

# Experimental and Theoretical High Energy Physics

Final report for ARRA funding

The Regents of the University of Minnesota

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## 1 Executive Summary

Three different groups received support from the ARRA program. The Cryogenic Dark Matter Experiment (CDMS), under the supervision of Prof. Cushman, used the funds received to construct a new passive shield to protect a high purity germanium detector located in the Soudan mine in Northern Minnesota from cosmic rays. The BESIII group lead by Prof. Poling purchased the computing hardware to assemble a computer farm, with supplementary university funding, that was used to generate large volumes of simulated data. These data were essential for the analysis of data collected at the Beijing Electron-Positron Collider (BEPCII) by the BESIII experiment in the study of charm quark resonances produced. The Compact Muon Solenoid (CMS) group under the guidance of Prof. Mans purchased computer hardware to assemble, also with University support, hardware to construct a computer ‘farm’ that acted as a Tier 3 computer center for the CMS collaboration.

In all three separate tasks the goals of experimental high energy physics were advanced. Specifically the CDMS experiment was able to new limits in their search for dark matter interacting with their detectors. The BESIII experiment continued their investigation of the charm meson sector, filling in details of the resonance structure with more precise measurements obtained with the

large volume of data obtained at the storage ring that were matched with the large number of events generated in the new computer farm. Similarly for the CMS experiment as the Large Hadron Collider began operation in 2010, the Minnesota Tier 3 center provided much-needed computing resources to analyze data being collected at the CERN Large Hadron Collider by the CMS collaboration.

## **2 Comparison with Proposal Objectives**

In all three sub-projects the proposal objectives were achieved or exceeded.

## **3 Project Summary**

### **3.1 CDMS**

The Cosmic Frontier group is engaged in a search for dark matter using the cryogenically cooled silicon and germanium detectors. The detectors are located deep underground to shield against the continuous flux of cosmic rays that impinge on the earth's surface. All materials that are used in the detector need to be tested for contamination from radioactive materials in them, as any radioactive material inadvertently introduced could add a background to the ultra-sensitive search for dark matter interactions. The CDMS group used ARRA funds to rebuild the shield for the high purity germanium detector (HPGe) located at the Soudan Lab using low activity lead and OFHC copper. The resulting reduction of background improved our sensitivity by a factor of 50-100 (depending on the energy range). We also added an automated radon purge and sample load lock which increased sample throughput. The HPGe was used to determine the backgrounds due to radiogenic sources in the CDMS dark matter experiment at Soudan, and therefore played an integral of every major physics paper produced by SuperCDMS. It is now in constant use assaying all materials which will be used in the generation-2 SuperCDMS dark matter experiment being constructed at SNOLAB. The results are used both to select materials and to construct our background model. Our program of screening for SuperCDMS would not have been possible at the sensitivity level and throughput prior to the new shield and radon enclosure.

### **3.2 BESIII**

The University of Minnesota Intensity Frontier group used its allocation of ARRA funding in 2010 to construct a dedicated computer farm for data analysis and the production of Monte Carlo samples for the BESIII experiment at the BEPCII collider in Beijing, China. The ARRA funds were augmented by University of Minnesota support and several upgrades subsequent to the initial acquisition also were University-funded. At present we have 12 Dell PowerEdge C6100 chassis with 4 dual-socket servers per chassis and 6 cores per processor

(X5670 CPU @3GHz). The 576 physical CPU cores function as 1152 virtual cores with hyperthreading and this is the maximum number of simultaneous jobs. Independent systems provide disk serving and the experimental calibration and noise databases. The farm also includes 668 TB of disk space. With this system, the largest computer resource of the BESIII collaboration outside the host laboratory, the Minnesota BESIII group provides about one-half of all simulated data samples, as well as providing analysis capabilities for our group and other U.S. BESIII collaborators. Our simulations contributed to essentially all of BESIII's approximately 30 publications in refereed journals per year.

### 3.3 CMS

The University of Minnesota Energy Frontier group used its allocation of ARRA funding in 2010 to construct a computer farm for data analysis for the CMS experiment at the LHC collider in Geneva, Switzerland. The ARRA funds were augmented by University of Minnesota support and several upgrades subsequent to the initial acquisition also were University-funded. At present we have 12 Dell PowerEdge chassis with 4 dual-socket servers per chassis and 4 hyper-threaded cores per processor (E5520 CPU@2.3GHz). The farm also hosts 250 TB of disk space used for storing primary data samples and dedicated simulation samples for both physics analysis and calibration efforts. The system has been heavily used for all the analysis efforts described as part of the Energy Frontier group reports since 2011 including at least ten papers or public results on physics or detector performance.

### 3.4 Products

### 3.5 Papers

The following papers have been published as a result of the investment of the ARRA funds for the CDMS group:

1. Z. Ahmed et al. (CDMS Collaboration), *Results from a Low-Energy Analysis of the CDMS II Germanium Data*, Phys. Rev. Lett. **106**, 131302 (2011).
2. D.S. Akerib et al. (CDMS Collaboration), *Low-threshold analysis of CDMS shallow-site data*, Phys. Rev. D **82**, 122004 (2010).
3. Z. Ahmed et al. (CDMS Collaboration), *Analysis of the low-energy electron-recoil spectrum of the CDMS experiment*, Phys. Rev. D **81**, 042002, (2010) [arXiv:0907.1438].
4. R. Agnese et al. (CDMS Collaboration), *Dark Matter Search Results Using the Silicon Detectors of CDMS II*, submitted to Phys.Rev.Lett. May 1, 2013 [arXiv:1304.4279].

5. R. Agnese et al. (CDMS Collaboration), *Silicon Detector Results from the First Five-Tower Run of CDMS II*, Phys. Rev. D **88**, 031104(R) (2013) [arXiv:1304.3706].
6. Z. Ahmed et al. (CDMS Collaboration), *Search for annual modulation in low-energy CDMS-II data*, [arxiv:1203.1309].
7. Z. Ahmed et al. (CDMS Collaboration), *Search for inelastic dark matter with the CDMS II experiment*, Phys. Rev. D **83**, 112002 (2011), [arXiv:1012.5078].
8. Z. Ahmed et al. (CDMS Collaboration), *Search for Axions with the CDMS Experiment*, Phys. Rev. Lett **103**, 141802 (2009) [arXiv:0902.4693].
9. Z. Ahmed et al. (CDMS Collaboration and Edelweiss Collaboration), *Combined limits on WIMPs from the CDMS and EDELWEISS experiments*, Phys. Rev. D **84**, 011102 (2011).
10. R. Agnese et al. (CDMS Collaboration), *Demonstration of Surface Electron Rejection with Interleaved Germanium Detectors for Dark Matter Search*, submitted to Phys. Rev. Lett., May 10 2013, [arXiv:1305.2405].

**The following papers have been published as a result of the investment of the ARRA funds for the CMS group:**

1. S. Chatrchyan *et al.* [CMS Collaboration], “Energy Calibration and Resolution of the CMS Electromagnetic Calorimeter in  $pp$  Collisions at  $\sqrt{s} = 7$  TeV,” JINST **8**, P09009 (2013)
2. S. Chatrchyan *et al.* [CMS Collaboration], “Measurement of the Rapidity and Transverse Momentum Distributions of Z Bosons in  $pp$  Collisions at  $\sqrt{s}=7$  TeV,” Phys. Rev. D. **85**, 032002 (2012) [arXiv:1110.4973 [hep-ex]].
3. S. Chatrchyan *et al.* [CMS Collaboration], “Search for long-lived particles in events with photons and missing energy in proton-proton collisions at  $\sqrt{s} = 7$  TeV,” Phys. Lett. **722**, 273 (2013) [arXiv:1212.1838 [hep-ex]].
4. S. Chatrchyan *et al.* [CMS Collaboration], “Search for new physics in events with photons, jets, and missing transverse energy in  $pp$  collisions at  $\sqrt{s} = 7$  TeV,” JHEP **03**, 111 (2013) [arXiv:1212.4784 [hep-ex]].
5. S. Chatrchyan *et al.* [CMS Collaboration], “Search for heavy long-lived charged particles in  $pp$  collisions at  $\sqrt{s} = 7$  TeV,” Phys. Lett. **713**, 408 (2012) [arXiv:1205.0272 [hep-ex]].
6. S. Chatrchyan *et al.* [CMS Collaboration], “Searches for long-lived charged particles in  $pp$  collisions at  $\sqrt{s} = 7$  and 8 TeV,” JHEP **07**, 122 (2013) [arXiv:1305.0491 [hep-ex]].

7. S. Chatrchyan *et al.* [CMS Collaboration], “Searches for long-lived charged particles in pp collisions at  $\sqrt{s}=7$  and 8 TeV,” arXiv:1305.0491 [hep-ex].
8. S. Chatrchyan *et al.* [CMS Collaboration], “Search for heavy neutrinos and W[R] bosons with right-handed couplings in a left-right symmetric model in pp collisions at  $\sqrt{s} = 7$  TeV,” Phys. Rev. Lett. **109**, 261802 (2012) [arXiv:1210.2402 [hep-ex]].

**The following papers have been published as a result of the investment of the ARRA funds for the BESIII group:**

1. M. Ablikim *et al.* [BESIII Collaboration], “Observation of a charged charmoniumlike structure in  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  at  $\sqrt{s} = 4.26$  GeV,” Phys. Rev. Lett. **110**, 252001 (2013) [arXiv:1303.5949 [hep-ex]].
2. M. Ablikim *et al.* [BESIII Collaboration], “Study of  $\psi(3686) \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$  via  $\eta_c$  exclusive decays,” Phys. Rev. D **86**, 092009 (2012) [arXiv:1209.4963 [hep-ex]].
3. M. Ablikim *et al.* [BESIII Collaboration], “Measurements of  $h_c(^1P_1)$  in  $\psi'$  Decays,” Phys. Rev. Lett. **104**, 132002 (2010) [arXiv:1002.0501 [hep-ex]].
4. M. Ablikim *et al.* [BESIII Collaboration], “Two-photon widths of the  $\chi_{c0,2}$  states and helicity analysis for  $\chi_{c2} \rightarrow \gamma\gamma$ ,” Phys. Rev. D **85**, 112008 (2012) [arXiv:1205.4284 [hep-ex]].
5. M. Ablikim *et al.* [BESIII Collaboration], “First observation of the M1 transition  $\psi(3686) \rightarrow \gamma \eta_c(2S)$ ,” Phys. Rev. Lett. **109**, 042003 (2012) [arXiv:1205.5103 [hep-ex]].
6. M. Ablikim *et al.* [BESIII Collaboration], “Higher-order multipole amplitude measurement in  $\psi(2S) \rightarrow \gamma \chi_{c2}$ ,” Phys. Rev. D **84**, 092006 (2011) [arXiv:1110.1742 [hep-ex]].
7. M. Ablikim *et al.* [BESIII Collaboration], “Search for  $CP$  and  $P$  violating pseudoscalar decays into  $\pi\pi$ ,” Phys. Rev. D **84**, 032006 (2011) [arXiv:1106.5118 [hep-ex]].

**The following university of Minnesota theses were written using the resources obtained with ARRA funding.**

1. “Search for heavy right-handed W Bosons and heavy right-handed neutrinos produced by 7 TeV pp collisions inside the CMS detector,” P. Dudero, 2011, <http://hdl.handle.net/11299/110135>.
2. “Search for heavy stable charged particles at the CMS experiment”, S. Cooper, 2012, <http://hdl.handle.net/11299/141457>
3. “Search for a heavy right-handed W Boson and heavy neutrino of the left-right symmetric standard model” J. Pastika, 2014, <http://hdl.handle.net/11299/167424>.

4. "Measurement of Non- $D\bar{D}$  Decays of the  $\psi(3770)$  Resonance at BESIII," D. Toth, 2014, <http://http://conservancy.umn.edu/handle/11299/173943>.
5. "Measurements of Z transverse momentum shape using novel variables with the CMS detector," K. Klapoetke, 2014, <http://hdl.handle.net/11299/171364>.
6. "Measurement of the phistar distribution of Z bosons decaying to electron pairs with the CMS experiment at a center-of-mass energy of 8 TeV", A Gude, 2015, <http://hdl.handle.net/11299/175445>.