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Prospects for exotica searches at ATLAS and CMS experiments

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Summary. — This paper presents an overview of prospects for searches for exotic physics beyond the Standard Model with the Large Hadron Collider at CERN. The results presented here are based on Monte Carlo simulations of the ATLAS and CMS detectors, assuming $100\,\mathrm{pb}^{-1}$ of collected integrated luminosity and proton-proton collisions at $\sqrt{s} = 14\,\mathrm{TeV}$. A selection of benchmark analyses is discussed, including searches for new physics in the di-lepton and di-jet channel, and a description of techniques to identify the production of heavy long-lived charged particles. The impact on discovery potential of ATLAS and CMS of having collisions at an energy lower than the design of the machine is discussed.

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1. – Introduction

This paper presents a brief overview of prospects for searches for exotic physics beyond the Standard Model (SM) of fundamental interactions with the Large Hadron Collider (LHC) at CERN. At the present time the LHC is still in the commissioning phase, and first collisions are expected in the Fall of 2009. The results presented here are therefore based on detailed Monte Carlo (MC) simulations of the ATLAS [1] and CMS [2] detectors, assuming $100\,\mathrm{pb}^{-1}$ of collected integrated luminosity and proton-proton collisions with a center-of-mass energy of $\sqrt{s} = 14\,\mathrm{TeV}$. A selection of three ATLAS and CMS benchmark analyses with different experimental issues is discussed.

2. – Di-lepton channel

New heavy states consisting of a narrow resonance that decays into two high-energy (several hundreds of GeV) leptons with opposite charge are predicted in many extensions of the SM including Grand Unified Theories, Technicolor, little Higgs models, and models with extra dimensions. The strictest direct limits on the existence of such heavy neutral

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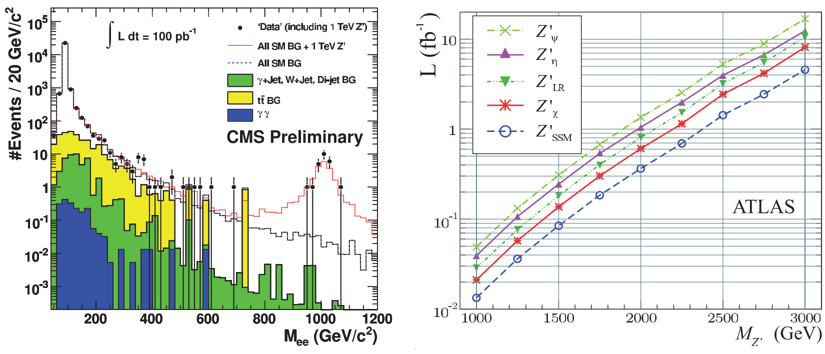

Fig. 1. – Left: di-electron invariant mass spectrum for a $100\,\mathrm{pb}^{-1}$ pseudo-experiment including a signal from $Z' \to ee$ with mass of $1\,\mathrm{TeV}/c^2$, compared to SM background estimates. Right: integrated luminosity needed for a 5σ discovery of $Z' \to ee$ as a function of the Z' mass for various benchmark models.

particles (for example the Z' boson, the hypothetical heavy partner of Z gauge boson of the SM) come from searches at the Tevatron, and the highest excluded mass is currently around $1\,\mathrm{TeV}/c^2$ [3].

Figure 1 (left) shows the distribution of the invariant mass of the two leading electrons, M_{ee}, in presence of a signal from $Z' \to ee$ with mass of $1\,\mathrm{TeV}/c^2$ from the CMS analysis [4]. Figure 1 (right) shows the ATLAS discovery potential for $Z' \to ee$ for various theory models, and suggests that resonances with mass above the current Tevatron limit could be discovered with $100\,\mathrm{pb}^{-1}$ of data [4]. The CMS analysis shows a similar discovery reach.

3. – Di-jet channel

Several theoretical models predict the existence of new high-mass resonances decaying to two jets. Even if the energy of the LHC is not sufficient to directly produce these new particles, the new physics might still appear as a quark contact interaction, and the LHC experiments should be able to identify its signatures by looking at di-jet events. We

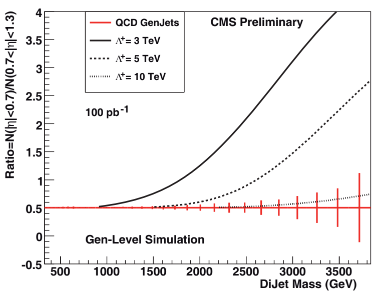

Fig. 2. – Di-jet ratio as a function of di-jet mass in the presence of contact interactions at different energy scales Λ^+, and for QCD multi-jet background.

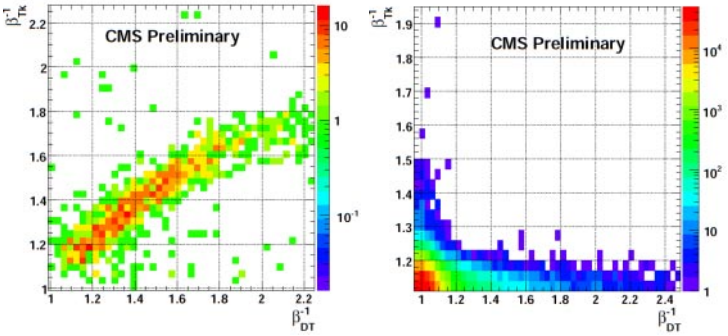

Fig. 3. – Distribution of $\beta_{\rm Tk}^{-1}$ *vs.* $\beta_{\rm DT}^{-1}$ for signal (stop with mass of $500\,{\rm GeV}/c^2$) and for SM background (right), for $100\,{\rm pb}^{-1}$ of data.

discuss here the CMS analysis [5](1) of the di-jet ratio(2) used to identify the presence of contact interactions. The most sensitive search for contact interactions at the Tevatron gives an exclusion on the contact interaction scale of $\Lambda^+ < 2.4\,{\rm TeV}$ [6]. Figure 2 shows the sensitivity of this measurement to contact interactions for different values of Λ^+. With $100\,{\rm pb}^{-1}$ of data, contact interaction with $\Lambda^+ < 6.8\,{\rm TeV}$ can be discovered, which is well above the current Tevatron limits.

4. – Heavy long-lived charged particles

Some models of new physics predict the existence of exotic particles that are heavy (mass of hundreds of ${\rm GeV}/c^2$), long-lived (enough to decay outside of the detector) and charged [7]. Such particles can be distinguished from SM particles by exploiting their unique signature: a low velocity ($\beta = p/E < 1$) associated with a high momentum (few hundreds of ${\rm GeV}/c$). Despite that these exotic particles arrive late in the muon system, and that those exotic particles with hadronic nature (so called R-hadrons, such as gluinos or stops) can experience the phenomena of "charge flipping" when interacting in the calorimeter, ATLAS and CMS experiments have a good trigger efficiency(3).

Two offline methods are used by the CMS analysis to measure β [8]: $\beta_{\rm DT}$ is measured from the time delay of the arrival of the particle at the muon chambers(4), while $\beta_{\rm Tk}$ is obtained from the ${\rm d}E/{\rm d}x$ measured in the silicon tracker (see fig. 3). The analysis results show that gluino, stop, and GMSB $\tilde{\tau}$ with mass of about $1\,{\rm TeV}/c^2$, $700\,{\rm GeV}/c^2$, and $200\,{\rm GeV}/c^2$, respectively, can be discovered with $100\,{\rm pb}^{-1}$ of data.

(1) Results from ATLAS analysis were not yet public at the time of the conference, and therefore not included in this paper.
(2) The di-jet ratio is an effective angular variable defined as $N(|\eta| < 0.7)/N(0.7 < |\eta| < 1.3)$, where N is the number of di-jet events with both jets satisfying the pseudo-rapidity requirements in parenthesis.
(3) See details in Massimiliano Chiorboli's talk during the conference.
(4) ATLAS performed studies to measure the value of β directly at the level 2 of the on-line trigger system [1].

5. – Conclusion

Three benchmark analyses have been presented to give an overview of preparation for Exotica searches in ATLAS and CMS experiments at the LHC. The results shown have been obtained with MC simulation, assuming $100\,\mathrm{pb}^{-1}$ of data and proton-proton collisions at $\sqrt{s} = 14\,\mathrm{TeV}$, which is the design energy of the LHC.

A few months before the conference, it was officially announced that the first LHC physics run will be taken at a lower energy ($\sqrt{s} = 10\,\mathrm{TeV}$) than the machine design. Preliminary studies, performed by the ATLAS and CMS Collaborations, have shown that the impact of the lower energy is not dramatic for the discovery potential of the experiments (for a Z' with mass of $1\,\mathrm{TeV}/c^2$, a factor 2 more integrated luminosity is needed to get the same sensitivity of 14 TeV collisions). In the absence of signal observed, ATLAS and CMS could set, already with the first $100\,\mathrm{pb}^{-1}$ of data, constraints on the models of new physics significantly more stringent than the current Tevatron reach. The updated results, for the 10 TeV scenario, of these analyses (and of many other searches not covered in this short overview) will be presented by ATLAS and CMS Collaborations in the next months.

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