Commissioning of Leptons and Prospects for Searches of Leptoquarks, W' and Z' in CMS

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Cosmic-ray data, beam splash events, and pp collisions have been used to commission electrons and muons as physics objects suitable for searches for BSM physics with leptons in the final state. In particular, the prospects for the search for new heavy gauge bosons, like W' and Z', are presented. Searches for pair production of first and second generation scalar leptoquarks are also discussed.

1 Detection of High p_T Leptons with CMS

At present (June 2010), the CMS experiment at the LHC proton-proton collider has started recording collision data and is being commissioned for high p_T leptons. Several searches for physics beyond the Standard Model are envisaged with early data to become competitive to Tevatron experimental limits.

The CMS design has been guided by several physics channels, amongst them the potential decay of a Standard Model Higgs Boson to four leptons, yielding an optimized performance of the detector for high p_T leptons. Other new particles beyond the Standard Model are also expected to manifest themselves clearly in their leptonic decay channels as an excess at very high momenta where the known background is very low. The key components of CMS in such searches are [1]:

- A very high magnetic field of B=3.8 T provided by a solenoid for the tracker and calorimeters. The required iron return yoke is embedded in the muon system.
- An excellent momentum resolution in the tracker constructed entirely of silicon (pixels for vertexing and strip detectors for tracking) of $\Delta p/p \sim 1\%$@100GeV.
- A good and redundant muon identification with four measuring stations everywhere along the muon's path and two complementary detection technologies. It provides about 10% stand-alone momentum resolution for TeV muons, mainly limited by multiple scattering in the iron return yoke. Combined with the excellent tracker the overall momentum resolution improves significantly, thus requiring a good alignment of the tracker to the muon system.
- Very high energy resolution ($\sigma_E/E \sim 0.01/\sqrt{E(GeV)}$) for electrons and photons provided by a fully sensitive electromagnetic calorimeter made of $PbWO_4$ crystals operated inside the 3.8 T solenoid.

In addition to test beam measurements of individual subdetector components, the CMS detector has undergone several commissioning campaigns with cosmic muons and beam splash events before taking first data from proton-proton collisions. In total about 350 million cosmic triggers were recorded and used to study the performance of different muon reconstruction algorithms [2], the internal alignment of the tracker and the muon system as well as the global alignment of both subsystems with respect to each other. Using cosmic muons, the precision achieved from alignment with tracks, has already superseded the earlier expectations concerning the alignment knowledge at startup. An insufficient alignment would wash out the signal and more luminosity would be needed to achieve a sensitivity comparable to the one with ideal detector knowledge. In addition trigger performance and efficiencies were studied with cosmic muons and the trigger timing was optimized. Horizontal beam splash events, although very few, were very useful to align the two muon endcaps with respect to each other, a task which cannot be done with cosmics muons as the rate of horizontal muons is too low. Large energy depositions in the calorimeters were used to study their performance.

2 Searches for New Particles

Searches for new particles, such as new additional heavy vector bosons Z' and W' or leptoquarks would manifest themselves in the detector as an excess of events in the lepton p_T spectrum or derived quantities. Fig 1 shows examples of simulated signals for those searches:

1. The neutral heavy vector boson Z' could decay into two leptons (leptons and muons were studied), representing itself as a resonant peak in the di-electron or di-muon spectrum at very high masses. An example is shown for m(Z')=1 TeV (see Fig 1-left).
2. Assuming Standard Model-like decays, the charged vector boson W' could manifest itself as a Jacobian peak in the transverse mass spectrum reconstructed from the high p_T electron or muon and the missing transverse energy caused by the neutrino. Also here, the excess would occur at very high momenta where background due to the Standard Model is negligible (see Fig 1-middle for m(W')=1 TeV, 1.5 TeV and 2 TeV).
3. Leptoquarks, particles that carry both colour and lepton flavour, should be produced in pairs with each of them decaying into a lepton + jet. They would provide a striking signature of two isolated and high p_T leptons and two high p_T jets (see Fig 1-right). First (electrons + jets) and second (muons + jets) generation leptoquarks have been studied at CMS and early data should provide a unprecedented sensitivity.

2.1 Selection of High p_T Leptons

Using simulated data, CMS has developed strategies to efficiently select high energy electrons and high momentum muons and suppress backgrounds or derive it from data. These selections are applied to all searches discussed in this paper.

For high p_T electrons at first a standard electron identification is required, meaning a single electron trigger, formation of EM clusters and their combination with pixel hits to be confirmed by tracker hits. The electron should fulfill $E_T < 25$ GeV and $|\eta| < 2.5$ and its tracker η, ϕ coordinates should match those measured in the calorimeter. Shower shape and energy deposition have to be consistent with the EM nature of the shower and be isolated in the calorimeter and

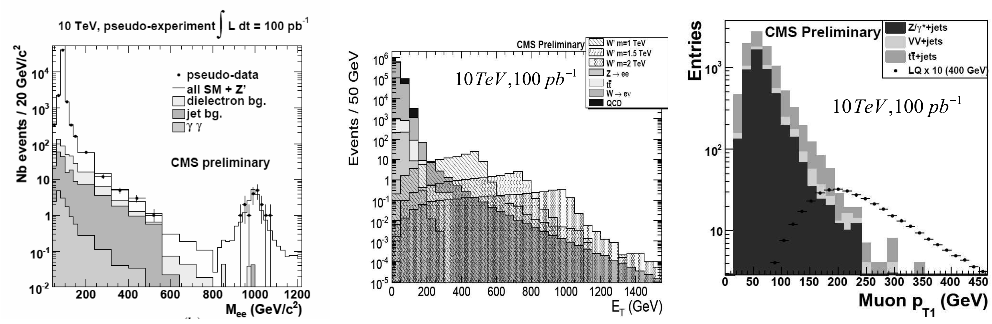

Figure 1: Examples of potential signals plotted along with their Standard Model background for three possible new particles. From the left: Z' vector bosons decaying to two leptons (electrons or muons), W' bosons deaying into an electron or muon and the corresponding neutrino, invariant mass of the lepton-quark system with an excess due to leptoquarks. All plots are for 10 TeV and 100 pb^{-1} of integrated luminosity.

the tracker. Also high p_T muons start from standard muon identification and must be triggered by the single muon trigger with the highest p_T threshold (depending on luminosity). Calorimeter energy should be consistent with a MIP signal. Calorimeter leakage is largely absorbed by the iron yoke between the muon stations. Muons can be reconstructed with hits from either the muon system or the tracker as well as a combination of both. Special reconstruction algorithms have been developed for TeV muons to treat showering and select very good quality muons. To suppress non-prompt muons isolation is required.

2.2 Search Strategies and Analyses

In the search for new, narrow resonances in the dilepton spectrum [3] with $\text{M}_{\ell\ell} > 800\text{GeV}$, the full Drell-Yan spectrum is studied from the Z-peak up to very high masses. Besides unexpected detector effects, this region should be almost free of known background processess. The signal, such as Z'-bosons or Randall-Sundrum gravitons, should manifest itself as an excess in the dilepton spectrum (left in Fig. 1). A competitive sensitivity can be reached with an integrated luminosity of about 100 pb^{-1} at 7 TeV center-of-mass energy, including systematic uncertainties due to the selection efficiency in the resonance mass region (4%), the impact on the invariant mass when extrapolating the DY background (50%) and an additional 10% uncertainty for k-factor and PDF, affecting both the signal and background.

Methods exists to check the ECAL linearity to the TeV scale. The electron efficiency will be determined from data using tag-and-probe, with $\sim$94% achieved for simulated data. The fake rate method will allow to measure the jet background in data (4.5 events in 100 pb^{-1} with 50% estimated systematic error).

In the muon channel additional background may be caused by mis-reconstruction and a good knowledge of alignment is essential for the invariant mass resolution. The analysis of the large cosmic muon sample has provided a sufficient basis. A small fraction of TeV-muons in the large cosmic muon sample even allowed to determine the momentum resolution ($\sim$10% @ 1TeV) and the charge misassigment fraction ($<$ 1.5%@1TeV). The overall muon efficiency was measured with tag-and-probe and simulated data to be (97.6$\pm$0.6)% at the Z-peak.

Potential charged heavy vector bosons, called W', would yield only one very high p_T charged lepton and E_T^{miss} [4] (see Fig. 1-middle). Also decays into jets are possible but difficult to separate from background. For leptonic channels, the signal region is almost free of background events, the few remaining ones coming from boosted (rejected by jet veto) and off-shell W-bosons (irreducible). At $\sqrt{s} = 7$ TeV a total of 11 background events is expected while a W' of 1 TeV mass would yield 43 events including trigger and reconstruction efficiencies. Three possible analysis strategies have been developed: the most advanced method uses the full kinematic information (reconstructed electron/muon and E_T^{miss}) and selects events with $0.4 < E_T^{lepton}/E_T^{miss} < 1.5$ and the angle between lepton and neutrino <2.5. In the case that E_T^{miss} is not yet fully commissioned, another search strategy relies only on the reconstructed lepton and rejects backgrounds by vetoing events with a jet of $p_T > 100$GeV in the direction opposite to the lepton. A third strategy would use MHT instead of E_T^{miss}. As the commissioning of E_T^{miss} appears to be in good shape, we plan to start with the first method. Including systematic uncertainties, such as alignment, calibration (1.5-4%), jet energy scale (7%), cross section (10%) and luminosity (10%), the existing Tevatron limit of m(W')=1 TeV can be challenged with 20-30 pb^{-1}.

Leptoquarks (LQ), being produced in pairs, would yield two very high p_T leptons (either electrons/muons or neutrinos) along with two jets [5]. In addition to the described lepton selections, jets with $p_T > 50$ GeV and $|\eta| < 3$ are selected. Both lepton-jet pairs are combined such that $\Delta M_{\ell j}$ is minimized. The scalar sum S_T of the p_T of the two leading leptons and two leading jets should fulfill $S_T > f(M_{LQ})$. Such selection would yield 39±0.15 signal and 1.5±0.3 background events in 100 pb^{-1}. Including systematic uncertainties, such an integrated luminosity would allow to search for leptoquarks with masses ranging from 250 to 500 GeV with the present experimental limit being 316 GeV.

3 Conclusions

The CMS detector is well suited to efficiently detect very high momentum leptons which may be a sign af new physics. Cosmic ray muons and beam splash events were used to align the detector, optimize triggers and reconstruction algorithms. Potential new particles, such as Z' and W' or leptoquarks would manifest themselves through an excess in single lepton or dilepton spectra. Selection criteria to select such signals were developed along with methods to quantify the background. With an integrated luminosity of 20-30 pb^{-1}, the search for W'-bosons will become competitive with the existing Tevatron limit. Further statistics will give access to searches for Z'-bosons and leptoquarks.

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