$\gamma + jet$ Final State as a Probe of q^* at the LHC

Satyaki Bhattacharya, Sushil S. Chauhan, Brajesh C. Choudhary, Debajyoti Choudhury
Department of Physics & Astrophysics, University of Delhi, Delhi 110007, India

If quarks are composite particles then its excited states are expected to play a role in the physics to be probed at the Large Hadron Collider (LHC). Concentrating on virtual effects and using CMS detection criteria we present a realistic examination of their effects at $\sqrt{s} = 14$ TeV in $\gamma + jet$ channel at the CERN LHC. The analysis shows that in the initial phase of the LHC operation, the discovery of $q*$ in the $\gamma + jet$ final state for $M_{q*} = 2(5)$ TeV is possible with an integrated luminosity of $200pb^{-1}(\sim 140fb^{-1})$.

1 Introduction

The replication of fermion families along with the mass hierarchies and mixings has led one to speculate about the possibility of quark-lepton compositeness. The fundamental matter constituents in such theories, very often termed *preons*[1], experience an hitherto unknown force on account of an asymptotically free but confining gauge interaction[2], which would become very strong at a characteristic scale Λ, thereby leading to bound states (composites) which are to be identified as quarks and leptons. Since our interest is in $q*$ contribution to the $\gamma + jet$ for their presence as a mass bump at hadron collider, it suffices to consider only the magnetic transition between ordinary and excited states. In general, it is often parameterized by

$$\mathcal{L}_{f^* f} = \frac{1}{2\Lambda} \bar{f}^*_R \, \sigma^{\mu\nu} \left[\sum_i g_i \; c_i \; T^a_i \; G^a_{i\,\mu\nu} \right] f_L + h.c., \tag{1}$$

where the index i runs over the three SM gauge groups, viz. $SU(3)$, $SU(2)$ and $U(1)$, and g_i, $G^a_{i\,\mu\nu}$ and T^a_i are the corresponding gauge couplings, field strength tensors and generators respectively. The Λ and M_{q*} are the compositeness scale and mass of the excited state respectively.

2 $pp \to \gamma + jet$ via $q*$

To study this process, the event generation for signal and for different background processes was done using PYTHIA-v6.325 [3]. For signal event generation the matrix elements for $qg \to \gamma + jet(q^*)$ were implemented inside the PYTHIA framwork. We used CTEQ 5L as PDF and $Q^2 = \hat{s}$ with other default parameters. A number of points were generated for $M_{q^*} = \Lambda$ with standard coupling value of f=1.0 and also with f=0.5. Signal and different backgrounds were generated above three $\hat{P_T}$ range, viz. 180GeV, 450GeV and 950GeV respectively. For final selection we used $P_T^{\gamma,jet} \geq$200, 500 and 1000 GeV for analysis of different mass points. The photons were required to be in the $|\eta^\gamma| < 2.5$ where $1.444 \leq |\eta^\gamma| \leq 1.566$ is excluded on account of the insensitive region between the barrel and endcaps[4]. The jets were required to be in $|\eta| \leq 3.0$ only.

We considered all the leading contributions for background processes and broadly categorize these into three classes viz.(i) where a direct photon and a hard jet is produced in the hard scattering (ii) QCD dijet, where one of the jets fragments into a high E_T $\pi^0(\rightarrow \gamma\gamma)$ which gets registered as a single photon (iii) photon + dijet production, where one of the jets is either lost or mismeasured such as $q\bar{q} \rightarrow q\bar{q}\gamma, gg\gamma$ processes or from $W/Z(\rightarrow jj) + \gamma$ production. To estimate the background reasonably at the generator level we have used a clustering algorithm to account for fake photons arising from jets [5]. For jet formation, we used Iterative Cone algorithm with jet size of ΔR =0.5.

Fake photon signals arising from a jet can be rejected by requiring either the absence of charged tracks above a certain minimum transverse momentum (P_{Tmin}^{trk}) associated with the photon or the absence of additional energetic particles in an annular cone (R_{iso}) around the photon candidate. We have considered two variables for the isolation purpose (a) the number of tracks (N_{trk}) and (b) the scalar sum of transverse energy (E_{TSUM}) inside a cone around the photon.

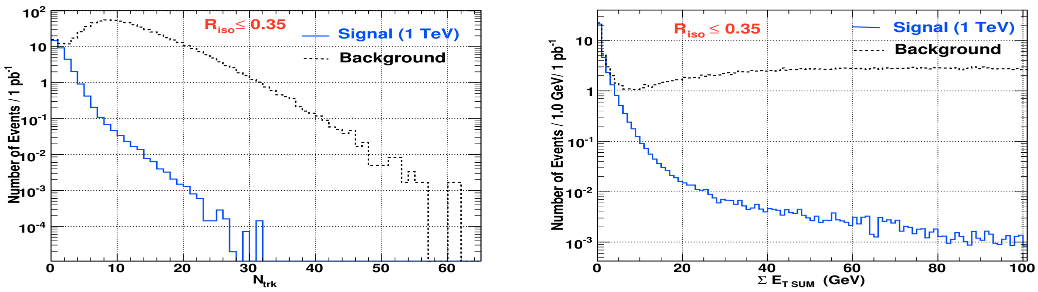

Figure 1: (Left) Number of tracks(N_{trk}) for the signal (1 TeV) and the background events around the photon. (Right) E_{TSUM} for the background and the signal events around photons for M_{q*} =1 TeV Signal.

Fig. 1(Left) shows the distribution of number of charged tracks (N_{trk}) for signal (M_{q^*} = 1 TeV) and the background around the leading photon within a cone size of $\Delta R \leq 0.35$. Since for the signal events the leading photon is the *true* photon, most of them have no associated tracks (N_{trk} =0) and the distribution falls off very rapidly for larger N_{trk}. For background events though, the distribution peaks at N_{trk} ∼7-8 and then falls slowly. The small rise at $N_{trk} = 0$ is due to the fact that $\gamma + jet$(SM) and $W/Z + \gamma$ backgrounds have true photons as the leading photon in the event and have no tracks around them, while the rising part along with the tail is mainly contributed by QCD dijet events with large number of tracks associated with fake photons. We also analyze the signal efficiency vs signal/background ratio (S/B) as a function of P_{Tmin}^{trk} to improve the selection efficiency for different signal mass points. We accept a photon to be an isolated one if there are no tracks with $P_{Tmin}^{trk} > 3.0$ GeV within $\Delta R = 0.35$. Figure 1(Right) shows the E_{TSUM} distribution for the leading photon in a cone of size $\Delta R = 0.35$ for $M_{q*} = 1$ TeV. It is evident that a large fraction of signal events have $E_{TSUM} < 5.0$ GeV whereas the background events typically have $E_{TSUM} \geq 5$ GeV. We used a threshold of $E_{TSUM} < 5$ GeV in $\Delta R = 0.35$ for this variable for photon selection.

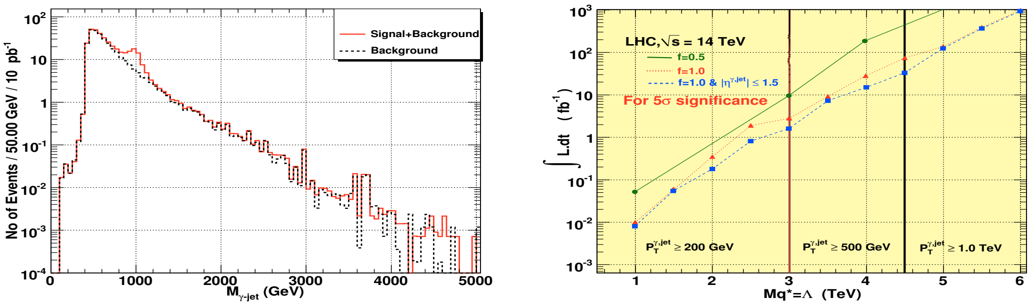

Figure 2: (Left)Invariant mass of $\gamma + jet$ system for signal+background and background only after applying the kinematic and isolation cuts for M_{q*} =1 TeV. (Right) Integrated luminosity distribution for 5σ significance as a function of M_{q*} for two different coupling strengths.

In Fig. 2(Left) we show invariant mass distribution for signal+background and background only after applying selection cuts to M_{q*} =1 TeV sample while Fig. 2(Right) shows the required luminosity needed for 5σ significance(calculated using *frequentist* approach) for the signal with different coupling strengths and pseudorapidity constraints. For estimating the luminosity we have exploited only the mass peak region of the signal over the SM background. We have used a mass window of $\pm \sim 3\Gamma(q*)$ around the mass peak. We also estimated various sources of systematic uncertainties and found that those arising from PDF, scale and luminoisty are the dominant ones.

3 Conclusions

To summarise, we have investigated the potential of using $\gamma + jet$ final state at the LHC for probing possible substructure of quarks. Presence of such a new state would alter the cross section for this process and the present analysis shows that a mass peak discovery for such excited states is possible in the initial phase of the LHC operation.

References

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