Subnuclear Physics: Past, Present and Future
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HIGHLIGHTS FROM CMS

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ABSTRACT

The LHC accelerator has collided protons and lead ions at unprecedented high energies. Outstanding progress has seen the proton-proton interaction rate increase from about 100/s in March 2010 to about 300 million/s in November 2011. The CMS experiment is also performing very well, close to the desired and ambitious design performance parameters laid down some fifteen years ago. The emerging physics measurements are confronting, more and more precisely, the predictions of the Standard Model of particle physics, whilst looking for a broad range of potentially new physics.

Keywords: LHC, CMS experiment, experimental measurements of standard model processes, experimental searches for new physics.

1. INTRODUCTION

The LHC Project [1], the accelerator and its experiments, have required a 20 year-long and painstaking effort to get to this point. This has been accomplished by a global project that is a tribute to human ingenuity, collaboration and resolve.

The Standard Model (SM) of particle physics contains the unification of electromagnetism and weak interaction elucidated in the 1960's. The programme of physics of CMS, and ATLAS, comprises a broad range of physics including the clarification of electro-weak symmetry breaking, identification of the particles that make up the dark matter in the universe, and the search for new physics at the TeV energy scale. CMS also has specific capabilities in the study of b-physics and in study of heavy ion collisions using hard probes.

The paper will briefly outline some of the challenges faced in the last 20 years during the construction of the CMS experiment, its operation and performance, the first physics results from the experiment, and the outlook.

2. THE CMS COLLABORATION AND DETECTOR

CMS today comprises 3375 scientists and engineers of which 1740 are Ph.D. physicists, 845 Ph.D students, and 790 engineers from 170 institutions in 40 countries. The talents and the resources of all these participants have been needed over the last 20 years for the phases of design, prototyping, construction, installation, commissioning, data-taking and now distributed data analysis.

The central feature of the CMS apparatus [2] is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the field volume is an all-silicon pixels (comprising ~ 65 million channels) and silicon strip tracker (comprising ~200 m^2 of detecting area), a scintillating crystals electromagnetic calorimeter (ECAL), and a brass-scintillator sampling hadron calorimeter (HCAL). Muons are detected in gas-ionization detectors embedded in the steel return yoke. In addition to the barrel and endcap detectors, CMS has extensive forward calorimetry. A transverse view of the CMS experiment during its installation in the underground cavern is shown in Fig. 1.

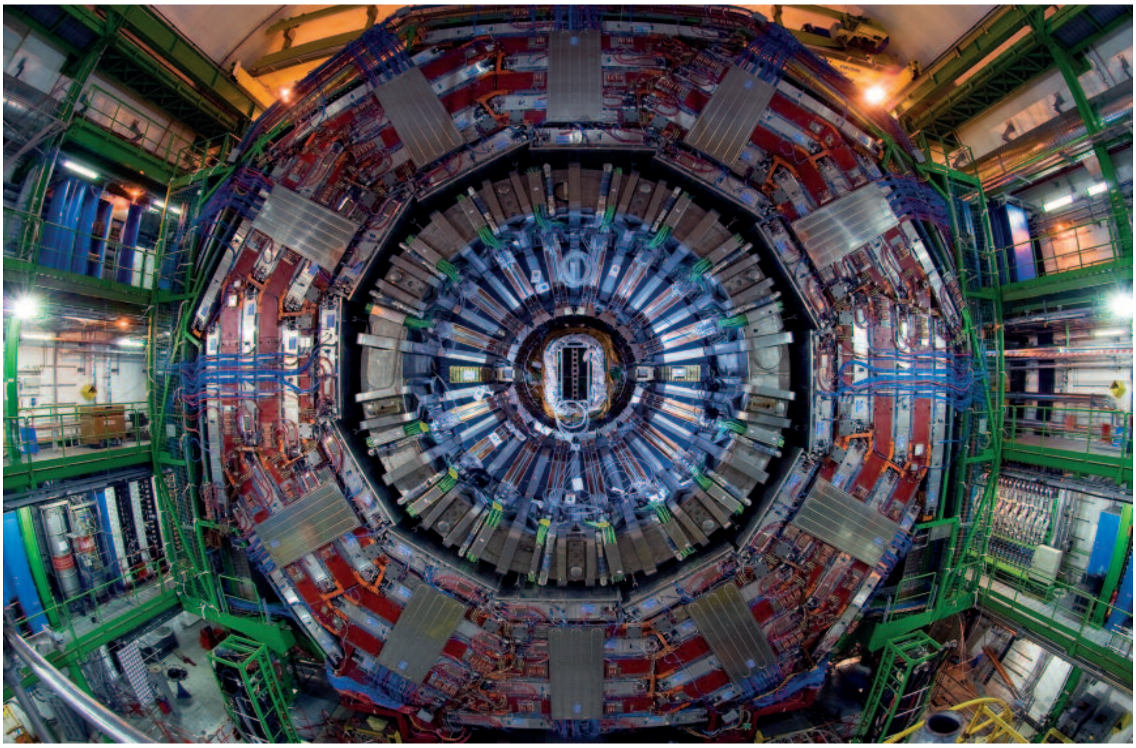


Fig. 1: A photograph of the transverse "cut" of CMS barrel showing the four principal layers namely, from inside out, the inner tracker, the electromagnetic calorimeter, the hadronic calorimeter, the superconducting solenoid, and the muon system sandwiching the field-return yoke.

The inner tracker measures charged particle trajectories in the pseudorapidity range $|\eta| < 2.5$ and provides an impact parameter resolution of ~15 μm and a transverse momentum (p_T) resolution of about 1% for charged particles with p_T ~40 GeV. The electromagnetic calorimeter provides a coverage in pseudorapidity of $|\eta| < 3.0$. The ECAL has an energy resolution of better than 0.5% for unconverted photons with transverse energies (E_T) above 100 GeV.

The jets and missing transverse energy resolutions are substantially improved with respect to only calorimetric reconstruction by using a particle flow (PF) algorithm. PF aims at reconstructing all stable particles in the event, i.e. electrons, muons, photons and charged and neutral hadrons, from the combined information from all CMS sub-detectors, to optimize the determination of particle types, directions and energies CMS is well suited for this due to its powerful Si tracker (the good tracker momentum resolution is used to improve the energy measurement of charged hadrons), its lead-tungstate ECAL with fine lateral granularity & small Moliere radius (the electromagnetic showers are very compact). It should be noted that the 4T magnetic field of CMS spreads out (of the jet defining cone) the energy carried by low-momentum charged particles and that its HCAL has a moderate performance (with a pion energy resolution of ΔE~100%/√E(GeV).

Muons are detected in the pseudorapidity window $|\eta| < 2.4$, with detection planes based on three gas-detector technologies: drift tubes, cathode strip chambers, and resistive plate chambers. A high-p_T muon originating from the interaction point produces track segments typically in three or four muon stations. Matching these segments to tracks measured in the inner tracker results in a p_T resolution between 1 and 2% for p_T values up to 100 GeV/c.

The first level of the CMS trigger system, composed of custom hardware processors, is designed to select the most interesting events in less than 4 μs, using information from the calorimeters and muon detectors. The High Level Trigger processor farm further decreases the event rate to a few hundred Hz before data storage.

During construction many challenges had to be faced. We list a few: the procurement of some 200 m^2 of silicon strip detectors, the development of deep-sub-micron (0.25 μm) radiation hard technology for the front-end electronics of the inner tracker and the ECAL, and the development and production, over ten years, of lead-tungstate scintillating crystals, the control of quality of all elements that were installed in the underground cavern, including their services (optical cables for signals, low and high voltage power cables, pipes for water and other cooling fluid etc.). It is difficult to do full justice to what it has taken to get to this point and the reader is referred to references [2] and [3] to get an idea.

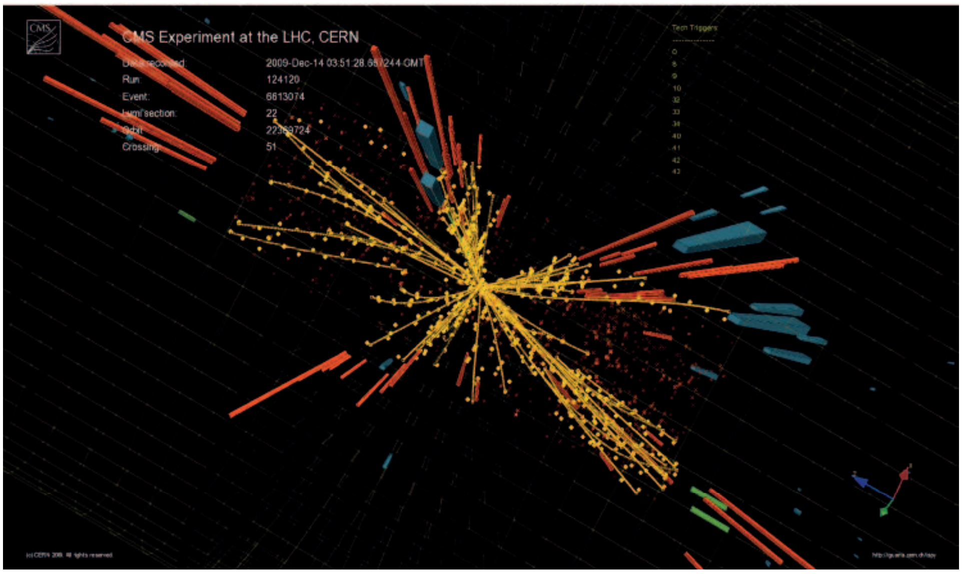


Fig. 2: A candidate multi-jet event from proton-proton collisions at the LHC.

3. THE RUNNING CONDITIONS AND THE PERFORMANCE OF CMS

The LHC accelerator and the CMS experiment are working very well. In the later stages of 2011 the bunch spacing was 50ns and each bunch contained some 1.5×10^{11} protons/bunch. The peak luminosity achieved was 3.65×10^{33} $cm^{-2}s^{-1}$ and some 500 pb^{-1} were delivered in the most productive week. The LHC delivered 5.75 fb^{-1} of which CMS recorded 91% on mass storage. The conditions of event pileup, at <12> interactions per crossing, were not far short of design.

Most (close to 100% of the channels) of the detector components in CMS were fully functional. The experiment is very well described in software code. Monte-Carlo simulated events are usually generated with a matrix-element generator interfaced with PYTHIA. After generation the events are passed through the full-detector simulation with GEANT4 and analysed with the same code as used for analysis of beam-data. The whole chain of CMS software, from simulation to reconstruction and distributed analysis has performed marvellously well.

An event display (Fig. 2) of a proton-proton collision in CMS illustrating the inner tracking detector hits and the energy deposits in the electromagnetic calorimeter (red) and the hadron calorimeter (blue). The height of the red and blue towers is indicative of the energy deposited. The muon system is not displayed. The production of "jets" is evident from the collimated bunches of particles.

The thorough preparation of the hardware and software of the CMS experiment meant that very rapid progress could be made in the first months of data taking in 2010. The data taken were used to establish that the performance of the experiment was indeed close to design. An example is shown in Figure 3 where the distribution is plotted of effective masses of all di-muon pairs detected in CMS upon examination of some 3 trillion proton-proton interactions (we have now examined some 300 trillion interactions). The sharpness (due to good mass resolution) and clarity of the signal peaks (due to high signal/background) is evident for several known particles that decay to di-muons. It is remarkable that the CMS experiment, arguably one of the most technologically challenging scientific instruments ever built, achieved close-to-design performance after only a few months of data-taking.

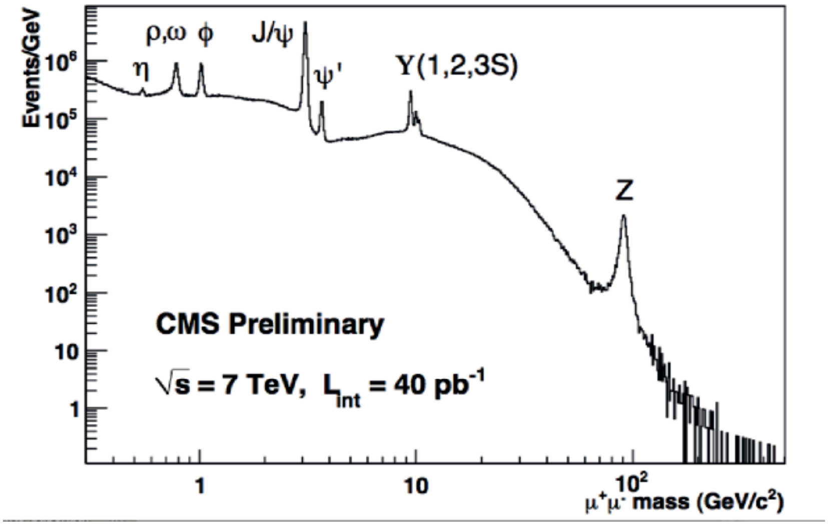


Fig. 3: The distribution of di-muon effective masses showing the various resonant states. The mass resolutions in the central region are; 28 MeV/c^2 (0.9%) for J/ψ, 69 MeV/c^2 (0.7%) for ϒ(1S), both dominated by instrumental resolution and Γ=2.5 GeV/c^2 for the Z dominated by its natural width.

4. THE PHYSICS RESULTS

The Standard Model makes precise predictions for the production of known particles such as quarks and gluons, manifesting themselves as jets, prompt γ's, J/ψ, Y, bottom and top quarks etc., W/Z boson and multi vector-boson (WW, WZ, ZZ) production, etc.. The CMS (and ATLAS) experiments must measure these processes and verify these precise predictions before being able to claim any discoveries. This is imperative as known processes can mimic signals of new physics and thus generate backgrounds, sometimes quite severe, to new physics. Already a very large number of measurements have been made, and published in around 100 papers by CMS. Here we shall only be able to discuss a few cases. These confirm the predictions of the Standard Model. In this sense we can consider the CMS to have been "physics commissioned".

4.1 Measuring Standard Model Processes

4.1.1 Inclusive quarks/gluons production

In order to understand whether the known standard model physics is reproduced correctly one of the important processes to study, and check, is the production of quarks or gluons (jets). The energy of a jet is determined by adding all the energy in a cone of half-angle of $R=\sqrt{(\Delta\eta^2+\Delta\phi^2)}=0.5$ (one-half of a unit of solid angle). Fig. 4 shows the rate of production of jets as a function of transverse momentum, and various angular ranges with respect to the beam direction [4]. It can be seen that the agreement is excellent with the theoretical predictions over about ten orders of magnitude and in the different angular ranges.

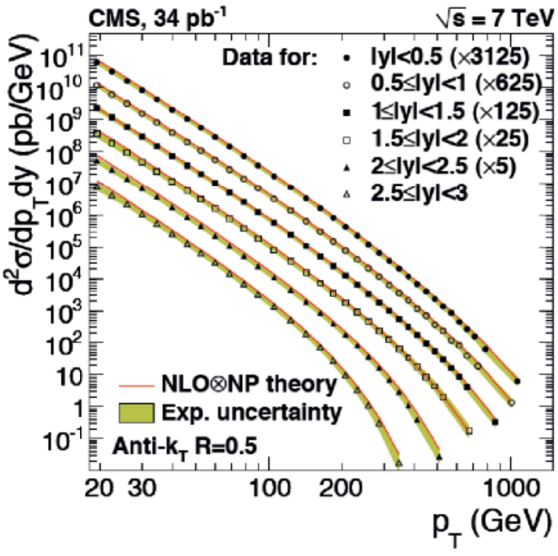


Fig. 4: The rate of production of jets as a function of transverse momentum and in various angular ranges.

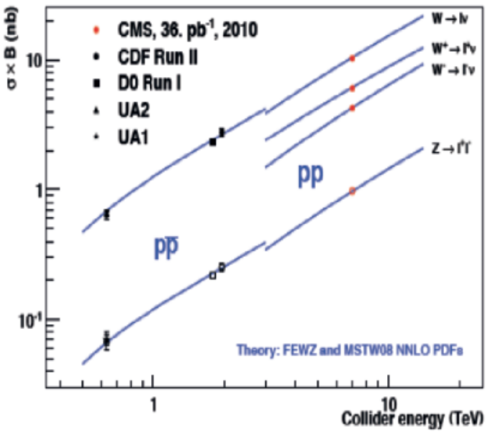


Fig. 5: Measurements of inclusive W and Z production cross sections times branching ratios as a function of center-of-mass energy for CMS and experiments at lower-energy colliders. The lines are the NNLO theory predictions.

4.1.2 Inclusive W and Z boson production

Another important process to understand well is the inclusive production of W and Z bosons as it presents substantial background to any new-physics that involves charged leptons and missing transverse energy such as the production of conjectured supersymmetric particles. This process also tests the efficiency and the accuracy of the reconstruction of charged leptons (electrons and muons) and missing transverse momentum (from neutrinos). As can be seen from Figure 5 the CMS measurements are already starting to test the theoretical predictions at the levels of the precision of these predictions (a few percent) [5].

4.1.3 Top quark production

Finally, we look at the production of top quarks. The top quark decay chain involves, charged leptons, neutrinos, b-quarks and light quarks. This is a particularly revealing measurement as it tests the efficiency and the accuracy of the reconstruction of all of the physics objects namely electrons, muons, missing E_T, b-quarks and light-quark jets. The top cross-section has been measured in many different decay-channels and is found to be consistent with the standard model predictions [6].

In summary, a wide range of measurements made by CMS [7] has shown that the SM predictions for known physics have been essentially spot on. This is no small measure due to the large amount of work carried out over the last decade or so by our theory colleagues along with the results from the other collider experiments at LEP, Tevatron, HERA, b-factories etc.

4.2 The Study of Quark-gluon Fluid

In 2010 the LHC has also collided lead ions at a centre-of-mass energy of 2.76 TeV per nucleon. CMS recorded collisions corresponding to an integrated luminosity of $10\mu b^{-1}$. Previous experiments, at lower energies, have already indicated that quark-gluon fluid is being formed. This is very clearly the case at the LHC. At the LHC hard probes such as high-p_T jets, prompt photons, upsilon production and W/Z bosons can be employed to study the properties of the fluid. For the creation of quark-gluon fluid the lead-lead ions must interact head-on. This latter aspect is determined by a quantity labeled centrality. Centrality is defined by the amount of transverse energy (E_T) measured in the forward calorimeters $|\eta| > 3.0$, and quantified by the percentile of events, in E_T. Central, head-on, events have a large amount of E_T in the forward region and hence a small value of centrality (e.g. 0-10%).

Fragmentation of quarks and gluons into jets is expected to be strongly modified as they traverse the quark-gluon medium created in the head-on (central) high-energy Pb-Pb collisions. We look for unbalanced two-jet events where one of the partons has suffered substantial modification whilst the other has not. Such situations arise when the parton-parton hard scattering takes place near the surface of the quark gluon fluid and one of the partons has to traverse much more fluid than the second one. This phenomenon is labeled “jet quenching”. Jets are reconstructed using the energy deposited in the CMS calorimeters and studied as a function of collision centrality. With increasingly central collisions (e.g. approaching very small percentile values), a striking imbalance in di-jet transverse momentum is observed, consistent with jet quenching [8]. The observed effect extends from the lower cutoff used in this study (jet p_T = 120 GeV/c) up to the statistical limit of the available data sample (jet $p_T \approx$ 210 GeV/c). Correlations of charged particle tracks with jets indicate that the momentum imbalance is accompanied by a softening of the fragmentation pattern of the second most energetic, away-side jet. The di-jet momentum balance is recovered when integrating low transverse momentum particles distributed over a wide angular range relative to the direction of the away-side jet. The results provide qualitative constraints on the nature of the jet modification in Pb-Pb collisions and quantitative input to models of the transport properties of the medium created in these collisions.

If the quark-gluon fluid is formed in heavy-ion collisions, it is expected to screen the confining potential of heavy quark-antiquark pairs, leading to the melting of charmonia (J/ψ, ψ',..), and bottomonia (Y(1S), Y(2S), Y(3S),…). The melting temperature depends on the binding energy of the quarkonium state. The ground states J/ψ, and Y(1S), are expected to dissolve at significantly higher temperatures than the more loosely bound excited states. Quenched lattice QCD calculations predict that the Y(nS) states melt at 1.2 *Tc* (3S), 1.6 *Tc* (2S), and above 4 *Tc* (1S), where *Tc* is the critical temperature at which the transition takes place to a quark-gluon fluid. CMS has observed suppression effects in the upsilon family [9]. More precisely the quantity measured is

$$\frac{[\mathrm{Y}(2S+3S)/\mathrm{Y}(1S)]_{PbPb}}{[\mathrm{Y}(2S+3S)/\mathrm{Y}(1S)]_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03$$

It is significantly different from unity indicating that the production of the excited states Y(2S and 3S) is being suppressed relative to that of Y(1S).

4.3 The Search for New Physics

A very wide range of new physics has been searched [7]. Here we only can give a few examples.

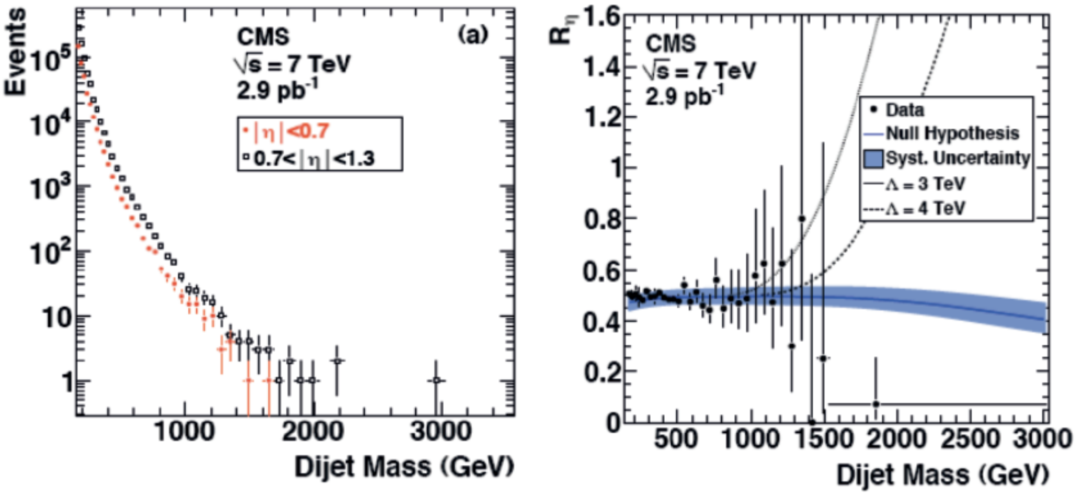


Fig. 6: (left) Event counts for di-jets in the two angular ranges examined, (right) the observed di-jet centrality ratio as function of m_{jj} compare with the null (QCD) hypothesis (solid line), including the total systematic uncertainty (band) and to hypotheses of quark contact interactions with Λ=3 TeV (dotted line) and 4 TeV (dashed line).

4.3.1 Search for Substructure

One of the first searches that is made at a new and higher energy accelerator is to look for sub-structure. In similarity with the experiment that Rutherford performed exactly

100 years ago we look for sub-structure in quarks by examining the production of quarks and gluons (jets) at large angles with respect to the beam-line. In QCD, the jet production rate peaks at small angles. Several new physics scenarios, including models of quark compositeness, produce a more isotropic angular distribution leading to enhanced jet production at large angles. The ratio, of the number of jet pairs produced in a more central region with that in an angular region closer to the beam-line, is compared with the predictions from QCD. No deviation is found from expectation (Fig. 6) and a limit is set on the size of the quarks is smaller than 5×10^{-18} cm.

4.3.2 Search for Supersymmetry

Even if the Higgs boson exists and is found (see Section 4.3.5), all is not completely well with the SM alone. The next question is "why is the mass of the Higgs boson so low". If a new symmetry (supersymmetry) is the answer, then it must manifest itself at the 1 TeV energy scale. Supersymmetry, predicts a doubling of the known particle spectrum, each known particle would have a super-partner with its mass determined by the parameters of the model being considerd. In models which conserve R-parity the lowest mass superpartner (LSP) is considered to be a prime candidate for dark matter. *R-parity* is defined as $P_R = (-1)^{S+3B+L}$, where S is the spin, B the baryon number and L the lepton number. The LSP is expected to escape detection leading to significant missing E_T in the final state. The rest of the cascade can result in an abundance of leptons, *b*-jets and/or *tau*-jets.

One example of such a search is to look for events with a large amount of hadronic transverse energy in events with multiple-jets and sizeable missing transverse energy. A quantity, α_T, is formed which quantifies the imbalance in the measured transverse energies of back-to-back "pseudo" jets. An excess of such events with respect to the predictions would indicate new physics. No such deviation from expectations is found and a limit on the mass of the squarks and gluinos is set at around 1 TeV/c^2 in the context of CMSSM [11]. Fig. 7 summarizes the current (August 2011) status of searches for supersymmetry in CMS using diverse signatures [7]. The searches are now starting to focus on well-motivated models where the squarks are at quite high masses (~10 TeV/c^2) with the gluinos around 1.5 TeV/c^2, the stops and sbottoms around 0.5 TeV/c^2.

4.3.3 The Search for Heavy Vector Bosons

Many models of new physics predict the existence of narrow resonances, at the TeV mass scale, that decay to a pair of charged leptons. These resonances are predicted in the context of Grand Unified Theories, theories with extra space dimensions, new strong interactions with a new charge such as "technicolour" in analogy with the "colour" charge of QCD, amongst others. A search has been made along the lines of W and Z production but at higher masses [12,13]. As can be seen from Fig. 7 no evidence has yet been found for such resonances and lower limits on their masses are set at around 2 TeV/c^2. In setting these limits the branching fraction to the leptonic decay modes has been assumed to be the one that is observed for the known W and Z particles. This does not have to be the case, and if so the limits would then be correspondingly weaker.

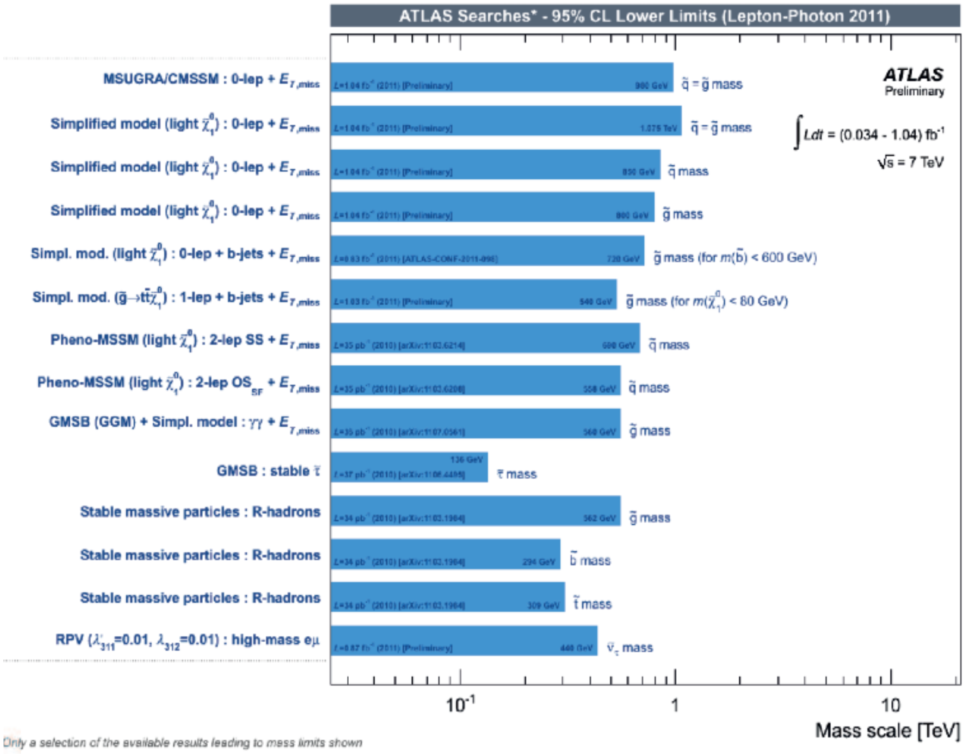


Fig. 7: The status of searches for supersymmetry in CMS using diverse signatures.

4.3.3 The Search for Heavy **Vector Bosons**

Many models of new physics predict the existence of narrow resonances, possibly at the TeV mass scale, that decay to a pair of charged leptons. These resonances are predicted in the context of Grand Unified Theories, theories with extra space dimensions, new strong interactions with a new charge such as “technicolour” in analogy with the “colour” charge of QCD, amongst others. A search has been made along the lines of W and Z production but at higher masses [12,13]. As can be seen from Figure 8 no evidence has yet been found for such resonances and lower limits on their masses is set at around 2 TeV/c^2. In setting these limits the branching fraction to the leptonic decay modes has been assumed to be the one that is observed for the known W and Z particles. This does not have to be the case, and if so the limits would then be correspondingly weaker.

4.3.4 Other Searches

Many other searches for new physics have been made in CMS [7]. These are summarized in Fig. 9.

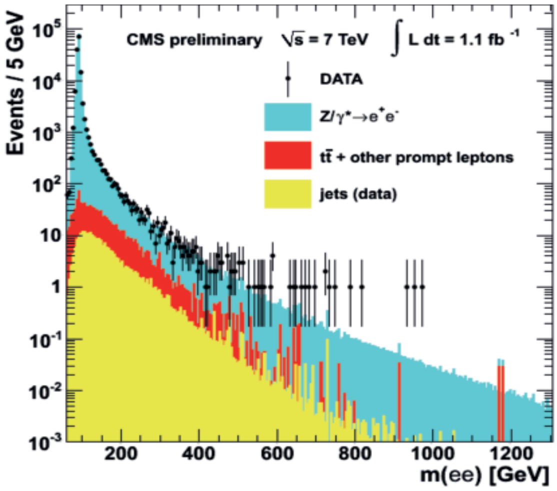


Fig. 8a: Invariant mass spectrum of e+e- events. The uncertainties on the data points (statistical only) represent 68% confidence intervals for the Poisson means. The filled histograms represent the expectations from SM processes as indicated in the legend.

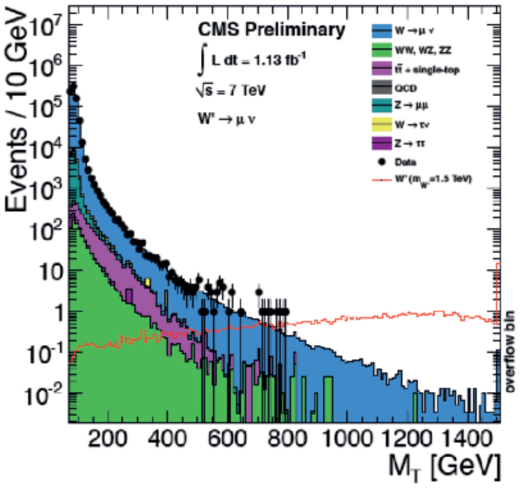
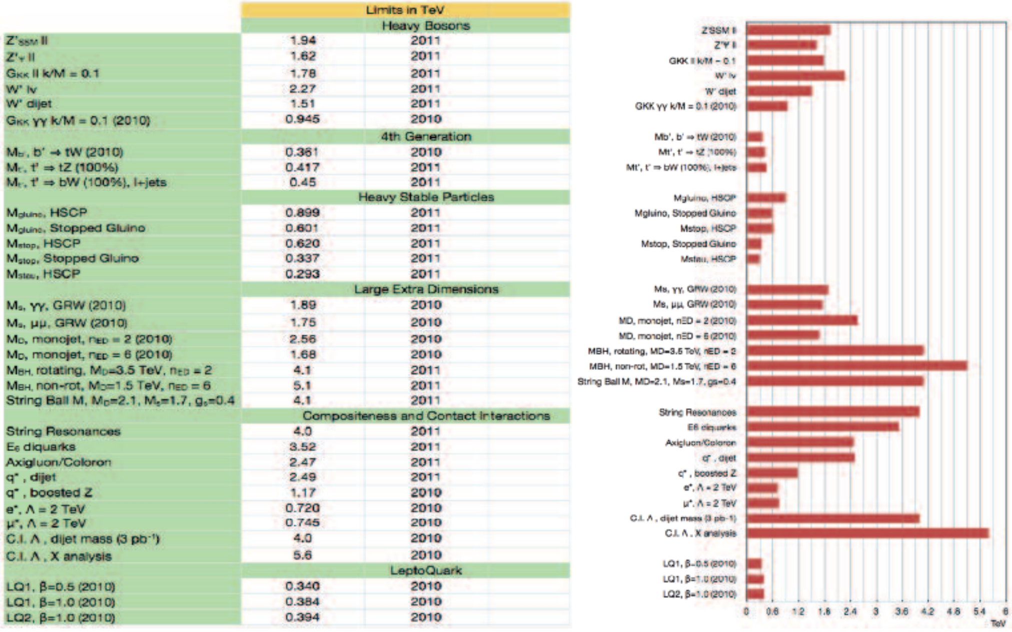


Fig. 8b: Transverse mass distribution for the muon channel. The uncertainties on the data points (statistical only) represent 68% confidence intervals for the Poisson means. The filled histograms represent the expectations from SM processes as indicated in the legend.



	Limits in TeV	
	Heavy Bosons	
Z'_{SSM} ll	1.94	2011
Z'_{ψ} ll	1.62	2011
G_{KK} ll k/M = 0.1	1.78	2011
W' lv	2.27	2011
W' dijet	1.51	2011
G_{KK} γγ k/M = 0.1 (2010)	0.945	2010
	4th Generation	
$M_{b'}$, b' → tW (2010)	0.361	2010
$M_{t'}$, t' ⇒ tZ (100%)	0.417	2011
$M_{t'}$, t' ⇒ bW (100%), l+jets	0.45	2011
	Heavy Stable Particles	
M_{gluino}, HSCP	0.899	2011
M_{gluino}, Stopped Gluino	0.601	2011
M_{stop}, HSCP	0.620	2011
M_{stop}, Stopped Gluino	0.337	2011
M_{stau}, HSCP	0.293	2011
	Large Extra Dimensions	
M_s, γγ, GRW (2010)	1.89	2010
M_s, μμ, GRW (2010)	1.75	2010
M_D, monojet, n_{ED} = 2 (2010)	2.56	2010
M_D, monojet, n_{ED} = 6 (2010)	1.68	2010
M_{BH}, rotating, M_D=3.5 TeV, n_{ED} = 2	4.1	2011
M_{BH}, non-rot, M_D=1.5 TeV, n_{ED} = 6	5.1	2011
String Ball M, M_D=2.1, M_s=1.7, g_s=0.4	4.1	2011
	Compositeness and Contact Interactions	
String Resonances	4.0	2011
E_6 diquarks	3.52	2011
Axigluon/Coloron	2.47	2011
q* , dijet	2.49	2011
q* , boosted Z	1.17	2010
e*, Λ = 2 TeV	0.720	2010
μ*, Λ = 2 TeV	0.745	2010
C.I. Λ , dijet mass (3 pb^{-1})	4.0	2010
C.I. Λ , X analysis	5.6	2010
	LeptoQuark	
LQ1, β=0.5 (2010)	0.340	2010
LQ1, β=1.0 (2010)	0.384	2010
LQ2, β=1.0 (2010)	0.394	2010

Fig. **9:** The status of searches for new physics in CMS (not including Supersymmetry).

4.3.5 The Search for the Standard Model Higgs Boson

The detection of the SM Higgs boson was a particularly appropriate benchmark to test the performance of the experiment designs in the early 1990's. The Higgs boson is the only particle in the Standard Model that has not yet been seen by experiments. Its mass is not predicted by theory. Its production cross-section and natural width vary widely over the allowed mass range (114 GeV/c^2 – 1 TeV/c^2). A search has to be made over this wide mass range leading to diverse final states: two photons; two tau leptons; two W bosons; or two Z bosons. The W is observed through its decay to an electron plus a neutrino, or a muon plus a neutrino. The Z is observed through its decay to a pair of electrons, or a pair of muons, or a pair of jets of hadronic particles. Analysing all these channels ensures that the search is sensitive to observing the Higgs irrespective of its mass. Particularly challenging is the search in the low mass region, a region indicated by the precision electro-weak measurements, and proscribed by supersymmetry ($M_H \leq 135$ GeV/c^2). CMS chose the lead tungstate crystals electromagnetic calorimeter partly to address the search in this region.

Analysis of the full 2011 data set is being pursued vigorously but the results presented here are the ones presented at the August 2011 International Symposium for Lepton-Photon Interactions at High Energies [14 and references therein]. The data from the two high mass-resolution channels is shown in Fig. 10. No excess is observed. Figure 11 summarizes the status of the search for the SM Higgs boson in CMS. So far we have not examined a sufficient number of such collisions to make any meaningful statement about the existence or not of the Standard Model Higgs boson in the mass range favoured by previous results (115 and 135 GeV/c^2). Nevertheless, current data disfavour, at a confidence level of 95%, the existence of a Higgs boson in the hatched ranges.

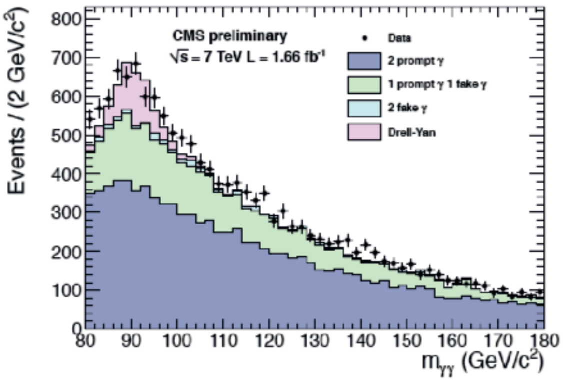


Fig. 10a: Diphoton mass distribution for data (points) and Monte Carlo simulation of SM processes which constitute the background to the search (histograms).

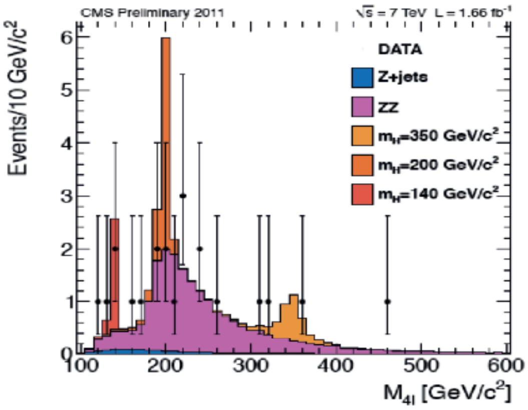


Fig. 10b: Distribution of four-lepton reconstructed mass for all 4l channels (ee, eμ, μμ). Points represent data, shaded histograms represent the signal and background expectations.

Figure 12 shows the best fit of the observed cross-section to the one predicted for the SM Higgs boson as a function of its mass. It can be concluded that in the mass range 114-135 GeV/c^2 a SM Higgs boson could still exist but, if found in this range the SM theory would still be incomplete; if found beyond 600 GeV it would become so strongly coupled needing some new physics; it could still be found in the range 135-500 GeV/c^2 but it would not have SM couplings – they would be weaker by some amount – and again some new type of physics would be needed. Even more interesting, especially from an experimentalist's point of view, would be if the Higgs boson were not to exist – this would really force us to rethink the ideas we have been pursuing over the last half a century!

It is anticipated that by the end of 2011 we shall have examined some 300 trillion proton-proton collisions and more significant results can be presented.

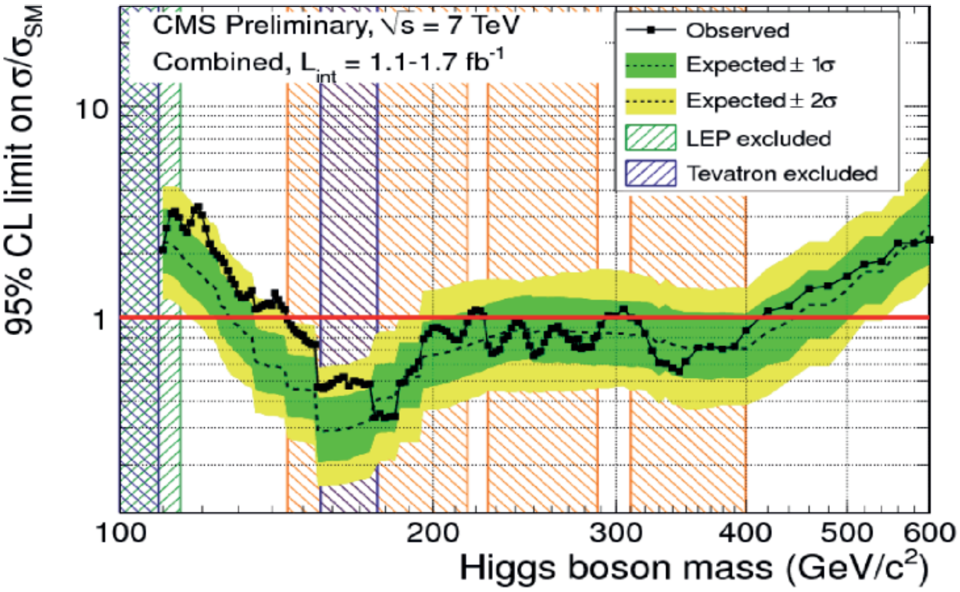


Fig. 11: The 95% CL upper limits on the signal strength parameter $\mu=\sigma/\sigma^{SM}$ for the SM Higgs boson hypothesis as a function of the Higgs boson mass. The dashed line indicates the median expected results for the background-only hypothesis while the green (dark) and yellow (light) bands indicate the ranges that are expected to contain 68% and 95% of all observed excursions from the median, respectively.

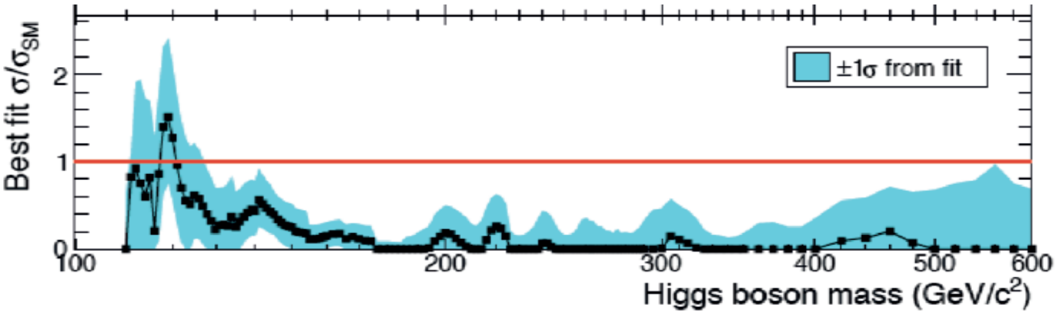


Fig. 12: The ratio of the best fit of the observed cross-section to the one predicted for the SM Higgs boson as a function of its mass

4.3.5 Physics **Summary and Outlook**

No sign of new physics has yet been found. However, these are early days and only a small fraction of the number of proton-proton collisions finally expected has been examined. By the end of 2012 we shall have increased, by a factor of 10, the sample used for the results presented here. This will not only allow a more precise confrontation with the predictions for known physics, but also the extension of the searches for new physics, and especially the making of a meaningful statement as to the existence or not of the Standard Model Higgs boson.

5. CONCLUSIONS

The LHC project (the accelerator and experiments) was conceived and designed to tackle fundamental questions in science: about the origin, the evolution and the composition of our universe. In particular, what is the origin of mass, what constitutes dark matter, do we live in more than 3 space dimensions, why is the universe composed of matter, and not anti-matter, and more.

CMS, the accelerator and the other LHC experiments, are unprecedented instruments in scale and complexity operating in an unprecedented & hostile environment. Driven by the science many technologies have been pushed to their limits in their construction.

After twenty years of design, R&D, prototyping, construction, assembly and commissioning CMS is recording high-energy collisions. It is operating well and has become a “physics-producing engine”. Much physics has already come out and it is exploring new territory but we are just at the beginning of this adventure and all the expectations are that what we shall find at the LHC will alter the way we view the universe at the fundamental level.

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