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CMS Search Plans and Sensitivity to New Physics using Dijets

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Abstract

CMS plans during the early LHC running to search for physics beyond the standard model are summarized. The inclusive jet cross section as a function of jet p_T with 10 pb^{-1} of integrated luminosity is sensitive to contact interactions beyond the exclusions of the Tevatron. The dijet mass distribution will be used to search for dijet resonances such as an excited quark. Finally, using a ratio of dijets in two distinct angular regions, a simple measure of the dijet angular distribution, both contact interactions and dijet resonances can be explored.

The Large Hadron Collider at CERN will produce many events with two energetic jets resulting from proton-proton collisions at $\sqrt{s} = 14$ TeV. These dijet events result from the parton-parton scatters produced by the strong interaction of quarks (q) and gluons (g) inside the protons. This paper discusses plans to search for two sources of new physics using dijets: contact interactions and resonances decaying into dijets. This generic search is applied to the following two models of quark compositeness, used as benchmarks of sensitivity to new physics. First, a contact interaction [1] among left-handed quarks at an energy scale Λ^+ in the process $qq \rightarrow qq$. Second, a dijet resonance signal from the decay of an excited quark (q*) [2] in the process $qg \rightarrow q* \rightarrow qg$. All processes presented here were simulated using PYTHIA [3].

A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere [4, 5]. The CMS coordinate system has the origin at the center of the detector, z axis along the proton beam, transverse coordinate perpendicular to the beam, azimuthal angle ϕ, polar angle θ, and pseudorapidity $\eta = -\ln\tan(\theta/2)$. The CMS calorimeter cells are grouped into projective towers for the trigger and offline analysis. In the region $|\eta| < 1.74$ these projective calorimeter towers have segmentation $\Delta\eta = \Delta\phi = 0.087$.

Jets are reconstructed using a cone algorithm. The jet energy E is defined as the scalar sum of the calorimeter tower energies inside a cone of radius $\sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.5$, centered on the jet axis. The jet momentum $\vec{p}$ is the corresponding vector sum: $\vec{p} = \sum E_i \hat{u}_i$ with $\hat{u}_i$ being the unit vector pointing from the origin to the energy deposition E_i inside the same cone. There is a definition of jets reconstructed from the Lorentz vectors of stable generated particles before detector simulation, called generated jets. The jet E and $\vec{p}$ are corrected for the non-linear response of the calorimeter to a generated jet. After corrections the transverse momentum of a jet is equal to the corresponding generated jet on average. The jet corrections estimated from a full simulation of the CMS detector increase the jet transverse momentum on average by roughly 50% (10%) for 70 GeV (3 TeV) jets in the region $|\eta| < 1.3$. Further details on jet reconstruction and jet energy corrections at CMS can be found elsewhere [6].

The dijet system is defined to be the two jets with the highest transverse momentum in an event (leading jets) with dijet mass $m = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$. The estimated dijet mass resolution varies from 9% at a dijet mass of 0.7 TeV to 4.5% at a dijet mass of 5 TeV [7]. CMS will record data that passes a first level trigger followed by a high level trigger. For an instantaneous luminosity of 10^{32} cm^{-2}s^{-1}, consider three event samples collected by requiring at least one jet in the high level triggers with corrected transverse energies of 60, 120 and 250 GeV, prescaled by a factor of 2000, 40 and 1, respectively. For an integrated luminosity of 100 pb^{-1}, the prescaling reduces the effective integrated luminosities to 0.05, 2.5, and 100 pb^{-1}, respectively for the three samples. The latter two event samples will be used to study dijets of mass above 330 and 670 GeV, respectively, where the trigger efficiencies are expected to be higher than 99% [8].

Backgrounds from cosmic-rays, beam halo, and detector noise are expected to produce events with unusually large or unbalanced energy depositions. They will be removed by requiring $\not{E}_T / \sum E_T < 0.3$ and $\sum E_T$ less than 14 TeV, where $\not{E}_T$ ($\sum E_T$) is the magnitude of the vector (scalar) sum of calorimeter tower transverse energy in the event. This cut is estimated to be greater than 99% efficient for both the QCD background and the signals of new physics considered. In the high p_T region relevant for this search, jet reconstruction is fully efficient.

CMS plans to search for contact interactions using the jet p_T distribution. Fig. 1 shows the inclusive jet cross section as a function of p_T for jet $|\eta| < 1$. Considering first the QCD background, the reconstructed and corrected quantities are compared with the QCD prediction for generated jets. After corrections, the reconstructed and generated distributions agree fairly well. The ratio of the corrected jet cross section to the generated jet cross section varies between 1.2 at p_T=100 GeV and 1.05 at p_T=500 GeV, and remains roughly constant for higher p_T. The deviation of this ratio from 1 is attributed to the smearing effect of the jet p_T resolution on the steeply falling spectrum. The measured spectrum could be further corrected for resolution smearing, and this ratio from Monte Carlo is an estimate of the size of that correction. The measurement uncertainties are predominantly systematic. The inset in Fig. 1 shows the effect on the jet rate of a 10% jet energy scale uncertainty that could be expected in early running when only 10 pb^{-1} of integrated luminosity have been accumulated. This experimental uncertainty is roughly ten times larger than the uncertainties from parton distributions, as estimated using CTEQ6.1 fits [9]. Fig. 1 shows that the effect of new physics from a contact interaction with scale $\Lambda^+ = 3$ TeV is convincingly above what could be expected for measurement uncertainties with only 10 pb^{-1}. For comparison, the Tevatron experiments have excluded contact interactions with scales Λ^+ below 2.7 TeV [10].

CMS plans to search for narrow dijet resonances using the dijet mass distribution. Fig. 2 shows the cross section versus dijet mass, where each leading jet has $|\eta| < 1$, and the mass bins have width roughly equal to the dijet mass resolution. Considering first the QCD background, the cross section for corrected jets agrees well with the QCD prediction from generated jets. To determine the background shape either the Monte Carlo prediction or a parameterized fit to the data can be used. The inset to Fig. 2 shows a simulation of narrow dijet resonances with a q* production cross section. This is compared to the QCD statistical uncertainties including trigger prescaling. This shows that with an integrated luminosity of 100 pb^{-1} a q* dijet resonance with a mass of 2 TeV would produce a convincing signal above the statistical uncertainties from the QCD background. For comparison, a Tevatron search has recently excluded q* dijet resonances with mass, M, below 0.87 TeV [11]. The heaviest dijet resonances that CMS can discover at five standard deviations with 100 pb^{-1} integrated luminosity, using this search technique and including the expected systematic uncertainties [12, 13], are: 2.5 TeV for q*, 2.2 TeV for axigluons [14] or colorons [15], 2.0 TeV for E_6 diquarks [16], and 1.5 TeV for color octet technirhos [17]. Studies of the jet η cut have found that the optimal sensitivity to new physics is achieved with $|\eta| < 1.3$ for a 2 TeV spin 1 dijet resonance decaying to $q\bar{q}$ [7].

CMS plans to search for both contact interactions and dijet resonances using the dijet ratio, $r = N(|\eta| < 0.7)/N(0.7 < |\eta| < 1.3)$, where N is the number of events with both jets in the specified $|\eta|$ region. The dijet ratio is sensitive to the dijet angular distribution. For the QCD background, the dijet rato is the same for corrected jets and generated jets, and is constant at $r = 0.5$ for dijet masses up to 6 TeV [7]. Fig. 3 shows the dijet ratio from contact interactions and dijet resonances, compared to the expected statistical uncertainty on the QCD background, for 100 pb^{-1} of integrated luminosity, including trigger prescaling. The signal from a contact interaction with scale $\Lambda^+ = 5$ TeV rises well above the QCD statistical errors at high dijet mass. Systematic uncertainties on the dijet ratio are expected to be small, since they predominantly cancel in the ratio as previously reported [12, 18]. Using the dijet ratio, CMS can discover a contact interaction scale $\Lambda^+ = 4$, 7 and 10 TeV with integrated luminosities of 10, 100, and 1000 pb^{-1}, respectively [7]. The signal from a 2 TeV spin 1/2 q* produces a convincing peak in the dijet ratio, both because it has a significant rate and a relatively isotropic angular distribution compared to the QCD t channel background. Fixing the cross section of the 2 TeV dijet resonance for $|\eta| < 1.3$ at 13.6 pb (from the q* model), the dijet ratio in the presence of QCD background increases by about 6% when considering a spin 2 resonance decaying to both $q\bar{q}$ and gg (such as a Randall-Sundrum graviton [19]), and the dijet ratio decreases by about 4% when considering a spin 1 resonance decaying to $q\bar{q}$ (such as a Z′, axigluon, or coloron) [7]. Hence, the sensitivity to a 2 TeV dijet resonance depends only weakly on the spin of the resonance. Nevertheless, with sufficient luminosity, this simple measure of the dijet angular distribution, or a more complete evaluation of the angular distribution, can be used to see these small variations and infer the spin of a dijet resonance.

In conclusion, CMS plans to use measurements of rate as a function of jet p_T and dijet mass, as well as a ratio of dijet rates in different η regions, to search for new physics in the data sample collected during early LHC running. With integrated luminosity samples in the range 10–100 pb^{-1}, CMS will be sensitive to contact interactions and dijet resonances beyond those currently excluded by the Tevatron.

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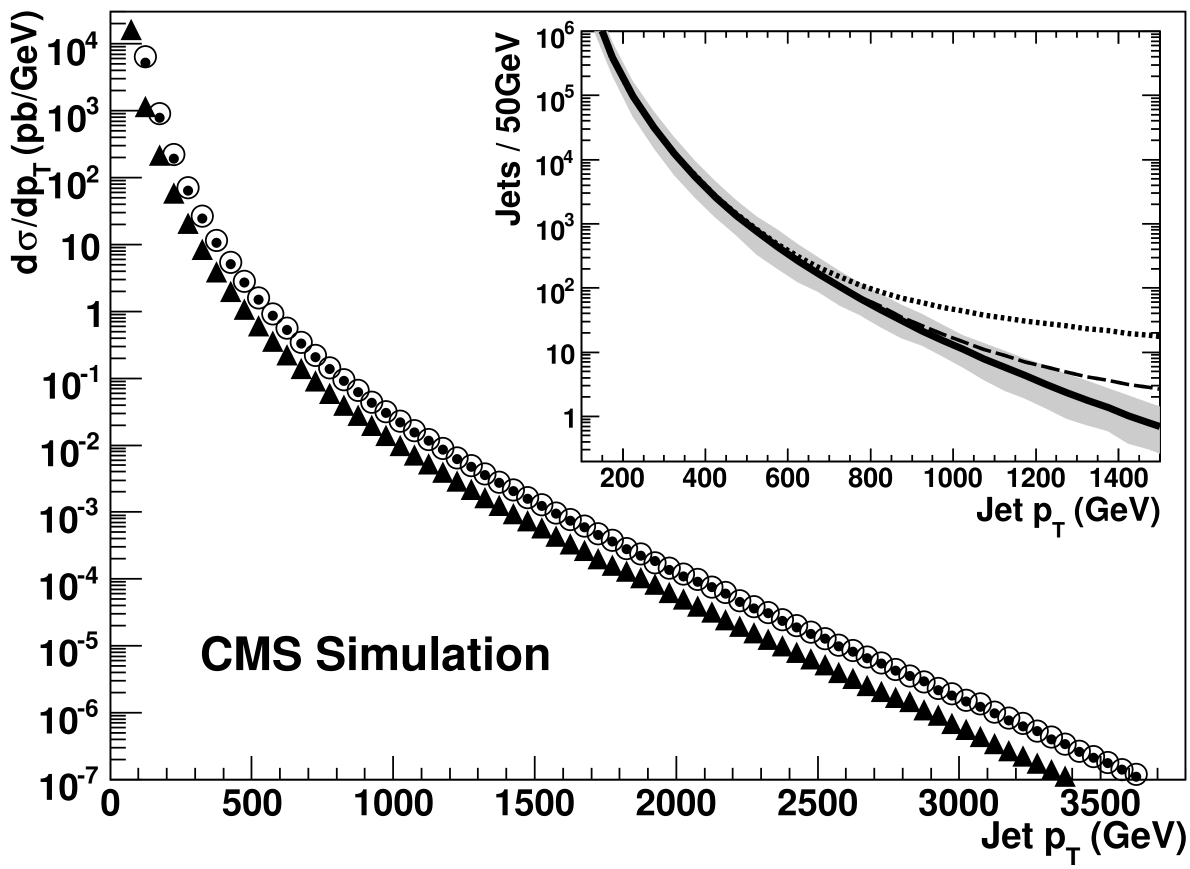

Figure 1: The inclusive jet differential cross section expected from QCD for $|\eta| < 1$ vs. jet p_T for generated jets (points), jets (triangles), and corrected jets (open circles). The inset shows the number of generated jets in 50 GeV bins for an integrated luminosity of 10 pb^{-1}. The size of a 10% uncertainty in the jet energy scale (shaded band) is shown centered on the QCD background (solid). The signal from a contact interaction is shown for scale $\Lambda^+ = 3$ TeV (dotted) and $\Lambda^+ = 5$ TeV (dashed).

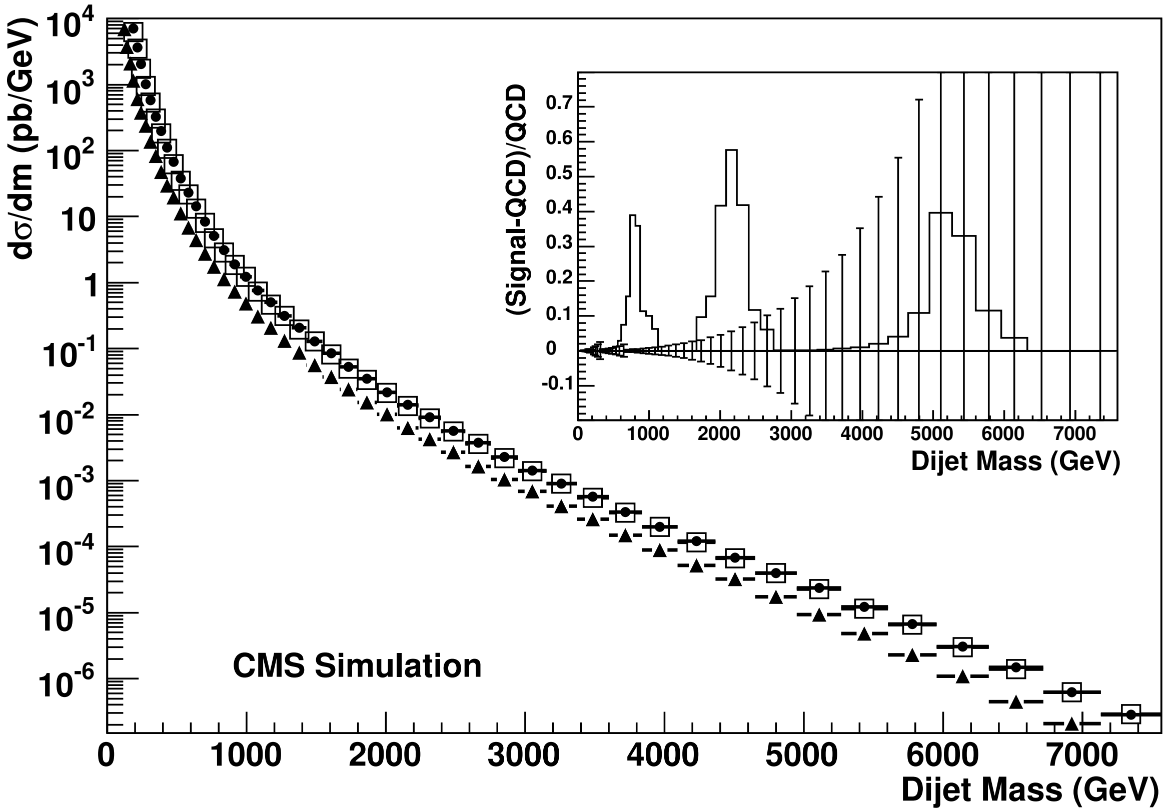

Figure 2: The dijet differential cross section expected from QCD for $|\eta| < 1$ vs. dijet mass for generated jets (points), jets (triangles), and corrected jets (open boxes). The inset shows dijet resonances reconstructed using corrected jets coming from q* signals of mass 0.7, 2, and 5 TeV. The fractional difference (histogram) between the q* signal and the QCD background is compared to the QCD statistical error (vertical bars) for an integrated luminosity of 100 pb^{-1}.

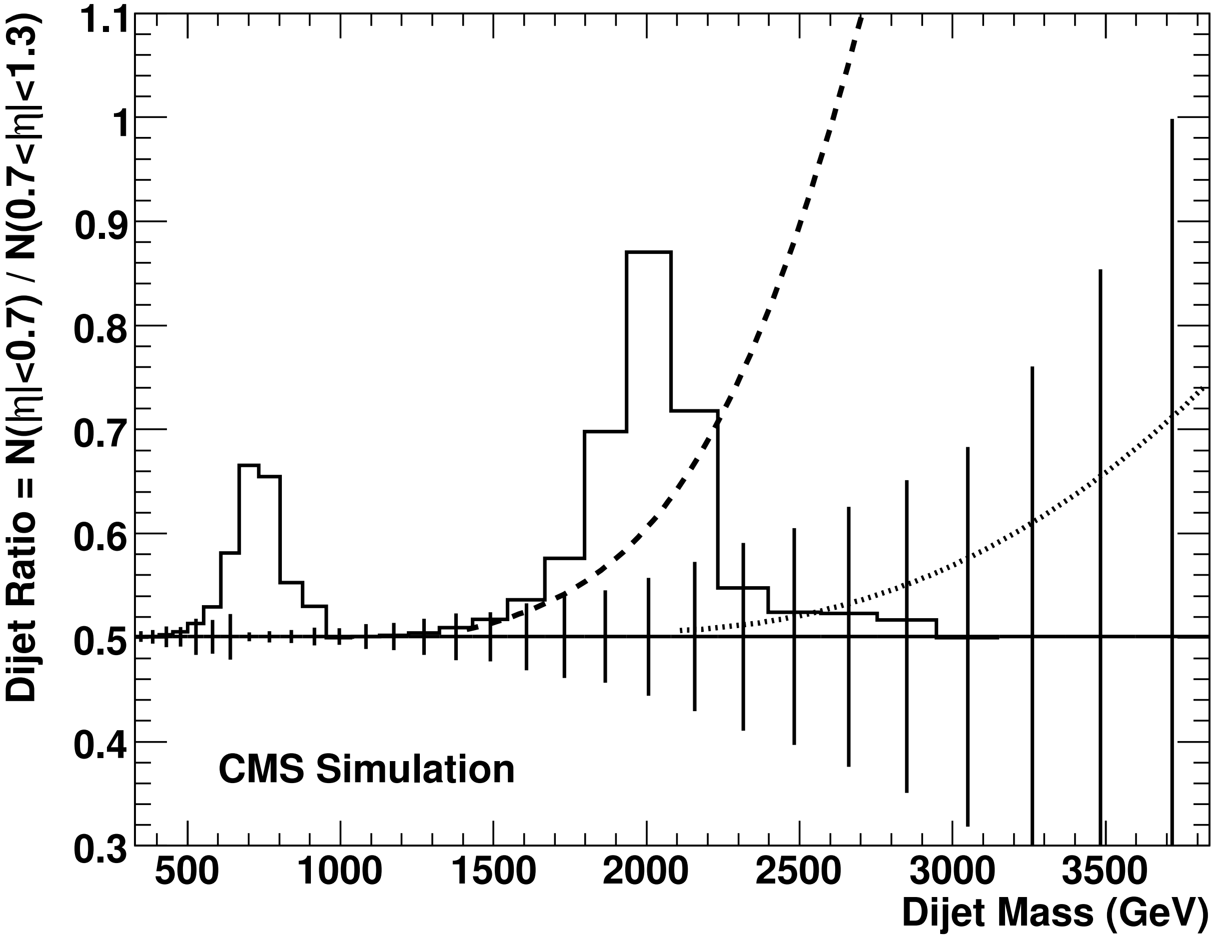

Figure 3: The dijet ratio for corrected jets expected from QCD (horizontal line), with statistical uncertainties (vertical bars) for an integrated luminosity of 100 pb^{-1}, is compared to QCD + contact interaction signals with a scale $\Lambda^+ = 5$ TeV (dashed) and $\Lambda^+ = 10$ TeV (dotted), as well as to QCD + dijet resonance signals (histogram) with q* masses of 0.7 and 2 TeV.