)	4600	2600	1600	800
γ^* ($M > 12$ MeV)	2400	1000	500	150
γ^* (M[4., 8.5] MeV)	2600	800	300	75
γ^* (M[1.3, 2.7] MeV)	1100	350	130	30

2.1 Signal: Z^0/γ^*+jet

For the Z^0/γ^*+jet rates, the pp cross sections were evaluated using the PYTHIAv6.32 event generator [10] with the default parameters. In order to shorten the time for generating enough statistics, a few PYTHIA switches were used. We started by turning off all PYTHIA processes[1] and then selecting only the $q+\overline{q} \to Z^0/\gamma^*+g$ process[2] and $q+g \to Z^0/\gamma^*+q$[3]. We separated the Z^0[4] and γ^*[5] contributions. To obtain good statistics at high transverse momentum, 10K events were simulated in 10 GeV wide $\widehat{p}_T$ bins between 10 and 300 GeV/c. After selecting only the dilepton decays and scaling by the total cross-section for each particular bin, all bins were added to give the final signal spectra.

The results of our PYTHIA signal simulations at $\sqrt{s} = 5.5$ TeV are presented in Fig. 1. The y-axis of this figure is the total integrated yield above the corresponding p_T for Z^0+jet, γ^*+jet (three different mass windows for γ^*) and for comparison, $\gamma+$jet. The highest mass interval ($M > 12$ MeV) is the default of PYTHIA. Aiming to increase the dilepton statistics for our tagged jets, we looked at lower mass windows, above low mass resonances (η, Φ) and below the J/Ψ mass, and between the Ψ' and the Υ family mass.

Table 1 gives the integrated boson + jet yield for four values of p_T^{min} from Fig. 1. At lower dilepton p_T, the contributions of the dileptons from virtual photons decay become significant (more than 50% below 30 GeV/c). How much lower we can choose the momentum of the dilepton is directly related to the physics we would like to address with our dilepton–hadron angular correlation analysis. Previous studies [11] showed that k_T effects become more and more important as we go to lower p_T of the hadrons. What this means is that there is a limit in which our initial assumption $p_T^{\mathrm{dilepton}} \approx p_T^{\mathrm{jet}}$ is valid, and this is given by k_T being small. The choice of the p_T lower limit is also driven by knowing that 20% of the initial parton transverse momentum is carried by the leading hadron (the hadron with the highest p_T in the jet). So a parton with $p_T^{\mathrm{parton}} = 25$ GeV/c will produce a leading hadron with $p_T^{\mathrm{leadingHadron}} \sim 5$ GeV/c.

2.2 Background: $D\overline{D}/B\overline{B} \to \mu\mu$

The two main processes contributing to the dimuon signal are the semi leptonic decays of the heavy charm and

[1] MSEL = 0
[2] ISUB = 15
[3] ISUB = 30
[4] MSTP(43)=2
[5] MSTP(43) = 1

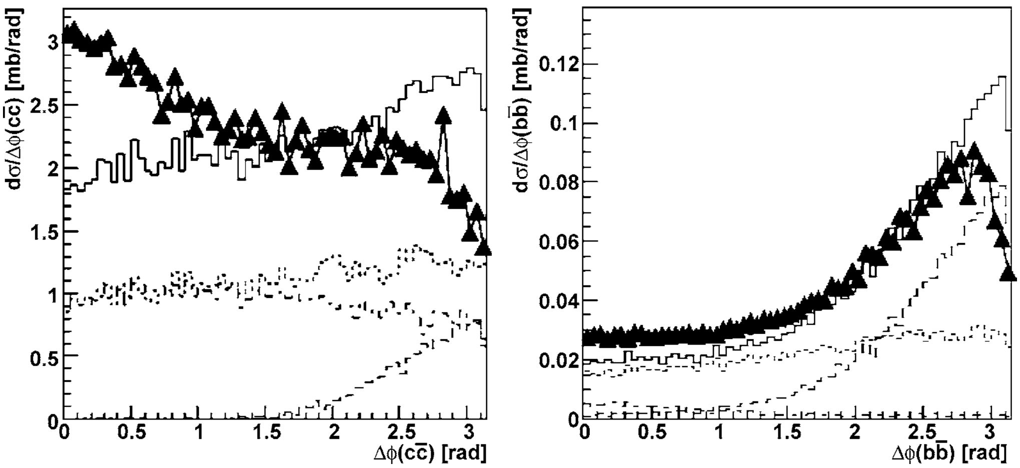

Fig. 2. $d\sigma/\Delta\Phi$ (mb/rad) for $c\bar{c}$ (*left*) and $b\bar{b}$ (*right*) from PYTHIA (*solid line*) and HVQMNR (*symbols*). Separate contributions are drawn for PYTHIA from gluon splitting (*dot-dashedline*), pair creation (*dashed line*) and flavor excitation (*dotted line*). The figures are from [13]

bottom mesons. A $D\overline{D}/B\overline{B} \to \mu\mu$ creates a dimuon pair that can fake the real dimuon signal from Z^0/γ^* decays. In order to analyze the background, HVQMNR code [12], a NLO calculation for the heavy quarks production, seems the appropriate tool. Studies on this subject were extensively done for LHC [13]. With PYTHIA tuned to reproduce the p_T spectrum of the $c\bar{c}$ and $b\bar{b}$ pairs, the azimuthal distribution of the heavy quarks pairs (and presumably of the further leptons from the semileptonic channel decays), differ in shape between PYTHIA and HVQMNR for charm quarks but agree for bottom quarks as can be seen in Fig. 2 [13].

Figure 2 shows that most of the charm quark pairs are peaked at small azimuthal angles (increasing the possibility for the leptons coming from them to mimic our signal-dilepton) while bottom pairs are mostly back-to-back. Through extrapolation, we would expect the same azimuthal behavior for the lepton pairs coming from the heavy mesons decay. Given the fact the all these decays are 3-body decays, the effect will probably be smeared. Nevertheless, the background exists and cuts have to be found to increase the signal to background ratio. This ratio was calculated by Srivastava et al. [9] for low mass virtual photons, following the same recipe for signal and background (using PYTHIA and MNR respectively), and found to be above unity for transverse momenta of the dileptons higher than 100 GeV/c.

Based on the kinematical observations of Fig. 2, provided that there are significant differences between the angular distributions of dileptons from heavy meson decay and those from Z^0/γ^* decays, an angular cut can be used to lower the background. Another obvious cut is on the displaced vertex position of the single leptons. Given the fact that the background-leptons come from secondary weak decay, they will be displaced from the primary vertex. All of the LHC detectors (ATLAS, CMS) have state of the art silicon track detectors making effective and efficient all the background rejection methods based on displaced vertex cuts.

In addition to these cuts based on decay kinematic differences between signal and background, the nature of the analysis that we will perform will help isolate the signal from the residual background contribution. The statistical analysis of the angular correlation of dimuons with hadrons in an event will produce a flat distribution in the case of combinatorial background-dimuons compared with signal-dimuons. Any shape deviation of the background correlation from flatness can be identified by doing same-sign lepton pairs correlations versus opposite-sign or different flavor lepton pairs (e.g. electron–muon) correlations. This latter case refers to correlated background for which the leptons in the dimuon are coming from decays of heavy mesons.

3 Conclusions and outlook

We present a case study for measuring dilepton-tagged jets via angular correlations in heavy-ion collisions at LHC. The signal rates ($Z^0/\gamma^*(\ell\ell)+$jet) were computed with PYTHIA event generator. The heavy mesons semileptonic decay background ($D\overline{D}/B\overline{B} \to \mu\mu$) will be analyzed at NLO order with the MNR code. Kinematical studies will be conducted for both background-dileptons and signal-dileptons, in search of cuts to increase the signal to background ratio.

References

1. RHIC White Papers, Nucl. Phys. A **757**, 1 (2005)
2. STAR Collaboration, C. Adler et al., Phys. Rev. Lett. **90**, 082302 (2003)
3. STAR Collaboration, J. Adams et al., Phys. Rev. Lett. **95**, 152301 (2005)
4. X.N. Wang, Z. Huang, I. Sarcevic, Phys. Rev. Lett. **77**, 231 (1996)
5. X.N. Wang, Z. Huang, Phys. Rev. C **55**, 3047 (1997)
6. P. Aurenche et al., Eur. Phys. J. C **9**, 107 (1999)

7. V. Kartvelishvili, R. Kvatadze, R. Shanidze, Phys. Lett. B **356**, 589 (1995)
8. I.P. Lokhtin, A.V. Sherstnev, A.M. Snigirev, Phys. Lett. B **599**, 260 (2004)
9. D. Srivastava, C. Gale, T.C. Awes, Phys. Rev. C **67**, 054 904 (2003)
10. T. Sjöstrand et al., hep-ph/0308153 (2003)
11. L. Apanasevich et al., Phys. Rev. D **59**, 074 007 (1999)
12. B. Mangano, P. Nason, G. Ridolfi, Nucl. Phys. B **373**, 295 (1992)
13. Hard probes in heavy-ion collisions at the LHC, http://doc.cern.ch/yellowrep/2004/2004-009/p247.pdf