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# First Look at the LHC 13 TeV Data With The CMS Detector

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**Abstract.** First results with the data collected in CMS detector after two months of Run II collisions at $\sqrt{s} = 13$ TeV, corresponding to few tens of inverse pb of luminsity, are presented in these proceedings. Data analyses are focused on the Physics commissioning and the first results and plots of Standard Model studies, b, top and Electroweak Physics. Some new results on searches for Physics beyond the Standard Model, Exotica and Susy, are also shown, with a particular emphasis on a dielectron event recently collected with an unexpected high invariant mass of 2.9 TeV.

## INTRODUCTION

After the recent starting of Run II at a collision energy of 13 TeV, the CMS Collaboration is working in three directions:

1. The Run I analyses that are still on-going with new precision results.
2. The Run II at 13 TeV with detector and Physics commissioning and first results from data collected.
3. The preparation for the future detector upgrades.

After a brief flash on the 8 TeV Run I analyses status, this presentation is mainly dedicated to the second item, the first look at the 13 TeV data. At the startup of the new Run of LHC, a problem with the cryogenic supply of the CMS magnet occurred. This caused a relevant amount of data, corresponding to the 35% of Luminosity collected so far, was taken without magnetic B field on. However recent data have been collected efficiently with the field on and the strategy is to wait for the winter shut down in order to investigate and fix this issue of the cold box system.

## RUN I LEGACY

So far CMS published more than 450 papers on the Run I data analyses, corresponding about to 20 $\text{fb}^{-1}$ collected at 8 TeV and 5 $\text{fb}^{-1}$ collected at 7 TeV. 2015 is still a very active year on this point of view, with many new precision analyses on the Standard Model, Electro-weak, top and B Physics recently submitted for a publication. An extensive study of the Higgs properties was performed and unfortunately no deviation from the Standard Models couplings was observed [2], as shown in Fig. 1. No evidence or hint of new Physics, Susy or Exotica in the 8 TeV data was observed. This made the 13 TeV data LHC Run II even more exiting since it will be a unique opportunity at CERN and in the whole world Particle Physics programs for the future years to open a window on the unknown and probe new Physics scenarios.

Among the many different analyses of Run I, in this proceeding I report as golden example, the new Vector Boson Fusion Higgs to $b\bar{b}$ measurement recently performed in CMS [3]. It is the first time at LHC this very difficult analysis is implemented, because of the huge QCD background rate. This measurement, considered as impossible only few years ago, was made with the help of the new sophisticated neural network techniques, such the color-reconnection and the quark-gluon separation, that helped to reduce the unfavored background rate to a decent ratio. Thanks to this new analysis that was included in a global fit with VH and ttH Higgs production channels, the Hbb coupling in CMS is now measured with a sensitivity of 2.6 $\sigma$ and its value is in total agreement with the Standard Model Higgs. Figure 2 shows the likelihood combination for this measurement.

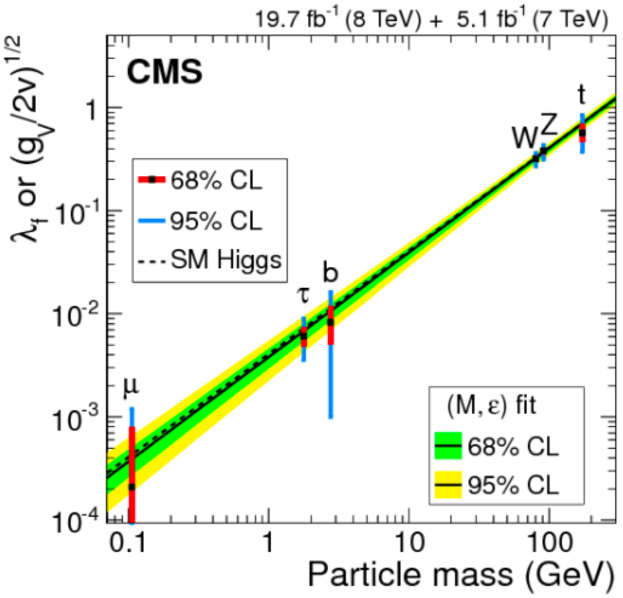


**FIGURE 1.** Higgs coupling to fermions measured by CMS in the Run I data

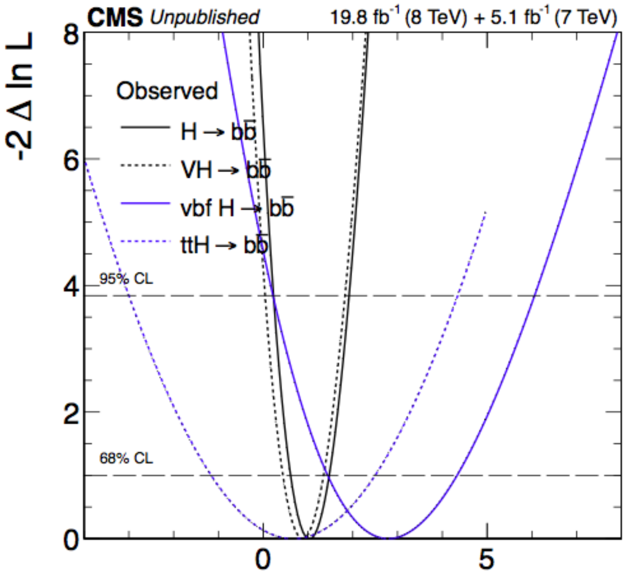


**FIGURE 2.** Signal strength relative to the Standard Model fit of the Higgs to bb decay channel with the combination of different production mode

## RUN II FEATURES and DETECTOR PREPARATION

The Run II at 13 TeV of collision energy has important new key points for the LHC Physics. For the first time this energy will be probe in a collider, opening possible scenarios of new Physics beyond the limits of Run I. Besides, thanks to the increased parton luminosity, the effective cross-section for the Standard Model and new Physics processes is dramatically increased leading to supersede the actual limits of Run I searches for new particles after few $\mathrm{fb}^{-1}$. This will be a unique and exciting opportunity for new discovery in Particle Physics.

The CMS detector is described here [1]. CMS prepared to this new Run with an upgrade of some parts of its sub-detectors implemented during the recent Long Shut-down (LS1). A new thinner beam pipe has been positioned in the interaction center to allow the next installation of a new inner Tracker layer. The pixel part of the Tracker is now operating by design with the $-20°$ C temperature to decrease the noise and improve the radiation hardness of the subdetector. New luminosity telescopes have been added in the forward region to improve luminosity measurements. A 4th muon station was installed in the end-caps as foreseen by design and new HCAL photosensors improved the hadronic calorimetry systems. Other minor recovery interventions and adjustments during LS1 allowed to have a optimal Run II start-up with all sub-detector operating with active channel fraction higher than Run I and always between 96 and 100%. Improved DAQ, Computing and Software will also allow to have a faster event reconstruction, new data format with compact high level data object and move to multi-threading with multi-core queues at CERN and Tier-1. On the Trigger side, L1 calorimeter trigger has been updated and further L1 upgrades are planned for 2016. Besides significant efforts on algorithm improvements with emphasis on pile-up mitigation have been implemented.

## FIRST COLLISIONS and PHYSICS COMMISSIONING

The first collision at 13 TeV in CMS was recorded in early morning on May 21st, 2015: a new hera in Particle Physics just started. Few weeks after, the first CMS paper, entitled *Pseudorapidity distribution of charged hadrons in proton-proton collisions at* $\sqrt{s} = 13$ *TeV* , was submitted to a publication [4]. This measurement, showed in Fig. 3, performed in CMS in a special early run at 13 TeV taken with B = 0 T, gives an handle on the relative weight of soft and hard scattering contribution, testing also the compatibility between data and simulations.

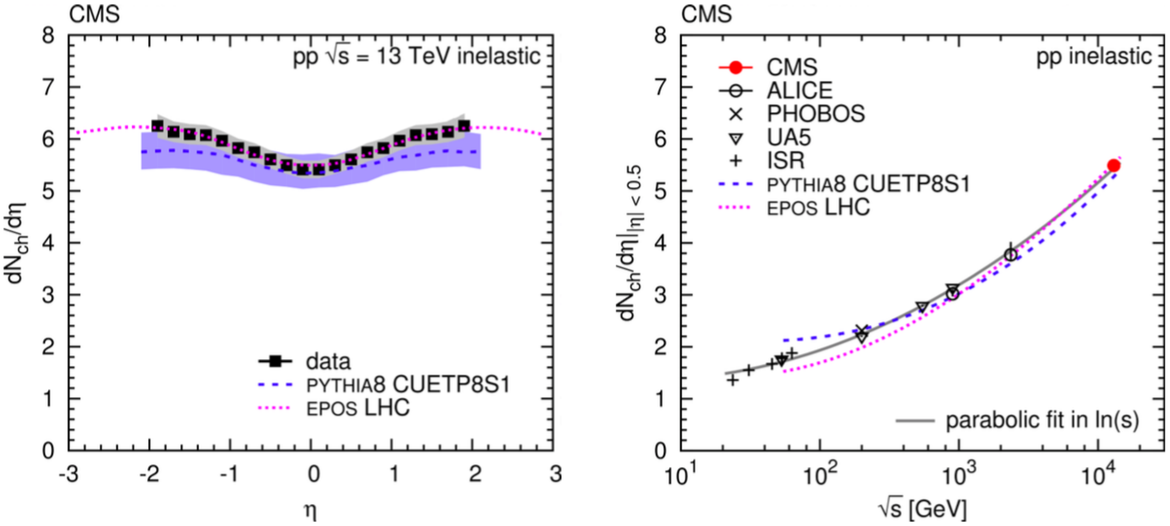


**FIGURE 3.** Pseudorapidity distribution of charged hadrons (left) and integrated cross-section in function of collision energy (right)

Then alignment was performed, first with Cosmics and after with collisions data, with nuclear interactions used as detector radiography to verify and map the Tracker inner layers position. A detailed dimuon spectroscopy allowed to "re-discover" all the Standard Model candles, from strange and charmed resonances, B Physics up to Z, as plotted in Fig. 4. Dielectron and ditau resonances were also measured.

The restart of the CMS magnet after LS1 was more complicated than anticipated due to a problem with the cryogenic system in providing liquid Helium. Inefficiencies of the oil separation system of the compressors for the warm

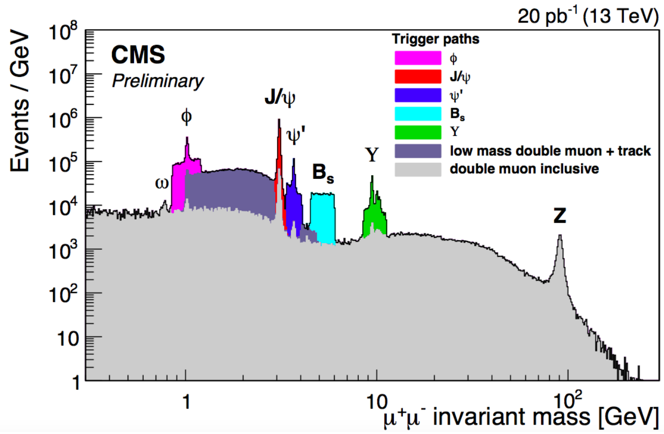


**FIGURE 4.** Muon spectroscopy for different trigger paths

Helium required several interventions and delayed the start of routine operation of the cryogenic system. The data delivered during the first two weeks of LHC re-commissioning with beams at low luminosity have been collected without magnetic field. Currently the magnet can be operated, but the continuous up-time is still limited by the performance of the cryogenic system requiring more frequent maintenance than usual. A comprehensive program to re-establish its nominal performance is underway. These recovery activities for the cryogenic system will be synchronized with the accelerator schedule in order to run for adequately long periods. Consolidation and repair program is ongoing during the technical stop while a full cleanup of the Cold Box is foreseen for the long Technical Stop at the end of the year

## EARLY ANALYSES RESULTS

Top Physics is one of the first topics expected to be covered by CMS Run II program. The top pair production cross-section, is considerably large to be measured with few tens of pb$^{-1}$ of luminosity collected in the very first data analyzed. The top pair cross-section is measured both in the dilepton and in the lepton+jet final states. The first measurement is obtained through the study of hadronic jets for events containing one isolated muon and one isolated electron forming an invariant mass greater than 50 GeV, the second allow to reconstruct hadronic top quark candidate mass for events containing one isolated muon and four jets candidates out of which two pass a tight b-tagging threshold. At the time of this presentation, the top pair inclusive cross-section was measured in dilepton final states [5] with 42 pb$^{-1}$ to be:

$$\sigma_{tt}(13TeV) = 772 \pm 60(sta) \pm 62(sys) \pm 93(lum)pb$$

This result, compared to the Run I ones, is in a perfect agreement with the theoretical curves as shown in Fig. 5. With the same analysis, also differential cross-section respect to all the typical kinematic variables were measured [5]. Besides, new Run I results have been recently published, and an updated measurement of the top pole mass from NNPDF30 pdf was extracted:

$$M_{top,pole} = 173.6^{+1.7}_{-1.8}\,GeV$$

The analyses searching for Supersymmetry need more statistics to be implemented. Nevertheless, key observables shape in data were checked with Montecarlo simulation, Trigger efficiencies measured and background estimation methods tested. Examples of this exercise are plotted in Fig 6.

Early searches for new Physics started in dijet, diphoton, dilepton and lepton+missing transverse energy (MET). Dijet analysis with the current integrated luminosity of 42 pb$^{-1}$ is expect to exceed the sensitivity of the 8 TeV Run I analyses for narrow resonances with masses greater than about 5 TeV. Figure 7 shows the invariant mass dijet spectrum: above 3.5 TeV about 5 background events are expected from the fit to data and 4 are observed, with a highest mass of 5.4 TeV.

In Fig. 8 the observed limits at 95% CL on the cross-sections of qq, qg, gg resonances are plotted: limits get worse when there are gluons in the final state because radiation increases and resolution degrades. Limits are reported

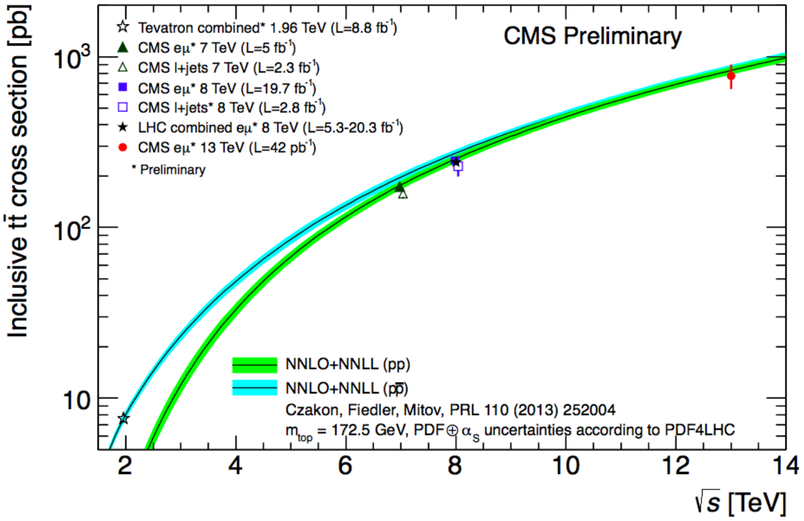


**FIGURE 5.** Inclusive cross-section of top pair production at the hadron colliders

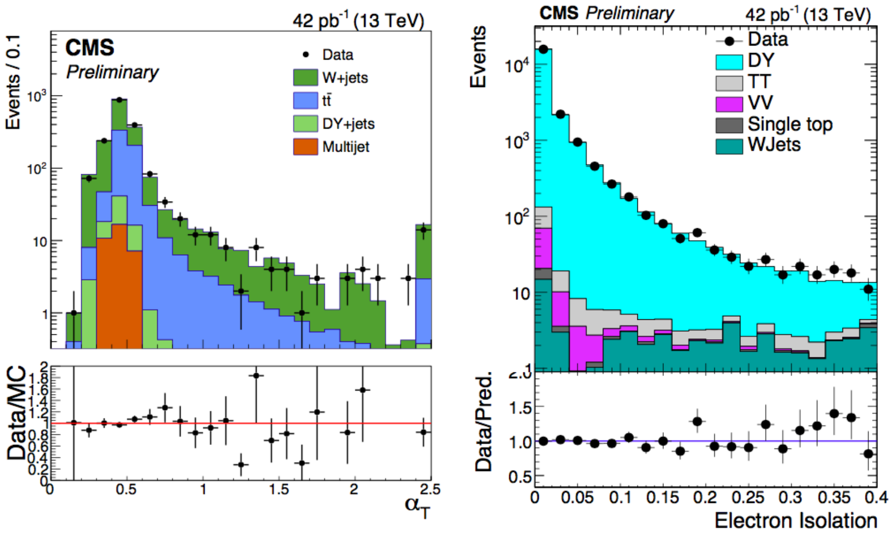


**FIGURE 6.** Comparison data vs simulations for two variables, $\alpha_T$ and electron isolation, commonly used in the SUSY search analyses

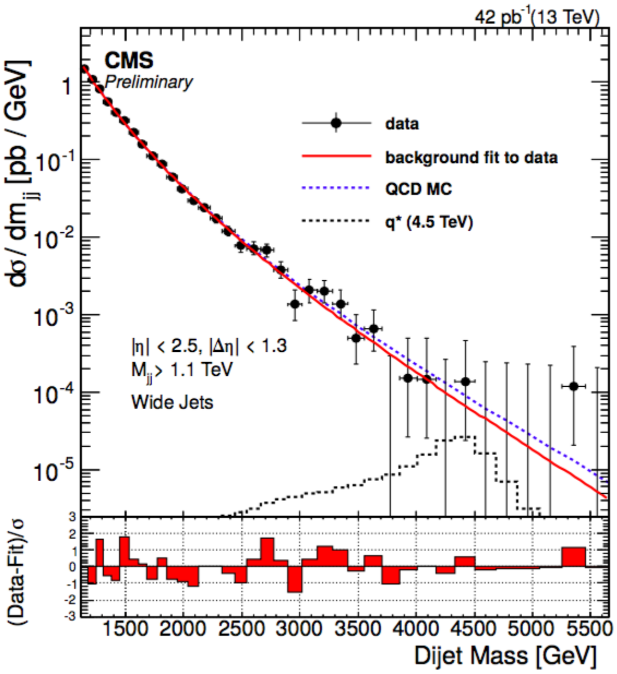


**FIGURE 7.** Dijet invariant mass

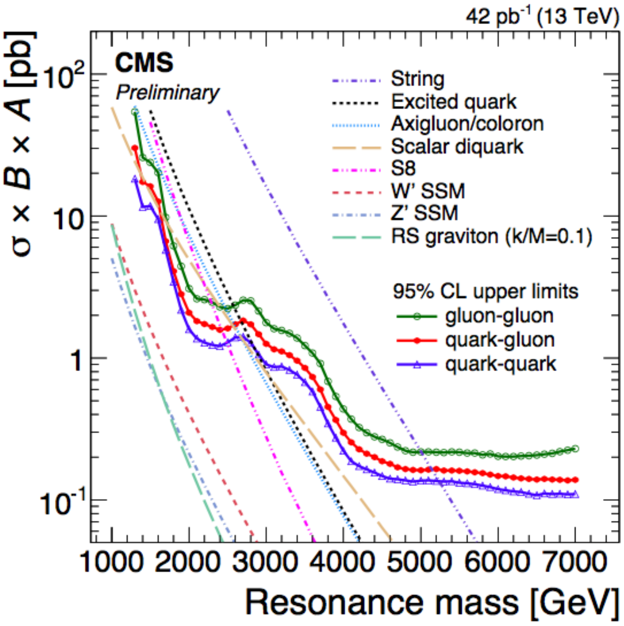
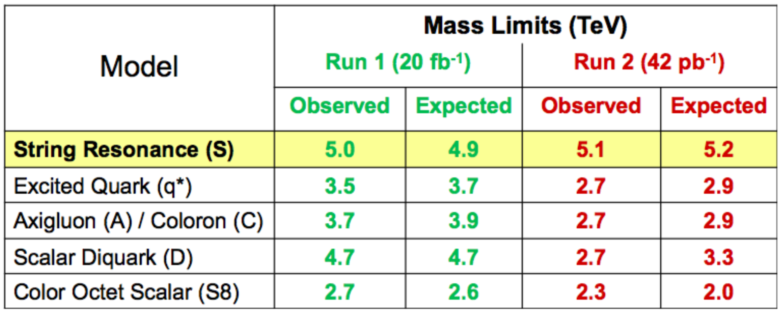


**FIGURE 8.** Limits for searches in dijet events



| Model | Mass Limits (TeV) | | | |
|---|---|---|---|---|
| | Run 1 (20 fb$^{-1}$) | | Run 2 (42 pb$^{-1}$) | |
| | Observed | Expected | Observed | Expected |
| **String Resonance (S)** | 5.0 | 4.9 | 5.1 | 5.2 |
| Excited Quark (q*) | 3.5 | 3.7 | 2.7 | 2.9 |
| Axigluon (A) / Coloron (C) | 3.7 | 3.9 | 2.7 | 2.9 |
| Scalar Diquark (D) | 4.7 | 4.7 | 2.7 | 3.3 |
| Color Octet Scalar (S8) | 2.7 | 2.6 | 2.3 | 2.0 |

**FIGURE 9.** Limits for searches in dijet events

in Fig. 9 with the comparison of the Run I results and confirmRun the Run II is already more sensitive than Run I for masses greater than 5 TeV[6].

Diphoton analysis recorded first high mass events, requiring a minimum transverse momentum of 100 GeV for each photon and a pseudorapidity lower than 2.5 with at least one photon candidate in the ECAL Barrel. Figure 10 displays the event with highest mass, namely 730 GeV.

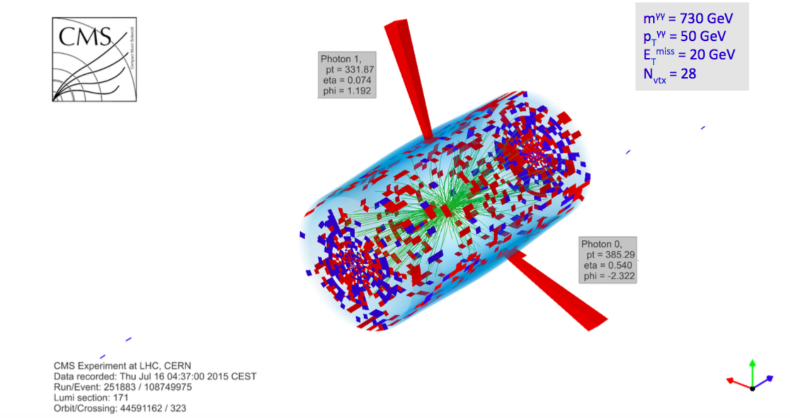


**FIGURE 10.** Event display for the highest mass diphoton event

The high momentum muons reconstruction still suffers for the early alignment used in data, nevertheless both dimuon and single muon with missing transverse energy (muon+MET) analyses gave first results on the search for Z' and W' respectively [8], [7]. Figure 11 and 12 show the dimuon invariant mass spectrum and the muon+MET transverse mass. In the dimuon analysis two isolated muons with transverse momentum greater than 48 GeV and pseudorapidity lower than 2.4 are required in the event. Highest mass dimuon event was observed at 920 GeV. For the muon+MET, a good-quality isolated high momentum muon, with transverse momentum greater than 55 GeV and pseudorapidity lower than 2.4, is selected when accompanied by a large missing transverse energy. In both cases the mass spectra in the data are compatible with the Montecarlo expectation from Standard Model and no excess is observed at high mass.

Also the dielectron search for a high mass resonance has been performed [8], requiring two electrons in ECAL with transverse energy greater than 35 GeV and at least one electron in the ECAL barrel. The invariant mass spectrum, showed in Fig. 13, with events up to 1 TeV, seemed to be in perfect agreement with simulations up to few days before this presentation when an extraordinary high mass event of 2.9 was observed in the data. The event display of this high mass event is showed in Fig. 14: the event consists in two perfectly balanced electrons and no other significant activity, with a negative Collins-Soper angle while Drell Yang background is peaked toward positive values. Previous highest mass event from Run Run II was 1.8 TeV (1.9 TeV for muons) and Run I limits for Z' Search do not exclude one Z' event at this mass with this luminosity. Background is very low but not negligible, about 0.002 events for mass greater

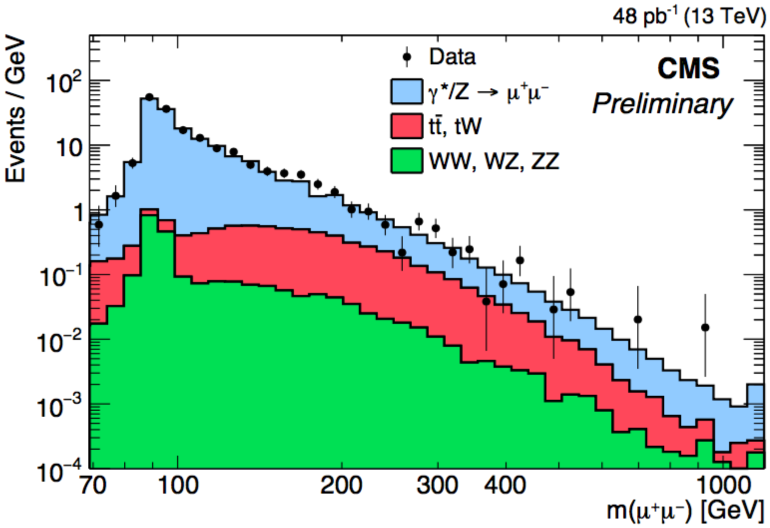


**FIGURE 11.** Invariant mass spectrum for dimuon events

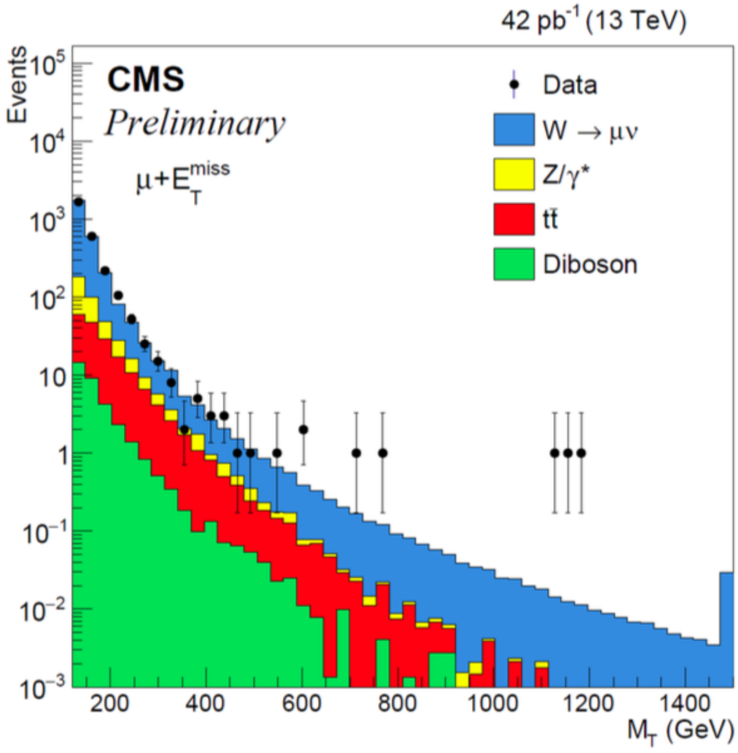


**FIGURE 12.** Transverse mass for muon+MET events

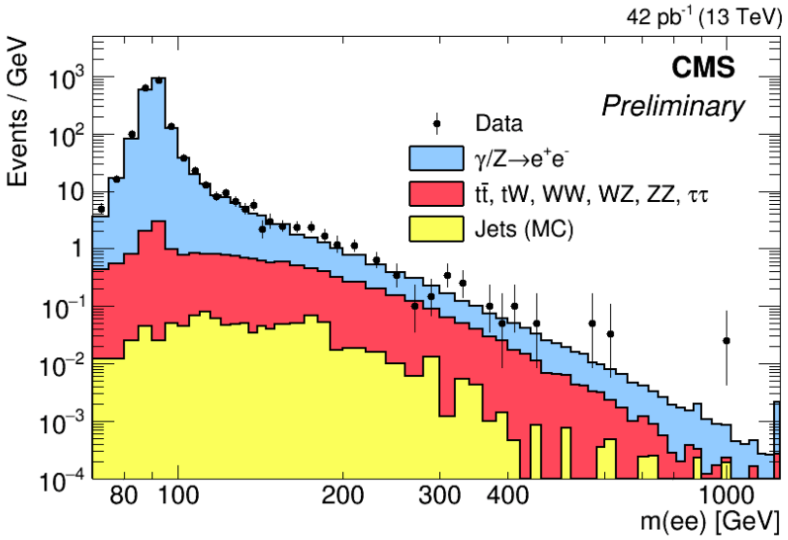


**FIGURE 13.** Invariant mass spectrum for dielectron events

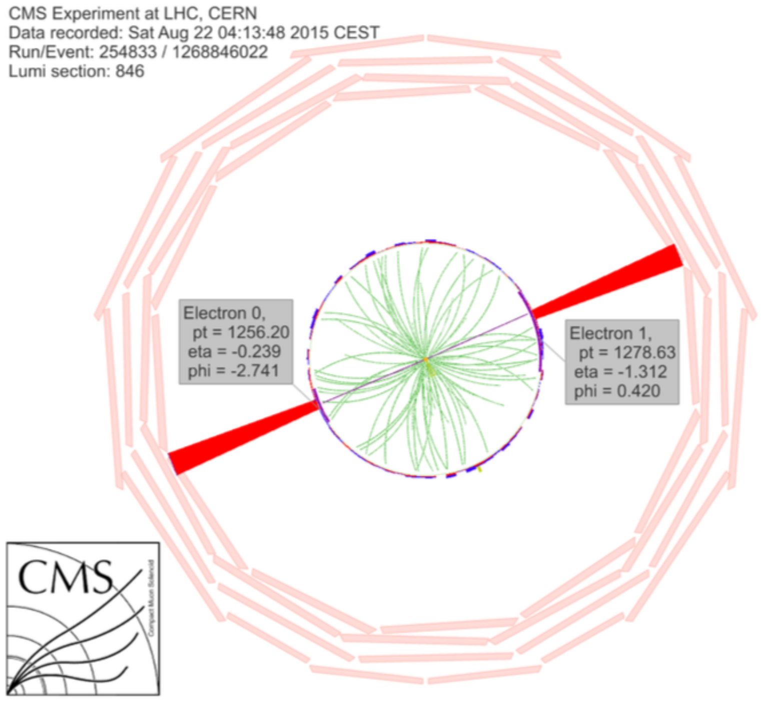


**FIGURE 14.** Event display for the dielectron event with invariant mass of 2.9 TeV

than 2.5 TeV, leading to a probability of a few per mille to observe this event from a fluctuation of the background. Nevertheless, this event can be a rare background fluctuation and we are waiting for new data, to understand if it is the case.

## CONCLUSIONS

A new challenging time just started with the LHC Run II at 13 TeV while Run I analyses of 8 TeV data are still on-going with new precision results. All the CMS sub-detectors are in an optimal shape and reconstruction algorithms optimized for higher pile up. First exciting events and results from 13 TeV are already public with a luminosity of about 50 $\text{pb}^{-1}$ while we are expecting to surpass the Run I search sensitivity for many New Physics signatures after a luminosity of few $\text{fb}^{-1}$ that will be collected in the next months. Interesting time are expected ahead of us.

## ACKNOWLEDGMENTS

I want to congratulate all the CMS members involved in the detector set up for Run II and in the analyses presented here for their contributions to the success of the CMS effort. These results presented on behalf of the CMS collaboration, were produced thanks to the work of our colleagues in the CERN accelerator departments.

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