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Early Standard Model Measurement and Determination of Standard Model Background for Searches

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The Large Hadron Collider (LHC) at CERN in Geneva (Switzerland) will go in operation in the coming months and will soon enable us to analyze the highest energy collisions ever produced at an accelerator. Beyond Standard Model searches at LHC require a detailed understanding of the detector performance, reconstruction algorithms and triggering. Precision measurements of Standard Model processes are also mandatory to acquire the necessary knowledge of Standard Model background. Both ATLAS and CMS e orts are hence addressed to determine the best calibration candles and to design a realistic plan for the initial period of data taking.

1. INTRODUCTION

ATLAS [1] and CMS [2] detector are two general detectors which have been designed in order to scrutinize proton–proton collisions of LHC. The major goal of these experiment is to search for beyond Standard Model processes and/or to push limits of Standard Model theory. The rst steps of these searches will be to establish with precision Standard Model processes for a center of mass of 14 TeV. Within the statistics delivered by LHC over the rst years of running, precised Standard Model measurements will constraint beyond Standard Model theories and allow us to understand these background for searches. In this paper, the Standard Model measurement will be presented as a function of increase luminosity. At each stage, these measurements will be exposed as a background for a given search.

Before collisions, the commissioning of the detectors is crucial to already understand their response. Then with 10pb^{1} of recorded collisions, detector synchronization, alignment of detectors and commissioning of rst physics objects will be done. The rst physics will be then dominated by jet physics. With less than 100pb^{1}, measurement of Standard Model processes using leptons can be addressed with a high precision and allow the start of the searches. Studies of complex nal states such as tt production will help the nalization of the commissioning period. Beyond 1000pb^{1}, the area of searches will begin.

2. FIRST PHYSICS USING JETS

The rst physics events that will be recorded by the detectors will be mainly minimum bias events. The minimum bias events will be used at the rst stage to calibrate and align detectors. In the meantime a rst look at the charged hadron spectrum at center of energy of 14 TeV will be possible. In the Fig. 1, ones can see the di erent $\frac{dE}{dX}$ from proton, kaons and pions for two of the CMS tracker detector.

In parallel, the studies of underlying events are mandatory at start up. The current simulation of these events is based on an extrapolation of the Tevatron energy at 2 TeV up to LHC energy at 14 TeV. These extrapolations lead to di erent values as shown in Fig. 2. It is them important to be able to discriminate between di erent extrapolations in order to ne tune the simulation as such events will play an crucial role in isolation criteria to de ned isolated leptons.

Jets will be the rst reconstructed objects at startup but these are also the most di cult objects to fully understand. It has to give a good description of jet/parton properties from an interpretation of calorimeters response. The

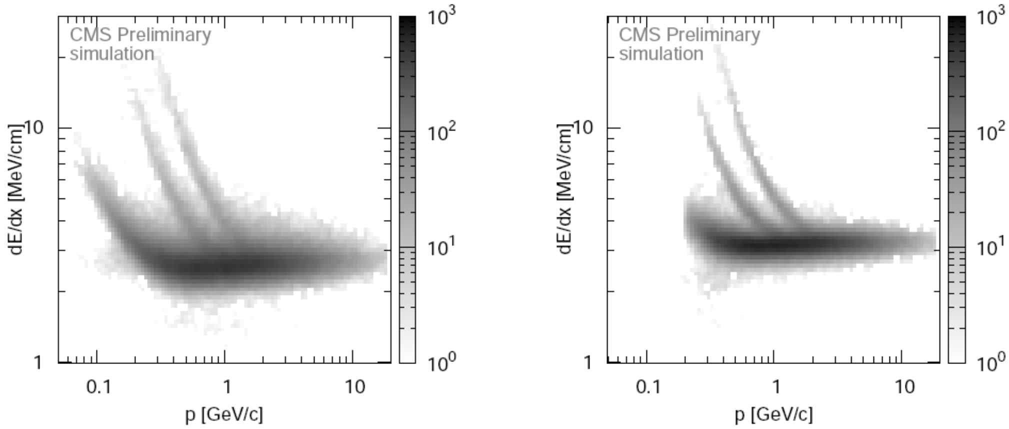

Figure 1: Distribution of the truncated mean estimator dE/dx as a function of momentum p for the pixels hits (left) and strip hits (right) of the CMS detector.

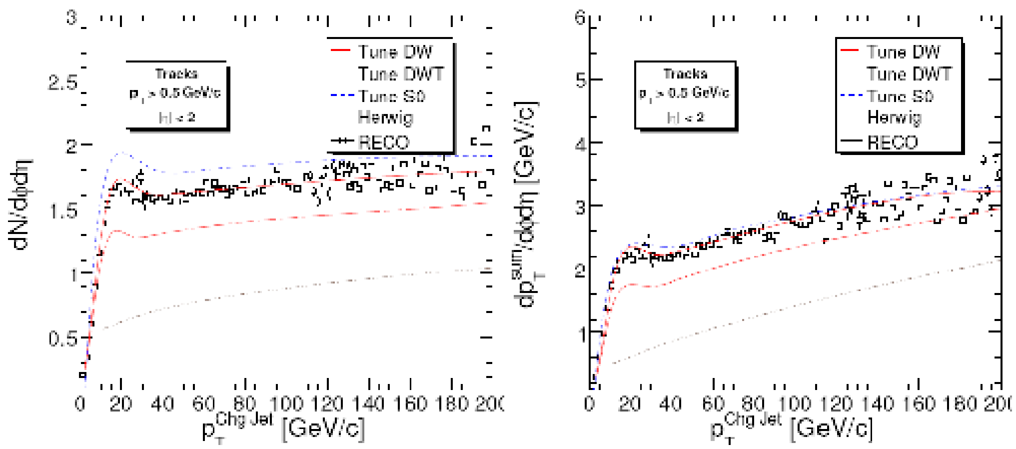

Figure 2: Densities $dN/d\eta d\phi$ (left) and $dp_T^{sum}/d\eta d\phi$ (right) for tracks with $p_T > 0.5$ GeV/c, as a function of the leading charged jet p_T, in the transverse region, for an integrated luminosity of 100 pb^{-1} collected by CMS detector.

response of the calorimeters will be influenced by experimental factors and physics factors. The main experimental factors that ones has to take care when building a jet are the amount of dead material in front of the calorimeters, longitudinal leakage and lateral shower size, non linearities in the read out as well as the non-compensated behavior of the calorimeter. The main physics factors are the understanding of initial/final state radiation, fragmentation, the amount of underlying events/minimum bias events.

Nevertheless, the physics program with jets is large and already some searches/complementary measurement of the Standard Model can be established. One of the first measurement can be the differential cross section of jets production which will allow a test of QCD theories: high momentum objects can be influenced by processes beyond Standard Model. The contact interaction will tend to enlarge the rate of production of jets at higher momentum as shown in Fig. 3. CMS analysis [3] describes with 10 pb^{-1} of data collected a sensitivity to $\Lambda^+ > 2.7$ TeV which is the current limit of Tevatron experiment.

The first advance event topology studied will be the studies of dijet events and mainly the invariant mass of dijet events. The dijet response will be used at start up in order to provide a first jet energy scale. This scale is mandatory to perform studies of invariant mass but, already, with a few of inverse picobarns of integrated luminosity, some tests beyond Standard Model can be performed.

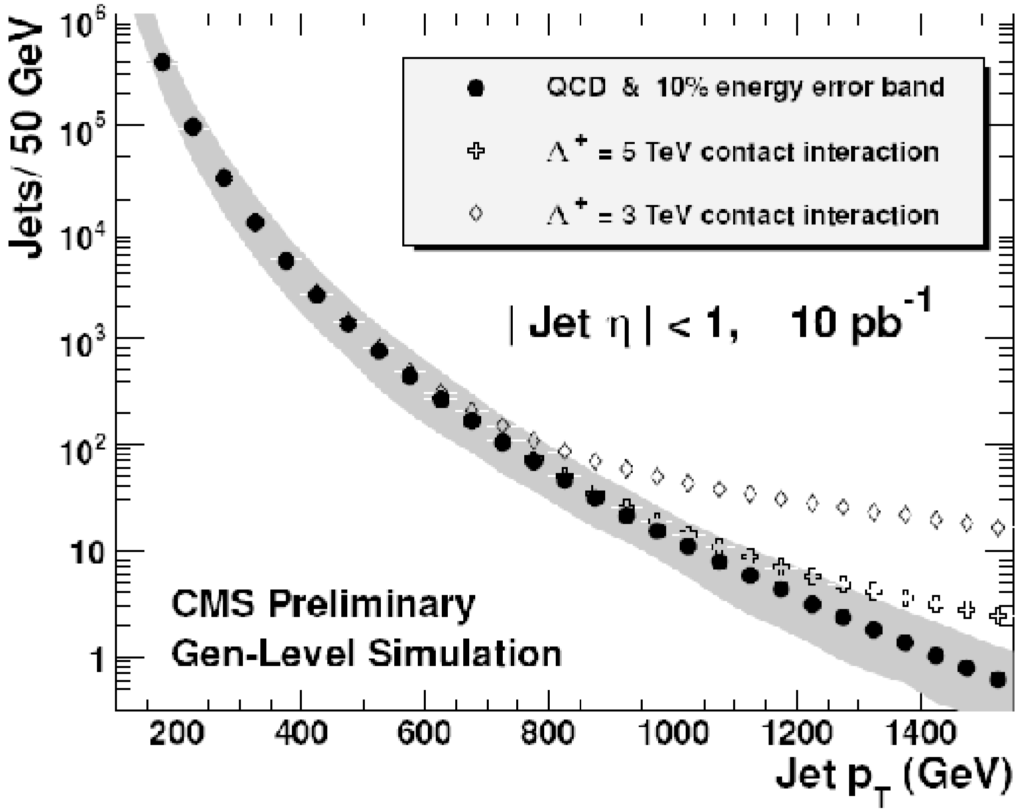

Figure 3: Rate of Jets within the central part of CMS detector as a function of energy for 10 pb^{-1} of expected integrated luminosity. Contact interaction will increase the rate at large energy.

3. CHALLENGING MISSING E_T

Even thought the missing E_T ($\not\!\!E_T$) variable can be calculated as soon as the detectors are close and ready, it will take some time before to fully understand it. In the meantime, $\not\!\!E_T$ is one of the variable the most sensitive to new physics. Sources of fake $\not\!\!E_T$ are mainly beam gas interactions, dead/hot/noisy cells/area in the calorimeter systems, non linearity/non-compensated detectors, finite energy resolution or from muons escaping detection as shown in Fig. 4 [5].

ATLAS and CMS collaboration develop techniques to handle the bias, for example, coming from jet energy scale correction [4]. Techniques are also developed in order to estimate the $\not\!\!E_T$ coming from physics events as $Z^0 \to \nu\nu$ from "visible processes" as $Z^0 \to ll$.

4. PHYSICS WITH LEPTONS

Jets and $\not\!\!E_T$ are mainly calorimetric object. The combination of the tracker with other detectors will bring the leptons into the game. But the leptons will mainly rely on the quality of the alignment of the tracker and also on the knowledge of magnetic fields. These quantities can be quickly estimated by looking at resonances as J/ψ and Υ within 1 pb^{-1} of integrated luminosity as shown in Fig. 5.

The LHC will be a $W^{\pm}/Z^0$ factories so with a few amount of data collected, cross section production can be established for a energy in the center of mass of 14 TeV. The main studies that will be done at the beginning with these events will be the commissioning ones. Indeed, Z^0 resonances are really important to tune the EM-scale of the calorimeter or to control electromagnetic calorimeter calibration in case of a decay in the electronic channel, to

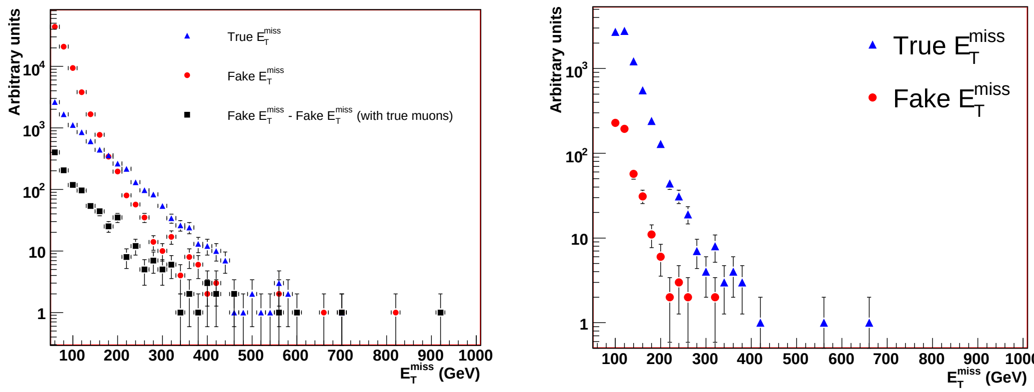

Figure 4: Left: Distribution of $\not\!\!E_T$ variable for generator information (triangle) and for fake $\not\!\!E_T$ (round). The fake $\not\!\!E_T$ from muon escaping the acceptance of ATLAS detector is compared to the overall fake $\not\!\!E_T$ (black point). Right: Distribution of $\not\!\!E_T$ variable for generator information (triangle) and for fake $\not\!\!E_T$ once the $\not\!\!E_T$ is corrected from muons escaping the acceptance of ATLAS detector (round).

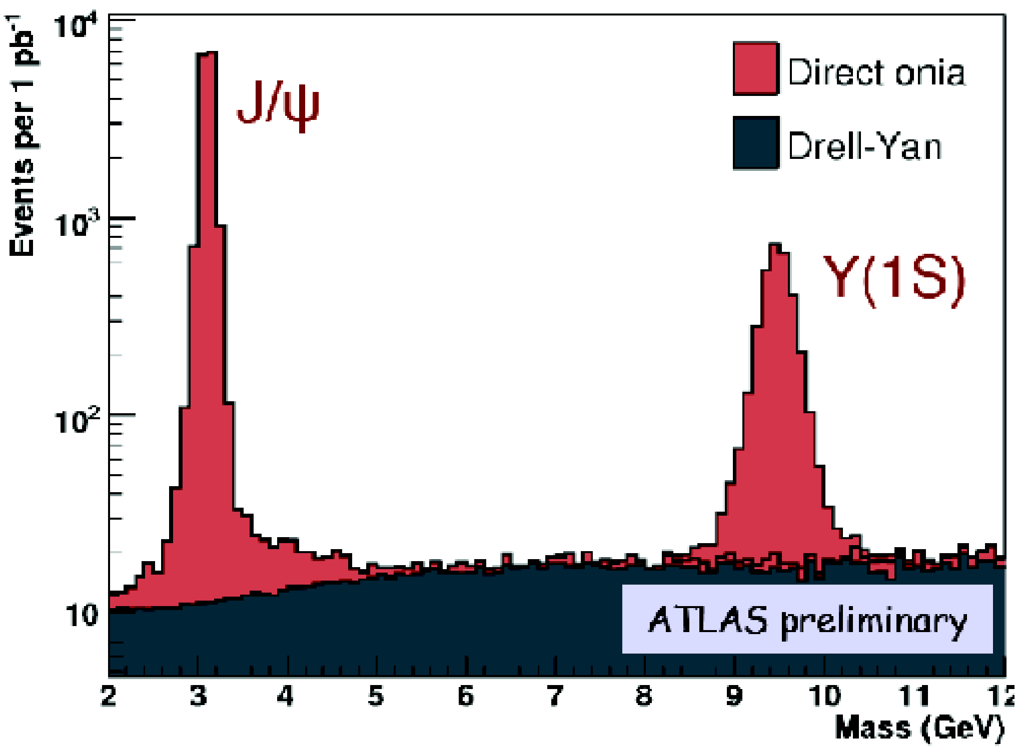

Figure 5: Dilepton invariant mass of the expected first inverse picobarns of data collected by ATLAS detector. J/ψ peak as well as Υ are clearly visible.

improve/validate the alignment of tracker and muons chambers in case of a decay muonically. The resonances will be also used to determine the efficiencies of the leptons by using the Tag-and-Probe method [6]. The Tag-and-Probe method rely on well known resonances. One of the leg of the resonances is asked to have a perfectly well identify lepton. The invariant mass of the two leptons should be within the resonance mass window. In that case the second lepton has a high probability to be a true isolated lepton and it is affected only by the bias from the kinematics of the resonance production. This second lepton sample can then be used to study lepton identification criteria.

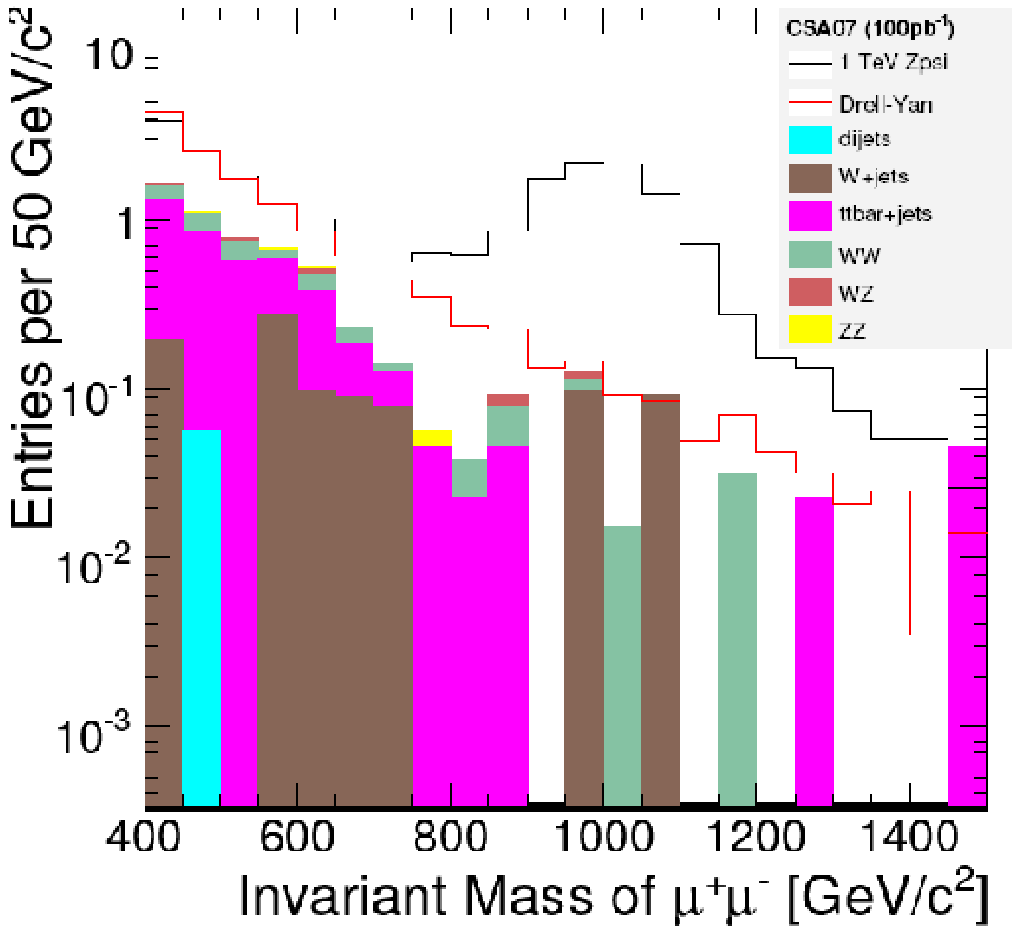

Figure 6: Invariant mass of two opposite charge muons within CMS detector for an expected luminosity of 100 pb ^{1}. A clear signal of Z will be seen on top of the di erent background.

In addition to cross section measurement, it will be possible to improve the constraints on PDF as at LHC, the W allow to access low-x range. With a few events, a measurement with a precision lower than 5% , a gain as large as 40% on systematics can be expected on low-x gluon shape [7].

At this stage, Standard Model physics using leptons as main nal state will be established. With a few inverse picobarn of data, main properties of such events at a center of mass of 14 TeV will be studied. Some early discoveries can happen in these topologies by simply looking at the tail of the invariant mass distribution. For example, CMS analysis with 100pb ^{1} of data can see an excess of events in the tail of the invariant mass of two opposite signed muons as shown in Fig. 6. For such analysis an optimal detector is not mandatory but the interpretation of such signal as a possible Z^0 candidate or as a graviton will require more studies.

5. TOP PHYSICS

The tt cross section production is a factor 100 greater than the one at Tevatron. The statistics of such events will be without comparison and so it will be possible to used these very complex events in order to validate/perform calibration. From the semi-leptonic decay of a tt event, it will be possible to constraint the two non b-jet to the invariant mass of the W and in that case to improve the jet energy scale. The presence of b-jet in dileptonic decay of such events will give us a high quantity of events with a high purity of b-jets in order to study b-tagging e ciency. The $\not{E}_T$ can also be controlled by constraining the semi-leptonic decay to the W mass. All these studies can be

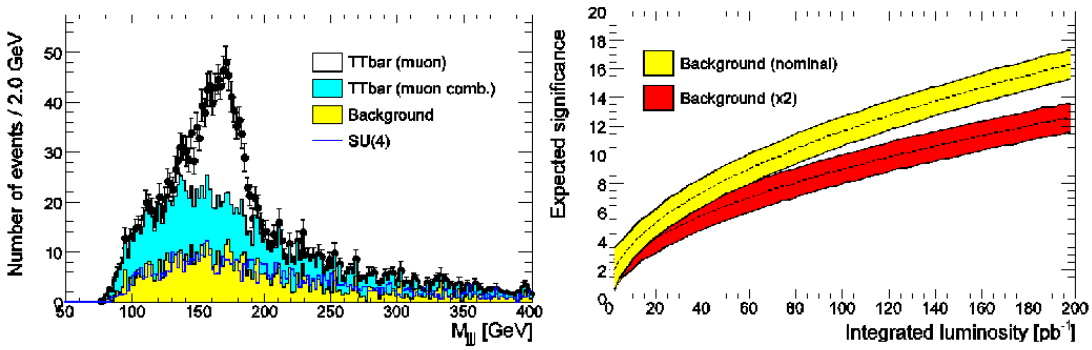

Figure 7: Left: Invariant mass of 3 jets in semileptonic $t\bar{t}$ events for $100\,pb^{-1}$ of expected luminosity recorded by ATLAS detector. SU4 signal will double the level of background. Right: Significance as a function of integrated luminosity with and without a SU4 signal which will double the background.

performed once only top events are seen in ATLAS and CMS detector. CMS analysis [8] shown that with $10\,pb^{-1}$ of collected data, the first measurement of the $t\bar{t}$ cross section production can be done. The analysis have been performed for three channels of dileptonic decay of $t\bar{t}$ events (di-electron, dimuon and one electron plus one muon) and in the case of $W \to \mu\nu$ for semileptonic decay.

Physics beyond Standard Model can also play an important role in the studies of $t\bar{t}$ signal at LHC. ATLAS analysis studied a squark signal within mSugra framework which will appear as doubling the background for $t\bar{t}$ semi-leptonic analysis. The invariant mass of 3 jets as well as significance as function of integrated luminosity are presented in Fig. 7.

Once $t\bar{t}$ production is established at a center of mass of 14 TeV studies of the invariant mass of the $t\bar{t}$ system can be scrutinized. An excess in such distribution can give a hint towards beyond Standard Model processes.

Contrary to $t\bar{t}$ system, the production of single top will require a integrated luminosity of around $1\,fb^{-1}$ to be established. Nevertheless, this processes will allow us to test quite some theories. The cross section production can be enlarged in case of $b^0; t^0$ production if $M_{b^0} > M_{t^0}$, W^0 production, flavor changing neutral current as well as Susy correction etc.

The top physics is a really challenging one due to the complex final state but this also conclude the commissioning phase of the detectors and allow us to push forward discoveries.

6. HIGGS BOSON SEARCH

The last remaining piece of the Standard Model which is still missing is the search for a Higgs signal. Depending on the mass of the Higgs boson, the Higgs boson can be discovered in a really clean and controlled multi lepton final state with a few hundreds of picobarns of data if the Higgs boson mass is larger than 130 GeV. In that case the Higgs boson decay will be essentially via a pair of W boson. These bosons will be studied in their leptonic decay and mainly electron and muon. Due to the large $\not{E}_T$ expected from the W boson decay, the mass of Higgs boson cannot be reconstructed. The Higgs boson is a spin 0 particle so the two leptons coming from W decay will tend to be collinear. This property gives a handle to discriminate Higgs boson decay from WW Standard Model production. Fig. 8 presents for CMS analysis, the invariant mass of the dilepton system and the azimuthal angular separation between the two leptons for the channel after the selection applied and for a Standard Model Higgs boson mass hypothesis of $m_H = 160$ GeV [9]

The Higgs boson discovery or its exclusion will play a crucial role for the seacrhes beyond Standard Model physics if by that time nothing would have been already observed.

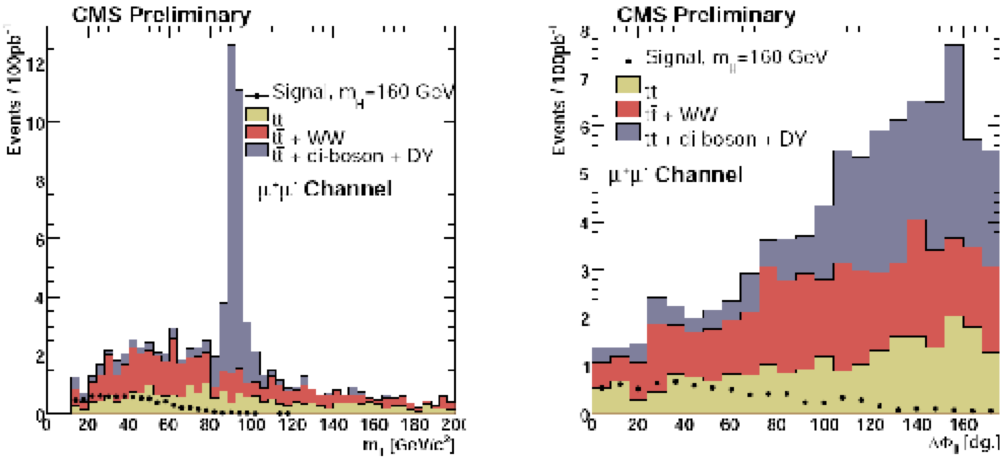

Figure 8: Left: Invariant mass of the dilepton system reconstructed in the CMS detector, right: azimuthal angular separation between the two leptons for the channel after the selection and for a Standard Model Higgs boson mass hypothesis of m_H = 160 GeV.

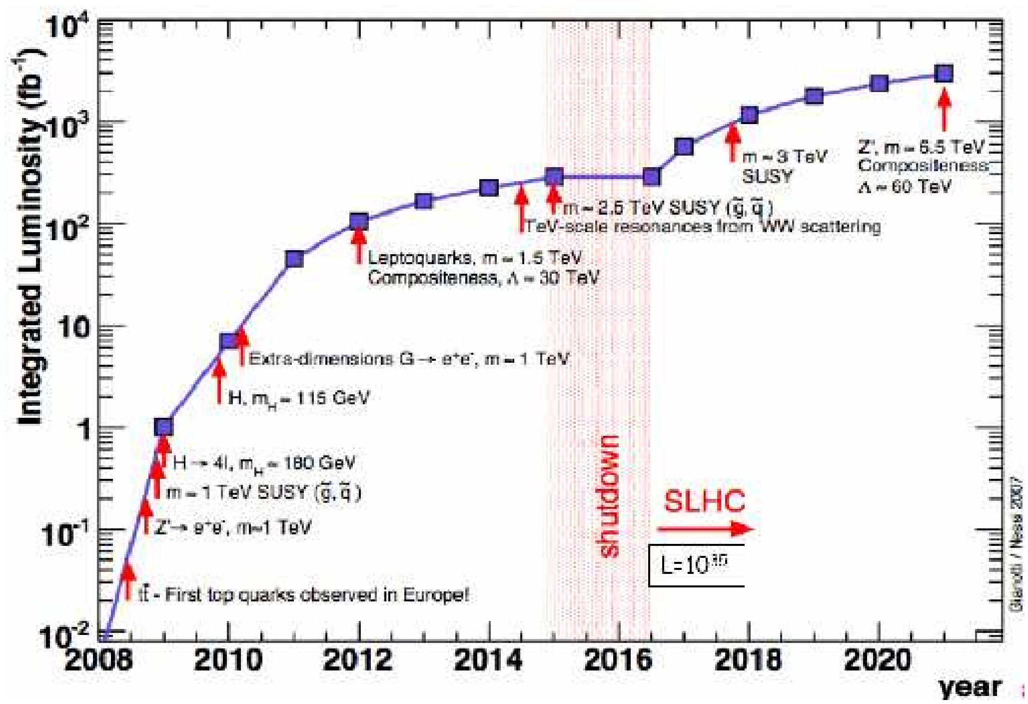

Figure 9: Integrated Luminosity as a function of time with expected point where discovery of process beyond Standard Model can be performed. LHC will allow us to achieve large searches.

7. CONCLUSION

Once the LHC will start and once ATLAS and CMS experiment will have commissioned their detectors using Standard Model processes, the vast area of searches for processes beyond Standard Model will really begin. Some processes can already appear within the commissioning phase or at least indicate that beyond Standard Model physics is at the corner. Fig. 9 presents as a function of time and integrated luminosity the discovery potential owing to LHC machine and detectors.

Acknowledgments

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