December 4, 2019

Sergey A. Uzunyan
Senior Research Scientist
Northern Illinois University (NIU), Department of Physics, DeKalb, IL, 60115
Phone : (815)753-6485, E-mail: suzunyan@niu.edu, Web: http://www.nicadd.niu.edu/∼serguei

Research Narrative

1 Outline

This document summarizes my research conducted at NIU for the Northern Illinois Center for Accelerator and Detector Development (NICADD). The major parts are the development and support of the NICADD and NIU computing systems (Section 2), recent work with the Mu2e collaboration at Fermilab (Sections 4), the development of the data acquisition system for the Proton Computed Tomography (pCT) project (Section 3) and analyses of the D0 detector data (Section 5). Smaller completed projects are described in Section 6.

To date, I am co-author of 399 publications and contributed to a number of grants obtained by NICADD groups, listed in Section 7.

2 NICADD and NIU computing

While working at the D0 experiment at Fermilab I took responsibility for supporting NIU computing resources at D0 and later became an administrator of one of four D0 desktop computer clusters (about 60 computers). I was attracted by the D0 model of delegating typical CPU-farm tasks like a batch processing to the end-users desktops and thus maximizing the efficiency of their CPU and disk usage. I used this idea to build a NICADD desktop cluster in 2003 using just several cheap desktops and one entry level server.

In 2004 I became the NICADD cluster's system manager and I built the first computational cluster (24 dual core workstations) for the NICADD Beam Physics and Astrophysics Group (which is now the Beam Physics and Accelerator Group). Since then the combined system was used by all NICADD's projects and after several upgrades became a powerful resource for the center. Following the completion of my Ph.D. I continued as NICADD's system manager but now with the added responsibility of being involved in determining the upgrade path of this resource, and helping to develop some of the proposals used to fund new hardware, including those listed below from DOD's office of Naval Research (ONR), Department of Defense Threat Research Agency (DTRA), and DOD's Defense Advanced Project Research Agency (DARPA).

The convenience of the system allowed me to successfully add in 2009-2012 the Tier 3 subcluster for the ATLAS experiment data analysis, funded by the $620,000 award from NSF's Major Research Instrumentation (MRI). In 2009 I joined the NIU ATLAS group and configured and installed a server capable of running ATLAS software and several virtual machines that I used for the evaluation of the Tier3 configuration (T3g) model developed by the ATLAS analysis support center at the Argonne National Laboratory (ANL). The results were reported to the ANL group and were used in 2010 to prepare the purchase of T3g hardware for the NIU subcluster, which is operating at NIU since 2011. I also developed the documentation for the NIU T3g usage: the tutorials on ATLAS analyses, data and software access and job submission to ATLAS GRID servers. In 2011-2012, I provided help in system design, and in setting up and maintaining a similar system (shown in Fig. 1) funded through the same MRI at California State University-Fresno: prepared a quote for the hardware; installed their cluster in April of 2011;

developed documentation; and, being 0.5 FTE funded by the MRI grant, administered the Fresno T3g cluster until March 2012. I also provided training for the Fresno system administrators.

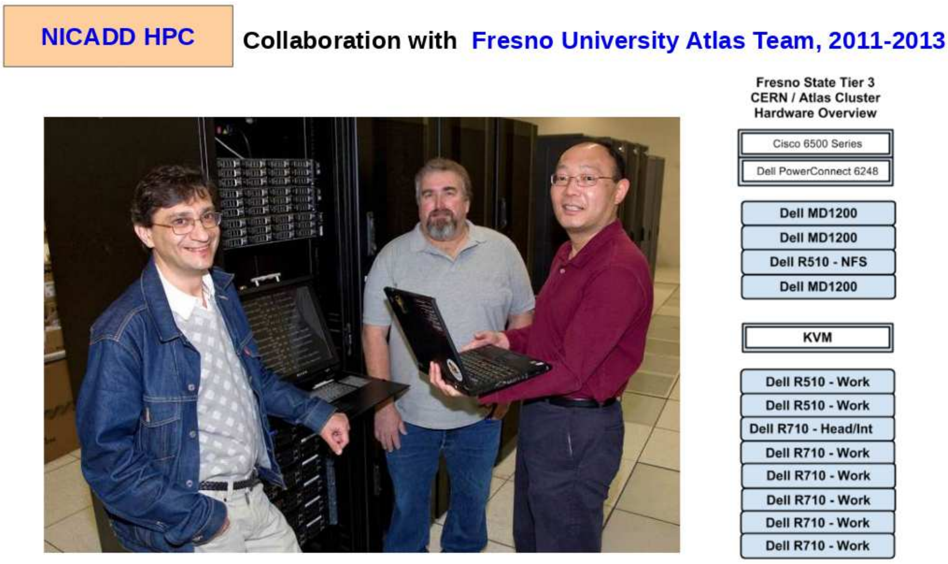

Figure 1: The CSU Fresno ATLAS Tier 3 cluster for ATLAS physics (2011). The cluster was funded by NSF MRI grant. "Dr. Sergey Uzunyan from Northern Illinois University (NIU) provided essential help in system design, setting up and maintaining the cluster. The CSU Fresno ATLAS Tier 3 cluster has been running and heavily used for ATLAS physics by our group members. The cluster is currently maintained by Jay Fowler and Choa-Lin Chou of CSU Fresno ITS department." , http://zimmer.csufresno.edu/ yogao/ATLAS/CSUF-ATLAS.html .

Also in 2009-2011 I prepared configuration for the parallel processing computer system funded trough the $50,000 American Recovery and Reinvestment Act (ARRA) grant for the Beam Physics and Accelerator Group. Three servers each configured to run up to 48 processes shared 128 GB memory and interconnected by the 40 Gbit/s Infiniband network were installed in May 2011. These machines were added to the T3 cluster to maximize their utilization.

In 2012 I developed a configuration for the cluster upgrade funded by the NIU's Great Journeys Strategic Plan award - four more modern 64 core/128 GB servers are currently being integrating into the cluster, to be shared by all NICADD users.

In 2012-2015 I also provided help for the NICADD cluster utilization for research in the field of bioinformatics and for the development of data analysis algorithms for the proton computed tomography in the context of NIU's Medical Physics program.

Today the NICADD cluster is serving ∼40 active accounts, and provides to users 700 processors slots under the HT CONDOR batch system management and 200 TB of shared disk space, with instant access to modern HEP applications. The system is also used by NICADD's data acquisition servers for collecting and analyzing test data for MU2E, DUNE, and beam experiments.

2.1 GAEA cluster upgrade at NIU

In 2017 I was invited to perform the system upgrade of the $843,000 GAEA High Performance Computer cluster at NIU, a powerful GPU-based (Tesla M2070) parallel processing system (60

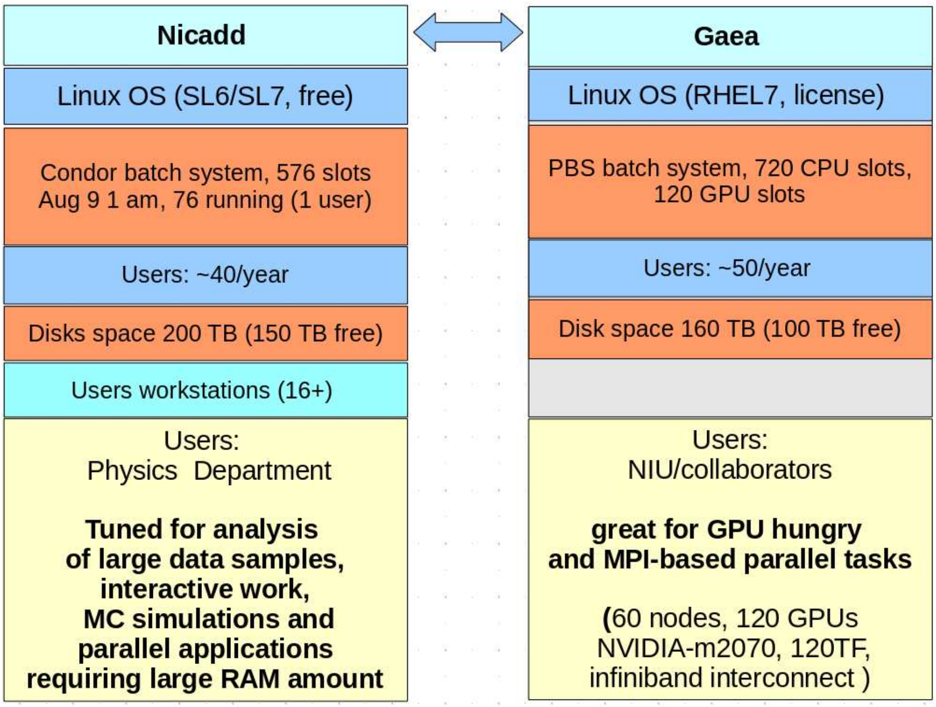

Figure 2: Highlights of “Gaea” and “Nicadd” compute clusters.

ProLiant SL390s servers interconnected via 40 Gbit/s Infiniband). This system was purchased in 2012 for the reconstruction of images obtained with proton tomography scanner in the frame of the NIU pCT program of 2011-2015. Initially, the system was operated by the NIU computer science department, but was converted to the university-wide compute center (CRCD) after completion of the project. I have developed and conducted the Red Hat 7 operating system installation on all cluster nodes, and since that supported the system and application software maintenance and monitoring.

3 The pCT scanner project at NIU

In 2011-2015 I worked with the NIU's proton computed tomography (pCT) group and was primary responsible for developing the Back-End data acquisition system for a new pCT scanner. The scanner provides data for reconstruction of medical images for proton therapy, using position and energy measurements of protons passing trough an object under studies.

My task was to develop a system that will:

• collect input from the the FPGA-based Front-End electronics boards (digitized signals from the fiber tracker planes and from the range stack detector)
• combine front-end data into events (a proton track associated with energy deposition in the calorimeter)
• provide monitoring and selection of events suitable for the image reconstruction
• format and transfer selected events to the image reconstruction computer cluster

I have built a mobile DAQ cluster consisting of six collector nodes operated under CentOS linux and developed the necessary software to manage it. The six worker nodes provided 24 input channels to collect Front-End data (UDP data streams), 72 CPU cores (running at 2.6 GHz) for the data processing and 9 TB disk storage space. All nodes were interconnected with 2 Gbit/s internal network. The head node ran cluster management software and was remotely accessible from an operator desktop in the facility control room. This DAQ system was able to accept data at an instant rate up to 50 MB/s per input stream with an error rate less than 0.06%.

In the spring of 2014 the development of the online part of the DAQ (data collectors) was completed and the DAQ cluster was included in the pCT scanner online framework. The detailed description of the DAQ system was presented at the international conferences in Alushta, Ukraine (2013) and San Antonio, TX (2014). In June-November of 2014 the assembled cluster was used to collect data during beam tests at CDH Proton Center at Warrenville, IL as shown in Figure 3 . The proton candidate collection rate of above 1 MHz obtained by November of 2014 did satisfy the system design requirements. The DAQ software was successfully used for quality monitoring and for the analysis of data obtained during pCT components tests.

In 2015 I led the analysis of the pCT scanner beam tests and presented results at the IEEE-2015 and CAARI-2016 international conferences. The detailed descriptions of this analysis is reported in the "Calibration and GEANT4 Simulations of the Phase II Proton Compute Tomography (pCT) Range Stack Detector", FERMILAB-TM-2617-AD-CD-E (2016) .

Figure 3: Fully assembled DAQ cluster system (left) and proton CT scanner (right) at CDH Proton center. From right to left, beam enters upstream tracker planes followed by downstream tracker planes and finally the calorimeter. The gap in the middle is where the rotation stage for rotating the head phantom in the horizontal plane is placed.

4 The Mu2e experiment

In 2015 I joined the Mu2e experiment at the Fermi National Accelerator Laboratory (Fermilab) to work on the cosmic ray veto (CRV) system. The CRV designed to identify incoming cosmic rays with an efficiency of 99.99% to suppress signals from cosmic ray interactions that mimic the muon-to-electron conversion signal. Cosmic ray detection is provided by four layers of scintillation counters with embedded wave length shifting (WLS) fibers connected to multi-pixel photon counters (MPPCs) on a mounting block, as shown in Fig. 4.

I've been primarily working on the analysis of radiation tests of Hamamatsu MPPCs . To meet the CRV detection efficiency requirement, summed signals from photodetectors at each end of a scintillation counter should provide a photoelectron (PE) yield of at least 25 PE/cm from a minimum ionizing particle traversing at normal incidence one meter from the counter end. The entire system will require 19,840 MPPCs, which are expected to accumulate a maximum radiation fluency of approximately 1×10^{10} neutrons/cm^2 from 1 MeV equivalent neutrons over the three year lifetime of the Mu2e experiment (expected to start in 2020).

I have developed a framework to analyze MPPC's photoelectron spectra to calculate gain and noise rates at different bias overvoltages, photoelectron thresholds, and LED illumination levels that were taken before and after irradiation (distinct sets of eight MPPCs were exposed to four different 1 MeV neutron equivalent doses of 200 MeV protons). I also participated in beam tests of CRV counters at Fermilab in 2015 and 2016. The results of this work presented at ICHEP-2016 and DPF-2017 conferences and contributed to the "Photoelectron Yields of Scintillation Counters with Embedded Wavelength-Shifting Fibers Read Out With Silicon Photomultipliers" (Nucl. Inst. and Meth. A, 890, 84-95 , 2018) and to the "Radiation Tests of Hamamatsu Multi-Pixel Photon Counters" papers (2018, submitted to Nucl. Inst. and Meth). The framework is used as a core for the test system developed at NIU to commission all required MPPC devices.

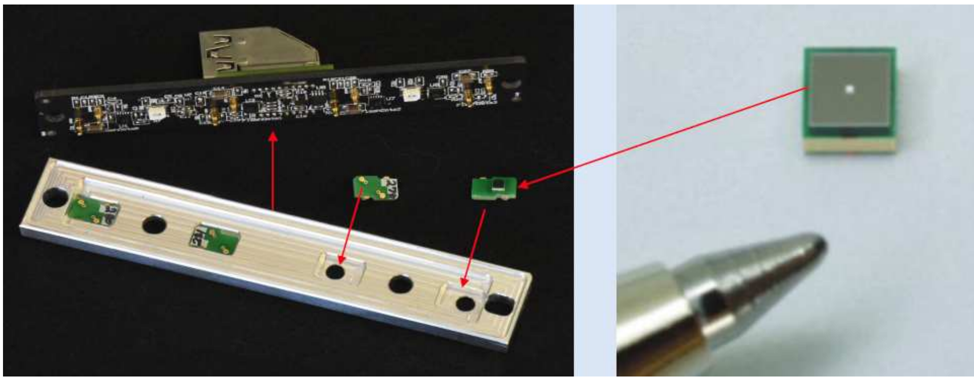

Figure 4: The MPPC mounting block (left), which accommodates four MPPCs mounted on carrier boards; a closeup of one 2.0×2.0 mm^2 S13360-2050VE Hamamatsu MPPC (right) with the tip of a ball-point pen for scale.

5 Contributions to the DZero experiment

I've been an active member of the D0 collaboration from the beginning of the major detector upgrade in 1998 to the detector's operations closure in 2011. My initial responsibility (1998-2001) was development and implementation of the Muon-track finding algorithms for the second level Muon trigger, which was a critical part of the experiment's data acquisition system. This software reconstructed muons from the collision and made a decision about the quality of the event based on their properties in order to help decide which events to write to permanent media for future analysis with an acceptable rate. It was both an interesting and challenging task due to a tight time budget ($\tilde{5}0$ microseconds) and the complexity of the hardware (more than 80 microprocessors running in parallel). The system became an effective and stable part of the

DZero experiment (see "The Level-2 Muon Trigger at D0", IEEE Trans. Nucl. Sci. 49, 1589 (2002) which is cited in the "The upgraded D0 detector," Nucl. Instrum. Meth. A **565**, 463 (2006)). In 2002 I joined the high energy physics group at Northern Illinois University in order to complete my Ph.D. I continued work for DZero as a member of the trigger experts team and made improvements in the Level 2 trigger system based on accumulated data.

In 2004 I began work with the New Phenomena DZero group and started the "Search for third generation leptoquarks" analysis. The results of this search were published in Physical Review Letters (2007), and was a significant contribution to the list of DZero results. Following the completion of my degree in 2006, I continued at NIU splitting my time between being the system manager of NICADD computing and continued work on DZero. In 2007 I was promoted to Research Scientist based upon my increased responsibilities as NICADD system manager (discussed above) and in 2007-2010 I led the efforts of the NIU team in searches for new particles with the extended D0 data set. This work includes extensions of the methods developed in the "Search for third generation leptoquarks" to the analysis of a process with a similar final state, the pair production of scalar bottom quarks. Scalar bottom quarks are assumed to decay to a neutralino and a b quark, and limits on the possibility of their production for a spectra of neutralino and b-quark masses was set. This was a significant extension of the regions excluded by previous DZero and CDF ("Collider Detector at Fermilab") analyses. The obtained limits on the leptoquark and sbottom masses were the world's most stringent until ATLAS and CMS analyses further extended the exclusion regions in 2013-2016 searches.

Below is a summary of my contributions to the experiment which were also recognized in three "Fermilab Today" articles as "Results of the Week":
http://www.fnal.gov/pub/today/archive_2004/today04-12-02.html
http://www.fnal.gov/pub/today/archive_2007/today07-06-28.html
http://www.fnal.gov/pub/today/archive_2009/today09-10-15.html

- Development of the L2 muon trigger. Primarily author of four D0 software packages that are necessary for the L2 muon trigger. Part of this code, the parallel muon track finder processors were running online during an entire D0 RunII data taking period , March 2001 - September 2011. Support of the DZero detector operations as **L2 trigger expert**.

- Ph.D. thesis "**A search for charge 1/3 third generation leptoquarks using muon triggered data**", 2006. Adviser Dr. David Hedin.

- Primary and corresponding author of the D0 *Physics Review Letters* paper V. M. Abazov *et al.* [D0 Collaboration], "**Search for third generation leptoquarks in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV**," Phys. Rev. Lett. **99**, 061801 (2007). (15 citations)

- Primary and corresponding author of the D0 *Physics Letters B* paper "**Search for scalar bottom quarks and third-generation leptoquarks in ppbar collisions at $\sqrt{s} = 1.96$ TeV**," Phys. Lett. B **693** (2010) 95; (31 citations)

- Presented conference talks at two American Physical Society meetings, three invited talks on DZero results at two Division of Particle and Fields conferences (2006 and 2009), and also presented invited overview talks of Tevatron results at the "LHC Days in Split" 2010 conference and the 2011 "New Trends in High Energy Physics" conference in Crimea, Ukraine.

- Primary author of four D0 internal notes and two public (conference) DZero Notes, and

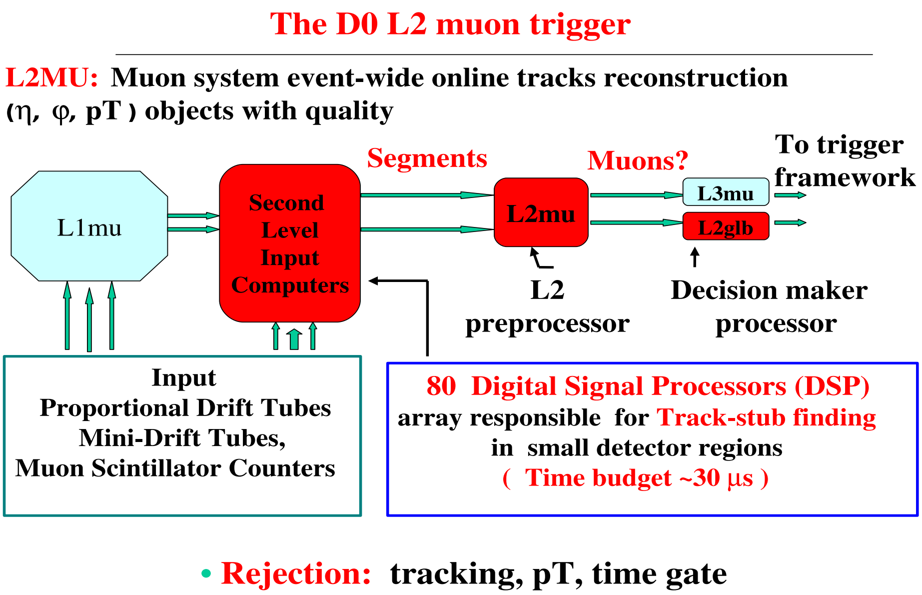

Figure 5: Data processing in the Level-2 muon trigger system.

Figure 6: The Dzero L2 team. For “Fermilab result of the week”, 02.12.2004.

made about 50 presentations at internal DZero meetings including New Phenomena and Higgs group meetings, New Phenomena workshops, D0 workshops, and “All D0 meetings” talks (which were pre-publication presentations).

6 Miscellaneous projects

While working on projects listed above I also completed a number of smaller, but also interesting tasks:

• created a linux friendly interface to operate data acquisition system based on DRS4 board

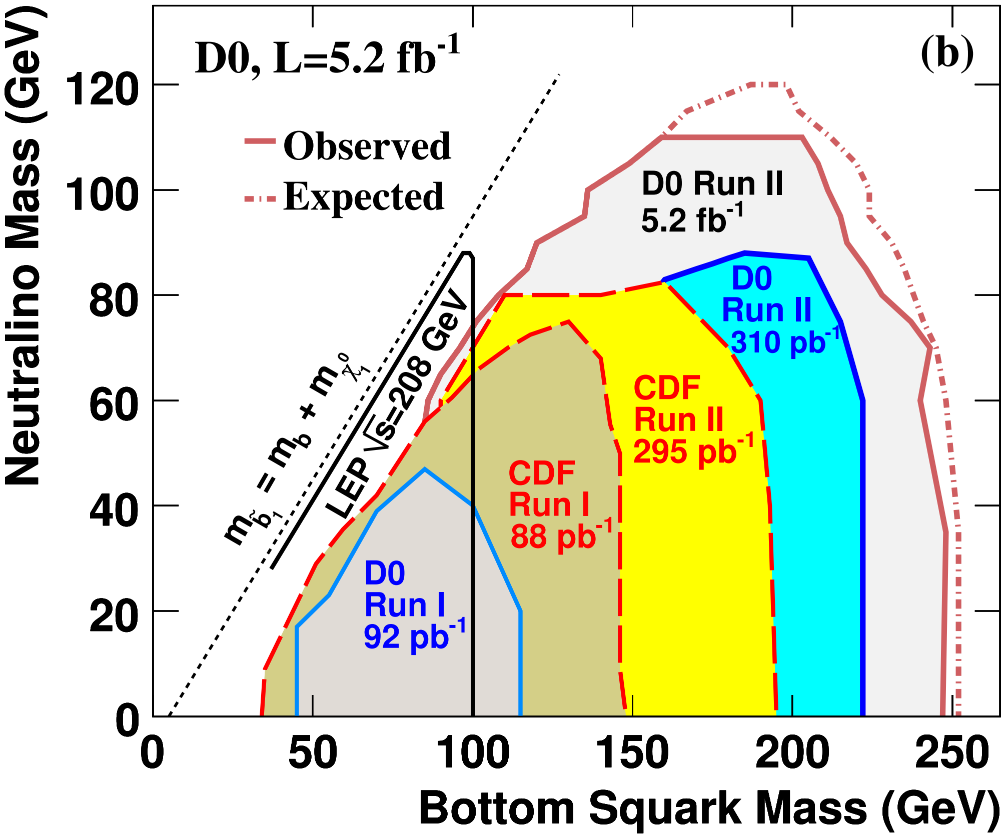

Figure 7: "Search for scalar bottom quarks and third-generation leptoquarks in ppbar collisions at sqrt(s) = 1.96 TeV". The exclusion contour in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}^0_1})$ plane. We exclude the production of bottom squarks for a range of values in the $(m_{\tilde{b}_1}, m_{\tilde{\chi}^0_1})$ mass plane such as $m_{\tilde{b}_1} > 247$ GeV for $m_{\tilde{\chi}^0_1} = 0$ and $m_{\tilde{\chi}^0_1} > 110$ GeV for $160 < m_{\tilde{b}_1} < 200$ GeV.

for 2017-2018 beam tests at Fermilab, "Beam Tests of Plastic Scintillator for the CMS HCAL Endcap Upgrade", CMS internal Note, 2017

• developed a framework for CMS data analyses for fast evaluation of different neural networks, specifically Deep Neural Networks using graphics processors, https://twiki.cern.ch/twiki/bin/view/Main/HzzTmv

• developed a GEANT4 based analysis of dose deposited in phantoms used in the Phase-II pCT scanner tests (the Loma-Linda group)

• configured DAQ servers for test stands working with different measurement systems for tests for Mu2e-CRV, DUNE , CALICE and beam group projects at NICADD

• customized and supported code management (CVS), agenda (CDSAGENDA), logbook (ELOG) and monitoring (GANGLIA, NAGIOS) tools for NICADD cluster users

7 Selected contributions to the NICADD grants awards

While I am a member of NIU's High Energy Physics group, I have listed only those grants where I took a role in preparing the grant materials, and not those grants where I only contributed to the research programs.

- NICADD Beam Physics and Accelerator group. Provided the NICADD cluster upgrade specifications; purchased, installed and supported hardware for the following projects

2012-current, \$200,000. Department of Defense Threat Research Agency (DTRA) for the developing a compact light x-ray sources.

2010-2012, \$600,000. DOD's Defense Advanced Project Research agency (DARPA) award for Advanced Accelerators and beam physics R&D development

2010, \$50,000. American Recovery and Reinvestment Act (ARRA) funding .

2007-2010, \$200,000. DOD's office of Naval research (ONR), for optimization of a high-power free-electron laser.

- NICADD US ATLAS group. Developed, installed and supported computing clusters at NIU and California State-Fresno for analyses of data from the ATLAS experiment at the Large Hadron Collider (CERN).

2010-2013, \$620,000. NSF's Major Research Instrumentation (MRI) program.