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CMS Preparations for New Physics Searches Involving Lepton Final States

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In 2007, the Large Hadron Collider (LHC) will circulate and collide proton-proton beams at an expected center-of-mass energy of 14 TeV. The Compact Muon Solenoid (CMS) is one of four experiments at the LHC and has been designed with particular attention to selecting and reconstructing muons with high redundancy. This paper briefly describes the CMS Muon System and provides an overview of CMS preparations for new physics searches involving lepton final states during the early phases of running at the LHC.

Keywords: LHC; CMS; Searches; Simulations.

1. The CMS Detector

The Compact Muon Solenoid (CMS) is a multi-purpose, nearly 4π solid-angle coverage detector[1] which is being constructed to discover a wide range of possible new physics processes at the future Large Hadron Collider (LHC) located at CERN near Geneva, Switzerland. Starting with CMS sub-detectors closest to the interaction point and moving outwards, a high resolution pixel detector combined with a large silicon strip tracker provide CMS with excellent vertex reconstruction and charged particle momentum resolution. Following this, a lead-tungstate crystal electromagnetic calorimeter (ECAL) surrounds the inner tracking volume, providing an energy resolution of about $1.5\%/\sqrt{E} \oplus 0.5\%$. A brass-scintillator tile hadronic calorimeter (HCAL) envelops the ECAL and provides very good hermiticity up to $|\eta| = 5$, important for $\not{E}_T$ measurement.

The guiding design principle of CMS revolves around a high 4 T superconducting solenoid which enables the construction of a relatively compact muon spectrometer, capable of detecting and reconstructing discriminating muons with high precision and efficiency. The muon system[2] lies outside the solenoid volume and is comprised of three different detector types, providing a high level of redundancy: drift tubes are located in the barrel region, cathode strip chambers (CSC) are located in the

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end-cap regions reaching up to $|\eta| < 2.4$, and resistive plate chambers (RPC), used for fast triggering, are located throughout the barrel and end-caps. This redundancy provides a very efficient system, greater than $\sim 95\%$, for reconstructing muons with very good transverse momentum resolution of about 5% for TeV muons.

Consistent with current funding, parts of the CMS detector will be staged[3] during the first physics run, including: 50% of the data acquisition system, the third end-cap of the pixel detector, 1/3 of the RPCs in the Muon End-cap (all RPCs with $|\eta| > 1.6$), and the fourth CSC muon end-cap (except the CSC chamber highest in $|\eta|$). The implication for detector performance, at low-luminosity, is primarily that of less redundancy for very forward muons and these staging plans are expected to have minimal overall impact on the early physics potential.

2. Simulation Studies in Preparation for New Physics Searches

It is expected that the LHC will initially deliver pp collisions at low luminosity (10^{33} cm^{-2} s^{-1}). In preparation for these early conditions, several benchmark search analyses, using the full CMS detector simulation (including digitization of electronic signals and trigger emulation) and event reconstruction with low-luminosity pileup, are underway. A few representative examples of these simulation studies, involving muon final states and corresponding to integrated luminosities from around 1 to 20 fb^{-1} of data, are summarized below.[a]

<u>Additional Heavy Neutral Gauge Bosons</u>[4]: A possible Z' decaying to muon pairs provides CMS with a very good benchmark analysis for possible discovery and for understanding the muon system. Standard Model Drell-Yan (DY) production of muon pairs posses an irreducible source of background, while di-boson production and QCD backgrounds (like $t\bar{t}$ and $b\bar{b}$) are much smaller and reducible. Owing to the well understood nature of DY production and the high Z' mass expectation, no background rejection cuts are made against the DY background and the efficiency for event selection is 70-75% for 1 TeV $< M_{Z'} <$ 5 TeV. Using an unbinned maximum likelihood fit (accounting for both signal and the DY background), the analysis finds[4] that a mere 0.1 fb^{-1} is needed to discover a Z' with mass of up to 1 TeV and that with 10 fb^{-1}, a Z' with 2.6 TeV $< M_{Z'} <$ 3.4 TeV could be discovered.

<u>Standard Model Higgs</u>[5]: The decay channel $H \to ZZ^* \to 4\mu$ provides a very clear signal and represents a signature discovery search for CMS. Background samples (ZZ^*, $t\bar{t}$, $Zb\bar{b}$, $Zc\bar{c}$) and signal samples (corresponding to Higgs masses between 115 GeV and 500 GeV) samples were simulated; the irreducible ZZ^* and reducible $t\bar{t}$ backgrounds are found to be most important, while the $Zc\bar{c}$ contribution is found to be negligible. Backgrounds are partly reduced by requiring that the four leading reconstructed muons in the event have high p_T and be isolated. In the case that

[a]While the analyses presented here use the full CMS simulation and reconstruction, they represent work in progress and currently assume a good understanding of the detector. To preserve the early physics potential, work is ongoing to anticipate and include possible sources of systematic effects.

$M_H < 2M_Z$, imposing a single $M_{\mu\mu} = M_Z$ hypothesis provides further discrimination. In the case that $M_H > 2M_Z$, an additional $M_{\mu\mu} = M_Z$ hypothesis is made on the other dimuon pair. For 200 GeV $< M_H <$ 400 GeV, the analysis finds[5] that discovery is possible within the first year of LHC running (assuming 20 fb^{-1} of collected data). If 125 GeV $< M_H <$ 140 GeV, then discovery is more challenging and would be possible after a few years of low luminosity running.[5]

<u>Semi-inclusive SUSY</u>[6]: One of the more striking possibilities at the LHC would be the production of events containing SUSY particles, which are characterized by large $\not{E}_T$ along with multiple high p_T jets. By requiring 2 same sign (SS), isolated, high p_T muons in the final state, simple clear trigger objects are available and the types of backgrounds which must be considered are significantly reduced (which may be particularly important at LHC start-up). Several SUSY benchmark points (m_0 vs $m_{1/2}$ in mSUGRA with $\tan\beta = 10$, $A_0 = 0$, $\mu > 0$) and background processes (including di- and tri-boson, $Zb\bar{b}$, $t\bar{t}$, etc) were simulated and a cut based approach is used to select events, based on quantities like $\not{E}_T$, jet E_T, and muon p_T. The results[6] indicate that with only 10 fb^{-1} of data collected, CMS can discover mSUGRA for $m_{1/2}$ up to 600 GeV and at least m_0 up to 1600 GeV.

3. Conclusion and Outlook

The CMS detector is designed to probe several prospects for new physics including searches for Higgs bosons, possible additional gauge bosons, and Supersymmetry. Some examples of current simulation efforts, using low-luminosity pileup with the full detector simulation and event reconstrution, to estimate the early reach of the CMS have been presented. When the LHC turns on, in 2007, CMS expects to have a detector capable of discovering a wide range of these new physics possibilities, even during the low luminosity, first physics run.

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