Large Area Cosmic Muon Flux Measurement

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Abstract

We are living in an invisible "rains" of cosmic showers which are originated in the upper atmosphere from nuclear reactions between air molecules and the energetic protons and other particles from outer space. These showers consist of different particle species (electrons, muons, protons, photons, etc.) with different energies and moving in different directions. To be able to detect these showering particles near the Earth's surface itself is a challenging and very important scientific endeavor. Even more important is the measurement of these surviving particles on a very large-scale on the surface of the Earth and the study of the correlation between cosmic muon particle flux and its effects on our environment, weather, electronics etc. The results from this measurement will also have profound implications on the fundamental theory of nuclear and particle physics and on astrophysics via searching for super-relativistic cosmic ray event which is impossible to create via laboratory particle accelerators. As equally important, with this research project, we are initiating a pilot outreach program at Georgia State University (GSU) to promote advanced science research activities in middle and high schools in our state to inspire students to get higher education in science.

The initial measurement will be performed in the metro Atlanta area. A set of fifteen muon monitoring stations will be built at GSU and installed at selected public schools. The further development of this project is to build and install about 200 networked muon monitoring stations within three to four years across the state of Georgia.

The main focus of this proposal is to develop small and cost effective cosmic muon monitoring stations in the nuclear physics laboratory at GSU. Each of these stations will be equipped with GPS chips for recording the muon particle signals with their position and arriving timing information via communicating with GSP satellites.

1 Project Description

1.1 Introduction

The increased interest to cosmic-ray physics in the field of high energy physics is the search for the quark-gluon plasma (QGP), the precursor of nuclear matter, in heavy ion collisions. The study of the GQP signatures is the major goal of the relativistic heavy ion collider (RHIC) project at the Brookhaven National Laboratory.[1] The principle investigator of this project, Xiaochun He, has been working on this research program for the past ten years with grant support from the United States Department of Energy.[2, 3]

In astrophysics, one of the most challenging issues is to understand the origin of cosmic rays with energies above $10^{20}eV$ when there are no obvious nearby sources. In 1966 Greisen, Zatsepin and Kuzmin pointed out that the universe is not transparent to protons above about 4×10^{19} eV as they would interact with the $2.7K$ microwave background radiation. This led to the argument that if the sources of cosmic-ray particles of such energies are extra-galactic, they must be relatively near (within 300 million light-years) otherwise no such particles will be observed.

It is also known that cosmic rays may cause soft fails in electronic logic or memory.[4] In order to predict electronic fail rates from cosmic particles, it is necessary to know the local cosmic ray flux. In summary, this cosmic ray muon measurement project bears several significant scientific applications:

- Cosmic muon distributions (flux) as a function of time, location and direction on the Earth.
- Astrophysics application.
- High energy physics application.
- Monitor environmental effects from cosmic particles.
- Cosmic ray effect on electronic logic or memory.

This project will be a joint venture between Georgia State University and the public school system in the state of Georgia for studying of high energy cosmic rays and measuring the "time-stamped" cosmic ray muon flux distribution. To develop environments that enable students learn science and participate advanced scientific research projects is the best way to inspire students to get higher education in science. This also requires that our higher educational system to develop suitable research projects for students to make meaningful and significant contributions in science.[6] Through this project, students will learn the basics of how to detector high energy particles, how to operate relatively simple data acquisition system, how to make plots of the observe data and present their thoughts and discoveries in public. Ultimately, they will learn the fundamental structures of matter and their interactions and be trained to pursue basic science research and its applications.

For making this program fruitful and increasing public awareness, we have started a pilot program in the metro Atlanta area by moving an existing cosmic ray muon detector to one middle school and one high school for students to measure cosmic muon flux distributions and learn the fundamentals of nuclear and particle physics. The PI has given three presentations: The first one was given at Griffin Middle School on October 16, 2002; the second was given at Chapel Hill High School (Douglasville, GA) on November 15, 2002; and the third one was given at Fatette County High School on February 5, 2003. A successful story about this project has been reported via Atlanta Journal-Constitution on December 2, 2002 (http://www.accessatlanta.com/ajc/metro/cobb/1202/03rays.html).

1.2 Large-scale Muon Flux Array Detectors

The initial experiments of the large-scale muon flux array will consist of four muon flux monitoring stations. Each station consists of three-fold plastic scintillators which will be read out by a common

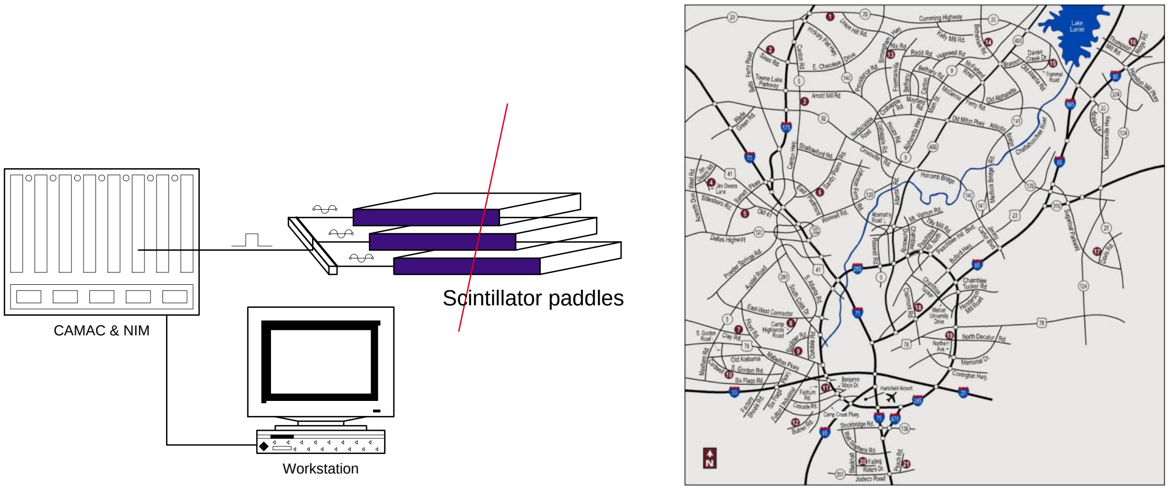

Figure 1: Muon monitoring station and the proposed area for the muon measurement.

electronic system. The data recorded at each site will be "time stamped" for a given detector orientation. These stations will be installed at the selected public schools in metro Atlanta area (see Figure 1) and one central monitoring station will be installed at Georgia State University. Figure 2 shows a photograph of a prototype detector arrangement. The detectors are mounted on a rotatable platform so that they can be oriented at any angle between 0° (vertical) and 90° (horizontal). At the time of preparing this proposal, this prototype system is taking data at Fayette County High School.

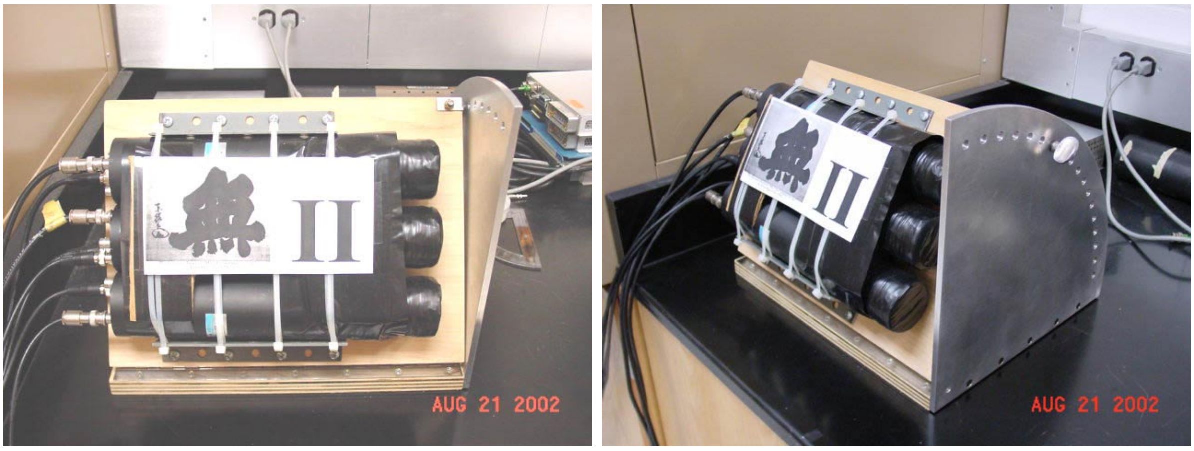

Figure 2: Mu II Cosmic Muon Flux Detector at Georgia State University

1.3 Cosmic Ray Flux Simulation

A Geant4[5] based cosmic muon simulation program has been set up for studying muon flux distributions. The Geant based detector simulations have played an important role in major nuclear and particle physics experiment in the world. It not only helps in optimizing a detector design, but also plays inseparable role for analyzing the experimental data. This simulation software has also been adopted in simulations for medical and industrial applications[5]. The current release of this simulation software, Geant4, is written in C++ programming language and have been proven to provide reliable simulation results.

A graduate student, Christopher Cleven, has been implementing a full scale Geant4 simulation for the cosmic muon flux studies. In this simulation program, a set of atmosphere layers have been implemented with realistic air densities within each layer. At the time of preparing this document, a non-uniform geomagnetic field is being installed in the simulation program in order to correctly simulate the trajectories of charged particles created from cosmic showers. Some initial results are shown in Fig. 3, which show the muon lateral distributions near the Earth's surface and their energies with energetic primary protons entering the top atmosphere at variable energies ranging from 10 GeV up to 500 GeV.

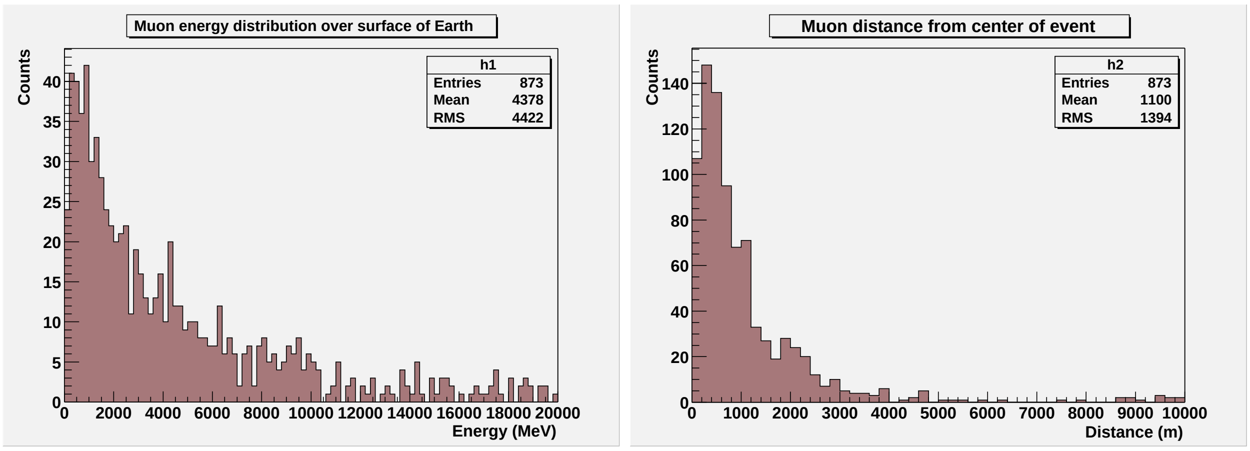

Figure 3: Very preliminary Geant-4 simulation results for the cosmic muon flux study.

1.4 Student Activities

The main activities which students will perform can be summarized as follows:

1. Detector assembling and testing. This step will mainly be done in the detector development lab at GSU. Students from each participating school will be scheduled to come to GSU working in the lab to help constructing the detector for the school.
2. Muon flux measurement. Once a detector is set up at a school, a series of muon flux measurements will be done in sync with other detectors online which includes monitoring the detector performance, recording the scaler count, barometer readings, high voltage setting, etc.
3. Running cosmic ray simulation program as mentioned above.
4. Working on data analysis and presenting results in workshops and conferences.

References

[1] Relativistic Heavy Ion Collider project at Brookhaven National Laboratory, http://www.rhic.bnl.gov/

[2] **Measurement of Differences between J/ψ and ψ' in p-A Collisions**, M.J. Leitch, *et al.*,, (for the Fermilab E866/NuSea Collaboration), Phys. Rev. Lett. **84**, 3256-3260 (2000).

[3] **Measurement of the Λ and $\bar{\Lambda}$ Particles in Au+Au Collisions at $\sqrt{s_{NN}} = 130$ GeV**, K. Adcox, ..., X. He, ... *et al.*, (for the PHENIX Collaboration), Phys. Rev. Lett. **89**, 092302 (2002).

[4] NASA/GSFC Radiation Effect and Analysis home page, http://radhome/gsfc.nasa.gov/

[5] *http://geant4.web.cern.ch/geant4/*

[6] National Research Council, *http://books.nap.edu/html/nses/html/index.html*, 1996.

2 Budget Justification

With this proposal, we request the support for the cost of constructing four sets of new cosmic ray muon detectors and the travel costs to schools for detector installation and tests. The detailed budget break-downs is described as follows.

2.1 Equipment

We expect to recruit fifteen groups from the middle and high schools in counties near the Georgia State campus. For the first year we will focus on providing each group with a compact, dedicated data acquisition system consisting of a pair of plastic scintillator paddle detectors mounted on photomultiplier tubes. These will be connected to a control and readout module on a single circuit board which will contain an inexpensive Cockroft-Walton type high voltage bias supply as well as discriminators for each of the anode signals and logic circuitry for selecting coincidence counts from the two detectors. The circuit board will have an output connection to the serial port of a desktop computer. The circuit boards and bases will either be purchased from the Quarknet group at Fermi National Accelerator Laborato ry or constructed in-house. The estimated minimum cost per station is $1,890 for the detector only which is tabulated below: The total cost of four detectors is $7,560.

Parts Name	Description	Qty	Costs
Photomultipliers	Hamamatus R580	2	$880.00
Bicron PM-base	Photomultiplier base	2	$210.00
Ortec	High voltage power supply	1	$700.00
Bicron scintillator	scintillator sheet (10in x 10in x 1cm)	1	$100.00

2.2 Travel

The current four members of the nuclear physics group at GSU, Xiaochun He, Carola Butler, Gus Petitt and Hakmana Sanjeewa (Ph.D student), will spend a great deal of time recruiting new schools and moving the existing and to-be-developed detector systems to these schools within the state of Georgia. The estimated number of site visits (a full day trip) will be around thirty (two trips per sites) and the estimated cost is $2,500. The travel cost is based on three-person trip for each site visit for thirty trips, which includes mileage ($0.28 per mile for an 80-mile round trip) and per diem ($20 per day).

3 Other Grant Support

Since 1998, when the PI became a tenure-track faculty at Georgia State University, he has received strong support for his research projects both from Georgia State University and from federal funding agencies. The list of grants received during the last five years is given below:

- US Department of Energy, (PI) "Research in Heavy Ion Nuclear Reactions", 04/01/02 - 03/31/05, $97,000 received for the first year and $130,000 will be received for the second year which will start April 1, 2003.
- US Department of Energy, "Research in Heavy Ion Nuclear Reactions", 06/01/99 - 03/31/02, $346,827 (PI).

- US Department of Energy, "Research in Heavy Ion Nuclear Reactions", 04/01/98 - 03/31/99, $75,000 (PI).
- Brookhaven National Laboratory, "Event Builder Upgrade for the PHENIX Experiment at Brookhaven National Lab", 12/21/99 - 06/30/02, $94,821 (PI).
- GSU Research Equipment Grant, "Level-2 Trigger System for the PHENIX Experiment at GSU", 1998-99, $15,000 (PI).
- GSU Research Team Grant, "Level-2 Trigger System for the PHENIX Experiment at GSU", 07/01/99 - 06/30/2000, $9,000 (co-PI with Dr. G. Chen, PI).
- GSU Research Team Grant, "High Speed Distributed Trigger Algorithm for the PHENIX/RHIC Experiment at GSU", 07/01/2000 - 06-30/01, $15,000 (PI with co-PIs: G. Chen, M. Weeks and K. Balakishnan).

4 Status Report Funded under GSU Internal Grants

The support from Georgia State University has played a significant factor for the PI's ability to obtain external funds for conducting research in the field of the relativistic heavy-ion physics at Brookhaven National Laboratory and Fermi National Accelerator Laboratory. Because of the nature of the research in the field of high energy nuclear and particle physics, which typically requires multi-year detector construction, data taking and analysis (> 10 years in this case), only the highlights which were directly resulted from GSU's internal grant support are listed below:

4.1 J/Ψ Polarization Study

After finishing up PHENIX/RHIC Run-2 data-taking, the main effort of the nuclear physics group was put on analyzing the Run-2 data. More specifically, this group has been focusing on the study of detector acceptance corrections for J/Ψ polarization measurement using the PHENIX muon arm system. An analysis notes from this study has been submitted to the PHENIX Collaboration. [https://www.phenix.bnl.gov/phenix/WWW/p/draft/hexc/polarization/acceptanceCorrection.pdf.] The CPU intensive simulation and the PHENIX offline analysis were performed on a local **Linux-based computer cluster which was purchased through an internal research grant from Georgia State University (GSU)**. Our post-doc, Dr. Mishra, in the meantime, has been studying the efficiencies of different techniques for the like-sign background subtraction for constructing J/Ψ signals and Drell-Yan events from the Run-2 pp data.

4.2 Preparation for Run-3

As an active member of the PHENIX Collaboration, our group has committed its best effort in working with other groups within this collaboration to get PHENIX ready for Run-3. As it has been for the past two years, we are upgrading the PHENIX Level-2 configuration and control software which has been partially tested and integrated into the PHENIX Event Builder and Run Control. Xiaochun He and Mishra have been taking turns traveling to BNL to finalize the software integration process. In the mean time, Xiaorong Wang and Xiaochun He just started developing new software for monitoring J/y peak online for Run-3 which will be fully operational before the end of current project period.

4.3 Geant4-based Detector Simulation

During these project periods, the graduate students in out group have been systematically exploring the functionalities which are currently installed in the new release of the Geant4 software package. Selected simulation results can be found at: http://petitt.phy-astr.gsu.edu/ qinw/project.html.

It is hoped that this research proposal will also be supported at Georgia State University for initiating this large scale cosmic muon flux measurement in the state of Georgia.