Second-Year Progress Report for NSF-PHY00-73057
Department of Physics and Astronomy
Rutgers - The State University of New Jersey

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1 General Comments

This report describes experimental work in High Energy Physics being done by physicists at Rutgers University. We are working on the following current and future projects:

- experiments with the Collider Detector at Fermilab (CDF),
- the High Resolution Fly's Eye experiment in Utah,
- preparations for the Compact Muon Solenoid (CMS) experiment at CERN,
- R&D work on chemical-vapor-deposition (CVD) diamond detectors,

Very recently, we joined RD50, a CERN collaboration formed to develop semiconductor detectors for the high luminosity environment. We are also working on the final stages of data analysis and publication for two past experiments:

- the KTEV project in the fixed target program at Fermilab,
- the SLD e^+e^- collider experiment at SLAC.

Last year, in July, we submitted a report on the first year funding of these projects. The current report is intended to be incremental, i.e. to emphasize progress since our last report. The following major things have taken place in the work supported by this grant:

- The Collider Detector at Fermilab is taking data. The experiment is fully commissioned and performing well. We expect to present preliminary results on important Higgs and new particle searches at conferences early in 2003.
- Prof. Steve Worm has been appointed leader of the Exotic Physics analysis group in CDF. The Rutgers group is providing the intellectual guidance for Fermilab's flagship analyses, Higgs and SUSY searches, at a critical phase of Run II.
- Prof. Steve Schnetzer and Prof. Gordon Thomson head the Rutgers group collaborating on the High Resolution Fly's Eye (HiRes) experiment. Two postdocs, two graduate students, and three undergraduates from Rutgers work with them.
- Gordon Thomson has been elected co-spokesperson of the HiRes collaboration starting September, 2002.

- HiRes data are consistent with a combination of two sources of ultra-high-energy cosmic rays: galactic and extragalactic. Extragalactic sources in the HiRes data clearly show the GZK cutoff. **This work should be considered the experimental discovery of the GZK cutoff.** Rutgers physicists participated heavily in the data analysis leading to this, and have written much of the text of the two papers on this which have been submitted for publication.

- Our group is developing electronics for the Compact Muon Solenoid being built for CERN's Large Hadron Collider (LHC). Rutgers continues to lead the US Forward Pixel DAQ/electronics effort for CMS. Prof. Steve Schnetzer is Level 2 Manager in this project.

- Rutgers engineer Ed Bartz designed for CMS a fully functional Token Bit Manager chip, a sophisticated, radiation-hard, mixed-mode integrated circuit. This chip is a key component of the CMS pixel readout system. The prototype chip has been received and it functions as intended.

- As part of our QuarkNet activities, this summer we held a three week long Associate Teachers Workshop at Rutgers in which ten New Jersey high school teachers were introduced to particle physics.

- We continue to work on the development of chemical-vapor-deposition diamond detectors. We have made preparations for a concluding series of test beam measurements to be carried out over the next year. These measurements will provide definitive side-by-side comparisons of the performance of diamond and silicon pixels both before and after irradiation.

- Rutgers participation in the KTEV effort should finish in the near future with impressive overall physics output. During the past year, Rutgers published four more papers on our KTEV work:

  - a Physical Review Letter (PRL) on $K_L \to e^+e^-e^+e^-$,
  - a PRL on the rare decay $K_L \to e^+e^-\mu^+\mu^-$,
  - a PRL on the radiative width measurements of excited neutral kaons,
  - a Physical Review D paper on the radiative decay $K_L^0 \to \pi e\nu\gamma$.

  We are preparing two more articles for publication: Ke_3 form factors and $K_L \to \pi^+\pi^-\gamma$.

- Rutgers' participation in the SLD experiment is nearing an end. Mohan Kalelkar continues to serve as the Manager of the Monte Carlo Farm for the entire experiment. His graduate student Hyejoo Kang successfully defended her PhD thesis on hadron production in quark, antiquark, and gluon jets. SLD published three refereed papers in the last year, including one on the single most precise measurement of the probability for gluon splitting into $b\bar{b}$.

The grant now supports the research of twelve principal investigators, ten on university lines, one grant-supported research faculty member and one emeritus professor. Rutgers contributes additional full-time salary for a computer specialist, two engineers and three machinists who participate heavily in projects for experimental high energy physics.

2 Personnel

We provide here a full list of the people working on the various tasks supported by this NSF grant during the currect reporting period.

Senior Physicists:	John Conway, Tom Devlin, Pieter Jacques, Mohan Kalelkar, Amit Lath, Richard Plano, Steve Schnetzer, Bob Stone, Sunil Somalwar, Gordon Thomson, Terry Watts, Steve Worm
Research Associates:	Anton Anastassov, Doug Bergman, Fedor Ratnikov, Lalith Perera, John Zhou, Peter McNamara (starting Sept. 2002), Noah Wallace (moved to U. Arizona, Jan. 2002)
Physicists:	Tim Koeth, Bill Hanlon
Computer Specialist:	John Doroshenko
Grad Students:	Suzanne Averitte, Paul DiTuro, Dongwook Jang, Hyejoo Kang, Zongru Wan, Jared Yamaoka, Andreas Zech, Adam Rogers, Stephan Karg
Undergraduates:	Aaron Becker, Carolyn Chun, Jesse Cunha, Paul Haitkin, Kent Horvath, Liam MacLynne, Nick Smolney

In addition, we receive substantial support at extremely low cost from our department's technical services facilities:

Electronics Engineers:	Ed Bartz, Stan Sherman
Electronics Technician:	Yuriy Streltsov
Machinists:	Val Myrnyj (foreman), Ernie Erskine, Arvid Knutsen, Eric Paduch, Bill Schneider

We are currently interviewing postdoc candidates to replace those who have moved on to other positions. In the sections below, we will list the people working on each of the individual projects.

3 CDF

Senior Physicists:	John Conway, Tom Devlin, Pieter Jacques, Amit Lath, Sunil Somalwar, Bob Stone, Terry Watts, Steve Worm
Postdocs:	Fedor Ratnikov, Anton Anastassov, John Zhou, Peter McNamara (starting Sept. 2002), Noah Wallace (moved to U. Arizona, Jan. 2002)
Grad Students:	Zongru Wan, Dongwook Jang, Paul DiTuro, Jared Yamaoka, Adam Rogers
Undergraduates:	Nick Smolney

The CDF experimental apparatus is in place, detecting $p\bar{p}$ collisions. Physicists are staffing round-the-clock shifts both for operating the detector and for processing the data emerging from it. Approximately 60 pb^{-1} of integrated luminosity have been delivered with 30 pb^{-1} written to tape. While this is somewhat less than hoped for, the collider is now performing well after recent fixes. We expect 100 pb^{-1} on tape by January, 2003. The detector is in excellent working shape. Analysis results in various areas are beginning to emerge and Rutgers physicists are playing a

leading role in the data analysis efforts. By Summer, 2003, we hope to have preliminary results ready for conferences on important higgs and exotic search topics.

Here are some highlights of Rutgers contributions to Run 2 physics analysis and detector commissioning and operation:

- Prof. Steve Worm is now co-convener of the Exotics physics analysis group, providing intellectual leadership and coordination of all new particle searches in CDF.
- Prof. John Conway is co-head of the Higgs Working Group which handles all the Higgs-related activities of the Exotics group.
- Prof. Terence Watts and Rutgers staff have designed and implemented a data handling system for a CDF satellite computing location at Rutgers based on the methods developed at CDF.
- Postdoc Fedor Ratnikov heads the Tau Working Group in CDF, and has written the backbone of the tau finding and triggering code for the experiment.
- Postdocs Anton Anastassov and John Zhou (who joined the group in December 2001) are heavily involved in monitoring and commissioning.
- Postdoc Anton Anastassov has written new software to perform π° reconstruction using the electromagnetic calorimeter shower max data; this is a crucial part of tau identification and also has general utility in photon and π° studies.
- Postdoc John Zhou is playing a key role in silicon detector commissioning and data validation, and has initiated a Run II SUSY multi-lepton analysis.
- Prof. Amit Lath headed until January 2002 the Run 2 silicon detector commissioning and operations group.
- Prof. Terence Watts, until January 2002, co-headed the CDF Data Handling group, charged with developing systems for storage and retrieval of the data following primary reconstruction.
- Graduate student Dongwook Jang served as a detector "ACE," doing a three-month tour of shift duty during data taking. He was DAQ ace on the shift that achieved record in the product of luminosity and detector efficiency.

The main physics analysis goals in the coming year focus on the area of (hadronically decaying) tau lepton reconstruction in new particle searches. The two senior graduate students resident at Fermilab are both working on tau-related studies, and should have results in the coming year. The coherence of this effort, involving postdocs and professors as well, and the fact that Rutgers has led the effort in tau reconstruction, gives the group a unique position from which to rapidly produce publishable physics results addressing the Higgs search and other new phenomena.

Rutgers personnel are also preparing for work in the area of the Run 2b silicon upgrade, and will most likely participate in the design, construction, and operation of the burn-in system to induce and detect failures of the detectors during the first 72 hours of simulated operation.

4 High Resolution Fly's Eye Experiment (HiRes)

Senior Physicists:	Steve Schnetzer, Gordon Thomson
Postdocs:	Doug Bergman, Lalith Perera
Physicist:	Bill Hanlon
Grad Students:	Andreas Zech, Stephan Karg
Undergraduates:	Paul Haitkin, Liam MacLynne, Jesse Cunha

The two HiRes detectors are located on the U.S. Army Dugway Proving Ground in Utah, and consist of mirrors of area 5.2 sq. m. that collect atmospheric fluorescence light from cosmic ray showers. HiRes-I, our older detector, has about four years of data, and the newer detector, HiRes-II, has almost two years of data.

Postdoc Doug Bergman, graduate student Andreas Zech and G. Thomson have analyzed the first part of the HiRes-II data and determined the spectrum of UHE cosmic rays seen monocularly. Our U. of Utah collaborators have done the same for HiRes-I data. The two monocular spectra agree with each other very well, and in our energy range (2×10^{17} to 3×10^{20} eV) show evidence for four spectral features, called the second knee, the ankle, the GZK pileup, and the GZK cutoff. This is to be compared with only one feature, called the first knee, seen at lower energies.

We have fit our data to a model consisting of galactic and extragalactic sources of cosmic rays, which works quite well. The extragalactic part of the model assumes uniformly distributed sources of cosmic rays, and energy loss during propagation across the universe through photo-pion production from the photons of the Cosmic Microwave Background Radiation (CMBR) which produces the GZK cutoff and pileup. It also includes e^+e^- pair production from the CMBR radiation. In this model pair production excavates the ankle and piles events at the location of the second knee. So all four spectral features in our data can be explained by one theory. This is a unique situation in cosmic ray physics.

We have submitted two papers for publication on the spectrum of UHE cosmic rays in the energy range 2×10^{17} to 3×10^{20} eV. One has been sent to Physical Review Letters (about 50% written by Rutgers personnel). The second is a long paper for Astroparticle Physics (almost 100% by Rutgers physicists) which details the innovative analysis work on the HiRes-II data that the Rutgers group has performed. A third paper is in preparation (also 100% by Rutgers people) on fitting our spectrum to various astrophysical models.

Our work on this is the first exploitation of all the capabilities of the flash ADC readout system of HiRes-II. We also have imported into cosmic ray physics some techniques of high energy physics dealing with Monte Carlo development and comparisons between data and Monte Carlo simulation.

A third publication is being prepared (by D. Bergman and G. Thomson) on fits to our data of several theories of the astrophysics of UHE cosmic ray sources and propagation.

Undergraduate J. Cunha, postdoc Lalith Perera, and S. Schnetzer have studied experimental methods for identifying cosmic ray showers from photon primaries. One important method is identifying showers with more than one peak in the shower-development profile. They are searching for events in the data that fit this signature.

Undergraduate Liam macLynne, with D. Bergman, A. Zech, and G. Thomson, is working to optimize design of a third HiRes detector. A big question is the altitude coverage. HiRes' parent experiment, the Fly's Eye, covered up to the zenith, while HiRes-II covers from just above the horizon to 31 degrees. Liam is studying increased altitude coverage to 45 degrees.

5 CMS

Senior Physicists:	Steve Schnetzer, Robert Stone, Steve Worm, Pieter Jacques
Research Associate:	Lalith Perera
Engineer:	Ed Bartz
Physicist:	Tim Koeth
Computer Specialist:	John Doroshenko
Undergraduate:	Steve Cavanaugh, Kent Horvath

Our group is playing a leading role in the development of the electronic readout system for the CMS Forward Pixels. The pixel detector will play an essential role in identifying the production of heavy quarks in the proton-proton collisions at the Large Hadron Collider (LHC) by measuring precisely the location of secondary vertices. The ability to identify heavy quarks will be a crucial part in most of the physics programs at the LHC.

One of our main responsibilities is the Token Bit Manager (TBM) a key part of the pixel readout for both the Barrel and Forward Pixels. The TBM is a custom, radiation-hard integrated circuit. It will control the readout of a group of front-end readout chips by initiating a token pass among the group. It will stack incoming triggers awaiting token passes and will send coded trigger information on to the readout chips. It will also function as the front-end hub for the Control Network System. This is the network that programs the various front-end chips. It operates during "data off" periods, such as orbit gaps and empty orbits. A primary function of this network will be to frequently download each pixel comparator threshold setting in the readout chips since these may be frequently corrupted by single event upsets.

The TBM will reside at the detector front-end and will be subjected to a very high level of radiation. It must be fabricated in a rad-hard process. We submitted a prototype TBM chip in DMILL, the same rad-hard process currently being used for the pixel readout chips. This prototype was delivered in May. Initial testing indicates that it performs according to specifications including the capability of operating at the full design speed of 40 MHz. We have now begun a translation of this chip into the denser and cheaper 0.25 micron technology.

We have also begun testing of a prototype Very High Density Interconnect (VHDI). The VHDI is a state-of-the-art high density circuit with 2 mil trace and space on which the forward pixel plaquettes of groups of readout chips and sensors will be mounted. We have successfully programmed and readout a prototype pixel readout chip mounted onto the VHDI. Full plaquettes, or groups of readout chips, bonded to the VHDI prototypes will be tested by the end of the year.

Another important part of our CMS program is our outreach effort. We are members of the Quarknet Project, a collaboration of several ATLAS and CMS institutions that allows high school physics teachers to be exposed to high energy physics research and to bring material based on this experience into their classrooms. This summer we held a three week long Associate Teachers Workshop in which ten New Jersey high school teachers were introduced to particle physics. This workshop was considered a great success by all involved with several of the teachers indicating that it will have a major impact on what they teach.

6 CVD Diamond Detectors

Senior Physicists:	Richard Plano, Steve Schnetzer, Robert Stone, Steve Worm
Research Associate:	Lalith Perera
Physicist:	Tim Koeth
Computer Specialist:	John Doroshenko
Undergraduates:	Steve Cavanaugh, Kent Horvath

Our group has made major advances in developing radiation-hard vertex detectors based on Chemical Vapor Deposited diamond wafers. Our recent work has been concentrated on the development of diamond pixel detectors for CMS with a focus on improving hit efficiency and spatial resolution. Support for this effort is from an NSF MRI award.

In a series of test beam studies this past year at CERN, we have measured the performance of diamond pixel detectors bump bonded to CMS prototype readout electronics. This electronics has an intrinsic noise and minimum threshold setting comparable to what will be used in CMS. With diamond that is currently available from production reactors, we have measured a hit efficiency of 94% for normally incident high energy tracks. This is a major breakthrough in the development of diamond detectors. Coupled with diamond's well determined radiation hardness and diamond's lack of need for cooling, it indicates that diamond may well be the sensor material of choice for the ATLAS and CMS pixel detectors. In the same set of beam tests, the spatial resolution of the diamond pixel detector was found to be 28 microns. This is not quite at the level expected from silicon pixels of about 15 to 20 microns.

We are currently preparing for another set of beam tests at Fermilab this year. Our primary goal in these tests will be to achieve a 99% hit efficiency. To this end, we are focusing on optimizing the thickness of the diamond sensor. We will be fabricate and test several pixel detectors with diamond sensor thicknesses ranging from 300 microns to 500 microns. We have developed a sophisticated simulation code that models the transport and trapping of charge in the diamond material. This simulation gives good agreement with the pulse height and charge sharing distributions seen in the data. It indicates that by optimizing the thickness of the sensor both the hit efficiency and the spatial resolution will be improved. In addition to diamond pixel data, this summer, we will also accumulate data on diamond microstrip detectors that will be used to further test and refine the simulation programs.

We have continued to work closely with DeBeers Industrial Diamond to further improve the quality of their detector grade diamond. DeBeers has completed a year long R&D effort aimed at increasing the carrier lieftime and improving the diamond uniformity. We expect to to fabricate and test CMS pixel detectors based on this material this year.

7 RD50

Senior Physicists:	Steve Schnetzer, Robert Stone, Steve Worm
Research Associate:	Lalith Perera

We have recently joined the RD50, a CERN collaboration formed to develop semiconductor detectors for the high luminosity environment of the LHC upgrades. The requirements at the Large Hadron Collider (LHC) at CERN have pushed the present day silicon tracking detectors to the very edge of the current technology. Future very high luminosity colliders will require semiconductor

detectors with substantially improved properties. Considering that possible LHC upgrades involve fluences of fast hadrons above 10^{16} cm^{-2} and a bunch-crossing interval of $\sim$10 ns, the detectors developed must be ultra radiation hard, provide a fast and efficient charge collection, and be as thin as possible.

As one of the founding institutions in this newly-formed collaboration, the Rutgers group will contribute to the development of a detector technology which is able to operate safely and efficiently in such an environment. We plan to contribute to the efforts to optimize and engineer the bulk material as well as the detector operational conditions. We will also contribute to the measurement and modeling of the electrical properties of the detectors.

8 KTEV

Senior Physicists:	Steve Schnetzer, Sunil Somalwar, Bob Stone, Gordon Thomson
Postdocs:	John Belz (now Asst. Prof at Univ of Montana),
	Rick Tesarek (now a Wilson Fellow at Fermilab),
	Amit Lath (now an Asst. professor at Rutgers),
	Doug Bergman (now working on Fly's-Eye/HiRes)
Grad Students:	Suzanne Averitte, Eva Halkiadakis (Now with CDF/Rochester)
Undergraduates:	Adam Cunha(now at UCSB/SLAC), David Medvigy(now at Harvard)

Recent Progress on Physics

- With undergraduates Adam Cunha and David Medvigy, Amit Lath and Sunil Somalwar have observed a 147-event signal for the Primakoff production of the mixed singlet-triplet axial vector resonance K* pair $K_1(1400)$ - $K_1(1270)$. They use this signal to measure the radiative widths of these states for the first time. They also place stringent upper limits on the vector K* resonance $K^*(1410)$ and the tensor $K_2^*(1430)$ and confront theoretical predictions for these resonances. The PRL article based on these results has been published recently to excellent reviews ("...superb physics...the kind of paper I wish there were more of... well written")

- Graduate student Eva Halkiadakis finished the branching ratio measurement, first form factor determination, and CP symmetry studies for the rare decay $K_L \to e^+e^-e^+e^-$. The paper based on the analysis was recently published in the PRL and garnered praise from the reviewers, "truly impressive experimental result....Not only an impressive technical achievement, [it] portends a better understanding of fundamental issues...well and clearly written... a beautiful result" (Phys.Rev.Lett. **86** 5425-5429, 2001).

- Prof. Amit Lath has increased the sample for the extremely rare decay $K_L \to e^+e^-\mu^+\mu^-$ from one event in a previous experiment to 43 events, with negligible backgrounds. He has measured the branching ratio for the decay, searched for CP violation, and also set upper limit on the combined branching ratios for the lepton flavor violating decays $K_L \to e^\pm e^\pm \mu^\mp \mu^\mp$. The paper has been published in PRL.

- Dr. Doug Bergman has performed a new measurement of the branching ratio of the decay $K_L \to \pi^\pm e^\mp \nu_e \gamma$ with respect to $K_L \to \pi^\pm e^\mp \nu_e$, and has carried out the first study of the photon energy spectrum in this decay. The paper based on the work has been published in PRD.

- Dr. John Belz performed studies of the direct emission (DE) and inner Bremsstrahlung (IB) vertices in the decay $K_L \to \pi^+\pi^-\gamma$, measured the a1/a2 DE form-factor parameter in the ρ-propagator parametrization, performed fits of the form factor to linear and quadratic functions, and concurrently measured the branching fraction for the decay and the DE/IB branching ratio. The PRL article based on these measurements was published in Phys.Rev.Lett. **86** 761-764, 2001.

- Rick Tesarek has completed a search for possible scalar and tensor couplings in K_{e3} decays by making the world's most precise measurement of the Dalitz plot distribution of these decays. The present analysis rules out an effect seen previously by two lower precision experiments. A PRL paper on this analysis is in preparation. Analysis is continuing on a seven times larger data sample that will be systematics limited. This extended analysis will provide further sensitivity to scalar and tensor couplings and will provide the first significant measurement of non-linear contributions in the form factor q^2 dependence. A Phys Rev. D paper on this extended analysis is under collaboration review.

- Graduate Student Suzanne Averitte is measuring CP violation in the decay $K_L^0 \to \pi\pi\gamma$. This decay is interesting because it should exhibit larger CP violation than that of the $\pi^+\pi^-$ decay. In addition she will analyze the photon spectrum to increase the statistical sensitivity to this physics.

  The analysis of data from the Fall96 run is complete. The magnitude and phase of $\eta_{+-\gamma}$ have been measured, as has the branching ratio for the K_S^0 decay to the $\pi^+\pi^-\gamma$ final state.

  Now Suzanne is analyzing the data from the (much longer) 1997 run. This analysis is progressing very well: the data has been cut, distributions from the Monte Carlo simulation agree very well with the data, and backgrounds are being measured. The results with systematic error should be available soon and result in a thesis and a publication.

Personnel Status and Changes

- Eva Halkiadakis is now a research associate on CDF with the Rochester group and making key contributions on both detector and analysis fronts.

- Dr. John Belz will become an assistant professor at University of Montana effective Fall, 2002, and will continue his work on the Fly's Eye / HiRes collaboration, amongst other projects.

- Dr. Doug Bergman has all but finished his KTeV committments and is now working full time on the Fly's Eye / HiRes collaboration.

Current Status

Rutgers KTeV group has had a tremendously productive run. To date, Rutgers has analyzed and authored a total of six PRL articles and two PRD articles out of a total of 25 KTEV publications. We expect the Rutgers KTeV work to be completely finished with the publication of two more articles by the end of year 2002.

9 SLD

Senior Physicists: Pieter Jacques, Mohan Kalelkar, Richard Plano
Grad Students: Hyejoo Kang

The SLD experiment is a study of e^+e^- interactions at a center of mass energy of 91 GeV, the mass of the weak boson Z^0. A unique feature of the experiment is 75% longitudinal polarization of the e^- beam. Data-taking is complete, with a total sample of 540K events. Highlights over the last year:

- Three refereed papers were published, including one on the single most precise measurement of the probability for gluon splitting into $b\bar{b}$.
- We also published the most precise measurements of A_b and A_c, the parity-violating couplings of the Z^0 boson to the bottom and charm quarks. Our result is consistent with the prediction of the Standard Model.
- Mohan Kalelkar continued his work as Manager of the Monte Carlo Farm for the entire SLD experiment, which is a very major responsibility, but is nearing an end.
- His graduate student Hyejoo Kang successfully defended her PhD thesis on identified particle production in quark, antiquark, and gluon jets. She is now a postdoc for Stanford University working at Fermilab on the MINOS neutrino oscillation experiment.

10 Correction to Old Hyperon Radiative Decay Measurements

Although we have not directly participated in the analysis of KTEV data on hyperons, that work has yielded an interesting correction to some results from the old hyperon collaboration: Michigan-Minnesota-Rutgers-Wisconsin. We published two measurements of the asymmetry parameter, α in the weak-radiative decays, $\Xi^0 \to \Lambda\gamma$ and $\Xi^0 \to \Sigma^0\gamma$ using the longitudinal polarization of the final-state Λ. We used the same sign convention for this as for similar measurements in hadronic decays. In fact, the sign is *reversed* for the radiative decays. Tom Devlin wrote two errata correcting one of these results and withdrawing the other. These errata have been accepted for publication in Physical Review Letters. We were unable to find in the published literature a clear presentation of this issue, and we included such a discussion in one of the errata.