Searches for physics beyond the Standard Model with CMS

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This contribution outlines some of the first results of the CMS experiment with data from the LHC machine, in the sector of searches for physics beyond Standard Model (SM). It will show that even at the current stage, important tools for the study in supersimmetry can be commissioned using real data. Some models of new physics, involving enhanced jets production or heavy stable charged particle, have been compared with data, leading to significantly improved exclusion limits after few integrated inverse picobarns.

This contribution has aimed to address a kind of studies of high transverse momenta in the CMS experiment [1], sketching the more advanced searches in both Supersimmetry (SUSY) and other new physics models ("exotic").

At the time of the ISMD conference, LHC delivered luminosity had exceeded $3\,\mathrm{pb}^{-1}$, so already in a position to start scratching current limits for few new physics models. In the subsequent weeks, the integrate luminosity steeply increased, ending in an amount of data about $40\,\mathrm{pb}^{-1}$ at the completion of 2010 proton-proton run (early November). The results presented here exploit the first few pb^{-1} of this total amount, while several results with improved statistic are on the way to the publication.

1 Introduction

The CMS analyses covering the searches for new physics, are related to models spanning a huge spectrum: from standard supersimmetry to splitted SUSY, from extra-dimensions to hidden valley, from enlarged gauge sectors to not-standard scenarios for electroweak symmetry breaking. As a consequence, there is a corresponding set of many different signatures: among them, dileptonic final state, high jets multiplicities, resonant states, large missing energy, or significant energy deposit during non-collision time. The more advanced study covering some of these signatures will be presented in the following.

2 Perspectives in SUSY searches

CMS has in plan a broad range of searches for SUSY particles. The initial searches will be performed in a variety of inclusive final states involving jets, leptons, photons, and missing transverse energy (MET), with a background determination derived as much as possible from data. The studies for the 7 TeV run based on Monte Carlo (for example, Ref. [2]) indicate that CMS should have sensitivity to regions of SUSY parameter space beyond the current Tevatron limits, after an amount of data close to $100\,\mathrm{pb}^{-1}$, provided that a good understanding of QCD background is reached. On the other hand, the cross sections for QCD processes are extremely large, hence even a small data sample allows to test key parts of methods for understanding these backgrounds. A couple of methods, to reject the contribution of fake MET and to quantify the tails of the MET distributions, are exemplified here.

2.1 Tools for SUSY searches: suppressing fake missing energy

The variable α_T [3] characterizes the overall transverse momentum balance of a multi-jet event, and is a powerful discriminator. While the QCD background is expected to be largely confined to the region α_T <0.5 (with a large tail below and a smaller tail above this value), the distributions of events from SUSY models and other SM backgrounds extend to well above. Figure 1(left) shows the shape of the distribution, made using only $12\,\mathrm{nb}^{-1}$ of data, after a cut on the scalar sum of jet energy, H_T >120 GeV. It has been demonstrated [3] that the fraction of QCD events that fail the α_T <0.5 veto is a decreasing function of H_T, so that a lower H_T sample can be used to determine an upper bound on the failure fraction.

2.2 Tools for SUSY searches: predicting missing energy contribution

To predict a MET distribution in a SUSY search, one needs to model genuine MET from neutrinos produced in the decays of SM particles and artificial MET generated by instrumental and non-collision backgrounds. Processes producing artificial MET in a $\gamma/Z/W$+jets process can be sampled and modeled in-situ using multi-jet QCD events. For each V+jets event, the MET distribution is modeled by a MET template measured in a sample of multi-jet QCD events, collected by jet triggers, that have approximately the same configuration of jets. Figure 1(right) shows MET predictions and measurements in γ+jets for events with 3 or more jets. For MET>15 GeV, the predicted and observed yields are statistically consistent. This method could be well-suited to an analysis in which the background produces mainly real MET, and the templates can provide an estimate of the residual MET from jet mis-measurement. This is typically the case in a leptonic SUSY search.

3 Searching new physics in dijet

Within the Standard Model, events with two energetic jets (dijet) arise in proton-proton collisions from scattered partons. QCD predicts a dijet mass spectrum that falls smoothly and steeply with increasing mass, together with a well-defined dependence of jets pseudorapidity from the angular distribution of the scattered partons. Therefore, possible signs of new physics phenomena can appear in both resonant structures in the dijet mass spectrum, and in modified jets angular distribution.

3.1 Search for Dijet Resonances in the Dijet Mass Distribution

Distribution of dijet in data can be compared with specific predictions from models of narrow dijet resonances, as 'string resonance' [4], excited quarks [5], axigluons [6], scalar diquark predicted by GUT based on the E_6 gauge group [7], new gauge bosons W' and Z' [8], and Randall-Sundrum (RS) model of extra dimensions predicting massive gravitons [9].

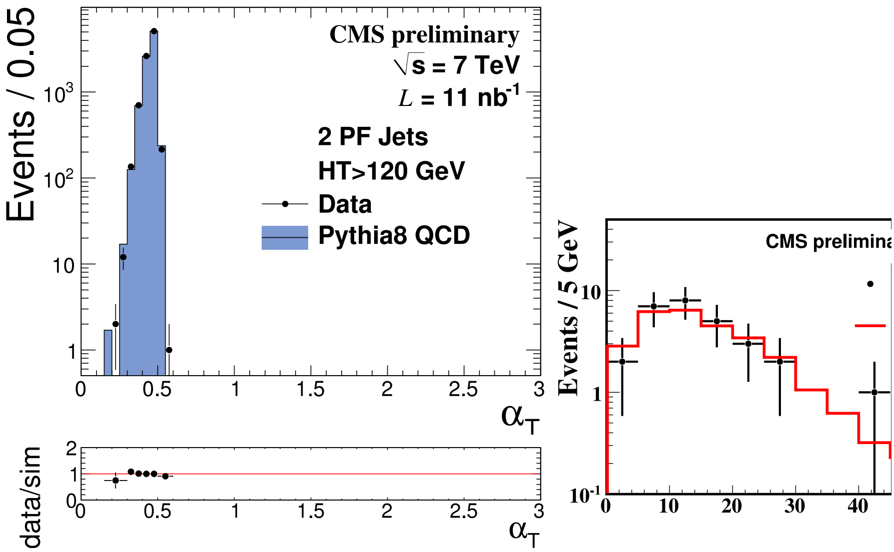

Figure 1: Left: Plots of the α_T distribution in the dijet events. Right: MET predictions, based on templates, compared to the observed MET in events with a γ and at least 3 jets. The data are shown by points with error bars and the predictions are shown by histograms.

In Fig. 2(left), the dijet mass distribution of the two leading jets is measured and compared to QCD predictions from PYTHIA [10], propagated through the CMS detector simulation. The pseudorapidity separation of the two jets is required to satisfy $|\Delta\eta| < 1.3$, with each jet inside the region $|\eta| < 2.5$. The highest observed dijet mass is 1.92 TeV after an integrated luminosity of $836 \pm 92\,\mathrm{nb}^{-1}$. The observed dijet mass spectrum is fitted with a smooth function [11] and the limits are set using a Bayesian formalism. The upper limits at 95% C.L. on the cross section, times branching ratio, times acceptance of centrally ($|\eta| < 1.3$) produced dijet mass resonances are shown in Fig. 2(right). Separate limits are reported for dijets with three different parton contents, quark-quark (qq), quark-gluon (qg) and gluon-gluon (gg). It is thus possible to exclude string resonances with mass less than 2.10 TeV, excited quarks with mass less than 1.14 TeV, axigluons and colorons with mass less than 1.06 TeV, and E_6 diquarks with mass less than 0.58 TeV. Recently, a paper using $2.9\,\mathrm{pb}^{-1}$ has been published [11], where the string resonances have a mass limits of 2.50 TeV (to be compared with the previous measurement 1.40 TeV, [12]), excited quarks are excluded below 1.58 TeV (to be compared with 1.26 TeV, [11]), axigluons and colorons with mass less than 1.32 TeV, and E_6 diquarks with mass less than 1.60 TeV, extending the previous exclusion of 0.63 TeV [12].

3.2 Search for New Physics with the Dijet Centrality Ratio

New physics beyond the SM typically produces more isotropic angular distributions than those predicted by QCD, resulting in more dijets at lower absolute values of pseudorapidity. The dijet centrality ratio $N(|\eta| < 0.7)/N(0.7 < |\eta| < 1.3)$ is defined as the number of events with both jets in the region $|\eta| < 0.7$ divided by the number of events with both jets in the region $0.7 < |\eta| < 1.3$. Since many sources of systematic uncertainty cancel in this ratio, the dijet

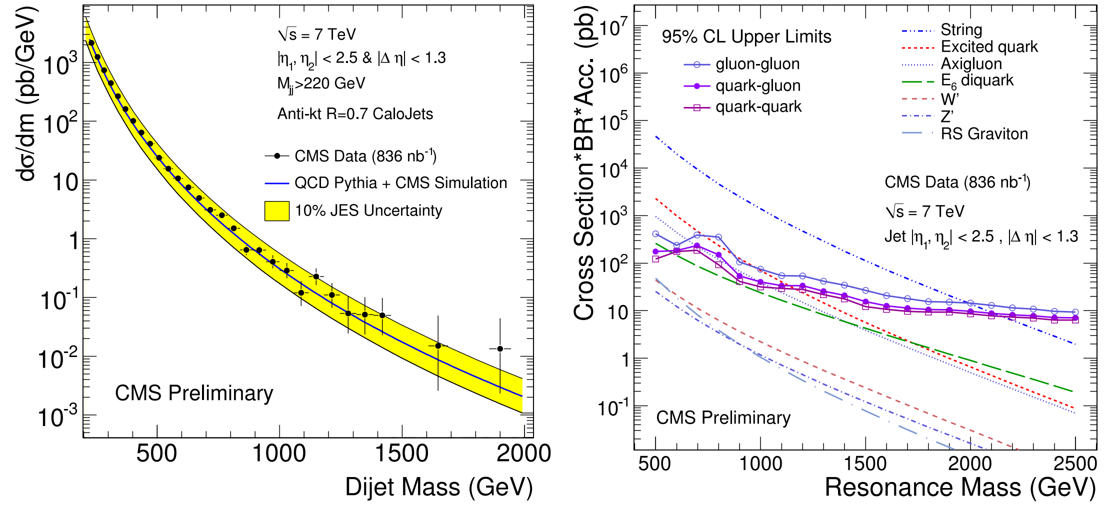

Figure 2: Left: The measured differential cross section data (points) in dijet mass compared to a QCD MC prediction (line). The yellow band shows the sensitivity to a 10% systematic uncertainty on the jet energy scale. Right: The 95% C.L. upper limits on the cross section times branching ratio times acceptance for dijet resonances (points) compared to predictions for several types of new particles decaying to dijets.

ratio provides a precise test of QCD and is sensitive to new physics.

Figure 3(left) shows a comparison of the measured centrality ratio as function of the invariant mass of the dijet system, with the predictions of NLO QCD and new physics models as excited quarks and contact interactions [13]. After the first $120\,\mathrm{nb}^{-1}$ of proton-proton collision data, there is a good agreement with the predictions of QCD. To quantitatively test for the presence of new physics in the dijet centrality ratio, a log-likelihood-ratio statistic (R_{LL}) is used, that compares the null hypothesis (SM only) to the hypothesis that new physics effects are present in addition to the SM. Figure 3(right) shows the R_{LL} for the data, the 95% C.L. points (from the CL_s method), and the SM expectation (with 1 and 2σ bands) versus the contact interaction scale Λ. A contact interaction with $\Lambda < 1.9\,\mathrm{TeV}$ is excluded. Recently, a paper using $2.9\,\mathrm{pb}^{-1}$ has been accepted for publication [14], where the sensitivity of the analysis is such that the expected limit is 2.9 TeV (to be compared with the previously measured 2.8 TeV, [15]). Because the observed value of the centrality ratio at high invariant mass is below the expectation, the observed limit is 4.0 TeV at the 95% confidence level.

4 Searches for Stopped Gluinos

Among models predicting heavy quasi-stable charged particles, the most promising at LHC is split supersymmetry [16] where the gluino decay is suppressed due to the large gluino/squark mass splitting. Gluinos can thus only decay through a highly virtual squark. If long-lived gluinos are produced at CMS, they will hadronize into $g\tilde{g}$, $\tilde{g}q\bar{q}$, $\tilde{g}qqq$ states which are collectively known as "R-hadrons". For low-β R-hadrons, this energy loss is sufficient to bring a significant fraction

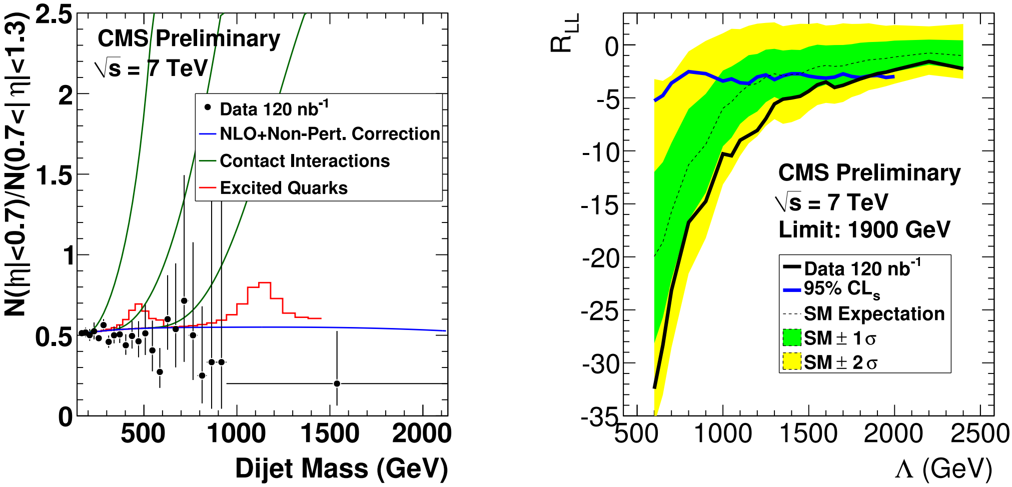

Figure 3: Left: Dijet centrality ratio as a function of the dijet invariant mass, compared to the predictions for new physics models. Right: Limit summary plot, as a function of contact interaction scale Λ.

of the produced particles to rest inside the CMS detector volume [17]. These stopped R-hadrons will decay seconds, days, or weeks later.

This atypical search [18] exploits a dedicated calorimeter jet trigger that fires at times when there are no collisions (gaps between bunch crossings). Events falling within 1 bunch crossing of any passage of beam have been excluded, and beam-halo effects are controlled by applying a veto to muons. After an accurate calorimeter noise rejection, a selection for jet with $p_T >$50 GeV and $|\eta| <$1.3 is applied. The signal was extracted via both a counting experiment and a time profile technique [18], where the latter exploits the difference between the time distribution of the background (that is not correlated with collision and is flat in time) and that from gluino, that is related to instantaneous luminosity and its own lifetime.

In a dataset with a peak instantaneous luminosity of $1.3 \cdot 10^{30}\text{cm}^{-2}\text{s}^{-1}$, an integrated luminosity of $203 \div 232\,\text{nb}^{-1}$ (depending on the gluino lifetime), and a search interval corresponding to 115 hours of LHC operation, no significant excess above background was observed. In the absence of a signal, a limit at 95% C.L. on gluino pair production can be set over 14 orders of magnitude of gluino lifetime. Assuming that $Br(\tilde{g} \to g\chi^0)$=100% and $M(\tilde{g}) - M(\chi^0) >$100 GeV, counting experiment excluded lifetimes in the range 75 ns$\div$6μs if $m(\tilde{g})$ =200 GeV, and time profile gives $m(\tilde{g}) <$229 GeV with $\tau_{\tilde{g}}$ =200 ns, that extends the $m(\tilde{g}) <$270 GeV and $\tau_{\tilde{g}} >$30μs measured at Tevatron [19]. Figure 4 shows the 95% confidence limit on gluino pair production cross-section as a function of gluino lifetime (left) and as a function of gluino mass (right). Recently, a paper using a peak instantaneous luminosity of $1 \cdot 10^{32}\text{cm}^{-2}\text{s}^{-1}$ and an integrated luminosity of $10\,\text{pb}^{-1}$ has been accepted for publication [18], and $m(\tilde{g}) <$370 GeV are excluded for lifetimes from 10 μs to 1000 s.

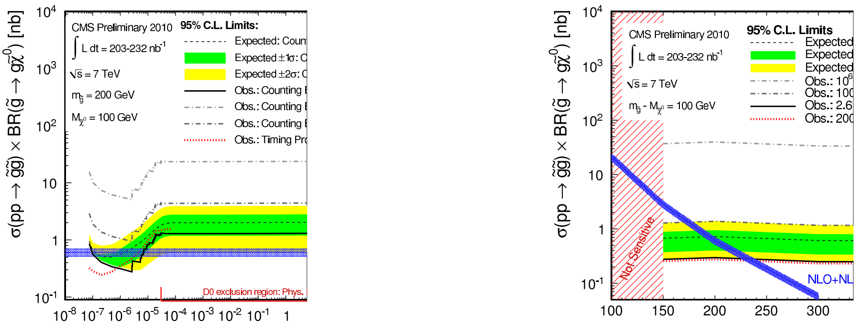

Figure 4: The 95% confidence limit on gluino pair production cross-section as a function of gluino lifetime (left) and gluino mass (right).

5 Conclusions

Some among the most advanced CMS results in high-p_T physics have been shown, related to search for effects beyond Standard Model. At the time of ISMD, several of the exotic searches were exceeding the previous limits, while the amount of data allowed a full commissionig of techniques for SUSY searches. Many more analyses exploiting part of the 2010 integrated luminosity are currently in the community-wide review stage, and will soon come to public papers.

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