CMS EXPERIMENT AT LHC: COMMISSIONING AND EARLY PHYSICS

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The CMS collaboration used the past year to greatly improve the level of detector readiness for the first collisions data. The acquired operational experience over this year, large gains in understanding the detector and improved preparedness for early physics will be instrumental in minimizing the time from the first collisions to first LHC physics. The following describes the status of the CMS experiment and outlines early physics plans with the first LHC data.

1 Introduction

With its first collisions expected at the end of 2009, the Large Hadron Collider (LHC) will become a new energy frontier in high energy physics. Experimental searches at the LHC are widely anticipated to yield major advances in particle physics explaining the mechanism of the electroweak symmetry breaking (EWSB) and revealing the underlying theory of matter and fundamental interactions. The LHC physics program is reach and broad aiming at a wide range of signatures in which new phenomena may reveal itself, from Higgs and well studied SM extensions such as Supersymmetry (SUSY) and Extra Dimensions to something yet unexpected.

Two flagship multi-purpose LHC experiments, CMS and ATLAS, have been actively preparing for the first LHC collisions. This contribution reports on the status of the CMS detector readiness for data and outlines early physics measurements aiming at establishing baseline detector performance. In addition to its focus on robust operation and collection of high quality data needed for Higgs and SUSY searches, CMS will also pursue a number of well motivated new physics scenarios accessible with already small amounts of LHC data.

2 CMS Detector Status and Commissioning

The Collider Muon Solenoid (CMS) experiment is a multi-purpose particle physics detector consisting of several sub-systems providing identification and momentum measurement of particles produced in the LHC proton-proton collisions. The main sub-systems are tracking (pixel and silicon strip detectors), calorimetry, muon chambers, data acquisition and trigger.

The construction and integration of the CMS sub-systems has been mostly completed and the experiment was ready for data in the Fall of 2008, even collecting data during the LHC single beam operations. Since the unexpected delay in the LHC schedule associated with the October incident, the CMS experiment has embarked on accomplishing many of the commissioning tasks typically performed with the early collisions data. To that end, the CMS has staged a several months long exercise collecting cosmic ray data. During these tests, the CMS detector was
partly removed

Approved CRAFT Results

Figure 1: (a) Timing in of the hadronic calorimeter using beam splash events from a nine minute long single beam LHC run (prior to timing corrections, the $\Delta T$ was scattered from $-15$ to $+15$ ns). (b): Muon stopping power $dE/dx$ measured by the calibrated CMS electromagnetic calorimeter as a function of muon momentum compared to the expectation.

continuously operating for several months with the fully deployed data acquisition and trigger systems. The data collected were used to accomplish many calibration and alignment tasks; a fraction of these measurements is described in what follows.

2.1 Commissioning with the 2008 Beam Data

In the Fall of 2008, CMS collected data during the LHC single beam running. While not optimal for ultimate commissioning, these data were used for a number of studies, e.g. to time in the calorimeters using spectacular beam splash events that lightened the entire calorimeter as particles were traversing the detector, see Fig. 1(a). The single beam data was also used to align parts of the CMS Endcap Muon (EMU) system. The EMU system consists of a set of cathode-strip chambers arranged in several rings around the beamline. Because EMU chambers are positioned perpendicular to the beamline, the beam halo muons were used to make effectively an X-ray test of the system. The small overlaps of the chambers allowed accurate alignment of all EMU rings that had all chambers operational during the 9 minute long single beam run. This measurement has demonstrated that with just a few minutes of beam data, the EMU system can be aligned to the design accuracy of $\sim 250 \mu m$.

2.2 Commissioning with the 2008 Cosmic Ray Data

Apart from providing invaluable operational experience of continuously running a large and highly complex system, the cosmic ray exercise provided a wealth of cosmic ray data. Analysis of the data allowed a large improvement in understanding the detector alignment, calibration as well as tuning and validating reconstruction algorithms.

Figure 1(b) shows the measurement of energy deposition by cosmic ray muons in the calibrated CMS electromagnetic calorimeter as a function of muon momentum. This measurement is compared to the expectation for muon stopping power $dE/dx$ in $PbWO_4$ showing a good agreement for both the lower momentum (dominated by collision losses) and higher momentum (dominated by bremsstrahlung radiation) ranges.

Precise alignment of the tracking system is one of the most important pre-requisites for most physics analyses at the LHC. Cosmic ray data was used to measure actual positions of sensitive elements of the tracker to obtain required alignment corrections. Figure 2(a) shows the improvement in the quality of muon tracks reconstructed in the tracking system as a result...
M tracks for alignment and 1M for validation

Figure 2: (a): Improvement in the quality of the reconstructed muon tracks with increase in the accuracy of tracker alignment measured using procedures based on Millepede and the Hits and Impact Points (HIP) algorithms. (b): Relative difference in curvature for tracks reconstructed using hits left by the same muon in either top or bottom part of the detector before (dashed) and after (solid) applying alignment corrections.

of these studies. For very high $p_T$ muons, maintaining the good momentum resolution requires precise alignment of the muon system. Figure 2(b) shows the improvement in the accuracy of muon momentum reconstruction for higher momentum ($p_T > 200$ GeV/c) muons with better precision of muon alignment. The plot compares curvature measured separately for the top and bottom part of the trajectory of a muon traversing the detector. Because the two tracks are reconstructed using different sets of hits, this comparison provides an unbiased measurement of the muon momentum resolution.

3 Early Physics Plans

Ultimate certification of the detector performance can only be established using collisions data. As with any other detector, the first physics measurements at CMS will aim at re-establishing the SM “standard candles”, tuning momentum and energy scales, understanding detector effects and backgrounds. For example, measurement of the di-lepton signatures $J/\psi(\Upsilon) \rightarrow \mu\mu, Z \rightarrow ee(\mu\mu)$ will be critical in achieving precision calibration of tracking momentum and calorimeter energy scales. Figure 3-a shows the expected di-electron invariant mass distribution for events to be selected for the $Z \rightarrow ee$ cross-section analysis with just 10 pb$^{-1}$ of data at $\sqrt{s} = 10$ TeV (at lower $\sqrt{s}$, the number of expected events decreases but remains substantial). Apart from providing a test of higher order QCD calculations and parton distribution functions, this measurement will be critical in tuning the absolute scale of the electromagnetic calorimeter and electron reconstruction techniques.

Similarly, measurements of $W \rightarrow e\nu$ and $W \rightarrow \mu\nu$ will be essential in understanding the missing energy resolution, which will be critical for future SUSY searches. The measurement of $Z \rightarrow \tau\tau$ cross-section will serve as an important test of cross-detector capabilities and understanding of tracking, calorimetry, validation of electron, muon, and hadronic tau reconstruction techniques, and the transverse missing energy resolution. At the LHC, an important new “standard candle” will be the $t\bar{t}$ events that will be produced in abundance due to a large increase in the production cross-section compared to the Tevatron. Experience in studying top properties will also be an invaluable tool in future searches in the context of SUSY and other new physics models.

While re-establishing the SM candles will have to precede any analyses targeting new physics, certain searches depending on a fraction of detector sub-systems can be performed with already
early data. One such example is a search for new resonances (or compositeness) in the di-jet channel. Figure 3b shows the reach for excited quark in early CMS data showing sensitivity of searches with 10-1000 pb\(^{-1}\) of data (results shown are for \(\sqrt{s} = 14\) TeV, for reference the excluded cross-section at \(\sqrt{s} = 10\) TeV is about 25-30\% higher). Searches for other high \(p_T\) signatures such as \(Z'\) and \(W'\) resonances in lepton modes will also surpass Tevatron sensitivity with already moderate amounts of early data.

4 Summary

While the most recent delay in the LHC start has been unfortunate, the CMS experiment has used this time to make large gains in understanding detector calibration, alignment and reconstruction techniques using real data collected during cosmic running. These improvements and the invaluable experience of continuous long-term detector operation will help bring the first physics from the LHC sooner.

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