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Progress Report for DE-SC0010158  
Physics with CMS and Electronic Upgrades  
Year 3: May 1, 2015 - March 31, 2016

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The current funding is for continued work on the Compact Muon Solenoid (CMS) at the CERN Large Hadron Collider (LHC) as part of the *Energy Frontier* experimental program. The current budget year covers the first year of physics running at 13 TeV (Run 2). During this period we have concentrated on commissioning of the  $\mu$ TCA electronics, a new standard for distribution of CMS trigger and timing control signals and high bandwidth data acquisition as well as participating in Run 2 physics.

## 1. Physics Beyond the Second Generation

One of the most exciting prospects for Run 2 involves searching for a 4th generation of quarks or leptons or yet unobserved behavior of the 3rd generation as the top quark provides unique detection capabilities for yet unobserved phenomena. The CMS group studying physics of the third generation and beyond is referred to as "beyond second generation" (B2G). Boston University has decided to concentrate its analysis in this area (collaboration with Prof. Tulika Bose) with 3 graduate students committed for Ph.D. theses. One of these, David Zou, is an advanced graduate student supported by this grant. The future physics program which extensive preparation has occurred in the current year involves quickly repeating the benchmark or so-called "legacy analyses" at high energy and then greatly expanding the physics searches to exploit the new energy regime of Run 2. The physics includes exciting new searches for  $Q' \rightarrow qW$ ,  $T'$  charge 5/3 quarks,  $T' \rightarrow tH$ ,

$B' \rightarrow tW$ , and searches for dark matter in t+MET and many related processes.

## 2. Electronics

For the upgraded CMS electronics based on  $\mu$ TCA, we have designed a dual function “advanced mezzanine card” (AMC13) which a) distributes the LHC machine trigger, timing, and control (TTC) signals to all modules in the crate, and b) serves the same event building, error checking, and data transmission functions as the previous generation of front-end-drivers (including the Boston-designed DCC), although at much higher bandwidth. The AMC13 is designed to have wide-spread general use in CMS and is being heavily used in the hadron calorimeter (HCAL), endcap muon, trigger, and pixel systems. During this period we have refined the firmware to enable reliable 10 Gigabit data link outputs and interfaced these to the DAQ computers and have built and tested 50 AMC13 units. The HCAL units have been installed and integrated at CERN and have successfully participated in physics in 2015-2016. Much time was spent in this year supporting the AMC13 operations in the HCAL readout and also with the trigger system and DAQ computers.

## 3. Papers

During this period, CMS published more than 100 papers. Our group contributed heavily to ensuring the quality of the data as well as to the jet calibrations and evaluation of detector efficiencies.

Selected publications:

Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at  $s= 7$  and  $8$  TeV / ATLAS and CMS Collaborations, arXiv:1606.02266 ; CERN-EP-2016-100 ; ATLAS-HIGG-2015-07 ; CMS-HIG-15-002. - 2016. - 70 p.

Search for dark matter and supersymmetry with a compressed mass spectrum in the vector boson fusion topology in proton-proton collisions at  $s= 8$  TeV / CMS Collaboration, CERN-EP-2016-096 ; CMS-SUS-14-019-004 ; arXiv:1605.09305. - 2016.

Search for lepton flavour violating decays of heavy resonances and quantum black holes to an e pair in proton-proton collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1604.05239; CERN-EP-2016-068; CMS-EXO-13-002.- Geneva : CERN, 2016 - 38 p. - Published in : Eur. Phys. J. C 76

(2016) 317.

Measurements of  $t\bar{t}$  charge asymmetry using dilepton final states in  $pp$  collisions at  $s= 8$  TeV / CMS Collaboration, CERN-EP-2016-059; CMS-TOP-15-009-003; arXiv:1603.06221.- Geneva : CERN, 2016 - Published in : Phys. Lett. B 760 (2016) 365

Search for heavy Majorana neutrinos in  $ee+$  jets and  $e+$  jets events in proton-proton collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1603.02248; CMS-EXO-14-014; CERN-EP-2016-032.- Geneva : CERN, 2016 - 43 p. - Published in : J. High Energy Phys. 04 (2016).

Search for supersymmetry in electroweak production with photons and large missing transverse energy in  $pp$  collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1602.08772; CERN-EP-2016-012; CMS-SUS-14-016.- Geneva : CERN, 2016 - 30 p. - Published in : Phys. Lett. B 759 (2016) 479.

Search for massive  $WH$  resonances decaying into the  $bb$  final state at  $s= 8$  TeV / CMS Collaboration, arXiv:1601.06431; CMS-EXO-14-010; CERN-PH-EP-2015-332.- Geneva : CERN, 2016 - 40 p. - Published in : Eur. Phys. J. C 76 (2016) 237.

Forward-backward asymmetry of Drell-Yan lepton pairs in  $pp$  collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1601.04768; CMS-SMP-14-004; CERN-PH-EP-2015-295.- Geneva : CERN, 2016 - 36 p. - Published in : Eur. Phys. J. C 76 (2016) 325.

Measurement of differential and integrated fiducial cross sections for Higgs boson production in the four-lepton decay channel in  $pp$  collisions at  $s= 7$  and  $8$  TeV / CMS Collaboration, arXiv:1512.08377; CMS-HIG-14-028; CERN-PH-EP-2015-285.- Geneva : CERN, 2016 - 42 p. - Published in : J. High Energy Phys. 04 (2016).

Search for narrow resonances decaying to dijets in proton-proton collisions at  $s= 13$  TeV / CMS Collaboration, arXiv:1512.01224; CMS-EXO-15-001-004; CERN-PH-EP-2015-317.- Geneva : CERN, 2016 - Published in : Phys. Rev. Lett. 116 (2016).

Search for excited leptons in proton-proton collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1511.01407; CMS-EXO-14-015; CERN-PH-EP-2015-281.- Geneva : CERN, 2016 - 54 p. - Published in : J. High Energy Phys. 03 (2016).

Search for the production of an excited bottom quark decaying to  $tW$  in proton-proton collisions at  $s= 8$  TeV / CMS Collaboration, arXiv:1509.08141; CMS-B2G-14-005; CERN-PH-EP-2015-246.-

Geneva : CERN, 2016 - 42 p. - Published in : J. High Energy Phys. 01 (2016).

## **4. Personnel**

This grant has supported the work of graduate student David Zou who has become an expert on the new AMC13 electronics and has become an essential support person for this electronics at CERN for Run 2 in 2015-16. In addition, a number of outstanding undergraduates have worked in our electronics lab providing various amounts of hardware and software support.

## **5. Budget**

We anticipate no unexpended funds for the current budget period.

One month of summer salary is for the support of the PI, James Rohlf. The graduate student support is for David Zou.

Domestic travel is for regular trips to the LPC at Fermilab and international travel supports frequent trips to CERN for electronics support and physics analysis.